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
- **Recent R&D results**
- Issues, tasks

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

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

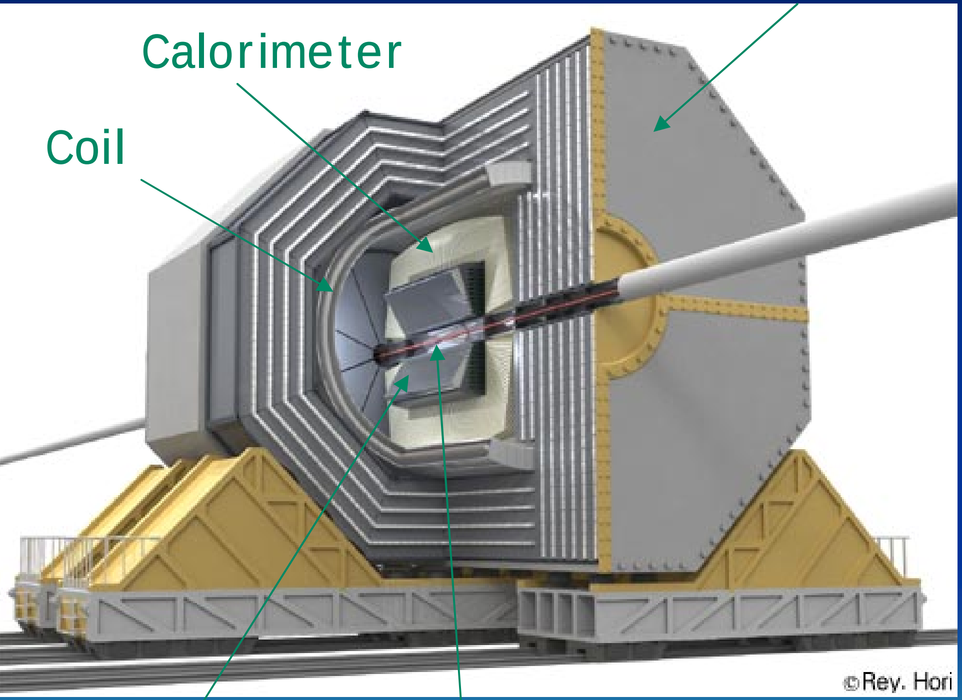
Other USA

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

,,,OTHER?

Detector for ILC experiments

Detector design Philosophy:

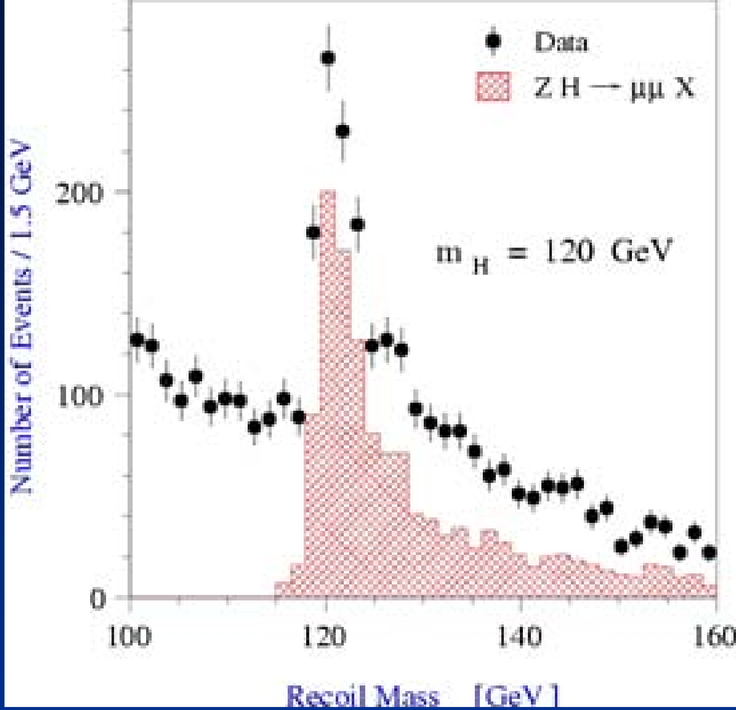


- Good jet energy resolution
  - → calorimeter inside a coil
  - → highly segmented calorimeter
- Efficient & High purity b/c tagging
  - → Thin VTX, put close to the IP
  - → Strong solenoid field
  - → Pixel type
- High momentum resolution
- Hermetic down to O(10)mrad
- Shielded enough against beam-related background

Physics determines detector design

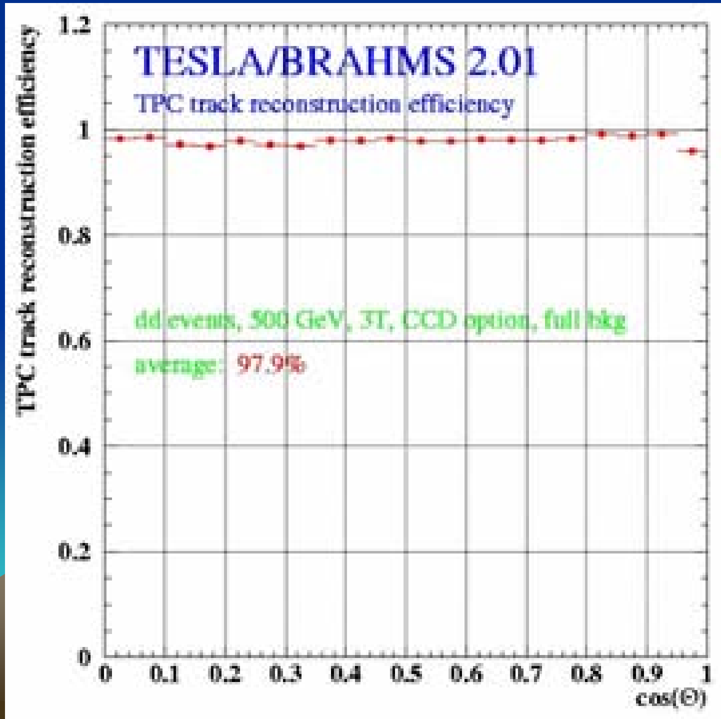
★ **momentum: d(1/p) ~ 10^{-4}/GeV(TPC only)**
~ 0.6×10^{-4}/GeV(w/vertex)
(1/10xLEP)

$e^+e^- \rightarrow ZH \rightarrow ll\,X$ goal: $\delta M_{\mu\mu} < 0.1 \times \Gamma_Z$
$\rightarrow \delta M_H$ 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 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

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) 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 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.

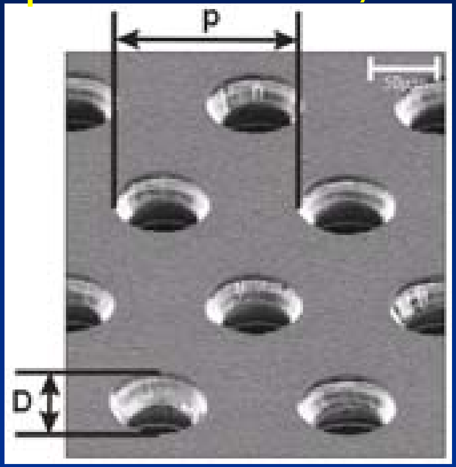
TPC milestones

2005	Continue testing, design large prototype
2006-2008	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

Gas-Amplification Systems: Wires & MPGDs→

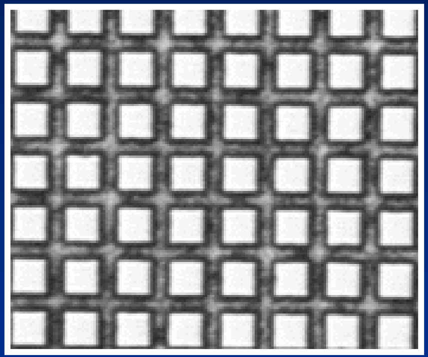
GEM: Two copper foils separated by kapton, multiplication takes place in holes, uses 2 or 3 stages

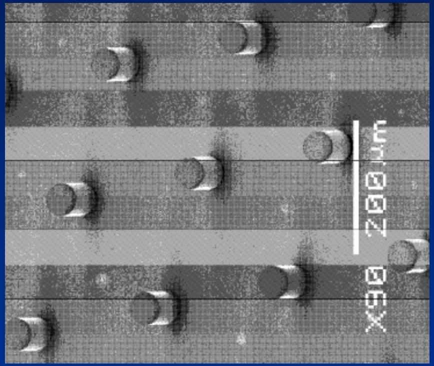
Micromegas: micromesh sustained by 50µm pillars, multiplication between anode and mesh, one stage



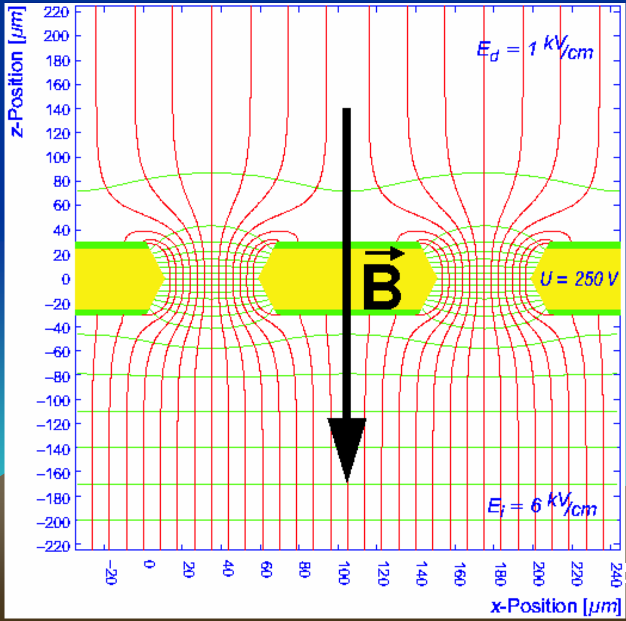
P~140 µm

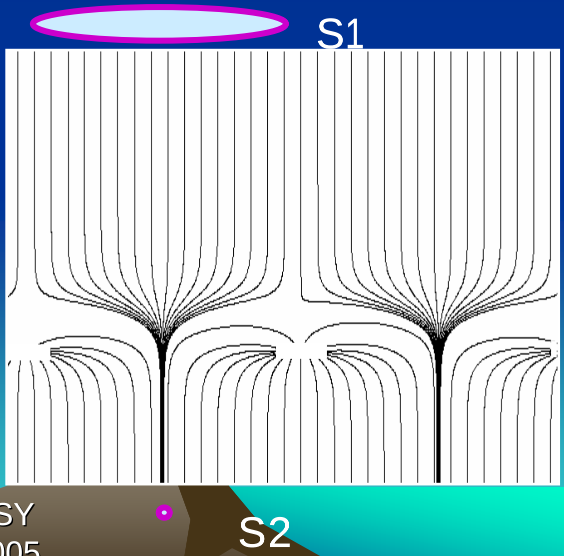
D~60 µm





S1/S2 ~ Eamplif / Edrift

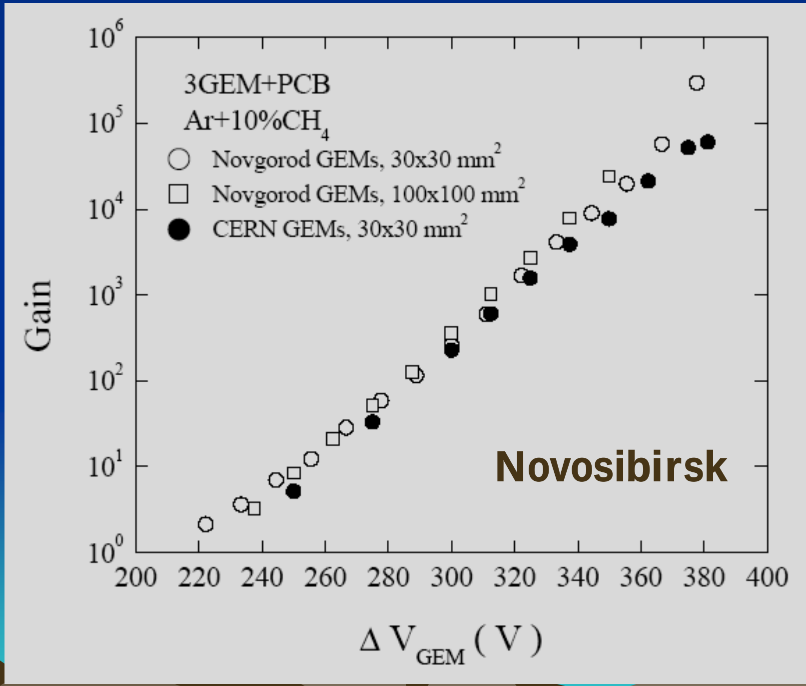




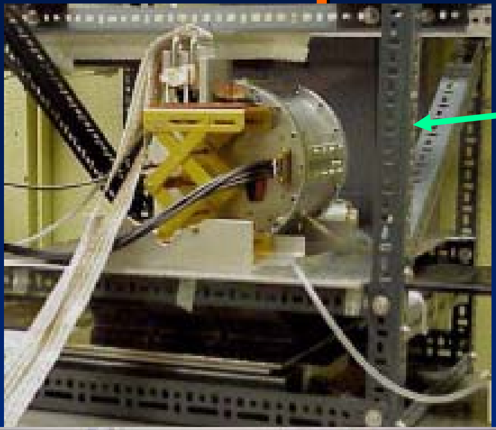
Gas-Amplification Systems:
Possible manufacturers

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



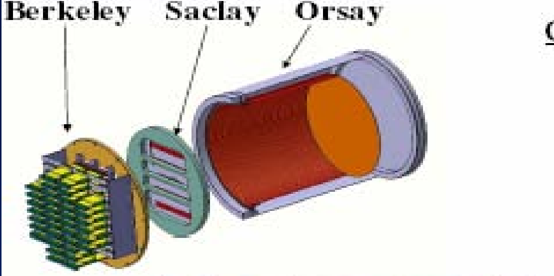
Examples of Prototype TPCs

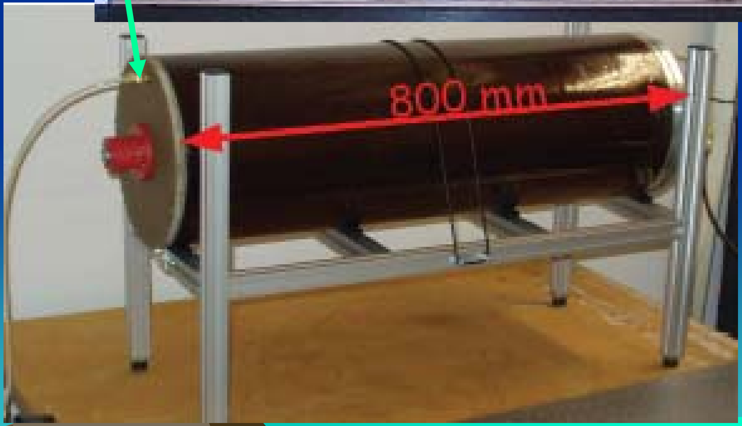


Carleton, Aachen,
Cornell/Purdue,Desy(n.s.)
for B=0or1T studies

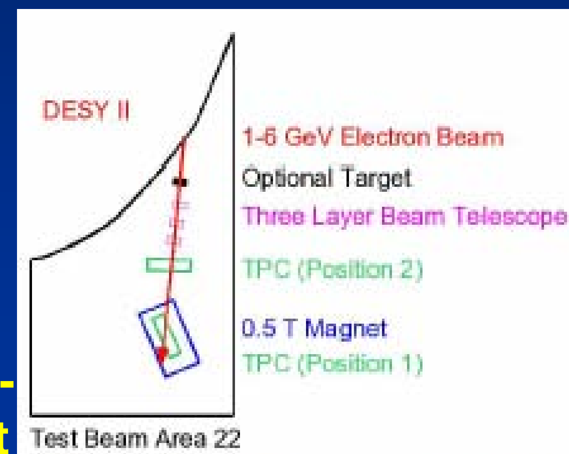
Saclay, Victoria, Desy
(fit in 2-5T magnets)

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





Facilities



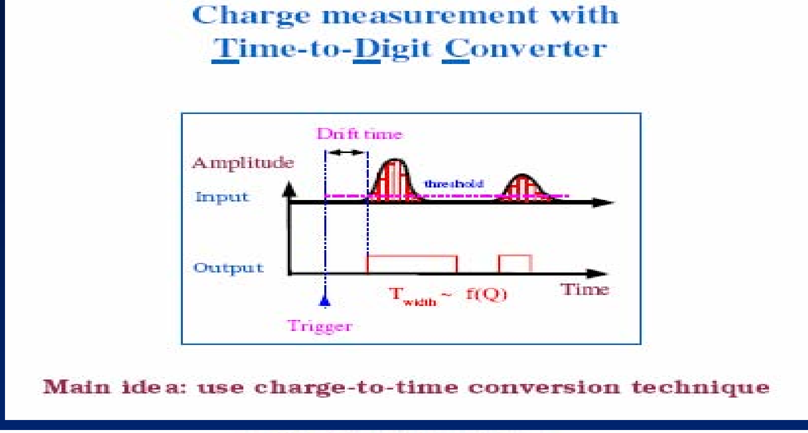
Cern test-beam (not shown)

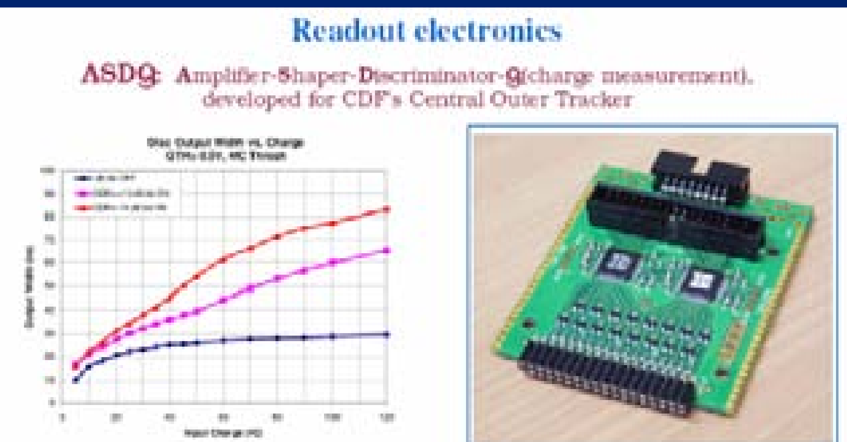
Recent TPC R&D results summer 2005

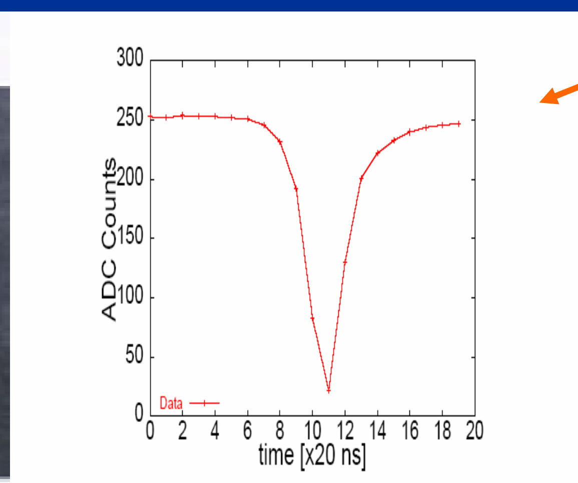
by the

LC TPC R&D Groups

Work on Electronics



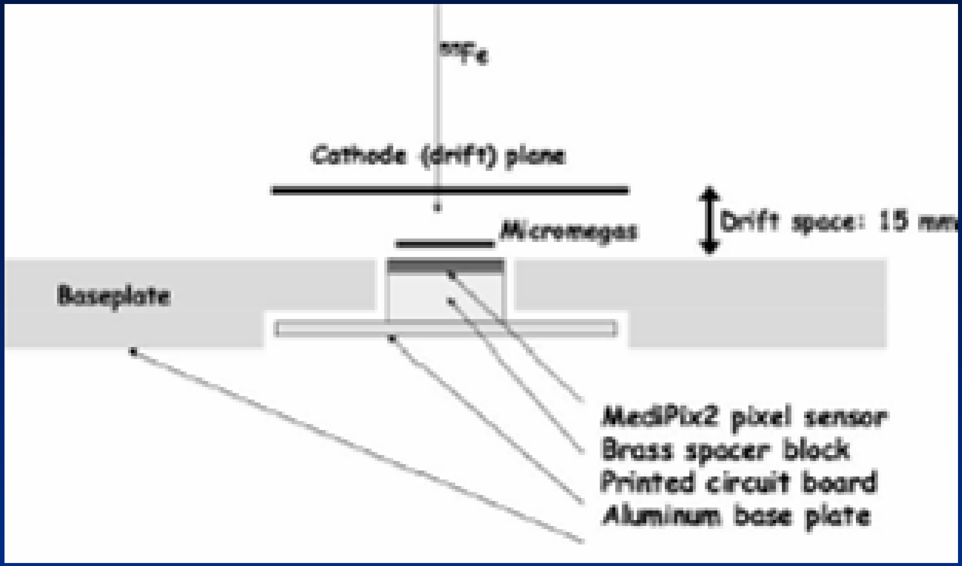


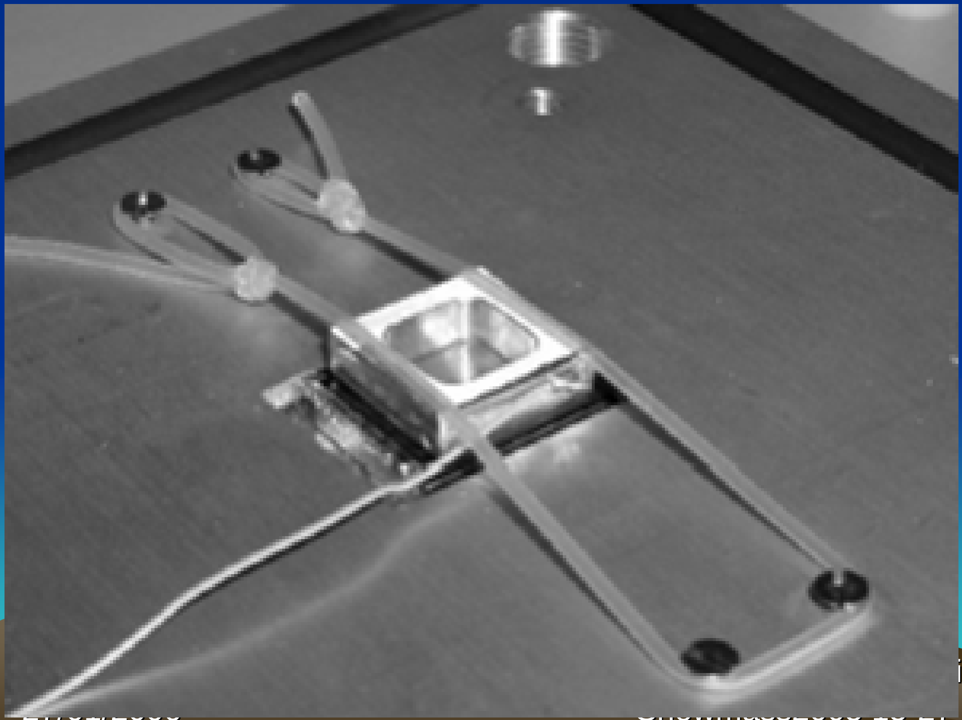


Aleph and Star setups (3 of each) used for prototype work don't take advantage of fast Gem/Mm signals from direct e-.

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

Electronics Development





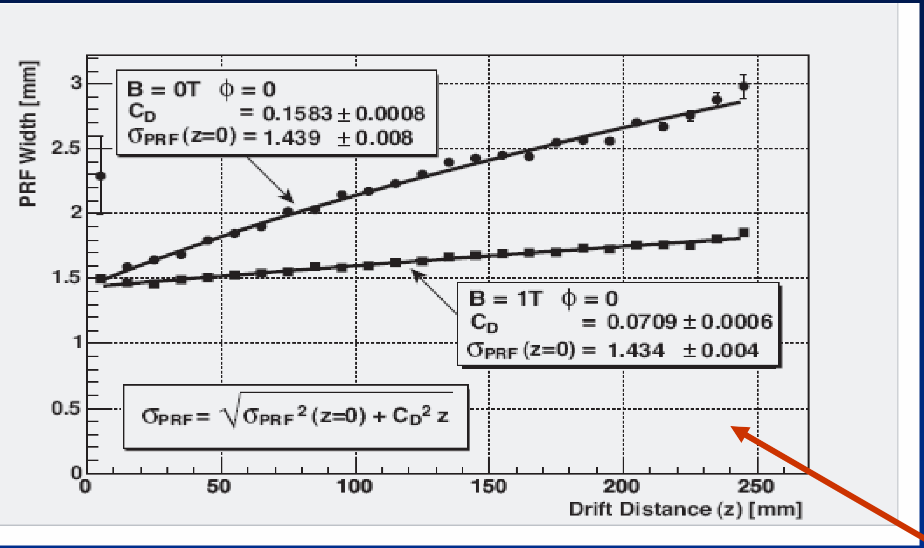
Nikhef on CMOS readout techniques, joined by Saclay

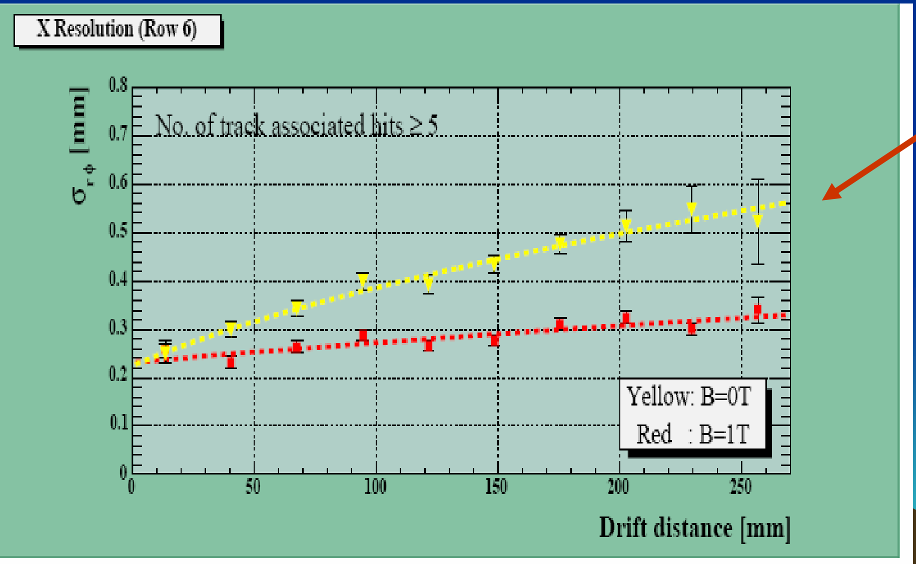
- ~ 50 x 50 μm^2 CMOS pixel matrix + Micromegas or Gem
- ~ preamp, discr, thr.daq, 14-bit ctr, time-stamp logic / pixel
- ~ huge granularity(digital TPC), diffusion limited, sensitive to indiv. clusters for right gas
- ~ 1st tests with Micromegas + MediPix2 chip

→ 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

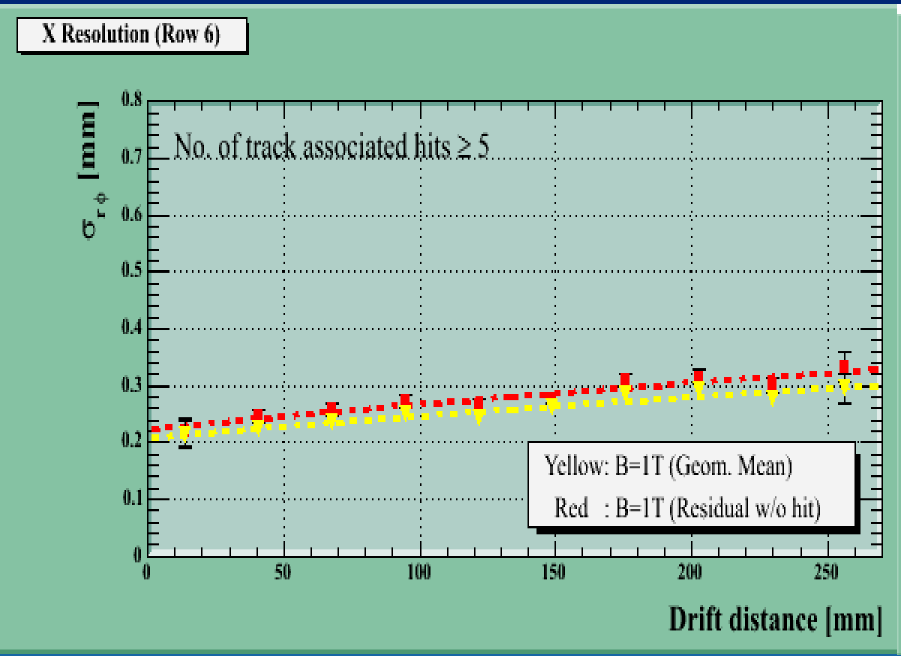
--PRF width measured to be = 1.43mm

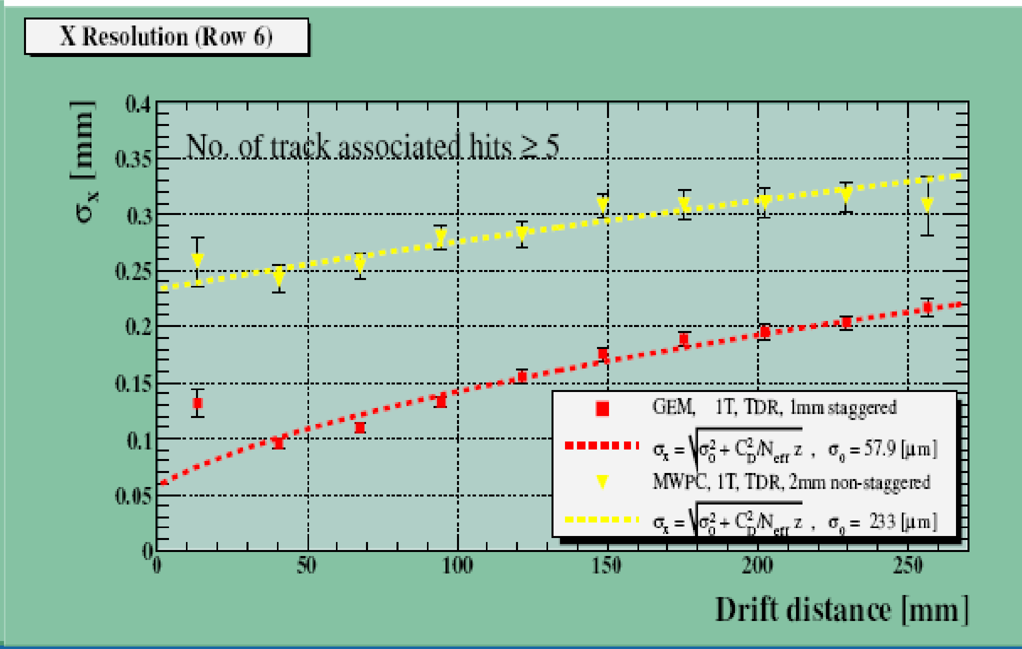
--Point resolution measured by fitting track to outer 6 rows and comparing track to hit on innermost 7th row. This method is known to overestimate the resolution (better method being implemented—see next slides)

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.

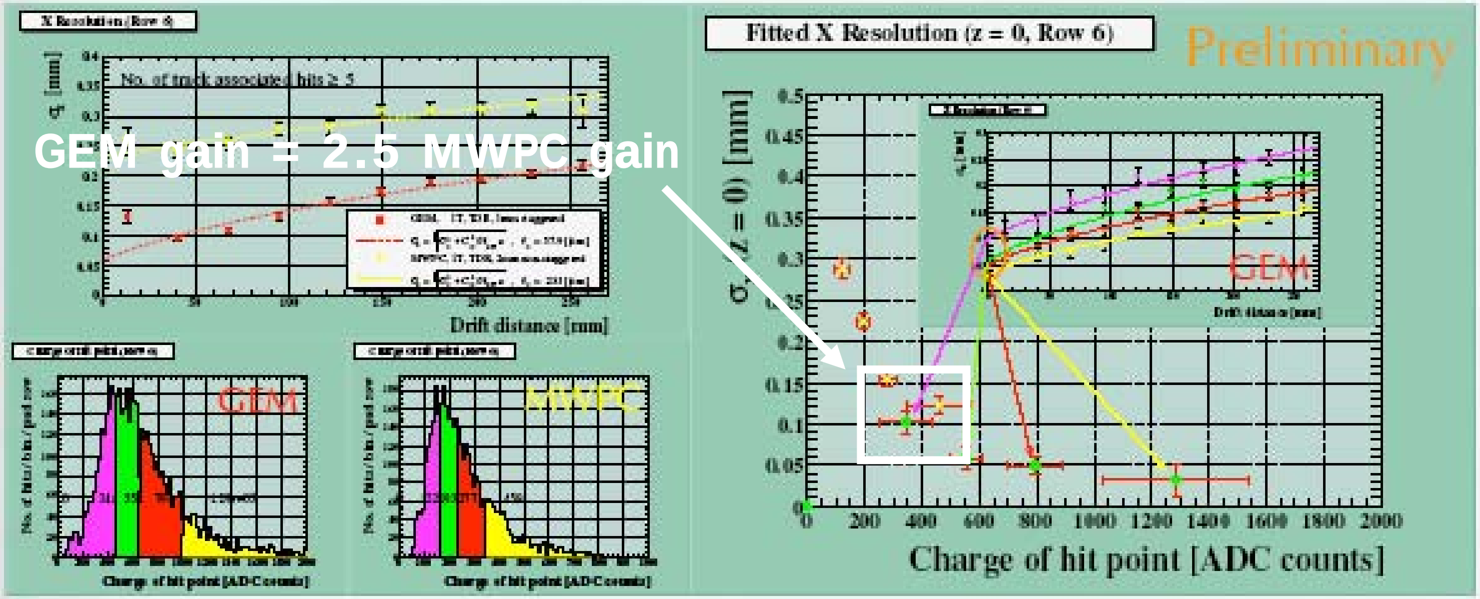
Wires, expect~170μm resolution: **GEM beamtest,compare to wires:**





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

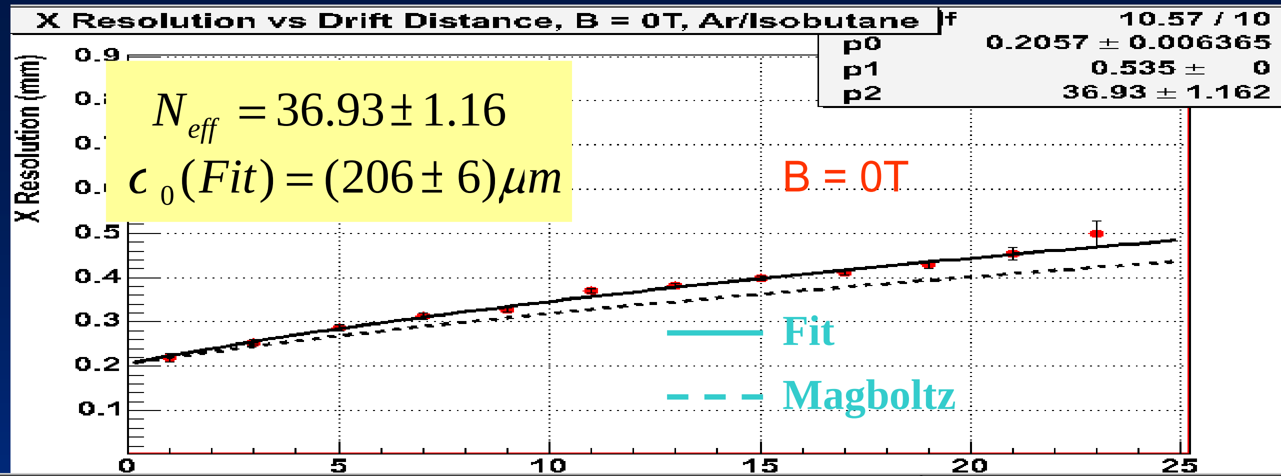
Katsumasa Ikematsu (DESY) / ACFA8

X Resolution of Micromegas@KEK beam test

$\sum$ 8Rows

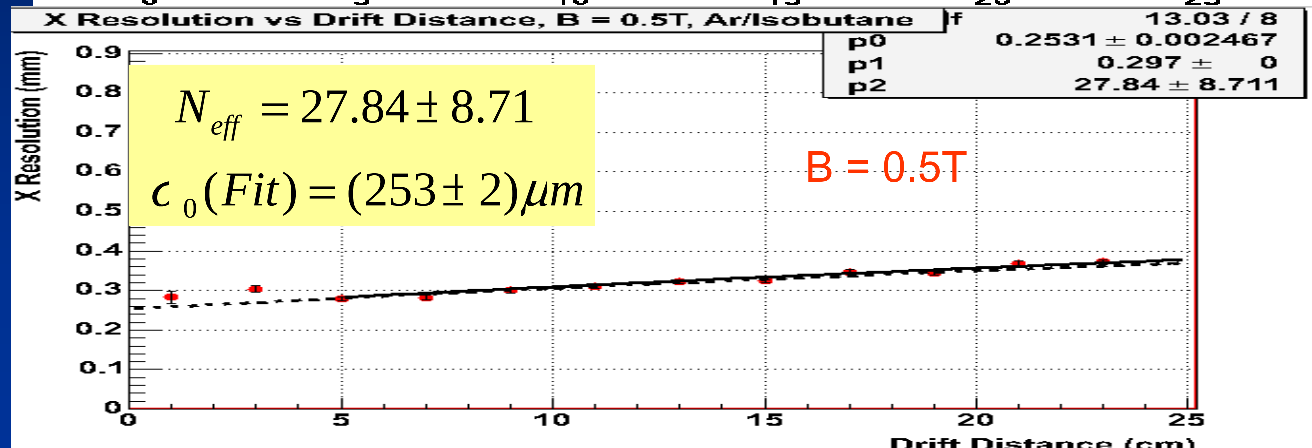
$Cd = Cd(PRF)$

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

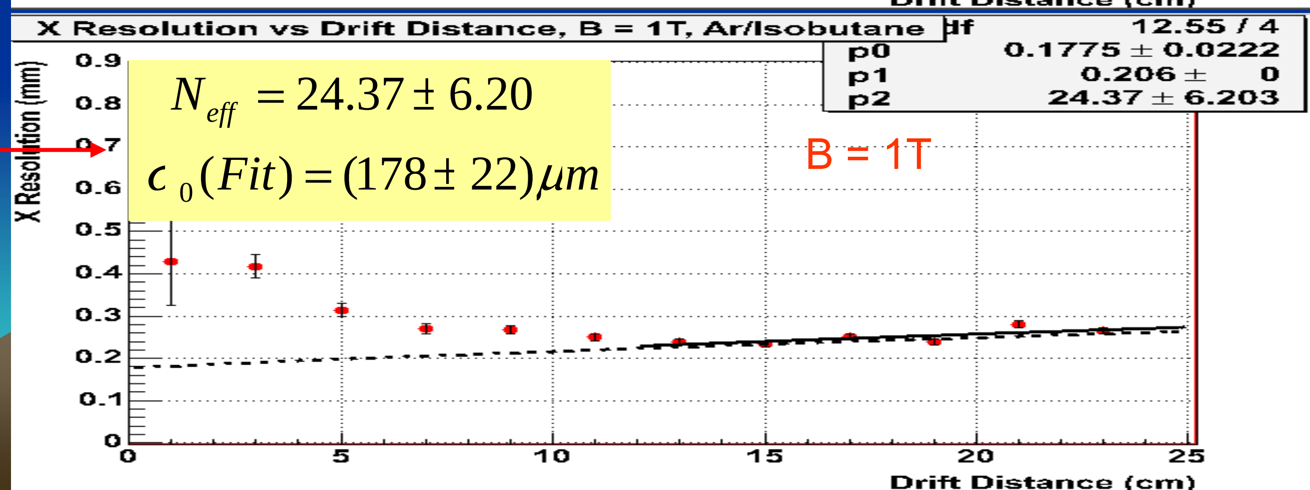


C_d fixed each B

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



$2.3mm / \sqrt{12}$



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

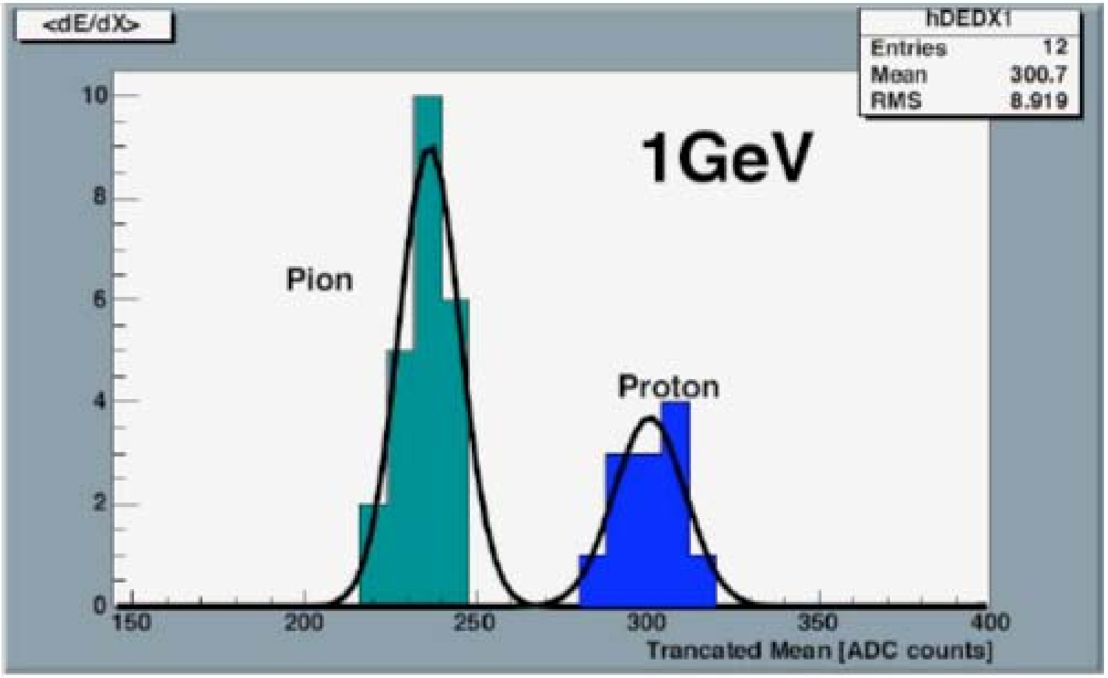
Prototype Results
dE/dx, wires, KEK beam test

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

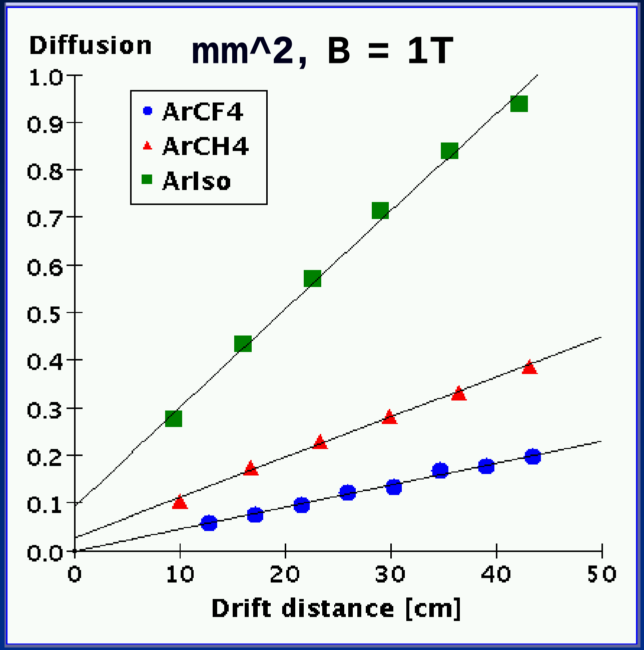


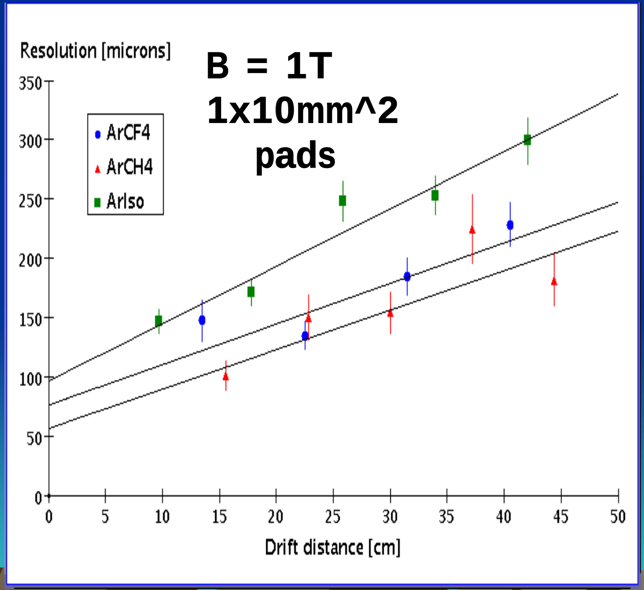
proton @1GeV/c
<dE/dx> 300.6
sigma 10.3

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

Prototype Results

Point resolution, Micromegas





Saclay/Orsay/Berkeley

--Ageing negligible

--Diffusion measurements ⇒ $\sigma\_pt < 100\mu m$ possible

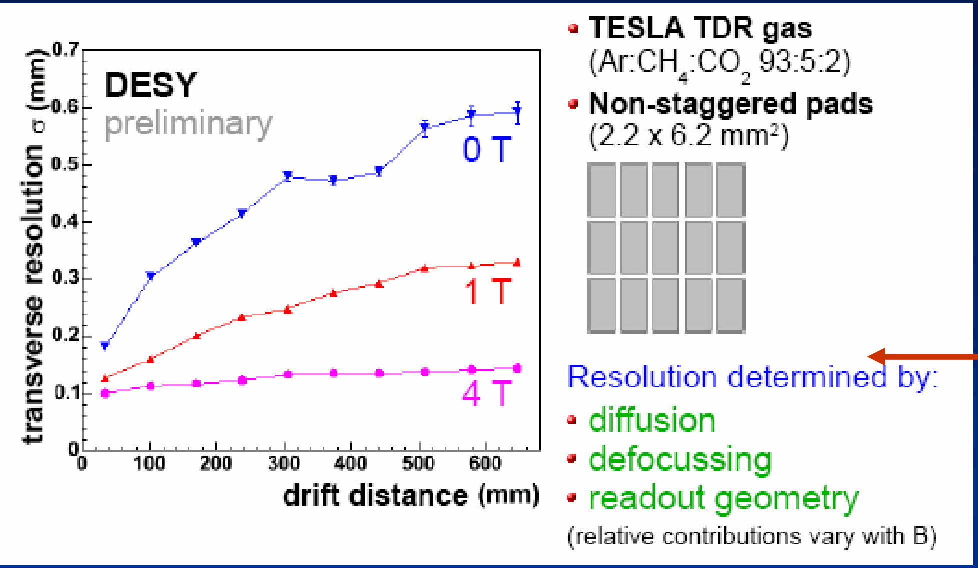
--At moment only achieved for short drift (intrinsic σ) for gain~5000 (350V mesh), noise~1000e

--Analysis continuing…

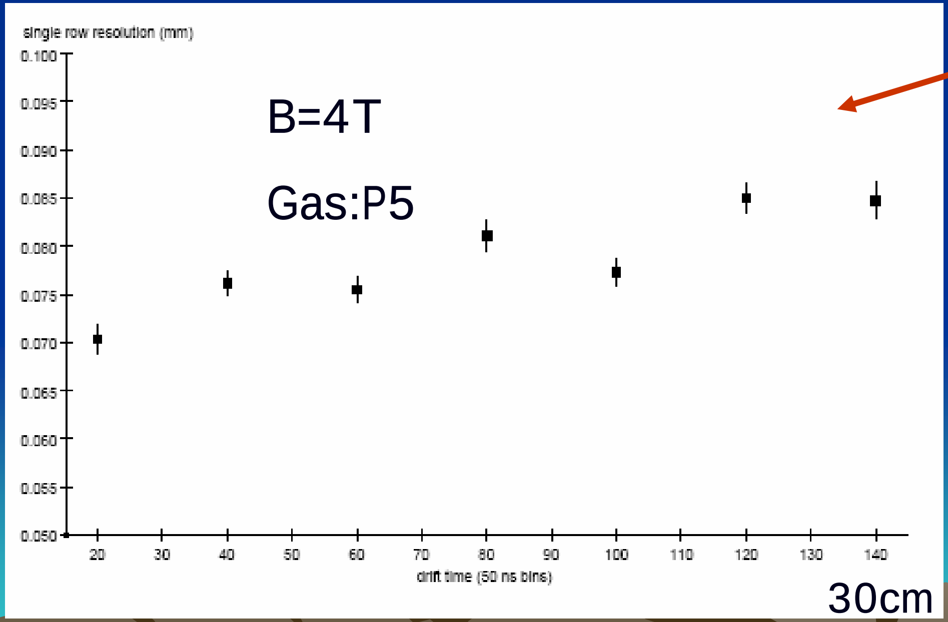
Prototype Results

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".

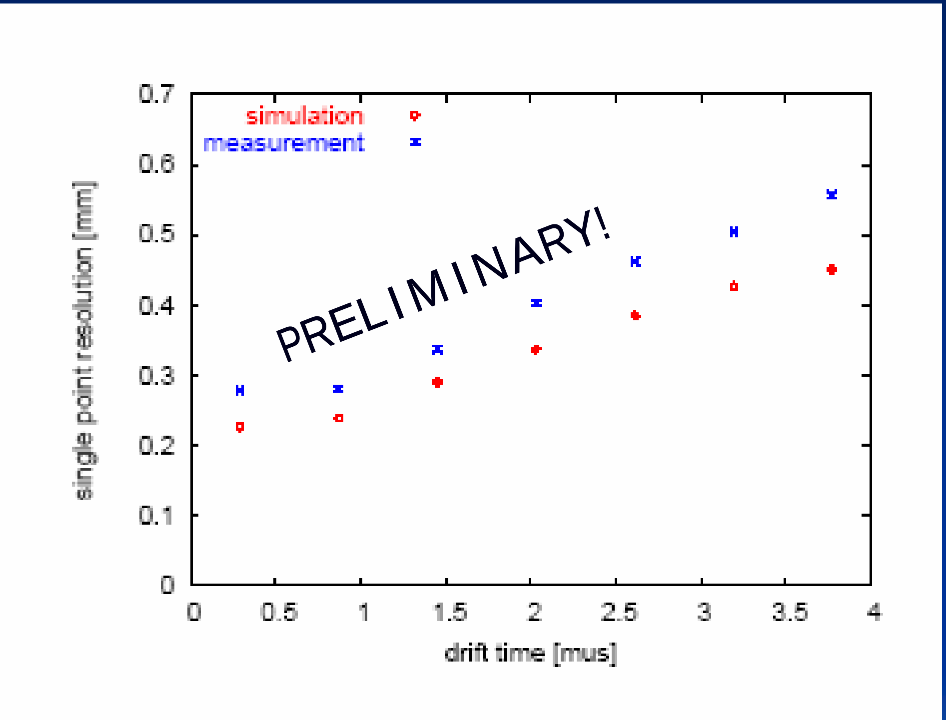


--Second, in Victoria chamber (double Gem), unbiased method used: track fit twice, with and without padrow in question, σ determined for each case; geometric mean of the two σ's gives the correct result.

--See next page...

Prototype Results

Point resolution, Gem

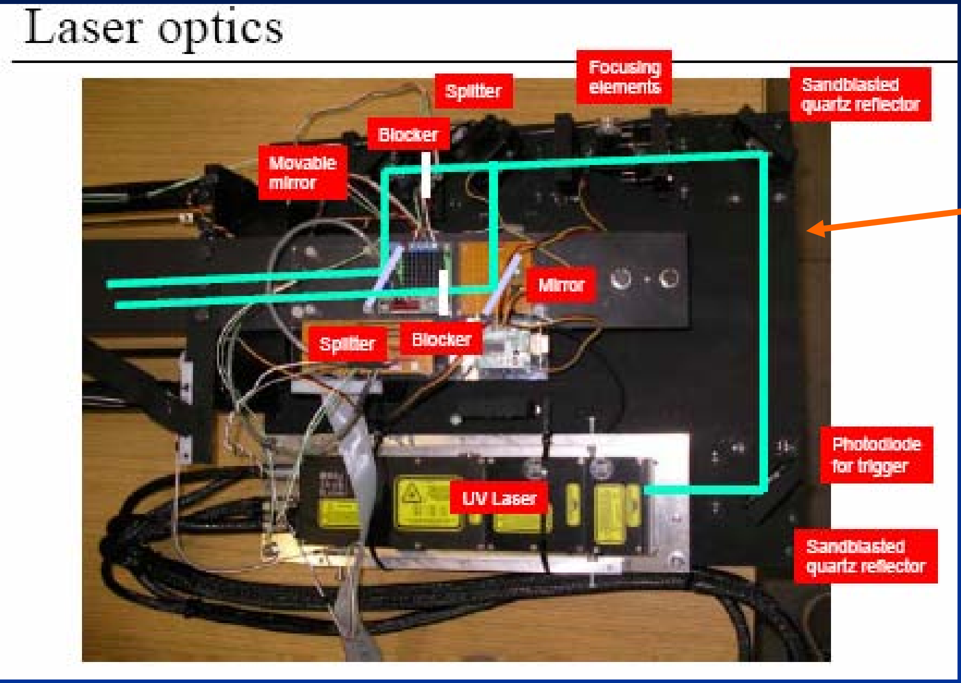


--Third example of σ_pt measured at Aachen Gems and 2x6mm^2 pads by comparing track position with a Si hodoscope.

--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

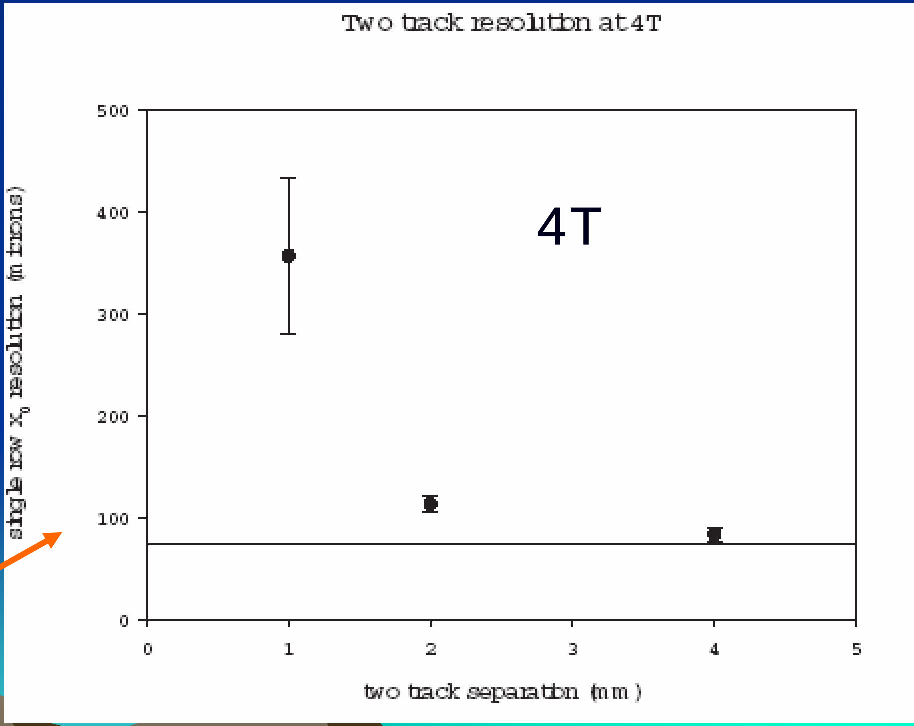


Studies just starting.

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.



Prototype Results

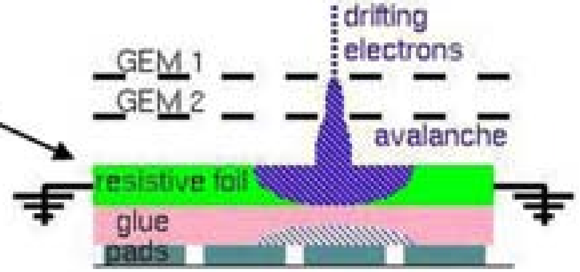
Carleton: improving point resolution with resistive foil

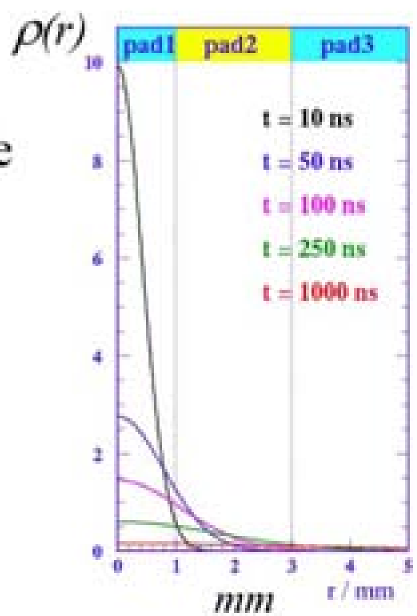
The Concept of Charge Dispersion

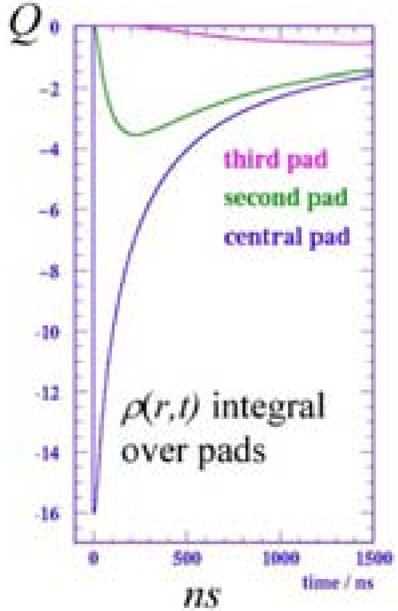
- Modified GEM anode with a high resistivity film bonded to a readout plane with an insulating spacer
- 2-dim continuous RC network defined by material properties and geometry
- Point charge at $r=0$ & $t=0$ disperses with time
- Time dependent anode charge density sampled by readout pads:

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

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



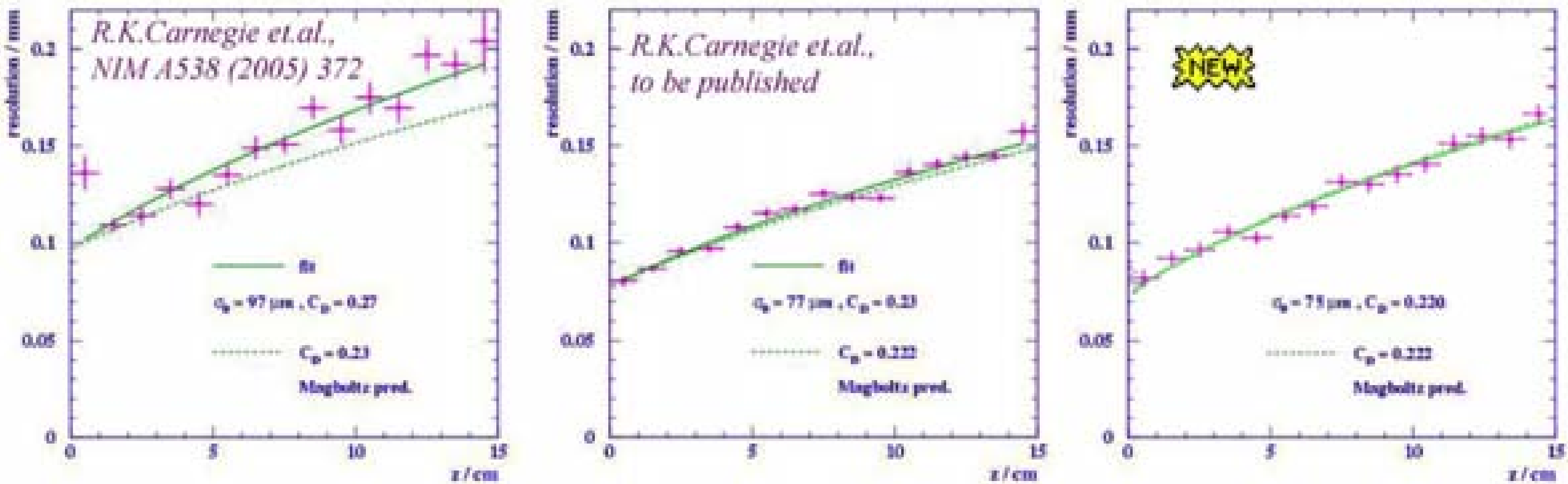




Carleton: resistive foil results

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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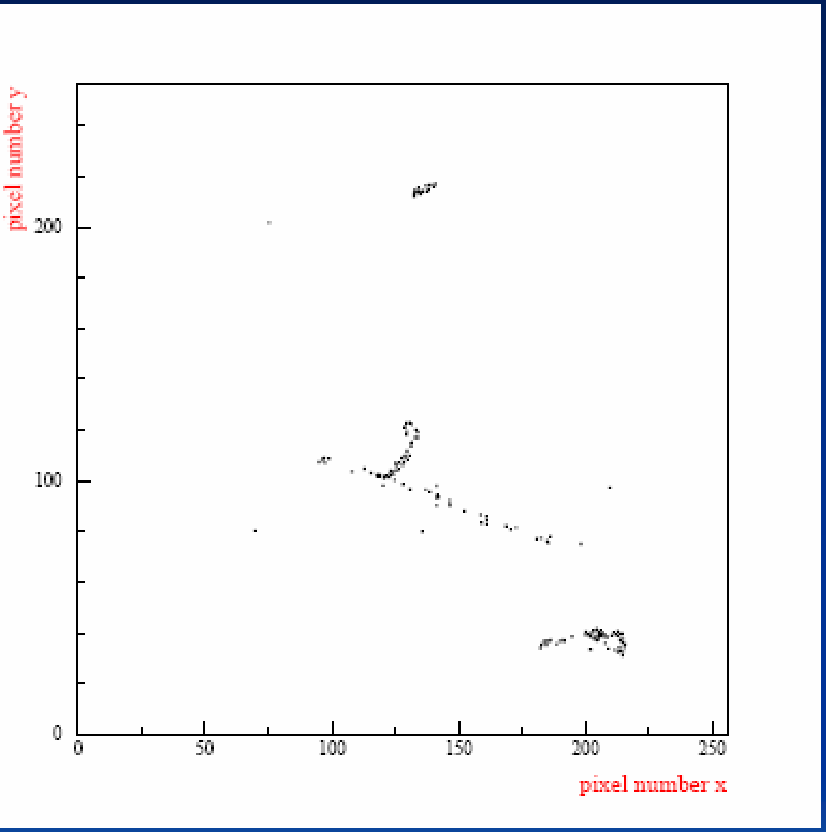
Medipix2+Micromegas: results@Nikhef



--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)

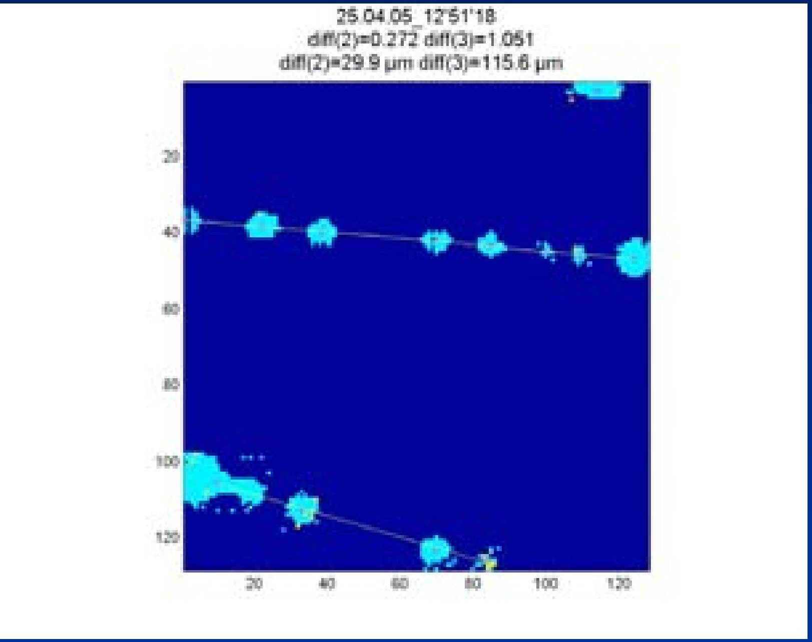
--Future: develop "*TimePixGrid*" prototype by Nikhef/Saclay/et.al. for TPC application: see next slide…

InGrid

Integrate GEM/Micromegas and pixel sensor

By 'wafer post processing'

Medipix2+GEMS: results@Freiburg



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

--Measure diffusion const.~ ?µm/ √cm

--Future: studies continuing

TPC R&D Summary

- Experience with MPGDs being gathered rapidly
- Gas properties rather well understood
- Diffusion-limited resolution seems feasible
- Resistive foil charge-spreading demonstrated
- CMOS RO demonstrated
- Design work starting

TPC central-tracker tasks

-> Snowmass concept and/or tracking sessions

ISSUES

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

Performance/Simulation

-> Snowmass concept session

- 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

-> Snowmass concept/tracking sessions

- Gas-Amplification technology $\rightarrow$ input from R&D projects at Snowmass tracking session
  - Chamber gas candidates
- 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

-> Snowmass concept/tracking sessions

- Revisit expected backgrounds
  - -> joint with MDI
- 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?