TPC Readout Development with Charge Dispersion Signal

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Outline

- Principle of Charge Dispersion Signal with MPGD
- Recent Results
- Applications: ILC & T2K & EXO
- Simulation Framework
- Summary

Motivation and Principle

Diffusion sets the fundamental limit on achievableTPC resolution

- The physics limit of TPC resolution comes from transverse diffusion:

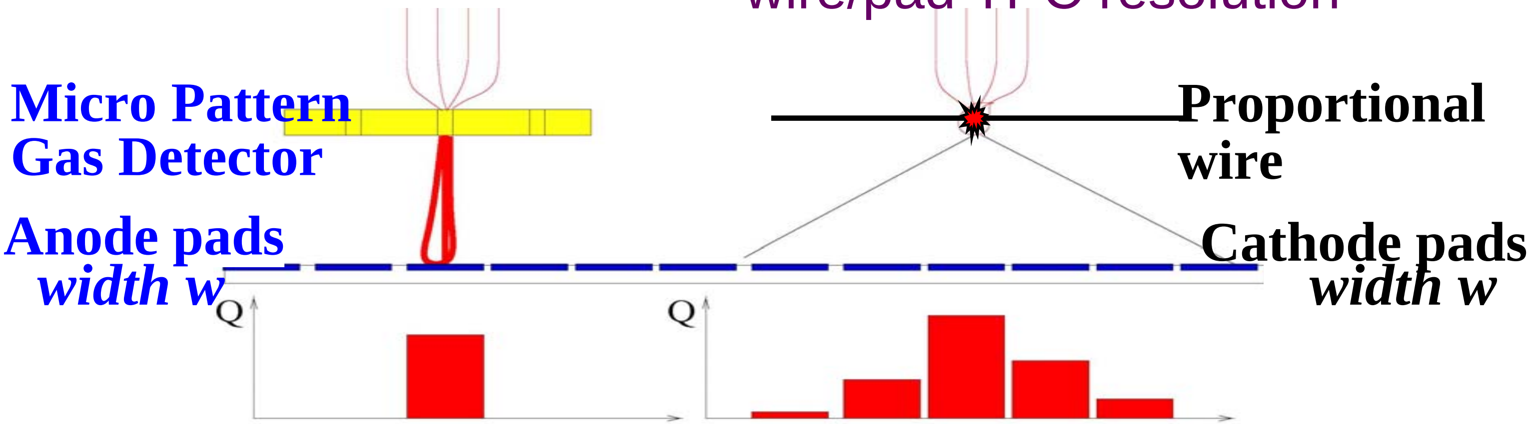
$$\sigma_x^{\ 2} \approx \frac{D_{Tr}^2 \cdot z}{N_{eff}}$$

N_{eff} = effective electron statistics.

- For best resolution, choose a gas with smallest diffusion in a high magnetic field

Pad width would limits MPGD TPC resolution

ExB systematics limits wire/pad TPC resolution



Direct signal on the MPGD anode pad

For small diffusion, less precise centroid for wide pads

$$\sigma_x^{\ 2} \approx \sigma_0^{\ 2} + \frac{1}{N_{eff}}\left[D_{Tr}^2 z + w^2/12\right]$$

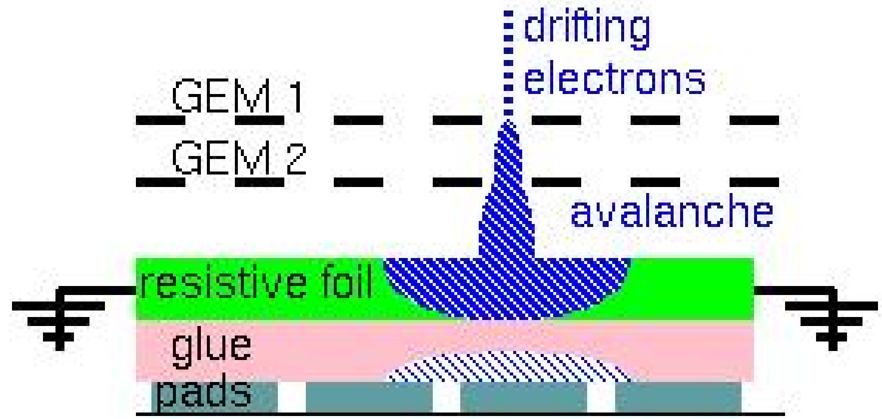
Induced cathode signal determined by geometry

Accurate centroid determination possible with wide pads

$$\sigma_x^{\ 2} \approx \sigma_0^{\ 2} + \frac{D_{Tr}^2 \cdot z}{N_{eff}}$$

Charge dispersion in a MPGD with a resistive anode

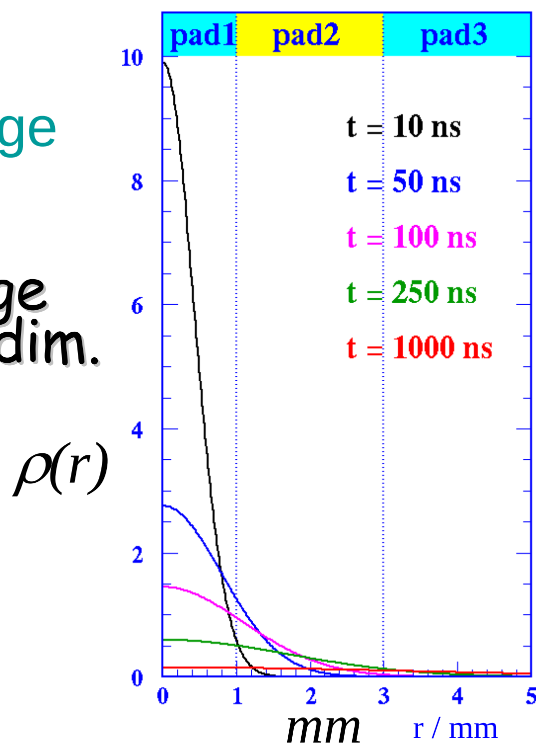
- Modified GEM anode with a high resistivity film bonded to a readout plane with an insulating spacer.
- 2-dimensional continuous RC network defined by material properties & geometry.
- Point charge at r = 0 & t = 0 disperses with time.
- Time dependent anode charge density sampled by readout pads.

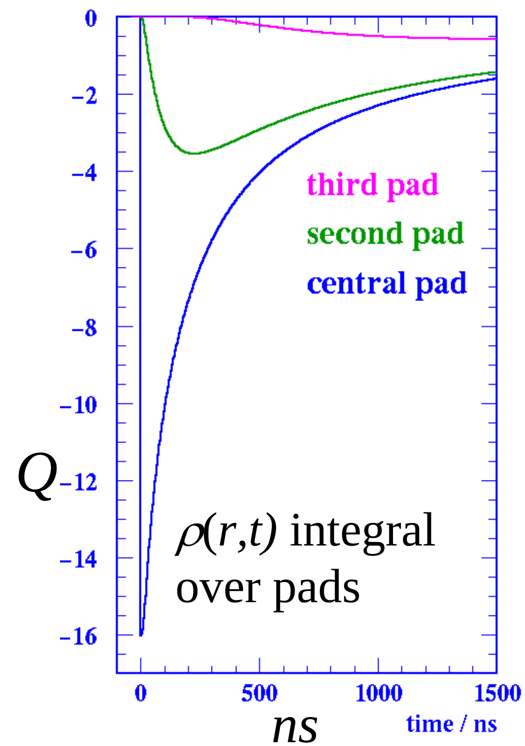


Equation for surface charge density function on the 2-dim. continuous RC network:

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

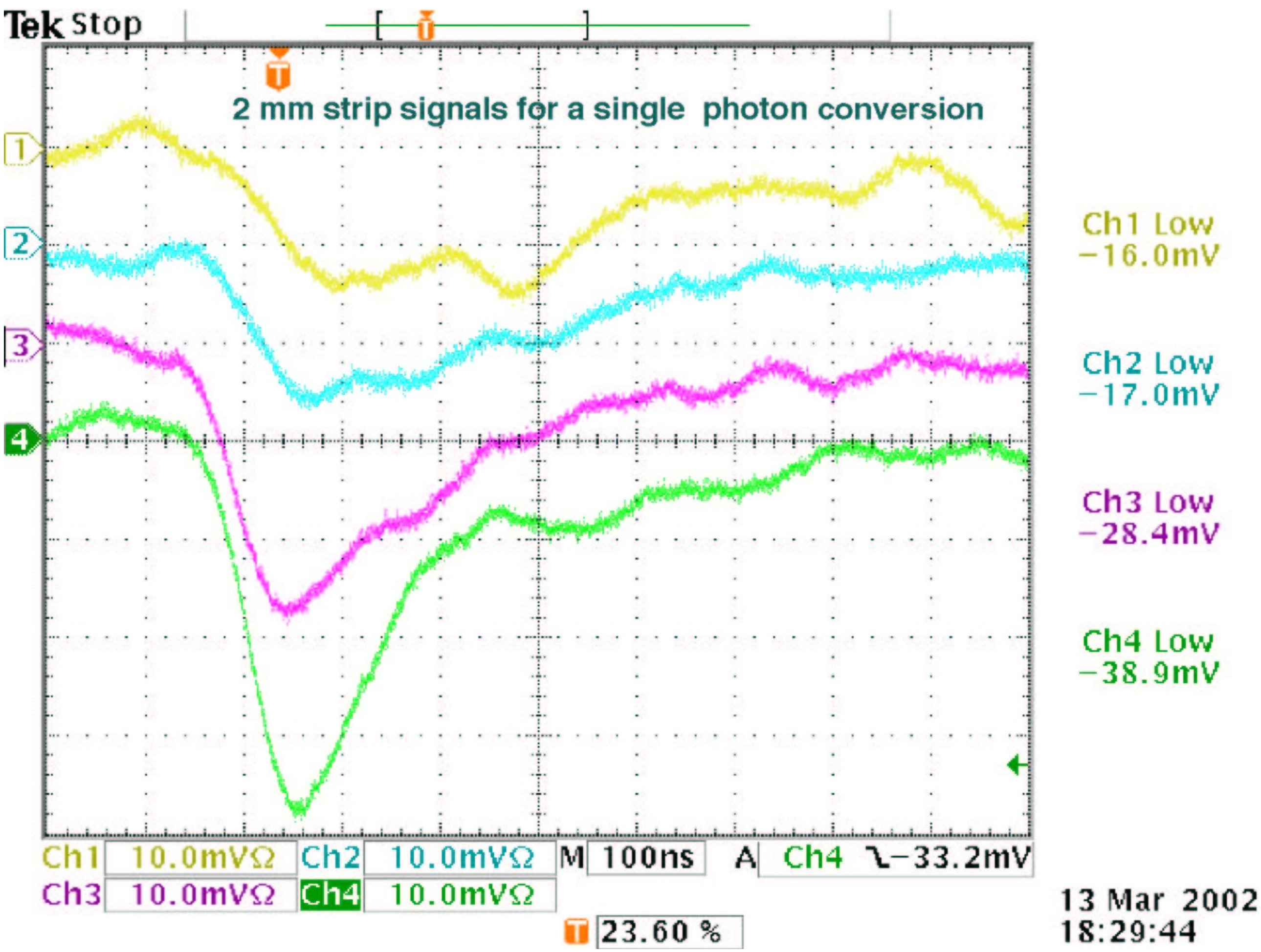
$$\Rightarrow \rho(r,t) = \frac{RC}{2t} e^{\frac{-r^2 RC}{4t}}$$

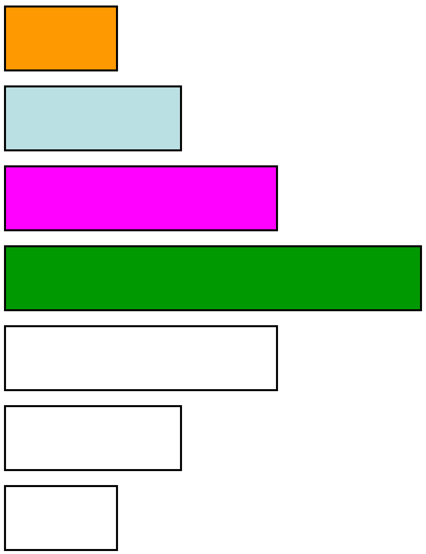




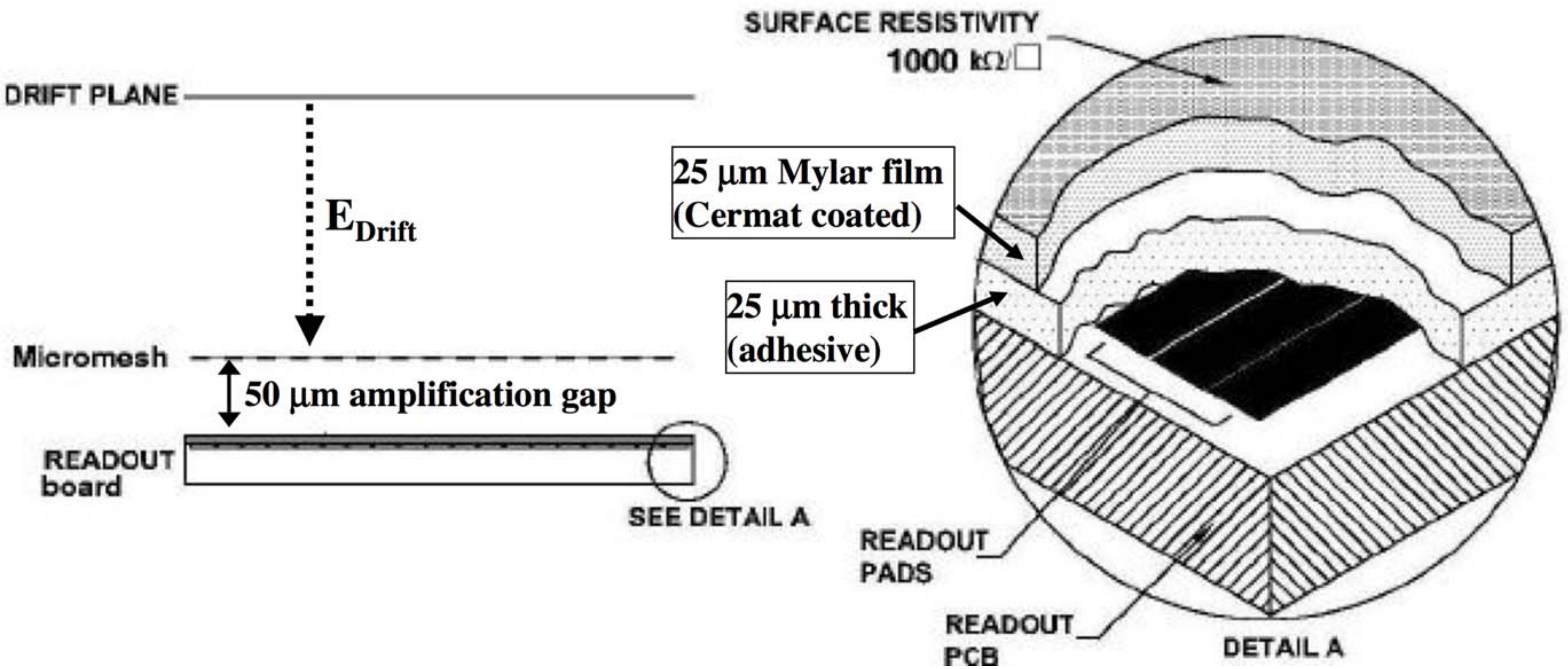
The proof - a 6 keV ^{55}Fe x-ray photon event as seen in our first GEM test cell with a resistive anode

Collimator size ~ 1 mm ; signal detected by ~7 anodes (2 mm width)





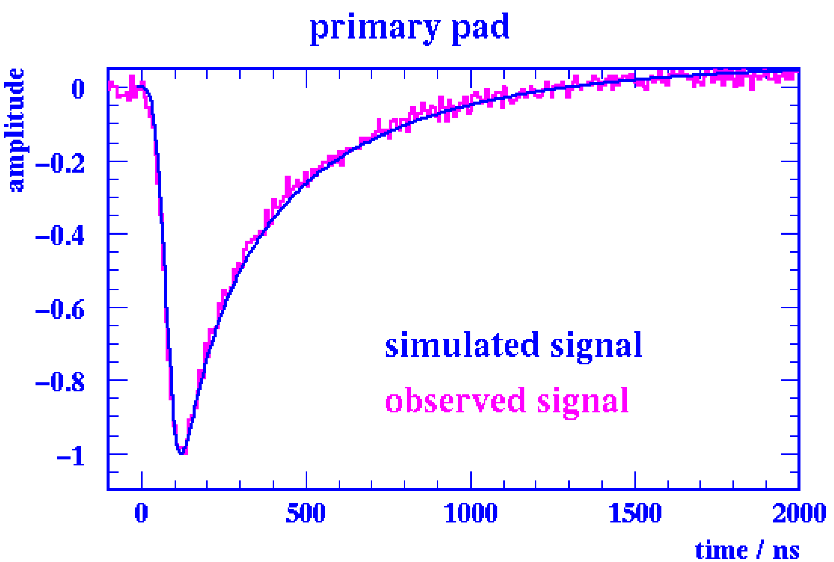
Micromegas with a resistive readout

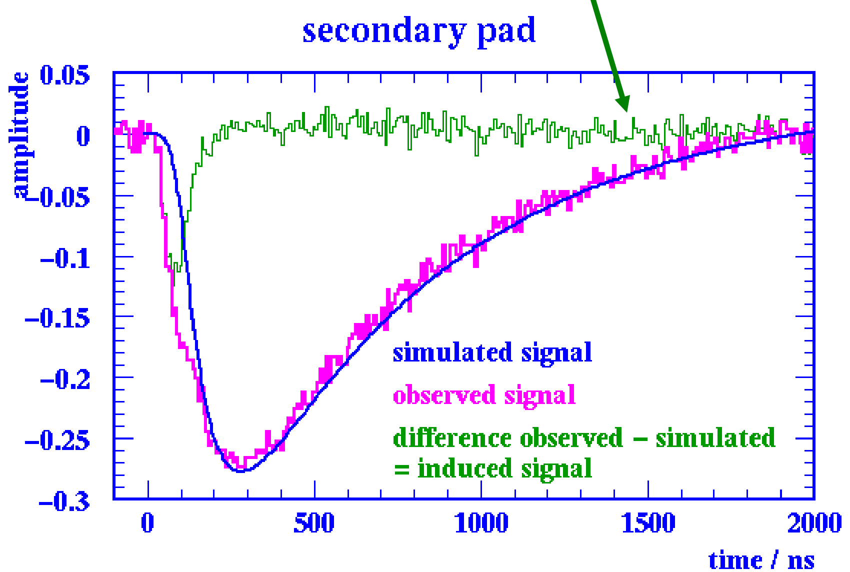


Charge dispersion signals for the GEM readout

Simulation vs. measurement for Ar+10%CO_2 (2 x 6 mm^2 pads)
Collimated ~ 50 μm 4.5 keV x-ray spot on pad centre.

Difference = induced signals (MPGD '99, Orsay & LCWS 2000) were not included in simulation).



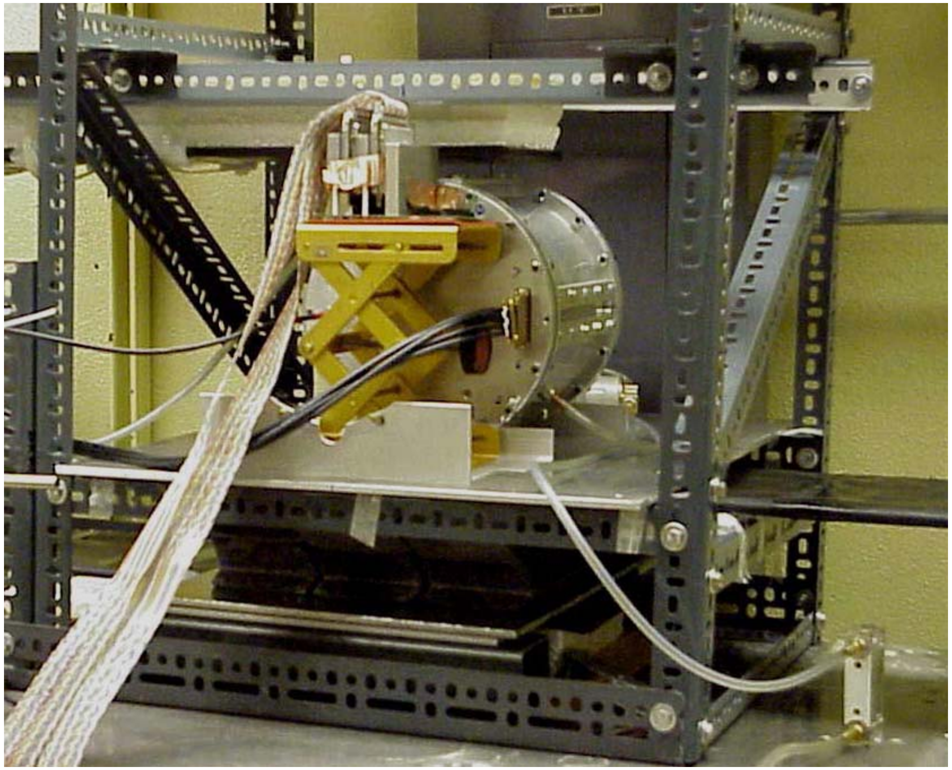


Simulated primary pulse is normalized to the data.

Primary pulse normalization used for the simulated secondary pulse

Initial B=0 Cosmic Ray Tests in Canada

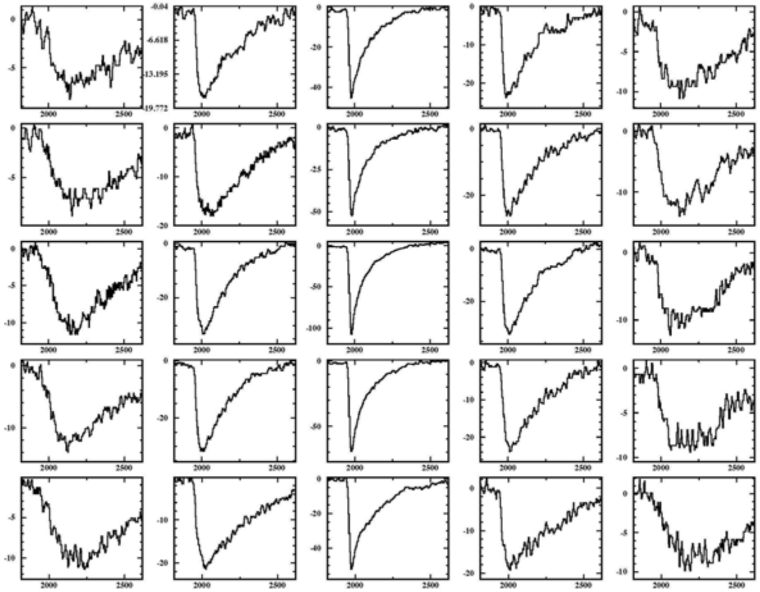
- 15 cm drift length with GEM or Micromegas readout
- Ar+10% CO_2 chosen to simulate low transverse diffusion in a magnetic field.
- Aleph charge preamps. τ_{Rise}= 40 ns, τ_{Fall} = 2 μs,
- 200 MHz FADCs rebinned to digitization effectively at 25 MHz.
- In contrast to normal practice, we use digitized preamp pulse with no shaping so as not to lose electron statistics.

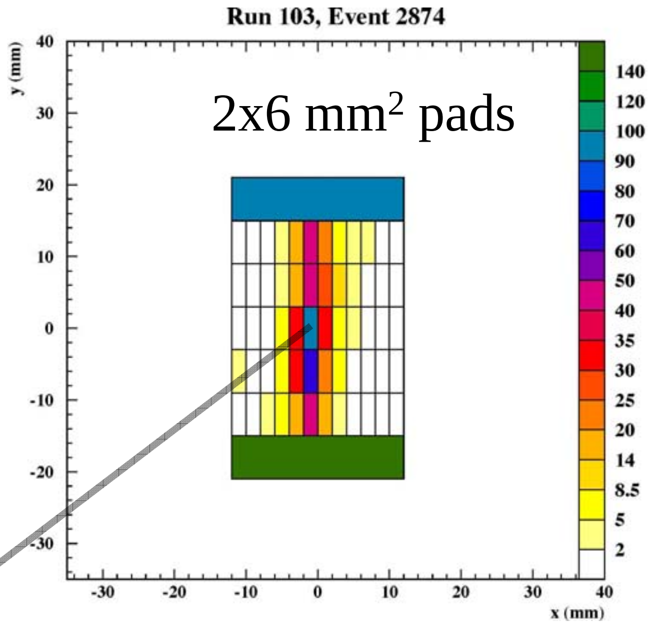


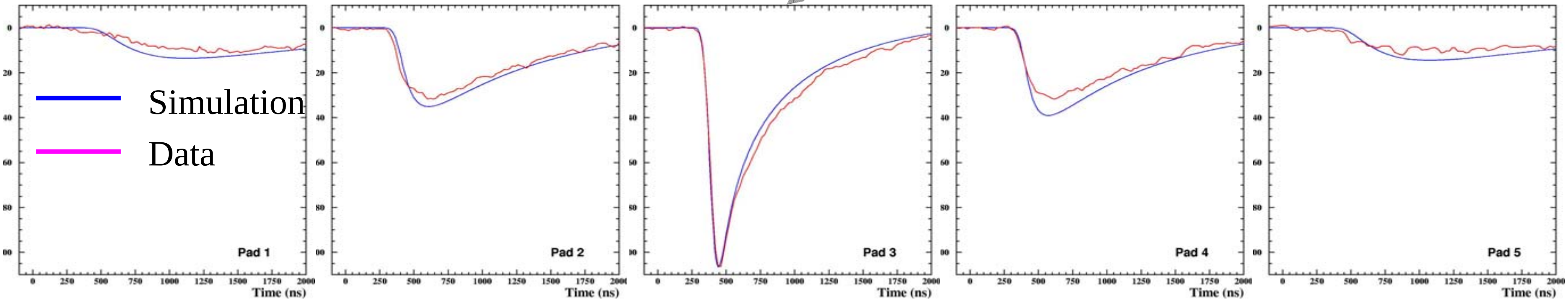
The GEM-TPC resolution was first measured with conventional direct charge TPC readout.

The resolution was next measured with a charge dispersion resistive anode readout with a double-GEM & with a Micromegas.

GEM TPC charge dispersion simulation (B=0)
Cosmic ray track, Z = 67 mm Ar+10%CO_2







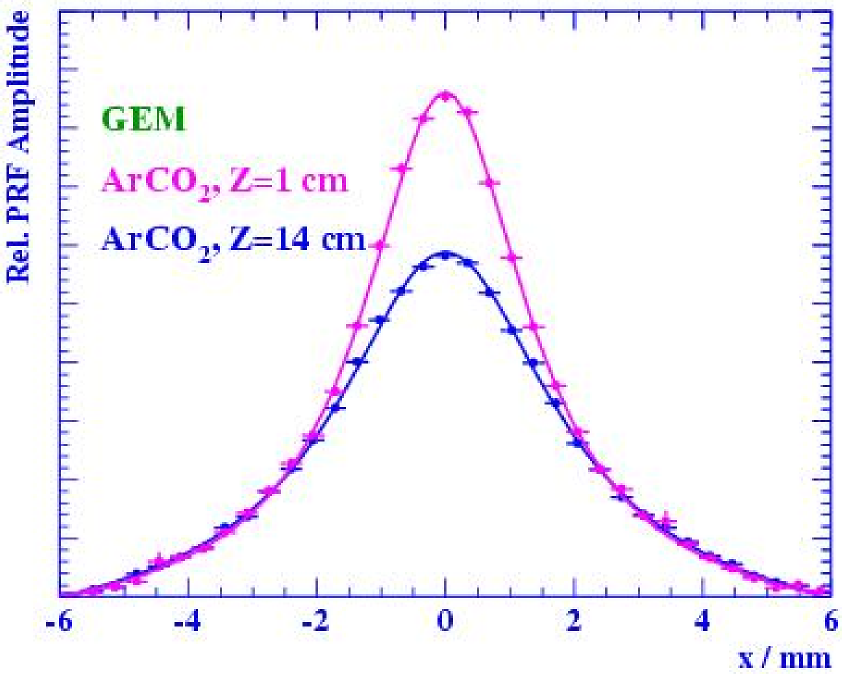
Centre pulse used for normalization - no other free parameters.

Charge dispersion pulses & pad response function (PRF)

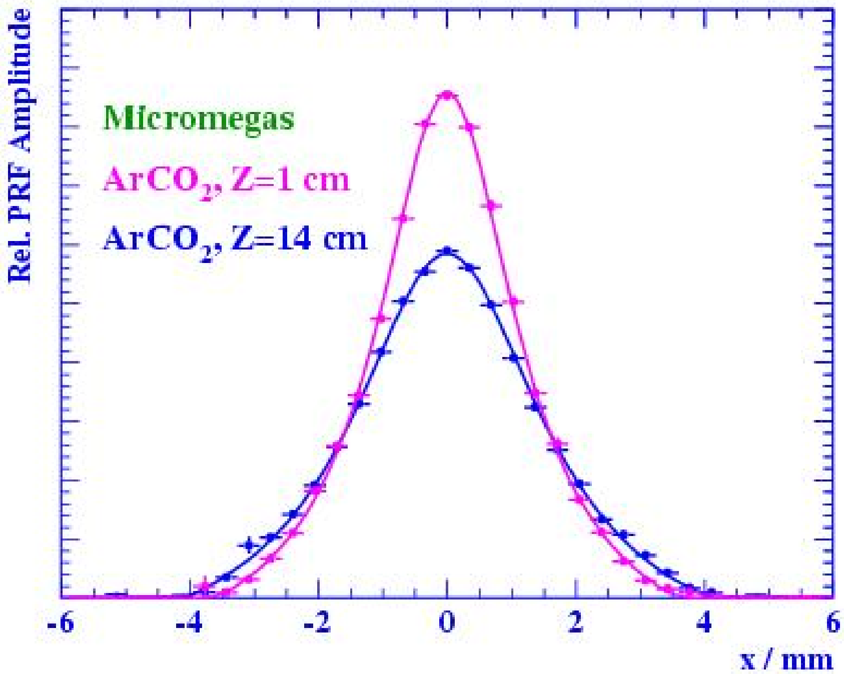
- Non-standard variable pulse shape; both the rise time & pulse amplitude depend on track position.
- The PRF is a measure of signal size as a function of track position relative to the pad.
- We use pulse shape information to optimize the PRF.
- The PRF can, in principle, be determined from simulation.
- However, system RC non-uniformities & geometrical effects introduce bias in absolute position determination.
- The position bias can be corrected by calibration.
- PRF and bias determined empirically using a subset of data used for calibration. Remaining data used for resolution studies.

GEM & Micromegas PRFs for tracks
Ar+10%CO2 2x6 mm^2 pads

The pad response function amplitude for longer drift distances is lower due to Z dependent normalization.



GEM PRFs



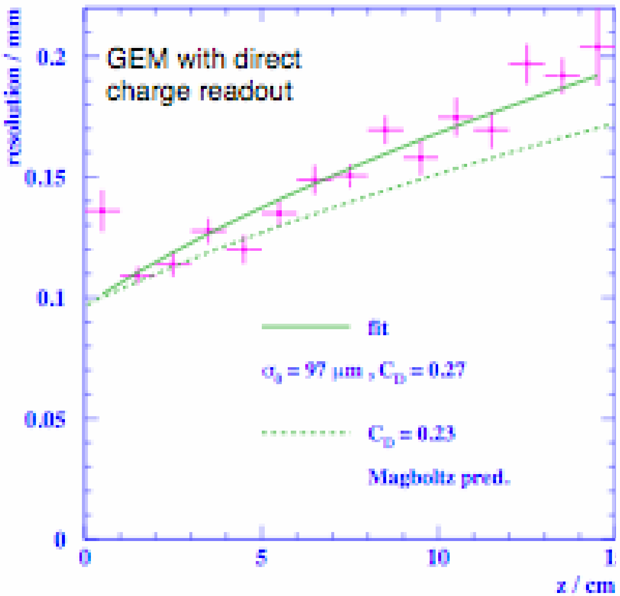
Micromegas PRFs

Micromegas PRF is narrower due to the use of higher resistivity anode & smaller diffusion than GEM after avalanche gain

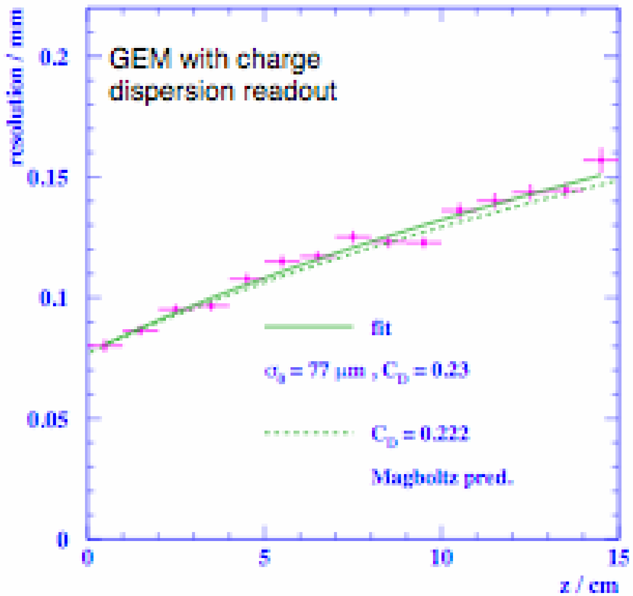
Results

B=0 Cosmic Ray Transverse Resolution
Ar+10%CO_2

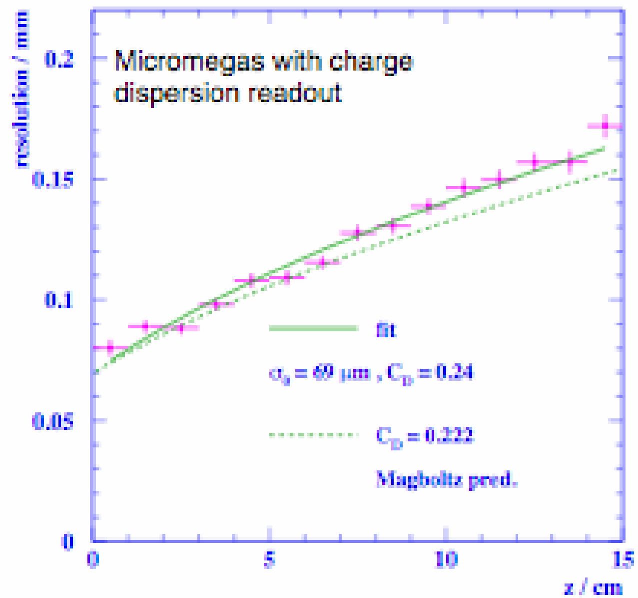
R.K.Carnegie et.al.,
NIM A538 (2005) 372



K. Boudjemline et.al.,
NIM A574 (2007) 22



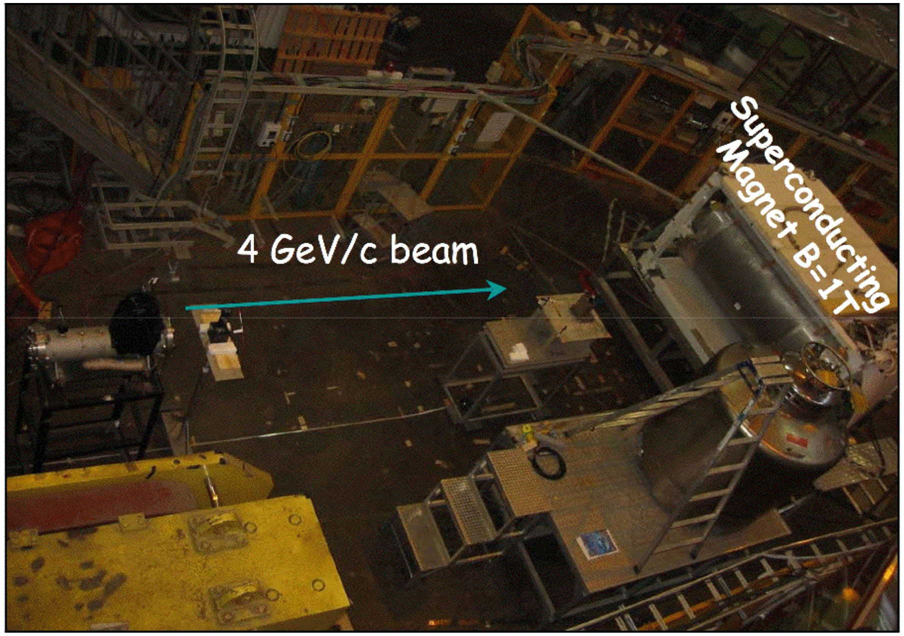
A. Bellerive et.al,
LCWS 2005, Stanford



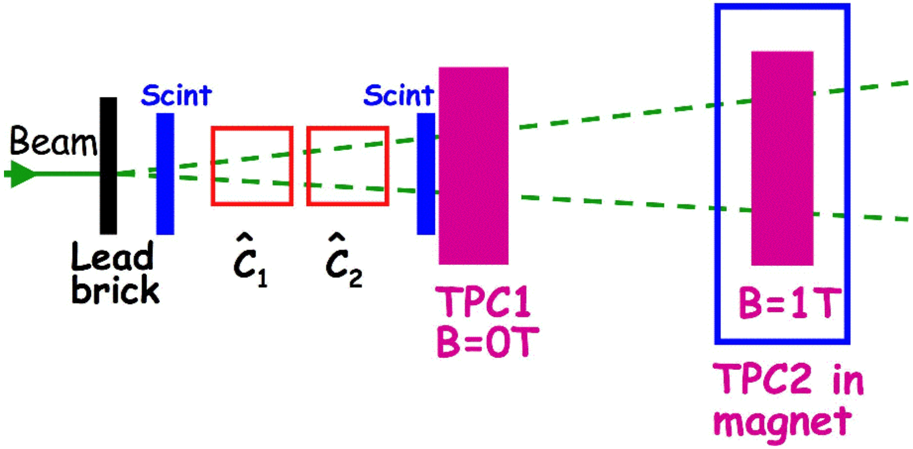
$$\sqrt{\sigma_0^{\,2} + \frac{C_D^{\,2}}{N_e} z}$$

Compared to conventional readout, charge dispersion gives better resolution for the GEM and the Micromegas.

KEK beam test in a magnet at 1 T Canadian/French & Japan/German TPCs



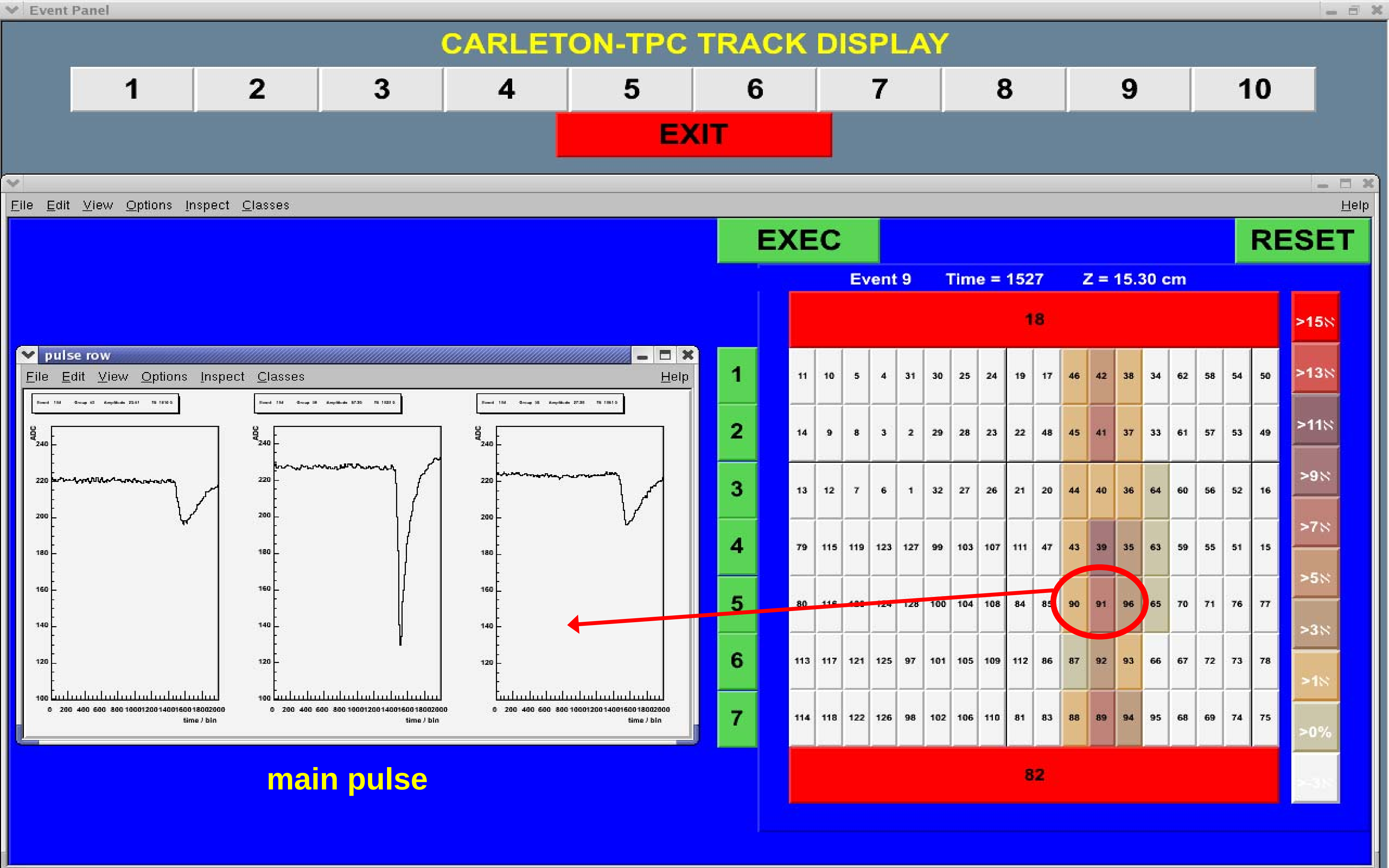
- 4 GeV/c hadrons (mostly π s)
- 0.5 & 1 GeV/c electrons
- Super conducting 1.2 T magnet without return yoke
- Inner diameter : 850 mm
- Effective length: 1 m



Canadian TPC in the beam outside the magnet

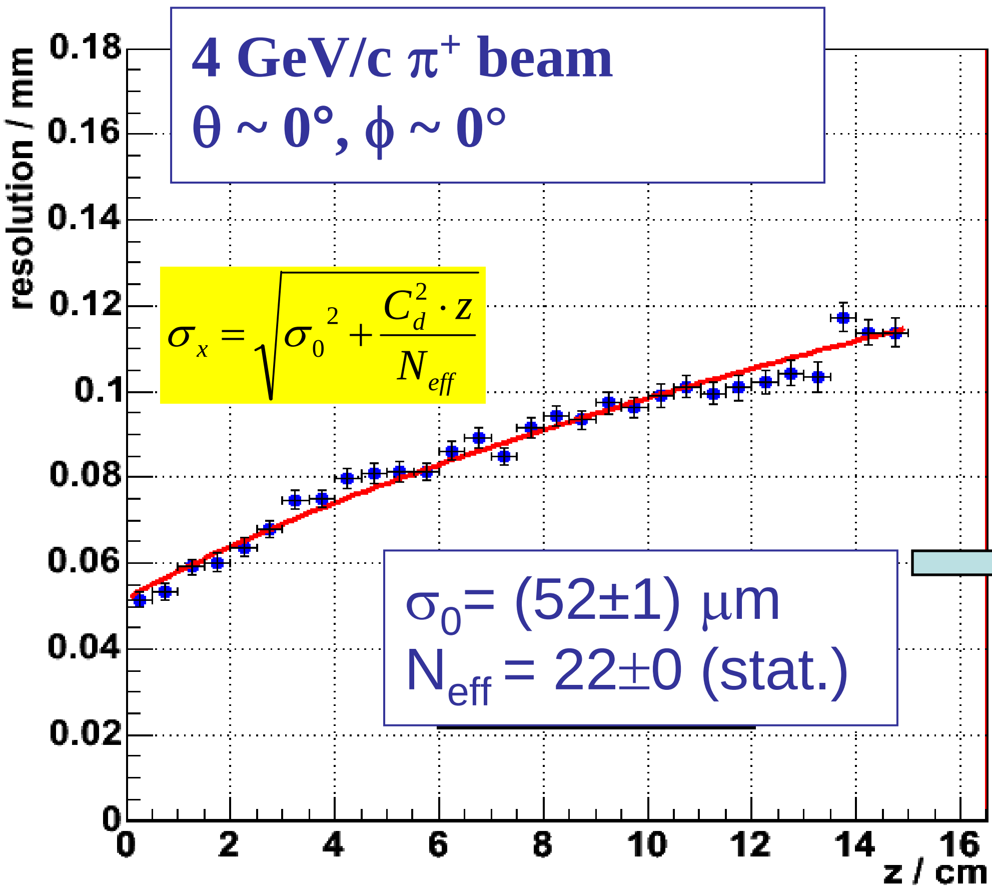
Track display - Ar+5%iC4H10
Micromegas 2 x 6 mm² pads B = 1 T

Z_{drift} = 15.3 cm



Transverse spatial resolution Ar+5%iC4H10 E=70V/cm D_{Tr} = 125 μm/√cm (Magboltz) @ B= 1T

Micromegas TPC 2 x 6 mm² pads - Charge dispersion readout



- Strong suppression of transverse diffusion at 4 T.

Examples:

D_{Tr}~ 25 μm/√cm (Ar/CH4 91/9) Aleph TPC gas

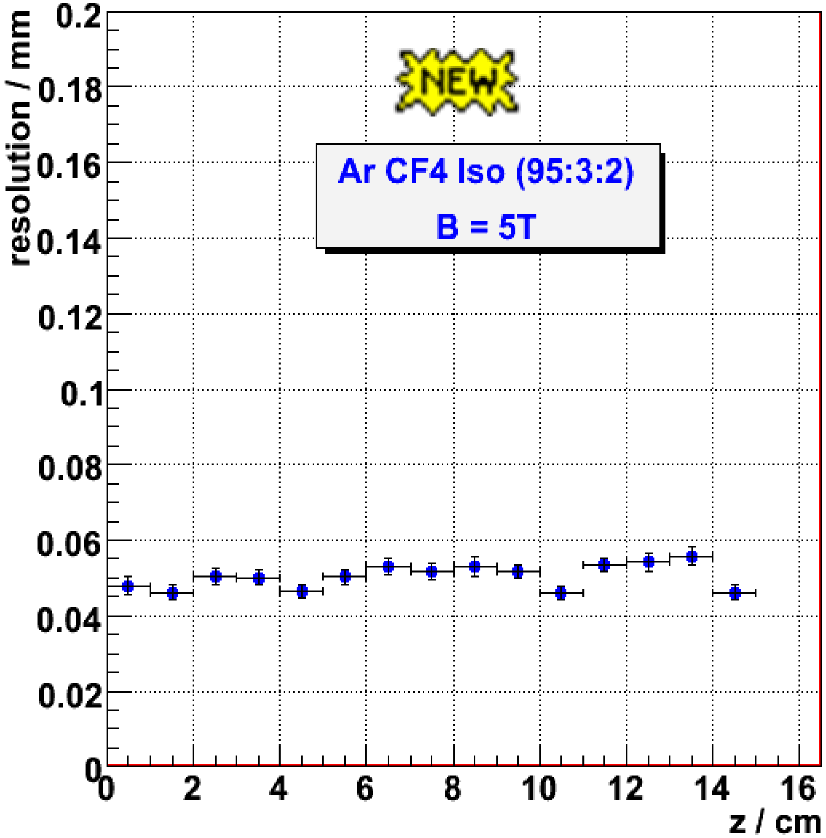
~ 20 μm/√cm (Ar/CF4 97/3)

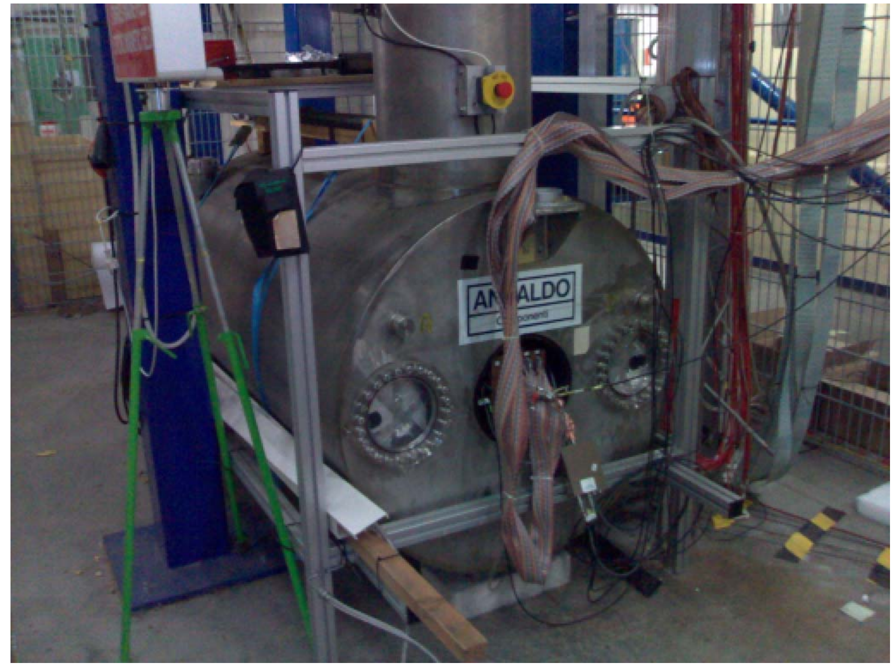
Extrapolate to B = 4T
Use D_{Tr} = 25 μm/√cm
Resolution (2x6 mm² pads)
$\sigma_{Tr} \approx$ 100 μm (2.5 m drift)

Extrapolation confirmed in 5 T cosmic tests at DESY

COSMo (Carleton, Orsay, Saclay, Montreal) Micromegas TPC

D_{Tr} = 19 μm/√cm, **2 x 6 mm² pads**





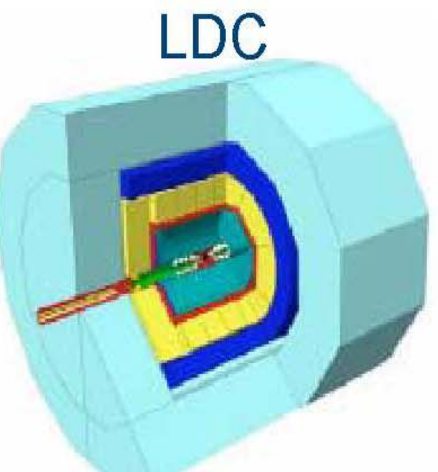
~ 50 μm av. resolution over 15 cm (diffusion negligible)
100 μm over 2 meters looks within reach!

Nov-Dec, 2006

M. Dixit et.al., NIM A (in press)
arXiv:physics/0703263v1

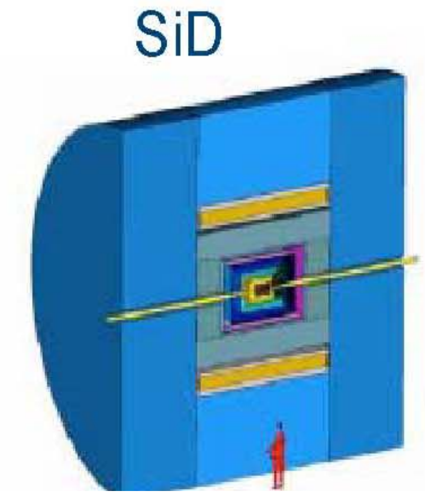
Applications

TPC tracker part of 3 present ILC detector concepts

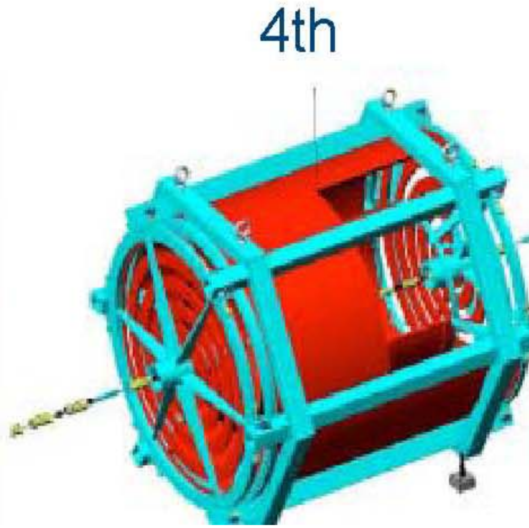


TPC (B=4T)

TPC (B=3T)



Silicon (B=5T)



TPC (B=3.5 T)

Demonstration phase ILC TPC R&D

- Canada has been involved from the beginning
- 2 mm x 6 mm pads (1,500,000 channels) for the readout with GEMs or Micromegas were proposed initially
- For the GEM, large transverse diffusion in the transfer & induction gaps provides a natural mechanism to disperse the charge and facilitate centroid determination.
  - The GEM will still need ~ 1 mm wide pads to achieve ~ 100 μm resolution goal with ~3,000,000 readout channels
  - Even narrower pads would be needed for the Micromegas

Development of the new concept of charge dispersion in a MPGD with a resistive anode makes position sensing insensitive to pad width

The technique works for both the GEM and the Micromegas

Charge dispersion concept to reduce #channels and hence cost

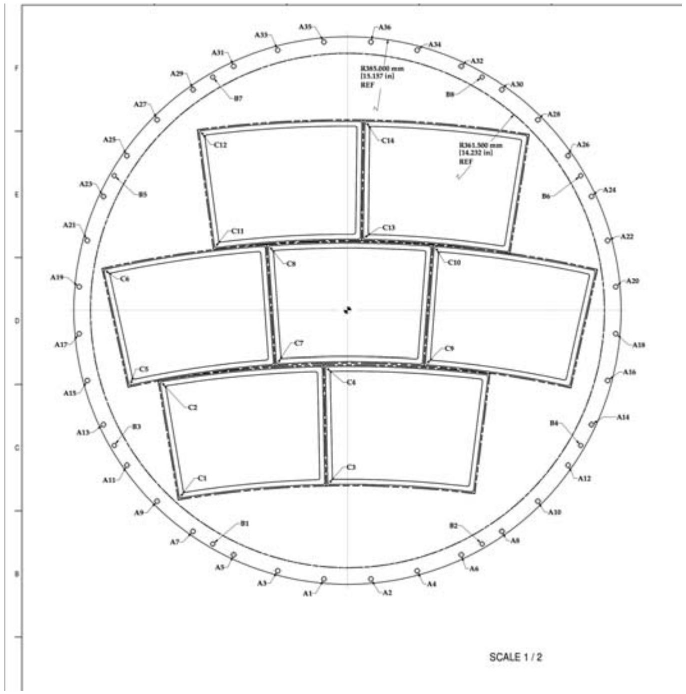
Preparing the detector for physics at ILC

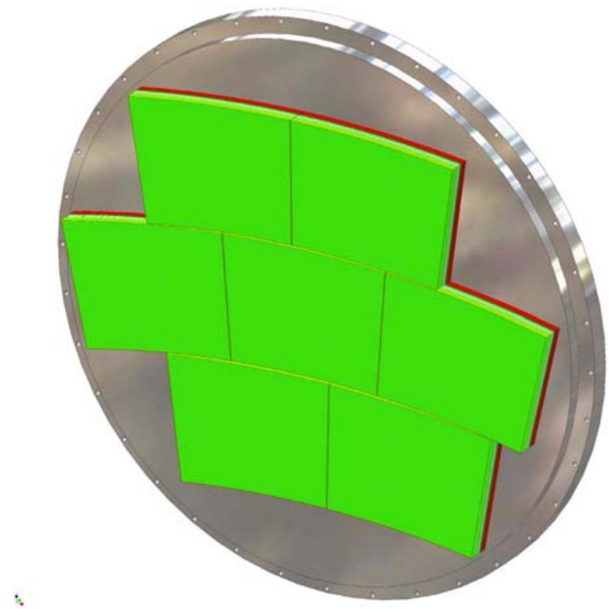
- A formal Linear Collider TPC (LC-TPC) collaboration recently formed
- Formal review of tracking systems at Beijing - First TPC assignment construct a 1 meter prototype & comprehensive beam tests in a 4 T magnet in a beam with ILC like time structure with **realistic electronics** by 2010 in time to write detector EDR.
- Test two possible readout options being developed

  1) GEM with 1 mm pads

  2) Micromegas with 2 mm pads with charge dispersion readout

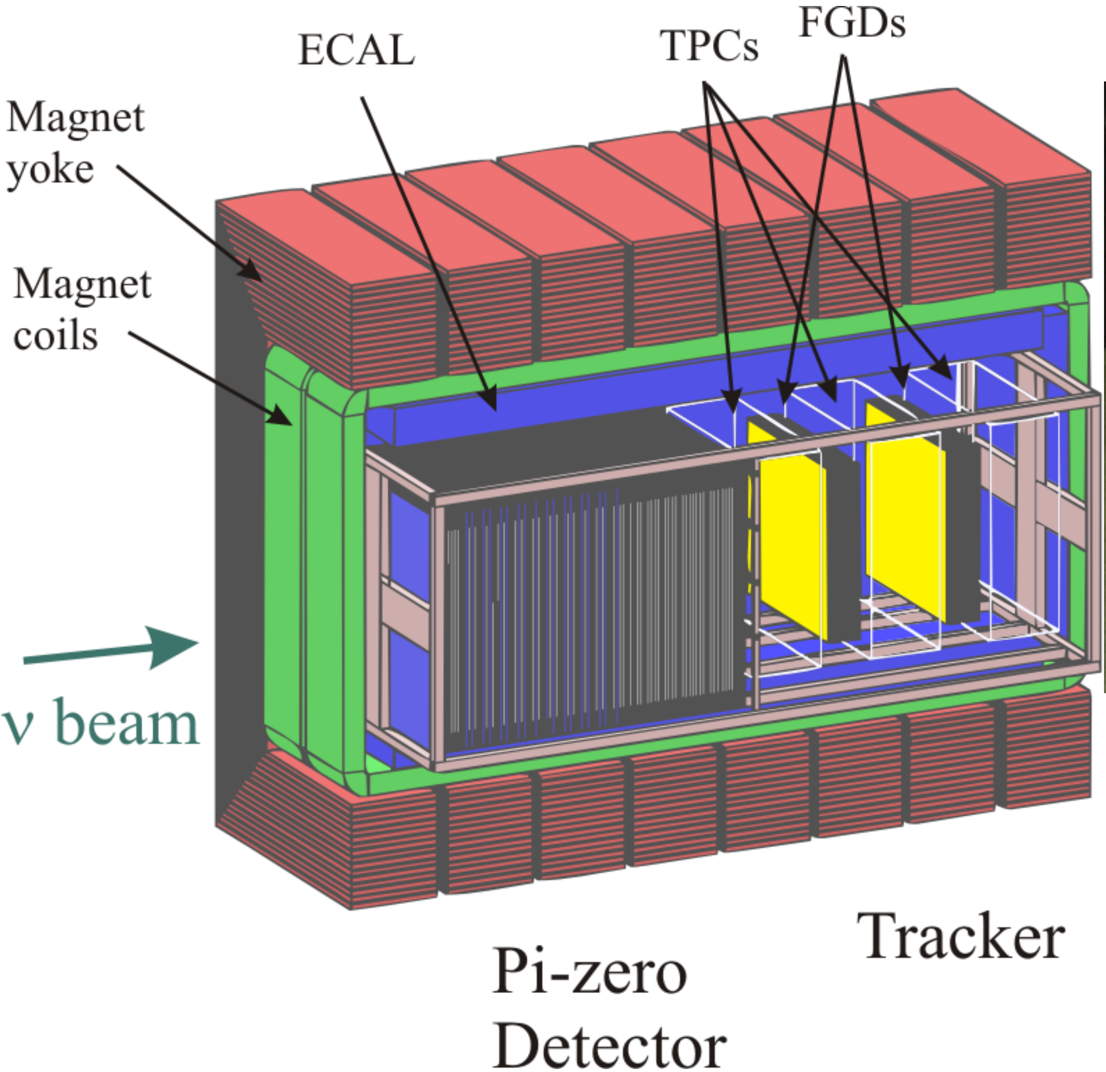
1 meter Large Prototype TPC being developed for 1 T tests at DESY (2008) & 4 T tests at Fermilab (2010)





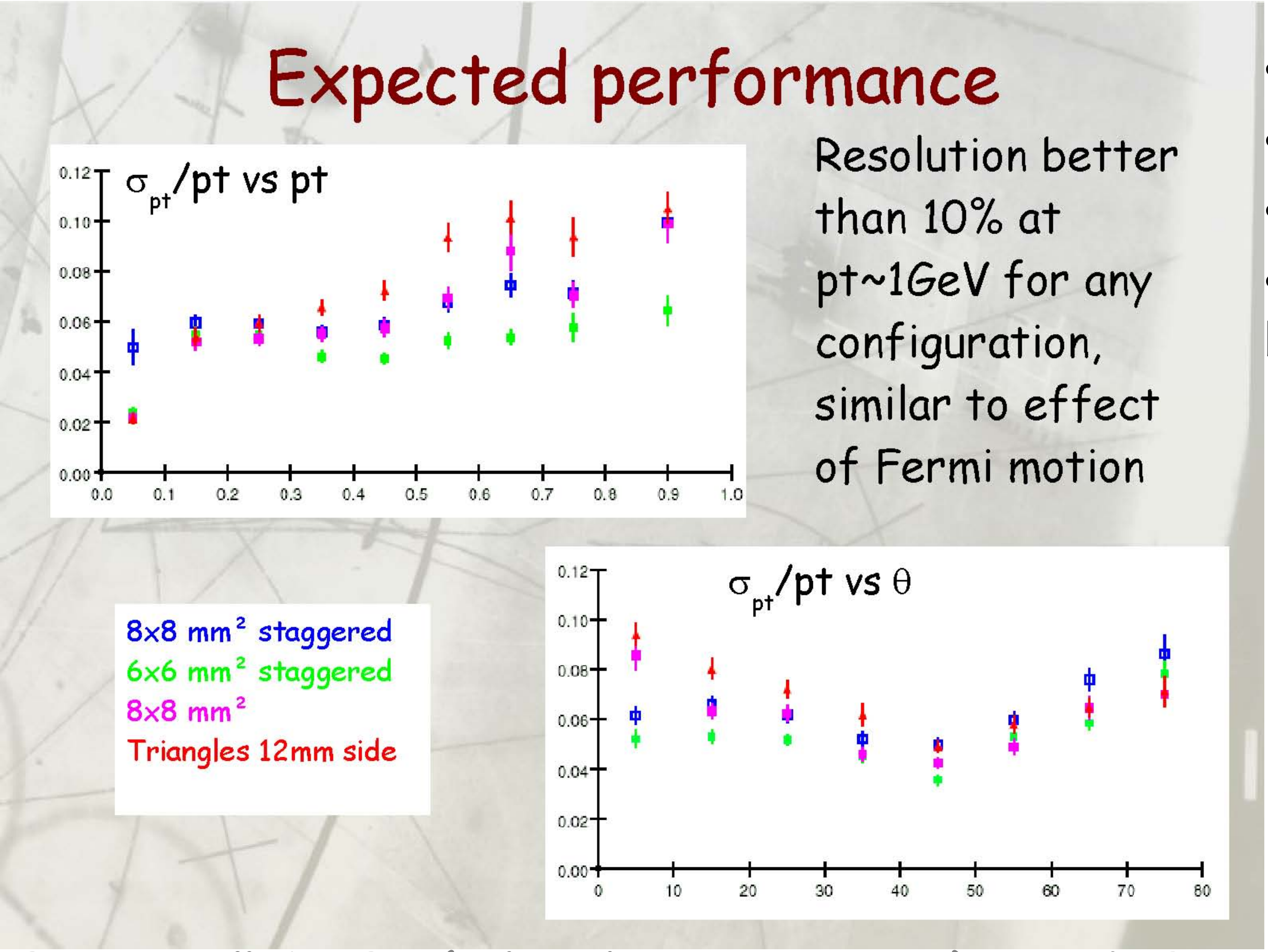
7 panels ~ GEMs with 1 mm pads and Micromegas with 2 mm wide pads
Up to 10,000 instrumented channels

T2K Near Detector - TPC



Building T2K TPC prototype
at TRIUMF

Application to T2K TPC



- 7x9 mm^2 pads
- 10% $\Delta p/p$ (1 GeV/c)
- Good enough
- Requirement limited by Fermi motion

Partnership between CARLETON & CEA/DAPHNIA

From a talk by F.Sánchez (Universitat Autònoma de Barcelona)

But better momentum resolution would be useful:

Better background rejection = More channels => $$?

Can one do it with the presently chosen pad dimensions?

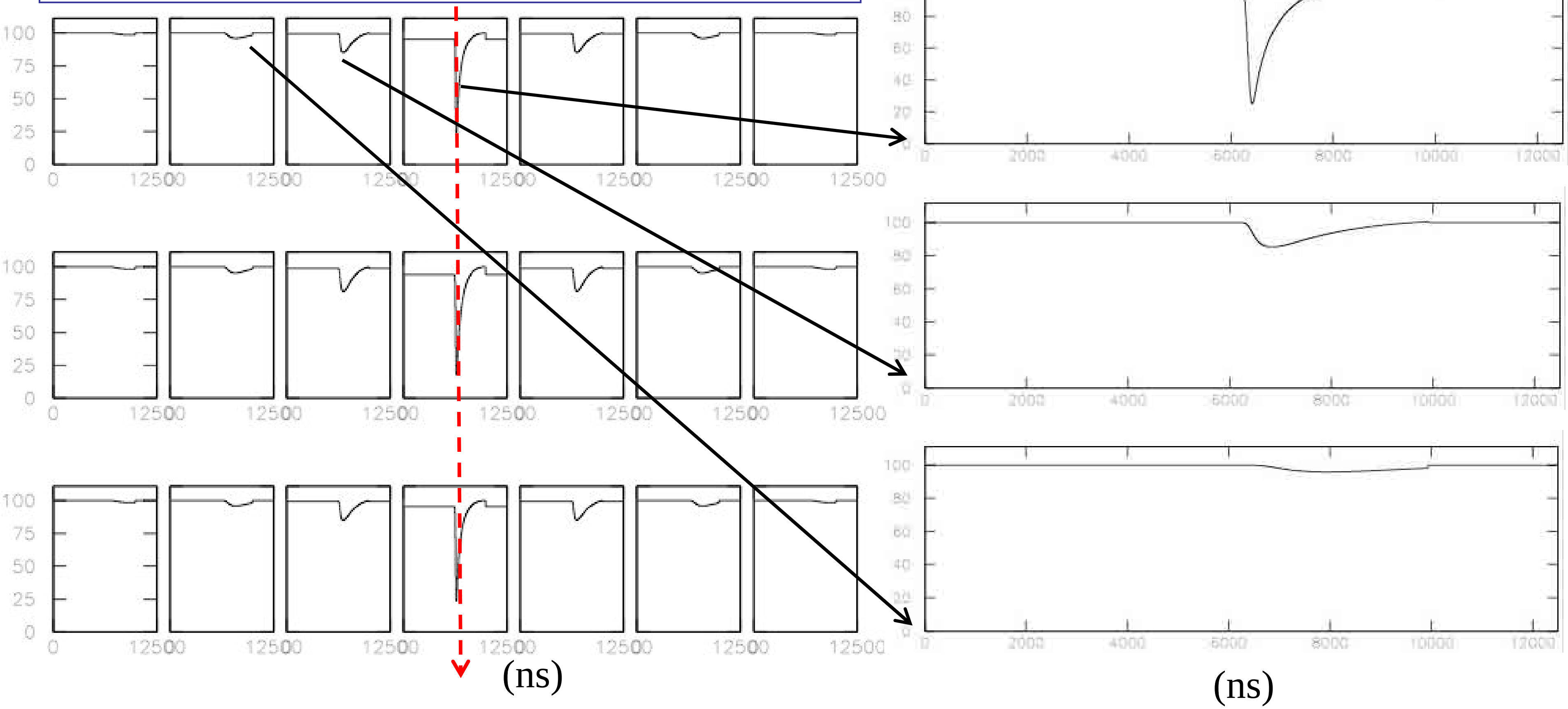
T2K simulation for 8 x 8 mm^2 pads

Track crosses no pad row or column boundaries

Ar+10% CO_2 , v_{Drift} = 28 μm/ns (E = 300 V/cm) Aleph preamp t_{Rise} = 40 ns, t_{Fall} = 2 μs

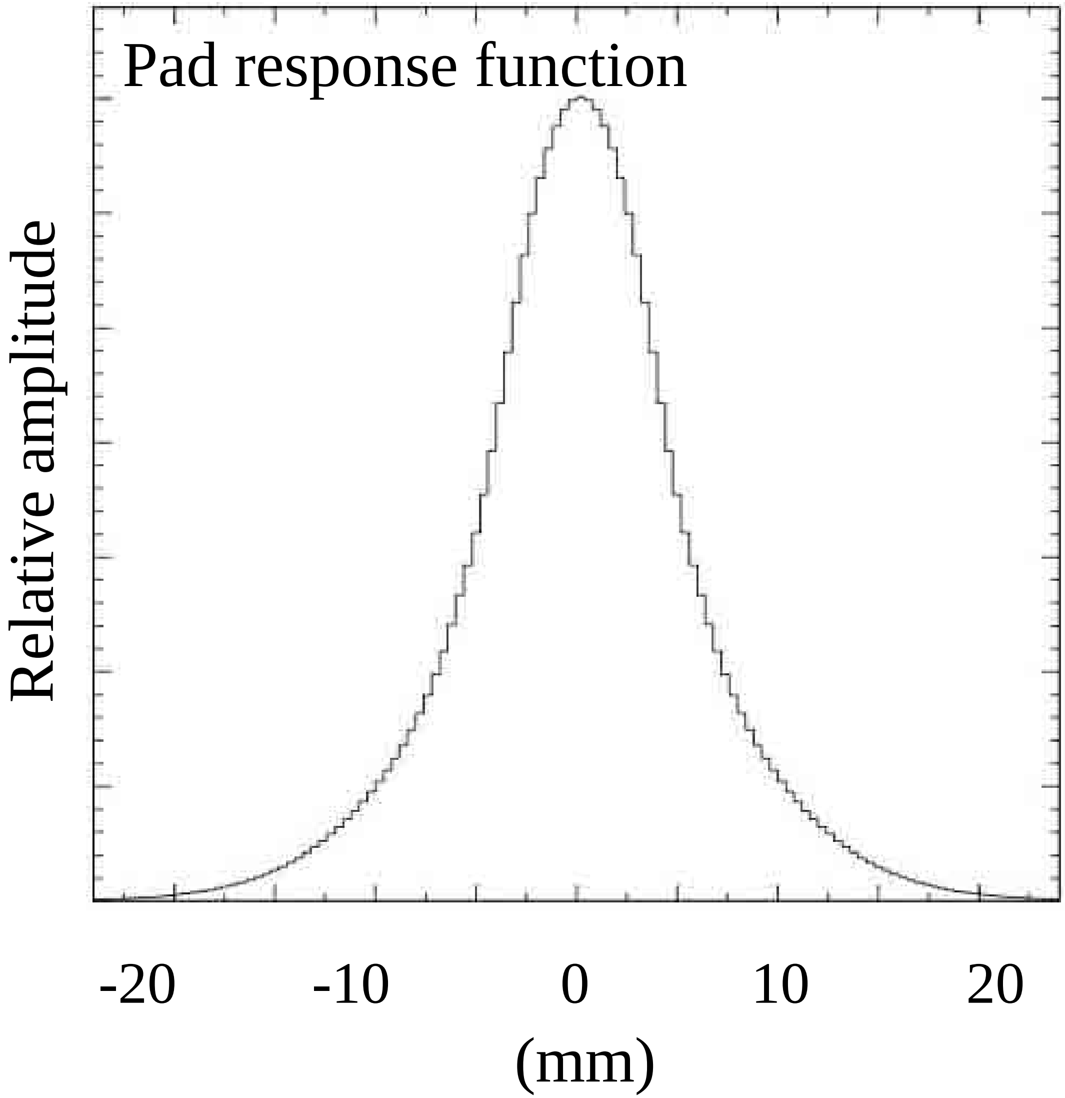
Anode surface resistivity 150 KΩ/□, dielectric gap = 75 μm

Track at z = 175 mm, x = 0, φ = 0 (uniform ionization)

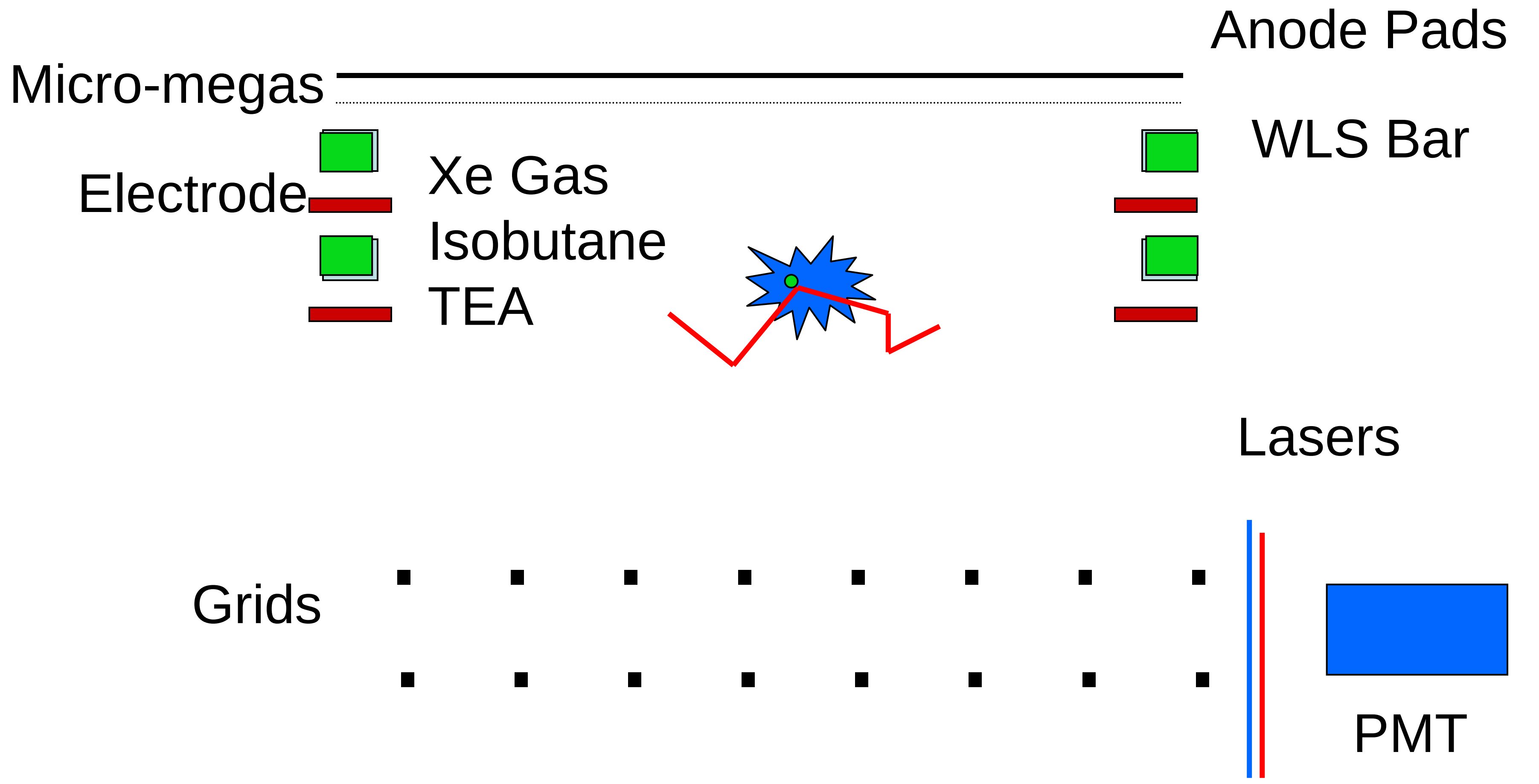


Micromegas TPC with resistive readout - Simulated PRF

8 x 8 mm^2 pads, Ar+10% CO_2@ 300 V/cm, 175 mm drift distance



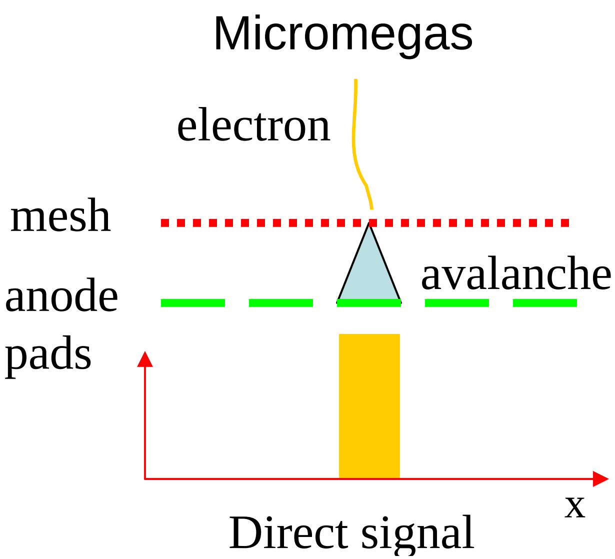
EXO at SNOLAB
Possible concept for a gas double beta counter

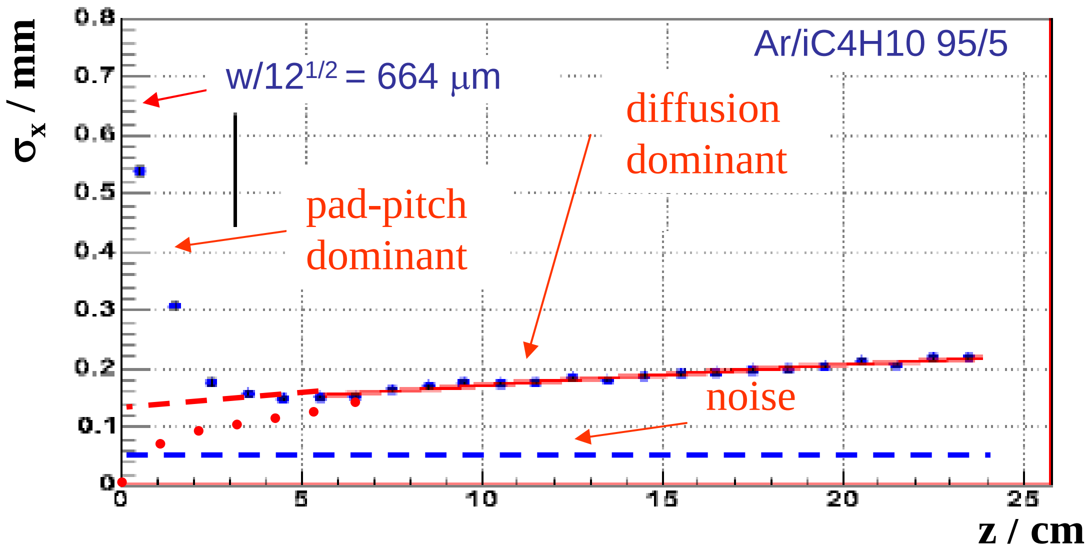


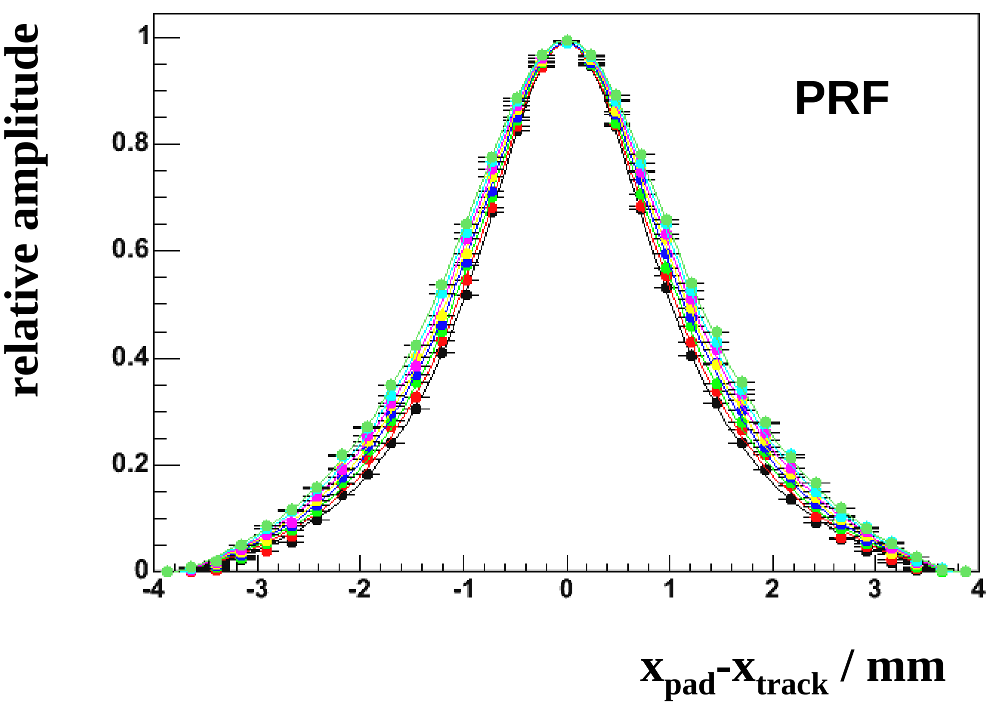
For 200 kg, 10 bar, box is 1.5 m on a side

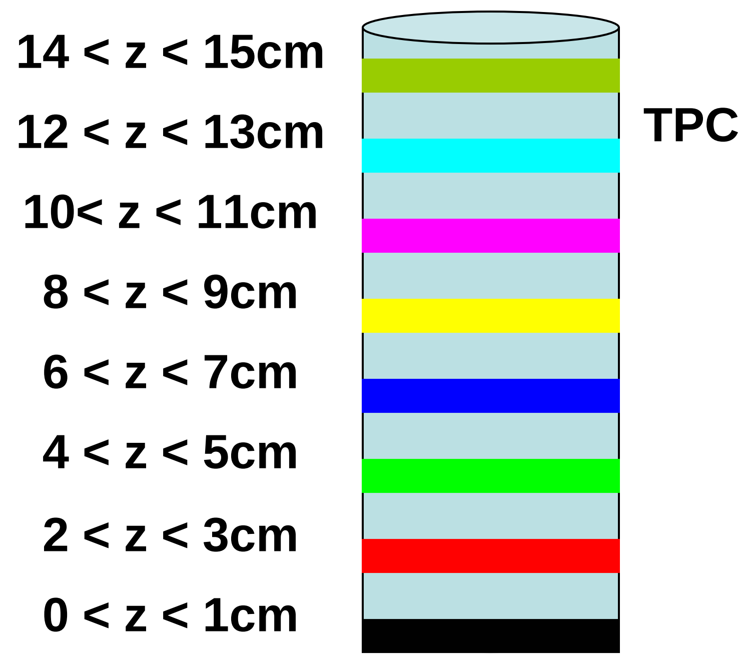
Simulation

MC Simulation – Resolution & PRF

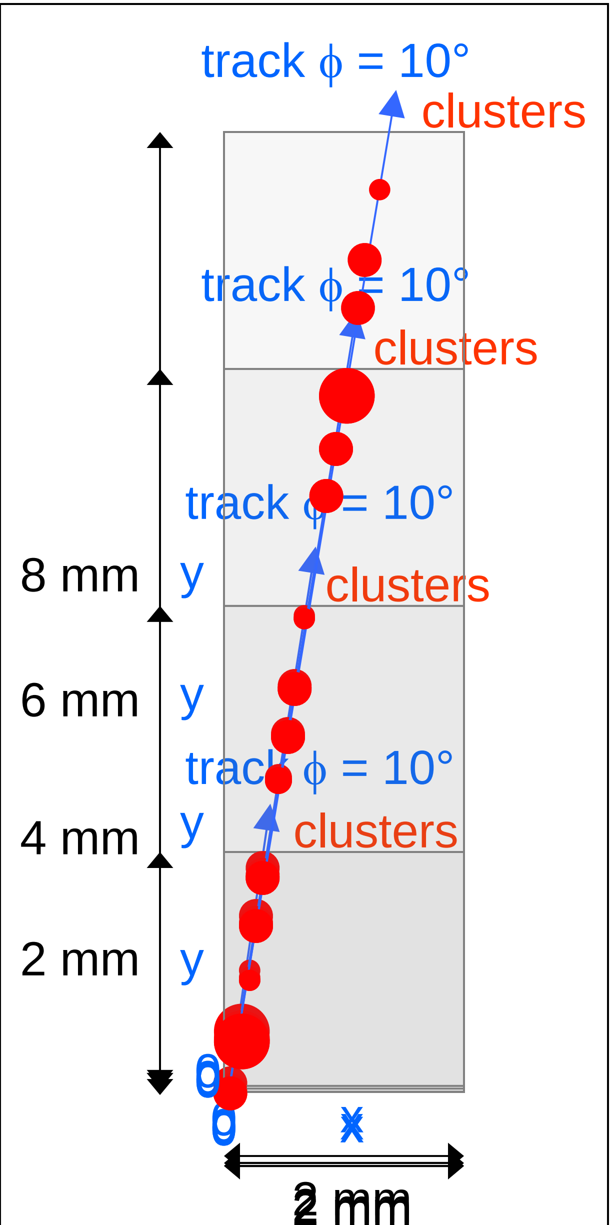






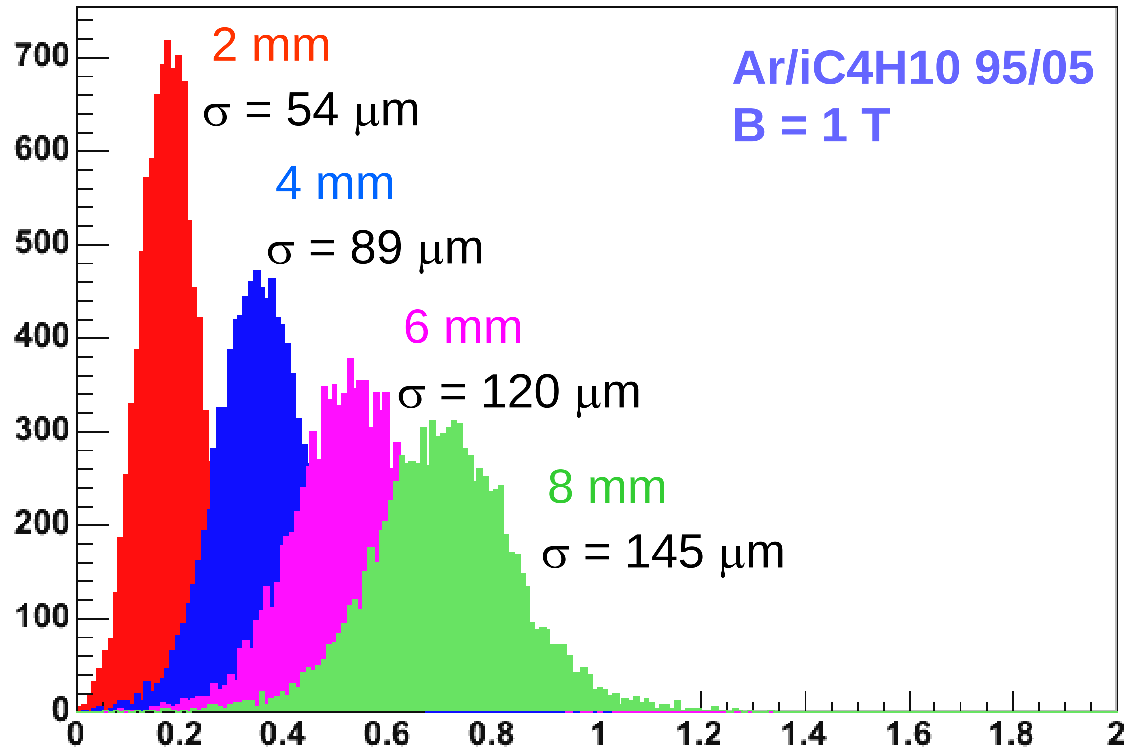


Transverse Spatial Resolution



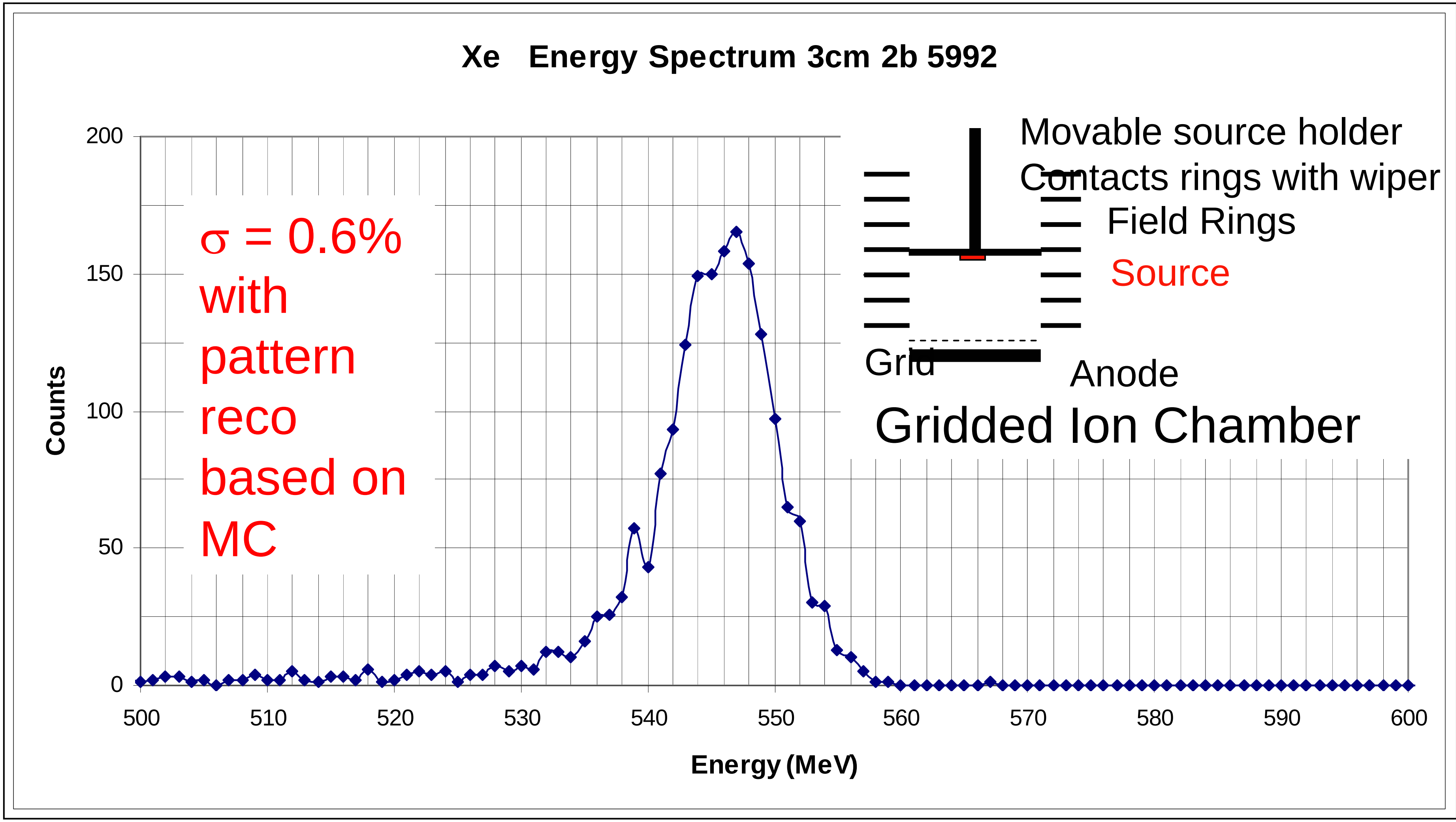
Ionization Statistics & Angle Effect

Monte Carlo Simulation



$$x = \sum_{clusters} x_c \cdot Ne_c \Big/ \sum_{clusters} Ne_c$$

Progress on energy resolution
Pure Xe, 2 Bar



Alpha spectrum at 2 b pressure.

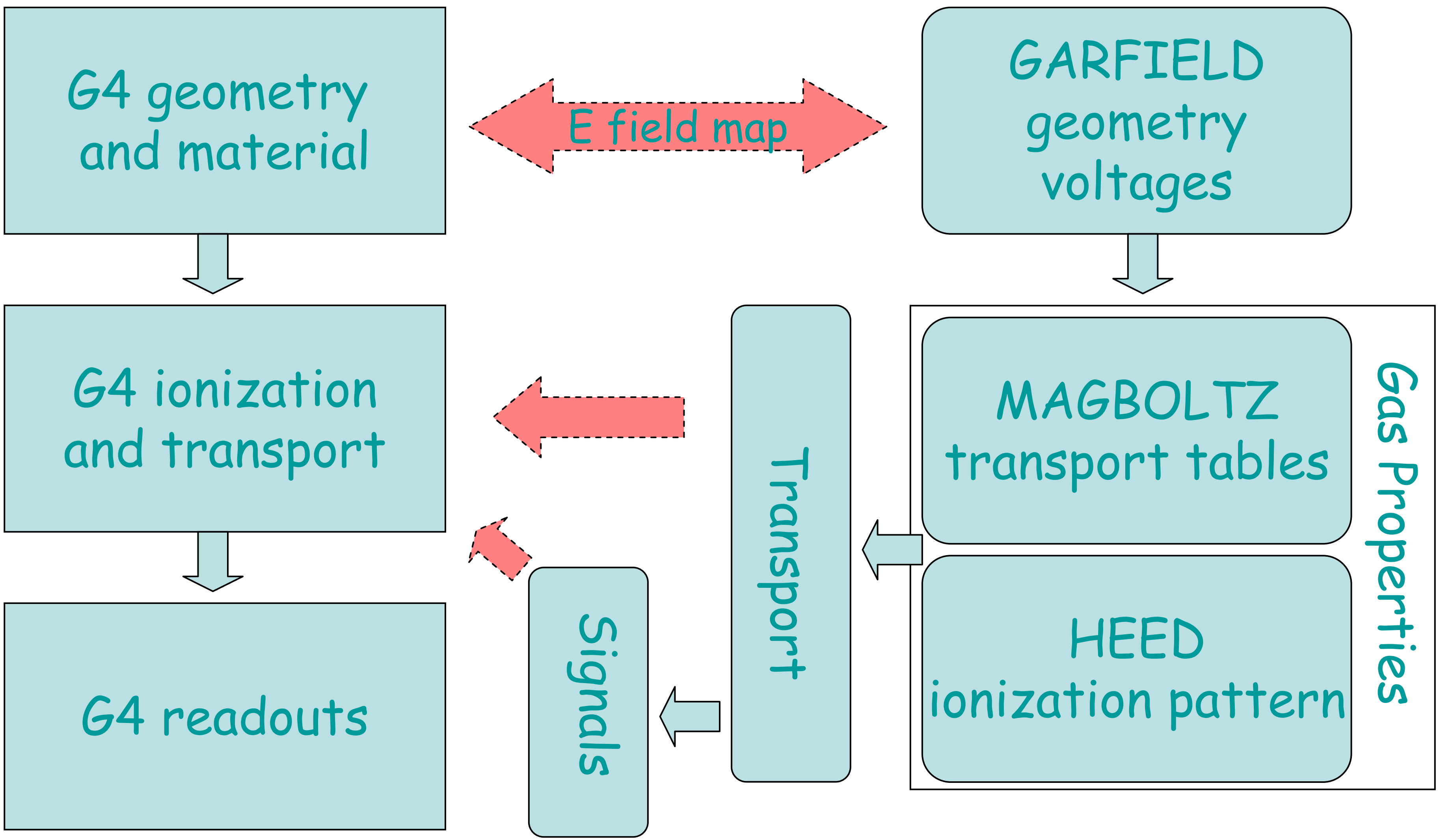
Simulation of TPC

- The standard is to use G4 for the definition of geometry and material
- Maps for **E** & **B** fields
- Use of the standard EM package
- Ionization at fixed intervals (~10 μm)
- Break out of G4 to drift clusters to readout pads
- Several groups uses different software packages: EXO, ILC/TPC, T2K, etc…

WHY NOT HAVING A COMMON FRAMEWORK EMBEDED WITHIN G4 ?!?

New Initiative

Incorporate 1) ionization statistics & transport in G4 based on GARFIELD
2) signal & avalanche in G4 based on GARFIELD
3) new cluster object in G4 (faster)



Conclusion

Summary

- A standard MPGD-TPC cannot get good resolution with wide pads
- With charge dispersion, wide pads can be used without sacrificing resolution. Charge dispersion works both for GEM and Micromegas.
- **At 5 T, an average ~ 50 μm resolution has been demonstrated with 2 x 6 mm² readout pads for drift distances up to 15 cm.**
- The ILC-TPC resolution goal ~100 μm for all tracks up to 2 m drift appears feasible.
- Canadian responsibilities for large 1 m prototype tests to 2010: Construct seven large Micromegas panels with charge dispersion shared with France (Carleton & Montréal)
- Application to T2K: R&D France/Canada
- **Development of common simulation framework for TPC**
- Ionization and transport in G4 [via Garfield capabilities]