GEM R&D for TPC Readout

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Outline

- Brief summary of LC tracking issues
- TPC readout with GEMs
- GEM R&D studies at Carleton
  - space point resolution (x-rays)
  - tracking resolution (cosmics)
- Summary
LC tracking systems

- Tracking requirements:
  - good momentum resolution for high energy isolated charged particles
    - recoil mass resolution for dileptons in HZ
    - end-point resolution for leptonic susy decays
      \[ \Delta(1/p_t) \approx 5 \times 10^{-5} \text{ (GeV/c)}^{-1} \]
  - reconstruction of hadron jets
    - good two-track separation
    - energy flow requires good absolute position resolution with minimal mass
To achieve these requirements:

- High magnetic fields (~ 4 T)
- Large tracking volume
- 3D space point measurements
  - less sensitive to accelerator backgrounds
TPC tracker for a future LC

- European design:
LC TPC R&D underway

- International collaboration formed:
  - Aachen, Carleton, CERN, DESY, Hamburg, Karlsruhe, Krakow, LBNL, Orsay, Saclay, MIT, NIKHEF, Novosibirsk, MPI Munich, Rostock

- Several issues:
  - gas choice
  - readout technology (emphasis of R&D):
    - Gas Electron Multiplier (GEM)
    - Micromesh Gaseous Structure (micromegas)
    - conventional pads or silicon
    - conventional wire chamber
  - pad geometry
  - electronics

- goal: complete R&D and prototype: 2-3 years
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Gas Electron Multiplier (GEM)

E_{\text{drift}} = 0.2 - 1.0 \text{ kV/cm}

\Delta V \approx 400 \text{ V}

E_{\text{transfer}} \approx 3 \text{ kV/cm}

\Delta V \approx 400 \text{ V}

E_{\text{induction}} \approx 3.5 \text{ kV/cm}

\Delta V \approx 400 \text{ V}

Readout pads
Using a GEM for TPC readout

Conventional TPC readout

Induced signals (motion of positive ions) spread over large area.

GEM TPC readout

Direct signals (electrons on pads) spread over smaller area. Induced signals (e⁻ motion) also present.
Potential advantages for GEM readout

- Improved space point resolution
  - $E \times B$ and track angle systematics suppressed

- Improved two particle separation power
  - $r - \phi$: signals distributed over smaller area
  - $z$: faster pulses ($v_e > v_{ion}$)

- Natural ion feedback suppression
  - no gating required (non-triggered expt.)

- Less mass in TPC endcap
  - no wires held under tension
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Point resolution studies at Carleton

x-ray tube

pin hole

GEM cell

2D micrometer stage
GEM foils and pads for this study fabricated at the CERN PCB workshop

GEM foil

50 µm

140 µm

GEM pads

2.5 mm pitch hexagons
Details

- x-ray mean energy: 4.5 keV
- pinhole diameter: ~50 µm
- Gas: Ar CO₂ (~90:10) / P10 : Ar CH₄ (90:10)
- pre-amps:
  - fast Lecroy HQV 810 with Ar CO₂
  - slower ALEPH TPC pre-amp with P10
- readout:
  - two 4-channel digital scopes (9 bit ADC)
    - 500 MHz sampling for HQV 810
    - 125 MHz sampling for ALEPH preamps
Localization from charge sharing

2D Gaussian model

PAD 2  PAD 8  PAD 1

x coordinate (mm)  y coordinate (mm)
Charge sharing result – P10

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

\[ \bar{x} = 0.408 \text{ mm} \]
\[ \sigma_x = 0.066 \text{ mm} \]

\[ \bar{y} = 1.265 \text{ mm} \]
\[ \sigma_y = 0.064 \text{ mm} \]
Scan over entire pad

100 µm circles centred at pin hole locations during scan

- With P10 gas:
  - cloud size 550 µm
  - x,y standard deviations: ~70 µm
Localization from charge sharing

- Method works only in regions where significant charge is deposited on 3 pads

```
Ar CO₂
Charge sharing regions

P10
Charge sharing region
```
Localization from induced signals

Distance from pad centre (mm)

Rel. signal amplitude
Scan over entire pad

- With P10 gas:
  - x,y standard deviations: ~80 µm
  - note: systematics in x clearly seen
Strip geometry – charge sharing

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

- Gaussian model
- Linear model

fraction of charge collected by strip 1

strip 1 strip 2
Strip geometry - induced signals

- Strip geometry has larger induced signals by factor of 2 – 3
  - x standard deviation: ~70 µm
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Tracking studies

- Mini-TPC constructed

15 cm
Tracking studies

- Cosmic ray telescope
- Readout pad layout

![Cosmic ray telescope diagram with readout pad layout](image)

5 mm

2.5 mm
Details – cosmic data taking

- **Gas:** Ar CH₄ (90:10)
- **Drift field:** 135 V/cm
- **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:**
  - 6 days of running (end of October, 2001)
First event

Run 438 Event 4
y_{max} = 10.
y_{min} = -50.

TOP

BOTTOM
Gain stability

- 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

- Not diffusion limited
  - pulse arrival time definition needs improving
- 800 micron resolution independent of drift length
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
Transverse width of line charge

- Results from fit of data: diffusion apparent
Track $x_0$ resolution

- $x_0$ 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 $x_0$

$\sigma_x = 220 \pm 20 \mu m$

$\sigma_x = 320 \pm 10 \mu m$

$\sigma_x = 420 \pm 8 \mu m$

$\sigma_x = 560 \pm 8 \mu m$
Centroid finding

- Linear weighted $x_0$ coordinate less accurate

Gaussian model

$\sigma_x = 220 \pm 20 \mu m$

$0 < z/mm < 10$

Linear weighting

$\sigma_x = 290 \pm 20 \mu m$

$0 < z/mm < 10$
Track angle effect

- Appears to be significant, but small statistics

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

\[ \sigma_x = 280 \pm 50 \, \mu m \]
Sample events ($z < 10 \text{ mm}, |\phi| < 0.05$)
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Future plans for Carleton studies

- Continue cosmic tracking studies
  - alternative gases (lower diffusion)
  - include calibration constants (none so far!)
  - alternative readout pad geometries
  - Q: can direct charge signals alone provide optimal resolution and two particle separation?
  - Q: are the small induced signals helpful?

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

- TPC is the leading candidate for a future linear collider

- Coordinated international effort for R&D for a LC TPC
  - emphasis is on new readout methods involving micro-pattern gas detectors

- Findings from Carleton GEM/TPC R&D:
  - Good space point resolution and tracking resolution achieved with relatively large pads
    - pad diameter $\sim 4 \times$ transverse diffusion is ok

- GEM readout for TPCs looks promising