Correcting distortions in the LC TPC

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Sources of distortions

- There are many effects that cause the measured pattern of ionization on the endplate to deviate from an exact projection of a helical track

- Such effects include:
  - field non-uniformity
  - field misalignment
  - readout module misplacement
  - channel to channel gain variations
  - biases from non-uniform resistive anodes

Distortions from field non-uniformity

- Two independent effects:
  - A non-uniform magnetic field will result in non-helical trajectories for charged particles passing through the TPC
  - The transverse electric and magnetic field components will result in transverse displacements of the drifting electrons
- The latter effect produces larger distortions from transverse magnetic field components

Effects of transverse magnetic field components

- Compare the situations with a perfect B field and the modified B field: $B' = B_0(\beta, 0, 1)$
  - When a charged particle that initially travels in the y direction:
    - for the perfect B field, the helix is in the transverse plane
    - for the modified B field, the helix is in the plane perpendicular to the B′ field at an angle $\sin^{-1}(\beta) \approx \beta$ wrt to the x-y plane
      - the x coordinates are related by: $x' = x\sqrt{1-\beta^2}$
  - Consider a particle that curves 10 mm in x. With a 3% transverse magnetic field component, the x displacement from the expected location is 5 μm

Effects of transverse magnetic field components

- The drifting electrons have a transverse velocity:

$$\frac{v_\perp}{v_z} = \frac{\omega\tau}{\sqrt{1+(\omega\tau)^2}}\beta$$

  - For an electron drifting 1 m, $\omega\tau=5$, a constant 3% transverse magnetic field component produces a transverse displacement of 30 mm!

- electron drift distortion is 4 orders of magnitude larger than the helix distortion, in this example

Electric vs. magnetic field distortions

- Electrons drift according to:

$$\vec{v} = \frac{\mu}{1+(\omega\tau)^2}\left\{\vec{E} + \frac{\omega\tau}{B}(\vec{E}\times\vec{B}) + (\omega\tau)^2\frac{\vec{E}\cdot\vec{B}}{B^2}\vec{B}\right\}$$

- Consider the case where

$$\vec{E} = E_0\left(\varepsilon_r\hat{r} + \varepsilon_\phi\hat{\phi} + \hat{z}\right) \quad \vec{B} = B_0\left(\beta_r\hat{r} + \beta_\phi\hat{\phi} + \hat{z}\right) \quad \varepsilon, \beta << 1$$

- To 1st order in εβ, the velocity components are:

$$v_z = \mu E_0 = v_0$$

$$v_\perp = \frac{v_0}{\sqrt{1+(\omega\tau)^2}}\sqrt{(\varepsilon_\phi + \omega\tau\beta_r)^2 + (\varepsilon_r - \omega\tau\beta_\phi)^2}$$

Electric vs. magnetic field distortions

- The displacements due to transverse electric and magnetic field components scale like:

$$\Delta_\varepsilon \approx \frac{v_\perp}{v_z} L \approx \frac{\varepsilon}{\sqrt{1+(\omega\tau)^2}} L \qquad \Delta_\beta \approx \frac{\omega\tau\beta}{\sqrt{1+(\omega\tau)^2}} L$$

  - where L is the drift length
- For $\varepsilon \sim 10^{-3}$, $\beta \sim 10^{-2}$, L=1m:

B (T)	$\omega\tau$	Δ_ε (mm)	Δ_β (mm)
0	0	1	0
1	1	0.7	7
4	10	0.1	10

Accounting for field distortions

- Momentum estimates are most sensitive to azimuthal corrections
- radial corrections may be less critical, but should not be neglected…

- Two ways to correct field distortions:
  - inverse method (hits)
    - azimuthal only or azimuthal+radial
  - direct approach (general)
    - azimuthal+radial

Inverse approach to field distortion corrections

- A traditional track fit forms “hits” from the data
  - hits are points, possibly with covariance estimate
  - with field non-uniformities, the observed hits are not in the correct locations
  - in the inverse approach, observed hits are moved to their correct location
    - eg. determine a mapping from “true” to “observed” locations: the inverse of this mapping corrects the hits
  - using the corrected hits, determine the optimal track parameters
- This approach can be memory intensive and systematics are not easily evaluated

Direct approach to field distortion corrections

- The likelihood fit does not use “hits”
  - Reminder of method:
    - given a set of track parameters, the likelihood of a track producing the observed sharing of charge in each row is calculated:
      - for each row, the local track segment coordinates are calculated from the track parameters, and the expected charge fractions are calculated
    - the track parameters are varied to maximize the overall likelihood
  - with field non-uniformities, the expected charge sharing given by a set of track parameters is incorrect

Direct approach to field distortion corrections

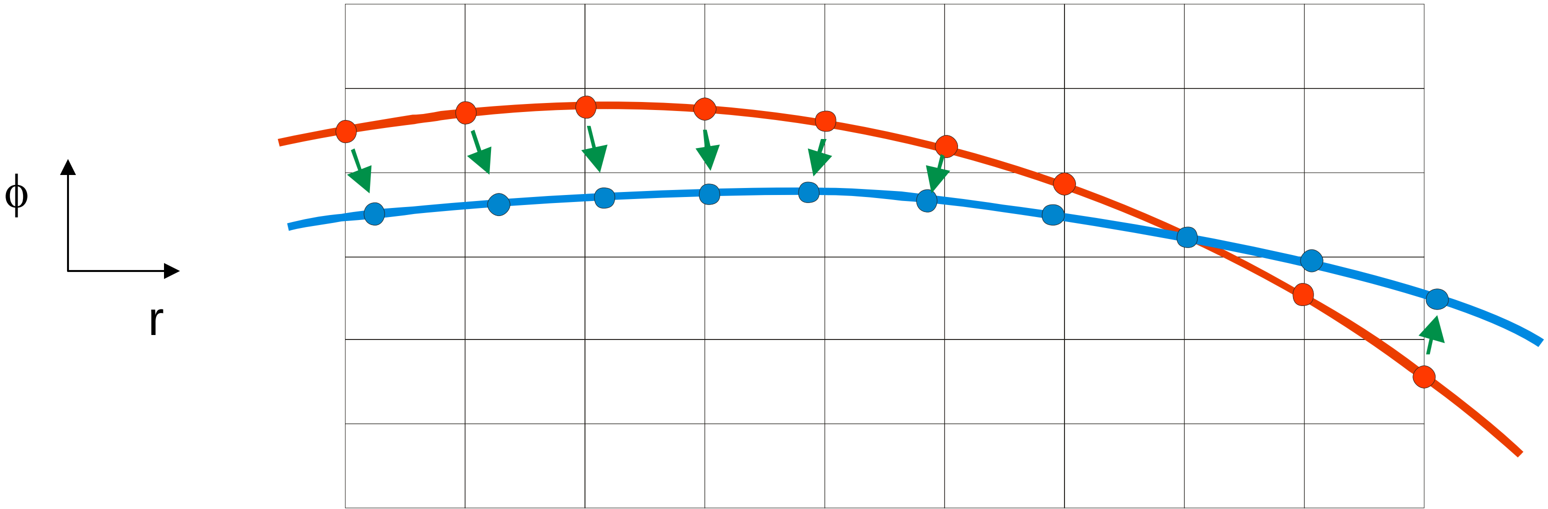
- To account for field non-uniformities in a direct fashion:
  - use the electron transport equations:

    $$\vec{v} = \frac{\mu}{1+(\omega\tau)^2}\left\{\vec{E} + \frac{\omega\tau}{B}(\vec{E}\times\vec{B}) + (\omega\tau)^2\frac{\vec{E}\cdot\vec{B}}{B^2}\vec{B}\right\}$$

    for various points along the track, to estimate the local track segment coordinates at the endplate
    - transport by using standard ODE solver (R-K, etc)
  - points separated by about 1 pad width should be sufficient

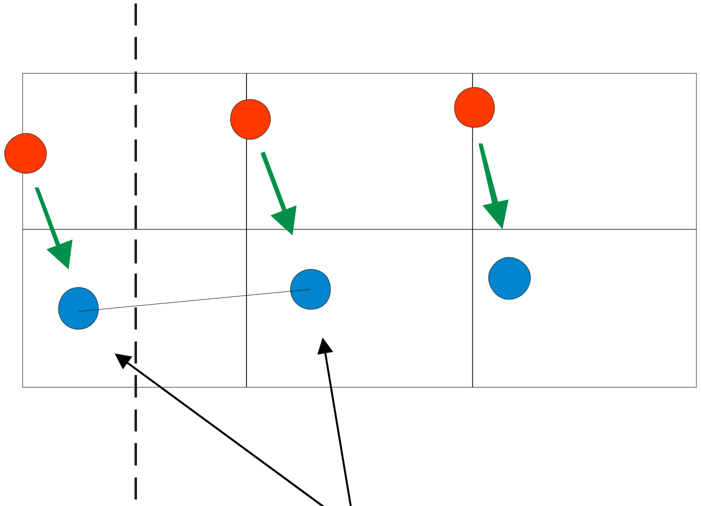
Direct approach to field distortion corrections

- Example:
  - red curve represents helix defined by track parameters
    - points along that track are transported to endplate
  - from the transported points, define the local track segment coordinates for each row - linear



Direct approach to field distortion corrections

- In more detail…



use these two points to calculate the coordinates of the line segment crossing the first row – the quantities that define the expected sharing in that column

- track parameters → corrected local coordinates → evaluate likelihood → repeat to find max L

Direct approach to field corrections

- The track fit will become significantly slower, since each likelihood evaluation involves solving the transport equation many times
  - careful optimization of numerical solution needed
- The fields are not perfectly known
  - A strategy must be developed to define parameterized corrections to the B and E fields
    - best if limited to a few parameters (eg. multipole moments) rather than a 3D grid (millions of parameters)
    - have to consider other sources of distortion…

Overall distortion correction program

- Measure readout module systematics in small test chambers with known ionization locations
- Study readout module misplacements and transverse electric field components in full TPC (B=0) – easier to do if ε is small
  - photoelectron data (full drift)
  - cosmic tracks (range of drifts)
- Study transverse magnetic field components (full B field, various anti-DID fields)
  - photoelectron data (full drift)
  - cosmic and interaction tracks (range of drifts)

Summary

- An approach to account for non-uniform fields in the likelihood track fit is proposed
  - CPU intensive rather than memory intensive
- Additional empirical corrections (field uncertainties etc) could be implemented by parameterized modifications to the E and B fields
  - systematic uncertainties can be evaluated by varying the scale of E&B corrections