How CYGNO can make use of electro-luminescence induced by non-ionizing electrons

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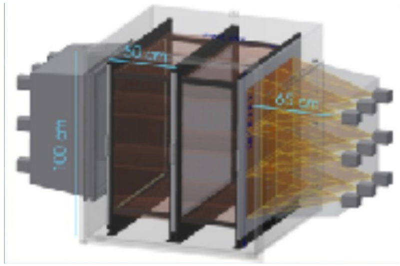
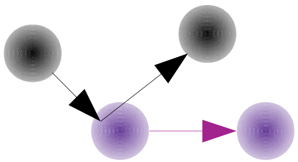
CYGNO



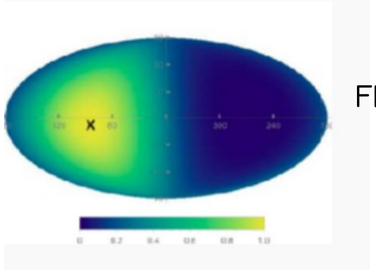
- CYGNO is the project of a directional detector, whose main goal is the direct detection of Dark Matter

For the direct detection, it uses a material (He:CF_4 gas) as target and looks at its recoils

Dark Matter particle



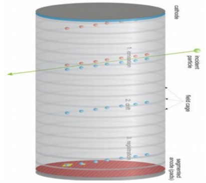
Detectable recoiling nucleus

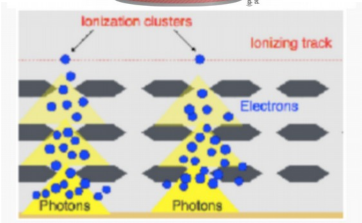


Fluorine recoil angular spectrum

See D. Pinci's talk

Time Projection Chamber



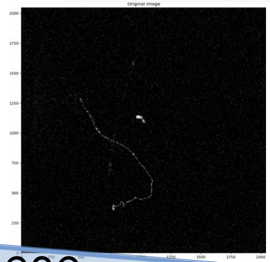


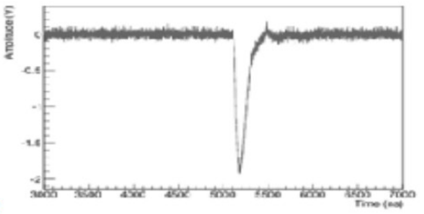
Triple GEM for charge amplification and light production

Optical readout

sCMOS camera

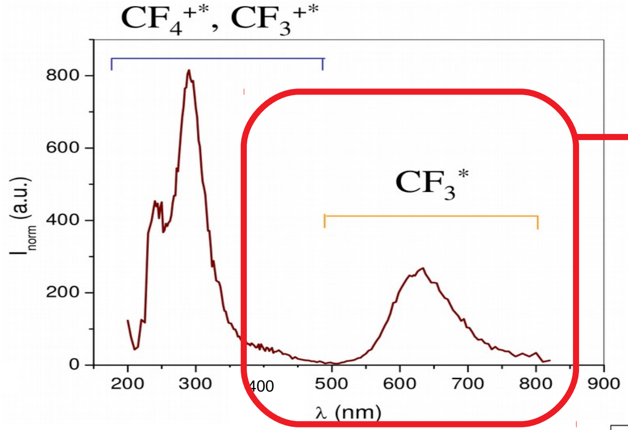
PMT



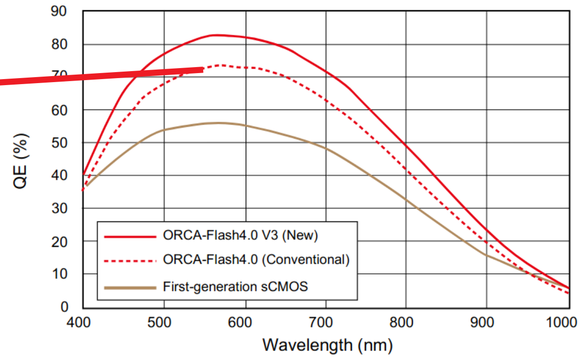


Luminescence in He:CF_4

- The light emission from CF_4, also in mixture with He, was studied in the past [1–2]



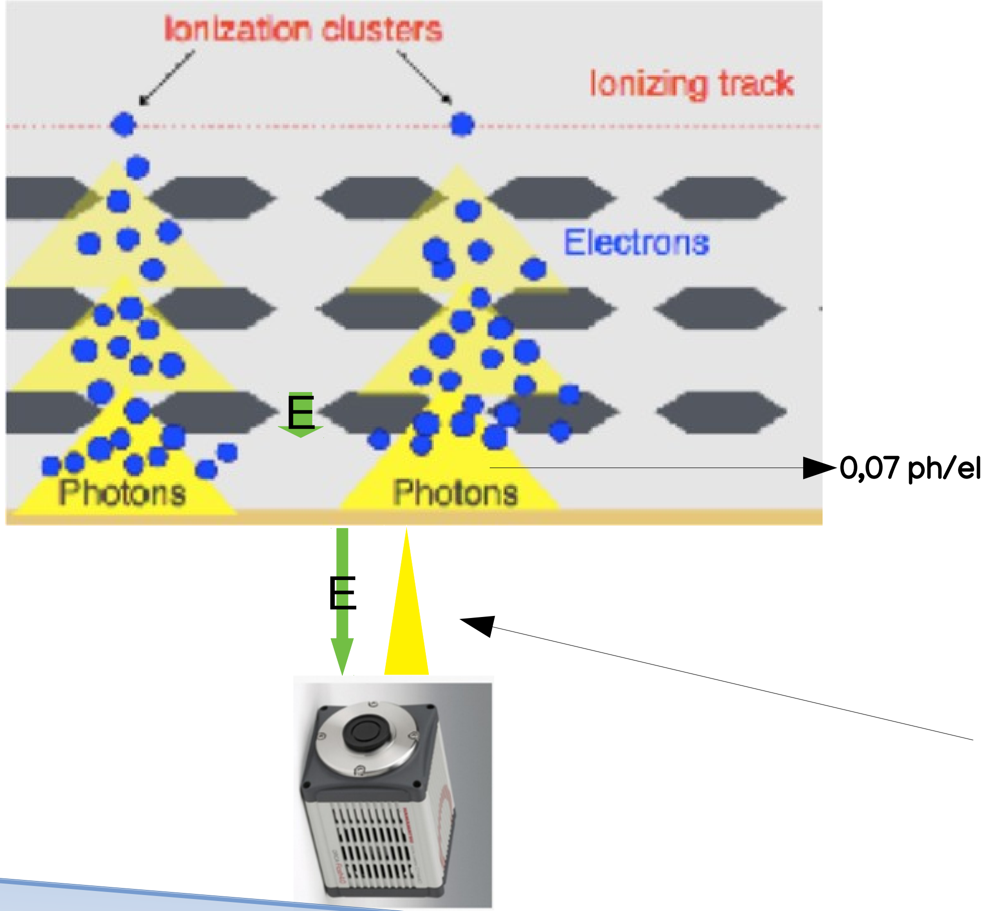
Region where the camera has maximum QE



Process	Threshold (eV)	Energy loss (eV)
Direct vibrational excitation ν_4 ν_3	0.078 0.159	0.078 0.159
Indirect vibrational excitation	4.0	0.4
Electron attachment	4.3	4.3
Electronic excitation (dissociation into neutral fragments)†	12.5 (10)	12.5 (10)
Dissociative ionization†	15.9	15.9

It should be possible to dissociate to neutral fragment before ionizing the molecule

Electro-Luminescence

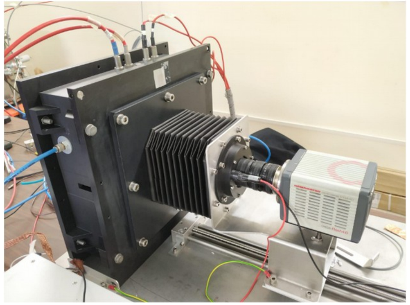


- The very intense electric field in GEM holes ionizes the gas and produce multiplication of charge in a small region
- During the ionization process also neutral fragment of CF_4 are produce with consequent emission of light
- Increasing the amount of light would improve the quality of data
- It could be useful to generate more photons, drifting the electrons at lower field for longer, exploiting excitation of the gas without any ionization

Electro-luminescence

MANGO

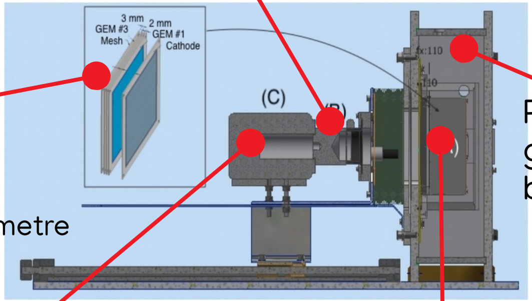
A **M**ultipurpose **A**pparatus for **N**egative ion studies with **G**EM **O**ptically readout



Lenses

17mm FL, f/0.95 Fast C Mount
https://www.schneideroptics.com

3 GEMs:
50 um thick
140 um pitch
70 um holes diametre



Plastic gas-tight box

sCMOS Camera
Orca flash 4.0.

2048x2048 pixels

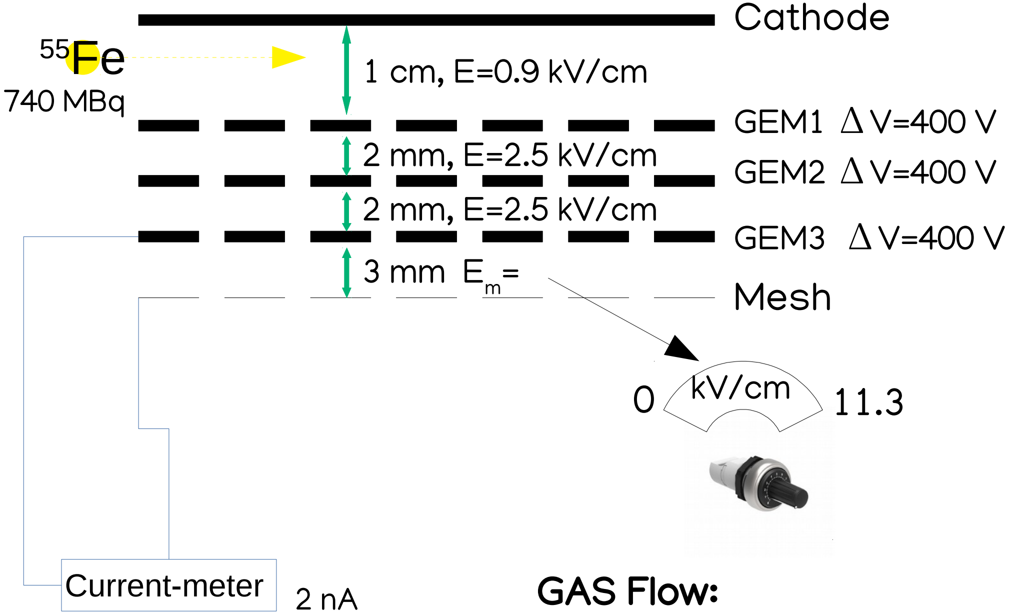
noise <2 ph/pixel

www.hamamatsu.com.

TPC volume:
Max volume 500 cm^3
(10x10 cm^2) area

He:CF_4 mixture 60/40

1 atm

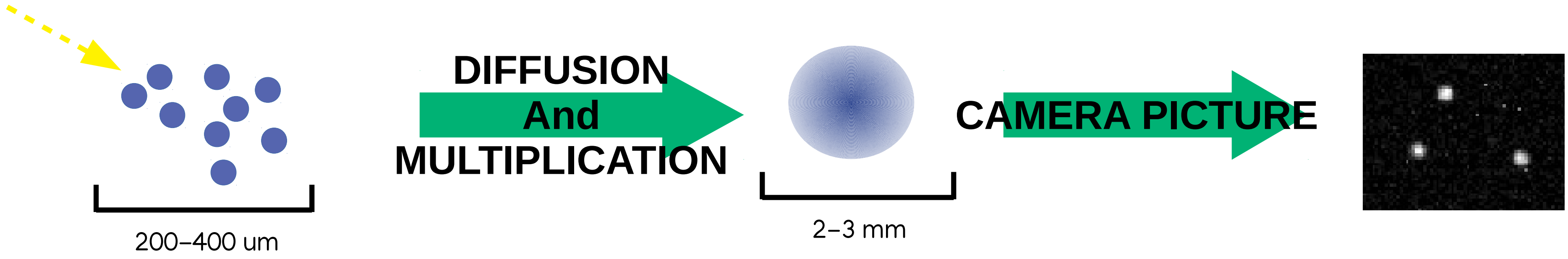


2 nA sensitivity

GAS Flow:
100 cc/min
1 atm
He:CF_4 60/40

^{55}Fe Expected Signal

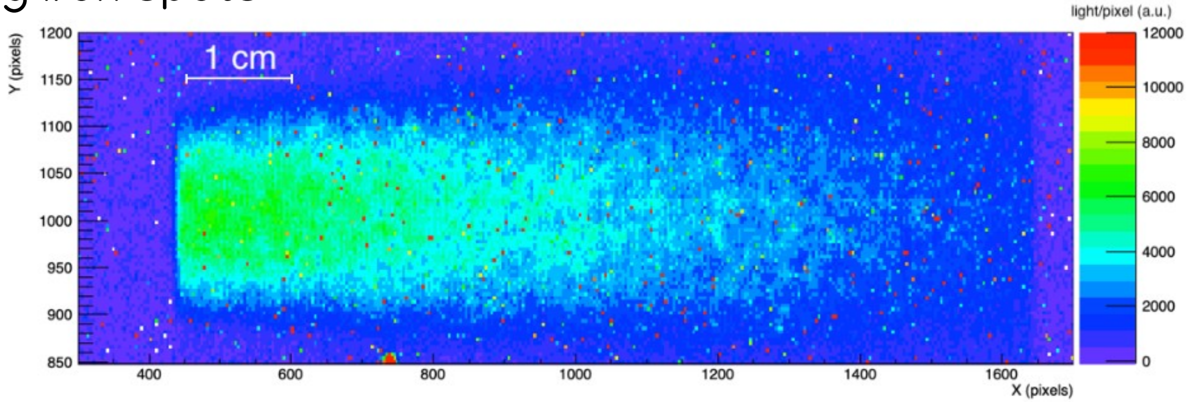
- The high activity of the source allows us to neglect natural radioactivity
- 5.9 keV X-ray emission is expected to be contained in few hundreds micrometers



- The diffusion (especially in GEMs) spreads the electrons to a round blob of 2–3 mm
- The signal in the camera picture will be round spots, quite easily distinguishable

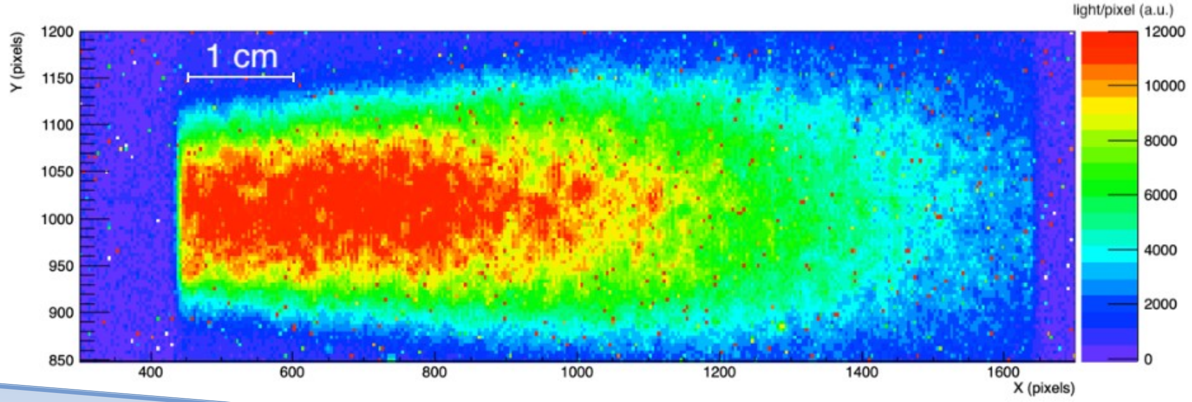
Long Exposure Data Set

- The long exposure (30 images of 10 s) allows to study the light output without the need of distinguishing iron spots



E_m 0 kV/cm

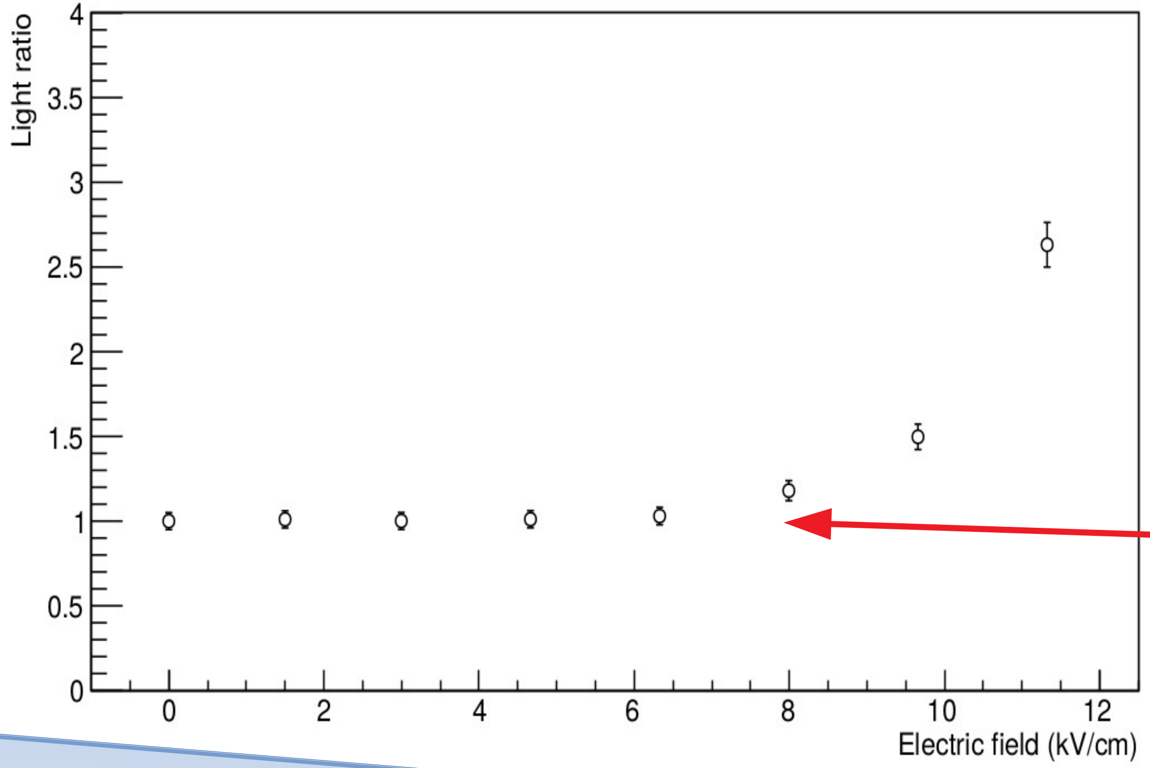
Visible light output increase



E_m 11.3 kV/cm

Long Exposure Data Set

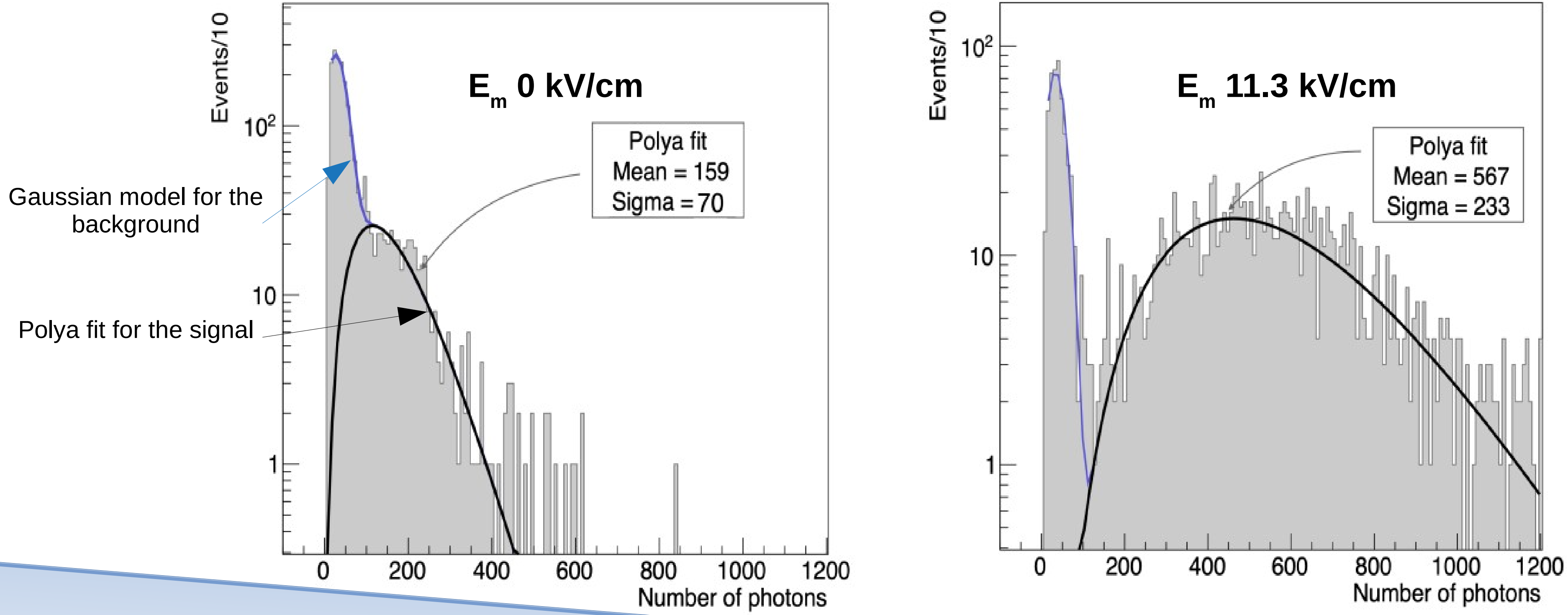
- Analysing the various electric fields applied it is visible a clear influence on the photon yield



Consistent with a threshold effect

Short Exposure Data Set

- With the short exposure (500 ms), an algorithm to find round spots was used
- More pictures (200) combined to have more statistics



Short Exposure Data Set

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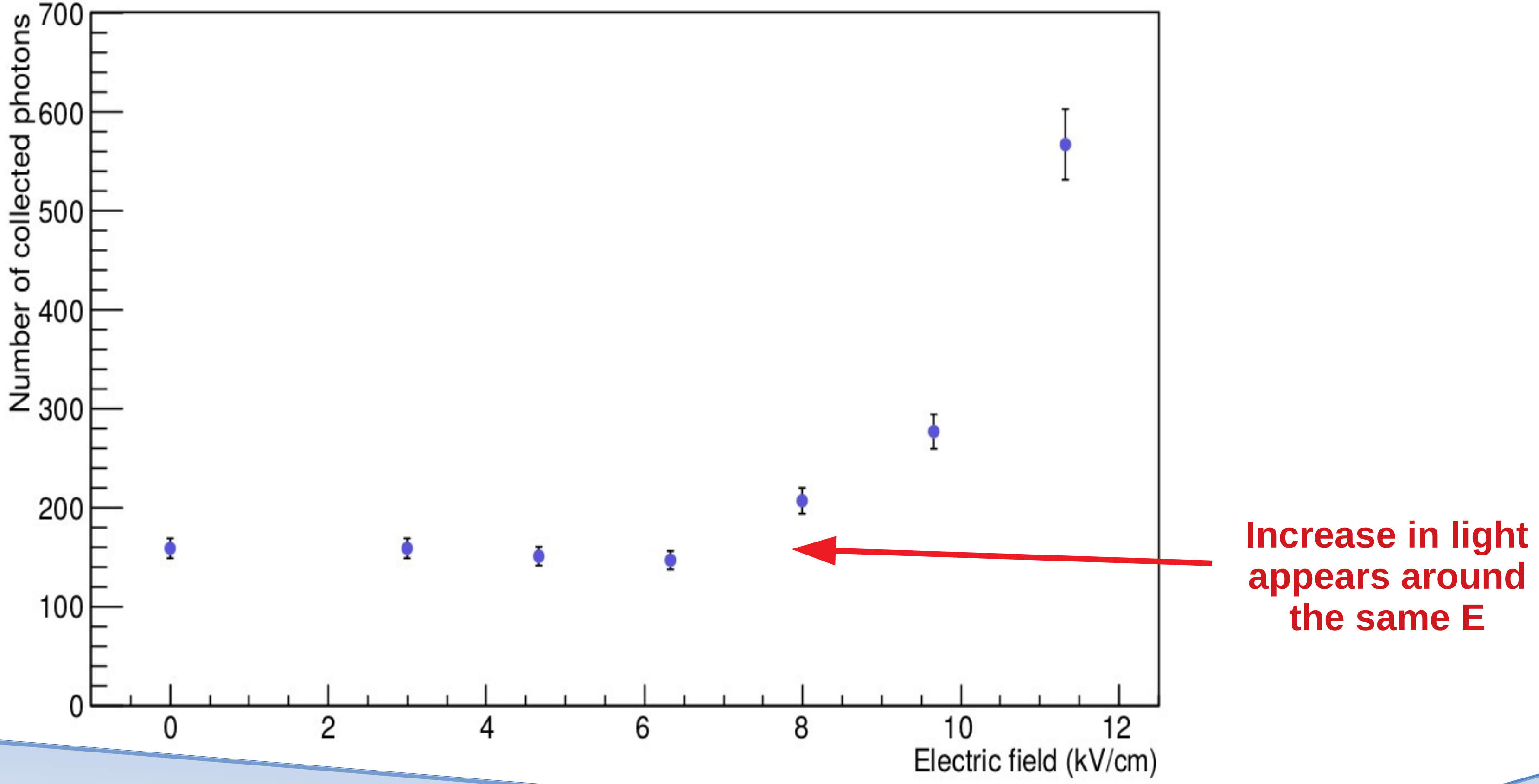


Charge Analysis

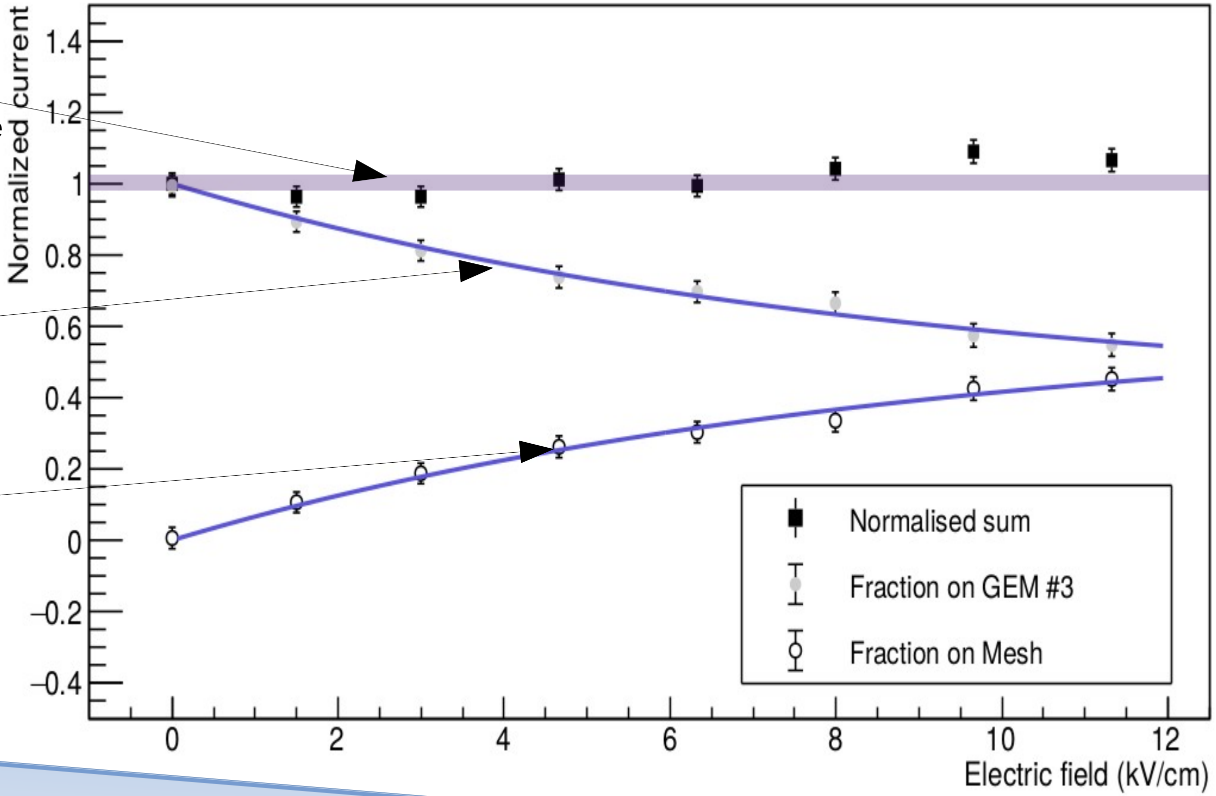
- Looking at the charge read with the current-meter

$I_{tot} = I_{GEM\,3} + I_{Mesh}$

Normalized to initial value

$\frac{I_{GEM\,3}}{I_{tot}}$

$\frac{I_{Mesh}}{I_{tot}}$



No significant increase in charge total charge collection

No increase of charge with increase of light output suggests pure electro-luminescence is happening

Photons per electron

- From the previous plot, it is possible to fit the extraction efficiency from the third GEM

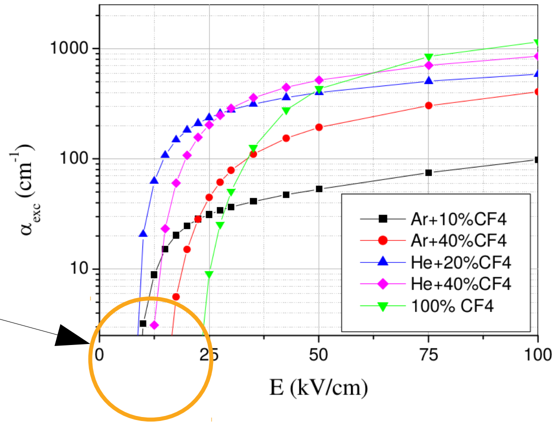
$$\epsilon_{extr} = I_{\text{mesh}}/I_{\text{tot}} = A \cdot (1 - e^{-E_A/b}) \longrightarrow A = 0.57 \pm 0.02$$

Consistent with precedent studies on electron collection [4]

- Using the data collected at 11.3 kV/cm, the probability of creating a photon per unit length can be evaluated (@ 11.3 kV/cm)

$$\alpha_{\text{exc}}(E_A) = \alpha_{\text{GEM}} \times \frac{1}{\epsilon_{extr}(E_A)} \times \frac{1}{\Delta z} \times \frac{n_{\text{exc}}(E_A)}{n_{\text{GEM}}} = 1.2 \pm 0.2 \text{ cm}^{-1}$$

Consistent with expectations [3]



Leading to a mean free path of around 1 cm

- Planning on testing higher electric fields

Conclusions

- In the context of a DM directional detector, based on gaseous TPC optically readout, it is of relevant importance to study the behaviour of light yield in different configurations.

- With the MANGO protoype a study was performed adding a conductive mesh underneath the bottom GEM.

- The application of intense electric field toward this mesh produced a visible increase in the light output without any trace of electron multiplication, suggesting that a form of electro-luminescence in a He:CF_4 mixture is taking place.

Bibliography

[1] M. M. F. R. Fraga, et al., *The GEM scintillation in He CF_4, Ar CF_4, Ar TEA and Xe TEA mixtures*, Nucl. Instrum.Meth. A504 (2003) 88.

[2] L. M. S. Margato et al., *Effective decay time of CF_4 secondary scintillation*, JINST 8 (2013) P07008.

[3] M. Fraga, *The GEM scintillation in He CF_4, Ar CF_4, Ar TEA and Xe TEA mixtures."* Talk presented at "New developments in photodetection", International Conference, Beaune, France, 2002. "http://ndip.in2p3.fr/beaune02/sessions/fraga.pdf".

[4] W. Bonivento et al., *A complete simulation of a triple-GEM detector*, IEEE Trans. Nucl. Sci. 49 (2002) 1638.