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

Alain Bellerive
on behalf of the LCTPC Collaboration

August 6, 2016

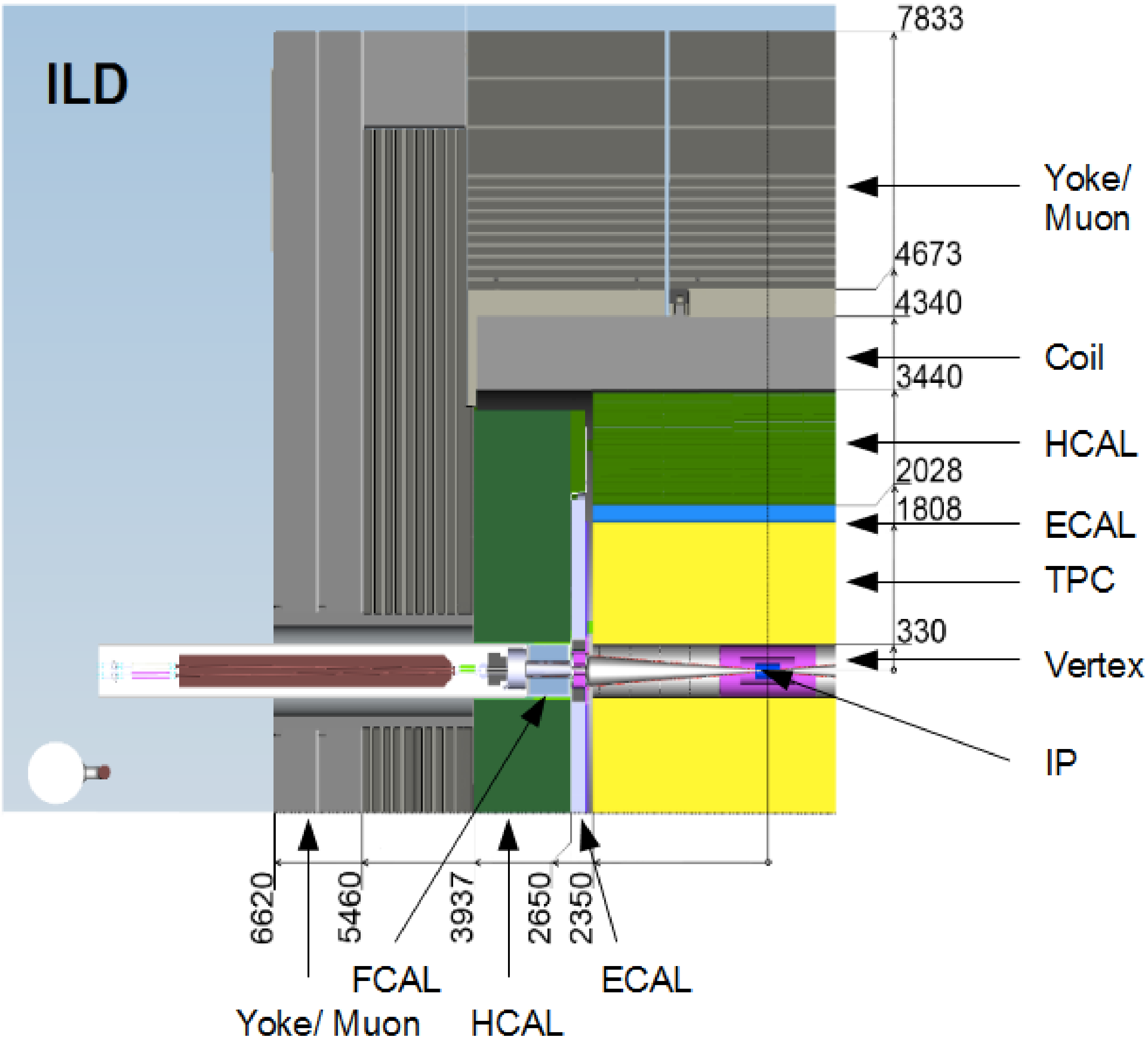
Outline

- International Linear Detector (ILD)
  - **Concept and Specifications**

- Large Prototype TPC (LCTPC) for the ILC
  - **TPC Requirements**
  - **Micro Pattern Gas Detector (MPGD)**
  - **Testbeam Results & Spatial Resolution ($\sigma_{r\varphi}$ and σ_z)**
  - **Ion Gating**

- Summary & Outlook

International Linear Detector



ILD:

E_{cm} = 0.5 & 1 TeV

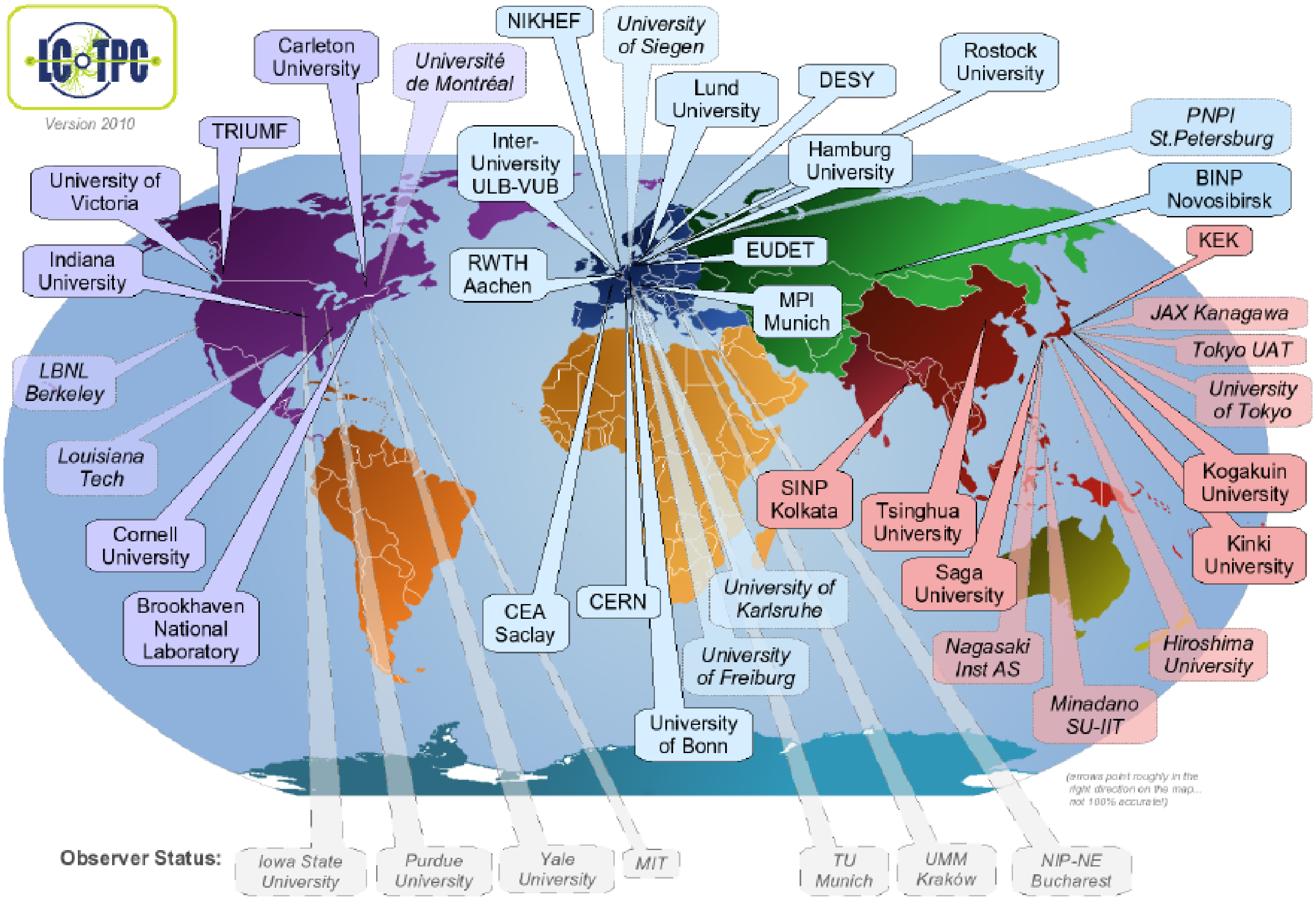
Components:

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

ILD Requirements:

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

LCTPC Collaboration



Total of 12 countries from 38 institutions members + 7 observer institutes

Need update xxxxx ?????

Time Projection Chamber (TPC) for ILD

TPC is the central tracker ILD

– Large number of 3D hits → continuous tracking

– More 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

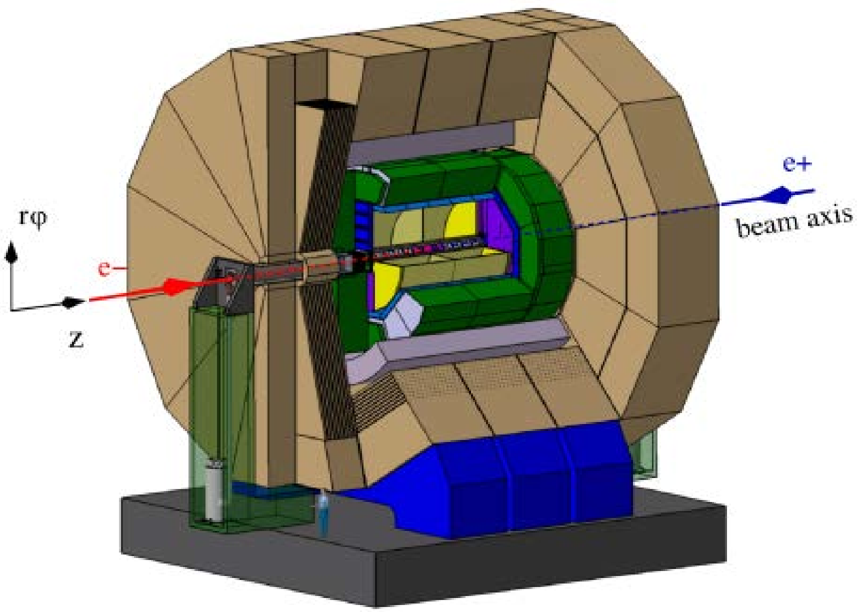
$\sigma(z)$ at z=0 ≈ 400 μm and $\sigma(z)$ < 1400 μm

Low material budget inside the calorimeters (PFA)

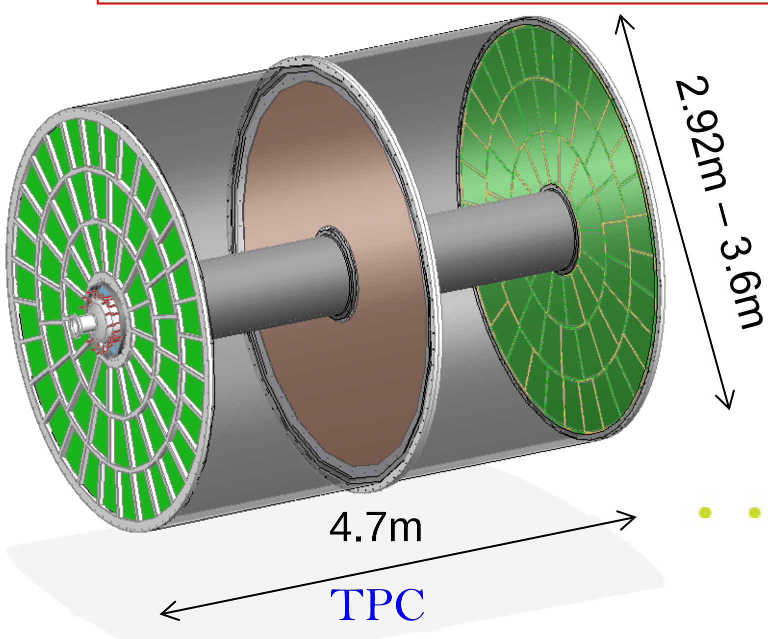
– Barrel: ~5% X_0 and Endplates: ~25% X_0

TPC Requirements:

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



ILD

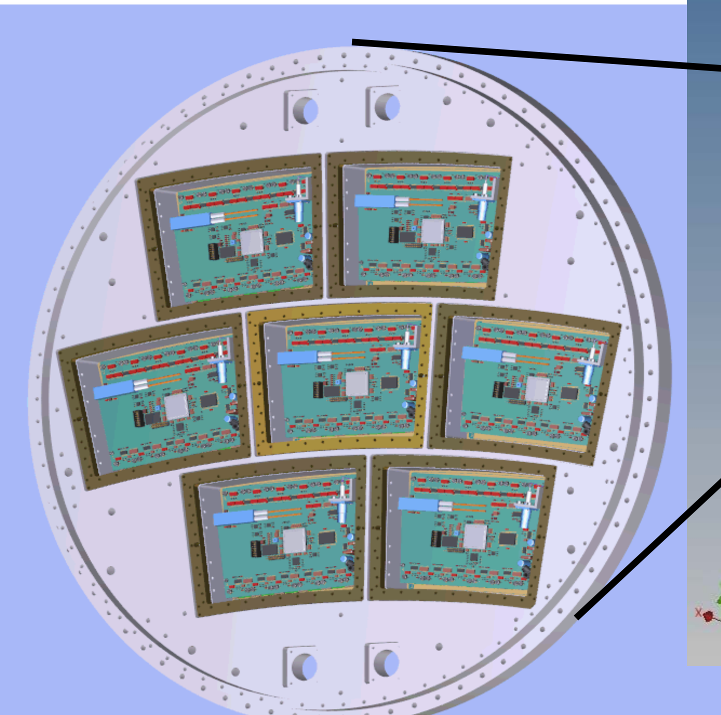


TPC

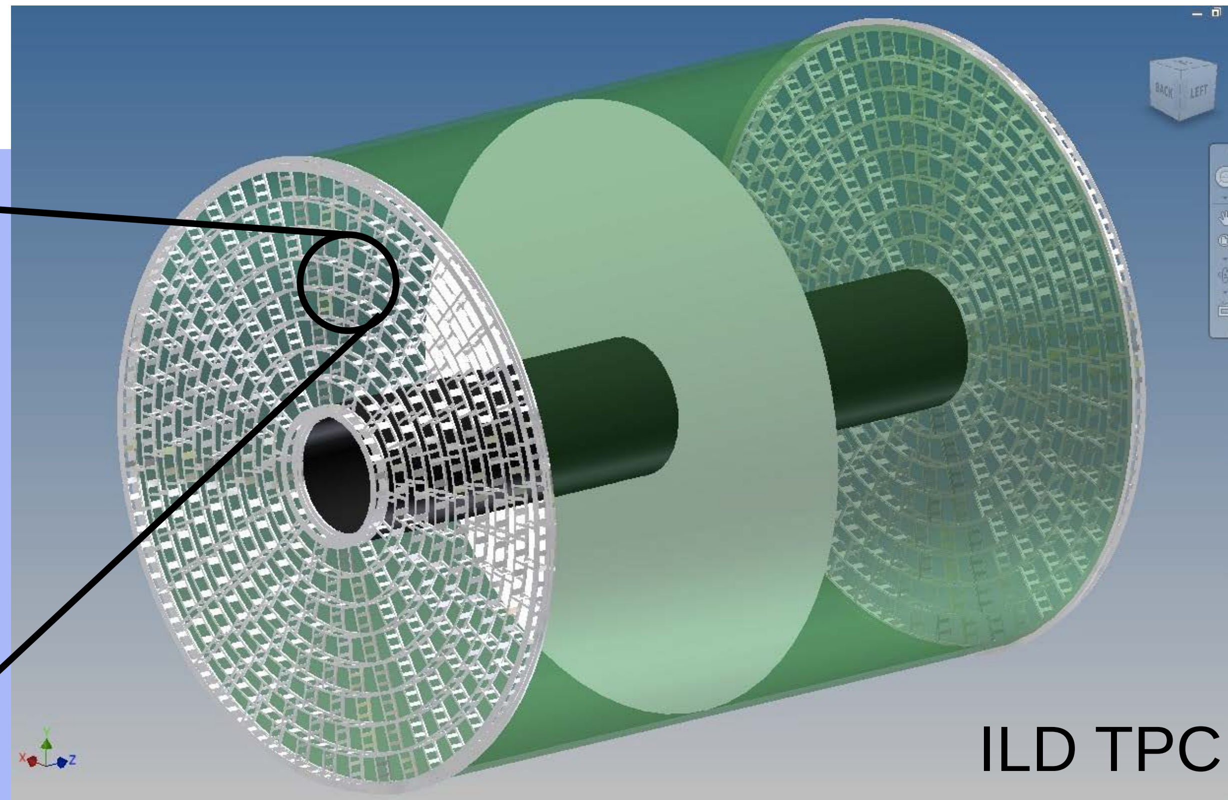
Large Prototype at DESY

- 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 (new)

Large Prototype TPC



Endplate of 7 panels, ø = 80 cm



Micro Pattern Gas Detector (MPGD)

Technology choice for TPC readout: Micro Pattern Gas Detector

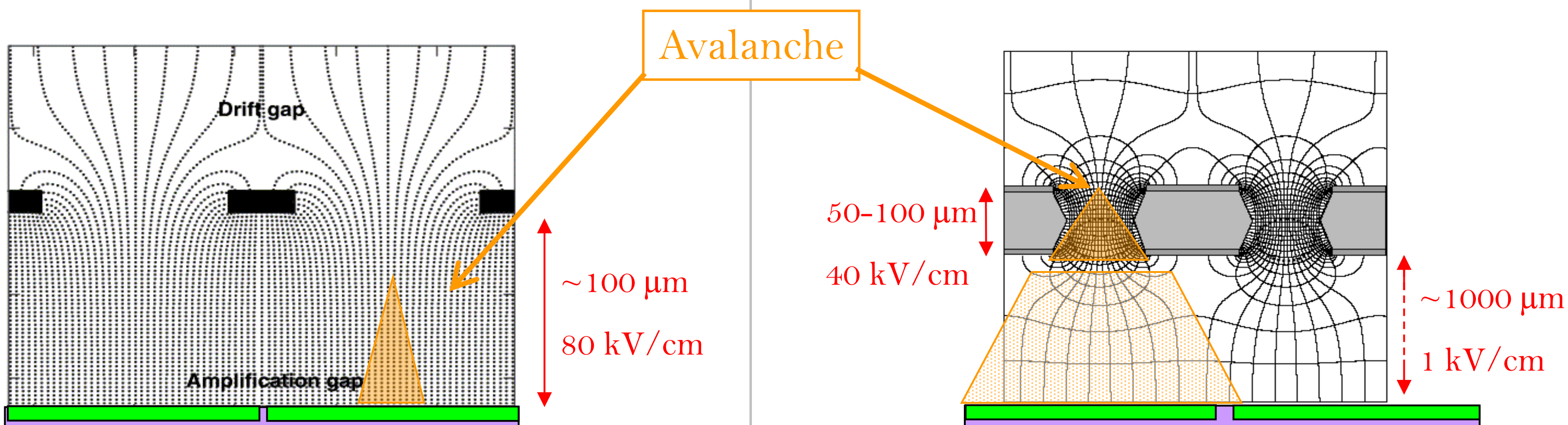
- no preference in track direction
- no E×B effect
- fast signal & high gain
- low ion backdrift
- better ageing properties
- easier to manufacture

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
- 2 copper foils separated by kapton
- multiplication takes place in holes, with 2-3 layers needed



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

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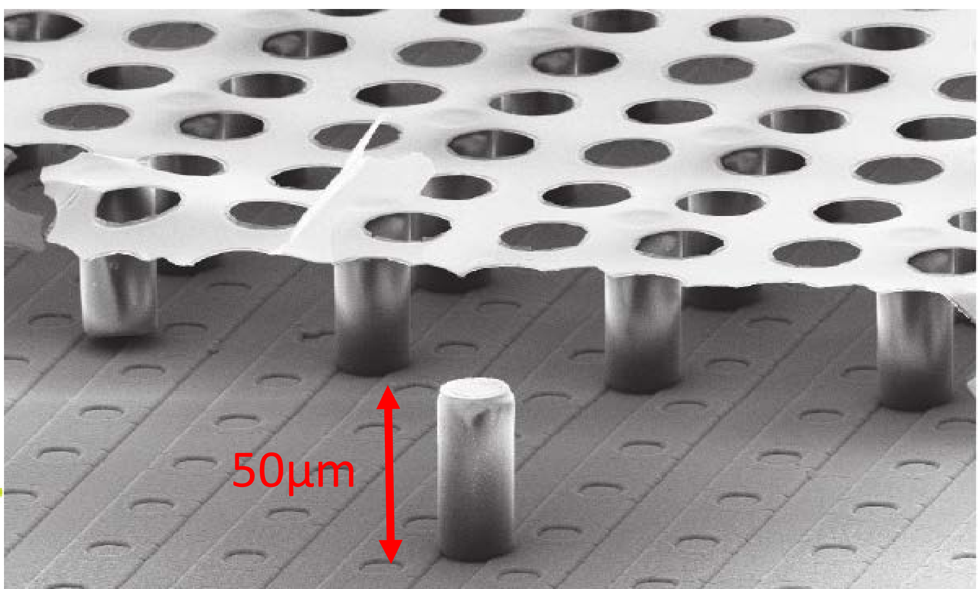
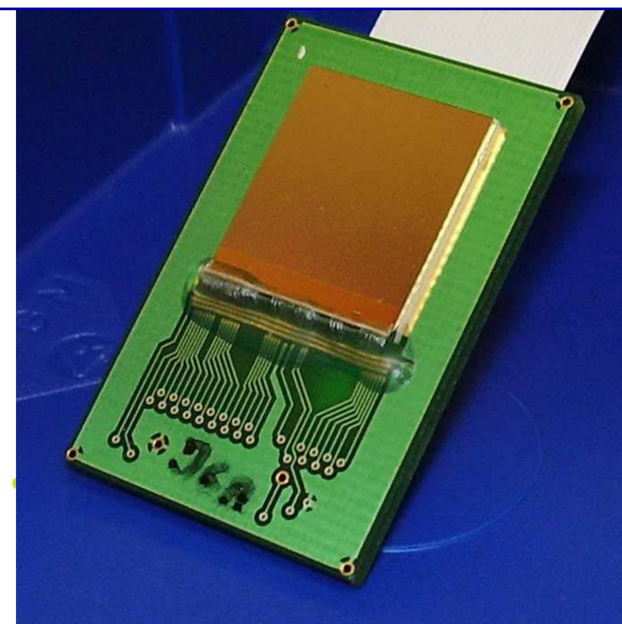
GridPix

- Aluminium mesh on chip: smaller pads/pixels
- hole to pixel alignment with pillar height uniformity
- match readout segmentation to MPGD cell size

TimePix Chip

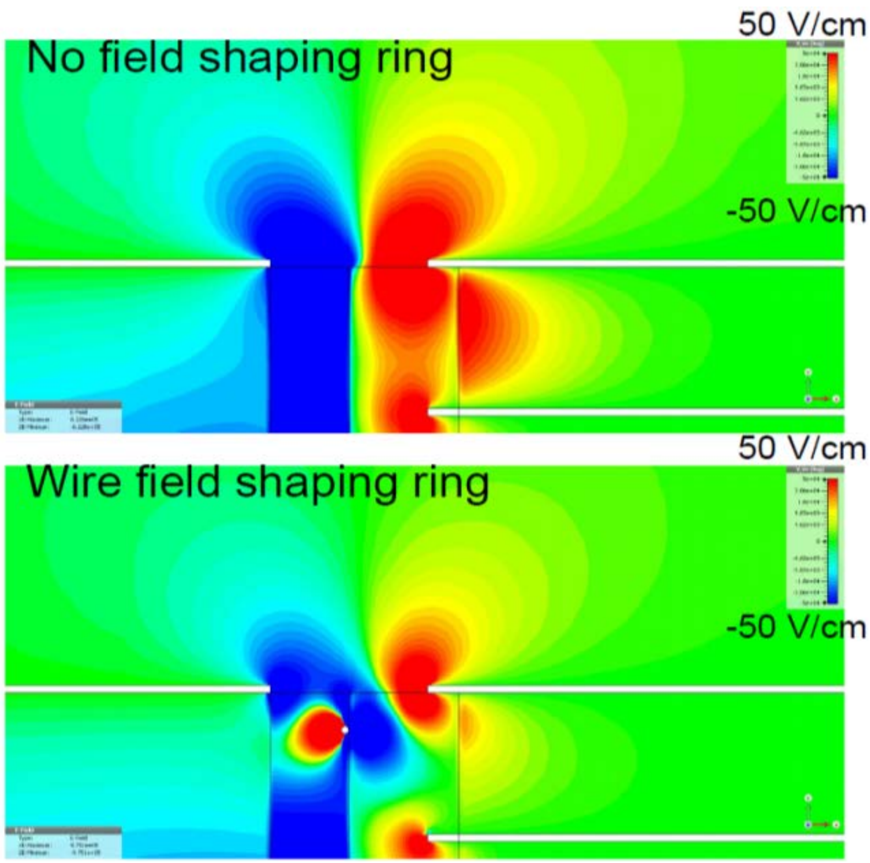
- 1.4 x 1.4 cm^2 active surface
- 55 x 55 μm^2 per pixel
- Amp, discriminator in each pixel
- Threshold level ~500 e- (90 e- ENC)

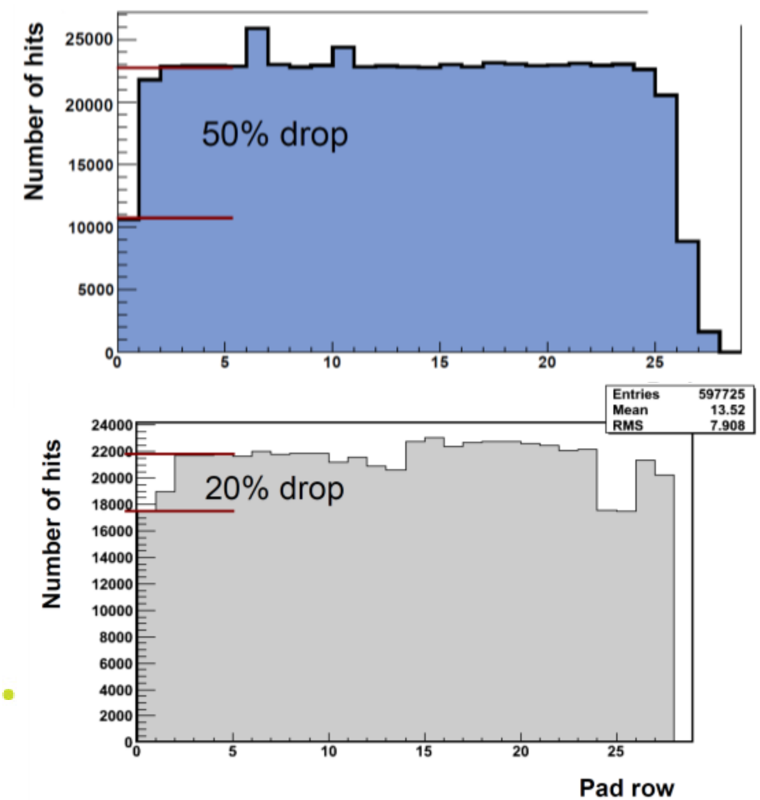




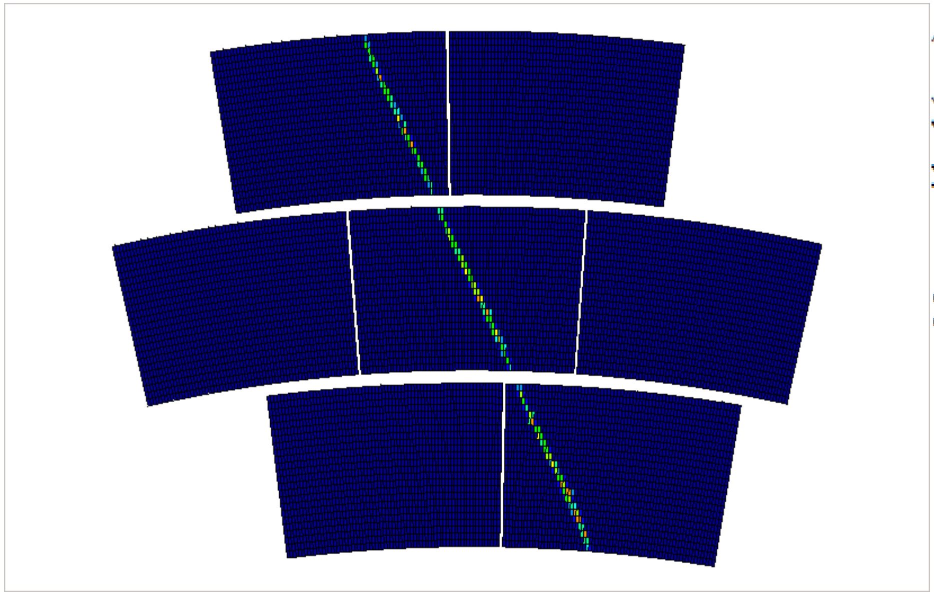
LCTPC Scientific Program

- 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

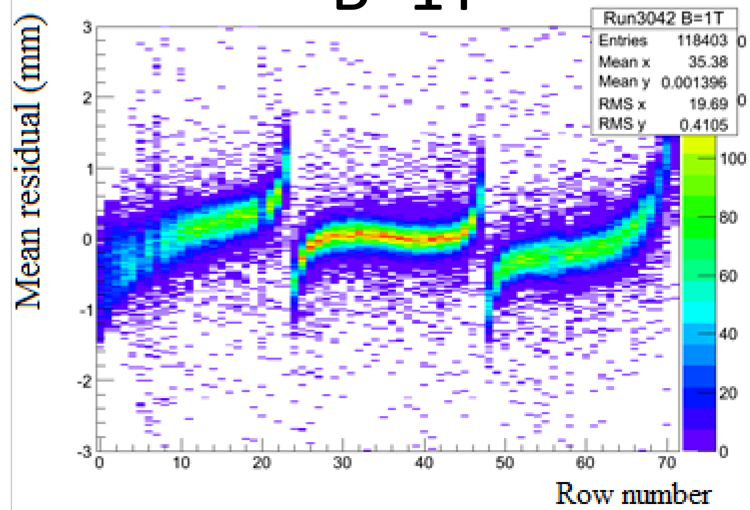




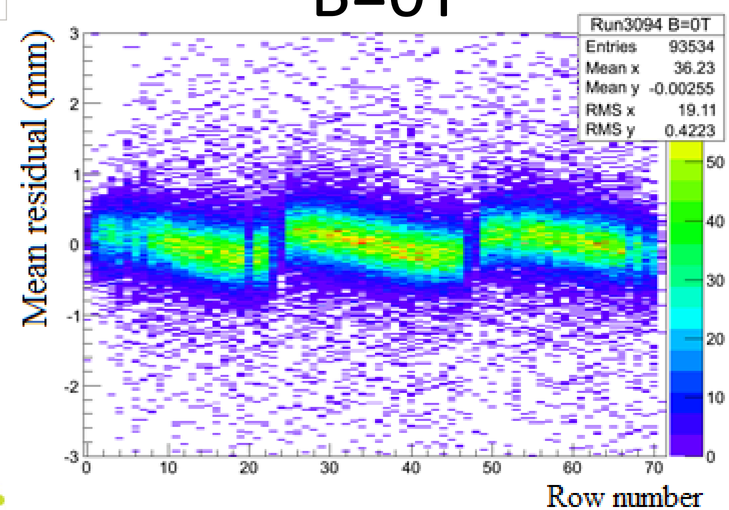
Field Distortions (E x B effect)



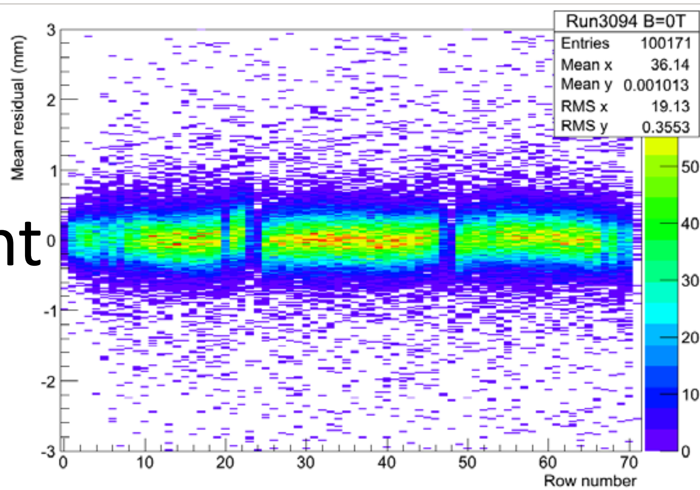
B=1T



B=0T



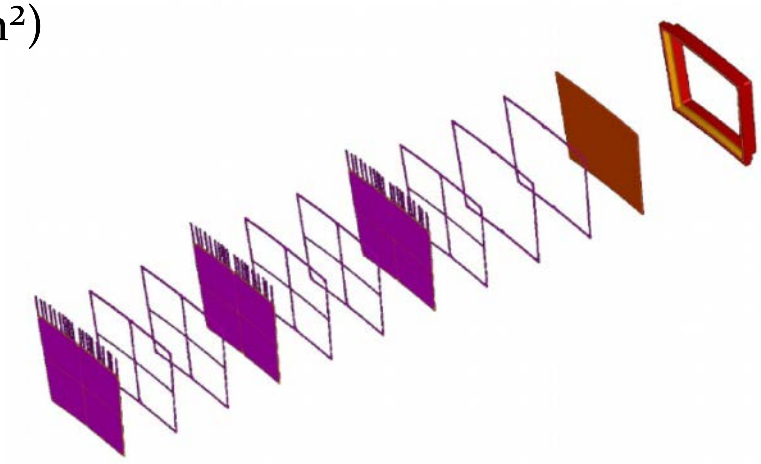
After alignment

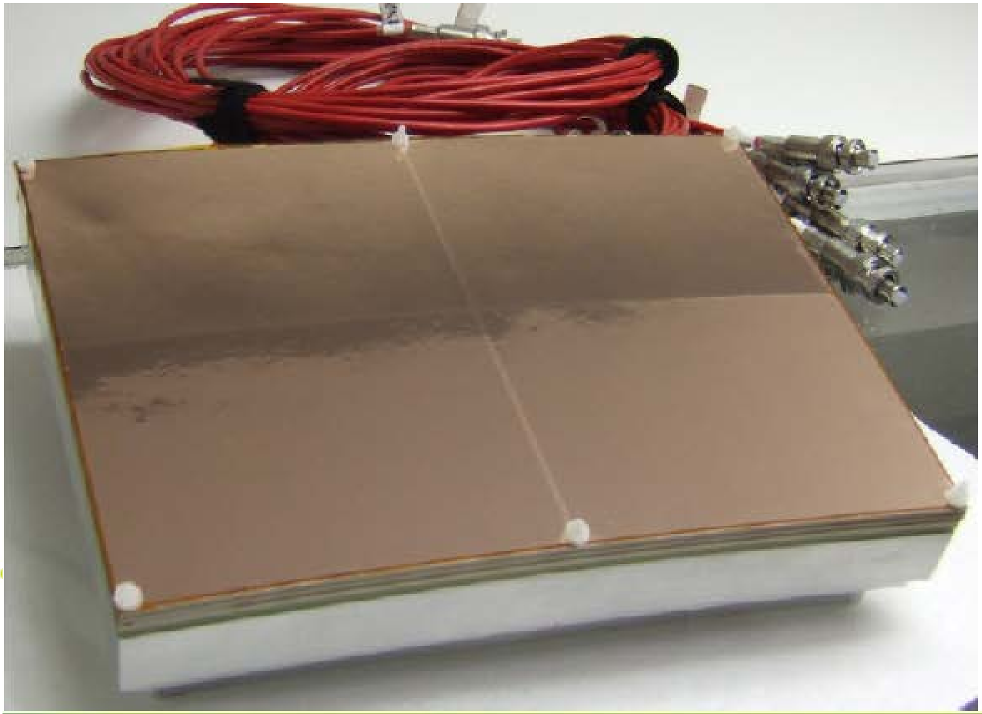


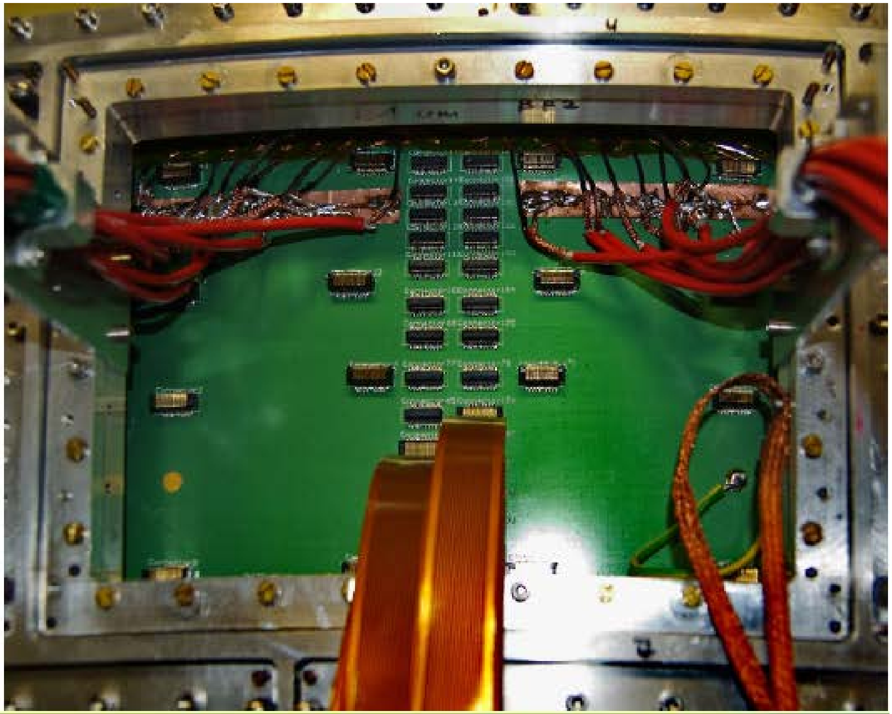
software off-line correction for module alignment and field distortion

Triple GEM Modules (European GEM)

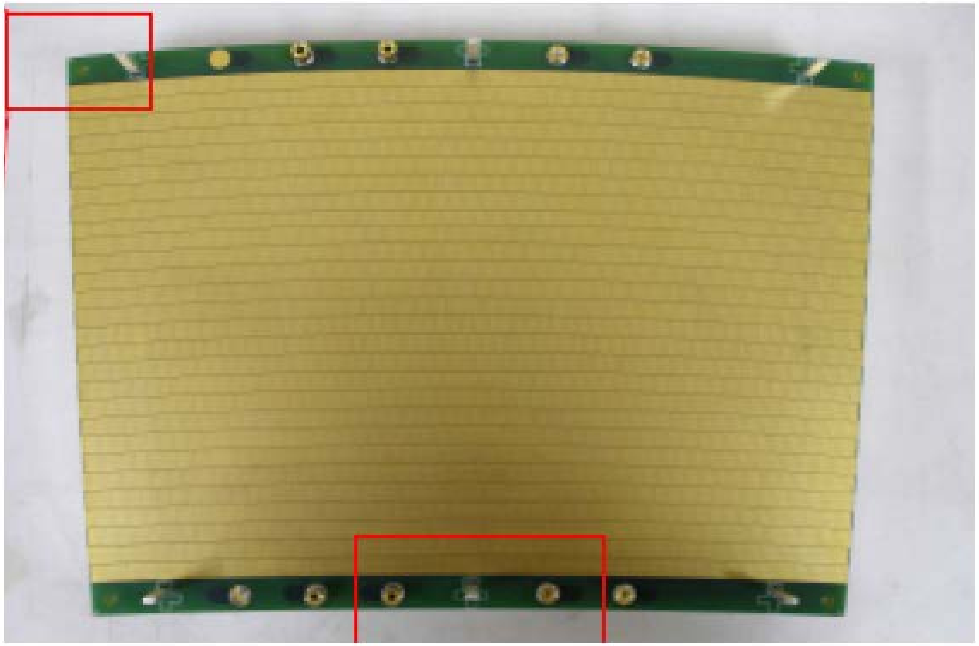
- Three standard CERN GEMs mounted on a light ceramic frame (1 mm)
- Partially equipped (1000 pads, 1.26 x 5.85 mm²)
- Read out by ALTRO electronics
- Segmented in four to reduce stored energy
- Top GEM electrode not segmented
- Bottom segmented into 4 sectors
- HV line for each GEM side
- Protection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



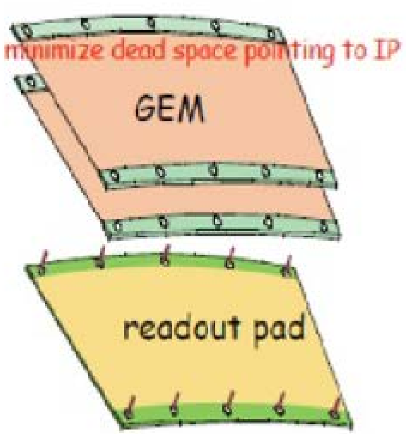


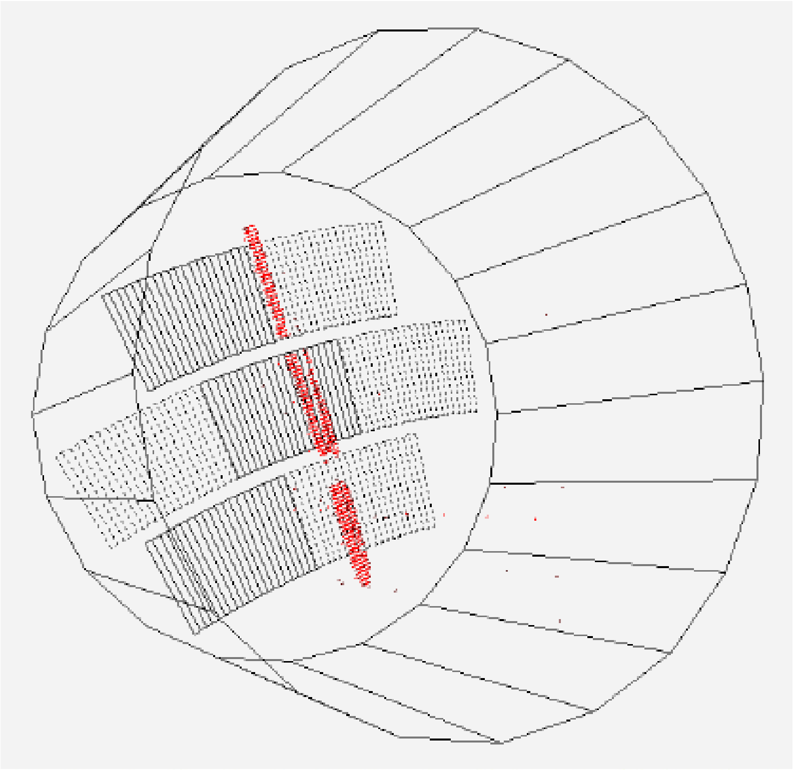


Double GEM Modules (Asian GEM)

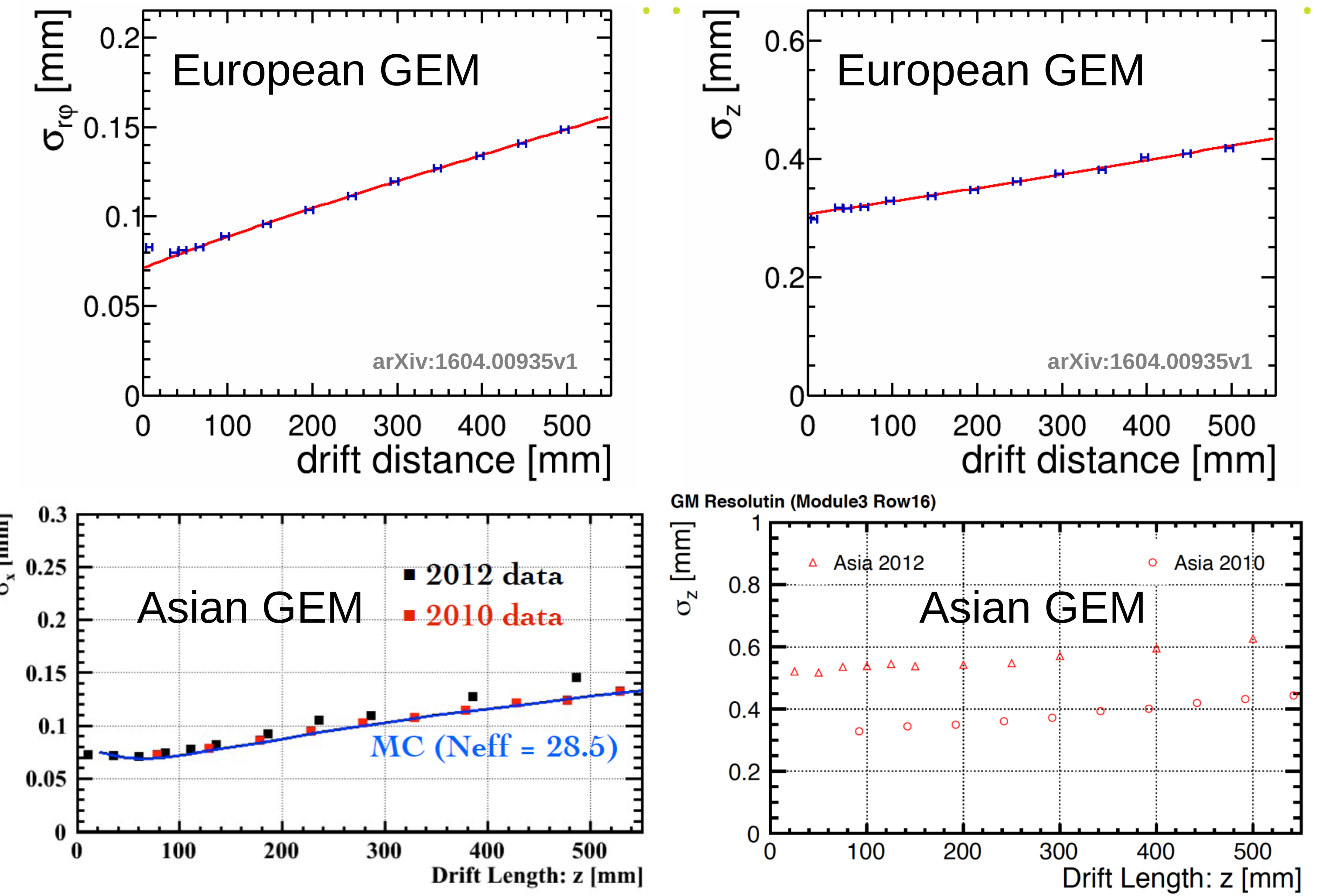


- Laser-etched Liquid Crystal Polymer by SciEnergy, Japan
- 100 μm thick
- 28 staggered rows of 176-192 pads
- Pad 1.2 x 5.4 mm²

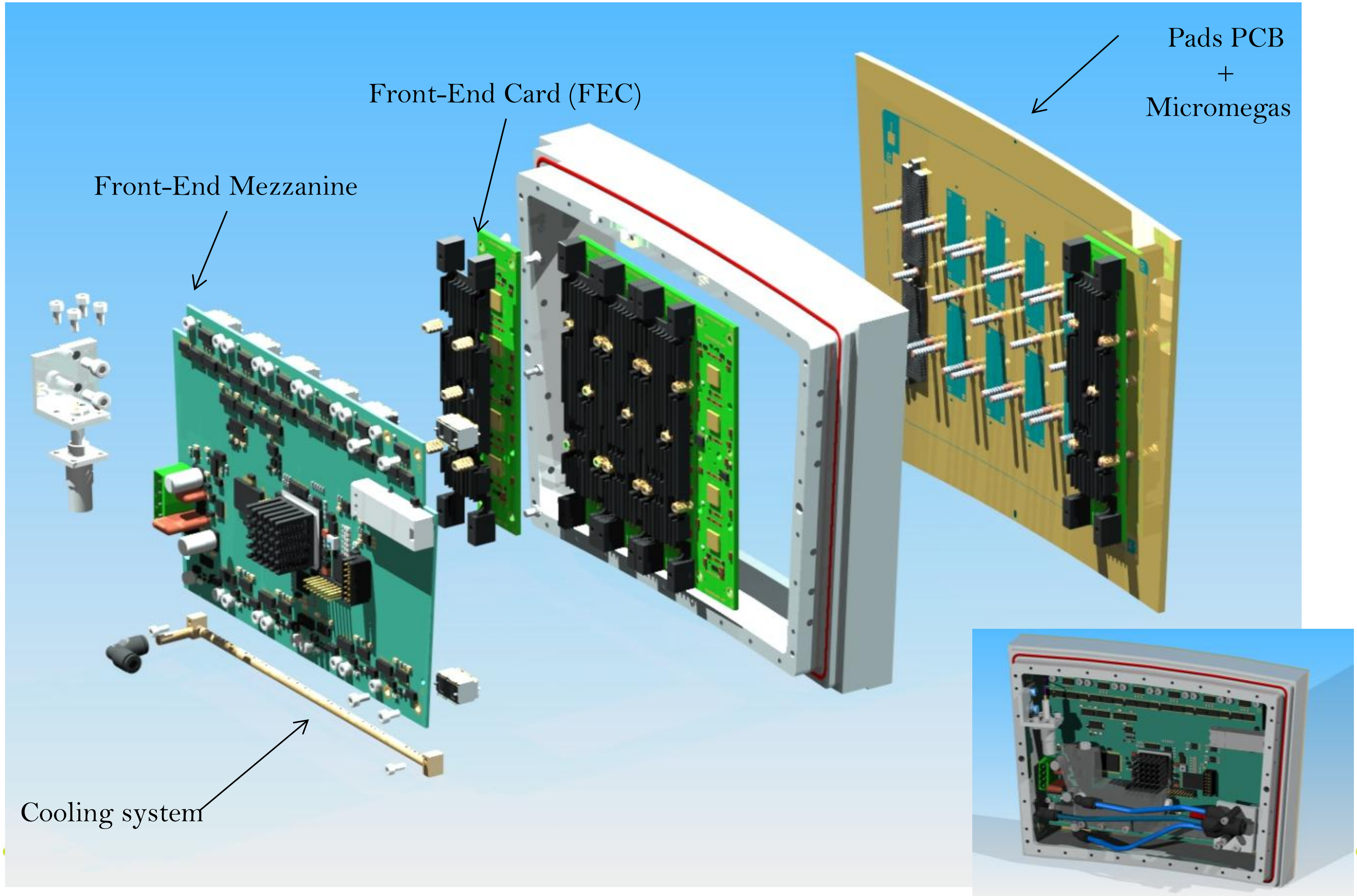




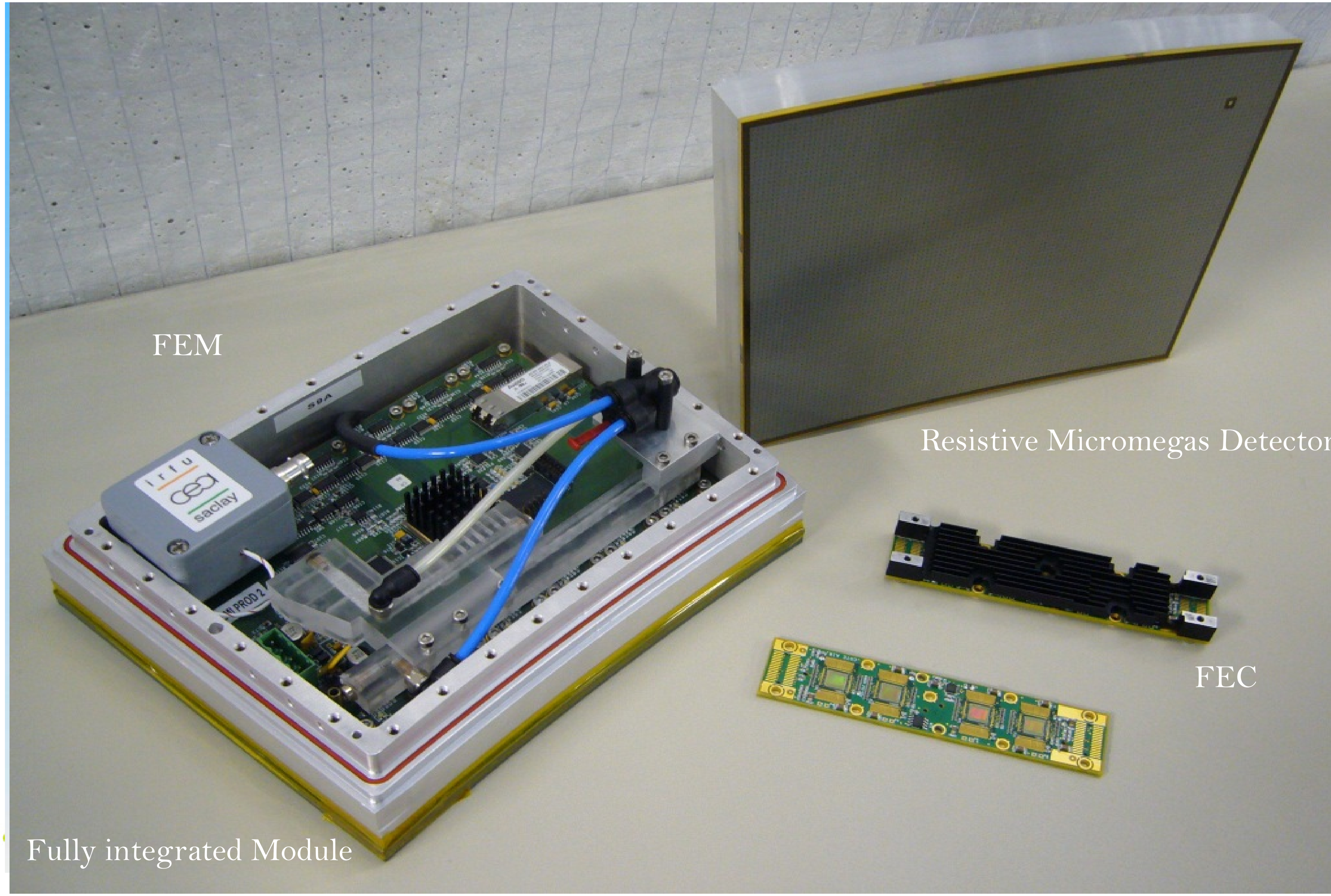
GEM Resolution



Micromegas: Module Design

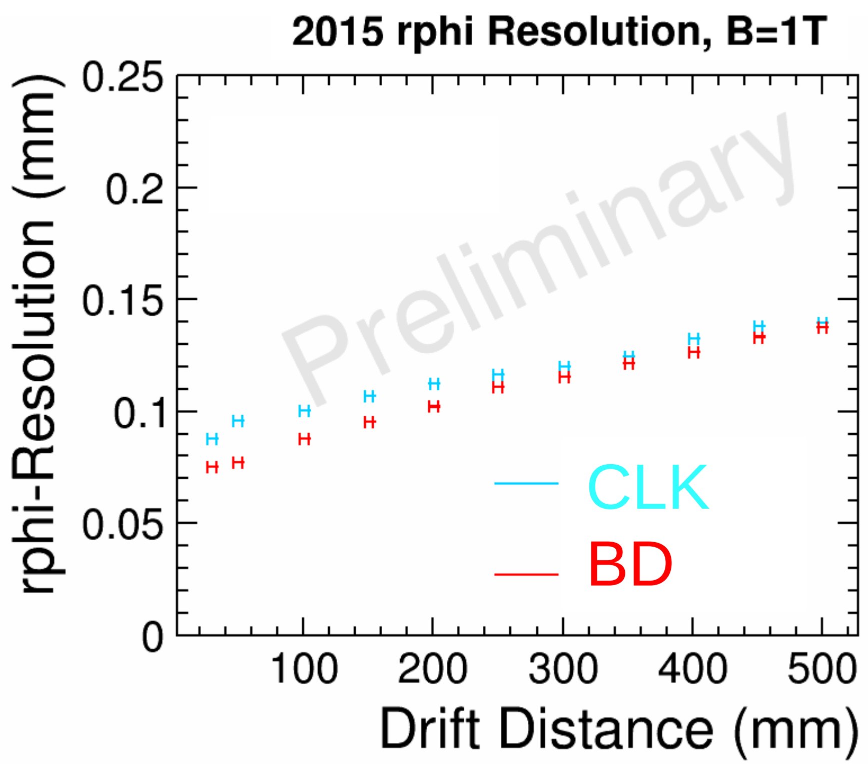


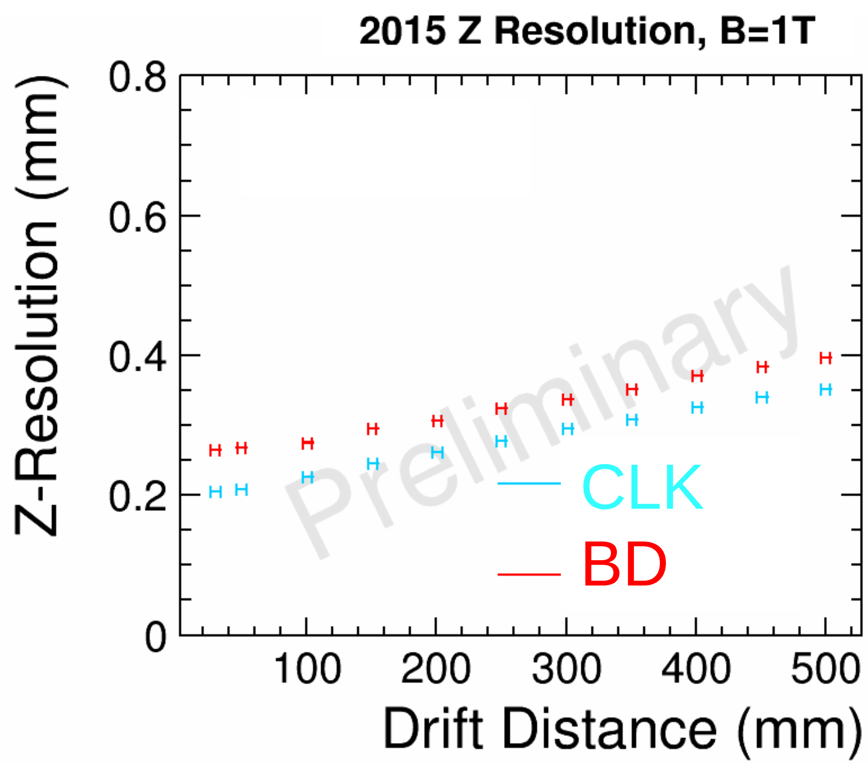
Micromegas: Module Design



Micromegas Resolutiuon

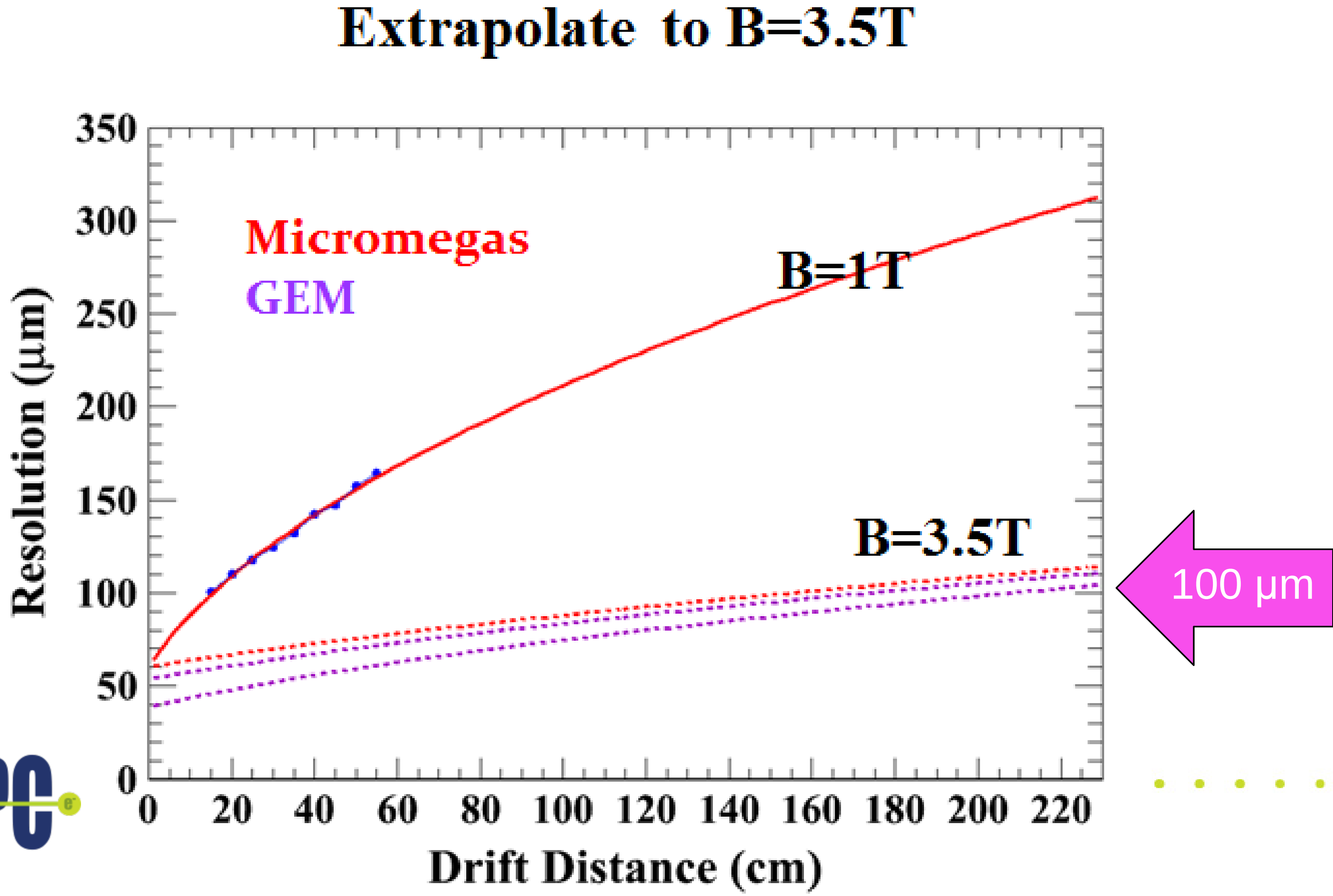
- R&D: Saclay & Carleton
- Endplate fully equipped (all modules populated)
- Read out by AFTER electronics
- Optimized shaping time and mesh voltage
- Resistive layer to spread charge for better clustering and centroid determination
- Two type of resistive layers: Carbon-Loaded Kapton (CLK) and Black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



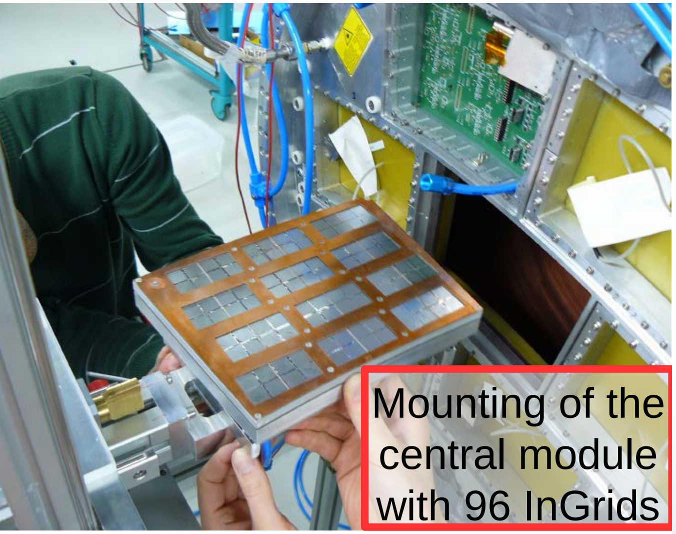


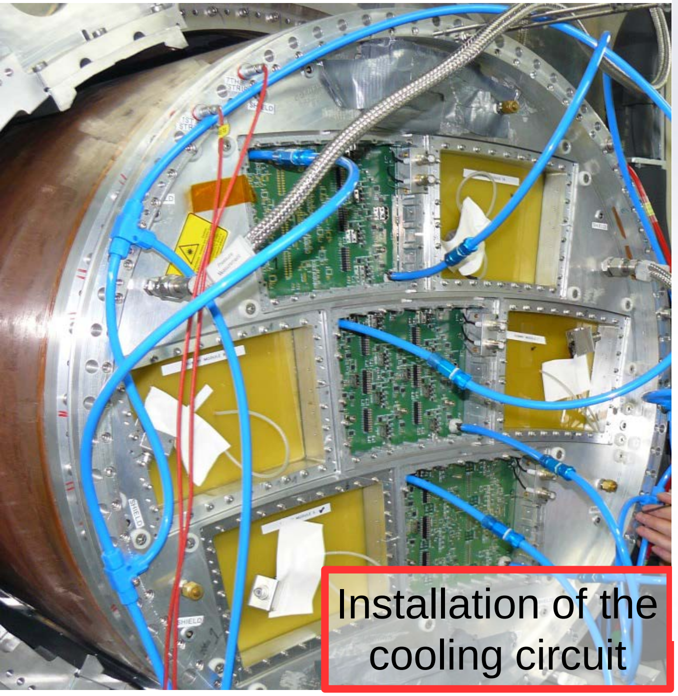
Transverse (r-Φ) Resolution

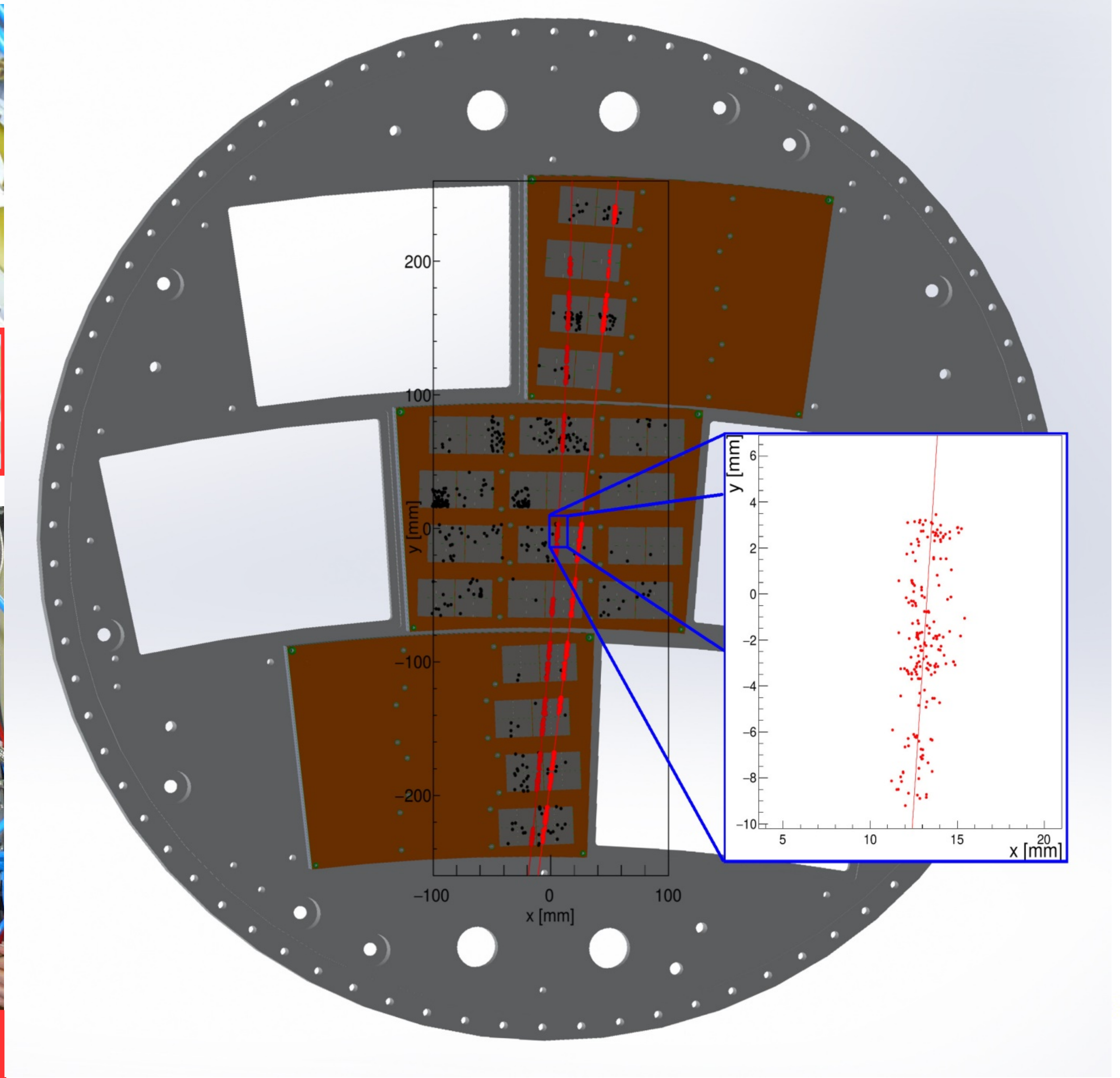
Micromegas 3×7 mm² pads and GEM 1.2×5.8 mm² pads



GridPix


Mounting of the central module with 96 InGrids

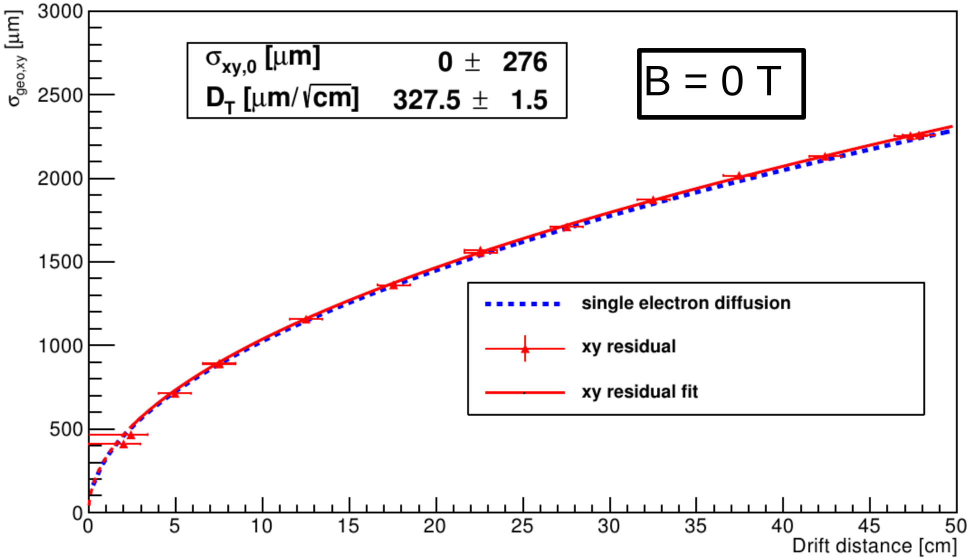

Installation of the cooling circuit

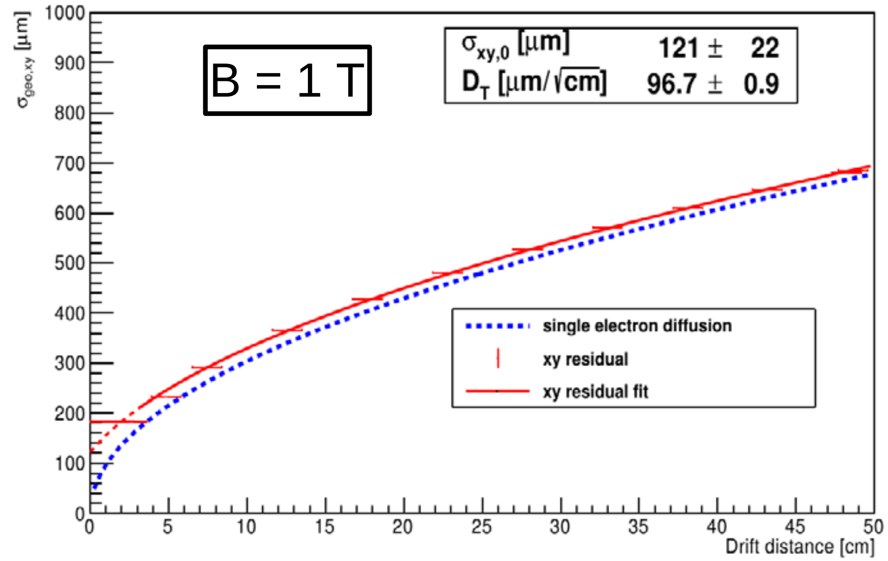

200
100
0
−100
−200
y [mm]
−100
0
100
x [mm]
6
4
2
0
−2
−4
−6
−8
−10
y [mm]
5
10
15
20
x [mm]

GridPix Resolution

Spatial resolution (*preliminary*):

In x-y plane, from residuals



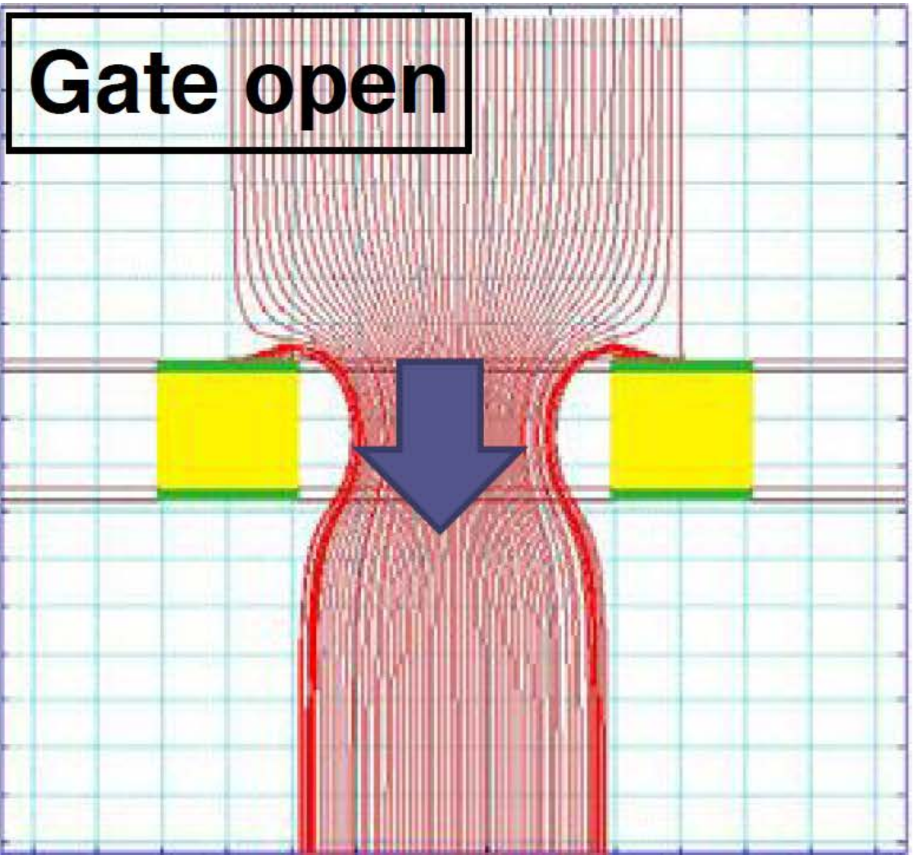


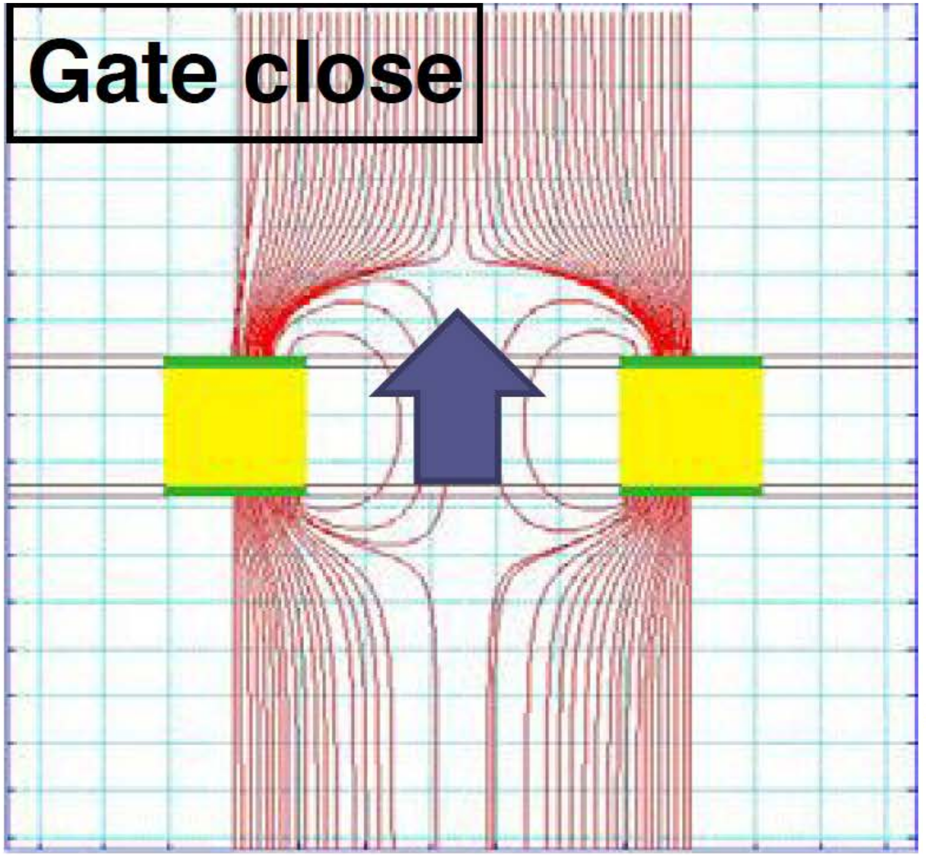
New!

- Transverse spatial resolution follows diffusion of single electrons
- The single hit resolution does not depend on the track angle
- Reconstructed diffusion constants in agreement with simulations

MPGD Ion Gate

- 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
- MPGD 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 meet 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 time resolution, ion grid, 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

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)

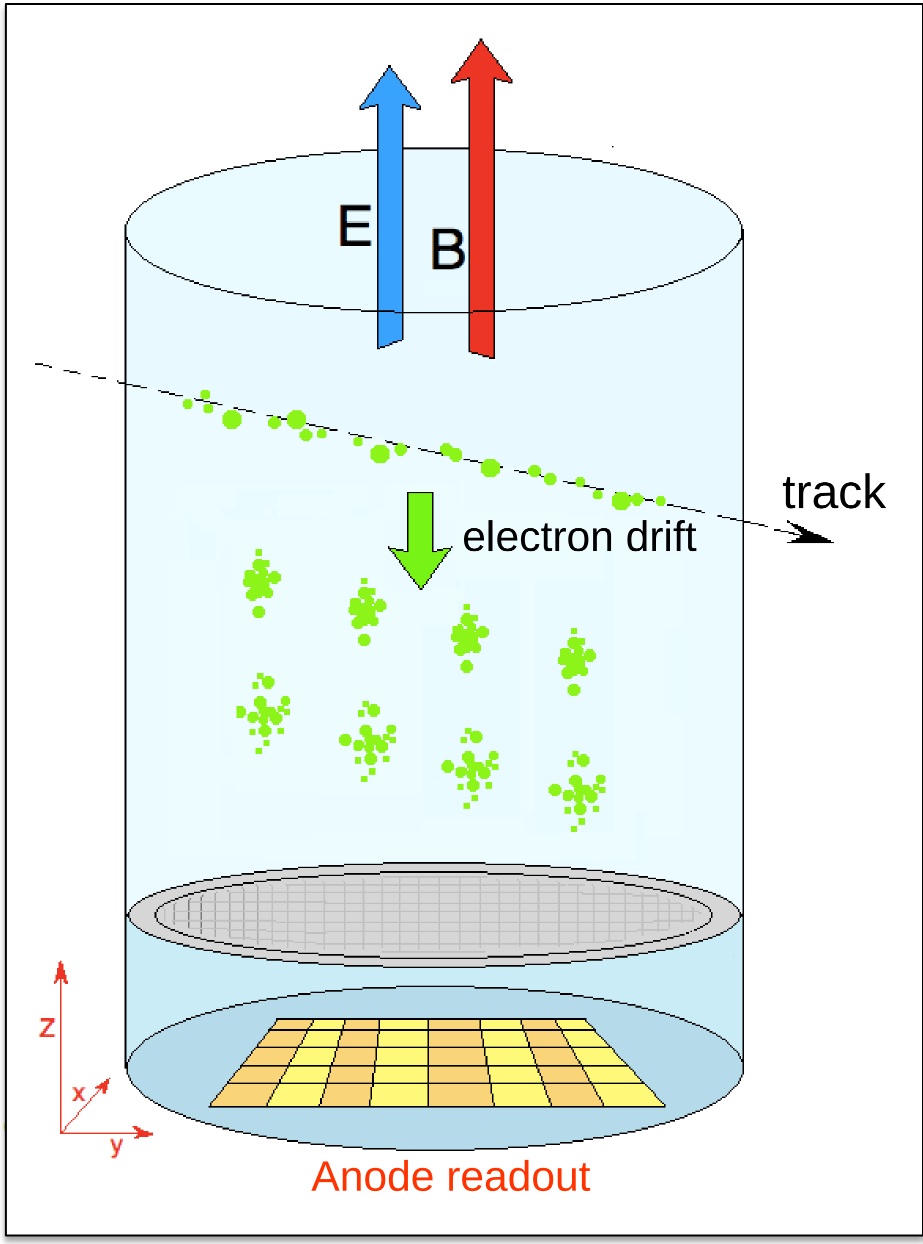
$$\sigma^2 = \sigma_0^2 + D^2 \cdot z$$

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

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

(3) Amplification: boost number of electrons

(4) Readout Pads: pads convert to digital record

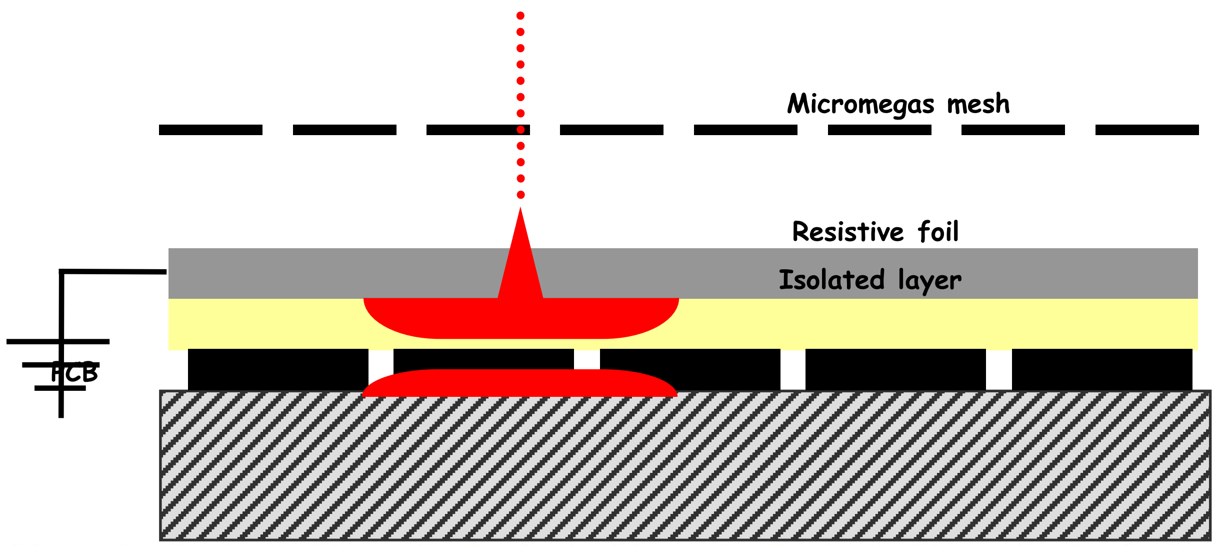


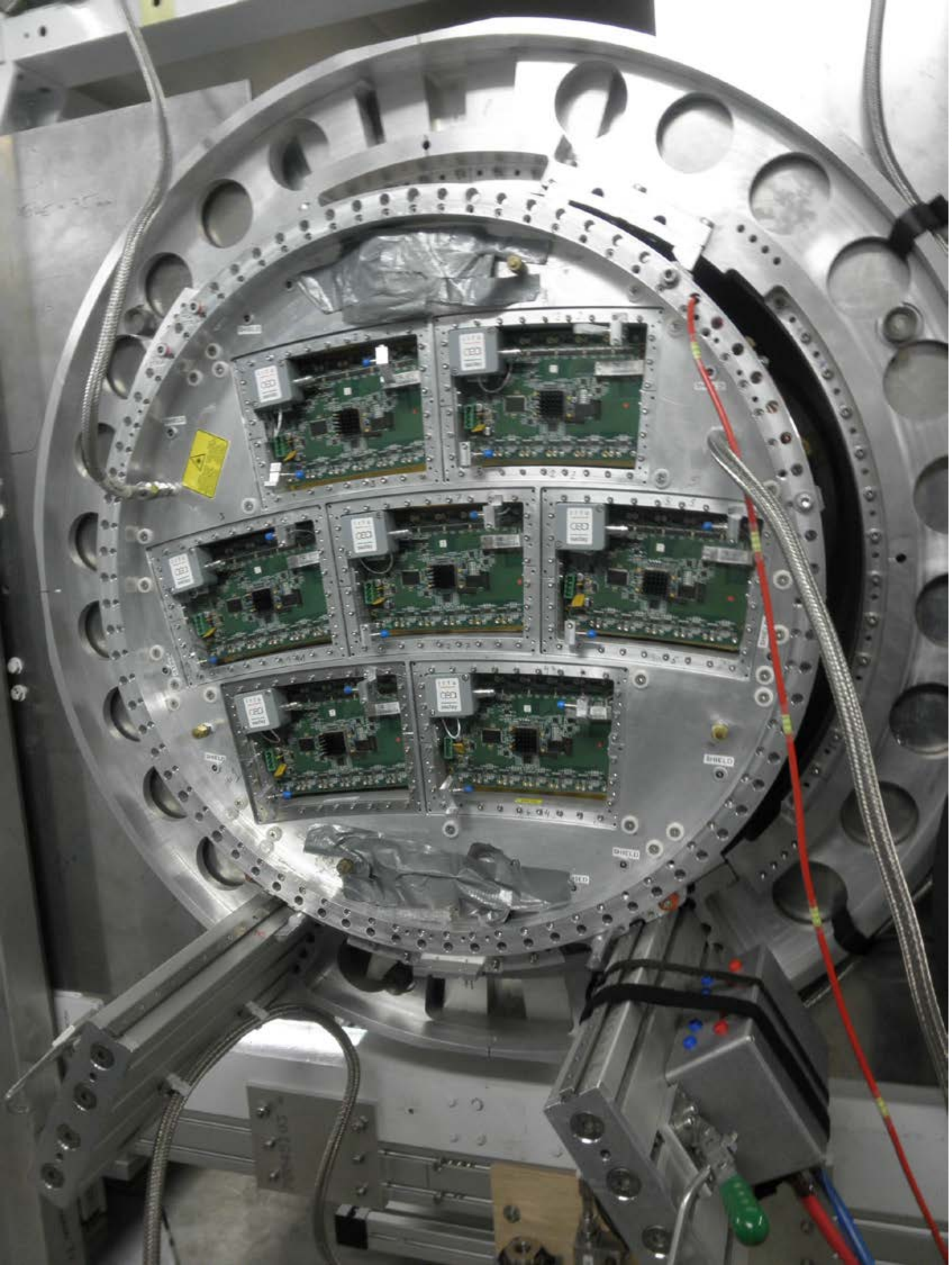
Micromegas (MM) Charge Dispersion

Resistive Anode

Canada / Carleton

A. Bellerive, M. Dixit, M.Sc. & summer students





Multi-module LCTPC

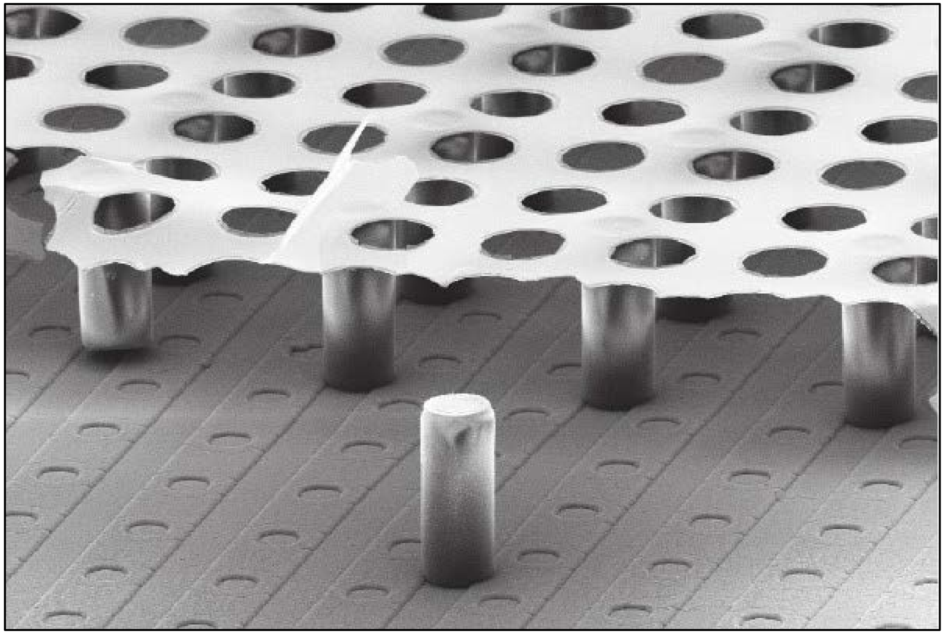
Period
2012-2015

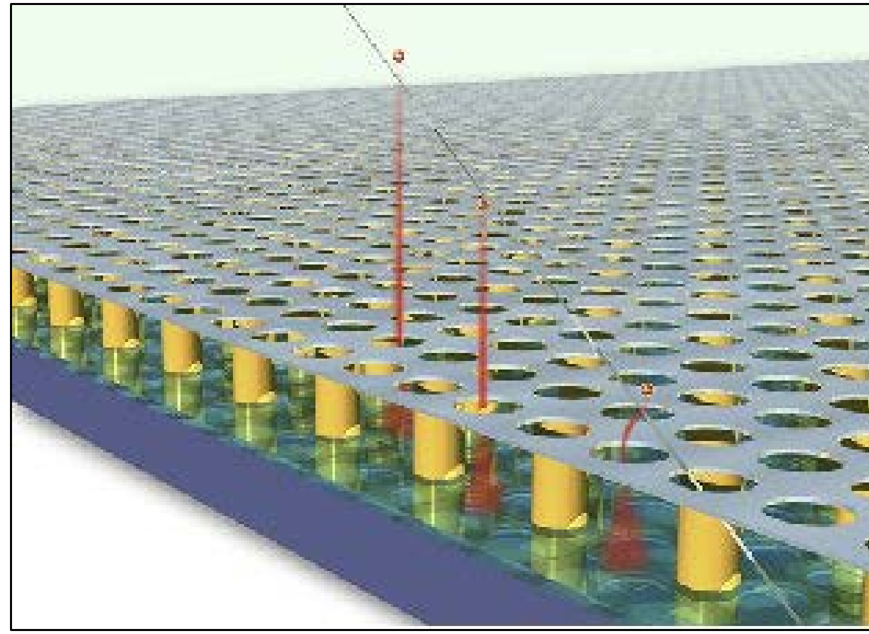
2013 data
6-module

2014 data
7-module with cooling

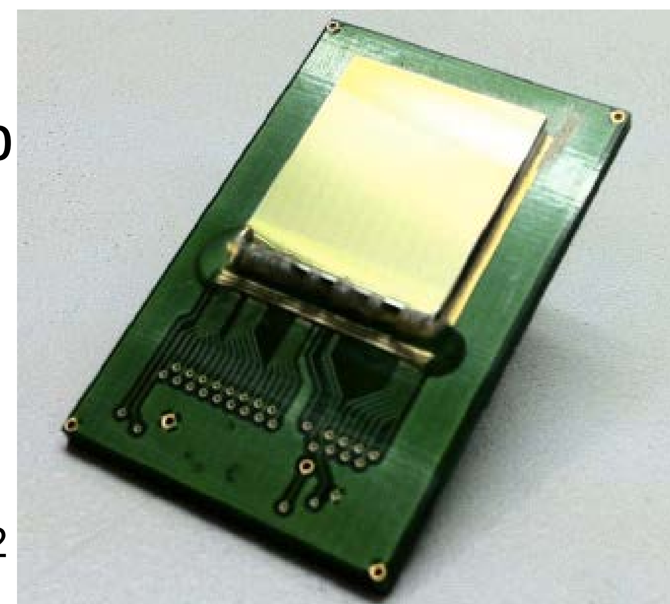
2015 data
7-module with cooling
2 new modules

Highly Pixelated Readout





- Micromegas on a pixelchip
- Insulating pillars between grid & pixelchip
- One hole above each pixel
- Amplication directly above the pixelchip
- Very high single point resolution

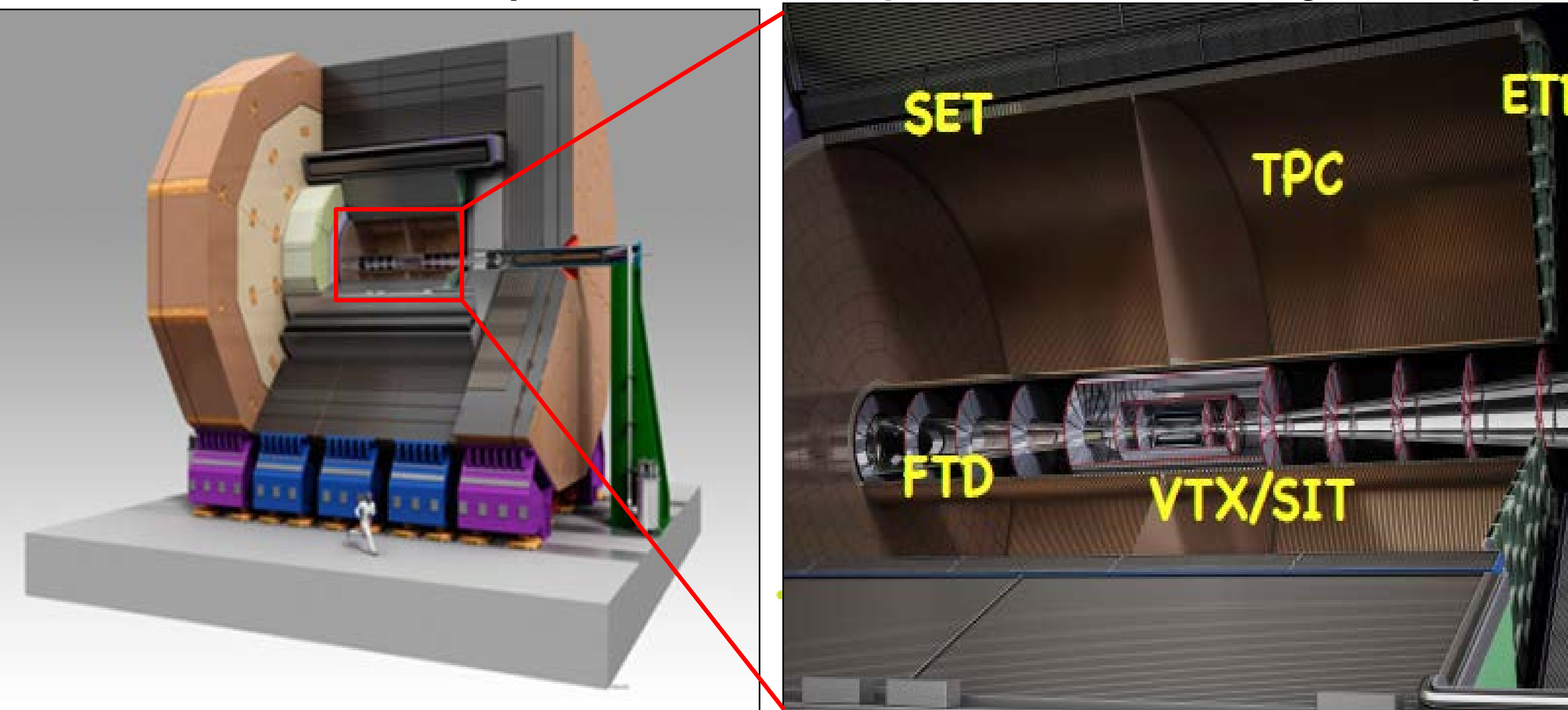


Timepix: 256 x 256 pixels of size 55 x 55 μm^2

International Linear 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 ≧200 continuous position measurements along each track in a gas with the point resolution of $\sigma_{r\varphi}$ < 100μm, 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 Linear Detector

ILD ECAL and HCAL

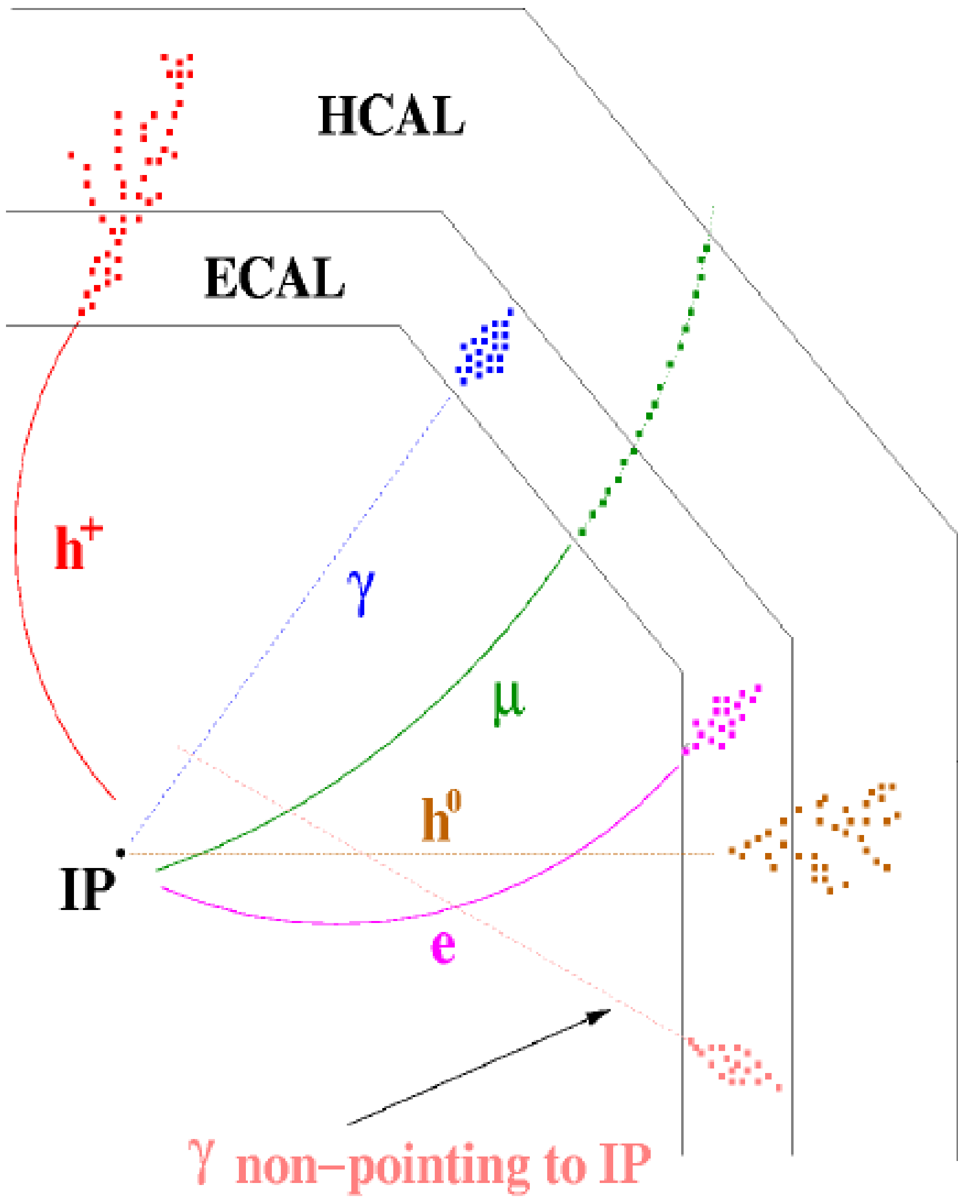
large radius and length
➔ to separate the particles
Hermitic, but compact (inside the coil of the solenoid)

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



Testbeam Facility (DESY)