Micromegas-TPC Z resolution with charge dispersion & r-φ resolution with an improved algorithm

Madhu Dixit
TRIUMF & Carleton University

Collaborators

S. Turnbull, R. Woods, D. Attie,
A. Bellerive, K. Boudjemline, P. Colas,
I. Giomataris, V. Lepeltier, J.-P. Martin,
K. Sachs & Y. Shin

Carleton University, University of Montreal,
LAL Orsay & IRFU, CEA Saclay

International Linear Collider Workshop
Beijing, China, March 26-30, 2010

Outline

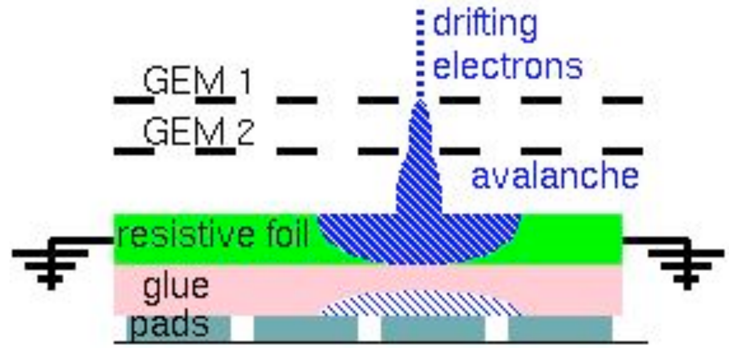
- ILD-TPC goal: $\sigma_0(r\text{-}\varphi) \leq 100\ \mu m$ (all tracks up to 2 m drift).
- Not possible with proportional wire/cathode pad TPC
  - -Resolution limited by intrinsic ExB effects.
- Possible with conventional MPGD-TPC readout, but:
  - sub-mm readout pads (~3,000,000 channels)
  - Detector cost, complexity & heat removal problems
- Alternative - charge dispersion MPGD readout
  - -σ_0 $(r\text{-}\varphi)$ ~50 μm for 2-3 mm pads - published results
  - But previous analysis techniques not robust.
- *A new more robust algorithm for r-φ resolution & results*
- *A first measurement of z(t) resolution for the charge dispersion readout.*

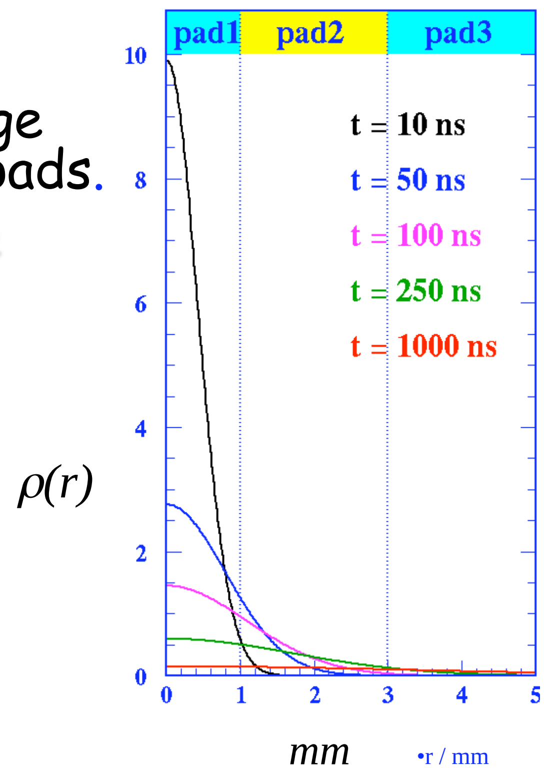
Charge dispersion in a MPGD with a resistive anode

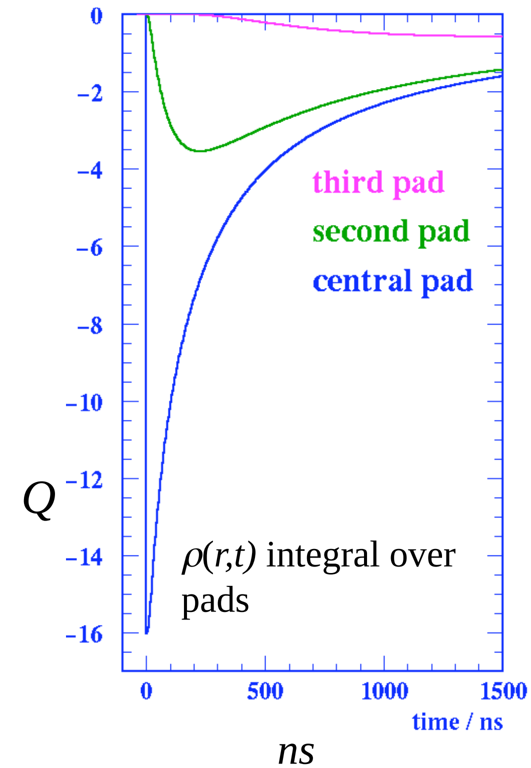
- Modified MPGD anode with a high resistivity film bonded to a readout plane with an insulating spacer.
- 2-dimensional continuous RC network
- Point charge at r = 0 & t = 0 disperses with time.
- Time dependent anode charge density sampled by readout pads.
- Equation for surface charge density function for the 2-D continuous RC network:

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

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



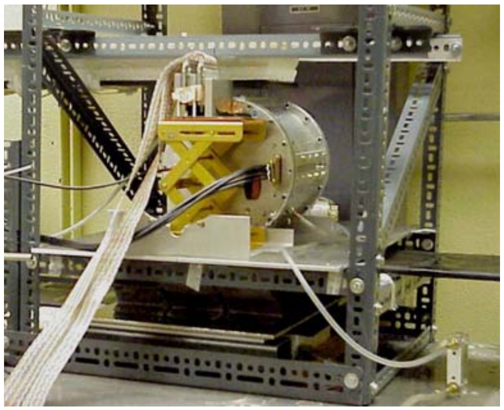


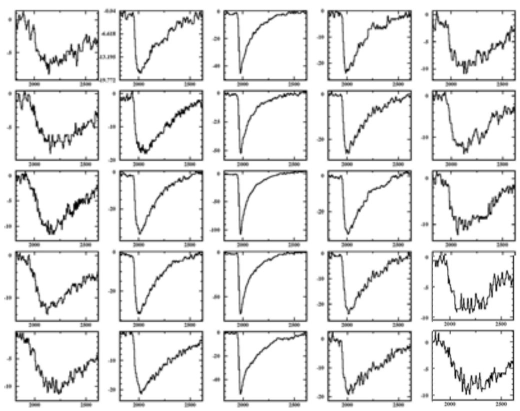


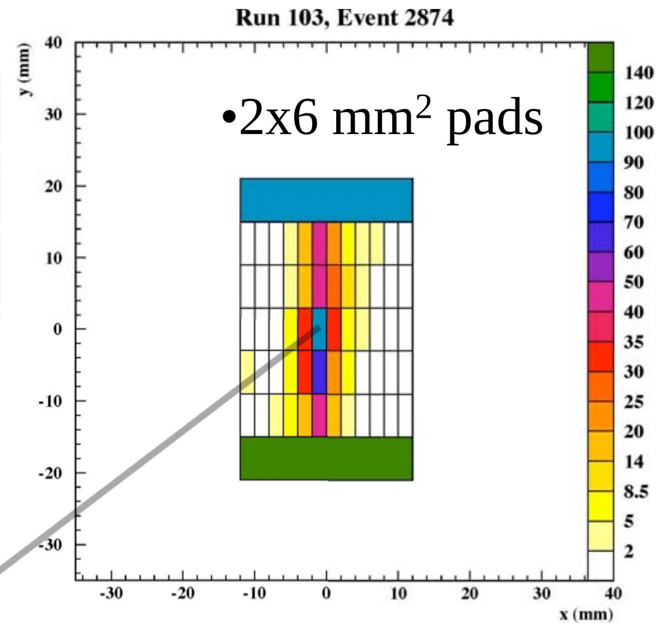
Using the charge dispersion signal for tracking

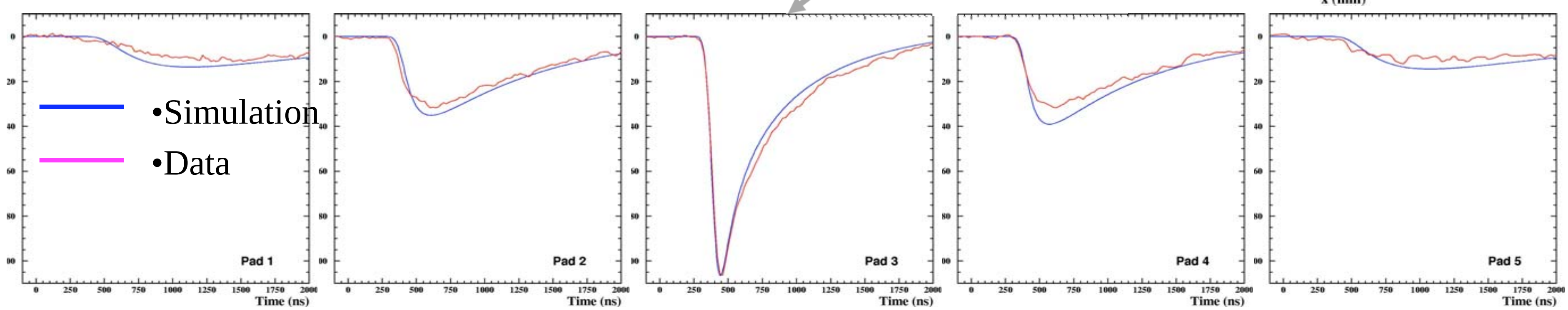
- Unusual highly variable pulse shape.
- *Pulse on the charge collecting pad*: Large pulses with fast rise-time. The decay time depends on the system RC, the pad size & on the position of the track.
- *Charge dispersion pulses on adjacent pads:* Smaller pulse height & slower rise & decay times determined by the system RC & pad location relative to the track.
- Both the pulse shape and the pulse height contain position information
- How to define the pad signal "amplitude" for optimum determination of position from the measured pulse?

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





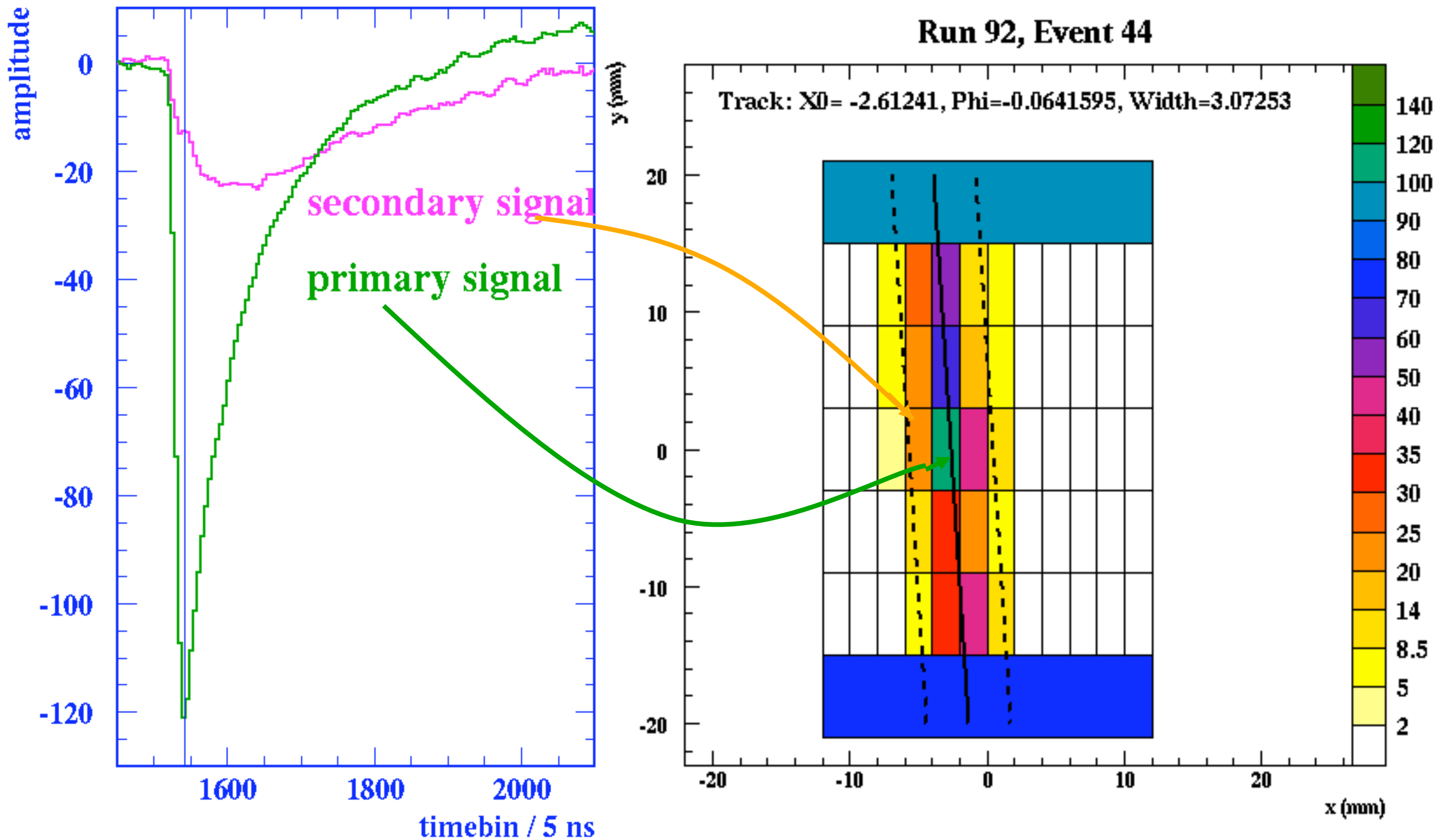




Centre pulse used for normalization - no other free parameters.

Cosmic ray track signals with charge dispersion readout

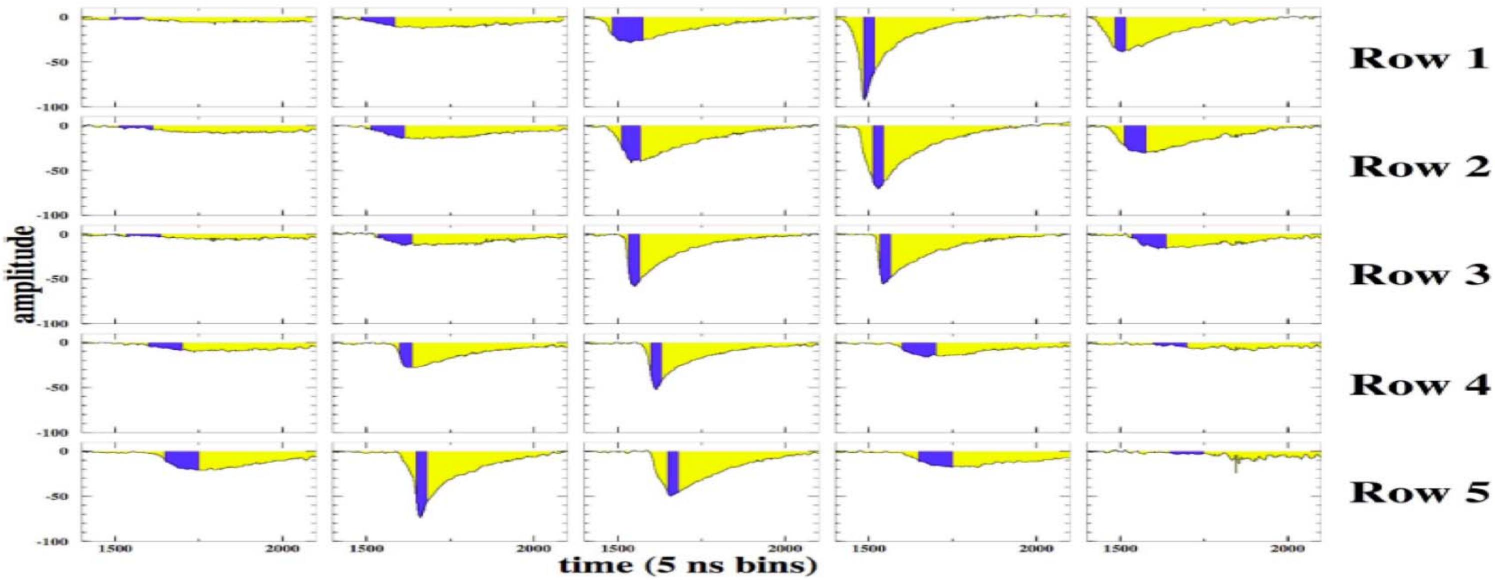
2 mm x 6 mm pads



The pad response function (PRF)

- The PRF is a measure of pad signal "amplitude" dependence on the track position.
- With variable pulse shape & both rise time & pulse height carrying position information,there is no unique algorithm to define the PRF.
- The PRF is a tool which may be optimized for specific analysis. It is not a fundamental property of data. Much more information is contained in the digitized charge pulse shape.
- More than one PRF can be defined, optimized for single track resolution, two track resolution etc.

The track pad response function (PRF)



- Our first PRF algorithm was developed for single hit (r-φ) resolution

•It integrated pulses over a time window with width determined by the details of pulse shape

•A σ_0 ~ 50μm was achieved for 2 mm x 6 mm pads

• However, the PRF algorithm needed tuning & was sensitive to noise.

The PRF shape is parameterized for track fit analysis

- The PRFs are not Gaussian.
- The PRF depends on track position relative to the pad: PRF = PRF(x,z)
- PRF can be characterized by its FWHM $\Gamma(z)$ & base width $\Delta(z)$.
- PRFs determined from the data have been fitted to a functional form consisting of a ratio of two symmetric 4th order polynomials.

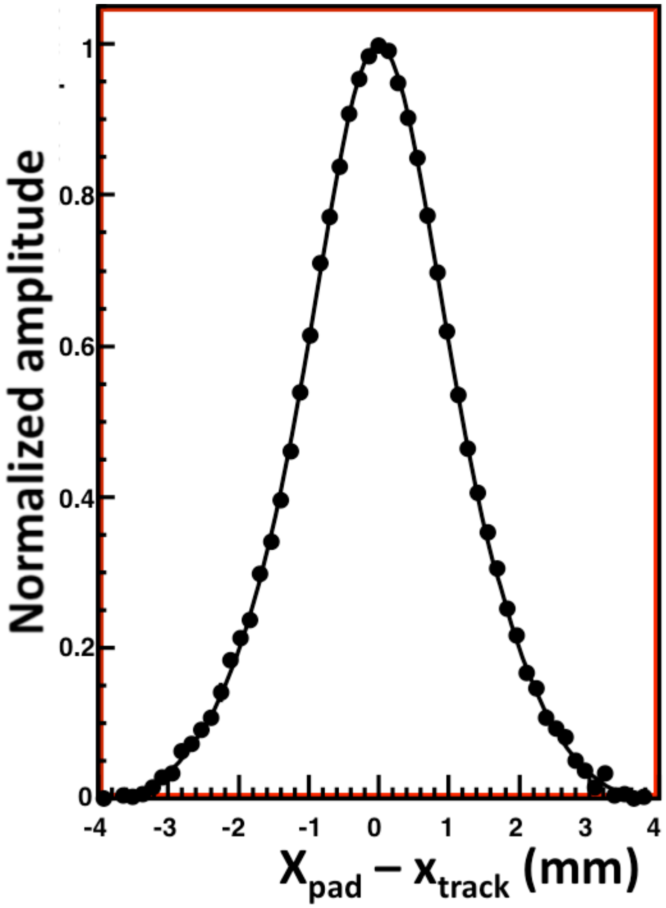
$$PRF[x,\Gamma(z),\Delta,a,b] = \frac{(1 + a_2 x^2 + a_4 x^4)}{(1 + b_2 x^2 + b_4 x^4)}$$

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

The PRF for a Micromegas-TPC in a 5 T field

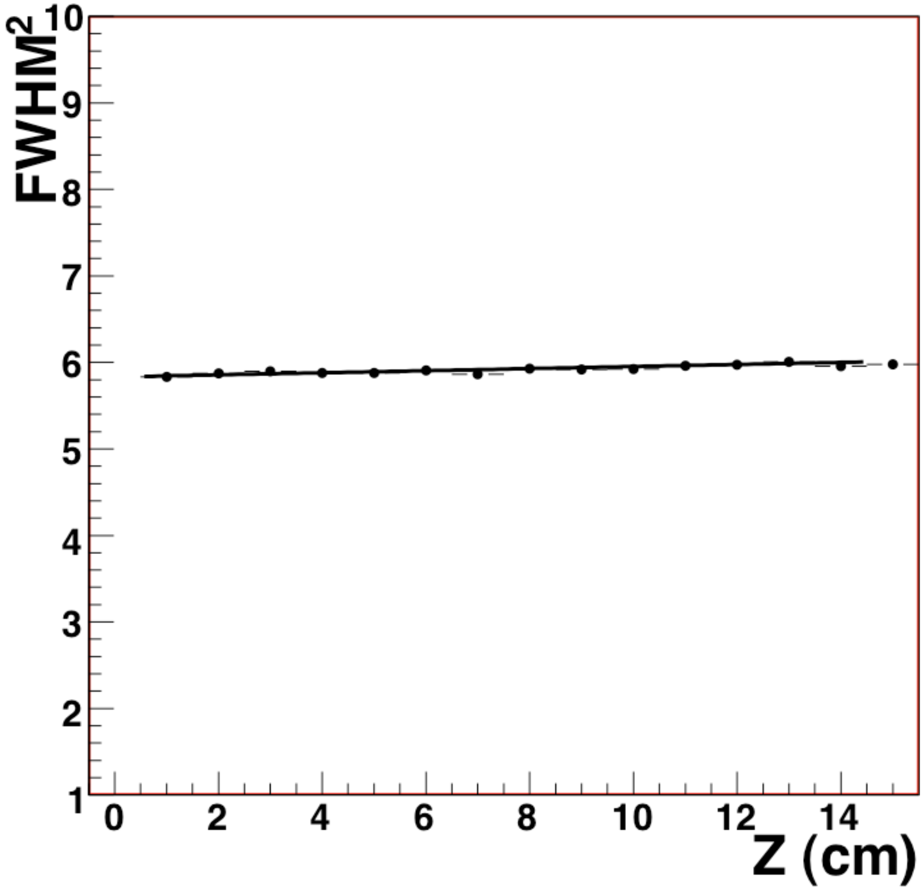
2 mm x 6 mm pads Ar+2%C4H10+3%CF4

PRF at 1 cm drift



(a)

The dependence of PRF width on z



(b)

A better algorithm for charge dispersion analysis

- The previous PRF algorithm parameters needed to be tuned if TPC operating conditions were changed
- We have developed a more robust algorithm not requiring fine tuning
- Tested several new ideas with simulated data
- The new algorithms were tested by reanalyzing old data
- Criteria: PRF can be applied consistently and easily over a wide range of TPC operating conditions.
- A simple fixed window algorithm works the best!

Two data sets were re-analyzed with the improved PRF algorithm & for z(t) resolution

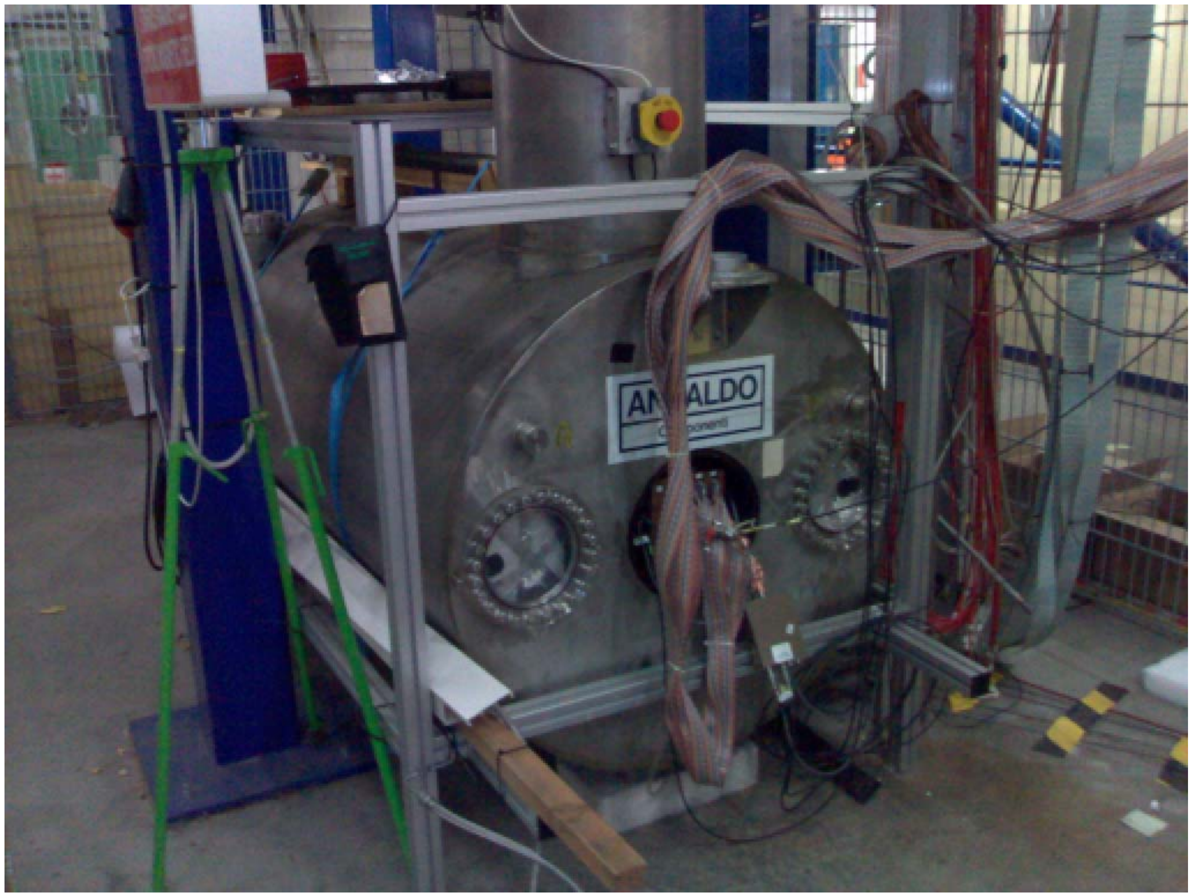
KEK: 4 GeV pi+ at 1 Tesla October-Nov 2005

1.	Number of Good Events: 12754	
2.	Gas Mixture: Argon(95%) + Isobutante(5%)	
3.	B Field:	1 T
4.	E Field:	70 V/cm
5.	Transverse Diffusion:	124 um/cm**0.5
6.	Longitudinal Diffusion:	479 um/cm**0.5
7.	Drift Velocity:	25.3 um/ns
8.	Theta Distribution:	[-5,5]

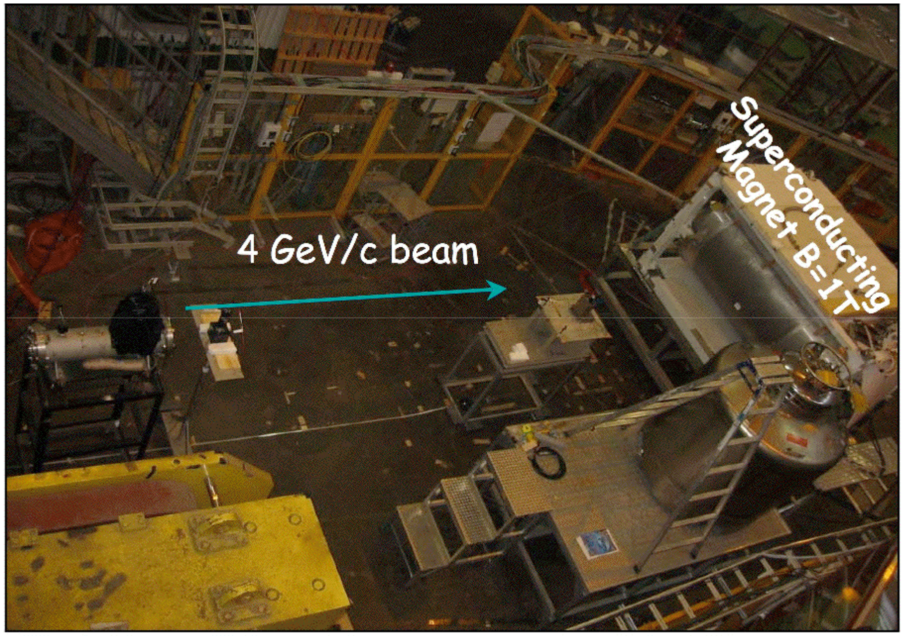
DESY: Cosmics tests at 5 Tesla Nov-Dec 2006

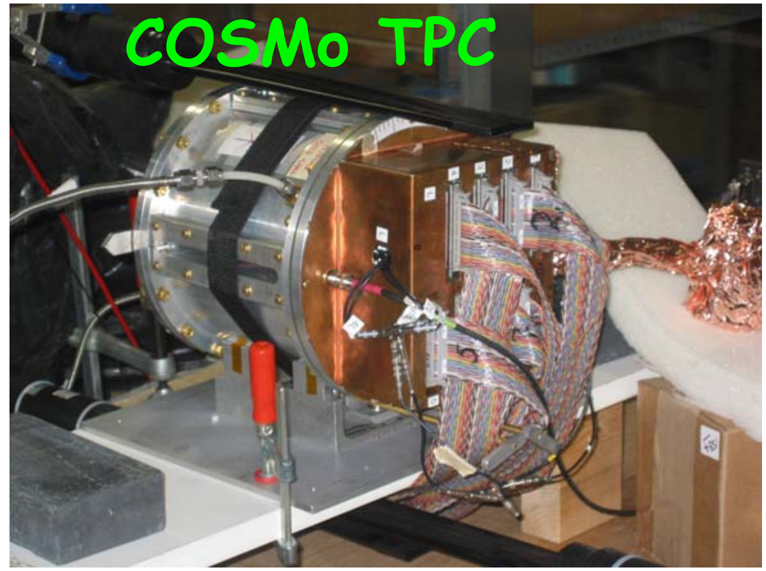
1.	Number of Good Events: 5663	
2.	Gas Mixture: Argon(95%) + Isobutante(2%) + CF4(3%)	
3.	B Field:	5 T
4.	E Field:	200 V/cm
5.	Transverse Diffusion:	18.6 um/cm**0.5
6.	Longitudinal Diffusion:	248 um/cm**0.5
7.	Drift Velocity:	72.7 um/ns
8.	Theta Distribution:	[-30,30]

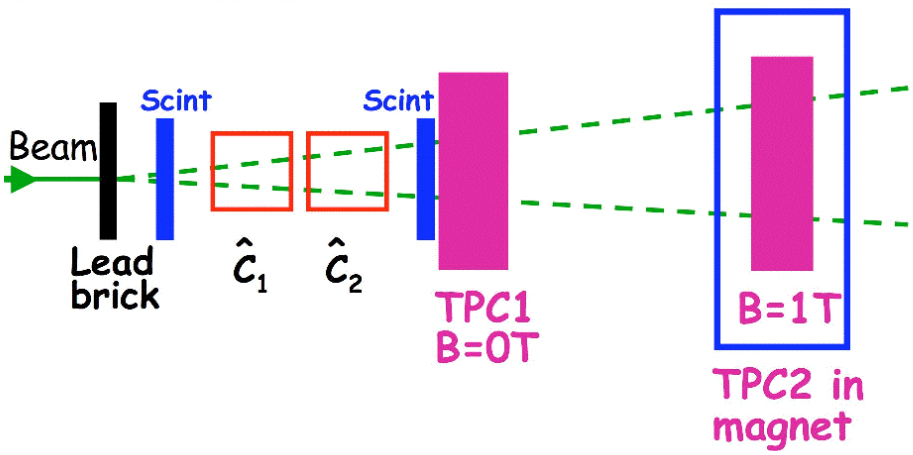
COSMo (Carleton-Orsay-Saclay-Montreal) TPC DESY cosmic ray tests at 5 T Nov-Dec 2006



4 GeV beam tests in a 1 Tesla magnetic field (2005)







- Micromegas 10x10 cm^2
- Drift distance: 16 cm
- 126 2 mm x 6 mm pads in 7 rows
- Preamps from ALEPH TPC at LEP

KEK 2005 beam test collaborators

Canada	A.Bellerive, K.Boudjemline,M.Dixit, E.Neuheimer, E.Rollin, K.Sachs &Y.Shin	*Carleton*
	J.-P. Martin	*Montreal*
France	J.Pouthas, V.Lepeltier & Th.Zerguerras	*LAL Orsay*
	P.Colas & A.Giganon & I.Giomataris	*Irfu CEA Saclay*
Germany	R. Settles	*MPI (Munich)*
Japan	T.Araki, H.Fujishima, T.Higashi, , K.Kodomatsu, A.Sugiyama, T.Yamamoto & Y.Tanaka	*Saga University*
	M.Habu, S.Matsushita, K.Nakamura & O.Nito	*TUAT, Tokyo*
	A.Yamaguchi	*Tsukuba University*
	K.Fujii, M.Kobayashi, T.Matsuda & H.Yamaoka	*KEK/IPNS*
	T.Watanabe	*Kogakuin University*
	Y.Kato	*Kinnki University*
	H.Kuroiwa & T.Takahashi	*Hiroshima Univ.*

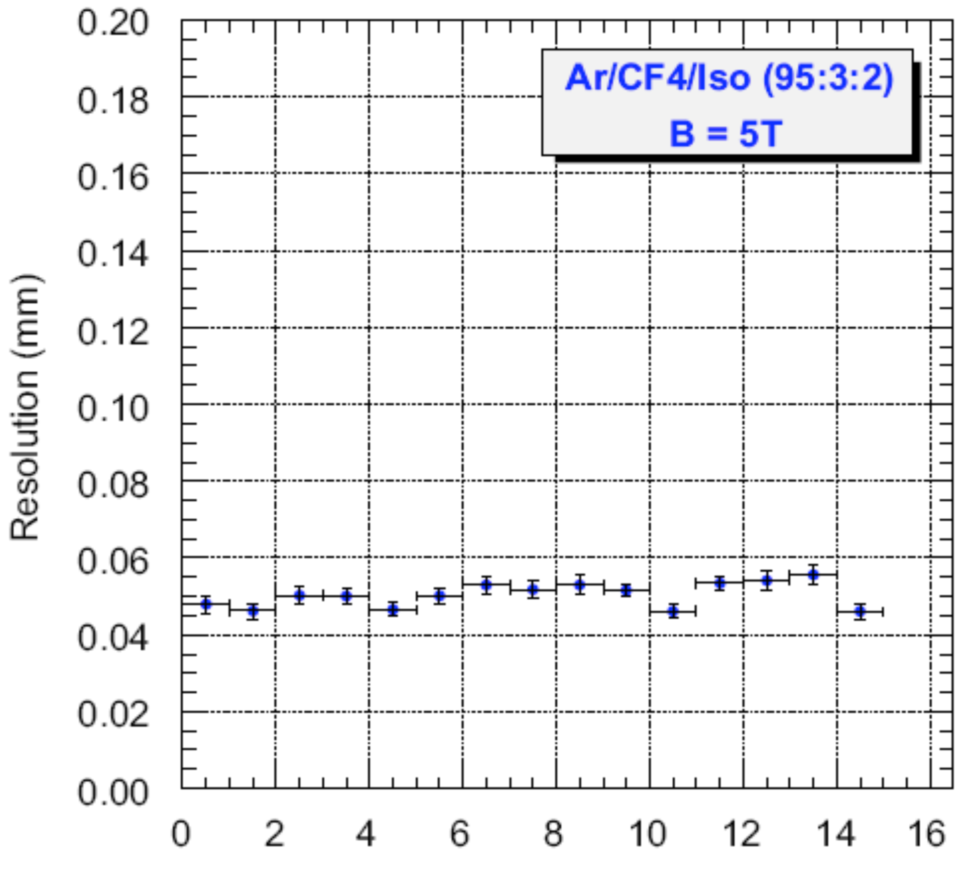
Resolution comparison - DESY 5 T cosmic ray tests
Old algorithm vs new fixed window PRF algorithm

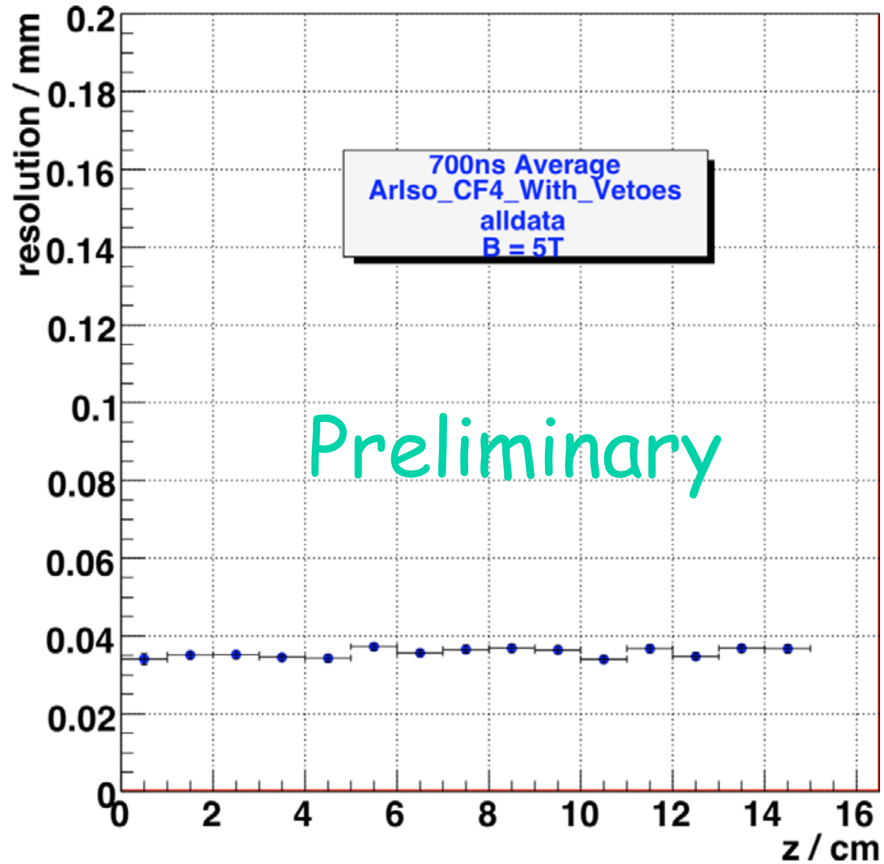
- Old algorithm 3652/17669

Constant ~ 50 μm resolution independent of z over 15 cm.

- New algorithm 5663/17669
- Constant ~35 μm resolution independent of z.

The new algorithm results in fewer track fit failures

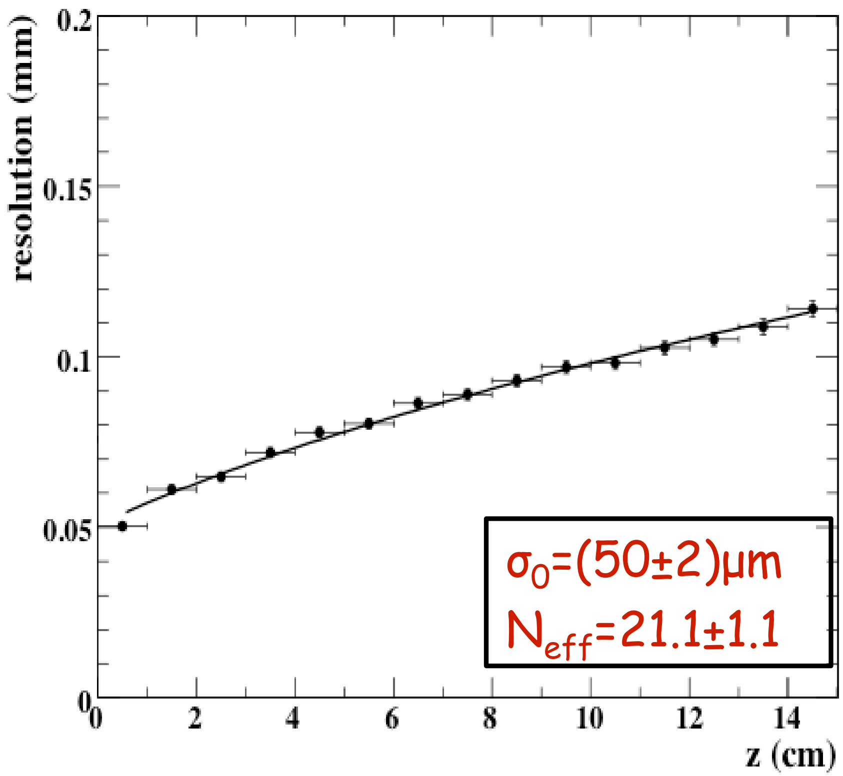


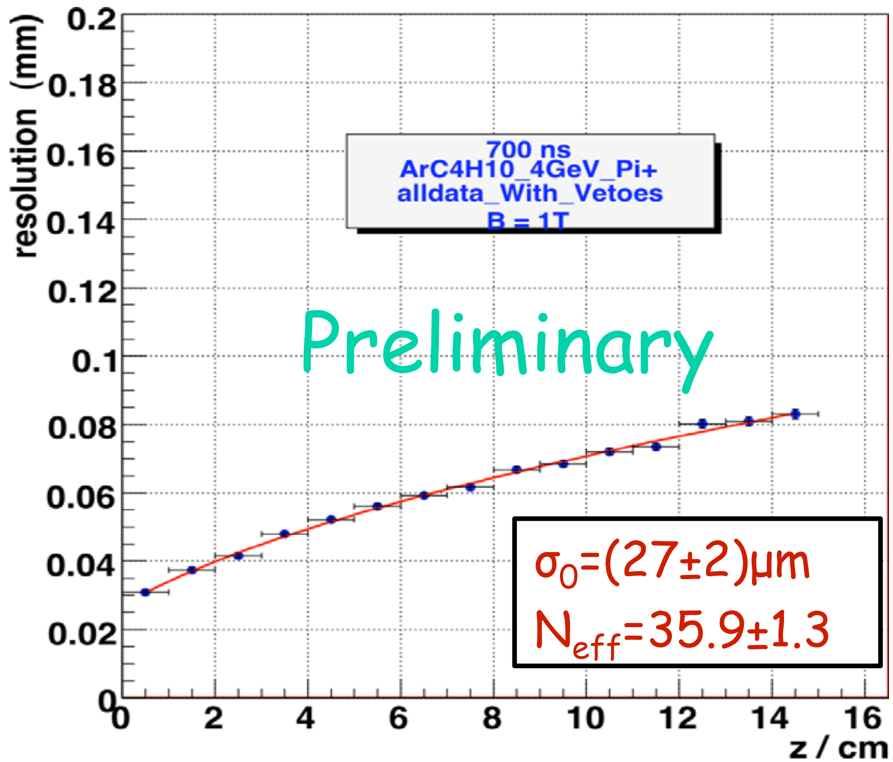


KEK B=1T 4 GeV π+ beam - resolution comparison
Old algorithm vs new fixed window PRF algorithm

Transverse spatial resolution Ar+5%iC4H10

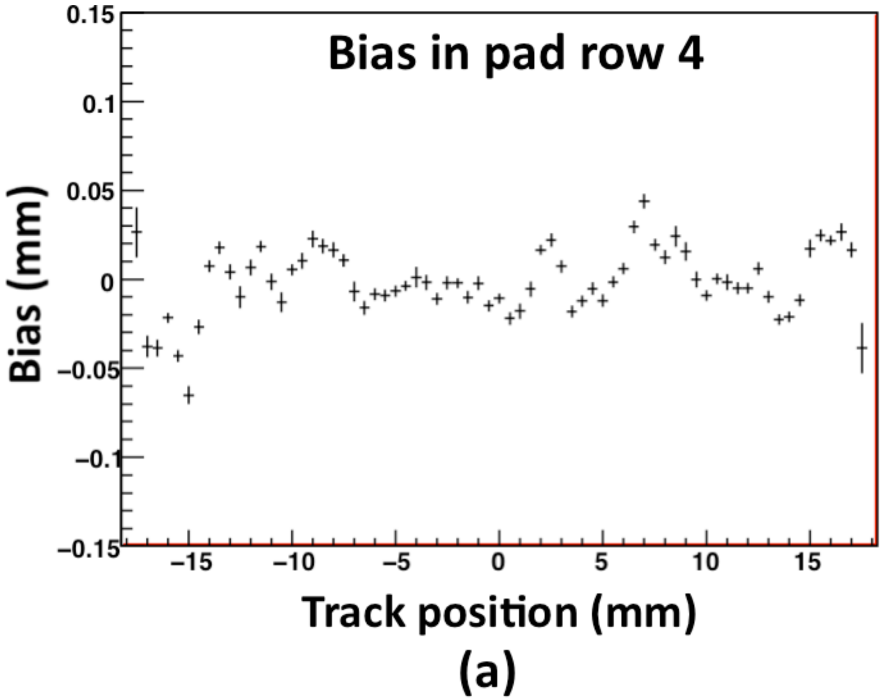
E=70V/cm D_{Tr} = 124 μ/√cm (Magboltz) @ B= 1T

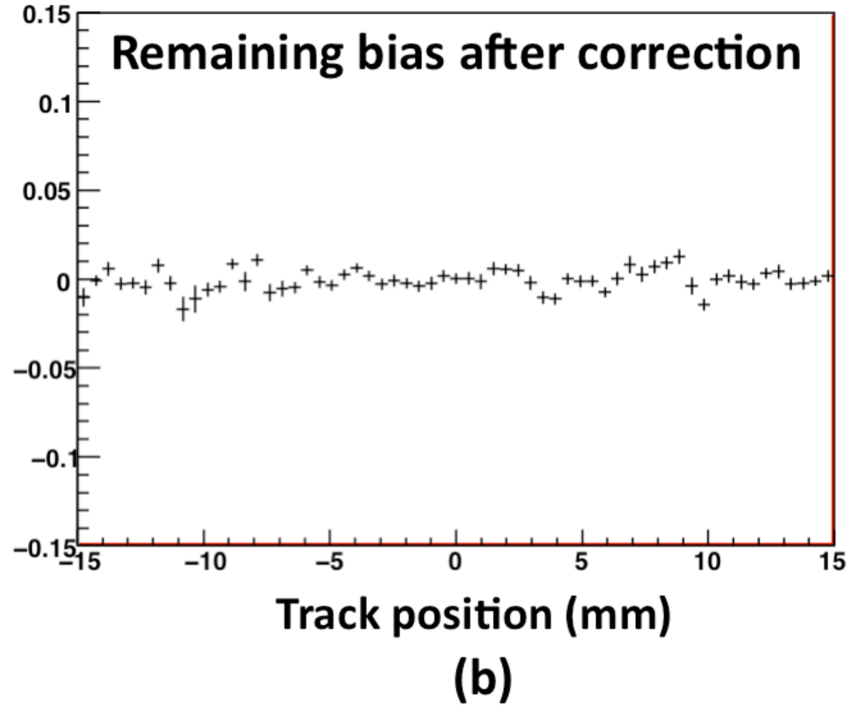




2 mm x 6 mm pads

Residual bias is now comparable with resolution





Bias remaining after correction ~ 20-25 μm

Residual bias is now significant and comparable to resolution achievable with charge dispersion $\sigma_0(r\text{-}\phi) \sim 30$ μm

Improved fabrication and better resistive films needed to minimize RC non-uniformities and to reduce bias further

Time resolution with charge dispersion readout from DESY 5Tesla cosmic ray & KEK 4 GeV beam test data sets

Determination of z or timing resolution

The time resolution is determined from r-z track fit following the r-ϕ *track fit*

r-ϕ track fit

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

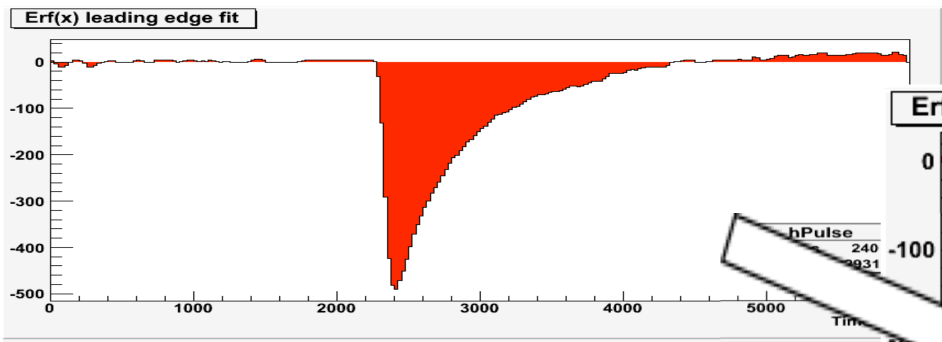
- Track parameters x_0 & ϕ for $x_{track} = x_0 + y \tan(\phi)$ from χ^2 minimization
- Identify main charge collecting pad in each row for z(t) resolution fit

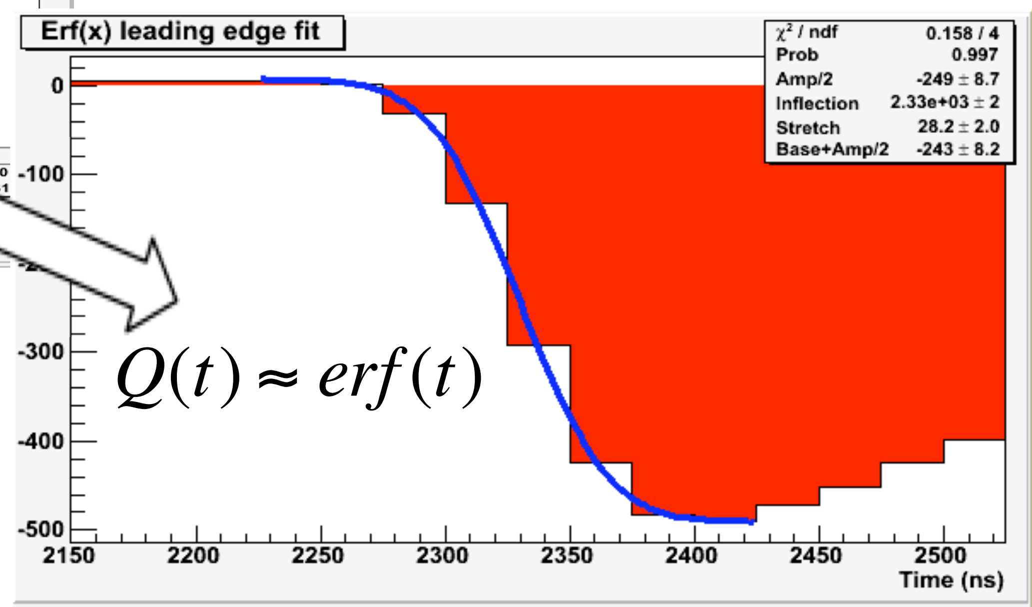
r-z(*t*) track fit performed *for main charge collecting pads only*

$$\chi^2 = \sum_{i=rows} \left(\frac{t_i - t_{track}}{\delta t_i} \right)^2$$

- Determine track parameters t_0 *and* θ *for* $t_{track} = t_0 + y \tan(\theta)$
- Determine t_{row} by fitting error function to main charge pulse
- Residuals: $R = t_{row} - t_{track}$
- Resolution determined from standard deviation of residuals

The main charge collecting pad signal shape is determined mainly by longitudinal diffusion



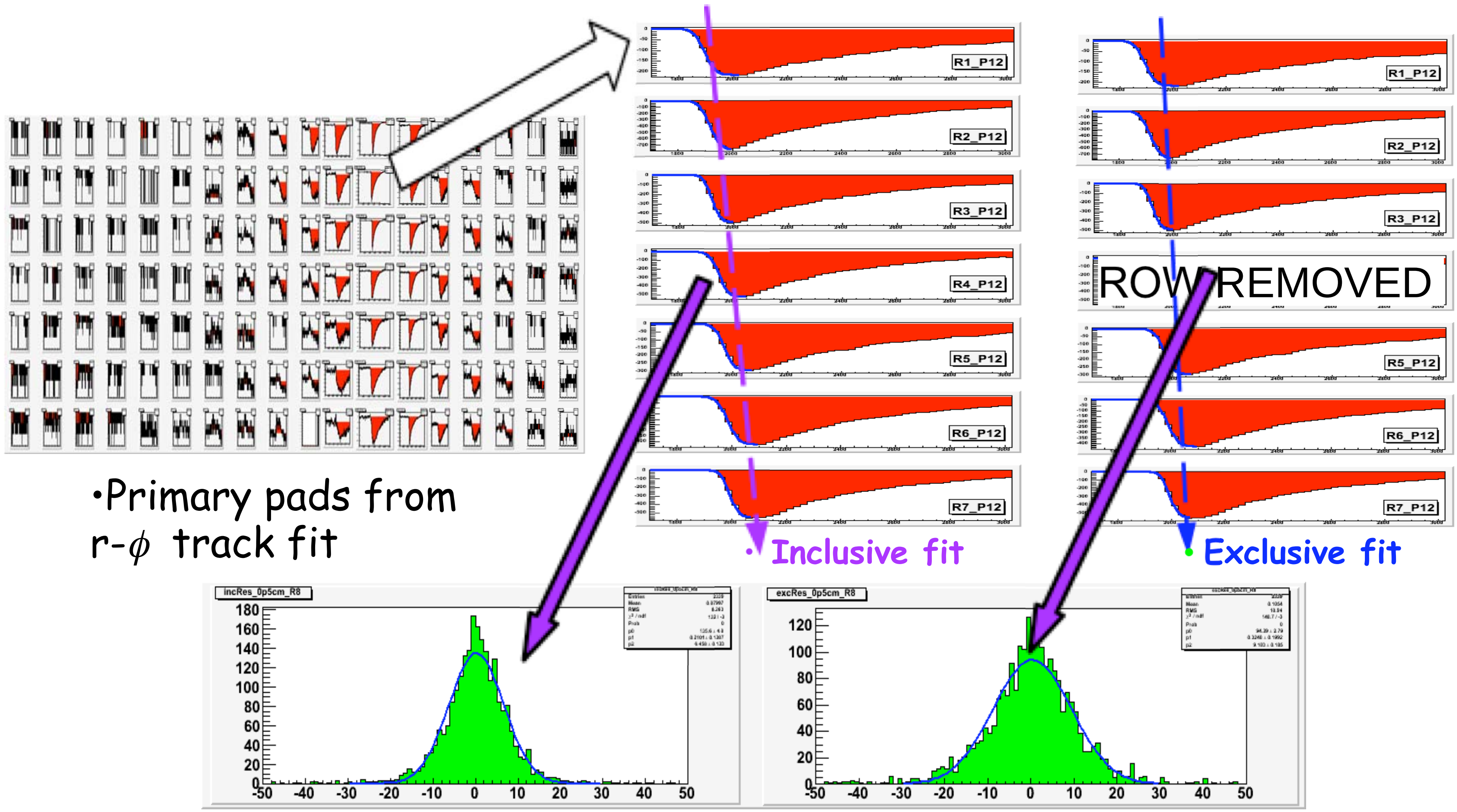


$$Q(t) \approx erf(t)$$

$$Q(\tau) = \frac{1}{\sigma_{Long}\sqrt{2\pi}} \int_{-\infty}^{\tau} exp\left(-t^2 / 2\sigma_{Long}{}^2\right) dt$$

Timing determined by error function fit to the leading edge

r-z(t) track fit



- Primary pads from r-ϕ track fit

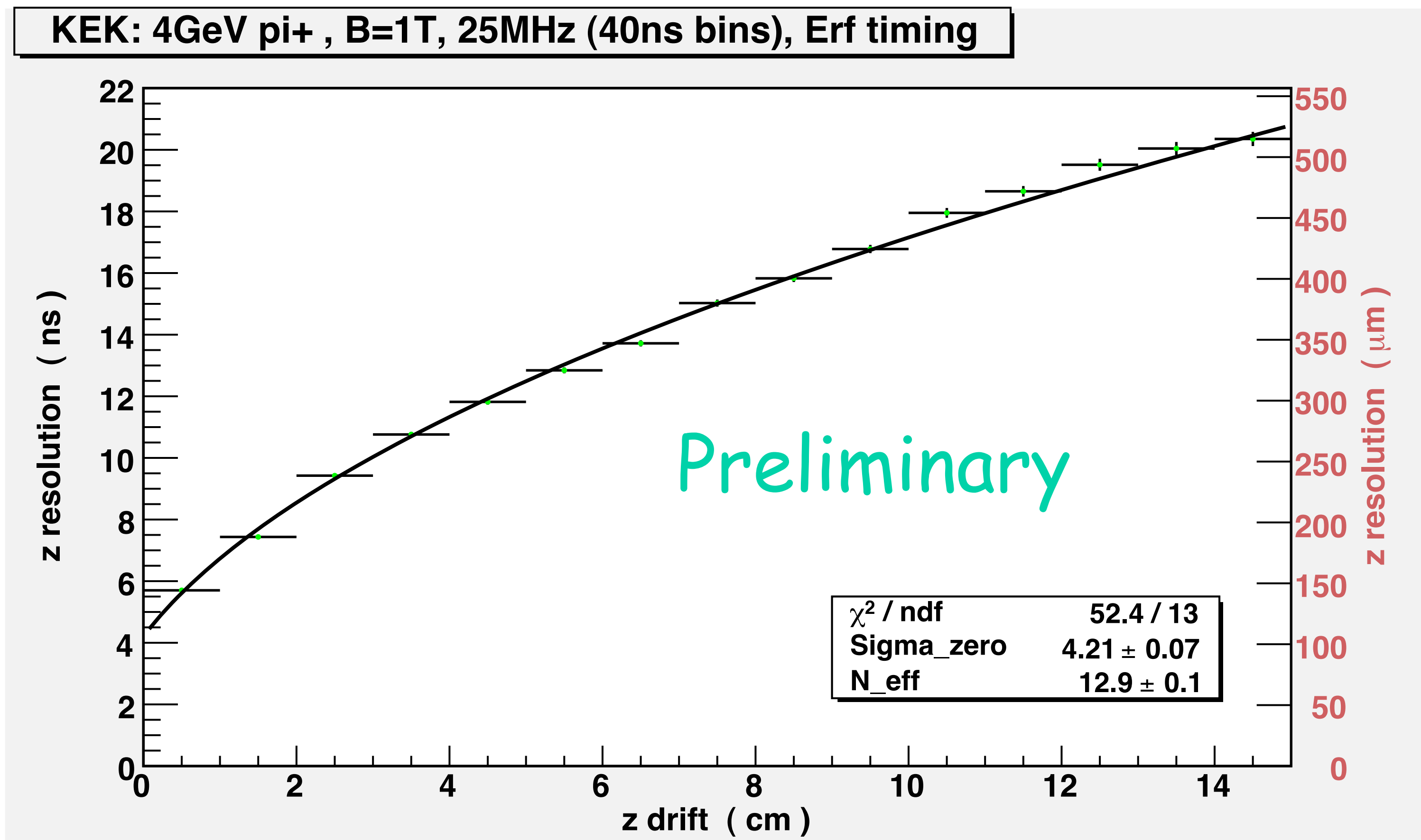
σ_{inc} σ_{exc}

$$\sigma = \sqrt{\sigma_{inc} * \sigma_{exc}}$$

KEK B=1T 4 GeV π+ beam time resolution

Ar+5%iC4H10

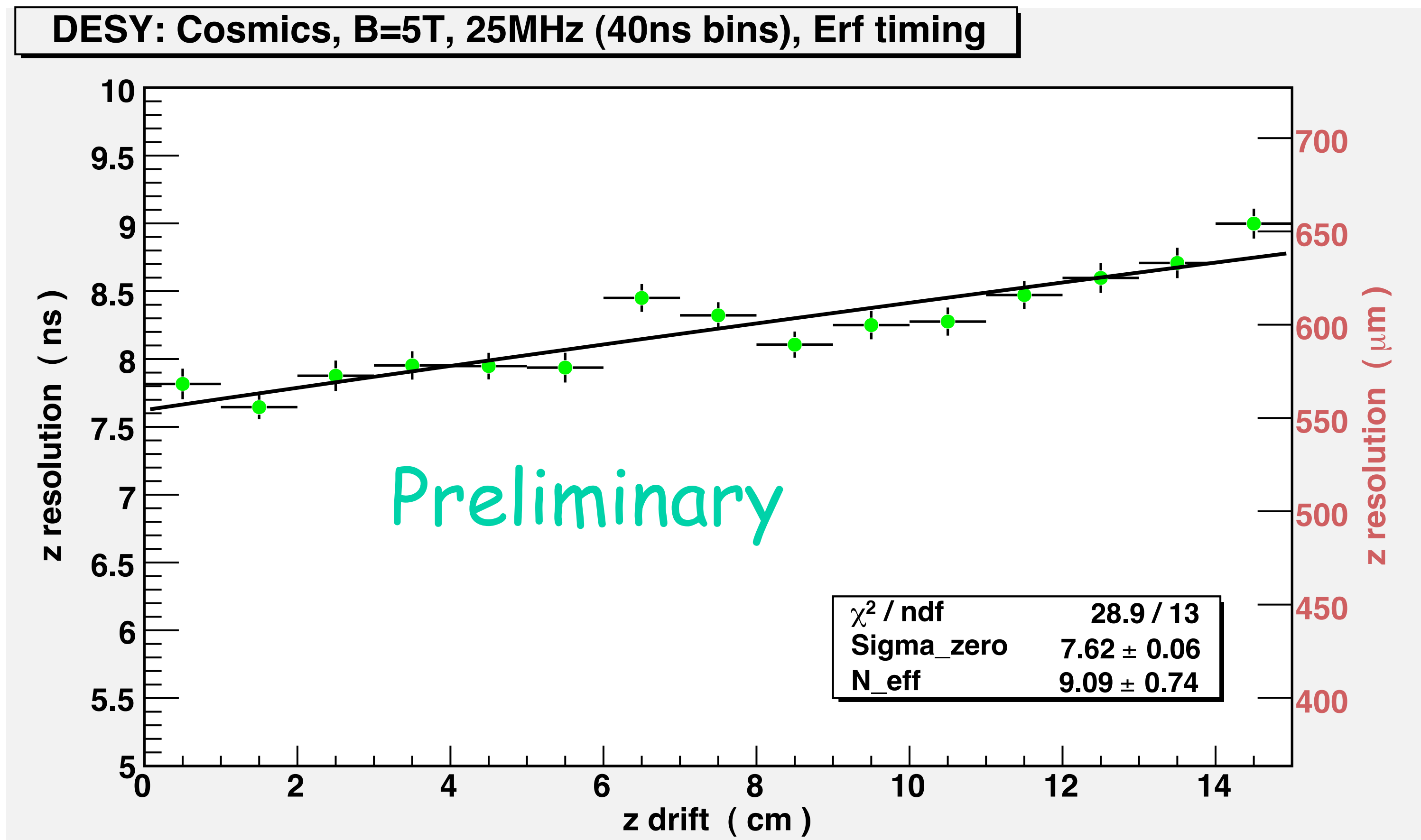
E=70V/cm V_{drift} =25 μm/ns, D_{Long} = 479 μ/√cm



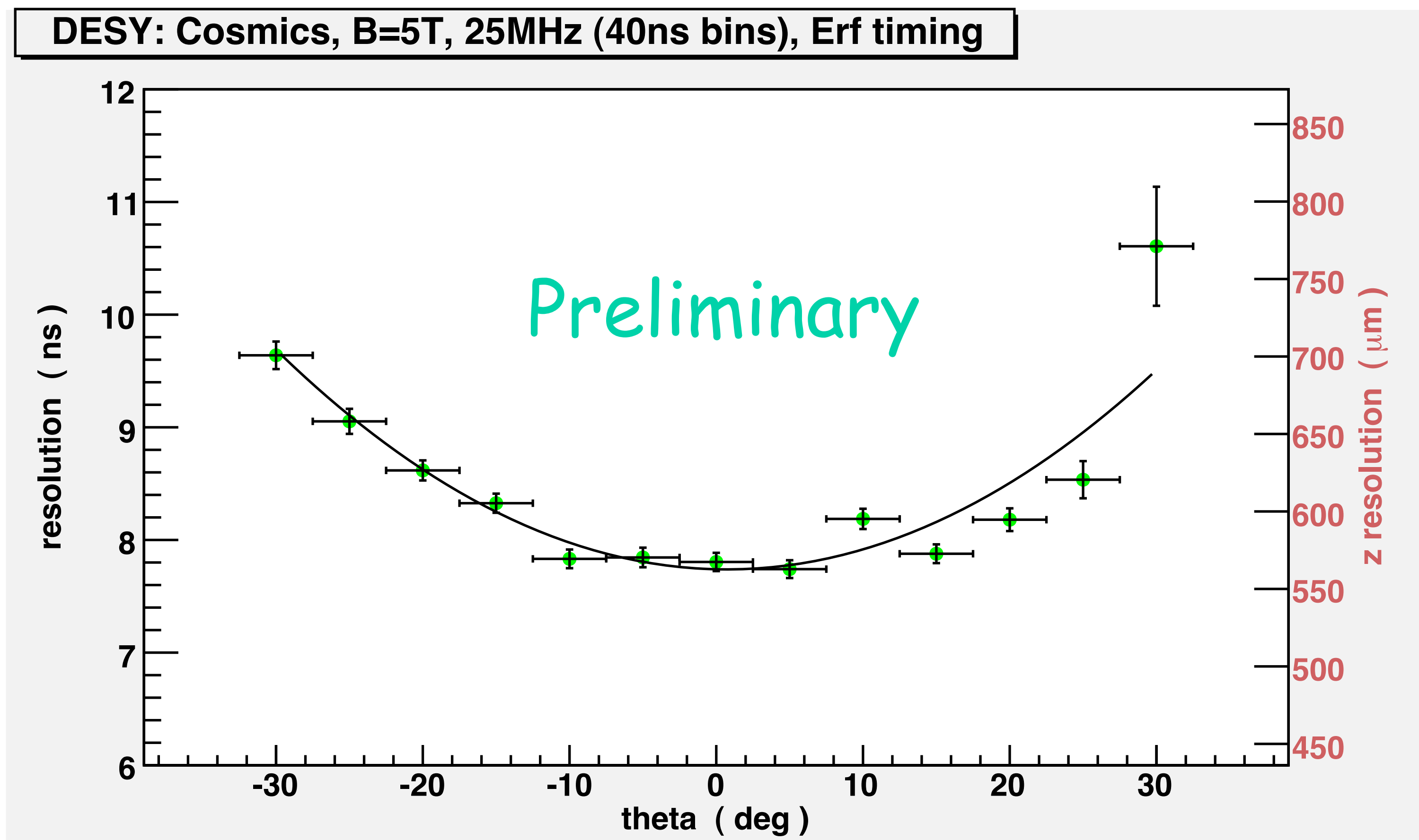
DESY 5 T cosmic tests

Ar+2%iC4H10+3%CF4

E=200V/cm V_{drift} =73 µm/ns, D_{Long} = 249µ/√cm



Track angle dependence of time resolution



Summary

- Charge dispersion makes MPGD position sensing independent of pad width. High resolution can be achieved with relatively wide pads
- The original PRF algorithm was "undemocratic" resulting in the analysis being sensitive to noise.
- $\sigma_0(r\text{-}\phi) \sim 30\ \mu m$ achieved for 2 mm x 6 mm pads is now comparable to the "residual bias" from anode structure RC non-uniformities.
- Improved materials and fabrication techniques should further reduce bias.
- A first measurement z resolution for Micromegas with charge dispersion readout:

  $\sigma_0(z) \sim 550\ \mu m$ (fast gas, $v_{Drift} = 73\ \mu m/ns$)

  $\sigma_0(z) \sim 100\ \mu m$ (slow gas, $v_{Drift} = 25\ \mu m/ns$)
- N_{eff} significantly smaller for longitudinal measurements than for transverse.