STAR TPC
Calibrations Review
February 2021

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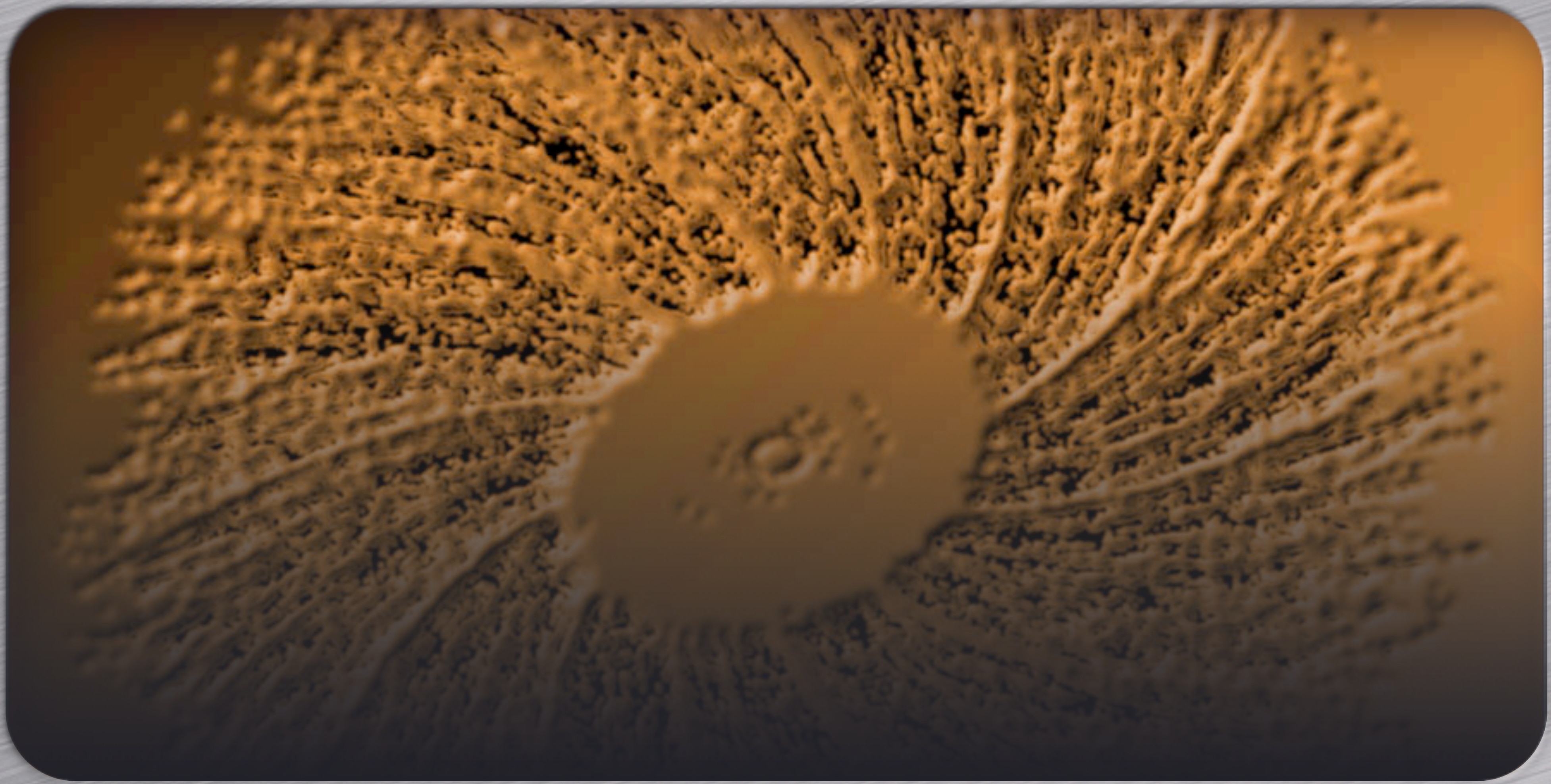


TPC Distortions

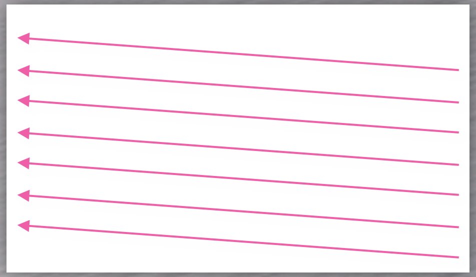
Possible Field Distortions

- Surfaces
  - Field cage rings at wrong potentials (shifted cages, electrical shorts, current leakage out of cages)
  - Wrong potentials between inner and outer sector gating grids
  - Gating grid wires at wrong potential
  - Gating grid displacements in drift direction
  - Central membrane displaced in drift direction
- Volume
  - Misaligned primary E and B fields
  - Non-uniformities in B field
  - Space charge ion build-up
  - Ion backflow, through or around the gating grid ("GridLeak")

Field Distortion Effects I

- Treatable as perturbations on top of standard TPC E field
  - Each distortion a separate perturbation
  - B field non-uniformities result in straightforward calculations
- In some cases, perturbing electric fields at all points are straightforward functions
- For others, boundary potentials and any charge density is expressed on a (2D or 3D) grid, and an iterative relaxation is performed to satisfy Poisson's equation at all points on the grid
  - Perturbing electric fields derived at all points on the grid
  - Real data points not on grid, interpolated (1st or 2nd order) between nearby grid points

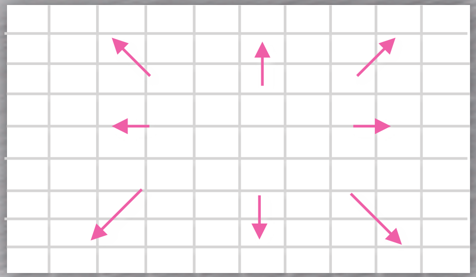
Straightforward example: misaligned E and B fields



$$-\nabla^2 \varphi = \frac{\rho}{\varepsilon}$$

$$\mathbf{E} = -\nabla \varphi$$

Not straightforward example: space charge

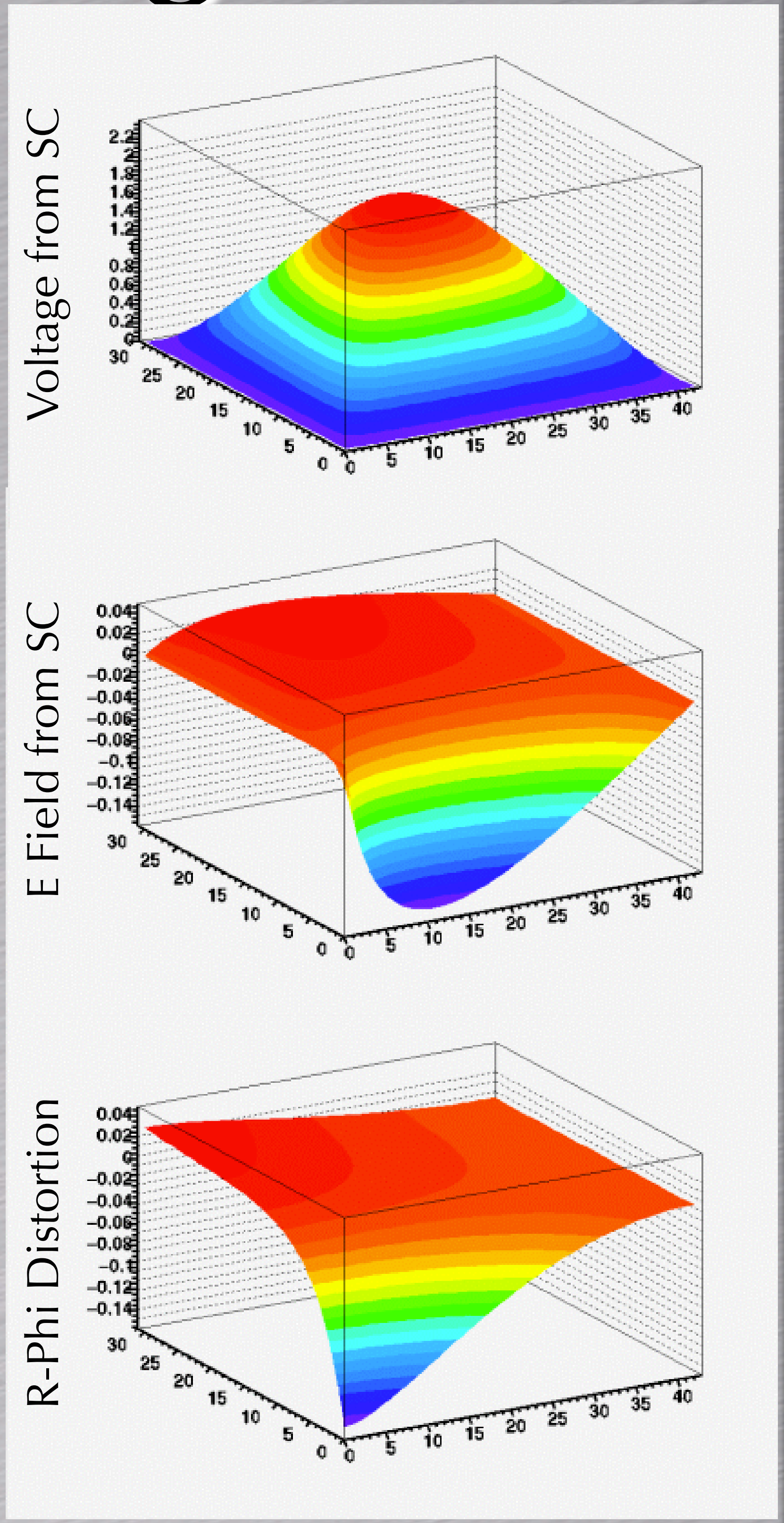


Field Distortion Effects II

- Perturbing E fields in drift direction (E_z) are a modification of the primary drift E field
  - Operating near the maximum of the drift velocity vs. E curve means that there is little impact on d.v. from this (<0.1%)
    - TPC-averaged drift velocity is anyhow measured
  - Ignoring E_z errors impacts calculations of perturbing E field maps, may be incorrect at levels of a few % at highest luminosities, where physics requirements for correction accuracy are not stringent
    - This is *the* consequence for separating each distortion!
- Displacement of drifting electrons determined by integrating Lorentz force over drift time (distance): $\vec{F} = q \bullet (\vec{E} + \vec{v} \times \vec{B})$
  - Use Langevin Equation, includes a friction term that allows a formulation of characteristic $\omega\tau$ (see backups)
  - Iterative calculation to "undo" distortion (measured position wasn't the original position)

Example: SpaceCharge

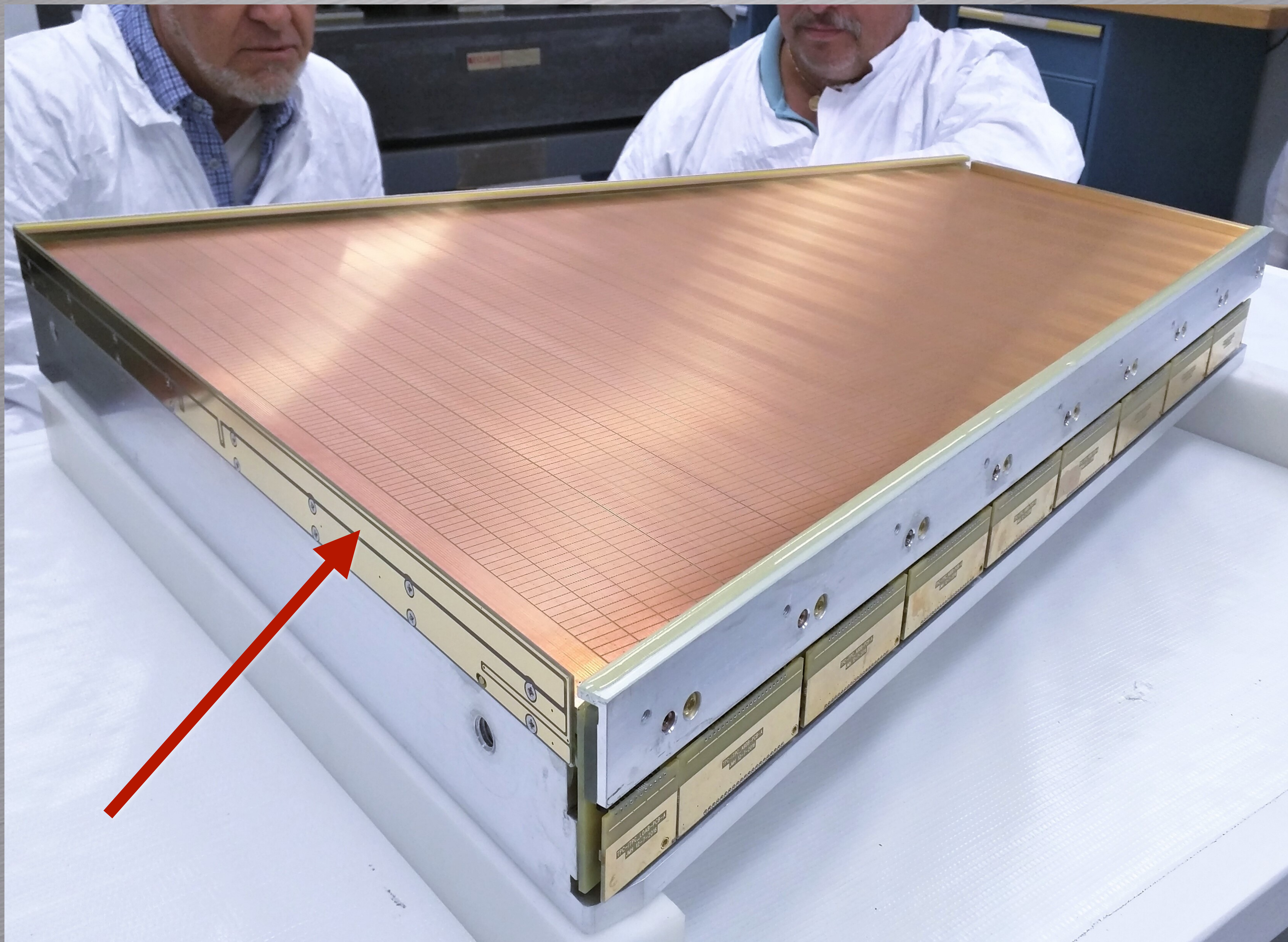
- Using our "event shape" model of charge
- Relaxation done on 5 cm x 5 cm 2D (r-z) grid (assume Φ symmetry)
  - For other distortions, grid granularity is more fine where rapid changes (discontinuities) are expected
- Radial perturbing E field (E_r, ignore E_z)
- Both radial and azimuthal (r-Φ) distortions
  - Helps to connect with Lorentz equation via:
    - E_r leads directly to radial distortion via E term
    - E_r leads indirectly to azimuthal distortion via v x B term: $E_r \Rightarrow v_r \times B_z \Rightarrow \Phi$ term (right hand rule)
    - These two components cycle between each other at cyclotron frequency



Calibrating distortions

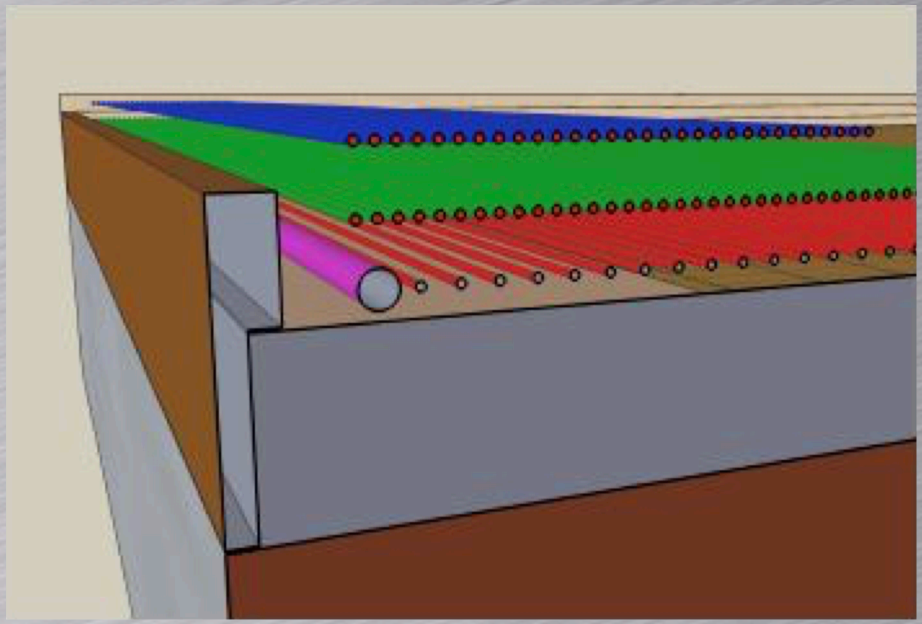
- Low sensitivity to radial distortions because tracks are radial
  - Difficult to measure, but also less important to measure well
- Typically each distortion has unique characteristics that make measuring it distinct
  - Some overlaps (such as GridLeak and incorrect potentials between inner and outer sector gating grids), but dependencies are different (luminosity and drift distance dependences vs. static and drift independent)
- Some distortions have no free parameters
  - This was leveraged to measure $\omega\tau$ components in 2006 by intentionally altering gating grid and field cage potentials
- SpaceCharge & GridLeak are the only distortions dependent on beam conditions, requiring re-calibration with every acquired dataset (in principle, should be the only distortions to worry about calibrating for BES-II) [*performed by helpers*]

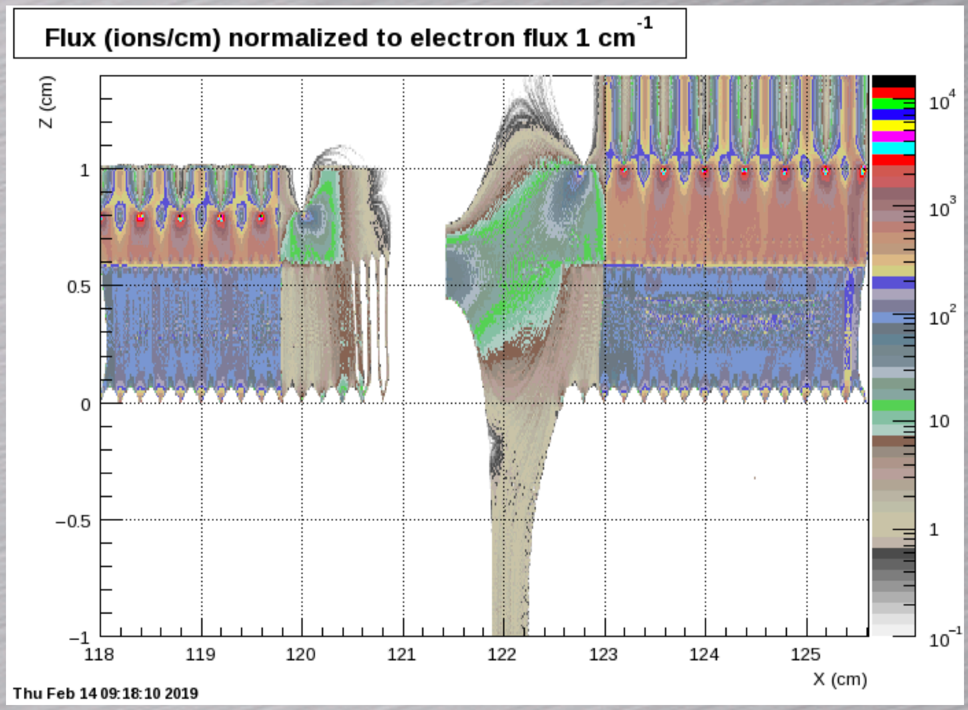
GridLeak wall

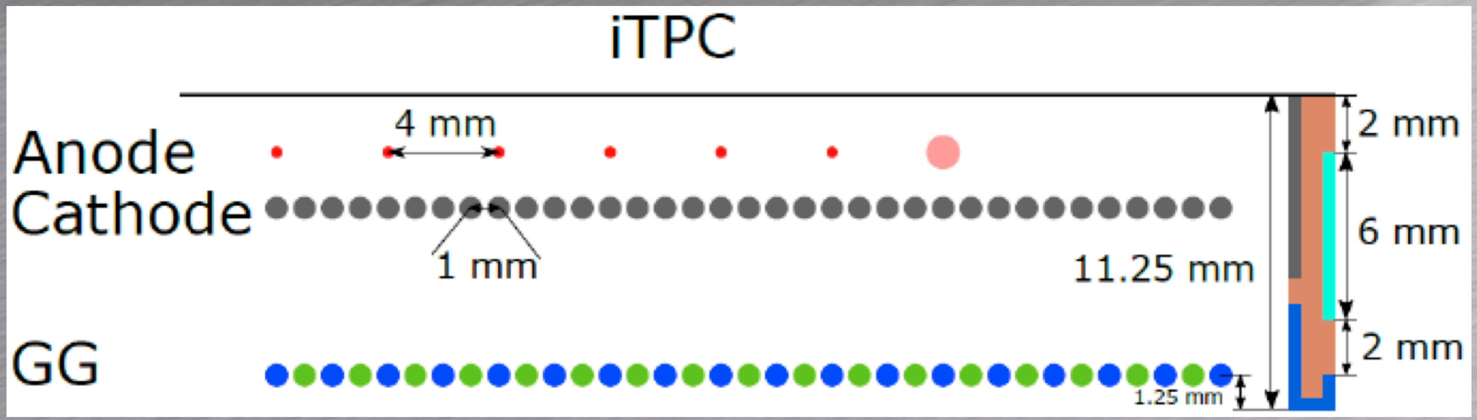


GridLeak wall

- Attached to new iTPC sectors
- Wall has plating to express three potentials: ground near inner anodes, gating grid voltage near tip, charge-attracting voltage on outside (last two are tunable)
- Garfield simulations used to determine optimal voltages to minimize GridLeak, at the cost of a static distortion (with no free parameters to calibrate)







Known shortcomings

- Inner field cage sees current drawn out likely due to space charge in air
- Don't measure the SpaceCharge radial charge distribution every year
- Drifting SC & GL ions push outward radially as they drift toward central membrane
- GridLeak seen to vary by sector

- Notes about current situation:
  - BES-II: low luminosity, so SpaceCharge & GridLeak are small
  - iTPC: GridLeak even further reduced by charge-collecting wall
  - GMT: would clarify if the SpaceCharge shape is wrong

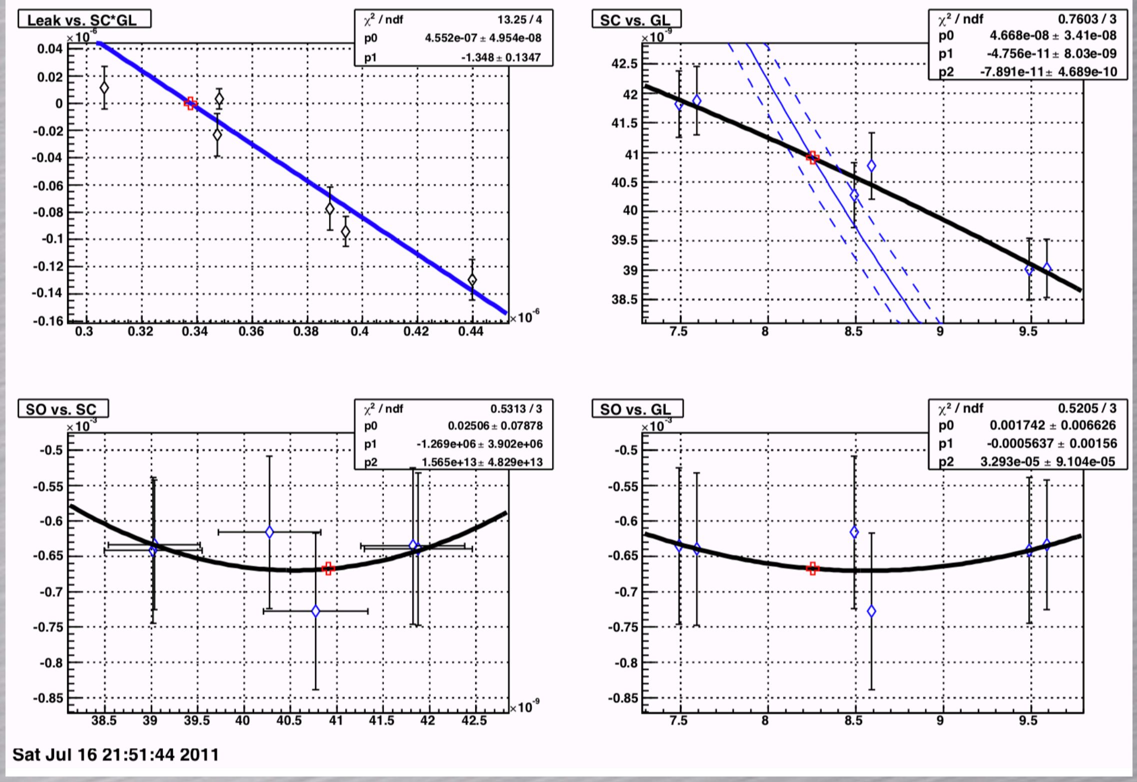
Unknown shortcomings

- AbortGapCleaning space charge distributions unmeasured
- SpaceCharge saw unexplained fill-by-fill variances in Run 17
- SpaceCharge east/west asymmetries don't match HIJING expectations
- SpaceCharge offsets at projection to zero luminosity
- Extrapolation of GridLeak residuals-gap metric to end-plane doesn't match the model

- Notes about current situation:
  - BES-II & iTPC: see previous slide (SC &GL are small)
  - Zero luminosity offsets most likely due to misalignment
    - This is the only shortcoming of concern for BES-II!

Documentation

- Documentation is linked from the TPC Calibrations web page
- SpaceCharge & GridLeak calibration is particularly pertinent because it is frequently exercised
  - "How-to" instructions are there
    - Likely need a re-fresh to capture current knowledge
  - Almost all dataset calibration results are listed
    - Holes that can be filled in should be



Final calibration values for the early runs:
SC = 3.952e-8((zdce+zdcw) - 1.286e+4) with GL = 8.11
Final calibration values for the late runs:
SC = 4.702e-8((zdce+zdcw) - 4.355e+4) with GL = 8.19

Conclusions

- Many years of successful STAR physics analyses implies reasonable handling of distortion corrections
    - Particularly so at low luminosities, where we are for BES-II
- Areas of current attention:
    - SpaceCharge degeneracy with alignment
    - New GridLeak wall static correction
    - Operations of Booster Main Magnet

Backups

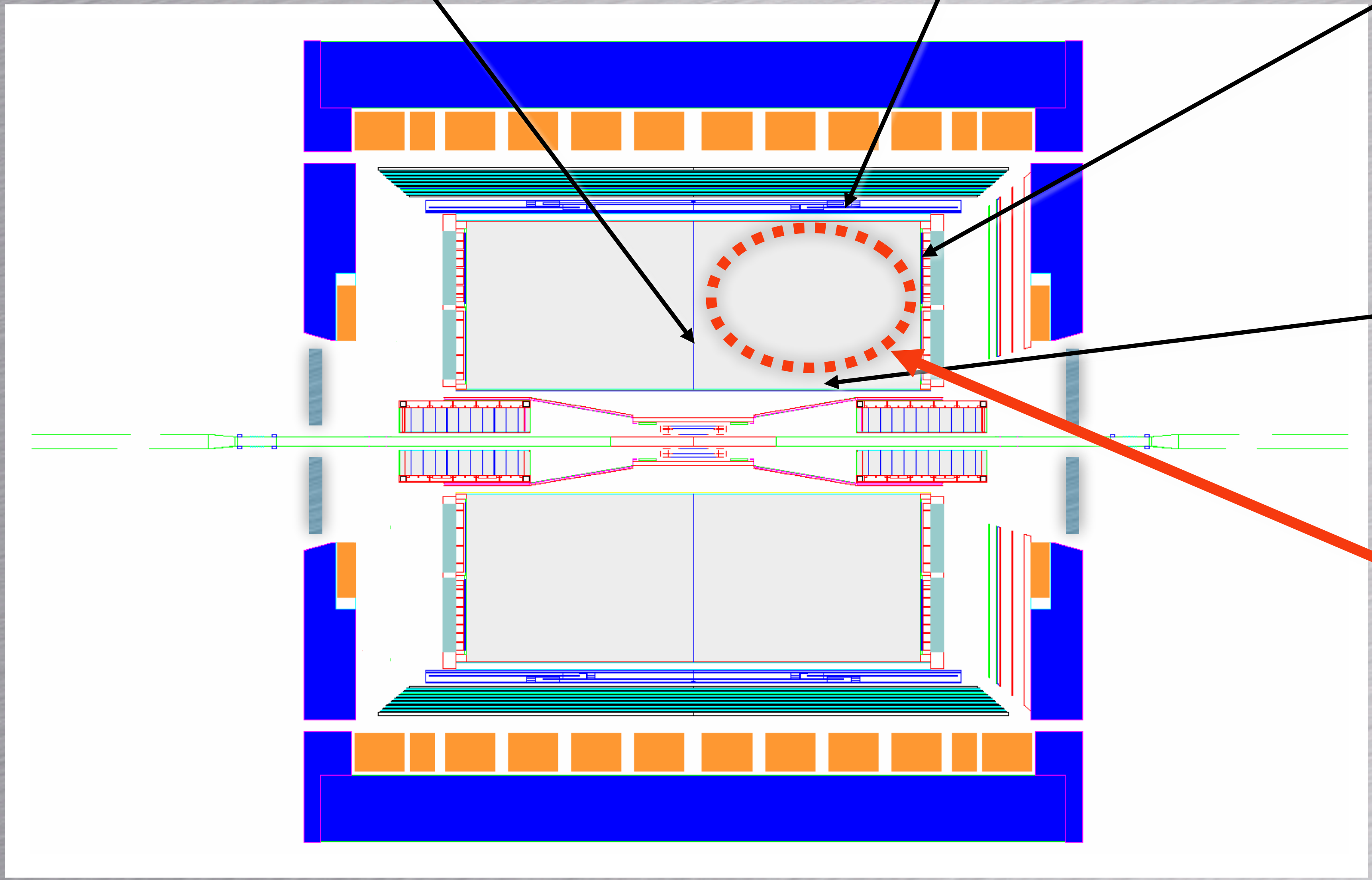
Potential locations of charge buildup

Central Membrane

Outer Field Cage

Endwheel and Padplane

Inner Field Cage



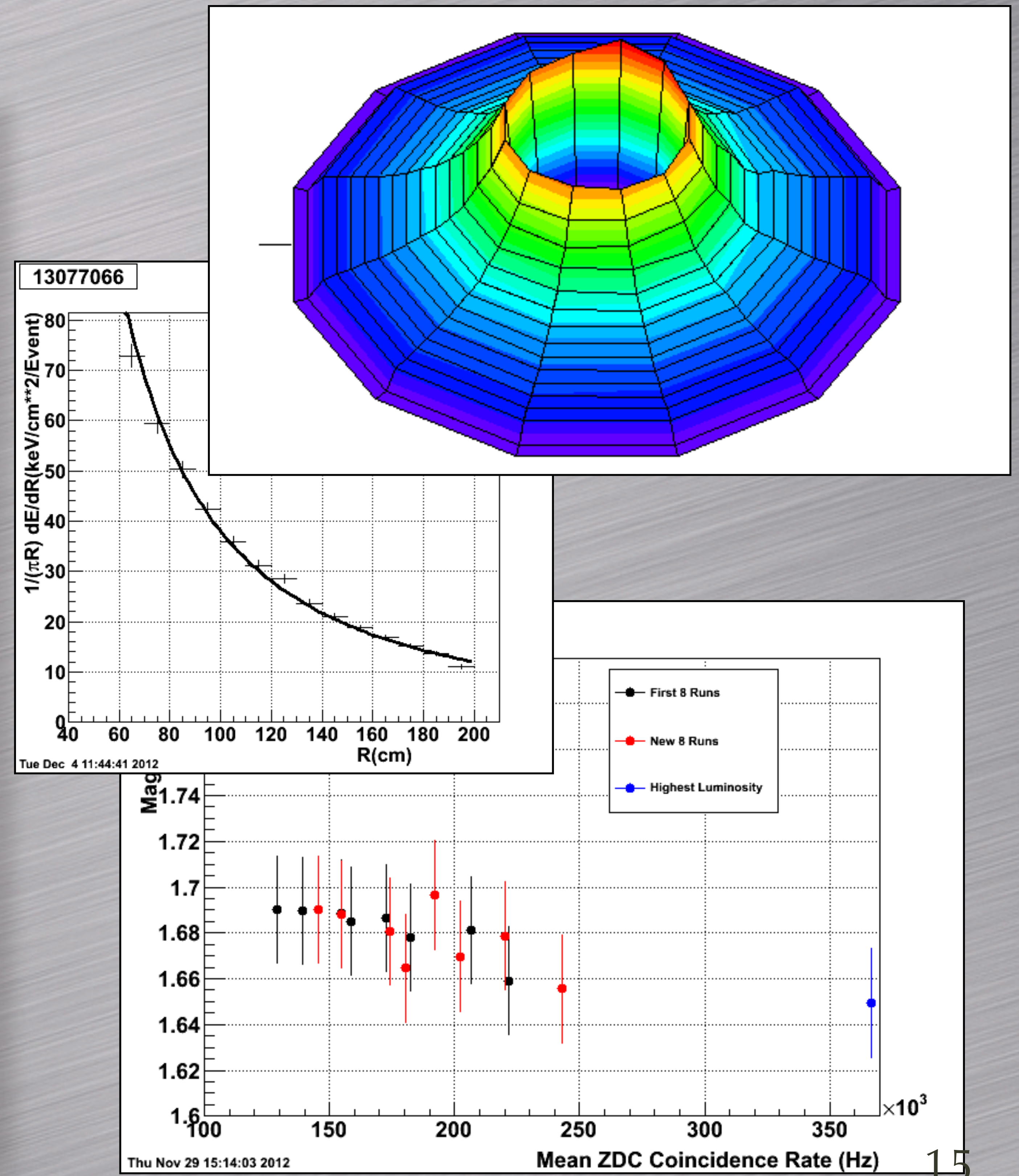
Volume Gas (ionization)

P10: Argon+Methane

Methane the likelier charge carrier, drift times of ~0.5 sec.

SpaceCharge: model of charge

- Use radial distribution of electrons arriving at end plane as a proxy for the distribution of primary ions
  - Zerobias, correct for dead channels, gains, distortions
- Examined a few times between 2002-2012
- Very minor luminosity dependence to shape
- Azimuthal dependencies seen in some early years, gone by 2012



Field Distortion Magnitudes

$$
\begin{aligned}
B_\Phi / B_z &\sim 10^{-6} \\
B_r / B_z &\sim 10^{-2} \\
E_\Phi / E_z &\sim 10^{-3} \\
E_r / E_z &\sim 10^{-1} \\
\delta(E_z) / E_{z0} &\sim 3 \times 10^{-2} \\
\delta(B_z) / B_{z0} &\sim 3 \times 10^{-3}
\end{aligned}
$$

Distortion equations

(see Blum & Rolandi)

Solve:

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

Langevin Equation with “Friction”

substituting:

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

subject to the steady state condition $\frac{d\bar{u}}{dt} = 0$ yields

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

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

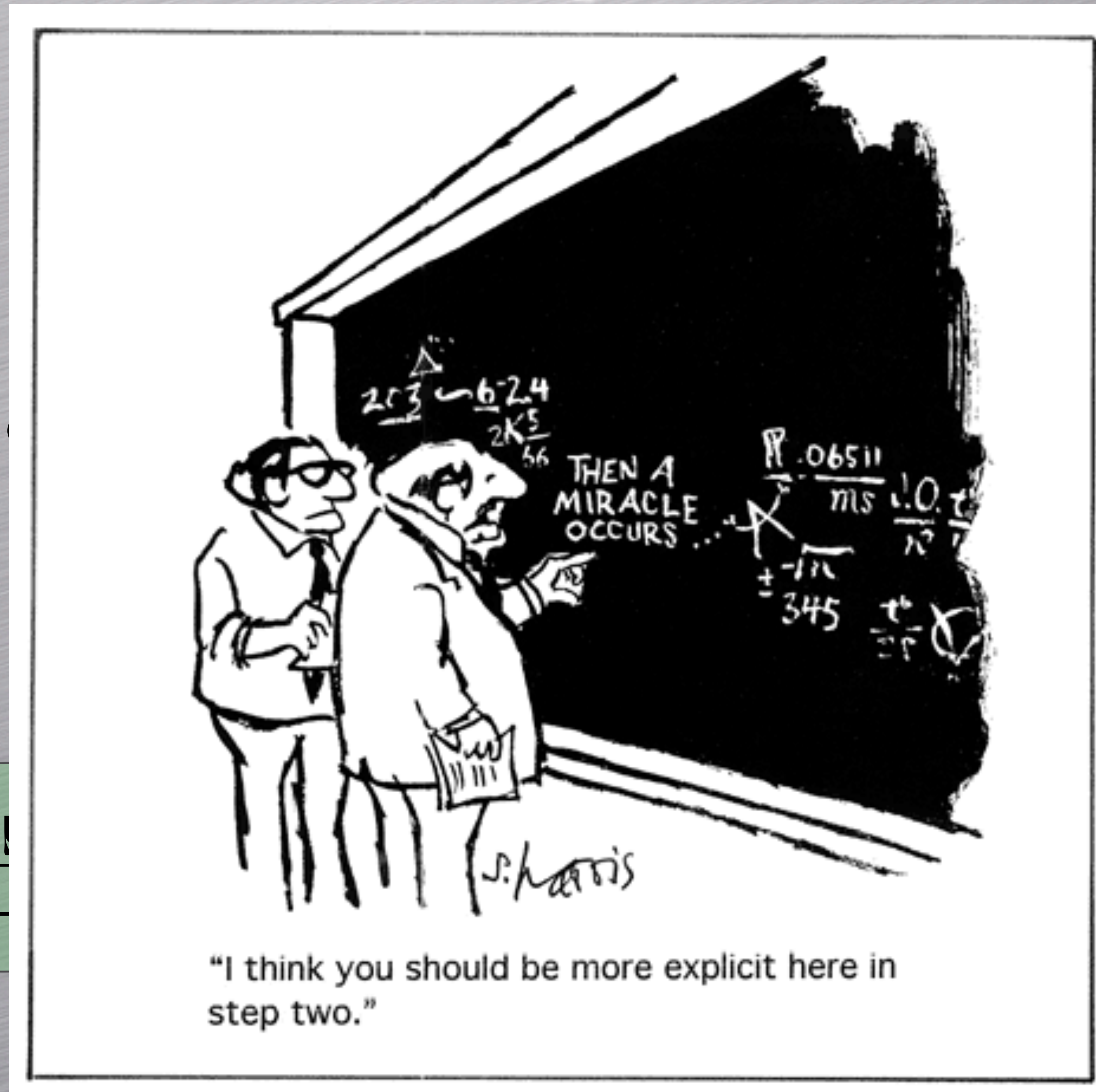
Distortion equations

Solve:

substituting: … on”

$$\tau = \frac{m}{K} , \quad \ldots \quad \frac{\bar{E}}{|\bar{E}|}$$

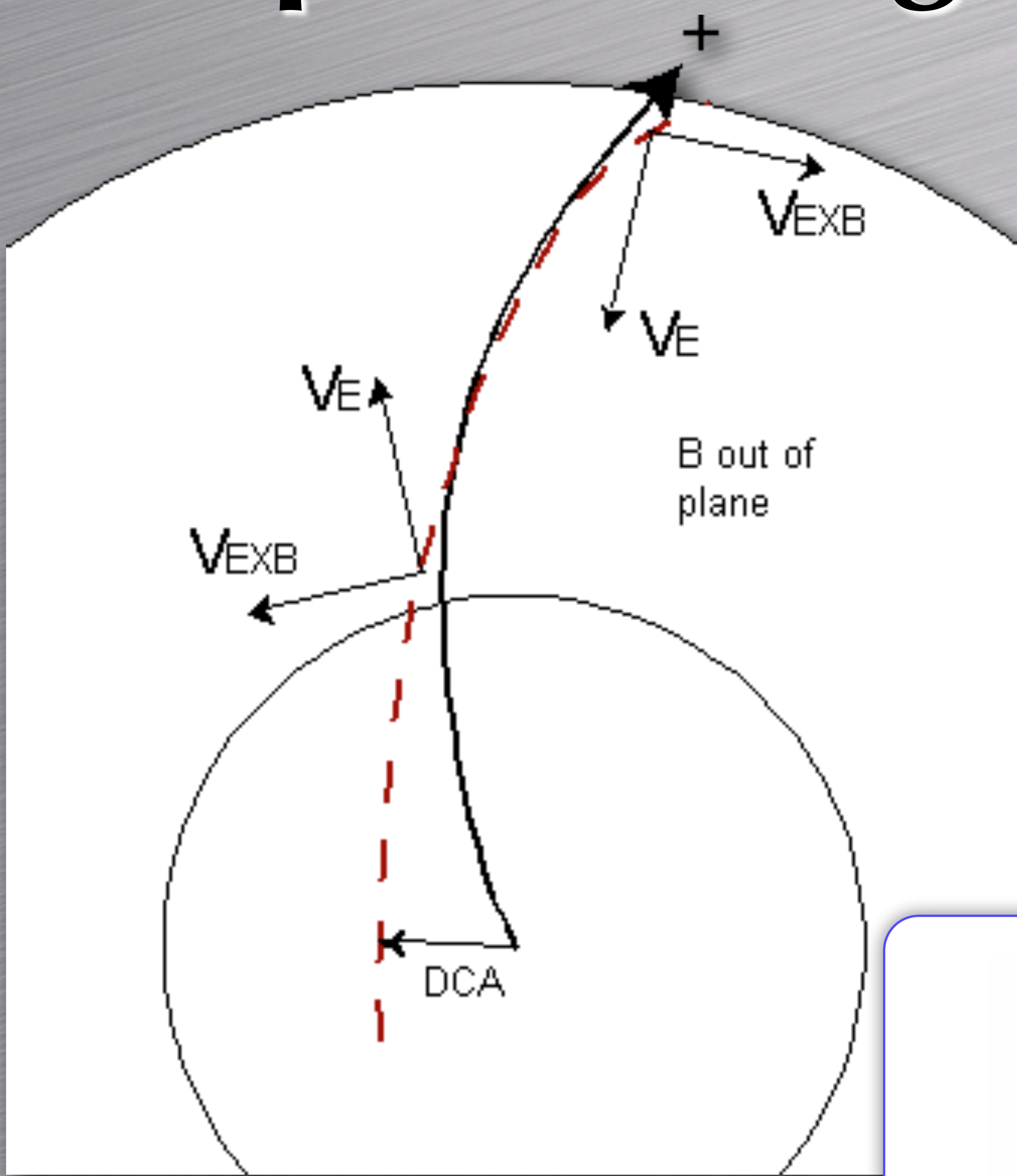
$$\bar{u} = \frac{\ldots}{(1 \ldots} \ldots \bullet \hat{B})\hat{B} \quad)$$



“I think you should be more explicit here in step two.”

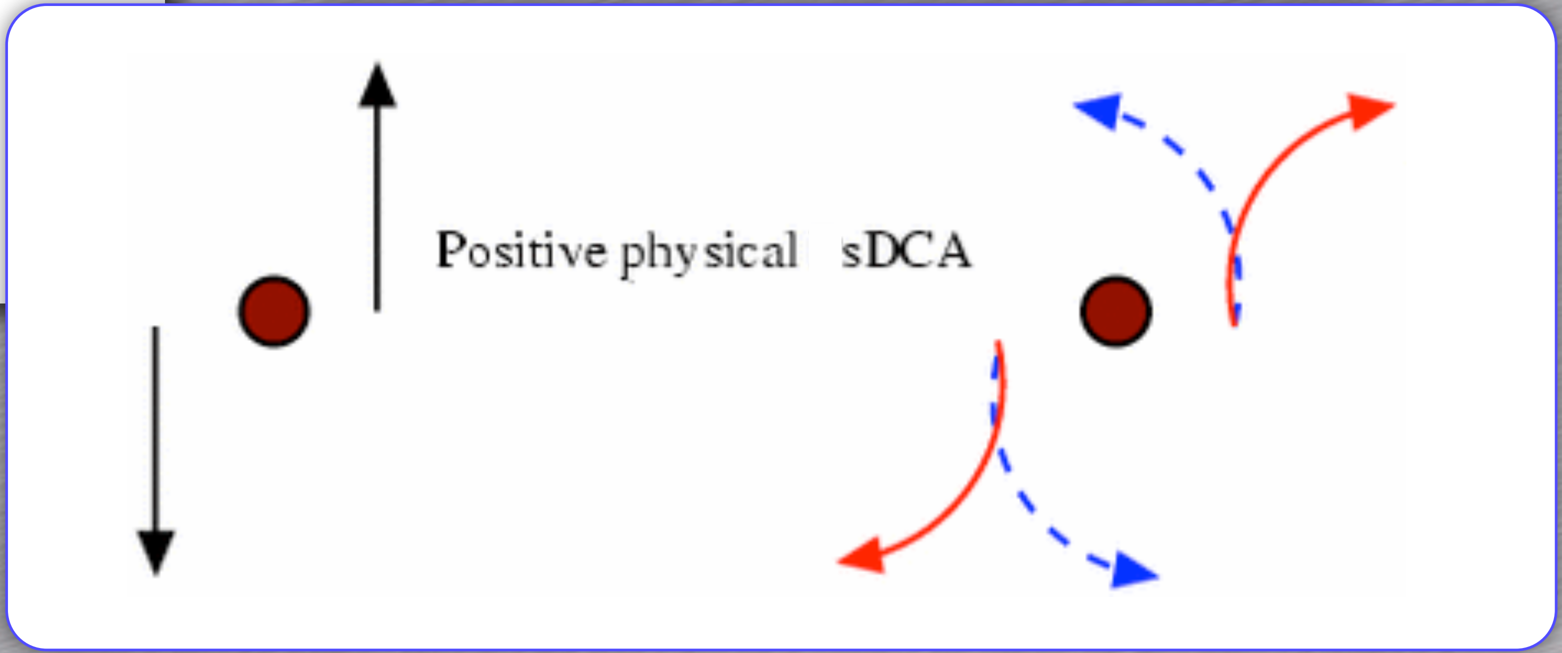
If you have a well defined model, and good data, then the distortion can be removed with great precision

SpaceCharge effect on sDCA

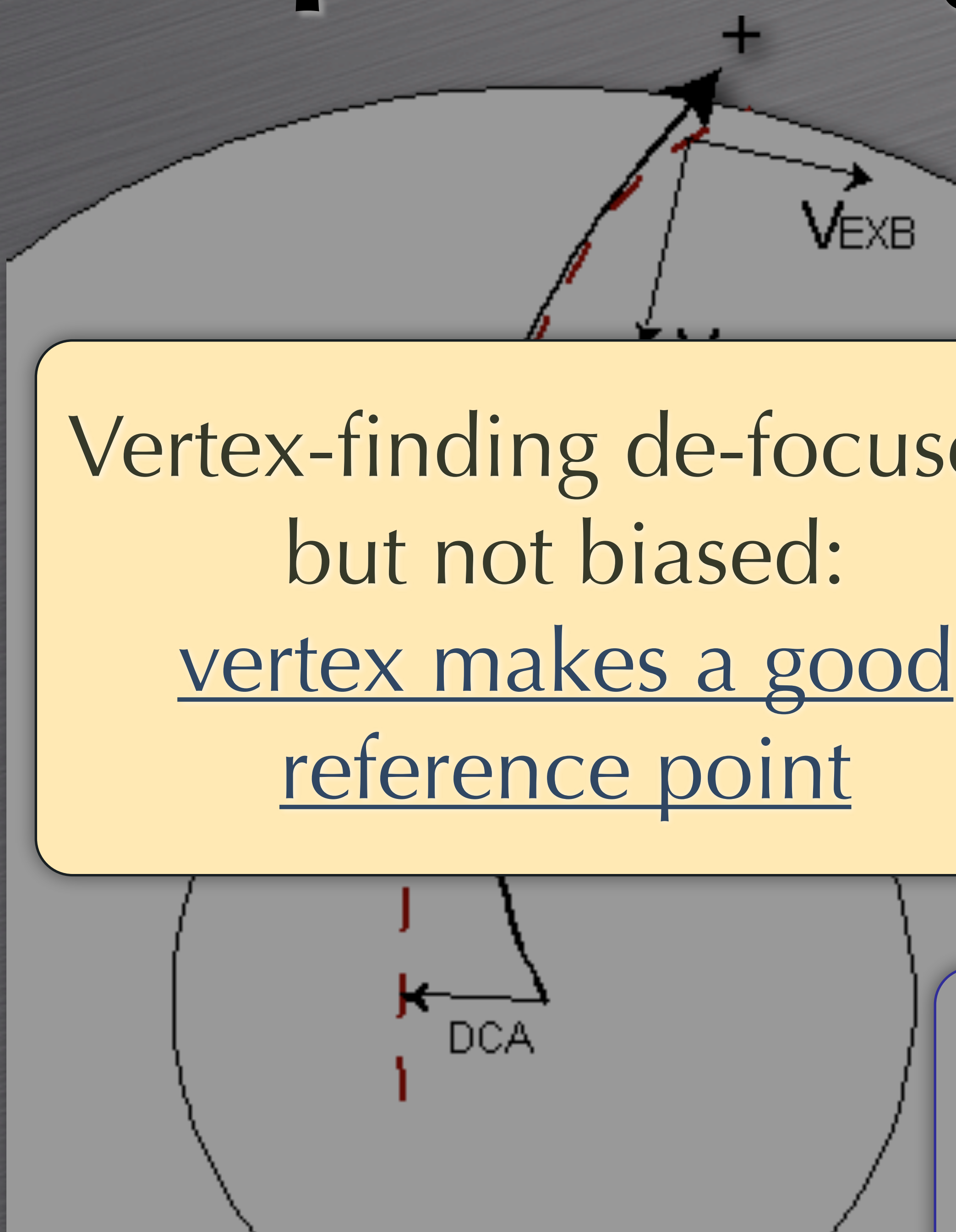


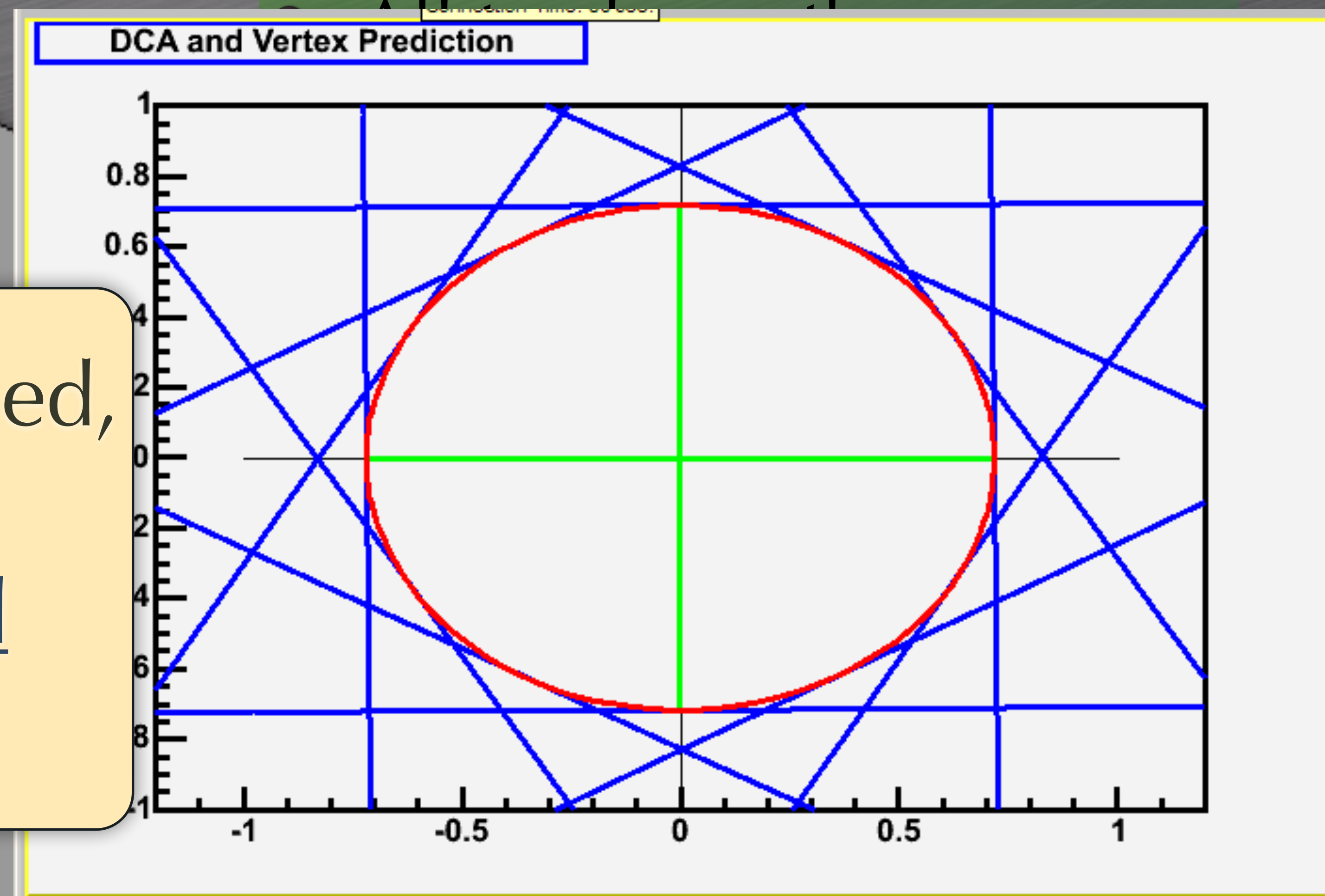
- All tracks go the same direction (pos. or neg.)
- Track charge independence
- Field dependence

sDCA = signed distance of closest approach



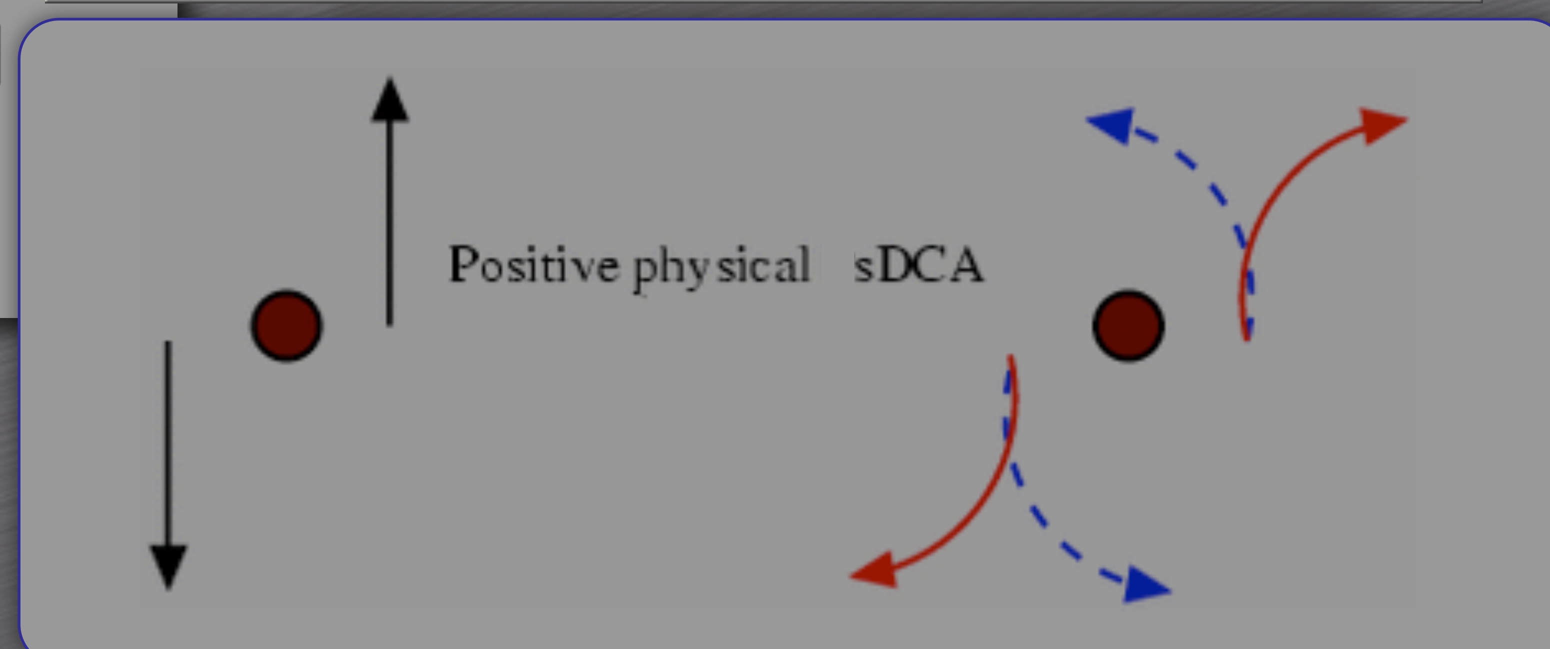
SpaceCharge effect on sDCA



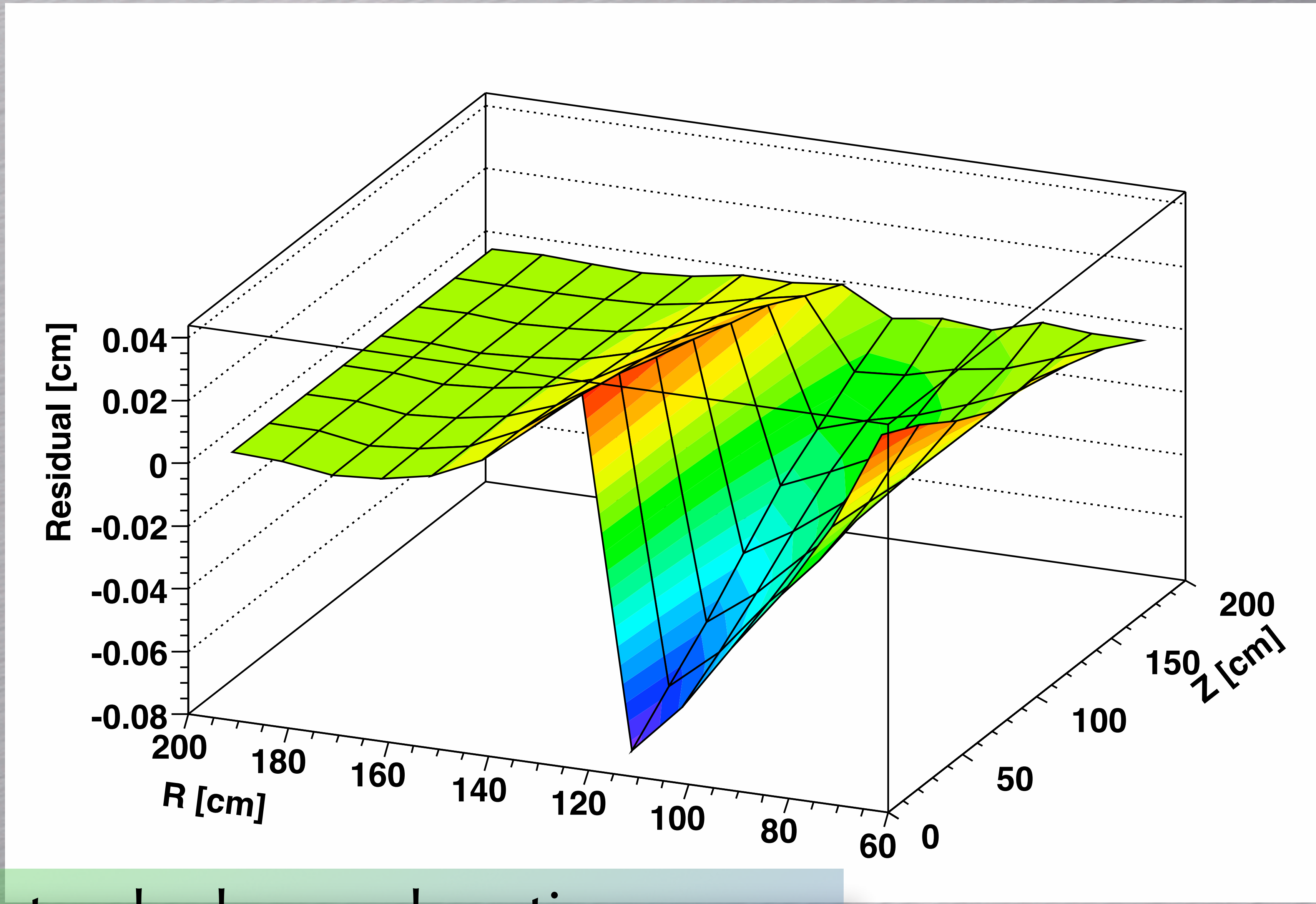


Vertex-finding de-focused, but not biased: vertex makes a good reference point

sDCA = signed distance of closest approach

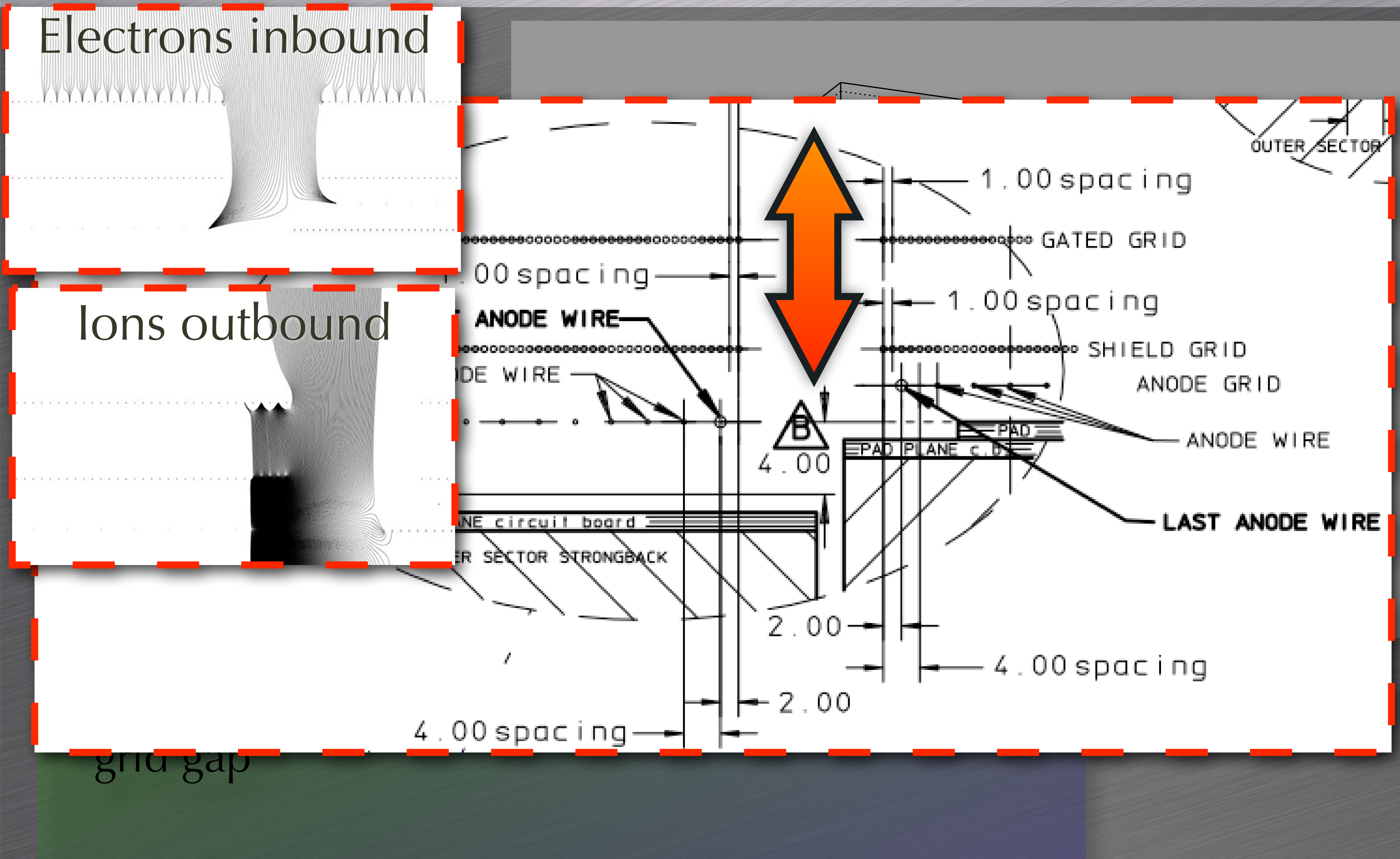


TPC GridLeak distortion



- Dependence on field, track charge, location, luminosity consistent with ion leakage at gating grid gap

TPC GridLeak distortion



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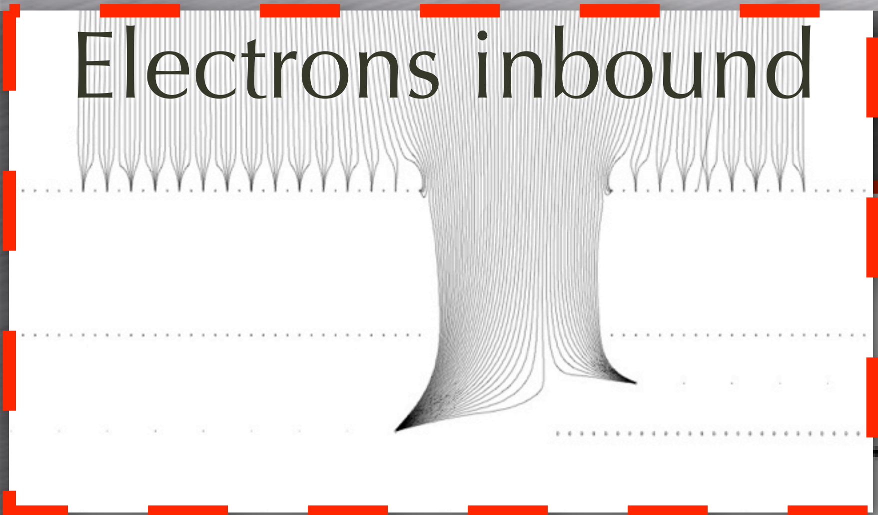
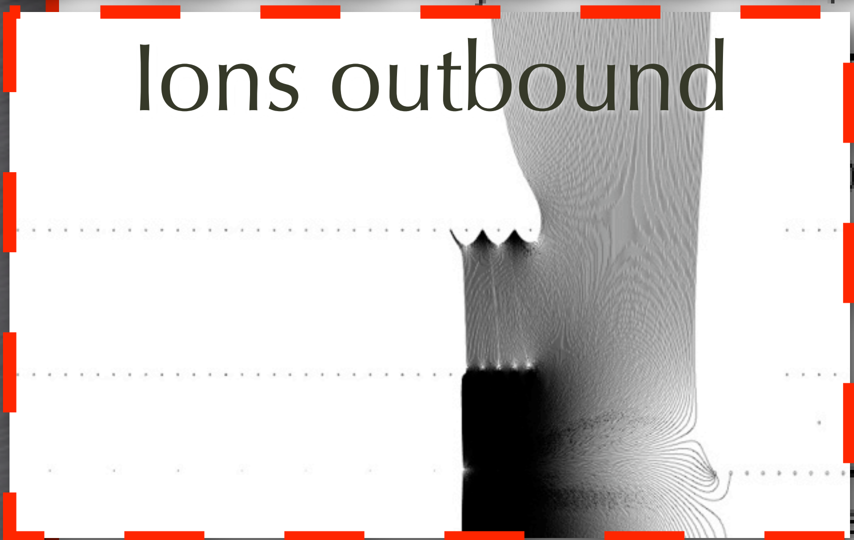
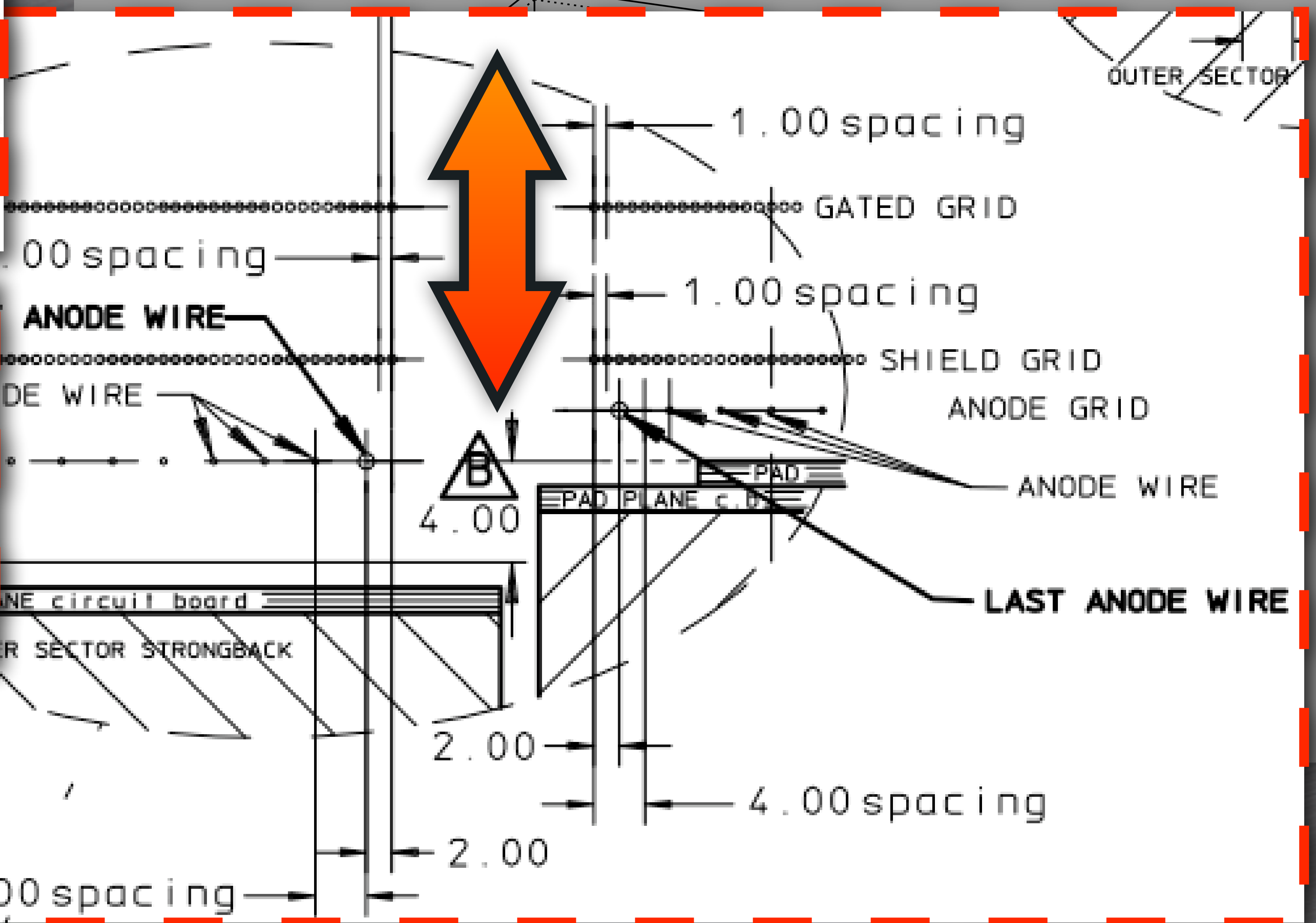




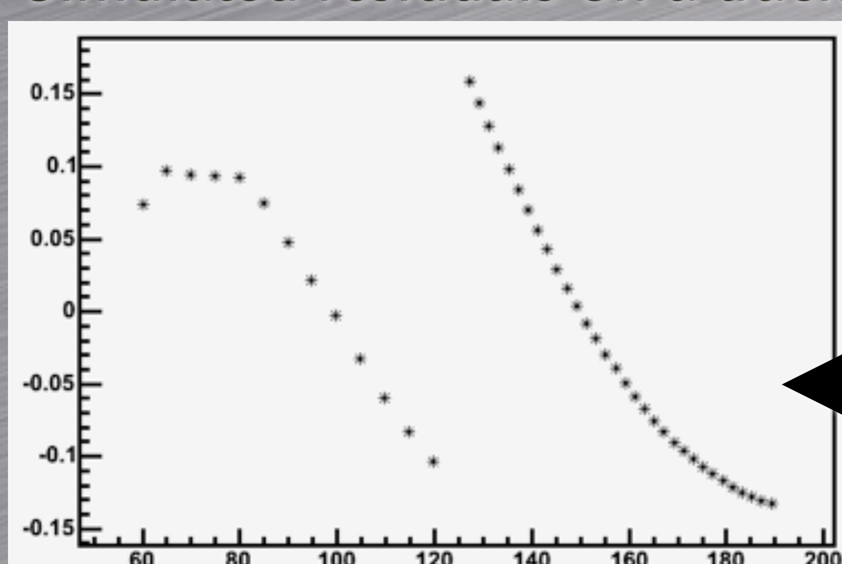


grid gap

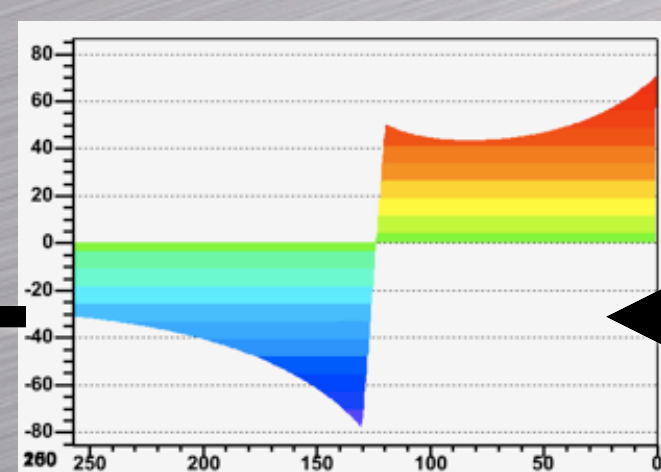
GridLeak Field Effects

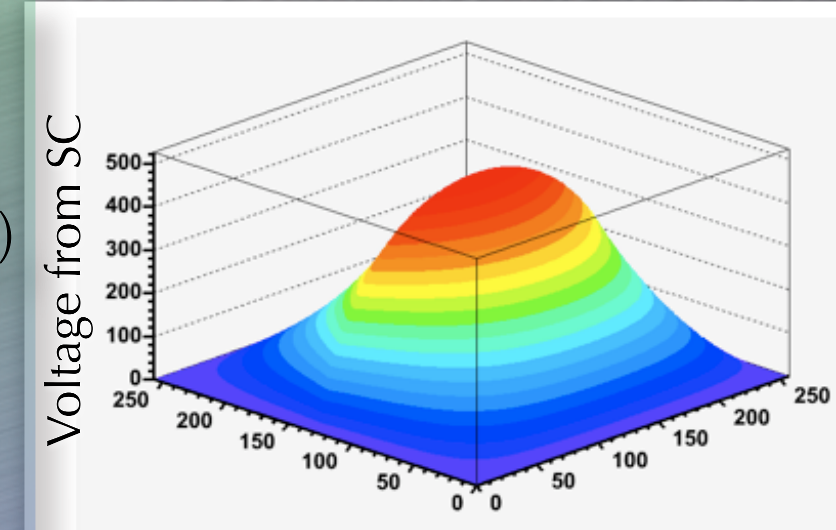
- Modeled sheets of charge
  - Relaxation done on custom 3D grid (plots assume Φ symmetry, but leak is 12-fold symmetry from grid shape)
  - E-field and distortion discontinuity at grid gap
- *GridLeak scales as SpaceCharge!*

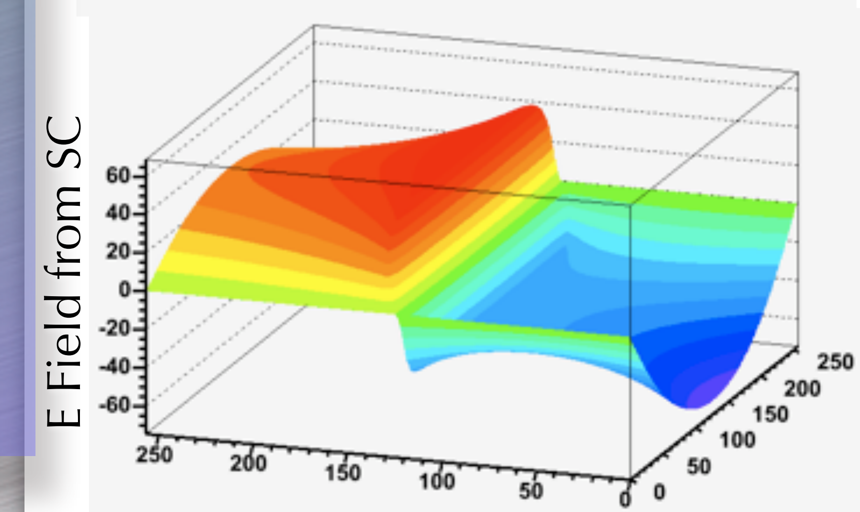
Simulated residuals on a track

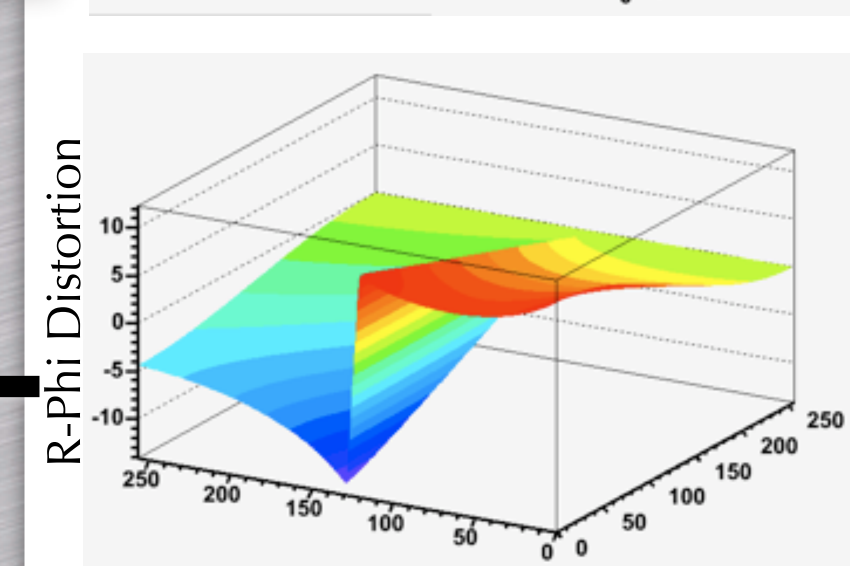


Distortion near CM





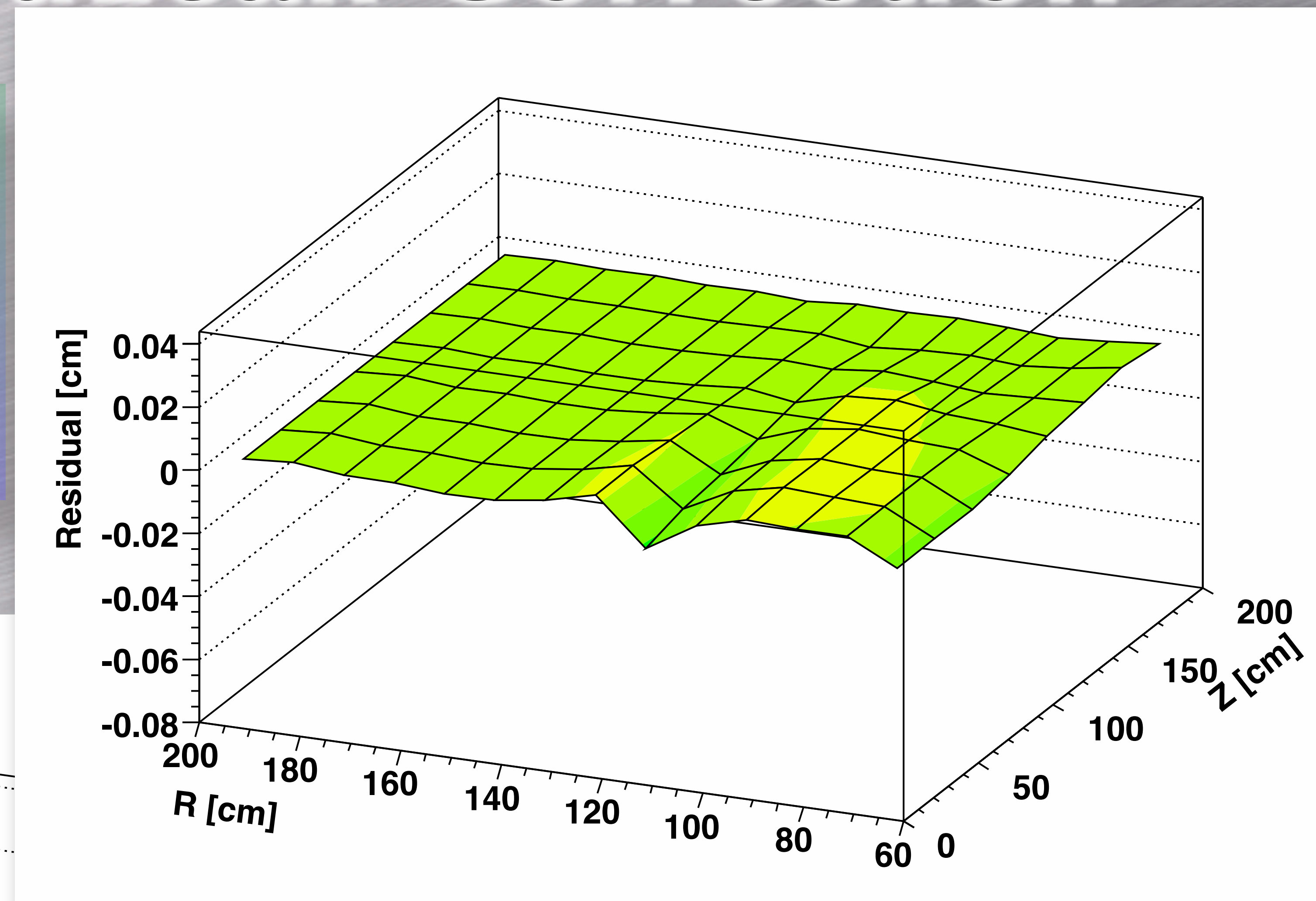


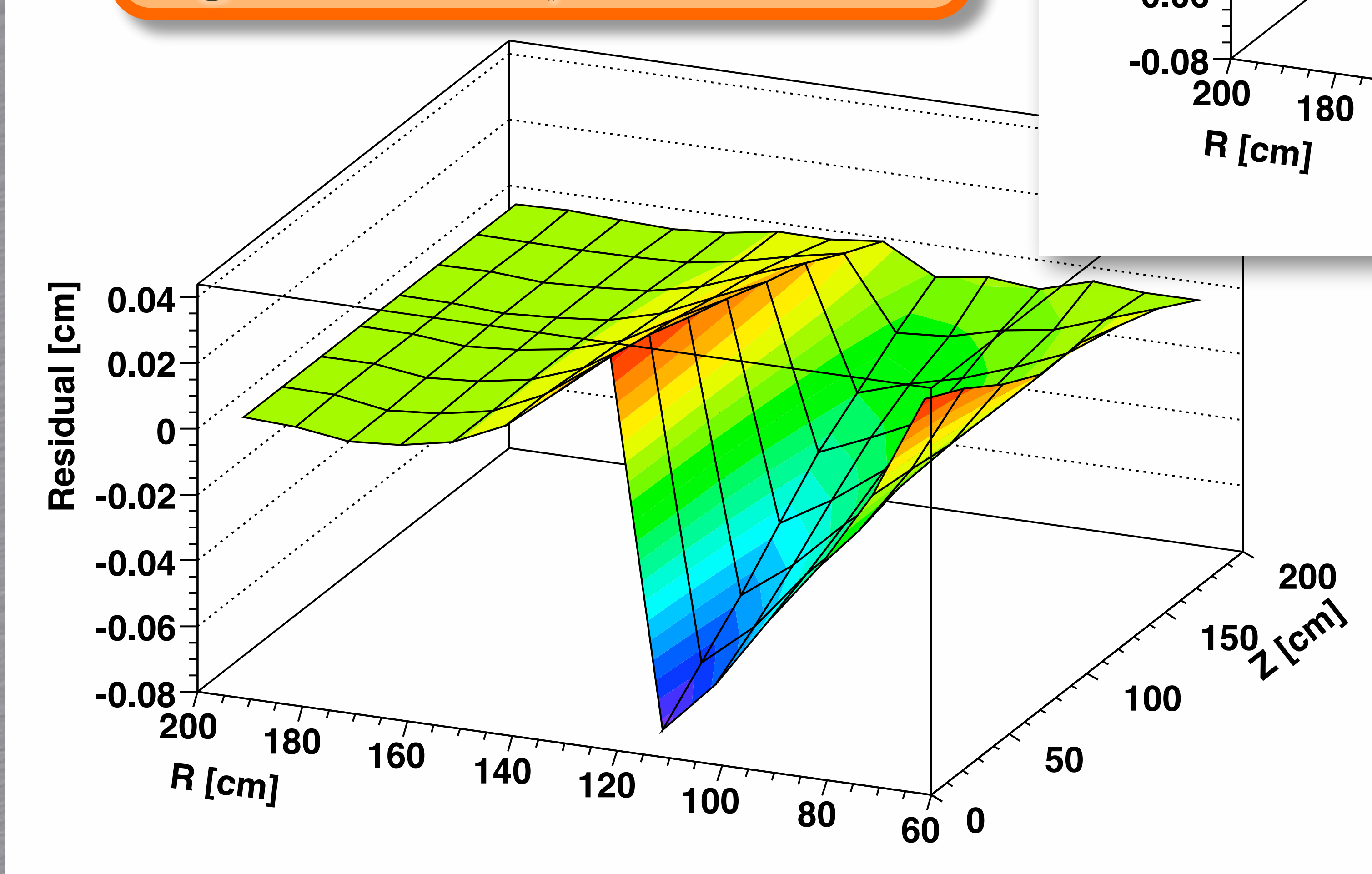


Applied GridLeak Correction

- Not perfect, but as good as design spec!

Distortions scale significantly reduced!





Before

After

First steps to corrections

- Observables (sDCA) can tell you the distortion quantity (ions in the TPC due to SpaceCharge buildup + GridLeakage)
- Easy with “ideal” tracks
  - Little or no dependencies on reconstruction itself
  - Observable maps easily to distortion quantity
    - sDCA = C * f(Z) * (SpaceCharge + GridLeak)
  - Generally need many events for stats
    - Could be many <u>*runs*</u> for pp collisions!

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- Observables (sDCA)
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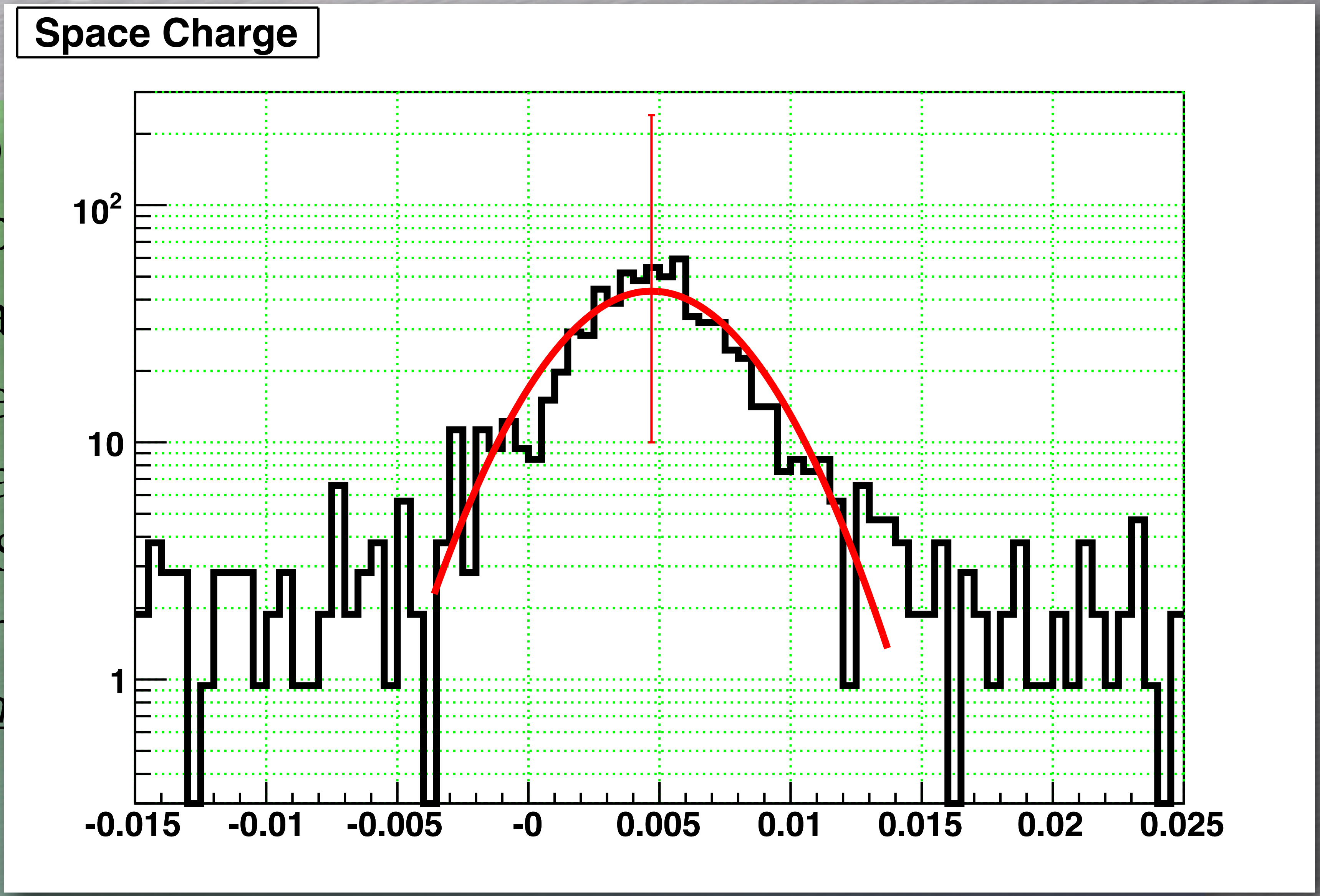
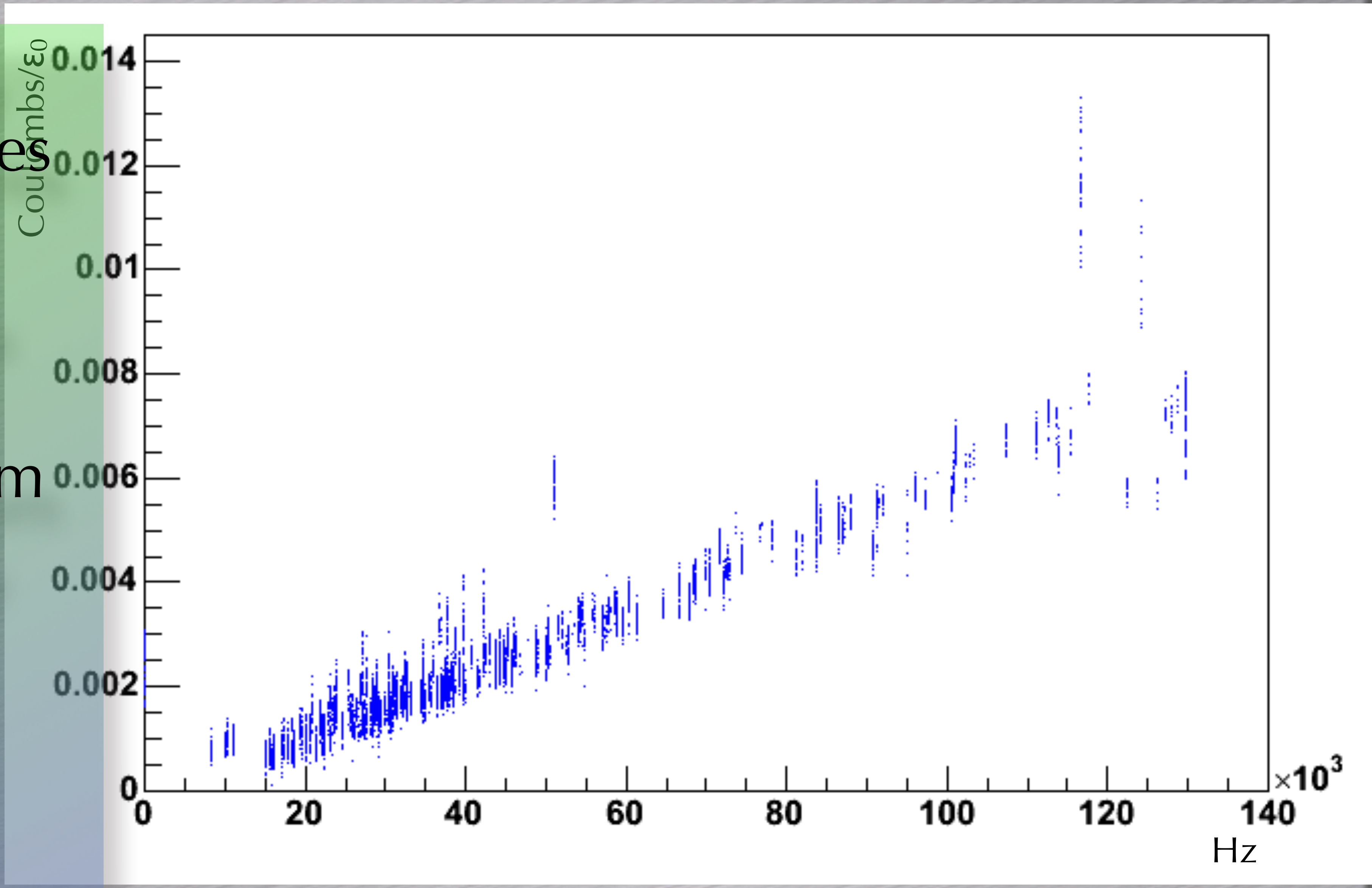


Ionization: Scalers

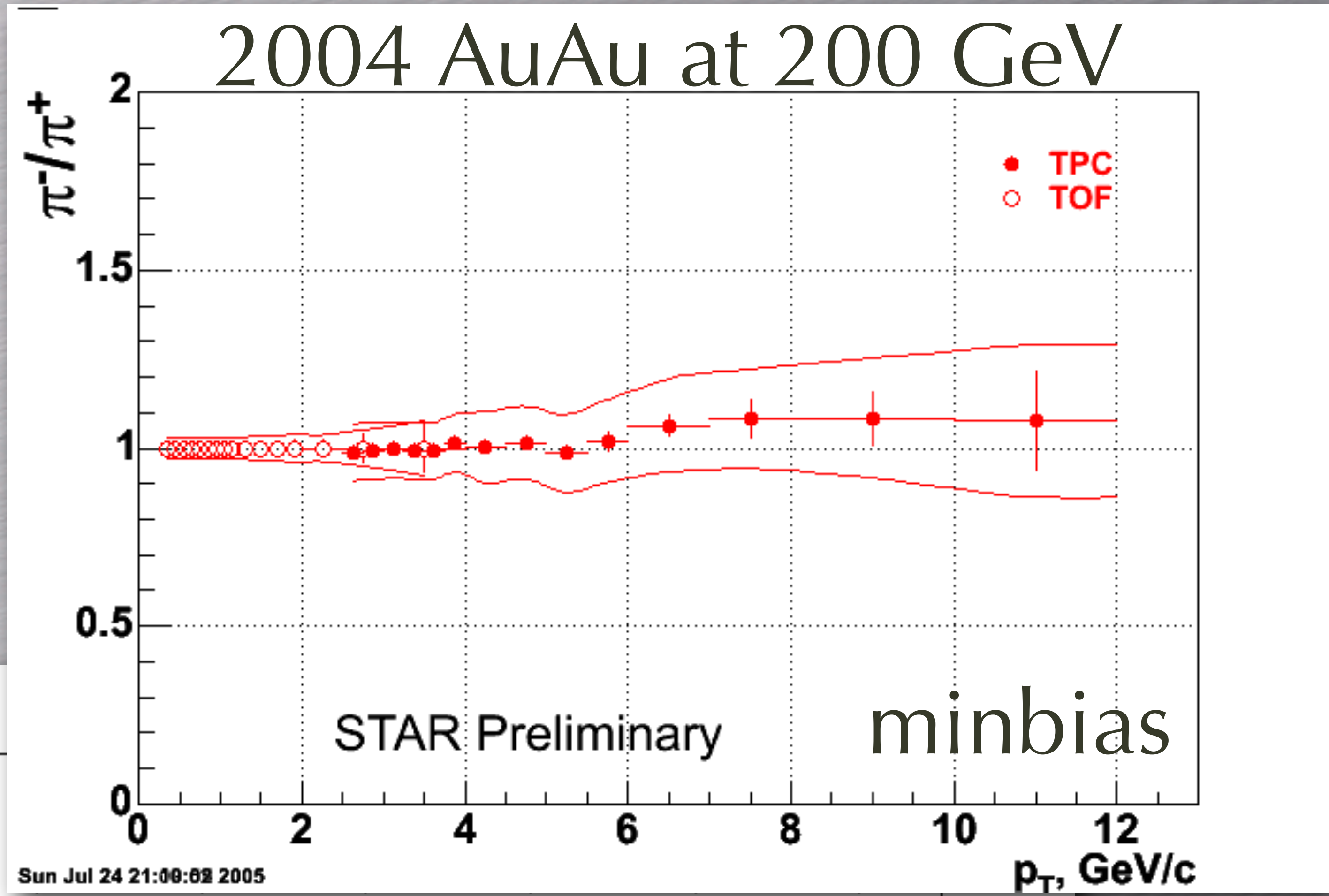
- Ionization is linear with scaler measures of luminosity
- Points out problem runs
- Some smearing from 30 second average

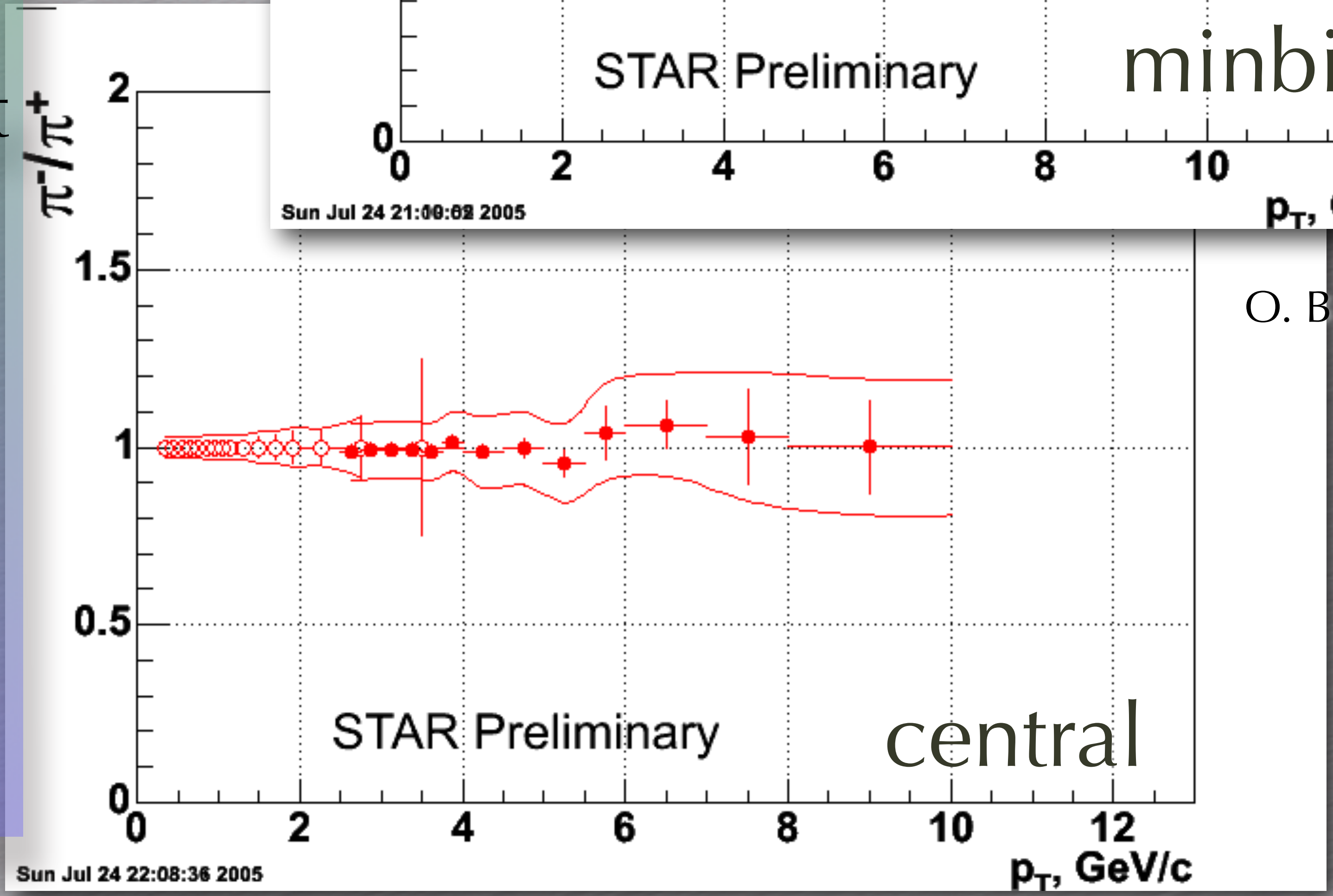


STAR records scaler rates on Zero Degree Calorimeters (ZDCs) and Beam-Beam Counters (BBCs)

Performance Measures: π^-/π^+

- TPC-measure of the ratio essentially flat all the way to p_T=12 GeV/c !
- Central triggers (taken at high luminosity) just about as good!

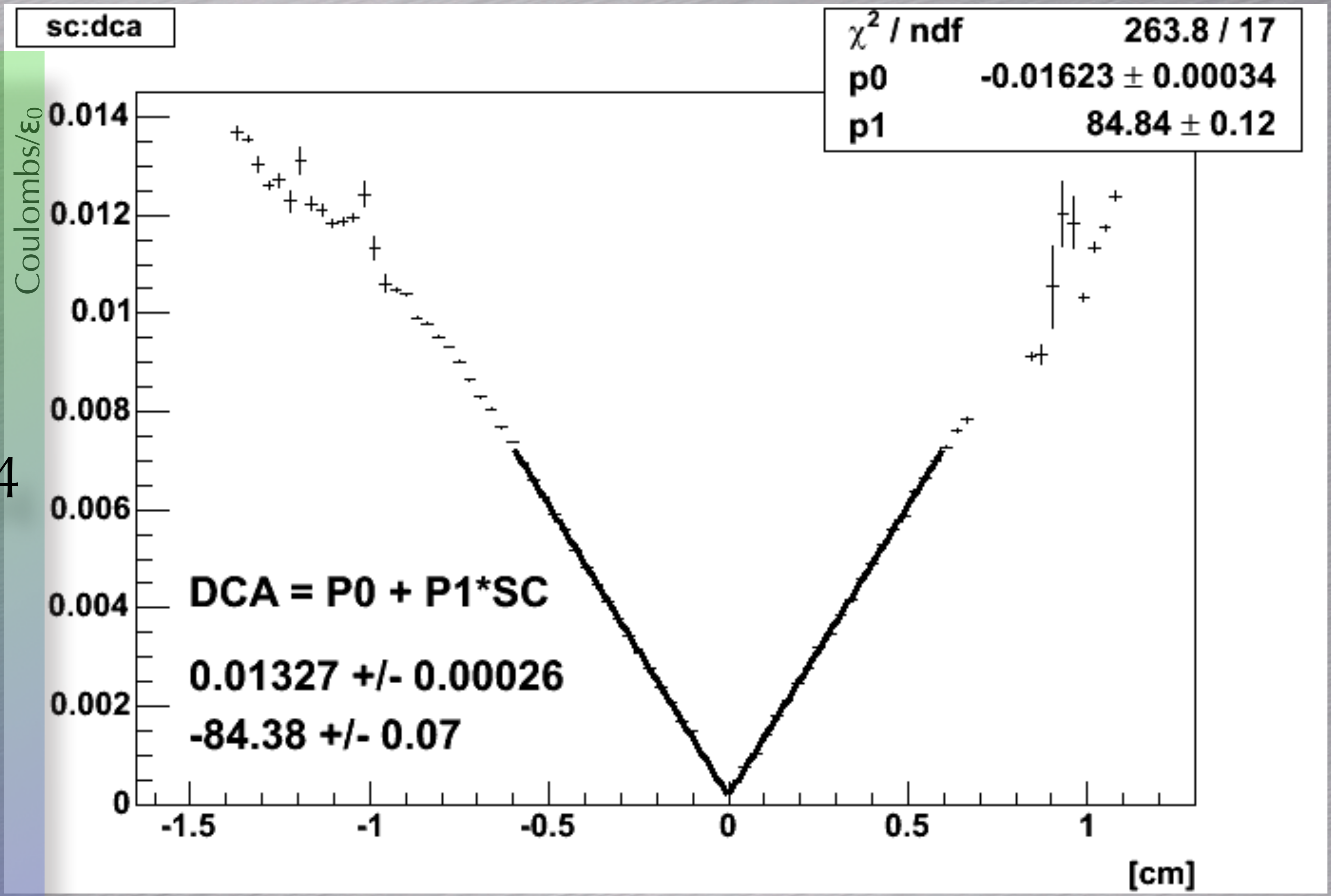




O. Barannikova

SpaceCharge : <sDCA>

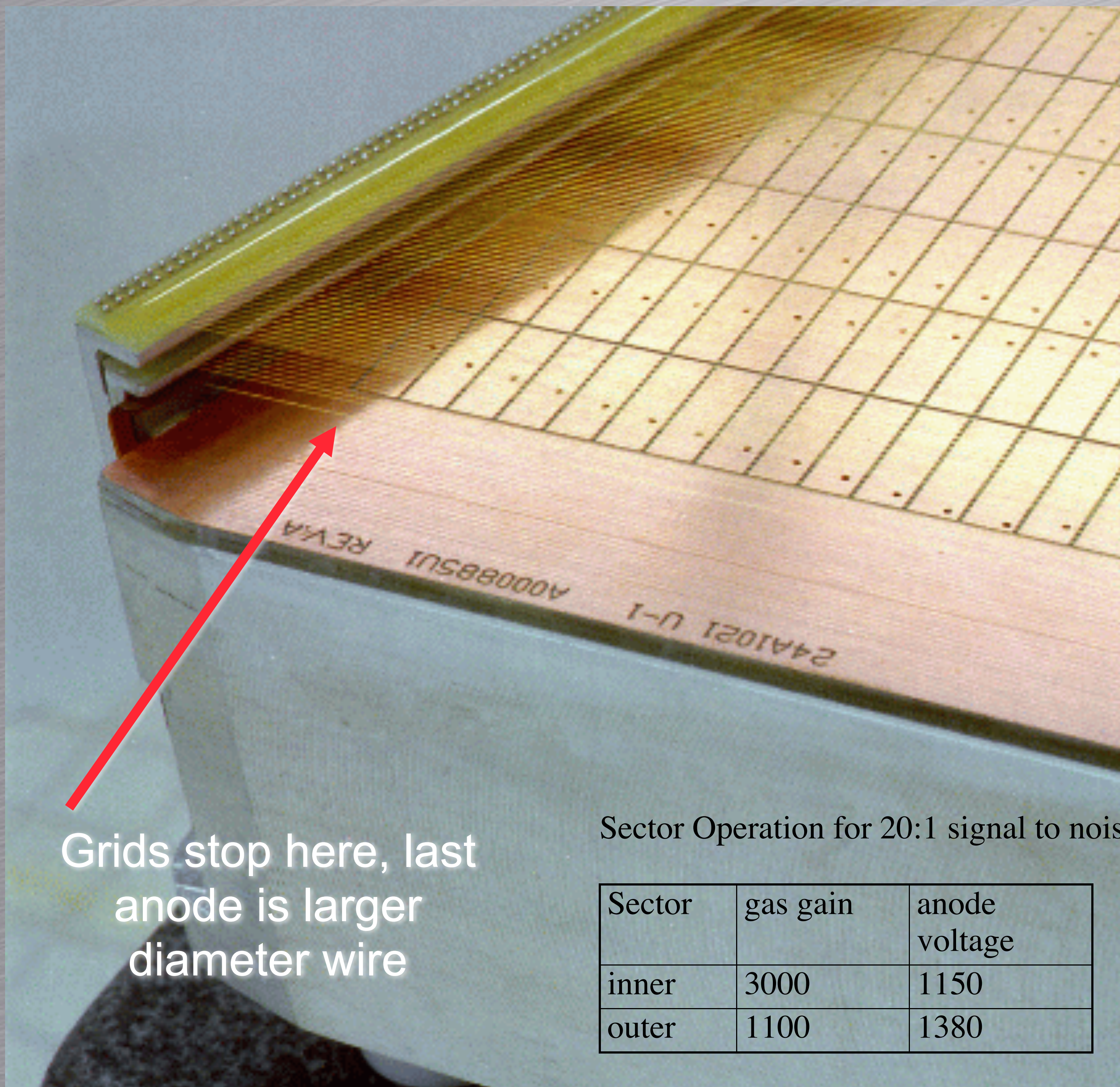
- Linear dependence
- sDCA changes sign with B field
- Saw <sDCA> of over 1cm in 2004 and 2005!



in collision rate conditions of:
2004: 200 GeV AuAu at ~10kHz
2005: 200 GeV CuCu at ~30kHz

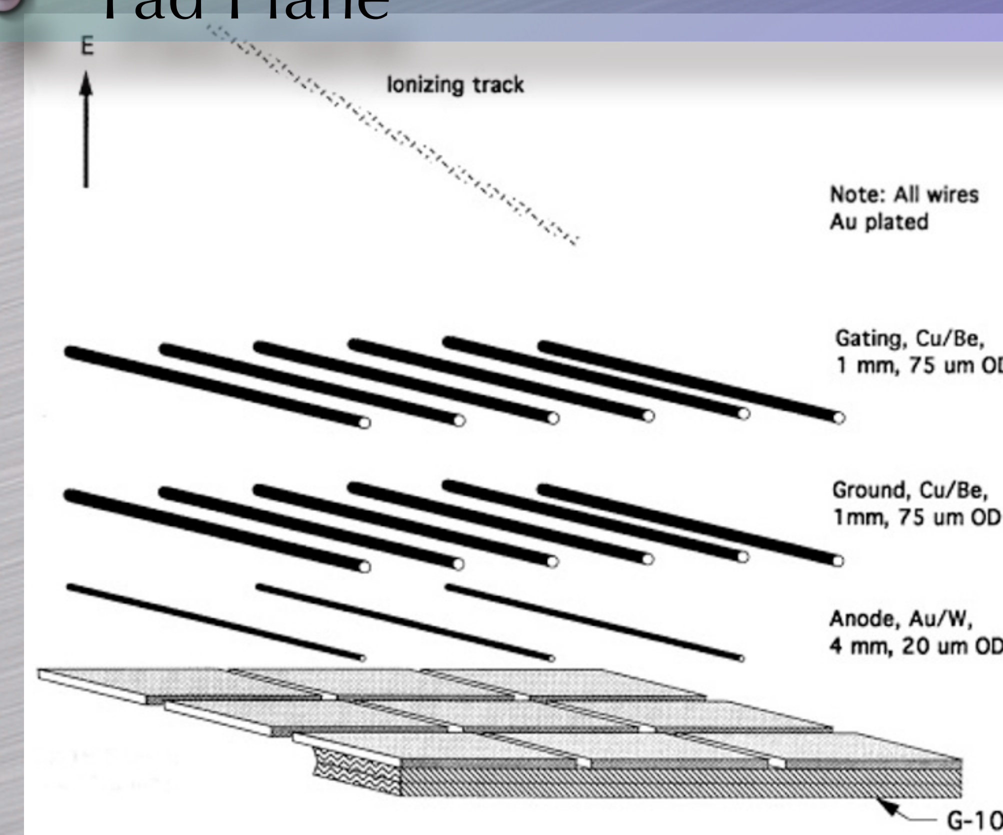
TPC Sector Detail

- Gating Grid
- Ground Plane of Wires
- Anodes
  - No field shaping wires
    - Simple and reliable
  - Individually terminated anode wires limit cross-talk
  - Low gain
- Pad Plane

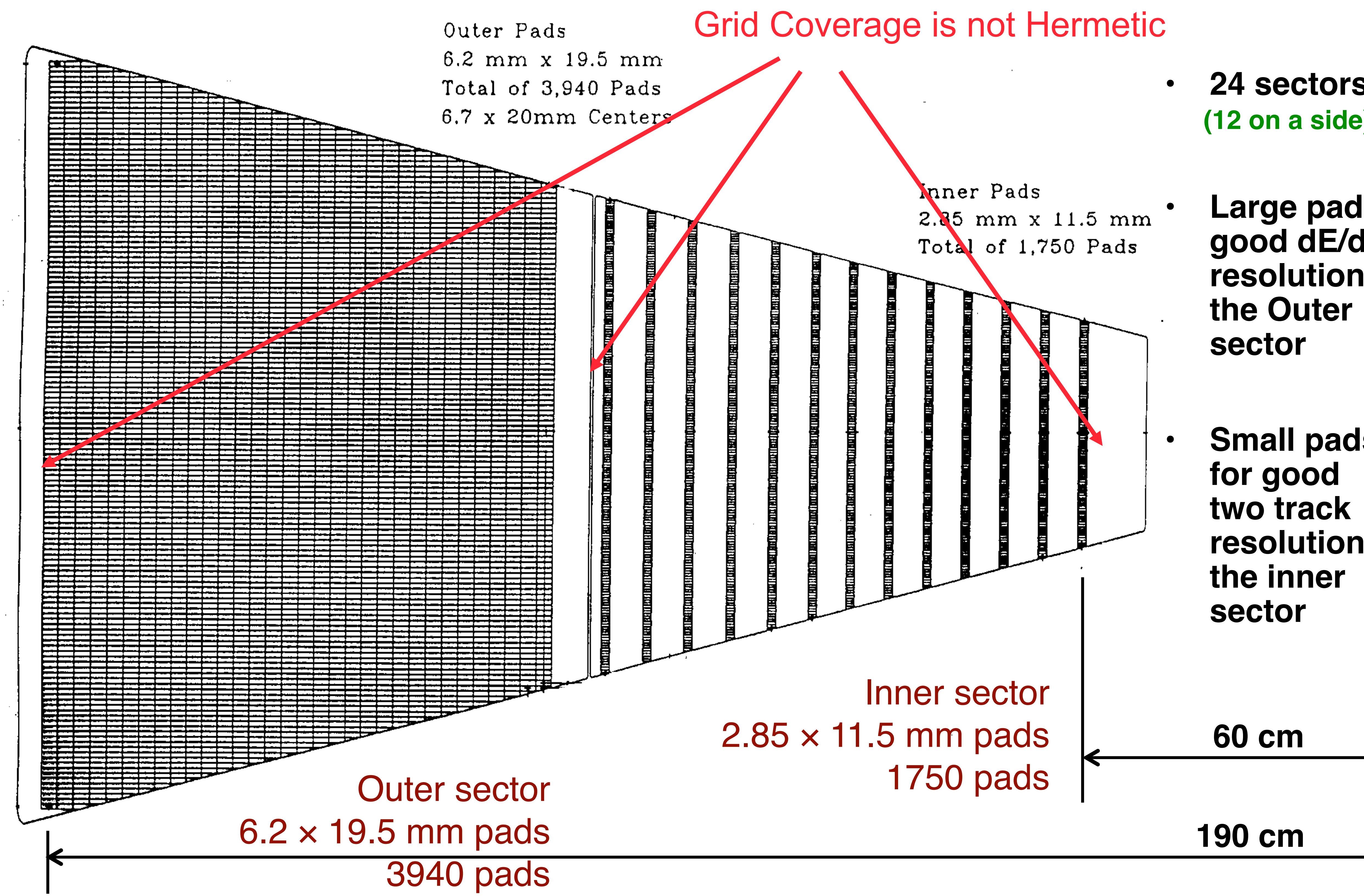


Sector Operation for 20:1 signal to noise

Sector	gas gain	anode voltage
inner	3000	1150
outer	1100	1380



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**

sDCA ⇒ SpaceCharge

- Using sDCA of high quality tracks, we can obtain a measurable SpaceCharge for individual tracks.
- Single events generally not enough stats