TPC Momentum Resolution
- a full simulation

D. Karlen / U. Victoria & TRIUMF
LC TPC mini workshop
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Introduction

Several groups (including Victoria) are using small prototype TPCs to characterize the performance for a LC TPC

- Our data taking run with cosmics and laser tracks in the DESY magnet last summer was very successful
  - presentation at Durham LCWS showed preliminary results
  - full analysis is getting underway – hope to have more complete results for the SLAC LCWS

This talk presents a simulation study of momentum resolution for a large GEM/MM TPC

- extrapolation of small prototypes to a full size TPC
Goals

- Check that the track fit can achieve desired momentum resolution
- Test resolution dependence on
  - pad sizes
  - channel to channel gain variations
  - electronics noise
  - thresholds
  - other systematic effects…
Momentum resolution study

Full simulation scheme:

- GEANT3 simulation of muon propagation and energy loss in a 140 cm length of TDR gas in 4.0 T field
  - Energy losses in 1 mm segments are saved to flat files

- jtpc simulation program:
  - Reads energy losses and converts to electron/ion pairs
  - Electrons drift, diffuse, pass through GEM holes, are amplified, diffuse, get collected on pads, pad signals generated, digitized, and signals stored in data files

- jtpc data analysis program:
  - Read data files, signals converted to charge estimates
  - Likelihood track fit performed to estimate track parameters
  - Momentum resolution determined
Comparison of prototype and simulation

- agreement is reasonably good

- B = 0, Dt = 700 \( \mu \text{m}/\sqrt{\text{cm}} \)

- B = 0.9 T, Dt = 170 \( \mu \text{m}/\sqrt{\text{cm}} \)

- B = 1.5 T, Dt = 110 \( \mu \text{m}/\sqrt{\text{cm}} \)

Target = 0.3 mm
Pad response function

- in a GEM (or micromegas) TPC this can be parameterized analytically, using a simple model
- Four track parameters:
  - \( x_0 \) (x at y=0)
  - \( \phi_0 \) (azimuthal angle at y=0)
  - \( \sigma \) (transverse s.d. of cloud)
  - \( 1/r \) (radius of curvature)
Traditional tracking

- The traditional approach:
  - examine data from each row separately: define a point along the track
Traditional tracking

- The traditional approach:
  - examine data from each row separately: define a point along the track
  - find best track that goes through points
Traditional tracking

Problem with the traditional approach:

- Information in one row is not sufficient to define a point along the track:
  - Charge sharing depends on:
    - X coordinate
    - Local azimuthal angle
    - Width of charge cloud
  - Effect is largest when few pads hit per row
- Dependence is non-linear:
  - Linear centroid finding degrades resolution
Whole track approach

- The whole track approach:
  - fit information from all rows to determine the track parameters at once

- Benefits of the whole track approach:
  - no empirical parameters
    - less calibration
  - reasonable estimates for error matrix
  - better resolution
TPC simulation

- TDR gas at 4 T assumed:

<table>
<thead>
<tr>
<th>Gas Gap: Drift Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness: 3,000 mm</td>
</tr>
<tr>
<td>Drift velocity: 45.48 um/ns</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GEM Foil: Foil 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain: 100</td>
</tr>
<tr>
<td>Foil hole layout: Hex Pack</td>
</tr>
<tr>
<td>y number: 10,001</td>
</tr>
<tr>
<td>Foil hole shape: Circle</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gas Gap: Transfer Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness: 5 mm</td>
</tr>
<tr>
<td>Drift velocity: 30.1 um/ns</td>
</tr>
</tbody>
</table>
TPC simulation

cont...

GEM Foil: Foil 1

Gain: 100
Collection eff.: 1
Extraction eff.: 0.7
Thickness: 0.1 mm

Foil hole layout:
Hex Pack
pitch: 0.14 mm

x number: 1,215
y number: 10,001
x origin: -150 mm
y origin: -690 mm

Foil hole shape: Circle
radius: 0.05 mm

Gas Gap: Induction Gap

Thickness: 5 mm
Drift velocity: 30.35 mm/ns
Trans. diff.: 334.24 um/sqrt(cm)
Long. diff.: 220.11 um/sqrt(cm)

Pad Row Layout: Readout Pads

Design Pad Row Layout
Batch Pad Row Layout

Pixel Size: 0.5 mm
x_min (left): -150 mm
y_min (bottom): -690 mm
x_max (right): 20 mm
y_max (top): 710 mm
### Other parameters:

#### Geant parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>x offset (mm)</td>
<td>0.0</td>
</tr>
<tr>
<td>y offset (mm)</td>
<td>0.0</td>
</tr>
<tr>
<td>z offset (mm)</td>
<td>2500.0</td>
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</tbody>
</table>

#### Pre-Amp parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>gain (mV/ADC)</td>
<td>14.0</td>
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<tr>
<td>rise time (ns)</td>
<td>500</td>
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</tbody>
</table>

#### FADC parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>gain (ch/mV)</td>
<td>2.0</td>
</tr>
<tr>
<td>delta t (ns)</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Use Geant file: data/testa_10GeV_hits.dat

Particle code: 6

W (eV): 26.0
**Example 10 GeV muon event**

- Pad size: $2 \times 7 \text{ mm}^2$
- Drift distance: 2.5 m

Event #1: true $p_t$: 10.0013 GeV/c  fit $p_t$: 10.0017 GeV/c  (Too good!)
Momentum resolution

- repeated events (same track parameters)

\[
\frac{p_{\perp}^{\text{fit}} - p_{\perp}^{\text{true}}}{p_{\perp}^{\text{true}}}
\]

\[
\frac{1}{p_{\perp}^{\text{fit}}} - \frac{1}{p_{\perp}^{\text{true}}}
\]

\[
\delta \left( \frac{1}{p_{\perp}} \right) = 2.8 \times 10^{-4} \text{ (GeV/c)}^{-1}
\]
Resolution vs pt

Momentum resolution

sigma(1/pt) (10^{-4} GeV/c^{-1})

pt (GeV/c)

TESLA TDR Goal

2 x 7
Wider pads

- Charge sharing is less effective for wider pads:

- $2 \times 7 \text{ mm}^2$
- $4 \times 8 \text{ mm}^2$
- $4 \times 14 \text{ mm}^2$
Wider pads

- 4 mm appears to be too wide

![Diagram of Momentum resolution vs. pt (GeV/c)]
Other pad sizes

- Longer or narrower...

2 × 7 mm²
2 × 14 mm²
1.5 × 10 mm²
Other pad sizes

- 2mm x 7 mm seems reasonable

![Momentum resolution graph]

- Momentum resolution $\sigma(1/pt)$ ($10^{-4}$ GeV/c$^{-1}$) vs. $p_t$ (GeV/c)
- Legend: 2 x 7, 2 x 14, 1.5 x 10
Influence of noise

- Number of electrons collected by a pad is estimated by integrating the pulse over 7 time bins (peak +/- 3).
  - Prior to fitting, Gaussian noise is added
  - Noise on each channel assumed to be independent
    (no common mode included)
Influence of noise

- Significant noise can be tolerated in this case

![Momentum resolution graph]

Effective GEM gain: 5000

- $\sigma(1/pt)$ (10^{-4} \text{ GeV/c})
- Pt (GeV/c)
- $2 \times 7$ no noise
- 10k e noise
- 5k e noise
Comparison to standard parameterizations

- Agreement with point resolution \(~ 300 \, \mu m\)

\[
\delta\left(\frac{1}{p_{\perp}}\right)_{\text{res}} = \frac{1}{0.3B} \frac{\varepsilon}{L^2} \sqrt{\frac{720}{N + 4}} = 0.78 \times 10^{-4} \left(\text{GeV/c}\right)^{-1} \frac{\varepsilon}{100 \, \mu m}
\]

\[
\delta\left(\frac{1}{p_{\perp}}\right)_{\text{ms}} = \frac{1}{0.3B} \frac{0.016}{Lp_{\perp} \cos \lambda} \sqrt{\frac{L}{X_0}} = \frac{10.7 \times 10^{-4}}{p_{\perp}}
\]
Summary

- Initial results encouraging:
  - likelihood track fit appears to work reasonably well
    - resolution roughly agrees with parameterization
  - TDR resolution goal nearly attained with TDR gas
  - with large diffusion: relatively insensitive to noise at 5-10k e level

- To do:
  - repeat analysis with lower diffusion gas: eg. P10
  - move tracks around
  - look at inclined tracks
  - look at other systematics?