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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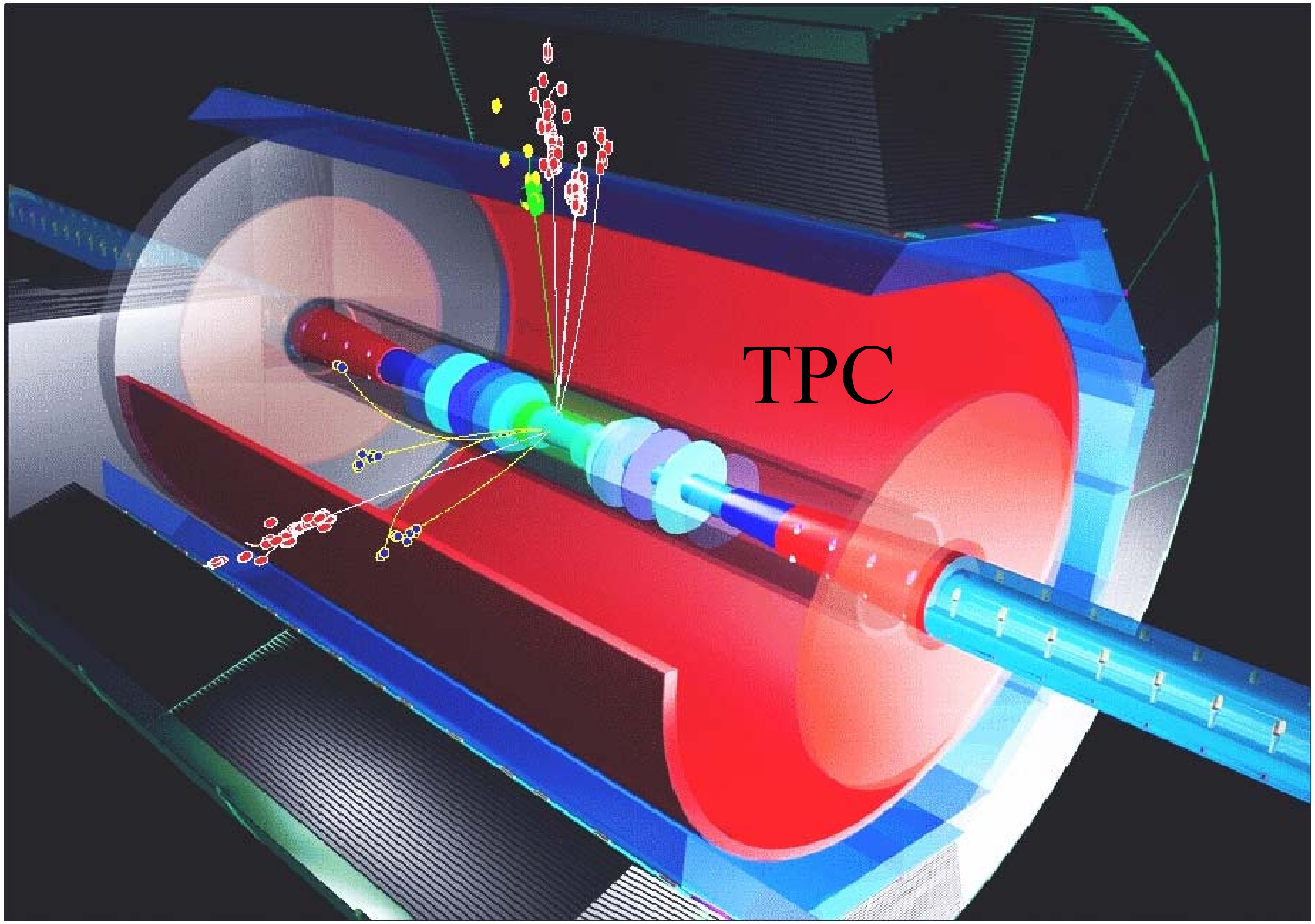
Detector Concept Design for the ILC



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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

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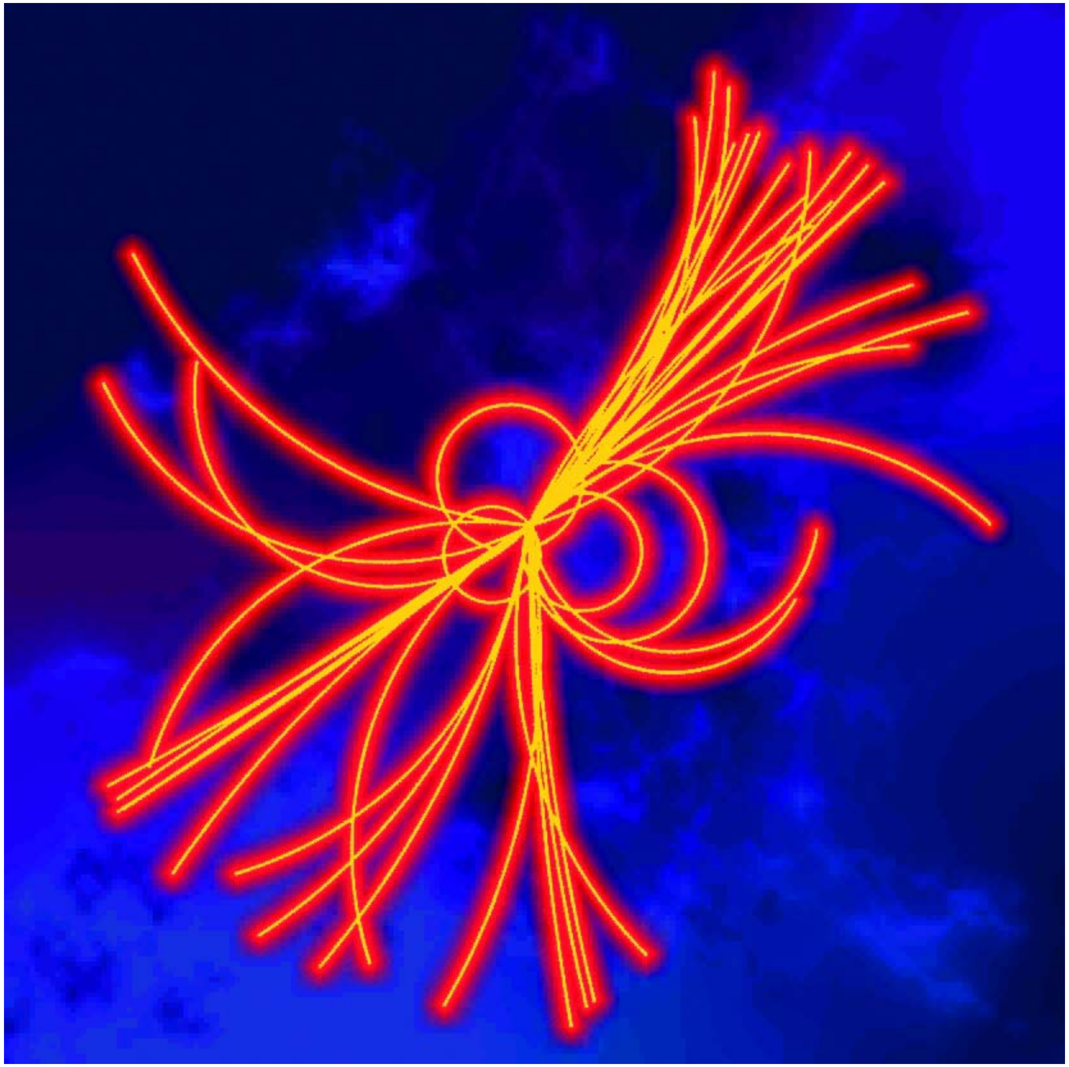
Precision measurements: Higgs Boson



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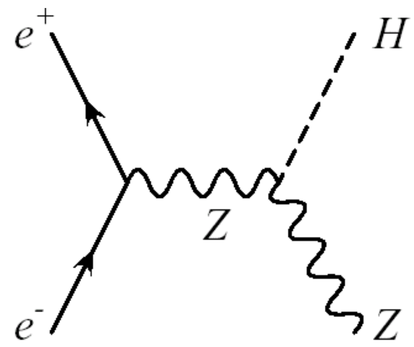
Tracking challenge

Model Independent Higgs reconstruction via the standard reference reaction:

$\sigma(1/p_t) \sim 2 \times 10^{-5}\ (GeV/c)^{-1}$ is necessary for the tracker

$\sigma(1/p_t) \sim 1.5 \times 10^{-4}\ (GeV/c)^{-1}$ for the TPC only



$$HZ \to \ell \ell X$$

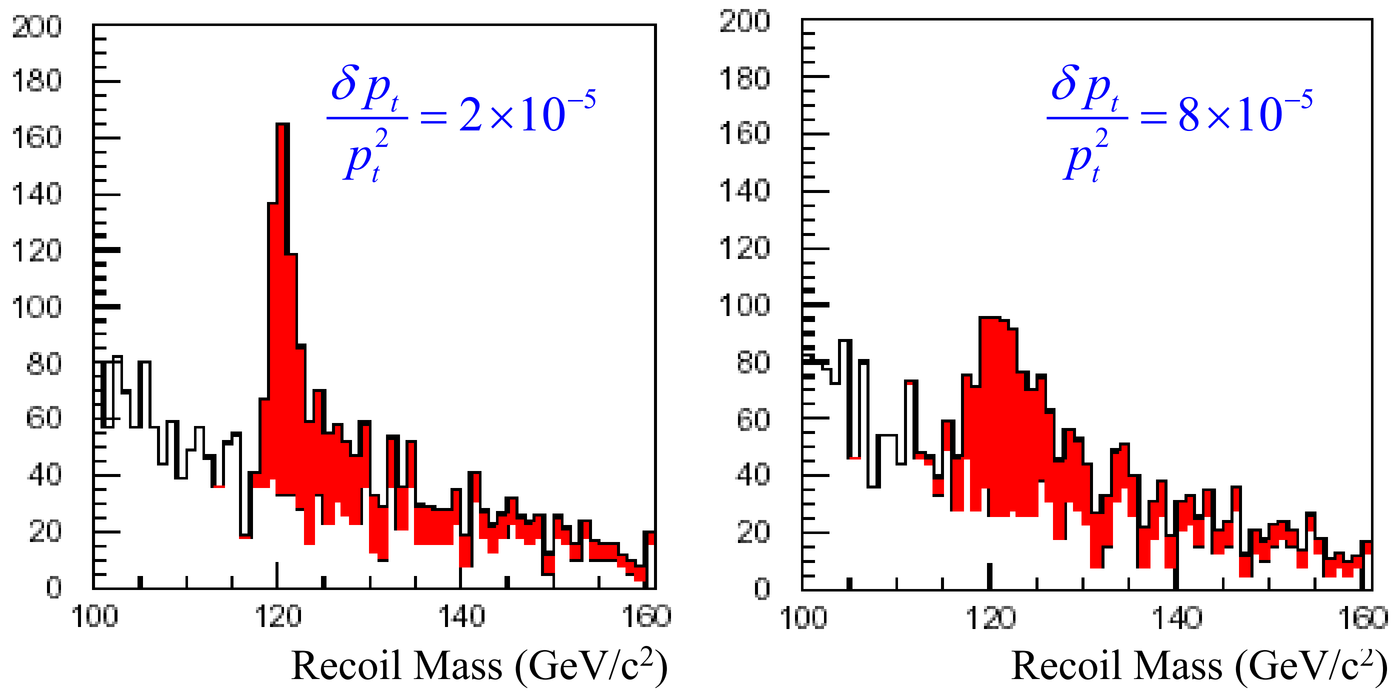
$M_H = 120\ \mathrm{GeV/c^2}$

Signal

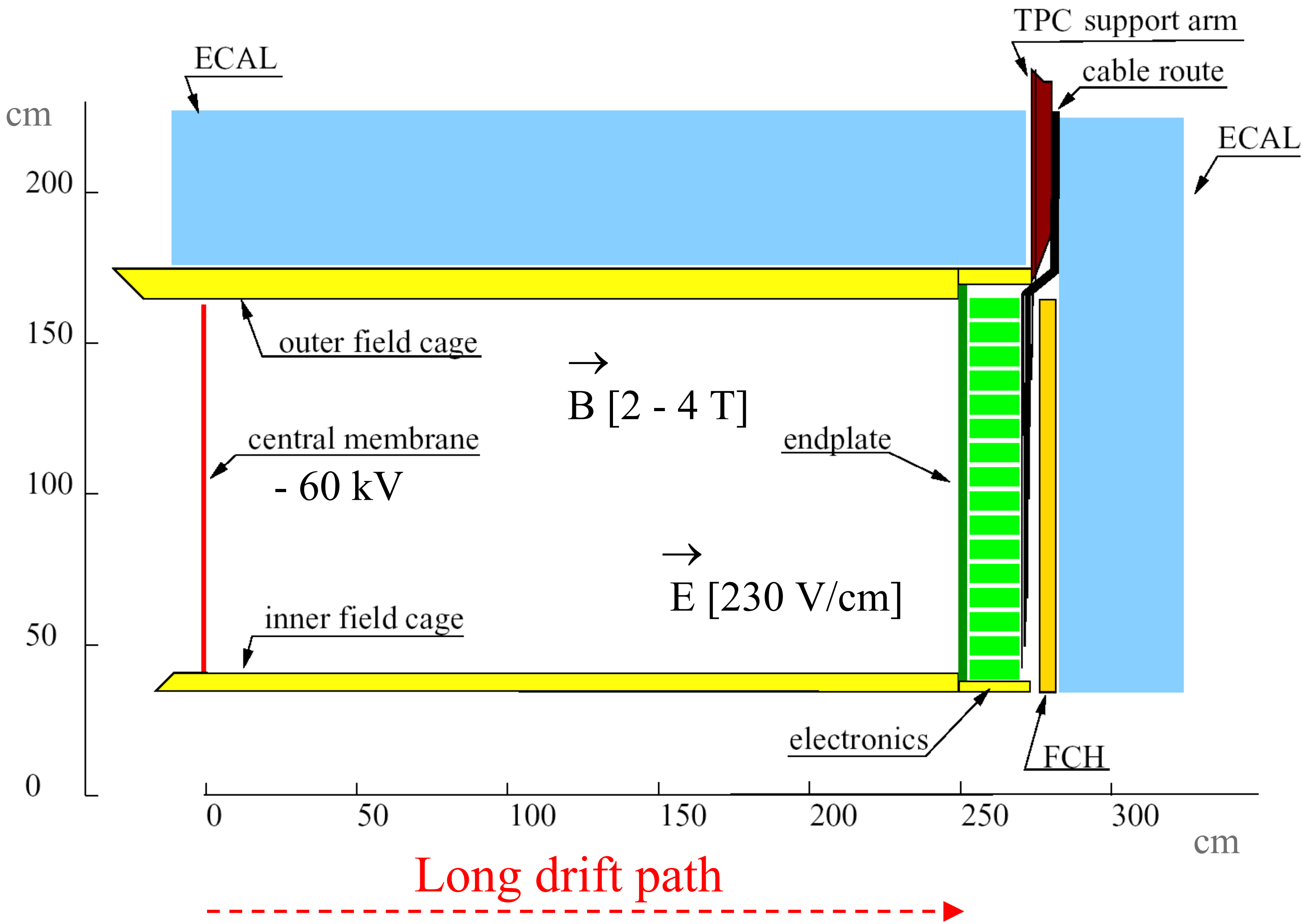
Background

$\sqrt{s} = 350\ GeV$

$L = 500\ fb^{-1}$



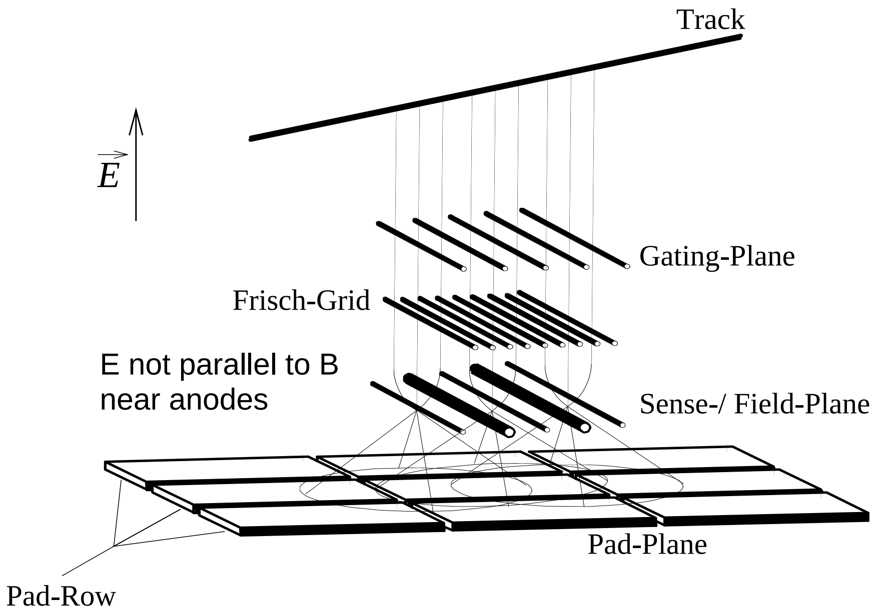
Time-Projection-Chamber (TPC)

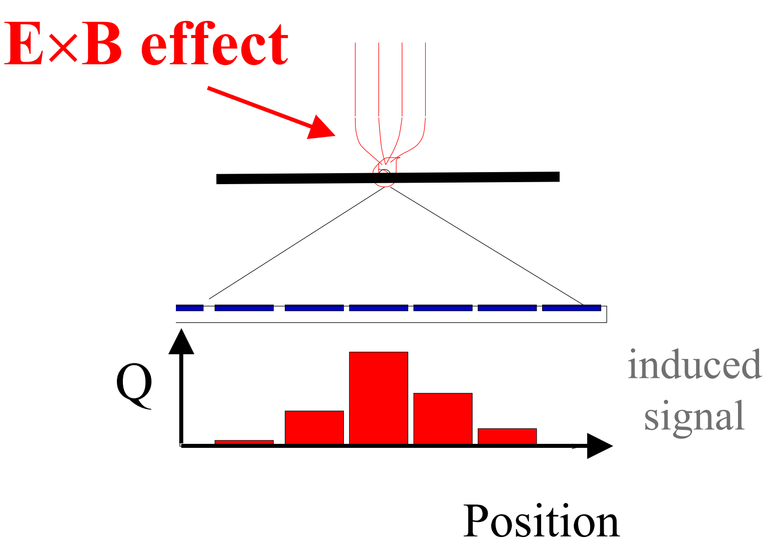


Conventional wire/pad TPC readout

- **E×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

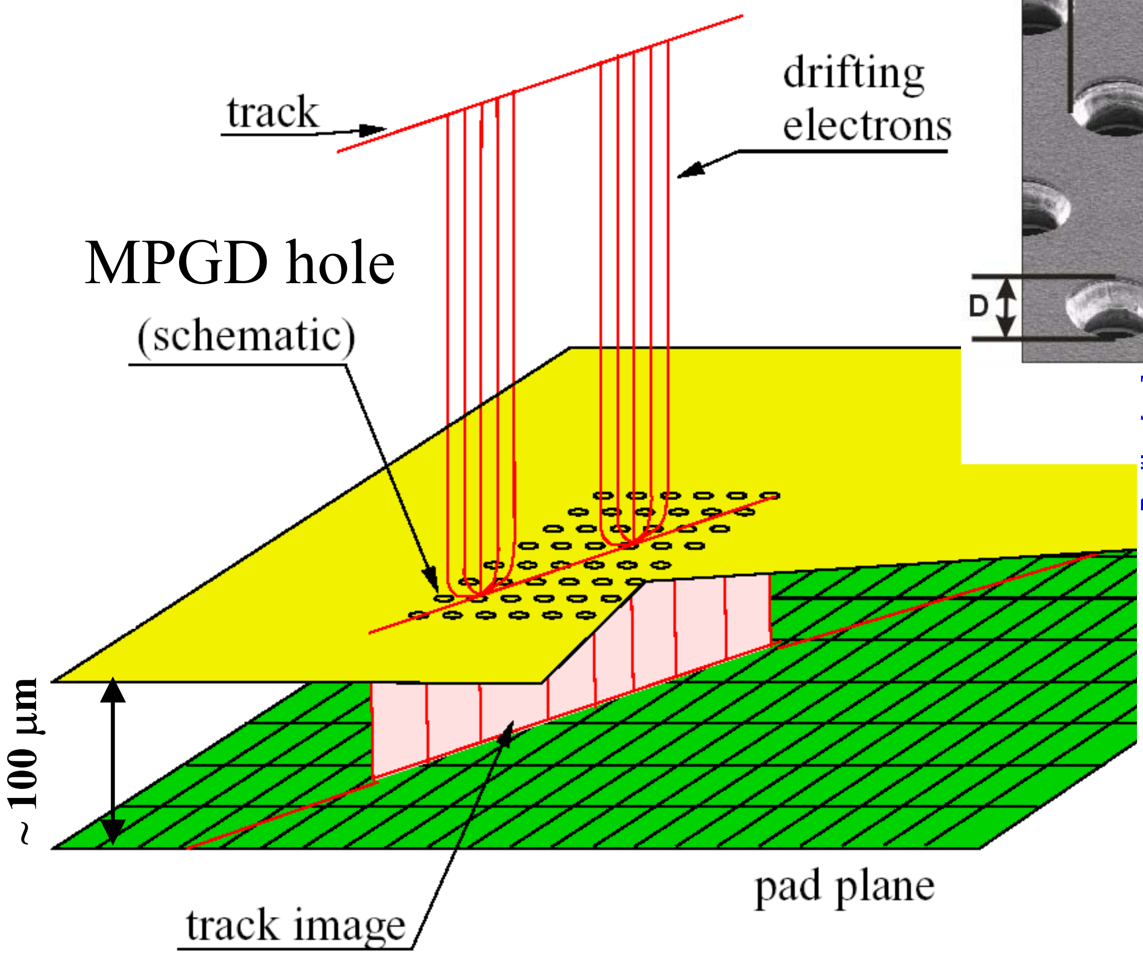
  with $\sigma = 200\ \mu m$ ☹

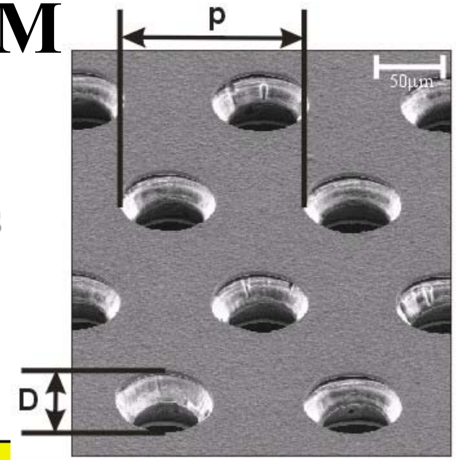




Micro-Pattern-Gas-Detector (MPGD) Readout

e.g. GEM

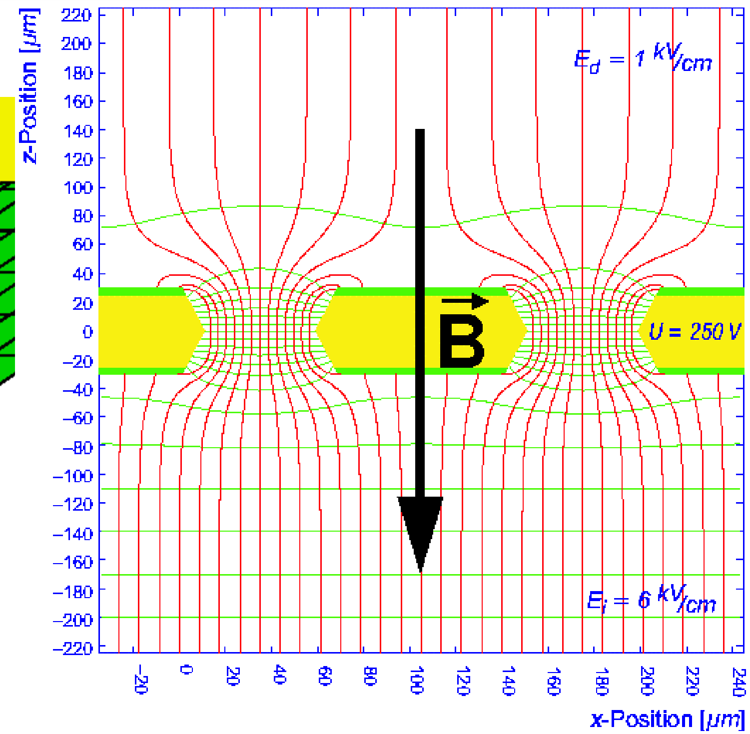




P ~ 140 µm

D ~ 60 µm

E×B effect reduced



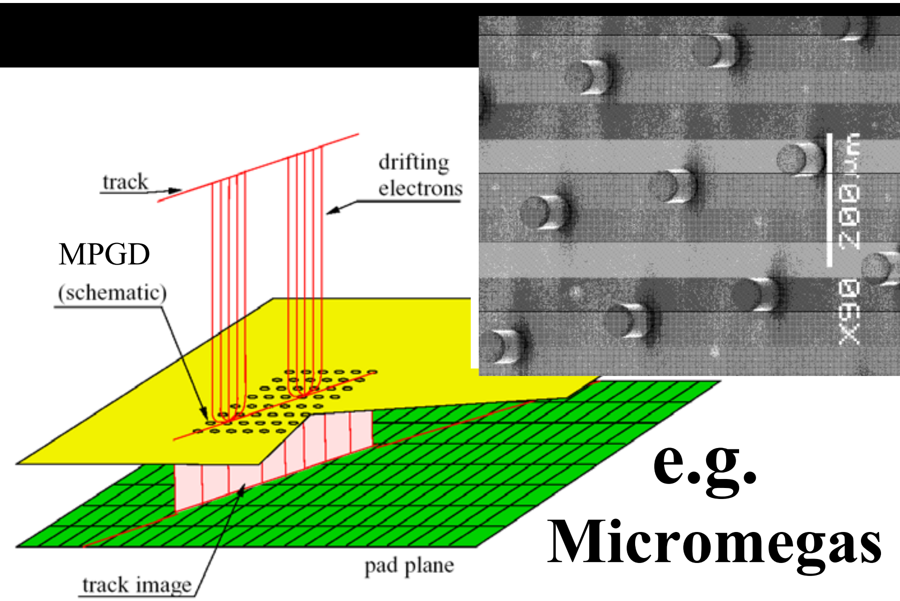
Charge Collection on MPGD Readout Pads

- No preferred direction for tracks
- Electric field very uniform
- Tiny amplification MPGD holes
- Small multiplication gap
- Positive ion feedback reduced
- Pads dimension 2 × 6 mm^2
- **Limited by charge collection on a single pad for a TPC in high B-field**
- Difficult centroid finding
- Resolution

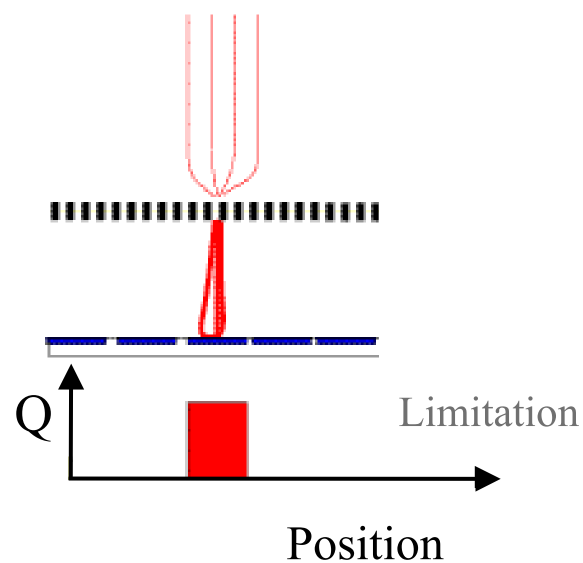
$$\sigma = 2\ \text{mm} / \sqrt{12} \approx 580\ \mu\text{m}$$

Optimize readout geometry and diffusion

Study induced signal on neighboring pads

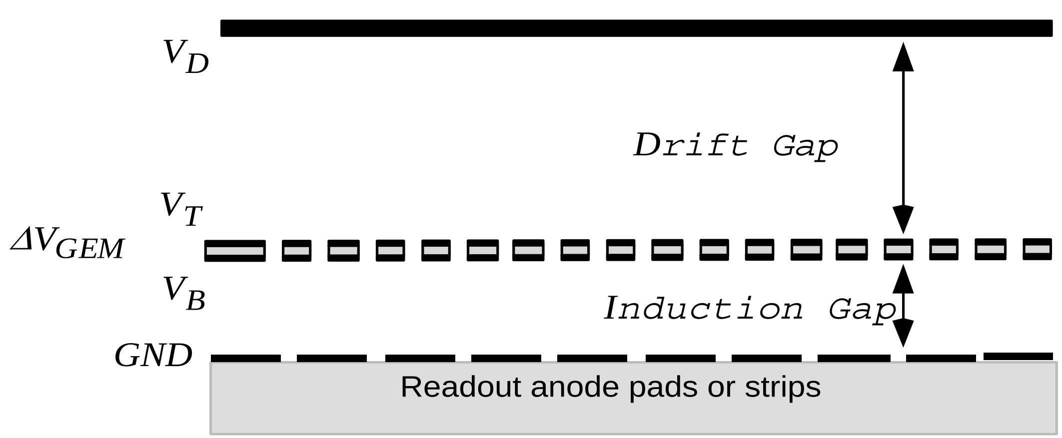


e.g. Micromegas

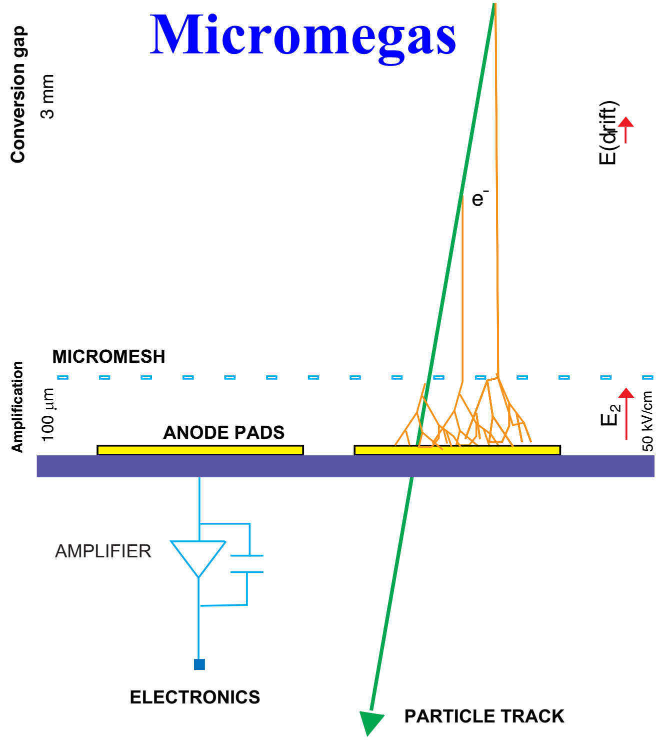


Gas Electron Multiplier (GEM) and Micromegas

The Gas Electron Multiplier (GEM)



Micromegas



MPGDs achieve excellent ≈ 40 µm resolution with 200 µm wide pads

↳ This implies a VERY large number of channels and high cost

ILC TPC channel count is already ~ $1.5x10^6$ with 2 mm wide pads

↳ Not practical to use pads much narrower than 2 mm

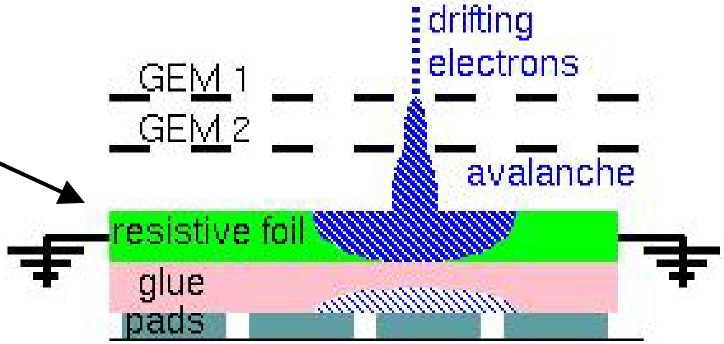
Maximize diffusion & multiple gap (GEM) – resistive anode (Micromegas)

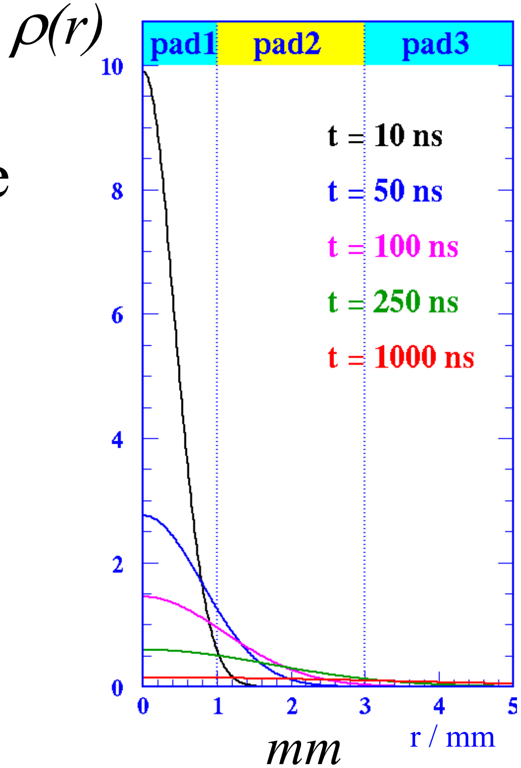
The Concept of Charge Dispersion

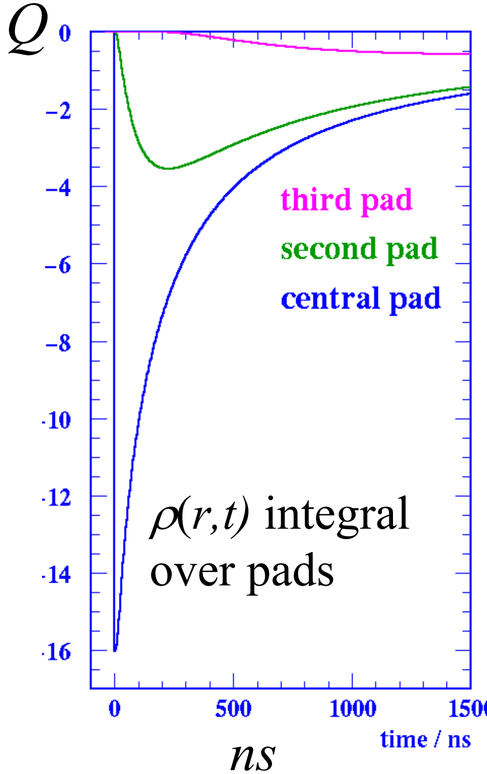
- **Modified GEM anode with a high resistivity film bonded to a readout plane with an insulating spacer**
- 2-dim continuous RC network defined by material properties and geometry
- Point charge at $r=0$ & $t=0$ disperses with time
- Time dependent anode charge density sampled by readout pads:

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

$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$

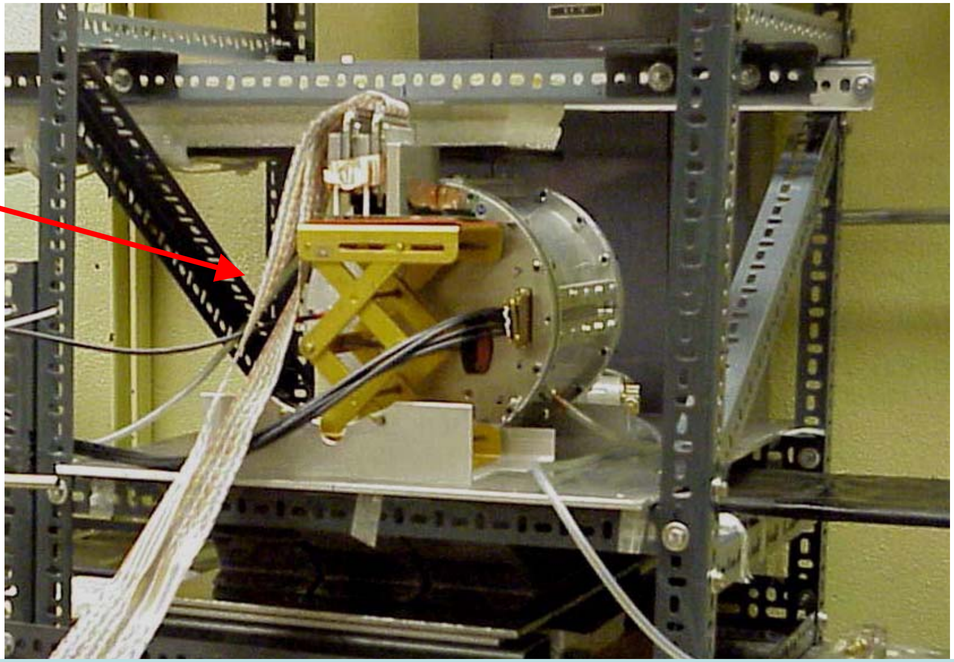


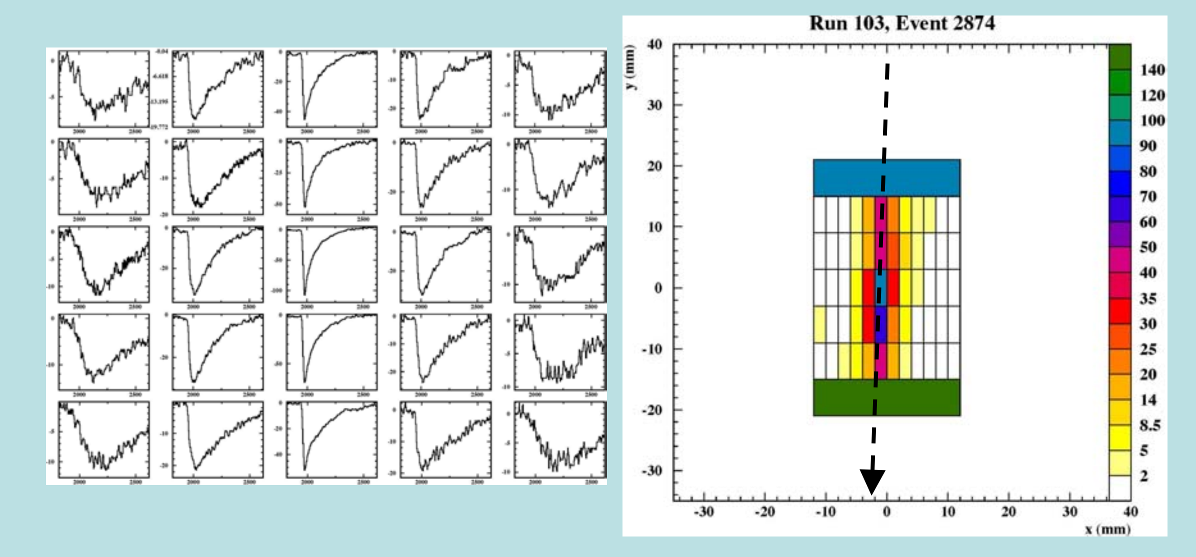




Cosmic Ray Resolution of a MPGD-TPC

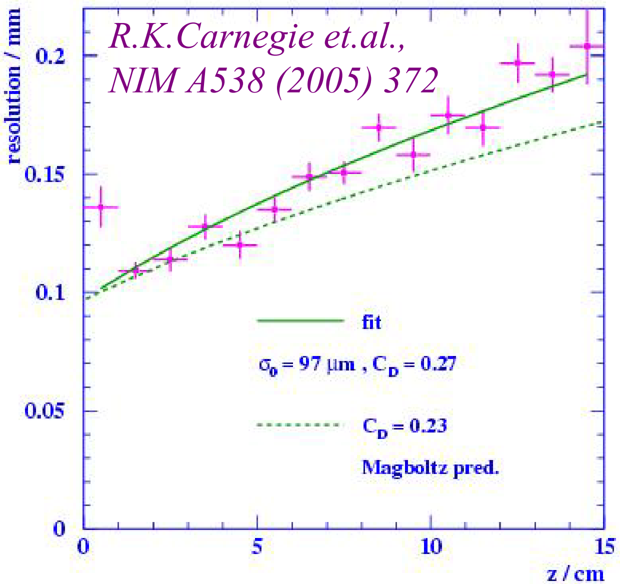
- Instrumentation lab at Carleton
- 15 cm drift length TPC: GEM & Micromegas readout [B=0]
- Ar:CO_2/90:10 chosen to simulate low transverse diffusion in a magnetic field.
- DAQ: 200 MHz custom 8 bit FADCs [UdeM]
- Aleph preamps
  τ_{Rise}= 40 ns τ_{Fall} = 2 μs
- 60 tracking pads
  2 x 6 mm^2
- 2 trigger pads
  24 x 6 mm^2

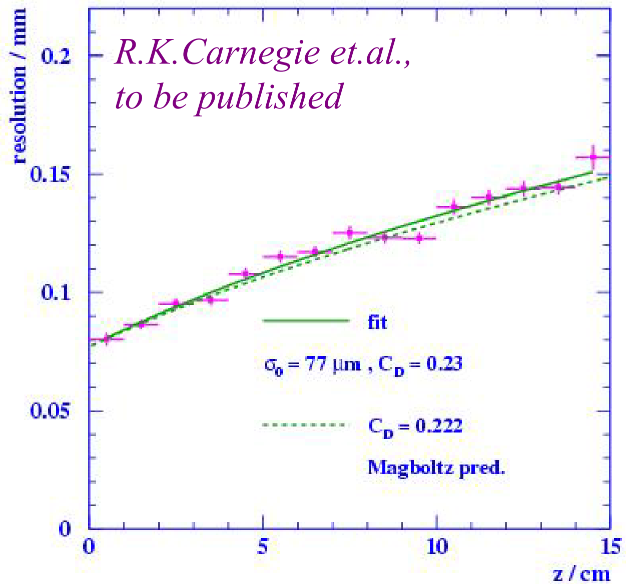


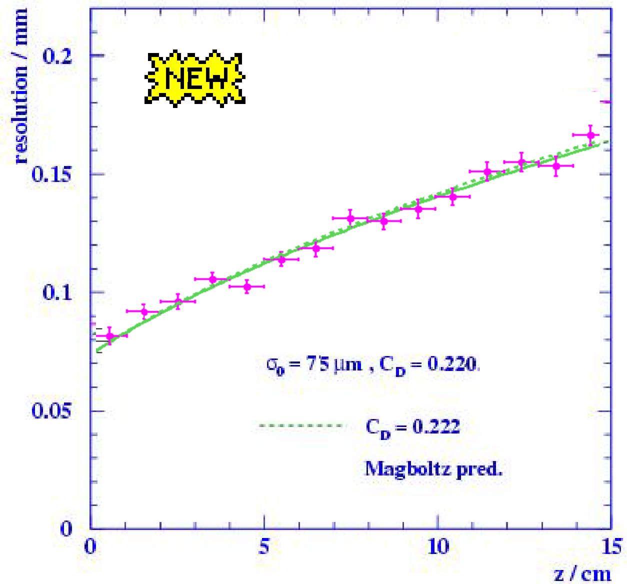


TPC transverse resolution for $Ar:CO_2$ (90:10)

GEM with direct charge readout	***GEM with charge dispersion readout***	***Micromegas with charge dispersion readout***





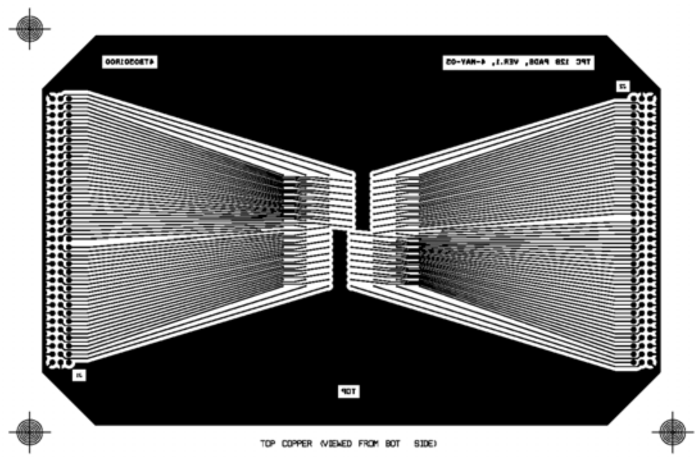


.... $\sqrt{\sigma_0{}^2 + \frac{C_D{}^2}{N_e} z}$ (Diffusion limit of resolution)

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.

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

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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

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Summary & outlook

- **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 ~100 μm 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**