Study of GEM-TPC Performance in Magnetic Fields

Dean Karlen, Paul Poffenberger, Gabe Rosenbaum

University of Victoria and TRIUMF, Canada

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Outline

- TPC prototype test in DESY magnet (2004)
  - UV laser system incorporated
    - single/double beams available under remote control
  - New readout plane with narrower pads
    - data taken with both sets of pads

- Cosmic ray simulation for DESY setup

- Results from 2004 data sample:
  - gas properties
  - dE/dx
  - resolution
  - two particle separation
TPC modifications for UV laser

- New outer acrylic vessel made with windows for laser entry – quartz glass inserted
Laser beam delivery system

- Approx. 2 m long to reach into magnet

Engineering by Mark Lenkowksi
University of Victoria
Laser optics

- Sandblasted quartz reflector
- UV Laser
- Movable mirror
- Photodiode for trigger
- Splitter
- Blocker
- Focusing elements
- Mirror
- Sandblasted quartz reflector

August 18, 2005
Study of GEM-TPC Performance in Magnetic Fields: Dean Karlen
Beam delivery

Movable mirror
Movable splitter, flip in or out of beam
Beam delivery – offset in x and z
Setup with the DESY magnet

- For safety reasons, the UV laser must be contained within a light tight box
Example laser event at 4 T in P5

- Single laser track:
Drift velocity monitor

- Laser very nice to monitor drift velocity (after changing gas or opening the detector):

![Graph showing mean time bin (50 ns bin) vs. time (minutes) with data points ranging from 74.5 to 80.5 and time ranging from 50 to 500 minutes. The graph indicates a trend where mean time bin decreases with increasing time.](image)

Entries: 10,000
Narrower readout plane

- The analysis of 2003 data set showed defocusing in P5 or TDR gas of around 0.4 mm at 4 T.
  - too small for our 2 mm pads ($\text{width}/\sigma_0 = 5$)
- To check effect of pad width, we built a new readout board replacing 2 mm pads with 1.2 mm pads
Cosmic data sets collected in 2004

<table>
<thead>
<tr>
<th>Name</th>
<th>Gas</th>
<th>B [T]</th>
<th>Pad pitch [mm]</th>
<th>Drift field [V/cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>p5B4w</td>
<td>“P5”</td>
<td>4</td>
<td>2</td>
<td>160</td>
</tr>
<tr>
<td>tdrB4w</td>
<td>TDR</td>
<td>4</td>
<td>2</td>
<td>230</td>
</tr>
<tr>
<td>p5B4n</td>
<td>P5</td>
<td>4</td>
<td>1.2</td>
<td>90</td>
</tr>
<tr>
<td>tdrB4n</td>
<td>TDR</td>
<td>4</td>
<td>1.2</td>
<td>230</td>
</tr>
<tr>
<td>tdrB1n</td>
<td>TDR</td>
<td>1</td>
<td>1.2</td>
<td>230</td>
</tr>
<tr>
<td>tdrB0n</td>
<td>TDR</td>
<td>0</td>
<td>1.2</td>
<td>230</td>
</tr>
</tbody>
</table>

- Initial run likely with large concentration of water
To better understand the results from the cosmic ray samples, a full GEANT3 simulation of cosmic events was developed:
Comparison at 4 Tesla

Data:

MC:

Data (p004b4000p5.aida):

MC (p006mc302.aida):
Spectrum/asymmetry of muons

Number of events

Inverse radius of curvature (1/m)

Data
Gas properties

- Diffusion measured on an event by event basis
  - $\sigma^2$ vs drift distance is linear
    - slope $\rightarrow$ diffusion constant ($D$)
    - intercept $\rightarrow$ defocusing term ($\sigma_0$)

![Graph showing variance vs drift distance for B = 1 T and B = 4 T](image)
## Gas properties

<table>
<thead>
<tr>
<th>Data</th>
<th>$v_d$ [cm/μs]</th>
<th>$v_{d,\text{sim}}$ [cm/μs]</th>
<th>$D$ [μm/√cm]</th>
<th>$D_{\text{sim}}$ [μm/√cm]</th>
<th>$\sigma_0$ [μm]</th>
<th>$\sigma_{0,\text{sim}}$ [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>p5B4w</td>
<td>3.84 ± 0.08</td>
<td>3.64</td>
<td>76 ± 5</td>
<td>67 ± 1</td>
<td>429 ± 2</td>
<td>350 ± 2</td>
</tr>
<tr>
<td>p5B4n</td>
<td>3.85 ± 0.04</td>
<td>4.14</td>
<td>34 ± 5</td>
<td>43 ± 1</td>
<td>382 ± 1</td>
<td>369 ± 1</td>
</tr>
<tr>
<td>tdrB4w</td>
<td>4.51 ± 0.05</td>
<td>4.52</td>
<td>71 ± 10</td>
<td>69 ± 1</td>
<td>367 ± 4</td>
<td>262 ± 1</td>
</tr>
<tr>
<td>tdrB4n</td>
<td>4.54 ± 0.06</td>
<td>4.52</td>
<td>70 ± 5</td>
<td>69 ± 1</td>
<td>319 ± 3</td>
<td>255 ± 1</td>
</tr>
<tr>
<td>tdrB1n</td>
<td>4.66 ± 0.06</td>
<td>4.52</td>
<td>205 ± 10</td>
<td>206 ± 2</td>
<td>509 ± 2</td>
<td>289 ± 2</td>
</tr>
<tr>
<td>tdrB0n</td>
<td>4.68 ± 0.06</td>
<td>4.52</td>
<td>348 ± 20</td>
<td>468 ± 10</td>
<td>918 ± 15</td>
<td>580 ± 1</td>
</tr>
</tbody>
</table>
**dE/dx study**

- Use all 11 rows – form truncated average number of electrons collected on the rows per mm of path length
- Overall resolution 17% (86 mm sample)
  - expected 16%
Transverse resolution (per row)

- P5 gas at 4T

![Graph showing transverse resolution vs drift distance for different gas configurations.]

- Systematic biases reported at LCWS05 understood
- Narrow pads incorrectly placed in Gerber files
Transverse resolution (cont.)

- **TDR gas at 4T**

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Resolution [(\mu m)] (data)</th>
<th>Resolution [(\mu m)] (sim.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>p5B4w</td>
<td>108 ± 1</td>
<td>92 ± 1</td>
</tr>
<tr>
<td>p5B4n</td>
<td>68 ± 1</td>
<td>68 ± 1</td>
</tr>
<tr>
<td>tdrB4w</td>
<td>117 ± 2</td>
<td>100 ± 1</td>
</tr>
<tr>
<td>tdrB4n</td>
<td>83 ± 1</td>
<td>87 ± 1</td>
</tr>
</tbody>
</table>

Summary for all drift distances
Transverse resolution for lower fields

![Graph showing transverse resolution for different fields](image-url)
Track angle effect

![Graph showing track angle effect](image-url)

The graph illustrates the resolution (in mm) as a function of the azimuthal angle (in radians) for different track widths and magnetic fields. The data points represent the performance of the GEM-TPC in magnetic fields, with symbols indicating wide, narrow, wide MC, and narrow MC tracks at 4T.

- **Wide** track
- **Wide MC** track
- **Narrow** track
- **Narrow MC** track

The resolution is plotted on the y-axis, while the azimuthal angle is on the x-axis. The graph shows how the resolution changes with varying azimuthal angles and track widths, highlighting the impact of magnetic fields on the GEM-TPC's performance.
Bias/resolution across a pad

- Bias function seen (and predicted) due to underestimate of cloud width
  - Small enough not to affect resolution
- Resolution best near edge of pad for wide pads

![Graphs showing bias and resolution across a pad]
Two track resolution studies

- Bring two laser beams close together at same $z$
  - example (runs 67-69): 3.8 mm separation, $\sigma = 0.5$ mm

![Event Display for Readout Pads](image)
Two track likelihood fit

- Modify maximum likelihood track fitter to allow for charge coming from two tracks to contribute
  - relative amplitudes of the charges from two tracks for each row are treated as nuisance parameters (1 per row)
- Fix sigma (known from \( z \))
- Maximize likelihood for 4 track parameters \( (x_{01}, \phi_{01}, x_{02}, \phi_{02}) \) + 8 nuisance parameters
  - for MIPs the 8 nuisance parameters are independent and maximum likelihood determined by setting \( \frac{\partial L}{\partial \alpha_i} = 0 \)
Double track fits: 2mm wide pads

\[ \Delta x = 3.8 \text{ mm} \]

\[ \sigma = 0.5 \text{ mm} \]

\[ \Delta x = 2.0 \text{ mm} \]

- dips between tracks
- no dips
Resolution degradation (wide pads)

![Graph showing resolution degradation](graph.png)

- Track separation (mm):
  - Two track resolution / single track resolution
  - Values: 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0

- Two track resolution / single track resolution values:
  - Wide, z = 140 mm
  - Laser simulation
Resolution degradation (narrow)
Resolution degradation (muon sim)

Two track resolution / single track resolution

- wide, z = 140 mm
- narrow, z = 54 mm
- narrow, z = 263 mm
- laser simulation
- laser simulation
- laser simulation

Track separation (mm)
Conclusions

- A very successful run at DESY in 2004

- Laser tracks are a useful tool for testing TPC operation
  - Our laser transport system is available for others for DESY laser tests

- GEM-TPC performance at 4T reaching design goals:
  - spatial resolution (~100 mm)
  - two track separation (~3 mm for 2 mm pads)

- Simulation roughly reproduces many features in the data
  - should be useful for optimizing TPC design parameters

- Thanks to the DESY group for the use of the magnet test facility and assistance