LC-TPC R&D
(Goals, Status, Plans)

DESY PRC 28.10.04

(and WWSOC review panel)

Ron Settles

MPI-Munich/DESY

for the LC TPC Groups

LC TPC Groups

Europe

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

America

Carleton U
LBNL
MIT
U Montreal
U Victoria

Other active LC TPC Groups

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

USA

Chicago/Purdue
Cornell (UCLC)
MIT (LCRD)
Temple/Wayne State (UCLC)
Yale

HISTORY

A DECADE OF TRACKING STUDIES

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 prop. for TPC (European & North American teams)***

- **Recommendations of 52nd Meeting of the DESY PRC 25-26 October 2001**

  PRC R&D-01/03: LC TPC R&D
  The PRC **recommends** the **approval** of the proposed R&D programme. It encourages the collaboration to perform high magnetic-field tests of the different end-plate technologies (GEM, MICROMEGAS and standard wire chambers).

- **Status Report given at DESY PRC meeting 07 May 2003**

  The PRC congratulates the collaboration for the progress achieved in many areas of the project and looks forward to tests of large area prototypes of the three readout technologies in high magnetic field. The PRC recommends the continuation of the program and looks forward to a status report in Autumn 2004.

Goal

To design and build an ultra-high performance

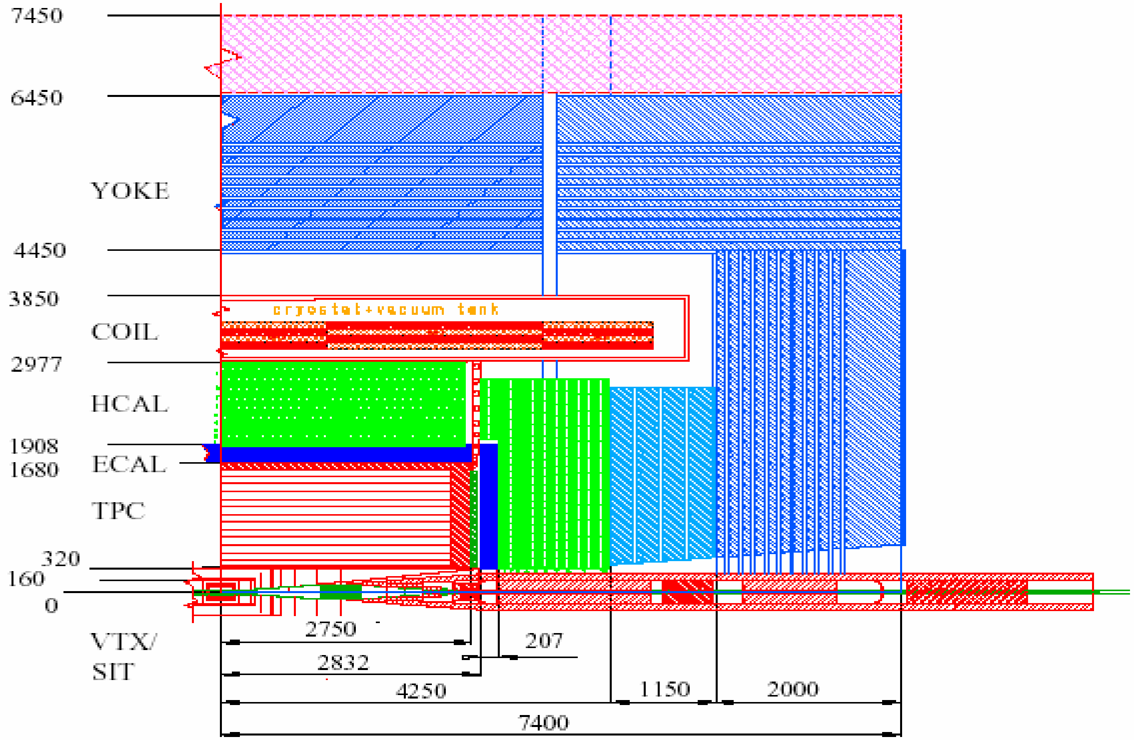
Time Projection Chamber

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

"Large" Detector example

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

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



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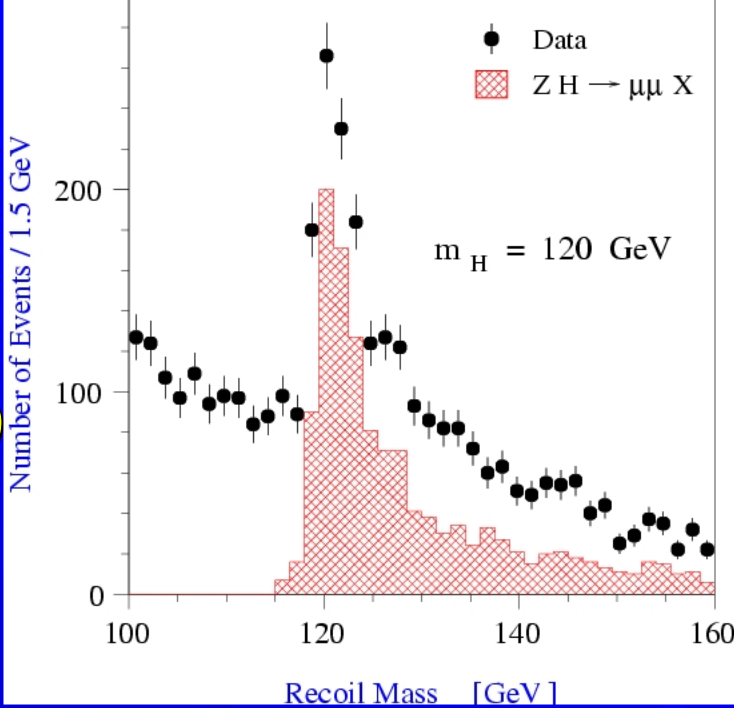
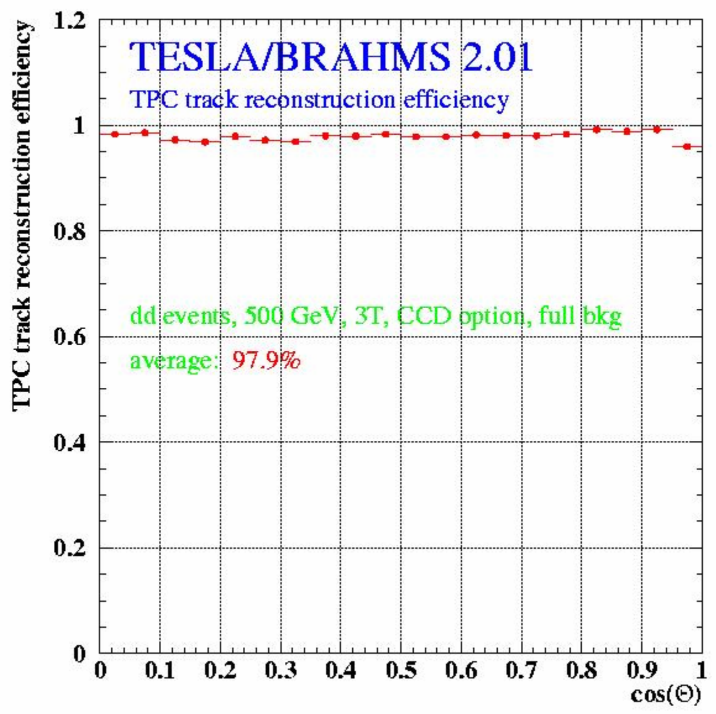
Physics determines detector design

★ **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/Goals

- Continuous tracking throughout large volume
- ~98% tracking efficiency in presence of backgrounds
- 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

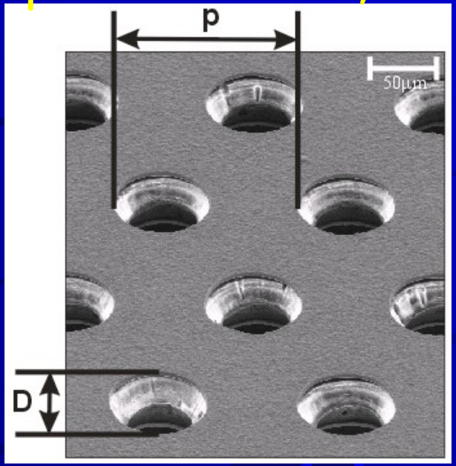
First, briefly,

- Gas-amplification systems
- Prototypes
- Facilities
- Overview a few activites which are still in early stages
  - Field cage
  - Electronics
  - Mechanics
  - Simulation

Then, PROTOTYPE RESULTS and PLANS...

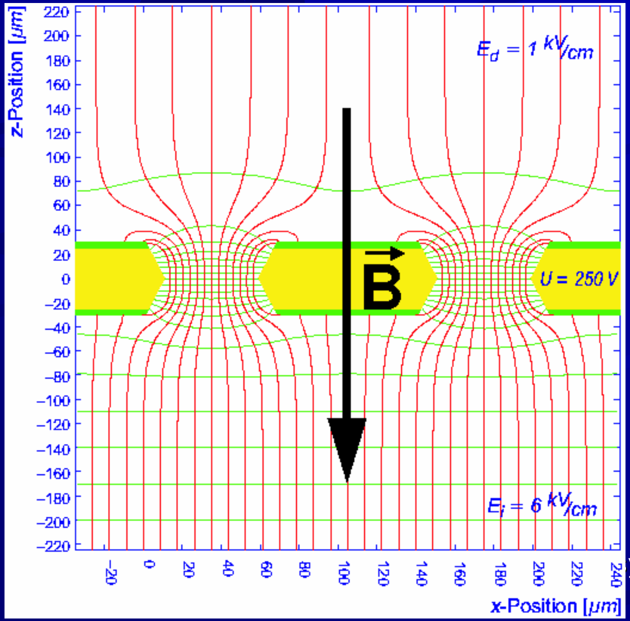
Gas-Amplification Systems: Wires & MPGDs→

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

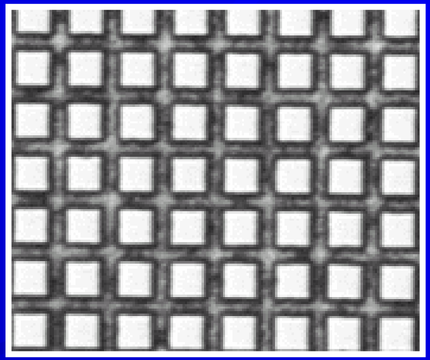


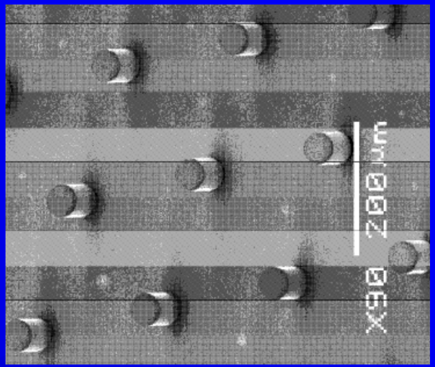
P~140 μm

D~60 μm

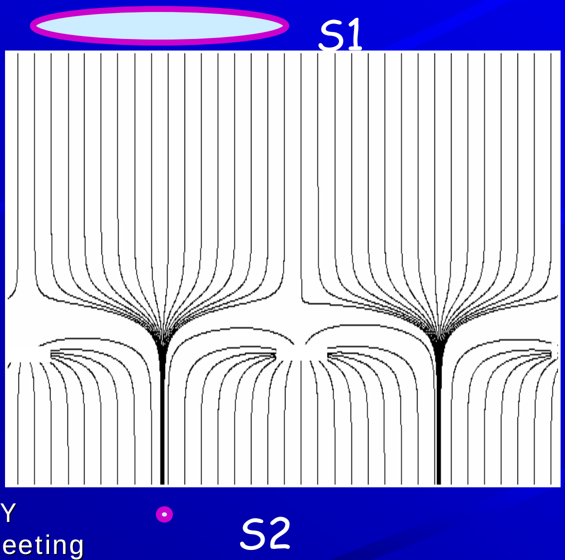


Micromegas: micromesh sustained by 50μm pillars, multiplication between anode and mesh, one stage





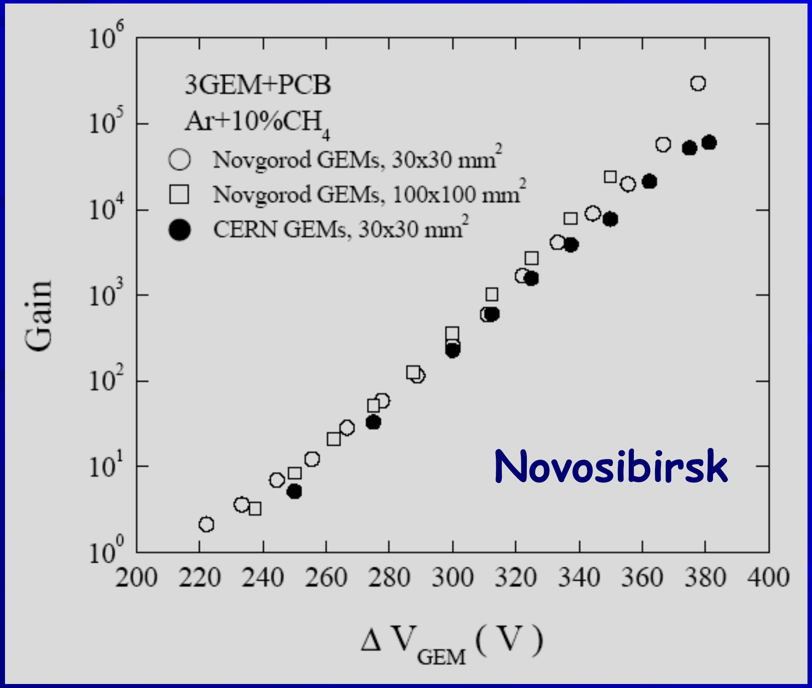
S1/S2 ~ Eamplif / Edrift



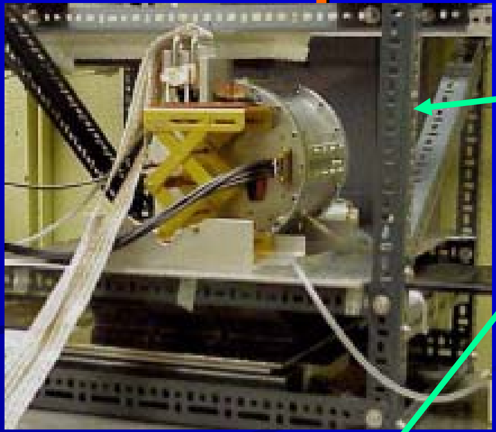
Gas-Amplification Systems:
Possible manufacturers

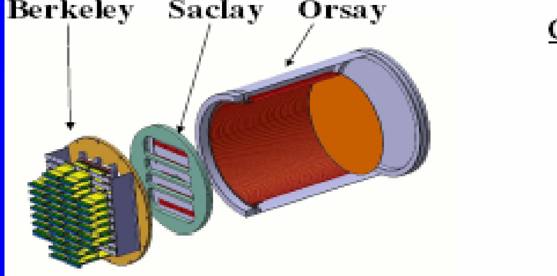
GEM: --CERN
--Novogorod (Russia)
--Purdue + 3M (USA)
--other companies interested in Europe, Japan and USA

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

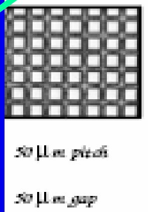


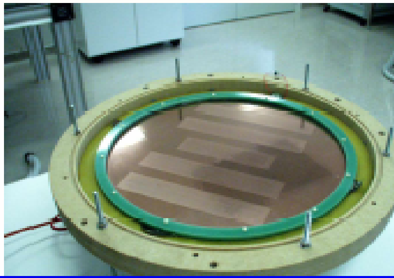
Examples of Prototype TPCs





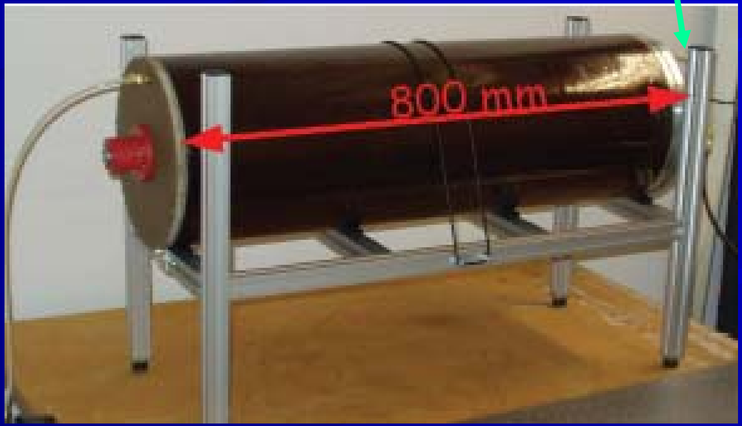
Carleton, Aachen, Desy(not shown) for B=0 studies



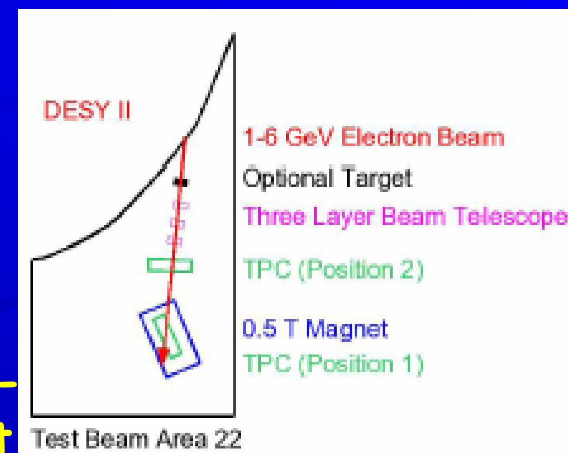


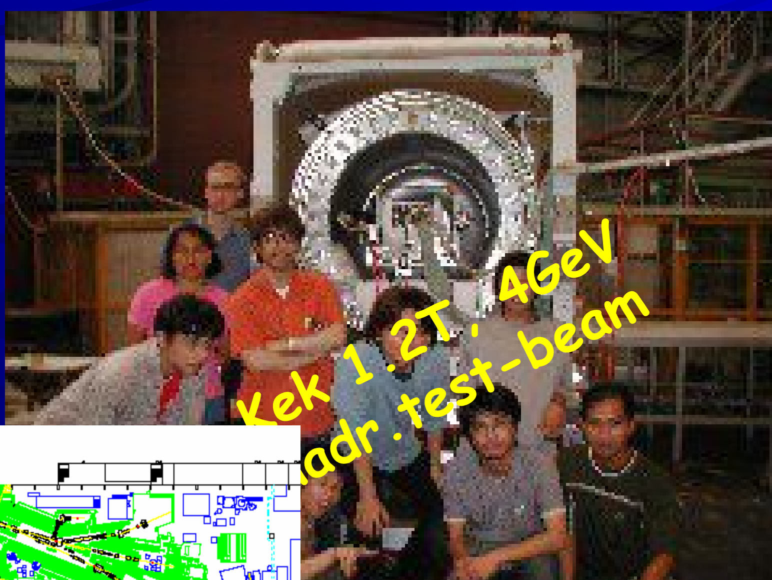
Desy, Victoria, Saclay (fit in 2-5T magnets)

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



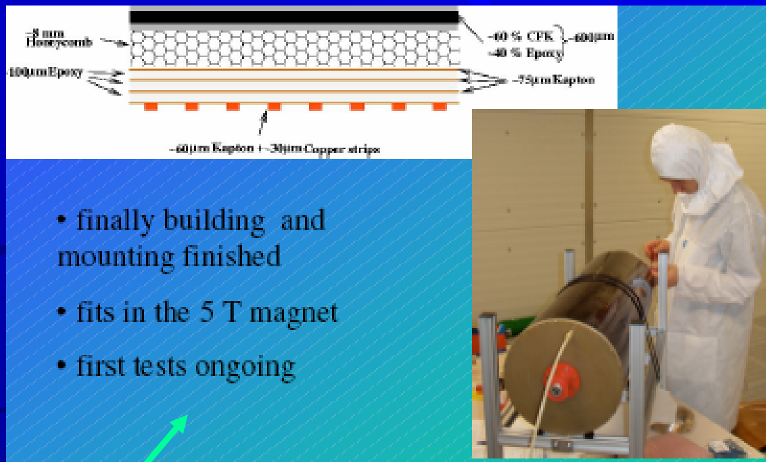
Facilities

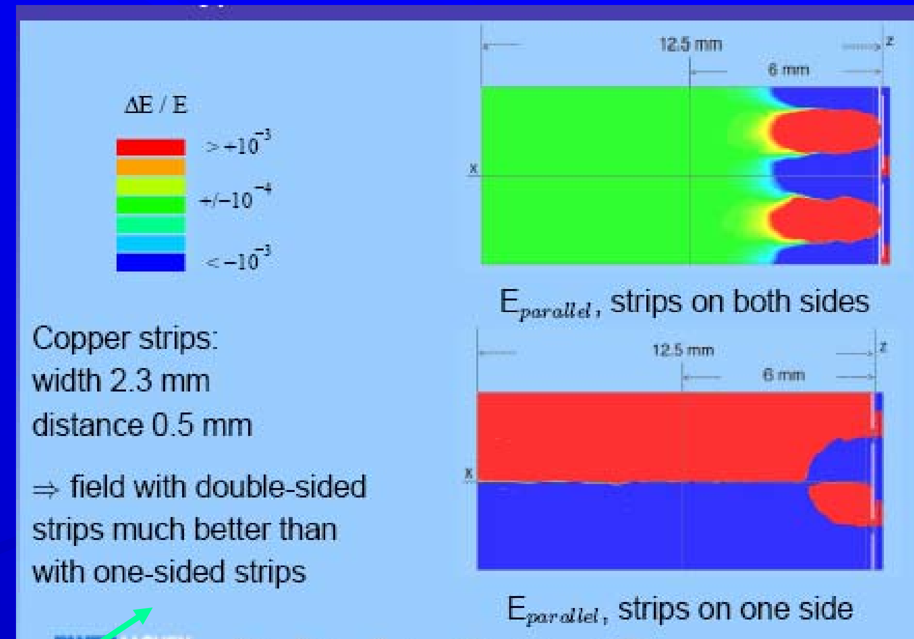




Cern test-beam (not shown)

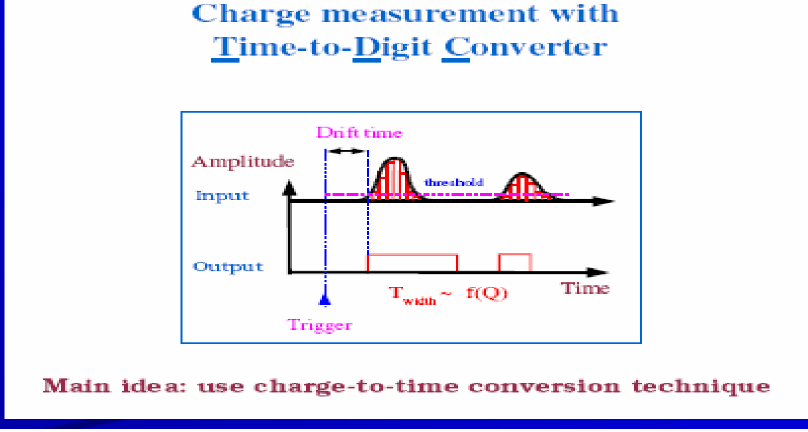
Field Cage Activities

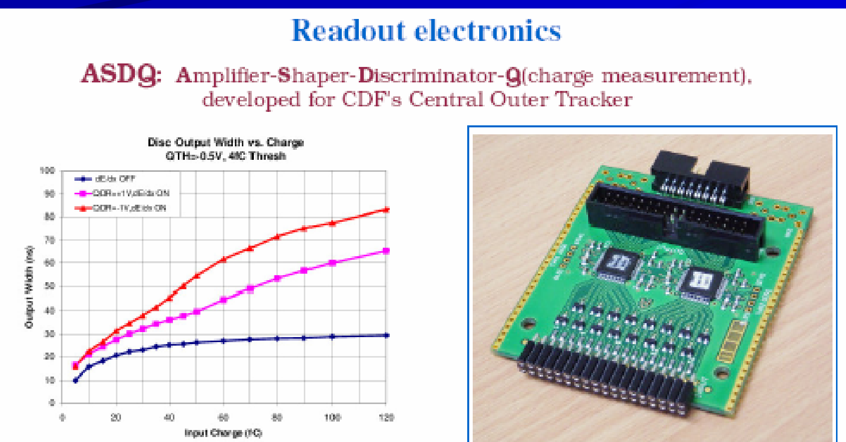


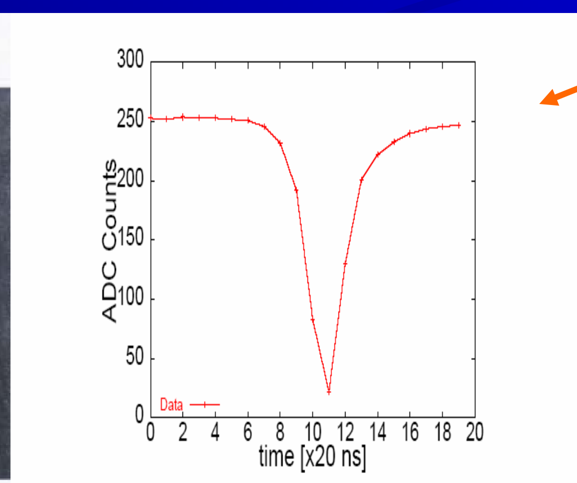


- FC ideas tried in Desy test TPC
- Software calculations at Aachen demonstrate need for double-sided strips, test chamber built.
- St.Petersburg calculations of several FC configurations.
- Need to study Alice FC ideas.

Work on Electronics

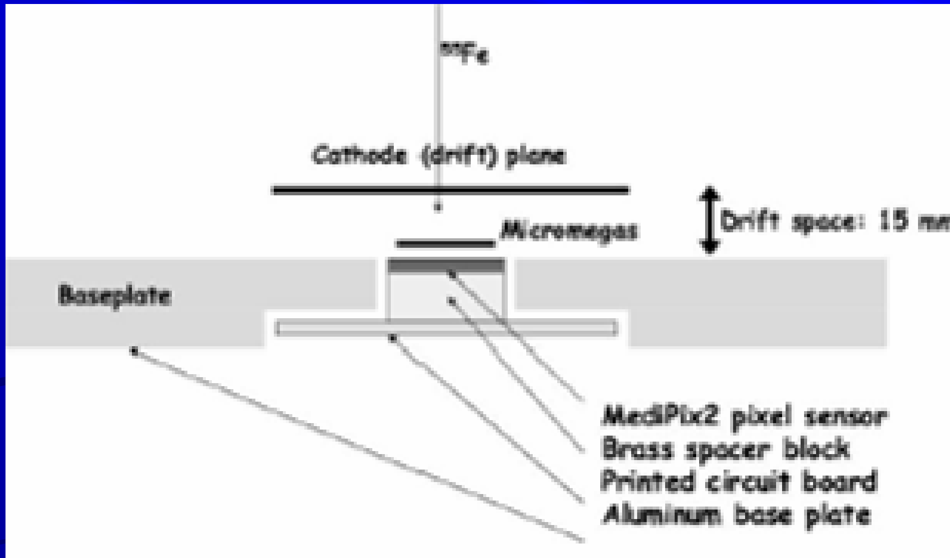






Aleph and Star setups (3 of each) used for prototype work don't take advantage of fast Gem/Mm signals from direct e-.

- Rostock working on TDC idea.
- Aachen studying highly integrated conventional approach.
- Nikhef developing “Si RO” concepts (next slide)



Electronics Development

Nikhef on CMOS readout techniques, joined by Saclay

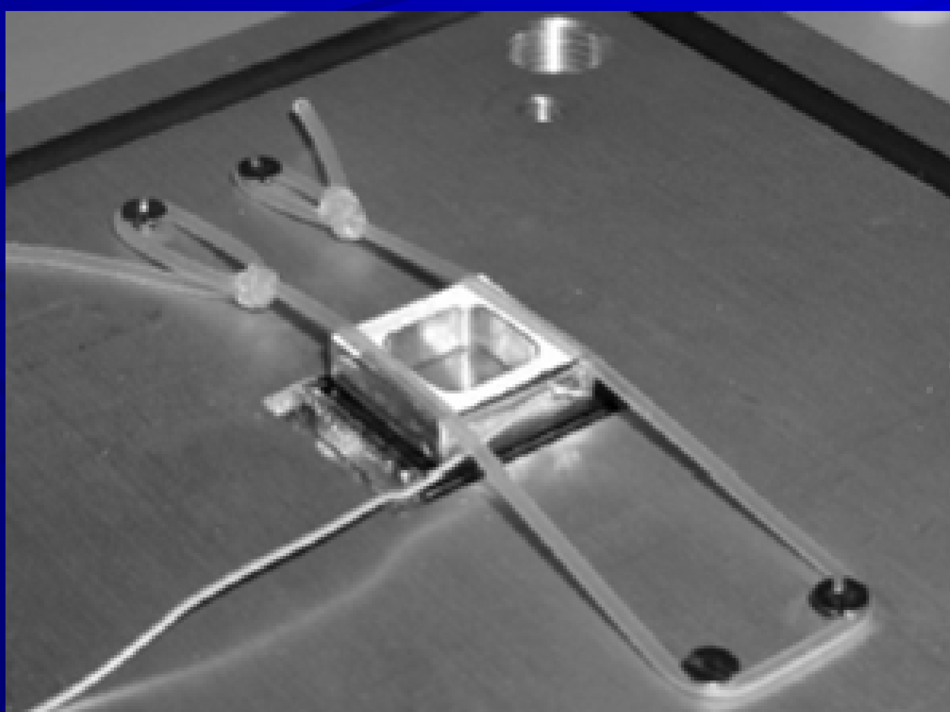
~ 50 x 50 µm^2 CMOS pixel matrix + Micromegas or Gem

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

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

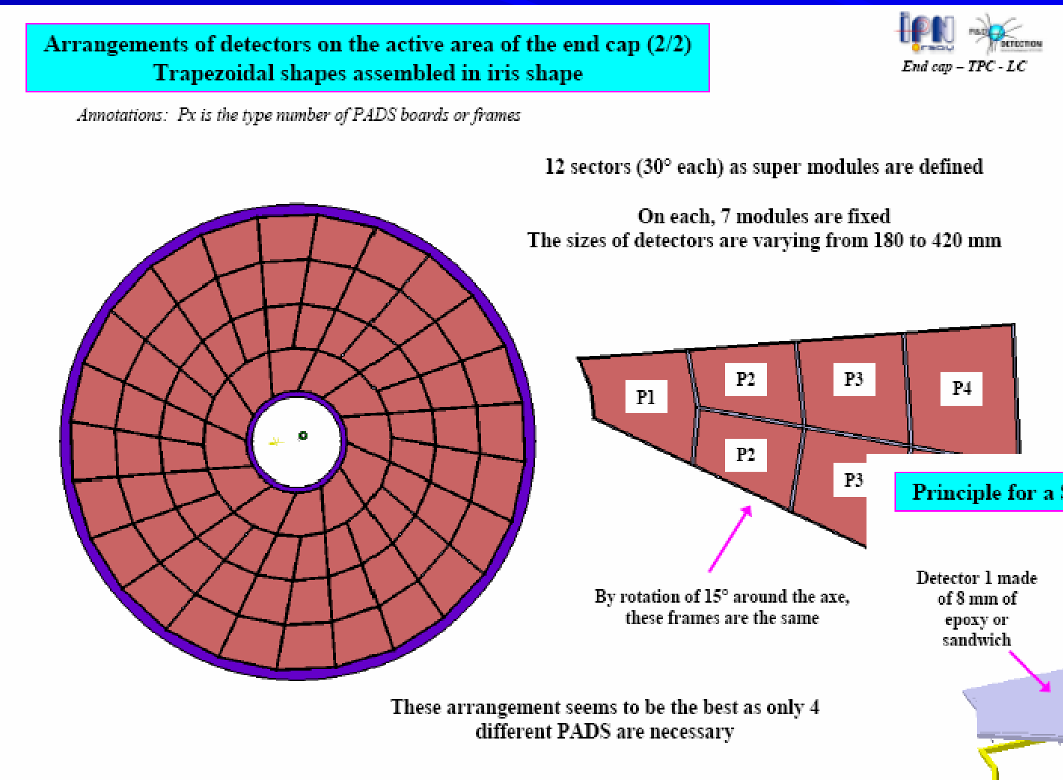
~ 1st tests with Micromegas + MediPix2 chip

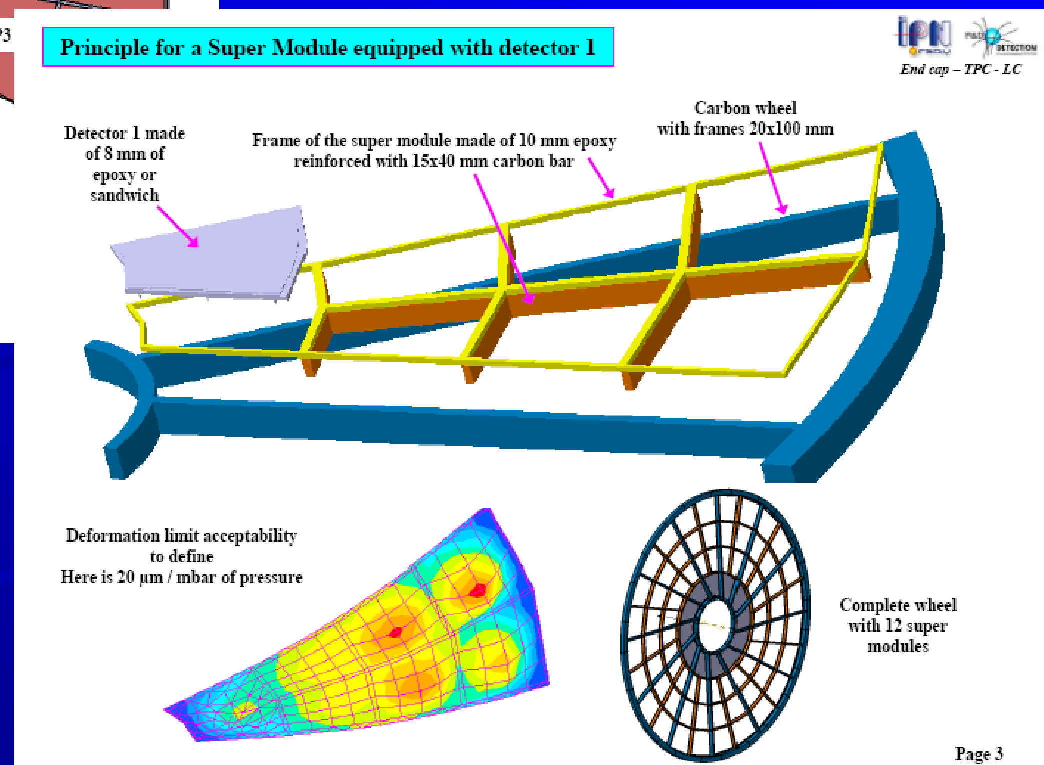
→ more later…



Work on Mechanics

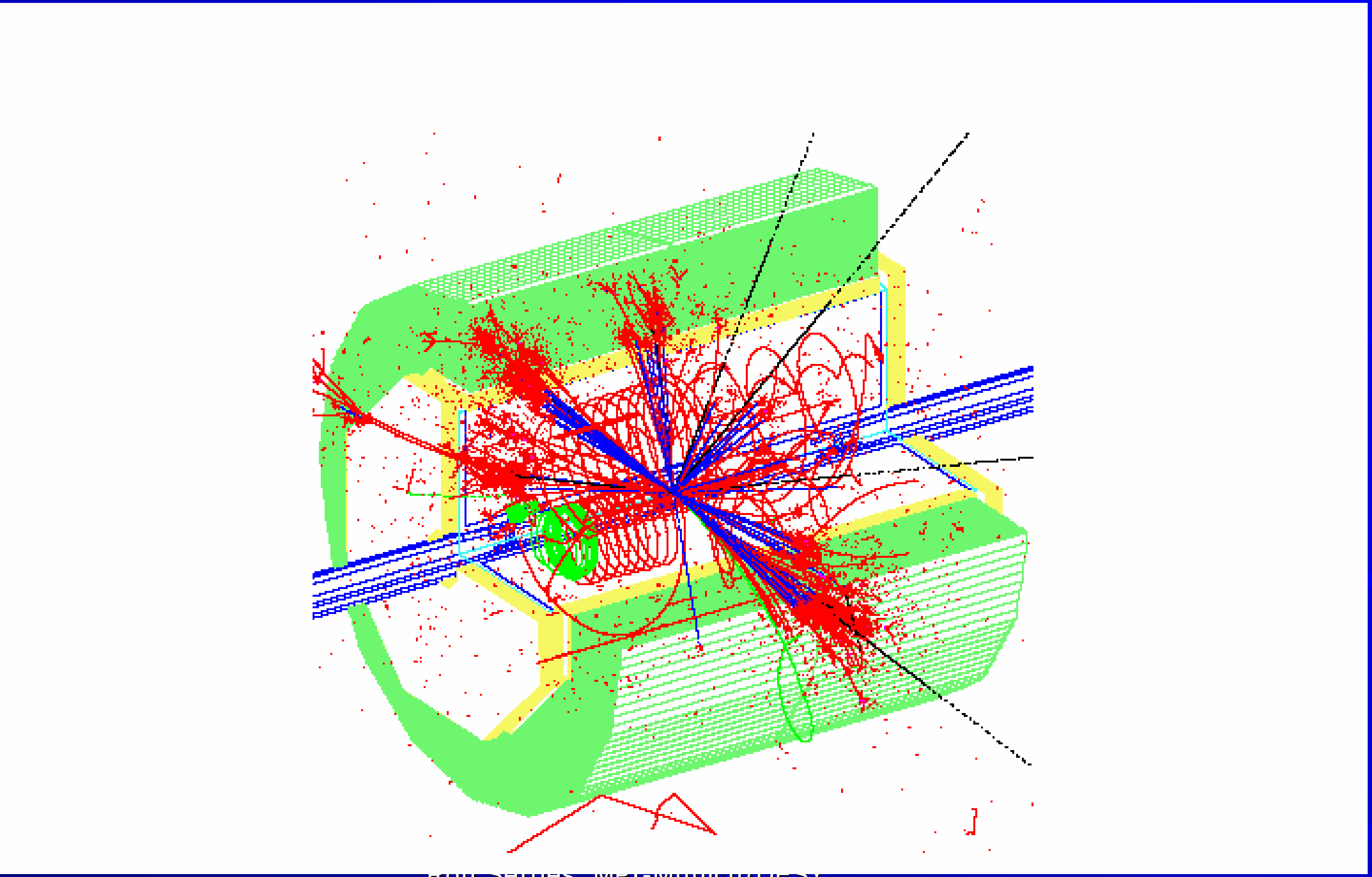
IPN Orsay





Simulation

- Much activity
- Simulations to understand prototype results
- Must recheck some issues now, like
  - robustness against backgrounds and
  - TPC design, overall performance
- Work started in Aachen, Desy, Asia…



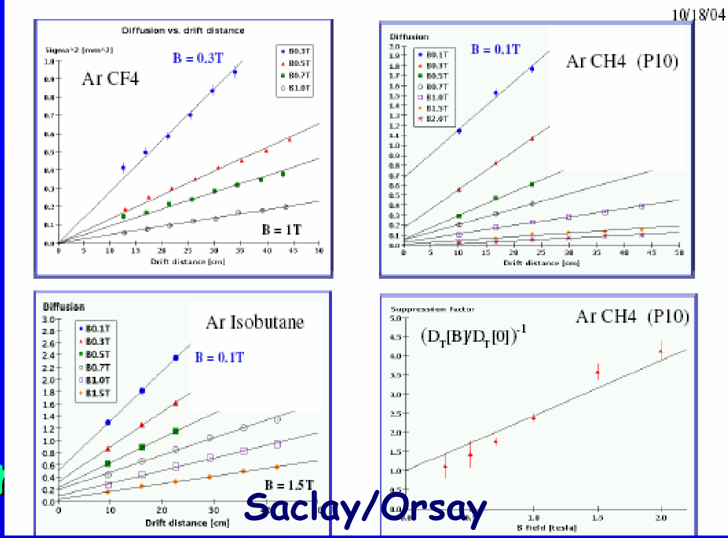
PROTOTYPE RESULTS

Presently mapping out parameter space: demonstration phase

- Gas studies
  - Drift velocity measurments
  - Ion backdrift
  - Track distortion studies
- Point resolution
  - Two-track resolution
- Methods for improving resolution
- Results from CMOS Pixel readout

Prototype Results

Gas studies

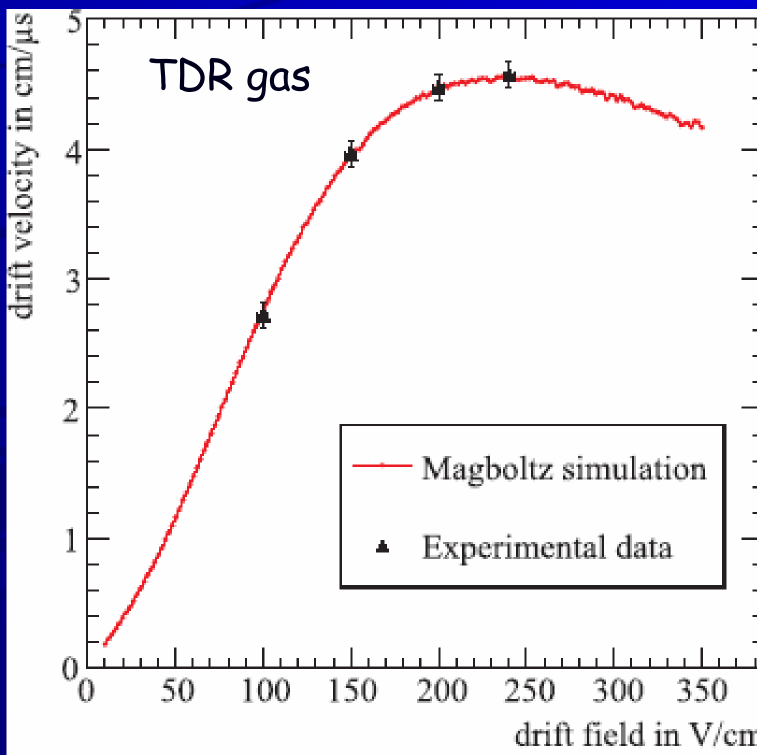


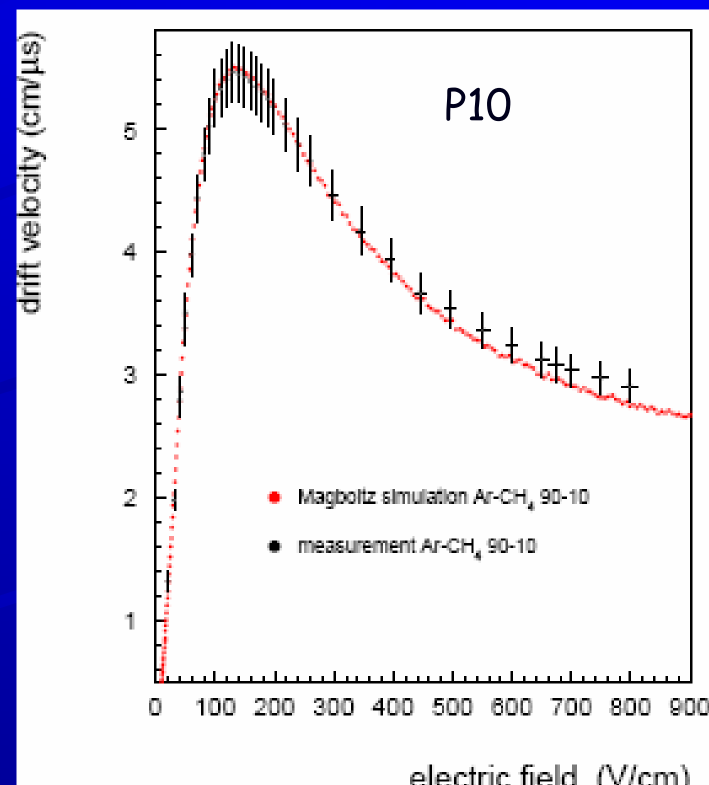
Saclay/Orsay

- Choice of gas crucial
  - Correlated to diffusion-limited resolutio
  - Drift field should not be too high
  - Drift velocity should not be too low
  - Hydrogen in quencher sensitive to neutron background
- Studied, e.g. (many done, more underway):
  - "TDR" Ar-CH4(5%)CO2(2%)
  - P5,P10 Ar-CH4(5%,10%)
  - Isobutane Ar-iC4H10(5%)
  - CF4 Ar-CF4(2-10%)
  - Helium-based
- Simulations will be useful since they have been checked (next slide)

Gas studies

Encouraging cross-checks to Magboltz simulation
Karlsruhe group (earlier by Saclay and others also):

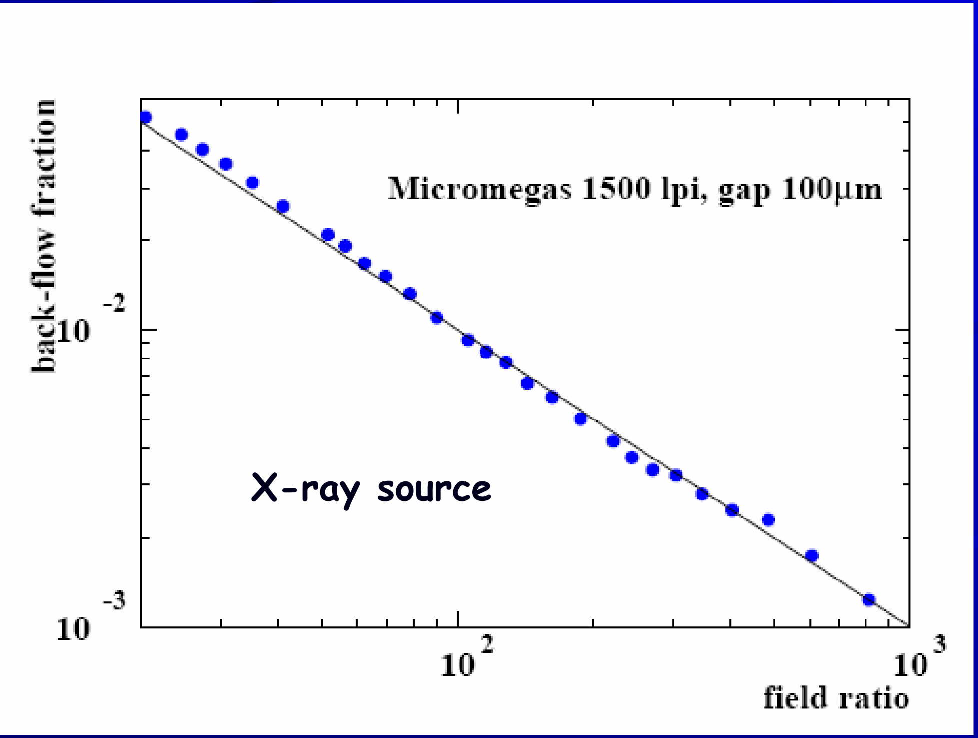




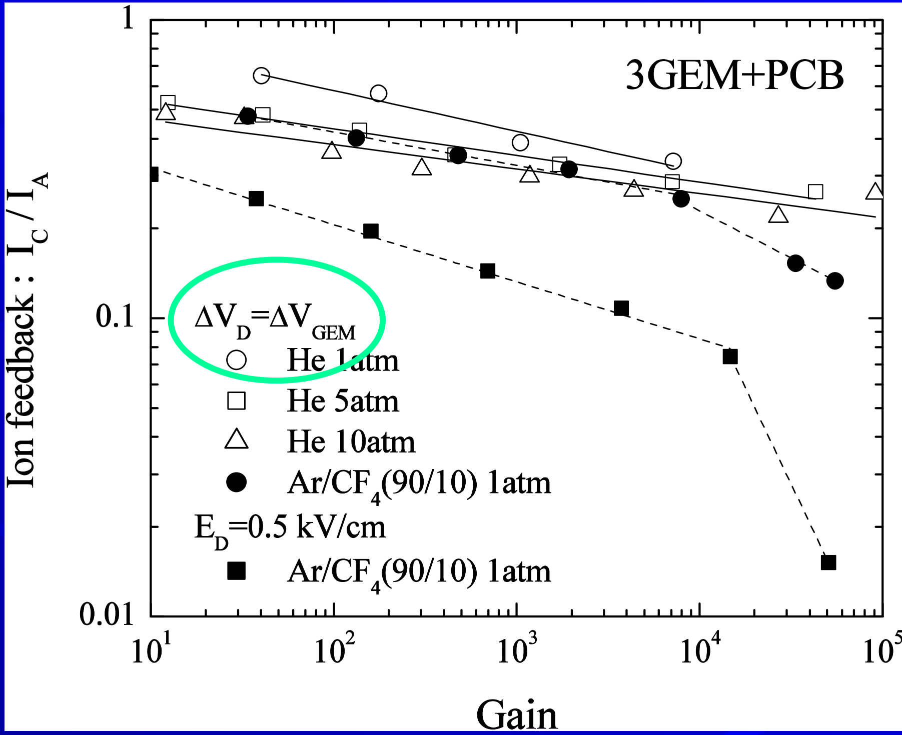
Gas studies: ion backdrift

Should be as small as possible to reduce ion buildup in gas-amplification region and possible ion leaking into drift volume.

Micromegas



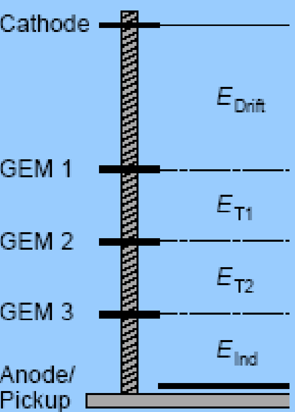
Gem



Prototype Results

Ion backdrift optimization

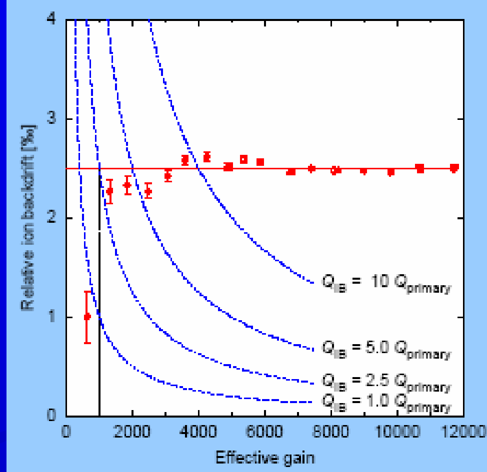
Aachen study for GEMs



Minimal ion backdrift can be achieved with:

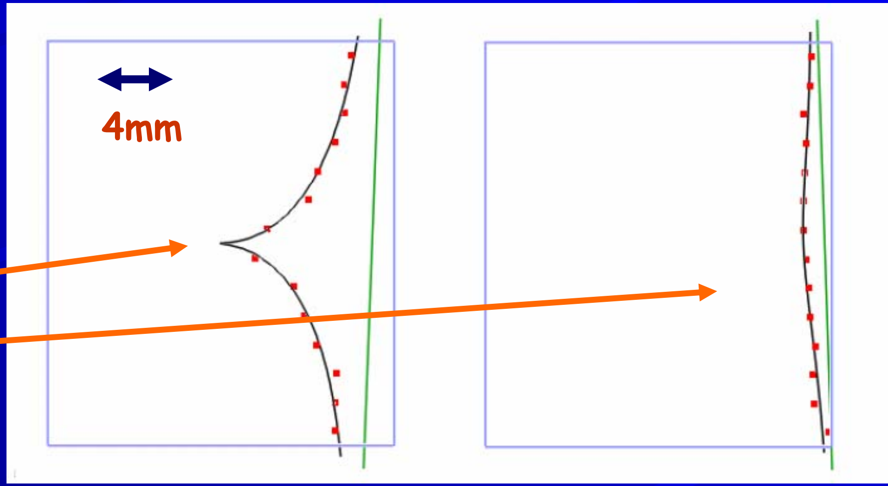
- E_{Drift} ..... fixed at 240 V/cm
- $U_{\mathrm{GEM\,1}}$ .... small influence
- E_{T1} .... maximal
- $U_{\mathrm{GEM\,2}}$ .... small influence
- E_{T2} .... minimal
- $U_{\mathrm{GEM\,3}}$ .... maximal
- E_{Ind} ...... maximal

$U_{\mathrm{GEM\,1}}$ and $U_{\mathrm{GEM\,2}}$ allow variation of effective gain without changing IB.



B = 4 T, measured at DESY

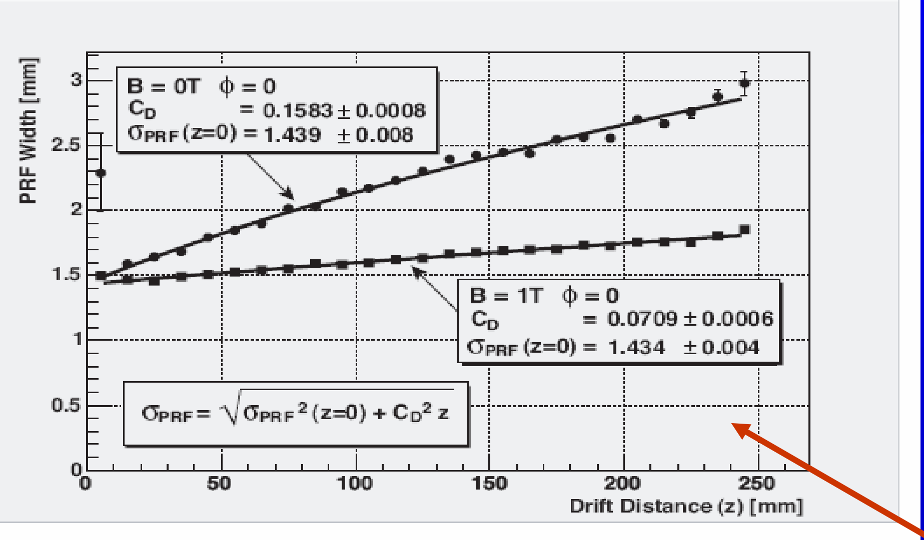
- Prediction from parametrisation: IB independent of G_{eff}
- Lower G_{eff} yields lower backdrifting charge Q_{IB}.
- For $G_{\mathrm{eff}} = 1000$: $Q_{\mathrm{IB}} \approx 2.5\, Q_{\mathrm{primary}}$
- Still an open question: How much ion backdrift can be tolerated?

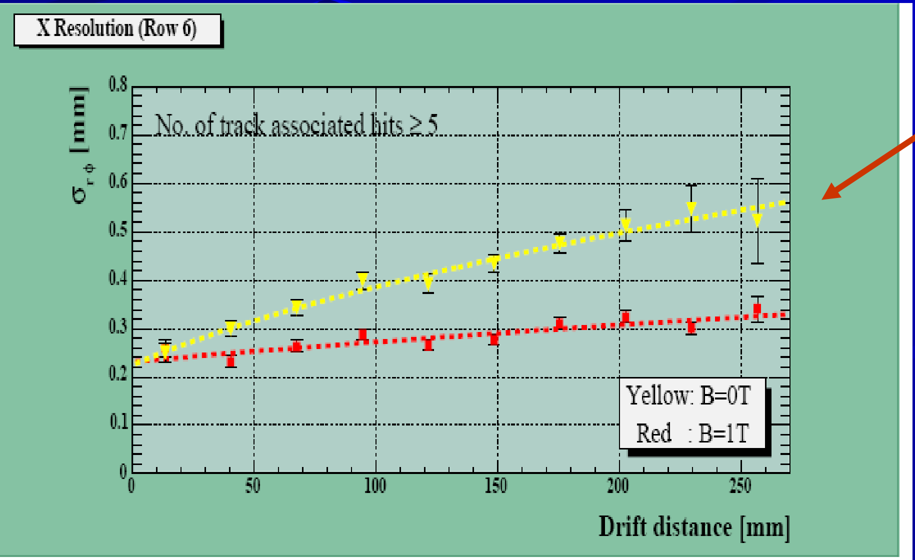


--With optimization, rel. ion backdrift ~2.5‰ indep. of gain

--Even with 10^5 more charge-density than expected, optimization dramatic

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

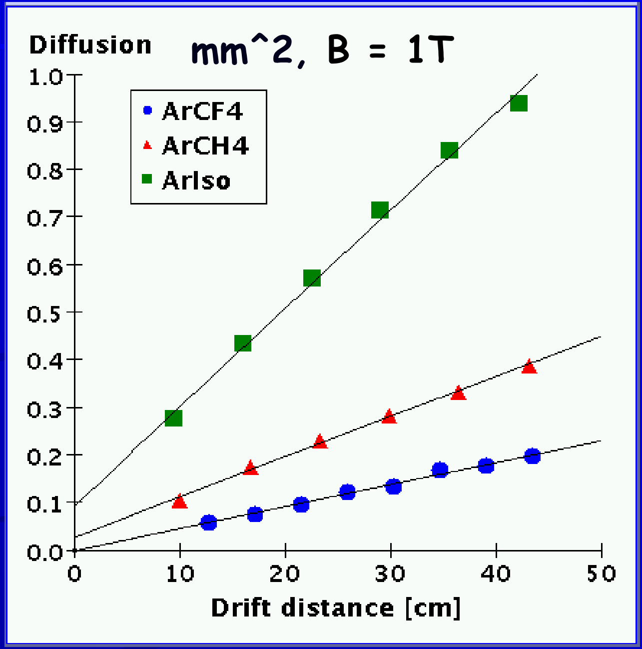
--2x6mm^2 pads, 1mm wire-to-pad gap

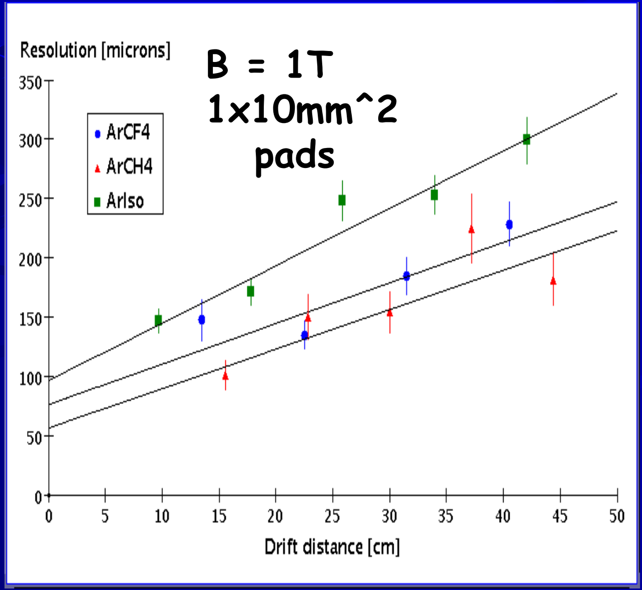
--PRF width measured to be = 1.43mm

--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)

Prototype Results

Point resolution, Micromegas





Saclay/Orsay/Berkeley

--Ageing negligible

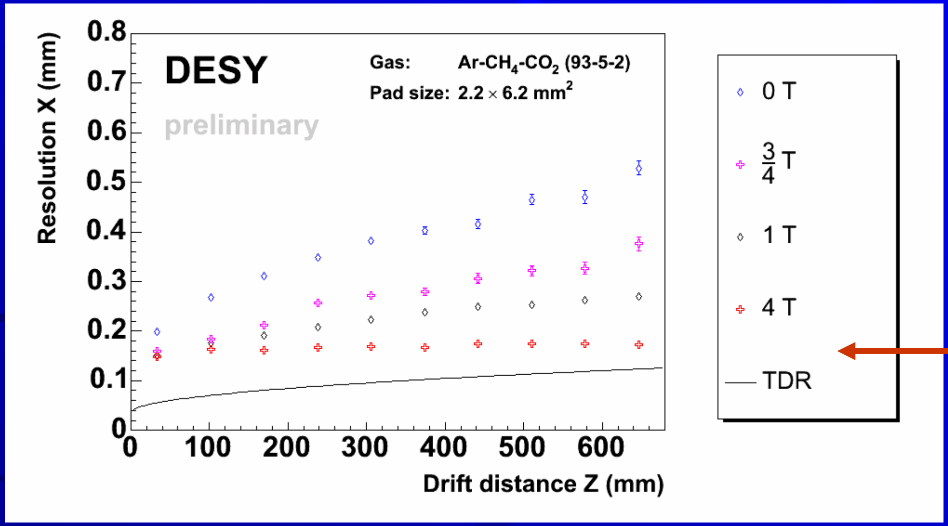
--Diffusion measurements ⇒ σ_pt < 100μm possible

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

--Analysis continuing…

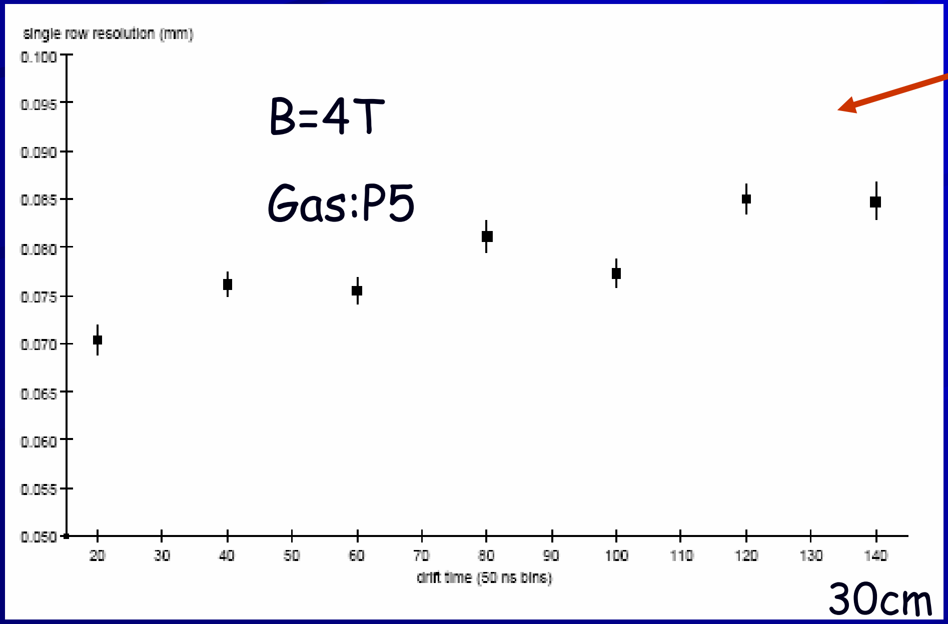
Prototype Results

Point resolution, Gem



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

--In Desy chamber (triple Gem), method of fitting track without one padrow whose hit is compared with track (overestimate of σ_pt).



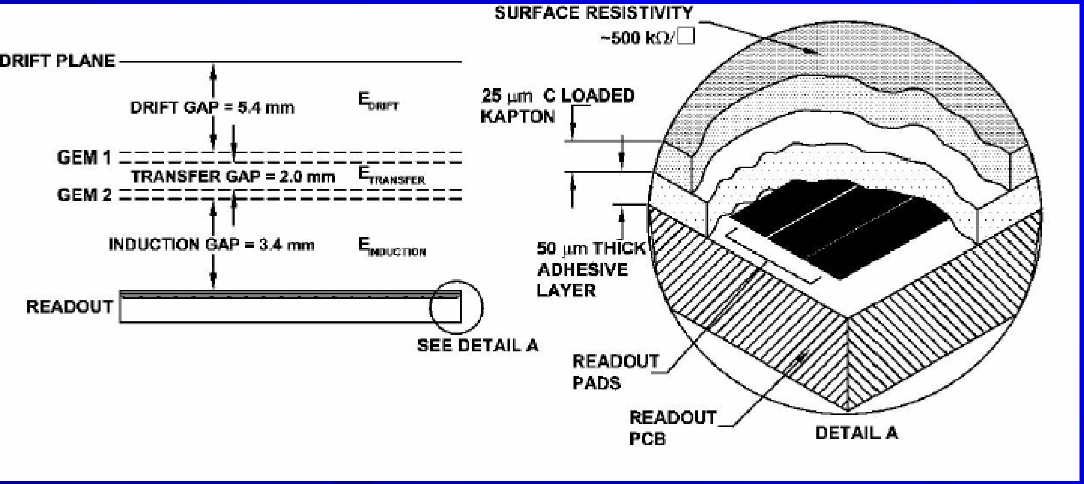
--In Victoria chamber (double Gem), unbiased method used: track fit twice, with and without padrow in question, σ determined for each case; geometric mean of the two σ's gives the correct result.

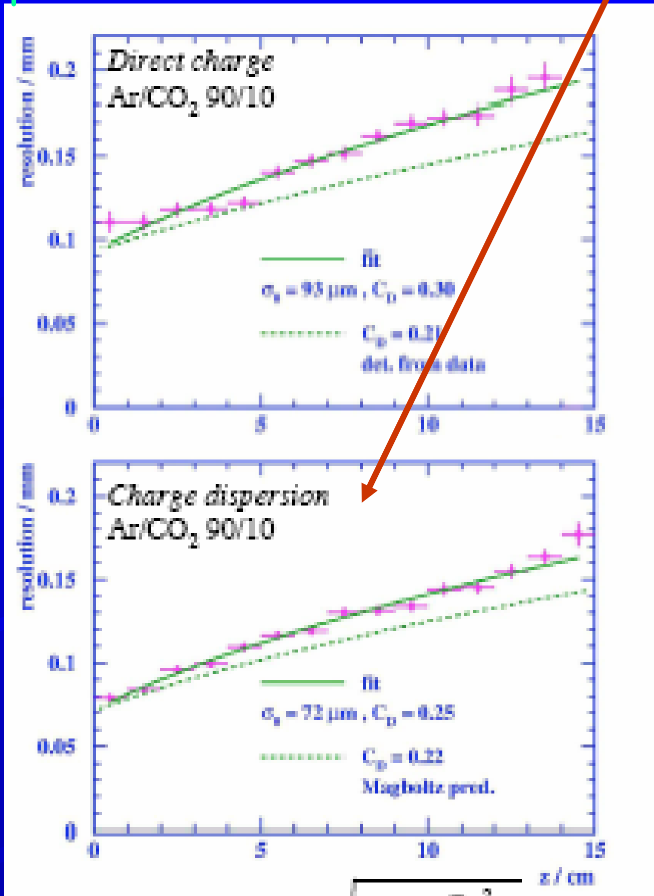
--In general (also for Micromegas) the resolution is not as good as simulations expect; we are searching for why (electronics, noise, method).

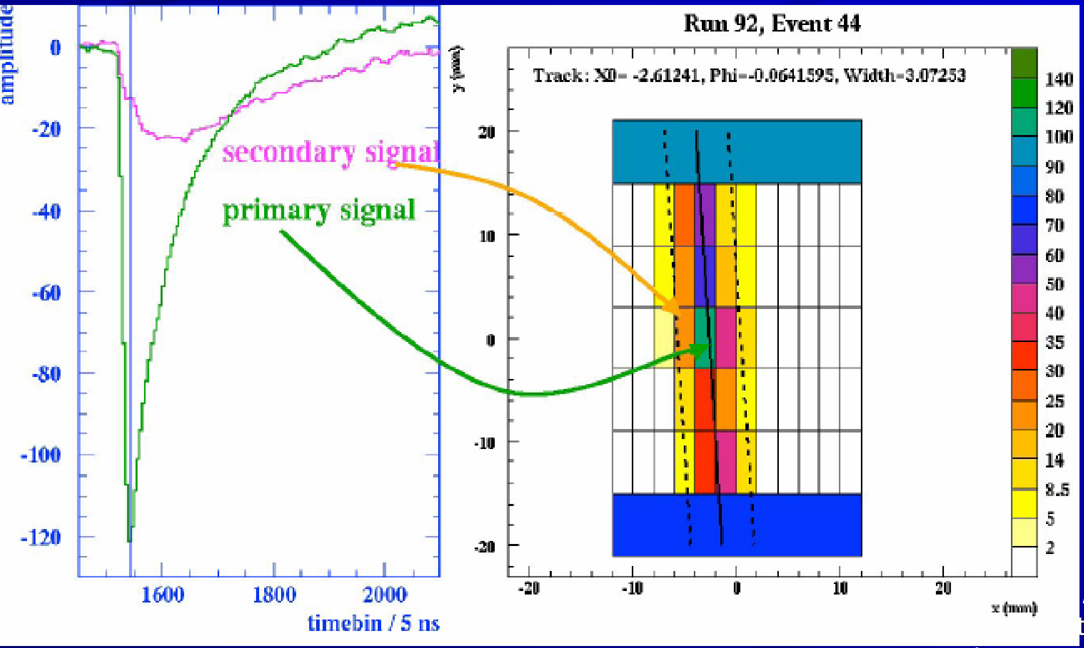
Prototype Results

Improving point resolution with resistive foil

Carleton work. Charge dispersion via resistive foil improves resolution: for B=0

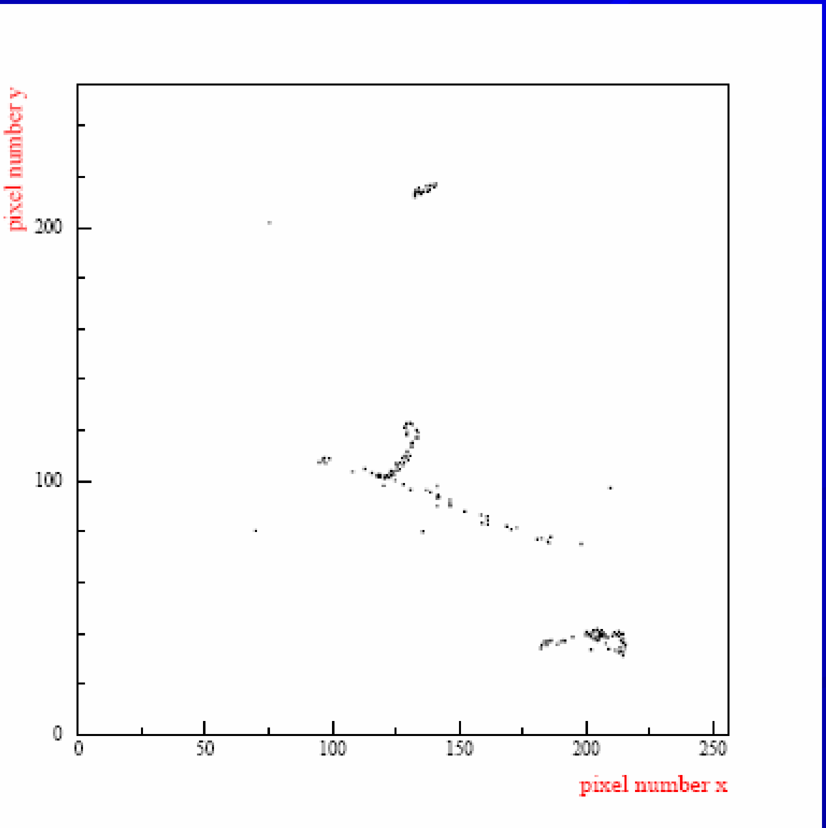






$$\sqrt{\sigma_0^2 + \frac{C_D^2}{N_e} z}$$

Medipix2+Micromegas: results

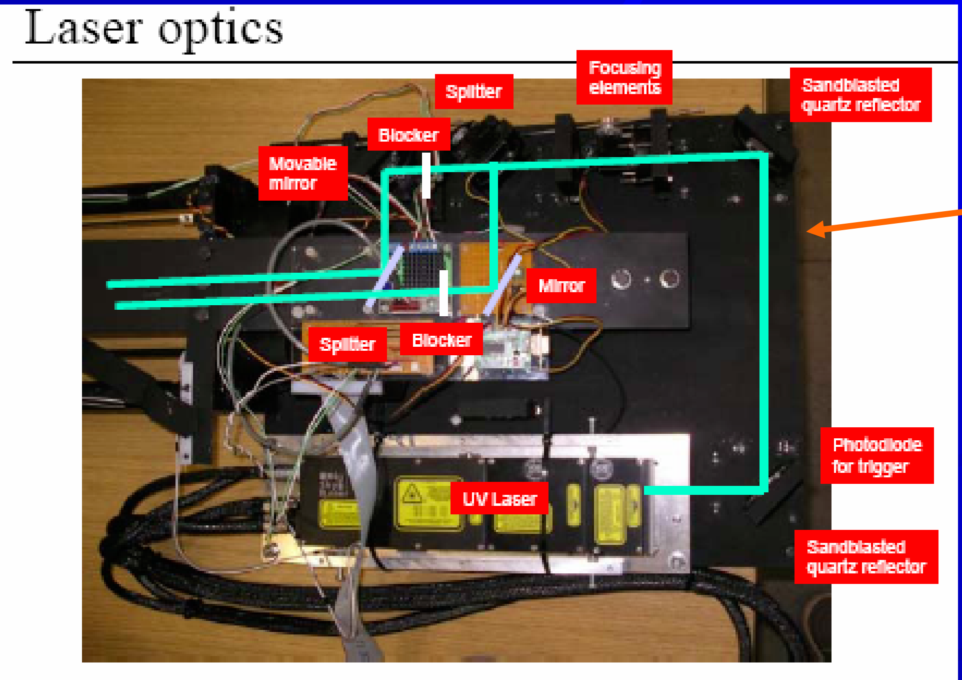


--Single-electron sensitivity demonstrated: Fe55 source, open30s/close, He/20%Isobut., threshold=3000e, gain=19K (-470V Mmegas), -1kV drift

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

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

Two-track resolution studies

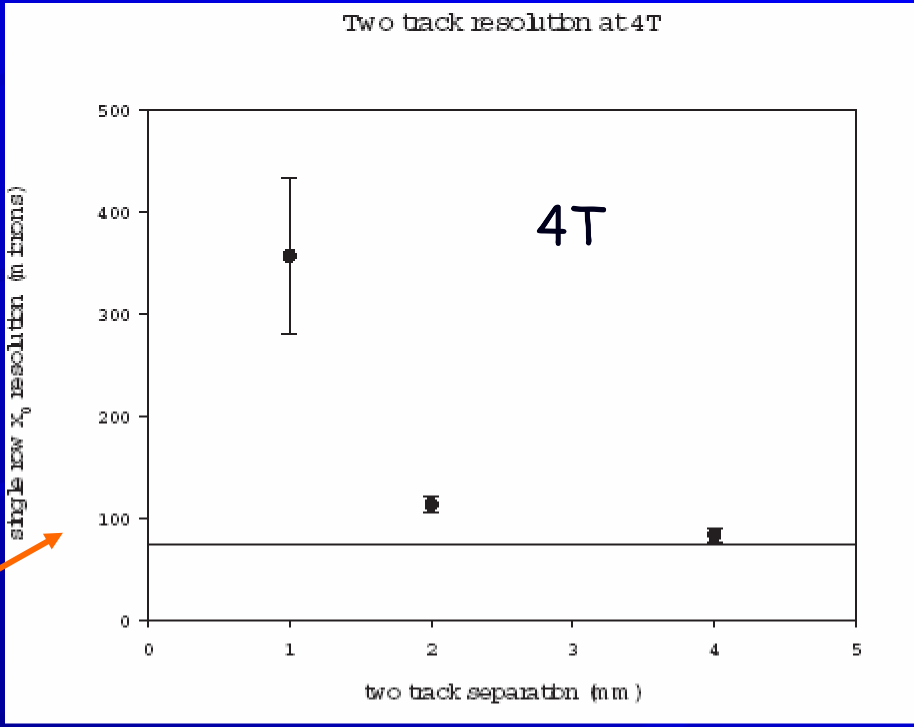


Studies just starting.

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.



Operational experience

- No systematic statistics yet
- Several groups have had problems with sparking (with both Gems and Micromegas)
- But it is too early to take this seriously (I had similar problems with Aleph)
- Needs systematic study (to avoid an msgc-type problem)...

Other activities:

MIT	Lorentz-angle meas., Gas studies, Gem resolution/manufacturing
Cornell	Simulation of pad size, resolution needed
Purdue	Gem manufacture together with 3M company
Cornell/ Purdue	Manufacture of prototype for studies

General Happenings…

- Steering group takes care of workshop/conference talks, phone/video meetings, contact with other labs, etc.
- Video, VRVS/phone TPC R&D meetings every few months
- Task-sharing among groups is very fruitful and productive, e.g.

  --LBNL providing Star electronics for Canadian, French, German labs
  --MPI providing Aleph electronics for Asian, Canadian, German labs
  --DESY 5T magnet to be used by Canadian and German groups
  --Saclay 2T magnet to be used by North American and French groups
  --Test beams in DESY and KEK being used by Asian. Canadian, German labs
  --MicroMEGAS work by Canadian, French and US groups
  --GEM progects by Canadian, German, Russian and US groups
  --Fieldcage studies started in Russia and Germany
  --Electronics work in Canada, Germany, Holland, France
  --Endplate mechanics/cooling studied by German, French groups

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.

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

Requests

- Continued support of PRC
- Positive recommendations to funding agencies
- PRC support for globalization of R&D
- Test beam facilities for next 3 years

TPC milestones

2005	Continue testing, design large prototype
2006-2007	Test large prototype, decide technology
2008	Proposal of/final design of LC TPC
2012	Four years for construction
2013	Commission TPC alone
2014	Install/integrate in detector