



in synergy with erc

**INTIUM**

funded from ERC in Horizon 2020  
program (grant agreement 818744)



# The CYGNO experiment: a gaseous optically readout TPC for rare events studies

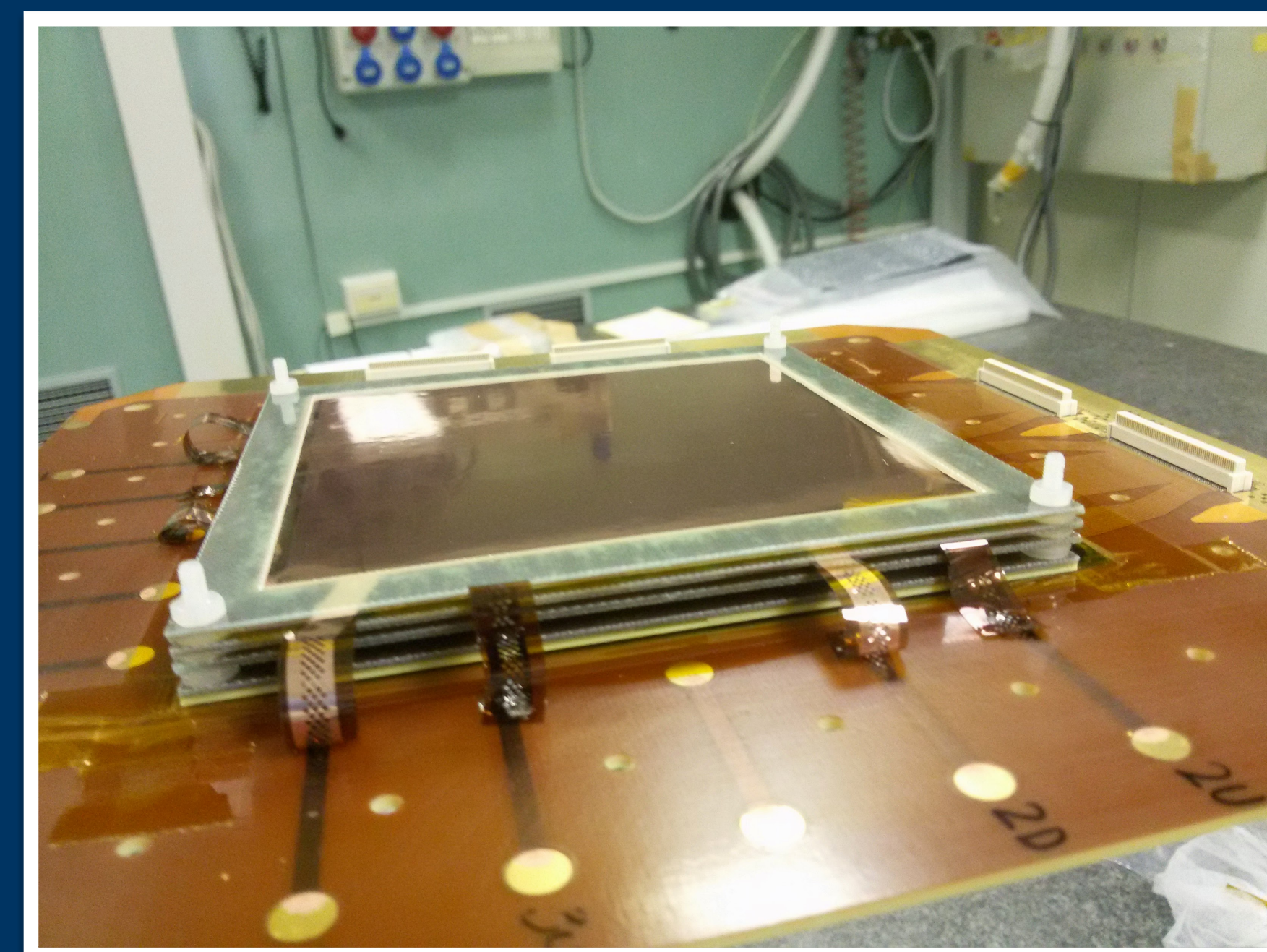
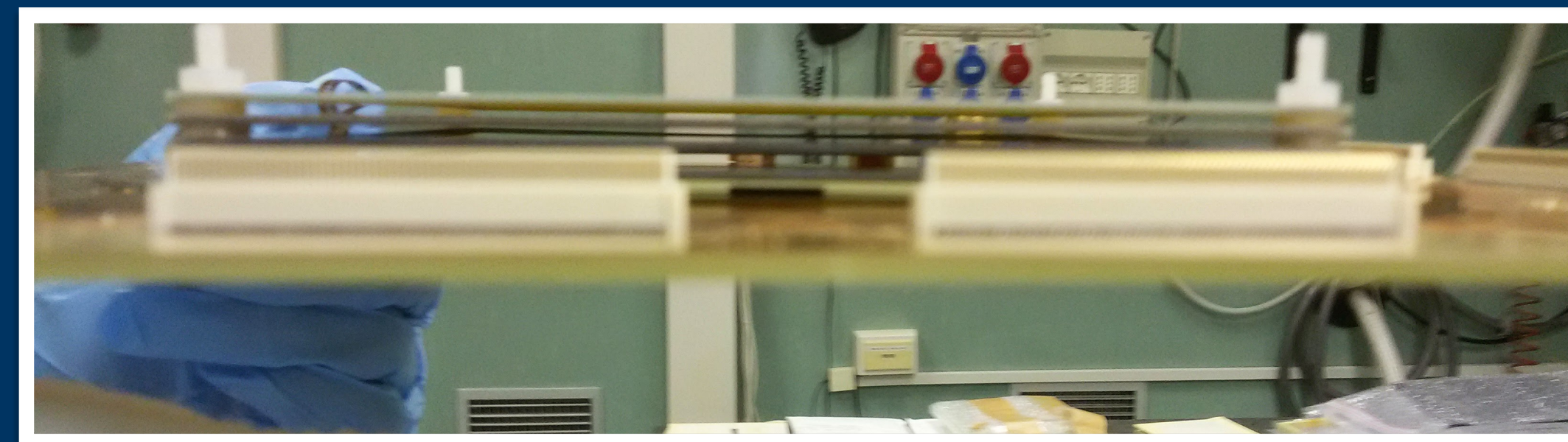
F. D. Amaro, E. Baracchini, L. Benussi, S. Bianco, C. Capocchia, M. Caponero, G. Cavoto, A. Cortez, R. J. de Cruz Roque, I. A. Costa, E. Dané, E. Di Marco, G. D'Imperio, G. Dho, F. Di Giambattista, R. R. M. Gregorio, F. Iacoangeli, H. P. Lima Júnior, G. Maccarrone, R. D. P. Mano, M. Marafini, G. Mazzitelli, 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





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, has now almost **50 collaborators**, from **8 Institutions in 4 Countries**



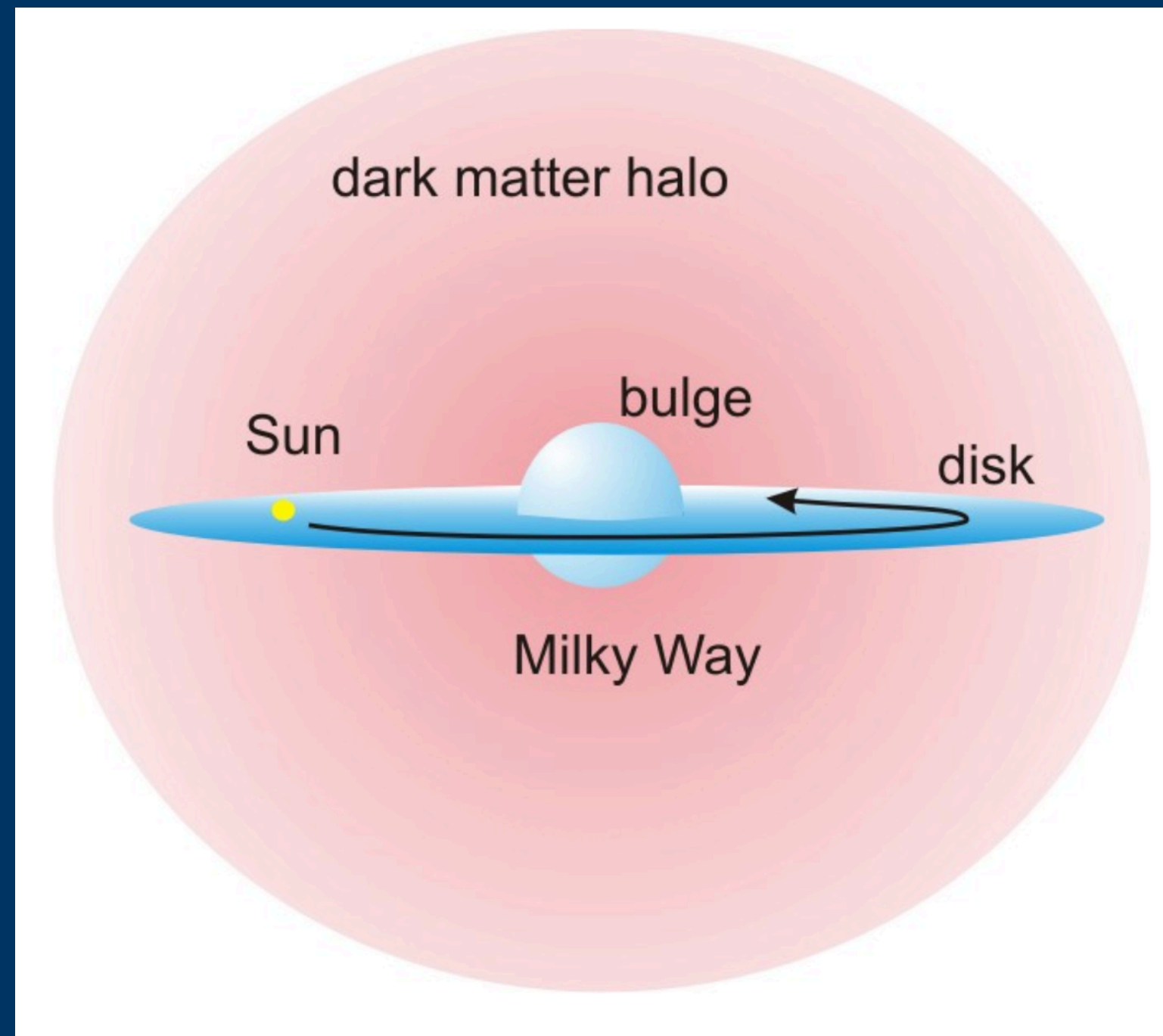
Istituto Nazionale di Fisica Nucleare





# DARK MATTER AND WIMPS

One of possible constituents of **Dark Matter** are the **Weakly Interacting Massive Particles**: neutral particles with a very low interaction probability with ordinary matter;



Our **Milky Way**, is surrounded by an approximately spherical **not luminous halo** of **WIMPs**.

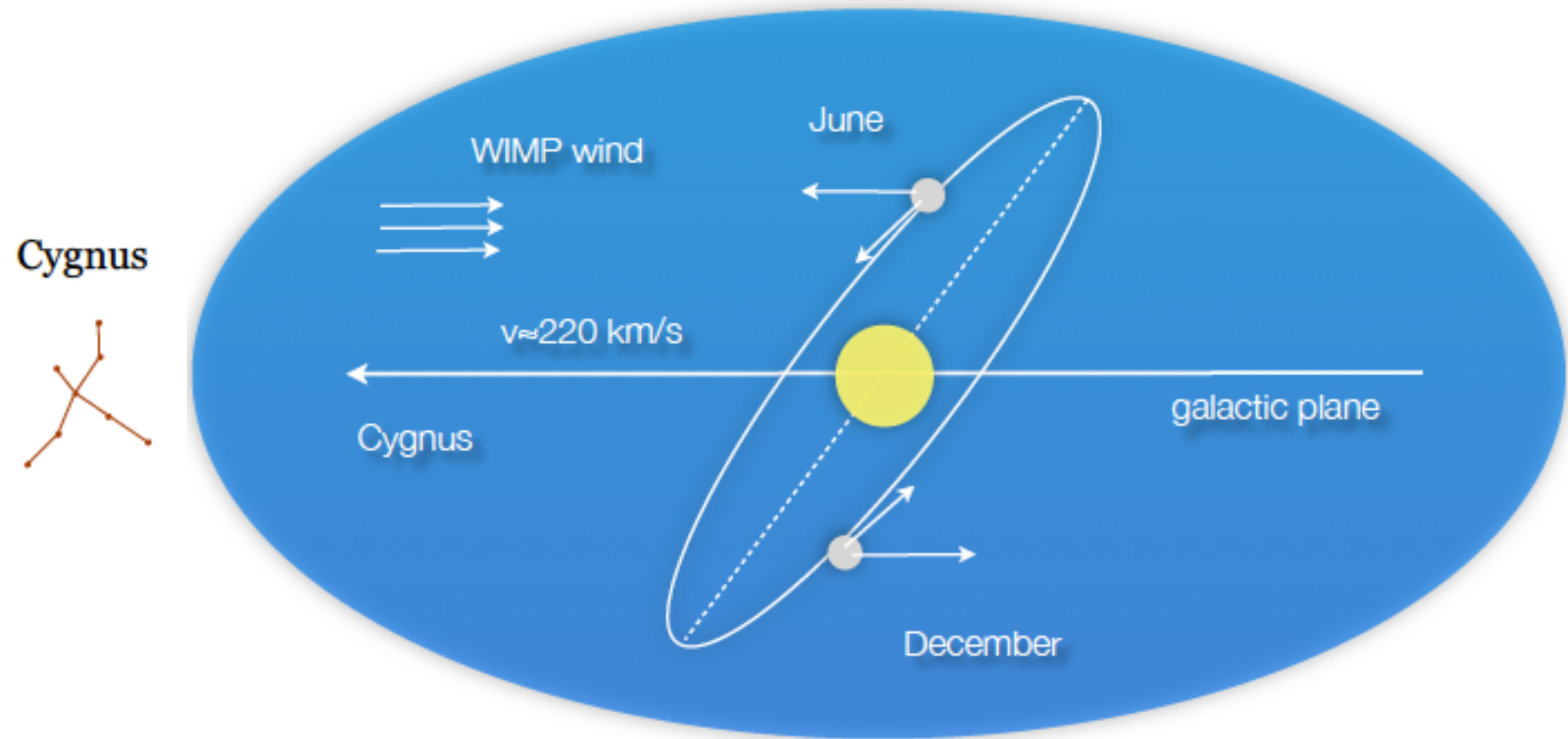
The Sun and the planets move through this halo at **220 km/s** preceded by the **CYGNUS**



WIMPs have a **Maxwell-Boltzmann-like** velocity distribution with **tail up to 600 km/s**  $\beta = 2 \cdot 10^{-3}$



# TIME MODULATION



$$v(t)_{DM} = v_{sun} + v_{orb} \cos \gamma \cos(\omega(t - t_0))$$

**Daily** based **modulation** of incoming particle direction

At a  $40^\circ$  latitude, direction is expected to oscillate between **vertical** and **horizontal** with a 12 h period

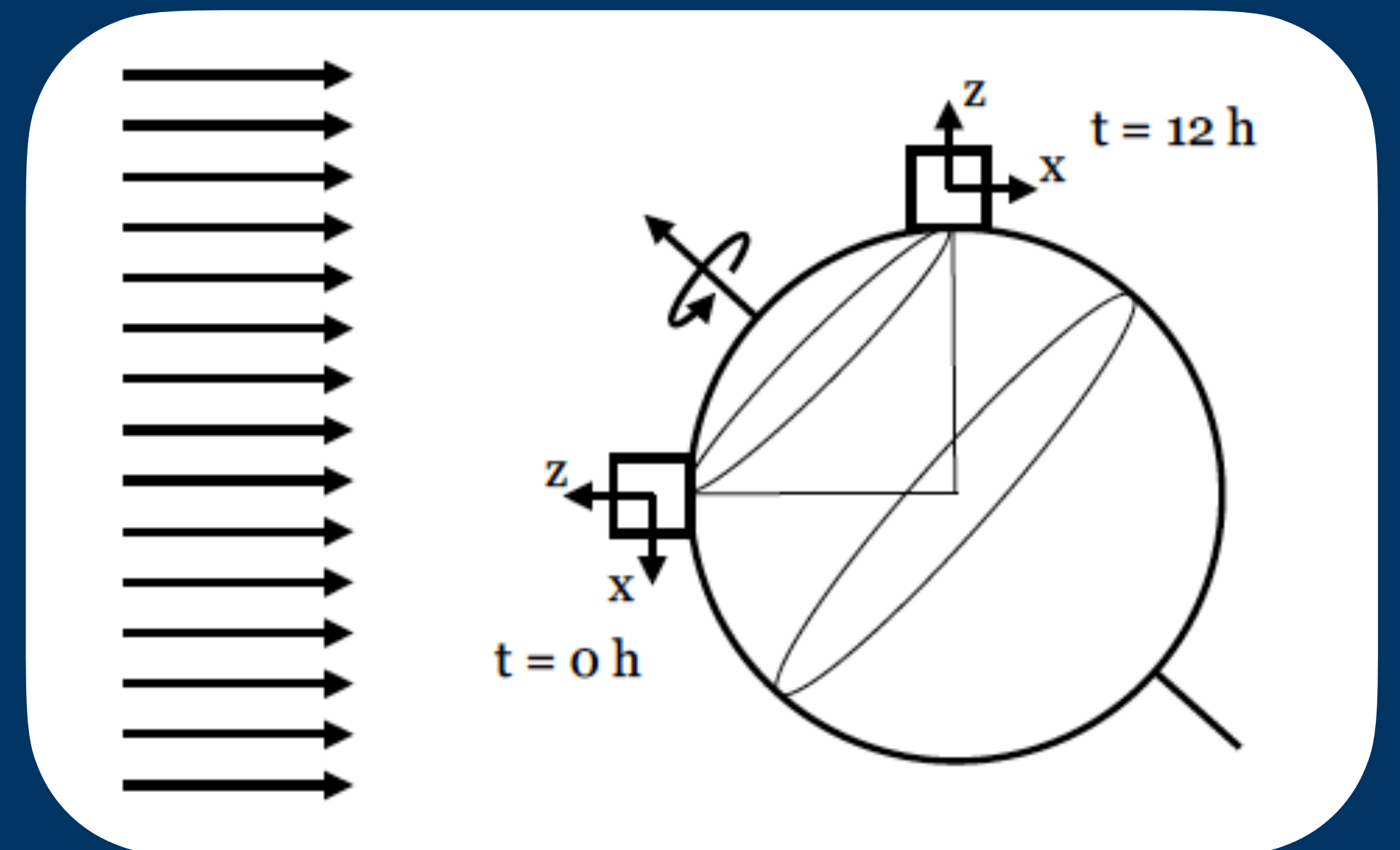
$$v_{sun} = 230 \text{ km/s}$$

$$v_{orb} = 30 \text{ km/s}$$

$$\gamma = 60^\circ$$

**Asymmetry** "forward-backward": 20%-100%

**Annual rate modulation**: 2%-10%

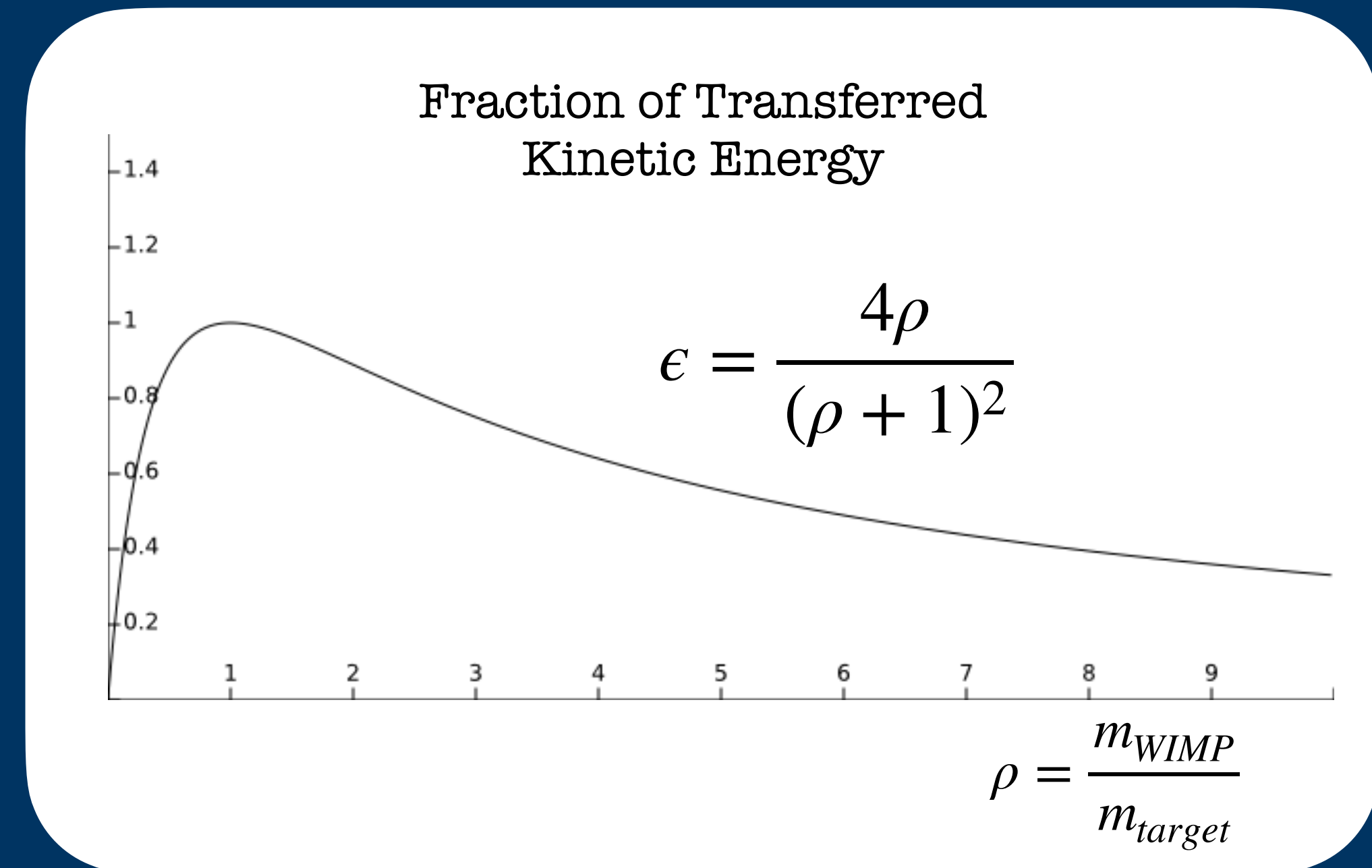
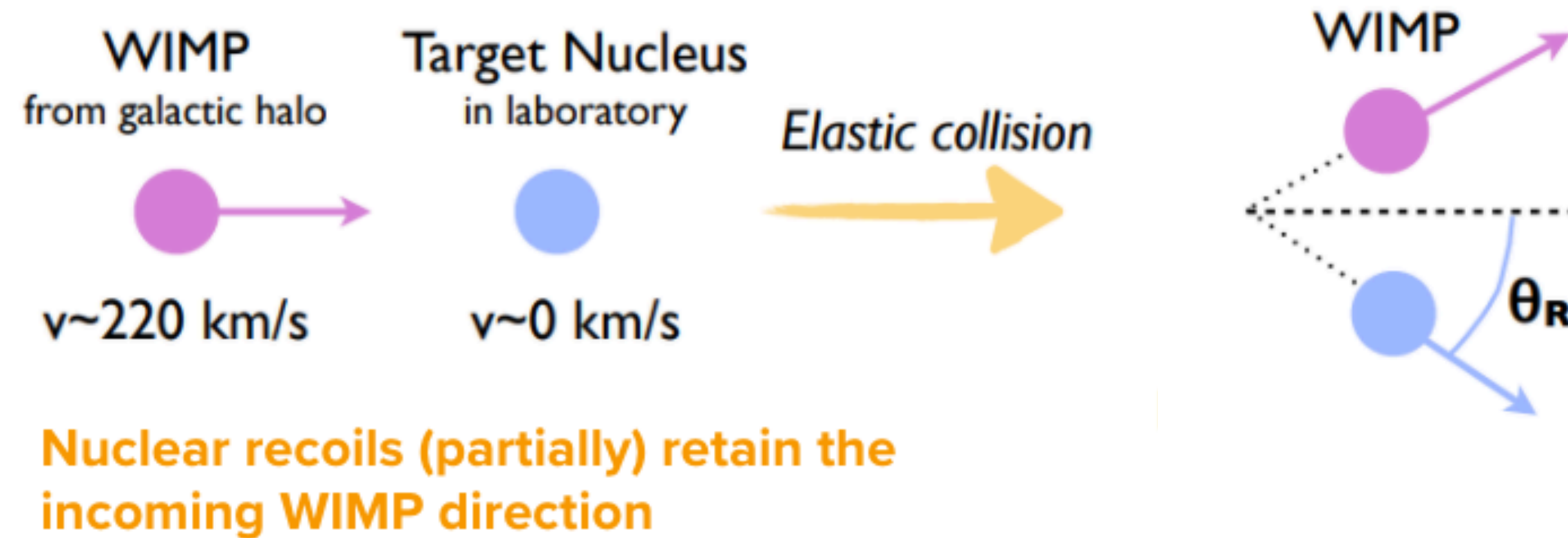


**Strong and unique signature**



# WIMPS AND HOW TO DETECT THEM

- One possibility is trying to detect the products of its **interactions with ordinary matter**, in particular with **charged particles** that we know how to detect;

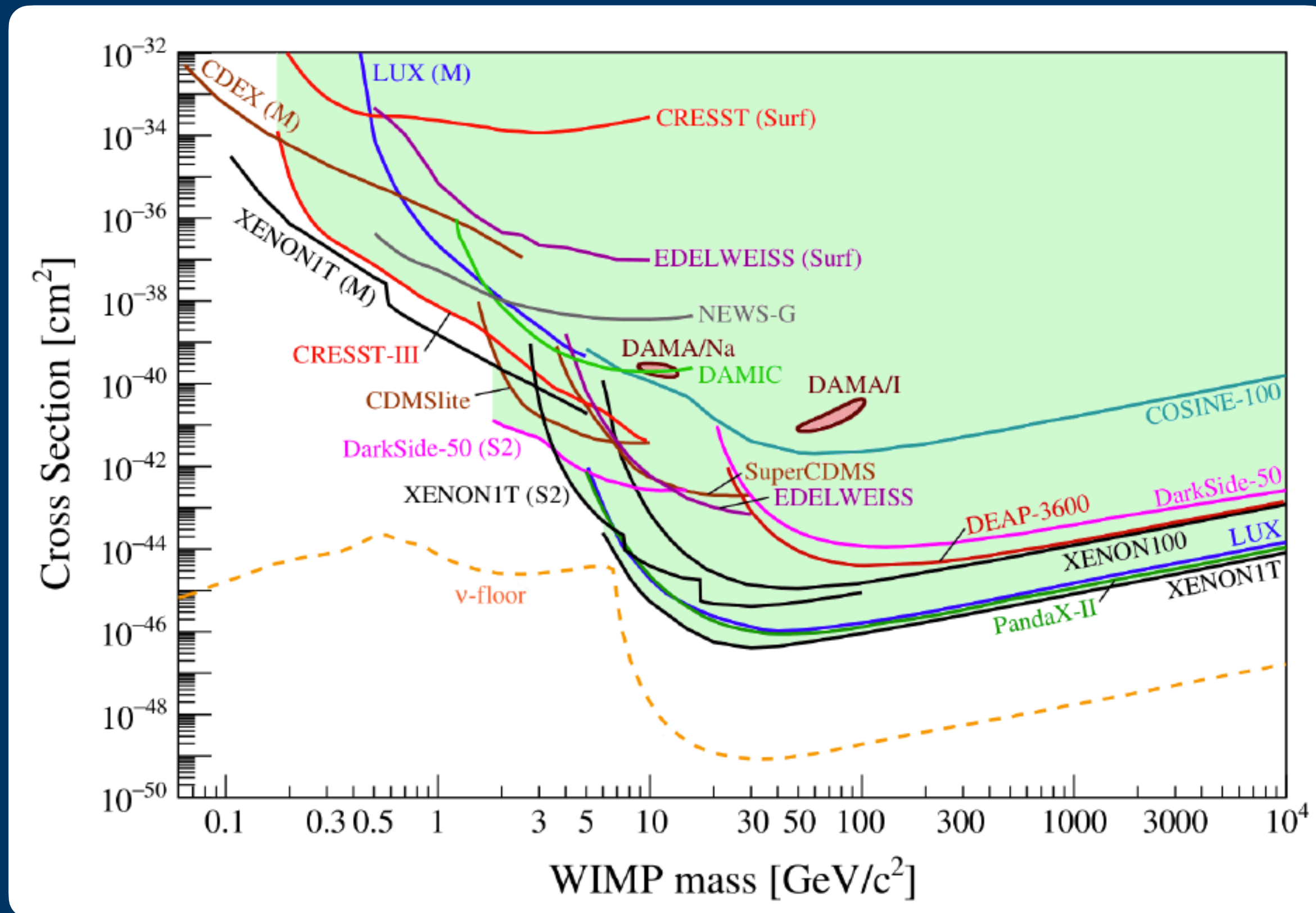


- How to choose a good target?
- In order to **maximise** the fraction of **transferred energy** it is then crucial to have target of almost **same mass**



# WIMP MASSES

- Large regions of **high masses** spectrum already explored **without** any confirmed **evidence of WIMP**;



- Future focus on **masses below 10 GeV**;

| 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                            |

(assuming  $\beta = 2 \times 10^{-3}$ )

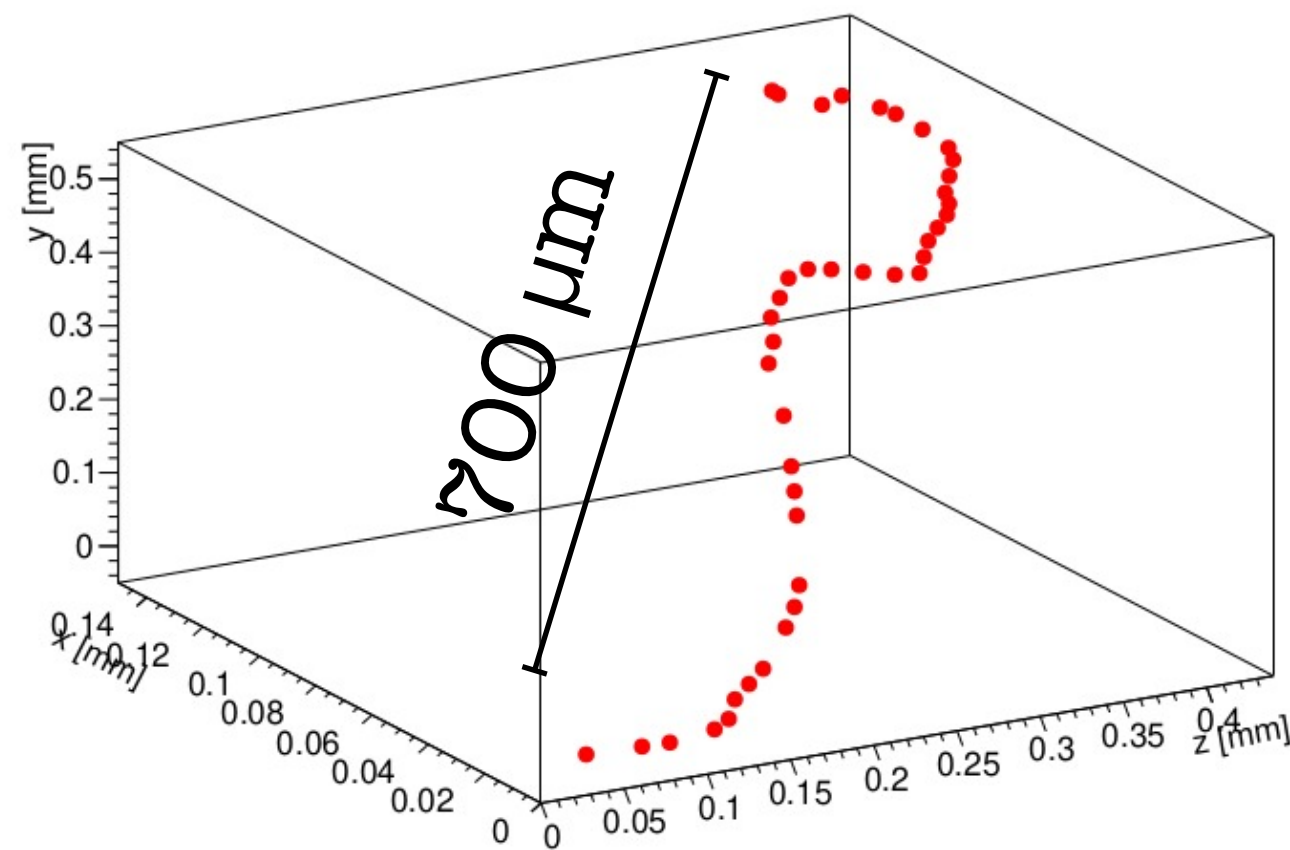
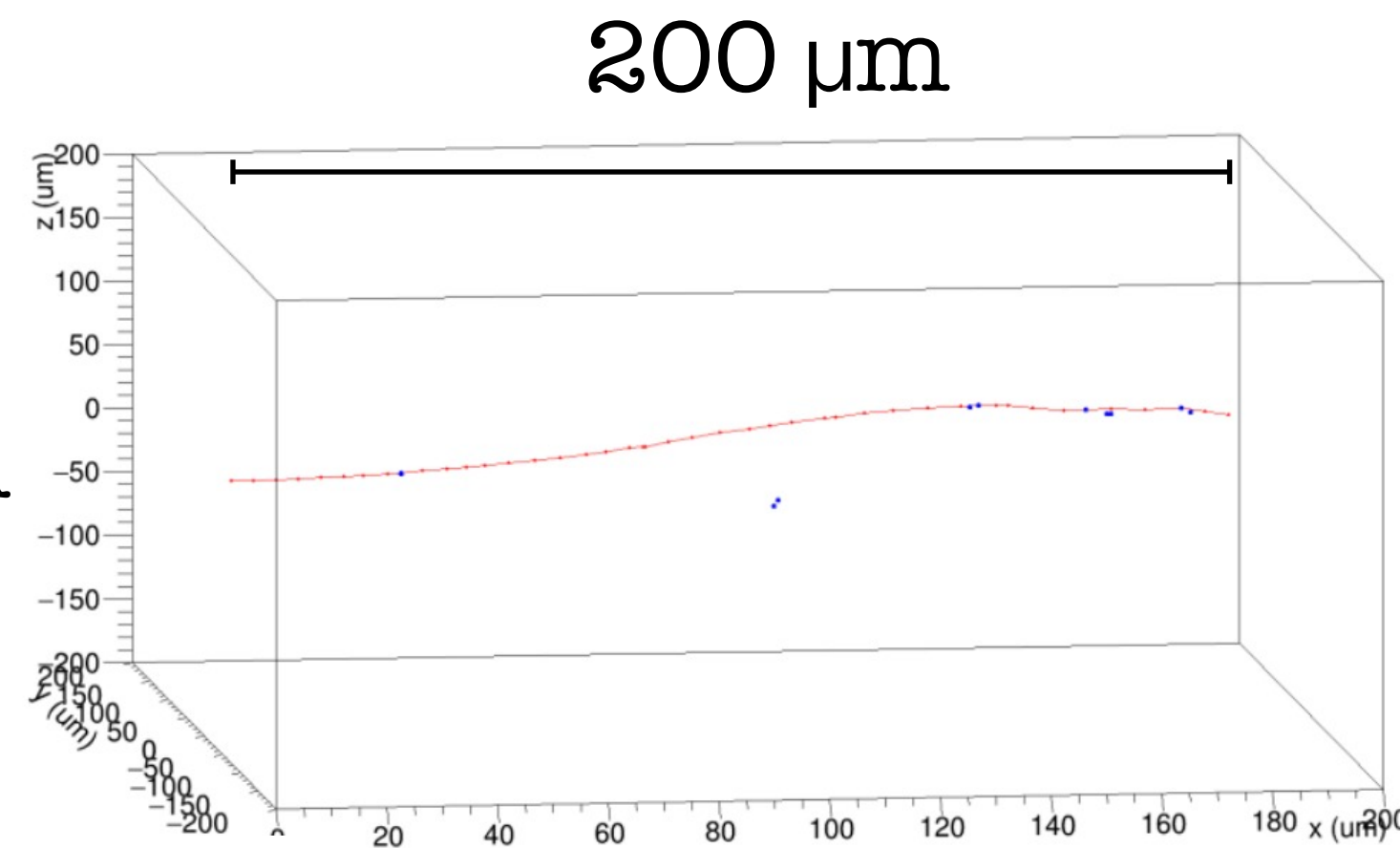
- To explore the GeV mass range, **best candidates** are **He** and **H**



# WIMP SEARCH

- **Hydrogen** is a **complicated** gas to manipulate (but we have some idea);

6 keV helium



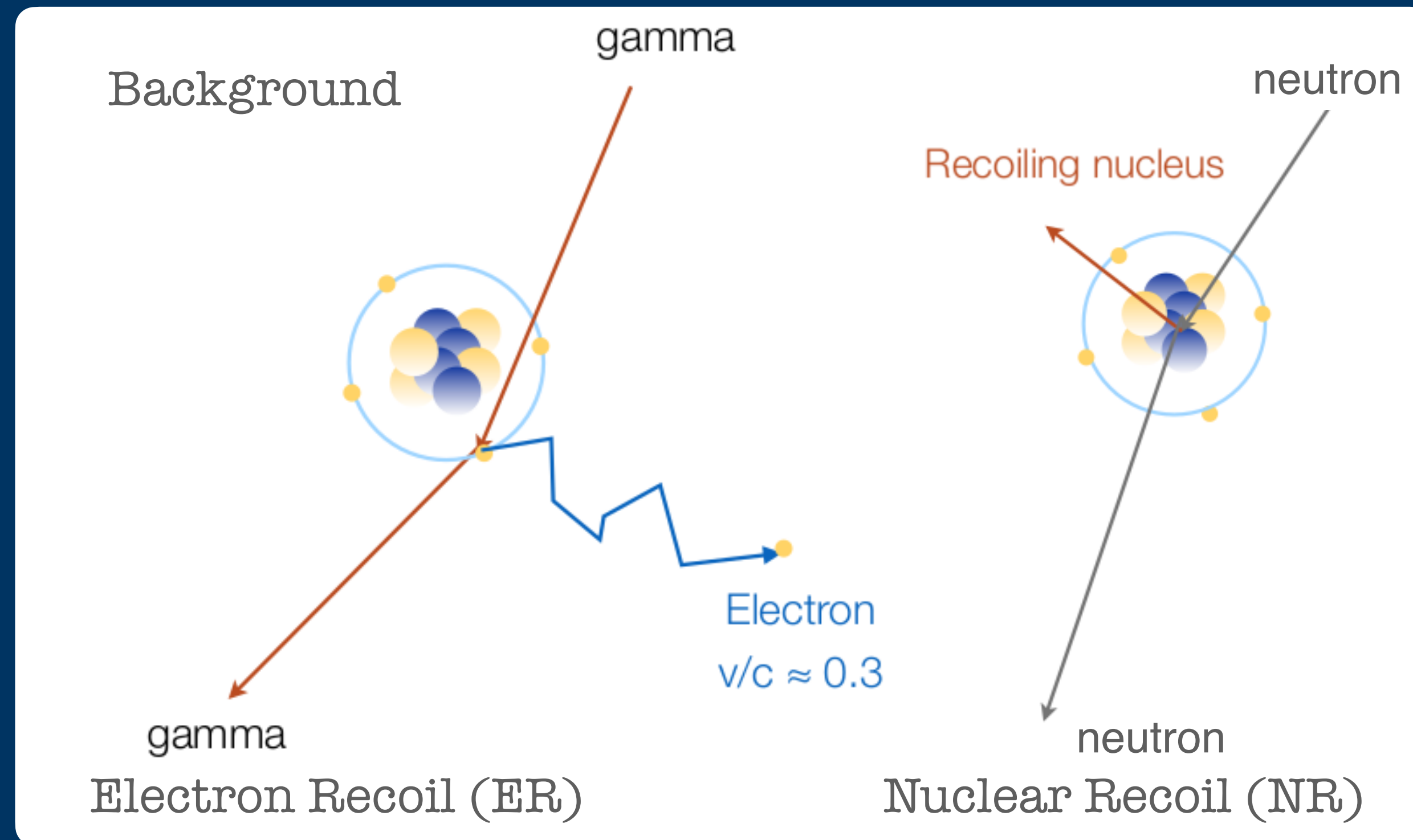
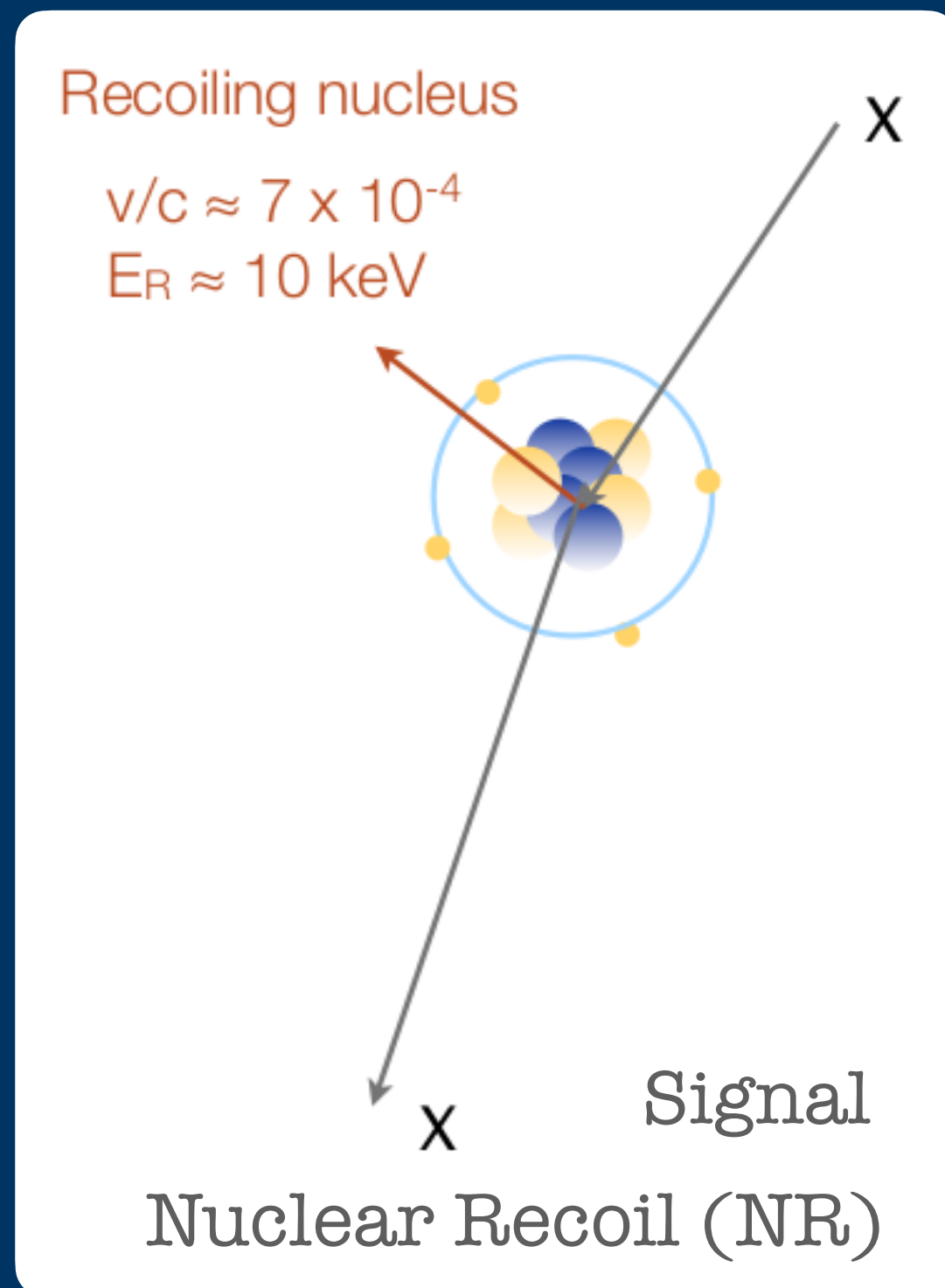
6 keV electron

- We started with **Helium**;
- In a Helium (based) **gas** mixture at **atmospheric pressure** a **6 keV He** nucleus has an average **range of 150  $\mu\text{m}$** , 4 time lesser than an electron;
- 10% of them have almost the double.
- If it would be possible to “**observe**” these events, not only it would be possible to **distinguish them**, but also to measure their **direction** (from CYGNUS?)



# NATURAL BACKGROUND

- Ambient or material radioactivity or cosmic rays can produce large background;
- In particular, neutral particles (gamma or neutrons) can mimic DM interactions.




- **Underground lab;**
- **Shield** from external radioactivity;
- **Reduce** internal **contamination;**

- **Identify particles** to distinguish and **reject** background.



# TIME PROJECTION CHAMBERS

- **3D tracking**: position and direction;
- total released **energy measurement**;
- **dE/dx** profile (pid, head-tail);
- **reduced readout** channel number with respect to other detectors;
- **Atmospheric pressure** largely more easy to manage



**90 m<sup>3</sup> ALICE - TPC**  
Installed on September 2020



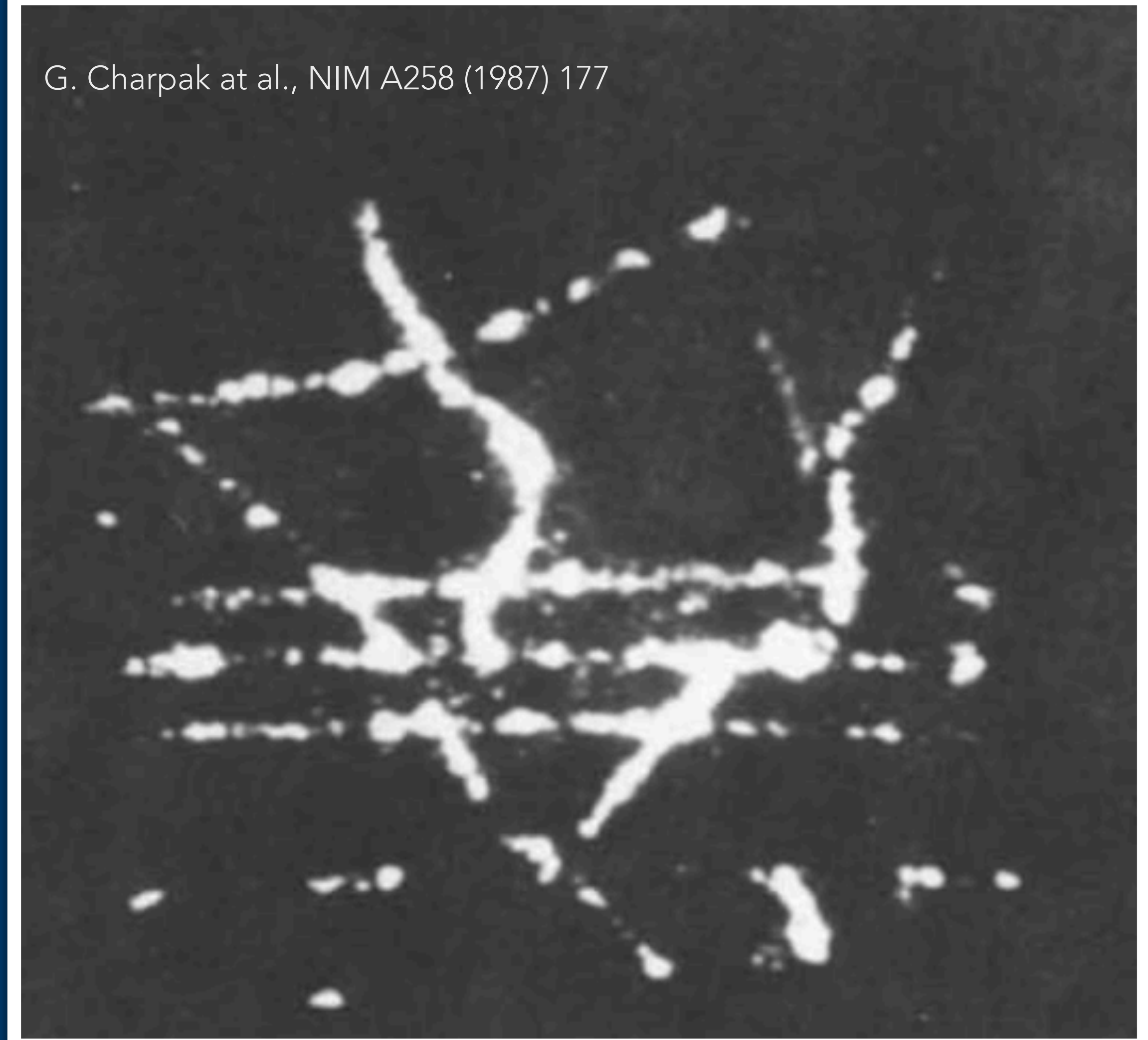
# OPTICAL READOUT

During the multiplication processes, **photons** are produced by the **de-excitation of gas** molecules

**We propose to readout the light** produced during the multiplication process:

- optical sensors provide **high granularities** along with very **low noise** and **high sensitivity**;
- optical **coupling** allows to keep **sensor out of the sensitive volume**;
- suitable **lens** allow to acquire **large surfaces** with **small sensors**;

G. Charpak et al., NIM A258 (1987) 177





# GAS ELECTRON MULTIPLIERS (GEM)

## GEM: A new concept for electron amplification in gas detectors

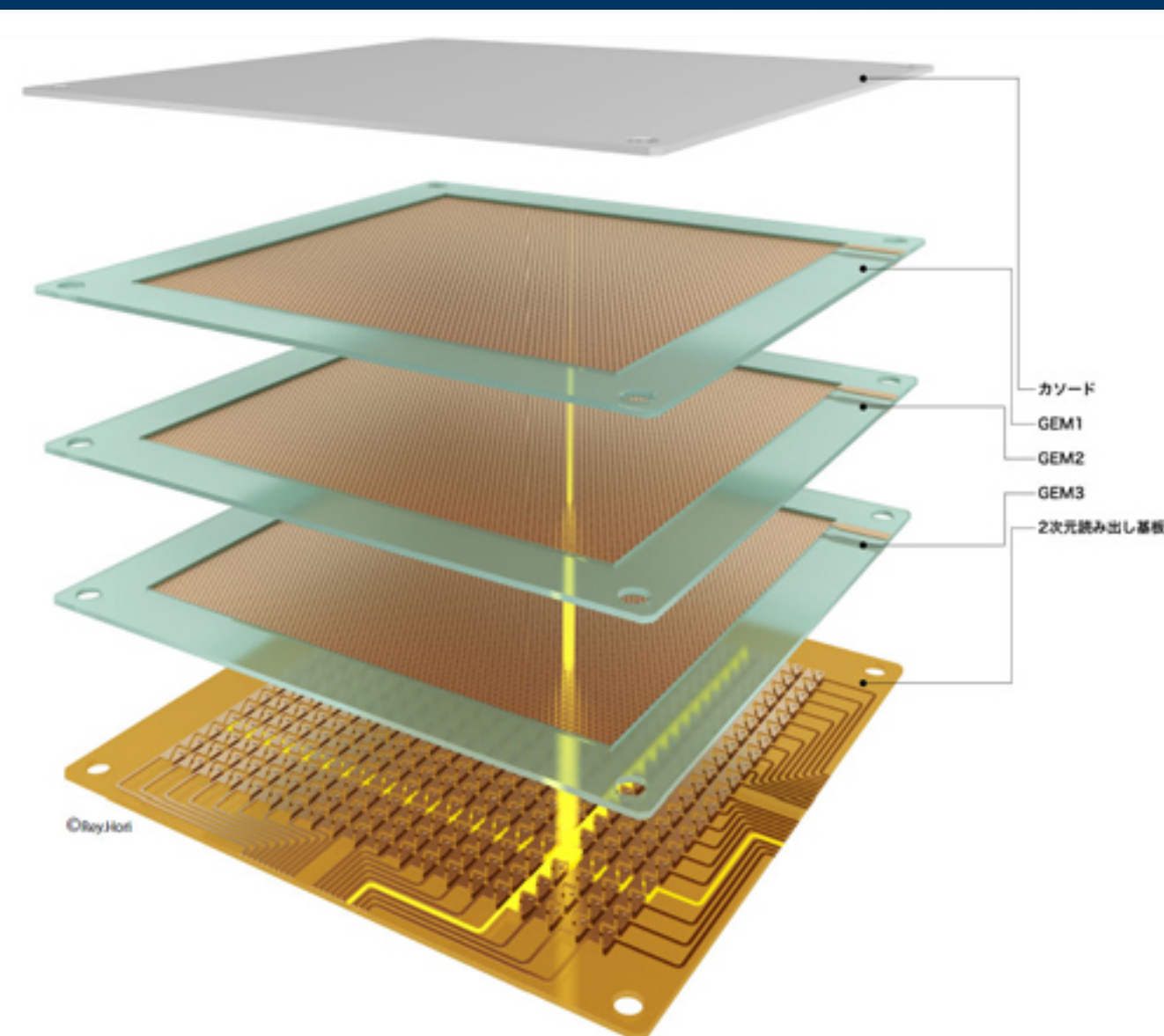
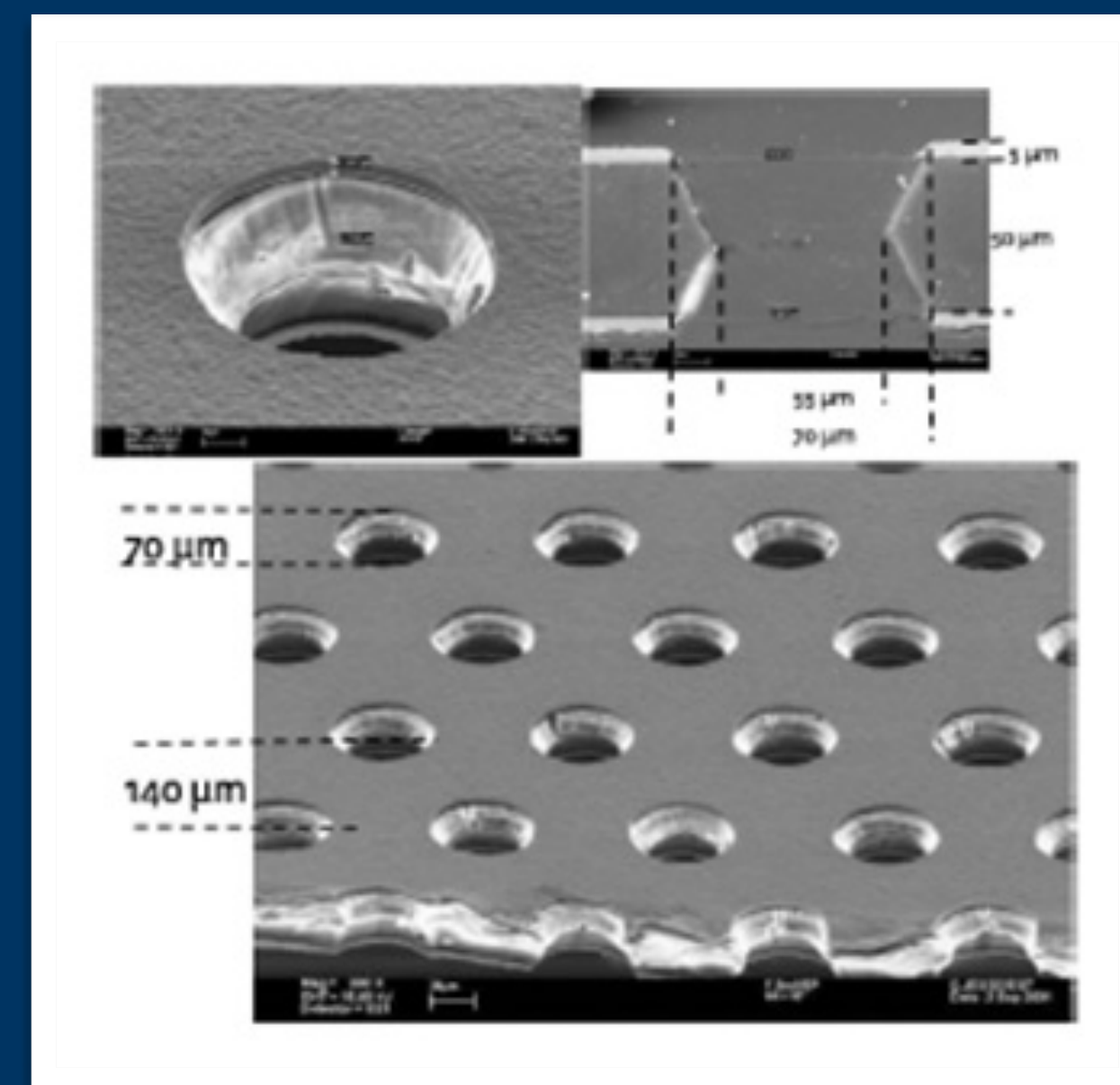
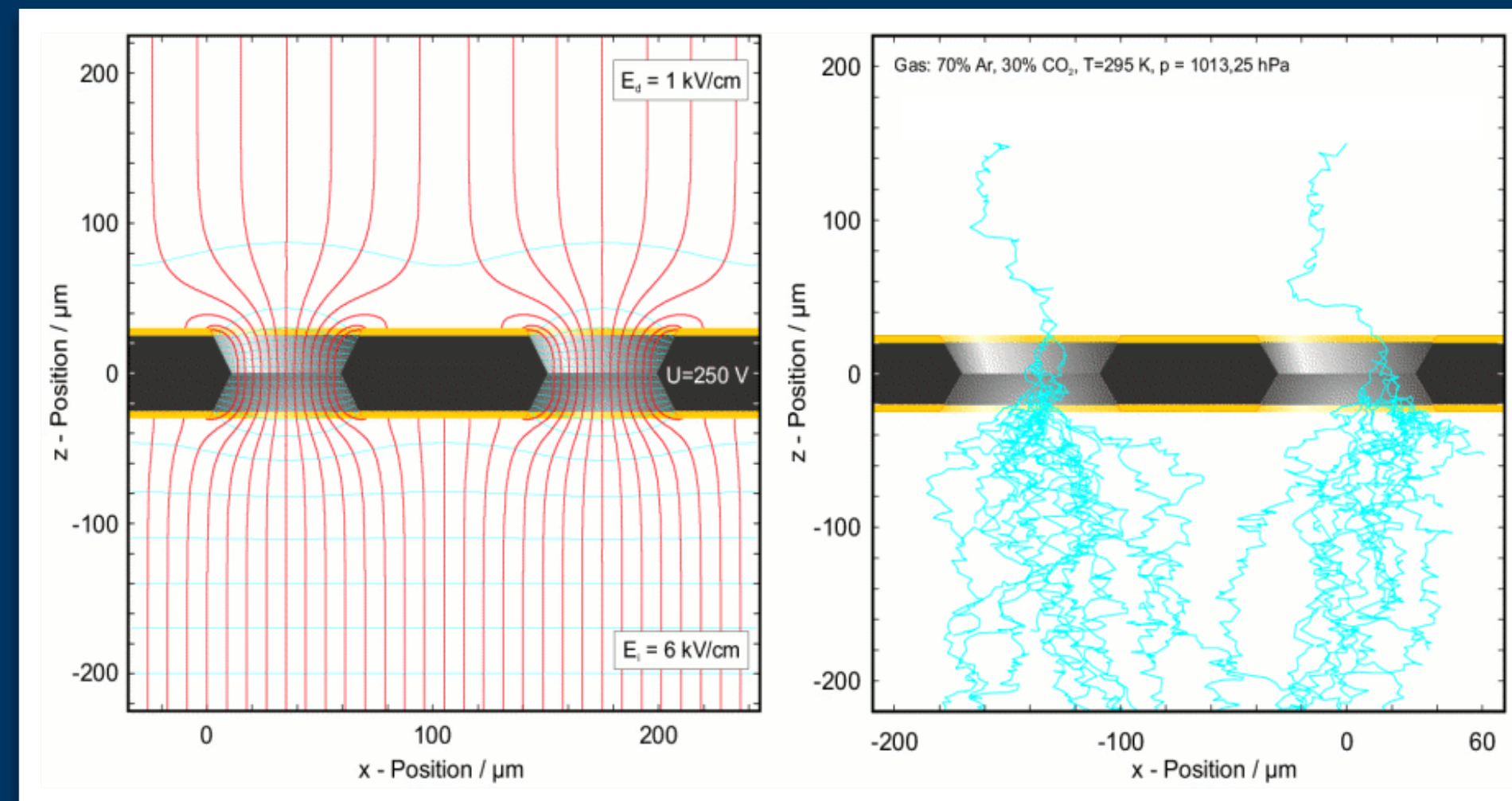
F. Sauli

CERN, CH-1211 Genève, Switzerland

Received 6 November 1996

### Abstract

We introduce the gas electrons multiplier (GEM), a composite grid consisting of two metal layers separated by a thin insulator, etched with a regular matrix of open channels. A GEM grid with the electrodes kept at a suitable difference of potential, inserted in a gas detector on the path of drifting electrons, allows to pre-amplify the charge drifting through the channels. Coupled to other devices, multiwire or microstrip chambers, it permits to obtain higher gains, or to operate in less critical conditions. The separation of sensitive and detection volumes offers other advantages: a built-in delay, a strong suppression of photon feedback. Applications are foreseen in high rate tracking and Cherenkov Ring Imaging detectors. Multiple GEM grids assembled in the same gas volume allow to obtain large effective amplification factors in a succession of steps.



**Primary electrons** drift toward the **GEM channels** where a high electric field **trigger avalanche** processes;

**Multiple GEM** structures can be used to **share the gain** and make more **stable detectors**.

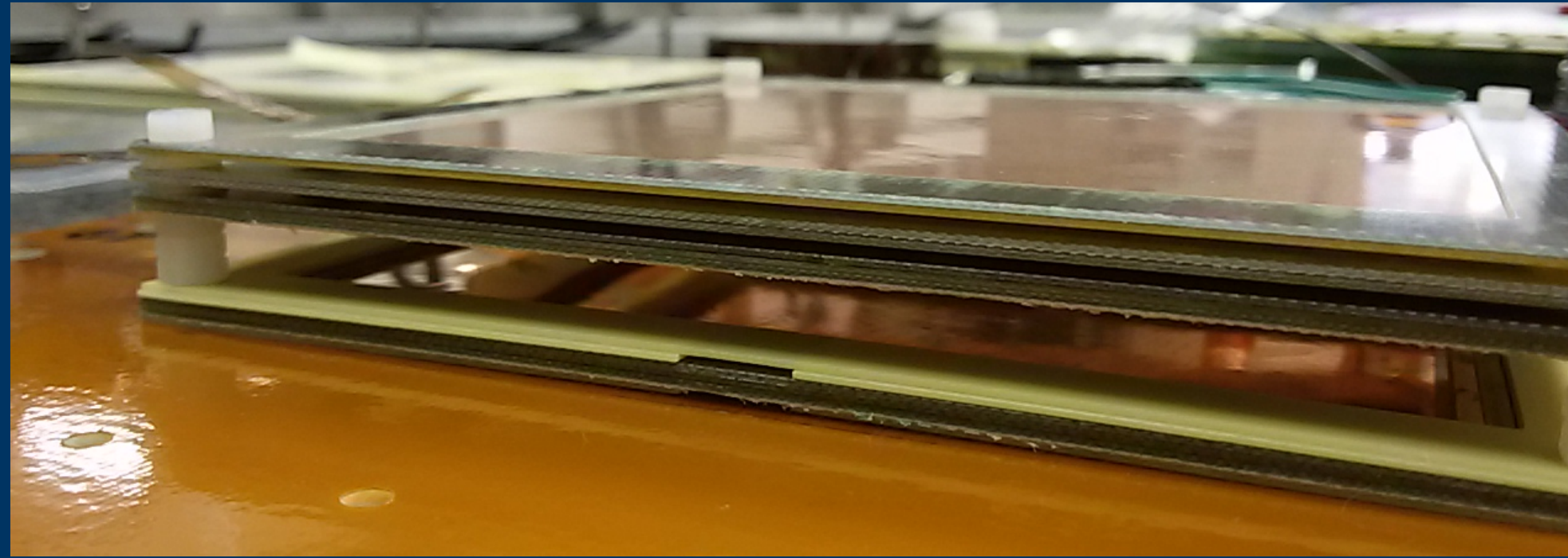
**Photons** are produced together with secondary electrons **within the channels**



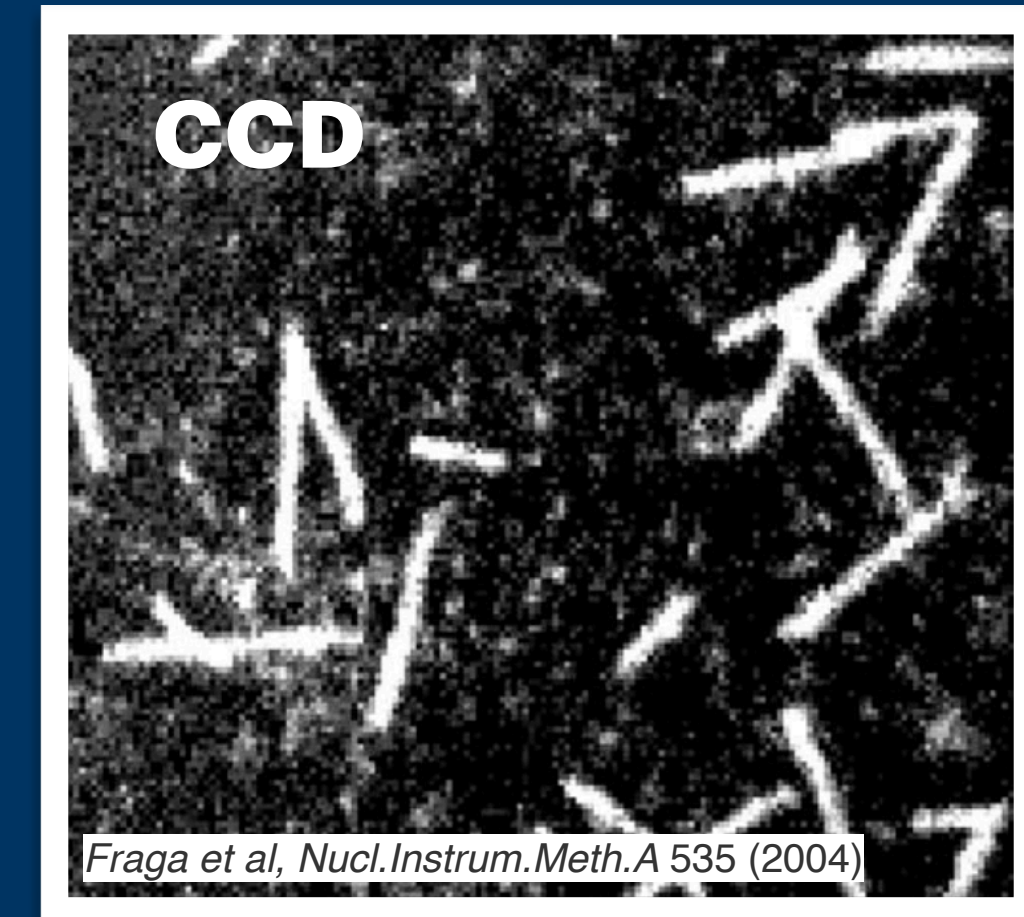
# ORANGE: AN OPTICALLY READOUT GEM

Triple GEM structure  
(10x10 cm<sup>2</sup>) with 1 cm  
sensitive gap.

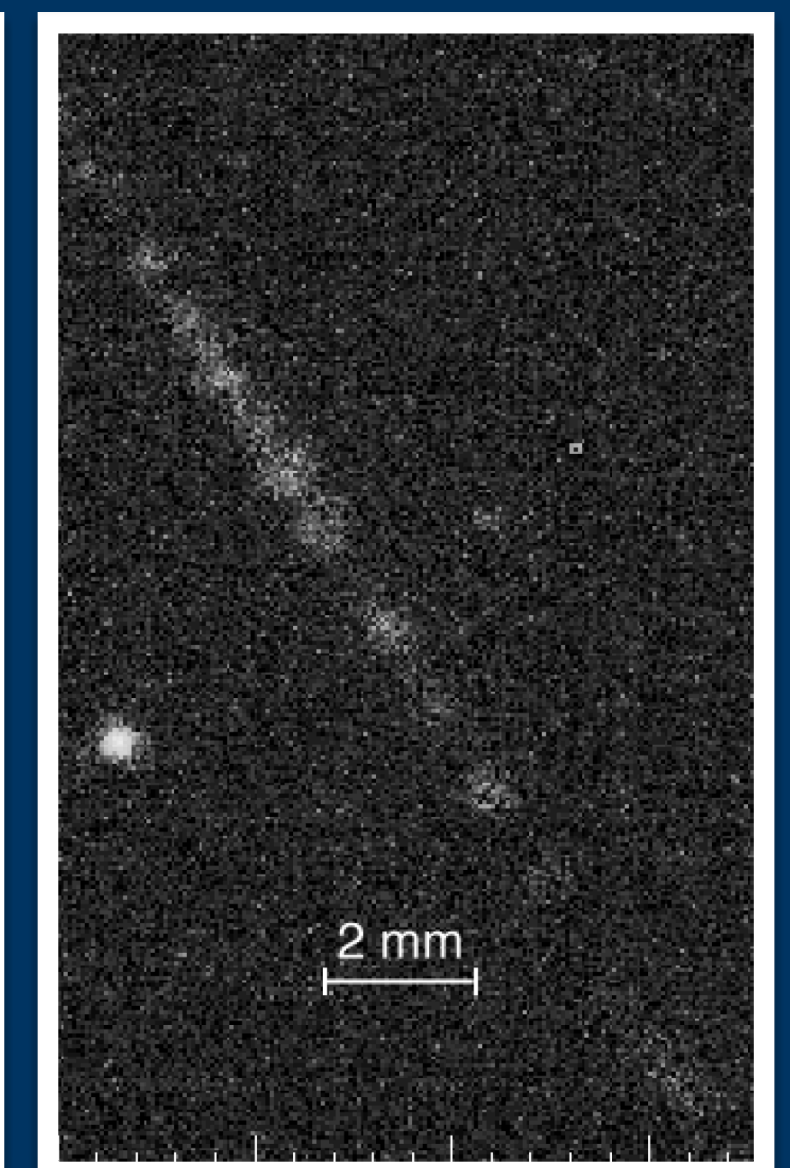
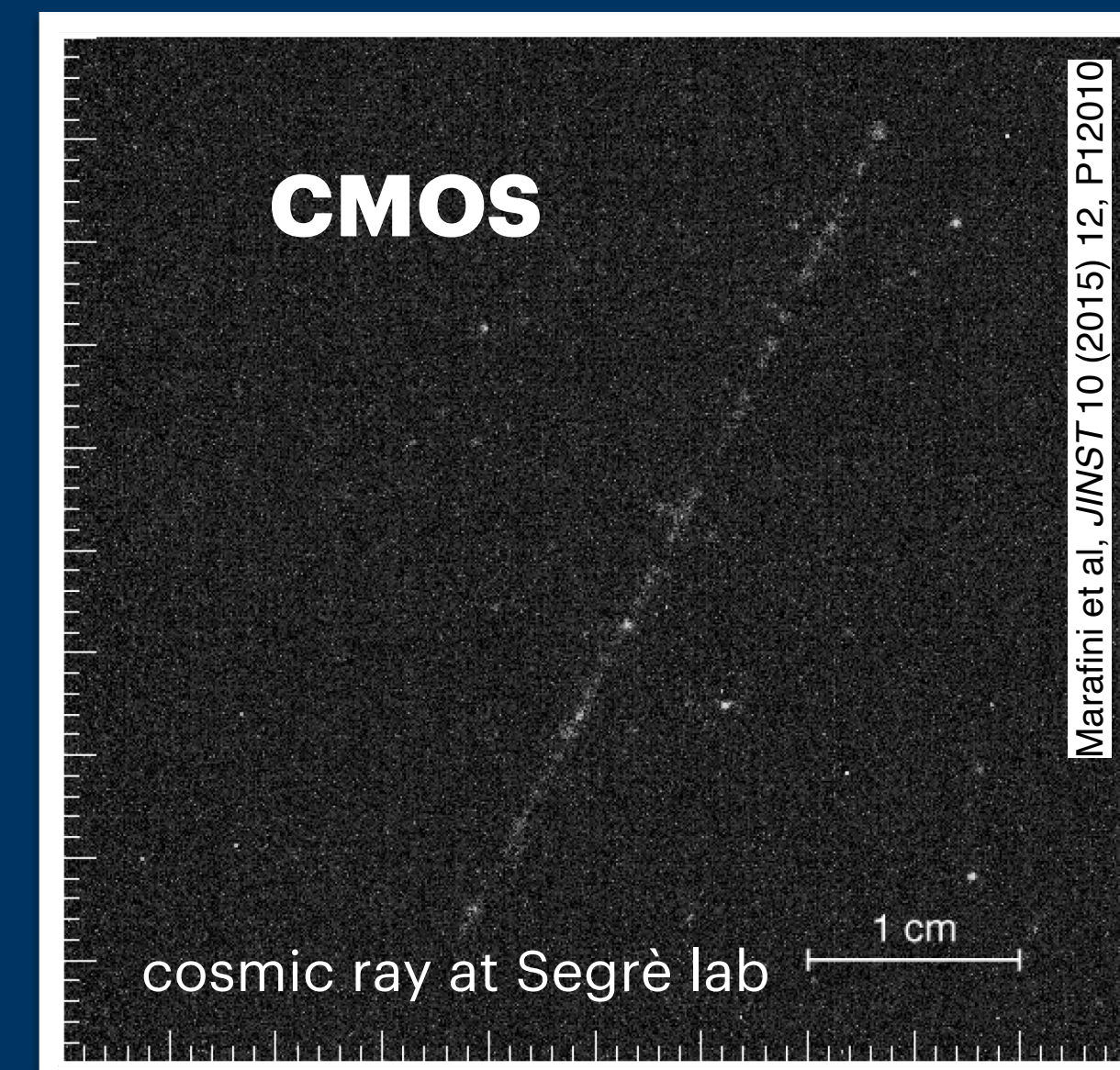
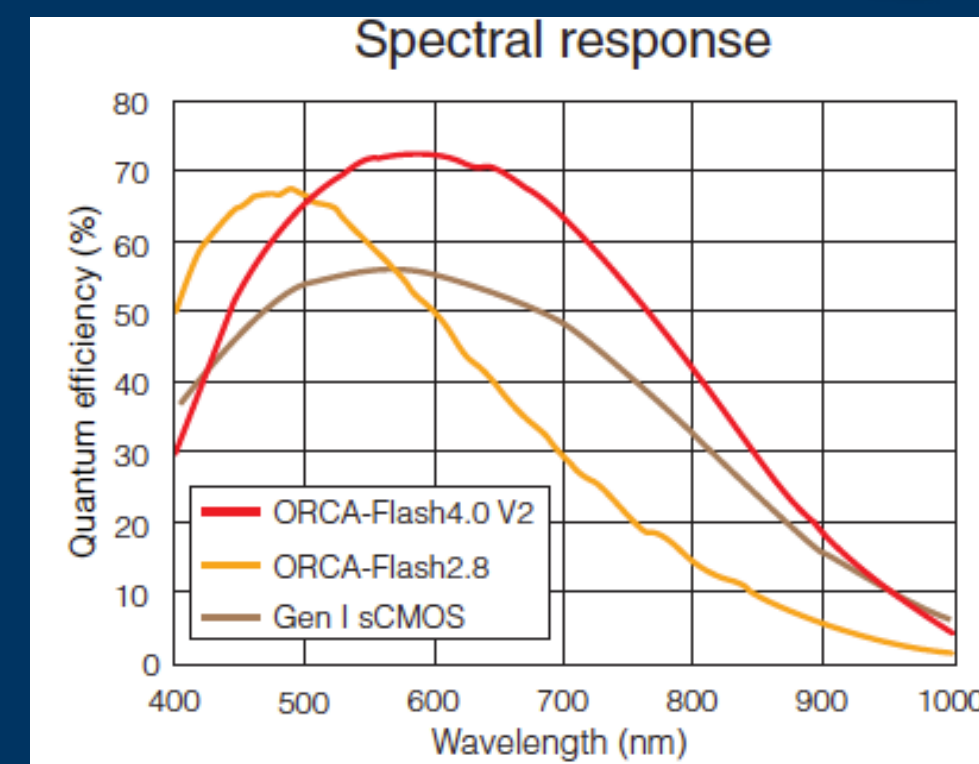
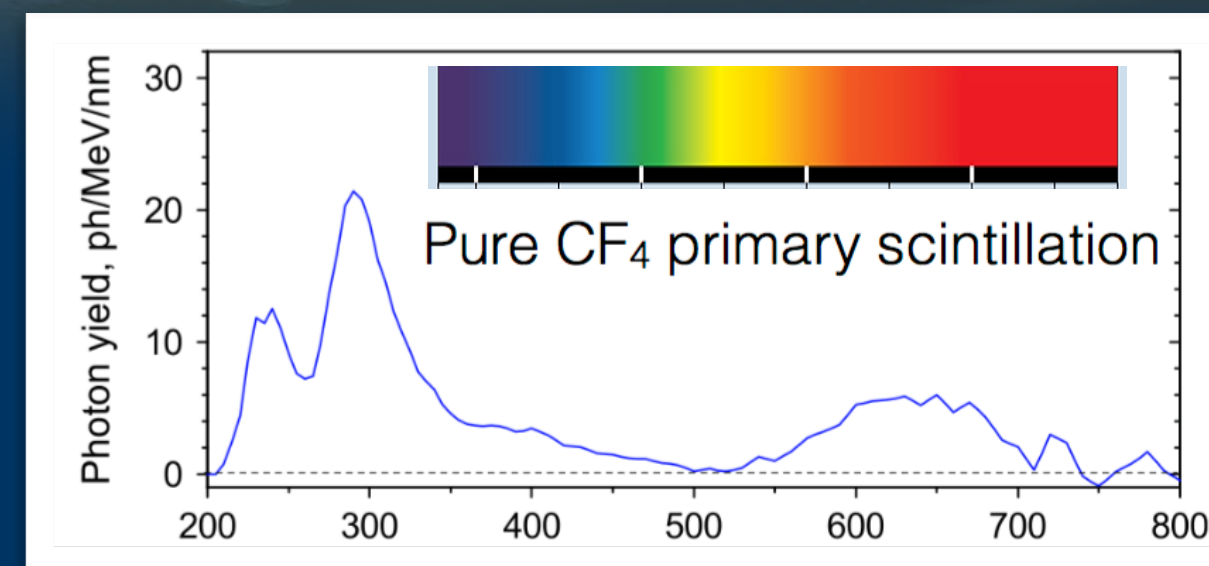
An He/CF<sub>4</sub> (60/40)  
mixture was used at  
atmospheric pressure



highly ionising tracks



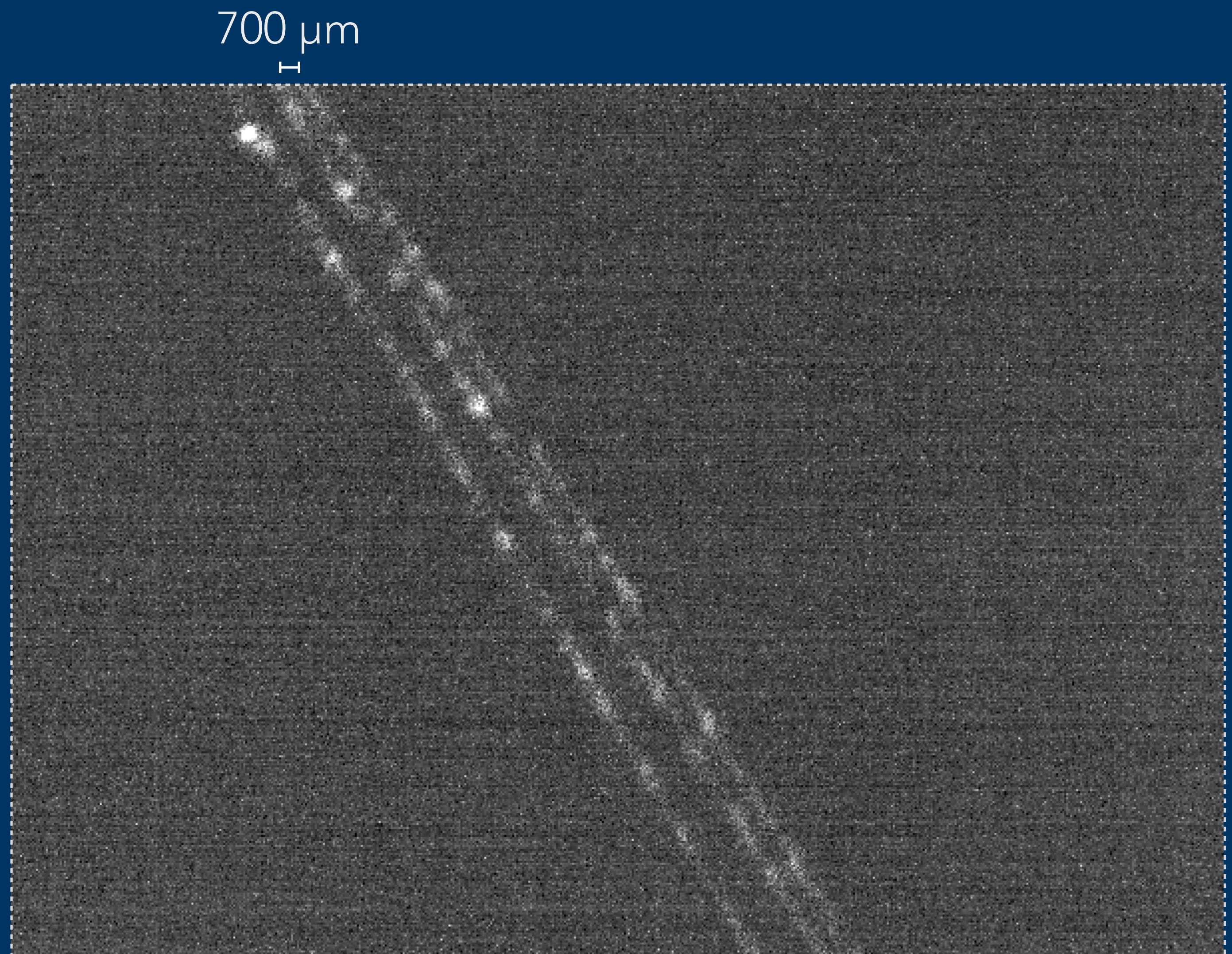
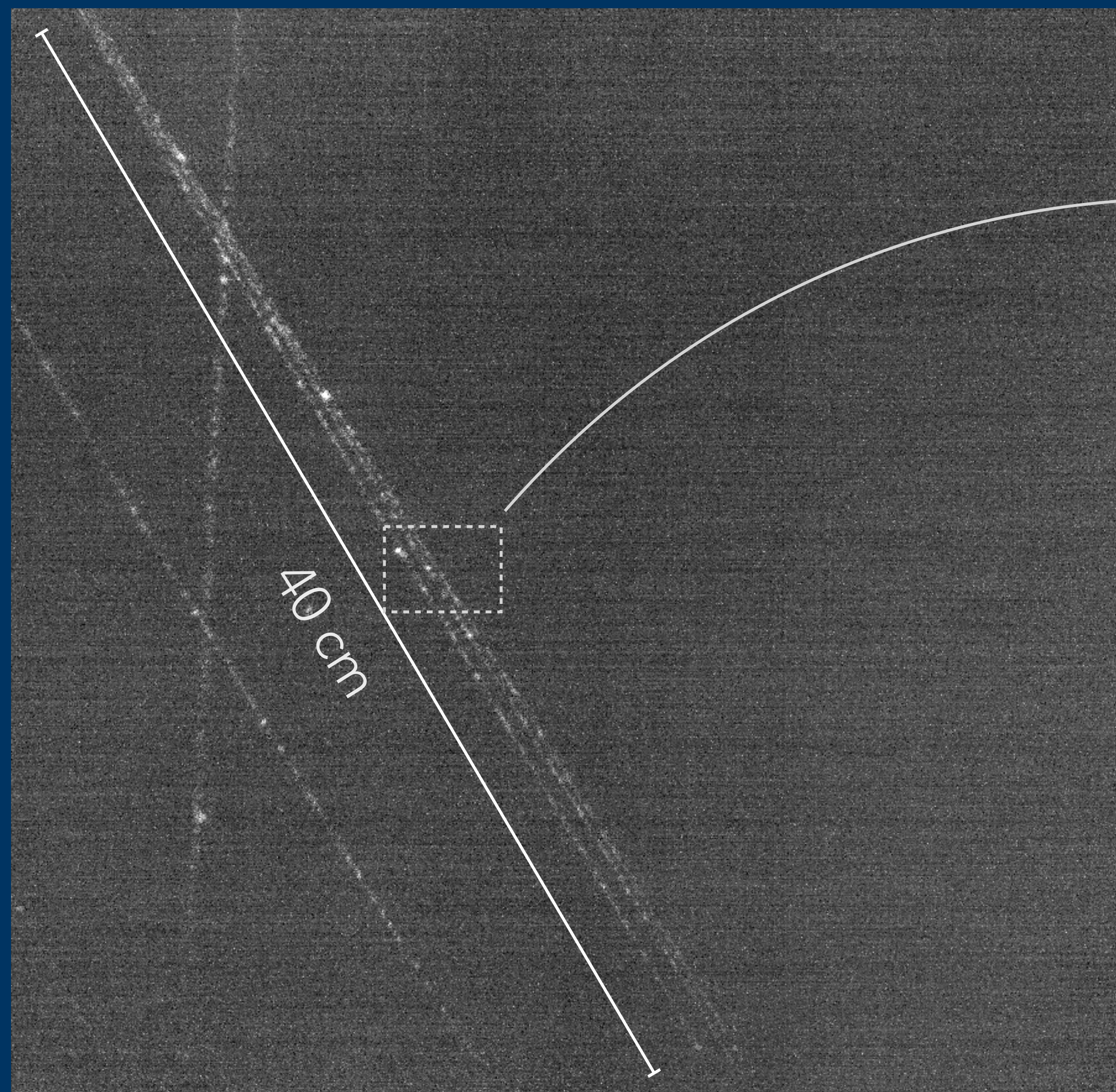
Significantly **lower noise** level of  
**APS** w.r.t **CCD** sensors resulted in a  
higher sensitivity



sCMOS Active Pixel Sensors (APS)  
provide very low noise and 4MPx  
granularity and sensitivity



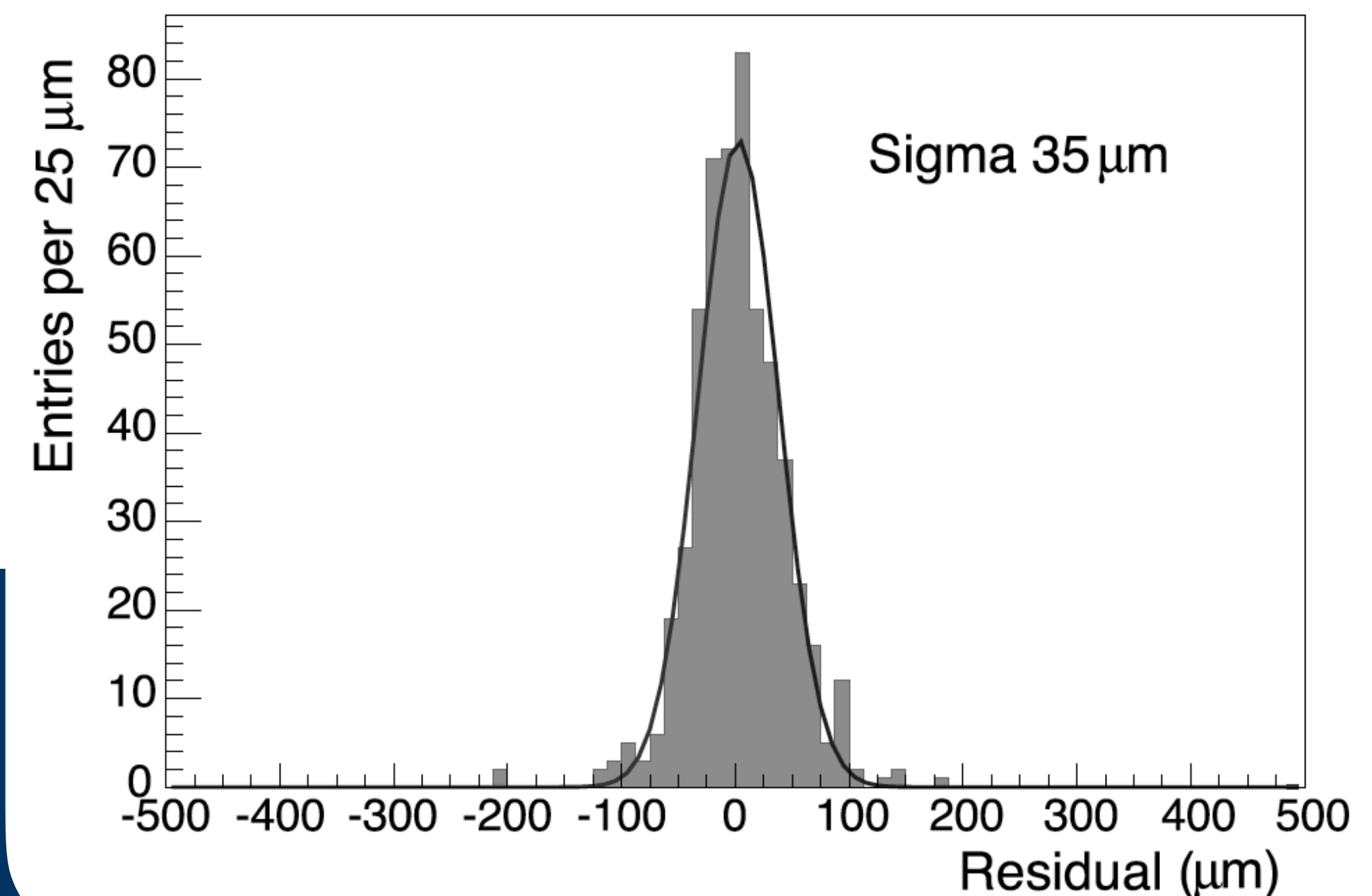
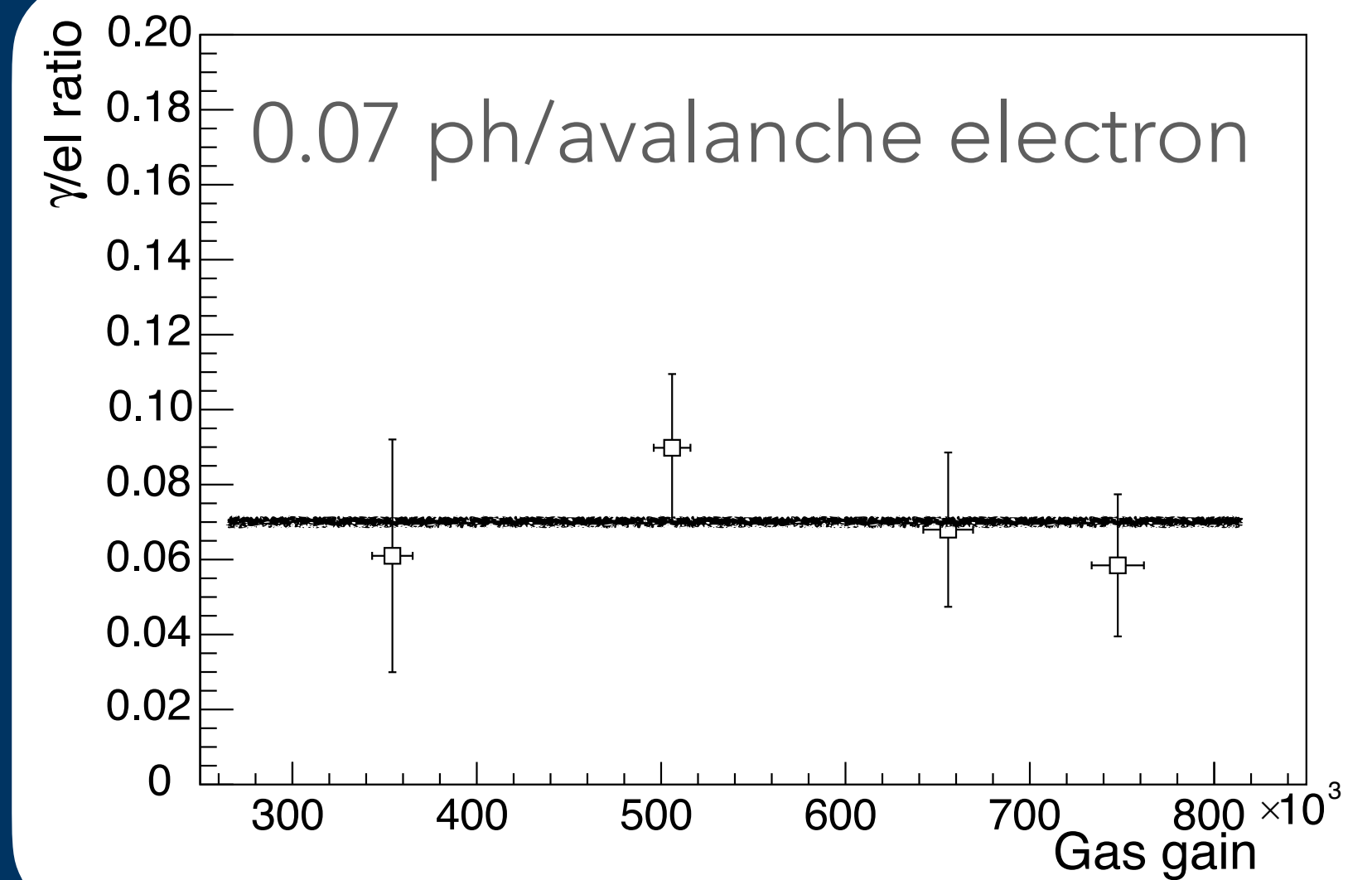
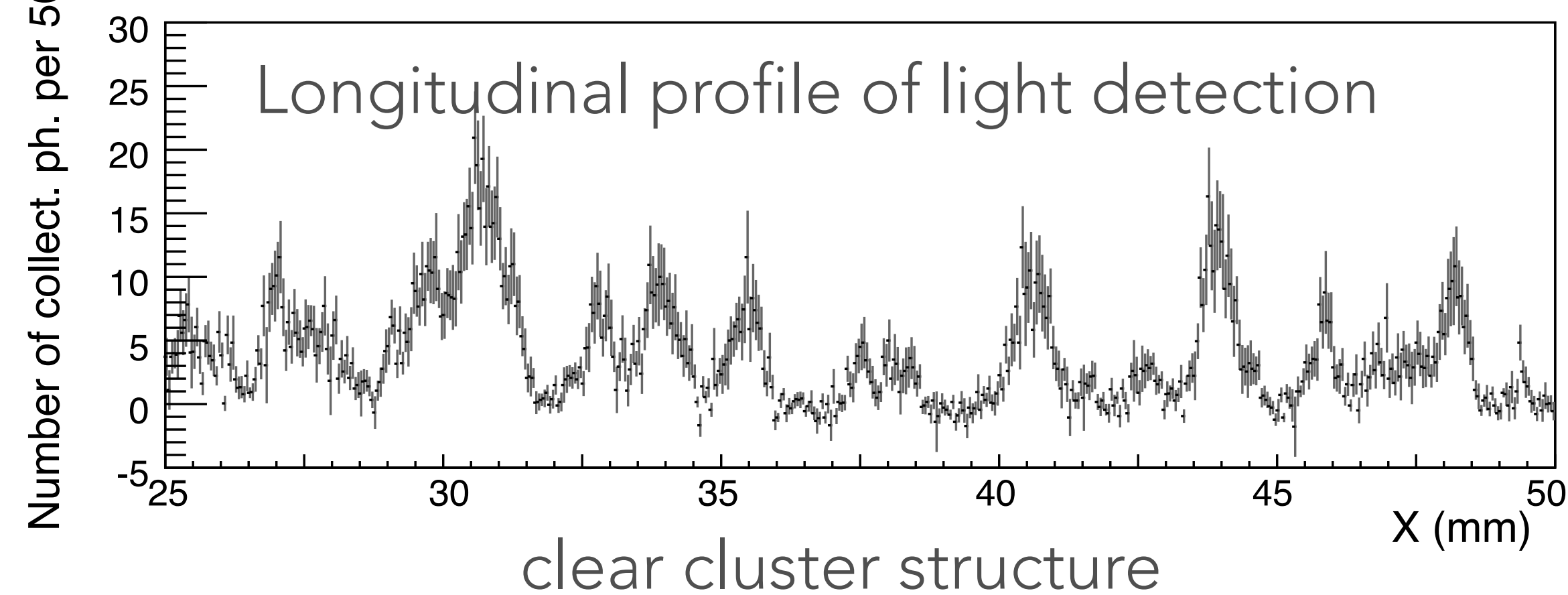
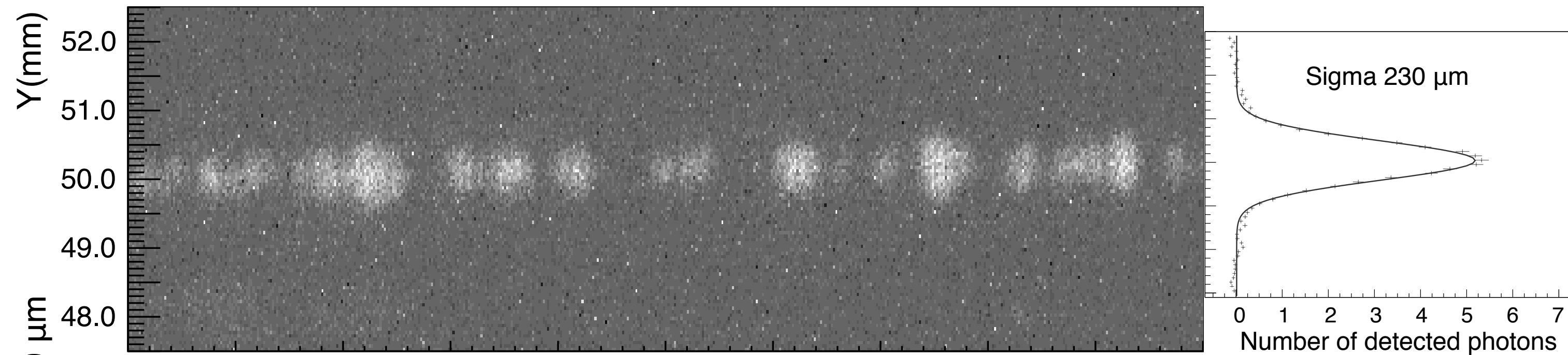
# OPTICALLY READOUT TPC





# CLUSTER DETAILS

Marafini et al, IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 65, NO. 1, JANUARY 2018



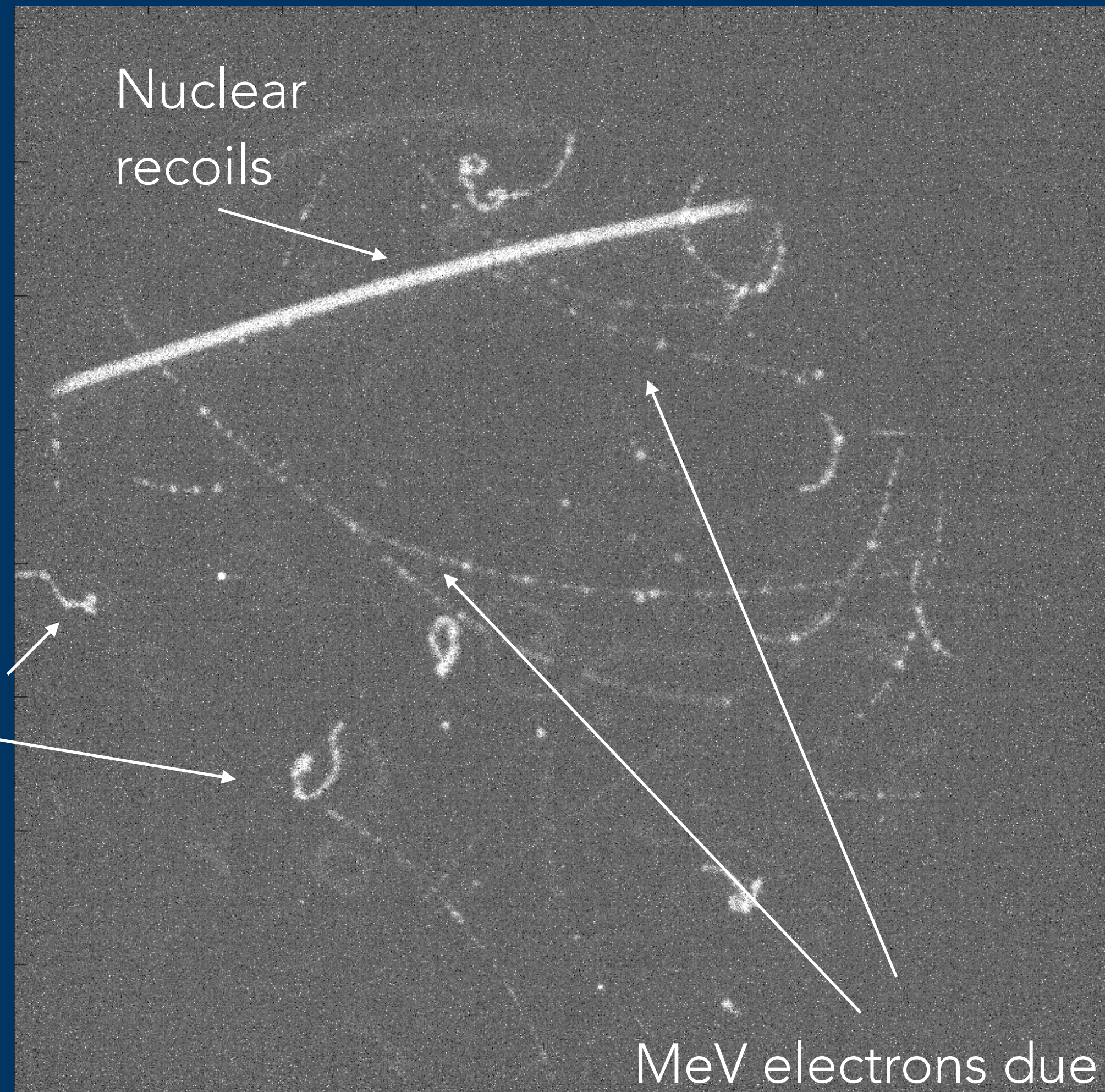
The average **energy** per **cluster** (i.e. 2 primary electrons) is around **90 eV**



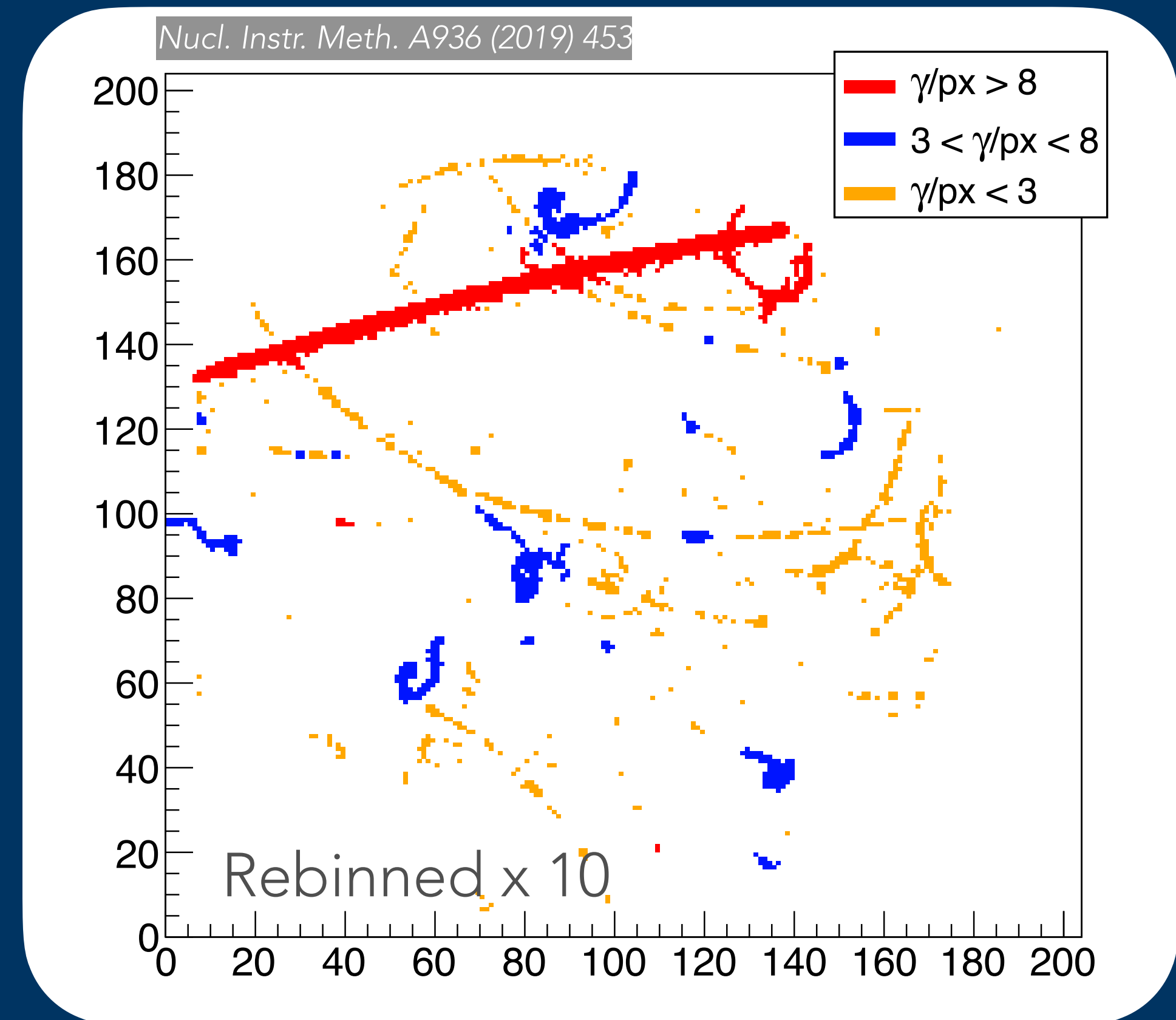
# PARTICLE IDENTIFICATION

Detector was exposed to an **AmBe** source, providing **1-10 MeV neutrons** along with **4 MeV and 59 keV photons**.  
A **0.2 T magnetic field** by a permanent magnet

Low energy electrons  
due to X rays



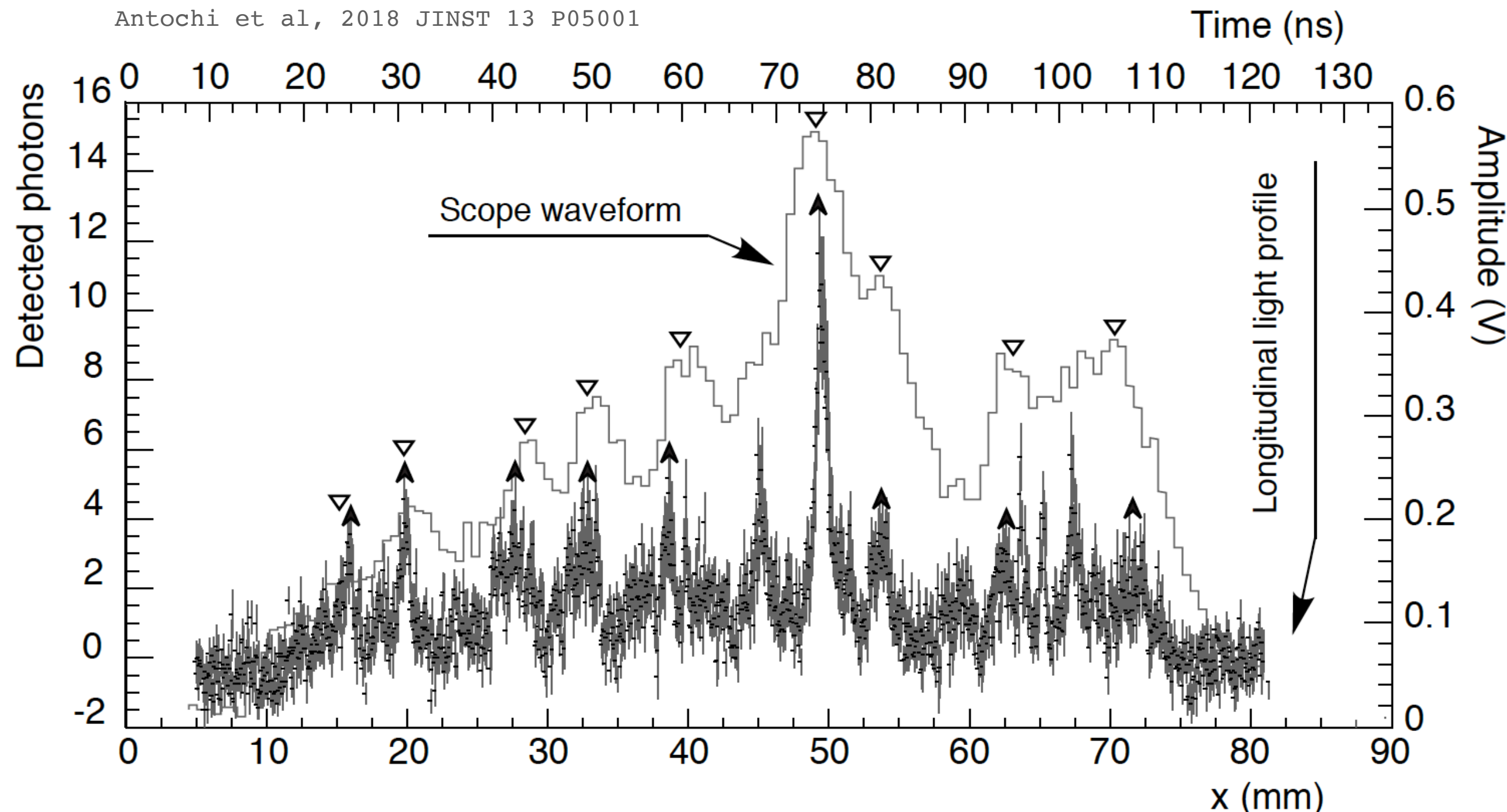
MeV electrons due  
to 4 MeV photons



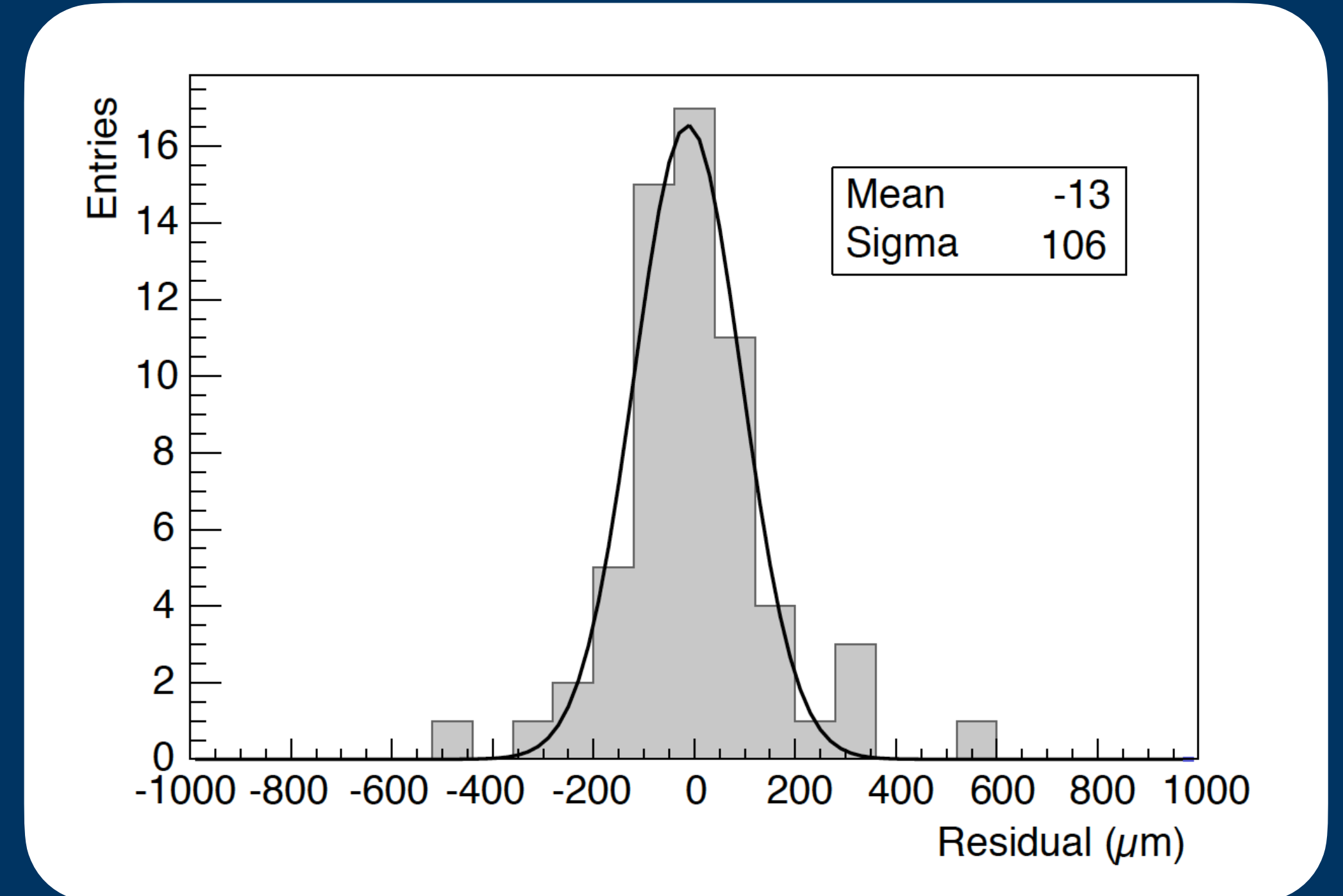
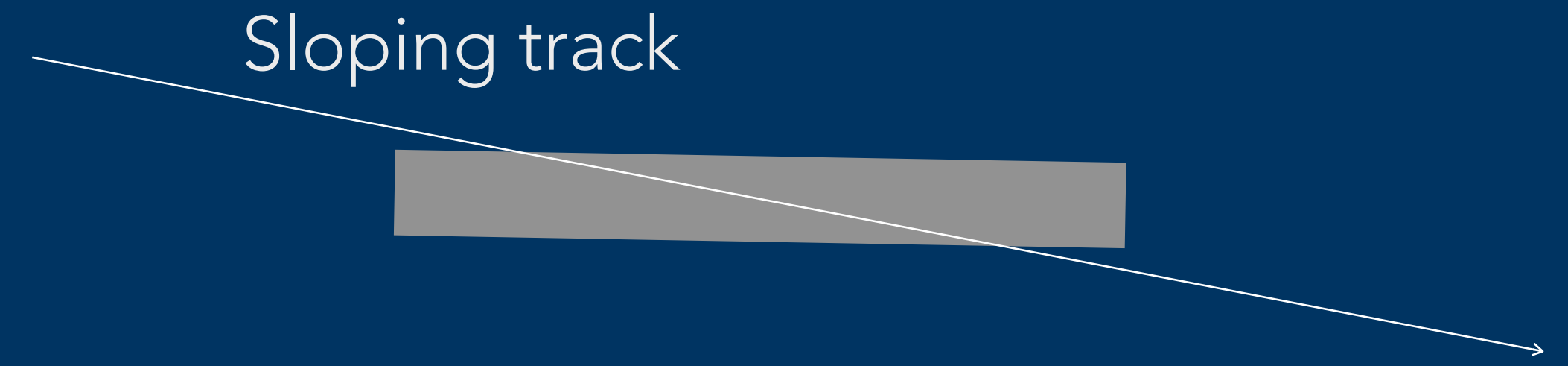
By simply assigning different **colours** to clusters as a function of their **average light density**, the three species are **almost completely separated**.



# COMBINED READOUT WITH PHOTOMULTIPLIER



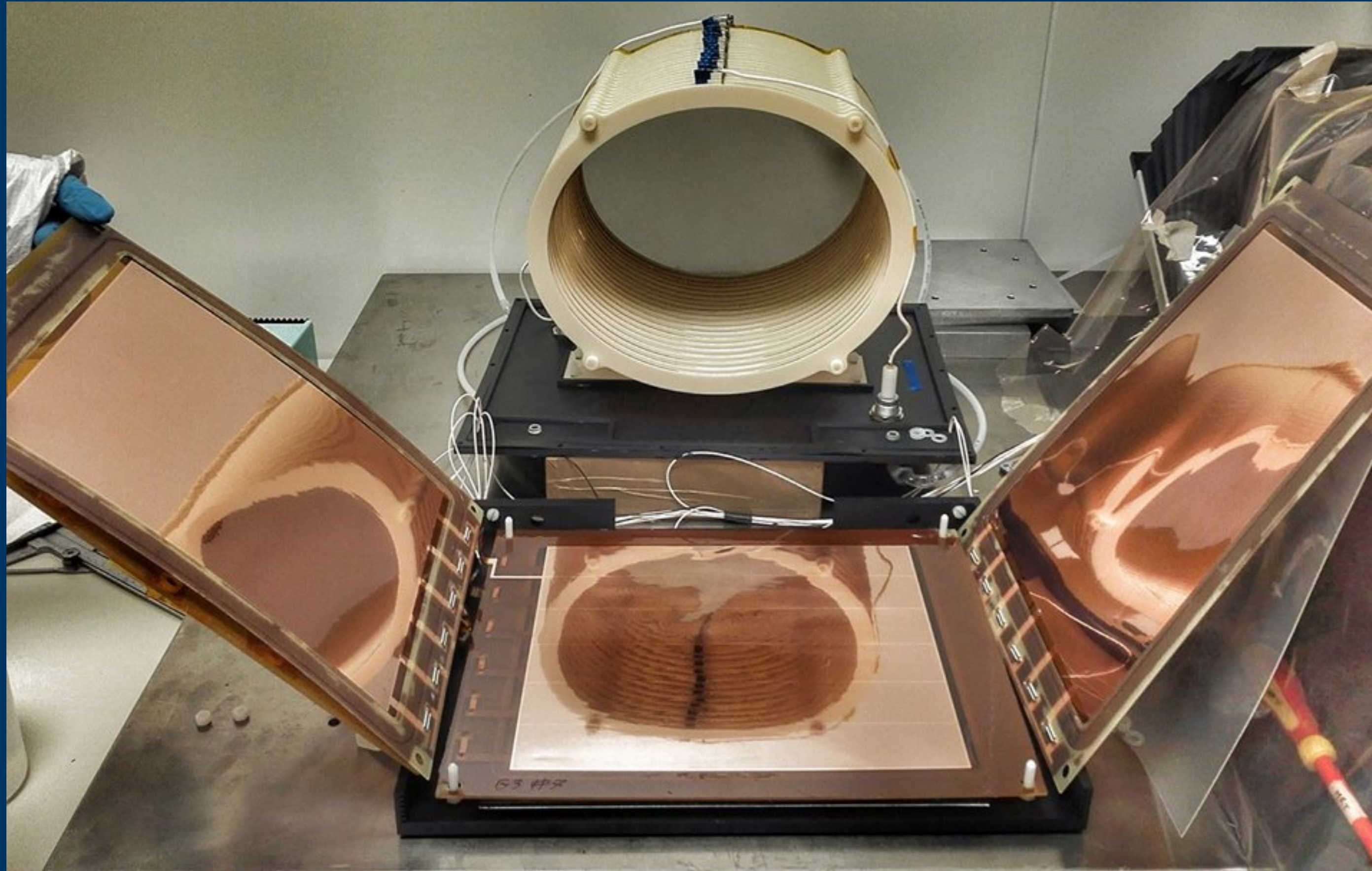
From the **comparison** of CMOS information about distribution of **clusters** along the track and PMT waveform, **z position** of each cluster can be easily evaluated.



**100  $\mu\text{m}$  resolution** on relative cluster z



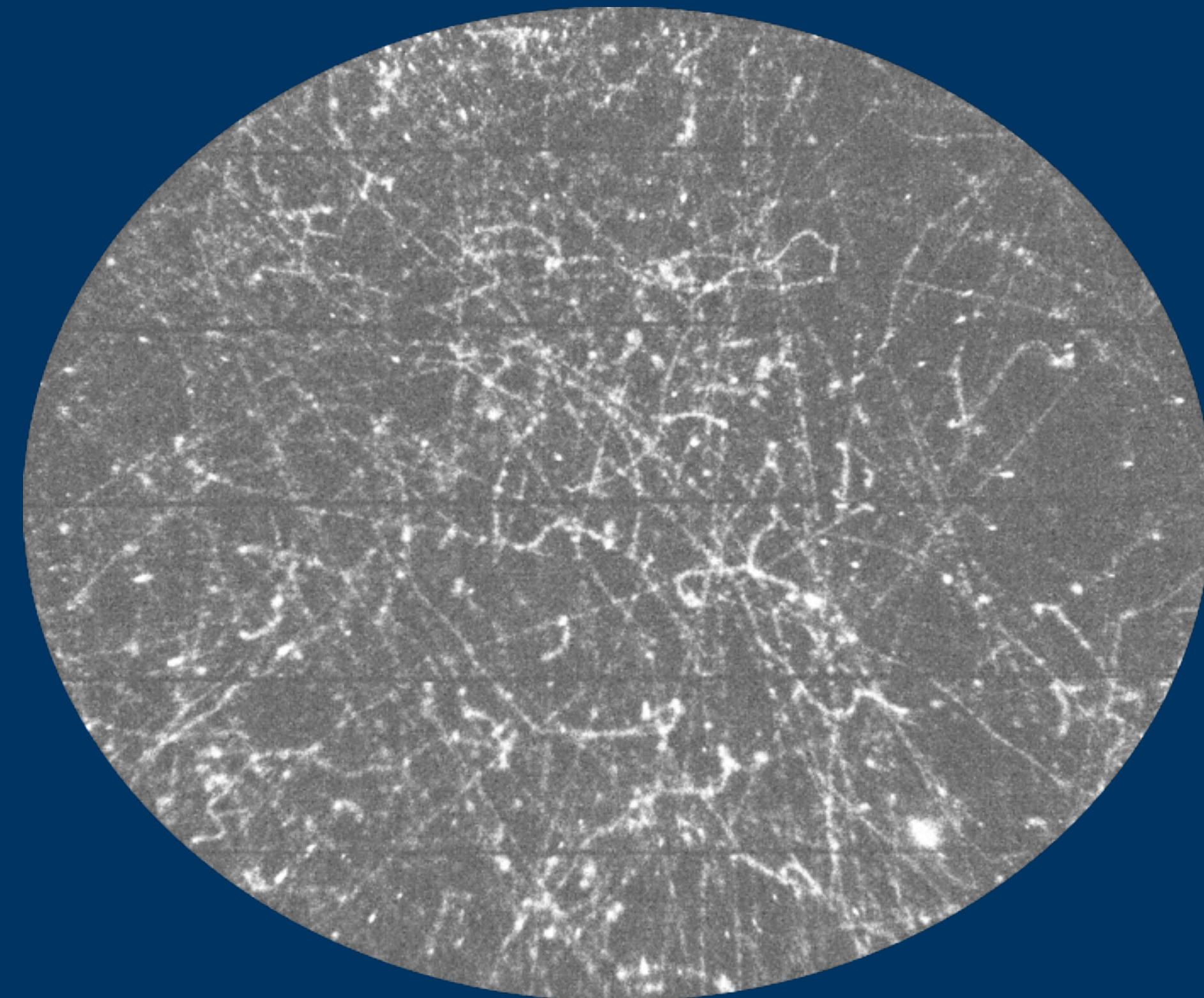
# LEMON: LARGE ELLIPTICAL MODULE OPTICALLY READOUT



- designed and assembled at LNF
- 3D printer realisation

- 7 litre sensitive volume;
- 500 cm<sup>2</sup> GEM surface;
- 20 cm long drift gap;

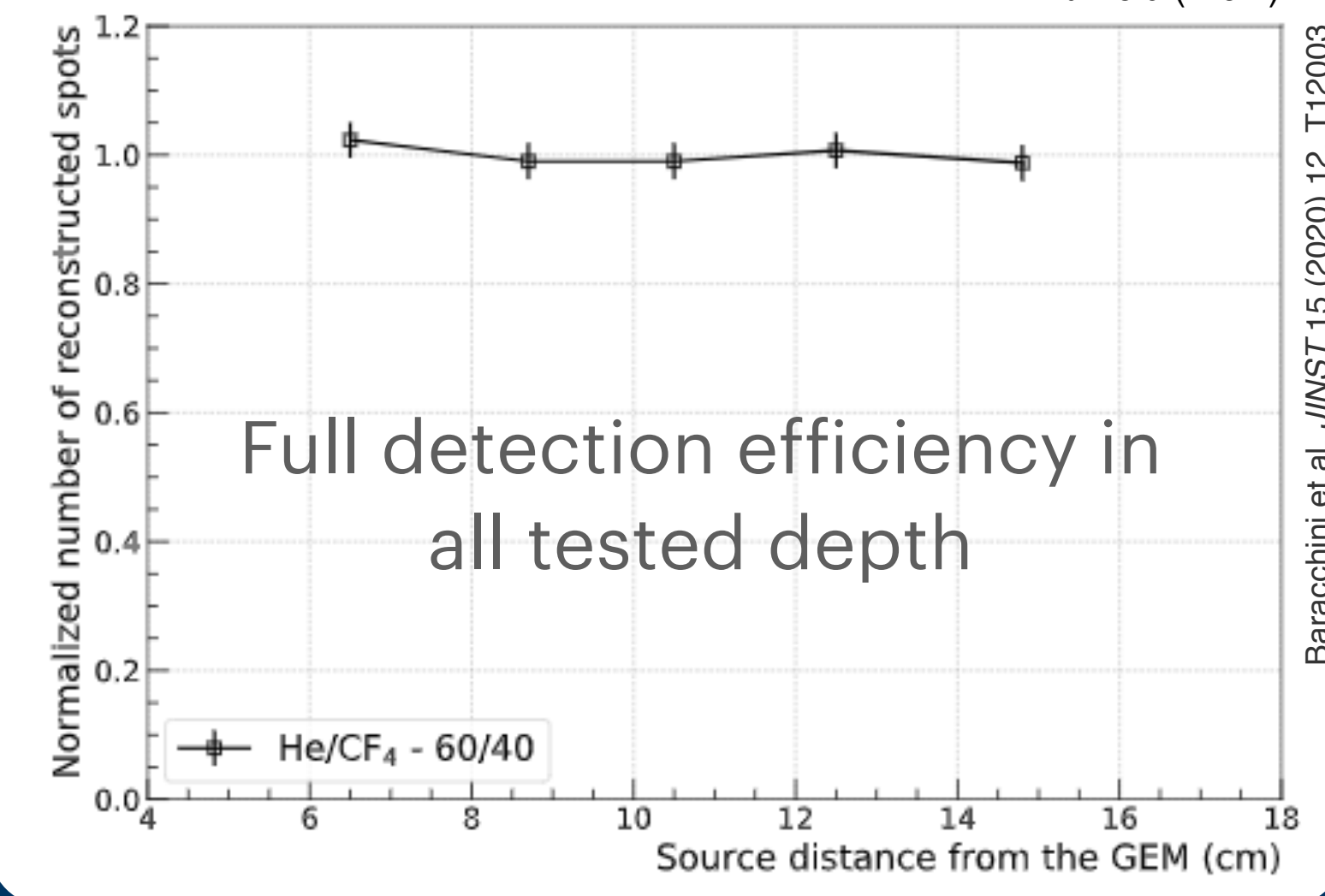
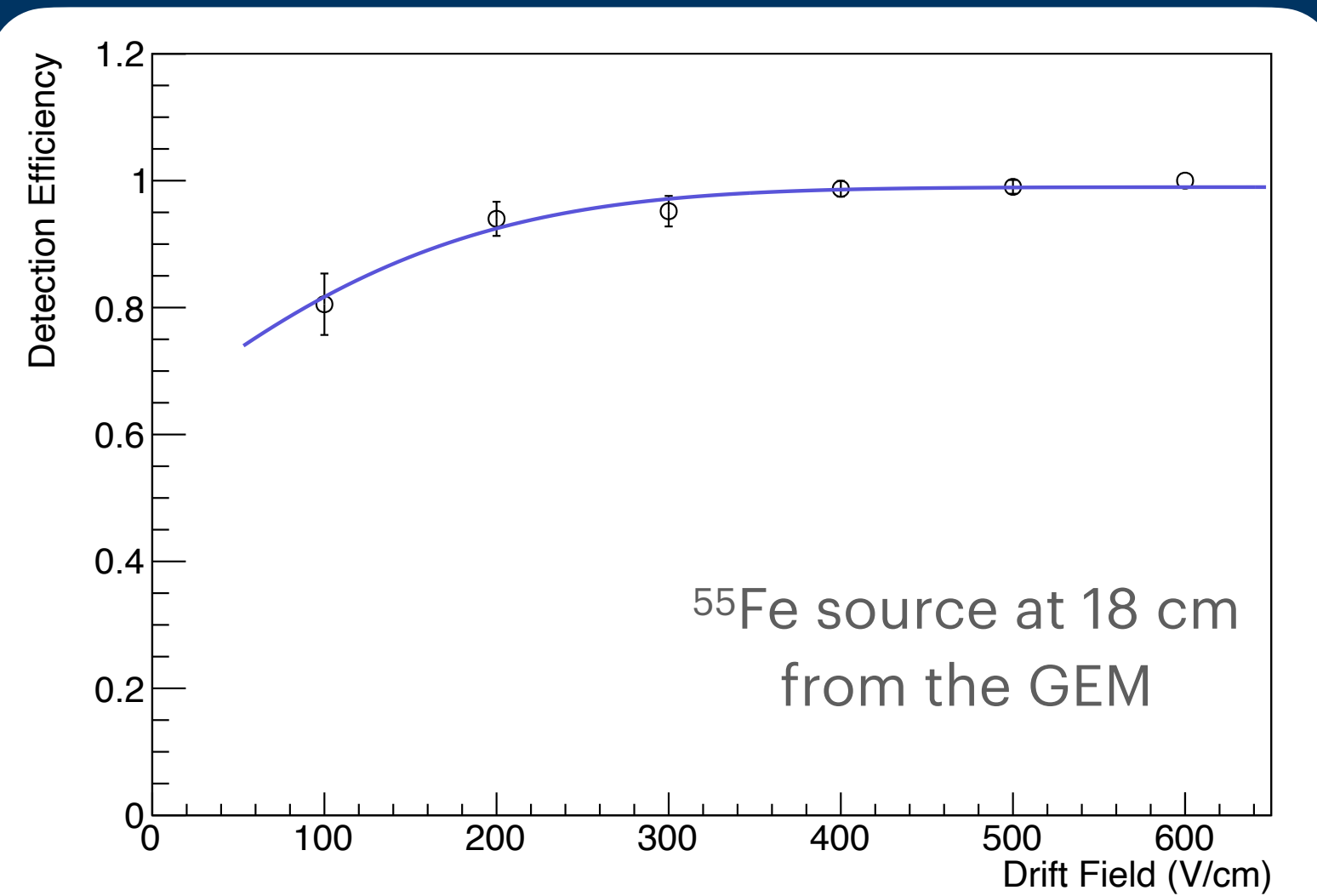
5 sec of natural background





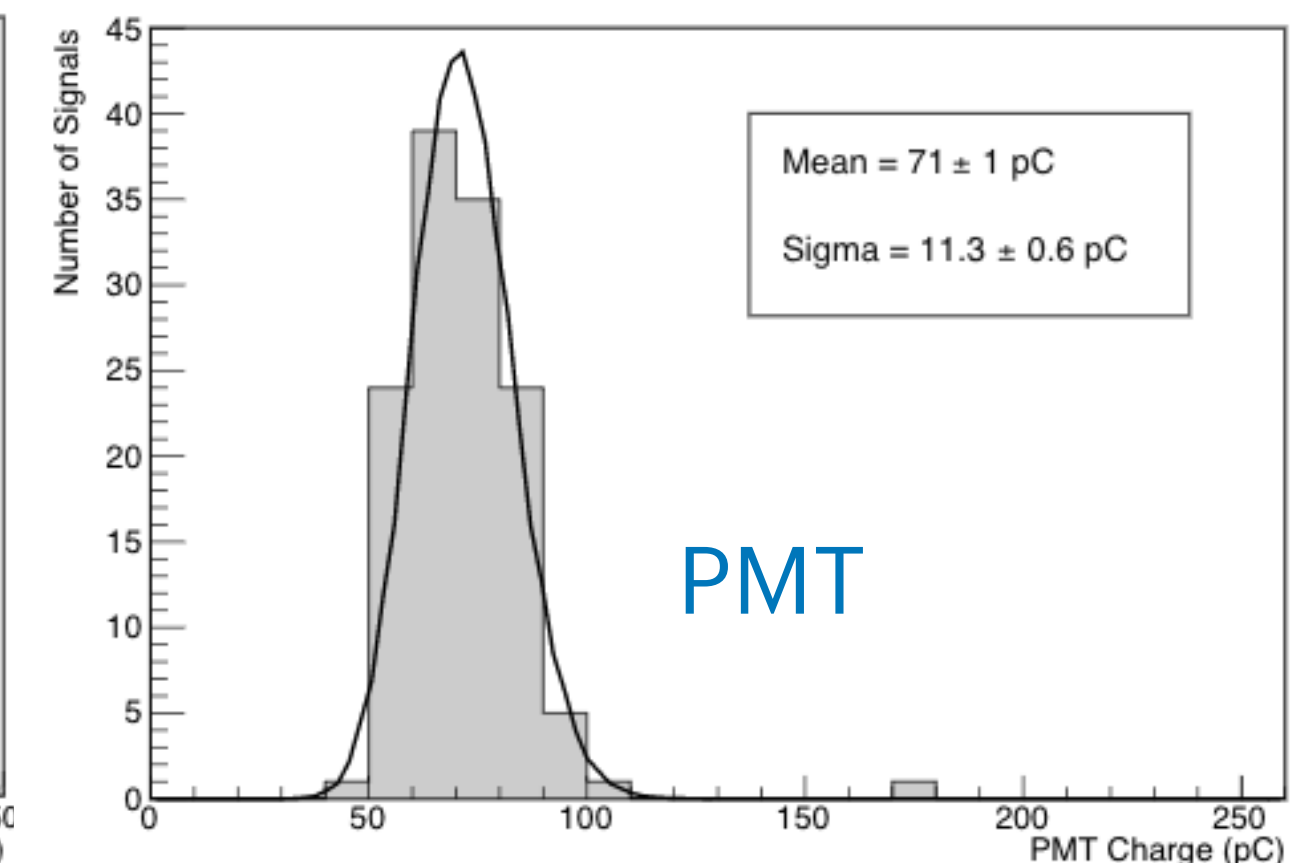
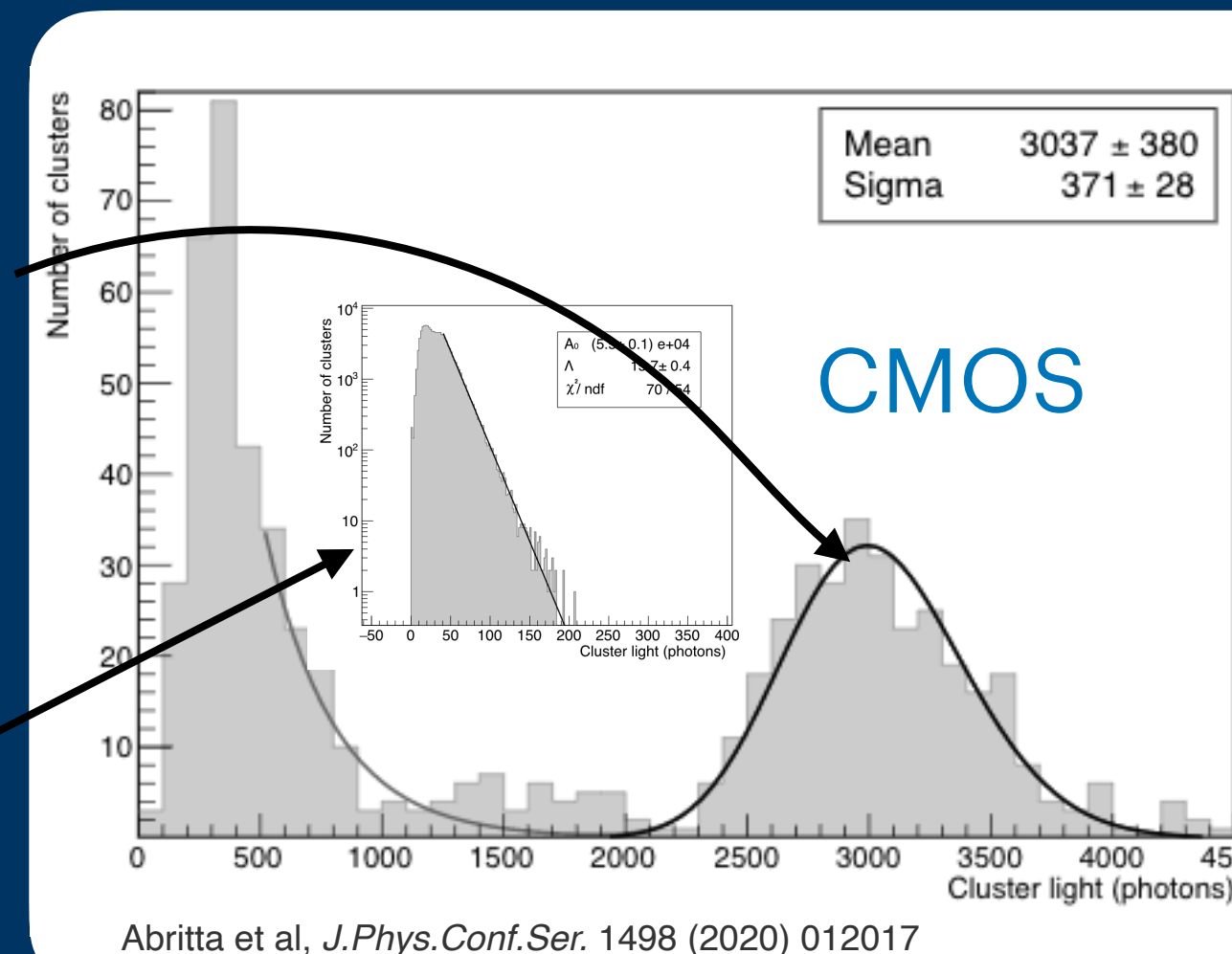
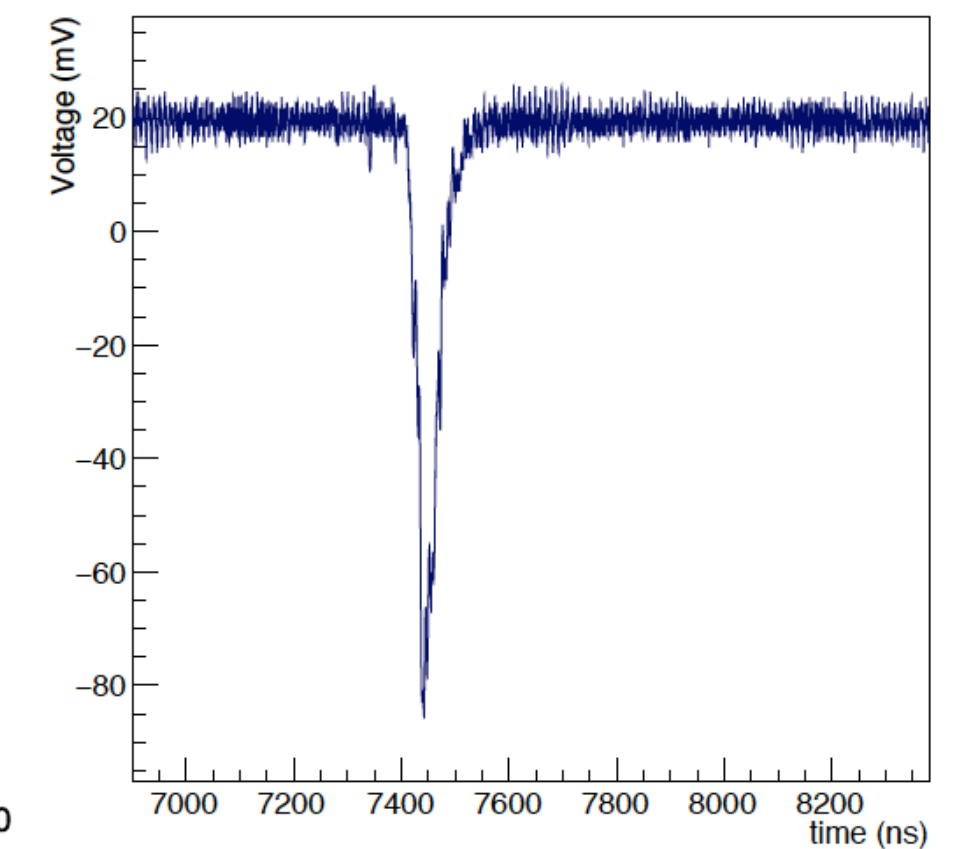
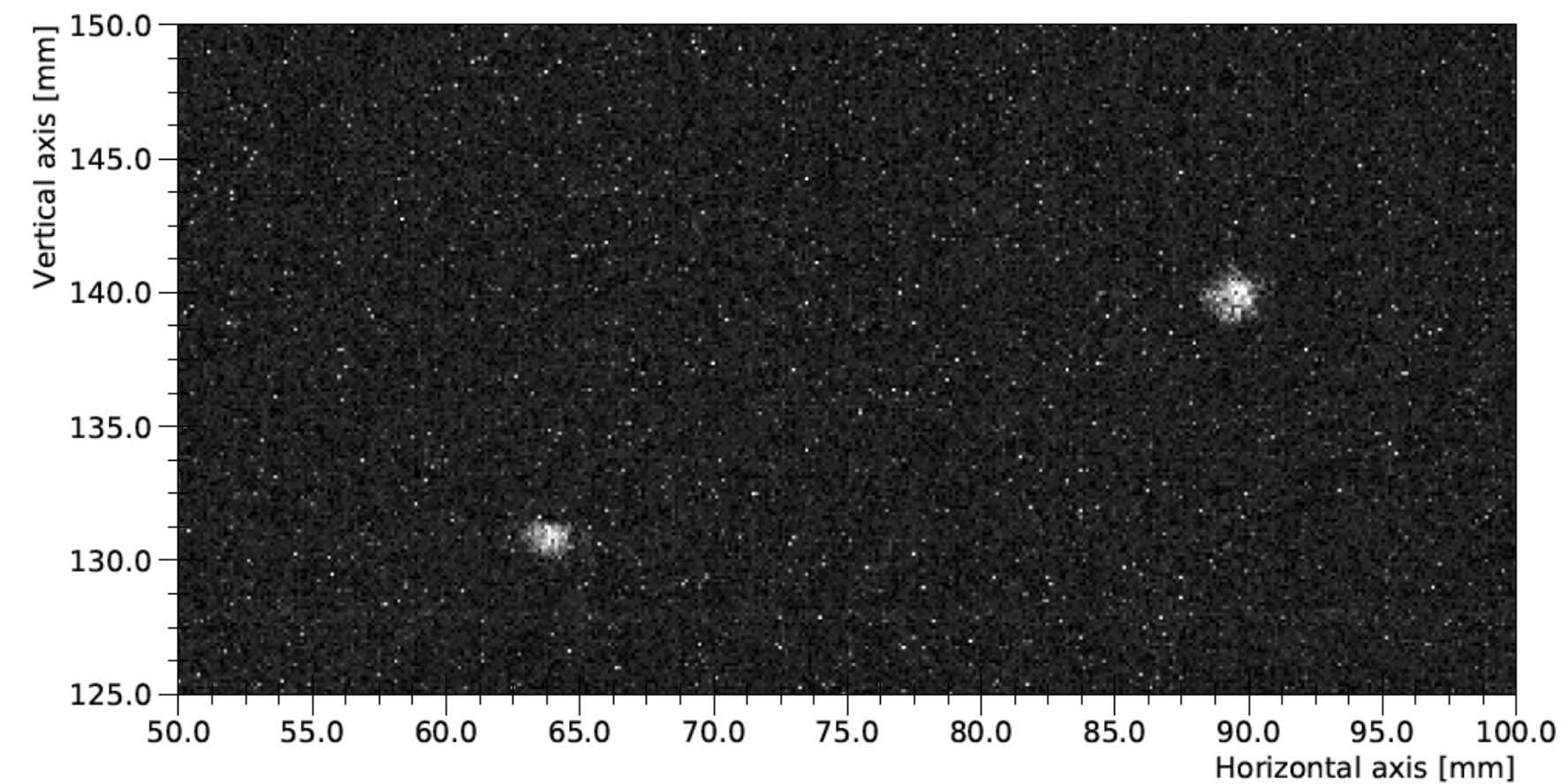
# PERFORMANCE WITH $^{55}\text{Fe}$ : SPOT SIGNALS

5.9 keV photons from  $^{55}\text{Fe}$  source were used to test detection efficiency and light yield.



500 photons per keV

Sensor noise below 200 photons (i.e. 400 eV)



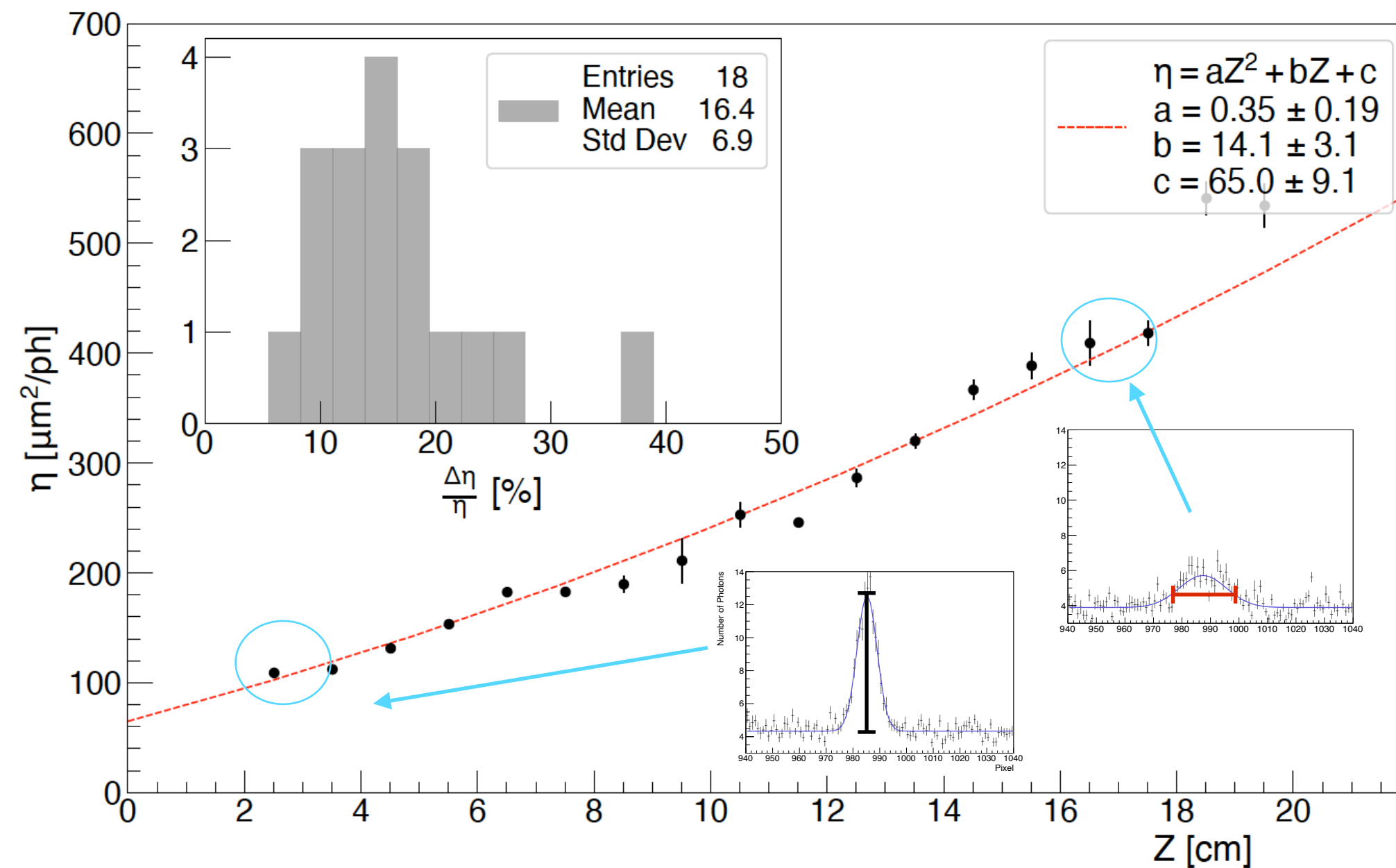


# Z RESOLUTION

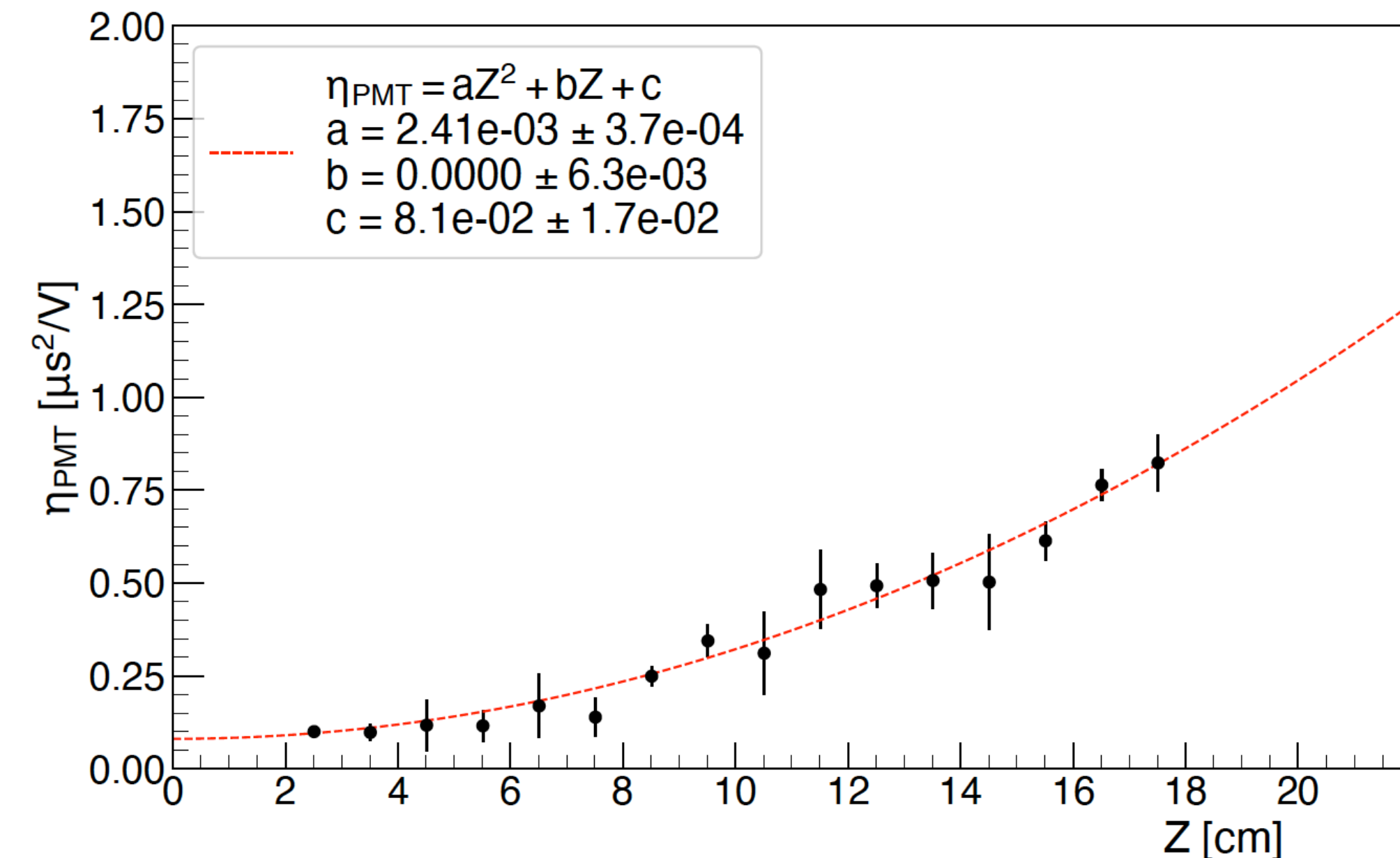
**Electron diffusion** in the drift gap can be exploited to evaluate the **z of the event**.

The **transverse light profile** and the **PMT signal waveform** are expected to become **lower** and **larger** as long as the event is **farther** from the GEM;

Since the width (S) increases and the amplitude (A) decreases with z, their ratio  $\eta = S/A$  increases



Antochi et al, Nucl.Instrum.Meth.A 999 (2021)

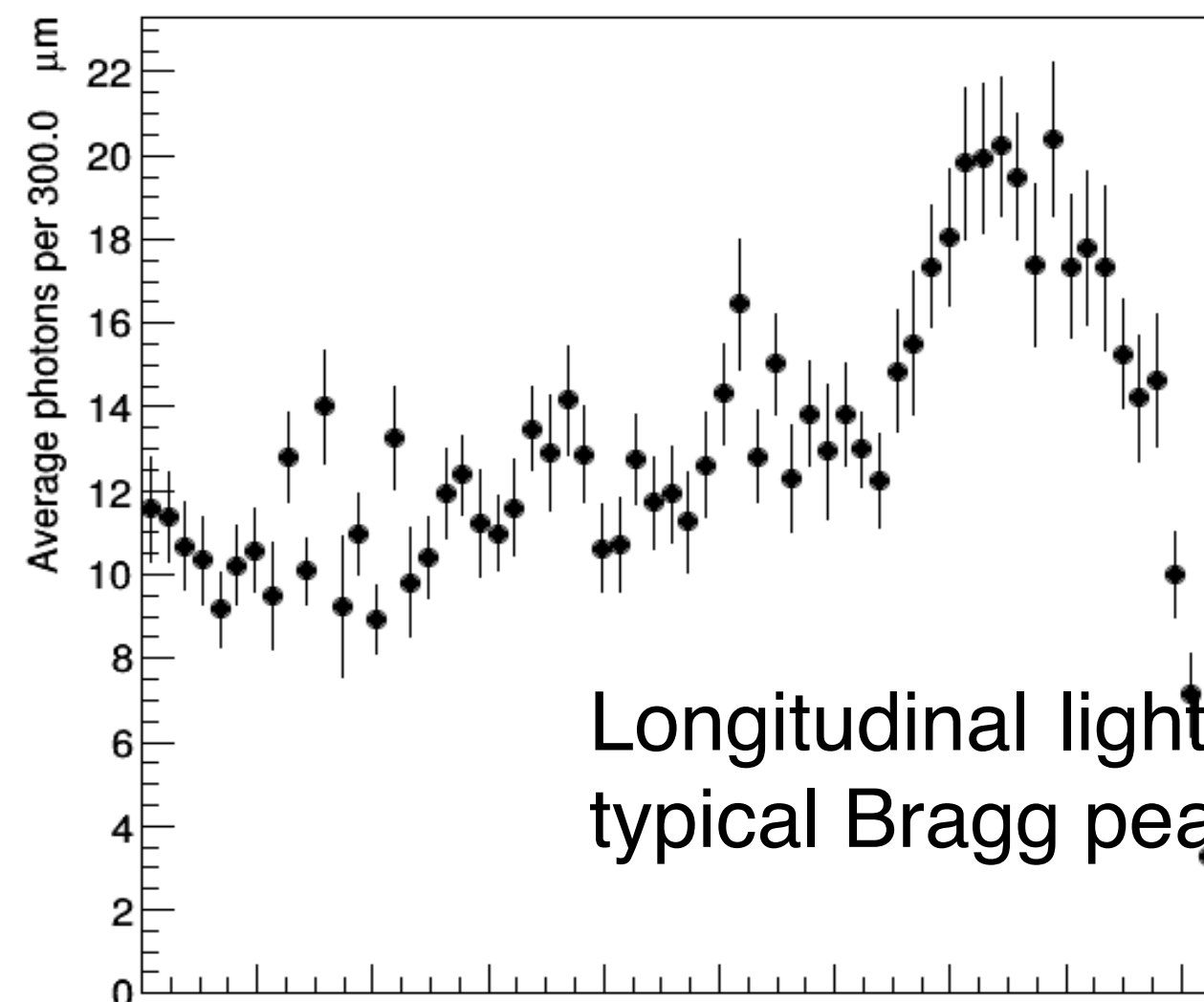


Both methods gives **15%** precision:  $\sigma_z \sim 7$  cm @ 50 cm



# NUCLEAR RECOILS IN LEMON

0.1s exposure @ 2.45 MeV neutrons  
Frascati Neutron Generator - ENEA



Longitudinal light profile shows a  
typical Bragg peak shape

**LEMON** was exposed to **neutrons** at Frascati Neutron Generator (**FNG-ENEA**) and to **AmBe** neutron source at **LNF**;

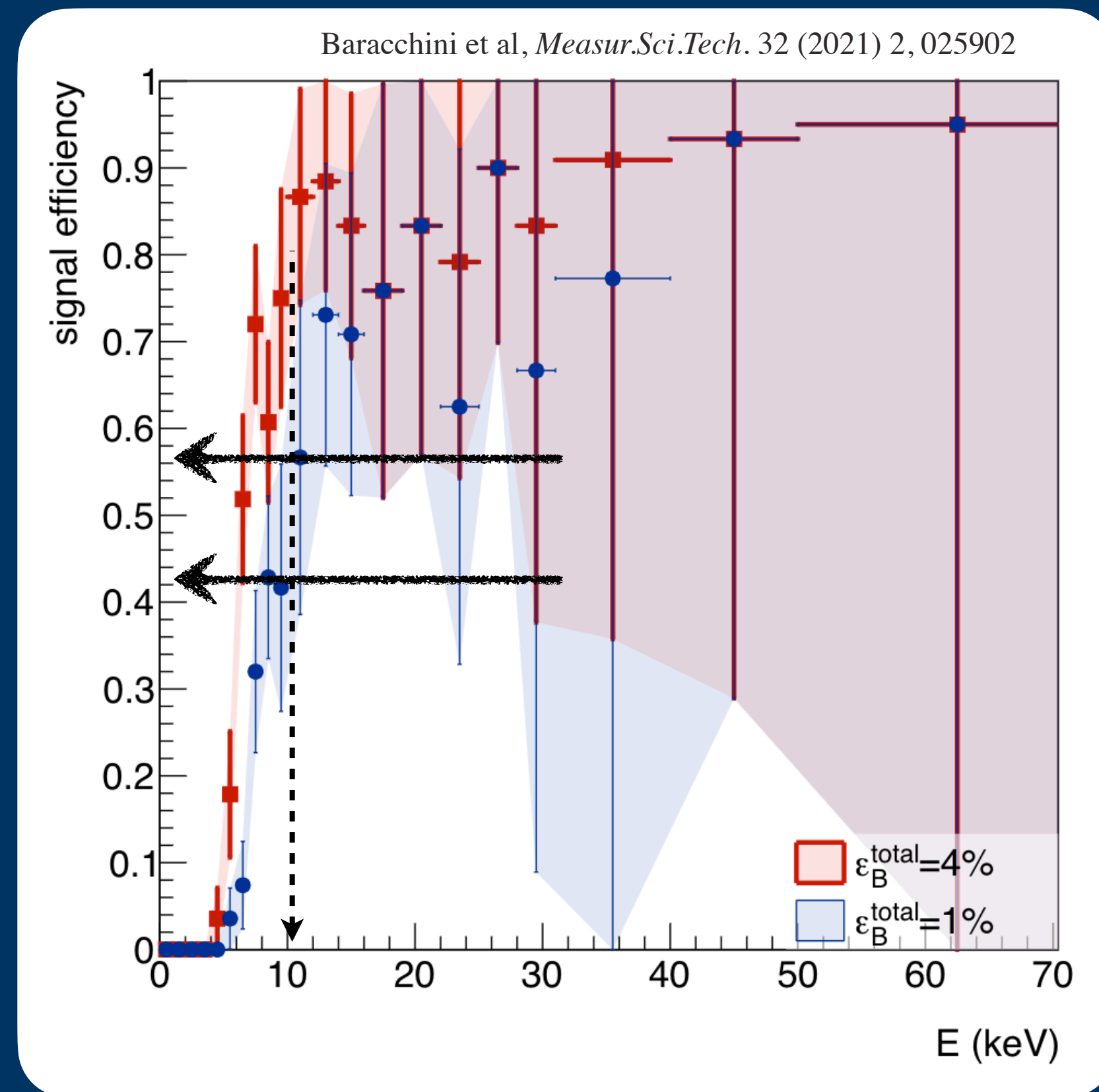
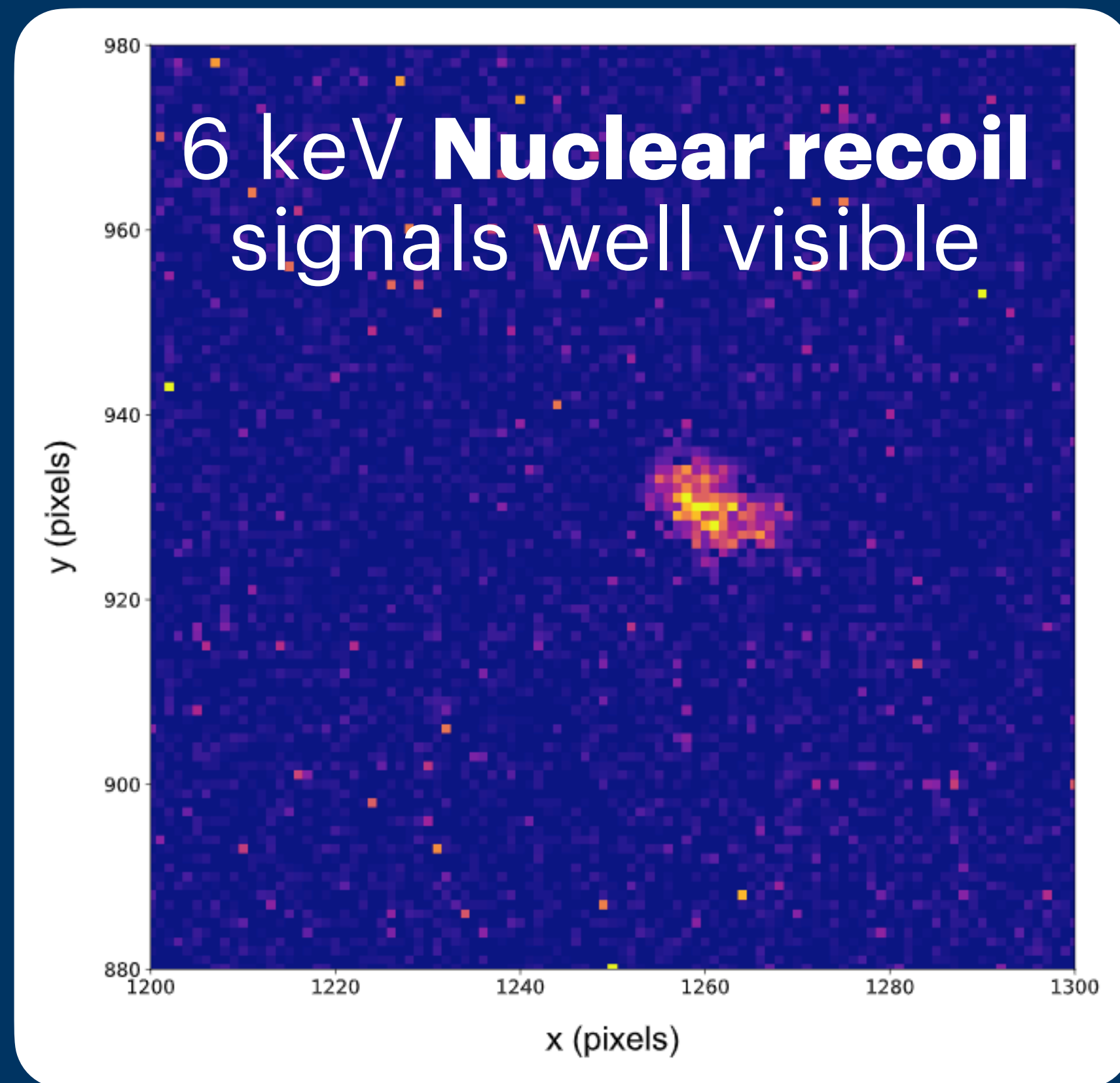
An **algorithm** was developed to **identify** the identity of **recoils** (either an electron or a nucleus) by exploiting the **topological informations** as shape, size and light density.



**Collaboration** with IDAO to exploit **ML-based** code to identify signals in the images



# PERFORMANCE WITH NUCLEAR RECOILS



A sizeable NR detection efficiency was measured:

- **40%** at 6 keV;

- **55%** at 10 keV;

In the same conditions more than **99% (95%)**  **$^{55}\text{Fe}$  photons** were **rejected**

First attempt to prove experimentally **rejection** capability **below 10 keV**

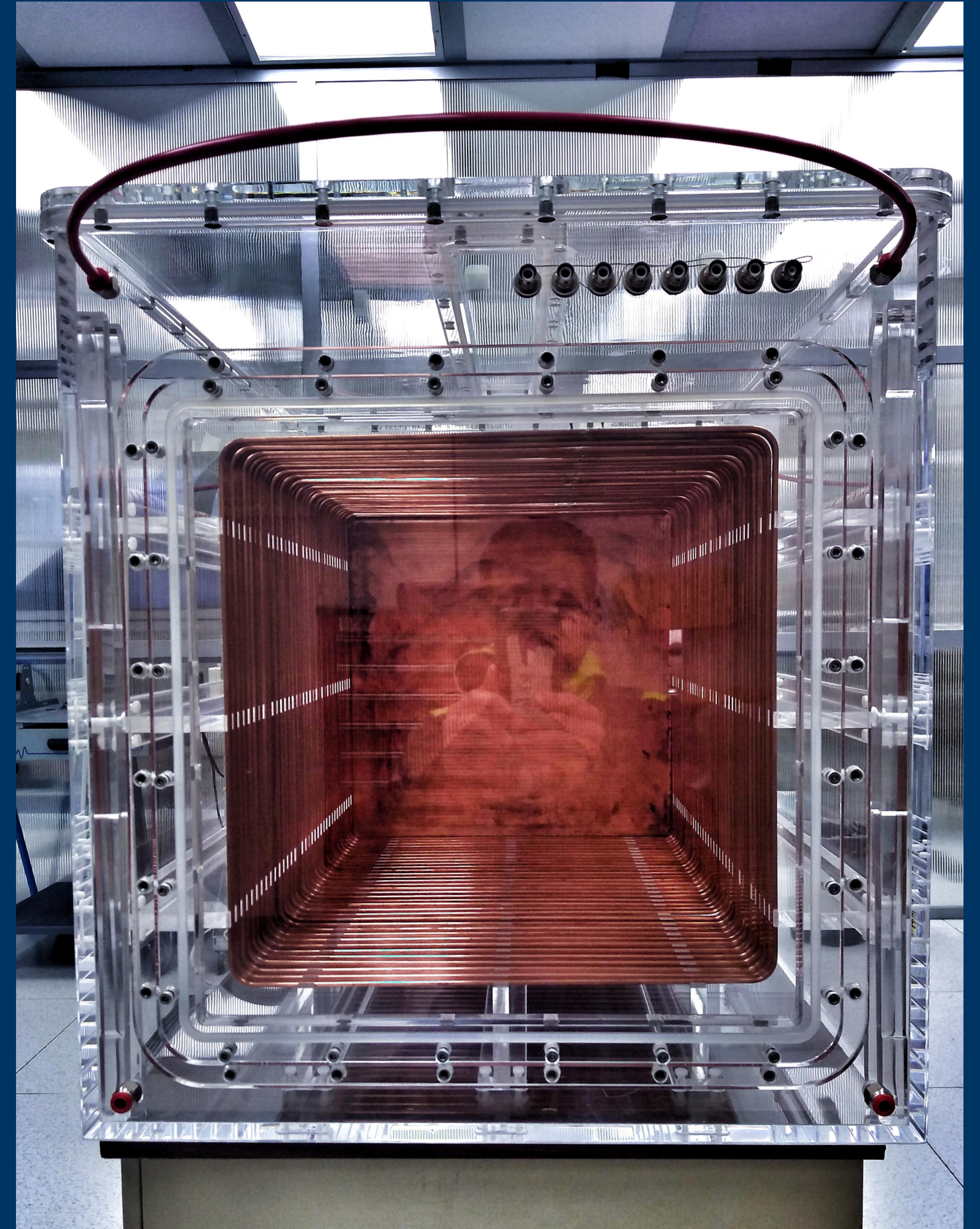
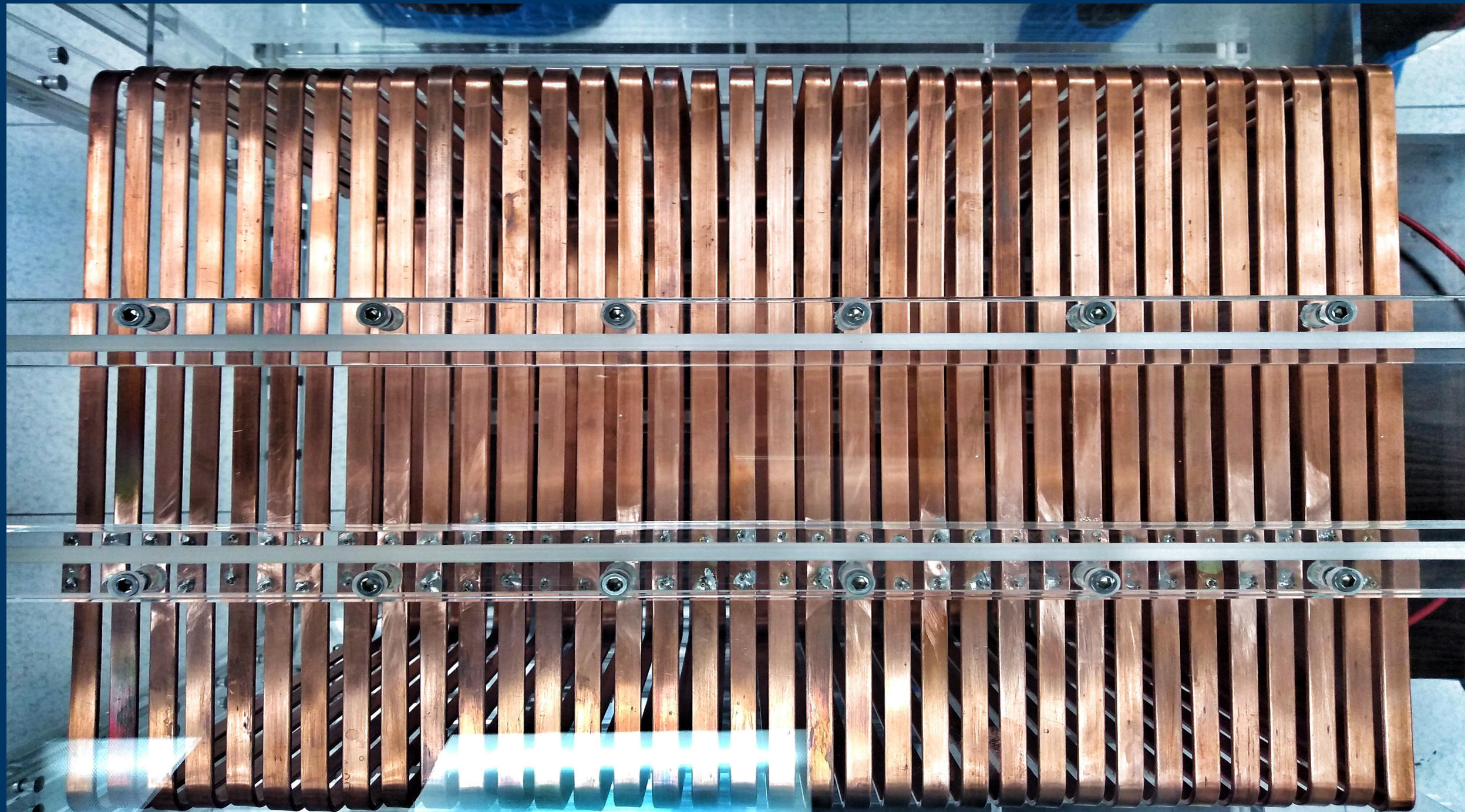


# LIME: LARGE IMAGING MODULE

**50 litres** sensitive volume:

- **33 x 33 ~ 1000 cm<sup>2</sup>** GEM surface;
- **50 cm** drift path;

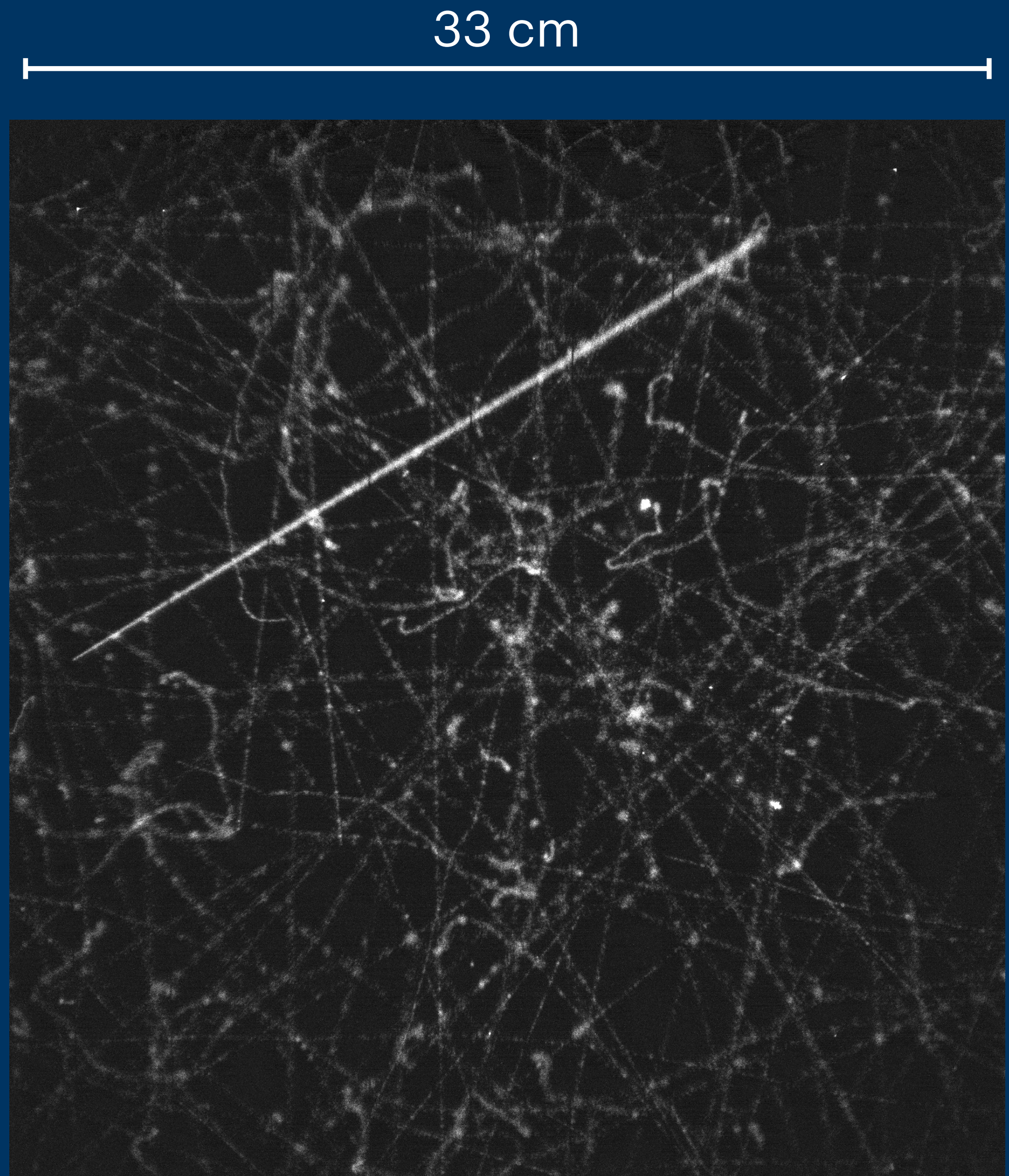
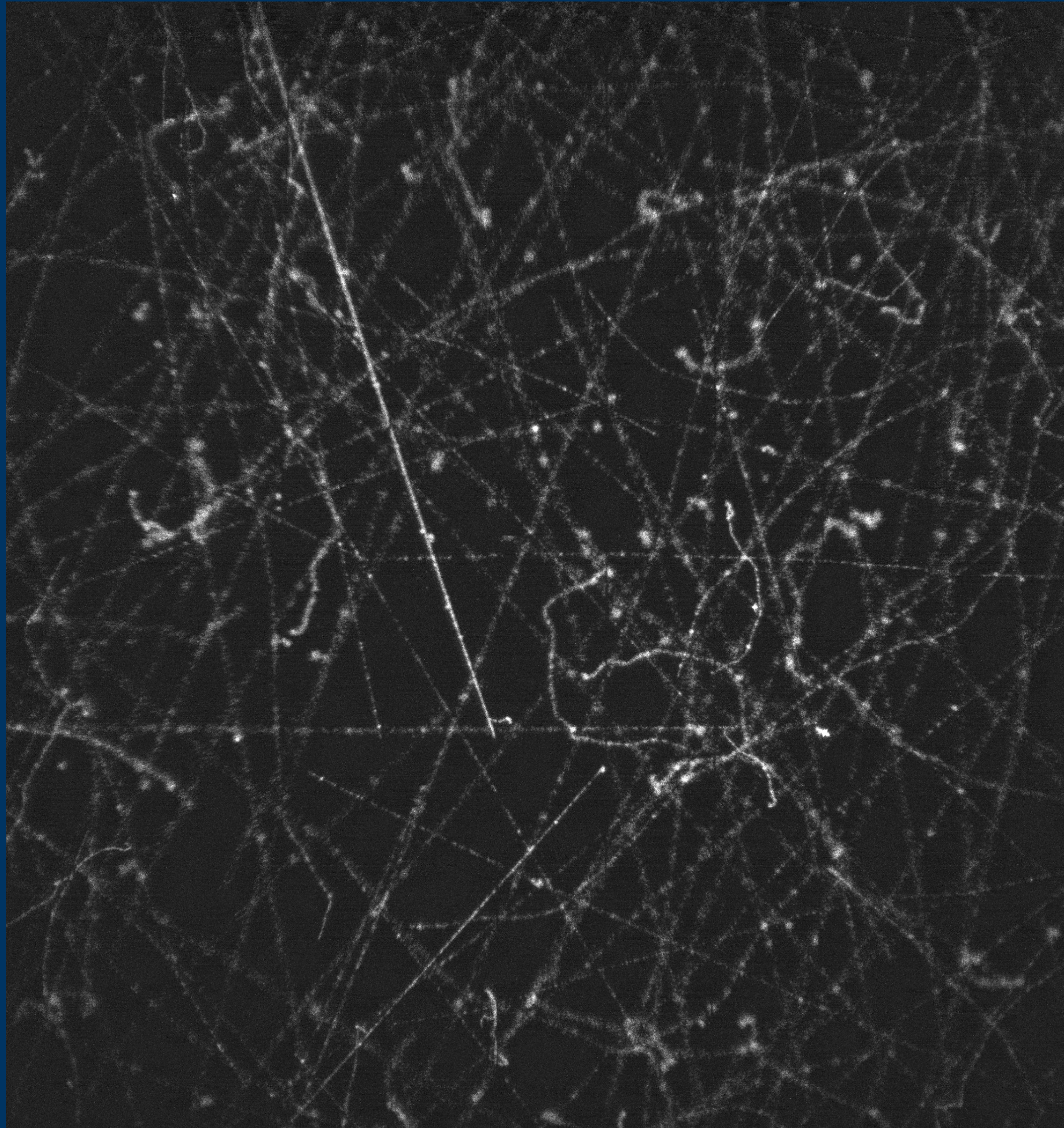
**Copper ring** field cage



**Acrylic** gas vessel



# LIME: IMAGES



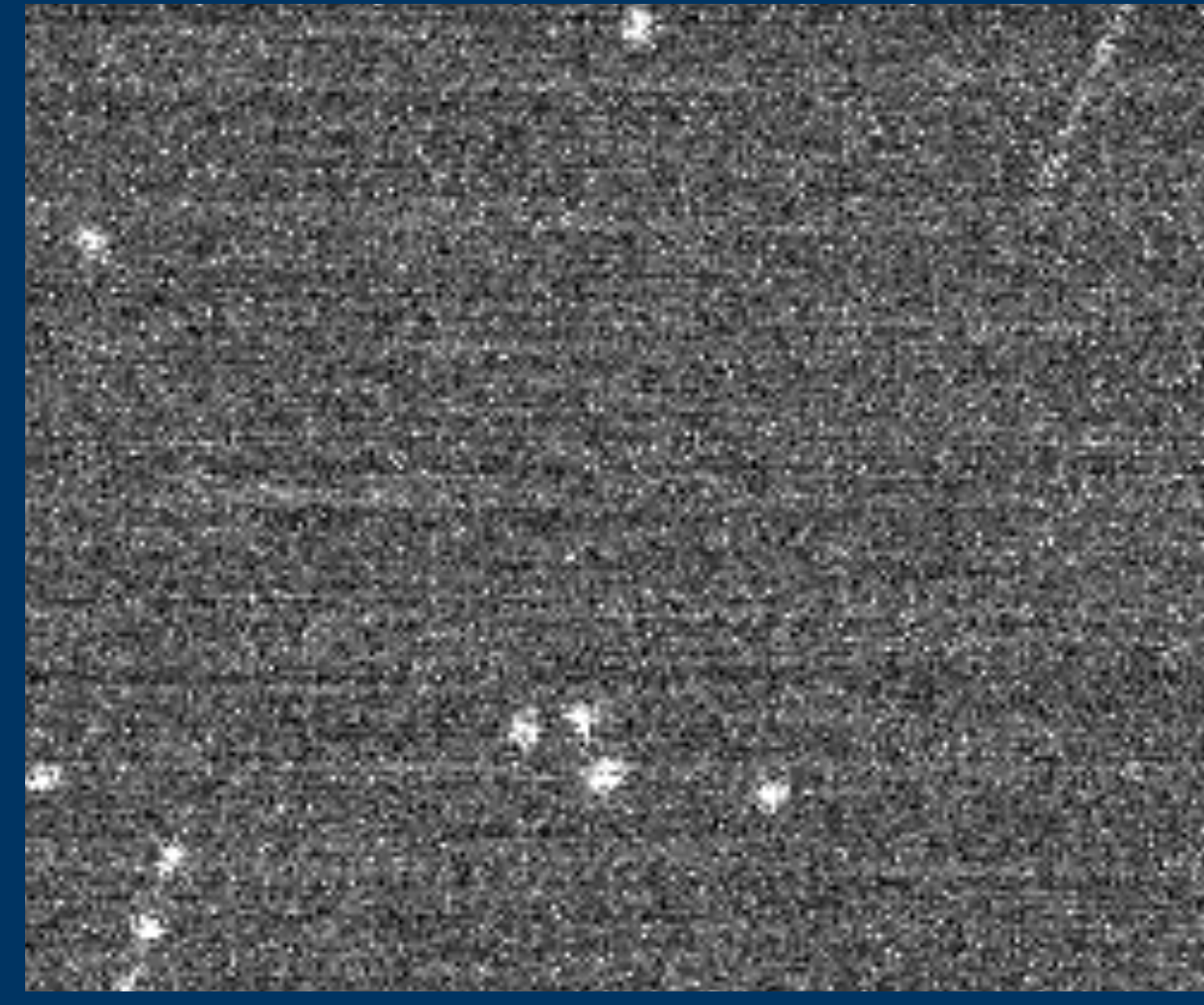
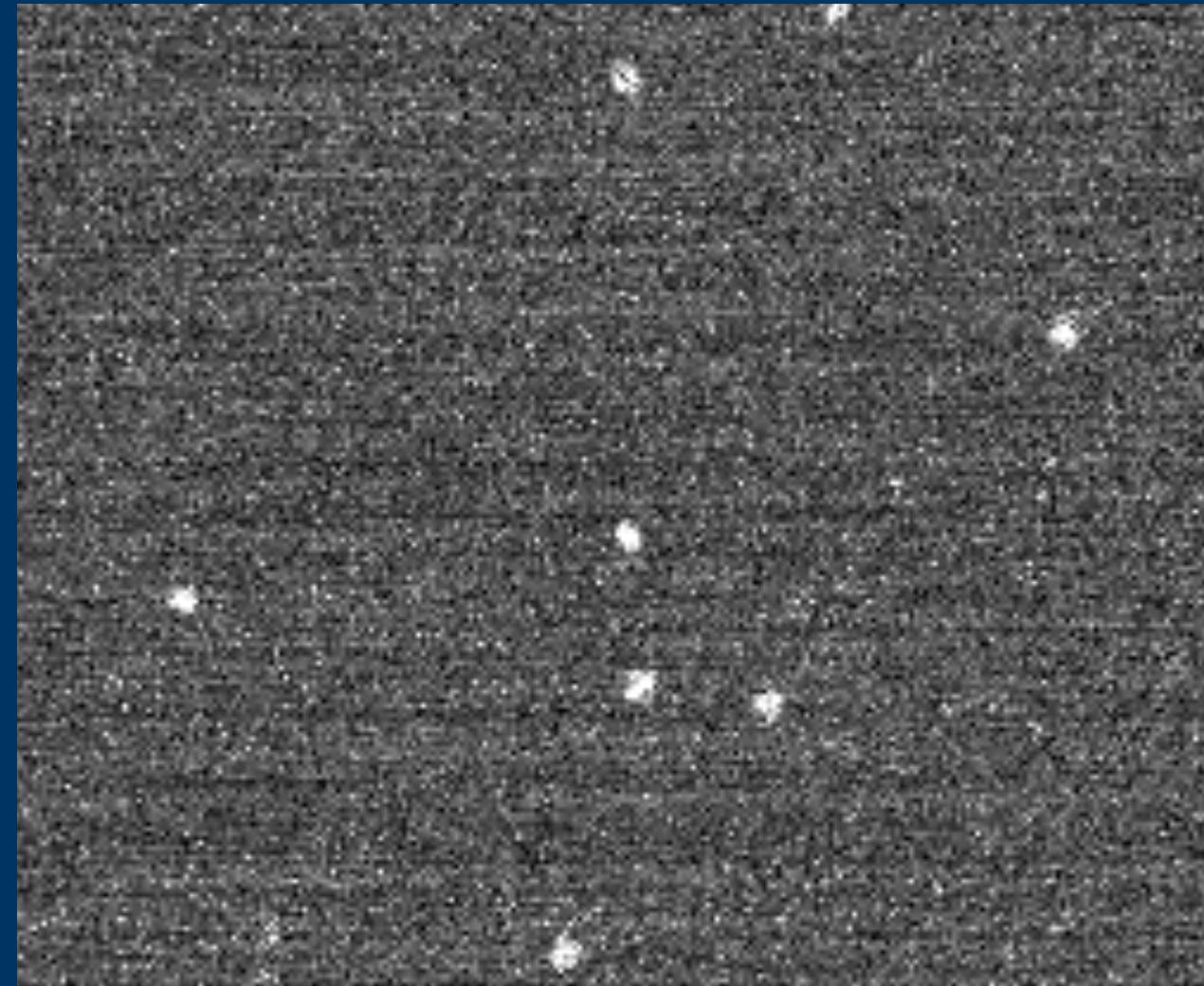
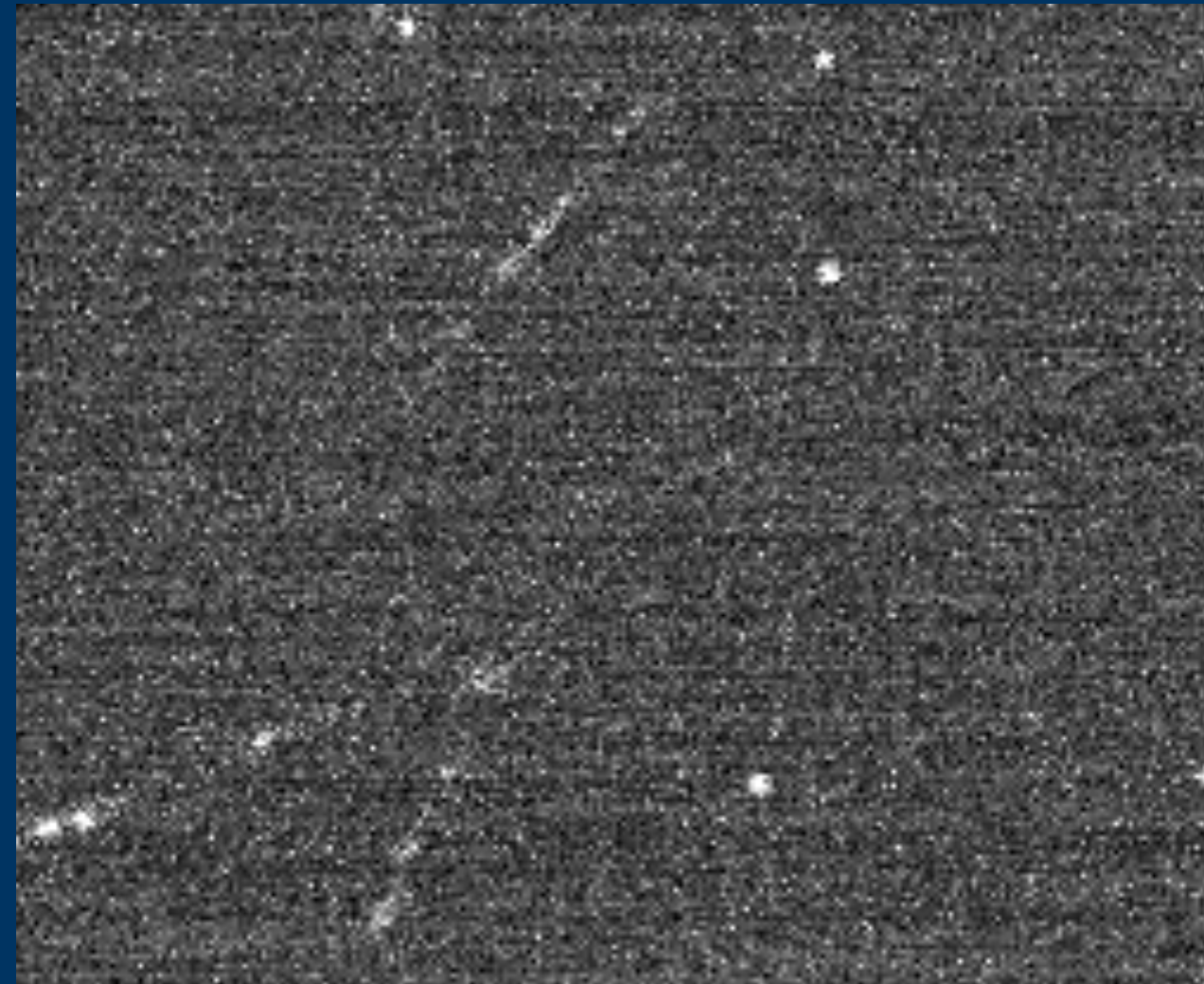


# PERFORMANCE WITH $^{55}\text{Fe}$ : SPOT SIGNALS

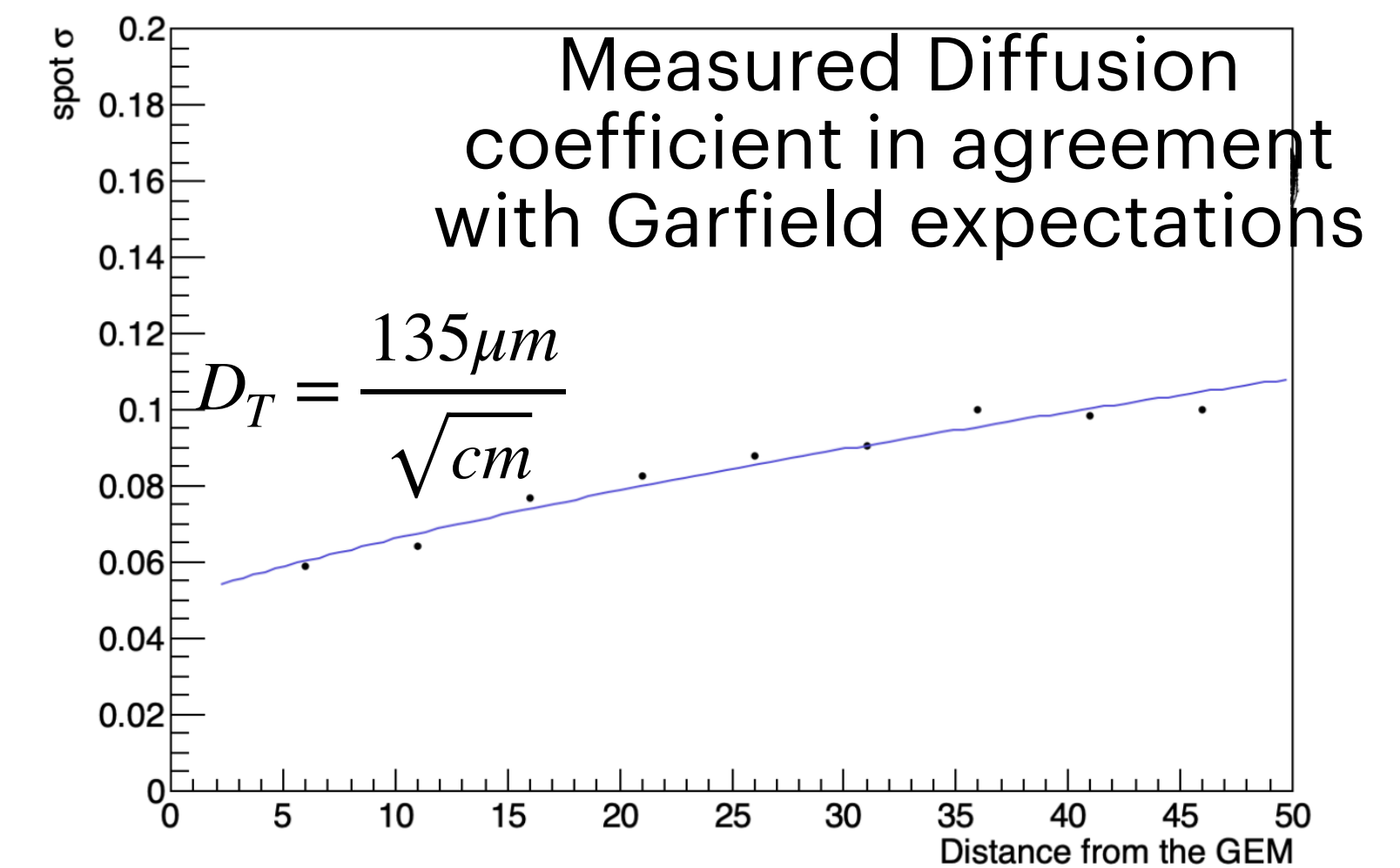
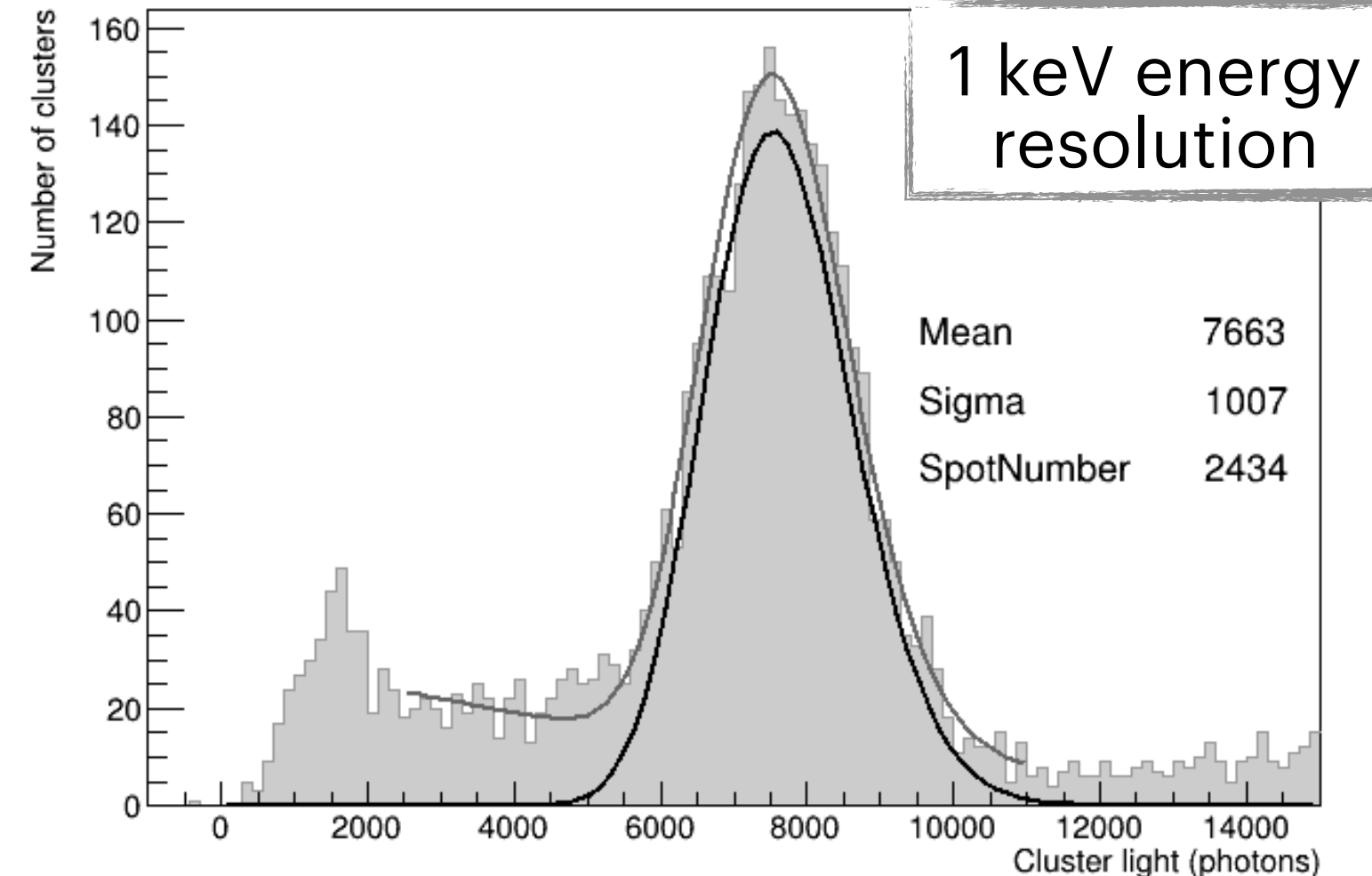
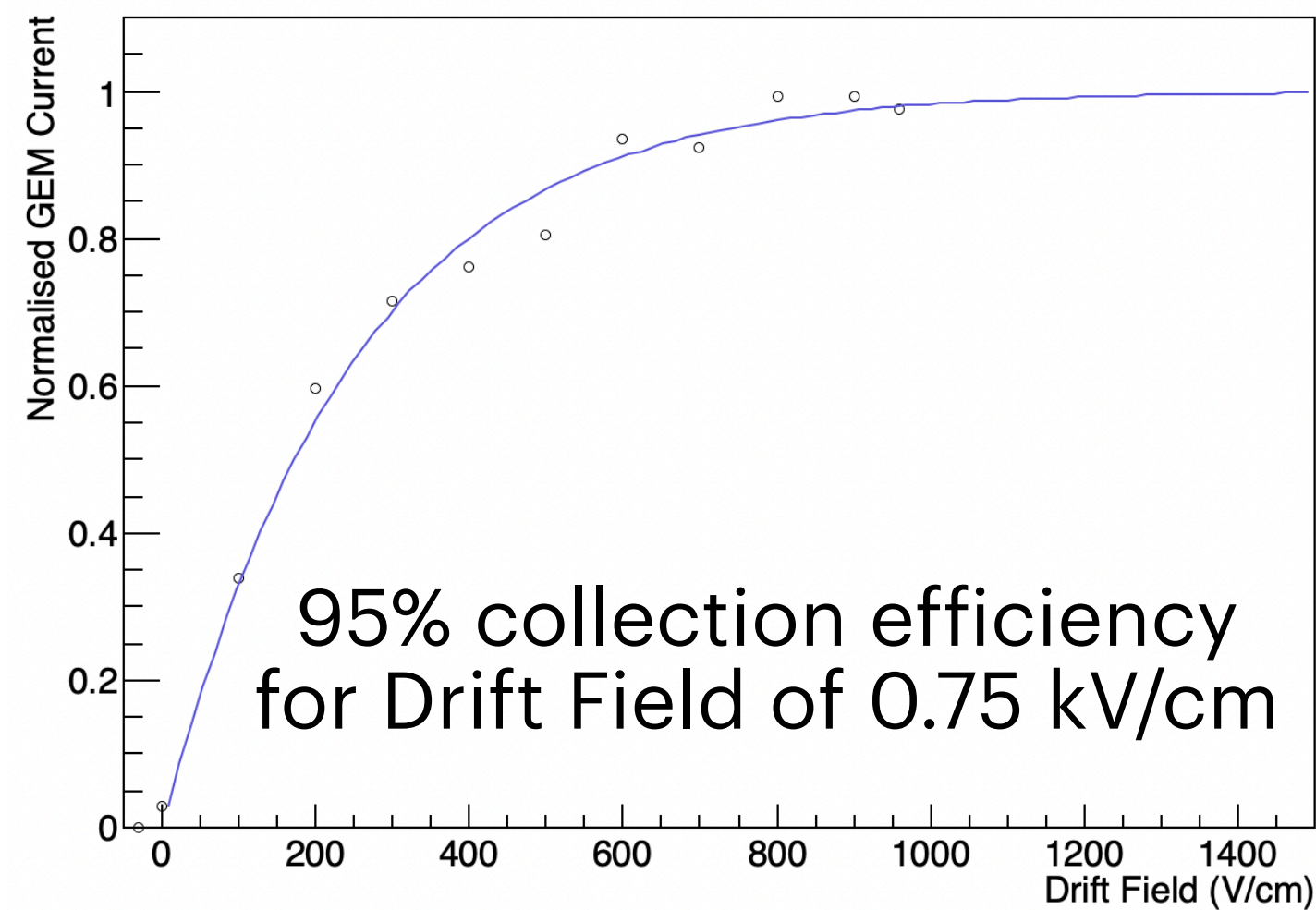
■ 5 cm from GEMs

■ 20 cm from GEMs

■ 45 cm from GEMs



Diffusion effect visible





# NOT ONLY SPOTS

Ti 4.5 keV

Fe 6 keV

Cu 8 keV

Rb 15 keV

Mo 18 keV

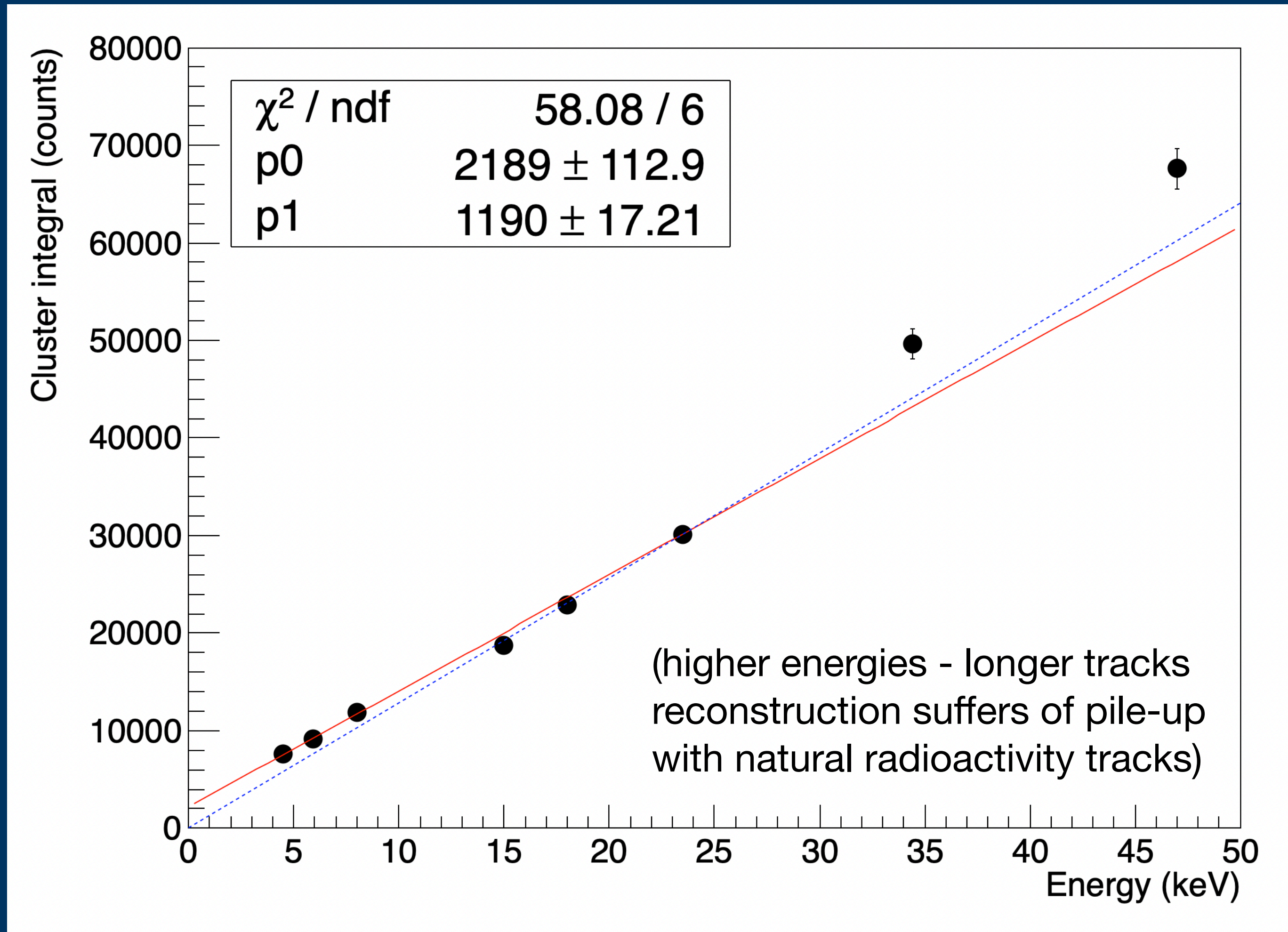
Ag 24 keV

Ba 35 keV

While below 10 keV signals are spot-like, electrons with larger energies travel in gas.



# RESPONSE LINEARITY



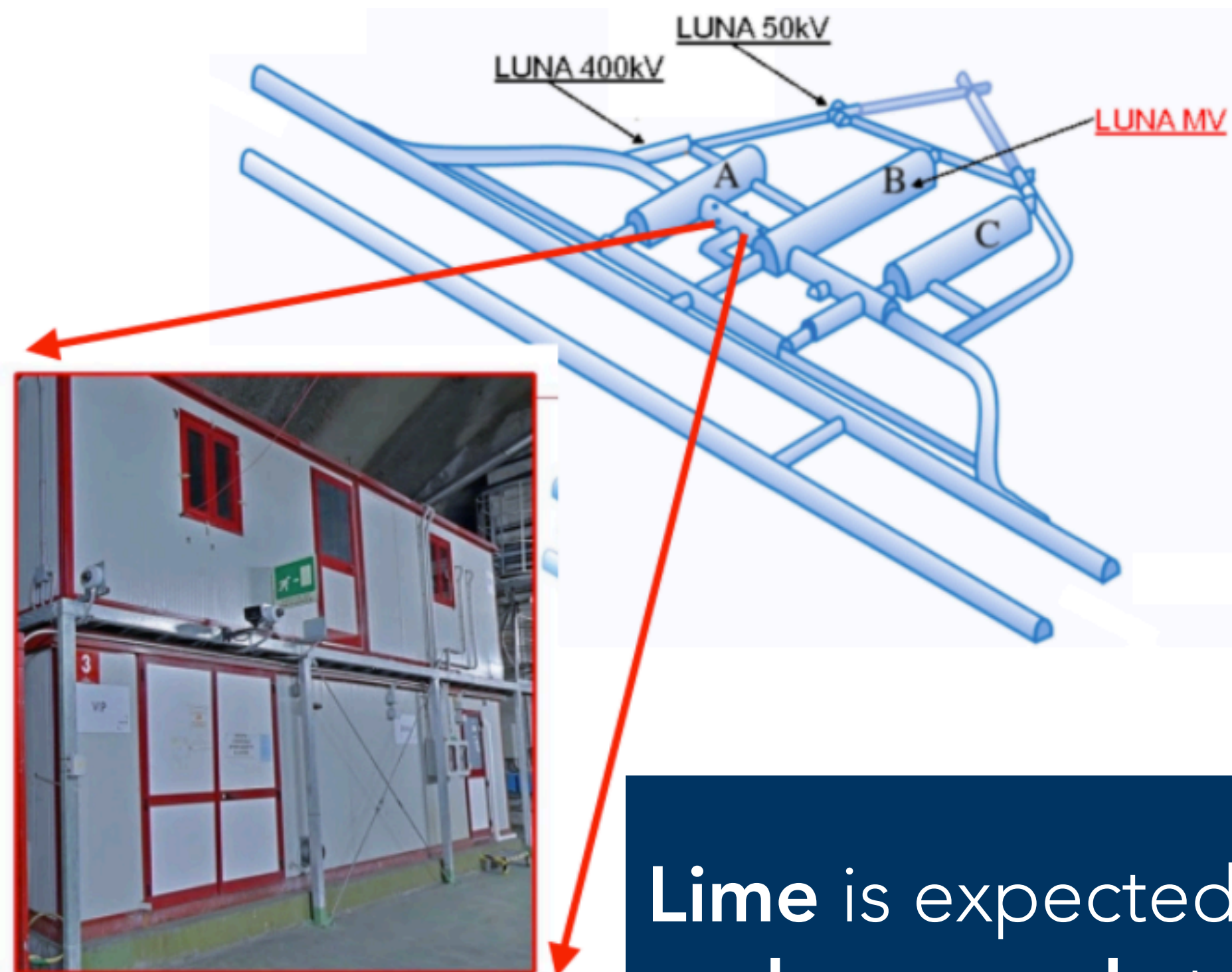
A preliminary analysis allowed to obtain a very good linearity in Energy response in the range 4.5 keV - 45 keV;

The full collected statistics is now under evaluation;

Data with 3.5 keV (Calcium) are being analysed;

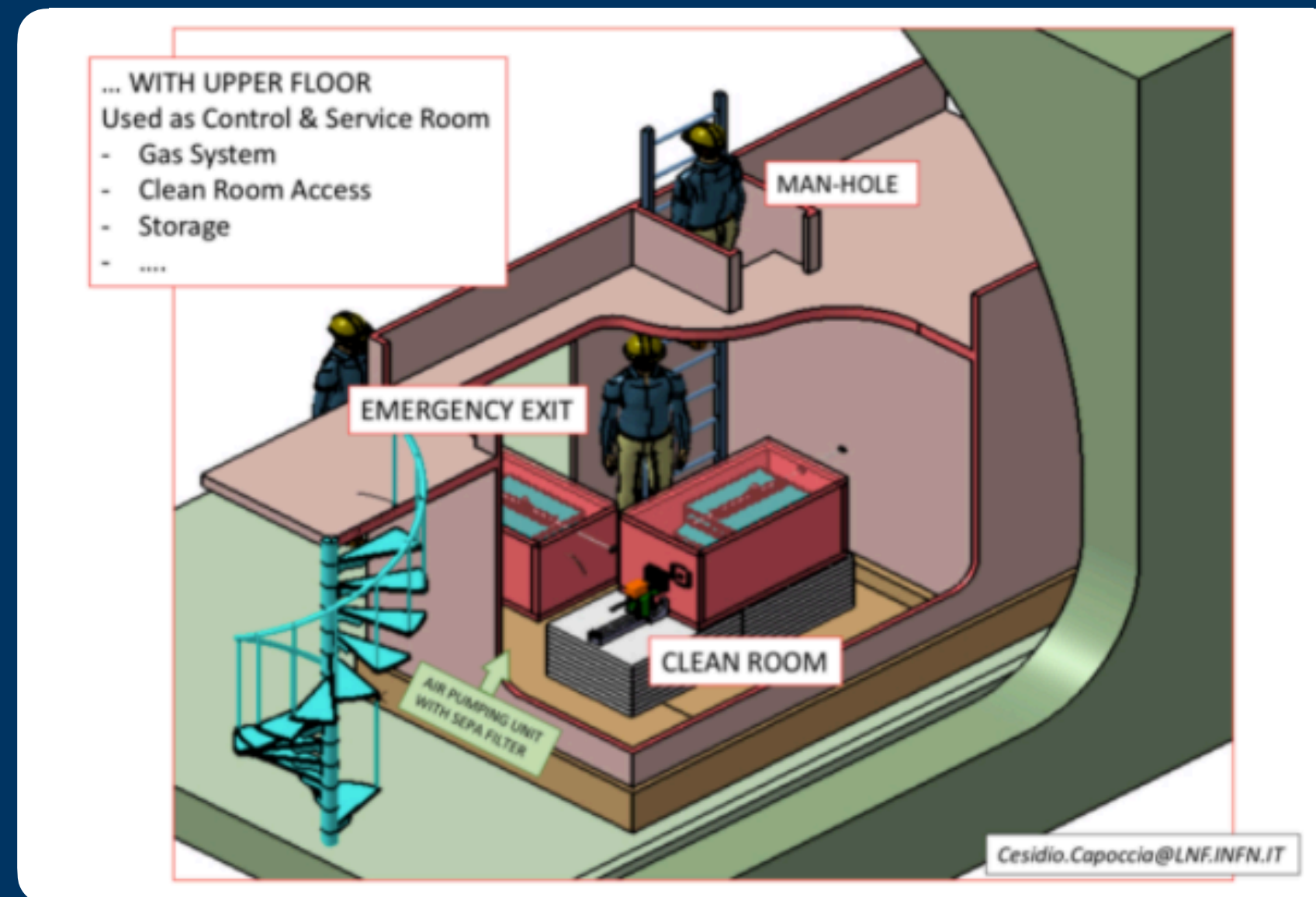


# LIME UNDERGROUND

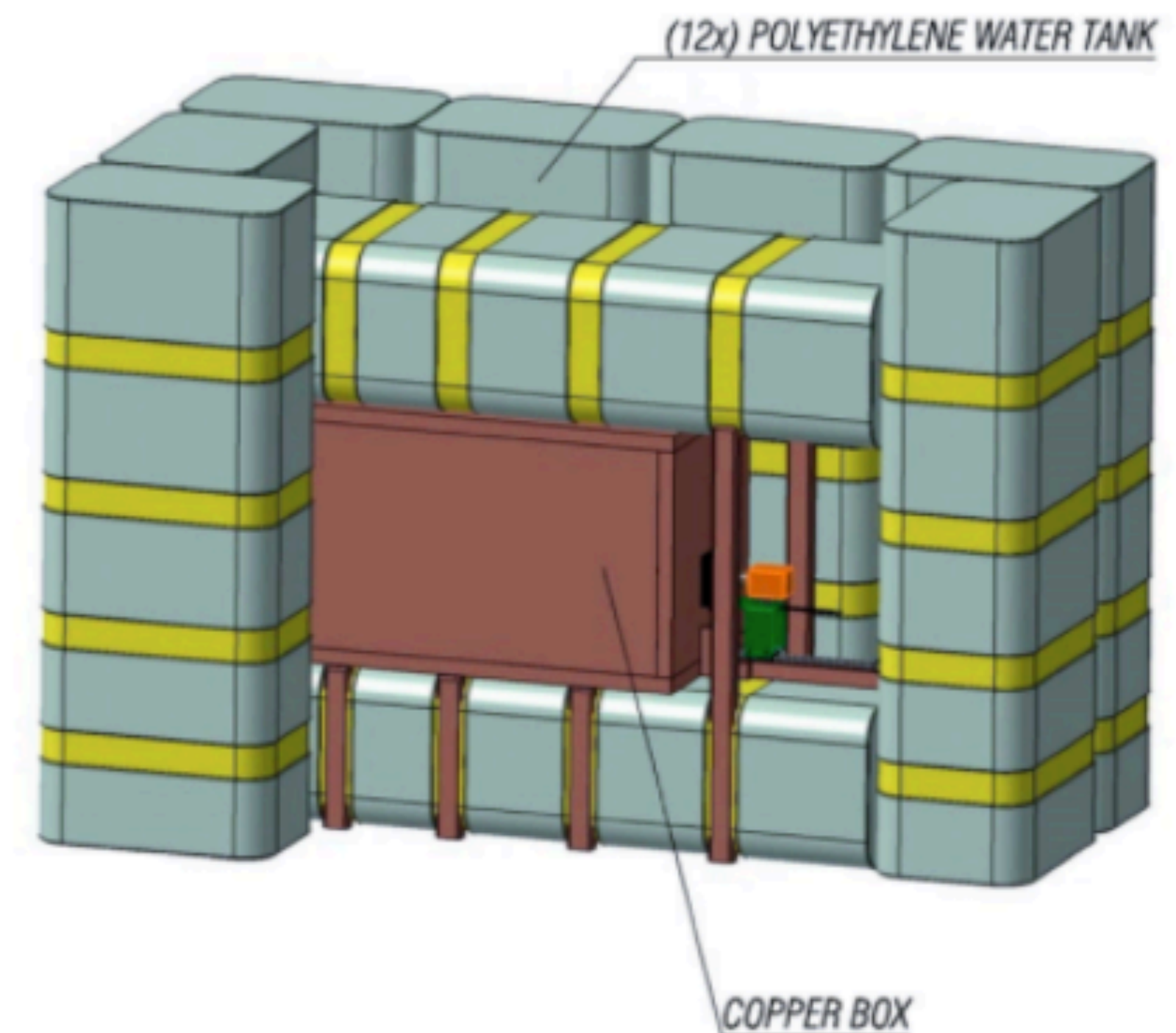


**Lime** is expected to be installed **underground** at LNGS (3600 m.w.e.) by 2021;

Then, **gamma** and **neutron shields** will be put in place to take data in shielded mode



Neutron and other background flux will be studied (activity funded by PRIN project Zero Radioactivity in Future Experiments)





# 1M<sup>3</sup> DEMONSTRATOR: BASELINE LAYOUT

**1 m<sup>3</sup>** of **He/CF<sub>4</sub> 60/40** (1.6 kg) at **atmospheric pressure** with a composed by two 50 cm long TPC with a central cathode and a drift field of about 1 kV/cm;

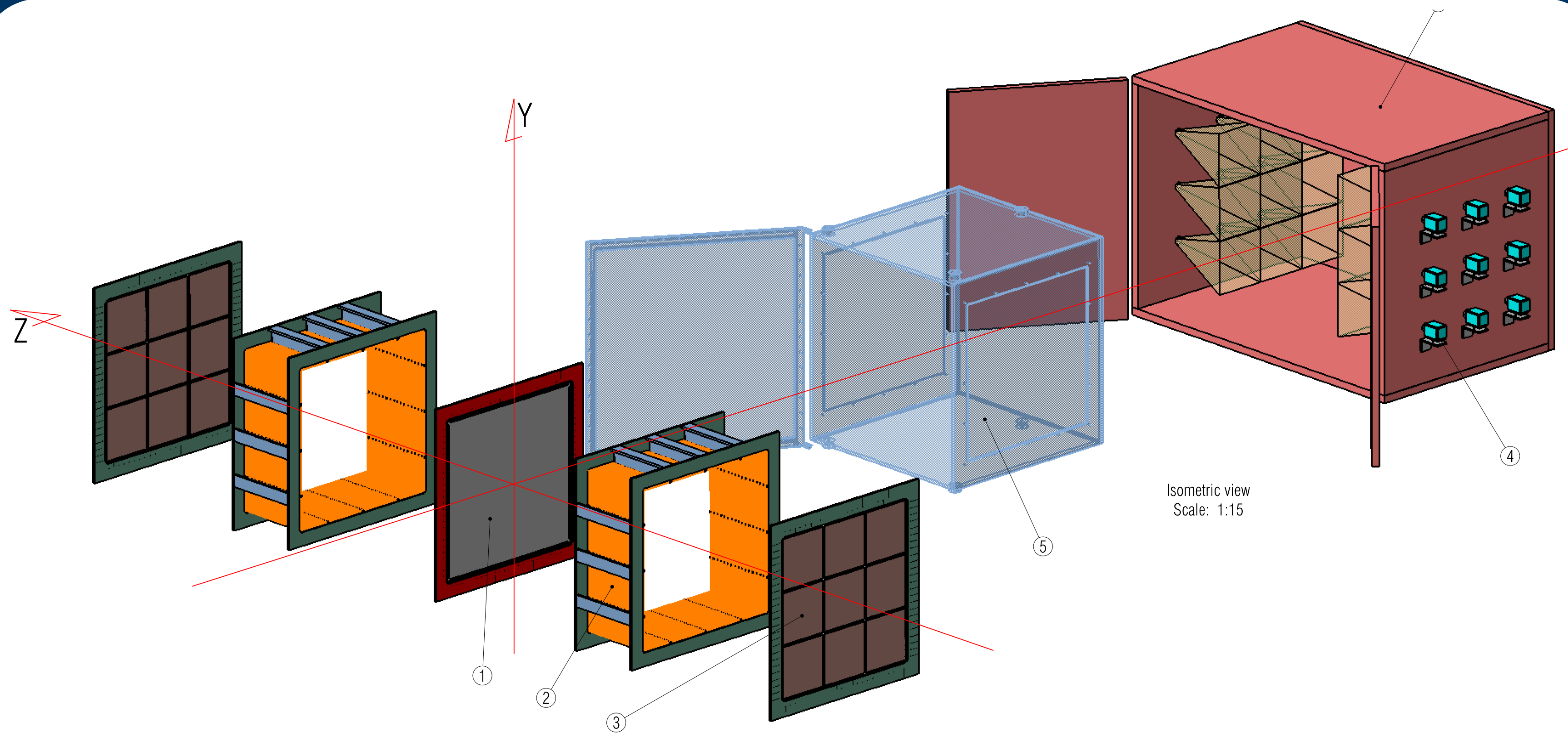
**Acrylic** vessel ensuring gas tightness and high voltage insulation;

Each side equipped by a 3x3 matrix of LIME-like:

- sCMOS sensor 65 cm away;
- Almost 10<sup>8</sup> readout pixels 165 x 165  $\mu\text{m}^2$
- Fast light detector (PMT or SiPM).

Radioactivity shielding:

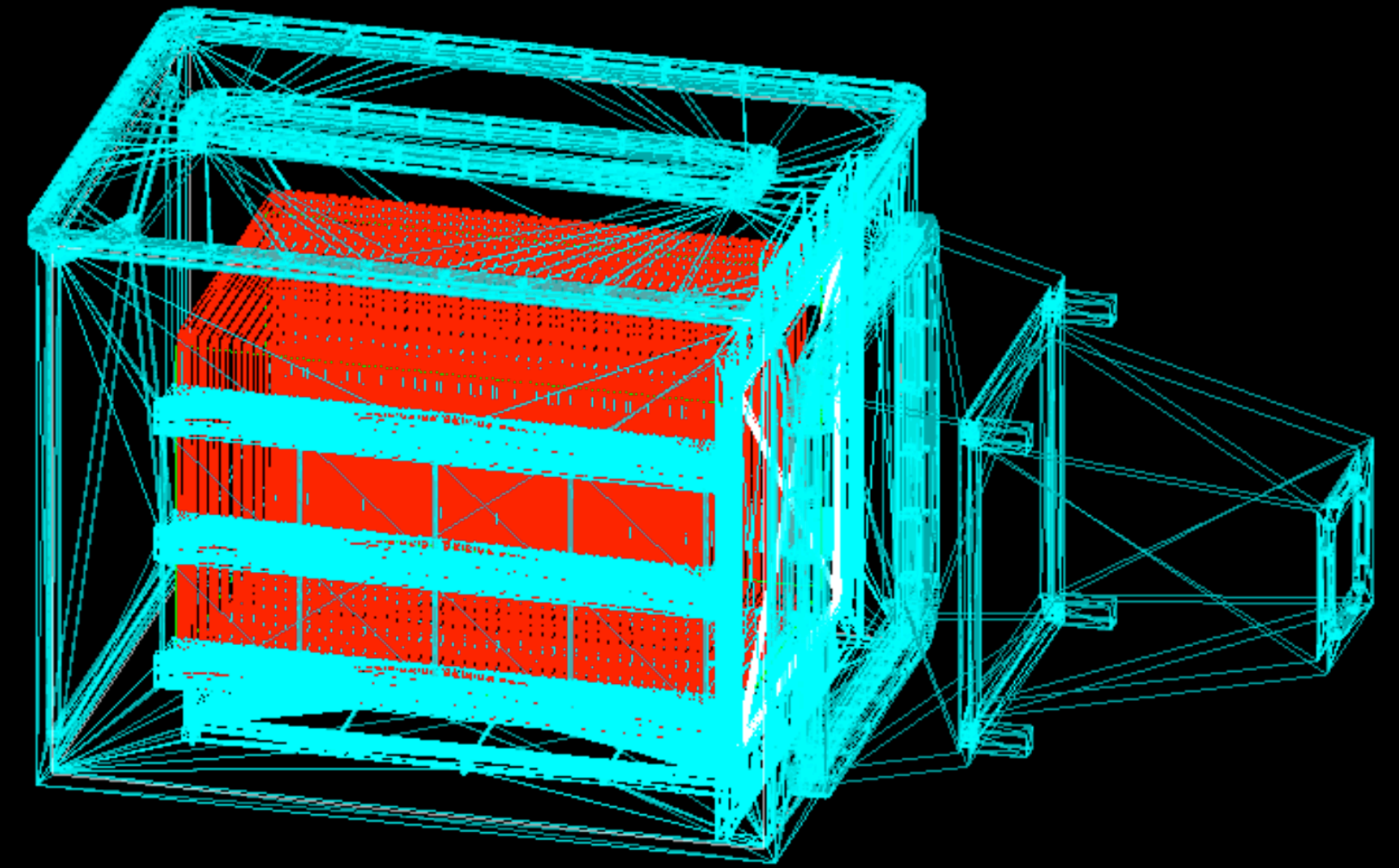
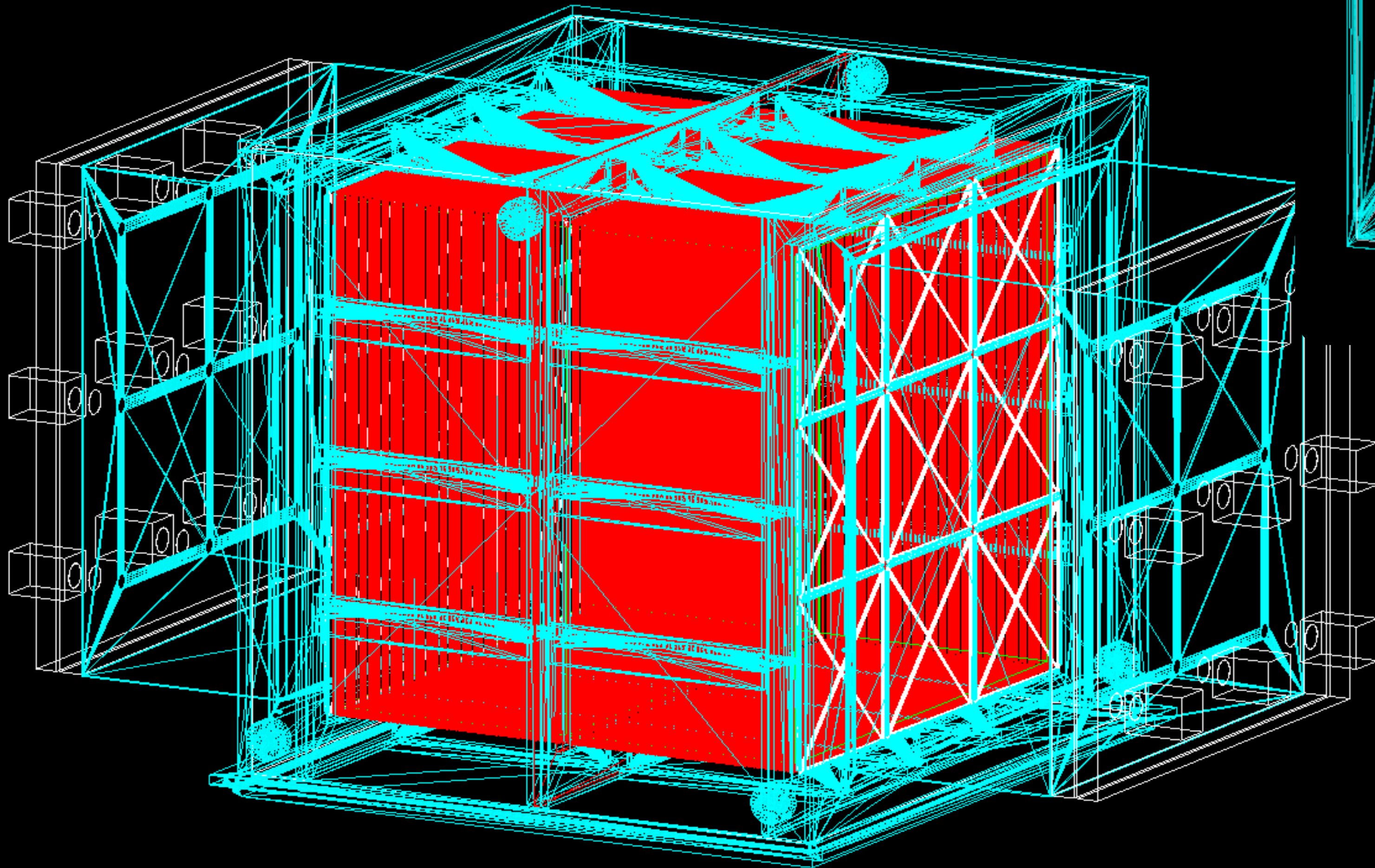
- **5 cm** thick **copper** box (Faraday cage too);
- **200 cm** of water.





# BACKGROUND STUDIES

Full Detector simulation in **GEANT4**

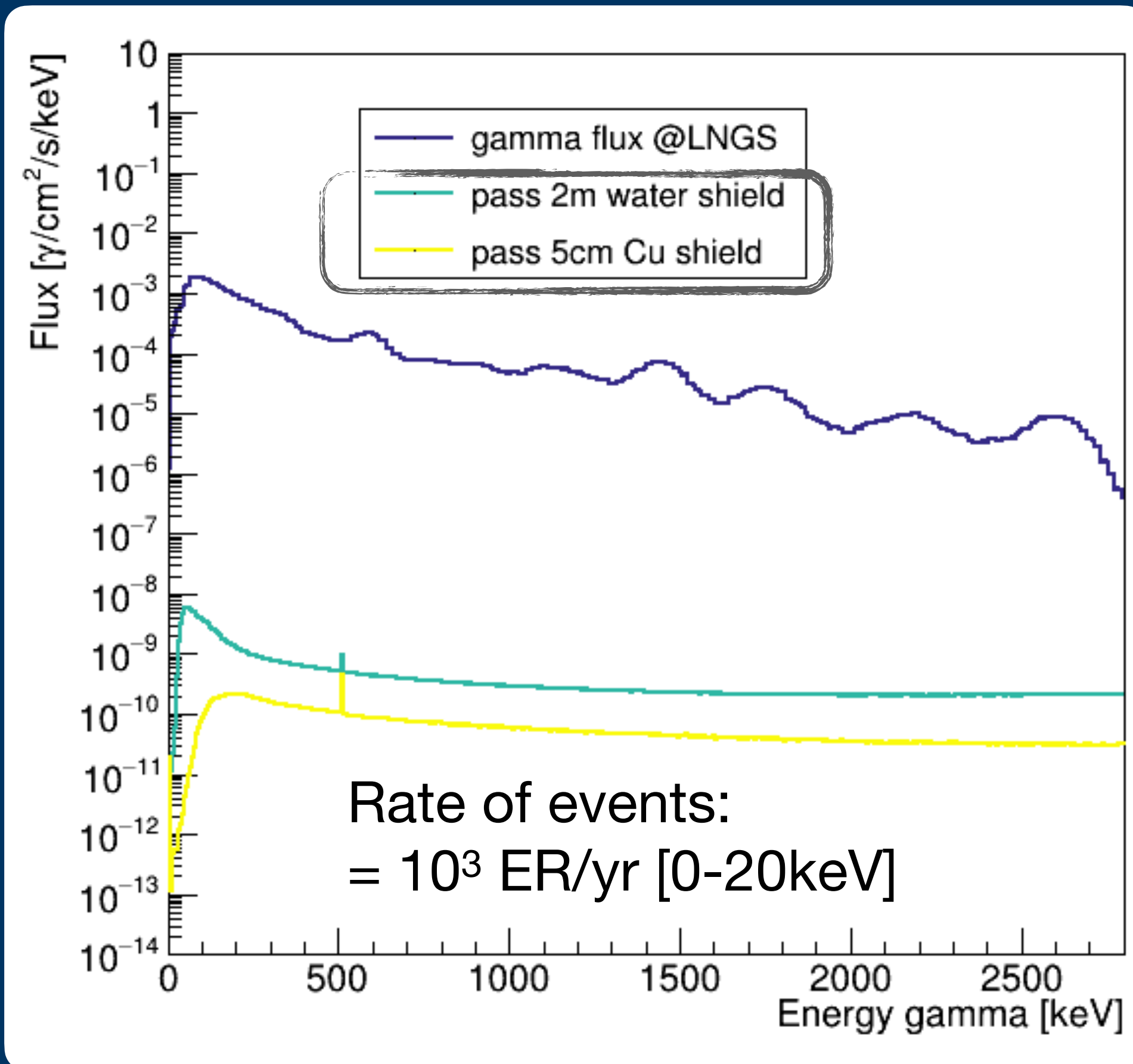


**Gamma** and **neutron**  
background due to **external**  
and **internal** radioactivity  
simulated.

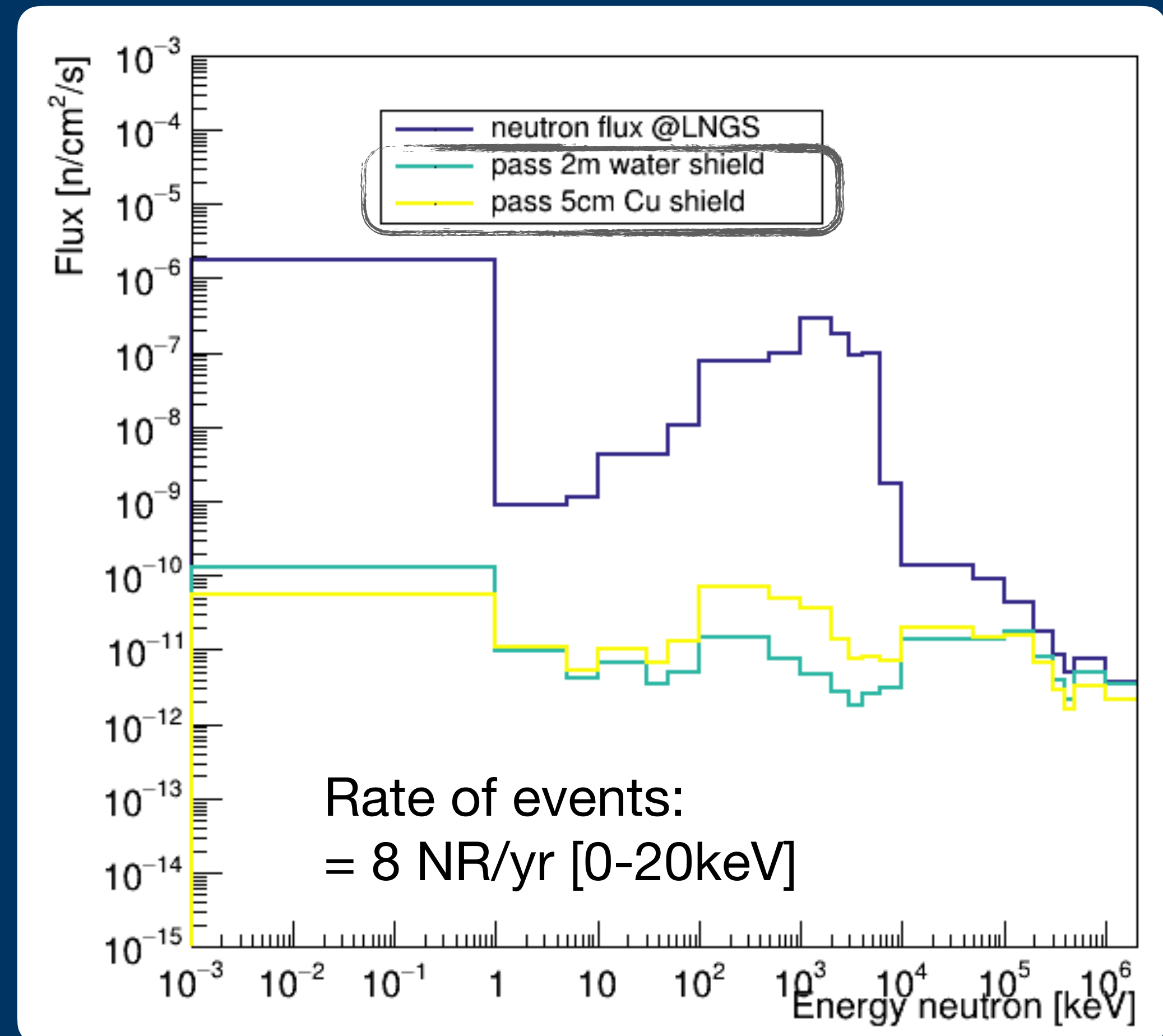


# BACKGROUND STUDIES: EXTERNAL

Gamma flux @LNGS (Hall C) -  
measured by SABRE :  $0.56 \text{ Hz/cm}^2$

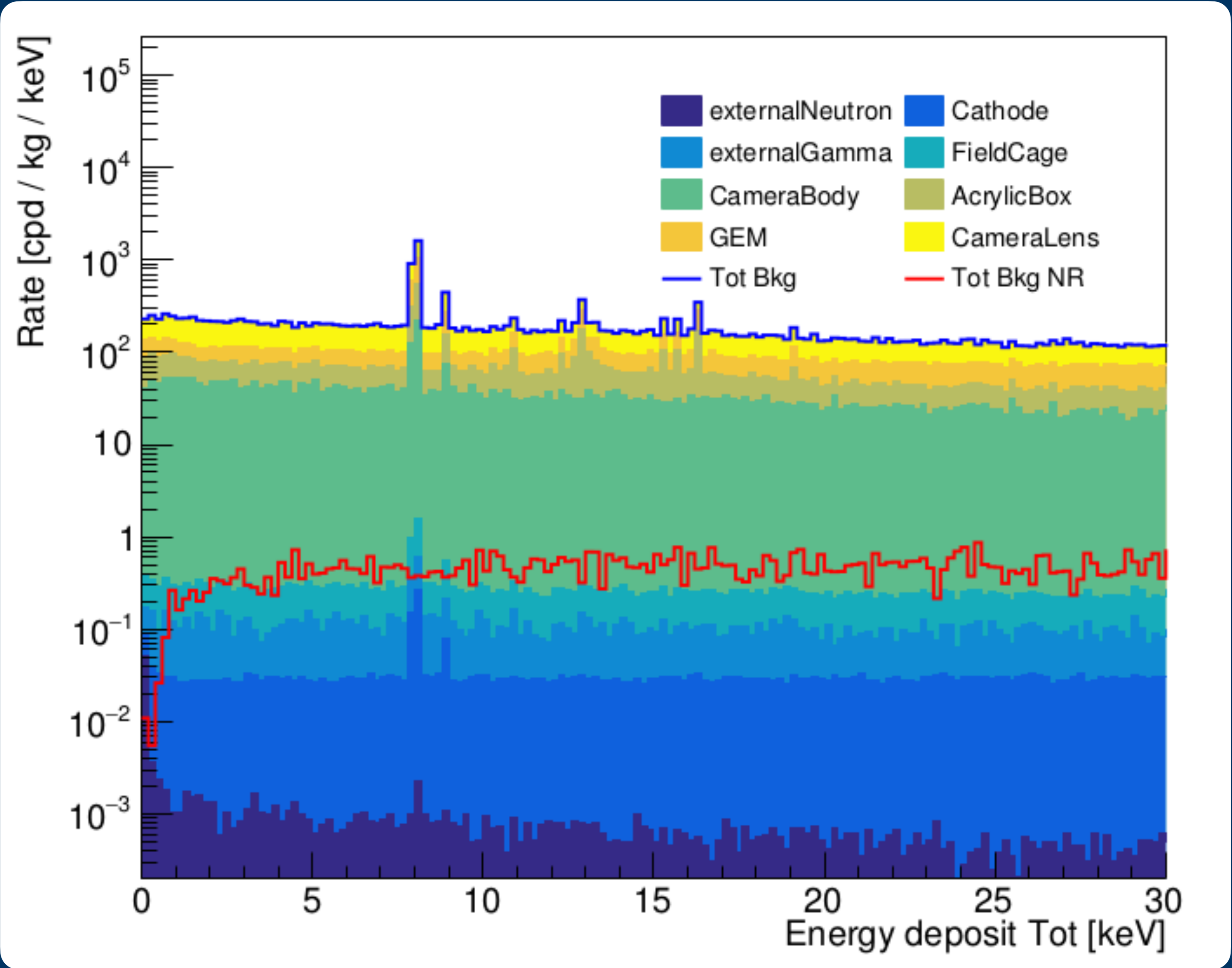


Neutron flux @LNGS (Hall C) -  
measured by CUORE :  $2.7 \times 10^{-6} \text{ Hz/cm}^2$





# BACKGROUND STUDIES: INTERNAL



To quantify **internal** background **radioactivity** of all detector **components** was measured at LNGS

Thanks to M.Laubenstein

| Camera Body  | Limit/M | Activity |
|--------------|---------|----------|
| Orca Flash   | eas     | (Bq/kg)  |
| U238 (Th234) | M       | 3.16E+00 |

| Camera Lens  | Limit/M | Activity |
|--------------|---------|----------|
| Orca Flash   | eas     | (Bq/kg)  |
| U238 (Th234) | M       | 4.22E+00 |
| K40          | M       | 5.15E+01 |

| GEM          | Limit/M | Activity |
|--------------|---------|----------|
|              | eas     | (Bq/kg)  |
| U238 (Th234) | M       | 1.63E-01 |
| K40          | L       | 3.58E-01 |

| Acrylic Box | Limit/M | Activity |
|-------------|---------|----------|
|             | eas     | (Bq/kg)  |
| K40         | L       | 3.50E-02 |

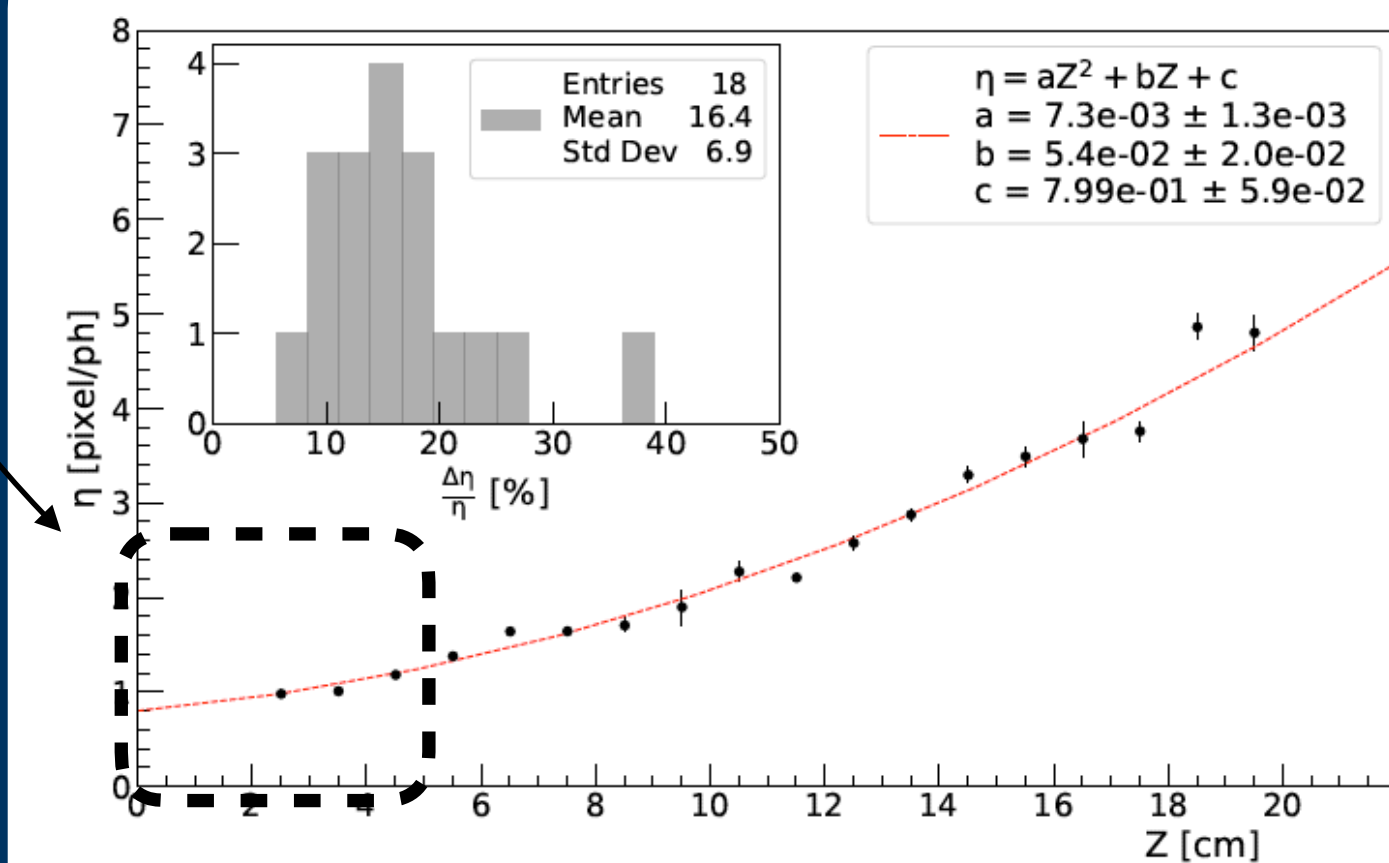
**Largest** contributions come from: **Camera, Lens, GEM and Acrylic.**



# REJECTION CAPABILITY

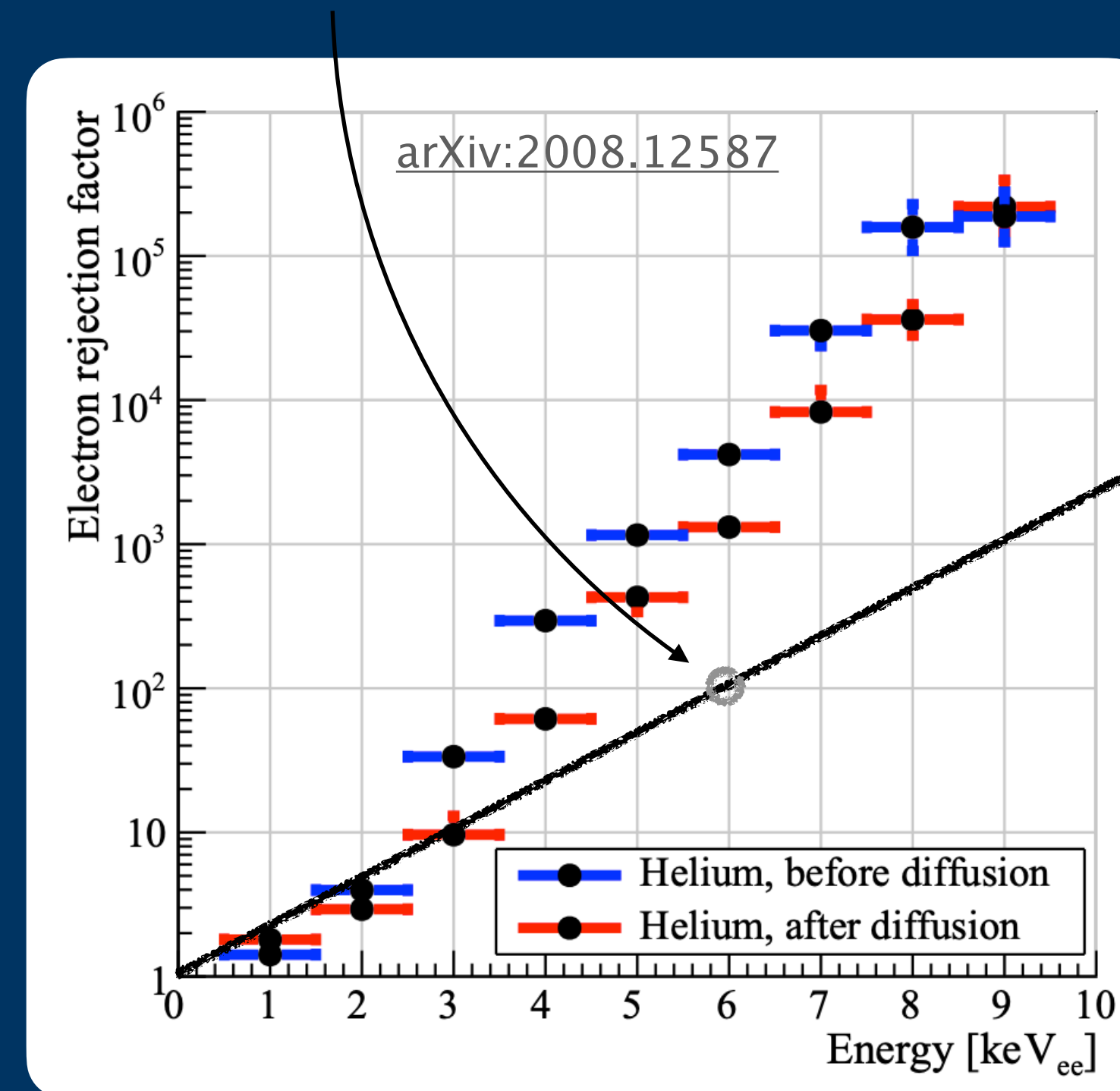
**NR** are all absorbed in the first 5 cm and thus easily *fiducialised*

50 cm drift volume



We expect:  $10^3$  NR/yr and  $2 \times 10^6$  ER/yr in  $1 \text{ m}^3$  [0-20 keV]. 10 times less in LIME.

For **ER** we already demonstrated a rejection of factor (RF) **99% at 6 keV** with 2D information



TPC **simulation** with 3D readout foresees a fast increasing RF

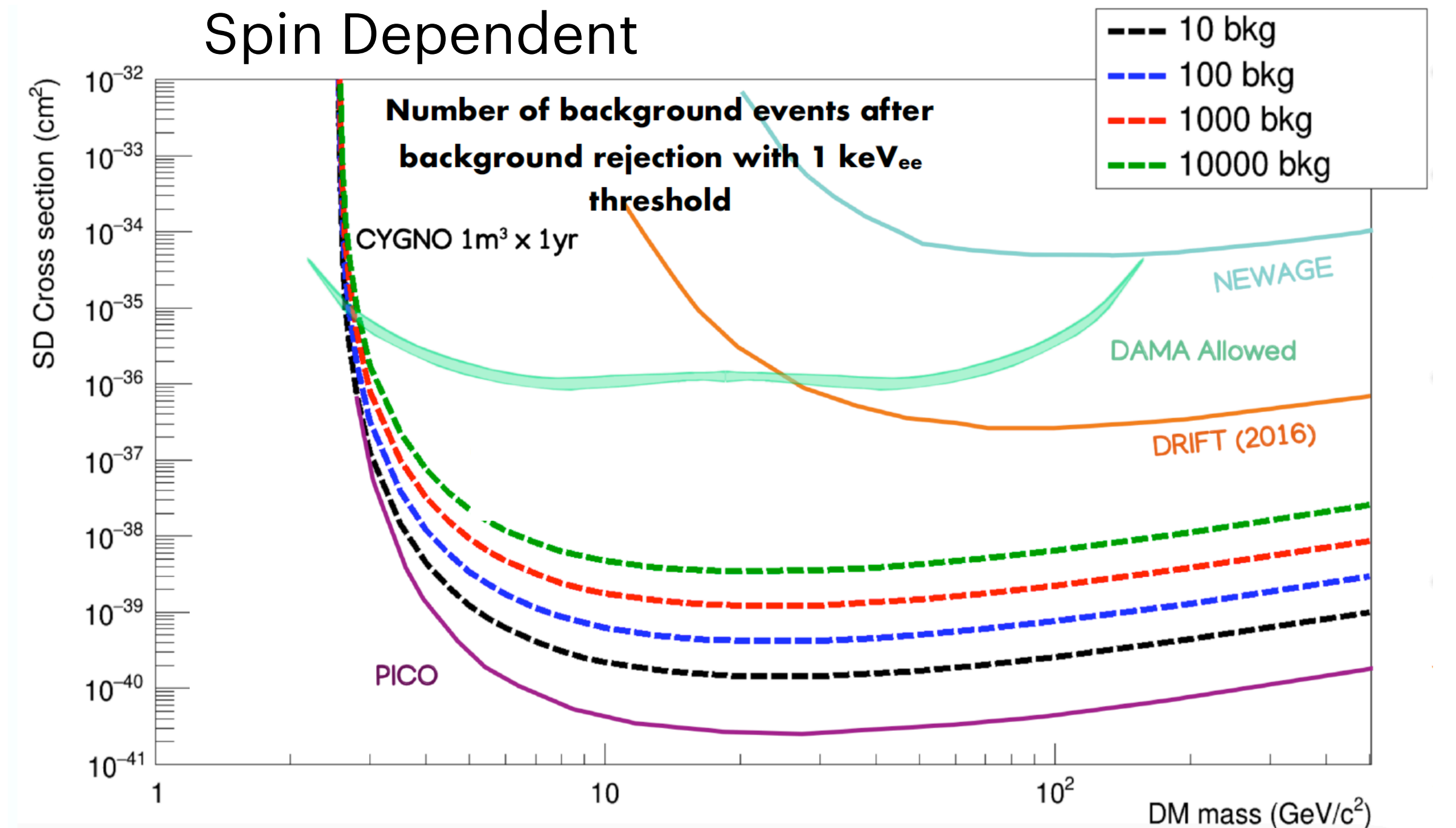
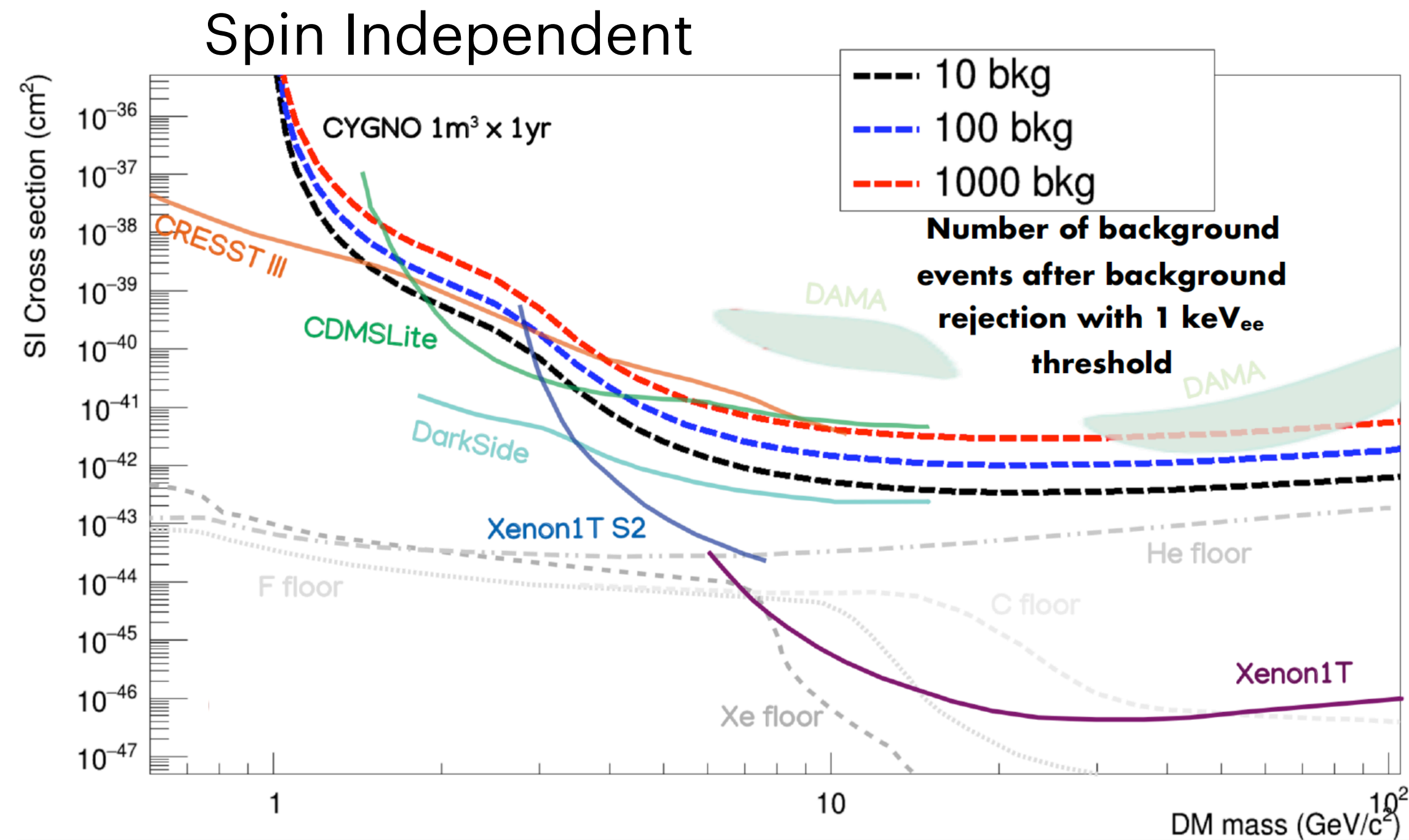
Assuming a slower increasing, an **average value of  $10^4$**  can be obtained in the **0-20 keV range**

Rate of bkg events =  $10^2 - 10^3$  ER/yr [0-20keV]



# WHAT CYGNO CAN DO: DM SEARCH AND STUDY

**1 cubic meter, 1 year exposure**



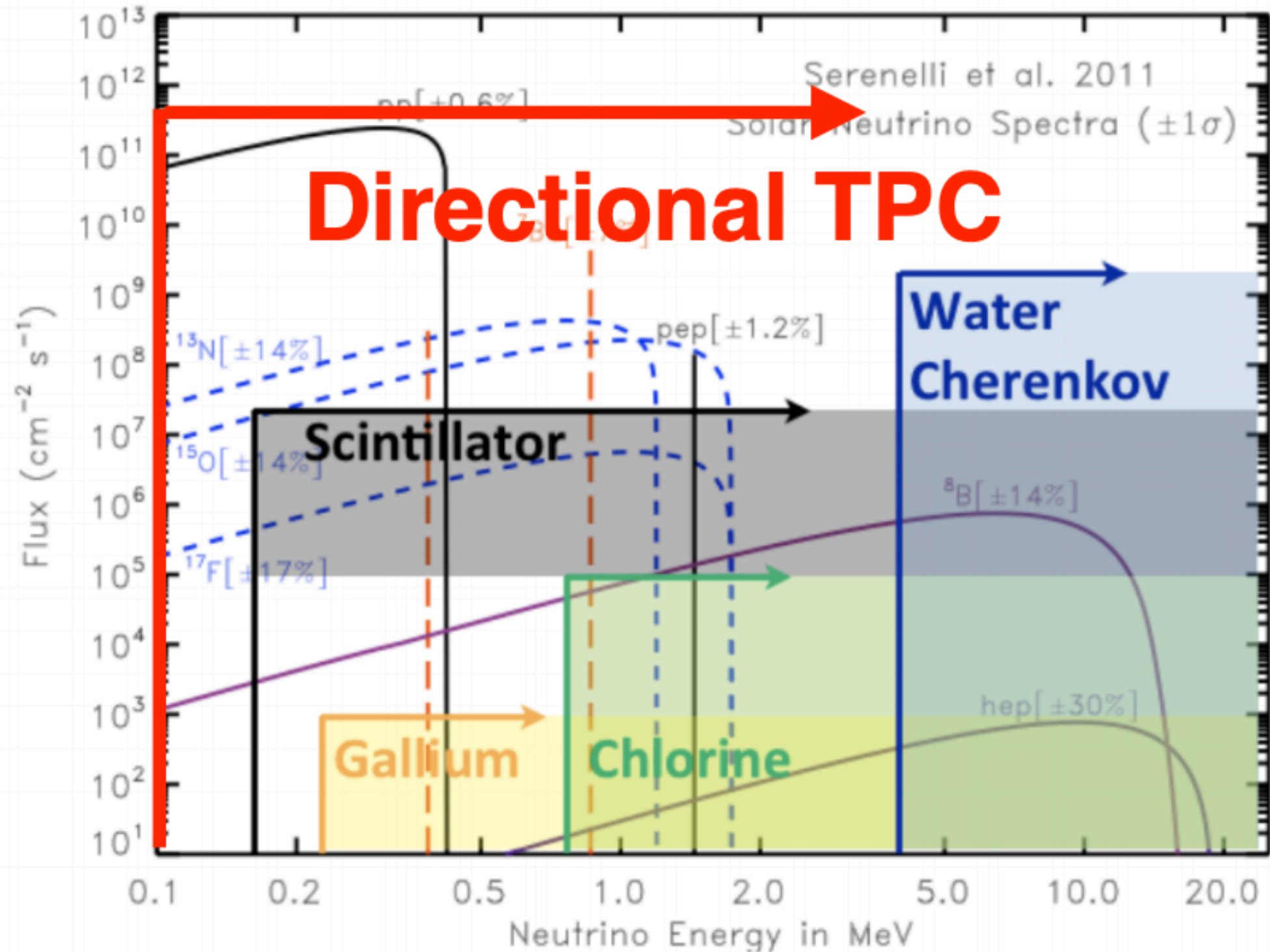
DAMA region covered even with 1000 bkg events

**If DM is found, directionality will be crucial to confirm discovery and individuate its source**

**30 cubic meters, 3 year = 150 kgyr exposure**



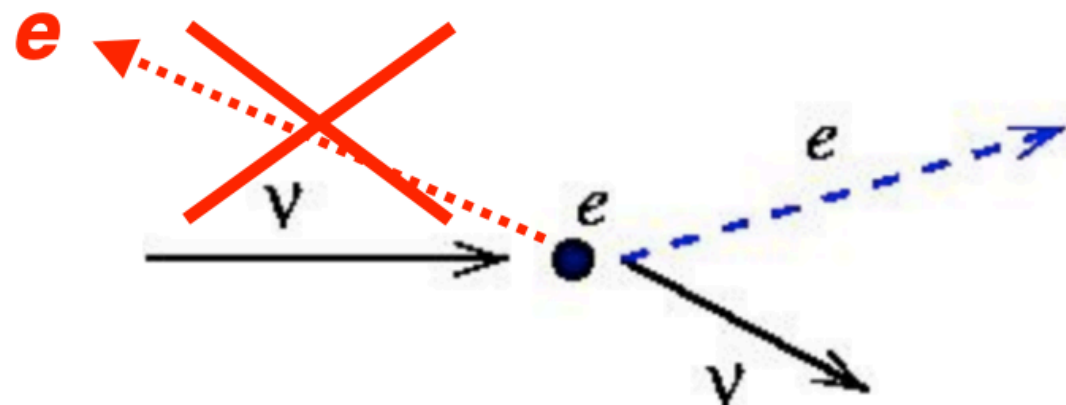
# WHAT CYGNO CAN DO: NEUTRINO SPECTROSCOPY



Elastic neutrino - electron scattering with gaseous TPC: revitalising old ideas

- **sub-millimetre** tracking capability
- 10 keV **directional** threshold on electrons
- **keV** energy resolution
- Order of **1 event/(m³ yr)** would be observed in the pp-Be energy range

*Given the Sun position, recoils in opposite direction are kinematically forbidden*



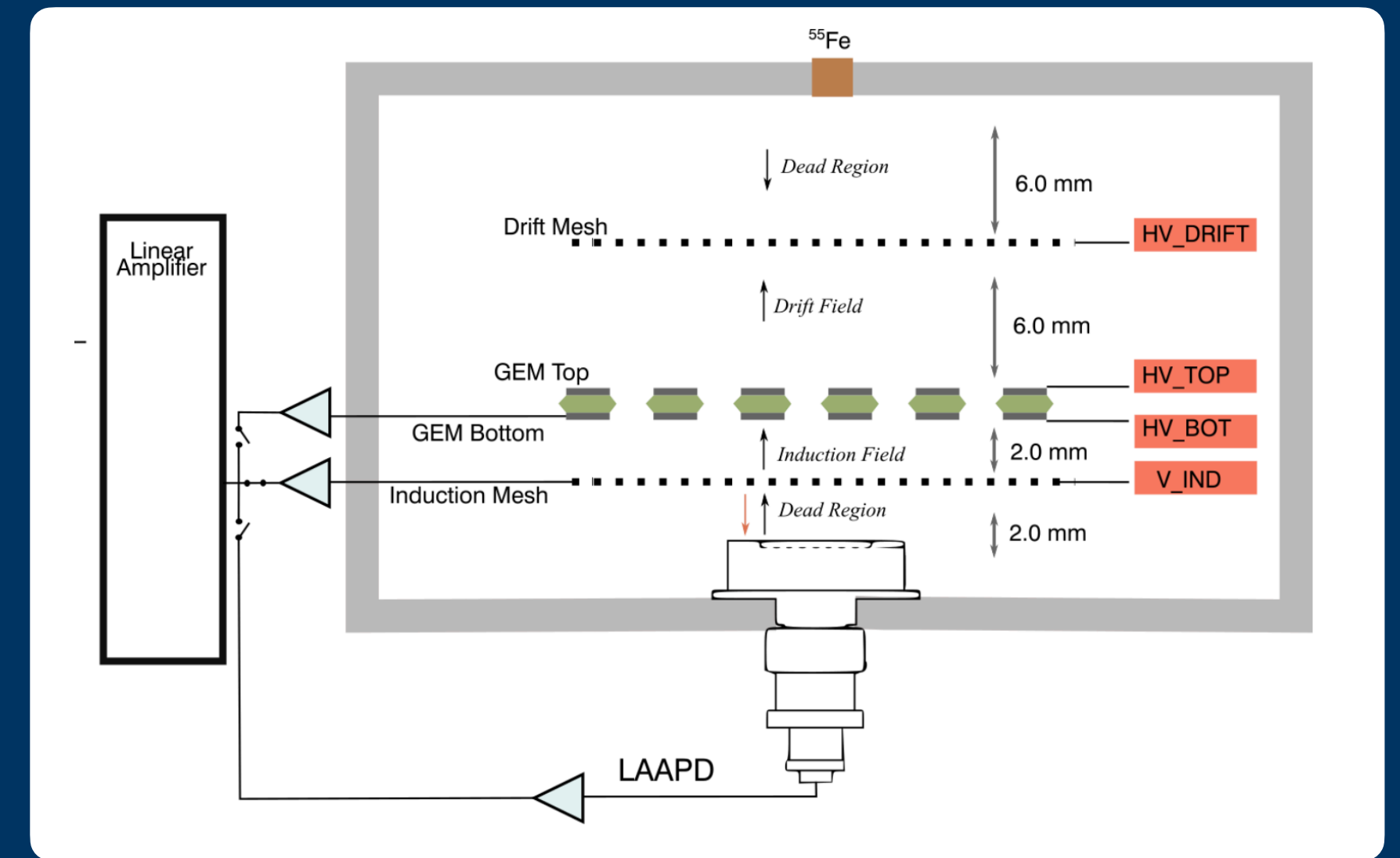
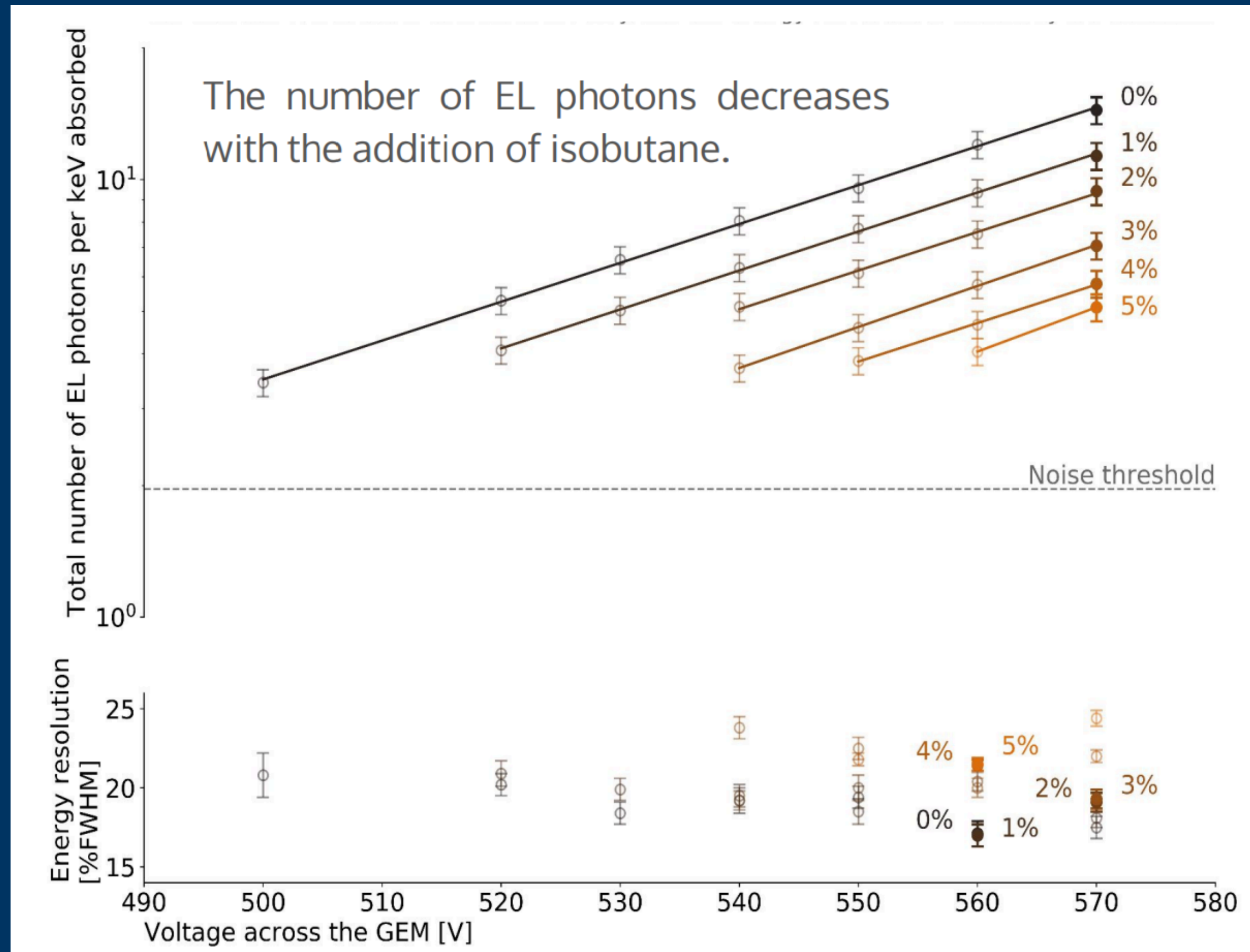
*Differently from WIMPs, background can be **measured** on sidebands data*

- Directionality will be crucial



# R&D: HYDROCARBONS

In tests performed with a single-GEM setup, a ternary gas mixture (He/CF<sub>4</sub>/C<sub>4</sub>H<sub>10</sub>) was tested with up to 5% of C<sub>4</sub>H<sub>10</sub>.



The addition of a e.g. 2% Isobutane component reduces:

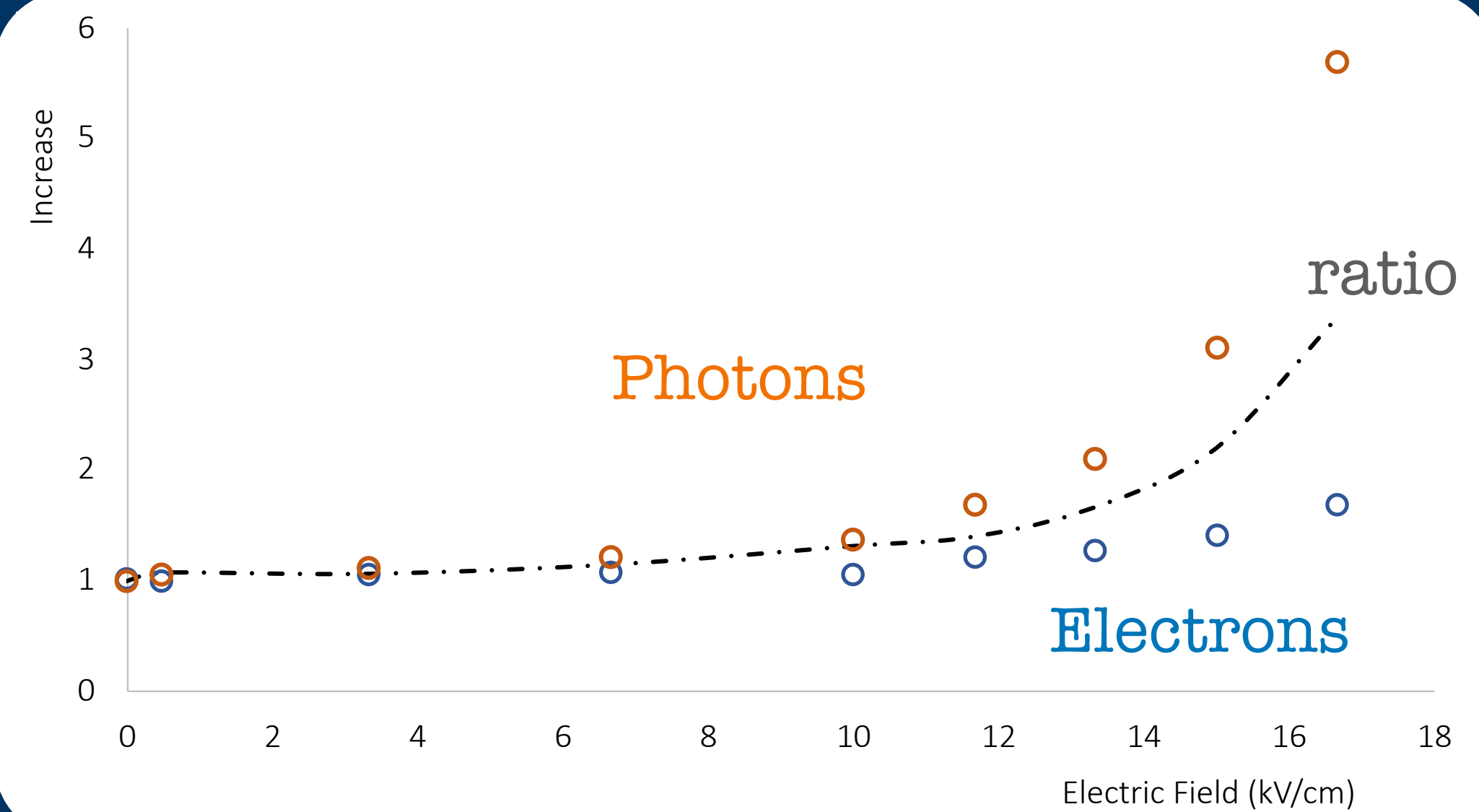
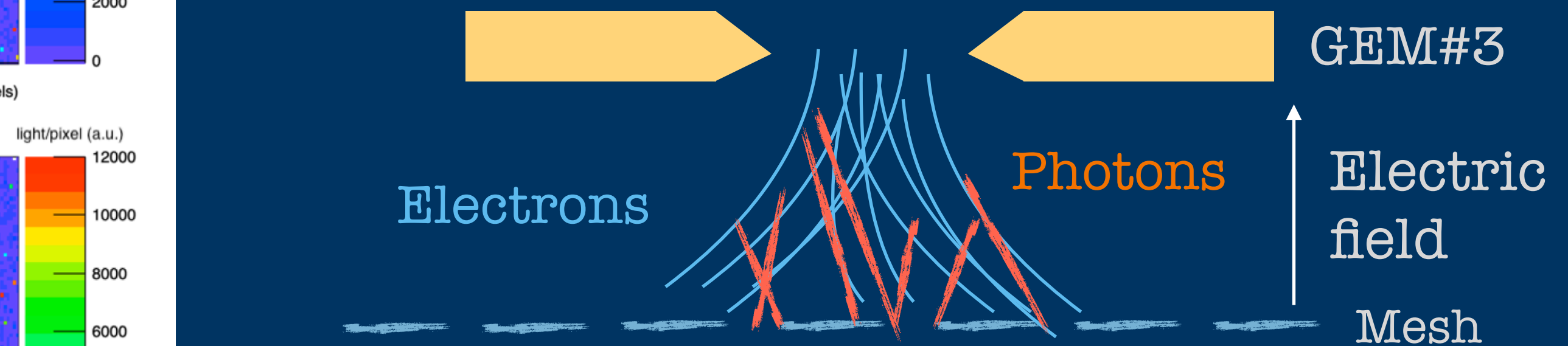
- by a factor 2.5 the Charge Yield;
- only 30% the Light Yield.

First demonstration of a very good light yield from a mixture with C<sub>4</sub>H<sub>10</sub>



# R&D: ELECTRO-LUMINESCENCE

Is it possible to induce luminescence in gas by accelerating electrons below last GEM?



**First evidence** of an increase of light production (factor 5.7) quite **larger** than total charge increase (factor 1.7).

Study partially funded as Common Project with RD51

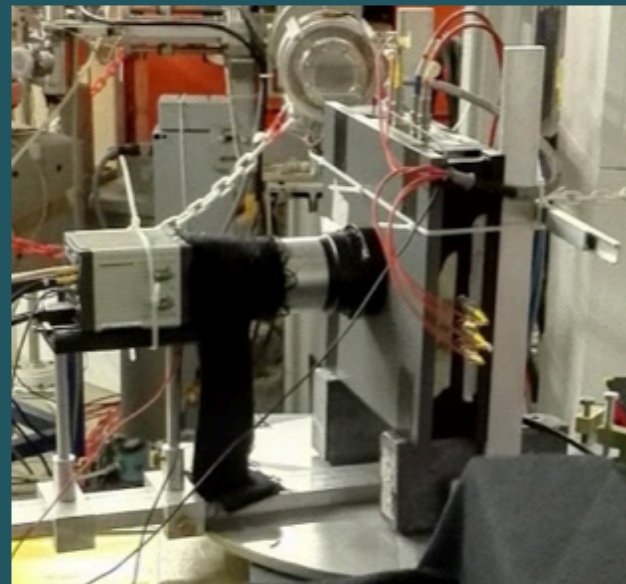


# CYGNO: PROJECT PHASES

## PHASE 0: R&D and prototypes

2015/16  
ROMA1

ORANGE



- 1 cm drift

2017/18  
LNF

LEMON



- 3D printing
- 20 cm drift

2019/21  
LNF/LNGS

LIME

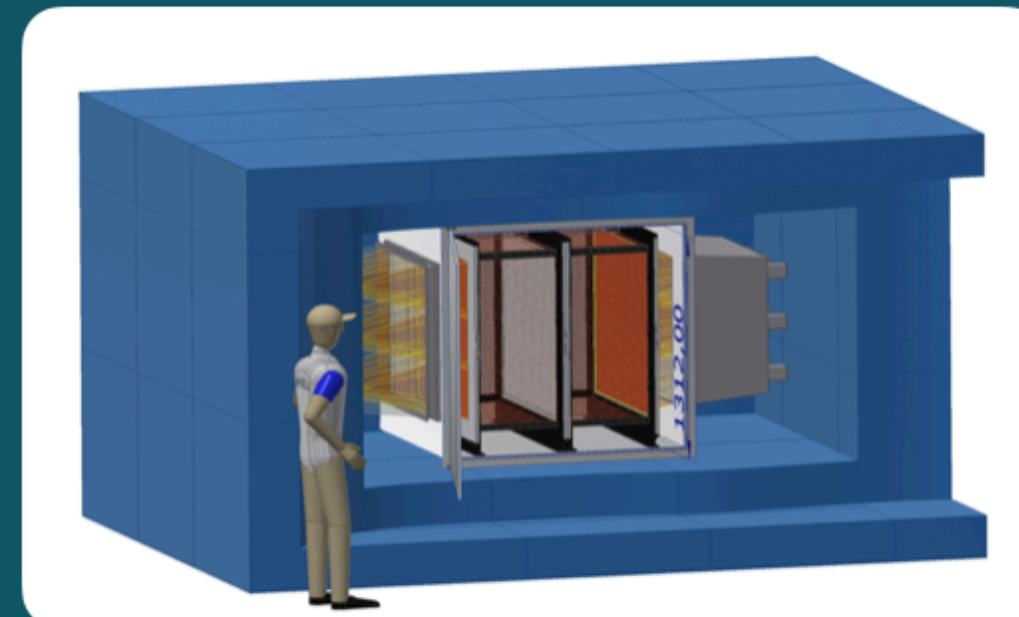


- 50 cm drift
- underground tests
- shielding

## PHASE 1: 1 m<sup>3</sup> Demonstrator

2022/25  
LNF/LNGS

CYGNO\_01

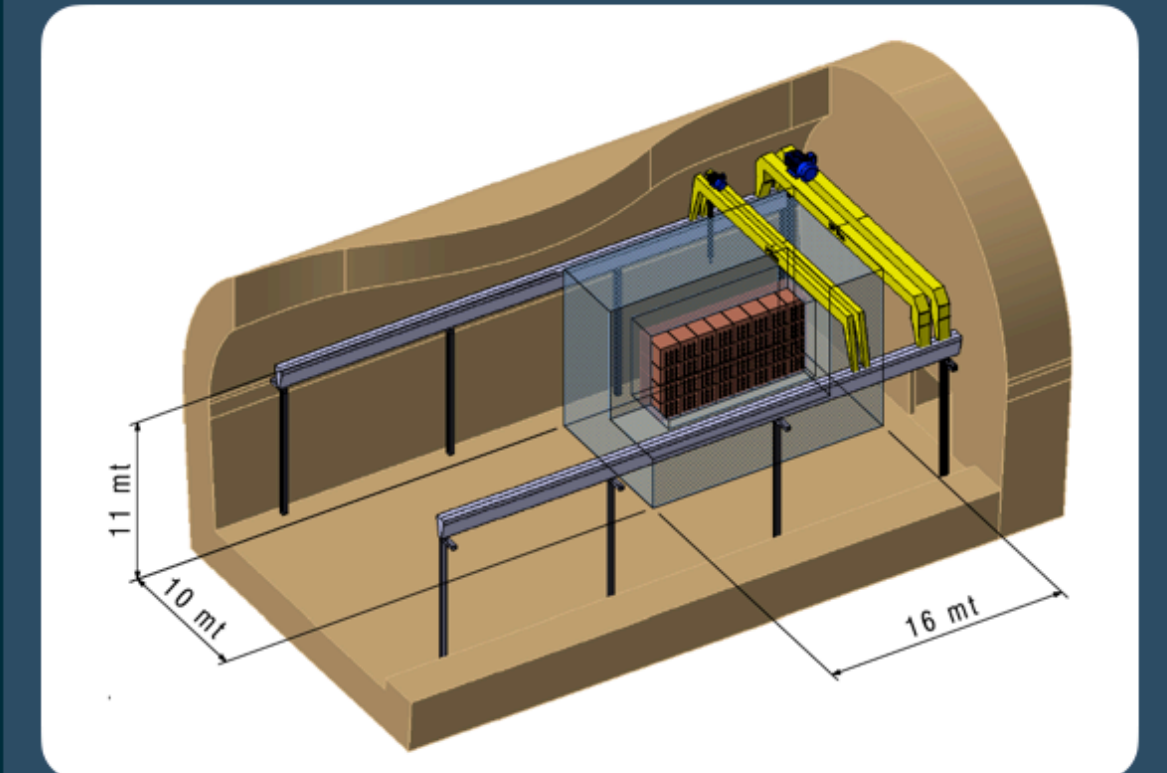


- background
- materials test, gas purification
- scalability

## PHASE 2: 30 m<sup>3</sup> Experiment

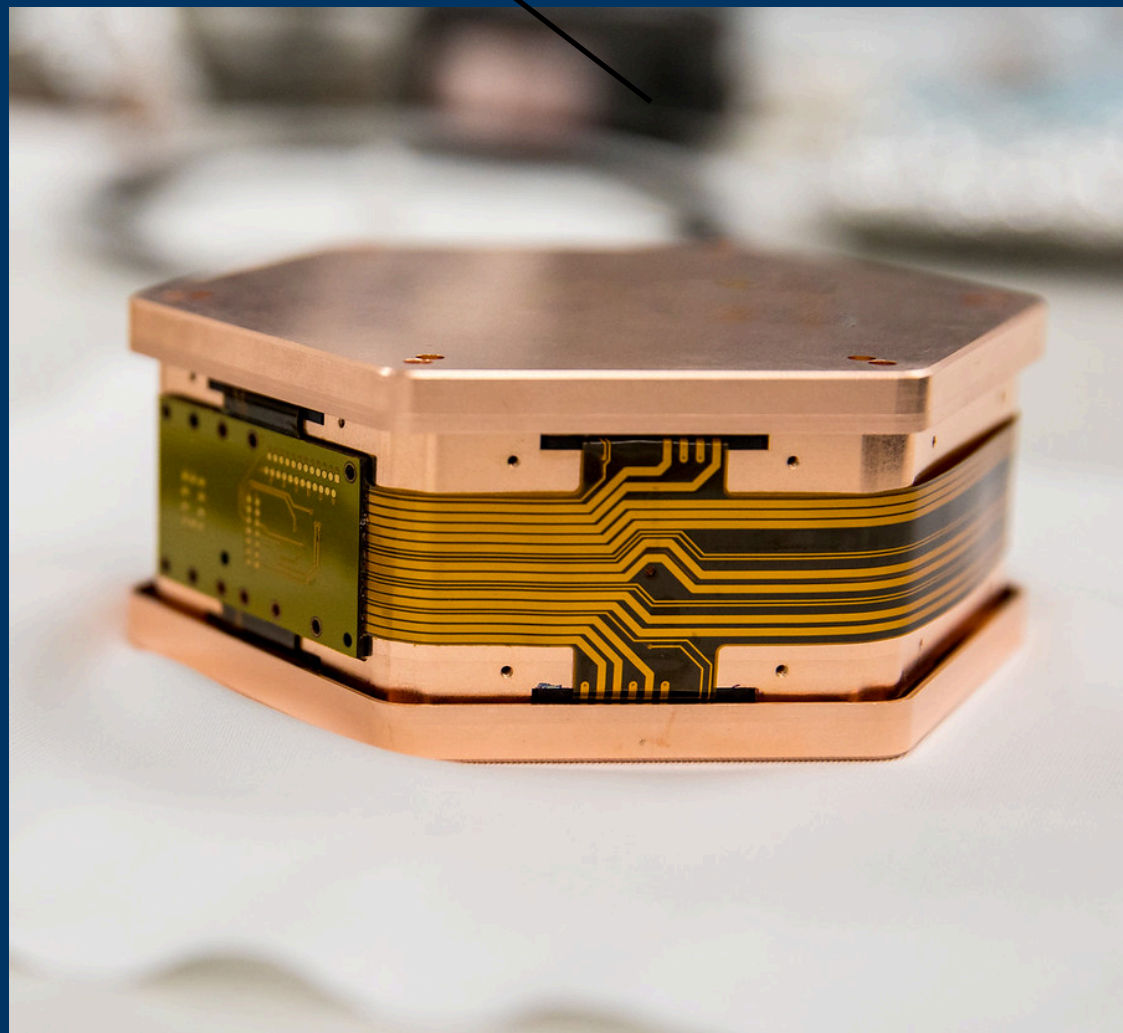
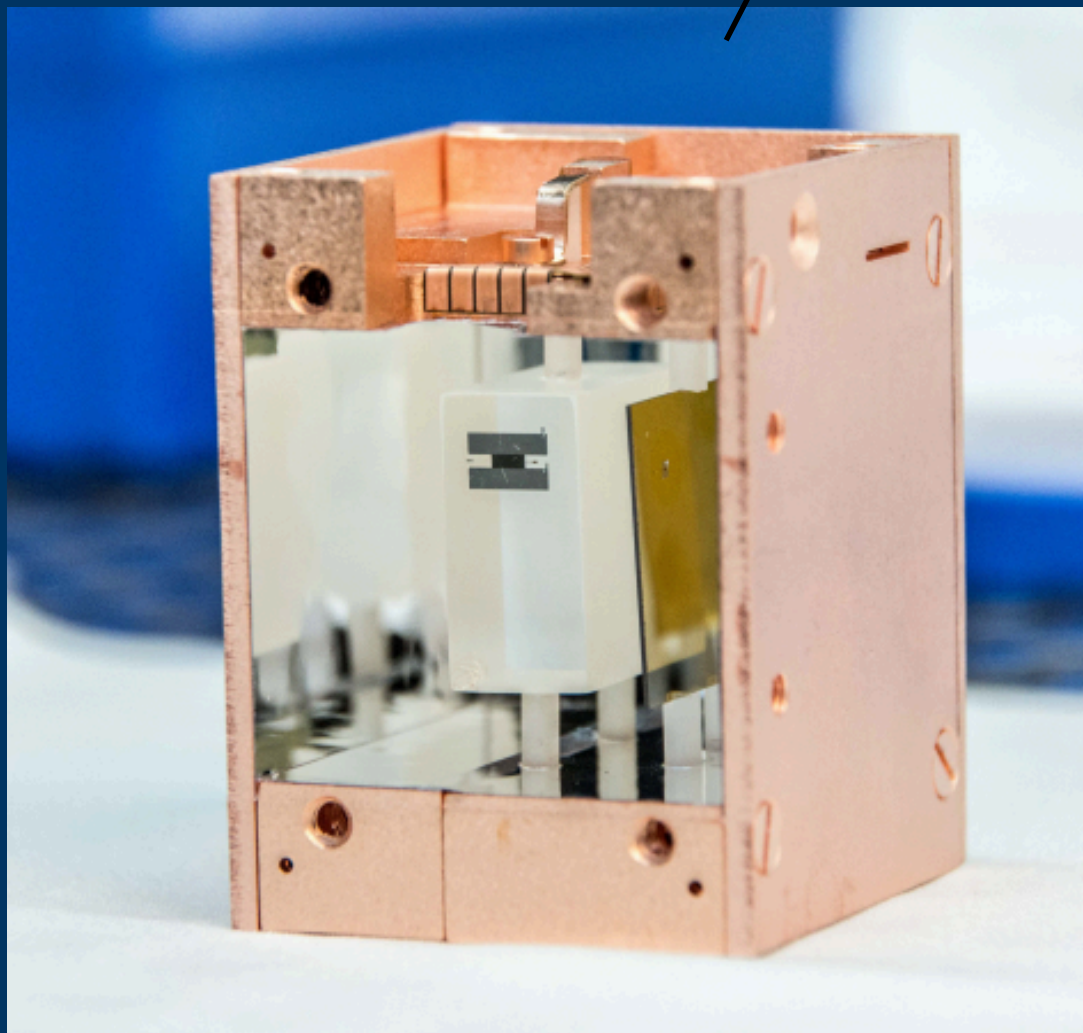
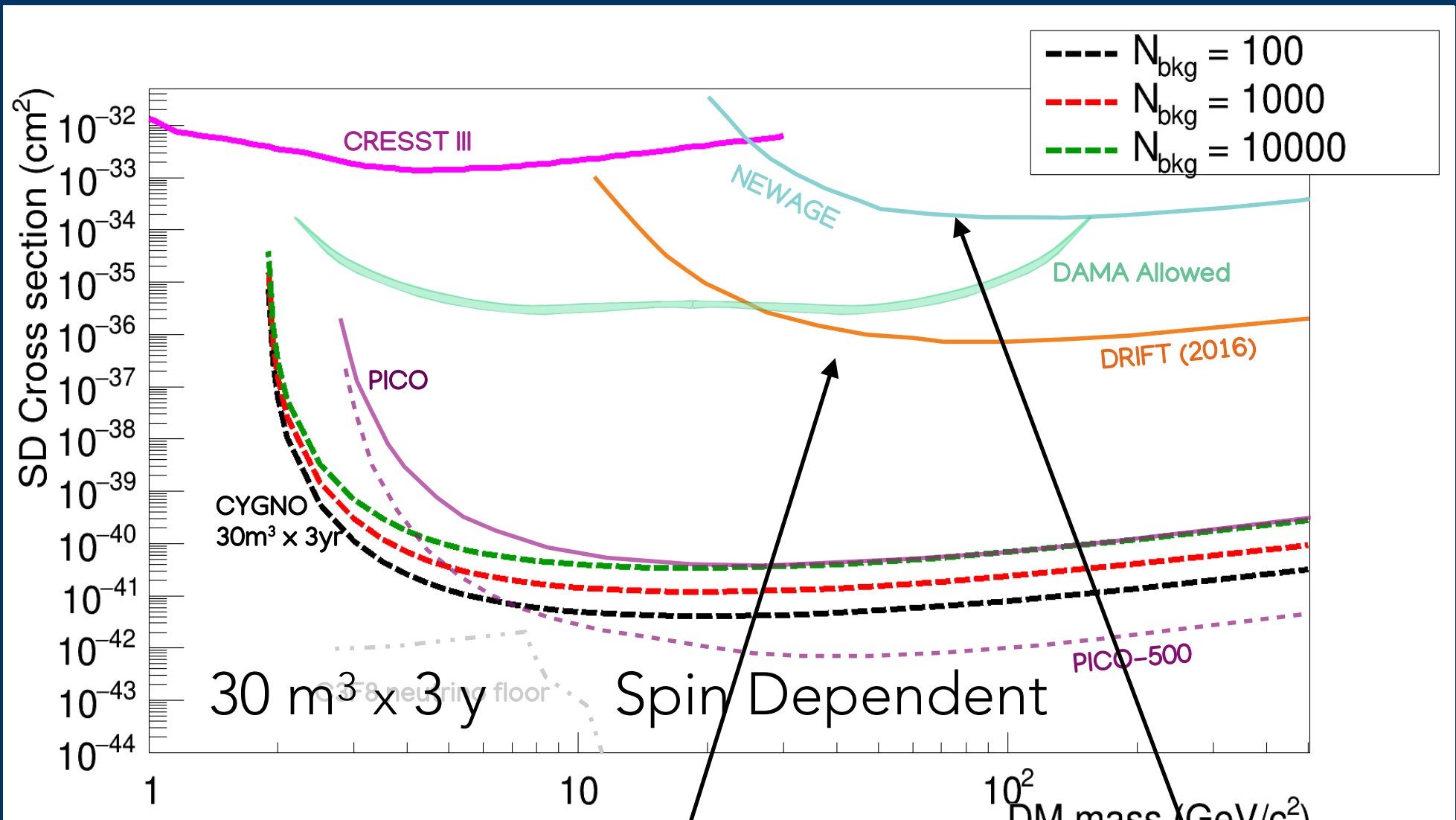
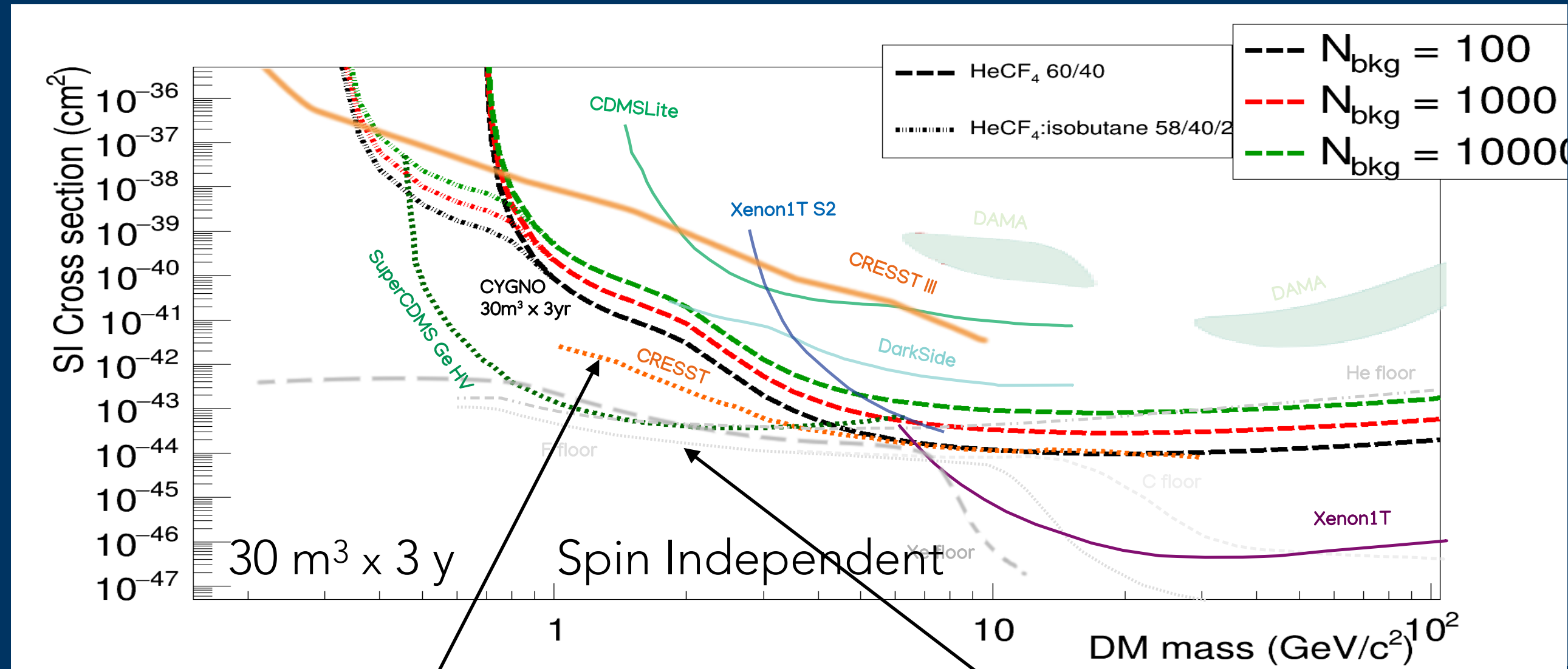
2026..  
LNGS

CYGNO\_30



- Physics research





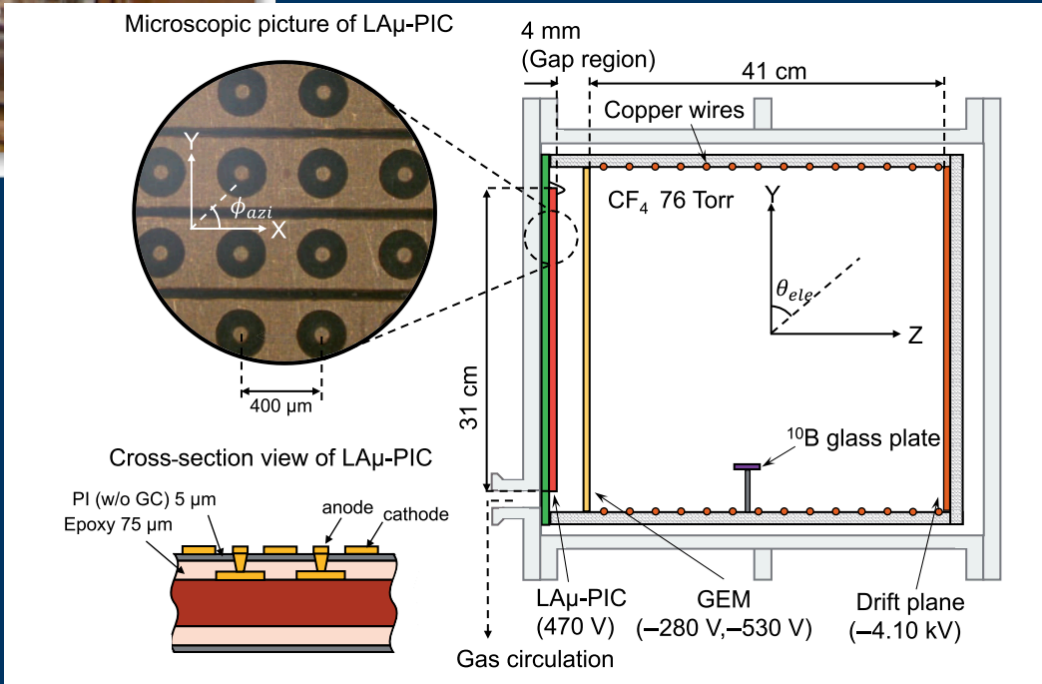
CDMS (SNOLAB):  
cryogenic semiconductor  
with double readout  
(charge and heat).  
Threshold: 10-50eV.  
No directionality



DRIFT set so far the  
best Spin Dependent  
limit for a directional  
experiment

CRESST (LNGS): bolometric scintillator with double  
readout (light and heat).  
Threshold 50-100 eV. No directionality.

NewAGE: 36 litres TPC operated with CF<sub>4</sub> at  
100 mbar.  
MPGD with electrical readout.  
Directional and sensitive to SD interactions.





# CONCLUSION

CYGNO project is developing a **GEM-based TPC optically readout** for rare event studies

Very promising performance was found in the (few) keV region:

- **high detection** capability;
- very good **energy** and **position resolution**;
- high **discrimination power** provided by the detailed acquisition of readout approach;
- R&D to improve these performance are going on.



**CYGNO** is working in the framework of **CYGNUS**: an international Collaboration aiming at the realisation of Multi-site Recoil Directional Observatory for WIMPs and neutrinos;

Signed members from UK, Japan, Italy, Spain, China focused on **gas TPCs with 2D or 3D direction sensitivity**;

**Join us!**







# INTERNAL BACKGROUND REDUCTION

Photometrics – Prime BSI Express stand alone components: stand alone sensor + engineering unit for radioactivity tests



Different cameras were measured (Thanks to M. Laubenstein)

Each internal component of the camera is being measured



## Radiopurity of Micromegas readout planes

S. Cebrián<sup>a</sup>, T. Dafni<sup>a</sup>, E. Ferrer-Ribas<sup>b</sup>, J. Galán<sup>a</sup>, I. Giomataris<sup>b</sup>, H. Gómez<sup>a,\*</sup>, F.J. Igua<sup>a,1</sup>, I.G. Irastorza<sup>a</sup>, G. Luzón<sup>a</sup>, R. de Oliveira<sup>c</sup>, A. Rodríguez<sup>a</sup>, L. Seguí<sup>a</sup>, A. Tomás<sup>a</sup>, J.A. Villar<sup>a</sup>

<sup>a</sup>Laboratorio de Física Nuclear y Astropartículas, Universidad de Zaragoza, 50009 Zaragoza, Spain

<sup>b</sup>CEA, IRFU, Centre d'études de Saclay, 91191 Gif-sur-Yvette, France

<sup>c</sup>European Organization for Nuclear Research (CERN), CH-1911 Genève, Switzerland

## Background assessment for the TREX dark matter experiment

J. Castel<sup>1,2</sup>, S. Cebrián<sup>1,2,3</sup>, I. Coarasa<sup>1,2</sup>, T. Dafni<sup>1,2</sup>, J. Galán<sup>1,2,3</sup>, F. J. Igua<sup>1,2,4</sup>, I. G. Irastorza<sup>1,2</sup>, G. Luzón<sup>1,2</sup>, H. Mirallas<sup>1,2</sup>, A. Ortiz de Solórzano<sup>1,2</sup>, E. Ruiz-Chóliz<sup>1,2</sup>

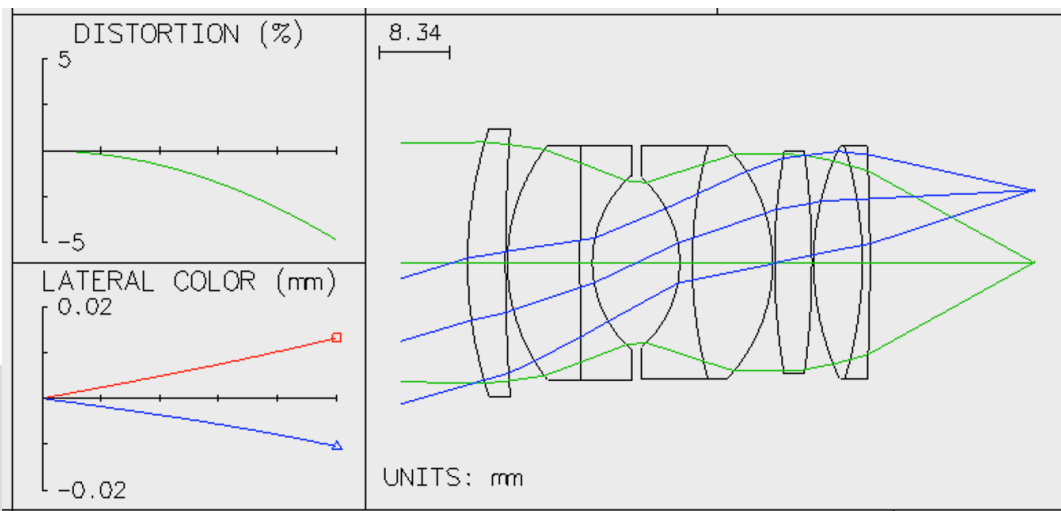

<sup>1</sup> Laboratorio de Física Nuclear y Astropartículas, Universidad de Zaragoza, Calle Pedro Cerbuna 12, 50009 Zaragoza, Spain

<sup>2</sup> Laboratorio Subterráneo de Canfranc, Paseo de los Ayerbe s/n, 22880 Canfranc Estación, Huesca, Spain

<sup>3</sup> Present Address: Shanghai Laboratory for Particle Physics and Cosmology, INPAC and Department of Physics and Astronomy, Shanghai Jiao Tong University, 200240 Shanghai, China

<sup>4</sup> Present Address: Synchrotron Soleil, BP 48, Saint-Aubin, 91192 Gif-sur-Yvette, France

We are studying low radioactive **fused silica** to produce fixed focus **lenses** (thanks to loan)



DISTORTION (%)

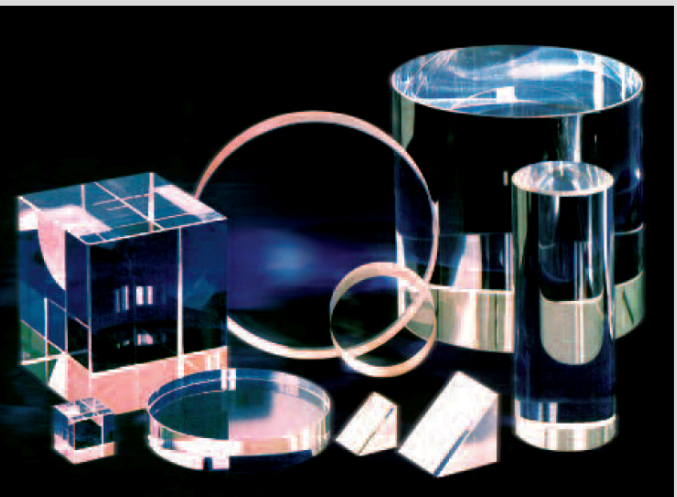
LATERAL COLOR (nm)

UNITS: mm

Spectrosil® synthetic fused silica is manufactured using a patented, environmentally friendly process resulting in a glass of exceptional purity and excellent visual quality. It is a very homogeneous synthetic fused silica glass for deep UV optical applications.

Spectrosil® is chlorine-free resulting in outstanding laser damage resistance due to the reduced tendency to form E' centres.

Spectrosil® 2000 is free of bubbles and inclusions and due to its ultra-high purity, has exceptional optical transmission in the deep ultraviolet and visible, with a useful range from below 180 nm through to 2000 nm.



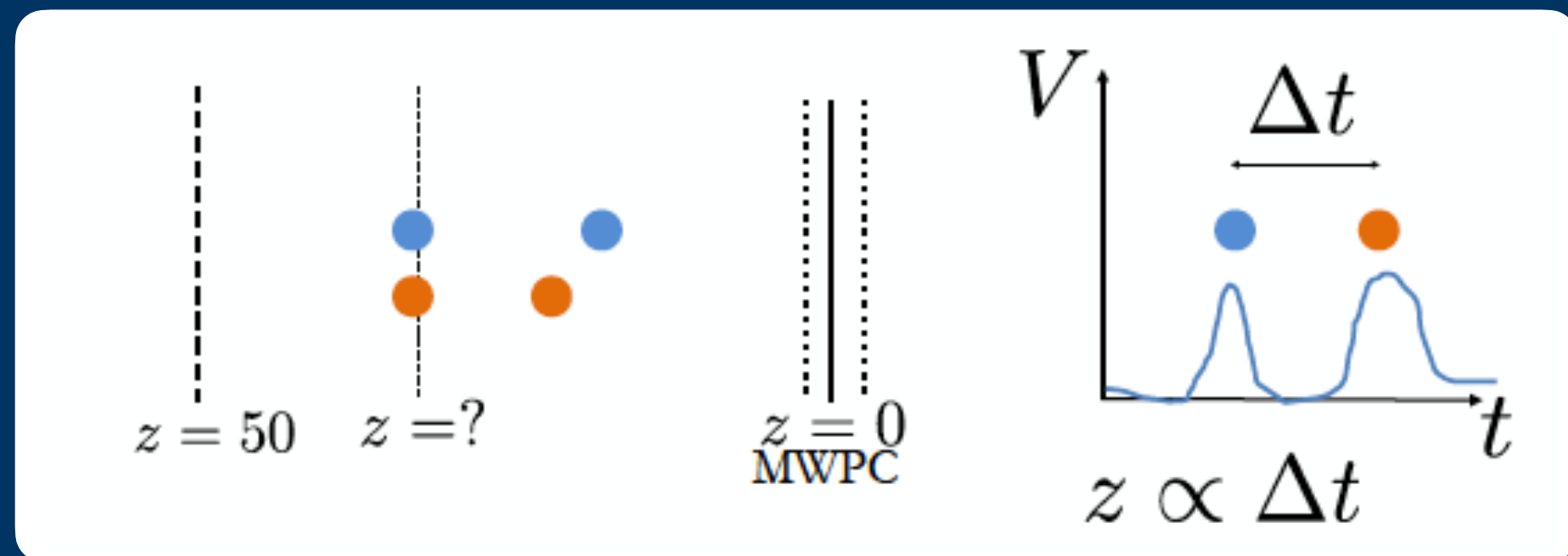
We are in contact with CERN **GEM producer** and T-REX people that developed low-radioactivity MPGD to follow **development of low radioactive GEM**



# NEGATIVE ION DRIFT

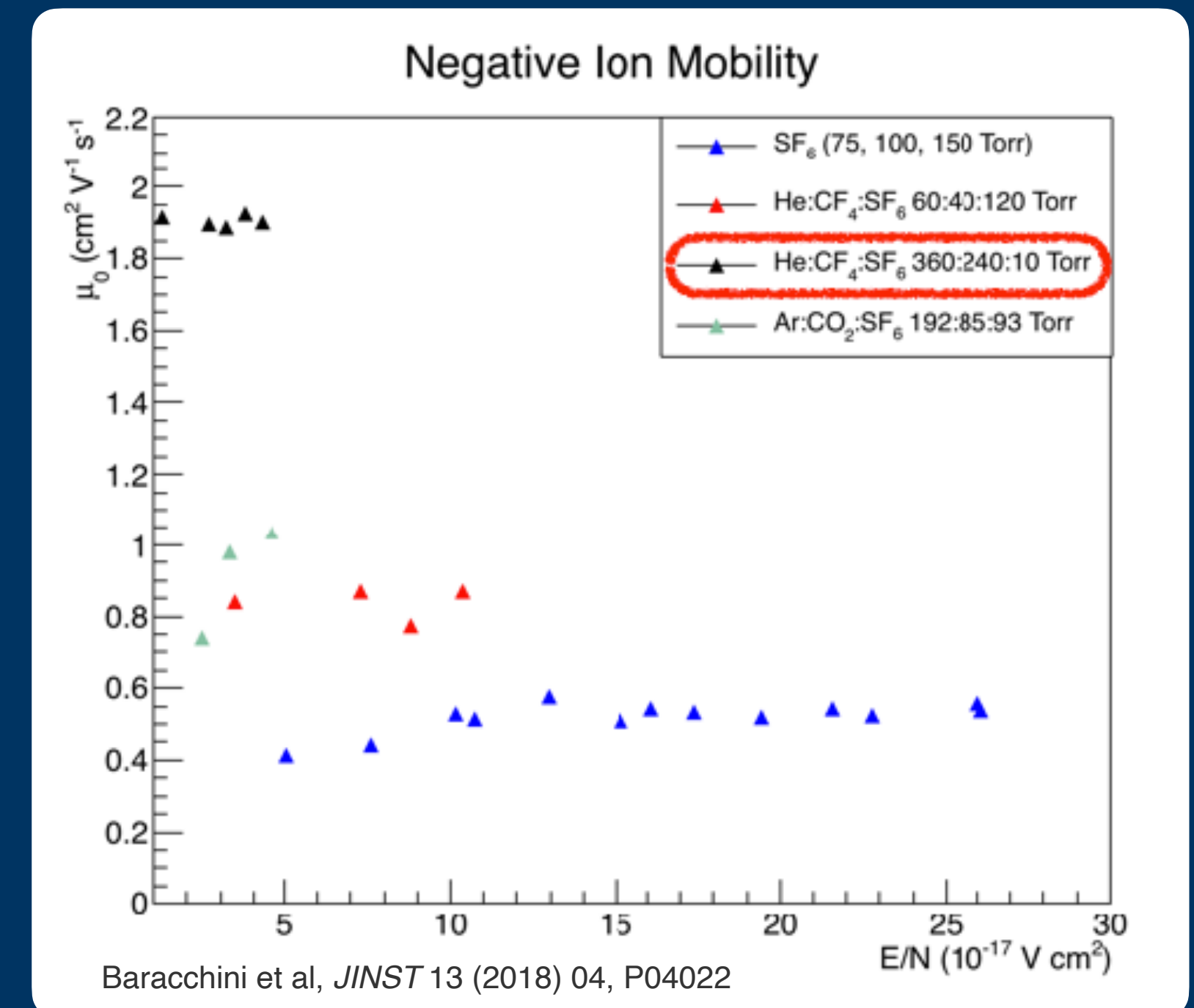
Adding a **highly electronegative** component to gas mixture (e.g.  $\text{SF}_6$ ) would allow to **trap primary electrons** and produce Negative Ions;

They will drift **without diffusion** and different fragments will have **different velocities**.



Absolute  $z$  can be evaluated with high accuracy from the  $\Delta t$

Tested **successfully** in low pressure gases ( $<100$  **mbar**), it was observed at nearly atmospheric pressure (**800 mbar**) by CYGNO team.





# THE INITIUM PROJECT

**Elisabetta Baracchini** (GSSI) won an **ERC Consolidator Grant** with **INITIUM**



The proposal, presented at the beginning of 2018, is based on the experience gained in NITEC and CYGNUS\_RD and aims at “the development and operation of the first **1 m<sup>3</sup> Negative Ion TPC** (NITPC) with Gas Electron Multipliers (**GEMs**) amplification [in **He/CF<sub>4</sub>/SF<sub>6</sub>** mixture] and **optical readout** with CMOS-based cameras and PMTs”

The image is a poster for the INITIUM project. It has a dark grey background with a large, faint, circular pattern. The title "INITIUM" is at the top in large, white, sans-serif capital letters. Below it, the subtitle "an Innovative Negative Ion Time projection chamber for Underground Dark Matter searches" is written in a smaller, orange and white font. The name "Elisabetta Baracchini" is prominently displayed in orange. Below her name, "Gran Sasso Science Institute" is written in orange. At the bottom, "ERC-COG-2018" and "Proposal number 818744" are listed in white, followed by "PE 2 - Fundamental Constituents of Matter". In the top left corner, there is a small logo with the letters "G S S I" in a grid. In the top right corner, the INFN logo is visible. At the bottom right, there is a small text block that reads: "\* Dark Matter-like signals (He recoils) in CYGNUS-RD 10 L TPC".