TPC R&D, Tasks towards the Design of the ILC TPC

LC TPC R&D Groups

OUTLINE of TALK

- Overview of the question
- Framework, R&D status
  - -Gas-amplification systems
  - -Prototypes
  - -Facilities
- Issues, tasks
- Back-up slides: recent R&D results

TPC R&D Groups

Europe

RWTH Aachen
DESY
U Hamburg
U Freiburg
U Karlsruhe
UMM Krakow
Lund/Stockholm
MPI-Munich
NIKHEF
BINP Novosibirsk
LAL Orsay
IPN Orsay
U Rostock
CEA Saclay
PNPI StPetersburg

America

Carleton U
Cornell/Purdue
LBNL
MIT
U Montreal
U Victoria

Asian ILC gaseous-tracking groups

Chiba U
Hiroshima U
Minadamo SU-IIT
Kinki U
U Osaka
Saga U
Tokyo UAT
U Tokyo
NRICP Tokyo
Kogakuin U Tokyo
KEK Tsukuba
U Tsukuba

Other USA

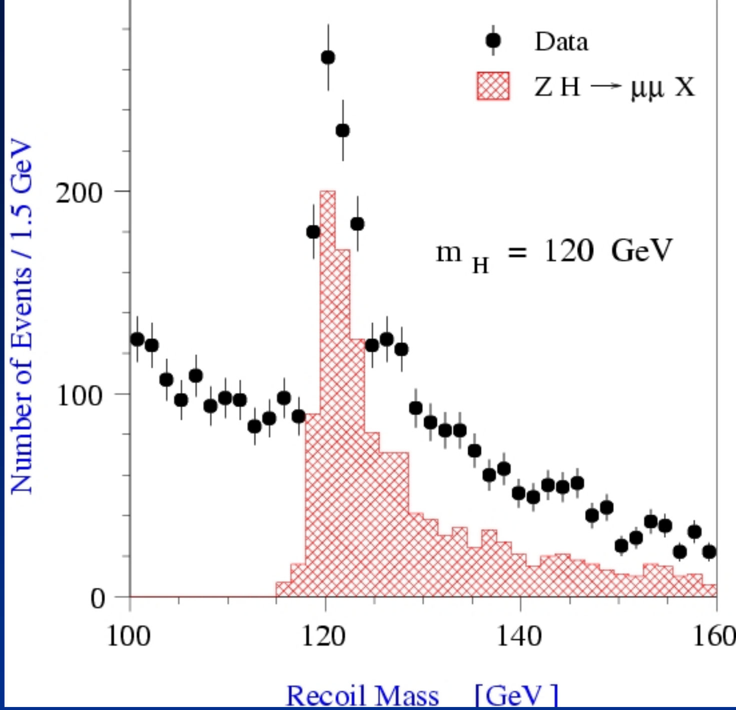
MIT (LCRD)
Temple/Wayne State (UCLC)
Yale

,,,OTHER?

Physics determines detector design

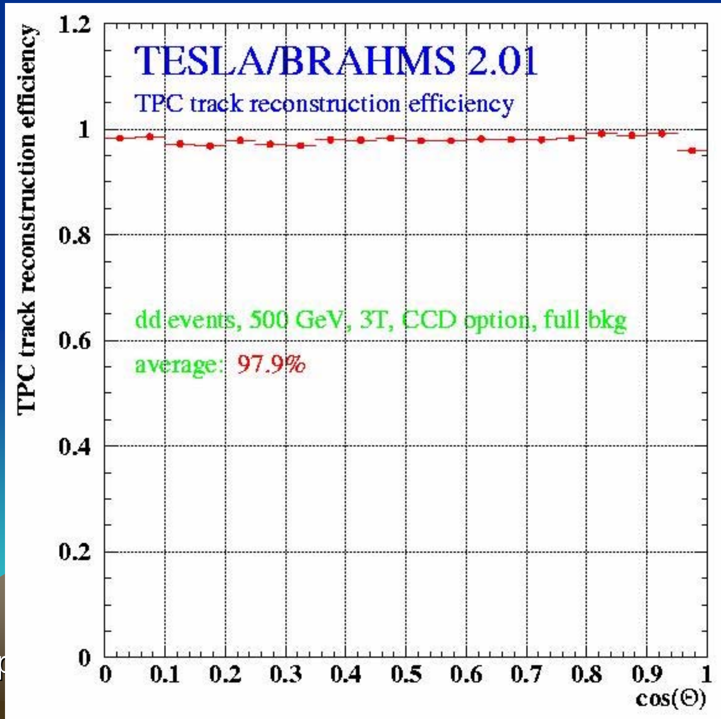
★ **momentum: d(1/p) ~ 10^{-4}/GeV(TPC only)**
~ 0.6×10^{-4}/GeV(w/vertex)
(1/10xLEP)

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

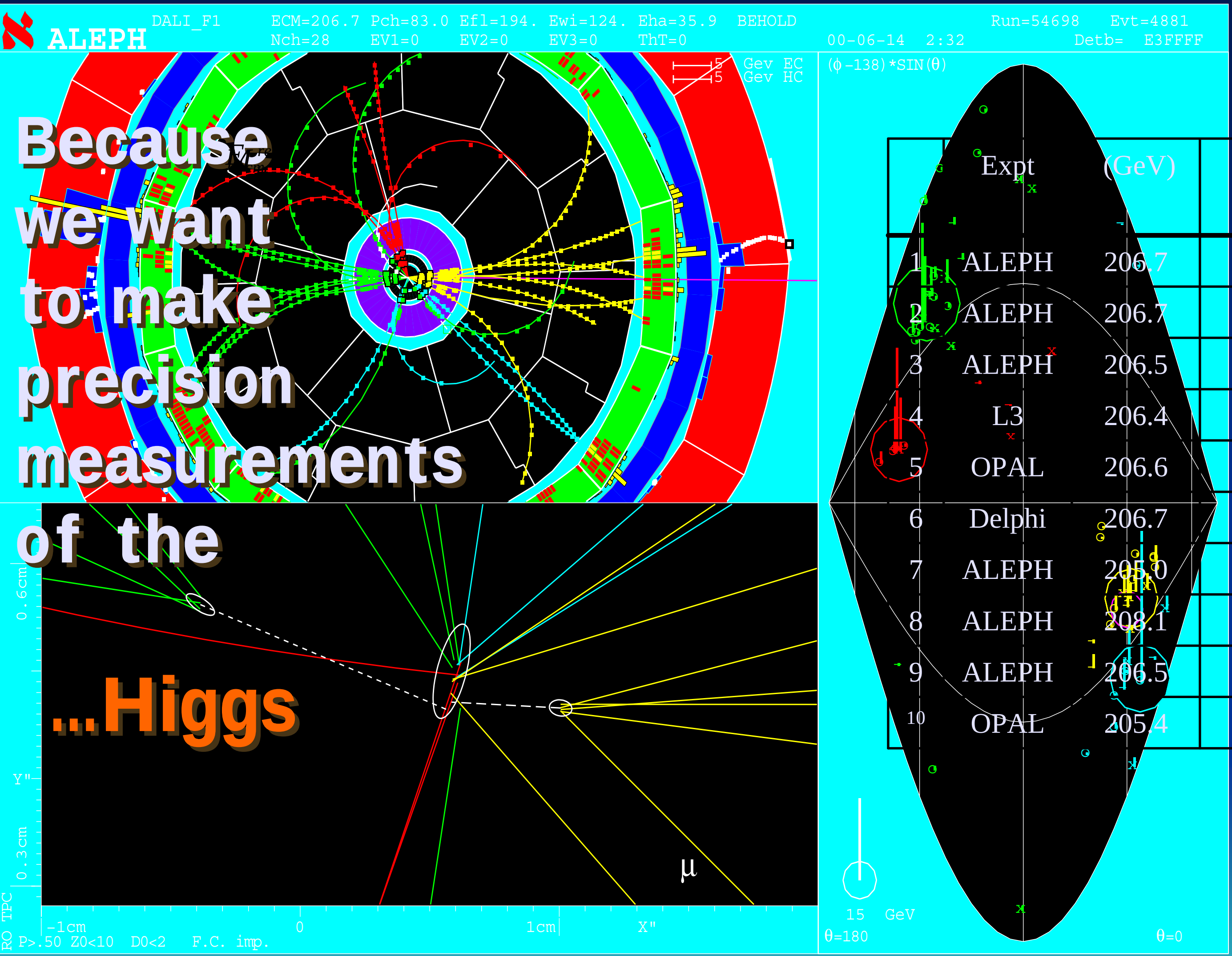


★ **tracking efficiency: 98% (overall)**

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



Motivation...



Because we want to make precision measurements of the

...Higgs

	Expt	(GeV)	Decay Channel	(GeV/c^2)	ln(1+s/b) 115 GeV/c^2
1	ALEPH	206.7	4-jet	114.3	1.73
2	ALEPH	206.7	4-jet	112.9	1.21
3	ALEPH	206.5	4-jet	110.0	0.64
4	L3	206.4	E-miss	115.0	0.53
5	OPAL	206.6	4-jet	110.7	0.53
6	Delphi	206.7	4-jet	114.3	0.49
7	ALEPH	206.0	Lept	118.1	0.47
8	ALEPH	208.1	Tau	115.4	0.41
9	ALEPH	206.5	4-jet	114.5	0.40
10	OPAL	205.4	4-jet	112.6	0.40

Motivation/Goals

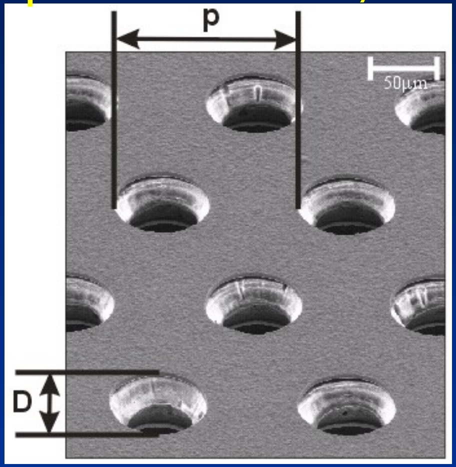
- Continuous 3-D tracking, easy pattern recognition throughout large volume
- ~98% tracking efficiency in presence of backgrounds
- Timing to 2 ns together with inner silicon layer
- Minimum of X_0 inside Ecal (<3% barrel, <30% endcaps)
- σ_pt ~ 100µm (rφ) and ~ 500µm (rz) @ 3,4T for right gas if diffusion limited
- 2-track resolution <2mm (rφ) and <5-10mm (rz)
- dE/dx resolution <5% -> e/pi separation, for example
- 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

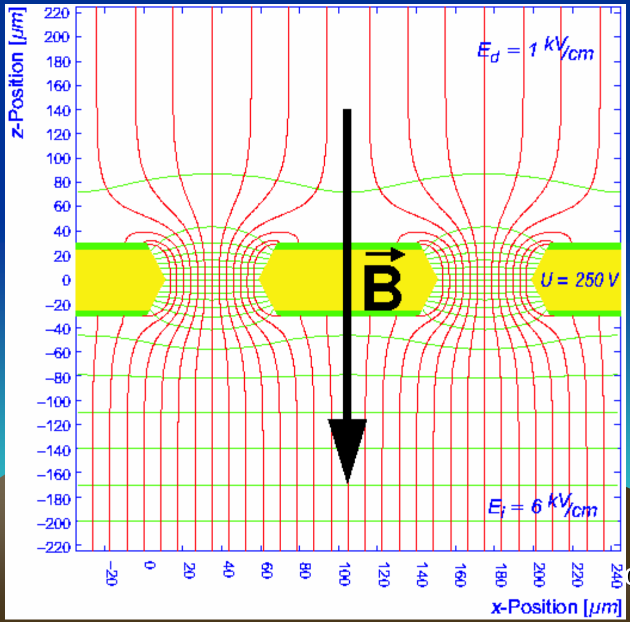
Gas-Amplification Systems: Wires & MPGDs→

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

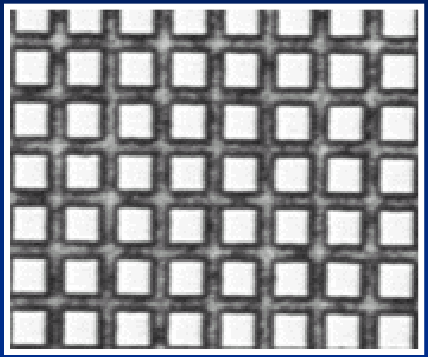


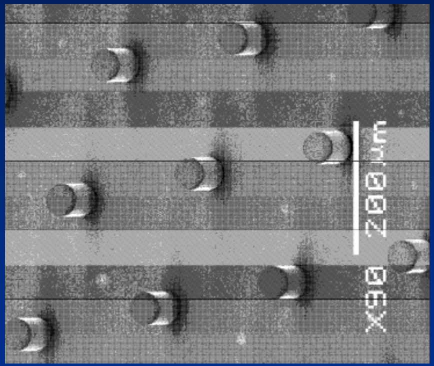
P~140 µm

D~60 µm

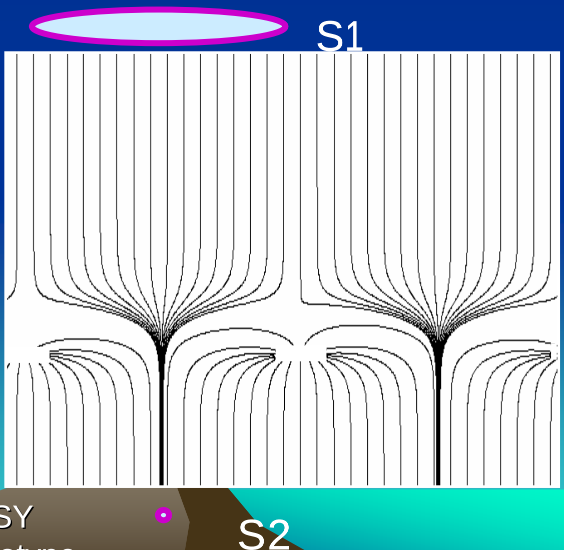


Micromegas: micromesh sustained by 50µm pillars, multiplication between anode and mesh, one stage

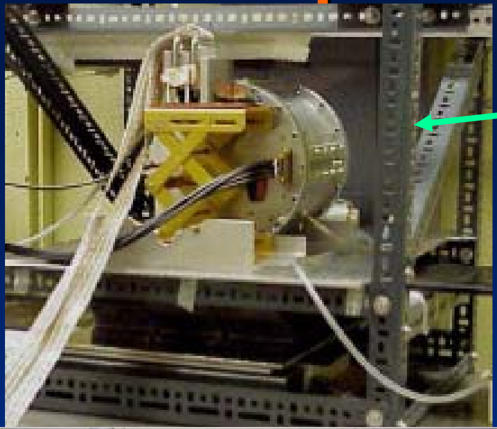




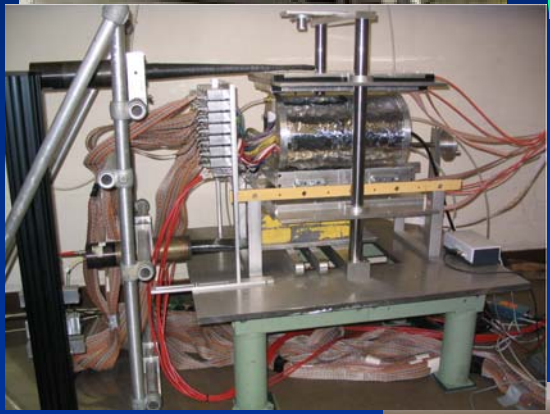
S1/S2 ~ Eamplif / Edrift

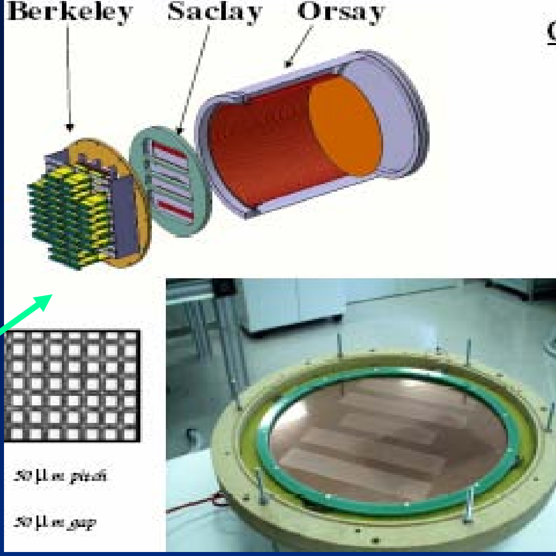


Examples of Prototype TPCs

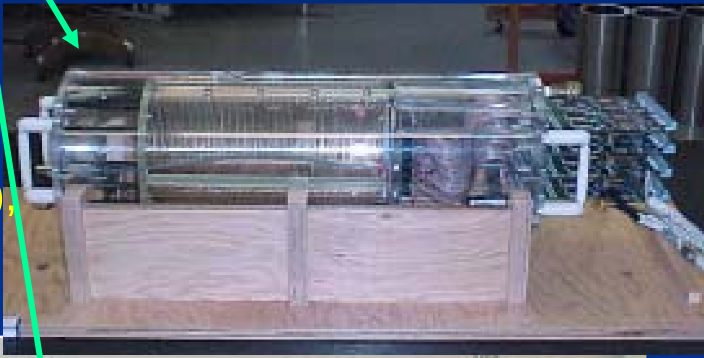


Carleton, Aachen,
Cornell/Purdue,Desy(n.s.)
for B=0or1T studies

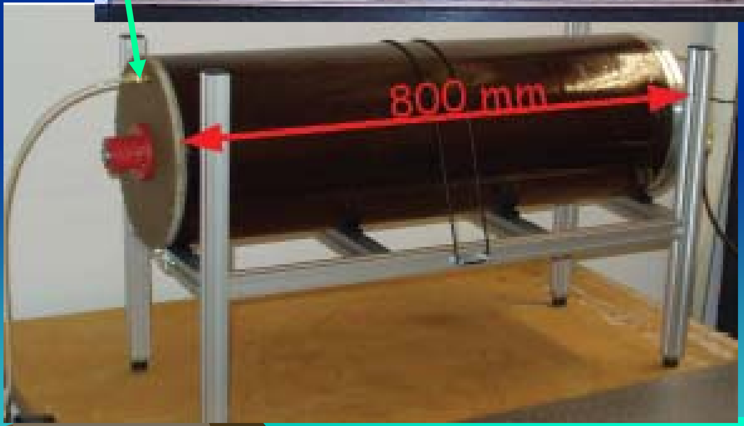




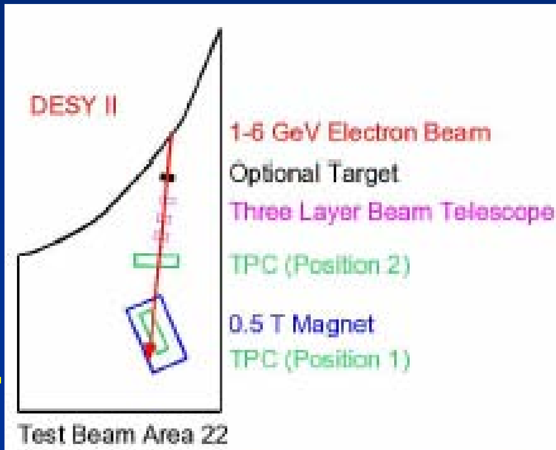
Saclay, Victoria, Desy
(fit in 2-5T magnets)



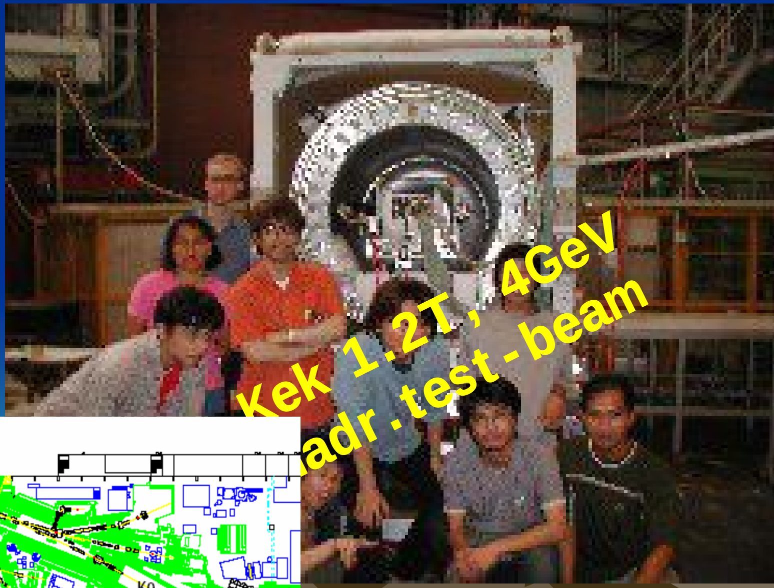
Karlsruhe, MPI/Asia,
Aachen built test TPCs
for magnets (not shown),
other groups built small
special-study chambers

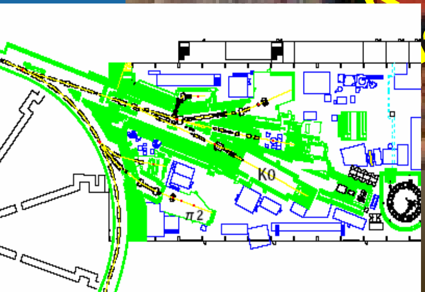


Facilities



Cern test-beam (not shown)





TPC R&D Summary

- Now 3 years of MPGD experience gathered
- Gas properties rather well understood
- Diffusion-limited resolution seems feasible
- Resistive foil charge-spreading demonstrated
- CMOS RO demonstrated
- Design work starting for the Large Prototype

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 ≥ 75cm, drift ≥ 100cm) within framework of EUDET grant from the EU 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 ~ 2-3 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.

TPC milestones

2005	Continue testing, design large prototype
2006-2009	Test Large Prototype, decide technology
2009	Proposal of/final design of LC TPC
2013	Four years for construction
2014	Commission TPC alone
2015	Install/integrate in detector

TPC central-tracker tasks

ISSUES

- Performance/Simulation
- Design
- Backgrounds, alignment, corrections

Performance/Simulation

- Momentum precision needed for overall tracking?
- Momentum precision needed for the TPC?
- Arguments for dE/dx, V° detection
- Requirements for
  - 2-track resolution (in rφ and z)?
  - track-gamma separation (in rφ and z)?
- Tolerance on the maximum endplate thickness?
- Tracking configuration
  - Calorimeter diameter
  - TPC
  - Other tracking detectors
- TPC outer diameter
- TPC inner diameter
- TPC length
- Required B-mapping accuracy in case of non-uniform B-field?

Design

- Gas-Amplification technology $\rightarrow$ input from R&D projects
- Chamber gas candidates: crucial decision!
- Electronics design: maximum density possible?
  - Zeroth-order "conventional-RO" design
  - Is there an optimum pad size for momentum, dE/dx resolution and electronics packaging?
  - Silicon RO: proof-of-principle
- Endplate design
  - Mechanics
  - Minimize thickness
  - Cooling
- Field cage design

Backgrounds/alignment/distortion-correction

- **Revisit expected backgrounds**
- **Maximum positive-ion buildup tolerable?**
- **Maximum occupancy tolerable?**
- **Effect of positive-ion backdrift: gating plane?**
- **Tools for correcting space charge in presence of bad backgrounds?**

First meeting at Paris LDC WS, 14 Jan '05

Second meeting at Stanford LCWS05, 21 March '05

TPC Group Leaders Meeting @ LCWS05

AGENDA

==========================

-Status

-Serpentinewindings

-Future of LC TPC R&D

-Large prototype

-Altro chip

-AOB

DESIGN OF THE LC TPC

MAIN QUESTIONS

1) ELECTRONICS
2) TECHNOLOGY
3) GAS

How to focus our efforts to answer these questions? One way which we are starting:

collaborate to build large prototype…

Large Prototype

- In a nutshell, we are discussion the building of a large prototype to enable the
- GEM-or-MicroMegas decision, which must be timely enough to allow
- Completion of the detector at the same time as the LC -- 2015
- The large prototype will also provide input for the final design of the LC TPC.

-Status: several grant requests

US-J, MONBUSHO GRANT-IN-AID (Asia)
EUDET (Europe + associated labs)
NSERC (Canada)
DOE/NSF (US)

Proposal full title	**Detector R&D towards the International Linear Collider**
Proposal acronym	**EUDET**

I3 Proposal → "Integrated Infrastructure Initiative"

Defacto approved! ~ 7 M€ over 4 years to provide infrastructure for detector R&D

EUDET I3 PROPOSAL

Fundamental Objectives

1. Objectives of the Proposed I3 Project and Relevance to the Scheme

1.1. Overall objectives

This proposal aims at creating a coordinated European effort towards research and development for the next generation of large-scale particle detectors. New and advanced detector technologies are needed to fully exploit the potential of future accelerators like the International Linear Collider (ILC) which is being designed in an emerging worldwide collaboration. The importance of the ILC as the next international large scale accelerator facility has been emphasised by the Global Science Forum, which brings together science policy officials from OECD countries[1]. The scientific case for the ILC is strongly supported by the worldwide community of High Energy Physics[2].

EUDET I3 PROPOSAL

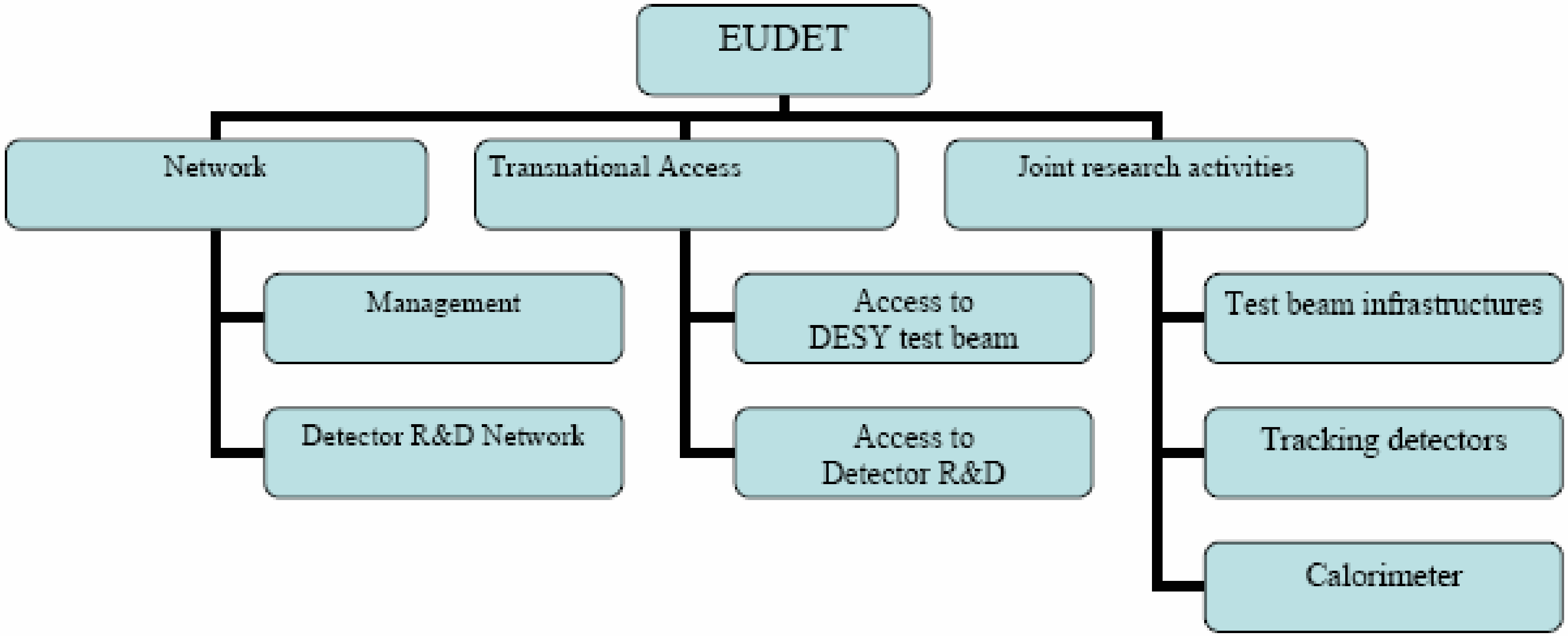
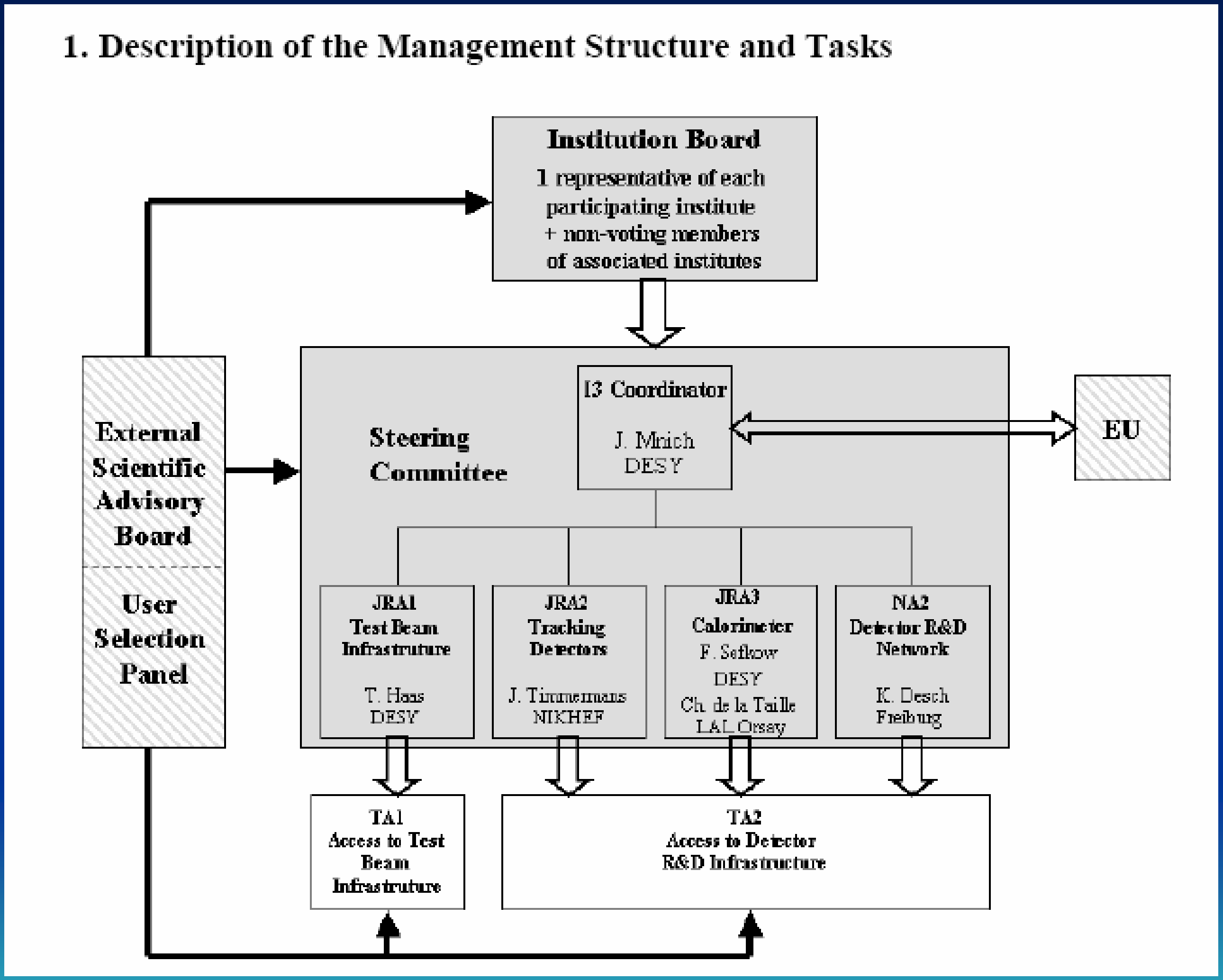


Figure 2: Structure of the I3 "Detector R&D for the International Linear Collider, EUDET"

EUDET I3 PROPOSAL



Large Prototype planning

- Breakdown
  - -Overall design
  - -Endplate design
  - -Magnet
  - -Field cage
  - -Endplates
  - -Electronics
  - -Test beam
  - -Software
  - -Simulation
  - -Calibration

- The idea is to define “Work Packages” within the EUDET framework to implement these components

- Now inquiring who is interested in working on what?

- The following list is PRELIMINARY and feedback is welcome.

Work Packages for Large Prototype

Workpackage EUDET Mechanics

-Overall set up of the EUDET facility including testbeam. Coordinated by the Desy/HH group.

-Magnet. Coordinated by KEK.

Workpackage LP Mechanics

-Overall design of the LP. Interested expressed by Desy/HH, IPN Orsay.

-Fieldcage. Interested are Aachen, Desy/HH, LBL, Victoria.

-Endplate->Gem, Micromegas, Pixel alternatives. Interested: Aachen, Carleton, Cornell/Purdue, Desy/HH, Freiburg, Kek/CDC, Nikhef, Saclay/Orsay, Victoria.

Workpackage LP Electronics

-Standard. Aachen, CDC/Kek, Desy/HH, Lund, Montreal, Rostock, Tsinghua have expressed interest.

-CMOS. Freiburg, Nikhef, Saclay, Ingrid groups are logical groups.

Workpackage Software/Simulation

-LP Software. Desy/HH, Kek/CDC.

-TPC Simulation. Aachen, Cornell/Purdue, Desy/HH, CERN, Kek/CDC

-Full detector simulation. Desy/HH, Kek/CDC.

Workpackage on Monitoring/Calibration

-Field Map

-Alignment

-Laser

-Correction software

-Other ideas...

Conclusions on the Large Prototype Plans

- START OF EUDET: JANUARY 2006
- SET UP LP WORKPACKAGES BY THEN
- ~ 1 – 2 YEARS TO DESIGN, BUILD
- ~ 2 YEARS TO DO R&D, then decide…

Back-up slides: Motivation,

TPC R&D example-results summer 2005

by the

LC TPC R&D Groups

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

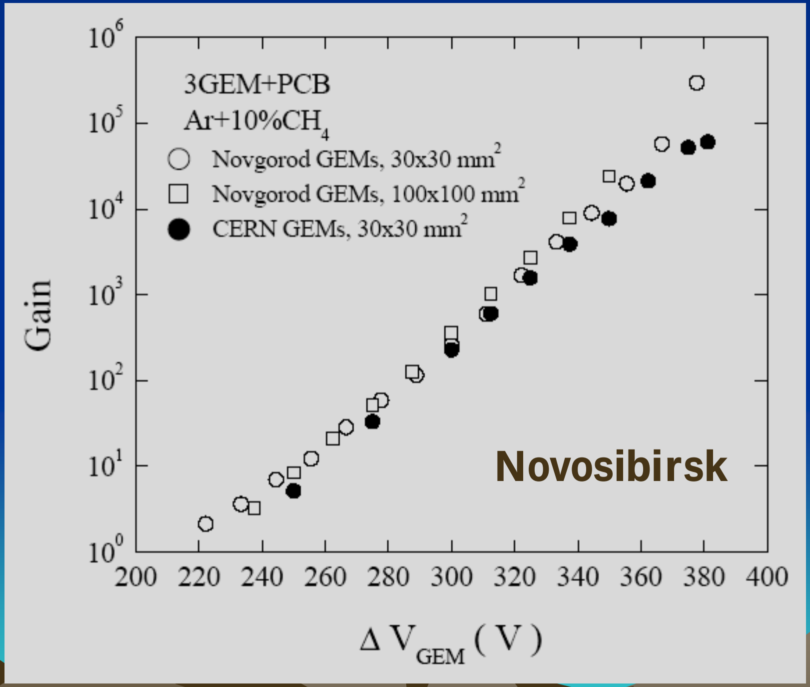
Time Projection Chamber

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

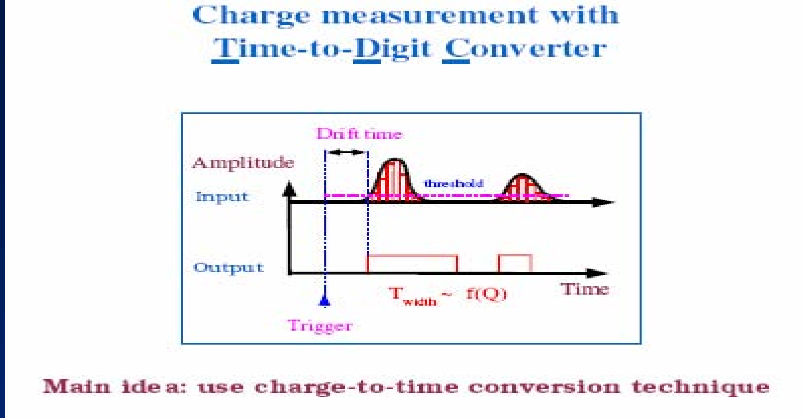
Gas-Amplification Systems:
Possible manufacturers

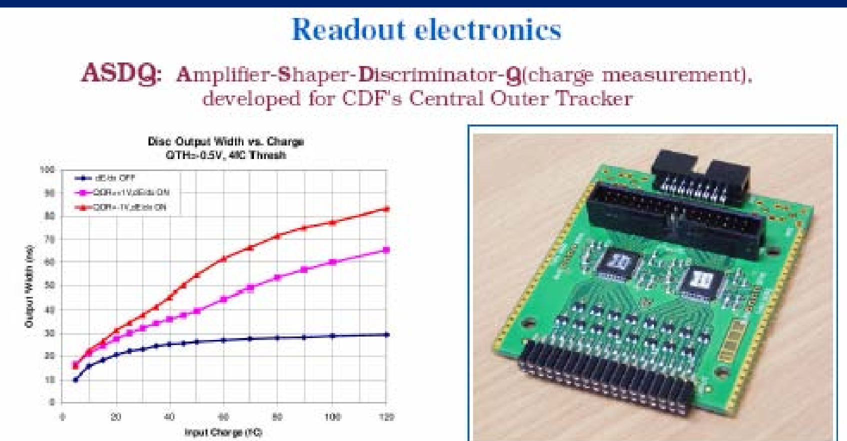
GEM: --CERN
--Novogorod (Russia)
--Purdue + 3M (USA)
--other companies interested in Europe, Japan and USA

Micromegas: --CERN together with Saclay/Orsay on techniques for common manuf. of anode + pillars
--Purdue/3M



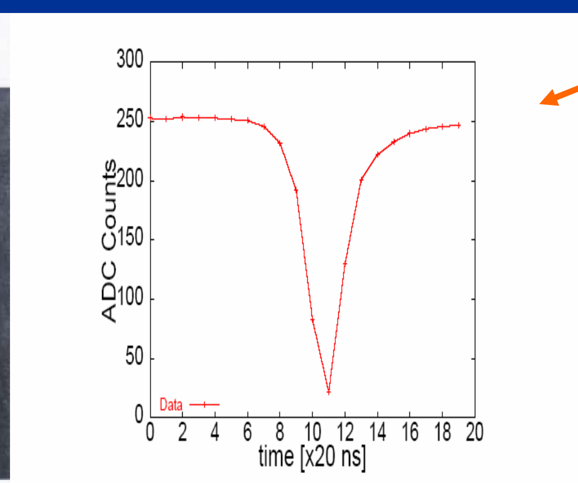
Work on Electronics



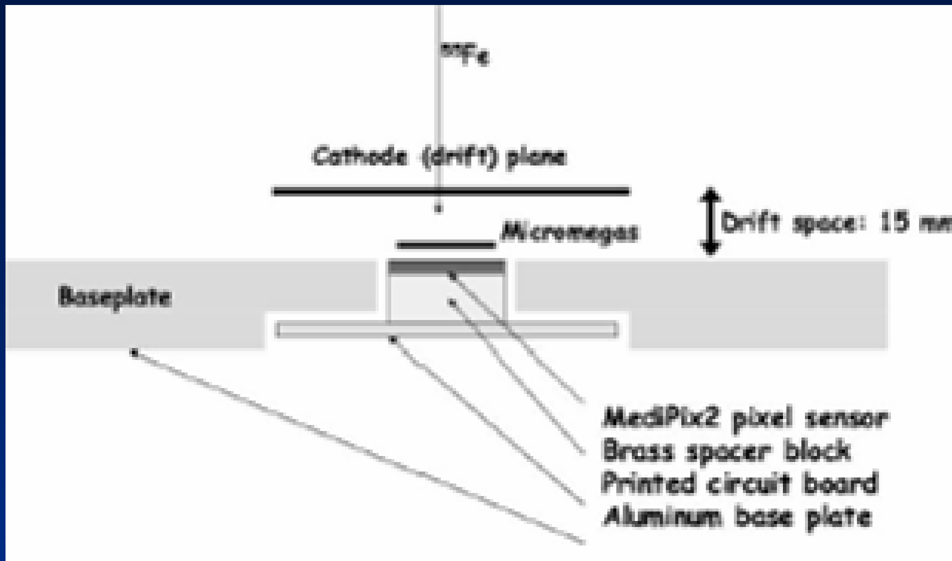


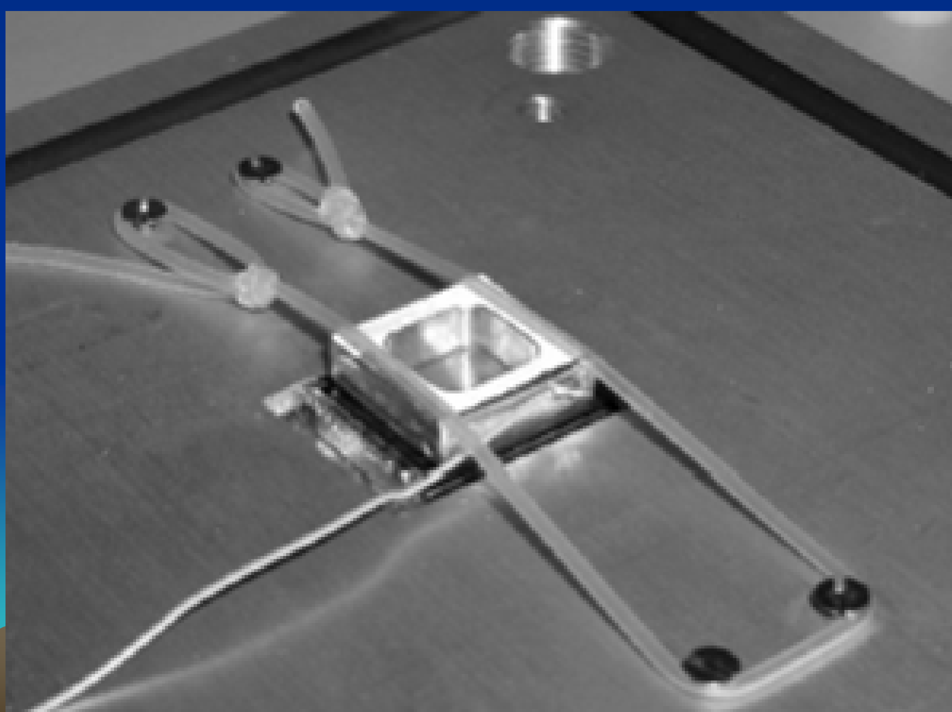
Aleph and Star setups (3 of each) used for prototype work don't take advantage of fast Gem/Mm signals from direct e-.

- Rostock working on TDC idea.
- Aachen/Desy/Lund studying highly integrated conventional approach.
- Nikhef developing "Si RO" concepts (next slide)



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

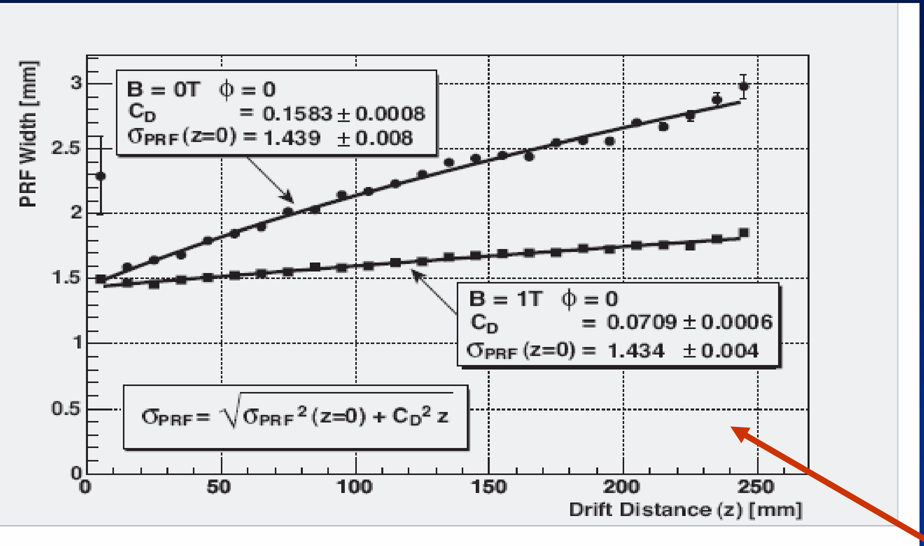
~ huge granularity(digital TPC), diffusion limited, sensitive to indiv. clusters for right gas

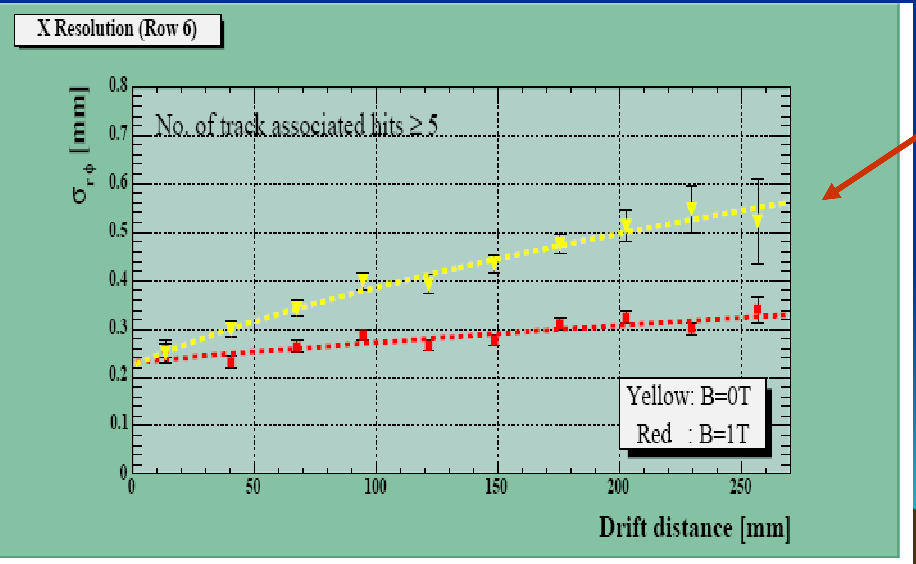
~ 1st tests with Micromegas + MediPix2 chip

→ more later...

Prototype Results

Point resolution, Wires





--Measured by Asia/MPI/Desy teams in MPI wire chamber and KEK magnet at KEK test beam (1-4 GeV hadrons with PID), B=0&1T, TDR gas

--2x6mm^2 pads, 1mm wire-to-pad gap

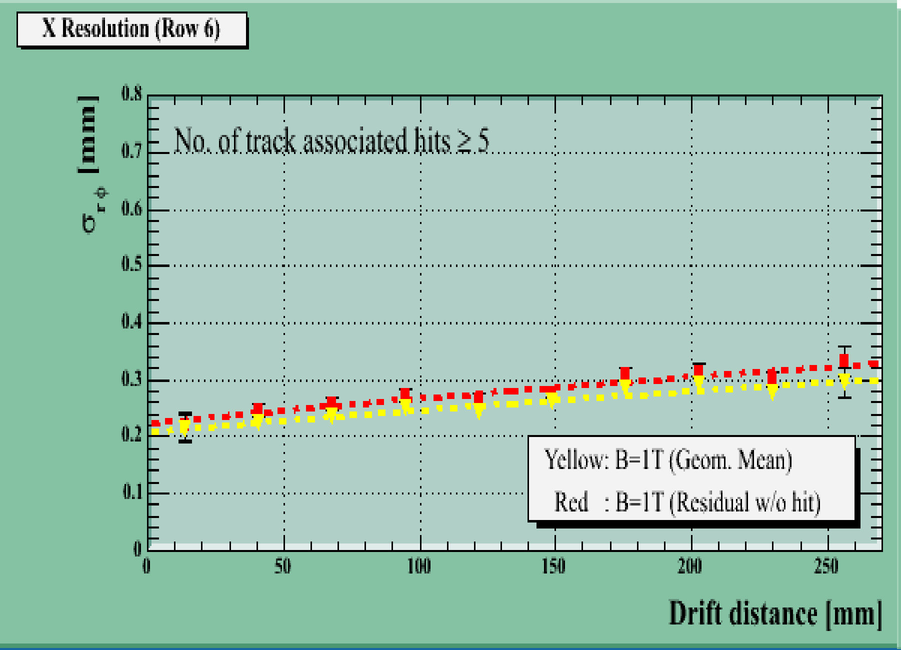
--PRF width measured to be = 1.43mm

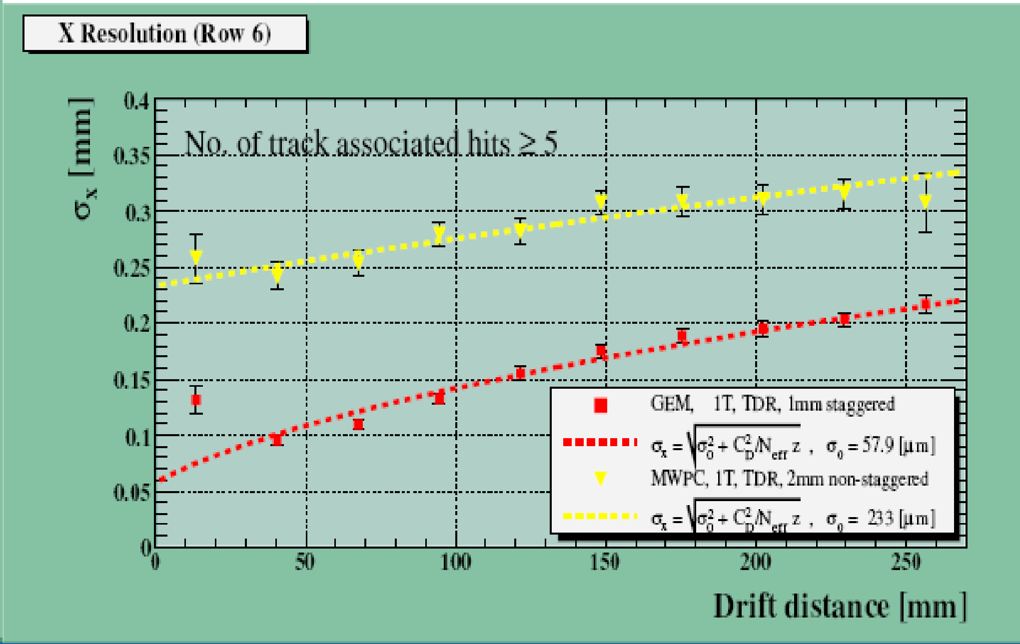
--Point resolution measured by fitting track to outer 6 rows and comparing track to hit on innermost 7th row. This method is known to overestimate the resolution (better method being implemented—see next slides)

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.

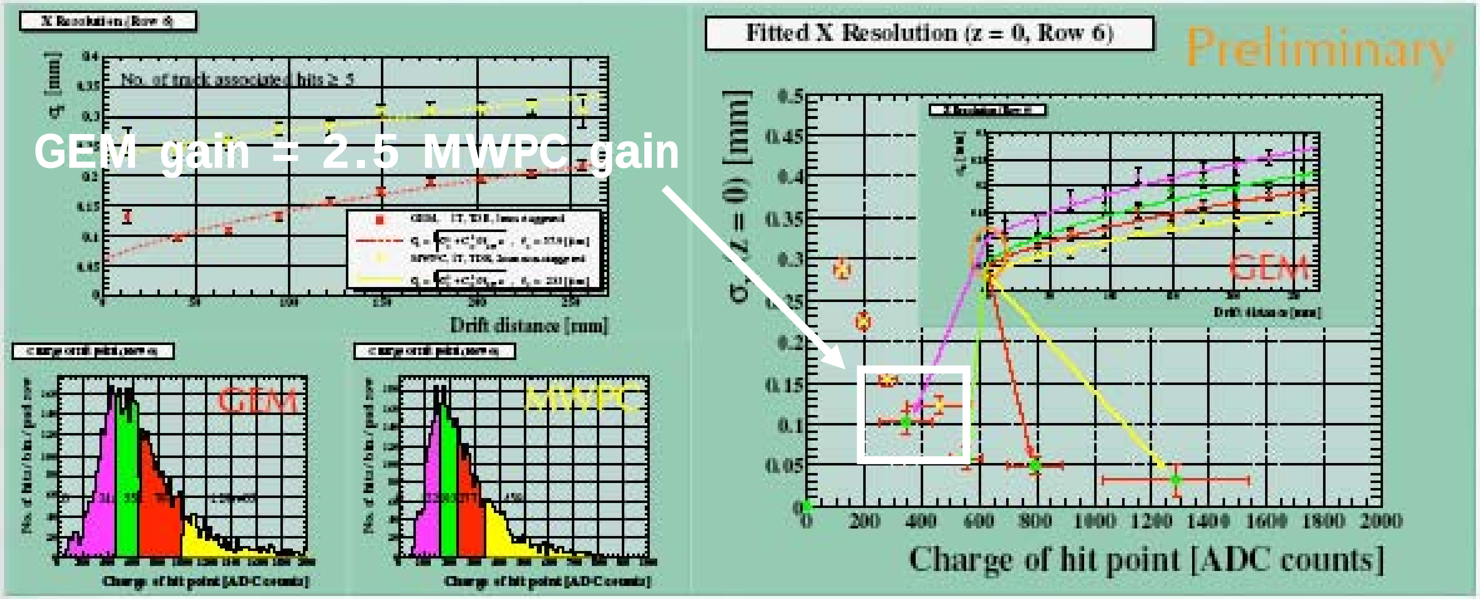
Wires, expect~170µm resolution: **GEM beamtest,compare to wires:**





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

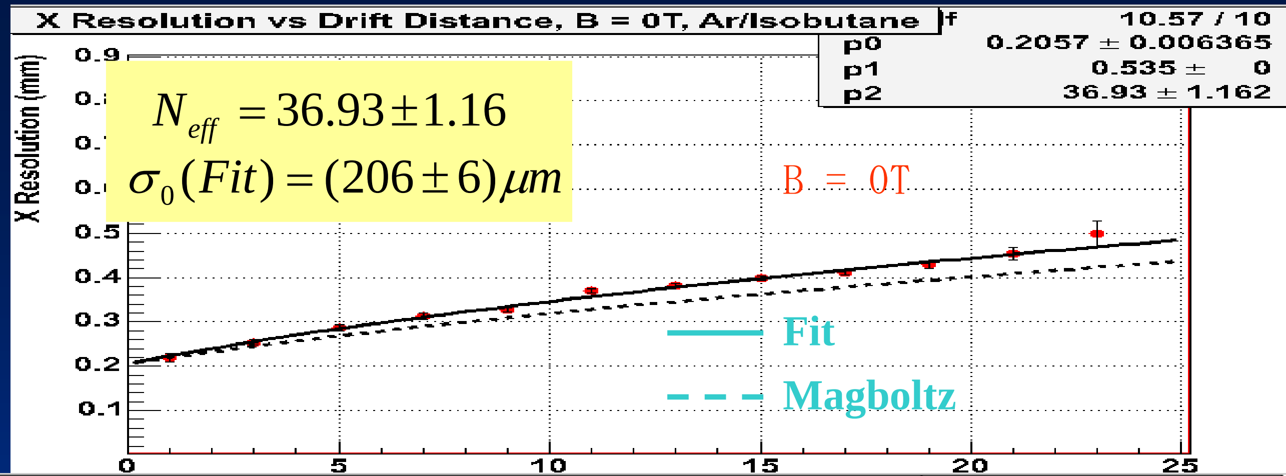
Katsumasa Ikematsu (DESY) / ACFA8

X Resolution of Micromegas@KEK beam test

$$\sum 8Rows$$

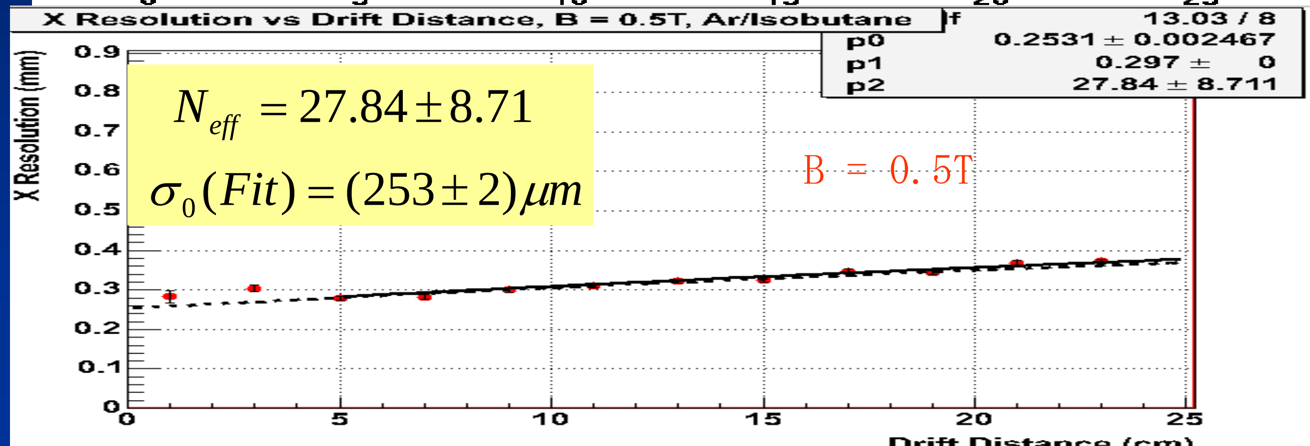
$$Cd = Cd(PRF)$$

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

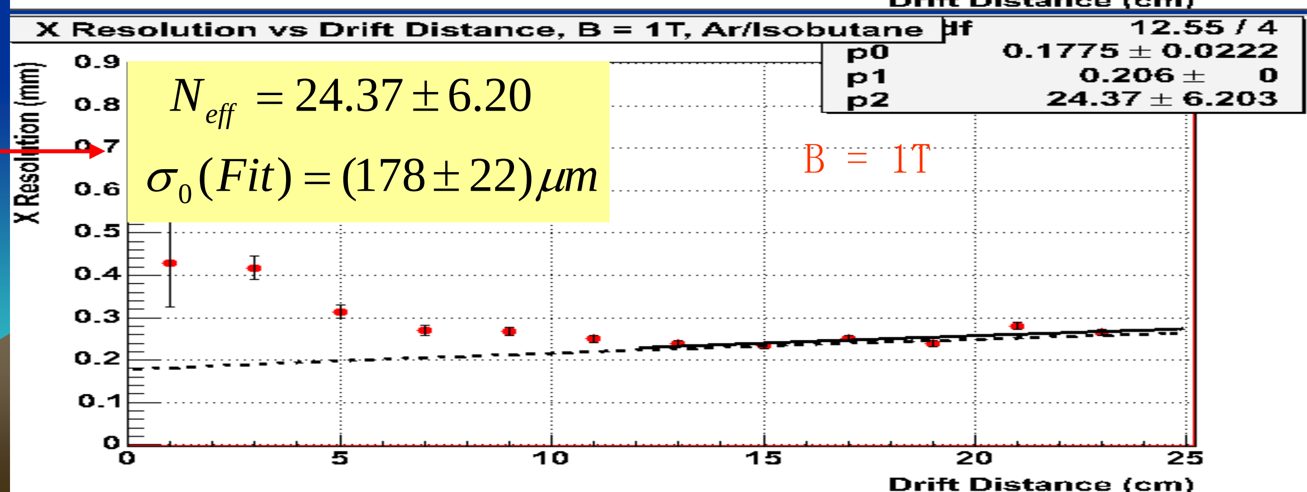


C_d fixed each B

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



$$2.3mm/\sqrt{12}$$



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

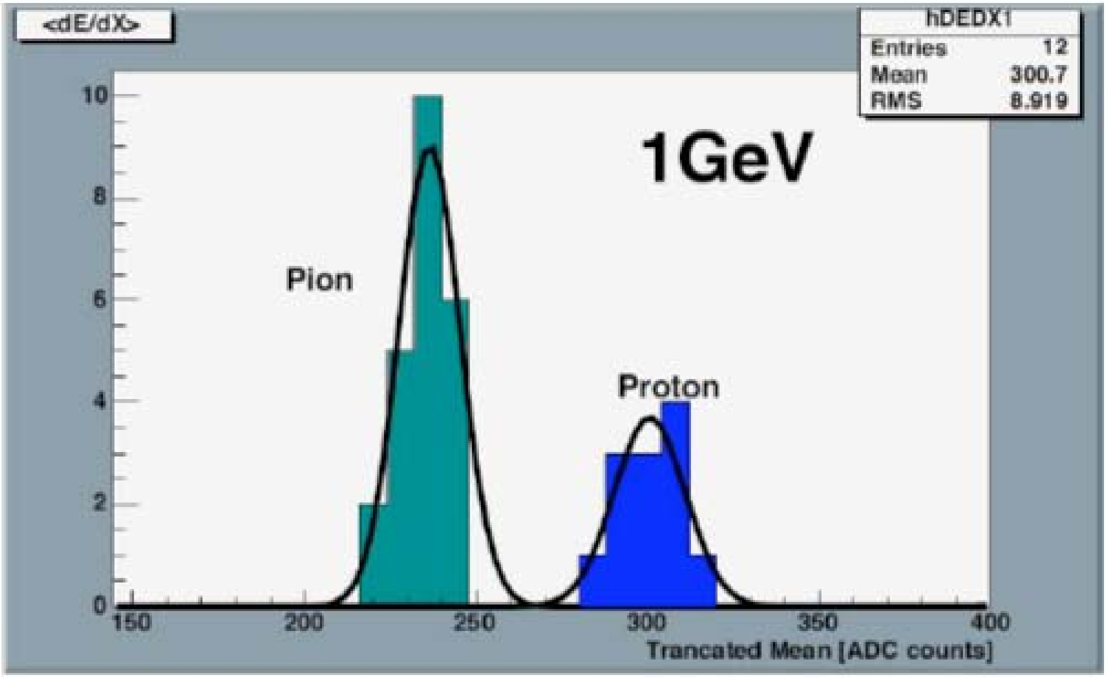
Prototype Results
dE/dx, wires, KEK beam test

dE/dx in TDR gas

7 pad-raw /event × 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

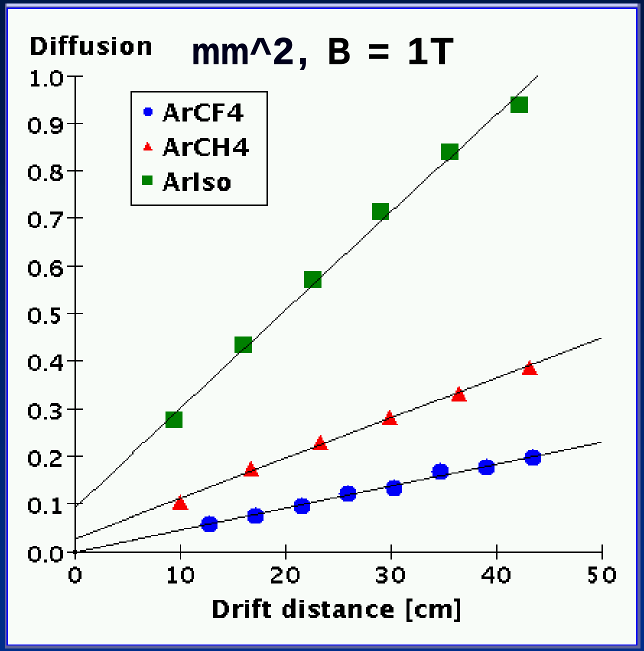


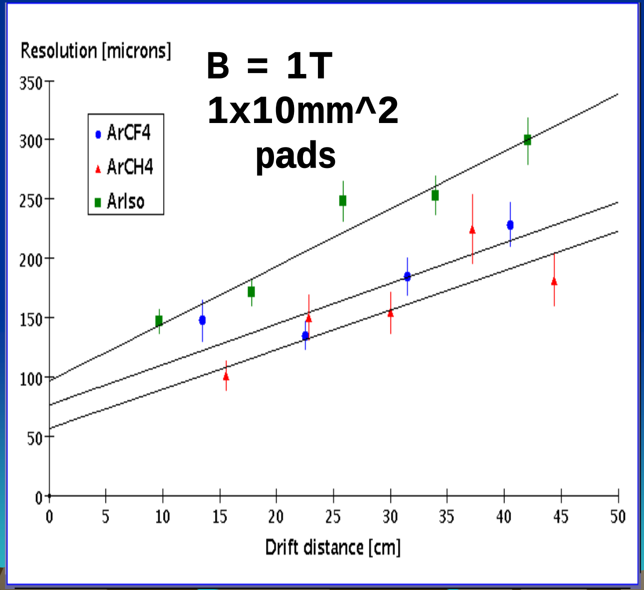
proton @1GeV/c
<dE/dx> 300.6
sigma 10.3

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

Prototype Results

Point resolution, Micromegas





Saclay/Orsay/Berkeley

--Ageing negligible

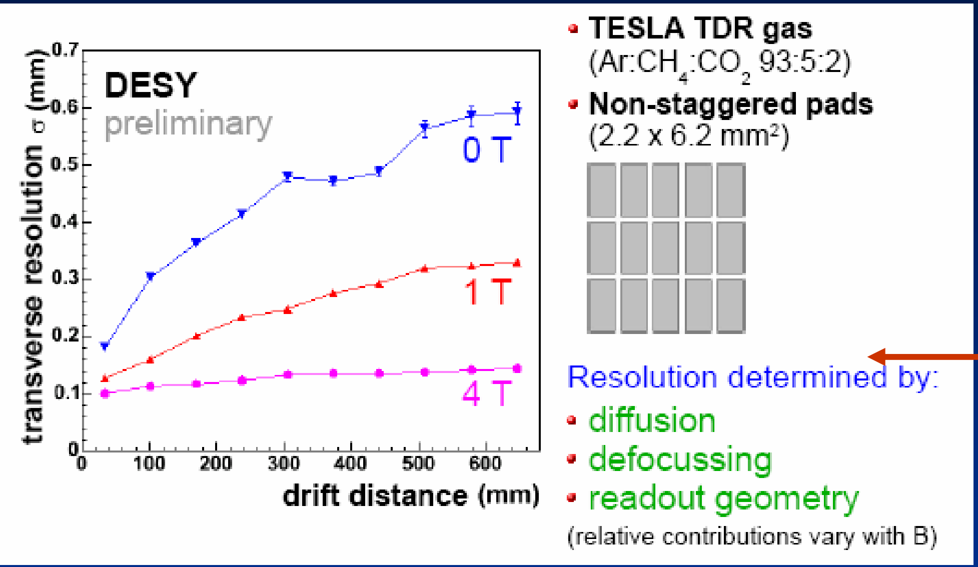
--Diffusion measurements ⇒ σ_pt < 100µm possible

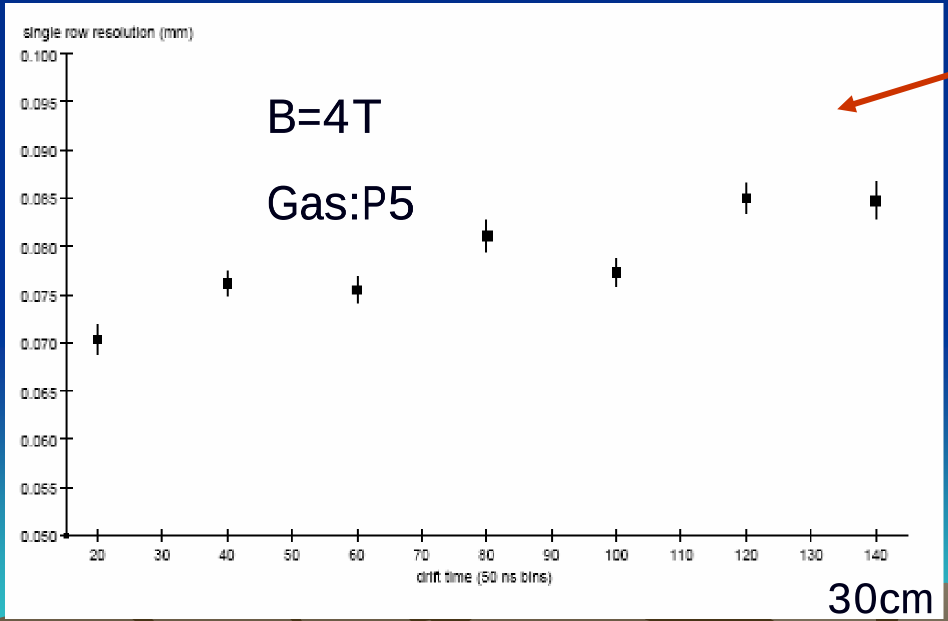
--At moment only achieved for short drift (intrinsic σ) for gain~5000 (350V mesh), noise~1000e

--Analysis continuing…

Prototype Results

Point resolution, Gem





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

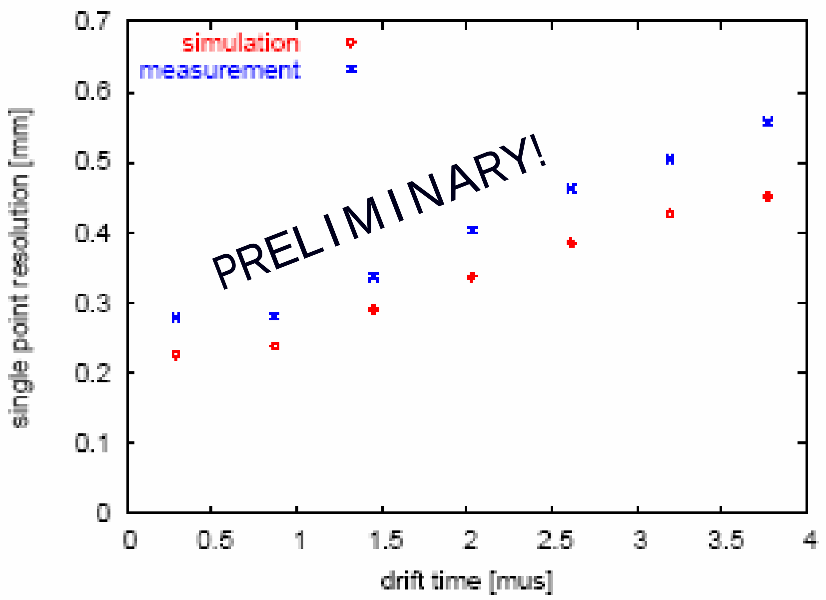
--First, in Desy chamber (triple Gem), resolution using "triplet method".

--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

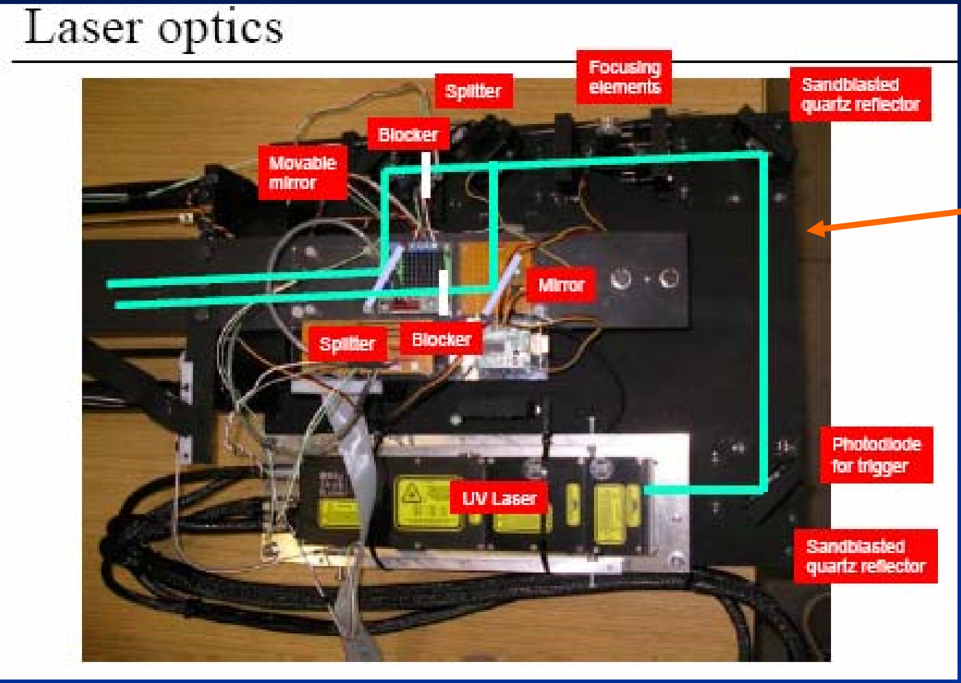


--Third example of σ_pt measured at Aachen Gems and 2x6mm^2 pads by comparing track position with a Si hodoscope.

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

Prototype Results

Two-track resolution studies

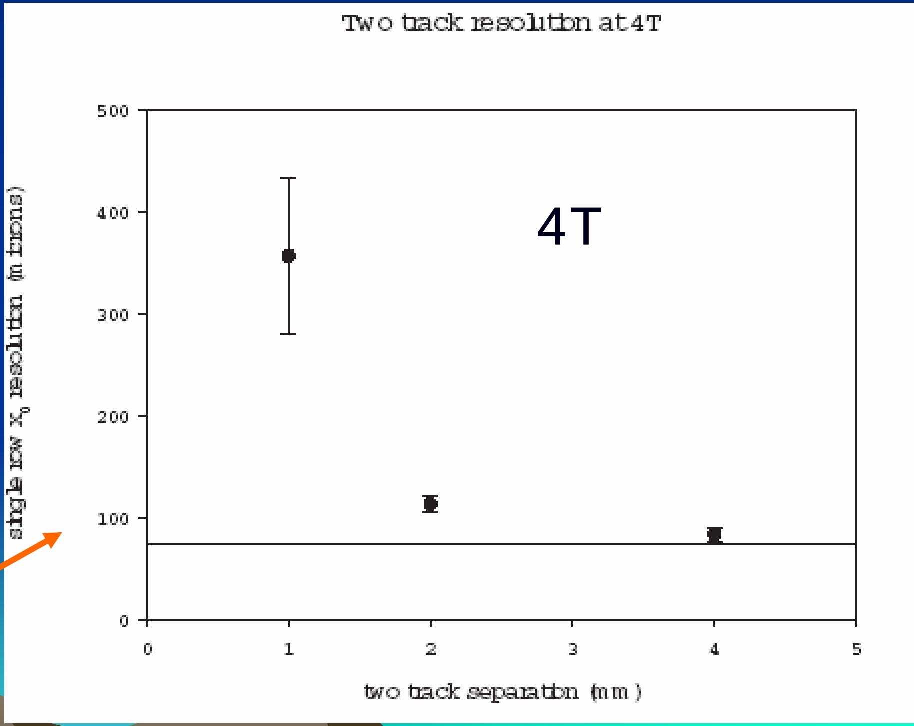


Studies just starting.

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.



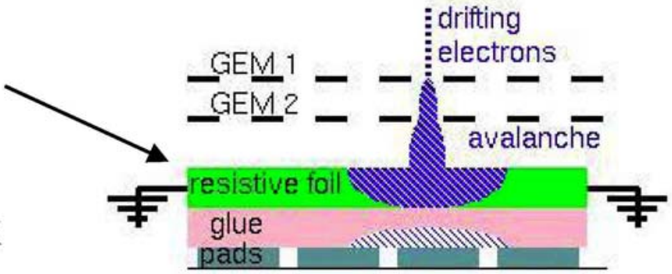
Carleton: improving point resolution with resistive foil

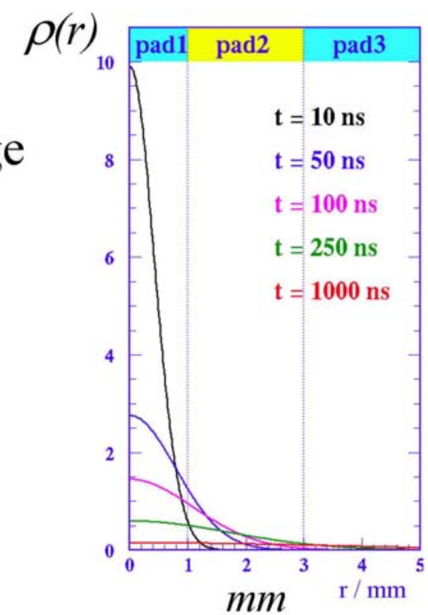
The Concept of Charge Dispersion

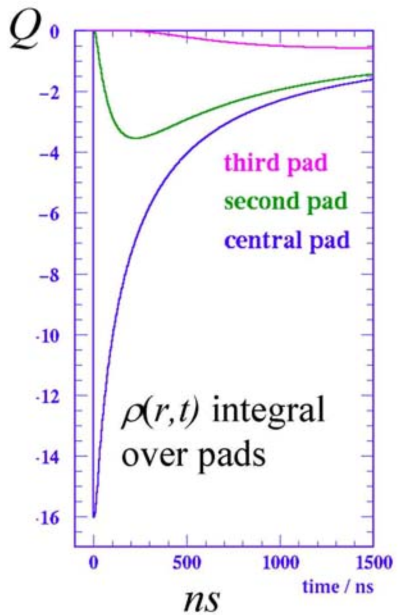
- **Modified GEM anode with a high resistivity film bonded to a readout plane with an insulating spacer**
- 2-dim continuous RC network defined by material properties and geometry
- Point charge at $r=0$ & $t=0$ disperses with time
- Time dependent anode charge density sampled by readout pads:

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

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



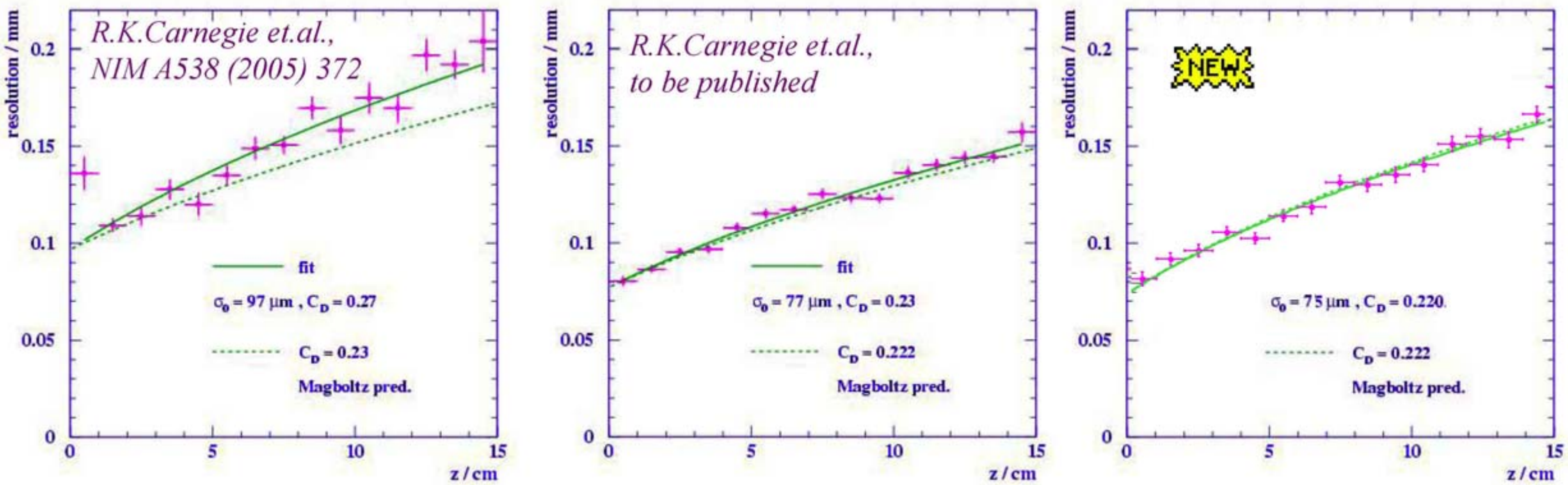




Carleton: resistive foil results

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.

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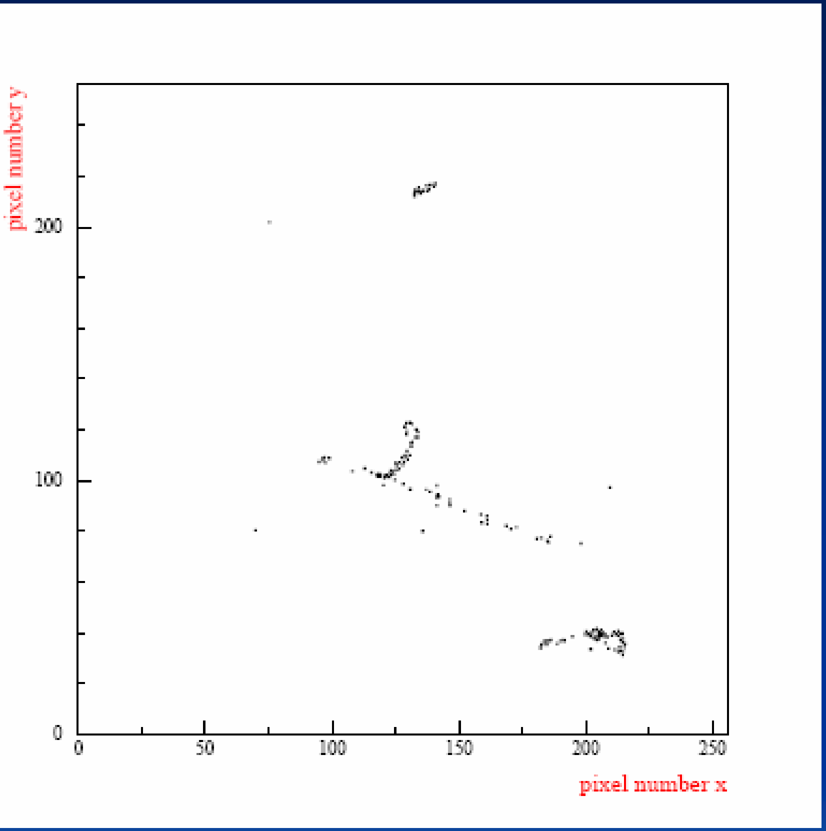
Medipix2+Micromegas: results@Nikhef



--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

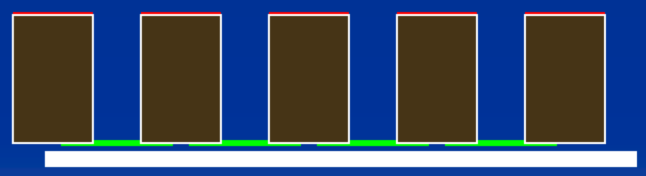
--NIM A540 (2005) 295 (physics/0409048)

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

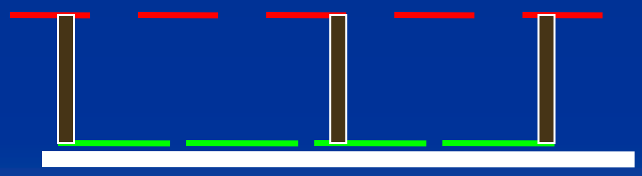
InGrid

Integrate GEM/Micromegas and pixel sensor

‘GEM’

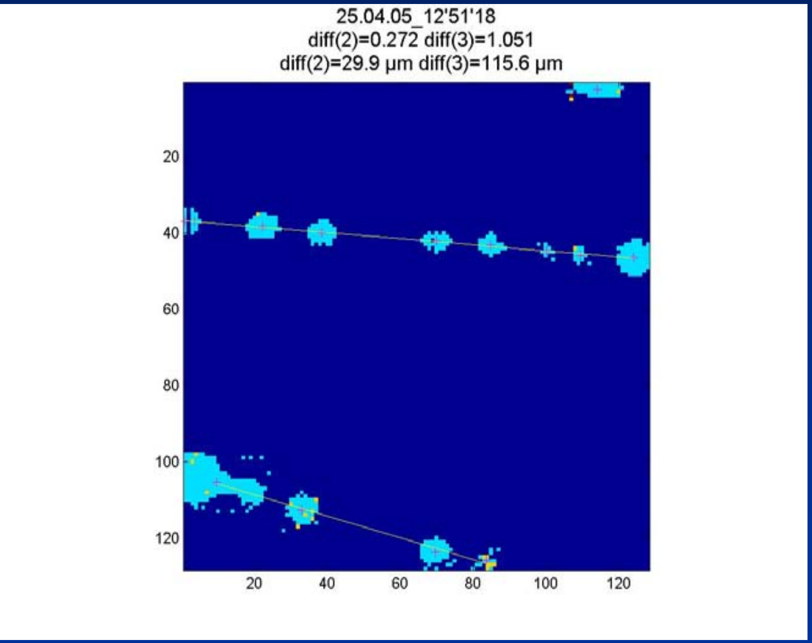


‘Micromegas’



By ‘wafer post processing’

Medipix2+GEMS: results@Freiburg



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

--Measure diffusion const.~ ?µm/√cm

--Future: studies continuing