Progress Report: Analysis and Removal of TPC Distortions Using Realistic Physical Models

Jim Thomas

with important contributions from M. Mager, S. Rossegger, and R. Shahoyan

17th May 2010

Challenges and Goals

- The TPC inherently uses Electric and Magnetic fields to guide the trail of secondary electrons, which form a track, to the readout plane
- It is a drift device …
  - It takes 96 μsec for an e to drift from the CE to one end of the TPC
  - The tracks are distorted during the drift due to imperfections in the approximately parallel Electric and Magnetic fields
- The orientation of the TPC with respect to these E&M fields is important because these fields are the cause of most distortions
- The orientation of the TPC with respect to the other detectors is also important
  - However, the orientation of the TPC with respect to the other detectors is an alignment issue … it is not a distortion
- Distortion and Alignment issues are difficult to distinguish and often get confused, one with the other
- The Goal of TPC Calibrations is to distinguish distortion and alignment issues and to remove them from the data (separately)

The primary goal of this talk is to discuss TPC Distortions and to suggest how to remove them

The Langevin Equation – (see Blum, Riegler and Rolandi)

Solve:

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

Microscopic Lorentz force with "Friction"

substituting:

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

subject to the steady state condition

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

yields

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

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

Then a miracle occurs …

Distortion Equations – related to integrals of the fields

distortion in x

$$\begin{pmatrix}\delta_x\\ \delta_y\end{pmatrix} = \begin{pmatrix} c_0 & c_1 \\ -c_1 & c_0\end{pmatrix}\begin{pmatrix}\int \frac{E_x}{E_z}\,dz \\ \int \frac{E_y}{E_z}\,dz\end{pmatrix}$$

$$\begin{pmatrix}\delta_x\\ \delta_y\end{pmatrix} = \begin{pmatrix} c_2 & -c_1 \\ c_1 & c_2\end{pmatrix}\begin{pmatrix}\int \frac{B_x}{B_z}\,dz \\ \int \frac{B_y}{B_z}\,dz\end{pmatrix}$$

Master Equations
simple linear equations

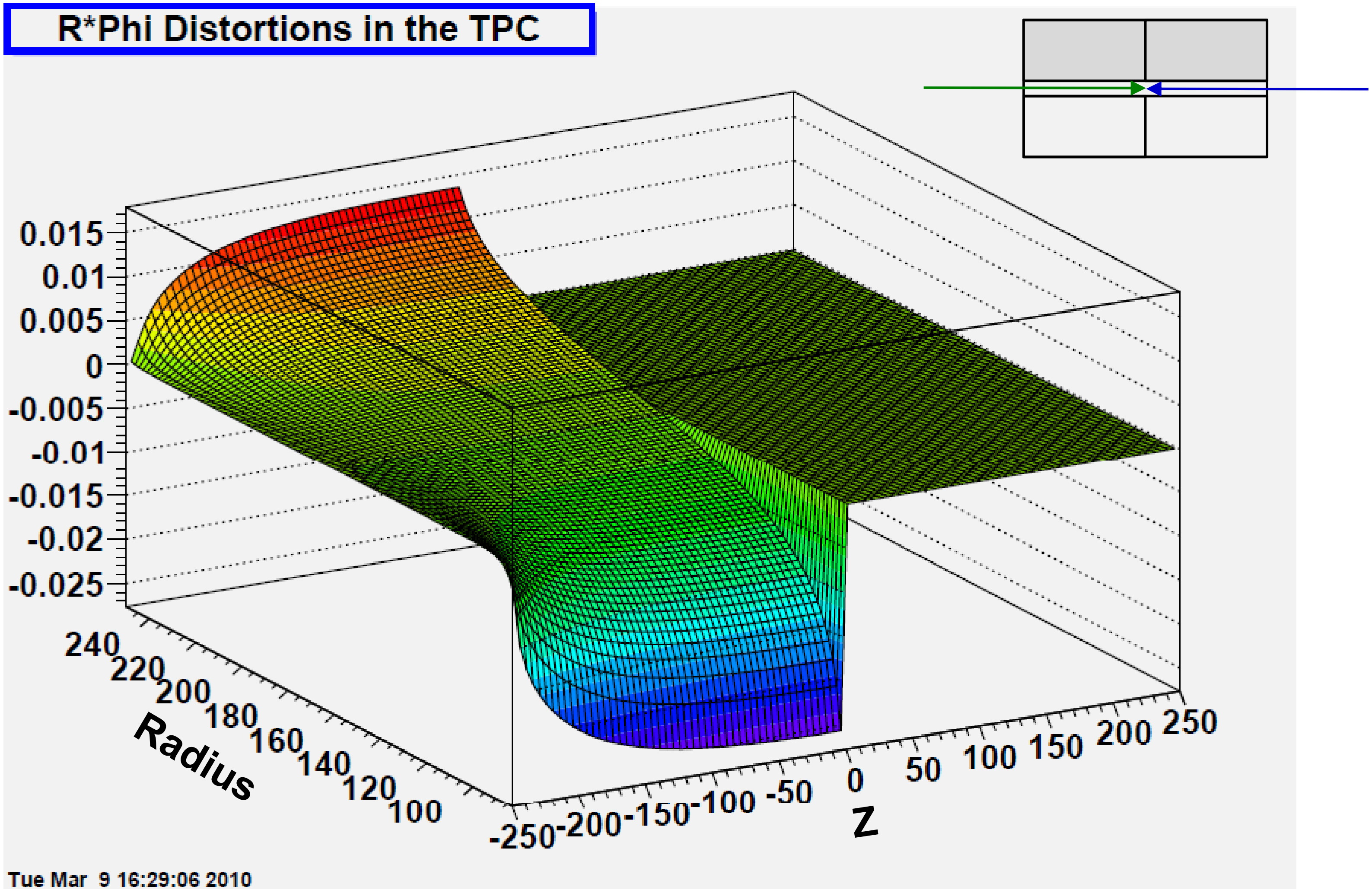
with $c_0 = \frac{1}{(1+T_2^2\omega^2\tau^2)}$, $c_1 = \frac{T_1\omega\tau}{(1+T_1^2\omega^2\tau^2)}$, and $c_2 = \frac{T_2^2\omega^2\tau^2}{(1+T_2^2\omega^2\tau^2)}$

$$\omega\tau = BField[kGauss] * \frac{-10. \; * \; |Drift\,Velocity[cm/\mu sec]|}{|Electric\ Drift\ Field\ Strength\ [V/cm]|}$$

- **Distortions in the TPC are directly related to integrals of the E and B fields**
- **These solutions of the Langevin Equation are exact to 2nd order**
  - **The matrices are rotations (with a pre-factor) related to the Lorentz angle**
  - **Since rotations commute in 2 dimensions, these matrices commute with other rotations and so these equations are valid in Cylindrical Coordinates, too**

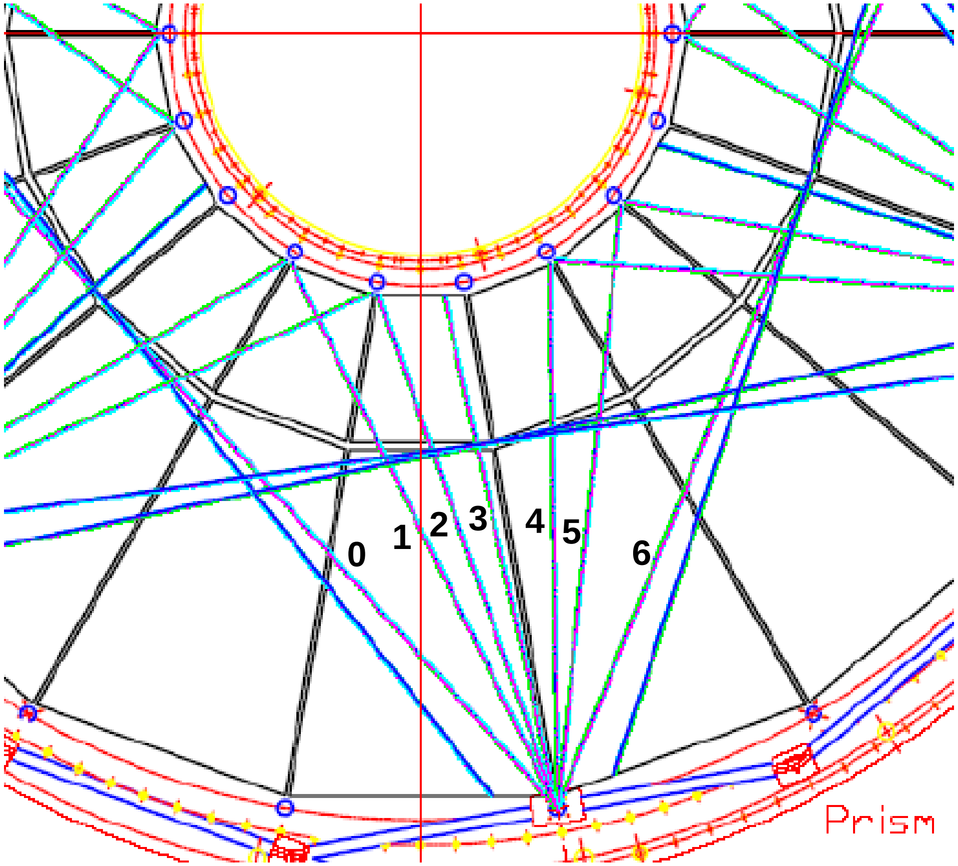
If you have a well defined model, and good data, then the distortion can be removed with great precision

Example: Create a known distortion then measure it



Gated Grid Voltage Error of 10 volts with B Field On, shown in one quadrant of the TPC

In More Detail – two parameters with laser data

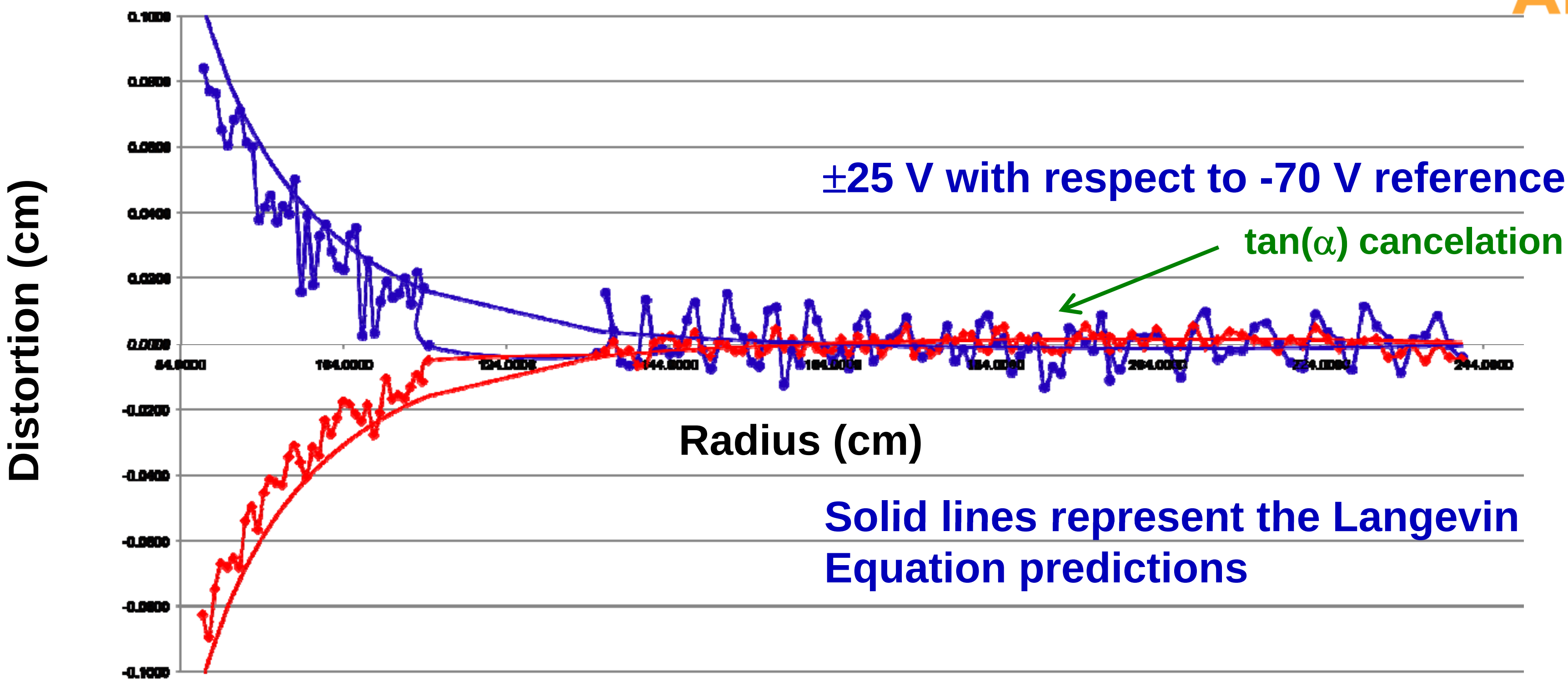


Focus on beams 1, 2 and 5'

- **Laser beam calibrations**
- **Δ is the measured displacement of a cluster, along the pad row, from its nominal position**
  - **θ is angle of the radial vector in the local coordinate system**
  - **Note that $E_\phi = 0$ for this distortion**
- **tan(α) is the crossing angle with respect to the local cartesian coordinate system**
  - ***it may change* if the track progresses from one sector into another**
- **c_0 and c_1 depend on the Drift Velocity, E_z and B_z but are assumed to be known with high precision**
  - **however … see the *fine print* on the next page**

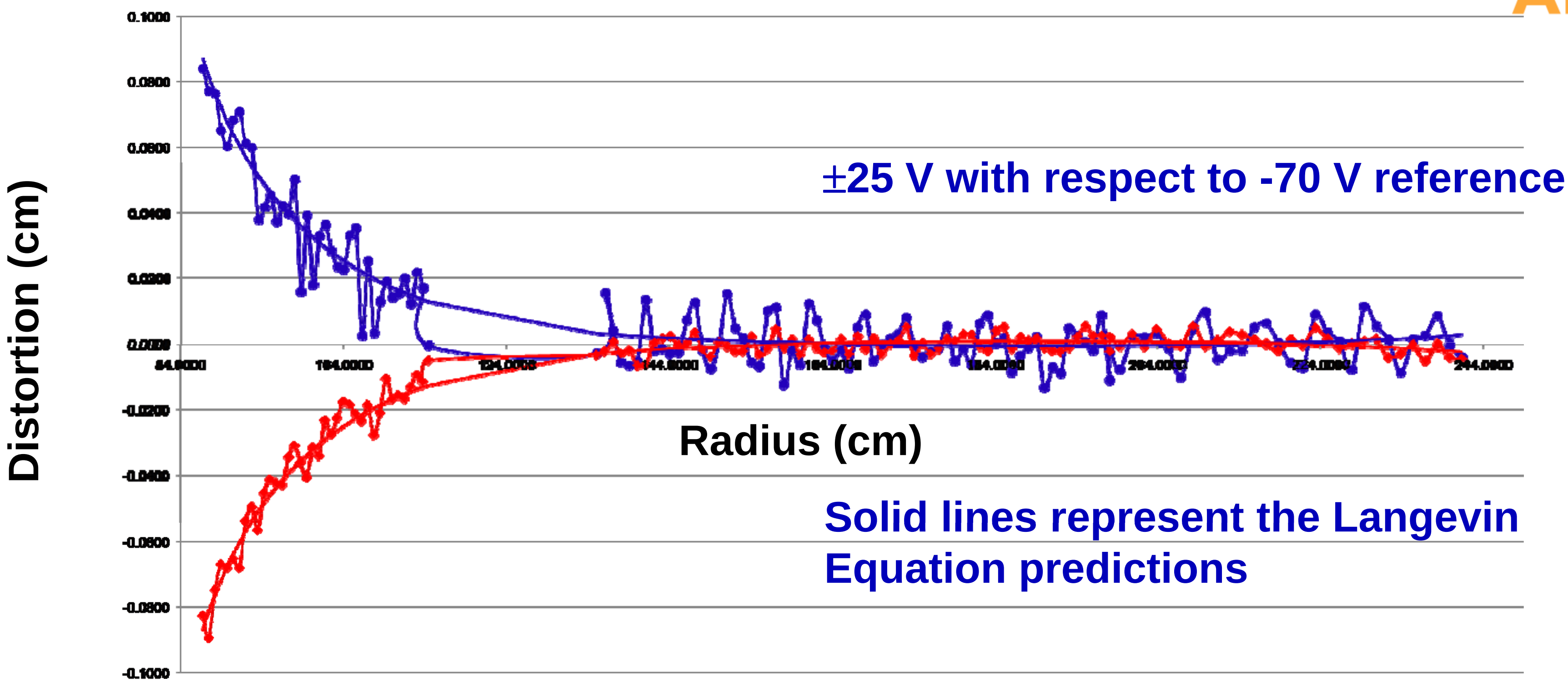
$$\Delta_{\text{PadRow}} = \left(c_0 - c_1 \tan(\alpha)\right) \sin(\theta) \int \frac{E_r}{E_z}\, dz - \left(c_1 + c_0 \tan(\alpha)\right) \cos(\theta) \int \frac{E_r}{E_z}\, dz$$

GG Scan: C Side Bundle 1 Rod 0 Beam 5



- If you read the 'small print' in Blum, Reigler and Rolandi you will find that the electric mobility is a tensor involving T_1 and T_2 and these have not been measured in Ne-CO_2-N_2 gas mixtures
  - T1 and T2 are scale factors between the drift velocities in the transverse plane and the drift velocity in the Z direction
- We have measured these universal gas constants with a Gated Grid scan
  - Measured ΔV_{GG} = ±30 , ±25, ±20, ±15, ±10, ±5, 0 and calculated T_1 and T_2

GG Scan: C Side Bundle 1 Rod 0 Beam 5



- **Before**
  - $T_1 = 0.9$ and $T_2 = 0.9$ (The canonical assumption would have been 1.0)
- **After**
  - $T_1 = 0.9$ and $T_2 = 1.5$ (Universal fit to all of the data taken in the GG scan)
  - Frankly, we expected results closer to 1.0 and 1.0 … but the data are what they are
- **Rolandi and Cherney *et al.* and STAR *et al.* measured the properties of P10**
  - $T_1 = 1.35$ and $T_2 = 1.0$

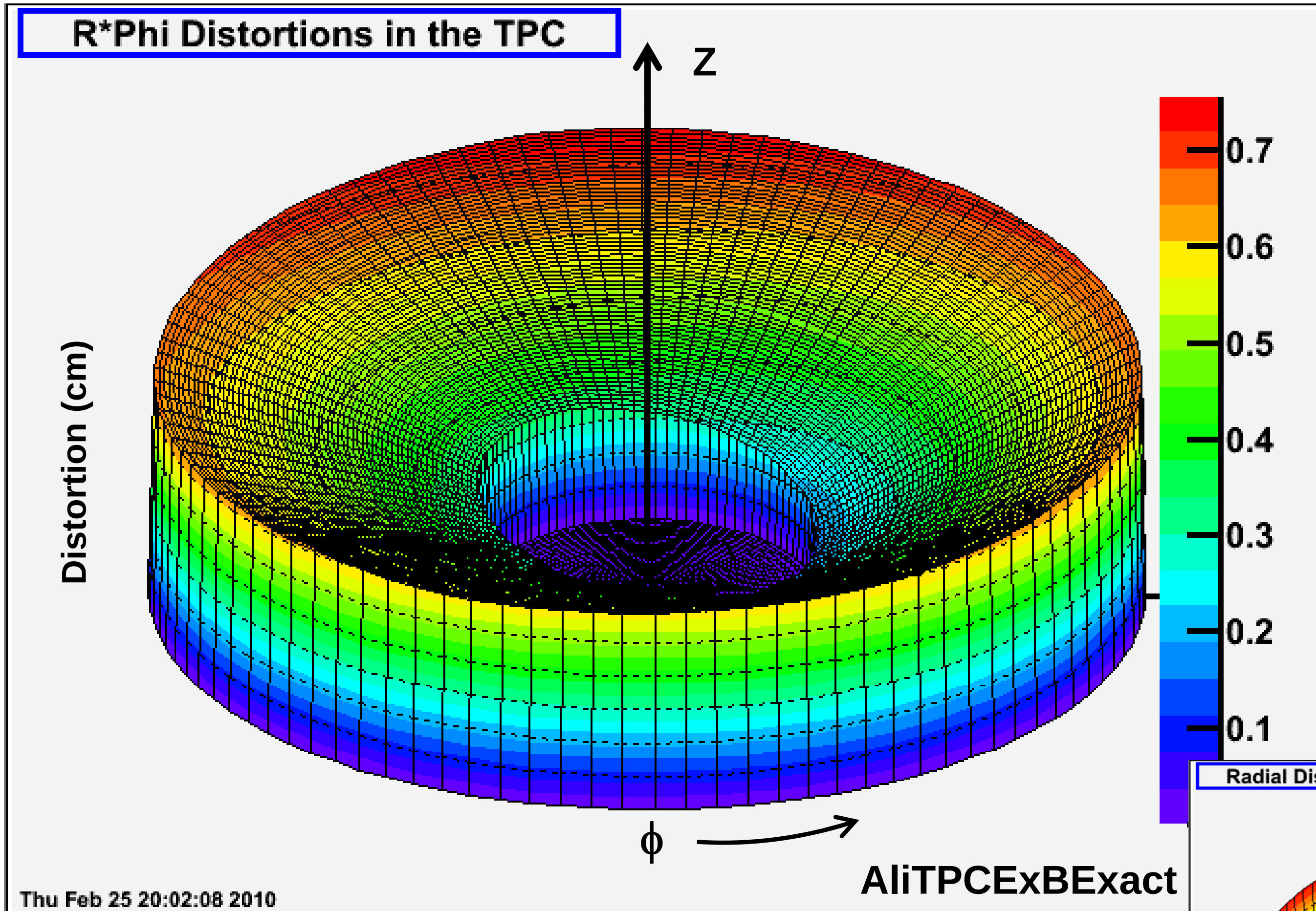
The Next Steps

- **The Langevin Equation is a good model**
  - **We know all of the necessary parameters to continue our work**

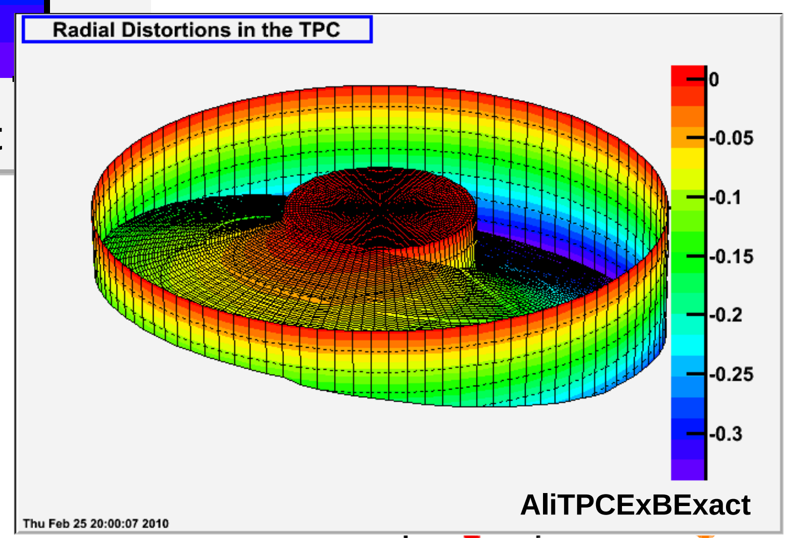
- **The next step is to understand, measure, and remove those distortions which we can identify from the event by event data**
  - **Start with the largest: The distortions due to the non-uniform shape of the magnetic field … we have a map and therefore can evaluate** $\int \frac{B_r}{B_z}\, dz$
  - **Determine the relative angle between the axis of E and B fields**
  - **Determine offsets in the GG voltages due to mislocation, if any**
  - **Determine if there is an offset between the IFC and the OFC**
    - **Two possible sources … simple offset and/or a 'tilt' of the field cage**
  - **Model distortions due to a shift of one or more resistor rods**
  - **Prepare for the effects of spacecharge build up in both pp and HI**
  - **and believe it or not, there are even more things on the list …**

- **All of these activities assume the TPC sectors are aligned etc.**
  - **This is important to get good results, but also a problem because distortions and alignment issues often look the same**
    - **The solutions are different, so we have to be careful**
    - **but fortunately they have different systematics …**

The Largest Distortion: ExB B Field Shape



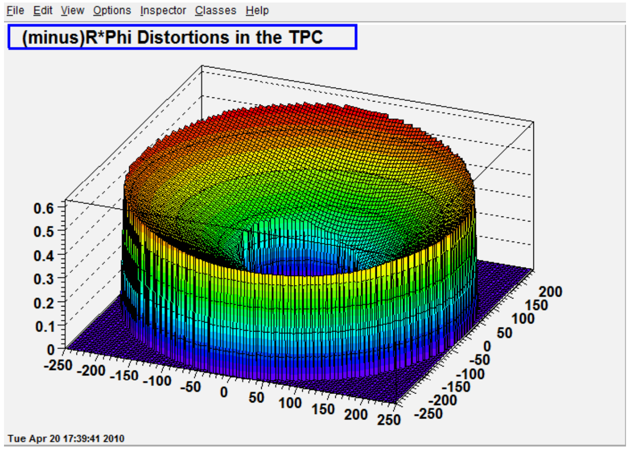
- $\pm$100 gauss B_r fluctuations
- $\pm$50 gauss B_ϕ fluctuations
- 8 mm scale distortions
- The tracks will suffer distortions in the R-ϕ direction as well as in the Radial direction



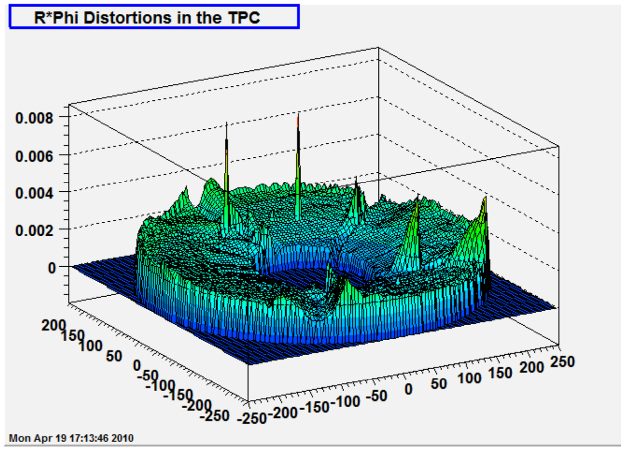
- Previously we noted that $\omega\tau$ is a tensor and so the components of $\omega\tau$ in the 'in-plane' and ExB directions can be different
- We have measured these components for $Ne/CO_2/N_2$ with the lasers & GG scan

B Field Shape: Compare 2^{nd} order and exact calculations

Distortion: Absolute Values



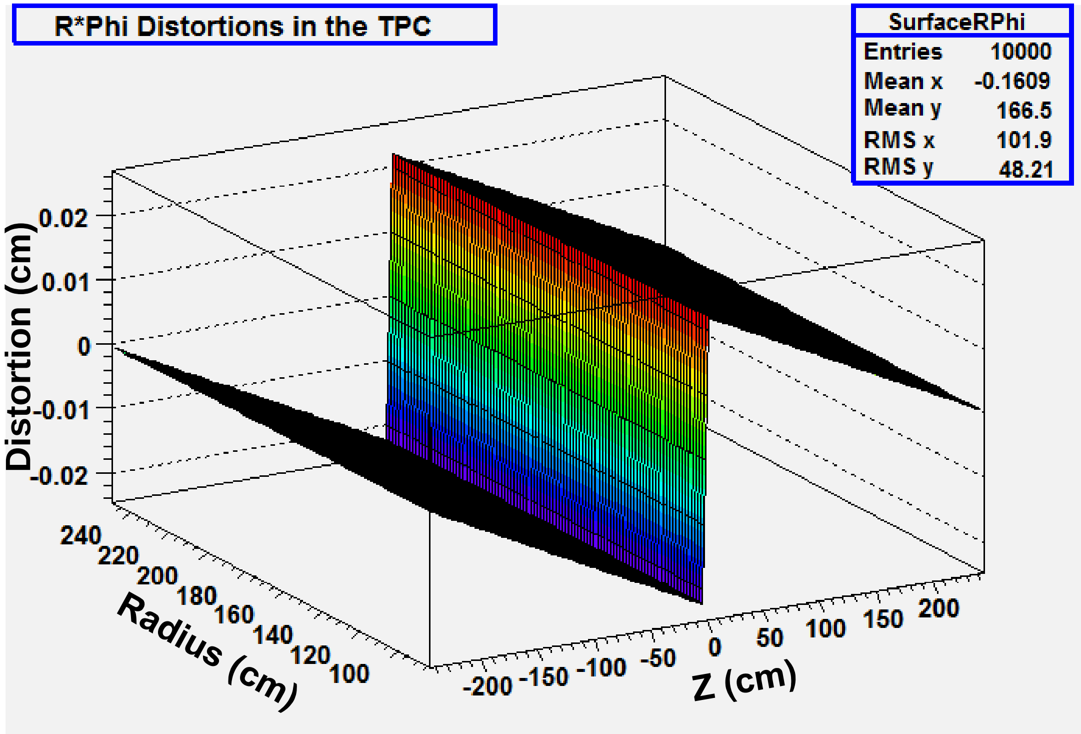
Distortion: Differences

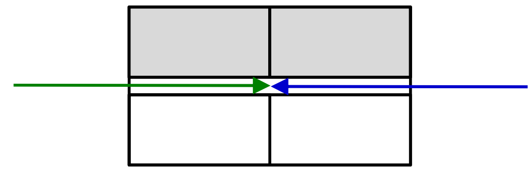


2^{nd} Order - Exact

- **Magnus Mager and Ruben Shahoyan have collaborated to write a new routine where they pre-compute the integrals of the field $\int \frac{B_r}{B_z}\, dz$ and $\int \frac{B_\phi}{B_z}\, dz$**
  - **The new routine is extremely fast and compact**
  - **Accurate to ~20-30 μm**

Another important example: ExB Twist





- A misalignment between the E and B fields
  - E and B should be parallel but are often misaligned by ~ 1 mRad
  - The resulting distortion causes the apparent position of pad planes to shift in opposite directions on each end of the TPC – a simple shift in Cartesian coords
- The angle between the axes of the E and B fields can be measured by reconstructing vertices with tracks from the A side and C side, separately
  - The reconstructed beam lines will not meet at the CE
  - The amount of mismatch is proportional to the angle of rotation or 'twist'

Twist is 'natural' in Cartesian Coordinates

$$\begin{pmatrix} \delta_x \\ \delta_y \end{pmatrix} = \begin{pmatrix} c_2 & -c_1 \\ c_1 & c_2 \end{pmatrix} \begin{pmatrix} \int \frac{B_x}{B_z}\, dz \\ \int \frac{B_y}{B_z}\, dz \end{pmatrix}$$

where $B_x = \theta_x * B_z$, $B_y = \theta_y * B_z$ and $\int \frac{B_x}{B_z}\, dz = \theta_x * Z_{drift}$

If you look at the twist distortion in a cylindrical coordinate system you may not see the natural simplicity of the distortion because

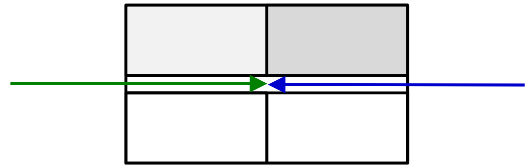
$$\begin{pmatrix} \delta_r \\ \delta_{r\phi} \end{pmatrix} = \begin{pmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} c_2 & -c_1 \\ c_1 & c_2 \end{pmatrix} \begin{pmatrix} \int \frac{B_x}{B_z}\, dz \\ \int \frac{B_y}{B_z}\, dz \end{pmatrix}$$

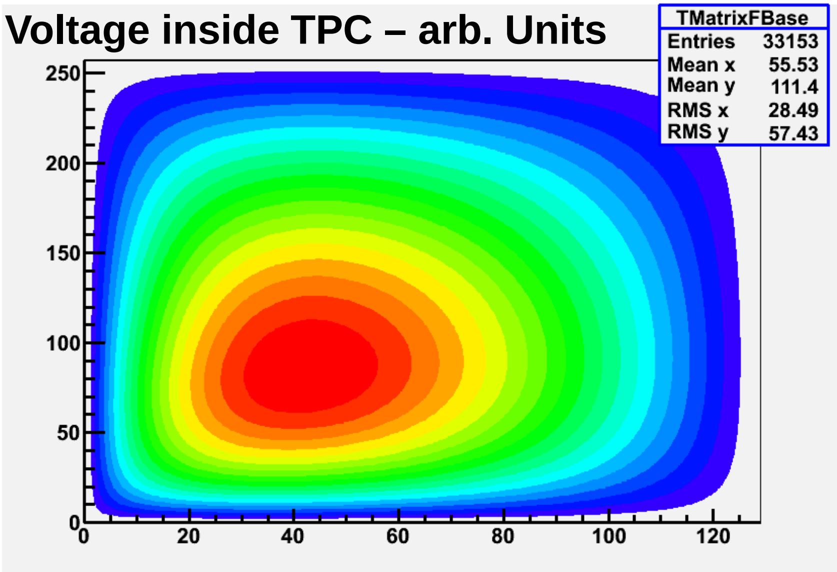
This equation looks like a complicated polynomial over sin and cos terms which hides the fact that the simplest way to view this distortion is in a Cartesian frame

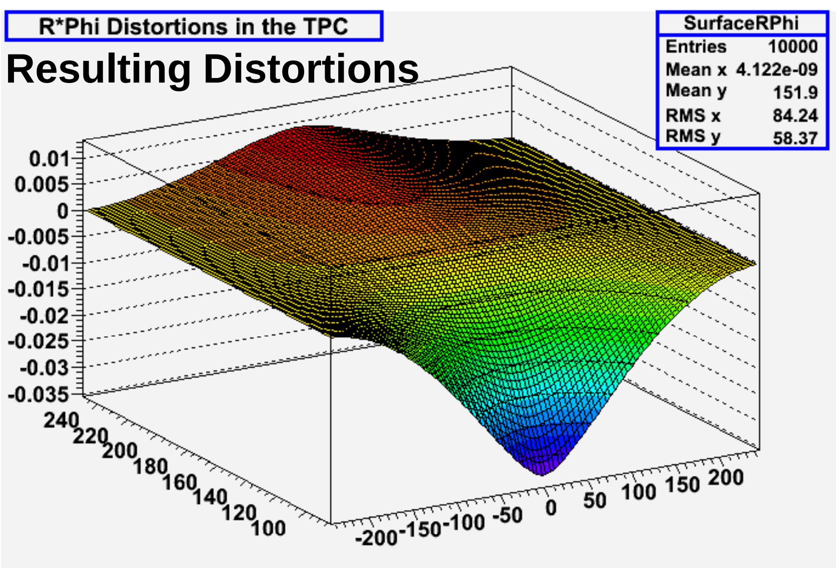
Obviously, rotations and translations of ITS with respect to the TPC will look similar and are easily confused with real distortions. Fortunately, we can tell the difference between the two because distortions decrease linearly with Z_{drift} in the TPC

Choosing the proper frame of reference simplifies the analysis. Distinguishing rotations and translations from 'distortions' can be done based on the systematics in Z and ϕ.

Finally - SpaceCharge







- Spacecharge is the result of ion build-up inside the TPC
- It can be a significant distortion at high luminosity … both pp and HI
- Stefan Rossegger is an award winning expert on space charge
- He said …
  - Alice Electric field is 3x
  - Ne-CO_2 Ion Mobility is 2.5x
  - Energy Loss is 1.5x less

  - 10x better than (I) expected
- Space Charge not a problem for HI
  - Needs attention but not at the same scale as ExB Shape
- 10x previously anticipated p-p $\mathcal{L}$ is not a problem (~$1\text{x}10^{32}$ should be OK)

Conclusions

- The Langevin equation is a microscopic Lorentz Force equation with *Friction* added to represent the macroscopic physics
  - It works. It is an accurate description of the distortions in the TPC
- We know the universal input parameters c_0, c_1 and c_2, and how they scale with E, B, and Drift Velocity
  - But we must know, or have a model for the integrals of the field: e.g. $\int \frac{B_x}{B_z}\, dz$
- If we have an accurate model for an imperfection, we can remove the distortion with high precision (if we don't, we can't, and probably shouldn't try)
- We are building a framework whereby Langevin distortion corrections can be easily implemented in the standard ALICE offline framework
- Homework
  - ExBShape distortions are included in the latest production release
  - ExBTwist needs to be measured (misalignment of ExB) then applied to data
  - GG settings need to be refined
  - We are ready for new applications, with lots of work still to be done …