Linear Collider TPC
R&D at Carleton University

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http://www.physics.carleton.ca/~karlen/gem
Overview of Carleton TPC R&D

- Focus on readout schemes and resolution studies
  - compared “charge-sharing” and induced signals resolutions
  - simulations of induced signals
  - new ideas to enhance induced signals

- This talk: only “charge-sharing” results presented:
  - space point resolution (x-rays) – brief review
  - tracking resolution (cosmics) – new!
Point resolution studies at Carleton

- x-ray tube
- pin hole
- GEM cell
- 2D micrometer stage
Localization from charge sharing

2D Gaussian model
Charge sharing result – P10

\( (x, y)_{\text{col}} = (0.4, 1.243) \text{ mm} \)

\( \bar{x} = 0.408 \text{ mm} \)
\( \sigma_x = 0.066 \text{ mm} \)

\( \bar{y} = 1.265 \text{ mm} \)
\( \sigma_y = 0.064 \text{ mm} \)
Strip geometry – charge sharing

With P10 gas:
- $x$ standard deviation: 
  - $\sim 70 \, \mu m$

![Graph showing Gaussian and Linear models](image)
Track resolution studies

- Mini-TPC constructed

15 cm
Tracking studies

- Cosmic ray telescope
- Readout pad layout
Details – cosmic data taking

- Gases: Ar CH₄ (90:10) and Ar CO₂ (90:10)
- Drift field: 135 V/cm, GEM gain: ~5000
- pre-amps: ALEPH TPC pre-amp
- readout: 32 channel custom FADC
  - 200 MHz sampling
  - 8 bit

- trigger rates:
  - cosmic telescope: 0.4 Hz
  - require at least one pad hit: 0.04 Hz

- Data:
  - Ar CH₄: 6 days of running (October, 2001)
  - Ar CO₂: 23 days of running (Nov/Dec, 2001)
First event - P10

Run 438 Event 4
ymax 10.
ymin -50.
Two track event – Ar CO$_2$
Gain stability – P10

- Charge per row
- Charge vs time

Stable within 5%
Gain stability – Ar CO₂

- Charge per row
- Charge vs time

Stable within 5%
Tracking studies

- Fit x-y and y-z separately

- y-z fit:
  - for each row form weighted average of pulse arrival time
  - perform unweighted linear fit of the 5 row y-coordinates vs row times
  - pulse arrival time (50% rise) dependant on pulse amplitude
    - needs further study
y-z fit results – P10

- Not diffusion limited
  - pulse arrival time definition needs improving
- 800 micron resolution independent of drift length
- \( v_d \sim 50 \, \mu m/ns \)
y-z fit results – Ar CO₂

- **Diffusion limited**
  - less sensitive to pulse arrival time problem because of slow drift

- 130 micron resolution for drift length < 1cm

- \( v_d \sim 9 \, \text{µm/ns} \)
x-y fit

- use model of uniform line of charge, with Gaussian transverse spread, $\sigma$
  - charge fractions given by integral over pad
- fit uses observed charge fractions within each row
  - $\min \chi^2$ with $x_0$, $\phi$ and $\sigma$ free
- ionization fluctuations
  - not included in model
  - unimportant for $\phi = 0$
  - leads to track angle effect on resolution
Line charge width – P10

- Results from fit of data: diffusion apparent

\[ \sigma = 0.045 \sqrt{d \cdot \text{cm}} \]
Line charge width – Ar CO$_2$

Results from fit of data: diffusion apparent

\[ \sigma = 0.019 \sqrt{d \cdot \text{cm}} \]
Track $x_0$ resolution - P10

- $x_0$ resolution from single row:
  - do fit excluding the row: $x_0$, $\phi$, $\sigma$ free
  - do fit for single row: only $x_0$ free
  - compare 1 row $x_0$ to 4 row $x_0$

\[
\sigma_x = 220 \pm 20 \, \mu m
\]

\[
\sigma_x = 320 \pm 10 \, \mu m
\]

\[
\sigma_x = 420 \pm 8 \, \mu m
\]

\[
\sigma_x = 560 \pm 8 \, \mu m
\]
Track $x_0$ resolution - Ar CO$_2$

- $x_0$ resolution from single row:
  - do fit excluding the row:
    - $x_0$, $\phi$ free
    - $\sigma$ fixed
  - do fit for single row: only $x_0$ free
  - compare 1 row $x_0$ to 4 row $x_0$

$\sigma_x = 260 \pm 10$ $\mu$m

$\sigma_x = 288 \pm 6$ $\mu$m

$\sigma_x = 319 \pm 4$ $\mu$m

$\sigma_x = 396 \pm 4$ $\mu$m
Centroid finding – P10

- Linear weighted $x_0$ coordinate less accurate

Gaussian model

\[ \sigma_x = 220 \pm 20 \, \mu m \]

linear weighting

\[ \sigma_x = 290 \pm 20 \, \mu m \]
Centroid finding – Ar CO₂

- Linear weighted $x_0$ coordinate less accurate

Gaussian model

$$\sigma_x = 260 \pm 10 \, \mu m$$

linear weighting

$$\sigma_x = 414 \pm 13 \, \mu m$$
Track angle effect – P10

Appears to be significant, but small statistics

\[ \sigma_x = 110 \pm 15 \, \mu m \]

\[ \sigma_x = 280 \pm 50 \, \mu m \]
Track angle effect – Ar CO$_2$

- Appears to be significant

\[ \sigma_x = 168 \pm 16 \, \mu \text{m} \]

\[ |\phi| < 0.05 \]
\[ z < 10 \, \text{mm} \]

\[ \sigma_x = 252 \pm 17 \, \mu \text{m} \]

\[ 0.05 < |\phi| < 0.15 \]
\[ z < 10 \, \text{mm} \]
Primary ionization effect – Ar CO$_2$

- Improvement of resolution with primary electron statistics
- For large ionisation resolution degrades
  - Delta-rays

\[ \sigma_x = 379 \pm 3 \, \mu m \]  
\[ \sigma_x = 302 \pm 4 \, \mu m \]  
\[ \sigma_x = 278 \pm 9 \, \mu m \]  
\[ \sigma_x = 339 \pm 22 \, \mu m \]
Sample events \((P10, z<10 \text{ mm}, |\phi|<0.05)\)
Sample events (P10, z<10 mm, |\phi| <0.05)
Sample events (P10, z<10 mm, |φ| <0.05)
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Sample events (P10, z < 10 mm, |ϕ| < 0.05)
Future plans for Carleton studies

- Continue cosmic tracking studies
  - improve track fit program: $\chi^2$ not done right!
    - ArCO$_2$ resolution should be better than P10!
  - comparison with simulations
  - alternative gases?
  - include calibration constants? (none so far!)
  - alternative readout pad geometries?
  - Q: can “charge sharing” signals alone provide optimal resolution and two particle separation?

- new ideas for spreading signal over more pads
  - resistive layer above pads that absorbs charge and leave only induced signals
Summary

Findings from charge sharing measurements:

- Good *space point* resolution with relatively large pads
  - 2D Gaussian model works well
- Good *tracking* resolution with relatively large pads
  - Line-Gaussian model works well
  - pad diameter $\sim 4 \times$ transverse diffusion is ok
  - do not need to increase transverse diffusion to match pad diameter!

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