The STAR iTPC Upgrade – status and news

Jim Thomas, and a cast of thousands

March 15th, 2016

I was not able to find a picture of a cast of thousands, but I was able to find a picture of a thousand casts

Who, what, when, where, why and how

- **Who**
  - **BNL, CTU Prague, Kent State, LBL, NPI Prague, SDU Shandong, SINAP Shanghai, UC Davis, UTA, USTC Hefei**
- **What**
  - **Upgrade the inner sectors of the STAR TPC to increase rapidity coverage and improve tracking and dE/dx at forward rapidities**
- **When**
  - **Proposed to BNL in 2011, presented to Tribble Committee in 2012**
  - **Funding to STAR this month (maybe), ready to take beam in March 2019**
- **Where**
  - **Key Science Institutions: BNL, Kent, LBL, UC Davis, USTC …**
  - **Key Projects at BNL (electronics & installation), LBL (sector mechanics), SDU (MWPCs)**
- **Why**
  - **Beam Energy Scan in 2019/2020**
- **How**
  - **Make as few changes to the existing apparatus as possible because this is a high risk upgrade due to the limited time left in the schedule**

Alex says I've been giving the same talk for 5 years. He is correct. If he starts snoring, just poke him gently to stop the noise but don't wake him up.

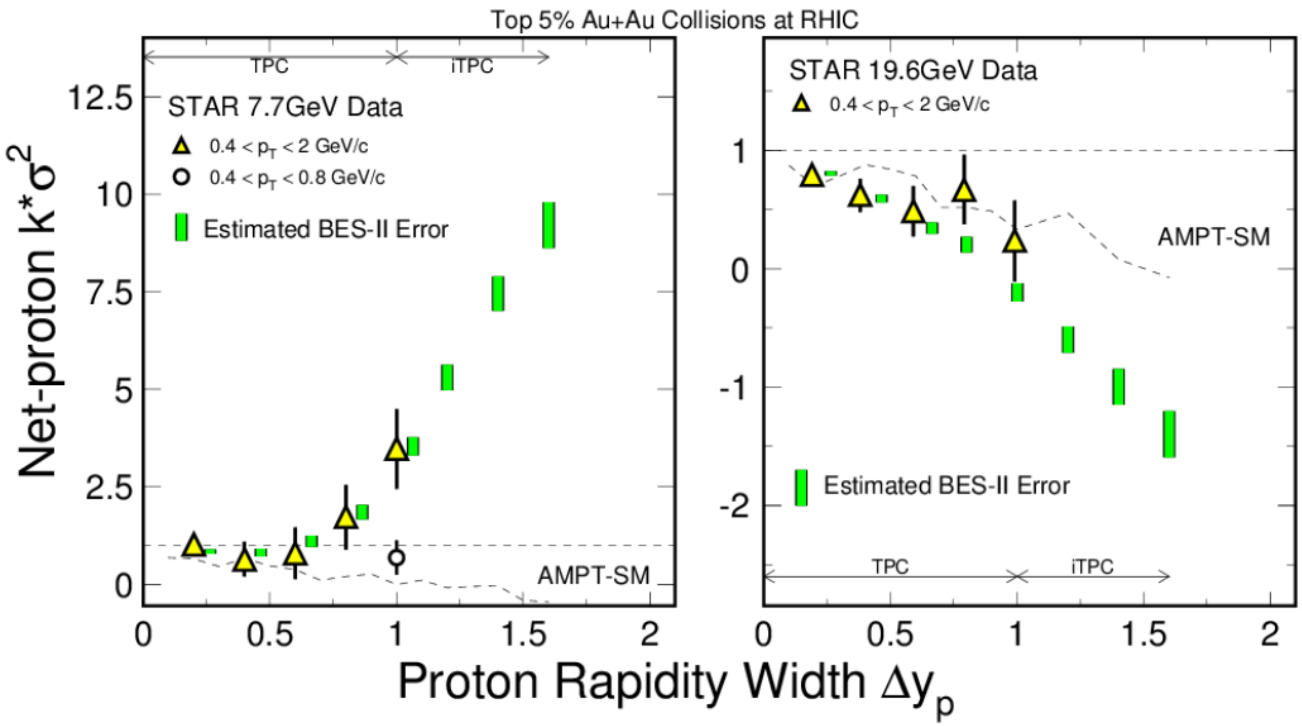
Beam Energy Scan – Topics and Commitment

Collision Energies (GeV):	**7.7**	**9.1**	**11.5**	**14.5**	**19.6**
Chemical Potential (MeV):	**420**	**370**	**315**	**260**	**205**
Observables	Millions of Events Needed				
R_{CP} up to p_T 4.5 GeV	NA	NA	160	92	22
Local Parity Violation (CME)	50	50	50	50	50
asHBT (proton-proton)	35	40	50	65	80
Directed Flow studies (v_1)	50	75	100	150	200
net-proton kurtosis ($\kappa\sigma^2$)	80	100	150	200	300
Elliptic Flow of ϕ meson (v_2)	100	150	200	300	400
Dileptons	100	160	230	300	400
Proposed Event Goals:	**100**	**160**	**230**	**300**	**400**
Projected Weeks with LEReC	14	9.5	5.0	2.5	3.0^+

BESII: an NSAC endorsed milestone in the LRP

iTPC PID/acceptance needed for net-proton Kurtosis

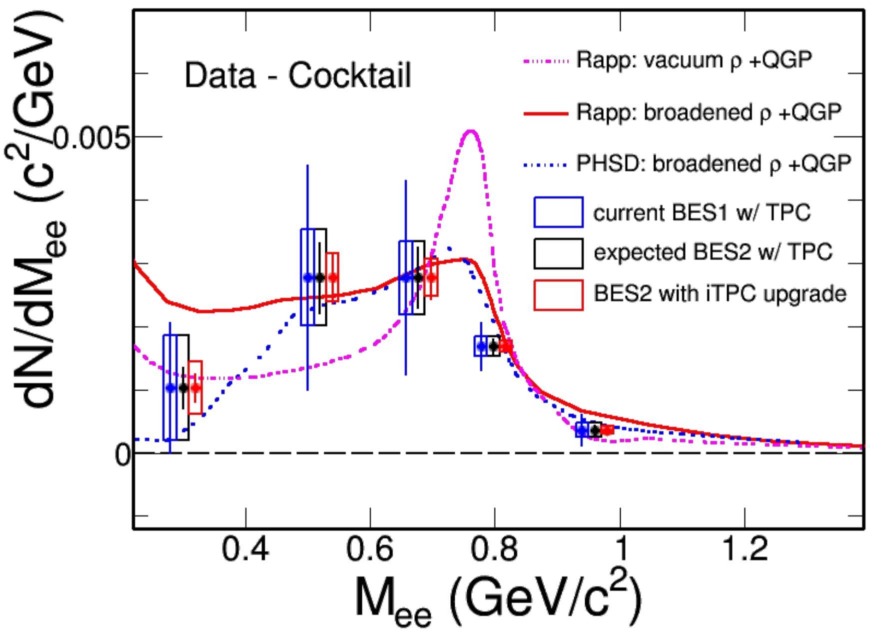
Money Plot #1

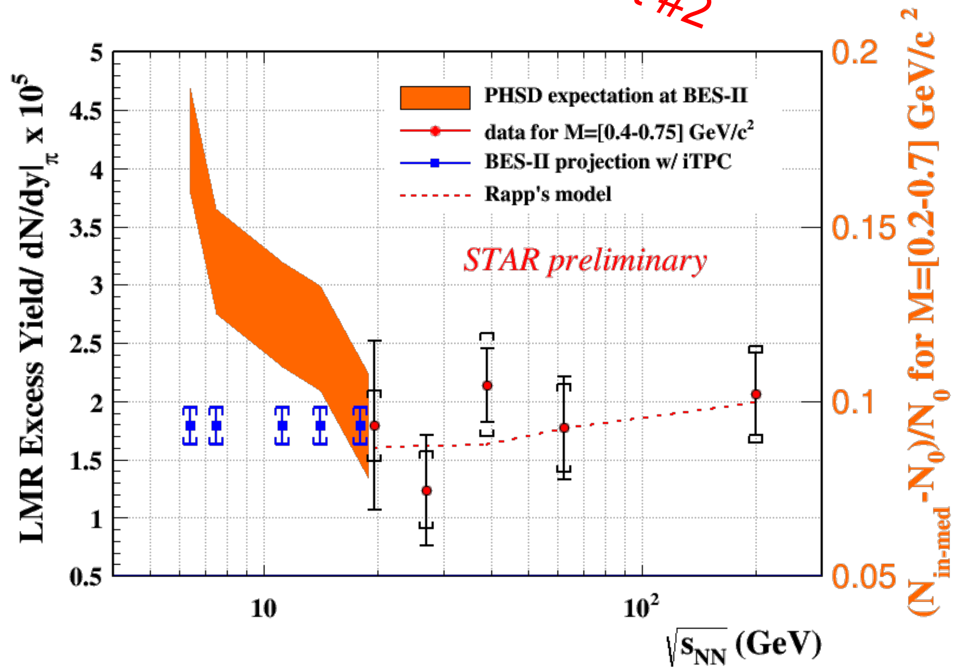


- **Net proton kurtosis expected to rise as the 4th power of acceptance if $\Delta y_{acc} < y_{corr}$**
- **Otherwise the growth is linear … so our results are sensitive to correlation length**
- **Significant measurements at high y are possible due to decrease in error bars**
  - **AMPT simulations shown, significance of measurements wrt theory is important**
  - **Xiaofeng Luo and Misha Stephanov have made important contributions to the theory/experiment interface**
    - **http://landau.phy.uic.edu/~misha/highmom-star/acceptance.pdf**

Enable Di-Electron Measurements

Money Plot #2

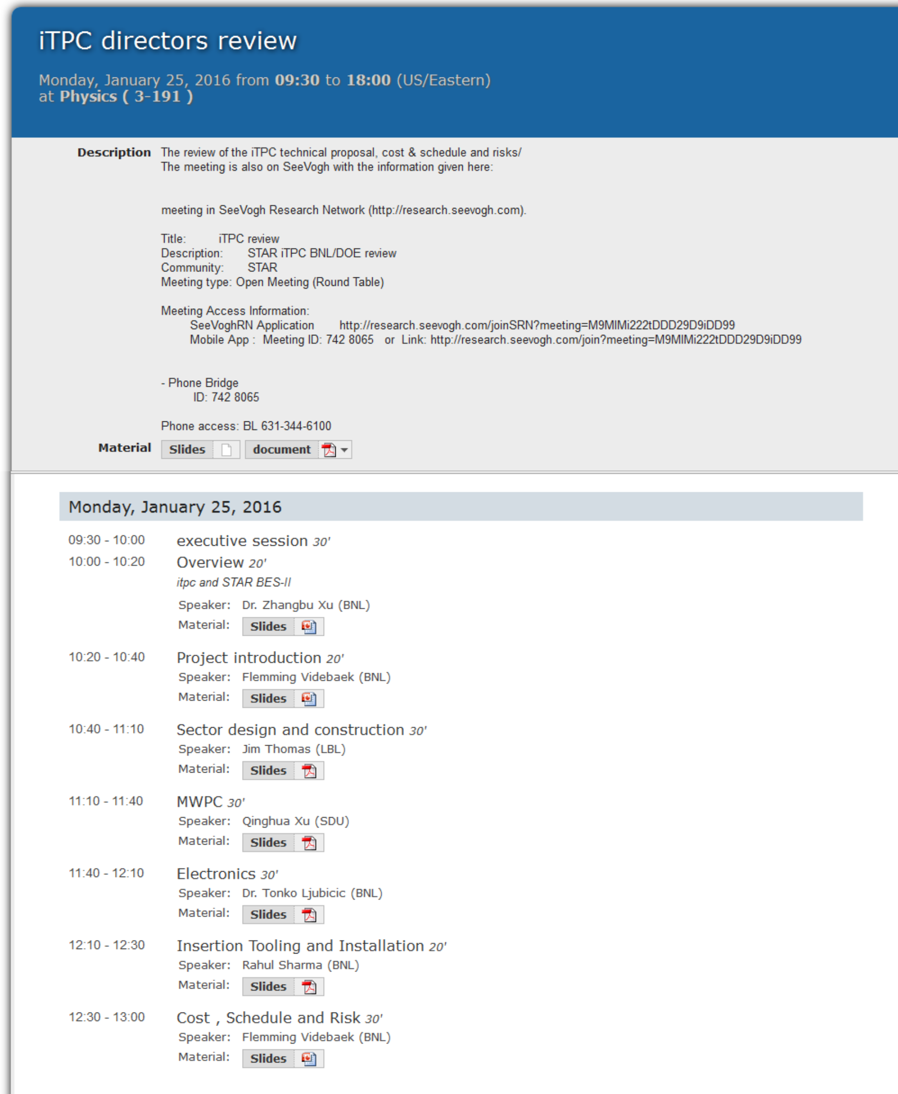




- Systematic study of di-electron continuum from $\sqrt{S_{NN}}$ = 7.7 – 19.6 GeV
  - Vector meson suppression due to (possible) Chiral symmetry restoration
- Inner Time Projection Chamber (iTPC) upgrade: reduce systematic error of the background (important), and improves acceptance for signal at $0.4 < M_{ee} < 0.7$
- Distinguish models with different ρ-meson broadening mechanisms (e.g. Rapp's method vs. PHSD)
- Study the total baryon density effect on LMR excess … projected error bars shown

Recent Reviews and Publications

- **iTPC Short Summary**
  - **https://drupal.star.bnl.gov/STAR/system/files/Summary_September14th_iTPC_final.pdf**
- **iTPC Proposal and CDR**
  - **STAR Note SN0629**
  - **https://drupal.star.bnl.gov/STAR/starnotes/public/sn0619**
- **Technical Design Report**
  - **STAR Note SN0644**
  - **https://drupal.star.bnl.gov/STAR/starnotes/public/sn0644**
- **Cost and Schedule review**
  - **https://indico.bnl.gov/conferenceDisplay.py?confId=1711**


iTPC directors review

Monday, January 25, 2016 from **09:30** to **18:00** (US/Eastern)
at **Physics (3-191)**

Description The review of the iTPC technical proposal, cost & schedule and risks/
The meeting is also on SeeVogh with the information given here:

meeting in SeeVogh Research Network (http://research.seevogh.com).

Title: iTPC review
Description: STAR iTPC BNL/DOE review
Community: STAR
Meeting type: Open Meeting (Round Table)

Meeting Access Information:
SeeVoghRN Application http://research.seevogh.com/joinSRN?meeting=M9MIMi222tDDD29D9iDD99
Mobile App : Meeting ID: 742 8065 or Link: http://research.seevogh.com/join?meeting=M9MIMi222tDDD29D9iDD99

- Phone Bridge
ID: 742 8065

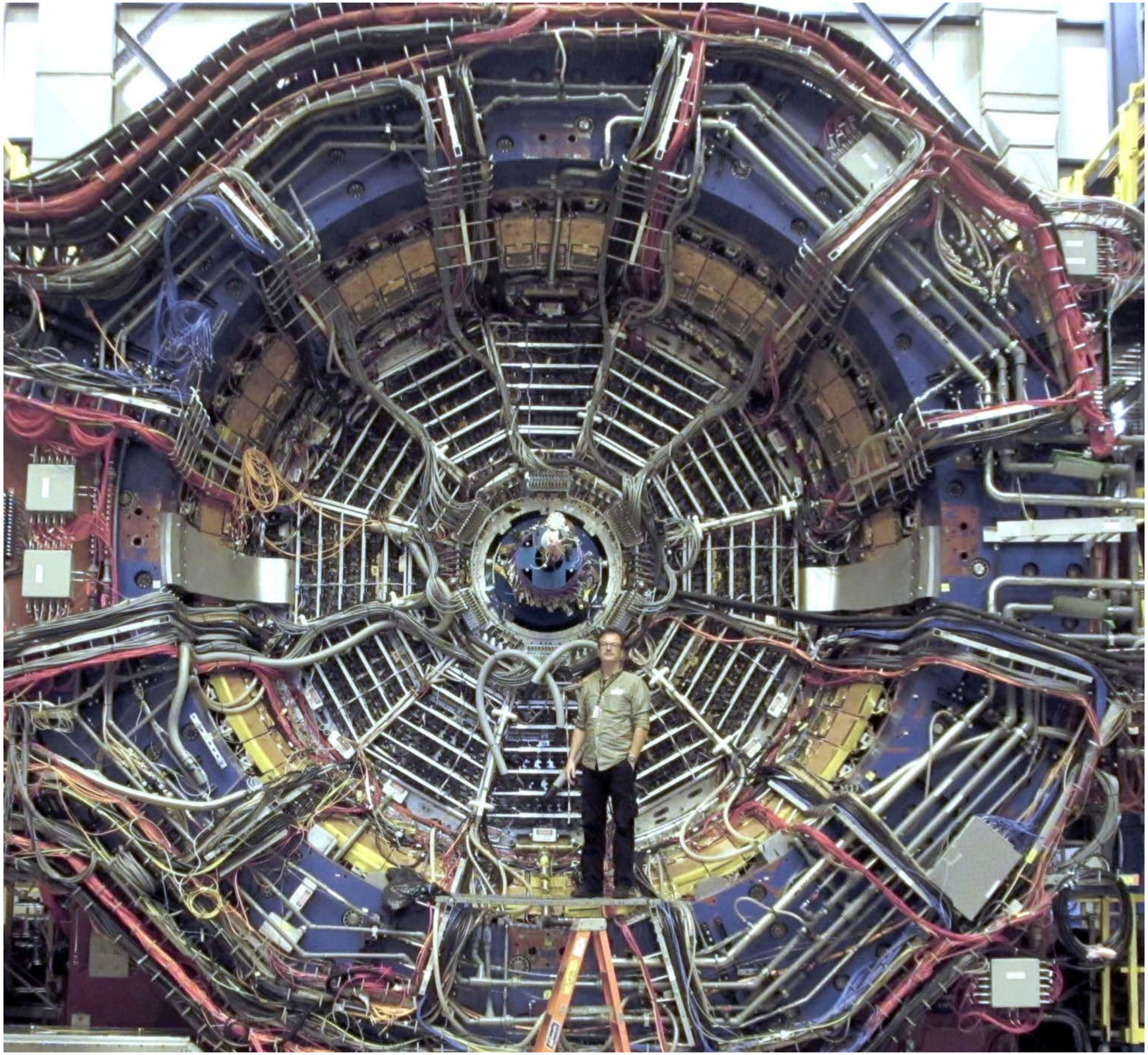
Phone access: BL 631-344-6100

Material Slides document

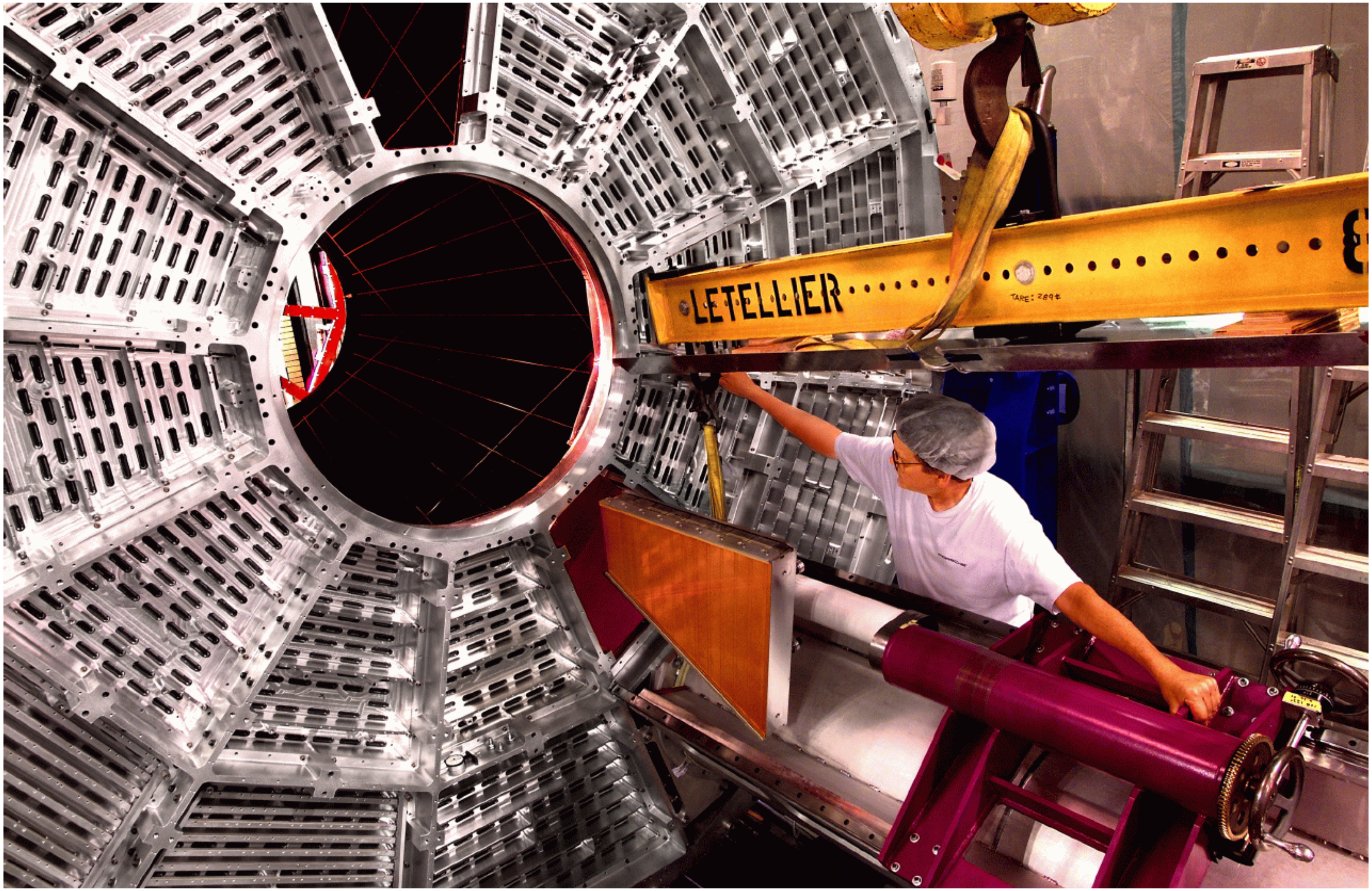
Monday, January 25, 2016

09:30 - 10:00	executive session *30'*
10:00 - 10:20	Overview *20'* *itpc and STAR BES-II* Speaker: Dr. Zhangbu Xu (BNL) Material: Slides
10:20 - 10:40	Project introduction *20'* Speaker: Flemming Videbaek (BNL) Material: Slides
10:40 - 11:10	Sector design and construction *30'* Speaker: Jim Thomas (LBL) Material: Slides
11:10 - 11:40	MWPC *30'* Speaker: Qinghua Xu (SDU) Material: Slides
11:40 - 12:10	Electronics *30'* Speaker: Dr. Tonko Ljubicic (BNL) Material: Slides
12:10 - 12:30	Insertion Tooling and Installation *20'* Speaker: Rahul Sharma (BNL) Material: Slides
12:30 - 13:00	Cost , Schedule and Risk *30'* Speaker: Flemming Videbaek (BNL) Material: Slides

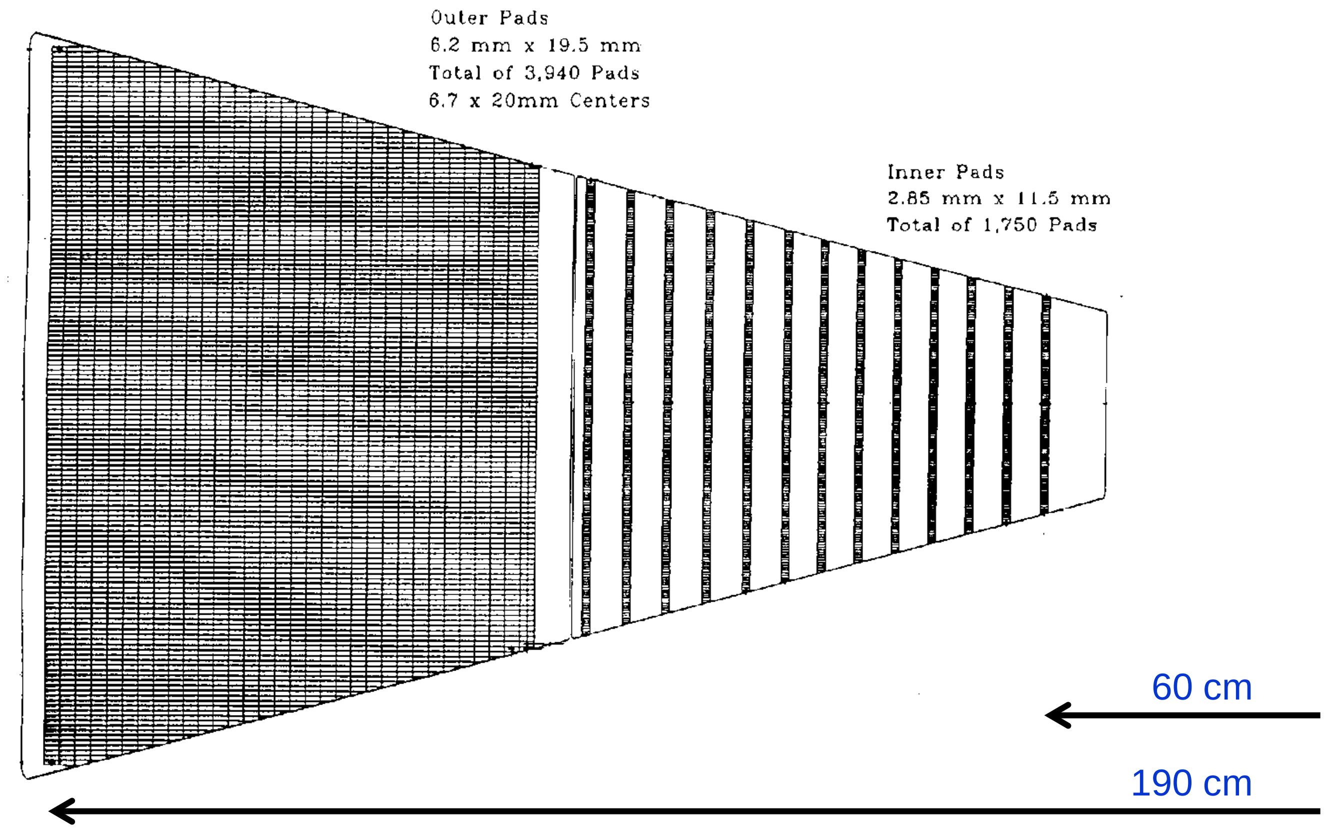
The STAR Detector at RHIC



Sector Insertion – special tools required ⇒ BNL



Goal: Hermetic coverage & better acceptance



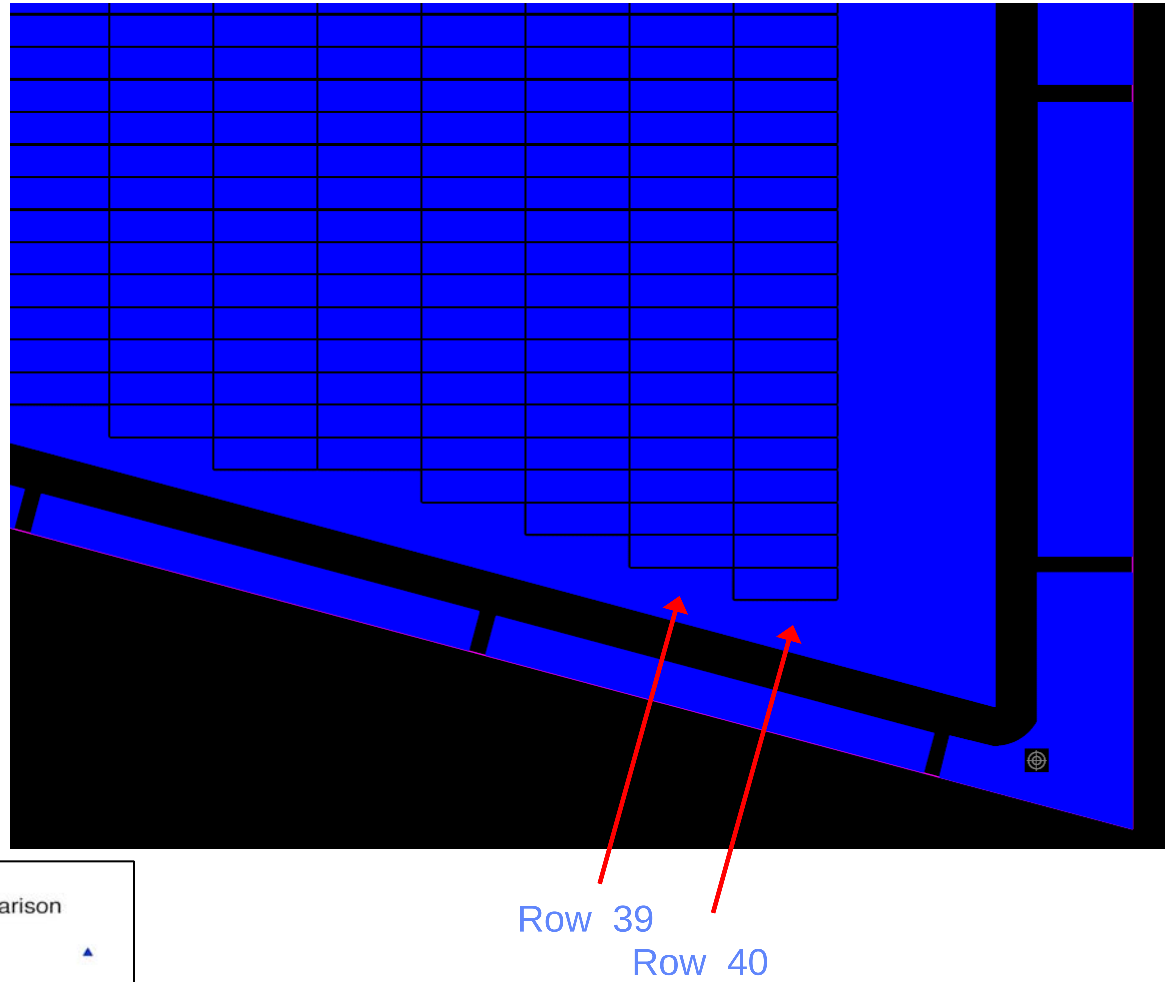
- Currently, the outer pad plane is hermetic while the inner pad plane is not
  - Goal: Add more pad rows on the inner sector, 2X total pad count

The upgrade will provide better momentum resolution, better dE/dx resolution, and improved acceptance at high η

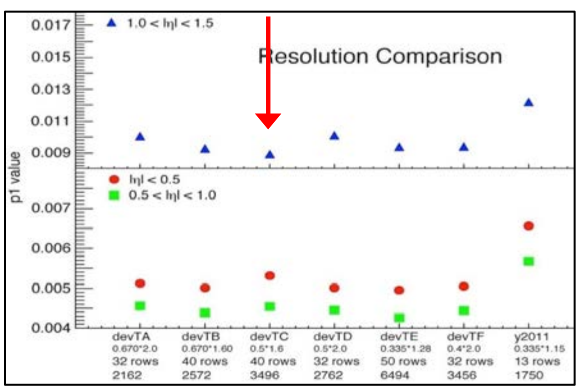
New Pad Plane design and layout

A corner of the new inner pad plane layout

by John Hammond & Bob Scheetz



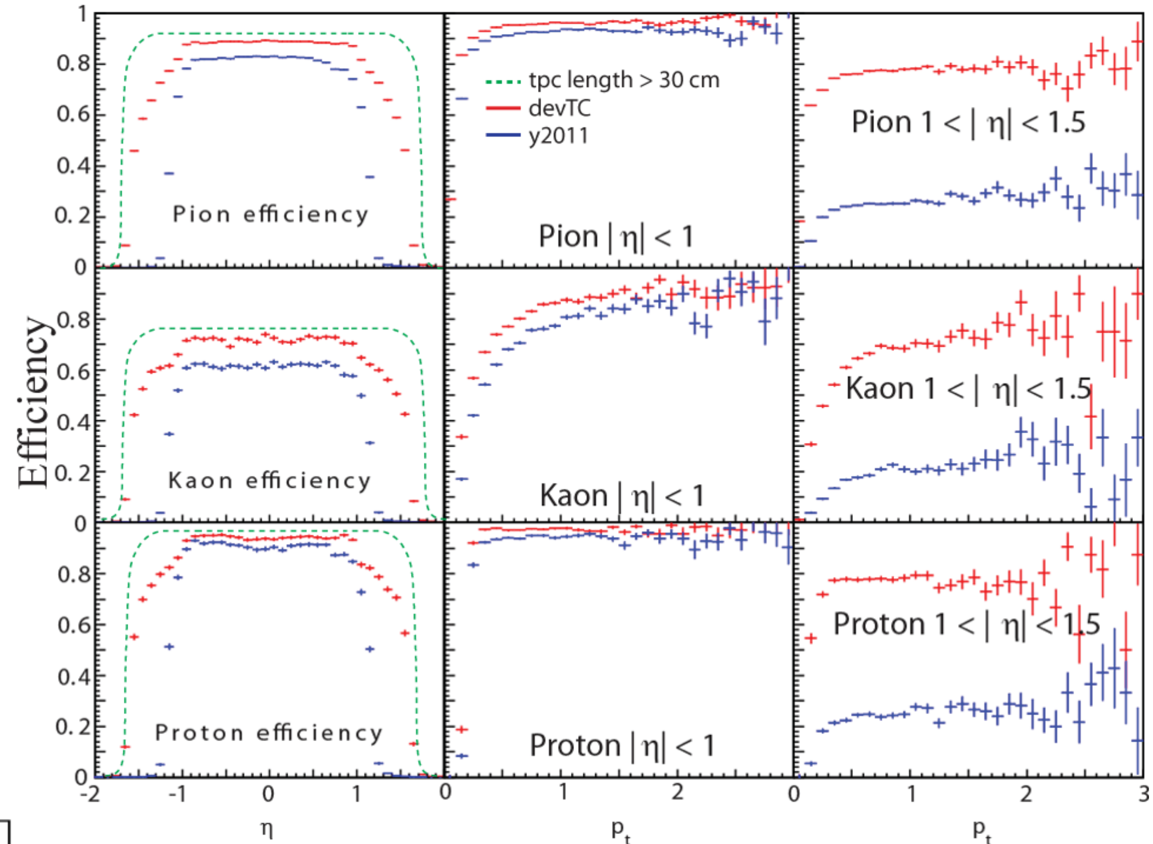
Pad Row	# of Pads
1	52
2	54
3	56
4	58
5	60
6	62
7	62
8	64
9	66
10	68
11	70
12	72
13	74
14	74
15	76
16	78
17	80
18	82
19	84
20	86
21	86
22	88
23	90
24	92
25	94
26	96
27	98
28	98
29	100
30	102
31	104
32	106
33	108
34	110
35	110
36	112
37	114
38	116
39	118
40	120
TOTAL	**3440**

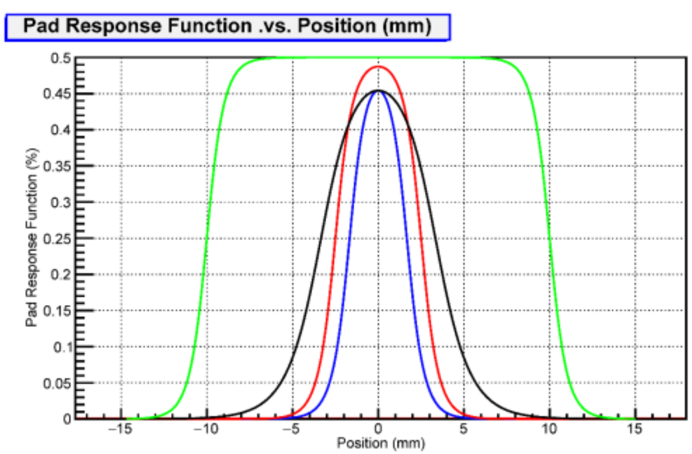


Momentum (and spatial) resolution not strongly dependent on pad design within the range studies … it's the extra rows that are important

New PadPlane Performance

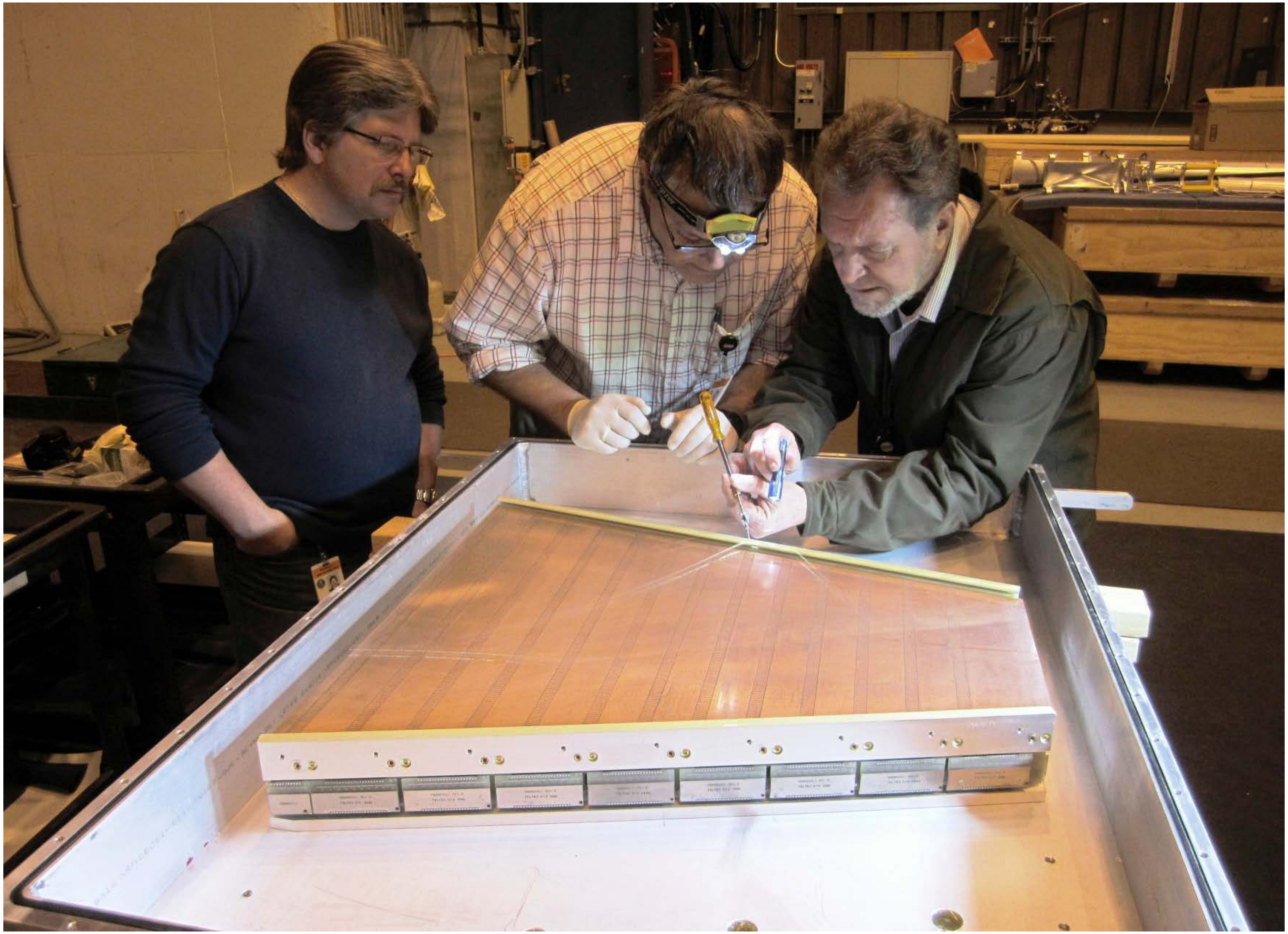
- **Efficiency as a function of η and p_T**
- **Acceptance increases from |η| < 1 to |η| < 1.5**





The pad response function for the outer sector is shown by the black line, the existing inner sector by the blue line, and the proposed inner sector by the red line. The pad spacing is 6.7 mm, 3.35 mm, and 5 mm respectively.

Project Scope: Mechanics, Electronics & MWPCs



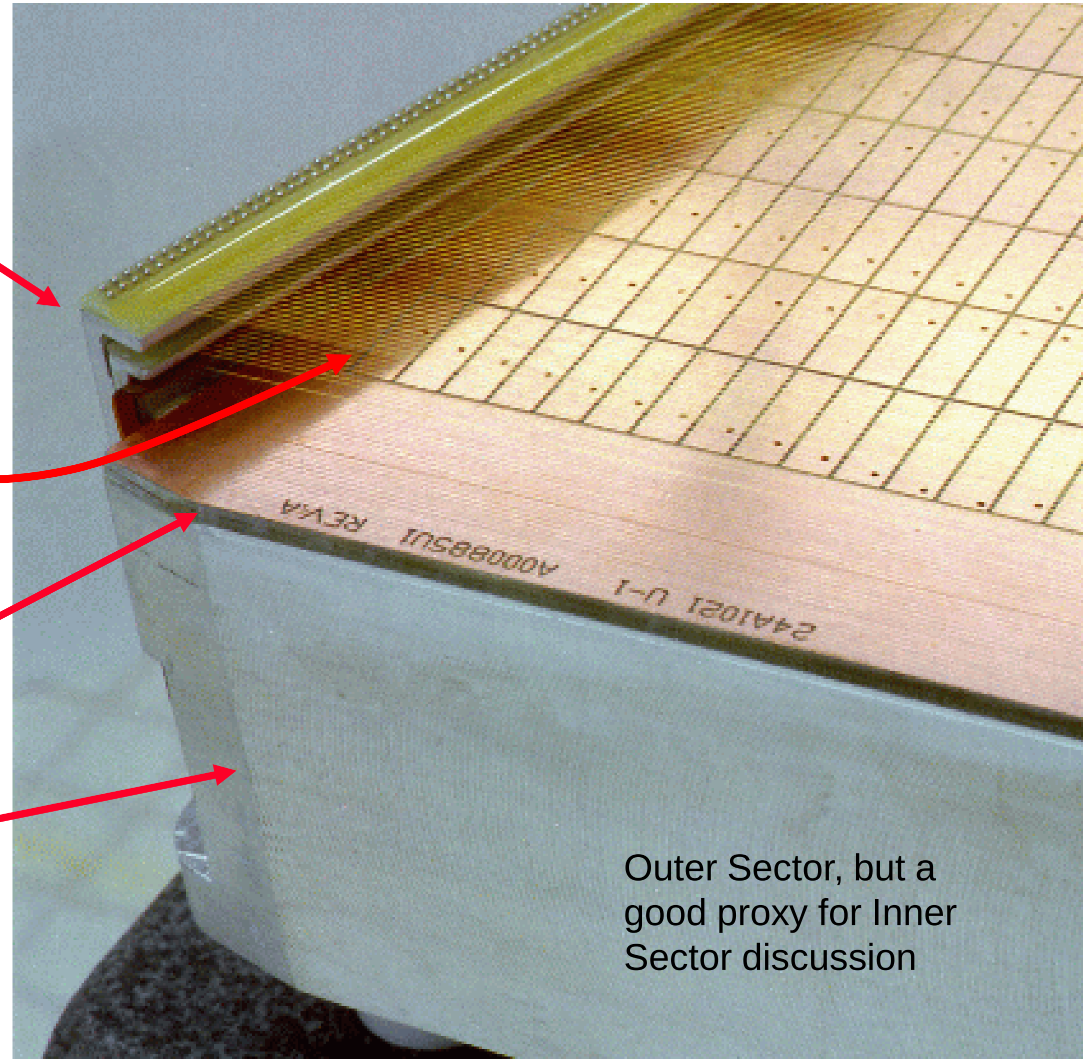
Major Items: Definition & Scope

Wire Mounts for Grids

Wire Planes:
Gated Grind, Cathode
Grid, and Ground Grid

Pad Plane with larger (5x16) pads, hermetic coverage

Strongback



Outer Sector, but a good proxy for Inner Sector discussion

Major Mechanical Tasks

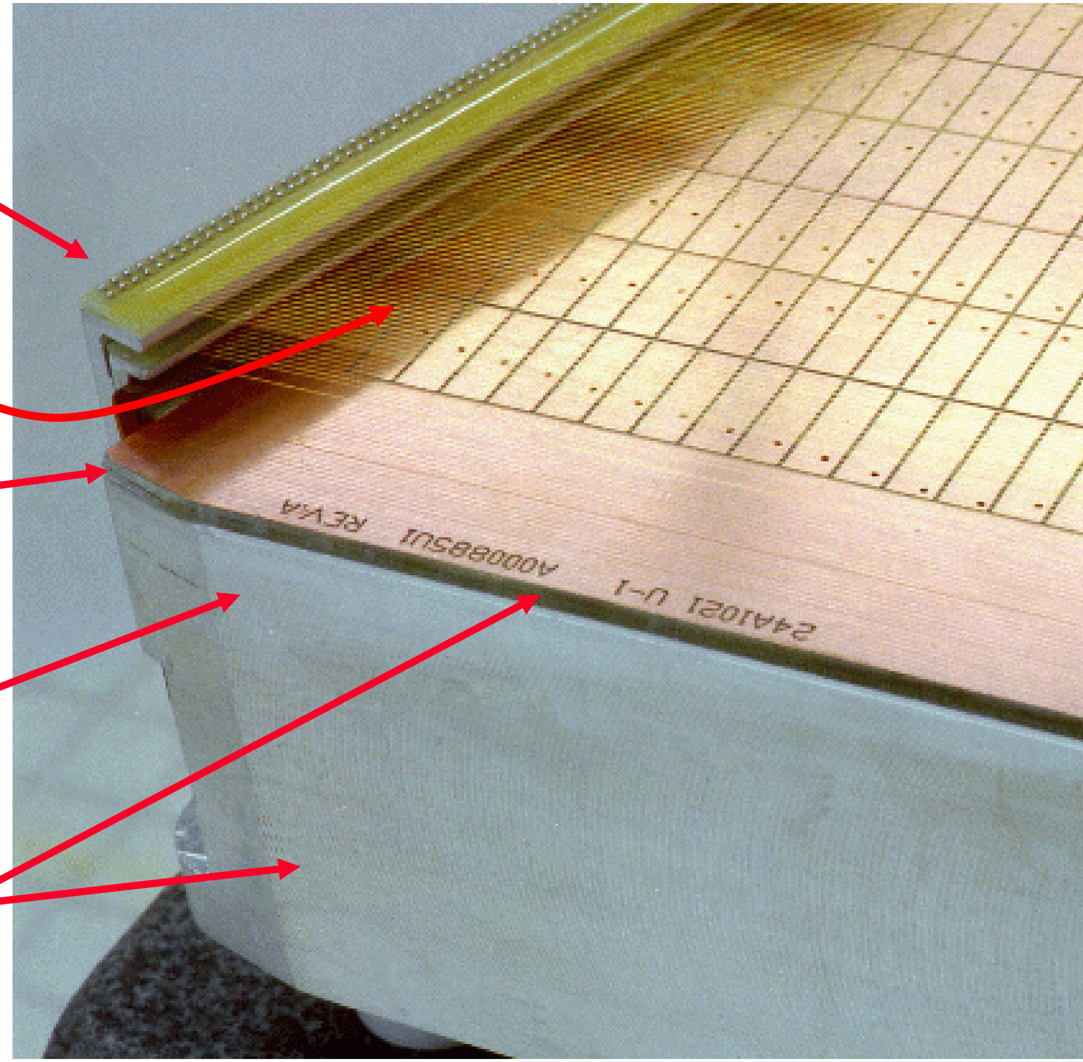
Fabricate, Align and Pin Wire Mounts (BNL & LBL)

Wind wire grids
(SDU, see Qinghua Xu's talk)

Fabricate, QA check
Align (50 μm)
Glue (< 20 μm flat)
& Trim padplane (BNL & LBL)
(See Tonko Ljubicic's talk)

Fabricate strongback & inspect (QA) (Outside vendor)

Cut to height, machine
O Ring groove,
Survey padplane &
Document mech. specs (LBL)



Cost Drivers

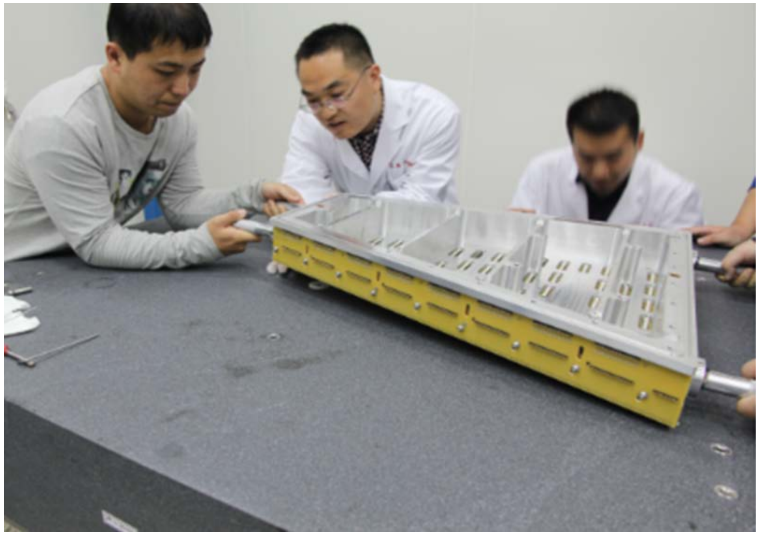
- **Padplane & Electronics** (BNL)
  - $96.4K for Padplanes
  - $1.4 M (approximately) for DAQ boards & electronics
- **Strongback** (Outside vendor, BNL procurement)
  - $418.9 K
  - Two preliminary vendor quotes & initial experience at UT Austin
- **Assembly of Padplane & Strongbacks** (LBL)
  - $551.8 k
  - Berkeley is the preferred location for the gluing of the PadPlane, and assembly of the Strongback and Wire Mounts
    - Close proximity to Engineers and Technicians who previously worked on STAR (circa 1995)
    - Nicely integrated Assembly shop, Machine Shop & Survey shop

We are proposing to bring the Assembly work to LBL
(primarily work for Eric Anderssen's group in B77)
This will need active support from NSD in order to succeed

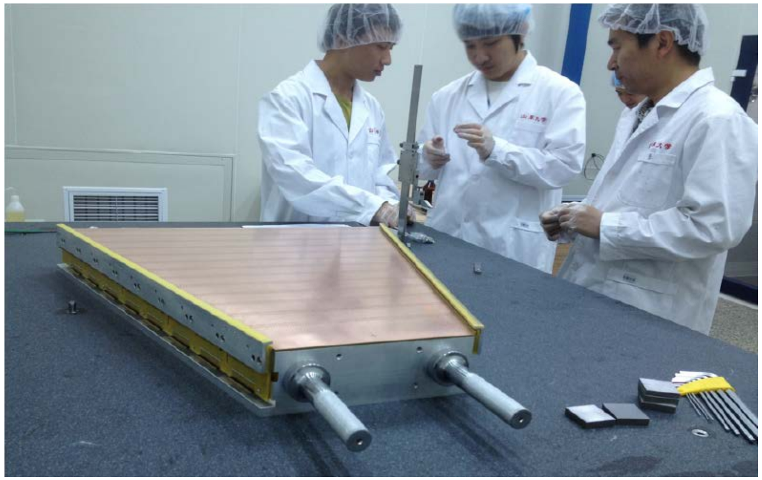
Schedule Drivers relevant to work at LBL

- **Strongback**
  - We must go to an outside vendor with multiple machines in order to fabricate the strongbacks
    - UT Austin is no longer an option
    - 6 to 8 weeks (.vs. 1 year), preliminary quotes from outside vendors
- **Padplane**
  - Work is being done by STAR Electronics group which is one of the projects greatest strengths. However, sharing the wealth of good manpower is a competitive process. Work has been delayed. (Affects QA and prototyping schedules)
- **Assembly**
  - Schedule is fast paced, only ~2 days allowed per sector
  - Tooling and time to set up work space
- **Critical Path**
  - The PadPlane and the Strongback are simultaneously on the critical path
    - Both must be available in Berkeley on August 1st
  - Berkeley assembly shops are busy with ALICE upgrade work, already
    - Only way to deal with this is to start early and Multi-task

MWPC Production at Shandong University



- Qinghua Xu is leading the Shandong University group
- iTPC Funded via CNSF & dedicated Labs built
- ~2 years technical work and lab preparation getting ready for this project
- One of the highlights of the iTPC team development



Full Project Summary schedule

Calendar Year		2016				2017				2018				2019			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Mechanical																	
padplane																	
Strongback production																	
Padplane Assembly																	
Assemble MWPC																	
Sector Installation																	
Electronics																	
RDO																	
SAMPA																	
FEE																	
Electronics installation																	
Roll-in and commisioning																	
Insertion Tool																	

Current schedule has STAR ready for data taking March 1 2019, with ~1.5 month of commissioning. Key goal of project is to have upgrade complete for Run-19.

Critical path goes through electronics path (SAMPA chips), installation and test, but the mechanical systems are essentially on the critical path, too.

Cost to DOE

Ayk$

WBS		FY16	FY17	FY18	Conting	Total
1	**Mgt**	50.6	94.5	97.4	45.5	288.0
2	**Padplane**	96.4	0.0	0.0	32.8	129.2
3	**Mechanics**	949.9	228.0	14.8	250.3	1,443.0
4	**Installation**	0.0	0.0	136.4	31.2	167.6
5	**Electronics**	45.7	310.3	934.3	238.4	1,528.6
	Total DOE	**1,142.6**	**632.8**	**1,182.8**	**598.1**	**3,556.4**

The NSF-China contribution is not included (~$1.0 M US)

The cost of Installation tooling not included (~$650 K US)

Risk – high level summary

- **Technical**
  - Better than 20 μm flatness requirement for PadPlane+Strongback
  - Excellent alignment of wires and padplane (20 μm), excellent control over tension on wires
  - Bromine free materials
    - A vigorous QA plan is essential
    - We have the elements of a good QA plan in place but we also need the will to stick to it
- **Schedule**
  - We are relying upon the ALICE SAMPA chip for the iTPC electronics
  - Pre-production prototype step for Strongbacks (etc) is in jeopardy
    - Schedule is tight and so we may be forced to skip traditional steps
  - Minor schedule slips can easily eliminate the opportunity to develop tooling and practice our techniques on a prototype
- **Management**
  - Major activities must complete this year, requires $$$ quickly
  - For example, we haven't spent any money this fiscal year

Summary

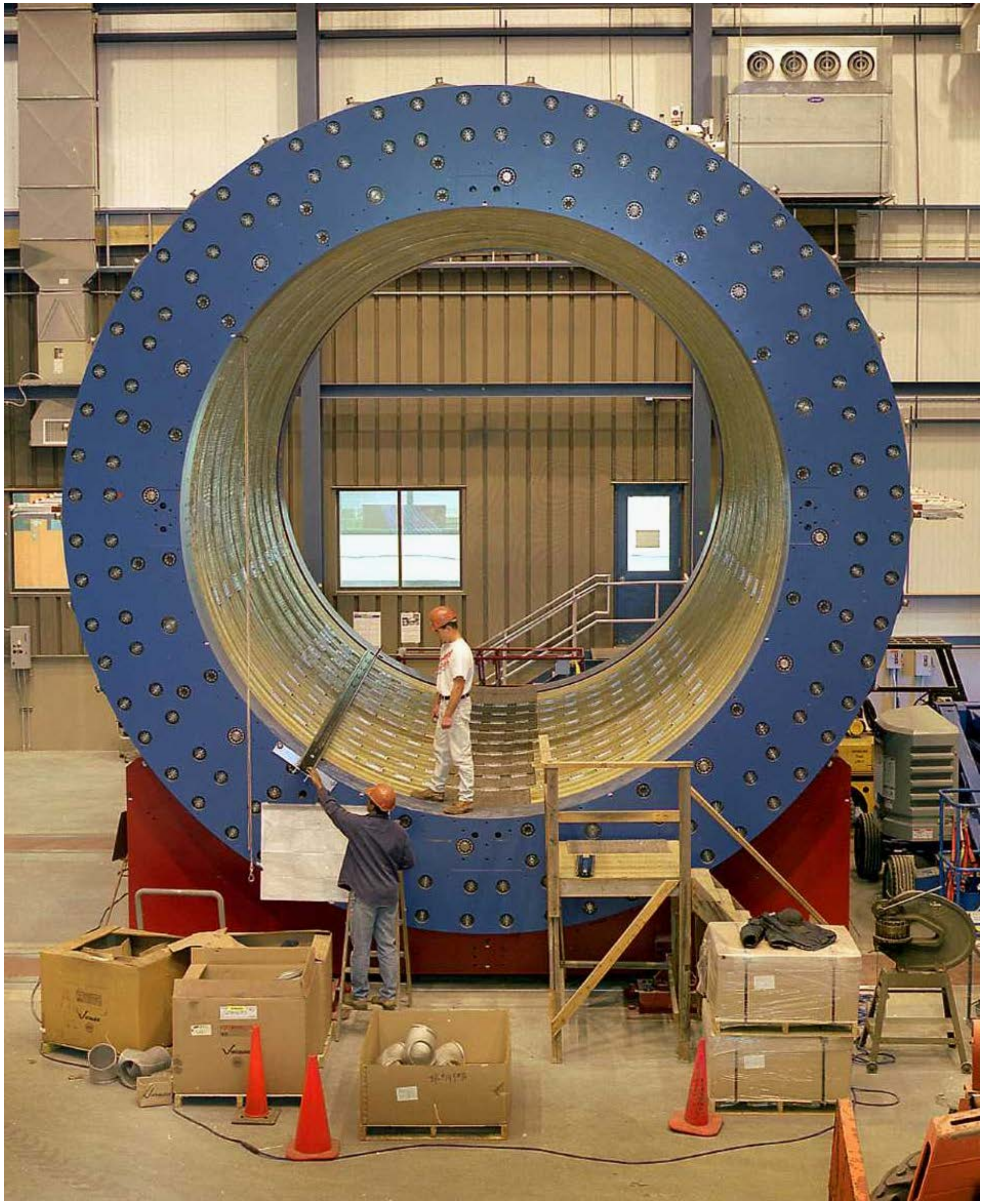
- **The iTPC upgrade will enable new physics with BES II**
  - **Enhanced Kurtosis measurements**
  - **Enhanced Di-electron measurements**
- **New PadPlane & Faster electronics**
  - **40 pad rows, 5 mm x 16 mm pads (center to center spacing), full coverage**
  - **Increase TPC acceptance from < 1.0 to < 1.5 units of pseudo-rapidity**
- **Strongback is 95% the same as before**
  - **Fix the grid-leak problem**
- **Cost and Schedule concerns**
  - **Very tight schedule. No float.**
  - **We are skipping the "prototype" step for nearly all work in the US**
  - **Final PadPlane, Strongbacks & wire mounts due in Berkeley on August 1st**
  - **Money must move from BNL to LBL very quickly, can it be done?**
  - **Spending large amounts of money – wisely – is hard to do**

An upgraded TPC with $500K of new work for NSD and Engineering

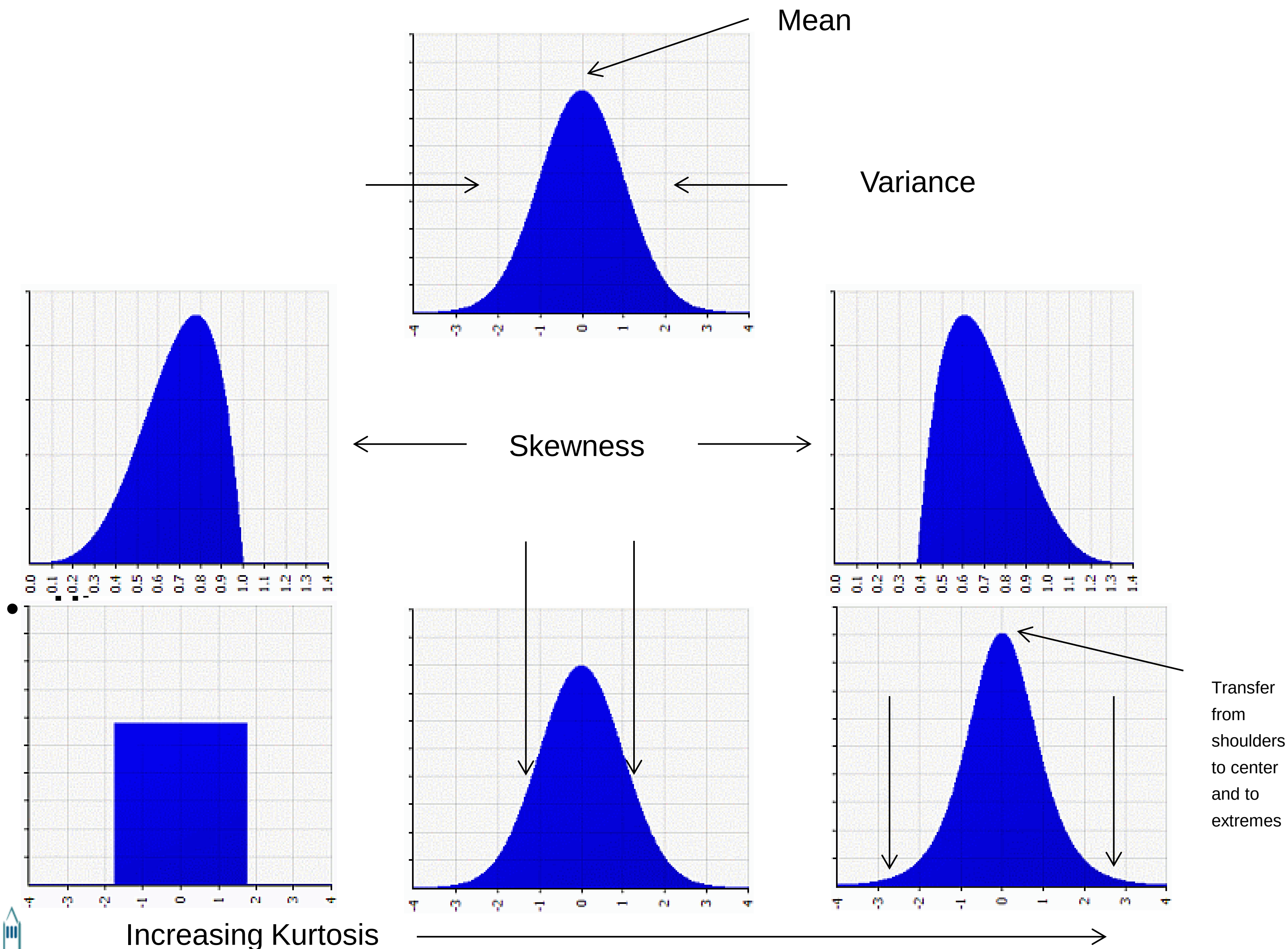
Backup Slides

The TPC is the Heart of STAR

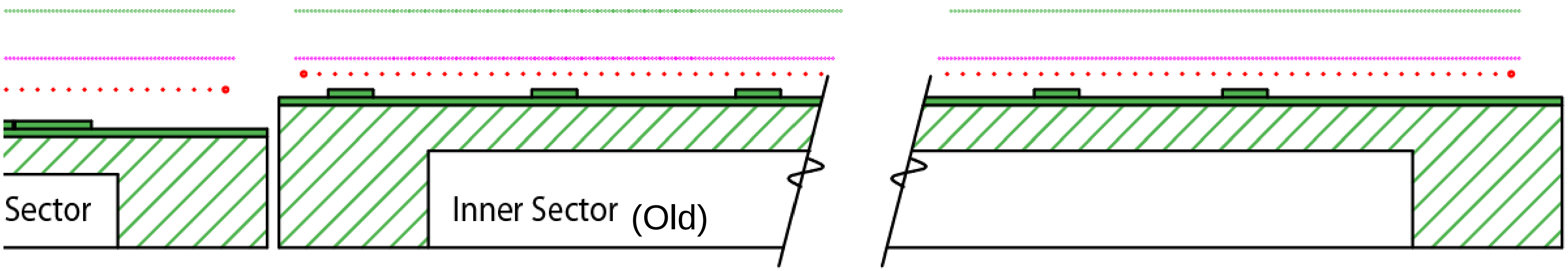
- **STAR without the TPC**



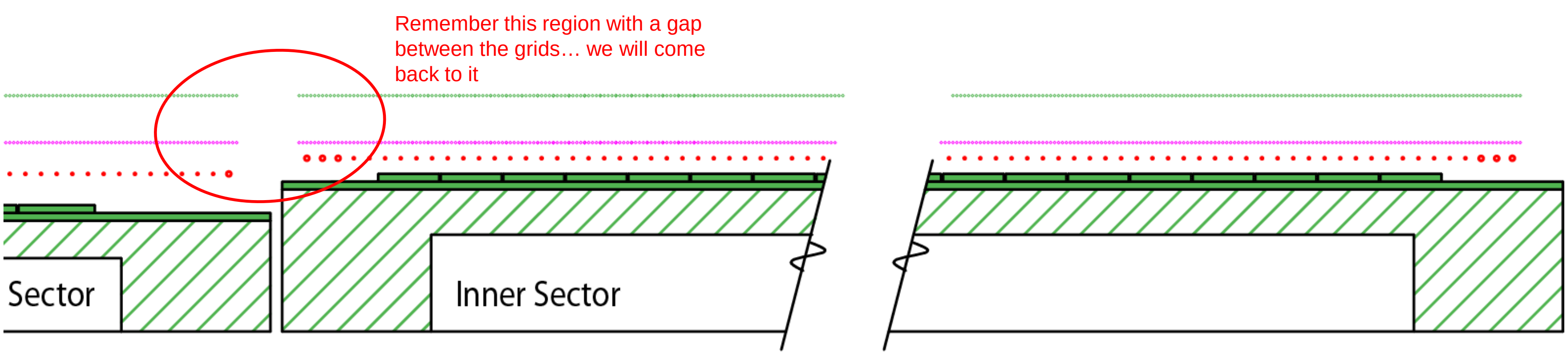
Mean, Variance, Skewness and Kurtosis



40 Pad Rows fit perfectly with the existing grid



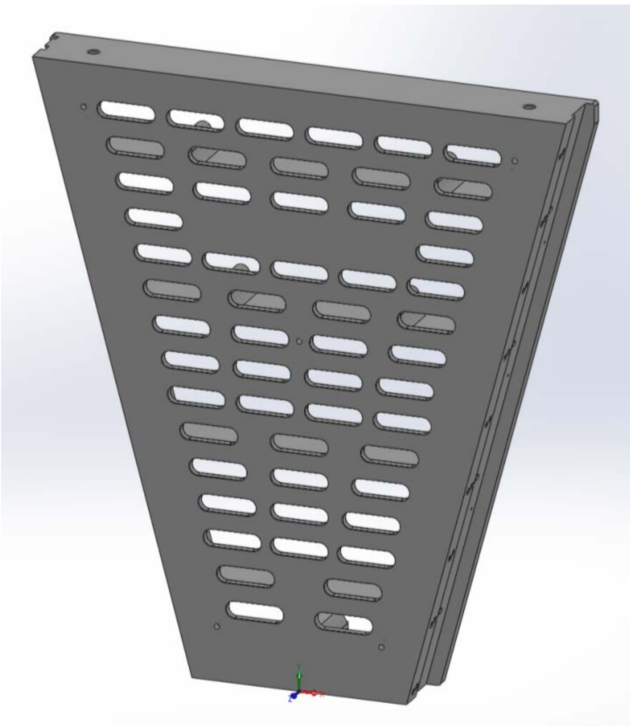
Anode wires spaced 4 mm apart (horizontally), Ground Shield and Gated grids spaced 1 mm apart



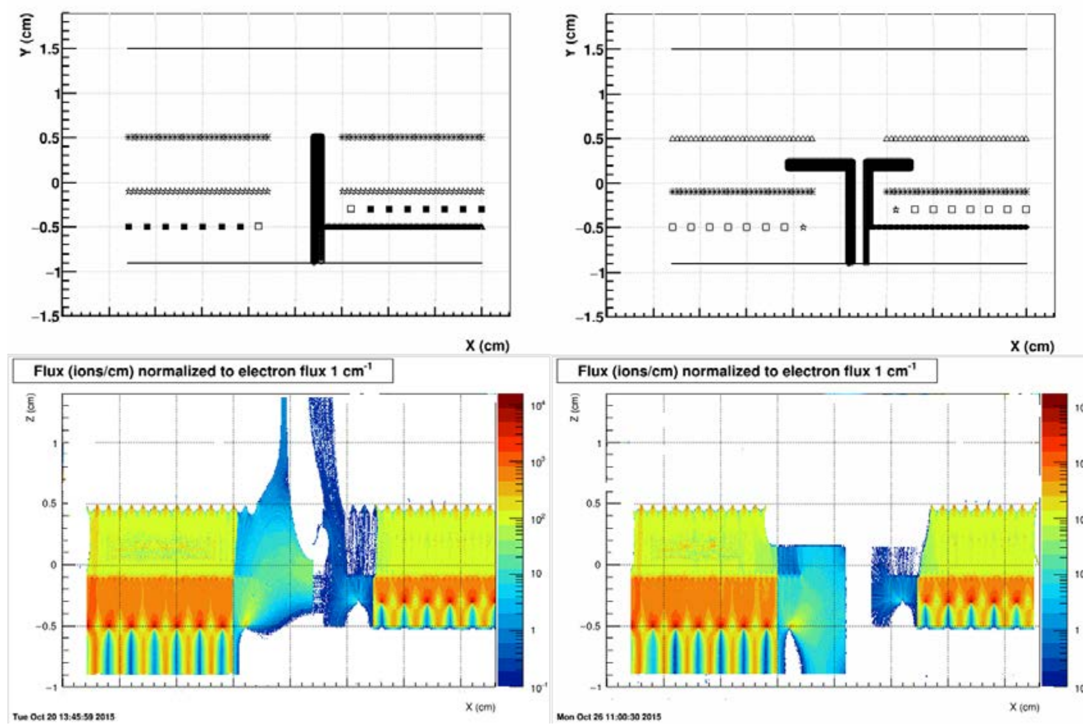
- **Identical pad response function on both ends of grid**
- **No need to change grid; wire locations remain the same!**
- **No need to add more ABDB or wire mount channels (good!)**

Changes since previous (1995) design

- **3D CAD design – (lower fabrication & inspection costs)**
- **Slots for electronics move down by 0.221”**
- **Wall to mitigate gridleak problem**



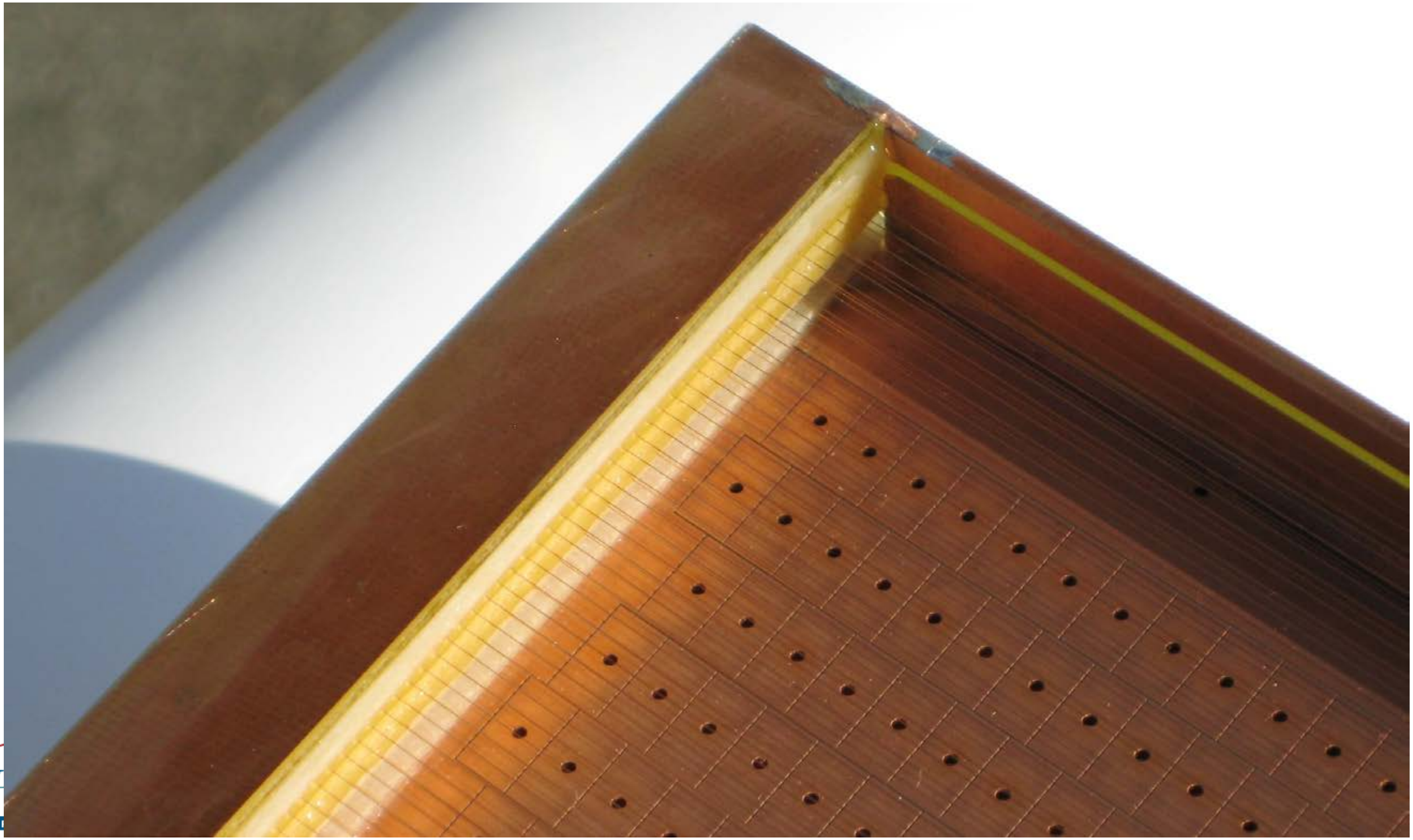
Slots for electronics are lower by 0.221” than previously. Otherwise, the same.



GARFIELD simulations of ions flowing away from the STAR TPC anode wires when the Gated Grid is closed. There is a 1.2 cm gap between the Inner and Outer sectors that is not covered by the Gated Grids. This gap allows ions to flow out of the MWPC region and into the tracking volume of the TPC. Putting a -690 volt bias (left panels) on the wall reduces the flow of ions, while the “L” shaped wall (right panels) completely stops the flow of ions. The “L” shaped wall was held at 0 volts in this simulation.

The Alice Solution to the Grid Leak problem

- **Multiple thick anode wires near the boundaries of the sectors**
- **A wall – to terminate the field lines from the Anode wires with ground potential and "cover" potential (match field gradient)**



Parameters for the old and new sectors

Item	Inner	Outer	iTPC	Comment
Pad Pitch (center to center)	3.35 x 12	6.70 x 20	5.0 x 16	mm
Isolation gap between pads	0.5	0.5	0.5	mm
Pad Size	2.85 x 11.5	6.20 x 19.5	4.5 x 15.5	mm
Number of Pads	1750	3940	3496	
Anode to pad plane spacing	2	4	2	mm
Anode voltage	1170 V	1390 V	~ 1120 V	20:1 S/N
Anode Gas Gain	3770	1230	~ 2000	nominal
Anode Wire diameter	20 μm	20 μm	20 μm	Au plated W
Anode Wire pitch	4	4	4	mm
Anode Wires phase locked to pad location	3 wires, #2 over center	5 wires, #3 over center	4 wires, over center	grp centered over the pad

Pad Plane & wire planes must be flat to better than 20 μm to keep dE/dx resolution uniform to 1%

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

Strongback Construction Prototype

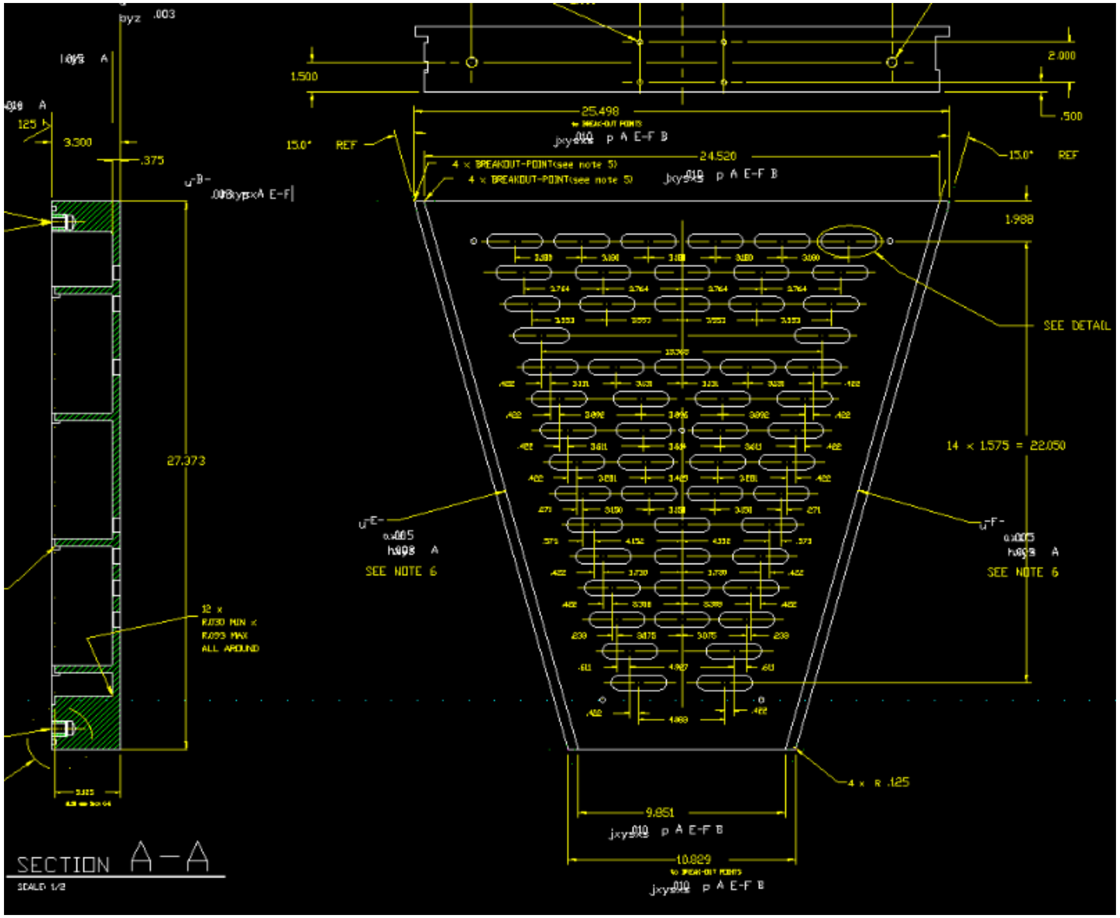
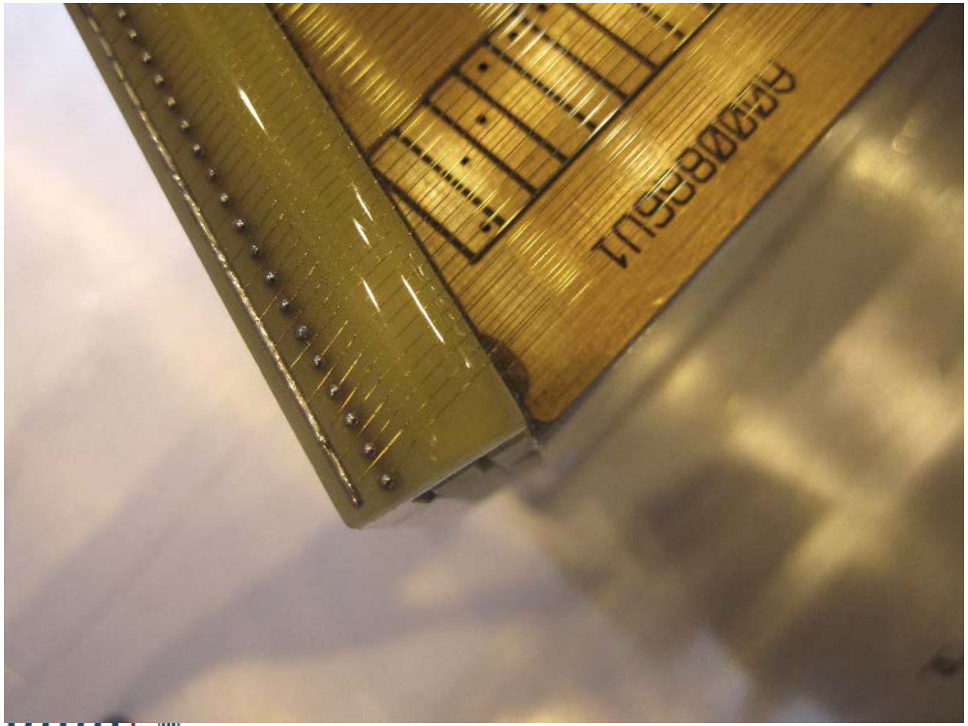
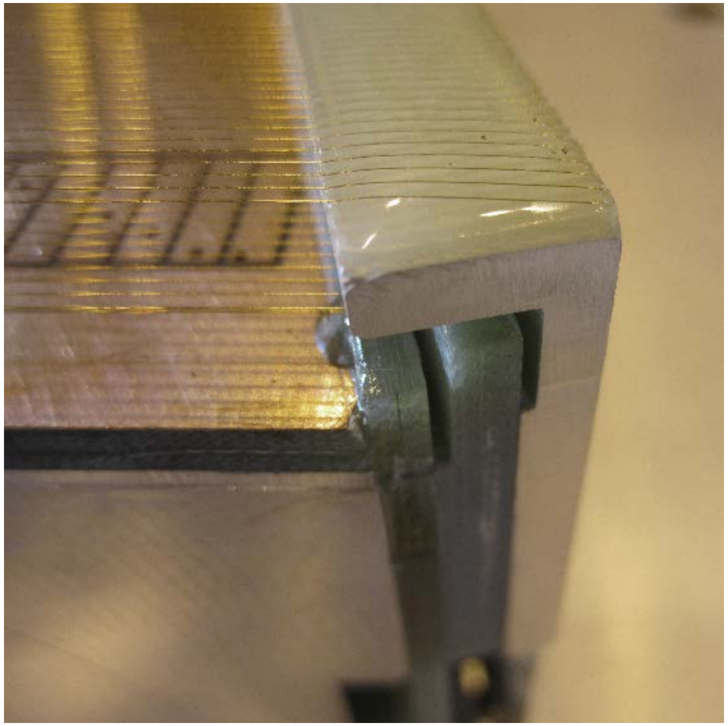


Figure 54: A prototype inner sector strongback is shown during fabrication at the University of Texas (circa 2013). The sector was machined out of a single piece of aluminum. Dimensions are: ~27 inches tall, ~25 inches wide and weight 73 lbs. The sector is viewed from the backside; the side upon which the electronics and cooling manifolds will eventually be mounted.

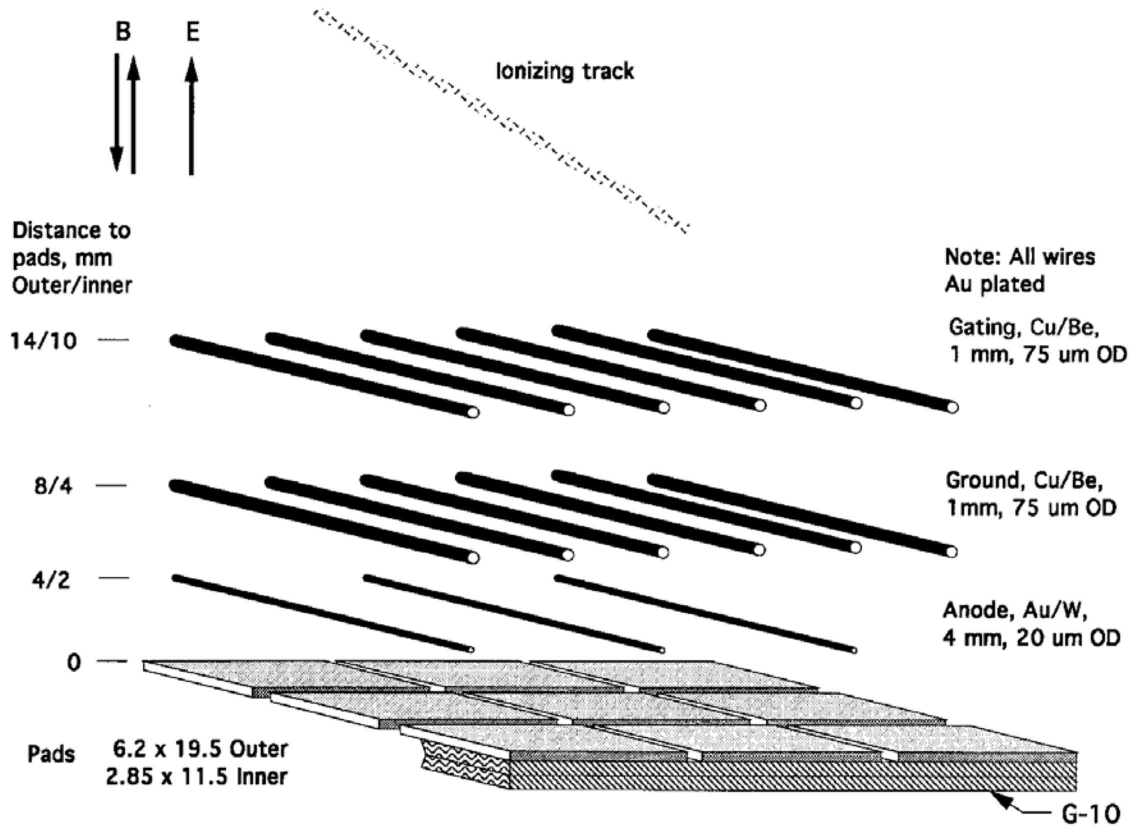
Wire locations near the gap will not change

- **The location of the wires near the inner/outer gap cannot change**
  - **Position and total number of wires on each plane remains the same**
- **Because … it is not possible to add more wires**
  - **The full extent of the side mounted wire mounts are already used**





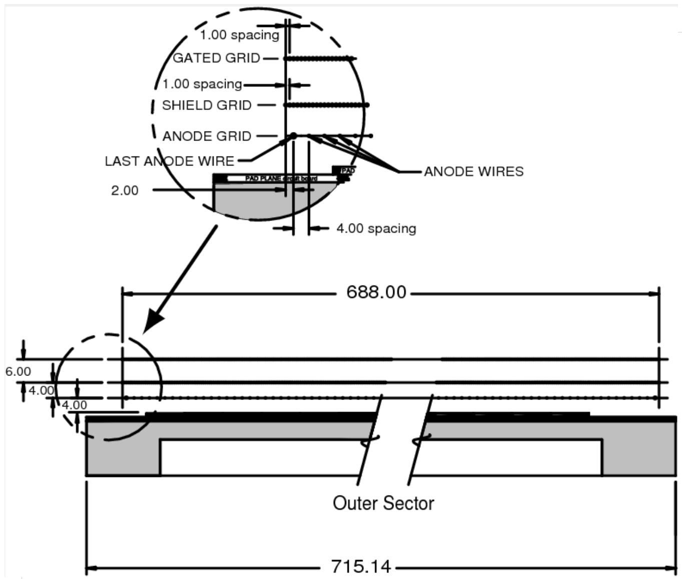
Sector Wire Geometry – special notes

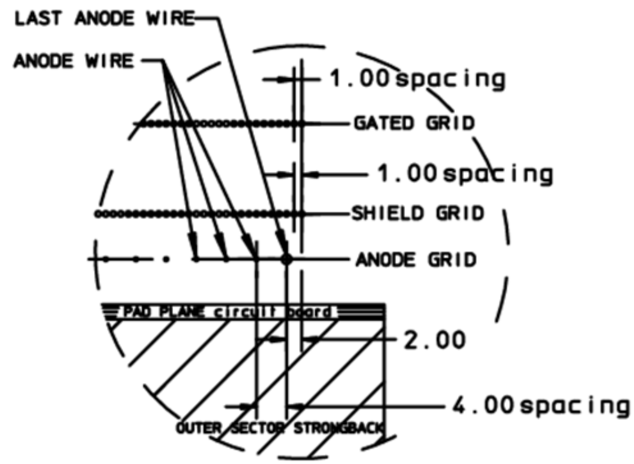


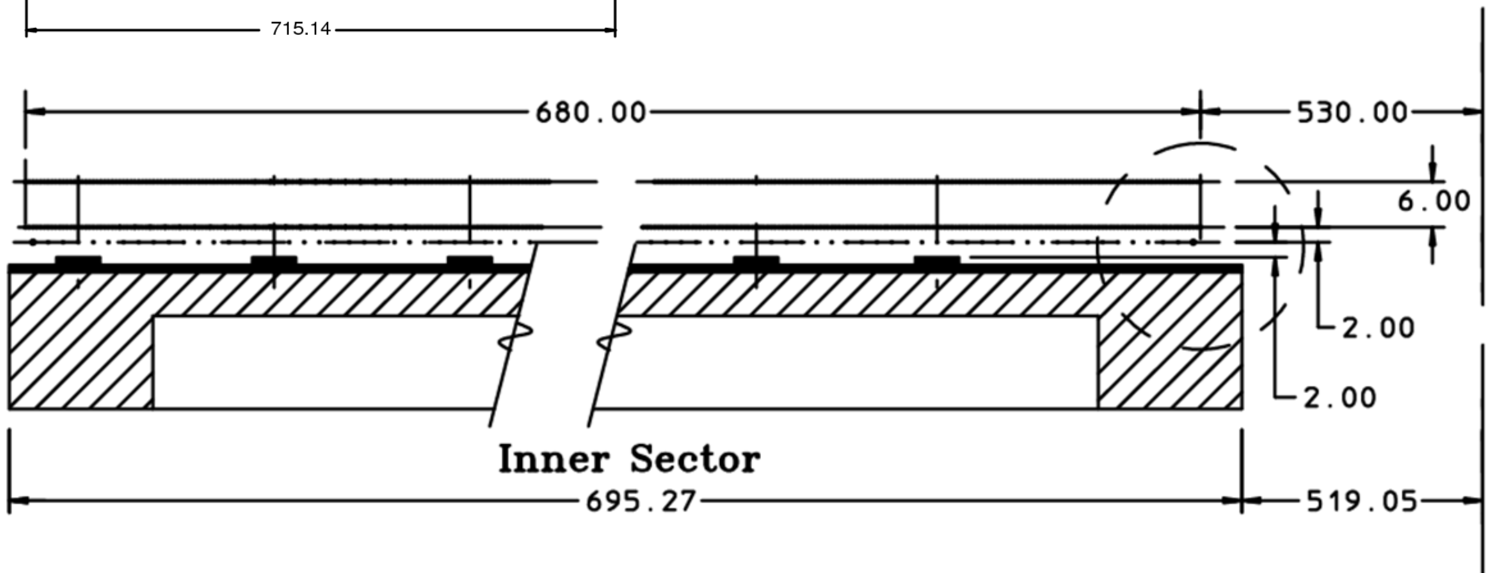
Wires are phase locked to the pad locations. 4 wires located over each pad row. We can probably tolerate a phase shift of 100 microns.

Ground wires placed directly over the Anode wires to limit sparking to pad plane.

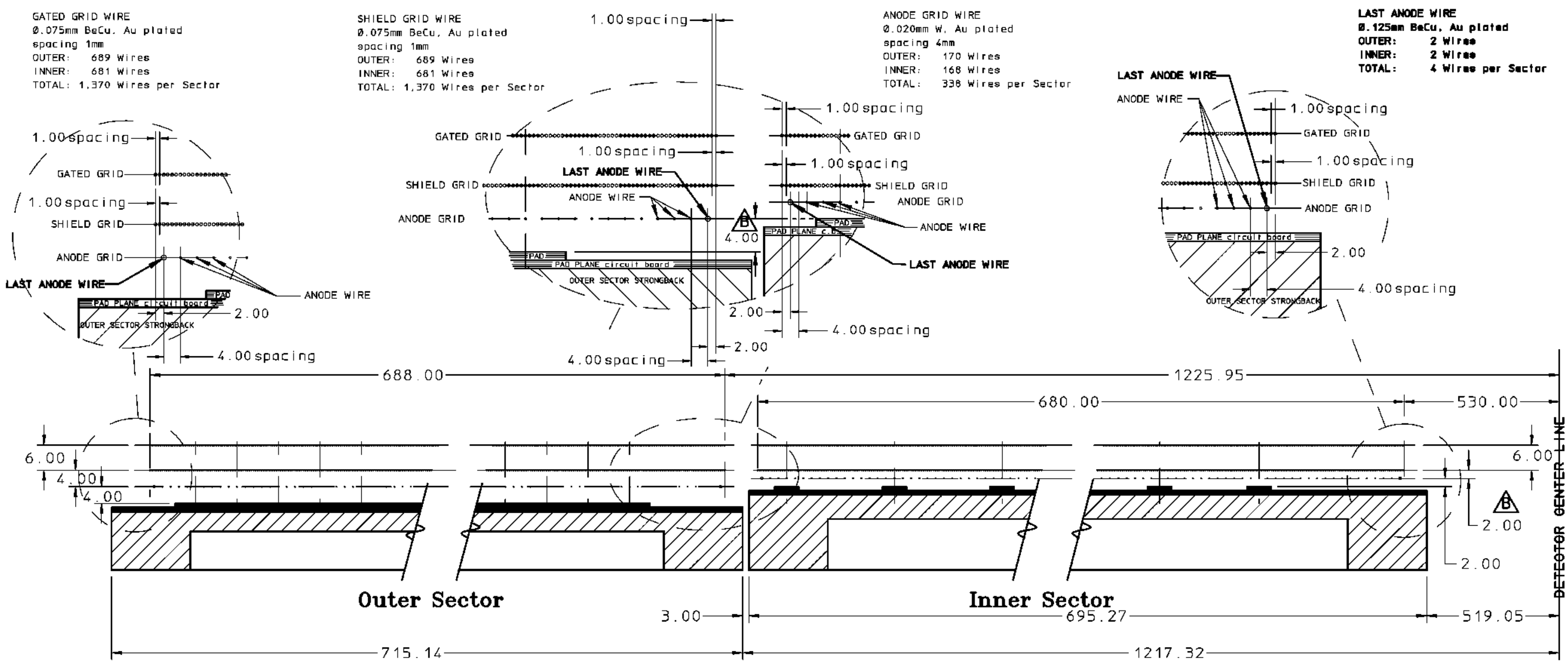
Inner sector detail







Inner / Outer sector detail



- Note that inner and outer pad planes are not at the same height
- Pad plane to wire grid heights not the same (4/4/6 vs 2/2/6)
- 3 mm gap between sectors, this is an issue during installation

Location of Wires and Pads

Radius (Y)	Description
0.00	Center of STAR Detector (vtx)
498.80	Bottom of Full size PC Board
512.70	Tertiary Fiducial L & R
519.05	Strongback Bottom Edge
530.00	Gated Grid Wire 1
531.00	Gated Grid Wire 2
532.00	Anode Wire 1 & GG W-3
536.00	Anode Wire 2 & GG W-7
540.00	Anode Wire 3 & GG W-11
540.25	Secondary Fiducial
544.00	Anode Wire 4 & GG W-15
548.00	Anode Wire 5 & GG W-19
558.00	Pad Row 1 - Center
574.00	Pad Row 2 - Center
1166.00	Pad Row 39 - Center
1179.45	Primary Fiducial
1182.00	Pad Row 40 - Center
1192.00	Anode Wire 166 & GG W-663
1196.00	Anode Wire 167 & GG W-667
1200.00	Anode Wire 168 & GG W-671
1204.00	Anode Wire 169 & GG W-675
1204.85	Alternate Primary Fiducial
1208.00	Anode Wire 170 & GG W-679
1209.00	Gated Grid Wire 680
1210.00	Gated Grid Wire 681
1214.32	Strongback Top Edge
1220.67	Tertiary Fiducial L & R
1235.42	Top of Full size PC Board

Repeat pad rows every 16 mm

GATED GRID WIRE
Ø.075mm BeCu , Au plated
spacing 1mm
OUTER : 689 Wires
INNER : 681 Wires
TOTAL : 1,370 Wires per Sector

SHIELD GRID WIRE
Ø.075mm BeCu , Au plated
spacing 1mm
OUTER : 689 Wires
INNER : 681 Wires
TOTAL : 1,370 Wires per Sector

ANODE GRID WIRE
Ø.020mm W, Au plated
spacing 4mm
OUTER : 170 Wires
INNER : 164 Wires (168 in old design)
TOTAL : 334 Wires per Sector (338 in old design)

LAST ANODE WIRE
Ø.125mm BeCu , Au plated
OUTER : 2 Wires
INNER : 6 Wires (2 in old design)
TOTAL : 8 Wires per Sector (4 in old design)

References:
LBL Drawings
24A055,
24A373,
24A374

Wire Locations are the same as before except for the replacement of 6 thin anode wires with larger diameter anode wires (0.020 mm ⇒ 0.125 mm)

Strongback – Preliminary quotation #1

SVP
SILICON VALLEY
PRECISION

Silicon Valley Precision, Inc
5625 Brisa St, Ste G
Livermore, CA 94550
Phone: 925-373-8259
Fax: 925-373-6025

Quotation

Quote To: Lawrence Berkeley Nat'l Lab
One Cyclotron Rd, Bldg 69
Berkeley, CA 94720
United States

Quote Number:	50158			**Contact:**	Katherine Ray
Quote Date:	12/05/14	**Expires:**	01/04/15	**Inquiry:**	
Customer:	LBNL			**Terms:**	Net 30 Days
Salesman:	House			**Phone:**	(510) 486-5415
Ship Via:				**FAX:**	
				Delivery:	Standard Leadtime: 6-8 weeks

Thank you for the opportunity to submit this quote.

Quote includes material, machining, stress relieving, grinding & inspection.

Quote includes drawing up parts as there are no 2D or 3D models.

Quoted 100% inspection of 3 parts and 20% inspection of qty 12 & 24.

Item	Part Number Description	Revision	Quantity	Price
1	24A368 Inner Sector Strongback	D	3	$11,203.00 /EA
			12	$6,017.00 /EA
			24	$5,141.00 /EA

Strongback – Preliminary quotation #2

IMT Precision, Inc.

Machining, Sheet Metal Fabrication, Inspection & Assembly

ISO 9001:2008 REGISTERED FIRM

IMT Precision, Inc.
31902 Hayman Street
Hayward, CA 94544

Ph: (510) 324-8926
Fax: (510) 324-8943

Quote

Number: 11546   Date: 04-Dec-14

To

Lawrence Berkeley National Lab
FOR THE US DEPT. OF ENERGY
One Cyclotron Road, BLDG. 69
Berkeley, CA 94720

Quote To

KATHERINE RAY
UC Lawrence Berkeley Lab
FOR THE US DEPT. OF ENERGY
One Cyclotron Road, BLDG. 69
Berkeley, CA 94720

Terms	Ship Via	Salesperson
Net 30 days	IMT Transport	JEFF N

Quantity	Description	Unit Price	Amount
	Line: 001 Expiration Date: 02-Feb-15 Part: 24A3685 Rev: D INNER SECTOR STRONGBACK		
3	ea	$3,887.50	$11,662.50
12	ea	$3,172.00	$38,064.00
24	ea	$2,995.00	$71,880.00
	** MATERIAL CERTS INCLUDED ** INSPECTION REPORT INCLUDED: 100% ON QUANTITY 3 PIECES 20% ON QUANTITY 12 & 24 PIECES *** LEAD TIME: 4 WEEKS (20 FULL WORKING DAYS) ARO.*** THANK YOU FOR THE OPPORTUNITY TO QUOTE. PLEASE CONTACT US SHOULD YOU HAVE ANY QUESTIONS. NOTE: THIS QUOTE DOES NOT INCLUDE MATERIAL CERTS OR FIRST ARTICLE INSPECTION REPORTS UNLESS REQUESTED.		

Critical Dimensions for the TPC

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: 90% Ar, 10% CH_4	He-Ethane as an option
Drift Velocity	5.45 cm/µsec	typical
Transverse diffusion (σ)	230 µm/√cm	135 V/cm & 0.5 T
Longitudinal diffusion (σ)	360 µm/√cm	135 V/cm & 0.5 T
Magnetic Field	0, ±0.25 T, ±0.5 T	Solenoidal

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	

Average mass distributions (±10°, 1.5 < η < 2.0)

FEE	3.60 %
FEE mounting bracket	3.45 %
FEE rib	0.45 %
FEE socket	0.15 %
Cooling manifold	3.25 %
RDO card	0.90 %
Ribs	2.70 %
Sector G10	0.45 %
Sector Aluminum	3.20 %
Cables	~1% (estimate)
FEE sub Total	**7.65%**
Total	**19.15%**

Table 6: The *average* radiation length budget for the components associated with a TPC inner sector (circa 1993) averaged over the fiducial volume of the sector. The average takes out the lumps in the mass distribution (for better or worse) but also illustrates how the budget for the Al on the front face compares to the electronics and cooling budget. The sector data have been averaged over a range from $1.5 < \eta < 2.0$ and $-10 < \phi < 10$ degrees. Geant simulations courtesy of Irakli Chakaberia.