From:	Tim Hallman
To:	starmail-l@lists.bnl.gov;
cc:	Werner Wiedenmann; Sally Dawson; Hallman; Tom Ludlam; Peter Seyboth; "Bond, Peter D"; Ronald Dean Settles; gsmith@bnl.gov;
Subject:	[Starmail-l] Report of the STAR TPC Review Committee
Date:	Thursday, November 02, 2006 1:53:02 PM
Attachments:	TPC_Review_Report_final.pdf ATT00177.txt

Dear STAR Collaborators,

As you know, recently STAR held a review at BNL to assess the robustness of continued operation the STAR Time Projection Chamber into the high luminosity era at RHIC. The members of the review panel were Peter Seyboth (MPI, Chair), Richard Majka (Yale), Mike Ronan (LBNL), Ron Settles (MPI), Graham Smith (BNL), Blair Stringfellow (Purdue), and Werner Wiedenmann (Wisconsin). Ex-Officio members of the panel included Carl Gagliardi, Hans Georg Ritter, Jerome Lauret, and myself.

The report of the Review Committee is attached. As a general conclusion, based on the level of distortion correction that has been demonstrated to be possible to date and on additional tools that may be brought to bear, the Committee believes there is no reason the TPC can not continue to meet the performance needed to achieve STAR's physics goals in the era of high luminosity at RHIC.

It goes without saying that this is a _very_ important conclusion for STAR's
planned upgrade path.

In addition to expressing STAR's sincere thanks to the members of the panel for participating in this most important deliberation, I would like to thank
Jerome Lauret, Jeff Landgraf, Jamie Dunlop, Mike Miller,
Jim Thomas, Gene Van Buren, Yuri Fisyak, Marco Can Leeuwan,
Jan Balewski, Howard Wieman, and Bill Christie for their diligence and hard work in preparing for this important review despite many other pressing demands on their time.

Sincerely,

Tim Hallman

STAR TPC Review
October 6-7, Brookhaven National Laboratory
Room 2-160, Building 510, Physics Department

Friday, October 6
Future RHIC Luminosity Projection and
Physics Driven Requirements on STAR TPC Tracking

09:00 – 09:15	Overview of basic operating parameters for the STAR TPC	R. Majka (10 + 5)
09:15 – 09:35	Expected evolution of RHIC luminosity for p+p,p+A, and A+A collisions; implications for track loading, and pile up based on experience to date and future projections	R. Majka (15 + 5)
09:35 – 10:15	Overview of major STAR p+A, and A+A physics goals; requirements on momentum, space, and dE/dx resolution to achieve the goals for high pt, quarkonia, secondary decays of particles containing strange and heavy quarks, particle identified spectra, and soft leptons	J. Dunlop (30+10)
10:15 – 10:50	Overview of major STAR p+p physics goals; requirements on pile-up rejection (primary vertex identification), momentum, space, and dE/dx resolutions to achieve the goals for jet reconstruction, W bosons, secondary decays of strange and charm particles	M. Miller (30 + 10)
10:50 – 11:10	Coffee Break	

TPC Performance Issues, present and future

11:10 – 12:50	TPC Distortions: present tracking performance and dE/dx resolution; types and level of tracking distortions and distortion corrections; estimated level of distortion and correction ability in the era of upgraded RHIC luminosity	Jim Thomas (20+10) Gene van Buren(40+10) Yuri Fisyak (20+10)
12:50 – 14:00	Lunch (working lunch provided for panel)	
14:00 – 14:30	TPC pileup: present level of pileup and projected Increase in the era of upgraded RHIC luminosity; Existing pileup rejection algorithms/future strategies	(M. VanLeewan/ J. Balewski) (20 + 10)
14:30 – 15:00	Detector Aging	Howard Wieman (20 + 10)

15:00 – 15:50	Infrastructure Aging (gas, cooling, lasers, gated grid)	Blair Stringfellow/ (40 + 10)
15:50 – 16:20	Planned FEE and DAQ1000 upgrades	Jeff Landgraf (20 + 10)
16:20 – 17:00	Coffee Break	
17:00 – 17:25	Potential hardware improvements, related R&D and associated risks	H. Wieman/ A. Lebedev (20 + 5)
17:25 – 17:45	Present and projected online, offline, calibration software needs (manpower and resources)	J. Lauret/ G. Van Buren (15 + 5)
17:45 – 18:00	Present and projected operational support and Management oversight; institutional commitments present and future	W. Christie/ T. Hallman
18:00 – 18:30	Discussion and questions for presenters	
19:00	Dinner at Local Restaurant	

Friday, October 7

09:00 – 10:00	Call backs for panel members/presentations left From previous day
10:00 – 11:45	Committee discussion, preliminary findings
11:45 – 12:45	Lunch
12:45 – 13:00	Closeout report

Charge for STAR TPC Review
October 6-7, Brookhaven National Laboratory

The STAR Collaboration is planning a number of compelling physics measurements in p+p, p+A, and A+A interactions that will extend well into the era when planned upgrades of the RHIC accelerator will increase the average luminosities for heavy ion and p+p interactions significantly over those achieved to date.

The review panel is asked to assess the ability of the STAR Time Projection Chamber, including planned upgrades of its front end electronics and readout, to meet the physics driven requirements of the experimental program in the high luminosity era at RHIC.

Specifically, the panel is asked to asses the following issues:

Distortions:
----

a Given the expected luminosities and projected TPC performance based on experience to date, will it continue to be possible to correct distortions at a level sufficient to meet the needs of the physics program?

b. If the answer to a) is yes or yes possibly with additional instrumentation or a change in the TPCs operational envelope (e.g. use of a faster gas) what changes and/or additional instrumentation/monitoring may be needed?

Event pile up:

For heavy ions, light ions, and p+p collisions is the pileup in the TPC manageable?

a. Are the current and planned detectors which surround the TPC adequate?

b. Is further software development required?

Detector Aging:

Is aging of the detector and its infrastructure – especially with higher trigger rates**--** a "show stopping" concern? What level of concern exists for:

a. Wire aging

b. Field cages, membrane

c. Aging of infrastructure (GG drivers, power supplies, controls, monitoring electronics, gas system, cooling system, lasers). Will the systems continue to operate and are there adequate spares?

R&D:

What if any plans exist for R&D on improved performance and/or diagnostic tools?

Software:
----

a. Is the current set of QA, calibration and tracking software adequate for the expected higher luminosities?

b. Is there adequate manpower for continued operation and any new software development that may be required?

Support for Operations:

Is the projected level of manpower available to support the operation of the TPC adequate manpower for its:

a. Operation

b. Maintenance

c. Calibration and analysis software

Report of the STAR TPC Review Committee

(November 2, 2006)

Dedicated to the memory of Michael T. Ronan in appreciation of his contributions to our field of research and to this review and report in particular.

Executive Summary

On October 6 – 7, 2006 a review was held at Brookhaven National Laboratory to assess the capabilities of the STAR TPC in the high luminosity era of RHIC. The review panel consisted of external reviewers and STAR collaborators. The members of the review panel were P.Seyboth (chair, STAR, Max-Planck-Institut für Physik, Munich), R.Majka (STAR, Yale University), M.Ronan (LBL), R.Settles (Max-Planck-Institut für Physik, Munich), G.Smith (BNL), B.Stringfellow (STAR, Purdue University), W.Wiedenmann (University of Wisconsin) and ex officio members C.Gagliardi, J.Lauret and H.-G.Ritter. This written report was unanimously approved. The charge to the panel is contained in Appendix I.

A series of presentations were given on the physics goals of STAR in the coming years, the planned luminosity increases of RHIC, the past and projected performance of the STAR TPC and the issues of maintenance, detector improvements and analysis software of the TPC.

The members of the committee were impressed by the excellent performance and the outstanding physics results obtained from the STAR TPC. It will clearly remain the main tracking detector in STAR for the foreseeable future. The committee notes that RHIC has achieved continued luminosity improvements to within about a factor five of the maximum instantaneous luminosity ultimately envisioned for RHIC II. The STAR TPC has been able to cope with this successfully due to the efforts of an enthusiastic and competent team.

Due to a vigorous effort mainly by G. Van Buren and J. Thomas the considerable distortion effects from the space charge in the TPC drift volume have been successfully corrected to the 100-200 μm level and there appears to be no problem in principle of attaining a similar precision at the higher luminosities. The committee recommends that information from the Si inner detectors and the laser system be used in addition to constrain and validate the corrections. Moreover, efficient procedures have been developed by J. Balewski and M. van Leeuwen to tackle the problem of event pileup in the TPC. These appear likely to be successful also at the higher luminosities. It is of high importance that the manpower devoted to the TPC software be at least maintained at the present level and that timely replacements for departures are found.

The committee recommends that interaction with collider operations be further intensified. More diagnostic measurements should be made available by STAR to diagnose and minimize time

dependent and localized backgrounds which can affect the accuracy of distortion corrections. The limiting aperture of RHIC should be moved away from the STAR interaction region if possible.

The TPC has been operated conservatively and reliably thanks to the efforts of B.Stringfellow and A.Lebedev. Minor hardware problems, which are usual for large experiments, have been solved efficiently. A growing shortage of readout electronics spares requires the replacement of the old electronics by an ALICE-type readout system in the context of the DAQ1000 upgrade. An R&D program of hardware improvements should be pursued for possible reduction of the gated grid leakage, for alternative gas mixtures and for fixes of the field cage imperfections. Such improvements could be implemented in case the software corrections turn out not to be fully satisfactory. The manpower and the know-how for the operation and maintenance of the TPC hardware must be maintained. In particular, a replacement with longer term commitment must be found for B.Stringfellow with sufficient overlap time. Finally, the possible use of a SF_6 admixture in the gas of the MRPC TOF system is strongly discouraged by the committee because small traces at the ppb level diffusing into the TPC gas would seriously compromise the TPC performance.

In summary, the committee believes that the TPC can be operated and produce excellent physics results at the projected higher luminosities. Solving the problems of distortions and pileup continue to pose a challenge, but there appear to be no problems in principle to prevent success.

Detailed assessment and recommendations

In the following more details are given on the results of the discussions of the items of the charge to the committee and the ensuing recommendations.

Distortions:

The peak luminosities in Au+Au operation of RHIC reached $1.5 \cdot 10^{27}$ in 2004, are expected to increase another factor of 2 in 2007 and reach $9 \cdot 10^{27}$ with electron cooling in the RHIC II era. It was demonstrated that correction methods for space charge distortions (as well as the imperfections in the field cages) based on analytical models were implemented which reduced the effect to the 100-200 μm level. The quality of the corrections has been evaluated via the sDCA technique. The development of additional probes based e.g. on track residuals should be considered. The present procedure follows the time dependence of space charge and uses azimuthal symmetry. A database needs to be implemented for recording distortion relevant parameters during the data taking runs in order to automate the procedure.

The committee recommends that the interaction with collider operations be further improved and additional diagnostic measurements be considered and supplied by STAR in order to check and minimize localized and fluctuating backgrounds. It may be possible to use the individual readout sector currents, or prompt TPC end-plane signals, as sensitive background monitors to be fed back to the RHIC operators. At present, the limiting aperture of RHIC is located near the STAR interaction region. In addition to the shielding already put in place, efforts should be made to move it further away in order to reduce backgrounds in STAR.

Gated grid leak at the sector boundaries has been identified to contribute about one third of the space charge distortion. STAR should therefore investigate if it would be possible to run the TPC at somewhat lower gain without significantly deteriorating tracking precision and dE/dx resolution. Moreover, R&D is encouraged to develop hardware modifications to prevent gated grid leak that could be implemented if the need arose.

Information from the Si tracking detectors has not yet been used. These were found to be very useful in constraining and validating the corrections for the ALEPH TPC. The committee recommends their use in STAR and understands that this is planned for the coming 2007 data taking period. The committee moreover recommends assessing how the laser system could be used to track the space charge distortions also during data taking.

An alternative gas mixture offering higher ion drift velocity to reduce space charge, and at the same time preserving the quality of dE/dx measurement, has not been identified. A discussed replacement of the CH_4 quencher by CF_4 may result in a stronger electron attachment and thus compromise the dE/dx measurement. Although distortion corrections are projected to be possible also at higher luminosity with the present gas mixture, R&D with the aim of searching for alternatives is encouraged.

Event Pileup

Effective methods to deal with pileup have been developed both for p+p and Cu+Cu collisions and have allowed STAR to obtain clean physics results. The methods are based on the use of signals from the fast detectors, i.e. CTB and ECAL, in addition to criteria of track quality and continuity across the central TPC membrane. The future availability of fast Si strip detectors and of the finely pixelled MRPC TOF system should further improve the efficiency of pileup rejection.

Detector Aging

Up to now no indications of wire aging have been detected. Projections of H.Wieman, based on published aging studies and projected integrated luminosity, suggest that none are to be expected for some years. No breakage of wires has occurred throughout operation of the TPC although numerous sector HV trips have occurred, especially in the inner sectors. Since it is known that the original sector insertion/extraction tool can no longer be used with the TPC in the STAR magnet, the committee urges that some re-engineering or redesign of this tooling be done now, before it becomes necessary to use it.

There have been a number of local field cage shorts, mostly caused by extraneous stray objects that fell into the inner field cage. Most of these were found and removed successfully in the past. There remains one unstable short in the Inner Field Cage East that is thought to be caused by some stray epoxy in a region that was worked on in 2005. It is felt that this problem can be fixed when the SVT cone is removed in 2007. Until then a combination of external resistors and offline distortion corrections can be used to restore full precision. There is also a bistable current fluctuation in the Outer Field Cage West that first appeared in March, 2005. The origin of this fluctuation is unknown, as is its location. So far the data have not been corrected for this fluctuation since it is relatively small and the position in z is unknown. The committee concurs that it is best at this time to not open the windows into the outer field cage because of the risk of contamination, but that some R & D should be done on the tooling necessary to hunt for this short if it becomes worse.

Most of the infrastructure maintenance and repair is covered by BNL and external group commitments. Replacements for failing readout electronics components are becoming scarce. This problem will be solved in the context of the DAQ1000 upgrade by the replacement of the present electronics by a new ALICE-type system which is under construction.

R&D

Except for the readout electronics no serious need for changes in the present hardware were identified. However, studies on reducing the grid leak and search for gas mixtures with faster ion drift velocity are encouraged. Tests should be performed in dedicated setups and not in the STAR TPC itself.

Software

As already stated above, and as far as the committee can judge, the calibration and tracking software will be able to cope with the increased luminosities. It was noted that after the DAQ1000 upgrade the dE/dx determination will have to be re-optimized. Also, the Monte Carlo simulation chain needs to be updated to incorporate the residual track distortions and the updated dE/dx determination with DAQ1000. With the expected sizable track distortions Monte Carlo simulation is a valuable tool to understand and develop fixes for possible problems of track pattern recognition potentially caused by the distortions. As the new data comes in new challenges will arise and sufficient manpower will be needed to deal with them. The present dedicated software manpower level of 1.5 FTE is considered rather low. A filling of the now vacant position of TPC software coordinator is urgently required. The STAR core software team also wishes to shift back more of the burden of calibration and corrections to collaborating institutions.

Support for Operations

The present support manpower is estimated at about 1.5 FTE and for most subsystems only a single expert is available. Present TPC system support: subsystem manager (Purdue, will retire in July 2008), gas system (MEPHI), electronics (BNL), TPC interlock system (LBNL), calibration software (LBNL, BNL), laser system (BNL). The committee suggests that BNL find in addition a local gas expert that could help during the coming runs. Continuation of the longer term support commitments are essential and a successor for the present subsystem manager must be found soon in order to ensure the transfer of the accumulated know how.

One final comment: the system – hardware, software and physics – has worked well to date because a general conservative approach has been followed. This conservatism should continue and also apply to manpower, namely adequate effort on each aspect of the TPC system.

The committee wishes to thank D. Majka, J. Dunlop, M. Miller, J. Thomas, Y. Fisyak, G.VanBuren, M.van Leeuwen, J. Balewski, H. Wieman, B. Stringfellow, J. Landgraf, J. Lauret and W. Christie for the preparation and presentation of their concise and informative reports.

Appendix I

Charge for STAR TPC Review Panel:

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Detector Aging

Wieman
RNC
LBNL

TPC Review
Friday 6 October 2006

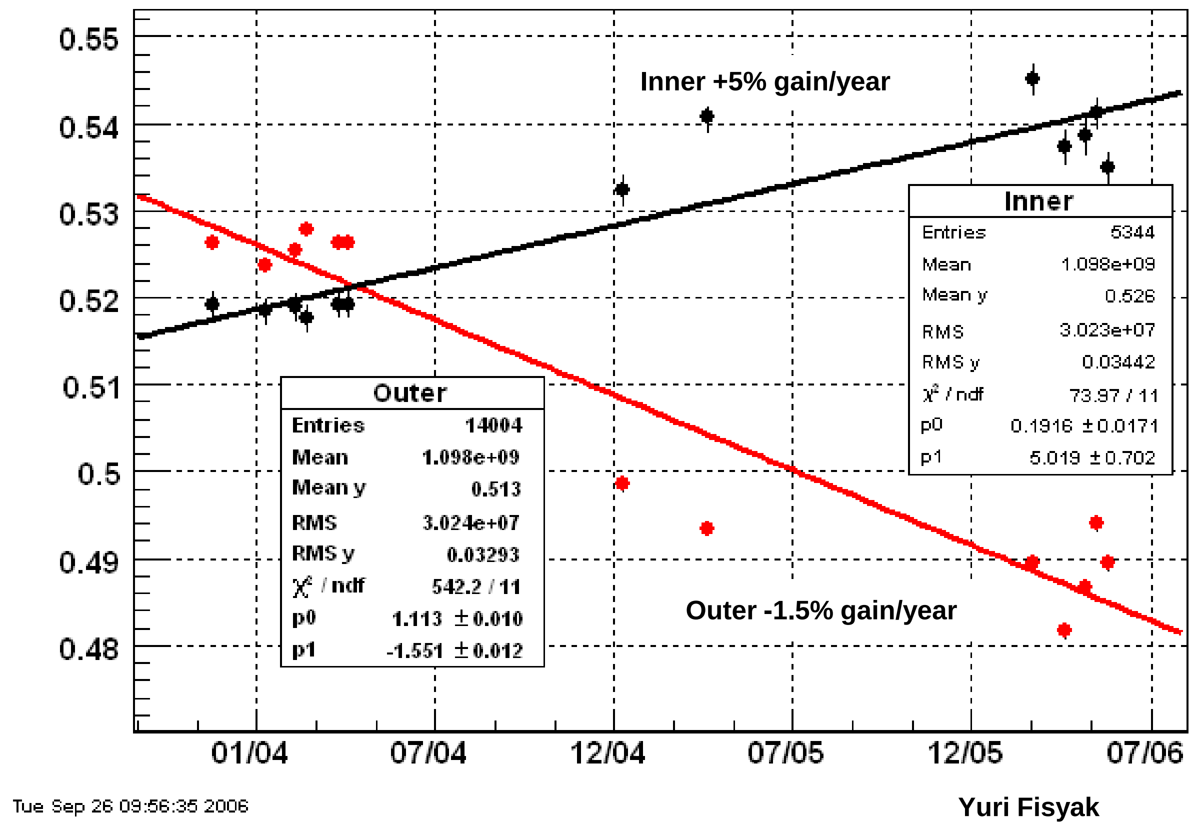
Wire aging

- Present condition
- Projection
- Chamber trips

Currently no evidence for aging

- Yuri Fisyak dE/Dx gain calibration is puzzling, Inner sector shows gain increase with time, but outer shows reduction. In any case no sign of aging
- Blair Stringfellow estimate of integrated charge on the inner wires is 0.0005 coul/cm so far
- So, don't expect aging yet since this is factor 200 below 0.1 coul/cm, a number where one might expect aging in P10

Wire gain as function of time



Yuri Fisyak

Wire aging projection from measured wire currents

- From max measured wire currents in pp operation (0.07 nA/cm inner most wire)
  - A gate closed component – depends on L and background
  - A gate open component – depends on L and background times gating rate
  - 260 yr before reach aging onset of 0.1 coul/cm at current rate
  - 29 yr before reach 0.1 coul/cm with 2008 L of 80×10^{30} $cm^{-2}Hz^{-1}$ and a gate rate of 1 kHz
  - 6 yr with RHIC II 400×10^{30} $cm^{-2}Hz^{-1}$
- From max wire currents in AuAu operation (also 0.07 nA/cm inner most wire), central trigger
  - Assume large interaction track density dominates over background and pileup so then wire current scales as gate frequency, no dependence on L or background
  - 320 yr before reach 0.1 coul/cm at 2004 gate frequency, 75 Hz
  - 24 yr before reach 0.1 coul/cm at 1 kHz gate frequency

Details: http://www-rnc.lbl.gov/~wieman/WireAgingLimits2006Estimate.htm

Anode trips

Run	Species	Inner trips per month (96 HVPS)	Outer trips per month (96 HVPS)
2003	dAu and pp	28.4	8.4
2004	AuAu	39.5	3.0
2005	CuCu and pp	45.2	9.6
2006	pp	42	3.8

B. Stringfellow

Note1: nearly all outer trips are caused by unplanned beam aborts

Note2: During 2006 pp running, average was 2 trips per shift with beam

RHIC II L 20 times 2006 – could mean trip every 12 minutes

Conclusion

- Aging does not appear to be an issue, but the 0.1 coul/cm limit is not guaranteed – could be a factor of 10 either way
- Anode trips on the inner sector could be a problem for the heaviest pp operation – faster automated recovery possible – without ending run.
    - But how trips can a sector survive

STAR TPC wire aging considerations with measured and projected ionization load

10/3/2006
H. Wieman

In P10 wire aging has been reported for wires that have an accumulated ionization exposure of 0.1 coul/cm. This limit however can vary by a factor of 10 either way depending on chamber details, in particular the amount of contaminants.
Blair Stringfellow reports various wire currents under different conditions which can provide some guidance for life time expectations.

Yuri Fisyak has done careful monitoring of the gas gain for purposes of dE/dX determination which could potentially provide a measure of wire aging as one expects the gain to diminish with the build up of contaminants on the wires. His results are confusing in that there appears to be a few percent rise in gain with time on the inner more heavily dosed wires while the outer sector show an opposite trend. The apparent lack of aging, however, is consistent with Blair's estimate of total accumulated charge to date: 0.0005 coul/cm on the inner wires, a factor of 200 below the aging onset charge of 0.1 coul/cm.

Initially with heavy ion running Blair observed that wire currents were dominated by gating frequency, but more recently closed gate currents have been observed for pp running which is fill dependent indicating contributions from background as well as from gated interactions.

Maximum closed gate pp inner section current: 20 to 30 nA

pp wire currents with triggered gate operation: 80 nA

Projecting wire life time during pp operation

In estimating the remaining years of operation there are two components that must be scaled. There is the wire current that exists when the gate is closed and the beam and anodes are on. There is also the wire current that appears when gated and this depends on the gating frequency.

The following current numbers are maximum values from pp running FY2006.

$\mathrm{TrigBase} = 250\mathrm{Hz}$	Trigger rate while following currents measured
$\mathrm{LBase} = 25\cdot 10^{30}\frac{1}{\mathrm{cm}^2\cdot\mathrm{Hz}}$	Luminosity FY 2006 pp run
$\mathrm{IppTriggeredBase} = 80\mathrm{nA}$	Section current when gating at TrigBase
$\mathrm{IppClose} = 20\mathrm{nA}$	Section current when gate closed. Depends on luminosity and background
$\mathrm{IppGate} = \mathrm{IppTriggeredBase} - \mathrm{IppClose}$	Section current, gate open. Depends on luminosity, background and trigger rate.
$\mathrm{WLS} = 290\mathrm{mm}$	Length of inner sector short wires

$$Nwps = \frac{(1270 - 600)\cdot mm}{4mm} \cdot \frac{1}{4}$$

number of wires per section

$$Qpp(rt, L, ta, tg) = \frac{IppClose \cdot \frac{L}{LBase} \cdot ta + IppGate \cdot \frac{L}{LBase} \cdot \frac{rt}{TrigBase} \cdot tg}{WLS \cdot Nwps}$$

Charge accumulated per cm

as a function of
rt trigger rate
L luminosity
ta time anode and beam on
tg time gating and beam on

$$Qlimit = 0.1\frac{coul}{cm}$$

Charge limit where wire aging could start to be a concern

$$DutyFactorGated = 0.3$$

The time that TPC is being gated during RHIC running

$$DutyFactorAnode = 0.6$$

The time that TPC anodes are on during RHIC running.

$$RHICRunFactor = 0.5$$

The fraction of the year that RHIC runs

$$rt06 = 250Hz$$

trigger rate 2006

$$Lpp06 = 25 \cdot 10^{30} \cdot \frac{1}{cm^2 \cdot Hz}$$

$$ta06 = 1yr \cdot RHICRunFactor \cdot DutyFactorAnode$$

time running anode with beam in 2006

$$tg06 = 1yr \cdot RHICRunFactor \cdot DutyFactorGated$$

time running gated with bean in 2006

$$Qpp2006 = Qpp(rt06, Lpp06, ta06, tg06)$$

$$Qpp2006 = 3.9 \times 10^{-4}\frac{coul}{cm}$$

$$Tproj = \frac{Qlimit}{Qpp2006} \qquad Tproj = 257$$

projected number of years of pp operation at 2006 pp level

$$Lpp08 = 80 \cdot 10^{30} \cdot \frac{1}{cm^2 \cdot Hz}$$

expected pp luminosity 2008

$rtFast = 1kHz$ future trigger rate

$$Tproj08 = \frac{Qlimit}{Qpp(rtFast, Lpp08, ta06, tg06)}$$

$Tproj08 = 29$ projected number of pp years operation with increased luminosity and increased trigger rate.

Projecting wire life time during AuAu operation

During AuAu operation the maximum section wire currents were close to the pp operation reported above, 80 nA. It is not known whether there was a significant gate closed component to the current when operating with AuAu at this level, but it was noted earlier in 2002 that the the wire currents depended primarily on gate rate and was not luminosity dependent. This seems reasonable since with AuAu operation the luminosities are much lower than with pp. The total current is about the same but unlike pp the ionization does not come from pileup but is a result of the many tracks associated with single AuAu collisions. In projecting AuAu numbers we therefore assume that the wire current scales as gate rate.

$IauauGate = 80 \cdot nA$ Measured section current AuAu operation

$TrigBaseAuAu = 75Hz$ Trigger rate during above current measurement

$$QAuAu(rt, tg) = \frac{IauauGate \cdot \frac{rt}{TrigBaseAuAu} \cdot tg}{WLS \cdot Nwps}$$ Charge accumulated per cm

as a function of
rt trigger rate
tg time gating with beam on

$QAuAu(75Hz, tg06) = 3.1 \times 10^{-4} \frac{coul}{cm}$ at 2004 operating conditions assuming 6 months operation of straight Au Au

$$TauauProj04 = \frac{Qlimit}{QAuAu(75Hz, tg06)}$$

$TauauProj04 = 321$ projected number of AuAu years operation with 2004 trigger rate rate

$$TauauProjFuture = \frac{Qlimit}{QAuAu(1kHz, tg06)}$$

$TauauProjFuture = 24$ projected number of AuAu years operation with 1 kHz trigger rate

TPC Distortion Corrections

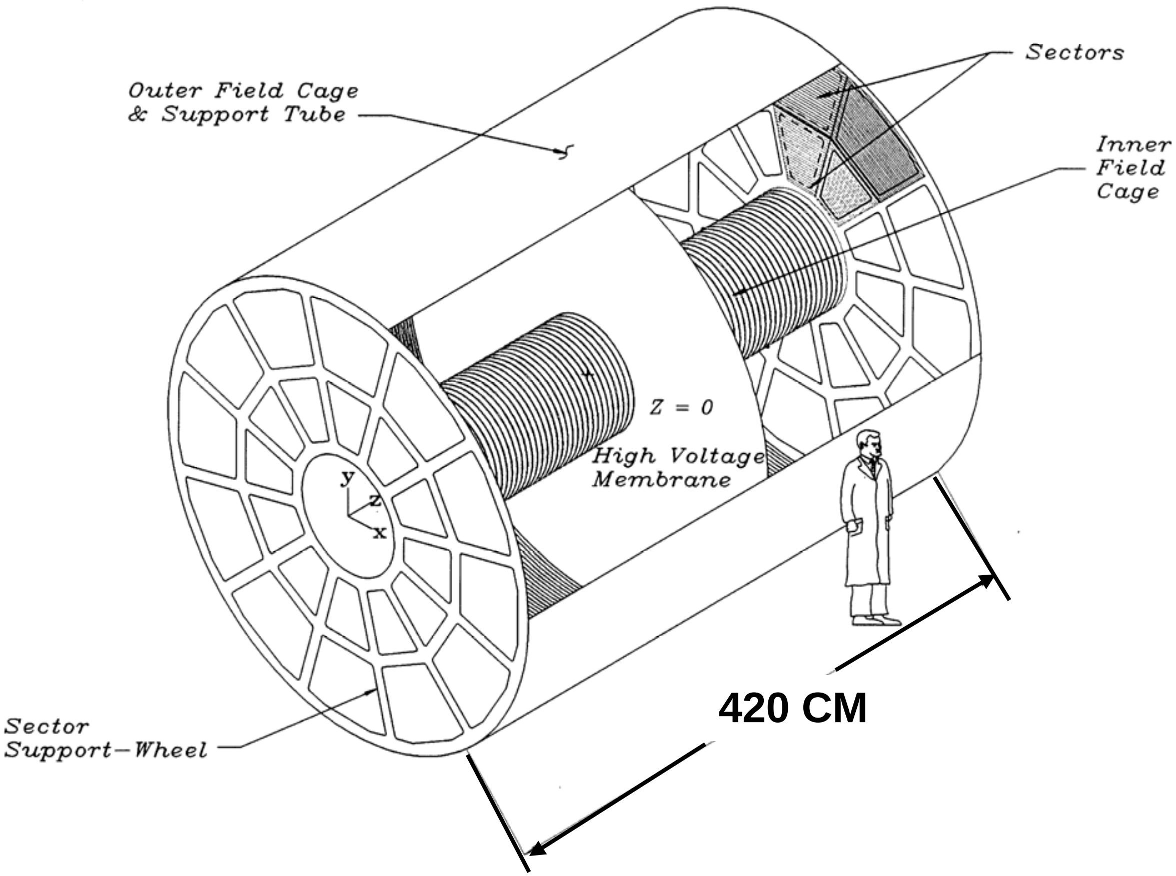
and their Possible Evolution in the Future

Jim Thomas

Lawrence Berkeley National Laboratory

October 06, 2006

Secondary e$^-$ Drift in Parallel E and B Fields



- **Voltage : - 28 kV at the central membrane**
  135 V/cm over 210 cm drift path

Some things are known. Sometimes things go wrong, for example, we've had 3 shorts in the IFC – one is still with us

Distortion Equations – (see Blum & Rolandi)

Solve:

$$m \frac{d\overline{u}}{dt} = e\,\overline{E} + e\left[\overline{u} \times \overline{B}\right] - K\,\overline{u}$$

Langevin Equation with "Friction"

substituting:

$$\tau = \frac{m}{K}\ , \quad \omega = \frac{e}{m}\,|\,\overline{B}\,|\ , \quad \mu = \frac{e}{m}\,\tau\ , \quad \text{and} \quad \hat{E} = \frac{\overline{E}}{|\,\overline{E}\,|}$$

subject to the steady state condition

$$\frac{d\overline{u}}{dt} = 0$$

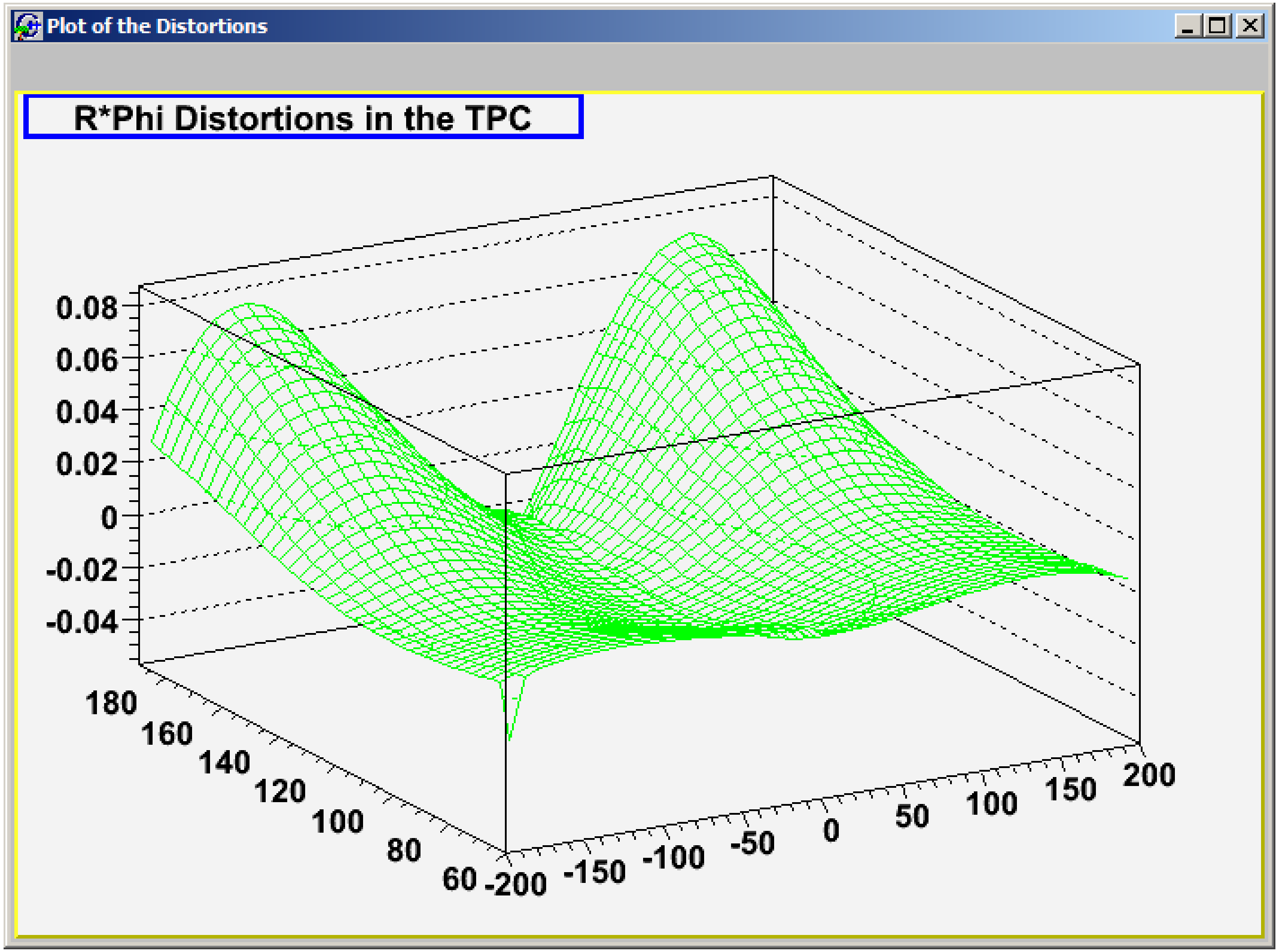
yields

$$\overline{u} = \frac{\mu\,|\,\overline{E}\,|}{\left(1 + \omega^2 \tau^2\right)} \left(\hat{E} + \omega\tau\left[\hat{E} \times \hat{B}\right] + \omega^2 \tau^2 \left(\hat{E} \bullet \hat{B}\right)\hat{B} \right)$$

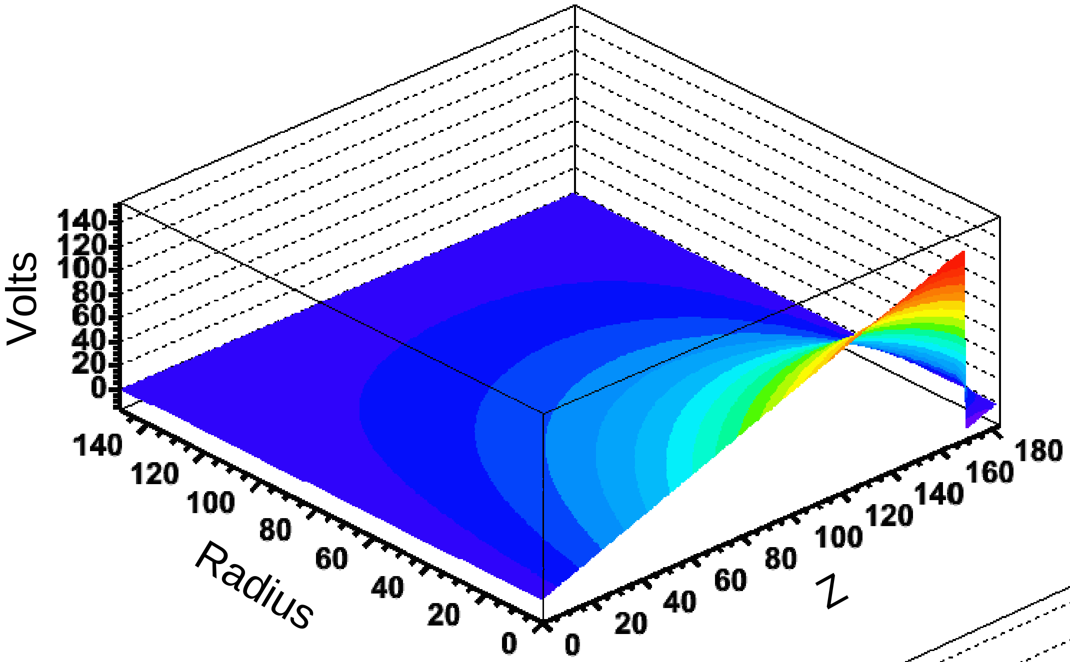
where B is a unit vector pointing in the direction of $\overline{B}$.

If you have a well defined model, and good data, then the distortion can be removed with great precision

Field Shape distortions



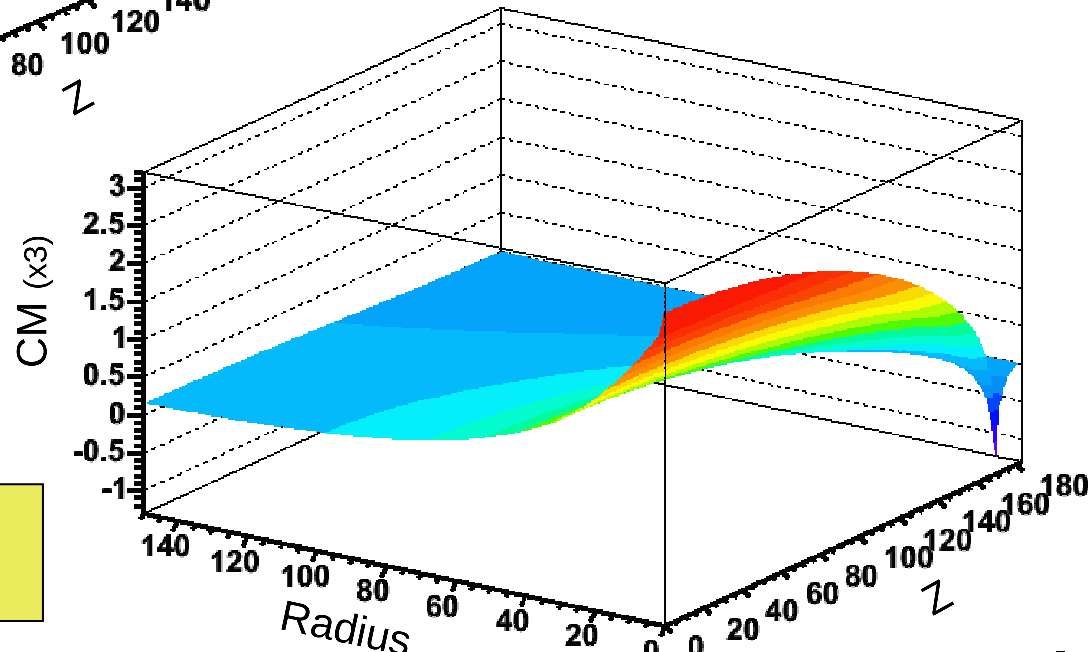
Shorted Ring – Error Potential (Volts) & Distortion (cm)



The error potential due to the shorted ring near one end of the TPC

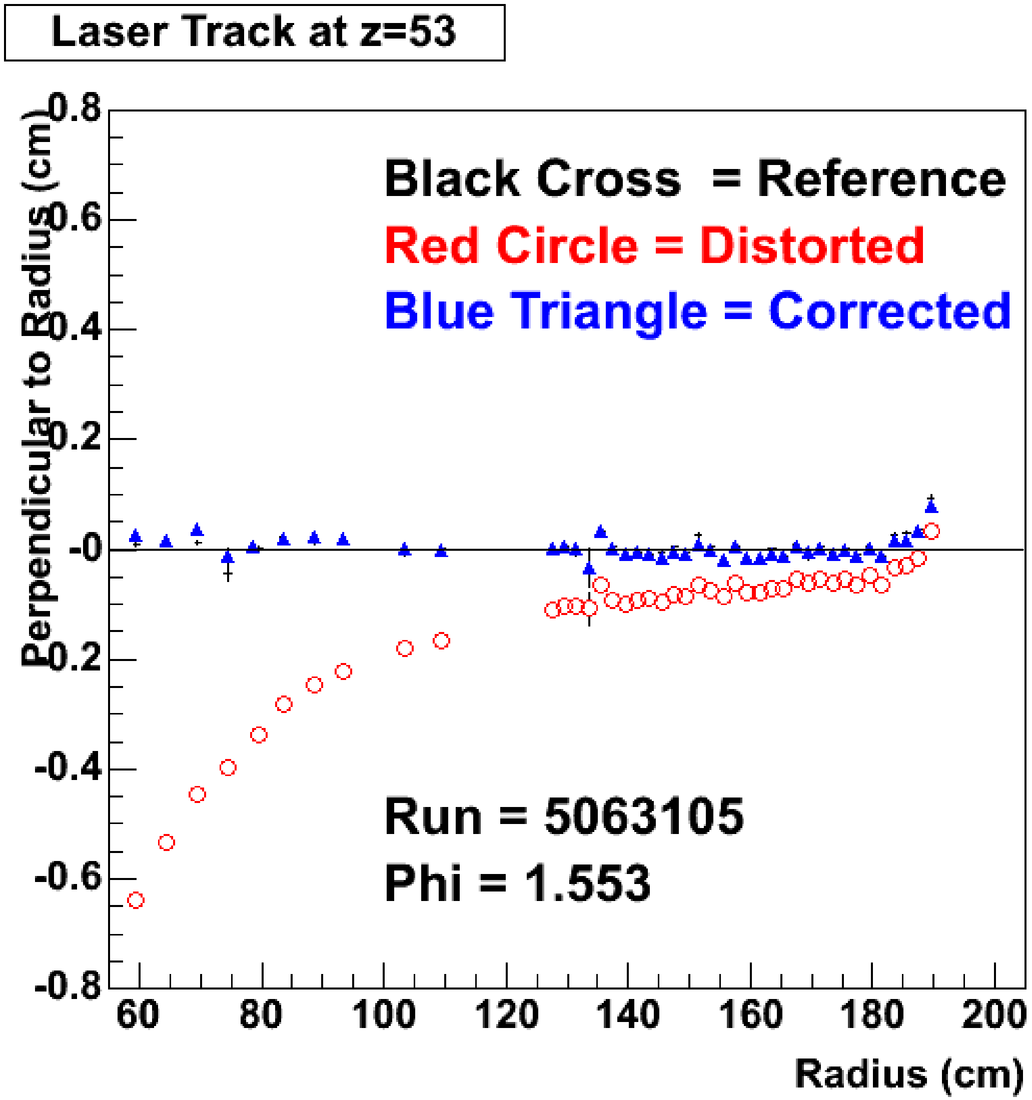
Requires full solution of Maxwell's equations

The resulting distortion in cm (x3)



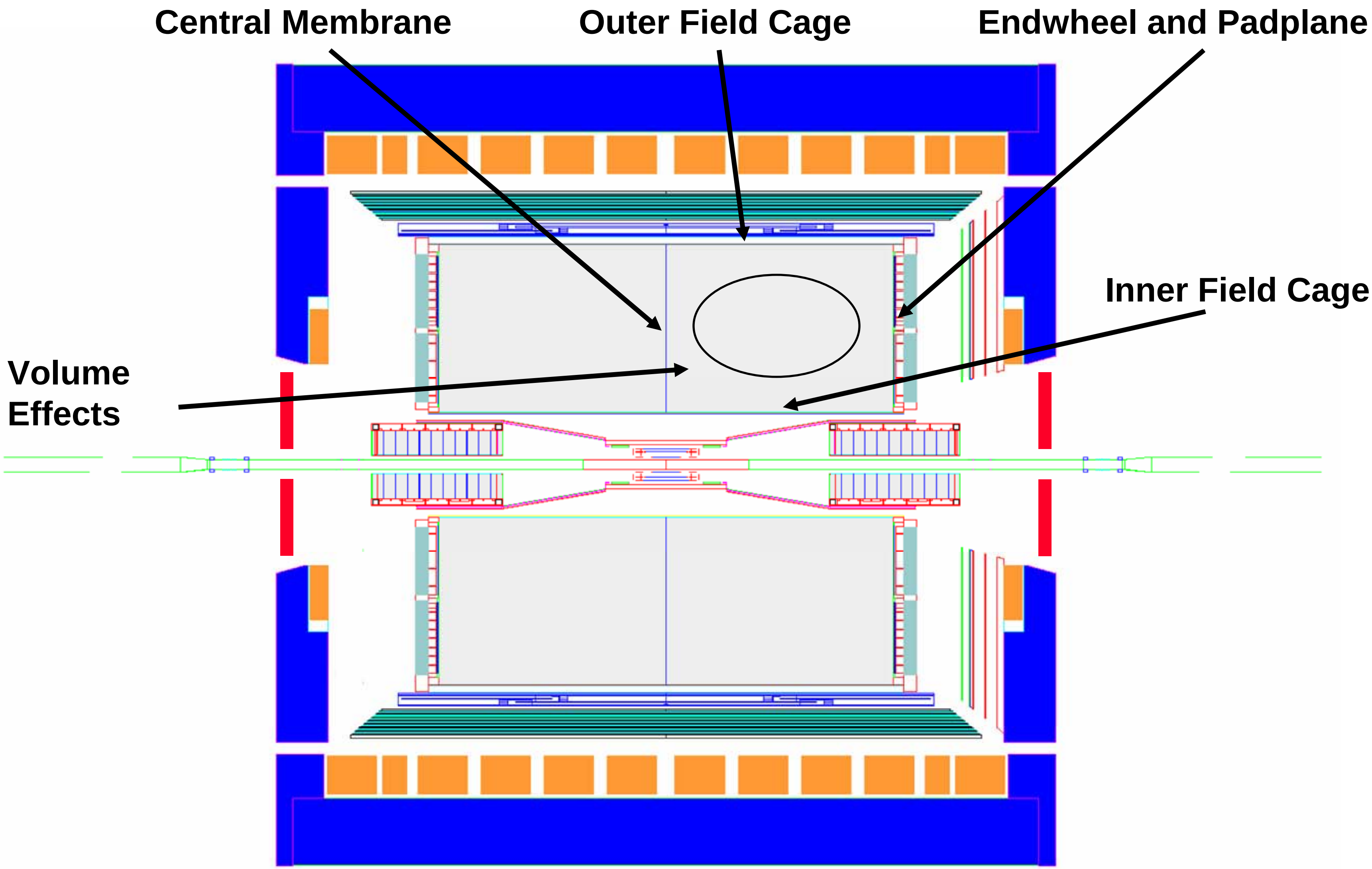
Probably the biggest distortion that we will ever see in the TPC

A Laser Track Distorted by a Shorted Ring



- **Laser tracks in the TPC were distorted by an "optional" shorted ring on the West end. This is a test.**
- **Black indicates the laser track without the short … "the control"**
- **Red indicates recorded data with the short**
- **Blue indicates corrected data**
- **Correction is good to 100-200 μm everywhere.**
- **Congratulations to Gene Van Buren, Howard Wieman, et al.**

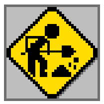
Visual Mnemonic for Listing the Possible Distortions



A List of Distortions in the Transverse Plane

The list can be enumerated by surfaces:

- ✓ Outer field cage corrections (shorts and shifts)
- ✓ Inner field cage corrections (shorts and shifts)



- Central membrane corrections
- End-wheel and pad-plane corrections
- ✓ Pad Row 13, grid leak corrections and other local electrostatic defects
- ✓ Rotation and miss-alignment of sectors with respect to their ideal locations
- ✓ Rotation of either TPC end-wheel with respect to its ideal location

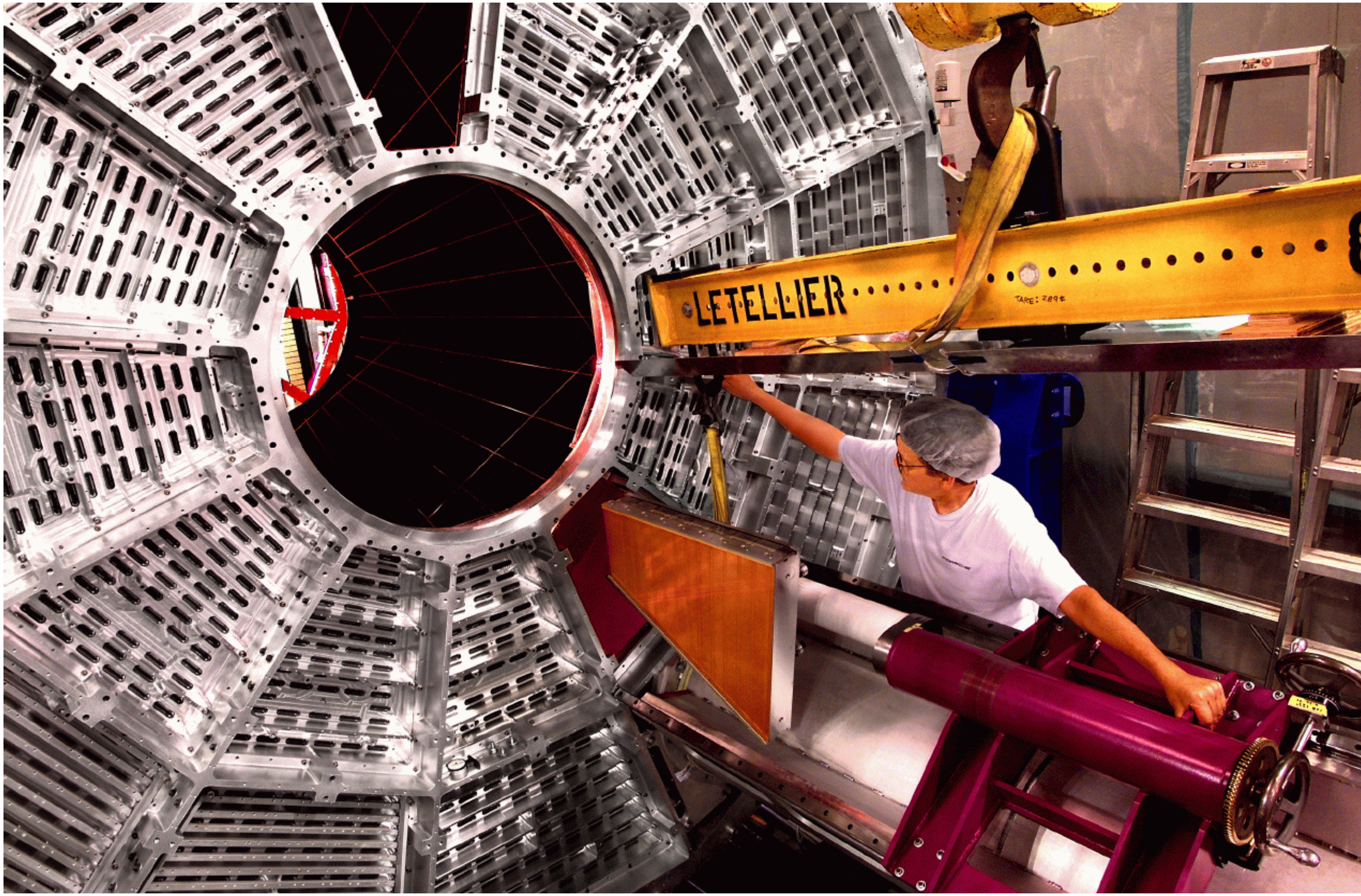
and by volume:

- ✓ Space Charge corrections due to charge in the volume of the TPC
- ✓ Magnetic field corrections due to B fields in the volume of the TPC
- ✓ Twist of the TPC with respect to the magnetic field axis and/or the measured map
- ✓ General coordinate transformations

A few additional items are listed for completeness.

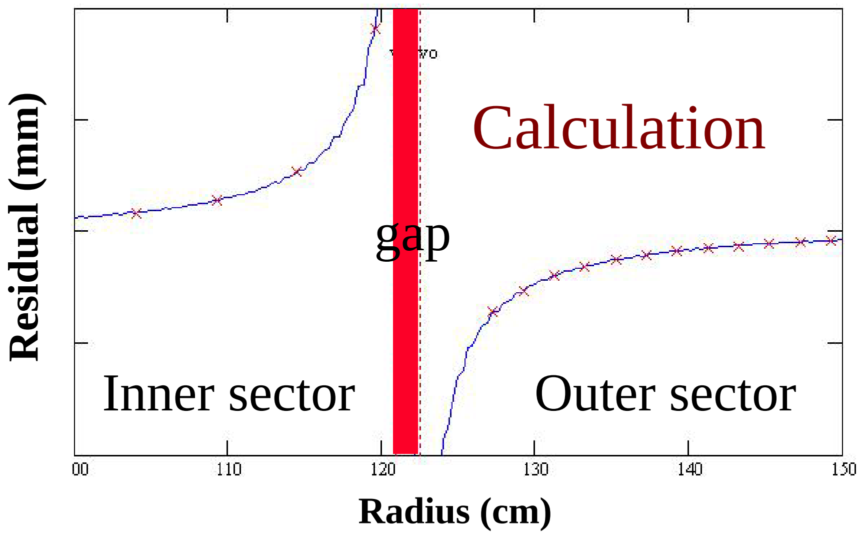
- Gas composition and variations in the drift velocity
- Barometric pressure changes and variations in the drift velocity
- Pressure variations as a function of height in the TPC
- Temperature gradients in the TPC

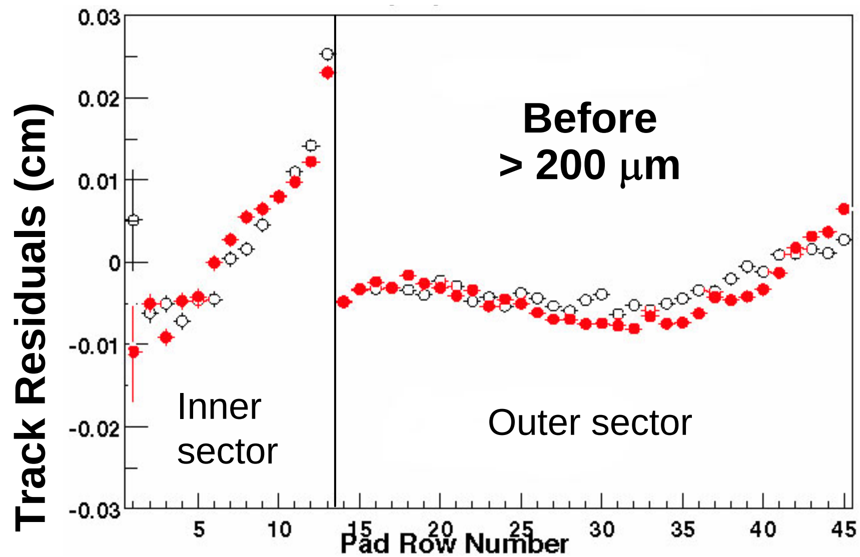
Sector Readout of Pad Planes



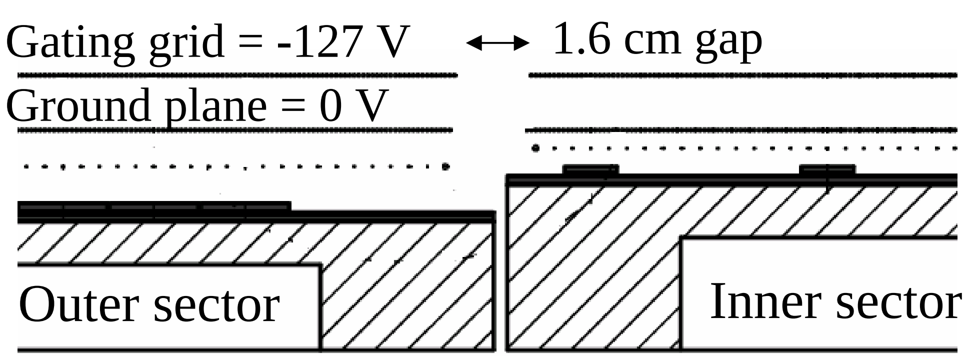
12 Sectors per end – One inner sector and one outer sector each

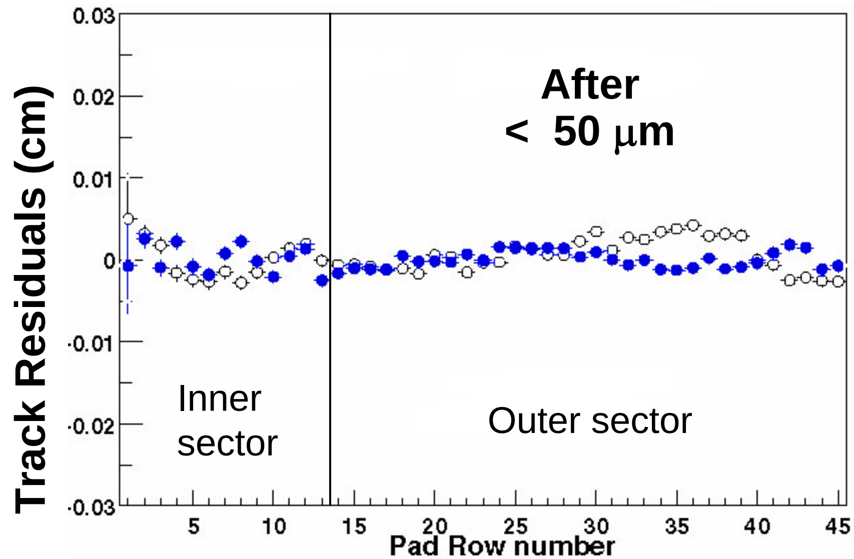
Static Electric Field Distortions





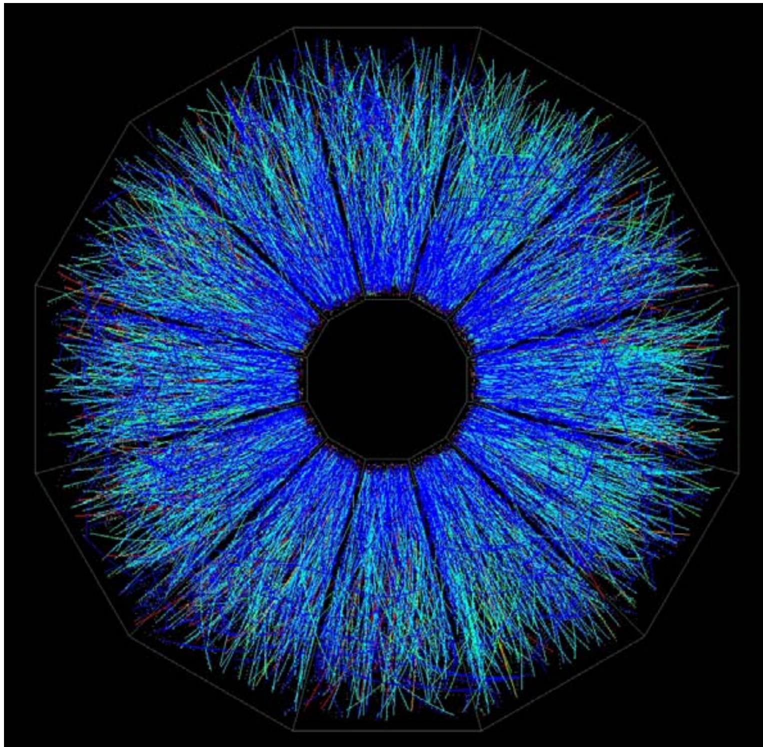
- **No wires at the boundary between the inner and outer sectors**
  - **E field leak ⇨ ExB effect in R and ϕ**





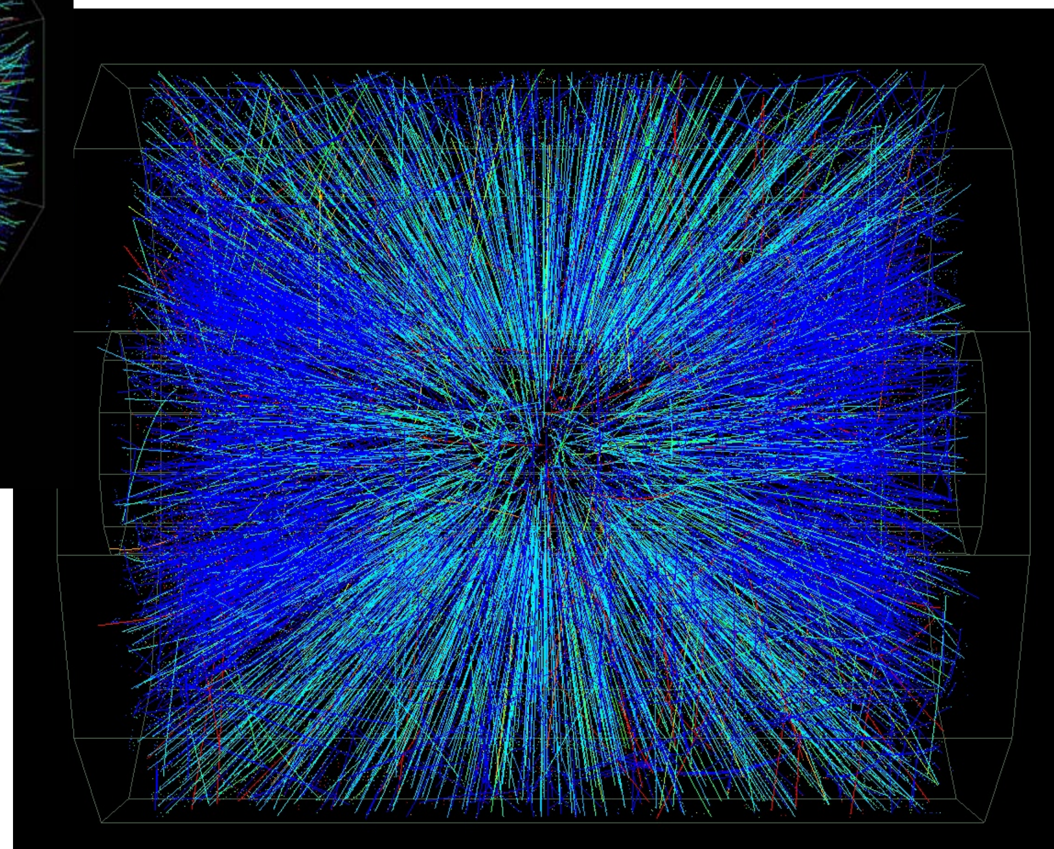
Wieman, JT (LBNL), Long, Trentalange (UCLA)

Dynamic E field distortions



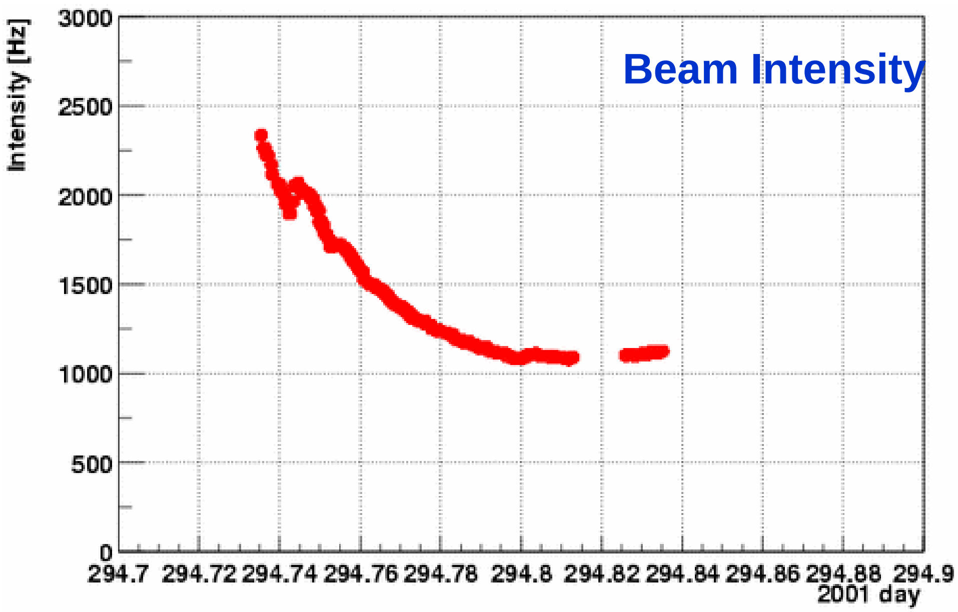
A Central Event

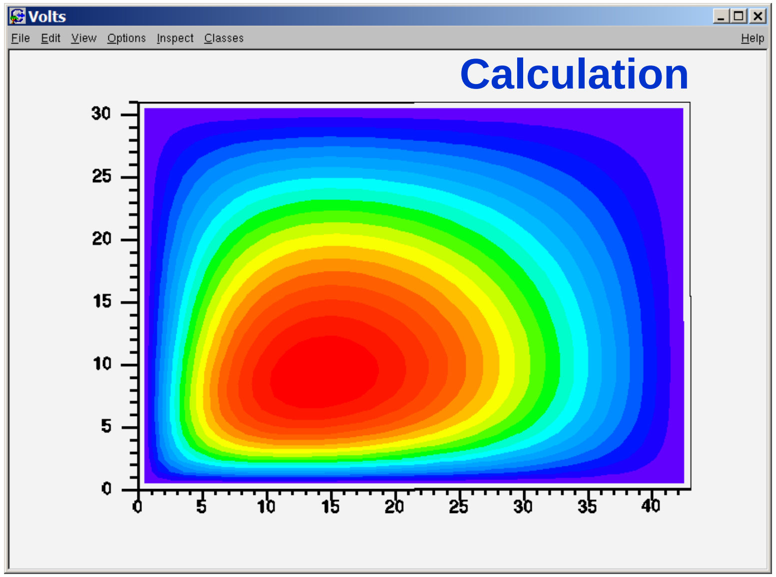
Typically 1000 to 2000 tracks
per event into the TPC

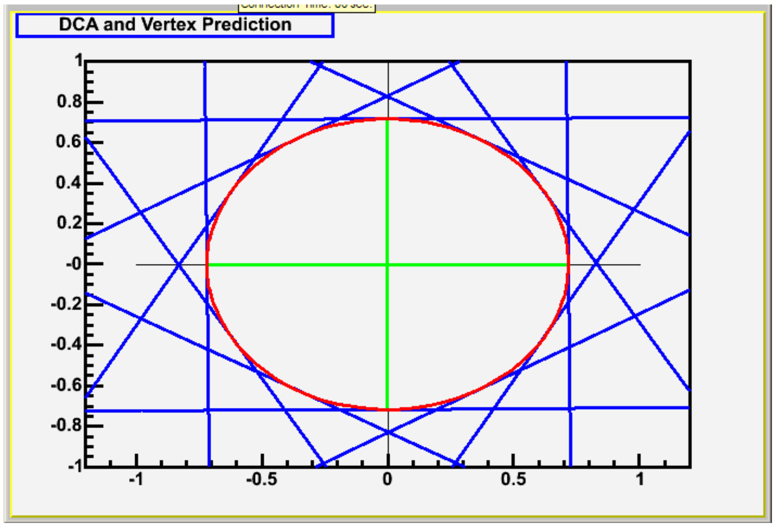


The primary tracks leave behind secondary electrons (good) and secondary ions (not so good). We call this “volume” spacecharge.

Space Charge

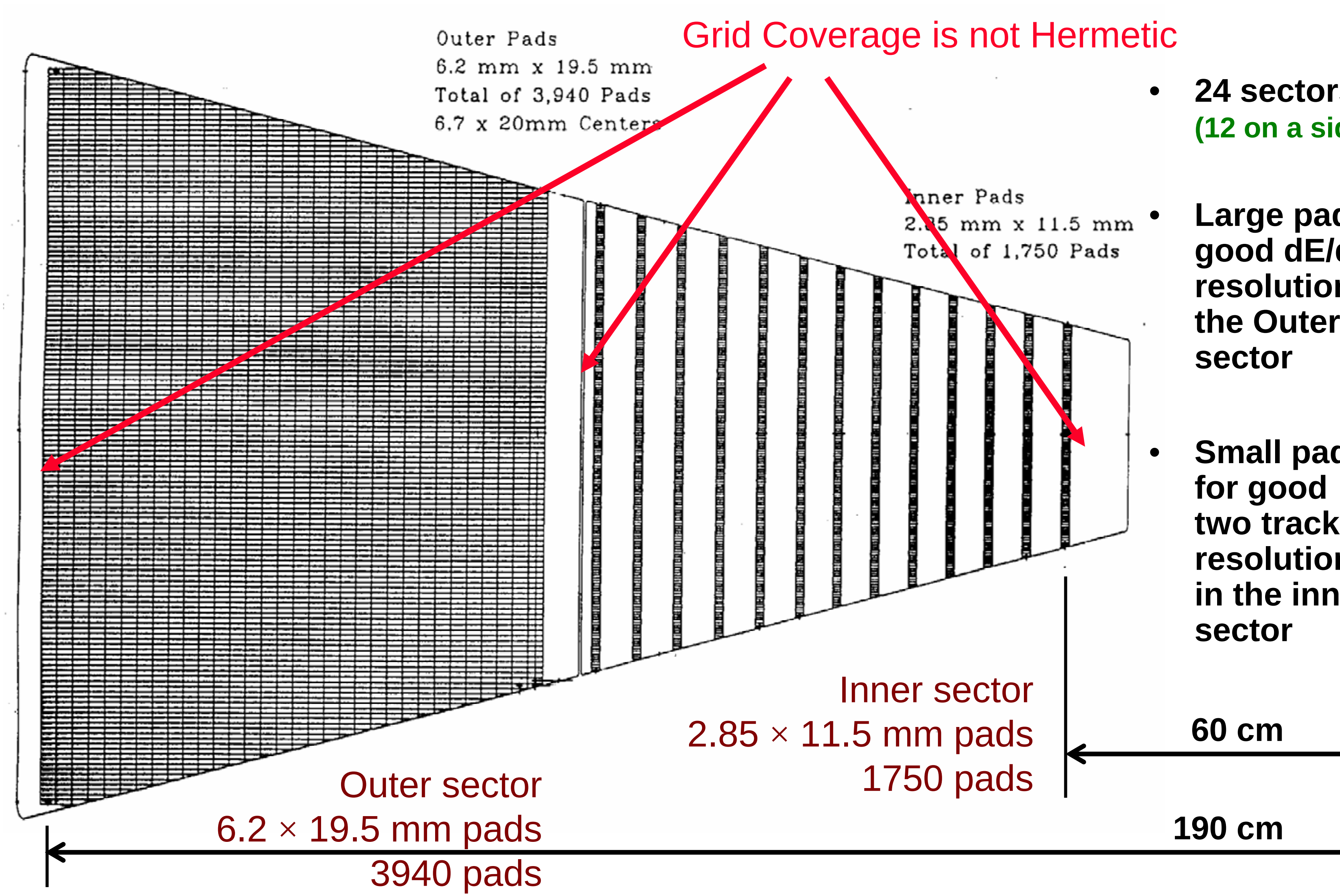






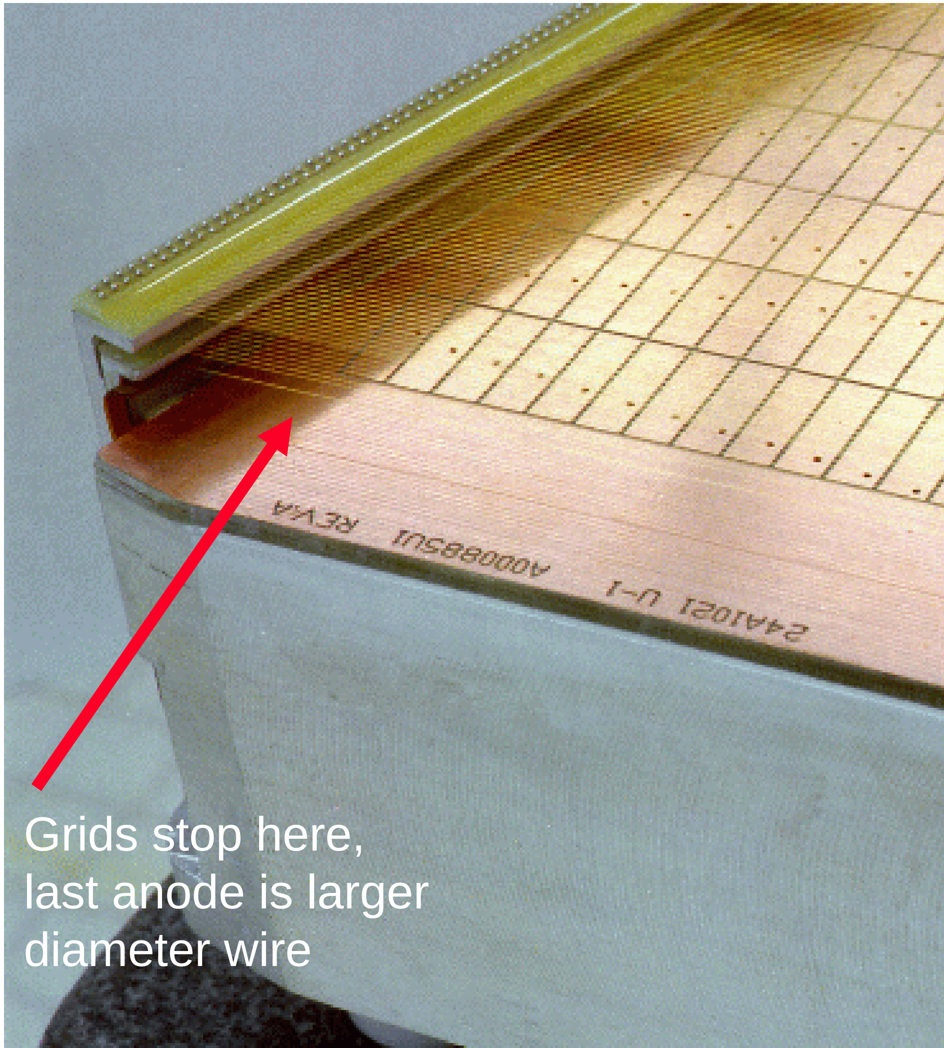
- Normal events leave a $1/R^2$ distribution of charge in the volume of the TPC
- Background ‘so far’ has had a similar shape … or was low
- We can model this and calculate effects … but it keeps changing with time
- See the talk by Gene VanBuren

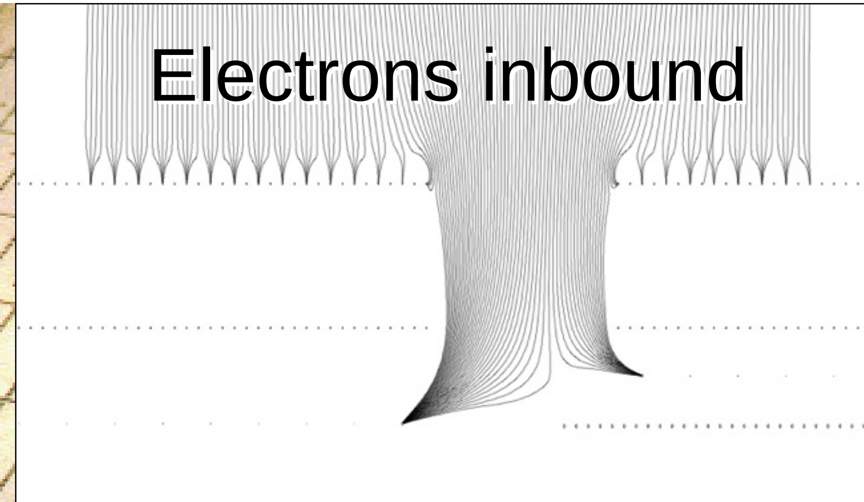
Outer and Inner Sectors of the Pad Plane

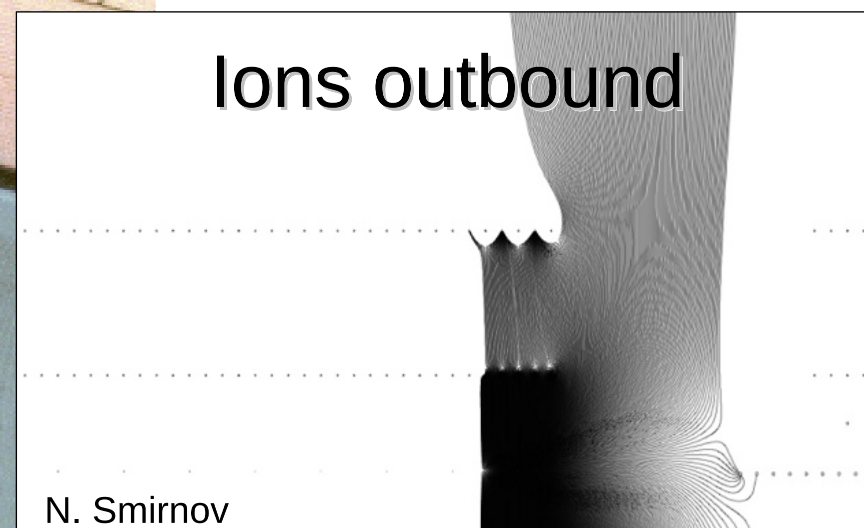


- **24 sectors (12 on a side)**
- **Large pads good dE/dx resolution in the Outer sector**
- **Small pads for good two track resolution in the inner sector**

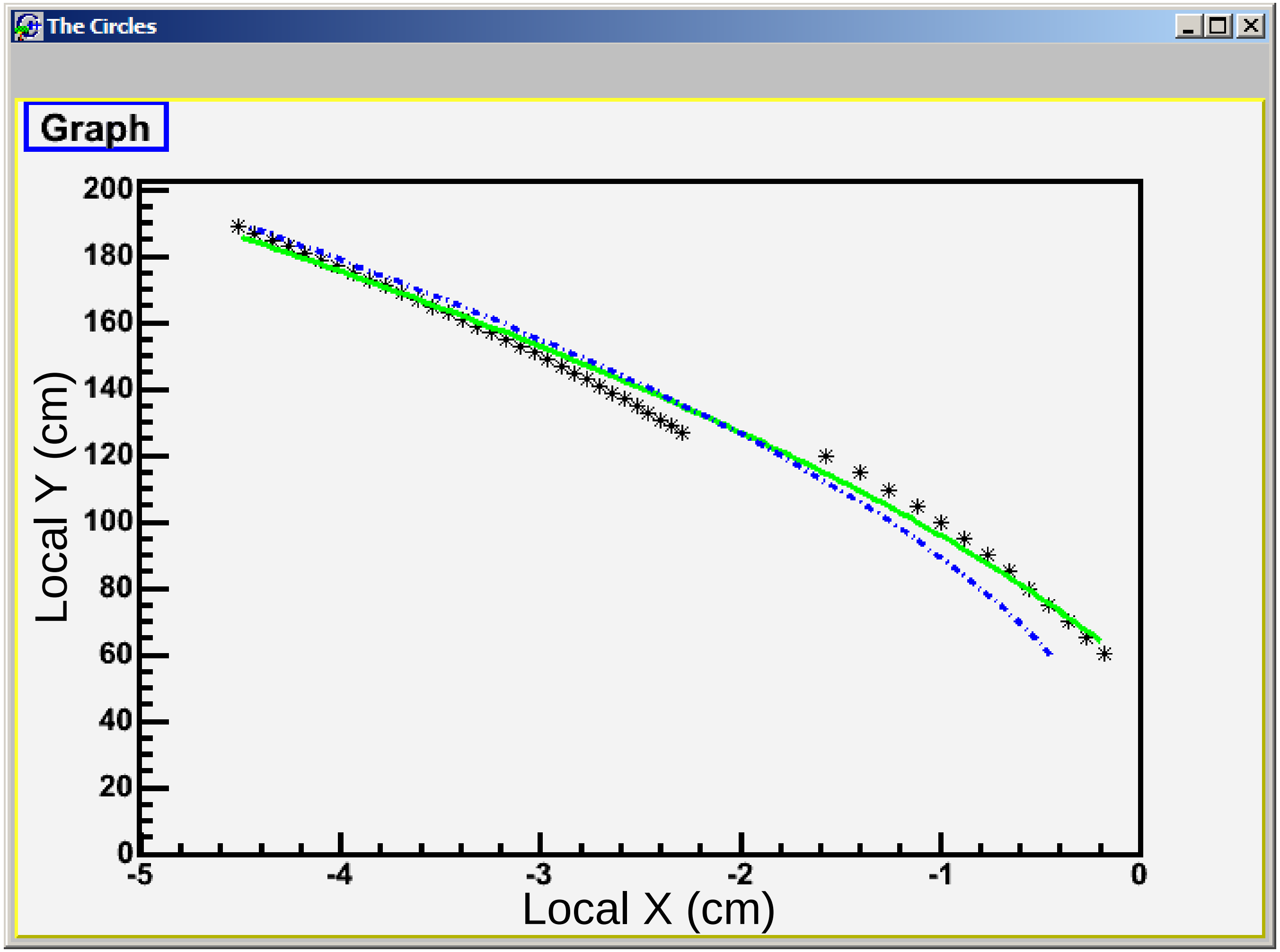
GridLeak - Ions Leaking Out of the Gap in the Grids







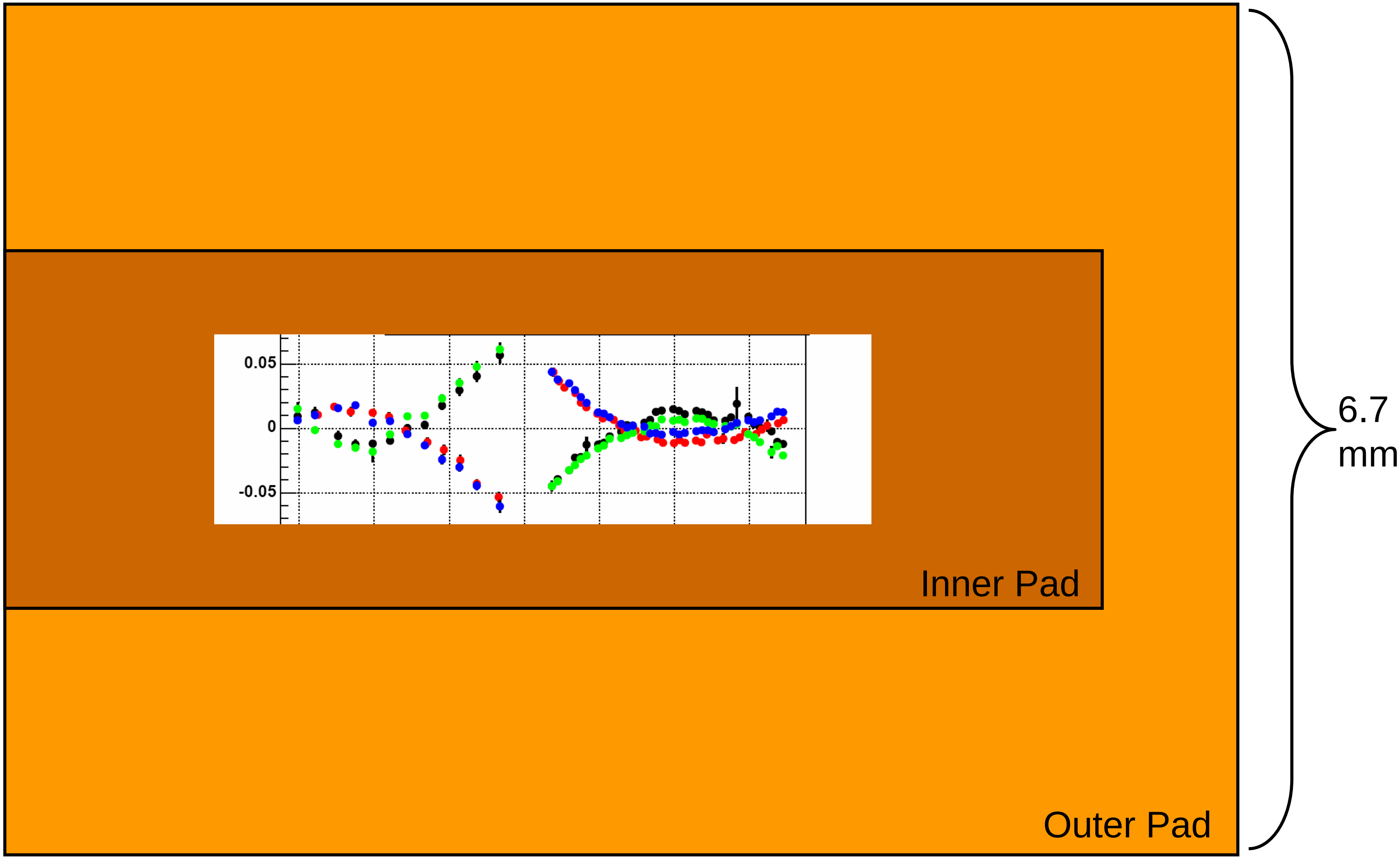
Effect of the Grid Leak on a Simulated Track



- The distortion is luminosity dependent
  - We did not see the grid leak in previous years because the L was low
- A 3 GeV track at our highest Luminosity is shown at left
  - A Global track
  - Positive Charge
- Track in blue
- Hits are black
- Fit in Green

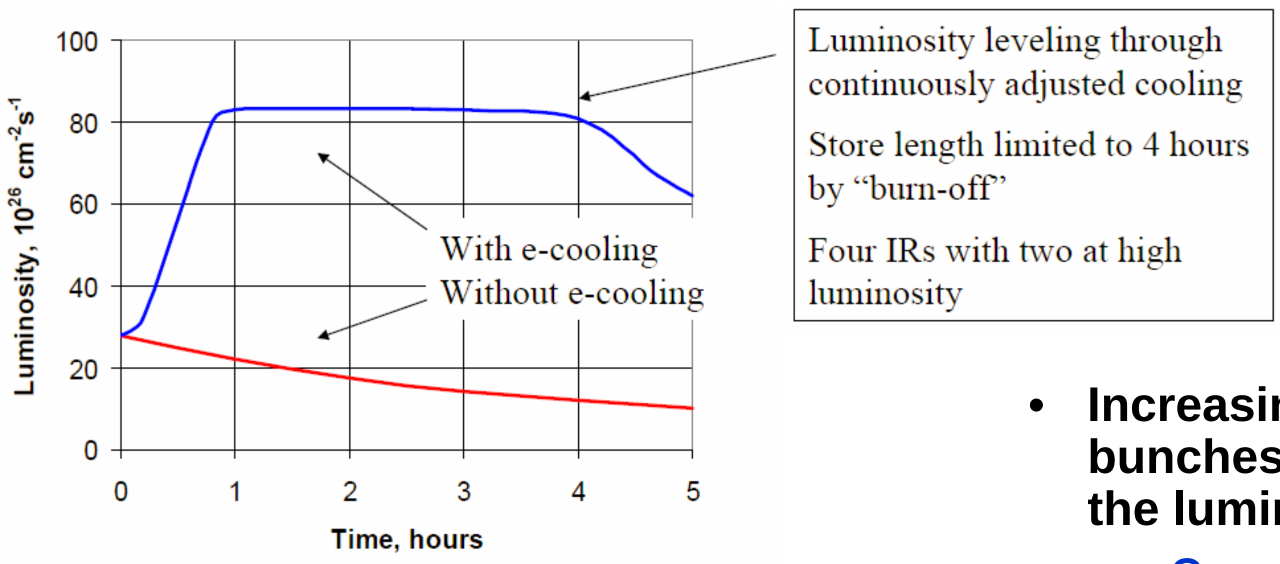
Principle effect is improper momentum determination and poor pointing at the vertex for global tracks
Primary tracks have a built in vertex constraint and so the effect is smaller for primaries than for global tracks.

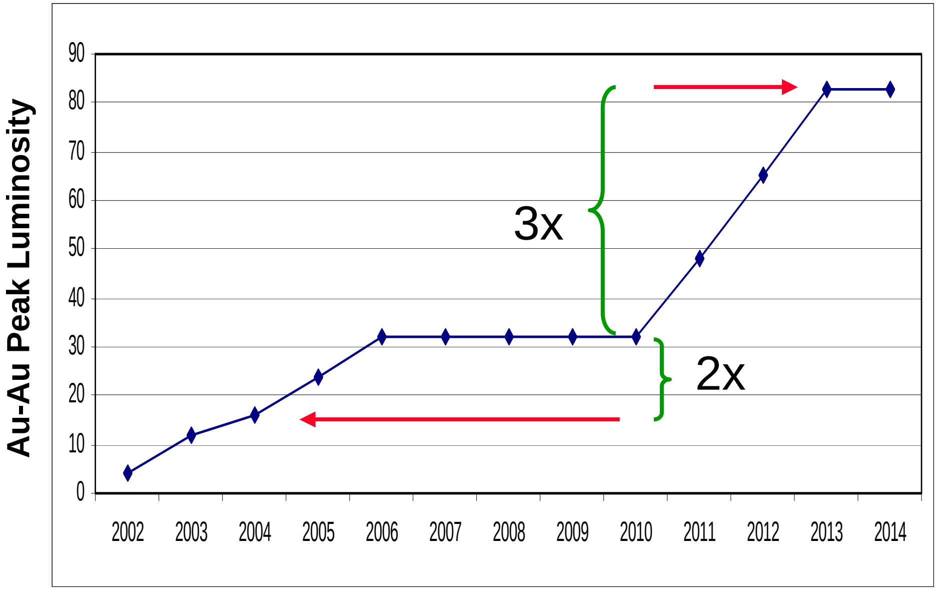
Grid Leak Distortion Relative to Inner/Outer Pad Size



The Grid leak is calculable and under control … but will it always be so?

Thomas Roser's e-Cooled Luminosity Projections





- **Increasing the number of bunches per ring increases the luminosity**
  - **Once we hit 112 bunches then no more luminosity increase is possible**
- **e-Cooling reduces the size of the beams**
  - **Curiously, it is a dynamic process that has to be tuned throughout the store**
- **2x increase in Luminosity before RHIC e-Cooling**
- **3x increase in Luminosity when e-Cooling turned on**

Luminosity Driven Distortions

- **Volume SpaceCharge**
  - 2x increase – I think we can handle this with Gene's EbyE tools
  - Additional 3x increase – we have a sporting chance
- **GridLeak**
  - 2x increase – I think we can handle this – oversize anode wire helps
    - total distortion is smaller than one pad on the inner sector
  - Additional 3x increase – we have a sporting chance
    - total distortion is smaller than one pad on the outer sector
- **Full-Grid Leak**
  - As the Gating Grid rate goes up, we expect the full grid to leak ions at some point simply because the GG is left open for a long time
    - Important for ReadOut & DAQ upgrade
    - Increased GG rate by an order of magnitude and saw no effect

Relative Magnitude of the Known Knowns and …

Distortion	Max Amplitude	Where	Comments
Field Shape	0.0800	OFC	Static
Twist	0.0400	CM	Annual
PadRow 13	0.0400	PadRow 13	Static
Clock	0.0800	OFC	Static
IFC Shift	0.0100	IFC at CM	Static
Space Charge	0.3000 (2004)	IFC at CM	Dynamic
Grid Leak	0.2500 (2004)	PadRow 13	Dynamic
Shorted Ring	0.5000	Unknown	Can Fluctuate (damn)
CM Shape	0.0150	IFC & OFC	Known Unknown
Endcap Shape	0.0150	IFC & OFC	Known Unknown

Will the TPC Last Forever?

- **Dynamic distortions driven by $\mathcal{L}$**
  - **2x increase is feasible and this takes us to 2010 and (probably) beyond.**
- **Some static distortions need work**
  - **e.g. Central Membrane is not flat**
    - **Probably of academic interest**
  - **Unlikely that any of these static unresolved issues will affect the useful lifetime of the TPC**
- **Beam backgrounds and ghost beams may be a problem**
  - **We have put up shielding blocks**
  - **Distortion corrections may need 3D**

3D calculations may be the biggest challenge for the future – the largest uncertainty will be lack of data from which to build the model

Space Charge Distortion in the STAR TPC, An Approximate Formula

H. Wieman
10/9/2006

Abstract:
A simple expression for the space charge distortion is derived which is based on the assumption that interactions produce tracks with dN/dη equal to a constant and that all the tracks are straight lines radiating out from the interaction point. This is for primary ionization in the TPC volume and does not include back ground tracks or positive ion leaks from the wire chambers. A closed form expression for the distortion is obtained by using a one dimensional solution to Poisson's equation. Results are shown for the highest projected AuAu luminosities at RHIC II. This note is based on work done in 1996 to predict space charge effects that we might encounter at RHIC startup.

The positive ion generation rate per unit volume:

$$S(r) = L \cdot \sigma \cdot \frac{dN}{d\eta} \cdot \frac{dq}{ds} \cdot \frac{1}{2 \cdot \pi \cdot r^2}$$

Derived in Appendix A1, this is eq. A1-8

Note, since this is a Mathcad document it has been convenient to express variable names for derivative values as follows, for example:

$\frac{dN}{d\eta}$ appears as $dNd\eta$

$dNd\eta = 170$

Measured number from James Dunlop for min-bias AuAu with the corresponding trigger cross section for the ZDC detectors

$\sigma = 10 barn$

$L = 90 \cdot 10^{26} \cdot \frac{1}{cm^2 \cdot sec}$

RHIC II predicted max luminosity with Au+Au

http://hepwww.physics.yale.edu/star/tpc-study/Luminosity.pdf

$minI = 96 \cdot \frac{qe}{cm}$

charge density along track for minimum Ionizing

$dqds = 146 \cdot \frac{qe}{cm}$

average charge density along track length from HIJET total charge (I. Sakrejda).

So use the HIJET number for ionization density along the track which is 50% higher than MinI

$S(50 \cdot cm) = 1 \cdot 10^5 \cdot \frac{qe}{cm^3 \cdot sec}$

positive ion creation rate at the inner radius, note the creation rate is uniform in z independent of where the interaction occurred. This is a consequence of the interaction occurred. This is a consequence of the uniform dN/dη assumption.

To give a quantitative feeling for this process, the positive ion creation density at the inner radius from a single average min bias AuAu event is:

$$\frac{S(50\cdot cm)}{L\cdot\sigma\cdot qe} = 1.6\cdot\frac{1}{cm^3}$$

The positive ions created through out the TPC volume drift to the central membrane where they are collected. The steady state positive ion density is obtained by integrating the positive ion source rate over z and by knowing the positive ion drift velocity.

$Zmax = 210\cdot cm$ drift length of TPC

$v = 250\cdot\frac{cm}{sec}$ positive ion drift velocity in the z direction, this comes from Fig. 2.5, p. 63 in Blume and Rolandi. It is the positive ion drift velocity in P10 at 130 V/cm

The charge density at points in the TPC caused by positive ions flowing from their points of creation to the central membrane is given as:

$$\rho(r,z) = \int_z^{Zmax}\frac{S(r,z)}{v}\,dz = L\cdot\sigma\cdot dNd\eta\cdot dqds\cdot\frac{1}{2\cdot\pi\cdot r^2}\cdot\frac{1}{v}\cdot\int_z^{Zmax}1\,dz$$

$$\rho(r,z) = L\cdot\sigma\cdot dNd\eta\cdot dqds\cdot\frac{1}{2\cdot\pi\cdot r^2}\cdot\frac{1}{v}\cdot(Zmax - z)$$ steady state positive ion density (space charge)

$$\rho(50cm,0cm) = 1.9\times10^{-14}\frac{coul}{cm^3}$$

$$\rho(50cm,0cm) = 1.2\times10^{5}\frac{qe}{cm^3}$$

With the much higher luminosity expected for RHIC II this positive ion density is 200 times what was predicted originally in Gulshan Rai's STAR note #3

In the following an approximation of the distortion is obtained from this space charge density by using a one dimensional solution to Poison's equation. The approximation over predicts the distortion and is ~50% larger than a full 3D Poison solution.

The radial E field (Er) can be approximated using Gausses law if we treat the TPC tube as ? length with a uniform charge density along the tube. Then:

$$\int_{surface} \vec{E}\,\vec{ds} = \frac{1}{\varepsilon_0}\cdot\int_{volume} \rho_t(r,z)\,dx^3$$

The integration surface is the inner field cage metal where the field is 0 and the outer cylinder is set at radius r where we wish to evaluate the radial field. The charge included in the volume of integration is the space charge derived above plus an induced surface charge, σ_{in} ,on the inner field cage.
The integrals above reduce to:

$$Er(r,z)\cdot 2\cdot\pi\cdot r\cdot\Delta z = \frac{\Delta z}{\varepsilon_0}\cdot\int_{r_{in}}^{r} \rho(rp,z)\cdot 2\cdot\pi\cdot rp\,drp + \frac{\Delta z\cdot 2\cdot\pi\cdot r_{in}}{\varepsilon_0}\cdot\sigma_{in}$$

$$Er(r,z)\cdot 2\cdot\pi\cdot r\cdot\Delta z = \frac{\Delta z}{\varepsilon_0}\cdot L\cdot\sigma\cdot dN d\eta\cdot dqds\cdot\frac{1}{v}\cdot(Zmax - z)\cdot\int_{r_{in}}^{r} \frac{1}{2\cdot\pi\cdot rp^2}\cdot 2\cdot\pi\cdot rp\,drp + \frac{\Delta z\cdot 2\cdot\pi\cdot r_{in}}{\varepsilon_0}\cdot\sigma_{in}$$

$$Er(r,z) = \frac{1}{2\cdot\pi\cdot r\cdot\varepsilon_0}\cdot L\cdot\sigma\cdot dN d\eta\cdot dqds\cdot\frac{1}{v}\cdot(Zmax - z)\cdot\int_{r_{in}}^{r} \frac{1}{rp}\,drp + \frac{r_{in}}{\varepsilon_0\cdot r}\cdot\sigma_{in}$$

$$Er(r,z) = \frac{1}{2\cdot\pi\cdot r\cdot\varepsilon_0}\cdot L\cdot\sigma\cdot dN d\eta\cdot dqds\cdot\frac{1}{v}\cdot(Zmax - z)\cdot\ln\left(\frac{r}{r_{in}}\right) + \frac{r_{in}}{\varepsilon_0\cdot r}\cdot\sigma_{in}$$

Keep in mind the confusing variable names, namely σ is the average min bias AuAu cross section and σ_{in} is the surface charge density on the inner field cage induced by the space charge.

The surface charge, σ_{in} , is obtained knowing that the potential between the inner and outer field cage is 0 at any given z.

$$\int_{r_{in}}^{r_{out}} Er(r,z)\,dr = \int_{r_{in}}^{r_{out}} \frac{1}{2\cdot\pi\cdot r\cdot\varepsilon_0}\cdot L\cdot\sigma\cdot dN d\eta\cdot dqds\cdot\frac{1}{v}\cdot(Zmax - z)\cdot\ln\left(\frac{r}{r_{in}}\right)dr + \frac{\sigma_{in}\cdot r_{in}}{\varepsilon_0}\cdot\int_{r_{in}}^{r_{out}} \frac{1}{r}\,dr = 0$$

$$\int_{r_{in}}^{r_{out}} Er(r,z)\,dr = \frac{1}{4}\cdot\ln\left(\frac{r_{out}}{r_{in}}\right)^2\cdot L\cdot\sigma\cdot dN d\eta\cdot dqds\cdot\frac{Zmax - z}{\pi\cdot(\varepsilon_0\cdot v)} + \sigma_{in}\cdot\frac{r_{in}}{\varepsilon_0}\cdot\ln\left(\frac{r_{out}}{r_{in}}\right) = 0$$

$$\sigma_{in} = \frac{-1}{4}\cdot(Zmax - z)\cdot dqds\cdot dN d\eta\cdot L\cdot\sigma\cdot\frac{\ln\left(\frac{r_{out}}{r_{in}}\right)}{r_{in}\cdot\pi\cdot v}$$

$$Er(r,z) = \frac{1}{2\cdot\pi\cdot r\cdot\varepsilon_0}\cdot L\cdot\sigma\cdot dN d\eta\cdot dqds\cdot\frac{1}{v}\cdot(Zmax - z)\cdot\ln\left(\frac{r}{r_{in}}\right) + \frac{r_{in}}{\varepsilon_0\cdot r}\cdot\sigma_{in}$$

$$Er(r,z) = \frac{1}{4}\cdot L\cdot\sigma\cdot dN d\eta\cdot dqds\cdot(Zmax - z)\cdot\frac{\ln\left(\frac{r^2}{r_{in}\cdot r_{out}}\right)}{\pi\cdot r\cdot\varepsilon_0\cdot v}$$

finally the radial component of the electric field caused by space charge

The distortion in the rϕ direction comes from the EXB term integrated along the drift path and is:

$$r\phi(r,z) = \frac{\omega\tau}{1+\omega\tau^2}\cdot\int_z^{Zmax}\frac{Er(r,z)}{Ez}\,dz = \frac{\omega\tau}{1+\omega\tau^2}\cdot\frac{1}{4}\cdot L\cdot\sigma\cdot dN d\eta\cdot dqds\cdot\frac{\ln\left(\frac{r^2}{r_{in}\cdot r_{out}}\right)}{\pi\cdot r\cdot\varepsilon_0\cdot v\cdot Ez}\cdot\int_z^{Zmax}(Zmax - zp)\,dzp$$

$$r\phi(r,z) = \frac{\omega\tau}{1+\omega\tau^2}\cdot L\cdot\sigma\cdot dN d\eta\cdot dqds\cdot\frac{\ln\left(\frac{r^2}{r_{in}\cdot r_{out}}\right)}{8\cdot\pi\cdot r\cdot\varepsilon_0\cdot v\cdot Ez}\cdot(Zmax - z)^2$$

distortion in the rϕ direction

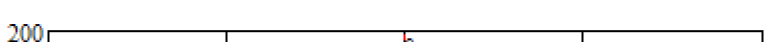
assume $\omega\tau$

$\omega\tau = 2.28$ — for 0.5 Tesla in P10, this may not be the latest value

$r_{in} = 48\cdot cm$ — inner field cage radius

$r_{out} = 200\cdot cm$ — outer field cage radius

$Ez = 130\cdot\frac{volt}{cm}$ — drift field



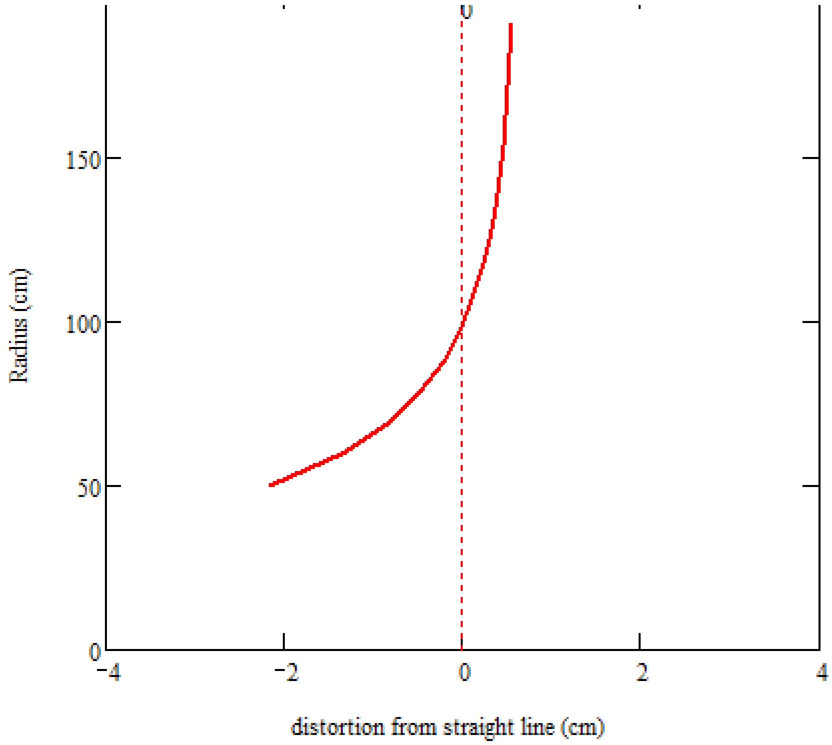
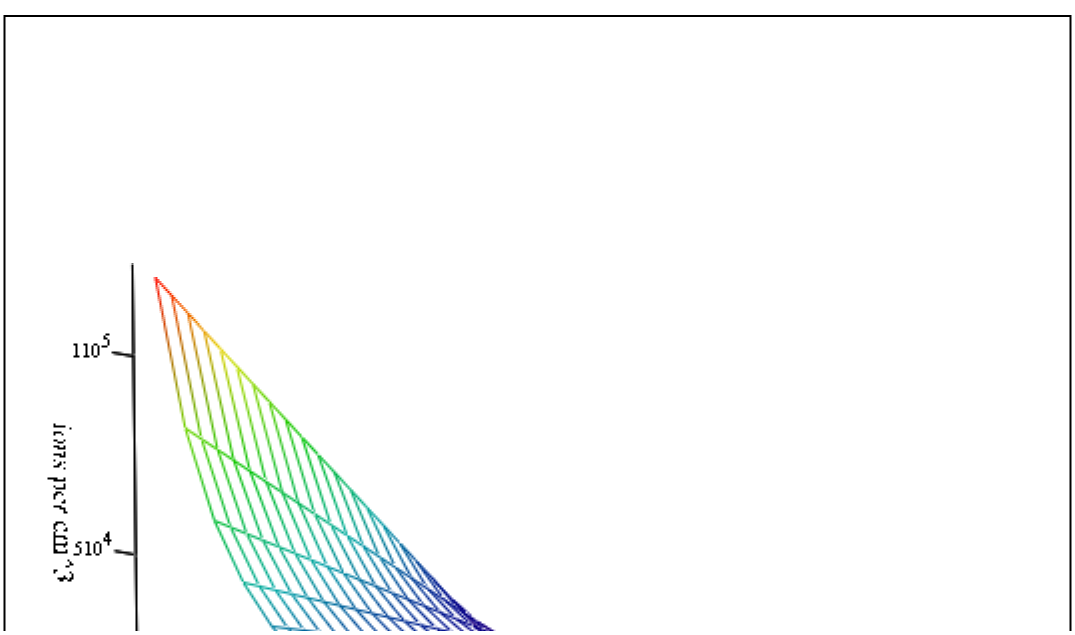
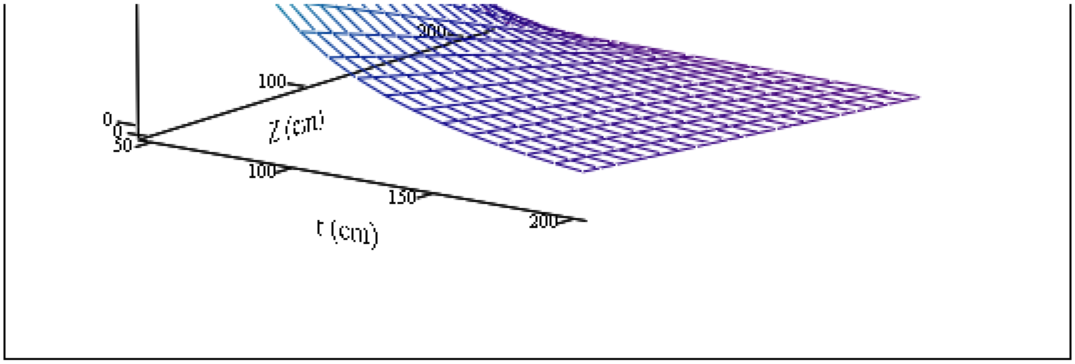


Fig. 1 rϕ distortion for a straight line track. A straight line vertical track at the center of TPC (dotted line) will be distorted by space charge and appears as the solid line.





ρ1

Fig. 2 Steady state positive ion density as a function of r and z in the TPC volume for RHIC II predicted AuAu luminosity. This is the positive ion density that produced the distortion shown in Fig. 1

Appendix A1

Derivation of

$$S(r) = \frac{dq}{dVdt} = L \cdot \sigma \cdot \frac{dN}{d\eta} \cdot \frac{dN_i}{ds} \cdot \frac{q_e}{2 \cdot \pi \cdot r^2}$$

Eq. A1-1 the rate of positive ion generation per volume

using a cylindrical coordinate geometry (Fig. A1-1).

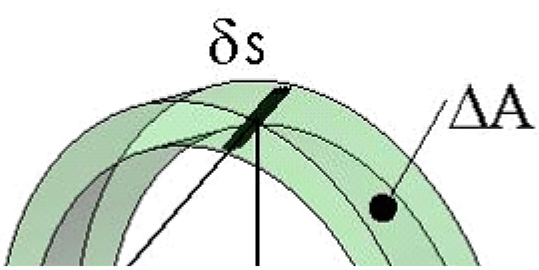
$\frac{dN}{d\eta}$ number of tracks per unit pseudo rapidity, assumed constant

$\frac{dN_i}{ds}$ number of ion-electron pairs created per unit length along the track

L Luminosity

σ cross section

q_e electron charge



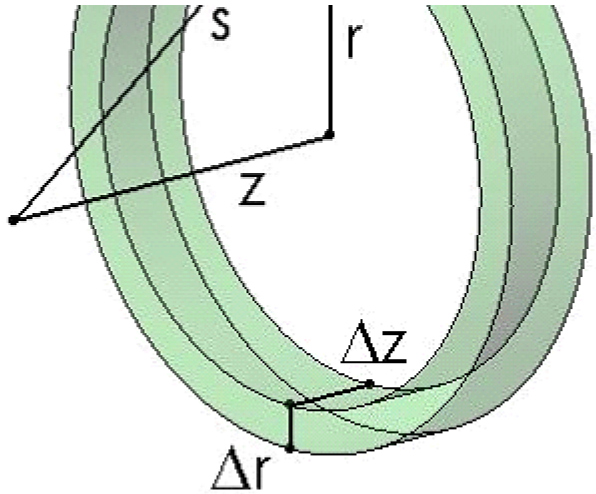


Fig. A1-1 Elemental volume with track along s leaving ionization segment δs

from the geometry illustrated in Fig. A1-1

$$\Delta q = \frac{dN}{dA} \cdot \Delta A \cdot \frac{dN_i}{ds} \cdot \delta s \cdot q_e$$ Eq. A1-2

where

$$\frac{dN}{dA} = \frac{dN}{dz} \cdot \frac{1}{2 \cdot \pi \cdot r} = \frac{dN}{d\eta} \cdot \frac{d\eta}{dz} \cdot \frac{1}{2 \cdot \pi \cdot r}$$ Eq. A1-3 is for a collision, the average number of tracks per area impinging on the inside surface of the elemental volume in Fig. A1-1

and $$\delta s = \Delta r \cdot \frac{s}{r} = \Delta r \cdot \frac{\sqrt{r^2 + z^2}}{r}$$ Eq. A1-4 is the length of the track segment passing through the elemental volume

$$\Delta V = \Delta A \cdot \Delta r$$ Eq. A1-5 is the elemental volume

combining Eq. A1-2 through Eq. A1-5 gives

$$\frac{dq}{dV} = \frac{\Delta q}{\Delta V} = \frac{\frac{dN}{d\eta} \cdot \frac{d\eta}{dz} \cdot \frac{1}{2 \cdot \pi \cdot r} \cdot \Delta A \cdot \frac{dN_i}{ds} \cdot \Delta r \cdot \frac{\sqrt{r^2 + z^2}}{r} \cdot q_e}{\Delta A \cdot \Delta r} = \frac{dN}{d\eta} \cdot \frac{d\eta}{dz} \cdot \frac{dN_i}{ds} \cdot \frac{\sqrt{r^2 + z^2}}{2 \cdot \pi \cdot r^2} \cdot q_e$$ Eq. A1-6

the charge volume density left by a single collision

To find $\frac{d\eta}{dz}$ use the definition of pseudo rapidity

$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$ and $$\theta = \operatorname{atan}\left(\frac{r}{z}\right)$$

to get

$$\eta(r,z) = \ln\left(\frac{\sqrt{z^2 + r^2} + z}{r}\right)$$

and taking the derivative

$$\frac{d\eta}{dz} = \frac{1}{\sqrt{r^2 + z^2}} \qquad \text{Eq. A1-7}$$

combine Eq. A1-7 and A1-6 to eliminate $\frac{d\eta}{dz}$

and multiply by the event rate $L \cdot \sigma$

gives the following expression for the generation rate of positive ions per volume

$$\frac{dq}{dV dt} = L \cdot \sigma \cdot \frac{dN}{d\eta} \cdot \frac{dN_i}{ds} \cdot \frac{q_e}{2 \cdot \pi \cdot r^2} \qquad \text{Eq. A1-8}$$

which is uniform in z, i.e. it does not matter where in z the collision occurred.

A similar and perhaps more straight forward derivation has been done starting with spherical coordinates which gives the same expression. This will be added later.

References:

1. C:\Documents and Settings\Howard Wieman\My Documents\space charge distortion STAR\ TwoD5.MCD