

# Electroluminescence studies in He-CF<sub>4</sub>-isobutane mixtures

RD51 Collaboration Meeting  
and Topical Workshop on FE electronics for gas detectors

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on behalf of the CYGNO Collaboration

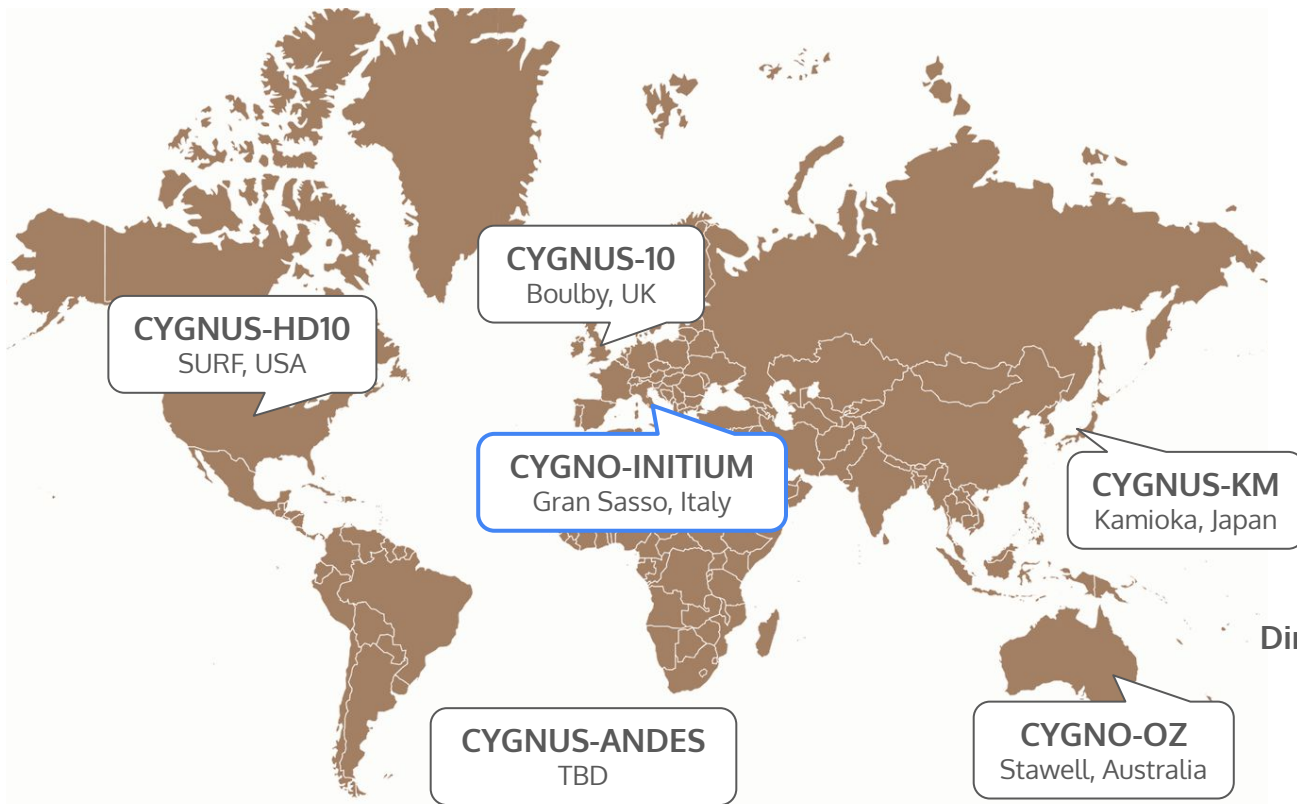


F.D. Amaro, E. Baracchini, L. Benussi, S. Bianco, C. Capocchia, M. Caponero, G. Cavoto, A. Cortez, I.A. Costa, E. Dané, E. Di Marco, G. D'Imperio, G. Dho, F. Di Giambattista, R.R.M. Gregorio, F. Iacoangeli, H.P. Lima Júnior, G. Maccarrone, R.D.P. Mano, M. Marafini, G. Mazzitelli, A.G. Mc Lean, A. Messina, M.L. Migliorini, C.M.B. Monteiro, R.A. Nóbrega, A. Orlandi, I.F. Pains, E. Paoletti, L. Passamonti, F. Petrucci, S. Pelosi, S. Piacentini, D. Piccolo, D. Pierluigi, D. Pinci, A. Prajapati, F. Renga, F. Rosatelli, A. Russo, J.M.F. dos Santos, G. Saviano, A. da Silva Lopes Júnior, N. Spooner, R. Tesauro, S. Tomassini, S. Torelli

# Summary

- **CYGNO/INITIUM**
- **Motivation**
- **Experimental Setup**
- **Results**
  - Number of avalanche electrons and energy resolution for He/CF<sub>4</sub> (60/40) + isobutane
  - Total number of EL photons per keV absorbed and energy resolution for He/CF<sub>4</sub> (60/40) + isobutane
  - Number of EL photons emitted per avalanche electron for He/CF<sub>4</sub> (60/40) + isobutane
  - Producing additional EL photons in the induction region for He/CF<sub>4</sub> (60/40)
- **Conclusions**

# The CYGNUS Galactic Nuclear Recoil Observatory



## Goals of the CYGNUS collaboration:

- Search and identify a clear **Dark Matter** signature for low WIMP mass (1-10 GeV);
- Detect **Coherent Neutrino Scattering** from the Sun.

**Directionality** and **Particle Identification** are key to achieve these goals.

# CYGNO-INITIUM

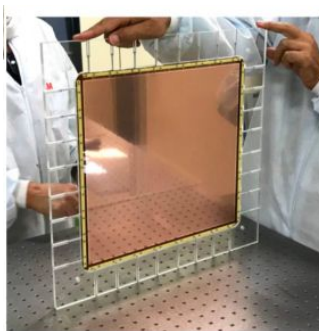
## LIME detector assembly at Laboratori Nazionali di Frascati



Field cage copper rings.



LIME inside the Faraday cage.



Triple GEM stretched with pullouts on a plexiglass frame.



The CYGNO-INITIUM collaboration will develop a **large TPC** for high precision tracking of low energy nuclear recoils ( $\sim$ keV).

**Current status:** 1 m<sup>3</sup> demonstrator based on a MPGD (triple GEM stack) where the EL signal will be detected by a low noise, high granularity sCMOS sensor.



The University  
Of Sheffield.



SAPIENZA  
UNIVERSITÀ DI ROMA



Currently there are:

almost 50 collaborators

from 8 institutions

in 4 countries



# Motivation

Goal of this work

Optimize the gas mixture for the CYGNO optical TPC

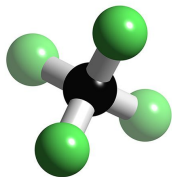
## Gas Mixture

### Helium: 60%



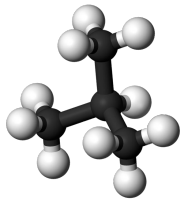
- Extends the sensitivity to low WIMP masses;
- Allows 1 atm operation.

### CF<sub>4</sub>: 40%



- Improves gas scintillation;
- Highly sensitive to Spin Dependent Coupling.

### Isobutane (i-C<sub>4</sub>H<sub>10</sub>): ? %



- Improves gas tracking properties;
- Maintains low target mass.



Low mass targets are essential to access low WIMP mass.

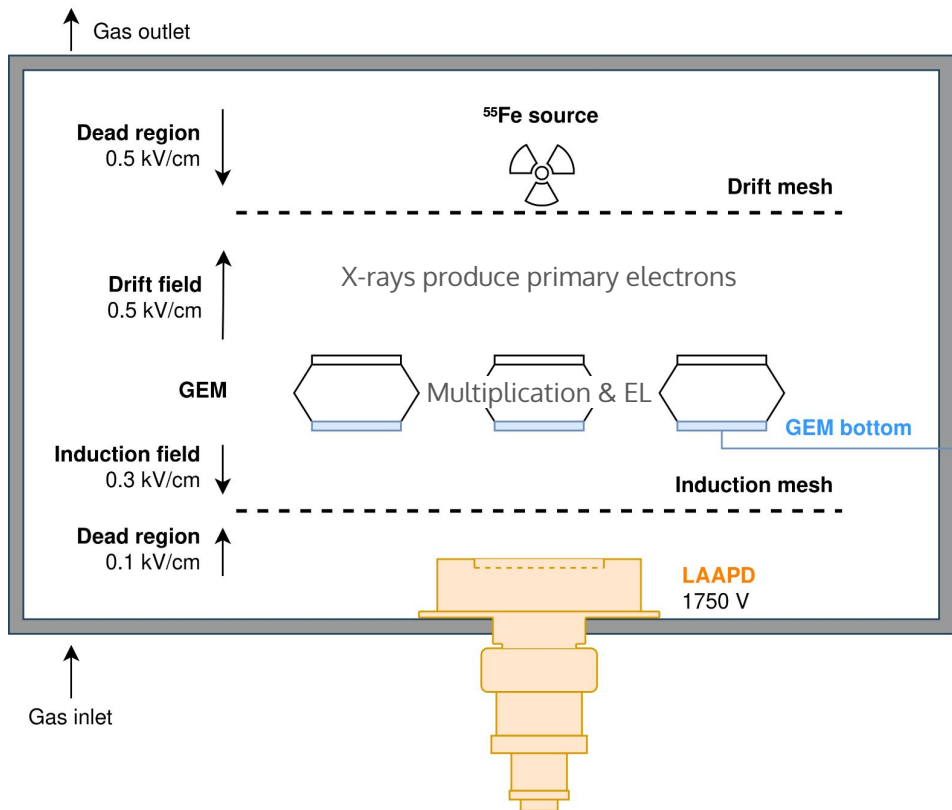
Element	Max E transferred by a 1 GeV WIMP	Min WIMP mass with 1 keV threshold
H	2.00 keV	0.5 GeV
He	1.30 keV	0.9 GeV
C	0.57 keV	1.4 GeV
F	0.38 keV	1.7 GeV
Na	0.32 keV	1.8 GeV
Si	0.27 keV	2.0 GeV
Ar	0.20 keV	2.4 GeV
Xe	0.06 keV	4.2 GeV

Study how the inclusion of isobutane influences the **Charge** and **EL** signals of the mixture.

# Experimental setup

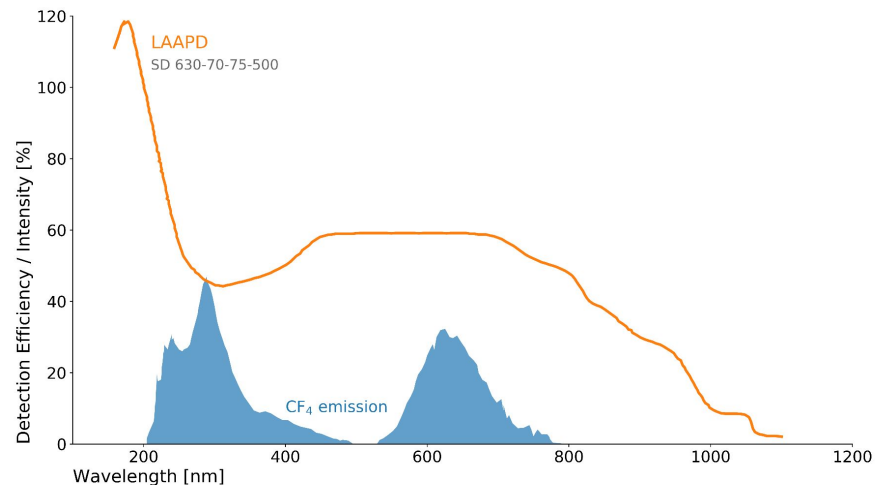
## Detector Layout

Detector operates in continuous flow mode at atmospheric pressure.



## Detector Components:

- **Meshes** with ~84% optical transparency;
- **Standard GEM** with 3 x 3 cm<sup>2</sup> area;
- **LAAPD**:
  - Active diameter: 16 mm;
  - Range: 150 - 1000 nm.

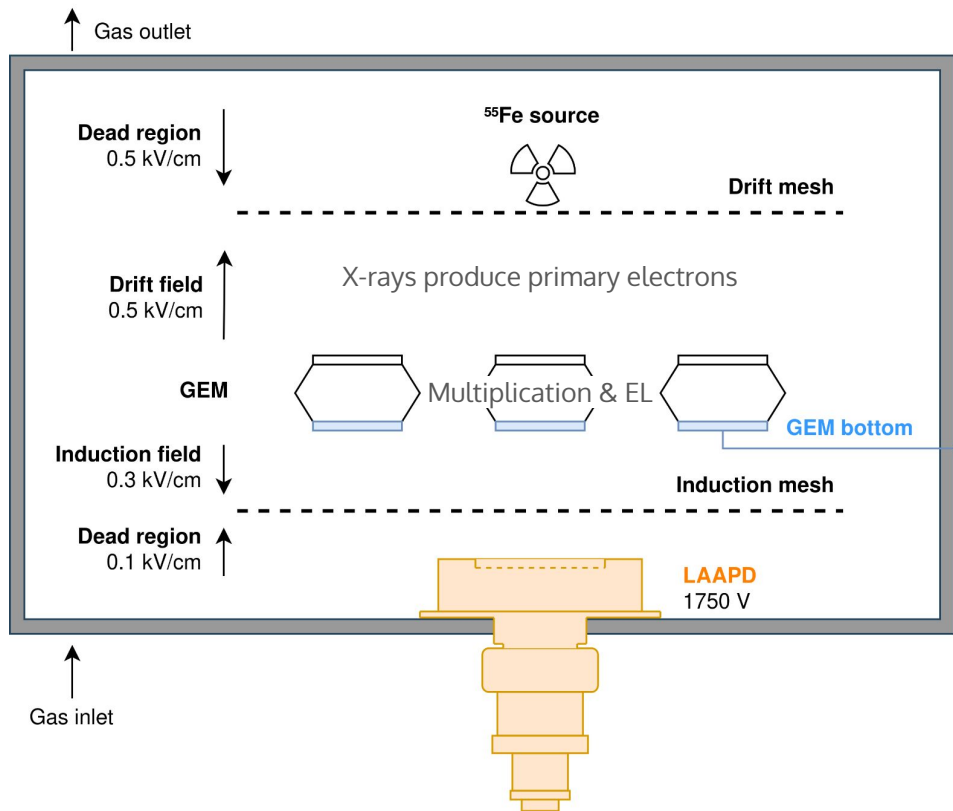


LAAPD QE and CF<sub>4</sub> EL emission curve.

# Experimental setup

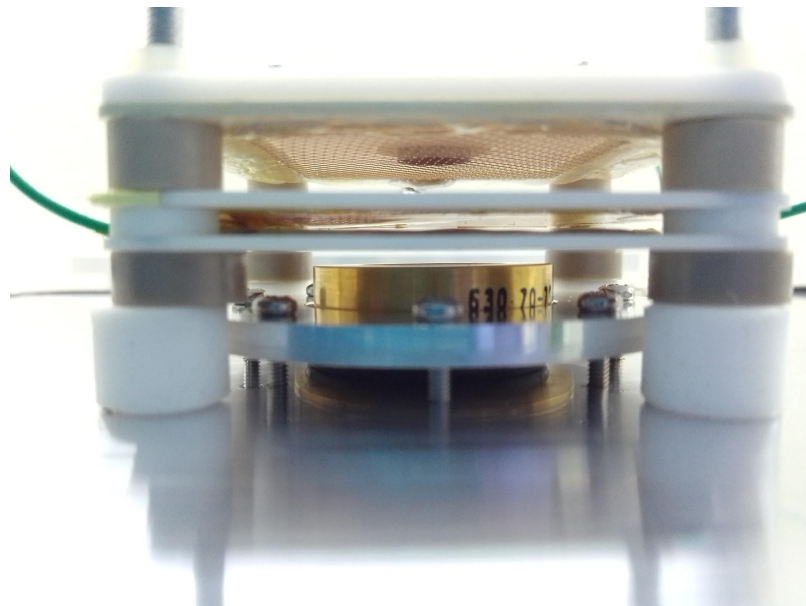
## Detector Layout

Detector operates in continuous flow mode at atmospheric pressure.



## Detector Components:

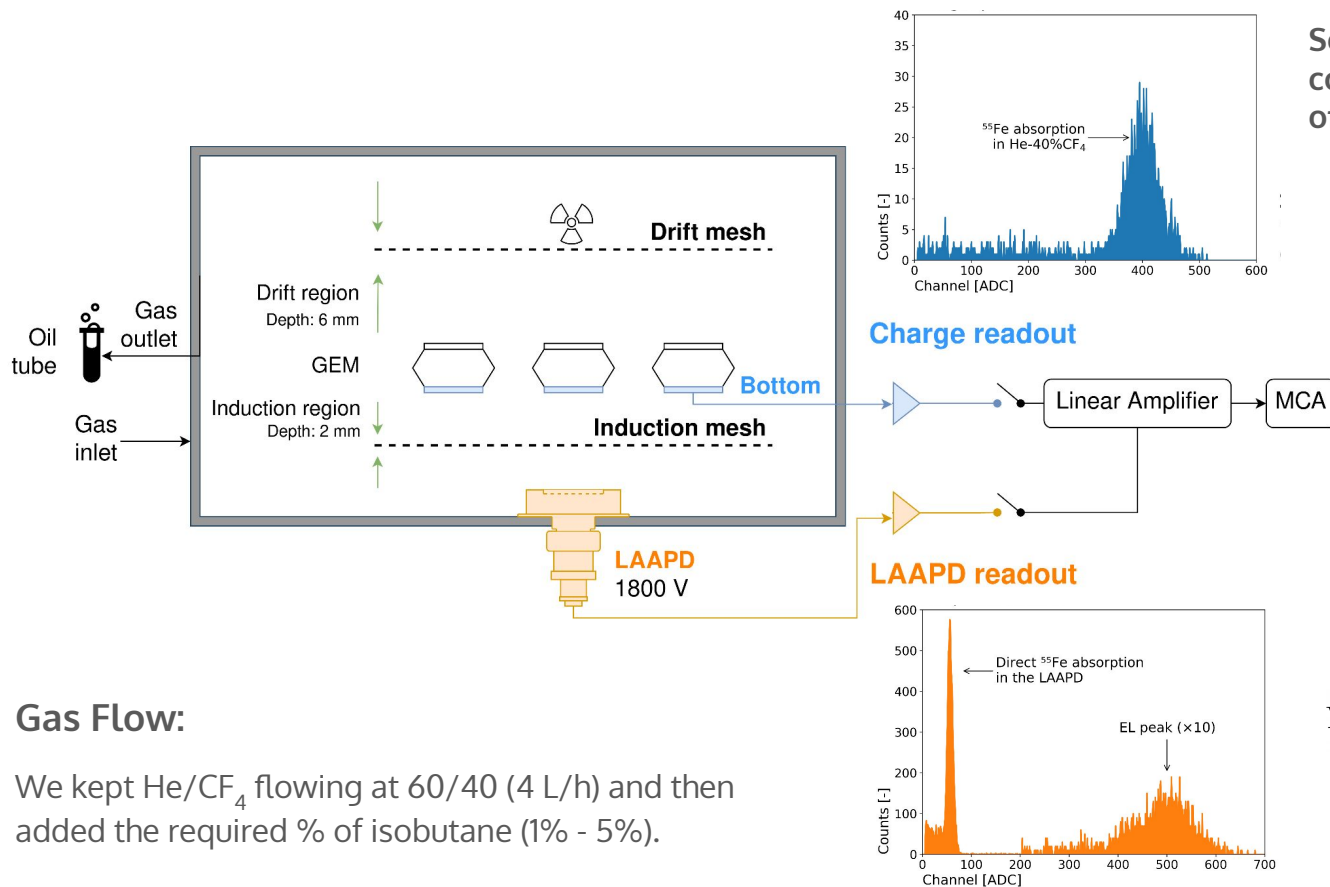
- **Meshes** with ~84% optical transparency;
- **Standard GEM** with 3 x 3 cm<sup>2</sup> area;
- **LAAPD**:
  - Active diameter: 16 mm;
  - Range: 150 - 1000 nm.



**Detector Setup:** LAAPD, induction mesh, GEM and drift mesh (from bottom to top).

# Experimental setup

## Electronic readout



Secondary electrons are collected at the bottom of the GEM.

The LAAPD detects the EL photons produced in the GEM avalanches.

## Gas Flow:

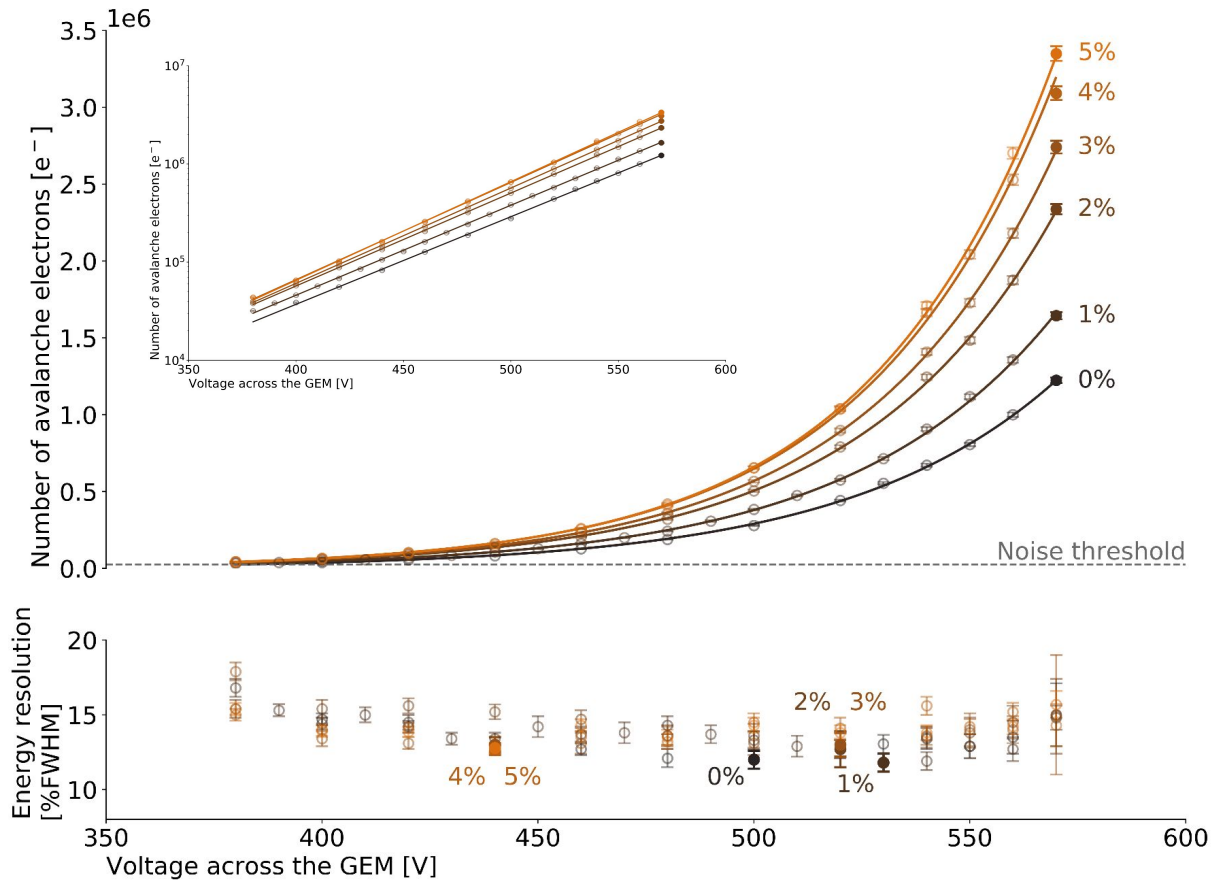
We kept He/CF<sub>4</sub> flowing at 60/40 (4 L/h) and then added the required % of isobutane (1% - 5%).

$$Y_{\text{EL}} = \frac{E_X}{w(\text{Si})} \times \frac{A_{\text{EL}}}{A_X} \times \frac{1}{QE \times \Omega \times T}$$

EL and  $^{55}\text{Fe}$  X-rays peak ratio  
 Radiation energy, silicon  $w$ -value  
 quantum efficiency, solid angle, mesh transparency

# Results

## Number of avalanche electrons and energy resolution for He/CF<sub>4</sub> (60/40) + isobutane



The number of avalanche electrons increases with increasing isobutane content

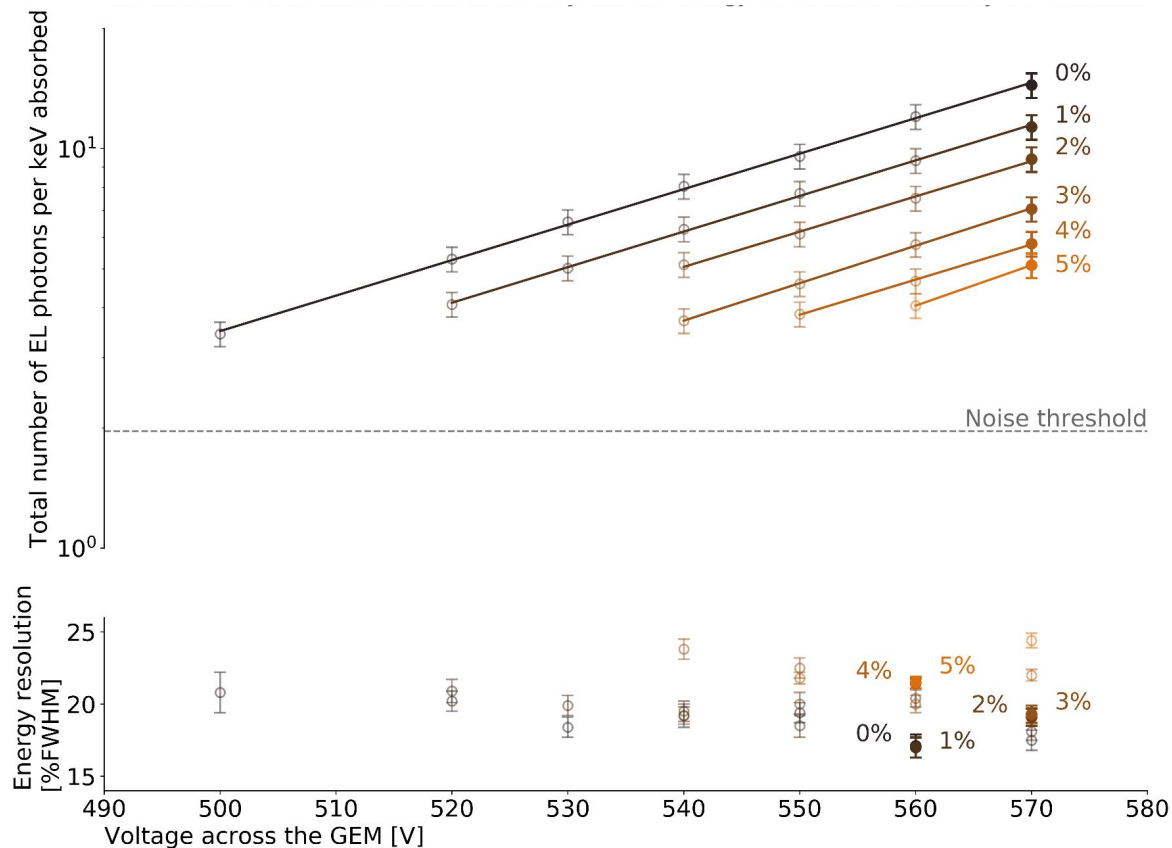
**2.7 fold** increase in the maximum number of avalanche electrons from 0% to 5% isobutane.

Energy resolution does not depend on the isobutane content

All studied mixtures have an energy resolution (FWHM) around 12% for the charge signals.

# Results

Total number of EL photons per keV absorbed and energy resolution for He/CF<sub>4</sub> (60/40) + isobutane



**Total number of EL photons per keV absorbed decreases with increasing isobutane content:**

isobutane converts EL photons into vibrational and rotational states.

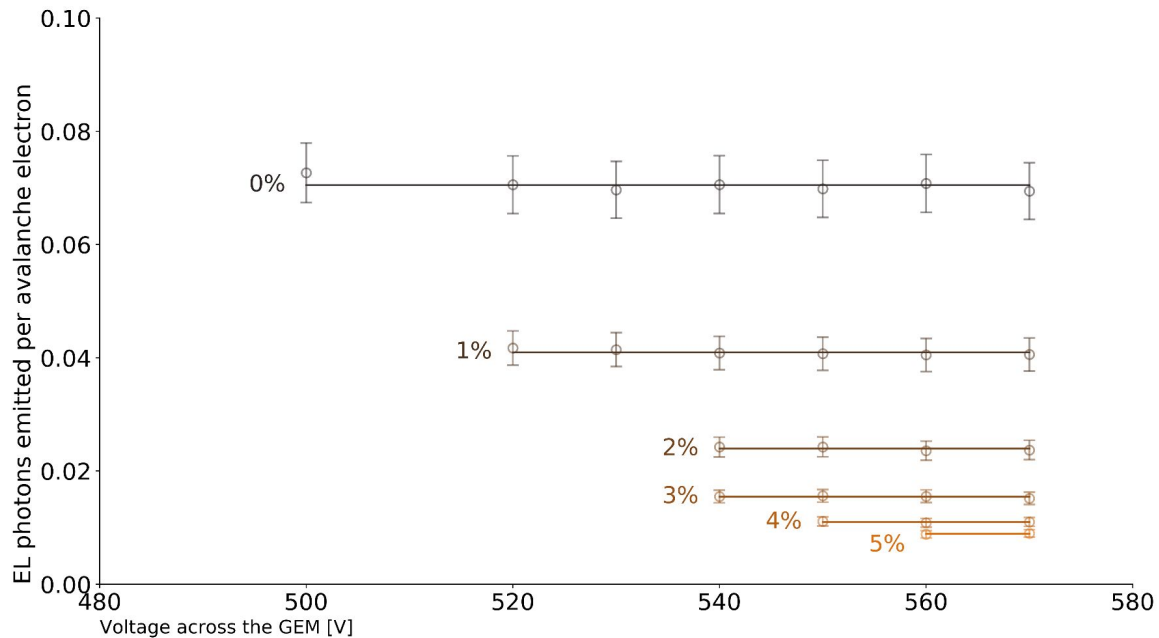
**2.8 fold decrease** in the total number of EL photons per keV absorbed from 0% to 5% isobutane.

**Energy resolution does not depend on the isobutane content**

The gradual degradation in energy resolution is attributed to low statistics and not to decreased detector performance.

# Results

Number of EL photons emitted per avalanche electron for He/CF<sub>4</sub> (60/40) + isobutane



The number of EL photons emitted per avalanche electron decreases with increasing isobutane content due to quenching.

7.9 fold decrease in the number of EL photons per avalanche electron from 0% isobutane to 5% isobutane.

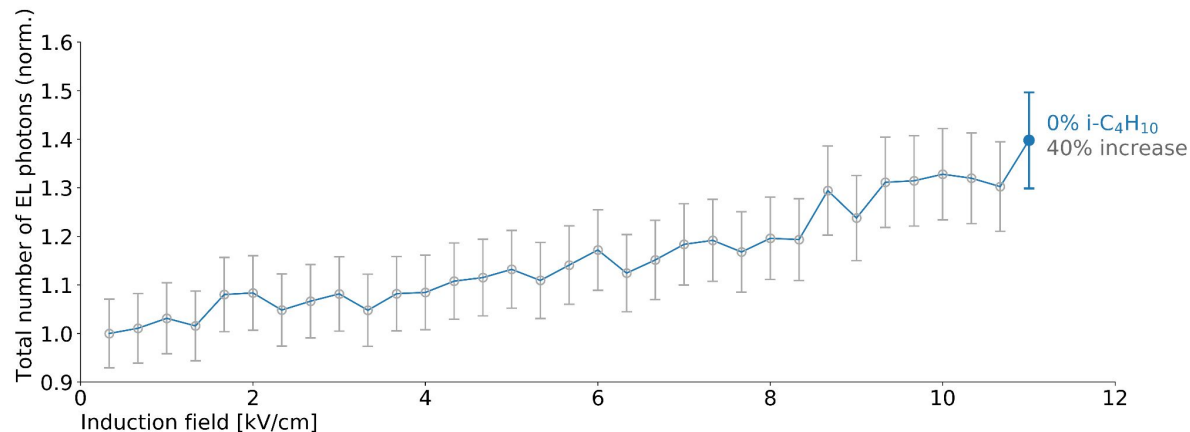
However, only 2.8 fold decrease in the total number of EL photons produced in the avalanche, from 0% to 5% isobutane.

This is due to the increasing number of avalanche electrons with increasing isobutane concentration.

% Isobutane	0%	1%	2%	3%	4%	5%
Average EL photons per avalanche electron	0.0705(11)	0.0410(5)	0.02395(35)	0.01546(20)	0.01099(13)	0.00890(12)

# Results

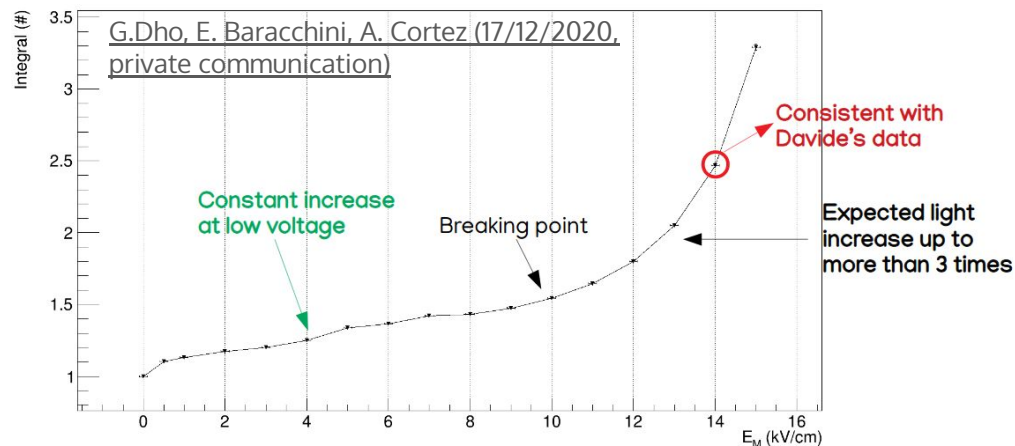
Producing additional EL photons in the induction region for He/CF<sub>4</sub> (60/40)



## Experimental conditions

The voltage across the GEM was kept at 540 V and the induction field was reversed to collect the electrons in the induction mesh.

**The goal was to produce additional EL photons in the induction gap.**



**We got a 40% increase in absolute EL for 11 kV/cm**

**There is a gradual increase in the number of emitted EL photons with increasing induction field.**

Other independent results within the collaboration obtained 42% increase in EL at 11 kV/cm with an ITO glass.

# Conclusions

Our results show that:

- **The number of avalanche electrons increases with the addition of isobutane:**
  - **2.7 fold increase** in 5% isobutane relatively to 0% isobutane;
- **The EL yield decreases with the addition of isobutane:**
  - **7.9 fold decrease** in total number of EL photons emitted per avalanche electron for 5% isobutane relatively to 0% isobutane;
  - **But only a 2.8 fold decrease in the number of EL photons** for 5% isobutane relatively to 0% isobutane;
- **Energy resolution stays unaffected (FWHM @ 5.9 keV):**
  - ~12% for charge signals;
  - ~20% for EL signals.
- **An additional 40% increase in the number of EL photons was achieved** by increasing the induction field from 0.3 kV/cm to 11 kV/cm.

# Thank you for your attention

## Any questions?

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Acknowledgement is due to the FCT PhD studentship (ref. SFRH/BD/143355/2019).

This work is supported by CERN/FIS-INS/0026/2019 and UID/FIS/04559/2020 (LIBPhys), funded by national funds through FCT/MCTES and co-financed by the European Regional Development Fund (ERDF) through the Portuguese Operational Program for Competitiveness and Internationalization, COMPETE 2020.



INITIUM Project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 programme (grant agreement No 818744). CYGNO Project is funded by INFN.

