TPC Gas System Manual
For Experts

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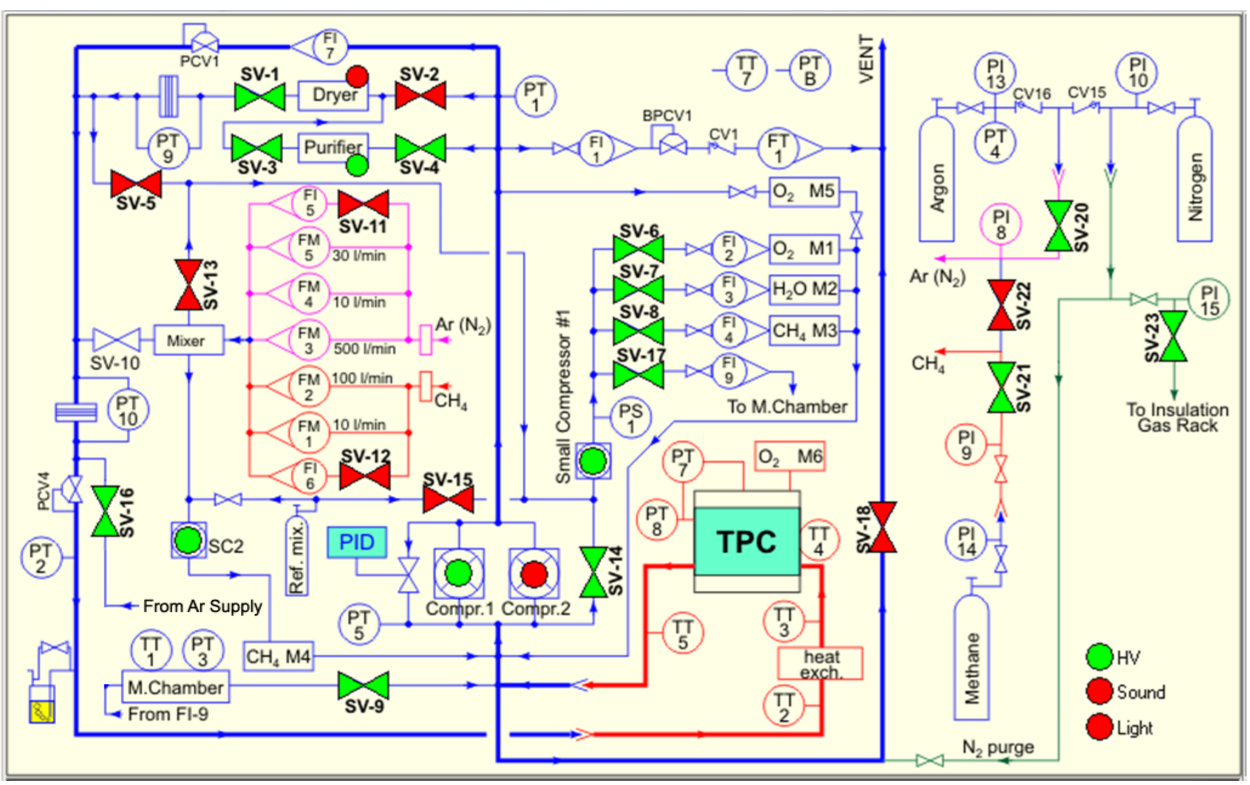
There is a short version of the original TPC and Gas system manuals. Many pages have been removed from the big manual in order to focus on the gas system, only.



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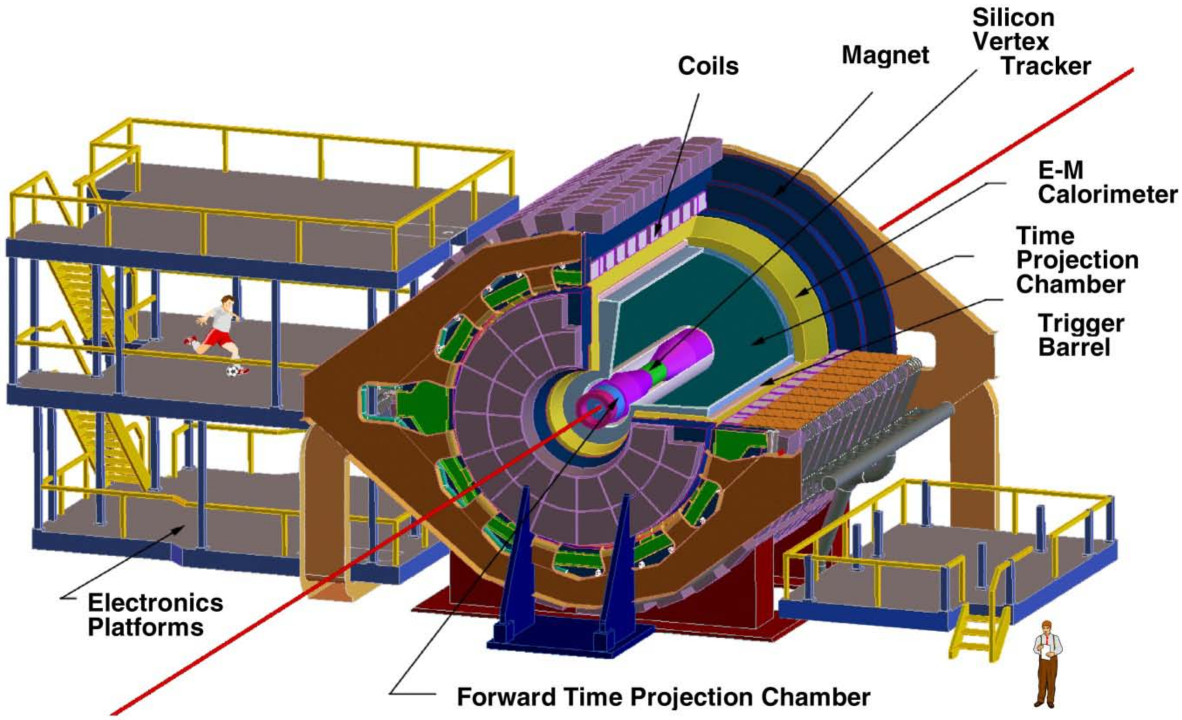
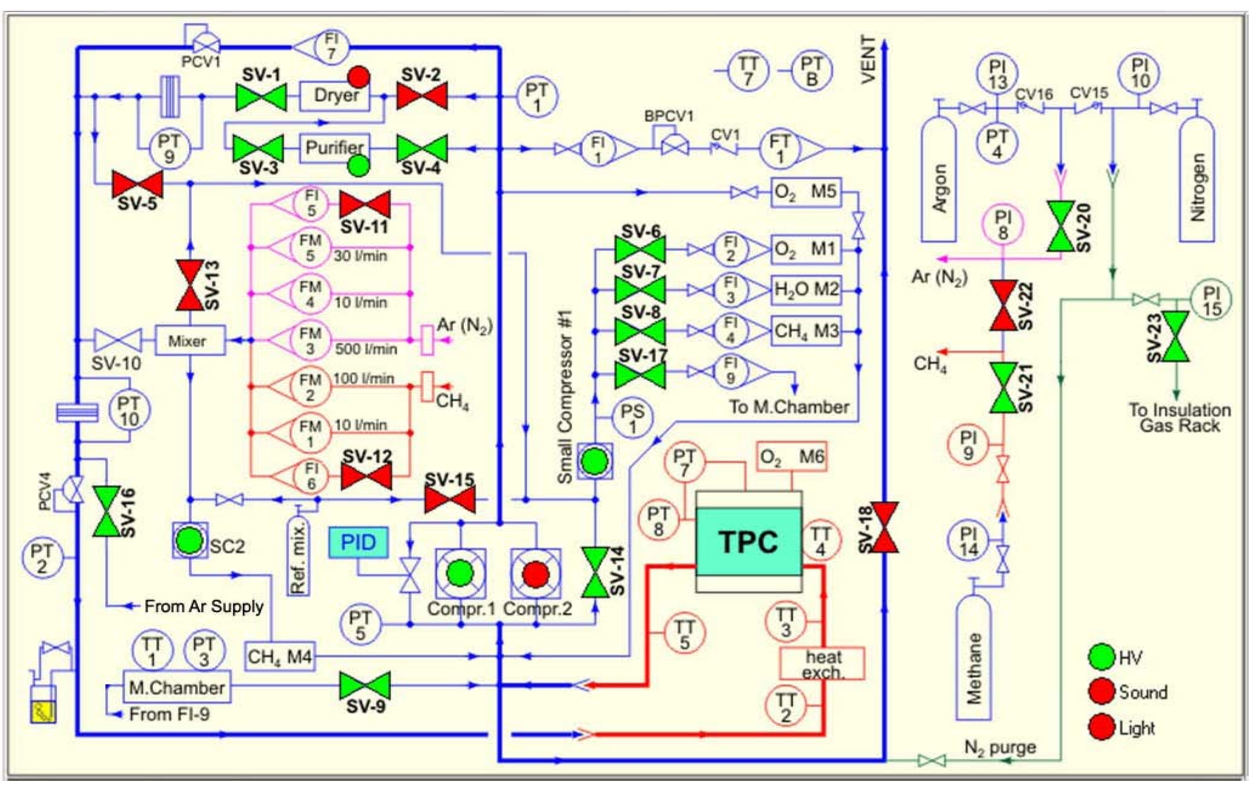
Introduction

The STAR TPC – Simplified Schematic of the Gas System





TPC passwords

Chaplin (TPC control PC in control room)	User: startpc Pass:
Sirius: PC in control room for alarm handler	Same as Chaplin
Deneb: (PC on second floor platform)	Same as Chaplin
Evp: event pool computer for pad monitor	User: startpc Pass:
Sc3: slow controls with fewer privileges	User: startpc Pass:
Sc5: new slow controls	User: sysuser Pass:
Gas System Computer in Gas room	User: sysuser Pass:
Startpc: Blair's computer in the counting house	User: stringfellow Pass:
RPS 1,2,3: remote power switches	No user Pass:

SGIS Global Interlocks (proceed with caution … you must be specially trained)

SGIS (Allen Bradley computer in DAQ room)	User: STAR Pass:

Silence the alarm (on the first page/screen). Check all of the screens (on different pages) for the system that led to the fault. Call Bill Christie or other authorized SGIS expert. Only an expert, while on the phone, can authorize you to proceed past this point. Bypass the alarmed system if you are certain that it is safe to do so and expert agrees. Fix whatever condition caused the alarm. Reset the alarm on the SGIS console screen. Look for Green screen everywhere before you clear the bypass, and then clear the bypass. (The system will alarm again if the alarm has not been cleared before you clear the bypass. This can be a real mess, so double check.) Logout.

If you had a water leak, and fixed it, then an expert must enter the STAR collision hall to reset the water leak sensor. The water leak detectors are located inside the SGIS rack on the 2nd floor of the South platform.

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The STAR time projection chamber: a unique tool for studying high multiplicity events at RHIC

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Abstract

The STAR Time Projection Chamber (TPC) is used to record the collisions at the Relativistic Heavy Ion Collider. The TPC is the central element in a suite of detectors that surrounds the interaction vertex. The TPC provides complete coverage around the beam-line, and provides complete tracking for charged particles within ± 1.8 units of pseudo-rapidity of the center-of-mass frame. Charged particles with momenta greater than 100 MeV/c are recorded. Multiplicities in excess of 3000 tracks per event are routinely reconstructed in the software. The TPC measures 4 m in diameter by 4.2 m long, making it the largest TPC in the world.

PACS: 29.40.−n; 29.40.Gx

Keywords: Detectors TPC; Time projection chambers; Drift chamber; Heavy ions

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1. Introduction

The Relativistic Heavy Ion Collider (RHIC) is located at Brookhaven National Laboratory. It accelerates heavy ions up to a top energy of 100 GeV per nucleon, per beam. The maximum center of mass energy for Au+Au collisions is $\sqrt{s_{NN}} = 200$ GeV per nucleon. Each collision produces a large number of charged particles. For example, a central Au–Au collision will produce more than 1000 primary particles per unit of pseudo-rapidity. The average transverse momentum per particle is about 500 MeV/c. Each collision also produces a high flux of secondary particles that are due to the interaction of the primary particles with the material in the detector, and the decay of short-lived primaries. These secondary particles must be tracked and identified along with the primary particles in order to accomplish the physics goals of the experiment. Thus, RHIC is a very demanding environment in which to operate a detector.

The STAR detector [1–3] uses the TPC as its primary tracking device [4,5]. The TPC records the tracks of particles, measures their momenta, and identifies the particles by measuring their ionization energy loss (dE/dx). Its acceptance covers ± 1.8 units of pseudo-rapidity through the full azimuthal angle and over the full range of multiplicities. Particles are identified over a momentum range from 100 MeV/c to greater than 1 GeV/c, and momenta are measured over a range of 100 MeV/c to 30 GeV/c.

The STAR TPC is shown schematically in Fig. 1. It sits in a large solenoidal magnet that operates at 0.5 T [6]. The TPC is 4.2 m long and 4 m in diameter. It is an empty volume of gas in a well-defined, uniform, electric field of ≈ 135 V/cm. The paths of primary ionizing particles passing through the gas volume are reconstructed with high precision from the released secondary electrons which drift to the readout end caps at the ends of the chamber. The uniform electric field which is required to drift the electrons is defined by a thin conductive Central Membrane (CM) at the center of the TPC, concentric field-cage cylinders and the readout end caps. Electric field uniformity is critical since track reconstruction precision is submillimeter and electron drift paths are up to 2.1 m.

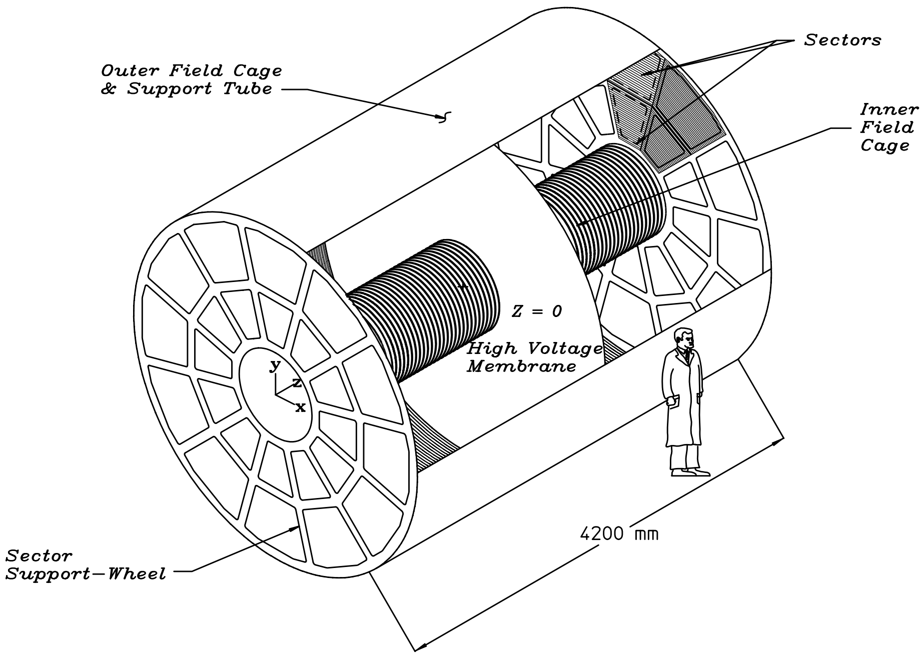

Fig. 1. The STAR TPC surrounds a beam–beam interaction region at RHIC. The collisions take place near the center of the TPC.

The readout system is based on Multi-Wire Proportional Chambers (MWPC) with readout pads. The drifting electrons avalanche in the high fields at the 20 μm anode wires providing an amplification of 1000–3000. The positive ions created in the avalanche induce a temporary image charge on the pads which disappears as the ions move away from the anode wire. The image charge is measured by a preamplifier/shaper/waveform digitizer system. The induced charge from an avalanche is shared over several adjacent pads, so the original track position can be reconstructed to a small fraction of a pad width. There are a total of 136,608 pads in the readout system.

The TPC is filled with P10 gas (10% methane, 90% argon) regulated at 2 mbar above atmospheric pressure [7]. This gas has long been used in TPCs. Its primary attribute is a fast drift velocity which peaks at a low electric field. Operating on the peak of the velocity curve makes the drift velocity stable and insensitive to small variations in temperature and pressure. Low voltage greatly simplifies the field cage design.

The design and specification strategy for the TPC have been guided by the limits of the gas and the financial limits on size. Diffusion of the drifting electrons and their limited number defines the position resolution. Ionization fluctuations and finite track length limit the dE/dx particle identification. The design specifications were adjusted accordingly to limit cost and complexity without seriously compromising the potential for tracking precision and particle identification.

Table 1 lists some basic parameters for the STAR TPC. The measured TPC performance has generally agreed with standard codes such as MAGBOLTZ [8] and GARFIELD [9]. Only for the most detailed studies has it been necessary to make custom measurements of the electrostatic or gas parameters (e.g., the drift velocity in the gas).

Table 1
Basic parameters for the STAR TPC and its associated hardware

Item	Dimension	Comment
Length of the TPC	420 cm	Two halves, 210 cm long
Outer diameter of the drift volume	400 cm	200 cm radius
Inner diameter of the drift volume	100 cm	50 cm radius
Distance: cathode to ground plane	209.3 cm	Each side
Cathode	400 cm diameter	At the center of the TPC
Cathode potential	28 kV	Typical
Drift gas	P10	10% methane, 90% argon
Pressure	Atmospheric +2 mbar	Regulated at 2 mbar above atm.
Drift velocity	5.45 cm/μs	Typical
Transverse diffusion (σ)	$230\ \mu m/\sqrt{cm}$	140 V/cm & 0.5 T
Longitudinal diffusion (σ)	$360\ \mu m/\sqrt{cm}$	140 V/cm
Number of anode sectors	24	12 per end
Number of pads	136 608	
Signal to noise ratio	20:1	
Electronics shaping time	180 ns	FWHM
Signal dynamic range	10 bits	
Sampling rate	9.4 MHz	
Sampling depth	512 time buckets	380 time buckets typical
Magnetic field	0, ± 0.25 T, ± 0.5 T	Solenoidal

2. Cathode and field cage

The uniform electric field in the TPC is defined by establishing the correct boundary conditions with the parallel disks of the CM, the end caps, and the concentric field cage cylinders. The central membrane is operated at 28 kV. The end caps are at ground. The field cage cylinders provide a series of equi-potential rings that divide the space between the central membrane and the anode planes into 182 equally spaced segments. One ring at the center is common to both ends. The central membrane is attached to this ring. The rings are biased by resistor chains of 183 precision 2 MΩ resistors which provide a uniform gradient between the central membrane and the grounded end caps.

The CM cathode, a disk with a central hole to pass the Inner Field Cage (IFC), is made of 70 μm

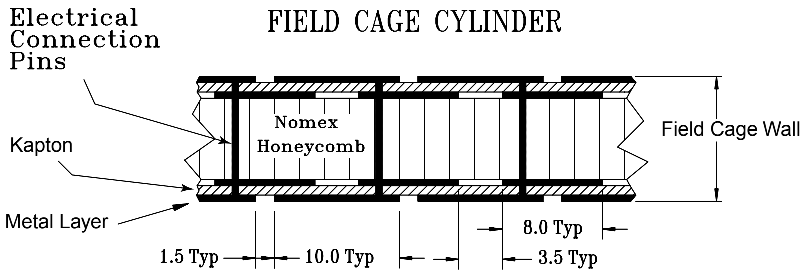

Fig. 2. An IFC showing the construction and composition of the cylinder wall. Dimensions are in mm.

thick carbon-loaded Kapton film with a surface resistance of 230 Ω per square. The membrane is constructed from several pie shape Kapton sections bonded with double-sided tape. The membrane is secured under tension to an outer support hoop which is mounted inside the Outer Field Cage (OFC) cylinder. There is no mechanical coupling to the IFC, other than a single electrical connection. This design minimizes material and maintains a good flat surface to within 0.5 mm.

Thirty six aluminum stripes have been attached to each side of the CM to provide a low work-function material as the target for the TPC laser calibration system [10,11]. Electrons are photo-ejected when ultraviolet laser photons hit the stripes, and since the position of the narrow stripes are precisely measured, the ejected electrons can be used for spatial calibration.

The field cage cylinders serve the dual purpose of both gas containment and electric field definition. The mechanical design was optimized to reduce mass, minimize track distortions from multiple Coulomb scattering, and reduce background from secondary particle production. Mechanically, the walls of the low mass self-supporting cylinders are effectively a bonded sandwich of two metal layers separated by NOMEX[1] honeycomb (see Fig. 2 for a cutaway view). The metal layers are in fact flexible PC material, Kapton with metal on both sides. The metal is etched to form electrically separated 10 mm strips separated by 1.5 mm. The pattern is offset on the two sides of the Kapton so that the composite structure behaves mechanically more like a continuous metal sheet. The 1.5 mm break is held to the minimum required to maintain the required voltage difference between rings safely. This limits the dielectric exposure in the drift volume thus reducing stray, distorting electric fields due to charge build up on the dielectric surfaces. Minimizing the break has the additional benefit of improving the mechanical strength. Punch-through pins were used to electrically connect the layers on the two sides of the sandwich.

The lay-up and bonding of the field cage sandwich was done on mandrels constructed of wood covered with rigid foam which was turned to form a good cylindrical surface. Commercially available metal-covered Kapton is limited in width to ≈20 cm so the lay-up was done with multiple etched metal-kapton sheets wrapped around the circumference of the mandrel. A laser interferometer optical tool was used to correctly position the sheets maintaining the equi-potential ring alignment to within 50 μm differentially and better than 500 μm, overall. The mandrels were constructed with a double rope layer under the foam. The ropes were unwound to release the mandrel from the field cage cylinder at completion of the lay-up.

A summary of the TPC material thicknesses in the tracking volume are presented in Table 2. The design emphasis was to limit material at the inner radius where multiple coulomb scattering is most important for accurate tracking and accurate momentum reconstruction. For this reason aluminum was used in the IFC, limiting it to only 0.5% radiation length (X_0). To simplify the construction, and electrical connections, copper was used for the OFC. Consequently, the OFC is significantly thicker, 1.3% X_0, but still not much more

[1] NOMEX, manufactured by DuPont.

Table 2
Material thickness for the inner (IFC) and outer (OFC) electrostatic field cages[a]

Structure	Material	Density (g/cm^3)	X_0 (g/cm^2)	Thickness (cm)	Thickness (%X_0)
Insulating gas	N_2	1.25e-03	37.99	40	0.13
TPC IFC	Al	2.700	24.01	0.004	0.04
TPC IFC	Kapton	1.420	40.30	0.015	0.05
TPC IFC	NOMEX	0.064	40	1.27	0.20
TPC IFC	Adhesive	1.20	40	0.08	0.23
IFC total (w/gas)					0.65
TPC gas	P10	1.56E-03	20.04	150.00	1.17
TPC OFC	Cu	8.96	12.86	0.013	0.91
TPC OFC	Kapton	1.420	40.30	0.015	0.05
TPC OFC	NOMEX	0.064	40	0.953	0.15
OFC	Adhesive	1.20	40	0.05	0.15
OFC total (w/gas)					2.43

[a] Adhesive is only an estimate.

than the detector gas itself. The sandwich structure of the OFC cylinder wall is 10 mm thick while the IFC has a wall thickness of 12.9 mm.

Nitrogen gas or air insulation was used to electrically isolate the field cage from surrounding ground structures. This design choice requires more space than solid insulators, but it has two significant advantages. One advantage is to reduce multiple scattering and secondary particle production. The second advantage is the insulator is not vulnerable to permanent damage. The gas insulator design was chosen after extensive tests showed that the field cage kapton structures and resistors could survive sparks with the stored energy of the full size field cage. The IFC gas insulation is air and it is 40 cm thick without any detectors inside the IFC. It is 18 cm thick with the current suite of inner detectors. The OFC has a nitrogen layer 5.7 cm thick isolating it from the outer shell of the TPC structure. The field cage surfaces facing the gas insulators are metallic potential graded structures which are the same as the surfaces facing the TPC drift volume. In addition to the mechanical advantages of a symmetric structure, this design avoids uncontrolled dielectric surfaces where charge migration can lead to local high fields and surface discharges in the gas insulator volume.

The outermost shell of the TPC is a structure that is a sandwich of material with two aluminum skins separated by an aluminum honeycomb. The skins are a multi-layer wraps of aluminum. The construction was done much like the field cage structures using the same cylindrical mandrel. The innermost layer, facing the OFC, is electrically isolated from the rest of the structure and it is used as a monitor of possible corona discharge across the gas insulator. The outer shell structure is completely covered by aluminum extrusion support rails bonded to the surface. The support rails carry the Central Trigger Barrel (CTB) trays. These extrusions have a central water channel for holding the structure at a fixed temperature. This system intercepts heat from external sources, the CTB modules and the magnet coils, which run at a temperature significantly higher than the TPC. This is just one part of the TPC temperature control system which also provides cooling water for the TPC electronics on the end-caps.

3. The TPC end-caps with the anodes and pad planes

The end-cap readout planes of STAR closely match the designs used in other TPCs such as

PEP4, ALEPH, EOS and NA49 but with some refinements to accommodate the high track density at RHIC and some other minor modifications to improve reliability and simplify construction. The readout planes, MWPC chambers with pad readout, are modular units mounted on aluminum support wheels. The readout modules, or sectors, are arranged as on a clock with 12 sectors around the circle. The modular design with manageable size sectors simplifies construction and maintenance. The sectors are installed on the inside of the spoked support wheel so that there are only 3 mm spaces between the sectors. This reduces the dead area between the chambers, but it is not hermetic like the more complicated ALEPH TPC design [12]. The simpler non-hermetic design was chosen since it is adequate for the physics in the STAR experiment.

The chambers consist of four components; a pad plane and three wire planes (see Fig. 3). The amplification/readout layer is composed of the anode wire plane of small, 20 μm, wires with the pad plane on one side and the ground wire plane on the other. The third wire plane is a gating grid which will be discussed later. Before addressing the details of the amplification region, a word about the chosen wire direction. The direction is set to best determine the momentum of the highest transverse momentum (p_T) particles whose tracks are nearly straight radial lines emanating from the interaction point (the momentum of low p_T particles is well determined without special consideration). The sagitta of the high p_T tracks is accurately determined by setting the anode wires roughly perpendicular to the straight radial tracks because position resolution is best along the direction of the anode wire. In the other direction, the resolution is limited by the quantized spacing of the wires (4 mm between anode wires). The dimensions of the rectangular pads are likewise

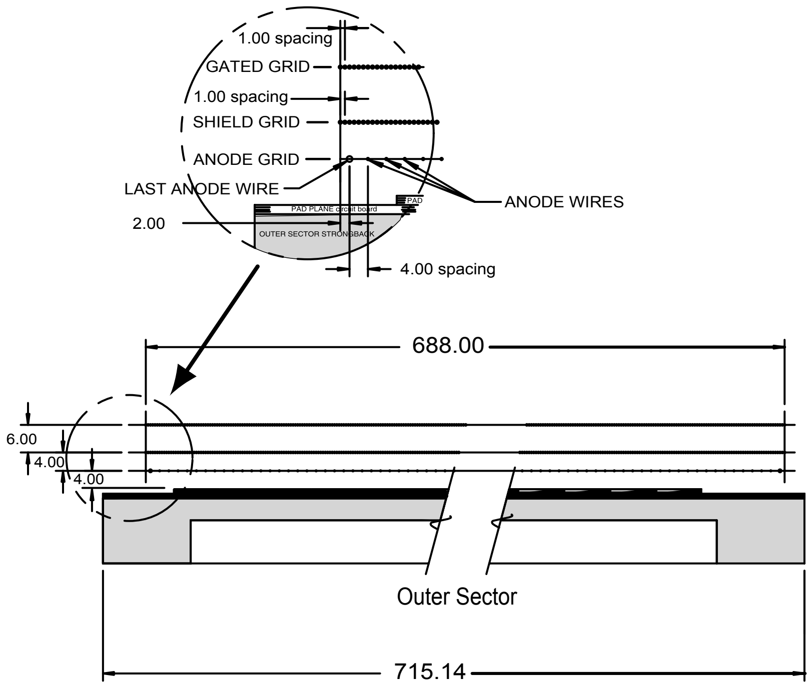

Fig. 3. A cut-away view of an outer subsector pad plane. The cut is taken along a radial line from the center of the TPC to the outer field cage so the center of the detector is to the right. The figure shows the spacing of the anode wires relative to the pad plane, the ground shield grid, and the gated grid. The bubble diagram shows additional detail about the wire spacing. The inner subsector pad plane has the same layout except the spacing around the anode plane is 2 mm instead of the 4 mm shown here. All dimensions are in millimeters.

optimized to give the best position resolution perpendicular to the stiff tracks. The width of the pad along the wire direction is chosen such that the induced charge from an avalanche point on the wire shares most of it's signal with only three pads. This is to say that the optimum pad width is set by the distance from the anode wire to the pad plane. Concentrating the avalanche signal on three pads gives the best centroid reconstruction using either a 3-point Gaussian fit or a weighted mean. Accuracy of the centroid determination depends on signal-to-noise and track angle, but it is typically better than 20% of the narrow pad dimension. There are additional tradeoffs dictating details of the pads' dimensions which will be discussed further in connection with our choice of two different sectors designs, one design for the inner radius where track density is highest and another design covering the outer radius region. Details of the two sector designs can be found in Table 3 and Fig. 4.

The outer radius subsectors have continuous pad coverage to optimize the dE/dx resolution (i.e., no space between pad rows). This is optimal because the full track ionization signal is collected and more ionization electrons improve statistics on

Table 3
Comparison of the inner and outer subsector geometries

Item	Inner subsector	Outer subsector	Comment
Pad size	2.85 mm × 11.5 mm	6.20 mm × 19.5 mm	
Isolation gap between pads	0.5 mm	0.5 mm	
Pad rows	13 (#1-#13)	32 (#14-#45)	
Number of pads	1750	3942	5692 total
Anode wire to pad plane spacing	2 mm	4 mm	
Anode voltage	1170 V	1390 V	20:1 signal:noise
Anode gas gain	3770	1230	

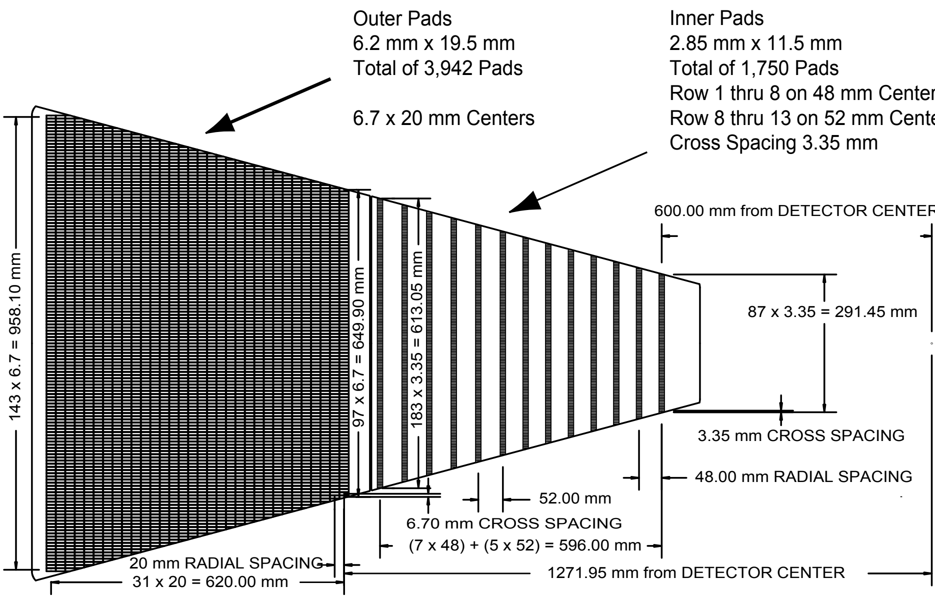

Fig. 4. The anode pad plane with one full sector shown. The inner subsector is on the right and it has small pads arranged in widely spaced rows. The outer subsector is on the left and it is densely packed with larger pads.

the dE/dx measurement. Another modest advantage of full pad coverage is an improvement in tracking resolution due to anti-correlation of errors between pad rows. There is an error in position determination for tracks crossing a pad row at an angle due to granularity in the ionization process (Landau fluctuations). If large clusters of ionization occur at the edge of the pad row they pull the measured centroid away from the true track center. But, there is a partially correcting effect in the adjacent pad row. The large clusters at the edge also induce signal on the adjacent pad row producing an oppositely directed error in the measured position in this adjacent row. This effective cross talk across pad rows, while helpful for tracking precision, causes a small reduction in dE/dx resolution.

On the outer radius subsectors the pads are arranged on a rectangular grid with a pitch of 6.7 mm along the wires and 20.0 mm perpendicular to the wires. The grid is phased with the anode wires so that a wire lies over the center of the pads. There is a 0.5 mm isolation gap between pads. The 6.7 mm pitch and the 4 mm distance between the anode wire plane is consistent with the transverse diffusion width of the electron cloud for tracks that drift the full 2 m distance. More explicitly, with a 4 mm separation between pad plane and anode plane the width of the induced surface charge from a point avalanche is the same as the diffusion width. The pad pitch of 6.7 mm places most of the signal on three pads which gives good centroid determination at minimum gas gain. This matching gives good signal-to-noise without serious compromise to two-track resolution. The pad size in the long direction (20.0 mm pitch) was driven by available electronic packaging density and funding, plus the match to longitudinal diffusion. The z projection of 20.0 mm on $\eta = 1$ tracks matches the longitudinal diffusion spread in z for $\eta = 0$ tracks drifting the full 2 m.

The inner subsectors are in the region of highest track density and thus are optimized for good two-hit resolution. This design uses smaller pads which are 3.35 mm by 12 mm pitch. The pad plane to anode wire spacing is reduced accordingly to 2 mm to match the induced signal width to ≈ 3 pads. The reduction of the induced surface charge width to less than the electron cloud diffusion width improves two-track resolution a small amount for stiff tracks $\sim$ perpendicular to the pad rows at $\eta \approx 0$. The main improvement in two-track resolution, however, is due to shorter pad length (12 mm instead of 20 mm). This is important for lower momentum tracks which cross the pad row at angles far from perpendicular and for tracks with large dip angle. The short pads give shorter projective widths in the r–ϕ direction (the direction along the pad row), and the z direction (the drift direction) for these angled tracks. The compromise inherent in the inner radius subsector design with smaller pads is the use of separate pad rows instead of continuous pad coverage. This constraint imposed by the available packing density of the front end electronics channels means that the inner sector does not contribute significantly to improving the dE/dx resolution. The inner sector only serves to extend the position measurements along the track to small radii thus improving the momentum resolution and the matching to the inner tracking detectors. An additional benefit is detection of particles with lower momentum.

The design choices, pad sizes, and wire-to-pad spacing for the two pad plane sector geometries were verified through simulation and testing with computer models [1,2], but none of the desired attributes: dE/dx resolution, momentum resolution and two-track resolution show a dramatic dependence on the design parameters. This is in part due to the large variation in track qualities such as dip angle, drift distance, and crossing angle. While it is not possible with a TPC to focus the design on a particular condition and optimize performance, a lot is gained through oversampling and averaging. In addition to simulations, prototype pad chambers were built and studied to verify charge-coupling parameters and to test stability at elevated voltages [13].

The anode wire plane has one design feature that is different than in other TPCs. It is a single plane of 20 μm wires on a 4 mm pitch without intervening field wires. The elimination of intervening field wires improves wire chamber stability and essentially eliminates initial voltage conditioning time. This is because in the traditional design both the field wire and the anode wires are captured in a single epoxy bead. The large potential difference on the field and anode wires places significant demands on the insulating condition of the epoxy surface. The surface is much less of a problem in our design where the epoxy bead supports only one potential. This wire chamber design requires a slightly higher voltage on the anode wires to achieve the same electric field at the anode wire surface (i.e., a higher voltage to achieve the same gas gain) but this is not a limitation on stability. Another small advantage in this design is that we can operate the chambers at a lower gas gain (35% lower for the inner sector) [13] since with this design the readout pads pick-up a larger fraction of the total avalanche signal. Like other TPCs, the edge wires on the anode wire plane are larger diameter to prevent the excess gain that would otherwise develop on the last wire.

Most of the anode wires are equipped with amplifiers and discriminators that are used in the trigger to detect tracks passing through the end cap. The discriminators are active before the electrons drift in from tracks in the drift volume.

Another special feature of the anode plane is a larger than normal (1 nF) capacitor to ground on each wire. This reduces the negative cross talk that is always induced on the pads under a wire whenever an avalanche generates charge anywhere along the wire. The negative cross talk comes from capacitive coupling between the wire and the pad. The AC component of the avalanche charge on a wire capacitively couples to the pads proportionally as C_p/C_{total} where C_p is the pad-to-wire capacitance and C_{total} is the total capacitance of the wire to ground. In the high track density at RHIC, there can be multiple avalanches on a wire at any time so it is important to minimize this source of cross-talk and noise. The 1 nF grounding capacitor is a compromise between cross talk reduction and wire damage risk. Our tests showed that the stored energy in larger capacitors can damage the wire in the event of a spark.

The gas gain, controlled by the anode wire voltage, has been set independently for the two sector types to maintain a 20:1 signal to noise for pads intercepting the center of tracks that have drifted the full 2 m. This choice provides minimum gain without significantly impacting the reconstructed position resolution due to electronic noise. The effective gas gain needed to achieve this signal-to-noise is 3770 for the inner sector and 1230 for the outer sector. As discussed in detail in Ref. [14] the required gas gain depends on diffusion size of the electron drift cloud, pad dimensions, amplifier shaping time, the avalanche-to-pad charge-coupling fractions and the electronic noise which for our front end electronics is ≈ 1000 electrons rms.

The ground grid plane of 75 μm wires completes the sector MWPC. The primary purpose of the ground grid is to terminate the field in the avalanche region and provide additional rf shielding for the pads. This grid can also be pulsed to calibrate the pad electronics. A resistive divider at the grid provides 50 Ω termination for the grid and 50 Ω termination for the pulser driver.

The outermost wire plane on the sector structure is the gating grid located 6 mm from the ground grid. This grid is a shutter to control entry of electrons from the TPC drift volume into the MWPC. It also blocks positive ions produced in the MWPC, keeping them from entering the drift volume where they would distort the drift field. The gating grid plane can have different voltages on every other wire. It is transparent to the drift of electrons while the event is being recorded and closed the rest of the time. The grid is 'open' when all of the wires are biased to the same potential (typically 110 V). The grid is 'closed' when the voltages alternate ± 75 V from the nominal value. The positive ions are too slow to escape during the open period and get captured during the closed period. The STAR gating grid design is standard. Its performance is very well described by the usual equations [12]. The gating grid driver has been designed to open and settle rapidly (100 V in 200 ns). Delays in opening the grid shorten the active volume of the TPC because electrons that drift into the grid prior to opening are lost. The combined delay of the trigger plus the opening time for the gating grid is 2.1 μs. This means that the useful length of the active volume is 12 cm less than the physical length of 210 cm. To limit initial data corruption at the opening of the gate, the plus and minus grid driving voltages are well matched in time and amplitude to nearly cancel the induced signal on the pads.

The gating grid establishes the boundary conditions defining the electric field in the TPC drift volume at the ends of the TPC. For this reason the gating wire planes on the inner and outer subsectors are aligned on a plane to preserve the uniform drift field. For the same reason the potential on the gating grid planes must be matched to the potential on the field cage cylinders at the intersection point. Aligning the gating grid plane separates the anode wire planes of the two sector types by 2 mm. The difference in drifting electron arrival time for the two cases is taken into account in the time-to-space position calibration. The time difference is the result of both the 2 mm offset and the different field strengths in the vicinity of the anode wires for the two sector types. The electron drift times near the anode plane was both measured and studied with MAGBOLTZ. The field is nearly uniform and constant from the CM to within 2 mm of the gating grid. We simulated the drift of ionization from 2 mm above the gating grid to the anode wires to estimate the difference between the inner and outer subsector drift times. These MAGBOLTZ simulations find that the drift from the CM to the outer subsectors requires 0.083 μs longer than from the CM to the inner subsectors. Measurement shows a slightly longer average time difference of 0.087 μs.

The construction of the sectors followed techniques developed for earlier TPCs. The pad planes are constructed of bromine-free G10 printed circuit board material bonded to a single-piece backing structure machined from solid aluminum plate. Specialized tooling was developed so that close tolerances could be achieved with minimum setup time. Pad plane flatness was assured by vacuum locking the pad plane to a flat granite work surface while the aluminum backer is bonded with epoxy to the pad plane. Wire placement is held to high tolerance with fixed combs on granite work tables during the assembly step of capturing the wires in epoxy beads on the sector backer. Mechanical details of the wires are given in Table 4. The final wire-placement error is less than 7 μm. Pad location along the plane is controlled to better than 100 μm. The sectors were qualified with overvoltage testing and gas-gain uniformity measurements with an ^{55}Fe source.

Table 4
Properties of the wires in the readout chambers

Wire	Diam. (μm)	Pitch (mm)	Composition	Tension (N)
Anodes	20	4	Au-plated W	0.50
Anodes—last wire	125	4	Au-plated Be–Cu	0.50
Ground plane	75	1	Au-plated Be–Cu	1.20
Gating grid	75	1	Au-plated Be–Cu	1.20

4. Drift gas

P10 (90% argon + 10% methane) is the working gas in the TPC. The gas system (discussed in detail in Ref. [7]) circulates the gas in the TPC and maintains purity, reducing electro-negative impurities such as oxygen and water which capture drifting electrons. To keep the electron absorption to a few percent, the oxygen is held below 100 parts per million and water less than 10 parts per million.

All materials used in the TPC construction that are exposed to the drift gas were tested for outgassing of electron capturing contaminants. This was done with a chamber designed to measure electron attenuation by drifting electrons through a 1 m long gas sample.

The transverse diffusion [8] in P10 is $230\ \mu\text{m}/\sqrt{\text{cm}}$ at 0.5 T or about $\sigma_T = 3.3$ mm after drifting 210 cm. This sets the scale for the wire chamber readout system in the X, Y plane. Similarly, the longitudinal diffusion of a cluster of electrons that drifts the full length of the TPC is $\sigma_L = 5.2$ mm. At a drift velocity of 5.45 cm/μs, the longitudinal diffusion width is equal to a spread in the drift time of about 230 ns full width half maximum (FWHM). This diffusion width sets the scale for the resolution of the tracking system in the drift direction and we have chosen the front-end pad amplifier shaping time and the electronic sampling time accordingly. The shaping time is

180 ns FWHM and the electronic sampling time is 9.4 MHz.

5. Performance of the TPC

This section will discuss the TPC performance using data taken in the RHIC beam in the 2000/2001 run cycle. The TPC performance with cosmic rays without magnetic field has been previously presented [15]. In 2000, the magnetic field was 0.25 T; in 2001 the field was raised to 0.5 T. The TPC performance is strongly affected by the magnetic field because, for example, the transverse diffusion of the electrons that drift through the gas is smaller in higher fields.

The track of an infinite-momentum particle passing through the TPC at mid-rapidity is sampled by 45 pad rows, but a finite momentum track may not cross all 45 rows. It depends on the radius of curvature of the track, the track pseudorapidity, fiducial cuts near sector boundaries, and other details about the particle's trajectory. While the wire chambers are sensitive to almost 100% of the secondary electrons arriving at the end-cap, the overall tracking efficiency is lower (80–90%) due to the fiducial cuts, track merging, and to lesser extent bad pads and dead channels. There are at most a few percent dead channels in any one run cycle.

The track of a primary particle passing through the TPC is reconstructed by finding ionization clusters along the track. The clusters are found separately in x, y and in z space. (The local x-axis is along the direction of the pad row, while the local y-axis extends from the beamline outward through the middle of, and perpendicular to, the pad rows. The z-axis lies along the beam line.) For example, the x-position cluster finder looks for ionization on adjacent pads, within a pad row, but with comparable drift times. And, for simple clusters, the energy from all pads is summed to give the total ionization in the cluster. If two-tracks are too close together, the ionization clusters will overlap. These complex clusters are split using an algorithm that looks for peaks with a valley between them and then the ionization is divided between the two tracks. These merged clusters are used only for tracking and not for dE/dx determination because of the uncertainty in the partitioning between the tracks. In central Au–Au events at 200 GeV, about 30% of the clusters are overlapping.

5.1. Reconstruction of the x, y position

The x and y coordinates of a cluster are determined by the charge measured on adjacent pads in a single pad row. Assuming that the signal distribution on the pads (pad response function) is Gaussian, the local x is given by a fit, where h_1, h_2 and h_3 are the amplitudes on three adjacent pads, with pad h_2 centered at $y = 0$:

$$x = \frac{\sigma^2}{2w} \ln\left(\frac{h_3}{h_1}\right) \tag{1}$$

where the width of the signal, σ, is given by

$$\sigma^2 = \frac{w^2}{\ln(h_2^2/h_1 h_3)} \tag{2}$$

and w is the pad width. The position uncertainty due to electronics noise may be fairly easily computed in this approach:

$$\Delta x = \frac{\Delta h}{h_c}\frac{\sigma^2}{2w}\sqrt{\left(1-\frac{2x}{w}\right)^2 \exp\left(\frac{-(x+w)^2}{\sigma^2}\right) + \frac{16x^2}{w^2}\exp\left(\frac{-x^2}{w^2}\right) + \left(1+\frac{2x}{w}\right)^2 \exp\left(\frac{-(x-w)^2}{\sigma^2}\right)}. \tag{3}$$

Here, Δh is the noise, h_c is the signal amplitude under a centered pad ($h_c = 0$), and the three terms in the root correspond to the errors on h_1, h_2, and h_3 respectively. For $\Delta h < 0.05h$ (a 20:1 signal-to-noise ratio), the noise contribution is small. The total signal is summed over all above-threshold time buckets. This equation is slightly different from the results in [16] because it includes the error in the σ determination.

The Gaussian approximation has some short comings. First, it does not exactly match onto the tails the true pad response function which introduces an x-dependent bias of a few hundred μm. More importantly, the algorithm deteriorates at large crossing angles. When a track crosses the pad row at large angles, it deposits ionization on many pads and any three adjacent pads will have similar amplitude signals. In this case, a weighted mean algorithm, using all of the pads above a certain threshold is much more effective.

Figs. 5a and c show the position resolution along the pad rows (local x) for both field settings of the magnet. The sigma is extracted by fitting a Gaussian to the residual distribution, i.e., the distance between the hit position and the track extrapolation.

5.2. Reconstruction of the z position in the TPC

The z coordinate of a point inside the TPC is determined by measuring the time of drift of a cluster of secondary electrons from the point of origin to the anodes on the endcap and dividing by the average drift velocity. The arrival time of the cluster is calculated by measuring the time of arrival of the electrons in "time buckets" and weighting the average by the amount of charge collected in each bucket. (Each time bucket is approximately 100 ns long.) The signal from a typical cluster covers several time buckets because of three phenomena: the longitudinal diffusion of the drifting electrons, the shaping of the signal by

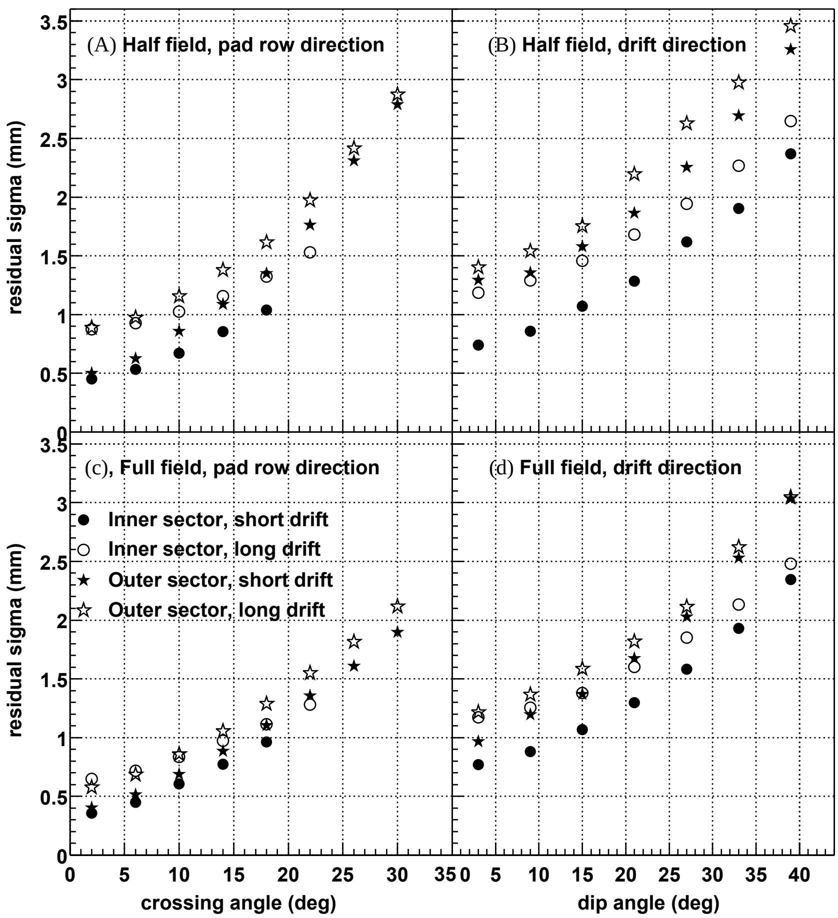

Fig. 5. Position resolution across the pad rows and along the z-axis of the TPC. The crossing angle is the angle between the particle momentum and the pad row direction. The dip angle is the angle between the particle momentum and the drift direction, $\theta = \cos^{-1}(p_z/p)$.

the preamplifier electronics, and the track dip angle. The preamplifier shaping time is chosen to correspond to the size of the electron cloud for particles drifting and diffusing the entire length of the TPC [29]. This setting smooths out the random fluctuations of the average cluster positions introduced by statistics and diffusion. The amplifier also has cancellation circuitry to remove the long current tail characteristic of MWPCs [17].

The length of the signal reaching a pad depends on the dip angle, θ, which is the angle between the particle momentum and the drift direction. The ionization electrons are spread over a distance d along the beam axis, with $d = L/\tan(\theta)$ and L is the length of the pad.

The drift velocity for the electrons in the gas must be known with a precision of 0.1% in order to convert the measured time into a position with sufficient accuracy. But the drift velocity will change with atmospheric pressure because the TPC is regulated and fixed at 2 mbar above atmospheric pressure. Velocity changes can also occur from small changes in gas composition. We minimize the effect of these variations in two ways. First, we set the cathode voltage so the electric field in the TPC corresponds to the peak in the drift velocity curve (i.e., velocity vs. electric field/pressure). The peak is broad and flat and small pressure changes do not have a large effect on the drift velocity at the peak. Second, we measure the drift velocity independently every few hours using artificial tracks created by lasers beams [10,11]. Table 1 gives the typical drift velocities and cathode potentials.

The conversion from time to position also depends on the timing of the first time bucket with respect to the collision time. This time offset has several origins: trigger delay, the time spent by the electron drifting from the gating grid to the anode wires, and shaping of the signal in the front end electronics. The delay is constant over the full volume of the TPC and so the timing offset can be adjusted, together with the drift velocity, by reconstructing the interaction vertex using data from one side of the TPC only and later matching it to the vertex found with data from the other side of the TPC. Local variations of the time offset can appear due to differences between different electronic channels and differences in geometry between the inner and outer sector pad planes. These electronic variations are measured and corrected for by applying a calibrated pulse on the ground plane. Fluctuations on the order of 0.2 time buckets are observed between different channels.

Figs. 5b and d show the position resolution along the z-axis of the TPC in 0.25 and 0.5 T magnetic fields, respectively. The resolution is best for short drift distances and small dip angles. The position resolution depends on the drift distance but the dependence is weak because of the large shaping time in the electronics, which when multiplied by the drift velocity (≈ 1 cm), is comparable to or greater than the longitudinal diffusion width (≈ 0.5 cm). The position resolution for the two magnetic field settings is similar. The resolution deteriorates, however, with increasing dip angle because the length of path received by a pad is greater than the shaping time of the electronics (times drift velocity) and the ionization fluctuations along the particle path are not fully integrated out of the problem.

5.3. Distortions

The position of a secondary electron at the pad plane can be distorted by non-uniformities and global misalignments in the electric and magnetic fields of the TPC. The non-uniformities in the fields lead to a non-uniform drift of the electrons from the point of origin to the pad plane. In the STAR TPC, the electric and magnetic fields are parallel and nearly uniform in r and z. The deviations from these ideal conditions are small and a typical distortion along the pad row is $\leqslant 1$ mm before applying corrections.

Millimeter-scale distortions in the direction transverse to the path of a particle, however, are important because they affect the transverse momentum determination for particles at high p_T. In order to understand these distortions, and correct for them, the magnetic field was carefully mapped with Hall probes and an NMR probe before the TPC was installed in the magnet [6]. It was not possible to measure the electric fields and so we calculated them from the known geometry

Table 5
The distortion corrections applied to STAR data; their cause, and the magnitude of their effect on the data

Cause of the distortion	Magnitude of the imperfection	Magnitude of the correction
Non-uniform B field	± 0.0040 T	0.10 cm
Geometrical effect between the inner and outer subsectors	Exact calculation based on geometry	0.05 cm (near pad row 13)
Cathode—non-flat shape and tilt	0.1 cm	0.04 cm
The angular offset between E and B field	0.2 mr	0.03 cm
TPC endcaps—non-flat shape and tilt	0.1 cm	0.03 cm
Misalignment between IFC and OFC	0.1 cm	0.03 cm
Space charge build up in the TPC	0.001 C/ε_0	0.03 cm average over volume

of the TPC. With the fields known, we correct the hit positions along the pad rows using the distortion equations for nearly parallel electric and magnetic fields [12].

$$\delta_x = \int \frac{-\omega\tau B_y + \omega^2\tau^2 B_x}{(1+\omega^2\tau^2)B_z}\,\mathrm{d}z + \int \frac{E_x + \omega\tau E_y}{(1+\omega^2\tau^2)E_z}\,\mathrm{d}z \tag{4}$$

$$\delta_y = \int \frac{\omega\tau B_x + \omega^2\tau^2 B_y}{(1+\omega^2\tau^2)B_z}\,\mathrm{d}z + \int \frac{E_y - \omega\tau E_x}{(1+\omega^2\tau^2)E_z}\,\mathrm{d}z \tag{5}$$

where δ_x is the distortion in the x direction, $\vec{E}$ and $\vec{B}$ are the electric and magnetic fields, ω is the signed cyclotron frequency, and τ is the characteristic time between collisions as the electron diffuses through the gas.

These are precisely the equations in Blum and Rolandi [12], except that they are valid for any $\vec{E}$ field or $\vec{B}$ field configuration while the equations in Blum and Rolandi are *not* valid for all orientations of $\vec{E}$ and $\vec{B}$. Our equations differ from Blum and Rolandi in the definition of $\omega\tau$. In Blum and Rolandi, $\omega\tau$ is always positive. Here, $\omega\tau$ is signed, with the sign depending on the directions of B_z, E_z and the drift velocity u_z:

$$\omega\tau = k\frac{u_z(\mathrm{cm}/\mu\mathrm{s})}{E_z(\mathrm{V/cm})}B_z(T) \tag{6}$$

where k is a constant. The negative charge of the drifting electrons is included in the sign of u_z. For example, the STAR electric field always points towards the central membrane and electrons always drift away from it, while B_z can point in either direction. Here, $k \approx 100$ and it depends on microscopic physics that is not represented in Eqs. (4) and (5). For precise work, k must be determined by measuring $\omega\tau$ directly [12,18]. In STAR, $k = 110$ and so $|\omega\tau| = 1.15$ at 0.25 T, rising to $|\omega\tau| = 2.30$ at 0.5 T. The magnitude of the distortion corrections are given in Table 5.

Fig. 6 shows the sum of the distortion corrections as a function of radius and z inside the active volume of the TPC. With these distortion corrections applied, the relative error between a point and the track-model fit is 50 μm while the absolute error for any one point is about 500 μm.

5.4. Two hit resolution

The inner and outer subsectors have different size pads and so their two-hit resolutions are different. Fig. 7 shows the efficiency of finding two hits as a function of the distance separating them. The efficiency depends on whether the track segment is observed in the inner or the outer subsectors. The efficiency is the ratio of the distributions of the distance separating two hits from the same event and two hits from different events. Two hits can be completely resolved when they are separated in the padrow direction (i.e., along the local x-axis) by at least 0.8 cm in the inner sector and 1.3 cm in the outer sector. Similarly, two hits are completely resolved when they are separated in the drift direction (i.e., along the z-axis) by 2.7 cm in the inner sector and 3.2 cm in the outer sector.

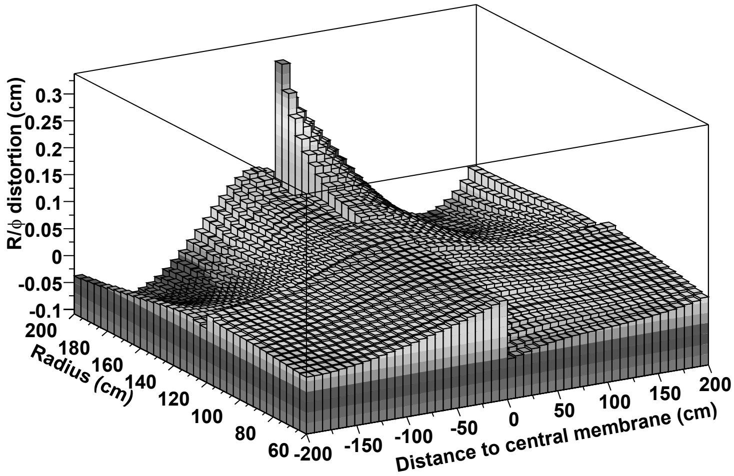

Fig. 6. The sum of all distortion corrections. The sum includes the distortions caused by the magnetic field non-uniformities, misalignment between the axis of the magnetic and electric fields, the effects of a tilted central membrane, non-flat end-caps, and local electric field imperfections at the junction of the inner and outer sectors at $R \approx 120$ cm.

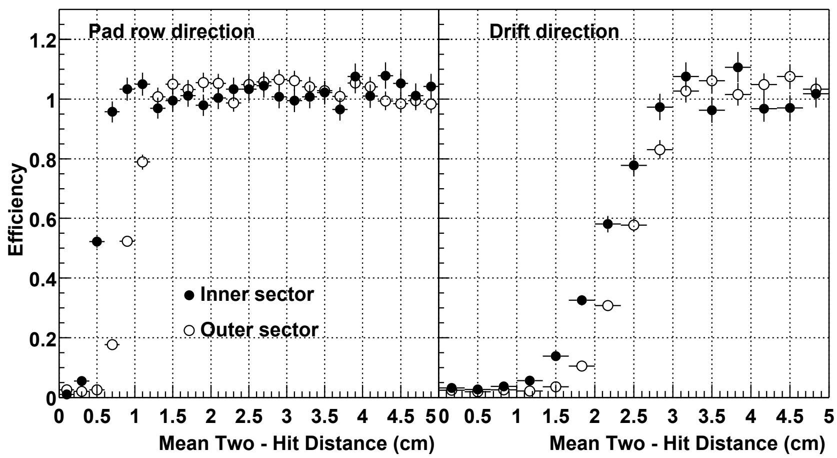

Fig. 7. Two-hit resolution in the STAR TPC. The drift direction is along the z-axis and the pad row direction is along the local x-axis.

5.5. Tracking efficiency

The tracking software performs two distinct tasks. First, the algorithms associate space points to form tracks and, second, they fit the points on a track with a track model to extract information such as the momentum of the particle. The track model is, to first order, a helix. Second-order effects include the energy lost in the gas which causes a particle trajectory to deviate slightly from the helix. In this section, we will discuss the efficiency of finding tracks with the software.

The tracking efficiency depends on the acceptance of the detector, the electronics detection efficiency, as well as the two-hit separation capability of the system. The acceptance of the TPC is 96% for high momentum tracks traveling perpendicular the beamline. The 4% inefficiency is caused by the spaces between the sectors which are required to mount the wires on the sectors. The software also ignores any space points that fall on the last two pads of a pad row. This fiducial cut is applied to avoid position errors that result from tracks not having symmetric pad coverage on both sides of the track. It also avoids possible local distortions in the drift field. This fiducial cut reduces the total acceptance to 94%.

The detection efficiency of the electronics is essentially 100% except for dead channels and the dead channel count is usually below 1% of the total. However, the system cannot always separate one hit from two hits on adjacent pads and this merging of hits reduces the tracking efficiency. The software also applies cuts to the data. For example, a track is required to have hits on at least 10 pad rows because shorter tracks are too likely to be broken track fragments. But this cut can also remove tracks traveling at a small angle with respect to the beamline and low momentum particles that curl up in the magnetic field. Since the merging and minimum pad rows effects are non-linear, we cannot do a simple calculation to estimate their effects on the data. We can simulate them, however.

In order to estimate the tracking efficiency, we embed simulated tracks inside real events and then count the number of simulated tracks that are in the data after the track reconstruction software has done its job. The technique allows us to account for detector effects and especially the losses related to a high density of tracks. The simulated tracks are very similar to the real tracks and the simulator tries to take into account all the processes that lead to the detection of particles including: ionization, electron drift, gas gain, signal collection, electronic amplification, electronic noise, and dead channels. The results of the embedding studies indicate that the systematic error on the tracking efficiency is about 6%.

Fig. 8 shows the pion reconstruction efficiency in Au + Au collisions with different multiplicities as a function of the transverse momentum of the primary particle [19]. In high multiplicity events it reaches a plateau of 80% for high p_T particles. Below 300 MeV/c the efficiency drops rapidly because the primary particles spiral up inside the TPC and do not reach the outer field cage. In addition, these low momentum particles interact

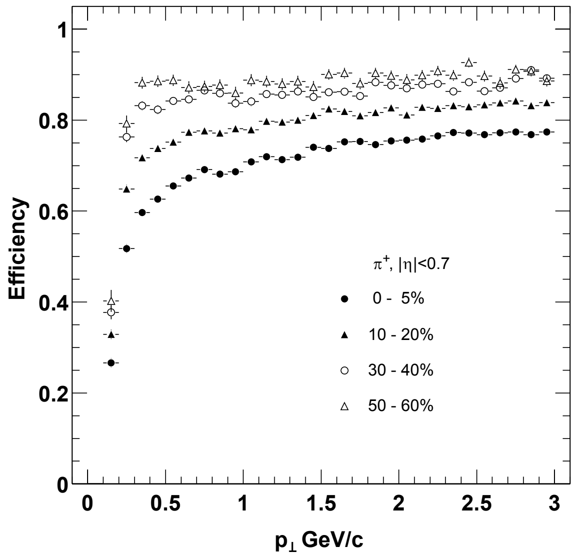

Fig. 8. The pion tracking efficiency in STAR for central Au + Au events at RHIC. Tracks with $|y| < 0.7$ were used to generate the figure and the magnetic field was set to 0.25 T. The data are binned by centrality. The most central collisions are the highest multiplicity data, they are shown as black dots. The lowest multiplicity data are shown as open triangles.

with the beam pipe and the inner field cage before entering the tracking volume of the TPC. As a function of mulitplicity, the efficiency goes up to the geometrical limit, minus software cuts, for low multiplicity events.

5.6. Vertex resolution

The primary vertex can used to improve the momentum resolution of the tracks and the secondary vertices can be separated from the primary vertices if the vertex resolution is good enough. Many of the strange particles produced in heavy ion collisions can be identified this way.

The primary vertex is found by considering all of the tracks reconstructed in the TPC and then extrapolating them back to the origin. The global average is the vertex position. The primary vertex resolution is shown in Fig. 9. It is calculated by comparing the position of the vertices that are reconstructed using each side of the TPC, separately. As expected, the resolution decreases as the square root of the number of tracks used in the

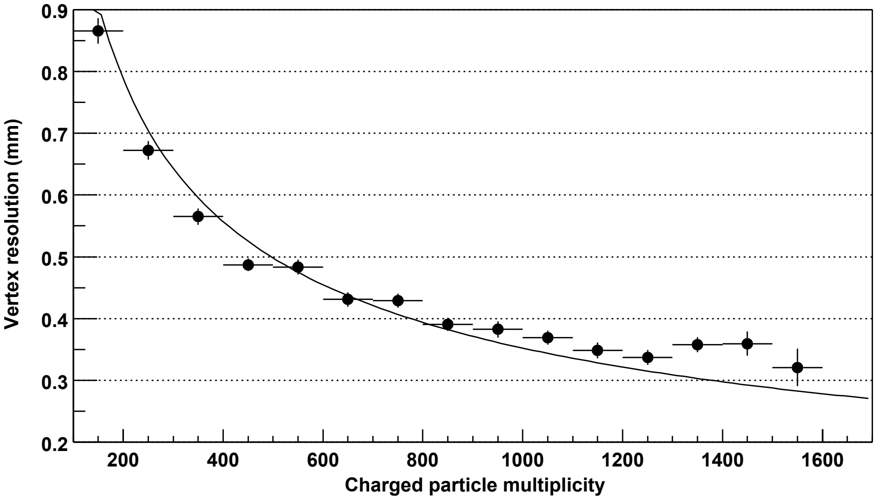

Fig. 9. Primary vertex resolution in the transverse plane.

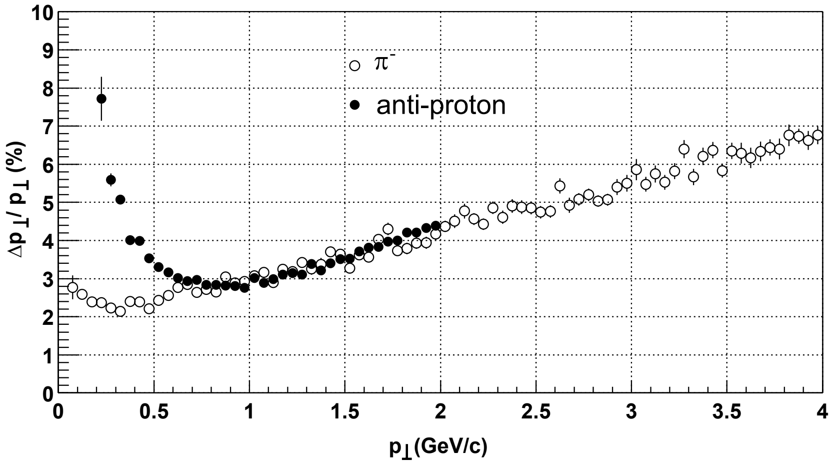

Fig. 10. Transverse momentum resolution of the STAR TPC for π^- and anti-protons in the 0.25 T magnetic field. Tracks are required to be formed by more than 15 hits. Tracks are embedded in minimum bias events. The momentum resolution is calculated as the Gaussian *sigma*.

calculation. A resolution of 350 μm is achieved when there are more than 1000 tracks.

5.7. Momentum resolution

The transverse momentum, p_T, of a track is determined by fitting a circle through the x, y coordinates of the vertex and the points along the track. The total momentum is calculated using this radius of curvature and the angle that the track makes with respect to the z-axis of the TPC. This procedure works for all primary particles coming from the vertex, but for secondary decays, such as Λ or K_s, the circle fit must be done without reference to the primary vertex.

In order to estimate the momentum resolution we use the embedding technique discussed above. The track simulator was used to create a track with a known momentum. The track was then embedded in a real event in order to simulate the momentum smearing effects of working in a high track density environment. Fig. 10

shows the p_T resolution for π^- and anti-protons in STAR. The figure shows two regimes: at low momentum, where multiple Coulomb scattering dominates (i.e., $p_T < 400$ MeV/c for pions, and $p_T < 800$ MeV/c for anti-protons), and at higher momentum where the momentum resolution is limited by the strength of the magnet field and the TPC spatial resolution. The best relative momentum resolution falls between these two extremes and it is 2% for pions.

5.8. Particle identification using dE/dx

Energy lost in the TPC gas is a valuable tool for identifying particle species. It works especially well for low momentum particles but as the particle energy rises, the energy loss becomes less mass dependent and it is hard to separate particles with velocities $v > 0.7c$. STAR was designed to be able to separate pions and protons up to 1.2 GeV/c. This requires a relative dE/dx resolution of 7%. The challenge, then, is to calibrate the TPC and understand the signal and gain variations well enough to be able to achieve this goal.

The measured dE/dx resolution depends on the gas gain which itself depends on the pressure in the TPC. Since the TPC is kept at a constant 2 mbar above atmospheric pressure, the TPC pressure varies with time. We monitor the gas gain with a wire chamber that operates in the TPC gas return line. It measures the gain from an ^{55}Fe source. It will be used to calibrate the 2001 data, but for the 2000 run, this chamber was not installed and so we monitored the gain by averaging the signal for tracks over the entire volume of the detector and we have done a relative calibration on each sector based on the global average. Local gas gain variations are calibrated by calculating the average signal measured on one row of pads on the pad plane and assuming that all pad-rows measure the same signal. The correction is done on the pad-row level because the anode wires lie on top of, and run the full length of, the pad rows.

The readout electronics also introduce uncertainties in the dE/dx signals. There are small variations between pads, and groups of pads, due to the different response of each readout board. These variations are monitored by pulsing the ground plane of the anode and pad plane read-out

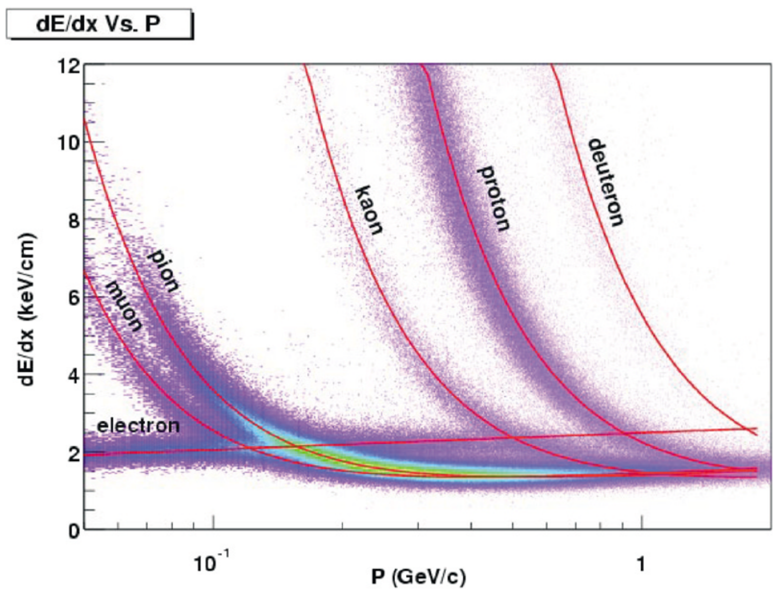

Fig. 11. The energy loss distribution for primary and secondary particles in the STAR TPC as a function of the p_T of the primary particle. The magnetic field was 0.25 T.

system and then assuming that the response will be the same on every pad.

The dE/dx is extracted from the energy loss measured on up to 45 padrows. The length over which the particle energy loss is measured (pad length modulo the crossing and dip angles) is too short to average out ionizations fluctuations. Indeed, particles lose energy going through the gas in frequent collisions with atoms where a few tens of eV are released, as well as, rare collisions where hundreds of eV are released [20]. Thus, it is not possible to accurately measure the average dE/dx. Instead, the most probable energy loss is measured. We do this by removing the largest ionization clusters. The truncated mean where a given fraction (typically 30%) of the clusters having the largest signal are removed, is an efficient tool to measure the most probable dE/dx. However, fitting the dE/dx distribution including all clusters associated to a given track was found to be more effective. It also allows us to account for the variation of the most probable energy loss with the length of the ionization samples (dx) [21].

Fig. 11 shows the energy loss for particles in the TPC as a function of the particle momentum. The data have been corrected for signal and gain variations and the data are plotted using a 70% truncated mean. The magnetic field setting is 0.25 T. The resolution is 8% for a track that crosses 40 pad-rows. At 0.5 T, the dE/dx resolution improves because the transverse diffusion is smaller, and this improves the signal-to-noise ratio for each cluster. Fig. 11 includes both primary and secondary particles. The prominent proton, deuteron, and muon bands come from secondary interactions in the beam pipe and IFC, and from pion and kaon decays. Pions and protons can be separated from each other up to 1 GeV/c.

6. Conclusions

The STAR TPC is up and running at RHIC. The detector finished its second year of operation on January 25, 2002 and the operation of the TPC was stable and reliable throughout both run cycles. Its performance is very close to the original design requirements in terms of tracking efficiency, momentum resolution, and energy-loss measurements. Many results from the 2000/2001 data have already been published and they demonstrate that the physics at RHIC is exciting and rich. We invite you to examine these papers [22–28].

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References

[1] The STAR Collaboration, The STAR Conceptual Design Report, June 15, 1992 LBL-PUB-5347.
[2] The STAR Collaboration, STAR Project CDR Update, January 1993 LBL-PUB-5347 Rev.
[3] http://www.star.bnl.gov and references therein. See especially www.star.bnl.gov → Group Documents → TPC → Hardware.
[4] H. Wieman, et al., IEEE Trans. Nucl. Sci. NS-44 (1997) 671.
[5] J. Thomas, et al., Nucl. Instr. and Meth. A 478 (2002) 166.
[6] F. Bergsma, et al., The STAR magnet system, Nucl. Instr. and Meth. A, this volume.
[7] L. Kotchenda, et al., The STAR TPC gas system, Nucl. Instr. and Meth. A, this volume.
[8] S.F. Biagi, MAGBOLTZ, a computer program, Nucl. Instr. and Meth. A 421 (1999) 234.

[9] R. Veenhof, GARFIELD, a computer program, A drift chamber simulation program, CERN Program Library, 1998.
[10] A. Lebedev, et al., The STAR laser system, Nucl. Instr. and Meth. A, this volume.
[11] A. Lebedev, Nucl. Instr. and Meth. A 478 (2002) 163.
[12] W. Blum, L. Rolandi, Particle Detection with Drift Chambers, Springer, Berlin, 1993.
[13] W. Betts, et al., Studies of several wire and pad geometries for the STAR TPC, STAR Note 263, 1996.
[14] M. Anderson, et al., A readout system for the STAR time projection chamber, Nucl. Instr. and Meth. A, this volume.
[15] W. Betts, et al., IEEE Trans. Nucl. Sci. NS-44 (1997) 592.
[16] G. Lynch, Thoughts on extracting information from pad data in the TPC, PEP4 Note TPC-LBL-78-17. April 18, 1978 (unpublished).
[17] E. Beuville, et al., IEEE Trans. Nucl. Sci. NS-43 (1996) 1619.
[18] S.R. Amendolia, et al., Nucl. Instr. and Meth. A 235 (1985) 296.
[19] Manuel Calderon de la Barca Sanchez, Charged Hadron Spectra in Au + Au Collisions at 130 GeV, Ph.D. Thesis, Yale University, December 2001.
[20] H. Bichsel, ''Energy loss in thin layers of argon'', STAR Note 418, http://www.star.bnl.gov/star/starlib/doc/www/sno/ice/sn0418.html.
[21] H. Bichsel, Comparison of Bethe-Bloch and Bichsel Functions, STAR Note 439, http://www.star.bnl.gov/star/starlib/doc/www/sno/ice/sn0439.html.
[22] K.H. Ackermann, et al., Phys. Rev. Lett. 86 (2001) 402.
[23] C. Adler, et al., Phys. Rev. Lett. 86 (2001) 4778.
[24] C. Adler, et al., Phys. Rev. Lett. 87 (2001) 082301.
[25] C. Adler, et al., Phys. Rev. Lett. 87 (2001) 112 303.
[26] C. Adler, et al., Phys. Rev. Lett. 87 (2001) 182 301.
[27] C. Adler et al., Phys. Rev. Lett. 87 (2001) 262 301-1.
[28] C. Adler et al., Phys. Rev. Lett. 89 (2002) 202 301.
[29] S. Klein, et al., IEEE Trans. Nucl. Sci. NS-43 (1996) 1768.

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STAR TPC gas system

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Abstract

The STAR TPC (Time Projection Chamber) Gas System supplies either of two mixtures, P10 (Ar 90% + CH_4 10%) or C_2H_6 50% + He 50%, to the STAR TPC (STAR Project, Brookhaven, USA) at a controlled pressure. This system regulates the pressure and composition of the gas while monitoring gas temperature, O_2 and H_2O. A computer data acquisition system collects and logs the gas system parameters, controls the purification of the recirculating mixture. A separate alarm and interlock system prevents the TPC from operating under unsafe conditions.

1. Description of STAR TPC gas system

The primary purpose of the STAR TPC [1] Gas System (Fig. 1) is to provide either of two pure gas mixtures, P10 or He + 50% C_2H_6, to the TPC at the correct temperature and pressure. Performance of the system is shown in Table 1.

A secondary function of the system is to cool the outer field cage resistor strings located in two channels at the top of the drift volume. The system operates nominally as a closed circuit gas system with the majority of gas recirculating through the TPC and delivery system. During normal operation a small amount of fresh mixture is added and an equivalent quantity (including TPC leakage) of the existing mixture is vented. The gas system can be operated in an open system configuration for purging.

The gas circulation rate is 36,000 l/h which, given the 50,000 l volume of the TPC, is one volume change every 1.4 h. The gas system contains two Rietschel's compressors, one active and one spare, each capable of 60,000 l/h at 100 mbar gauge. The 100 mbar output pressure from the compressor is reduced to 30 mbar by the first pressure regulator (PCV-1) and then to 2.4 mbar by the second one (PCV-4) upstream of the TPC. A water-cooled heat exchanger downstream of the compressors is used to remove the compression heat. The return gas manifold is maintained at 0.5–1.6 mbar above atmospheric pressure by a differential Dwyer's pressure transmitter (PT-6) and electropneumatic microprocessor (PID) controller that operates a bypass valve. The bypass shunts flow from the compressor discharge line directly back to the compressor's

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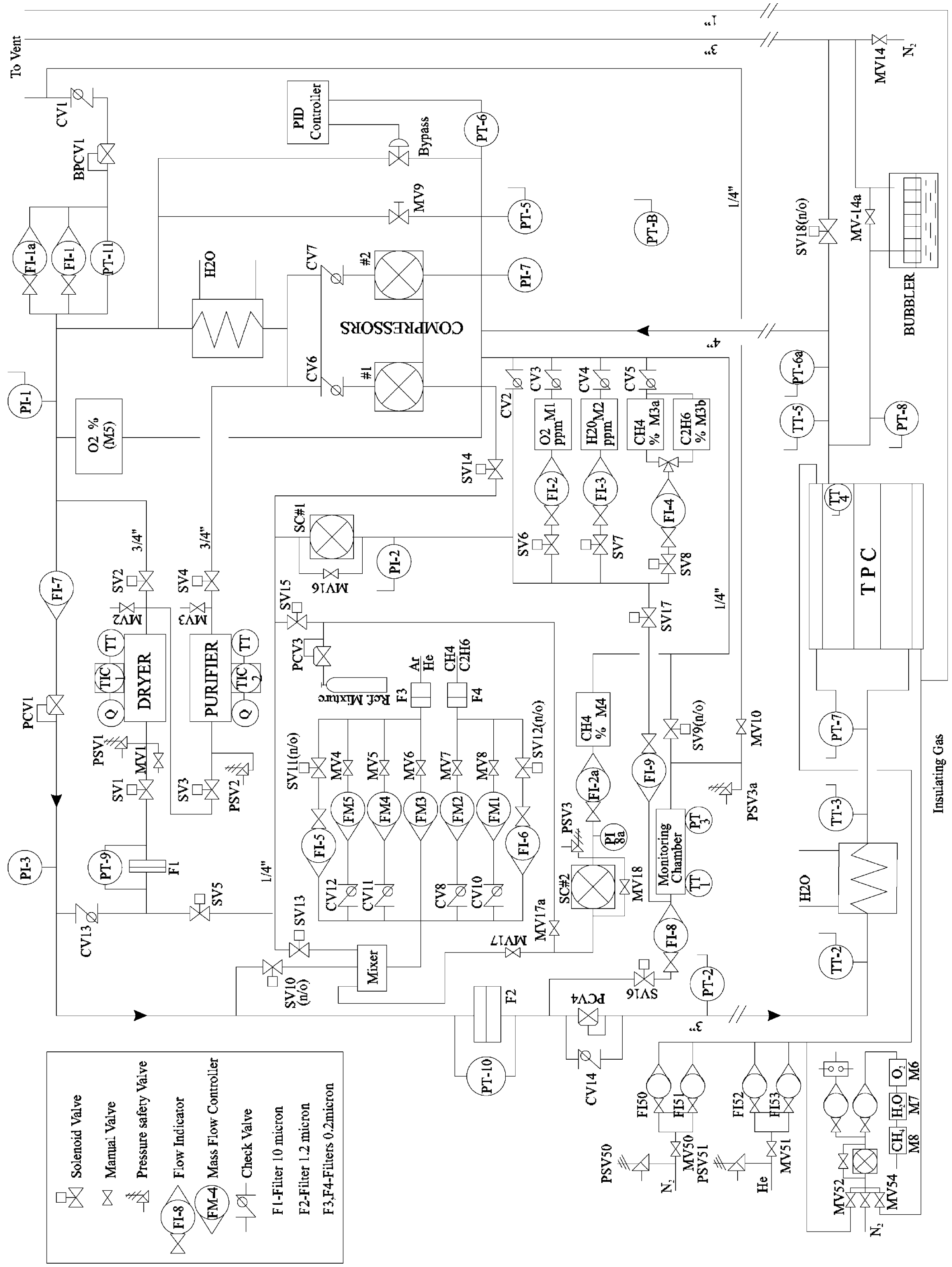

Fig. 1. STAR TPC gas system.

intake. A second bypass valve (MV-9) is manually adjusted to enable the automatic control loop to be used within its optimum range.

The purity and composition of the TPC mixture is monitored using O_2, CH_4 (C_2H_6) and H_2O analyzers. An additional CH_4 analyzer is installed to constantly measure the CH_4 content of the fresh mixture. A fraction of the recirculating mixture can be passed through a dryer and purifier to remove H_2O and contaminants as needed. Fresh gas is provided by the Gas Storage/Supply System.

A computer driven data acquisition/control system (Fig. 2) monitors all of the process variables. The computer system flags quantities that fall outside of predefined limits and initiates corrective action. However, where the safety of equipment or personnel are concerned, a relay-based, hard-wired interlock system connected to a redundant set of sensors controls the action of all key valves. The relay-based controls will bring the gas system to a safe state in the event the computer-based controls fail.

It is imperative, for the safety of the TPC, that the TPC pressure accurately tracks ambient pressure. A rapid change in atmospheric pressure is typical preceding storms and hurricanes, not uncommon in the Long Island area. To assure that the TPC follows a fast rise in ambient pressure, a relatively large flow of inert gas will be admitted into the vessel if normal pressure controls fail to keep up with falling external pressure. The vent lines and associated valves are sized to allow for rapid venting of the TPC gas to prevent a high internal pressure should the external ambient pressure fall faster than the closed system controls can accommodate. A large valve (SV-18) is opened if rapid venting is required and a bubbler connected to the TPC exhaust manifold will vent in the event that all other measures fail. The SV-18 valve is a "normally open" solenoid valve, so it

Table 1
Gas system parameters

TPC Volume	50,000 l
Mixture	(10±0.1%) CH_4 in Ar, (50±0.1%) C_2H_6 in He
Compressor pressure	90–120 mbar
Supply pressure	2.2–2.4 mbar
Return pressure	0.5–1.6 mbar
Internal TPC pressure	2.0±0.03 mbar
Recirculation flow	36,000 l/h
Purge flow	12,000 l/h
Make-up gas flow	3.0–33 l/h
Oxygen content	<25 ppm
Water content	<20 ppm

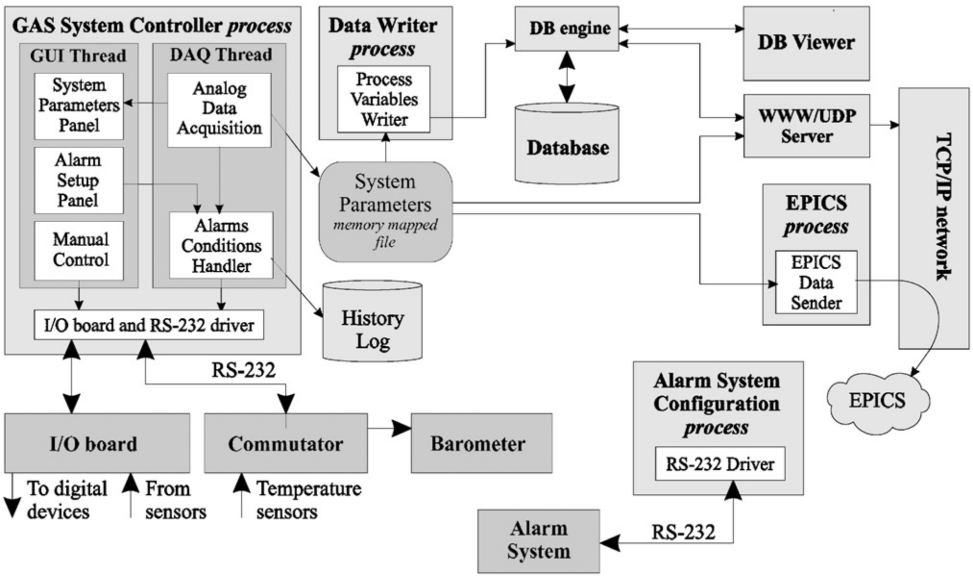

Fig. 2. DAQ and control diagram.

opens automatically when there is a power failure. A restrictive orifice has been placed upstream of the high-pressure regulators to assure that the TPC and vent piping is not overwhelmed by a high intake flow.

1.1. Pressure control

There are two sources of pressure in the gas system. The first is the compressor located at the exit of the TPC. The second is the flow of fresh gas through the mixing manifold. Normally the pressure within the TPC is controlled by maintaining a constant pressure downstream of the TPC by regulating the amount of gas shunted from the compressor output to intake.

As mentioned above, the output from the compressor is 60, 000 l/h at 100 mbar. The back pressure regulator (BPCV-1) in the outlet line maintains the 100 mbar pressure independent of compressor output and provides an exhaust to make up for the influx of fresh gas. Two pressure levels of 30 mbar and 2.4 mbar are controlled by the pressure regulators PCV-1 and PCV-4 upstream of the TPC. The TPC exhaust pressure, measured at the return gas manifold may be maintained in the range of 0.5–1.6 mbar by a Tescom electropneumatic microprocessor PID controller (ER2000). A Dwyer 0–2.5 mbar differential pressure transmitter (PT-6) produces a 4–20 mA output that the PID controller compares to a set point value. If the transmitter signal is different from the set point, the controller sends a pneumatic output signal to the bypass control valve. The bypass shunts flow from the compressor discharge line directly back to the compressor intake. Opening the bypass valve causes the TPC's exhaust pressure to rise and closing it makes the pressure fall. A second bypass valve (MV-9), manually adjusted during the initial system set-up, enables this automatic control loop to be used within its optimum range. Using PT-6a pressure transmitter, setting on the TPC instead of PT-6 permits to have more high TPC pressure stability.

There are additional levels of control in the event the primary pressure control loop fails or is insufficient to keep up with external pressure changes. When the internal TPC pressure, as measured by PT-5 and PI-7, is more than 2.0 mbar above ambient, the gas control system will close the solenoid valves SV-10, SV-20 and SV-21 in the gas supply lines and open the vent valve SV-18 allowing the TPC to vent directly to the atmosphere. If the pressure exceeds 3.0 mbar, the excess TPC mixture will vent to the atmosphere through the bubbler as well. This system of backups protects the TPC from over pressure due to mass flowmeter malfunction, rapidly dropping atmospheric pressure and a failure of the back-pressure regulator.

The TPC is also protected from under pressure. If there is a rapid rise in atmospheric pressure or, effectively, a fast drop in the TPC's internal pressure, the dual set point Dwyer differential pressure transmitter (PT-5) in the return manifold will trip as the pressure falls below 0.5 mbar, causing an audible and visual alarm. If the pressure at PT-5 falls further, to 0.3 mbar, a second set point trips and the computer control system will stop the compressor, shut-off the flow of flammable gas closing SV-21, 21a (Fig. 3) and pass inert gas through the CH_4 (C_2H_6) mass flowmeters by opening valves SV-22, SV-12, SV11 and maintain SV-10 in the open position to supply an additional 300 l/min of inert gas. This system can keep up with a rate of increase of atmospheric pressure of up to 6 mbar/min. An added level of protection against TPC under pressure is provided by another pressure-indicating switch (PI-7) with dual set points installed in the return manifold. This switch is not connected to the computer control system, but, instead, is hardwired to perform the same functions as the computer control system in the event of falling TPC pressure.

To protect TPC cylindrical case from the damage in the case of the overpressure inside the TPC insulation gap, PT7 measures differential pressure. If this pressure is less 0.0 mbar, SV23 will be closed by the control system.

The TPC is also protected from pressure extremes in case of power failure. A power failure will cause solenoid valves, SV-10, 11, 12, 19, 20 and 22 to open or remain open and will cause SV-21, 21a to close, causing 60 l/min of inert gas to flow through the TPC. This flow rate is adequate

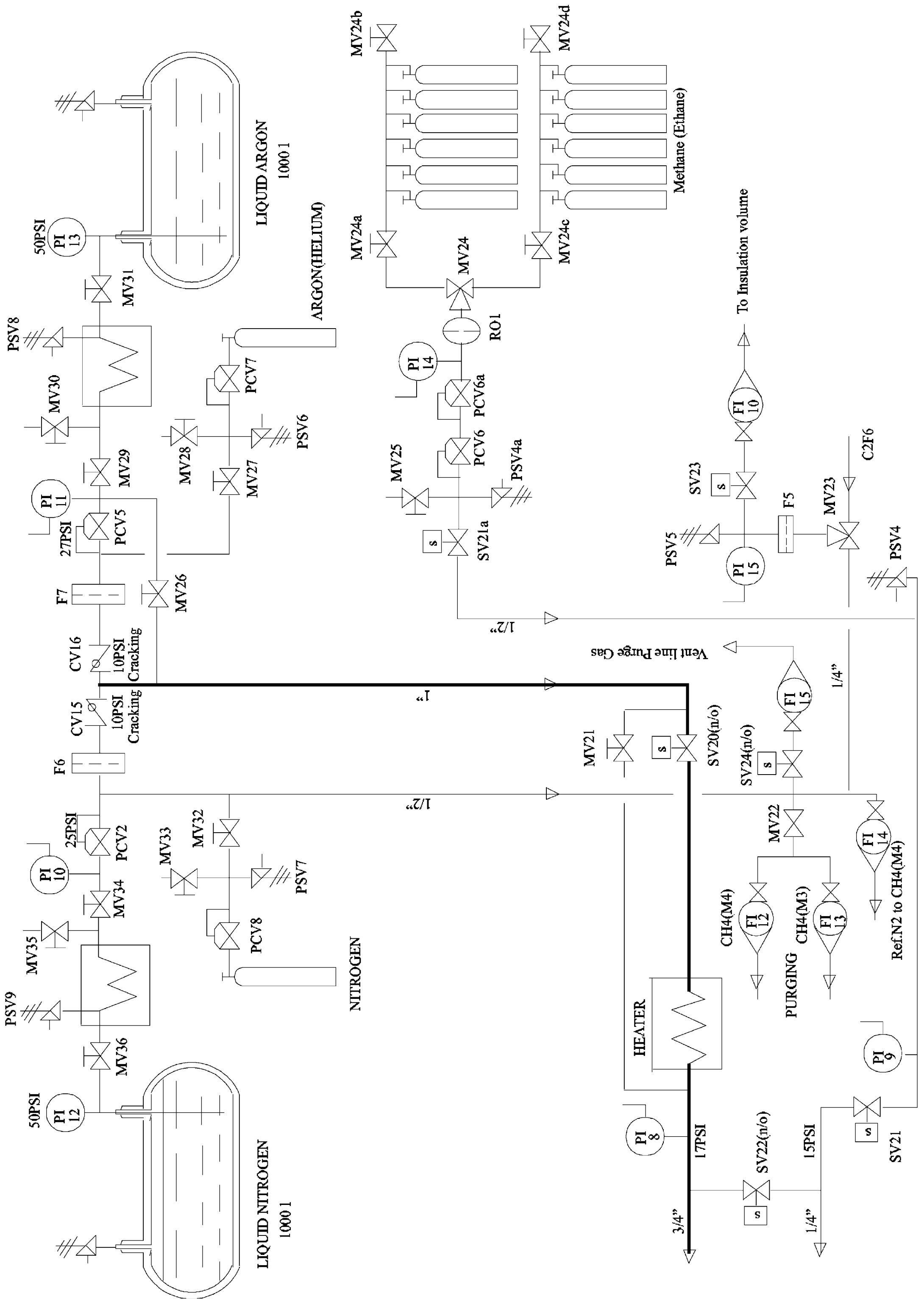

Fig. 3. STAR TPC gas storage/supply system.

to assure that fluctuations in the atmospheric pressure will not result in an excessive external pressure in the field cage and the TPC gas will not be contaminated by air being drawn back in through the exhaust vent. In the event that the Ar (He) supply is exhausted before power is restored, N_2 will automatically flow into the system to assure an adequate purge of all flammable mixtures. This N_2 back up of the Ar (or He) is provided by a completely passive system, see Fig. 3, where the supply of N_2 is maintained at a lower pressure than the Ar (or He) supply. As the primary gas runs out and the pressure falls, the N_2 begins to flow when the pressure exceeds the sum of the primary gas pressure and the check valve-cracking pressure. The check valves (CV-15, CV-16) cracking and reseal pressures were selected in conjunction with the delivery pressure of the primary (Ar or He) gas and N_2 to assure that back flow of either gas does not occur.

1.2. Mixture control

The gas mixture is controlled with mass flow meters, which feed fresh gas into the circulation loop between pressure regulators PCV-1 and PCV-4. The fresh gas mixing ratio is controlled for two different flow ranges by using different sets of flow meters. To rapidly purge the TPC, mass flow meters FM-2 and FM-3 are used to deliver fresh gas mixture at up to 200 l/min. Mass flow meters FM-1, FM-2, FM-3 and FM-4 are used for long term stable delivery at a reduced flow rate of 3.0–33 l/min for Ar–CH_4 or up to 50 l/min for the He–C_2H_6 mixture. The flow meters are operated as master-slave with FM-1 slaved to FM-4 and FM-2 slaved to FM-3. The masters are normally remotely controlled by computer but may be controlled locally if necessary.

1.3. Temperature measurement, drift and gas gain monitoring

Four temperature transmitters (TT-2, TT-3, TT-4 and TT-5) are used to measure the mixture temperature within the TPC. A fifth temperature transmitter, TT-1, measures the mixture temperature within the monitoring chamber. The temperature control of the TPC is a function of the cooling system and is independent of the gas system. The measured temperatures in the TPC are logged in a database.

Drift and Gas Gain measurements are provided by a separate, specially constructed chamber built and tested by Purdue University, for use in this application. Output from this chamber is read and evaluated by a separate data acquisition unit and archived for future reference.

1.4. Mixture sampling

The gas system is equipped with O_2, H_2O and CH_4 (or C_2H_6) monitors plumbed such that each section of the gas system can be selected separately for evaluation. Since some sample points are at low pressure, a small membrane compressor is used to maintain gas flow through the analyzers.

In the interest of safety, a second O_2 monitor upstream of the 30 mbar pressure regulator (PCV-1) provides a continuous monitor of the recirculating gas mixture. If the O_2 content exceeds the 0.1% set point, the flow of flammable gas will be shut off and inert gas will flow in its place. As an added precaution, during P10 running, a dedicated gas monitor at the output of the mixing manifold continuously measures the CH_4 content of the incoming mixture. In the event that the CH_4 content exceeds 11%, the monitor will trip and shut off the flow of CH_4 to the system. All analyzers are read and archived with the computer-based Data Acquisition System.

1.5. Purification

O_2 and H_2O contamination is controlled with a dryer and purifier which withdraw a portion, about 40–45 l/min, of the flow upstream of the 30 mbar regulator and deliver the conditioned mixture to the recirculating flow upstream of the 2.4 mbar regulator. This loop is controlled by the computer control system and used only as needed to maintain low O_2 and H_2O levels.

The dryer is made from a stainless steel tube containing 10 lbs (4.5 kg) of molecular sieve (Zeolite 13X) adsorbent. This amount permits the removal of about 3 lbs (1.4 kg) of water vapor to a level of 2–5 ppm at room temperature. Filters are installed upstream and downstream of the adsorbent to prevent Zeolite dust contamination of the rest of the system. The absorbent column is equipped with a heater coil and insulating jacket for regenerating the absorbent. The dryer is regenerated by heating to 350–400°C while purging with Ar or He gas. The purge gas enters at the top of the dryer and exits at the bottom, carrying with it the water vapor. A temperature transmitter fixed on the outside of the tube and connected to a Dwyer controller (TIC-1) regulates the coil temperature. Solenoid valves installed at the intake and outlet of the dryer isolate the unit from the main circuit when it's not in use. A H_2O analyzer is used to measure the quantity of H_2O in the circuit before and after the dryer to determine when the adsorbent is saturated.

The purifier is similar in mechanical construction to the dryer, but it is filled with a catalyzer that permits the oxidization of CH_4 (C_2H_6) by O_2, present as an impurity, to form alcohol. The dryer subsequently removes the alcohol. The catalyzed oxidization process takes place at 210–220°C. This purifier does not require regeneration but must work in conjunction with the dryer. The dryer can be used separately as required. Initial tests with the TPC show that the catalyzer must be used continuously to maintain an acceptable 19–22 ppm O_2 level with a gas refresh rate of 15 l/min. The equilibrium O_2 level is 60 ppm without the catalyzer.

Two safety valves, PSV-1 and PSV-2, prevent accidental over pressure of the dryer and purifier during purging. A 10-μm filter is installed after the purifier/dryer prevents dust from passing into the main mixture supply line. Dust buildup in the filter is monitored with a Dwyer's differential pressure transmitter (PT-9).

2. TPC gas system control and data acquisition

2.1. Alarm and interlock system

The alarm/interlock system provides warnings, prevents fault conditions and takes corrective action automatically if specified parameter limits

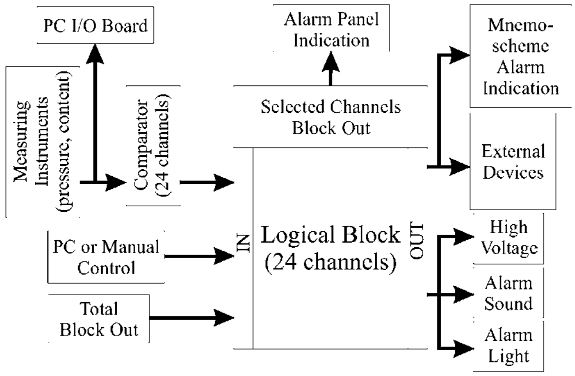

Fig. 4. Block diagram of alarm/interlock subsystem.

are exceeded. These actions include stopping the gas system compressor and shutting off ignition sources in the TPC and turning off flammable gas at the source. The alarm/interlock system design is based on solid-state relays. This system operates in parallel with the computer control system and in many cases provides redundant control. A block scheme of the Alarm system is shown in Fig. 4. A list of fault conditions and the system's response is contained in Table 2.

2.2. Data acquisition and control

The gas system is controlled by a PC-based DAQ subsystem (Fig. 2) that consists of three separate devices. The first one is a barometer for measuring the atmospheric pressure [3]. The second is a commutator for temperature measurements at multiple points. Each of these two devices is based on an Intel 8031 microcontroller and is connected to the main computer with a standard RS-232 interface. The third device is a custom I/O board, which was developed for the Gas System. This I/O board has 32 analog input channels, 8 analog output channels, 32 digital output channels and, optionally, 8 digital input channels. There are 32 sensors connected to this board: 10 pressure transmitters, 6 pressure indicators, 5 flowmeters, 2 flow indicators and 9 content analyzers. The board also controls 22 solenoid valves, 3 compressors, 2 alarm indicators and an interlock for ignition sources in the TPC. Analog output channels are used to control flowmeters. Each analog input

Table 2
List of fault conditions

Condition	Description	Action
PT1 < 50 mbar	Output of compressor—input of PCV1	Alarm
PT7 < 0.0 mbar	TPC Volume-TPC Gap	Alarm
PT5 < 0.3 mbar	Output of TPC—input of compressor	Alarm, stop compressor & HV, Purge
PT1 > 2.5 mbar	Output of TPC—input of compressor	Alarm, stop HV, Fresh Gas, Open SV18 (Vent)
CH_4 < 9.0%	M3a Methane return gas	Alarm, Stop HV
CH_4 > 11.0%	M3a Methane return gas	Alarm, Stop HV & Methane In
C_2H_6 < 49.6%	M3b Ethane return gas	Alarm, Stop HV
C_2H_6 > 50.4%	M3b Ethane return gas	Alarm, Stop HV & Ethane In
O_2 > 80 ppm	M1 Oxygen content of return gas	Alarm, Stop HV & Compressor
H_2O > 80 ppm	M2 Water content of return gas	Alarm, Stop HV & Compressor
PT9 > 80 mbar	Pressure across dryer filter	Alarm
PT10 > 12 mbar	Pressure across main filter	Alarm
PS1 < 0.5 mbar	Small compressor	Alarm
CH_4 > 11.0%	M4 Fresh methane	Alarm
PI8 < 0.5 bar	Argon supply Rack 3	Alarm
PI9 < 0.5 bar	Methane supply Rack 3	Alarm
PI13 < 0.5 bar	Argon supply on pad	Alarm
PI14 < 0.5 bar	Methane supply on pad	Alarm
PI15 < 0.5 bar	Nitrogen supply Rack 3	Alarm
PT2 > 2.5 mbar	TPC Inlet pressure	Alarm
O_2 > 0.1%	M5 Oxygen meter	Alarm

channel has overvoltage protection and uses signal averaging (0.2 mV accuracy in 0.7 s) to reduce the noise effect in the cables.

The software for microcontroller devices was written in 8051 assembly code. The barometer software reads out the pressure sensor, shows pressure in one of the three allowed units (mbar, mmHg and kPa) on a LCD indicator and responds to the main computer requests for pressure values. The commutator software provides reading of up to 16 temperature sensors connected in a four-wire scheme. The commutator code also handles four RS-232 ports, one master port for main computer and three slave ports for other devices. One of the slave ports is connected to the barometer. The software accepts requests from the main computer to establish a "transparent" connection to one of the slave ports or to send all the temperature values.

The main computer software (Fig. 2) has been developed with Borland Delphi 5 [2] for Windows 2000. It provides reliable data acquisition, alarm conditions handling and manual control of the Gas System. The software also logs all events and process variables, transfers data to EPICS [4] and publishes all the process variables on the World Wide Web. All these tasks are distributed between multiple processes that communicate making use of special operating system kernel objects.

Gas System Controller is the heart of the DAQ software. In order to make DAQ more reliable it has been divided into two threads: one for the Graphical User Interface (GUI) and one for the data acquisition. The GUI thread is composed of three windows: manual control window, system parameters window that shows process variables, and configuration window for all preferences and settings. The DAQ thread acquires all the process variables, writes them into shared memory and checks alarm conditions. Every alarm settings contains alarm threshold, alarm message and control template, which indicates alarm set and release action for every controlled device, e.g. valve or compressor. This allows user to have a very flexible configuration of system behavior.

The Data Writer reads current process variables acquired by the main process and writes them to the MS Access database. Using a separate process for this critical operation improves overall software stability and decreases response time for gas system events. The EPICS process is very similar. It just sends all process variables to EPICS software through a TCP/IP network [5]. There are two ways for the data—it can be either saved to a remote disk on a Unix machine or sent directly to the EPICS database making use EZCA library for Win32 platform.

All data from the TPC gas system are kept in MS Access database, giving one a possibility to use native MS Access tools for converting and analyzing these data. Besides, this simplifies dramatically access to the certain data in a huge database (for example, 3.5 month database has approximately 200 thousands of records). Sometimes it is useful to get fast results and charts from the database during the gas system operation. A special tool for working with the database has been developed. This program (DB Viewer) provides visualization of the data from any system sensor at any given date for one of three periods (day, week or month). It also allows user to convert data from the database to tab-delimited text file for external analysis. Web server for the gas system was built with Delphi and provides remote access to the database and current system parameters. It also works as a server for the special client using XDR-based UDP protocol.

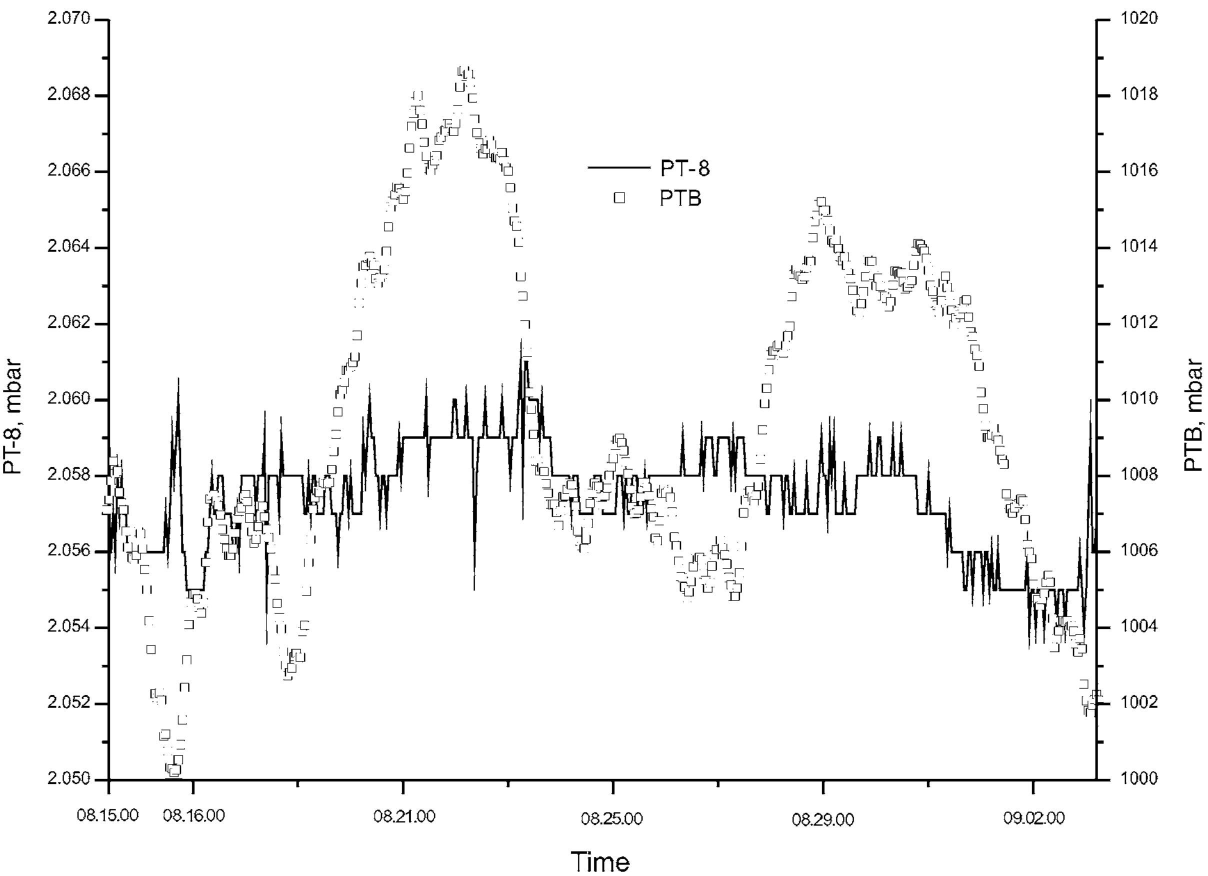

Fig. 5. TPC Pressure stability test. Rectangles correspond to barometric pressure (PTB), TPC internal pressure (PT-8) is shown as a solid line.

3. TPC gas system experimental pressure stability

The STAR TPC Gas System was tested at Lawrence Berkeley National Laboratory and Brookhaven National Laboratory.

The results of the pressure stability test with the full TPC volume are shown in Fig. 5, along with the barometric pressure. In this test the PT-6a pressure transmitter signal was used as the feedback signal by PID Controller. The pressure was measured with PT-8 pressure transmitter setting on the TPC. Although the barometric pressure varied in the range of ± 9.3 mbar during the testing period, the inside TPC pressure was stable at 2.057 mbar within the range of ± 0.0035 mbar. This shows that the TPC Gas System can support a constant pressure difference between the inside pressure and the outside barometric pressure with a stability of ± 0.004 mbar.

Using the PT-6 pressure transmitter as the feedback PID Controller signal gives ± 0.03 mbar internal TPC pressure stability.

References

[1] H. Wieman, et al., STAR TPC at RHIC, IEEE Trans. Nucl. Sci. 44 (1997) 671.

[2] Borland Delphi Home Page http://www.borland.com/delphi.

[3] S. Kozlov, L. Kotchenda, P. Kravtsov, Digital Barometer for Slow Control Systems, Instrum. Exp. Tech. 3 (2000) 166.

[4] A.J. Kozubal, et al., Experimental Physics and Industrial Control System, ICALEPCS89 Proceedings, Vancouver, 1989, p. 288.

[5] J. Lin, et al., Hardware Controls for the STAR Experiment at RHIC, IEEE Trans. Nucl. Sci. 47 (2000) 210.

Gas System

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The on-screen version of the Collider-Accelerator Department Procedure is the Official Version.
Hard copies of all signed, official, C-A Operating Procedures are available by contacting the ESSHQ Procedures Coordinator, Bldg. 911A

C-A OPERATIONS PROCEDURES MANUAL

11.4.1 STAR Flammable Gas Procedure

Text Pages 2 through 3

Hand Processed Changes

HPC No.	Date	Page Nos.	Initials

Approved: ___________***Signature on File***_________________ ______
Collider-Accelerator Department Chairman Date

W. Christie

11.4.1 STAR Flammable Gas Procedure

1. Purpose

The scope of this procedure is those safeguards and operations that are necessary for turning on flammable gas for a STAR detector gas system.

2. Responsibilities

The flammable gas system operator is responsible for seeing that all steps and conditions outlined in this procedure are followed or complied with when introducing flammable gas into the detector.

3. Prerequisites

In order to operate any of the STAR flammable gas detection systems, the following requirements must be met:

3.1 C-A User training

3.2 STAR Gas system authorization. (See C-A-OPM-ATT 11.4.1.a and C-A-OPM-ATT 11.4.1.b)

3.3 All personnel working on any electrical system or equipment in the C-AD shall be familiar with BNL SBMS Electrical Safety, BNL SBMS Lockout/Tagout (LO/TO), C-A-OPM 1.5, "Electrical Safety Implementation Plan", C-A-OPM 1.5.3 "Procedure to Open or Close Breakers and Switches and Connecting/Disconnecting Plugs", C-A-OPM 2.36, "Lockout/Tagout for Control of Hazardous Energy". C-AD will provide on-site/work specific training to individuals in the electrical safety aspects of their job functions and assignments.

4. Precautions

Before initiating flow of flammable gas, the following precautions must be taken.
The checklist for items 4.1 through 4.10 below, available as C-A-OPM-ATT 11.4.1.c, must be filled out by the gas system operator and filed with either the STAR Detector Support group leader, or the STAR Technical Support group leader:

4.1 A shift schedule must be in place. For the duration of time that the flammable gas is in the detector system, a manned shift must be in place at the STAR site.

4.2 The chamber to receive the flammable gas must have been properly purged.

4.3 All high voltage to the subsystem receiving flammable gas must be off.

4.4 The flammable gas detection system, which resides on level 2 of the South electronics platform, must be operational.

4.5 The STAR Global Interlock System (SGIS) must be operational.

4.6 The flammable gas operator must get the approval of the relevant detector subsystem manager. The relevant detector subsystem manager must receive the permission of the STAR Detector Support group leader.

4.7 The C-A Operations Coordinator (OC), (x4662), and the MCR Group Leader/Deputy Group Leader, must be informed that flammable gas is about to be introduced into the detector. The MCR Group Leader and Deputy should be informed via email (ingrassia@bnl.gov and sampson@bnl.gov).

4.8 The Collider-Accelerator Support (CAS) watch supervisor must be informed that flammable gas is about to be introduced into the detector. This can be accomplished by asking the C-A Operations Coordinator to inform the CAS watch supervisor.

4.9 The "Blue sheet" for the SGIS must be currently certified.

4.10 A list of experts for the relevant gas system, with phone numbers, must be posted.

5. Procedure

See the STAR Documented Work Procedure (DWP) for the appropriate subsystem listed in section 6.0.

6. Documentation

Each subsystem using flammable gas has its own procedure for start up, maintenance, and monitoring.

6.1 Operating the TPC Gas System SOP-TPC-GAS-03-A

7. References

7.1 C-A-OPM 1.5, "Electrical Safety Implementation Plan".
7.2 C-A-OPM 1.5.3 "Procedure to Open or Close Breakers and Switches and Connecting/Disconnecting Plugs".
7.3 C-A-OPM 2.36, "Lockout/Tagout for Control of Hazardous Energy".
7.4 SBMS Electrical Safety.
7.5 SBMS Lockout/Tagout (LOTO).

8. Attachments

8.1 C-A-OPM-ATT 11.4.1.a "List of authorized operators for the STAR TPC gas system".
8.2 C-A-OPM-ATT 11.4.1.c "STAR Flammable Gas Procedure Checklist".

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Ordering TPC gas (methane and Argon) valid summer 2008

We order methane and Argon from Praxair, who are the official suppliers of gas for all of BNL. However, the ordering goes through different paths.

Methane:

STAR owns three sixpacks (6 1A size cylinders ganged together on a cart). The STAR sixpacks are made up of silver colored cylinders that are marked BNL, STAR and 1006. The bottles were recently re-certified by Praxair and don't need to be certified again until 2012. Praxair usually will repair any damage to the manifold on top of the six pack. For normal operation we only use these 3 six packs since we know they only have had high purity methane in them. As a back up emergency I keep on hand a Praxair owned six pack (red bottles) to be used only if none of ours are available. This happened in 2007 because of the Christmas and New Year's holidays and a problem with one of our 6 packs.
We use "Ultra High Purity" methane (Praxair grade 3.7). which should have $O_2 < 10$ ppm and $N_2 < 40$ ppm. One six pack under normal usage (i.e. recirculation mode) lasts 2 weeks. Praxair usually sends a truck for pickup and delivery once a week on Tuesday, and it takes 2 weeks to refill a 6 pack. So, under normal usage, one 6 pack is in use, one is in standby, and one is being filled.

To order a pickup or to check on delivery:

1. Call Praxair at 1-800-772-4059
2. Ask for our account rep, who is currently Jennie. Identify yourself as being from BNL and Bldg 1006 - use my name to jog her memory!
3. Tell her you have a methane 6 pack ready for pickup and confirm if they have one coming back.
4. Make sure the 6 pack for pickup is rolled out to the edge of the covered area on the gas pad. The truck usually comes at ~ 8:30 on Tuesdays and I try and be around when he delivers. The driver will load and unload.
5. The methane is paid for using a BNL standing PO. Usually once a year it has to be refilled with money by transferring funds from STAR. Contact Liz Mogavero or Bob Soja to arrange this.

ARGON:

We have a 900 gallon liquid Ar tank on the gas pad. The tank is rented from Praxair and they are responsible for maintenance and repair, if needed. (We've never had a problem.) We pay a monthly rental fee and for bulk LAr when the tank gets filled. As for methane, there is a standing PO to pay for the rental and LAr which gets renewed every year - see Liz or Bob for particulars. The quantity on hand in the tank is measured by a gauge at the tank - measurement is in inches. A full tank is 120 inches and we usually call for a refill when the tank gets to 30 inches. (We are required to keep sufficient product on hand to

purge the TPC in an emergency, hence the limit of 30.) The contract requires Praxair to fill the tank within 48 hours of our phone call. You do not have to be present for the delivery - the driver knows what to do and refilling does not interfere with the Ar flowing to the TPC gas system. The driver is already qualified to get past the BNL gate and the posted signs if we are running. The driver will leave the invoice in a green canister at the tank.
For normal operation, a full tank will last 2 months. If STAR is shutdown a small amount of gas is still used by the PMD group and the rest is lost to boil off - in this case a full tank lasts 3 months. We never let the tank warmup - to refill a warm tank takes ~ 50% more LAr, so it is cost effective to always keep it cold.

To order a refill:

1. Call 1-800-praxair (1-800-772-9247)
2. It is an automated system to start with - select the choices to order product for an existing account.
3. When asked, enter our Praxair number - 8523548
4. An operator will come on the line - tell her you want a refill of our tank. She will ask you the reading and when it was taken and your name etc. Request the fill within 48 hours. She will give you a confirmation number.
5. Hang up.
6. Check after 48 hours that the tank got filled - note that I normally don't ask for delivery over the weekend or after hours because of possible BNL gate or receiving problems.

A folder labeled "Supply-Gas" with historical documents (initial spec on the tank etc) and past order history is kept in my desk drawer at the counting house.

Startup of TPC gas system after summer shutdown valid 7/14/2009

This procedure brings the TPC gas system to a ready state after the long summer shutdown. During the shutdown power to all racks is off and the TPC is continuously purged with N2 through the analog flowmeter FI5. This procedure will power all racks, boot the control computer, turn on all meters (O2, H2O, CH4 etc) and start the small compressors.

1. Make sure the circuit breakers on top of Racks 2, 3, and 4 are on. Turn them on if they are off - use appropriate PPE.
2. Push the green button on the TPC interlock panel (Rack 4) labeled "Gas System Power".
3. Check that the red LED on the solid state relay mounted on the wall between Racks 2 and 3 is on - this supplies the power to Rack 2.
4. Turn on the CAI methane meter M3a (Rack 3)
5. Turn on the two Illinois Oxygen meters M5 and M1 (AC switch on the back of each meter inside Rack 3)
6. Open the exhaust valve for M1 and M5 (mounted on the back of the meter)
7. Crack open the input valve on M1 and M5 ¼ turn (mounted on the back of the meter.)
8. Plug in the small compressor SC3 (located inside Rack 3) (Supplies flow to M5)
9. Adjust the flow on M5 by turning the input valve - set flow to be between 0.1 and 0.2 lpm. If you need to make a courser adjustment than is allowed by the input valve, then adjust the unmarked bypass valve that goes around SC3.
10. Turn on the CAI methane meter M4 (top of Rack 2)
11. Confirm that there is N2 flowing to the TPC through FI5 (Rack 2) - adjust to the arrow if needed.
12. Turn on the lower hardware alarm box (Rack 1). The AC switch is on the back of the box.
13. Turn on the power for the SCXI input/output crate (Inside Rack 1)
14. Turn on the power for the temperature controller MUX box (Inside Rack 1). AC switch is on top of the box.
15. Turn on the power for the three Hastings mass flow controllers (Rack 1). The AC on is a rotary dial on each controller.
16. Plug in the water meter M2 (inside Rack 1)
17. Turn on the control computer and monitor and allow it to boot up.
18. Log into the control computer and start the gas system control program - double click on the icon labeled "Star_New".
19. Using the control program close SV12 if it is open. (Closed = red)
20. Open SV13 (open = green). This is the inlet valve for the small compressor SC1
21. Open SV6,SV7, SV8, SV17
22. Using the control program, start Small Compressor 1 (SC1) and Small Compressor 2 (SC2).
23. Check the output pressure for SC1 on PI2 (Rack2). Adjust the pressure to be between the marks using the bypass valve MV16.

24. Check the output pressure for SC2 on PI8a (back of Rack 2). Adjust the pressure to be on the indicator line using the bypass valve MV17.
25. Check the flow for M2 on FI3 (back of rack 2). See the checklist for flow range.
26. Check the flow for M4 on FI2a (front of Rack 2) and adjust if needed.
27. Check the flow for M3a on FI4 (front of Rack 3) and adjust if needed.
28. Adjust the flow for M1 Oxygen meter by turning the input valve for M1 (inside Rack 3) - set the flow between the marks on FI2. (This is very sensitive!)

This next section starts the meters and pump for the gap gas (N_2):
During the summer shutdown, ~ 10 lpm N_2 goes to the gap through FI10 (Rack 3).

1. At Rack 4, open MV52 and close MV54 - this path selects fresh gas for the meters.
2. Plug in M7 (H_2O) (inside Rack 4) and turn on M6 (O_2) (AC switch on back of the meter.)
3. Check that FI10 (Rack 3) reads ~ 10 lpm.
4. Turn on the sample pump (switch on the control panel in Rack 4)
5. Check the sample flow (FI55) - it should be ~ 2 lpm.
6. Let the meters warm up for a few hours.
7. Open MV52 and close MV54 - this will sample the return gas from the gap.
8. After a few hours, check the meters readings. H_2O < 10ppm, O_2 < 20 ppm.

If this startup is in preparation for a new run, then you can also do the following steps:

1. If Leonid has already regenerated the purifier and dryer and the run will start in a week or so then turn the Purifier on using the computer control, The purifier will come on and heat up to the set point (~ 210 degrees C). Check after a few hours that it is regulating at this setpoint. For normal running the dryer is OFF.
2. Check that the computer data is being written out to slow controls. In the lower task bar (right side) find and left click on the icon "EPICS communicator". If the data is being successfully written you should see the message "Data saved to files" with a date and time stamp. The box next to "File writing to" should be checked and the path should be \\sc.starp.bnl.gov\gas_sys_data\ The box labeled "Direct connection to Epics channels" should NOT be checked. This process writes the gas system data to SC. You should also check the gas system GUI on CHAPLIN (accessible from the Top Level GUI) - the data should be refreshed every ~ 1 minute. If the data is not being written to SC or is not being updated on the GUI contact Wayne Betts and a slow controls expert. Also see page 148 in the gas system logbook.
3. If this is the start of a new run you also need to create a new local database on the gas system control PC. In the task bar (lower right) left click on "dbwriter". You should see the message "Data saved to database" with a date and time stamp. Click on the "Create New Database" button and create a new database identified by the year's run number (currently Run8). Close the window. Then from the desktop open the program dBviewer and click on "Change database". Select the new database that you just created (should be in the folder "databases"). After a

few minutes , check that the dBviewer program is displaying data from the new database (i.e. there should not be any data before the current day.)

Go to the "Procedure to start 100 lpm Argon Purge in TPC".

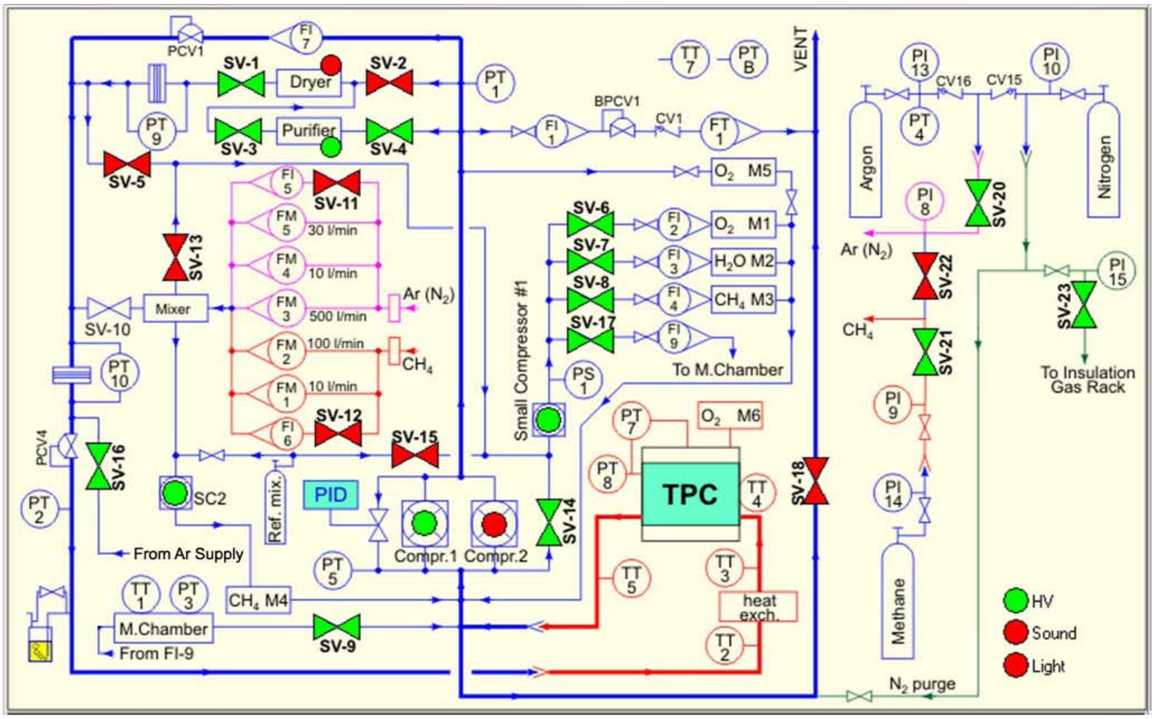

Figure 1: Gas System Schematic Diagram: Normal Circulation Mode Shown

11/19/2007
BCS

Procedure to start 100 lpm Argon Purge in TPC

1. Open MV30 (Ar inlet) located on the wall in mixing room. As Ar pressurizes the line you should hear the opposing check valves (CV15 & CV16) click - this stops the N2 flow and lets the Ar start flowing to the chamber.
2. Reduce the N2 regulator PCV2 to ~18 PSIG (located on the wall.) This further seals the check valves.
3. Open MV6 (Inlet valve for FM3 on rack 2)
4. On right Hastings controller (Rack 1) select FM3 (Channel 3)
5. Using computer, set FM3 to 100 lpm The Hastings response is sometimes ~slow.
6. Close SV11 (use computer) - stops the maintenance purge flow - red light means closed.

Note: Always stop the maintenance flow by closing SV11. NEVER close the manual valve on the flowmeter FI5 itself - this manual valve should remain open to provide the purge flow if the system shuts down automatically during running.

7. Check FM3 command/flow - command should be 100, flow should be 98 - 102. If flow is < 100, increase the delivery pressure for the Ar on PCV5 on the wall.
8. Close MV9 fully - this stops Ar from back-flowing through the compressor bypass valve.
9. To purge the supply stub that goes to the bubbler, open MV14a (bubbler bypass)
10. Read level at Ar tank
11. Note time in logbook.
12. If N2 has been in the chamber, flow Ar at 100 lpm for six volume exchanges. TPC volume is 50,000 l, so this takes ~ 50 hours.

At various times during this purge open MV9 all the way and run each of the big compressors for a few minutes (one at a time!). Leave SV18 OPEN. This gets N2 out of the nooks and crannies. Be sure and close MV9 fully after this or the Ar will short circuit out the vent.

The day before the P10 purge calibrate the methane meters. (Zero and span).

Go to the “Procedure to start high flow P10 purge in the TPC”

Procedure to start high flow P10 purge in the TPC valid 7/14/2009

This procedure is used to flow P10 gas into the TPC before turning on the recirculation.

1. Make sure the TPC is filled with AR - see the Ar purge procedure. Typically you should flow Argon at 100 lpm for 50 hours to exchange 6 volumes of gas. This will remove all of the N2.
2. Obtain a copy of the “STAR Flammable Gas Procedure Checklist” from the CAD web pages (http://www.c-ad.bnl.gov/ESSHQ/SND/OPM/Ch11/11-4-1-c.pdf) or obtain a copy from the TPC Operations page (listed as “Checklist for Flammable Gas Startup and Blue Sheet”). Fill out this checklist as you go through the remainder of the P10 startup procedure. When the checklist is complete, keep it on file as proof that the blue sheet was signed (see below).
3. STAR is not allowed to flow methane until the safety systems have been certified for the year. If this has been done (contact Bill Christie and the STAR liason engineer), call the RHIC MCR and ask for the operations coordinator. Tell the operations coordinator that you are ready to start flowing flammable gas (methane) and ask them to send the CAS watch down to STAR with the “blue sheet”. As TPC system manager, sign the blue sheet in the areas indicated by the CAS watch - this certifies that the TPC has been readied for methane etc.
4. Confirm from the STAR shift sign-up page that there is a 24 hour watch in place for STAR (at least one shiftleader and one detector operator.) Tell the current shiftleader that you will be starting methane flow. Make sure the TPC alarm box on the wall is plugged in and active. Make sure the contact numbers for the gas system expert are posted in the STAR control room and in the gas mixing room.
5. In the gas room, confirm that there is 100 lpm Ar flow in FM3.
6. On the gas pad, connect the flexible hose from one of the methane 6-packs to the wall mounted methane manifold. CGA connections are LEFT handed threads.
7. Open the bottle valve for each of the 6 bottles.
8. Open the 6-pack outlet valve which is connected to the flexible hose.
9. Using a wrench, crack open the fitting where the flexible hose connects to the manifold - this will purge the line. Let gas flow for ~ 10 seconds. Tighten the connection.
10. Open the manifold inlet valve, (MV26A or MV26B) and turn the two way valve MV26 so it selects the attached 6 pack. Confirm the delivery pressure on PI14 - it should be ~2000 PSIG for a full 6 pack.
11. In the gas mixing room open the manual valve MV25, behind Rack 3.
12. Using the control PC, close SV22 and open SV21.
13. Confirm the methane delivery pressure on PI9 (Rack 3) Should be ~ 15 PSIG.
14. Open the manual valve MV7 on rack 2. This is the inlet valve for FM2.
15. In Rack 1, select FM2 on the left hand Hastings controller. FM2 is the high-flow methane flow meter that is slaved to FM3. Check that the command value for FM2 is ~ 10.7. Switch to flow and confirm methane flow of 10.7.
16. Confirm on methane analyzers (M4 and M3) that input gas is now ~ 10.0 %. If needed, adjust the slave pot on the FM2 controller to get 10.0% methane in.

Note: Before starting P10 purge flow, the methane analyzers M3 and M4 should have been calibrated. However, the methane reading will vary with barometric pressure, so this needs to be taken into account. The variation is ~0.1% per mbar. Use the Excel spreadsheet on the TPC operation web page to create a calibration plot.

The purpose of this initial purge is to get close to 10% methane in the chamber. The final (constant) percentage will be set by setting the mass flowmeters during normal running. This process will take a few days.

17. Record the time, Ar level in the tank and the methane bottle pressure (PI14).
18. Since the system is in purge mode the alarms are still not active. During the P10 purge we have the STAR shift crew check the system every 2 hours through the night. So put post-it notes with canonical values and ranges on the following gauges: M4, M3, FM2, FM3, PT8, PI8, PI9, M1. The crew should call the expert if readings deviate from the posted values over night. Let the system purge 18 hours.
19. Send an email to the following people informing them that you have started flowing P10 in the TPC: ingrassia@bnl.gov, sampson@bnl.gov, pendzick@bnl.gov, chrisite@bnl.gov, soja@bnl.gov
20. Confirm that MV3A and MV3B are directed to "P10 to SV16" position
21. Open P10 cylinder and set 22PSIG pressure on PI52 using PCV50 pressure regulator(Gas Pad)
22. Open SV16 to purge the line for 20seconds and then close SV16 using PC

After the 16 hour purge we need to make sure P10 gets to all parts of the system and also check the return methane percentage and oxygen level.

1. Open SV1, SV3, SV4 using the PC. This opens the purifier/dryer path.
2. Open the bubbler bypass valve MV14a for ~ 1 hour.
3. Open MV9 (the big compressor bypass valve) fully.
4. Make sure SV18 is open.
5. Turn on the circuit breaker for the big compressor 2 (BC2) at the bottom of rack 2. Using the PC turn BC2 on and run for ~ 1 minute.
6. Turn BC2 off and turn BC2 breaker off.
7. Turn BC1 on. Running in this mode (SV18 open, MV 9 open, PID controller OFF) allows for purging and recirculation simultaneously.
8. With BC1 on, check the return gas. Open SV14 and close SV13.
9. Read the return O2 on M1 (should be ~ 10 ppm) and the return water on M2 (should be < 20 ppm).
10. Check the return methane content on M3. It will probably read low (<9.5%).
11. Leave the system in recirculation/purge mode. At this point, you can raise the input methane content to ~11% by adjusting the FM2 slave pot.
12. Continue like this until the return methane content is 10.0% adjusted for barometric pressure.

(continued on next page)

When the return methane content is ~10.0%, prepare the system for normal operation.

1. Open SV13 and close SV14.
2. Turn off BC1
3. Set the FM2 slave pot back to ~10.7.
4. Close the bubbler bypass valve MV14a.
5. Close MV9 fully.
6. Go to the recirculation startup procedure "Procedure to put TPC gas system into normal operation (recirculation mode)". The final adjustment of the methane ratio will be done during normal recirculation and takes a couple days.

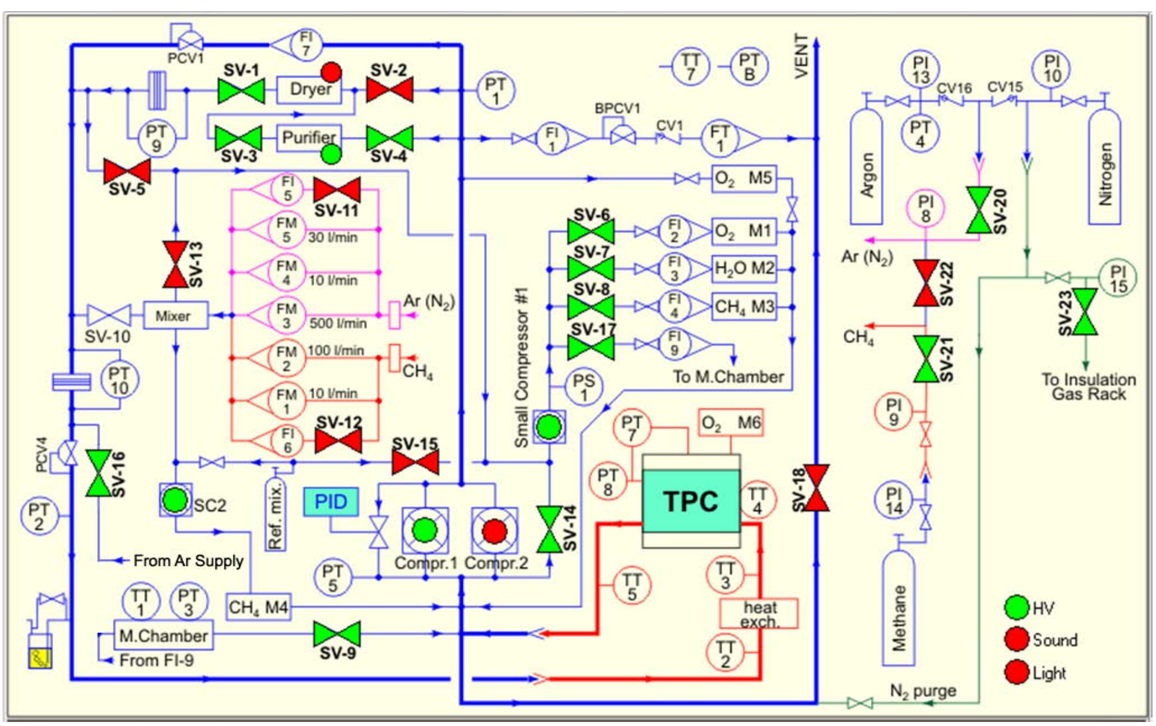

Figure 1: Gas System Schematic Diagram: Normal Circulation Mode Shown

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11/21/2007

Procedure to put TPC gas system into normal operation (recirculation mode).

This procedure assumes that the system in is P10 high purge mode (i.e. 100 lpm Ar and 10 lpm Methane flow rates).

1. Open MV4 (manual valve for FM5). Open MV8 (manual valve for FM1.)
2. On the computer, set FM3 to 0 and set FM5 to 16.0 (this is the fresh gas makeup flow for recirculation mode). The course setting for Flow Meters is done with the mouse and the slider. Fine adjustment can be done with the right arrow to increase the flow by a small increment.
3. Close the manual valves MV6 and MV7.
4. On the right hand Hastings controller, select FM5 and confirm the command and flow are set to 16.0. If the reading are unstable, adjusting the argon or methane pressure in step 6 will help.
5. On the left hand Hastings controller, select FM1 and set the slave pot to a command of 1.55. This sets the canonical methane percentage for the run.
6. Reduce the Argon regulator PCV5 to ~18PSIG. On Rack 3 confirm that the Argon delivery pressure (PI8) is ~ 2 PSIG greater than both the methane pressure (PI9) and the N2 pressure (PI15).
7. Confirm again the settings for FM5 and FM1. Also check the methane content reading on M3 and M4 - they should be ~ equal, within the calibration accuracy.
8. Make sure MV10 (Rack 2) and the bubbler bypass valve are closed.
9. Confirm that SV11 and SV12 are closed (red) and that SV1, SV 3, and SV4 are open (purifier path).
10. Open MV9 (compressor bypass valve, Rack 2) ~ ¾ of a turn.
11. Turn on the PID controller (power supply inside Rack 1 at bottom right.) If not done before- check power for flowmeter FI7 and Hydrometer(M2) on rack1.
12. Open the PID controller display program (PID_NEW) and click on “Start”. The program should start to scroll and show the set point (red line) and reference pressure (yellow line).
13. On rack 2, clear the latch for both SV18 and the big compressor (push buttons).
14. Close SV18 (bang!).
15. Watch pressure rise - when TPC pressure (PT8) reaches ~ 1300 microbar, start BC1.
16. On the PID display the yellow reference pressure should slowly rise up to the setpoint. At the setpoint the PID controller should start to regulate by pushing gas to the vent through FI1a. For normal operation, FI1a should vary around ~30 and PT8 should vary around 1850 microbar. The stable yellow line should be a little bit below setpoint line and it’s position is regulated by manual MV9 valve. Sometimes it could takes 10-15 minutes to stabilize. Closing MV9 pushes the yellow line down.
17. Let the system run for 5 minutes to check for stability. Then open SV14 and close SV13 - this will sample the return gas. Record the O2 and methane levels.

18. Check the hardware alarm box in Rack 1 - all of the red lights in the top row should be out - i.e., no alarms. If this is the case, enter 79 on the keypad and push unblock. All the lights on the bottom row should go out. Alarms are now active.
19. In Rack 2, adjust the redlines for PI7 to the marks on the face of the gauge.
20. Using the PC, click the HV button to change it from red to green. Confirm on the Allen-Bradley PLC panel in rack 4 that the top row of lights are all green. Push any buttons on the bottom row of green buttons that are not lit - this sets the permissive for the anode, cathode etc. There now should be NO red lights on this panel unless a key is in the over-ride position. To reset flashing button that has been in over-ride, you have to insert a key and move it to the vertical position, then remove the key.
21. Finally, on the PC, click the “Enable Alarms” button - the program should acknowledge that the alarms are active.
22. After one hour, fill out the two page check list to make sure all parameters are within normal limits.
23. Confirm that the “Flammable Gas” signs on the two access doors into the WAH are turned around.
24. Make a STAR shift log entry that P10 is started and alarms are active.
25. At the first opportunity (no beam or stable beam) turn on the TPC HV and do a laser run - for good gas the flash off the central membrane should be in ~time bins 345 to 350.

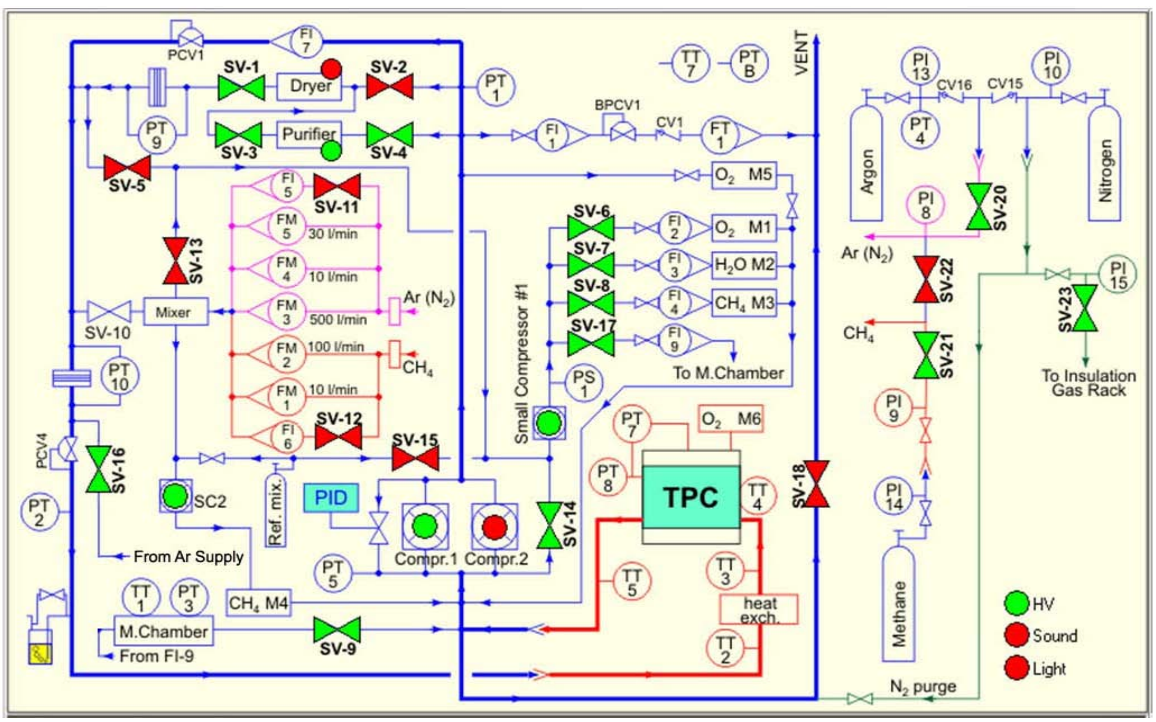


Figure 1: Gas System Schematic Diagram: Normal Circulation Mode Shown

Unanticipated shutdown and recovery of the TPC gas system. valid 7/14/2009

Gas Room (631) 344-3122
Alexei Lebedev Cell (631) 255-4977
TPC Desk in Control Room (631) 344-8243
Jim Thomas Cell (510) 759-4936

If you have a gas alarm and you hear a recurring sound in the gas room that sounds like a person hammering on the pipes, look to see if M4 is oscillating. If so, go to the gas room computer and close SV21 immediately. This will close off the methane supply lines.

Recovery From a Re-circuation Fault

This procedure is meant to get the system back to a state where you can start a high flow P10 purge or the normal P10 recirculation mode, depending on how long the system was shut down. See the discussion at the end of this document for more information.

1. Silence the alarm (if not already silenced by the shift crew).

2. Block the hardware alarm box (enter 79, then "block alarms).

3. On the PC control screen, disable alarms. Also look at the gas system log window on the computer for clues to what might have happened.

4. If the system was shut down by SGIS then make sure SGIS is cleared and the problem fixed. Turn on the power for Rack 2; if it is off. If it is off then go to the TPC AB alarm panel and push the left-most green button on the lower row of buttons. This should turn the power back on Rack 2 by energizing the solid state relay on the wall of the gas room. You should hear the small compressors start up, and see the temperature controller for the purifier light up etc. While you are at it, check that the power is on for all 4 racks. Use appropriate personal protection to turn breakers on/off.

5. On the PC control make sure BC1 is set to "off" (i.e. red).

6. Open SV13 and close SV14. This makes SC1 sample fresh gas.

7. The Ar mass flowmeter should still be set to the recirculation value (16.0 lpm) - confirm this. If not, set it to the canonical value using the PC.

8. Close SV11 and SV12 to stop the purge flow. Confirm again that the mass flowmeter is giving 16.0 lpm

9. Close SV22 (cross-connect valve) and open SV21 (methane). Wait a bit and confirm that you have methane flow on the methane mass flowmeter (~1.55 lpm). Watch for variation of flow meters and it should be stable.

10. Check and open, if necessary, SV23 to allow nitrogen flow to the gap (it may be closed to protect the TPC. It closes when we have a PT-7 low alarm … the pressure between gap and TPC chamber goes out of range and then shuts to prevent N2 into TPC).

11. Wait a bit more and confirm that M4 and M3 read ~ 10% and M1 reads < 10 ppm.

12. Look at the dB plots around the time of the shutdown to see what might have happened while you wait for the methane content to rise inside the TPC.

13. At this point the system is stable and flowing P10 again. Go to the "Procedure to put TPC gas system into normal operation (recirculation mode)". Skip the initial steps of this

procedure (but check that all conditions are true) and start at about bullet 13. Note that you will have to lower the orange lower limit line on PI7 to zero so you can reset the interlock (red button on rack 2) and start BC1; when needed.

Once you get to normal recirculation mode, you can leave the system in this configuration and the methane concentration will slowly recover to its nominal value (10%) over a period of several days.

14. Or, alternatively, you can proceed to the instructions for starting the high rate P10 purge flow (100 lpm) by using the high flow mass flowmeters etc. The high rate P10 purge will recover the methane concentration in about 6 hours.

Go to the "Procedure to start high flow P10 purge in the TPC". Once this procedure is complete, and the high rate purge flow has started, check the return gas for the methane content and O2. To do this: open MV9 all the way, turn on the PID controller, leave SV18 open and start BC1. Make sure that SV14 is open and SV13 is closed (if they are not already in this state). Once you have a stable readings for CH4 and O2, turn off BC1, turn off the PID controller, and close MV9. The methane level you measure at the beginning of the purge will tell you how long you'll need to purge before restarting recirculation. Clearly, the longer the system was shut down and on Ar purge, the longer it will take to get going again. (It takes about an hour for every 0.1% below 10% if FM3 is set at 11.2).

When you are back to P10, start the system like you normally would with normal P10 makeup flow using the "Procedure to put TPC gas system into normal operation (recirculation mode)". Don't forget to unblock the hardware alarm box.

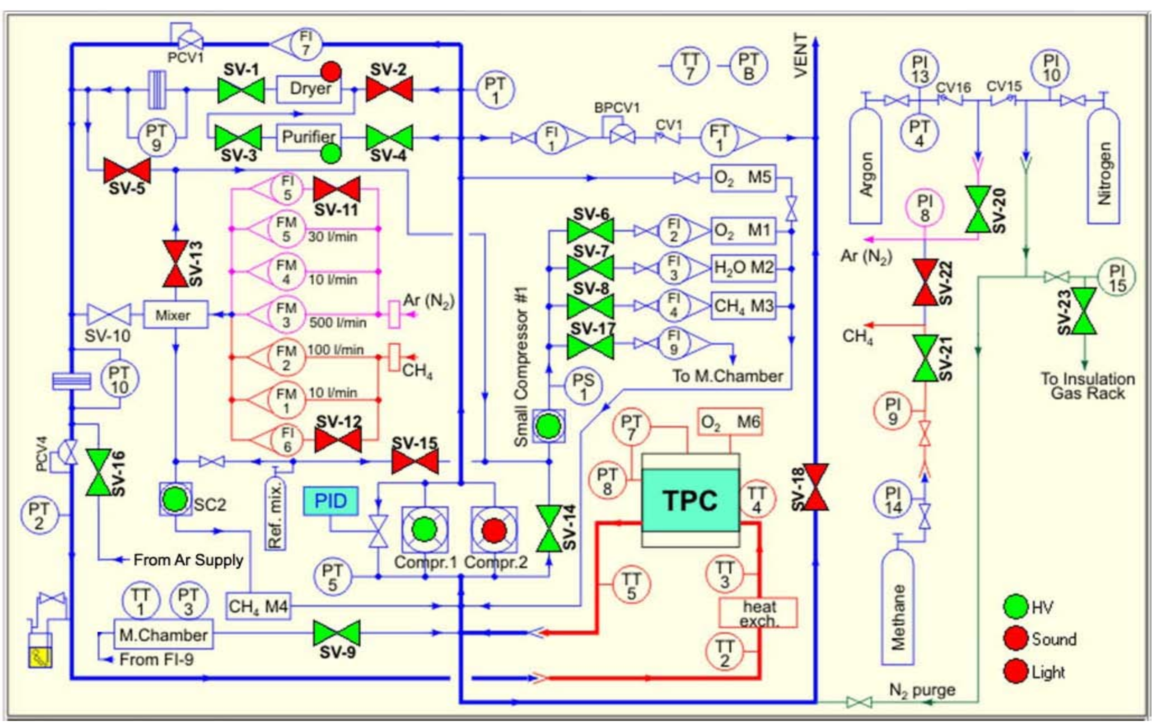


Figure 1: Gas System Schematic Diagram: Normal Circulation Mode Shown

Additional thoughts and notes from BCS 2/24/2009

I'll try and cover some of the past unplanned shutdowns of the system and the recovery procedure I used. The most probable reasons for shutdown are a valid (rare) or false shutdown signal from SGIS, a rapid RISE in the atmospheric pressure, excursions in the methane percentage above or below the alarm limit, an increase of O2 in the return gas above 80 ppm, pressure imbalance or oscillation in PT5 or PT8.

SGIS shutdown:

SGIS will send a kill signal for various reasons (high methane in the hall is the major one). This signal is passed to Jim's AB interlock system and turns off the AC power for rack 2. This shuts down BC1, SC1 and 2, the purifier, shuts off the methane (SV21) and starts the Ar purge through FI5. The chamber is in safe mode since SV18 is open and the purge flow keeps the O2 from increasing. Clearly, the methane percentage in the chamber is being spoiled from the time the shutdown occurred, so the longer the system is in this state, the longer it will take to recover to P10.

Atmospheric rise or fall:

The most common shutdown is due to a rapid rise in the barometric pressure. It is a characteristic of thunderstorms that roll through BNL that the barometric pressure will fall until the front arrives and then there always seems to be a rapid rise - the most violent I remember was ~ 3 mbar rise in < 5 minutes. The system is referenced to barometric pressure (PTB) and tries to stay 2 mbar above PTB. Unfortunately, in recirculation mode we are only putting a maximum of ~ 16 lpm of fresh gas in (if none is going out F1 or F1a) and this is not sufficient to maintain 2 mbar above PTB if the rise in PTB is too rapid or goes on too long. I'm assuming this is what happened when you had a storm last Sunday, 2/22. If you look at the dB for PTB and PT8 during that time you should see what I've just described. If the rise is too great and PT8 falls too much the system will alarm and shutdown BC1, open SV18, close the methane and start the Ar purge. Power to rack 2 will stay ON, however, so the small compressors and the purifier will stay on. (Note that an attempt was made last year by Leonid, Peter and I to have the PC control program sense the drop in PT8 and send a command to increase the fresh flow to 30 lpm until PT8 recovered. Unfortunately, when this was tried, there was a lag in the slaved methane flowmeter which is slaved to the Ar one and the fresh gas mixture deviated quite a bit from 10% - this also caused an alarm that shut the system down. So, at the moment. we have no automatic protection against these rises - pray for no thunderstorms!)

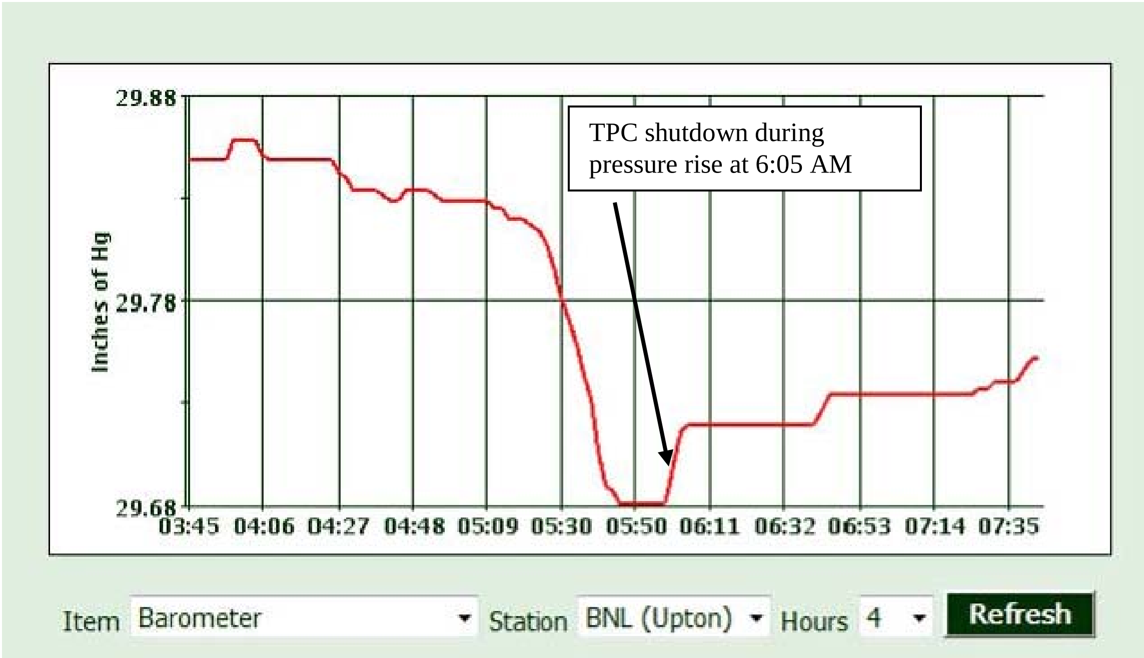
However, the system IS protected against a rapid drop in PTB. Normally, the TPC vents gas through F1 or F1a during recirculation mode. If PTB drops rapidly it could happen that F1 is not enough and PT8 will start to rise. In this case Leonid added a red-line gauge (I believe PI4) that will open a valve that vents more gas to the stack. This will continue until the pressure drops back below redline and the normal recirculation process takes over again. Since this was installed I have not seen a shutdown due to PTB fall.

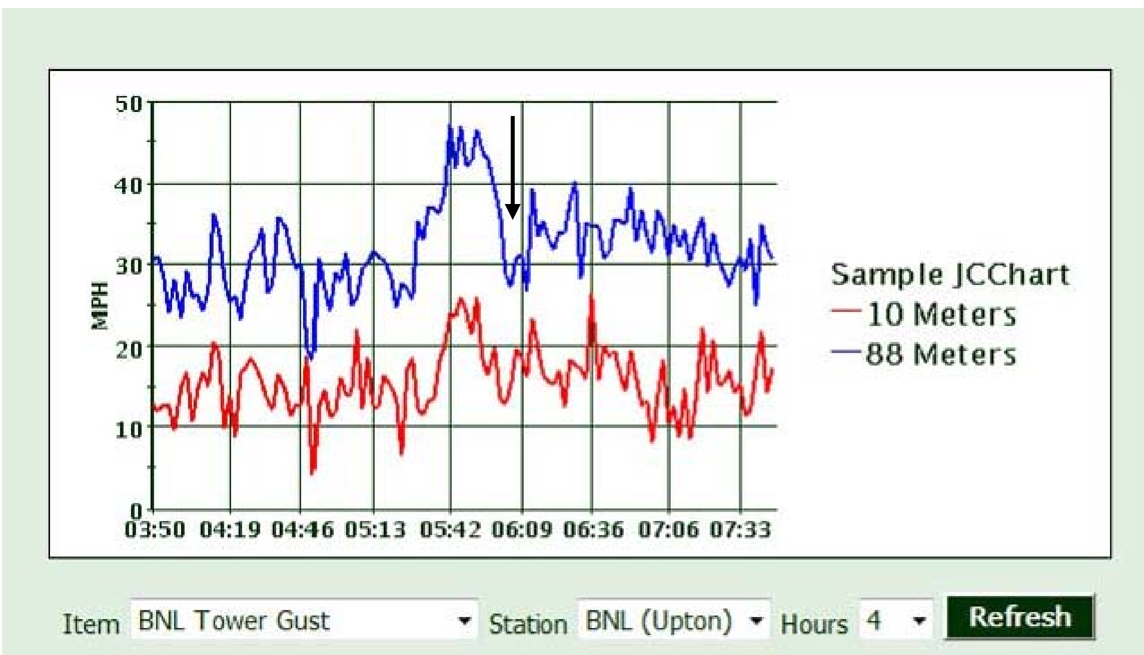
Methane excursions or O2 rise

These alarms will also cause the system to shutdown - the alarm limits are listed on the truth tables posted in the gas room. If either M4 or M3 goes too high or too low or the O2 goes above 80 ppm the system will shutdown - essentially BC1 will stop, SV18 will open, the methane is stopped (SV21) and the Ar purge is started. Everything else stays on (I believe). There are various obvious reasons for these alarms (running out of gas, methane analyzer malfunction, leak etc.) Note that when the methane bank is getting low there will be an informational alarm (no action) from PI14, at around 100 PSIG. Usually if I planned to swap banks when I came in the next morning I would warn the overnight shift that they might get an alarm - this saves getting called at 3 AM. 100 PSIG of methane should last 12 hours or more.

Pressure imbalance or oscillations in the PID controller

Usually, once the recirculation is started and the PID system is correctly adjusted the system will operate very stably. It even copes with high winds, although the excursions from the set point become somewhat greater. It can happen, however, that the system will go into rather violent oscillations, with rapid swings in the pressure before BC1 that is the reference for the PID controller (PT5). This happened to me last year after we had run smoothly for weeks(!?). I spent some time fiddling with the system, but never found a smoking gun as to why it has decided to become unstable. I finished out the run by further adjusting the PID parameters in order to decrease the gain and damp out oscillations - the system response became slower, so lazy excursions from the set point became the norm, but the oscillations did stop. I should point out that Leonid and I differed somewhat on the PID setup - his engineering instincts wanted a "properly" tuned system but I just wanted some peace and quiet.... You can find your own way in this parameter space.
If the oscillations are not too violent the system can usually recover itself without shutting down, but if the PT5 variations are too great it will trip the limit and shut down.


TPC shutdown during
pressure rise at 6:05 AM
Inches of Hg
29.88
29.78
29.68
03:45 04:06 04:27 04:48 05:09 05:30 05:50 06:11 06:32 06:53 07:14 07:35
Item Barometer
Station BNL (Upton)
Hours 4
Refresh


MPH
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40
30
20
10
0
03:50 04:19 04:46 05:13 05:42 06:09 06:36 07:06 07:33
Sample JCChart
10 Meters
88 Meters
Item BNL Tower Gust
Station BNL (Upton)
Hours 4
Refresh

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July 4th, 2009

Procedure to stop recirculation mode, start Ar purge, in preparation to shut the gas system down for the summer.

STOPPING RECIRCULATION MODE

1. Make sure all TPC high voltages are ramped to zero and turned off.
2. In the mixing room, in Rack 1, input 79 into the hardware alarm keypad and push the * button (block alarms). The bottom row of red LEDs should now be lit - all alarms are blocked. [Top row indicates alarm – bottom row indicates if blocked]
3. On the PC control GUI, click on the "Alarms Enabled" button. The button should now read "Alarms disabled".
4. On the PC GUI click on SV13 (should turn from red to green.)
5. On the PC GUI, click on SV14 (should turn from green to red.) This switches the input gas for the meters from return gas to fresh gas. (Oxygen should drop to ~5.)
6. If SV16 is green, first click on SV17 (red to green) then click on SV16 (green to red). This switches the monitor line from recirculation to fresh gas. (The plumbing has changed. Is this still correct?)
7. Click on BC1 (big compressor) and immediately click on SV18 (red to Green). This stops the recirculation pump and opens the main vent valve. PT8 will drop.
8. Click on the "HV" button (green to red). This drops the HV interlocks at the AB panel and sets off the alarm. Silence the alarm by pushing the acknowledge button in rack 4.
9. Raise the lower redline for PI7 (Rack 2) until it trips the indicator needle - this will latch the BC1 off. Lower the redline back to the set point. Push the red button on SV18 to unlatch BC1. This will allow computer control of BC1.

At this point the system is in P10 purge mode with the normal 16 lpm refresh flow. If the plan is to purge the TPC and shutdown for the summer, proceed as follows:

STARTING ARGON PURGE

1. On the PC, kill the PID control program (scrolling display).
2. Turn off the PID power supply (inside Rack1 on the bottom right, silver toggle.)
3. Turn off the purifier using the GUI.
4. On the gas pad, close the 6 bottle valves for the methane 6-pack that is currently in use. Check the other 6 pack and close these valves if necessary. Do not close main valve, yet.
5. In the mixing room, wait for the methane line to bleed down - M3 and M4 will eventually go to zero. This will take several minutes.
6. When the methane reads zero, go to the gas pad and close the main output valve on the 6 pack, and close the corresponding input valve on the manifold.
7. Using the GUI, open SV22 and close SV21 - this puts Argon into the methane line.

8. Close the manual methane input valve (MV25, behind rack 3)
9. Close manual methane inlet valve MV8 (Rack 2)
10. Open manual Ar inlet valve MV6 - this is the inlet valve for the 500 lpm flowmeter.
11. On the PC, set FM5 to 0 and set FM3 to 100 and click on "Set flowmeters".
12. Close inlet valve MV4 at Rack 2
13. On the Hastings mass flowmeter controller select FM3 - confirm that the setpoint is 100 and that the flow is some value other than 0.
14. Once flow starts in FM3, raise the Ar delivery regulator pressure (PCV5) on the wall of the mixing room. Maximum pressure on this regulator should make the flow reach 100 lpm.
15. Open the bubbler bypass valve (MV14a). This will purge the supply stub that goes to the bubbler. Close MV9, fully, to prevent purge from going backward.
16. We typically run this purge flow until ~ 6 volumes have been exchanged. TPC volume = 50,000 l, so 6 volumes is ~ 48 hours. Since this is for the summer shutdown, you can probably switch to a N2 purge after 24 hours.
17. CAD mandates that we maintain a gas watch as long as the methane is > 8 %. To check the return flow from the chamber during purge:
    1. Open manual valve MV9 fully (Rack 2)
    2. Lower the PI7 red line to zero.
    3. Reset the BC1 latch (red button, Rack 2)
    4. Using the GUI start big compressor 1 (BC1). Make sure SV18 is OPEN!
    5. Using the GUI, open SV14 and close SV13. This will sample the return gas - M3 will measure the return methane percentage.
    6. The system can run in this mode stably so you can watch the methane drop. Caution: the system is stable but no alarms are active – no automatic actions will be taken to protect the system.
    7. To go back to straight purge mode, open SV13, close SV14, stop BC1 and fully close MV9.
18. Once the methane percentage is < 8%, call the RHIC MCR and ask for the operations coordinator. Tell him that the chamber is purged of P10 and ask him to send the CAD watch down with the STAR bluesheet. When the watch comes, sign the bluesheet in the appropriate box (chamber purged).
19. Turn over the two flammable gas signs on the doors to the WAH, and remove the signs that are posted in the WAH. Unplug the TPC gas/water alarm box in the STAR control room.
20. Send emails to Bill Christie, Bob Soja, Al Pendzick, Peter Ingrassia and Paul Sampson stating that the chamber is purged and the gas watch is cancelled. Make an entry in the electronic log and also send mail to star-ops mailing list.
21. Turn the bubbler valve MV14a back off after 24-48 hours of purge.

Go to the procedure for the "Complete Shutdown of the TPC gas system and setup of summer N2 purge"

July 6th, 2009

<u>Complete Shutdown of the TPC gas system and set up of summer N2 purge</u>

Assumes gas system is in 100 lpm Argon purge mode (ie no methane in the chamber) and that you have executed the “Procedure to stop circulation and start Ar purge”.

1. Using the PC GUI, open SV11 and SV12.
2. Using the PC, set the flow for FM3 to zero (slider) and click on “set flowmeters). Confirm that flow through FM3 goes to zero.
3. On rack 2, close MV6 (manual valve for FM3)
4. Reduce the Ar regulator pressure (PCV 5 on the wall) to ~ 18 PSIG
5. Close the Ar inlet valve MV30 at the manifold on the wall. This allows N2 to flow into the Ar line.
6. Adjust the N2 pressure regulator (PCV2) and the flowmeter valve for FI-5 so that the N2 pressure increases and the flow is set to the arrow on the flowmeter - this is the standard shutdown maintenance flow for the TPC.
7. Confirm that the power for the purifier is off (TIC1 on Rack 2 should be off and the purifier control on the GUI should be red. If purifier is still on, turn it off.
8. Close SV4, SV3 and SV1 using the PC. (SV2 should already be closed). This closes off the purifier-dryer loop.
9. Using the PC, stop small compressor SC2. Turn off M4 (top of Rack 2)
10. Using the PC, stop small compressor SC1 and close SV6, SV7, SV8 and SV17.
11. Inside Rack 3, close the inlet valve first, then the outlet valve on oxygen analyzer M1 (do NOT allow the meter to be pressurized!)
12. Inside rack 3, unplug the small compressor SC3. Close the inlet valve then the outlet valve for oxygen analyzer M5.
13. Turn off M1, M5, and methane analyzer M3.
14. At rack 1, turn off the power for the three Hastings mass flow controllers. (Turn the rotary switch on the front of each meter to off.)
15. Remove the side panel of Rack 1.
16. Inside rack 1, turn off the power for the hardware alarm box, the SCXI crate and the temperature controller MUX box.
17. Unplug the water meter (M2).
18. Make sure the PID controller power supply (bottom of Rack 1) is off.
19. Put all side panels back on.
20. On the PC, kill the gas system control program and shutdown the PC. (If automatic software updates are pending, reboot once, then shutdown).
21. Turn off the breaker at the top of Racks 1, 2 and 3 (use appropriate PPE). DO NOT turn the breaker for Rack 4 off - it powers the TPC interlock system and stays on all the time.
22. At the bottom of rack 2, make sure that the breakers for BC1 and BC2 are off.
23. Turn off the “power to gas system” button on the AB interlock panel.

The next section is for the gap gas system:

1. At rack 4, open MV52 and close MV54 (selects fresh gas instead of return gas.)
2. Turn off M6 (oxygen meter) and unplug M7 (water meter).
3. Turn off the pump (toggle switch on front panel - Rack 4).
4. Confirm that there is ~ 10 lpm through FI51 - this is the summer maintenance flow for the insulation gap.
5. The N2 comes from Rack 3 - FI 10 at the bottom of that rack should also have 10 lpm flow.

Gas Pad:

Double-check the gas pad. Everything should be clean, neat, and explosive gases off.

Argon tank – Order new gas when the pressure drops to 30 inches. Full = 120 inches. This will be approximately every 2 months during the run. Every 3 months in the summer.

Methane – Order methane as needed. Use silver tanks. Red tanks are for emergencies, only. Vent the methane line whenever you install a new bottle or six pack by cracking the joint. Swith MV26 as required. Methane should last 2 weeks under normal conditions.

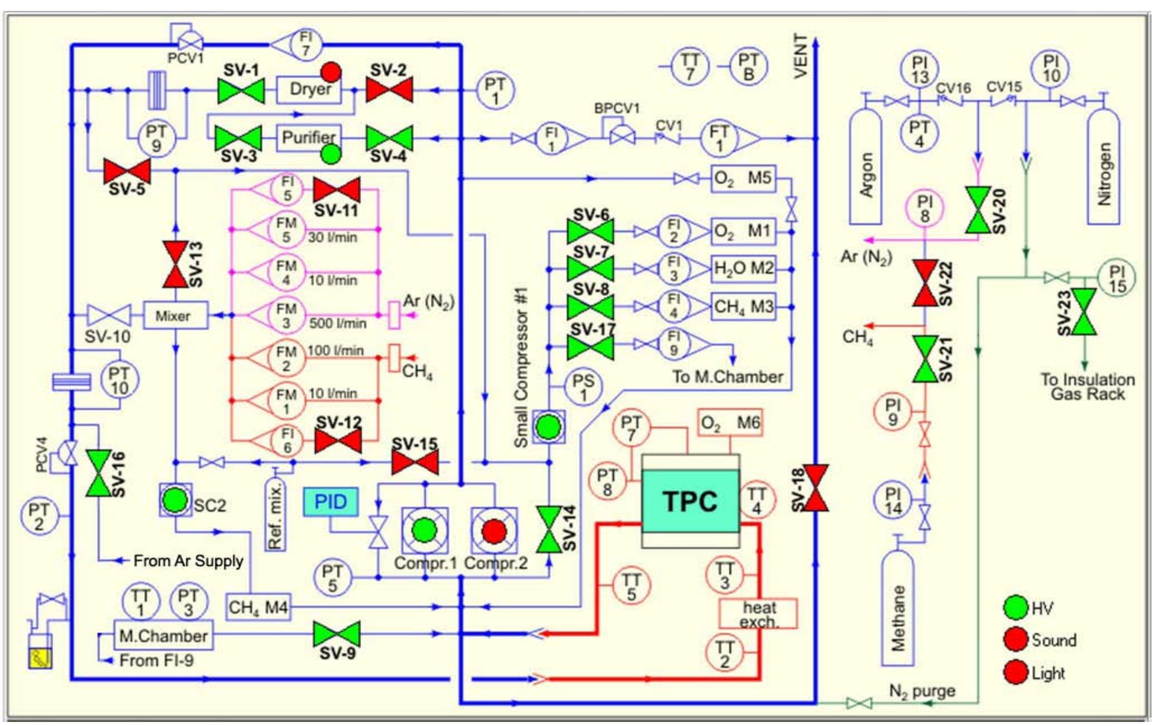


Figure 1: Gas System Schematic Diagram: Normal Circulation Mode Shown

Methane analyzer calibration AL 02.18.2009, Rev 03.02.09

The gas system has 2 methane analyzers to measure the methane concentration in the TPC gas. They are labeled M4 (for fresh gas) and M3a (return gas from the TPC). Their performance strongly depends on the pressure and ambient temperature. (An Excel spread sheet is available on the STAR TPC web page to help calibrate the meters and produce graphs for daily use.) The calibration constants for M3a and M4 should be determined before each run and anytime you suspect the calibration has been lost (not more than once/month). Choose a day with stable barometric pressure, the preferred number is 1010 mbar on PTB, which is in the middle of the TPC operating range. For other pressures there is a formula from Leonid Kotchenda:

CH4(true) = CH4(reading) + 0.012% * (Pc-P) + MeterOffset

where CH4(reading) is the current reading from the analyzer, P is the barometric pressure at the current time and Pc is the barometric pressure at the time of calibration.

Calibration is best performed with high Ar flow and for each analyzer separately. The procedure begins with Zeroing each meter. For M3a open SV13, close sv5, sv15, sv14. For M4 open mv17, close mv17a. When Ar flow is established, go to the analyzer, check the flow meters feeding the analyzers, for M4 it is FI2a(rack 2), for M3 it is FI4(rack 3). When the readings have stabilized (about 20 minutes), press ZERO, then CAL buttons. Zeroing will proceed.

To calibrate methane content we have 2 bottles with certified methane-argon ratio - P10 and P20, but exact numbers are 10.2% and 19.9% of methane in Ar. Both bottles are sitting on the gas pad outside the gas room. P10- 40 liters P20- 20 liters, both connected to a 3 way valve. Open the valves on the bottles, then manual valves MV43a, MV43b, the pressure reducers are already adjusted for ~12 PSI: see gauge on ¼” line coming to gas room.

Open the 3-way valve for P20 first, confirm ~12 PSI. Go to the gas room. On rack #1 go to the right hand Hastings meter, choose channel 4 (labeled REF P10) and request flow ~ 3.0 l/min. To calibrate M3a open sv15, close sv5, sv13, sv14, mv17a. Check flow on FI4. During calibration O2 (M1) could be high due to oxygen buildup through long ¼” line. Wait 20 minutes for the readings to stabilize. The readings for O2 should go to ~ 3-5ppm. When the readings are stable, Press SPAN, than CAL buttons. ATTENTION!! Only P20 calibration gas should be used for SPAN calibration, not the P10 gas!! Write numbers in logbook. Sometimes actual readings don’t coincide with a number from reference bottle and this offset needs to be accounted in Leonid’s formula. Open SV14, close SV15.

To calibrate M4, reduce the flow on the Hastings Meter down to ~ 1.0 l/min. Open mv17a, close mv17 on the back of rack2. Check flow on FI2. Proceed with a span calibration as was done for M3: see previous paragraph. When the calibration is finished, about 20 minutes, check and proceed if it is not already done: open SV14, close sv15, open mv17, close mv17a. These operations will restore flow for fresh gas to M4 and return-gas from the TPC to M3a.

Repeat proceeding operations, described earlier, with a fresh Ar to remove P20 from lines and verify ZERO for both M3 and M4.

Open 3-way valve to P10 bottle. Repeat calibration procedure for M3 and M4. Do not Zero or Span the meters with the P10 gas. At this point you are just checking the readings on M3 and M4 and comparing it with the canonical value of 10.2% for the bottle. Put a note in logbook.

Always, if possible, follows a chain: pure Ar-ZEROING ⇒ P20-SPAN ⇒ pure Ar-check ZERO ⇒ P10 check reference gas. Each step takes about 20 minutes to get an accurate reading.

If re-calibration needs to be done during the run (with TPC gas circulating), all alarms should be blocked. On alarm box press 79 on keyboard and press * button- it will block hardware alarm. At this point the lower row of LEDs will be red. Go to the gas system PC and press "Alarms disabled" button. This action will prevent all gas alarms (so don't forget to re-enable them, later.)

After a calibration in circulation mode ⇒ remove the lock from alarm box ⇒ press 79 and # , on gas system PC enable alarms, press appropriate button "Alarms disabled" and label on button will change to " Alarms enabled" with a recording in the log. It should say "ALARMS enabled".

On gas pad close valves on P10 and P20 bottles. Also close the valves installed after pressure reducers. Put 3-ways valve in P10 position.

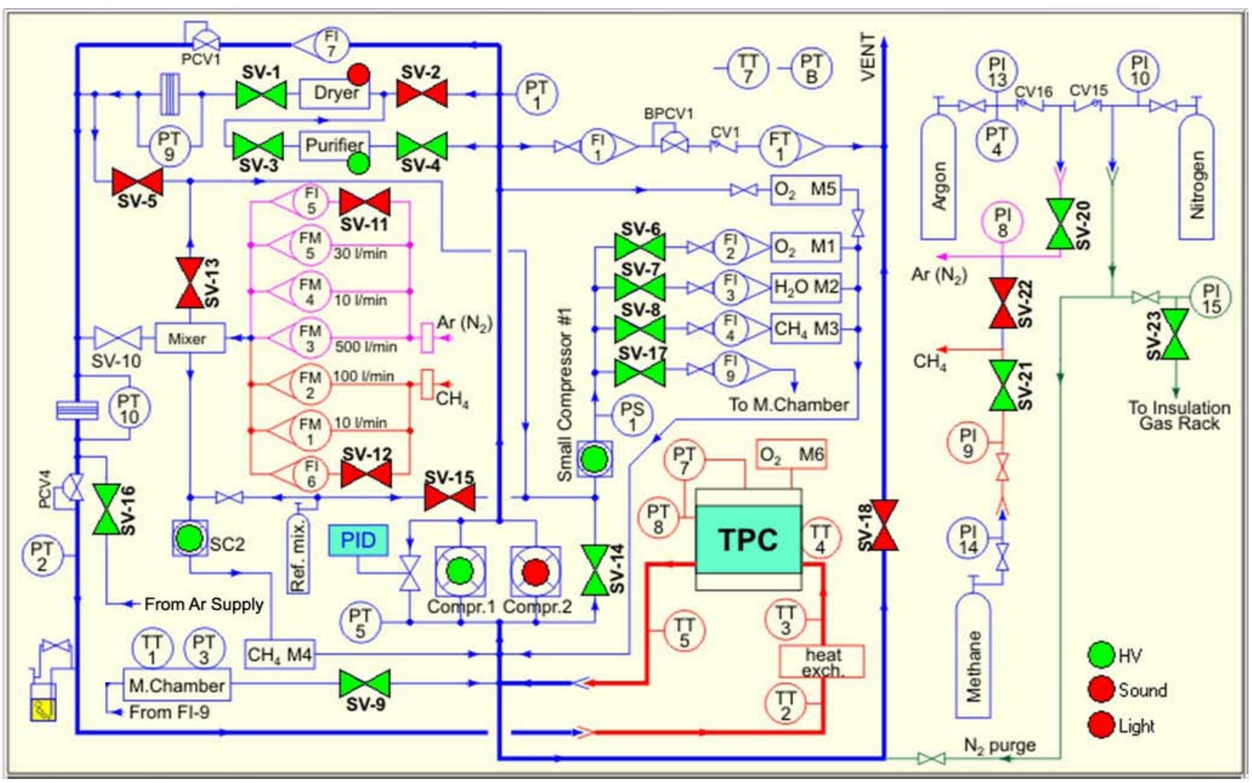


Figure 1: Gas System Schematic Diagram: Normal Circulation Mode Shown

TPC Seal and Purge Manual (Preliminary - this procedure may be incomplete) 11/19/07

Before starting the TPC circulation it is necessary to check whether it is sealed or not. This can be done by Argon or by Nitrogen. In summer TPC is kept on Nitrogen. Therefore before run starts TPC is usually on Nitrogen flow.

1. On Rack 2 open manually FM5 - (MV4 valve) (all others : FM3 (MV6), FM4 (MV5) are closed)

2. Install on FM5 - 16 l/min flow (Computer: Slide FM5 to 16 l/m and click on Set Flow Meters)

3. Close SV 11 by clicking it on Computer (Green turns to Red). This Stops a purge flow through the FI5. Clear Interlock for SV18 on Rack 2 by pushing the button (SV 18 Reset button on Rack 2, right)

4. Confirm that MV10 (Rack1 lower left) is closed and confirm that MV14a (bubbler bypass, rear end of the gas mixing room) is closed.

5. To check seal, close SV 18 by clicking on the computer (Green turns into the Red). Listen for a sound - "Bang"!

6. The pressure on Rack 1, shown by "Inside TPC Pressure (PT8) PI6" on Rack 1 starts to rise up. It should reach value 1300. This will take ~ 5 minutes.

7. After PI6 is close to 1300, open SV18 by clicking on the computer SV l8 button (Red turns to Green) and PI6 drops rapidly

8. One can start PID program to follow pressure change. Before starting the PID program, the switch at the power supply, located at the right bottom of Rack I should be switched on.

9. Start a PID program. Click on a start button. Two evolving lines will appear. The upper line is a set point value (Red) taken by a computer from DB. Lower line is yellow, which starts to rise, showing rising pressure in PT8. Watch lines, until the lower line reaches the top line. Just before reaching, click on SV18 button on the computer screen (Red turns to Green as in p. 7.)

10. During p.9, when lower line goes up, it might be some delay in rise, which is a result of outer pressure variation (wind, pressure change outside and etc.)

<u>To get gas system into a purging mode after the seal check</u>

I. Put the FM5 flow to 0 by computer

2. After PI6 pressure drops below 100, manually close FM5 (MV4 valve) on Rack 2.

3. Close the PID program and switch back a power supply switch on the box located at the Rack 1 (lower right)

4. Open SV11 by clicking SV11 button on the computer display (Both SV11 and SV18 should be Green during the purge mode)

5. Can firm a purge flow on FI5 (indicated by a line on FI5 on Rack 2)

Here is the original document as a .jpg file.

TPC Seal and Purge Manual 11/19/07

Before starting the TPC circulation it is necessary to check whether it is sealed or not. This can be done by Argon or by Nitrogen. In summer TPC is kept on Nitrogen. Therefore before run starts TPC is usually on Nitrogen flow.

1. On Rack 2 open manually FM5- (MV4 valve) (all others: FM3 (MV6), FM4 (MV5) are closed)
2. Install on FM5 – 16 l/min flow (Computer: Slide FM5 to 16 l/m and click on Setflowmeters
3. Close SV11 by clicking it on Computer (Green turns to Red). This Stops a purge flow through the FI5. Clear Interlock for SV18 on Rack 2 by pushing the button (SV18 Reset button on Rack 2, right)
4. Confirm that MV10 (Rack2 lower left) is closed and confirm that MV14a (bubbler bypass, rear end of the gas mixing room) is closed
5. To check sealing, close SV18 by clicking on the computer (Green turns into the Red). Listen for a sound – "Bang"
6. The pressure on Rack 1, shown by "Inside TPC Pressure (PT8) PI6" on Rack1 starts to rise up. It ~~could~~ should reach value 1300. This will take 5 – ~~10~~ minutes
7. After PI6 is close to 1300, open SV18 by clicking on the computer SV18 button (Red turns to Green) and PI6 drops rapidly
8. One can start PID program to follow pressure change. Before starting the PID program, the switch at the power supply, located at the right bottom of Rack 1 should be switched on
9. Start a PID program. Click on a start button. Two evolving lines will appear. The upper line is a set point value (Red) taken by a computer from DB. Lower line is yellow, which starts to rise, showing rising pressure in PT8. Watch lines, until the lower line reaches the top line. Just before reaching, click on SV18 button on the computer screen (Red turns to Green as in p.7.)
10. During p.9, when lower line goes up, it might be some delay in rise, which is a result of outer pressure variation (wind, pressure change outside and etc)

To get gas system into a purging mode after the seal check

1. Put the FM5 flow to 0 by computer
2. After PI6 pressure drops below 100, manually close FM5 (MV4 valve) on Rack 2
3. Close the PID program and switch back a power supply switch on the box located at the Rack 1 (lower right)
4. Open SV11 by clicking SV11 button on the computer display (Both SV11 and SV18 should be Green during the purge mode)
5. Confirm a purge flow on FI5 (indicated by a line on FI5 on Rack 2)

Procedure to Regenerate the STAR TPC Gas System Purifier

Leonid Kotchenda and Blair Stringfellow

10/07/2009

PURPOSE: To remove impurities and increase the efficiency of the STAR TPC gas purifier located in Rack 2 in the STAR gas mixing room.

BACKGROUND: To control the level of O2 and H2O contamination in the TPC ~ 10% of the gas in circulation is sent through a purifier/dryer path. (Flow through the purifier = 50 lpm.) The combination of 17 lpm of fresh gas that is introduced into the recirculation stream, and the purifier/dryer serves to hold the TPC O2 contamination to ~ 30 ppm. The current purifier has been in use since 1998 and we are starting to get evidence that its efficiency is deteriorating. We would therefore like to attempt to regenerate this purifier rather than replace it.

The purifier is installed in the TPC gas system in Rack 2. During normal operation the purifier is heated to 220 deg C using a heating coil and insulating blanket. The temperature is held constant by a TIC (temperature indicating controller.) For the regeneration procedure we will also heat the purifier to 220 deg C using the same system.

The regeneration will occur by passing a continuous flow of 95% Argon - 5% H2 gas through the heated purifier. Two chemical reactions will serve to regenerate the catalyst:

$$NiO + H_2 = Ni + H_2O$$

$$Cr_2O_3 + 3H_2 = 2\ Cr + 3\ H_2O$$

Thus, the byproduct is water. The flow rate of the Ar-H2 mixture will be 180-200 ccm and the regeneration time is estimated to be 48 hours.

The Ar-H2 mixture will be purchased pre-mixed from Spectra-Gas and the gas from the exhaust of the purifier will be either vented out the normal TPC gas stack or through an auxilliary vent line to the outdoors. The purifier already has a pressure relief valve installed to prevent accidental overpressure.

Note that this procedure is similar to the one that is used to regenerate the dryer which is done before each run. In that case the gas used is Ar only.

PROCEDURE:

1. Set MV3A to (Ar/5%H2 to Purifier) direction in Mixing Room
2. Set MV3B to (Ar/5%H2 to Purifier) direction on STAR Gas Pad

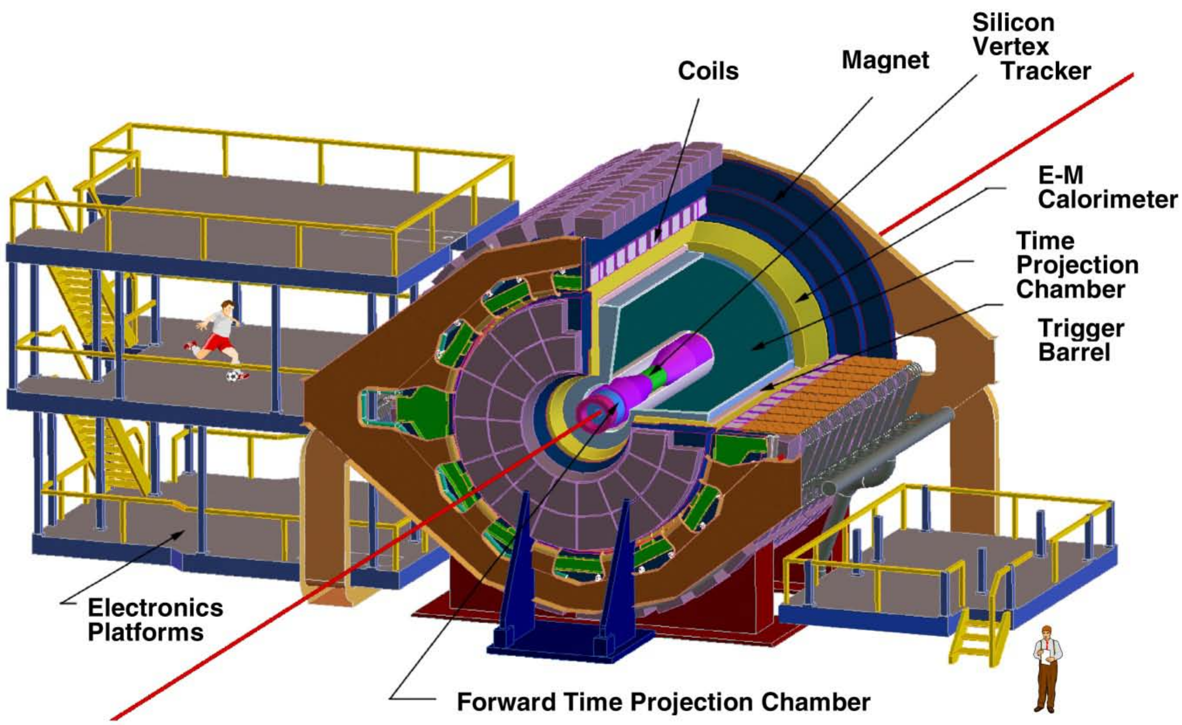
3. Open the gas cylinder
4. Set the regulator PCV50 to ~5 PSIG PI52 delivery pressure.
5. Turn on the purifier heater using the toggle switch in Rack 2.
6. Confirm that the Temperature Indicator Controller (TIC) has a set point of 220 degrees C. If not, adjust the set point using the push buttons on the front of the TIC (located in Rack 2).
7. Open MV2B inside Gas Rack 2.
8. Open MV2A inside Gas Rack 2.
9. Open MV3 inside Gas Rack 2.
10. Wait for the purifier to heat to the setpoint (usually 2-3 hours).
11. Adjust FI8A flow to 180-200 ccm
12. When regeneration is complete (estimate 48 hours) turn off the purifier heater using the toggle switch.
13. Reduce FI8A flow to 50ccm
14. Wait when the purifier will be cooled (estimate 24 hours)
15. Set MV3B to (P10 to SV16) direction on STAR Gas Pad.
16. Close the gas cylinder
17. Set MV3A to (P10 to SV16) direction in Mixing Room
18. Close FI8A manual valve.
19. Close MV3 inside Gas Rack 2.
20. Close MV2A inside Gas Rack 2.
21. Close MV2B . inside Gas Rack 2

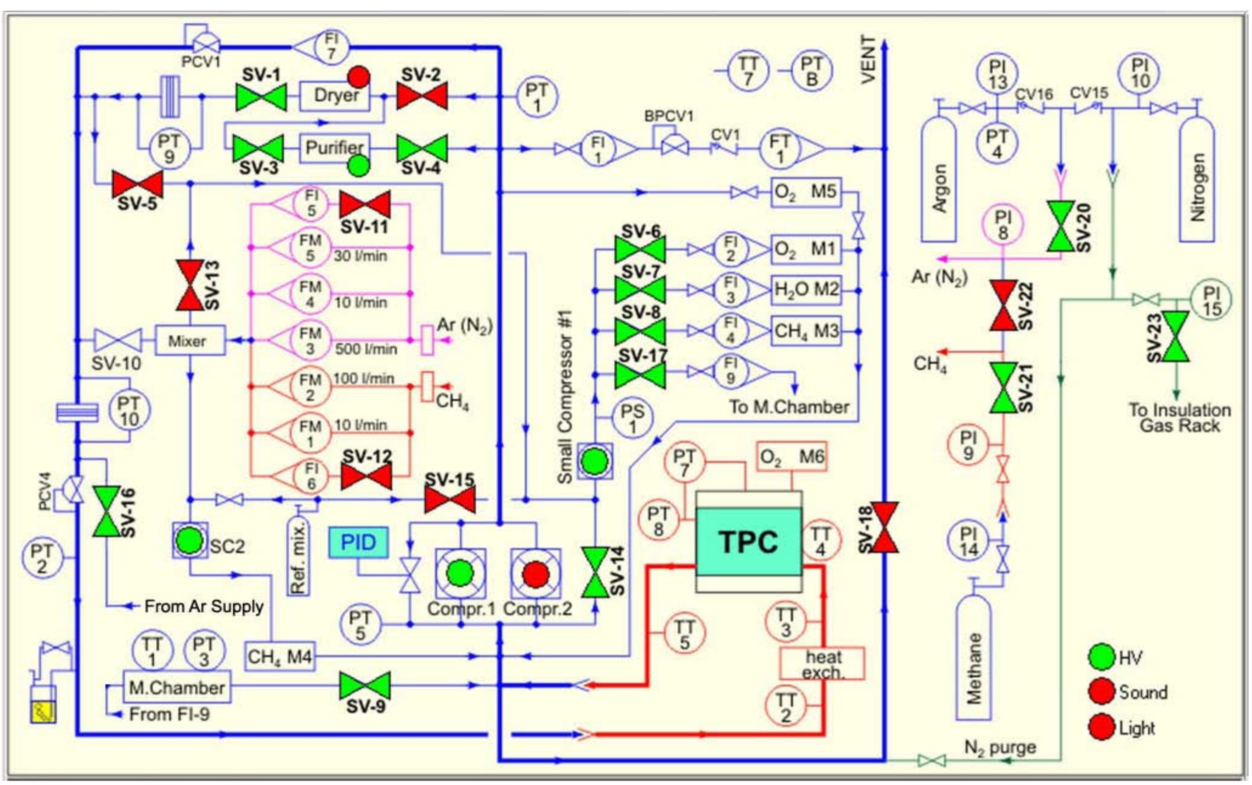
EXPERTS:

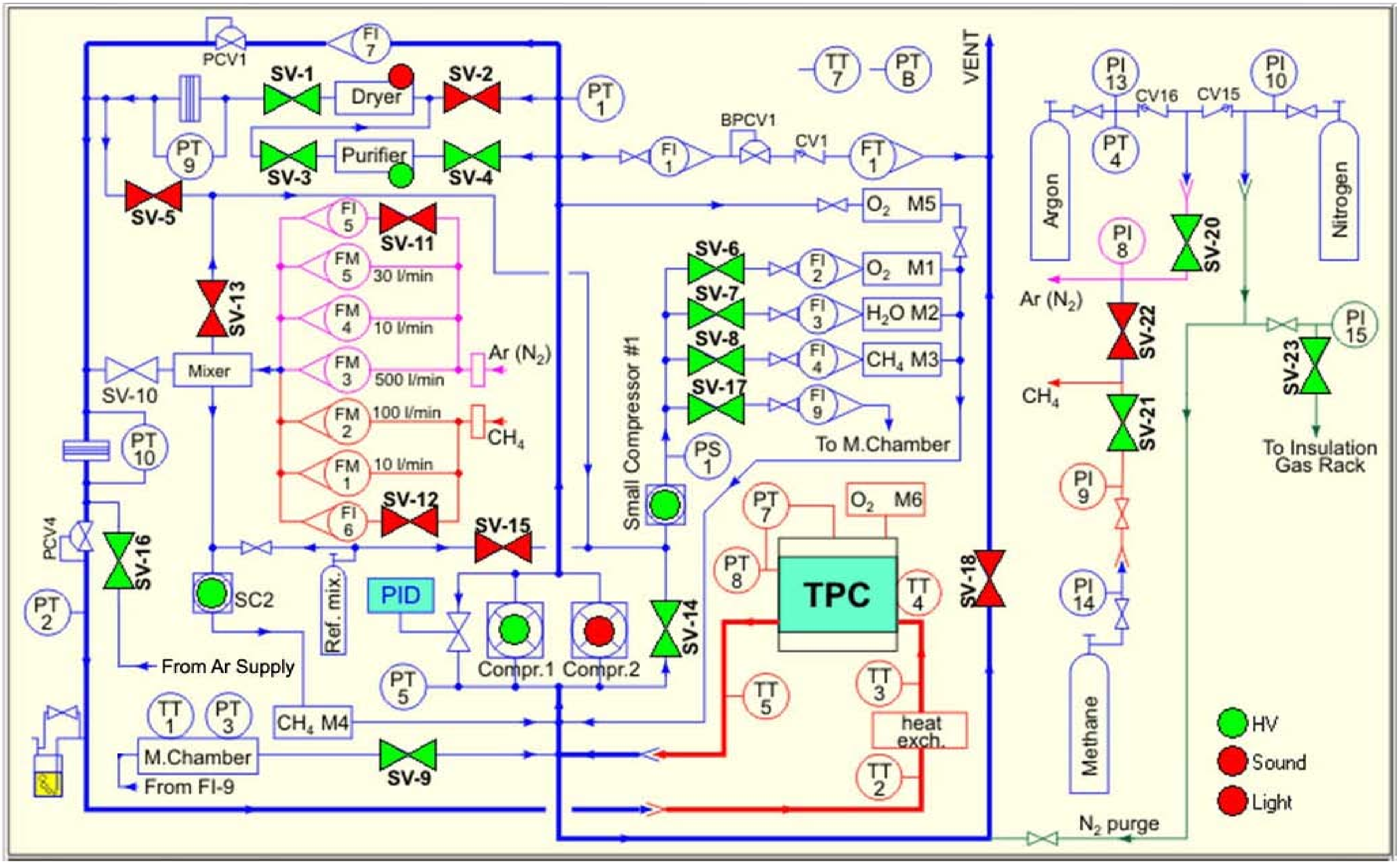
Leonid Kotchenda
STAR TPC gas system engineer
X5379

Diagrams

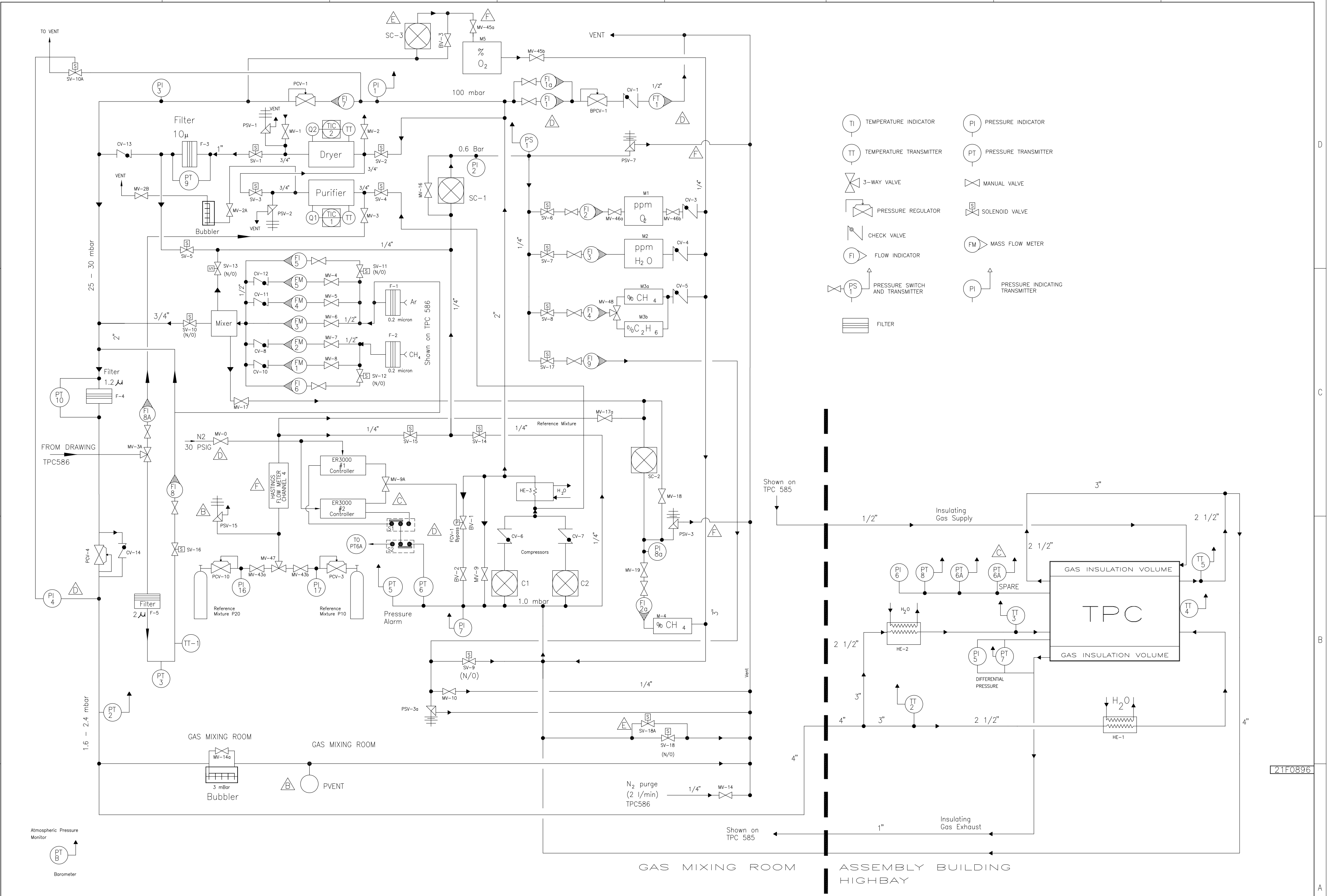
The STAR TPC – Simplified Schematic of the Gas System







PCV1
FI 7
SV-1
Dryer
SV-2
PT 1
TT 7
PT B
VENT
PT 9
SV-3
Purifier
SV-4
FI 1
BPCV1
CV1
FT 1
SV-5
FI 5
SV-11
O2 M5
FM 5 30 l/min
SV-6
FI 2
O2 M1
FM 4 10 l/min
SV-13
SV-7
FI 3
H2O M2
Mixer
FM 3 500 l/min
Ar (N2)
SV-8
FI 4
CH4 M3
SV-10
FM 2 100 l/min
CH4
SV-17
FI 9
To M.Chamber
PT 10
FM 1 10 l/min
Small Compressor #1
PS 1
FI 6
SV-12
SV-15
PT 7
O2 M6
PCV4
SV-16
PT 8
TPC
TT 4
SV-18
SC2
Ref. mix.
PID
PT 2
SV-14
From Ar Supply
Compr.1
Compr.2
PT 5
TT 3
TT 5
TT 1
PT 3
CH4 M4
heat exch.
M.Chamber
SV-9
From FI-9
TT 2
PI 13
CV16
CV15
PI 10
PT 4
Argon
Nitrogen
PI 8
SV-20
Ar (N2)
SV-22
PI 15
SV-23
CH4
SV-21
To Insulation Gas Rack
PI 9
PI 14
Methane
HV
Sound
Light
N2 purge



TPC P10 GAS SYSTEM
TPC584-E-1 REV. H

REV.	DWN.	CHK.	ZONE	DATE	CHANGES
H	JAS	LEONID		10-6-09	REVISIONS PER ECN #TPC584H
G	JAS	LEONID		3/14/08	REVISIONS PER ECN #TPC019
F	JAS	LEONID		11/14/07	REVISIONS PER ECN #TPC018
E	JAS	LEONID		11/14/03	REVISIONS PER ECN #TPC017
D	JAS	LEONID		5/2/02	REVISIONS PER ECN #TPC016
C	JAS	BS		10/18/00	REVISIONS PER ECN #TPC014
B	JAS	BS		4/13/99	REVISIONS PER ECN #TPC584E1B
A	RW	RW		4/7/98	RELEASED FOR FABRICATION

SHOP ORDERS
ACCT. NO.: SER. NO.:
DATE ISS'D: DATE REQ'D: NO. REQ'D:
SURFACE TREATMENT: DEGREASE
IDENTIFICATION METHOD: TAG

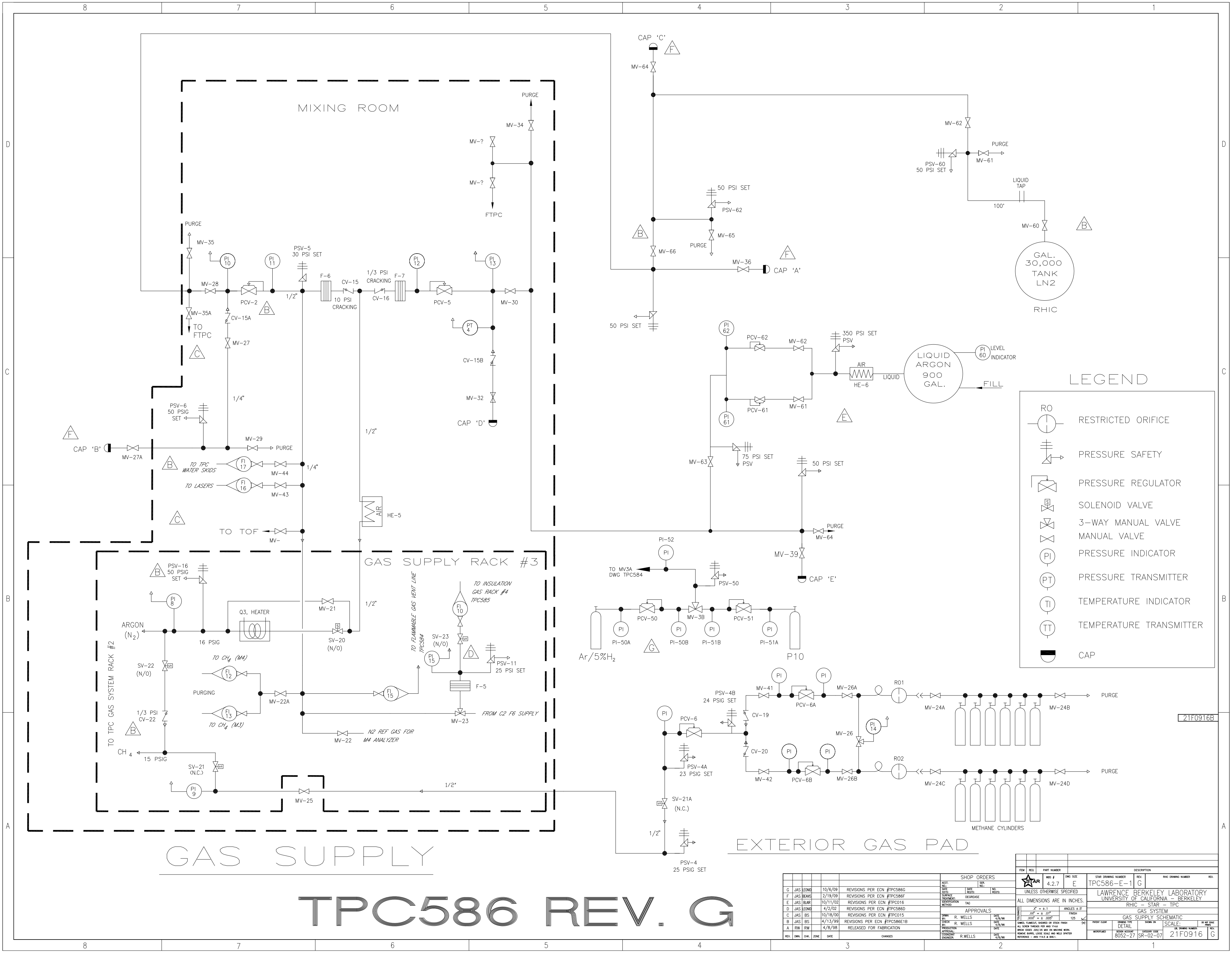
APPROVALS
DRWN BY: R. WELLS DATE 4/7/98
CHECK BY: R. WELLS DATE 4/7/98
PRODUCTION APPROVAL: DATE
COGNIZANT ENGINEER: R.WELLS DATE 4/7/98

ITEM | REQ | PART NUMBER | DESCRIPTION

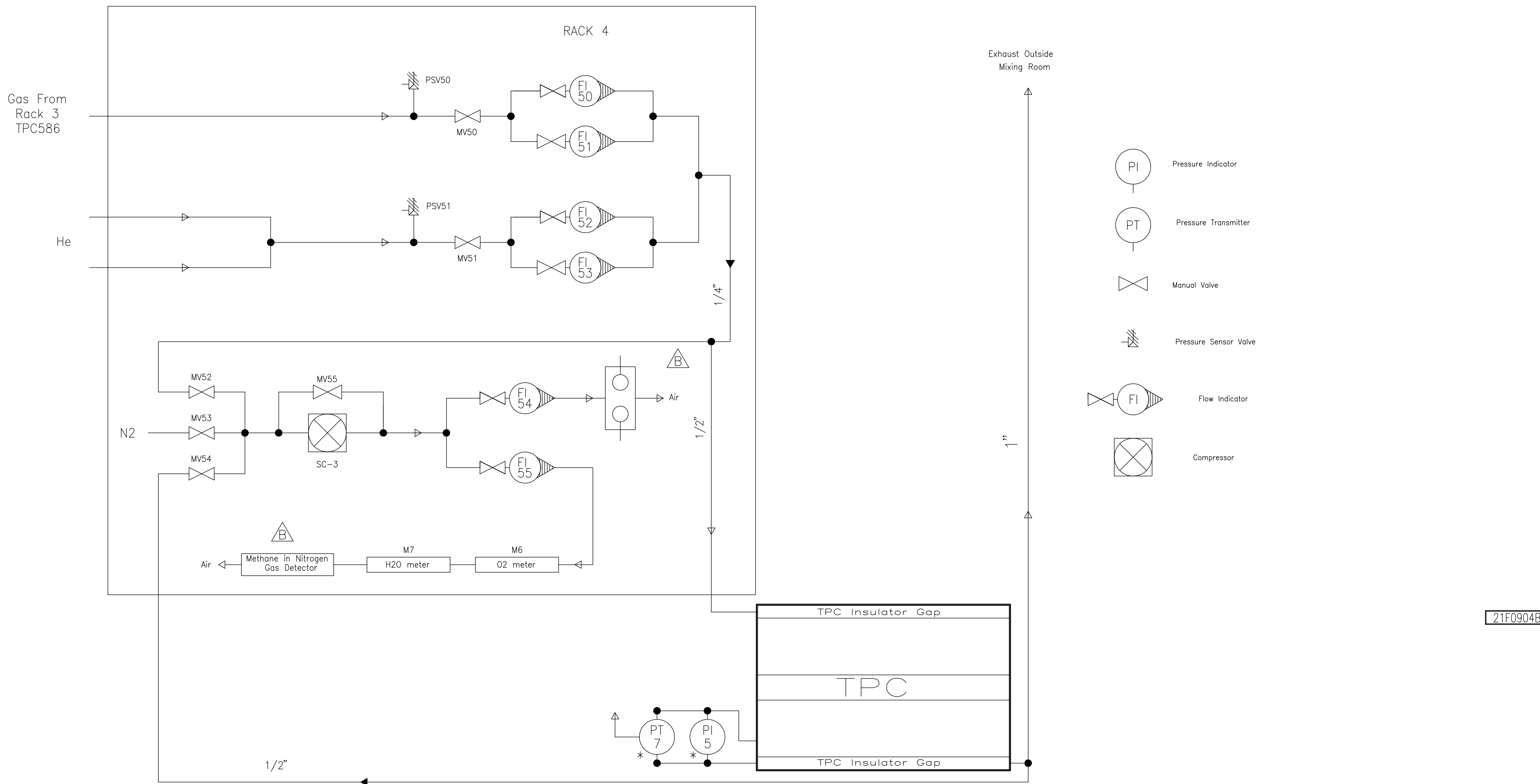
STAR | WBS # 4.2.7 | DWG SIZE E | STAR DRAWING NUMBER TPC584-E-1 | REV. H | RHIC DRAWING NUMBER | REV. -

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES.
TOLERANCES .X" = ± | ANGLES ±.5°
.XX" = ± .01" | FINISH
.XXX" = ± .005" | 125
SAWED, FLAMECUT, SHEARED OR STOCK FINISH ALL SCREW THREADS PER ANSI Y14.6 BREAK EDGES .020/.05 MAX ON MACHINE WORK. REMOVE BURRS, LOOSE SCALE AND WELD SPATTER REFERENCE – ANSI Y14.5 & B46.1.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA – BERKELEY
RHIC – STAR – TPC
GAS SYSTEM
P10 GAS SYSTEM SCHEMATIC
PATENT CLEAR | DRAWING TYPE DETAIL | SHOWN ON | SCALE: NONE | DO NOT SCALE PRINTS
MICROFILMED | DESIGN ACCOUNT 8052-27 | CATEGORY CODE SR-02-07 | LBL DRAWING NUMBER: 21F0896 | REV. H


MIXING ROOM
GAS SUPPLY RACK #3
GAS SUPPLY
EXTERIOR GAS PAD
LEGEND
RO RESTRICTED ORIFICE
PRESSURE SAFETY
PRESSURE REGULATOR
SOLENOID VALVE
3-WAY MANUAL VALVE
MANUAL VALVE
PI PRESSURE INDICATOR
PT PRESSURE TRANSMITTER
TI TEMPERATURE INDICATOR
TT TEMPERATURE TRANSMITTER
CAP
GAL. 30,000 TANK LN2
RHIC
LIQUID ARGON 900 GAL.
FILL
LIQUID
AIR
HE-6
LEVEL INDICATOR
LIQUID TAP
100'
CAP 'A'
CAP 'B'
CAP 'C'
CAP 'D'
CAP 'E'
PURGE
FTPC
TO FTPC
TO TOF
TO TPC WATER SKIDS
TO LASERS
PSV-5 30 PSI SET
PSV-6 50 PSIG SET
PSV-16 50 PSIG SET
PSV-11 25 PSI SET
PSV-60 50 PSI SET
PSV-62 50 PSI SET
350 PSI SET PSV
75 PSI SET PSV
50 PSI SET
10 PSI CRACKING
1/3 PSI CRACKING
Q3, HEATER
ARGON (N2)
16 PSIG
CH 4
15 PSIG
PURGING
TO CH4 (M4)
TO CH4 (M3)
TO TPC GAS SYSTEM RACK #2
TO FLAMMABLE GAS VENT LINE TPC584
TO INSULATION GAS RACK #4 TPC585
FROM C2 F6 SUPPLY
N2 REF GAS FOR M4 ANALYZER
TO MV3A DWG TPC584
Ar/5%H2
P10
PSV-4B 24 PSIG SET
PSV-4A 23 PSIG SET
PSV-4 25 PSIG SET
SV-21A (N.C.)
METHANE CYLINDERS
21F0916B
TPC586 REV. G
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA – BERKELEY
RHIC – STAR – TPC
GAS SYSTEM
GAS SUPPLY SCHEMATIC
TPC586-E-1
21F0916
G JAS LEONG 10/6/09 REVISIONS PER ECN #TPC586G
F JAS BEAMS 2/19/09 REVISIONS PER ECN #TPC586F
E JAS BLAIR 10/11/02 REVISIONS PER ECN #TPC016
D JAS LEONG 4/2/02 REVISIONS PER ECN #TPC586D
C JAS BS 10/18/00 REVISIONS PER ECN #TPC015
B JAS BS 4/13/99 REVISIONS PER ECN #TPC586E1B
A RW RW 4/8/98 RELEASED FOR FABRICATION

INSULATOR GAS CONTROL SYSTEM SCHEMATIC



TPC585 REV. B
4/13/99

NOTES:

∗ ALSO SHOWN ON TPC584

REV.	DWN.	CHK.	ZONE	DATE	CHANGES
B	JAS	BS		4/13/99	REVISION PER ECN #TPC585D1B
A	GK	RW		11/20/95	RELEASED FOR FABRICATION

SHOP ORDERS
ACCT. NO.: SER. NO.:
DATE ISS'D: DATE REQ'D: NO. REQ'D:
SURFACE TREATMENT: DEGREASE
IDENTIFICATION METHOD: TAG

APPROVALS
DRWN BY: J. ORTIZ DATE 4/8/98
CHECK BY: DATE
PRODUCTION APPROVAL: R. WELLS DATE 4/8/98
COGNIZANT ENGINEER: R. WELLS DATE 4/8/98

ITEM	REQ	PART NUMBER	DESCRIPTION

STAR | WBS # 4.2.7 | DWG SIZE D | STAR DRAWING NUMBER TPC585-D-1 | REV. B | RHIC DRAWING NUMBER | REV.

UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE
TOLERANCES .X" = ±.060" .XX" = ± 0.015" .XXX" = ± .004"
ANGLES ±.5°
FINISH 125
SAWED, FLAMECUT, SHEARED OR STOCK FINISH
ALL SCREW THREADS PER ANSI Y14.6
BREAK EDGES .020/.05 MAX ON MACHINE WORK.
REMOVE BURRS, LOOSE SCALE AND WELD SPATTER
REFERENCE – ANSI Y14.5 & B46.1.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA – BERKELEY
RHIC – STAR – TPC
GAS SYSTEM
INSULATOR GAS CONTROL SYSTEM SCHEMATIC

PATENT CLEAR | DRAWING TYPE DETAIL | SHOWN ON | SCALE: FULL | DO NOT SCALE PRINTS
MICROFILMED | DESIGN ACCOUNT 8052-27 | CATEGORY CODE SR-02-07 | LBL DRAWING NUMBER: 21F0904 | REV. B

LBL DRAWING NUMBER	REV.	STAR DRAWING NUMBER	REV.	SHEET #	RHIC DRAWING NUMBER	REV.	ALL DIMENSIONS ARE
24A1401	G	SIM140-A-1	G	1of1	XXXXXXXXXX	-	INCHES / CENTIMETERS

DRWN BY	DATE	COGNIZANT ENG	DATE	PRODUCTION APP	DATE	CAT.CODE/WBS
Doug Fritz	8/26/93	JER	8/26/93		x/xx/xx	SR1301

LAWRENCE BERKELEY LABORATORY

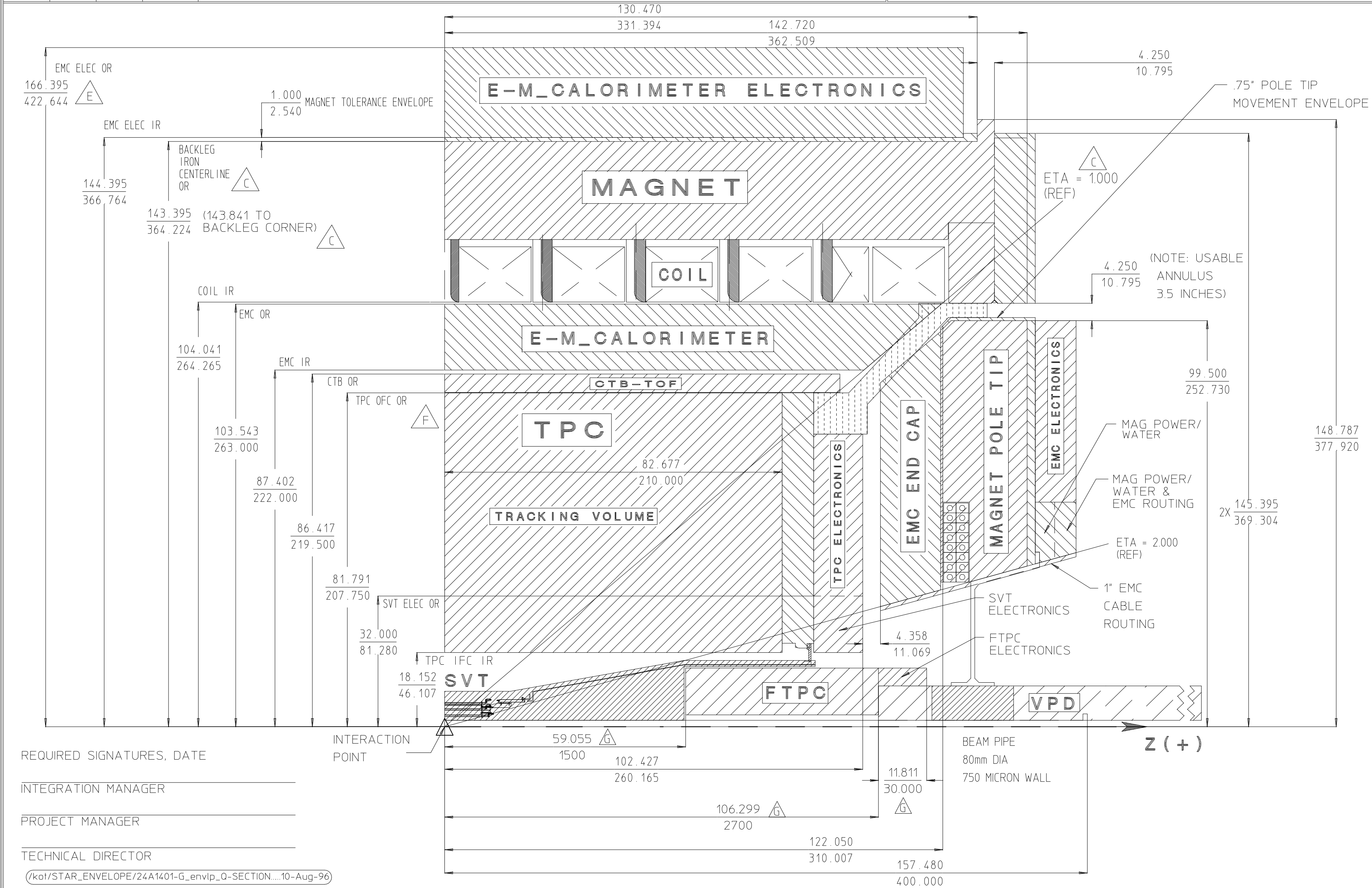
UNIVERSITY OF CALIFORNIA - BERKELEY

RHIC/STAR DETECTOR - S.I.

MECHANICAL COMPONENTS

QUARTER SECTION INTERFACE ENVELOPE

REV.	DWN.	CHK.	DATE	CHANGES
D	SMH	DCF	8-27-95	UPDATED VPD GEOMETRY AND ADDED VPD LOCATION ENVELOPE, ECN TRG003
E	RES	DCF	10-13-95	INCREASED THE EMC B.L. ELECTRONICS AREA (OUTER RADIUS TO 166.395" WAS 159.307"), ECN EMC002
F	DCF	DCF	5-13-96	INCREASED CTB/TOF ENVELOPE IN "Z" (NOW 246 CM, WAS 240 CM) ECN TRG002
G	DCF	DCF	8-08-96	ADDED FTPC ENVELOPE, MODIFIED SVT GEOMETRY AND VPD MOVEMENT ENVELOPE, ECN SIM013



REQUIRED SIGNATURES, DATE

INTEGRATION MANAGER

PROJECT MANAGER

TECHNICAL DIRECTOR

(/kot/STAR_ENVELOPE/24A1401-G_envlp_Q-SECTION....10-Aug-96)

MICROFILMED	PATENT CLR		DES ACCT NO 8052-24	CATEGORY SR-04-02	SCALE: NONE
DWN BY J. BOEHM	DATE 93-01-27	CHK BY J. BERCOVITZ	DATE 93-01-27		

UNIVERSITY of CALIFORNIA-BERKELEY

LAWRENCE BERKELEY LABORATORY

RHIC-STAR-TPC

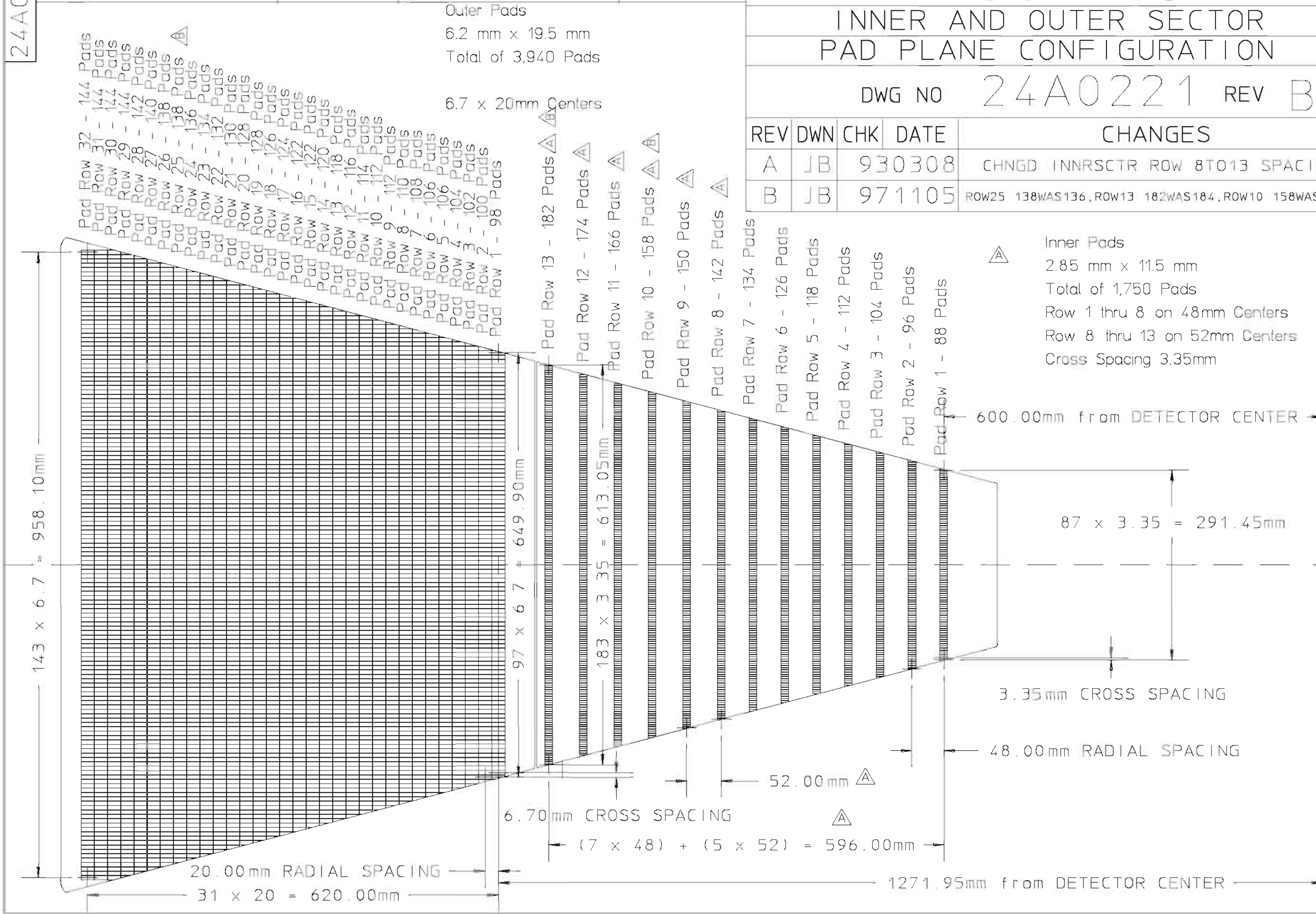
INNER AND OUTER SECTOR

PAD PLANE CONFIGURATION

DWG NO 24A0221 REV B

24A0221B

REV	DWN	CHK	DATE	CHANGES
A	JB		930308	CHNGD INNRSCTR ROW 8TO13 SPACING
B	JB		971105	ROW25 138WAS136, ROW13 182WAS184, ROW10 158WAS156



Lawrence Berkeley Laboratory - University of California **Engineering Note**		Code SR0210	Serial M7724	STAR Doc # SN 0373	Page 1 of 1
Author Russell Wells	Department Mechanical Engineering		Date 10/16/98	STAR WBS # 4.2.10	

Program

Solenoidal Tracker at RHIC

Sub program

Time Projection Chamber - Assembly and Test

Title

Weight of TPC and TPC Supported Hardware

Introduction:

The following table contains the weight of the Time Projection Chamber's (TPC) components, TPC supported hardware and detector subsystems. The weight categories correspond to various phases of the TPC's construction and installation. Max LBNL was the weight during transcontinental shipping, Max BNL Lift is the weight at the time of installation into the STAR Magnet, Installed Wt. W/CTB is the weight with all 120 CTB modules mounted, Installed Wt. W/TOF assumes all Central Trigger Barrel modules have been replaced with Time of Flight modules. The basis for the weights shown is listed in the right hand column. Where the weight of an item is a significant portion of the total, either a detailed accounting of the volume and density of its constituents or direct measurement was used.

Weight of TPC (lb.)

Item	Max LBNL	Max BNL Lift	Installed Wt. w/ CTB	Installed Wt. w/ TOF	Basis
IFC	107	107	107	107	close est
OFC	4991	4991	4991	4991	close est
Wheel	3100	3100	3100	3100	measured
Wheel Brkts/Adj	227	227	227	227	rough est
TOF rails	1080	1080	1080	1080	exact
Outer Sectors	2520	2520	2520	2520	measured
Inner Sectors	1752	1752	1752	1752	close est 75# ea,
Gas Manifolds at wheel	0	0	200	200	removed for lift
FEE	128	1539	1539	1539	measured
FEE Manifolds	480	480	480	480	rough
RDO	51	607	607	607	close est.
RDO manifolds	15	360	360	360	rough
RDO/FEE Cable	39	468	468	468	close est
Dist Manif/hose	240	390	390	390	rough
CTB modules (120 ea.)	0	660	3960	0	measured/ 33# ea.
TOF modules (120 ea.)	0	0	0	4800	Est, G.Mutchler 9/98
TOF cables/hose	0	0	240	240	rough
RDO elect. brkts	24	24	24	24	rough
SVT, Cone Assy &SSD	0	0	365	365	Mech Des Rev 3/98
FTPC	0	0	809	809	FDR action item 1
TOTAL	14753	18304	22409	23249	

Notes:

TPC partially populated with CTB (20 of 120) at initial installation

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STAR TPC Operating Procedures - back cover