Operation of Thick Kapton based Gas Electron Multipliers

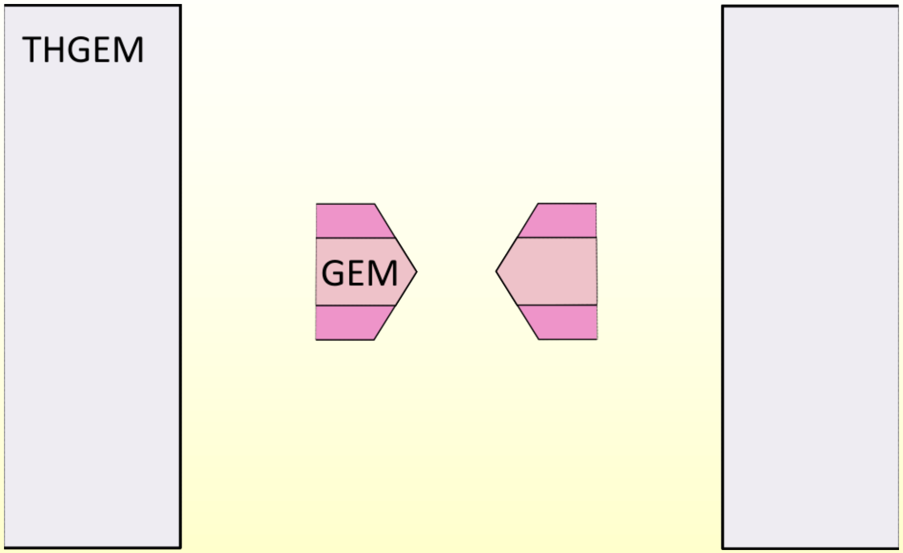
Fernando Amaro, R. Roque , N. Viseu , A. Cortez , J. Mir, J.M.F dos Santos,
H. N. da Luz, X. Carvalho
LibPhys - Coimbra University, Portugal

C.D. Azevedo, L. Carramate
I3N - Aveiro University, Portugal

LIBPhys

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

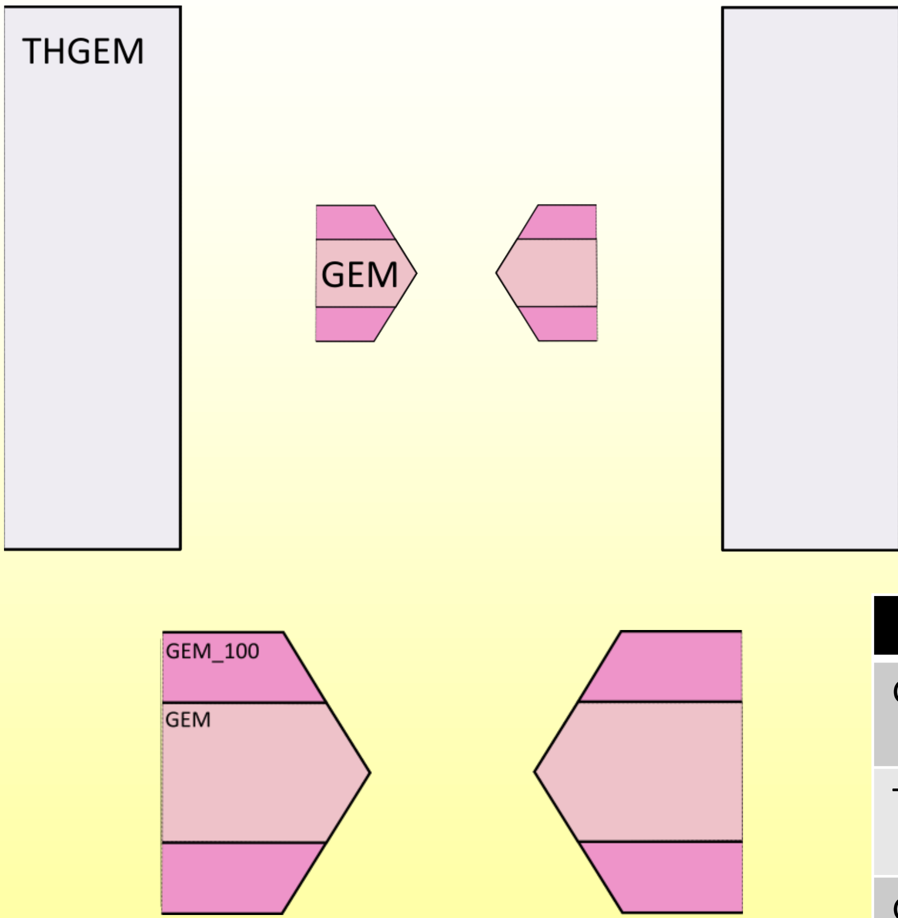
GEM 100



GEM 100:
With twice the thickness of a "standard" GEM
Made of Kapton foil

	Material	Thickness	Hole
GEM	Kapton / Copper	50 mμ	70 - 50 mμ
THGEM	FR4 – G10 / Copper	400 - 500 mμ	400 mμ
GEM 100	Kapton / Copper	100 mμ	120 - 50 mμ

GEM 100

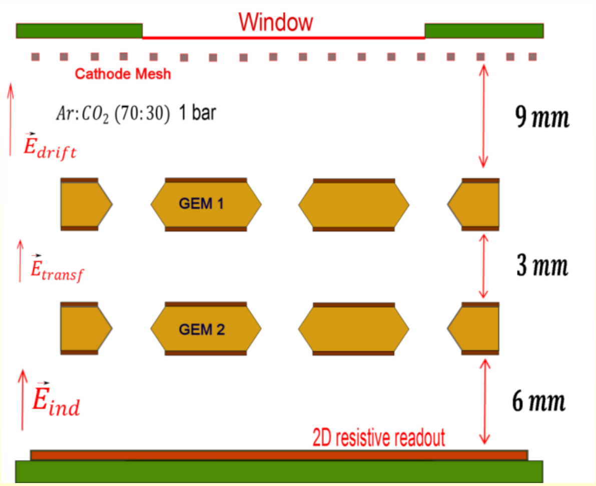


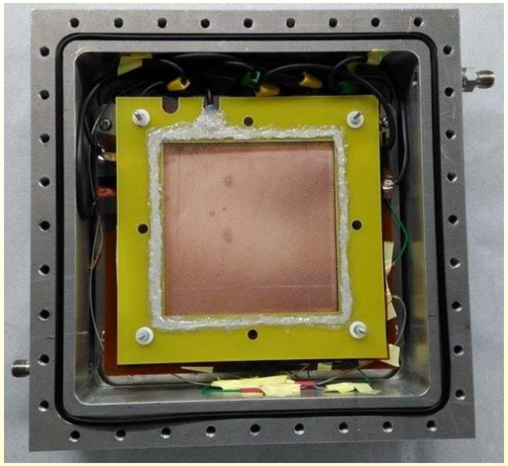
GEM 100:
With twice the thickness of a "standard" GEM
Made of Kapton foil

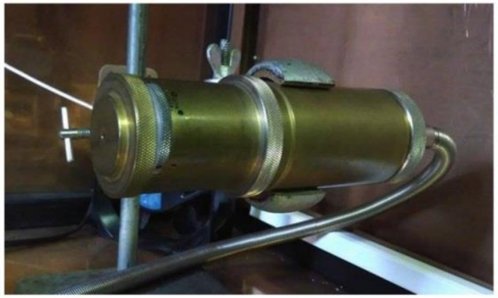
	Material	Thickness	Hole
GEM	Kapton / Copper	50 mμ	70 - 50 mμ
THGEM	FR4 – G10 / Copper	400 - 500 mμ	400 mμ
GEM 100	Kapton / Copper	100 mμ	120 - 50 mμ

GEM 100

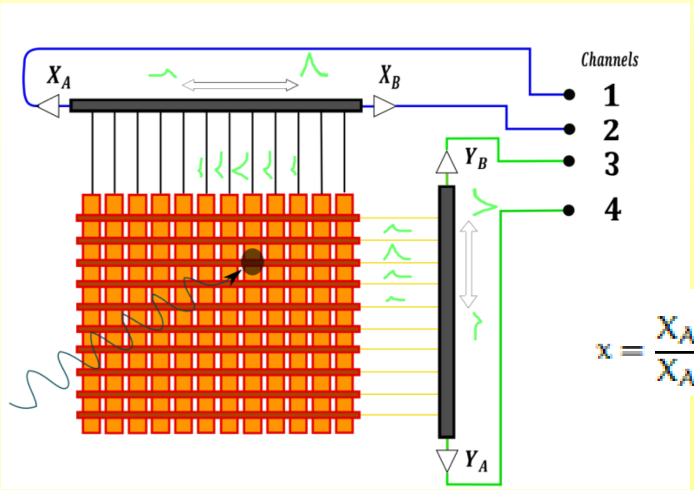
Experimental setup – Double GEM 100x100 mm^2 foils



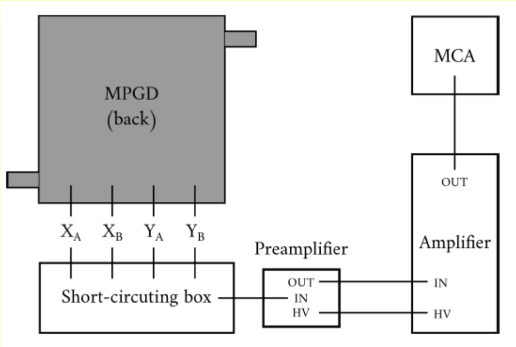




Detector was equipped with 2D(strips) resistive line readout (100×100 mm^2). **Only 4 channels used** for position reconstruction.



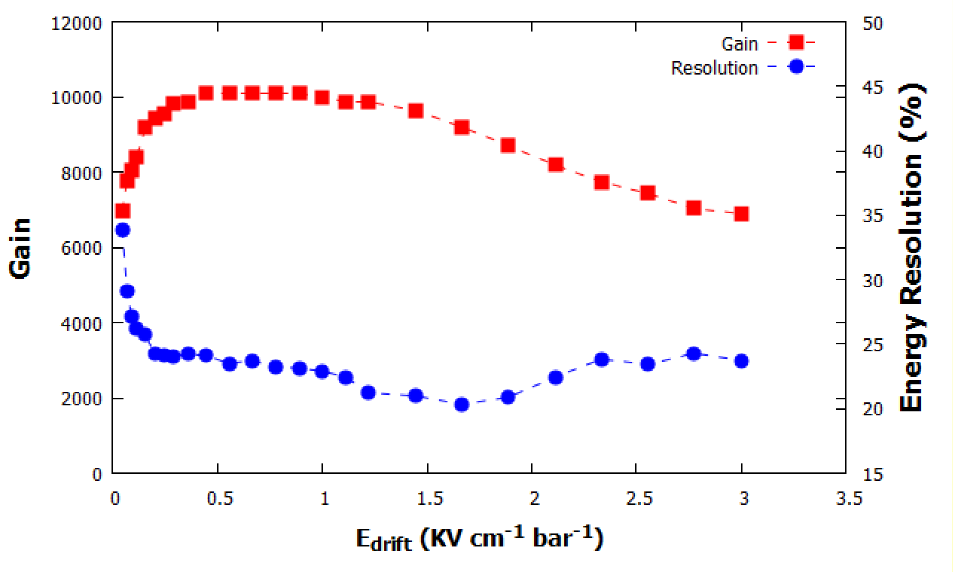
$$x = \frac{X_A - X_B}{X_A + X_B} \times L \qquad y = \frac{Y_A - Y_B}{Y_A + Y_B} \times L$$



GEM 100

Electric Field Optimization – Double GEM Cascade

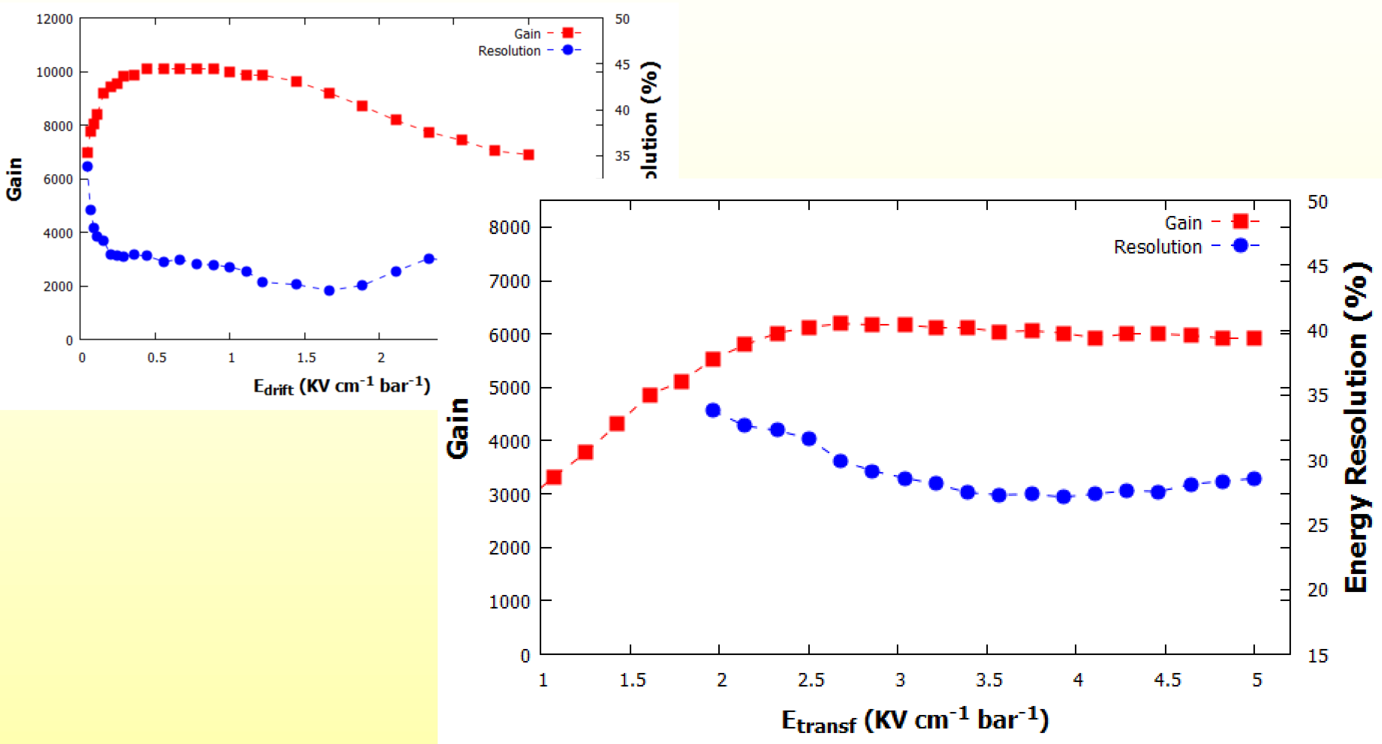
Ar (70%)-CO_2(30%)



GEM 100

Electric Field Optimization – Double GEM Cascade

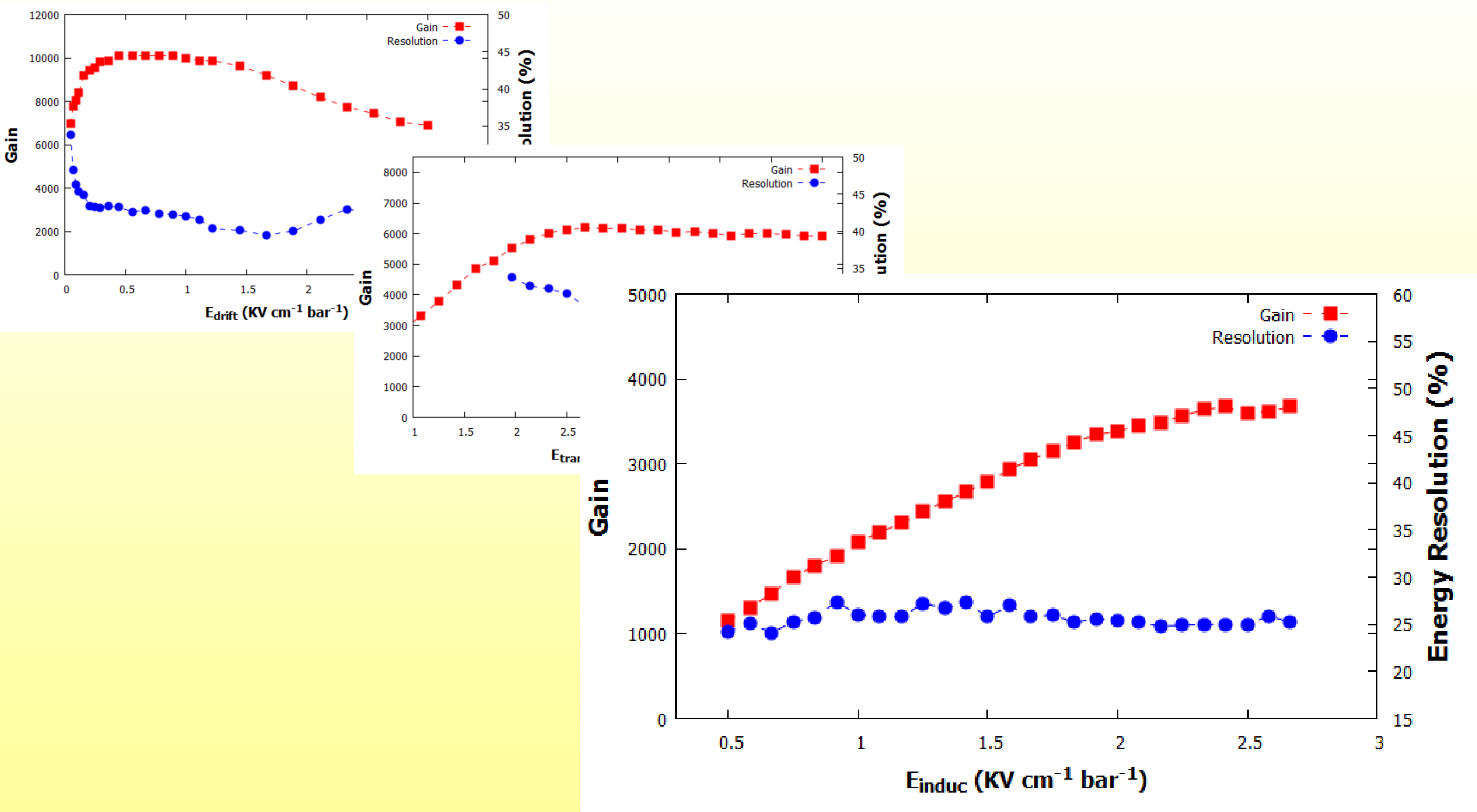
Ar (70%)-CO_2(30%)



GEM 100

Electric Field Optimization – Double GEM Cascade

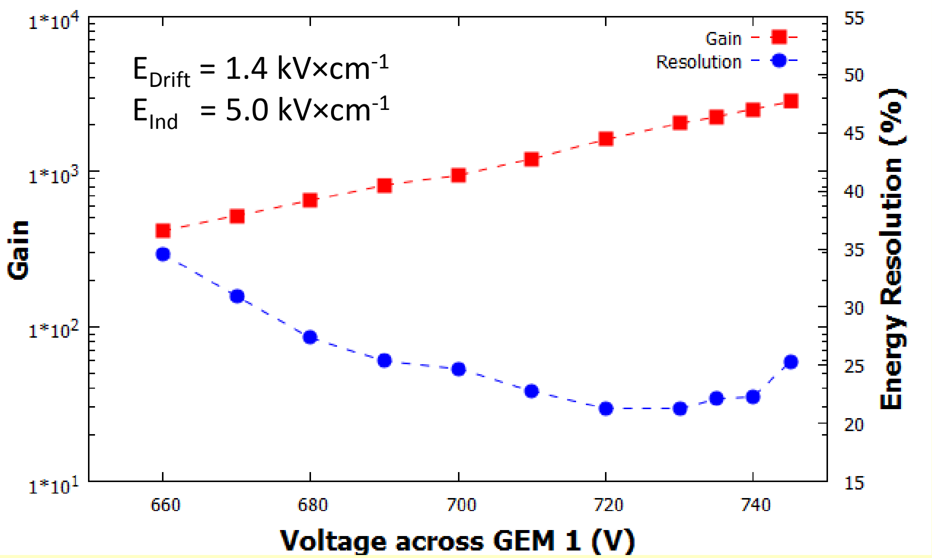
Ar (70%)-CO_2(30%)

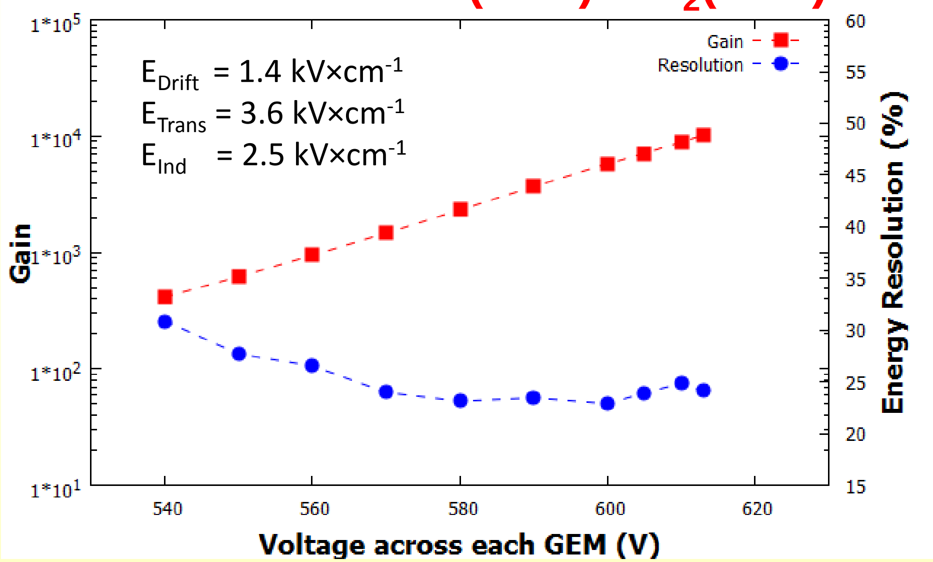


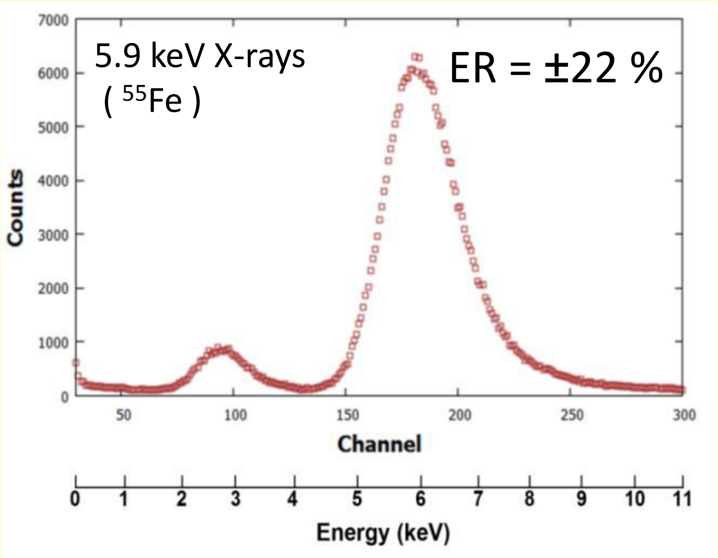
GEM 100

Electric Field Optimization – Double GEM Cascade

Ar (70%)-CO_2(30%)

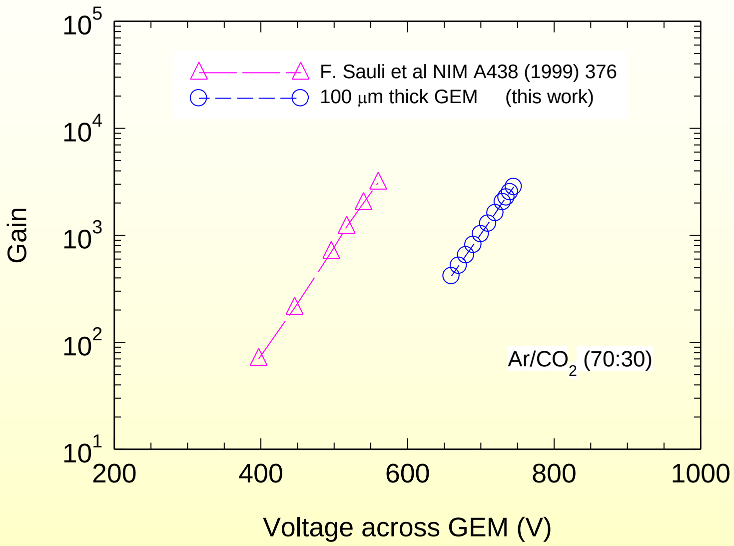


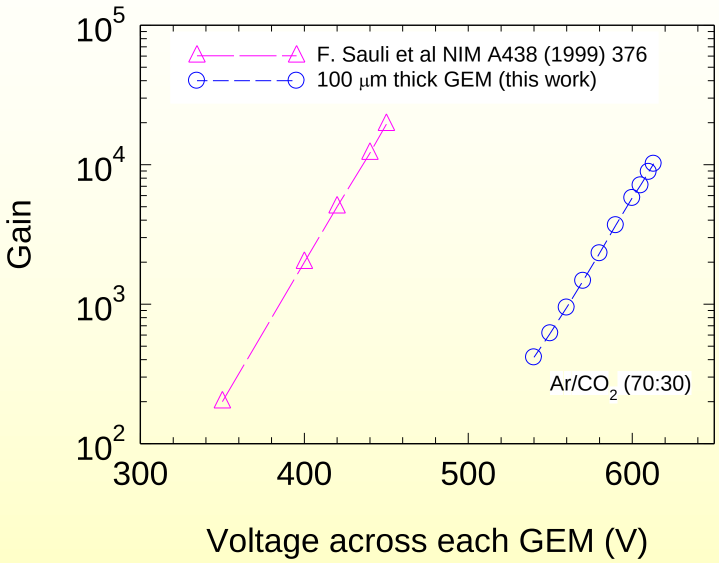




GEM 100

GEM_100 and standard GEM





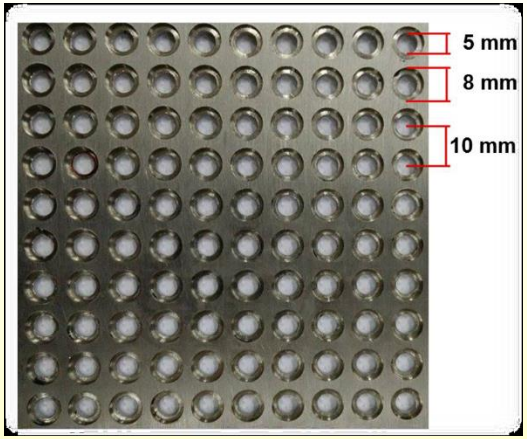
SINGLE: Charge gain characteristics of the single GEM_100 using Ar (70%)-CO_2(30%) gas mixture. In order to compare the gain response with 50 μm thick GEM, data from elsewhere [**Sauli et al 1999**] is included for comparison.

DOUBLE: Charge gain characteristics of the double GEM_100 configuration using Ar (70%)-CO_2(30%) gas mixture. Uppermost charge gains for 50 μm thick and 100 μm thick GEM are of the same order of magnitude.

As expected, the gain characteristics of the thicker GEM are shifted towards higher voltages but the uppermost charge gains are approximately the same.

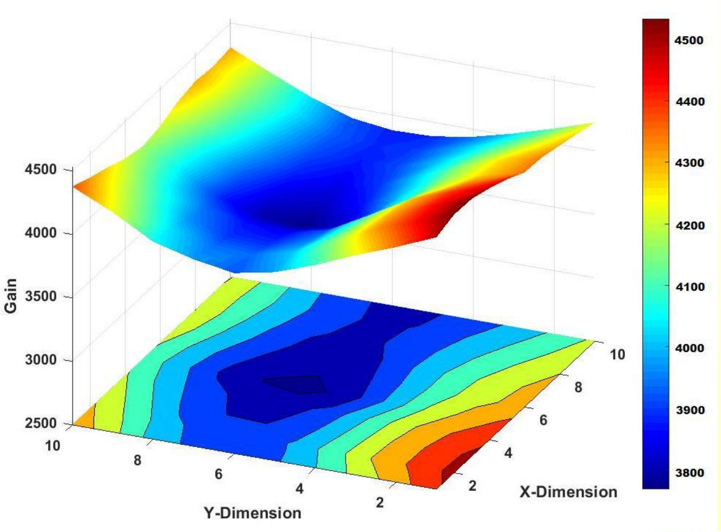
GEM 100

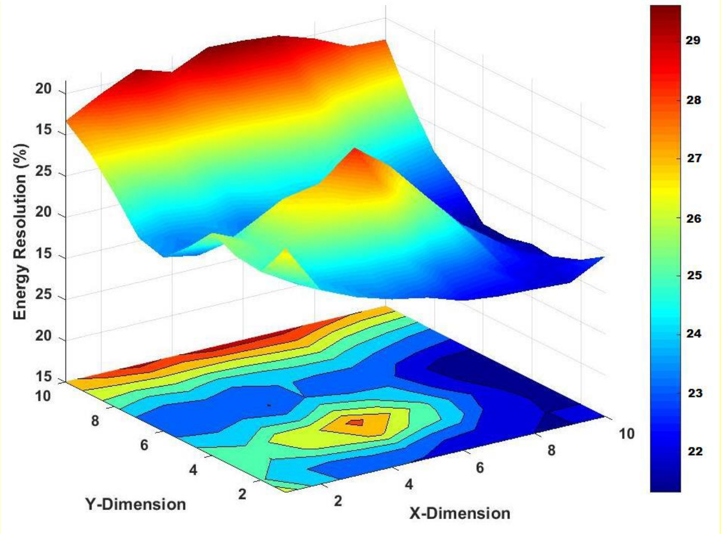
Gain and energy resolution mapping over the 100×100 mm^2 area of the GEM_100



A stainless steel mask, with an array of 100 holes.
Each hole acted as suport for the colimated **^{55}Fe source**.

E_{Drift} = 1.4 kV×cm^{-1}
E_{Trans} = 3.3 kV×cm^{-1}
E_{Ind} = 1.8 kV×cm^{-1}
ΔV_{GEM} = 580 V





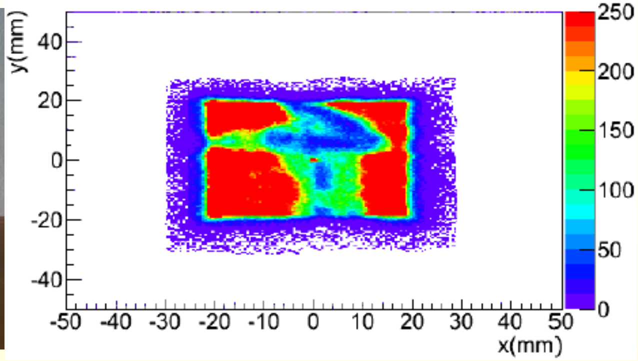
<u>Average charge gain</u>:
4×10^3
(10% max deviation)

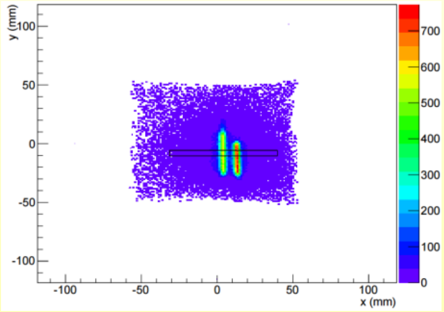
<u>Average energy resolution</u>:
24.4%
(5% max deviation)

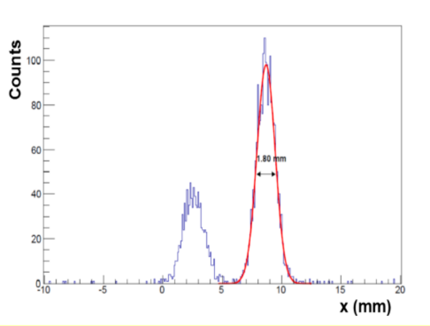
Influence of the 2D readout??

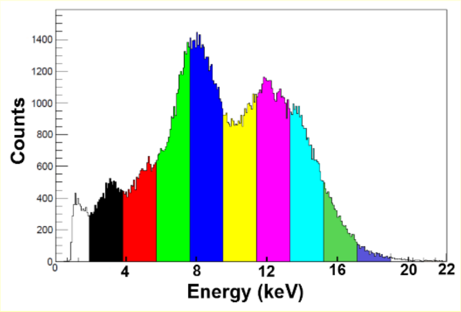
GEM 100

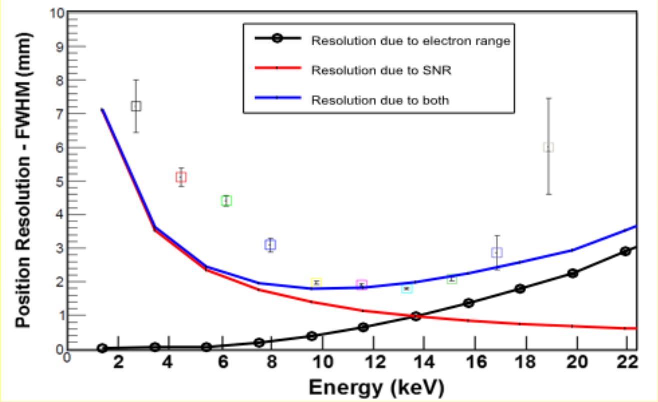
Imaging Results - Ar (70%)-CO_2(30%)







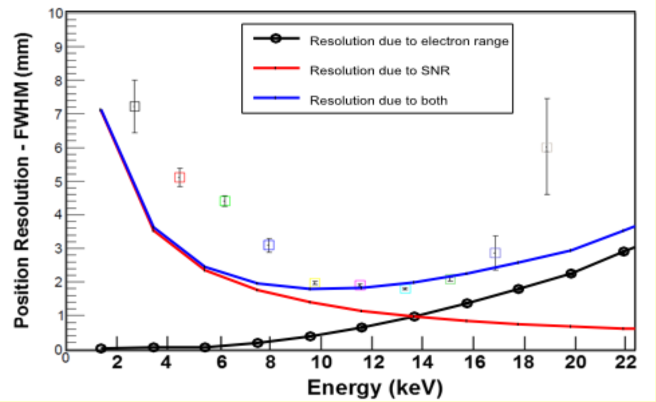




Position resolution vs Energy.

For the lower energies the SNR limits the position resolution. At higher energies it is the range of the photoelectrons that limits the position resolution.

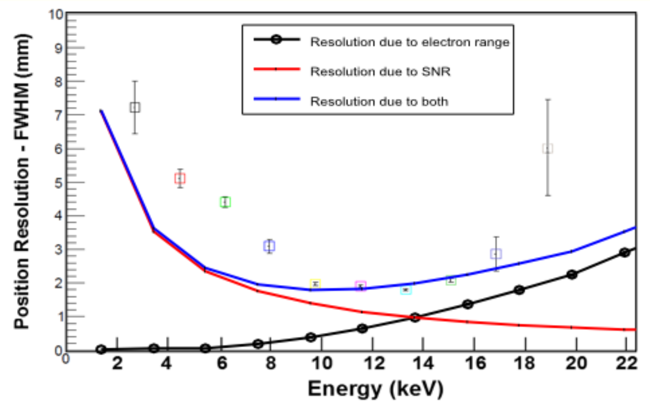
GEM 100

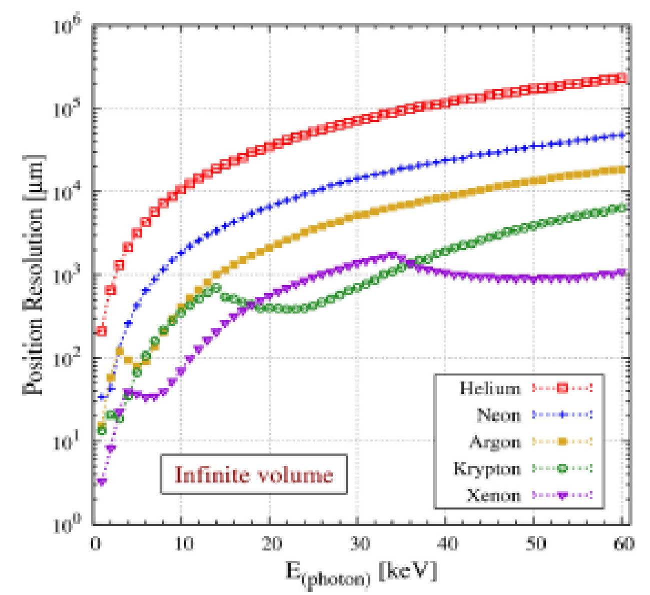


Resolution due to electron range
Resolution due to SNR
Resolution due to both
Position Resolution - FWHM (mm)
Energy (keV)

GEM 100

Operation in pure Kr and Kr-CO_2 mixtures - Motivation





[C. D. R. Azevedo et. al., Position resolution limits in pure noble gaseous detectors for X-ray energies from 1 to 60 keV, Physics Letters B 741, 2015, pp. 272-275.]

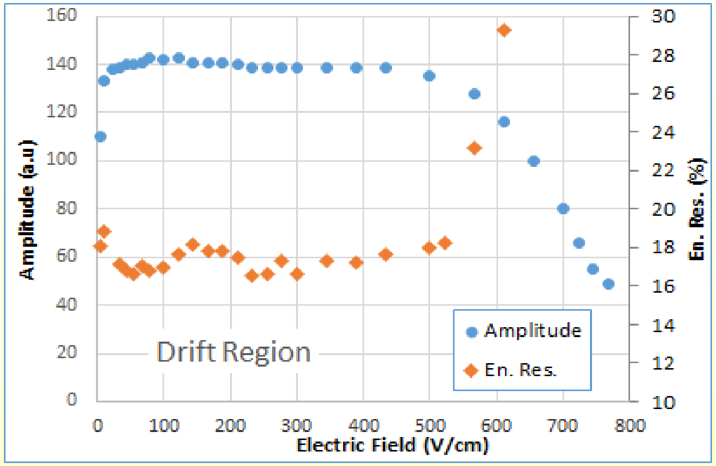
Position Resolution in our system is dominated by SNR (for lower energies) and by the range of the photo-electron in the gas mixture used.

The use of krypton as filling gas has the potential to improve position resolution, particularly at higher energies, were the photo-electron range in the gas mixture is the main contributor to position resolution.

Krypton is a good candidate for x-ray imaging applications as it presents the lowest intrinsic position resolution of the noble gases, for energies in the range from 16 to 35 keV. For low energies its behaviour is similar to the one of argon. The operation of an x-ray imaging system made from a double GEM cascade detector operating in Krypton based mixtures should therefore present superior performances, particularly for energies above 16 keV.

GEM 100

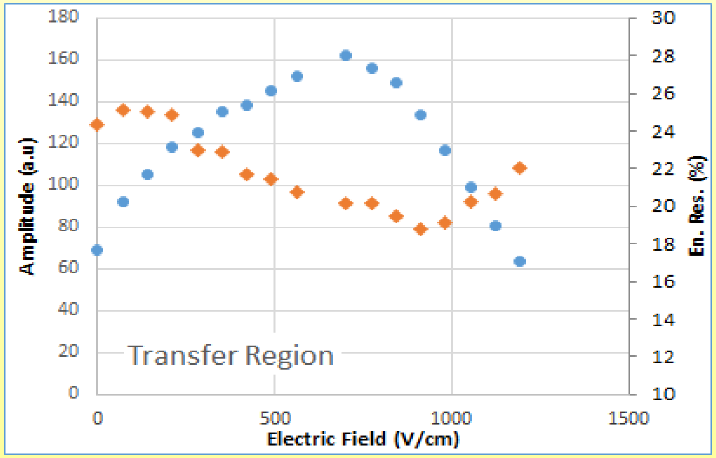
Operation in pure Kr - Electric Field Optimization

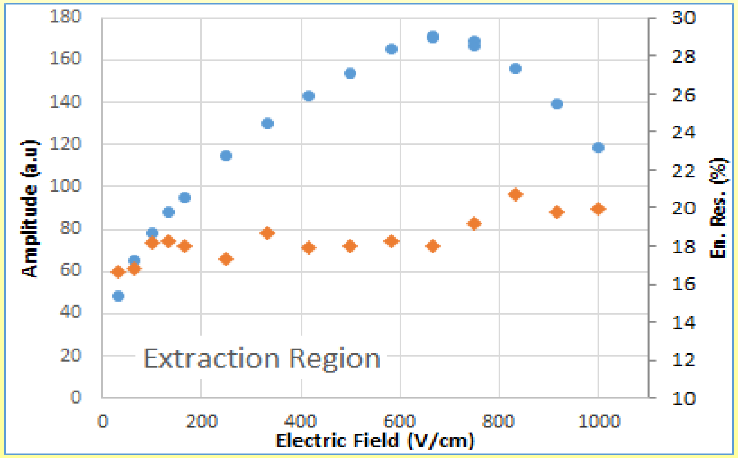


Double GEM Cascade electric field optimization was done in pure Krypton with a discrete ^{55}Fe source. Results show an improved energy resolution and requirement for lower electric fields to operate the detector.

Krypton show an improved energy resolution, relative to $Ar:CO_2$, (typical values are below 20%, for 5.9 keV).

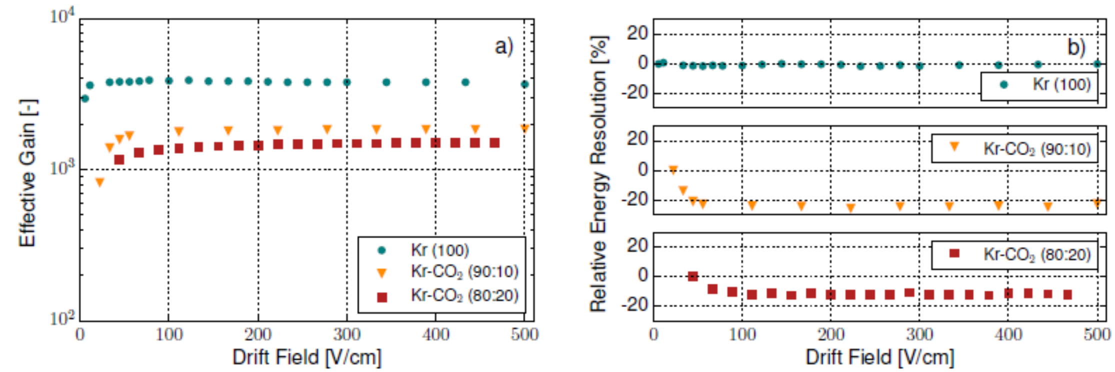
Lower Induction and Transfer fields are required when compared with $Ar:CO_2$ (E_{drift} = 1.4 kV/cm; E_{transf} = 3.6 kV/cm; E_{ind} = 2.5 kV/cm).

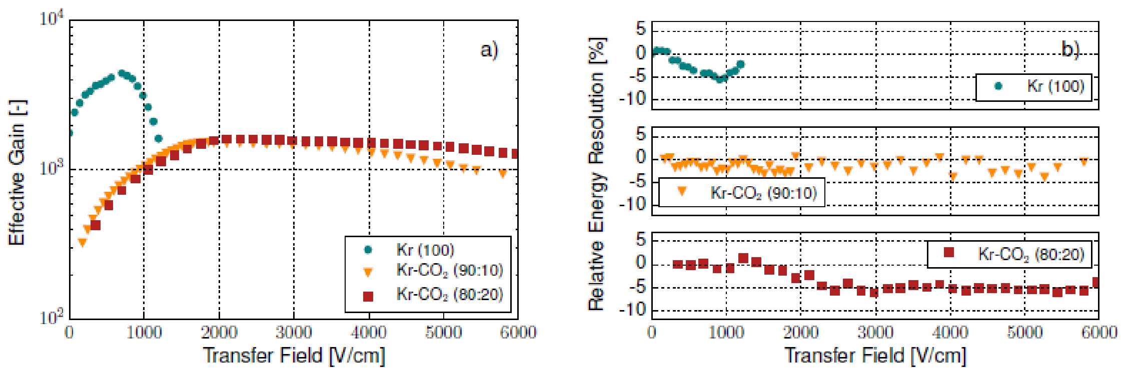


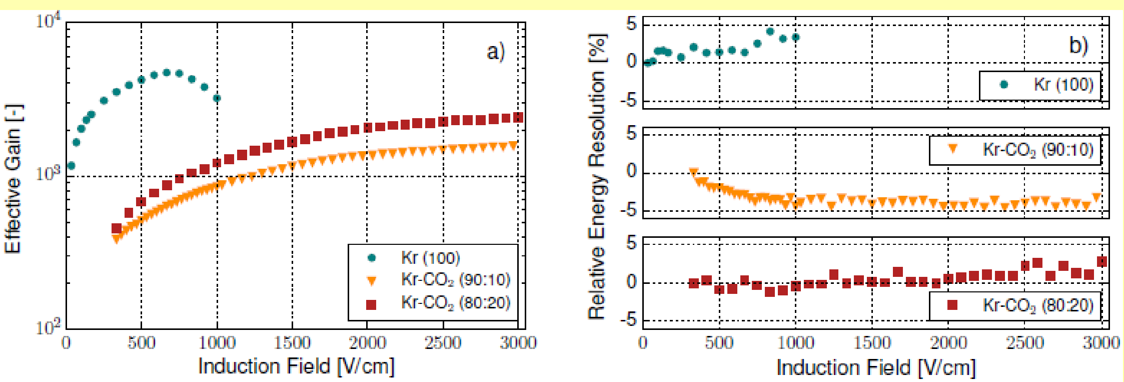


GEM 100

Operation in pure Kr and Kr-CO_2 mixtures – Field Optimization





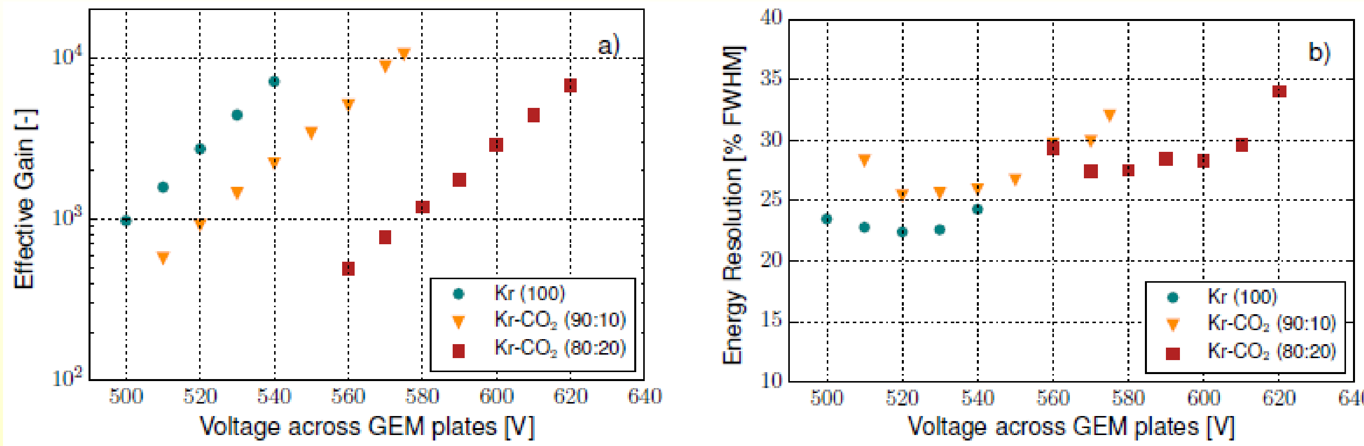


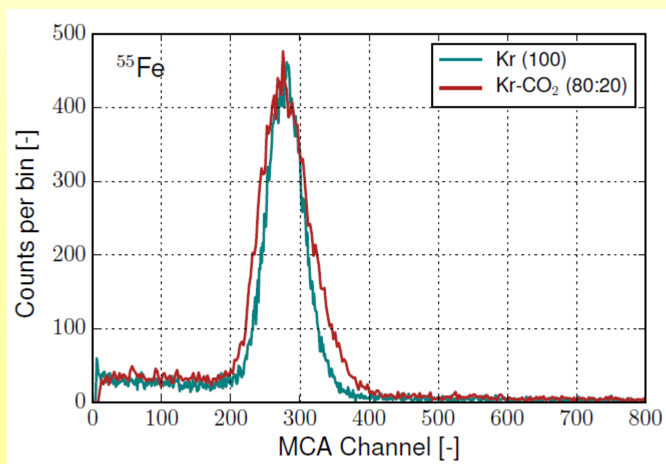
Inclusion of CO_2 increases Induction and Transfer fields.

REGION	PURE KRYPTON ($V\,cm^{-1}$)	90:10 ($V\,cm^{-1}$)	80:20 ($V\,cm^{-1}$)
DRIFT	200	333	310
TRANSFER	650	1930	2800
INDUCTION	580	2500	1500

GEM 100

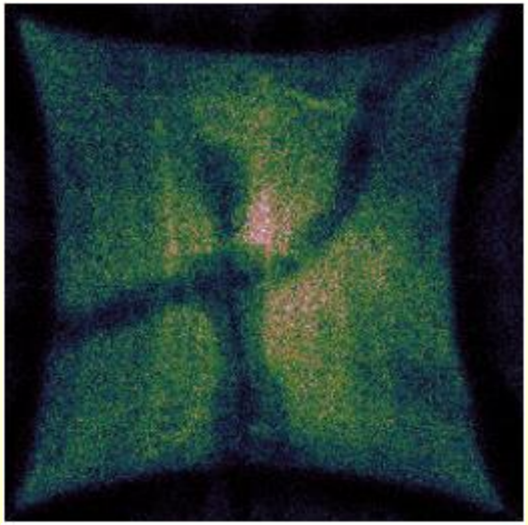
Operation in pure Kr and Kr-CO_2 mixtures



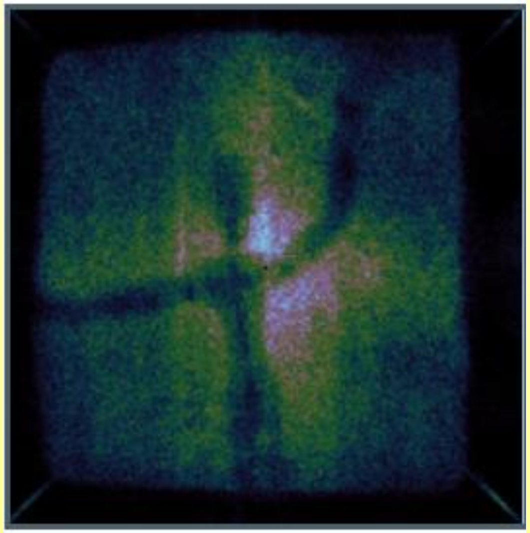


GEM 100

Operation in pure Kr and Kr-CO_2 mixtures – Imaging



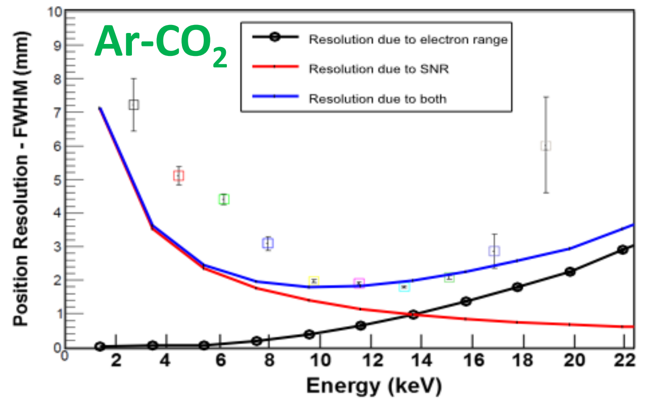
$$x = \frac{X_A - X_B}{X_A + X_B} \times L \qquad y = \frac{Y_A - Y_B}{Y_A + Y_B} \times L$$

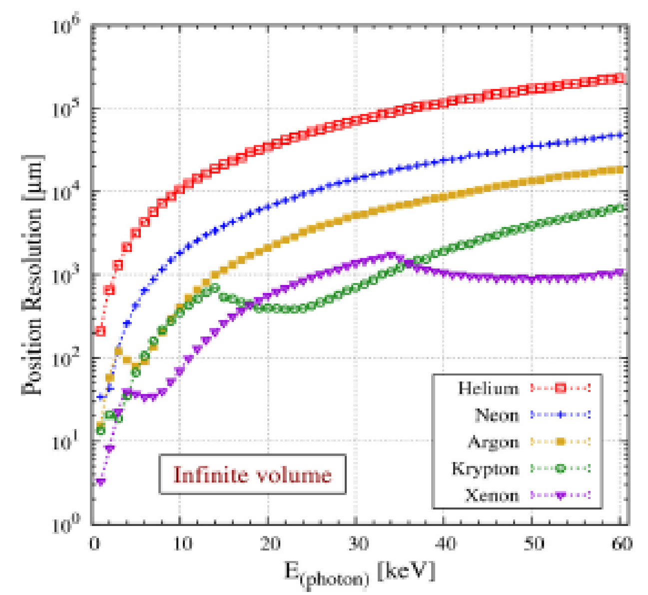


$$x = \frac{X_A - X_B}{X_A + X_B + Y_A + Y_B} \times L \qquad y = \frac{Y_A - Y_B}{X_A + X_B + Y_A + Y_B} \times L$$

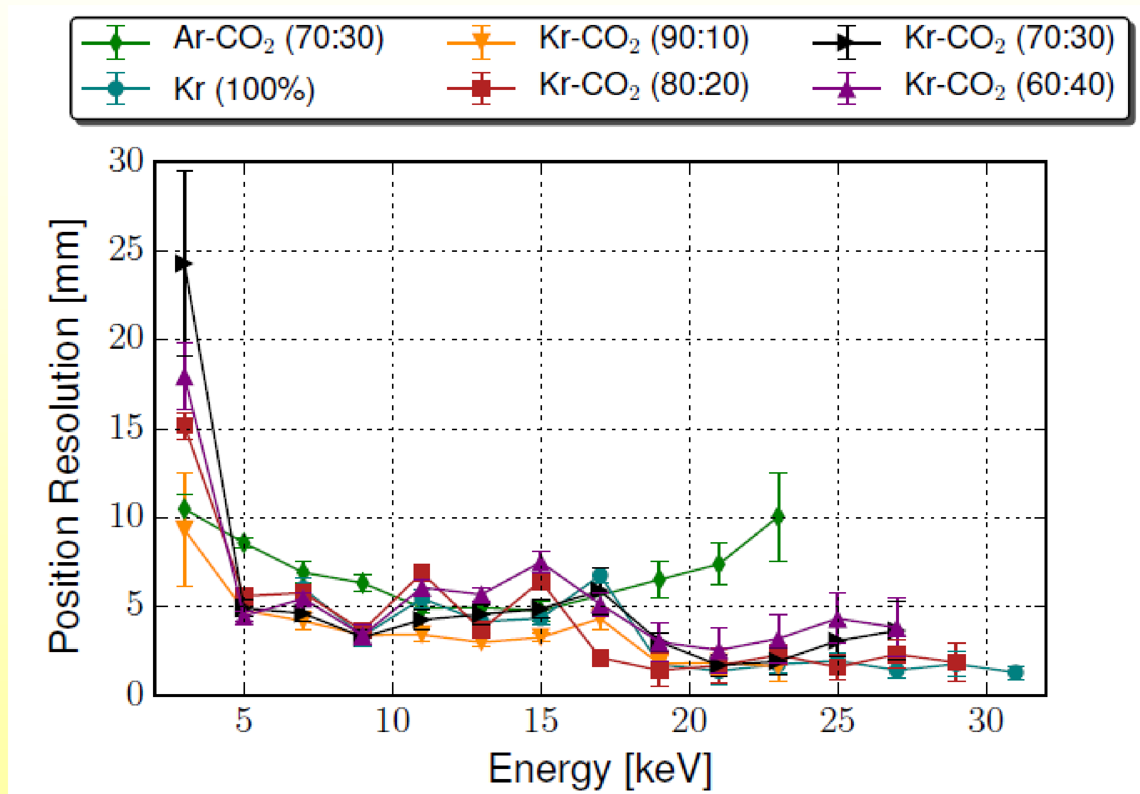
GEM 100

Operation in pure Kr and Kr-CO_2 mixtures - Motivation





[C. D. R. Azevedo et. al., Position resolution limits in pure noble gaseous detectors for X-ray energies from 1 to 60 keV, Physics Letters B 741, 2015, pp. 272-275.]



GEM 100

- 2 Master thesis:

  [1] X. Carvalho, Large Area Cascaded Gas Electron Multipliers for Imaging Applications, 2015 Coimbra University

  [2] R. Roque, X-ray imaging using 100 µm thick Gas Electron Multipliers operating in Kr-CO2 mixtures, 2018 Coimbra University
- 5 papers:

  [1] H. Natal da Luz et al., X-ray imaging with GEMs using 100 µm thick foils, 2014 JINST 9 C06007

  [2] F.D. Amaro et al., A robust large area x-ray imaging system based on100 mm thick Gas Electron Multiplier, 2015 JINST 10 C12005

  [3] J.A. Mir et al.,Gain Characteristics of a 100 µm thick Gas Electron Multiplier (GEM), 2015 JINST 10 C12006

  [4] R. Roque et al., Gain characteristics of a 100 µm thick GEM in Krypton-CO2 mixtures, 2017 JINST 12 C12061

  [5] R. Roque et al., Spatial resolution properties of krypton-based mixtures using a 100 µm thick Gas Electron Multiplier, 2018 JINST 13 P10010
- Countless hours of x-ray exposures, detector flooding
- Electric field optimizations for several gas mixtures, gains of 10^{3-4}

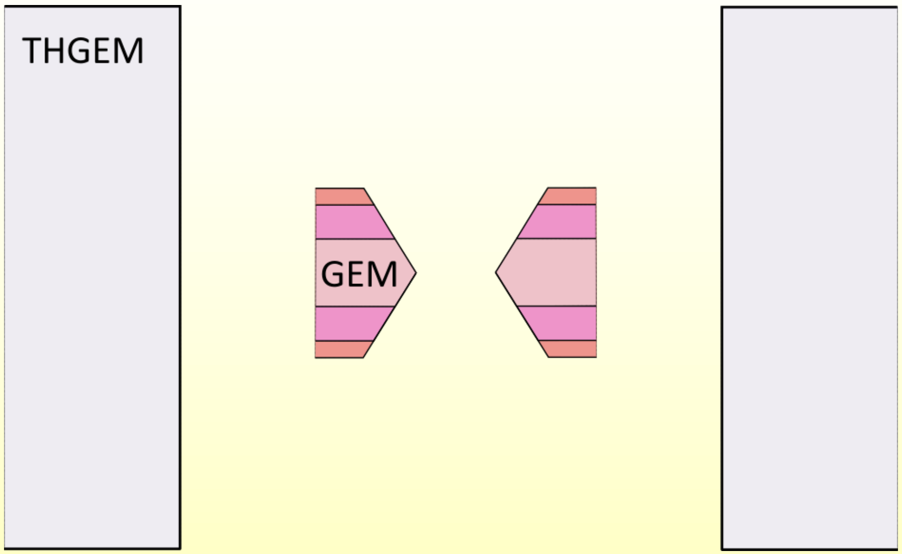
0 foils damaged during the process!

COBRA_125

Life was way too easy with the GEM_100!

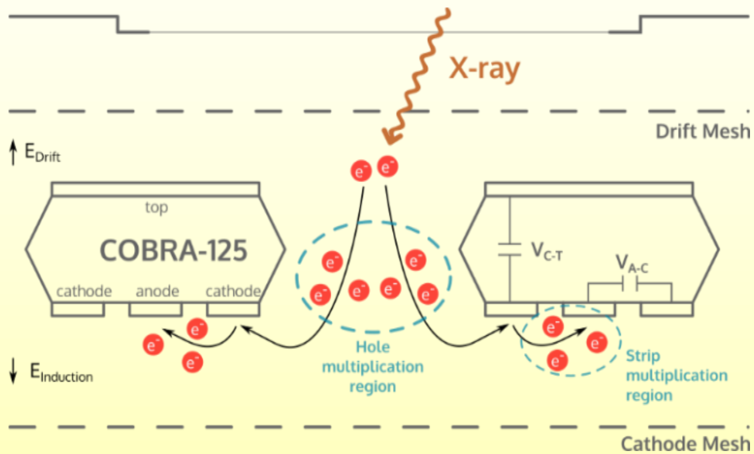
COBRA_125

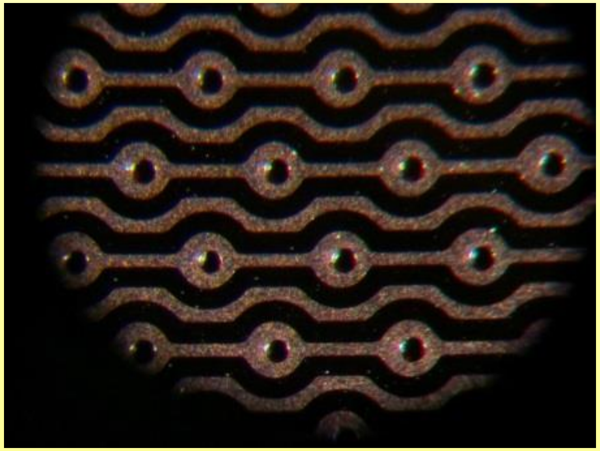
Life was way too easy with the GEM_100!



	Material	Thickness	Hole
GEM	Kapton / Copper	50 mμ	70 - 50 mμ
THGEM	FR4 – G10 / Copper	400 - 500 mμ	400 mμ
GEM 100	Kapton / Copper	100 mμ	120 - 50 mμ
COBRA_125	Kapton / Copper	125 mμ	100 μm

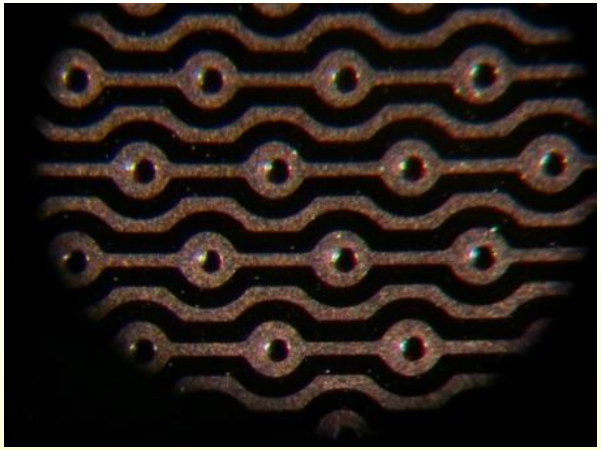
Similar operating principle as the MHSP and THCOBRA
but
more robust than the MHSP and with lower operating voltages than THCOBRA (and made of kapton)





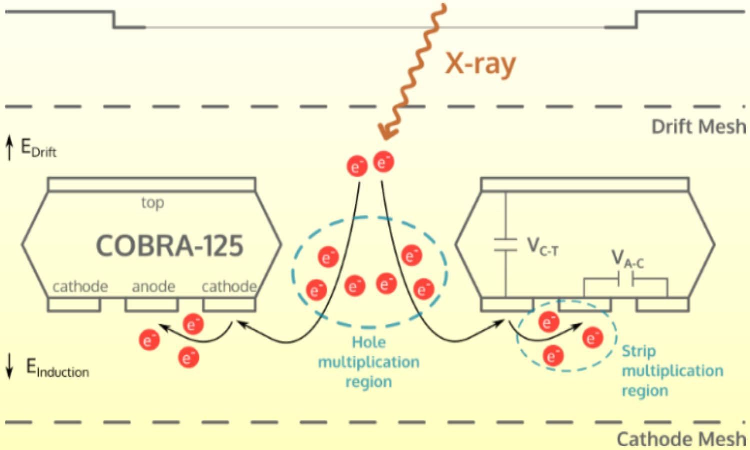
Several 100×100 mm² foils produced

COBRA_125



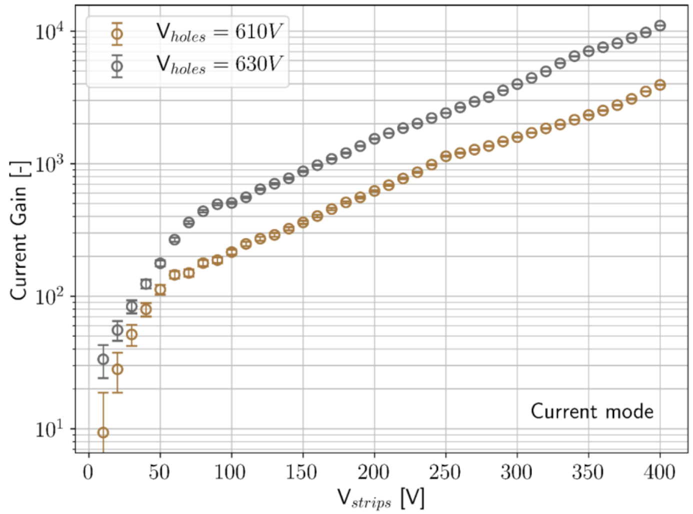
Hole spacing	400/460 µm
Cathode – Anode distance	60 µm
Bottom electrodes width	60 µm

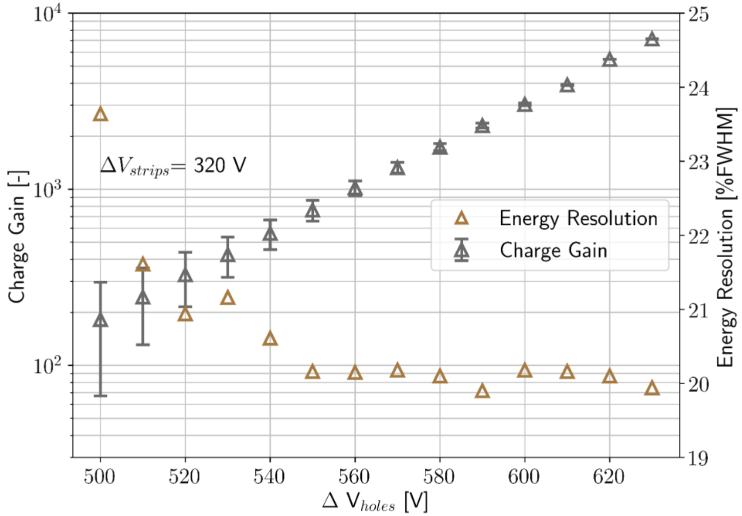
Similar operating principle as the MHSP and THCOBRA
but
more robust than the MHSP and with lower operating voltages than THCOBRA (and made of kapton)

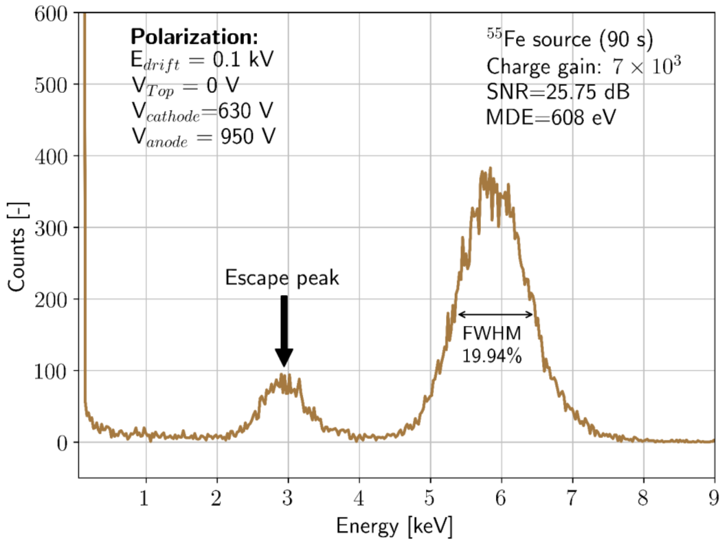


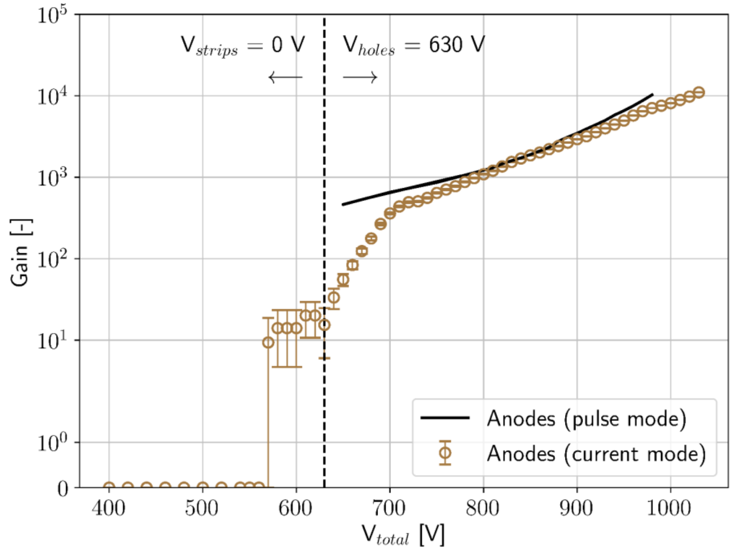
COBRA_125

P10 1 bar



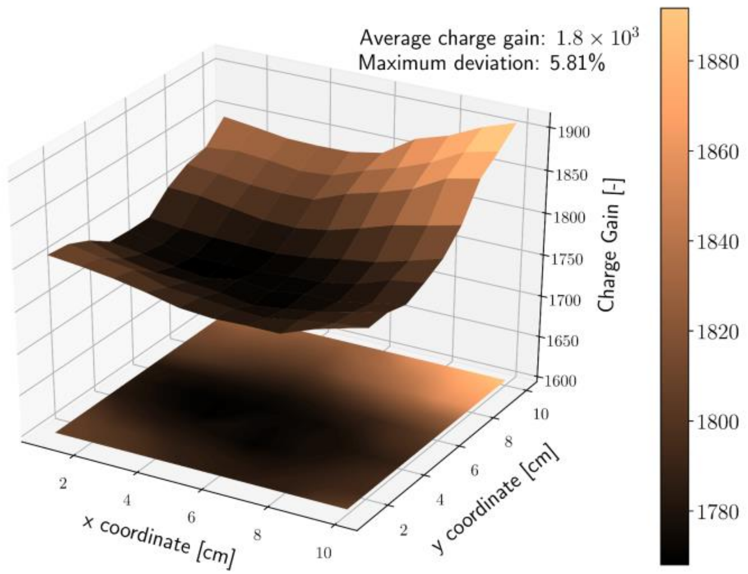


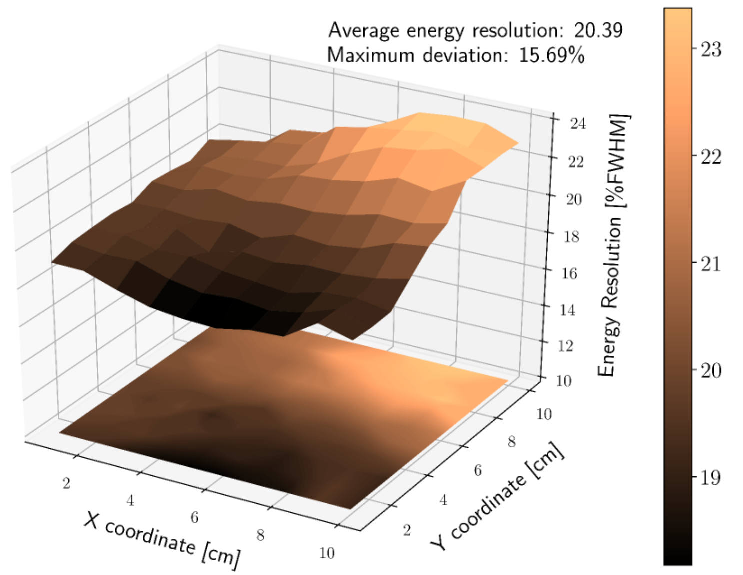




COBRA_125

	Av. Gain	Max Dev	ER (%)	Max Dev
Double GEM_100	$4{\times}10^3$	10 %	24.4	20%
COBRA_125	$1.8{\times}10^3$	6%	20.4	16%





1 foil damaged during the measurements!

COBRA_125

Next steps:

- Application to Ion Back Flow reduction (PACEM/ZERO IBF readout with SiPm)
- Resistive line made of SMD resistors soldered on the COBRA_125.
  (Already produced)

Operation of Thick Kapton based Gas Electron Multipliers

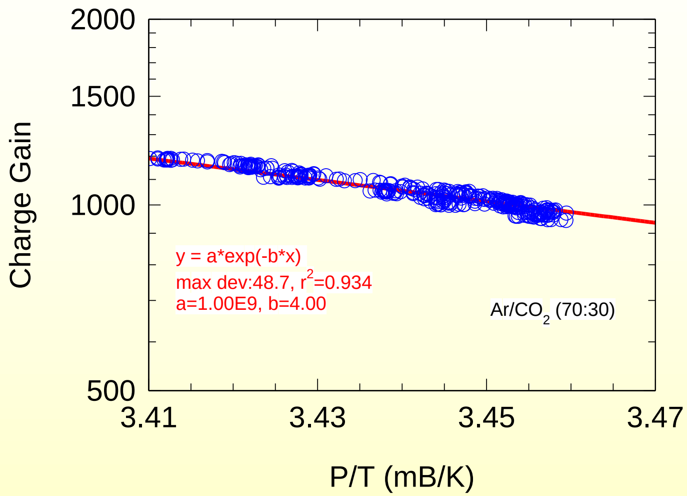
Fernando Amaro, R. Roque , N. Viseu , A. Cortez , J. Mir, J.M.F dos Santos,
H. N. da Luz, X. Carvalho
LibPhys - Coimbra University, Portugal

C.D. Azevedo, L. Carramate
I3N - Aveiro University, Portugal

LIBPhys

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

GEM 100

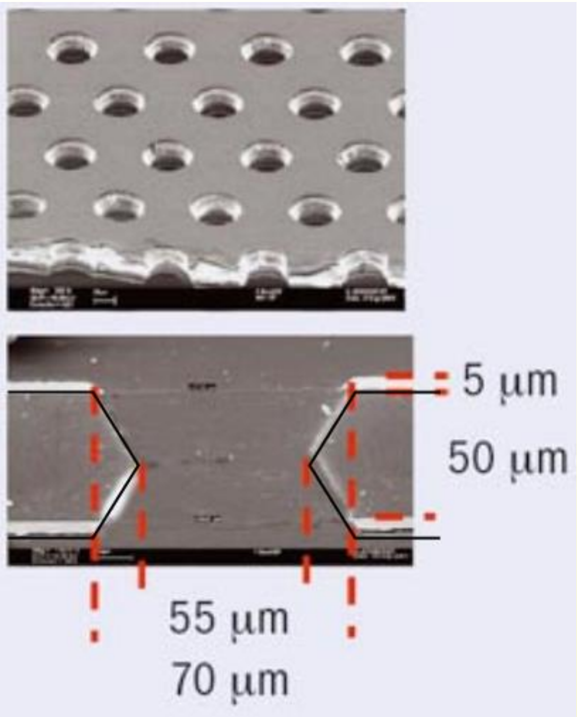


P/T GAIN SENSITIVITY: The effective gain of the present GEM over 3 weeks plotted as a function of P/T yielding sensitivity to 4.0 K/mB. This is over two times larger than the P/T sensitivity of a 50 µm GEM. Assuming that P is roughly constant at around 1000 mB and allowing for maximum temperature excursion of ±5 ºC from 20 ºC would result in a maximum gain excursion of 22.9 %.

During the course of these measurements we observed 290 sparks where the gain collapsed and data rejected for the following 5 minutes. Remarkably, the gain recovered to its original value as shown in this figure.

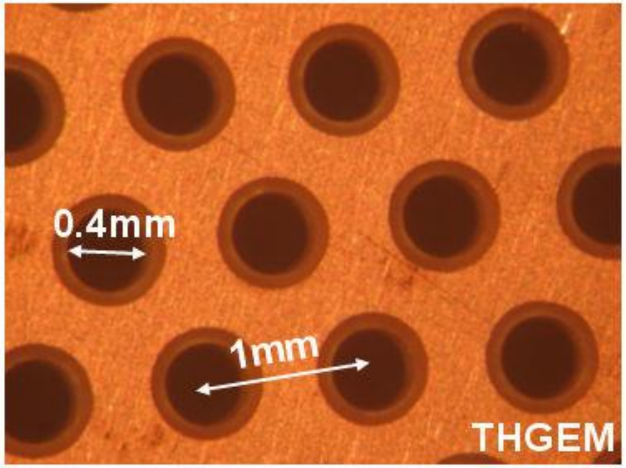
GEM 100

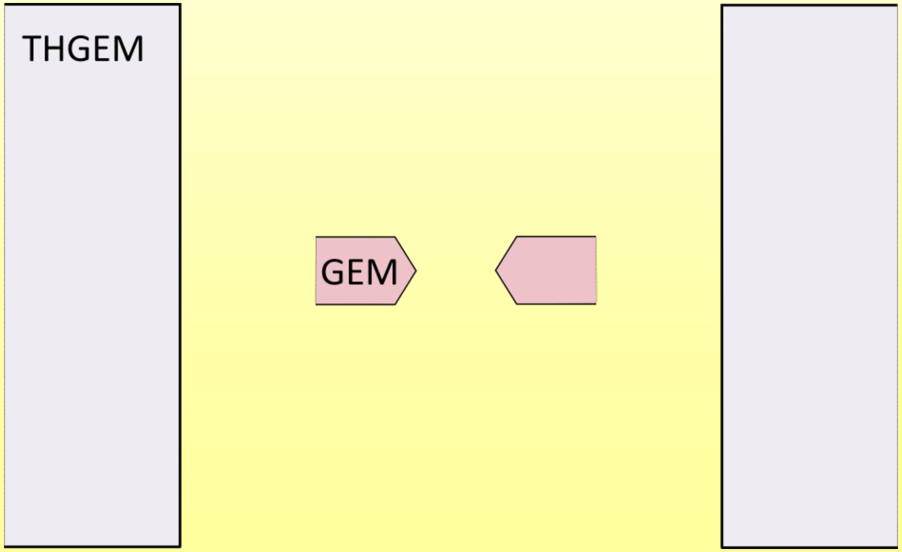
GAS ELECTRON MULTIPLIER



	Material	Thickness	Hole
GEM	Kapton / Copper	50 mµ	70 - 50 mµ
THGEM	FR4 – G10 / Copper	400 - 500 mµ	400 mµ

THICK GAS ELECTRON MULTIPLIER





Plenty of space between the GEM and THGEM

COBRA 125

Active area	100 cm^2
Hole size	100 µm
Thickness	125 µm
Hole spacing	400/460 µm
Cathode – Anode distance	60 µm
Bottom electrodes width	60 µm

- Low operating voltages;
- More resistant to discharges;
- Higher gains;
- Good energy resolution;

GEM 100

The standard Gas Electron Multiplier (GEM) high density holes etched in 50 micron thick copper clad Kapton.
Gain characteristics of a non-standard 100 µm thick Gas Electron Multiplier, fabricated using a wet chemical etch process at CERN.
It was possible to sustain charge gains of $3x10^3$ and $1x10^4$ using a single stage and double stage configurations, respectively.
Crucially, we found that We also measured the gain dependence on ambient variables such as pressure and temperature and found the gain sensitivity from to be 4.0 K/mbar when compared with 1.55 K/mbar for the standard GEM.

Introduction The industry standard thickness of 50µm kapton used to fabricate the GEMs could be more prone to permanent damage during a spark than a thicker substrate. A number of other fabrication techniques have been devised over the past decade involving various substrates. These include physical drilling in PCB substrate to form a Thick-GEM, laser ablation or more recent technique using a photosensitive glass. However, these techniques are either considerably expensive or time intensive. In this work, we report on the performance of a 100 µm thick Kapton GEM that has been fabricated at CERN using the wet chemical etch process. We demonstrate that it is possible to achieve , whilst avoiding the failure that follows sparking

50 micron Kapton foil
70 micron holes
140 micron pitch

hole-diameter of d = 0.4mm
with 0.1mm etched rim,
spaced by a=1mm