TPC Distortion Corrections
and their Possible Evolution in the Future

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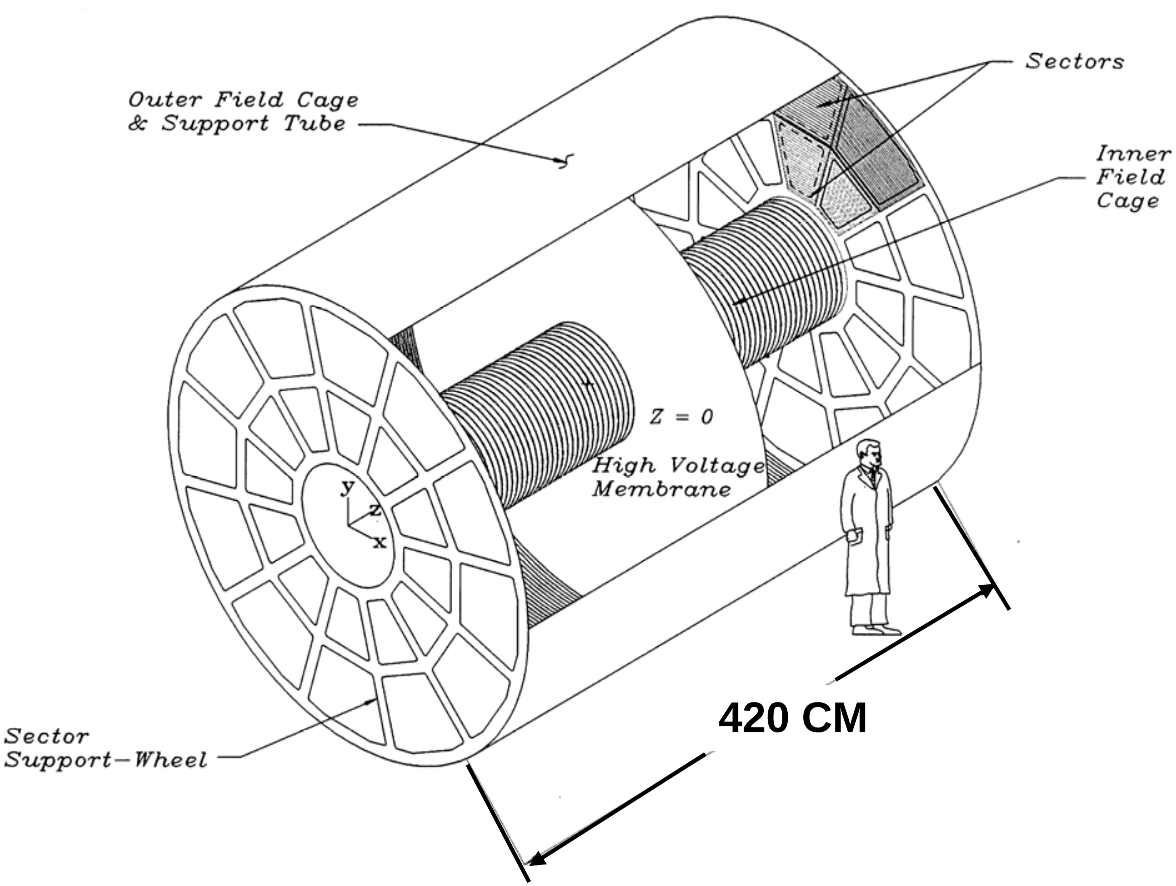
Secondary e$^-$ Drift in Parallel E and B Fields



- **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:

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

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

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

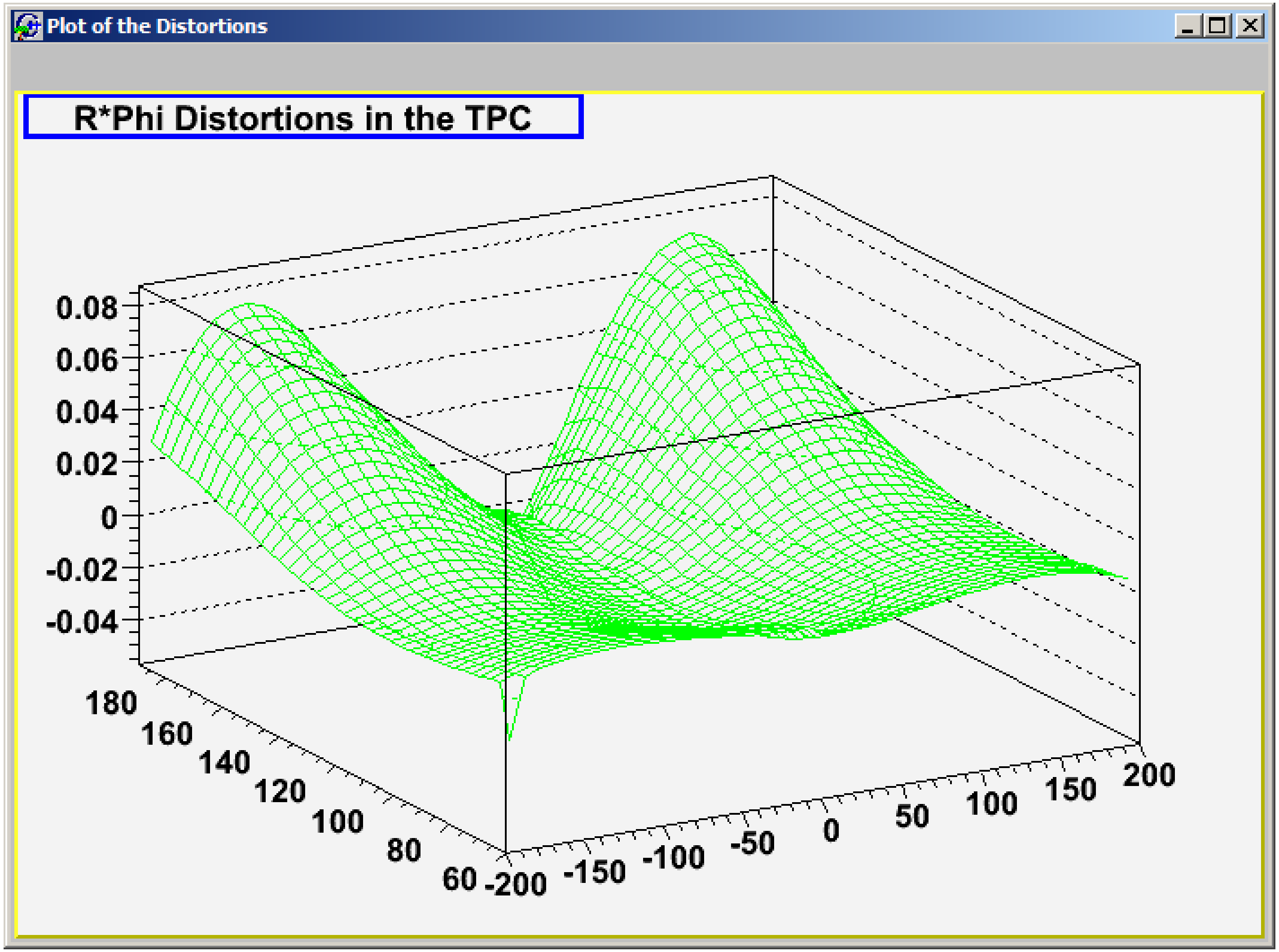
yields

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

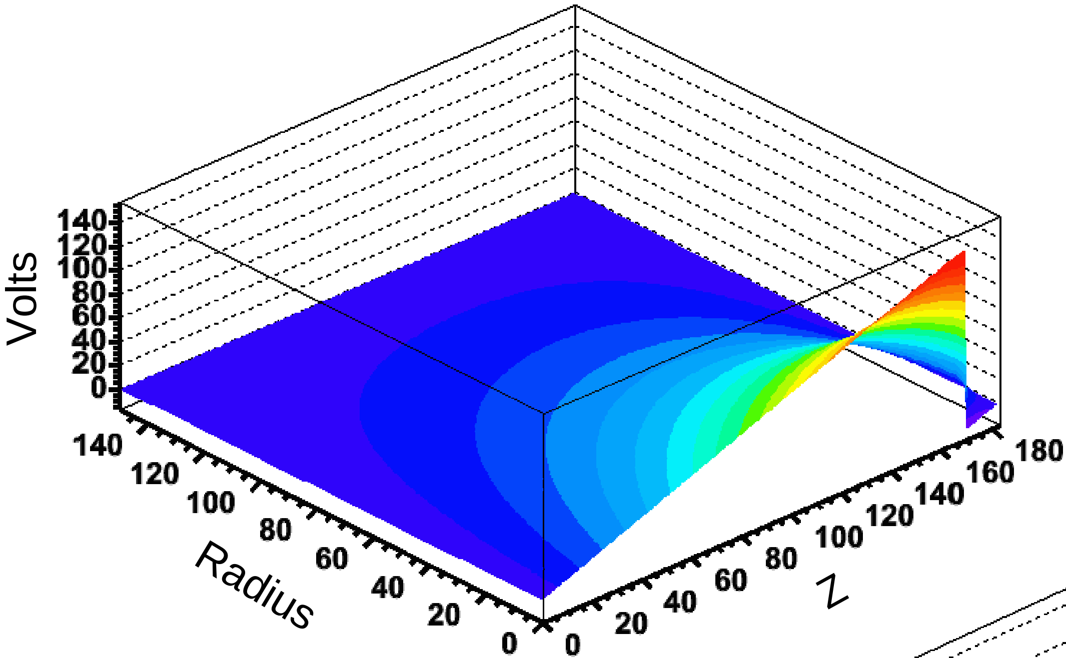
where B is a unit vector pointing in the direction of $\overline{\text{B}}$.

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

Field Shape distortions



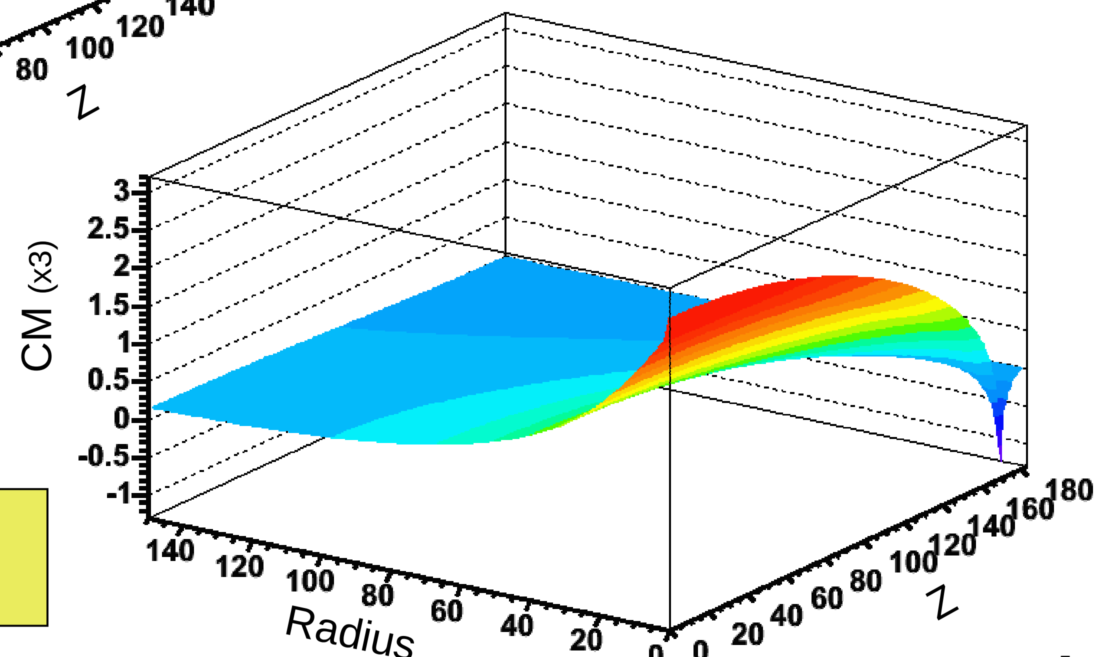
Shorted Ring – Error Potential (Volts) & Distortion (cm)



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

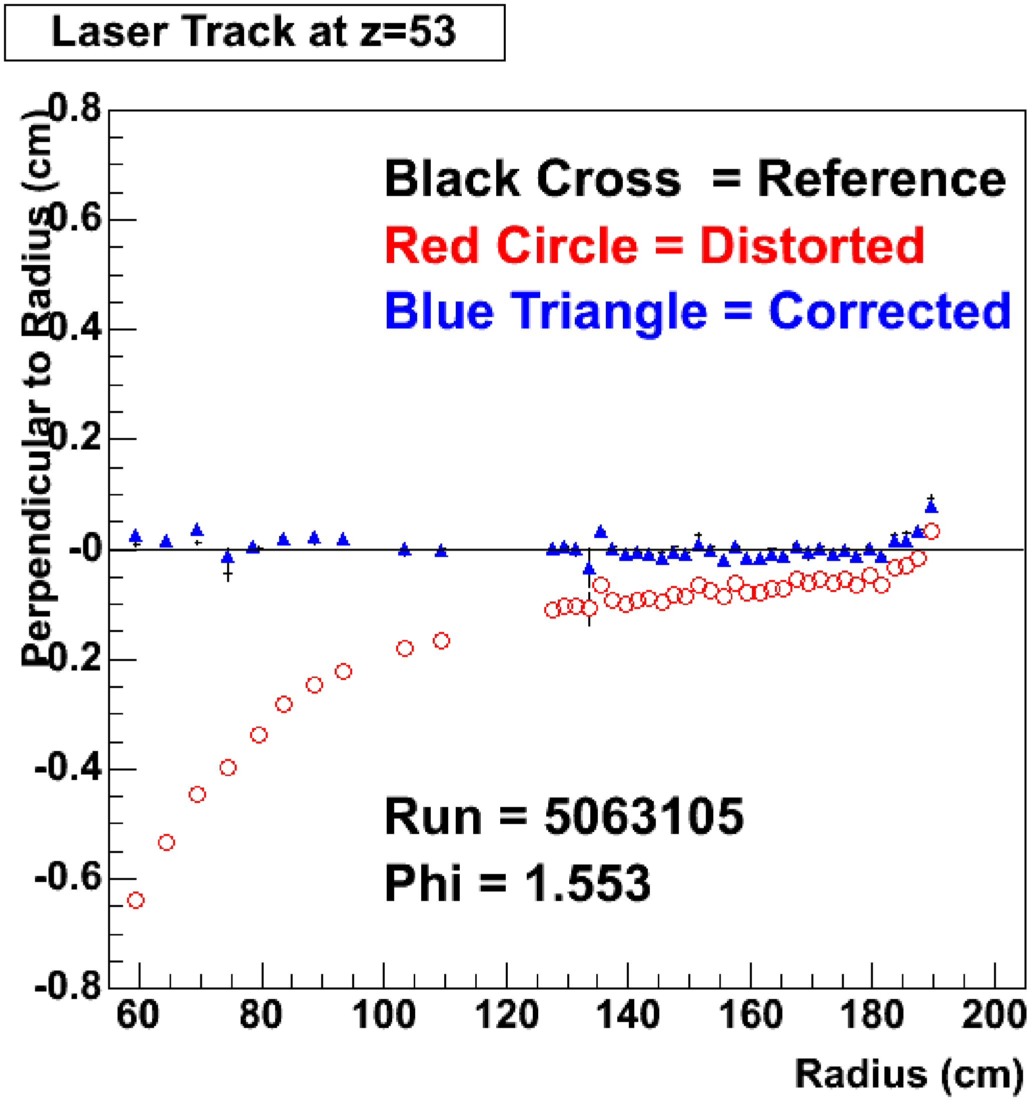
Requires full solution of Maxwell's equations

The resulting distortion in cm (x3)



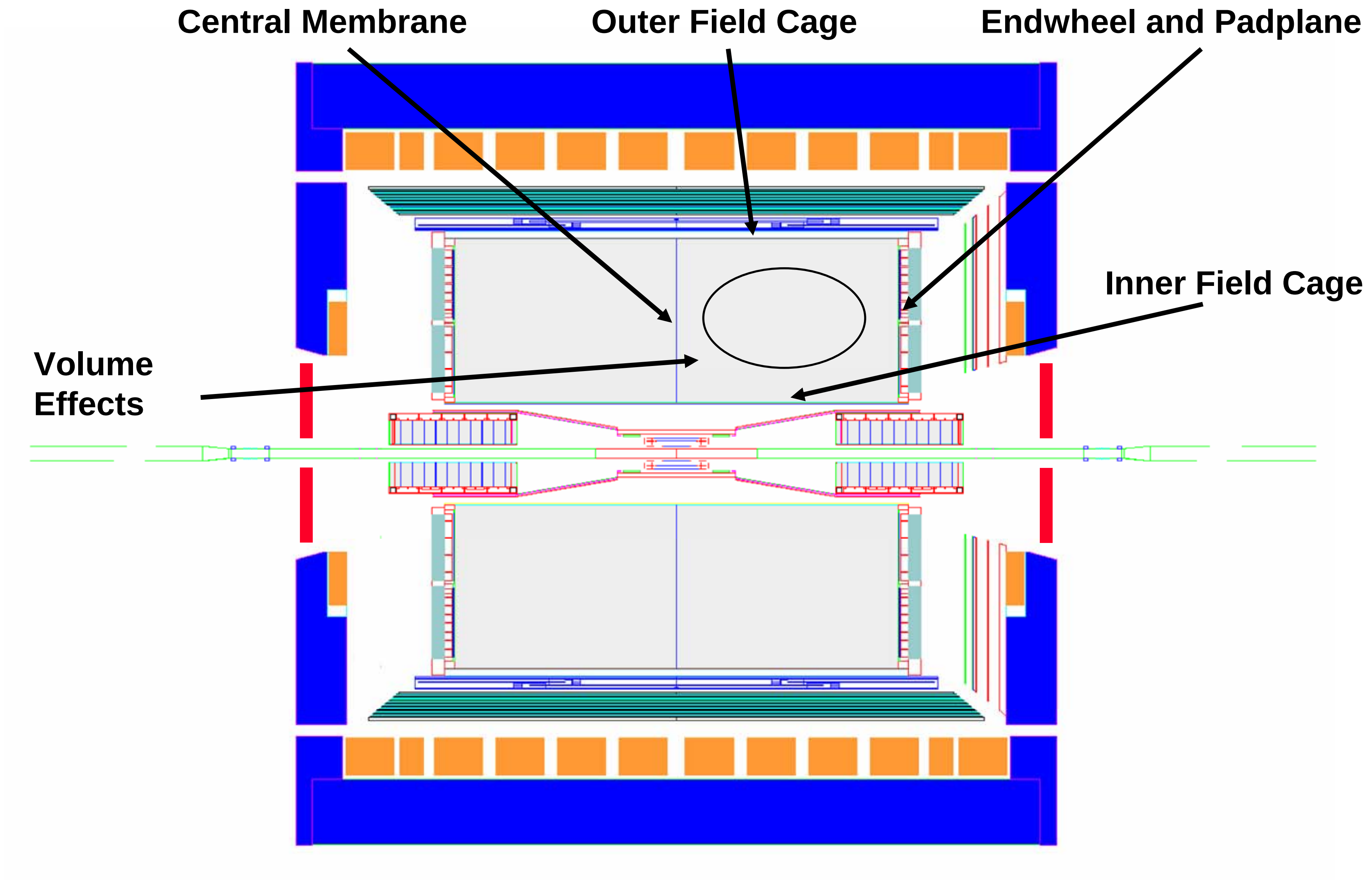
Probably the biggest distortion that we will ever see in the TPC

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

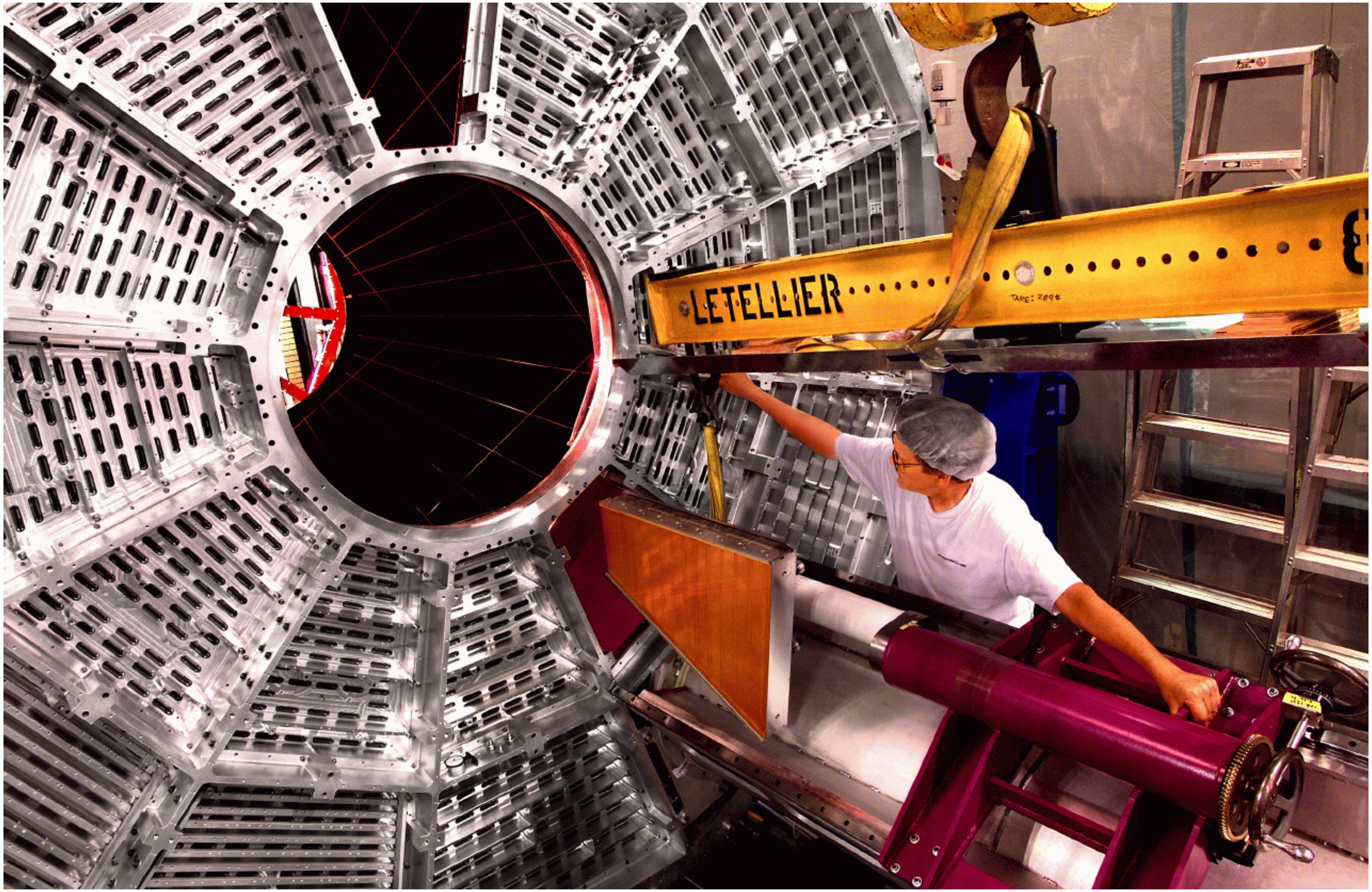
and by volume:

- ✓ 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.

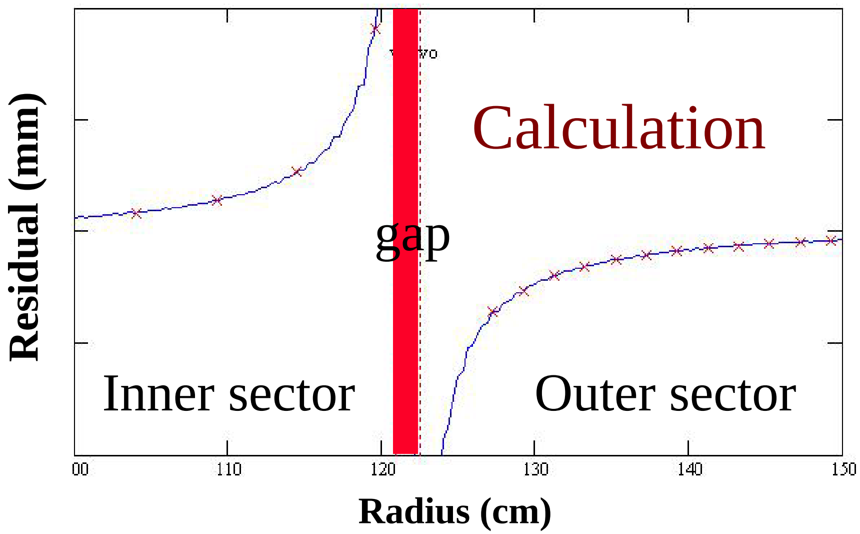
- Gas composition and variations in the drift velocity
- Barometric pressure changes and variations in the drift velocity
- Pressure variations as a function of height in the TPC
- Temperature gradients in the TPC

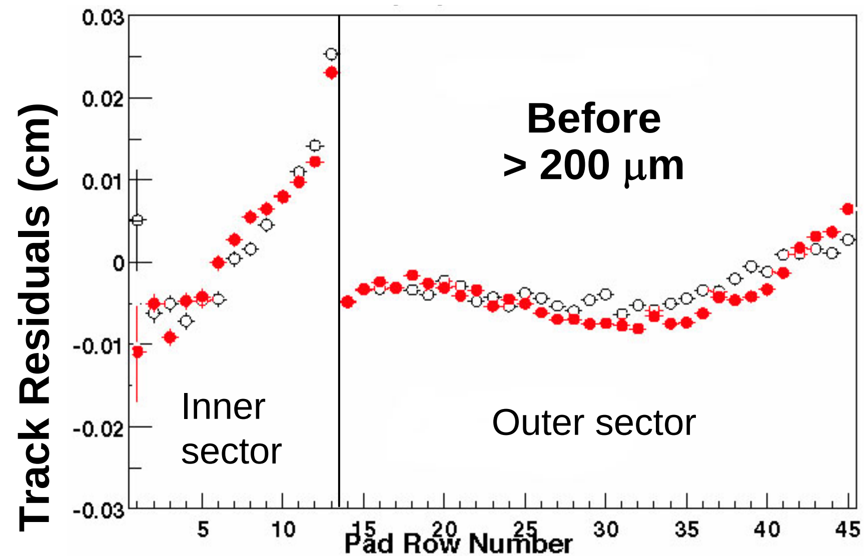
Sector Readout of Pad Planes



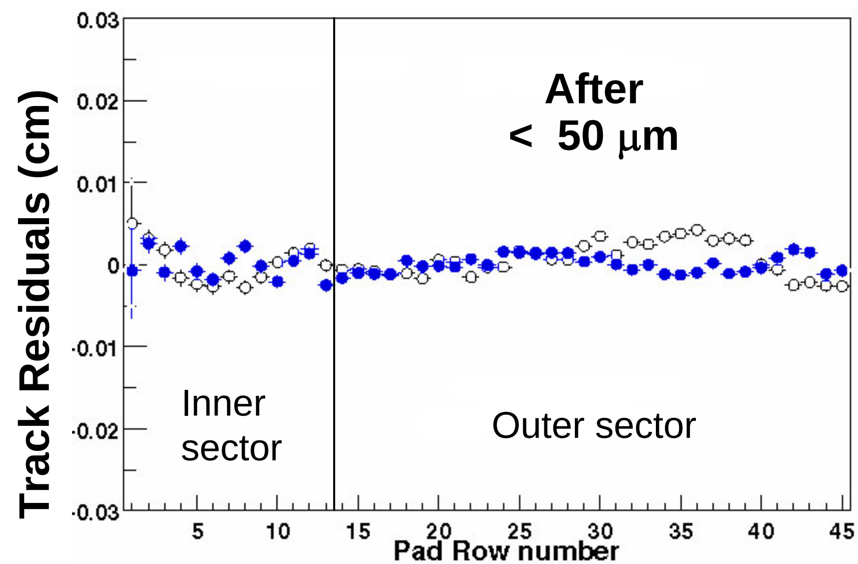
12 Sectors per end – One inner sector and one outer sector each

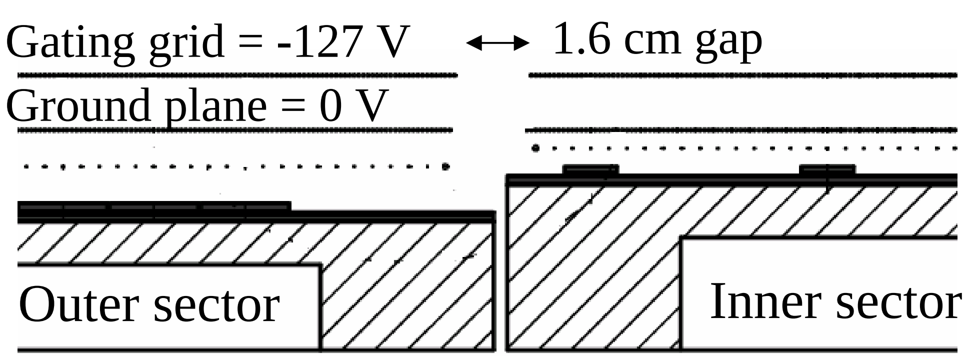
Static Electric Field Distortions





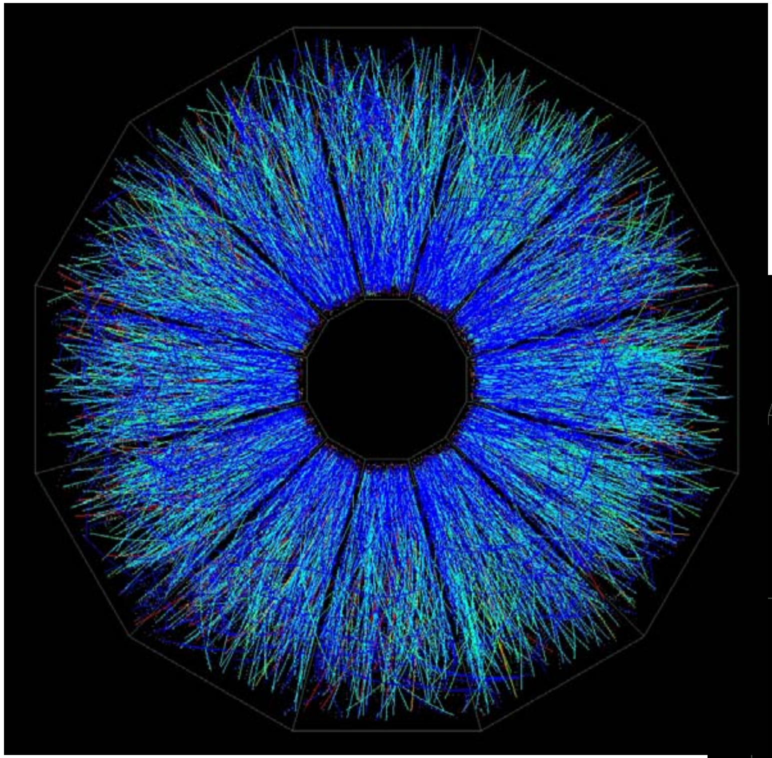
- **No wires at the boundary between the inner and outer sectors**
  - **E field leak ⇨ ExB effect in R and ϕ**





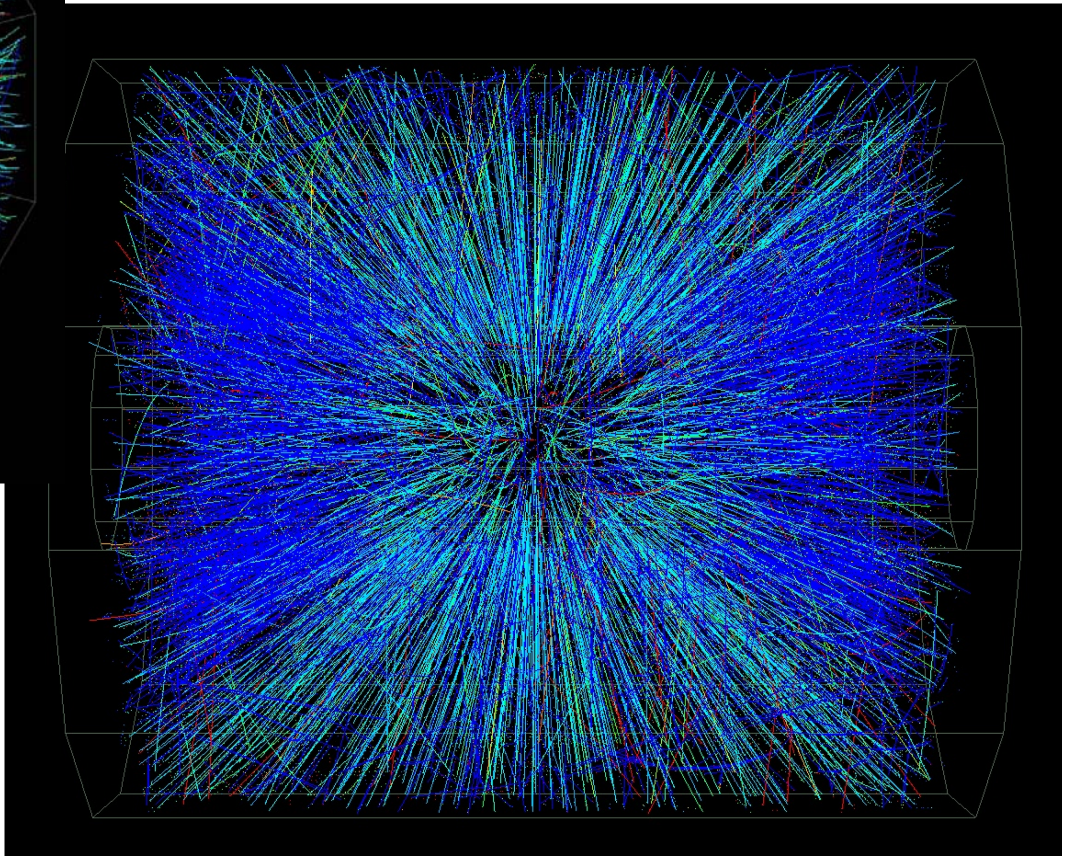
Wieman, JT (LBNL), Long, Trentalange (UCLA)

Dynamic E field distortions



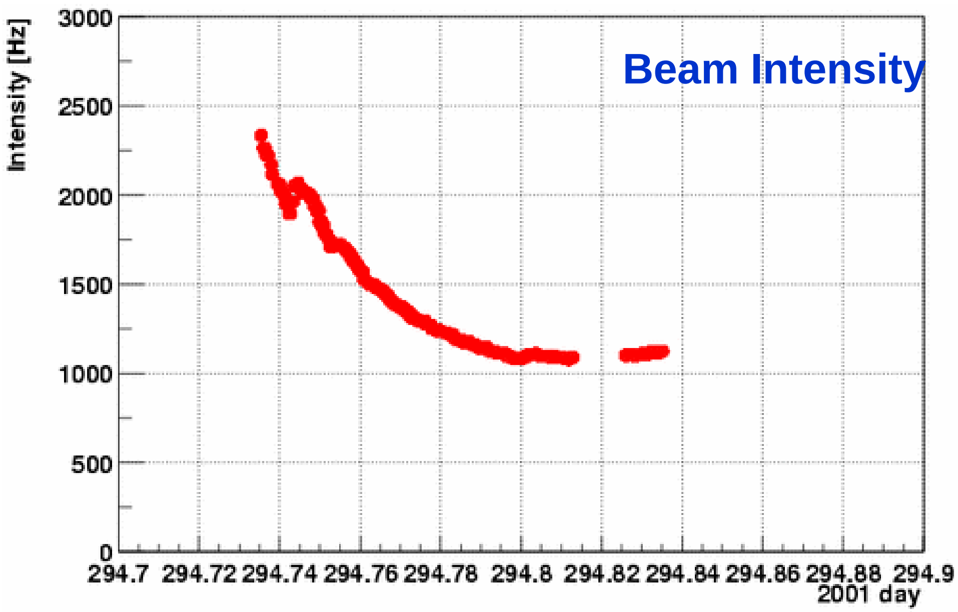
A Central Event

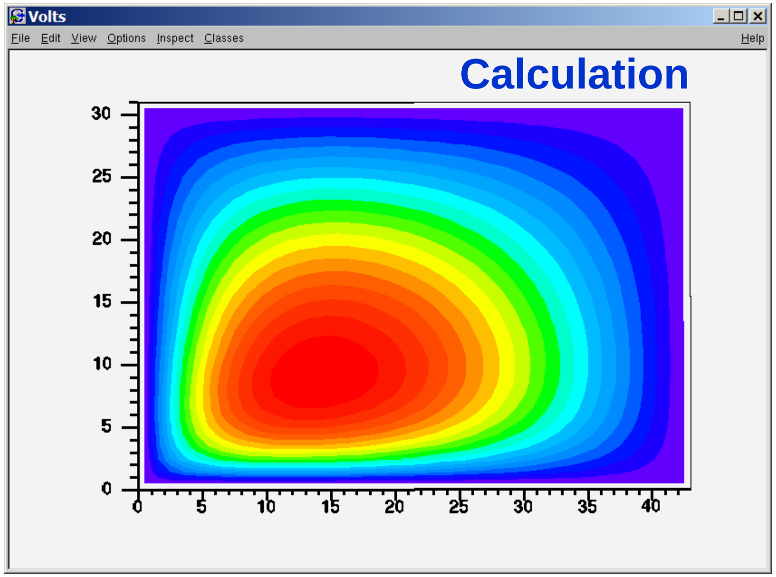
Typically 1000 to 2000 tracks
per event into the TPC



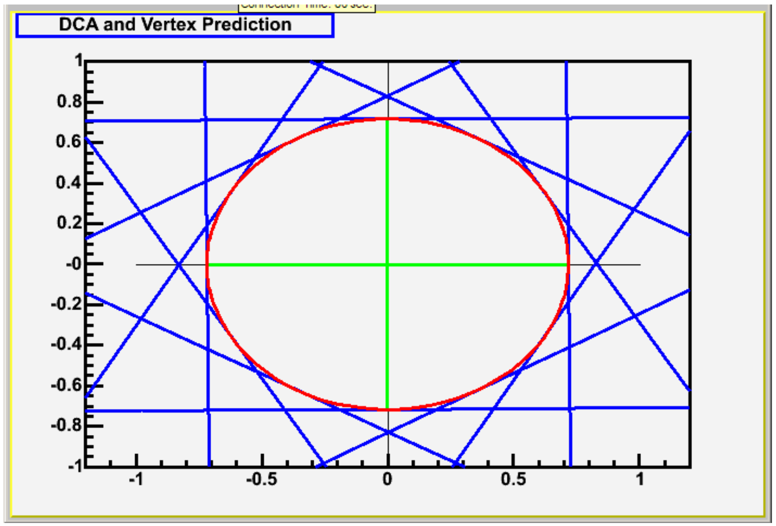
The primary tracks leave behind secondary electrons (good) and secondary ions (not so good). We call this "volume" spacecharge.

Space Charge

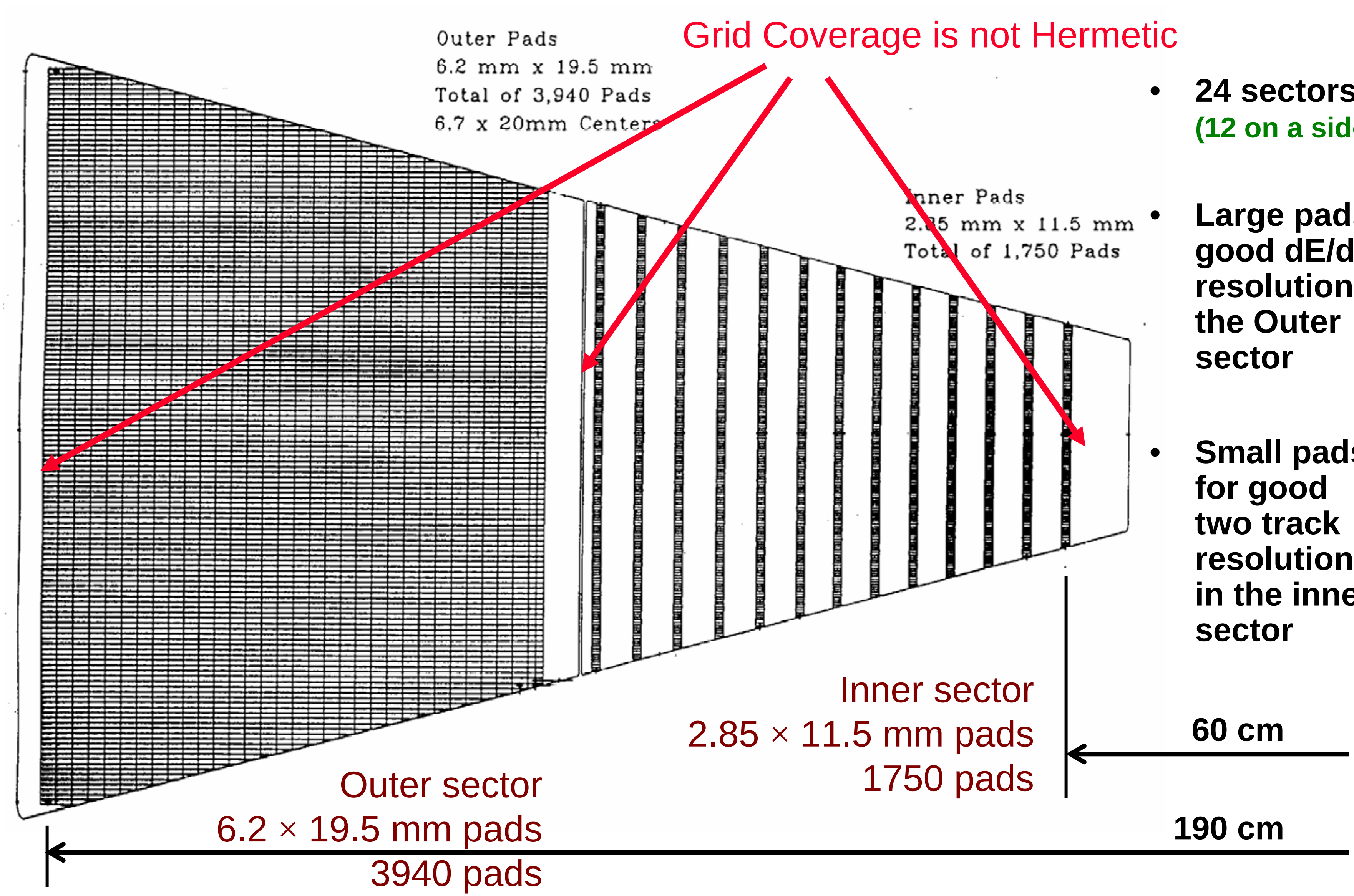




- Normal events leave a $1/R^2$ distribution of charge in the volume of the TPC
- Background 'so far' has had a similar shape … or was low
- We can model this and calculate effects … but it keeps changing with time
- See the talk by Gene VanBuren

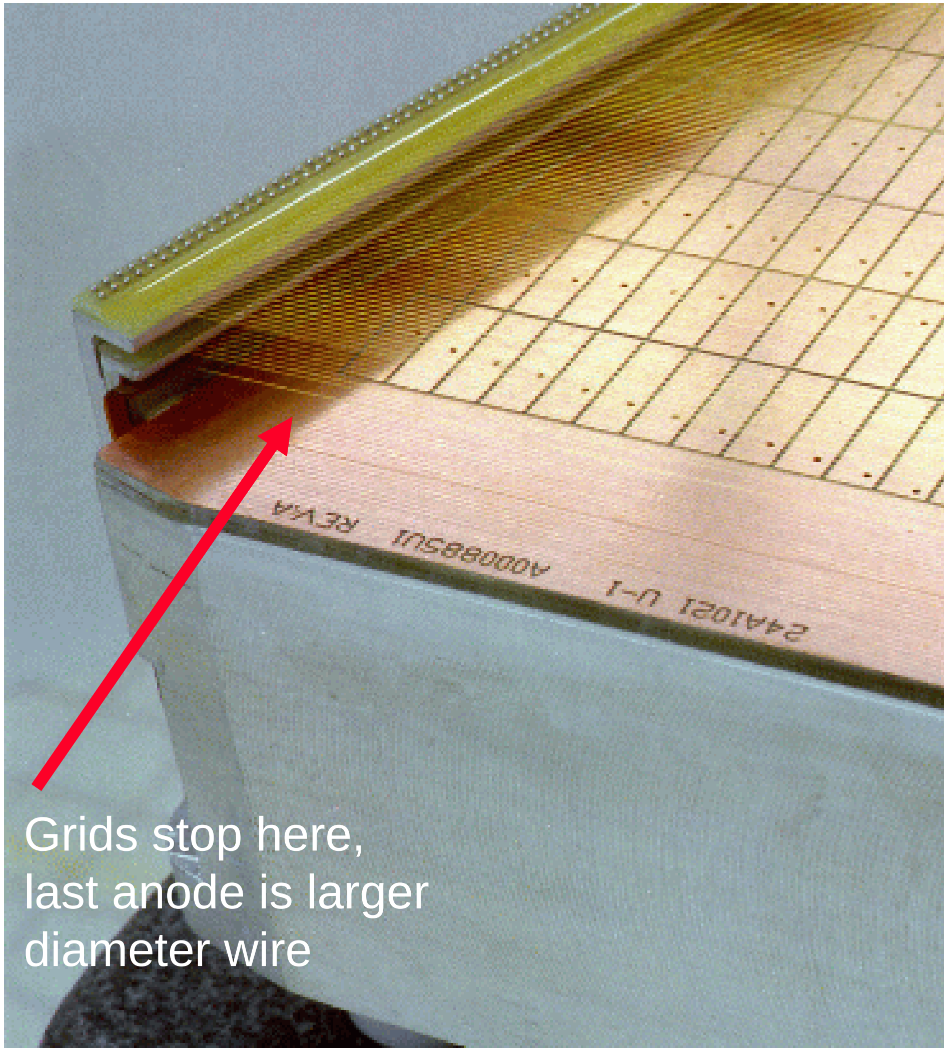


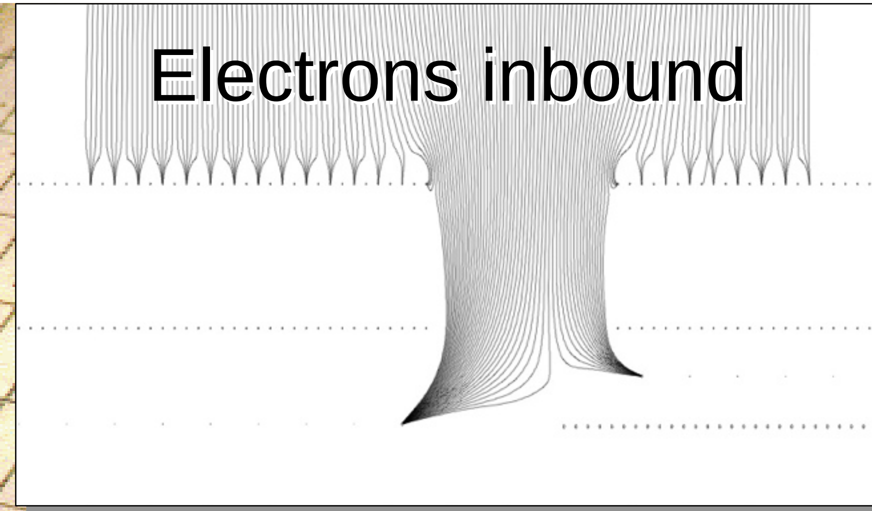
Outer and Inner Sectors of the Pad Plane

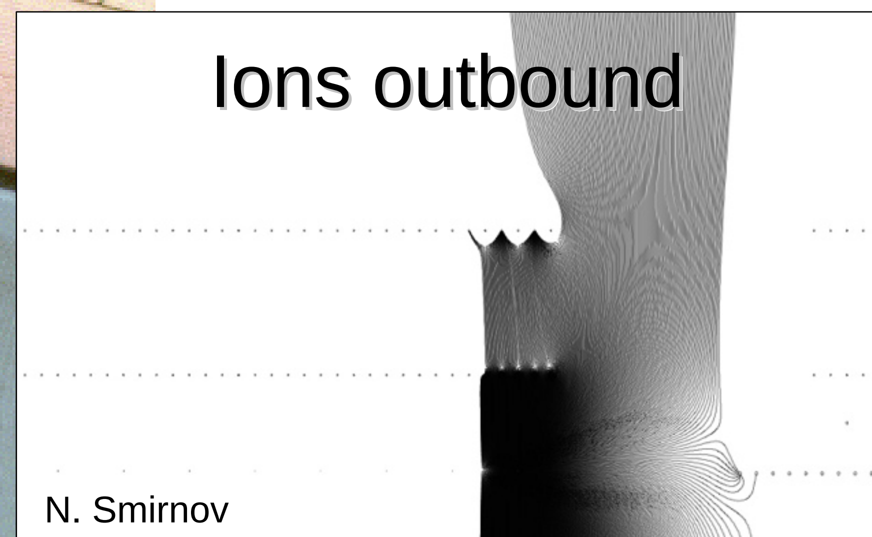


- **24 sectors (12 on a side)**
- **Large pads good dE/dx resolution in the Outer sector**
- **Small pads for good two track resolution in the inner sector**

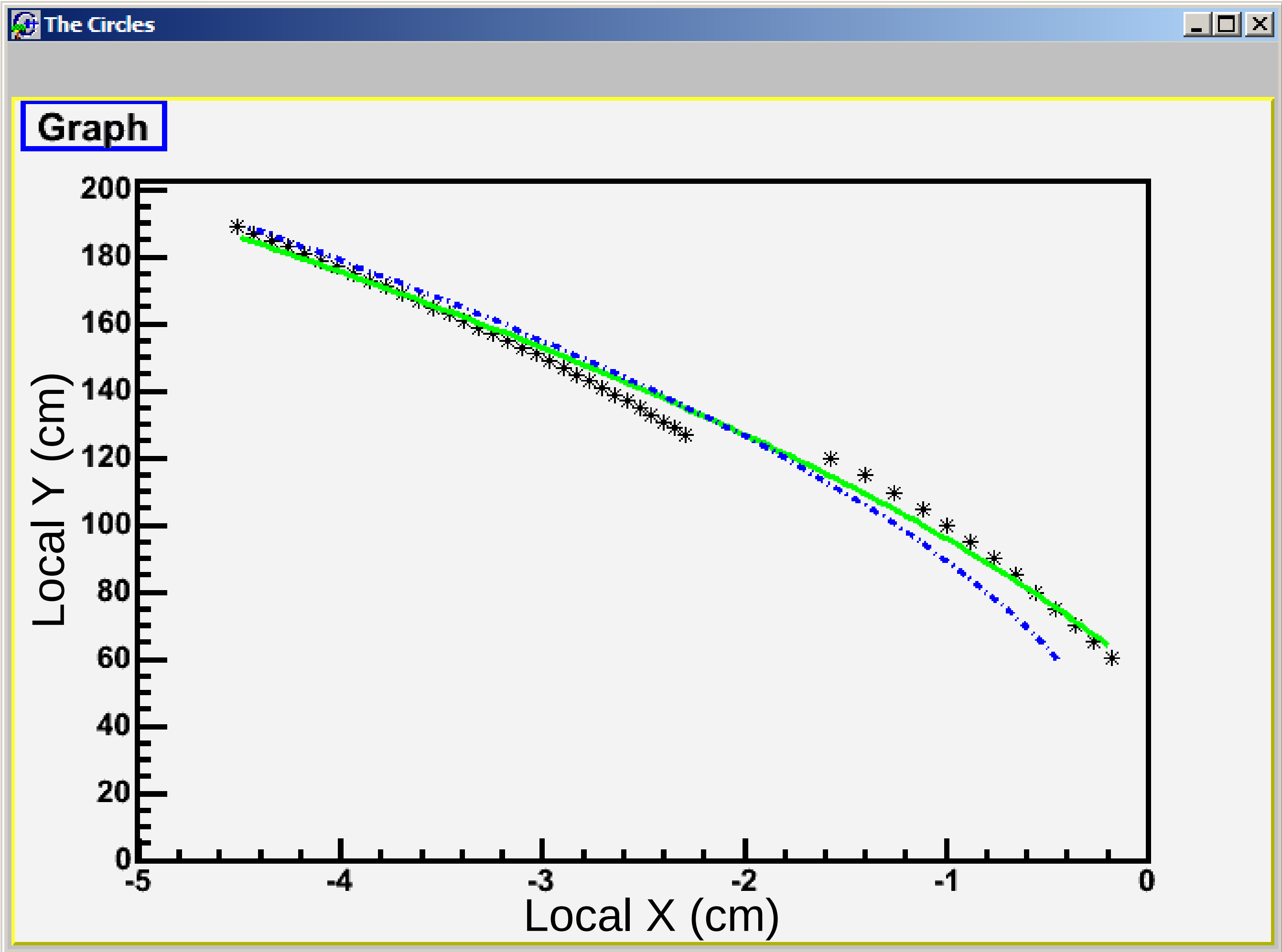
GridLeak - Ions Leaking Out of the Gap in the Grids







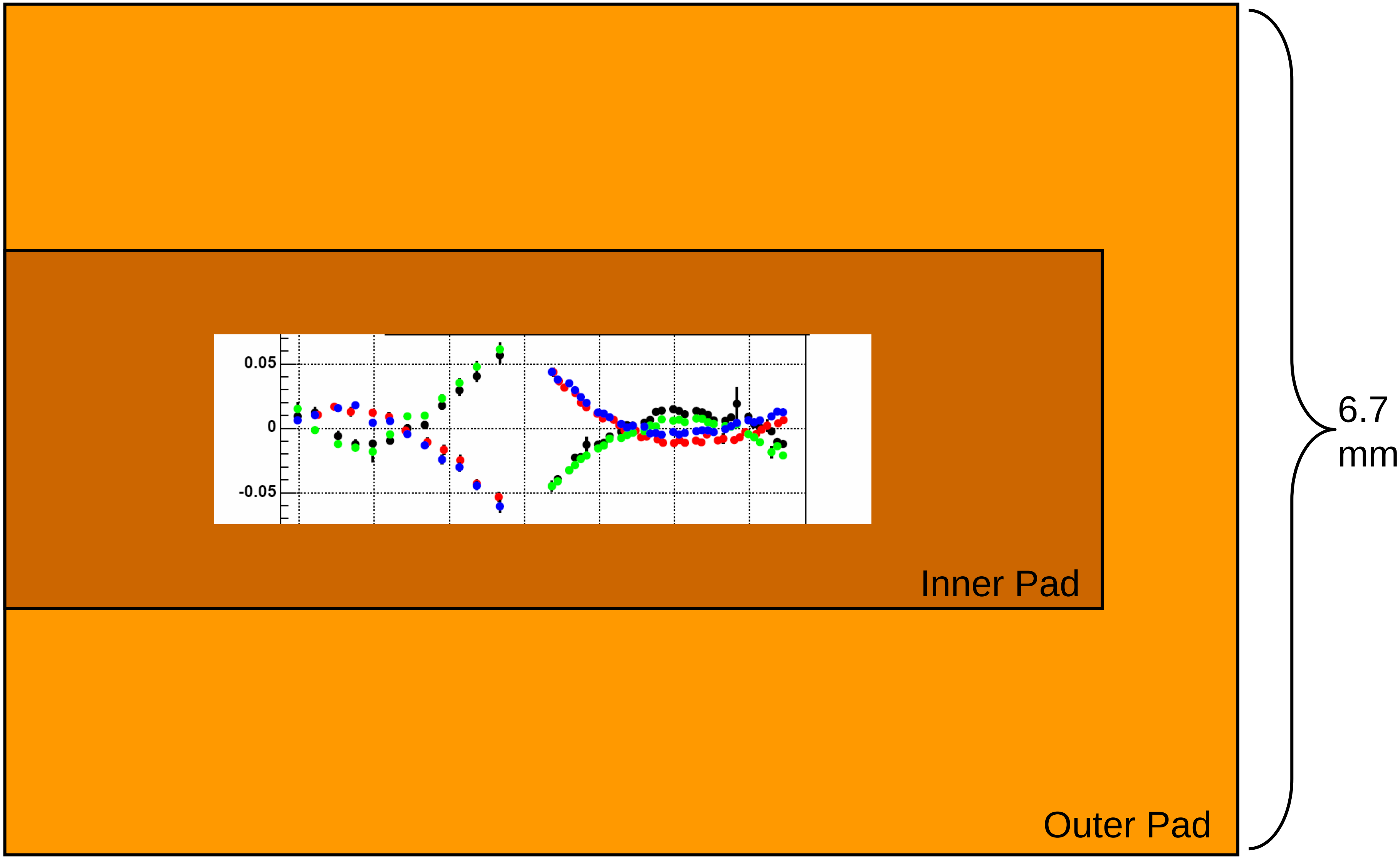
Effect of the Grid Leak on a Simulated Track



- 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

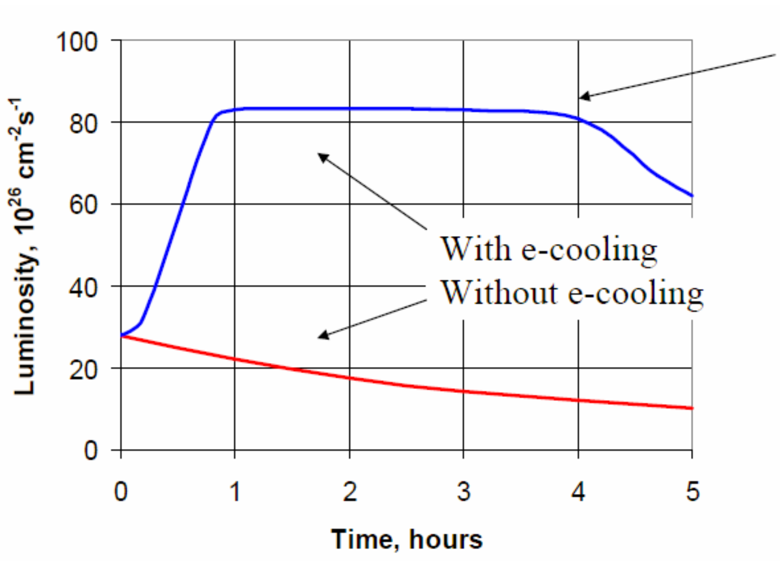
Principle effect is improper momentum determination and poor pointing at the vertex for global tracks
Primary tracks have a built in vertex constraint and so the effect is smaller for primaries than for global tracks.

Grid Leak Distortion Relative to Inner/Outer Pad Size



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

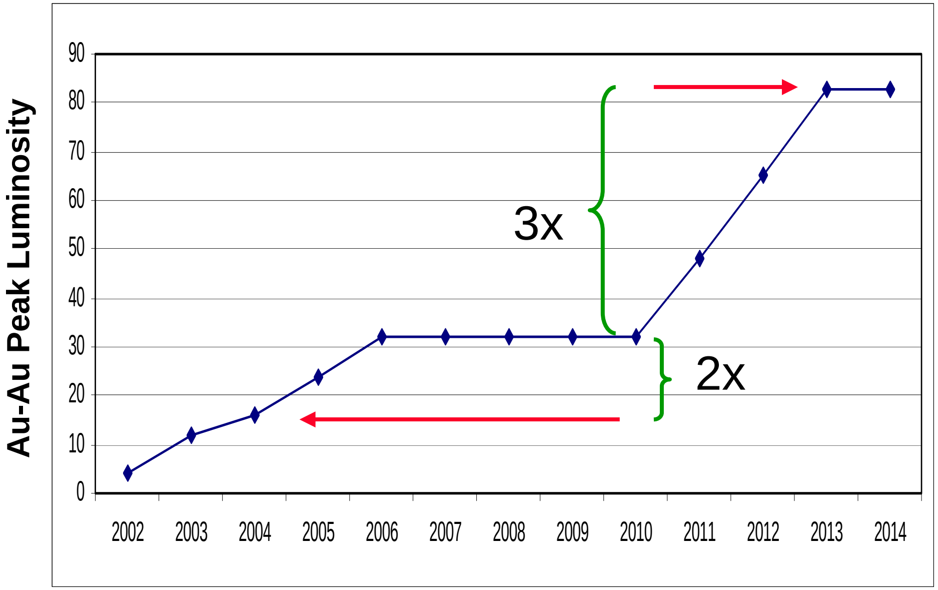
Thomas Roser's e-Cooled Luminosity Projections



Luminosity leveling through continuously adjusted cooling

Store length limited to 4 hours by "burn-off"

Four IRs with two at high luminosity



- **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 …

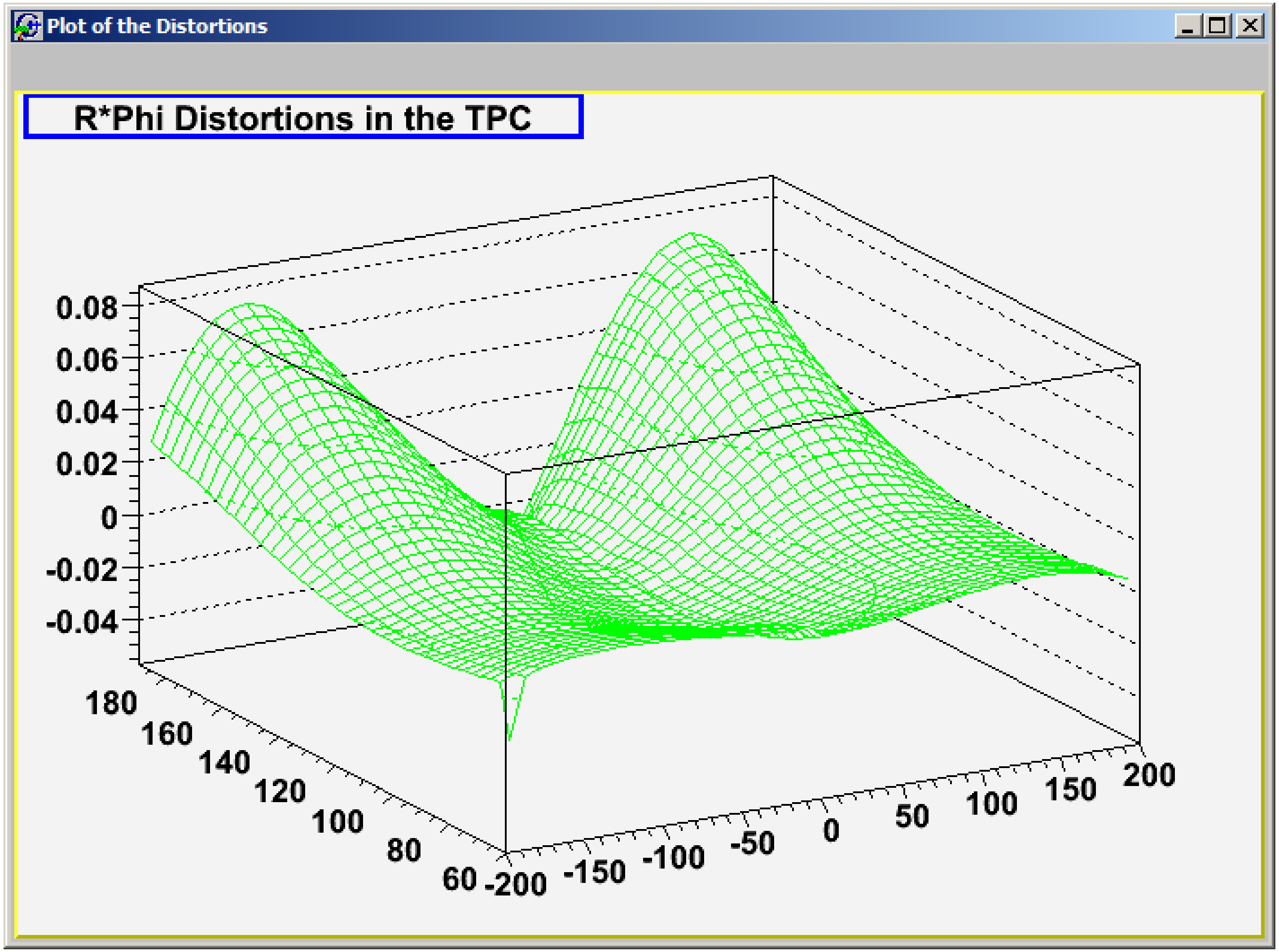
Distortion	Max Amplitude	Where	Comments
Field Shape	0.0800	OFC	Static
Twist	0.0400	CM	Annual
PadRow 13	0.0400	PadRow 13	Static
Clock	0.0800	OFC	Static
IFC Shift	0.0100	IFC at CM	Static
Space Charge	0.3000 (2004)	IFC at CM	Dynamic
Grid Leak	0.2500 (2004)	PadRow 13	Dynamic
Shorted Ring	0.5000	Unknown	Can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

Will the TPC Last Forever?

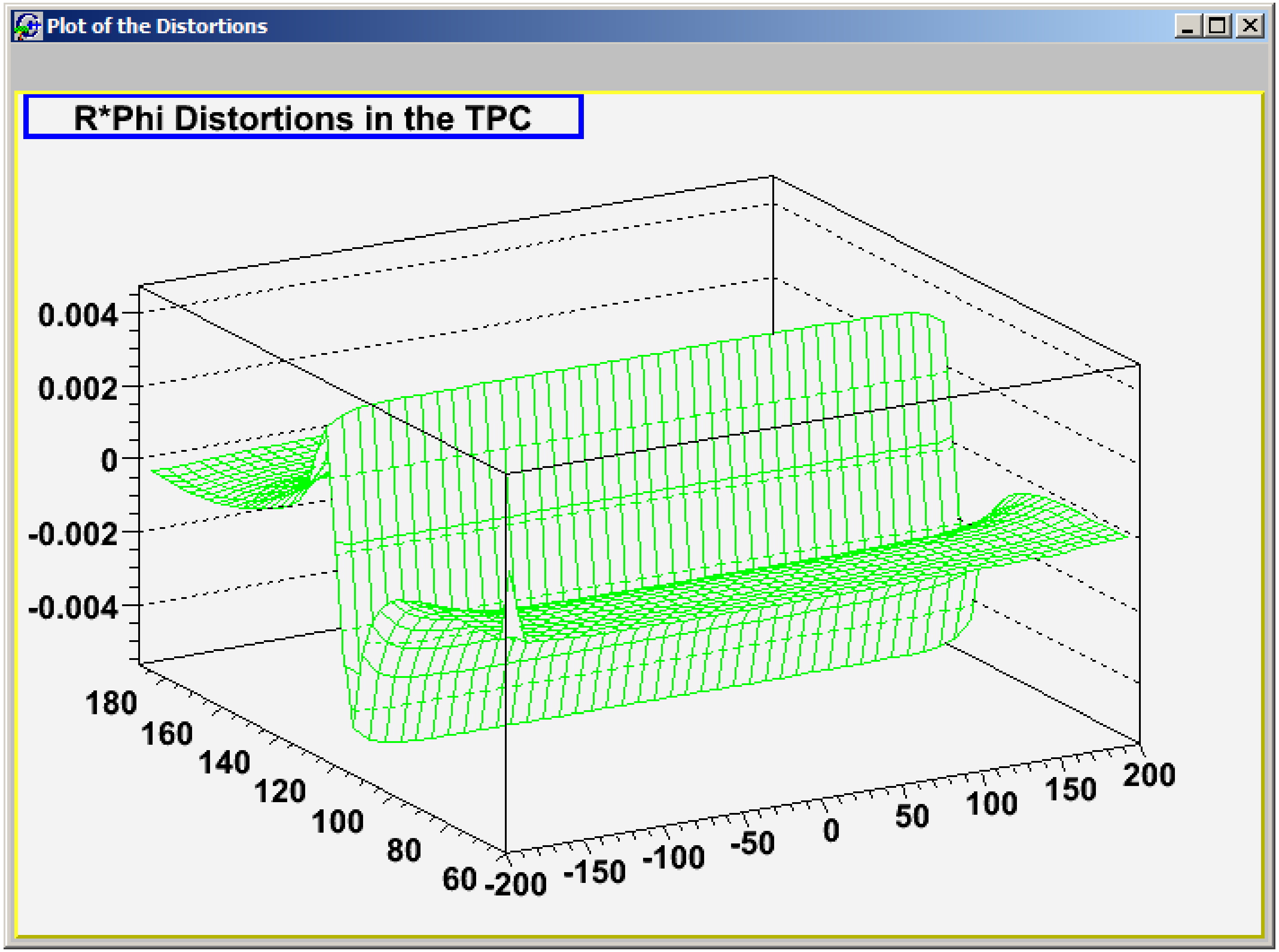
- **Dynamic distortions driven by $\mathcal{L}$**
  - **2x increase is feasible and this takes us to 2010 and (probably) beyond.**
- **Some static distortions need work**
  - **e.g. Central Membrane is not flat**
    - **Probably of academic interest**
  - **Unlikely that any of these static unresolved 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

Field Shape distortions

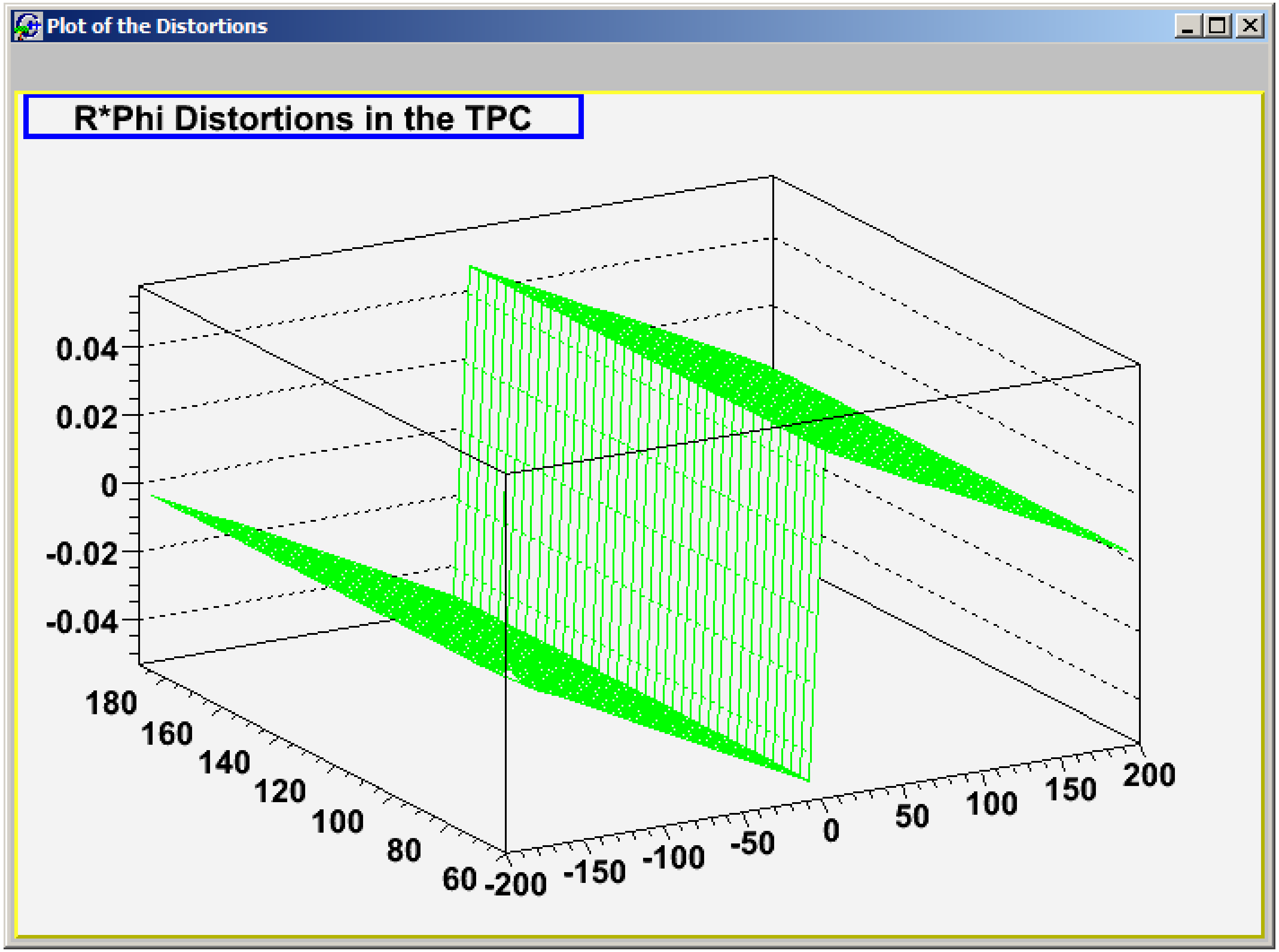


PadRow13

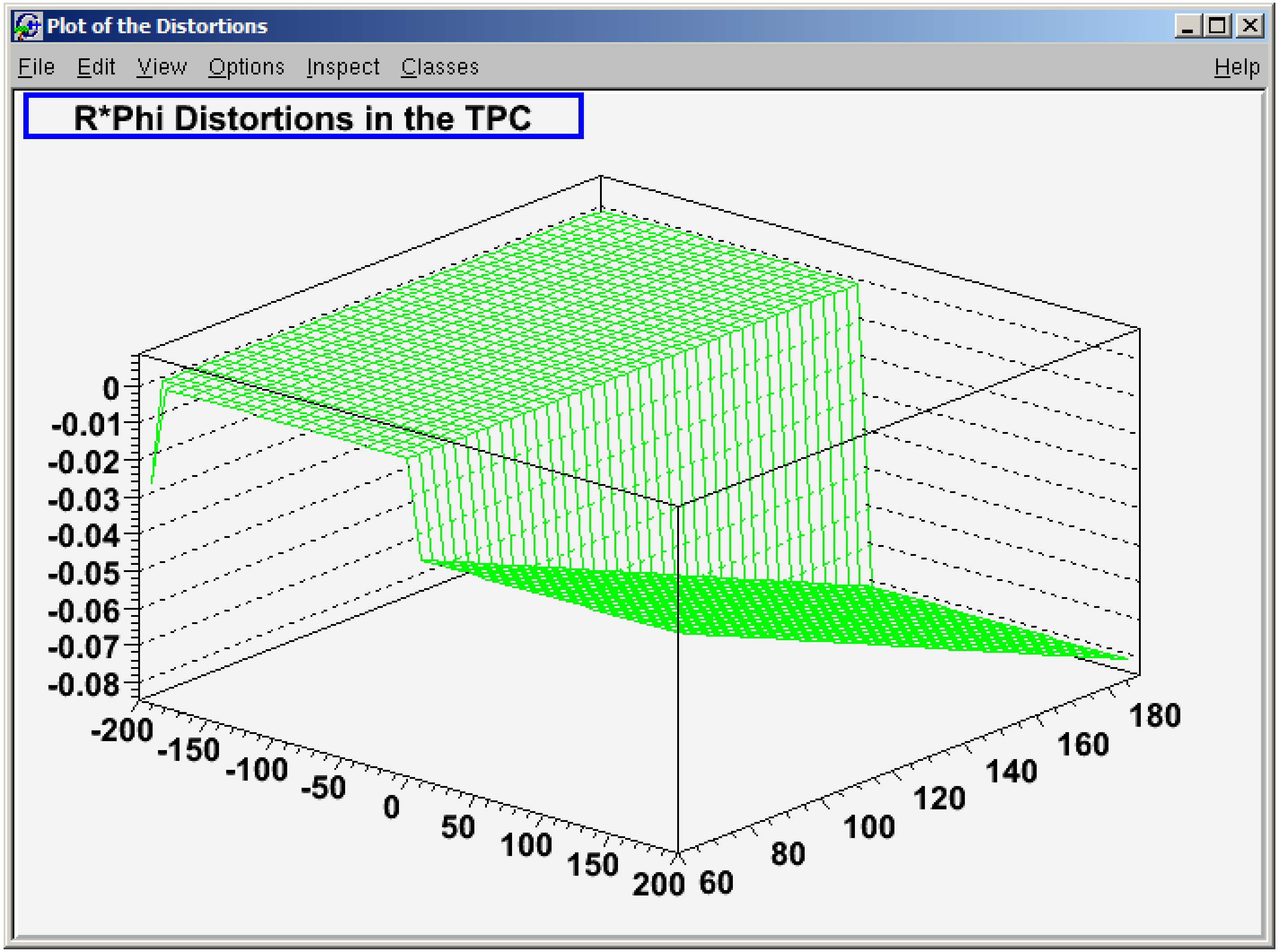


Plot of the Distortions
R*Phi Distortions in the TPC
0.004
0.002
0
-0.002
-0.004
180
160
140
120
100
80
60
-200
-150
-100
-50
0
50
100
150
200

Twist

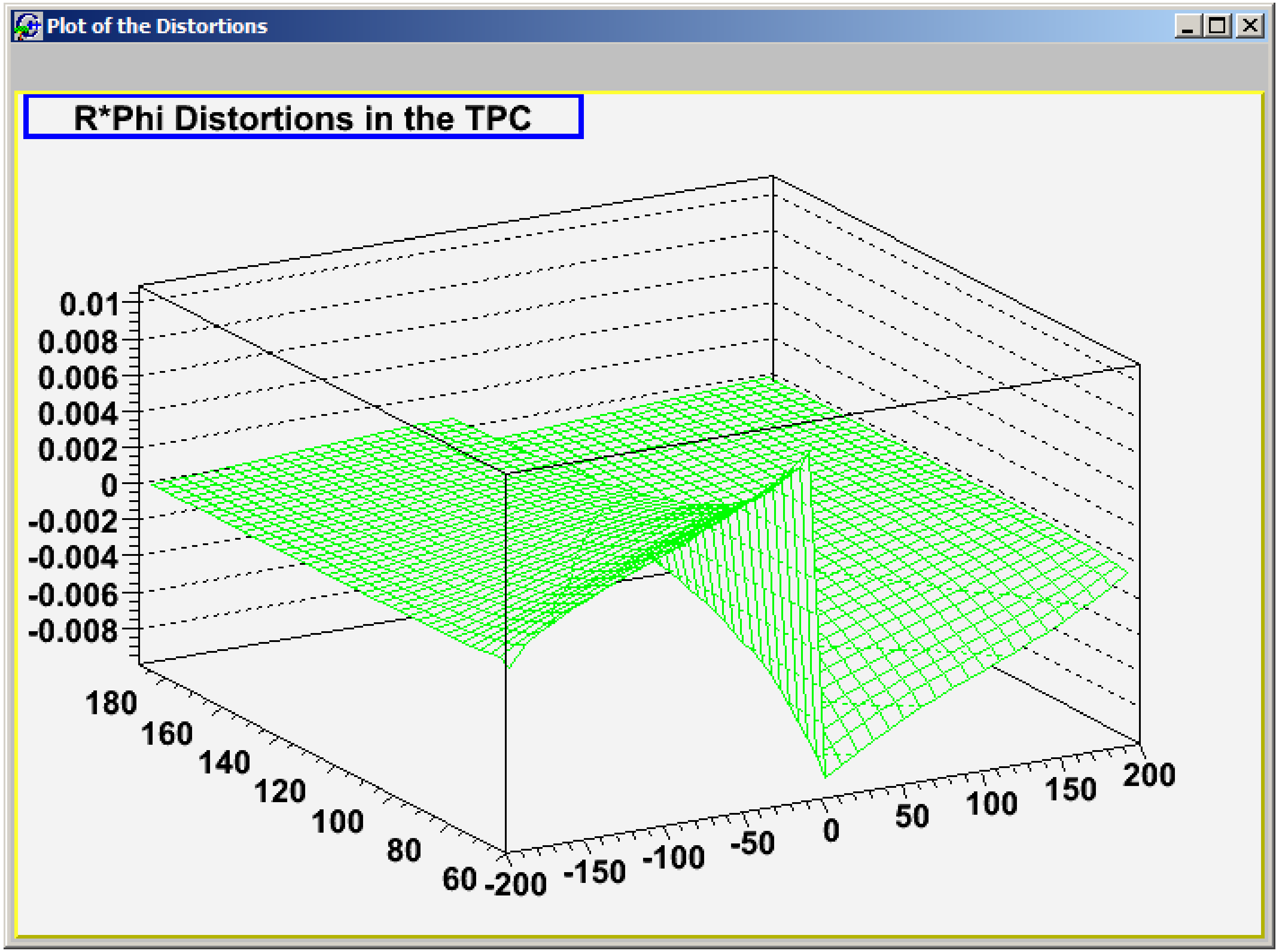

Plot of the Distortions
R*Phi Distortions in the TPC
0.04
0.02
0
-0.02
-0.04
180
160
140
120
100
80
60
-200
-150
-100
-50
0
50
100
150
200

Clock



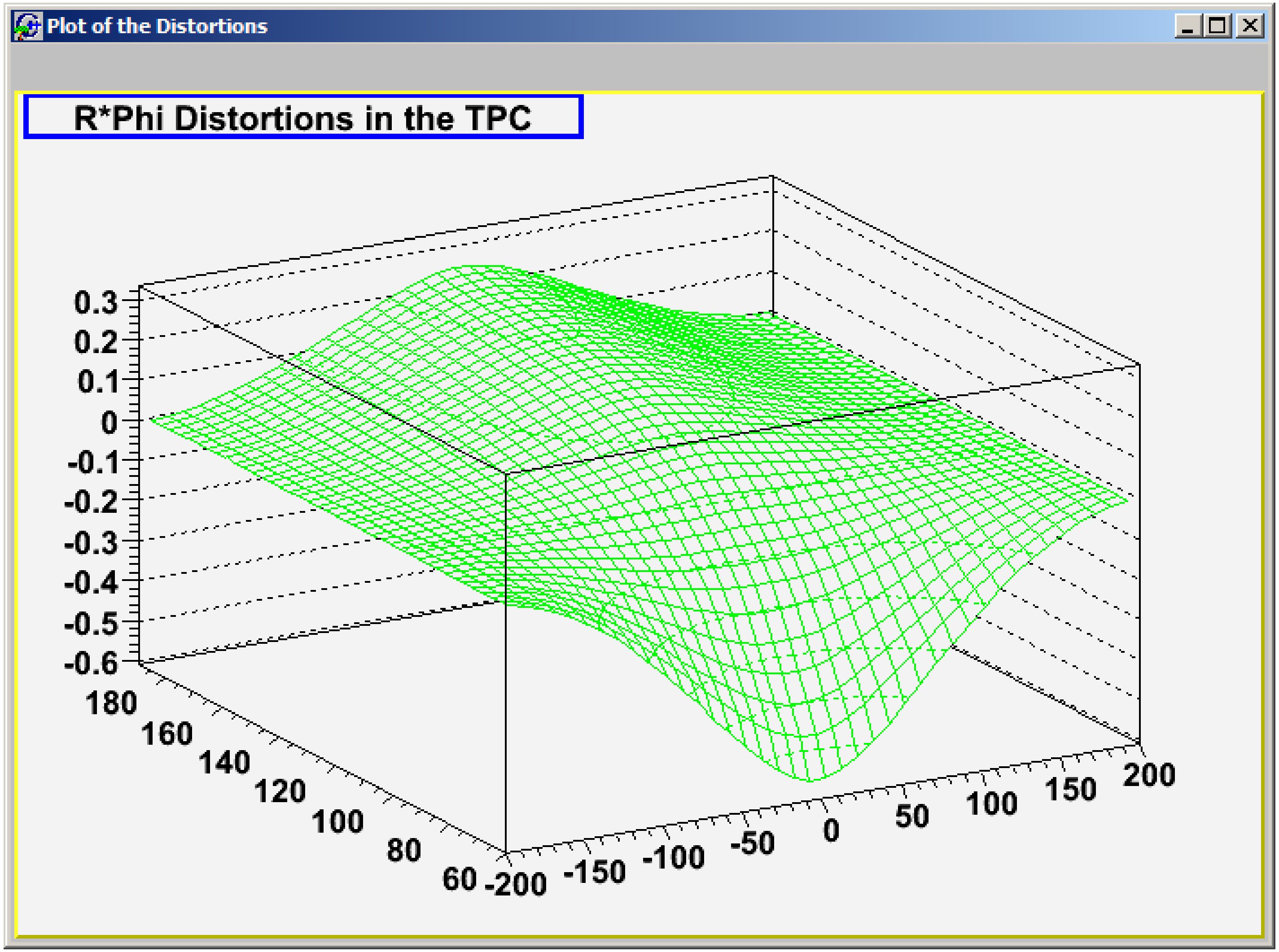
Plot of the Distortions
File Edit View Options Inspect Classes Help
R*Phi Distortions in the TPC
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-200 -150 -100 -50 0 50 100 150 200
60 80 100 120 140 160 180

IFC Shift

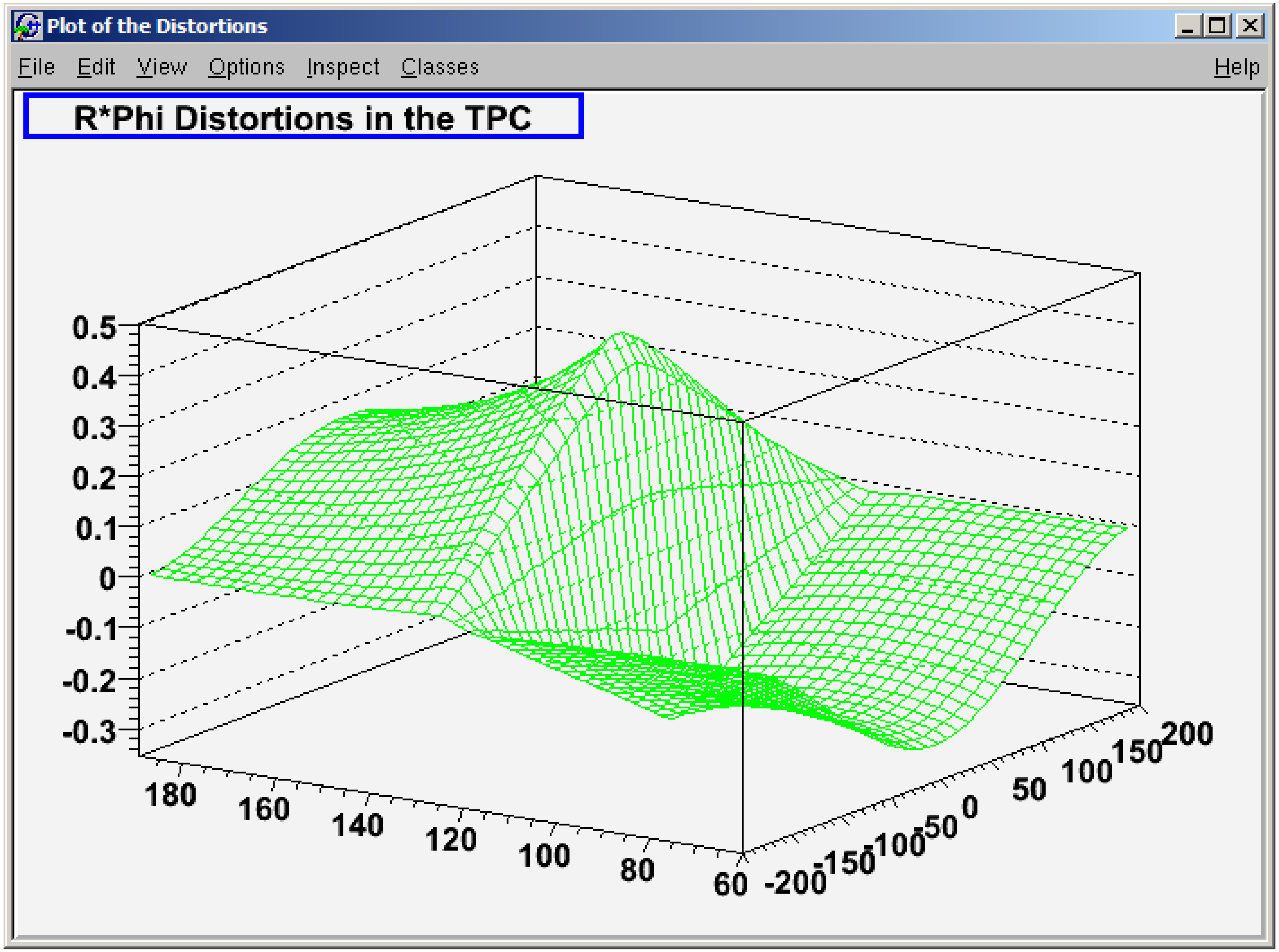


Plot of the Distortions
R*Phi Distortions in the TPC
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
180
160
140
120
100
80
60
-200
-150
-100
-50
0
50
100
150
200

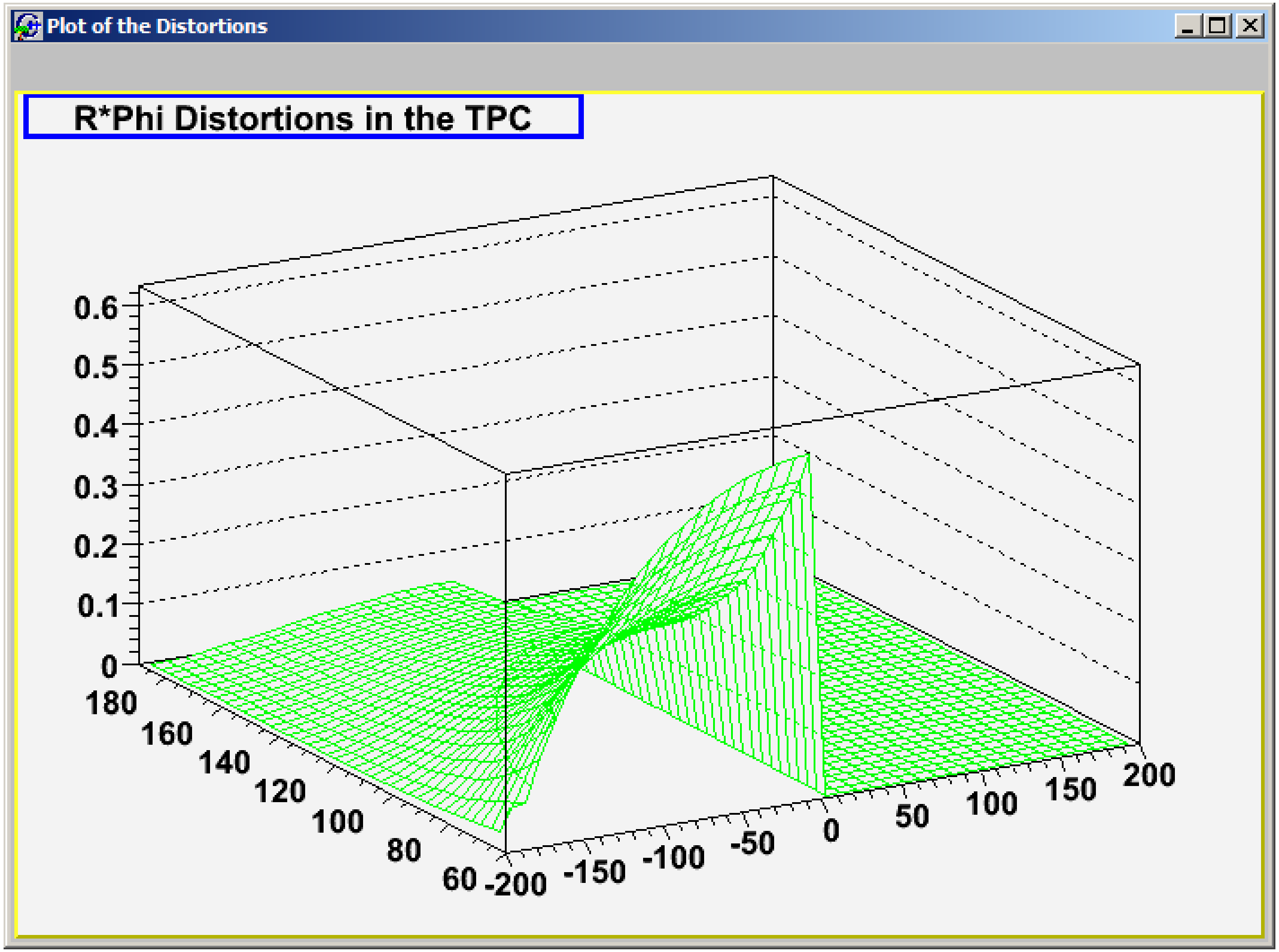
Space Charge at 2x 2004 levels



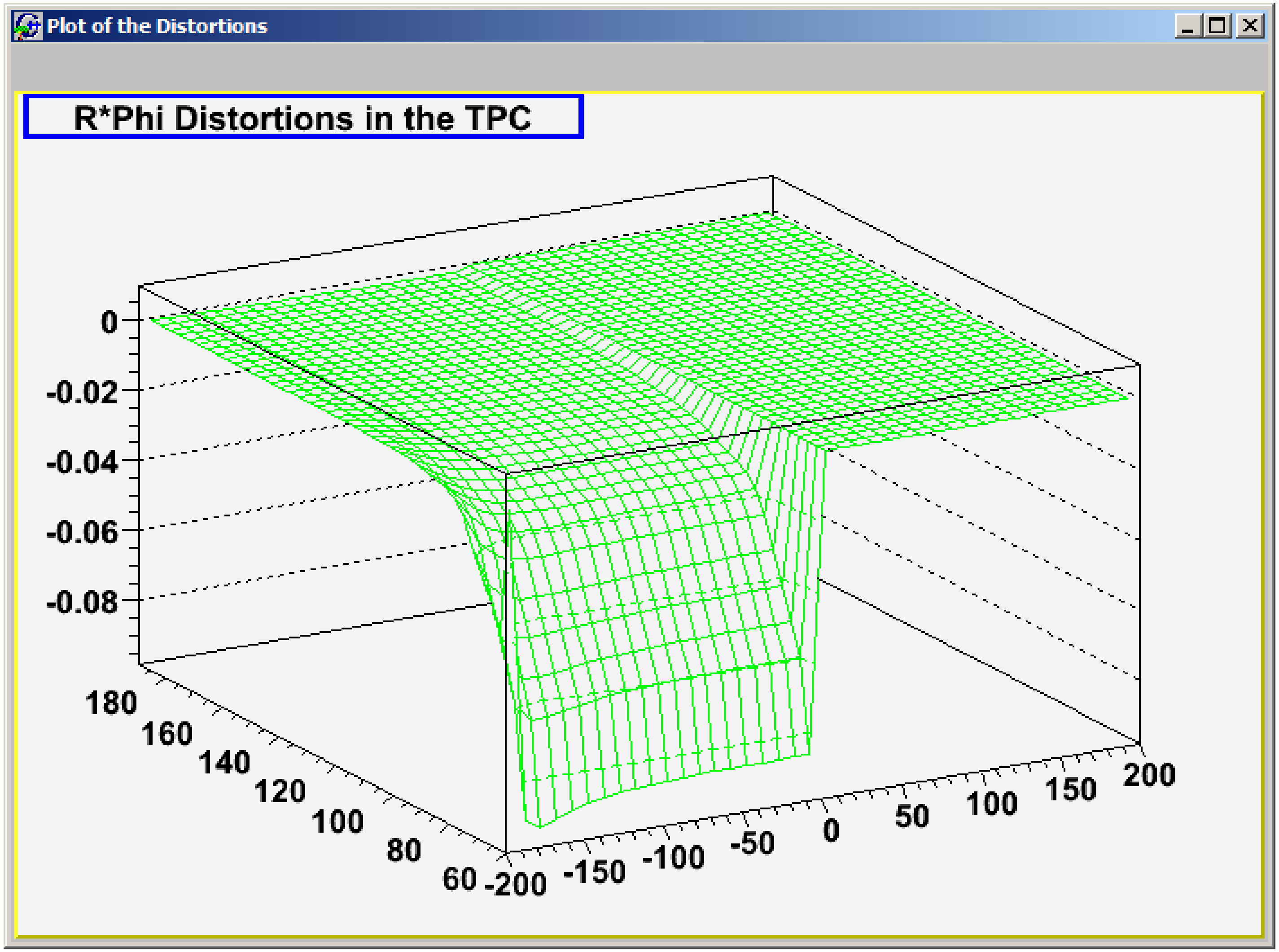
Grid Leak at 2x 2004 levels



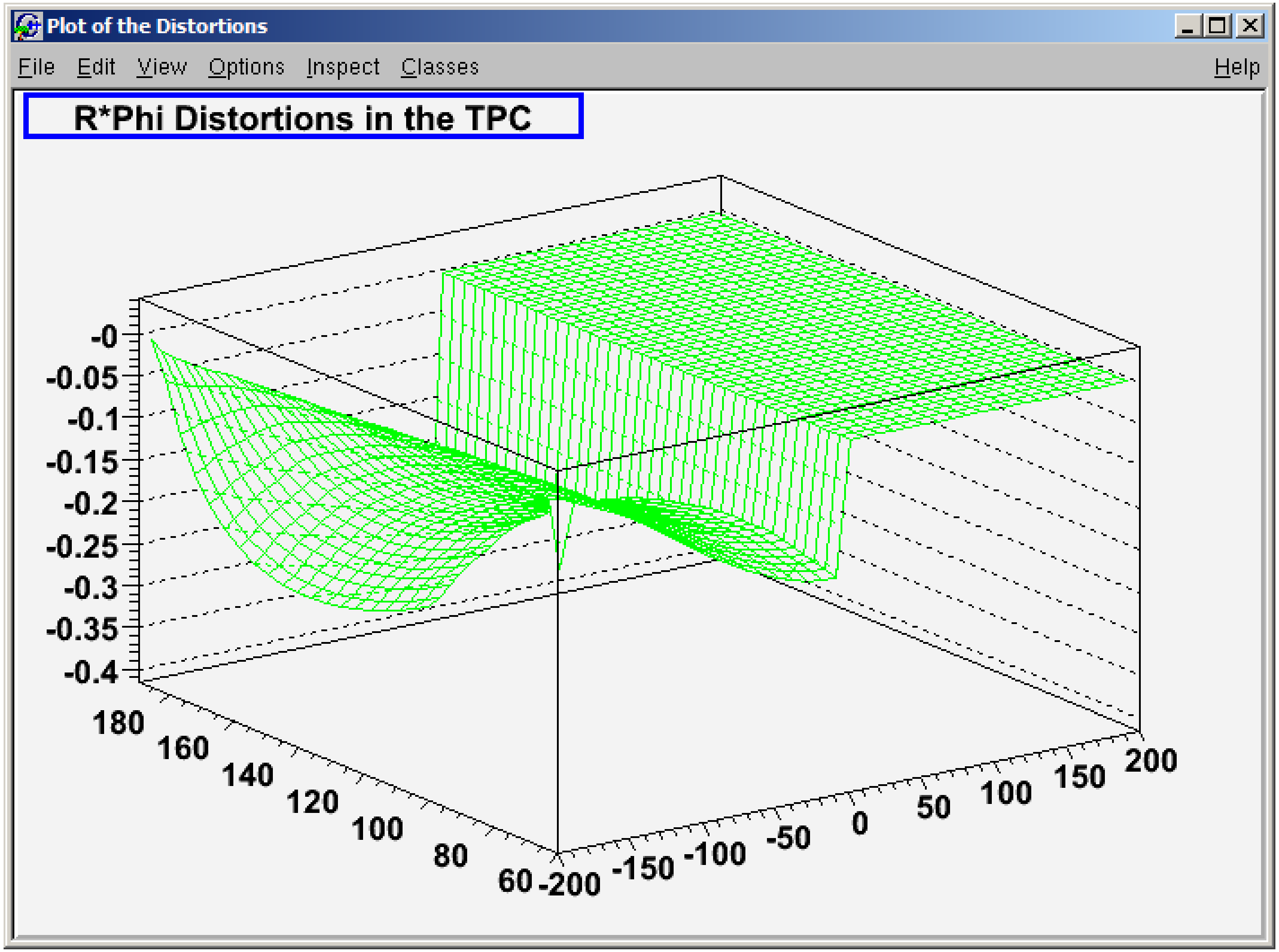
Shorted Ring (162.5 without compensation)



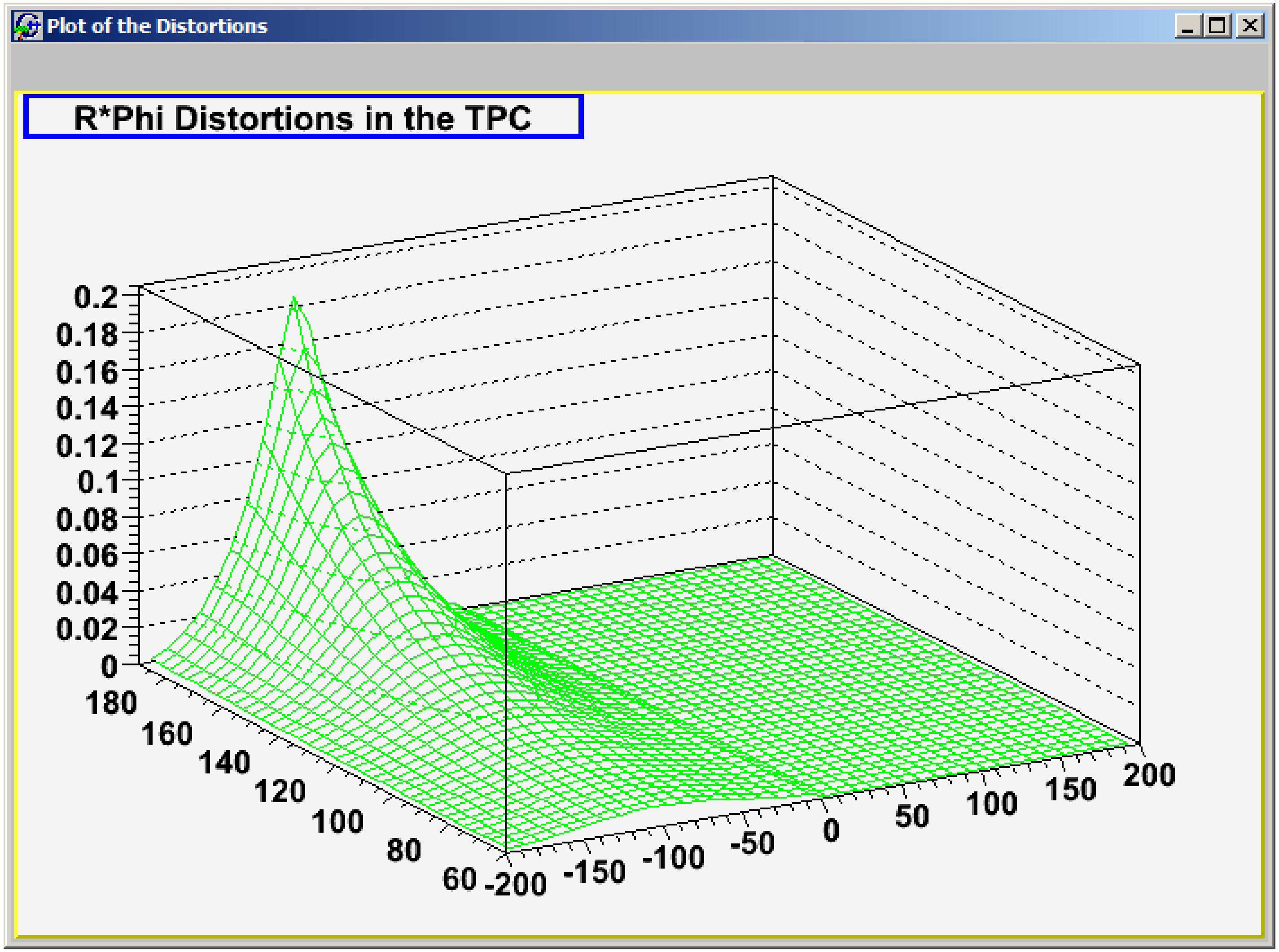
Shorted Ring (162.5 with compensation)



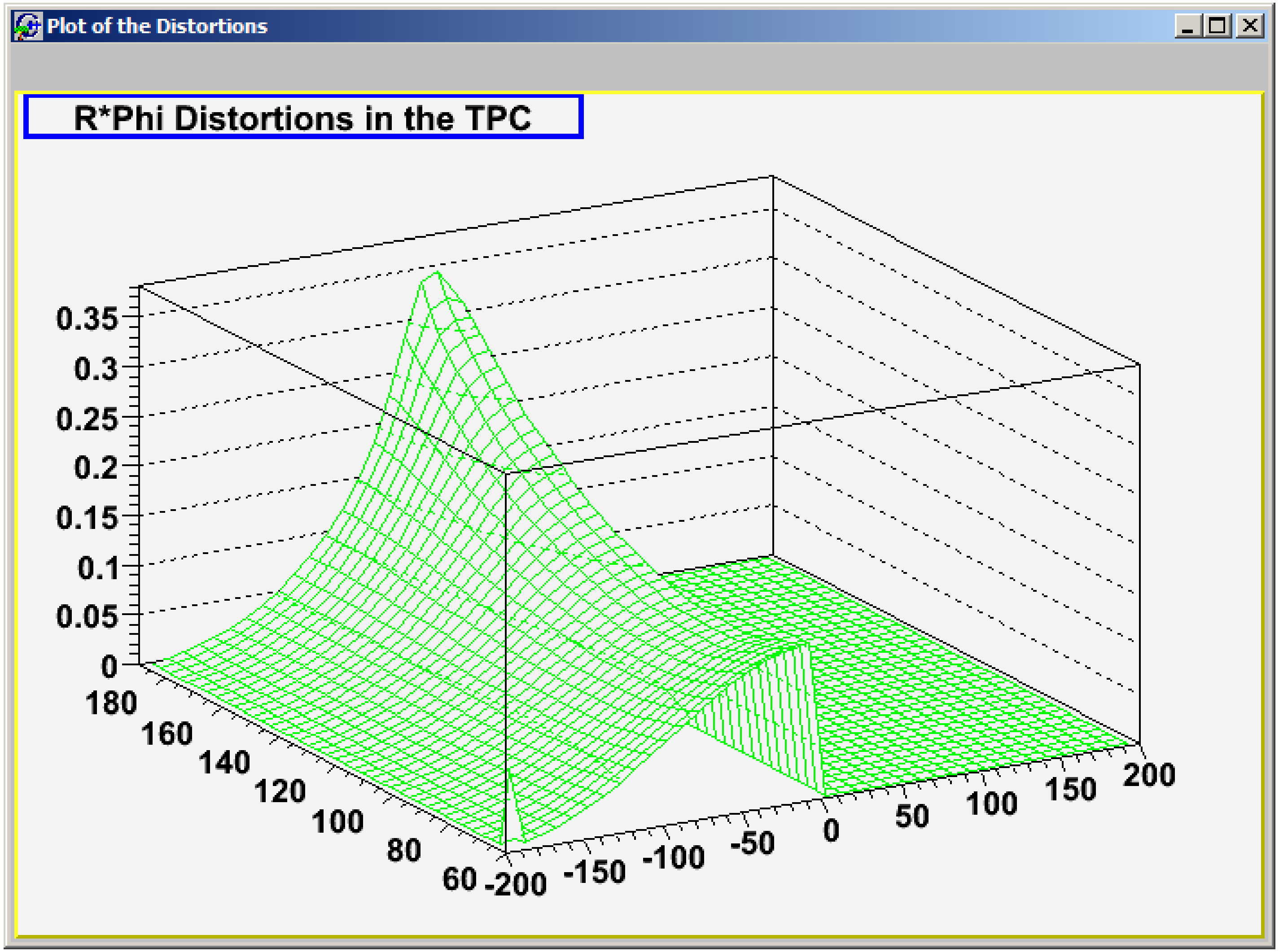
Shorted OFC Ring (169.5)



Shorted OFC Ring (90.5)



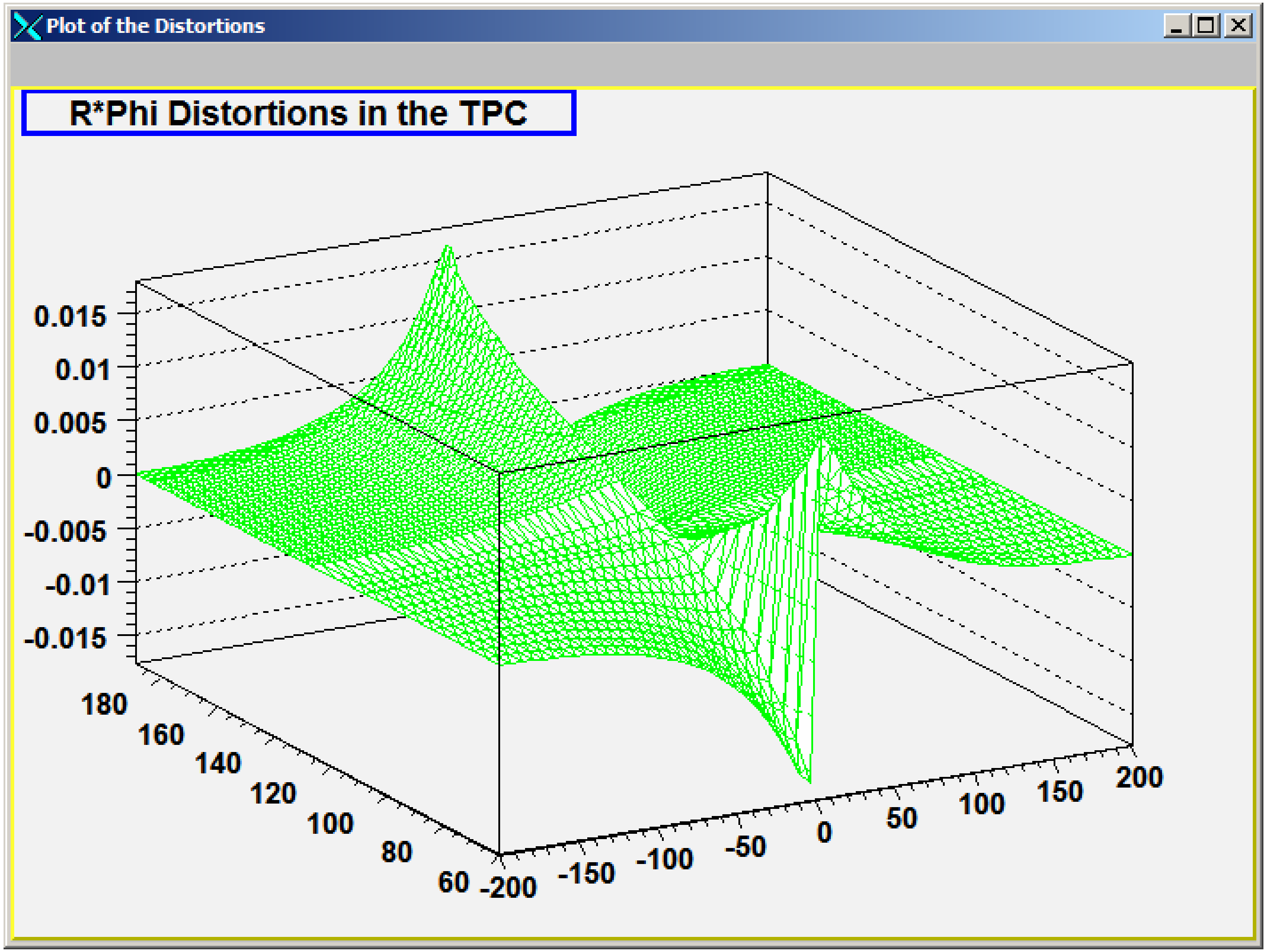
Shorted OFC Ring (20.5)



Parameters

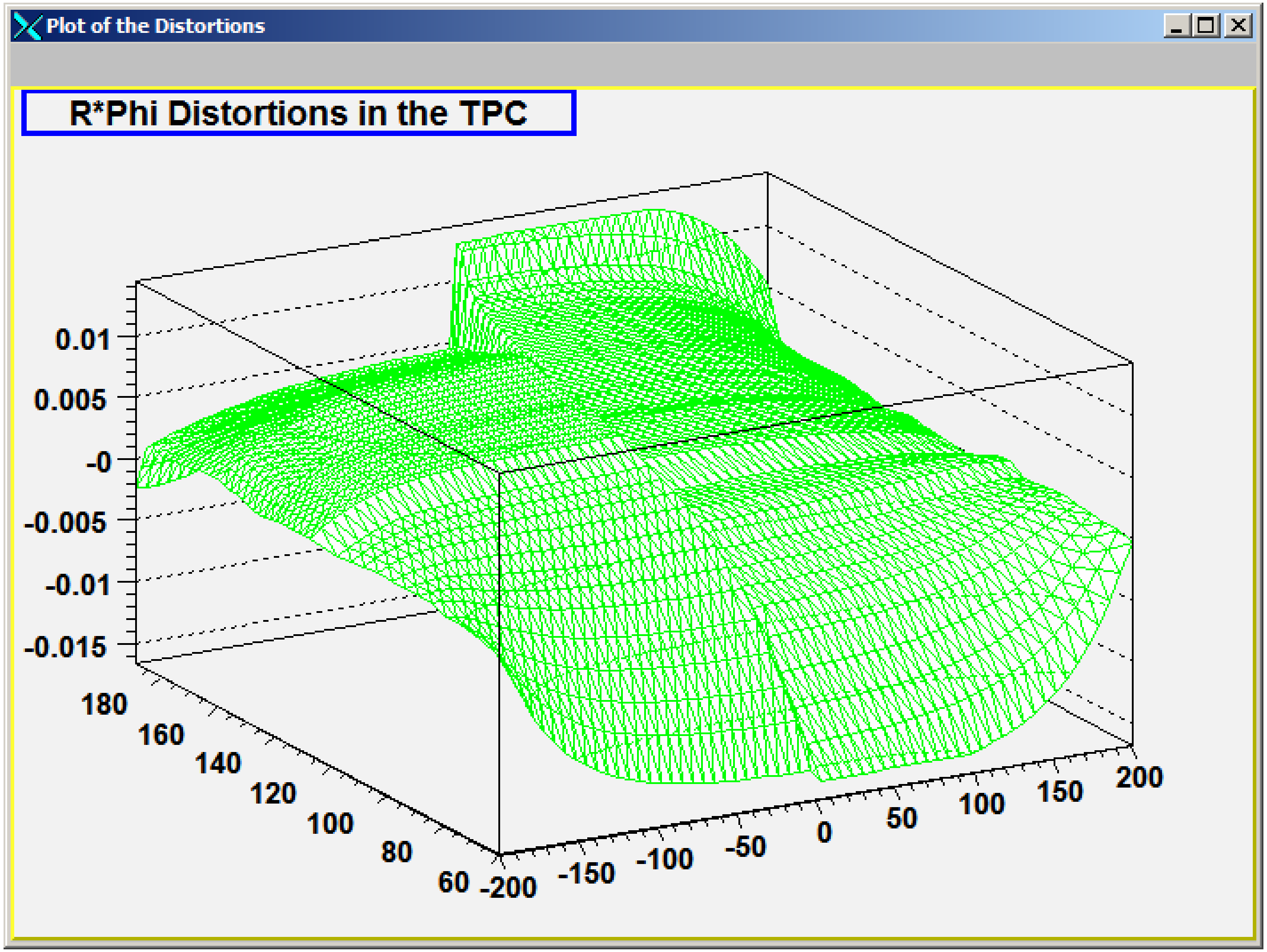
```
StMagUtilities::DriftVel      =  5.54 cm/microsec
StMagUtilities::TPC_Z0        =  208.7 cm
StMagUtilities::TensorV1+V2   =  1.35 1.1
StMagUtilities::OmegaTau1+2   =  -2.79246 -2.27534
StMagUtilities::XTWIST        =  -0.165 mrad
StMagUtilities::YTWIST        =  0.219 mrad
StMagUtilities::SpaceCharge   =  0 Coulombs/epsilon-nought
StMagUtilities::SpaceChargeR2 =  0 Coulombs/epsilon-nought
StMagUtilities::IFCShift      =  0.008 cm
StMagUtilities::CathodeV      =  -27950 volts
StMagUtilities::GG            =  -115 volts
StMagUtilities::EastClock     =  0 mrad
StMagUtilities::WestClock     =  -0.43 mrad
StMagUtilities::Side          =  Location of Short E=0 / W=1
StMagUtilities::Cage          =  Location of Short IFC = 0 / OFC = 1
StMagUtilities::Ring          =  Rings - Location of Short counting from the CM
StMagUtilities::MissingOhms   =  MOhms Missing Resistance
StMagUtilities::CompResistor  =  MOhm Compensating Resistor Value
StMagUtilities::InnerGridLeak =  0 53 0
StMagUtilities::MiddlGridLeak =  15 121.8 3
StMagUtilities::OuterGridLeak =  0 195 0
StMagUtilities::UndoShort  Please wait for the tables to fill ... ~10 seconds
```

Central Membrane Shape Distortions



Model not well known for lack of good survey data

EndCap Shape Distortions



Model not well known for lack of good survey data

The Case of E Parallel to B

$$\delta_r = \int \frac{u_r}{u_z}\, dz, \qquad \delta_\phi = \int \frac{u_\phi}{u_z}\, dz$$

Electric field strength cancels out!

$$u_\phi = \frac{\mu\left|\overline{E}\right|}{\left(1+\omega^2\tau^2\right)} \left(\cancel{\hat{E}_\phi} - \omega\tau\left(\hat{E}_r\hat{B}_z - \hat{E}_z\hat{B}_r\right) + \omega^2\tau^2 \cancel{\hat{B}_\phi}\right)$$

etc…so

assuming that $E = E_z$ and $B_z >> B_r$ or B_ϕ

$$\delta_r = \frac{\omega^2\tau^2}{\left(1+\omega^2\tau^2\right)} \int \frac{\hat{B}_r}{\hat{B}_z}\, dz$$

Simple first order equations

$$\delta_\phi = \frac{\omega\,\tau}{\left(1+\omega^2\tau^2\right)} \int \frac{\hat{B}_r}{\hat{B}_z}\, dz$$

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