Spatial Resolution of a MPGD readout TPC Using the Charge Dispersion Signal

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CAP2005 – Instrumentation for Particle Physics
Outline

- Detector Design for the ILC
- Physics Challenge
- R&D on TPC at Carleton
- Results from Cosmic Data
- Planning Ahead
- Summary

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CAP2005 – Instrumentation for Particle Physics
Detector Concept Design for the ILC
Tracking Requirements

- Excellent momentum resolution
- Precision vertexing (b-tagging)
- **Measure about 200 track points with a resolution of 100 µm or less for all tracks**
- Resolution goal near the ultimate limit from diffusion & electron statistics
- Hermetic & minimized material
- Operate continuously throughout ~1 ms train
- Particle flow for overall event reconstruction
- Robust, reliable, stable, affordable & long life time
Precision measurements: Higgs Boson
Tracking challenge

Model Independent Higgs reconstruction via the standard reference reaction:

\[ \sigma \left( \frac{1}{p_t} \right) \sim 2 \times 10^{-5} \text{ (GeV/c)}^{-1} \text{ is necessary for the tracker} \]

\[ \sigma \left( \frac{1}{p_t} \right) \sim 1.5 \times 10^{-4} \text{ (GeV/c)}^{-1} \text{ for the TPC only} \]

\[ H \, Z \rightarrow \ell \, \ell \, X \]

\[ M_H = 120 \text{ GeV/c}^2 \]

- Signal
- Background

\[ \sqrt{s} = 350 \text{ GeV} \]

\[ L = 500 \text{ fb}^{-1} \]
Time-Projection-Chamber (TPC)

Long drift path

E [230 V/cm]

B [2 - 4 T]

- 60 kV

outer field cage

central membrane

inner field cage

cable route

TPC support arm

electronics

FCH

endplate
Conventional wire/pad TPC readout

- $E \times B$ and track angle systematic effects cannot be avoided in a wire/pad TPC (wires few mm apart)
- Even when systematics cancel, the resolution is determined by the width of the pad response function and not by physics of diffusion
- Large pad response function further limits the TPC two-track resolving power
- Positive ion space-charge effect also adds complication
- Technology used at LEP with $\sigma = 200 \, \mu m$
Micro-Pattern-Gas-Detector (MPGD) Readout

MPGD hole
(schematic)

track

100 µm

MPGD hole

track image

drifting electrons

pad plane

P ~ 140 µm
D ~ 60 µm

E×B effect reduced

e.g. GEM
Charge Collection on MPGD Readout Pads

- No preferred direction for tracks
- Electric field very uniform
- Tiny amplification MPGD holes
- Small multiplication gap
- Positive ion feedback reduced
- Pads dimension $2 \times 6 \text{ mm}^2$
- **Limited by charge collection on a single pad for a TPC in high B-field**
- Difficult centroid finding
- Resolution
  \[ \sigma = 2 \text{ mm} / \sqrt{12} \approx 580 \text{ \(\mu\)m} \]

- Optimize readout geometry and diffusion
- Study induced signal on neighboring pads
Gas Electron Multiplier (GEM) and Micromegas

The Gas Electron Multiplier (GEM)

- $V_D$
- $V_T$
- $V_B$
- $GND$
- $\Delta V_{GEM}$

Drift Gap

Induction Gap

Readout anode pads or strips

Micromegas

- Conversion gap: 3 mm
- Amplification

MPGDs achieve excellent $\approx 40 \, \mu m$ resolution with $200 \, \mu m$ wide pads

This implies a VERY large number of channels and high cost

ILC TPC channel count is already $\sim 1.5 \times 10^6$ with 2 mm wide pads

Not practical to use pads much narrower than 2 mm

Maximize diffusion & multiple gap (GEM) – resistive anode (Micromegas)
The Concept of Charge Dispersion

- Modified GEM anode with a high resistivity film bonded to a readout plane with an insulating spacer
- 2-dim continuous RC network defined by material properties and geometry
- Point charge at $r=0$ & $t=0$ disperses with time
- Time dependent anode charge density sampled by readout pads:

\[
\frac{\partial \rho}{\partial t} = \frac{1}{RC} \left[ \frac{\partial^2 \rho}{\partial r^2} + \frac{1}{r} \frac{\partial \rho}{\partial r} \right]
\]

\[
\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{-\frac{r^2RC}{4t}}
\]
Cosmic Ray Resolution of a MPGD-TPC

- Instrumentation lab at Carleton
- 15 cm drift length TPC: GEM & Micromegas readout [B=0]
- Ar:CO\textsubscript{2}/90:10 chosen to simulate low transverse diffusion in a magnetic field.
- DAQ: 200 MHz custom 8 bit FADCs [UdeM]
- Aleph preamps
  \( \tau_{\text{Rise}} = 40 \text{ ns} \quad \tau_{\text{Fall}} = 2 \mu\text{s} \)
- 60 tracking pads
  2 x 6 mm\textsuperscript{2}
- 2 trigger pads
  24 x 6 mm\textsuperscript{2}
Compared to direct charge readout, charge dispersion gives better resolution for GEM with Z dependence close to the diffusion limit. For Micromegas, the resolution is also better than for direct charge GEM readout.

\[ \sqrt{\sigma_0^2 + \frac{C_D^2}{N_e} z} \] (Diffusion limit of resolution)
Goals of the Upcoming Test Beam

- Location: KEK 1-4 GeV/c hadron beam
- Superconducting Jacee magnet: 1.2 Tesla
- New readout pads with 128 channels
- Test the resolution of GEM and Micromegas with resistive foils within a magnetic field
- Investigate two-track reconstruction
- Study concept of new fast-electronics
Future & International Detector Design

- Strong collaboration on TPC R&D between:
  - UVIC/Carleton/UdeM (Canada)
  - Aachen/Hamburg/Karlsruhe/MPI-Munich (Germany)
  - Orsay/Saclay (France)
  - Berkeley/Cornel/Purdue (USA)
  - KEK & DESY

- The ILC detector Conceptual Design Report ~2007/8
- Strong commitments to be part of these activities

- Large prototype at DESY with the Jacee magnet:
  - Simulation and two-track pattern recognition
  - Field cage and investigation of non-uniformity
  - Design of the end plate readout and electronics

- Good timing to join the ILC/Canada effort
TPC with MPGD readout is a very well suited technology for the ILC
Better space point resolution has been achieved for GEM & Micromegas readout TPC with a resistive anode than for the conventional direct charge readout TPC
Measured resolution near the diffusion limit in cosmic tests with no magnetic field for MPGD with resistive anodes
With suitable choice of technology, gas, & electronics for a resolution of \( \sim 100 \, \mu m \) for all tracks (2.5 m drift) appears within reach for the ILC tracking system
The diffusion limit will be lower in a magnetic field: cosmic & beam tests planned to confirm the diffusion limit of resolution for a TPC in a magnet [KEK and DESY]
Future large scale prototype: Canada is engaged in the design and construction of a large international prototype with MPGD readout