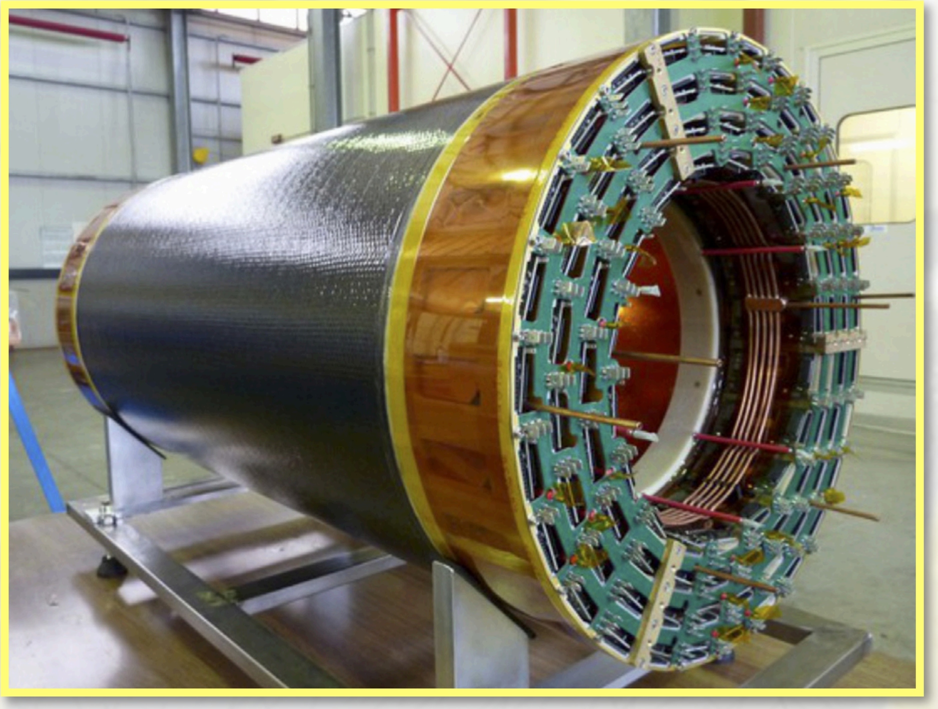


The KLOE-2 Cylindrical GEM Inner Tracker

Alessandro Di Cicco, INFN - Roma Tre (Rome)
For the KLOE-2 Collaboration

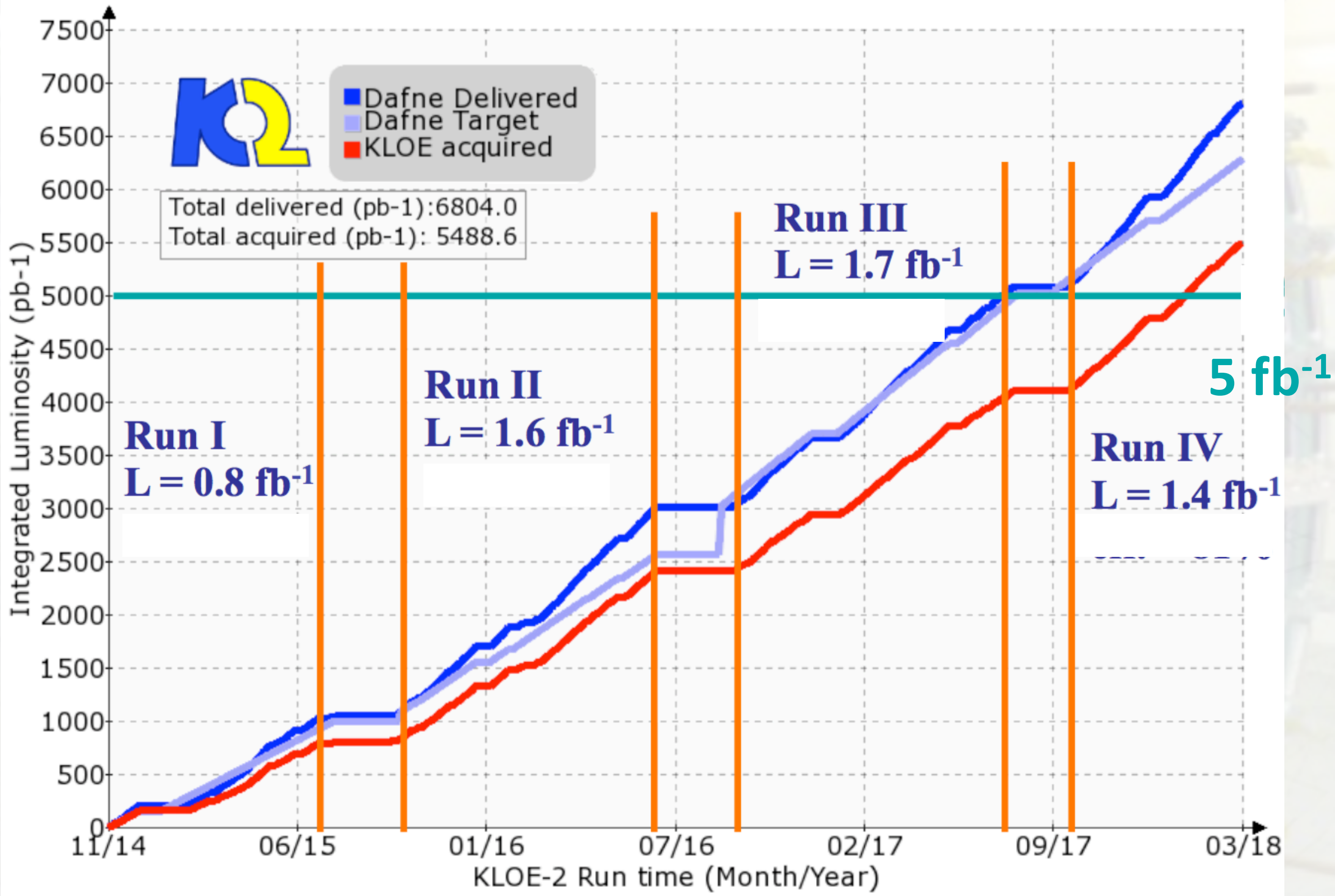
Super c-tau Factory Workshop
May 26th – 27th 2018, Novosibirsk (Russia)

The KLOE-2 Experiment

KLOE-2 concluded data taking in March at **DAϕNE** ϕ-factory
e^+e^- collider at √s = 1019.4 MeV

Physics Program [EPJ C68 (2010)]

- Light hadron spectroscopy
- γγ physics
- Neutral Kaon Interferometry
- Dark Photon searches



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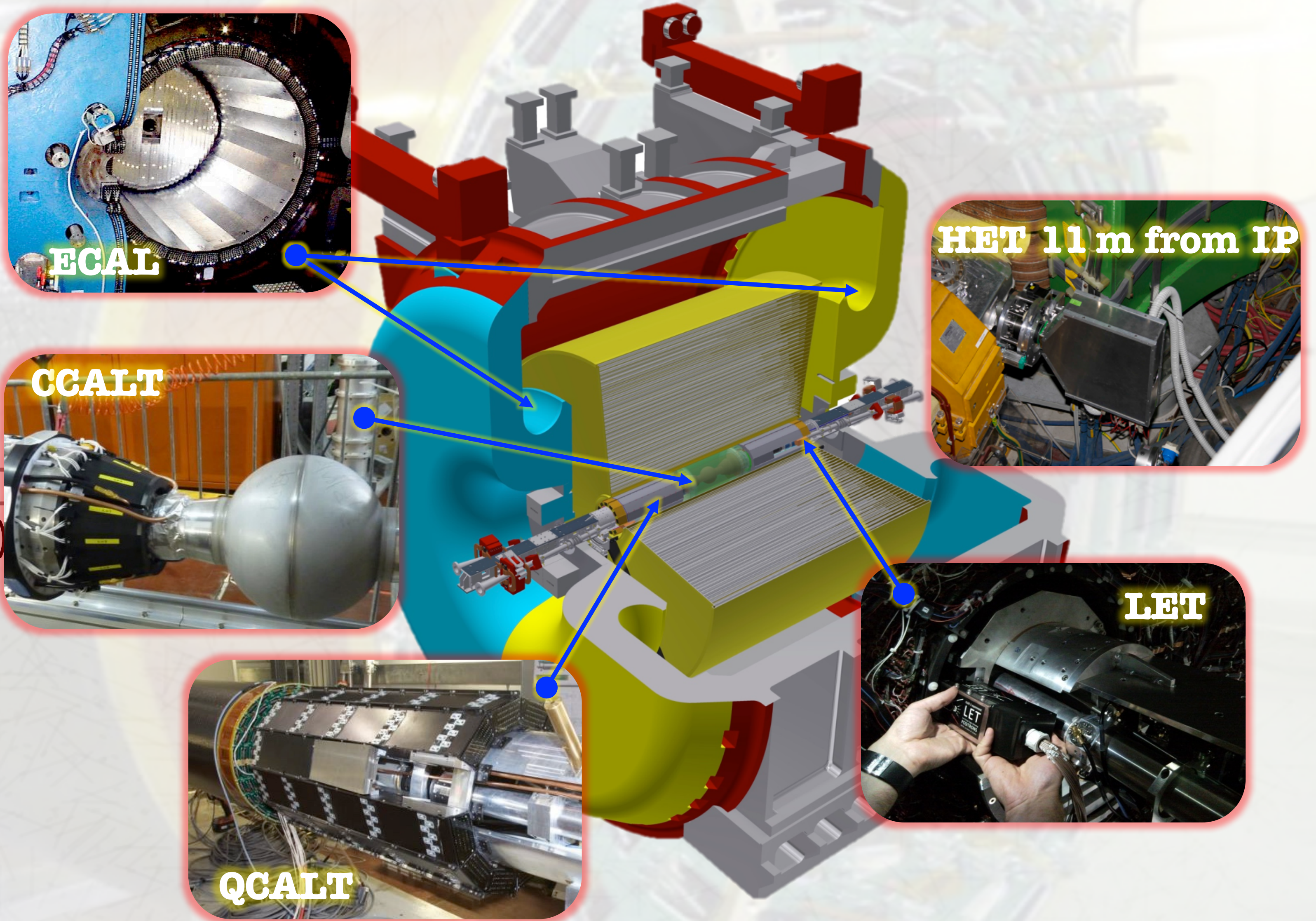
Calorimeter System
- **ECAL** - Pb/Scint Fibers w PMTs
- **LET** - LYSO+SiPMs
- **HET** - Scint+PMTs [Talk by F. Curciarello]
- **QCALT** - W+ Scint Tiles w SiPMs (Quads)
- **CCALT** - LYSO+APDs (Low-beta)



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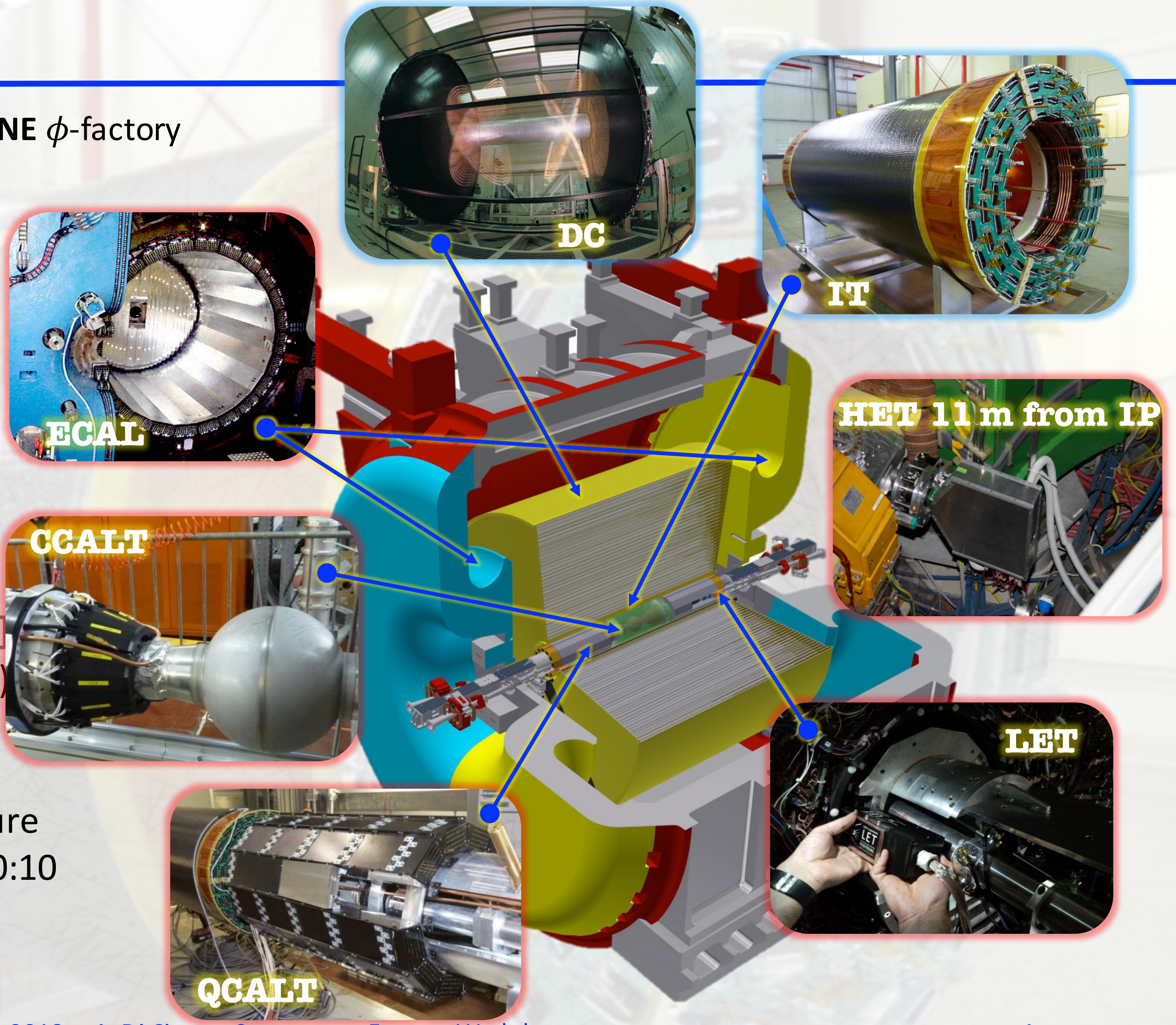
Tracking System

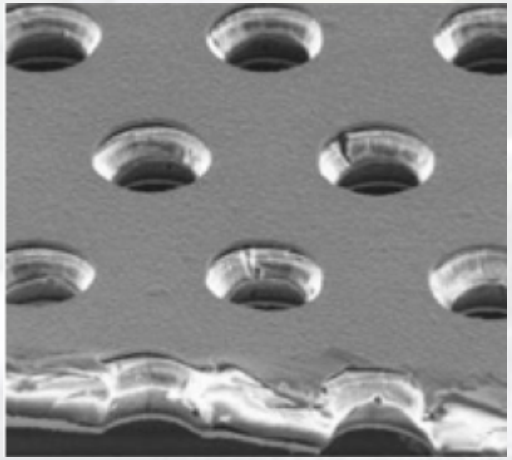
- **DC** – 3.7x4 m^2 $He:C_4H_{10}$ 90:10 gas mixture
- **IT** – 4 cylindrical GEM layers $Ar:C_4H_{10}$ 90:10

Superconductive Magnet

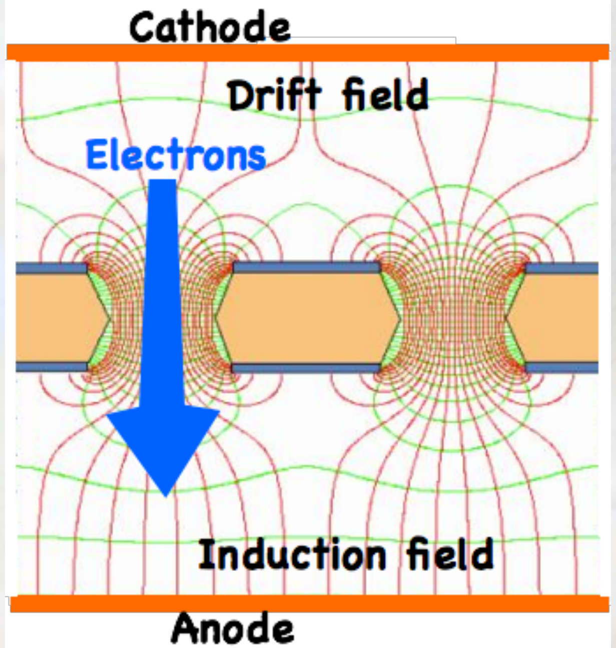
- 0.52 T axial magnetic field



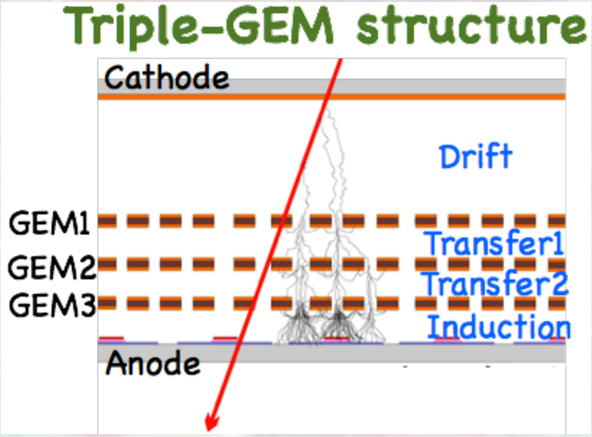
Operation Principles of a Gas Electron Multiplier



Kapton (50 µm) cladded with Copper (5 µm) on both sides
High density of equidistant holes in parallel offset rows
diameter = 70 µm, pitch = 140 µm
Standard GEMs manufactured with double-mask etching technique
KLOE-2 CGEMs manufactured with single-mask technique



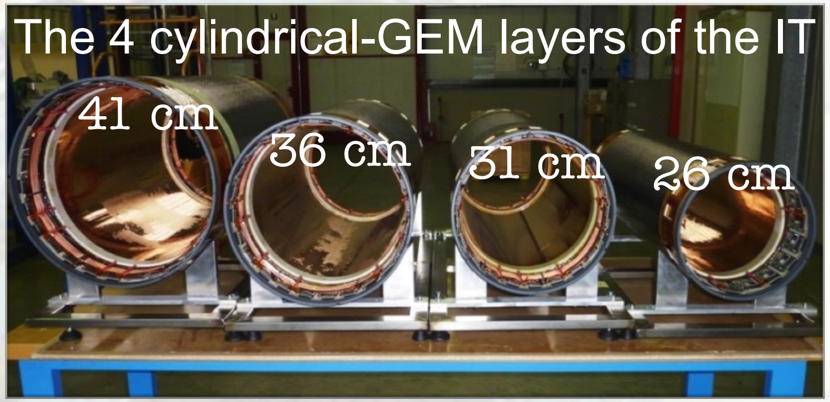
V_{GEM} = 500 V ➔ E_{hole} = 100 kV/cm
Drift field drives ionization charges into holes
Charge amplification occurs into holes
Avalanche charges moves towards anode following induction field lines



Multi-GEM layouts allow to reach higher gains with safer working conditions

The Inner Tracker of KLOE-2

- Improve VTX reconstruction at IP (x2 σ_{VTX})
- First batch ever of GEM foils produced with a single-mask etching developed by CERN-TE-MPE-EM for large area foils
- Ulta-light detector (< 2% X_0 material budget)
- 70 cm active length
- 650 µm strip/pad two-view readout
- 25k channels GASTONE FEE [NIM A 732 (2013)]
- 1.6k HV channels
- FEE (INFN- Bari) & DAQ system (INFN – LNF) [JINST 08 T04004 (2013)]



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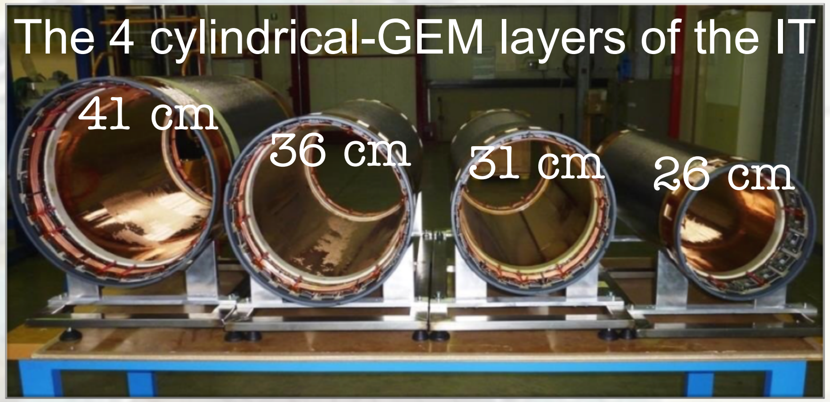

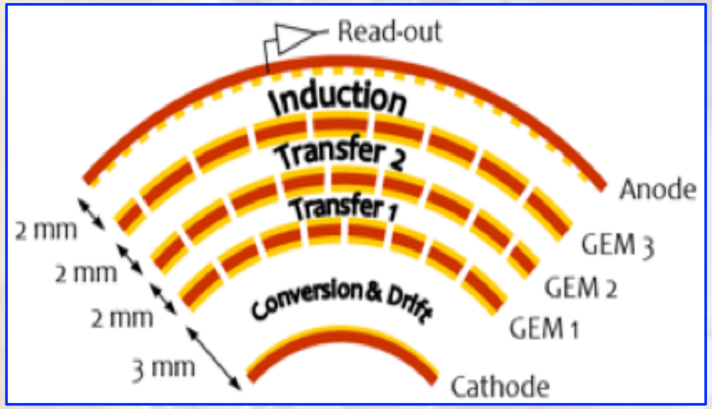

Each layer is a triple-GEM detector with 3/2/2/2 mm gap layout

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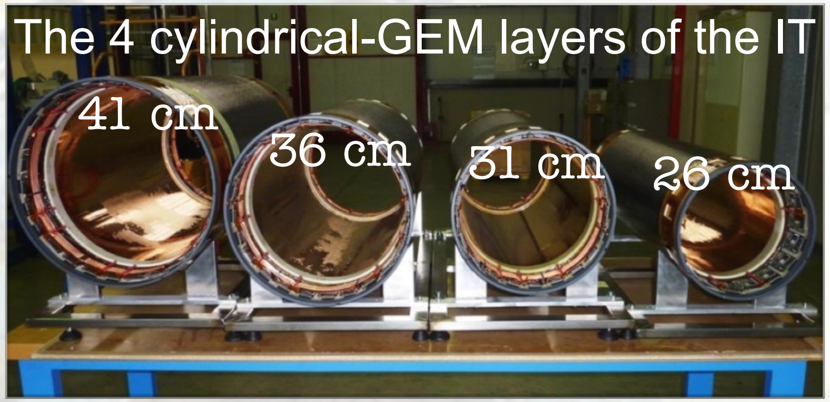
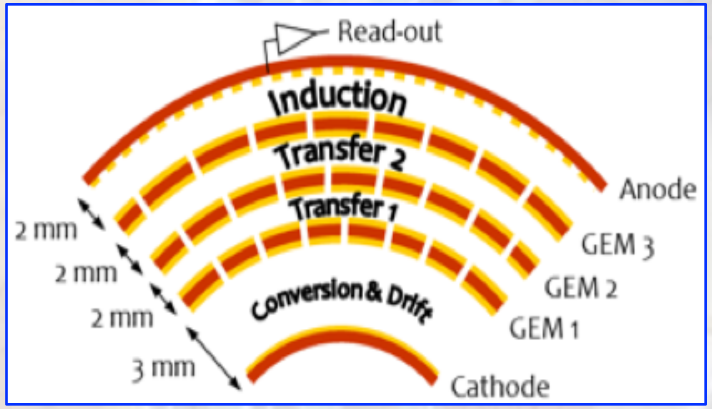


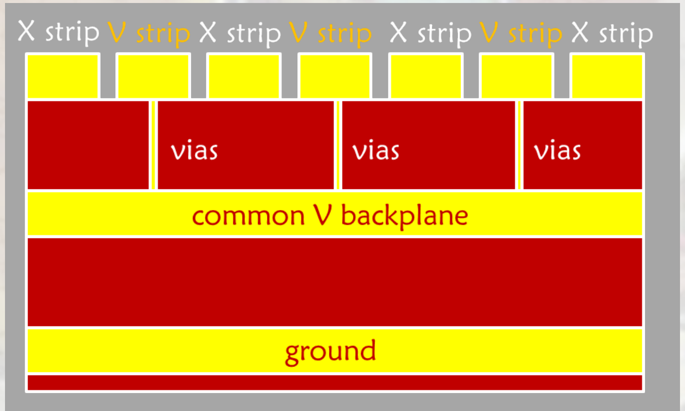


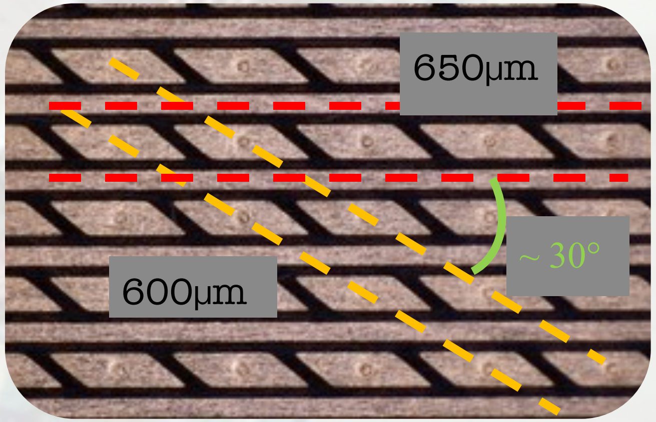
Each layer is a triple-GEM detector with 3/2/2/2 mm gap layout

Kapton/Copper flexible multilayer readout circuit built at CERN TE-MPE-EM, 300 µm tot thickness

X-view: longitudinal strips

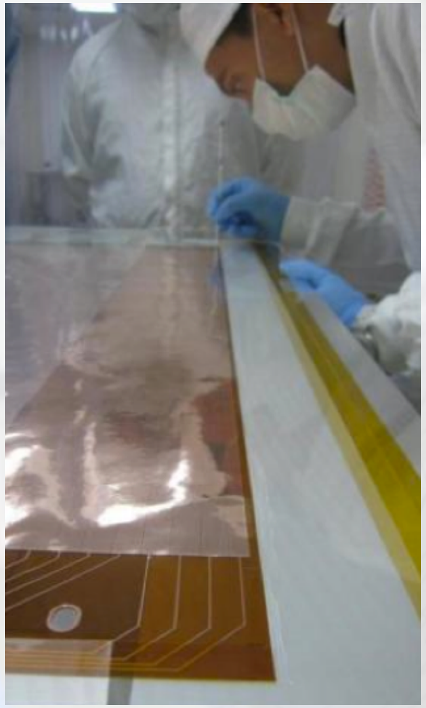
V-view: connection of pads through conductive vias and common backplane

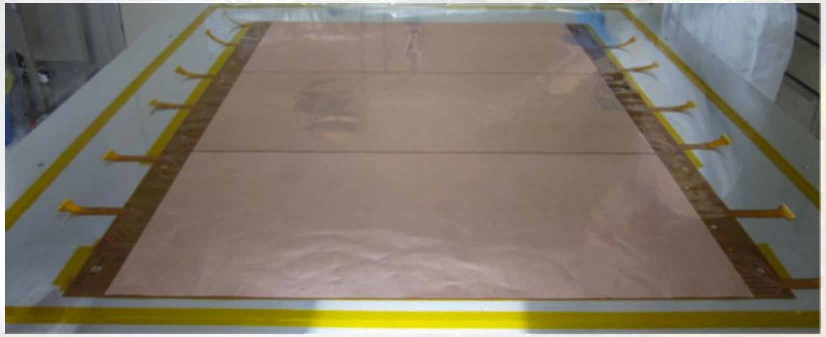




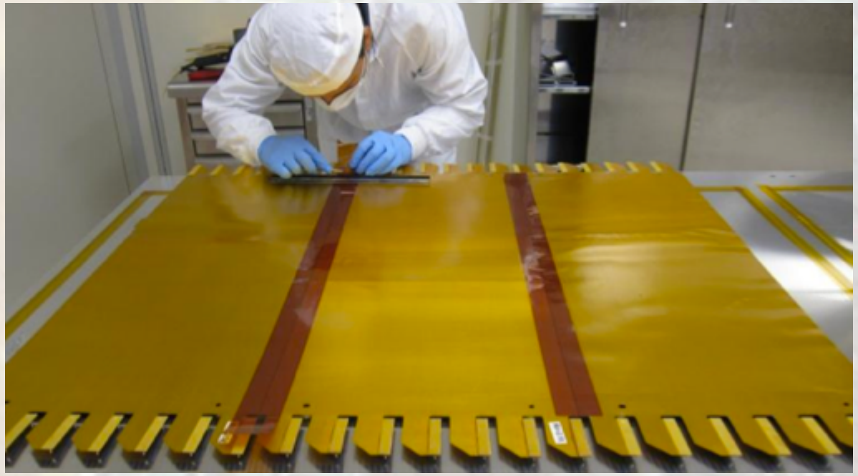
Construction of the KLOE-2 Inner Tracker

Technology fully developed at Frascati National Laboratory of INFN





Epoxy glue on 3 mm wide region
3 foils spliced together with 3 mm overlap
Large-area GEM foils are made cyclidrical by rolling them on Aluminum moulds



3 anode foils spliced together *without overlap* to minimize dead surface
Kapton strips on head-to-head joints.
CF/Nomex/CF (0.25/3/0.25 mm) supports readout foil

Construction of the KLOE-2 Inner Tracker

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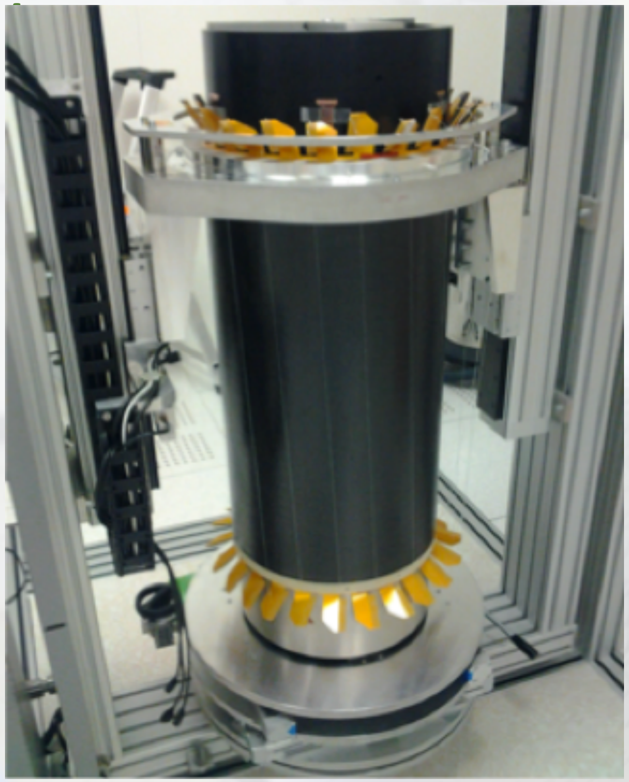
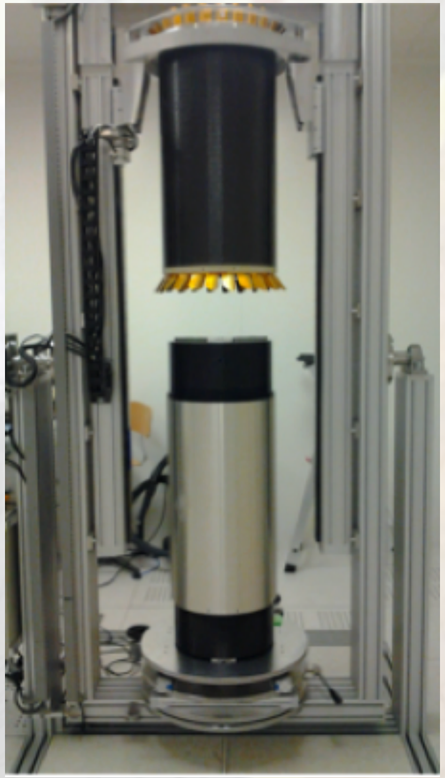
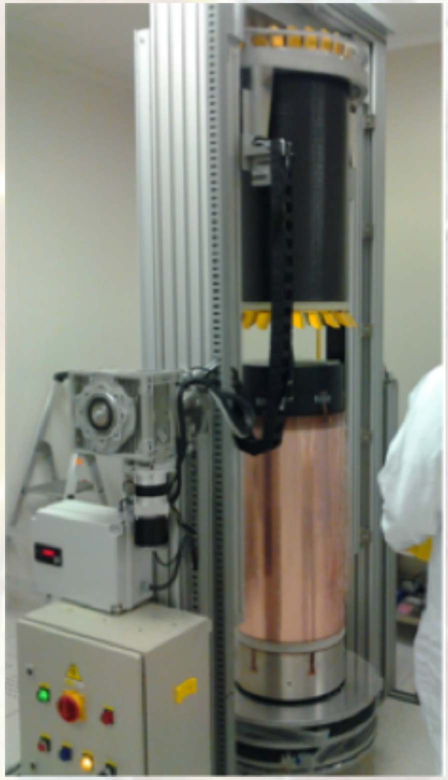





The **Vertical Insertion System** (in collaboration with INFN-RM1) lets one electrode be inserted into the other with an *alignment precision of 0.1mm/1.5m*:

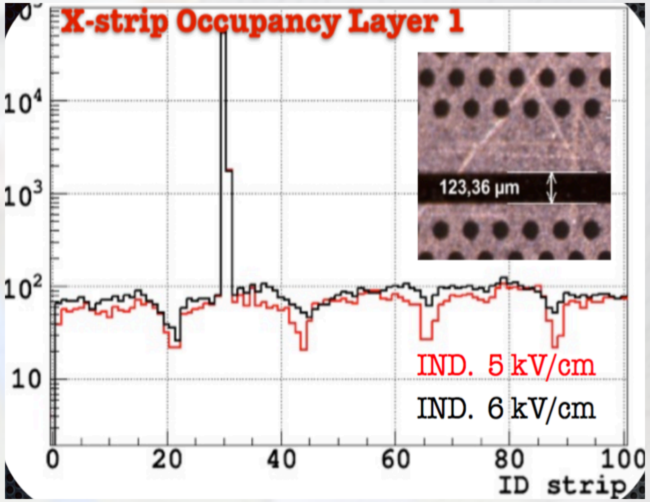
1) put the Anode in the machine with its mould
2) lift the Anode up
3) remove the Anode mould and put the GEM3 electrode in the machine with its mould
4) lift the Anode down till the GEM3 is completely inserted
5) follow the procedure for the other electrodes

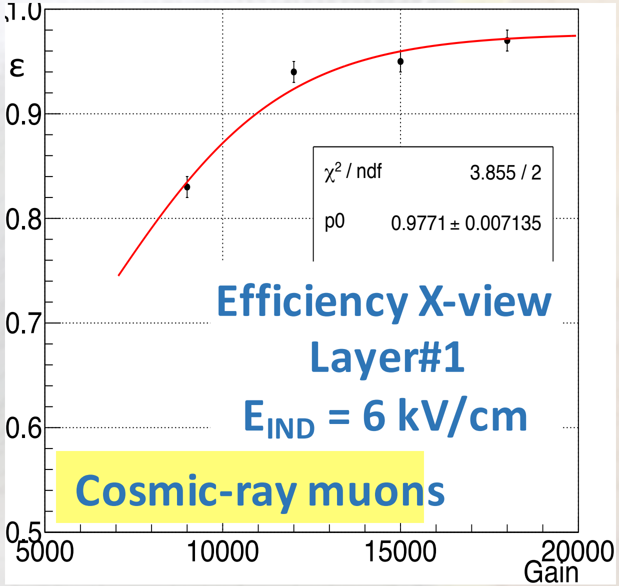
Inner Tracker Operation

- Cosmic-ray muon DC tracks extrapolated to IT
- Take closest reconstructed IT cluster to expected position from DC track

Dips in occupancy due to GEM foil micro-sector structure

10% improvement with E_{IND}=6kV/cm





$\varepsilon_{signle\text{-}view}$ = 94% single-view @ Gain = 12000

Good compromise between IT clustering efficiency and detector operation with colliding beams

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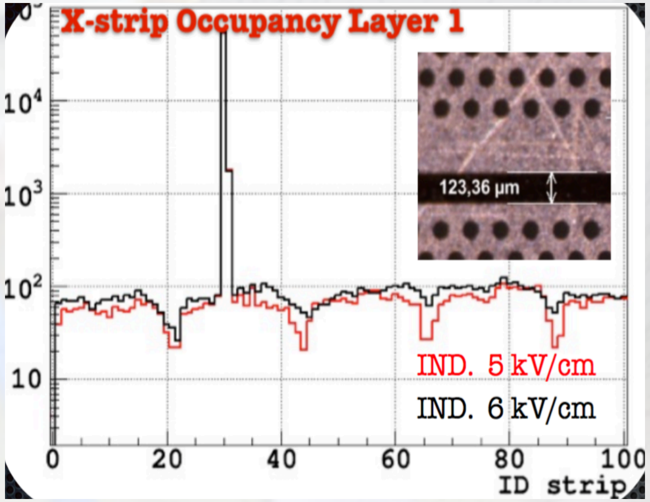

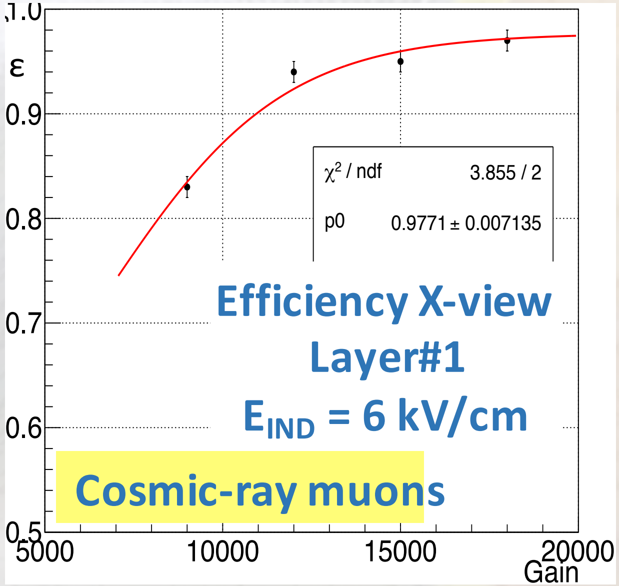

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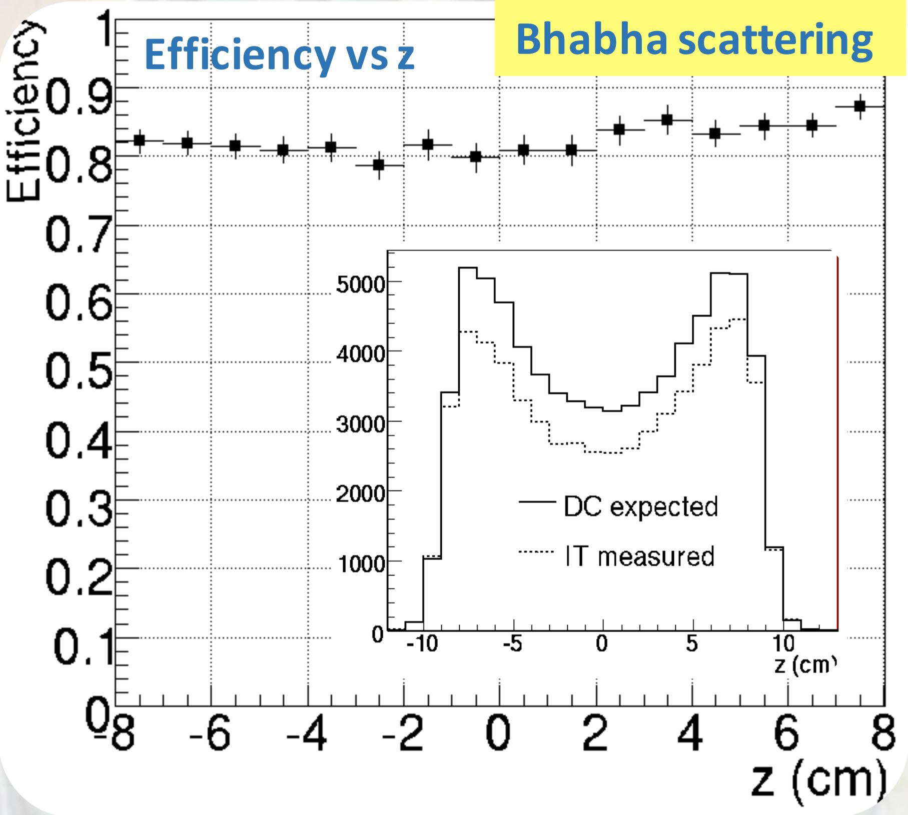
Good compromise between IT clustering efficiency and detector operation with colliding beams

- Bhabha scattering events selected using DC track information

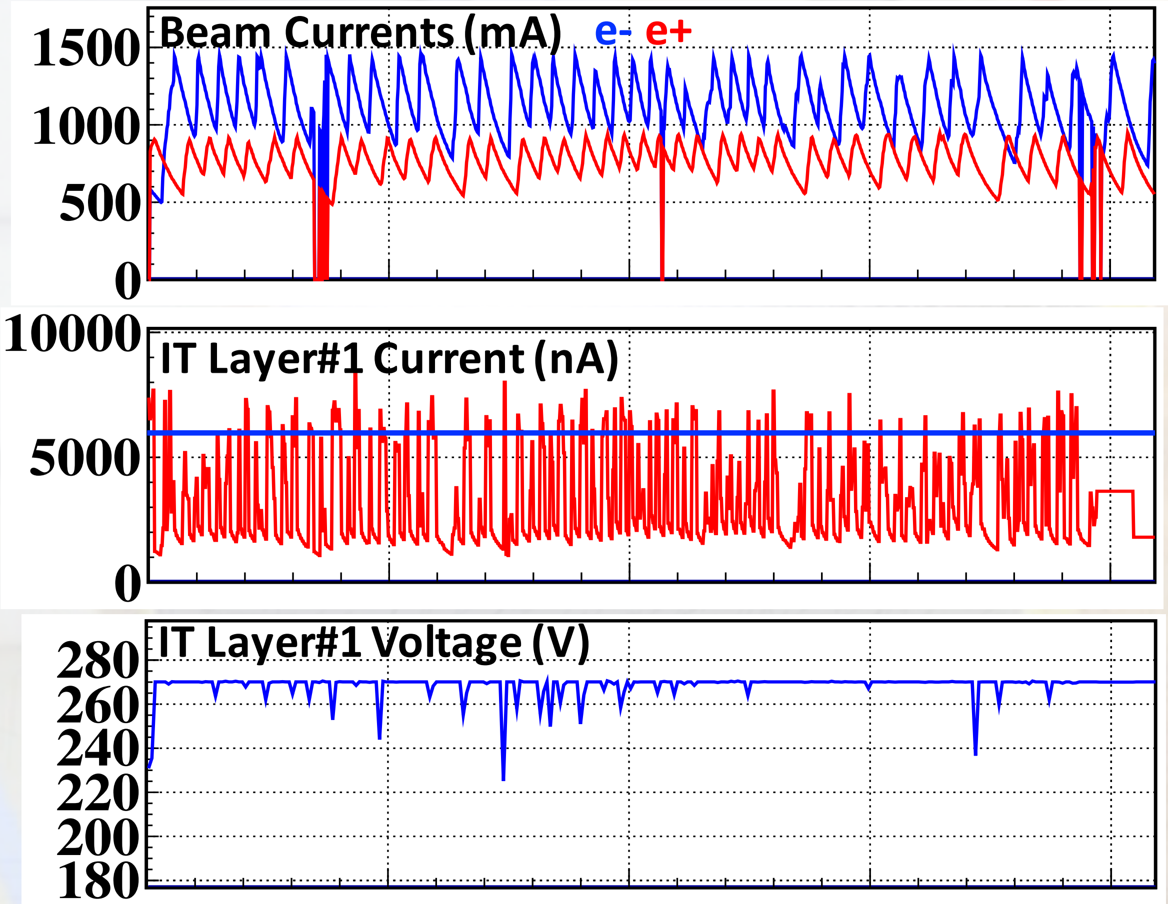


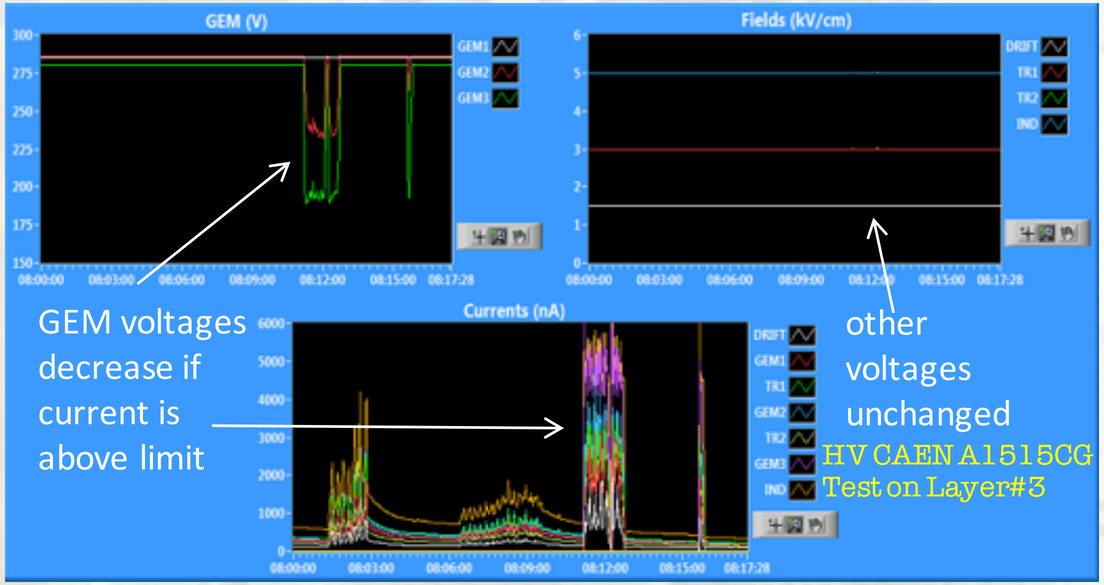
Two-view efficiency measurement with IT operating during collisions

in agreement with cosmic-ray data analysis

Inner Tracker Operation with Collisions

Online monitoring – IT operation with collisions





Current spikes over threshold may occur at beam injections with GEM voltage drops

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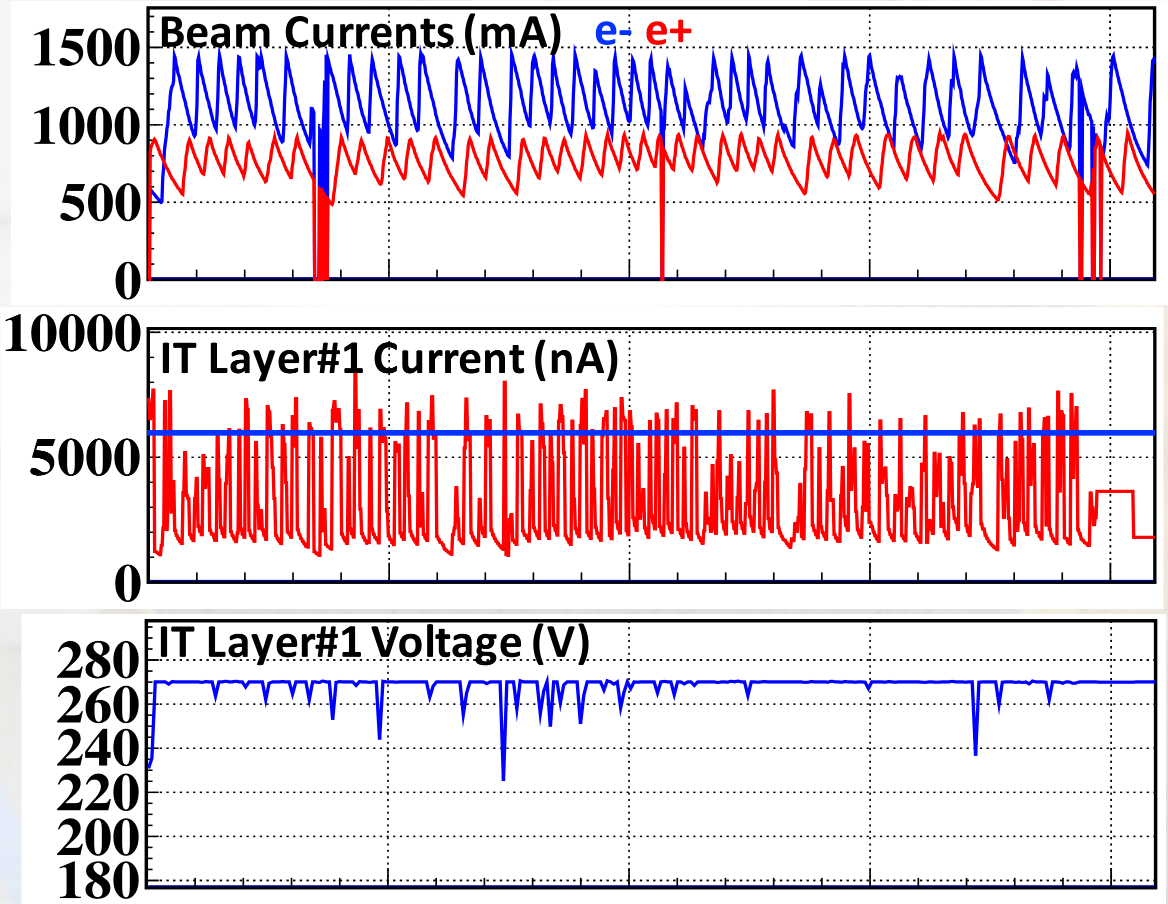
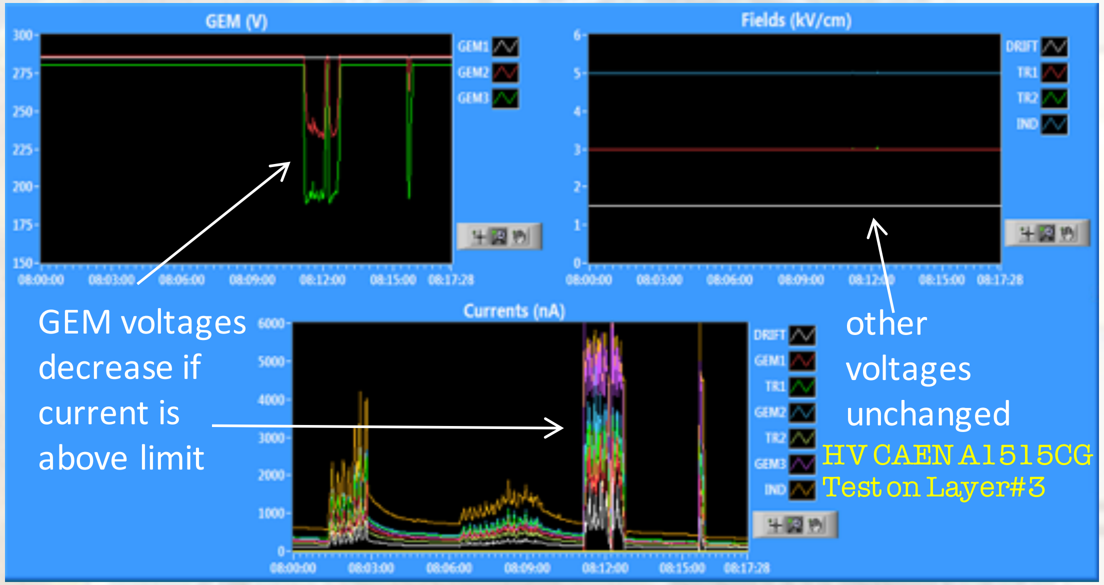




Current spikes over threshold may occur at beam injections with GEM voltage drops *without discharges propagating through GEM stages*

Dedicated HV CAEN Board A1515CG

Successfully tested and installed in Sep 2016 on all layers for safer operation

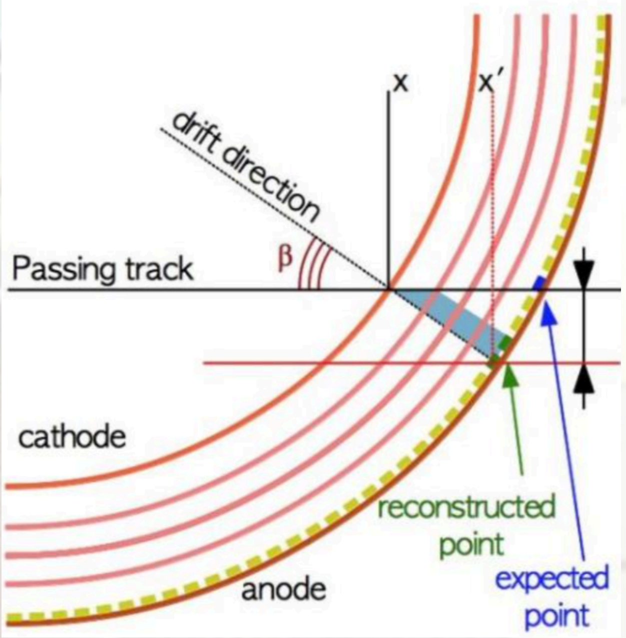
7 independent *floating* channels

Single voltage adjustment allowed

IT Calibration Strategy

1. NON-RADIAL TRACKS The angle formed by a track and the radial E-field direction introduces **shift & spread** of the electron cloud

2. MAGNETIC FIELD 0.52 T B-field orthogonal to GEM stages E-field lines: **shift** and **larger spread** of the electron cloud



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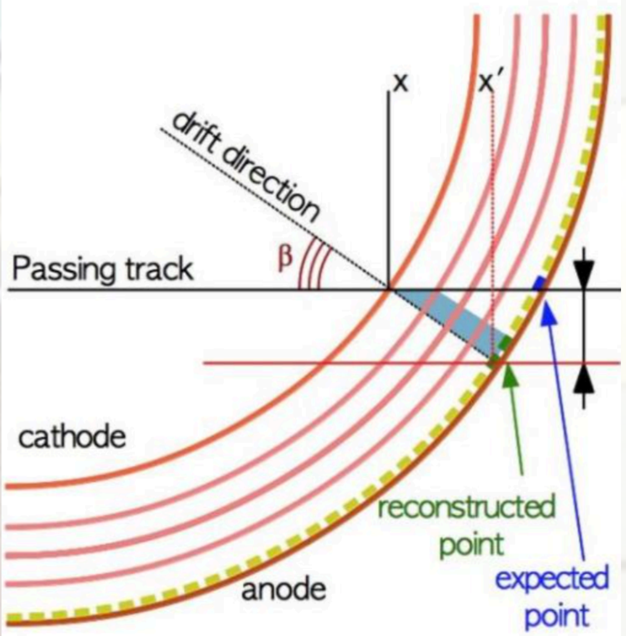
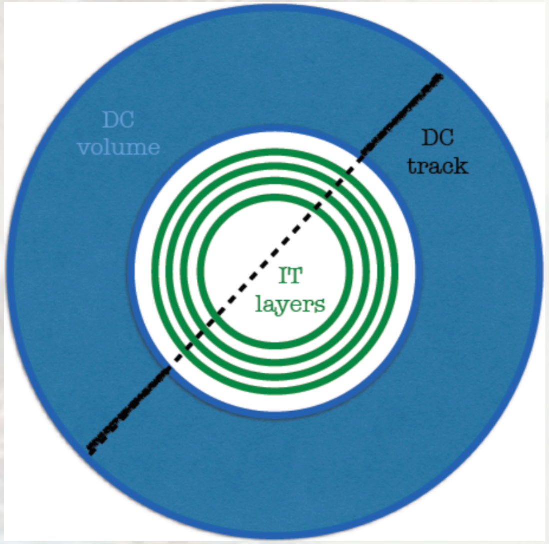


Cosmic-ray muon data acquired with B-field OFF

- Calibration of *Non-radial track effect*
- Select DC tracks crossing IT at 2 points
- Shifts and rotations to align the IT



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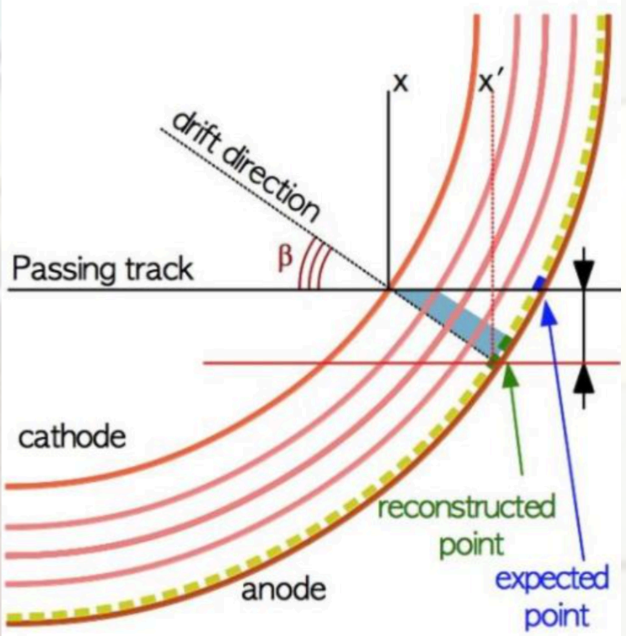
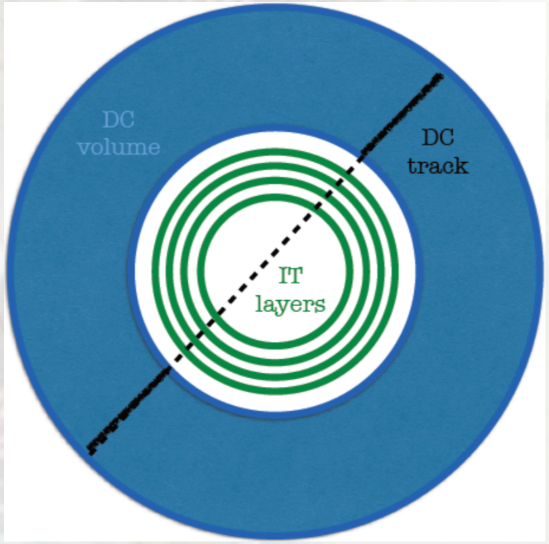


Cosmic-ray muon data acquired with B-field OFF

- ◎ Calibration of *Non-radial track effect*
- ◎ Select DC tracks crossing IT at 2 points
- ◎ Shifts and rotations to align the IT

Cosmic-ray muon data acquired with B-field ON

- ◎ Calibration of *Non-Radial track & B-field effects*
- ◎ Corrections, Shifts and rotations from B-field OFF sample



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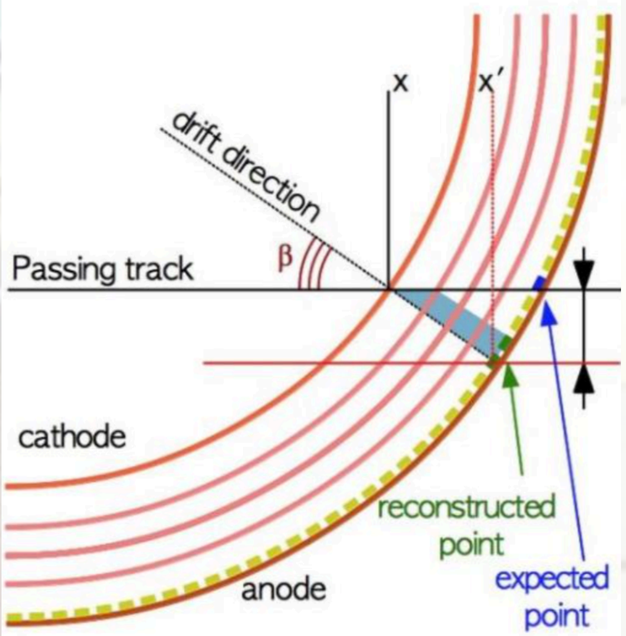

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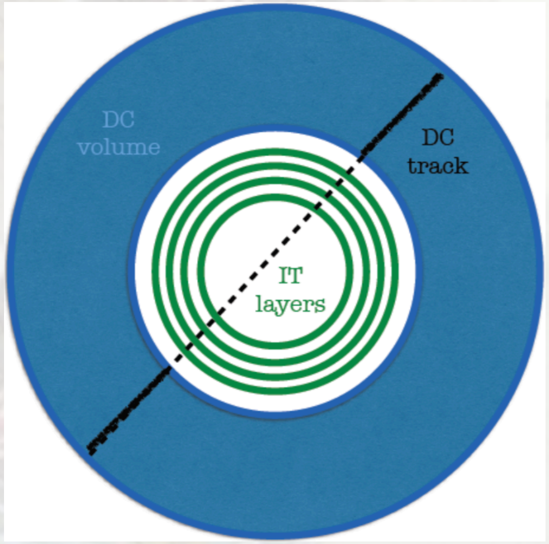
Cosmic-ray muon data acquired with B-field ON

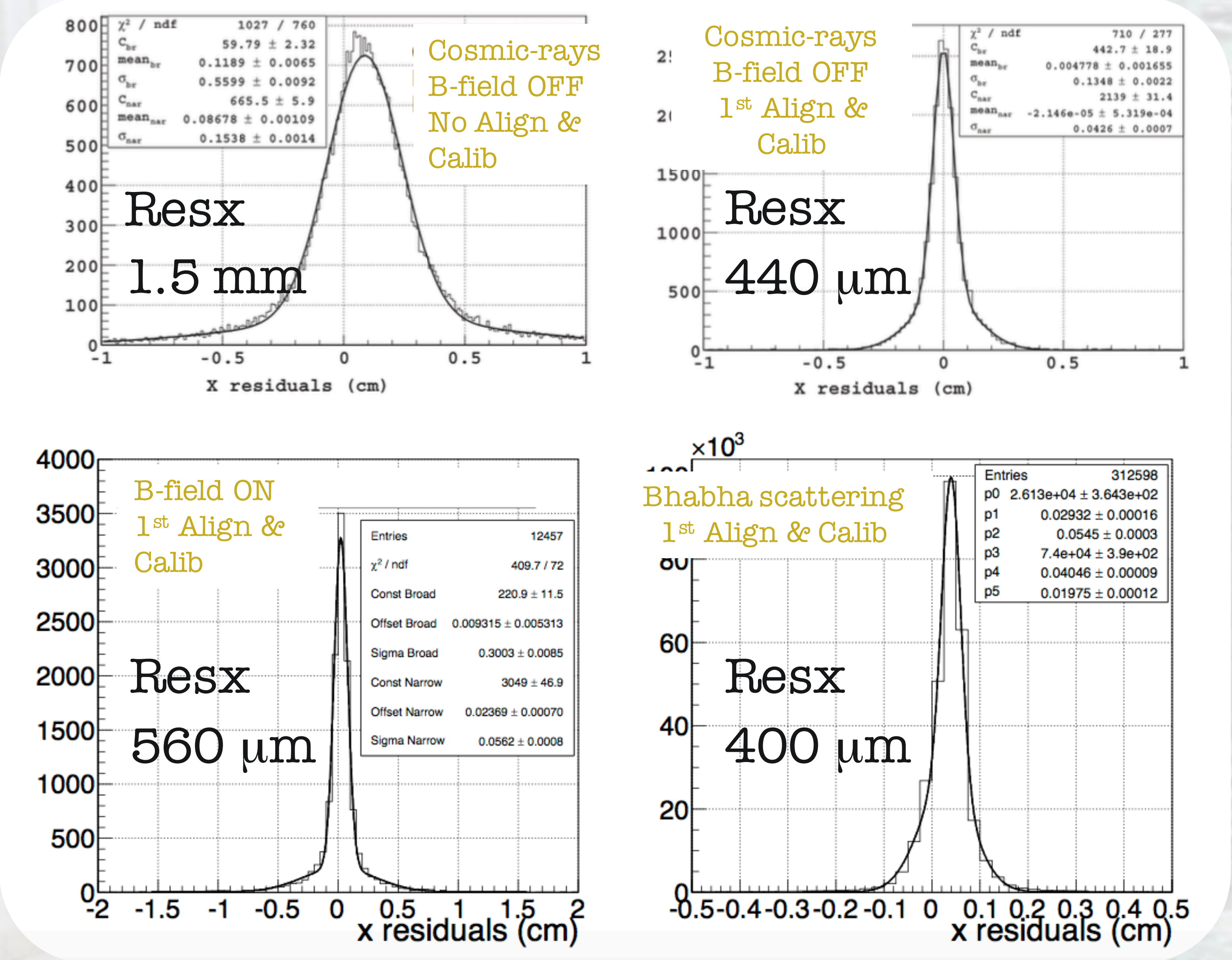
- Calibration of *Non-Radial track & B-field effects*
- Corrections, Shifts and rotations from B-field OFF sample

Bhabha scattering events

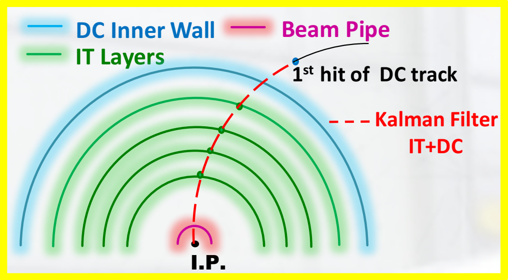
- *Validate calibration* of Non-radial track & B-field effects
- Corrections , Shifts and rotations from cosmic-ray muon data analysis with B-field ON sample



The Road to the First Calibration of the IT

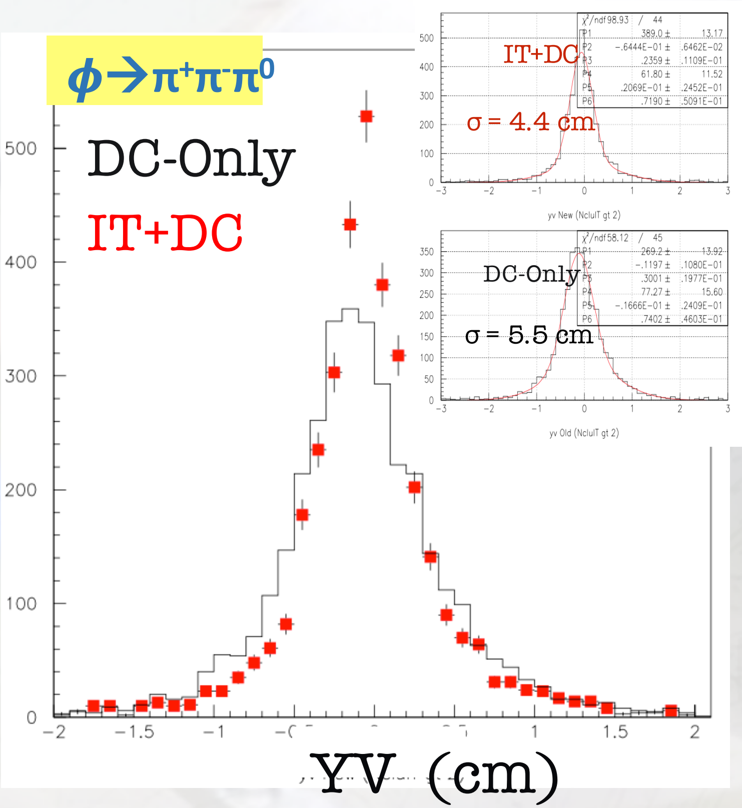


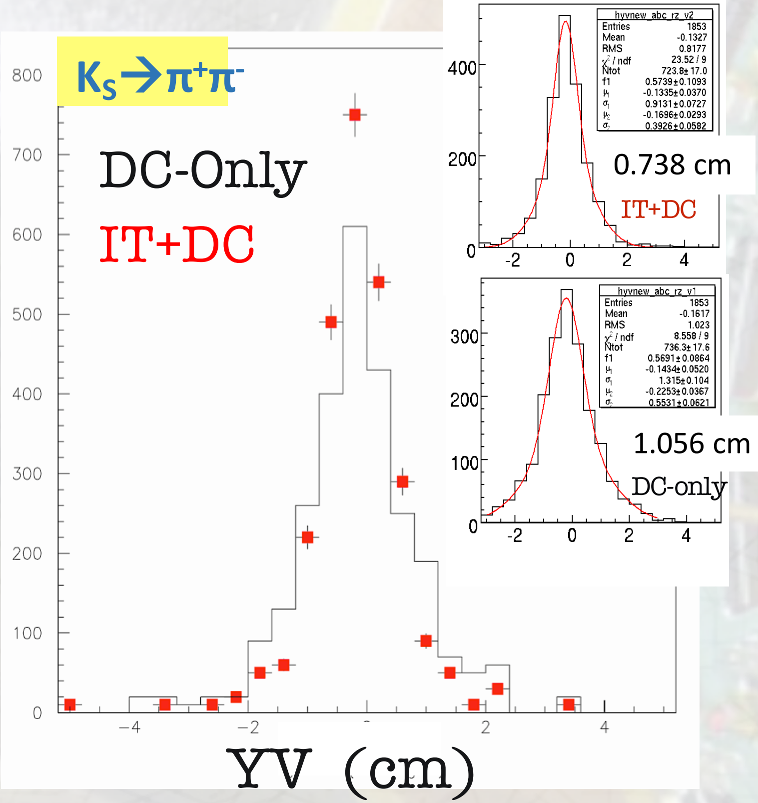
Tracking with IT+DC



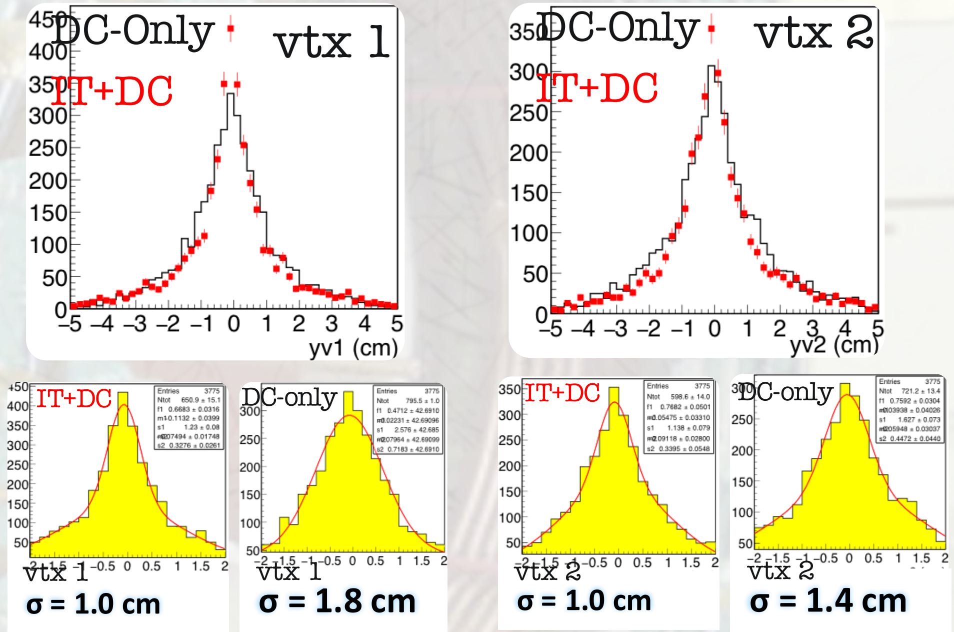
Start with DC reconstructed tracks
Add IT clusters and reconstruct IT+DC tracks
Make vertices using IT+DC tracks when IT contributes to track reconstruction

Improvement in vertex reconstruction observed with IT+DC tracking
Using 1st set of calibration constants



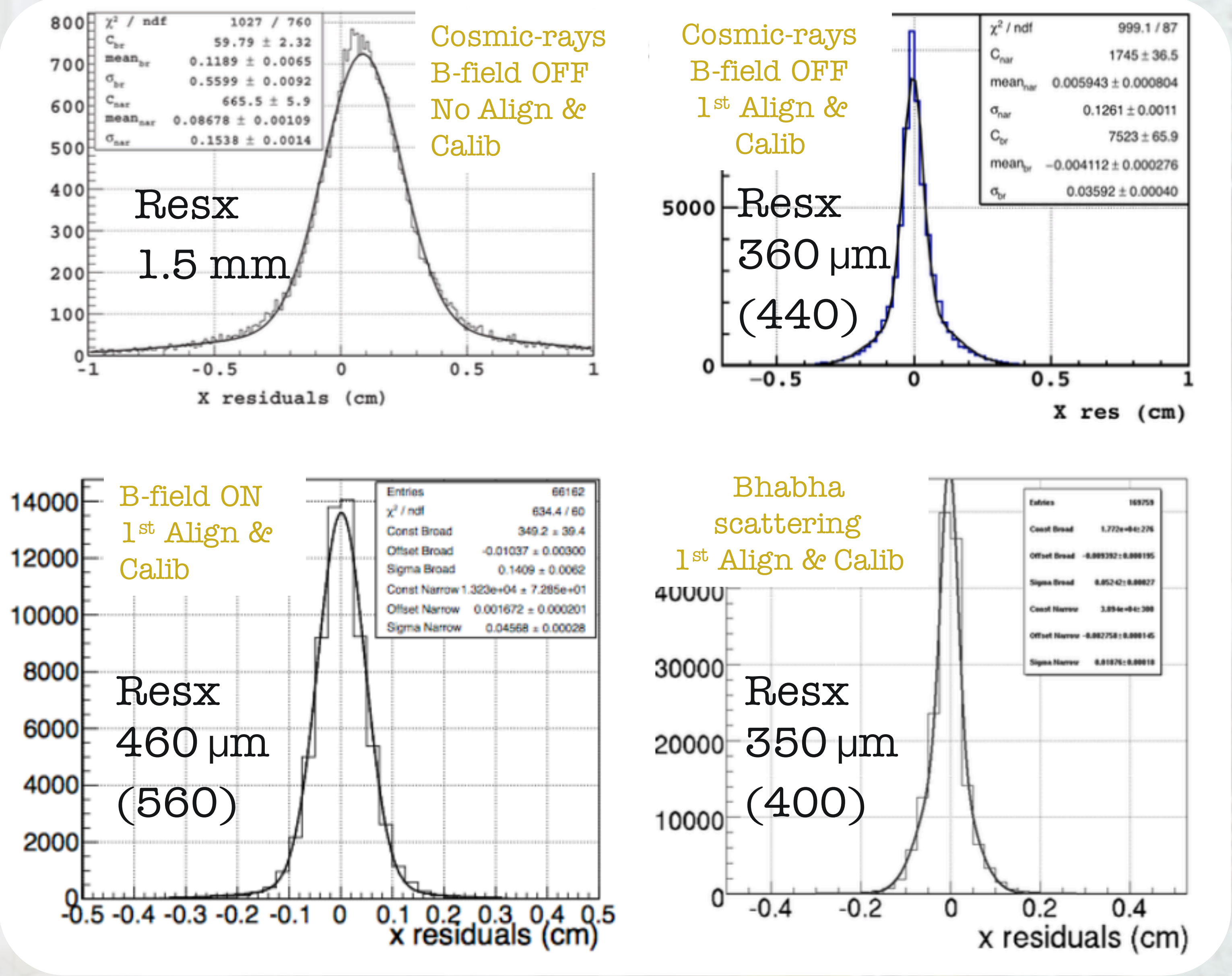


$K_S K_L \to 4$ tracks



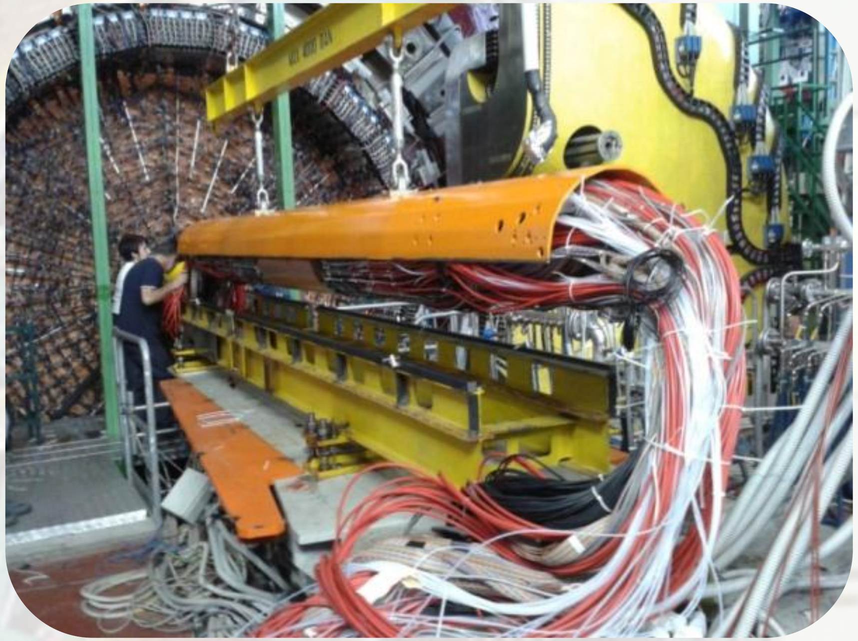
Further improvements expected using refined calibrations

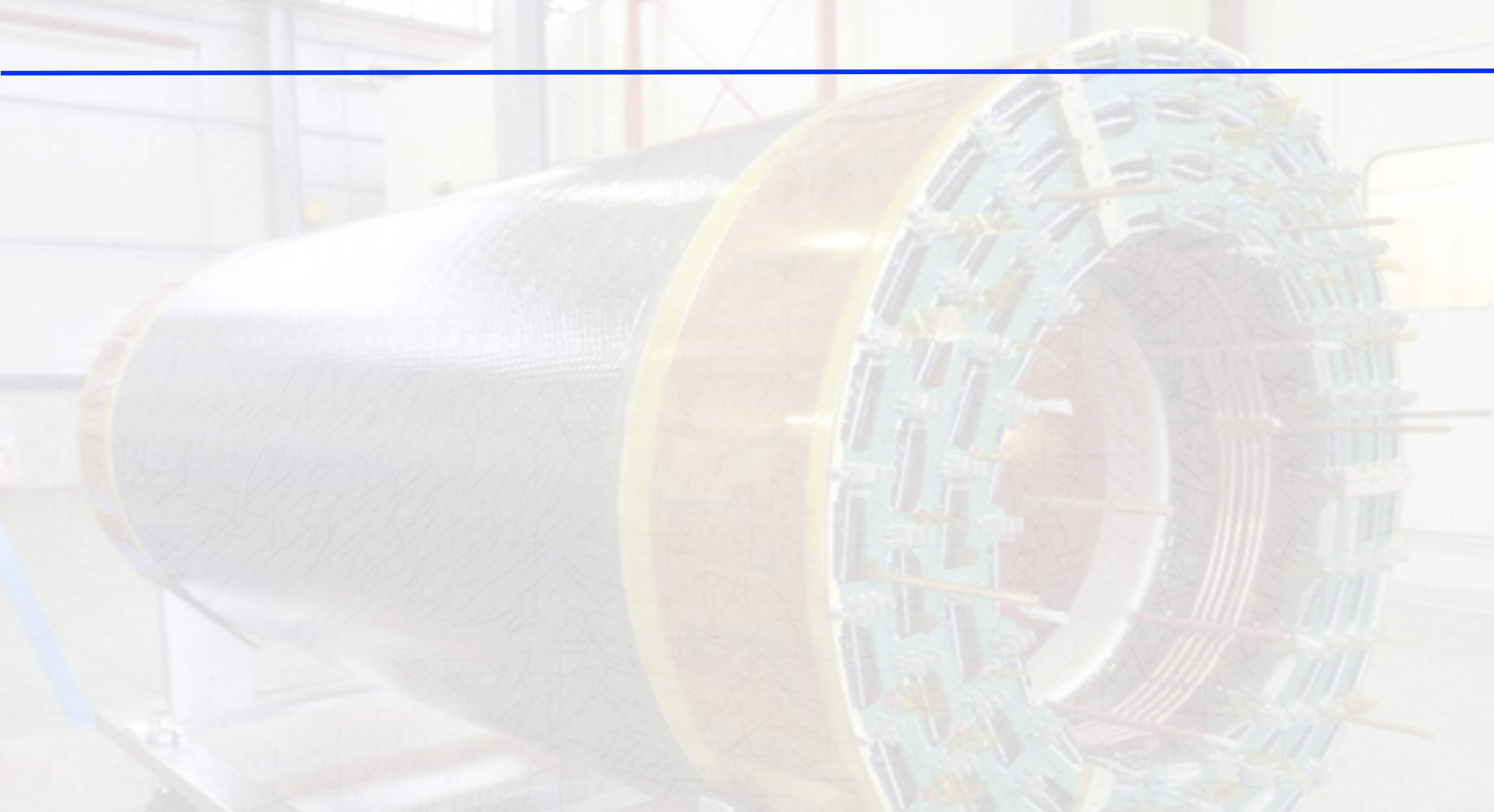
Improved Calibrations of the IT



Conclusions

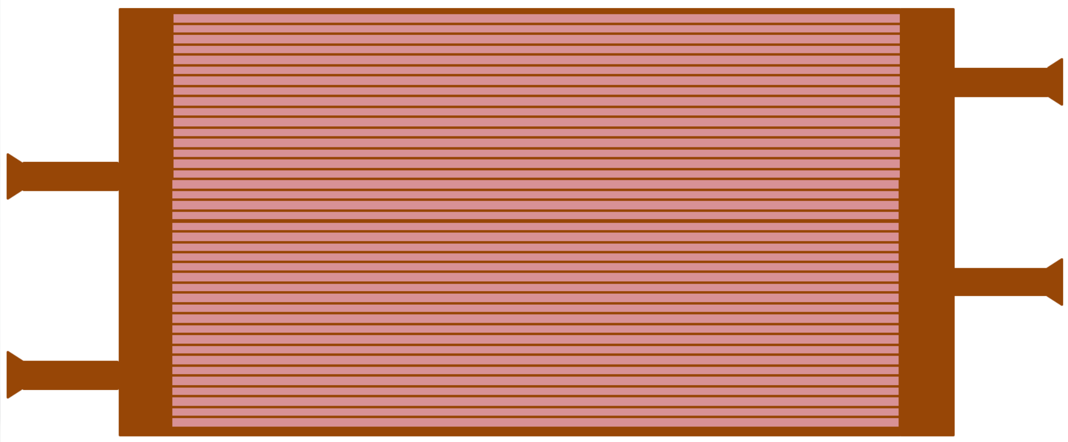
- KLOE-2 experiment successfully finished its data taking in March 2018 acquiring more than expected 5 fb^{-1}
- KLOE-2 Inner Tracker is the first cylindrical GEM detector ever used in high energy physics experiments
  - *Technology fully developed at Frascati National Lab facilities*
  - Big efforts have been devoted to operate this novel detector with colliding beams while keeping good performance
- First detector alignment and calibration successfully performed using cosmic-ray muon and Bhabha scattering data
  - *Challenging task to be accomplished. Never done before.*
- IT+DC tracking and vertexing fine tuning is ongoing
  - Good improvements in tracking & vertexing already observed in many physics channels
  - Further improvements expected using refined set of calibration constants



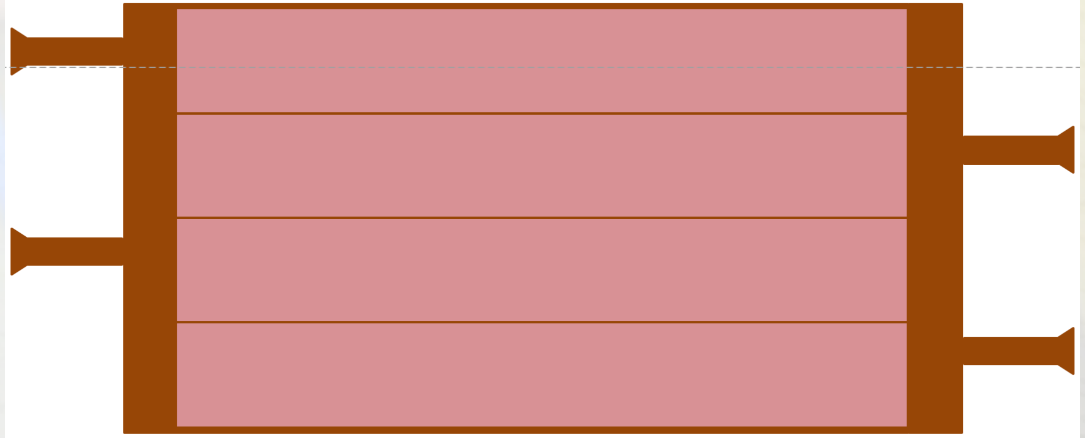


Inner Tracker Operation – "The Edge Effect"

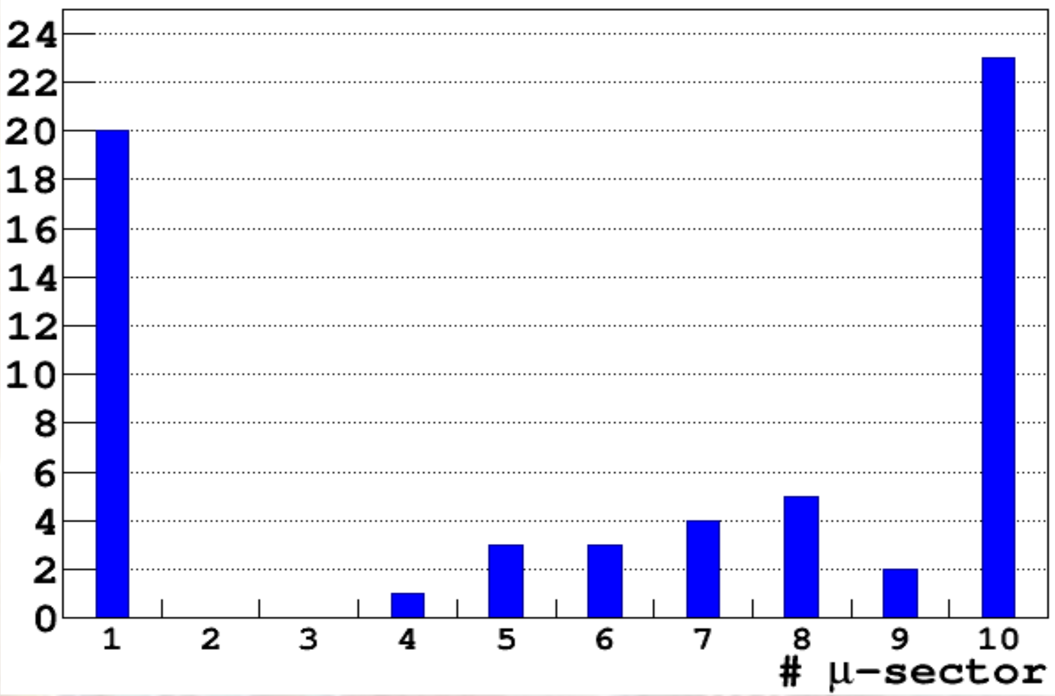
GEM TOP: 40 HV micro-sectors



GEM BOTTOM: 4 HV sectors



Short-circuit distribution per micro-sector



- Segmentation of the GEM foils causes a distortion of the effective gain
- Higher gains at the borders of HV sectors
- Observed also by ALICE, COMPASS-THGEM
- Solution: increase GEM hole diameter

Front-end Electronics

128-channel custom GASTONE boards:

- 1 board has 2 chips (64+64 channels)
- Mixed analog-digital circuit
- Low power consumption, high modularity
- Low equivalent noise charge:
  0.77fC at C_{DET}=100pF

GASTONE main features	
N. channels/chip	64
Chip dimensions	4.5x4.5 mm^2
Z_{IN}	120 Ω
C_{DET}	1-200 pF
Charge gain	~19 mV/fC (C_{DET}=100pF)
Peaking time	90 ns (C_{DET}=100pF)
ENC (erms)	800e^-+40e^-/pF
Power consumption	~6 mW/channel
Readout	Serial LVDS

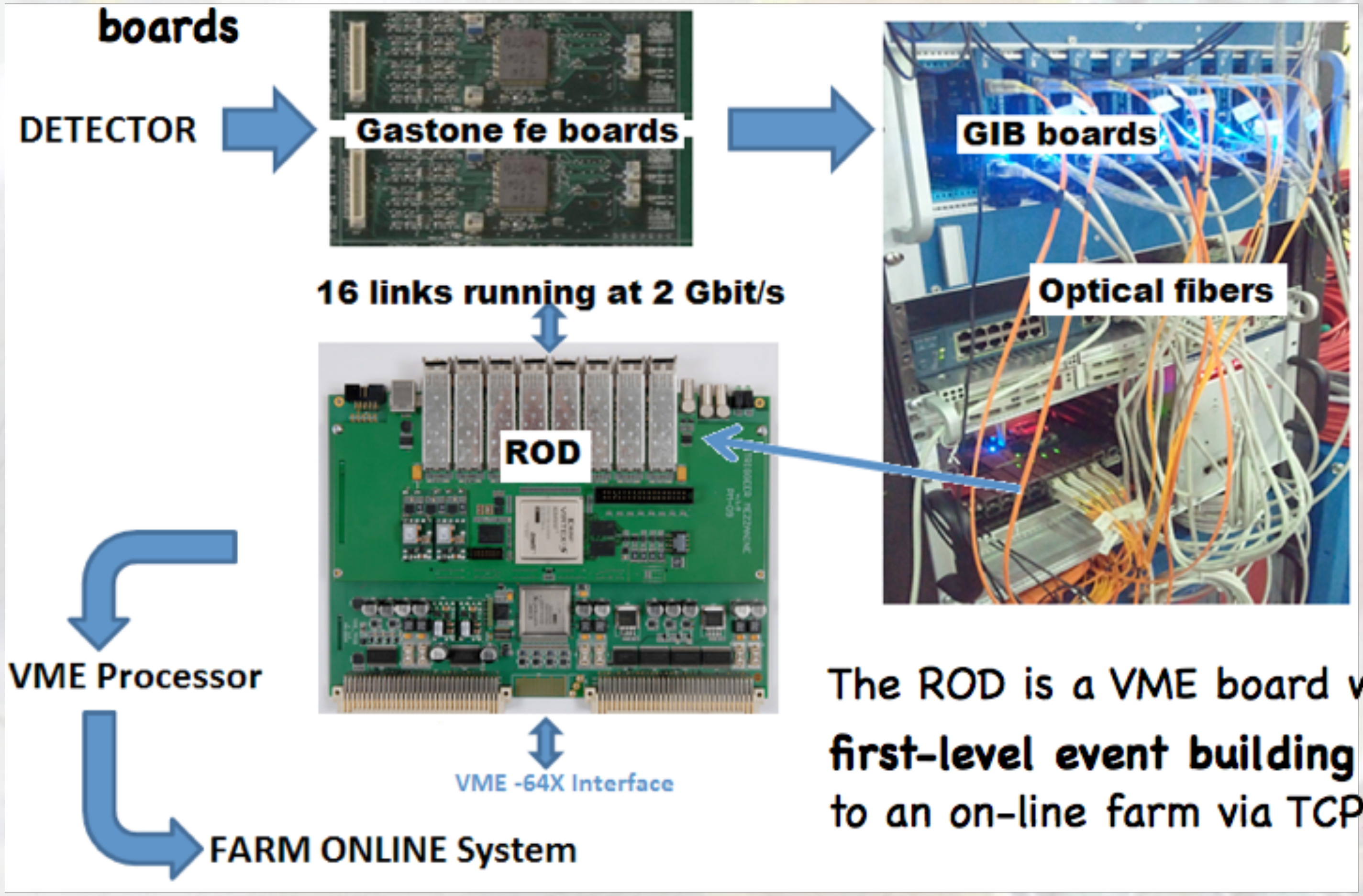
S/N = 5 if thr = 3.85 fC

thr_{CGEM} = 4.3 fC

Off-detector Electronics and DAQ

Data from the CGEM are readout by the **GASTONE boards**

The **GIB boards** acquire data froma the FE boards to deliver them to the **ROD** using **Optical Fibers**



The ROD is a VME board which performs a **first-level event building** and sends data to an on-line farm via TCP/IP.

[JINST 8 T04004 (2013)]