TPC R&D towards the Design of the ILC TPC

LC TPC R&D Groups

TPC R&D Groups

Europe	America	Asian ILC gaseous-tracking groups	Other USA
RWTH Aachen	Carleton U	Chiba U	MIT (LCRD)
DESY	Cornell/Purdue	Hiroshima U	Temple/Wayne State (UCLC)
U Hamburg	LBNL	Minadamo SU-IIT	Yale
U Freiburg	MIT	Kinki U	
U Karlsruhe	U Montreal	U Osaka	
UMM Krakow	U Victoria	Saga U	
Lund/Stockholm		Tokyo UAT	
MPI-Munich		U Tokyo	
NIKHEF		NRICP Tokyo	
BINP Novosibirsk		Kogakuin U Tokyo	
LAL Orsay		KEK Tsukuba	
IPN Orsay		U Tsukuba	
U Rostock			
CEA Saclay			
PNPI StPetersburg			

Please let me know if I forgot someone!

HISTORY

1992: *First discussions on detectors in Garmisch-Partenkirschen (LC92). Silicon? Gas?*
1996-1997: *TESLA Conceptual Design Report. Large wire TPC, 0.7Mchan.*
1/2001: *TESLA Technical Design Report. Micropattern (GEM, Micromegas) as a baseline, 1.5Mchan.*
5/2001: *Kick-off of Detector R&D*
11/2001: *DESY PRC proposal. for TPC R&D (European & North American teams)*
2002: *UCLC/LCRD proposals*
2004: *After ITRP,*
WWS R&D panel

Europe
Chris Damerell (Rutherford Lab. UK)
Jean-Claude Brient (Ecole Polytechnique, France)
Wolfgang Lohmann (DESY-Zeuthen, Germany)

Asia
HongJoo Kim (Korean National U.)
Tohru Takeshita (Shinsu U., Japan)
Yasuhiro Sugimoto (KEK, Japan)

North America
Dan Peterson (Cornell U., USA)
Ray Frey (U. of Oregon, USA)
Harry Weerts (Fermilab, USA)

GOAL

To design and build an ultra-high performance

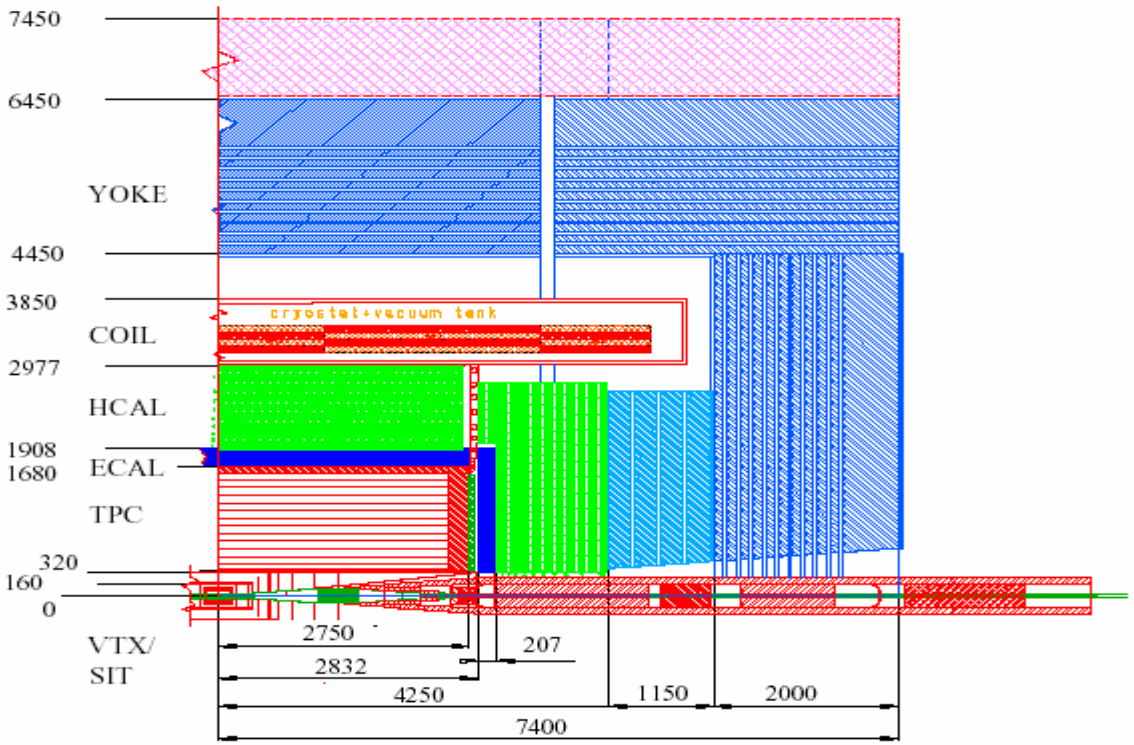
Time Projection Chamber

...as central tracker for the ILC detector, where excellent vertex, momentum and jet-energy precision are required

"Large" Detector example

- Flavor tag $\delta(\mathrm{IP}) \sim 5\mu\mathrm{m} \oplus \frac{10\mu m\ \mathrm{GeV}/c}{\mathrm{p}\sin^{3/2}\theta}$
- Track momentum $\delta(1/p_t) \sim 6\text{x}10^{-5}\ \mathrm{GeV}/c^{-1}$
- Particle Flow $\delta E/E \sim .30/\sqrt{E}$

Energy flow
– granularity
– hermeticity
– min. material inside calos
– calos inside 4 T coil



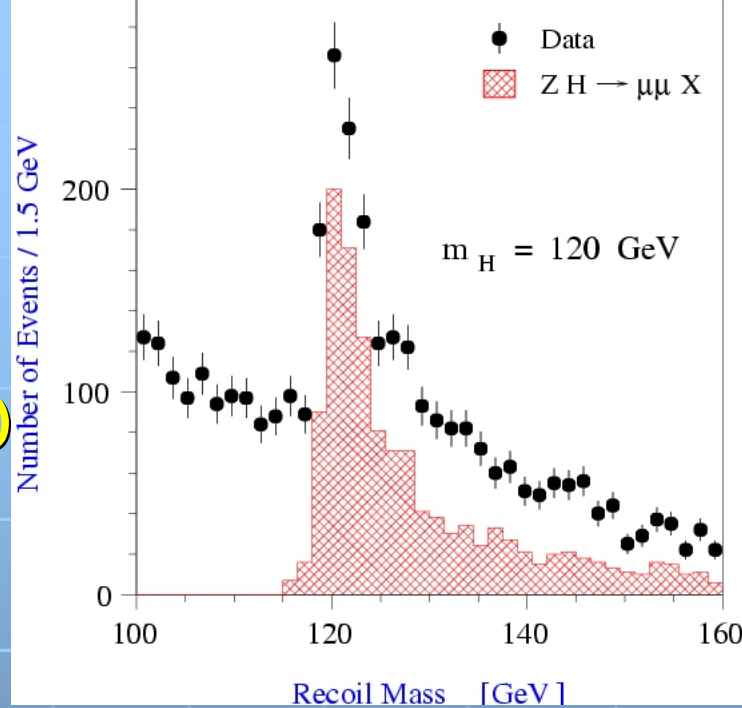
Physics determines detector design

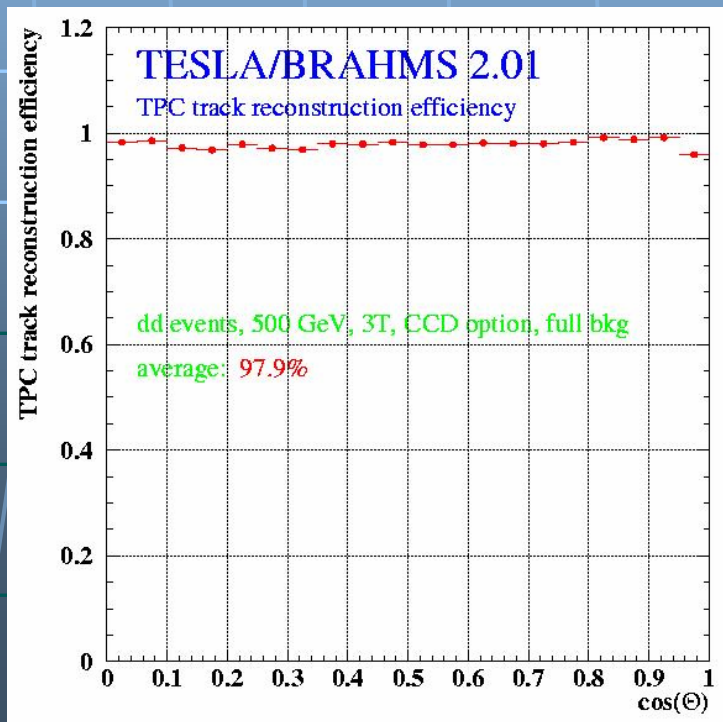
- ★ momentum: d(1/p) ~ 10^{-4}/GeV(TPC only)
  ~ 0.6×10^{-4}/GeV(w/vertex)
  (1/10xLEP)

$e^+e^- \to ZH \to ll\ X$ goal: $\delta M_{\mu\mu} < 0.1 \times \Gamma_Z$
→ δM_H dominated by beamstrahlung

- ★ tracking efficiency: 98% (overall)

excellent and robust tracking efficiency by combining vertex detector and TPC, each with excellent tracking efficiency





Motivation/Goals

- Continuous tracking throughout large volume
- ~98% tracking efficiency in presence of backgrounds
- Timing to 1 ns together with inner silicon layer
- Minimum of X_0 inside Ecal (<3% barrel, <30% endcaps)
- σ_pt ~ 100μm (rφ) and ~ 500μm (rz) @ 4T for right gas if diffusion limited
- 2-track resolution <2mm (rφ) and <5mm (rz)
- dE/dx resolution <5%
- Full precision/efficiency at 30 x estimated backgrounds

R&D program

- gain experience with MPGD-TPCs, compare with wires
- study charge transfer properties, minimize ion feedback
- measure performance with different B fields and gases
- find ways to achieve the desired precision
- investigate Si-readout techniques
- start electronics design for 1-2 million pads
- study design of thin field cage
- study design thin endplate: mechanics, electronics, cooling
- devise methods for robust performance in high backgrounds
- pursue software and simulation developments

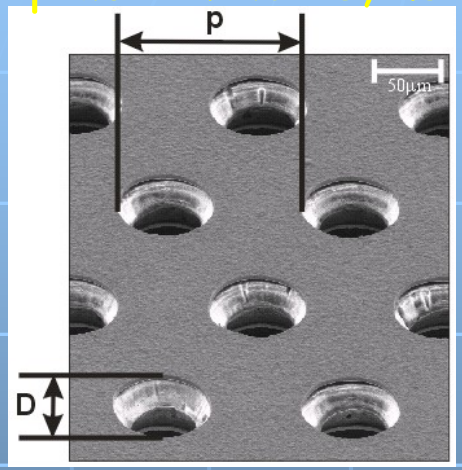
OUTLINE

- Gas-amplification systems
- Prototypes
- Facilities
- Latest results, summer 2005

Gas-Amplification Systems: Wires & MPGDs→

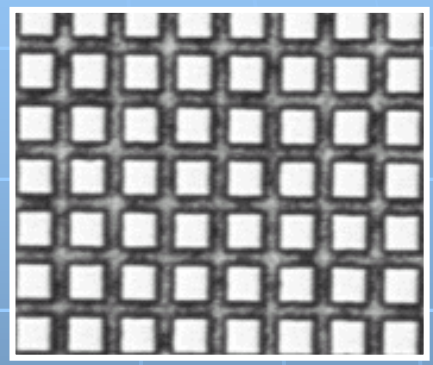
GEM: Two copper foils separated by kapton, multiplication takes place in holes, uses 2 or 3 stages

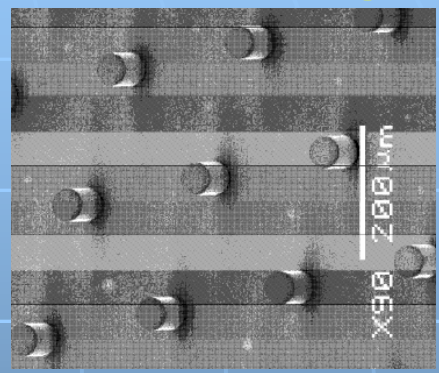
Micromegas: micromesh sustained by 50μm pillars, multiplication between anode and mesh, one stage



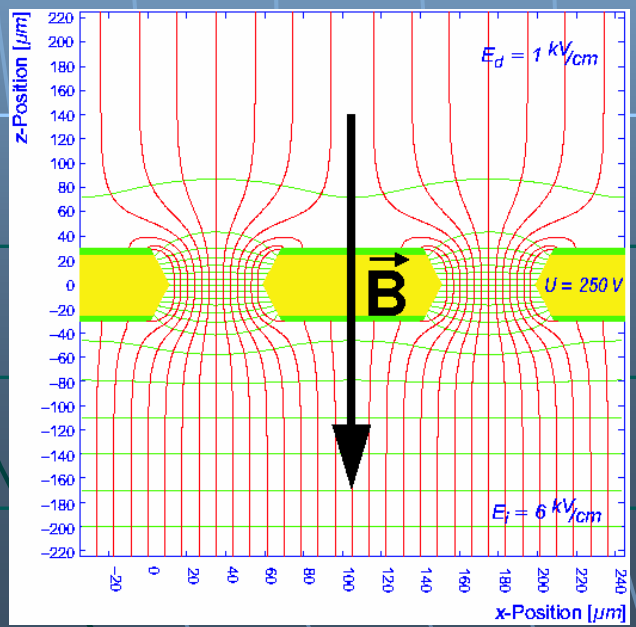
P~140 μm

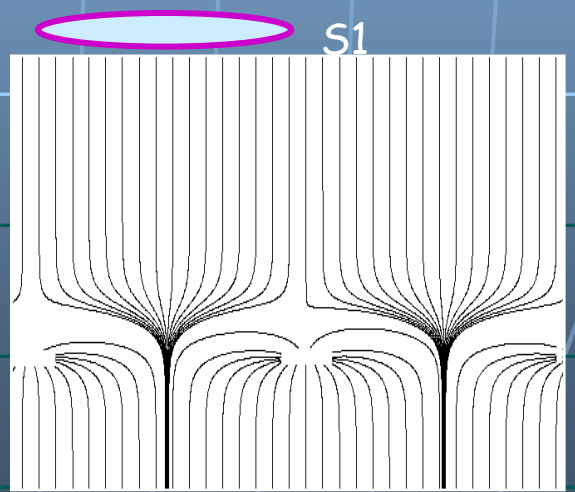
D~60 μm



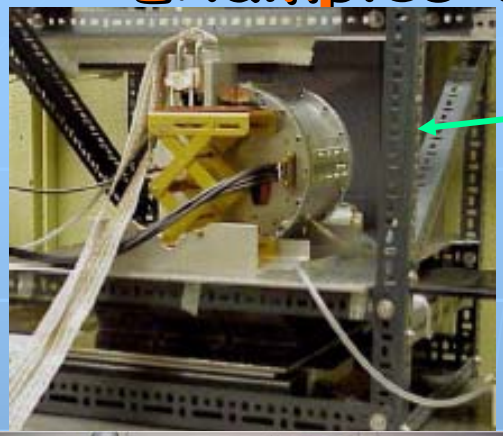


S1/S2 ~ Eamplif / Edrift

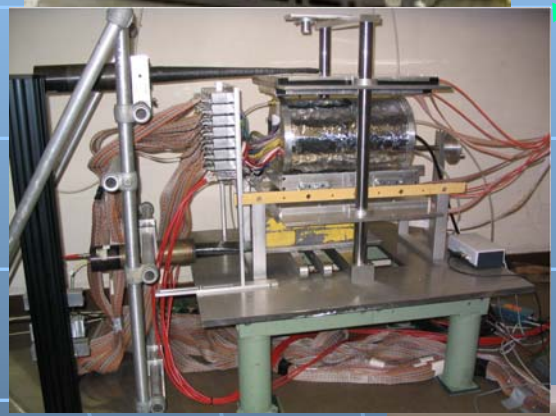


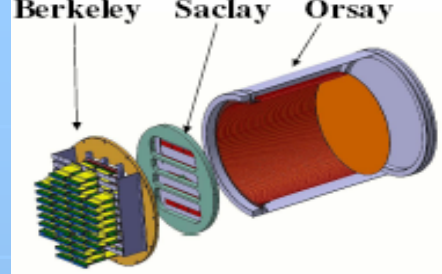


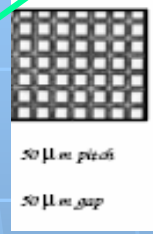
Examples of Prototype TPCs

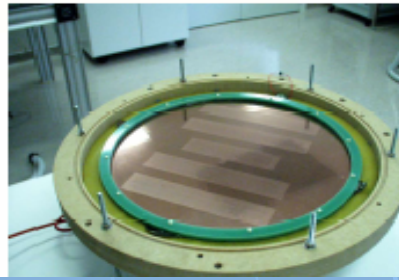


Carleton, Aachen, Cornell/Purdue,Desy(n.s.) for B=0or1T studies



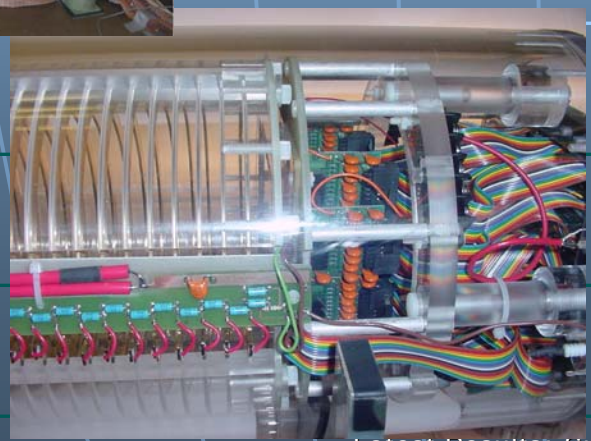


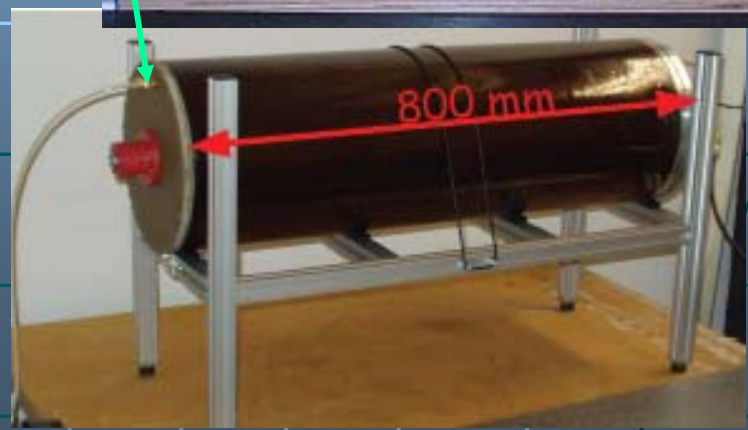




Saclay, Victoria, Desy (fit in 2-5T magnets)

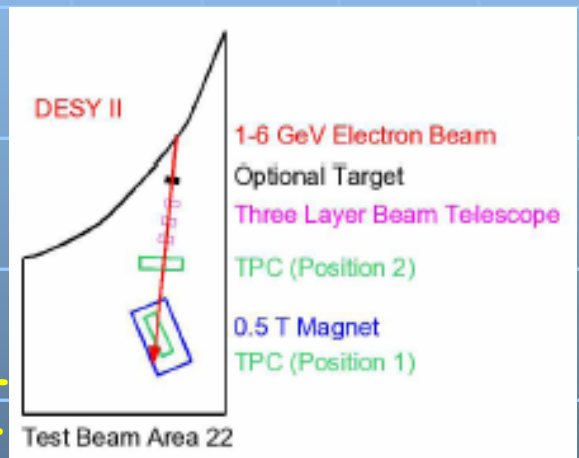
Karlsruhe, MPI/Asia, Aachen built test TPCs for magnets (not shown), other groups built small special-study chambers

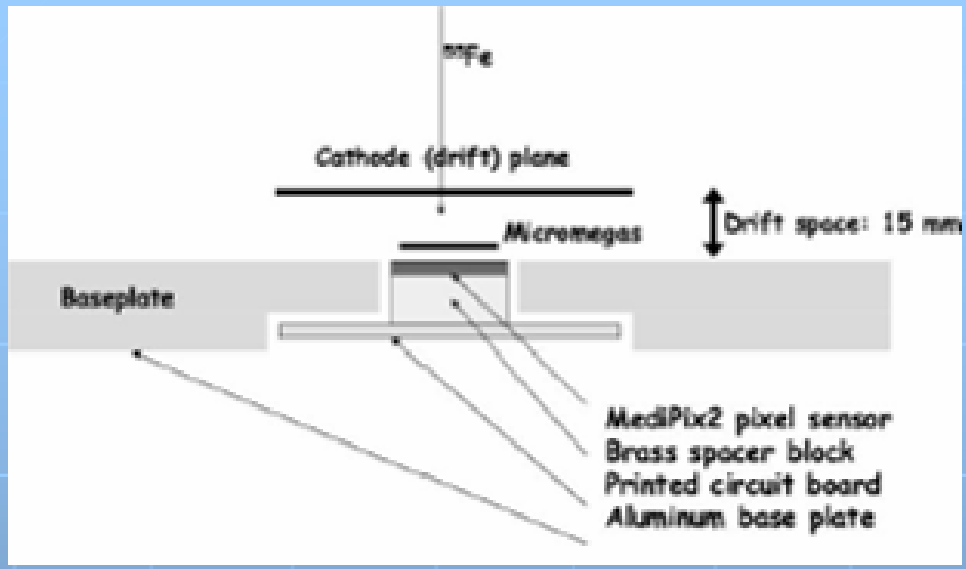


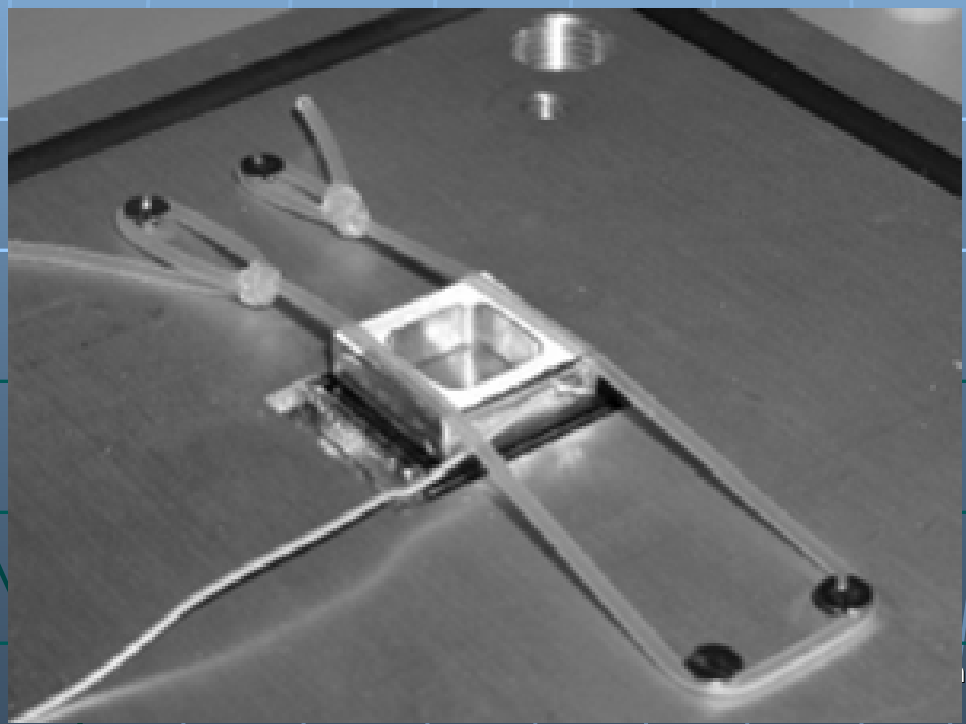


Facilities

Cern test-beam (not shown)







Electronics Development

Nikhef on CMOS readout techniques, joined by Saclay

~ 50 x 50 μm^2 CMOS pixel matrix + Micromegas or Gem

~ preamp, discr, thr.daq, 14-bit ctr, time-stamp logic / pixel

~ huge granularity(digital TPC), diffusion limited, sensitive to indiv. clusters for right gas

~ 1st tests with Micromegas + MediPix2 chip

→ more later…

LATEST RESULTS SUMMER 2005

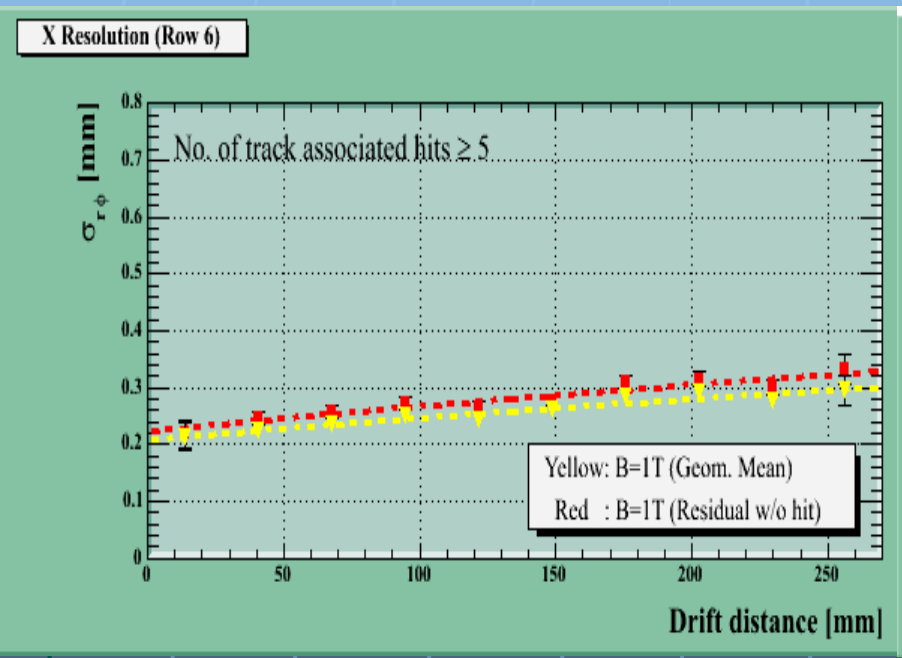
Presently mapping out parameter space: demonstration phase

- Point resolution
- Results from CMOS Pixel readout

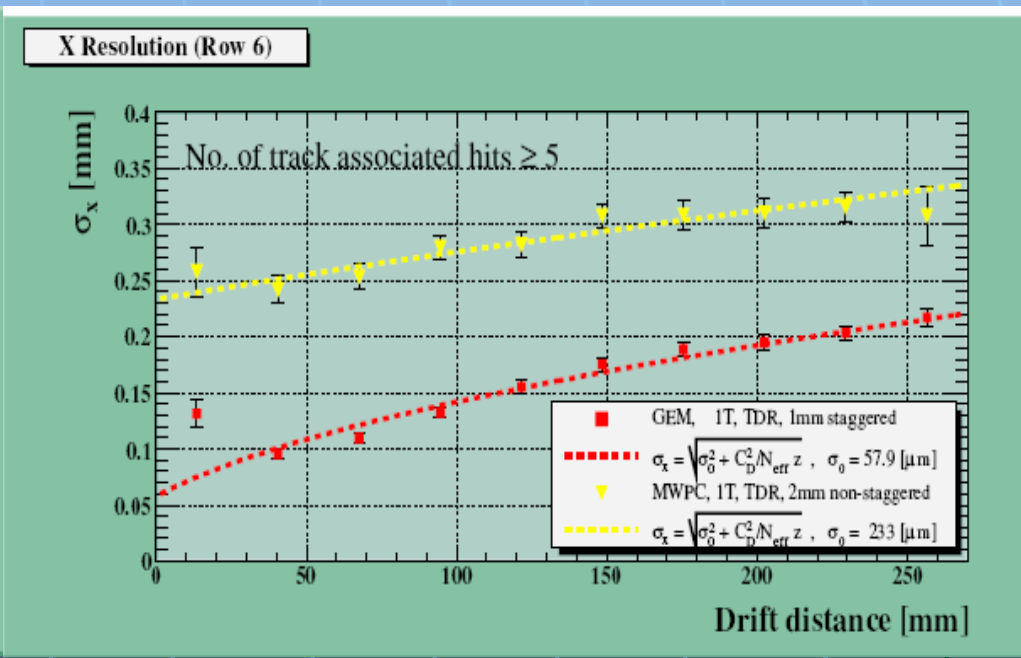
KEK/MPI beam test: resolution as function of drift distance at B = 1T.

Method: fit track with and without row in question (row#6). Geometric mean of the two results gives the correct resolution.

Wires, expect~170μm resolution:

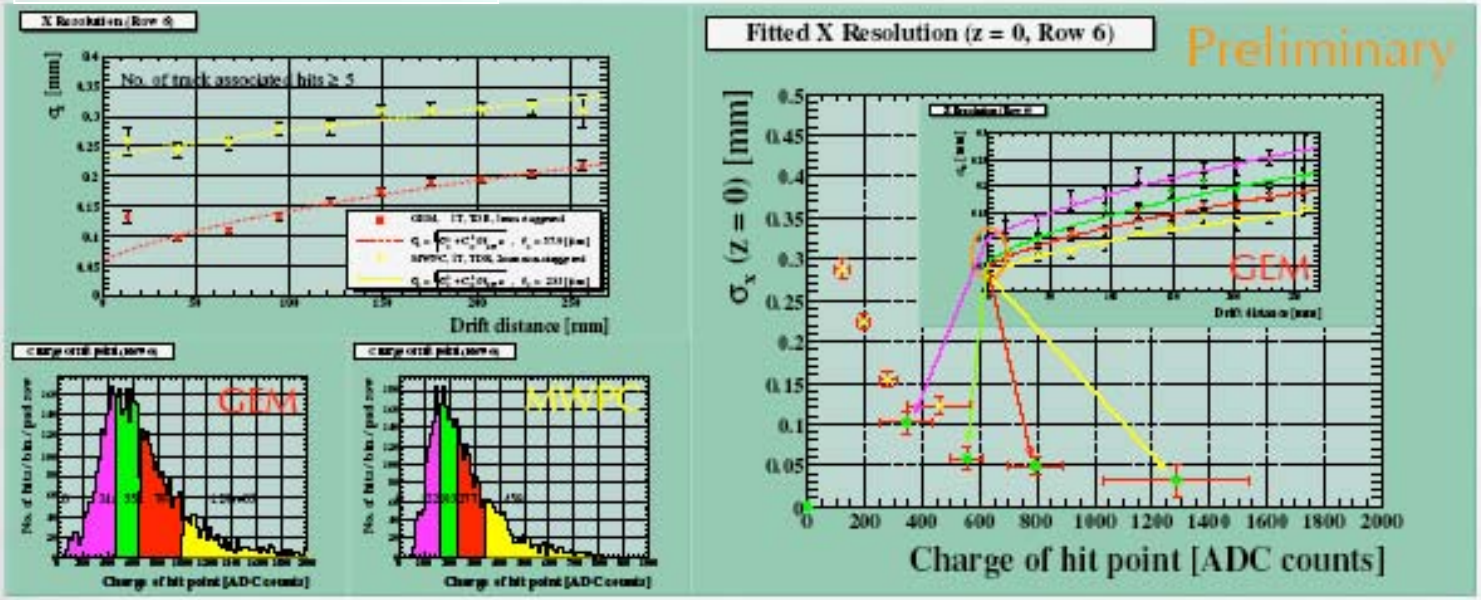


GEM beamtest,compare to wires:



Comparison between GEM & MWPC

KEK/MPI beam test



Pulse hight dist.

sigma_0 as a function of pulse hight

- GEM: 1 mm staggered, MWPC: 2 mm non-stagg. pad (1T, TDR)
- S/N ratio was small in the case of MWPC readout -> large sigma_0

Katsumasa Ikematsu (DESY) / ACFA8

X Resolution of Micromegas@KEK beam test

$\sum 8Rows$

$Cd = Cd(PRF)$

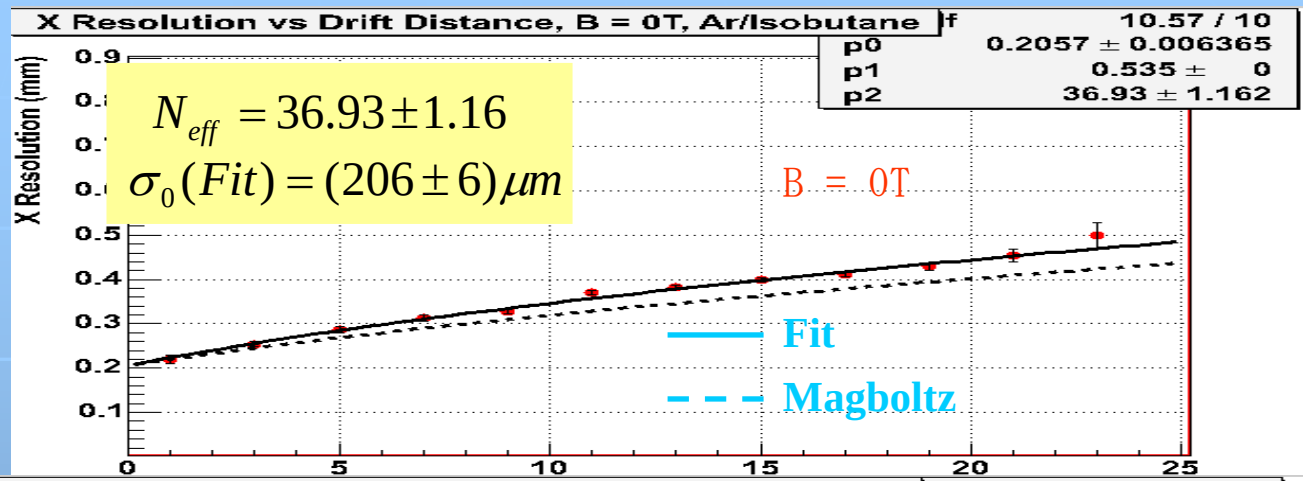
$C_d(Mag) = 469\mu m/\sqrt{cm}$

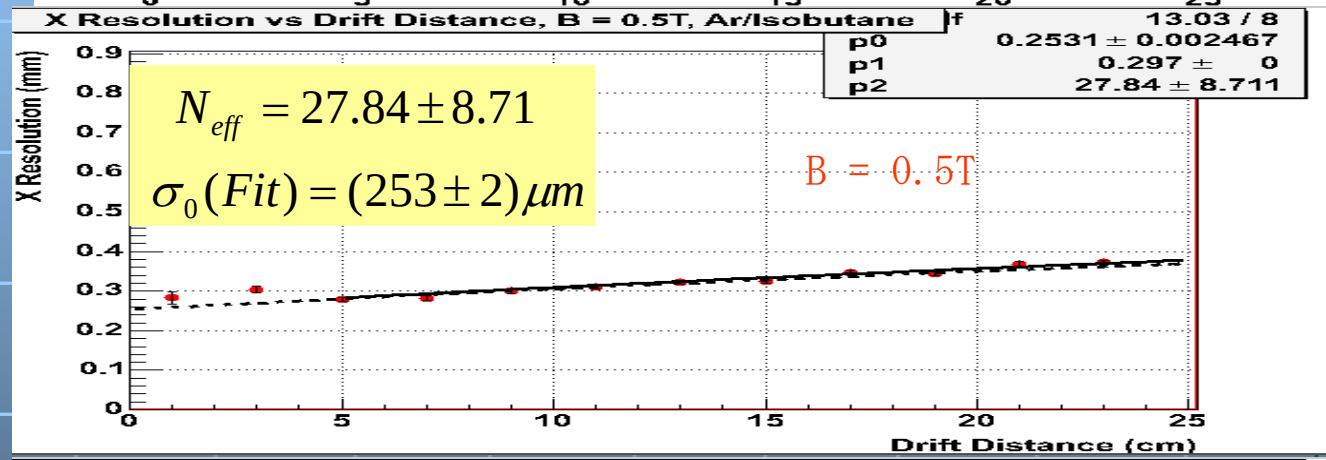
C_d fixed each B

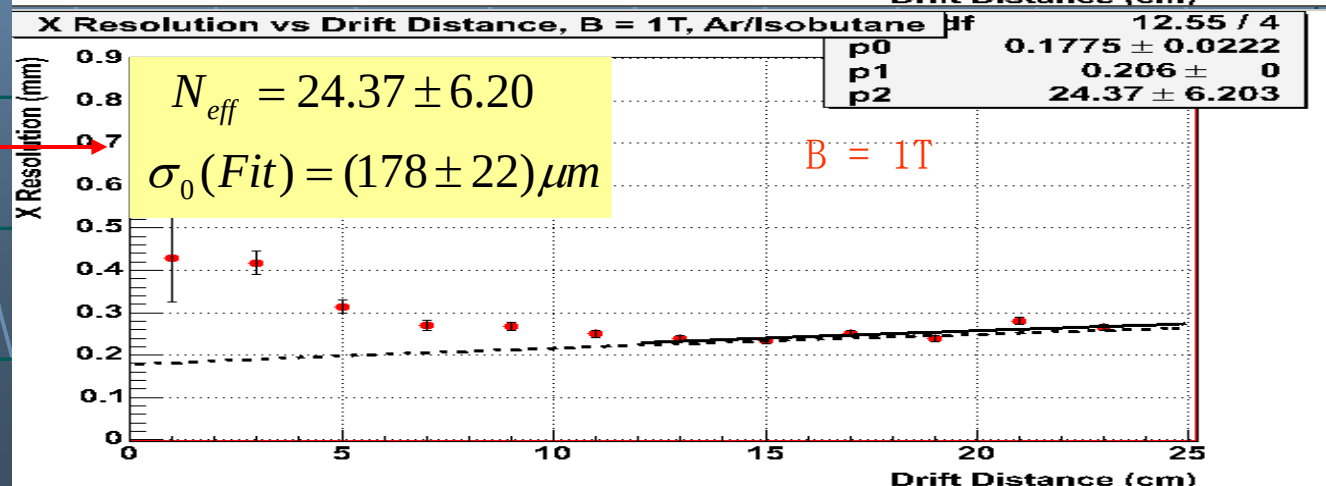
$C_d(Mag) = 285\mu m/\sqrt{cm}$

$2.3mm/\sqrt{12}$

$C_d(Mag) = 193\mu m/\sqrt{cm}$





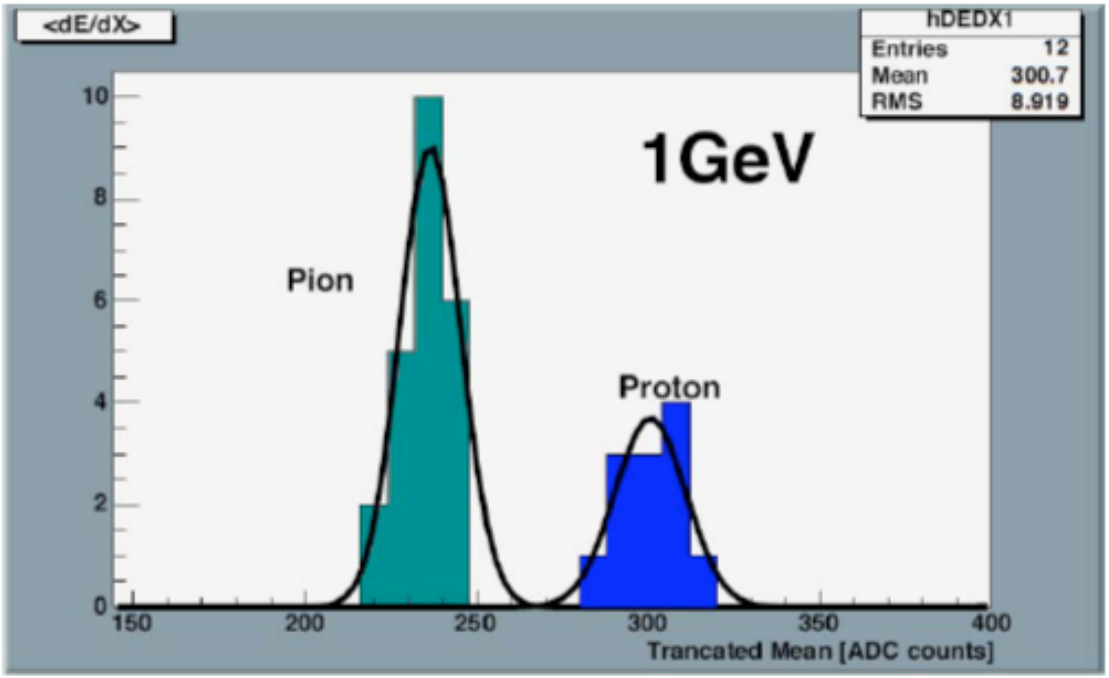


dE/dx in TDR gas

7 pad-raw /event x 30 events -> 210 sampling

$\sigma_{dE/dx}$ ~ 3.4% (-> 7.9% w/ 40 samples)

not a correct truncated mean.
good w/o calib., any corrections

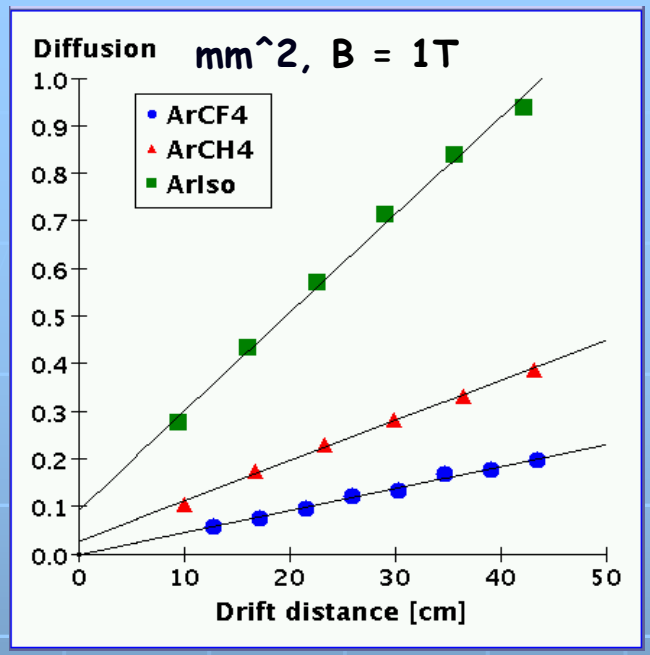


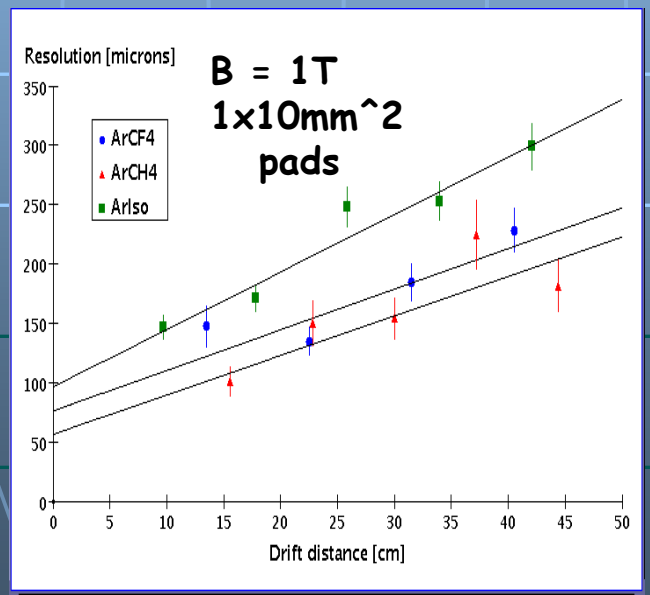
proton @1GeV/c
<dE/dx> 300.6
sigma 10.3

pi @1GeV/c
<dE/dx> 236.4
sigma 8.9

Prototype Results

Point resolution, Micromegas





Saclay/Orsay/Berkeley

--Ageing negligible

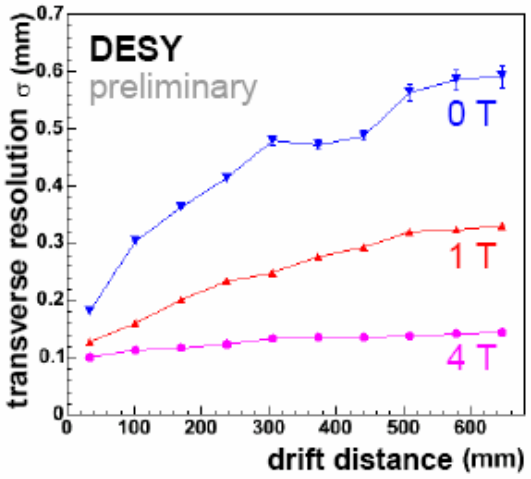
--Diffusion measurements ⇒ σ_pt < 100μm possible

--At moment only achieved for short drift (intrinsic σ) for gain~5000 (350V mesh), noise~1000e

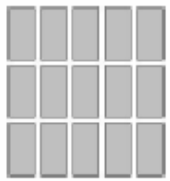
--Analysis continuing…

Prototype Results

Point resolution, Gem

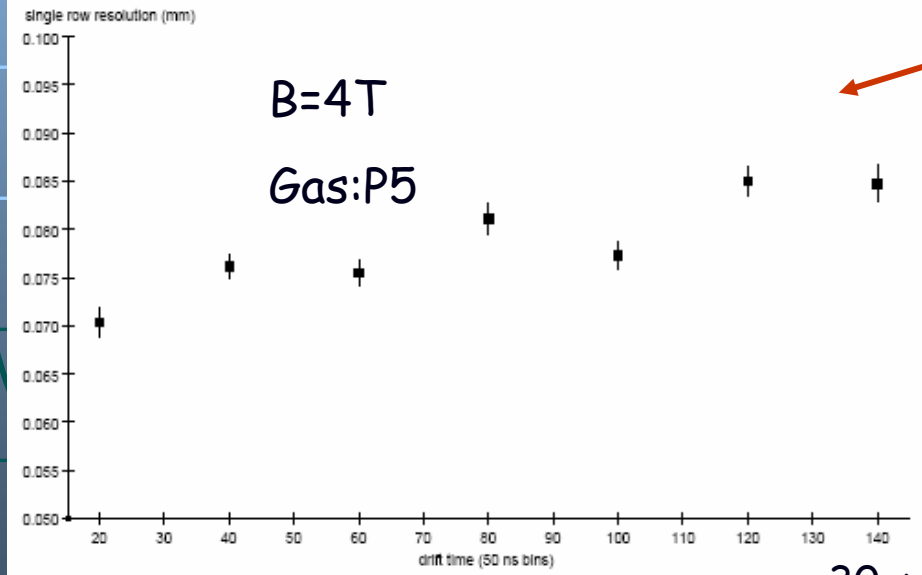


- **TESLA TDR gas** ($Ar:CH_4:CO_2$ 93:5:2)
- **Non-staggered pads** (2.2 x 6.2 mm²)



Resolution determined by:
- diffusion
- defocussing
- readout geometry

(relative contributions vary with B)



--Three examples of σ_pt measured for Gems and 2x6mm^2 pads.

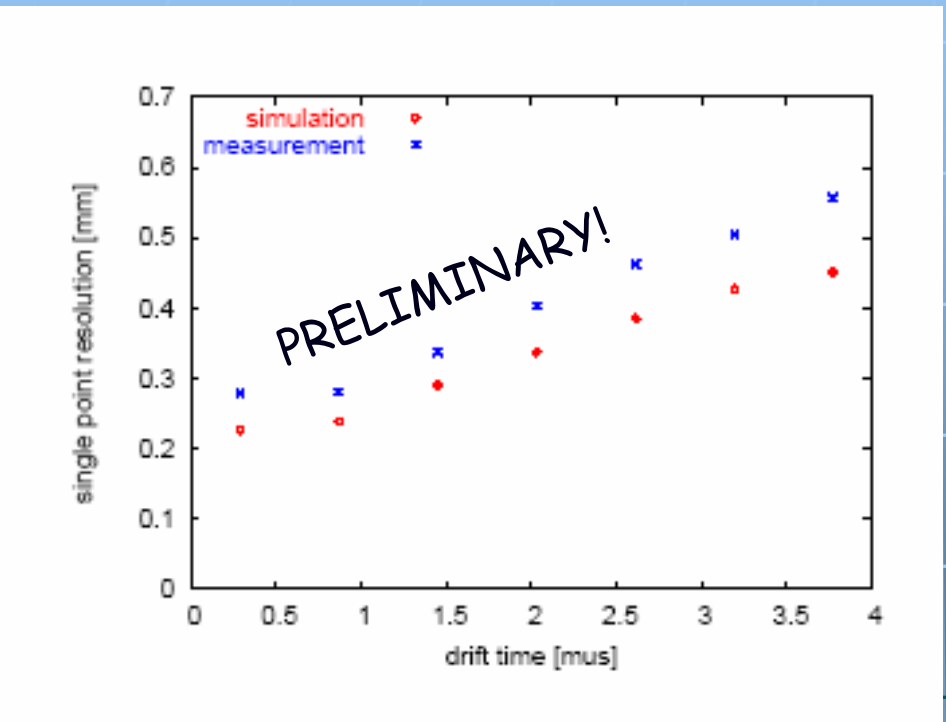
--First, in Desy chamber (triple Gem), resolution using "triplet method".

--Second, in Victoria chamber (double Gem), unbiased method used: track fit twice, with and without padrow in question, σ determined for each case; geometric mean of the two σ's gives the correct result.

--See next page…

Prototype Results

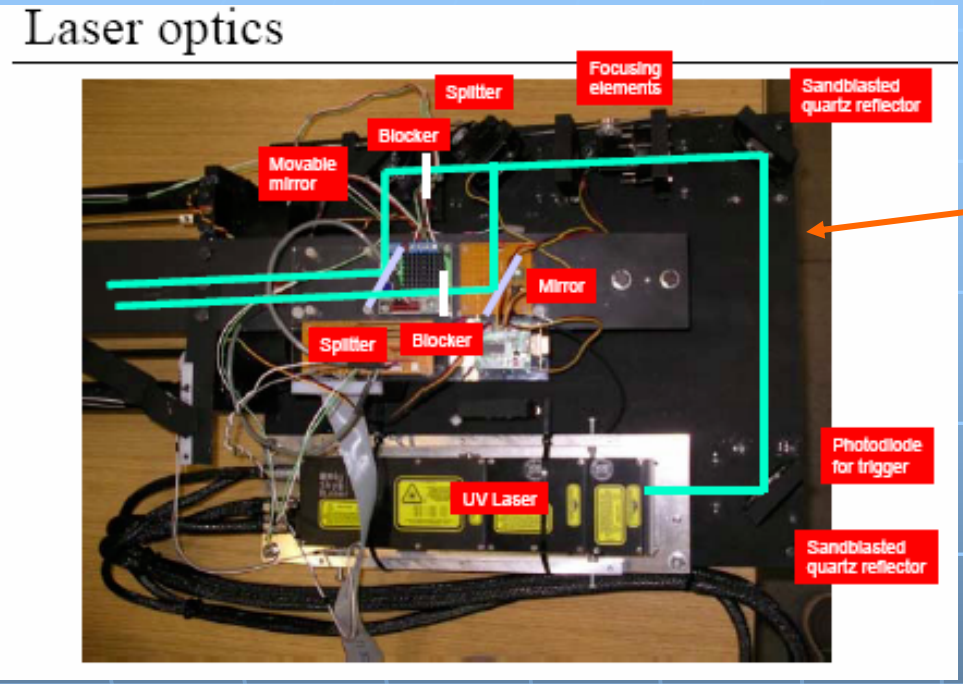
Point resolution, Gem



--Third example of σ_pt measured at Aachen Gems and 2x6mm^2 pads by comparing track position with a Si hodoscope.

--In general (also for Micromegas) the resolution is not as good as simulations expect; we are searching for why (electronics, noise, method).

Two-track resolution studies

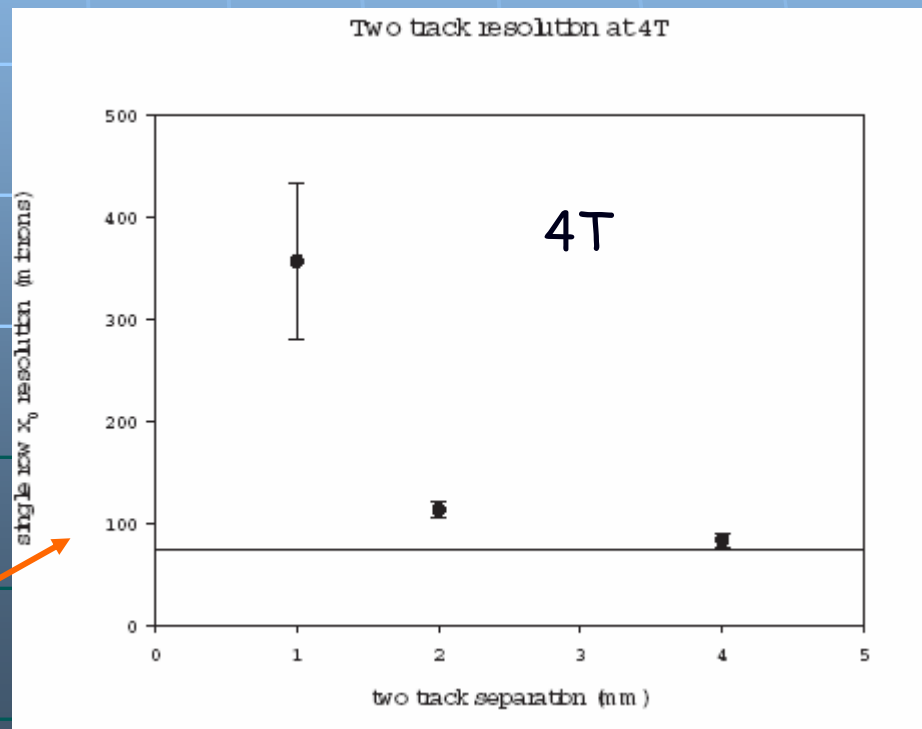


Studies just starting.

Victoria steering mechanics, Desy laser and 5T magnet.

σ_point for cosmics ~ laser ~ 80μm

2-track resol. for lasers ~ 1-2mm: how the resolution on one track is affected by presence of a nearby parallel track at same drift dist.



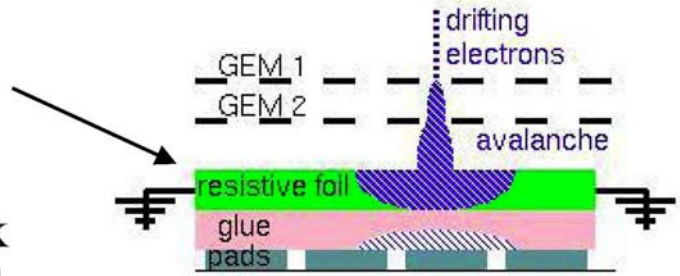
Carleton: improving point resolution with resistive foil

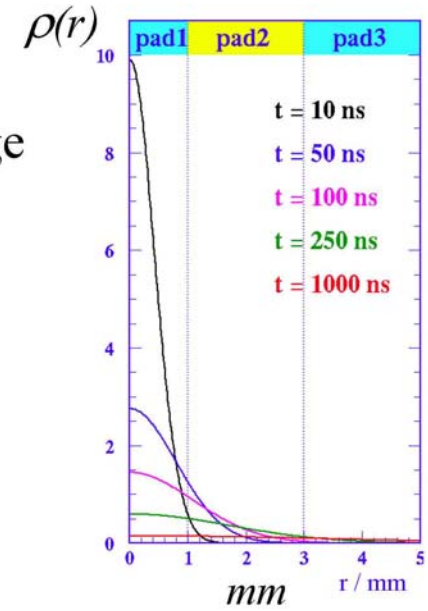
The Concept of Charge Dispersion

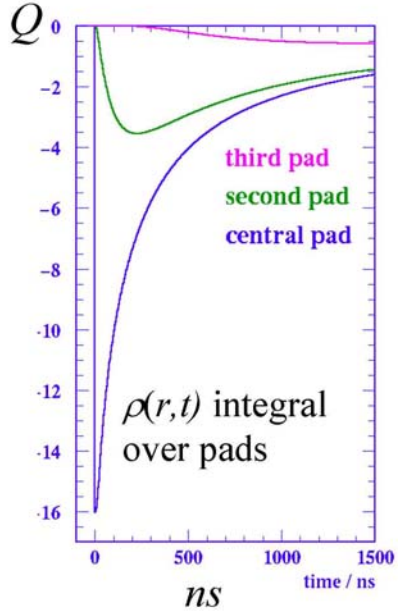
- **Modified GEM anode with a high resistivity film bonded to a readout plane with an insulating spacer**
- 2-dim continuous RC network defined by material properties and geometry
- Point charge at $r=0$ & $t=0$ disperses with time
- Time dependent anode charge density sampled by readout pads:

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

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



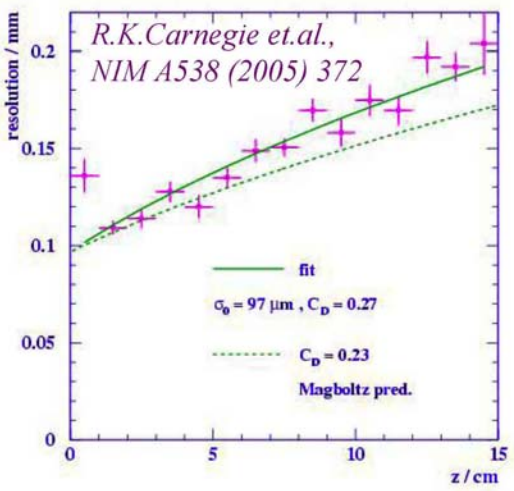




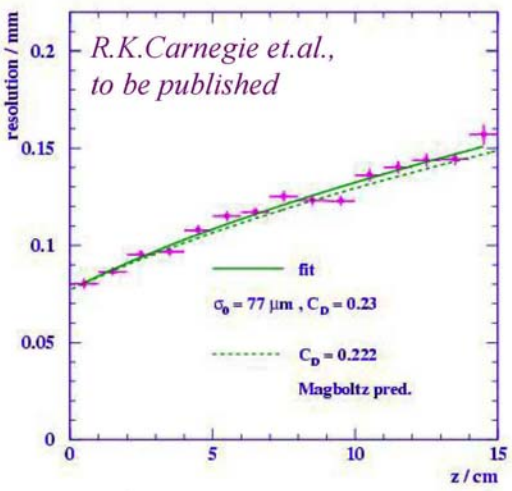
Carleton: resistive foil results

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

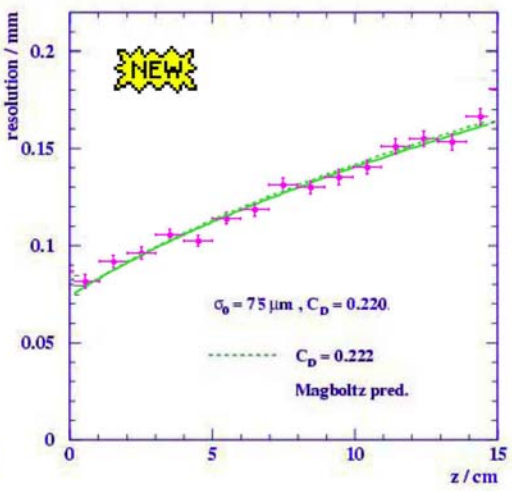
GEM with direct charge readout



GEM with charge dispersion readout



Micromegas with charge dispersion readout

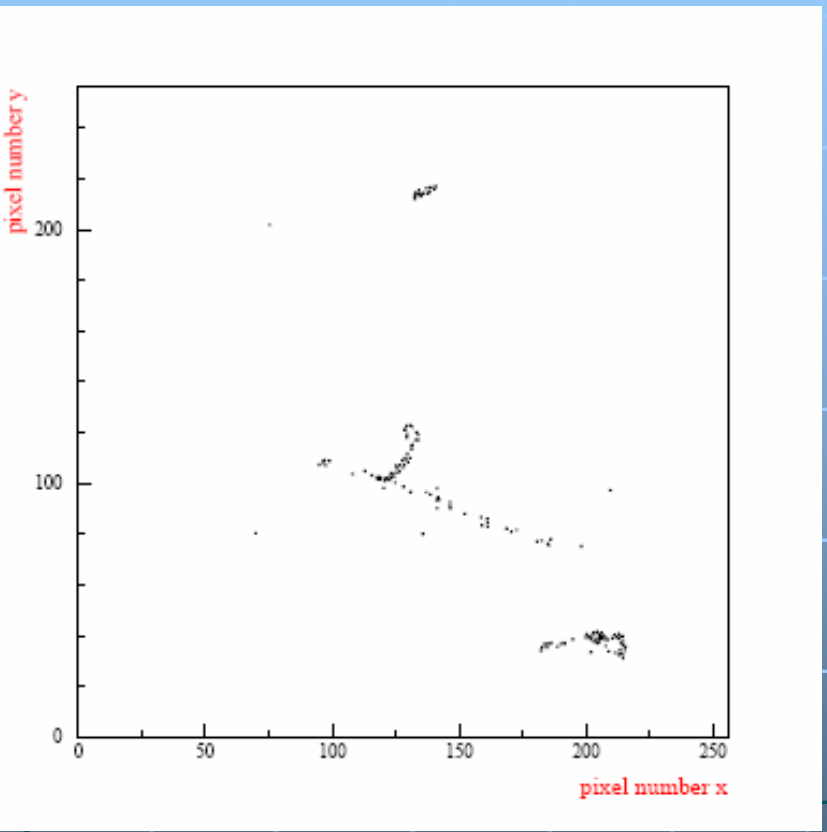


$$\sqrt{\sigma_0^{\,2} + \frac{C_D^{\,2}}{N_e} z}$$ (Diffusion limit of resolution)

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.

15

Medipix2+Micromegas: results@Nikhef



--Single-electron sensitivity demonstrated: Fe55 source, open30s/close, He/20%Isobut., threshold=3000e, gain=19K (-470V Mmegas), -1kV drift

--Measure diffusion const.~ 220μm/√cm, N_cluster~0.52/mm, in reasonable agreement with simulation

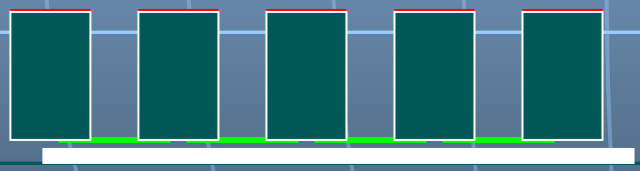
--NIM A540 (2005) 295 (physics/0409048)

--Future: develop "*TimePixGrid*" prototype by Nikhef/Saclay/et.al. for TPC application: see next slide…

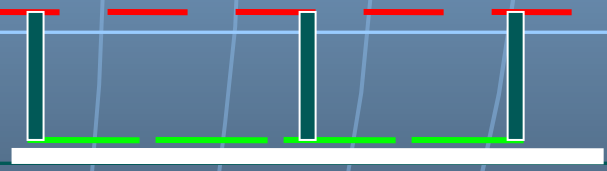
InGrid

Integrate GEM/Micromegas and pixel sensor

‘GEM’

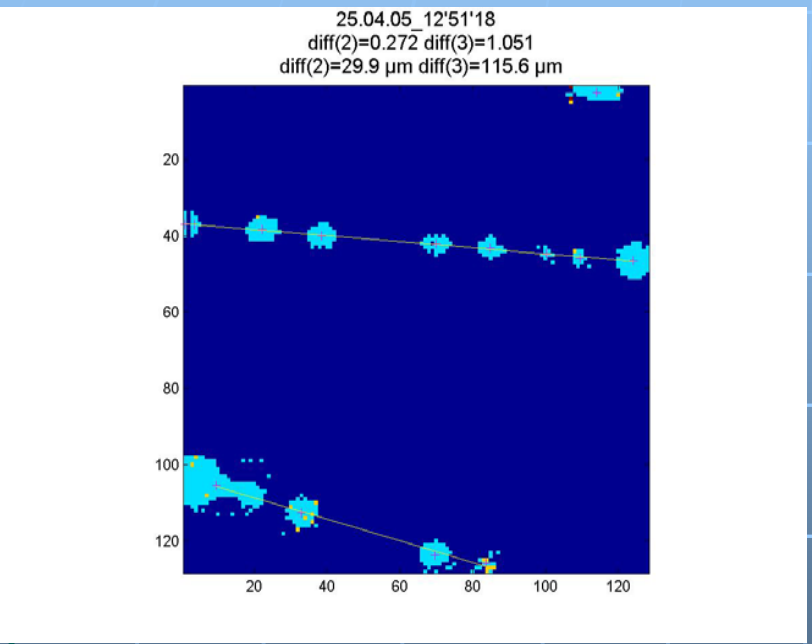


‘Micromegas’



By ‘wafer post processing’

Medipix2+GEMS: results@Freiburg



--GEM+Medipix2 sensitivity demonstrated: Cosmic by external telescope

--Measure diffusion const.~ ?µm/√cm

--Future: studies continuing

Plans

- 1) Demonstration phase
  - Continue work for ~1 year with small prototypes on mapping out parameter space, understanding resolution, etc, to prove feasibility of an MPGD TPC. For Si-based ideas this will include a basic proof-of-principle.
- 2) Consolidation phase
  - Build and operate "large" prototype (Ø ≥ 70cm, drift ≥ 50cm) which allows any MPGD technology, to test manufacturing techniques for MPGD endplates, fieldcage and electronics. Design work would start in ~1/2 year, building and testing another ~ 2 years.
- 3) Design phase
  - After phase 2, the decision as to which endplate technology to use for the LC TPC would be taken and final design started.