

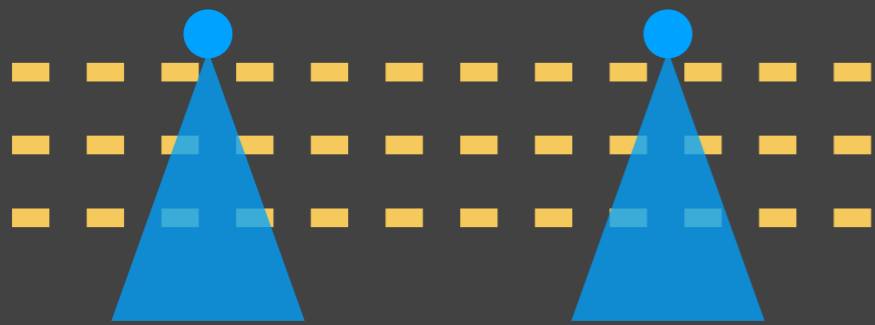
CYGN O P R O J E C T

E. Baracchini,^{a,b} L. Benussi,^c S. Bianco,^c C. Capoccia,^c M. Caponero,^{c,d} G. Cavoto,^{e,f} A. Cortez,^{a,b} I. A. Costa,^g E. Di Marco,^e G. D'Imperio,^e G. Dho,^{a,b} F. Iacoangeli,^e G. Maccarrone,^c M. Marafini,^{e,h} G. Mazzitelli,^c A. Messina,^{e,f} R. A. Nobrega,^g A. Orlandi,^c E. Paoletti,^c L. Passamonti,^c F. Petrucci,^{i,j} D. Piccolo,^c D. Pierluigi,^c D. Pinci,^{e,1} F. Renga,^e F. Rosatelli,^c A. Russo,^c G. Saviano,^{c,k} and S. Tomassini^c

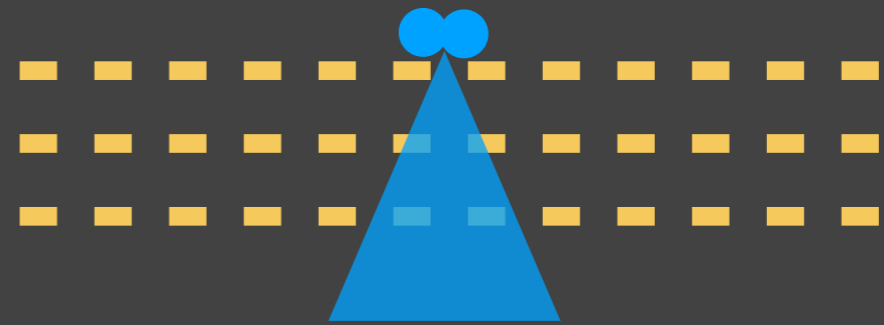
GAIN NON LINEARITY

We discovered a non linear behavior of GEM response;

Gain seems to saturate when the density of electrons (i.e. the number of electrons in each single channel) is too high;



If primary electrons are sparse, GEM gain is linear



If primary electrons are too dense, avalanche can shield GEM electric field and gain is lower

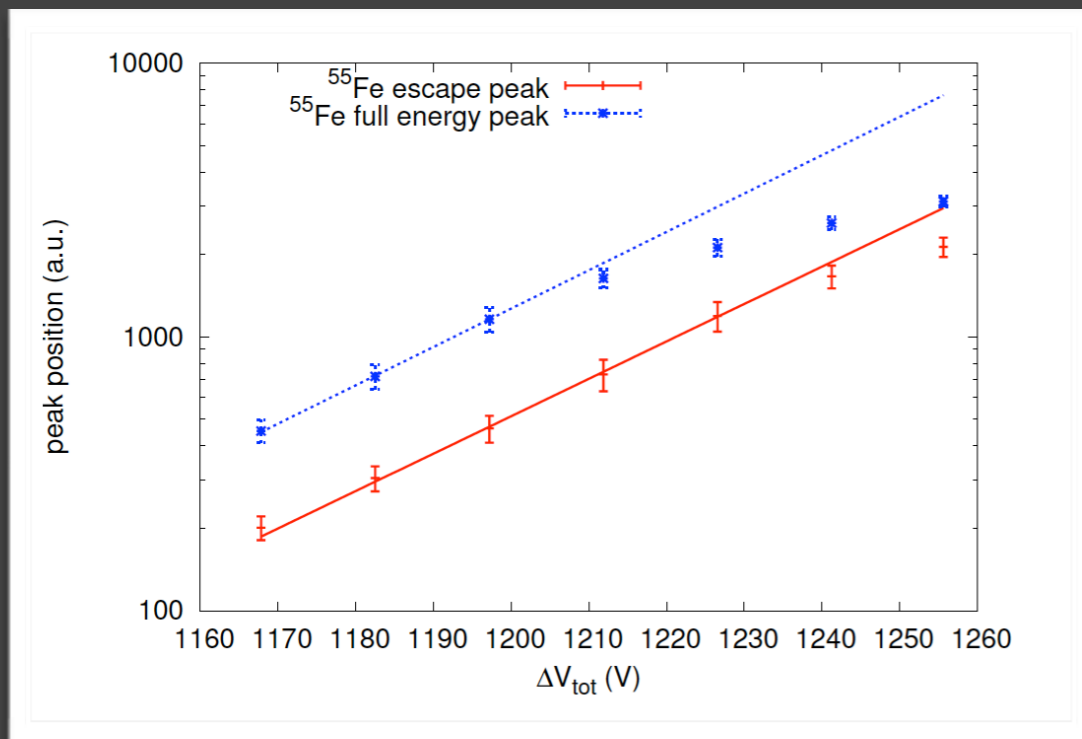
Less secondary electrons mean less light

GAIN NON LINEARITY

This phenomenon was already seen at CERN

Effects of High Charge Densities in Multi-GEM Detectors

S. Franchino¹, D. Gonzalez Diaz¹, R. Hall-Wilton², H. Muller¹, E. Oliveri¹, D. Pfeiffer^{1,2}, F. Resnati^{*,1,2},
L. Ropelewski¹, M. Van Stenis¹, C. Strelis³, P. Thuiner^{1,3}, R. Veenhof¹
¹ CERN, Geneva, Switzerland. ² ESS, Lund, Sweden. ³ TUW, Wien, Austria.



for very high gain ($1.7 \cdot 10^5$)

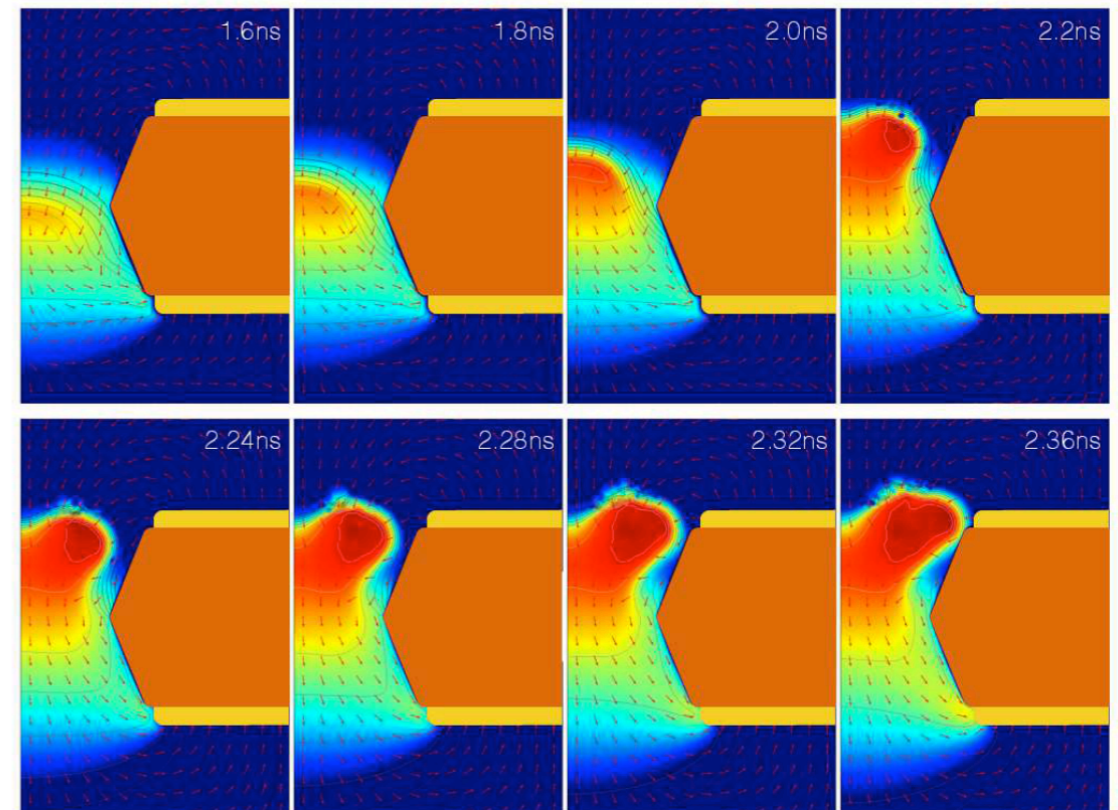
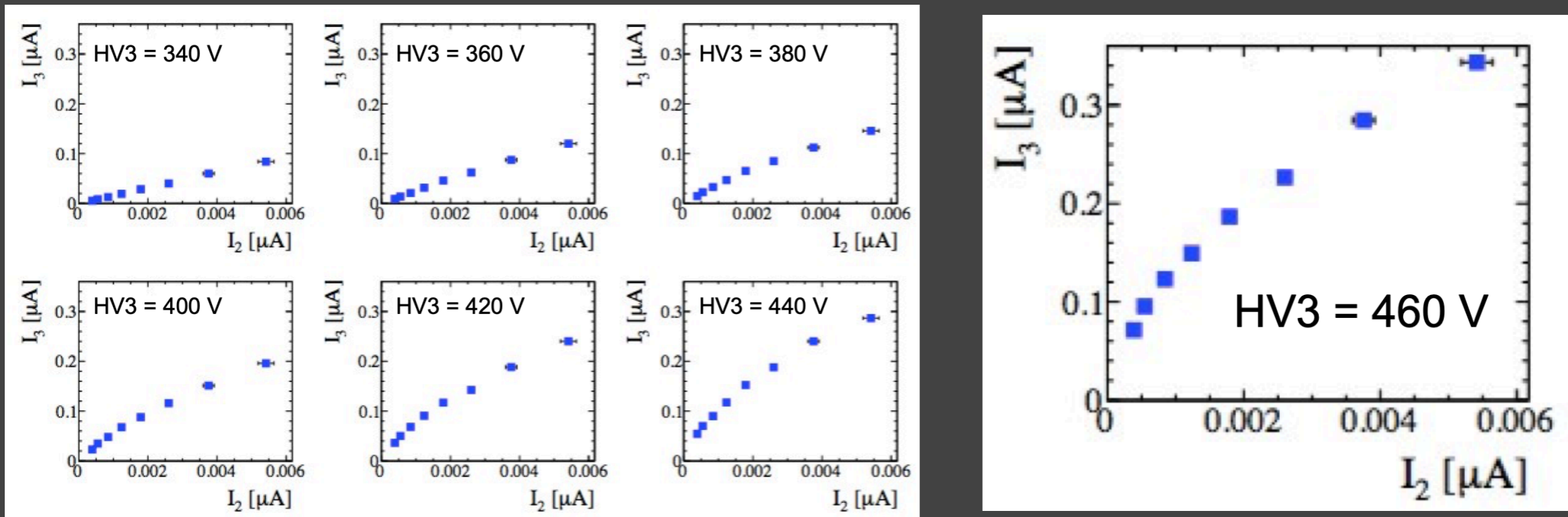


Fig. 6. Formation and propagation of a streamer in a GEM hole in cylindrical coordinates. The colour map represents the ion density in arbitrary units.

GAIN NON LINEARITY

By increasing the gain in first GEM, we simulated different energy releases



These plots give the charge coming out from GEM-3 as a function of the charge coming in. Less linear as long as the V_{GEM} increases; Good linearity with 5 times less gain.

POSSIBLE SOLUTIONS

We studied two possible solutions to the issue:

- exploit electro-luminescence to decrease the electron gain while keeping the same light yield;
- correct data according to performed measurements

Saturation on GEM-3

Karolina Kmiec and Francesco Renga

INFN Sezione di Roma

April 21, 2020

1 Measurements of saturation

The saturation effect have been studied looking at the trends of the currents on GEM-2 and GEM-3 (I_2 and I_3 , respectively) as a function of the high voltage applied on GEM-1 (HV_1). Changing HV_1 simulates indeed the effect on GEM-2 and GEM-3 of different energy deposits inside the chamber.

The chamber was exposed to a ^{55}Fe source and the current through the HV_3 bias circuit was measured. Since the bias circuit and the current readout introduce a $25\text{ M}\Omega$ resistance in the supply line, and currents up to a few μA are observed in GEM-3, there can be a relevant voltage drop (up to several volts) from the power supply to the GEM. We compensated on the fly for this voltage drop by increasing the set voltage according to the drop predicted by the measured current.

The measurements of I_2 and I_3 have been performed alternatively, switching off the high voltage on GEM-3 (HV_3) when the current on GEM-2 was readout, in order to not have any influence on GEM-2 from the ions going up from GEM-3 when it is on. GEM-2 is always kept at 460 V .

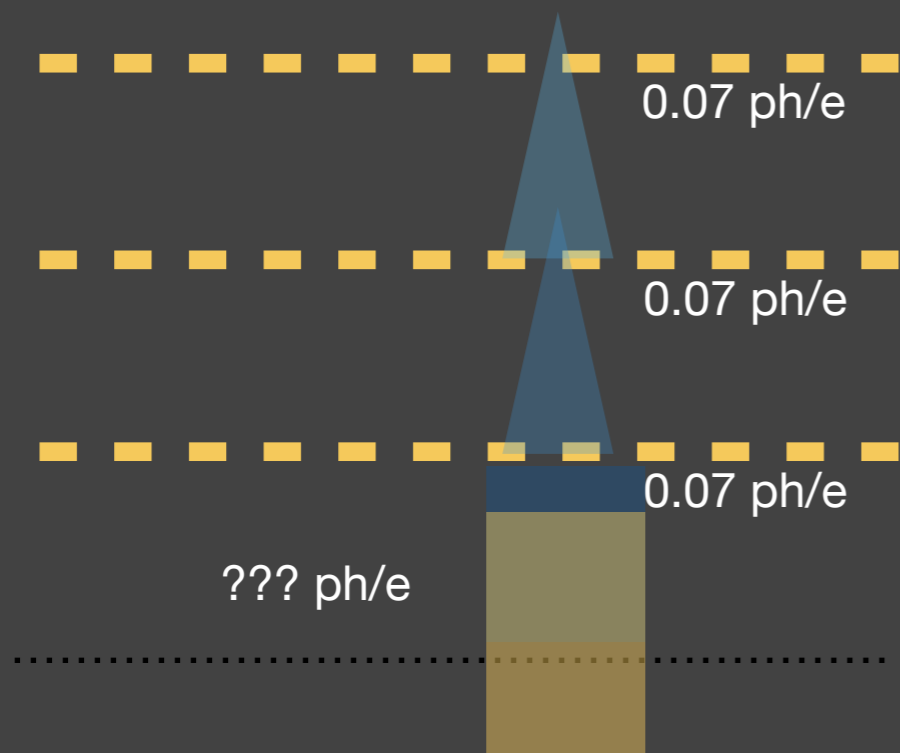
The measurements on GEM-3 have been always performed with a collimator in front of ^{55}Fe source, in order to not have an excessive current through the HV_3 bias circuit, that would have made unsafely large the necessary voltage compensation. Measurements on GEM-2 have been performed both with and without the collimator. In Fig. 1 we show the trends of I_2 versus HV_1 . Since the measurements without collimator are affected by large relative errors, we will use the measurements without collimator in the following, but

ELECTRO-LUMINESCENCE

In Optical Readout GEM detectors, light is produced by gas molecules hit by electrons in the avalanche;

Since the ratio ph/el is constant, more electrons are needed to have more photons;

Is it possible to stimulate the gas to produce light without ionising it?



We added a grid below the third GEM to accelerate electrons

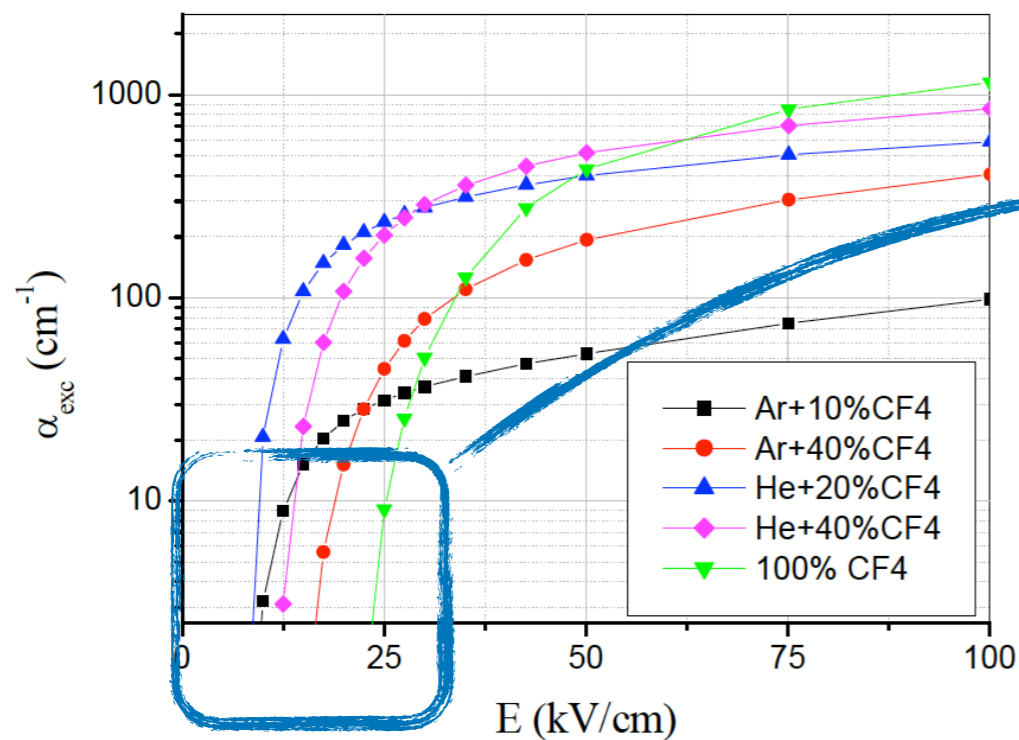
3 mm distance between mesh and GEM

$\Delta V =$ tension between mesh and GEM

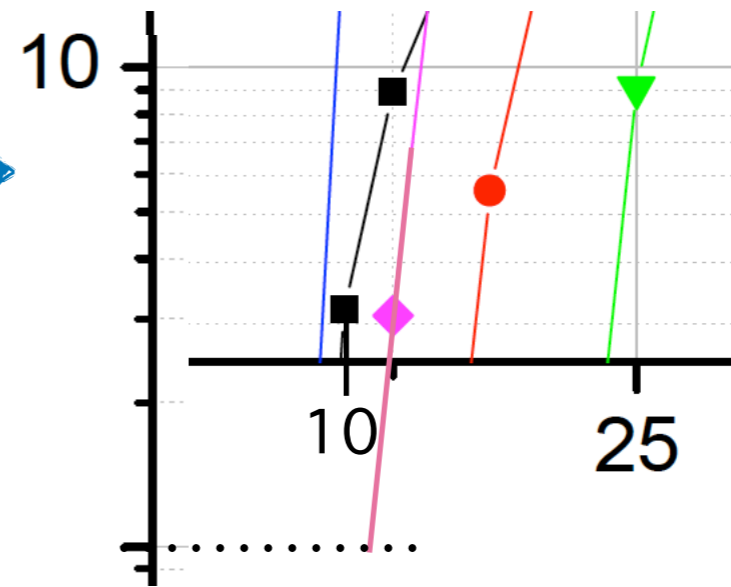
ELECTRO-LUMINESCENCE

The GEM scintillation in He-CF₄,
Ar-CF₄, Ar-TEA and Xe-TEA mixtures

M. M. Fraga, F. A. F. Fraga, S. T. G. Fetal, L. M. S. Margato,
R. Ferreira Marques and A. J. P. L. Policarpo



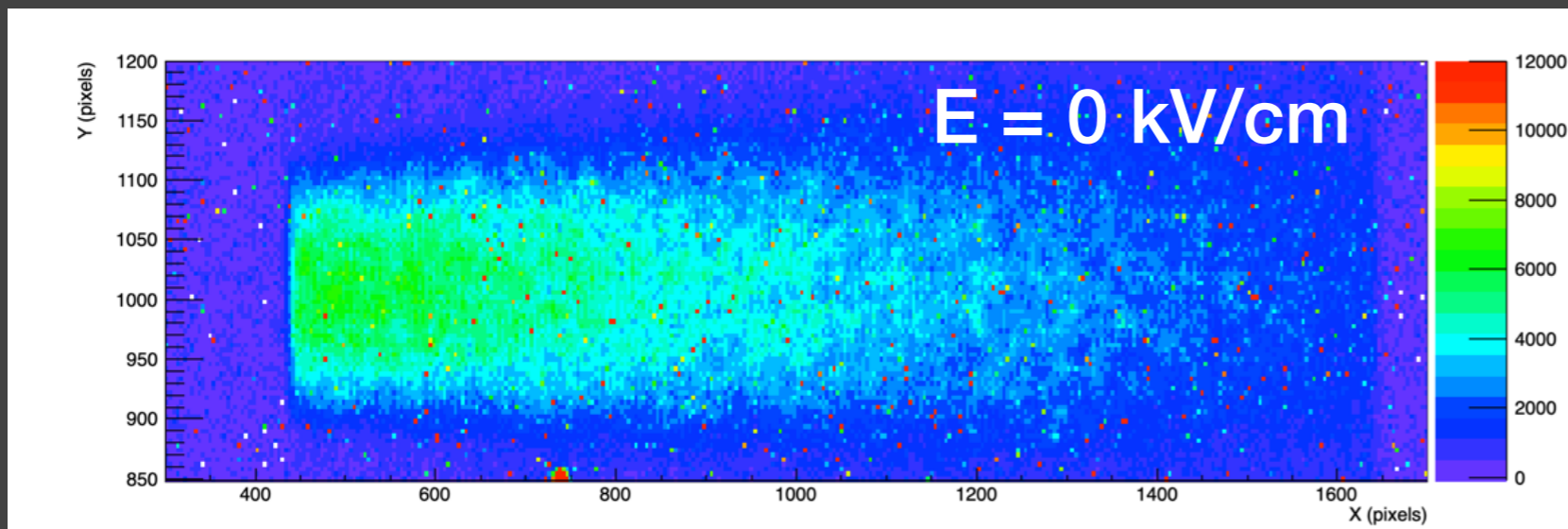
Number of collisions per cm leading to dissociation of CF₄ into neutral fragments, as a function of the electric field.



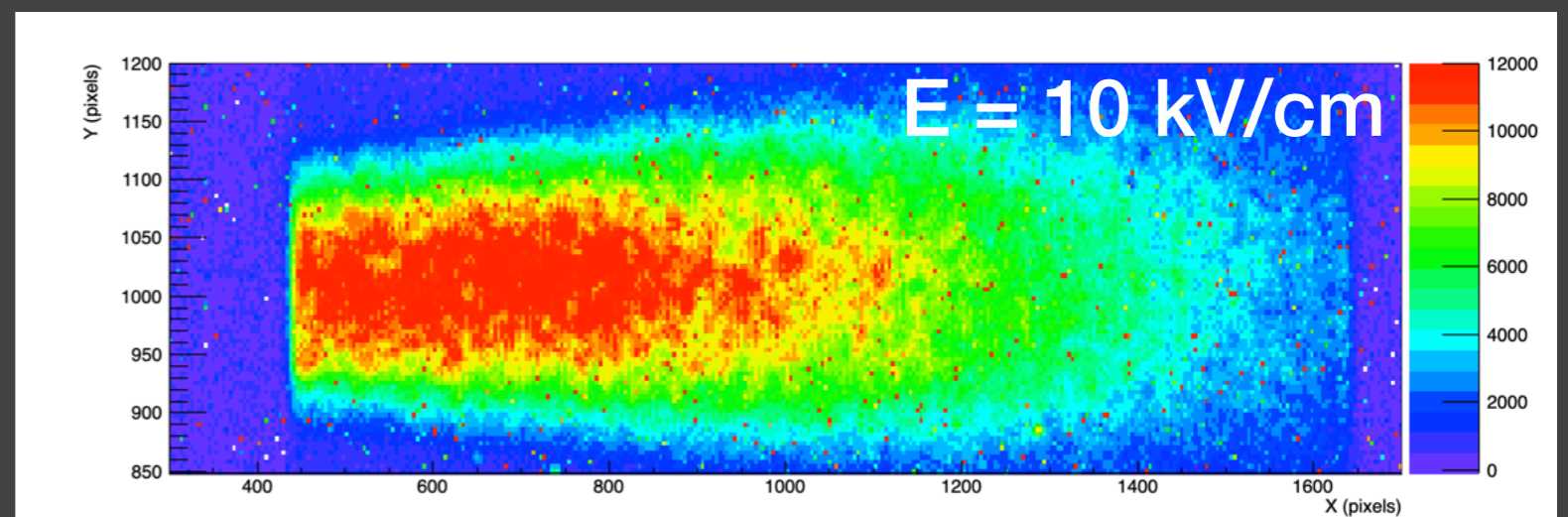
With a field of 10-12 kV/cm we expected 1 ph/el per cm

ELECTRO-LUMINESCENCE

We set a ΔV from 0 to 3.5 kV (unfortunately there were discharges and we stopped there), i.e. an electric field from 0 to 11.5 kV/cm; Detector was illuminated with a strong ^{55}Fe

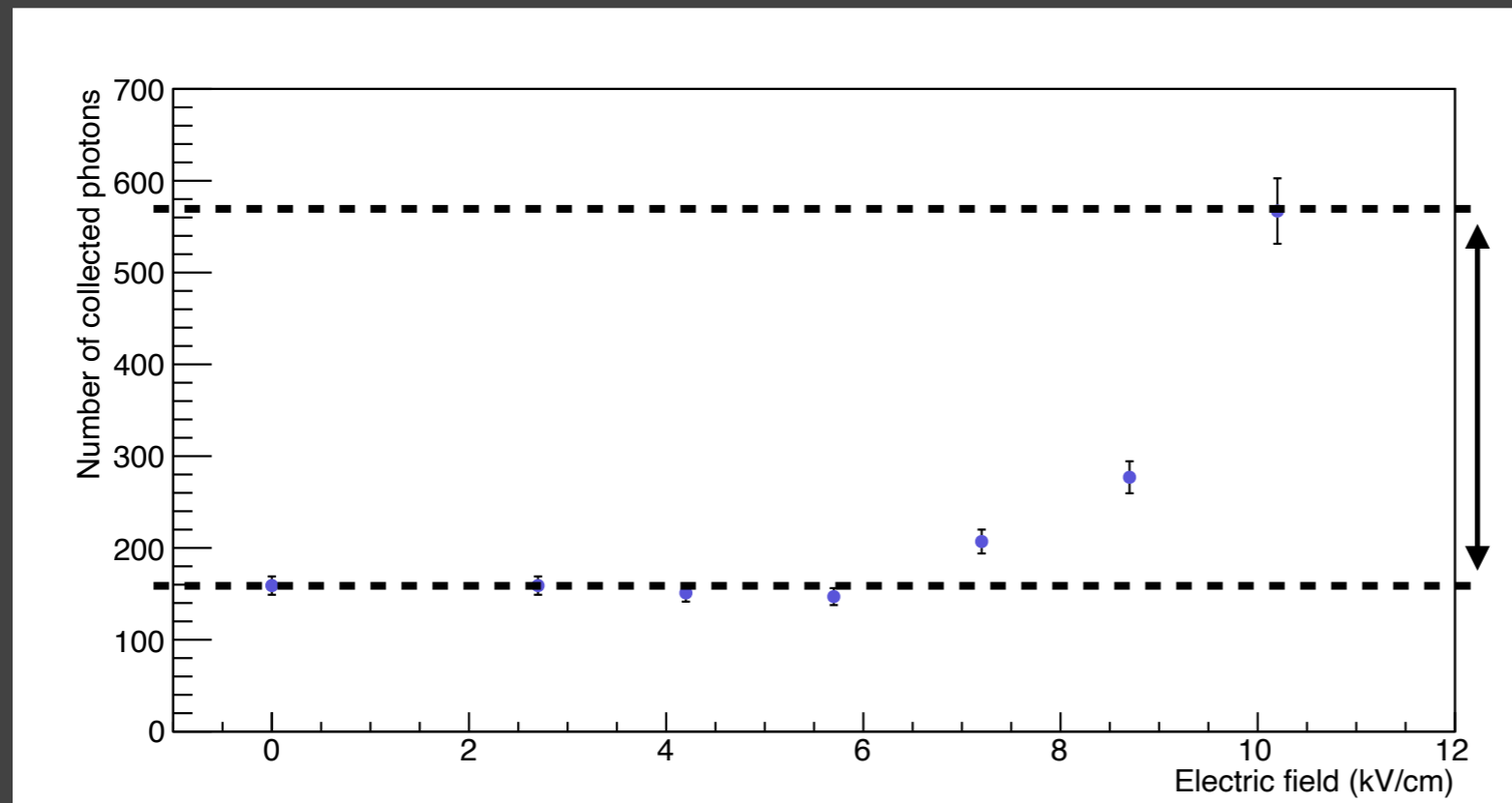
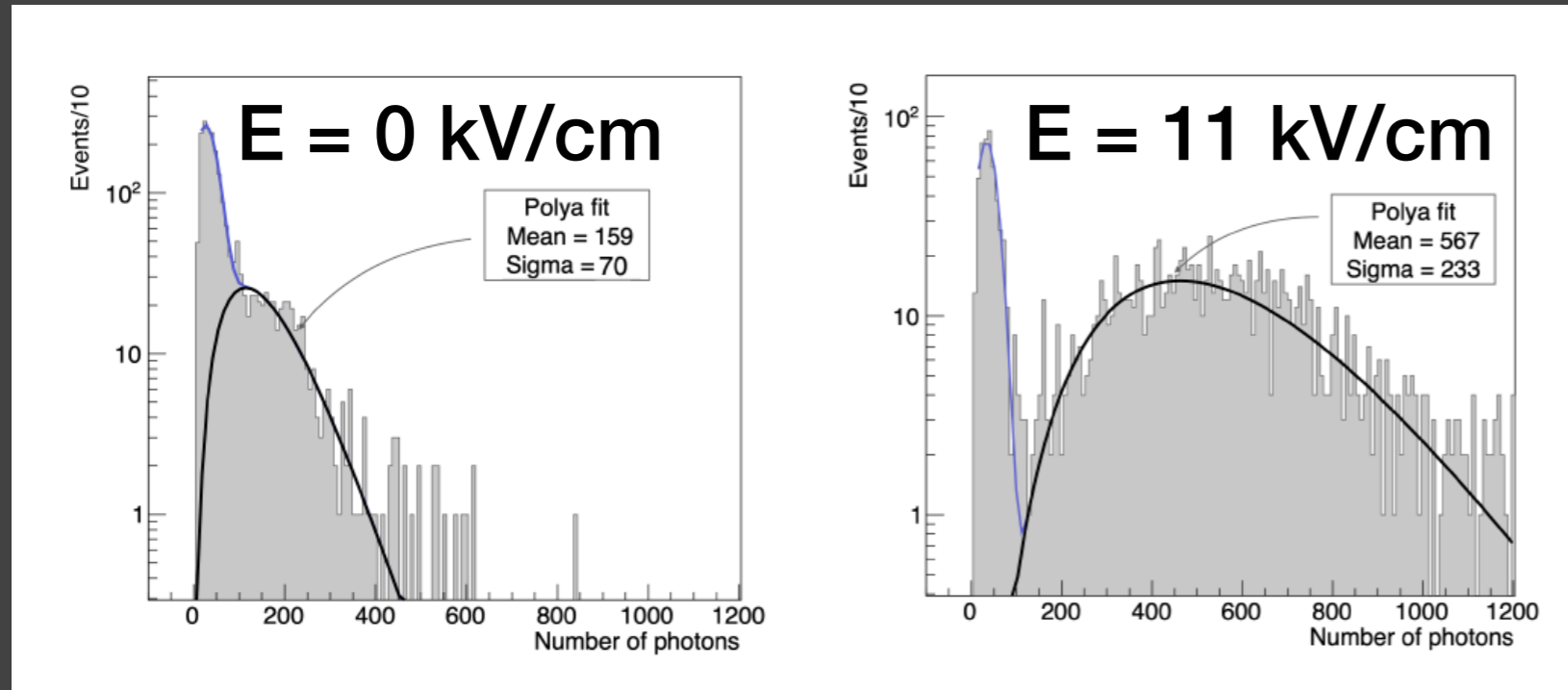


Photon yield visibly increases



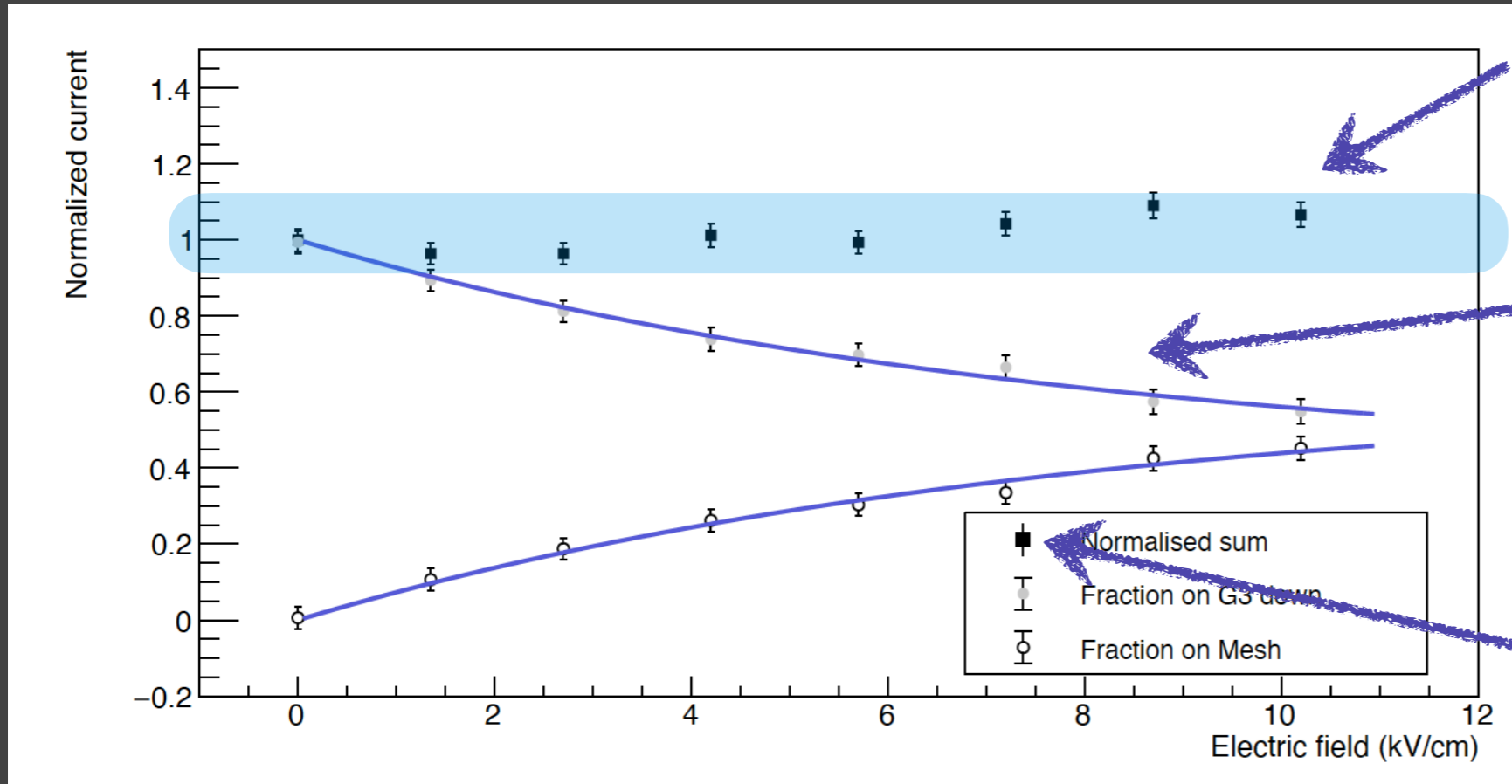
ELECTRO-LUMINESCENCE

Short exposure data (100 x 0.5 sec) to study in detail the ^{55}Fe peak position;



400 photons more

The currents drawn by the bottom electrode of last GEM and by the mesh were monitored, to check possible increase in total charge, indicating a multiplication process

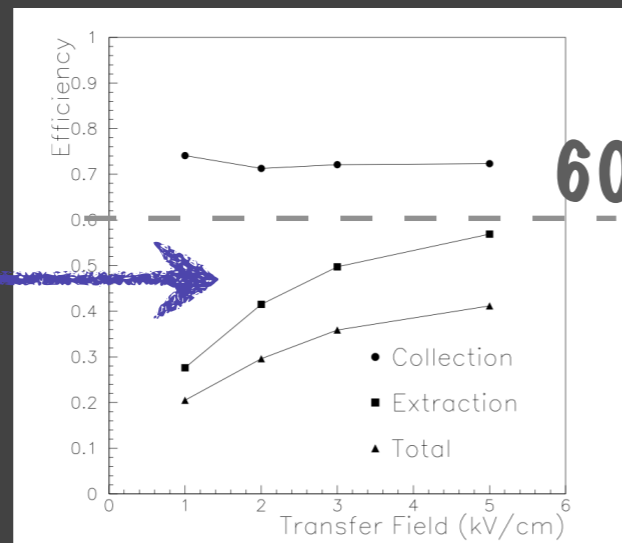


Sum of currents

Fraction of current on G3 down

Fraction of current on Mesh (at max 60%)

Garfield simu



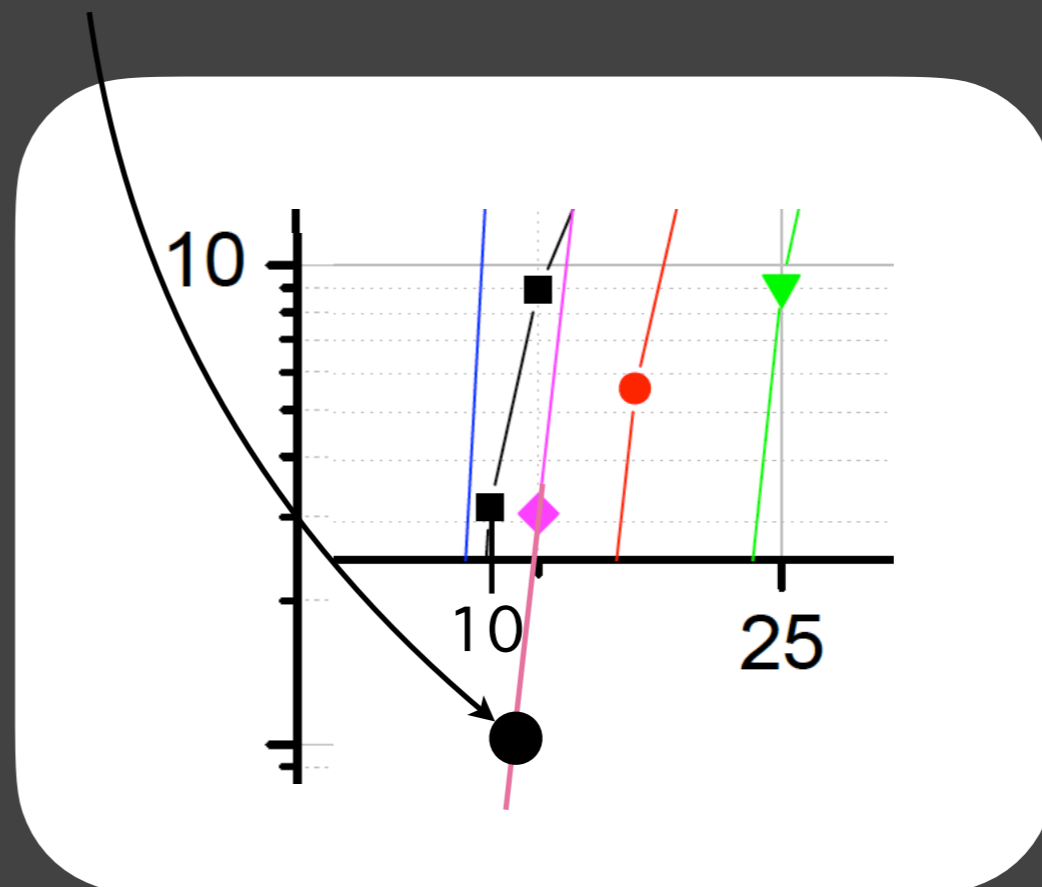
Sum is constant and sharing changes

We can now evaluate the “photon production efficiency”

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

0.4 ph/electron in 3 mm gaps, means a mean free path of about 1 cm

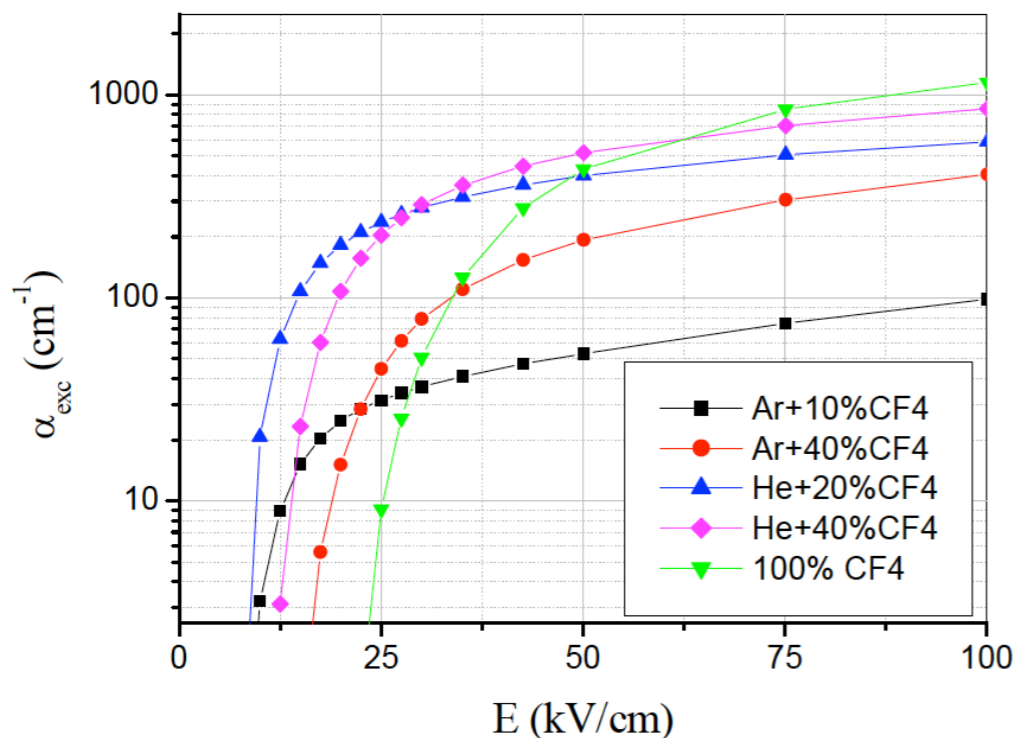
Good agreement



ELECTRO-LUMINESCENCE

Since the production efficiency increase very quickly with the electric field, by putting ΔV to 4.5 kV (i.e. with an electric field of 15 kV/cm) we can have 30 ph/el/cm

Therefore, with a 3 mm distant gap, we should be able to reduce the electron gain by a factor 10 and have a linear behavior;



Number of collisions per cm leading to dissociation of CF_4 into neutral fragments, as a function of the electric field.

arXiv:2004.10493v1 [physics.ins-det] 22 Apr 2020

First evidence of luminescence in a He/CF₄ gas mixture induced by non-ionizing electrons

E. Baracchini,^{a,b} L. Benussi,^c S. Bianco,^c C. Capocchia,^c M. Caponero,^{c,d} G. Cavoto,^{e,f} A. Cortez,^{a,b} I. A. Costa,^e E. Di Marco,^e G. D'Imperio,^e G. Dho,^{a,b} F. Iacoangeli,^e G. Maccarrone,^c M. Marafini,^{e,g} G. Mazzitelli,^c A. Messina,^{e,f} A. Orlandi,^c E. Paoletti,^c L. Passamonti,^c F. Petrucchi,^{h,i} D. Piccolo,^c D. Pierluigi,^c D. Pinci,^{e,i} F. Renga,^e F. Rosatelli,^c A. Russo,^c G. Saviano,^{e,j} and S. Tomassini^c

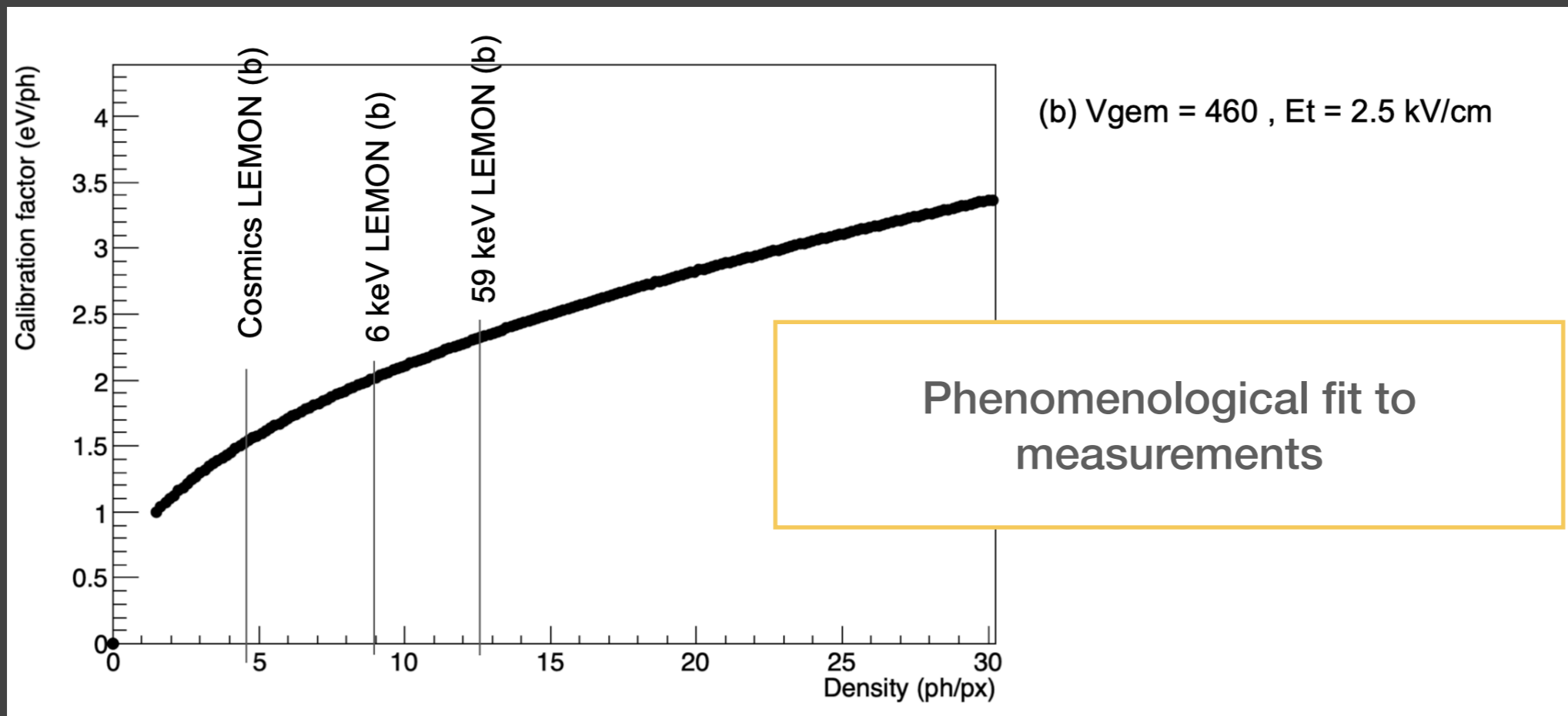
^aGran Sasso Science Institute, L'Aquila, I-67100, Italy
^bIstituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Gran Sasso, Assergi, Italy
^cIstituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, I-00044, Italy
^dENEA Centro Ricerche Frascati, Frascati, Italy
^eIstituto Nazionale di Fisica Nucleare, Sezione di Roma, I-00185, Italy
^fDipartimento di Fisica Sapienza Università di Roma, I-00185, Italy
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^hDipartimento di Matematica e Fisica, Università Roma TRE, Roma, Italy
ⁱIstituto Nazionale di Fisica Nucleare, Sezione di Roma TRE, Roma, Italy
^jDipartimento di Ingegneria Chimica, Materiali e Ambiente, Sapienza Università di Roma, Roma, Italy
 E-mail: davide.pinci@roma1.infn.it

ABSTRACT:
 Optical readout of Gas Electron Multipliers (GEM) provides very interesting performances and has been proposed for different applications in particle physics. In particular, thanks to its good efficiency in the keV energy range, it is being developed for low-energy and rare event studies, such as Dark Matter search. So far, the optical approach exploits the light produced during the avalanche processes in GEM channels.
 Further luminescence in the gas can be induced by electrons accelerated by a suitable electric field. The CYGNO collaboration studied this process with a combined use of a triple-GEM structure and a grid in an He/CF₄ (60/40) gas mixture at atmospheric pressure. Results reported in this paper allow to conclude that with an electric field of about 11 kV/cm a photon production mean free path of about 1.0 cm was found.

ⁱCorresponding author.

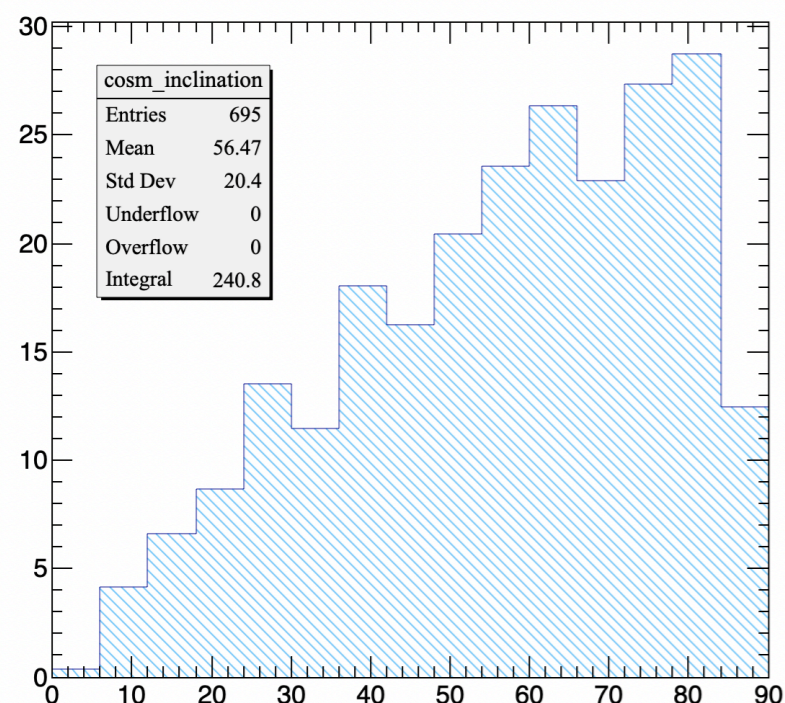
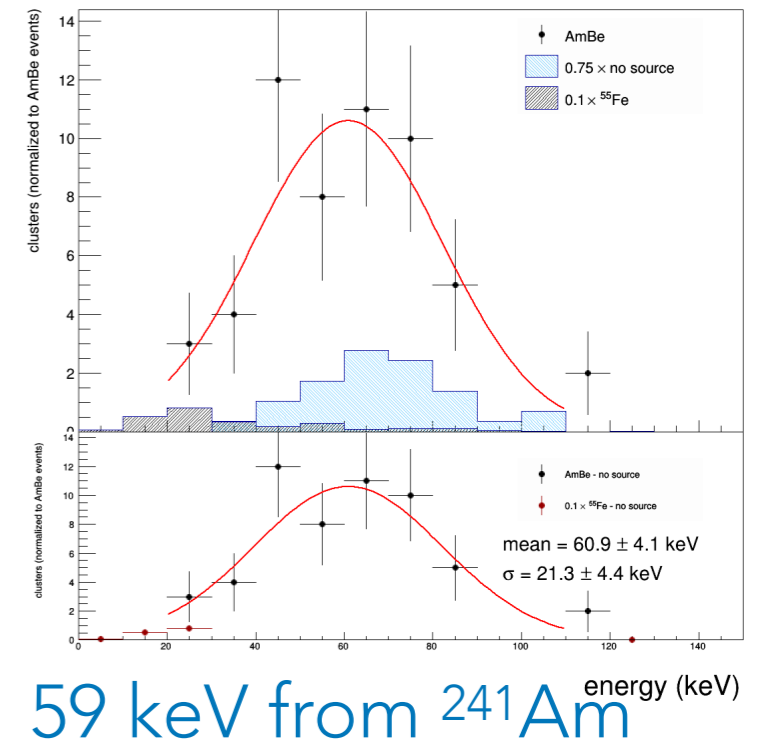
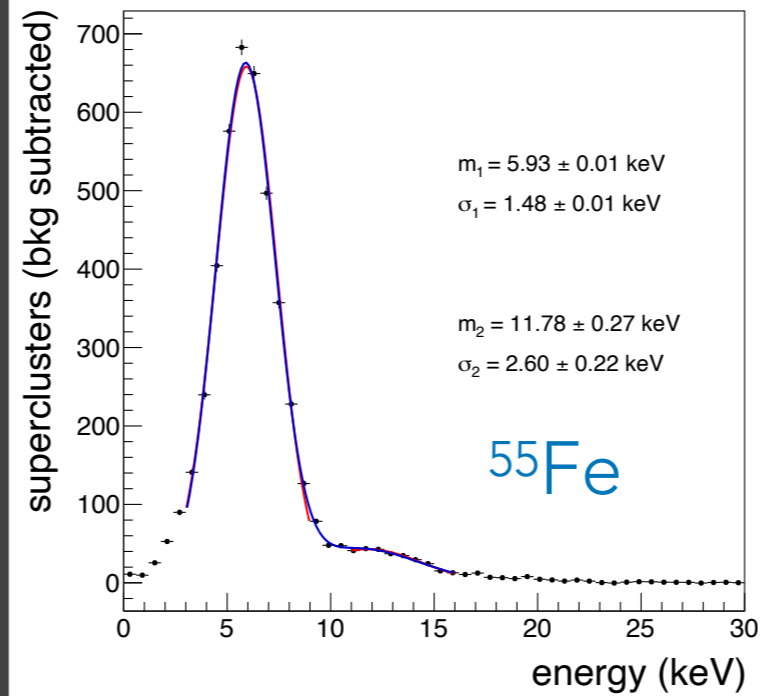
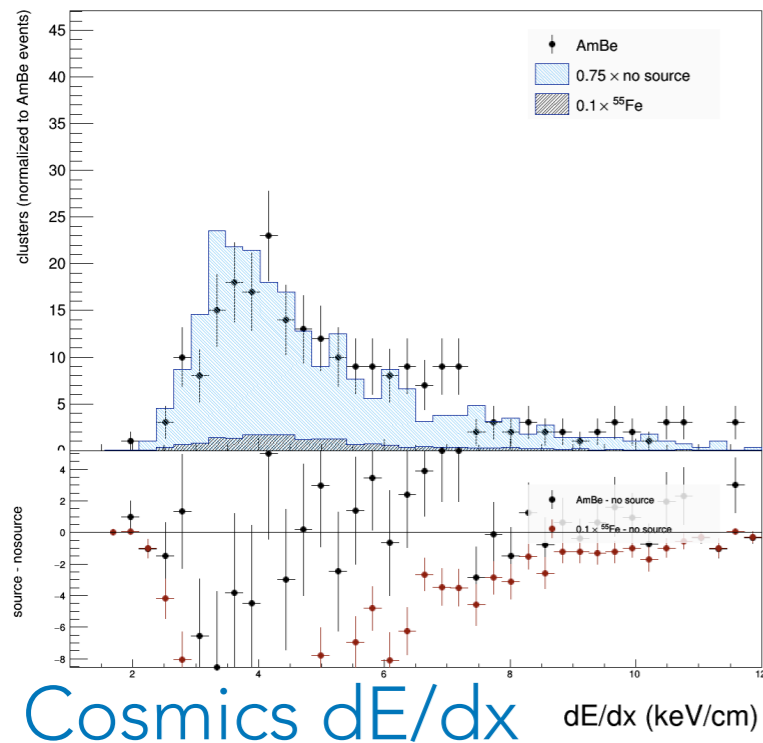
GAIN NON LINEARITY

The other method is a “software” compensation of the non linearity based on measurements



For the moment we tried to use a **running sensitivity constant** (eV/ph) dependent on the light density (ph/pixel) for an average correction of signal energy

GAIN NON LINEARITY



Once corrected by the average angle:
 $\text{mode}_{dE/dx} = 2.5$ keV/cm
 (instead of 2.3 keV/cm)

60.9 keV in good agreement with 59 keV expected

BACKGROUND REJECTION

To evaluate the background (electron recoils) rejection capability and the signal (nuclear recoils) efficiency, we tested LEMON with ^{55}Fe and AmBe sources.

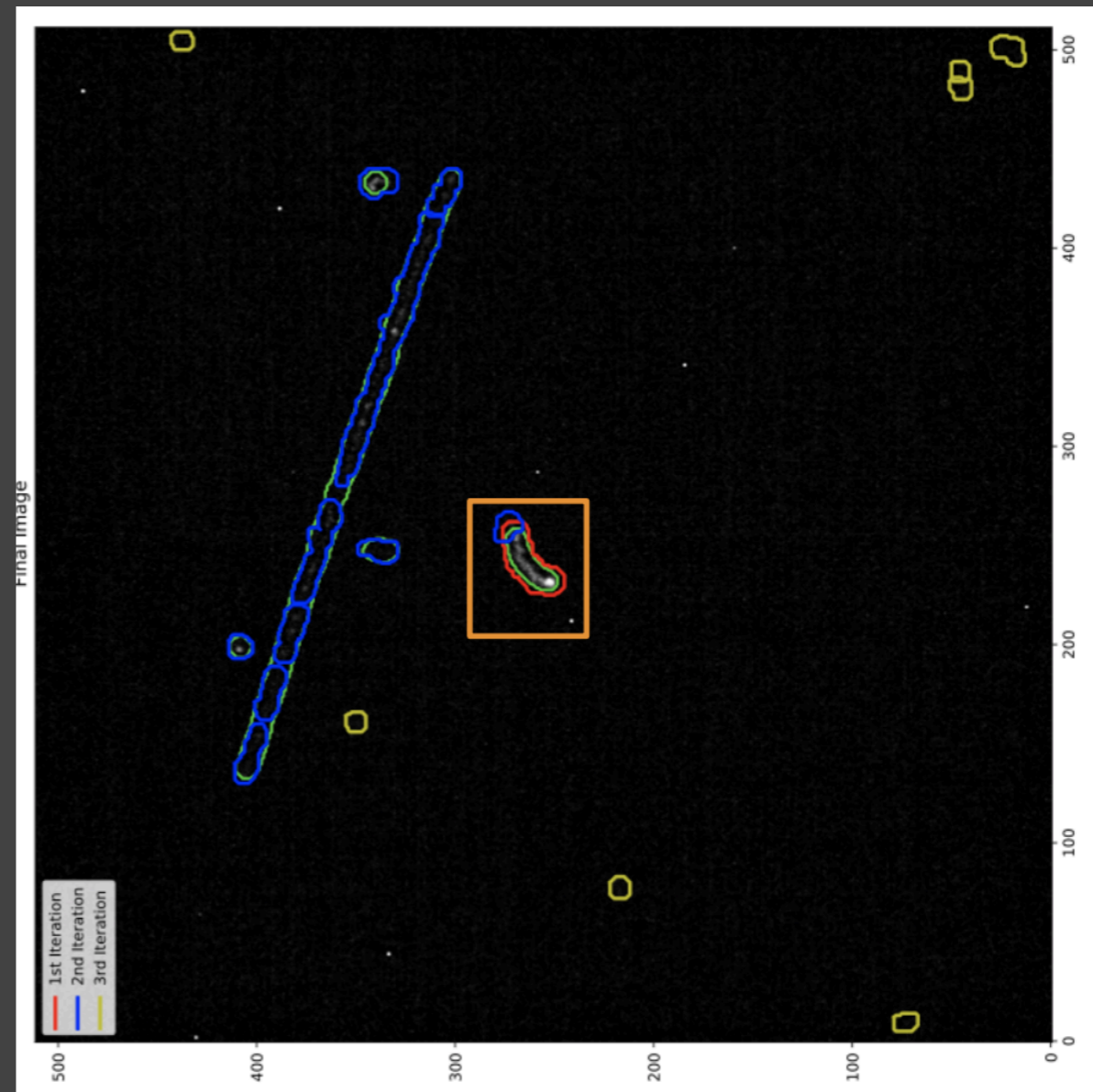
AmBe produces:

- 59 keV photons;
- 4 MeV photons;
- 1-10 MeV neutrons;

A 5 cm Pb shield was used

Unfortunately in all cases cosmics and natural radioactivity produce an unknown background that piles-up to signals.

Need to go underground.



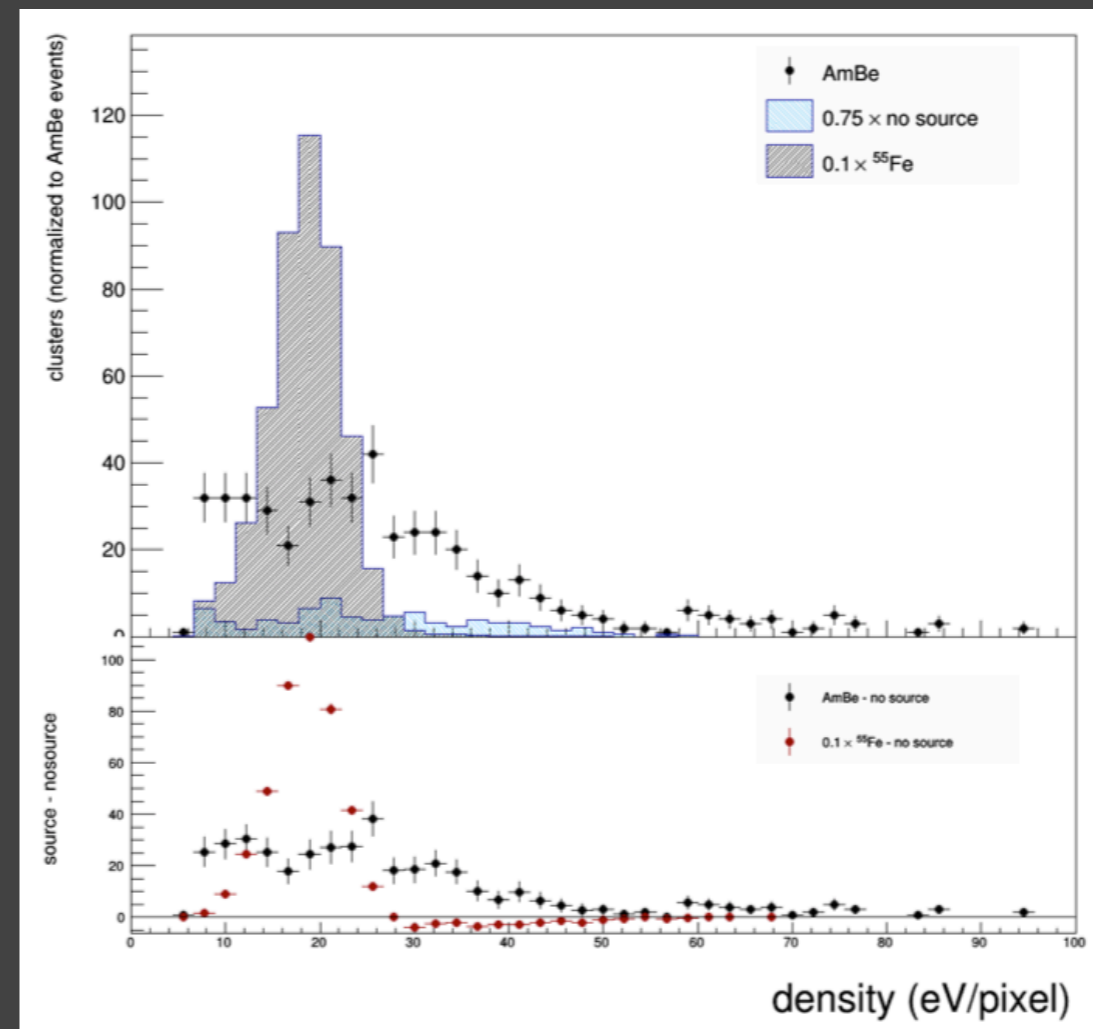
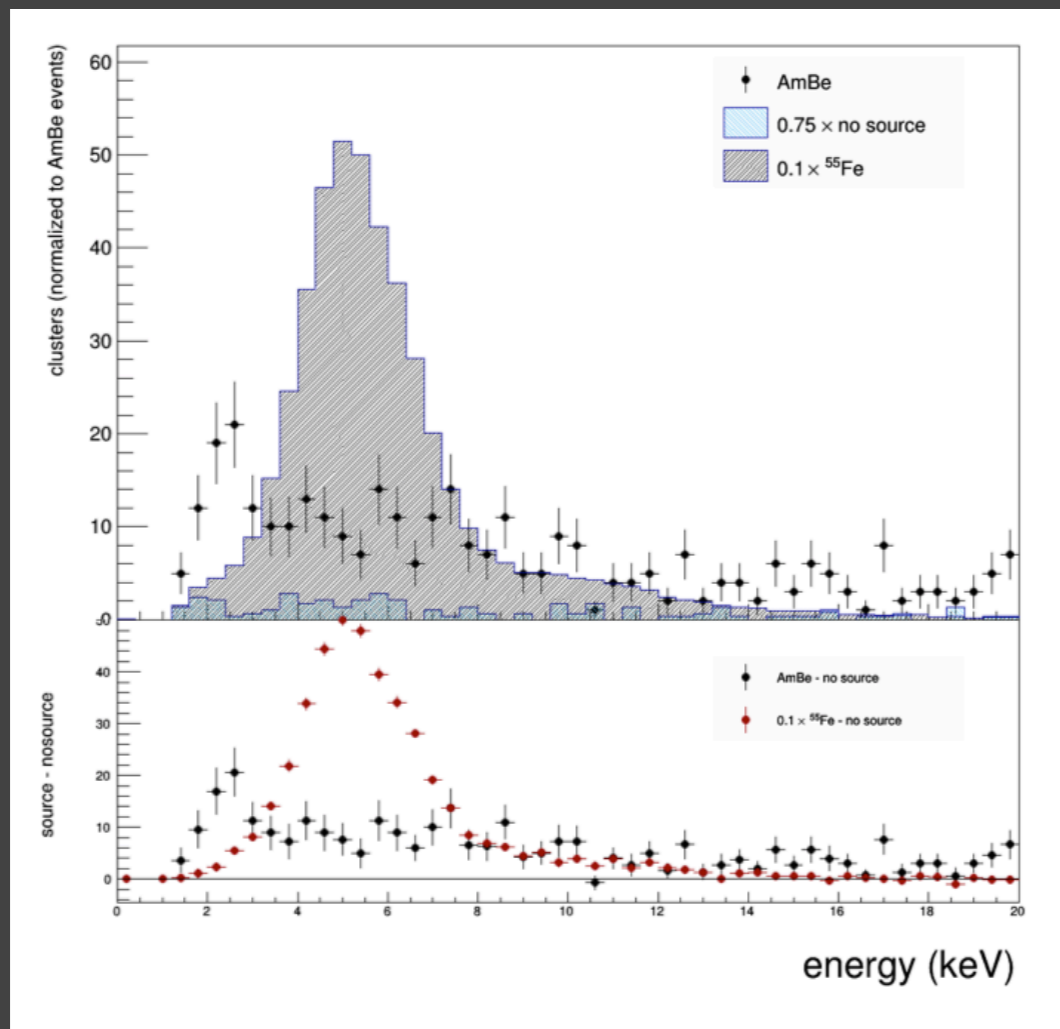
BACKGROUND REJECTION

In both cases, after energy re-calibration, a first event selection was applied:

- Field cage efficient region (geometry);
- Track length < 6 cm and slimness > 0.3 (remove cosmics);
- Density > 5 ph/pix (remove residual split cosmic tracks);
- 60 keV component removed;

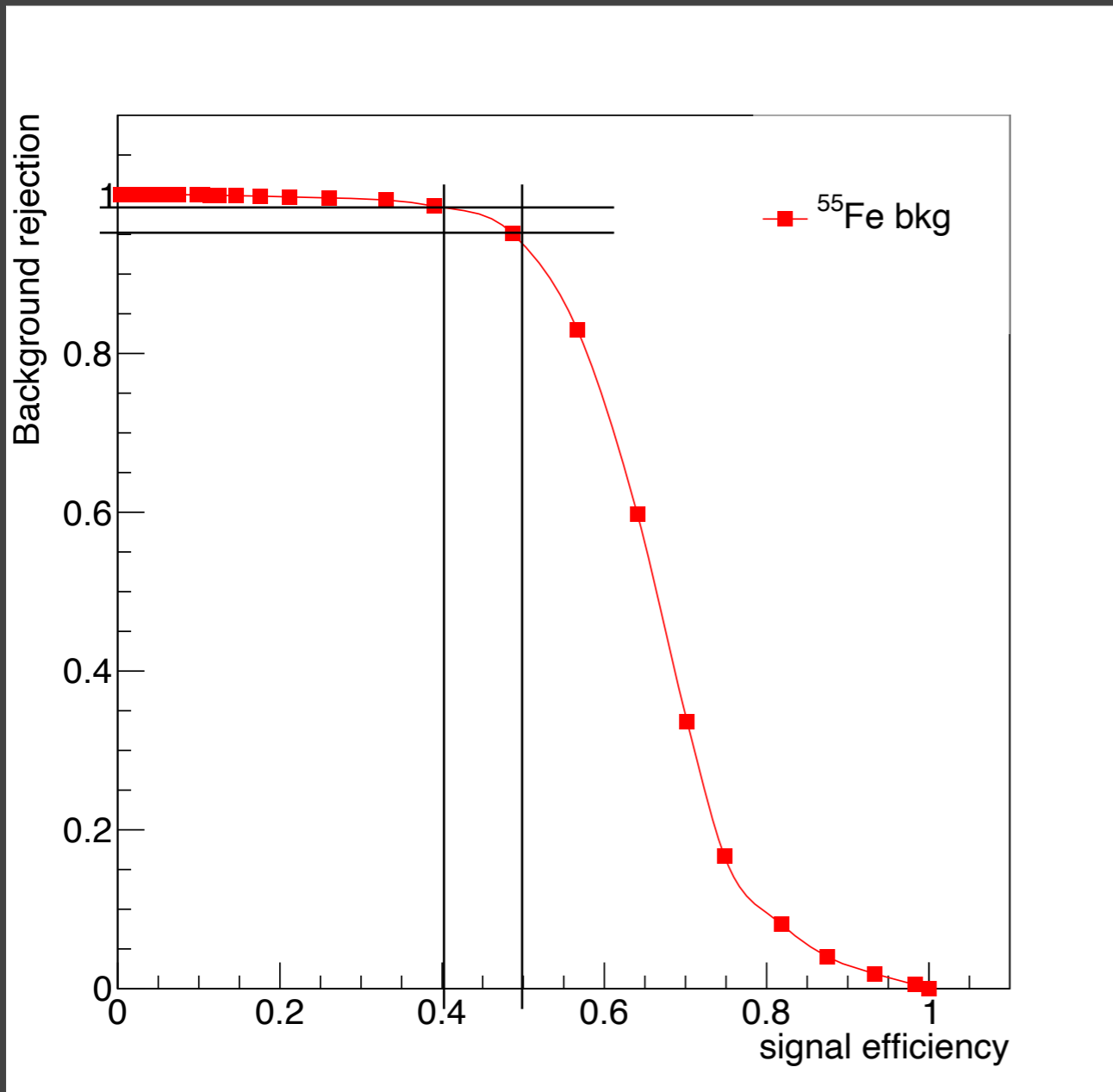
BACKGROUND REJECTION

We evaluated the distributions of re-calibrated energy and density for the selected samples



BACKGROUND REJECTION

Adding selection on the final variable (energy density):



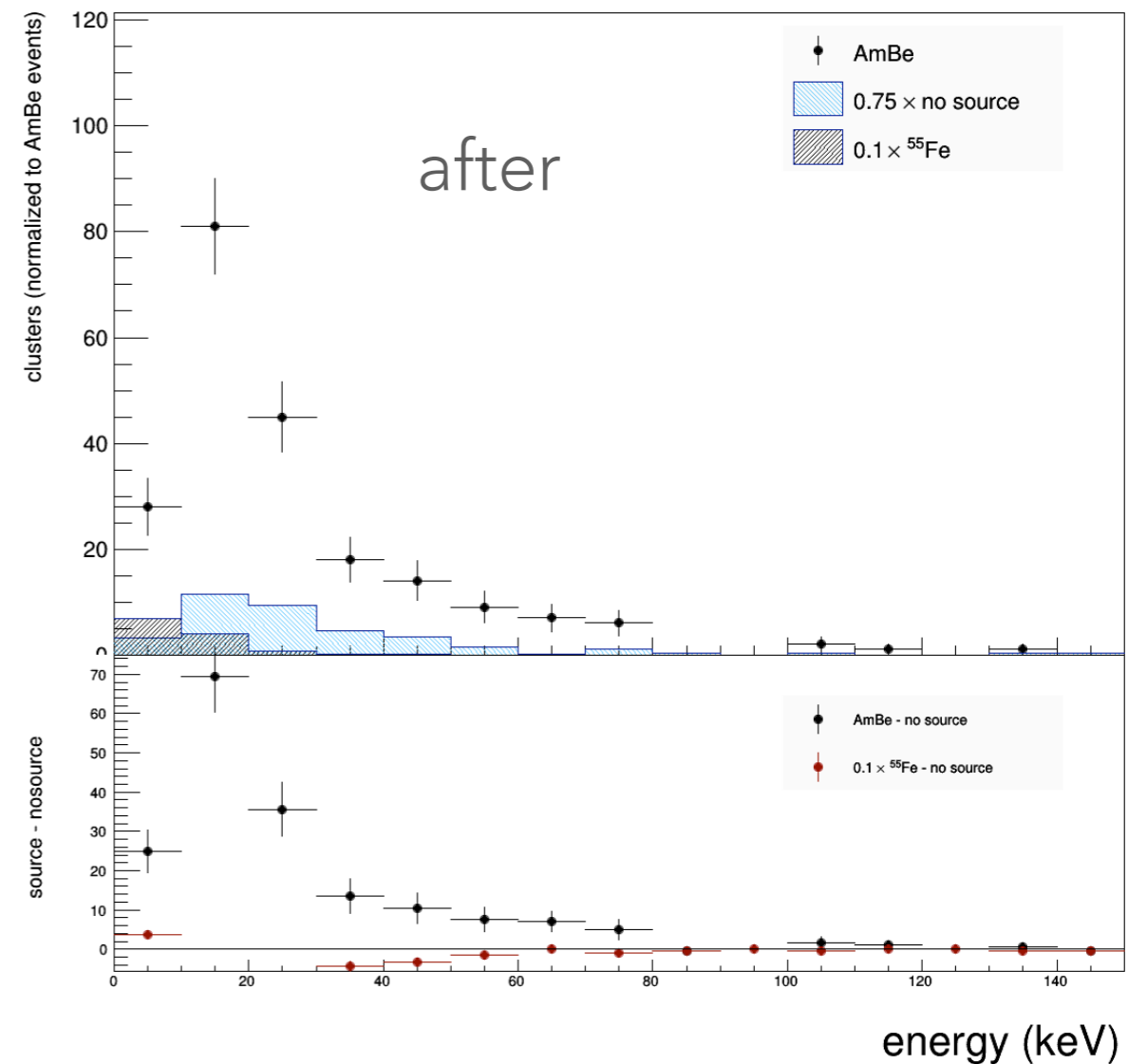
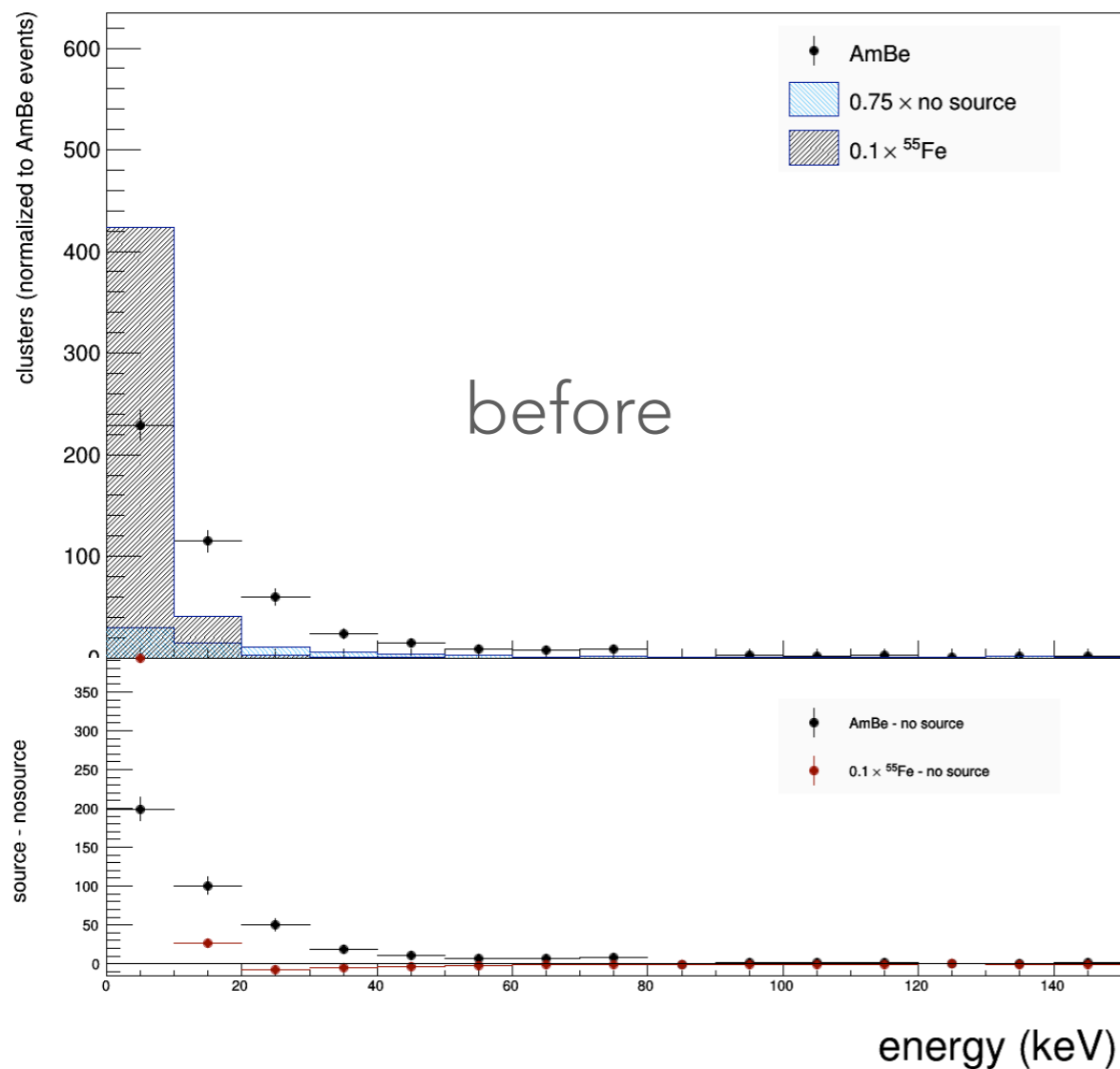
- $\text{eff}(S) \sim 50\% [40\%]$

- $\text{eff}(B) \sim 0.88 * 0.05 [0.012] \sim 4\% [1\%]$

Background suppression of 10^{-2}
together with a signal efficiency of 40%

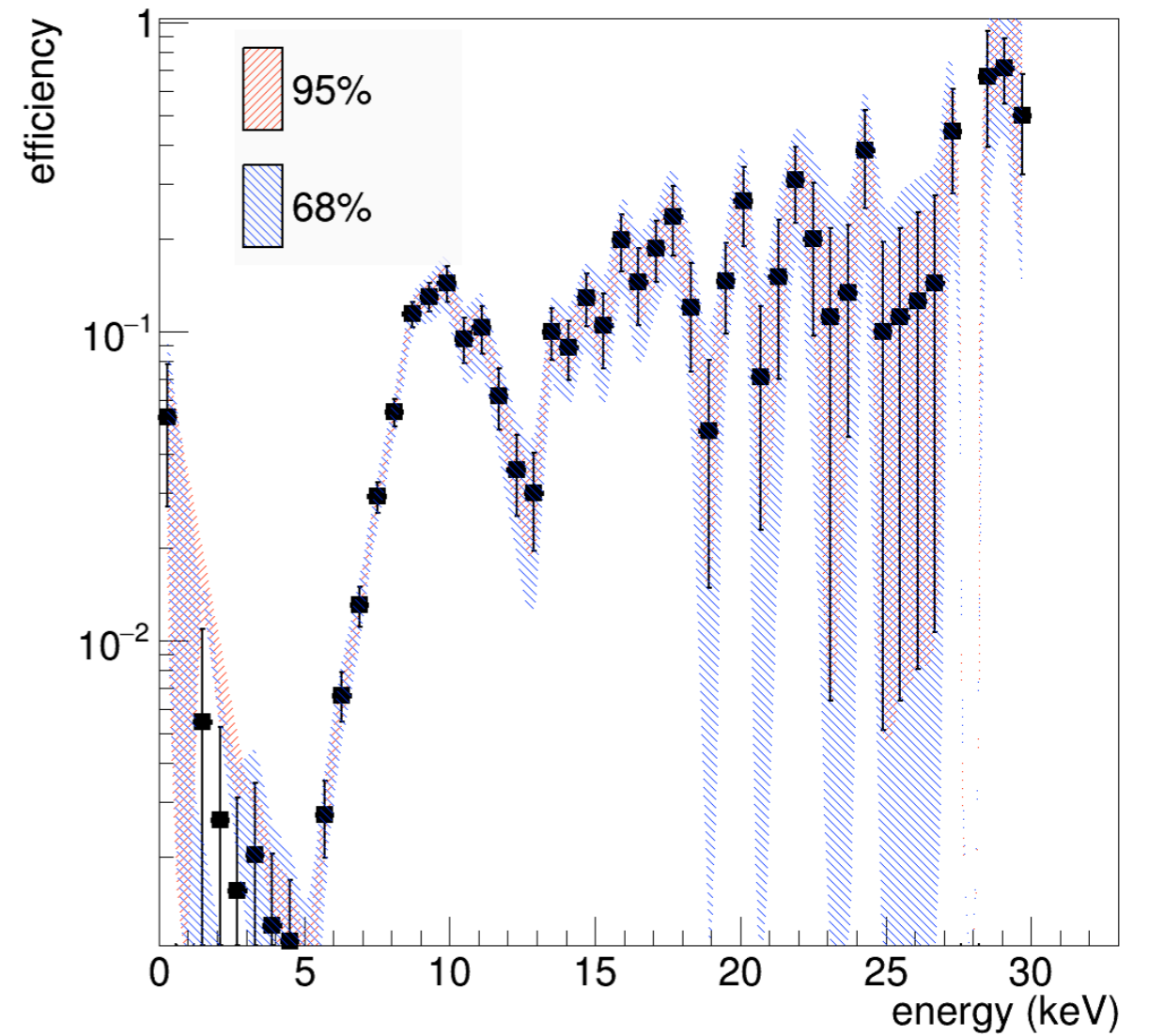
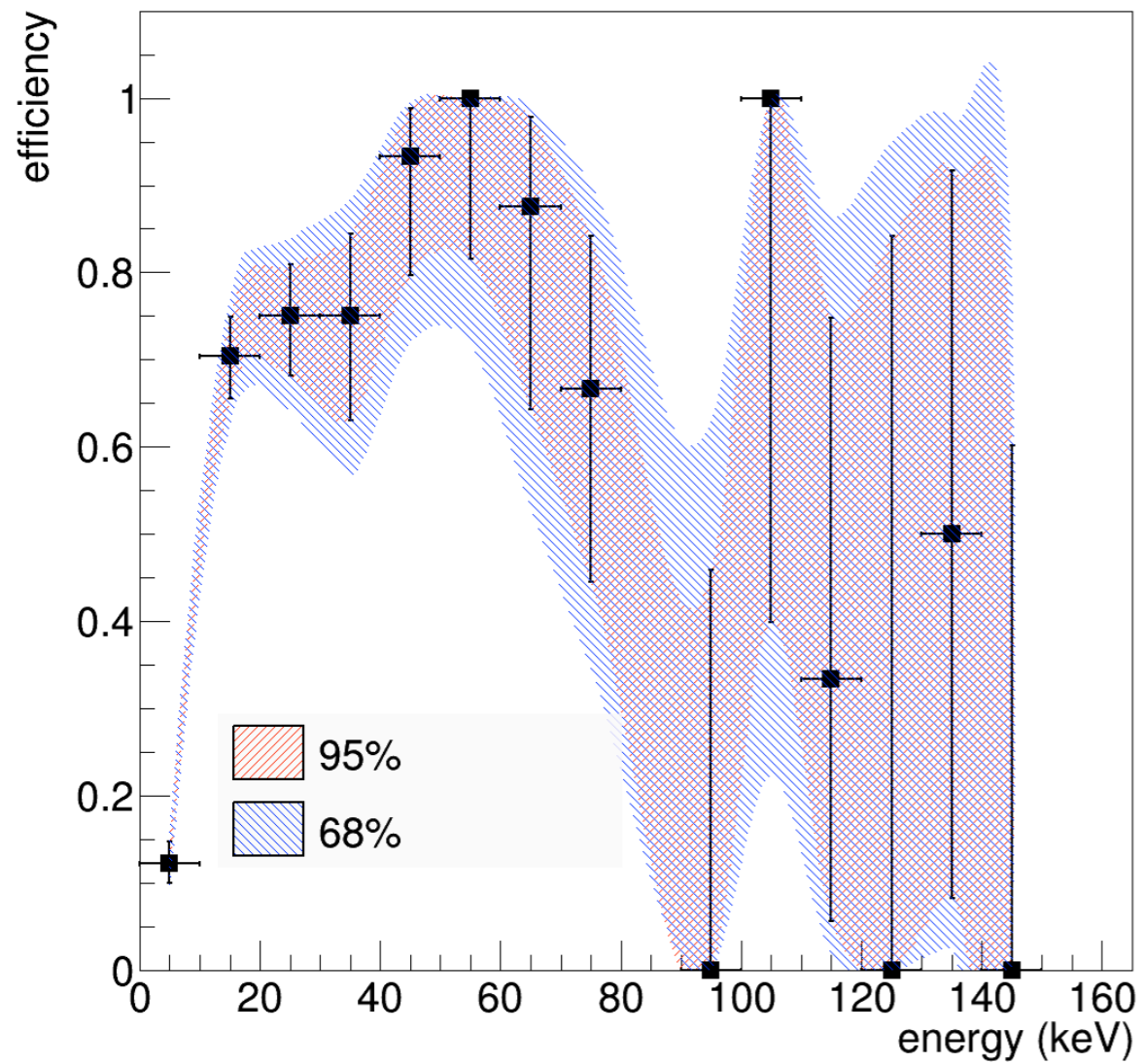
SIGNAL EFFICIENCY

Comparing the signal spectra and after the cuts:



SIGNAL EFFICIENCY

Comparing the signal spectra and after the cuts:



SITUATION AT LNGS

We had a meeting with LNGS
Director in November.

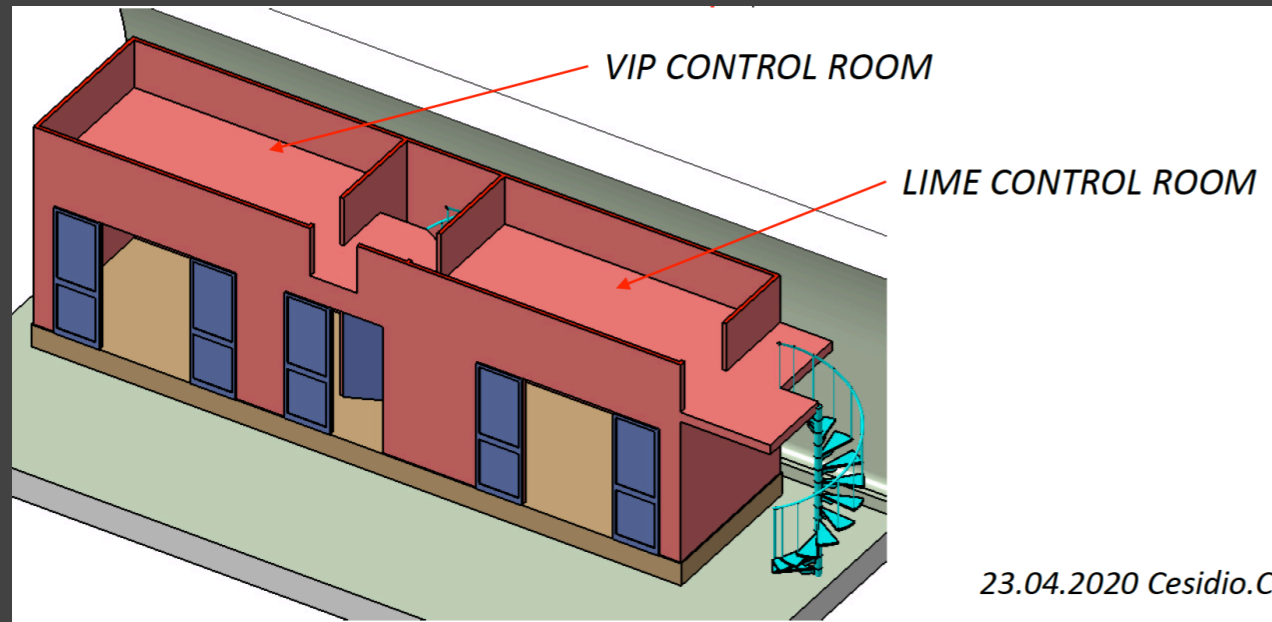
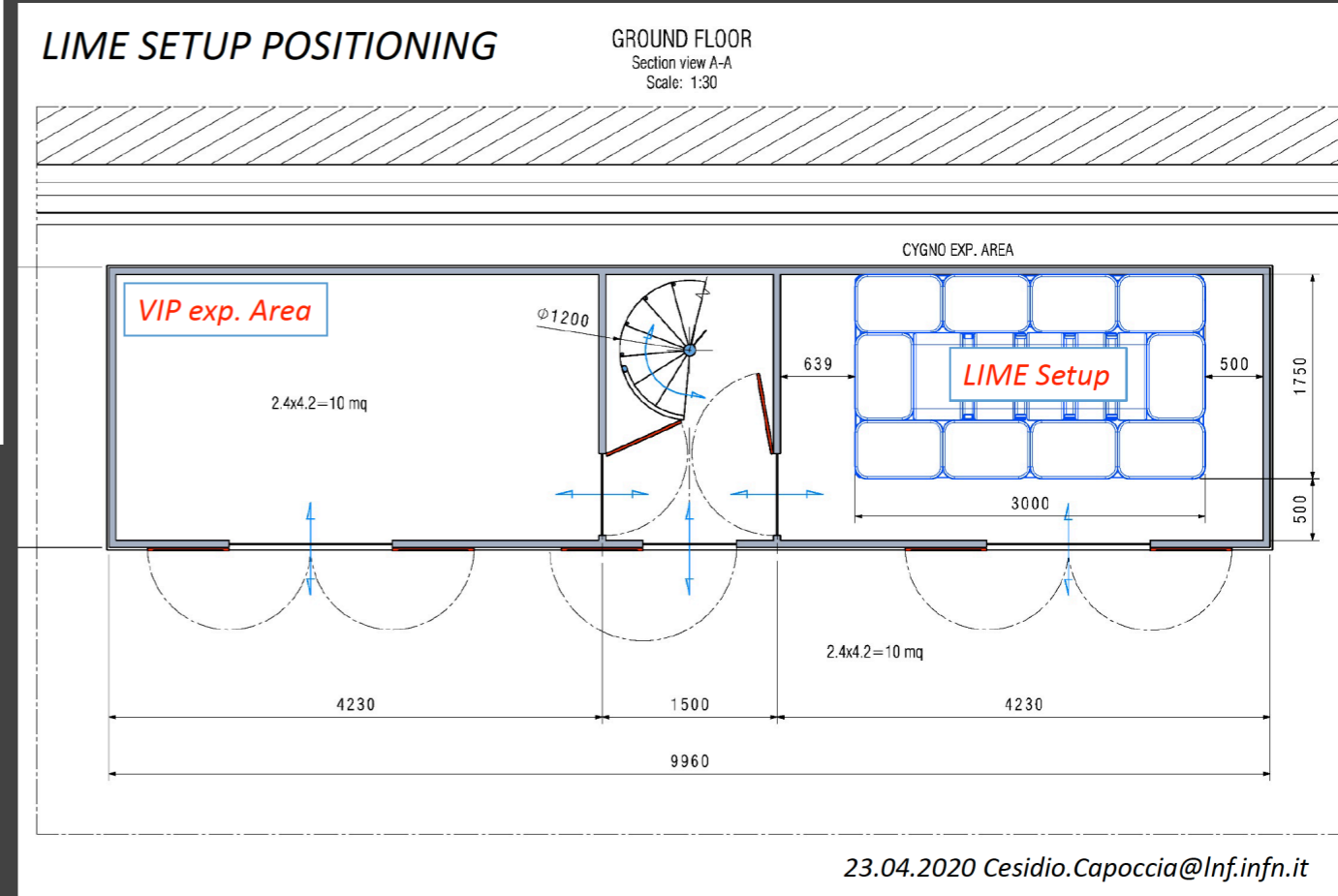
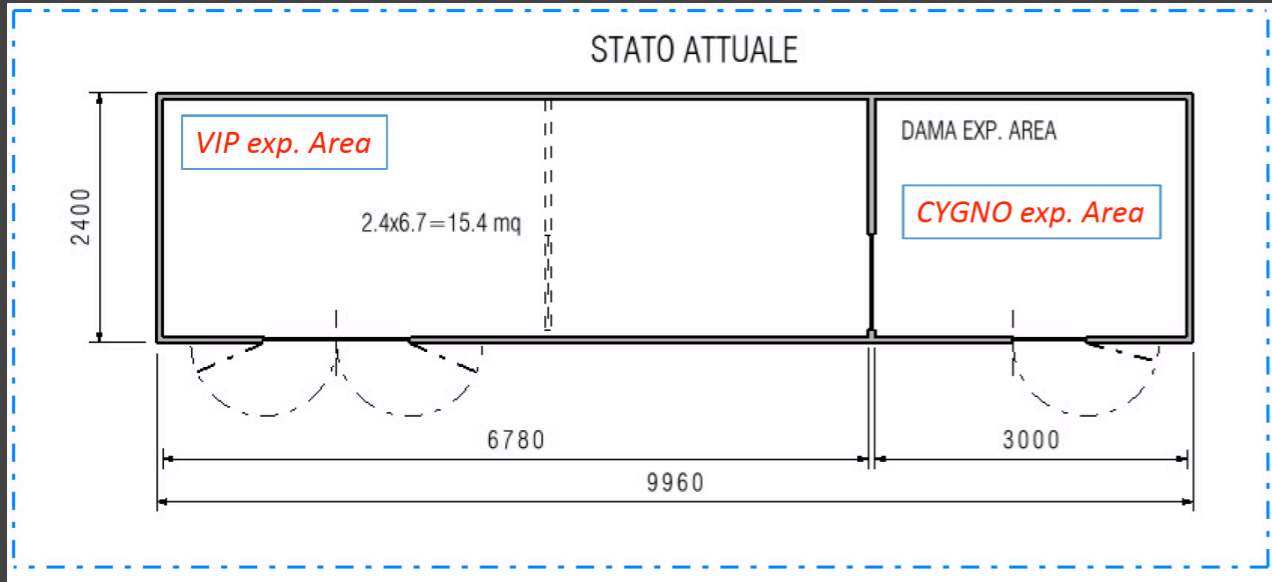


Beginning of February,
we made an inspection
to Lab proposed for
LIME

We can easily fit LIME
and test shieldings

It's hard to foresee the
future of the organisation
of room at LNGS

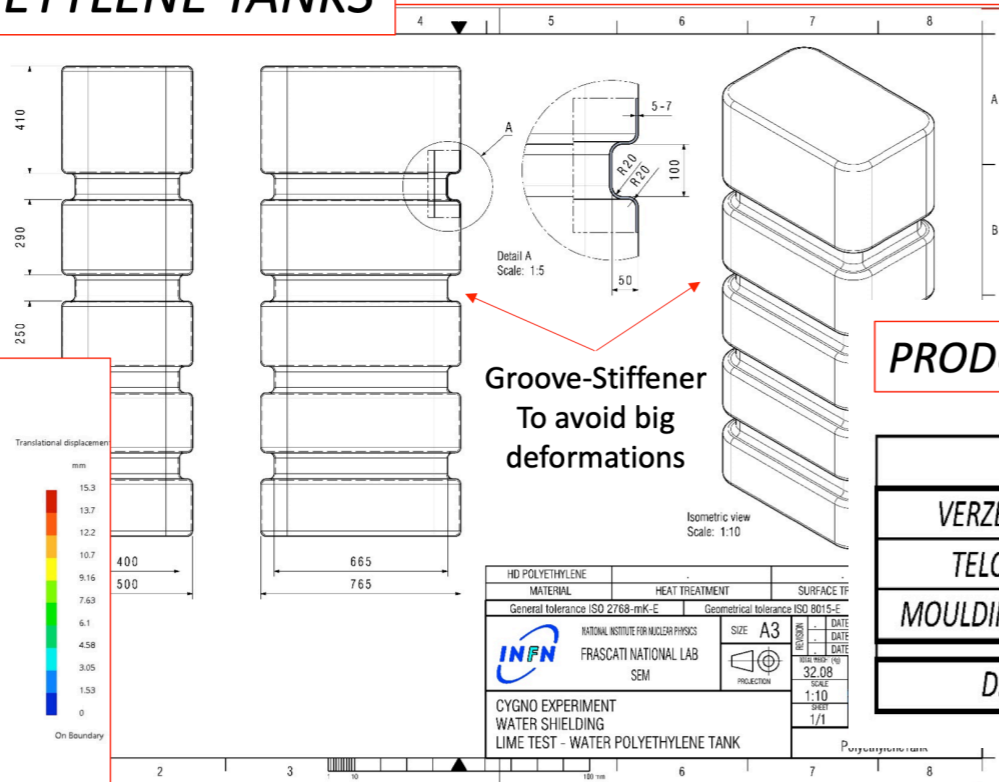
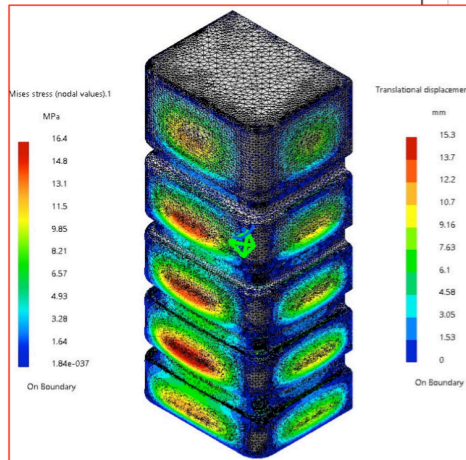
SITE INSPECTION



LIME SHIELD

CUSTOM POLYETHYLENE TANKS

The exercise has been done in order to evaluate costs & setup aspect using custom polyethylene tanks instead of the British tanks (Baseline setup)



23.04.2020 Cesidioi.Capoccia@Inf.infn.it

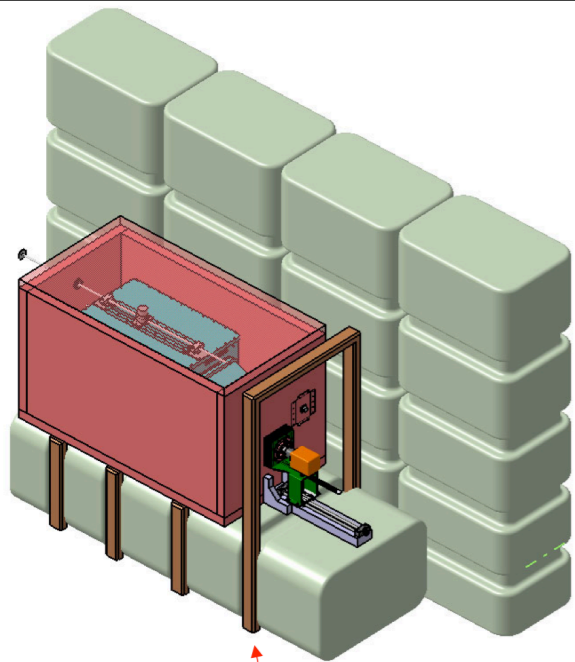
We are investigating the possibility of building custom tanks

PRODUCTION COSTS

	MOLD-TOOLING	DRAW-DOCUM	ROT. MOULDING	N.TANK	TOTAL
VERZELLES SRL	Refused to carry out an evaluation due to the low quantity				
TELCOM SPA	€ 42,500.00	€ 3,000.00	€ 260.00	12	€ 48,620.00
MOULDING SERV. SRL	€ 15,900.00	€ 1,200.00	€ 235.00	12	€ 19,920.00
Diff (%)	267%	250%	111%		244%

- LIME shield would cost 20 k€, 16 k€ of "tooling" and 250 €/tank
- this would significantly reduce the cost of CYGNO shield

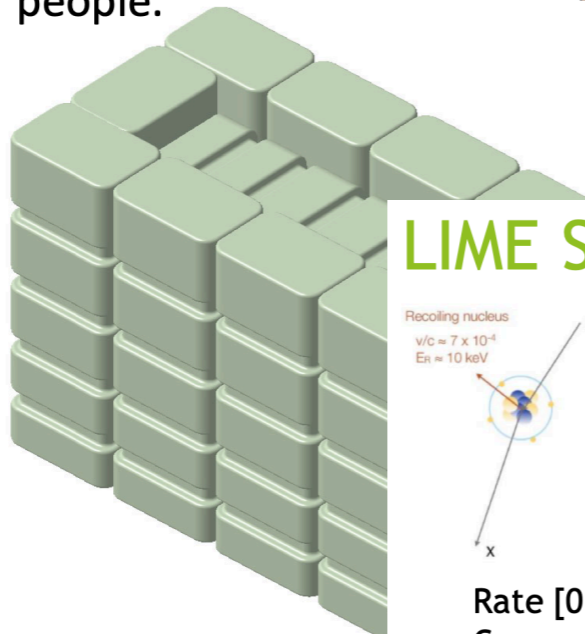
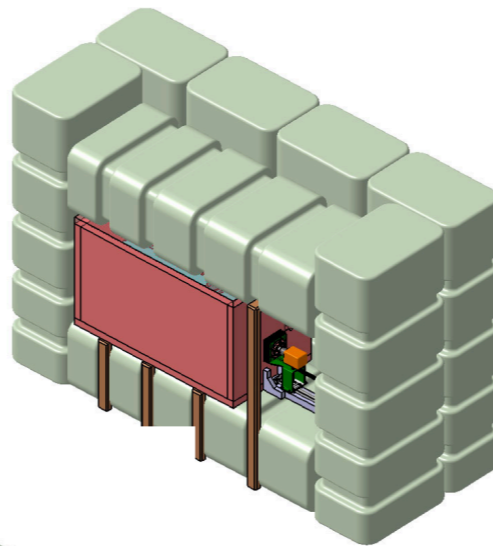
LIME SHIELD



COPPER SUPPORT-LEGS
IN THE TANK-GROOVE

INSTALLATION

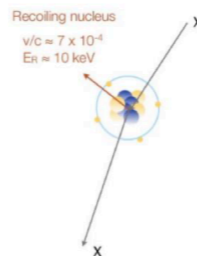
Note: the weight of each empty tank is about 50Kg. the handling can be done by two people.



We started studying 50 cm water + 5 cm copper shield

23.04.2020 Cesidioi.Capoccia@Inf.infn.it

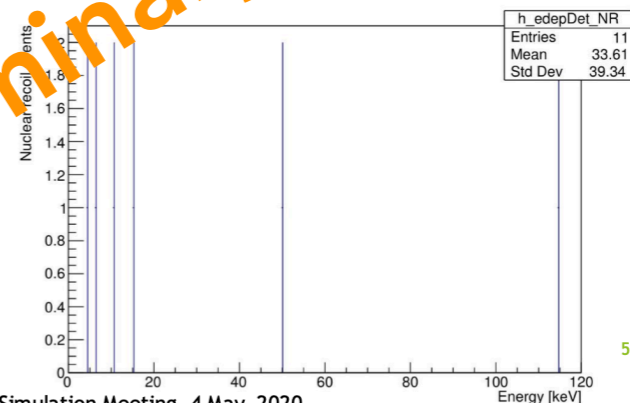
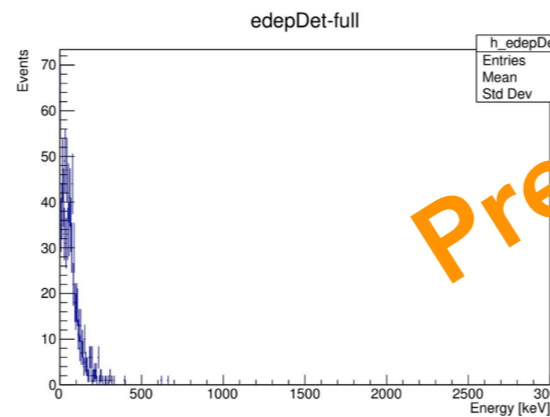
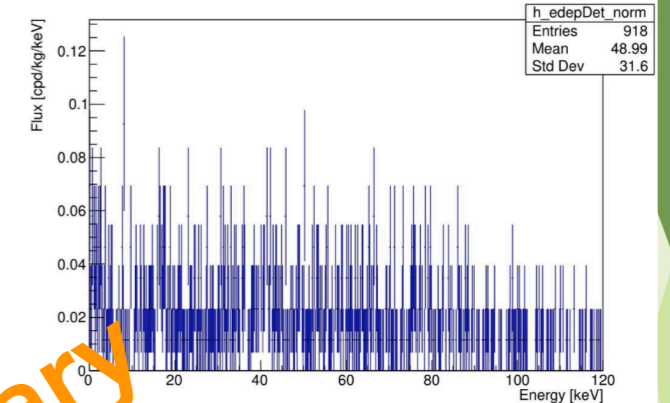
LIME Simulation Results - Neutron Background



Shielding - 50 cm water plus 5 cm Cu

- 5000M events generated
- Consistent with previous work

Rate [0-20] keV = 0.052448 cpd/kg/keV
Corresponds to about 27 cts/yr in LIME



Preliminary

CYGNO Simulation Meeting, 4 May, 2020

PAPERS AND WORKSHOPS

Two papers submitted

Two papers under internal review

A GEM-based Optically Readout Time Projection Chamber for charged particle tracking

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¹*Istituto Nazionale di Fisica Nucleare Sezione di Roma, I-00185, Italy*
²*Gran Sasso Science Institute L'Aquila, I-67100, Italy*
³*Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati, I-00040, Italy*
^a*Universidade Federal de Juiz de Fora, Juiz de Fora, MG, 36000-000, Brazil*
^b*Dipartimento di Matematica e Fisica, Università Roma TRE, Roma, I-00146, Italy*

(Dated: 6 May 2020)

The Time Projection Chamber (TPC) is an ideal candidate to track particles in a wide range of energies. Large volume TPCs can be readout with a suitable number of channels offering a complete 3D reconstruction of the charged particle tracks and of their released energy allowing the identification of their mass. Moreover, He-based TPCs are very promising to study keV energy particles, opening the possibility for directional searches of Dark Matter (DM) and the study of Solar Neutrinos (SN). On the other hand, in order to reach a keV energy threshold, a large number of channels is required to obtain a high granularity, that could be expensive and hard to manage. A small prototype (named LEMOn) to test and validate an innovative read-out technique is described here. It is based on the amplification of the ionization in Micro Pattern Gas Detector (MPGD) producing visible light collected by a sub-millimeter position resolution sCMOS (scientific CMOS) camera. This type of readout - in conjunction with a fast light detection - allows a 3D reconstruction of the tracks, a sensitivity to the track direction and a very promising particle identification capability useful to distinguish DM nuclear recoils from a γ -induced background.

Large Time Projection Chambers (TPC) have various applications in high energy physics and nuclear physics. These detectors are among the best in offering good charged particle energy resolution and to allow the identification of the particle's mass. This can be obtained along with a very good performance in tracking the particle's trajectory with competitive spatial resolution. The study of such a technology for ultra-rare events searches as the directional search of Dark Matter¹⁻³ (DM) and the detection of neutrinos coming from the Sun (SN)^{4,5} is currently being pursued by several groups, which are part of the CYGNUS⁶ international network⁷.

A longer term project for tens of m³ volume TPC requires the construction of 1 m³ demonstrators. In this paper we describe the performance of a smaller 7 litres prototype (named LEMOn) in tracking ultra-relativistic electrons. LEMOn is based on Micro Pattern Gaseous Detectors (MPGD), namely a large triple Gas Electron Mul-

tiplier (GEM)⁸, optically read-out by means of a low noise and high granularity sCMOS sensor^{9,10}. Many smaller scale prototypes have been tested so far showing promising results to design the CYGNUS 1 m³ demonstrator to be constructed in 2020-2021 and to be hosted at the INFN National Laboratory of Gran Sasso (LNGS). In a later phase, a 30-100 m³ detector is foreseen, as a brick of a world distributed observatory for DM and SN within the CYGNUS international network.

1. INTRODUCTION

The purpose of the current R&D phase is to assess the performance of a relatively large TPC based on the drift of the ionization electrons within a He-based gas mixture operated at atmospheric pressure and equipped with a high granularity and high sensitivity optical readout of GEMs. In this respect the test of the LEMOn prototype with ultra-relativistic electrons presented here is meant to study the capability of the optically readout TPC to detect and to reconstruct within the TPC drift region the positions of clusters with few ionization electrons each. The pattern of contiguous clusters represents the "track" of the ultra-relativistic electron trajectory and are exploited to identify it, demonstrating that LEMOn would also be an excellent beam monitoring device.

In absence of a reference time for the events, electron drift time can not be exploited to extract information about their depth inside the detector. In this paper, we study a method to measure the longitudinal position of an ionizing particle in the TPC drift volume based on the electron diffusion and there-

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First evidence of luminescence in a He/CF₄ gas mixture induced by non-ionizing electrons

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ABSTRACT:

Optical readout of Gas Electron Multipliers (GEM) provides very interesting performances and has been proposed for different applications in particle physics. In particular, thanks to its good efficiency in the keV energy range, it is being developed for low-energy and rare event studies, such as Dark Matter search. So far, the optical approach exploits the light produced during the avalanche processes in GEM channels.

Further luminescence in the gas can be induced by electrons accelerated by a suitable electric field. The CYGNUS collaboration studied this process with a combined use of a triple-GEM structure and a grid in an He/CF₄ (60/40) gas mixture at atmospheric pressure. Results reported in this paper allow to conclude that with an electric field of about 11 kV/cm a photon production mean free path of about 1.0 cm was found.

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A density-based clustering algorithm for the CYGNO data analysis

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ABSTRACT: Time Projection Chambers (TPCs) working in combination with Gas Electron Multipliers (GEMs) produces a very sensitive detector capable of detecting low energy events by capturing photons generated during the GEM electron multiplication process by means of a high-resolution photo camera. The CYGNO Experiment has recently developed a TPC-Triple GEM detector coupled to a low noise and high spatial resolution CMOS sensor. For the image analysis, an algorithm based on an adapted version of the well-known DBSCAN was implemented. In this paper a description of the CYGNO's DBSCAN-based algorithm will be given, including test and validation of its parameters, and a comparison with a widely used algorithm known as Nearest Neighbor Clustering (NNC). The results will show that the adapted version of DBSCAN is capable of providing full signal detection efficiency and very good energy resolution while improving the detector background rejection.

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Stability and detection performance of a GEM-based Optical Readout TPC with He/CF₄ based gas mixtures

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ABSTRACT: The performance and long term stability of an optically readout Time Projection Chambers with an electron amplification structure based on three Gas Electron Multipliers was studied. He/CF₄ based gas mixtures were used in two different proportions (60/40 and 70/30) in a CYGNO prototype with 7 litre sensitive volume. With electrical configurations providing very similar electron gains, an almost full detection efficiency in the whole detector volume was found with both mixtures, while a light yields almost 20% larger for the 60/40 was found. The electrostatic stability was tested by monitoring voltages and currents for 25 days. The detector worked in very stable and safe condition for the whole period. Anyway, in the presence of less CF₄, a larger probability of unstable events was clearly detected.

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We proposed 3 talks to RD51 workshop in June (on-line only)