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
The CYGNO Collaboration:

The shortest possible intro on Directional Dark Matter

- Neutrinos (SUN)
- WIMP wind (CYGNUS)

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

DM signature: daily modulation
CYGNUS - Galactic Nuclear Recoil Observatory

- **CYGNUS-10**
  - Boulby, UK
  - 10m³ He:SF₆
  - GEM+wire readout

- **CYGNUS-HD10**
  - SURF, USA
  - He:CF₄:X
  - Strip readout

- **CYGNUS-KM**
  - Kamioka, Japan
  - He:SF₆(CF₄)
  - Strip readout

- **CYGNO-INIQUUM**
  - Gran Sasso, Italy
  - HeCF₄(SF₆)
  - sCMOS+PMT readout

- **CYGNO-OZ**
  - Stawell, Australia
  - R&D leading to 1m³

- **CYGNUS-ANDES**
  - New proposal t.b.d.
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

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/
The inclusion of Hydrogen is well motivated.

But H itself is a difficult gas to work with.

Hydrocarbons are excellent alternatives.
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 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**
**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
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.
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:

$$Y_{EL} = \frac{\eta_{\gamma}}{\eta_{e^-}} = \frac{w(gas)}{w(Si)} \times \frac{A_{EL}}{A_X} \times \frac{1}{QE \times \Omega \times T}$$

$A_{EL}, A_X$ 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)
$\Omega$ is the solid angle (0.263)
$T$ is the mesh transparency (84%)
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.

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
CF$_4$: GEM gain

Radiation source: $^{55}$Fe
Gas mixture: CF$_4$
Drift field = 3.3 kV/cm
Induction field = -300 V/cm
LAAPD bias = 1750 V

Charge Gain (GEM bottom)
EL Yield (LAAPD)

Counts [-]
Channel [ADC]

Energy resolution [%FWMH]

Voltage across GEM [V]
During the drift region optimization we encountered an unexpected behavior:

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 behavior.

A test with P10 showed a more typical behavior.
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

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- Charge Gain (GEM bottom)
- EL Yield (LAAPD)

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- Charge (GEM bottom)
- EL (LAAPD)

- Radiation source: $^{55}$Fe
- Gas mixture: He+$\text{40\%}$CF$_4$
- Drift field = 500 V/cm
- Induction field = -300 V/cm
- LAAPD bias = 1800 V

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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.

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.

Data taken at 1 bar in continuous flow mode. The isobutane was added to a mixture of He/CF$_4$ (60/40).
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%.
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

This work is supported by CERN/FIS-INS/0025/2017 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