GEM-TPC Track Resolution Studies

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GEM-TPC Resolution Studies

- A TPC read out by micropattern gas avalanche detectors can provide excellent track resolution
  - Can we achieve this with reasonably large pads?

- Outline of Presentation:
  - Simulation studies on pad geometry (Jeju results)
    - rectangles vs. chevrons
    - rectangular pad width optimization
    - benefit of staggering rectangular pads
  - Analysis of new data sample with different pad sizes
  - Future plans
Simulation Studies

- Java based framework for TPC simulation and data analysis
  - ionization drifted/diffused/multiplied/collectioned

ionization on pads, pad signals
Track Fitting

- x-y track fit uses a linear Gaussian model for the ionization cloud
  - i.e. no fluctuations
- three parameter fit:
  - $x_0$ (x at y=0)
  - $\phi$ (azimuthal angle)
  - $\sigma$ (transverse s.d. of cloud)
- maximize the likelihood of the observed charge fractions from each row
TPC gas selection

- Possible gas mix: Ar CF$_4$
  - fast at low fields
    - small transverse diffusion in magnetic fields
  - much larger diffusion at higher fields
- Example: 98% Ar, 2% CF$_4$
- more conventional, but contains hydrogen
**GEM TPC**

\[
\sigma^D_\perp = 27 \mu m / \sqrt{cm} \quad \sigma^G_\perp = 500 \mu m / \sqrt{cm}
\]

- Naïve calculation for optimum resolution:

\[
\delta x = \frac{\sigma^D_\perp \sqrt{\ell \ [cm]}}{\sqrt{N_{\text{primary}}}} = \frac{27 \mu m \sqrt{200}}{\sqrt{30 \text{ mm} \times 9 \text{ e} / \text{mm}}} = 23 \mu m
\]

(Ar CF$_4$ 98:2)

200 cm 1 cm

defocusing region

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GEM TPC

Ar CF4 (98:2): 5 rows of 2 mm x 6 mm pads

- standard row layout
- chevron 2
- chevron 4
- chevron 10
- optimum (naive)

Chevrons unnecessary in Ar CF₄
GEM TPC
TPC Without Defocusing

\( \sigma^D_{\perp} = 27 \, \mu m / \sqrt{cm} \)

- Naïve calculation for optimum resolution:

\[
\delta x = \frac{\sigma^D_{\perp} \sqrt{\ell \, [cm]}}{\sqrt{N_{\text{primary}}}} = \frac{27 \, \mu m \sqrt{200}}{\sqrt{30 \, \text{mm} \times 9 \, \text{e}/\text{mm}}} = 23 \, \mu m
\]
TPC Without Defocusing

Ar CF4 (98:2): 5 rows of 2 mm x 6 mm pads

Drift length (cm)

$X_0$ resolution (microns)

- standard row layout
- chevron 2
- chevron 4
- chevron 10
- optimum (naive)

Defocusing required for micromegas
Comparison of Pad Widths

50 cm drift: corresponds to transverse cloud s.d. of 0.58 mm

Pad width (mm)

Number of σ (cloud std. dev.s)

x₀ resolution (microns)

Cost (arb. currency)

2 parameter fit
3 parameter fit
Cost
Staggering Comparison (3 par. fit)

Cloud width poorly determined

“Track angle effect”

Track angle effect

Cloud width poorly determined

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Staggering Comparison (2 par. fit)

cloud width fixed to 0.58 mm

$x_0$ resolution (microns)

local $\phi$ (rad)

1 mm staggered  
2 mm staggered  
4 mm staggered  
1 mm not staggered  
2 mm not staggered  
4 mm not staggered
GEM-TPC Data Analysis
GEM-TPC Data Analysis

- Canadian LC - TPC Group:
  - J.-P. Martin – University of Montreal
  - P. Birney, D. Karlen, G. Rosenbaum – University of Victoria / TRIUMF

- TPC 1B:
  - 15 cm drift (no B field)
  - double GEM
  - ALEPH preamp + custom FADC readout
We have recorded a large dataset with a new pad layout:

- 3x multiplexed
- Ar CO₂ (90:10) and P10
- ~ 400 K events
- ~ 75 GB
Example Events

- Outer 6 rows are used to define track parameters
  - inner two rows: resolution studies (fit for $x_0$ alone)
  - 2 mm x 6 mm / 3 mm x 5 mm
Transverse Diffusion

- Transverse cloud size: \( \sigma^2 = \sigma_0^2 + \left(D \sqrt{d[cm]}\right)^2 \)

\( \sigma_0 = 450-500 \mu m \)
\( D = 190 \mu m / \sqrt{cm} \)

\( \sigma_0 = 450-500 \mu m \)
\( D = 500 \mu m / \sqrt{cm} \)

Drift time (5 ns bins)

Ar CO\(_2\)

Uncorrected drift time (5 ns bins)

P10
**$x_0$ Resolution**

- Example: for Ar CO$_2$ (90:10)
  - $d < 2$ cm
  - $|\phi| < 0.1$ rad
  - pad width: 2 mm
  - $<\sigma> = 0.5$ mm
  - $w/<\sigma> = 4$
  - resolution: 140 $\mu$m

![Graph showing residual distribution](image)
Resolution vs. Drift Distance

- Ar CO₂
- |φ| < 0.1

- 3 mm x 5 mm pads
- 2 mm x 6 mm pads

Naïve optimum:
- all primaries collected
  - upper: $\sigma_0$ before amp.
  - lower: $\sigma_0$ after amp.

MC simulations:
- GEM efficiencies:
  - collection 1.0
  - extraction 0.7
Resolution vs. Drift Distance

<table>
<thead>
<tr>
<th>Drift distance (cm)</th>
<th>Resolution (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
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<tr>
<td>4</td>
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</tr>
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<td>12</td>
<td>600</td>
</tr>
<tr>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

- **Naive optimum:**
  - all primaries collected
  - upper: $\sigma_0$ before amp.
  - lower: $\sigma_0$ after amp.

- **It appears that a small fraction of primaries contribute to track fit.**

- **3 mm x 5 mm pads**
- **2 mm x 6 mm pads**

$|\phi| < 0.1$
possible explanation...

A Complete Simulation of a Triple-GEM Detector

W. Bonivento, A. Cardini, G. Bencivenni, F. Murta, and D. Pinci

\[ E_{\text{drift}} = 3 \text{ kV/cm} \]
\[ E_{\text{transfer}} = 5 \text{ kV/cm} \]
Pad Size Effect on Resolution

Resolution (microns)

Distance to edge of pad (mm)

|φ| < 0.05
d < 4 cm
<σ> = 0.52 mm

3 mm x 5 mm pads
2 mm x 6 mm pads

Ar CO₂
Fixing the Cloud Width

- Small improvement in resolution for 2 par. fit
  - Ar CO₂ (90:10)
  - d < 2 cm
  - |φ| < 0.05 rad
  - pad width: 2 mm
  - <σ> = 0.5 mm
  - w/<σ> = 4
  - resolution: 130 µm

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Future Plans

- Second TPC about to be commissioned
  - designed for TRIUMF & DESY magnet tests

STAR electronics front end board
Simulation studies

- Rectangular pads favoured
- Pad widths should be kept below $3-4 \times$ cloud s.d.
  - pad width may be determined by 2 track resolution
- Staggering helps determine cloud width

TPC data analysis

- Large new data set: analysis only just begun
- Have attained 130 $\mu$m resolution with $2 \times 6$ mm$^2$ pads
  - equivalent to LD-Mar01 design (100 $\mu$m for 10 mm long pads)
  - should be able to do better!
- New TPC being prepared for magnet tests