A Zero Ion Backflow electron multiplier operating in noble gases

Fernando D. Amaro, E.D.C. Freitas, C.A.O. Henriques, M.R. Jorge, M. Ball, J.F.C.A. Veloso, J.M.F. dos Santos

Coimbra University, Portugal
Aveiro University, Portugal
Technische Universitat Munchen, Germany

Technische Universität München

TIPP ' 2014 - International Conference on Technology and Instrumentation in Particle Physics

Ion Back Flow in gaseous electron multipliers

Ions in gaseous detectors
- Primary Ions.
- Secondary Ions. From gas amplification at the readout.

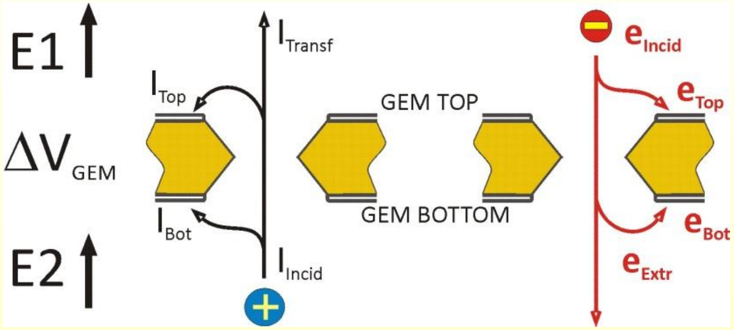
Ion Back Flow (IBF) is the ratio of ions that reach the cathode of the detector to the electrons collected at the anode.

In a open geometry (wire) detector this figure is =1. All ions are collected at the cathode.

Slow moving ions in the drif volume = Field distortions = track distortion.

Ion Back Flow in gaseous electron multipliers

The development of the hole type multipliers (GEM) and the cascading of these electron multipliers, allowed a significant reduction of the IBF.



3-GEM: IBF of 0.5% At a gain of 10^4 and a drift field of 0.2 kV/cm (the goal is 1/G).

M. Killenberg, S. Lotze, J. Mnich, A. Munnich, S. Roth, F. Sefkow, M.Tonutti, M. Weber, P. Wienemann. Charge transfer and charge broadening of GEM structures in high magnetic fields, Nuclear Instruments and Methods in Physics Research A 530 (2004) 251-257.

Pulsed electrodes/GEM acting as gate for the ions

limited count rate -> not feasible in ILC (?)

Alternative Solutions

- DC trapping of ions (R-MHSP)

  Successful operation of Gaseous Photomultiplier equipped with a visible sensitive photocathode

  [A. Lyashenko, et al. Nuclear Instruments and Methods in Physics Research Section A 610 (2009)]

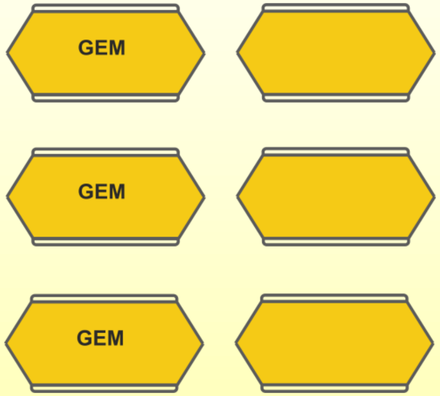
- Use of the secondary scintillation to propagate the signal in the detector

  (PACEM & Zero IBF electron multiplier)

  [J. F. C. A. Veloso, et al. “The Photon-Assisted Cascaded Electron Multiplier: a concept for potential avalanche-ion blocking”, 2006 JINST 1 P08003]
  [F. D. Amaro et al. “Zero Ion Backflow electron multiplier operating in noble gases, 2014_JINST_9_P02004]

Ion Back Flow- Alternatives

Standard Cascaded Electron Multiplier



Electric Field Optimization

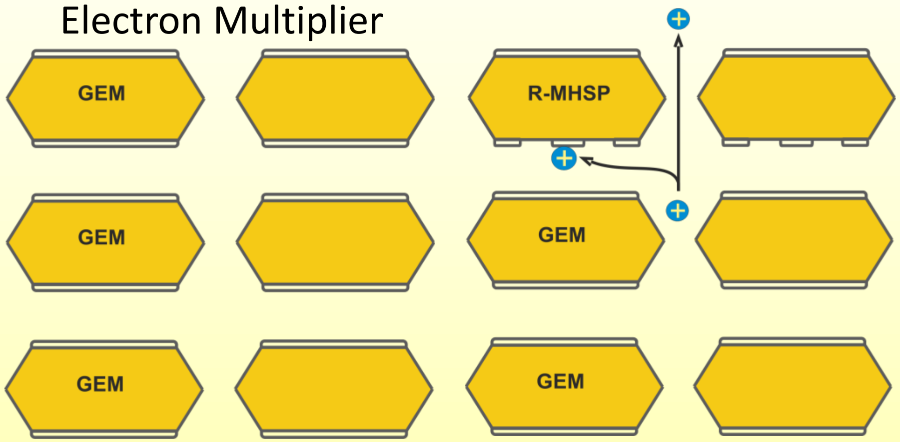
IBF = 0.5% at a gain of 10^4.

50 ions/primary electron

Ion Back Flow- Alternatives

Standard Cascaded Electron Multiplier

"Reversed" MHSP



Electric Field Optimization

IBF = 0.5% at a gain of 10^4.

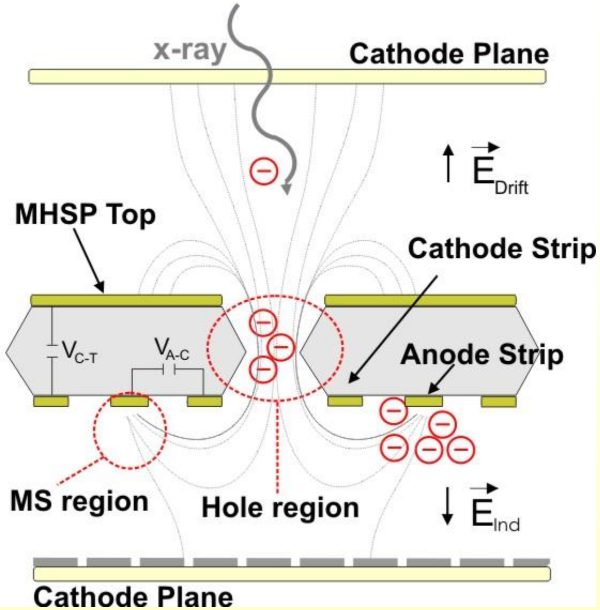
50 ions/primary electron

Trapping of ions at the strips on the MHSP

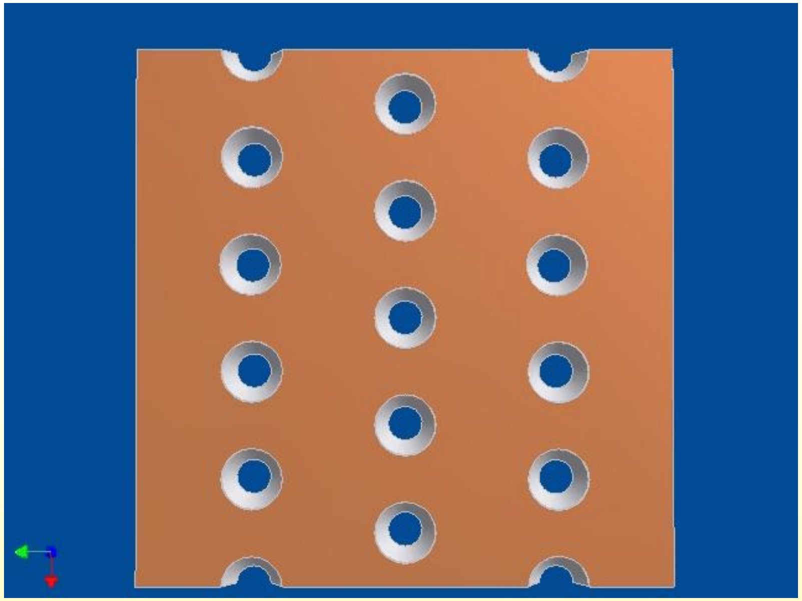
IBF = 0.06% at a gain of 10^4.

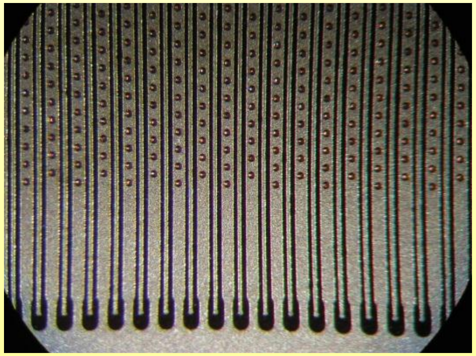
6 ions/primary electron

The Micro Hole and Strip Plate (MHSP)



[J. F. C. A. Veloso, et al., Rev. Sci. Instrum. 71 (2000).]

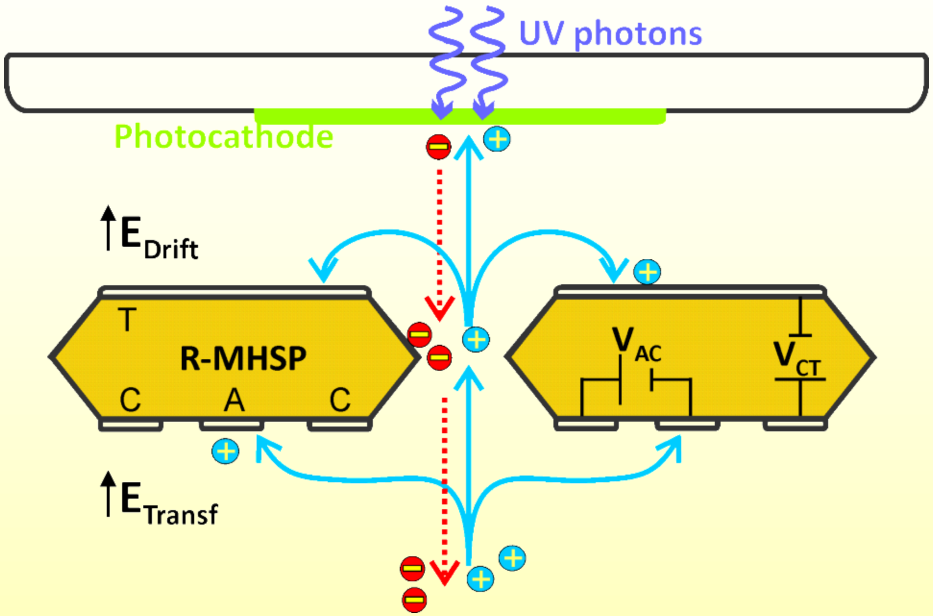




- Same technology as GEM
- 3 Independent set of Electrodes:
  - **Top** similar patterned as GEM
  - Bottom side has 2 type of electrodes, **Cathodes** and **Anodes**, in a micro-strip pattern.

High gain in a single structure

The MHSP Reverse mode operation

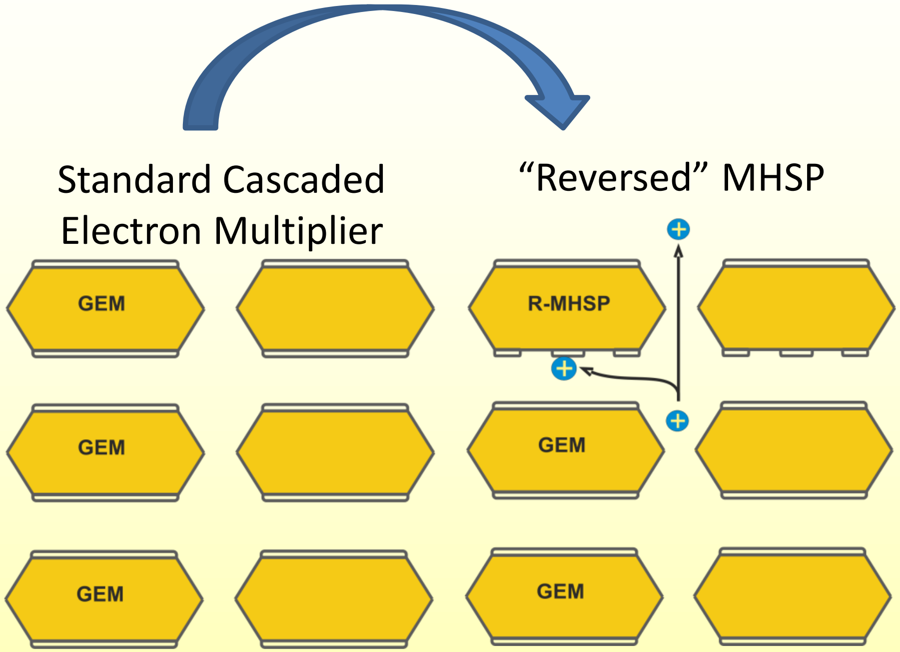


Replacing the first GEM of a cascade by an MHSP.

This MHSP is operated in “reversed mode”, that is, with the anodes at a lower potential that the cathodes:

- no multiplication between the anode-cathode strips
- trapping of positive ions backflowing from the lower stages of the cascade.

Ion Back Flow- Alternatives



Electric Field Optimization

IBF = 0.5% at a gain of 10^4.

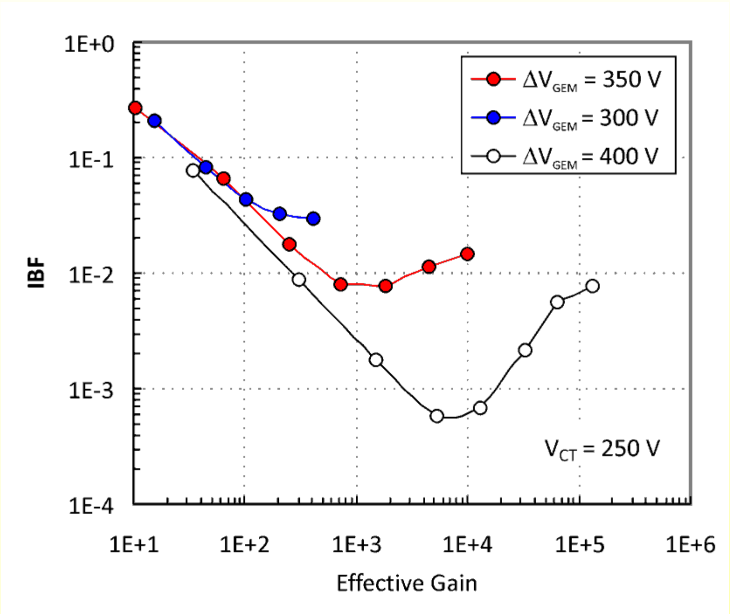
50 ions/primary electron

Trapping of ions at the strips on the MHSP

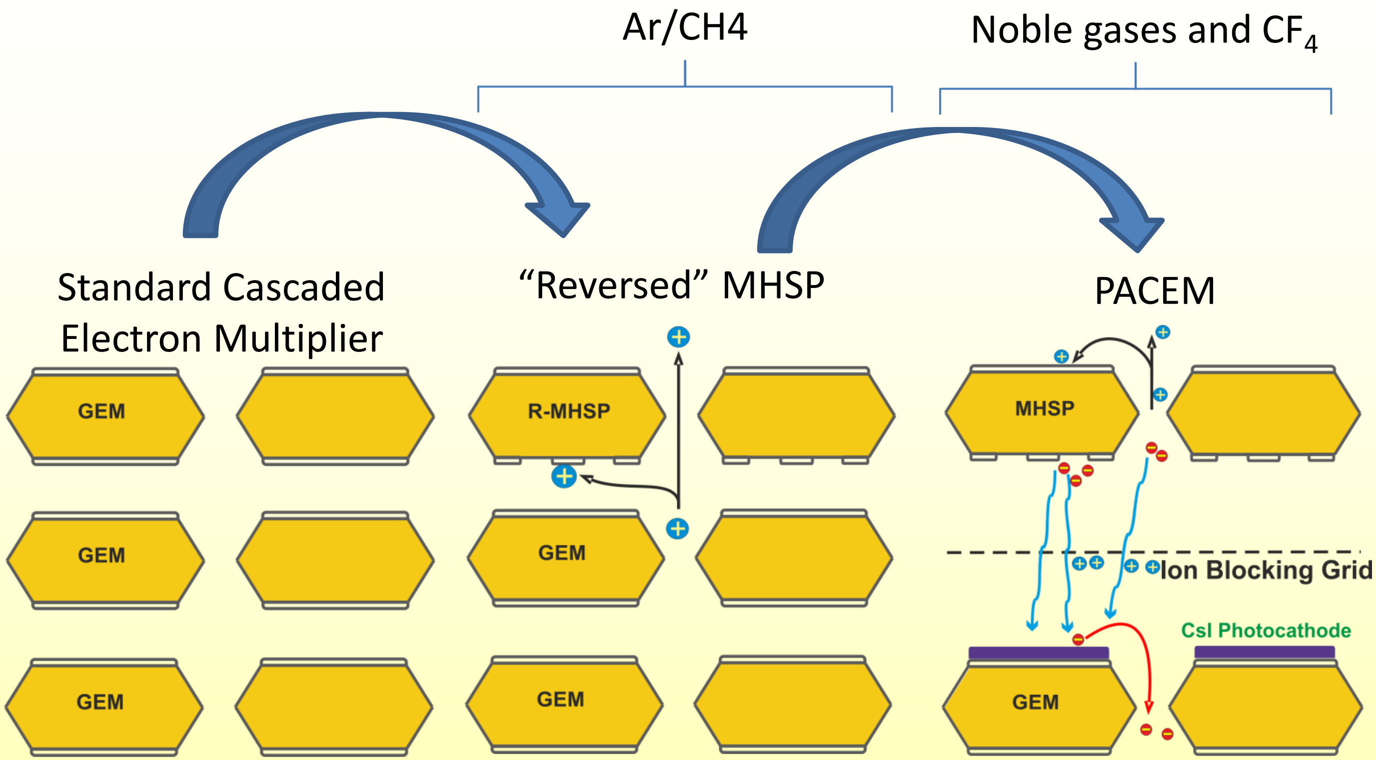
IBF = 0.06% at a gain of 10^4.

6 ions/primary electron

IBF is dependent on gain



Ion Back Flow- Alternatives

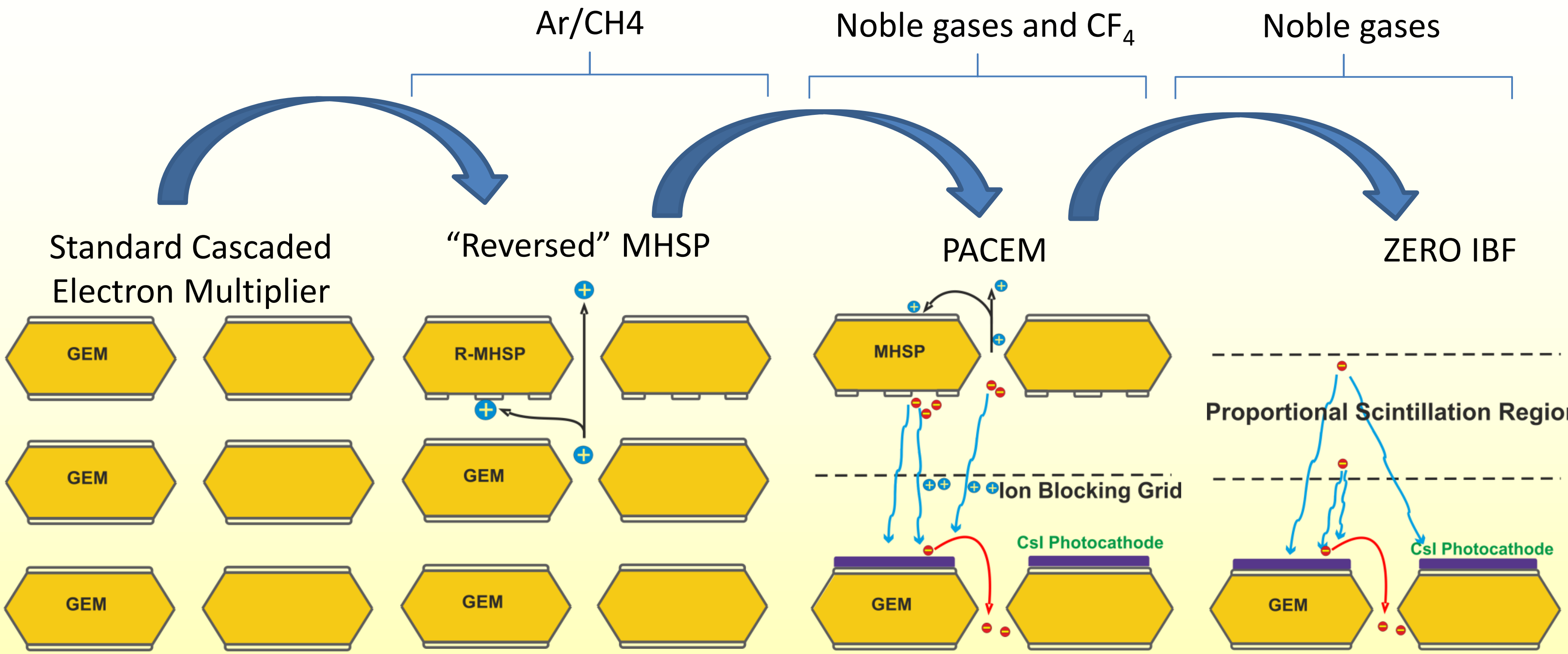


Electric Field Optimization
IBF = 0.5% at a gain of 10^4.
50 ions/primary electron

Trapping of ions at the strips on the MHSP
IBF = 0.06% at a gain of 10^4.
6 ions/primary electron

Use of secondary scintillation on MHSP To propagate the signal
IBF independent on GAIN
2 ions/primary electron (CF_4)

Ion Back Flow- Alternatives



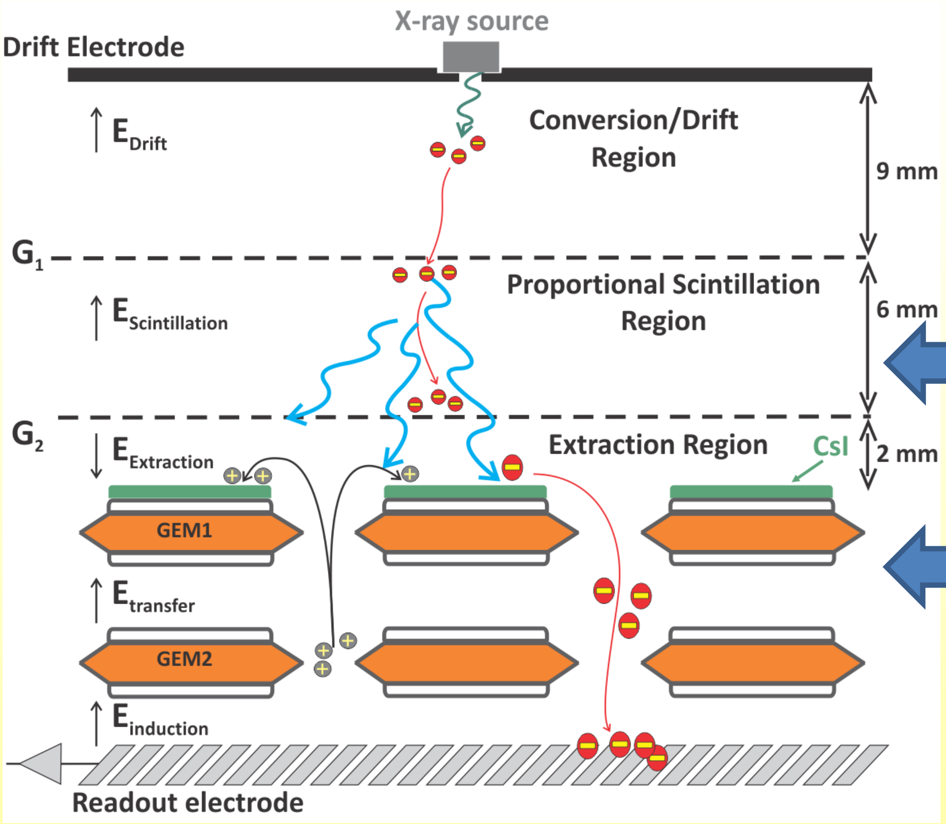
Electric Field Optimization
IBF = 0.5% at a gain of 10^4.
50 ions/primary electron

Trapping of ions at the strips on the MHSP
IBF = 0.06% at a gain of 10^4.
6 ions/primary electron

Use of <u>secondary scintillation</u> on MHSP To propagate the signal
IBF independent on GAIN
2 ions/primary electron (CF_4)

NO ions produced in the proportional scintillation region
0 ions/primary electron
(only primary ionization)

The Zero Ion Back Flow Electron Multiplier



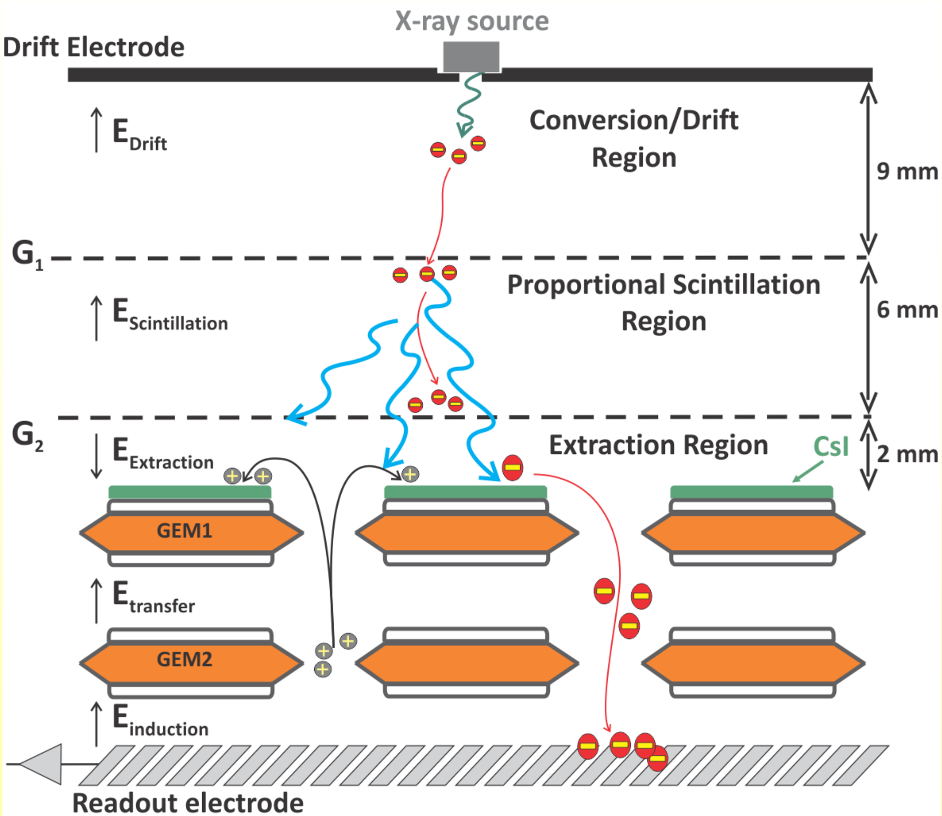
Proportional scintillation region: Primary electron cloud drifts under an electric field below the threshold for ionization. No secondary charges are created. Secondary scintillation is produced and emitted isotropically.

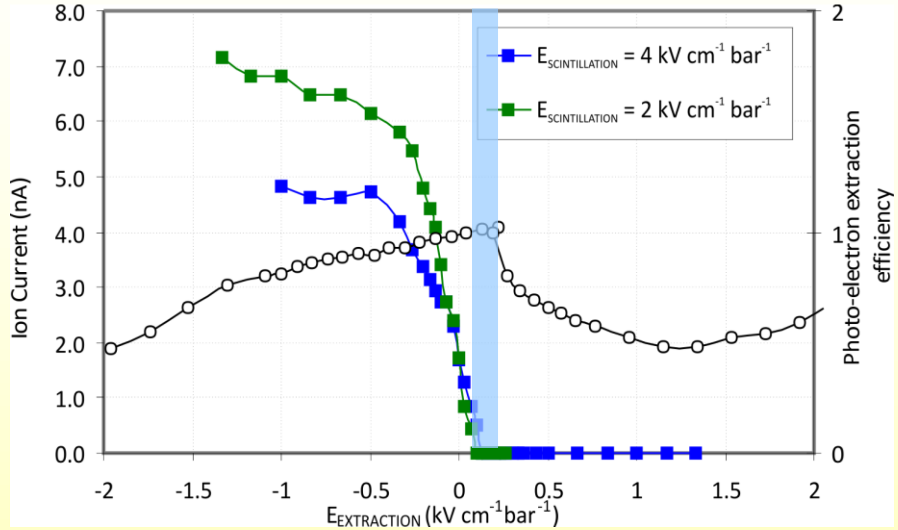
Gaseous Photomultiplier: Collects a fraction of the secondary scintillation.

The ultimate stage on Ion Back Flow Suppression

Only the primary ions are present on the conversion region. The primary electron cloud is amplified in the detector and no secondary ions return to the conversion region.

The Zero Ion Back Flow Electron Multiplier





Extraction field plays a critical part on ion back flow suppression as well as in photo-electron extraction

The ultimate stage on Ion Back Flow Suppression

Only the primary ions are present on the conversion region. The primary electron cloud is amplified in the detector and no secondary ions return to the conversion region.

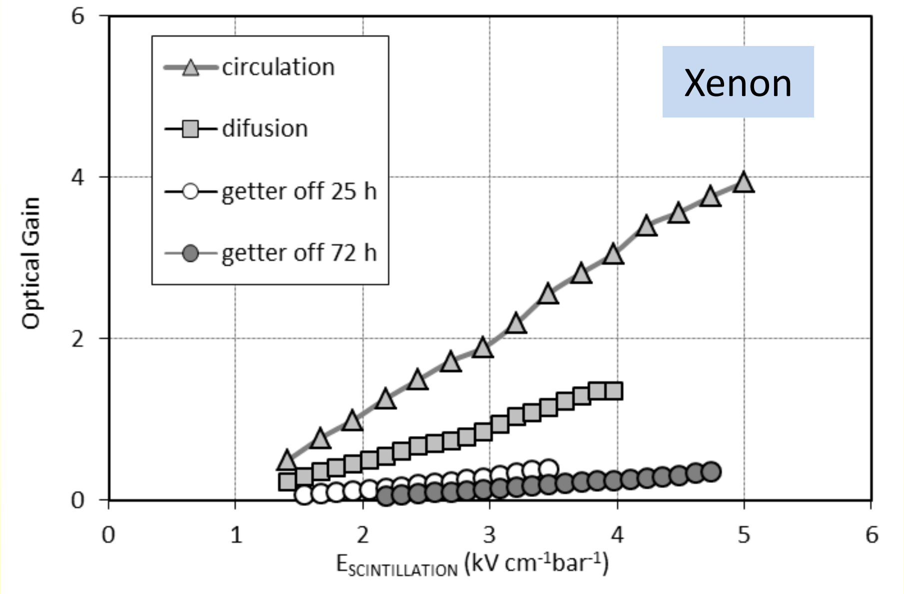
Optical Gain

Ratio between the number of photo-electrons detected by the GPM and the number of primary electrons converted in the absorption region.

$$Optical\ Gain \propto Nph \times \Omega \times mesh\ trans \times active\ area\ CsI \times Q.E.(Csi) \times \xi ph$$

- Nph = number of photons emitted per primary electron
  (≈ 350 per cm in xenon)
- Ω = Solid angle subtended by CsI photocathode
  (≈ 40% for our setup)
- mesh trans = mesh optical transparency
- active area of CsI = % of the GEM covered with copper
- CsI quantum efficiency ≈ 20 % (170 nm)
- ξph = photo-electron backscaterring

Optical Gain



The optical gain is strongly dependent on the purity conditions of the gas.

Detector was operated in sealed mode, with the purification done by circulating the gas through non-evaporable getters.

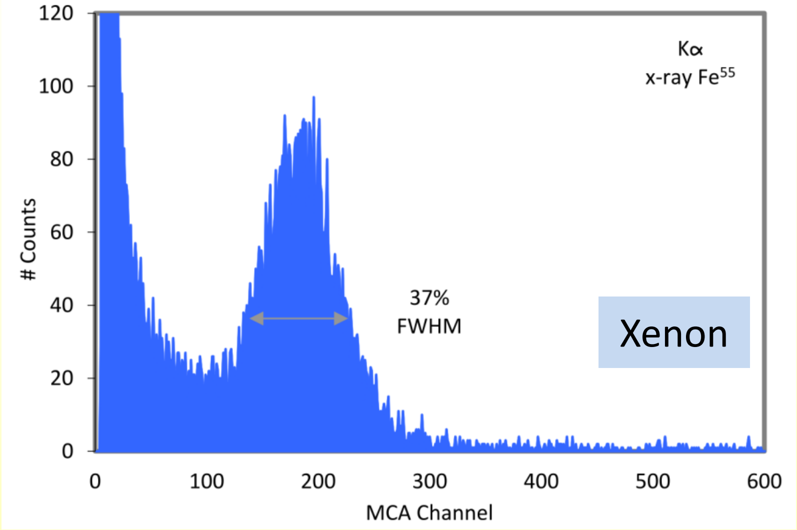
Some geometrical factors that influence the optical gain:

- proportional scintillation region size (current setup was 6 mm). Increase to 10 mm would increase the optical gain from 4 to 6
- Larger solid angle (larger photocathode; the one used was 28*28 mm^2)

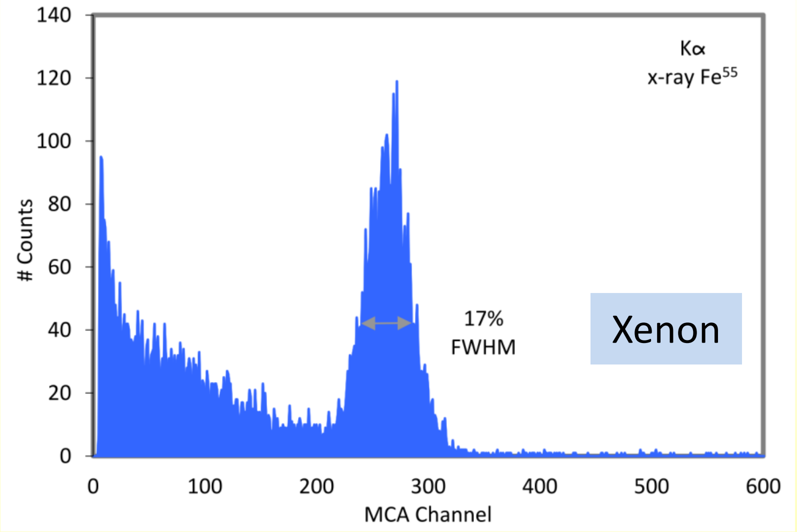
Despite the relatively modest optical gain, the energy resolution is not compromised

Energy resolution

Charge multiplication



Scintillation + Charge multiplication



Direct signal: resulting from the direct interaction in the gap above the photocathode.

Scintillation signal: 17% energy resolution for an electric field of 4.7 kV cm^{-1} bar^{-1}

Zero IBF in Argon

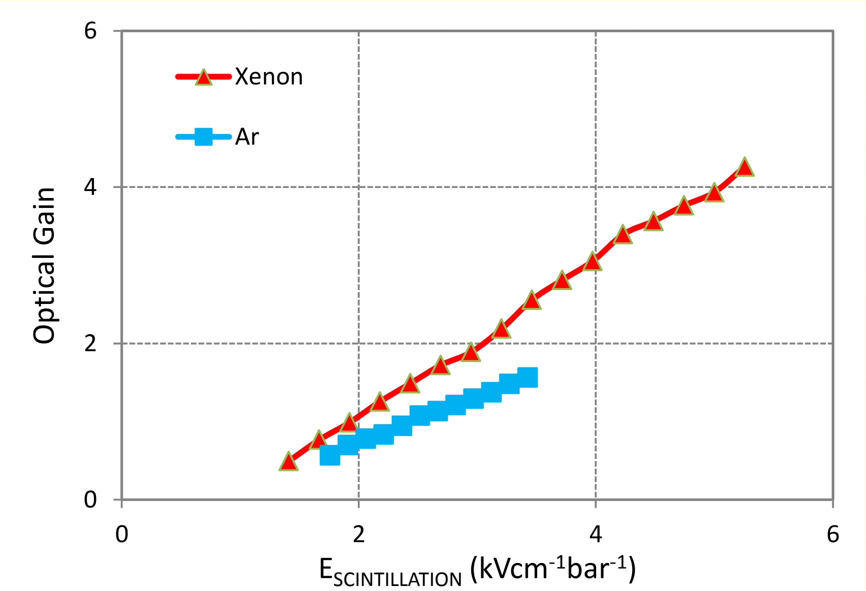
$$\textbf{Optical Gain} \propto \text{Nph} \times \Omega \times \text{mesh trans} \times \text{active area CsI} \times \text{Q.E.}\,(\text{Csi}) \times \xi\text{ph}$$

	Xenon	Argon
Nph	203	130
CsI Q.E.	≈ 20 % (170 nm)	> 35 % (120 nm)
PhotoElectron Collection efficiency	≈ 25 %	≈ 45 %

Zero IBF in Argon

$$\textbf{Optical Gain} \propto Nph \times \Omega \times \text{mesh trans} \times \text{active area CsI} \times Q.E.(Csi) \times \xi ph$$

	Xenon	Argon
Nph	203	130
CsI Q.E.	≈ 20 % (170 nm)	> 35 % (120 nm)
PhotoElectron Collection efficiency	≈ 25 %	≈ 45 %



Slightly higher optical gains expected with Argon

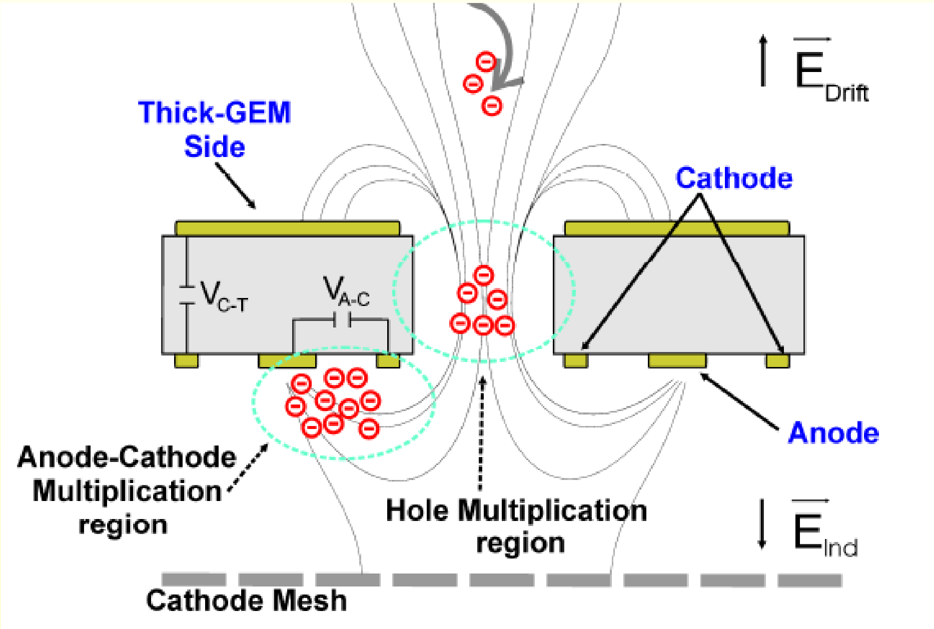
Double GEM
(Kapton)

THCOBRA
Thick Hole multiplier
(G10)

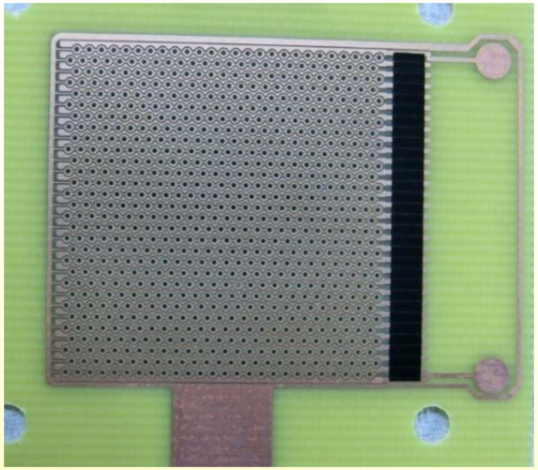
THCOBRA

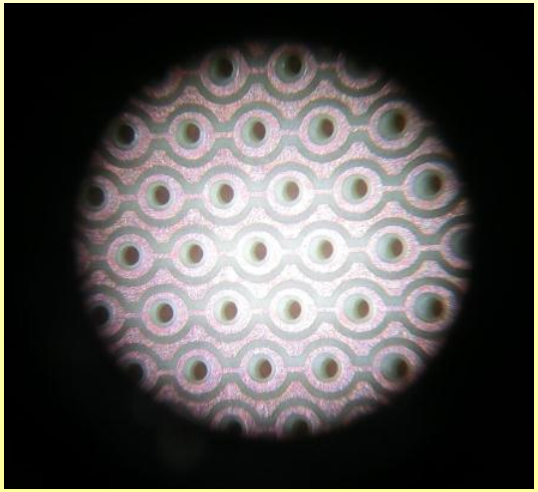
THICK Electron Multiplier.

- 2 Independent Multiplication regions
- Very Robust



[F D Amaro et al. "The Thick-COBRA: a new gaseous electron multiplier for radiation detectors" 2010 JINST 5 P10002]

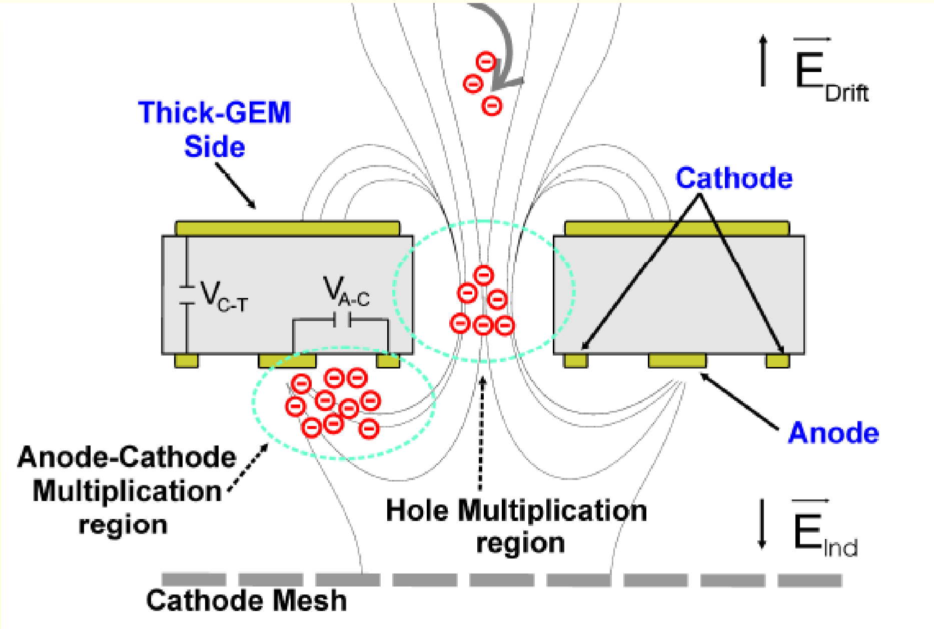




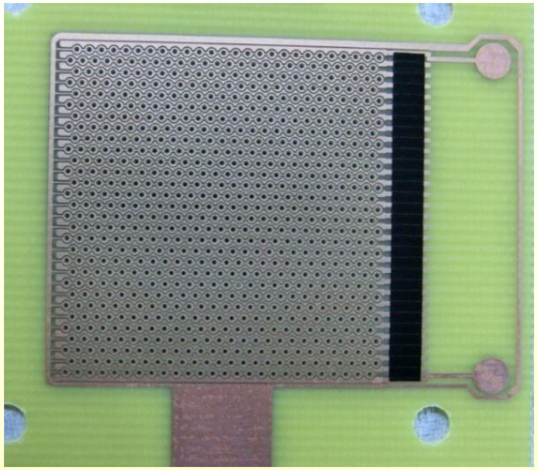
THCOBRA

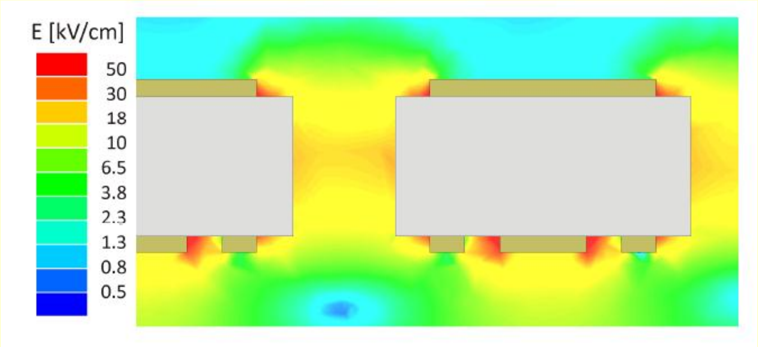
THICK Electron Multiplier.

- 2 Independent Multiplication regions
- Very Robust



[F D Amaro et al. "The Thick-COBRA: a new gaseous electron multiplier for radiation detectors" 2010 JINST 5 P10002]

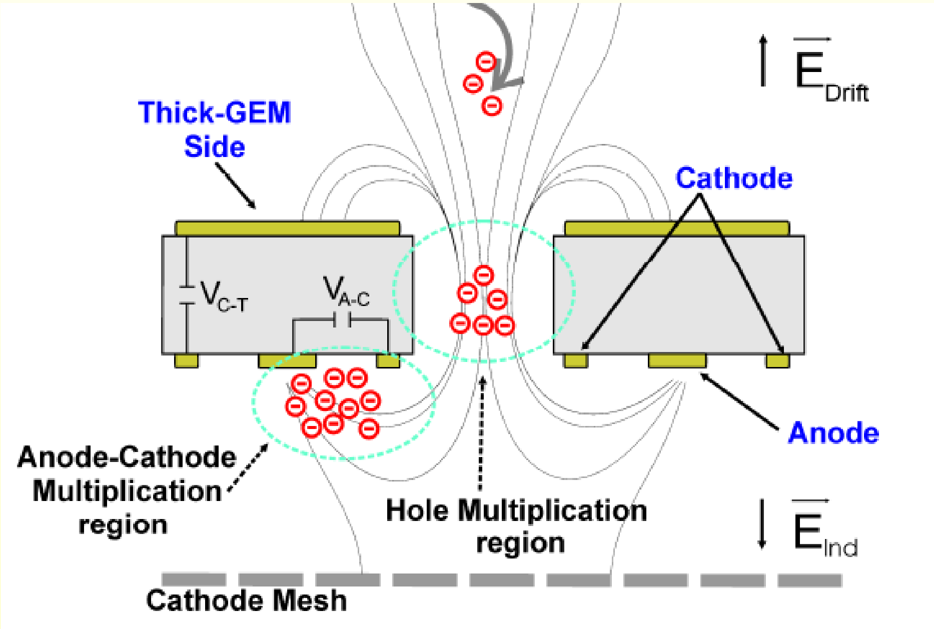




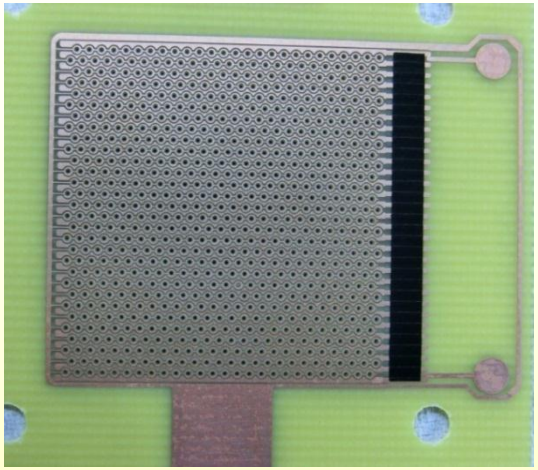
THCOBRA

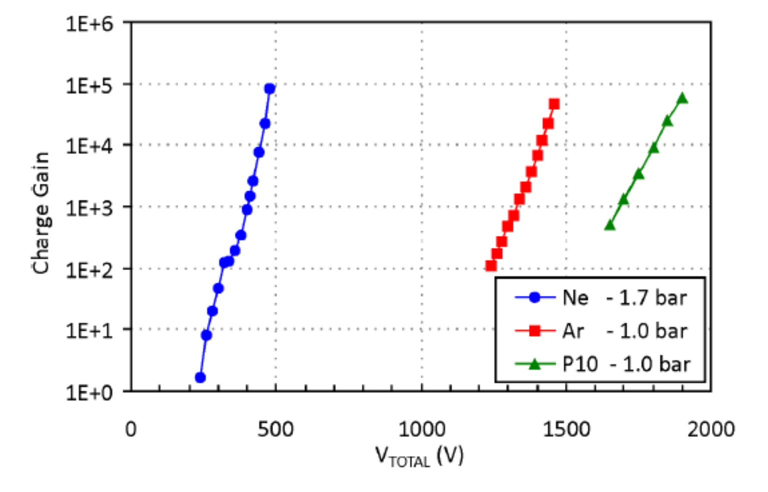
THICK Electron Multiplier.

- 2 Independent Multiplication regions
- Very Robust



[F D Amaro et al. “The Thick-COBRA: a new gaseous electron multiplier for radiation detectors” 2010 JINST 5 P10002]

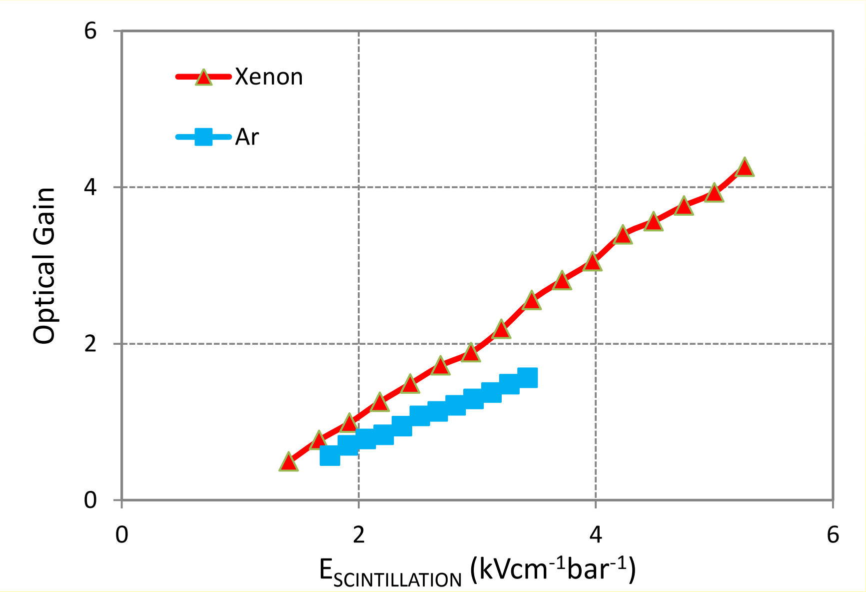




Zero IBF in Argon

$$\textbf{Optical Gain} \propto \text{Nph} \times \Omega \times \text{mesh trans} \times \text{active area CsI} \times \text{Q.E.(Csi)} \times \xi\text{ph}$$

	Xenon	Argon
Nph	203	130
CsI Q.E.	≈ 20 % (170 nm)	> 35 % (120 nm)
PhotoElectron Collection efficiency	≈ 25 %	≈ 45 %



Slightly higher optical gains expected with Argon

Double GEM
(Kapton)

↓

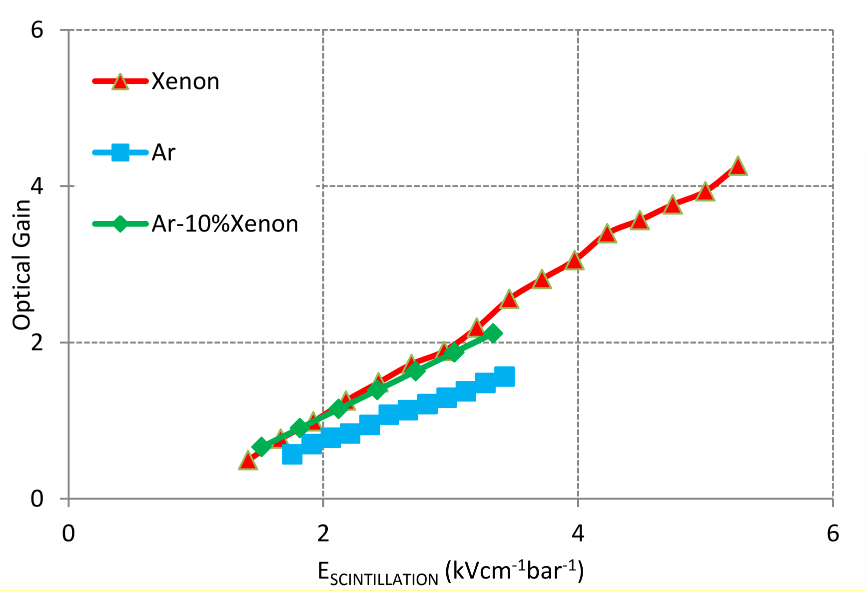
THCOBRA
Thick Hole multiplier
(G10)

Argon-Xenon mixtures

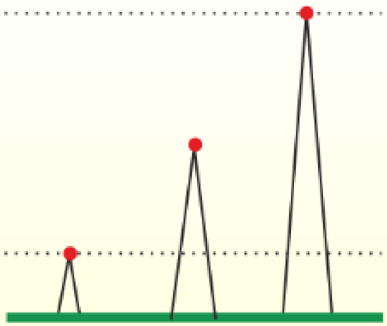
"the best of both worlds"

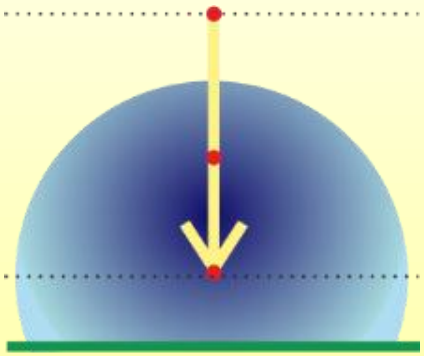
$$\textbf{Optical Gain} \propto \text{Nph} \times \Omega \times \text{mesh trans} \times \text{active area CsI} \times \text{Q.E.(Csi)} \times \xi\text{ph}$$

	Xenon	Argon
Nph	203	130
CsI Q.E.	≈ 20 % (170 nm)	> 35 % (120 nm)
PhotoElectron Collection efficiency	≈ 25 %	≈ 45 %



Position information





Electroluminescence is emitted isotropicaly .
Optical Gain of 4

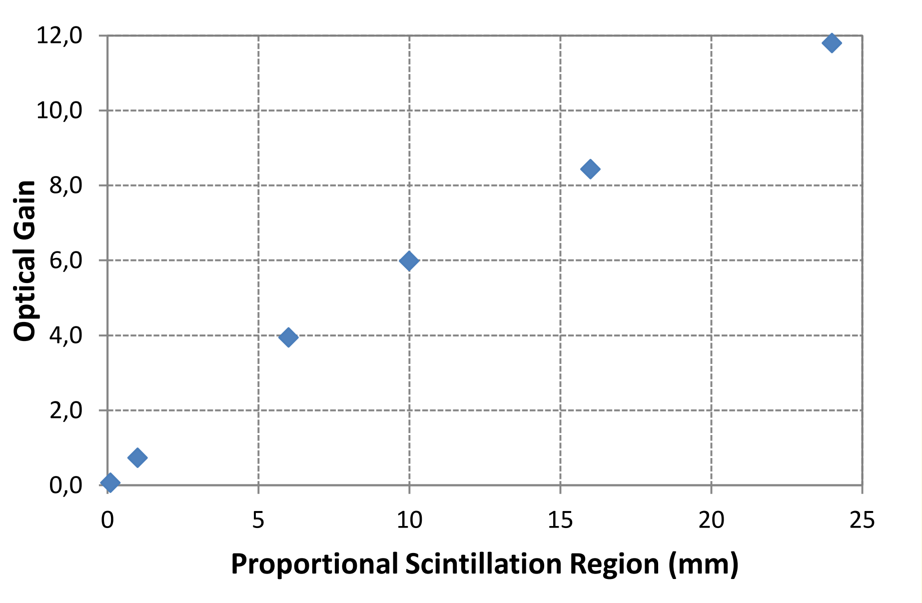
4 photons collected from our photocathode per primary electron

A simple monte-carlo model:

- electron is moving in straight line through the scintillation region
- emits radiation in all directions with a given probability per step.
- The number of photons emitted in each step was adjusted to match our experimental values
- A photo-sensor collects part of this radiation.

No electron diffusion. No primary electron cloud size.
Only spread from scintillation.

Optical gain estimation

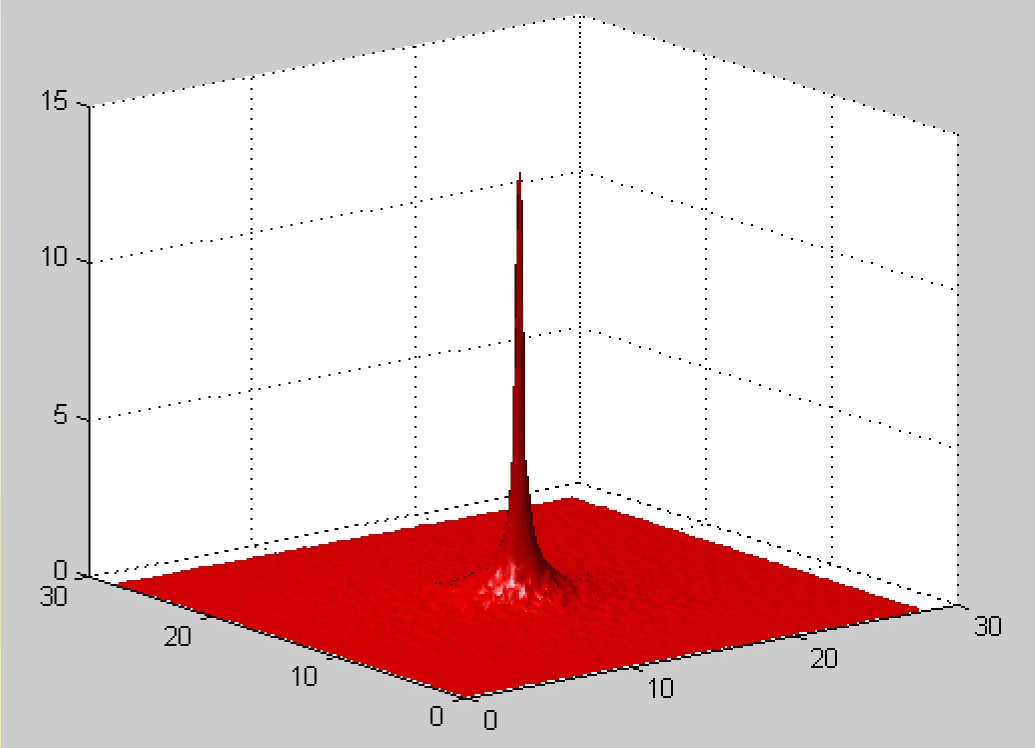


Changing the geometry of our model gives us an estimation of the optical gain as a function of the scintillation region size.

Result calculated from the experimental conditions of our double GEM detector in Xenon:

- 6 mm scintillation region
- 28x28 mm^2 photo-sensor
- optical gain of 4.

Single electron position correlation



270 primary electrons ≈ Fe^{55} conversion in Xenon

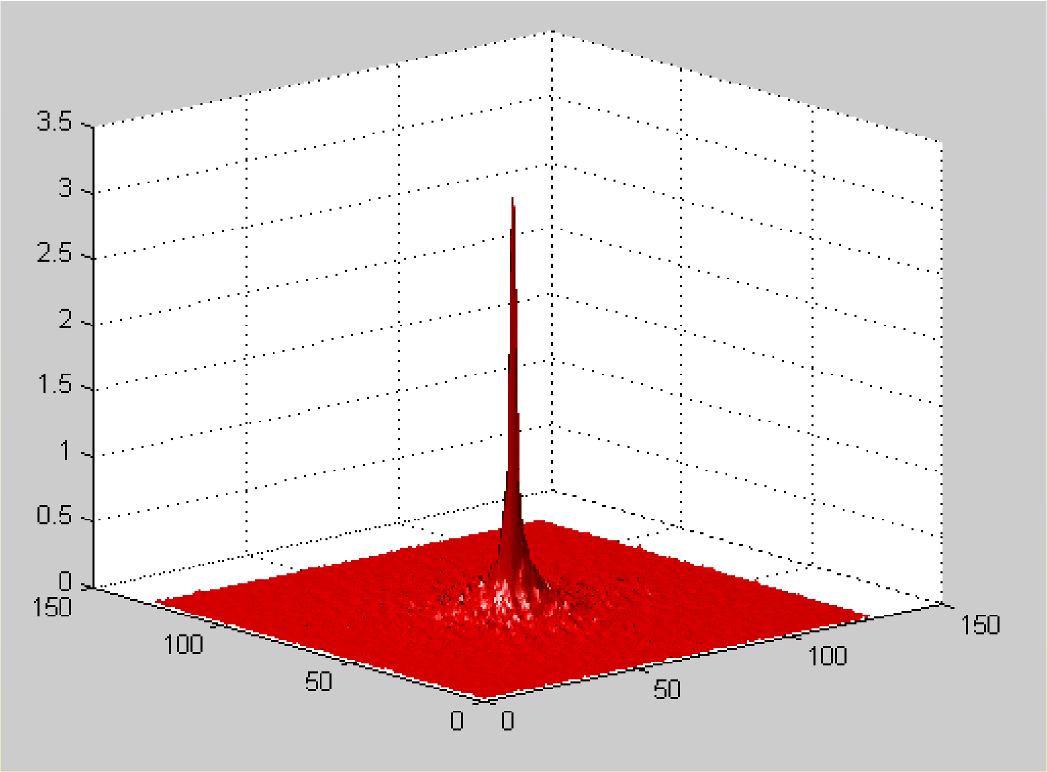
Optical Gain =4

Nph collected at the photocathode = 1080

Result calculated from the experimental conditions of our double GEM detector in Xenon:

- 6 mm scintillation region
- 28x28 mm^2 photosensor
- optical gain of 4.

Single electron position correlation



270 primary electrons ≈ Fe^{55} conversion in Xenon

Optical Gain =1

Nph collected at the photocathode = 270

Result calculated from the experimental conditions of our double GEM detector in Xenon:

- 6 mm scintillation region
- 28x28 mm^2 photosensor
- optical gain of 1.

Conclusions

- R-MHSP: Trapping of ions using the strips on the bottom of the MHSP
  - Works in Ar/CH4 mixtures
  - 6 ions/primary electron
  - Successful operation of visible sensitive GPM
- Photon Assisted Cascaded Electron Multiplier
  - Noble Gases and CF4 and their mixtures
  - 2 ions/primary electron in CF4
- Zero IBF cascaded electron multiplier
  - Works in noble gases
  - Ultimage stage on ion supression ➡ primary ions

A Zero Ion Backflow electron multiplier operating in noble gases

Fernando D. Amaro, E.D.C. Freitas, C.A.O. Henriques, M.R. Jorge, M. Ball, J.F.C.A. Veloso, J.M.F. dos Santos

Coimbra University, Portugal
Aveiro University, Portugal
Technische Universitat Munchen, Germany

Technische Universität München