Erika De Lucia
for the KLOE-2 Inner Tracker Group

Status of Cylindrical-GEM project for the KLOE-2 Inner Tracker

The KLOE-2 Inner Tracker Group

G. De Robertis, N. Lacalamita, R. Liuzzi, F. Loddo, M. Mongelli, A. Ranieri, V. Valentino
INFN Bari, Bari, Italy

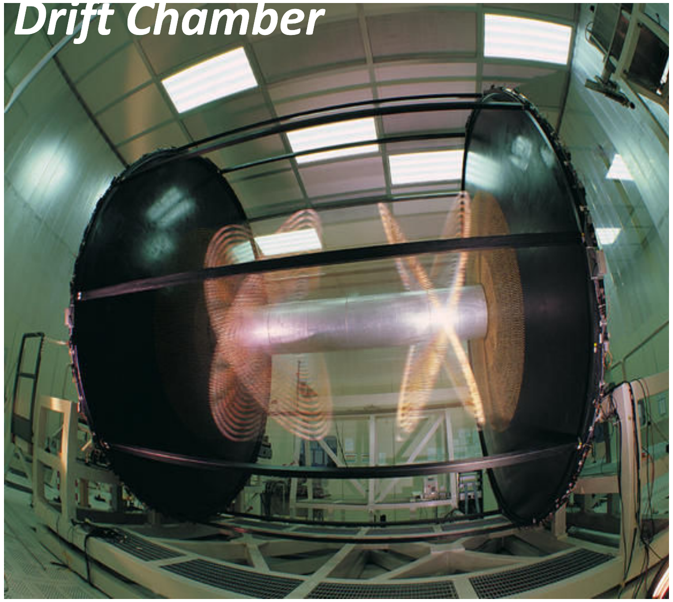
G. Morello, M. Schioppa
INFN Cosenza, gruppo collegato LNF, Cosenza, Italy

A. Balla, G. Bencivenni, S. Cerioni, P. Ciambrone, E. De Lucia, D. Domenici, J.Dong, G. Felici, M. Gatta, M. Jacewicz, S. Lauciani, V. Patera, M. Pistilli, L. Quintieri, E. Tshadadze
Laboratori Nazionali di Frascati - INFN, Frascati, Italy

A. Di Domenico, M. Capodiferro, A. Pelosi
INFN Roma, Roma, Italy

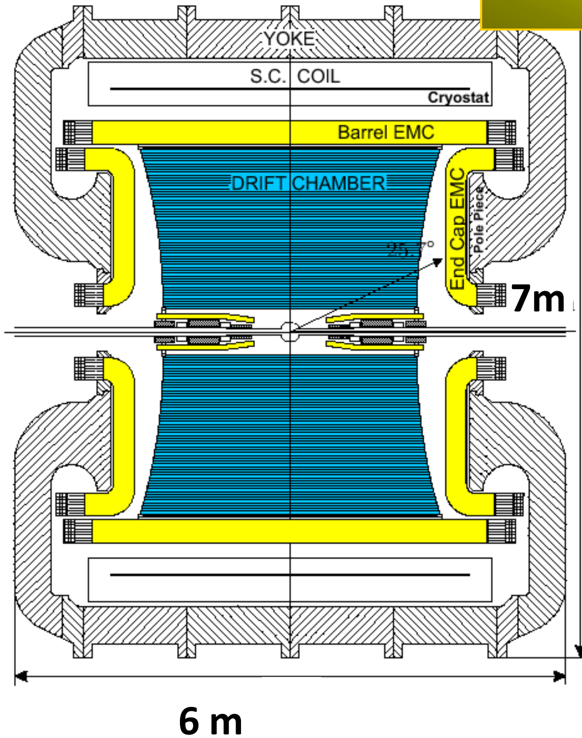
KLOE at DAΦNE ϕ-factory

- 4 m diameter 3.3 m length
- 90% helium, 10% isobutane
- 12582/52140 sense/tot wires
- All-stereo geometry



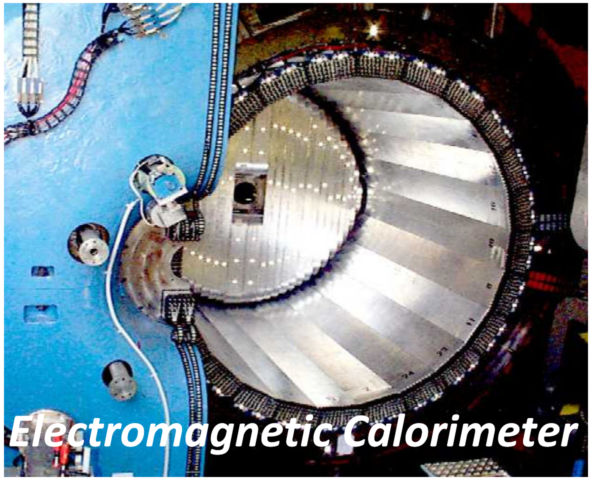
$\sigma_{r\phi}$ = 150 μm σ_z = 2 mm
σ_V = 3 mm σ_p/p = 0.4 %

λ_{KS} = 0.6 cm
λ_{KL} = 340 cm
$\lambda_{K\pm}$ = 95 cm



B = 0.52 T

- Lead/scintillating fiber
- 98% coverage of solid angle
- 88 modules (barrel + end-caps)
- 4880 PMTs (two side read-out)



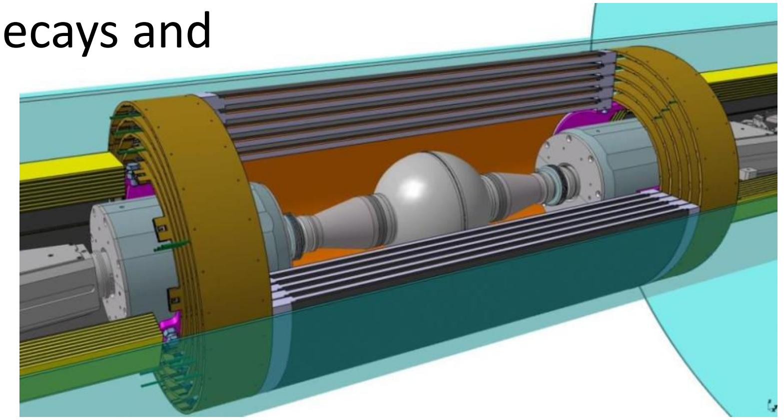
$\sigma_E/E = 5.4\%/\sqrt{E(GeV)}$

$\sigma_t = 54\ \text{ps}/\sqrt{E(GeV)} \oplus 50\ \text{ps}$(calib)

KLOE-2 Inner Tracker Upgrade

For fine vertex reconstruction of **K_s , η and η'** rare decays and **K_s- K_L interference measurements :**

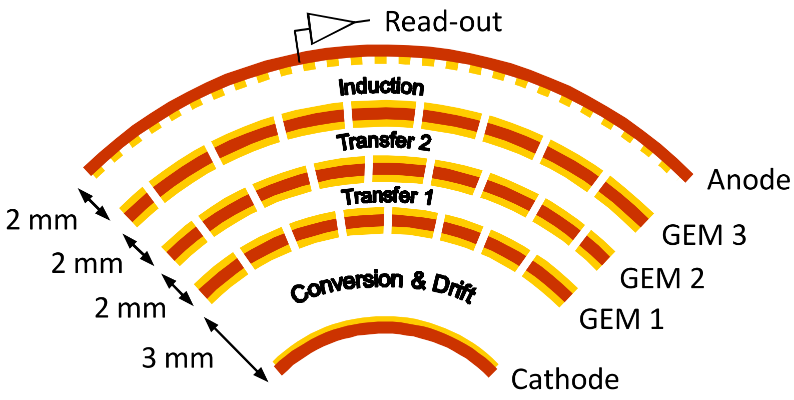
- **$\sigma_{r\phi} \sim 200\ \mu m$ and $\sigma_z \sim 500 \mu m$**
- **low material budget**:<2%X_0
- 5 kHz/cm^2 rate capability



Cylindrical GEM detector is the adopted solution

- **5 CGEM** layers with radii from **13** to **23** cm from IP and before DC Inner Wall
- **700 mm** active length
- **XV strips-pads readout (40° stereo angle)**
- **1.5% X_0** total radiation length in the active region with Carbon Fiber supports

Cylindrical Triple GEM



$K_S \rightarrow \pi\ \pi$ vertex resolution will improve of about a factor 3 from present **6mm**

The IT with CGEM technology

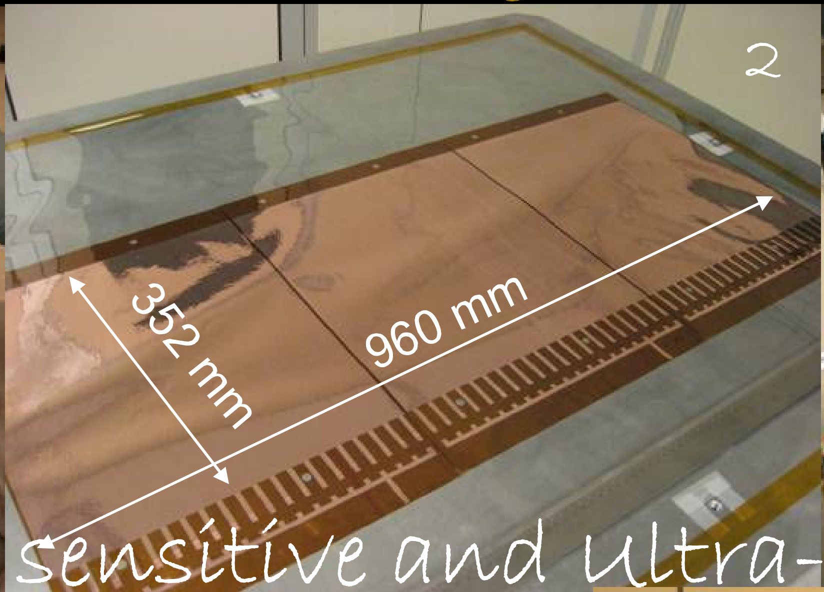
The **CGEM** is a ***low-mass, fully cylindrical*** and ***dead-zone-free*** GEM based detector: **no support frames are required inside the active area**

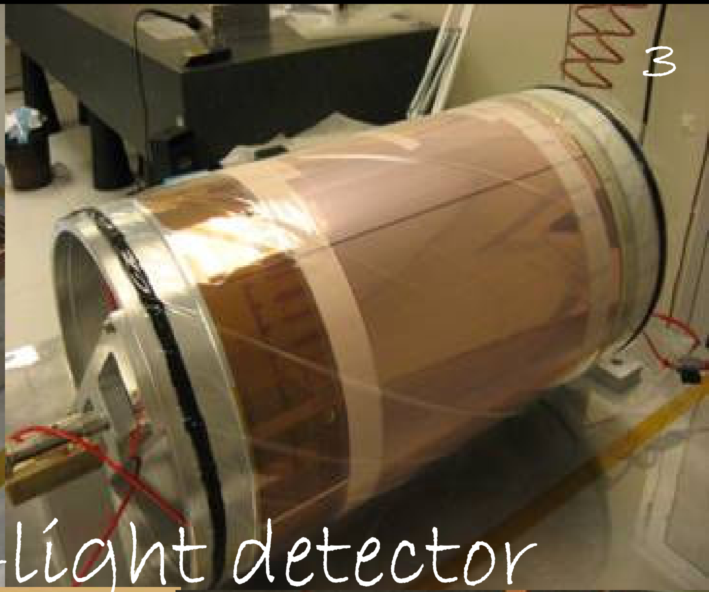
The main steps of the R&D project:

1. Construction and complete characterization of a **full scale CGEM prototype**
2. Study the **XV strip** readout configuration and its operation in **magnetic field**
3. 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: construnction





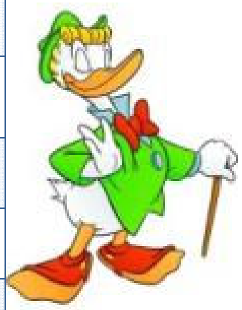
Full sensitive and Ultra-light detector

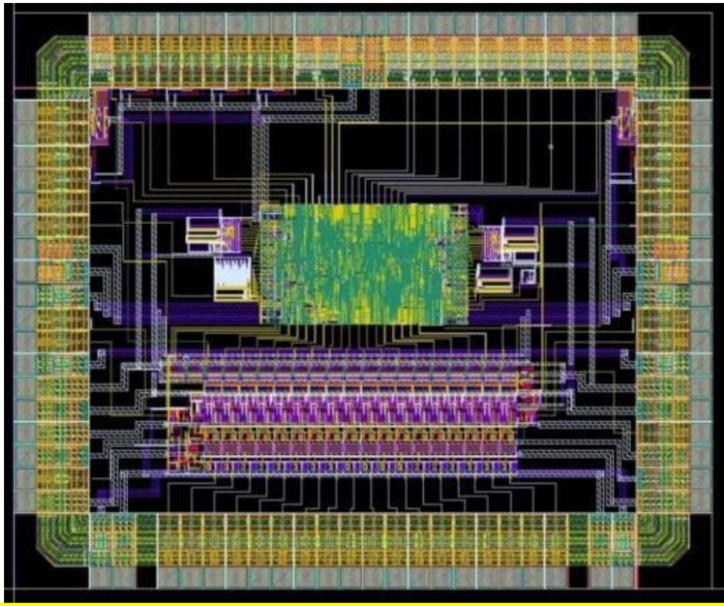
1. Distribution of epoxy on foil edge
2. 3 spliced foils ~1000mm long
3. Cylindrical mould in vacuum bag
4. Cylindrical GEM foil
5. Cylindrical Cathode with annular fiberglass support flanges

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

GASTONE: the IT dedicated FEE chip

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 (erms)	800 e^- + 40 e^-/pF
Channels/chip	64*
Readout	LVDS/Serial
Power consum.	≈ 0.6 mA/ch



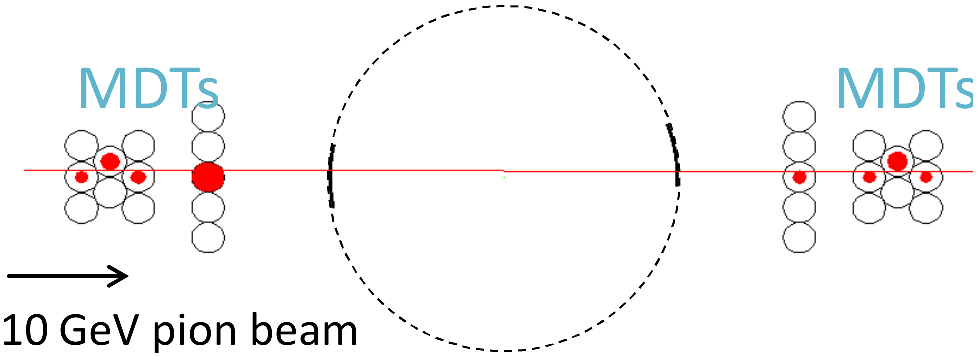


0.35 CMOS technology- no Rad-Hard

- **Mixed analog-digital circuit** (KLOE-2 dedicated);
- **Low input equivalent noise, low power consumption** and **high integrated chip;**
- 4 blocks:
  - **charge sensitive preamplifier**
  - **shaper**
  - **leading-edge discriminator** (prog. thr.)
  - **monostable** (stretch digital signal for trigger)

16-chs GASTONE prototype

(1) CGEM prototype: test-beam

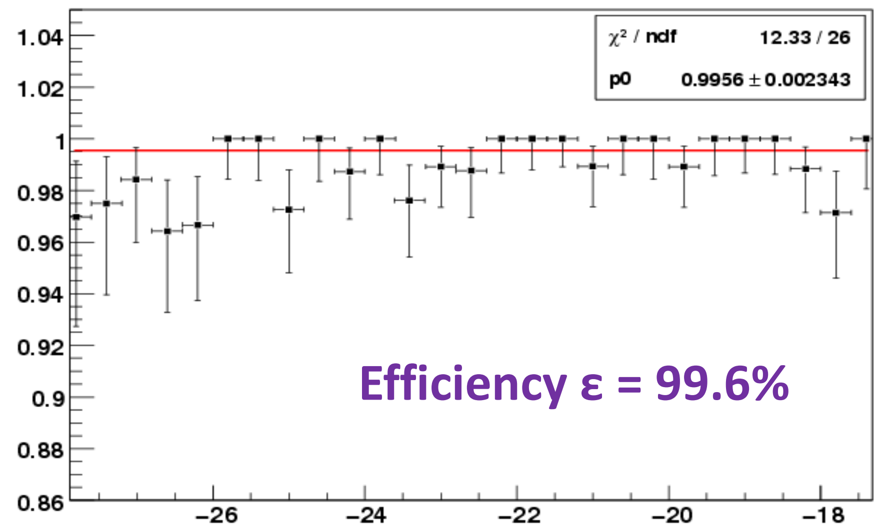


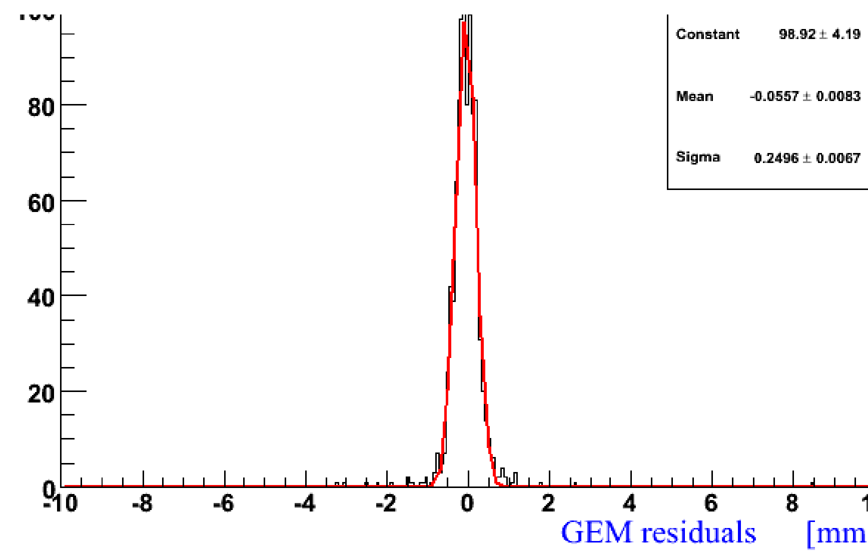
10 GeV pion beam
CERN-PS T9 area

Gas: Ar/CO_2 = 70/30
Fields: 1.5/2.5/2.5 /4 kV/cm
V_{GEM}: 390-380-370 =1140V, gain~$2 \cdot 10^4$

FEE: 16-channels GASTONE [NIMA 604 (2009)]
Trigger: 2x8-MDT stations -- External Tracking
Overall detector stretching load 50 kg

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

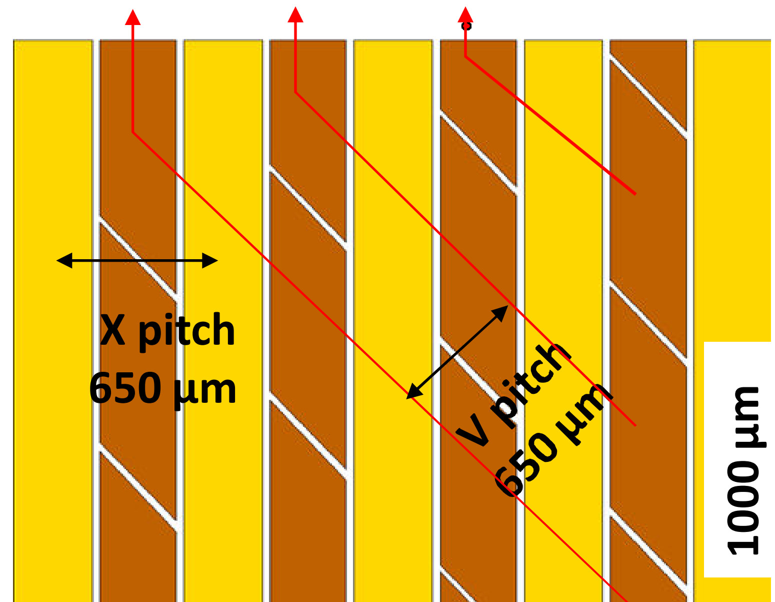


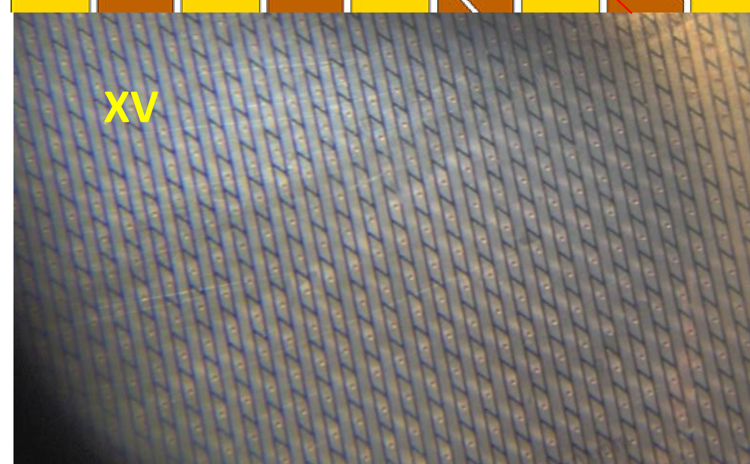


(2) XV readout and magnetic field

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

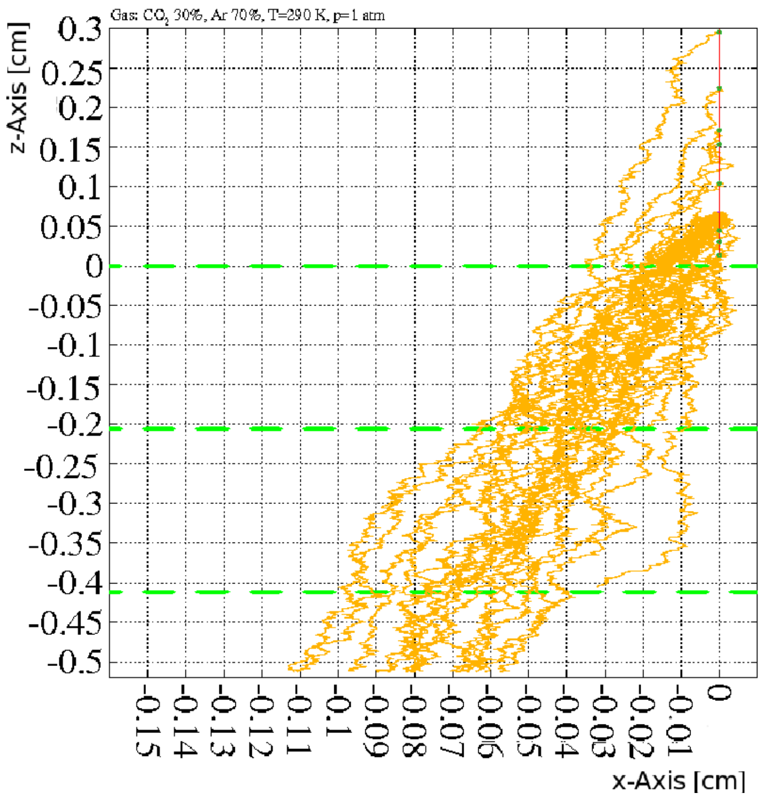




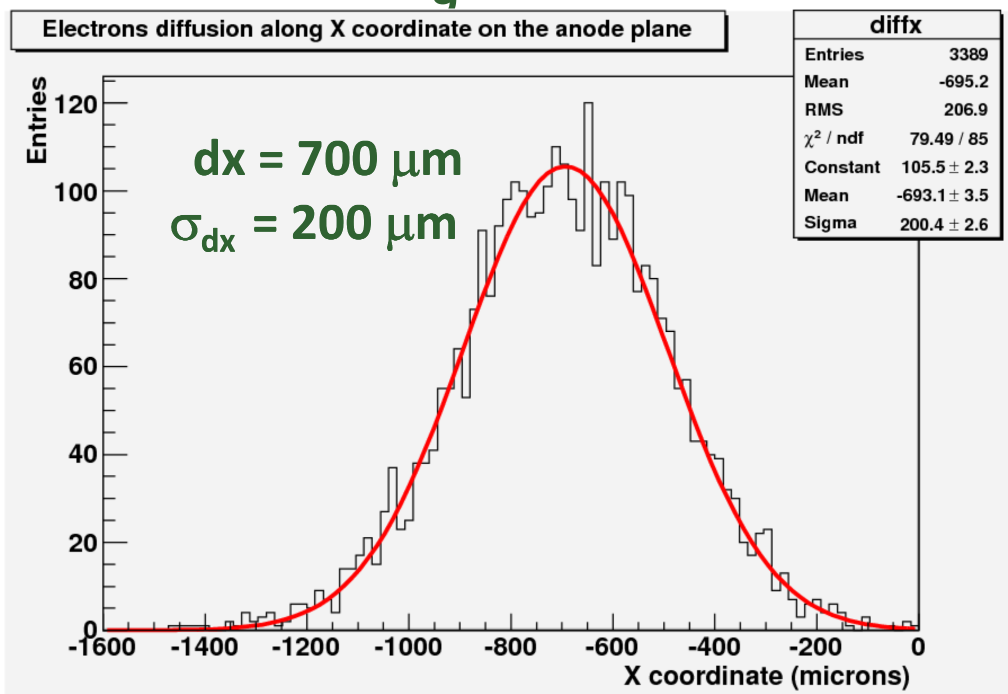
(2) XV readout and magnetic field

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

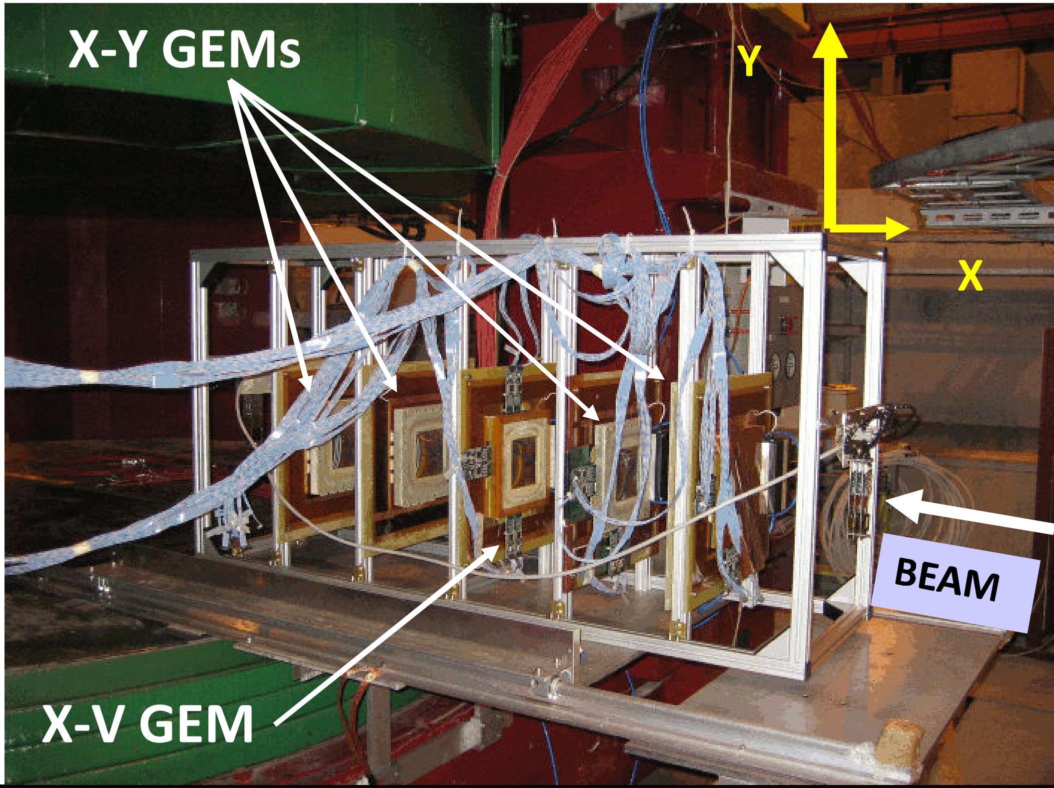
- H4 beam-line at CERN-SPS: **150 GeV pions**
- Goliath Magnet: dipole field up to **1.5T** in a **~3x3x1m³**
- Semi-permanent setup for RD51 users

Gas: Ar/CO_2 = 70/30
Fields: 1.5 - 3.0 - 3.0 - 5.0 kV/cm
V_{GEM}: 390-380-370 =1140V, gain~$2 \cdot 10^4$

FEE: GEMs partially equipped with 22 GASTONE boards

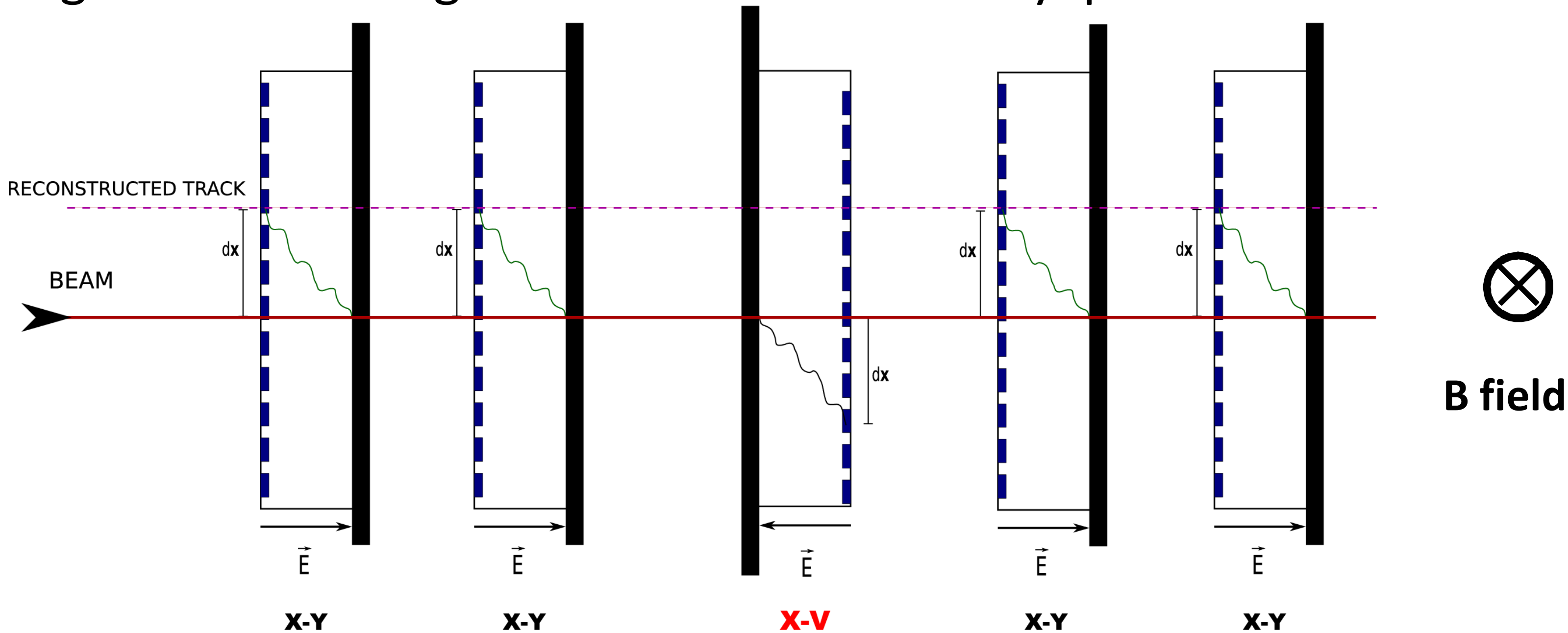
Trigger: 6 scintillators with SiPM (3 upstream, 3 downstream)

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

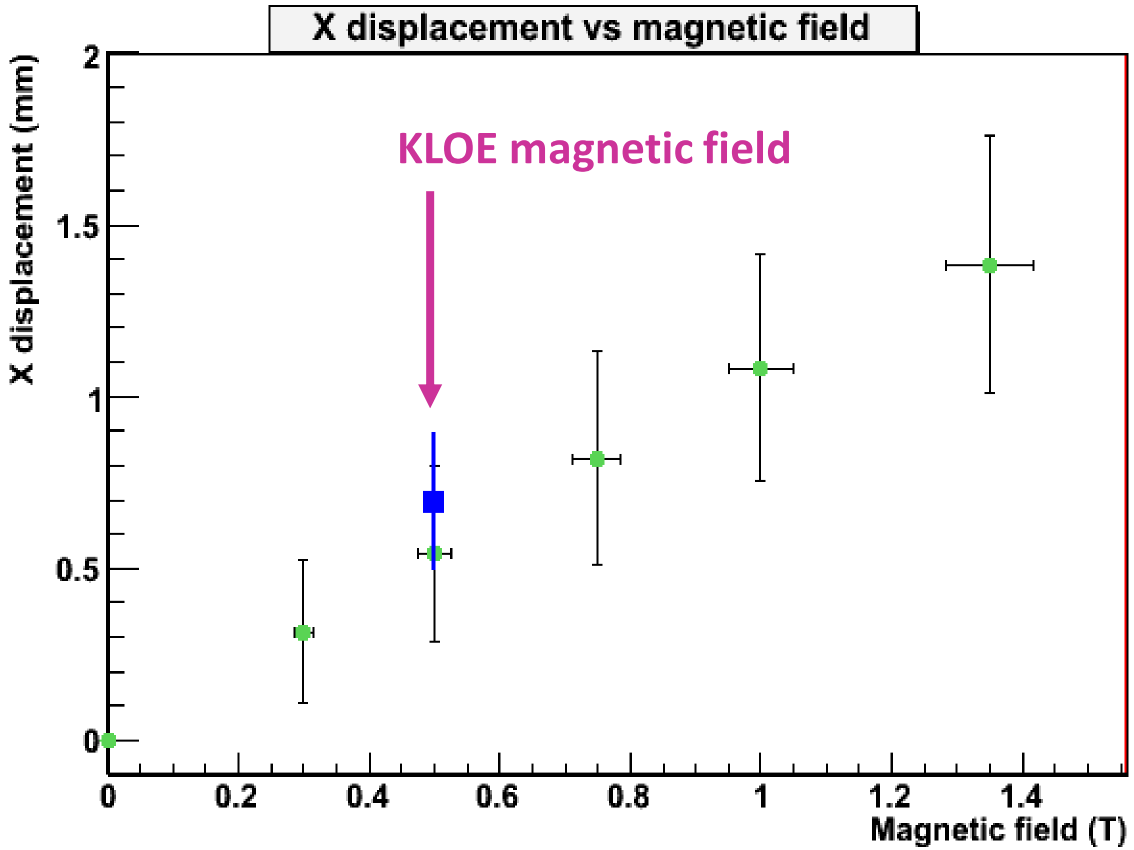


- Align the setup with B = 0
- Turn on B field
- Track reconstruction using the 4 X-Y GEMs (<u>likewise oriented</u>)
- Measure the displacement on the X-V GEM (<u>reversed wrt the other GEMs</u>)

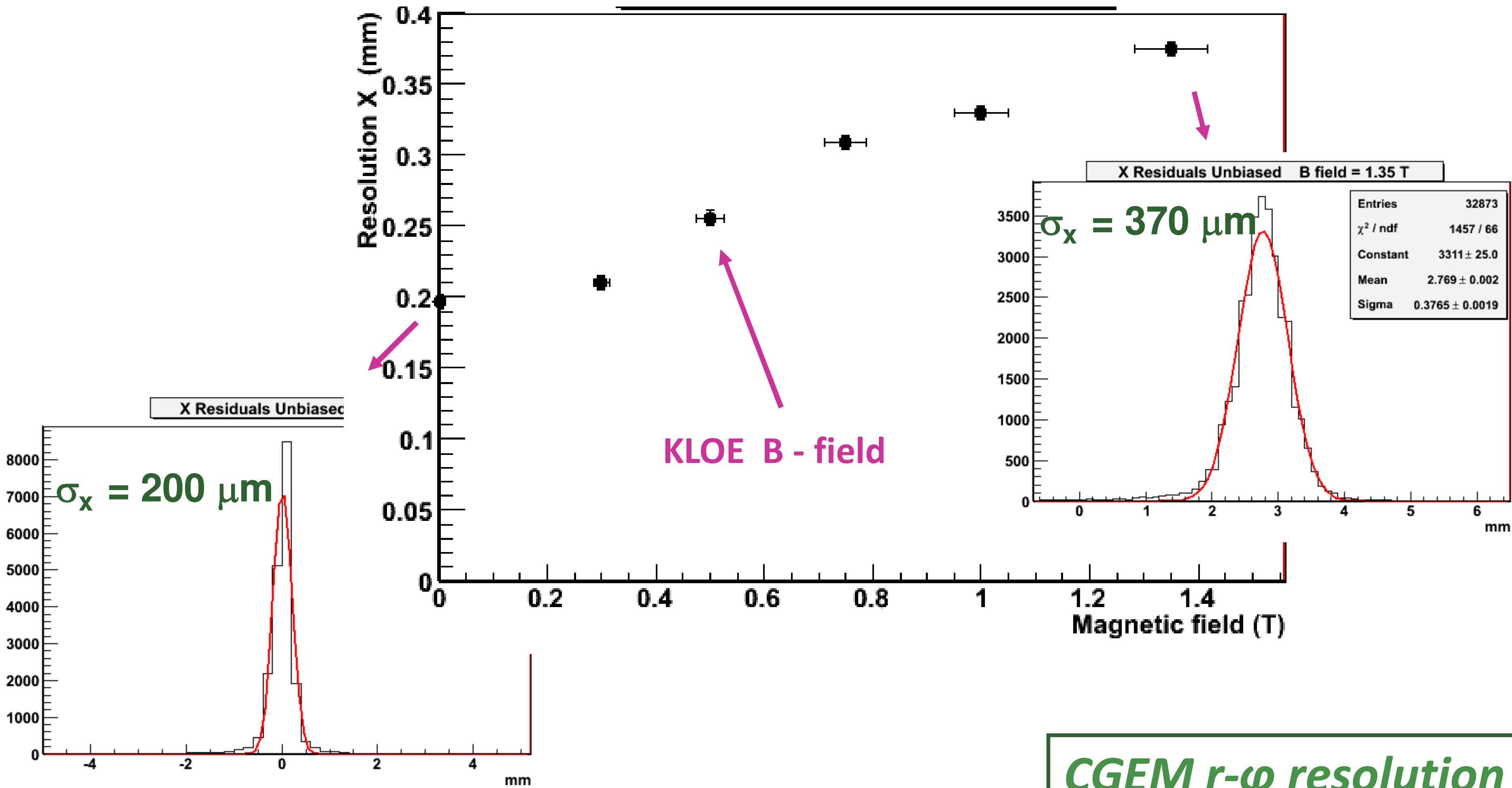
D = 2 × dx → $\tan(\theta_L) = \mathbf{D}/2r$ (r = effective detector thickness)

(2) B-induced displacement

Distribution of **dx = D (measured displacement)/2** as a function of B field
The blue point is the displacement value from GARFIELD simulation at B=0.5T



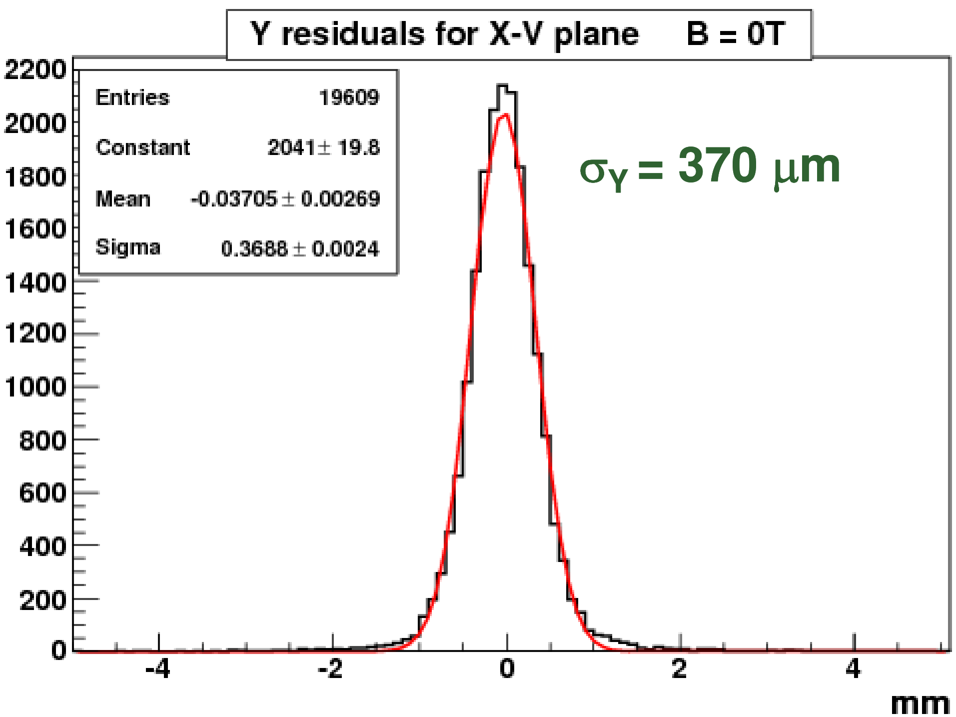
(2) Spatial resolution: X-view

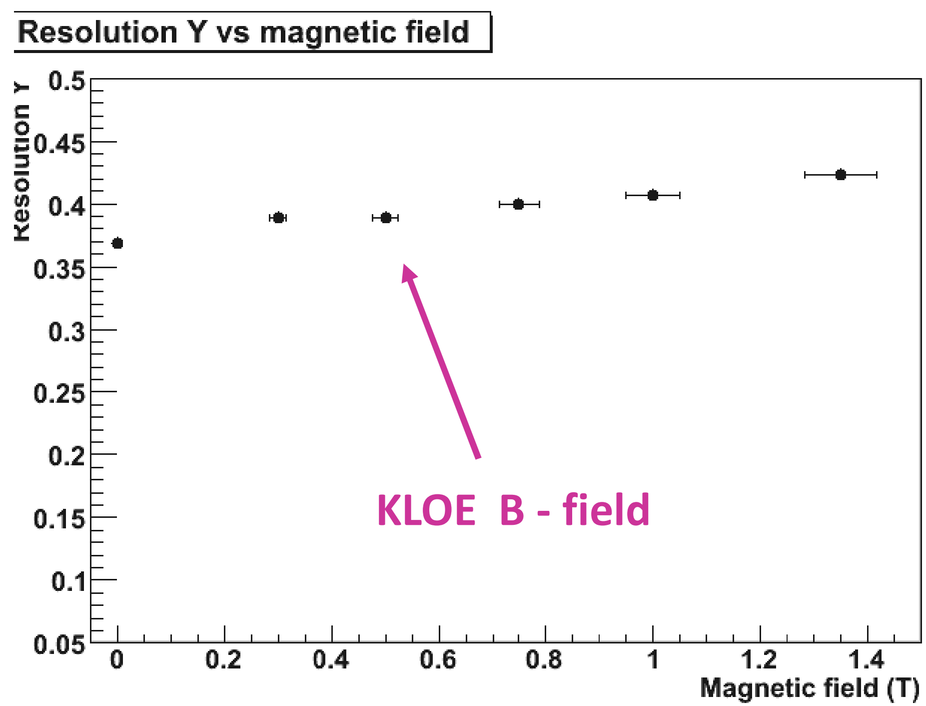


CGEM r-φ resolution

(2) Spatial resolution : Y coordinate

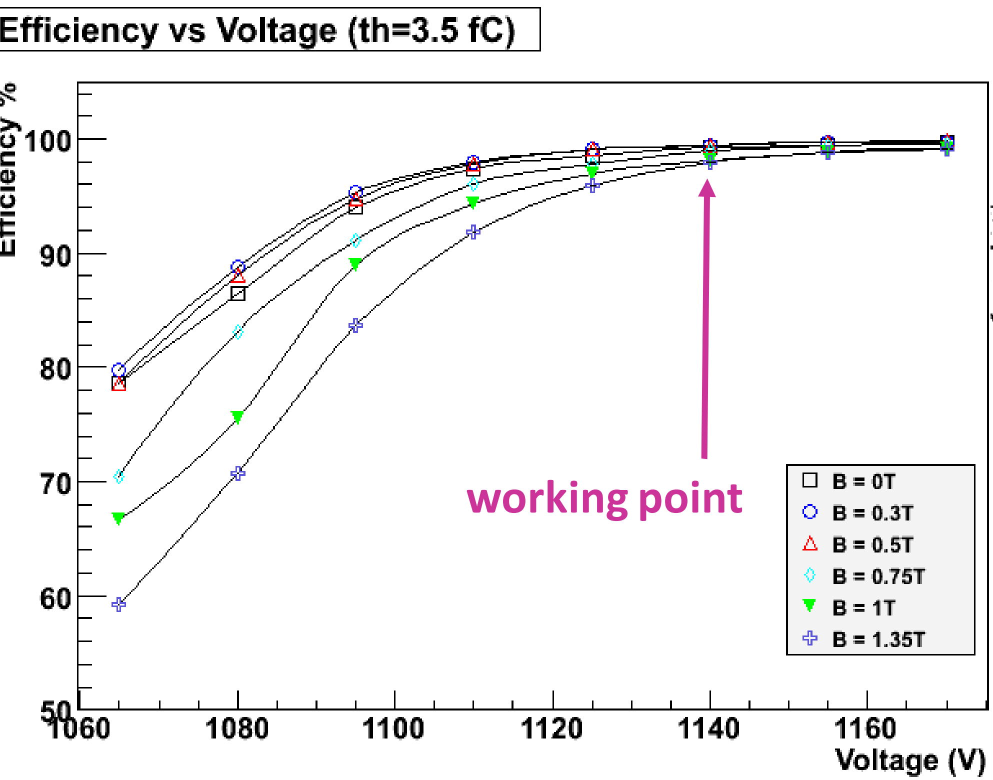
The Y coordinated is measured from the crossing of X and V views



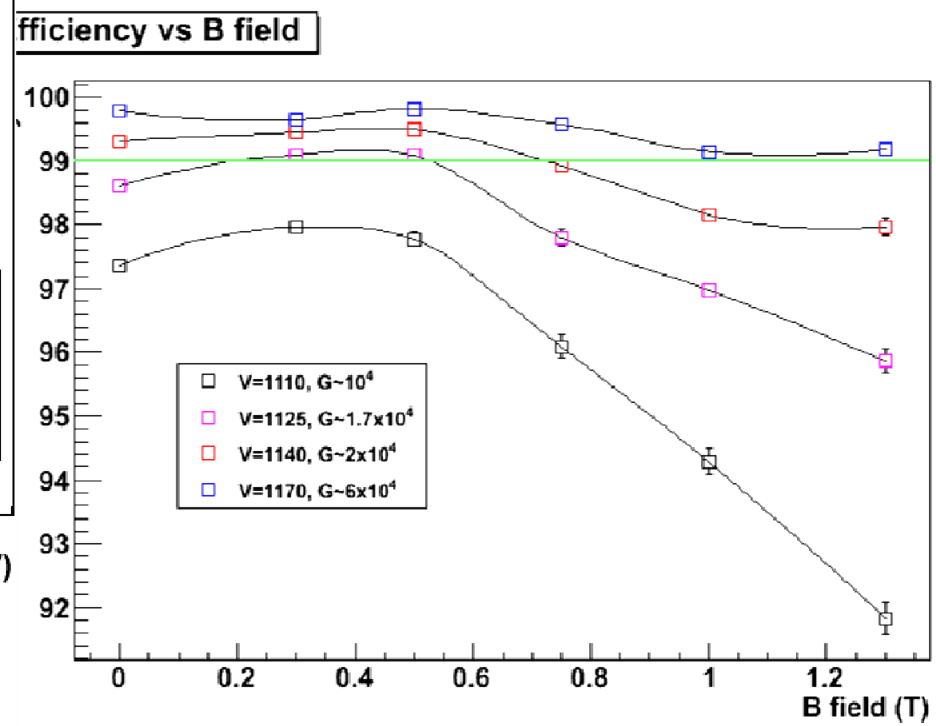


CGEM z resolution

(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**

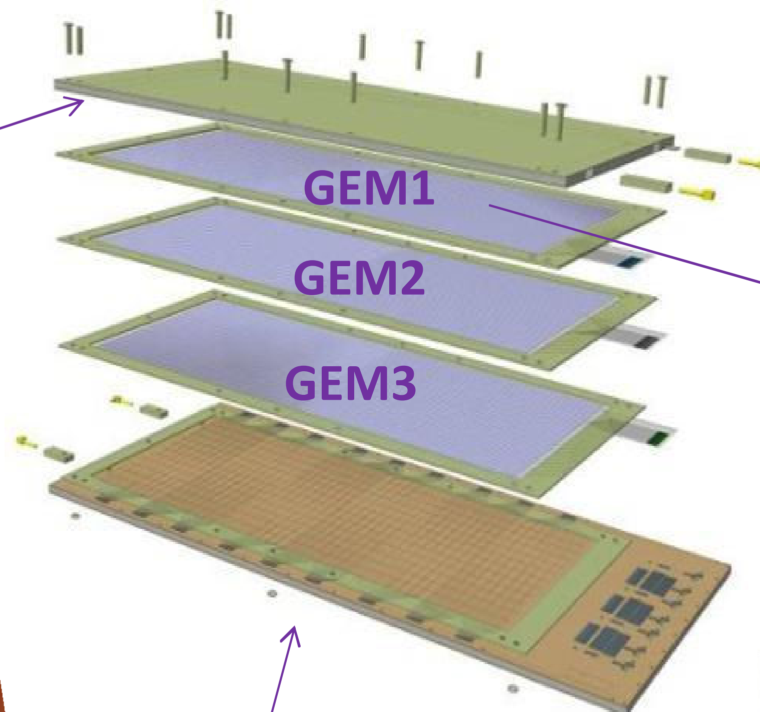


The **increase of the magnetic field,** increasing the spread of the charge over the readout strips (less charge is collected by each single pre-amp channel) results in an efficiency drop, thus **requiring for higher gain to efficiently operate the detector.**

(3) Large Area GEM: Planar Prototype

70x30 cm^2 Triple-GEM planar Single-mask foils using latest CERN technique (*M. Villa*) for quality and uniformity test & equipped with GASTONE 64-channels final release

Cathode PCB



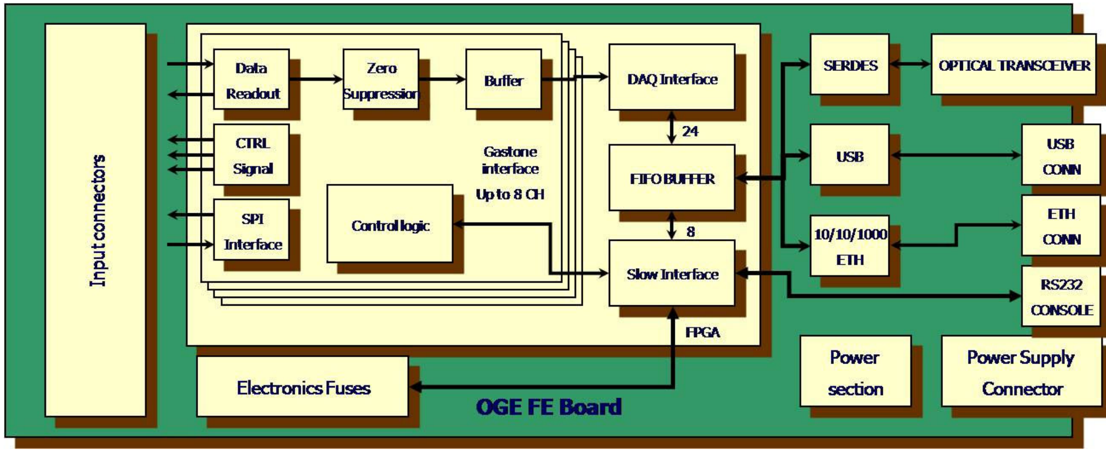
1.5x2.5 cm^2 pad readout PCB

GASTONE 64-chs

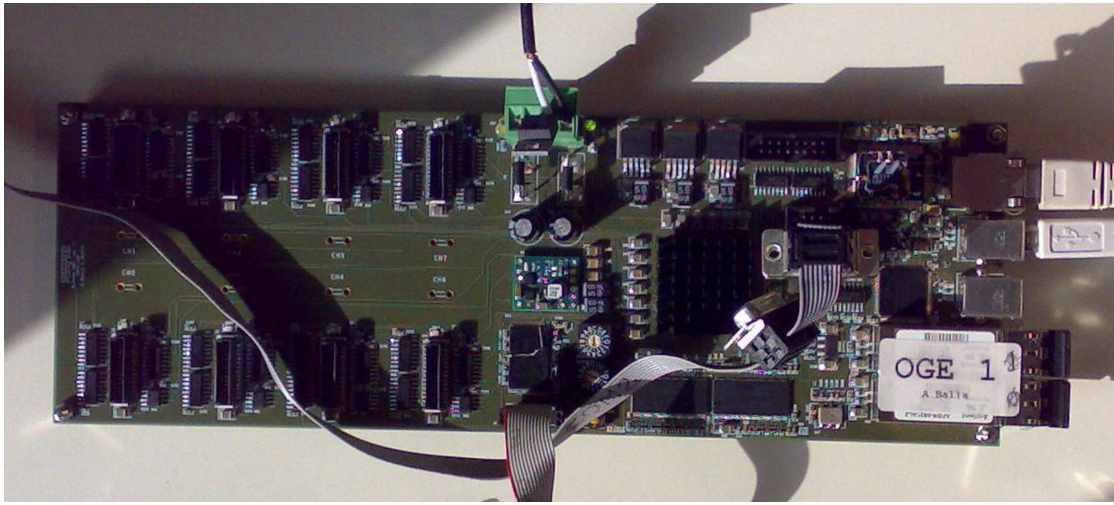
Off Gastone Electronic (OGE) Board

FPGA based board **Xilinx VIRTEX 4FX**

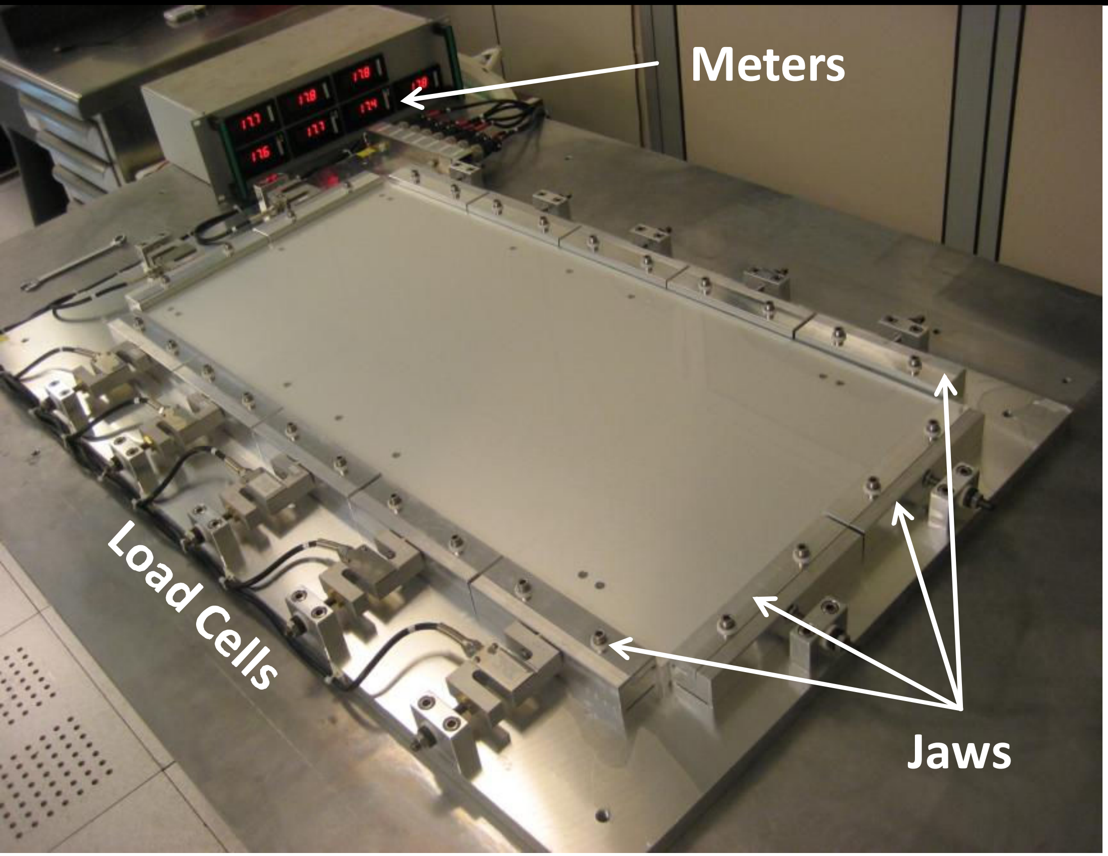
- Manages 1024 channels (8 Gastone Boards)
  - 10 serial-link (100Mb/s) read-out
  - zero suppression algorithm and L1 event building



- Interface
  - Gigabit Ethernet and USB for monitor and debug
  - 2Gbit/s optical link for:
    - DAQ data transmission
    - Trigger signal
    - Slow Control commands



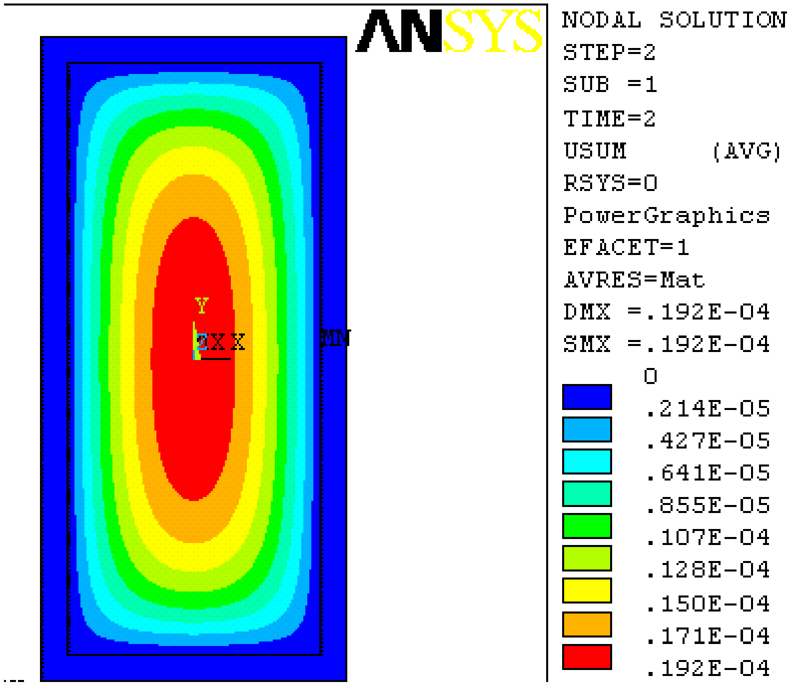
(3) Large Area GEM: Tools & Simulation



A very large **tensioning tool** has been designed. The frame gluing will be performed by using the "**vacuum bag**" technique, tested in the construction of the CGEM

Finite element simulation (ANSYS) with **1 kg/cm**, indicates a maximum gravitational+electrostatic sag of the order of **20 µm**
(O(5 µm) electrostatic only)

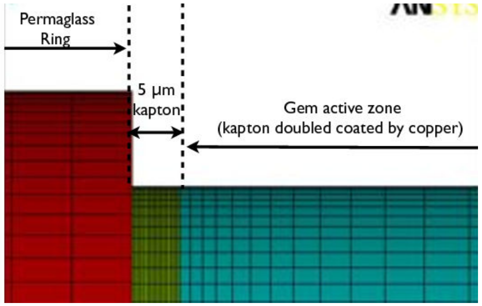
[NIMA doi:10.1016/j.nima.2009.06.063]



Finalizing the project

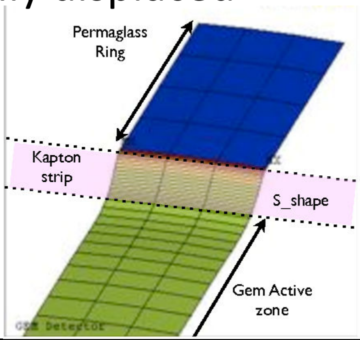
ANSYS finite element 3-D simulation of the CGEM to estimate structural response under tensile loads: induced strain, stress and displacements

- ❖Material characterization to implement accurate description of mechanical behavior:
- ❖Model validation by comparison with CGEM and PGEM prototypes

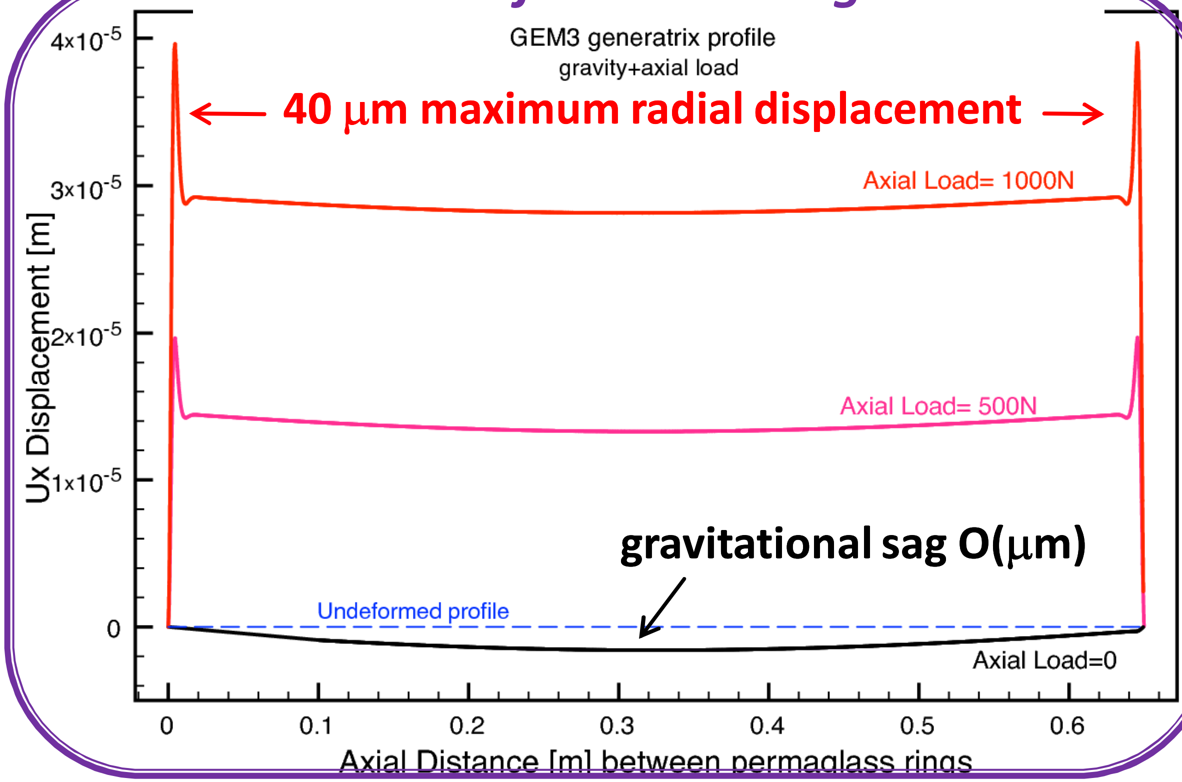


Kapton connects two more rigid structures radially displaced

S-shaped deformation



Simulation of 700 mm length CGEM



Conclusions

- The **CGEM full-size prototype** has been built and tested under different conditions, **validating the new detector idea**

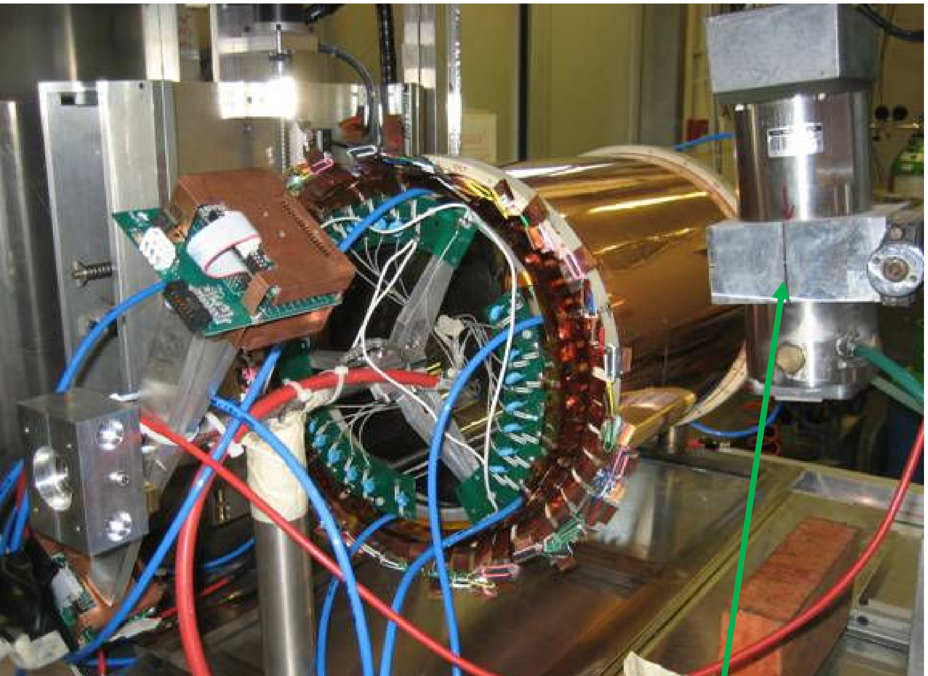
- The final **XV readout configuration** has been succesfully tested in **magnetic field** with small planar GEMs

- We are going to build a l**arge (70x30 cm^2) planar GEM prototype** to test **its quality and homogeneity** and **GASTONE 64-channels FEE** and **OGE Board**

- The **project of the KLOE-2 Inner Tracker** has been **recently approved** : its construction will start in 2010 to be ready for insertion in the KLOE detector by summer 2011

SPARE SLIDES

CGEM characterization with X-ray Test



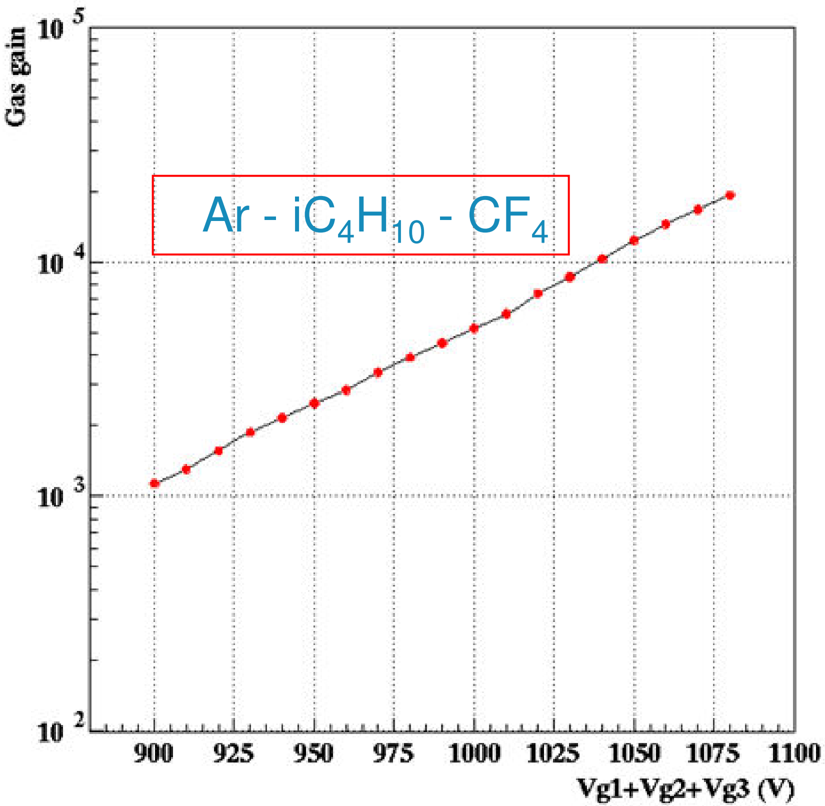
- CGEM in current mode
- $10x10cm^2$ GEM as reference (for pressure/temperature effects)
- Gain and electron transparency measurements were performed
- Uniformity measurement throughout the whole CGEM surface

6 keV X-ray gun

Ref GEM

C-GEM characterization with X-ray Test

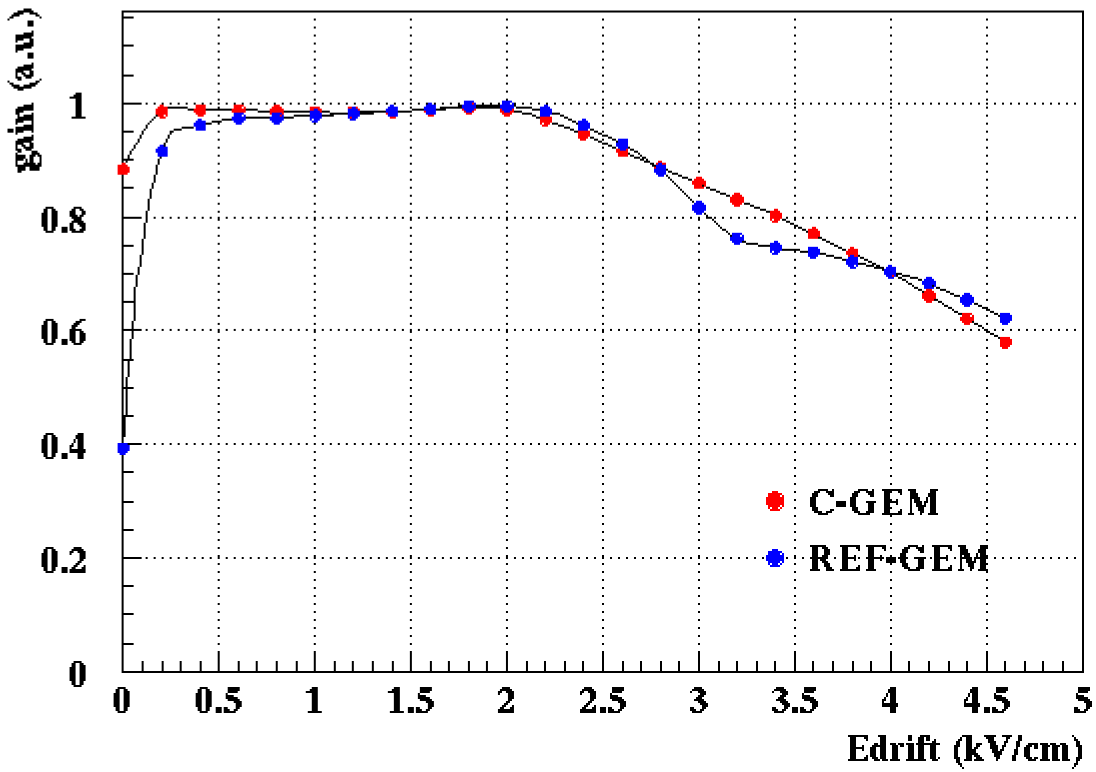
- The *standard* GEM gas mixture is **Ar/CO_2 =70/30**
- The detector is being flushed with a **$Ar/\ iC_4H_{10}\ /\ CF_4 = 65\ /\ 7\ /\ 28$** gas mixture (already characterized by LHCb GEM group)
  - CF_4 helps to match the fast electronics available at the (ASDQ)
  - Isobutane makes safer the detector operation
- Gas gain measured up to **20000**
- **No discharges** or **leakage currents** observed



C-GEM characterization with X-ray Test

GEM polarization: 375/365/355 V

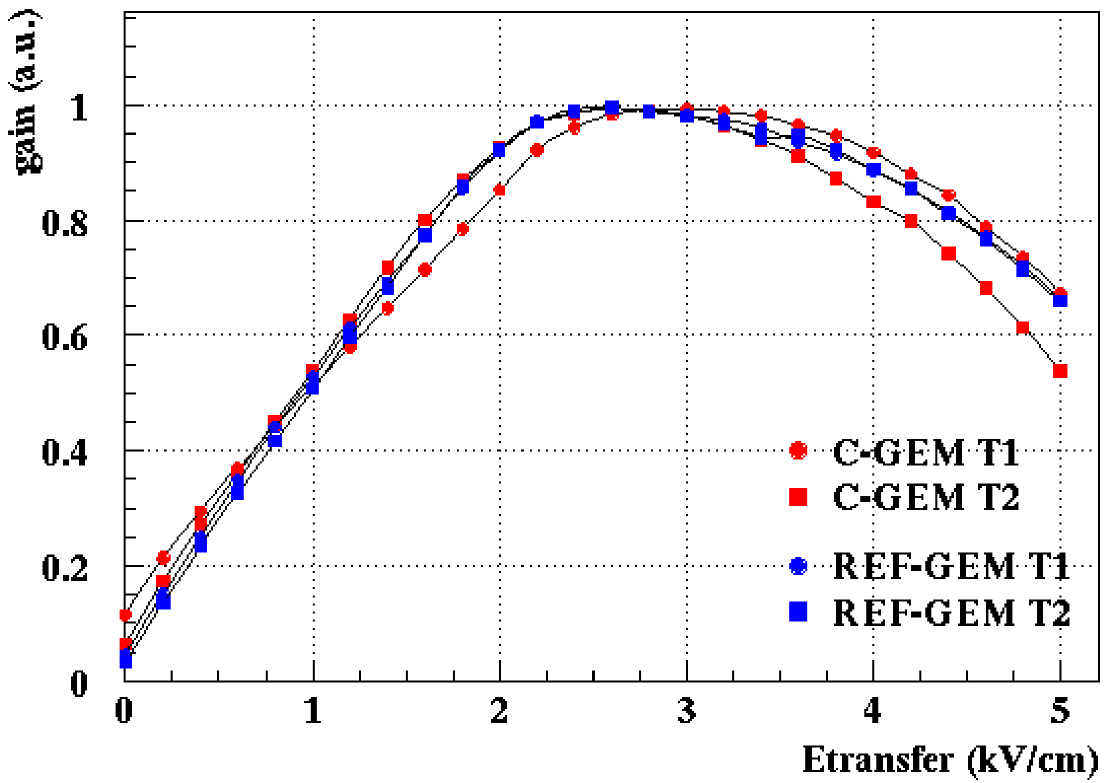
Norm. gain



Drift field

C-GEM characterization with X-ray Test

GEM polarization: 375/365/355 V



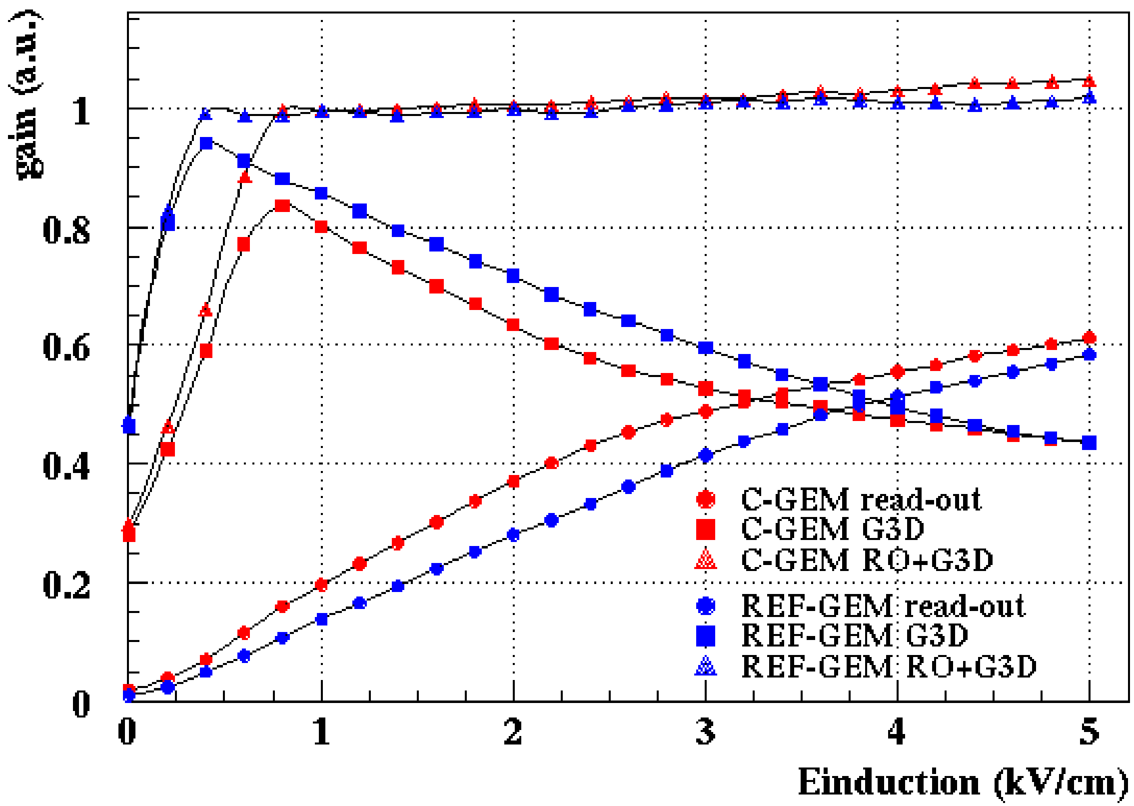
Norm. gain

Transfer fields

C-GEM characterization with X-ray Test

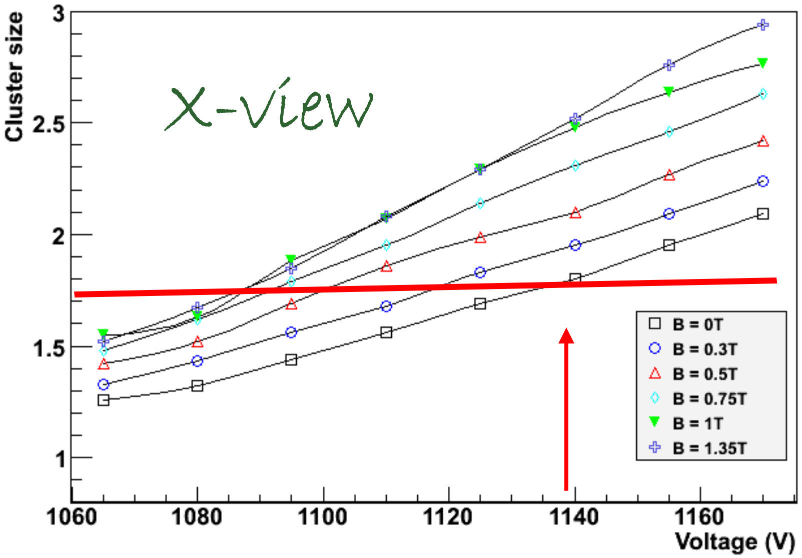
GEM polarization: 375/365/355 V

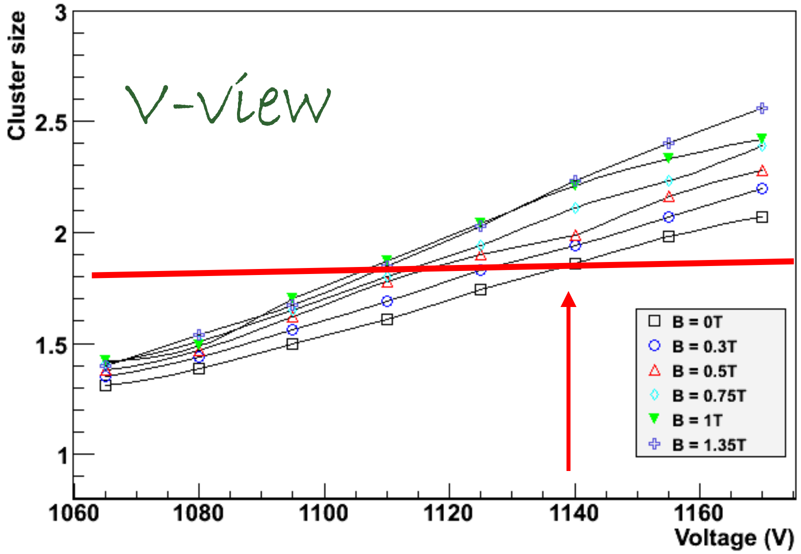
Norm. gain

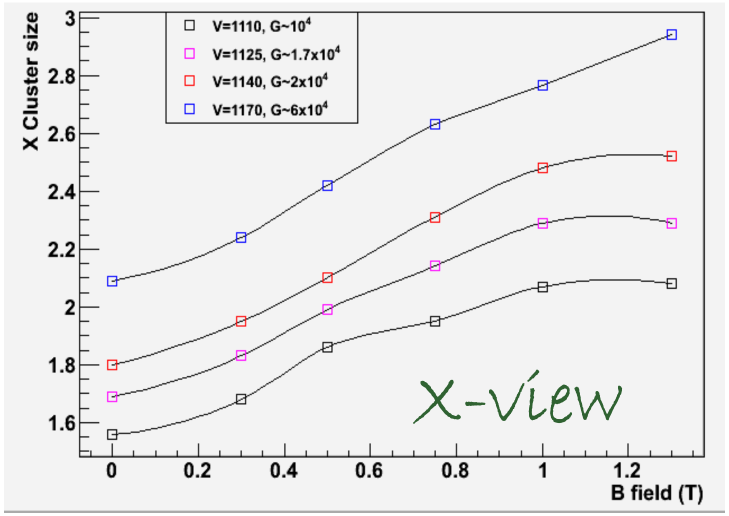


Induction field

(2) XV readout: Cluster size measurements





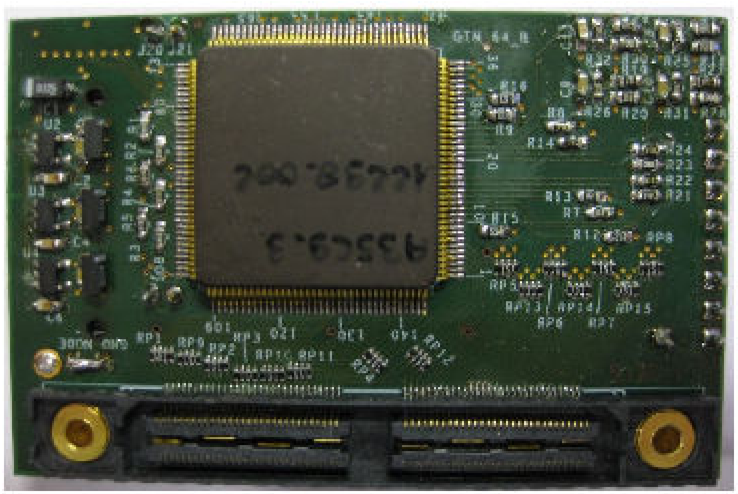


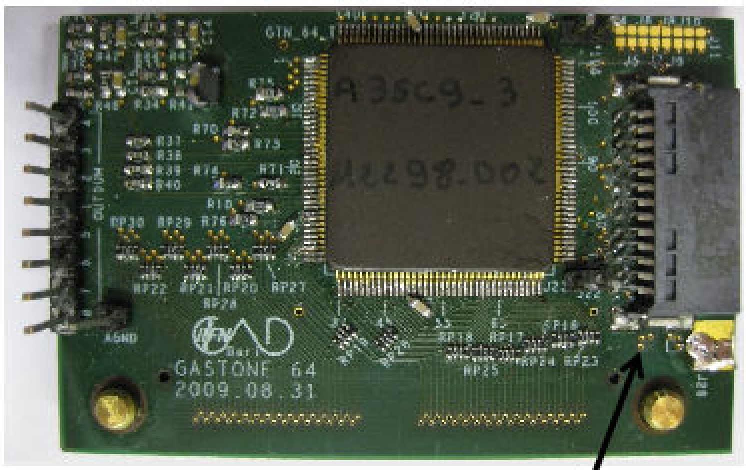
The two strips view are well equalized

The cluster size increases as magnetic field increases because of the larger spread of electrons in the gas gaps

Gastone Front-End Board (120 chs)

Dimensions: 62x40 mm^2





Input connector (GEM)
- 120 strips
- GND

I/O connector
- Power supplies
- SPI slow control bus
- Readout bus

Large GEM R&D : single vs double mask

Starting raw material: 50µm Kapton foil with 5µm Copper clad

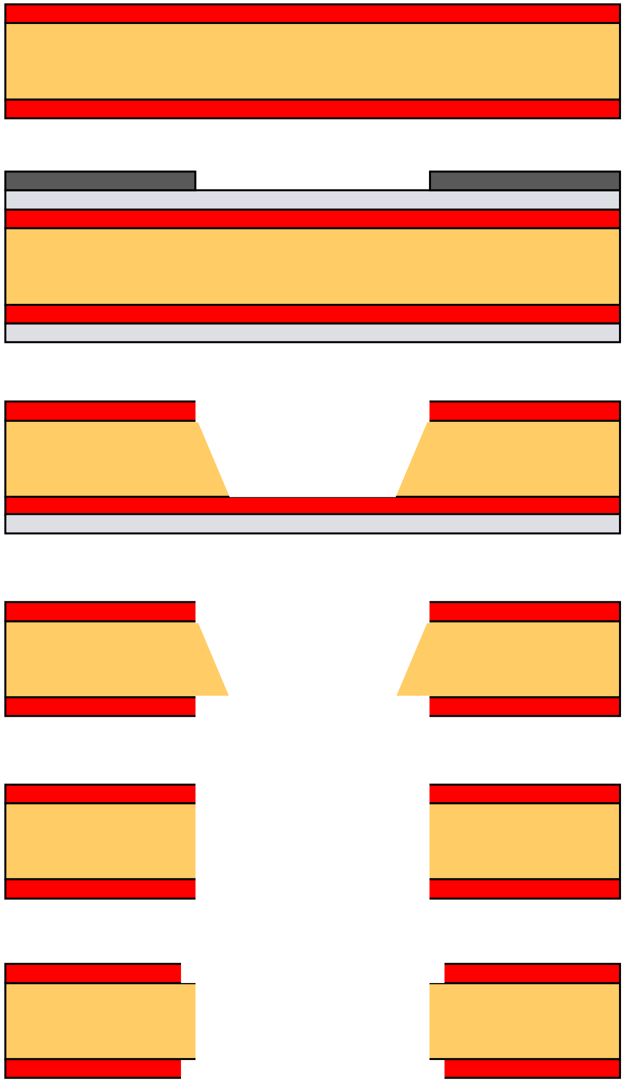
Photoresist deposition, **Single Mask**

Hole is opened with metal and kapton etching on one side

Bottom side metal etching. Top side metal is preserved with **Cathodic Protection** technique

Back to kapton etching to get almost cylindrical shaped hole

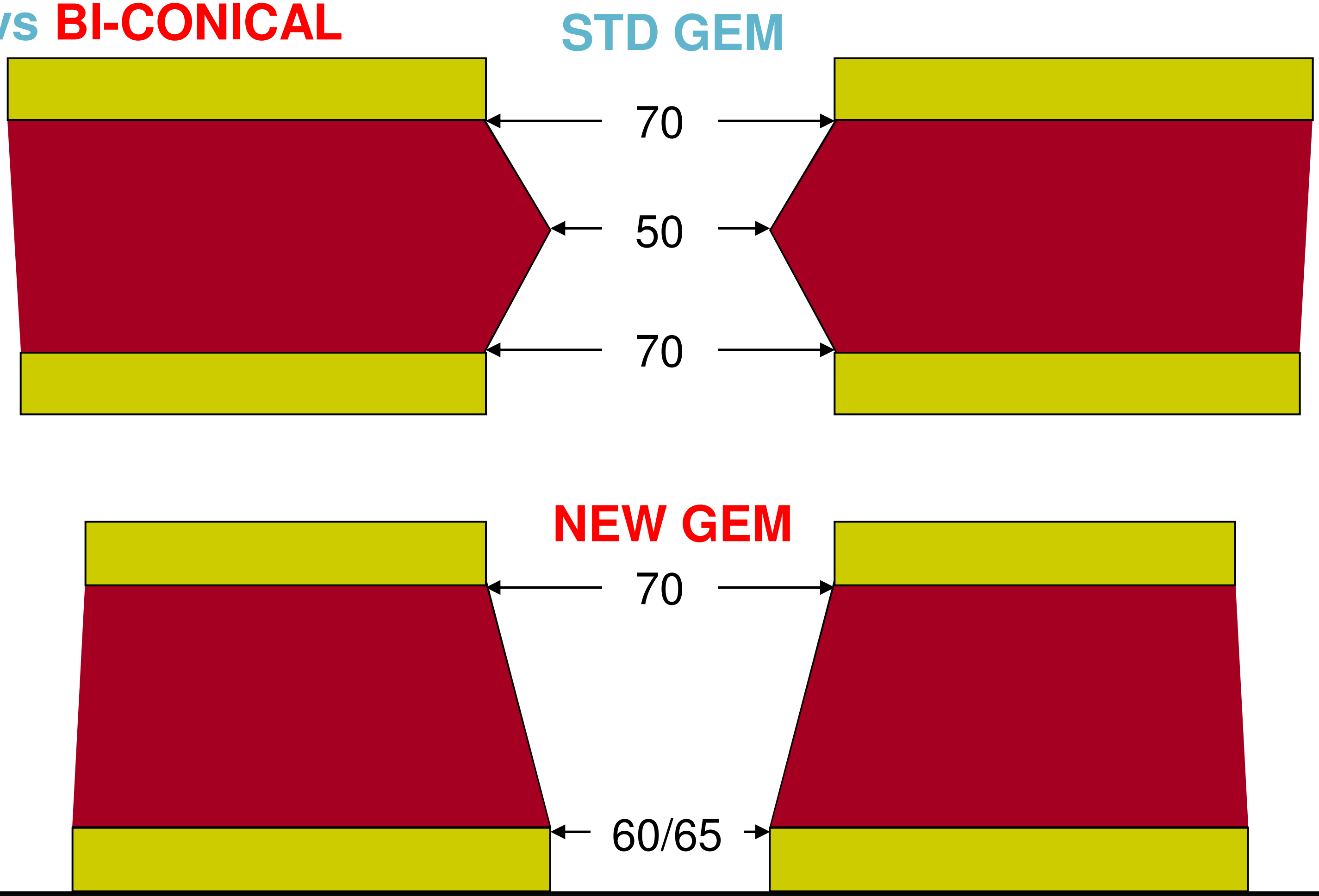
Further metal etching to form a small rim and eventually to reduce the copper thickness



R&D large GEM: single vs double

With an **X-ray** gun, we compared, in **CURRENT MODE**, the basic performance of the new single-mask GEM with the standard double-mask.

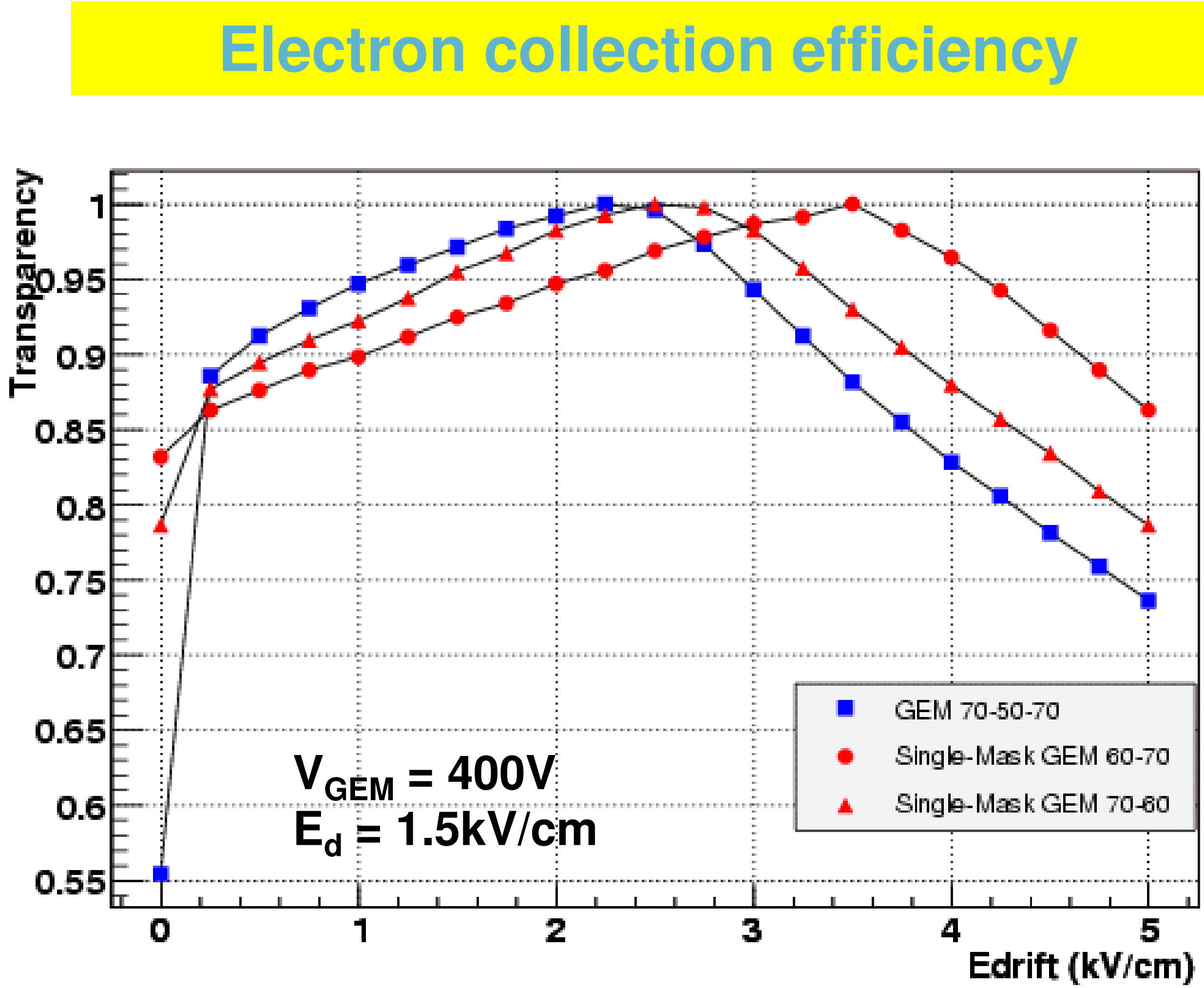
CONICAL vs BI-CONICAL



R&D large GEM: single vs double

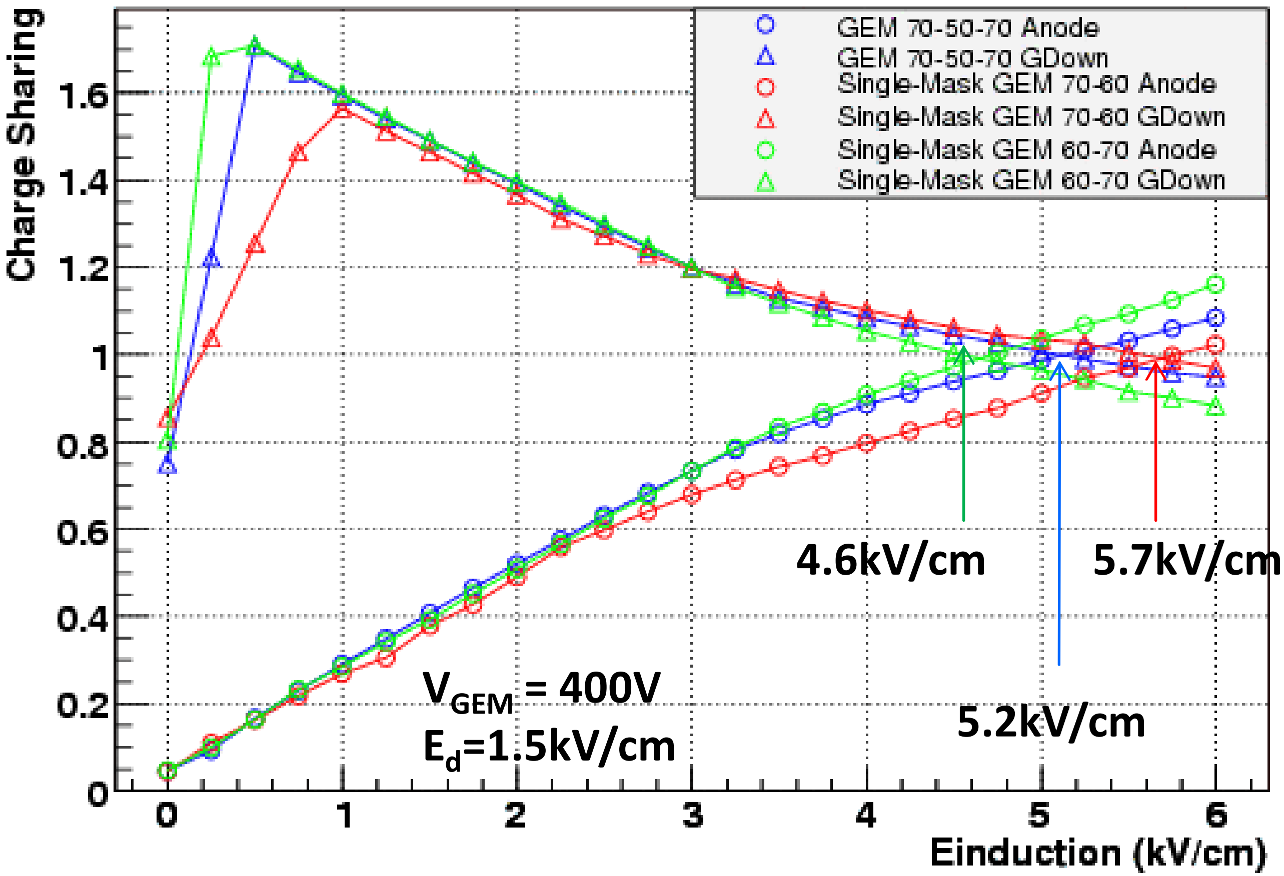
80% at 0 Field: larger Optical Transparency due to larger diameter.

Difference between the two orientations of the single mask.



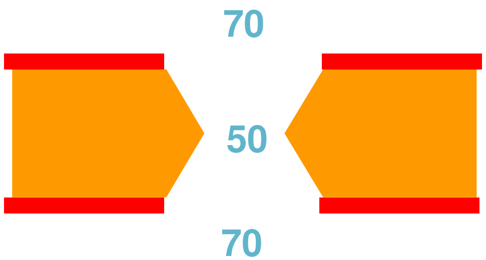
R&D large GEM: single vs double

Extraction efficiency & Charge Sharing

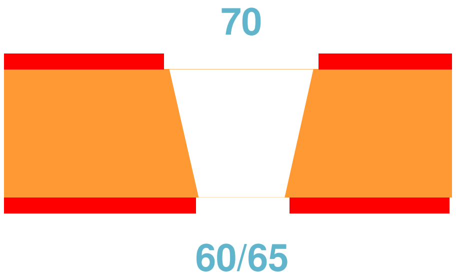


Equal Sharing Field highly dependent on GEM orientation for the single mask GEMs.

R&D on large GEM (GDD-CERN group + R.de Oliveira)



Max size= 400x400 mm²



Max size= >1000x400 mm²

double mask → double conical

single mask → conical /quasi-cylindrical

$G_{60\text{-}70} / G_{std} = 0.67$

$G_{70\text{-}60} / G_{std} = 0.80$

Additional 10 ÷ 20 V needed to operate at the same Gain as Standard GEM