

IDM2026



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



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Istituto Nazionale di Fisica Nucleare

Commissioning and design of the CYGNO-04 detector at LNGS



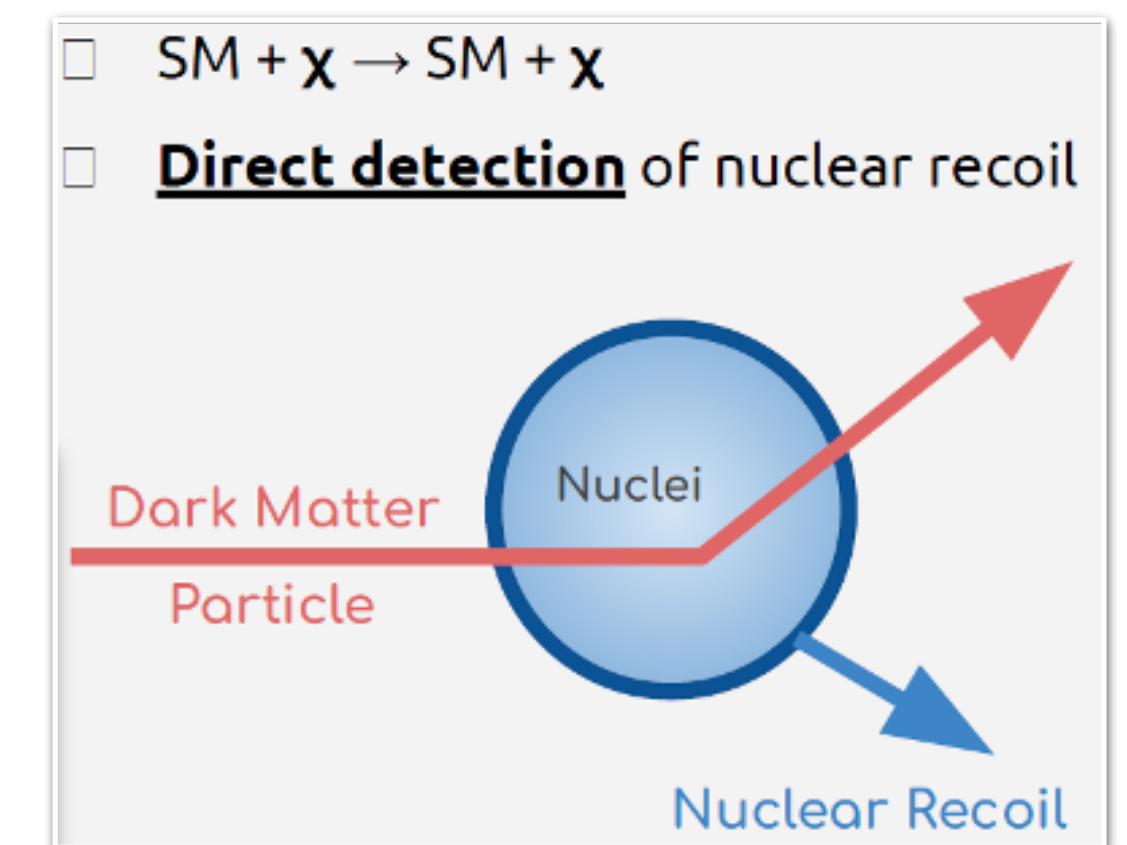
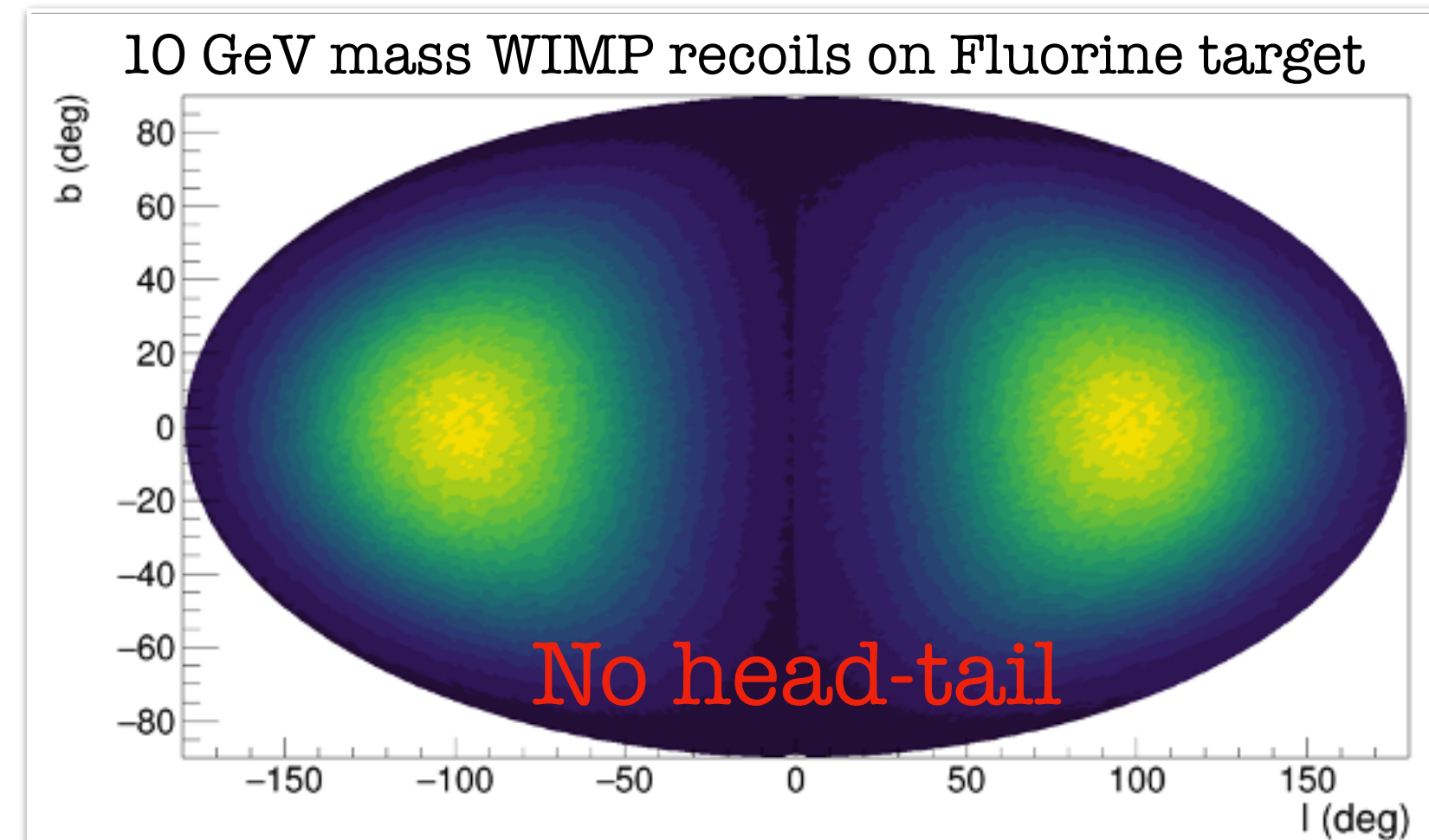
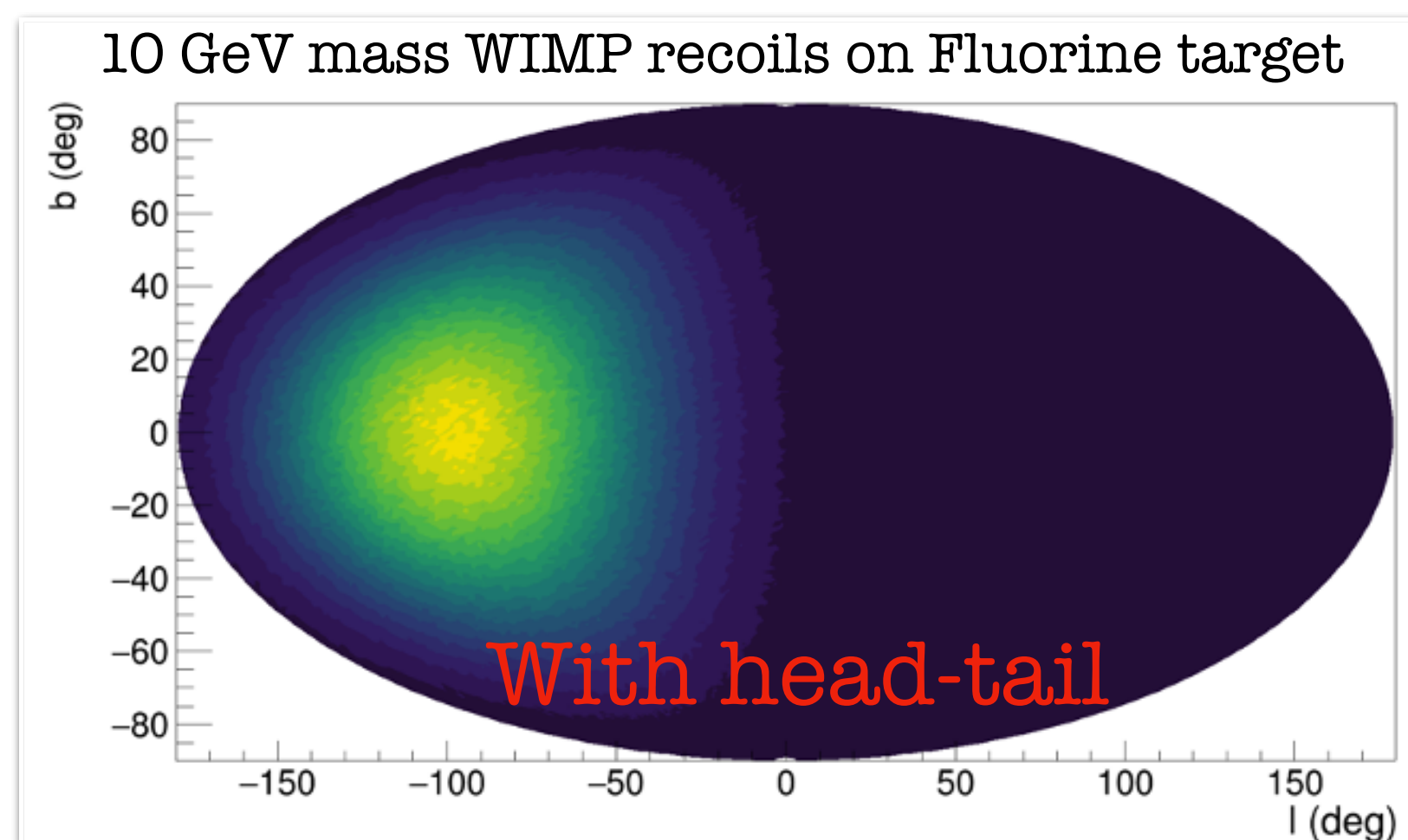
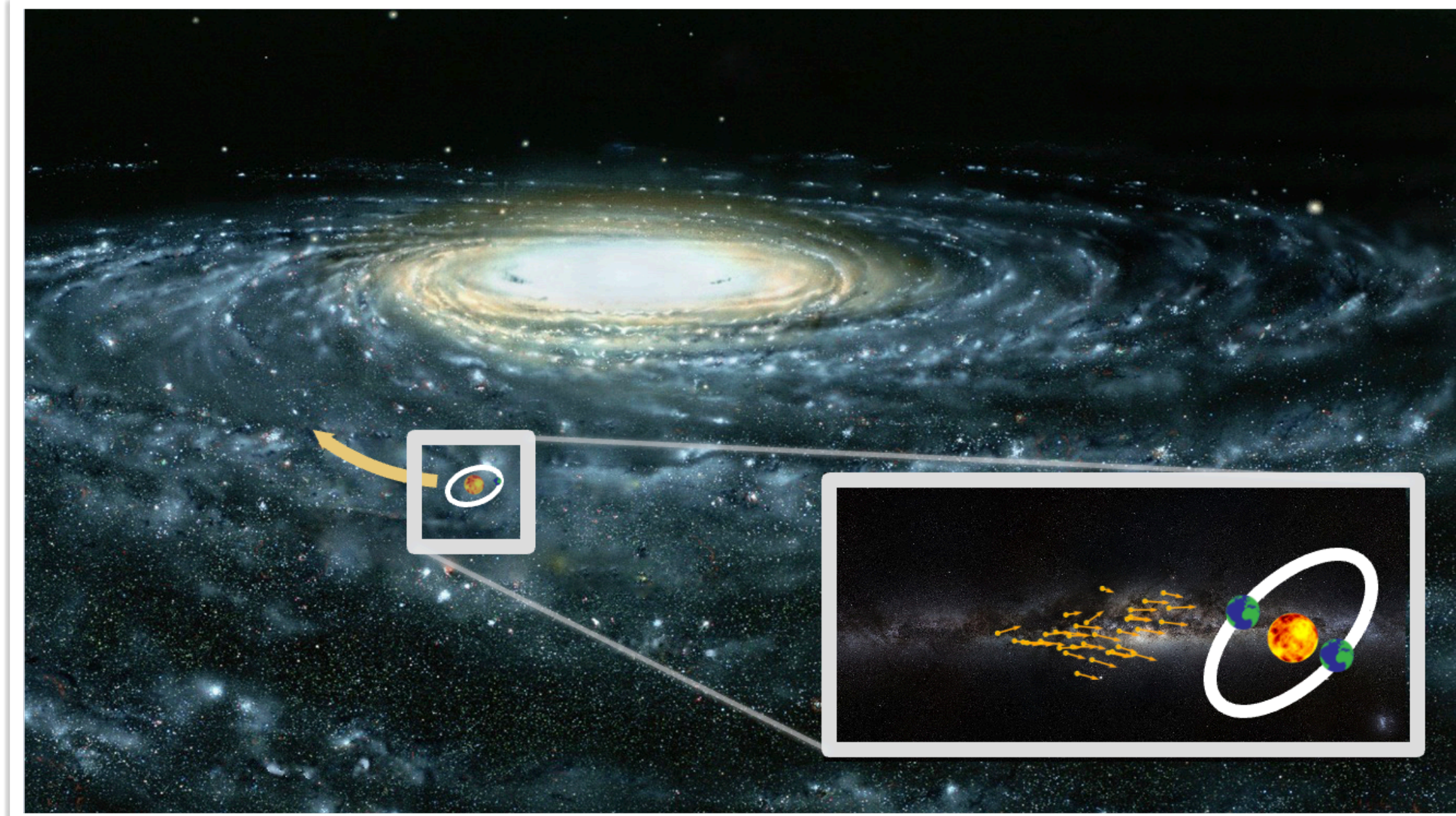
S. Piacentini for the CYGNO collaboration

F. D. Amaro, E. Baracchini, L. Benussi, C. Capoccia, M. Caponero, L. G. M. de Carvalho, G. Cavoto, I. A. Costa, A. Croce, M. D'Astolfo, G. D'Imperio, G. Dho, E. Di Marco, J. M. F. dos Santos, D. Fiorina, F. Iacoangeli, Z. u. Islam, E. Kemp, H. P. Lima Jr, G. Maccarrone, R. D. P. Mano, D. J. G. Marques, G. Mazzitelli, P. Meloni, A. Messina, V. Monno, C. M. B. Monteiro, R. A. Nobrega, G. M. Oppedisano, I. F. Pains, E. Paoletti, F. Petrucci, S. Piacentini, D. Pierluigi, D. Pinci, F. Renga, A. Russo, G. Saviano, F. Scamporlino, P. A. O. C. Silva, N. J. Spooner, R. Tesauo, S. Tomassini

A directional Dark Matter

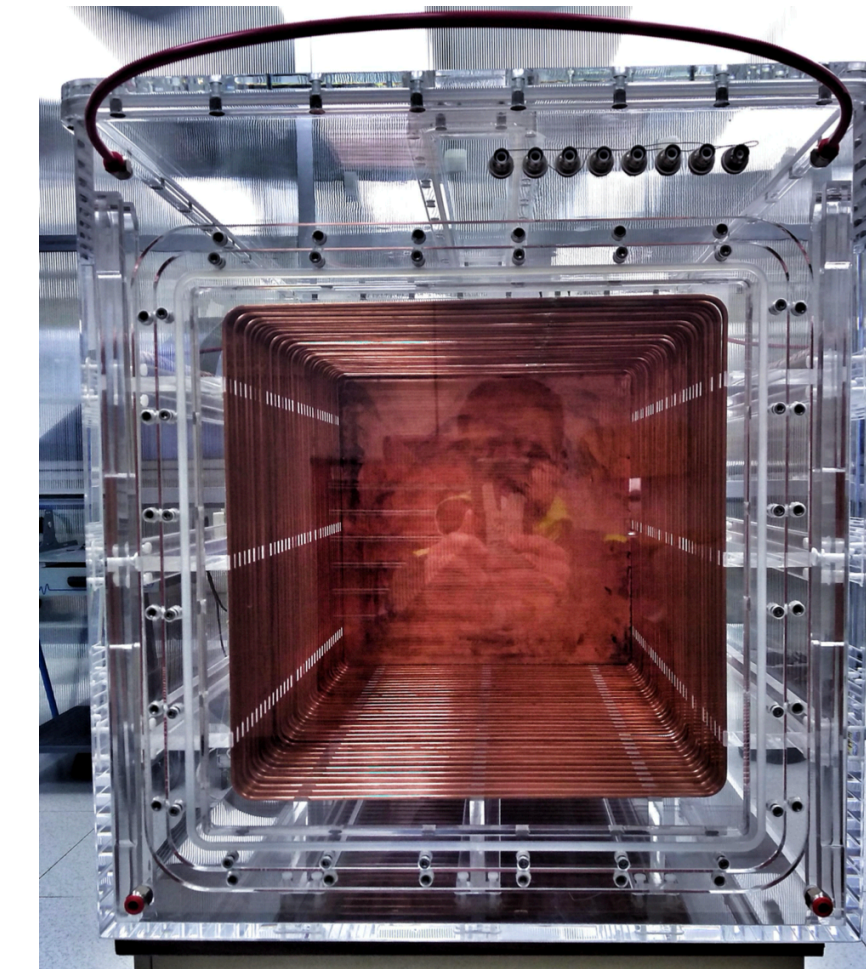


- **Direction** of Dark Matter (DM) induced nuclear recoils aligned with the direction of the **CYGNUS constellation**
- **With Head-tail** → expected highly-anisotropic angular distribution
 - ◎ Strong rejection of isotropic background
 - ◎ Strong rejection of CEvNS from solar neutrinos
 - ◎ Very strong confirmation of DM signature in case of observed excess in data

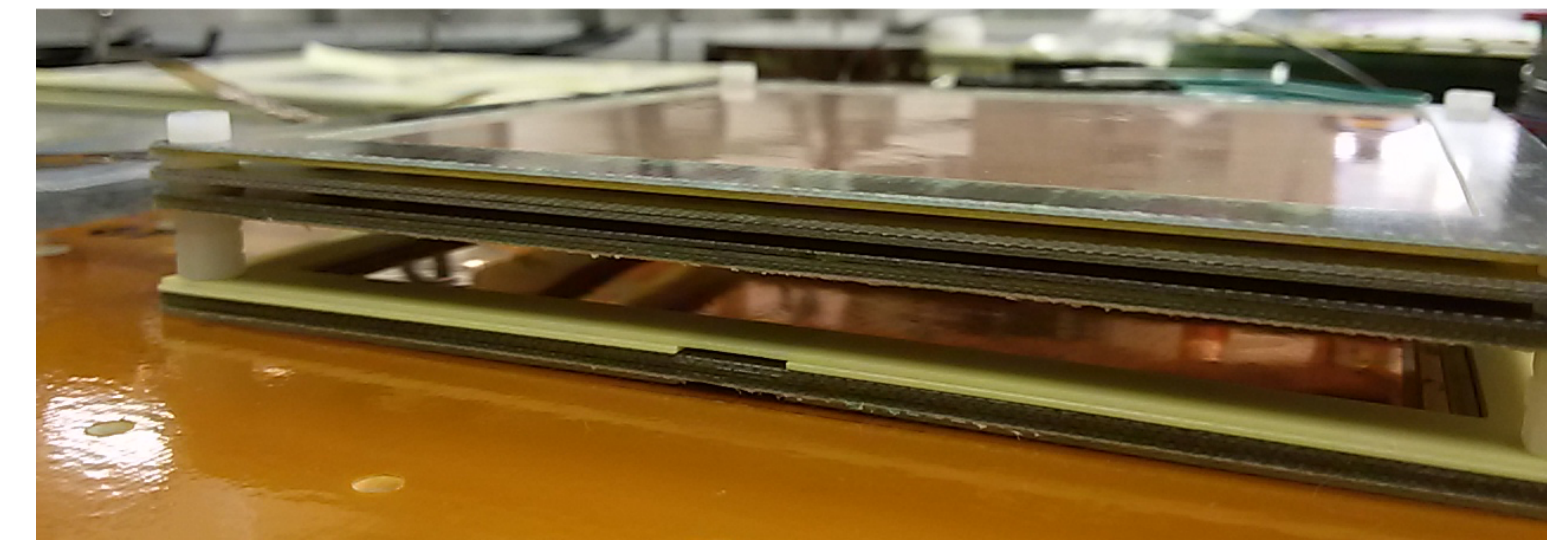


The CXGNO project

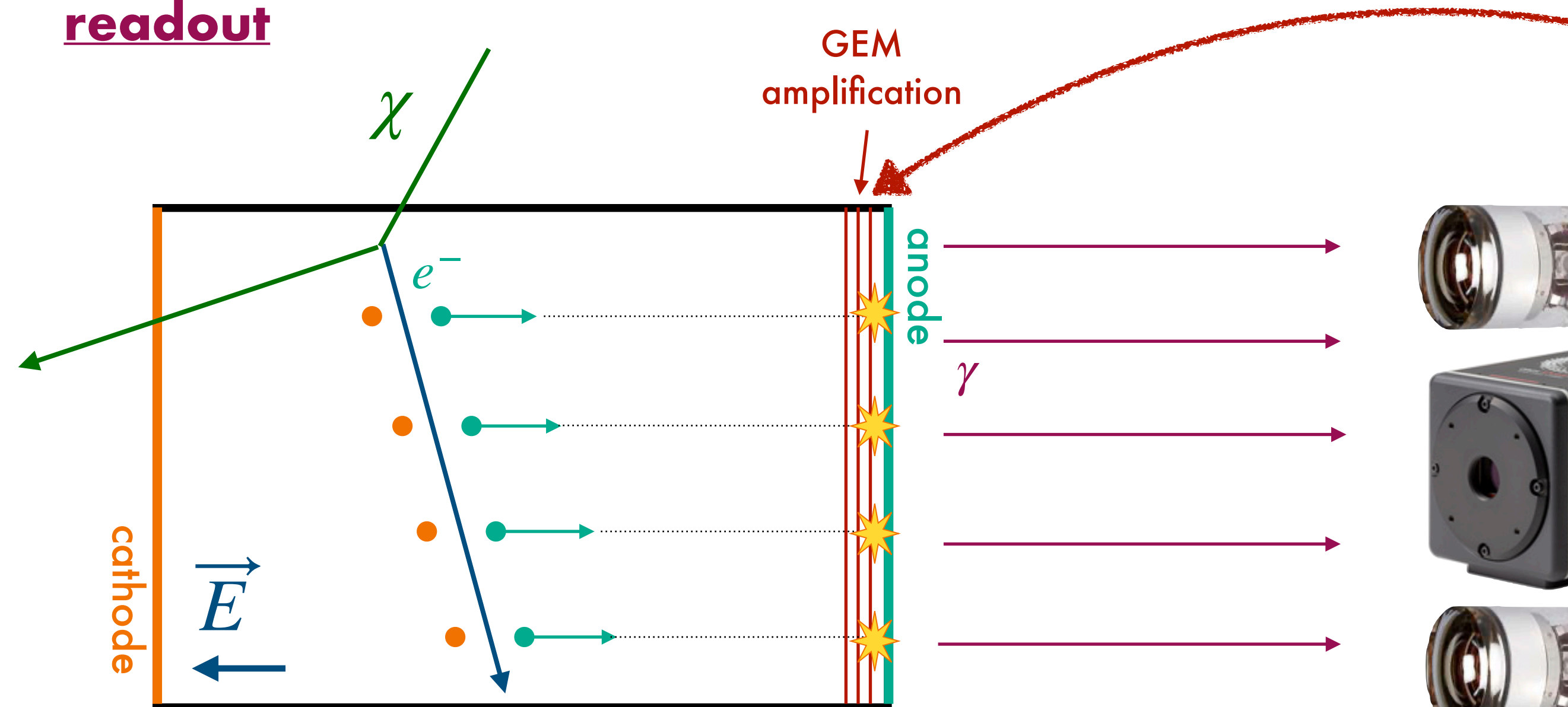
- **Aiming for** a large detector for high precision **3D tracking of rare low energy nuclear recoils** (keV) possibly induced by **dark matter (DM)** particles and solar neutrinos
- **Experimental challenges:** rate $O(\text{evt/kg/year})$, background rejection, and energy threshold (keV)
- **Strategy:** photograph nuclear recoils in a (1 atm) He:CF₄ TPC with a GEM amplification stage
 - ➔ low energy events in 1 atm gas $\Rightarrow$ visible tracks $\Rightarrow$ optical readout



TPC of the LIME prototype @ LNF



Amplification with GEMS



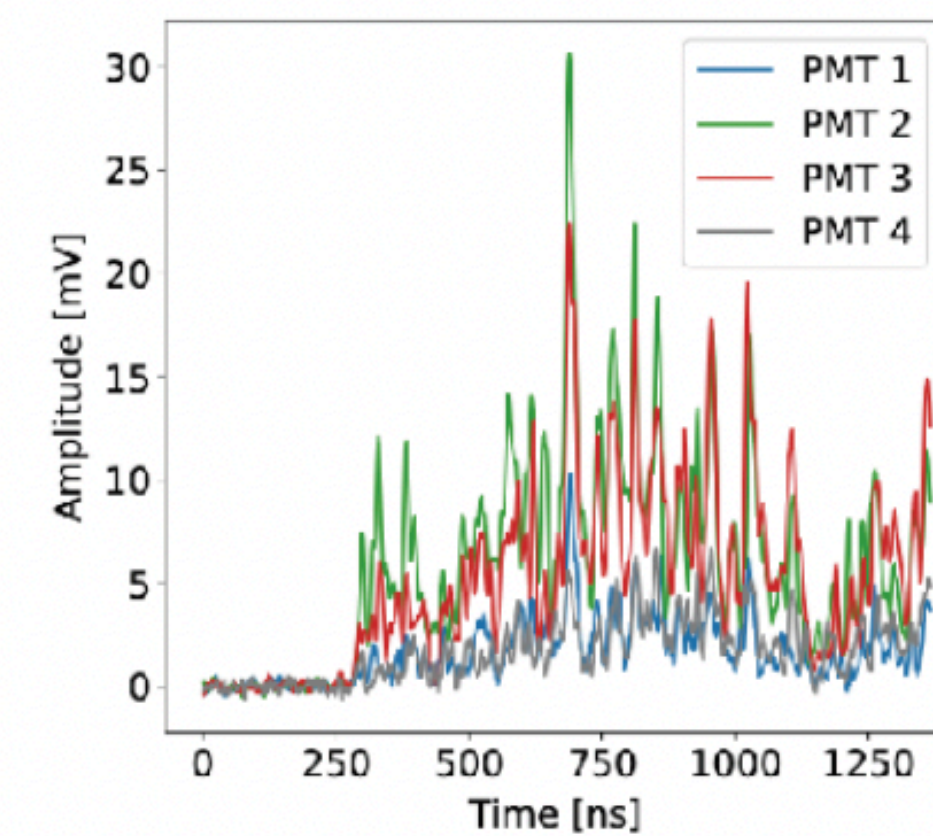
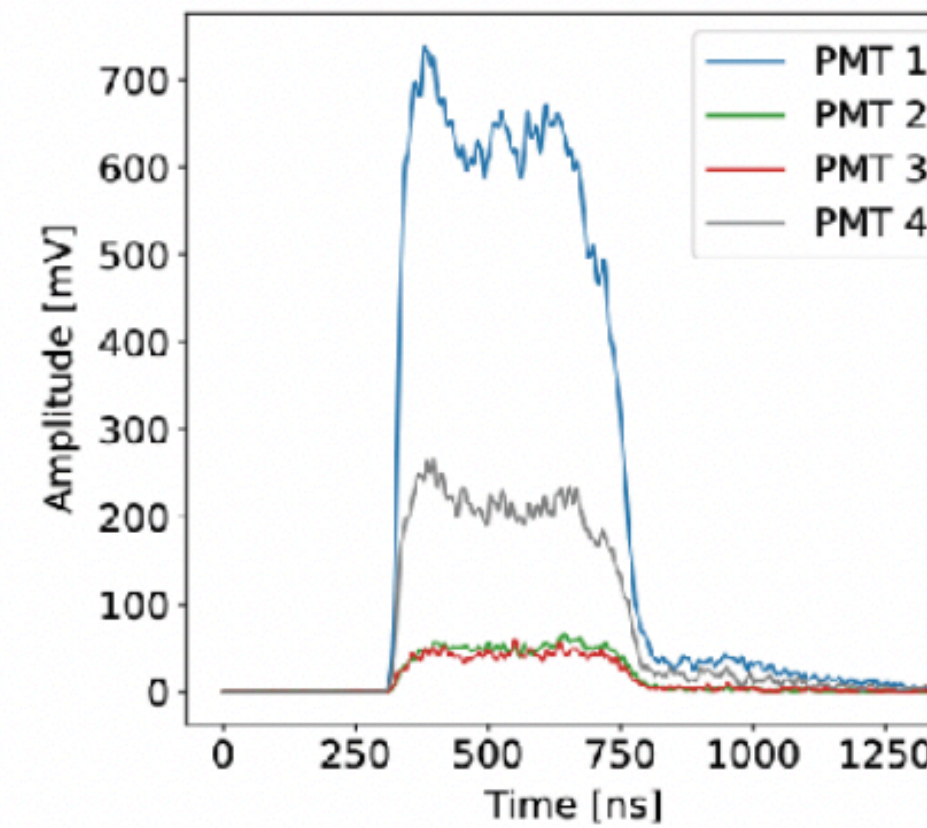
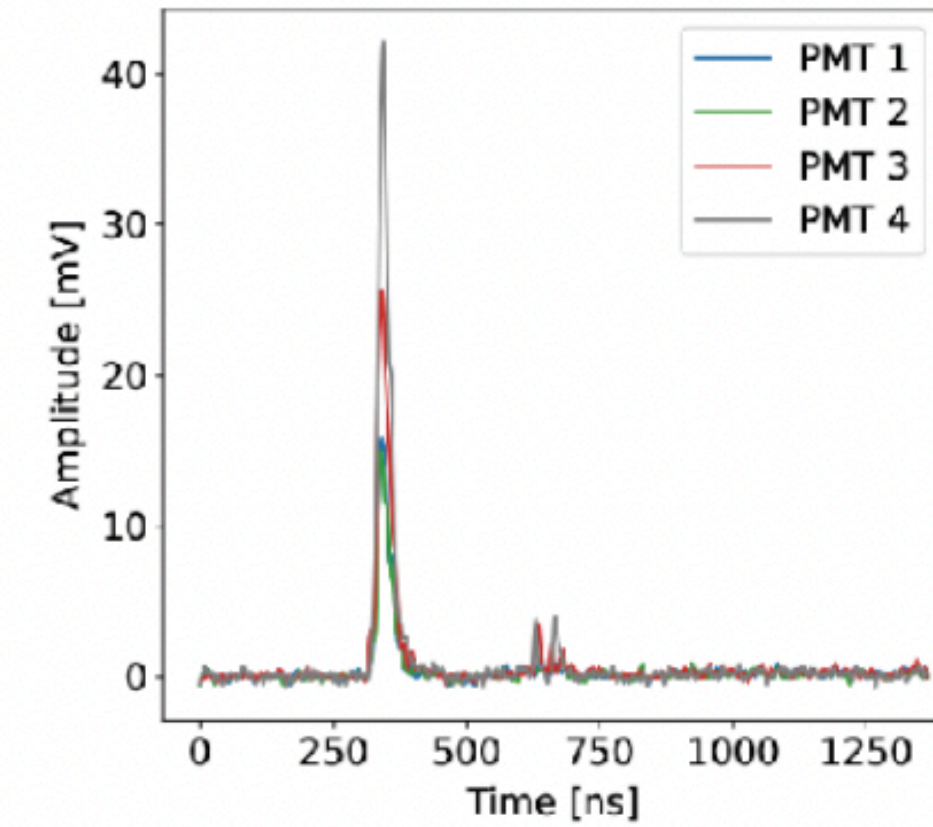
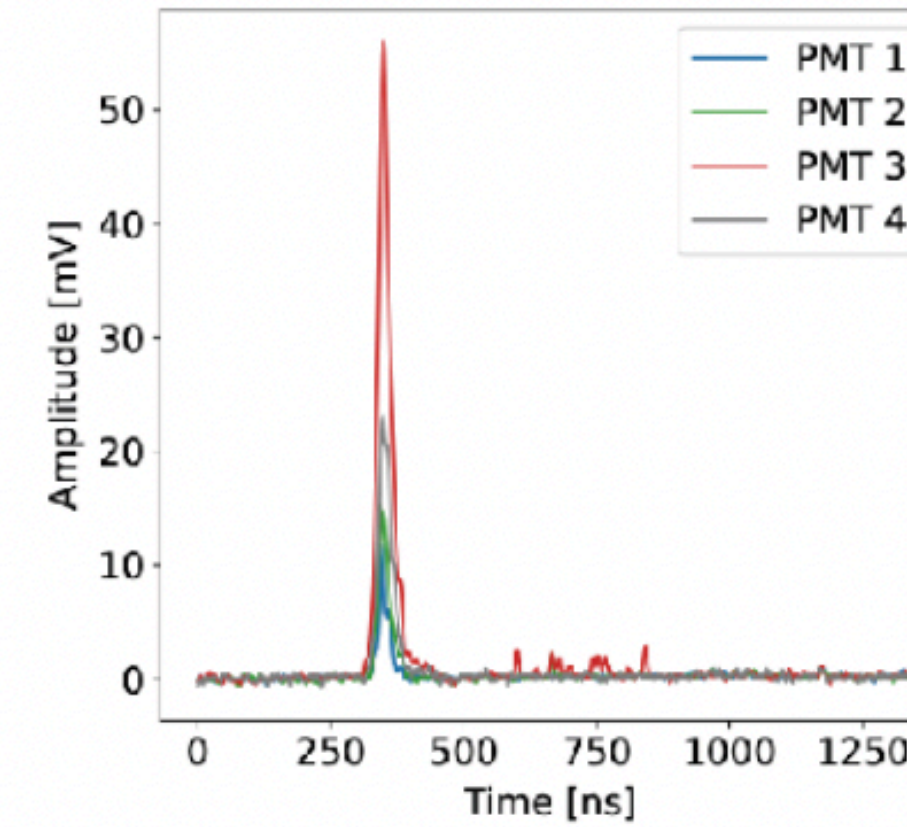
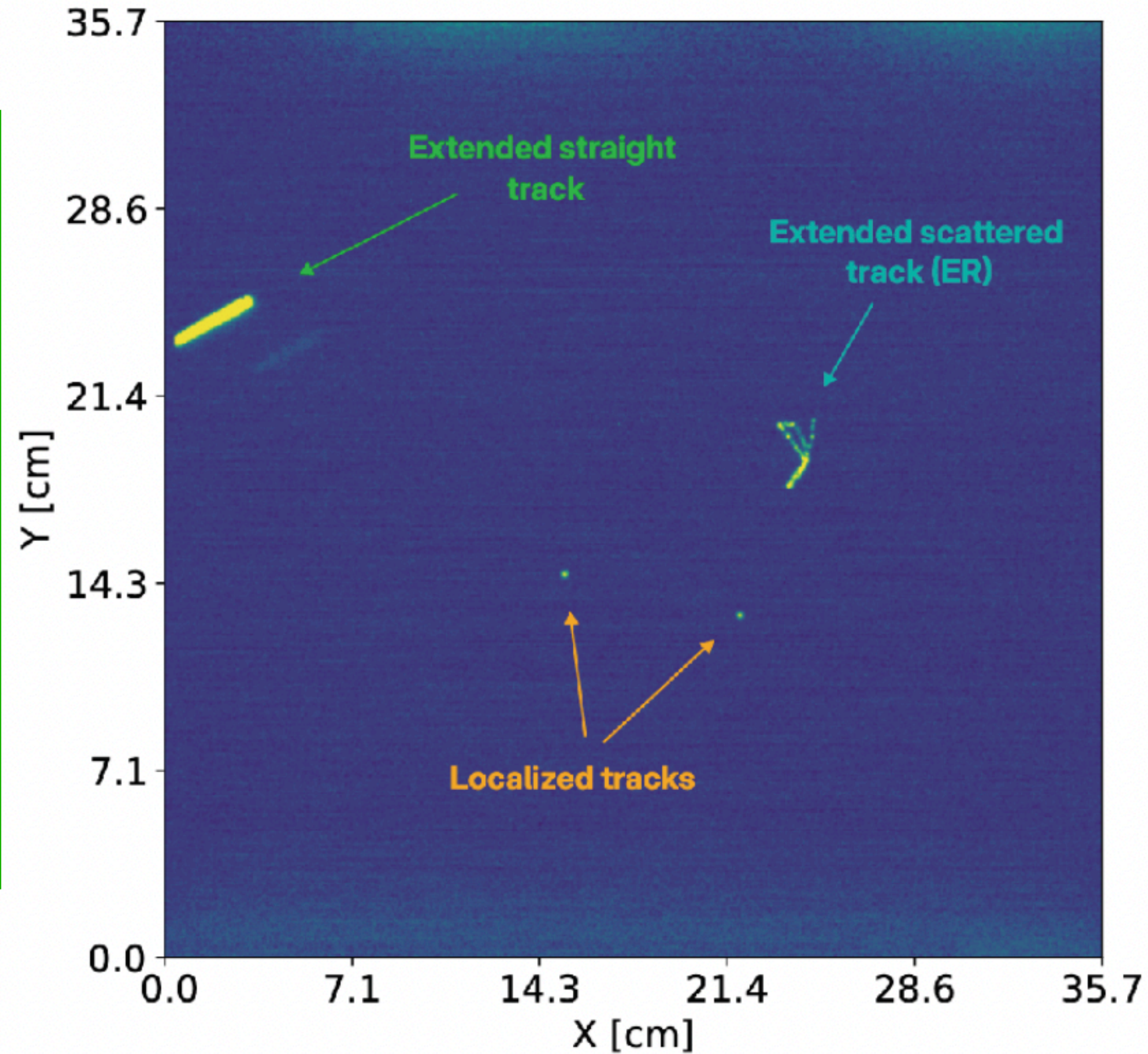
sCMOS camera
[Hamamatsu Orca-Quest2]

A set of PMTs
[Hamamatsu R7378]

The CXGNO paradigm



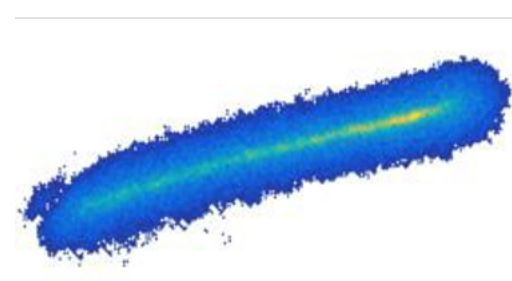
Photo exposure time ~ 100 ms



Signal time ~ 1 μ s

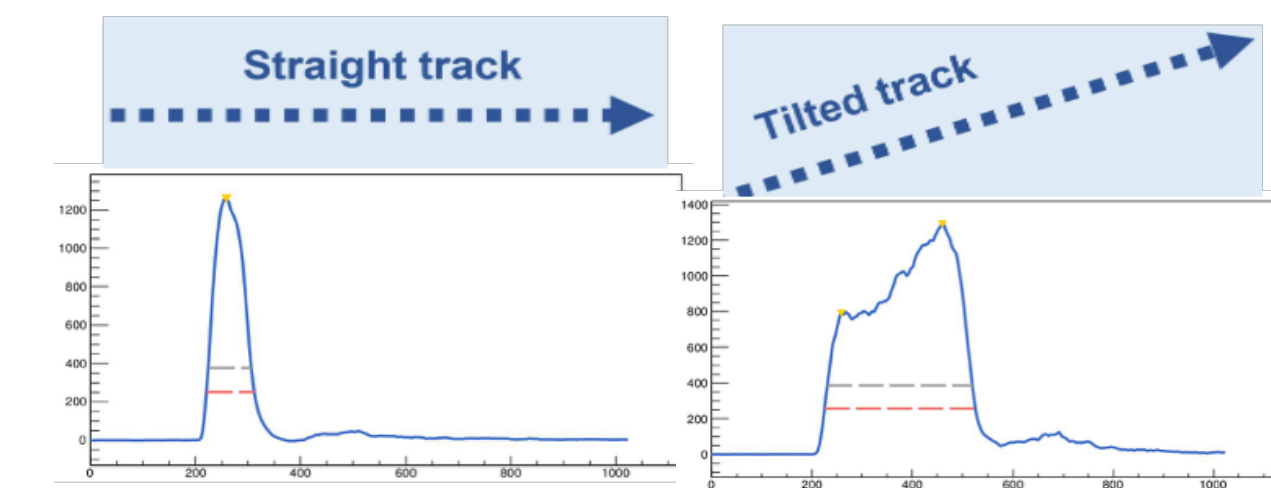
With the high granularity of the camera, we measure

energy + X & Y coordinates

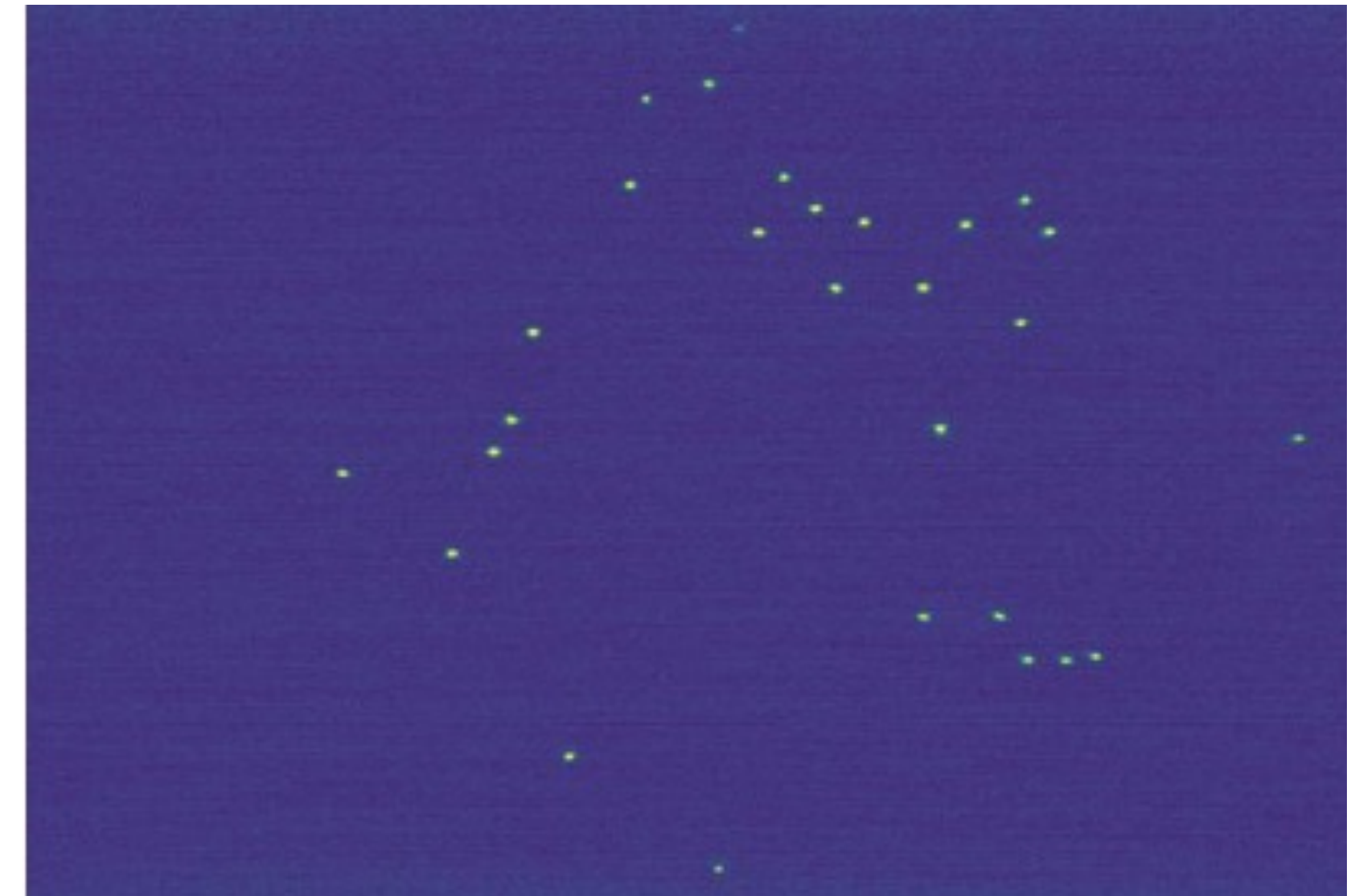
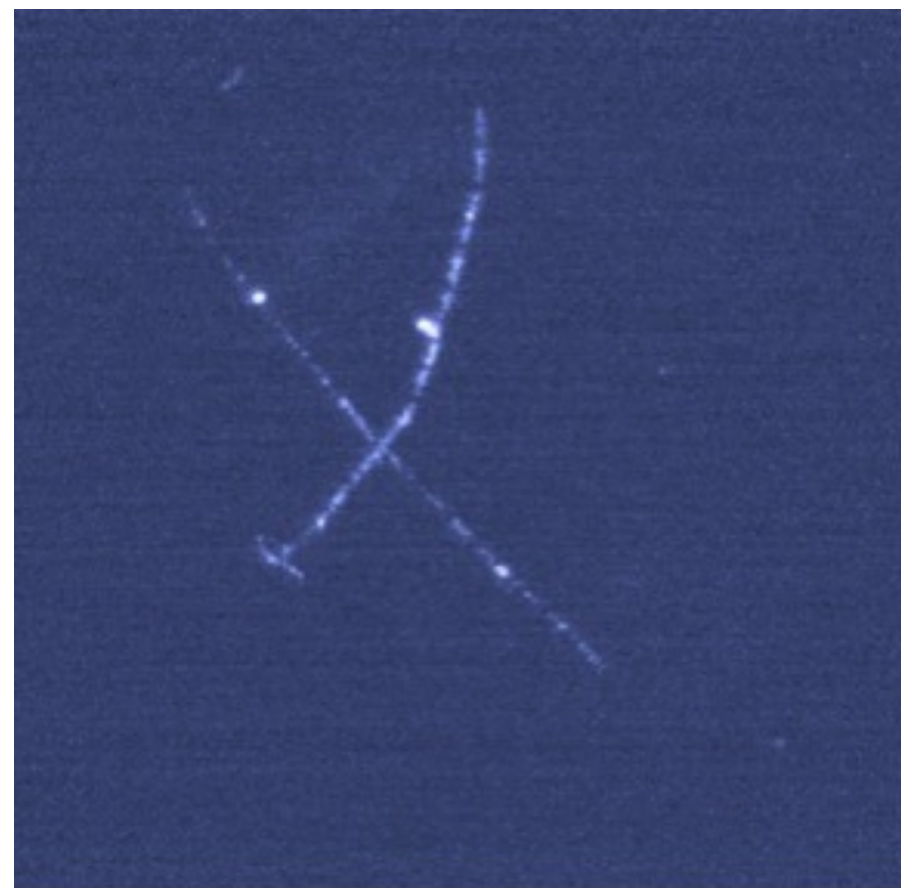
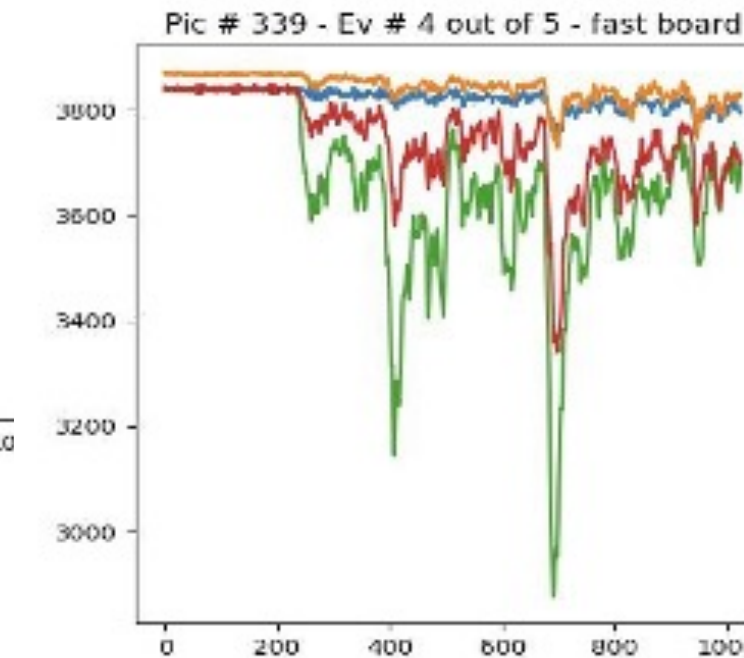
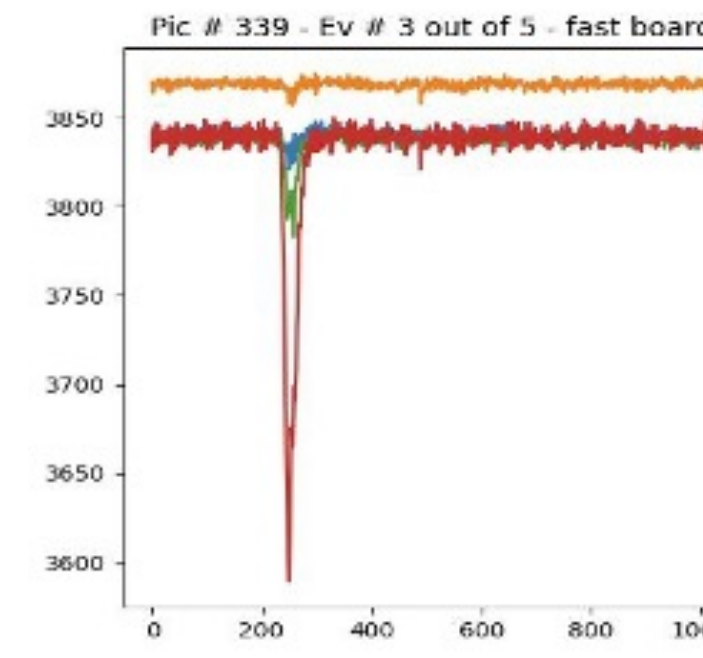
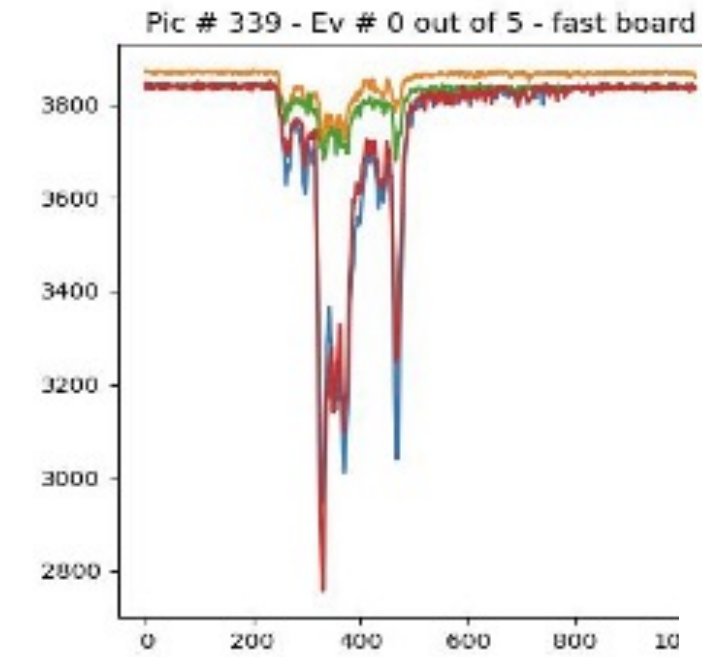
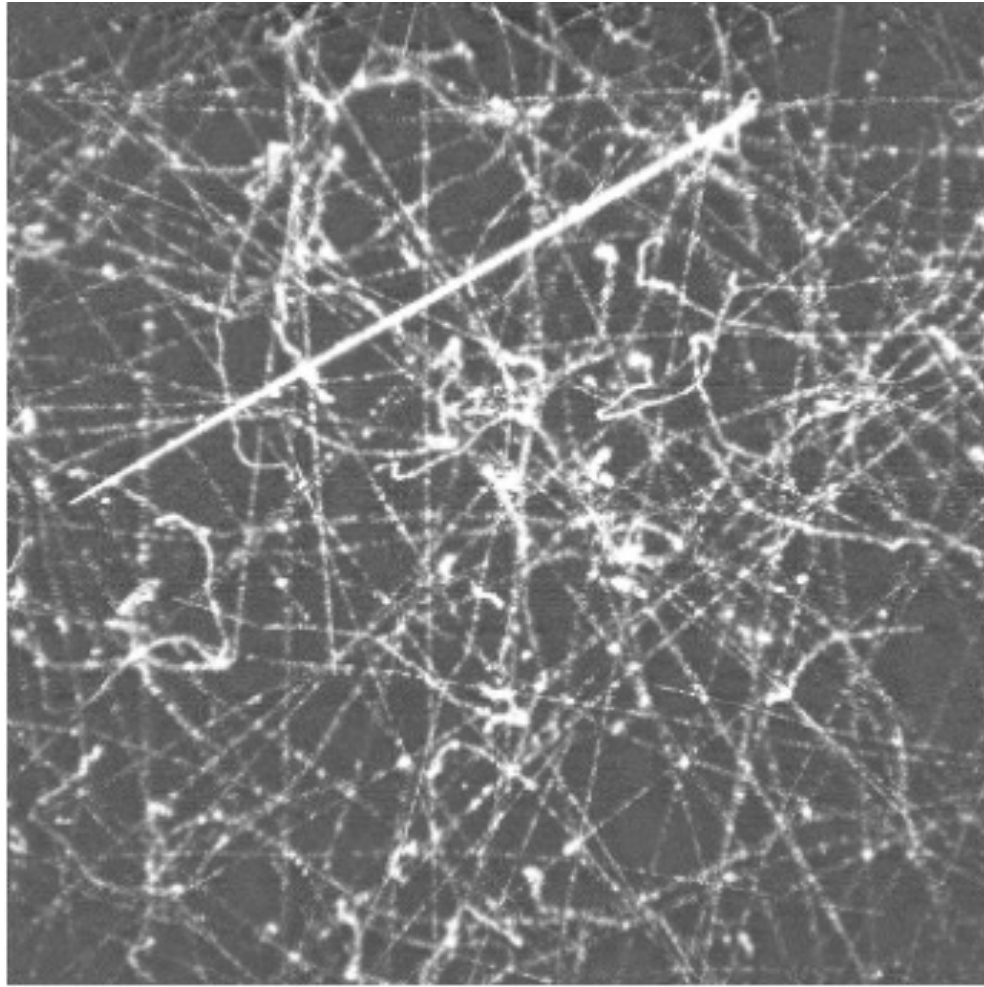


With the high time resolution of the PMTs, we measure

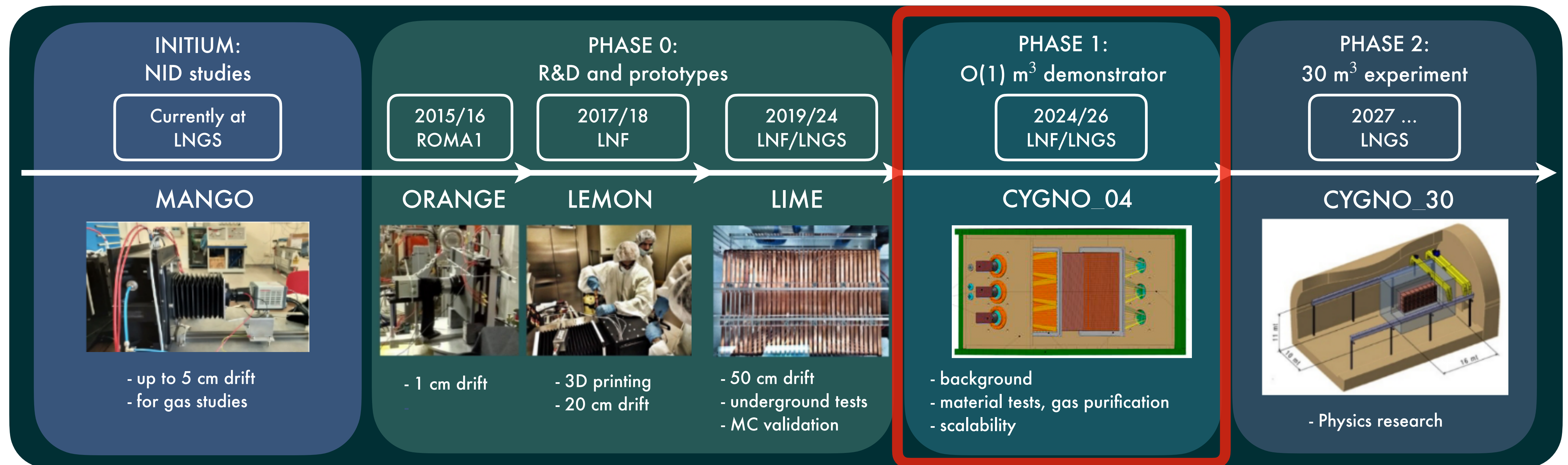
energy + ΔZ coordinate



The CXGNO data



The **CXGNO** timeline



JINST 21 (2026) 04, T04004

Mach.Learn.Sci.Tech. 7 (2026) 2, 025058

Eur.Phys.J.C 86 (2026) 2, 123

Eur.Phys.J.C 85 (2025) 11, 1261

Eur.Phys.J.C 84 (2024) 10, 1122

Phys.Lett.B 855 (2024) 138759

Eur.Phys.J.C 83 (2023) 10, 946

Instruments 6 (2022) 1, 6

Measur.Sci.Tech. 32 (2021) 2, 025902

NIM A 999 (2021) 165209

JINST 15 (2020) 12, T12003

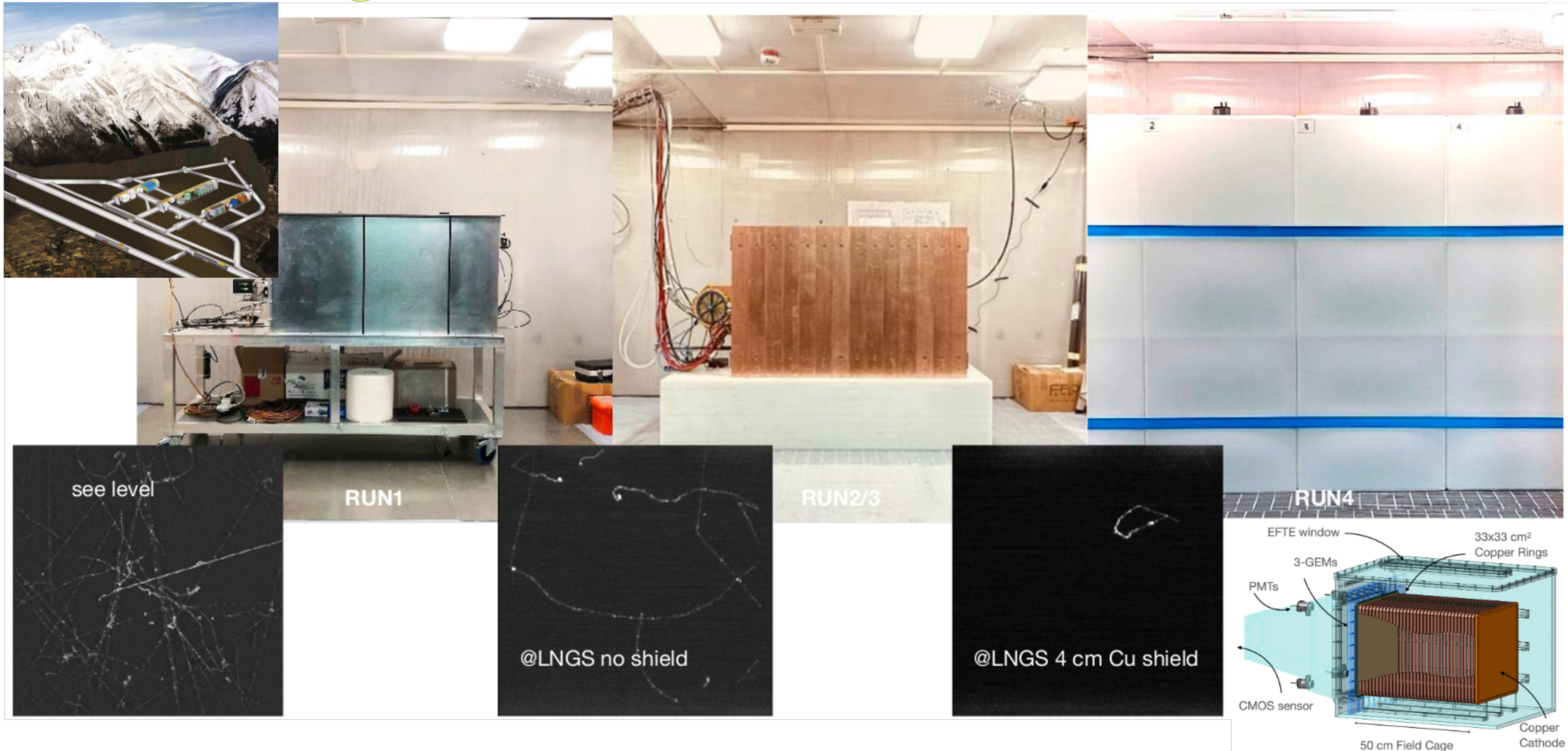
JINST 15 (2020) P10001

JINST 15 (2020) P08018

2019 JINST 14 P07011

The LIME underground experience

CYGNO
Experiment

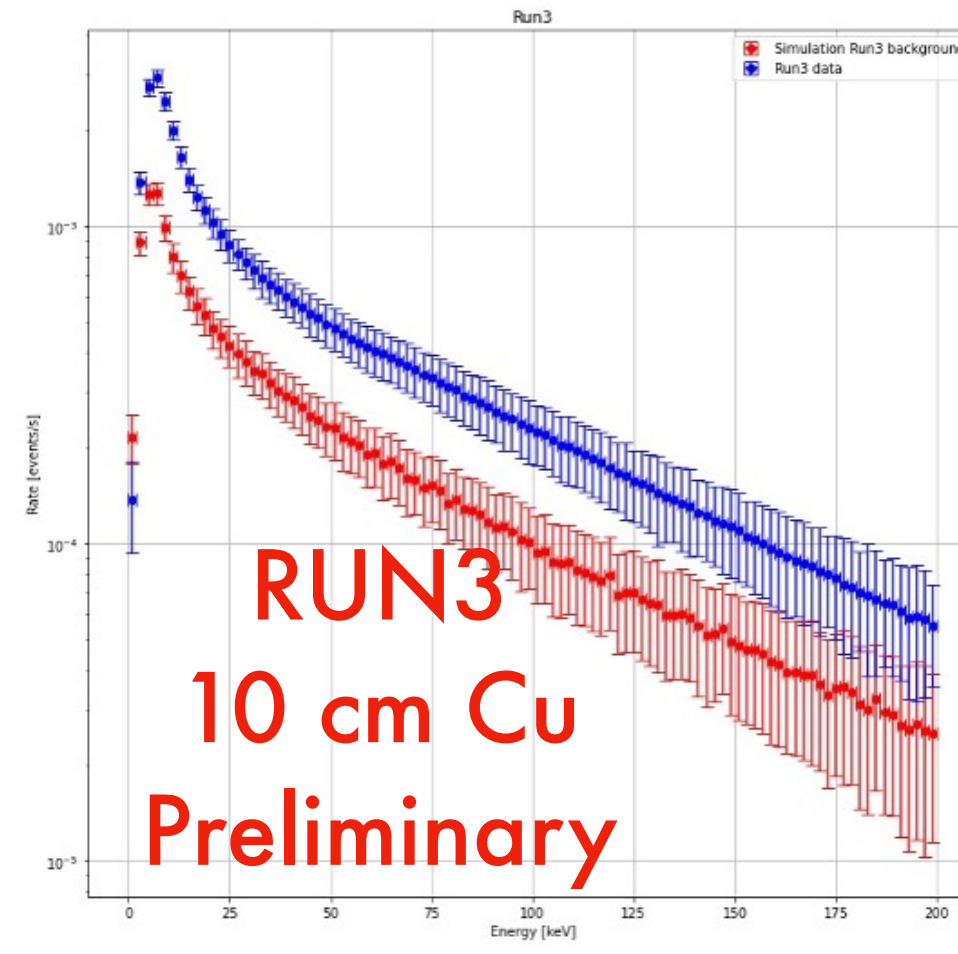
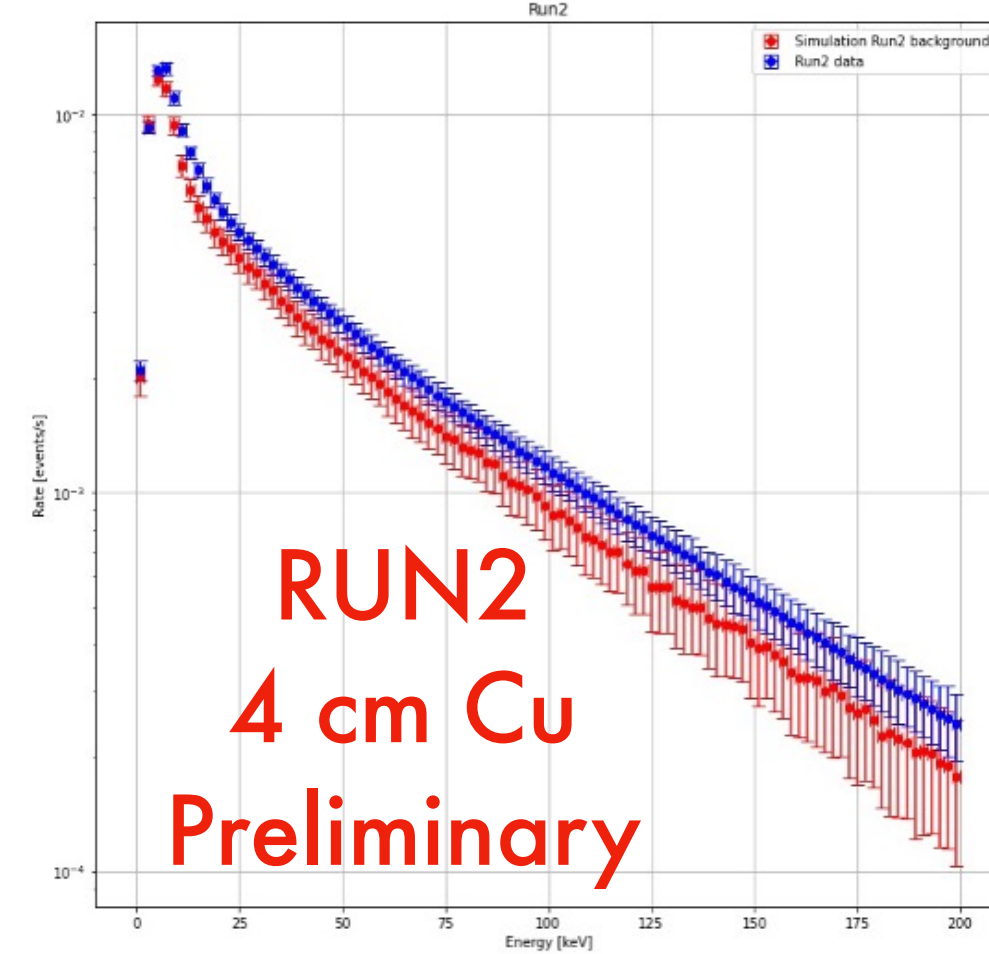
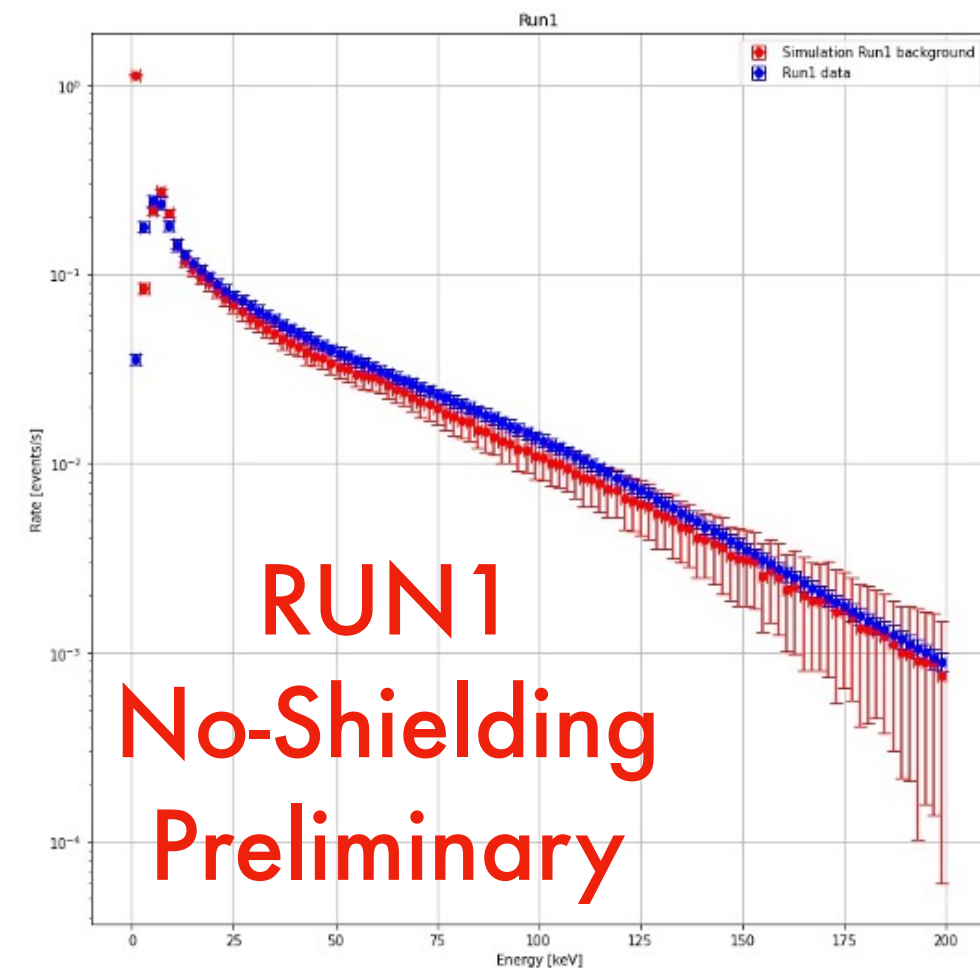


See Melba D'Astolfo talk: [Underground environmental neutron flux measurement with the CYGNO project](#)

The LIME underground experience

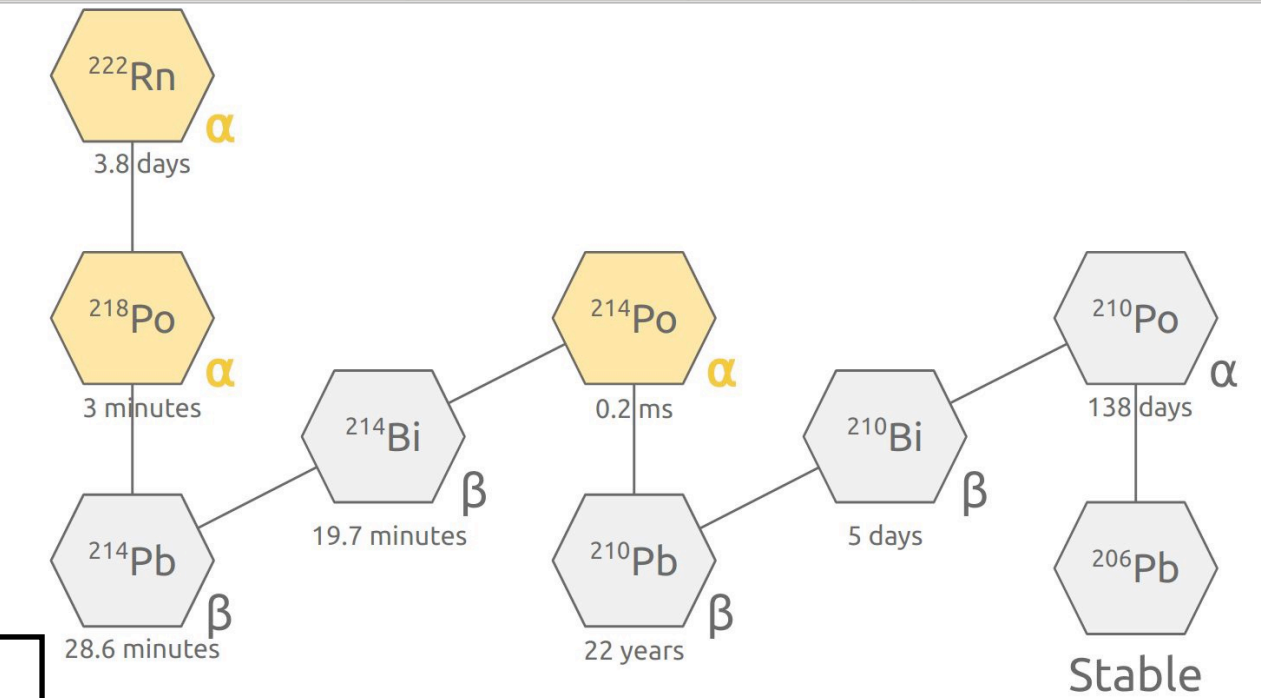


Data-MC comparison suggesting a **missing internal background component**:

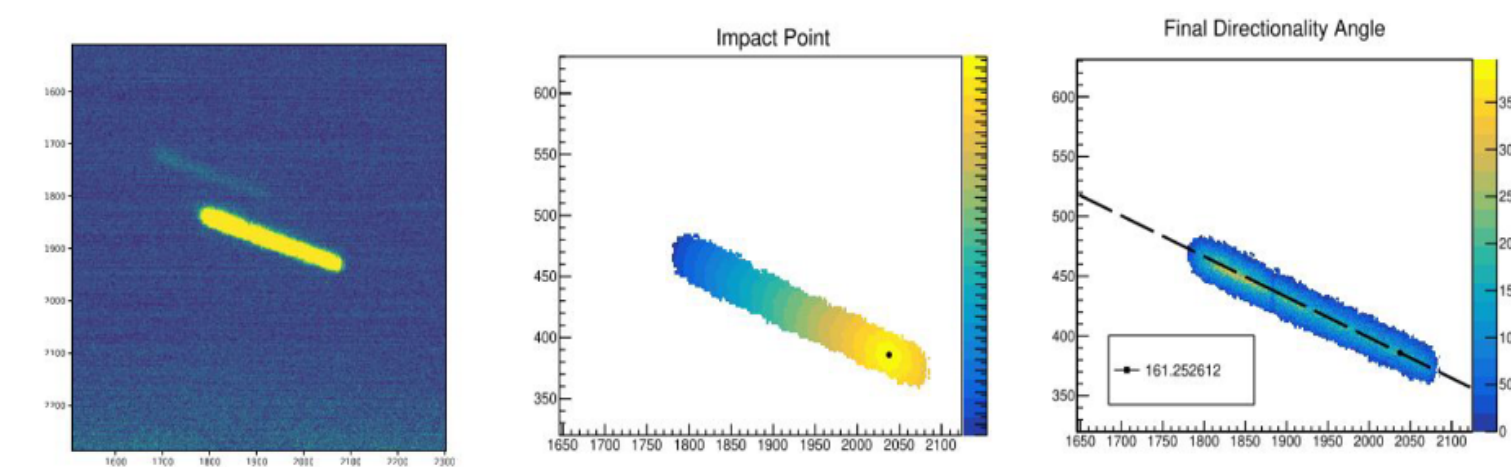


	Time slot	Number of pictures	Event rate	Number of events
RUN 1: No-shielding	3 Nov 2022 - 15 Dec 2022	$4 \cdot 10^5$	35 Hz	$4 \cdot 10^6$
RUN 2: 4 cm Cu shielding	15 Feb 2023 - 15 March 2023	$4.5 \cdot 10^5$	3.5 Hz	$5 \cdot 10^5$
RUN 3: 10 cm Cu shielding	5 May 2023 - 16 Nov 2023	$1.6 \cdot 10^6$	1.5 Hz	$7.3 \cdot 10^5$
RUN 4: 10 cm Cu + 40 cm water shielding	30 Nov 2023 - 31 March 2024	$2 \cdot 10^6$	1.0 Hz	$6 \cdot 10^5$
RUN 5: 10 cm Cu shielding (neutron flux measurements)	17 May 2024 - 1 Dec 2024	$12 \cdot 10^6$	1.5 Hz	$5.4 \cdot 10^6$

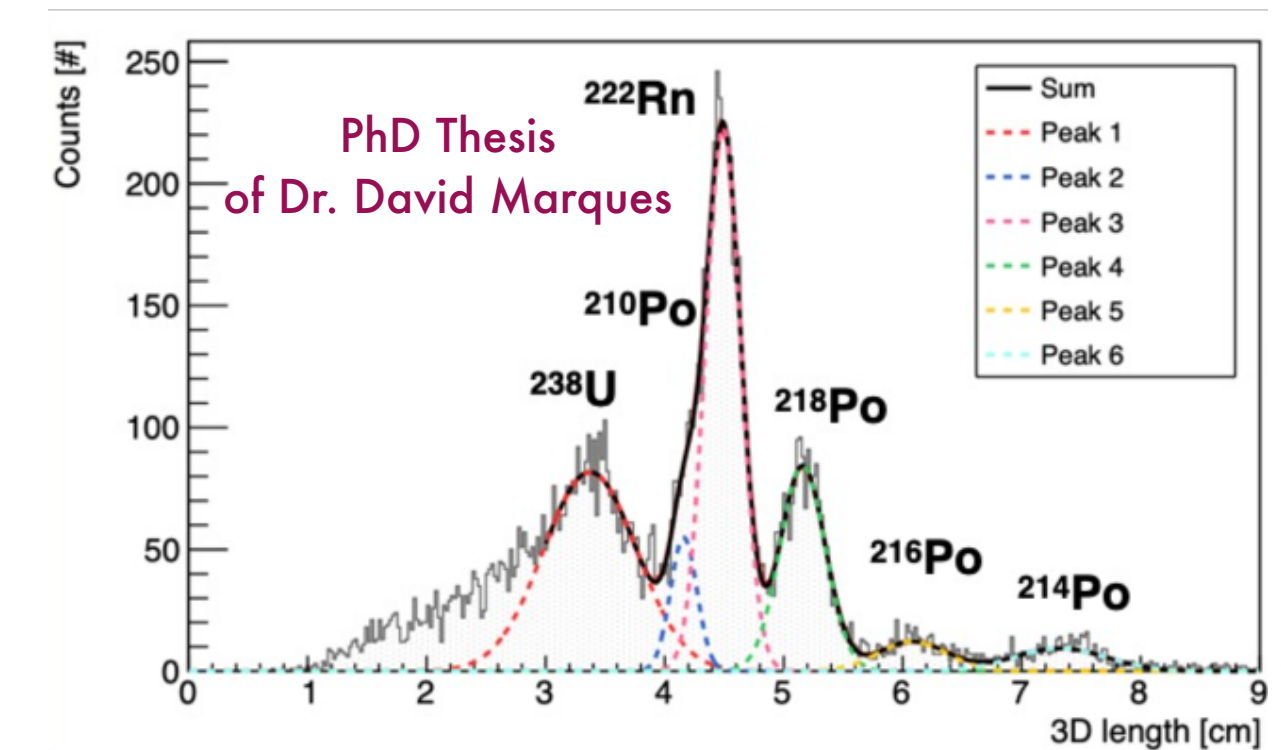
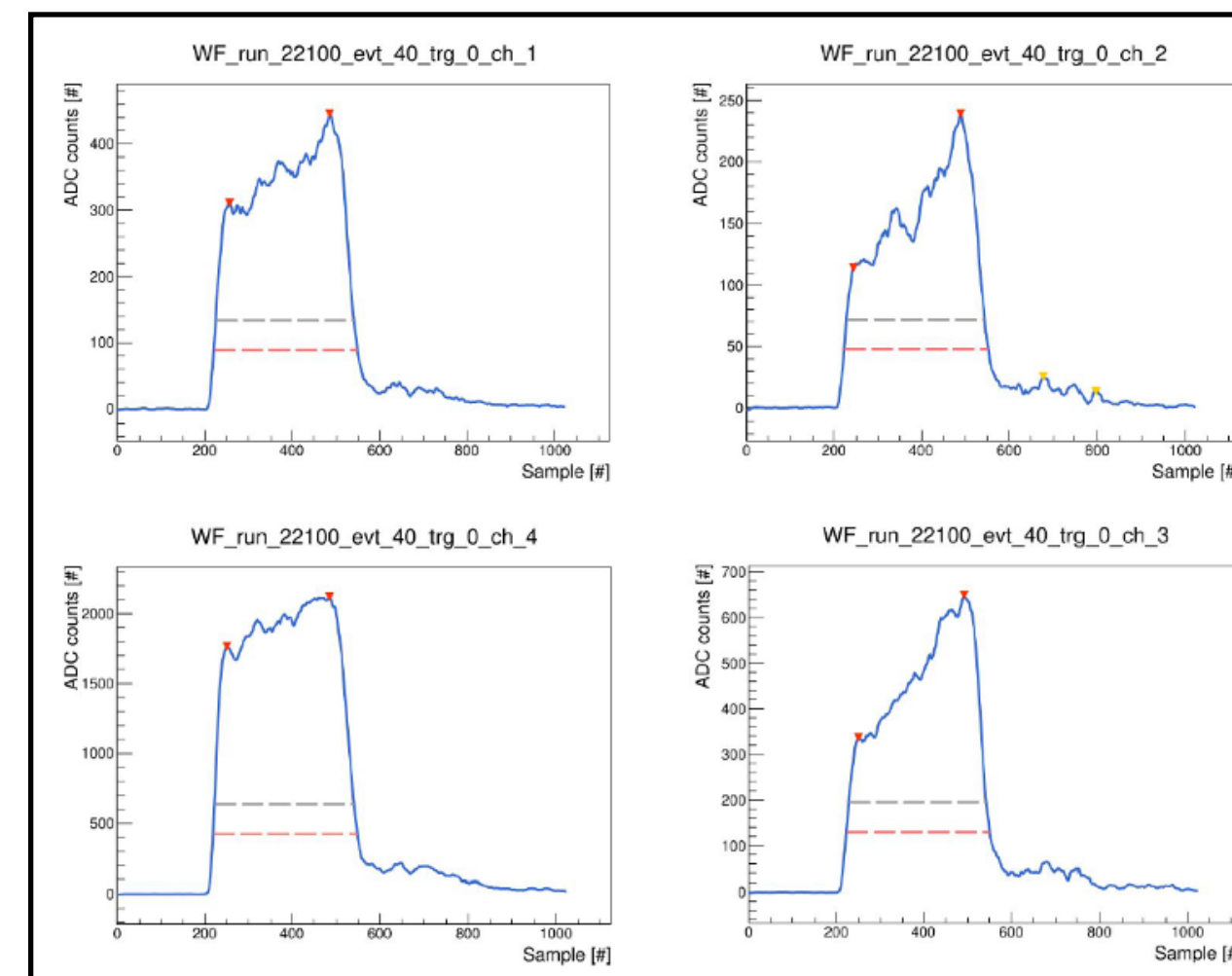
Major suspect: **Rn contamination** → focused on alpha spectroscopy to get confirmation:



Full 3D
reconstruction
of alpha-
induced
tracks

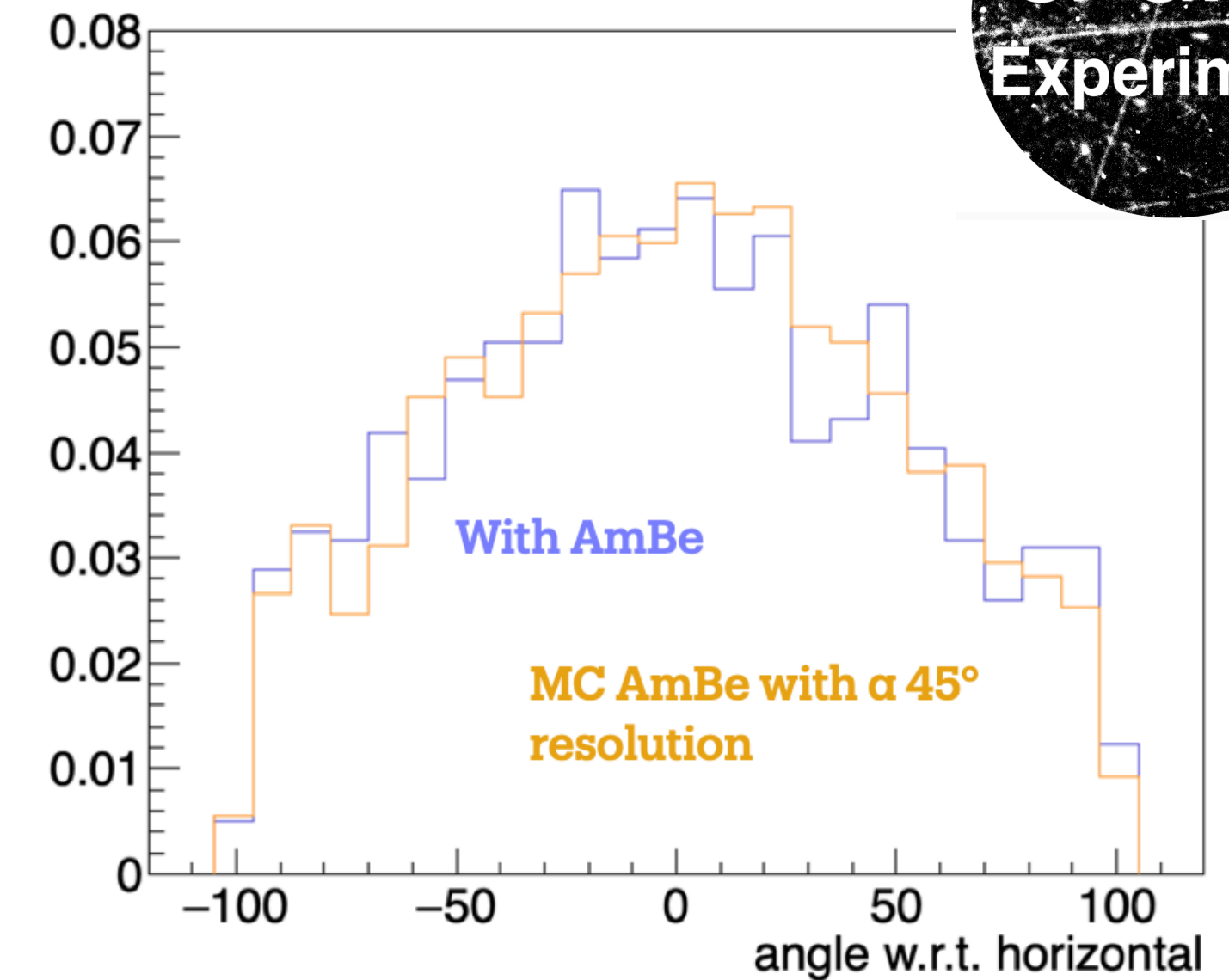
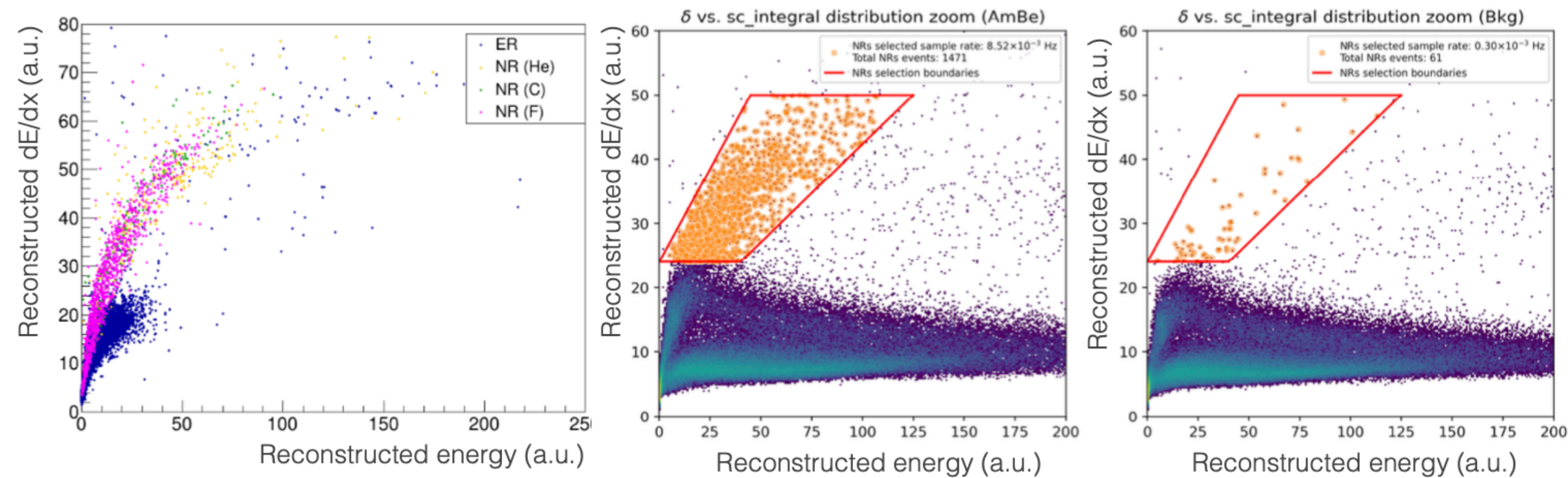


- Alpha tracks so bright → **saturated** energy readout → spectroscopy **using 3D length**
- Multivariate Bayesian network for PMT-to-track association
- Association validated to effective to distinguish tracks as separated as ~ 1 cm
- Published in [Eur.Phys.J.C 85 \(2025\) 11, 1261](#)

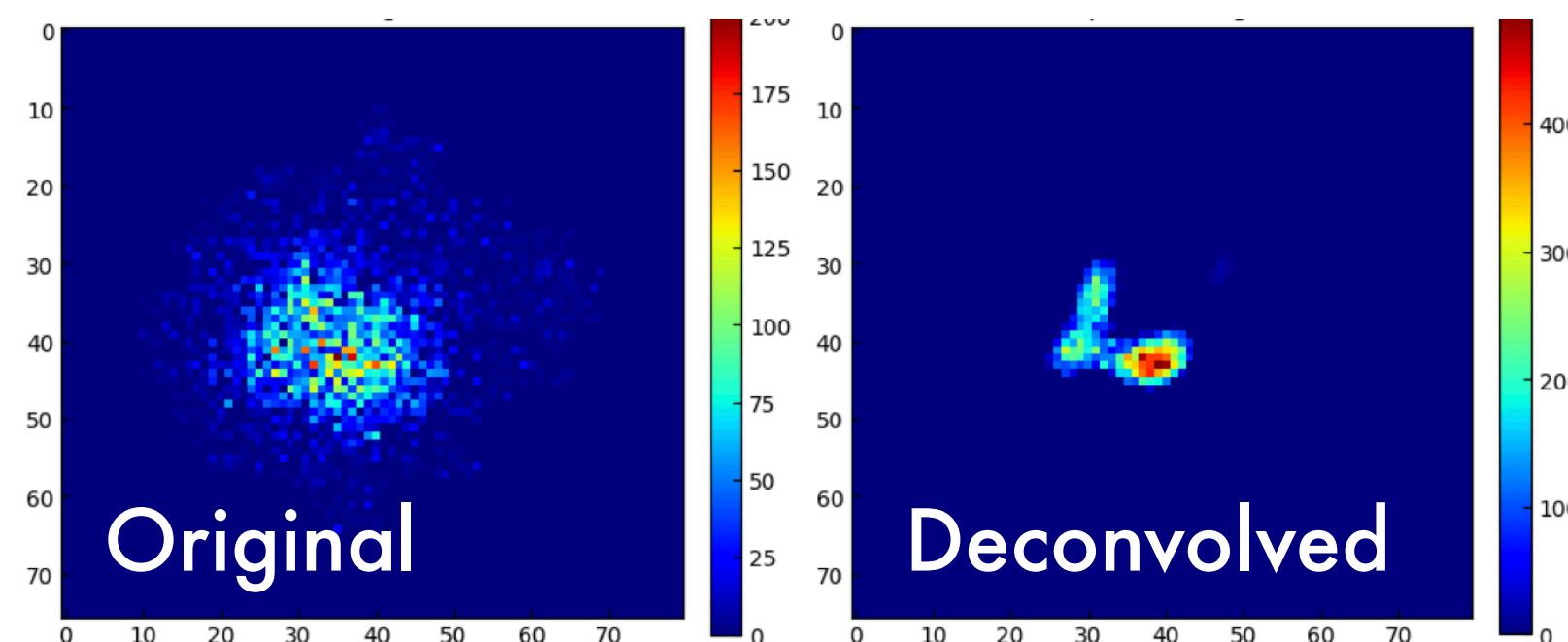


Full 3D reconstruction enables radon progeny spectroscopy!

Directionality

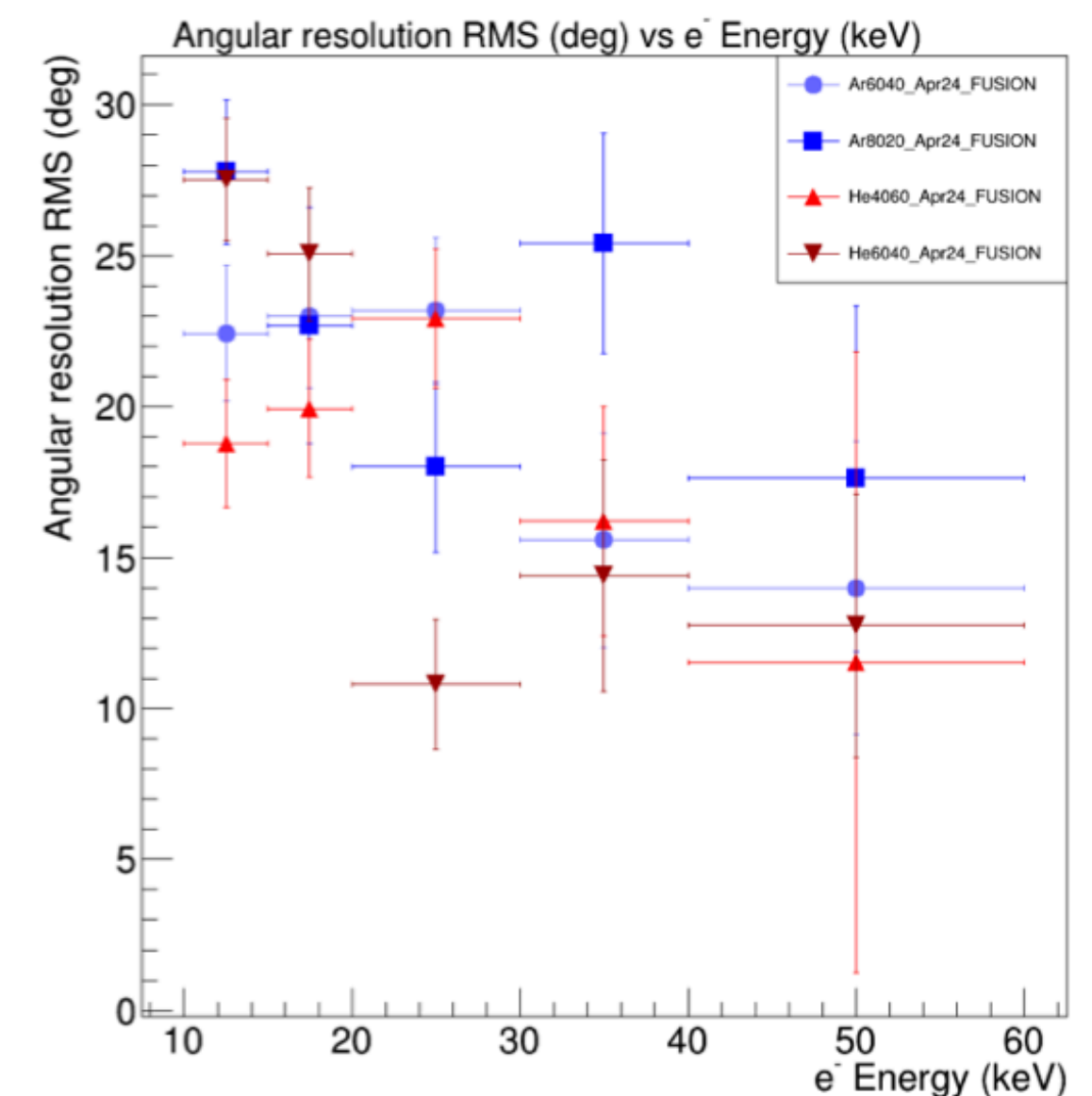


- The analysis of data taken with an AmBe neutron source shows a clear sensitivity to the **direction of NRs** induced by neutron scattering with an evaluated average 2D angular resolution of **45° over the entire spectrum**
- With a small LIME-like prototype (MANGO), **direction ER resolution between 10° and 30°** was measured in the 10-50 keV range (paper submitted to EPJC)
- Improved directionality by means of **diffusion deconvolution**



see **Federico Scamporlino** poster:

[Diffusion deconvolution method and fiducialization for the CYGNO experiment](#)



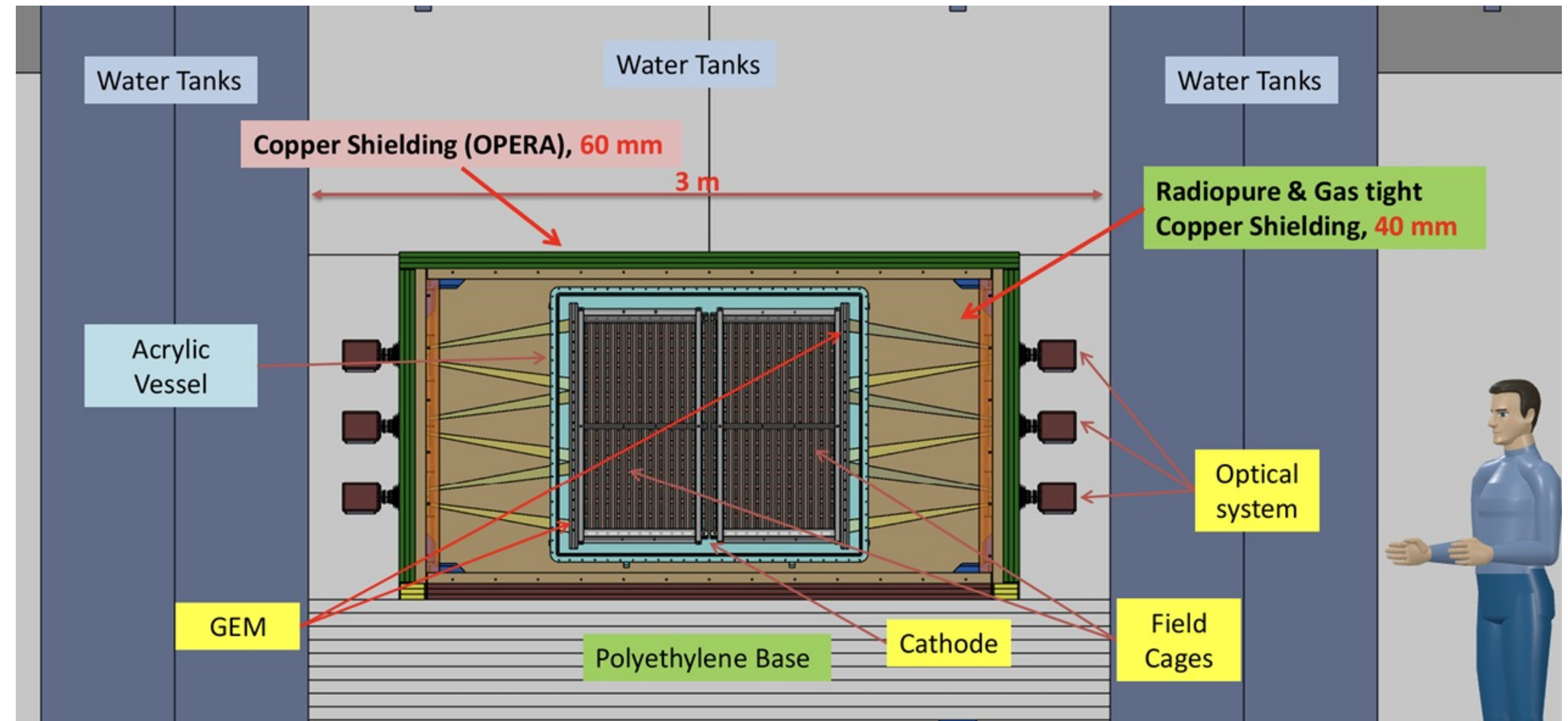
CXGNO PHASE 1: CYGNO_04



Designed at LNF and to be installed at LNGS

- **Design:**

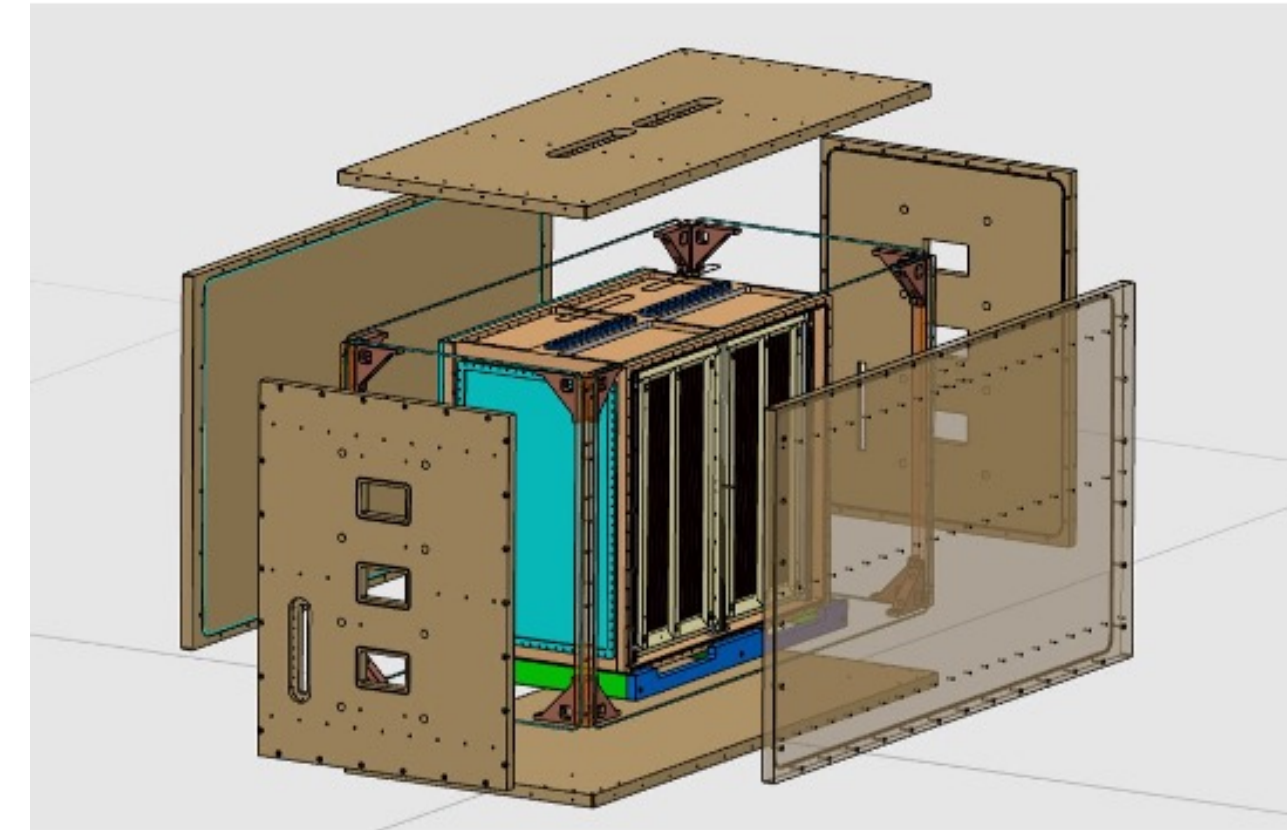
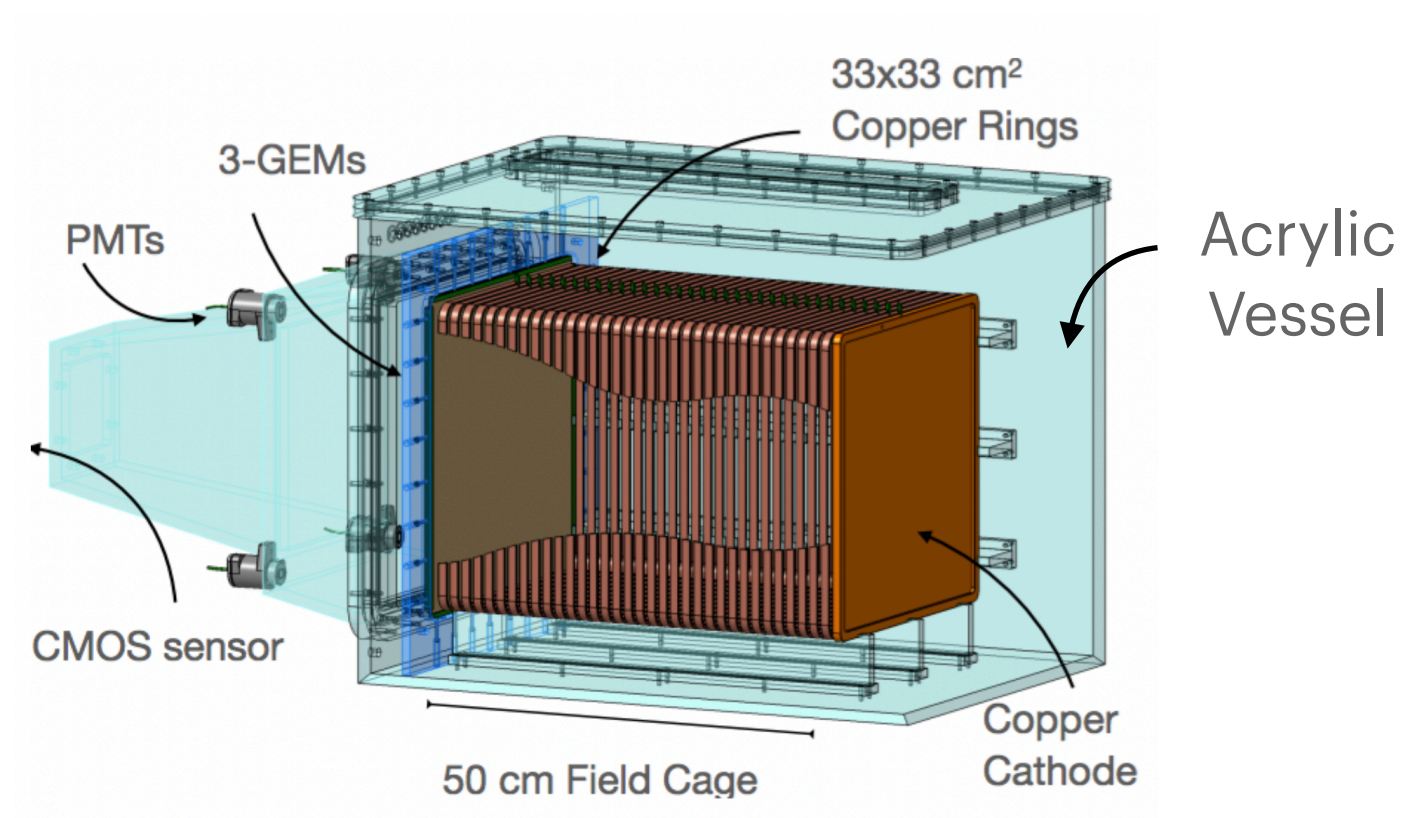
- ◎ TPC made of **2 chambers** with a **common cathode**.
- ◎ Closed by 2 sets of **50 cm x 80 cm triple GEMs**
- ◎ **Readout** of each GEM side: 3 cameras with rectangular sensors (ORCA Quest) + 8 PMTs
- ◎ **Vessel:** low radioactivity PMMA
- ◎ **Shielding:** 10 cm copper + 100 cm water with a polyethylene base



Purpose of CYGNO-04:

- Feasibility large scale detector (radiopure materials, gas purification)
- Demonstrate scalability of the technology

Scaling from LIME to CYGNO-04

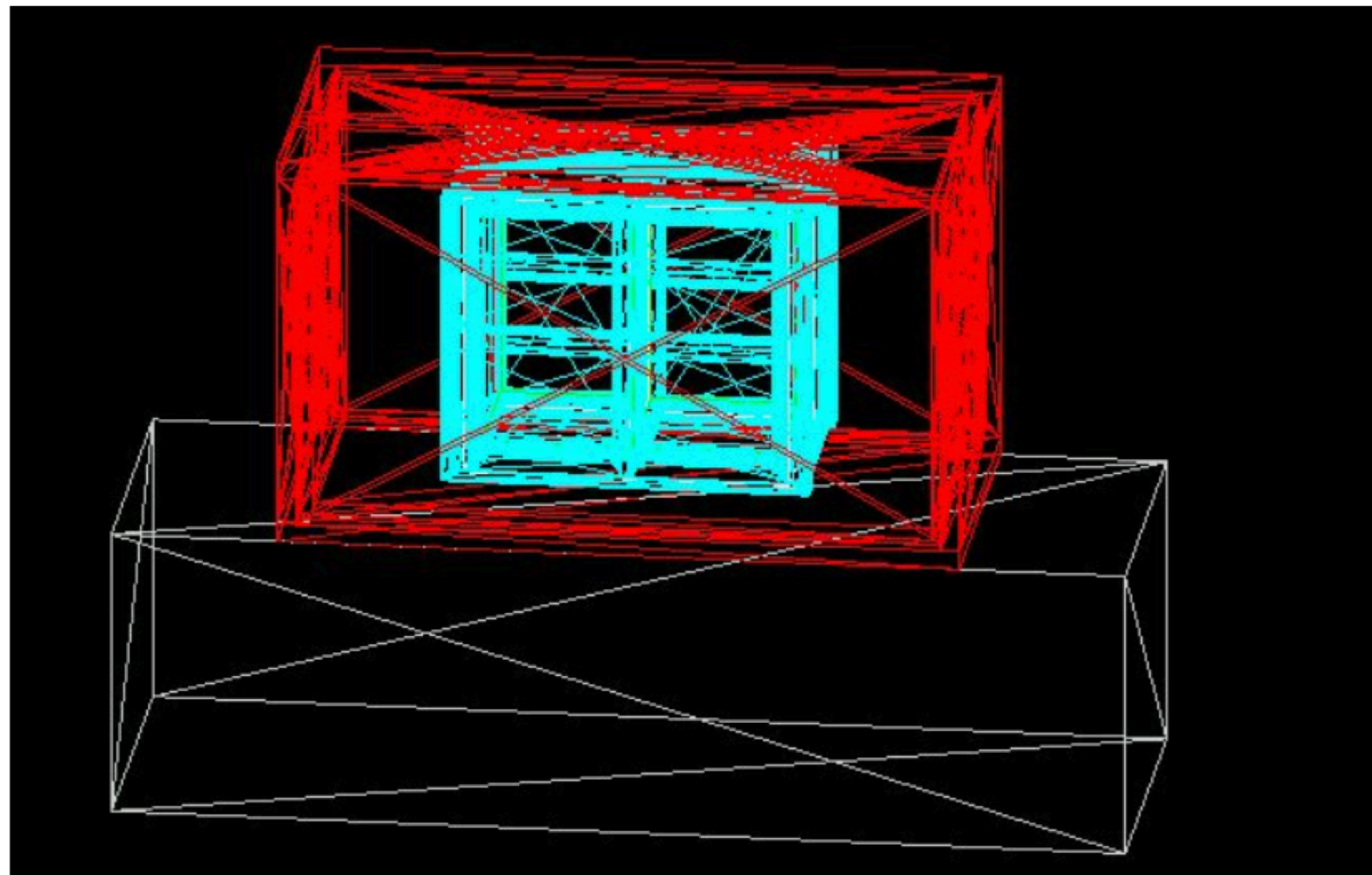


- Detector **active volume**: 50 L $\rightarrow$ 400 L (0.4 m^3) [a factor 8]
- Transverse **area**: $33 \times 33 \text{ cm}^2$ GEMs $\rightarrow$ $50 \times 80 \text{ cm}^2$ GEMs [a factor ~ 3.7]
- **Readout system**:
 - $\Rightarrow$ 1 Orca-Fusion $\rightarrow$ 6 Orca-Quest2 [a factor 6]
 - $\Rightarrow$ 4 PMTs $\rightarrow$ 16 PMTs [a factor 4]
- **Data Throughput** (raw): 20 MB/s $\rightarrow$ 350 MB/s [a factor 17.5]

Background of CYGNO-04



- All material assay measurements are leading to the **simulation of all backgrounds foreseen** in CYGNO-04

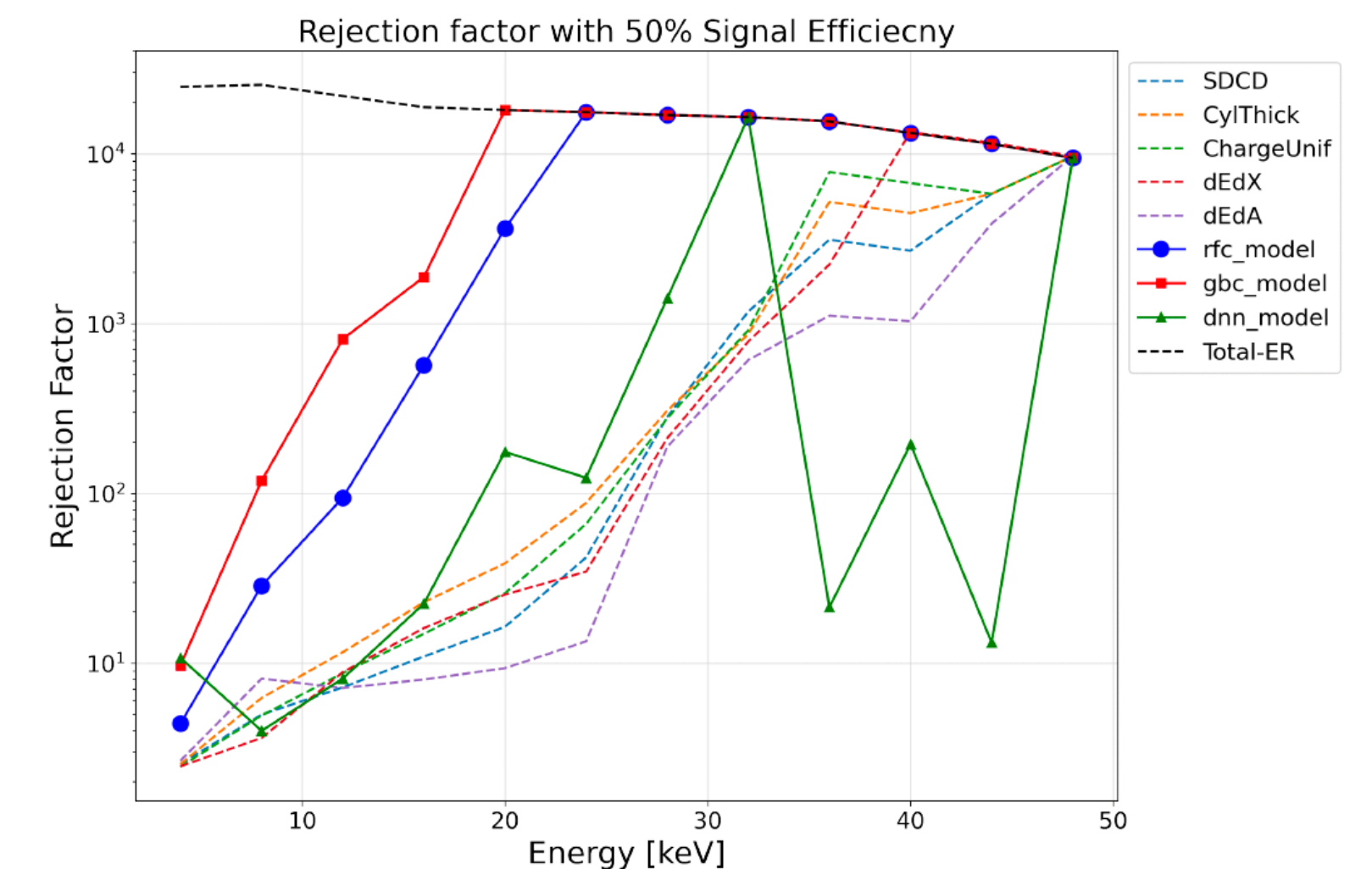


	CYGNO-04	
Summary Table	NR/yr 1-20 keV	ER/yr 1-20 keV
GEM		8.94E+04
AcrylicBox		4.55E+04
CameraBody	0.00E+00	5.19E+04
CameraLens	0.00E+00	9.35E+04
Cathode (Cu)	5.00E+00	1.98E+03
Field Cage (Kapton+Cu)	4.1E+01	9.27E+04
GEM frame		2.45E+03
Cathode frame		1.78E+03
Cu Shielding	0.00E+00	3.45E+04
Total (internal)	4.60E+01	4.14E+05
External Gamma	0.00E+00	1.00E+04
External Neutrons	7.50E+00	3.41E+00
Total (external)	7.50E+00	1.00E+04
Tot	5.35E+01	4.24E+05

10^5 events/year are expected in the 1-20 keV range

Rejection capability will play a crucial role in reducing them!

From Dr. Atul Prajapati PhD Thesis



Preliminary ER/NR discrimination with ML techniques:

10^3 per keV @ 10 keV

10^4 per keV @ 20 keV

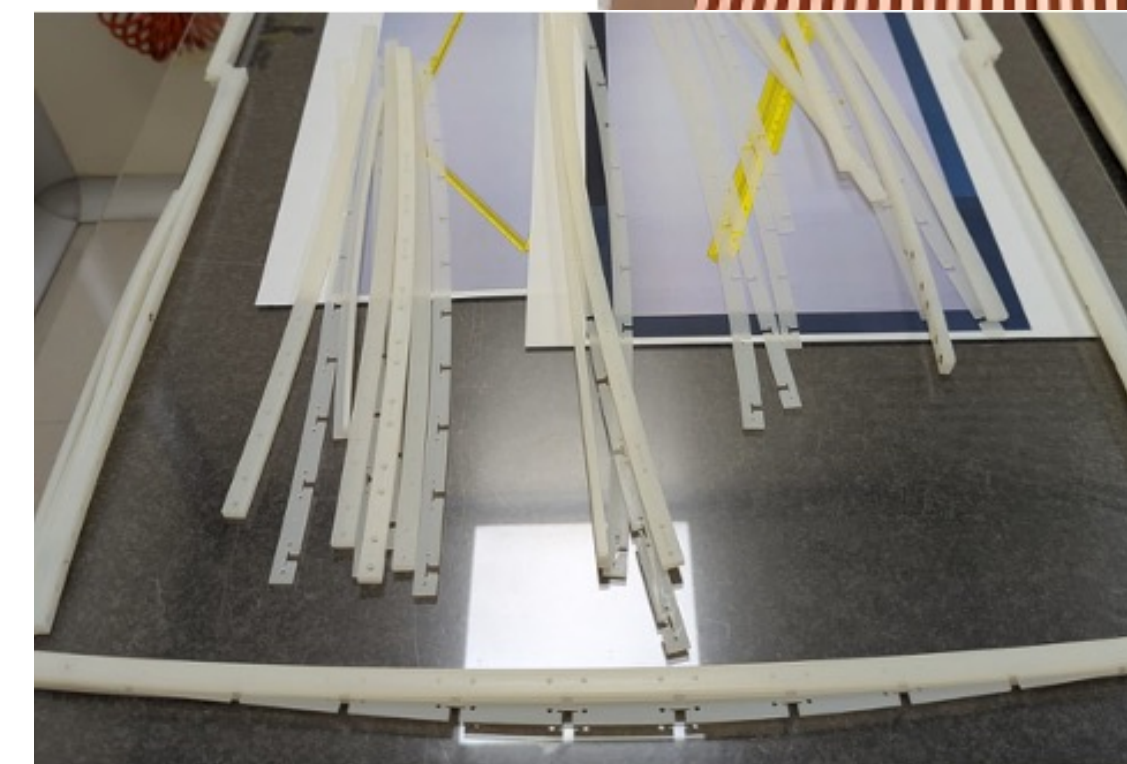
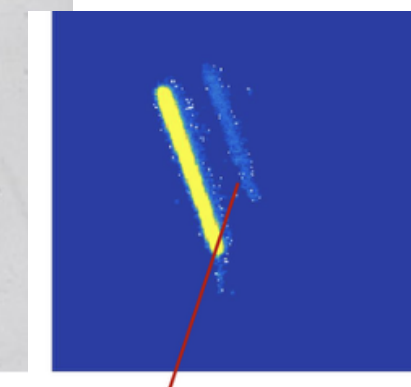
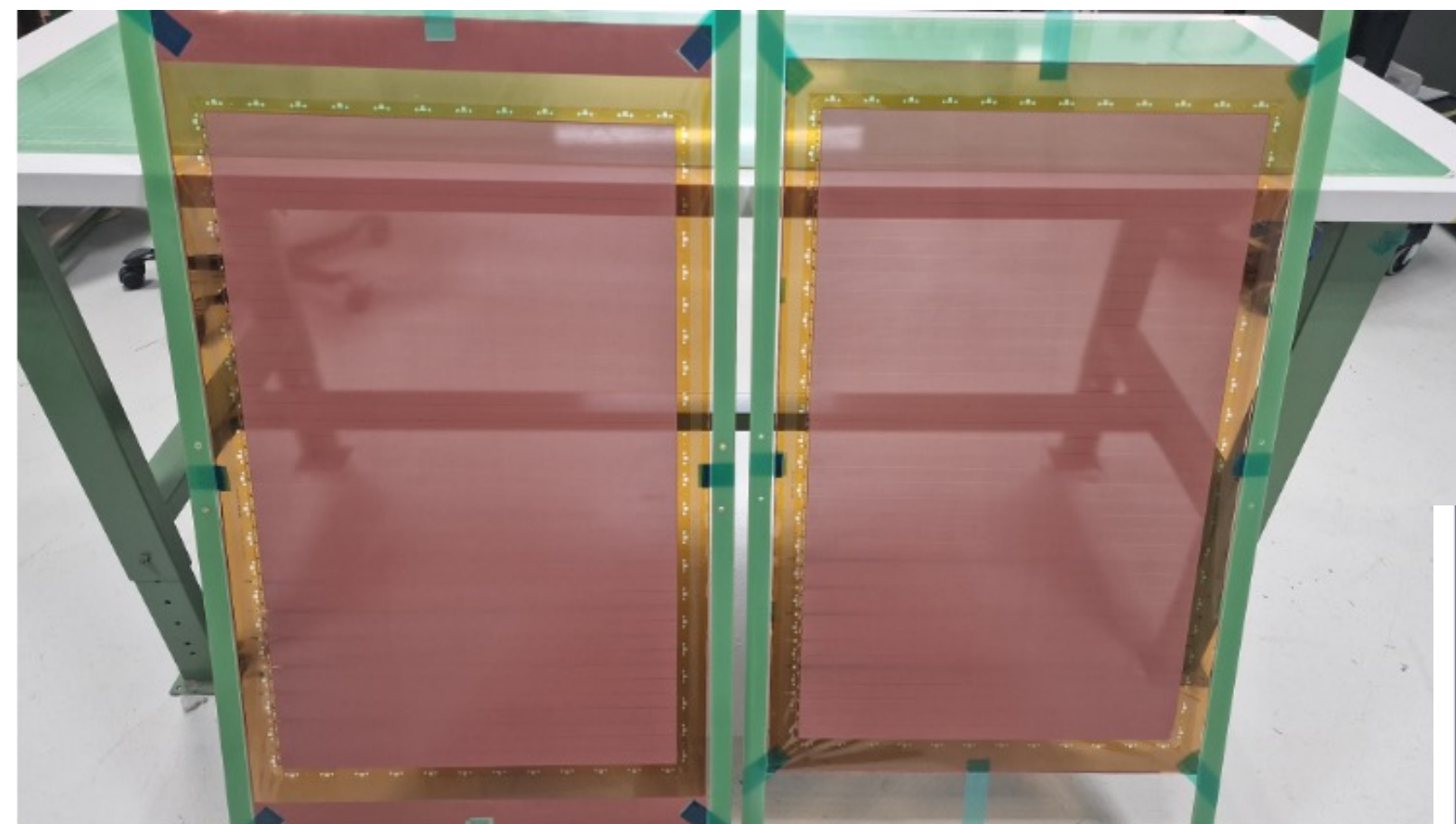
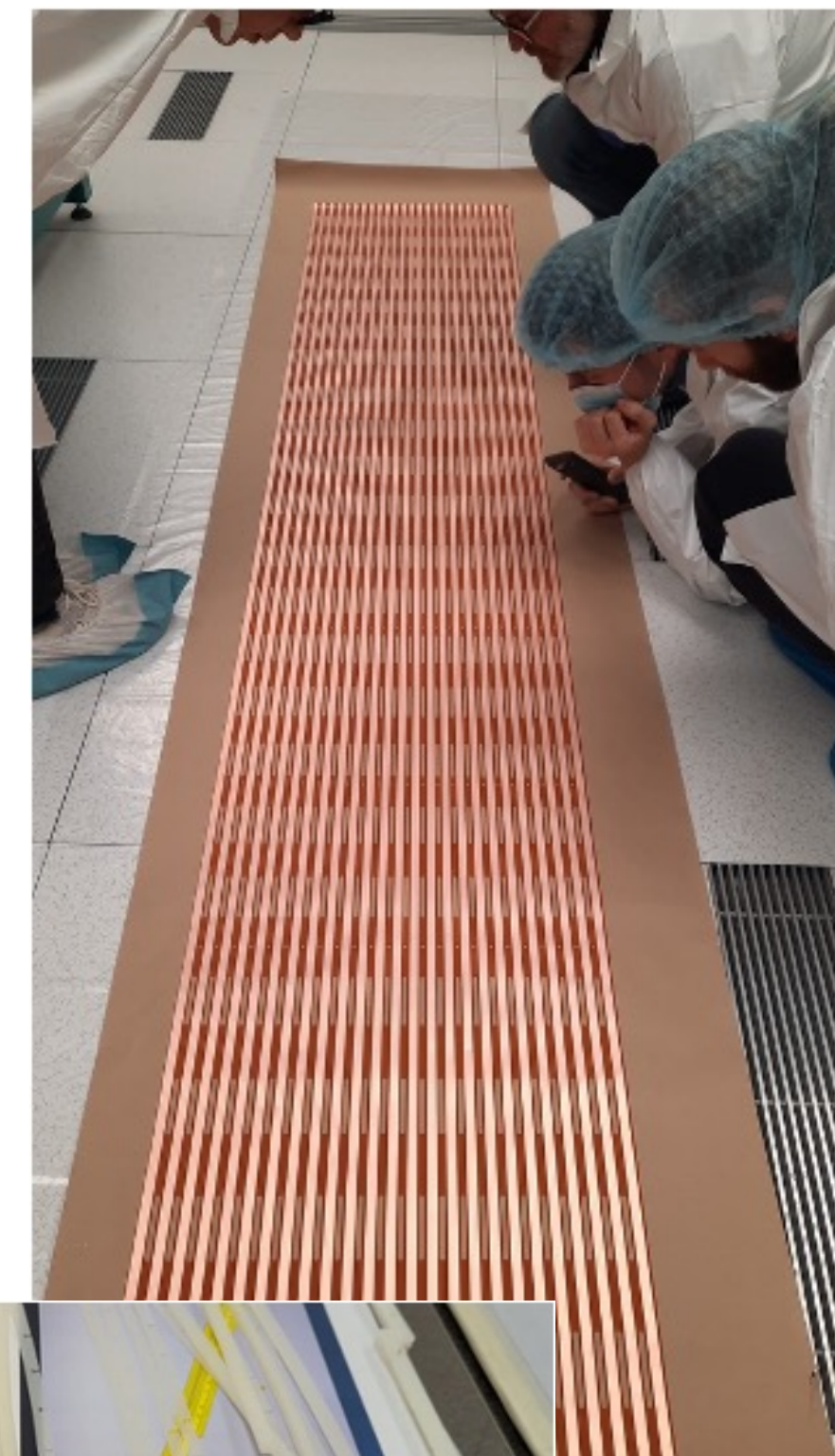
Status of the commissioning: the detector



GEM and field cage: copper clad kapton

V-bonded GEMs to remove reflections (also showing much less saturation!)

Inner frame of GEM stack in **Nylon 66** (radiopure + non-igroscopic)

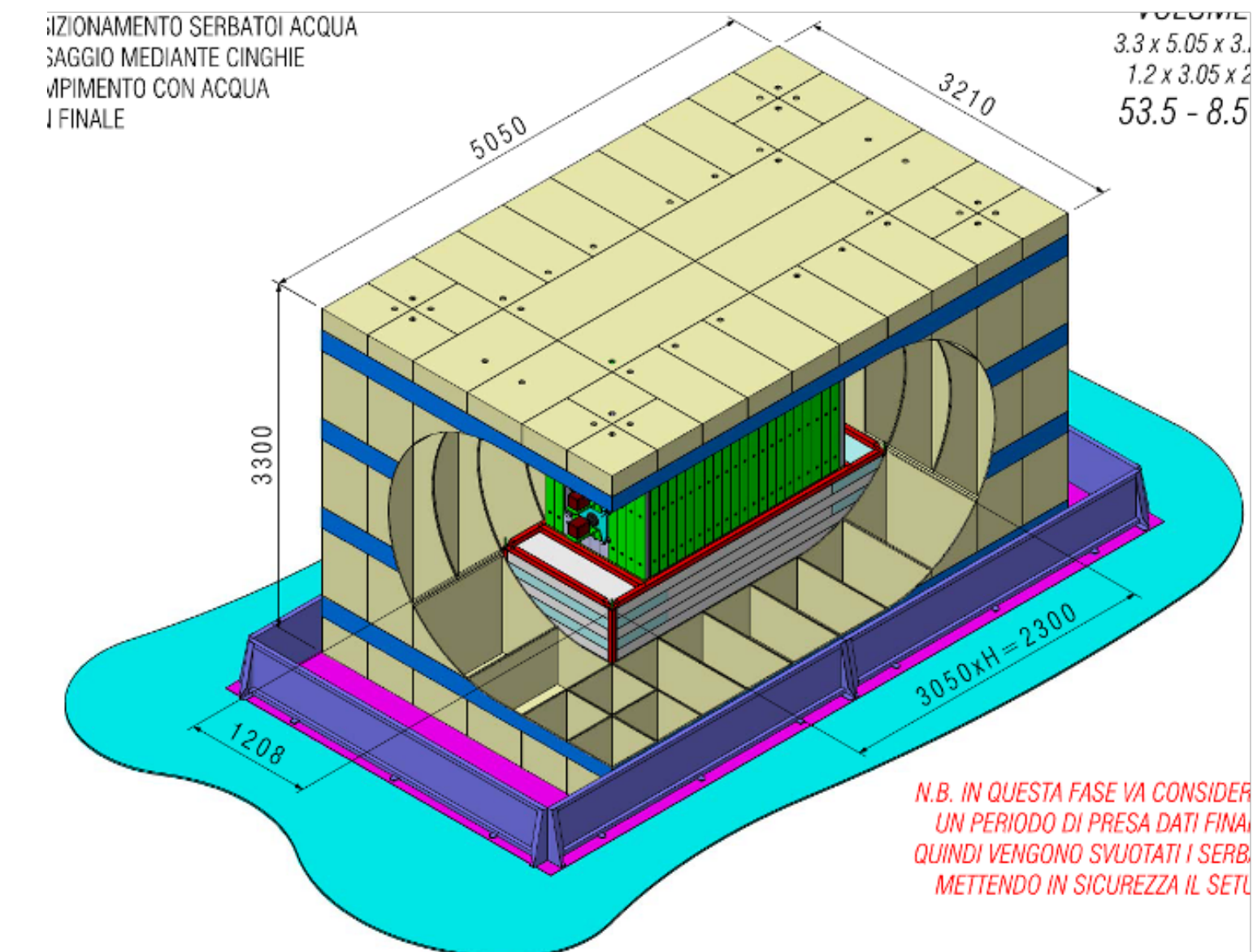
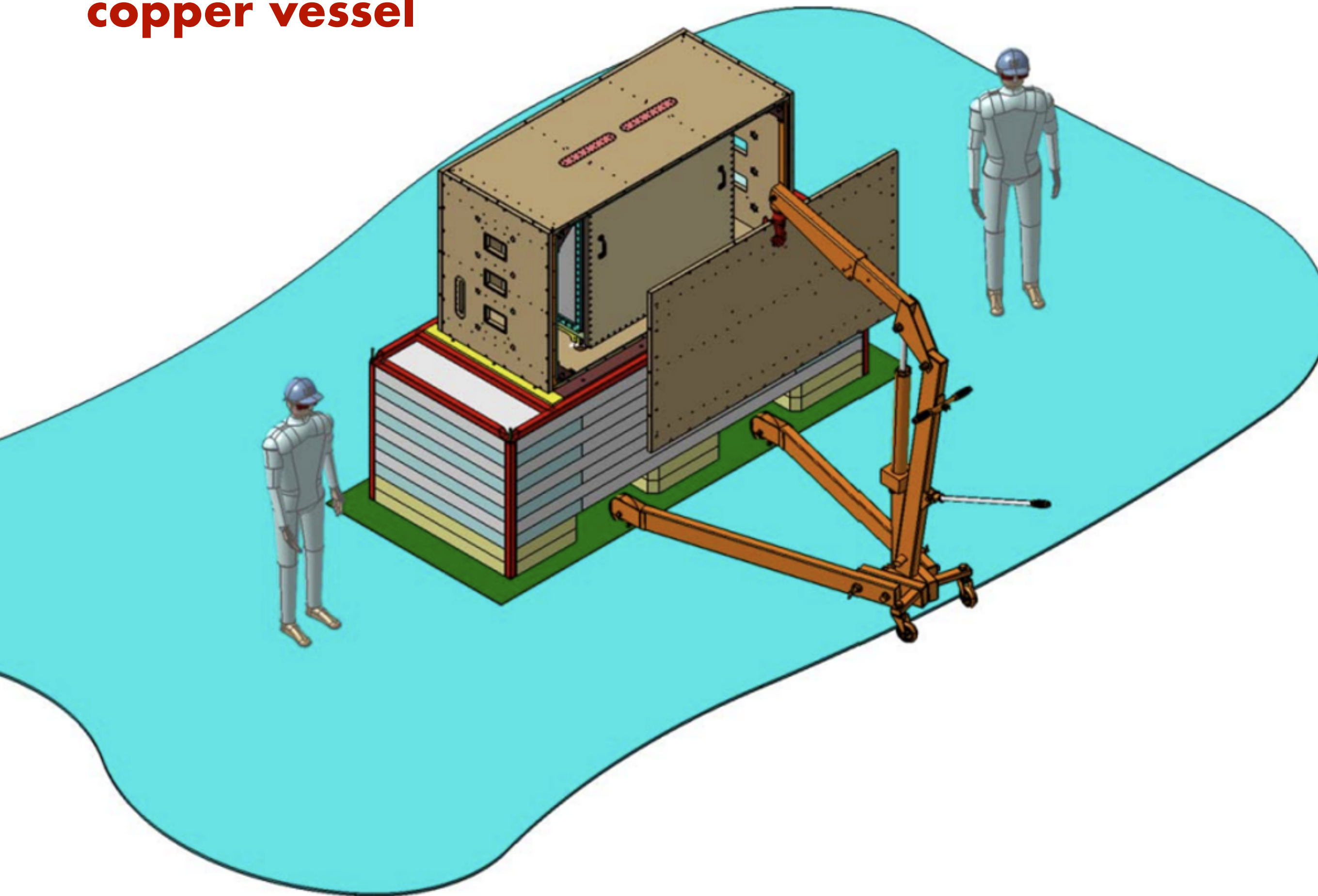


- **20mm PMMA gas-tight box** (6mm thick windows)
- **Detector structure** in **Nylon 66**

Status of the commissioning: infrastructure



The inner detector hosted in a gas and light tight **radiopure copper vessel**



Shielding:

- 36 mm of radiopure copper
- 60 mm of standard copper
- 90 cm of water in polyethylene tanks

Mitigation of external contaminants:

- Oxygen and humidity filters
- Nitrogen flushing in the copper box (300 L /h)
- (Radon filters)

Conclusions



- **CYGNO** is developing an **innovative gaseous TPC with optical readout** for directional Dark Matter searches and rare event searches
- The **underground operation of LIME** provided crucial experience on:
 - ➡ detector stability
 - ➡ background characterization and mitigation
 - ➡ reconstruction and ML-based analysis techniques
- The **detector commissioning of CYGNO-04 is progressing**, with detector components and services currently being installed and pre-tested
- CYGNO-04 will validate the **scalability** of the technology toward a future $\sim 30 \text{ m}^3$ experiment
- **Installation at LNGS** and beginning of the data taking are foreseen at the end of 2026/ start of 2027

Acknowledgements

This project has received fundings under the European Union's Horizon 2020 research and innovation programme from the Marie Skłodowska-Curie grant agreement No 657751 and from the European Research Council (ERC) grant agreement No 818744

CYGNO Project is funded by INFN.



Thanks for the attention!

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BACKUP

The **CXGNO** collaboration:

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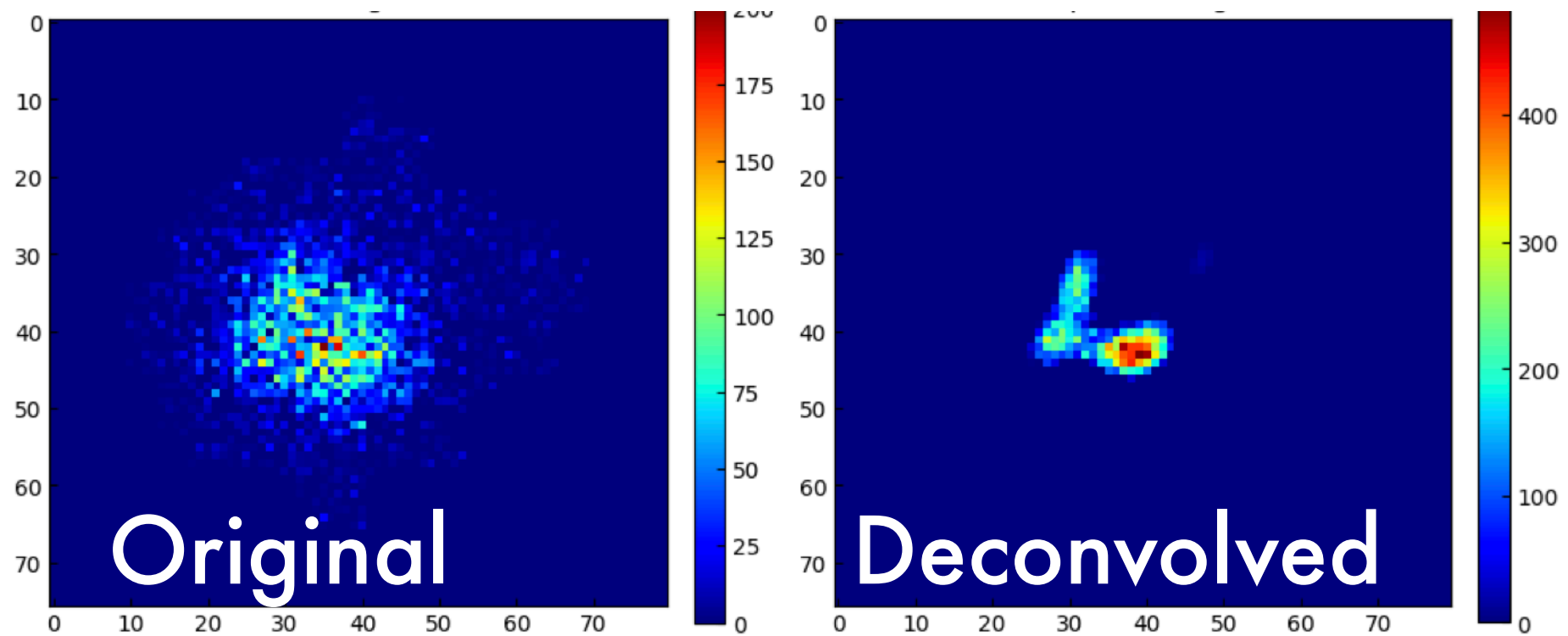
Istituto Nazionale di Fisica Nucleare

The LIME underground experience



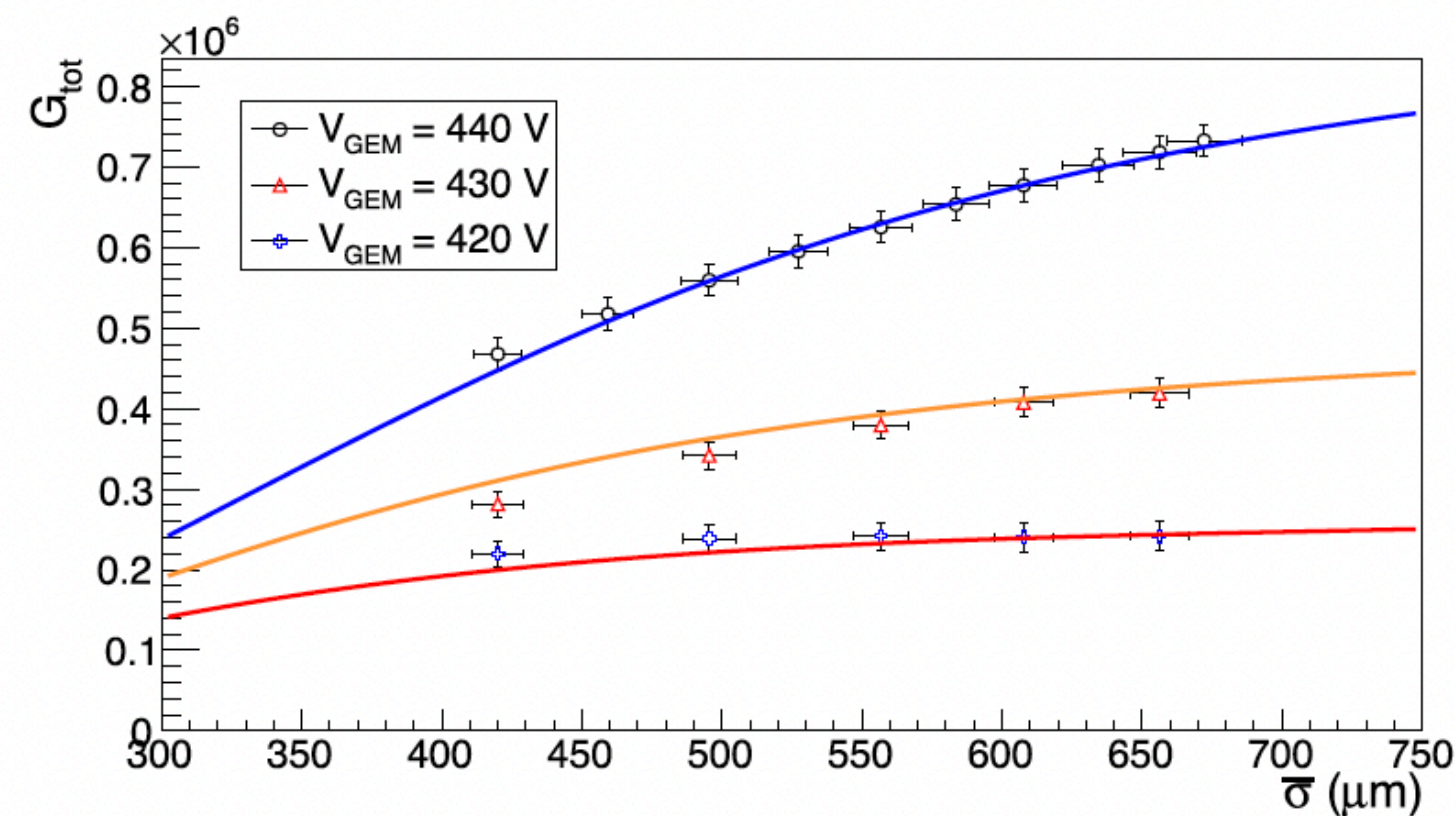
- (Not complete) snapshot of other analysis lines born and developed from LIME adventure:

Improved diffusion by deconvolution



See **Federico Scamporlino** poster: [Diffusion deconvolution method and fiducialization for the CYGNO experiment](#)

Study, modelization, and simulation of saturation of the GEM gain:

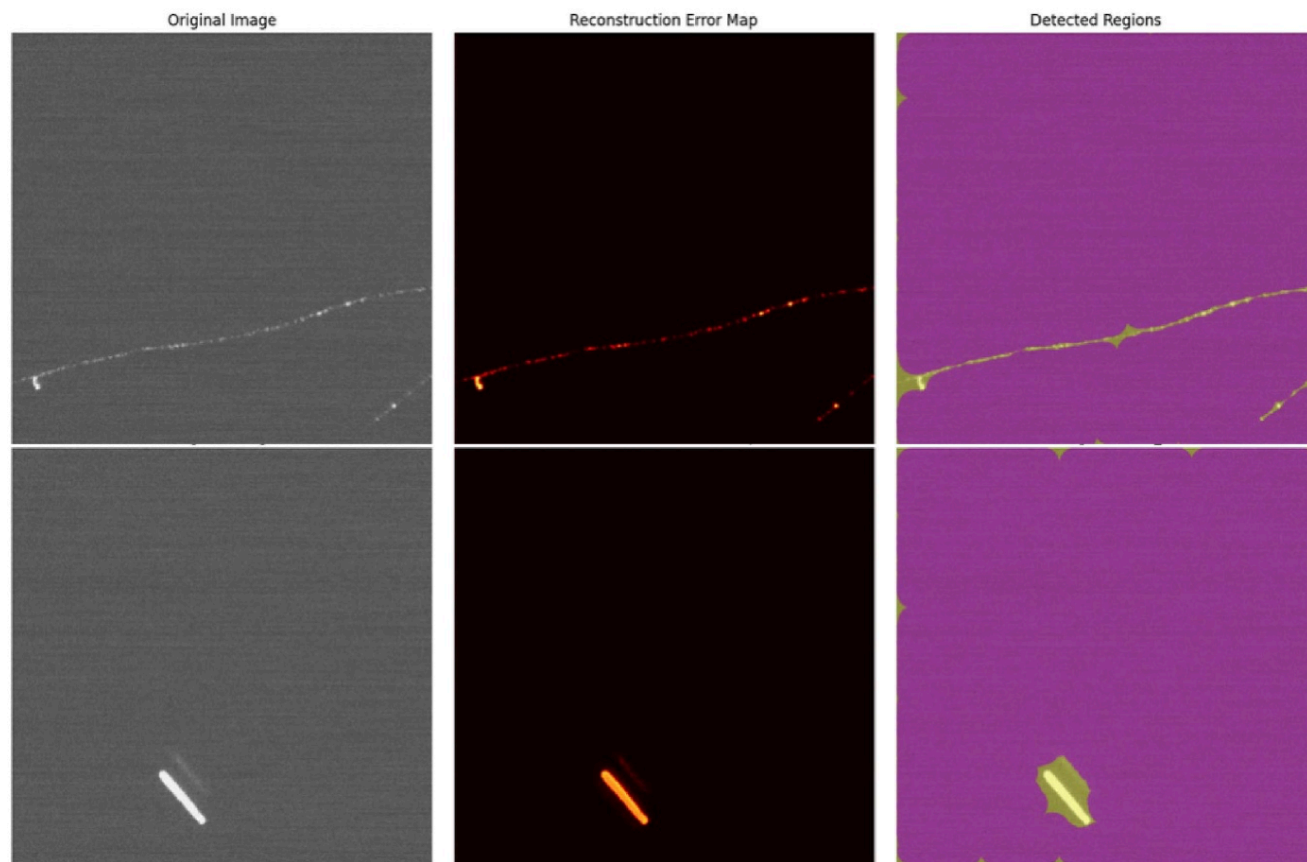


Published in [Eur.Phys.J.C 86 \(2026\) 2, 123](#)

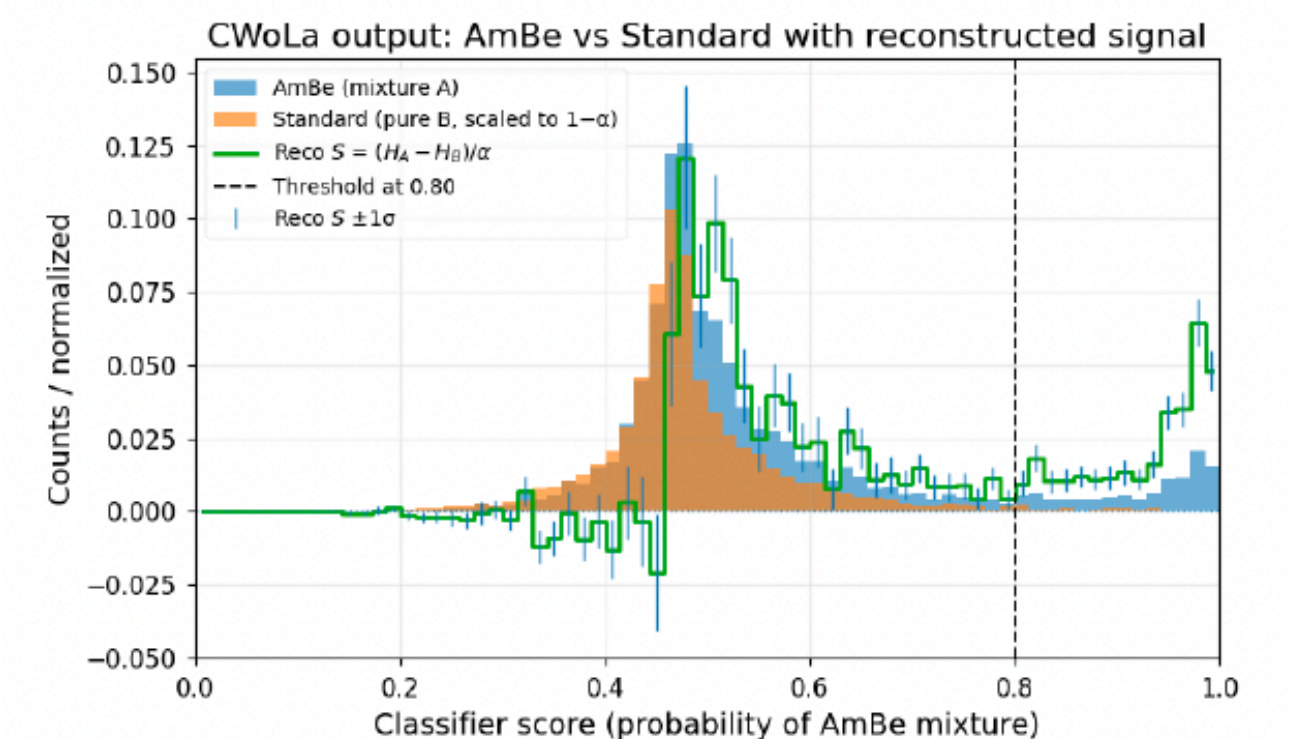
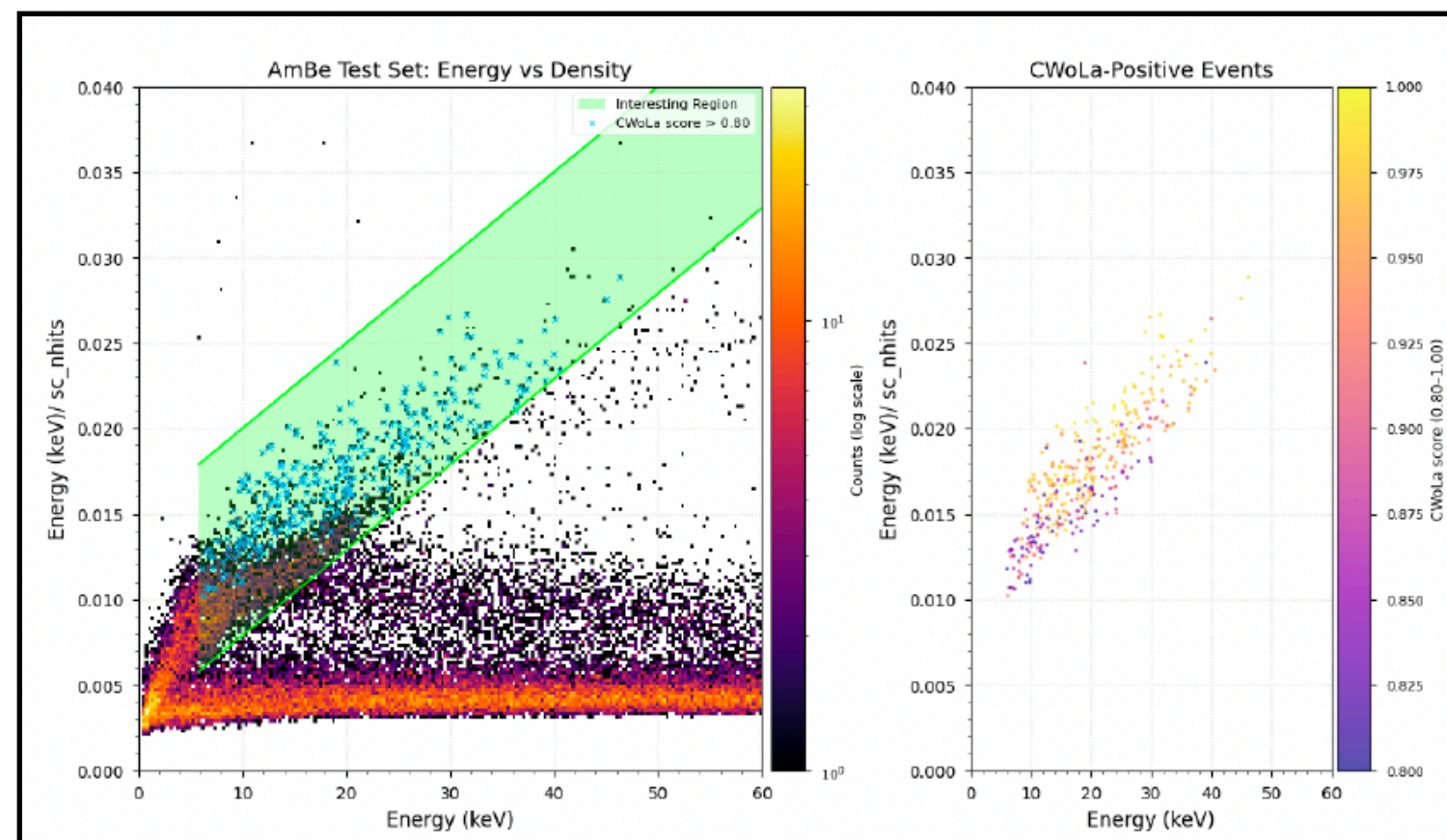
Modeling the light response of an optically readout GEM based TPC for the CYGNO experiment

Fernando Domingues Amaro¹, Rita Antonietti^{2,3}, Elisabetta Baracchini^{4,5}, Luigi Benussi⁶, Stefano Bianco⁶, Roberto Campagnola⁶, Cesidio Capocchia⁶, Michele Caponero^{6,9}, Gianluca Cavoto^{7,8}, Igor Abritta Costa⁶, Antonio Croce⁶, Emiliano Dan⁶, Melba D'Astolfo^{4,5}, Giorgio Dho⁶, Flaminia Di Giambattista^{4,5}, Emanuele Di Marco⁷, Giulia D'Imperio⁷, Joaquim Marques Ferreira dos Santos¹, Davide Fiorina^{4,5}, Francesco Iacoangeli⁷, Zahoor Ul Islam^{4,5}, Herman Pessoa Lima^{4,5}, Ernesto Kemp¹⁰, Francesca Lewis⁸, Giovanni Maccarrone⁶, Rui Daniel Passos Mano¹, Robert Renz Marcelo Gregorio¹¹, David José Gaspar Marques^{4,5}

Fast noise suppression with ML:



Background rejection with ML using CWOLA:



Published in [Mach.Learn.Sci.Tech. 7 \(2026\) 2, 025058](#)