30th International Symposium on Lepton Photon Interactions at High Energies

Istituto Nazionale di Fisica Nucleare

The CYGNO Experiment

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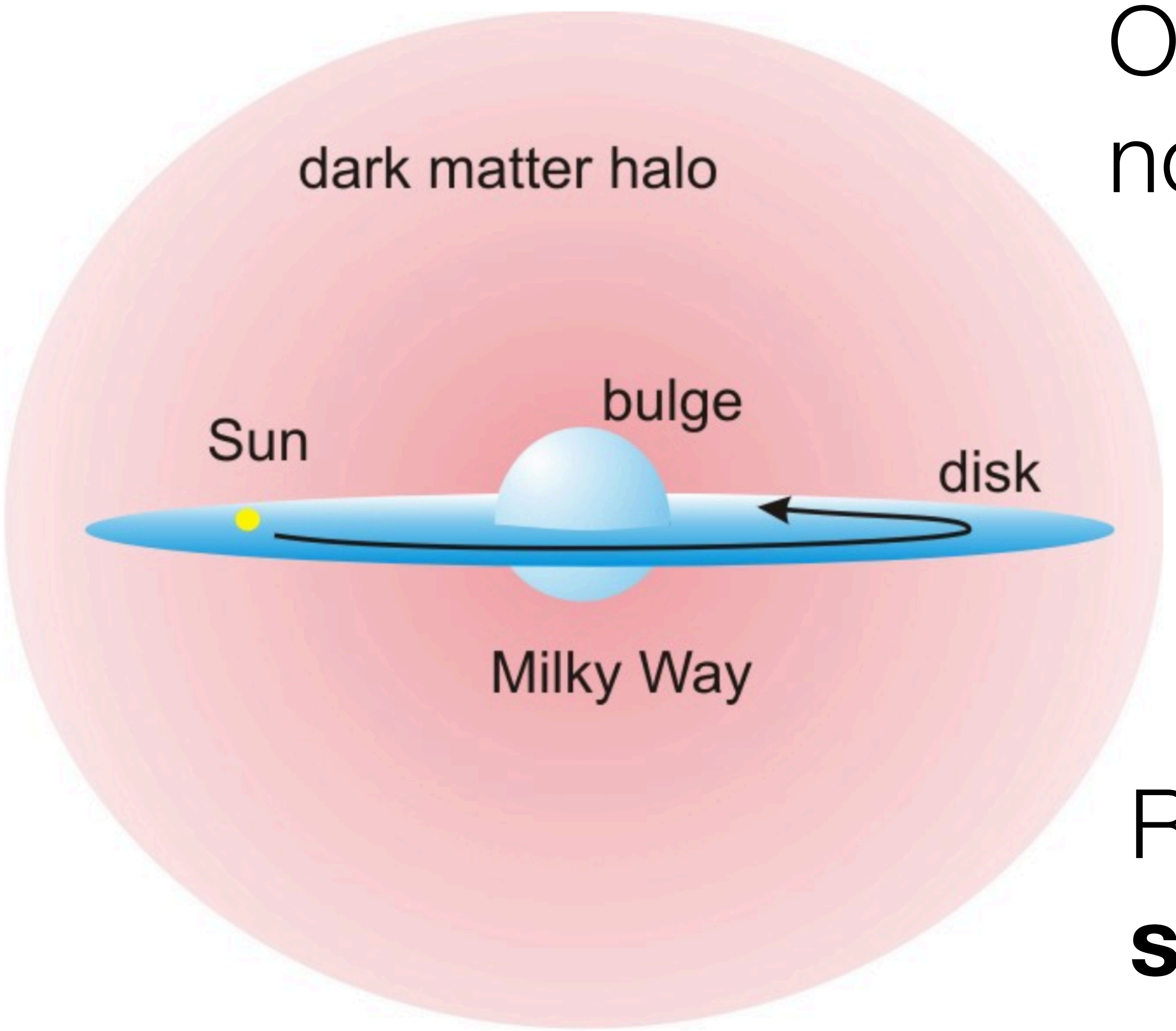
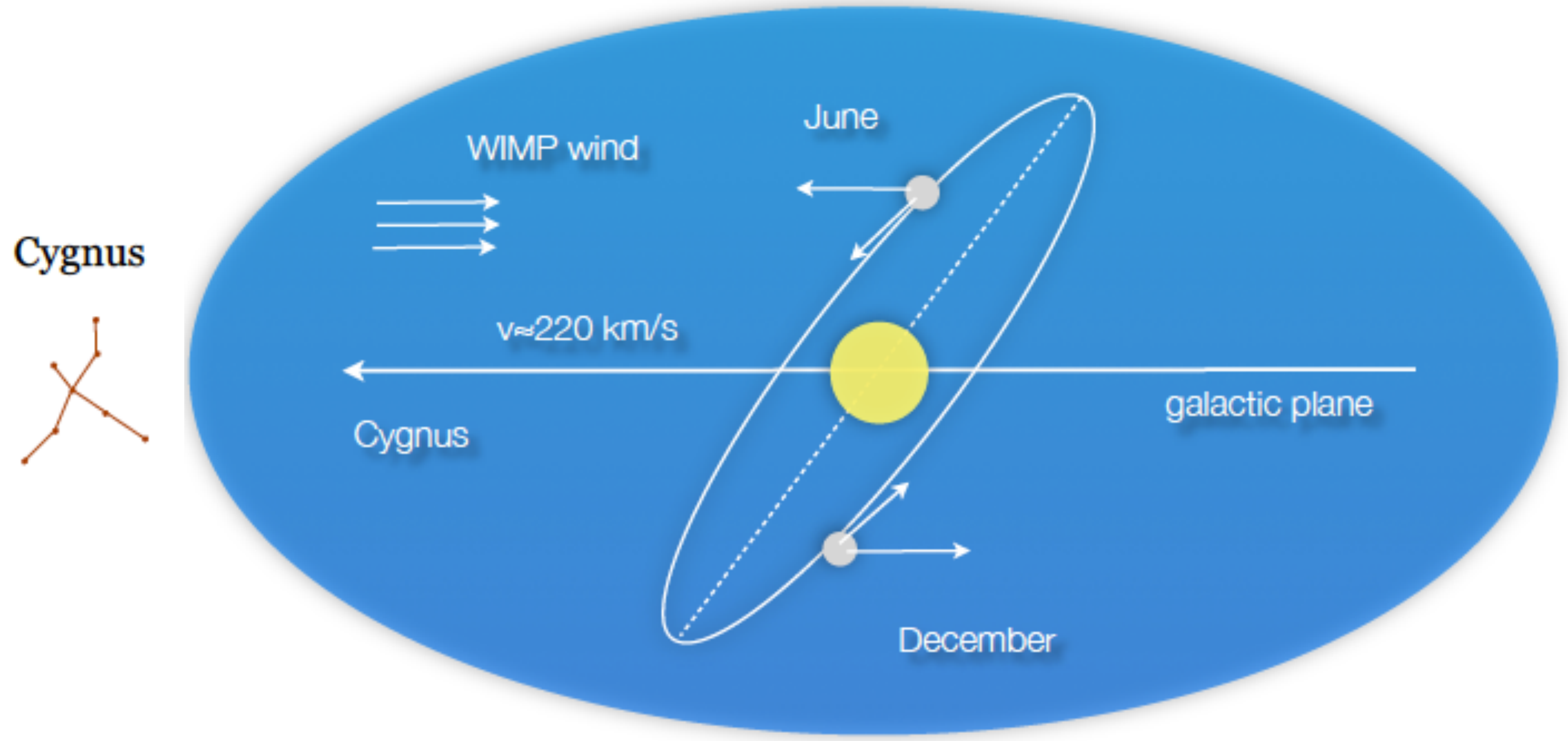
Dark Matter and WIMPs

- 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.

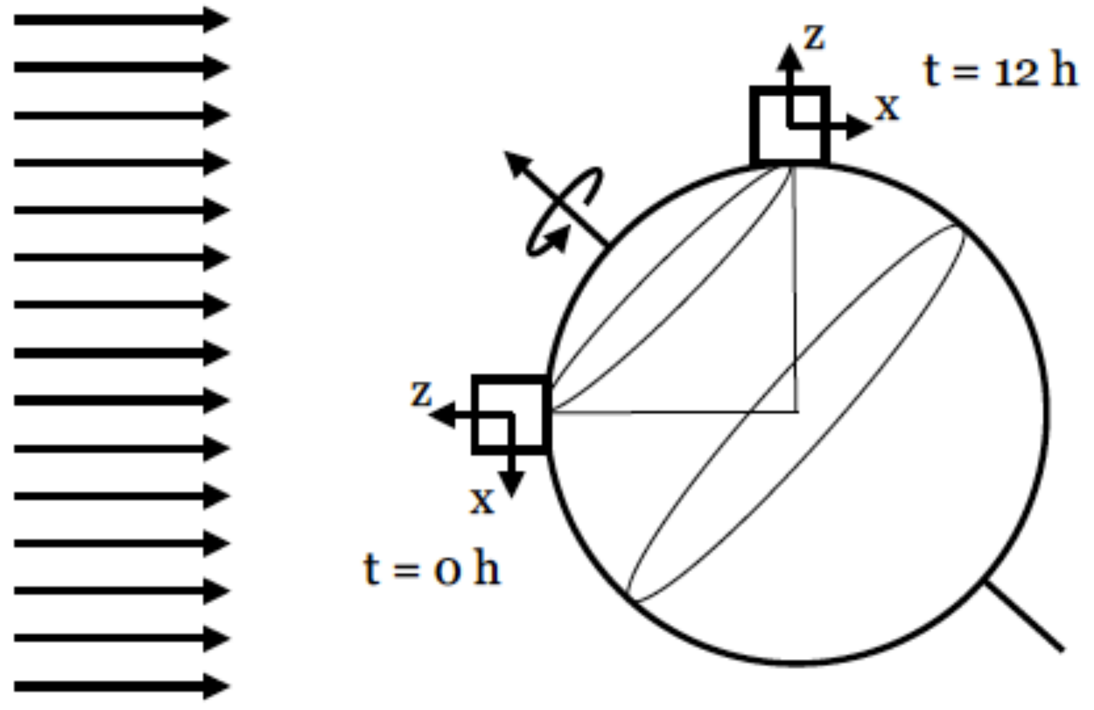
The Sun and the planets move through this halo at 220 km/s preceded by the CYGNUS



Rate and direction modulation: **strong signature**

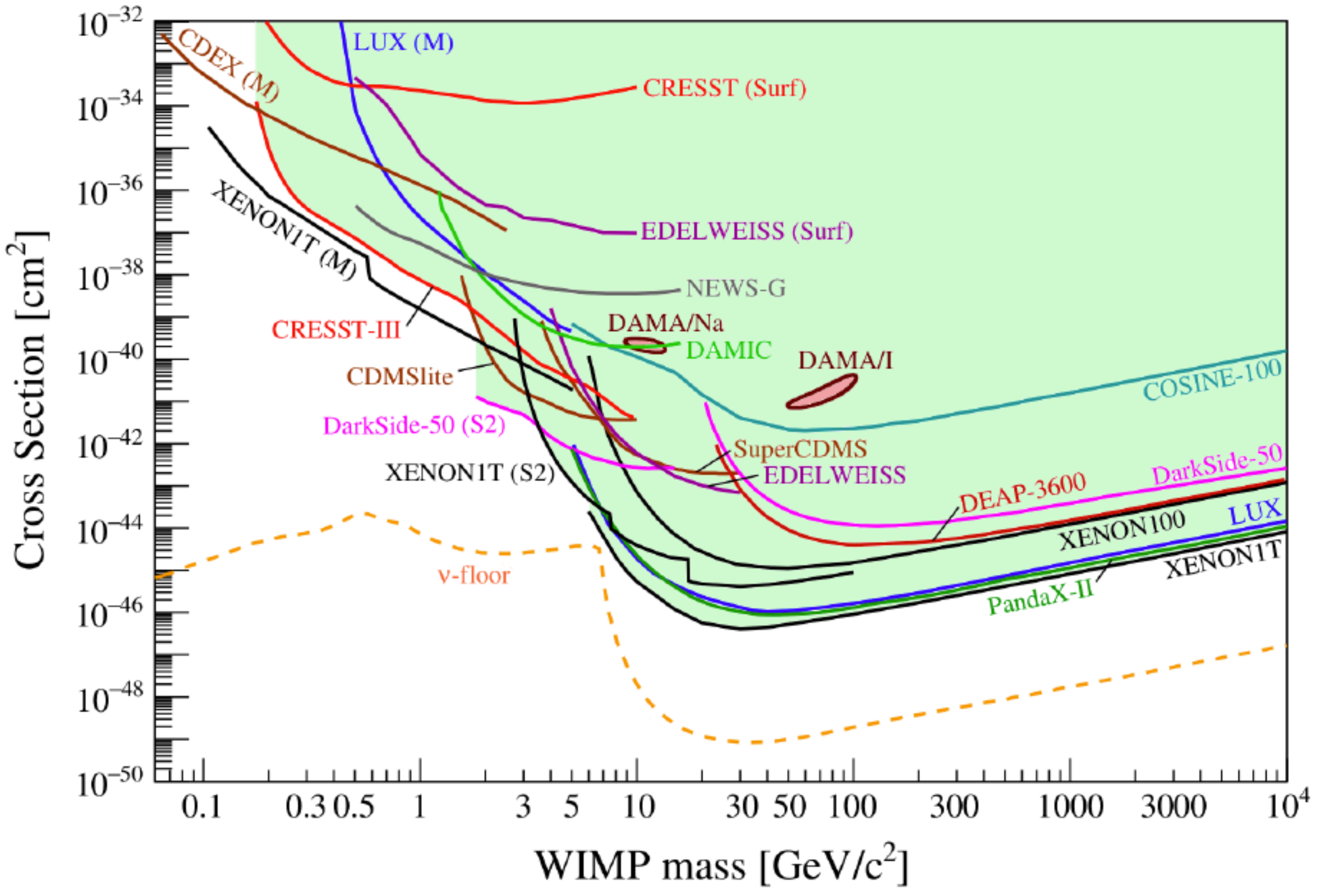
$$v(t)_{DM} = v_{sun} + v_{orb}\ cos\gamma\ cos(\omega(t - t_0))$$

A **directional** detector will be crucial to **confirm** any future detection of DM and to **determine** its **origin**



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 (and below) mass range:

- **keV** (and below) energy **thresholds**;
- **light** nuclei: best candidates are **He** and **H**

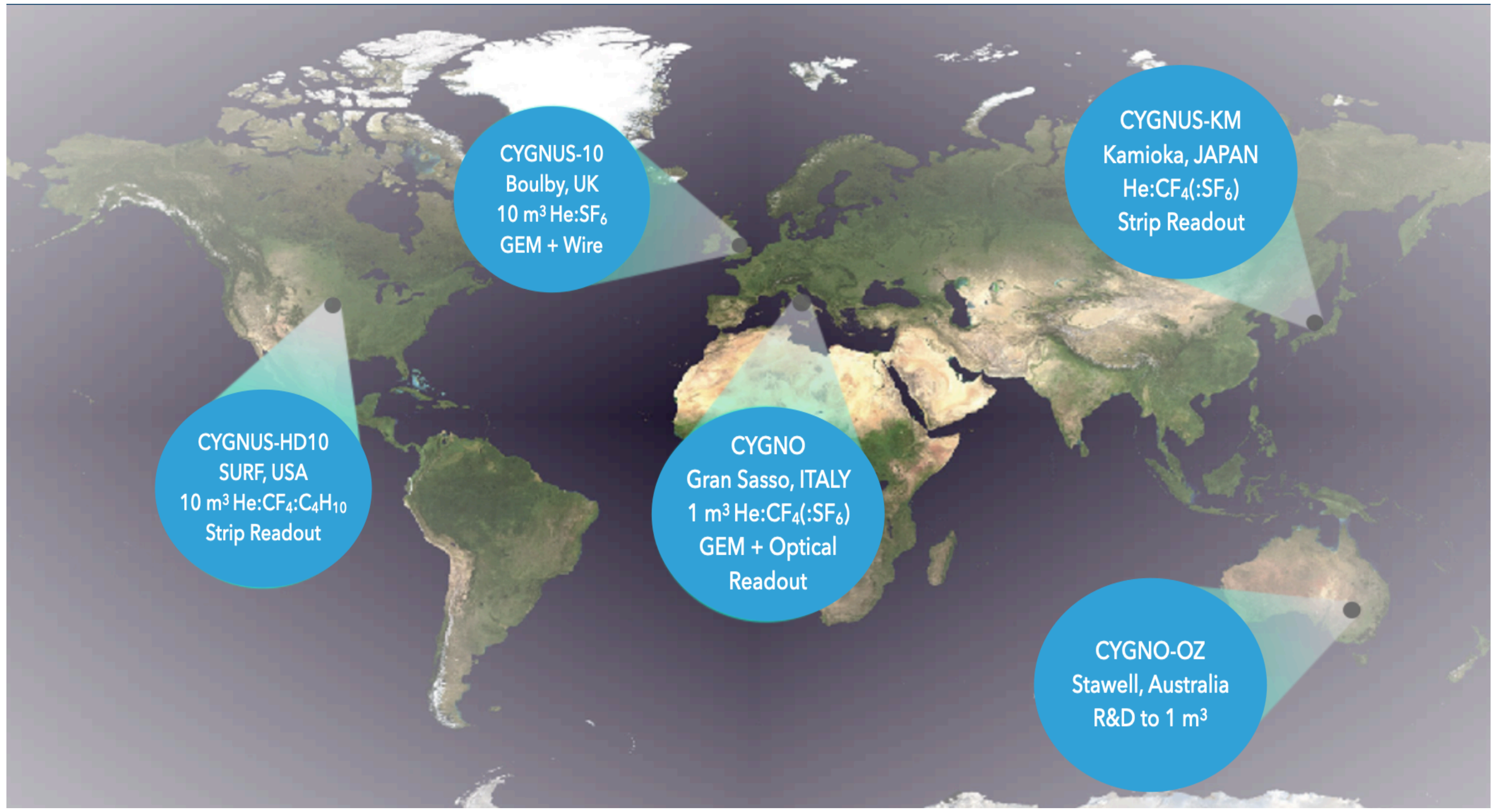
The CYGNO project

The **CYGNO** collaboration is **developing** and **optimising** a **new technique** for the detailed study of Low Energy Rare Events;

Started by few a people in Rome in **2016,** CYGNO has now **50 collaborators**, from **8 Institutions** in 4 Countries

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**;

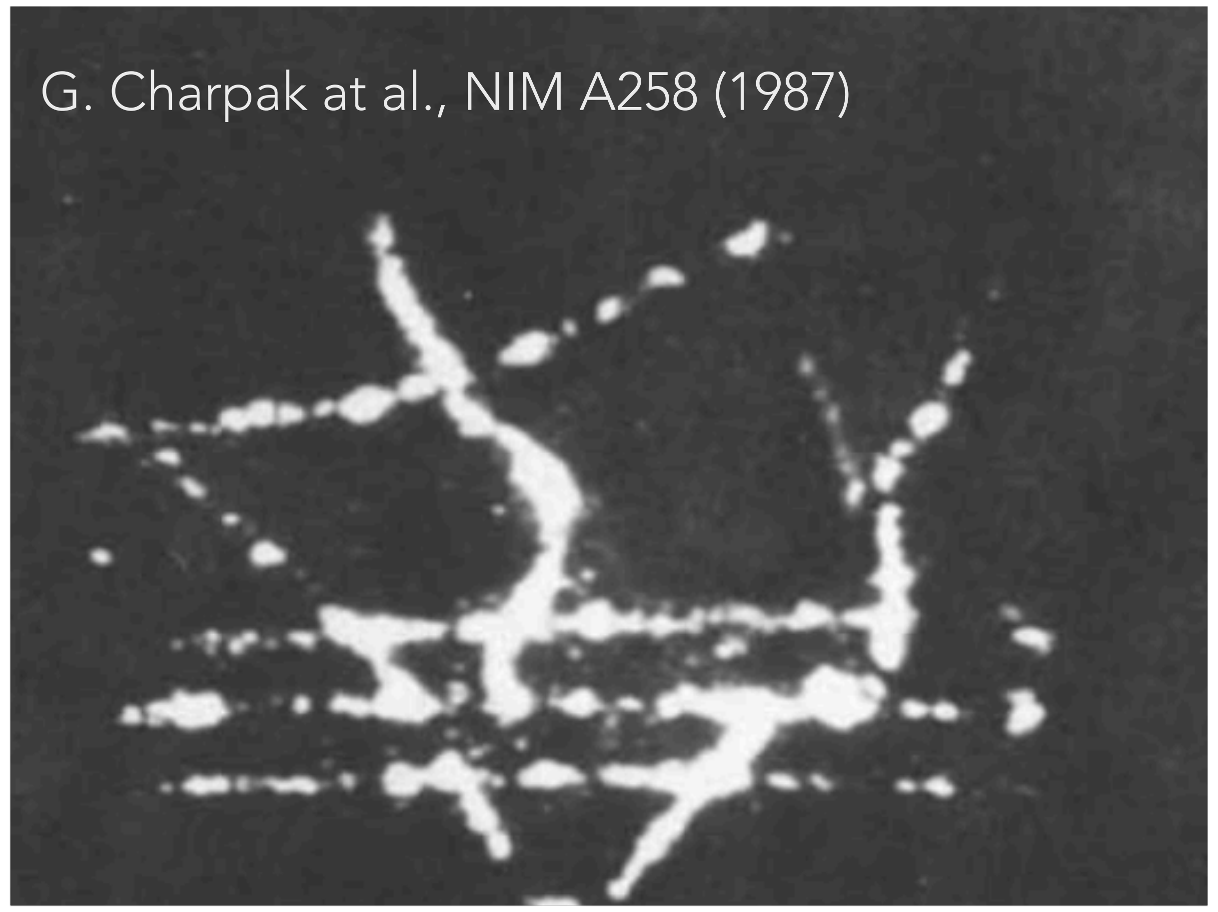
Signed members from UK, Japan, Italy, Spain, China and US focused on **gaseous TPCs** with 2D or 3D direction sensitivity;



The CYGNO idea

TPC: E_{tot}, dE/dx profile, track position and direction, **hundreds eV** threshold;

The CYGNO collaboration proposed to develop a **GEM based TPC** exploiting the **optical readout** of the **electroluminescence light** produced in GEM channels during the avalanche processes;

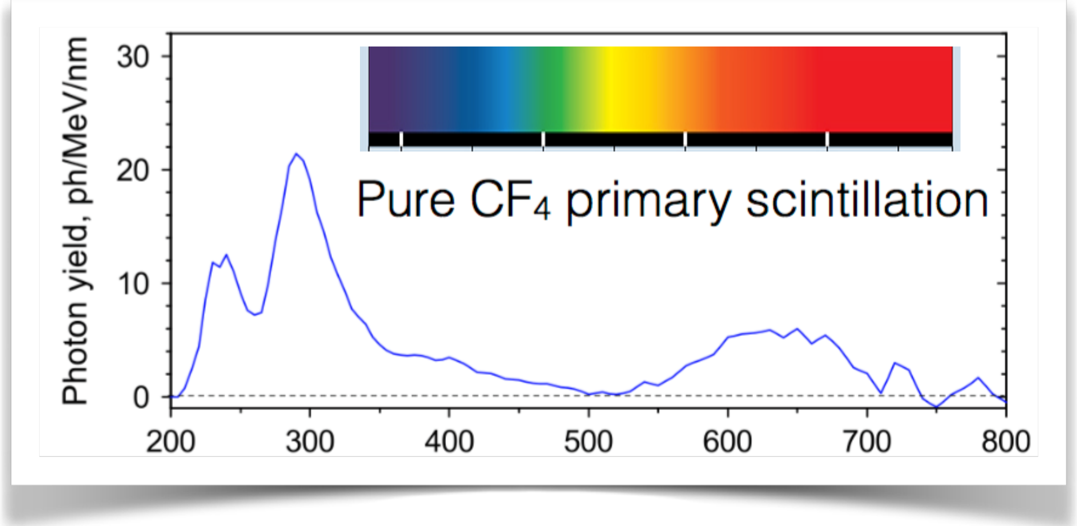


Combined Optical readout

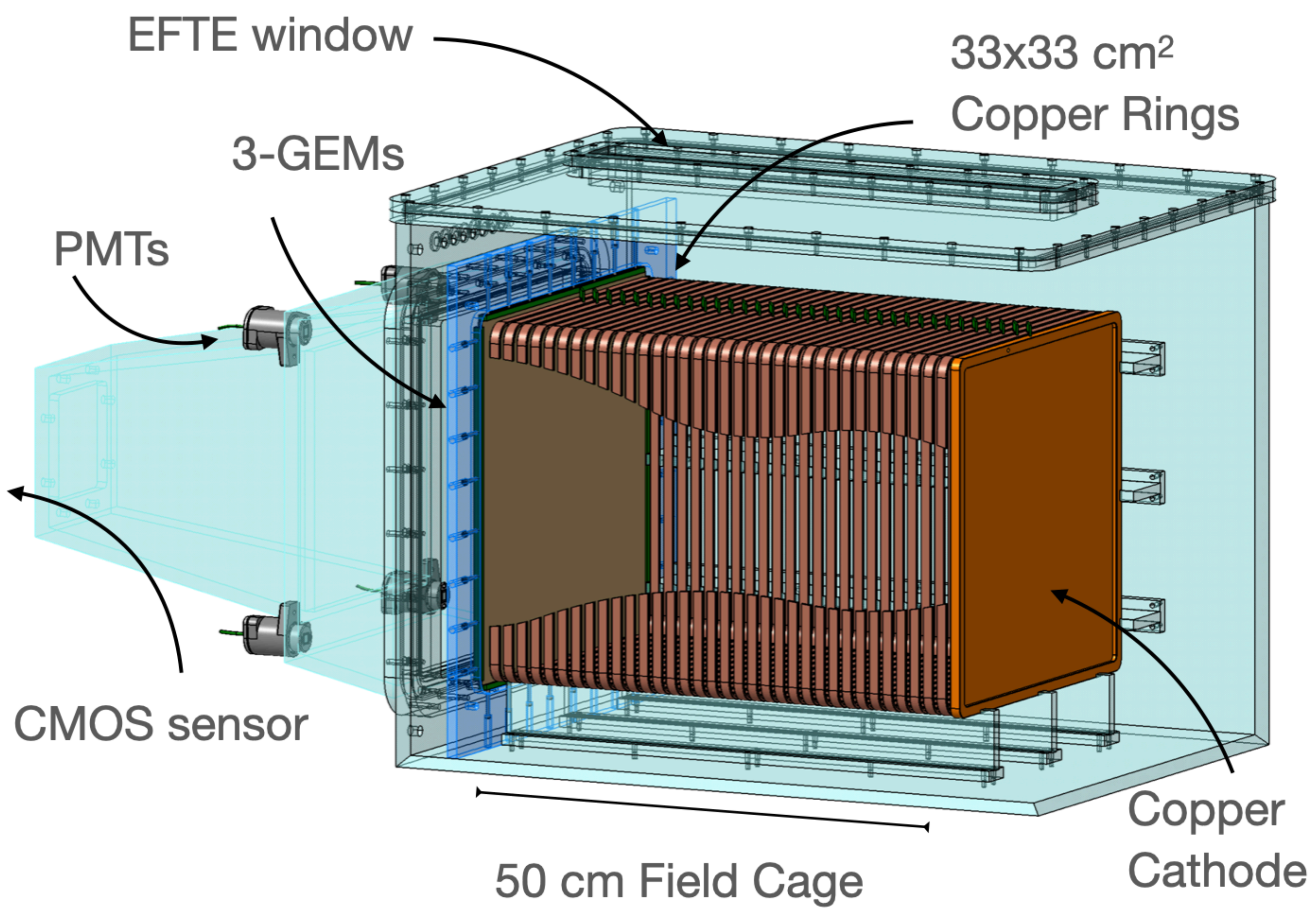
- in last years, high **granularities** and very **low noisy** and high **sensitivity** sCMOS Active Pixel optical sensors have been developed;
- **combined** with time resolved optical sensors (SiPM or PMT) provide **3D** informations
- optical coupling allows to keep sensors **out of the sensitive volume** reducing any contaminations and suitable lens allow to acquire **large surfaces** with small sensors;

LIME: the latest CYGNO prototype

50 litres sensitive volume with an **He/CF_4** based mixture (**+ C_4H_{10}**) at **atmospheric pressure**



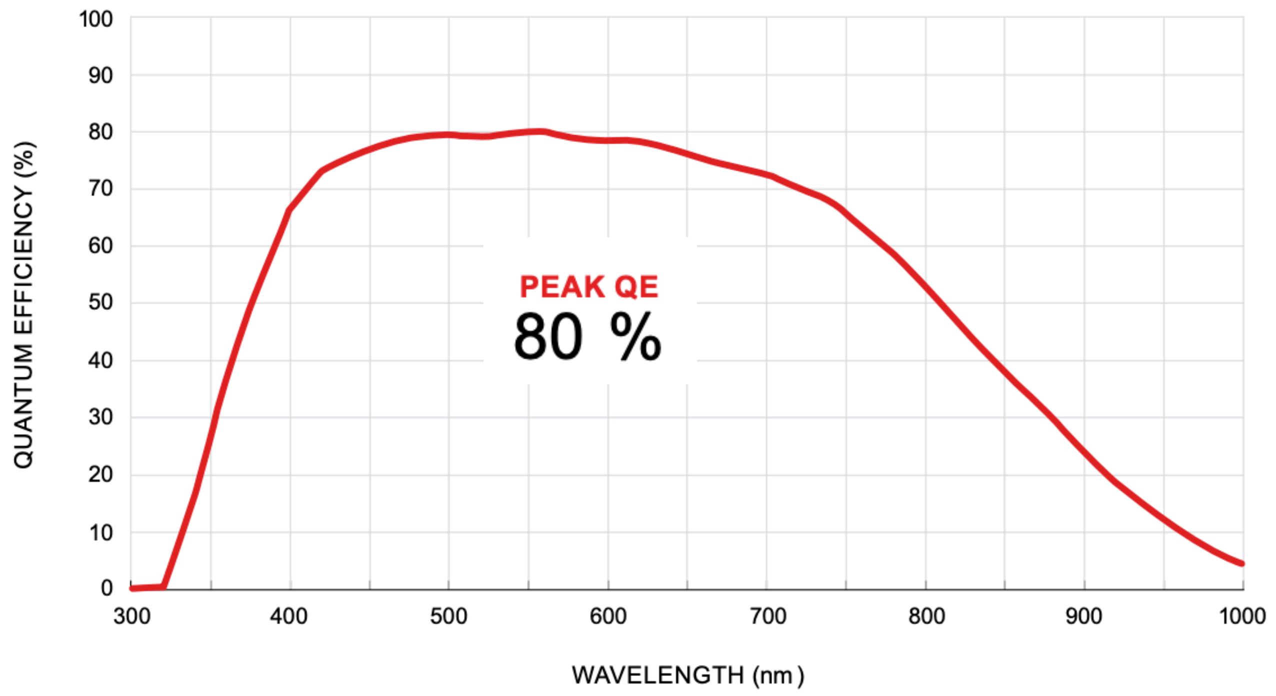
plexiglass vessel,
50 cm drift path;
1000 cm^2 GEM;



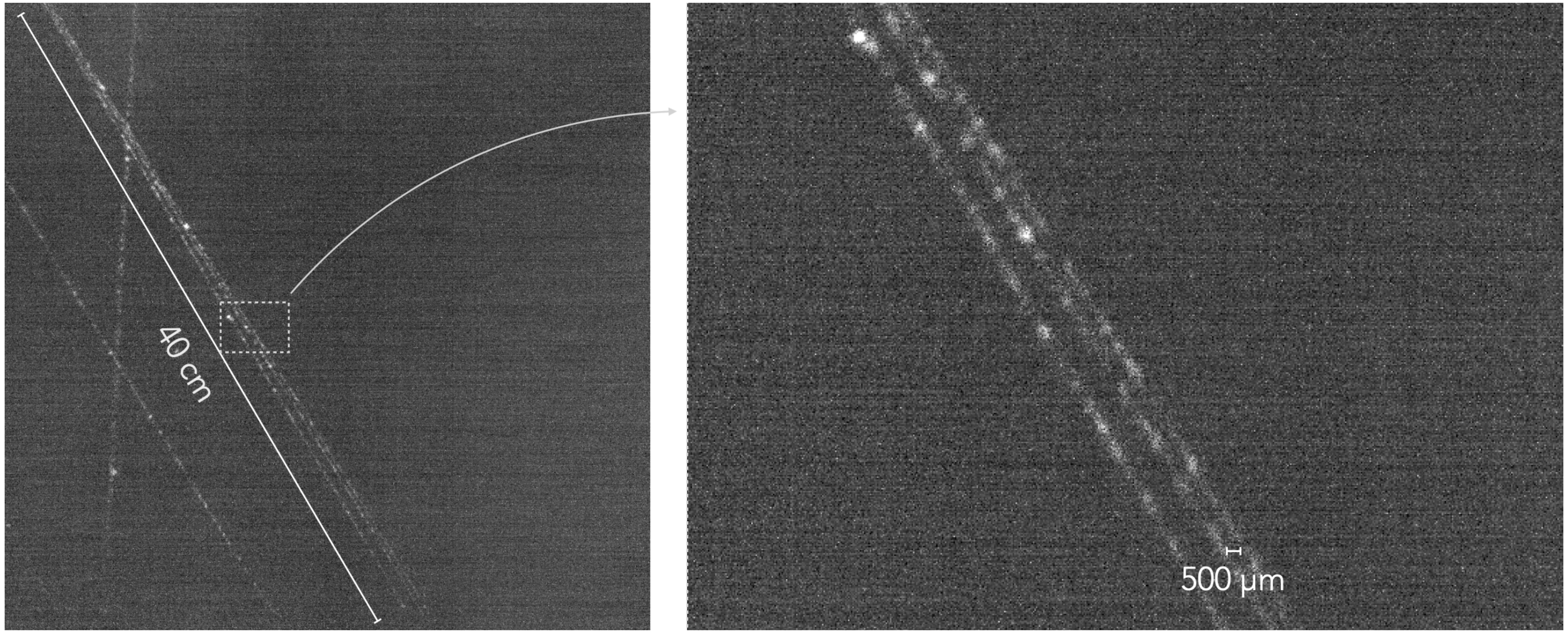
ORCA-Fusion

HIGH RESOLUTION
2304 × 2304
5.3 Megapixels

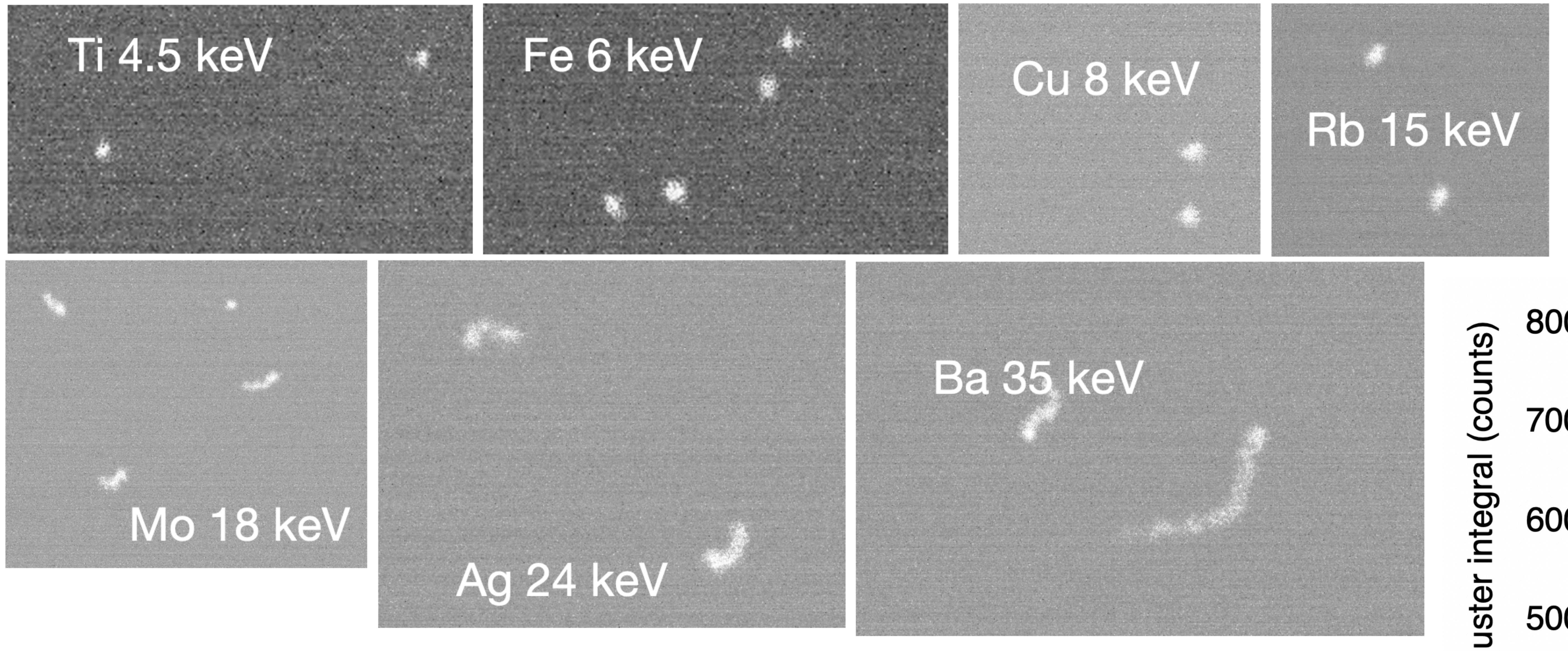
READOUT NOISE
0.7 electrons rms
Ultra-quiet Scan



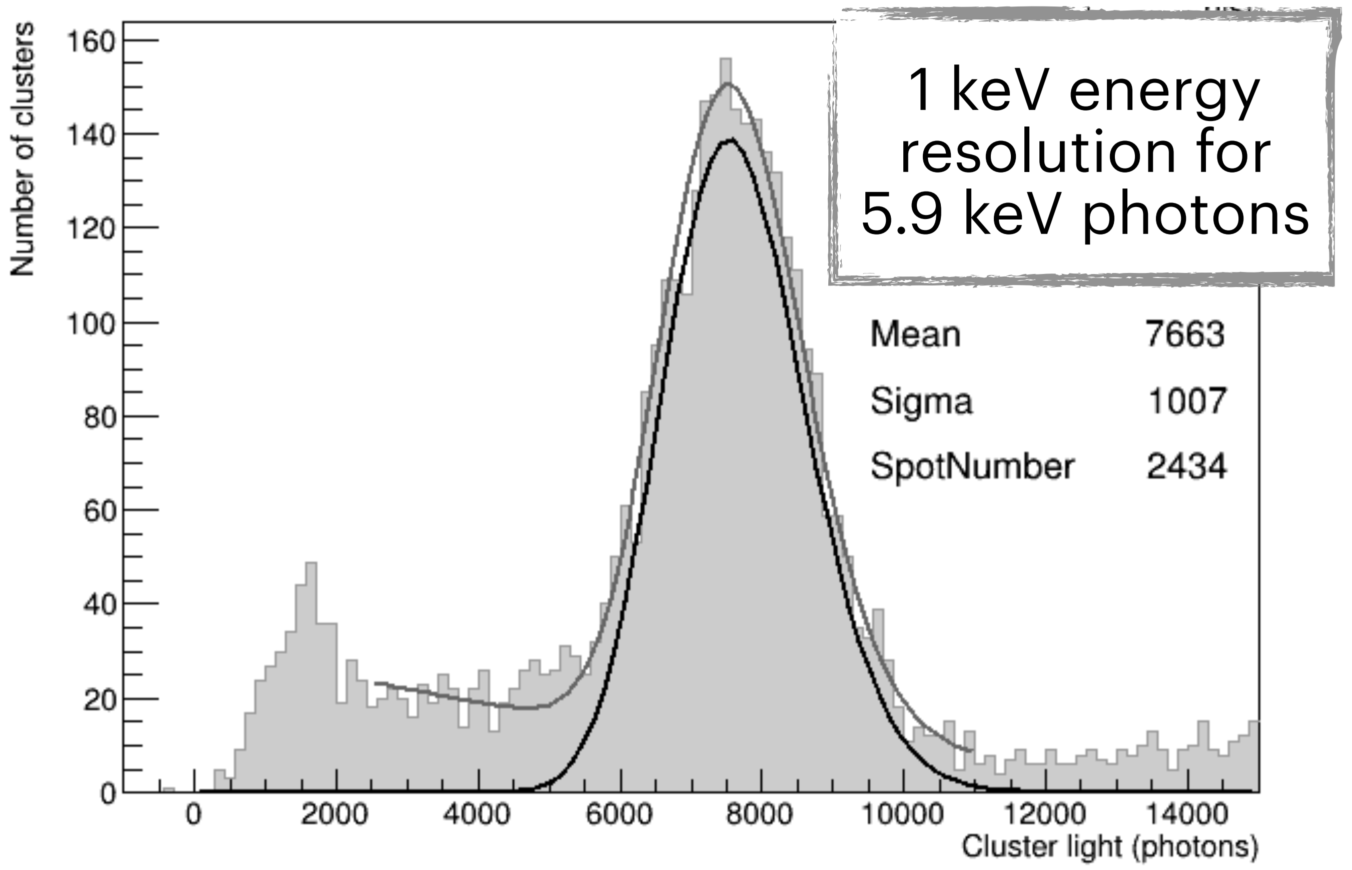
Example of a few cosmic tracks in LIME (Long Imaging ModulE)

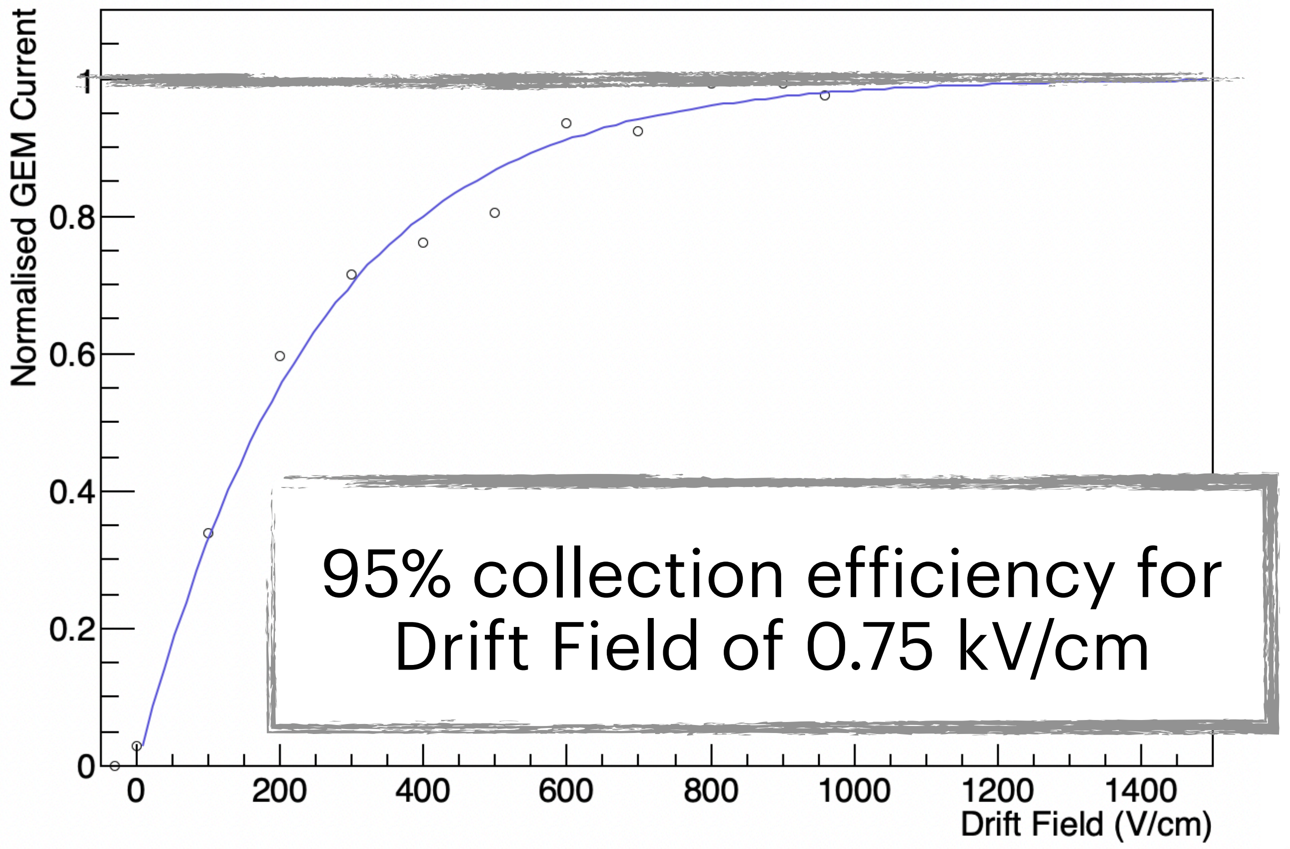


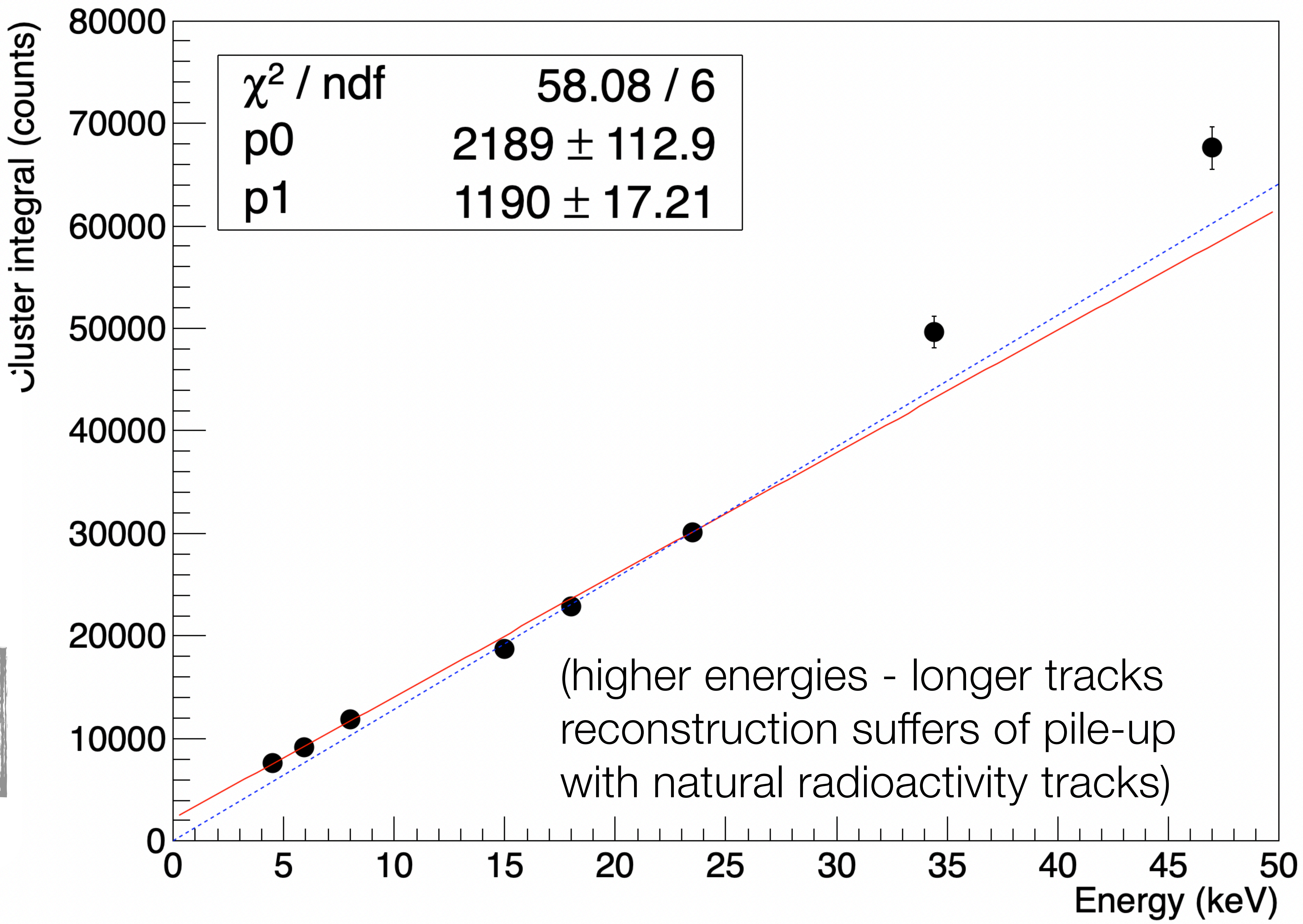
LIME performance with X rays



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



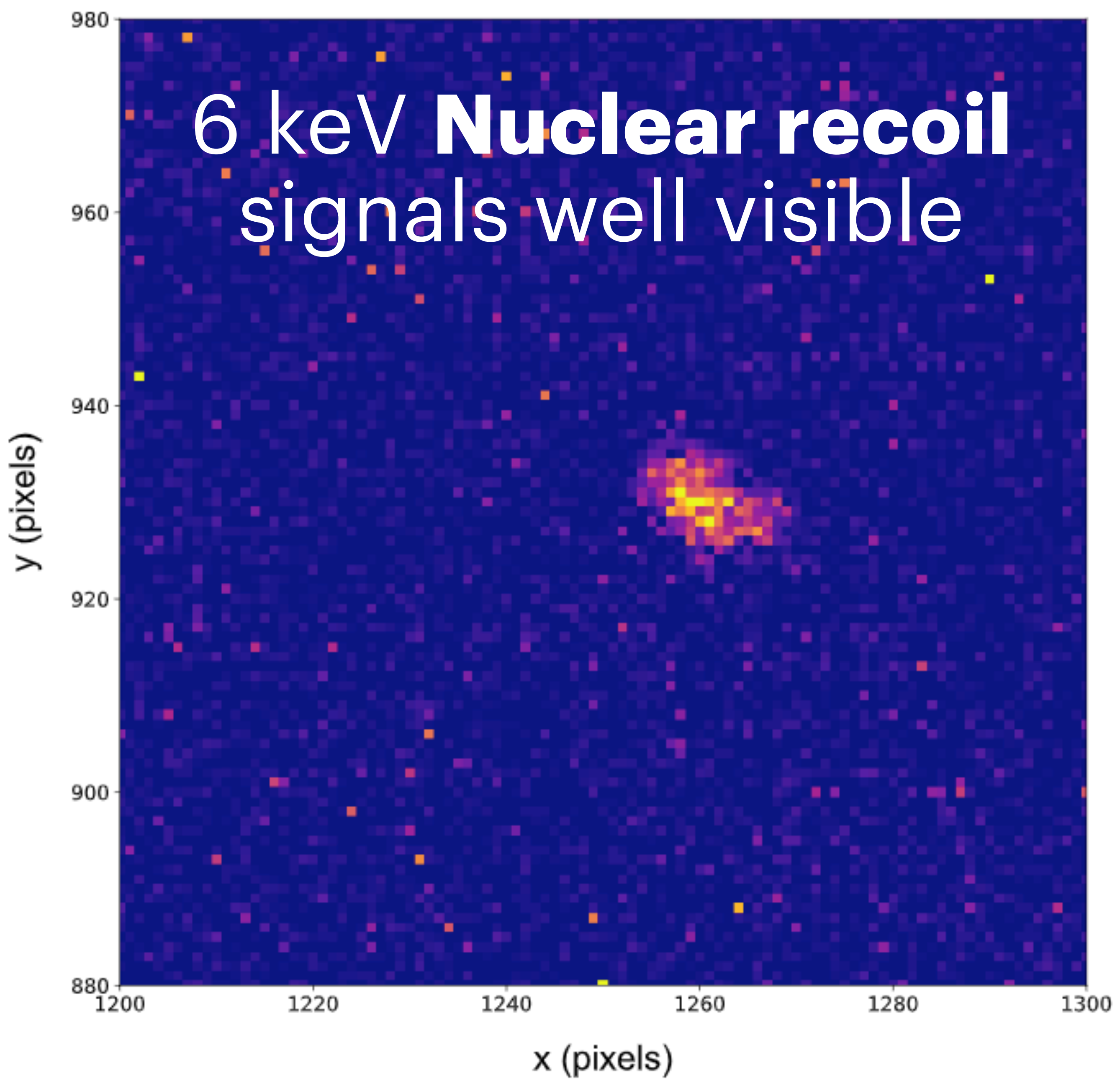


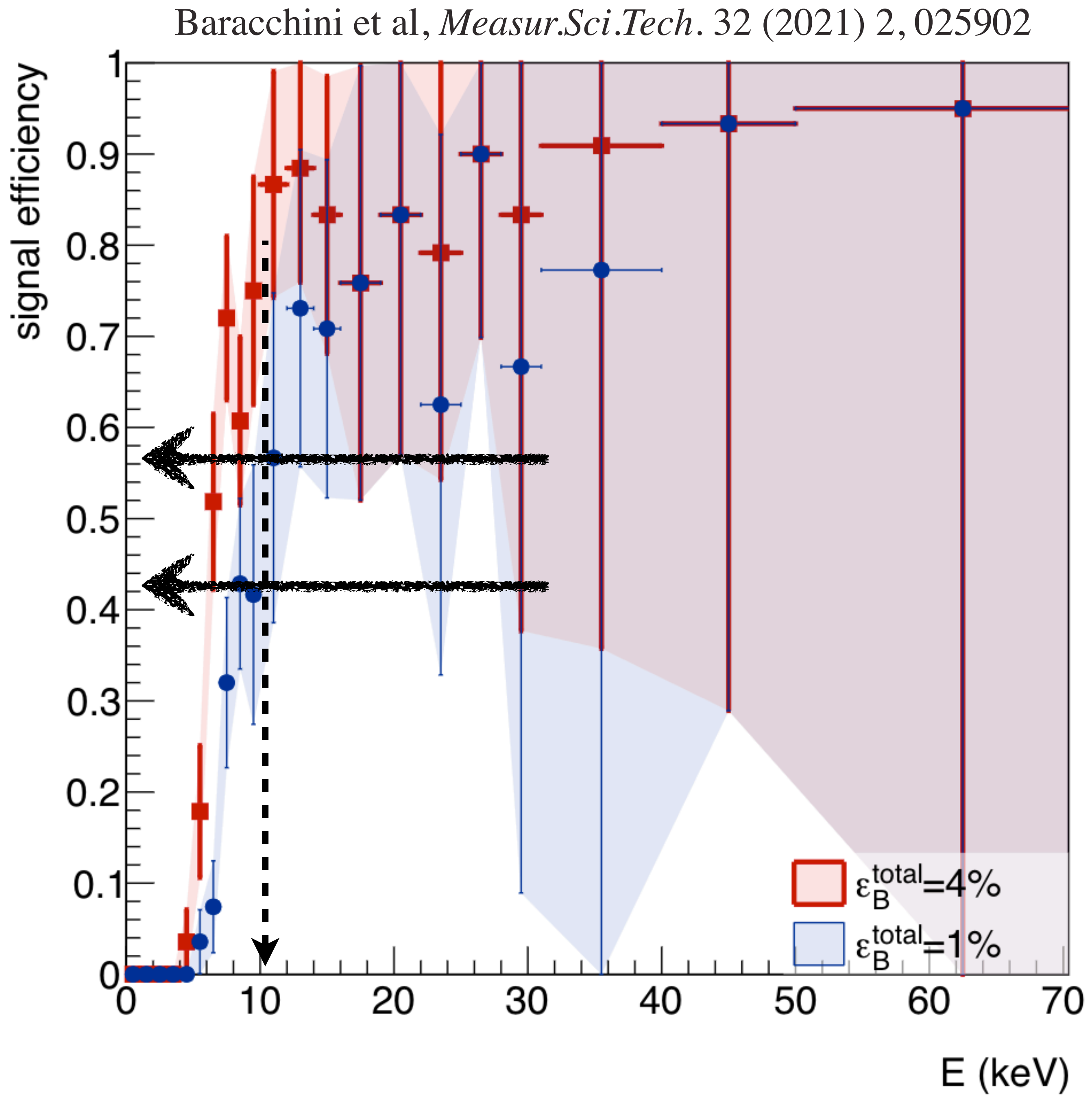


Good **response linearity** in the Energy range 4.5 keV - 45 keV

Rejection capability

By **exploiting** the information on their **shapes** is possible to discriminate electron recoils from the denser nuclear recoils



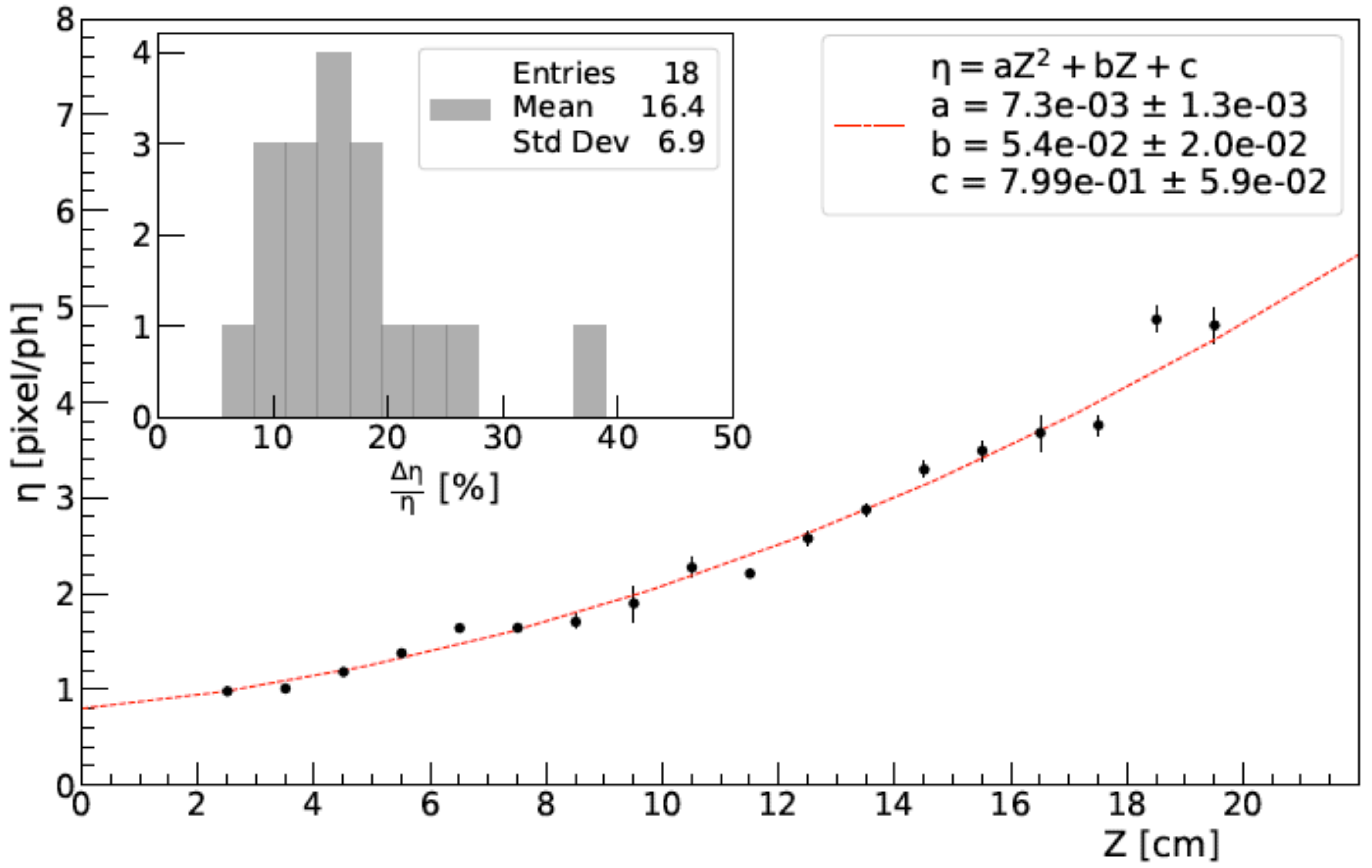


A sizeable **NR detection efficiency** was measured: **40% at 6 keV** and 55% at 10 keV;

In the same conditions more than **95% ER were rejected**;

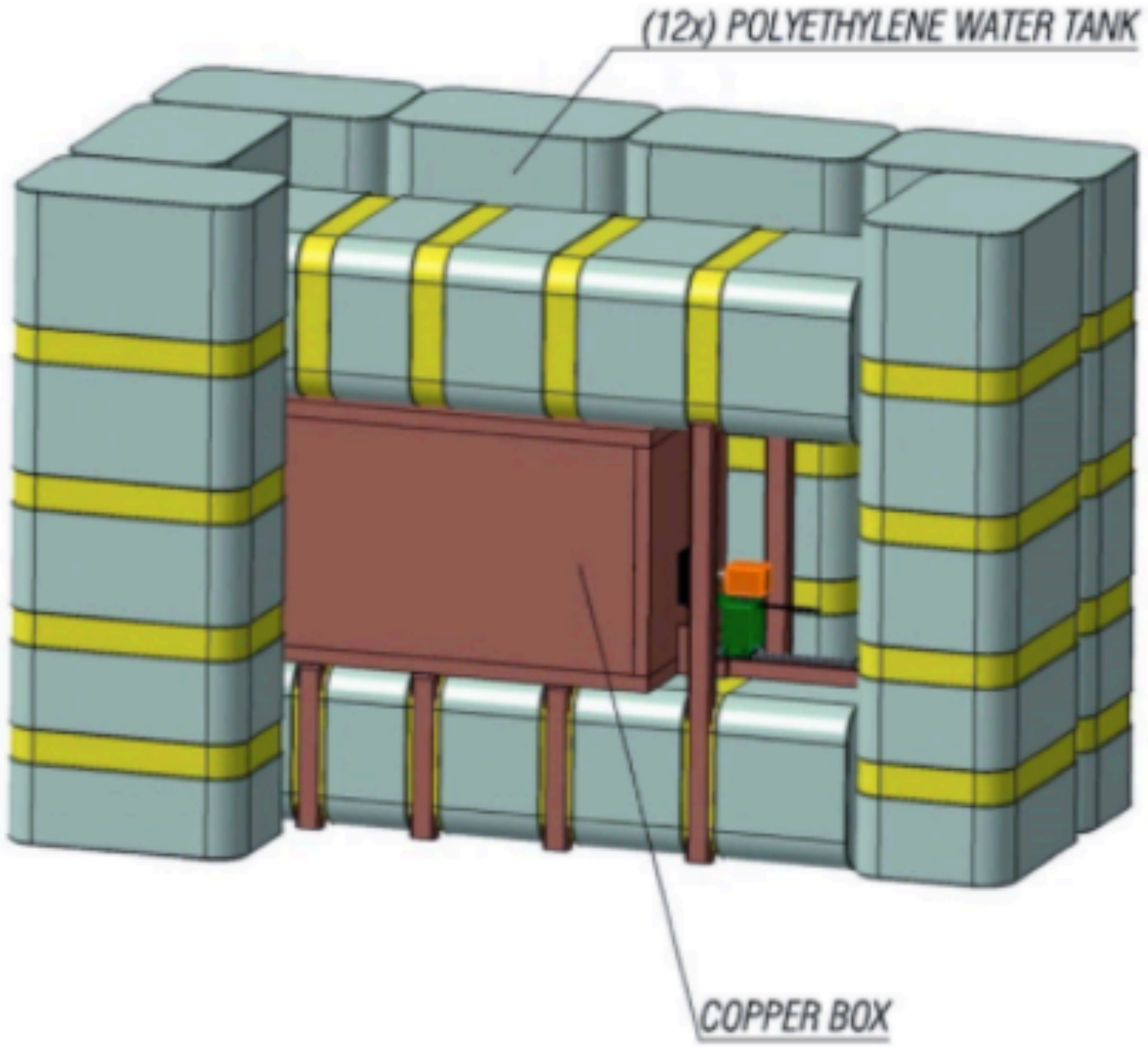
First experimental evidence of rejection capability below 10 keV at atmospheric pressure

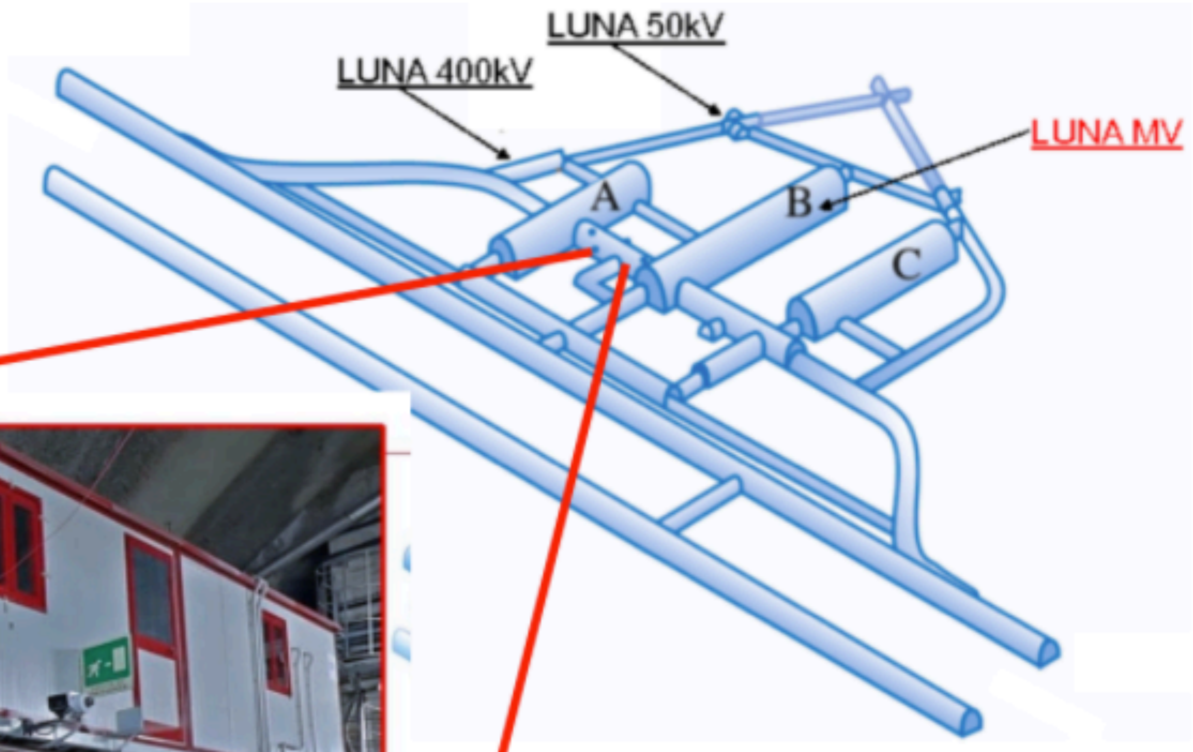
The effects of electron **diffusion** during the drift can be positively used to determine the event depth (***z***) in the gas volume and reject events due to material radioactivity (***fiducialization***)

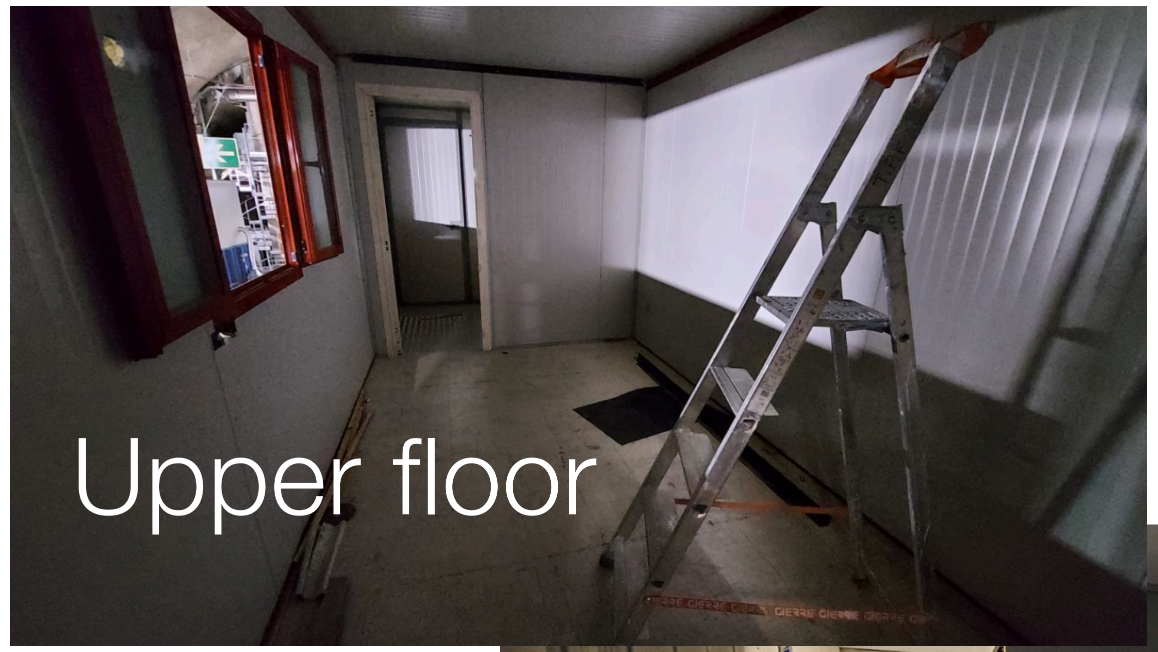


LIME underground

Lime is going to be installed underground at LNGS (3600 m.w.e.) in next months;







The site is ready

Service systems setting up

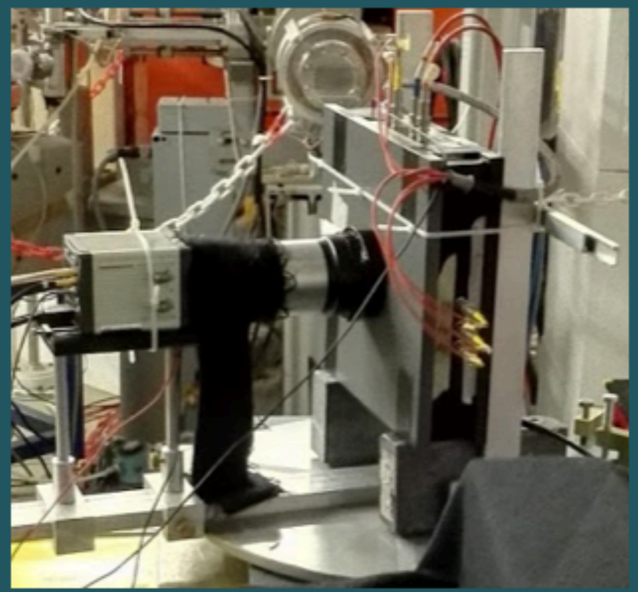
Then, gamma and neutron shields will be put in place to take date in shielded mode

The CYGNO project

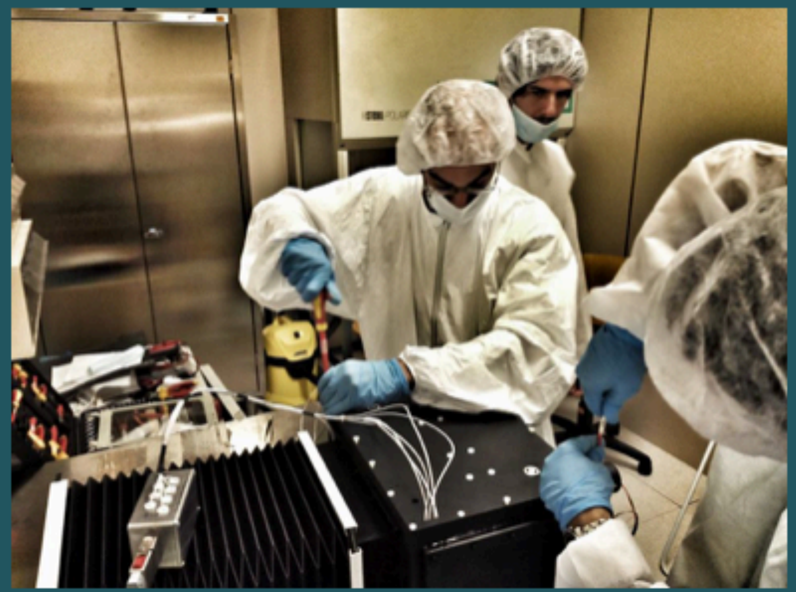
We are here

PHASE 0:
R&D and prototypes

2015/16 ROMA1	2017/18 LNF	2019/21 LNF/LNGS
ORANGE	LEMON	LIME



- 1 cm drift



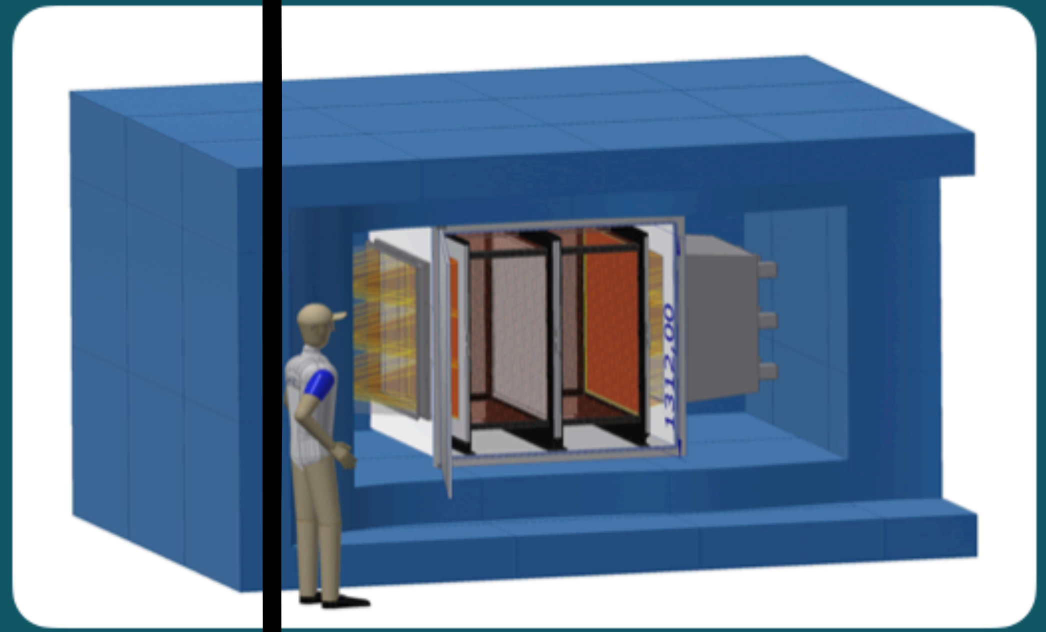
- 3D printing
- 20 cm drift

- 50 cm drift
- underground tests
- shielding

PHASE 1:
1 m^3 Demonstrator

2022/25
LNF/LNGS

CYGNO_01

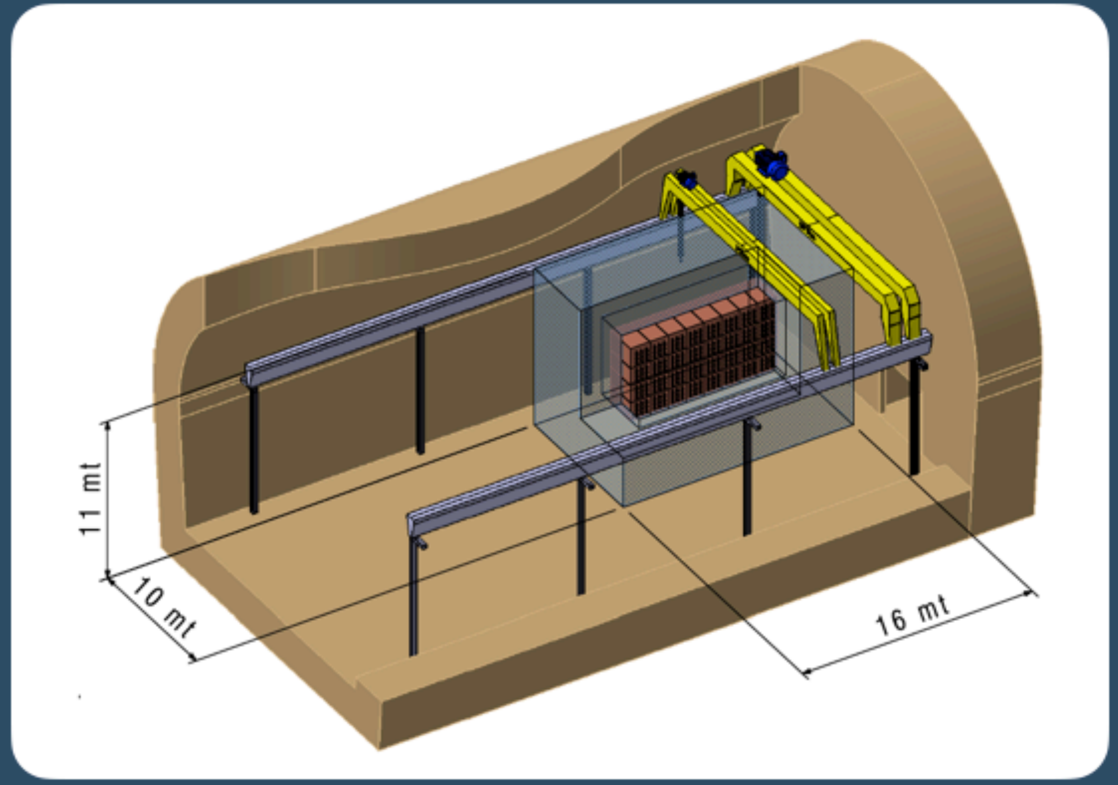


- background
- materials test, gas purification
- scalability

PHASE 2:
30 m^3 Experiment

2026..
LNGS

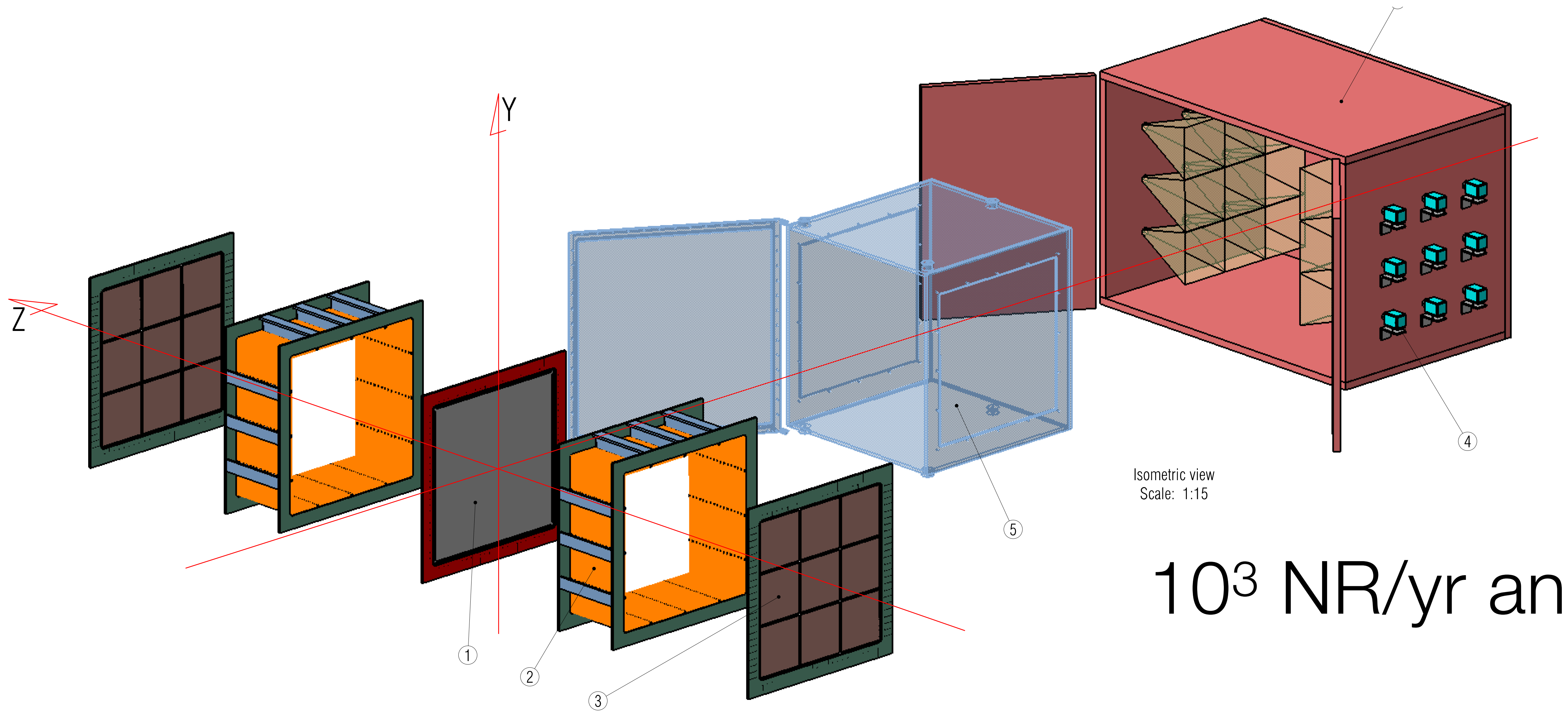
CYGNO_30



- Physics research

$1m^3$ demonstrator: BASELINE layout

1 m^3 of He/CF4 60/40 (1.6 kg) in an acrylic vessel at atmospheric pressure composed by two 50 cm long TPC with a central cathode and a drift field of about 1 kV/cm;



Radioactivity shielding: 5 cm thick copper layer and 200 cm of water.

External and internal radioactivities simulated by means of a complete GEANT4 simulation

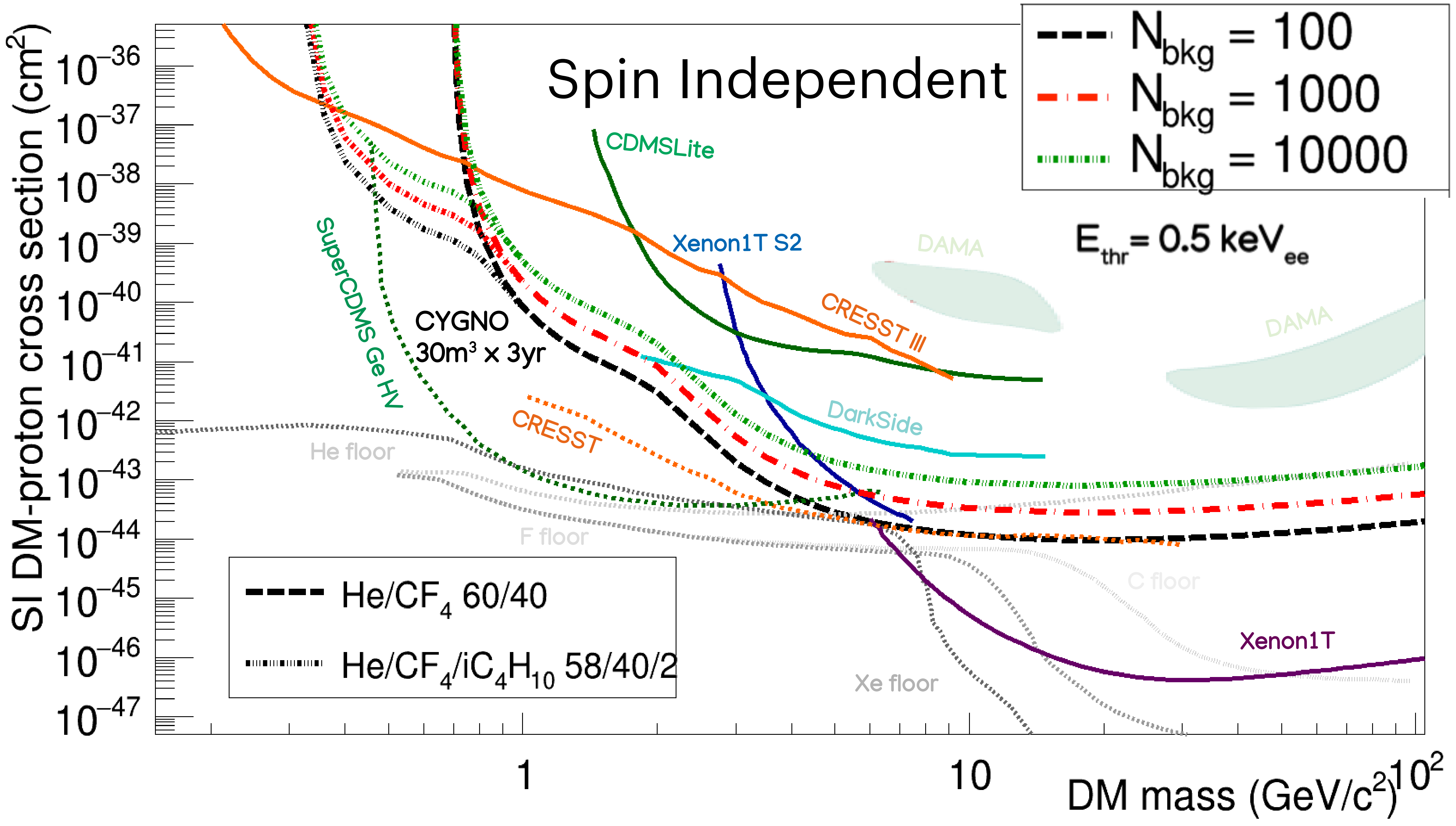
10^3 NR/yr and 2 x 10^6 ER/yr in 1 m^3 [0-20 keV]

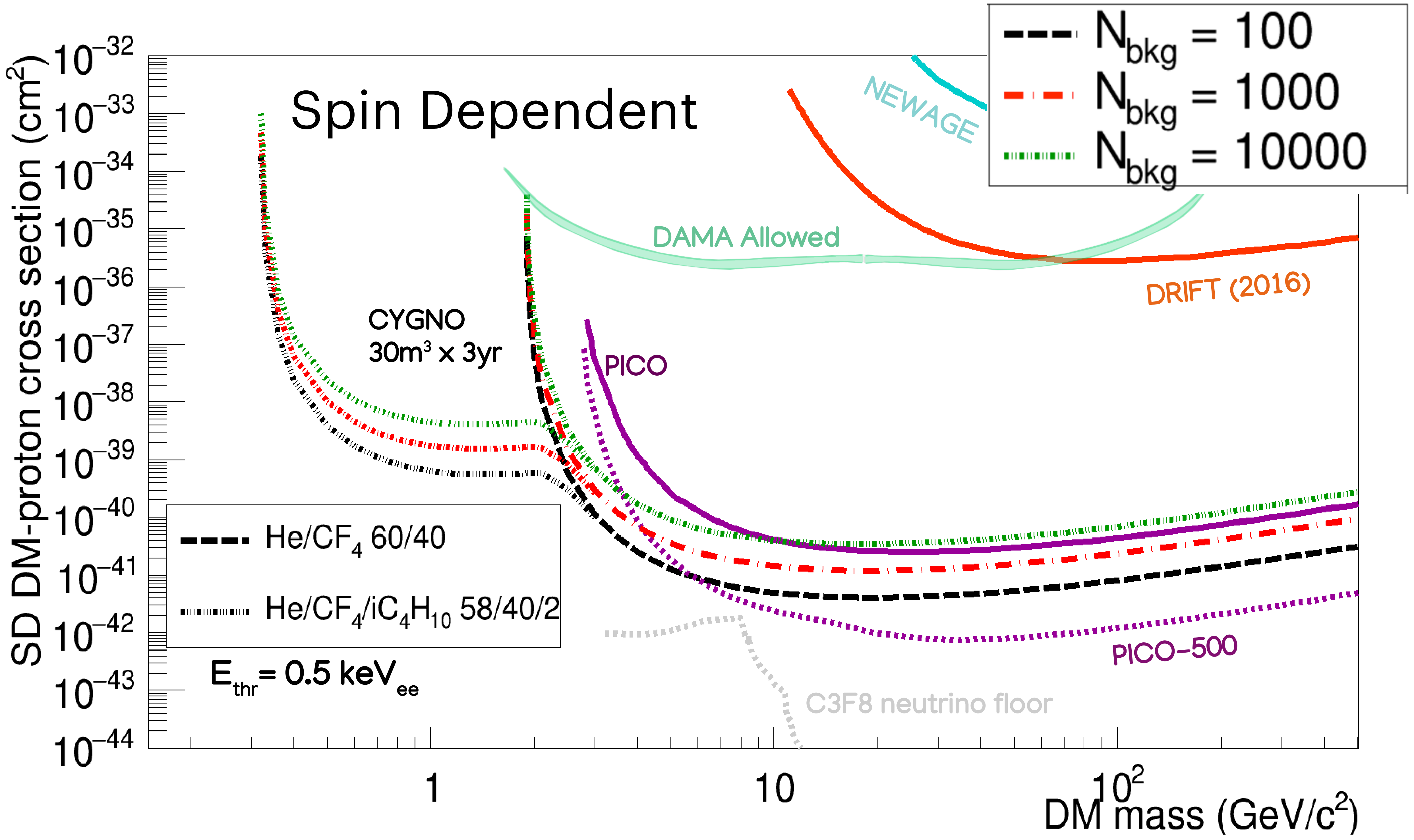
Assuming a conservative ER rejection of 10^3-10^4, a **bkg event rate of 10^2-10^3 ER/yr** is expected in the energy range [0-20 keV];

The main goal is the demonstration of the **technique scalability** and the study and **reduction of radioactive background** produced by the detector materials.

What CYGNO can do: DM search and study

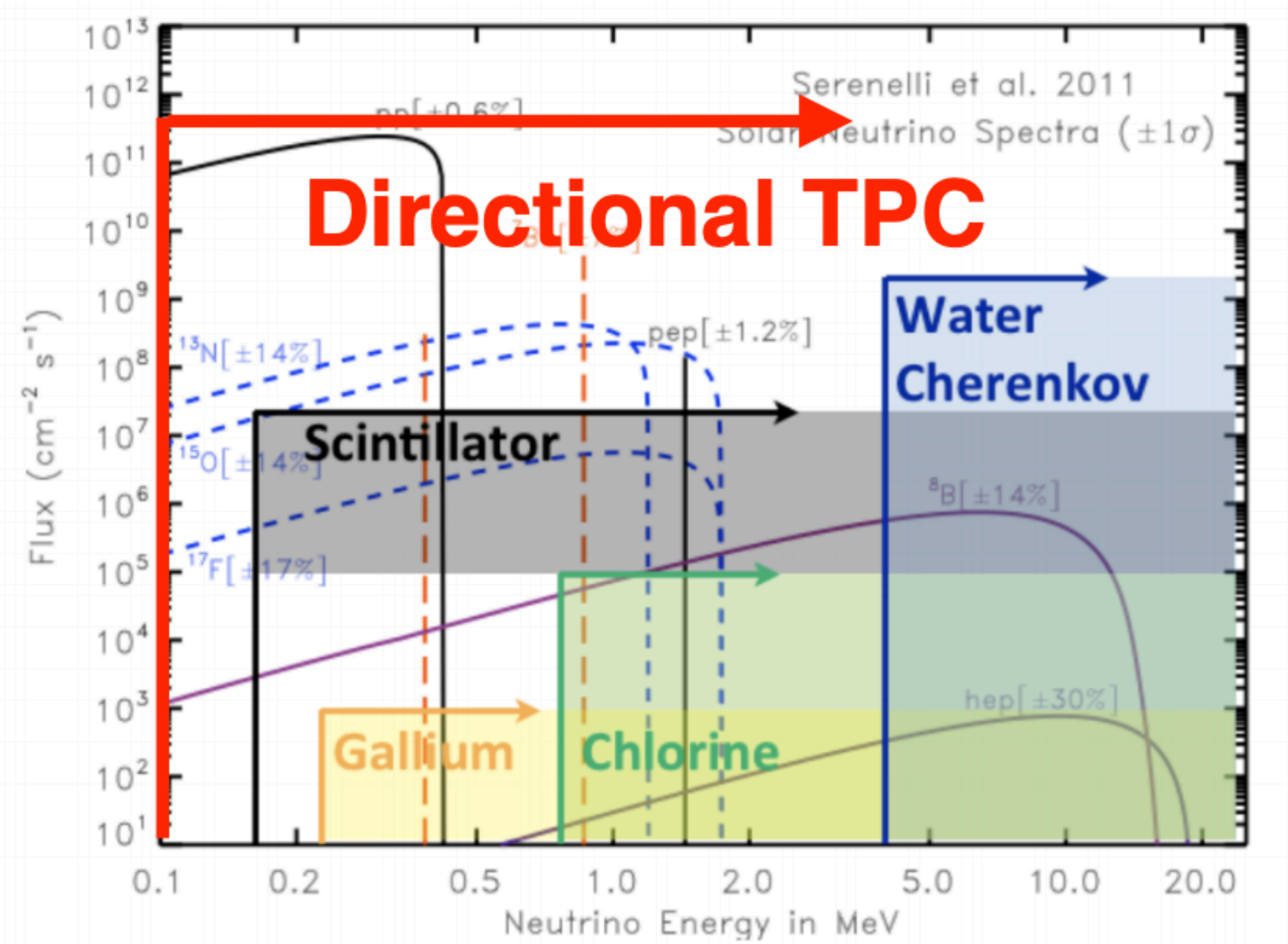
A possible apparatus with a sensitive **volume of 30 m³**, **operating for 3 years** (150 kg x yr exposure) would be able to **explore mass regions even below 1 GeV** not explored to date.





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

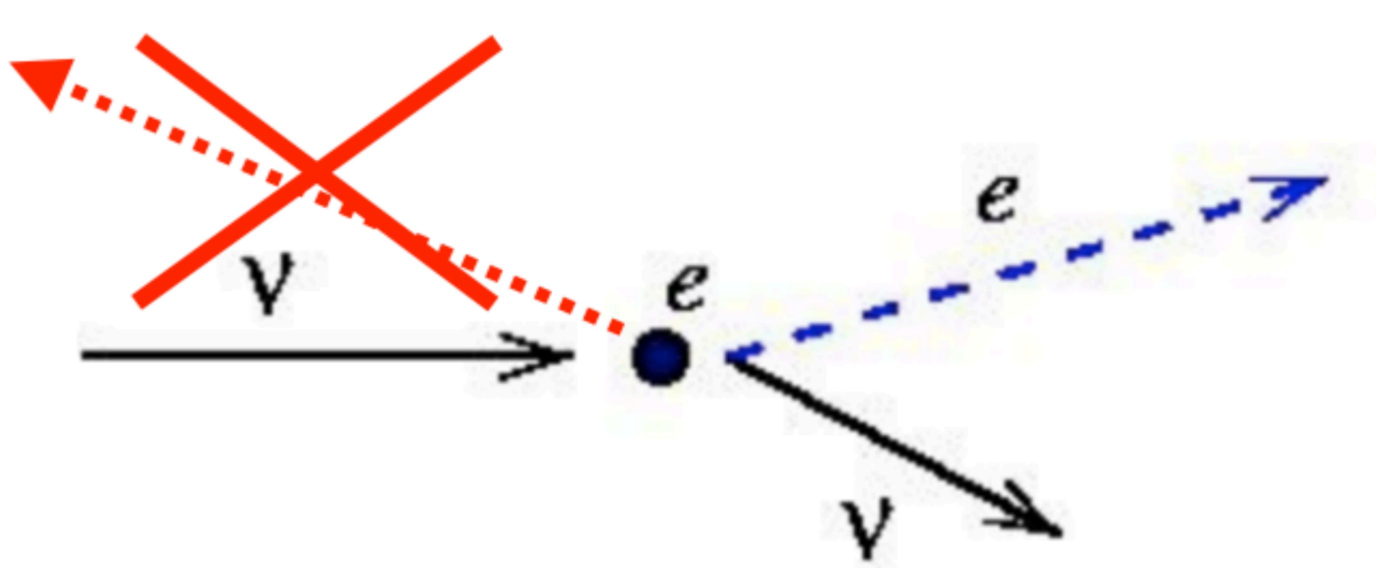
What CYGNO can do: neutrino spectroscopy



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

Conclusion

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

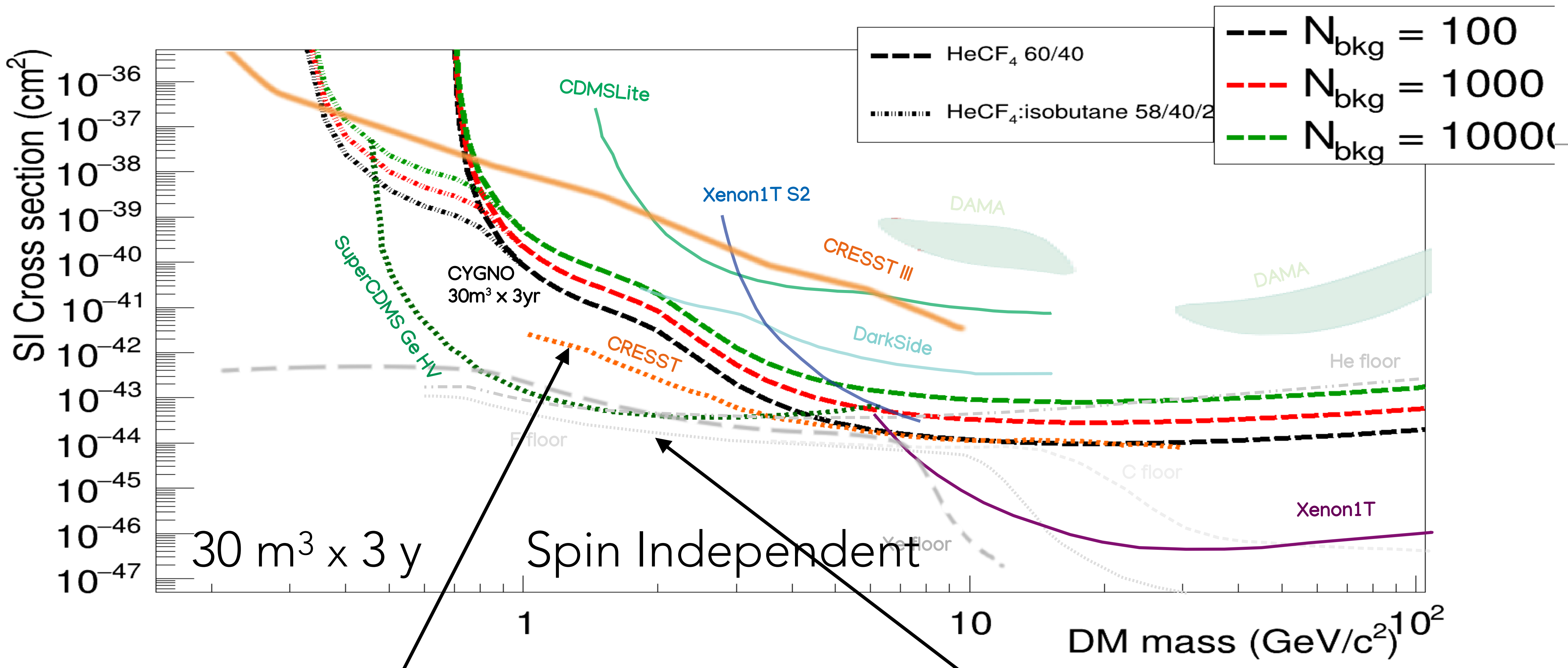
Very promising performance was found in the (few) keV region:

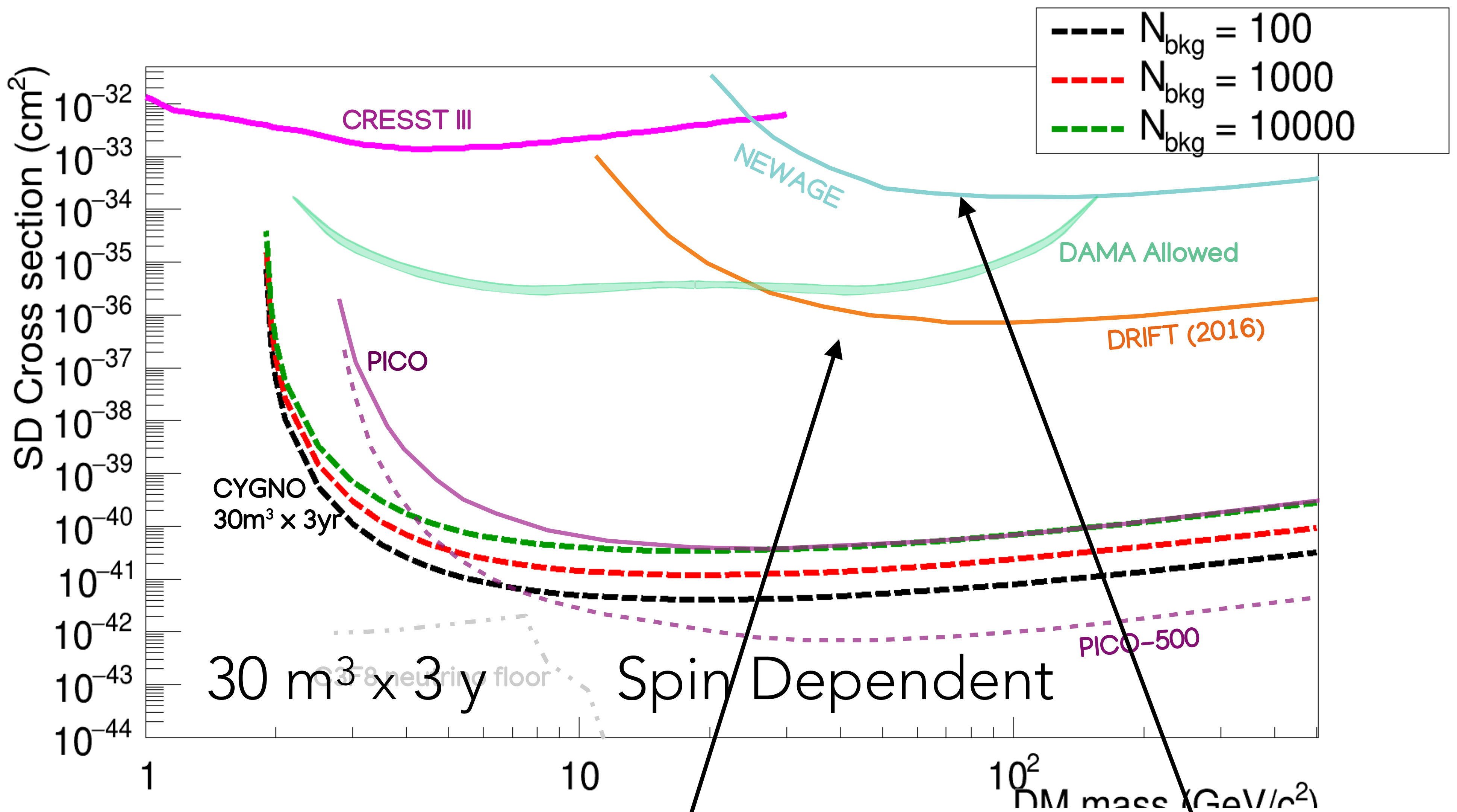
- **high detection** capability;
- very good **energy** and **position resolution**;
- high **discrimination power** provided by the detailed acquisition of readout approach;

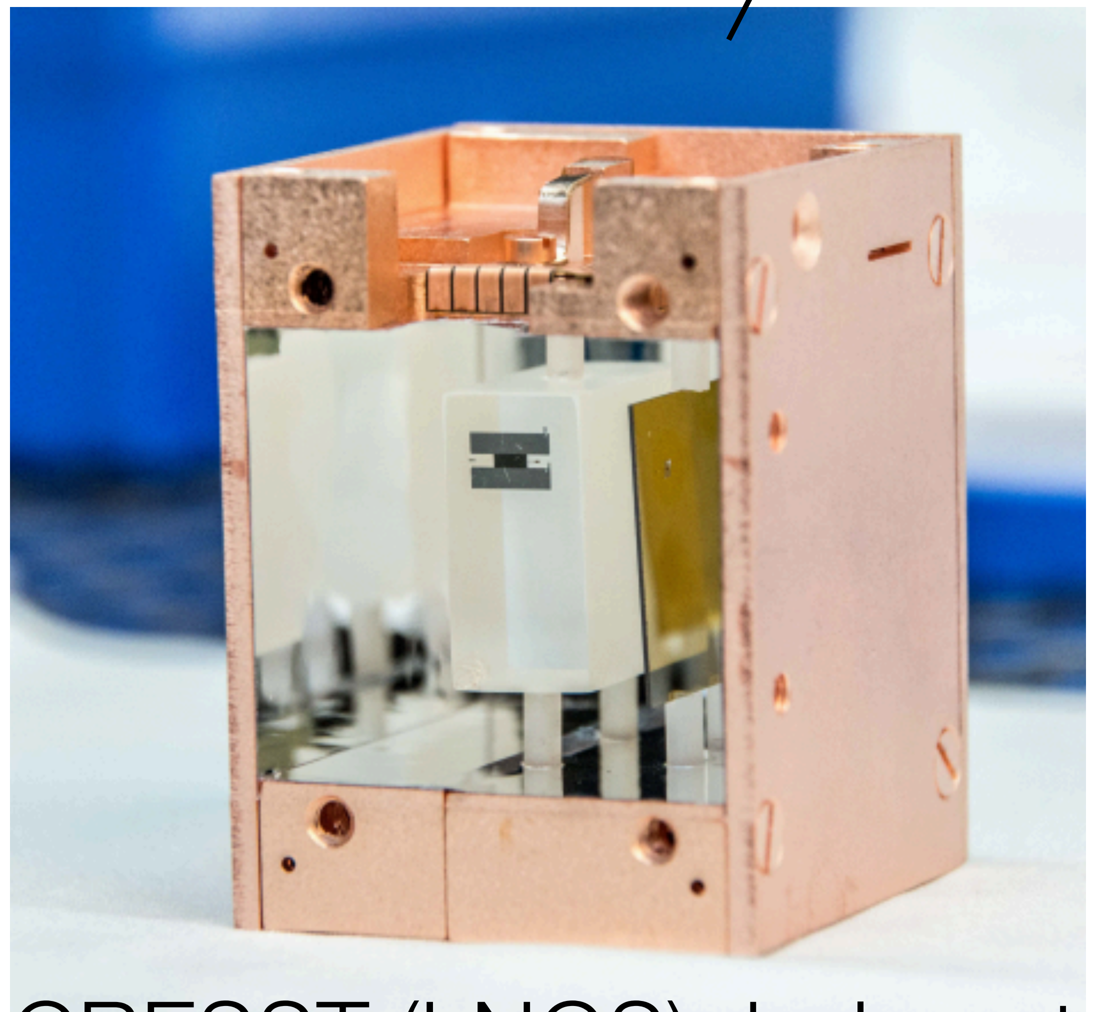
A **50 litre prototype is going** underground at **Gran Sasso** Laboratories and a **1 cubic meter demonstrator will be realised** and installed in the next years.

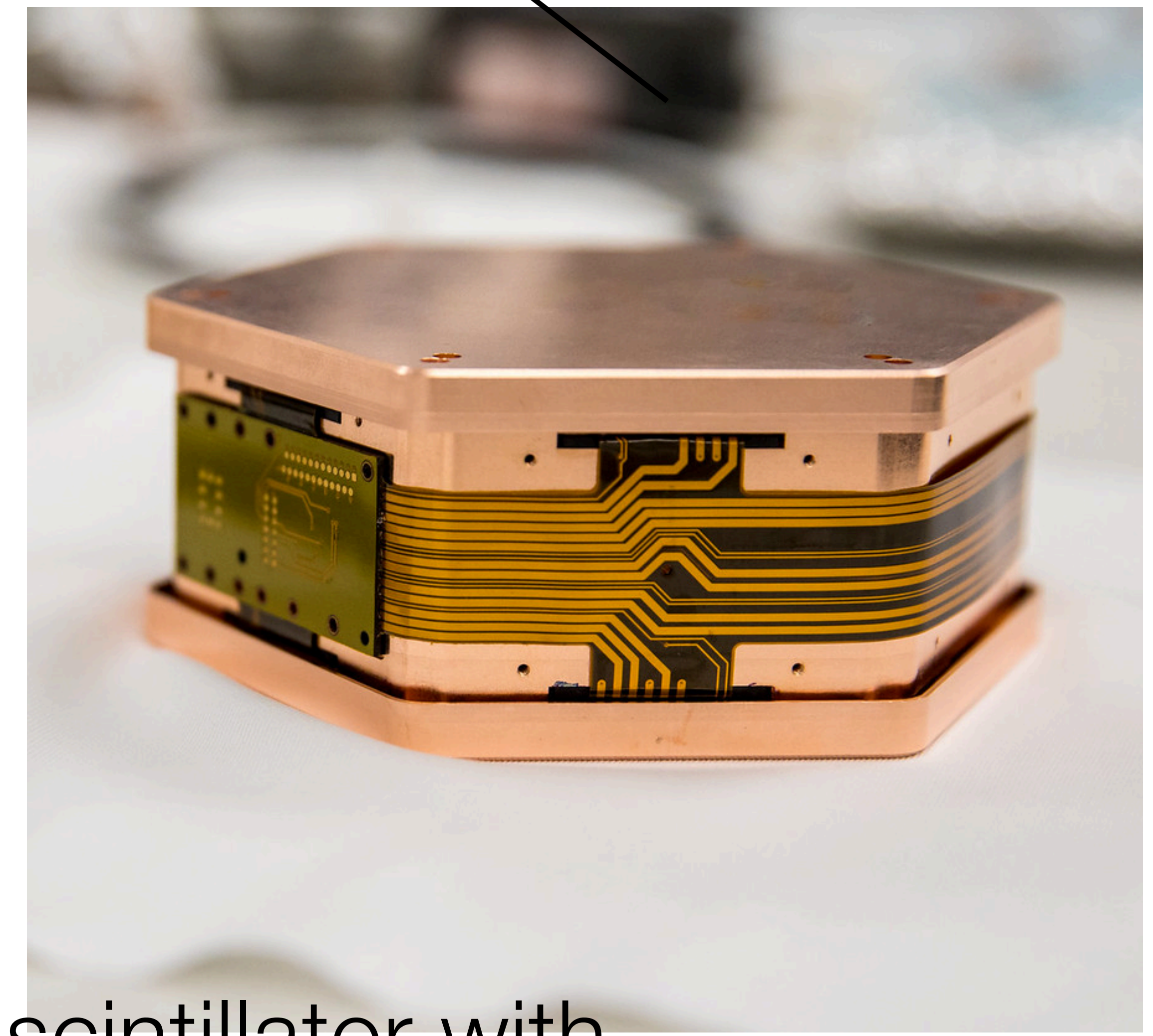
A **proposal** for a **larger scale (tens of m^3) experiment** will be then evaluated and submitted.


PULP FICTION
Rita Roque
Cristina Bernardes Monteiro
Fernando Amaro
Daniel Maño
THANKS!









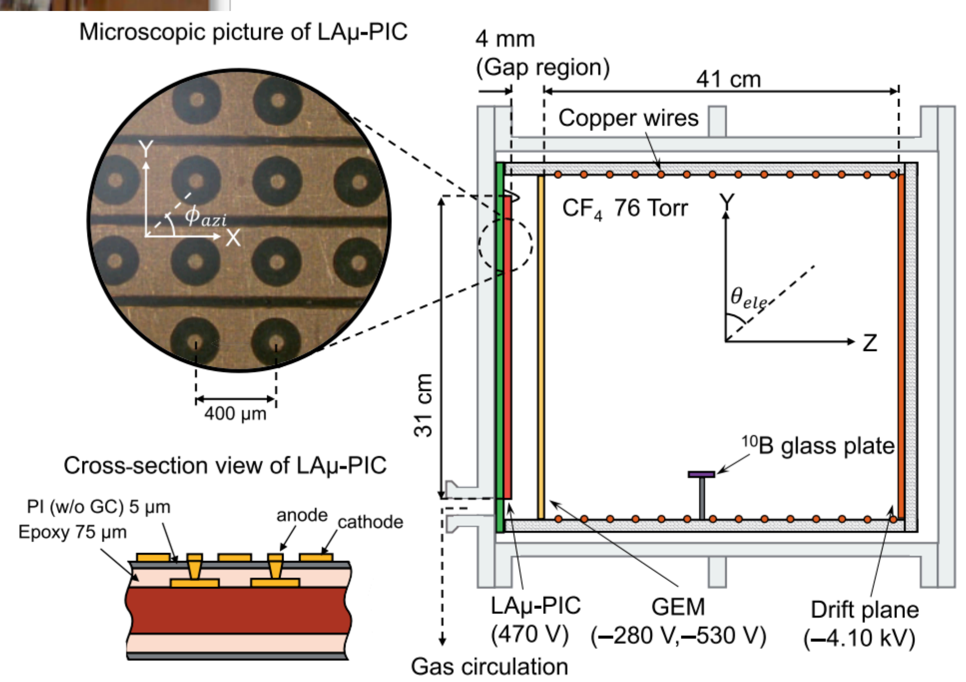
CDMS (SNOLAB): cryogenic semiconductor with double readout (charge and heat). Threshold: 10-50eV.

No directionality

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

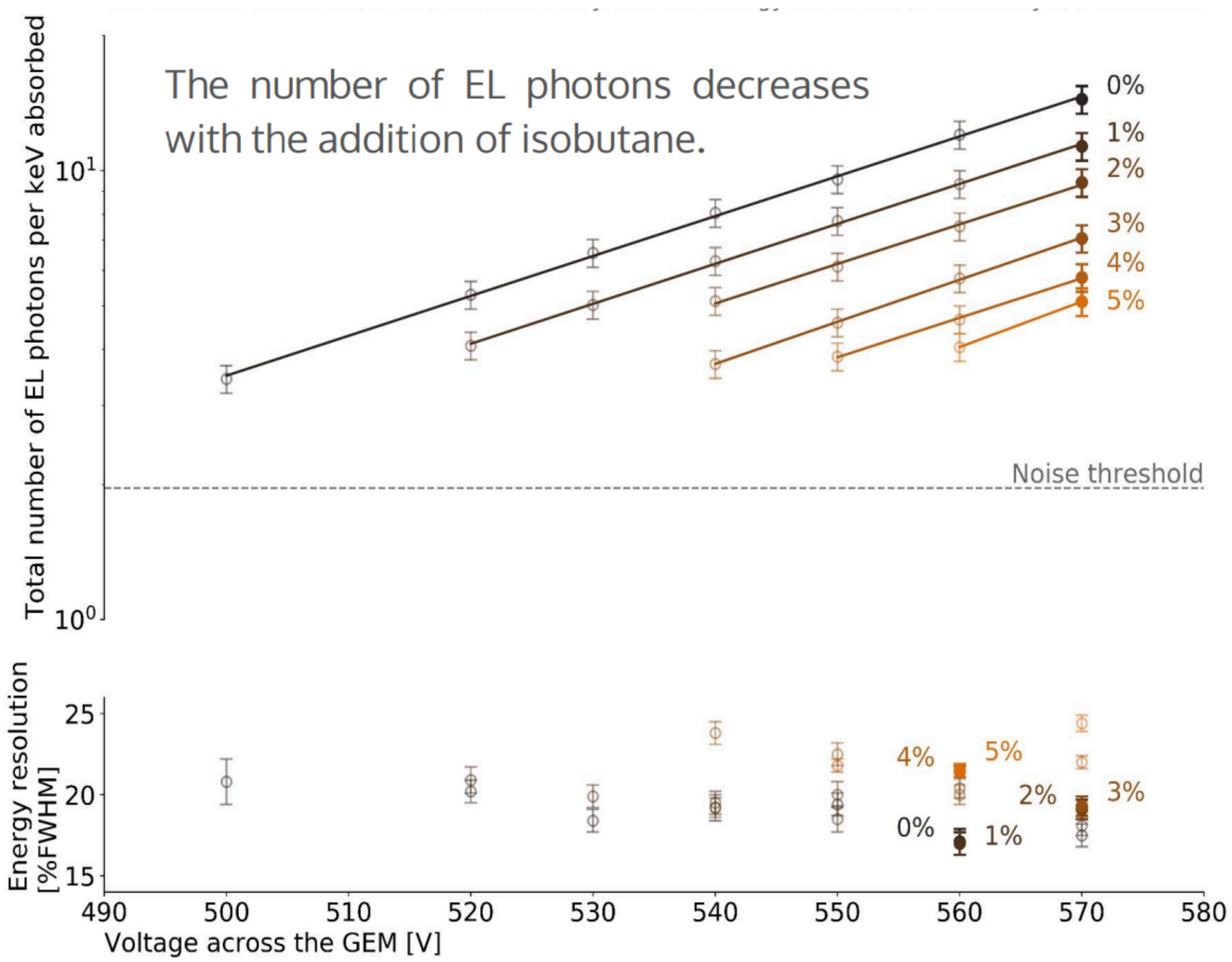
CRESST (LNGS): bolometric scintillator with double readout (light and heat). Threshold 50-100 eV. No directionality.

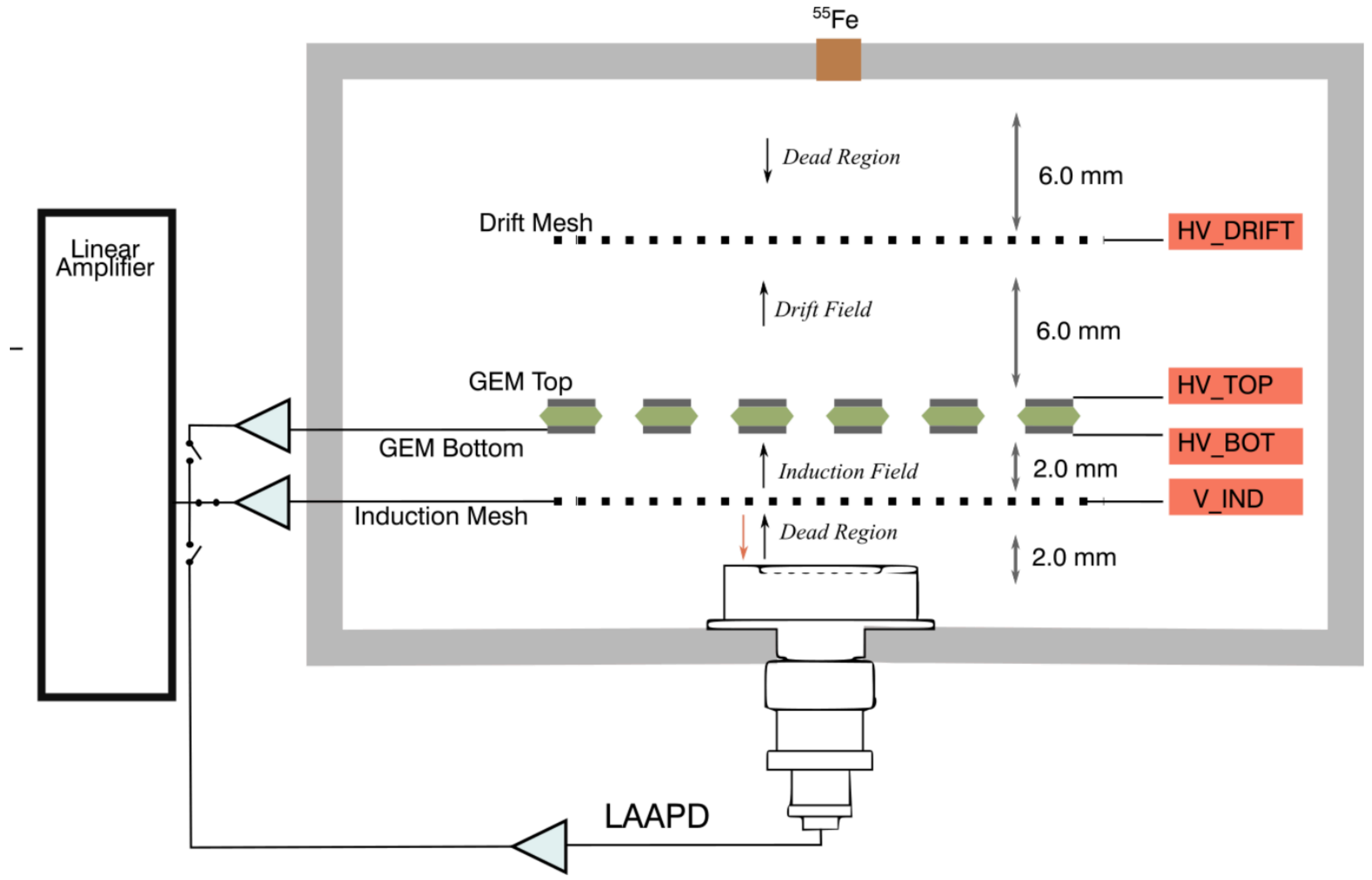
NewAGE: 36 litres TPC operated with CF_4 at 100 mbar.
MPGD with electrical readout.
Directional and sensitive to SD interactions.



R&D: Hydrocarbons

In tests performed with a single-GEM setup, a ternary gas mixture ($He/CF_4/C_4H_{10}$) was tested with up to 5% of C_4H_{10}.





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_4H_{10}

LNGS site for lime


Upper floor


Ground floor


LIME trolley

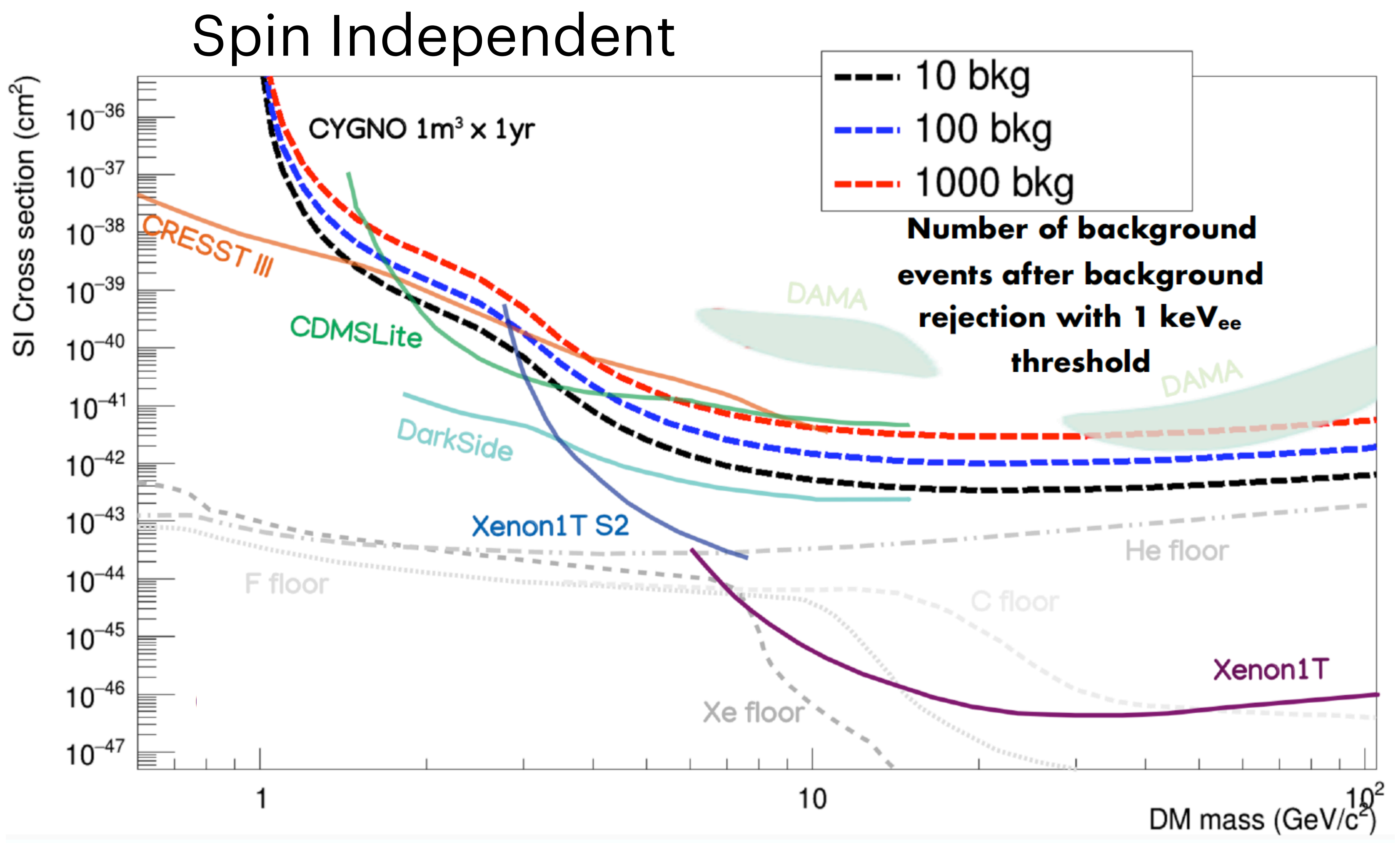

Gas system

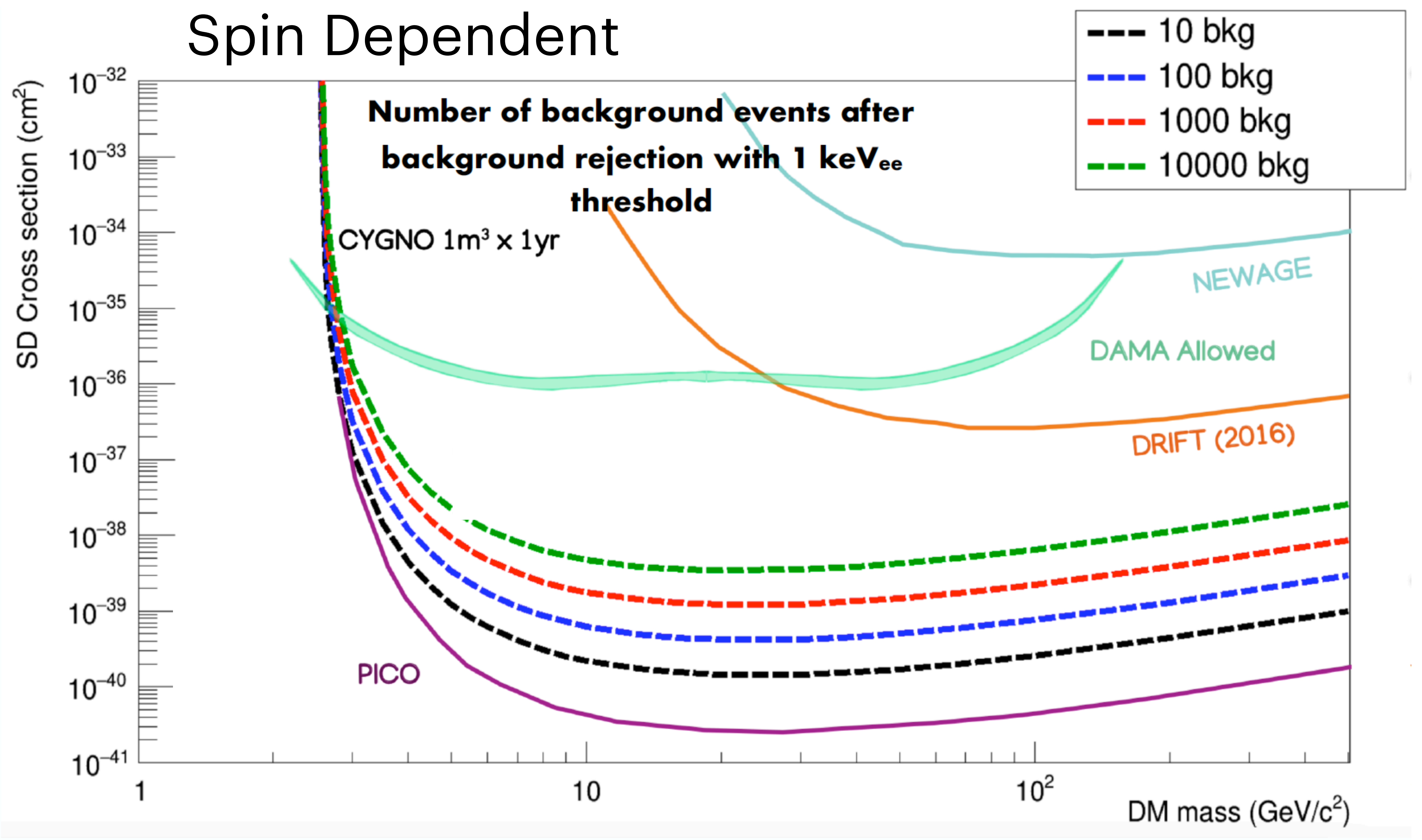

Rack and passthru


main gate with steps

WHAT CYGNO CAN DO: DM SEARCH AND STUDY

1 cubic meter, 1 year exposure





DAMA region covered even with 1000 bkg events

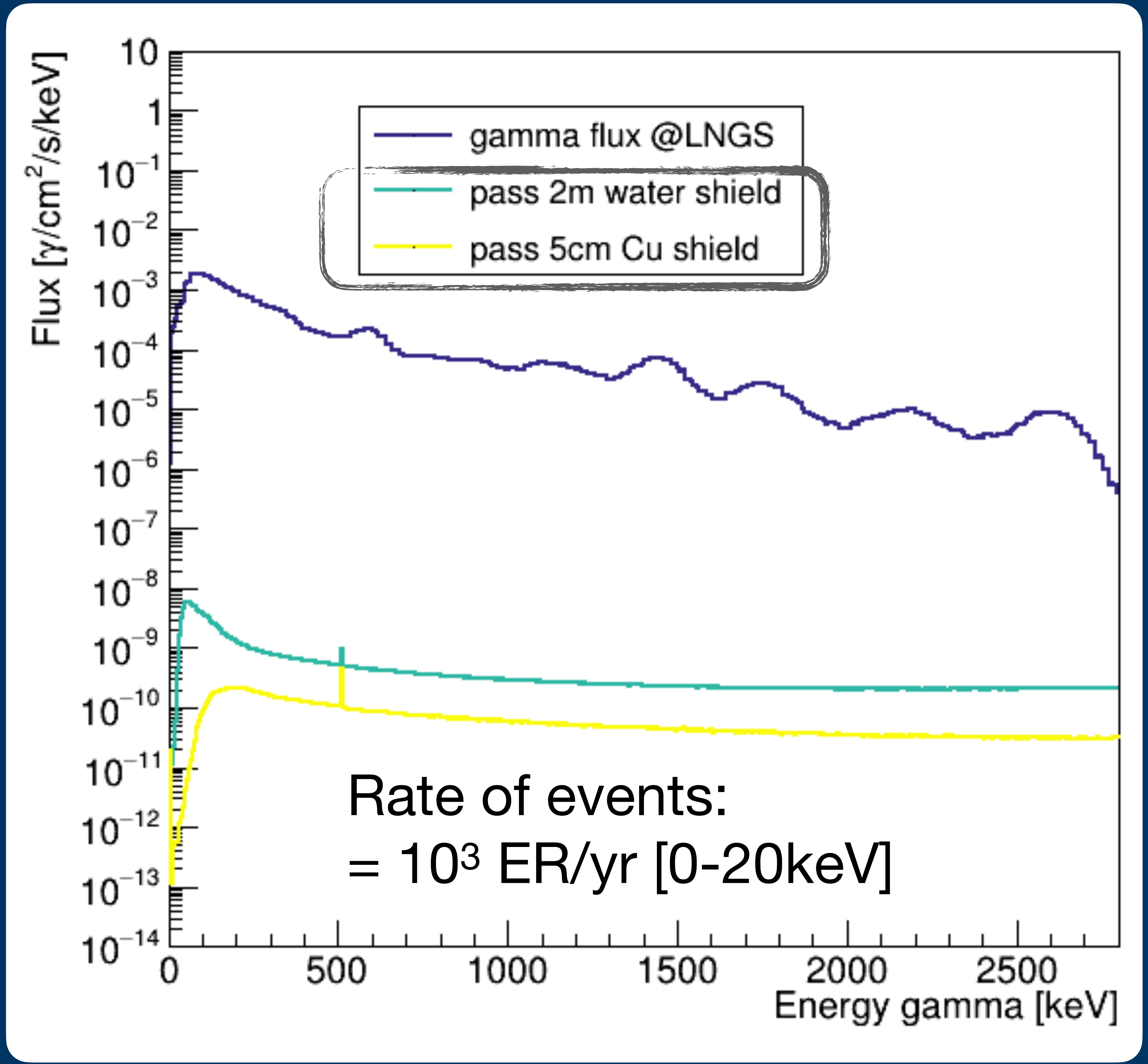
If DM is found, directionality will be crucial to confirm discovery and individuate its source

30 cubic meters, 3 year = 150 kgyr exposure

BACKGROUND STUDIES: EXTERNAL

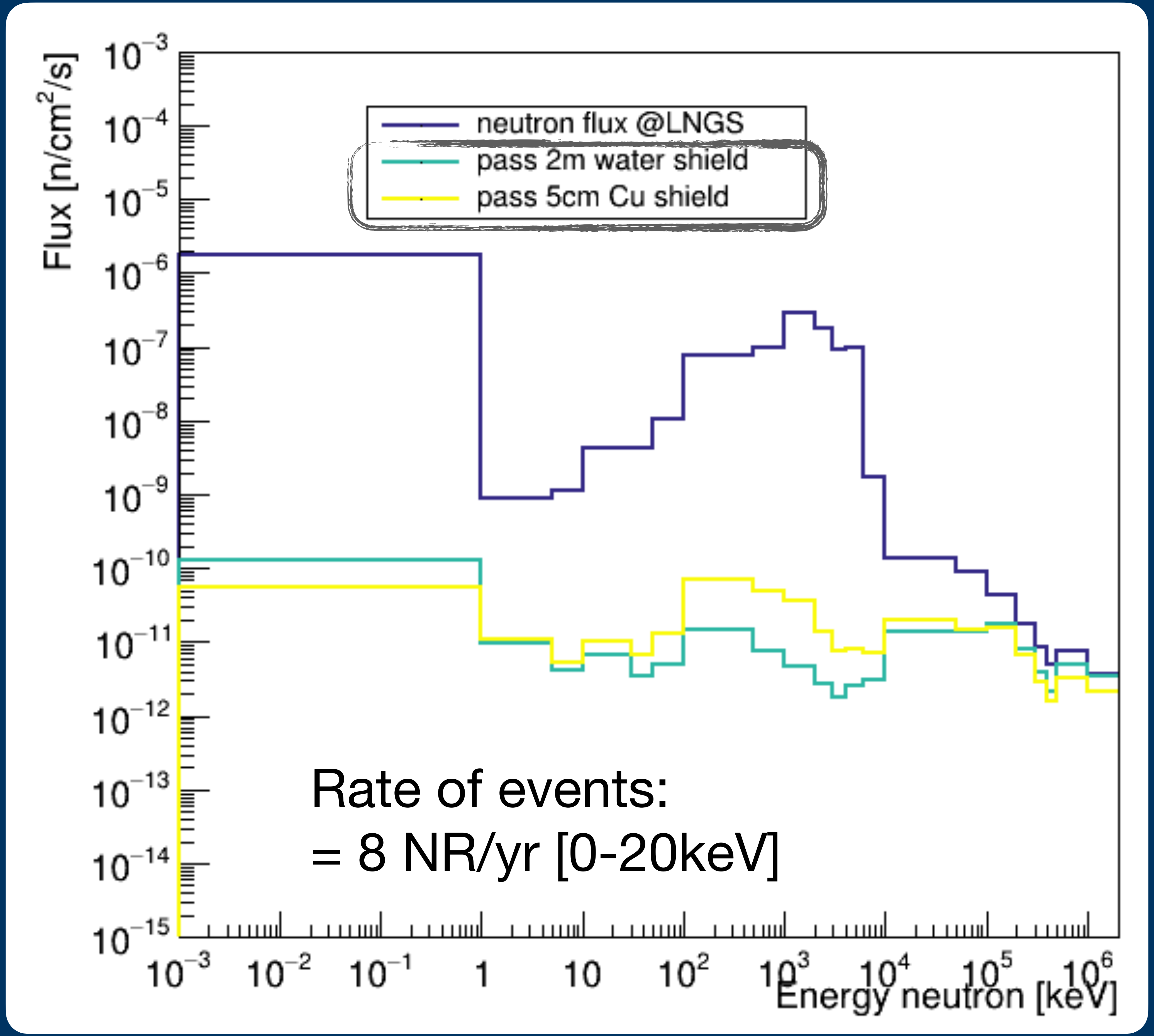
Gamma flux @LNGS (Hall C) -

measured by SABRE : 0.56 Hz/cm^2

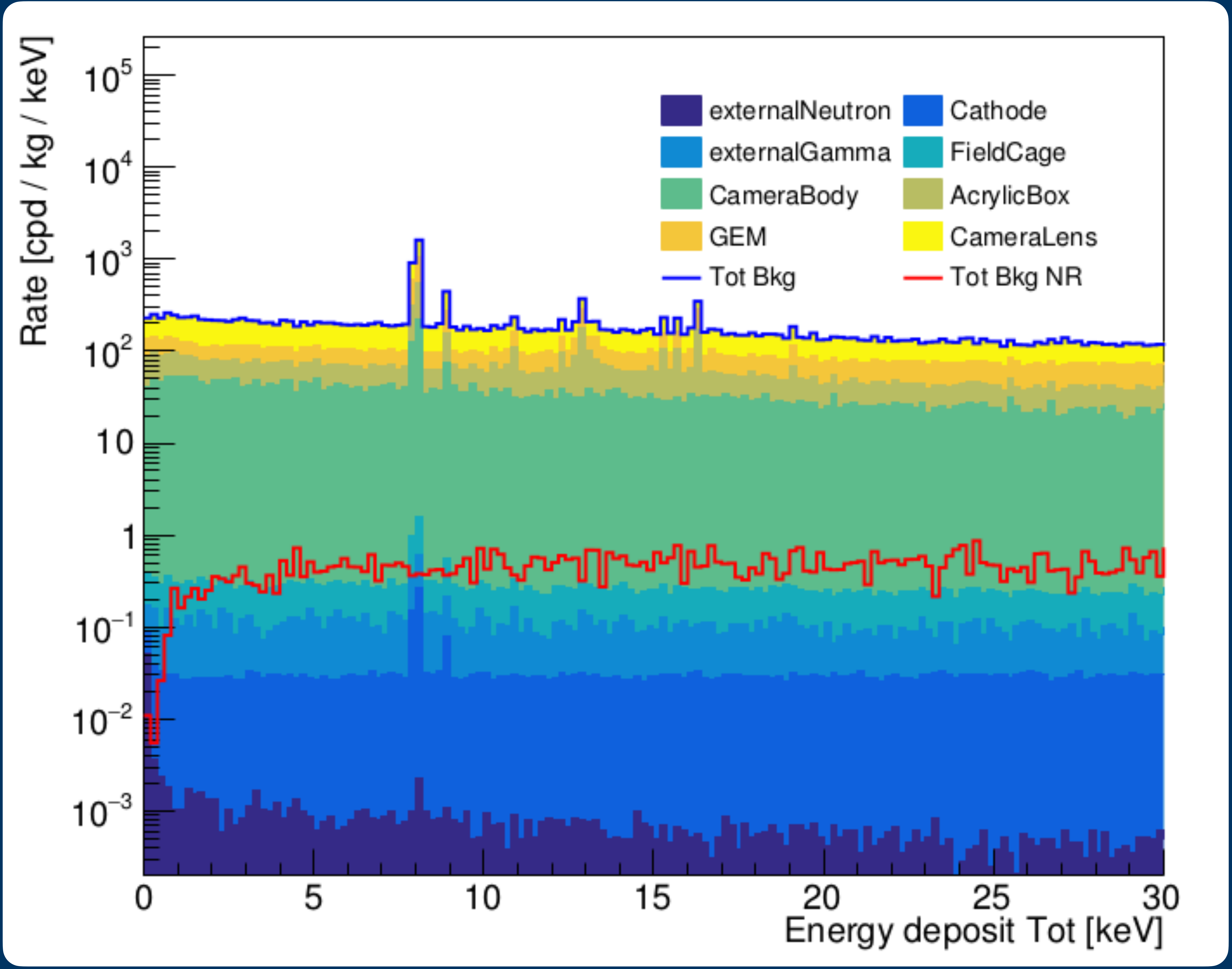


Neutron flux @LNGS (Hall C) -

measured by CUORE : 2.7x10^{-6} 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 Orca Flash	Limit/Meas	Activity (Bq/kg)
U238 (Th234)	M	3.16E+00

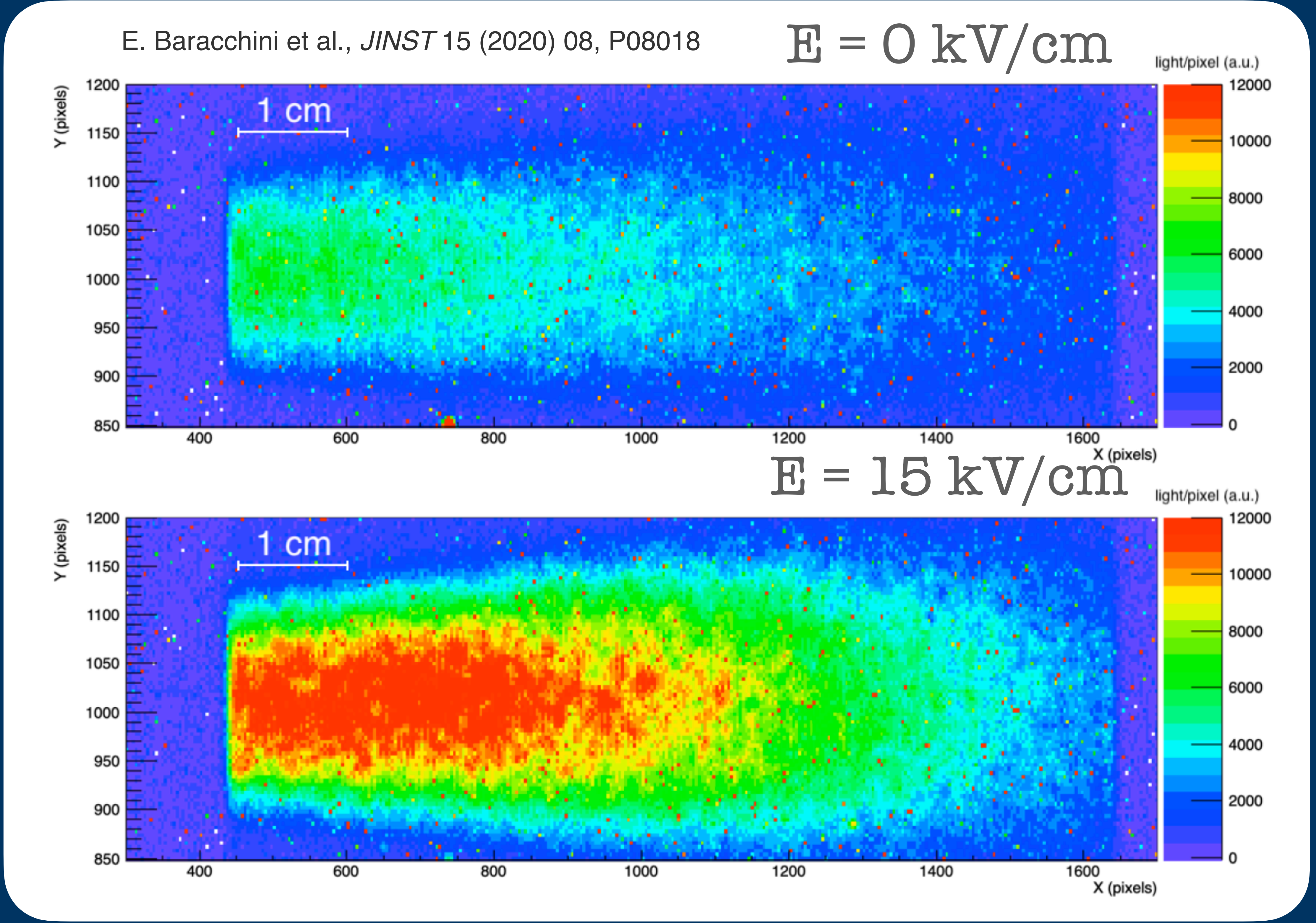
Camera Lens Orca Flash	Limit/Meas	Activity (Bq/kg)
U238 (Th234)	M	4.22E+00
K40	M	5.15E+01

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

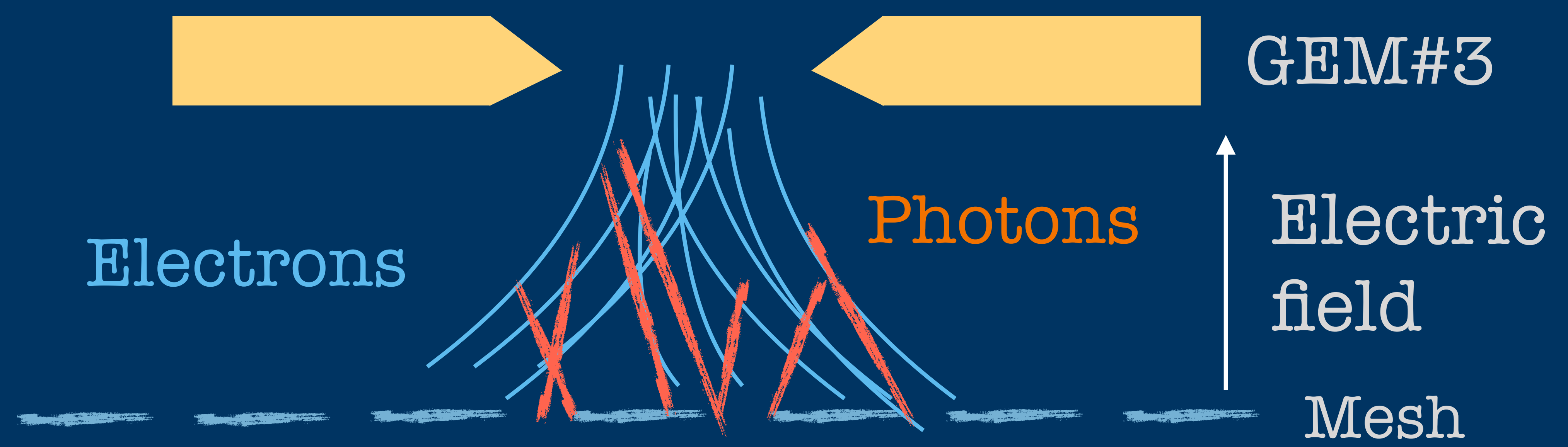
Acrylic Box	Limit/Meas	Activity (Bq/kg)
K40	L	3.50E-02

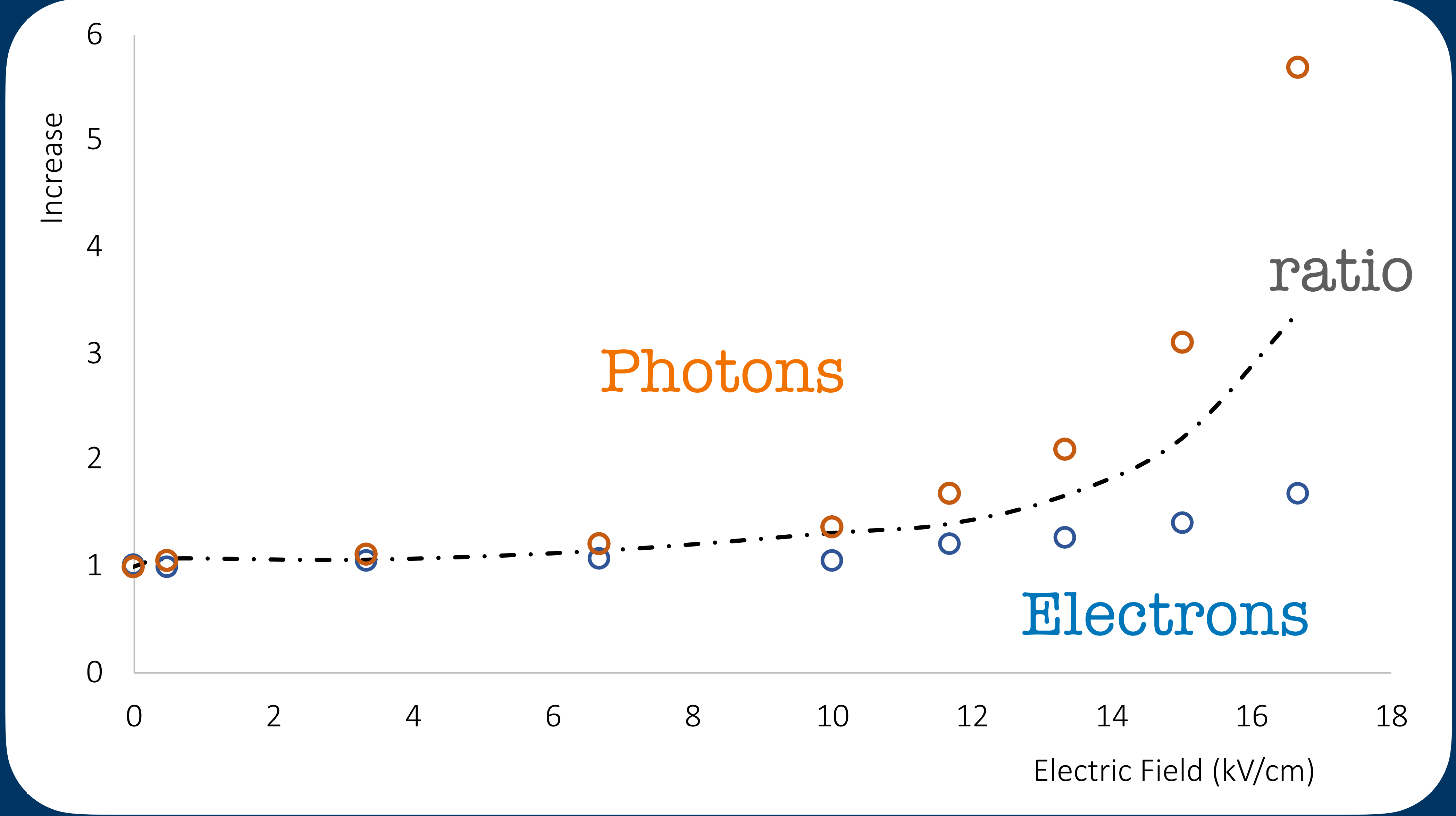
Largest contributions come from: **Camera**, **Lens**, **GEM** and **Acrylic**.

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

CAMERA Background reduction

description	piece	Ra228 from Th232 [Bq]	Th228 from Th232 [Bq]	Ra226 from U238 [Bq]	Th234 from U238 [Bq]	Pa234m from U238 [Bq]	K40 [Bq]	U235 [Bq]	Cs 137 [Bq]
CMOS sensor	1	0.0052	0.0053	0.0068	0.011	0.007	3.5	0.00091	0.00042
sensor frame	1	0.113	0.111	0.08	0.29	0.14	0.08	0.006	0.00086
sensor frame holder	1	0.007	0.016	0.0046	0.5	0.26	0.08	0.015	0.001
peltier cooler	1	0.00036	0.00024	0.00017	0.012	0.021	0.0026	0.0002	0.000054
electronic board	1	0.208	0.202	0.187	0.16	0.25	0.24	0.009	0.002
electronic board	1	0.248	0.229	0.335	0.12	0.2	0.19	0.0075	0.0025
electronic board	1	0.0679	0.0639	0.0552	0.053	0.1	0.053	0.0017	0.00047
electronic board	1	0.104	0.1	0.072	0.12	0.266	0.07	0.002	0.0011
cooling fan	1	0.07	0.0687	0.0558	0.1	0.2	1.4	0.0013	0.0011
metal supports	1	0.0012	0.0007	0.00031	0.024	0.036	0.0052	0.00074	0.0004
plastic support	1	0.0048	0.002	0.0024	0.08	0.16	0.1	0.004	0.00085
metal support	1	0.01	0.0067	0.003	0.8	1.1	0.015	0.039	0.0015
plastic objective support	1	0.006	0.0073	0.003	1.6	1.2	0.02	0.052	0.00093
camera case	1	0.0028	0.013	0.001	0.24	0.2	0.01	0.008	0.00031
camera objective case	1	0.0025	0.028	0.001	0.36	0.33	0.012	0.013	0.00029
sensor plastic frame	1	0.0004	0.00025	0.00011	0.0011	0.0081	0.0025	0.0004	0.00008
glass window	1	0.00033	0.00022	0.0002	0.0023	0.0016	0.006	0.0002	0.00024
plastic o-ring	1	0.001	0.001	0.00043	0.027	0.06	0.0032	0.001	0.00013
plastic o-rings	1	0.0011	0.00041	0.00049	0.0059	0.02	0.0043	0.00027	0.00009
Total		0.85359	0.85572	0.80851	4.5063	4.5597	5.7938	0.16222	0.014324

Different **cameras** were **measured** (Thanks to M. Laubenstein)

We had separate meetings with **Hamamatsu** and **Teledyne-Photometrics** both expressed interest in **investigating the possibility of reducing** as much as possible the **radio-activity**;

Radon filtration

The University Of Sheffield. | DURRIDGE Radon Capture & Analytics | EPSRC Pioneering research and skills

SUbbLIME MS

Sheffield **U**niversity Scru**bb**er for **LIME** – **M**olecular **S**ieves

CYGNUS MEETING
22nd April 2021

Identify a filter that:

- Purify* CF_4 and Helium
- Removes radon from CF_4 and Helium
- Conserves the CF_4:He mixing ratio
- Low background MS (Nihon-University)

Vacuum Regeneration Operation

- Assist with the application of vacuum regeneration in LIME gas system
- Determine the breakthrough time and ideal VSA Operation
- Zero emission of CF_4 into the atmosphere

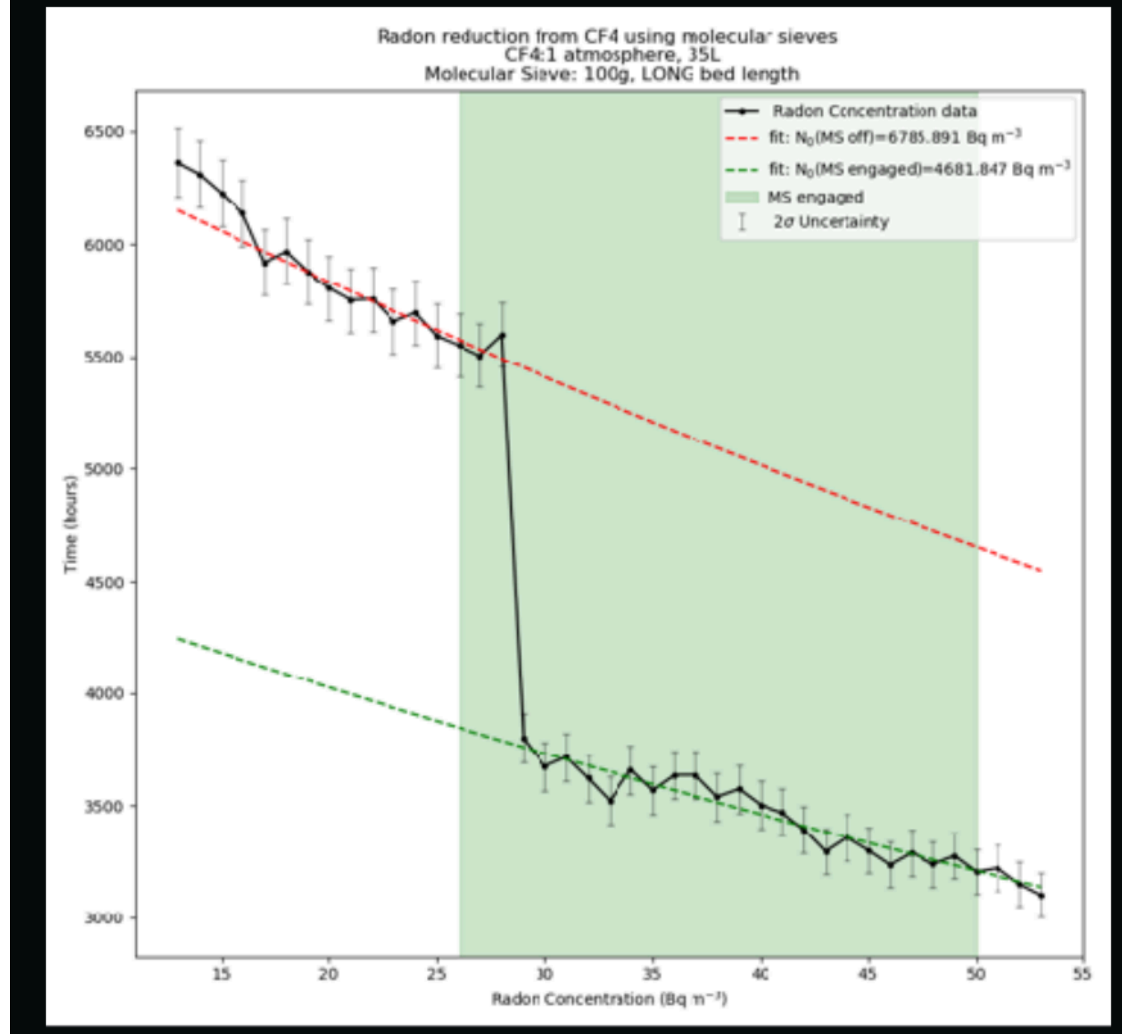
CYGNO Experiment

Target Gas Absorption Test Results

Molecular Sieve Filter	Helium Captured (Torr/kg)	CF_4 Captured (Torr/Kg)	Notes
Activated Charcoal	-	197±11	Control - Absorbs CF_4
3A	-4±12	*	Does not absorb He or CF_4
4A	-8±12	-3±6	Does not absorb He or CF_4
5A	-8±12	87±7	Absorb CF_4 not He
13X	*	67±8	Control (MS) (Rod geometry)

3A & 4A - Used for water, nitrogen and oxygen removal
5A - Used for radon removal

Does 5A MS still absorb radon from CF_4 ?

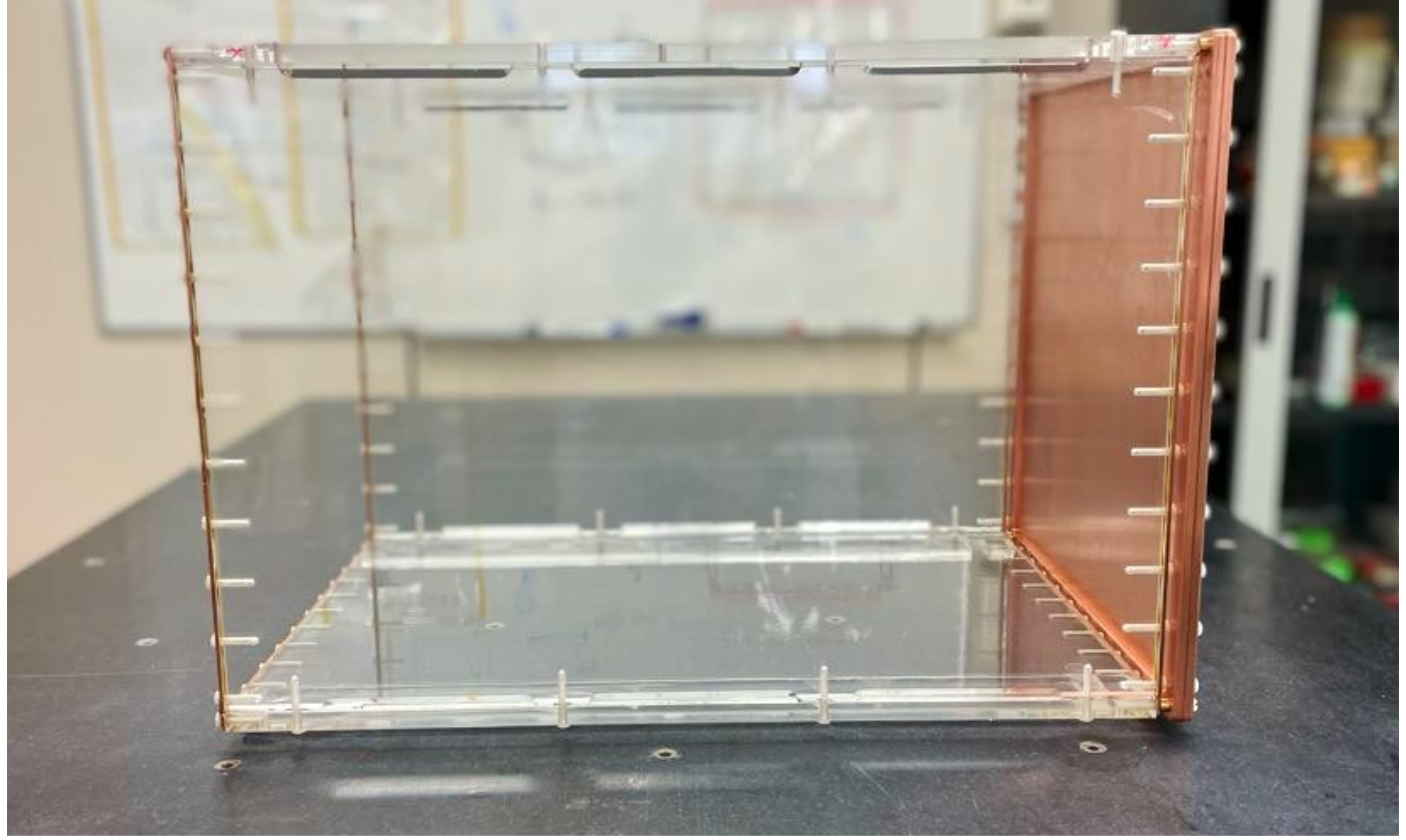


Radon is still captured from CF_4 at comparable capacity to SF_6 work but CF_4 pressure decreases....

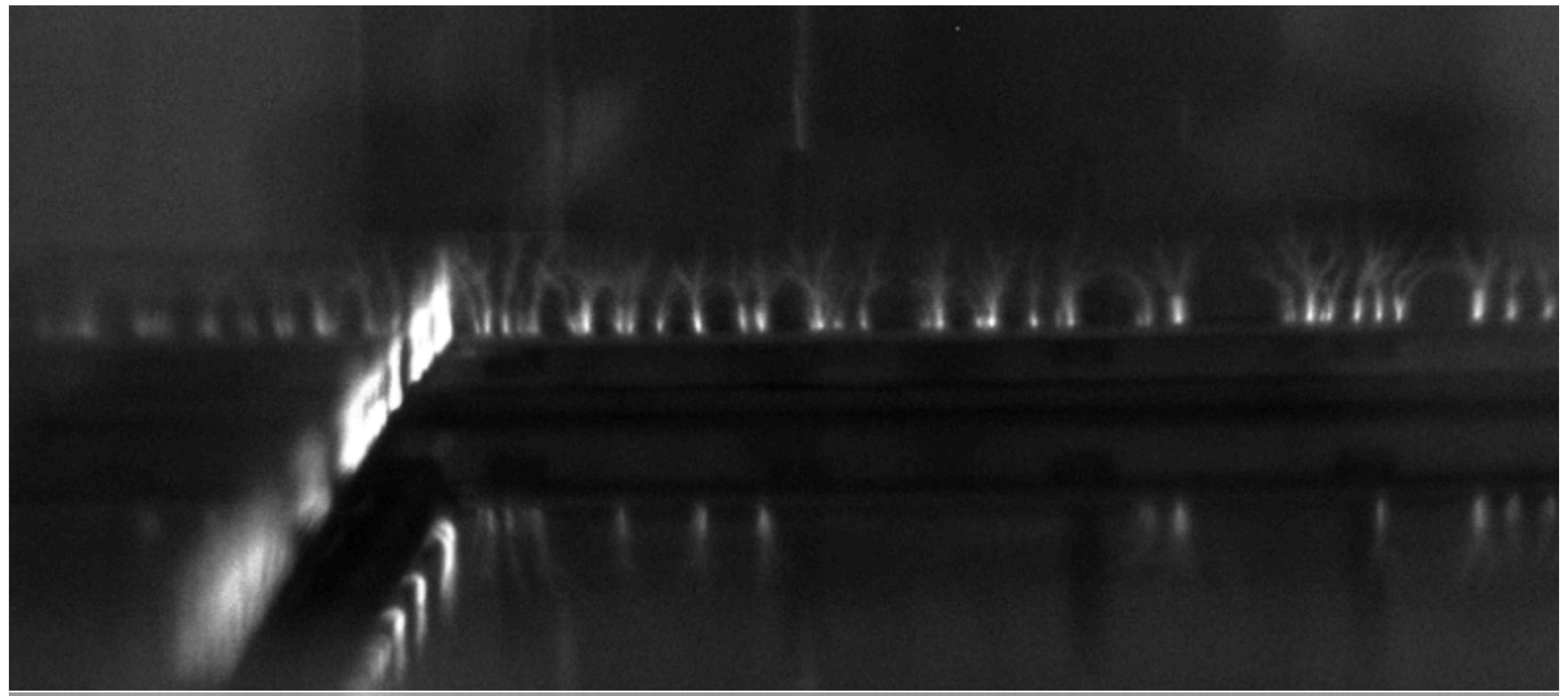
The University Of Sheffield.

R&D: Resistive foil Field cage

We are testing a **transparent plastic resistive foil** (R=30 GΩ/□) as possible solution to provide the **drift field**.



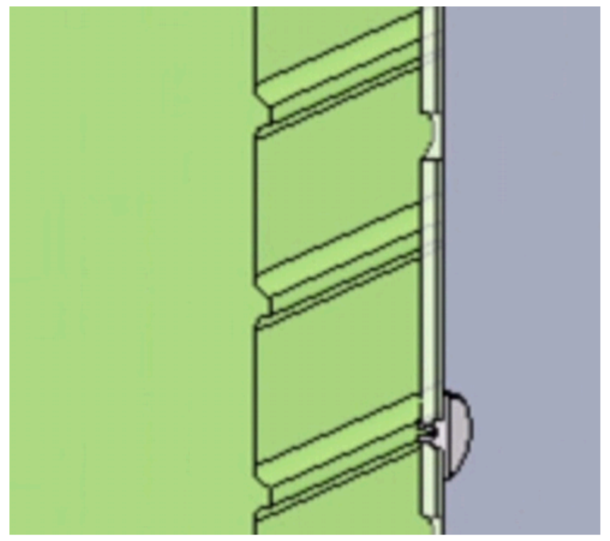
Very good preliminary results with cosmics and ^{55}Fe, indicating an **excellent uniformity** of the electric field

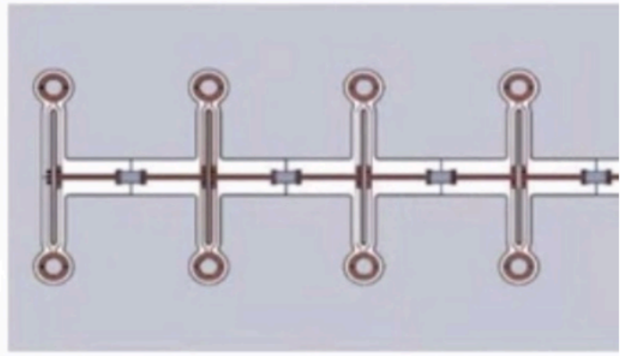


Under investigation

Unfortunately, after a week of operation, **small discharges** appeared all around the copper-plastic interface.

DARKSIDE: for **“copperless” FC**: we could shape the acrylic box and paint it with clevios



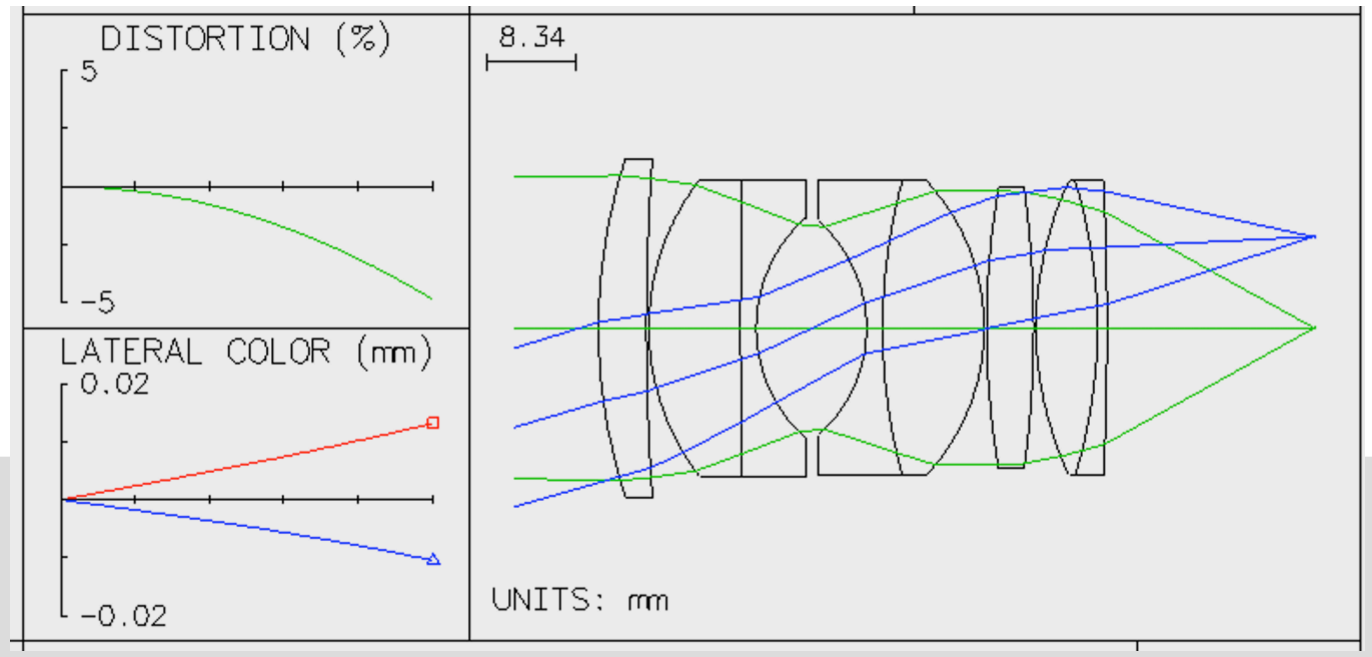


They can indicate low radioactive resistors

We had a couple of meetings with DarkSide colleagues to investigate the possibility of using the “clevios” solution

Lens background reduction

We studied low radioactive **fused silica** to produce fixed focus **lenses** (thanks to Ioan Dafinei)

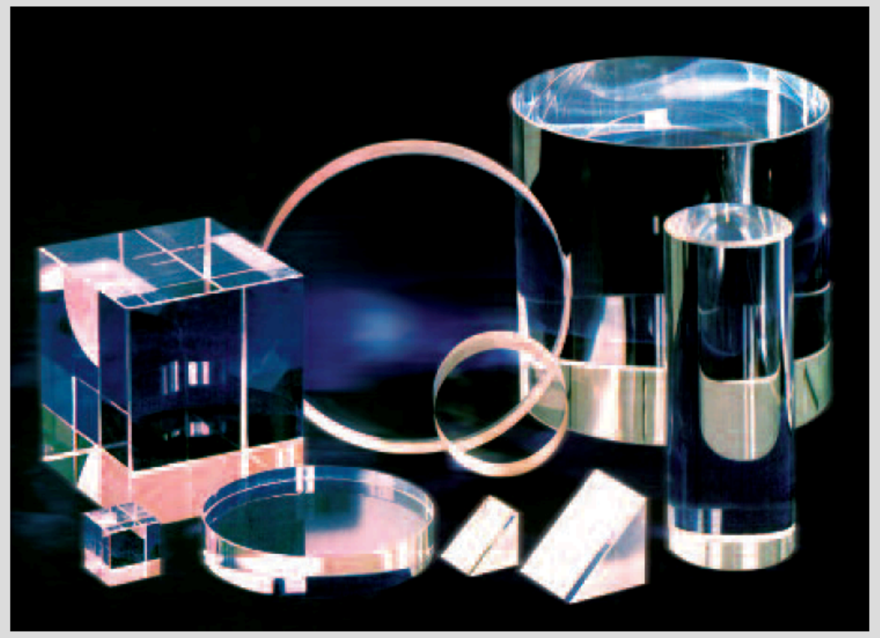


Heraeus

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.



LOBRE SRL

Ottica ed apparecchi ottici speciali,
Obiettivi per proiezione,Microproiettori,
Lenti di ingrandimento,Specchi,Prismi,
Mirini fotografici,filtri di luce,Cannocchiali Lettori

LABORATORIO OTTICO BRESCIANO / BREVETTI ING. S.MARCUCCI

DNV·GL ISO 9001 — CERTIFICAZIONE DI SISTEMA QUALITÀ
Sede certificata di Carpenedolo

Documento	Numero	Data	Pagina
OFFERTA CLIENTI	114	02/04/2021	1

Mail	Referente	Fax
info@lobre.it		

Intestato a
INFN
ROMA
IT - ITALIA

Con la presente per sottoporVi la nostra migliore offerta , come segue:

Cod.Articolo	Descrizione	UM	Quantità	Prezzo[cad]	Consegna
	STUDIO DI FATTIBILITA' PER UN OTTICA PER CYGNO	n.	1,00	5.000,00	
	STUDIO DI PROGETTAZIONE PER UN OTTICA PER CYGNO	n.	1,00	15.000,00	
	TEMPI DI CONSEGNA : 45/60GG PER LA FATTIBILITA'				
	TEMPI DI CONSEGNA : 60/90GG PER LA PROGETTAZIONE				
	PAGAMENTO DA CONCORDARE				

```
sample:          Heraeus Spectrosil disks, 298.8 g, CYGNUS
number:          4
live time:       2034019 s
detector:        GeMPI4

radionuclide concentrations:

Th-232:
Ra-228:          < 62 microBq/disk
Th-228:          < 24 microBq/disk

U-238:
Ra-226           < 48 microBq/disk
Th-234           < 0.86 mBq/disk
Pa-234m          < 1.0 mBq/disk

U-235:           < 30 microBq/disk

K-40:            (0.6 +- 0.3) mBq/disk

Cs-137:          < 8.3 microBq/disk

upper limits with k=1.645,
uncertainties are given with k=1 (approx. 68% CL);

Ra-228 from Ac-228;
Th-228 from Pb-212 & Bi-212 & Tl-208;
Ra-226 from Pb-214 & Bi-214;
U-235 from U-235 & Ra-226/Pb-214/Bi-214
```

Feasibility study started in 2021:

- one single crystal won't work;
- investigating the CaF_2 option;