Overview of the studies on He-CF_4 mixtures with hydrocarbon additives performed during the past year in Coimbra

Coimbra Group

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Topics:

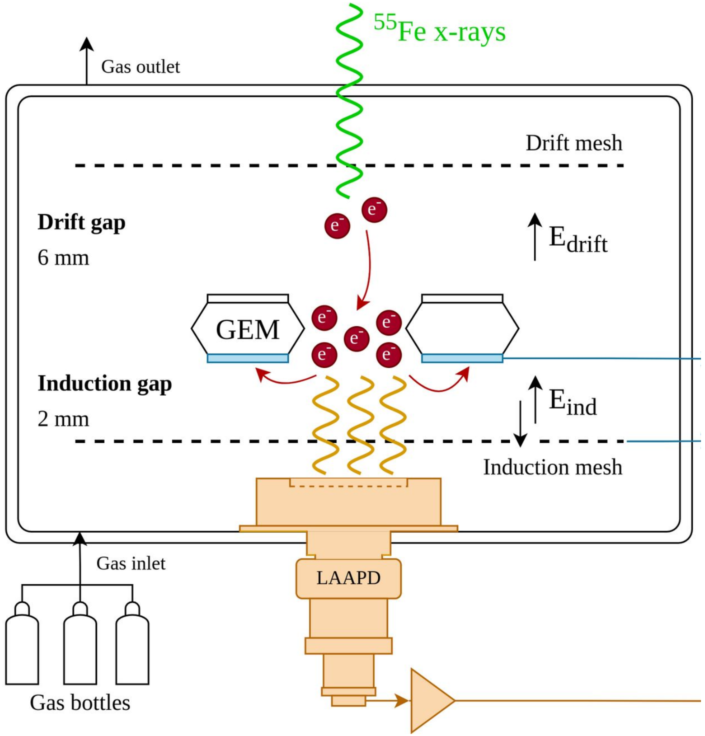
- Isobutane admixtures
- Methane admixtures
- COBRA_125 vs GEM

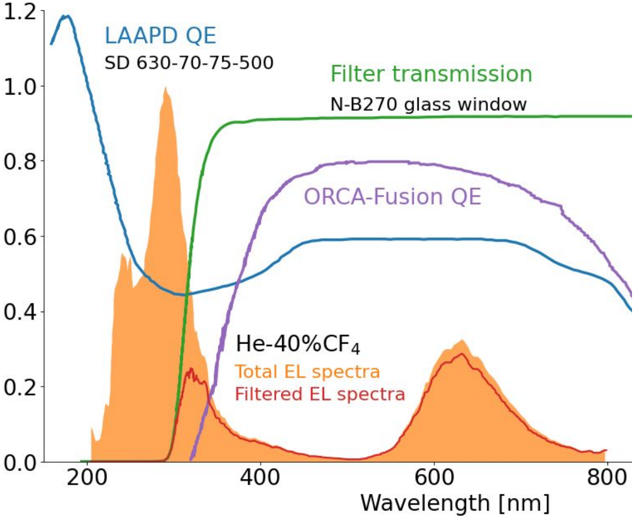
CYGNO International Collaboration Meeting 2022

Sapienza, Rome, Italy, 19 - 20 December 2022

Experimental Setup

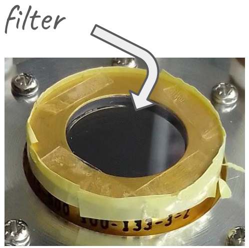
A Large Area Avalanche Photodiode (LAAPD) was used to readout the EL produced in the avalanches of a Gas Electron Multiplier (GEM).



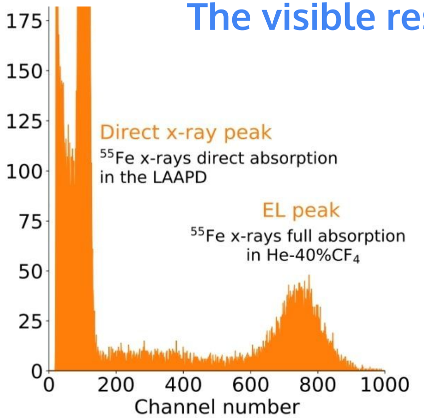


Total EL yield
The LAAPD is sensitive in the range 150-1050 nm.

Visible EL yield
The borosilicate glass is only transparent to visible photons (>300 nm).



The visible results are finally calibrated!



The EL yield is given by the formula:

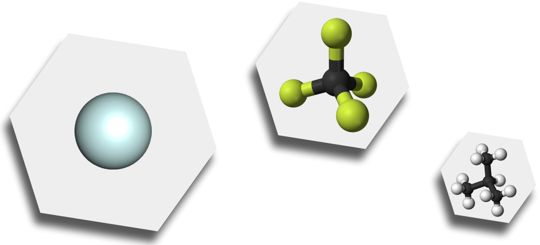
$$\frac{\eta_\gamma}{\mathrm{keV}} = \frac{A_{EL}}{A_X} \times \frac{1}{w(Si) \times QE \times \Omega \times T}$$

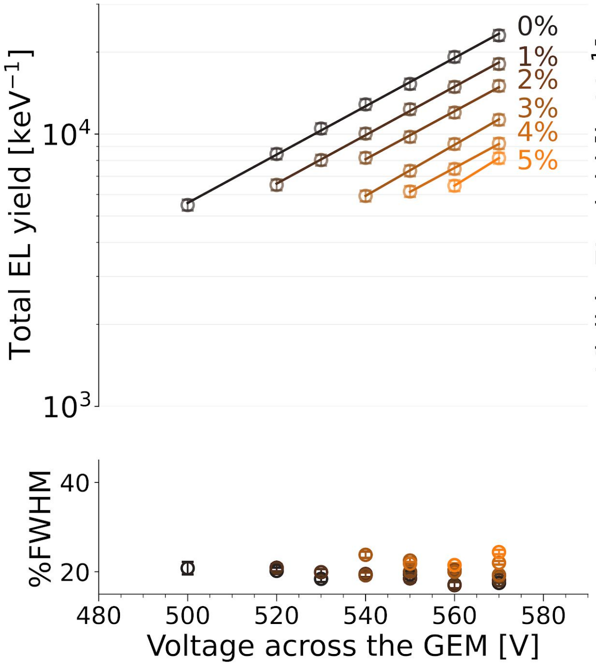
EL and ^{55}Fe x-rays peak ratio

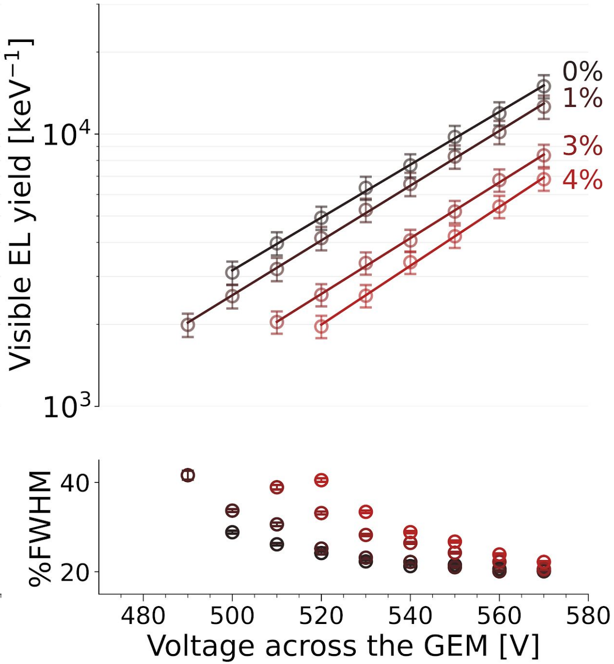
w-value (silicon), quantum efficiency, solid angle, mesh transparency

Isobutane admixtures to He-40%CF_4

Total and visible EL yields





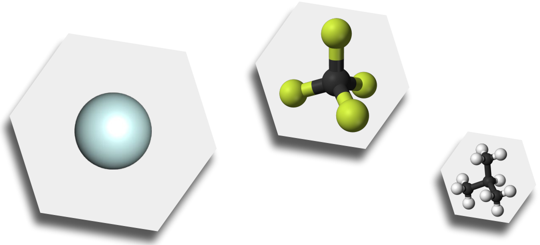


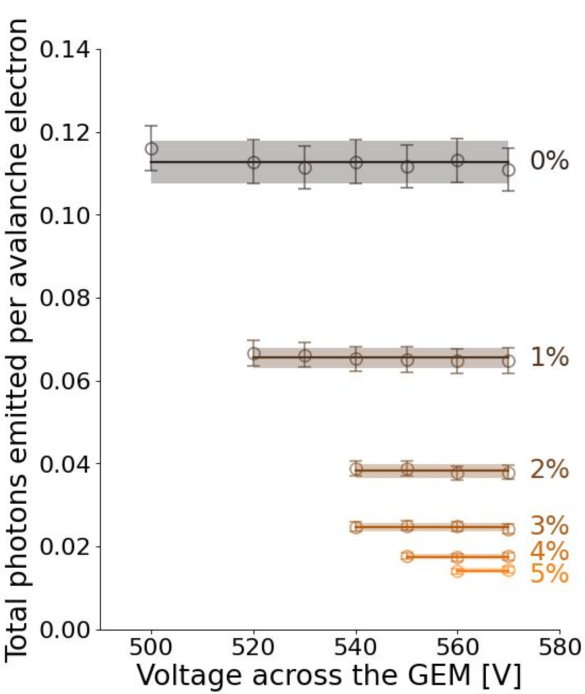
We evaluated isobutane concentrations up to 5% and found that:

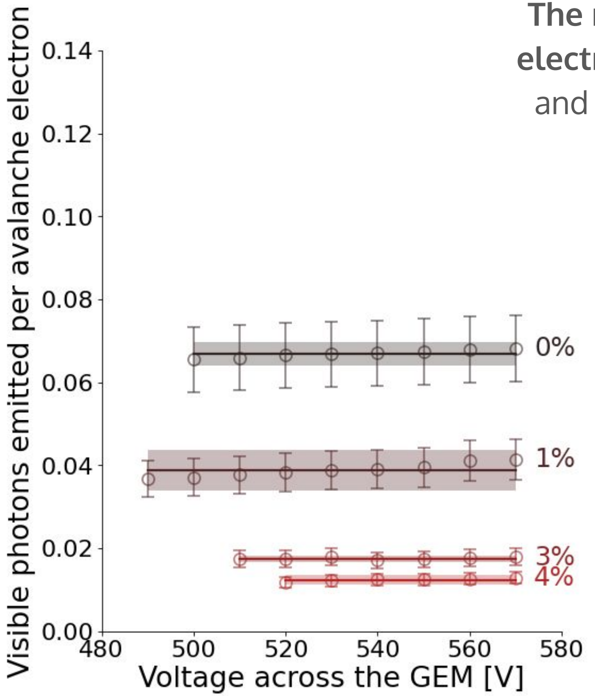
- Adding isobutane decreases the total and visible EL yields, meaning that **isobutane absorbs the visible and UV photons emitted by He-40%CF_4.**
- The best energy resolution is about 20% for all mixtures.

Isobutane admixtures to He-40%CF_4

Photons emitted per avalanche electron





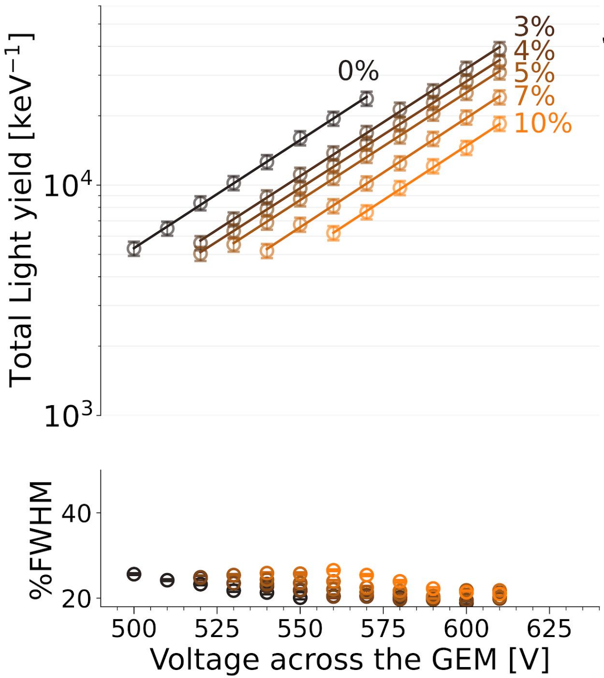


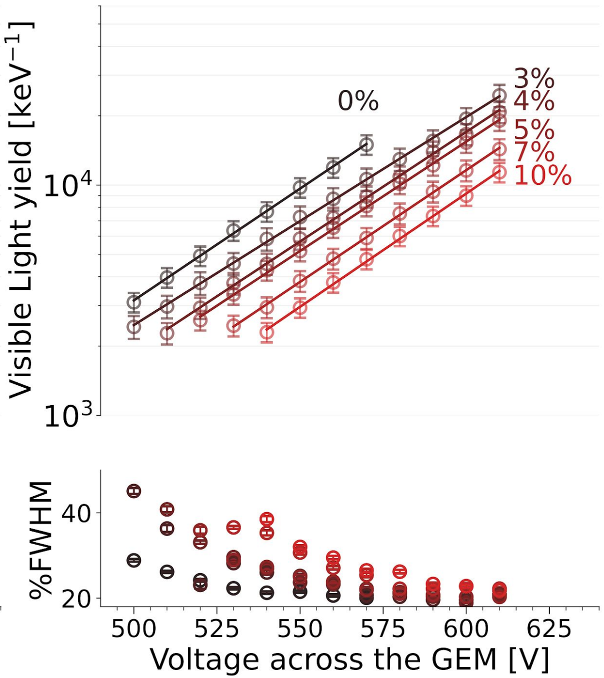
The number of photons emitted per avalanche electron is constant for each isobutane admixture and independent of the voltage across the GEM.

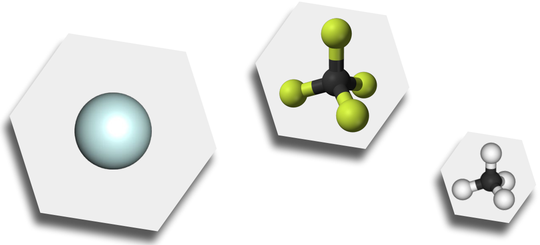
%i-C_4H_{10}	Total	Visible
0%	0.113(5)	0.0669(27)
1%	0.0655(24)	0.039(5)
2%	0.0383(17)	-
3%	0.0247(10)	0.0175(8)
4%	0.0176(6)	0.0124(12)
5%	0.0142(6)	-

Methane admixtures to He-40%CF_4

Total and visible EL yields





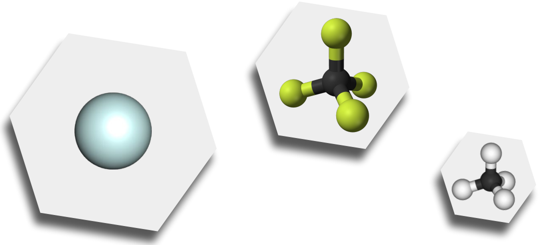


We evaluated methane concentrations between 3% and 10% and found that:

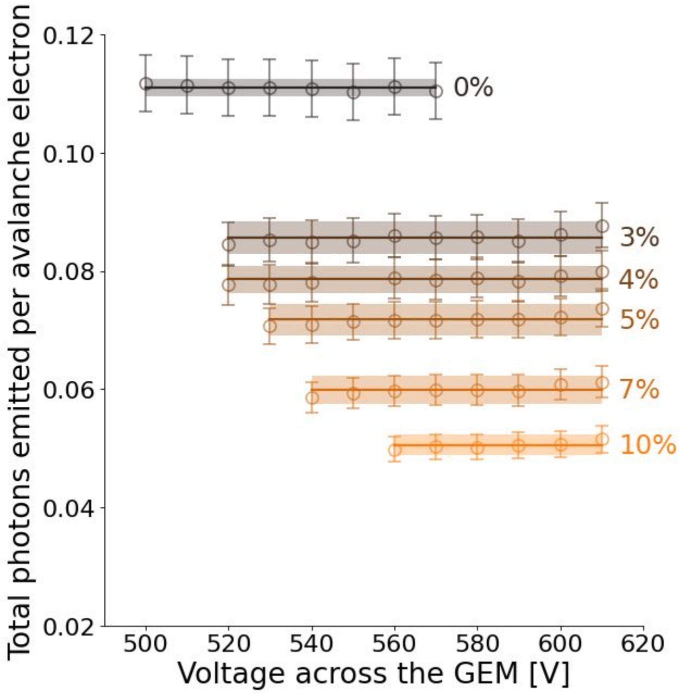
- Increasing the amount of methane decreases the total and visible EL yields, meaning that **methane absorbs the visible and UV photons emitted by He-40%CF_4.**
- The best energy resolution is about 20% for all mixtures.
- **Methane admixtures increased the electrical stability of the detector,** allowing to achieve higher EL yields than with He-40%CF_4.

Methane admixtures to He-40%CF_4

Photons emitted per avalanche electron



The number of photons emitted per avalanche electron is independent of the biasing voltage for each methane admixture.



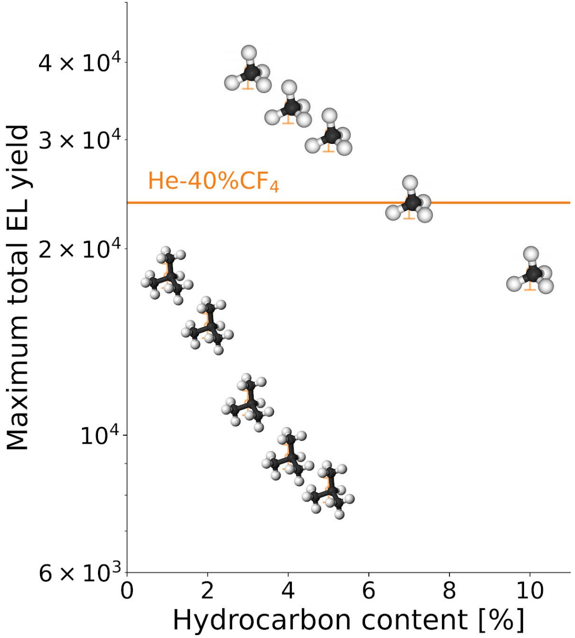
Methane quenches less EL photons that isobutane.

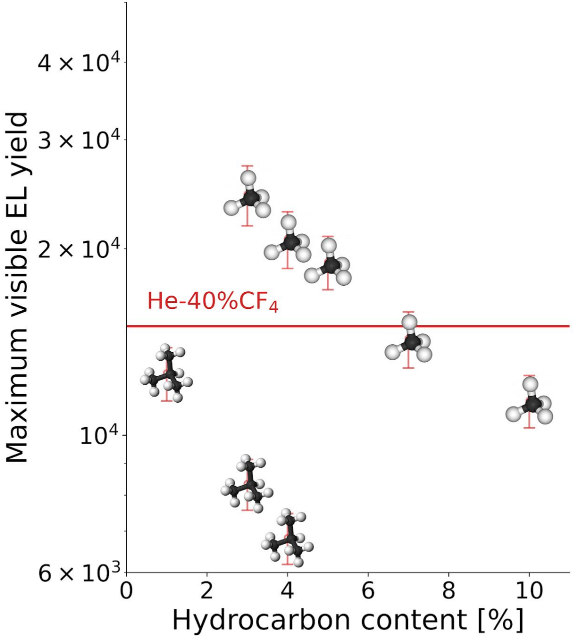
%	CH_4 Total	i-C_4H_{10} Total
0%	**0.1110(5)**	0.113(5)
3%	**0.0856(9)**	0.0247(10)
4%	**0.0786(7)**	0.0176(6)
5%	**0.0717(9)**	0.0142(6)
7%	**0.0599(8)**	–
10%	**0.0505**	–

Isobutane versus Methane

Maximum EL yield

Both isobutane and methane quench the visible and UV photons emitted by He-40%CF_4, but they do not completely absorb the optical signal.





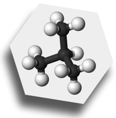
Methane seems to be a better additive to He-40%CF_4 because:

- Increases the electrical stability of the detector.
- Achieves higher EL yields than He-40%CF_4.

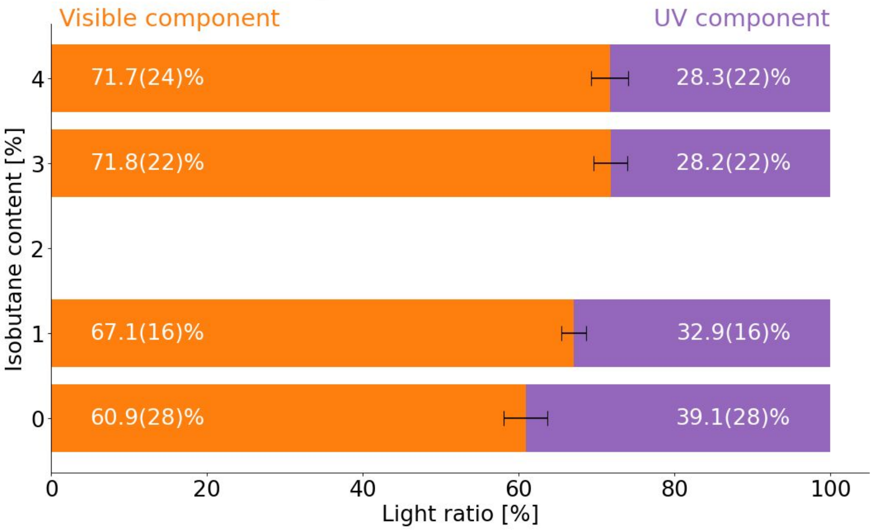
Using up to 7% methane to increase the WIMP sensitivity will not compromise the optical readout.

Isobutane versus Methane

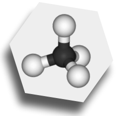
Visible and UV quenching behaviour



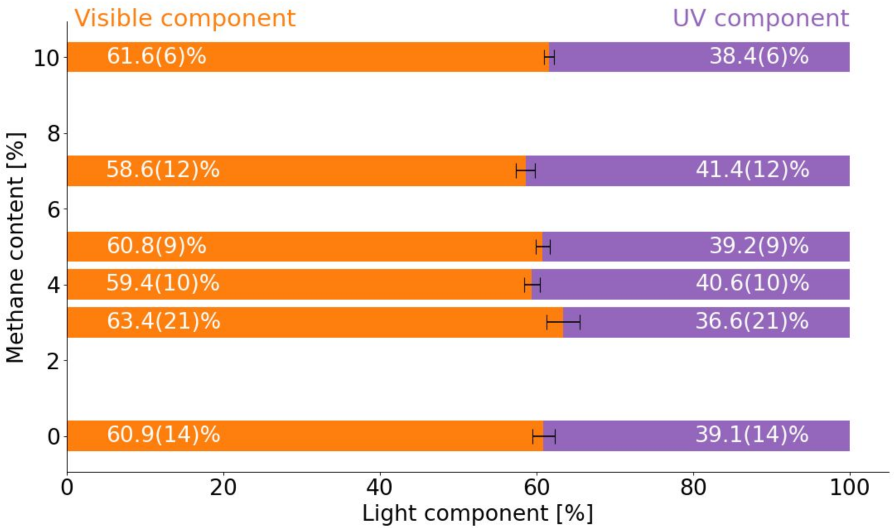
Isobutane



Isobutane seems to have a slight preference for quenching the UV photons emitted by He-40%CF_4.



Methane



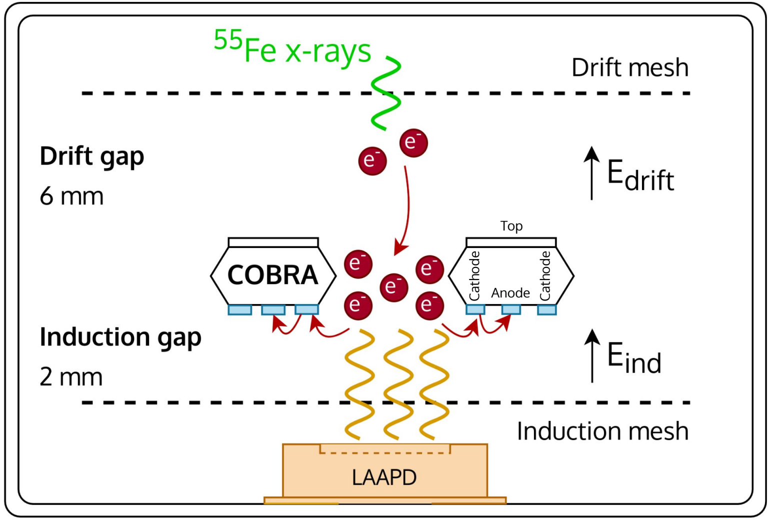
Methane seems to equally quench the visible and UV photons emitted by He-40%CF_4.

Experimental Setup

We have replaced our 50 µm GEM with a 125 µm COBRA:

- **Increased thickness:** more robust to electric discharges.
- **Third electrode:** additional multiplication region in the bottom strips.

Lyashenko, Alexey, et al. "Efficient ion blocking in gaseous detectors and its application to gas-avalanche photomultipliers sensitive in the visible-light range." NIMA 598.1 (2009): 116-120.

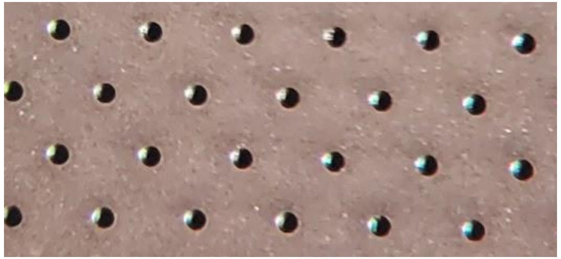


Both features of the COBRA_125 may increase the light yield.

But how much?

GEOMETRY	GEM	COBRA_125
Hole spacing	140 µm	400 µm
Hole in kapton/ copper	50 µm/ 70 µm	60 µm/ 120 µm
Strip width	–	60 µm
Strip separation	-	60 µm

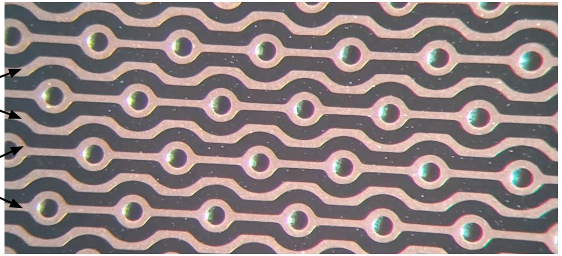
Top electrode



Bottom electrodes

Anodes
(between the holes)

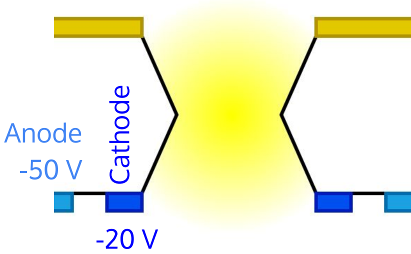
Cathodes
(around the holes)



He-40%CF_4: GEM Mode

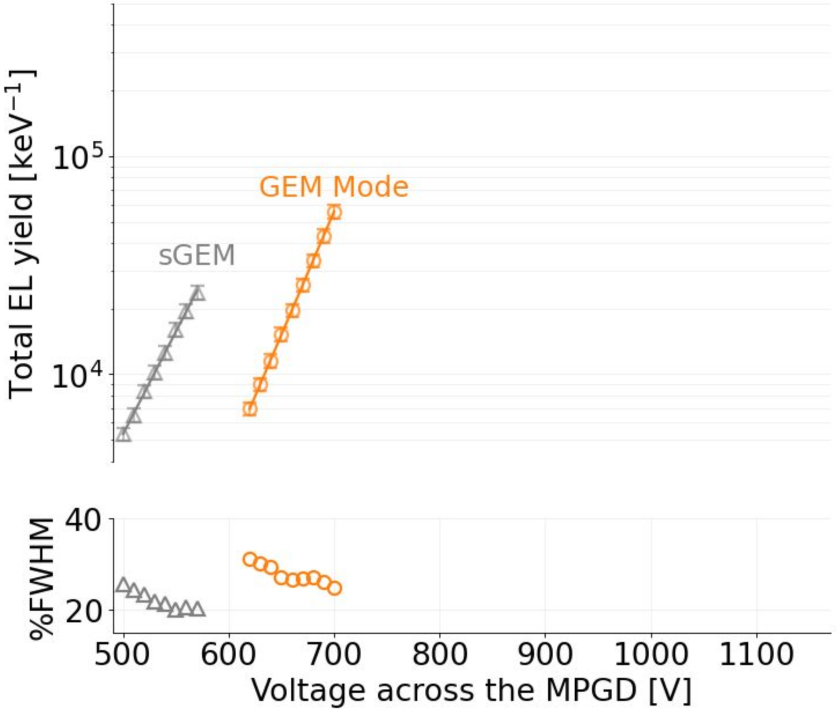
Light is only produced within the holes:

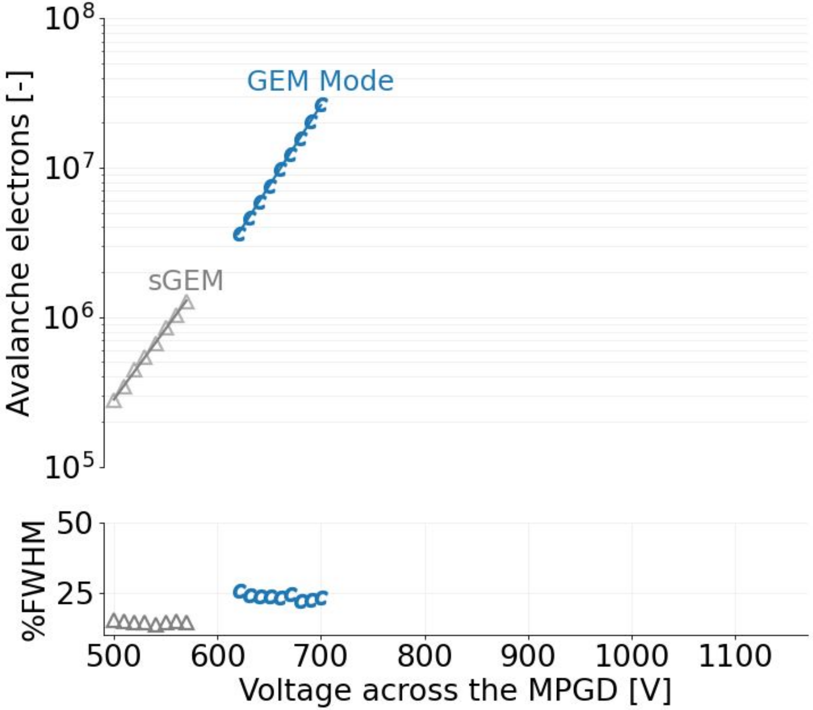
- Hole bias is increased.
- Strip bias is constant.



Light and Charge increases with increasing bias.
2.3-fold increase in light yield with the COBRA operating in GEM Mode.

Minimum energy resolution (FWHM) is 22% for charge and 24% for light signals.



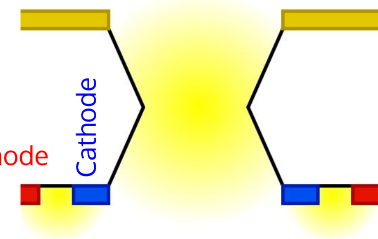


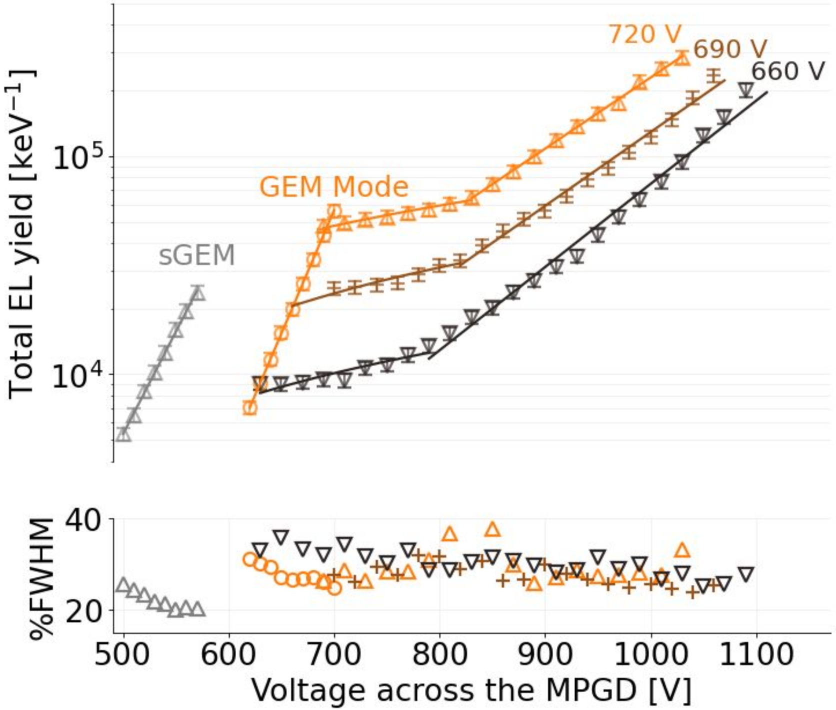
He-40%CF_4: Full-COBRA

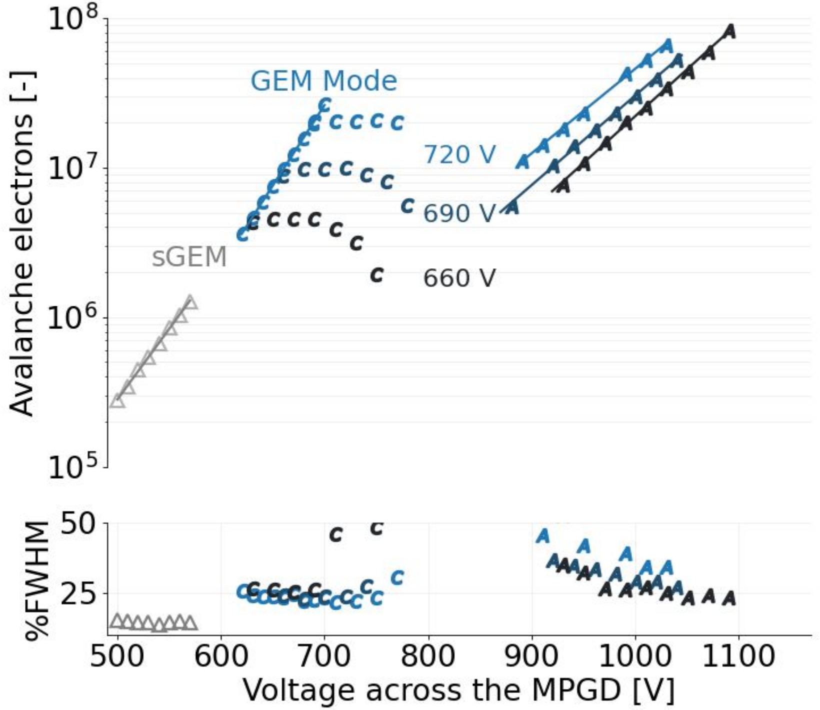
Light first increases linearly and then exponentially.
At first, charge is transferred to the anode and then increases exponentially with increasing bias.

Light is produced in the holes and strips:

- Hole bias is constant.
- Strip bias is increased.



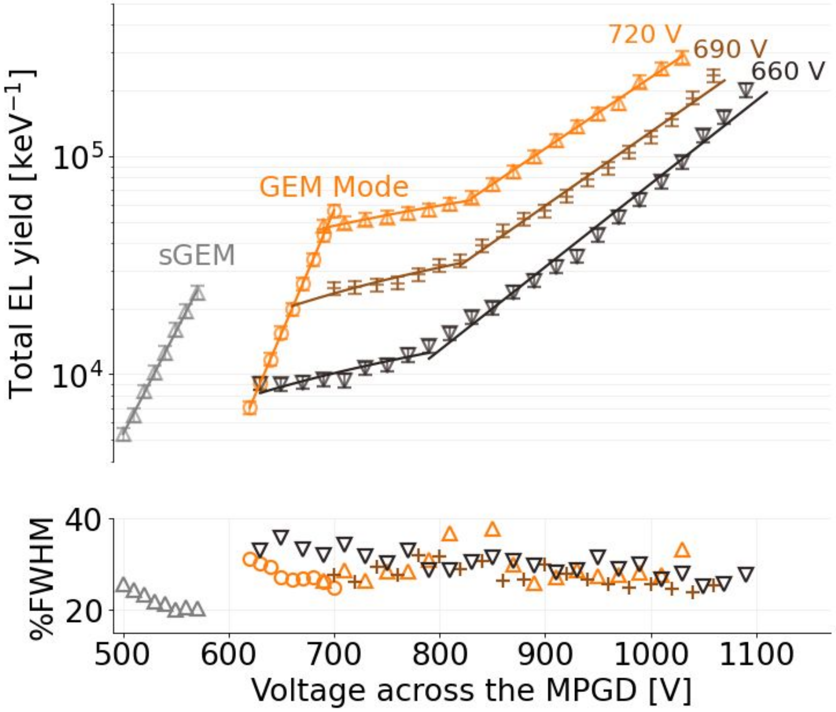




He-40%CF_4: Comparison with a standard GEM (sGEM)

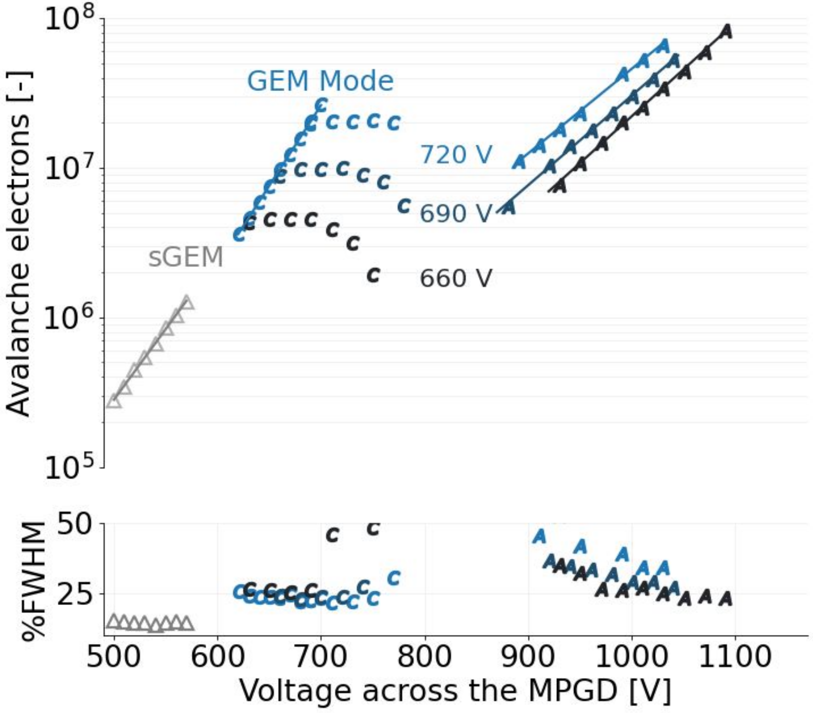
The Maximum Light Yield can be increased by

- **2.3-fold** (GEM Mode)
- **11.8-fold** (full-COBRA Mode)



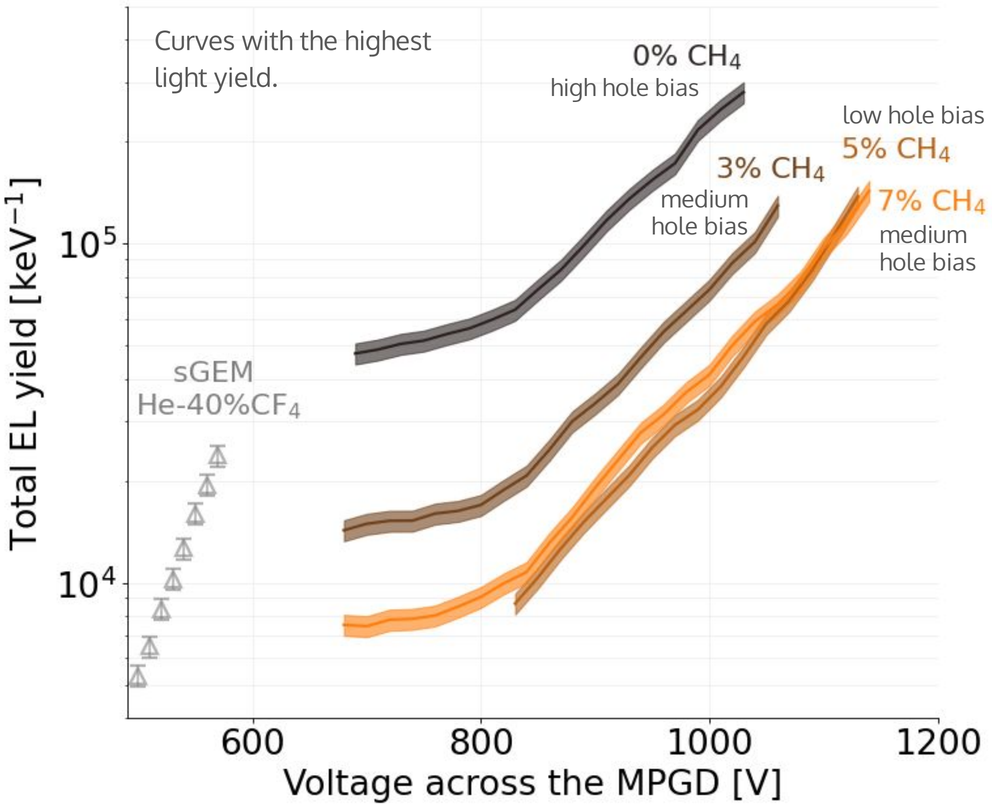
The Maximum Charge can be increased by

- **21.0-fold** (GEM Mode)
- **65.4-fold** (full-COBRA Mode)



Methane Admixtures to He-40%CF_4

We also evaluated the light yield of 3%, 5% and 7%CH_4.

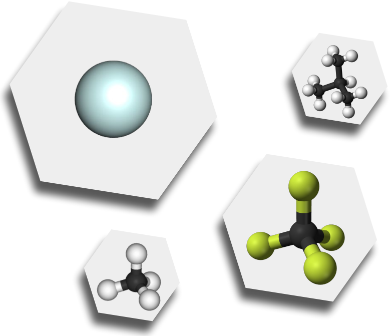


Maximum Light Yield for each mixture

He-40%CF_4	GEM	COBRA
0% CH_4	2.37(17)x10^4	2.80(20)x10^5
3% CH_4	3.90(28)x10^4	1.30(9)x10^5
5% CH4	3.09(22)x10^4	1.38(10)x10^5
7% CH_4	2.41(17)x10^4	1.43(10)x10^5

The light yield of CH_4 admixtures with a COBRA_125 is about **6 times higher** than the light yield of He-40%CF4 with a sGEM.

Conclusions



- **Small concentrations of methane and isobutane do not completely quench the EL of He-40%CF_4**
  They affect both the UV and visible component of the EL.

- **Methane admixtures show better optical properties than isobutane admixtures**
  They quench less EL than isobutane and increase the electrical stability of the detector

The light yield can be increased 11.8-fold in He-40%CF_4 with a COBRA_125 due to:

- **The thickness of the COBRA (125 µm):** increases the threshold for self-sustained micro-discharges.
- **The second multiplication region:** additional light is created in the strips.
- **With a COBRA_125, the light yield of methane admixtures is 6 times higher** than the light yield of He-40%CF_4 produced with a standard GEM.

Grazie per l'attenzione

Any questions or suggestions?

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