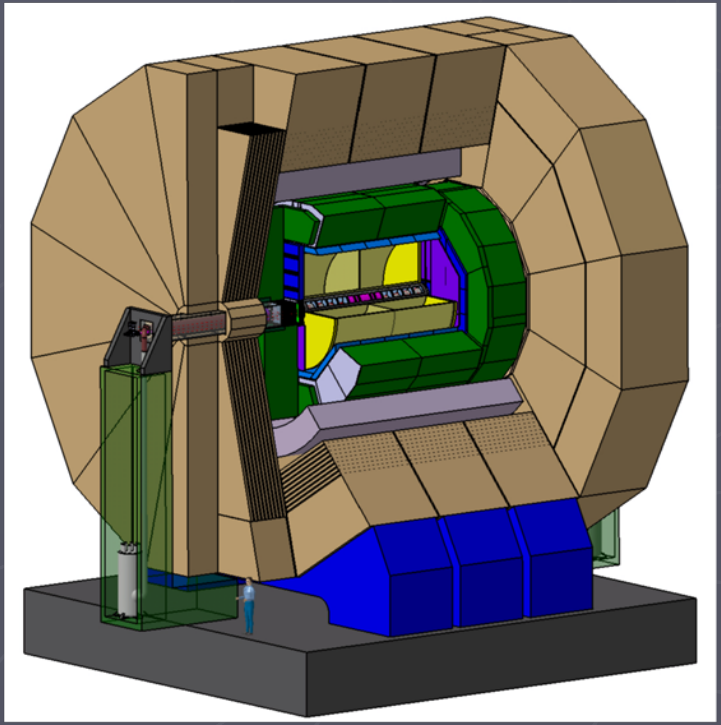
Beam Test Results of a GEM Large TPC Prototype Readout by New ATRLO Electronics

Current Status

LC TPC Collaboration

Presented by
Takeshi Matsuda
LC TPC Asian Group
(DESY/KEK)
@MPGD2009



Proposed ILD Detector

Tracking at ILC: Momentum Resolution

ILC-RDR
LDC LOI

1. **Higgs recoil mass: $e^+e^- \rightarrow ZH\ (Z \rightarrow \mu\mu/ee) + X$:**
   If $\delta M(\mu\mu/ee) << \Gamma_z$, then the beam energy spread dominates when $\delta(1/pt) \leqq 5 \times 10^{-5}$.
2. **Slepton and the LSP masses though the end point measurement:**
   σM (Momentum resolution) ~ σM (Parent mass) at 1 ab^{-1}
   when $\delta(1/pt) \leqq 5 \times 10^{-5}$
3. **E_{cm} determination from $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$:**
4. **Rare decay Br ($H \rightarrow \mu\mu$) in $e^+e^- \rightarrow ZH$ and $H\nu\nu$:**

$\delta(1/pt) \leqq 5 \times 10^{-5}$

ILD example for 1.
$\Delta M_H \sim 70$ MeV

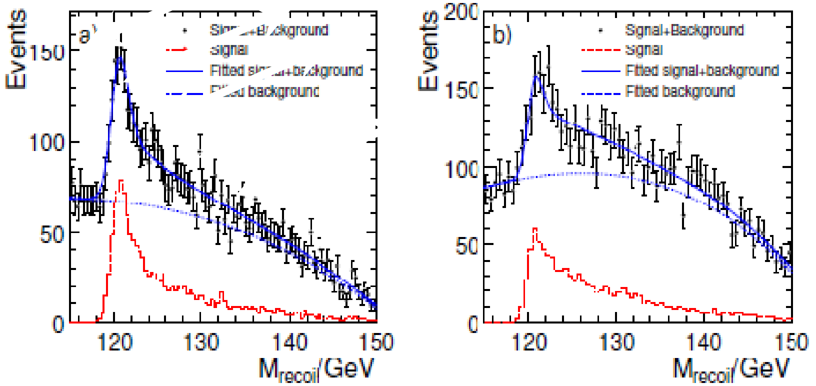


FIGURE 3.3-7. Results of the model independent analysis of the Higgs-strahlung process $e^+e^- \rightarrow HZ$ in which a) $Z \rightarrow \mu^+\mu^-$ and b) $Z \rightarrow e^+e^-$. The results are shown are for the $P(e^+, e^-) = (+30\,\%, -80\,\%)$ beam polarisation.

Tracking at ILC

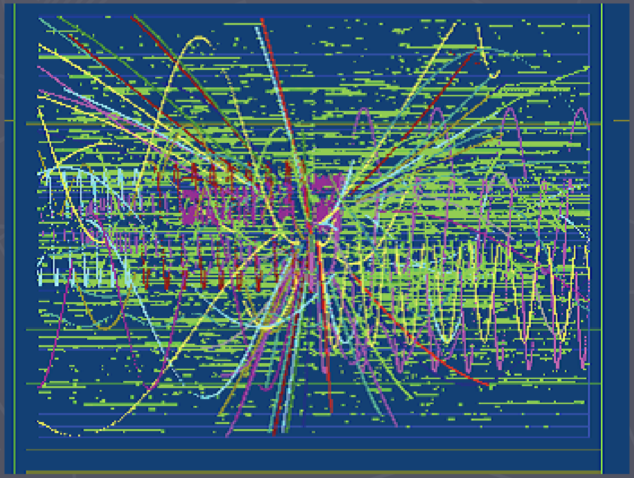
Performance requirement greatly exceeds the achievements of existing truckers for colliders

- **High Momentum resolution:** $\delta(1/pt) \leqq 5 \times 10\text{-}5$

  → ~ 200 position measurements along each track with the point resolution of $\sigma_{r\varphi}$~ < 100μm at 3-4T → TPC

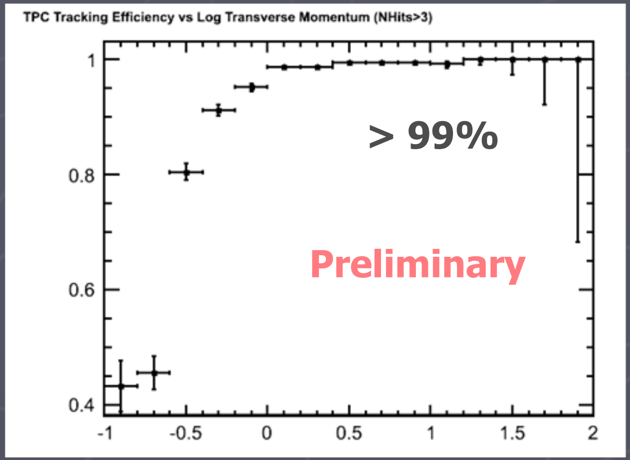
  → ~ a several position measurements with $\sigma_{r\varphi}$~ 10μm at 5T → SiTR

- High tracking efficiency down to low momentum (for PFA)
- Minimum material of trucker for PFA (→ challenging!)
- dE/dX (also for PFA)



ttbar overlayed with 100BX of pair backgrounds

still

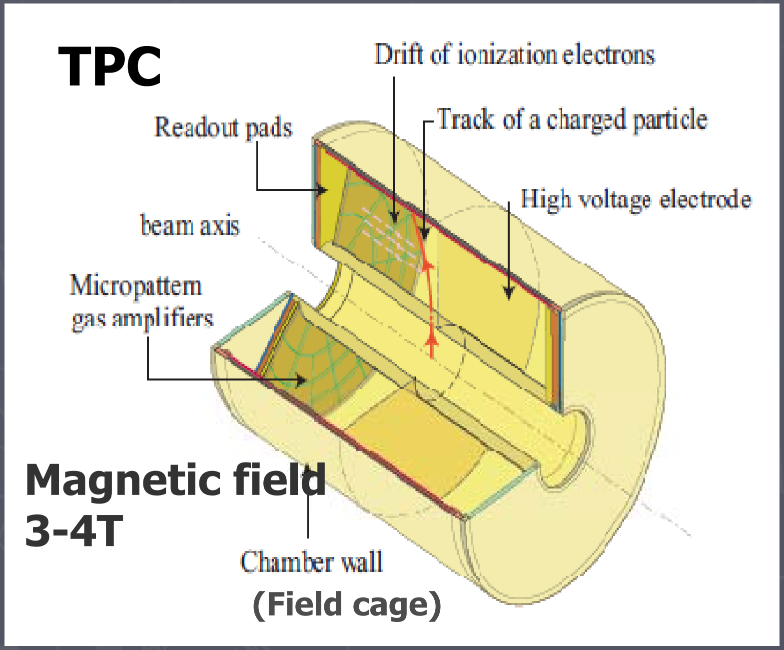


Tracking efficiency w pair background (S. Aplin & F. Gaede)

TPC with Micro Pattern Gas Detectors (MPGD)

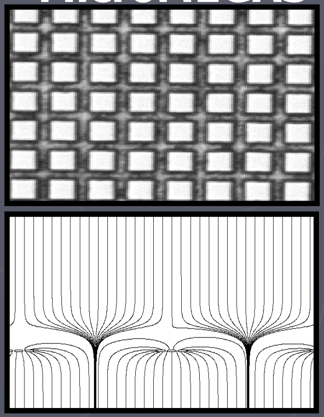
The traditional TPC with MWPC has limited space resolution due to the E x B effect in high magnetic field. Also the structure to support many wires inevitably introduces significant dead regions and material:

→ **MPGD TPC.**

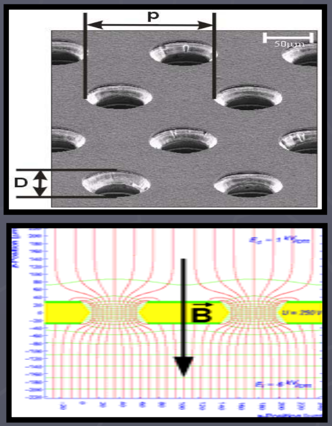


(4 m in outer diameter and 5 m long)

MicroMEGAS



GEM



- **Two gas amplification schemes**
- **Analog TPC vs. Digital TPC**
  - A: Standard pad readout (need signal broadening)
  - D: Pixel (TimePix) readout (need to detect all electrons individually)

Candidates of MPGD TPC for ILC (ILD)

(Based on the studies with Small MPGD TPC Prototypes)

Analog TPC:

GEM + narrow pad readout:

Defocusing by multilayer GEM

Narrow (1mm) pads → Large readout channels

MicroMEGAS + resistive anode:

Widening signal by resistive anode

(in space but also in time) → Track separation

With possibly wider (> 2-3 mm) pads

GEM + Timepix:

As an analog TPC with finer "pad = pixel"

Digital TPC:

Ingrid-MicroMEGAS + Timepix: Elegant solution

Free from the gas gain fluctuation

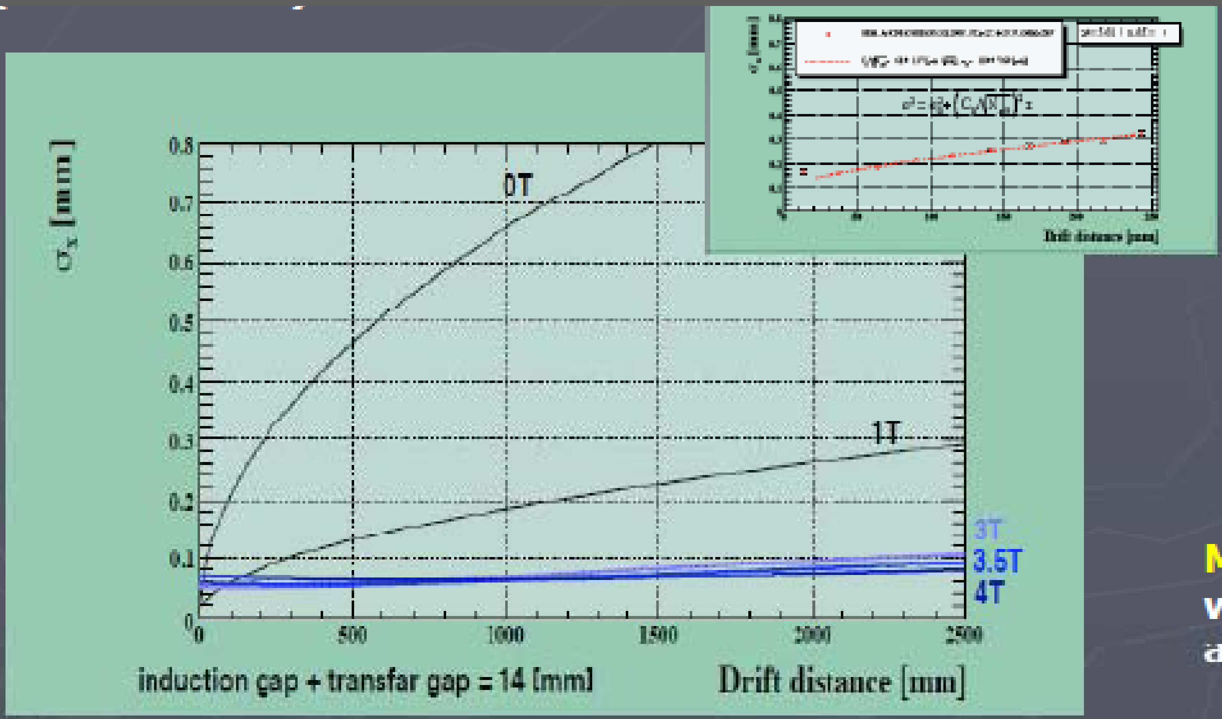
→ More information from primary electrons and thus better point resolution (not yet probed)

GEM + Timepix:

Need to improve the efficiency for primary electrons

Spatial Resolution of MPGD TPC
The point resolution of $\sigma_{r\phi} \leqq 100\,\mu m$ at 3-5T

(A) Extrapolation of Measurements at 1T for a three GEM TPC with narrow (1.17mm) pads (MP-TPC at KEK) to 3-4T using a full analytic formula for TPC point resolution



MP-TPC in its cosmic ray set up with 1T superconducting magnet at the KEK cryogenic center.

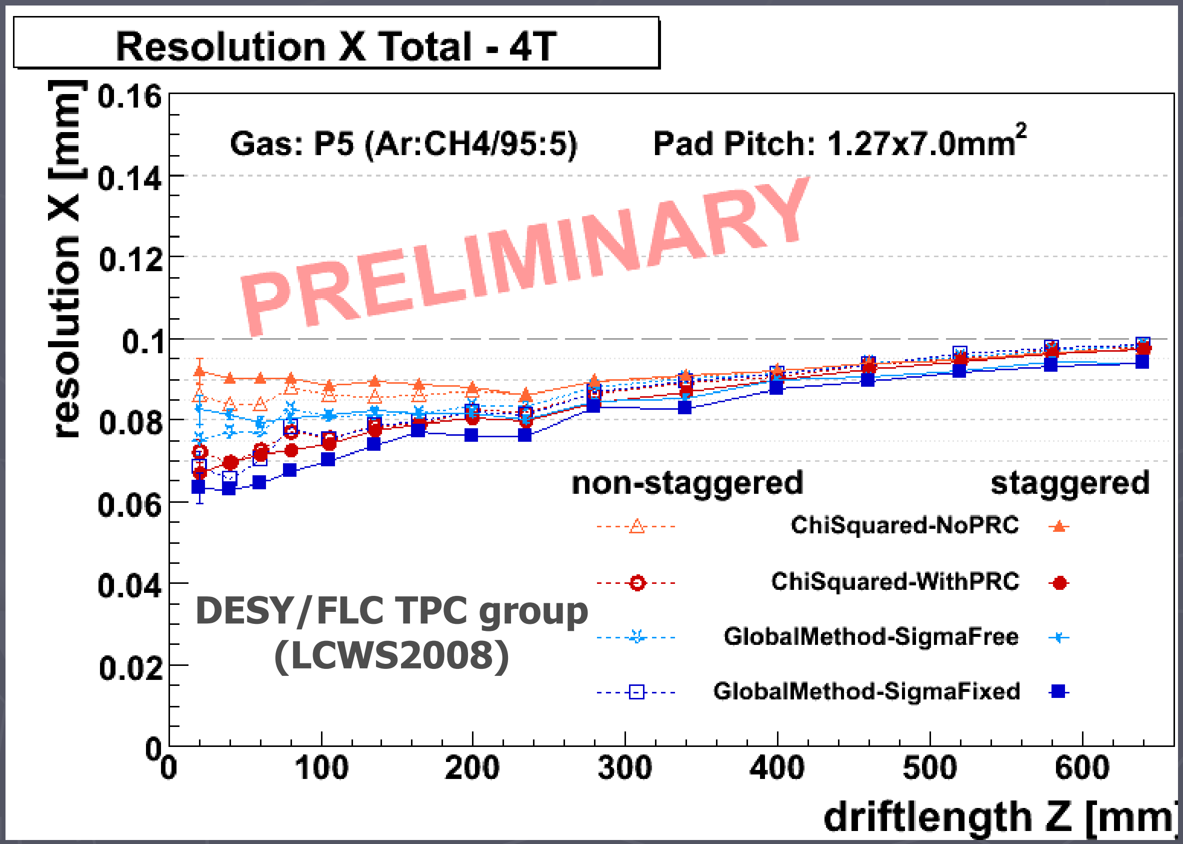
Extrapolation to I LC TPC from measurements at 0/1T ($\theta = \phi = 0$: no angular pad effect).

Ar/CF4(3%)/isobutene (2%) at E_{drift} = 200V/cm=. The number of effective electrons Neff = 22. (R. Yonamine et. al. 2008)

(*) Measurements with DESY Midi-TPC in 5T magnet come soon but so far for P5. Also TU-TPC.

Spatial Resolution of GEM MPGD TPC
$\sigma_{r\varphi} \leqq 100\mu m$ at 3-4T

(B) Measurements in 4T with DESY Midi-TPC with P5 gas (LCSW2008)



Momentum Resolution Expected for ILC (ILD)TPC

Single muon in full simulation with no systematic

TPC point resolution

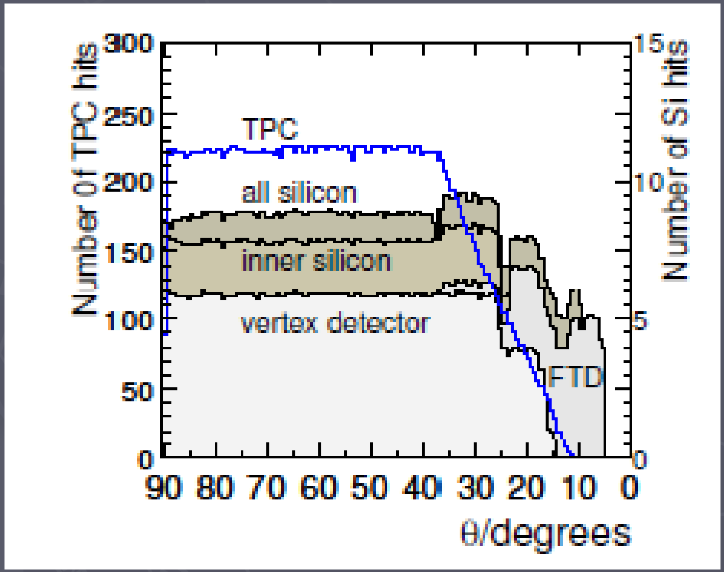
$$\sigma_{r\varphi}^2(\mu m^2) = P + QL$$

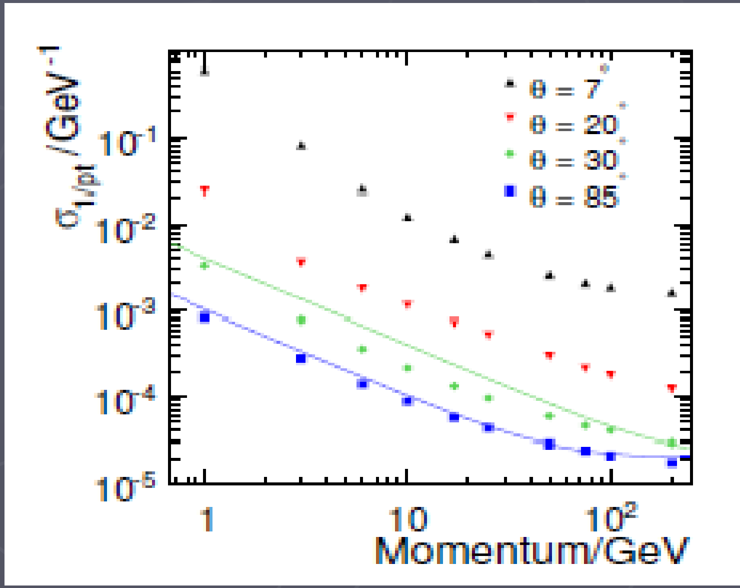
$$P = 50^2 + 900^2 \sin^2\varphi \; : (\mu \mathrm{m})^2$$

$$Q = (25^2/22)\times(4/B)^2 \sin\theta \; : \; (\mu m/\sqrt{cm})$$, B in Tesla

L : drift length [cm]

$$\sigma_z^2(\mu m^2) = 40^2 + 8^2 \times L(cm)$$





Detector model: ILD LOI(00) Model, VTX + Si-tracker + TPC. Magnetic filed of 3.5T. With an empirical angular pad effect. By Full simulator using Mokka (and Jupiter for comparison).

TPC Large Prototype (LP) Beam Test at DESY by LC TPC Collaboration using EUDET Facility

Goals:

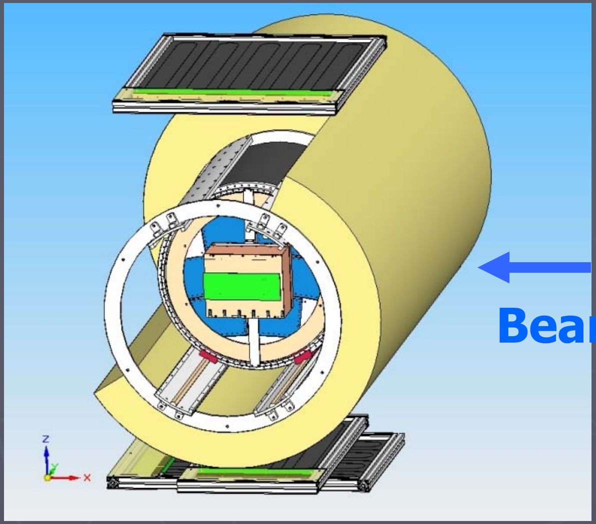
- Study, in practice, design and fabrication of all components of MPGD TPC in larger scale; field cage, endplate, detector modules, front-end electronics and field mapping of non uniform magnetic field. (But not yet the engineering stage.)

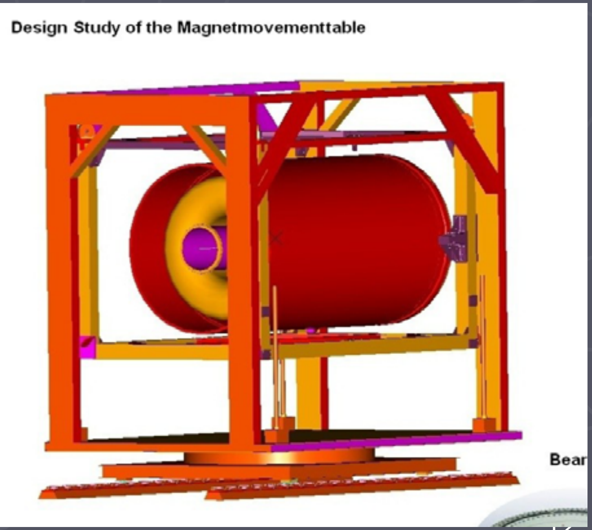
- **Demonstrate full-volume trucking in non-uniform magnetic field, trying to provide a proof for the momentum resolution at LC TPC.**

- Demonstrate dE/dX capability of MPGD TPC.
- Study effects of detector boundaries.

- Develop methods and software for alignment, calibration, and corrections.

(Beijing tracker review, Jan 2007)





We are still far away from the goals!

LC TPC Large Prototype Beam Test at DESY
LC TPC Collaboration with EUDET Facility

Pixel beam telescope
(EUDET)

Si strip detector
(EUDET/SiLC)

Magnet: PCMAG
(LC TPC/KEK,CERN)

Endplate
(LC TPC/Cornell)

Field cage &
All Mechanics
(EUDET: DESY)

Test beam (DESY)

Gas system
(EUDET:DESY)

Different MPGD
Detector
Modules
(LC TPC: Asian
group, Saclay &
Carleton, NIKEHF,
Bonn etc)

DAQ & Monitoring
(EUDET)

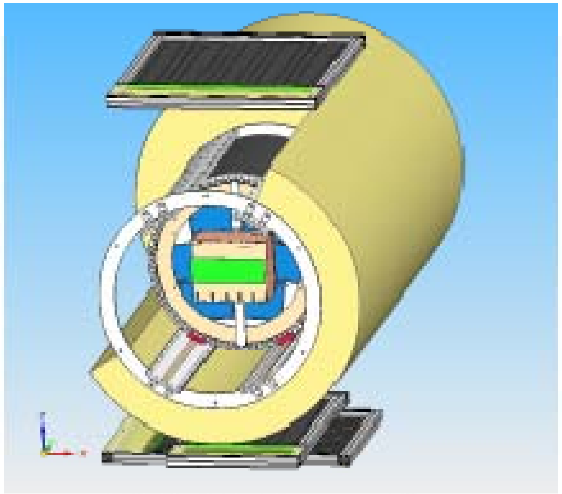
Cosmic trigger
(LC TPC/KEK, Saclay)

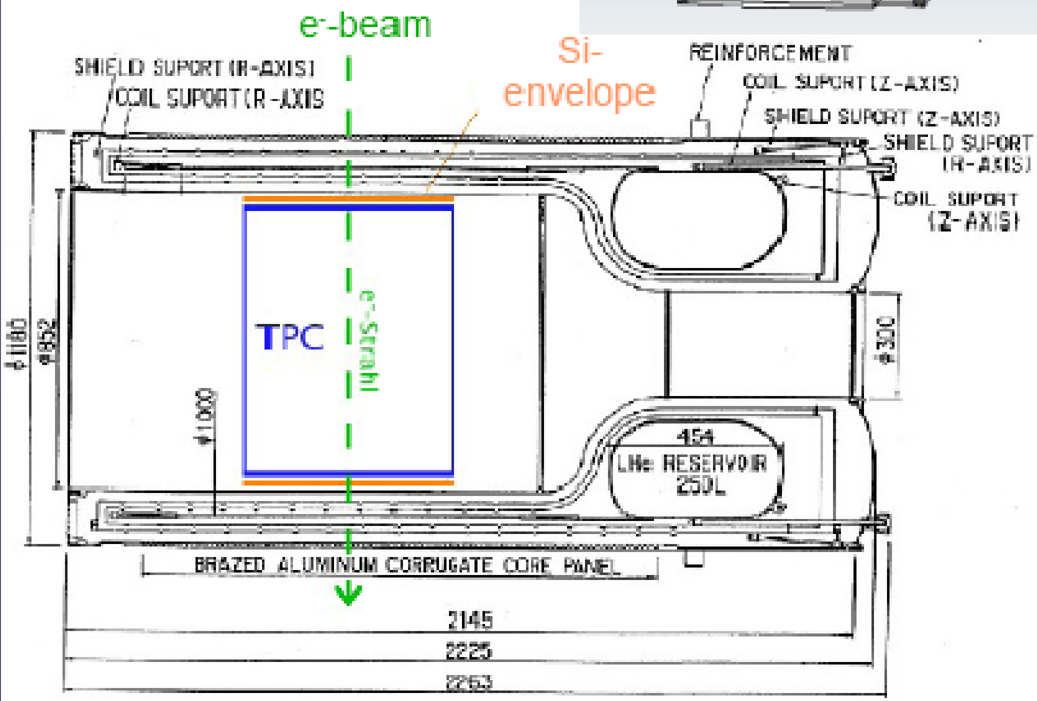
Two types of Readout electronics
(EUDET:CERN, Lund & LC TPC; CDC group, Saclay)

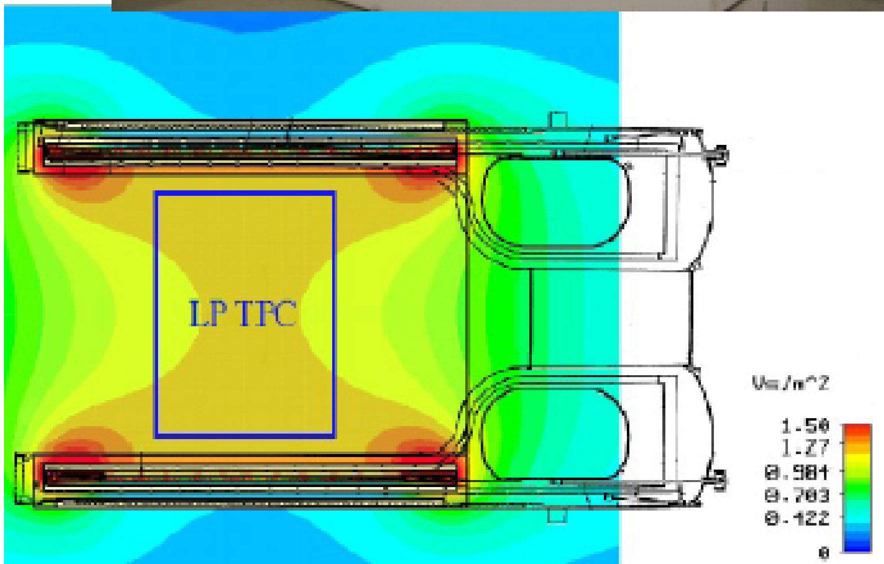
Software development
(EUDET & LC TPC)

DESY Setup

- *e*⁻ test beam @DESY
- PCMAG





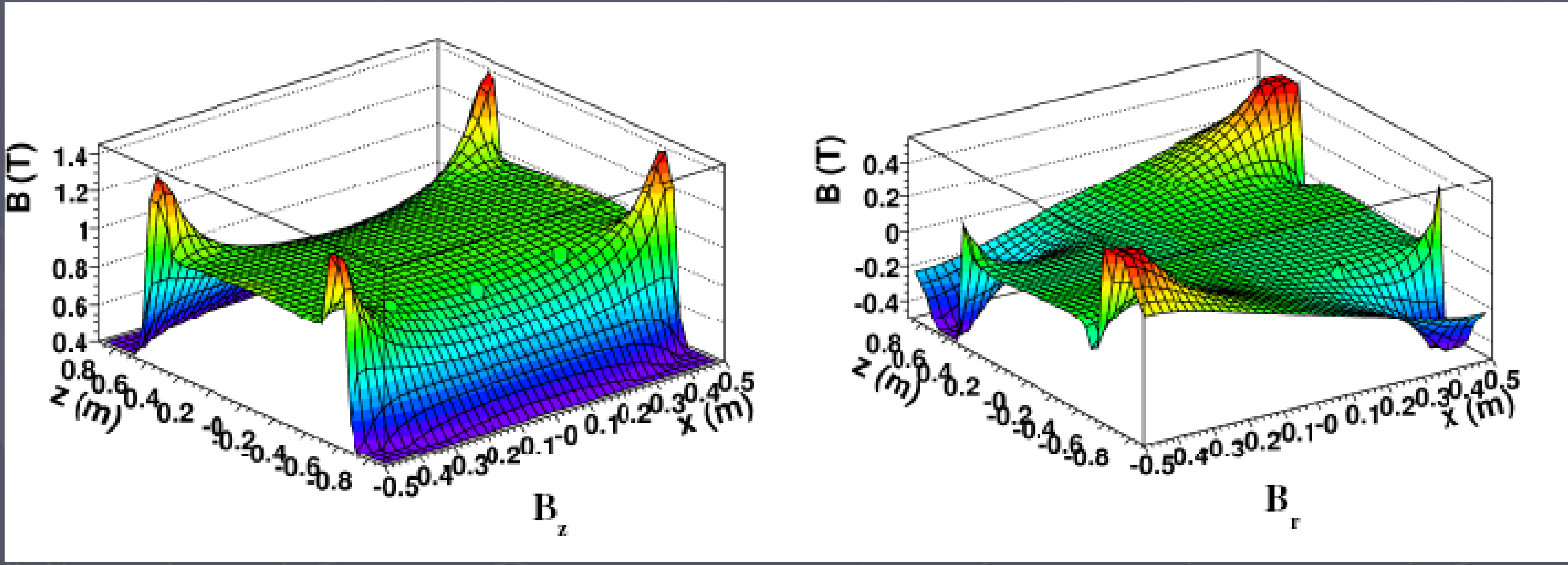


Filed mapping done in 2007 (CERN)

PCMAG
Magnetic Filed Measurement and Field Models

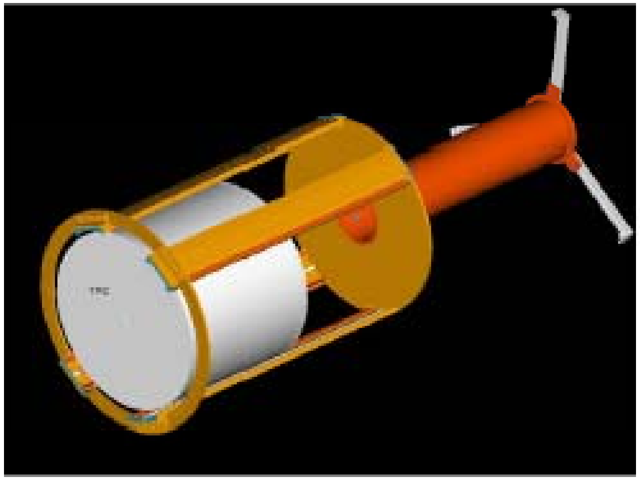
Our claim: Correction for non-uniform magnetic field can be done when the field is mapped down to O(1G) a la ALEPH (Settles & Wiedemann)

Precision filed measurement done by CERN group (Lucie) . The precision is down to 5-10 gauss in 3D components. Field model is implemented in Marlin TPC and is ready to be used.

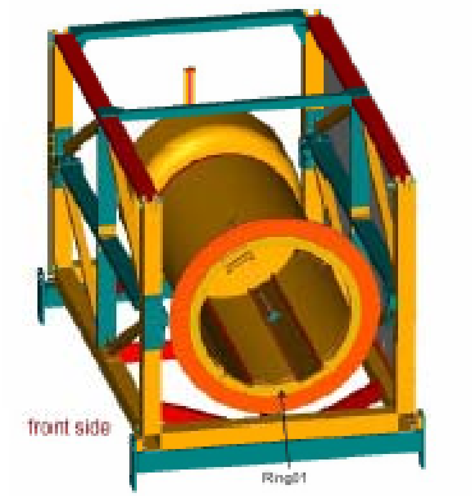


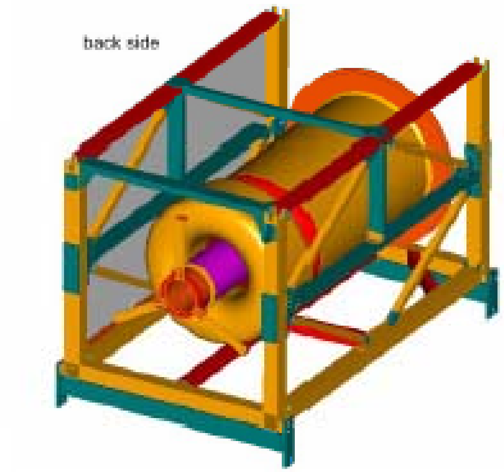
We are better to make use of them performing full tracking in TPC Large Prototype!

LP Mechanics



(installed in 2008)



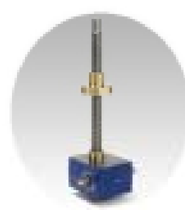


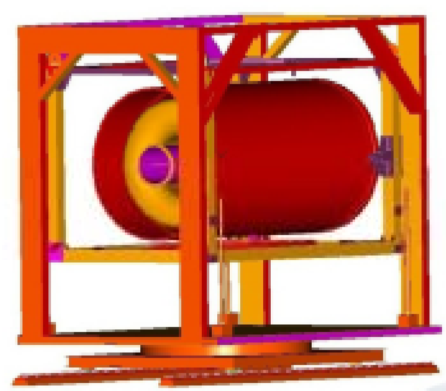
Support structures:

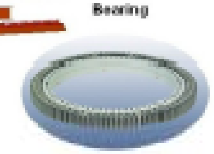
- TPC
- PCMAG

F. Hegner, V. Prahl, R. Volkenborn, DESY

Design Study of the Magnetmovementtable







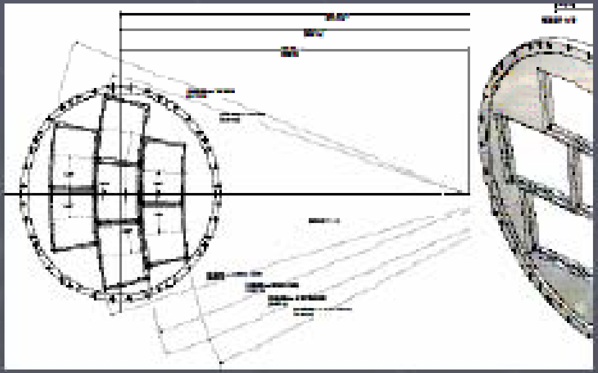
(In Summer 2009)

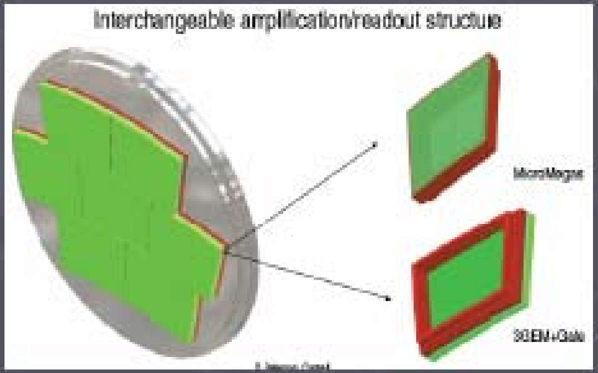
TPC Large Prototype (LP1) Endplate

Cornell University

LP1 endplate made of Al, accommodates 7 detector modules. The diameter of the endplate is about 770 mm.

The shape and size of the detector module was decided to simulate one at LC TPC of the size of GEM widely available. All 7 detector modules have the same outer shape so that they are interchangeable on the endplate. However, we do not plan to mix the detector modules of different MPGD since they are normally in different operation conditions (such as the voltage applied to their front face). The endplate is designed at Cornell Univ. The endplate has arrived at DESY. Need design R&D for a light structure.

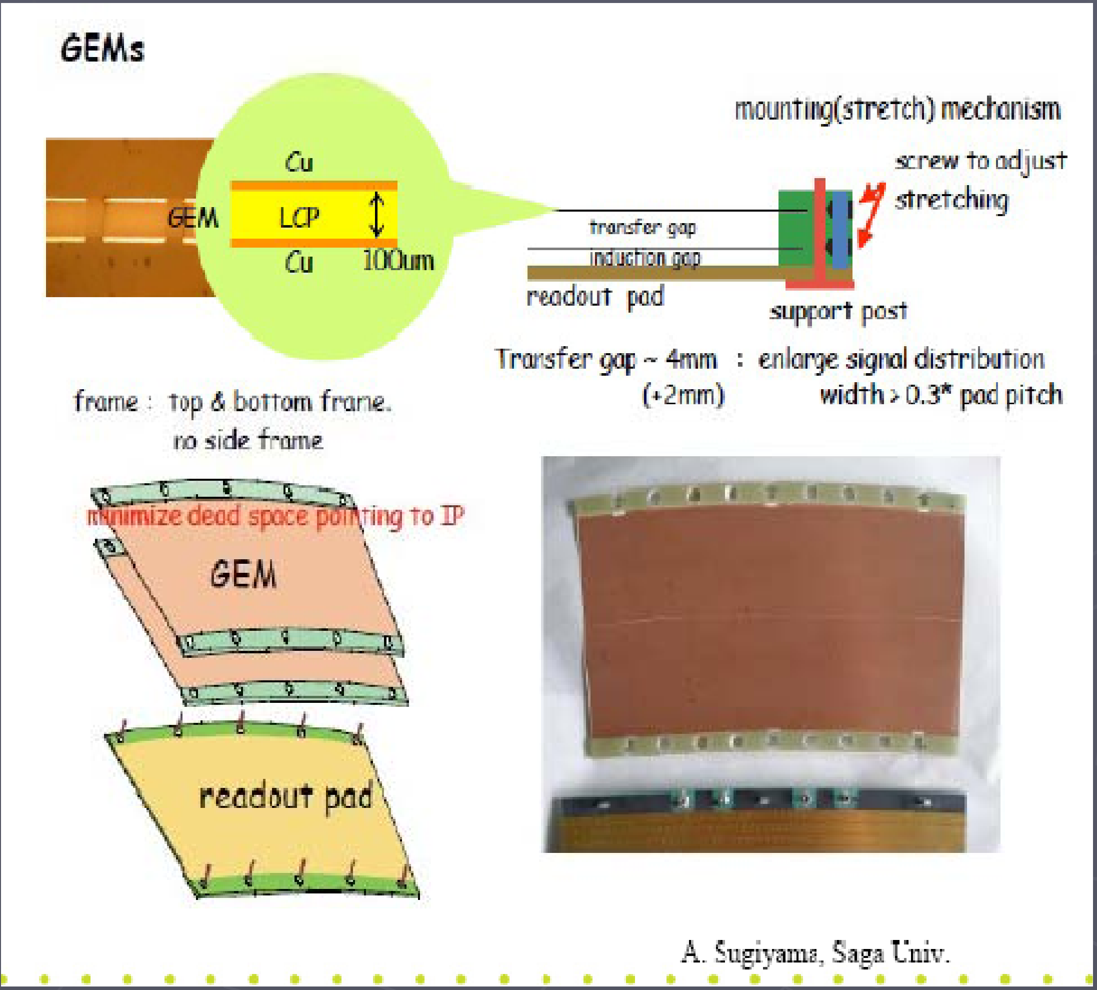




LP1 GEM Module by LC TPC Asian Group
Two layers of thick GEMs + Gating GEM

LC TPC Asian group

GEM Module (w/o Gating GEM)



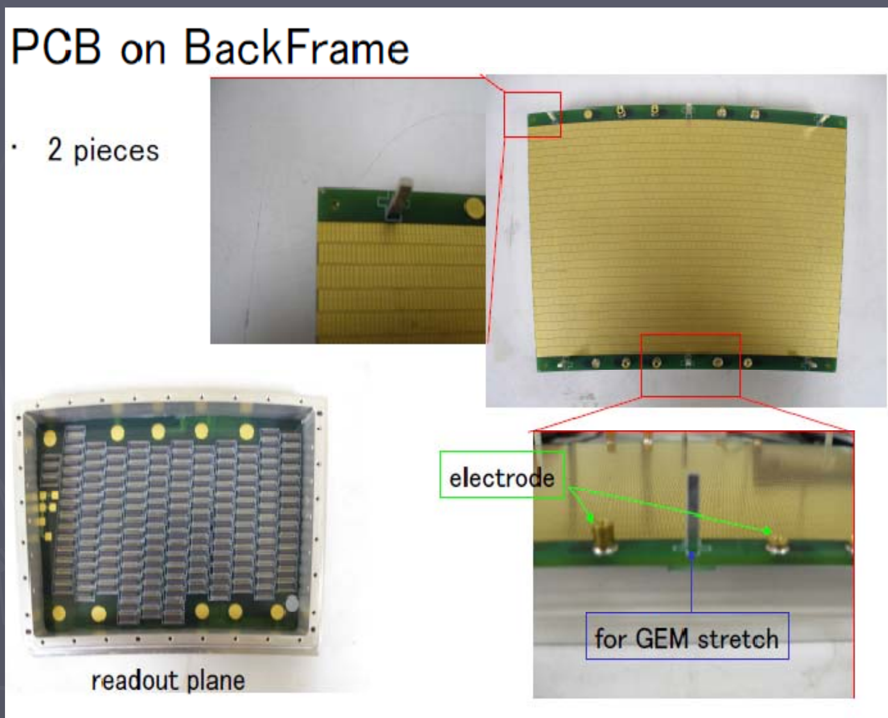
- 28 pad-rows of 176 -194 pads
- Pad size ~ 1.1 x 5.4 mm^2
- Total 5152 pads/modules

- GEMs: 2 layers of GEM (100μmt)
  (w/o Gating GEM this time.)
  Electrically divided in 2
  Transfer gap = 4 mm
  Induction gap = 2 mm
  (Gating = 10 mm)

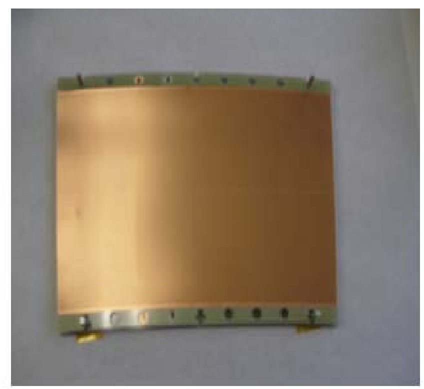
- 4 modules made and 3modules installed to cover full length of beam
- GEMs from SiEnergy & PCB layout/fabricated by Tsinghua University

LP1 GEM Module by LC TPC Asian Group
Some details

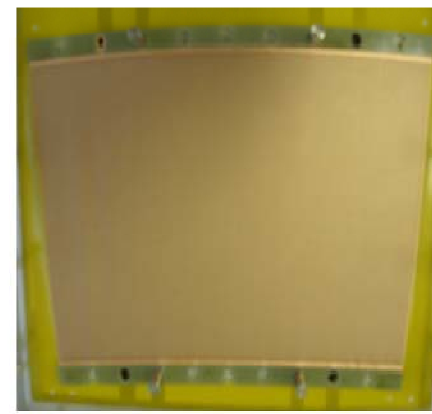
LC TPC Asian group



- Amp. GEM
  - 100μm-thick
  - 70μm ϕ , 140μm pitch
  - Insulator : LCP
  - 12 pieces



- Gate GEM
  - 14μm-thick
  - 90μm ϕ , 140μm pitch
  - 3 pieces



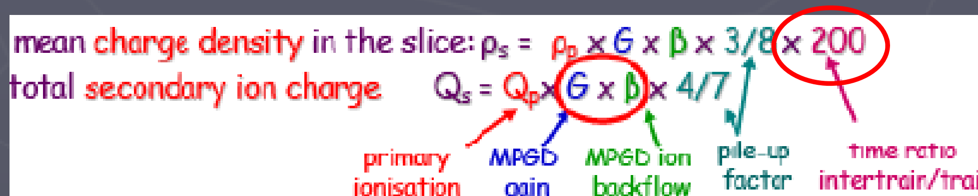
Current module structure: Minimize dead area in Rφ but tolerate those in R
Easy to replace each GEM layer.
Problem of bias voltage contact (once in LP test)
Open to consider other solutions to hold/bias GEMs.

Ion in ILC TPC

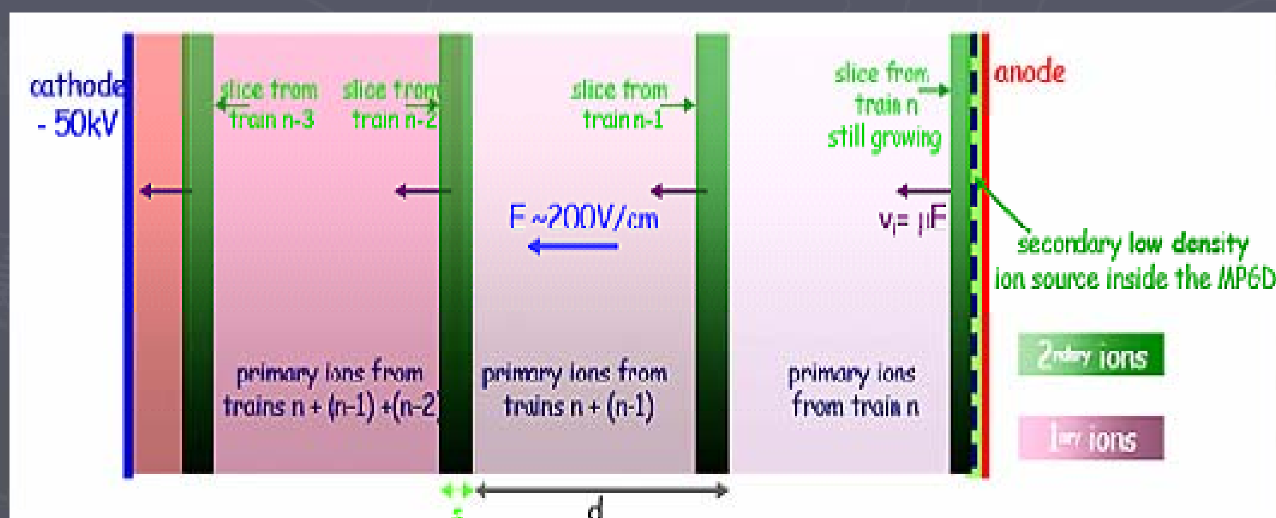
V. Lepeltier,
TILC08 March 2008

- Ions in the TPC drift volume, if its density is high, introduce the E-field distortion.
- Two sources of ions; primarily ions and feed back ions from the amplification region.
- The collection time of ions is slow: 600ms for the drift filed of 200V/cm compared to the electron drift time of about 40 micro sec.
- If the ion feedback ration β is height, the feed back ions build up the a few ion sdisks in the TPC drift volume.
- G x β is the key factor for the secondary ions. If > 1, we need an ion gating device.

Ion density



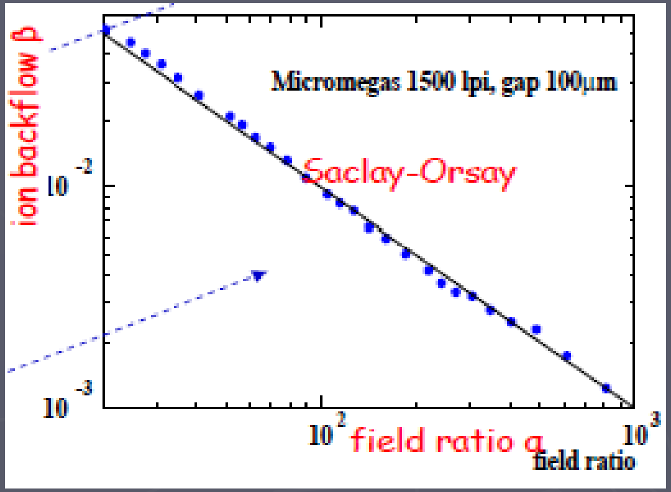
Ion disks



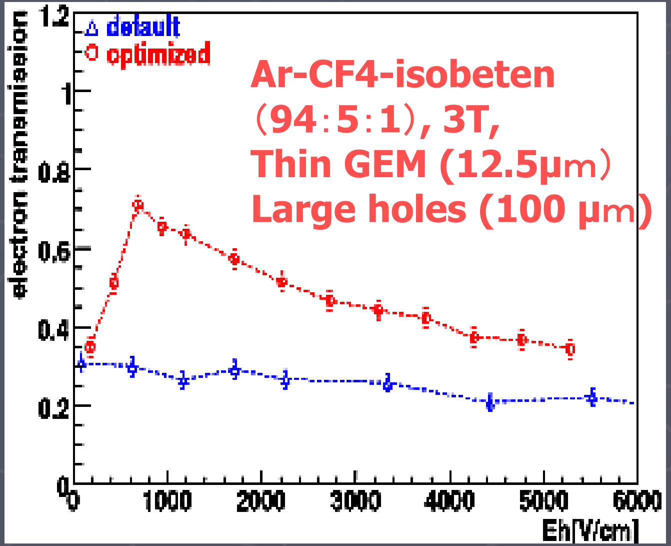
Detailed simulation underway using Marlin TPC (Bonn)
(L. Hallerman/LCWS08)

LP1 GEM Module by LC TPC Asian Group
Gating with special GEM

- **The ion feedback ratios of MicroMEGAS and triple GEM can be O(0.1) %.** If the gas gain of the MPGD system is < 1,000, the total amount of the feed back ions is in the same order of the primary ions. **Still the charge density in the ion disks may be 200 times of that of primary ions.**
- **With the two layers of (thick) GEMs, a gating device may be mandatory.**
- **GEM Gating**: The wire gating is efficient but introduces a mechanical complication. GEM gating can stop the feed back ions. But electron transmission through gating GEM may be 70 % at the best, thus introduces some degradation of the spatial resolution. Between the gating device and MPGD, there will be still an ion dick.



Ion feedback ratio MicroMEGAS

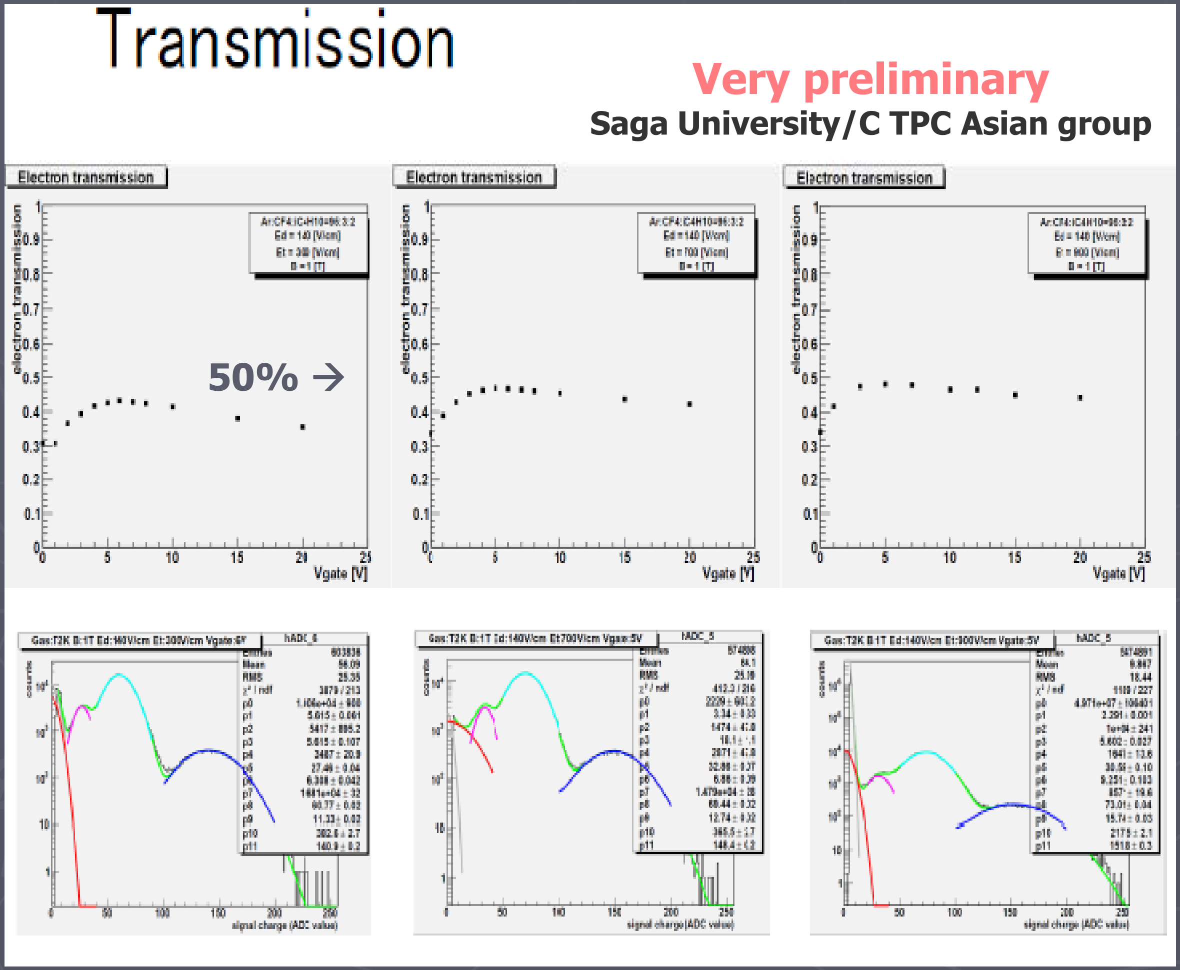


Electron transmission of gating GEM
(Simulation: Saga/CDC group)

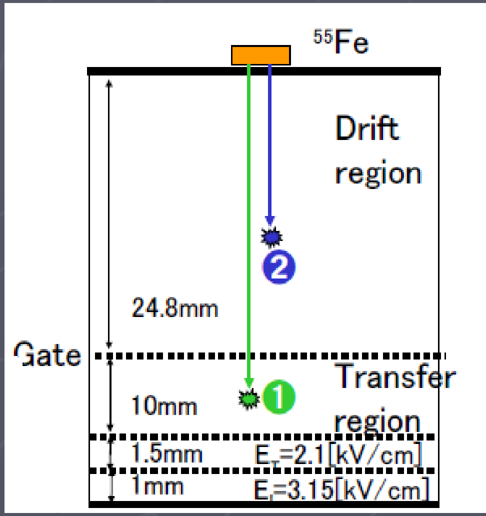
LP1 GEM Module by LC TPC Asian Group

Gating with special GEM

Measured transmission of the thin (14μm) gating GEM is measured to be around 50% or less (Saga University/LC PC Asian group). The point resolution with the gating GEM will be deteriorated accordingly. Still tolerable?



Gating GEM for LP test



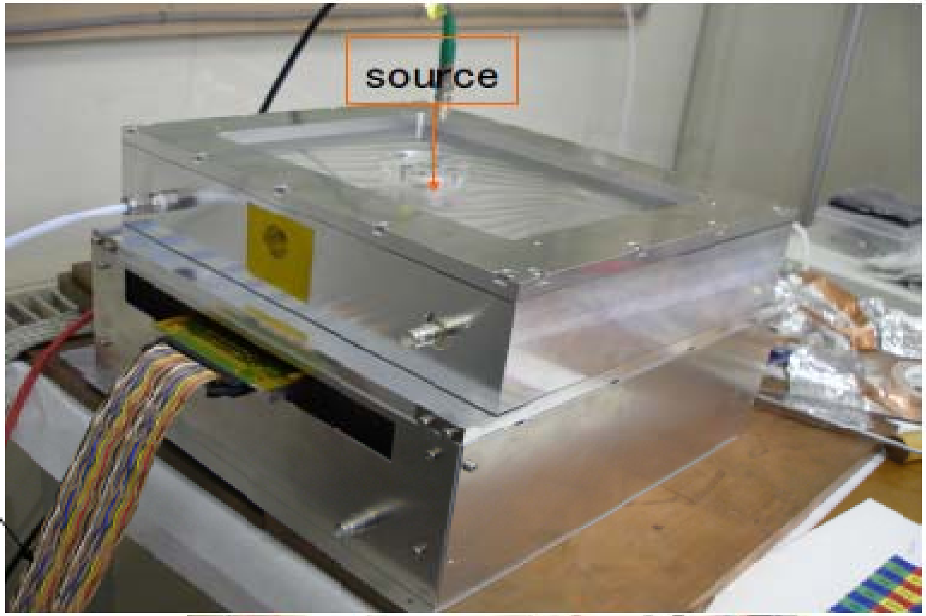
Compare the pulse height for conversions in the drift region and the transfer region.

LP1 GEM Module by LC TPC Asian Group

Laboratory test

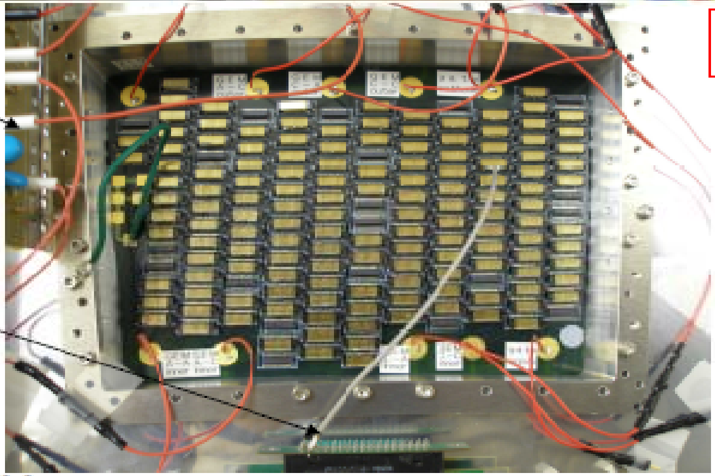
Sygiyama
Kuroiwa
@Saga

Test Box



to post amp.
and oscilloscope

H.V. distribution board



Without Gate

readout elec.
16 pads*2 layers
(other pads are grounded)

readout plane

LP1 GEM Module by LC TPC Asian Group

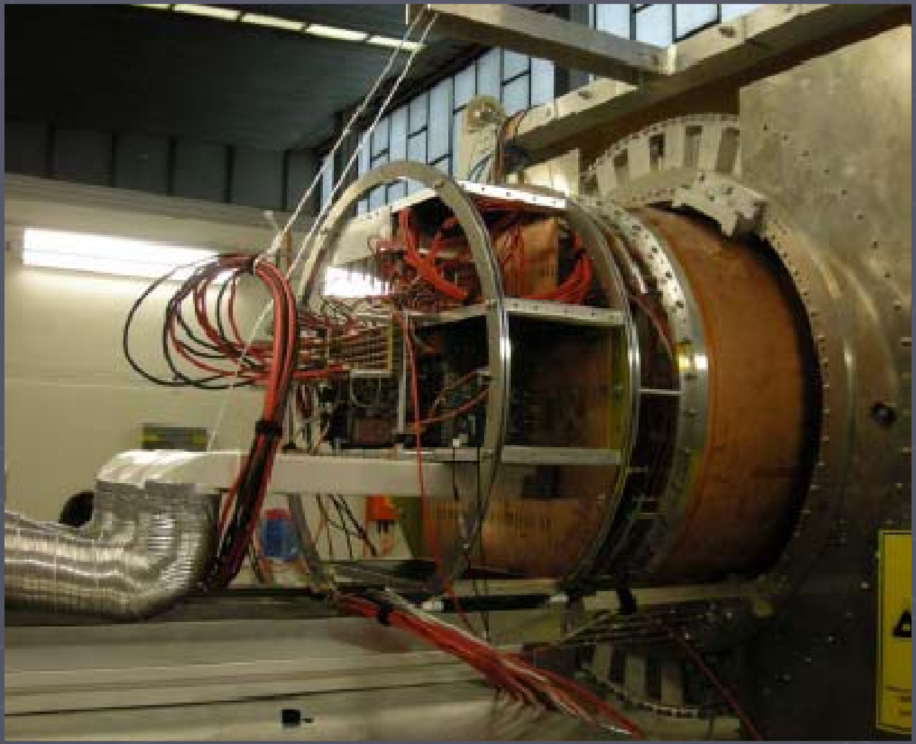
The First Beam Test at DESY in Spring 2009

The first beam test in spring 2009 at DESY with 5GeV/c electron beam

- With 3 GEM modules mounted
- Without the gating GEM
- Readout with 3,000ch ALTRO electronics

Next beam test before April 2010:

- With the gating GEM
- With 10,000ch ALTRO electronics

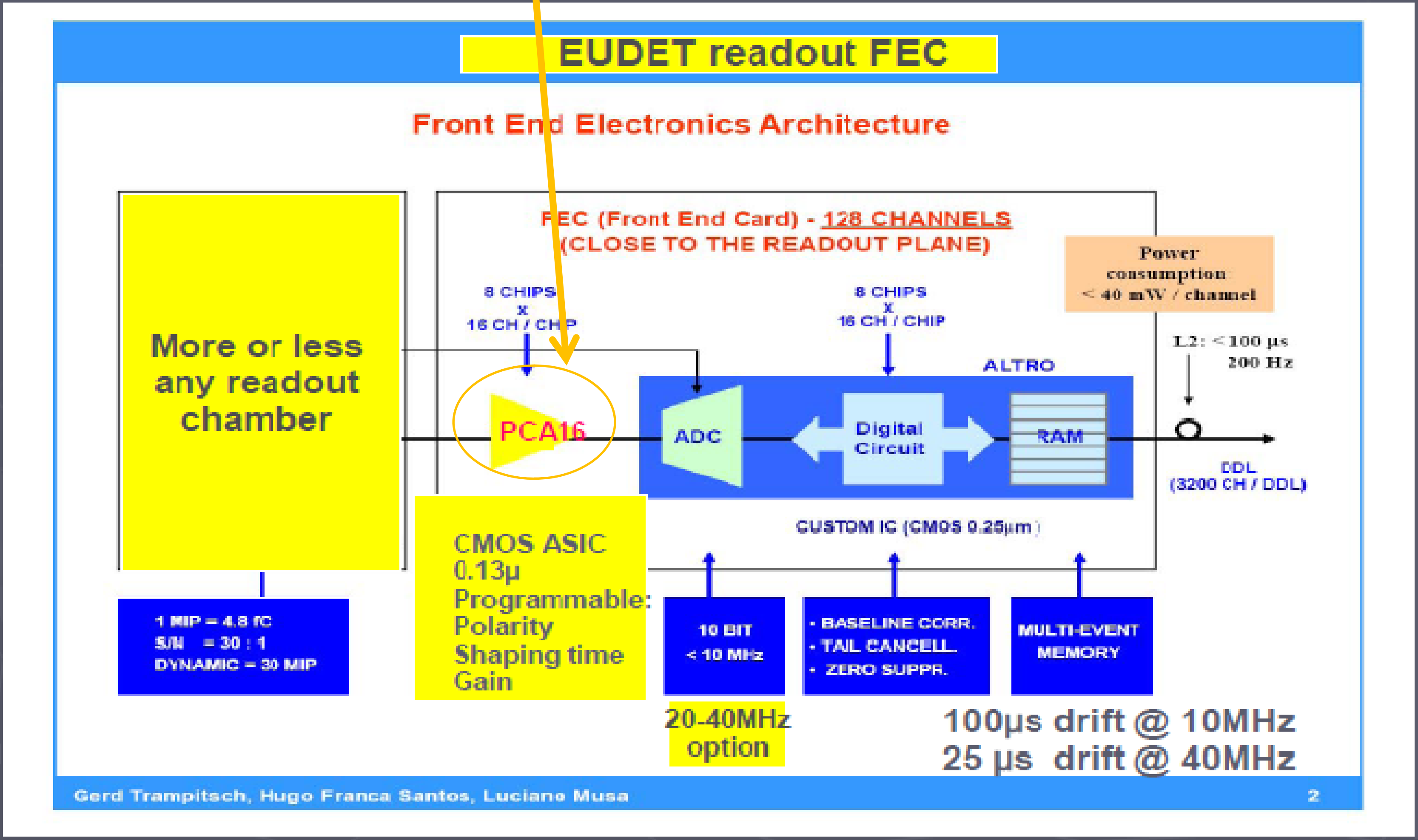


LP1 GEM Module by LC TPC Asian Group
Readout Electronics

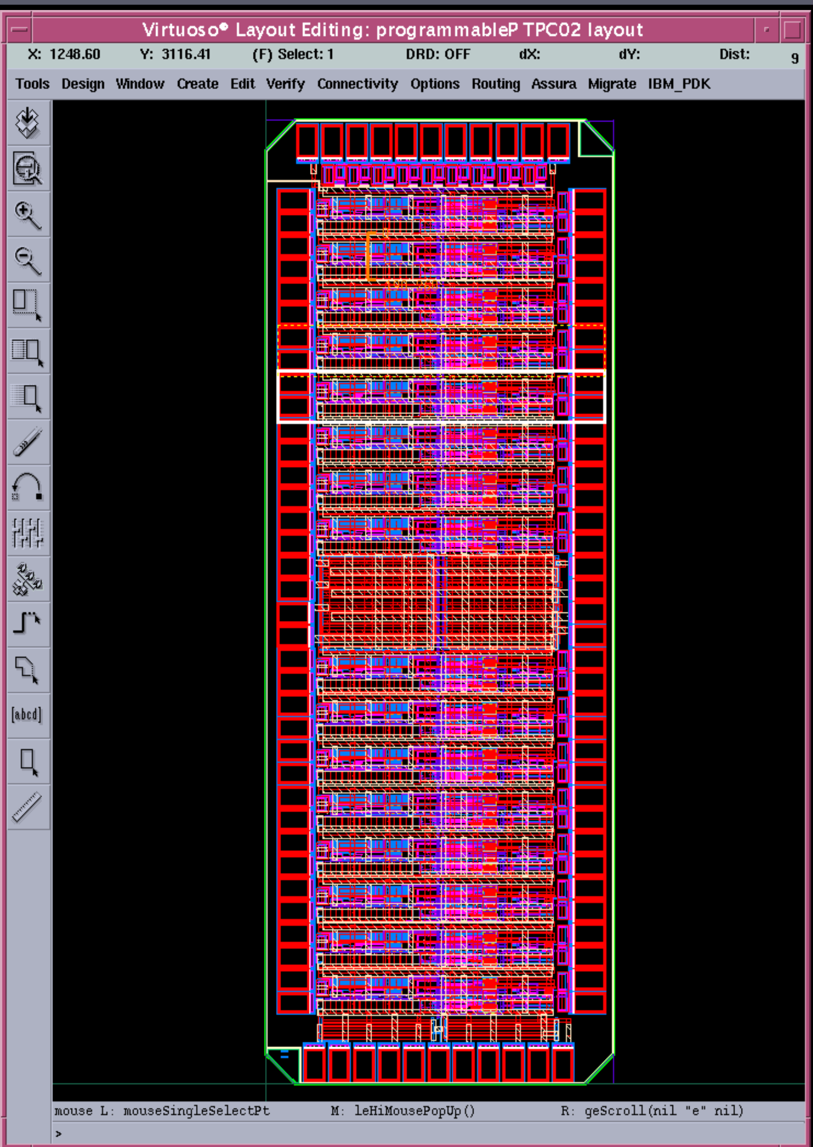
ALTRO GEM Electronics: S-ALTRO

CERN/Lund

Based on the existing PASA + ALTRO electronics designed for the Alice TPC
PASA is replaced by PCA16 for MPGD readout.



ALTRO Electronics
New Programmable Charge Amplifier (PCA 16)



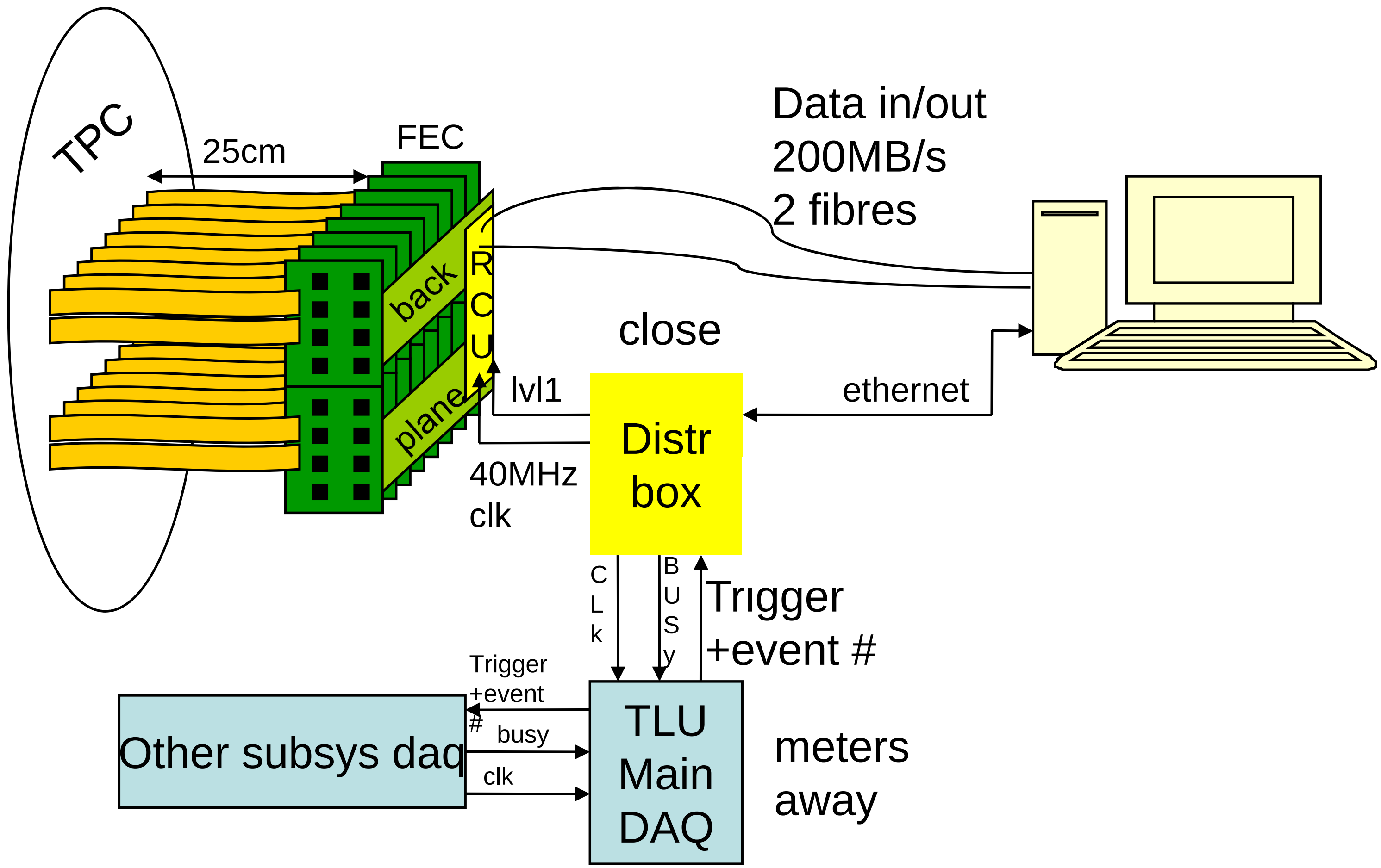
Both for MPGD & MWPC

- 1.5 V Supply,
- power consumption < 8 mW/channel
- 16 channel charge amplifier + anti-aliasing filter
- Single ended preamplifier
- Fully differential output amplifier
- Both signal polarities
- Power down mode (wake-up time = 1 ms)
- Programmable peaking time (30 ns – 120 ns) – 3rd order semi Gaussian pulse shape
- Programmable gain in 4 steps (12 – 27 mV/fC)
- Pre-amp-out mode (by pass shaper)
- Tunable time constant of the preamplifier
- Pitch 190.26um, Channel length 1026um,
- Chip dimensions = 1.5mm x 4mm

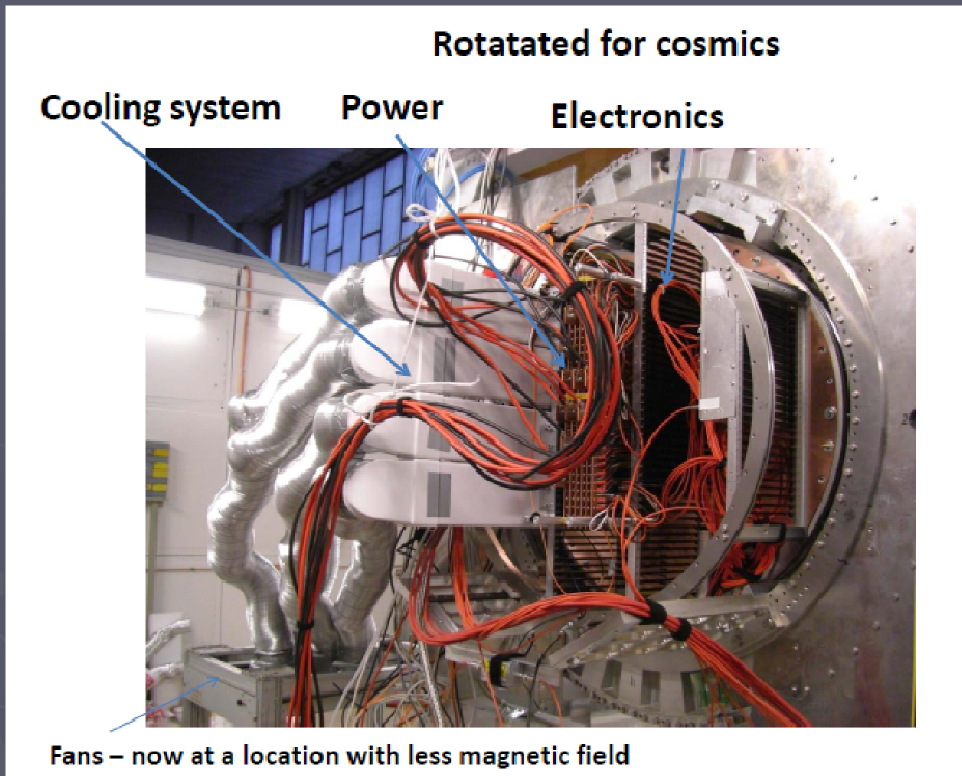
Most of data were taken with 120ns peaking time and With the highest gain.

ALTRO GEM Electronics

2048ch (16 FEC) (EUDET) → 10,000ch (LP test)



LP1 GEM Module by LC TPC Asian Group
3,000ch S-ALTRO Electronics: Installation

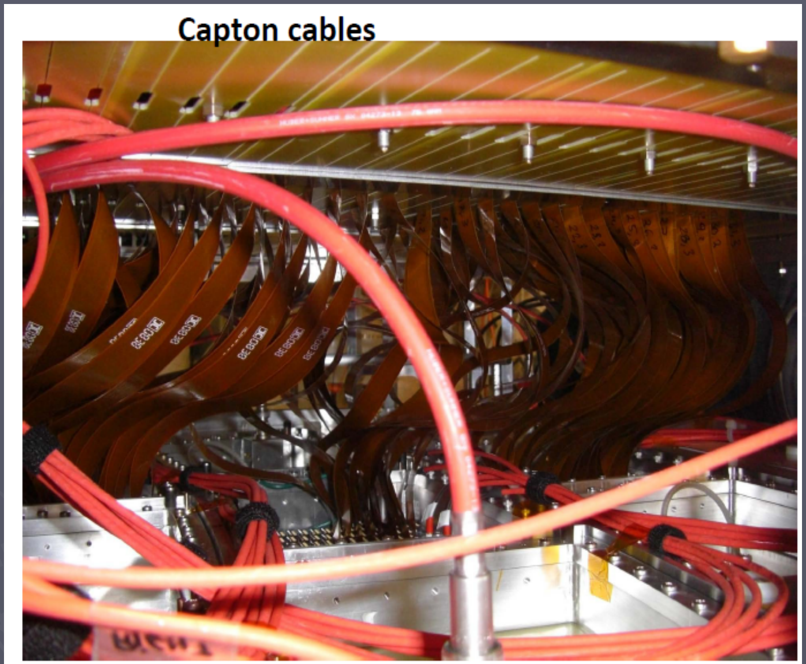


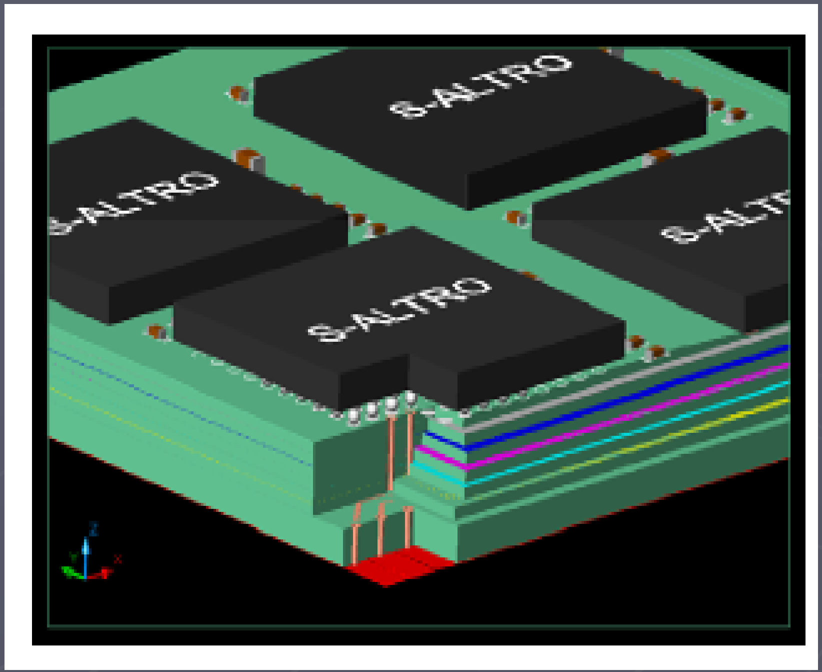
Only parts (red) of the modules were equipped with the electronics.

The status of the readout DAQ system was satisfactory from the time of commissioning:

- 3% of all events corrupted due to problem with zero-suppression.
- (now known to be a software problem)
- 16 (1chip) channels dead..
- 1 channel has an offset of 12,50 ADC counts in every event.
- A few channels have noise, roughly 130 kHz (due to near by HV cables).
- Some channels saturate (gain=3).

LP1 GEM Module by LC TPC Asian Group
S-ALTRO Project and Advanced Endplate





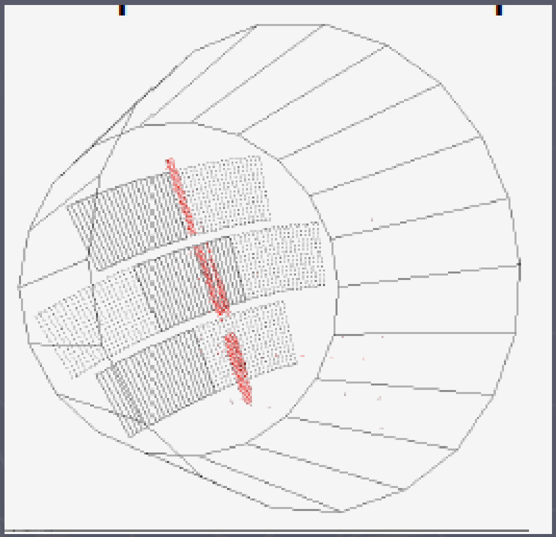
Advanced Endplate

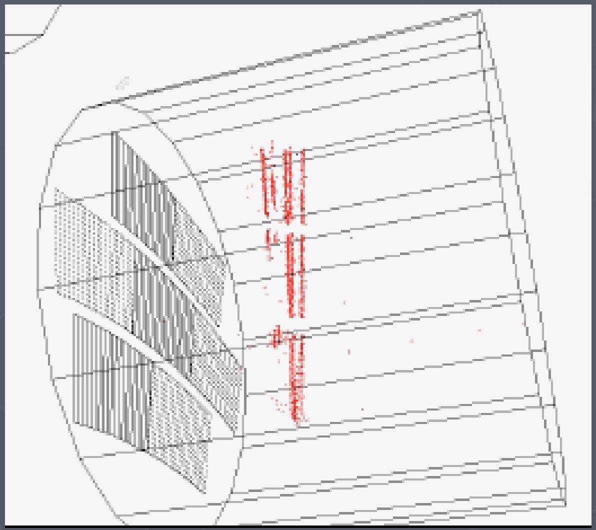
10,000ch with the flexible cable connections may still be manageable but not more.
S-ALTRO project (and also a similar project for the T2K electronics) is underway.

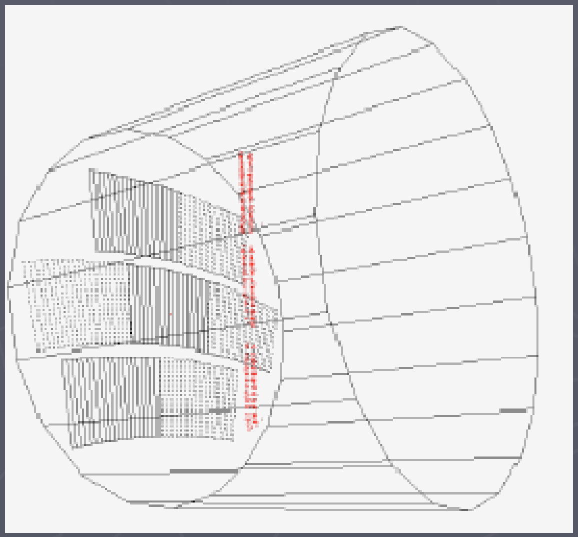
LP1 GEM Module by LC TPC Asian Group

The First Beam Test at DESY in Spring 2009

3,000ch ALTRO electronics were distributed along beam in the most of data taking.

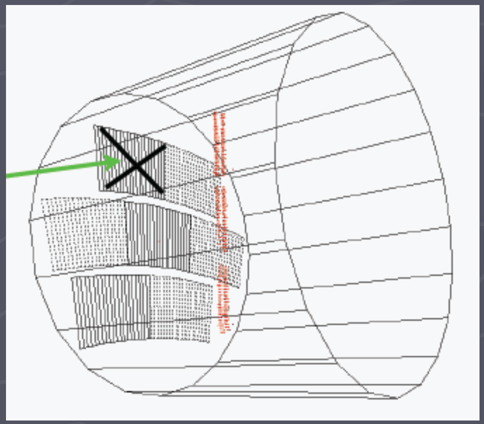






One of the modules started to draw current due to the provisional electrode on the frame of the top GEM in the absence of the gating GEM.

The rest (most) of the data taking was performed only with two modules.



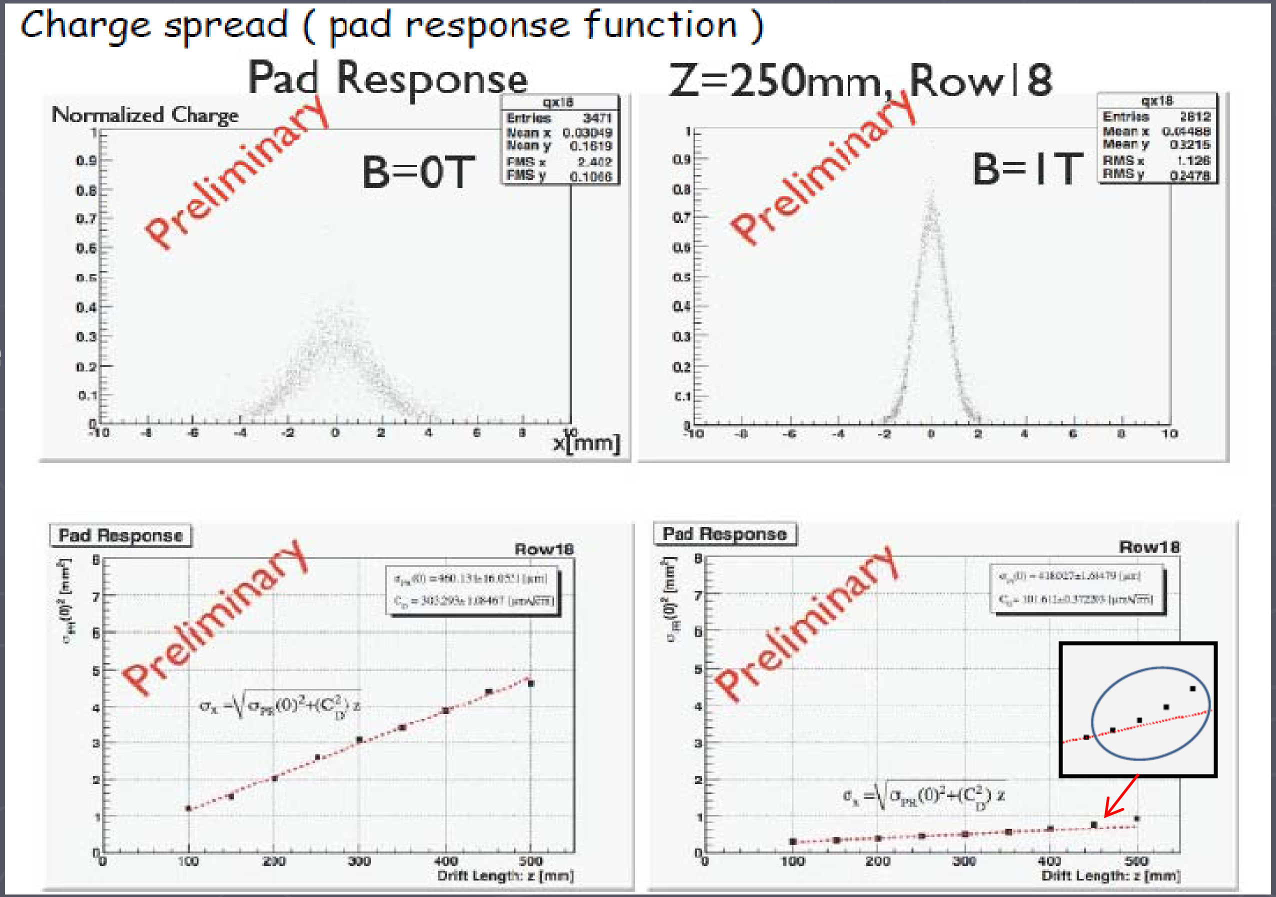
LP1 GEM Module by LC TPC Asian Group
Some Preliminary Results

Analysis: (1) Confirm the results from small prototype test
(2) Full volume (length) tracking (now starting)

(A) Pad response

Deviation from the expectation at large drift distances at 1T are due to the change of PCMAG at its end.

Need the PCMAG movable table soon.



LP1 GEM Module by LC TPC Asian Group
Some Preliminary Results

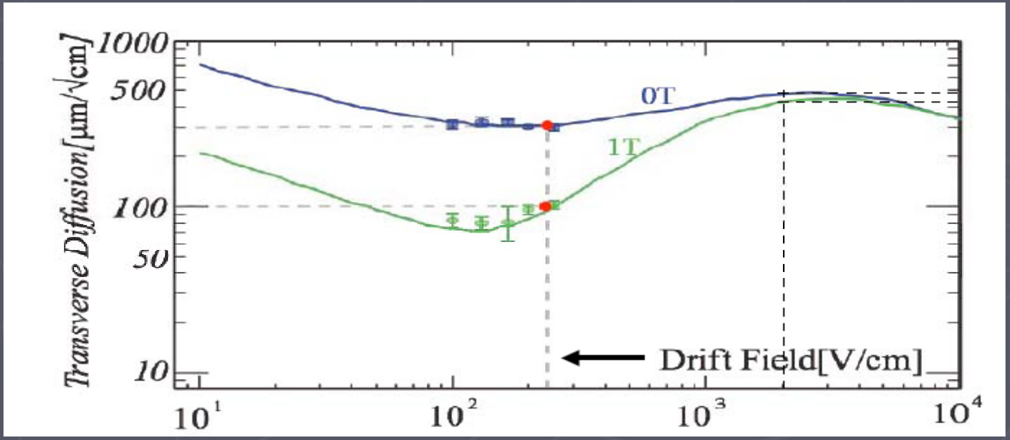
(B) Drift velocity

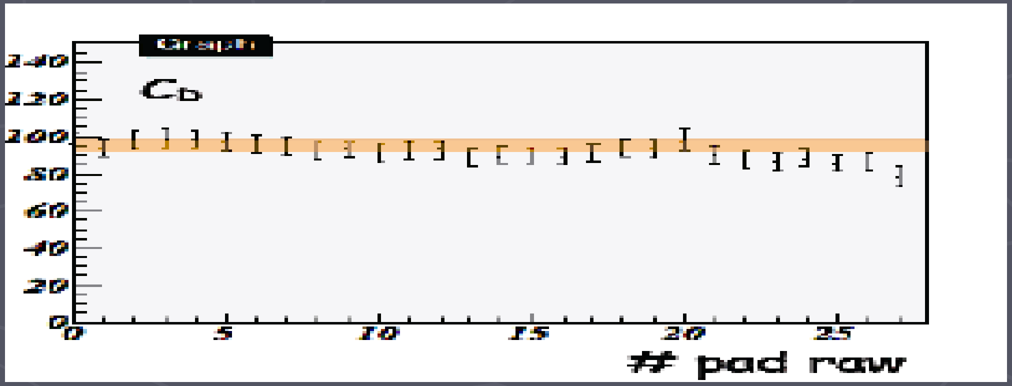
Agree well to our expectation (MagBoltz simulation) and Our previous measurments.

The green and bleu points are from the small TPC (MP-TPC) prototype.

Pad raw dependence of measured Cd.

Raw 18	B = 0 T	B = 1 T
C_D [um/√cm]	303	102
error	1	1



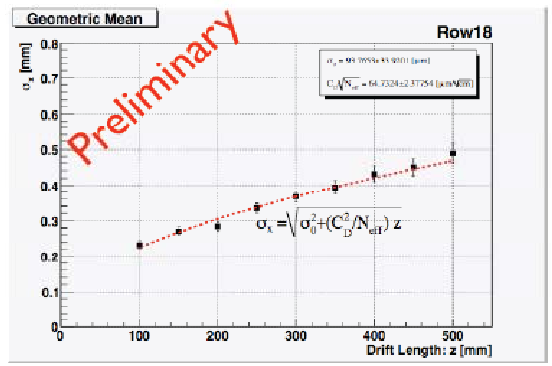


LP1 GEM Module by LC TPC Asian Group
Some Preliminary Results

(C) Point resolution

Confirmed the results from the small TPC (MP-TPC) prototype test.

Neff consistent with that (21 +- 2) from the small TPC (MP -TPC) prototype considering the differences of pad length (5.7mm vs. 6.4mm) and beams (5GeV/c) electrons vs. cosmic muons).



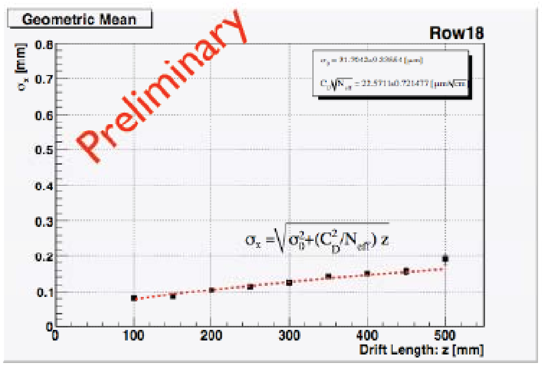
B=0T

fitting result

$$\frac{C_D}{\sqrt{N_{eff}}} = 65 \pm 2[\mu m/\sqrt{cm}]$$

$$\begin{cases} C_D = 303 \pm 1[\mu/\sqrt{cm}] \\ \frac{C_D}{\sqrt{N_{eff}}} = 65 \pm 2[\mu m/\sqrt{cm}] \end{cases}$$

$$\longrightarrow N_{eff} \sim 22 \pm 1$$



B=1T

fitting result

$$\frac{C_D}{\sqrt{N_{eff}}} = 22.6 \pm 0.7[\mu m/\sqrt{cm}]$$

$$\begin{cases} C_D = 101.6 \pm 0.4[\mu/\sqrt{cm}] \\ \frac{C_D}{\sqrt{N_{eff}}} = 22.6 \pm 0.7[\mu m/\sqrt{cm}] \end{cases}$$

$$\longrightarrow N_{eff} \sim 20 \pm 1$$

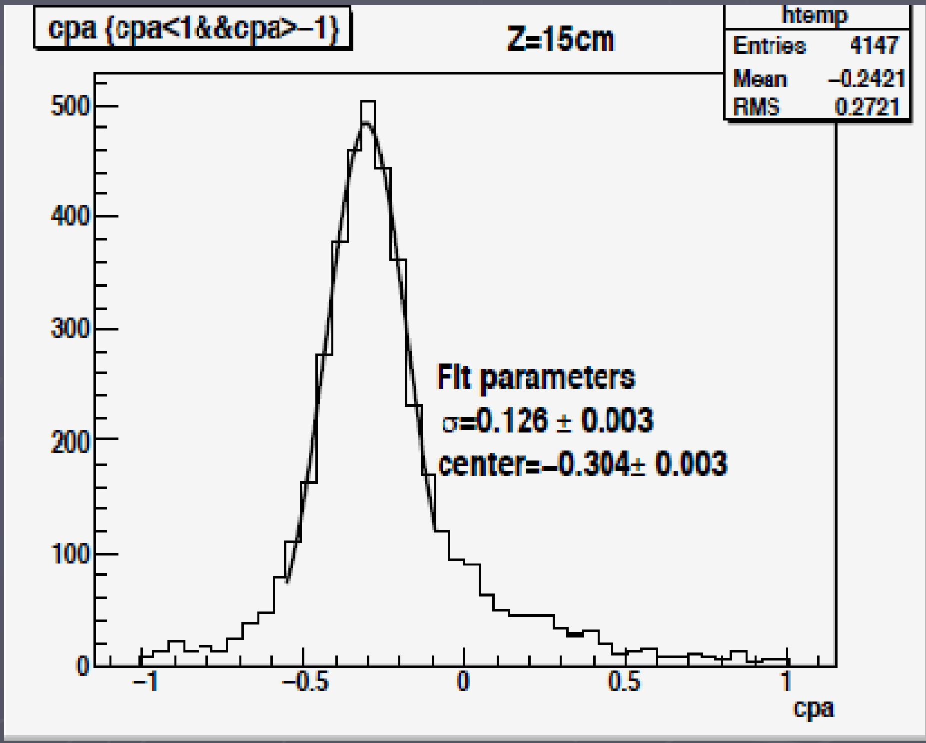
LP1 GEM Module by LC TPC Asian Group
Toward Full Volume Tracking

(D) Momentum measurement
(One/central module)

Fit all tracks by Kalamn Filter.
No selection of events/tracks.
The peak momentum of around 3GeV/c instead of 5GeV/c (due to the shower events).
Now need to understand the width of distribution.

(E) Tracking with multiple modules:

Still provisional tool now available.
Need to work with the non-uniform magnetic field and to correct/remove the effect of E-field distortion if any.



1/p distribution for the central module

Conclusions

MPGD provides a new TPC with large number of space points and the excellent point resolution of 100 microns or less over 2.5m drift distance, a truly-visual 3D tracker works in high magnetic filed providing the performance necessary for the experimentation at ILC.

The TPC Large Prototype test has started. The full volume tracking is still to be demonstrated (in 2010).

The GEM modules with thick GEM were tested in the Large Prototype . The results confirmed those from the small prototype tests (point resolution).

The issue of ion feed back still remains.

There are important engineering issues to realize MPGD TPC, in particular, the sirface mounting of electronics on the endplate (modules). R&D's for the advanced endplate design for all options are urgent.