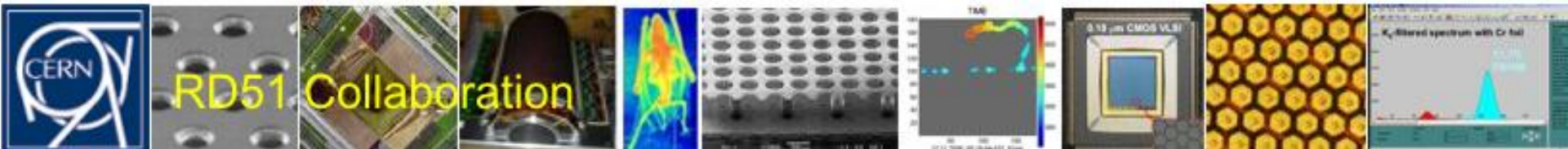
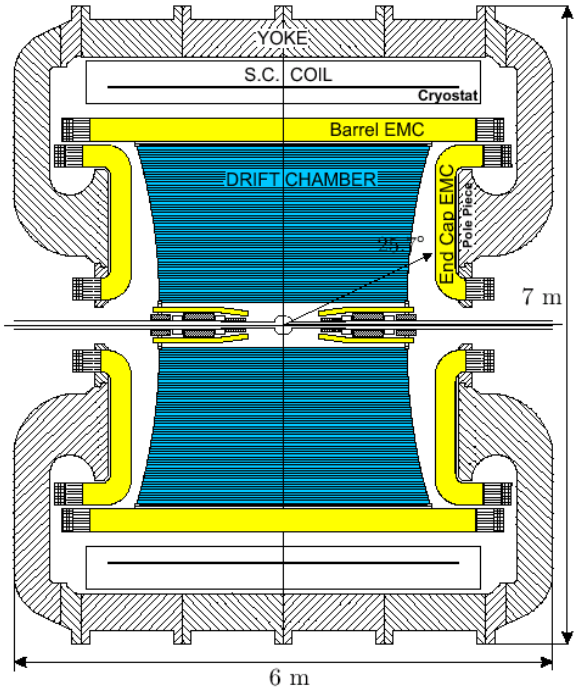
Construction and commissioning of the KLOE-2 Inner Tracker

G. Morello on behalf of the KLOE-2 IT group,
Third International Conference on
Technology and Instrumentation in Particle Physics
June 3rd, Amsterdam (NL)



KLOE-2 at DAΦNE ϕ-factory



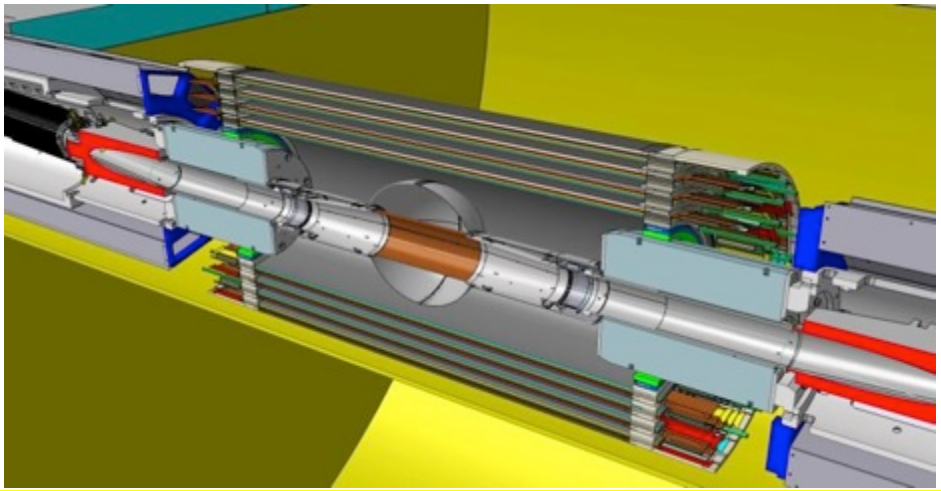
The KLOE apparatus, consisting of a huge **Drift Chamber** and an **Electromagnetic Calorimeter** working in a **0.5 T** axial magnetic field, has been upgraded with new subdetectors for a new data taking campaign. The required inner tracker performances are :

- **200 μm** spatial resolution on the transverse plane and **500 μm** along the beam line
- Material budget less than **2% X_0**
- **5 kHz/cm^2** rate capability

The inner tracker is composed of 4 coaxial cylindrical triple-GEMs with

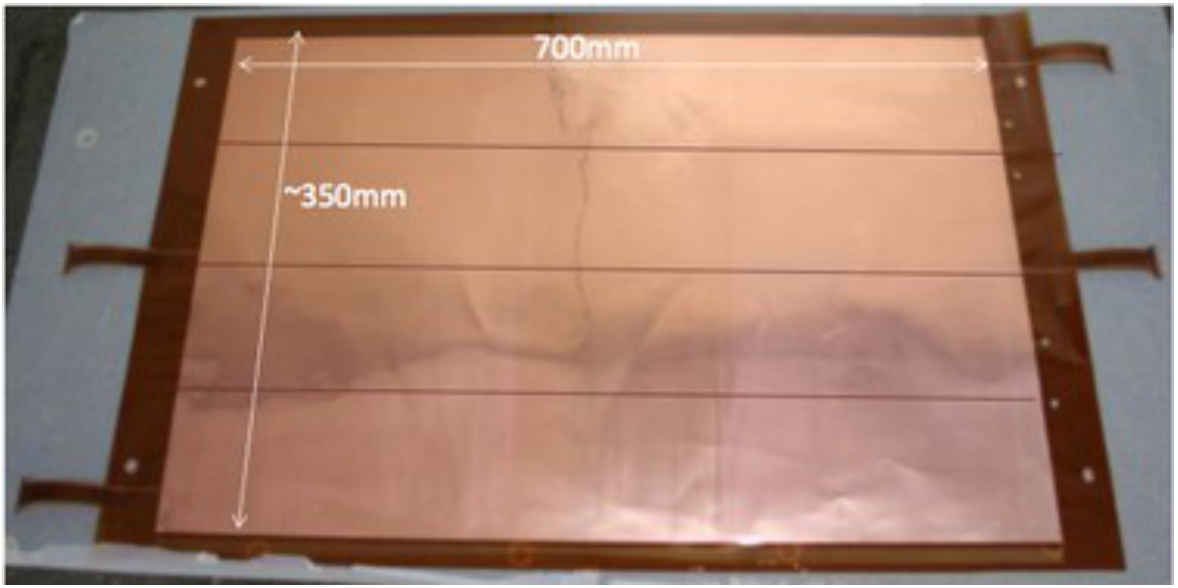
- **700 mm** active length
- Radii between **130** and **205 mm**
- X-V stereo readout

Very low mass detector



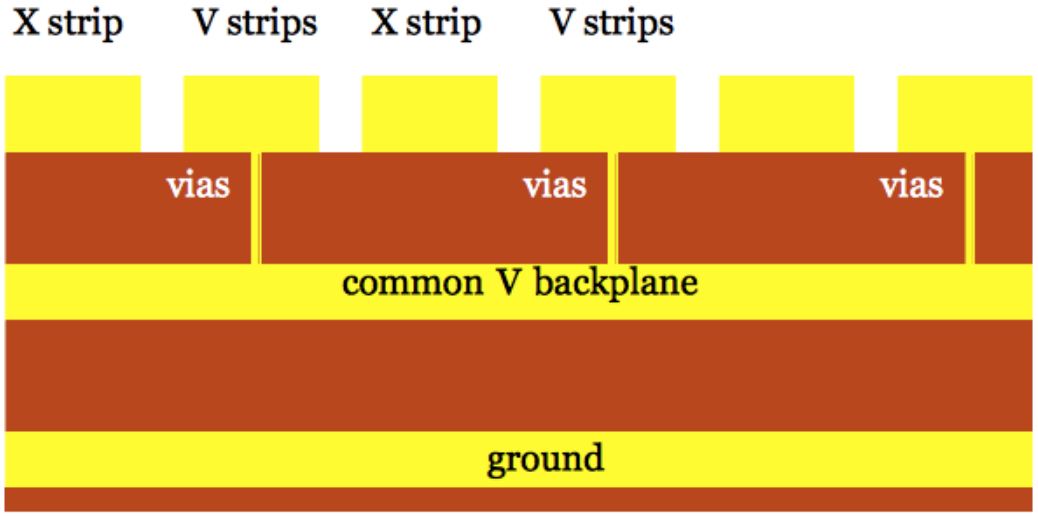
The electrodes of the IT

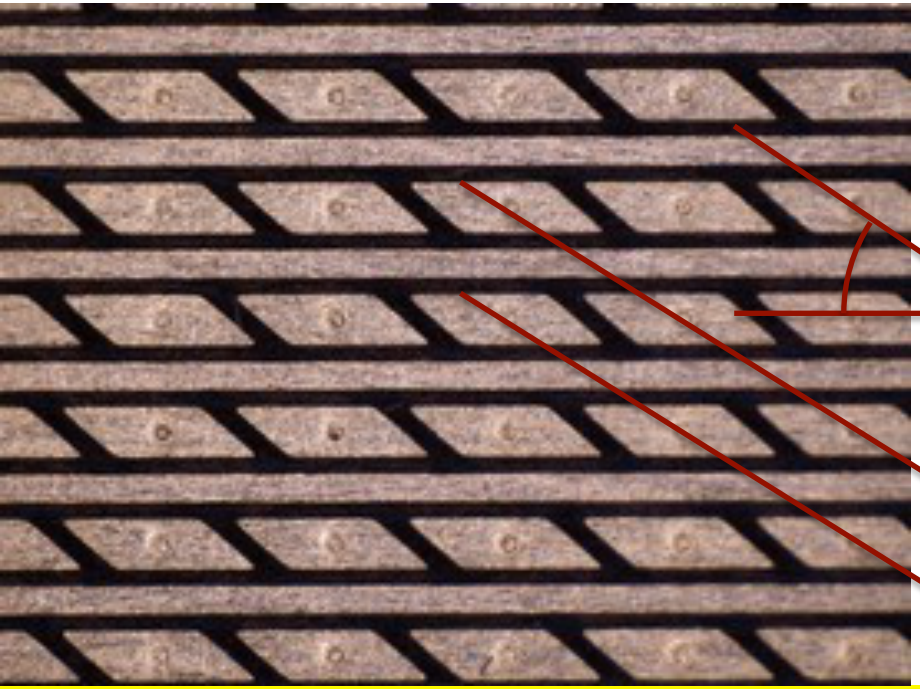
- Every layer of the Inner Tracker is a triple-CGEM composed of a cylindrical anode, 3 CGEM and a cylindrical cathode
- The dimensions of the electrodes required a **new production technique**
- The CERN TE-MPE-EM workshop (Rui de Oliveira) produced large area GEM foils (up to **350 x 700 mm^2**) using the single-mask technique (**first time for an experiment**)
- Each GEM foil is divided in 40 HV sectors (**1.5 x 70 cm^2**) on the top side and 4 HV sectors on the bottom side in order to reduce the energy of discharges
- Each cylindrical electrode is realized with the wrapping technique developed at LNF

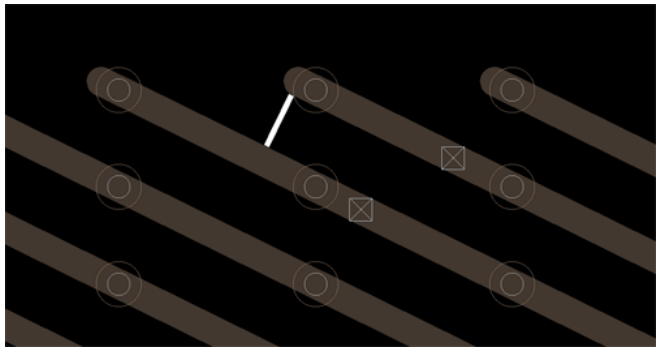


The readout of the IT

The readout of the IT is a flexible kapton/copper circuit.
The 2-dimensional reconstruction is given by the X strips (parallel to the axis of the CGEM) and V pads connected by vias to a common backplane







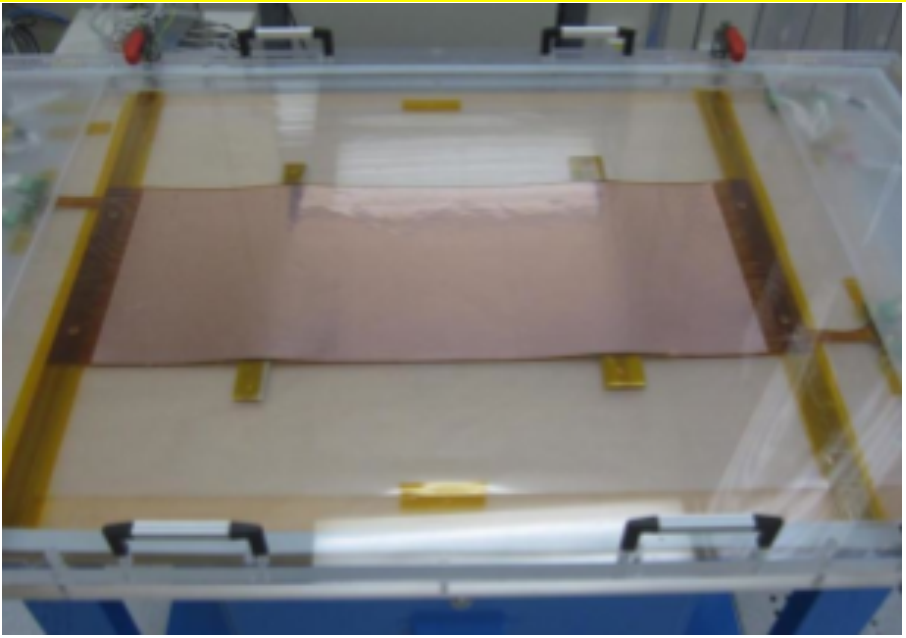
GASTONE: the FEE for the IT

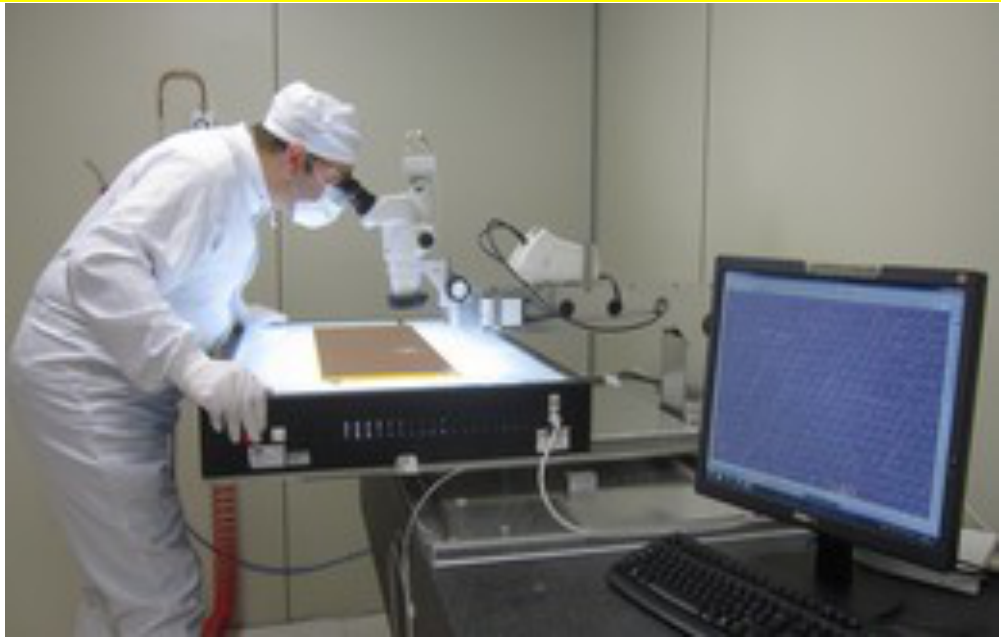
- Mixed analog-digital circuit
- Low input equivalent noise, low power consumption and high integrated chip
- 4 blocks:
  - charge sensitive amplifier
  - shaper
  - leading-edge discriminator (programmable threshold)
  - monostable (stretch digital signal for trigger)

Developed by INFN Bari and LNF

Sensitivity (pF)	**20 mV/fC**
Z_{IN}	**400 Ω (low frequency)**
C_{DET}	**1-50 pF**
Peaking time	**90-200 ns (1-50 pF)**
Noise (rms)	**800 e^- + 40 e^-/pF**
Channels/chip	**64**
Readout	**LVDS/Serial**

Quality check





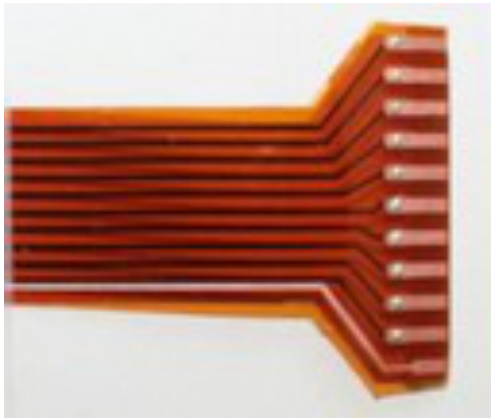
The GEM foils are tested in a N_2 flushed box for humidity reduction (RH below **10%**)

Each sector of the foil is supplied with up to **600 V**

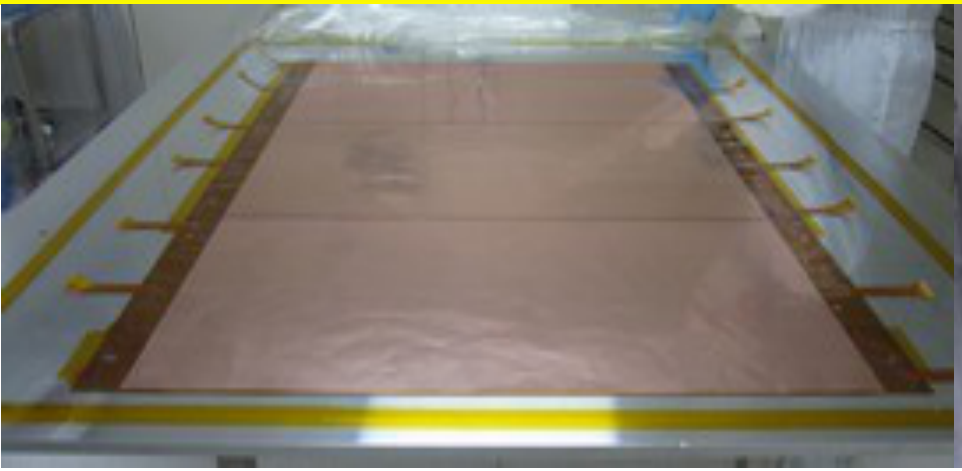
Discharge rate (**O(1) h-1 @ 600 V**) and current leaks (**<1nA**) are monitored

HV connections are checked to have R **< 2 Ω**

A complete test takes ~ **4 h**



Construction details



Three foils are spliced together along the kapton frame

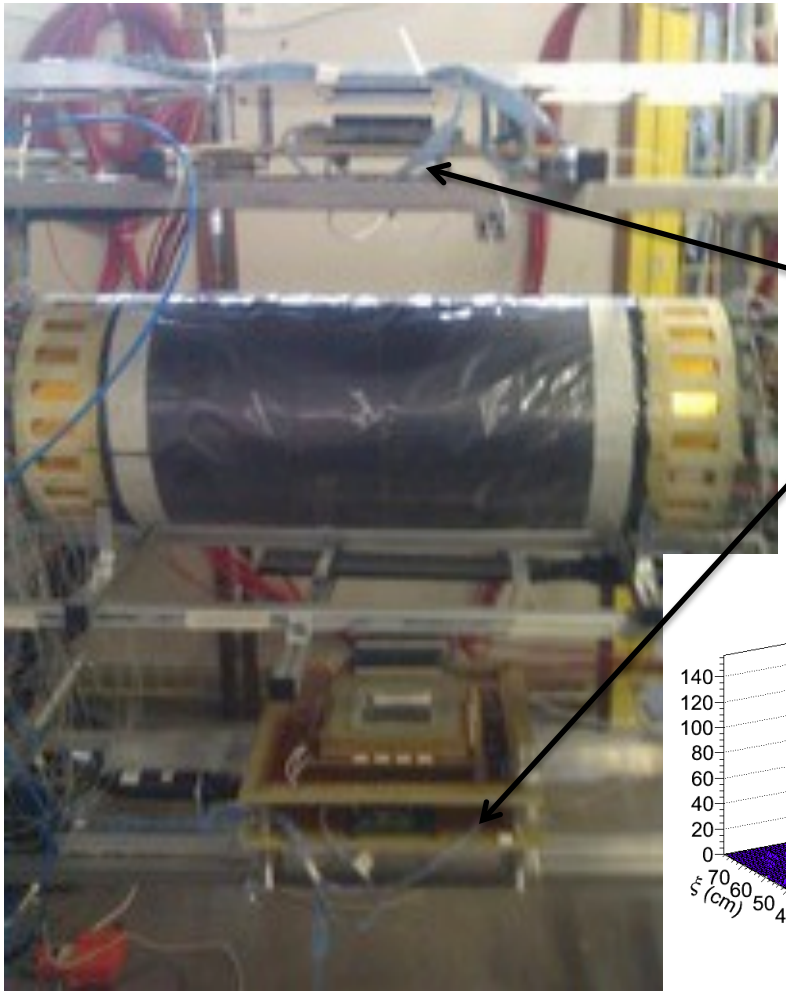
The large electrode is then rolled on a Teflon machined mould, glued and polymerized with the vacuum bag technique

Fiberglass rings acting as spacers

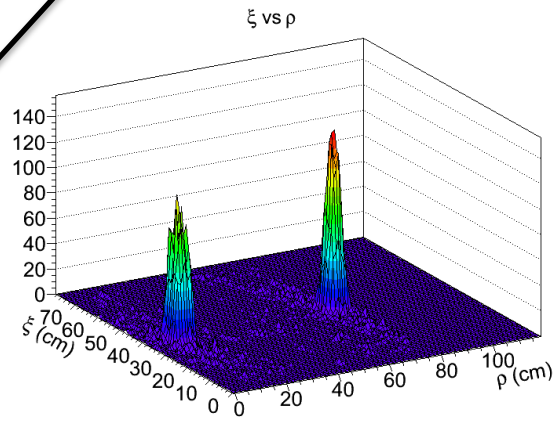
The cylindrical GEM is ready to be extracted from the mould: the very low friction of the Teflon reduces the mechanical tensions on the foil

Assembly and test

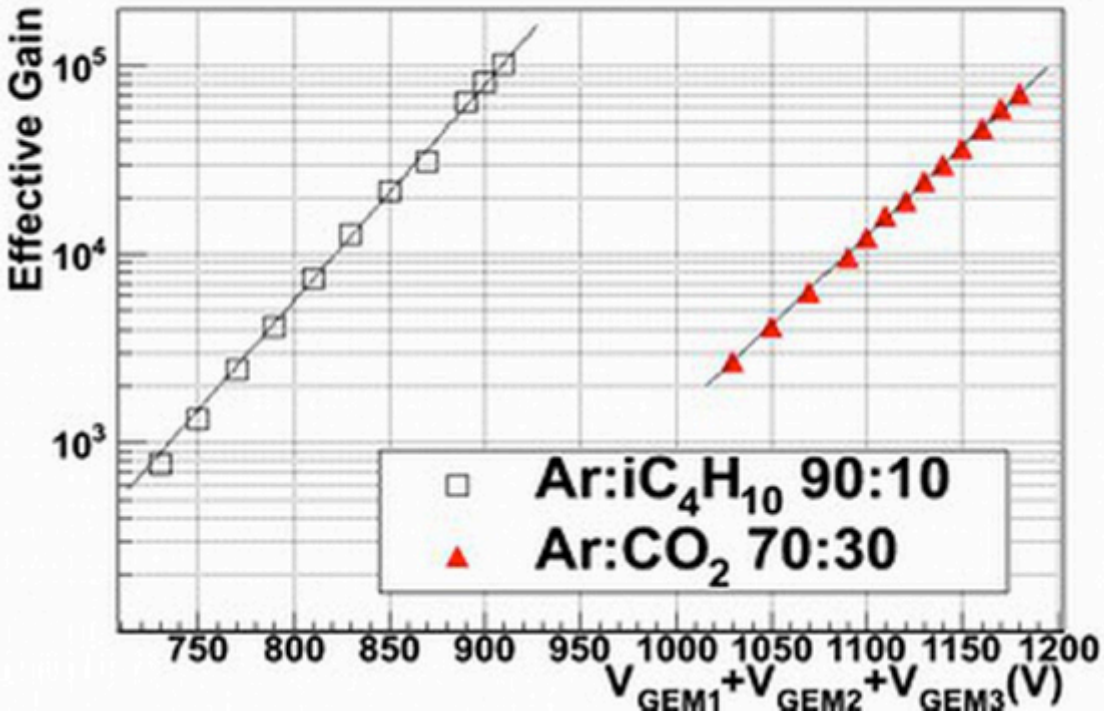
The Vertical Insertion System provides the insertion of all the cylindrical electrodes, one into the other, with an accuracy of less than 100 μm over 1 m length

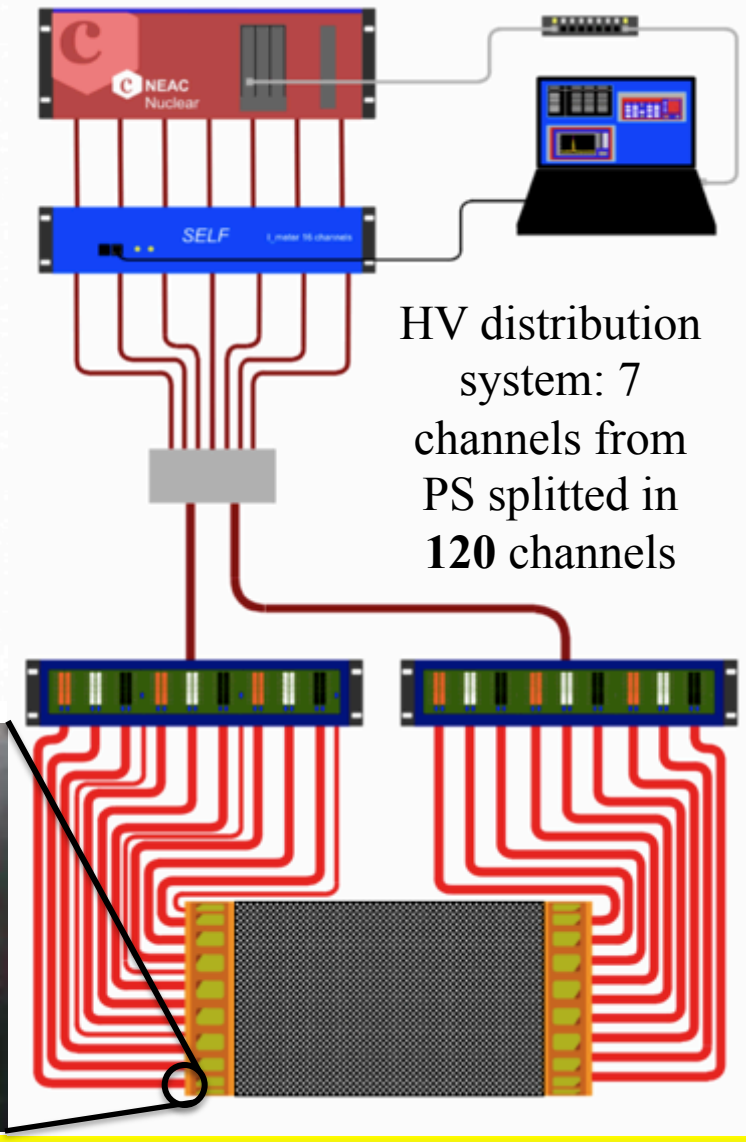


- ^{90}Sr source test to check the functioning over the cylindrical surface
- Cosmic-ray test with scintillators trigger and 3 PGEMs as external trackers



Operational parameters

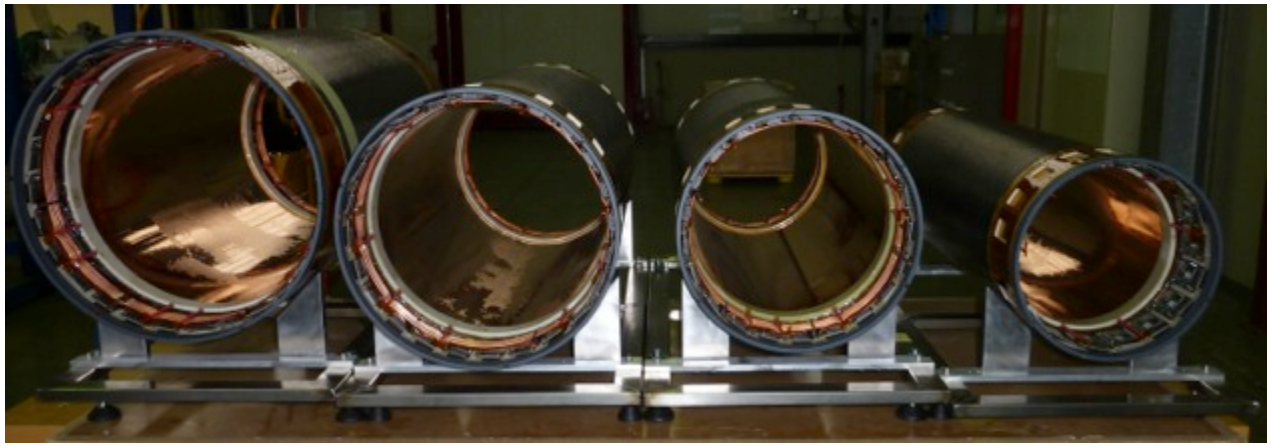


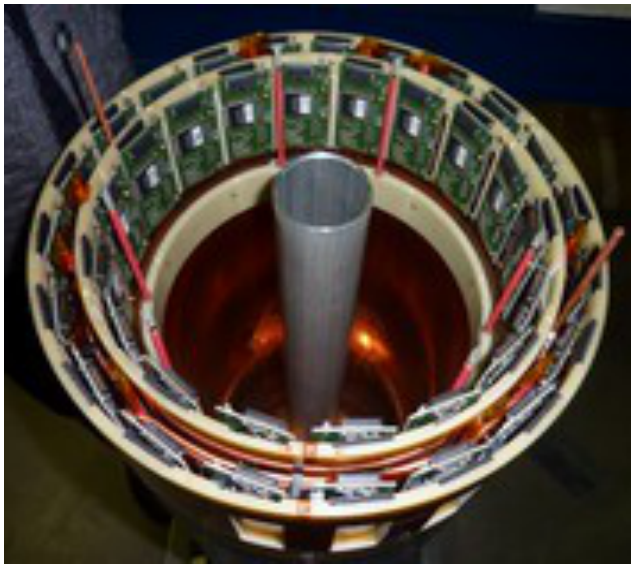


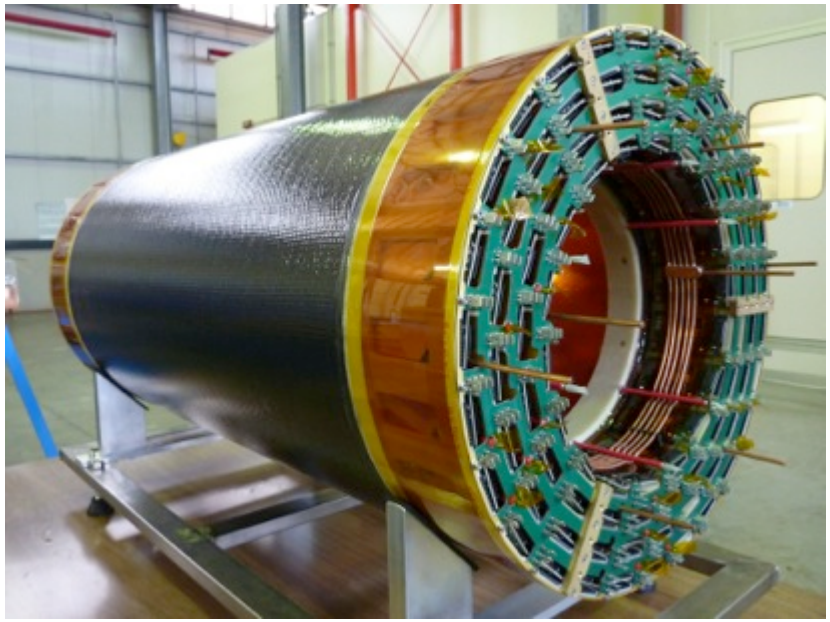
HV distribution system: 7 channels from PS splitted in **120** channels

Gas mixture: Ar:iC$_4$H$_{10}$ 90:10
e$^-$/ions pair (3 mm): 10 $\pi^{\pm}$, 100 K$^{\pm}$ (at DAΦNE)
Fields: **1/1.5/1.5/5 kV/cm**
GEM voltages: **295/285/280 V**
Gain: **O(10^4)**

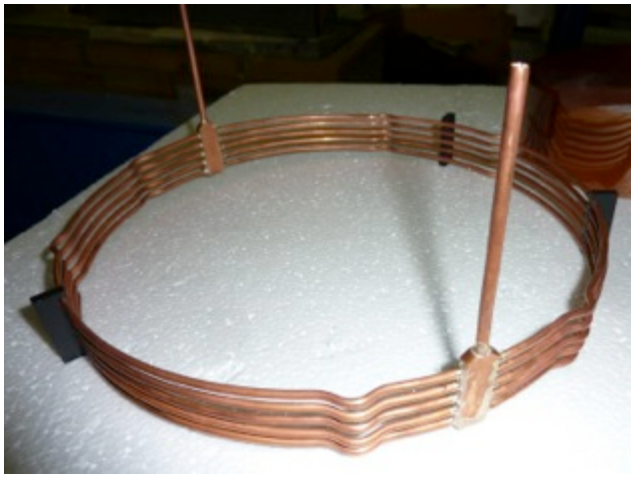
IT final assembly



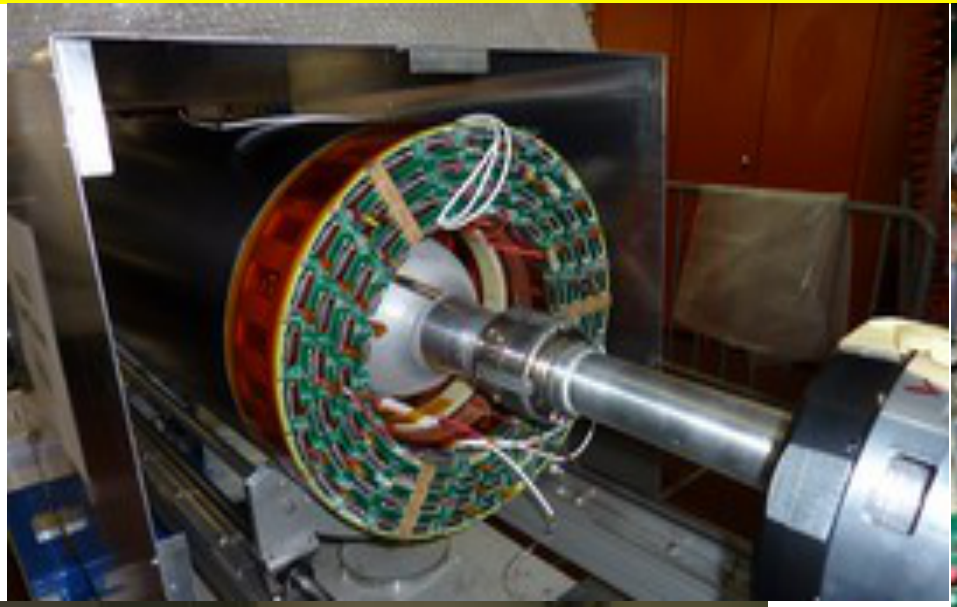


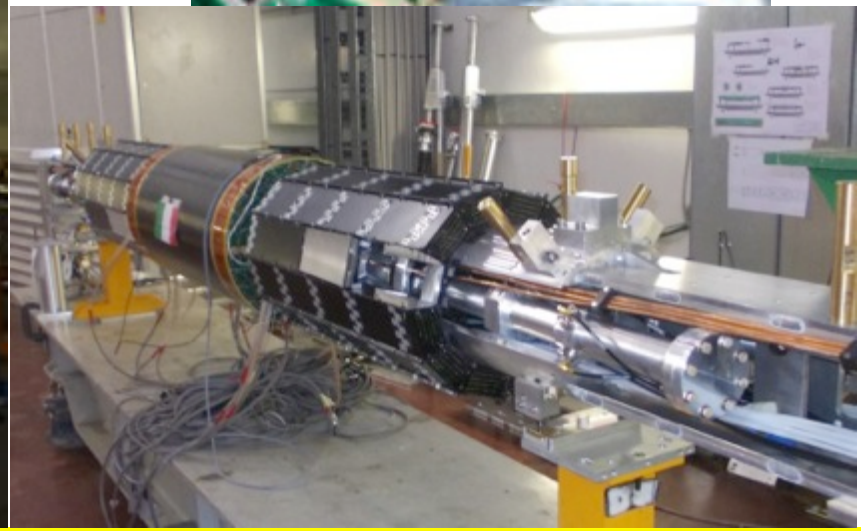


The final assembly of the KLOE-2 Inner Tracker, with the insertion of all the triple-CGEMs one into the other took place in March 2013



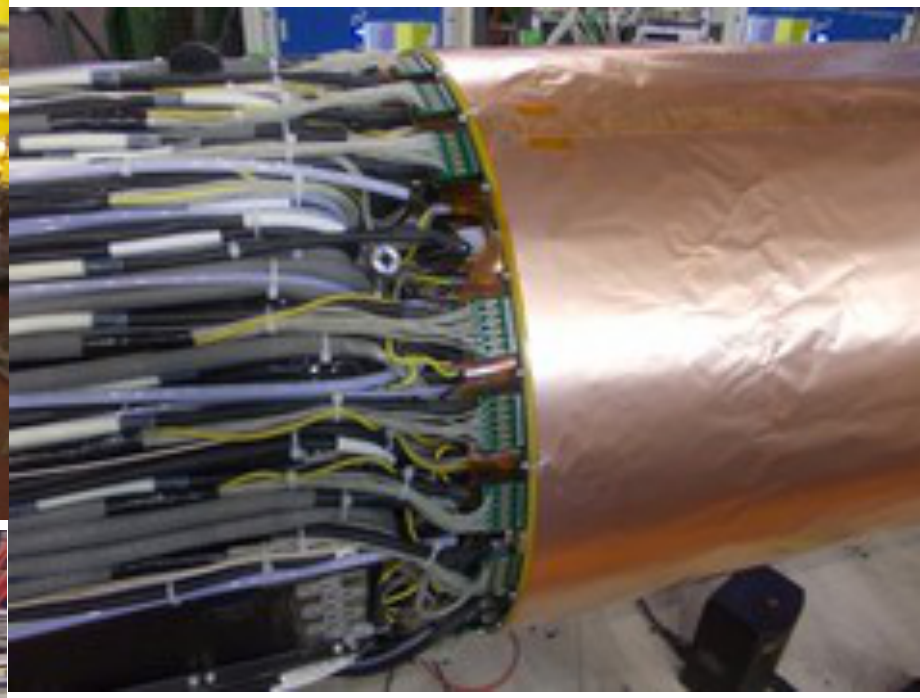
IT integration: insertion on the BP

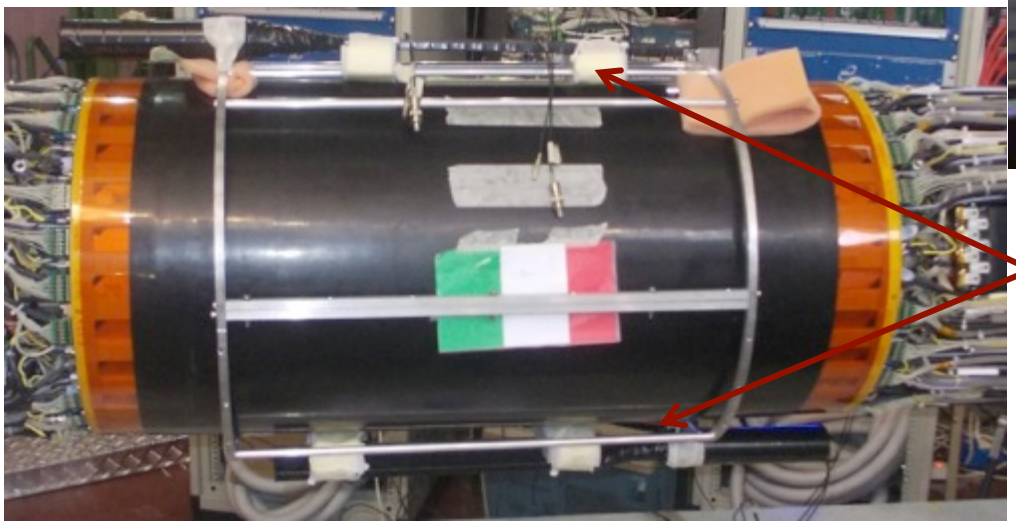




IT integration

Faraday cage completed with a **18 µm** shield connected to the PCB end caps





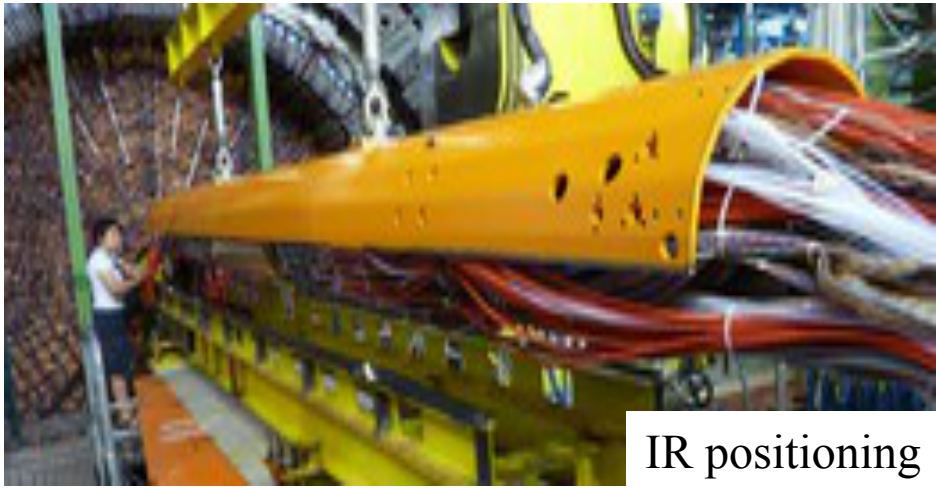
Scintillators for cosmic-ray trigger mounted on a cylindrical rotating support for acquisition on different sectors of the Inner Tracker

IT integration

Protection shell installation

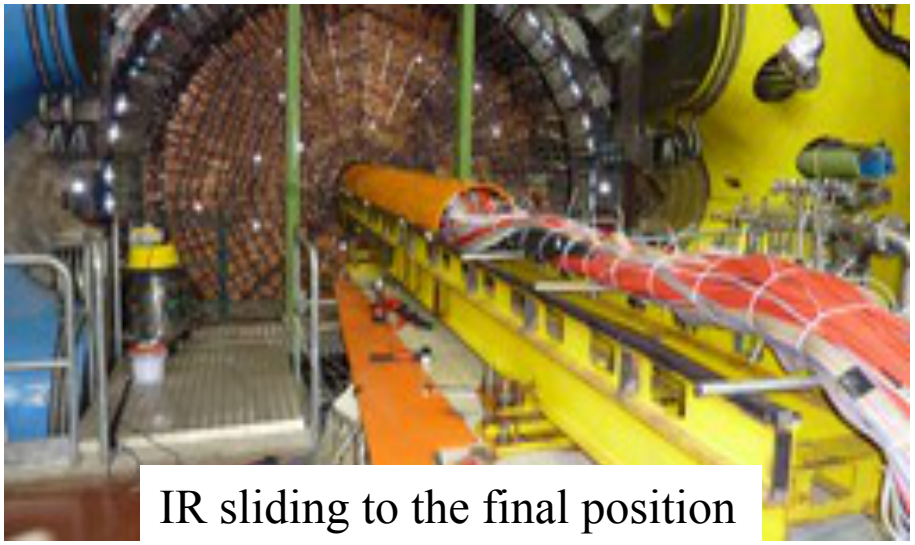
Interaction region movement

Kapton protection on the HV boards

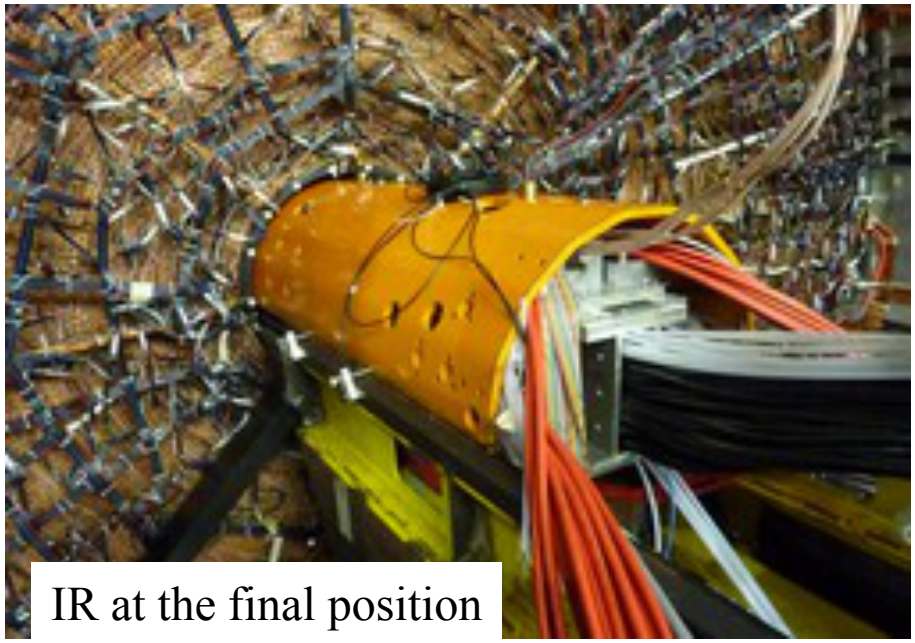


IR positioning

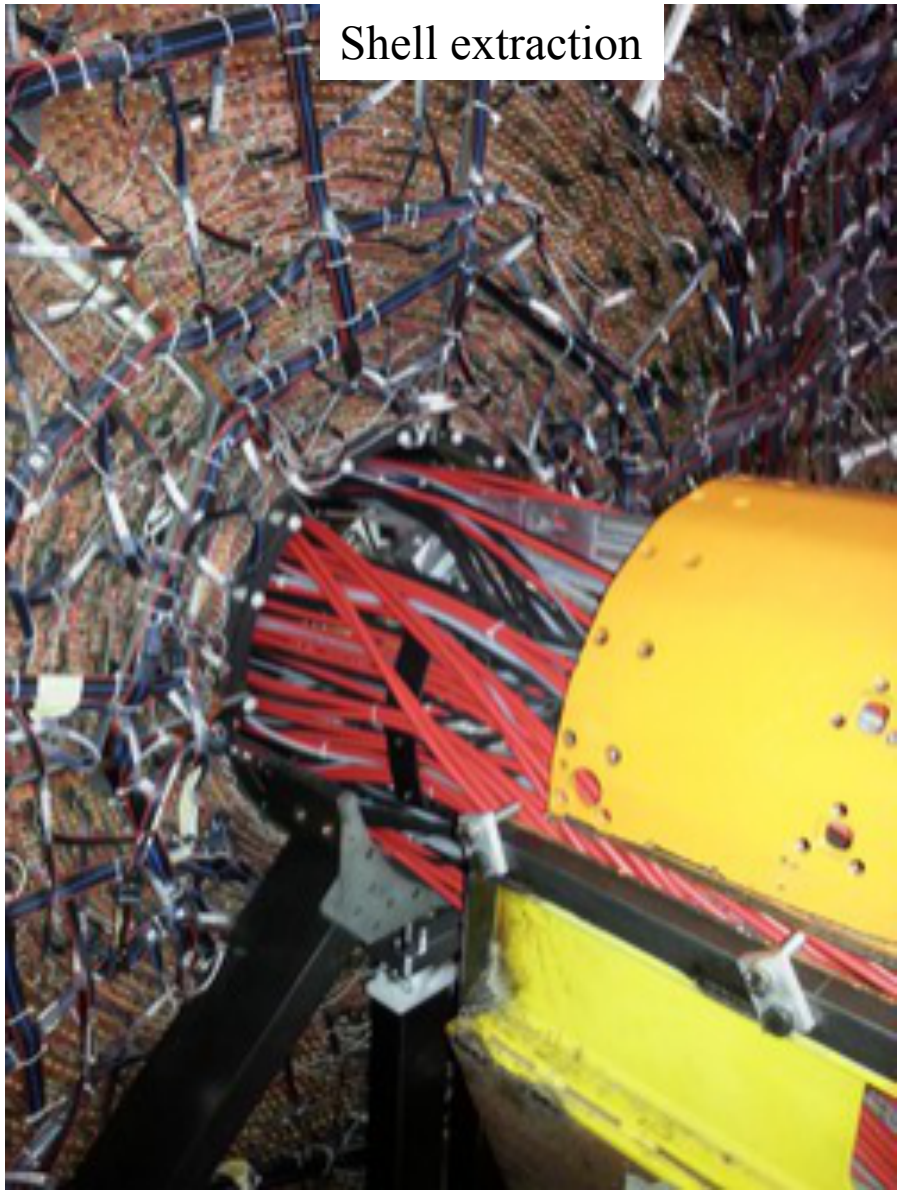
IT integration



IR sliding to the final position

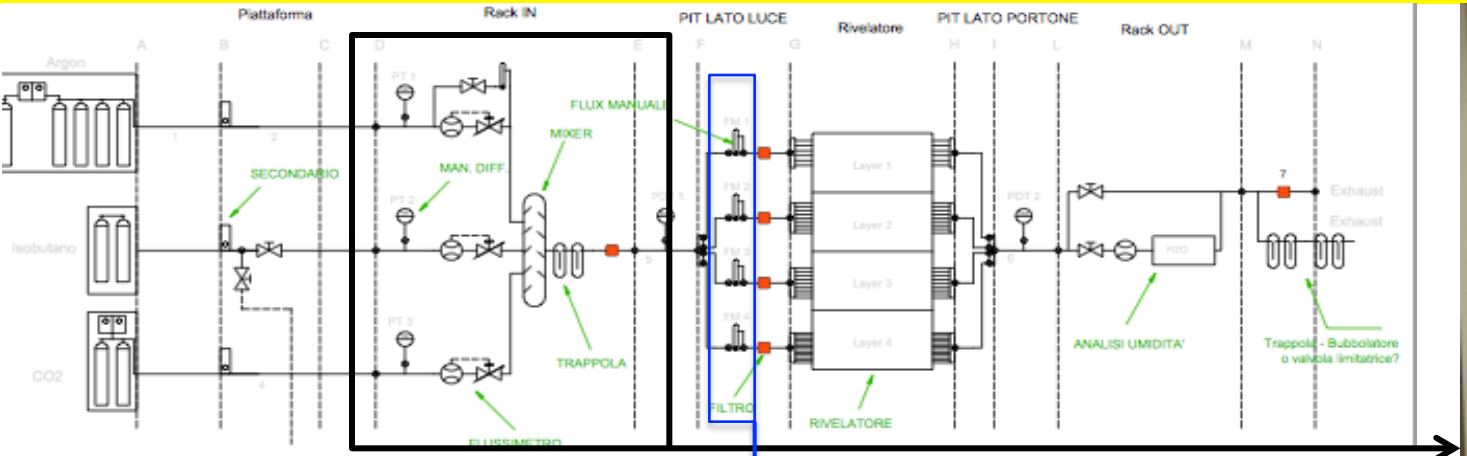


IR at the final position



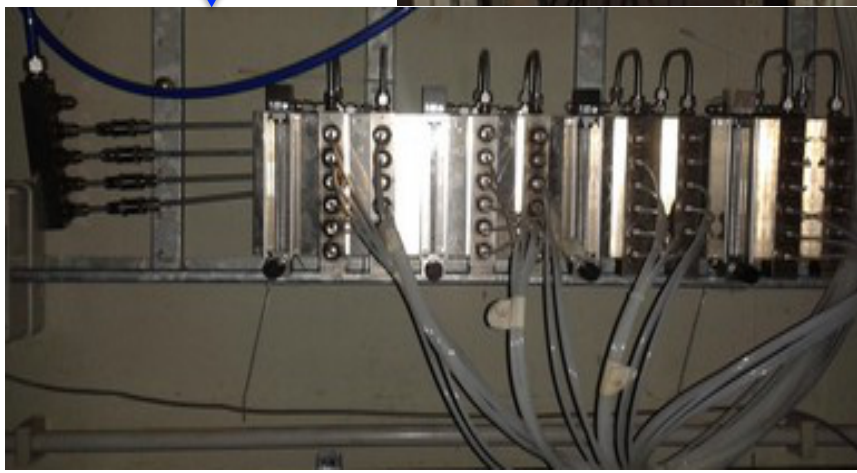
Shell extraction

Inner Tracker gas system

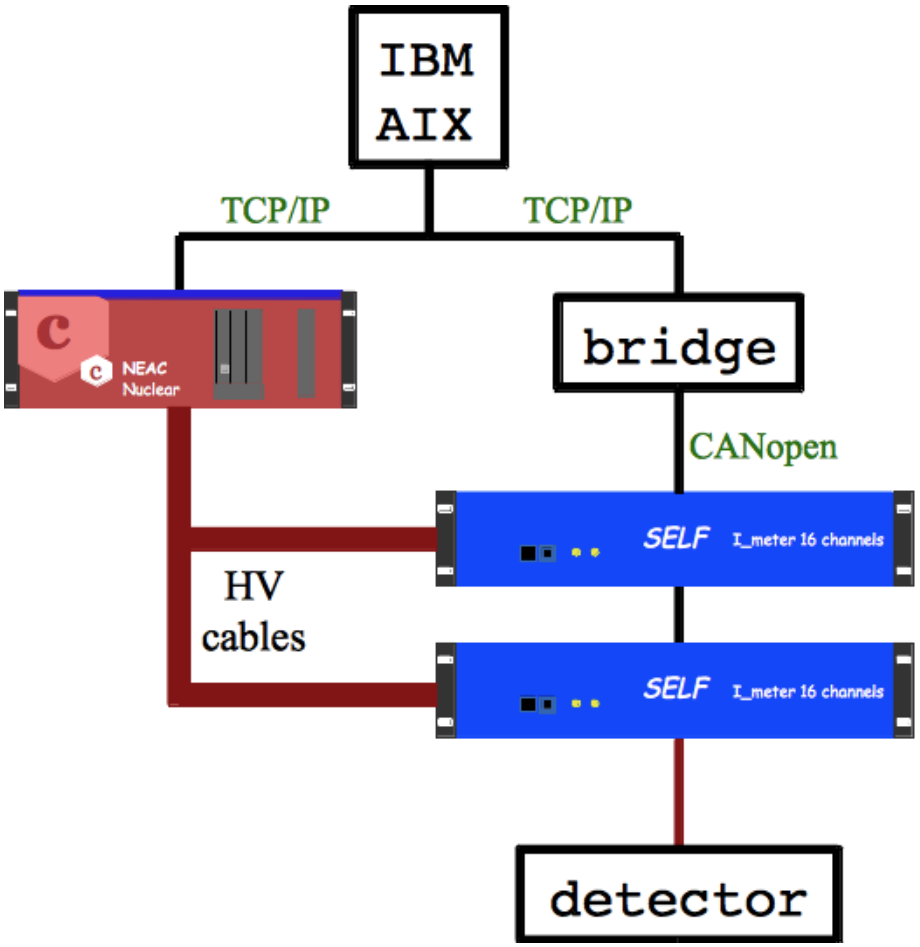


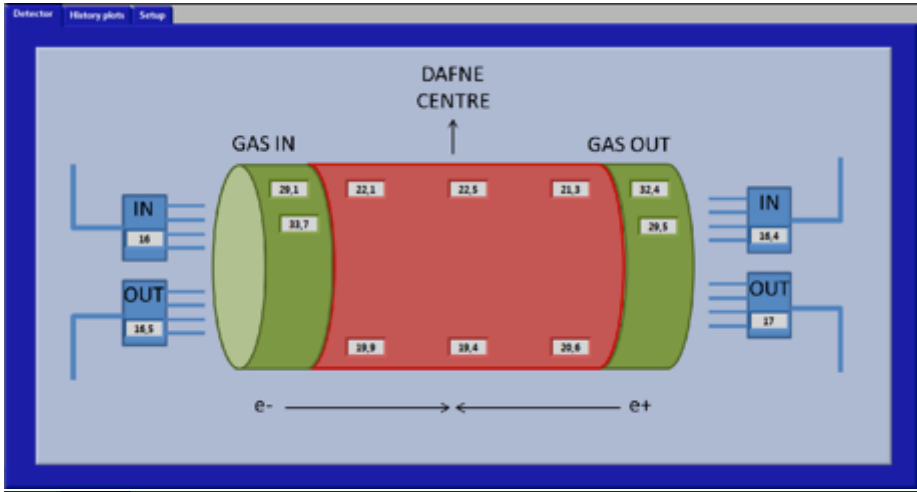
- The IT is flushed at **30 l/h**
- Filters present along the inlets of each layer
- Isobutane sniffer close to the IT to detect gas leakage

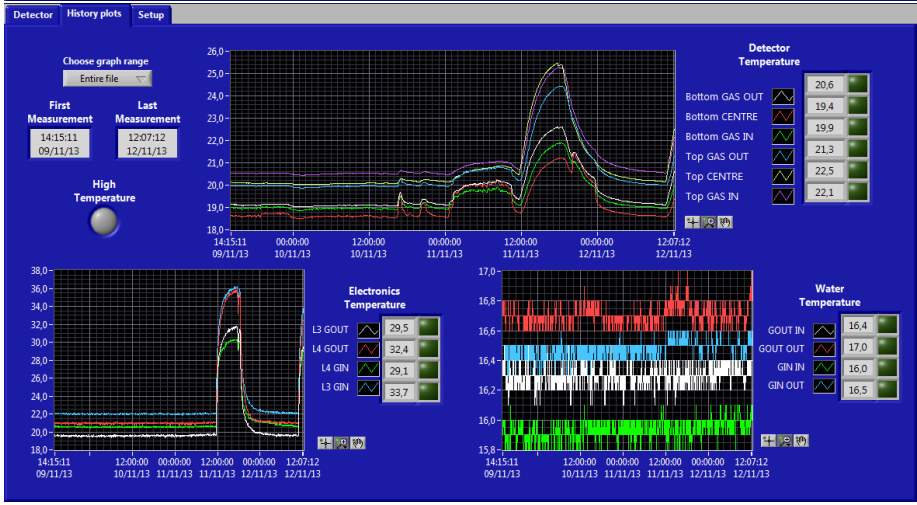
- The flux can be set for each layer and monitor the overpressure of the line
- Gas parameters read on a dedicated PC
- Data transmission to slow control for the implementation of the alarm



HV and temperature slow control







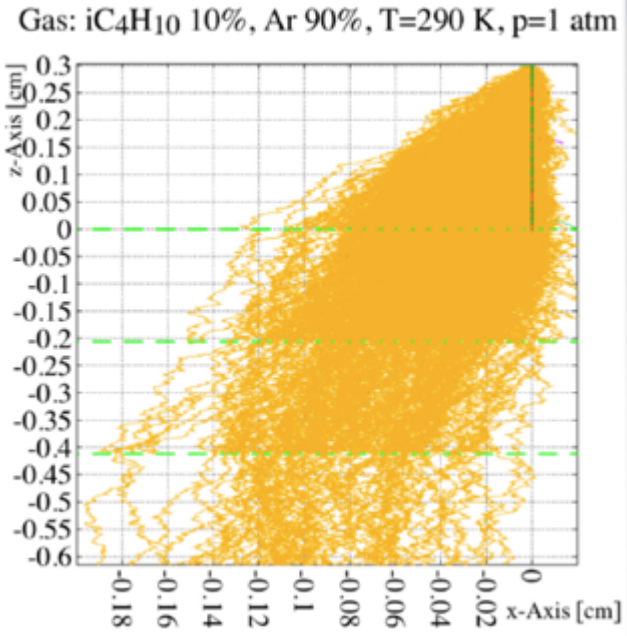
Final HV slow control is being set up
A semi-graphical and a HTML interface are foreseen

- **6 probes** on the innermost surface of the IT
- **4 probes** on the FEE
- **4 probes** on the water cooling circuit for the GASTONE boards

First runs: need for calibration

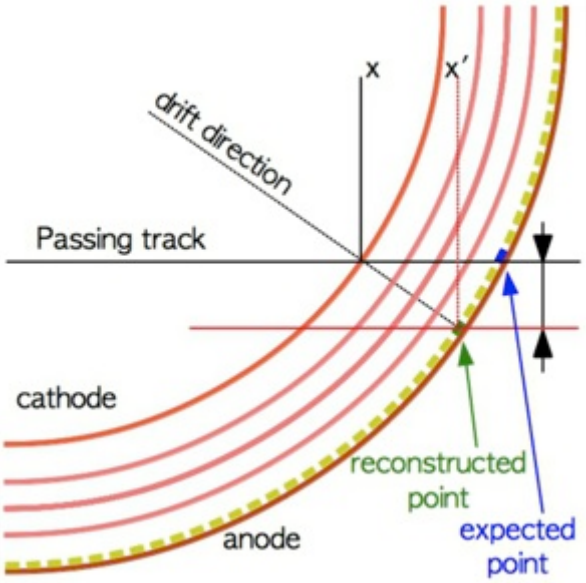
MAGNETIC FIELD

The KLOE-2 magnetic field is orthogonal to the electric fields of the triple-GEMs, introducing two systematic effects: a **shift** $\Delta x(\alpha_L)$ and consequently a **larger spread of the electron cloud.**



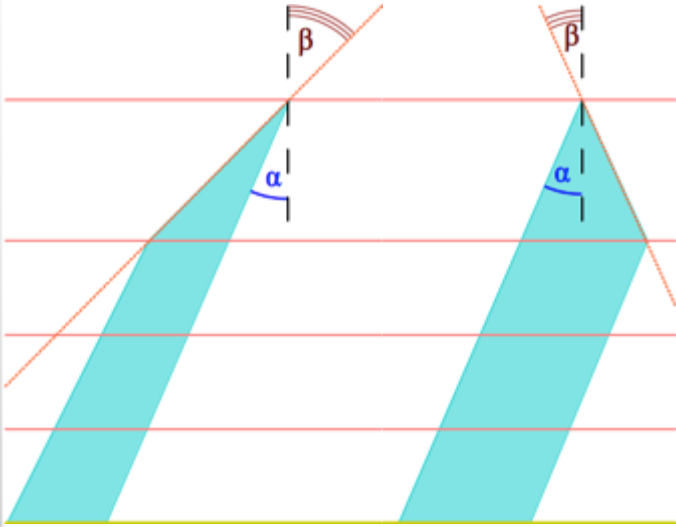
NON-RADIAL TRACKS

The angle formed by a track and the orthogonal to the cathode influences the reconstruction.



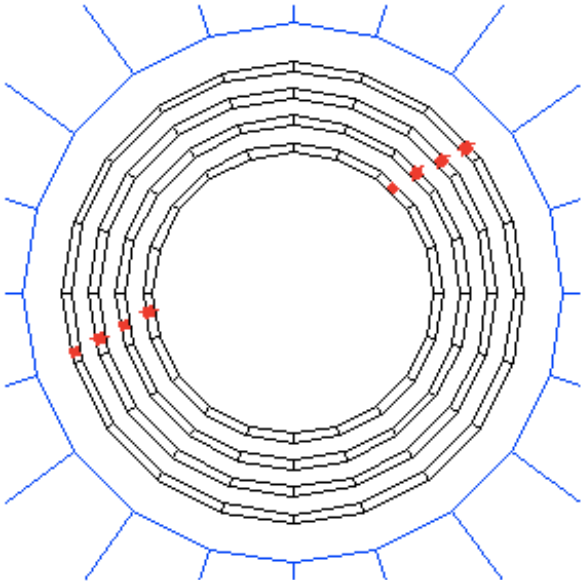
COMBINED EFFECTS

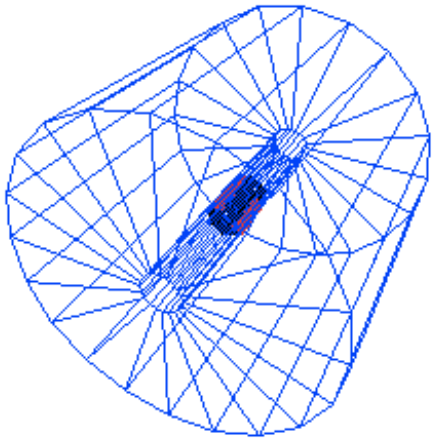
The total contribution of the two effects is simplified in the picture: the electrons are focused or defocused if the angles α_L and β have the same sign



Dedicated runs are scheduled with cosmic-ray muons, w/wo B field and Bhabha scattering events to separately evaluate the two effects

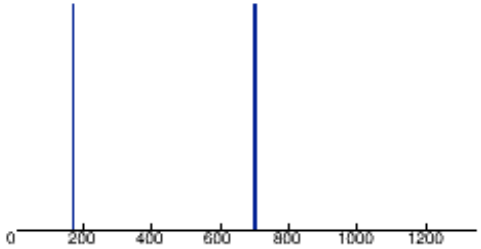
Raw hits from early KLOE-2 runs



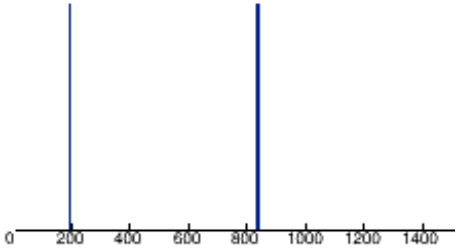


Root-based event display beta version.
Cosmic-ray run, B field on.

X-view Layer 1

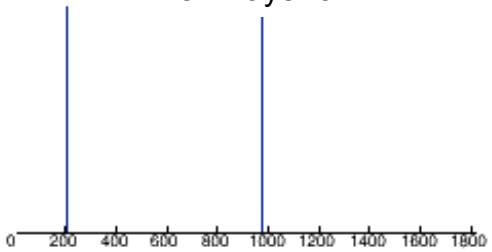


X-view Layer 2

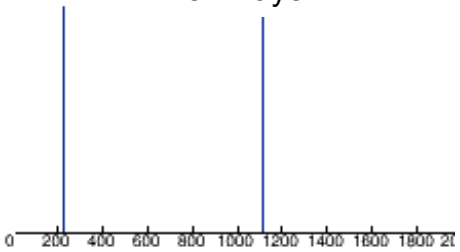


X-view occupancies per event, for each layer.

X-view Layer 3

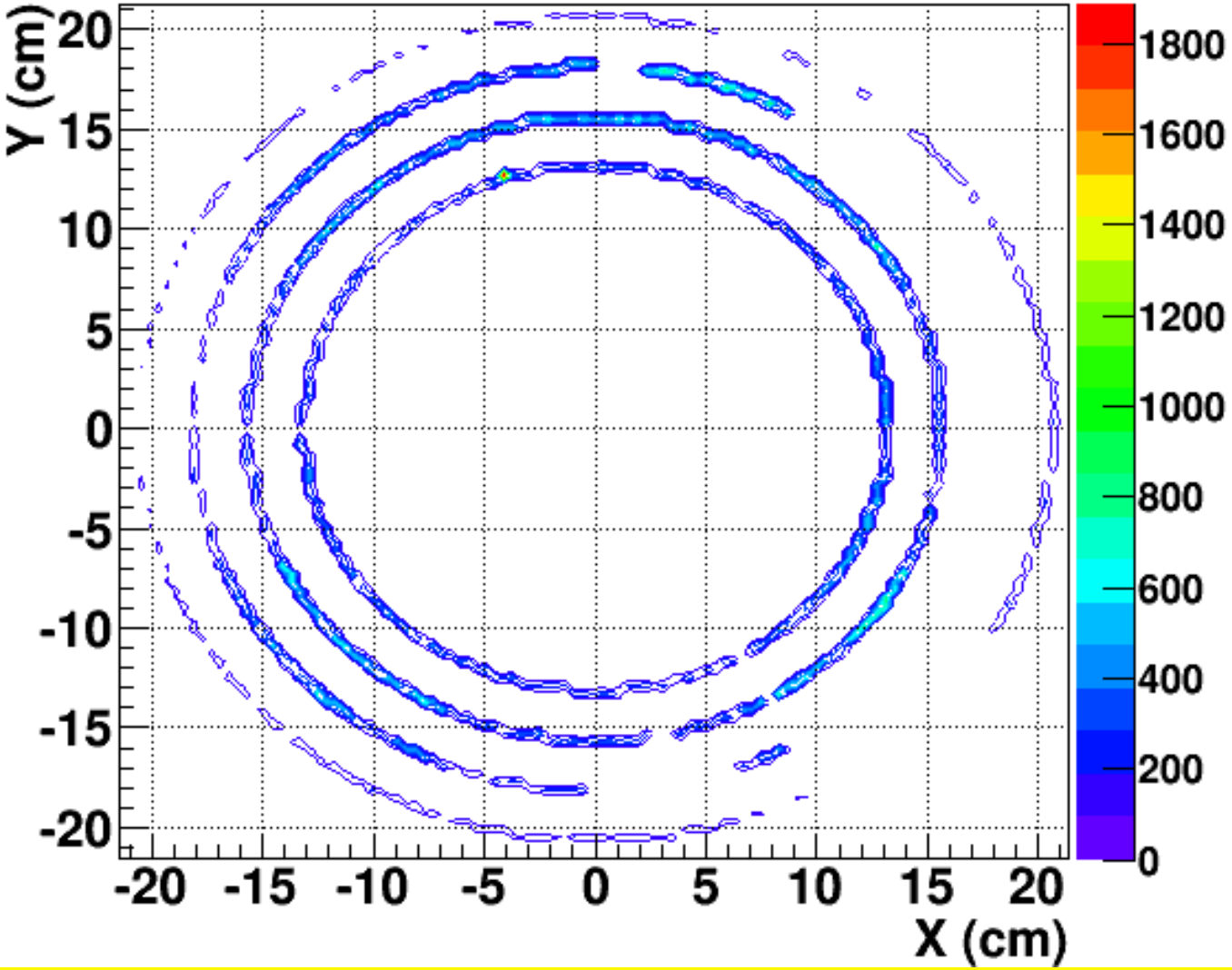


X-view Layer 4



Strips clusters from early KLOE-2 runs

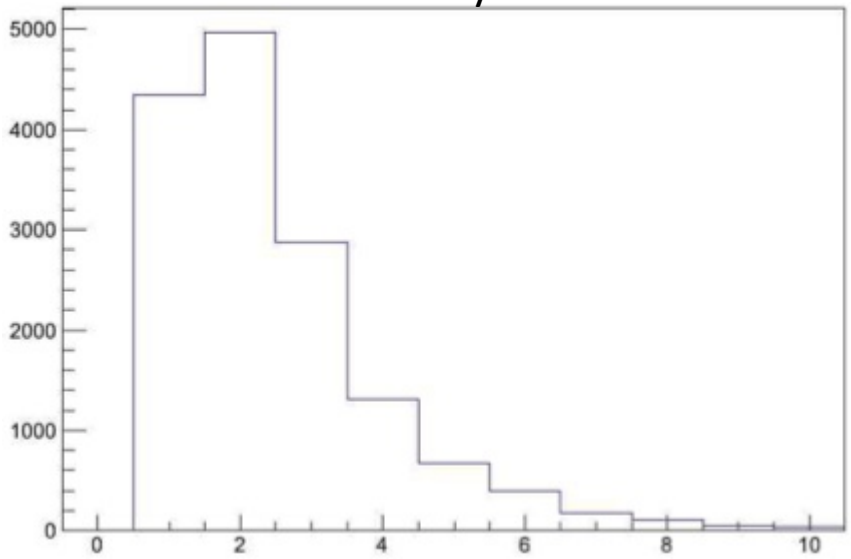
Raw hits are grouped in clusters and then processed using a Kalman filter to reconstruct tracks.



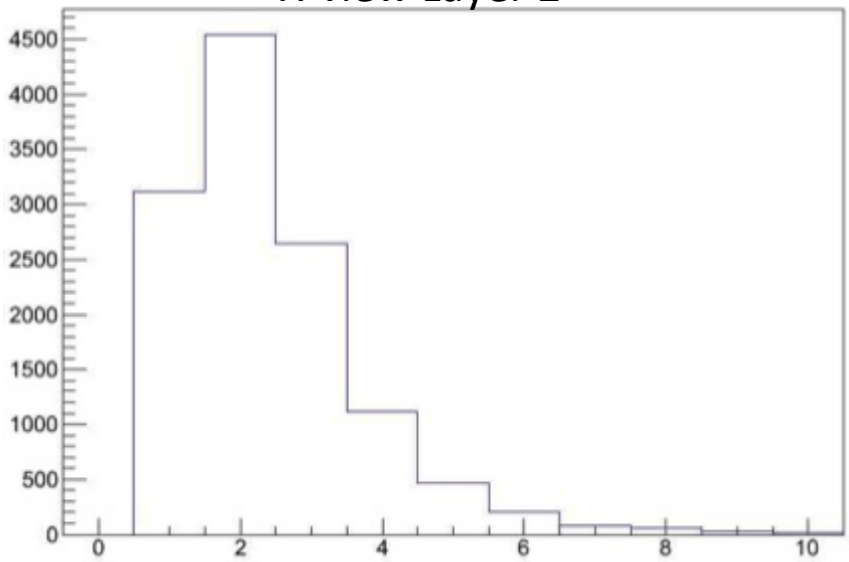
Layer 4 at lower gain with respect to lother layers and layer 3 with some HV sectors off. Gain optimization in progress.

Strips clusters from early KLOE-2 runs

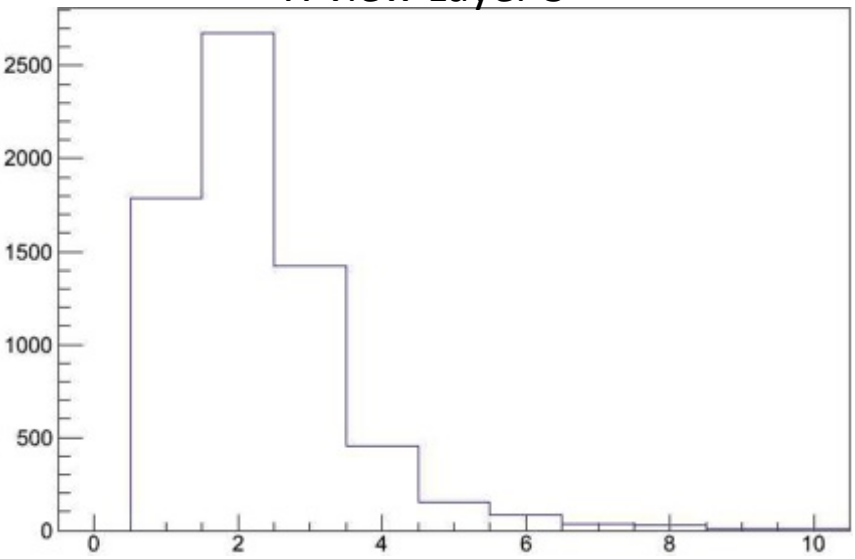
X-view Layer 1



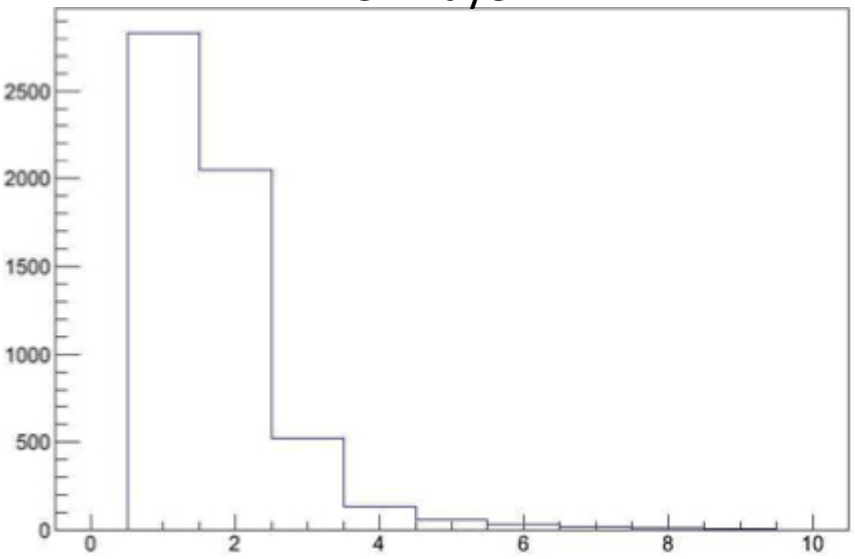
X-view Layer 2



X-view Layer 3

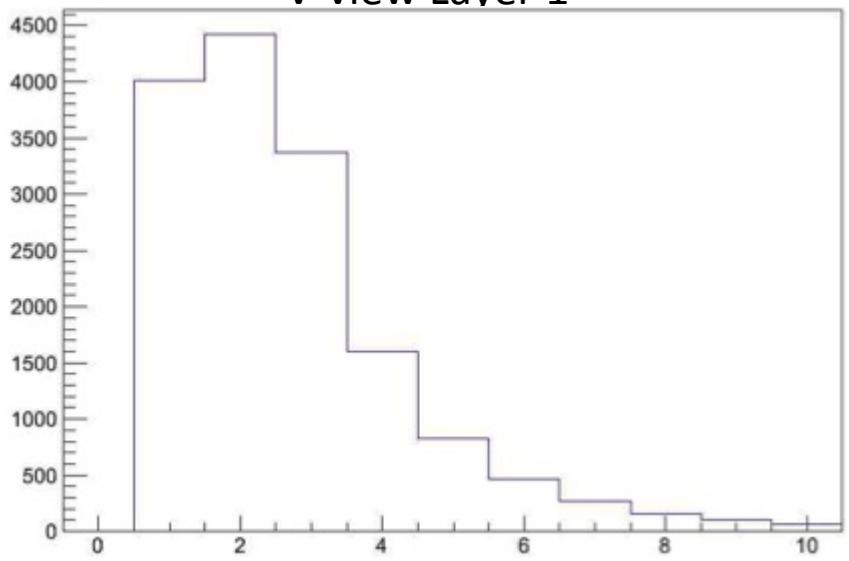


X-view Layer 4

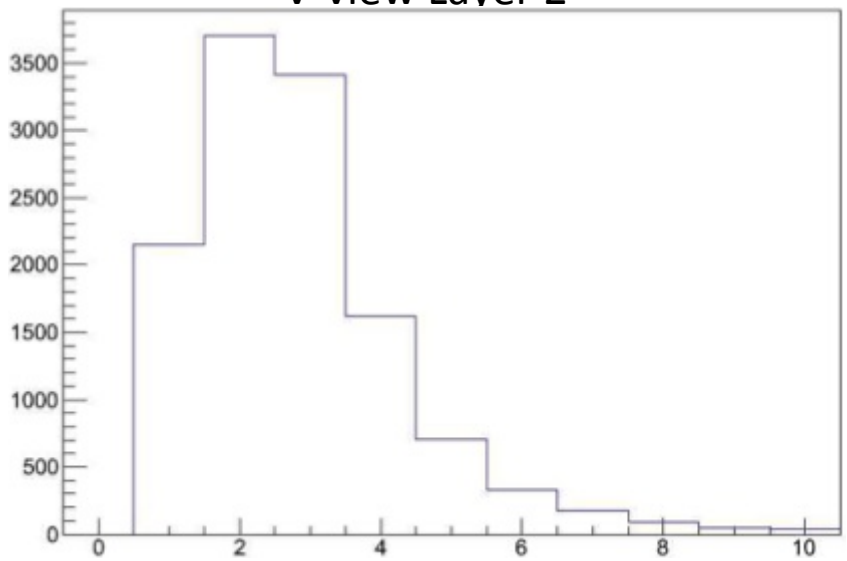


Strips clusters from early KLOE-2 runs

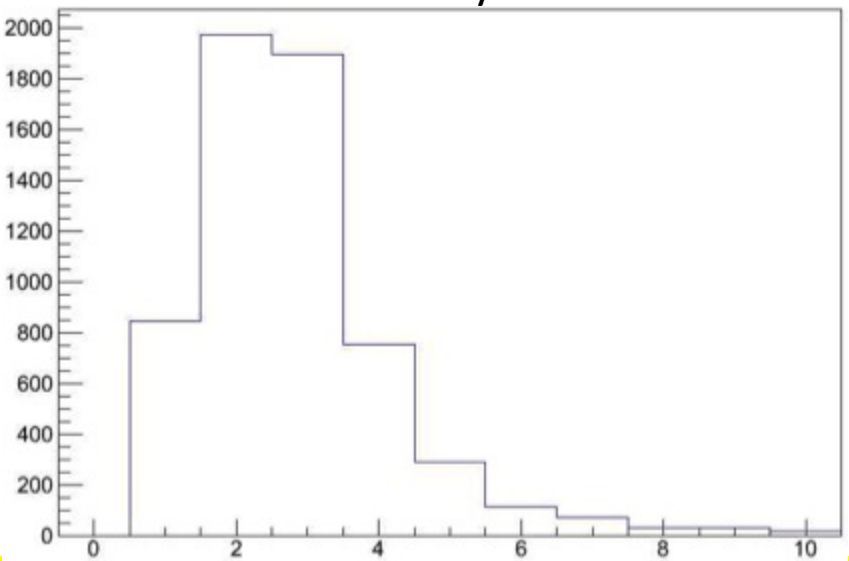
V-view Layer 1



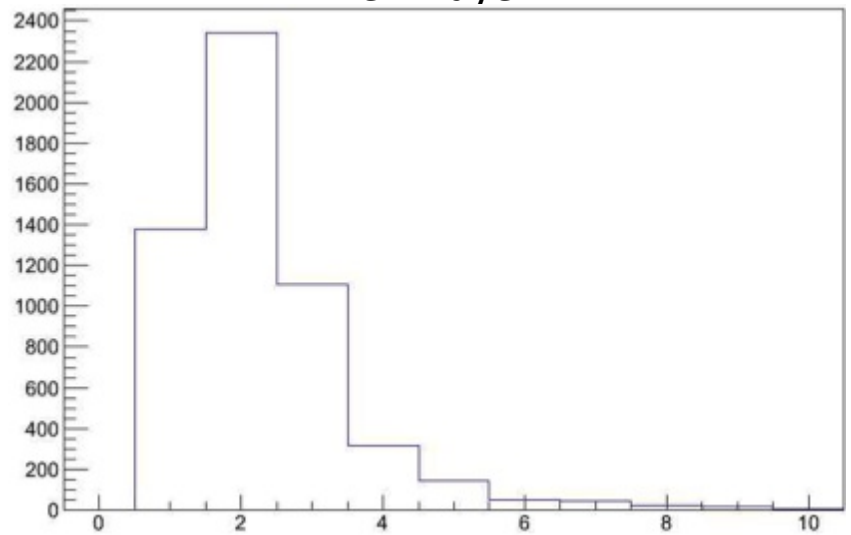
V-view Layer 2



V-view Layer 3

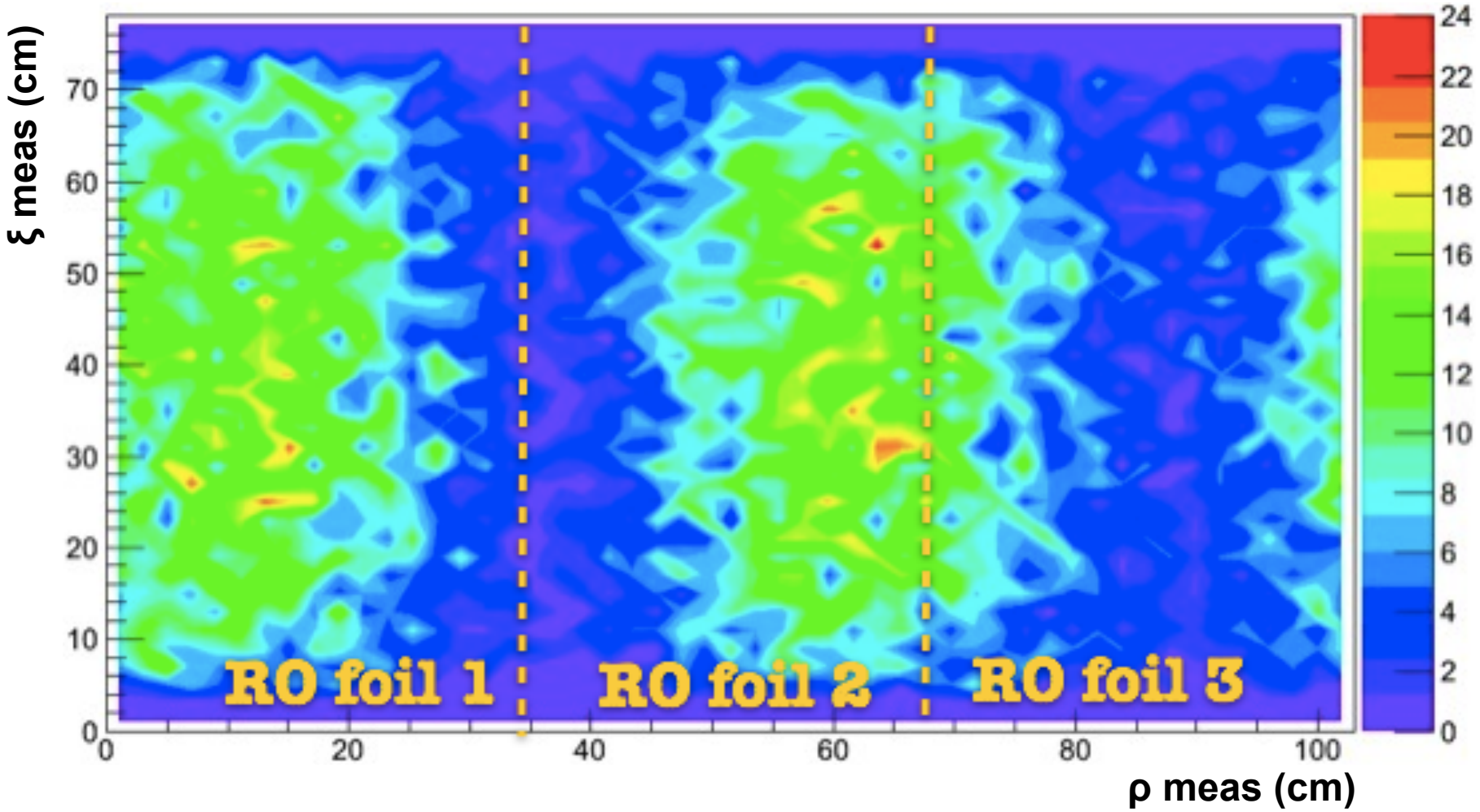


V-view Layer 4



Strips clusters from early KLOE-2 runs

Layer 2: unrolled Read-out reference frame



Summary and outlook

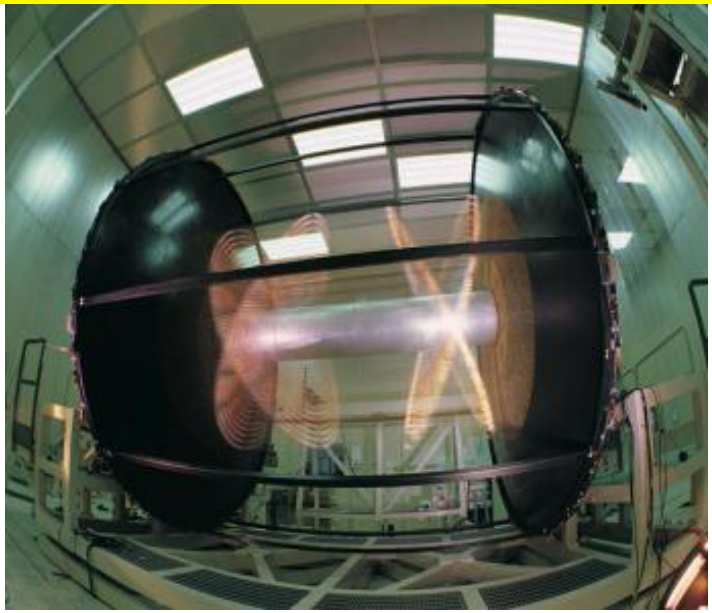
- The Inner Tracker has been completed and installed on DAΦNE

Detector commissioning ongoing

- Optimization of the operating parameters
- Calibration and alignment of the detector using the DC track extrapolation
- Monitoring of useful parameters

Spare slides

KLOE experiment



- Pb-Scintillating Fiber Calorimeter with excellent timing performance:

$$\sigma_t = 54\ ps / \sqrt{E\,(GeV)} \oplus 100\ ps$$

- Energy resolution:

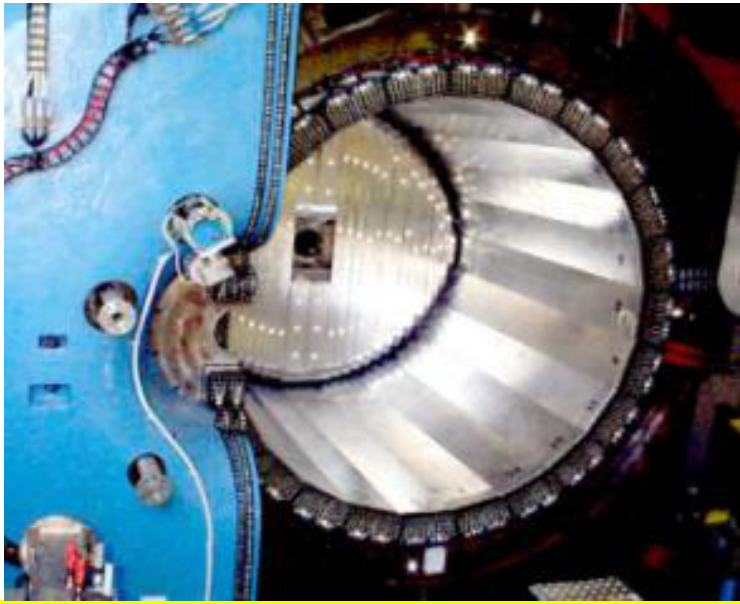
$$\sigma_E / E = 5.7\,\% / \sqrt{E\,(GeV)}$$

- 4 m long, 98% solid angle coverage

- Huge, transparent Drift Chamber in 5.2 kGauss field of a SC coil
- 2 m outer radius, 25 cm inner radius, 4 m long, He/iC_4H_{10} gas mixture, all-stereo geometry
- Momentum resolution: $\sigma(p_T)/p_T \sim 0.4\%$

$$< \vec{p}_K > \simeq 120\ MeV\ ,\ < \vec{p}_\pi > \simeq 200\ MeV$$

- Spatial resolution: $\sigma_{r\varphi} \simeq 150\ \mu m\ ,\ \sigma_z \simeq 2\ mm$

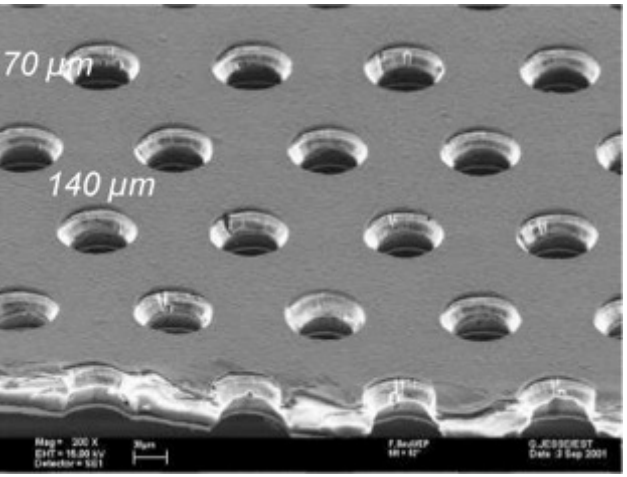


GEM: principle of operation

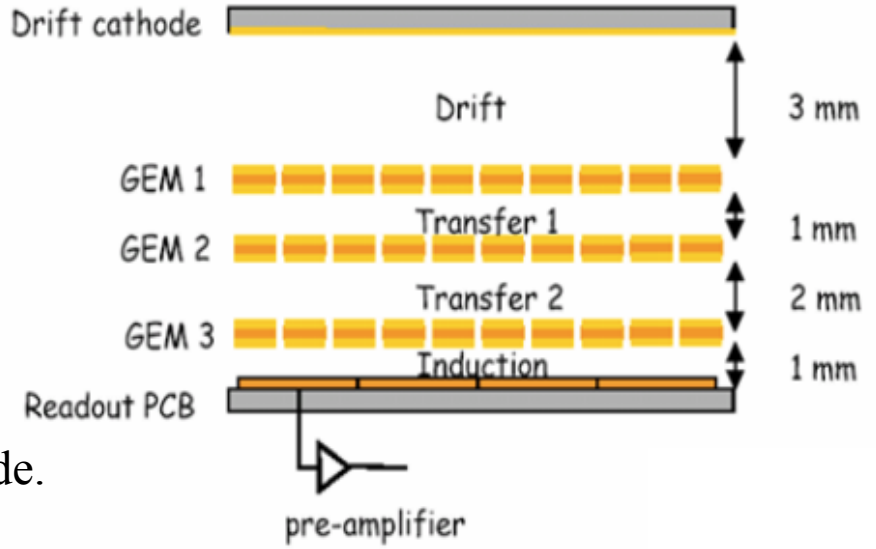
The GEM (Gas Electron Multiplier) [F.Sauli, NIM A386 (1997) 531] is a thin (**50 µm**) metal coated kapton foil, perforated by a high density of holes (**70 µm** diameter, pitch of **140 µm**) standard photo-lithographic technology.

By applying **400-500 V** between the two copper sides, an electric field as high as **~100 kV/cm** is produced into the holes which act as multiplication channels for electrons produced in the gas by a ionizing particle.

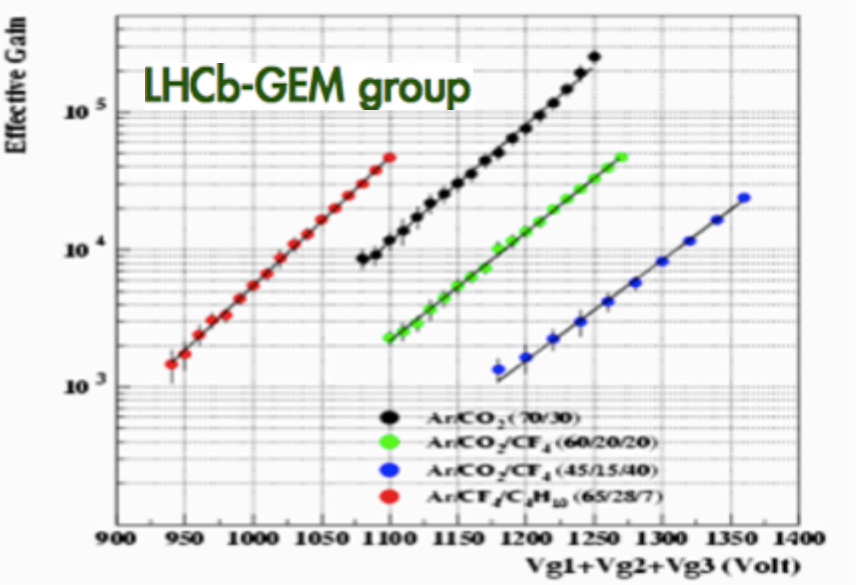
Gains up to 1000 can be easily reached with a single GEM foil. Higher gains (and/or safer working conditions) are usually obtained by cascading two or three GEM foils.

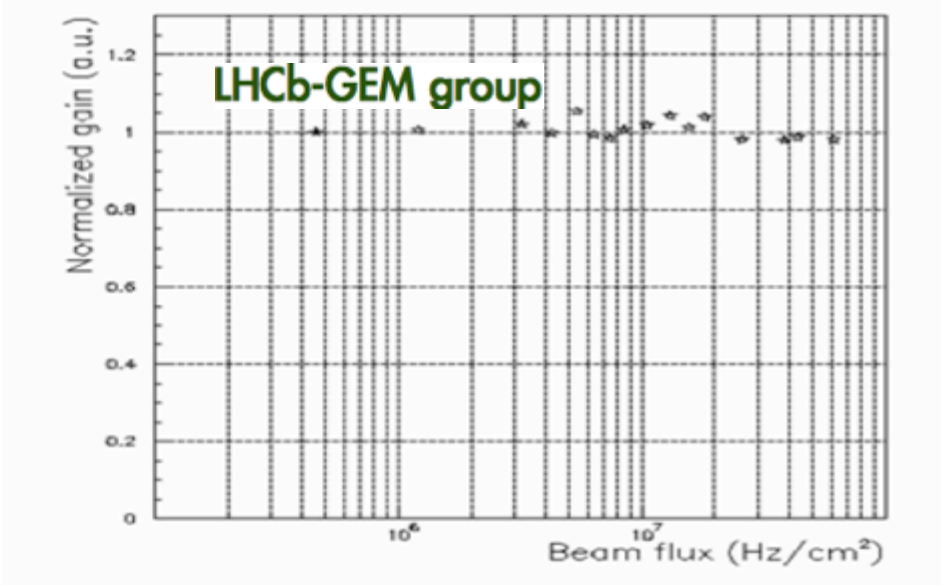


A Triple-GEM detector is built by inserting three GEM foils between two planar electrodes, which act as the cathode and the anode.



GEM: principle of operation





- flexible geometry, arbitrary detector shape: rectangular/square, annular, cylindrical …
- ultra-light structure, very low material budget: **~3‰ X_0**/detector
- gas multiplication separated from readout stage, arbitrary readout pattern: pad, strips (XY, UV), mixed …
- high rate capability: **> 50 MHz/cm^2**
- Safe high gains: **> 10^4**
- high reliability: discharge free; P_d **< 10^{-12}** per incoming particle
- rad. hard.: up to **2.2 C/cm^2** integrated over the whole active area without permanent damages (corresponding to 10 years of operation at LHCb)
- high spatial resolution: down to **70 µm** (with analog readout) (COMPASS)
- good time resolution: down to **3 ns** (with CF4) (LHCb)

DAQ system

DETECTOR

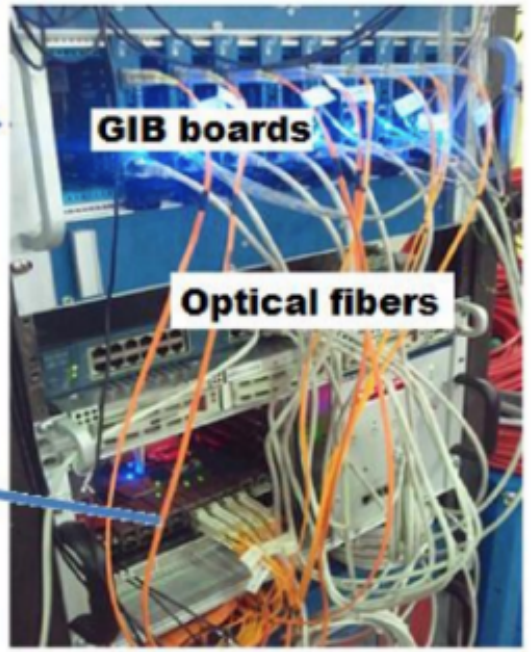
Data from the detector are collected using the front-end **Gastone boards** interconnected to the **GIB Boards**.

16 links running at 2 Gbit/s

VME -64X Interface

VME Processor

FARM ONLINE System

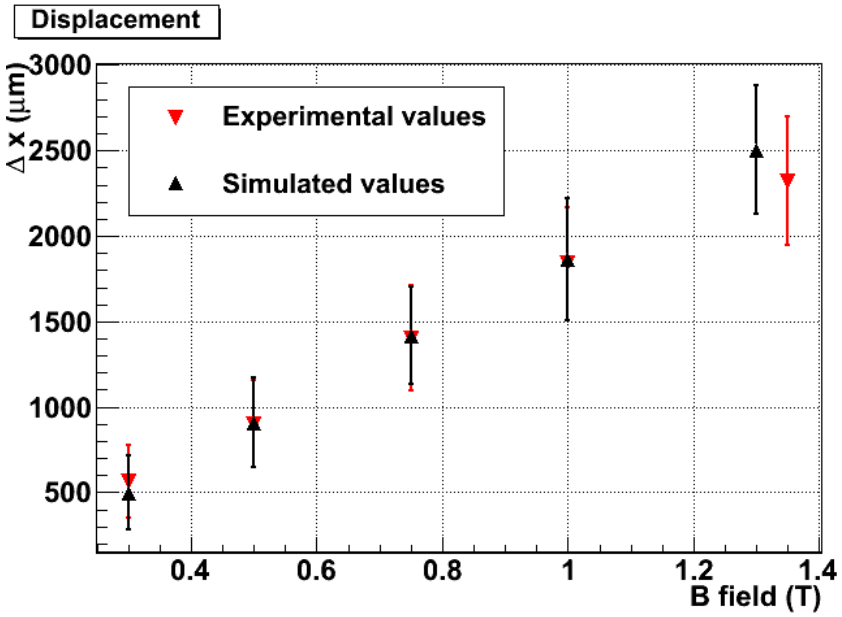


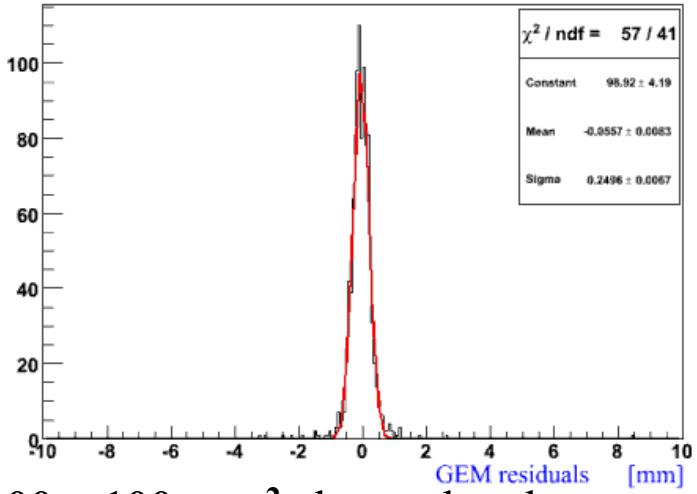
The data are then delivered to the **ROD** using **Optical fiber**s connection. A **VME CPU** board collects data from the ROD and sends them to the Farm on-line system through TCP/IP

Finally, the data are written to the storage disks.

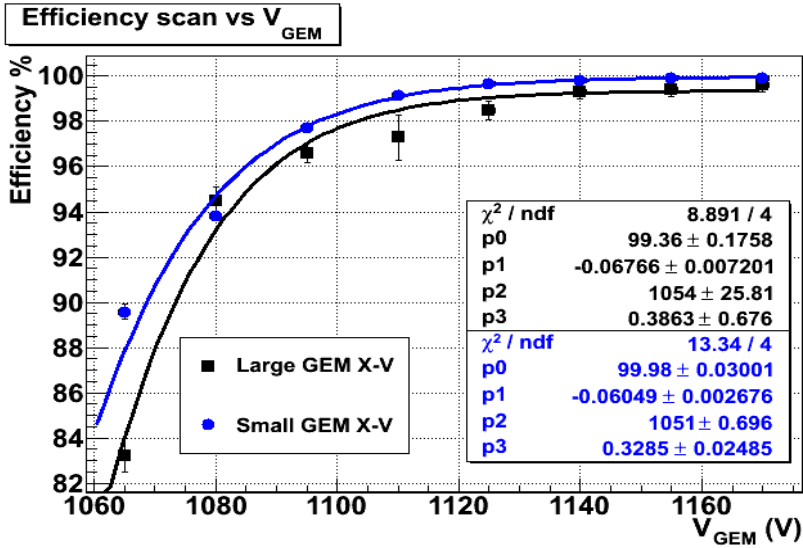
The R&D of the Inner Tracker

Construction and characterization of a CGEM prototype (test beam 2008) built using 3 GEM foils (**354 x 330 mm²**) spliced together. Axial strips (single view).





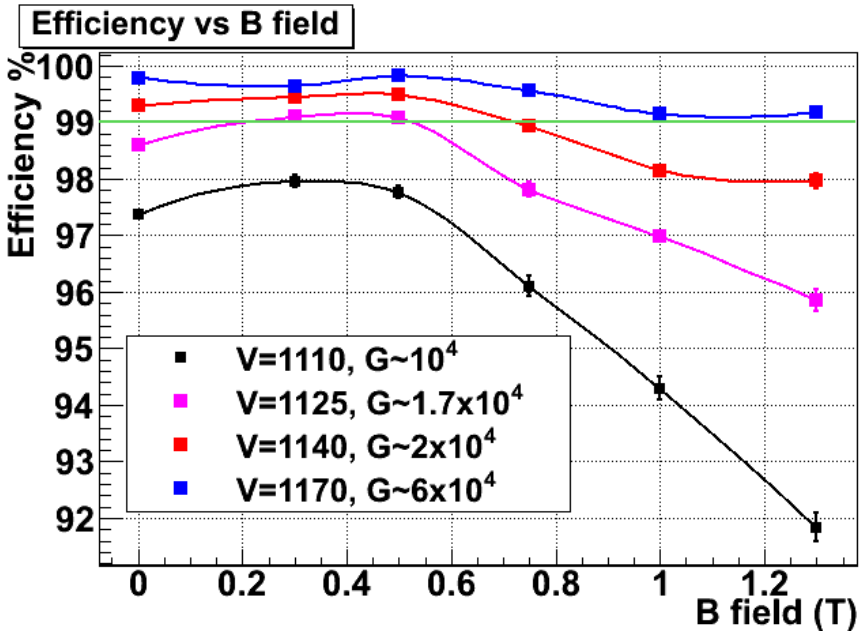
Construction of **100 x 100 mm²** planar chambers equipped with new concept for X-V readout and study of their behaviour in magnetic field.

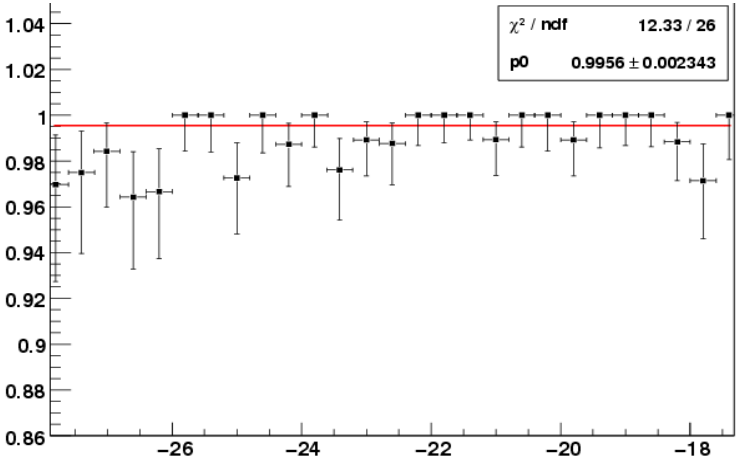


Construction and characterization of two large planar chambers with the new single-mask photolitographic technique equipped with final X-V readout (test beam 2010).

The R&D of the Inner Tracker

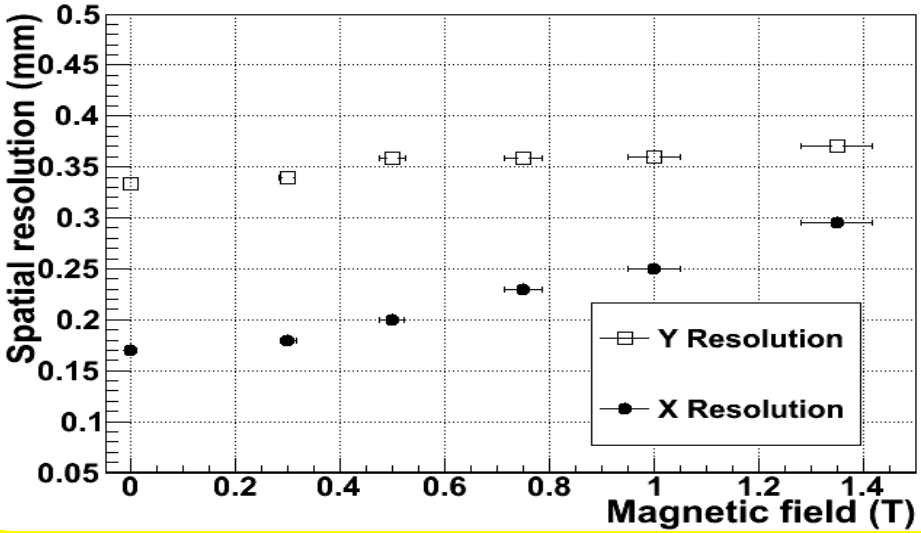
Construction and characterization of a CGEM prototype (test beam 2008) built using 3 GEM foils (**354 x 330 mm^2**) spliced together. Axial strips (single view).



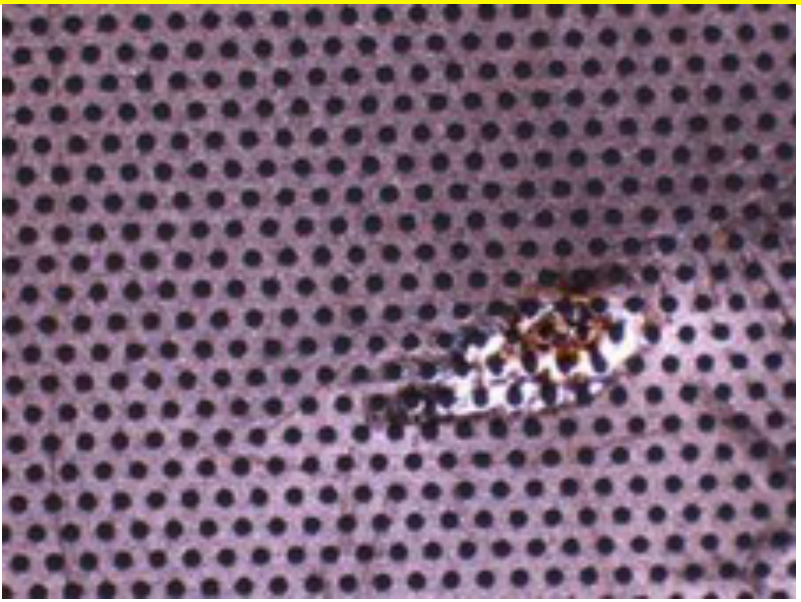


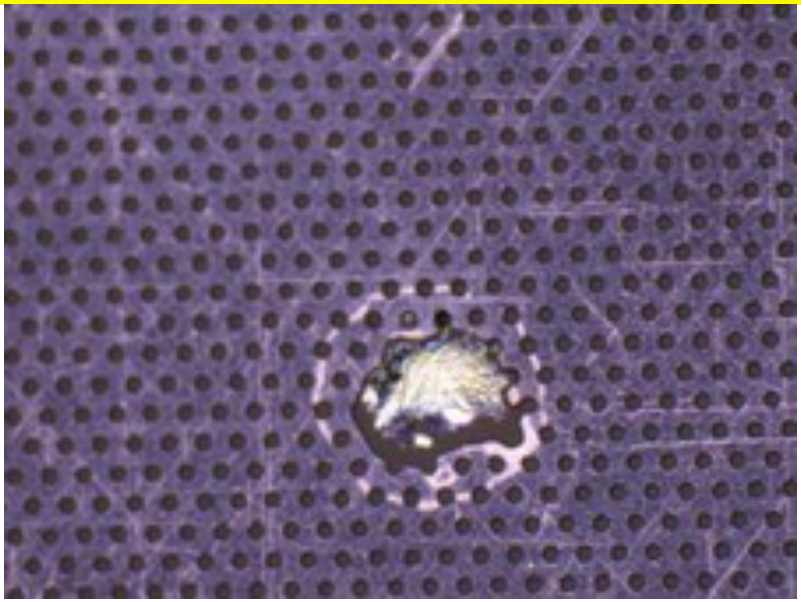
Construction of **100 x 100 mm^2** planar chambers equipped with new concept for X-V readout and study of their behaviour in magnetic field.

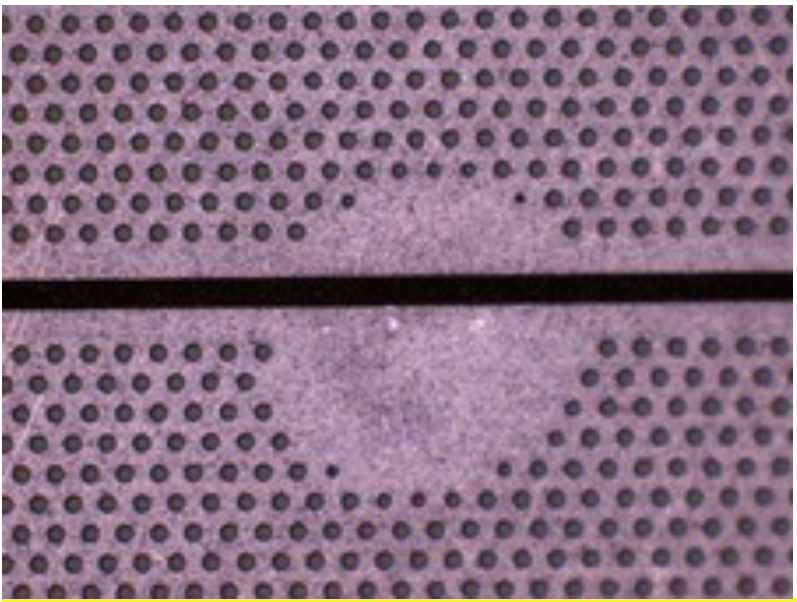
Construction and characterization of two large planar chambers with the new single-mask photolitographic technique equipped with final X-V readout (test beam 2010).

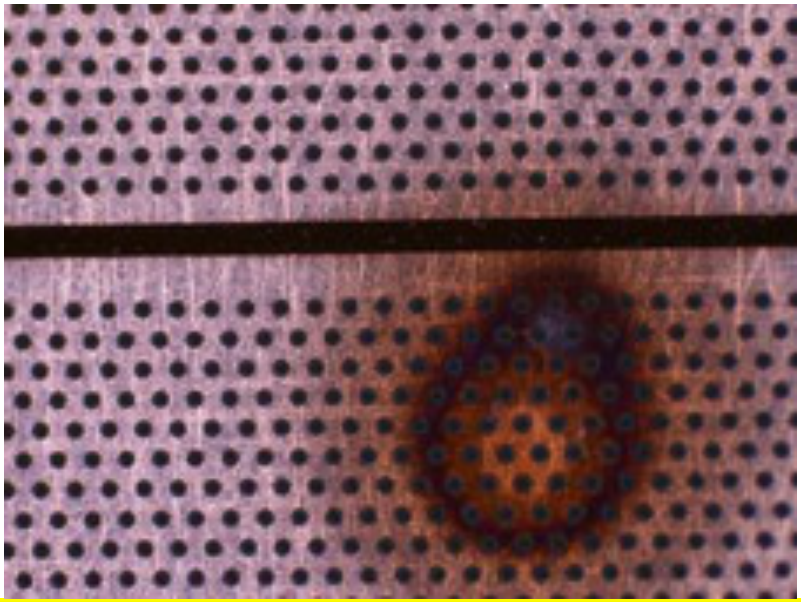


Quality check details





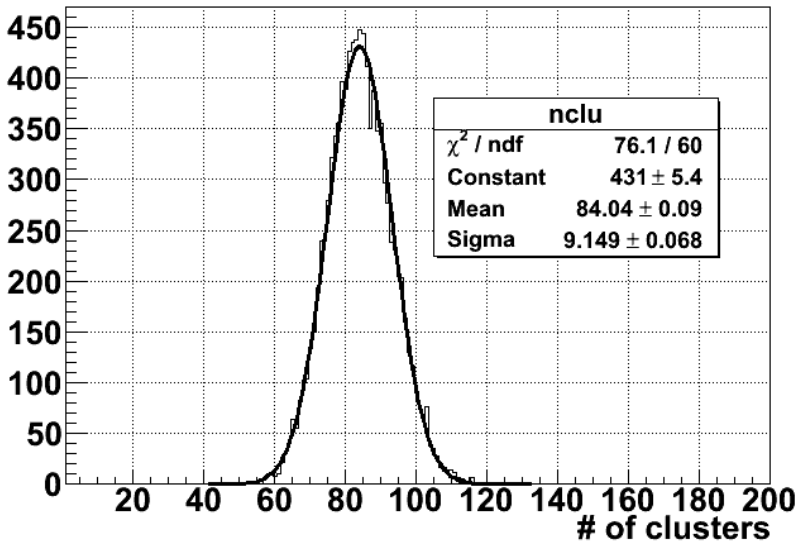




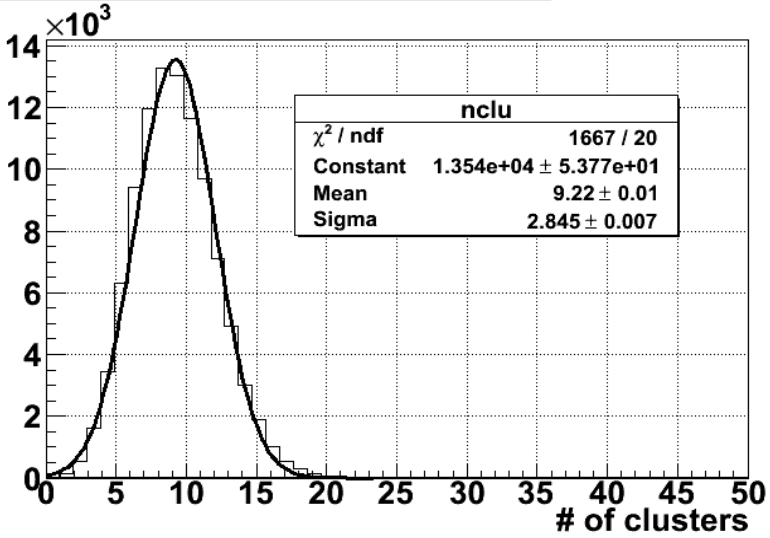
9 GEM foils bad: over-etching with discharges, leakage currents, roughly defined sectors
3 foils with high resistance on HV vias connections

GARFIELD Simulations

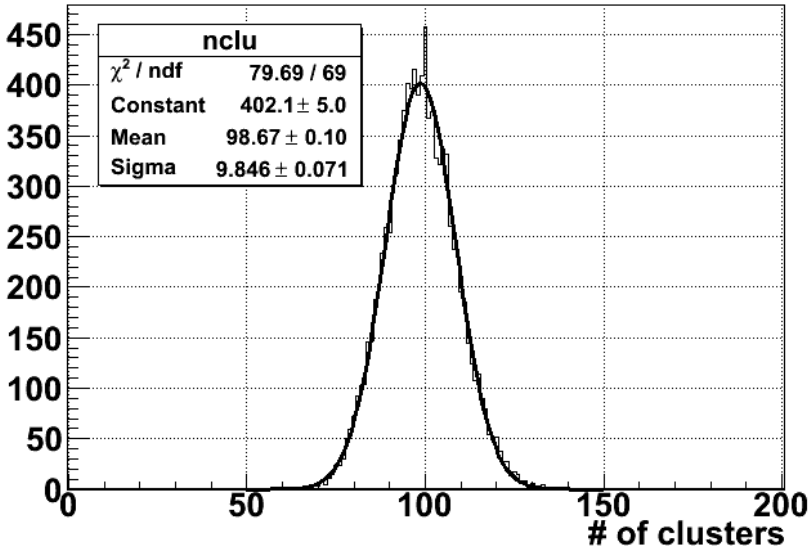
Ionization in 3 mm of $Ar:CO_2$ 70:30, $\beta\gamma$=0.26



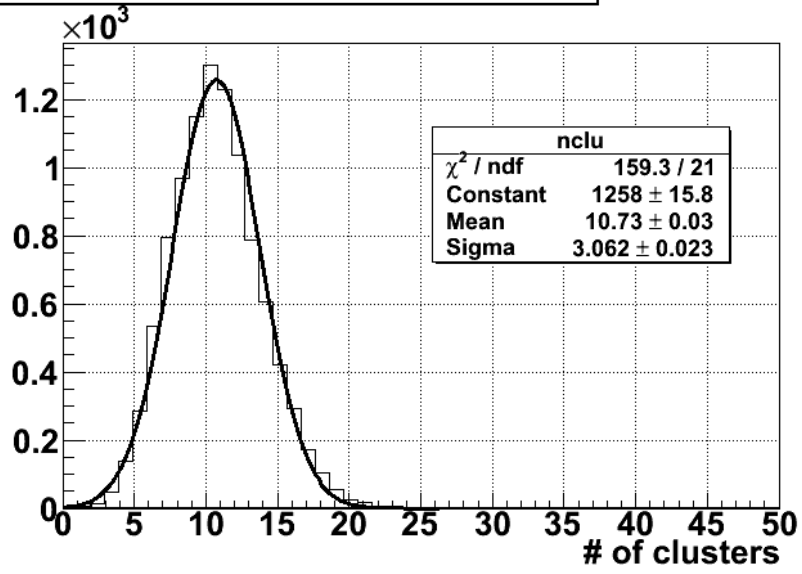
Ionization in 3 mm of $Ar:CO_2$ 70:30, $\beta\gamma$=2.21



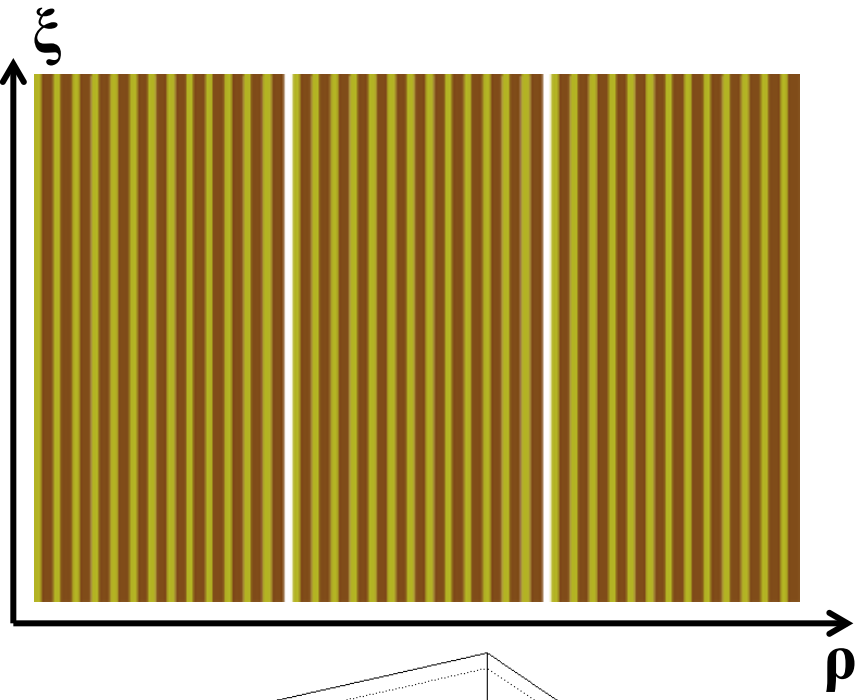
Ionization in 3 mm $Ar:isoC_4H_{10}$ 90:10, $\beta\gamma$=0.26

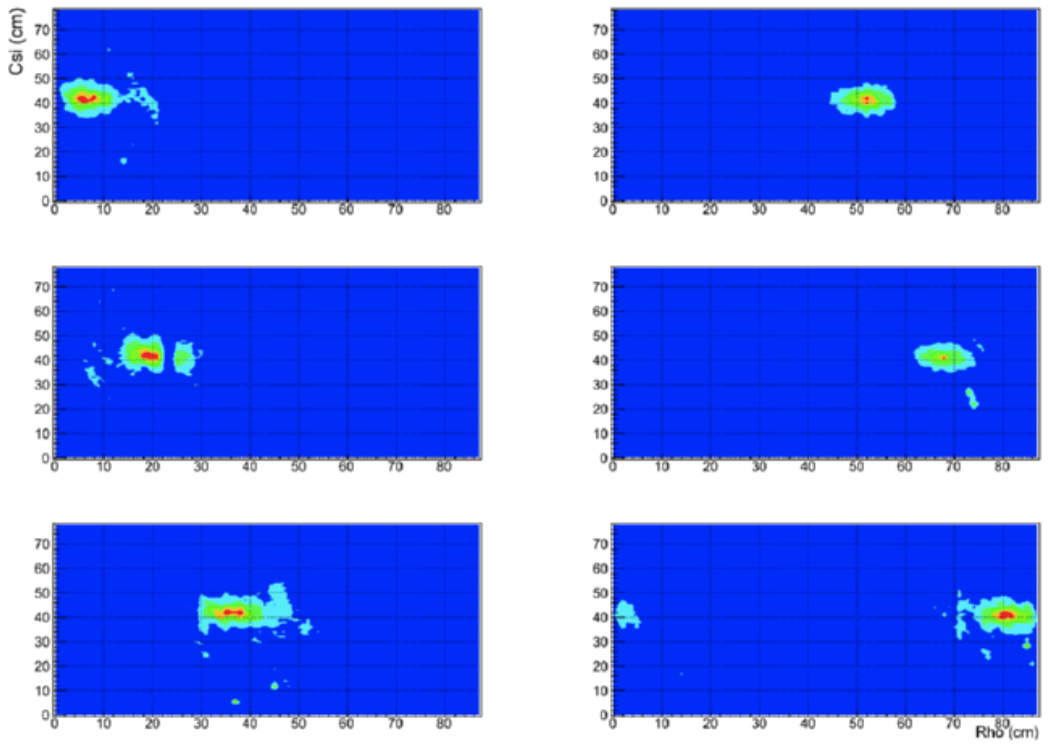


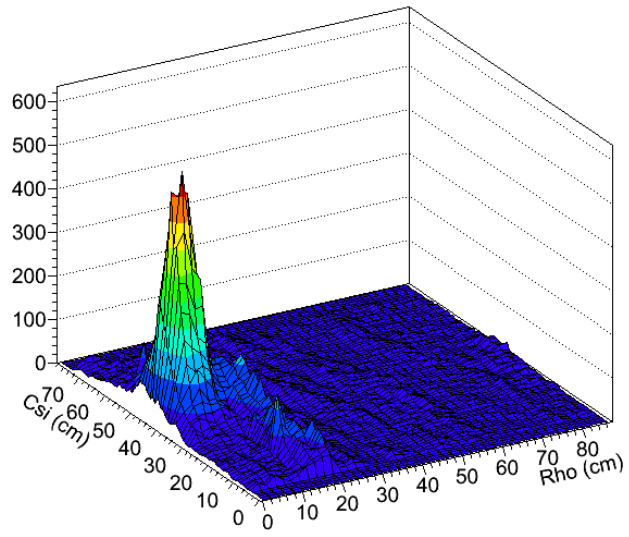
Ionization in 3 mm $Ar:isoC_4H_{10}$ 90:10, $\beta\gamma$=2.21



Test results from ^{90}Sr source



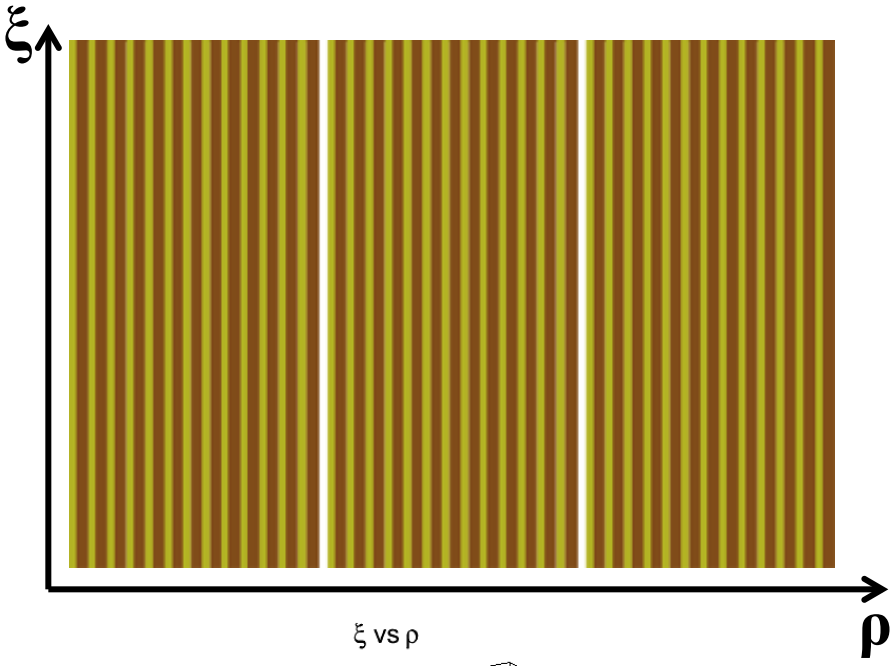


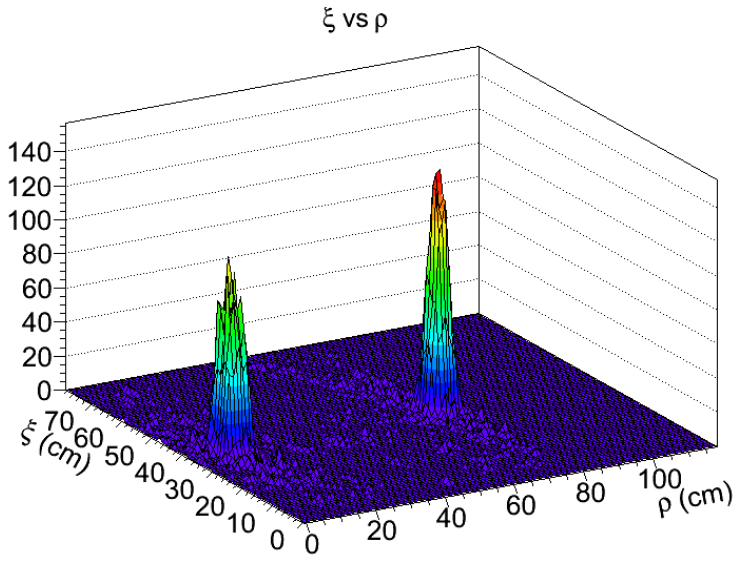


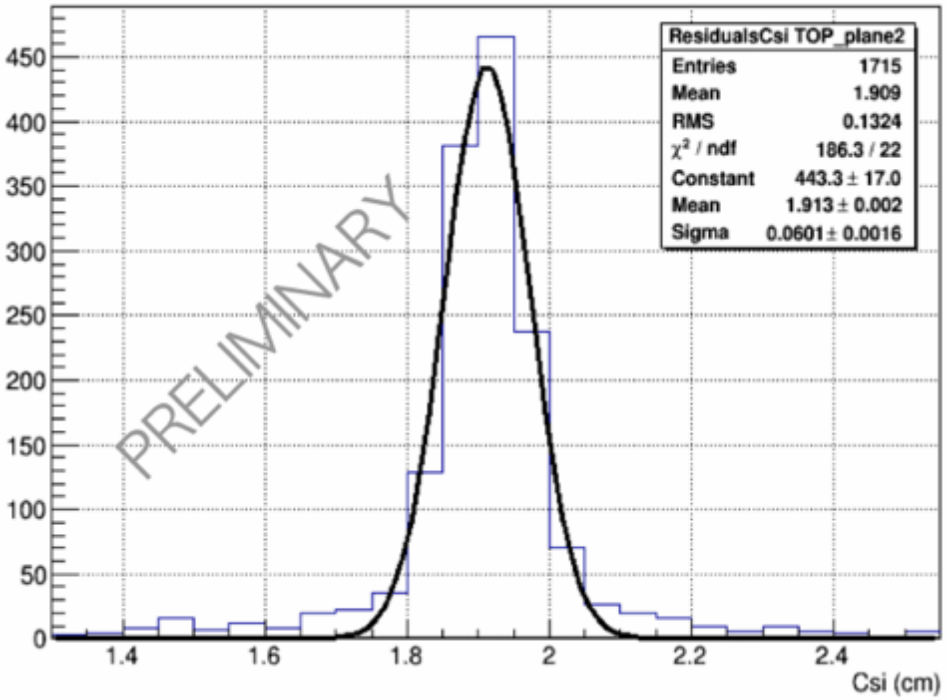
The profile of the source in 6 different positions is reconstructed by triggering the DAQ with a clock signal

This fast test allows to check the cabling

Test results from cosmic rays events



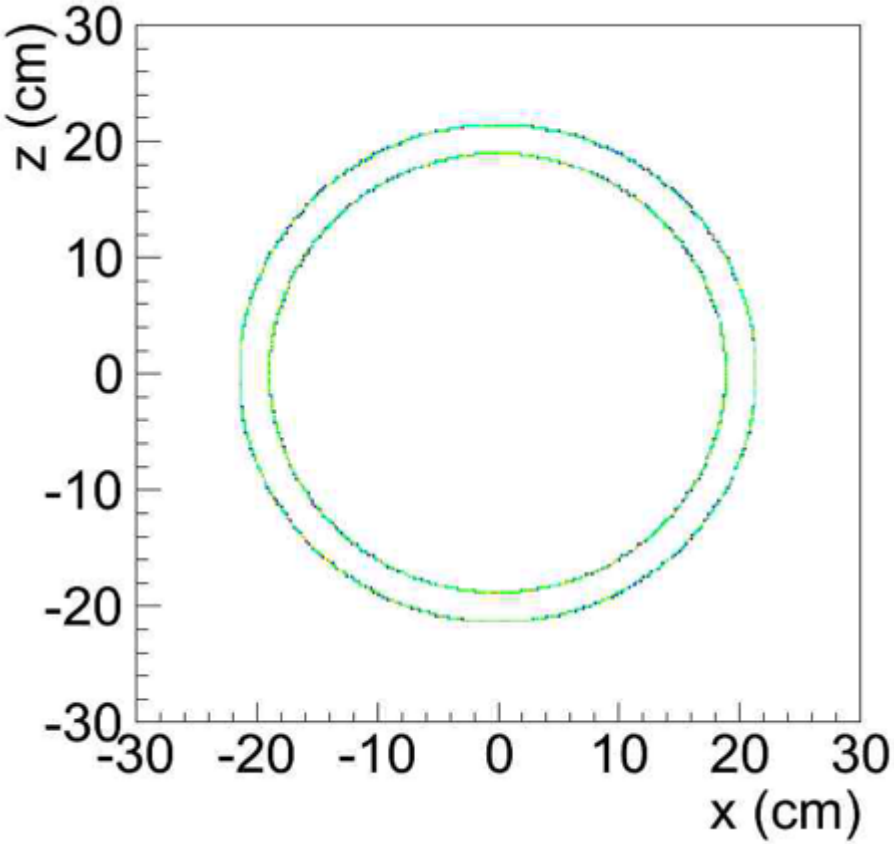




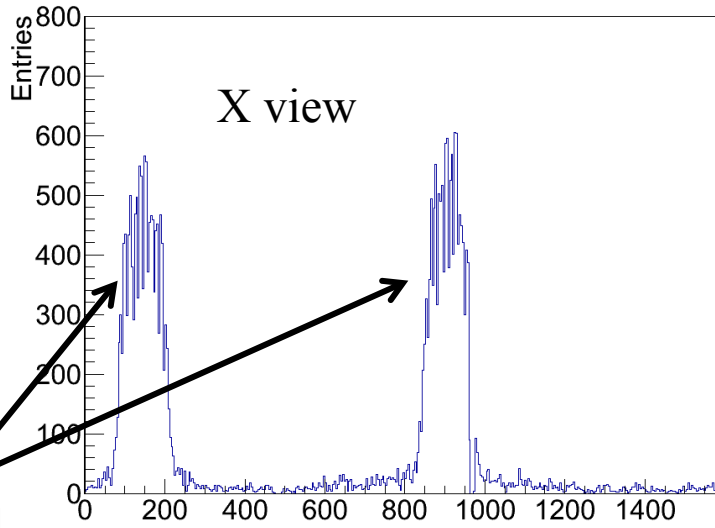
Events selected using External Tracking provided by 3 Planar Triple-GEM

Pre-insertion test

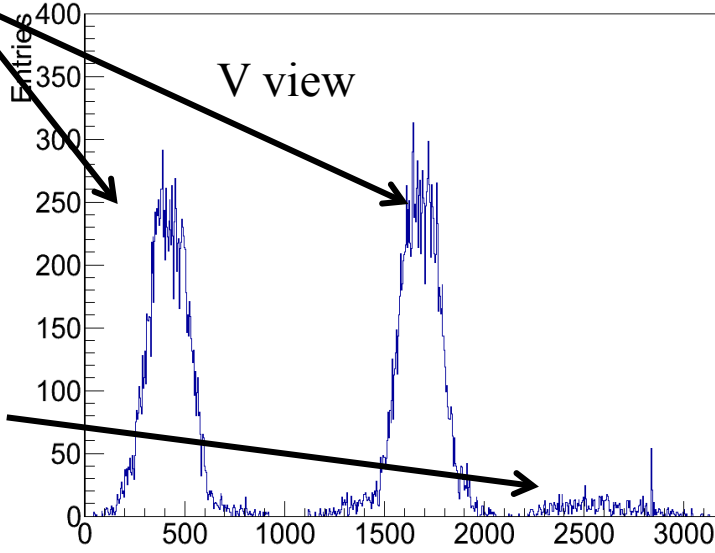
After the final cabling each layer was tested



Noise run with Layer 3 & 4



peaks related to cosmic rays



noise correlated to the V strips length