CYGNO

He/CF_4 + Iso-butane Electroluminescence measurements

for Directional Dark Matter Searches with the CYGNO Time Projection Chamber

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on behalf of

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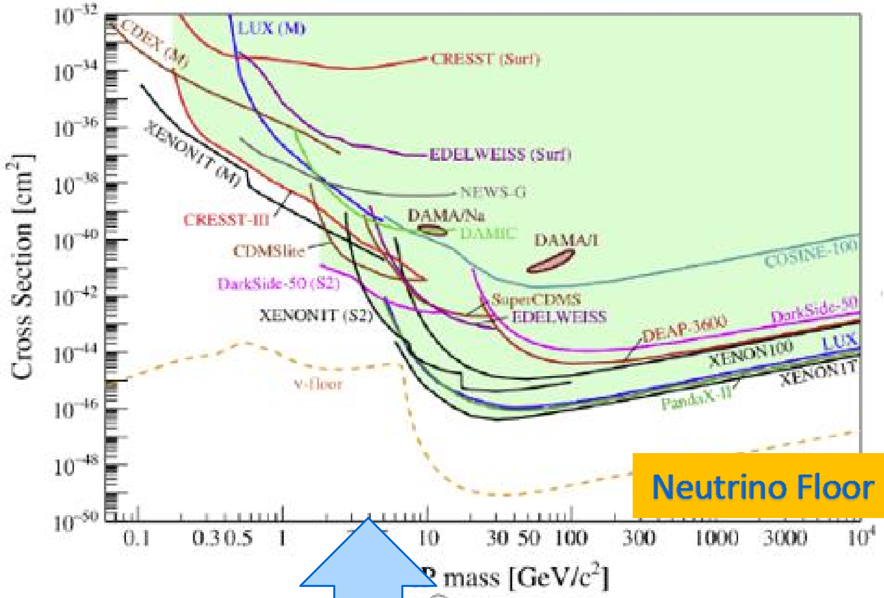
CYGNO Experiment

INTIUM

LIBPhys

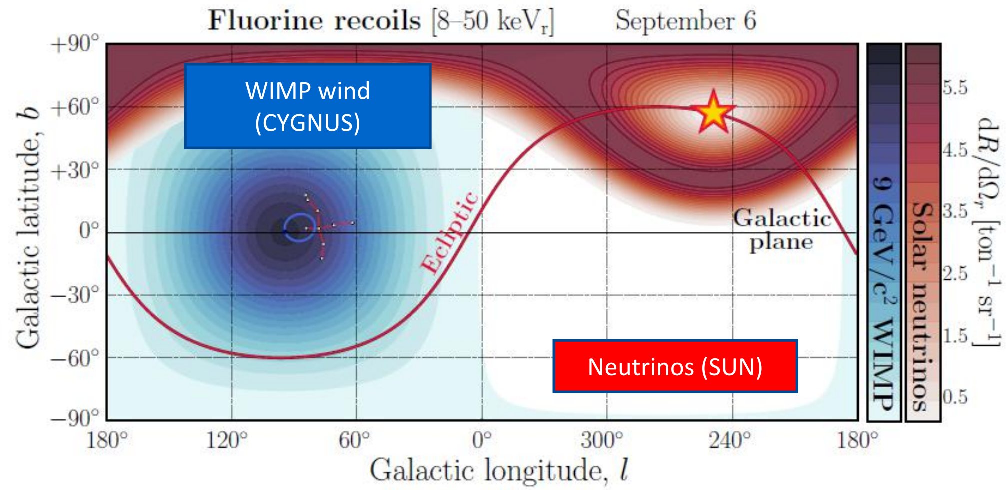
The shortest possible intro on Directional Dark Matter



Neutrino Floor

1-10 GeV range accessible with light atoms as target (H, He)

DM signature : daily modulation



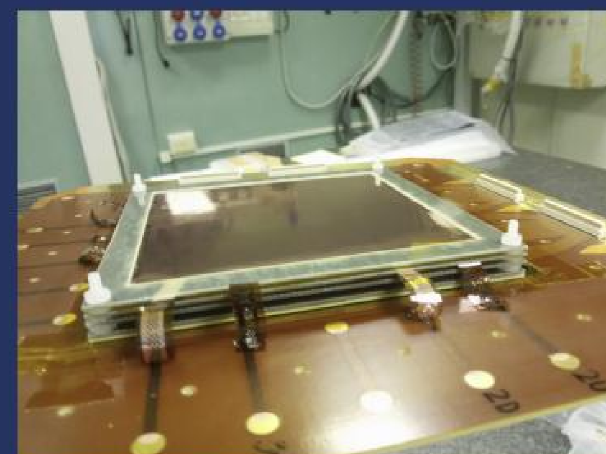
CYGNUS

CYGNUS - Galactic Nuclear Recoil Observatory

CYGNO Experiment

The **CYGNO** collaboration is **developing** and optimising a new **technique** for the detailed study of Low Energy Rare Events;

This project, started by few people in Rome in 2015, with a small prototype assembled in the Clean Room in Officina Meccanica has now almost **50 collaborators**, from **8 Institutions** in **4 Countries**



INFN Istituto Nazionale di Fisica Nucleare

Universidade de Coimbra

The University Of Sheffield.

Roma Tre Università degli Studi

GSSI

ufjf Universidade Federal de Juiz de Fora

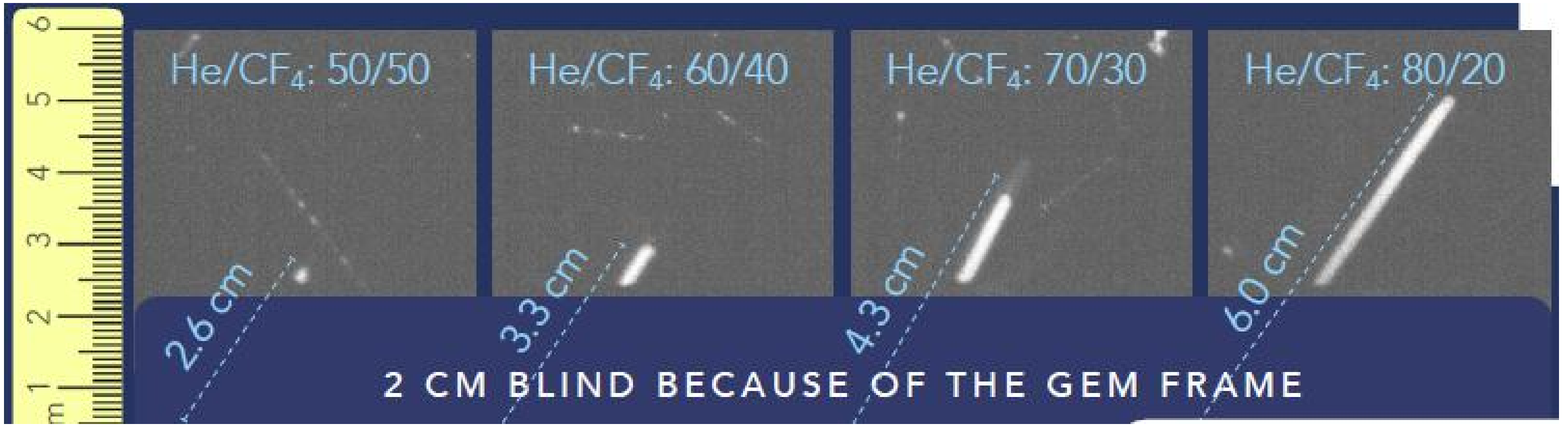
CBPF

More about CYGNO on TIPP2021:

CYGNO: Optically Readout TPC for Directional Study of Rare Events by Samuele Torelli (26 May 2021, 05:00)

Poster Experiments: Dark Matter Detectors https://indico.cern.ch/event/981823/contributions/4295412/

CYGNO



Element	Max E transferred by a 1 GeV WIMP	Min WIMP mass with 1 keV threshold
H	2.00 keV	0.5 GeV
He	1.30 keV	0.9 GeV
C	0.57 keV	1.4 GeV
F	0.38 keV	1.7 GeV
Na	0.32 keV	1.8 GeV
Si	0.27 keV	2.0 GeV
Ar	0.20 keV	2.4 GeV
Xe	0.06 keV	4.2 GeV

The inclusion of Hydrogen is well motivated.

But H itself is a dificult gas to work with.

Hydrocarbons are excellent alternatives

He/CF_4 + Iso-butane Electroluminescence

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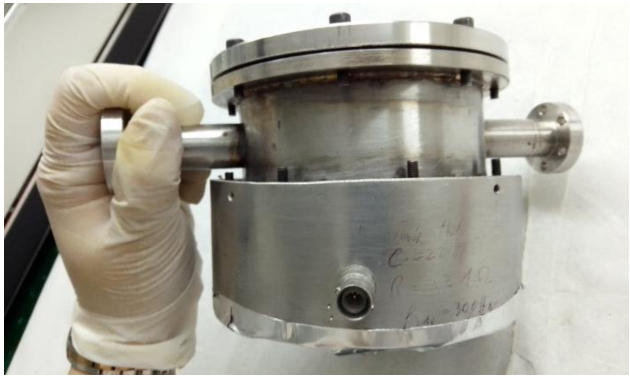
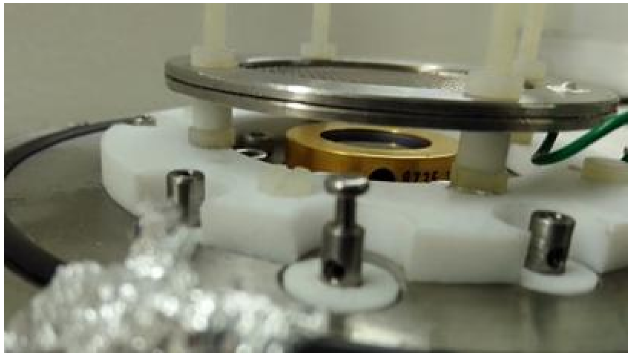
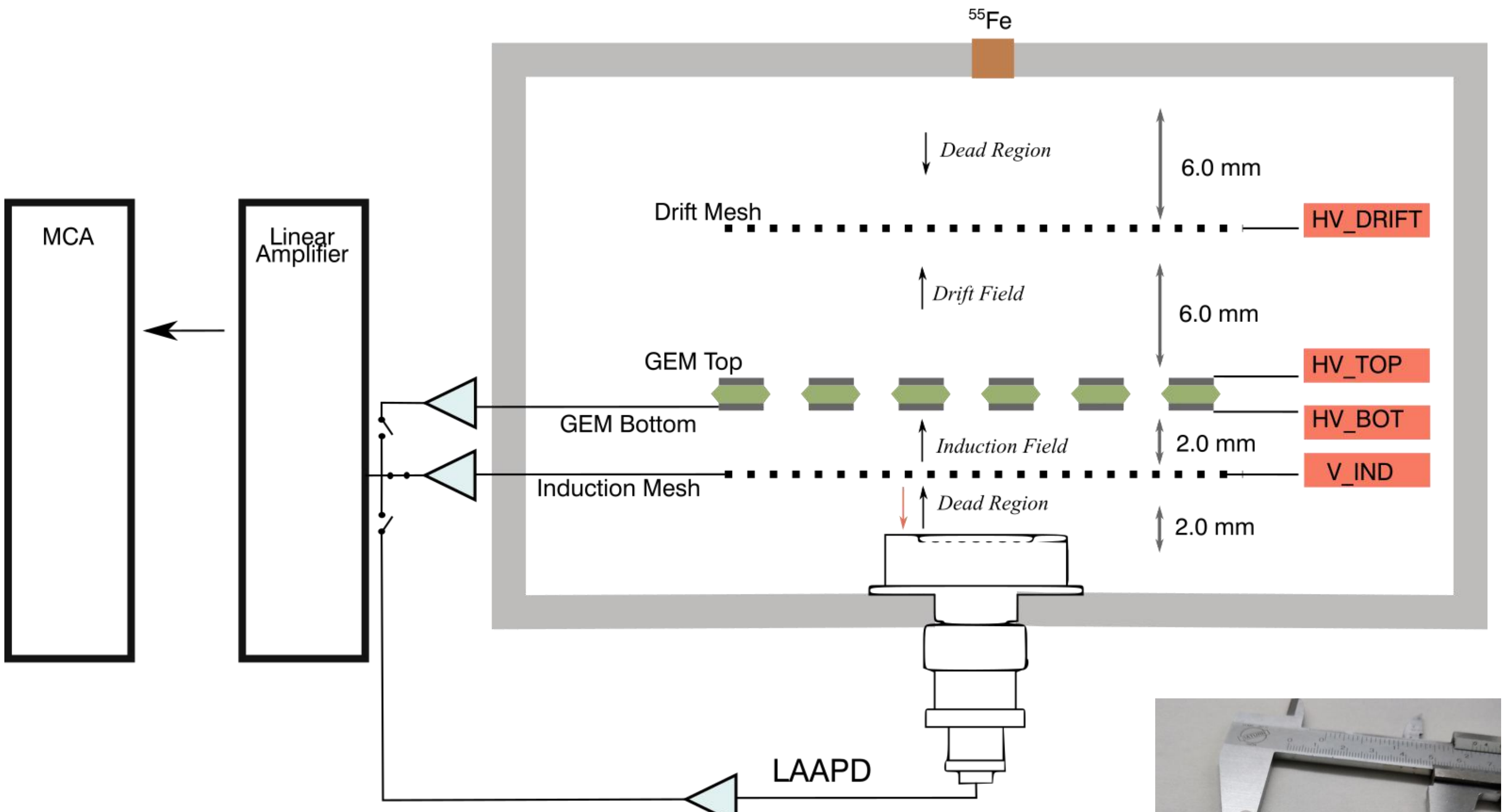




A small stainless steel chamber, equipped with a **Large Area Avalanche Photodiode** was used for several Electroluminescence yield (photons / primary electron) measurements in uniform field (parallel grids gap) and avalanche generated EL (in GEM, THGEM and Micro-Megas).

- A. S. Conceição et al., GEM scintillation readout with avalanche photodiodes, JINST P09010, 2007.
- C.M.B. Monteiro et al., Secondary scintillation yield in pure xenon, JINST P05001.(2007)
- C.M.B. Monteiro et al., Secondary scintillation yield in pure argon, Phys. Lett. B 668 (2008)
- Hugo Natal da Luz et al., GEM Operation in High-Pressure CF_4 : Studies of Charge and Scintillation Properties, IEEE TNS, 2009
- C. M. B. Monteiro et al., Electroluminescence from gaseous micropatterned electron multipliers in dark matter detection, Phys. Lett. B, 2009
- C.M.B. Monteiro et al., Secondary scintillation yield from GEM and THGEM gaseous electron multipliers for direct dark matter search, Phys. Lett. B 714 (2012)
- C.A.O. Henriques, et al., "Electroluminescence TPCs at the thermal diffusion limit". JHEP 2019, 27 (2019).

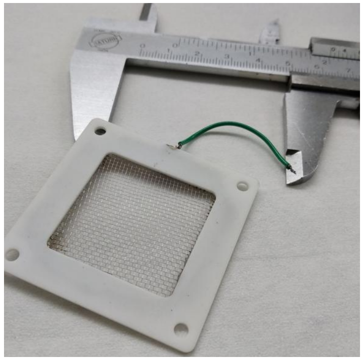
Setup



A dc140 GEM (50 micron thick, 70/50 micron hole, 2.9 x 2.9 cm^2) was used for EL production

The LAAPD used for the EL readout was made by Advanced Photonics Instruments (16 mm diameter active area)

Gas flow at 2L/hour



LAAPD

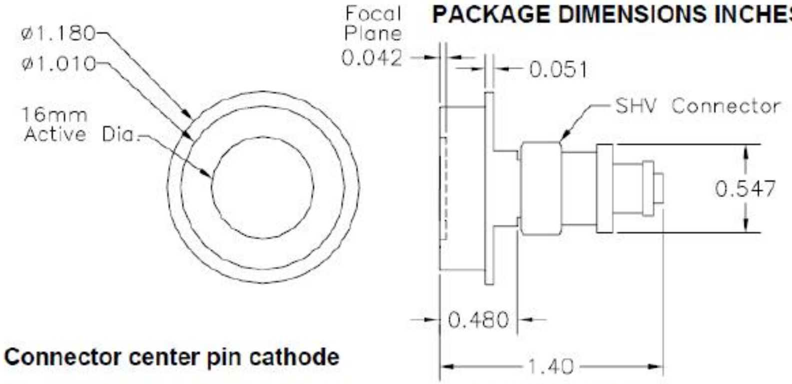
LUNA OPTOELECTRONICS

Non-Cooled Large Area DUV Silicon Avalanche Photodiode

SD 630-70-75-500

WWW.LUNAINC.COM **Precision – Control – Results**

PACKAGE DIMENSIONS INCHES



Connector center pin cathode

Connector outer jacket anode

SHV PACKAGE

DESCRIPTION

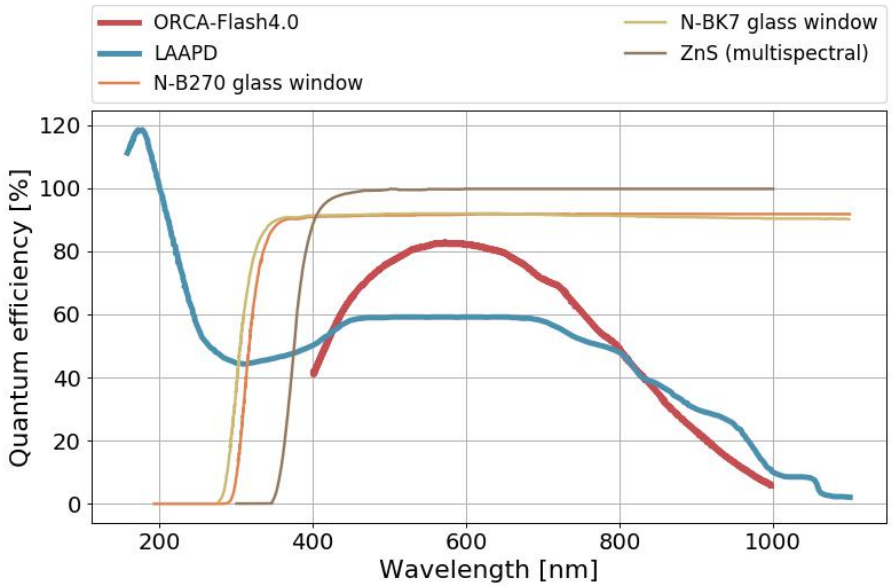
The **SD 630-70-75-500** is a windowless non-cooled large area DUV enhanced silicon avalanche photodiode (APD) with high gain and low noise in a SHV package.

FEATURES

- Low Noise
- High Gain
- High Speed

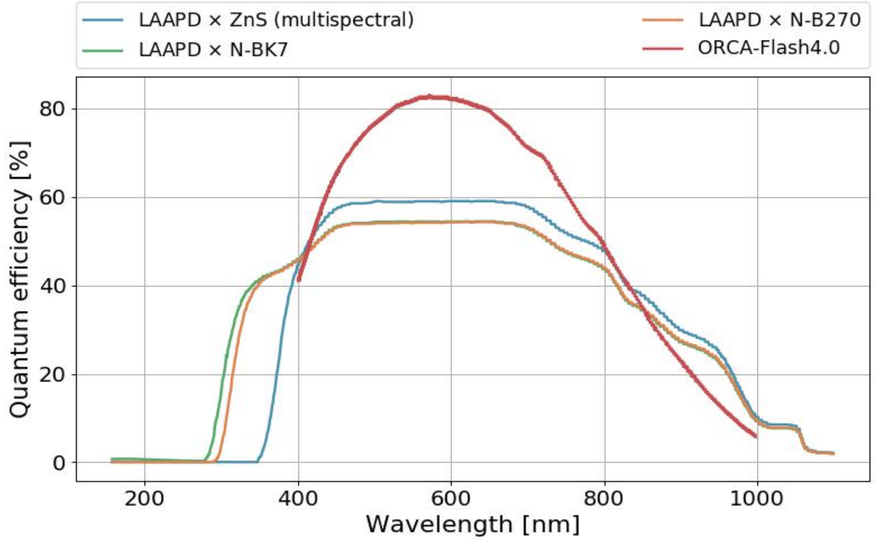
LAAPD

The LAPPD sensitivity overlaps the one of the ORCA camera in the visible, but extends down to the deep UV.



In the future a N-BK7 optical filter will be used to remove the UV component, allow to obtain a similar response as the ORCA camera.

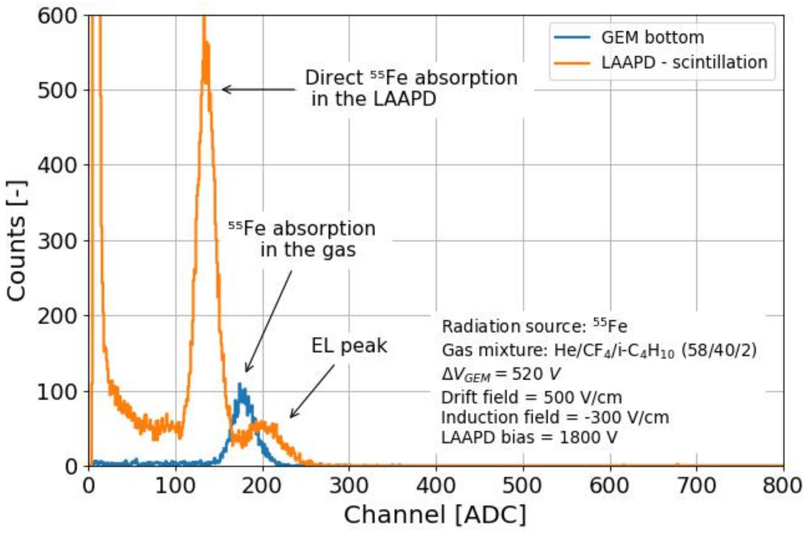
The optical window is not yet installed in our system. As so the results we present cover the spectra down to the VUV.



EL YIELD measurements with the LAAPD

The LAAPD response comprises two main components:

1) The direct x-rays, which also impinge on the LAAPD and produce a signal. For a given LAAPD biasing, the position of this peak is constant.
2) The Electroluminescence (EL) peak: which depends on the GEM voltage and electric fields in the detector.

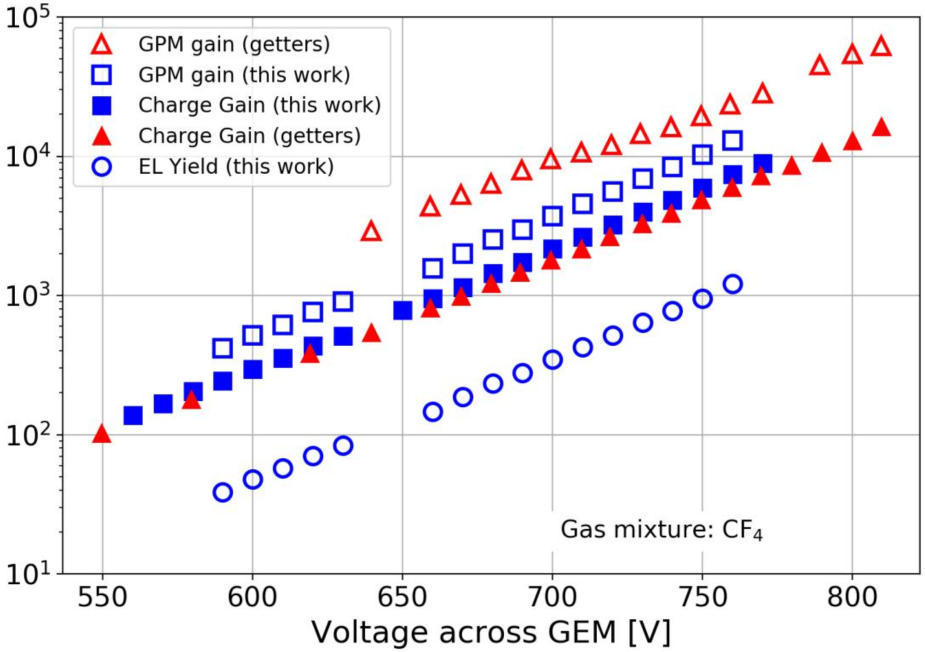


The Electroluminescence Yield is obtained from these 2 components:

$$Y_{\mathrm{EL}} = \frac{\eta_\gamma}{\eta_{e^-}} = \frac{w(\mathrm{gas})}{w(Si)} \times \frac{A_{EL}}{A_X} \times \frac{1}{QE \times \Omega \times T} \qquad [\mathrm{photons} / \mathrm{electron}]$$

A_{EL}, A_X are the centroids of the EL and direct peaks in the LAAPD.
QE used was the value for the plateau at the visible region (0.6)
Ω is the solid angle (0.263)
T is the mesh transparency (84%)

CF_4

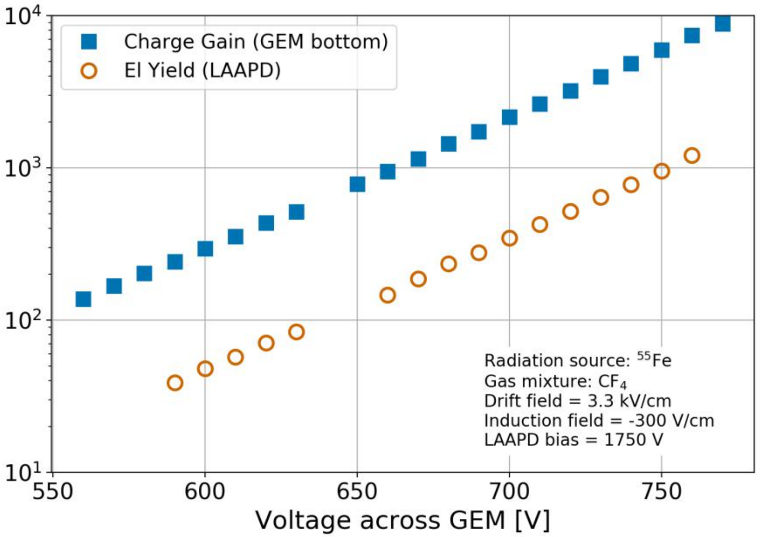


Work with getters: Hugo Natal da Luz et al., GEM Operation in High-Pressure CF_4 : Studies of Charge and Scintillation Properties, IEEE TNS, 2009

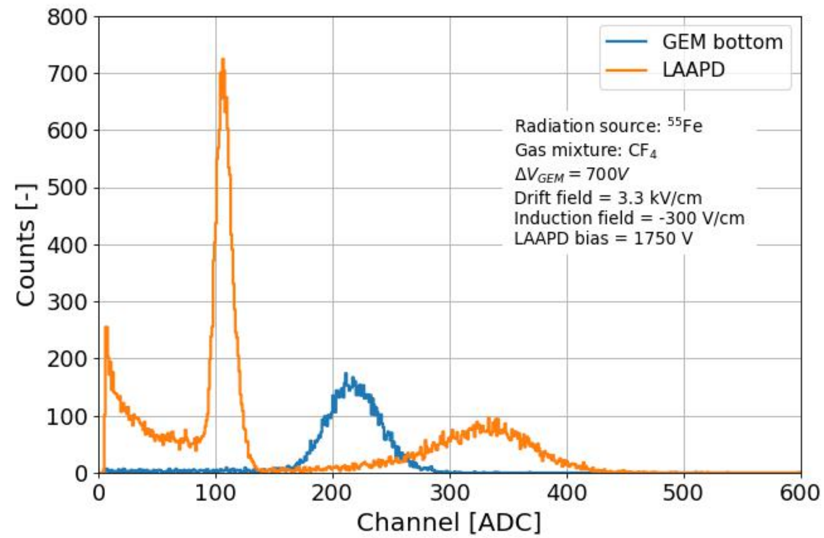
First measurements were done in CF_4, to allow for comparison between this work (in flow mode) with previous one (with gas recirculation and purification with getters) :

- The charge gains are spot on
- The GPM (GEM + LAAPD) gain drops by a small factor: expected, since the gas purity has influence over the EL yield. Main effect should be in the VUV.

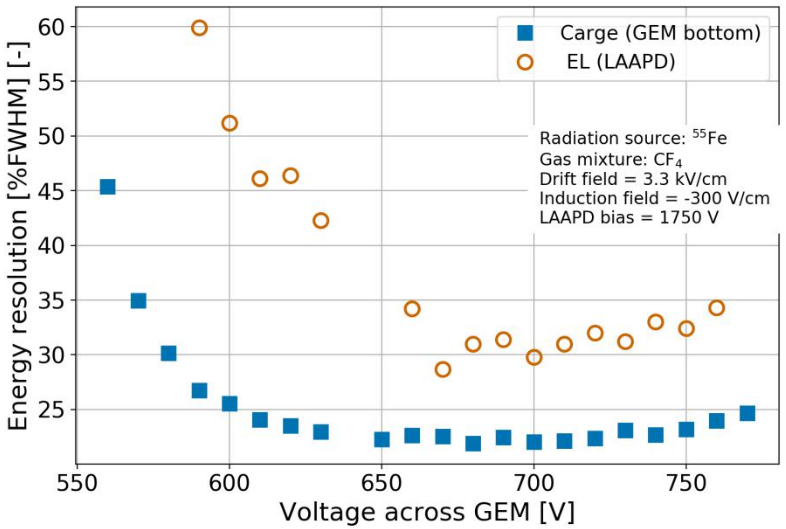
CF_4: GEM gain



Charge Gain (GEM bottom)
El Yield (LAAPD)
Radiation source: ^{55}Fe
Gas mixture: CF_4
Drift field = 3.3 kV/cm
Induction field = -300 V/cm
LAAPD bias = 1750 V
10^4
10^3
10^2
10^1
550
600
650
700
750
Voltage across GEM [V]



GEM bottom
LAAPD
Radiation source: ^{55}Fe
Gas mixture: CF_4
$\Delta V_{GEM} = 700V$
Drift field = 3.3 kV/cm
Induction field = -300 V/cm
LAAPD bias = 1750 V
Counts [-]
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
Channel [ADC]



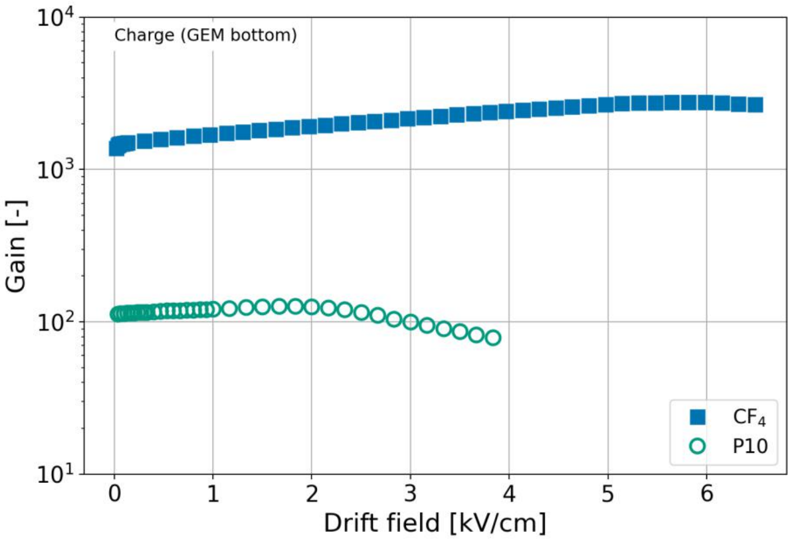
Carge (GEM bottom)
EL (LAAPD)
Radiation source: ^{55}Fe
Gas mixture: CF_4
Drift field = 3.3 kV/cm
Induction field = -300 V/cm
LAAPD bias = 1750 V
Energy resolution [%FWHM] [-]
60
55
50
45
40
35
30
25
550
600
650
700
750
Voltage across GEM [V]

CF_4: Drift Region Optimization

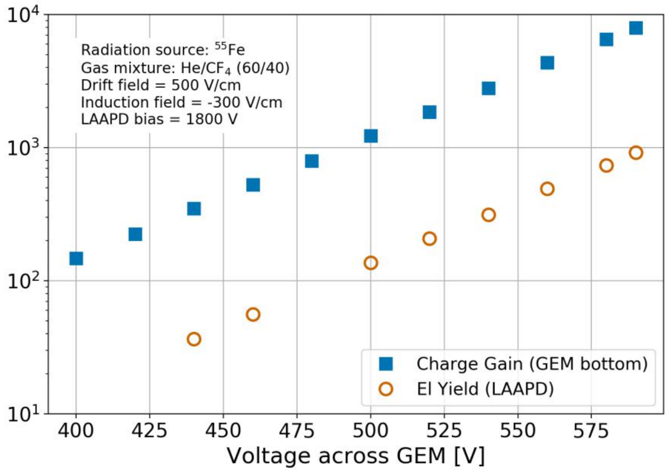
During the drift region optimization we encountered a unexpected behaviour:

The charge gains measured on the GEM continued to increase with the drift field for longer than anticipated (no plateau). The El yield (LAAPD) followed the same behaviour.

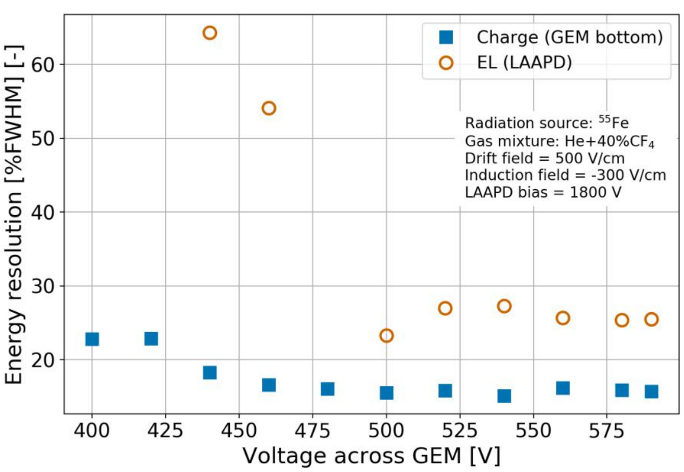
A test with P10 showed a more typical behaviour



He/CF_4 (60/40)



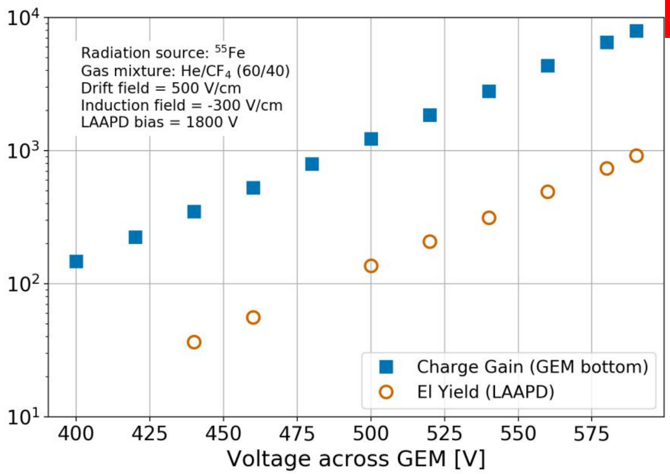
Radiation source: ^{55}Fe
Gas mixture: He/CF_4 (60/40)
Drift field = 500 V/cm
Induction field = -300 V/cm
LAAPD bias = 1800 V
Charge Gain (GEM bottom)
El Yield (LAAPD)
10^4
10^3
10^2
10^1
400 425 450 475 500 525 550 575
Voltage across GEM [V]

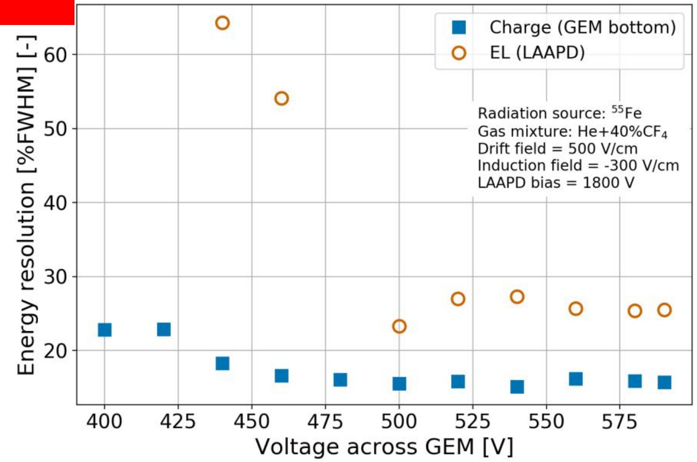


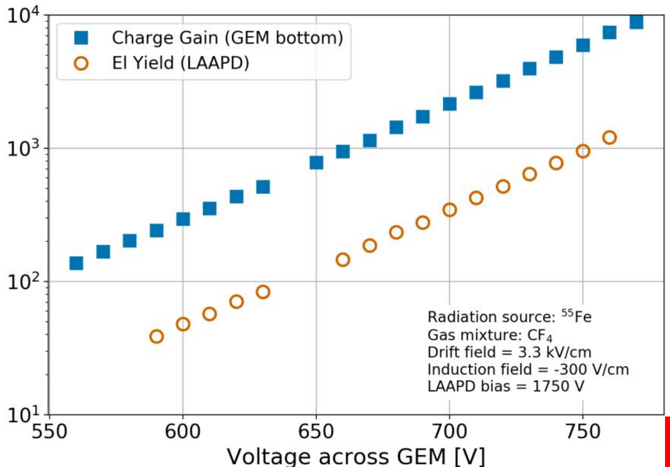
Charge (GEM bottom)
EL (LAAPD)
Radiation source: ^{55}Fe
Gas mixture: He+40%CF_4
Drift field = 500 V/cm
Induction field = -300 V/cm
LAAPD bias = 1800 V
Energy resolution [%FWHM] [-]
20 30 40 50 60
400 425 450 475 500 525 550 575
Voltage across GEM [V]

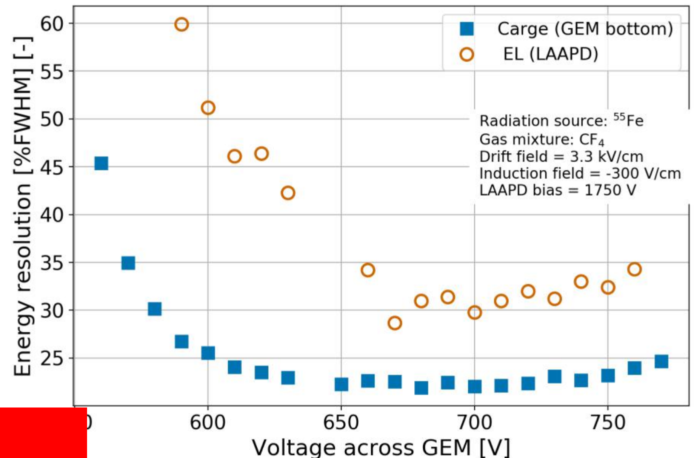
He/CF_4 (60/40) vs CF_4

He/CF_4





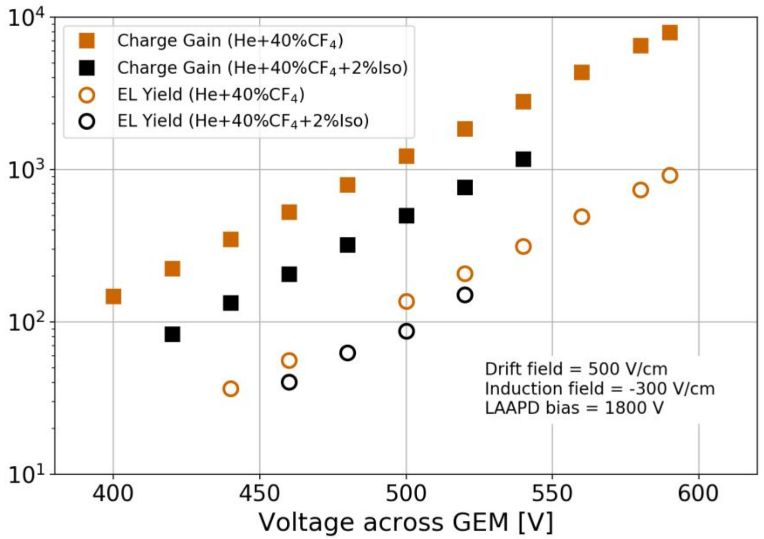


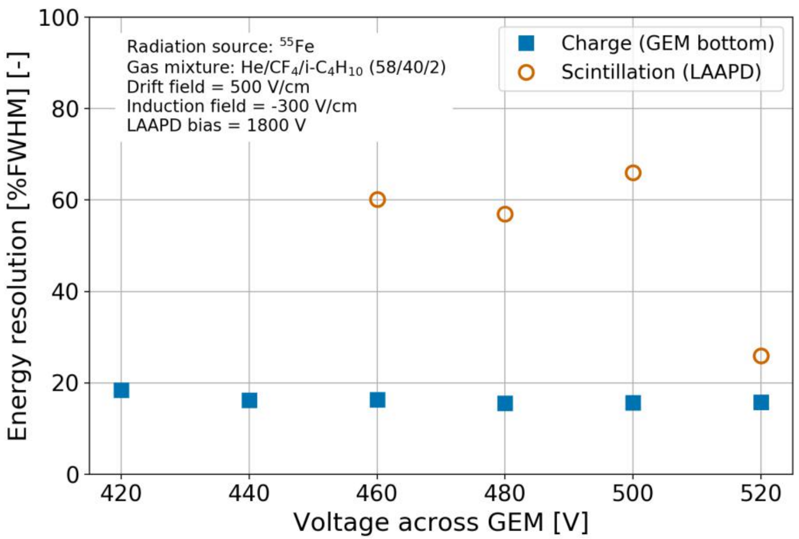


CF_4

Decrease in the GEM applied voltages

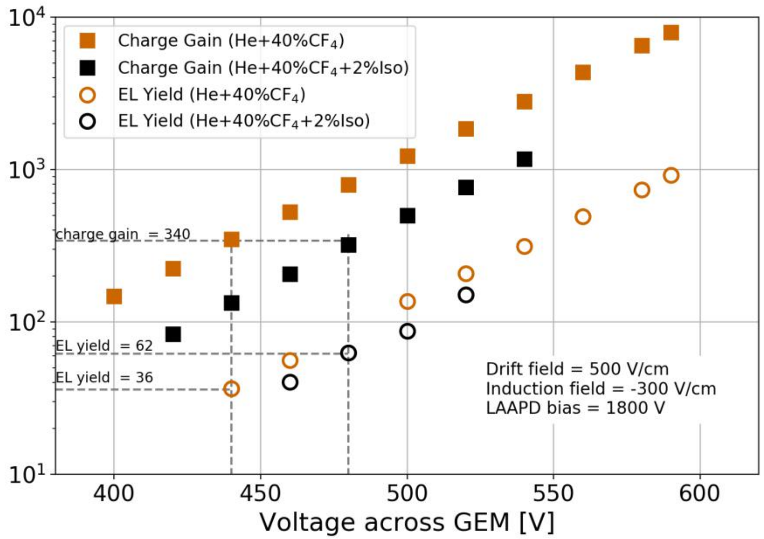
He/CF4/Iso-Butane (58/40/2)

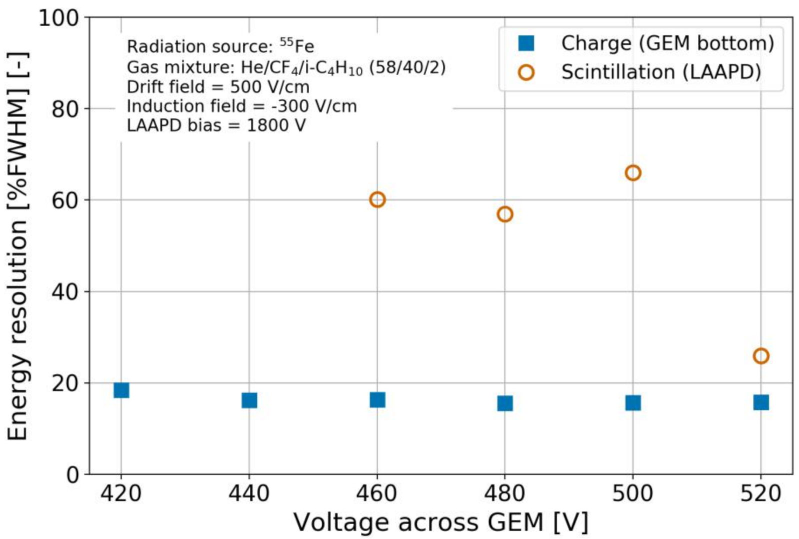




Onset of discharges sooner with the inclusion of Iso-butane

He/CF4/Iso-Butane (58/40/2)



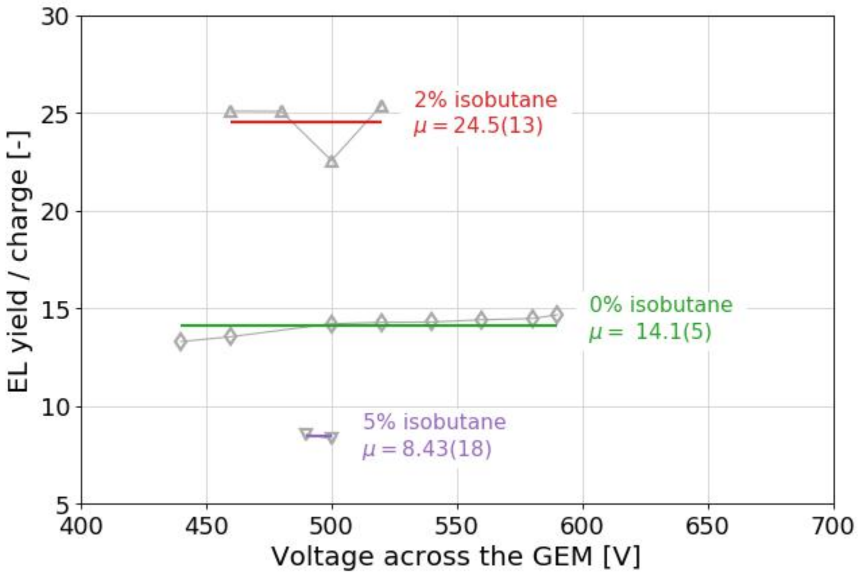


For same charge gain, higher EL yield in He/CF4/Iso (58/40/2) ?

He/CF4/Iso-Butane

Adding 2% isobutane increases the EL efficiency

but 5% isobutane lowers the number of EL photons per secondary electron

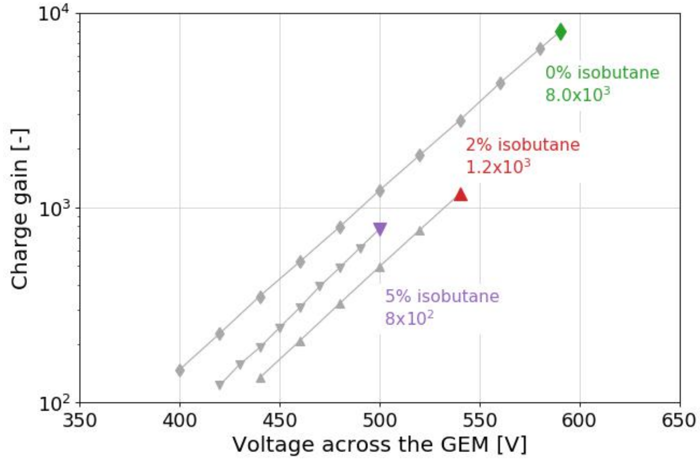


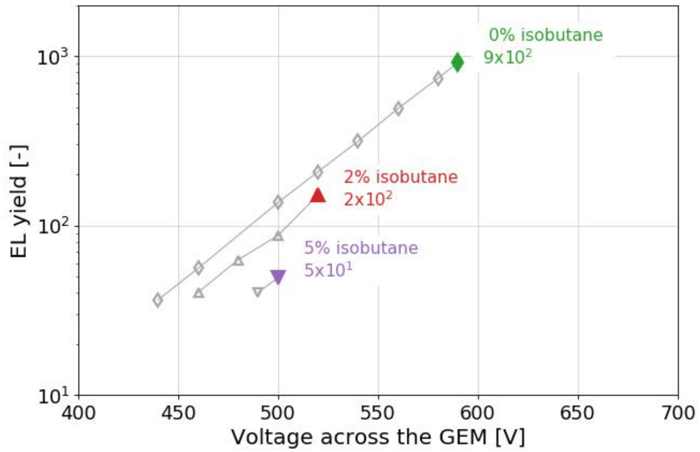
Data taken at 1 bar in continuous flow mode. The isobutane was added to a mixture of He/CF_4 (60/40).

In fact, the number of **photons per avalanche electron** increases with the inclusion of 2% Iso-butane.

Increasing the Iso-butane fraction to 5% leads to a decrease.

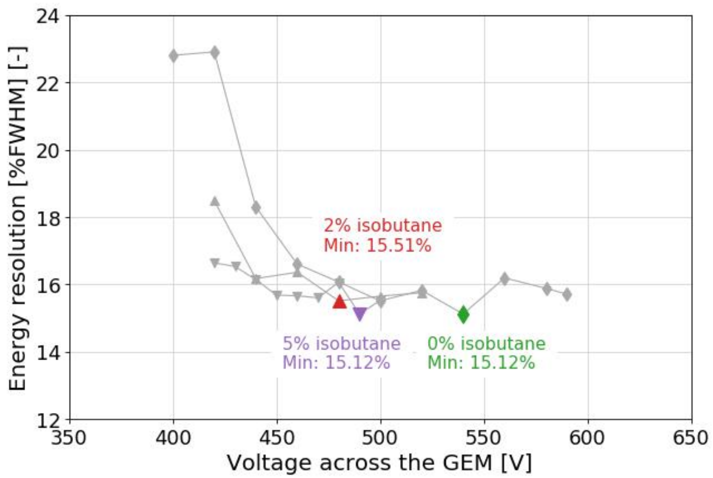
He/CF4/ISO-Butane





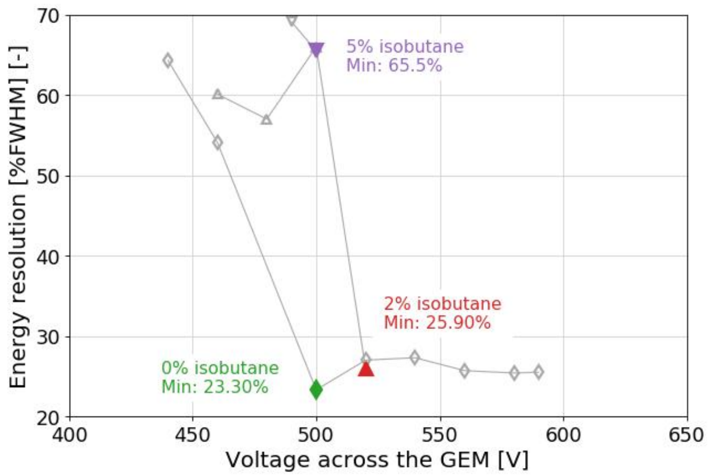
There is a decrease in the range of voltages applicable to the GEM with the ISO-Butane fraction increase (and also an increase in the instabilities) which seems to limit the usability of Iso-Butane fractions above 5%.

He/CF4/ISO-Butane



Energy resolution (charge) is not affected: Adding Iso-butane does not affect the energy resolution of charge signals.

all mixtures showed minimum energy resolution ~15%.



Lowest energy resolution with the LAAPD increases with iso-butane fraction

Adding Iso-butane worsens the energy resolution of EL signals.

Future Work

- Optimize Iso-butane % in the He/CF_4/Iso mix
- Include optical glass window for VUV component removal
- **Sealed mode operation (using getters)**

Electroluminescence Yield increase and Energy Resolution improvement

Acknowledgements

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