E. De Lucia
on behalf of KLOE2 IT Group

Prototypes Test beam results & Validation of final CGEM detectors

Cylindrical GEM Mini-Workshop - LNF October 25th 2012

The IT with CGEM Technology

The **CGEM** is a ***low-mass, fully cylindrical*** and ***dead-zone-free*** GEM based detector:

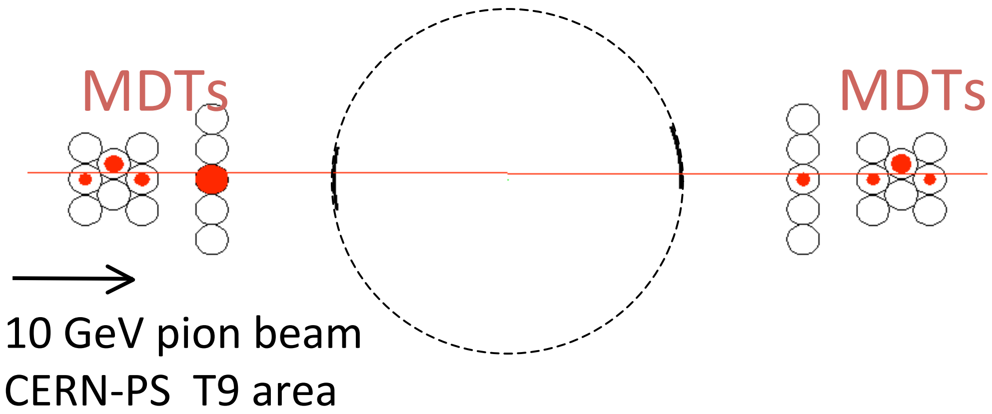
The main steps of the R&D project:

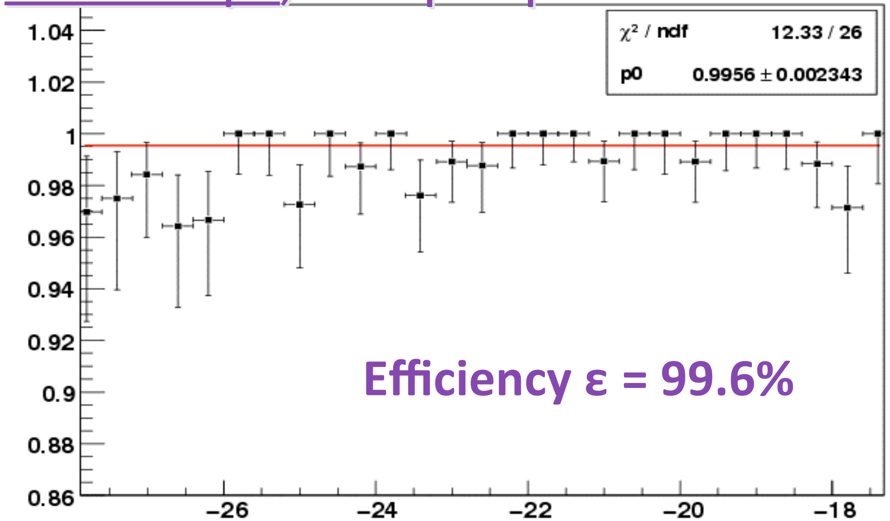
- Construction and complete characterization of a **full scale CGEM prototype**
- Study the **XV strip** readout configuration and its operation in **magnetic field**
- Construction and characterization of a **large area GEM** realized with the new single-mask photolitografic technique (KLOE2 IT needs GEM foil as large as 450x700mm^2)

Technical Design Report of the Inner Tracker for the KLOE-2 experiment [arXiv:1002.2572]

(1) CGEM prototype: test-beam

Proto0.1: Ø=300mm,L=350mm; 1538 axial strips, 650 μm pitch

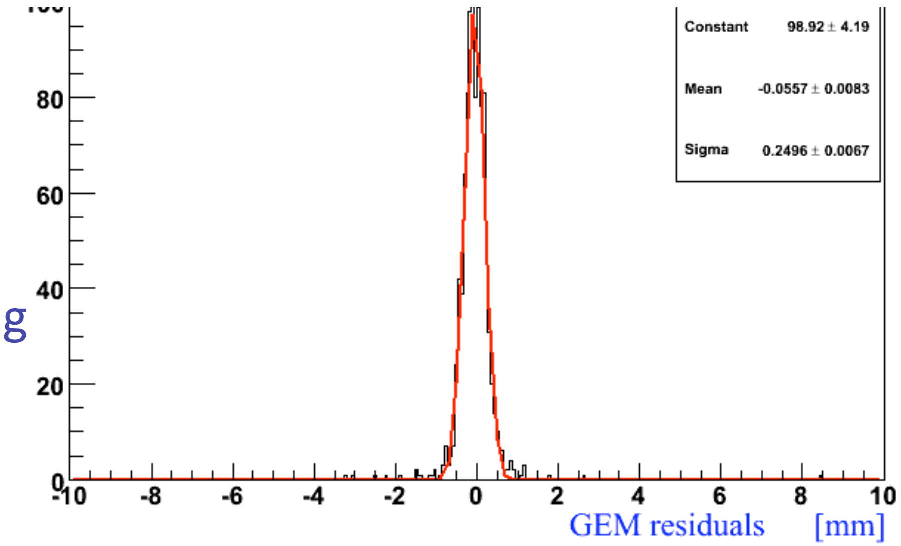




Gas: Ar/CO_2 = 70/30
Fields: 1.5/2.5/2.5 /4 kV/cm
V_{GEM}: 390-380-370 =1140V, gain~$2\cdot10^4$

FEE: 16-channels GASTONE [NIMA 604 (2009)]
Trigger: 2x8-MDT stations -- External Tracking

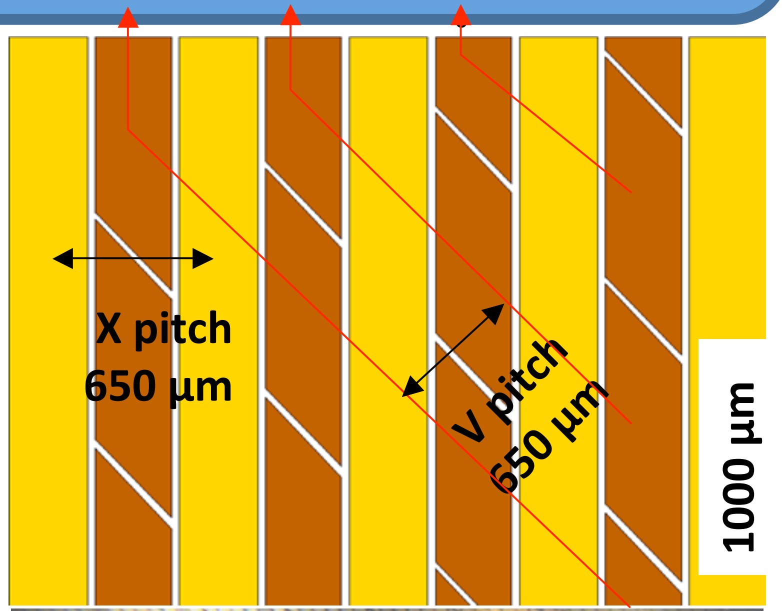
Spatial Resolution [NSS Conf. Rec.(2009)]
$\sigma(GEM) = \sqrt{(250\mu m)^2 - (140\mu m)^2} \sim 200\mu m$

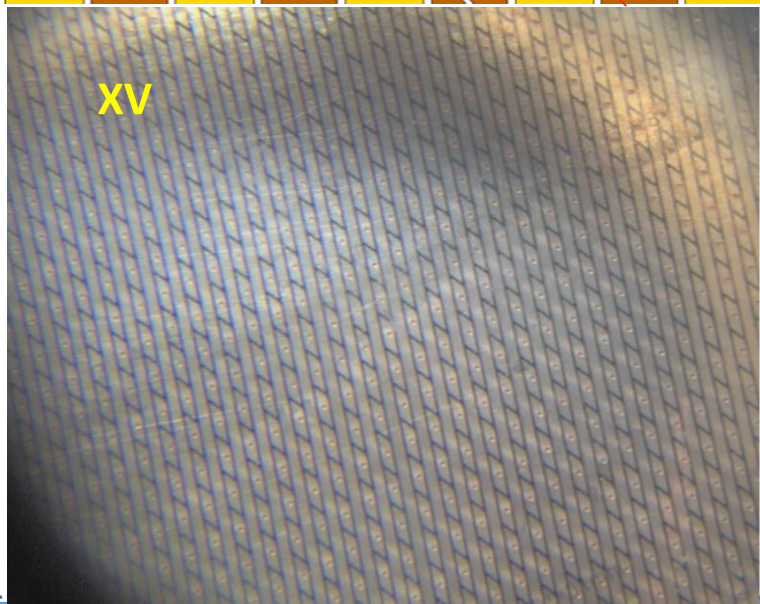


(2) XV readout and magnetic field

A 10x10 cm^2 Planar GEM w/650 μm pitch **XV strips** has been realized and tested in magnetic field:

- X-view will provide r-ϕ coordinate in CGEM
- V-view made of pads connected by internal vias and with ~40°stereo angle
- XV crossing will provide z coordinate in CGEM
- readout w/GASTONE

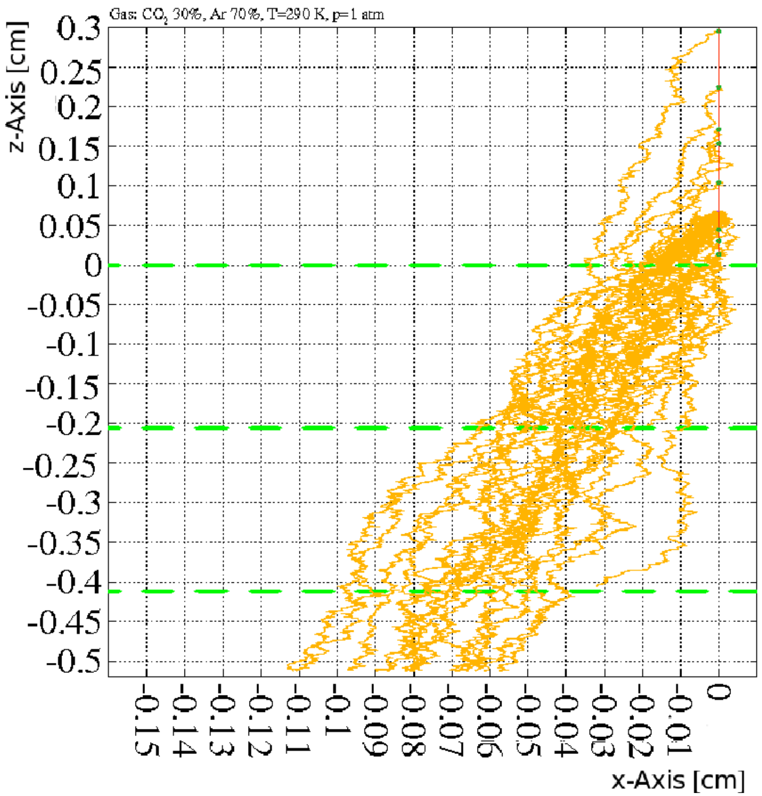




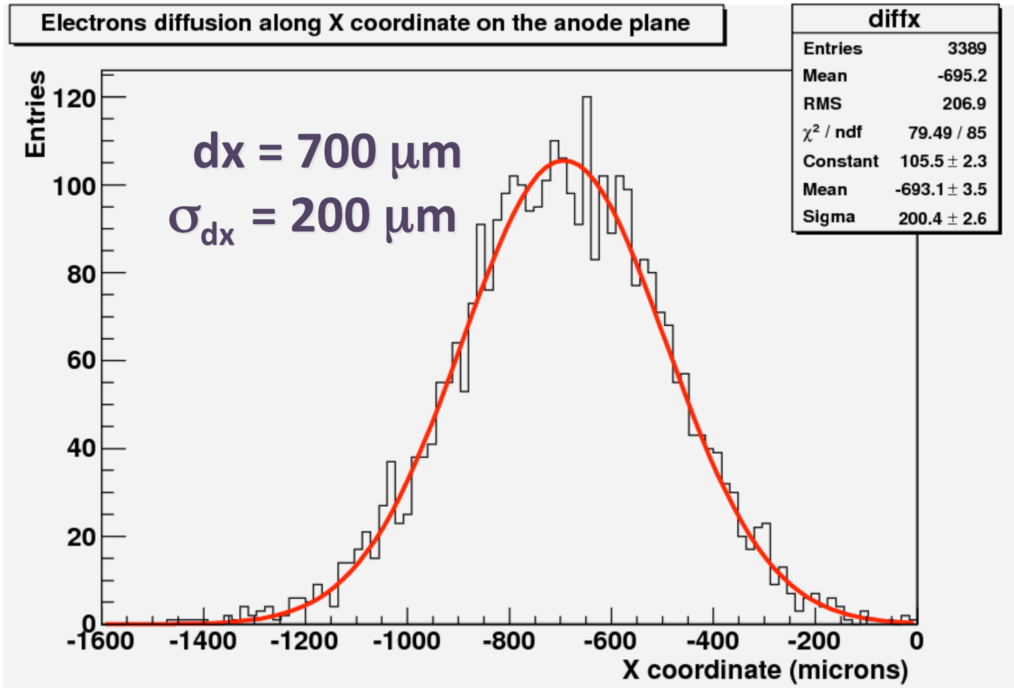
(2) XV readout and magnetic field

❖The effect of the magnetic field is *twofold*: a ***displacement*** (**dx**) and a ***spread*** of the charge over the readout plane (effect visible only on the "*bending plane*")

Garfield Simulation



Ar/CO_2=70/30 and B=0.5 T
average Lorentz angle α_L = 8°- 9°



(2) XV readout : test beam

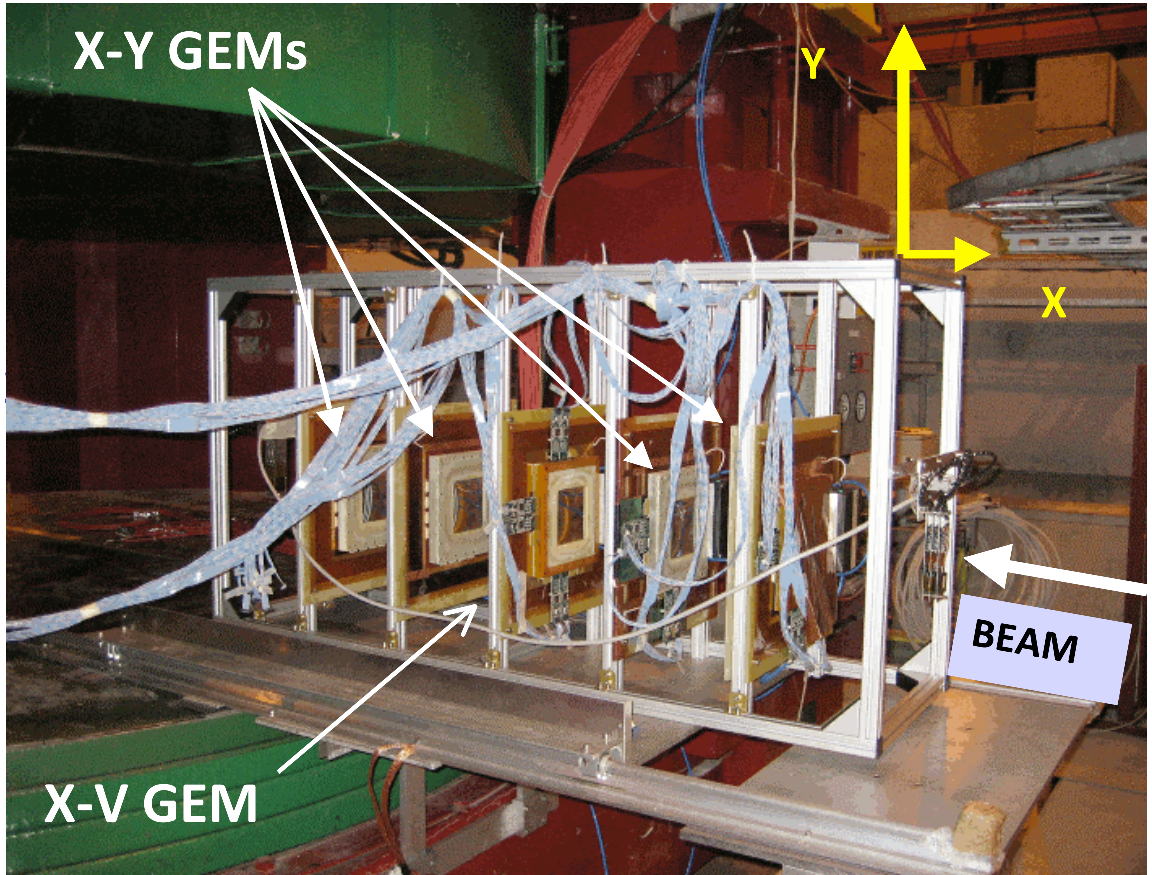
- H4 beam-line at CERN-SPS: **150 GeV pions**
- Goliath Magnet: dipole field up to **1.5T** in a **~3x3x1m^3**
- Semi-permanent setup for RD51 users

Gas: Ar/CO_2 = 70/30
Fields: 1.5 - 3.0 - 3.0 - 5.0 kV/cm
V_{GEM}: 390-380-370 =1140V,
gain~$2\cdot10^4$

FEE: GEMs partially equipped with GASTONE boards

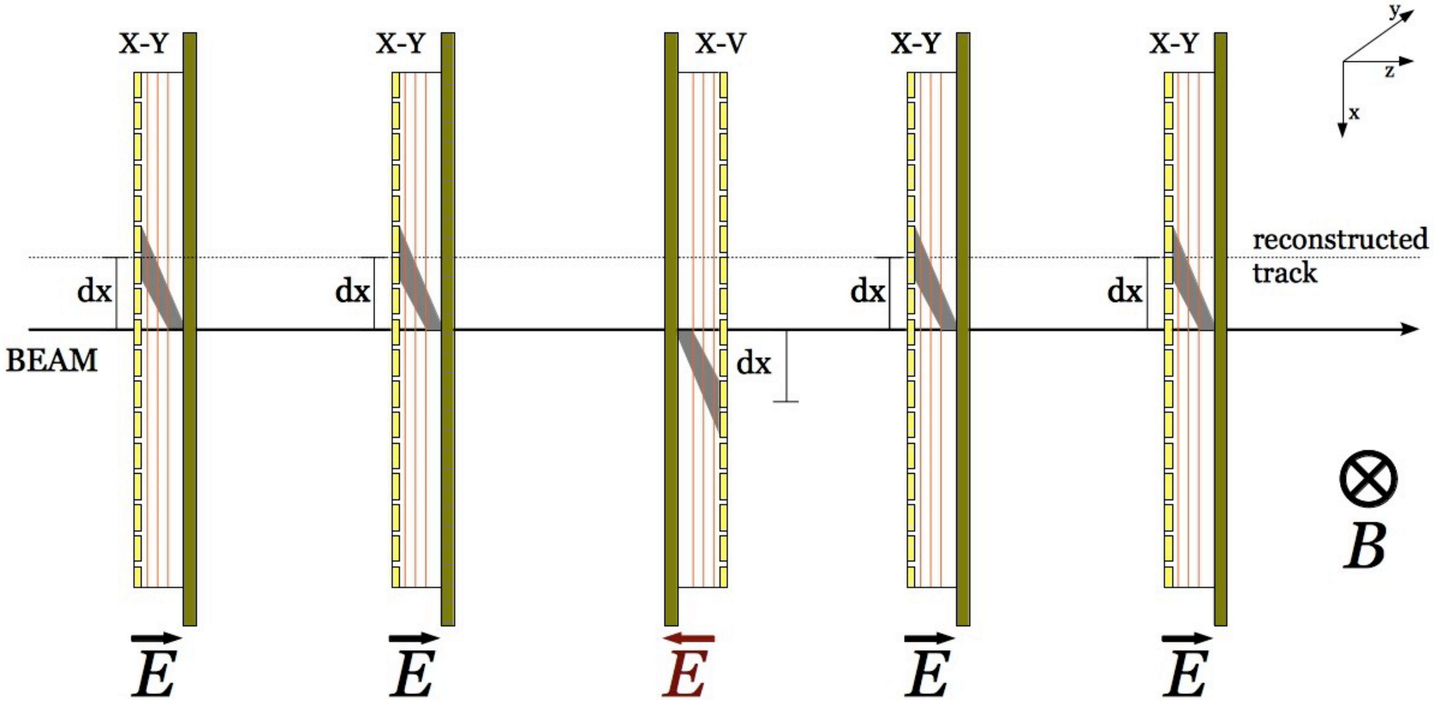
Trigger: 6 scintillators with SiPM (3 upstream, 3 downstream)

External Trackers: **4 planar GEMs** w/650 μm pitch **XY strips**



(2) B-induced displacement

❖In our configuration the magnetic field effect is mainly present on the X-view

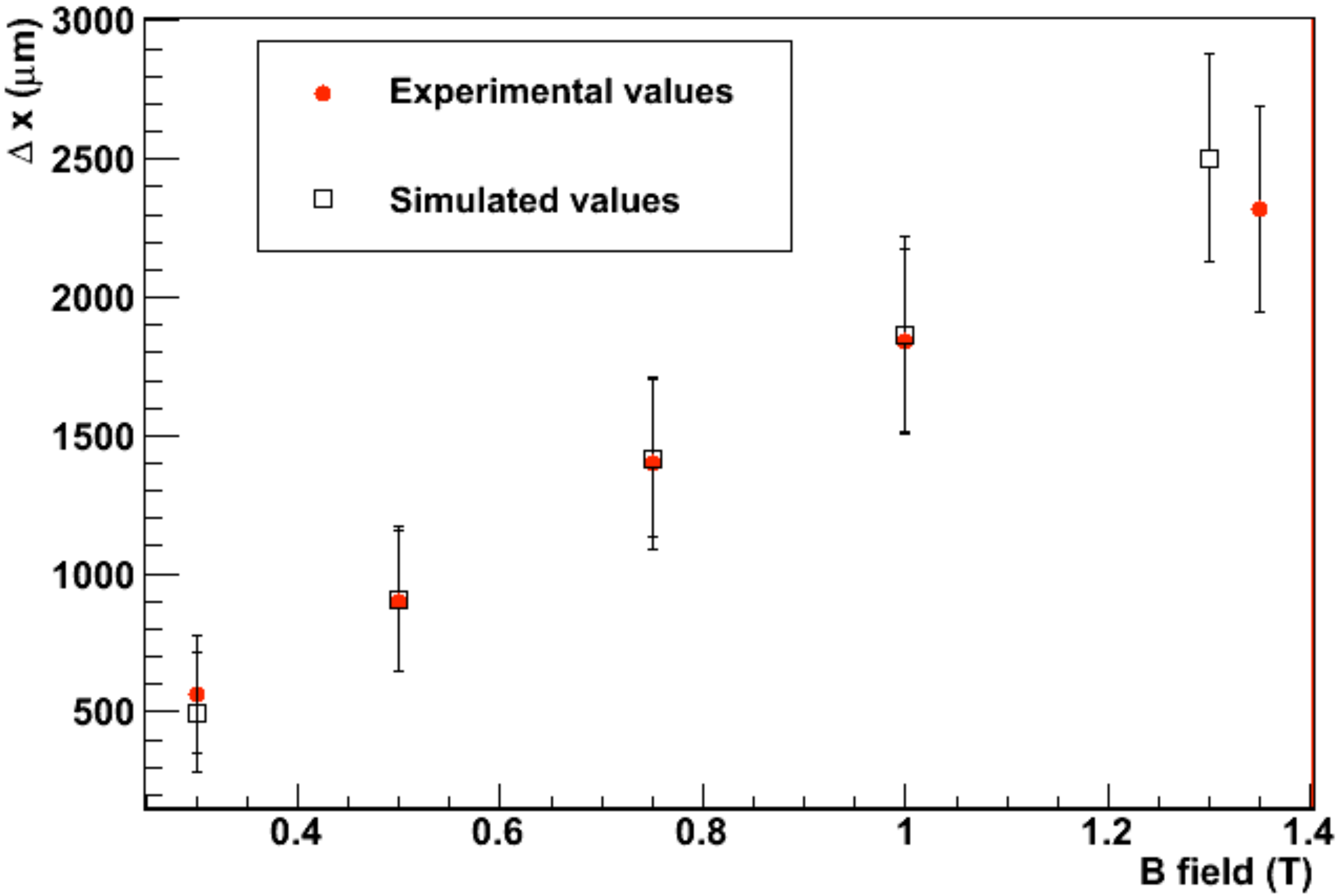


i. Align the setup with B = 0
ii. Turn on B field
iii. Track reconstruction using the 4 X-Y GEMs (<u>likewise oriented</u>)
iv. Measure the displacement on the X-V GEM (<u>reversed wrt the other GEMs</u>)

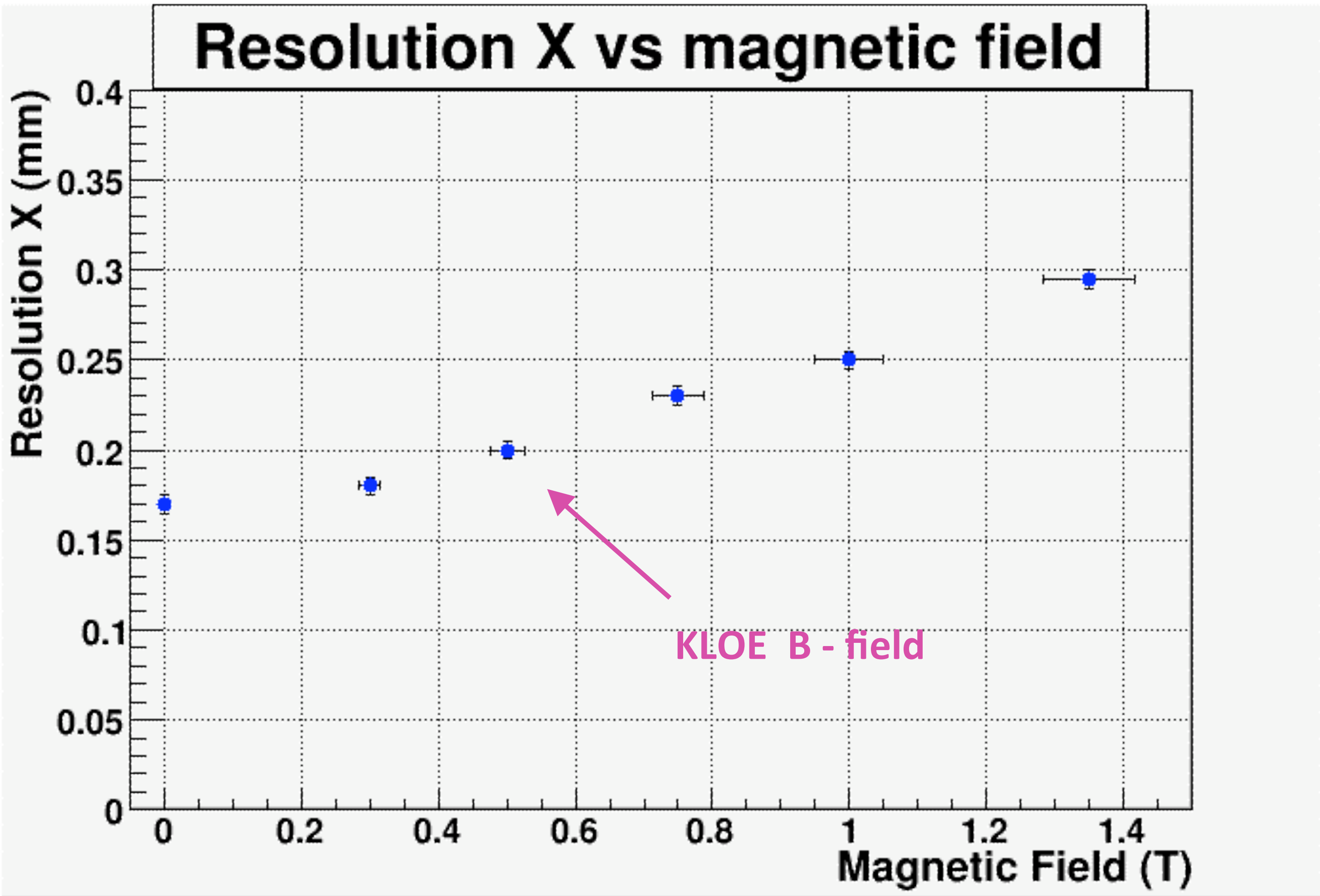
D = 2 × dx → $\tan(\theta_L) = \mathbf{D} / 2\boldsymbol{r}$ ($\boldsymbol{r}$ = effective detector thickness)

(2) B-induced displacement

❖ Distribution of **dx = D (measured displacement)/2** as a function of B field
The black open squares are from GARFIELD simulation



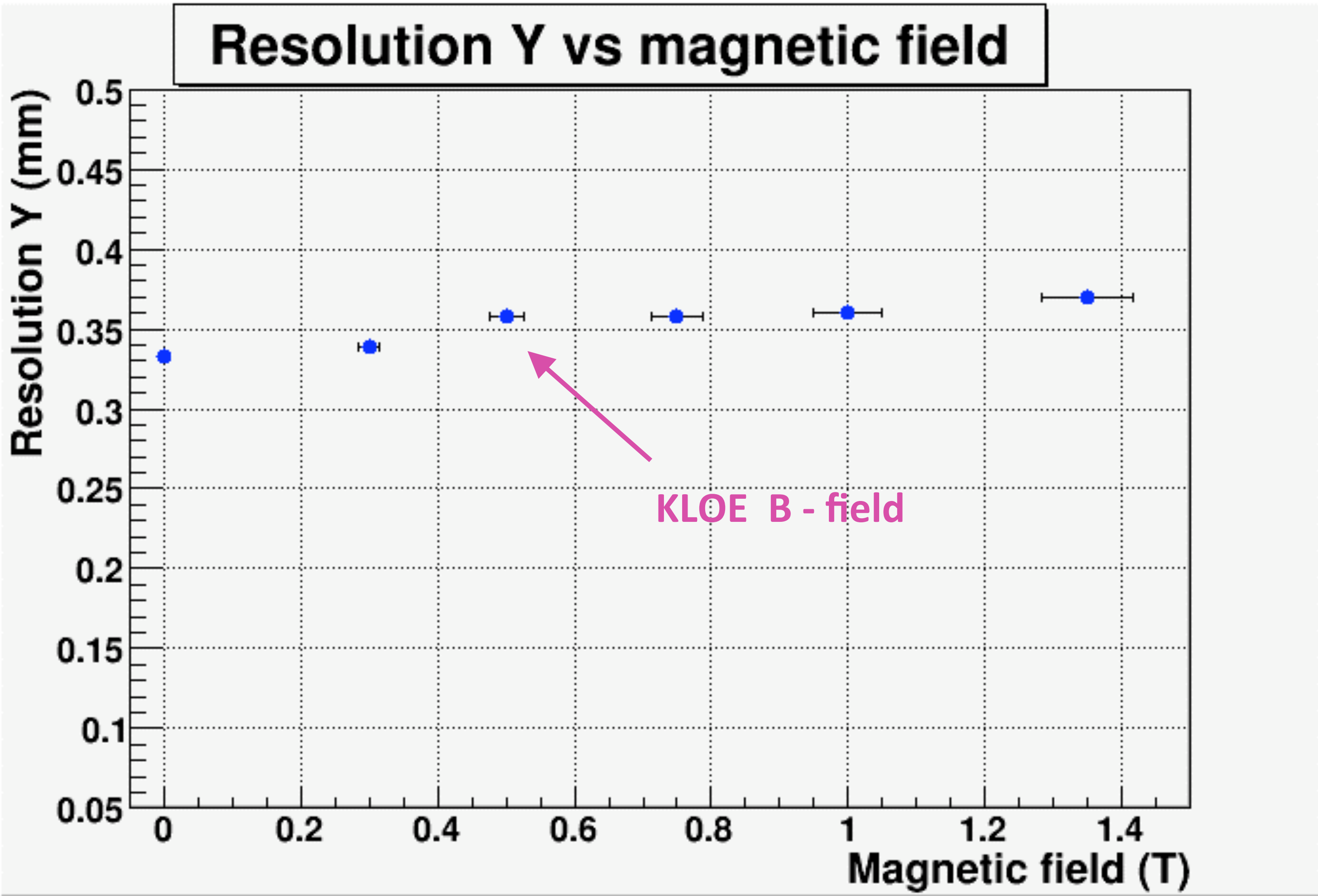
(2) Spatial resolution: X-view



CGEM r-φ resolution

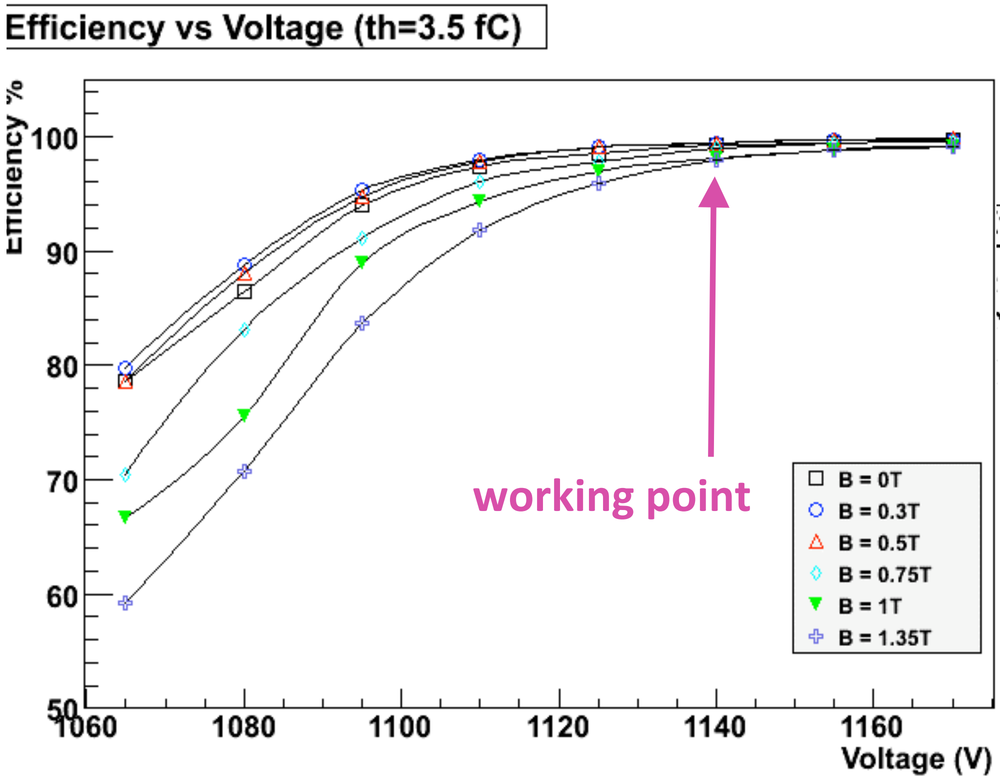
(2) Spatial resolution : Y coordinate

❖ The Y coordinated is measured from the crossing of X and V views

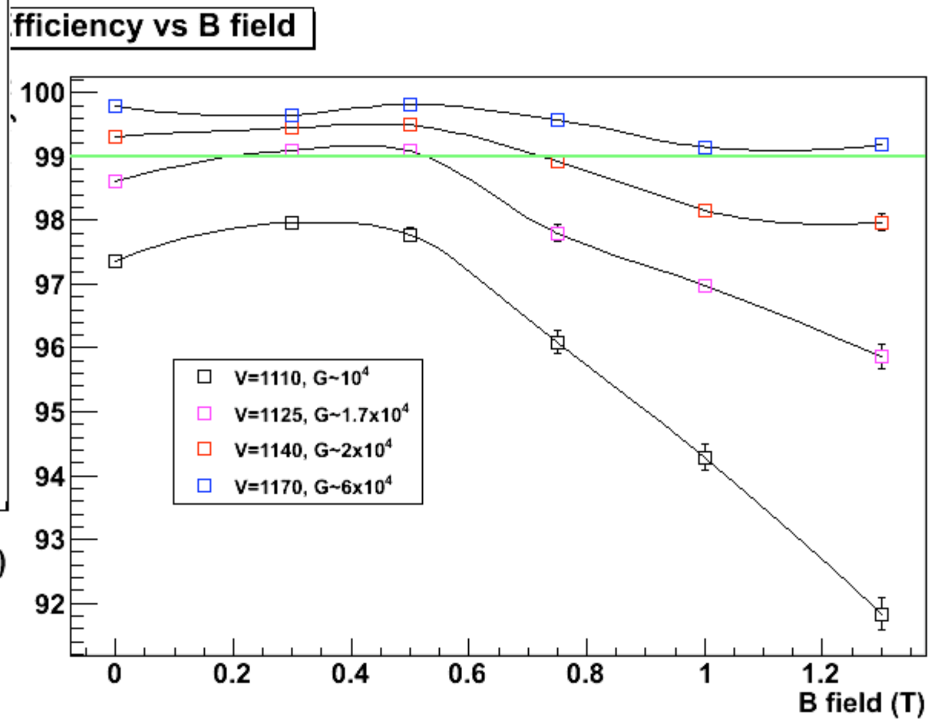


CGEM z resolution

(2) Efficiency vs B field and Gain



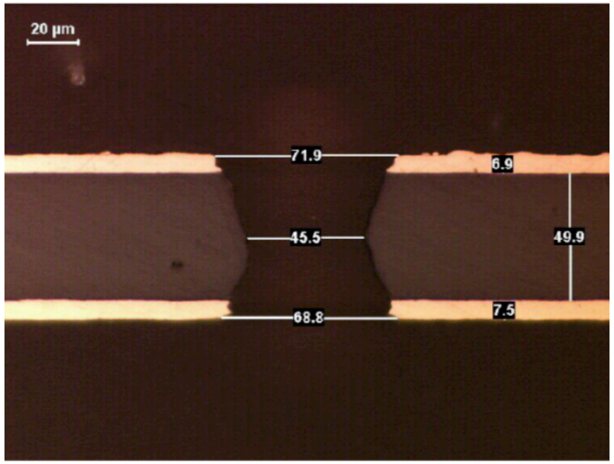
At working point, V_G = 1140 Volt, G~2x10^4, **efficiency drop is negligible for B < 0.5 T**

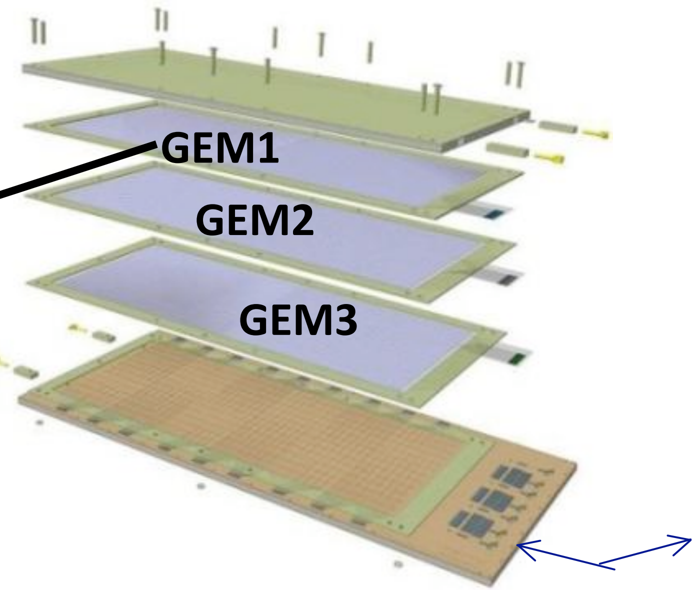


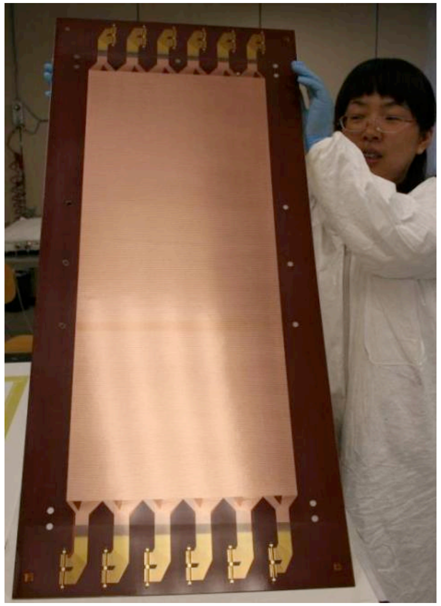
The **increase of the magnetic field,** increasing the spread of the charge over the readout strips (less charge is collected by each single pre-amp channel) results in an efficiency drop, thus **requiring for higher gain to efficiently operate the detector.**

(3) Large Area XV

❖The KLOE-2 Inner Tracker requires GEM foils with an area of 350 x 700 mm^2 (splicing 3 of them to obtain 1 electrode).
❖This required a change in the GEM manufacturing: **the single-mask photolitographic technique**
<u>The foils are produced by the CERN TE-MPE-EM group</u>

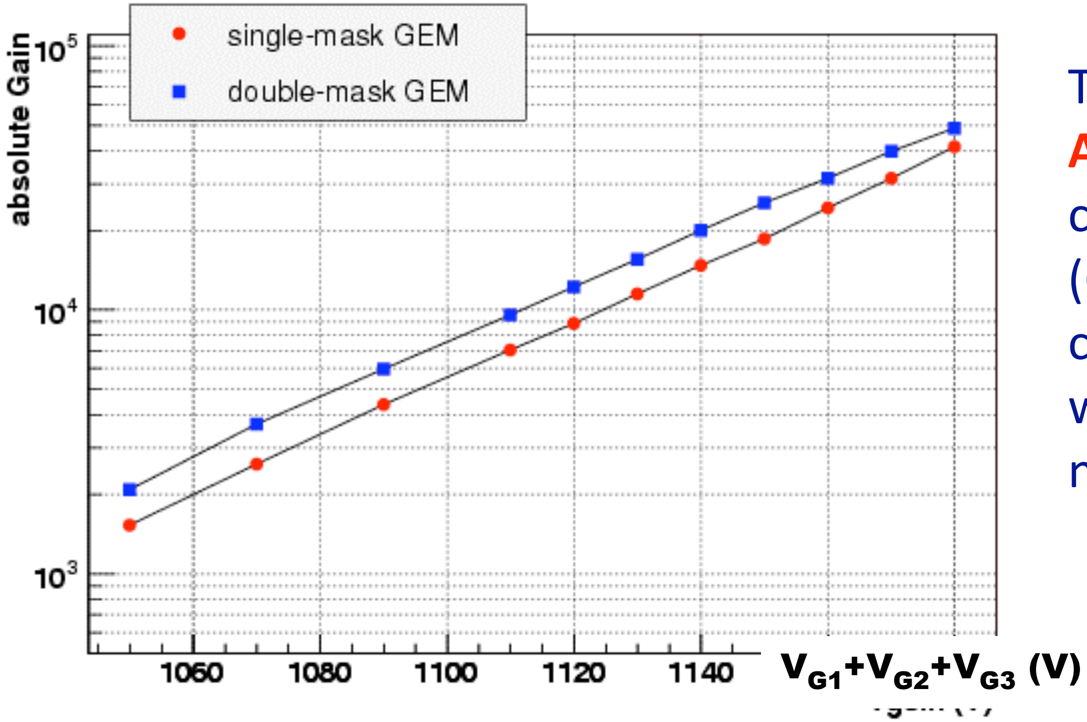






Pad readout PCB

(3) Large Area XV



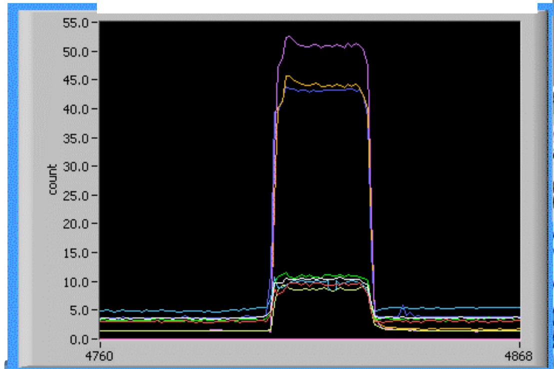
The detector was flushed with **Ar/CO_2 (70/30)** and tested in current-mode with a **^{137}Cs source** (660 keV photons). A 10x10 cm^2 chamber with double-mask foils was used as reference and normalization of performance

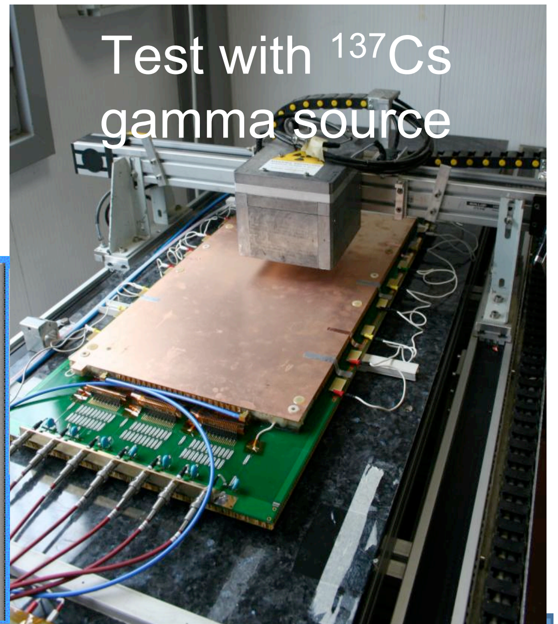
GAIN ~25% lower in single-mask GEM

~20 V difference between the two distributions

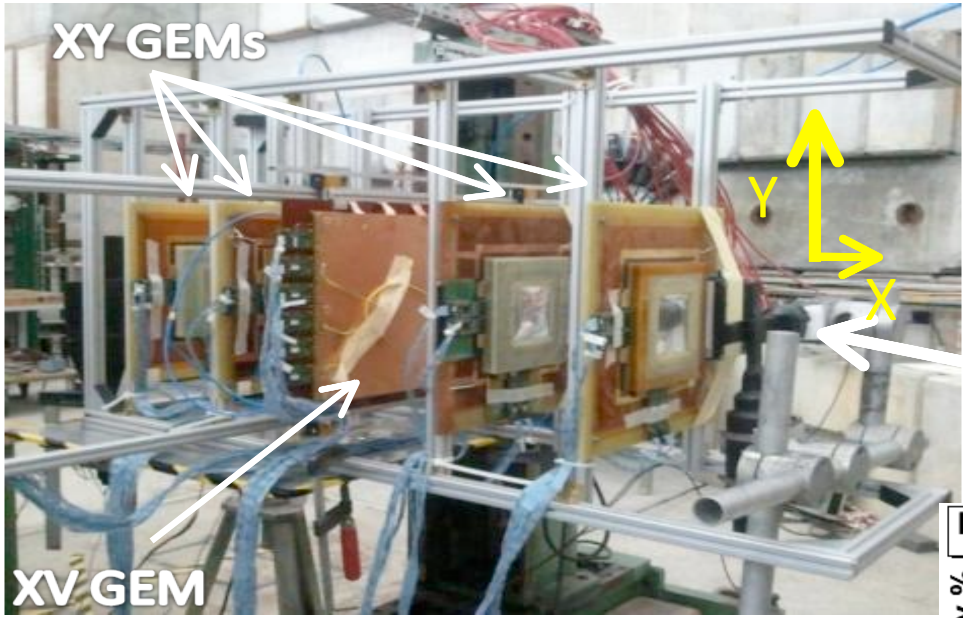
NO DISCHARGE OBSERVED DURING MEASUREMENTS

Electrode currents





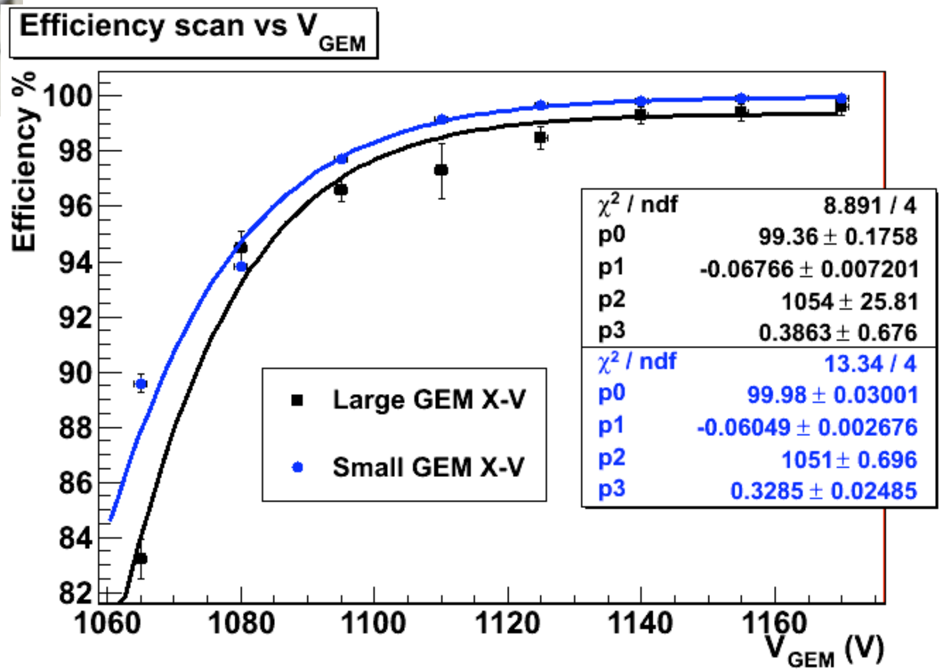
(3) Large Area XV



The Large area planar prototype was tested at CERN-PS T9, equipped with the final X-V readout strips-pads

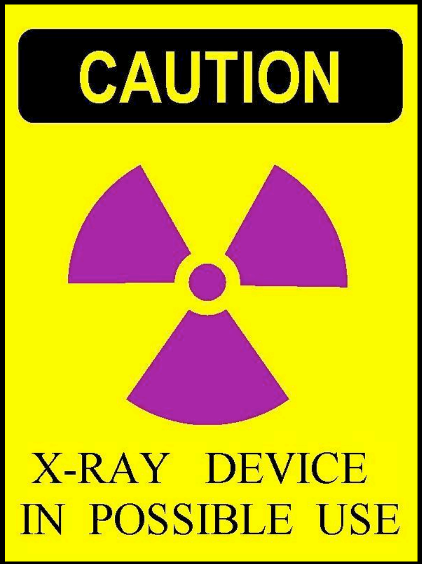
BEAM

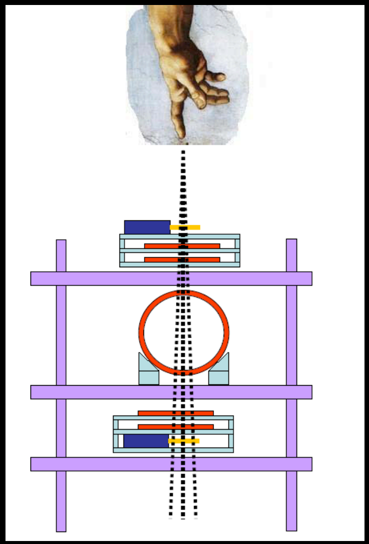
- GAS MIXTURE: Ar/CO_2 70/30
- GAIN : $2\cdot10^4$, $3\cdot10^4$



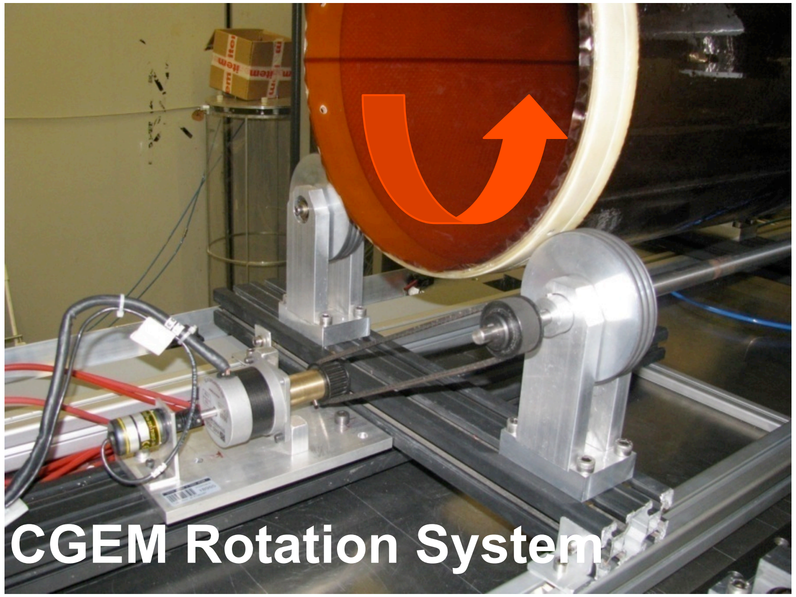
- Final DAQ+electronics chain test: GASTONE64 + Interface board + General Intermediate Boards (GIB) + Software Interface
- External tracking: 4 planar GEMs, 650 **μm** pitch X-Y strips
- Trigger: 4 scintillators (2 upstream, 2 downstream)

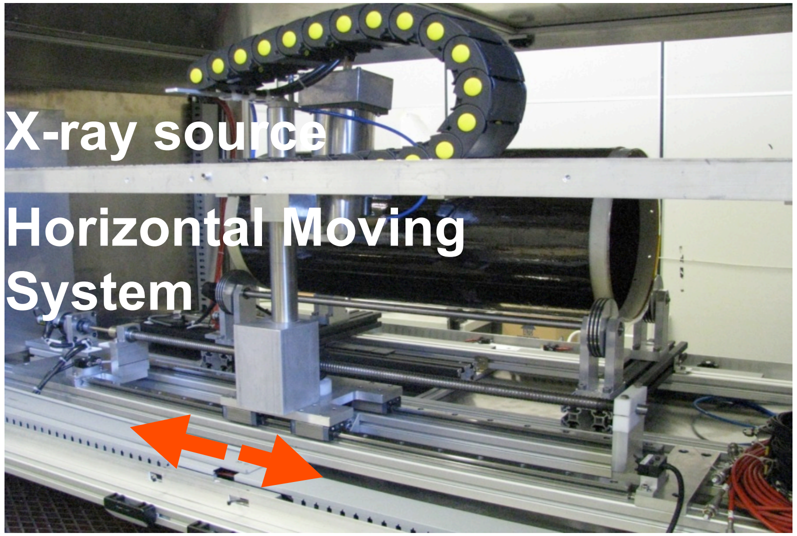
Inner Tracker Validation Tests



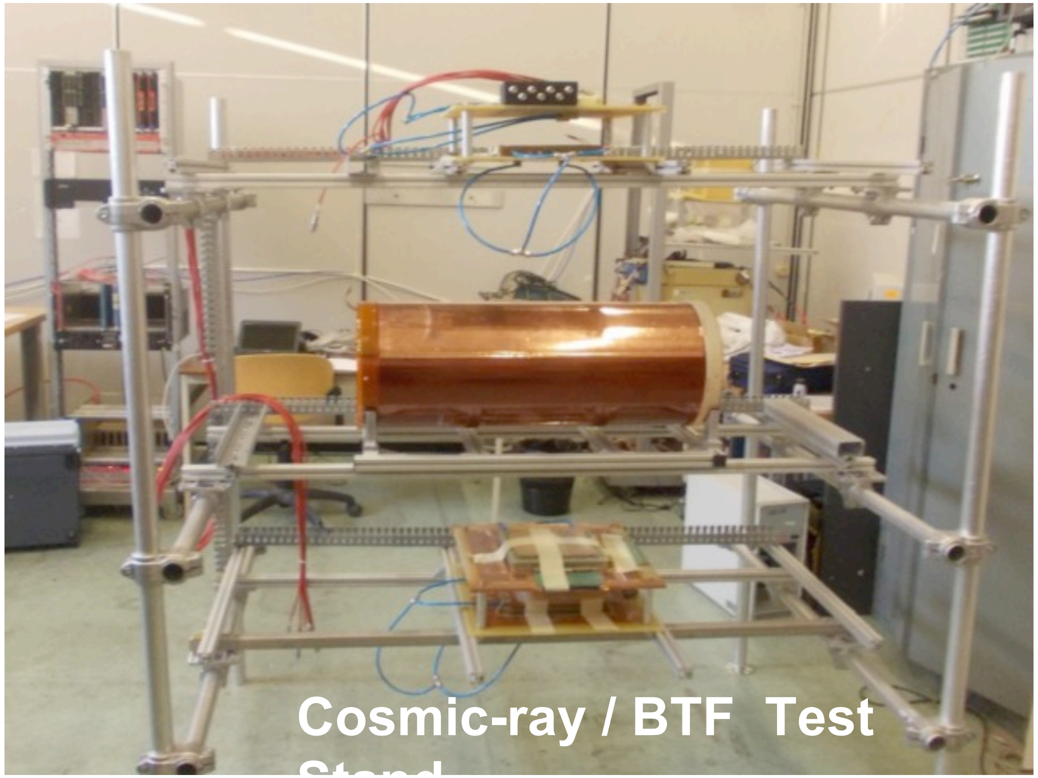


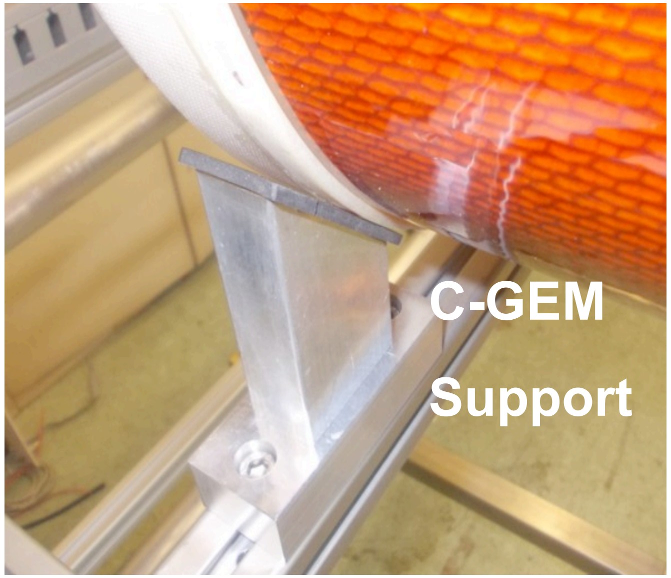
X-ray Test Stand

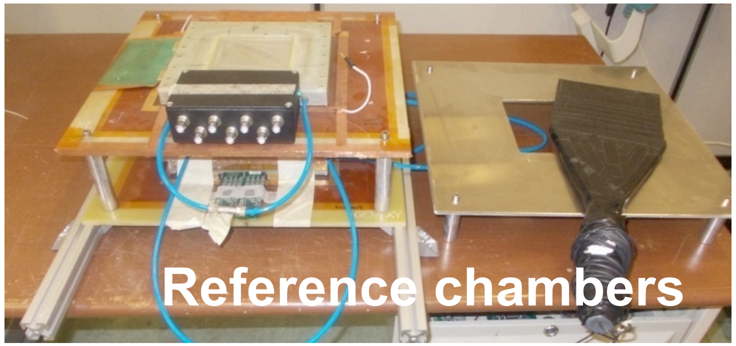




Cosmic-ray Test Stand







Reference chambers and Triggering Scintillators

Final Setup for Cosmic-ray Stand (I)

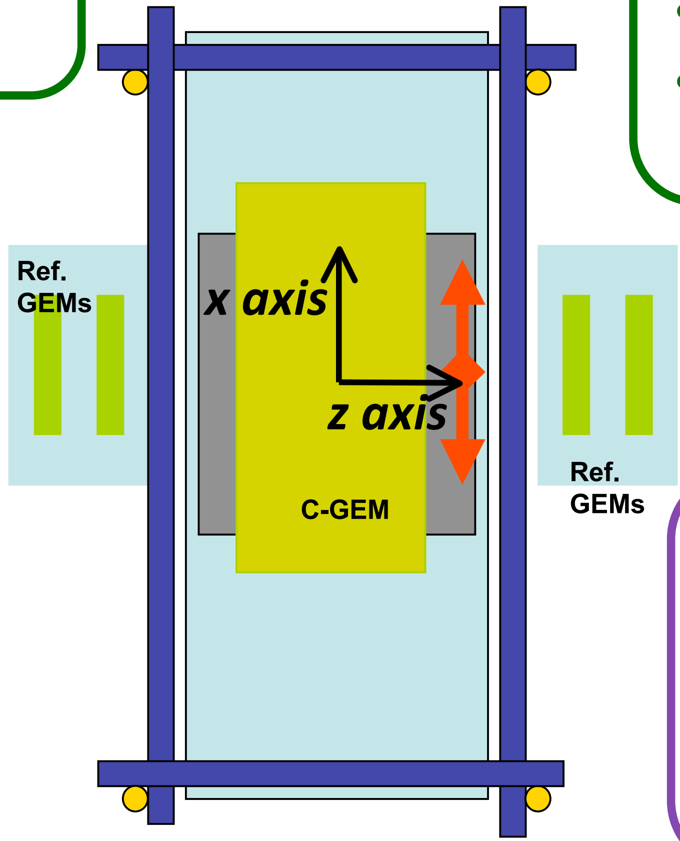
3 XY PGEMs

- 8 Gastone64 Boards
- 2 (GIB+TB)
- TB/FEE Cables

CGEM

- 42 Gastone64 Boards
- 6 (GIB+TB) and 1 Crate
- TB/FEE Final Cables

2 Triggering Scintillators



3 XY PGEMs

- HVCAEN Crate
- Amperometer
- 28 HV Cables
- 4 HV boxes

CGEM

- HVCAEN
- Amperometer
- 2 HV Patch Panels
- 39 HV Cables
- 39 HV cards

Final Setup for Cosmic-ray Stand (II)

GIB-TB

- Optical Receiver Interface
- Final Crate and Transition Board
- TB/Gastone Cables

FEE

- Gastone64

HV

- Final HV Cables and Distribution

DAQ

- Using both GIB Ethernet Interface and Optical Interface

Software for Reconstruction (I)

Cabling & FEE	GIB-TB Noise Test Software ✓
Mapping Gastone to Strip X/V	*Need Position of 1st Strip X/V*
CGEM Geometry in KLOE Official Ref.	Software ready ✓ *GasIn Position for StripV Orientation*
Separate X- and V-view Clustering	Software ready ✓
Cluster Position in Lab. Frame (x,y,z)	Software ready ✓
Expected CGEM Cluster Position from 3XY PGEMs External Tracking	Software ready ✓
CGEM Alignment wrt 3XY PGEMs	Software ready ✓

Software for reconstruction (II)

Cabling & FEE $\Rightarrow$ *Global Mapping, FEE Threshold & Noise Study*

Mapping Gastone to Strip X/V $\Rightarrow$ *Occupancy*

CGEM Geometry in KLOE Official Ref.

Separate X- and V-view Clustering $\Rightarrow$ *Cluster Size X/V-view*

Cluster Position in Lab. Frame (x,y,z)

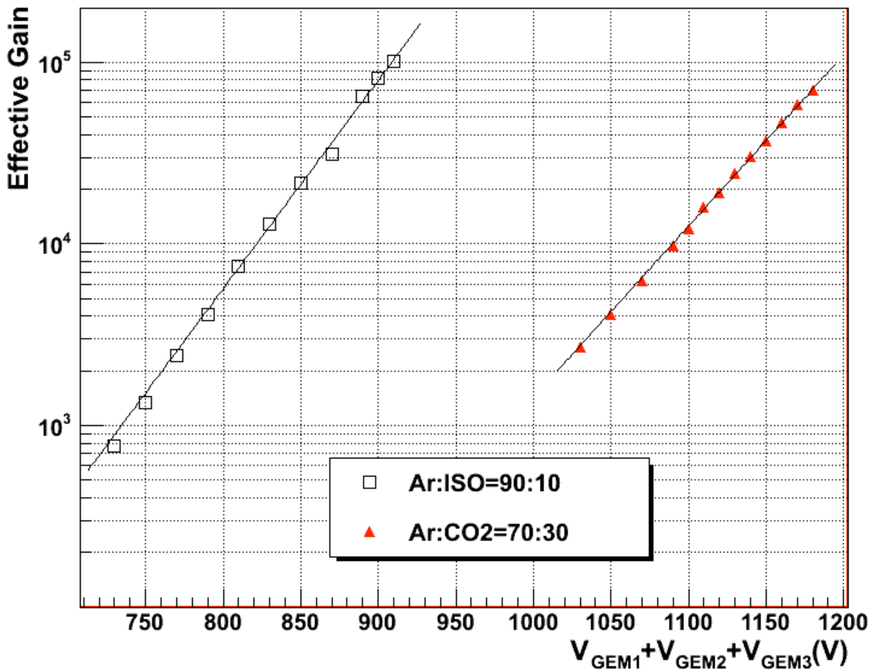
Expected CGEM Cluster Position from 3XY External Tracking $\Rightarrow$ *Efficiency, Resolution & Glued Zone Effect*

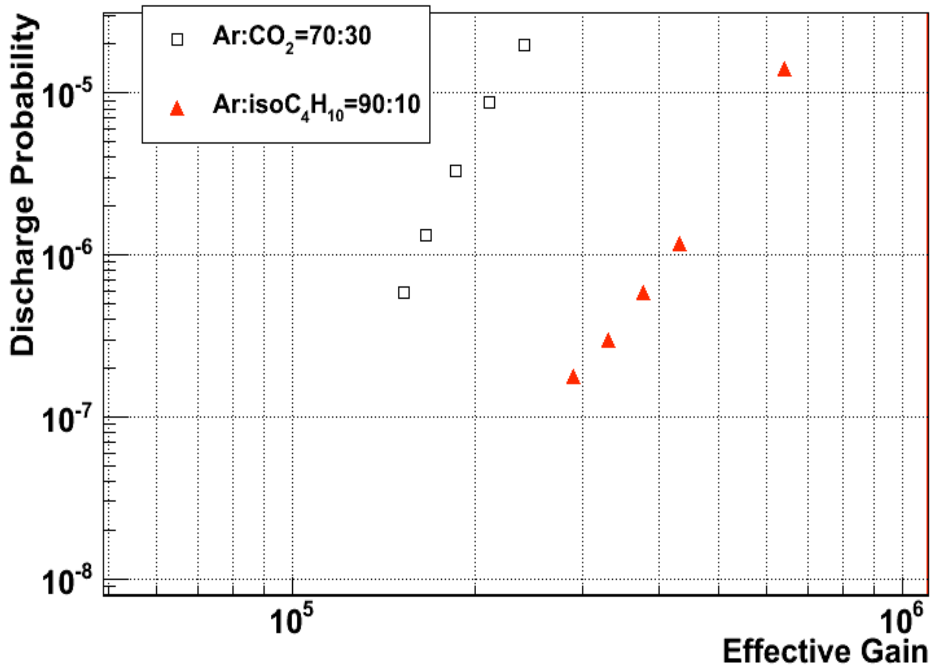
CGEM Alignment wrt 3XY

Results on Final CGEM

Layer1/Layer2/Layer3 X-rays Test

- Layer1,Layer2 and Layer3 tested in current mode with 6 keV photons
- Two gas mixtures characterized using α particles from ^{241}Am source :
  - Ar/CO_2 (70/30) : 2×10^4 Gain reached
  - $Ar/i\text{-}C_4H_{10}$ (90/10) : same Gain reached with <u>higher stability</u> (#discharges suppressed) and at <u>lower voltage</u> (Vmax = 3800V → 2800V)
- Good gain uniformity found over the surface



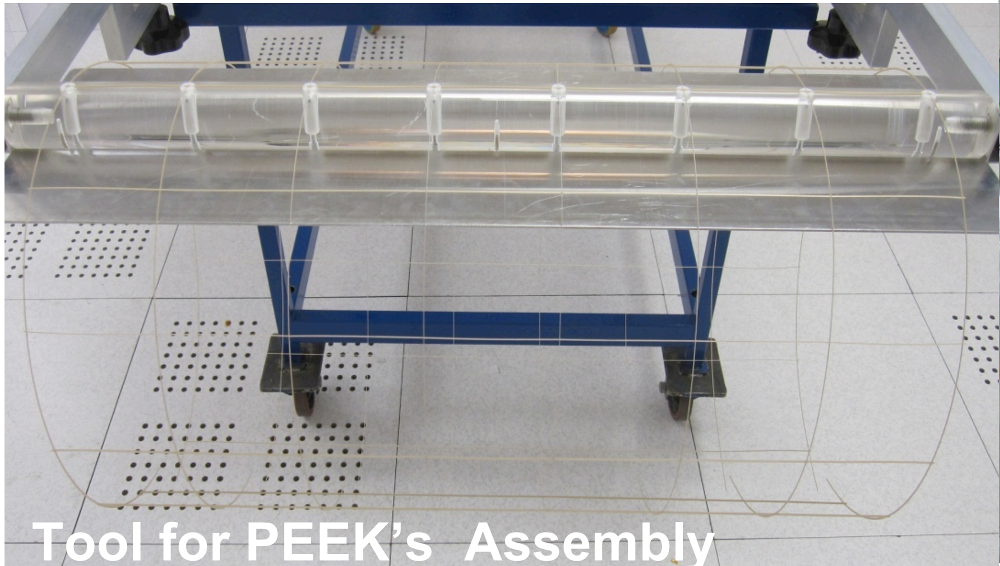


Layer 2 Temperature Test

- DAΦNE beam pipe achieved temperatures higher than those foreseen (up to 50 °C)
- Temperature tests on Layer2 showed some instability for T > 35-40 °C, due to the mechanical "relaxing" of the GEM electrodes

To cope with this problem:

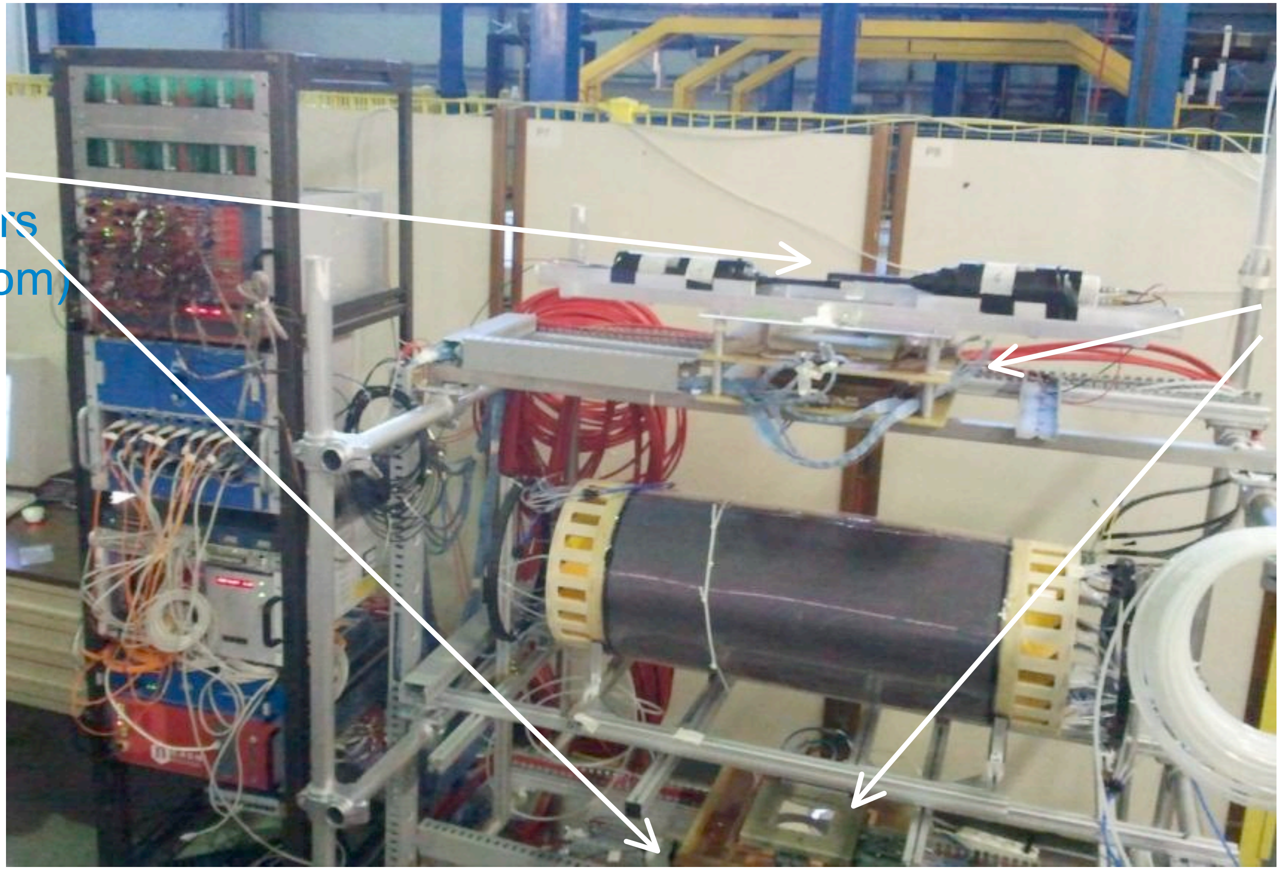
- A cooling system of the DAΦNE Interaction Point is foreseen: mock-up tests indicate that the operation temperature of the IP can be kept under 30 °C.
- Introduce a 300 μm thick support grid (**PEEK** from CERN PCB workshop) between GEM electrodes for Layer3 and Layer4



Layer 2/Layer3 Test with ^{90}Sr Source (I)

- Layer2/3 instrumented with:
  - ✓ Final HV cables and distribution
  - ✓ Final Gastone FEE and Signal cables

Trigger:
2 scintillators
(Top - Bottom)



External Tracking System provided by three Triple Planar GEMs PGEMs (Top - 2 Bottom)

- The DAQ System uses the Final custom Global Interface Boards (GIB) and Transition Boards (TB) **IEEE TNS 58 (2011) 1544**

Layer 2/Layer3 Test with ^{90}Sr Source (II)

- S1-S12 HV Sectors
- Source Scan positioning ^{90}Sr on each HV sector

Unrolled Anode Foil: X-view Strips

FEE Boards →

Source on S1

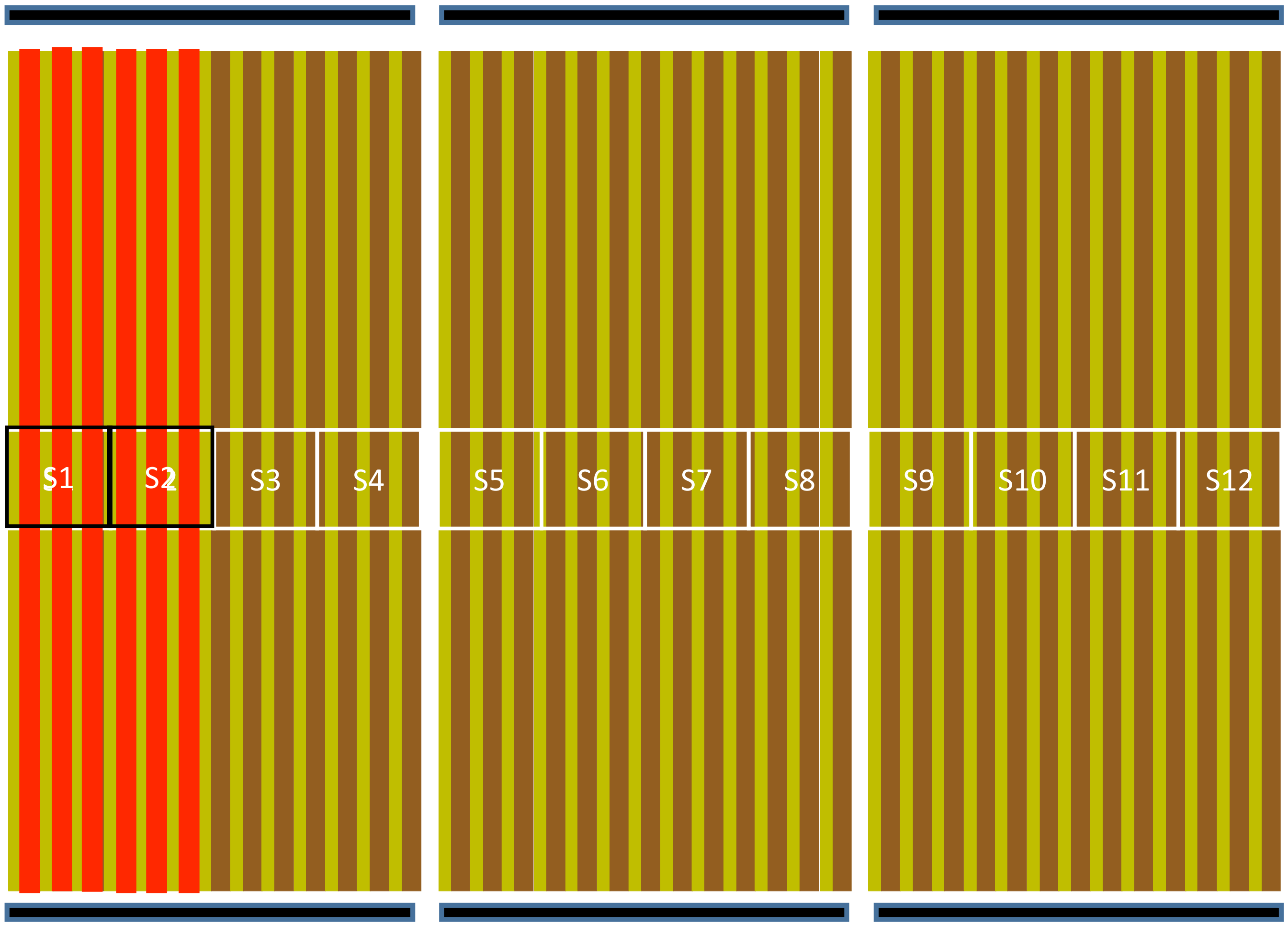
X-view Fired Strips

All X-view Strip illuminated with ^{90}Sr

Source on S2

X-view Fired Strips

FEE Boards →



Layer 2/Layer3 Test with ^{90}Sr Source (III)

- S1-S12 HV Sectors
- Source Scan positioning ^{90}Sr on each HV sector

Unrolled Anode Foil: V-view Strips

FEE Boards →

Source on S1

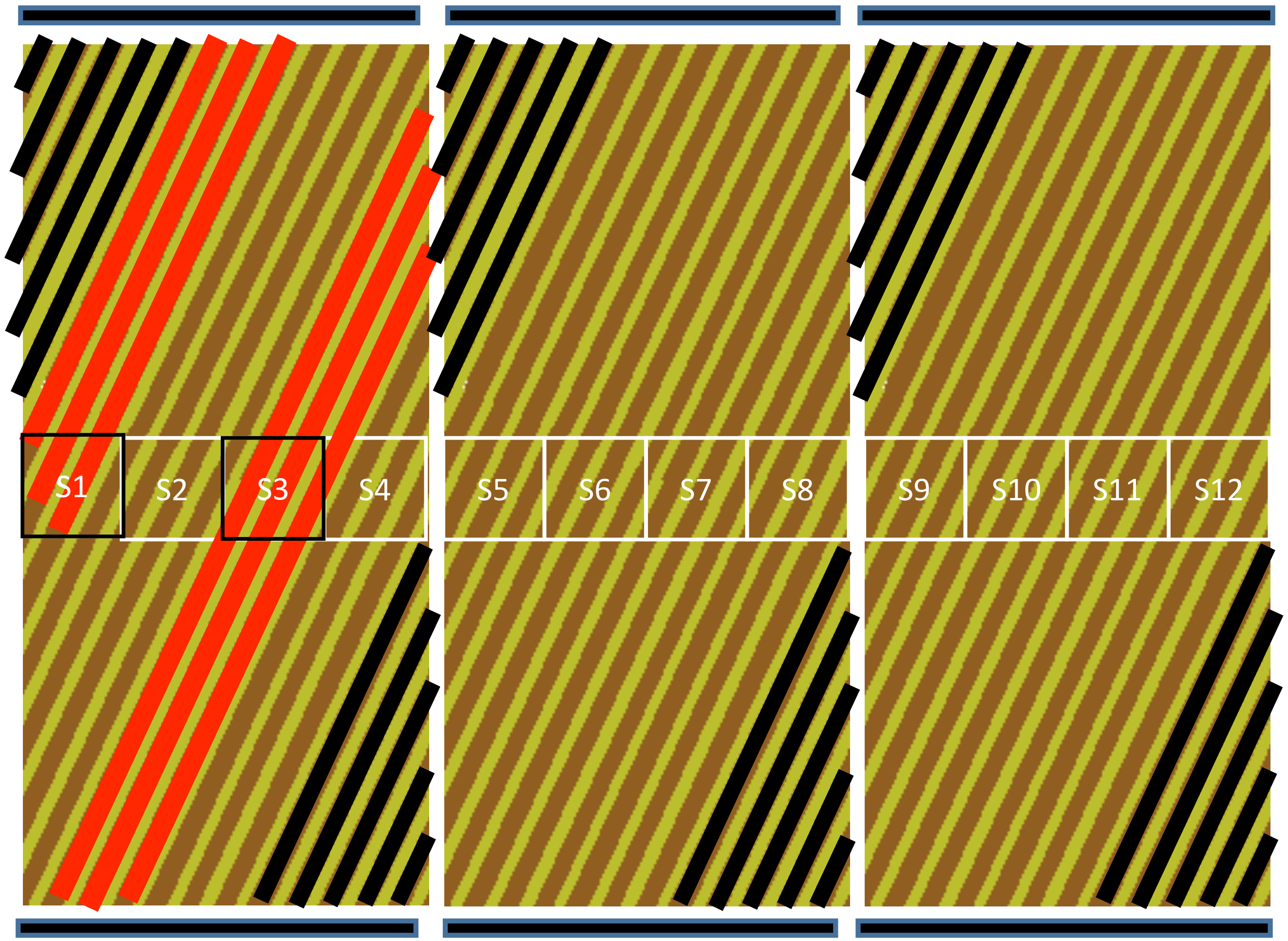
V-view Fired Strips

V-view Strips not illuminated with ^{90}Sr

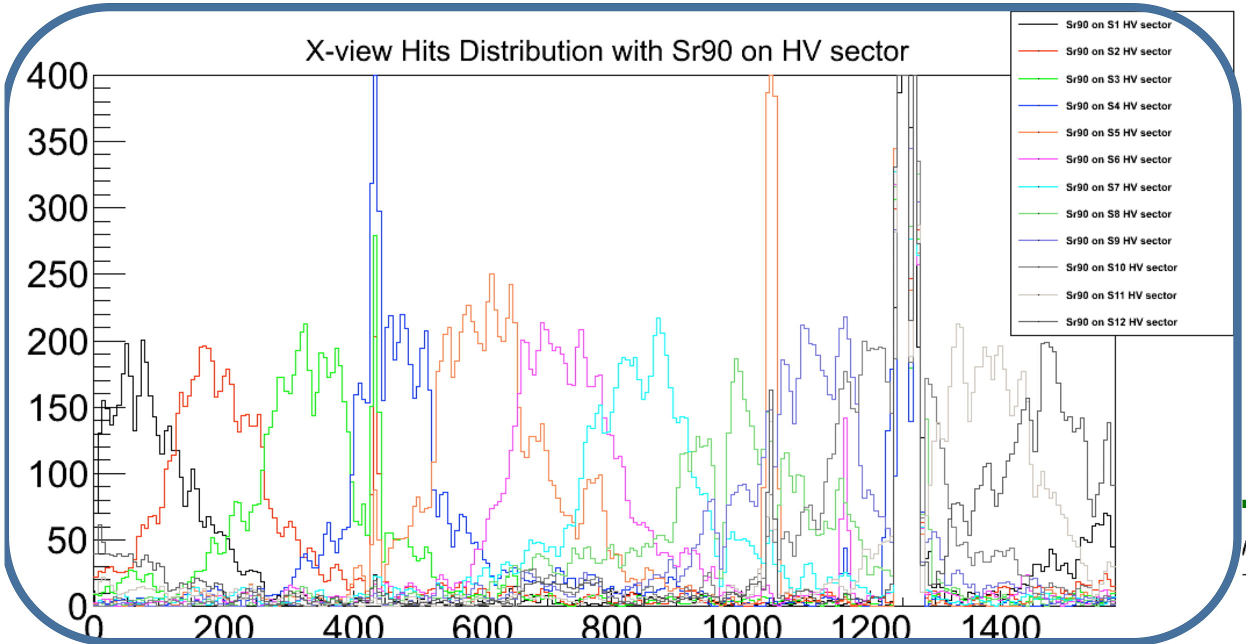
Source on S3

V-view Fired Strips

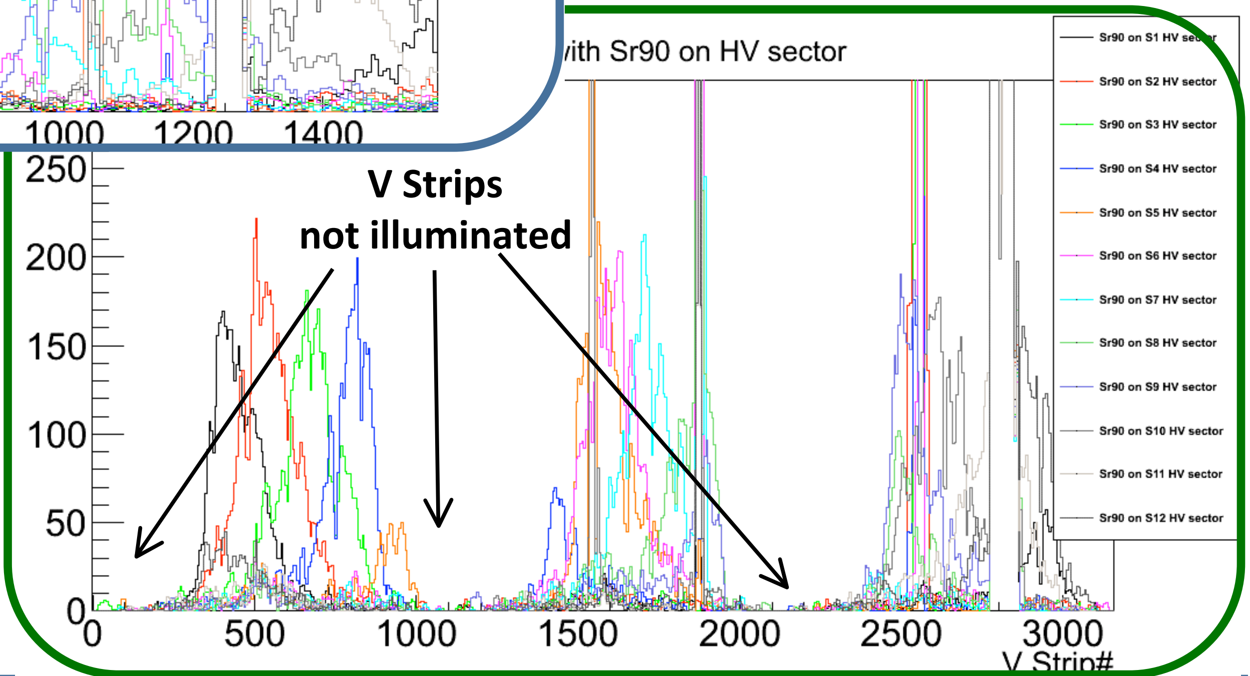
FEE Boards →



Layer 2 ^{90}Sr Source Scan



❖**X-view Hits Distribution** obtained with ^{90}Sr Scan on HV Sectors



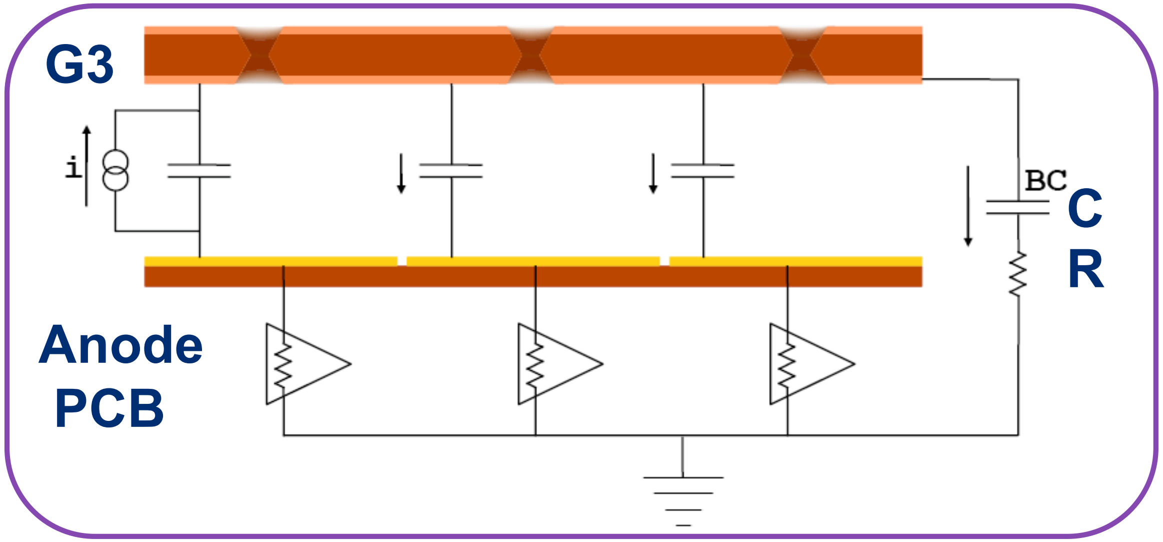
❖**V-view Hits Distribution** obtained with ^{90}Sr Scan on HV Sectors

HV Network of 3rd GEM foil(I)

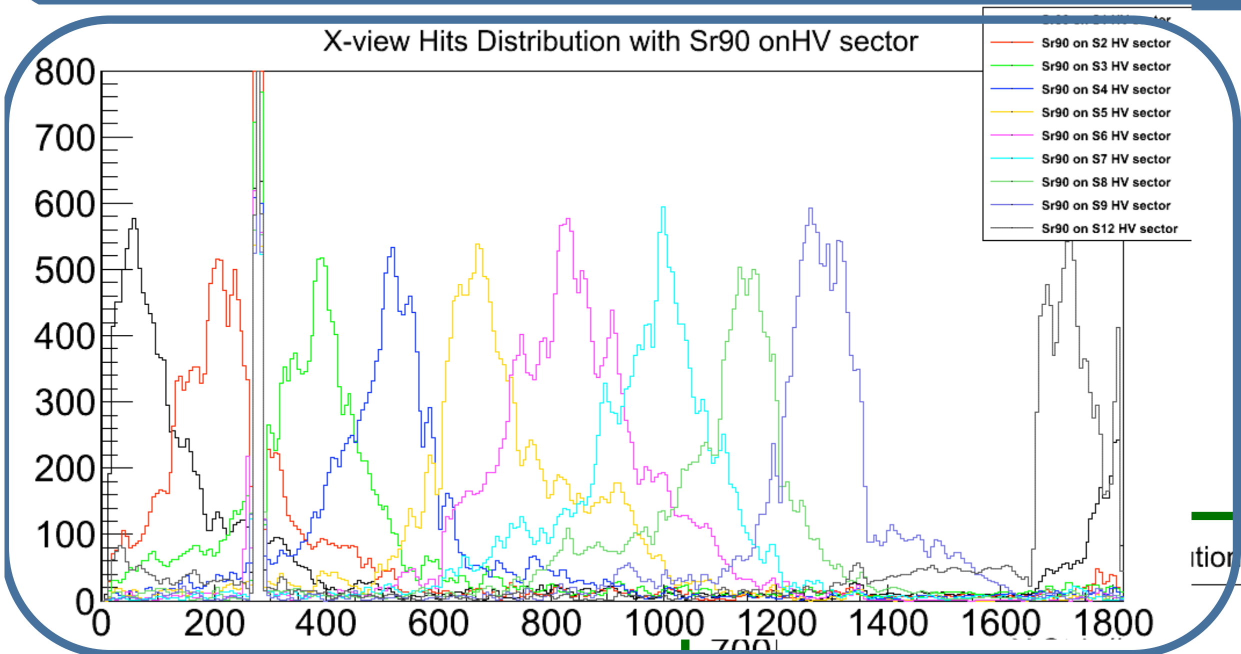
❖ Correlated noise O(10%) observed on the CGEM (the first time in LHCb-GEMs)

❖ Effect explained as cross-talk due to capacitive coupling between G3_bottom and Readout plane: in events with large charge deposit, the current on the common G3_bottom could induce overthreshold signals on neighboring strips/pads (facing G3_bottom) , originating Splash Events: Large Hit Multiplicity Events

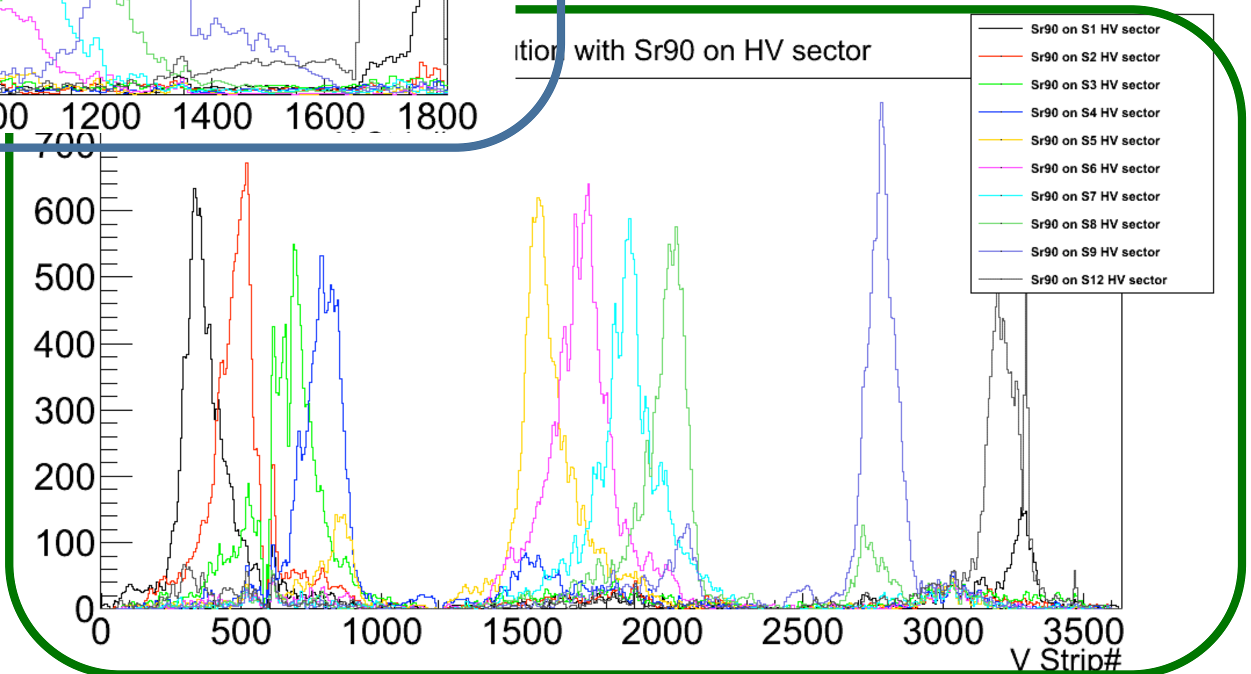
❖ Splash Events are strongly suppressed by the insertion of a **Blocking Capacitor (BC):** by suitable tuning of the R and C values , the current induced on G3_bottom flows through the BC rather than through detectors.



Layer 3 with BC ^{90}Sr Source Scan



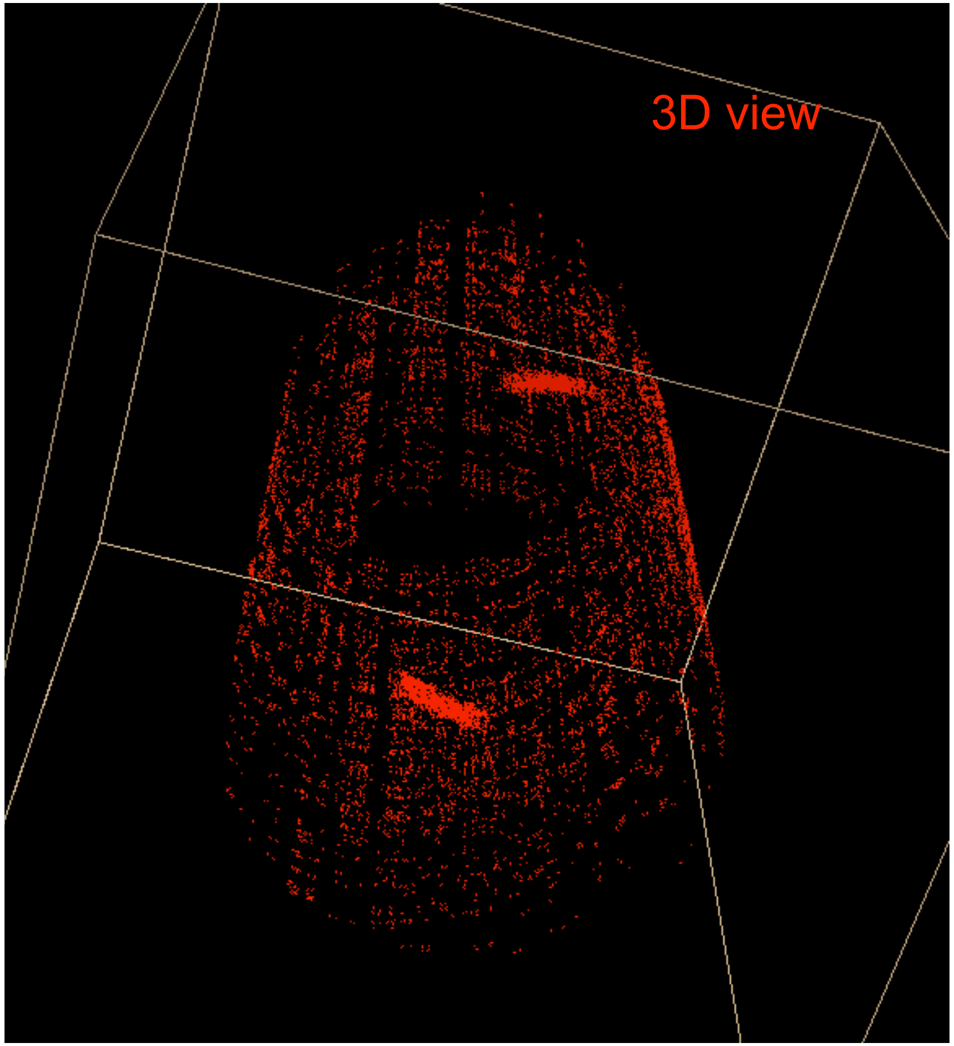
❖ **X-view Hits Distribution** obtained with ^{90}Sr Scan on HV Sectors



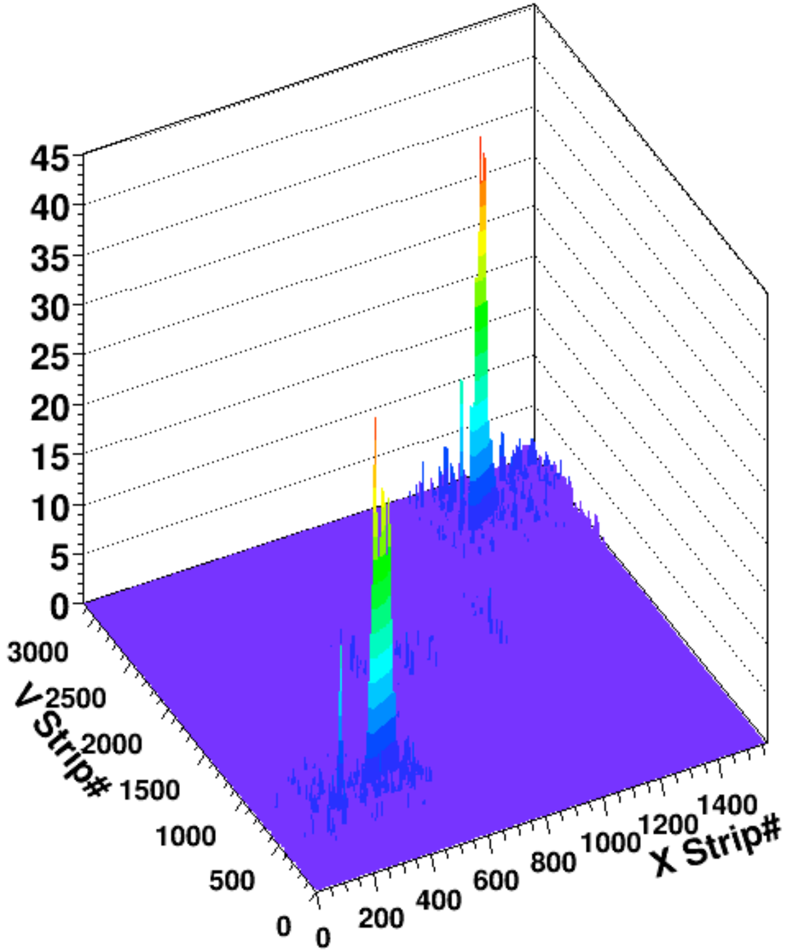
❖ **V-view Hits Distribution** obtained with ^{90}Sr Scan on HV Sectors

Layer 2 Validation with cosmic-ray muons

❖ Selecting events using External Tracking provided by 3 Planar Triple-GEM



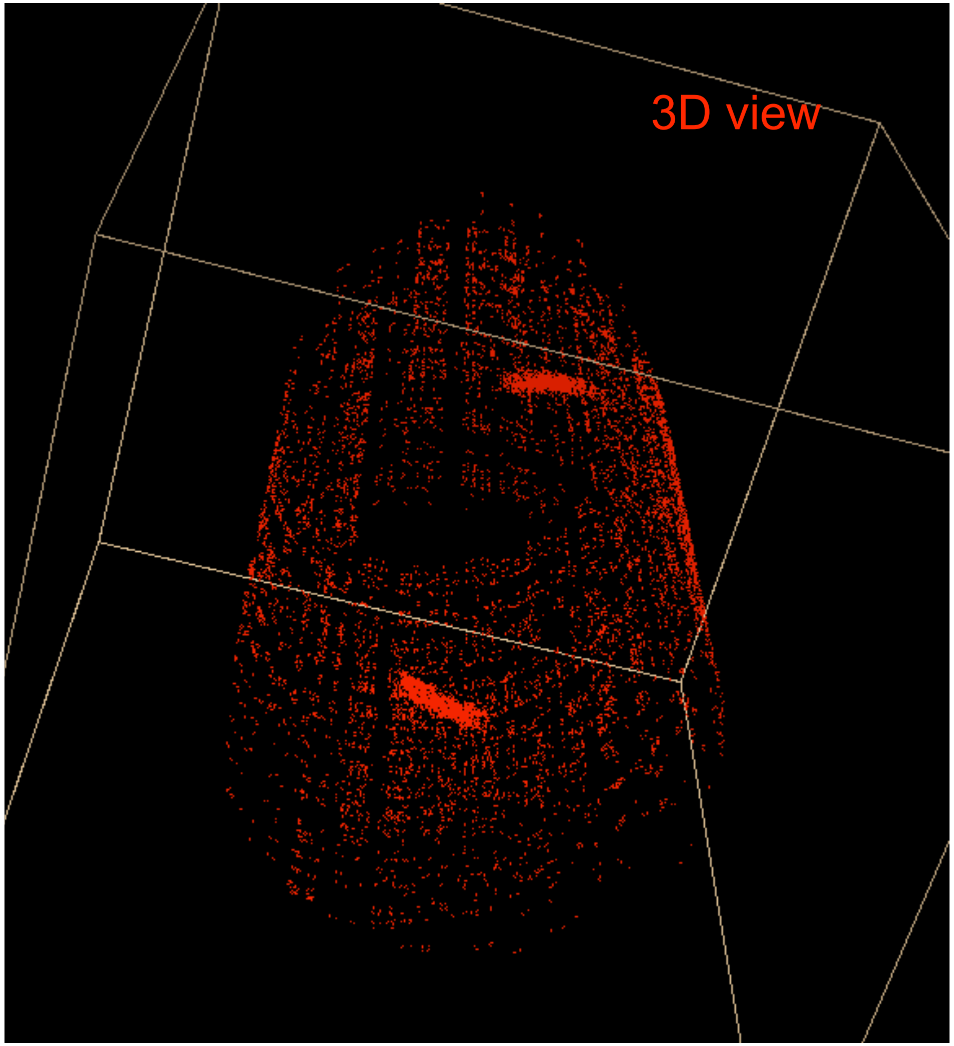
Work In Progres

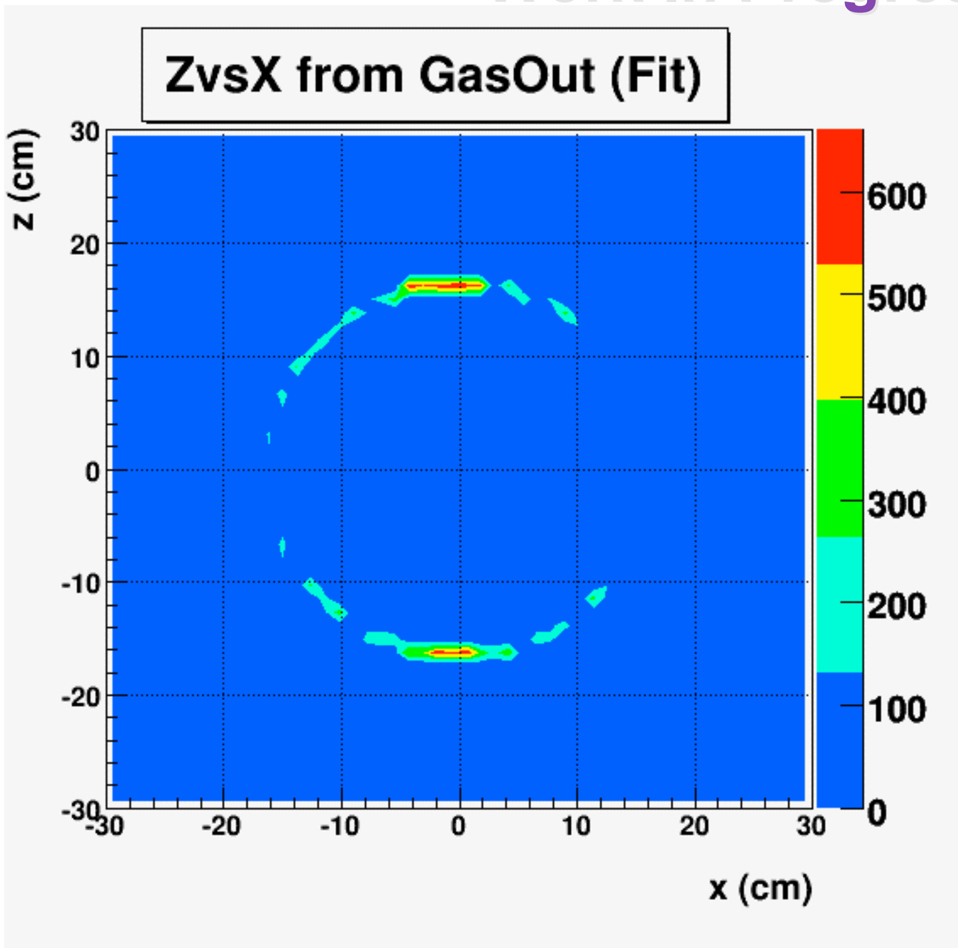


Layer 2 Validation with cosmic-ray muons

❖ Selecting events using External Tracking provided by 3 Planar Triple-GEM

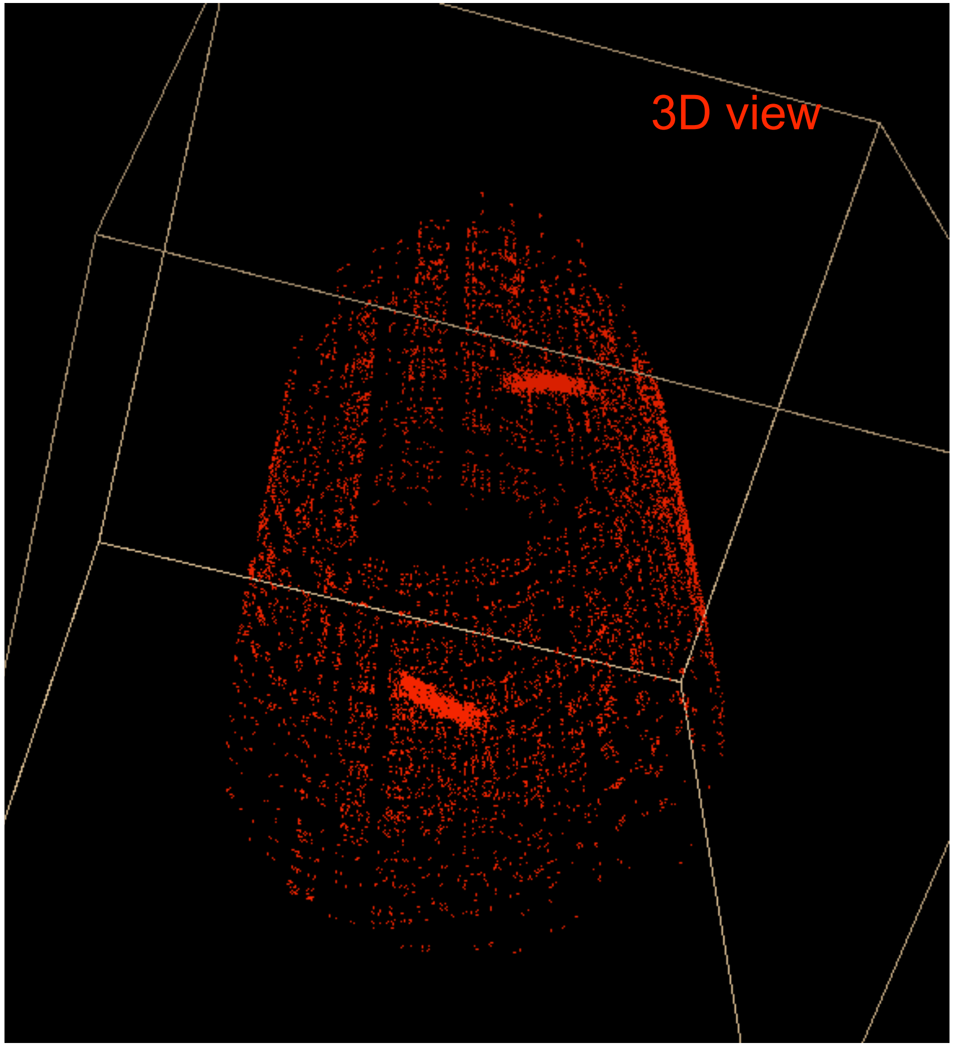
Work In Progres





Layer 2 Validation with cosmic-ray muons

❖ Selecting events using External Tracking provided by 3 Planar Triple-GEM



Work In Progres