Gaseous Tracker R&D

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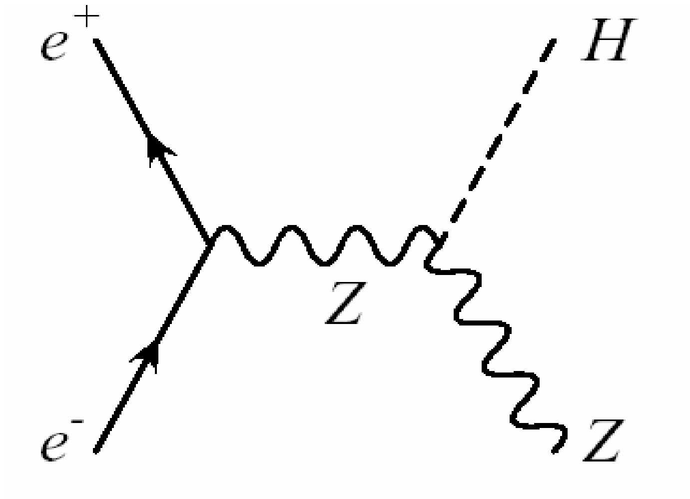
ILC Physics Motivation

- Critical to fully understanding LHC physics results.
- Model independent Higgs measurements including invisible decays of the Higgs:
  - $e^+ e^- \to Z^\circ H^\circ$ or $Z^\circ Z^\circ$
  - Measure recoil mass against $Z^\circ \to l^+ l^-$

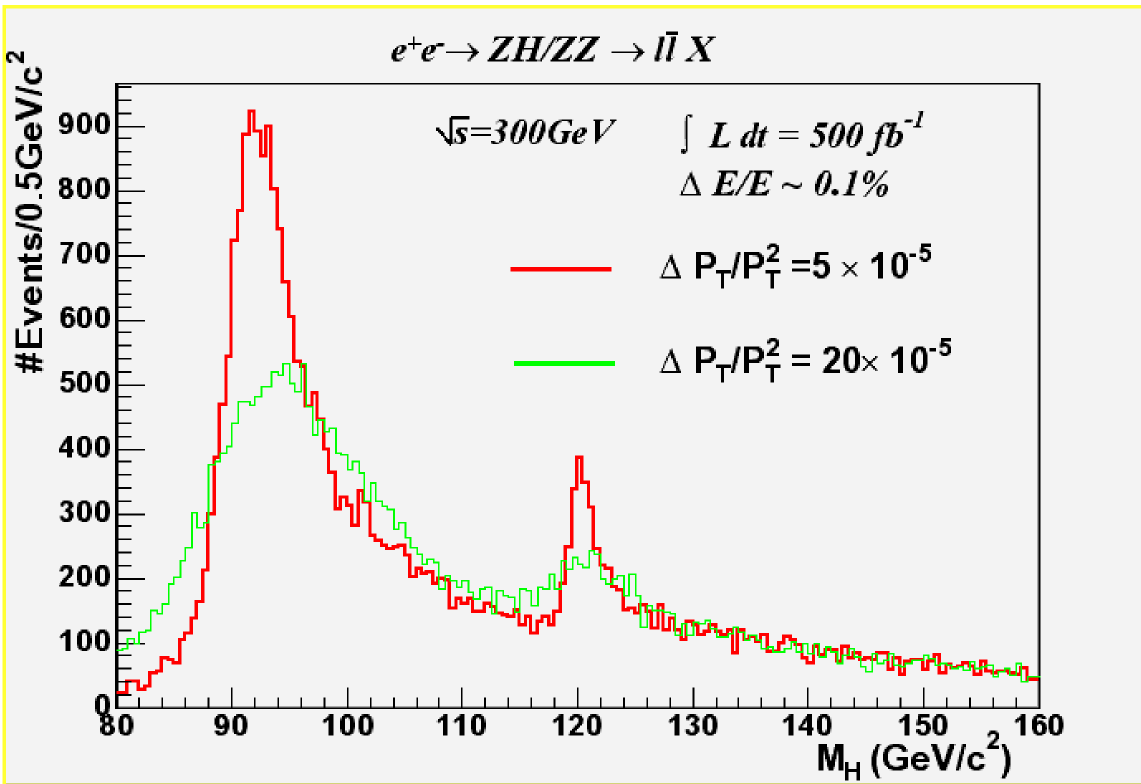


- Precision measurements
  - $\Delta M_{Top} \approx 100$ MeV, $\Delta\Gamma_{Top} \approx 2\%$
  - ΔM_Z & $\Delta M_W \approx 5$ MeV (from 30 MeV)
  - $\Delta(\sin^2\vartheta) \approx 10^{-5}$ (from $2\cdot10^{-4}$)
- Cover any LHC blindspots

ILC tracker resolution driver

Measure Higgs recoil mass accuracy limited by beam energy spread.

$\Delta(1/p_T) \sim 3 \times 10^{-5}$ (GeV/c)$^{-1}$ (more than 10 times better than at LEP!)



M_H = 120 GeV/c^2

ILC tracker performance requirements

- Small cross sections < 100 fb, low rates, no fast trigger.
- Higgs measurements & SUSY searches require:
  - **Good particle flow measurement.**
  - **Minimum material before calorimeters.**
  - **Good pattern recognition**
  - **Excellent primary and secondary b, c, τ decay vertex reconstruction**.
- TPC an ideal central tracker for ILC - low mass, high granularity continuous tracking for superior pattern recognition.

  $\Delta(1/p_T) \sim 1 \times 10^{-4}$ (GeV^{-1}) (TPC alone)

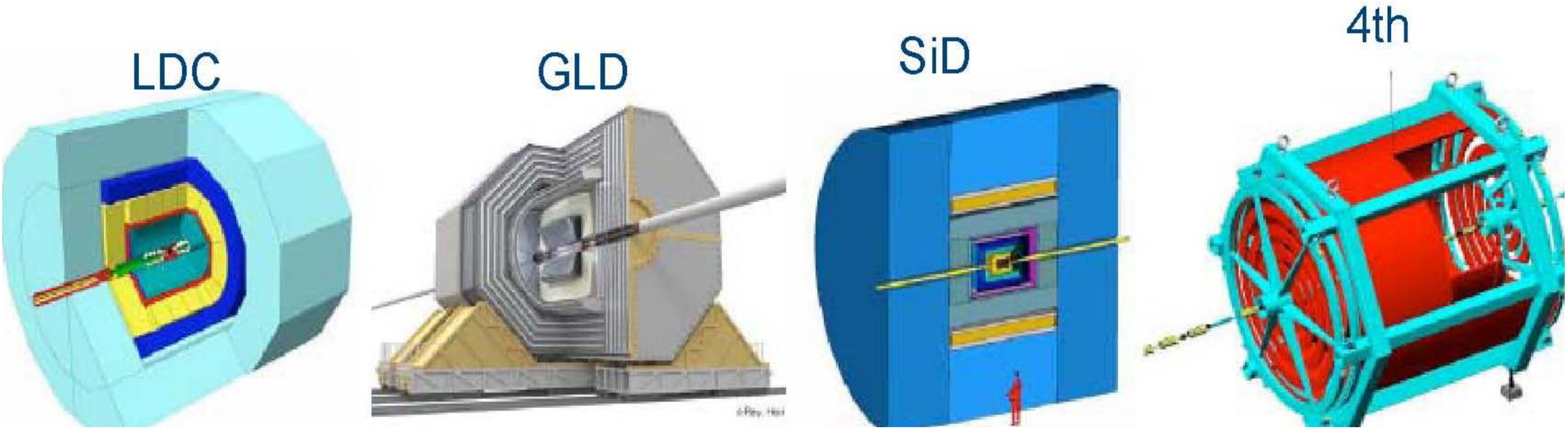
  $\sim 3.10^{-5}$ (GeV^{-1}) (vertex + Si inner tracker + TPC)
- TPC parameters:

  ~ 200 track points; $\sigma(r, \varphi) \sim 100$ μm & $\sigma(z) \sim 500$ μm

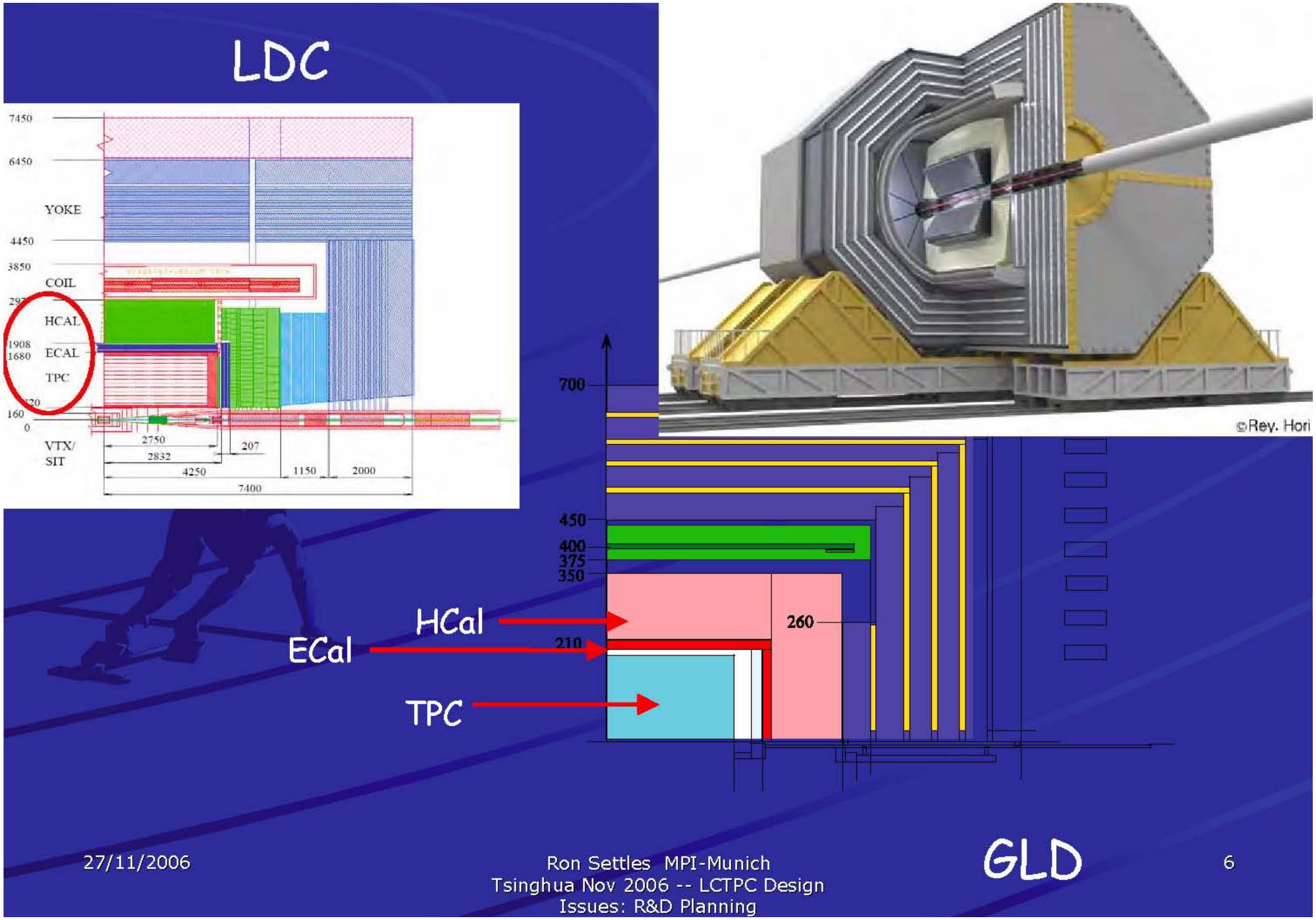
  2 track resolution ~ 2mm (r, φ) & ~ 5 mm (z)

  dE/dx ~ 5%

TPC tracker part of 3 ILC detector concepts



TPC (B=4T) TPC (B=3T) Silicon (B=5T) TPC (B=3.5 T)

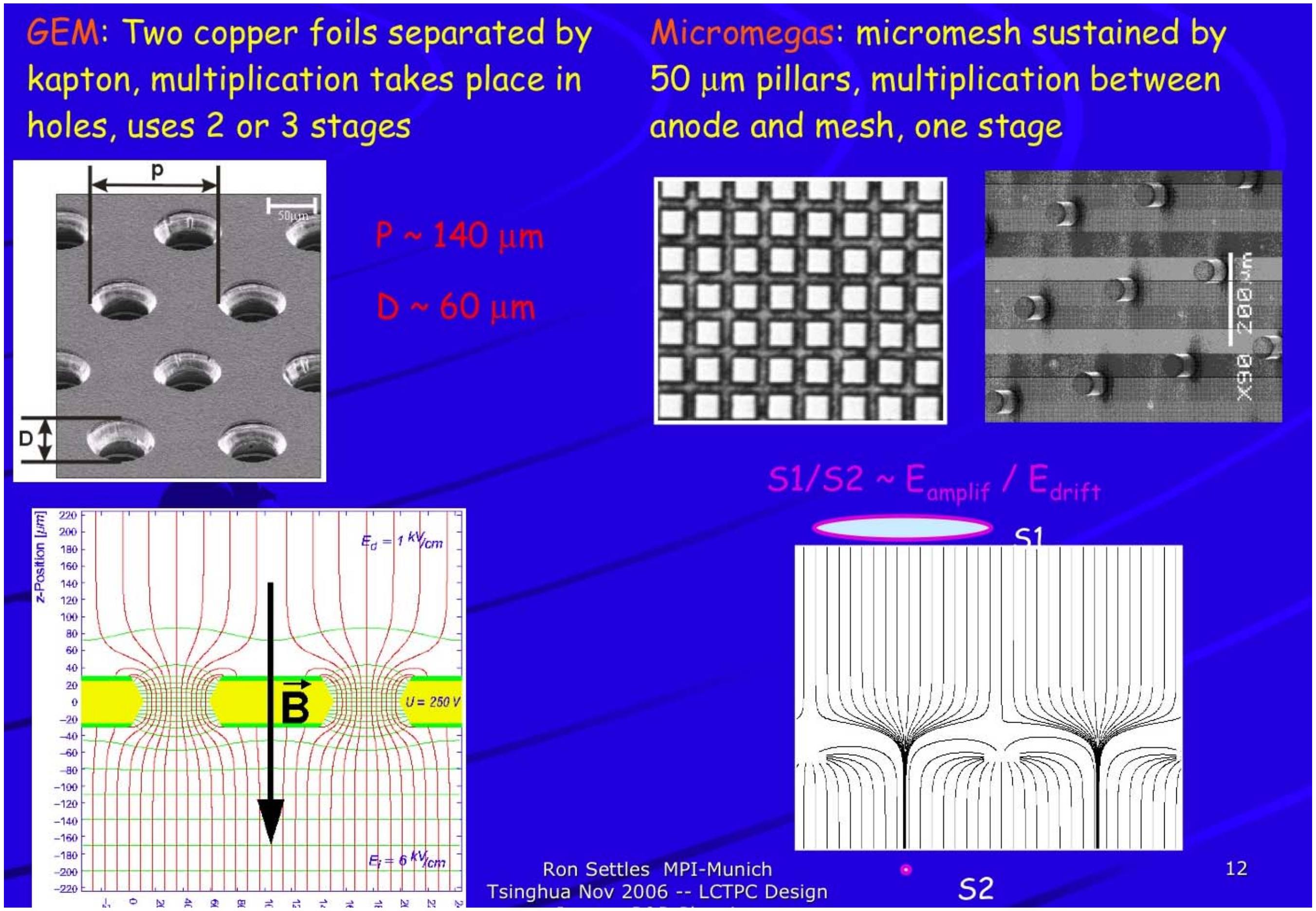


TPC ~ 2 m max. drift, 1.8 m radius

ILC challenge: σ_{Tr} ~ 100 μm (all tracks 2 m drift)

Classical anode wire/cathode pad TPC limited by ExB effects

Micro Pattern Gas Detectors (MPGD) not limited by ExB effect



Worldwide R&D to develop MPGD readout for the ILC TPC

LCTPC/LP Groups (19Sept06)

Americas

Carleton
Montreal
Victoria
Cornell
Indiana
LBNL
Purdue (observer)

Asia

Tsinghua
CDC:
Hiroshima
KEK
Kinki U
Saga
Kogakuin
Tokyo UA&T
U Tokyo
U Tsukuba
Minadano SU-IIT

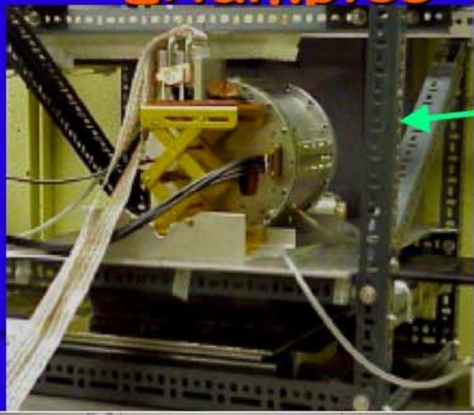
Europe

LAL Orsay
IPN Orsay
CEA Saclay
Aachen
Bonn
DESY
U Hamburg
Freiburg
MPI-Munich
TU Munich (observer)
Rostock
Siegen
NIKHEF
Novosibirsk
Lund
CERN

Other groups

MIT
MIT (LCRD)
Temple/Wayne State (UCLC)
Yale
Karlsruhe
UMM Krakow
Bucharest

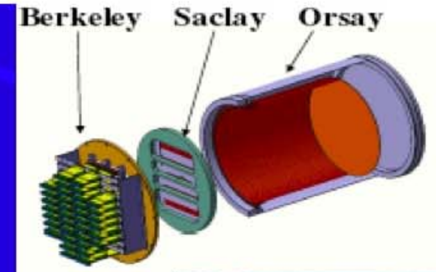
Examples of Prototype TPCs

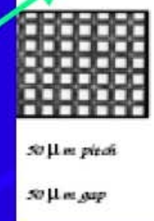


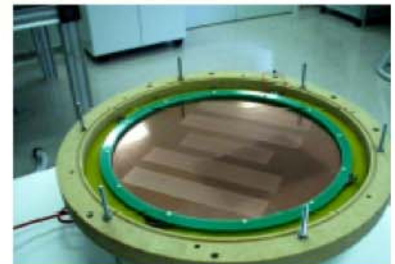
Carleton, Aachen,
Cornell/Purdue,Desy(n.s.)
for B=0or1T studies

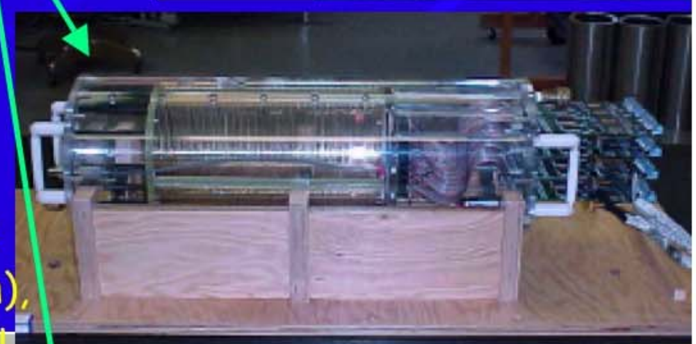
Saclay, Victoria, Desy
(fit in 2-5T magnets)

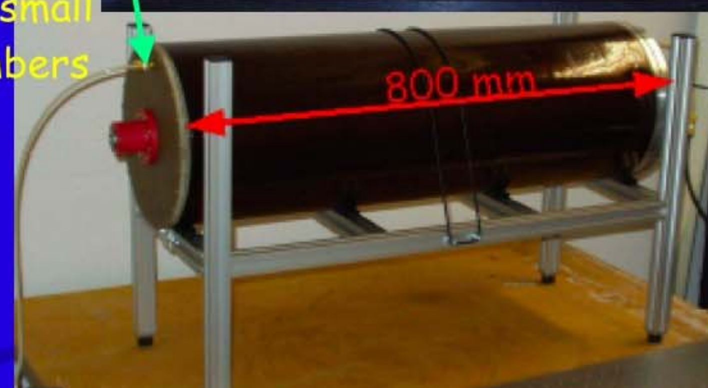
Karlsruhe, MPI/Asia,
Aachen built test TPCs
for magnets (not shown),
built small
chambers







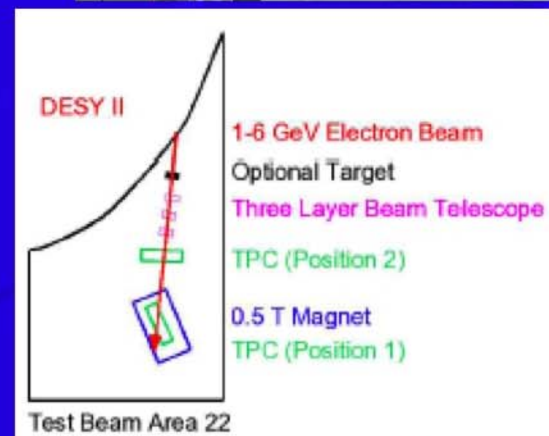




Facilities

Cern test-beam (not shown)

EUDET



R&D Planning

- 1) Demonstration phase
  - Continue work with small prototypes on mapping out parameter space, understanding resolution, etc, to prove feasibility of an MPGD TPC. For CMOS-based pixel TPC ideas this will include proof-of-principle tests.
- 2) Consolidation phase
  - Build and operate the Large Prototype (LP), Ø ~ 80cm, drift ~ 60cm, with EUDET infrastructure as basis, to test manufacturing techniques for MPGD endplates, fieldcage and electronics. LP design is starting → building and testing will take another ~ 3-4 years.
- 3) Design phase
  - During phase 2, the decision as to which endplate technology to use for the LC TPC would be taken and final design started.

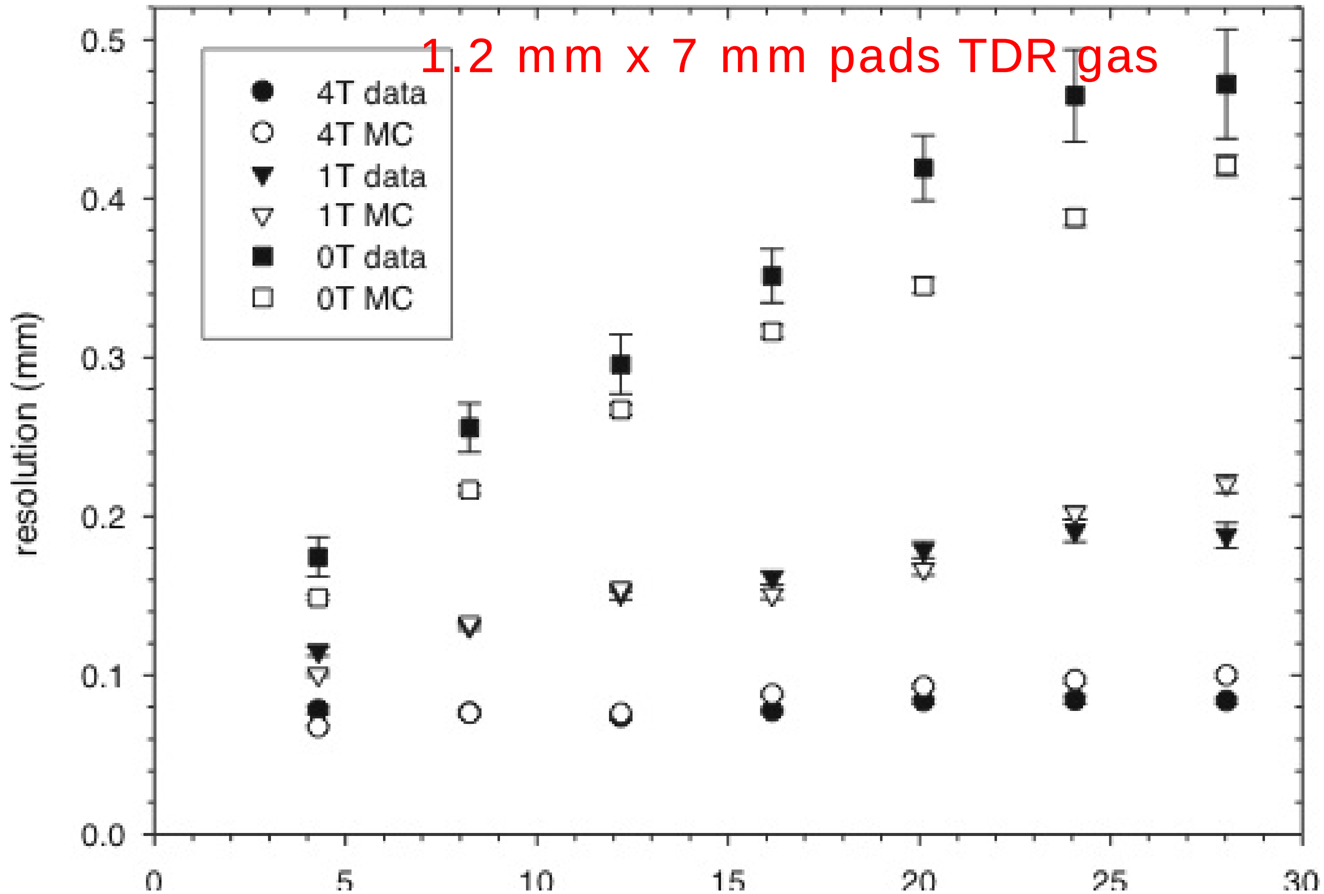
Demonstration phase R&D with small prototypes

- Many groups working on GEMs & Micromegas.
- Point resolution as a function of readout pad width
- Techniques to improve resolution for wide pads
    - Increased diffusion after avalanche gain in GEM
    - New concept of charge dispersion for Micromegas
- Resolution with cosmics for B = 0 & up to 5 T.
- 6 GeV electron beam tests & with hadrons to 9 GeV
- Two track resolution studies using a laser
- Ion feedback studies
- Gas studies for better resolution & for reduced neutron induced backgrounds
- Aging studies.
- Development of analysis and simulation software.

R&D summary to date

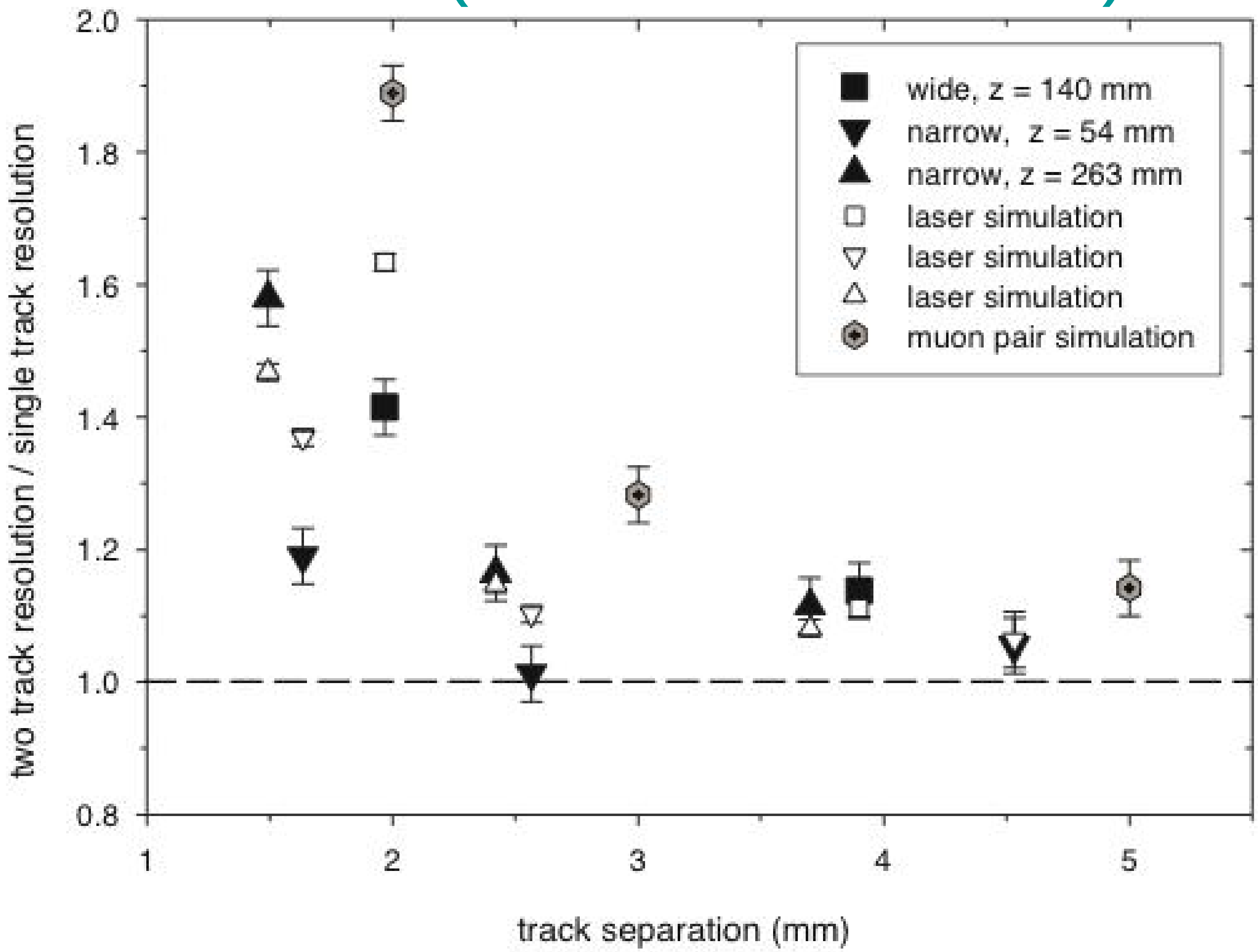
- 4 years of R&D with GEMs & Micromegas
- Gas properties well understood
- Diffusion limit of best achievable resolution understood
- GEM-TPC requires ~ 1 mm or narrower pads for good resolution
- Micromegas-TPC can achieve good resolution with wider pads using the new concept of charge dispersion readout.
- Digital readout TPC concept with CMOS pixels demonstrated
- Work starting on the Large Prototype TPC (LP)
- A selection of small prototype test results……

Transverse resolution vs. B field
(Victoria GEM-TPC, DESY magnet)



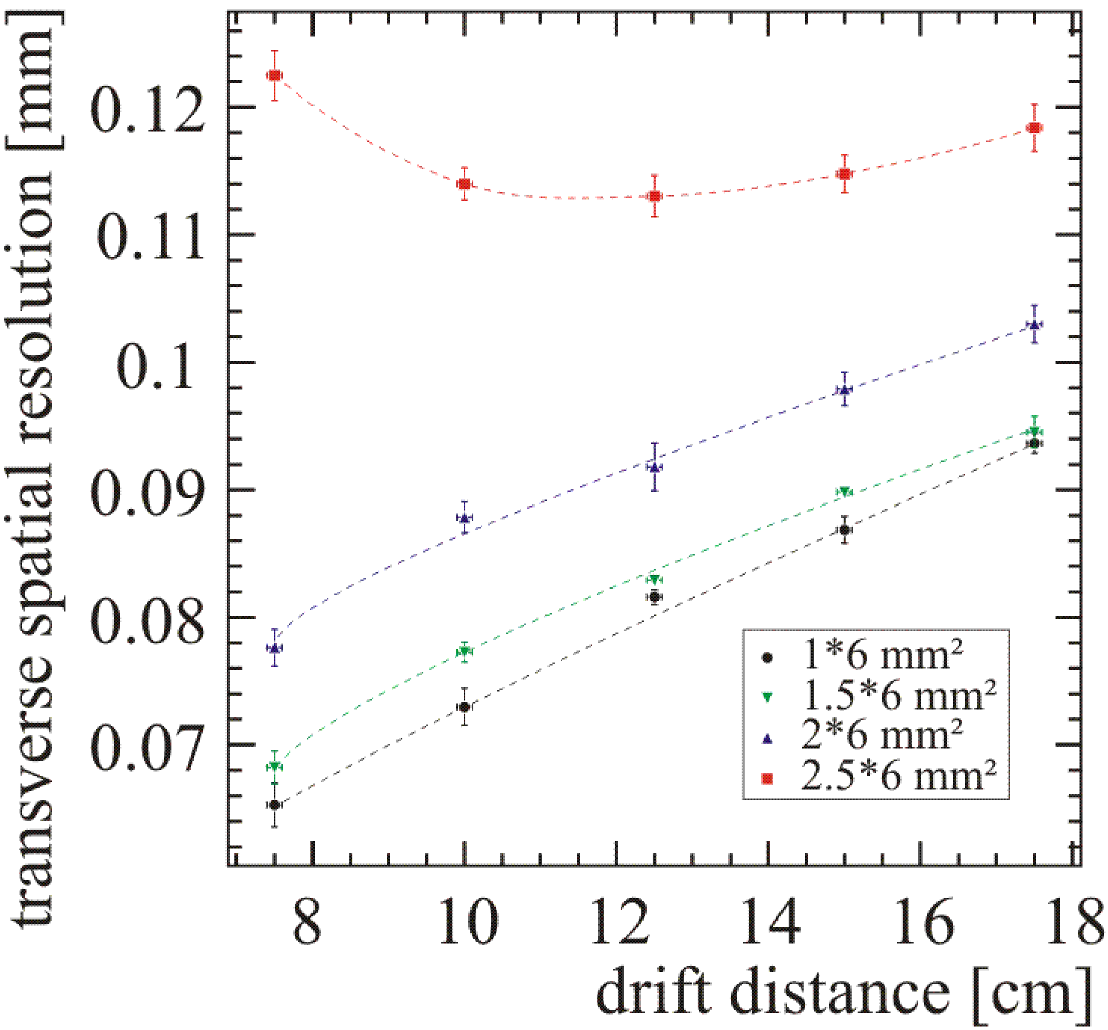
Resolution gets better with B & for smaller width pads

Transverse 2-track resolution measured with a laser (Victoria GEM-TPC)



Good resolution achieved for tracks separated by > 1.5 x pad width

GEM-TPC DESY 5.2 GeV electrons B= 1 T, P5 gas (Aachen group)

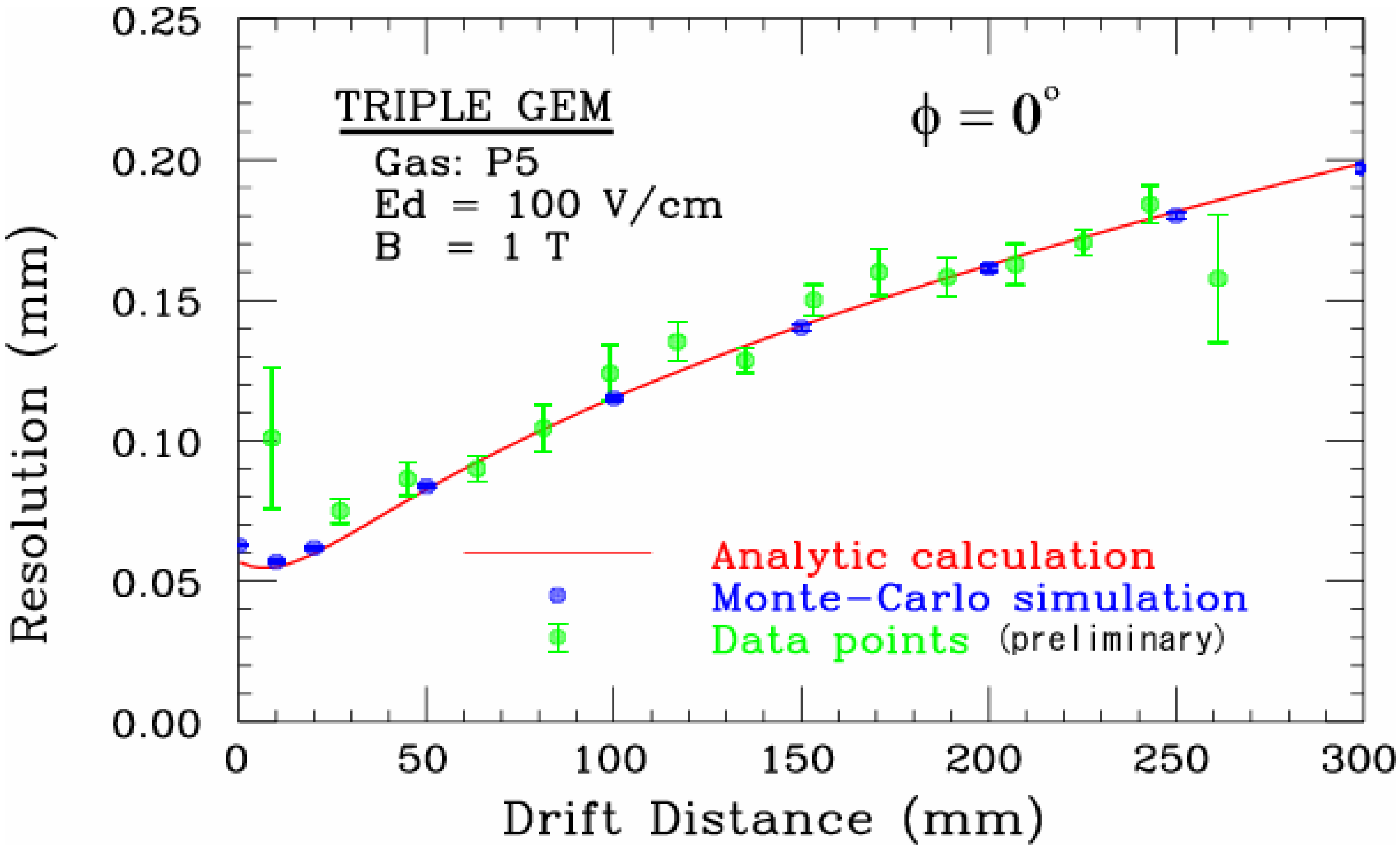


Better resolution for ~ 1 mm width pads.

GEM readout MP TPC

(1.27 mm x 6.3 mm pads)

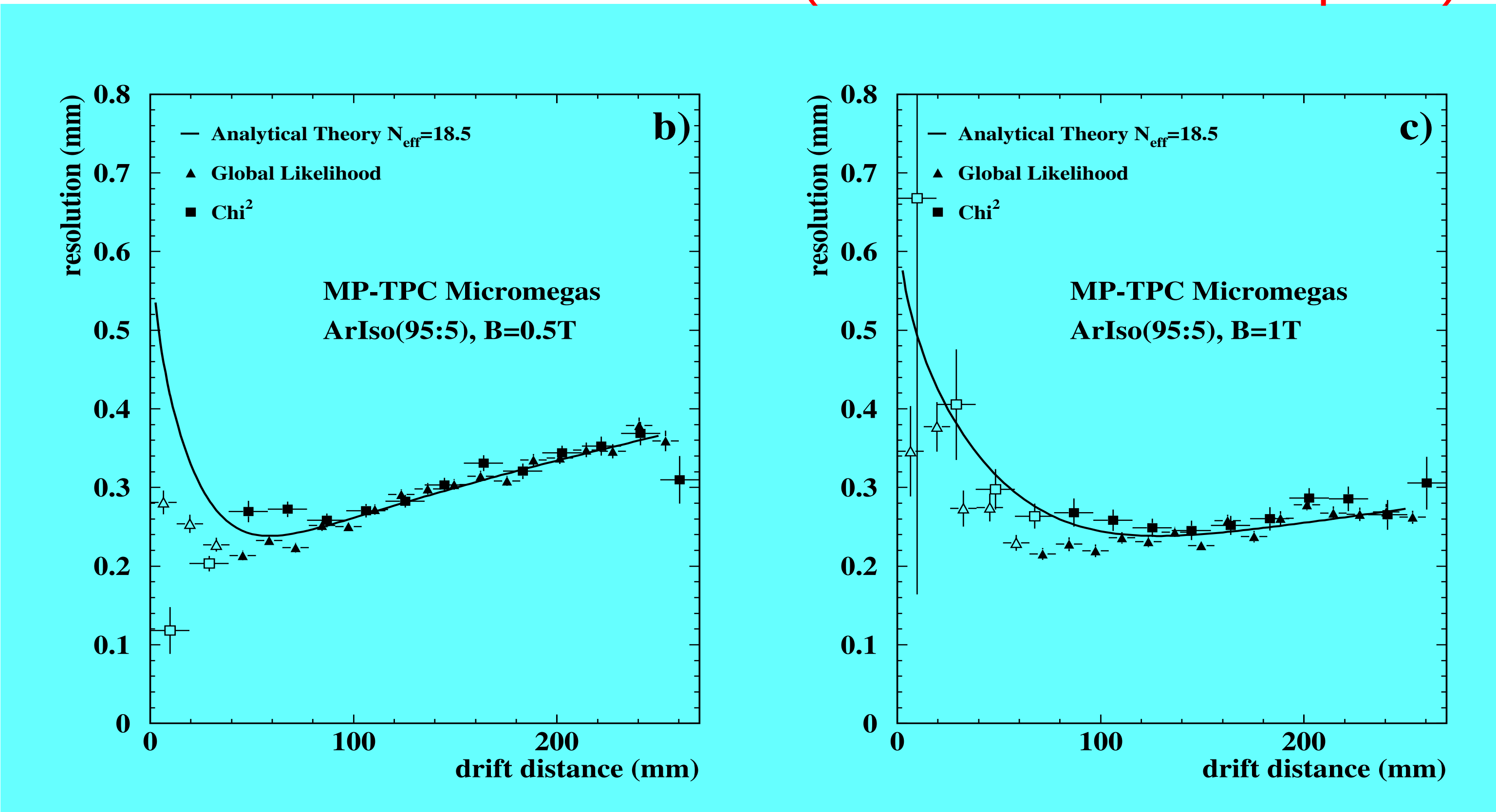
KEK PS 4 Gev/c hadron test beam



Presented at IEEE San Diego 2006 (Makoto Kobayashi)

MP-TPC with Micromegas readout Resolution at B=0.5 and 1T

KEK PS 4 Gev/c hadron test beam -(2.3 mm x 6.3 mm pads)



Presented at IEEE 2006, San Diego (Colas)

Resolution at short drift limited by pad width

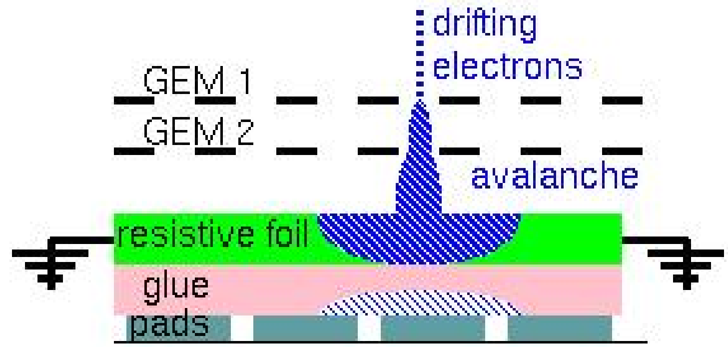
Charge dispersion in a MPGD with a resistive anode

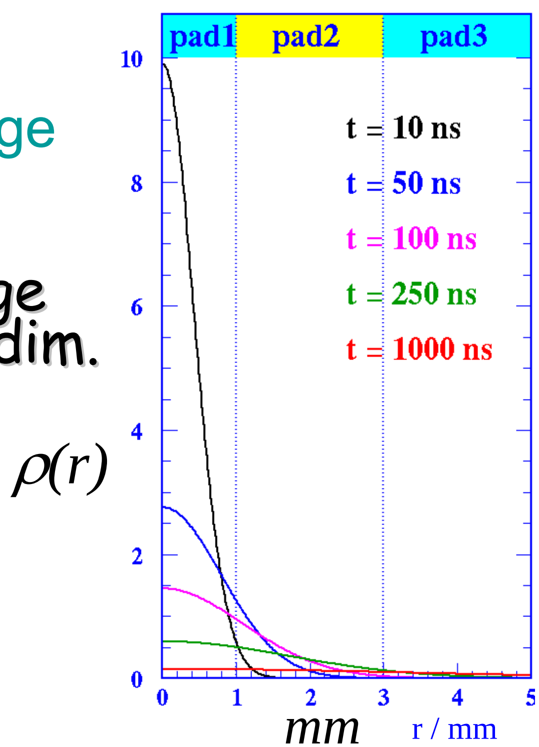
- Modified GEM anode with a high resistivity film bonded to a readout plane with an insulating spacer.
- 2-dimensional continuous RC network defined by material properties & geometry.
- Point charge at r = 0 & t = 0 disperses with time.
- Time dependent anode charge density sampled by readout pads.

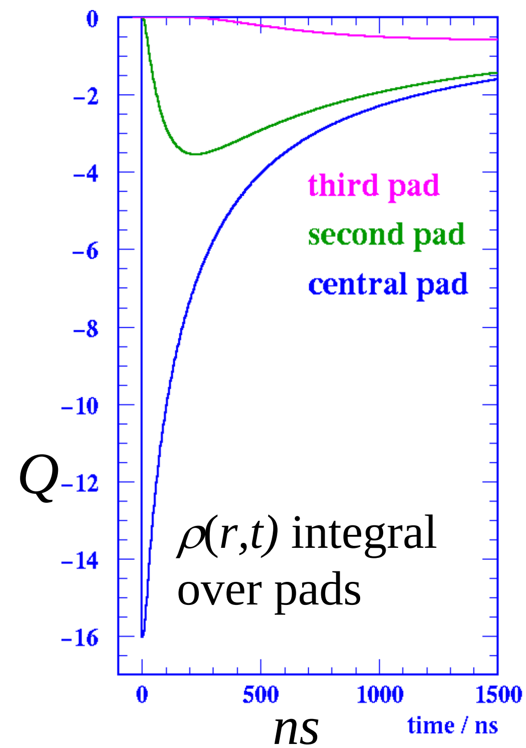
Equation for surface charge density function on the 2-dim. continuous RC network:

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

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



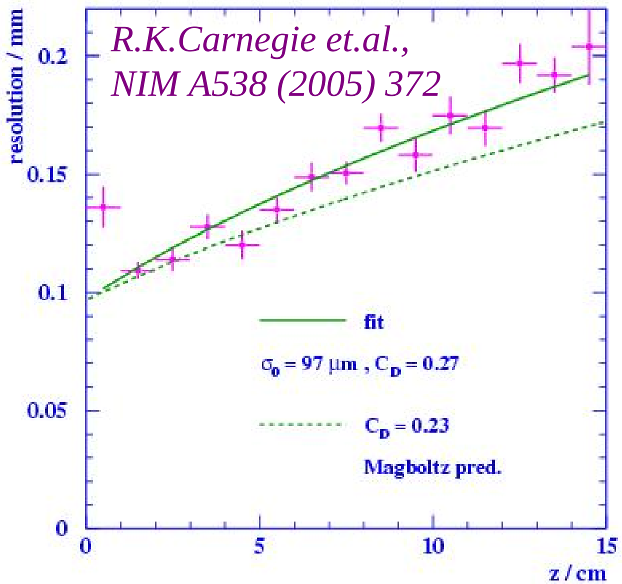




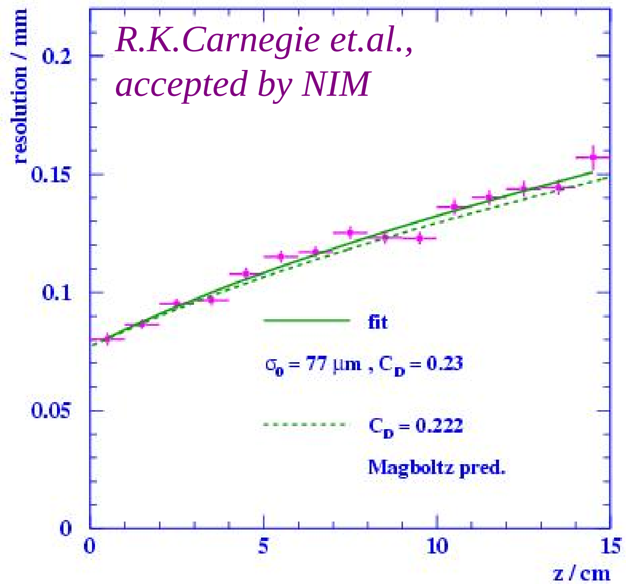
TPC transverse resolution with cosmic rays

B = 0, Ar:CO2 (90:10) 2 mm x 6 mm pads

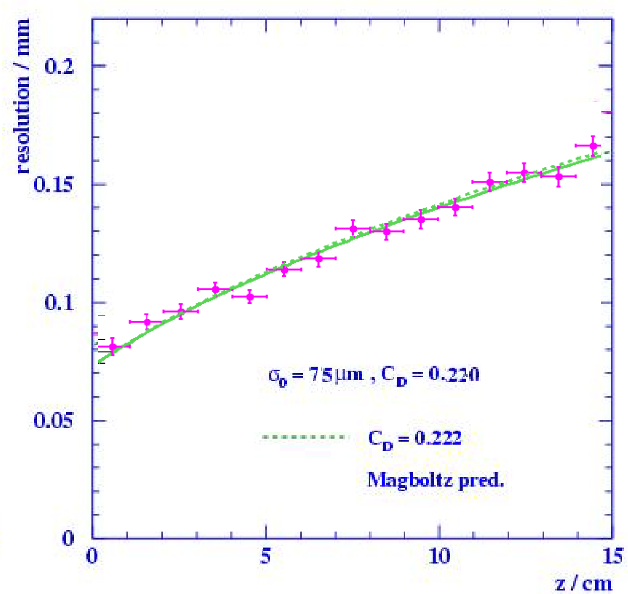
Standard GEM readout



GEM with charge dispersion readout



Micromegas with charge dispersion readout

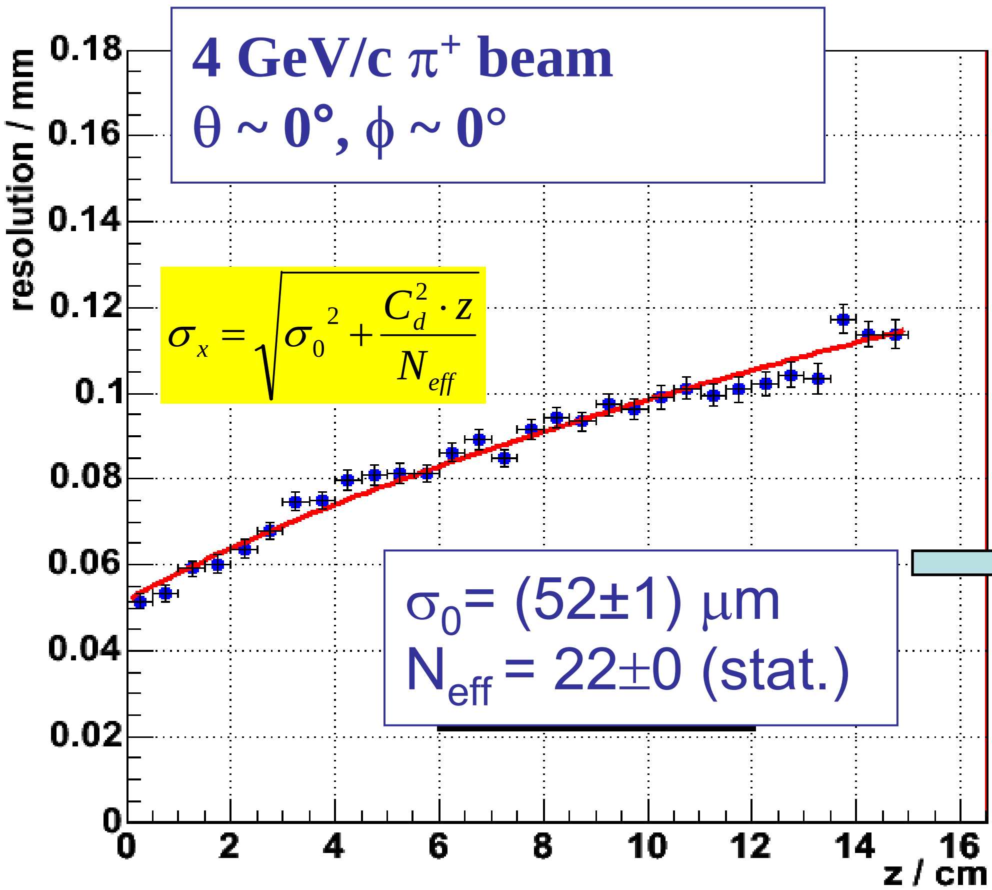


$$\sqrt{\sigma_0^{\,2} + \frac{C_D^{\,2}}{N_e} z}$$

Compared to standard readout, charge dispersion readout gives better resolution for the GEM and the Micromegas readout.

Transverse spatial resolution Ar+5%iC4H10 E=70V/cm D_{Tr} = 125 μm/√cm (Magboltz) @ B= 1T

Micromegas TPC 2 x 6 mm^2 pads - Charge dispersion readout



- **Strong suppression of transverse diffusion at 4 T.**

Examples:

D_{Tr}~ 25 μm/√cm (Ar/CH4 91/9) Aleph TPC gas

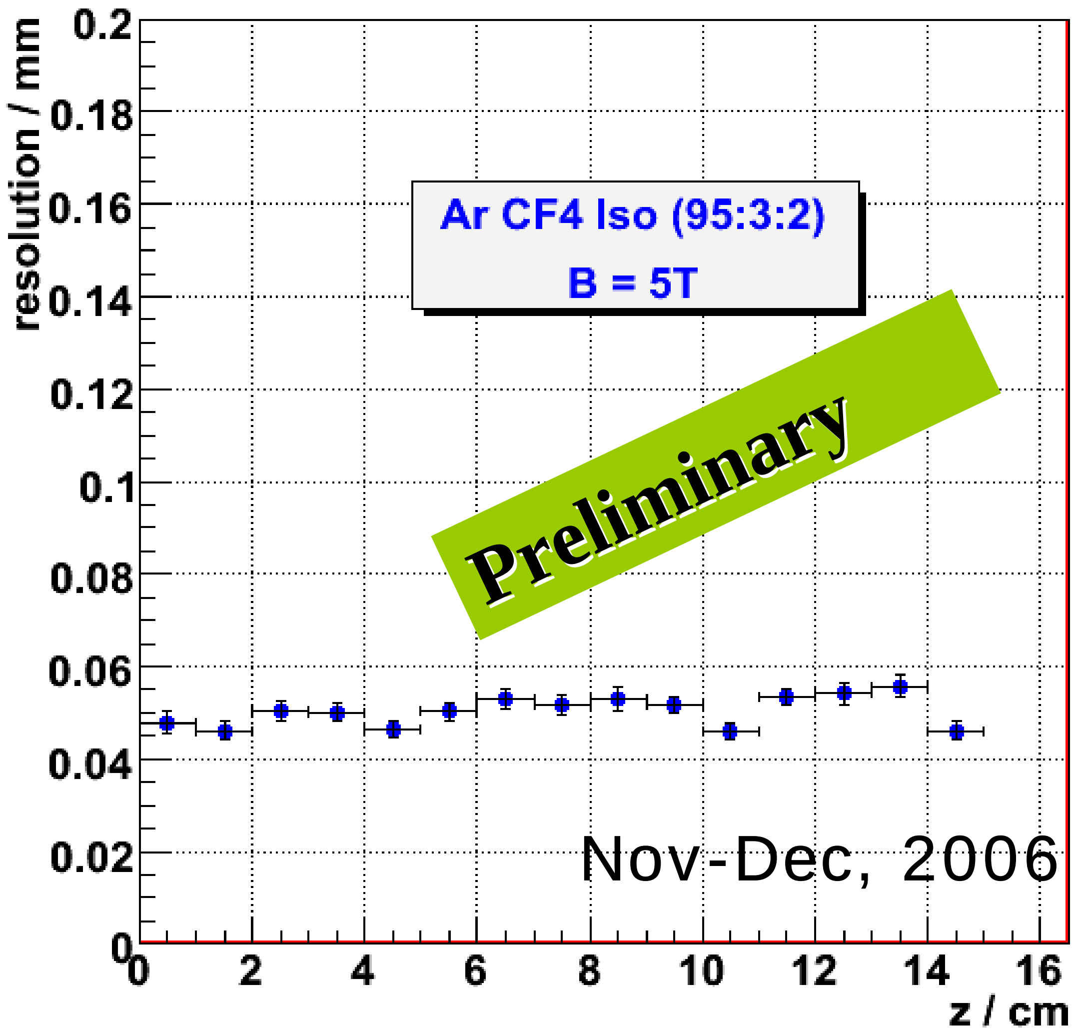
~ 20 μm/√cm (Ar/CF4 97/3)

Extrapolate to B = 4T
Use D_{Tr} = 25 μm/√cm
Resolution (2x6 mm^2 pads)
σ_{Tr} ≈ 100 μm (2.5 m drift)

Confirmation - 5 T cosmic tests at DESY

COSMo (Carleton, Orsay, Saclay, Montreal) Micromegas TPC

D_{Tr}= 19 μm/√cm, **2 x 6 mm² pads**



~ 50 μm av. resolution (diffusion negligible over 15 cm)

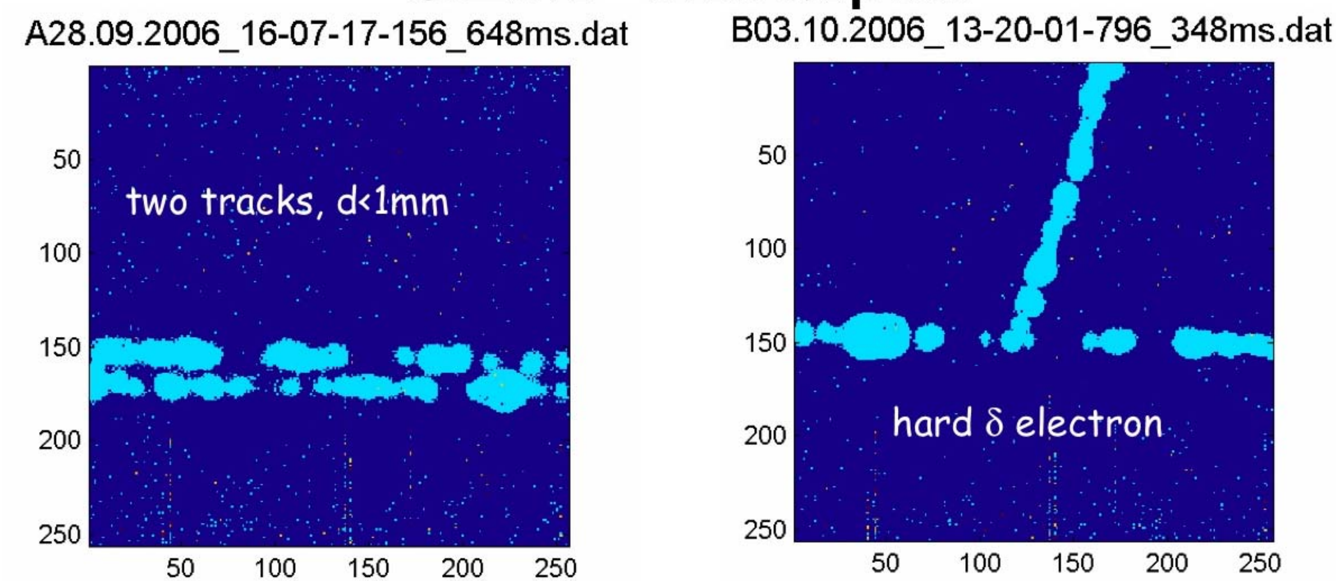
100 μm over 2 meters appears feasible

(~ 30 μm systematics Aleph TPC experience)

Digital TPC readout with CMOS Pixels

4. Testbeam at DESY: 3-GEM+Medipix

Freiburg
Bonn



Lots of data to be analyzed
Still the same Medipix chip as 1.5 years ago
Prepare for Testbeam with Timepix in same setup a.s.a.p.

Phase II - Measurements with Large Prototype

- LP will be used for:
  - Sector/panel shapes & pad geometry
  - Gas studies
  - Positive ion space charge effects & gating schemes
  - LCTPC electronics
  - Choice of technology GEMs or MicroMegas
- Finally, the LP will be used to confirm that the ILC-TPC design performance can be reached at high magnetic field.
  - Momentum resolution ~ $\Delta(1/p_T)$ ~ 1 x 10^{-4} (GeV^{-1})
  - 2 track resolution ~ 2mm (r, φ) & ~ 5 mm (z)
  - dE/dx ~ 5%

Test beam facilities - the gaseous tracker wish list

- Next 2-3 years - Eudet infrastructure gets us started:
  - 6 GeV electrons at DESY, B = 1 Tesla (PC magnet)
- Need for tests with hadron beams after initial tests.
- Momentum $\geq$ 50 Gev/c, wide or narrow (~1%) momentum bites
- Mixed hadron beams, particle ID if possible (for dE/dx)
- Intensity - variable from low to high
- External high resolution silicon tracker
- Particle multiplicity trigger.
- Large volume high field magnet, with B ~ 2 T and above
- Ability to rotate and, translate the magnet platform

Summary

Good progress in all areas with small prototype TPCs
R&D so far indicates that ILC resolution goal of 100 μm can be achieved.
Large Prototype (LP) being developed & will be used to confirm the viability of the ILC TPC performance goals
Further measurements in test beams will be used to come up with the ILC-TPC design parameters
TPC milestones

2006-2010	Continue LCTPC R&D via small-prototypes and LP tests with cosmics and test beams
2010	Decide on TPC parameters
2011	Final design of the LCTPC
2015	Four years construction
2016	Commission/Install TPC in the LC Detector