TPC Development for the International Linear Collider

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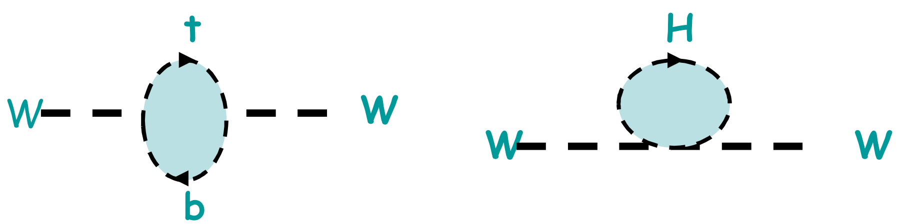
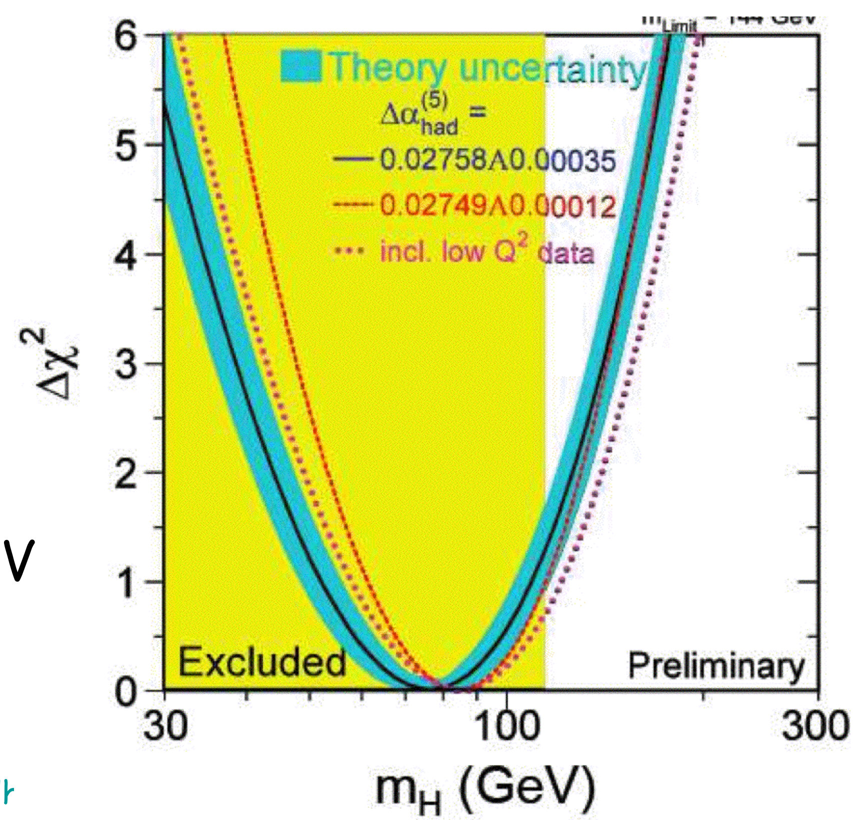
Standard Model (SM)

- Standard Model - the most comprehensive existing unified field theory of electromagnetism & weak interactions
- Theory internally consistent & remarkably successful in describing observed phenomena at the level of ~0.1%

- Higgs - the missing ingredient
- Higgs coupling proportional to mass & therefore especially sensitive to M_t & M_W



M_H(fit)=76 GeV & 114.4 < M_{Hi}< 144 GeV from LEP exclusion & EW fits with latest M_t & M_W from CDF & D0



Standard Model must be an incomplete theory

In spite of its remarkable success, there are problems with the SM
The SM Higgs below 150 GeV is much too light compared to its expected much higher renormalized mass which diverges quadratically:

$m_0^2 \Rightarrow m_0^2 + \delta m^2$ where $\delta m^2 \sim \Lambda^2$ (Λ high energy cut off scale)

Existence of cold dark matter well established. 1 TeV "Weakly Interacting Massive Particles (WIMP) could explain the observed dark matter density. But there are no WIMPs in the Standard Model

- Existence of new physics such as Super Symmetry could stabilize the Higgs mass below 1 TeV and at the same time solve the dark matter problem
- LHC starting in 2008 is expected to provide some of the answers

The International Linear Collider

LHC 14 TeV p-p collisions
Quark and gluon collisions - CM energy not well defined
Should find the Higgs if it exists
With less restrictive initial state quantum numbers
May provide unexpected surprises.

ILC will collider $e^+ e^-$ at CM energies 500 GeV (upgradeable to 1 TeV)
Point like particles cleaner collisions
Well defined CM energy & state quantum numbers
Precision measurements, detailed study of particle properties

Complementary approaches of the LHC and the ILC will be essential to clarify physics beyond the Standard Model

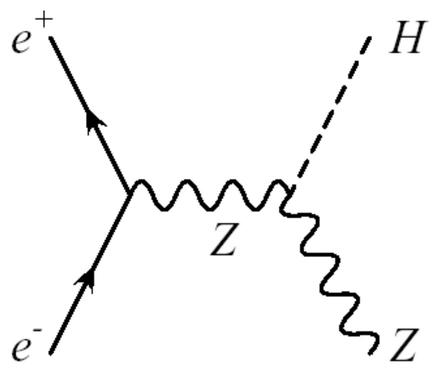
LHC/ILC complementary

- ILC will be able to study in detail any LHC Higgs discovery
- Detailed Higgs property measurement at ILC
  - spin, parity, couplings
  - Confirm if it is SM Higgs by measuring couplings to Z, W, b, c, τ,...
- ILC will untangle LHC discovery/measurements of SUSY, new gauge interactions, extra dimensions…
  - By selecting specific states using polarization
  - By measuring SUSY mass spectrum & parameters, etc.
- Precision measurements
  - $\Delta M_{Top} \approx$ 100 MeV, $\Delta\Gamma_{Top} \approx$ 2%
  - ΔM_Z & $\Delta M_W \approx$ 5 MeV (from 30 MeV)
  - $\Delta(\sin^2\vartheta) \approx 10^{-5}$ (from $2\cdot10^{-4}$)

Model independent Higgs studies require a powerful tracker

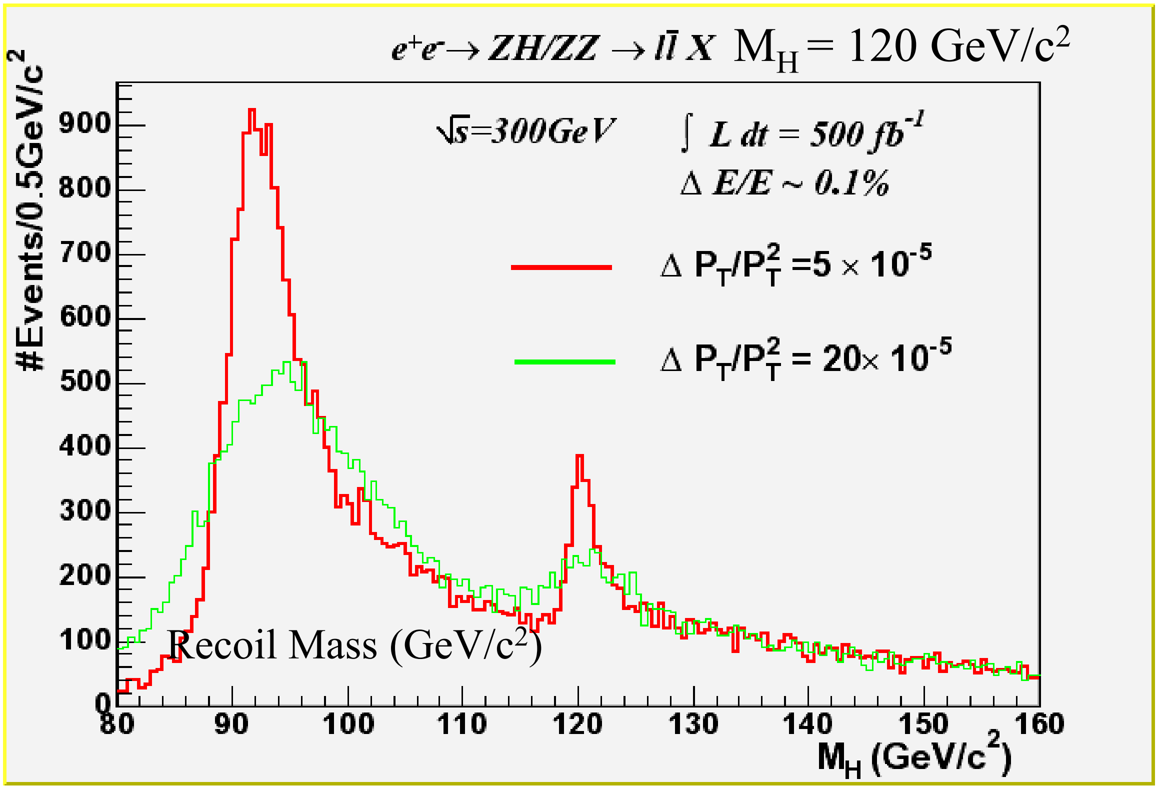
Measure recoil mass against Z to detect even invisible Higgs decays with accuracy limited only by beam energy

$\Delta(1/p_T) \sim 2$ to 3×10^{-5} $(GeV/c)^{-1}$ more than 10 times better than at LEP!



$HZ \rightarrow llX$

$ZZ \rightarrow llX$



ILC tracker performance requirements

- Small cross sections < 100 fb, low rates, no fast trigger.
- Higgs measurements & SUSY searches require:
  - Good particle flow measurement.
  - Minimum material before calorimeters.
  - Good pattern recognition
  - Excellent primary and secondary b, c, τ decay vertex reconstruction.
- TPC an ideal tracker - low mass, high granularity continuous tracking, excellent pattern recognition, particle identification.

  $\Delta(1/p_T) \sim 1 \times 10^{-4}$ (GeV^{-1}) (TPC alone)

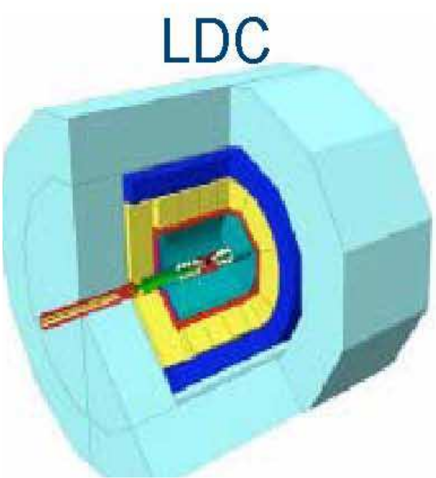
  $\sim 3.10^{-5}$ (GeV^{-1}) (vertex + Si inner tracker + TPC)
- TPC parameters:

  ~ 200 track points; $\sigma(r, \varphi) \sim 100$ µm at 2 m drift & $\sigma(z) \sim 500$ µm

  2 track resolution ~ 2mm (r, φ) & ~ 5 mm (z)

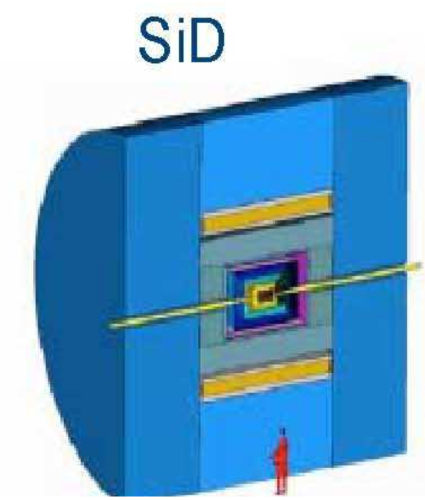
  dE/dx ~ 5%

TPC tracker part of 3 present ILC detector concepts

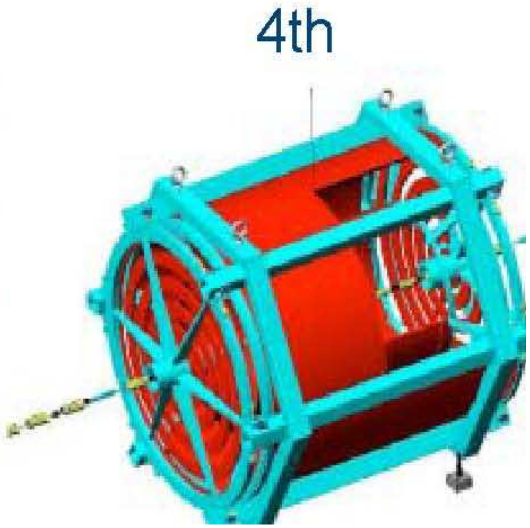


TPC (B=4T)

TPC (B=3T)



Silicon (B=5T)



TPC (B=3.5 T)

Diffusion sets the fundamental limit on achievableTPC resolution

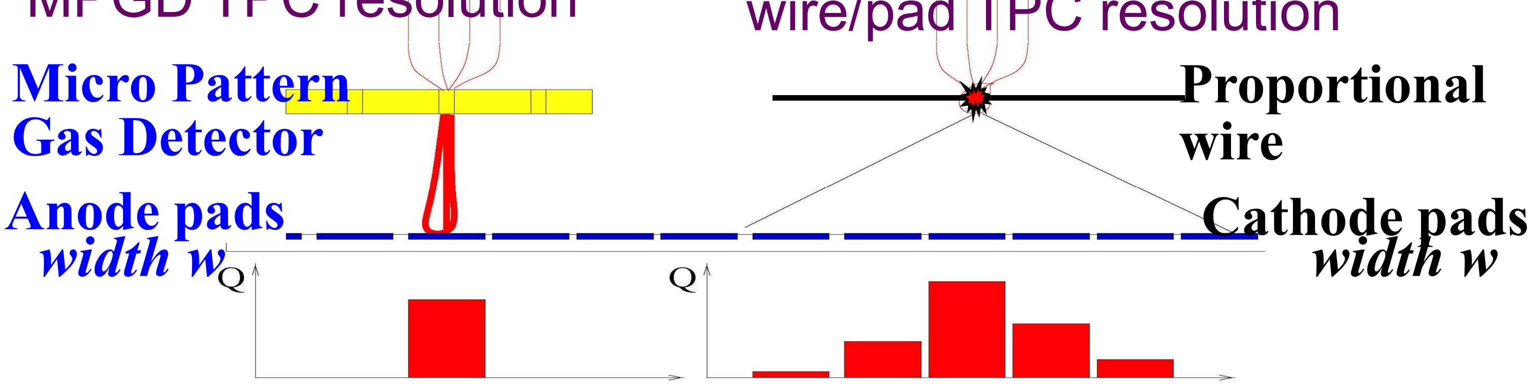
- The physics limit of TPC resolution comes from transverse diffusion:

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

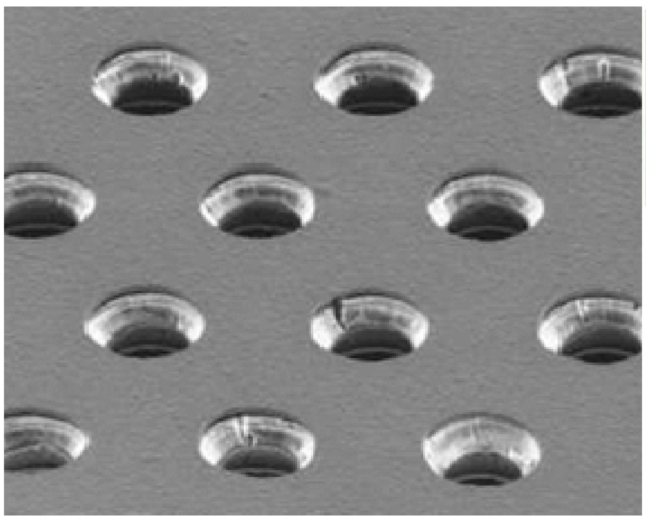
Accurate centroid determination possible with wide pads

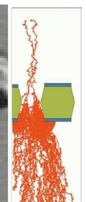
$$\sigma_x^2 \approx \sigma_0^2 + \frac{D_{Tr}^2 \cdot z}{N_{eff}}$$

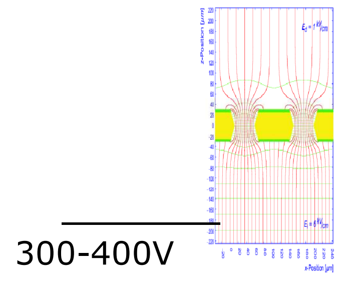
No ExB effects in MicroPattern Gas Detectors (MPGD)

GEM a thin film proportional detector

Gas gain in narrow channels with high electric field







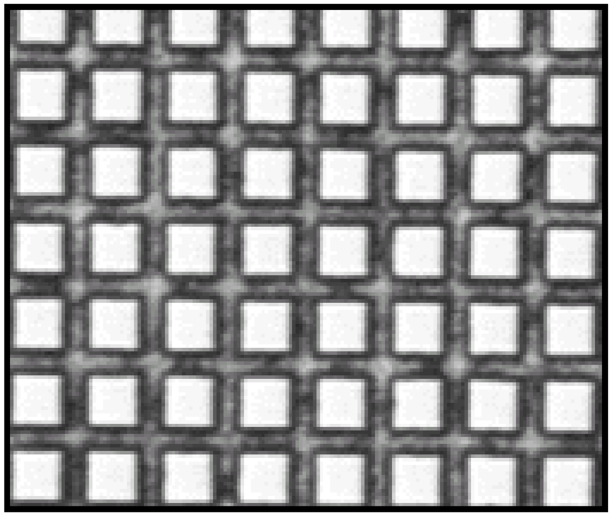
Thin ~ 50 μm double-sided copper clad Kapton foil

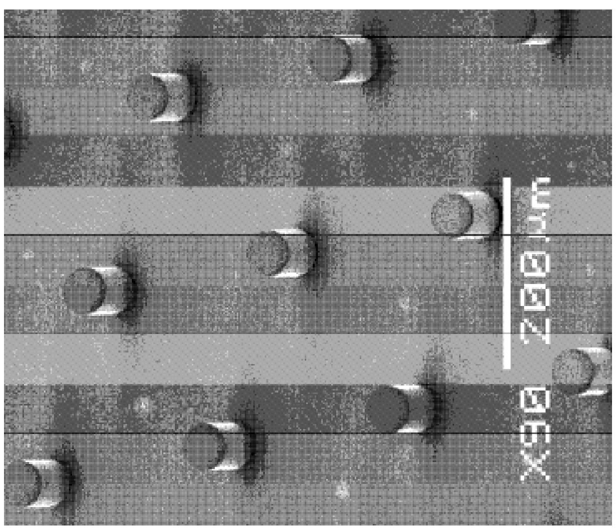
Matrix of 50-70 μm diameter channels ~ 140 μm pitch

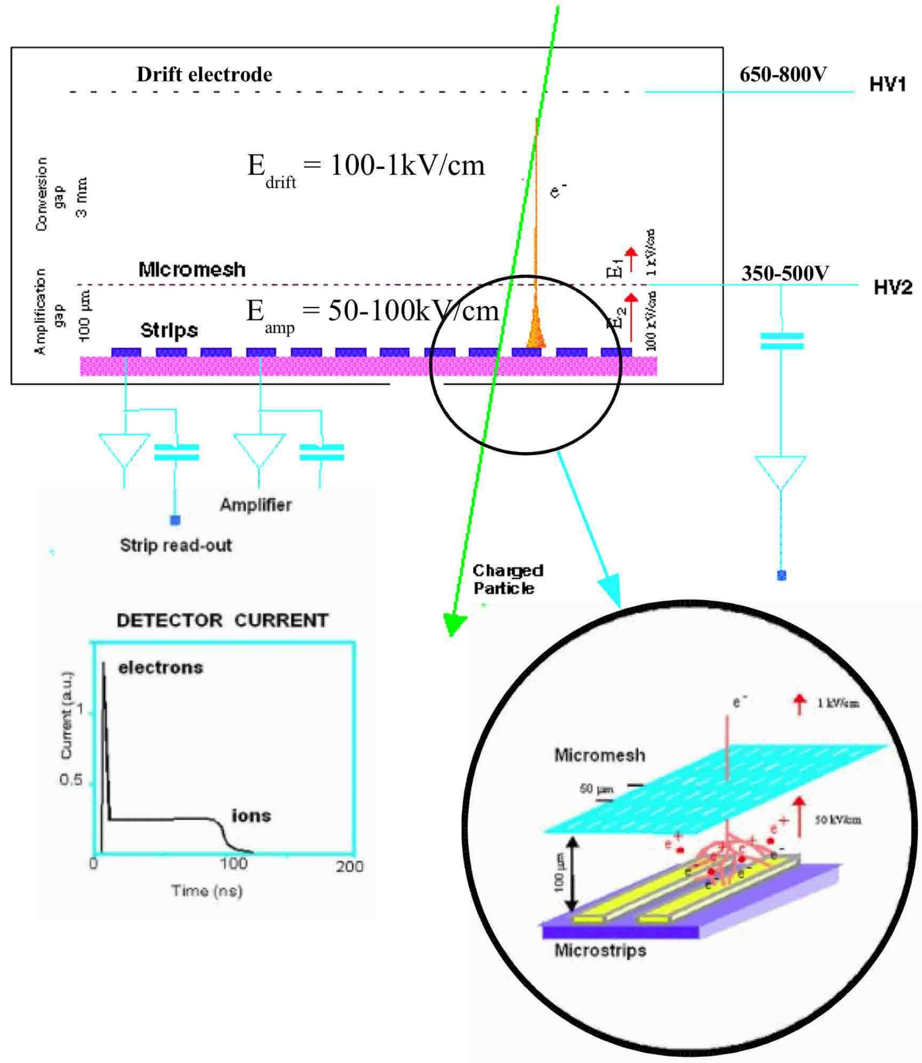
Up to 80 kV/cm electric field inside channels

Micromegas - A small gap parallel plate proportional detector

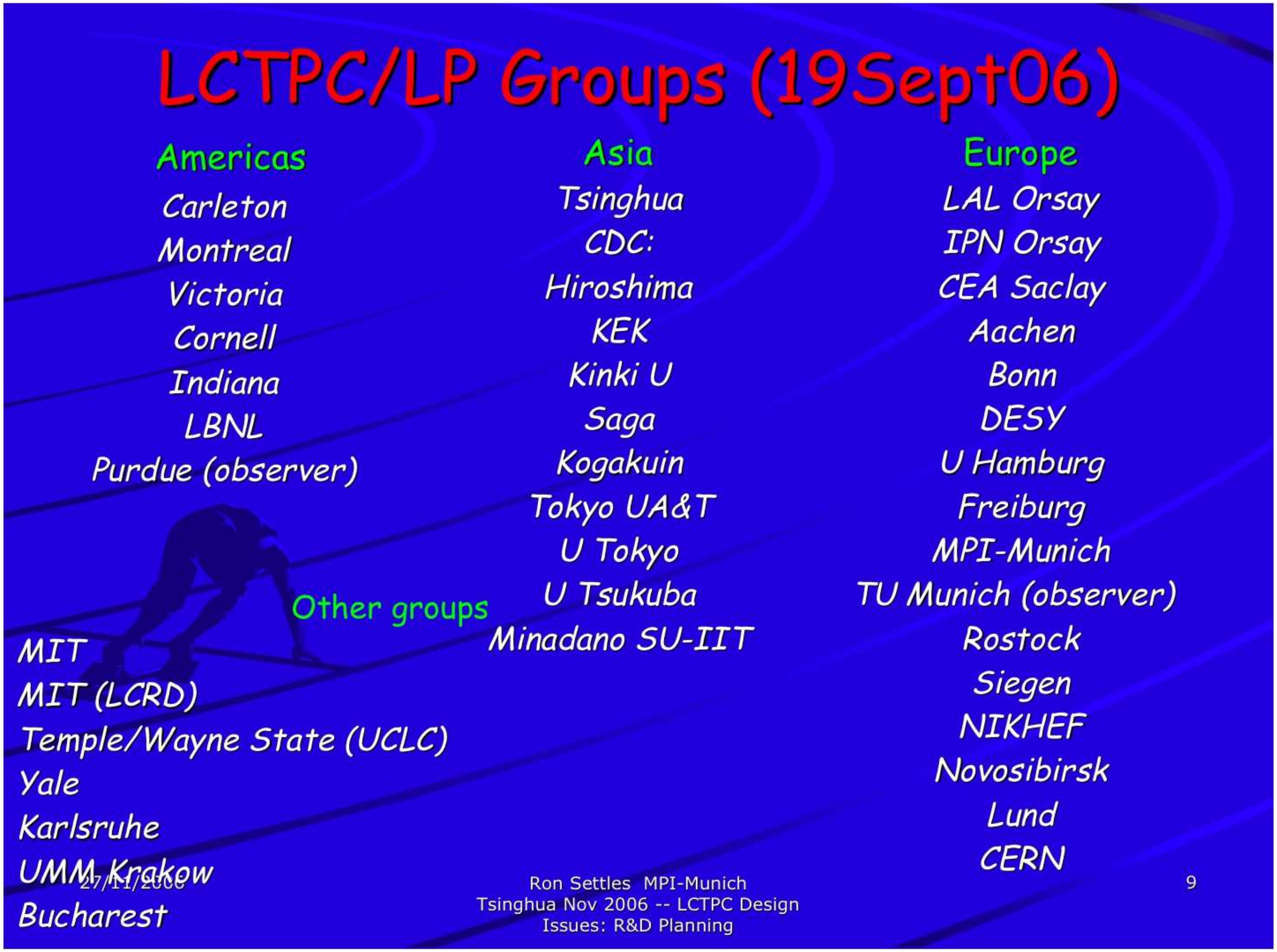
Micromesh supported by ~ 50 μm pillars above anode







TPC R&D for the ILC - a world wide effort



R&D Planning

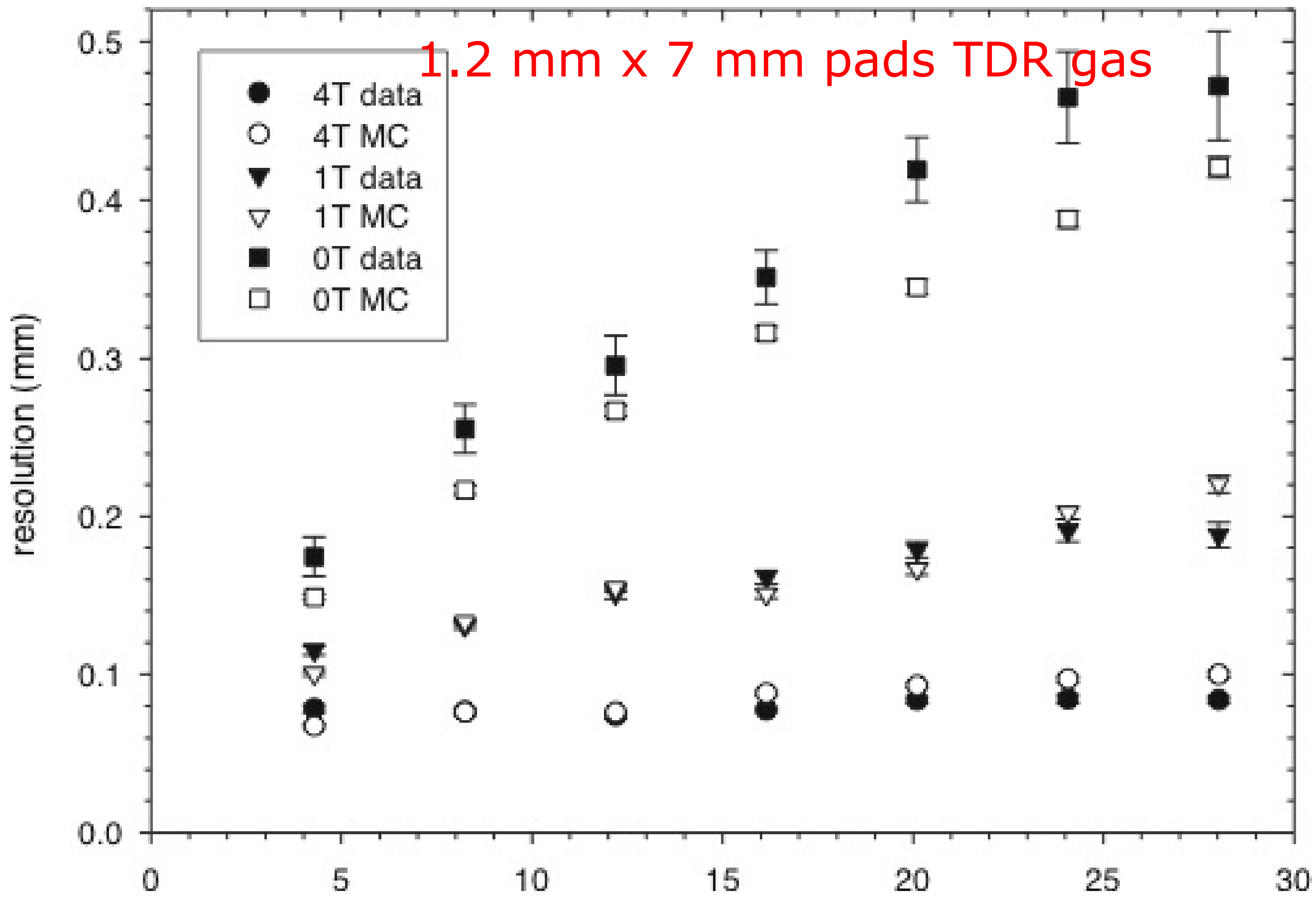
- 1) Demonstration phase
  - Continue work with small prototypes on mapping out parameter space, understanding resolution, etc, to prove feasibility of an MPGD TPC. For CMOS-based pixel TPC ideas this will include proof-of-principle tests.
- 2) Consolidation phase
  - Build and operate the Large Prototype (LP), Ø ~ 80cm, drift ~ 60cm, with EUDET infrastructure as basis, to test manufacturing techniques for MPGD endplates, fieldcage and electronics. LP design is starting → building and testing will take another ~ 3-4 years.
- 3) Design phase
  - During phase 2, the decision as to which endplate technology to use for the LC TPC would be taken and final design started.

Demonstration phase ILC TPC R&D

- Canada has been a leading group 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 a new concept of charge dispersion in a MPGD with a resistive anode - a mechanism to disperse the avalanche charge.
It makes position sensing insensitive to pad width.
The technique works for both the GEM and the Micromegas

GEM-TPC cosmic tests at DESY done by Victoria Group
Transverse resolution vs. B field



Resolution gets better with B

Transverse 2-track resolution measured with a laser (Victoria group)

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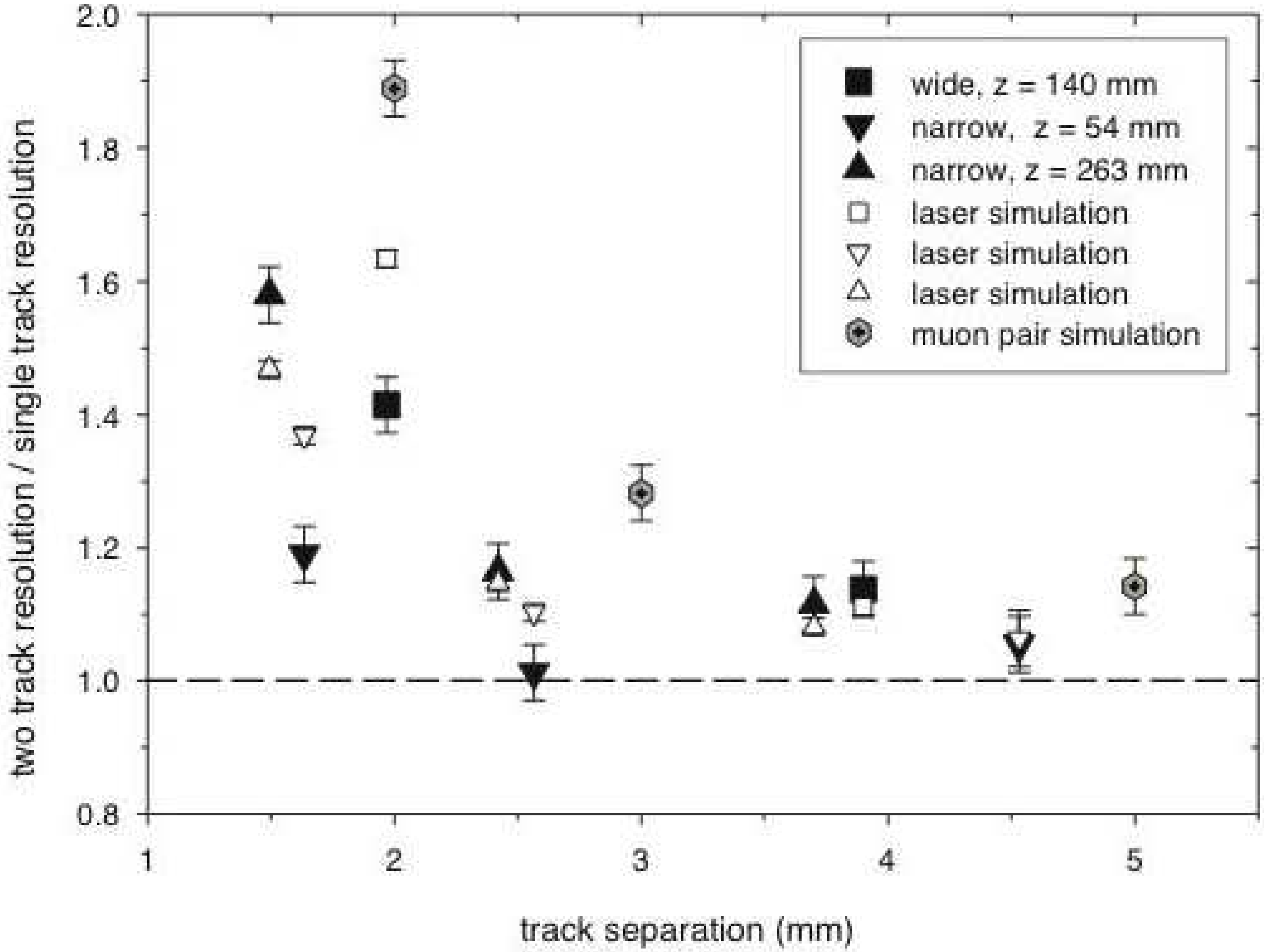


Good resolution achieved for tracks separated by > 1.5 x pad width

Position sensing from charge dispersion in a MPGD with a resistive anode

Position sensing on a resistive anode proportional wire from charge division

Telegraph equation (1-D):

$$\frac{L}{R}\frac{\partial^2 Q}{\partial t^2} + \frac{\partial Q}{\partial t} = \frac{1}{RC}\frac{\partial^2 Q}{\partial x^2}$$

Deposit point charge at t=0

Solution for charge density (L ~ 0)

$$Q(x,t) = \sqrt{\frac{RC}{4\pi t}}\, e^{\frac{-x^2 RC}{4t}}$$

Generalize charge division on a resistive wire to 2 D

Position sensing from charge dispersion in MPGDs with a resistive anode

Equivalent to Telegraph equation in 2-D

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

Solution for charge density in 2-D

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

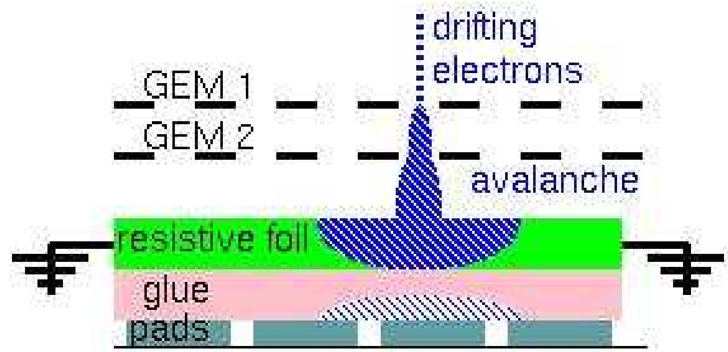
Charge dispersion in a MPGD with a resistive anode

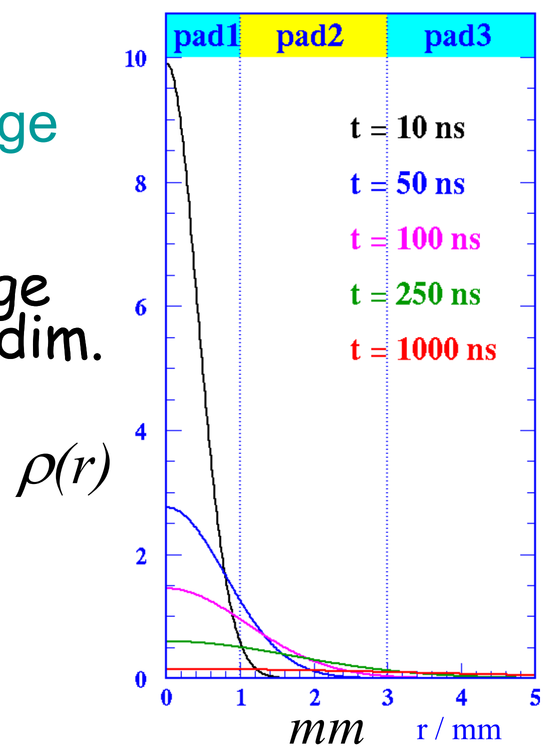
- Modified GEM anode with a high resistivity film bonded to a readout plane with an insulating spacer.
- 2-dimensional continuous RC network defined by material properties & geometry.
- Point charge at r = 0 & t = 0 disperses with time.
- Time dependent anode charge density sampled by readout pads.

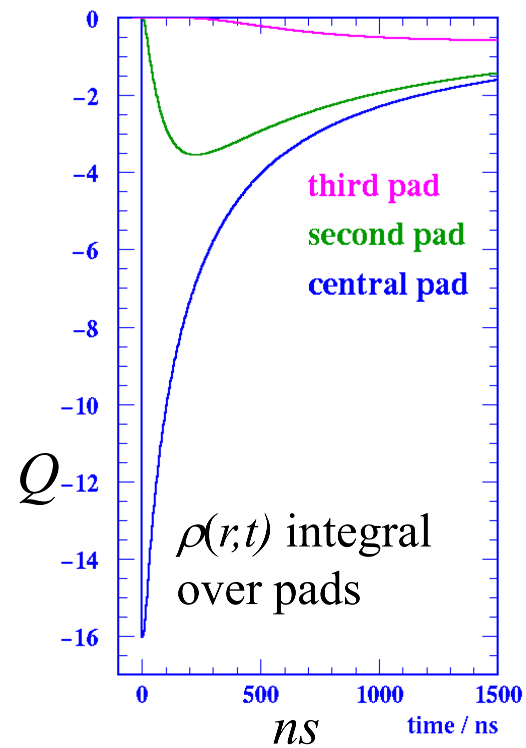
Equation for surface charge density function on the 2-dim. continuous RC network:

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

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

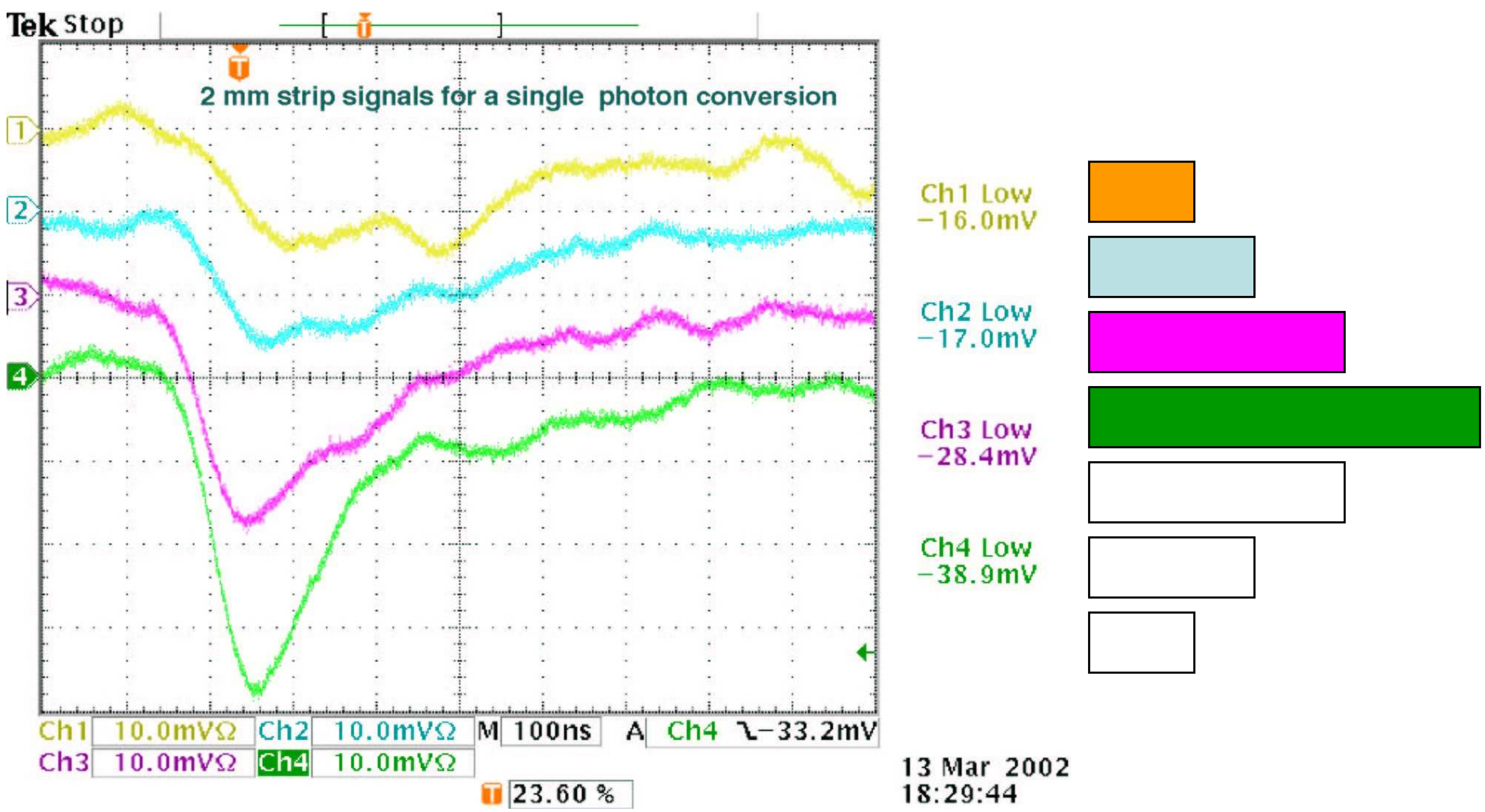




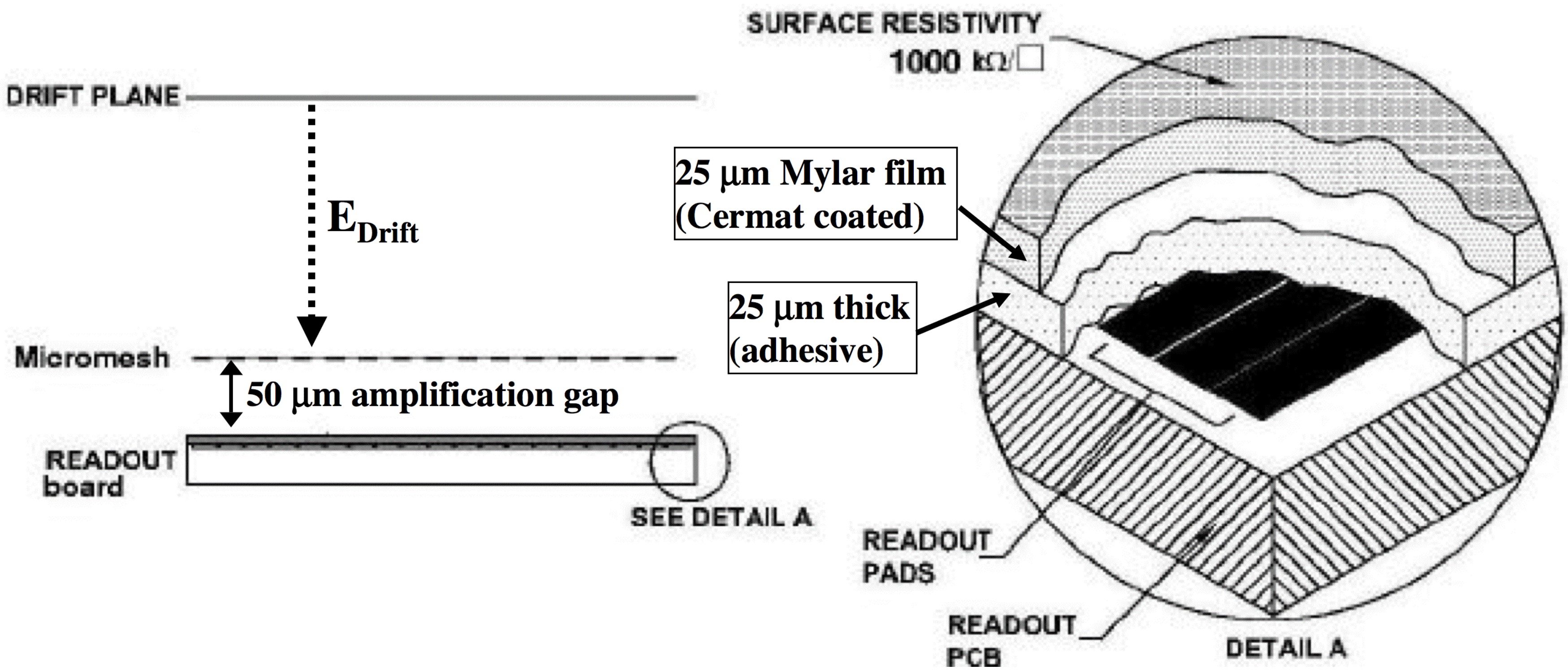


The proof - a 6 keV ^{55}Fe x-ray photon event as seen in our first GEM test cell with a resistive anode

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



Micromegas with a resistive readout



Simulating the charge dispersion phenomenon

- The charge dispersion equation describe the time evolution of a point like charge deposited on the MPGD resistive anode at $t = 0$.
- No standard pulse shape. For improved understanding & to compare to experiment, one must include the effects of:
    - Longitudinal & transverse diffusion in the gas.
    - Intrinsic rise time T_{rise} of the detector charge pulse.
    - The effect of preamplifier rise and fall times t_r & t_f.
    - And for particle tracks, the effects of primary ionization clustering.

The simulation for a single charge cluster

The charge density function for a point charge in Cartesian coordinates:

$$\rho\delta(x,y,t) = \frac{\tau}{4\pi t} exp\left[-\tau\left(x^2+y^2\right)/4t\right] \; where \; \tau = RC$$

Physics effects included in simulation in two parts: 1) as effects which depend on spatial coordinates x & y, or; 2) as effects which depend on time.

1) The spatial effects function includes charge dispersion phenomena & transverse size *w* of the charge cluster due to transverse diffusion.

$Q_{pad}(t)$ is the pad signal from charge dispersion when a charge Nq_e of size *w* is deposited on the anode at $t = 0$;

$$Q_{pad} = \frac{Nq_e}{4}\left[erf\left(\frac{x_{high}}{\sqrt{2}\sigma_{xy}}\right) - erf\left(\frac{x_{low}}{\sqrt{2}\sigma_{xy}}\right)\right]\left[erf\left(\frac{y_{high}}{\sqrt{2}\sigma_{xy}}\right) - erf\left(\frac{y_{low}}{\sqrt{2}\sigma_{xy}}\right)\right] \quad (1)$$

x_{high}, x_{low}, y_{high}, y_{low} define the pad boundaries & $\sigma_{xy} = \sqrt{2t/\tau + w^2}$

$$I(t)=\frac{1}{2T_{rise}}\left[\begin{array}{l} exp\left(\sigma^2a^2/2-at\right)\left[erf\left(\frac{t-T_{rise}-\sigma^2a}{\sigma\sqrt{2}}\right)+1\right]- \\ exp\left(\sigma^2b^2/2-bt\right)\left[erf\left(\frac{t-T_{rise}-\sigma^2b}{\sigma\sqrt{2}}\right)+1\right]+ \\ exp\left(\sigma^2a^2/2-a(t-T_{rise})\right)\left[erf\left(\frac{t-2T_{rise}-\sigma^2a}{\sigma\sqrt{2}}\right)+1\right]- \\ exp\left(\sigma^2b^2/2-b(t-T_{rise})\right)\left[erf\left(\frac{t-2T_{rise}-\sigma^2b}{\sigma\sqrt{2}}\right)+1\right]+ \\ exp\left(\sigma^2a^2/2-at\right)\left[erf\left(\frac{t-\sigma^2a}{\sigma\sqrt{2}}\right)+erf\left(\frac{t-T_{rise}-\sigma^2a}{\sigma\sqrt{2}}\right)\right]- \\ exp\left(\sigma^2b^2/2-bt\right)\left[erf\left(\frac{t-\sigma^2b}{\sigma\sqrt{2}}\right)+erf\left(\frac{t-T_{rise}-\sigma^2b}{\sigma\sqrt{2}}\right)\right] \end{array}\right] \quad (2)$$

I(t) incorporates intrinsic rise time, longitudinal diffusion & electronics shaping times as time dependent effects. $a=1/t_f\,;\,b=1/t_f+1/t_r$

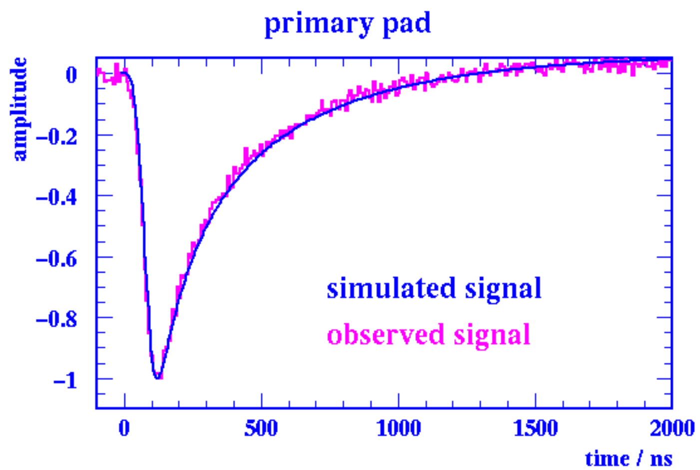
(1) and (2) are convoluted numerically for the model simulation.

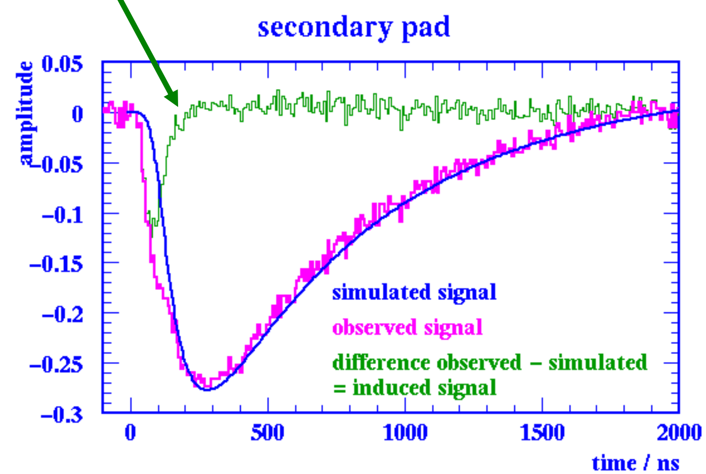
Charge dispersion signals for the GEM readout

Simulation vs. measurement for $Ar+10\%CO_2$ (2×6 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).



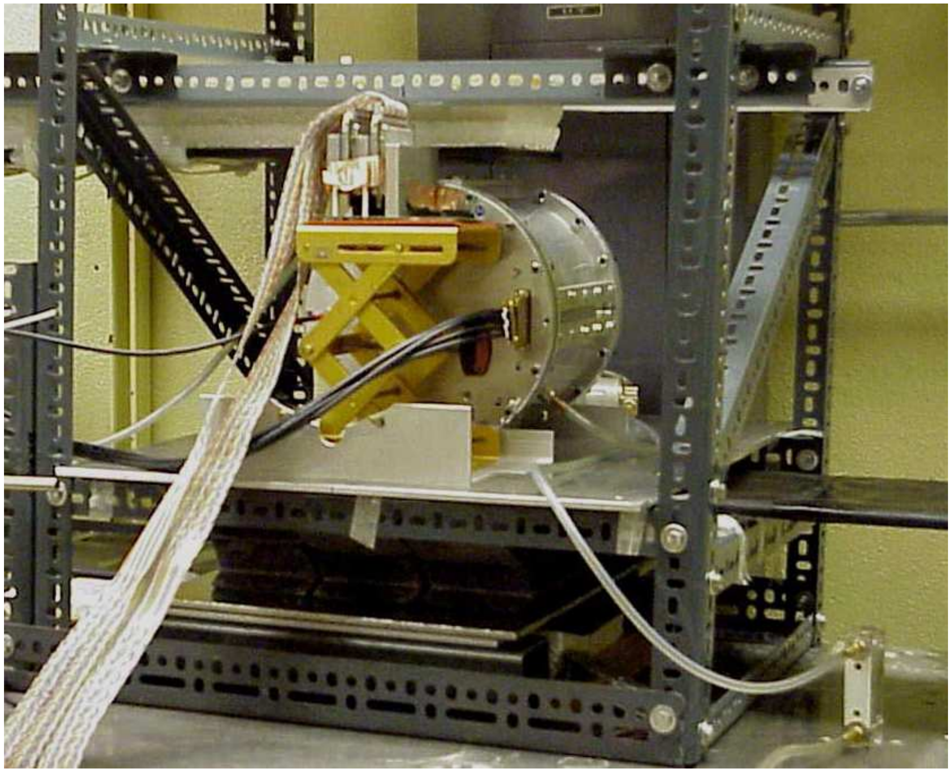


Simulated primary pulse is normalized to the data.

Primary pulse normalization used for the simulated secondary pulse

Initial B=0 Cosmic Ray Tests in Canada

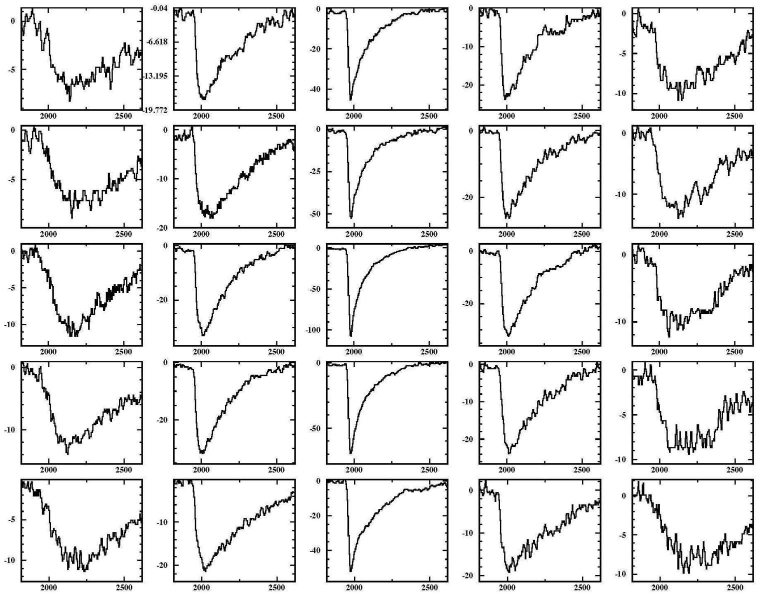
- 15 cm drift length with GEM or Micromegas readout
- Ar+10% CO_2 chosen to simulate low transverse diffusion in a magnetic field.
- Aleph charge preamps. τ_{Rise}= 40 ns, τ_{Fall} = 2 μs,
- 200 MHz FADCs rebinned to digitization effectively at 25 MHz.
- In contrast to normal practice, we use digitized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

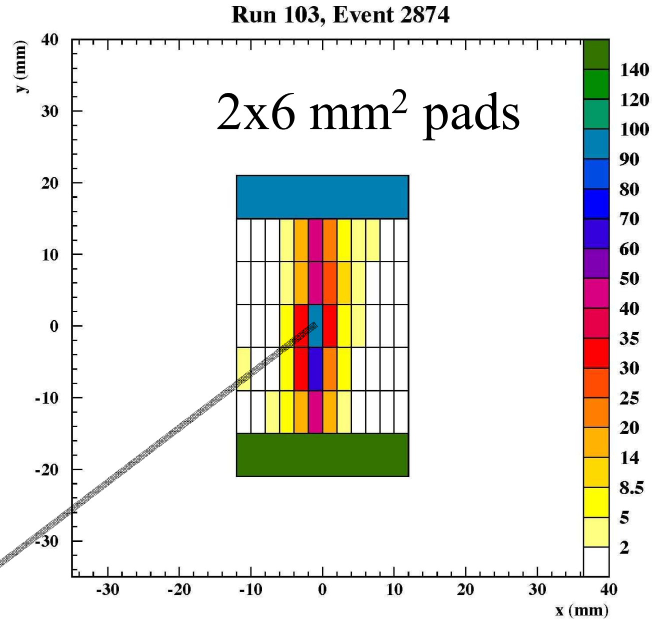


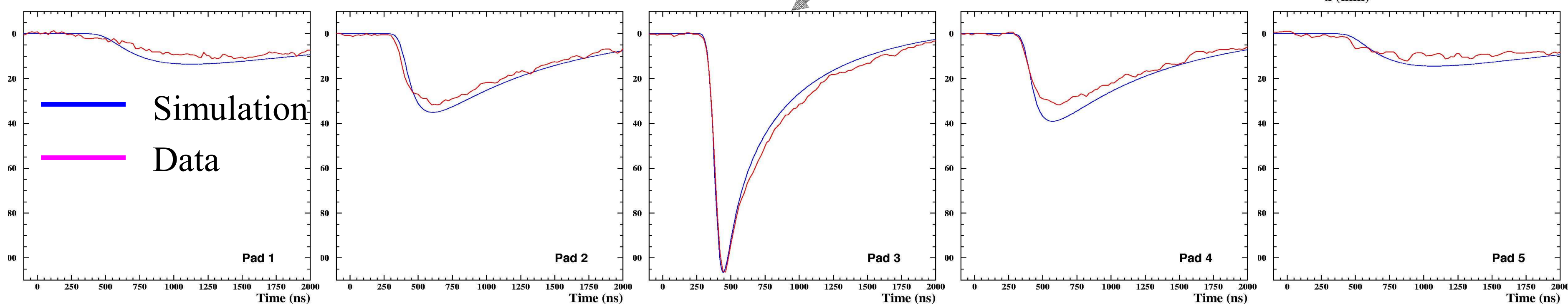
The GEM-TPC resolution was first measured with conventional direct charge TPC readout.

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.

Track PRFs with GEM & Micromegas readout

The PRFs are not Gaussian.
The PRF depends on track position relative to the pad.

PRF = PRF(x,z)

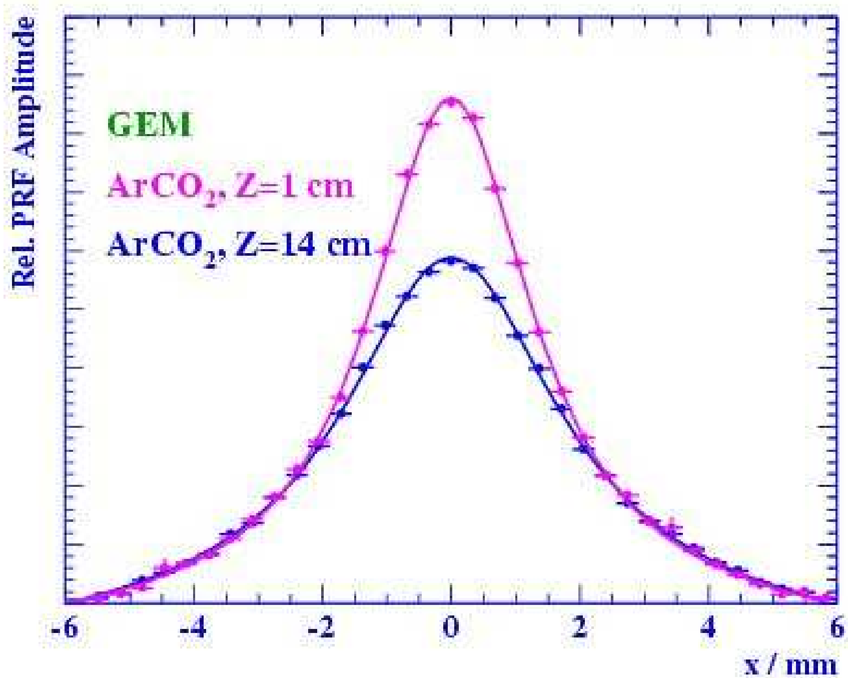
PRF can be characterized by FWHM $\Gamma(z)$ & base width $\Delta(z)$.
PRFs determined from the data parameterized by a ratio of two symmetric 4th order polynomials.

$$PRF[x,\Gamma(z),\Delta(z),a,b] = \frac{(1 + a_2 x^2 + a_4 x^4)}{(1 + b_2 x^2 + b_4 x^4)}$$

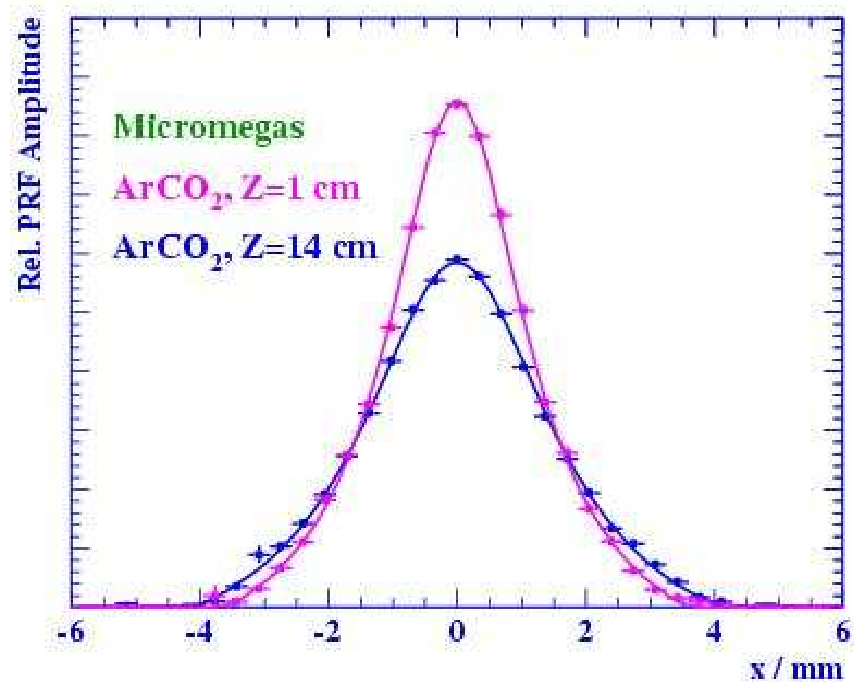
a_2 a_4 b_2 & b_4 can be written down in terms of Γ and Δ & two scale parameters a & b.

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



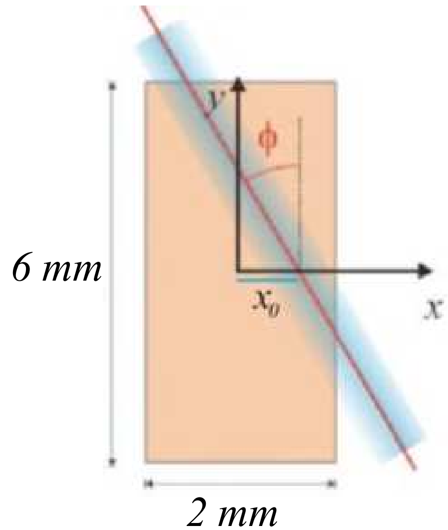
Micromegas PRFs

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

Track fit using the the PRF

Track at: $x_{track} = x_0 + \tan(\phi)\, y_{row}$

$$\chi^2 = \sum_{rows} \sum_{i=pads} \left(\frac{A_i - PRF_i}{\partial A_i} \right)^2$$



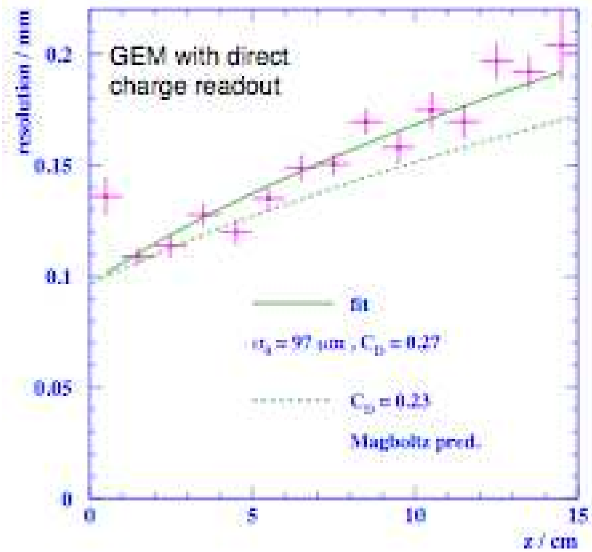
Determine x_0 & ϕ by minimizing χ^2 for the entire event

Definitions:

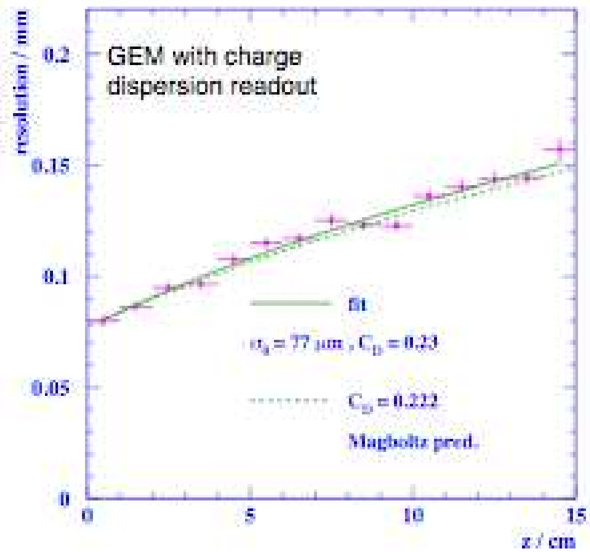
- residual: $x_{row} - x_{track}$
- bias: mean of $x_{row} - x_{track} = f(x_{track})$
- resolution: standard deviation of residuals

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

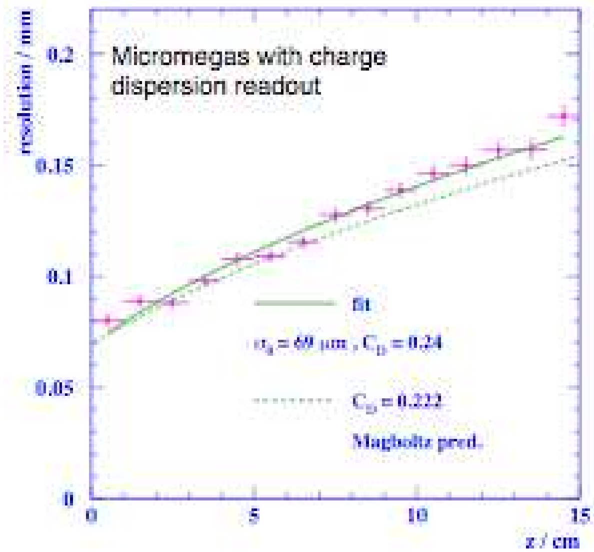
R.K.Carnegie et.al.,
NIM A538 (2005) 372



K. Boudjemline et.al.,
NIM A - in press



A. Bellerive et al,
LCWS 2005, Stanford



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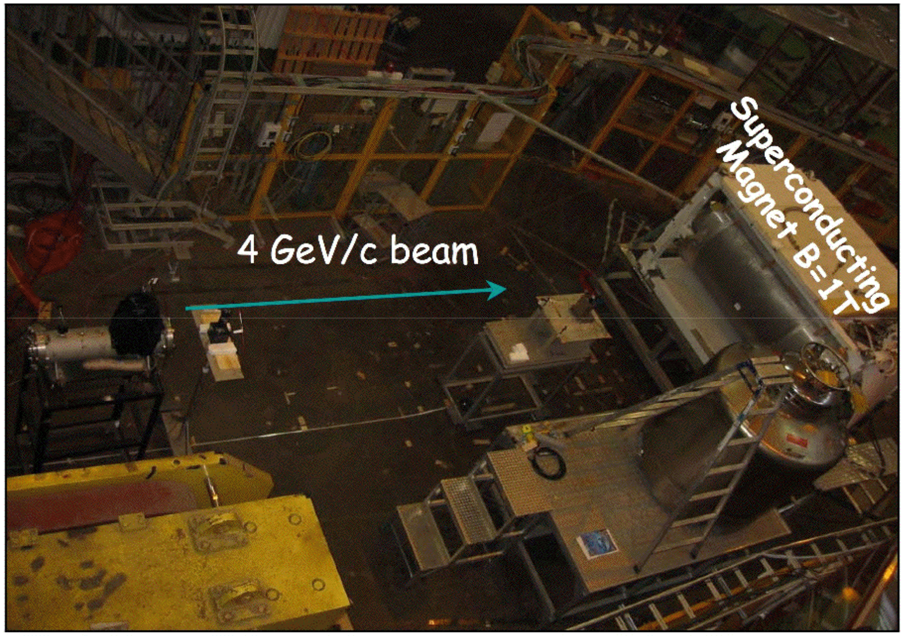
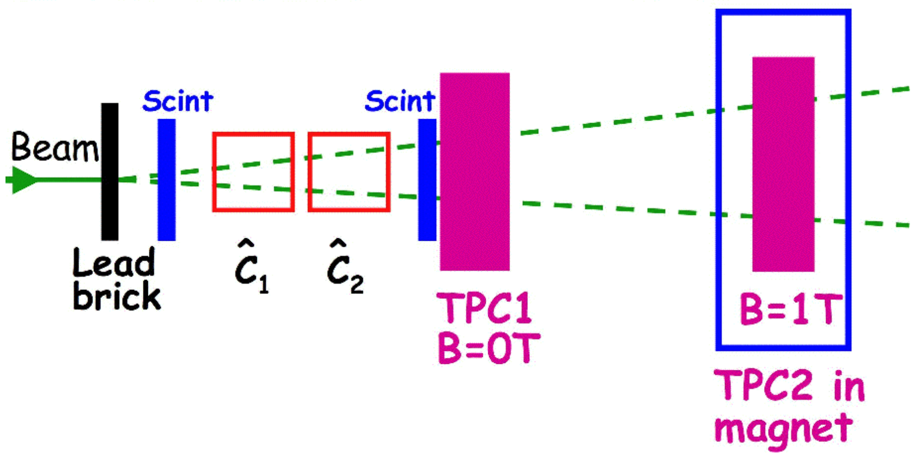
$$\sqrt{\sigma_0{}^2 + \frac{C_D{}^2}{N_e} z}$$

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





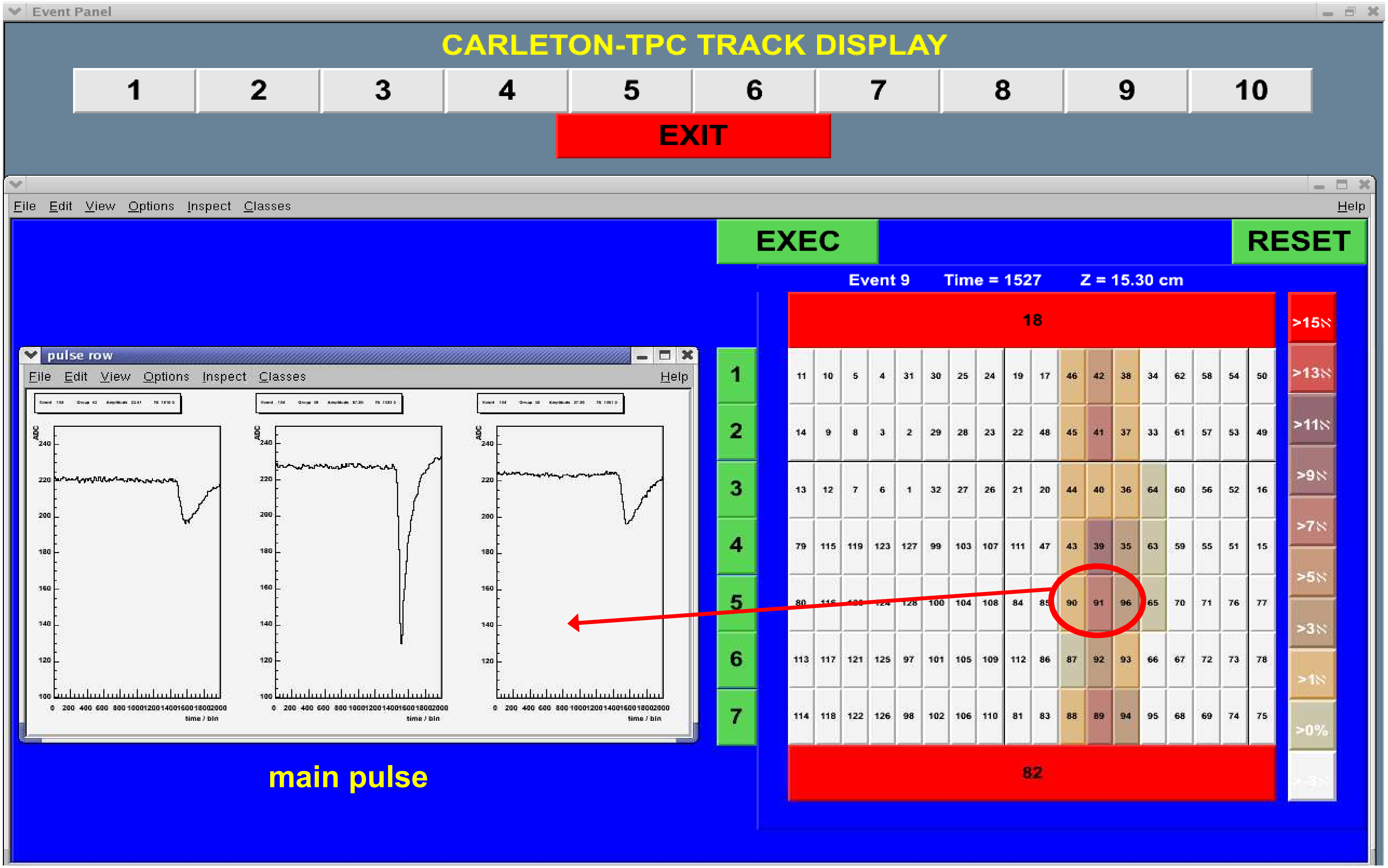
- 4 GeV/c hadrons (mostly πs)
- 0.5 & 1 GeV/c electrons
- Super conducting 1.2 T magnet without return yoke
- Inner diameter : 850 mm
- Effective length: 1 m

Canadian TPC in the beam outside the magnet

Track display - Ar+5%iC4H10

Micromegas 2 x 6 mm^2 pads B = 1 T

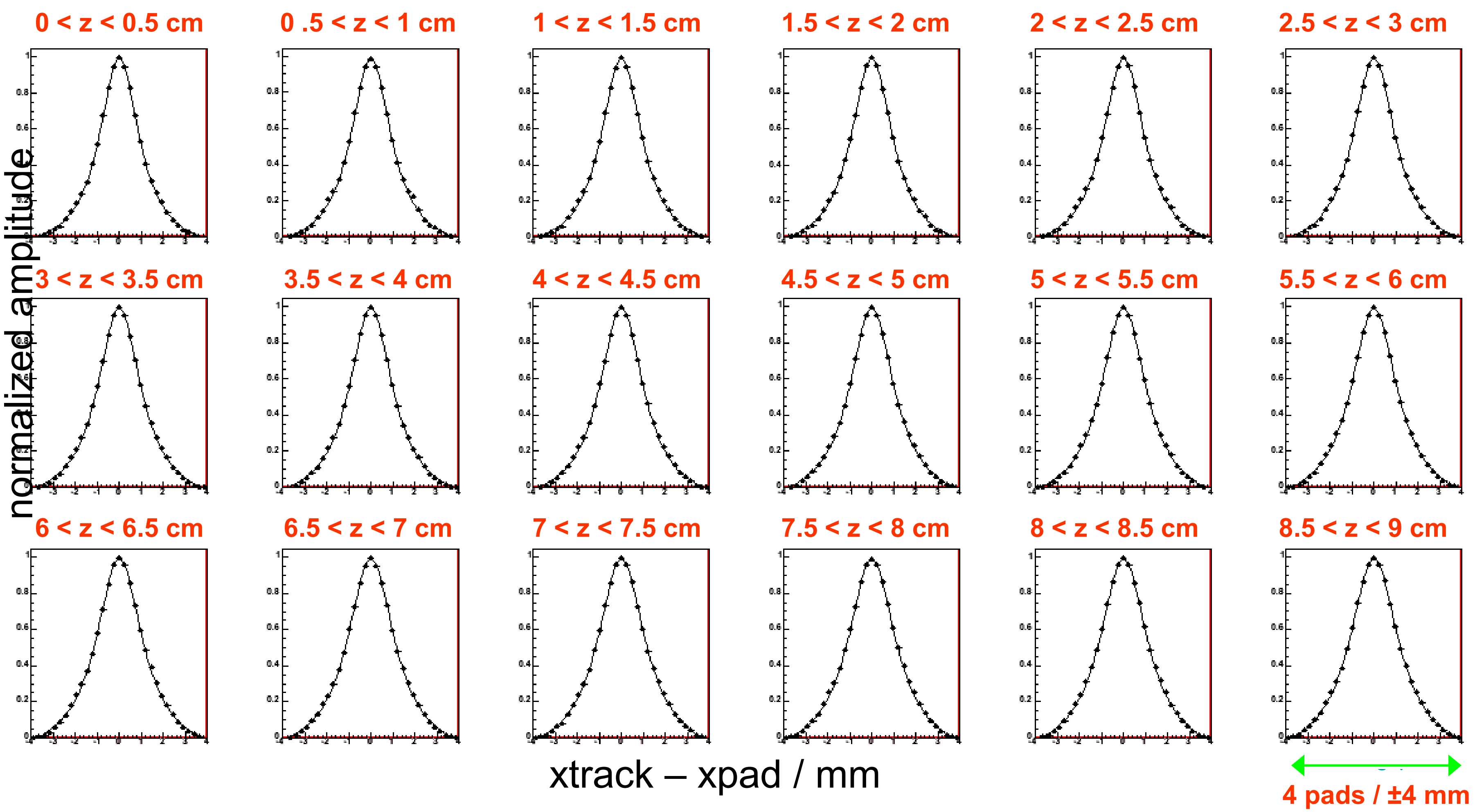
Z_{drift} = 15.3 cm



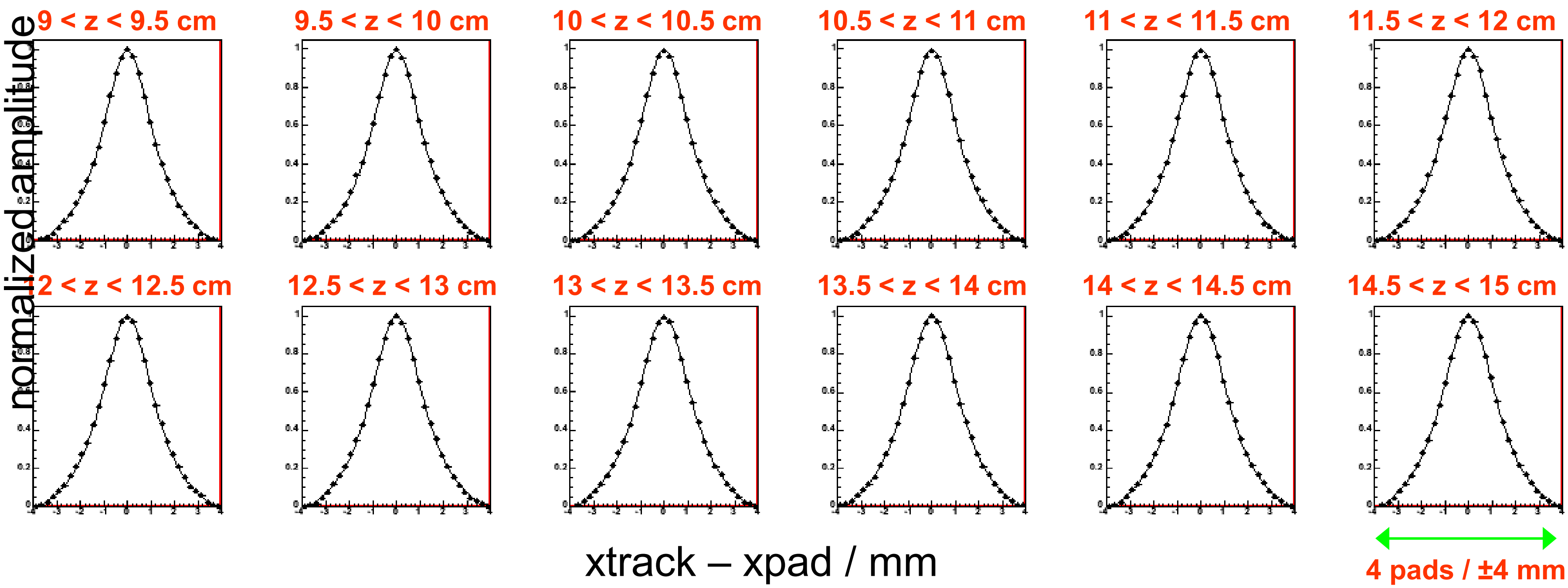
Pad Response Function / Ar+5%iC4H10

Micromegas+Carleton TPC 2 x 6 mm² pads, B = 1 T

30 z regions /
0.5 cm step



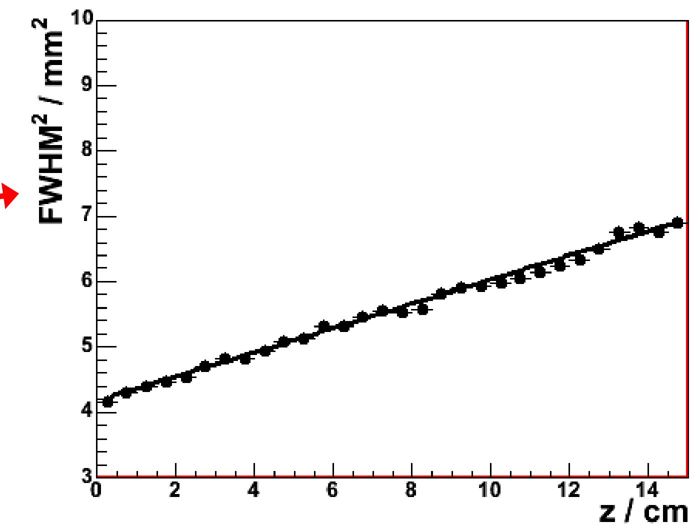
Pad Response Function / Ar+5%iC4H10



PRF parameters

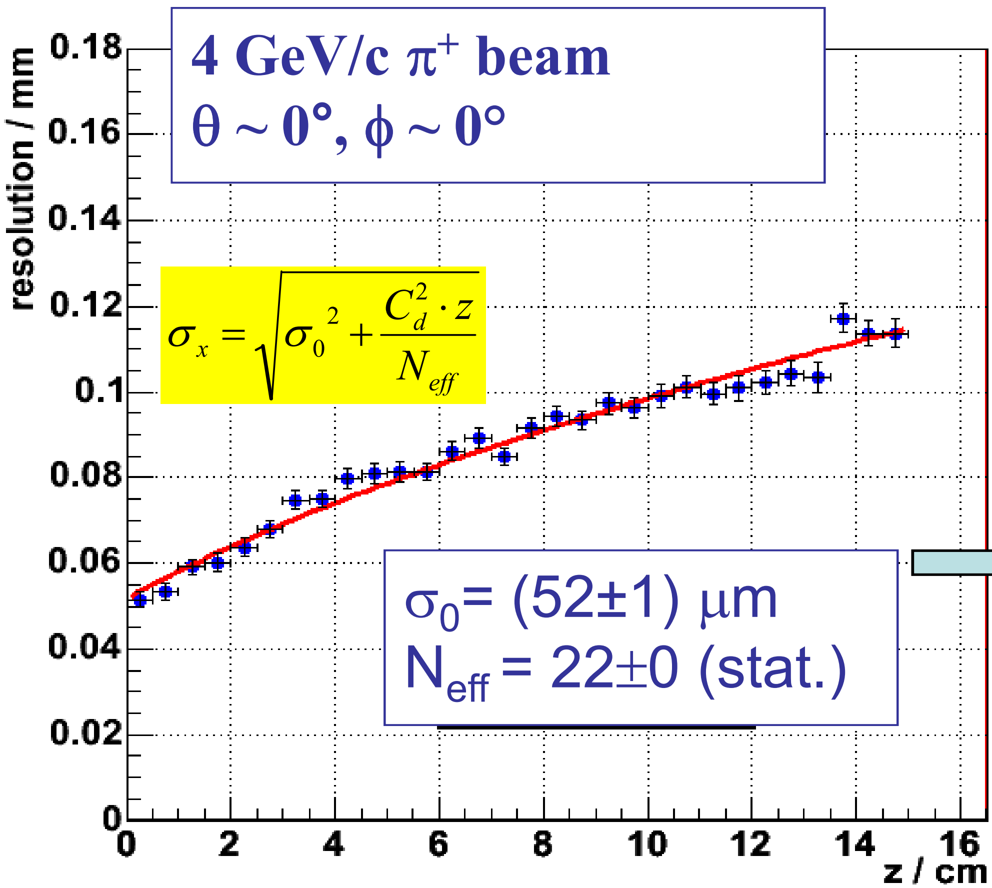
- **a = b = 0**
- **Δ = base width = 7.3 mm**
- **Γ = FWHM = f(z)**

The parameters depend on TPC gas & operational details



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

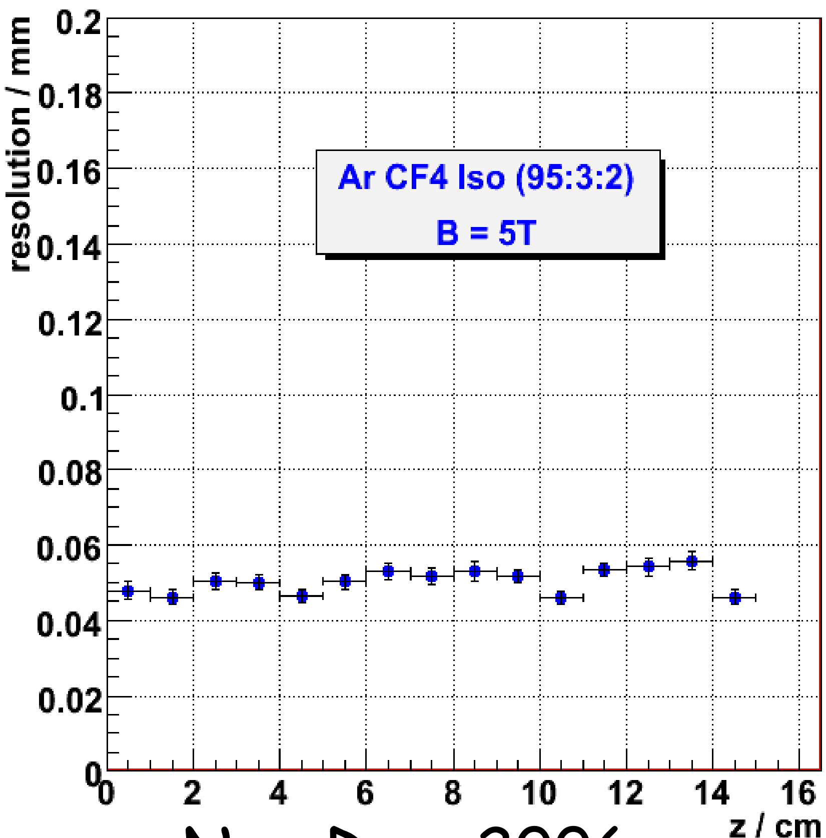
Resolution (2x6 mm² pads)

$\sigma_{Tr} \approx$ 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



Nov-Dec, 2006

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

What next in view of proposed ambitious timeline for ILC?

- Feb 2007 Global Design Effort (GDE) releases the accelerator Reference Design Report (RDR)
- 2010 end – Target date for the accelerator Engineering Design Report (EDR)
- Detector concepts - the 4 existing concepts are described in the ILC Detector RDR released recently.
- 2008 Summer - Detector Letters of Intent invited by World Wide Study (WWS)
- 2009 Summer Target date for formation of two Detector Collaborations
- 2010 Target date for detector EDRs
- Use ILC accelerator and detector EDRs as basis to get the project approved, select the site and secure international funding
- 2012 start construction
- 2019 ILC operational

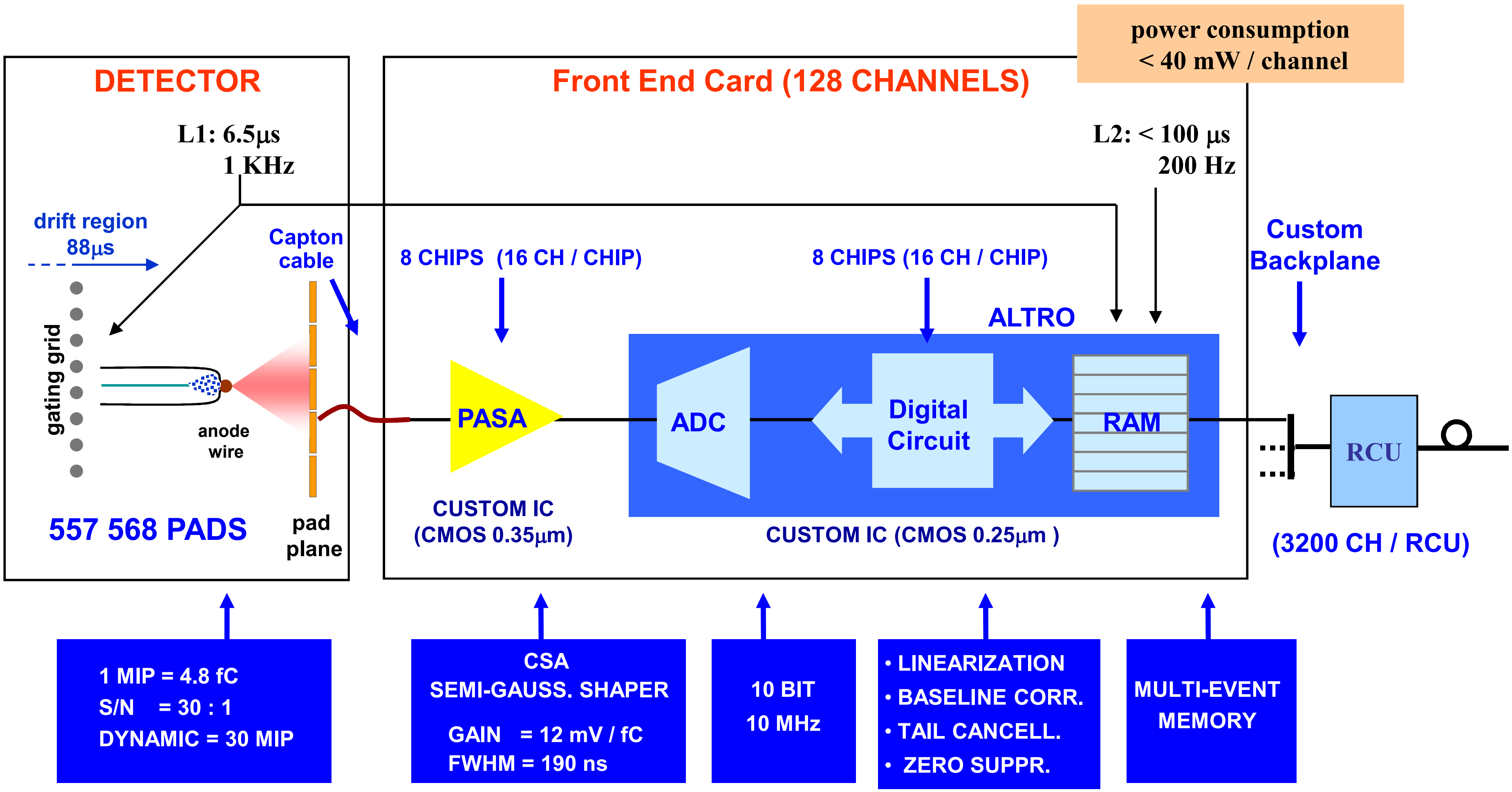
Preparing the detector for physics at ILC

- 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

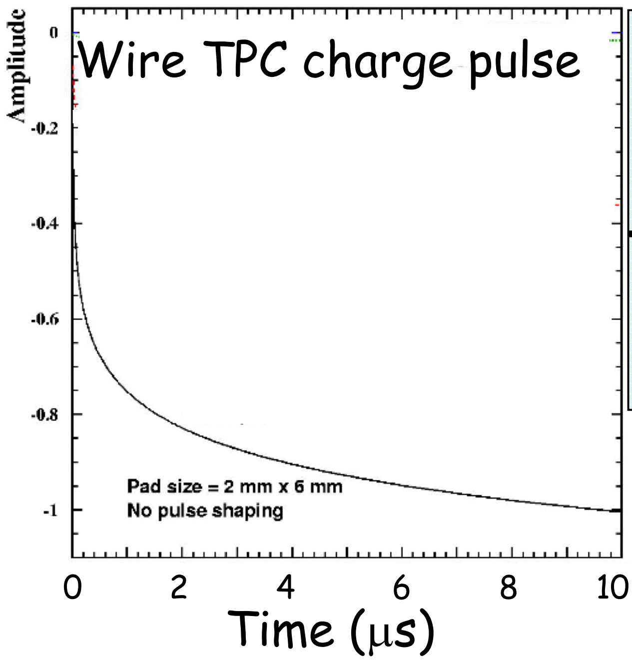
Electronics

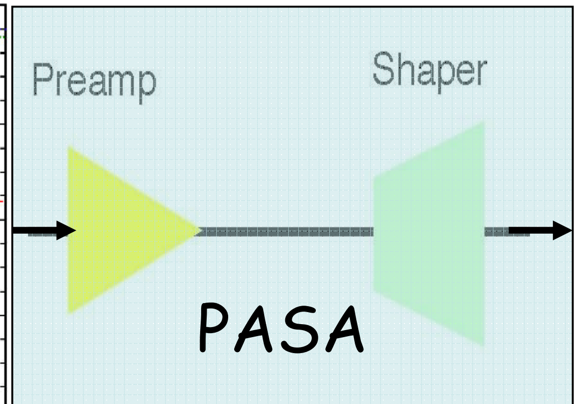
- Development for LP TPC presently based on ALICE TPC ALTRO digitizing electronics.
- ILC TPC requirements: highest flexibility in terms of pad geometry and shape of pad panels.
- Design for 1 x 4 mm^2 pads to accommodate narrow pads required for the GEM readout
- 10,000 Altro channels will be acquired for LP TPC tests.

Alice TPC front end readout electronics

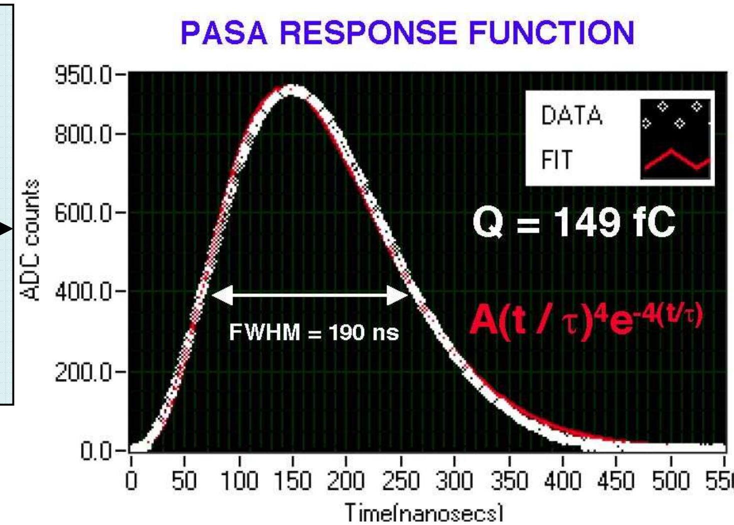


PASA designed for wire chamber pulses with long ion tails





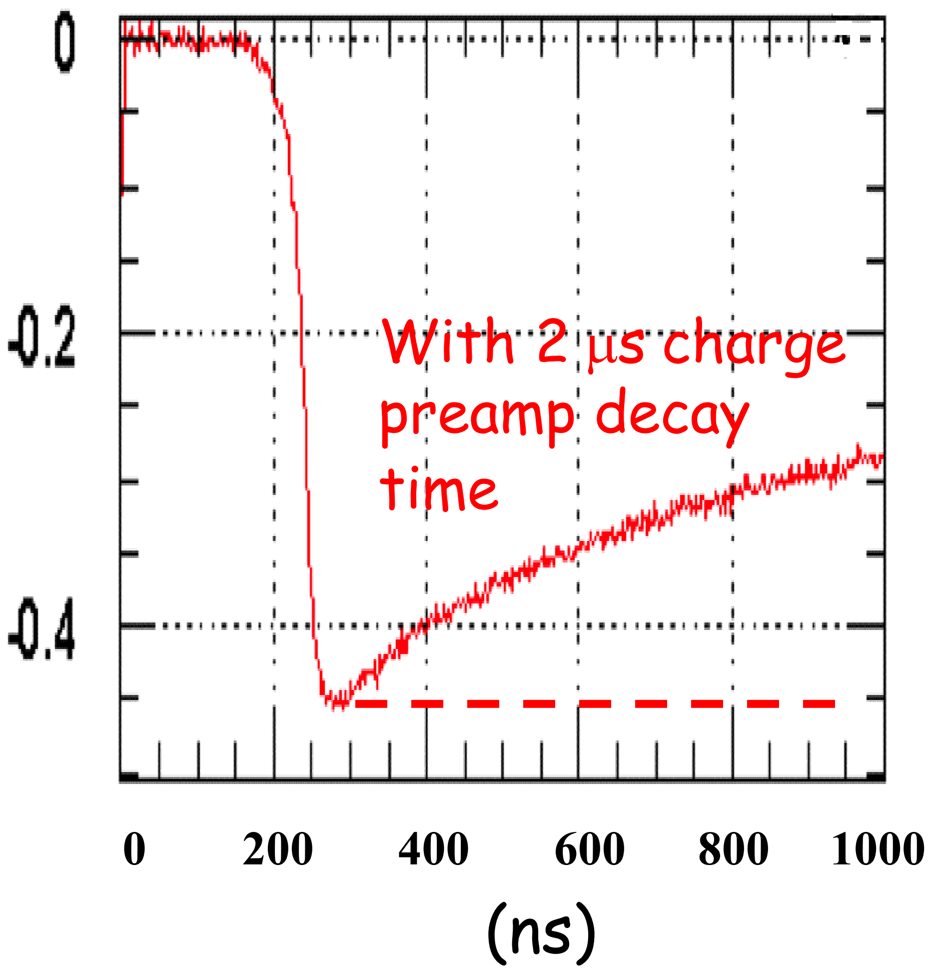
Tail cancellation and shaping



Semi-Gaussian output pulse with ~200 ns integration produced for the digitizer. (base width ~ 450 ns)

Redesign PASA for MPGD-TPC to achieve ILC resolution goal

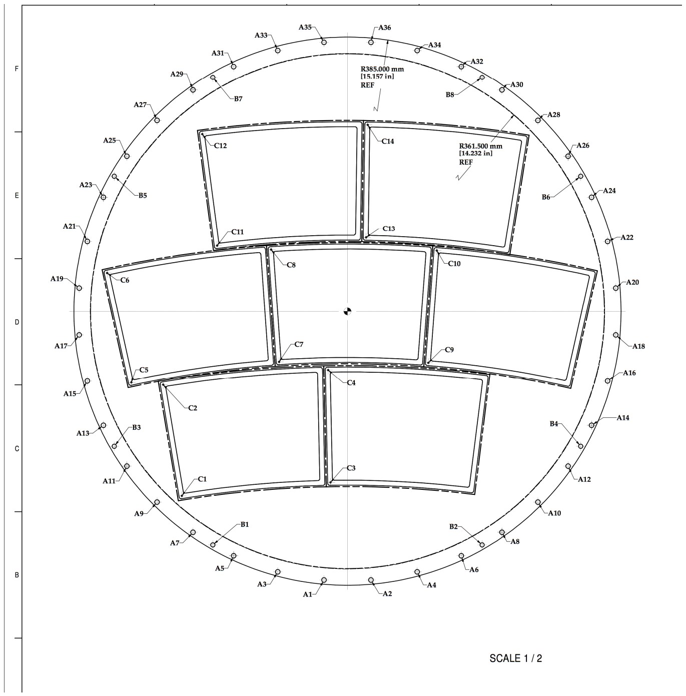
GEM charge pulse - point x ray source

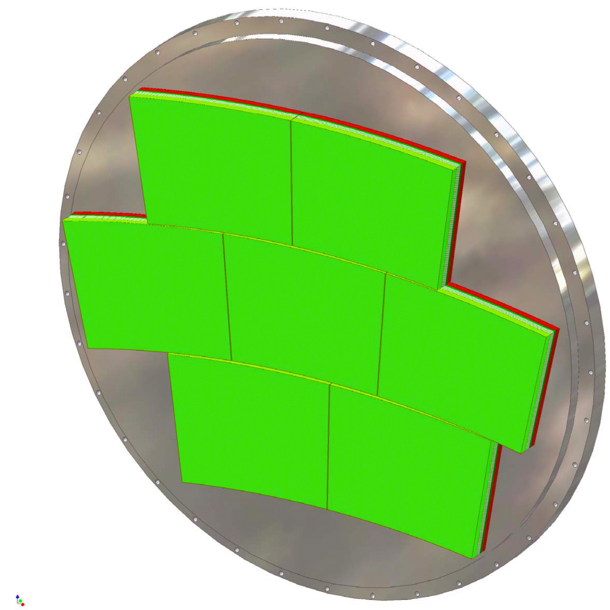


Charge pulse rise times will be much longer up to ~ 500 ns to due to longitudinal diffusion & track angles.

- For ILC resolution near statistical limit of diffusion must collect over 90% of electrons
- No optimum shaping time for both good single hit and 2-track resolution
- Following our suggestion a new modified PASA without shaping being designed at the expense of 120 k Euros for 1 m TPC tests

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



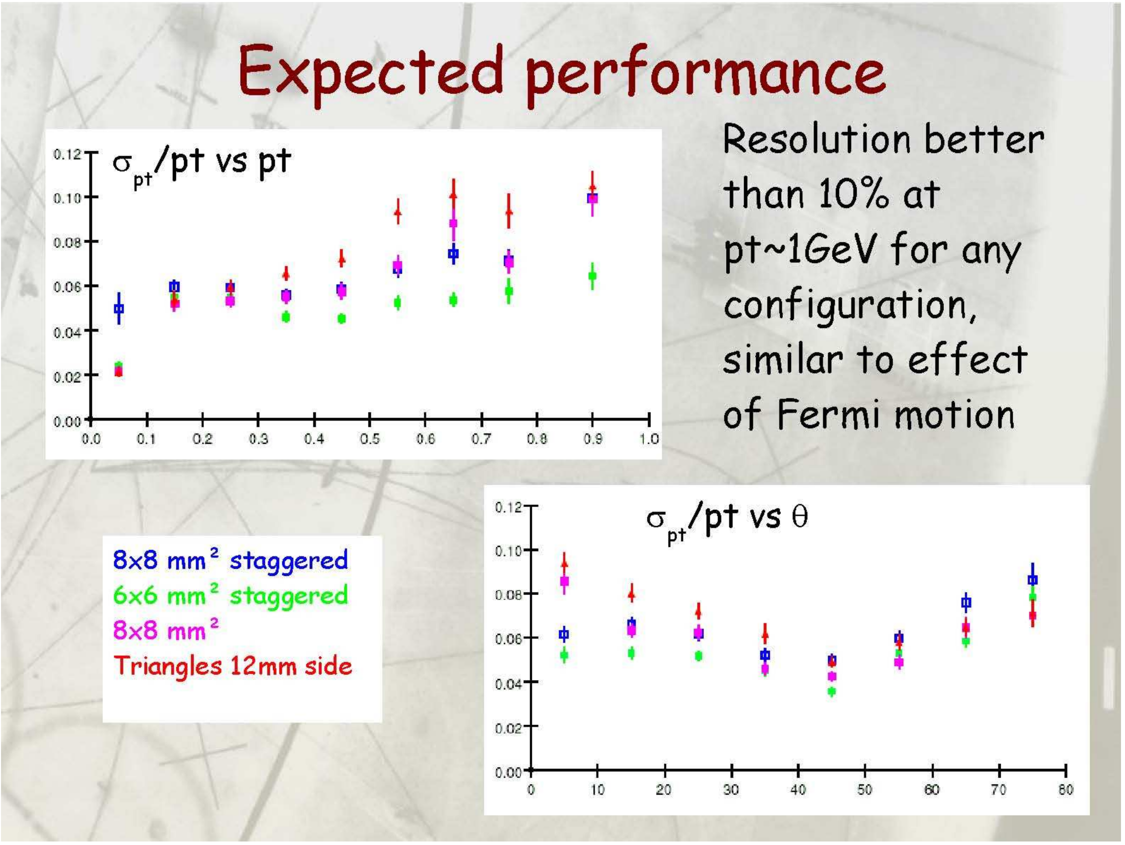


7 panels ~ GEMs with 1 mm pads and Micromegas with 2 mm wide pads
Up to 10,000 instrumented channels

Summary

- A standard MPGD-TPC cannot good resolution with wide pads
- With charge dispersion, wide pads can be used without sacrificing resolution. Charge dispersion works both for the GEM and the Micromegas.
- At 5 T, an average ~ 50 μm resolution has been demonstrated with 2 x 6 mm^2 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.
- Plans for Fermilab beam tests in 2008 to measure 2-track resolution & to test prototype power-pulsed electronics.
- Canadian responsibilities for large 1 m prototype tests to 2010:
    - Construct seven large Micromegas panels with charge dispersion shared with France (Carleton & Montreal)
    - Calibration (Victoria)
    - Electronics development

Application to T2K TPC



- 7x9 mm² pads
- 10% Δp/p (1 GeV/c)
- Good enough
- Requirement limited by Fermi motion

(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?

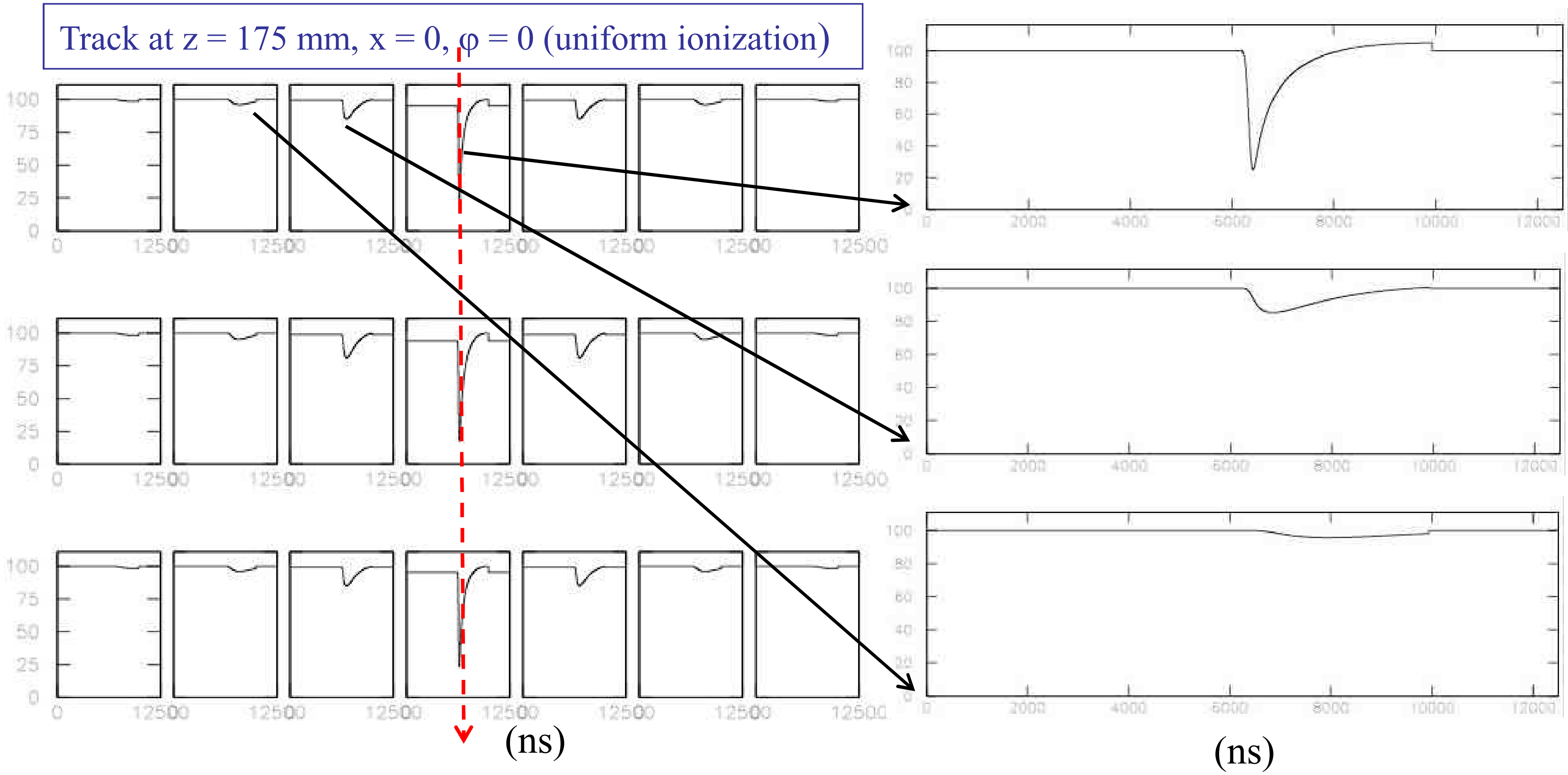
T2K simulation for 8 x 8 mm² pads

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

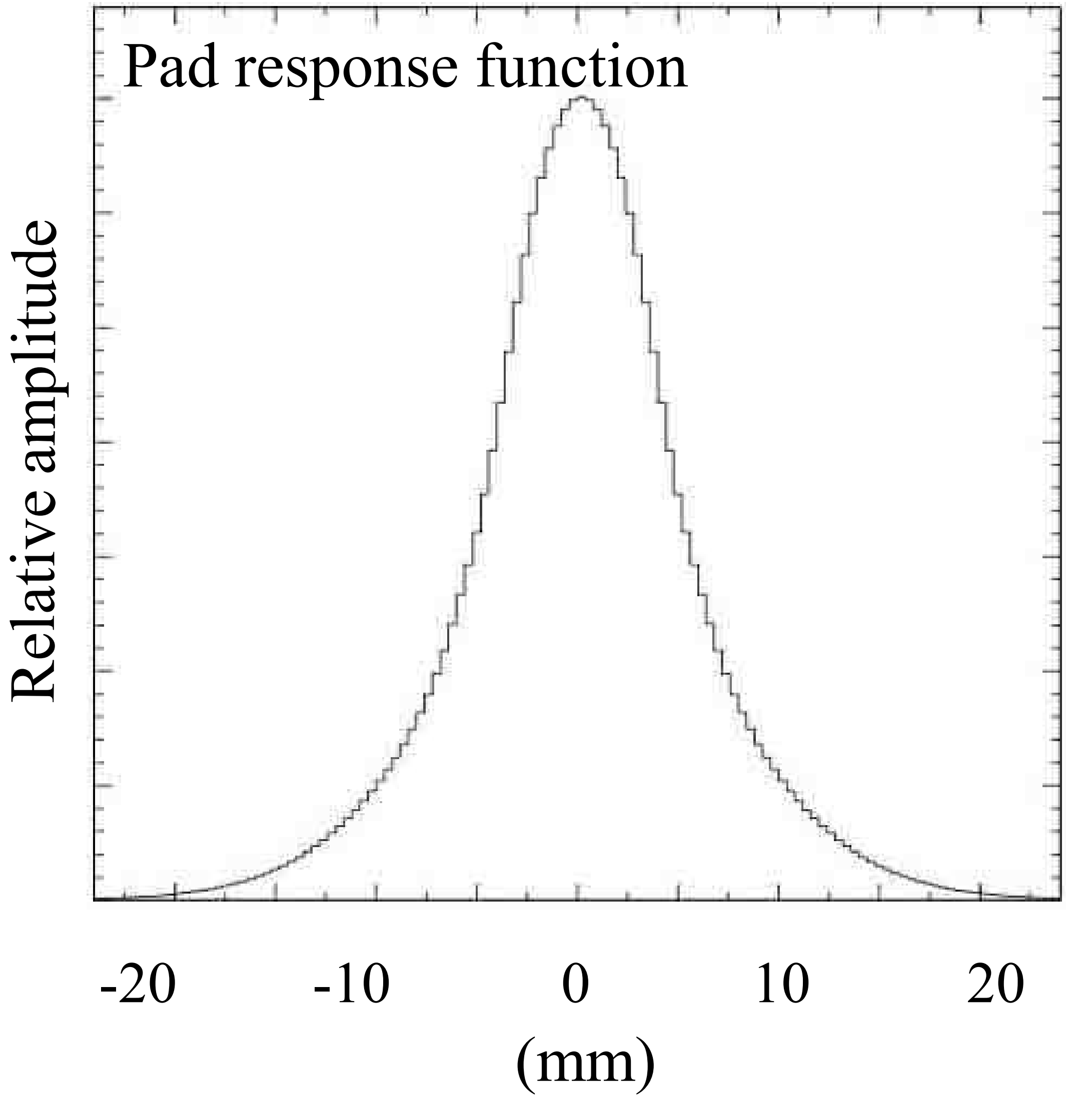
Anode surface resistivity 150 KΩ/□, dielectric gap = 75 µm, K = 2

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



Abstract

CERN LHC will begin its quest for the Standard Model Higgs or signs of new physics next year. Presently, there is also significant worldwide R&D effort to finalize the design of the proposed 500 GeV e+ e- International Linear Collider, a machine critical to supplementing LHC physics. The goal at present is to produce complete Engineering Design Reports by 2011 for the ILC machine as well as for two complementary detector collaborations for physics. A two meter drift Time Projection Chamber with an ambitious 100 micron resolution goal for all tracks is a strong candidate for the gaseous tracking detector option. To meet the challenge, groups from all over the world have been developing Micro Pattern Gas Detectors (MPGD) for the TPC readout. Canadian TPC groups are at the forefront of this research and we have developed a new MPGD readout concept of charge dispersion for improved TPC resolution. Our 15 cm drift prototype TPC has recently achieved an unprecedented 50 micron resolution in a 5 Tesla magnet at DESY – an important step in demonstrating the feasibility of achieving the ILC TPC resolution goal. A Linear Collider TPC collaboration has been formed recently with first task to construct and test a large 1 m prototype TPC in time for the ILC detector engineering design report. Canadian and French groups have proposed to jointly design and construct the charge dispersion MPGD readout panels for the large prototype. An overview of our ILC TPC R&D activities and plans for the future will be presented.