Studies of Micro Pattern Gas Detector modules of a Large Prototype TPC for the ILD at ILC

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on behalf of the LCTPC Collaboration

LCTPC

Carleton UNIVERSITY

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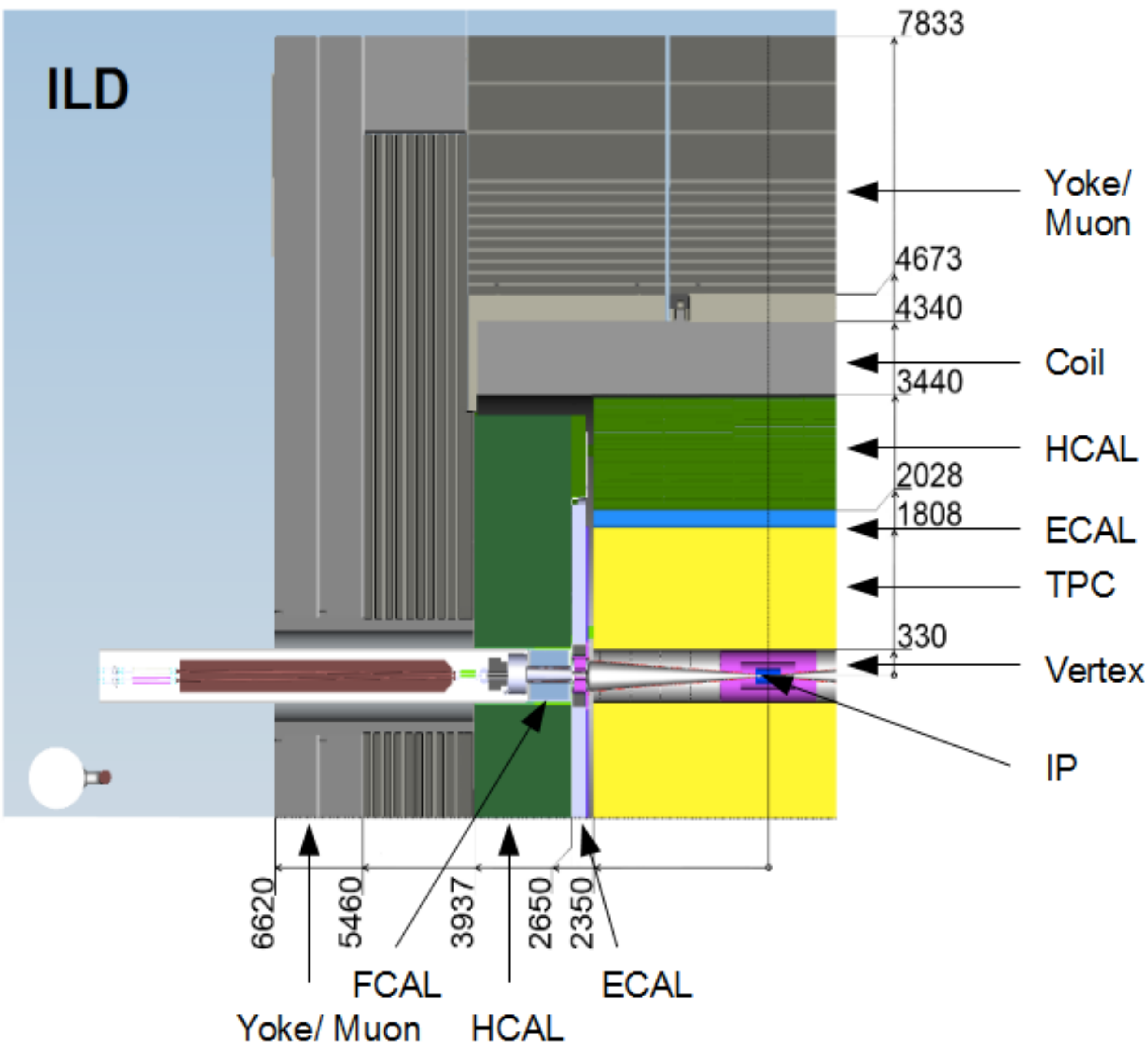
International Large Detector



ILD:

E_{cm} = 0.5 & 1 TeV

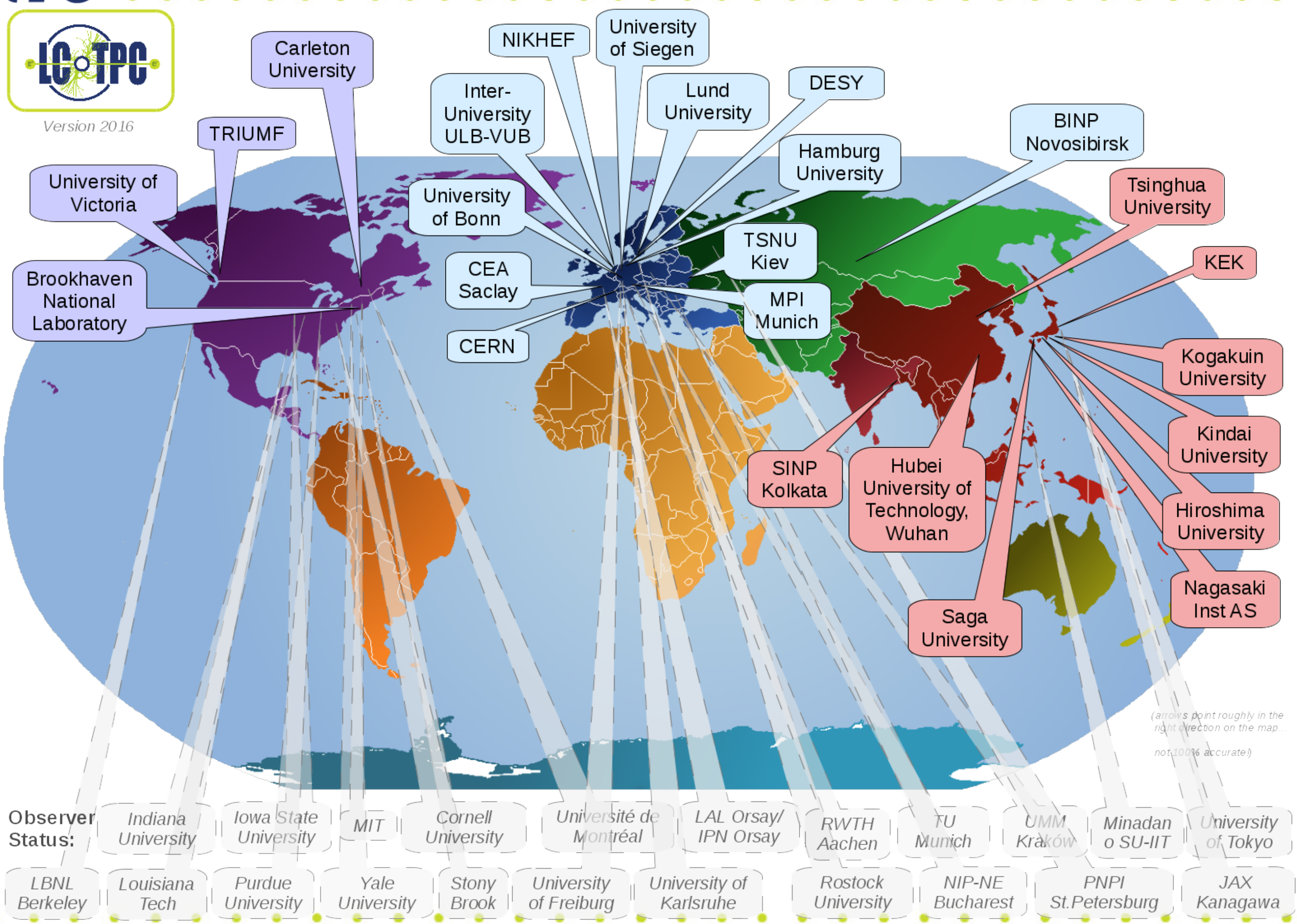
Components:

- Vertex
- Silicon tracking (SIT/SET/ETD/FTD)
- Gaseous TPC
- ECAL/HCAL/FCAL
- SC coil (3.5 or 4 Tesla)
- Muon in Iron Yoke

ILD Requirements:

- **Momentum resolution:** $\delta(1/p_T) < 2\times10^{-5}$ GeV^{-1}
- **Impact parameters:** $\sigma(r\phi) < 5$ μm
- **Jet energy resolution:** $\sigma_E/E \sim 3\text{-}4\%$

LCTPC Collaboration



Total of 12 countries from 25 institutions members + several observer institutes

Time Projection Chamber (TPC) for ILD

TPC is the central tracker for ILD

– Large number of 3D hits → continuous tracking

– Up to 200 positions measurements along each track

– Good track separation and pattern recognition

– **Single hit $\sigma(r\phi)$ at z=0 ≈ 60 μm and $\sigma(r\phi)$ < 100 μm**

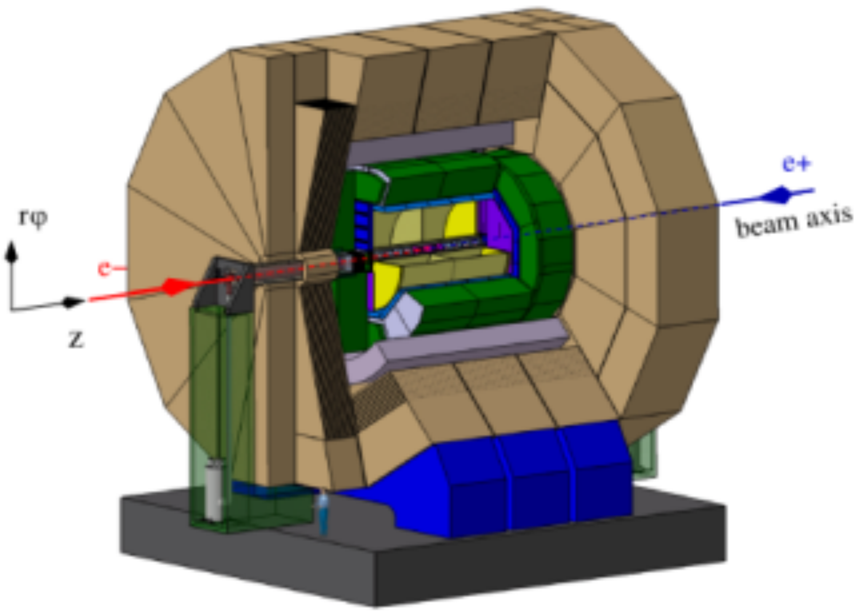
$\sigma(z)$ at z=0 ≈ 400 μm and $\sigma(z)$ < 1400 μm

Low material budget inside the calorimeters (PFA)

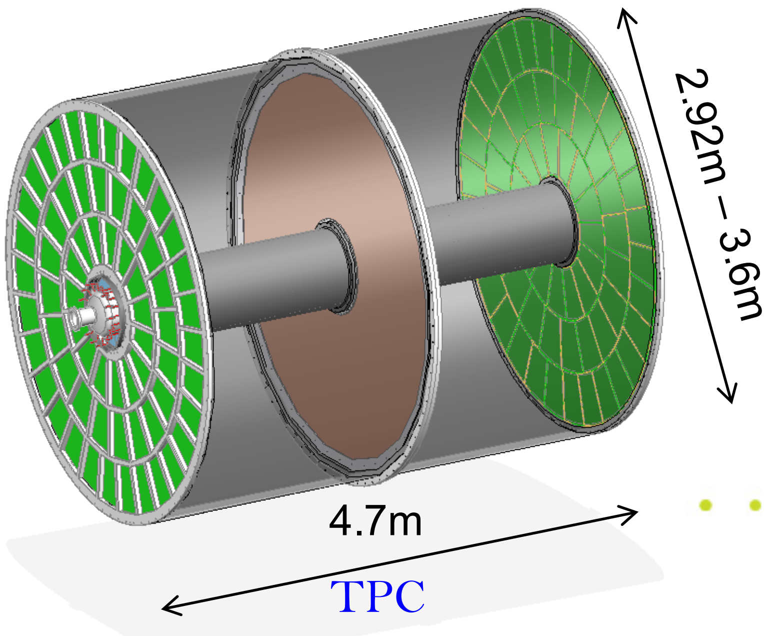
– Barrel: ~5% X_0 and Endplates: ~25% X_0

TPC Requirements:

- **Momentum resolution:** $\delta(1/p_T) < 9\times10^{-5}$ GeV^{-1}
- **Single hit resolution 3.5T:** $\sigma(r\phi) < 100\ \mu m$, $\sigma(z) \approx 500\ \mu m$
- **Tracking eff.** for p_T>1 GeV: > 97%
- **dE/dx resolution** ~5%



ILD

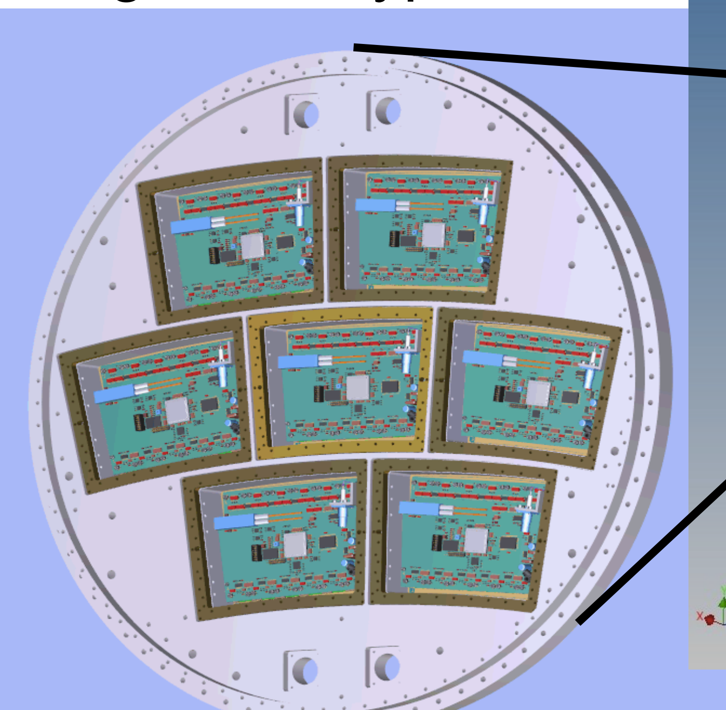


TPC

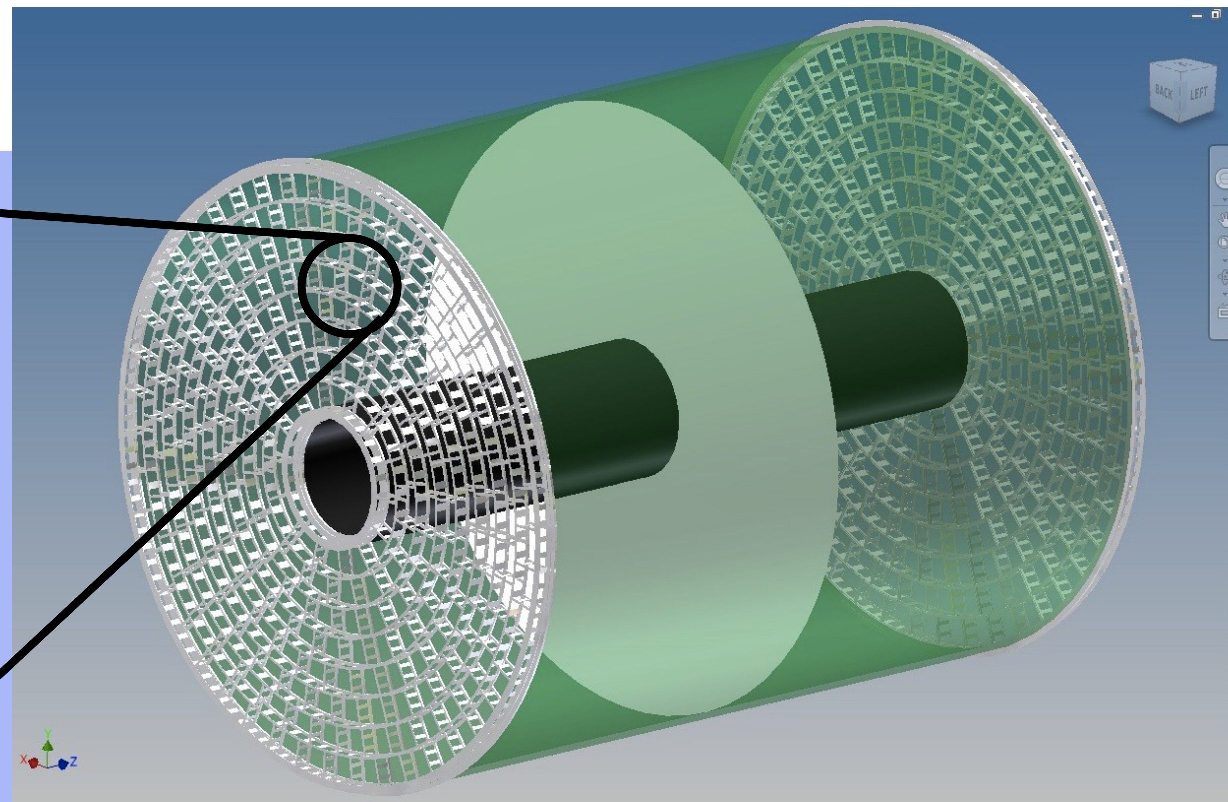
Large Prototype at DESY

- Two options for endplate readout with **pads**:
  - **GEM:** 1.2×5.8 mm² pads (smaller pad – more electronics)
  - **Resistive Micromegas:** 3×7 mm² pads (larger pads – less electronics)
- Alternative: **pixel** readout with pixel size ~55×55 μm² (newest)

Large Prototype TPC



Endplate of 7 panels, ø = 80 cm



ILD TPC: 240 modules

Micro Pattern Gas Detector (MPGD)

Technology choice for TPC readout: Micro Pattern Gas Detector

- no preference in track direction
- fast signal & high gain
- better ageing properties
- no E×B effect
- low ion backdrift
- easier to manufacture

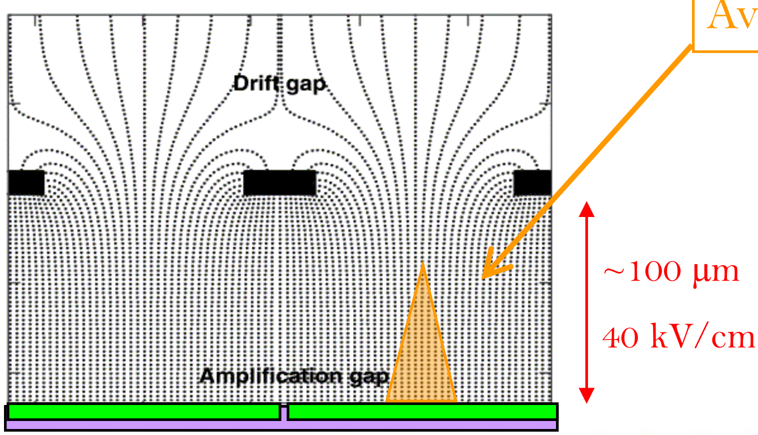
Resistive Micromegas (MM)

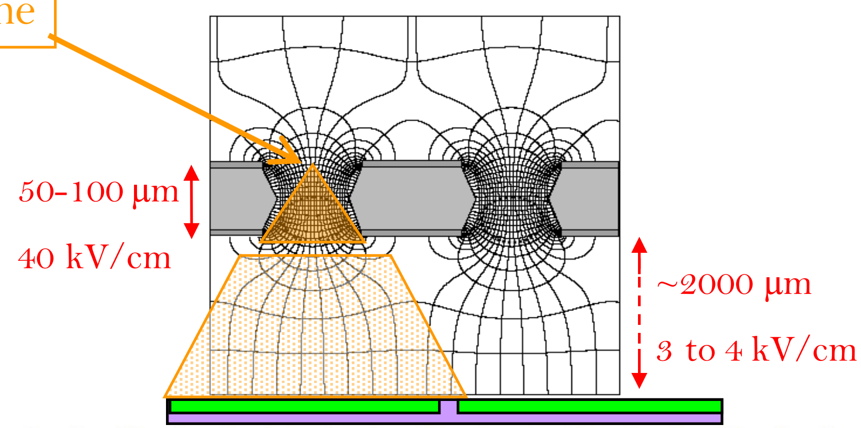
- MICROMEsh GAseous Structure
- metallic micromesh (typical pitch 50μm)
- supported by 50 μm pillars, multiplication between anode and mesh, high gain

GEM

- Gas Electron Multiplier
- doublesided copper clad Kapton
- multiplication takes place in holes, with 2-3 layers needed

Avalanche



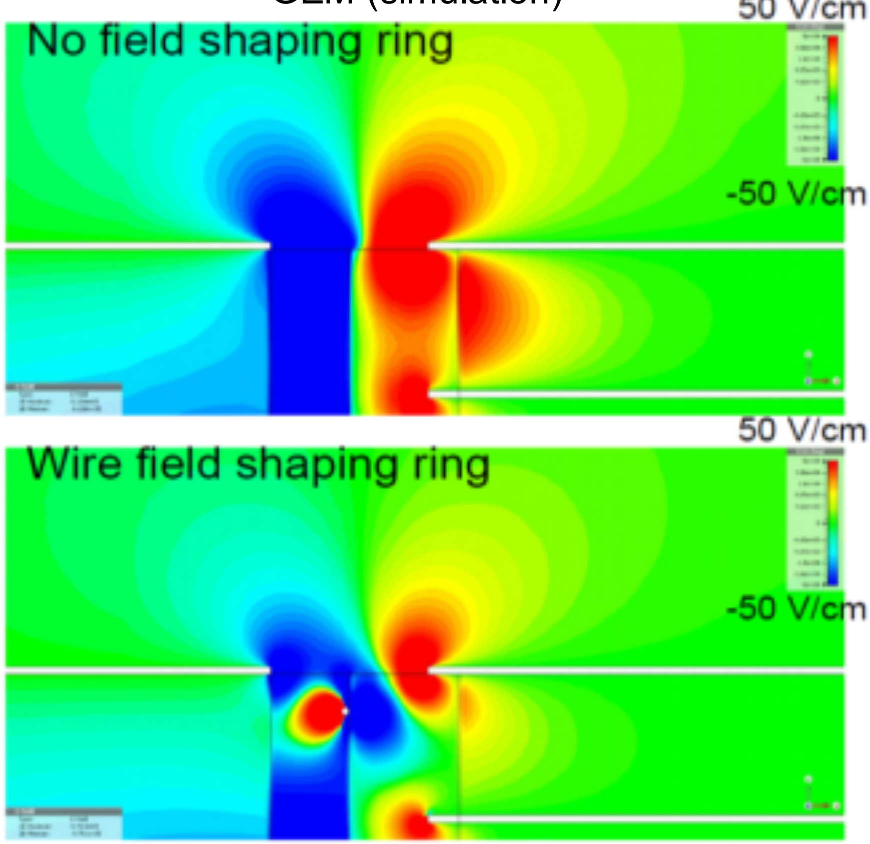


Discharge probability and consequences can be mastered (use of resistive coatings, several step amplification, segmentation) – MPGD more robust mechanically than wires

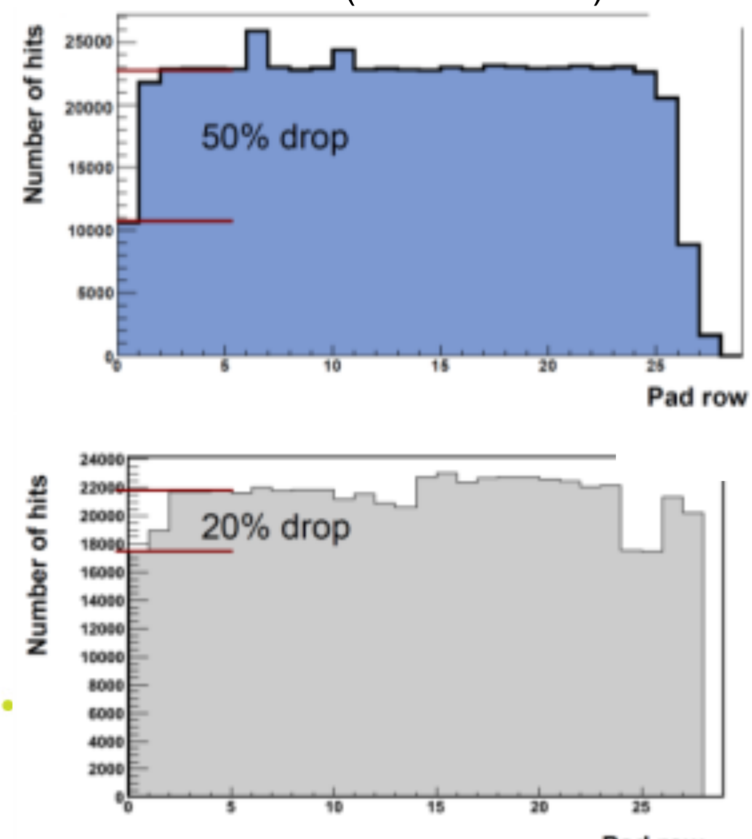
LCTPC Scientific Program

- Development of MPGD assembly procedure with integrated readout
- Measurement of transverse and longitudinal resolution
- Optimization (i.e. reduction) of field distortion in amplification gap
- Further R&D in progress at the hardware/design/construction level

GEM (simulation)

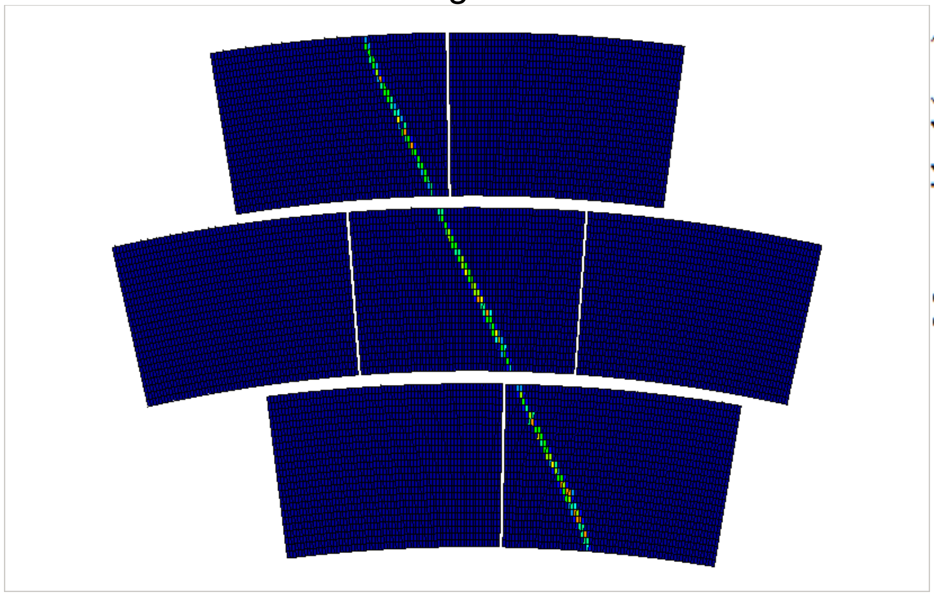


GEM (measurement)

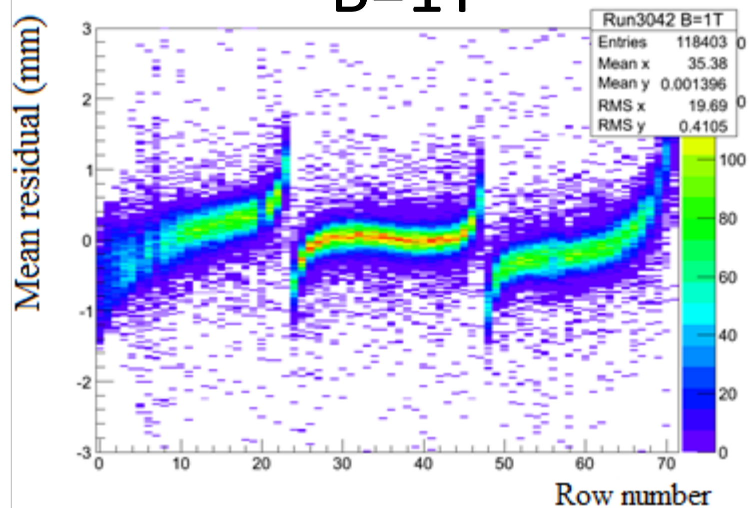


Field Distortions (E x B effect)

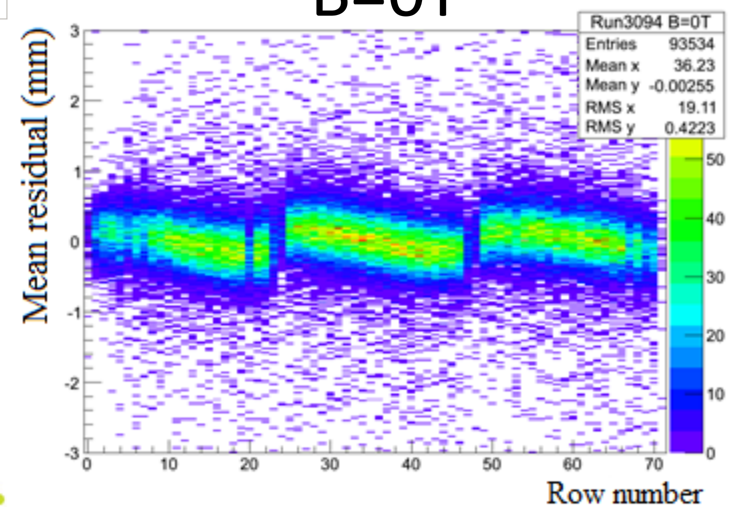
Micromegas modules



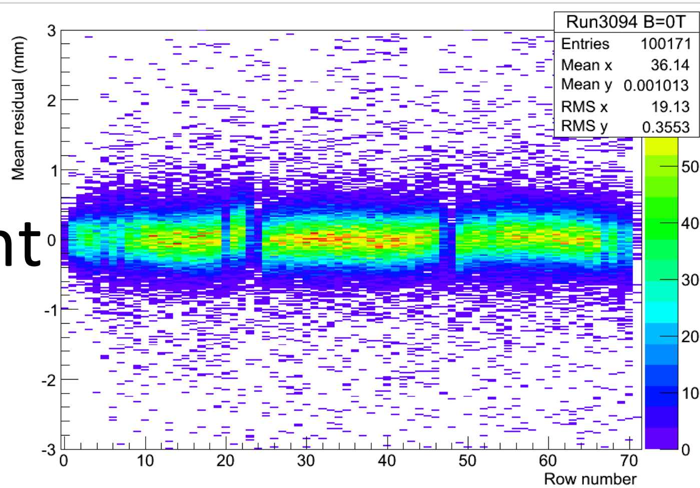
B=1T



B=0T



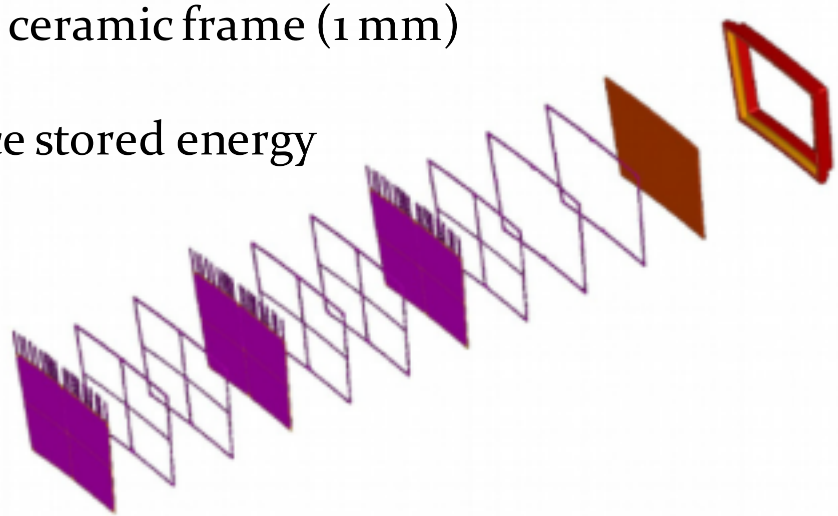
After alignment

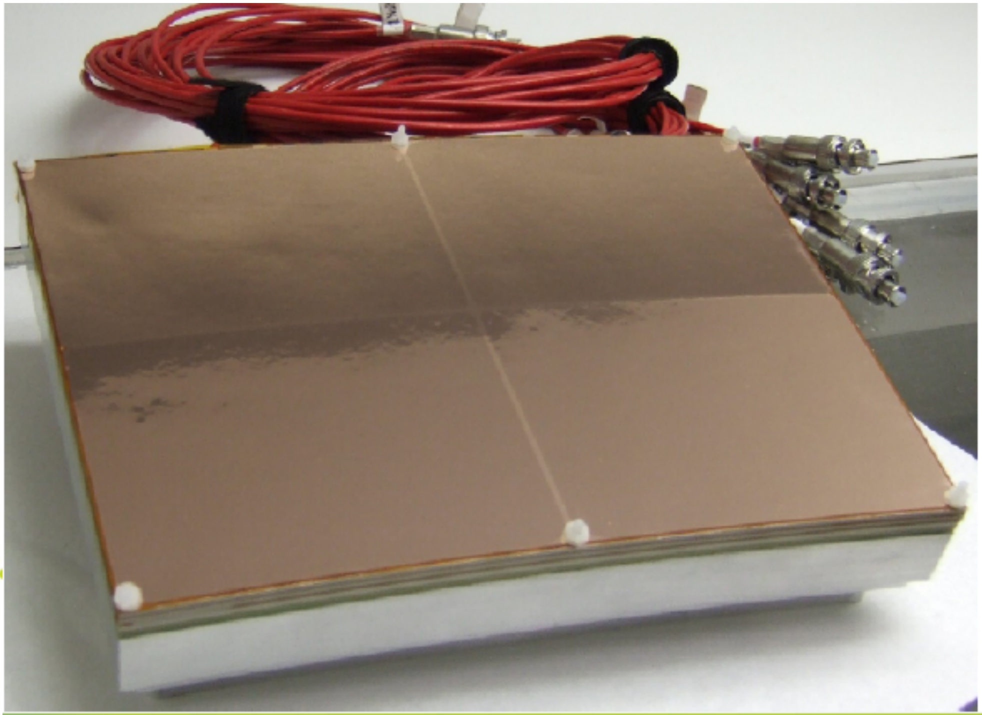


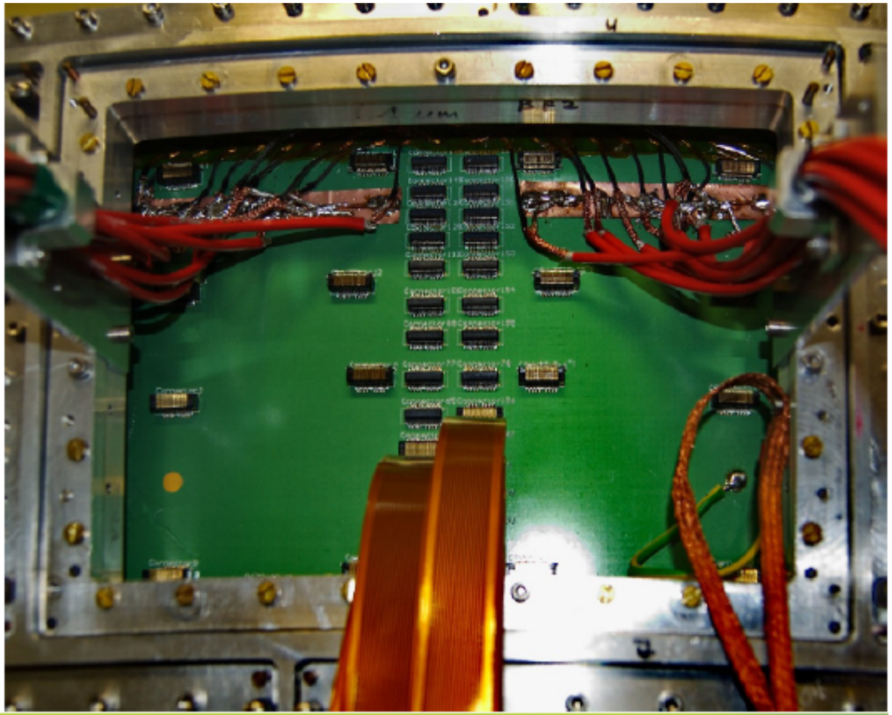
software off-line correction for module alignment and field distortion

Triple GEM Modules (European GEM)

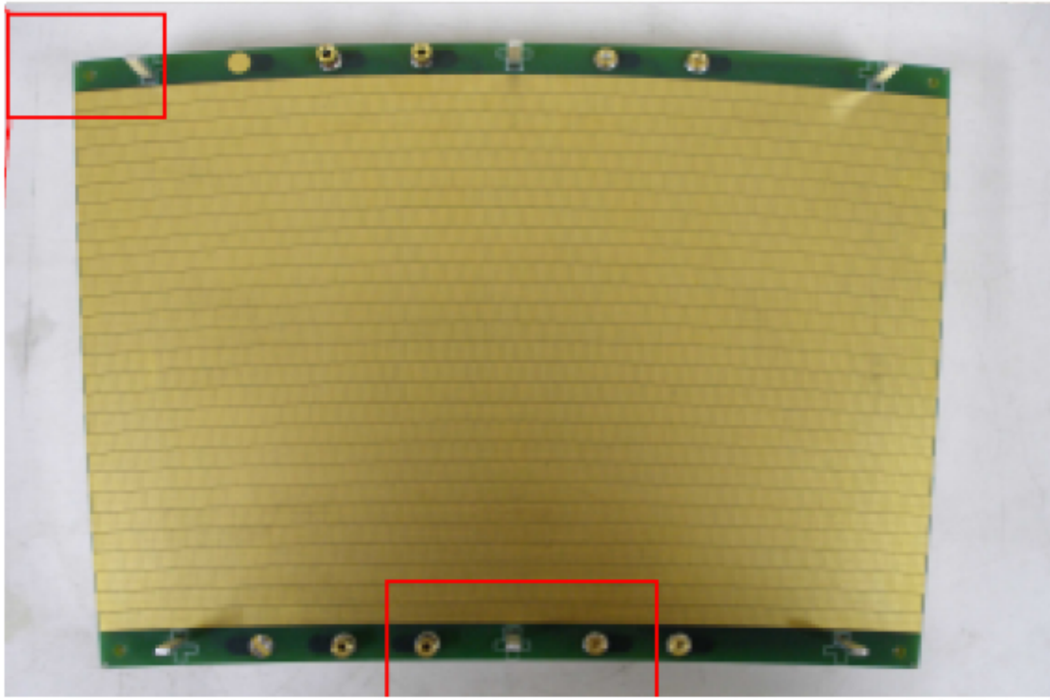
- Three standard CERN GEMs mounted on a light ceramic frame (1 mm)
- Partially equipped (1000 pads, 1.26 x 5.85 mm²)
- Bottom GEMs segmented into 4 sectors to reduce stored energy
- Top GEM electrode not segmented
- Read out by ALTRO electronics
- HV line for each GEM side
- Protection resistors very close to GEM
- 5000 pad version being built



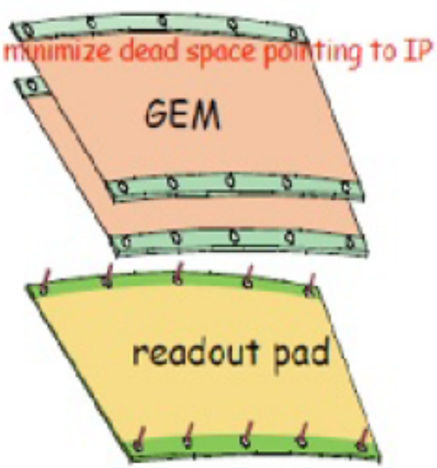


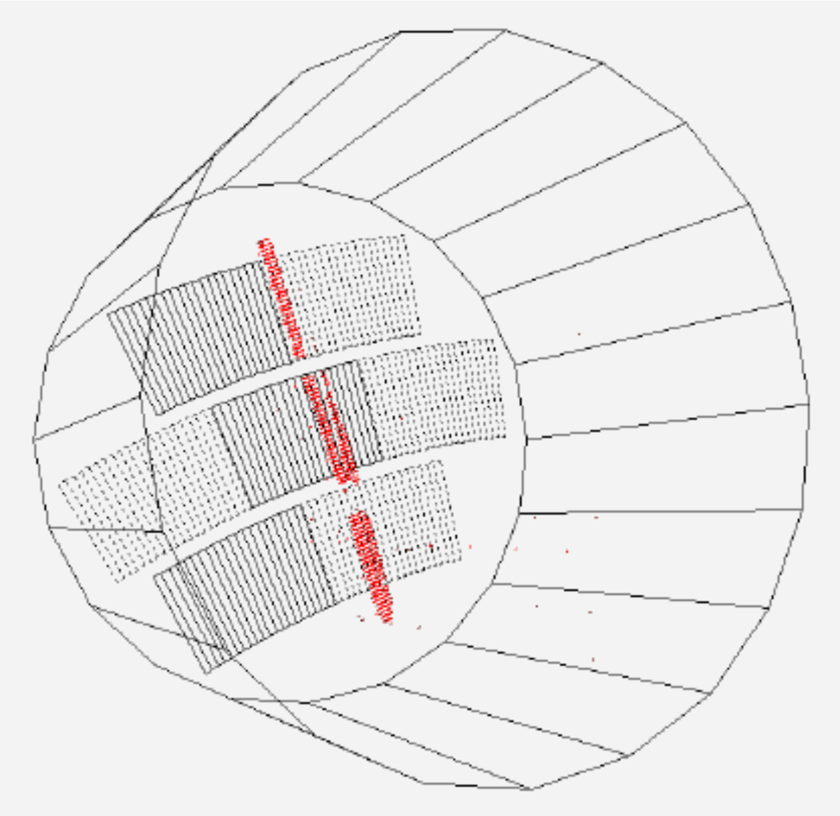


Double GEM Modules (Asian GEM)

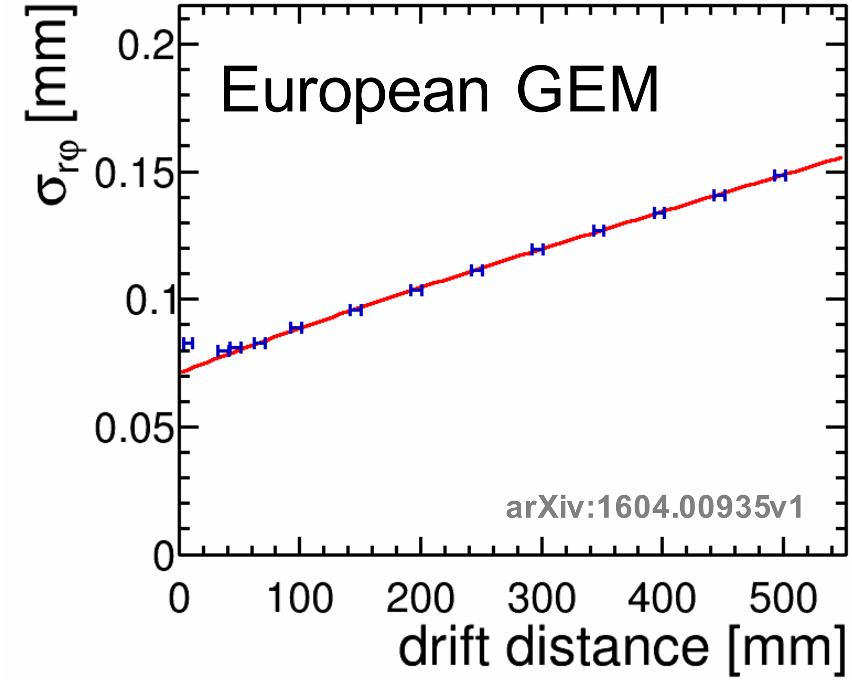


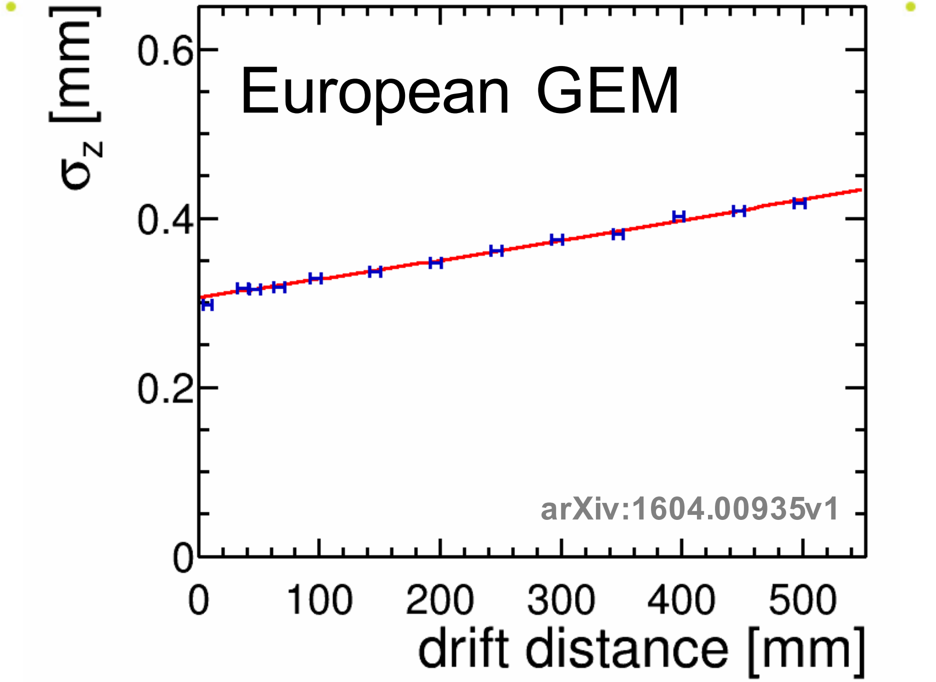
- Laser-etched Liquid Crystal Polymer by SciEnergy, Japan
- 100 μm thick
- 28 staggered rows of 176-192 pads
- Pad 1.2 x 5.4 mm^2

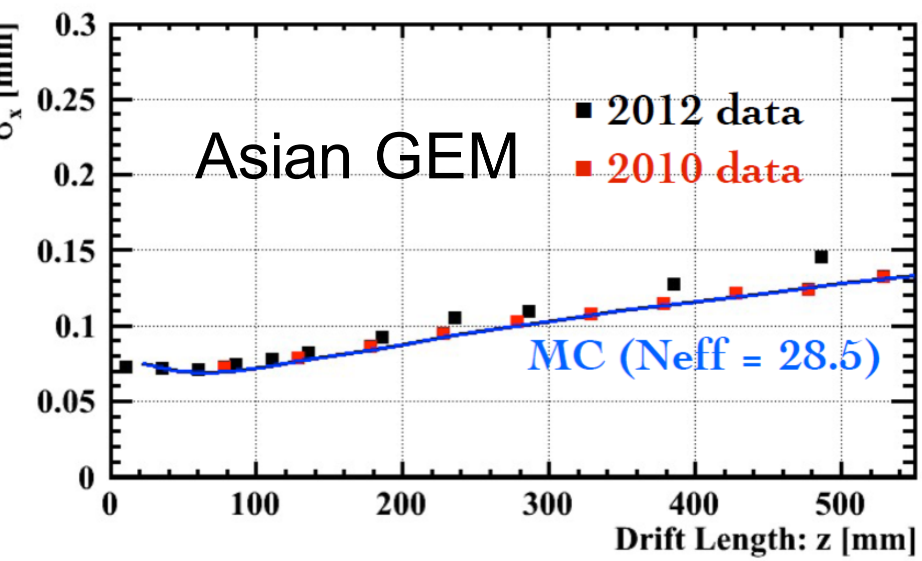


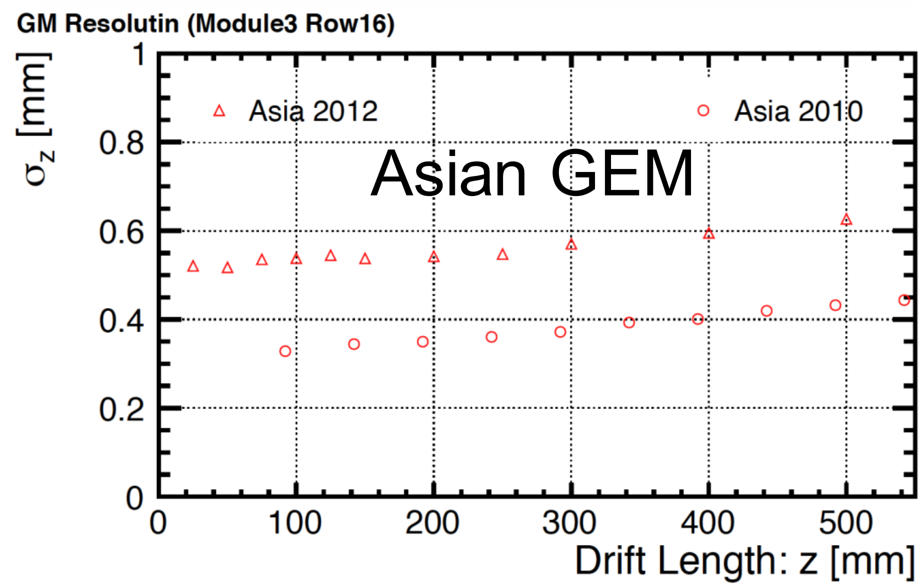


GEM Resolution

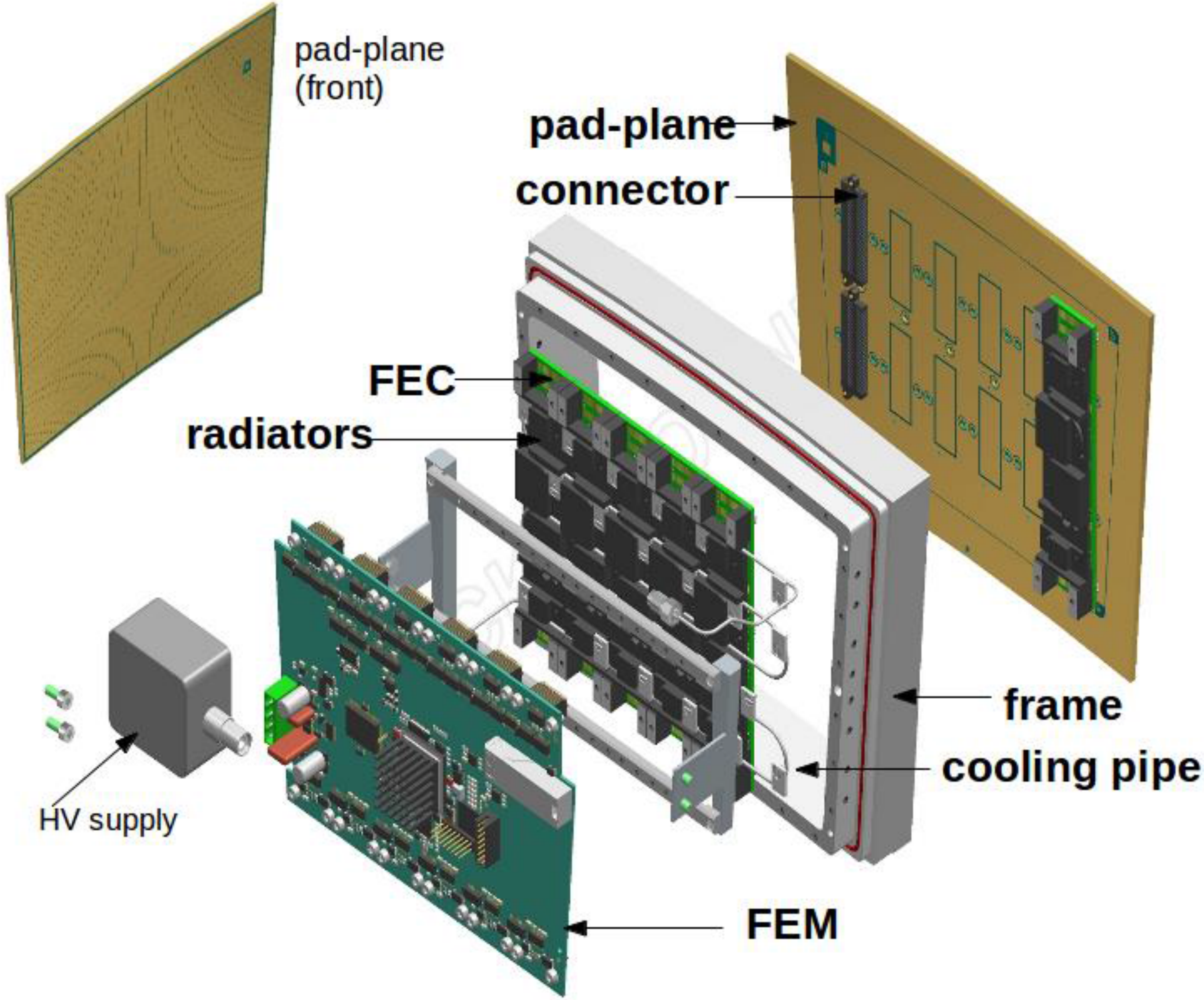






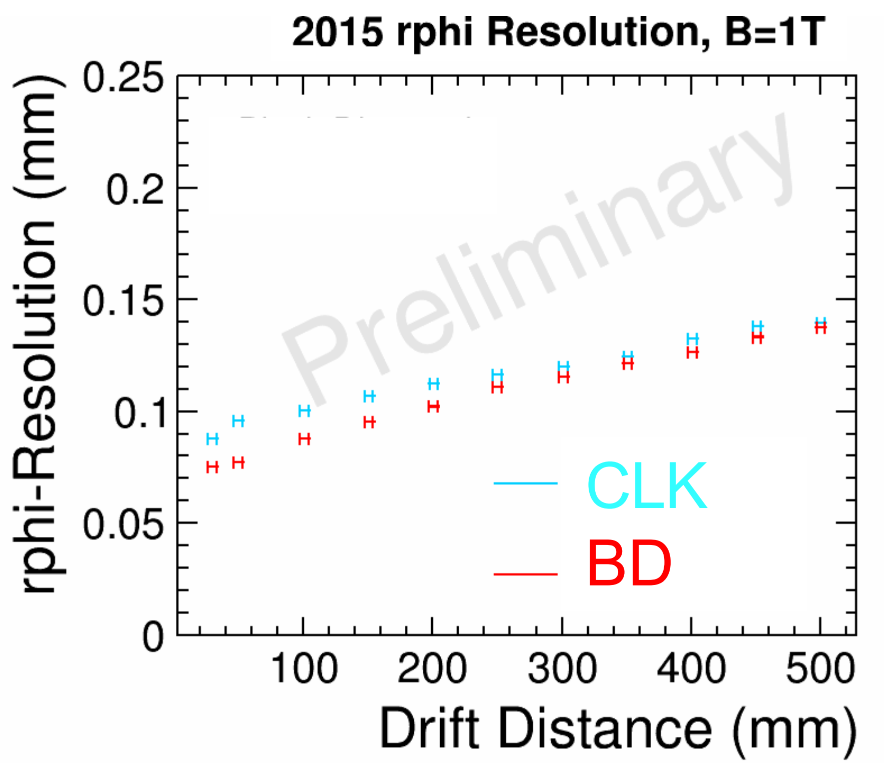


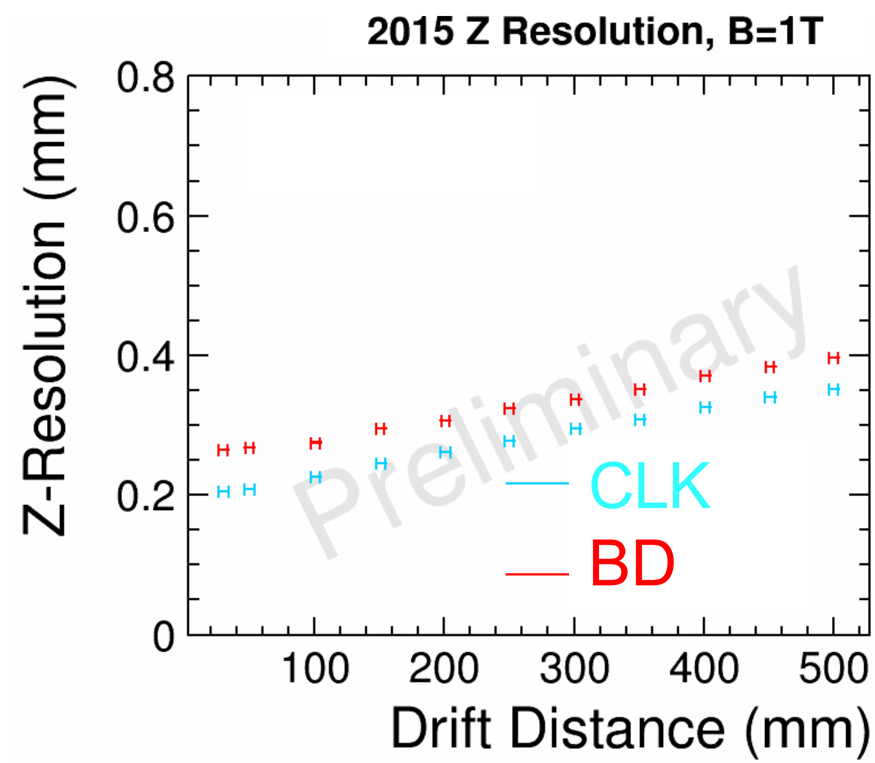
Micromegas: Module Design



Micromegas Resolution

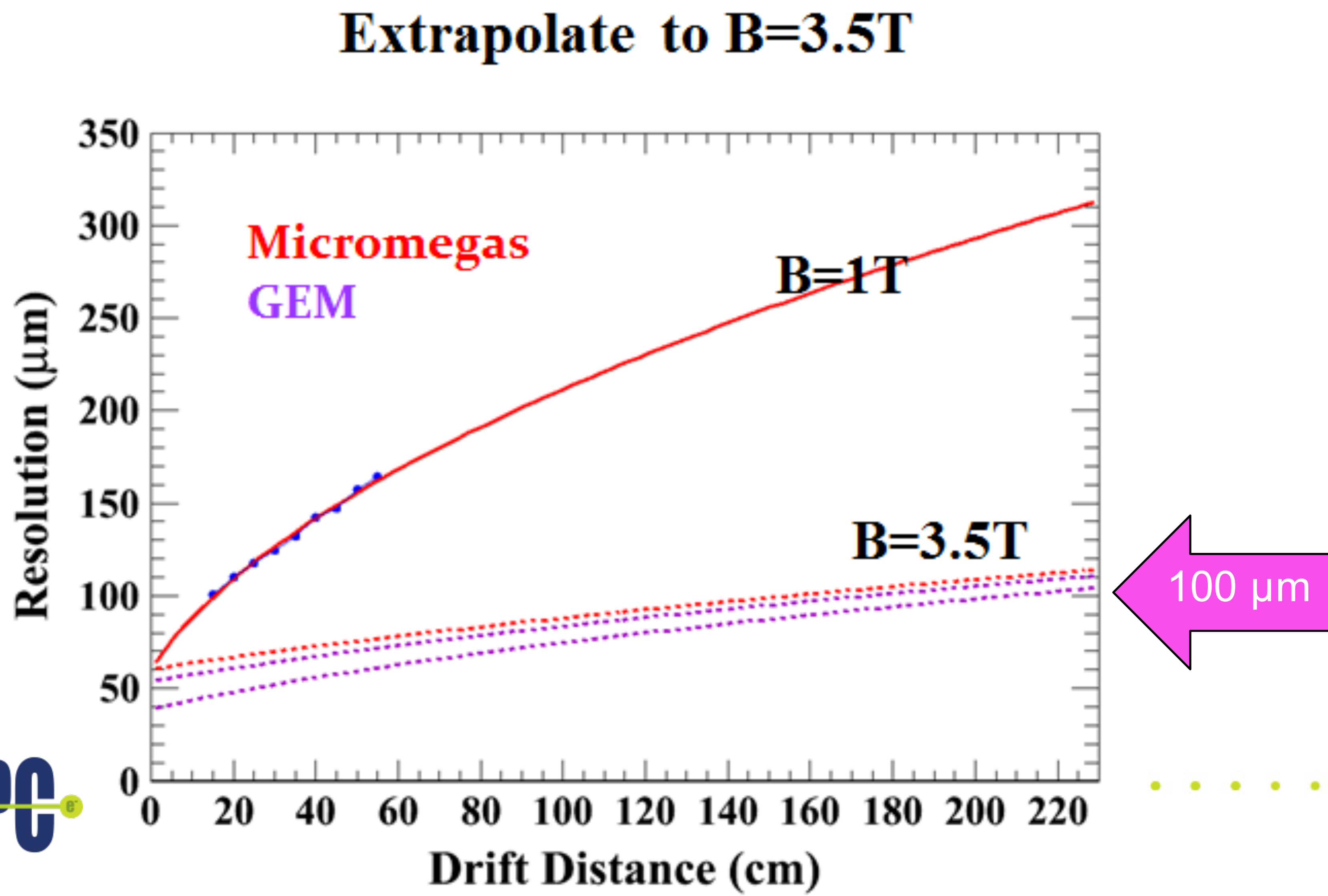
- R&D: Saclay & Carleton
- Endplate fully equipped (all modules populated)
- Read out by AFTER electronics
- Optimized shaping time and mesh voltage
- Resistive layer to spread charge for better clustering and centroid determination
- Two type of resistive layers: Carbon-Loaded Kapton (CLK) and Black Diamond (BD)
- Full CO_2 cooling system (with NIKHEF & KEK) in 2015 testbeam



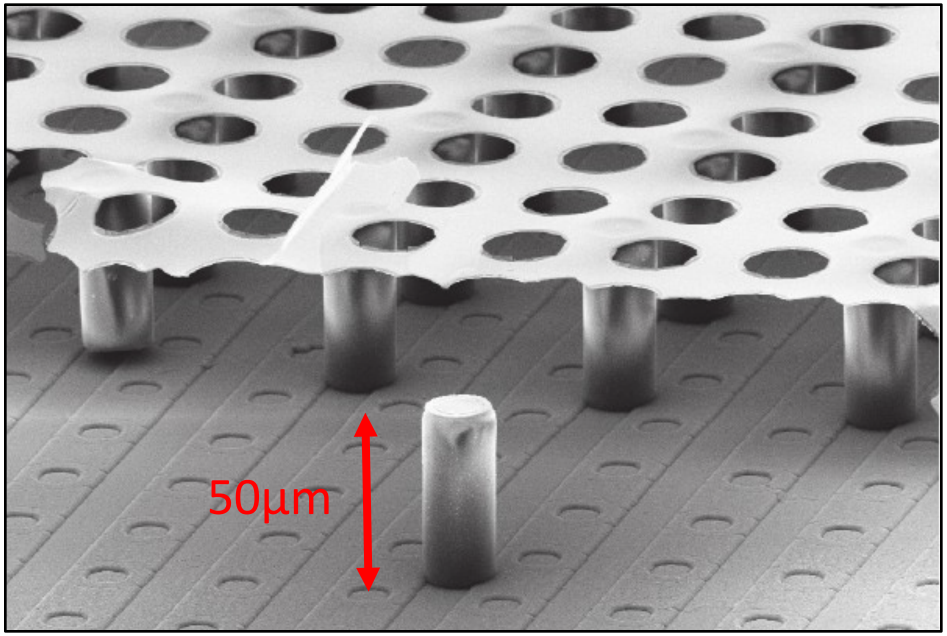


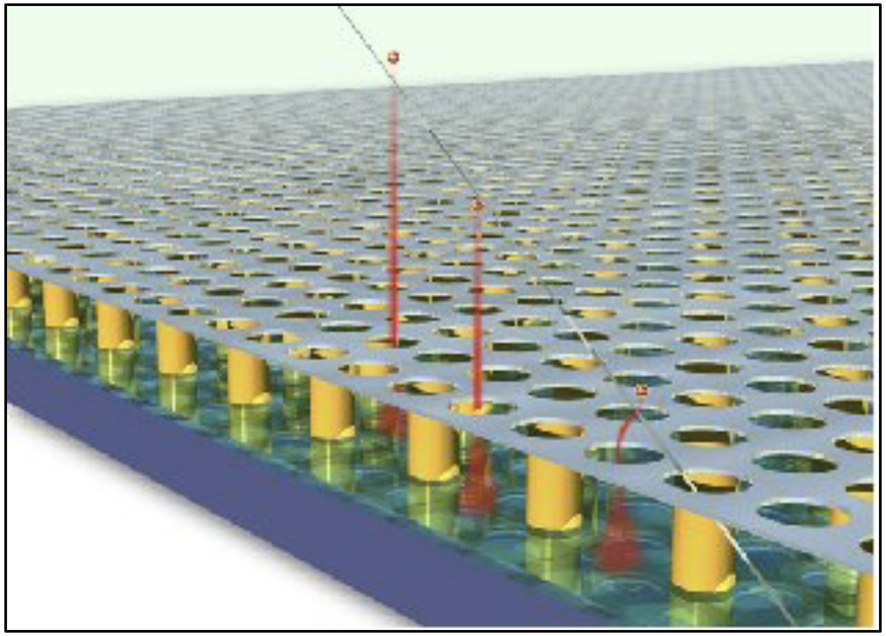
Transverse (r-Φ) Resolution

Micromegas 3×7 mm² pads and GEM 1.2×5.8 mm² pads

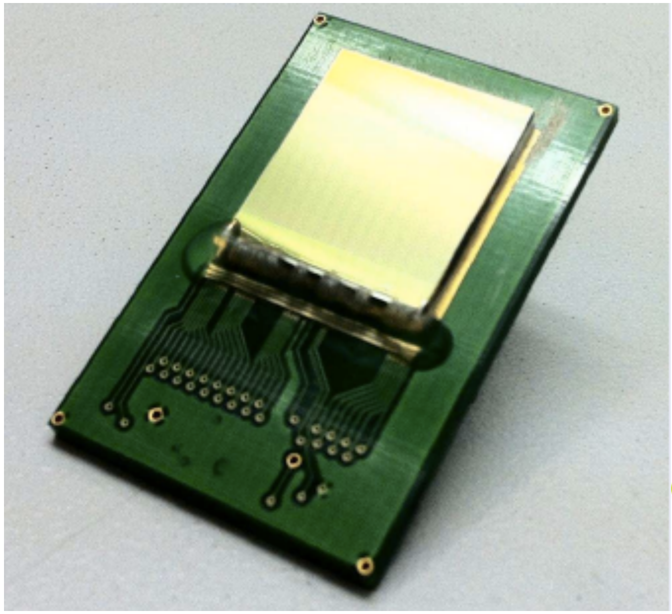


Highly Pixelated Readout (GridPix)





- Micromegas on a pixelchip
- Resistive protection layer (4-8 µm) on top of chip
- Insulating pillars between grid & pixelchip
- One hole above each pixel
- Amplification directly above the pixelchip
- Very high single point resolution

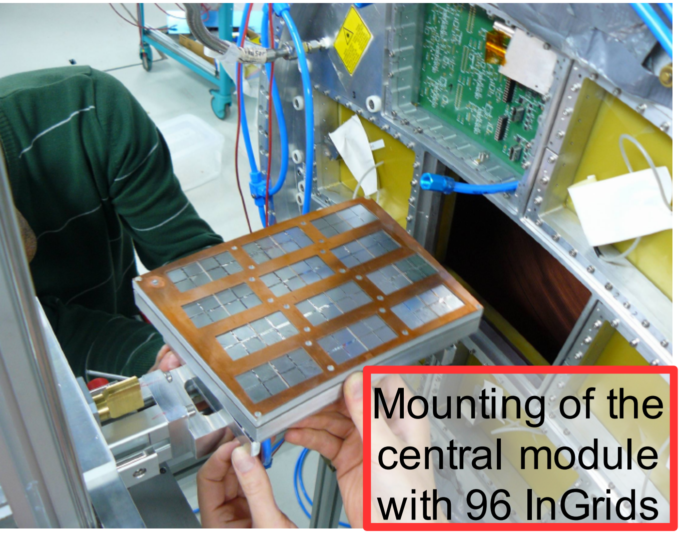


Timepix: 256 x 256 pixels of size 55 x 55 µm^2

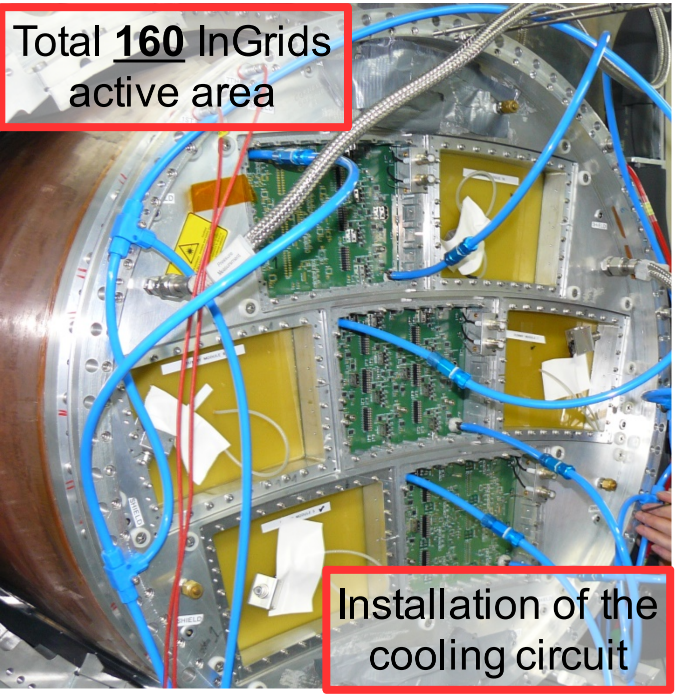
➢ low threshold level ~500 e- (90 e- ENC)

GridPix

Large scale application / Large active area

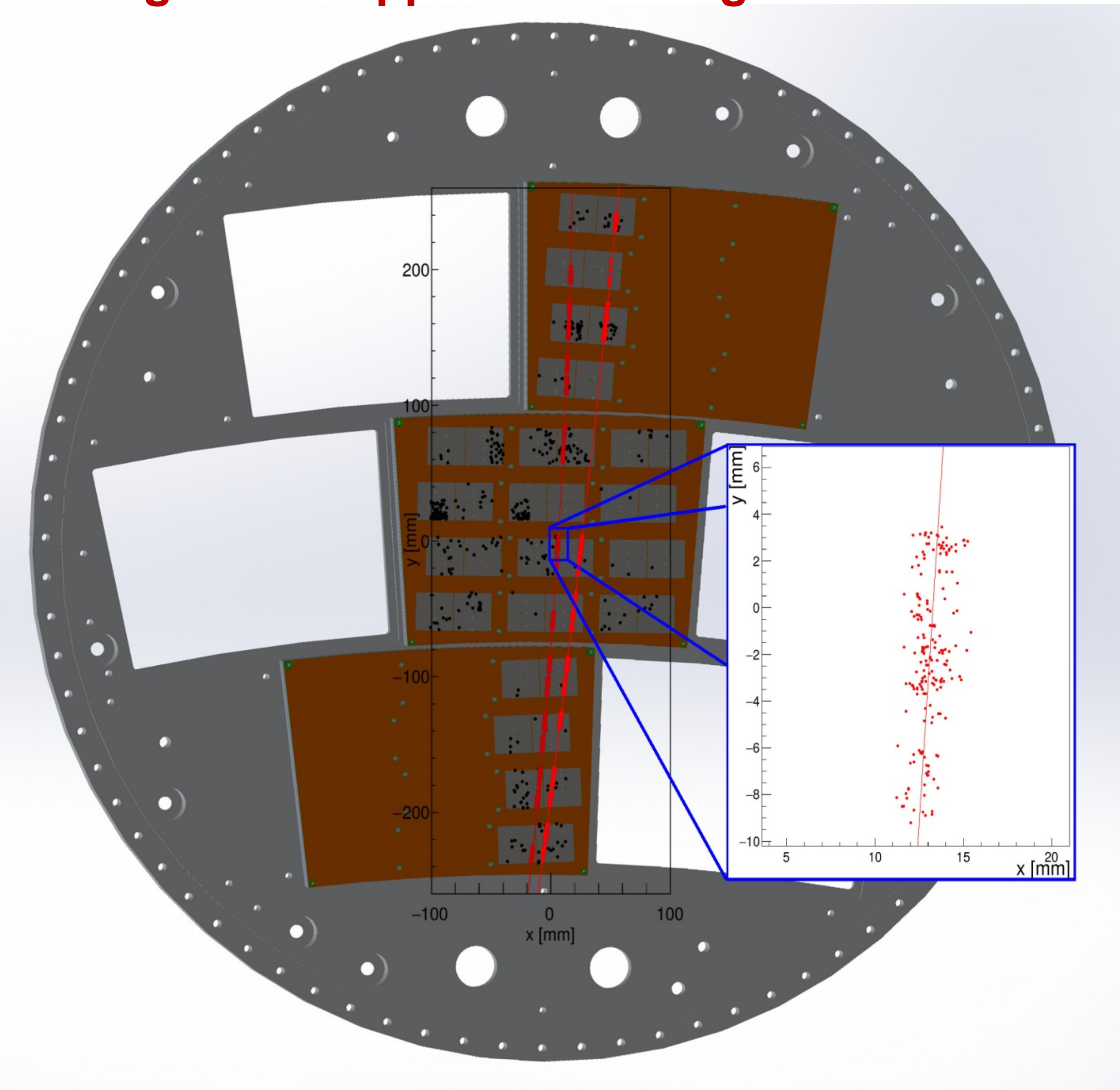


Mounting of the central module with 96 InGrids



Total **160** InGrids active area

Installation of the cooling circuit

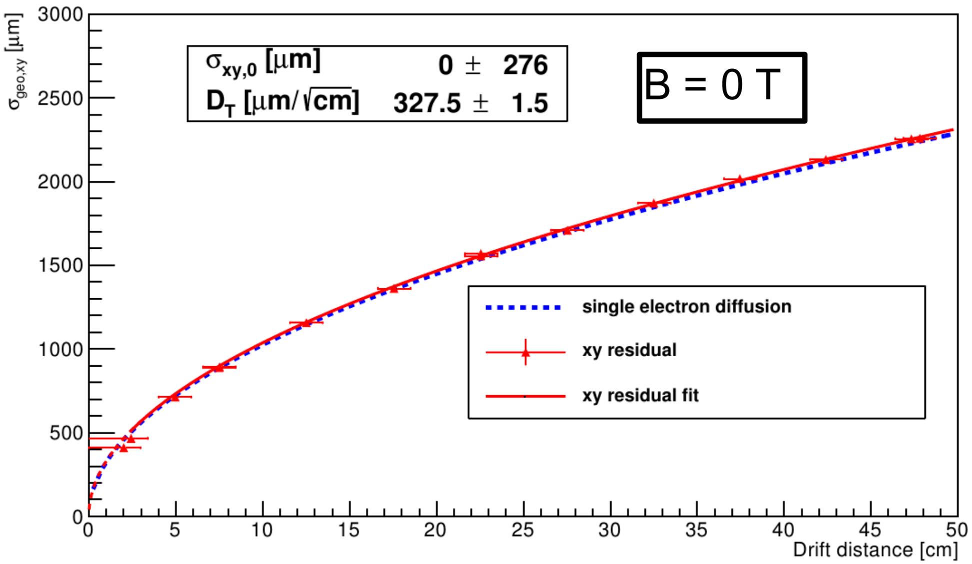


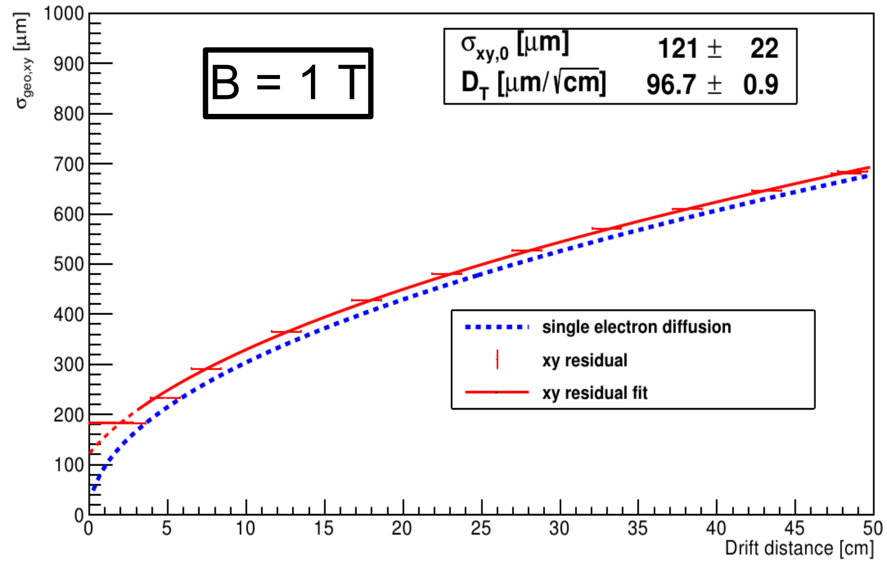
GridPix Resolution

New!

Spatial resolution (*preliminary*):

In x-y plane, from residuals, with and without B-field

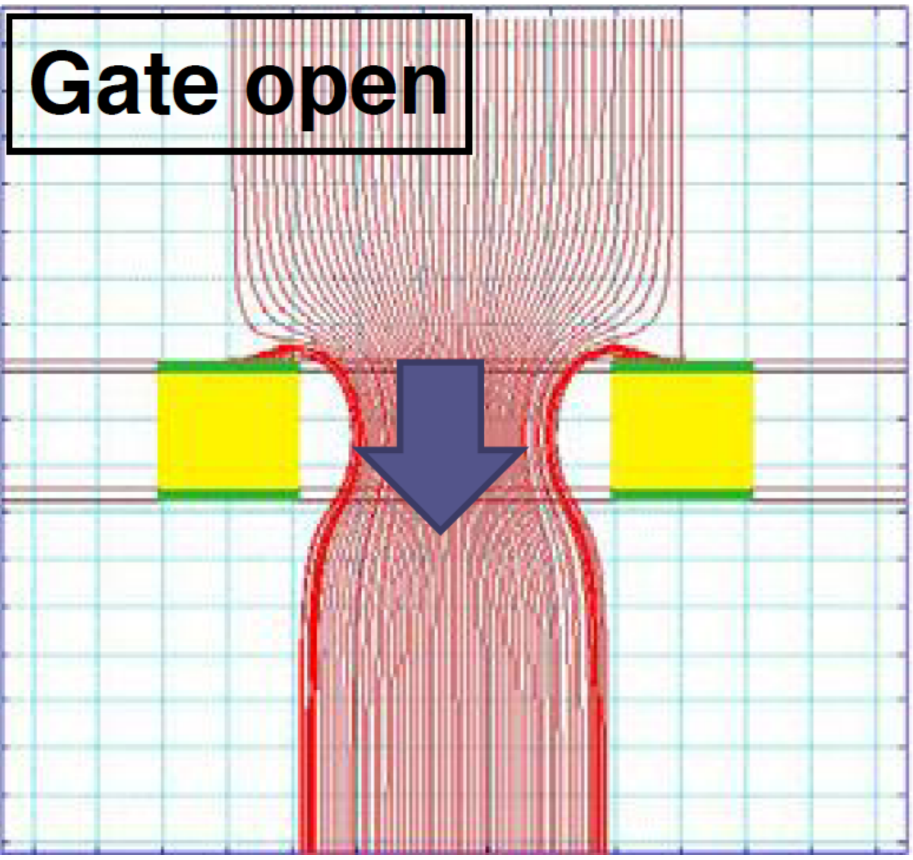


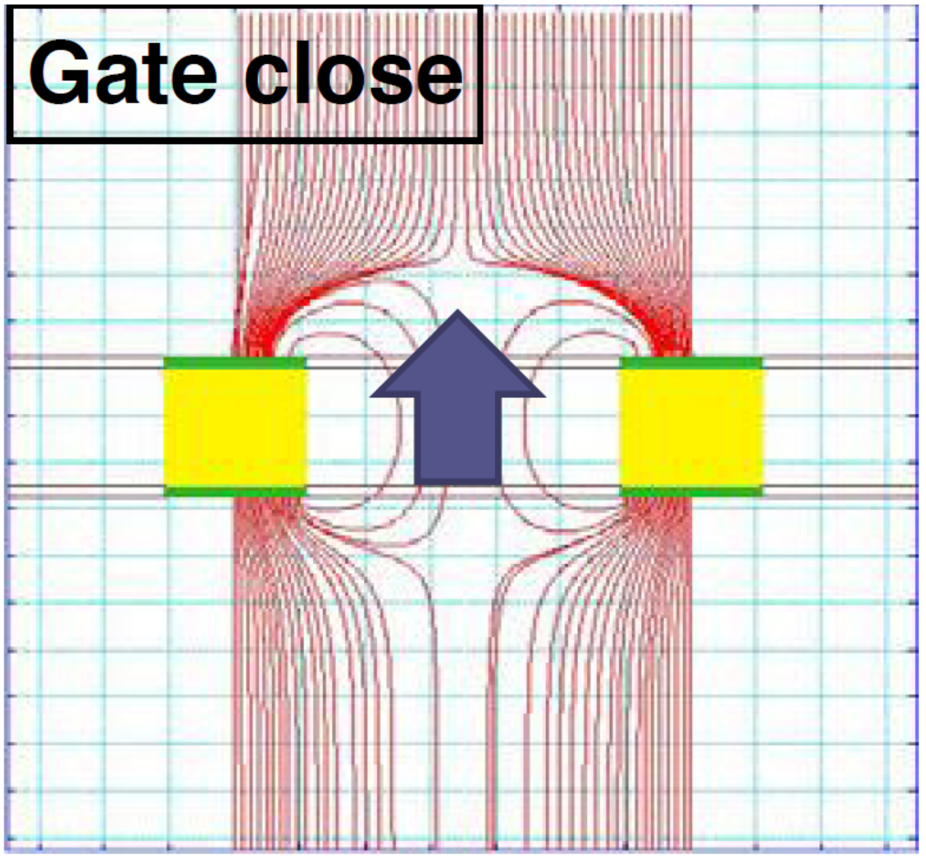


- Transverse spatial resolution follows diffusion of *<u>single</u>* electrons
- The single hit resolution does not depend on the track angle
- Expected resolution as good, or better, than MPGD pad readout
- Reconstructed diffusion constants in agreement with simulations

Ion Gate for the TPC

- Ion Gating: suppress ion backflow into the main TPC drift volume
- Radial profile of the ion disk produced during the avalanche is dominated by machine-induced background during a bunch train
- Expect 60 μm distortion when drift electrons pass through ion disk
- GEM gating system testbeam in preparation by Japanese group





Summary – Outlook

- A lot of experience has been gained in building and operating MPGD TPC panels within the LCTPC collaboration
- The characteristics of the MPGD, such as the uniformity, spatial resolution, stability studied in detail. Steady progress. R&D mature.
- Results of LCTPC indicate that it meets resolution goal at ILC:

  $\sigma(r\phi)$ at z=0 ≈ 60 μm and $\sigma(r\phi)$ < 100 μm
  $\sigma(z)$ at z=0 ≈ 400 μm and $\sigma(z)$ < 1400 μm

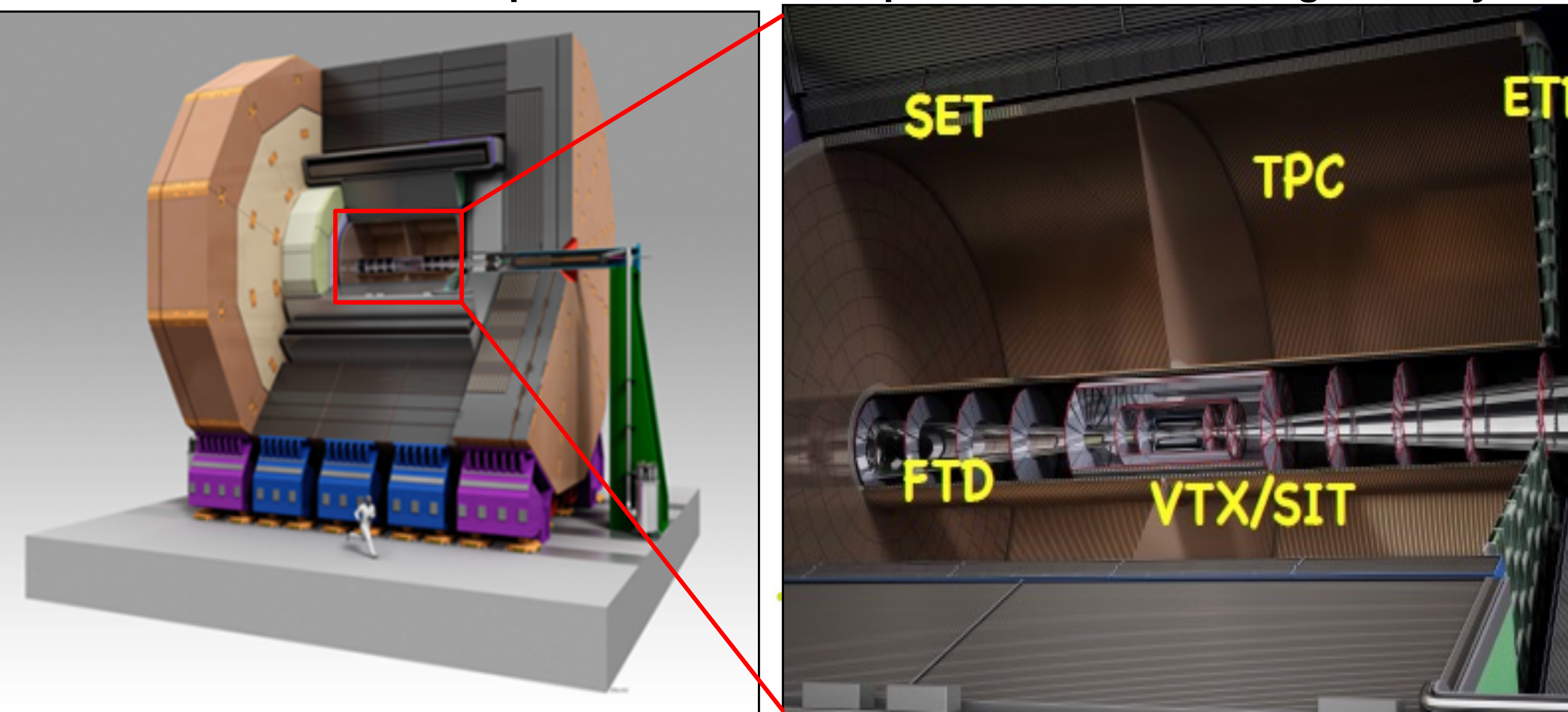
- On-going progress on ion grid (gating), power pulsing electronics, multi-track pattern recognition as well as detailed simulation
  - Precise & reproducible MPGD assembly within mechanical tolerance
  - Large area module with minimal field distortion in amplification gap
- There is renewed optimism for the ILC going forward
- LCTPC is in a good position and ready for a call for the ILD experiment

Extra slides

International Large Detector

- Time Projection Chamber (TPC)
- Vertex (VTX) detector is realized with multi-layer of pixels
- Silicon strip (SIT) detectors are arranged to bridge the gap VTX and the TPC

TPC $\lesssim$200 continuous position measurements along each track in a gas with the point resolution of $\sigma_{r\varphi} < 100\mu m$, and a lever arm of around 2m in the magnetic field of 3.5-4T . 2-track separation: 2 mm in Rφ and 6 mm in z in a high density



International Large Detector

ILD ECAL and HCAL

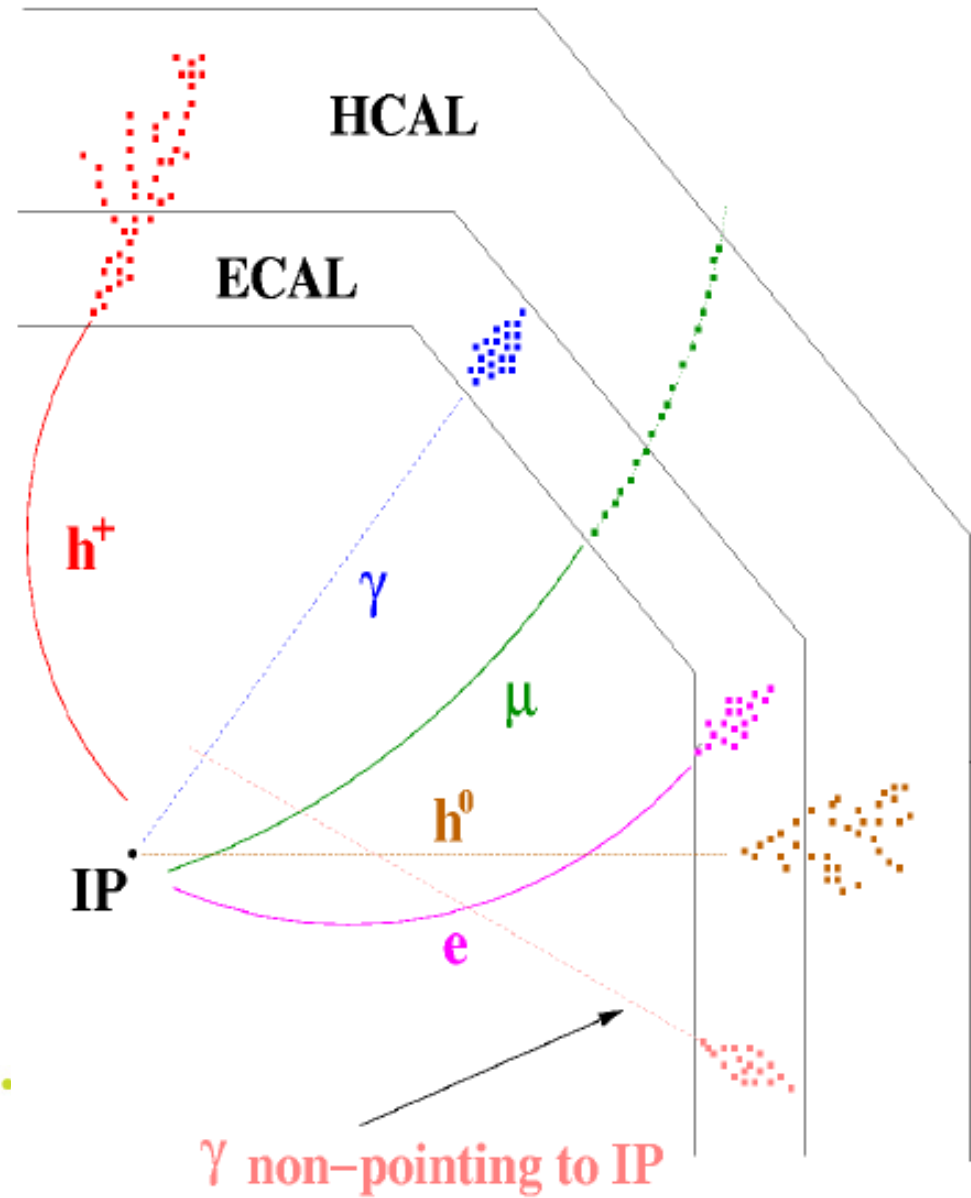
large radius and length
➔ to separate the particles
Hermitic, but compact (inside the coil of the solenoid)

large magnetic field
➔ to sweep out charged tracks

“no” material in front of calorimeters
➔ stay inside coil

small Molière radius of calorimeters
➔ to minimize shower overlap

high granularity of calorimeters
➔ to separate overlapping showers



Conceptual Design of a TPC

A 3D camera, which captures the passage of charged particles.

(1) Ionization: along path of charged particle

(2) Drift & Diffusion: spread as Gaussians in Transverse and Longitudinal planes (statistical)

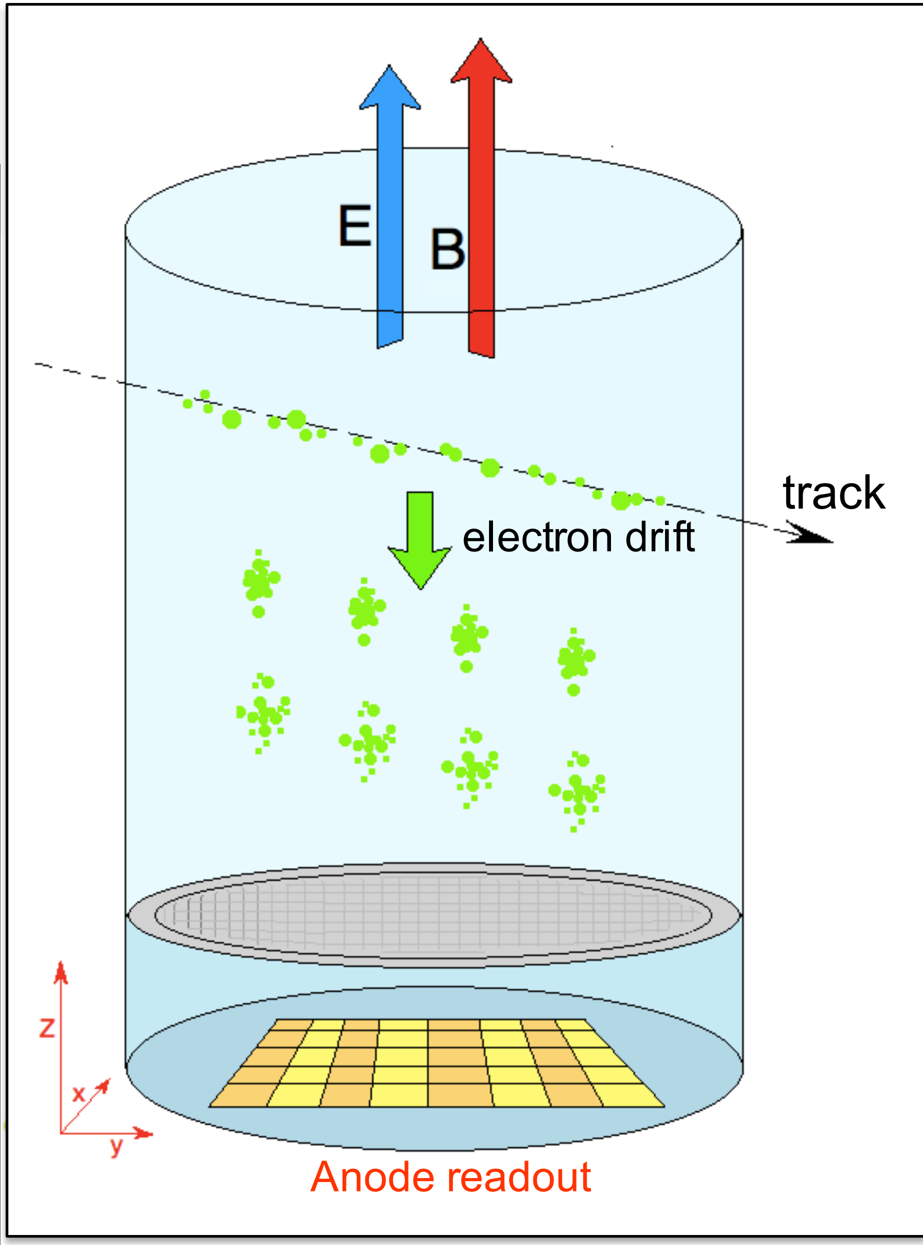
$$\sigma^2 = \sigma_0^2 + D^2 \cdot z$$

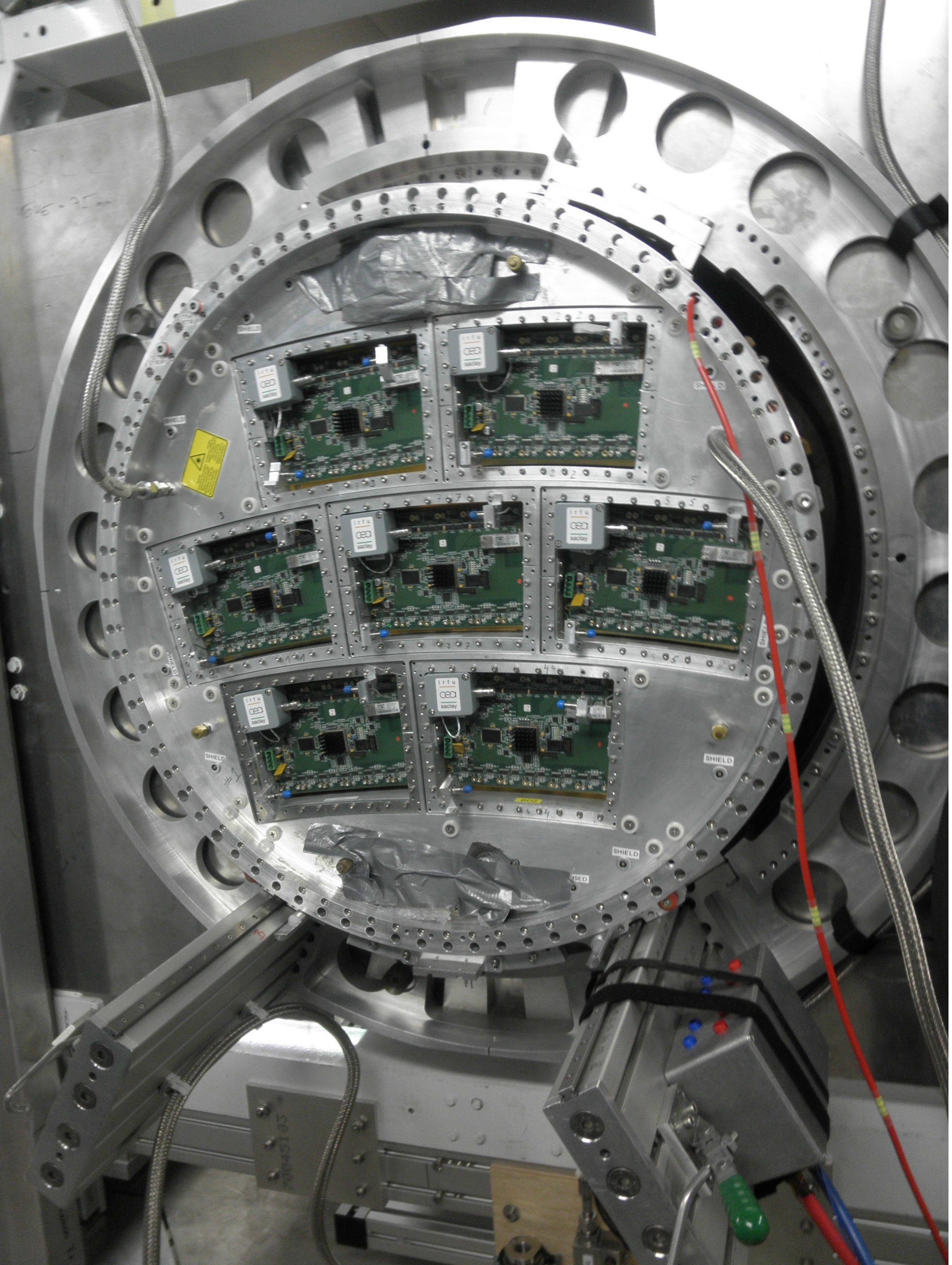
$$D = \text{diffusion}\left(\frac{\mu m}{\sqrt{cm}}\right)$$

Transverse diffusion is suppressed by the Magnetic field (Lorentz Force)

(3) Amplification: boost number of electrons

(4) Readout Pads: pads convert to digital record





Multi-module LCTPC

Period
2012-2015

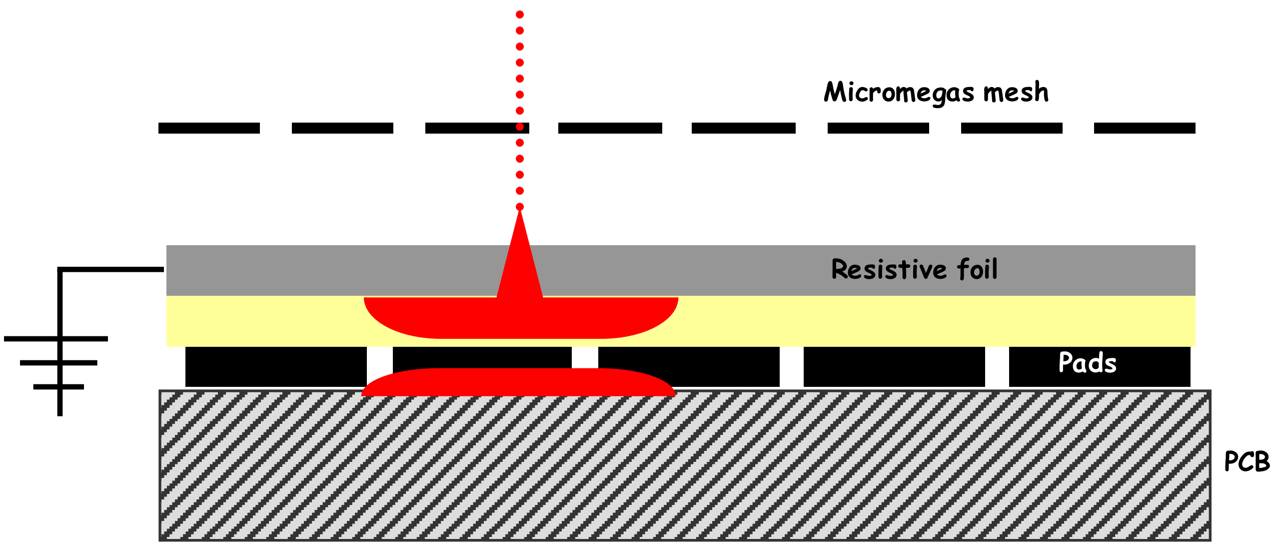
2013 data
6-module

2014 data
7-module with cooling

2015 data
7-module with cooling
2 new modules

Micromegas (MM) Charge Dispersion

Resistive Anode



Testbeam Facility (DESY)