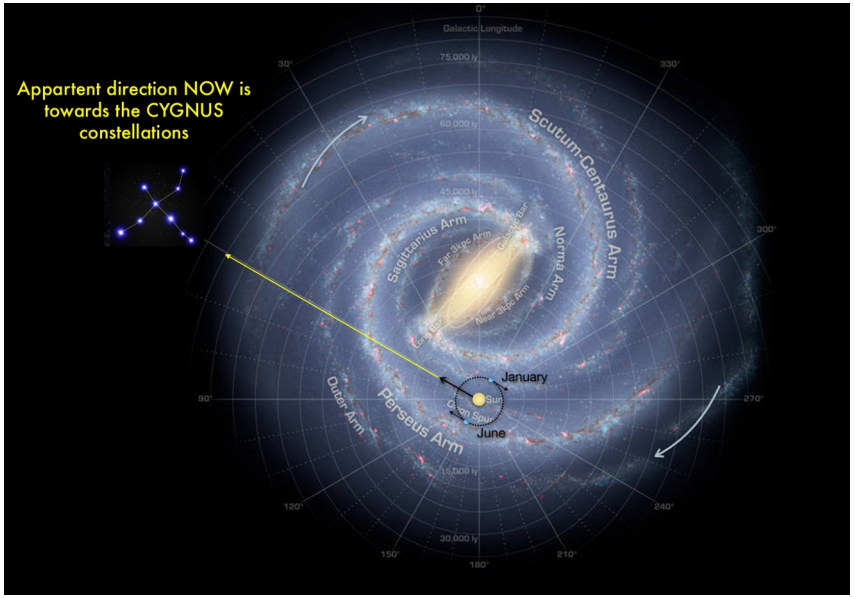
The LIME detector prototype for the CYGNO experiment

F.Di Giambattista on behalf of the CYGNO Collaboration:
F.D.Amaro, E.Baracchini, L.Benussi, S.Bianco, C.Capoccia, M.Caponero, D.S.Cardoso, G.Cavoto, A.Cortez, I.A.Costa, R.J.d.C.Roque, E.Dané, G.Dho, F.Di Giambattista, E.Di Marco, G.Grilli di Cortona, G.D'Imperio, F.Iacoangeli, H.P.Lima Júnior, G.S.Pinheiro Lopes, A.d.S.Lopes Júnior, G.Maccarrone, R.D.P.Mano, M.Marafini, R.R.Marcelo Gregorio, D.J.G.Marques, G.Mazzitelli, A.G.McLean, A.Messina, C.M.Bernardes Monteiro, R.A.Nobrega, I.F.Pains, E.Paoletti, L.Passamonti, S.Pelosi, F.Petrucci, S.Piacentini, D.Piccolo, D.Pierluigi, D.Pinci, A.Prajapati, F.Renga, F.Rosatelli, A.Russo, J.M.F.dos Santos, G.Saviano, N.J.C.Spooner, R.Tesauro, S.Tomassini, S.Torelli

26 September 2023, Siena, IPRD23

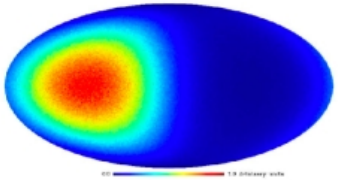
Directional rare events search



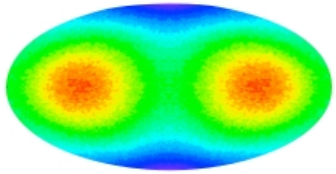
A. M. Green et. al, Astropart. Phys. 27 (2007) 142

C. O'Hare et al, Phys. Rev. D 92 063518 (2015)

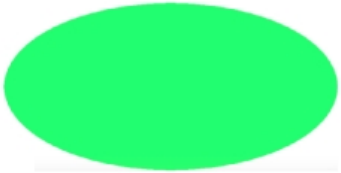
Nuclear recoil map (**direction+head-tail**)

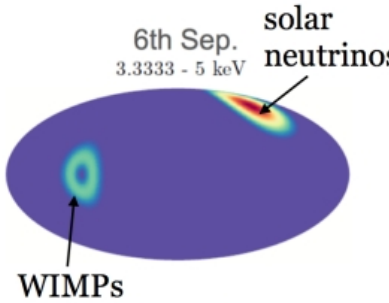


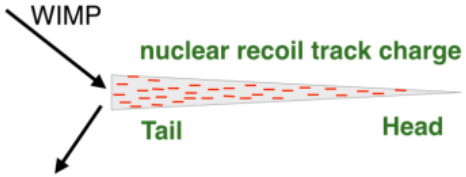
Nuclear recoil map (**only direction**)



Background (**isotropic**)



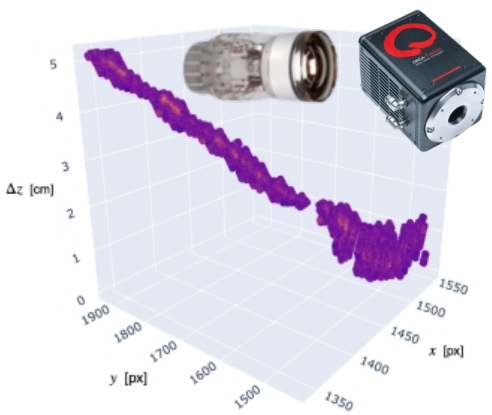


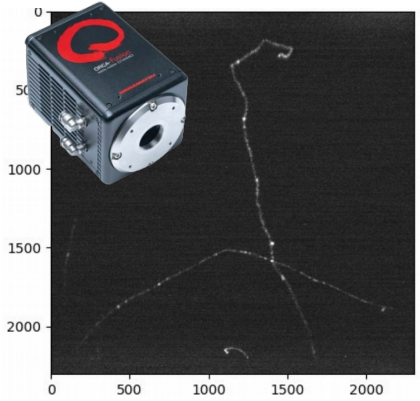


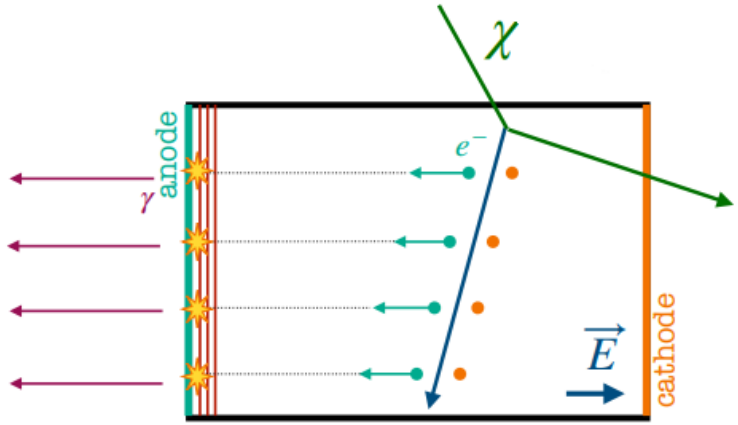
NR (partially) retain the direction

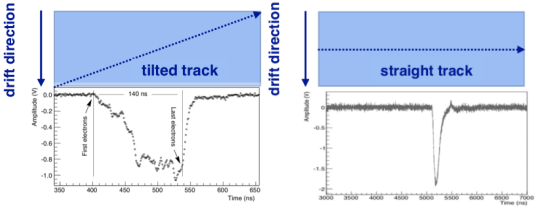
Dark Matter and solar neutrinos carry a **directional** information, and the two signals never overlap (and they are not mimicked by any background)

Gaseous TPC with optical readout

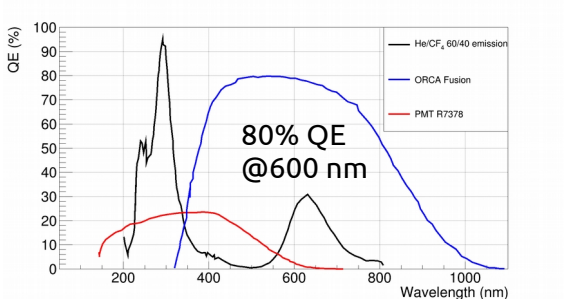








PMTs:
Energy, **z** component of track from time structure of signal

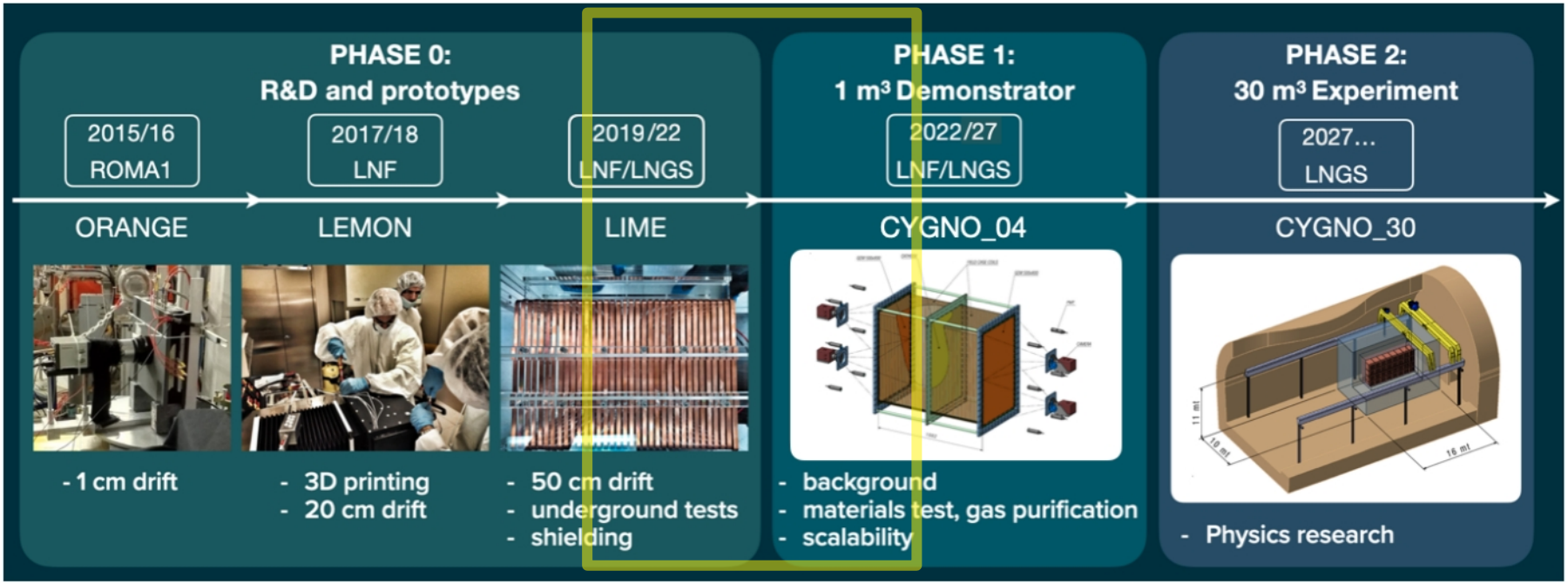


sCMOS camera:
Energy, **xy** track projection

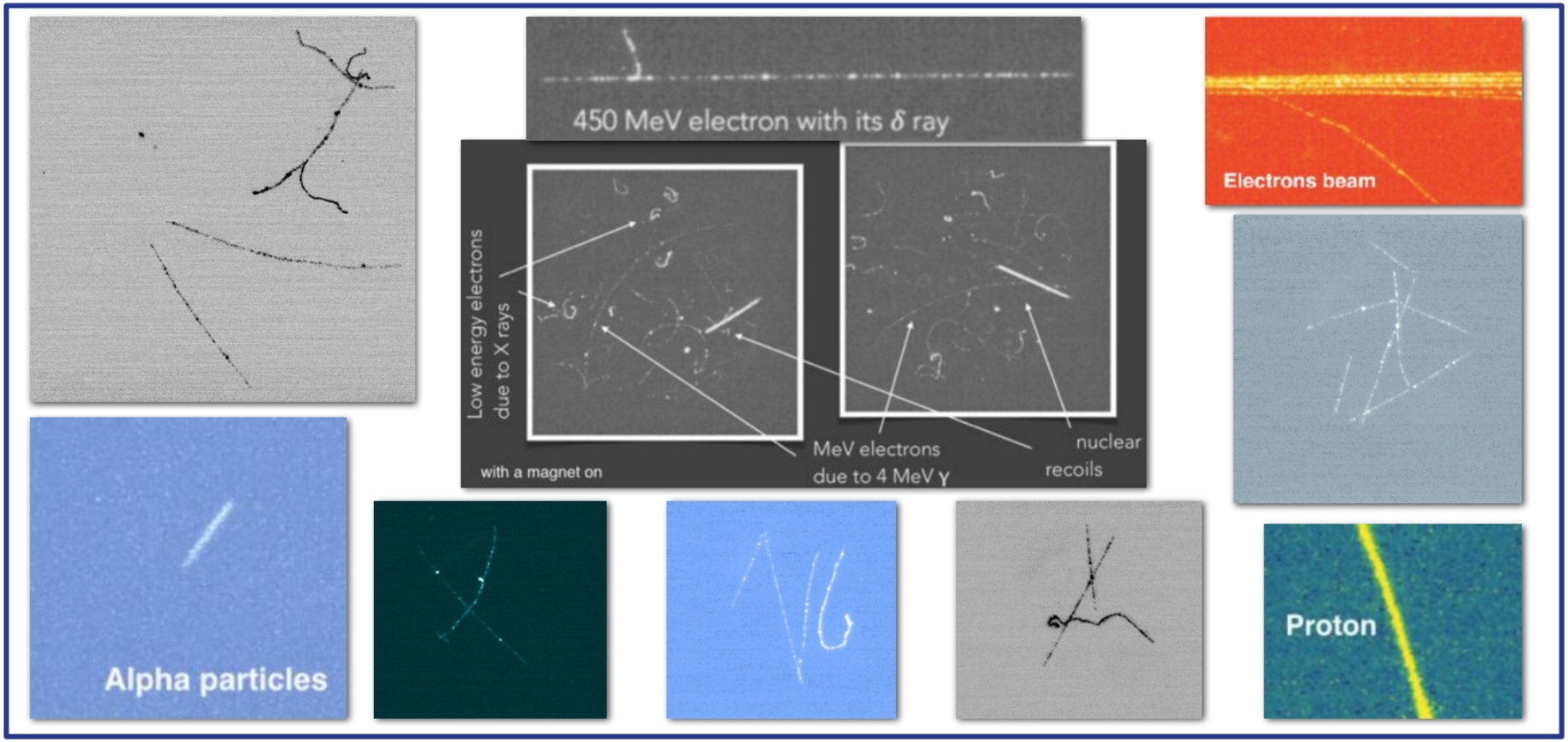
- He:CF_4 (60:40) at **atmospheric pressure**, GEM amplification, **optical readout** (sCMOS+PMT)
  - With suitable lenses we can **image large areas** O(1 m^2) with single sensor, with effective pixel area O(100 µm)
- **3D reconstruction** capability: directionality, particle ID, background rejection, fiducialization
- **Low threshold** (< 1 keV)

The CYGNO experiment

Instruments 2022, 6(1), 6

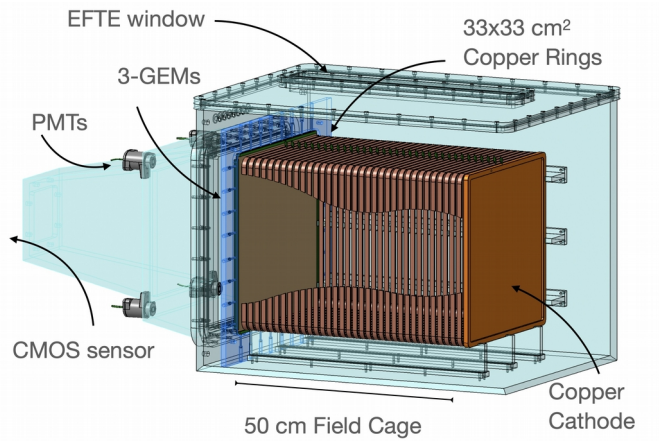


Some images from the sCMOS



LIME: the Long Imaging Module

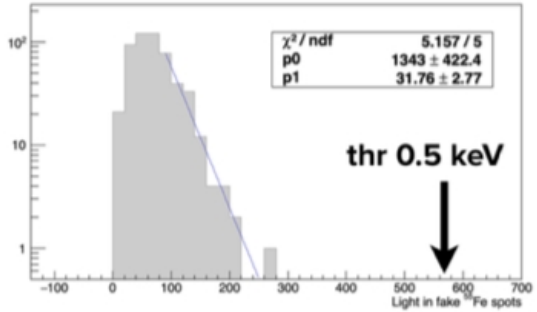
- Our **largest** prototype: 50L sensitive volume
  - 33×33 cm² thin (50 μm) triple GEMs, 50 cm drift
- Optical readout:
  - **4 PMTs** at the corners (Hamamatsu R7378)
  - **1 sCMOS camera** (Hamamatsu ORCA Fusion)
    - 2304×2304 pixels, low noise (1 ph/pixel), high granularity 150×150 μm², 2 counts/photon



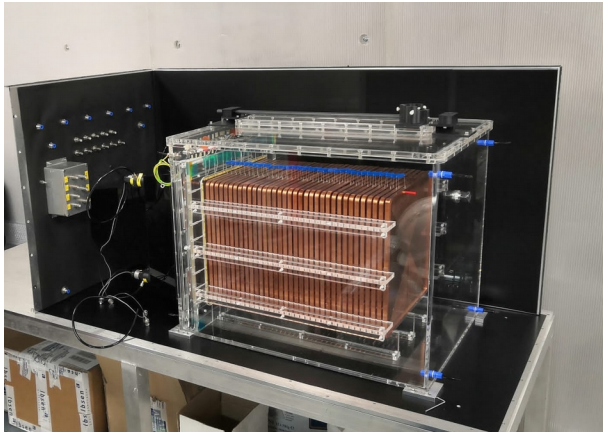
ORCA-Fusion

Energy threshold

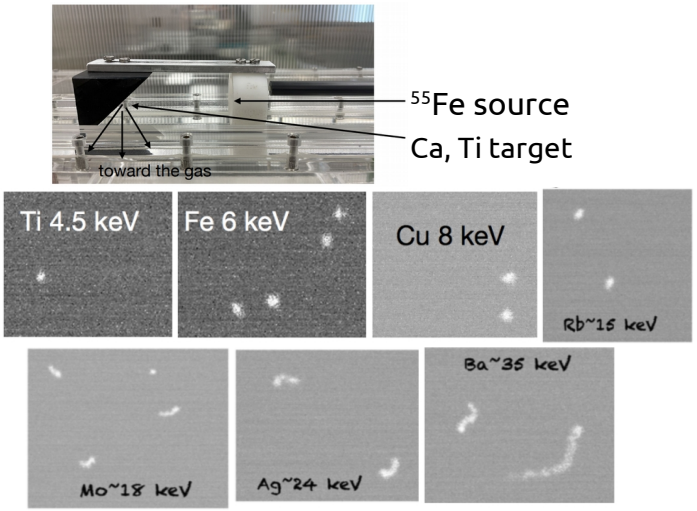
<10 fake events/year (tested with ^{55}Fe)

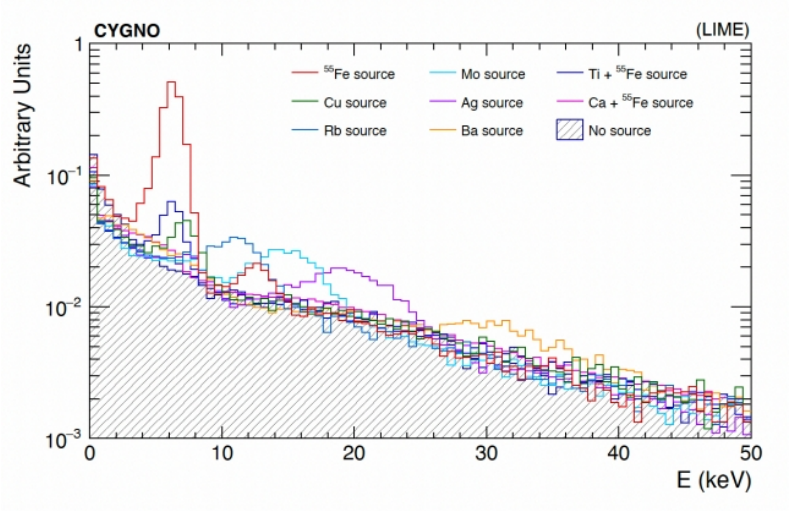


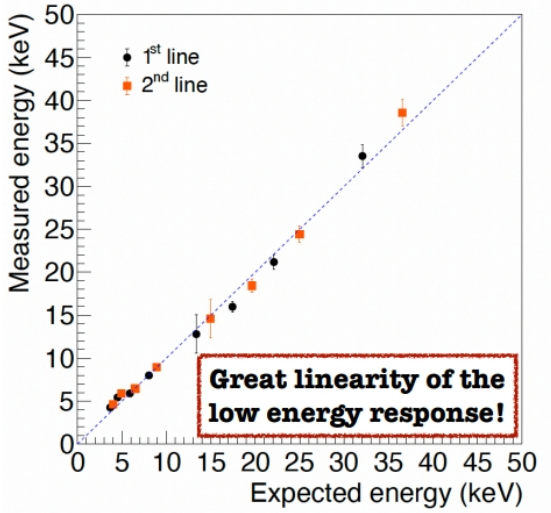
1200 counts = 1 keV



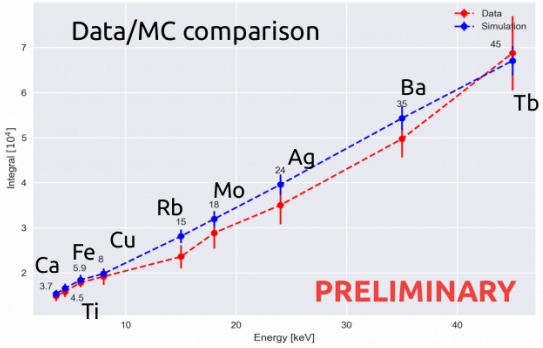
LIME response studies at LNF-INFN







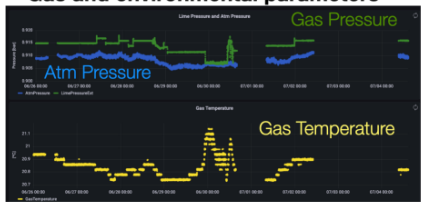
- LIME was tested overground at National Laboratories of Frascati (INFN) with multiple **X-rays** source
- **Linear energy response** was found between 3.7 keV and 35 keV
- 100% reconstruction* efficiency at 5.9 keV in the whole volume
- **Energy resolution 14%** at 5.9 keV in the whole volume



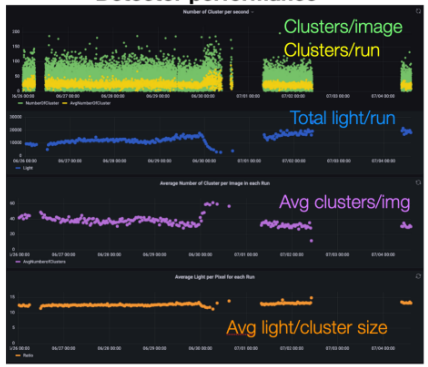
*E. Baracchini *et al.*, JINST 15 no.12, T12003 (2020)

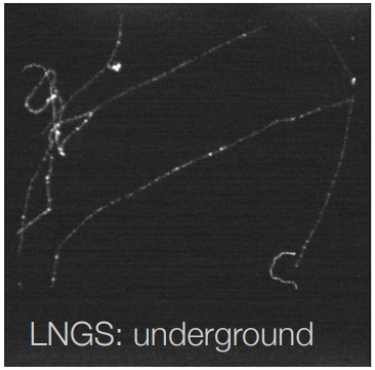
LIME underground at LNGS-INFN

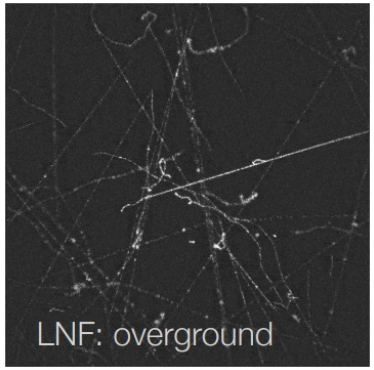
Gas and environmental parameters

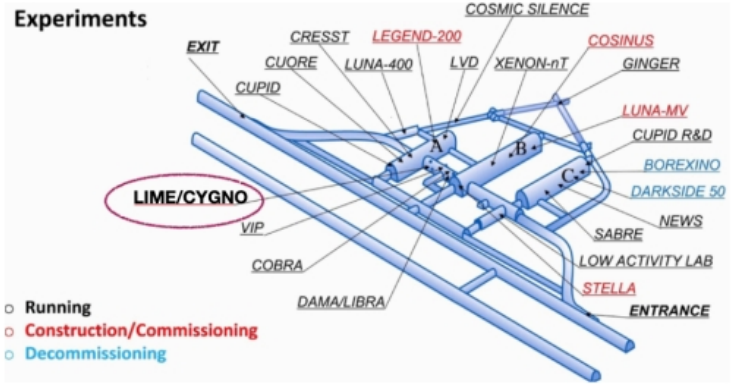


Detector performance









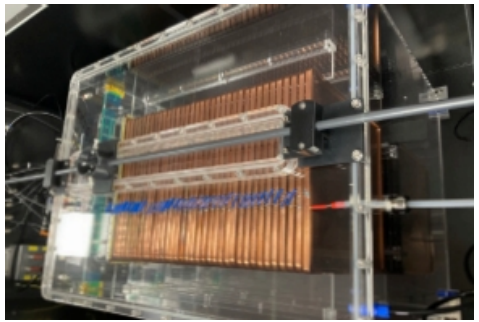
Data taking @LNGS

Run1

No shielding

Oct 8 – Dec 6, 2022

- ~4x10^5 background pictures
- ~33 h camera exposure
- Event rate ~35Hz



Run2

4cm Cu shielding

Feb 15 – Mar 9, 2023

- ~4.5x10^5 background pictures
- ~38 h camera exposure
- Event rate ~3.5Hz

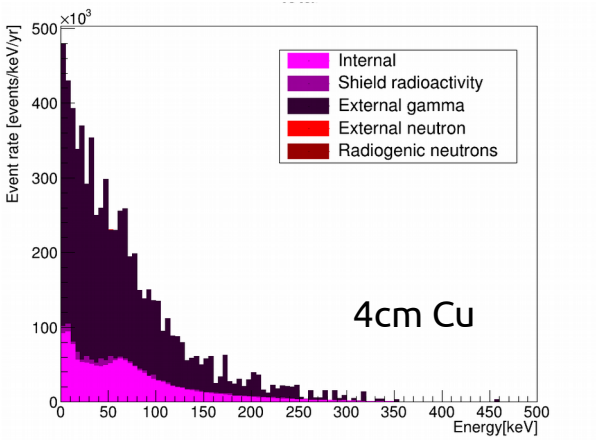
Run3

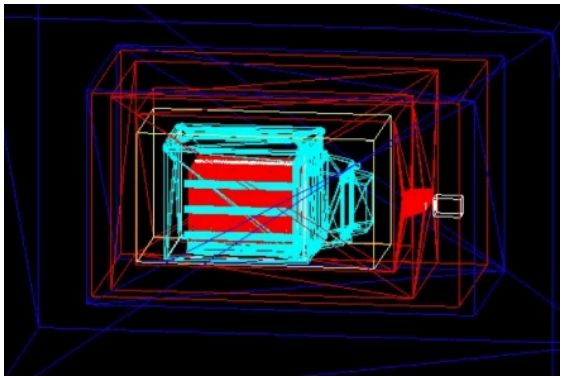
10cm Cu shielding

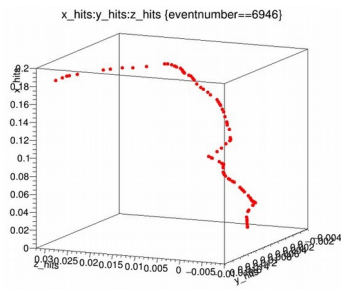
May 13 – ongoing, 2023

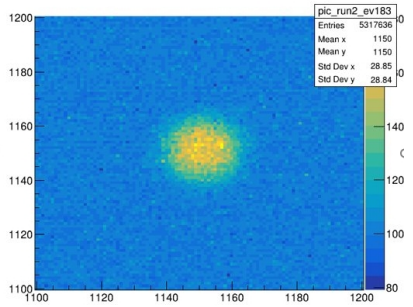
- ~6x10^5 background pictures
- ~17 h camera exposure
- Event rate ~1.5Hz
- Ambe: ~2x10^5 pictures

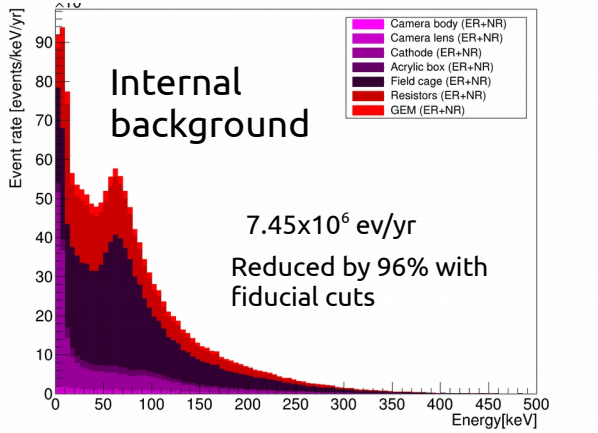
Background simulation







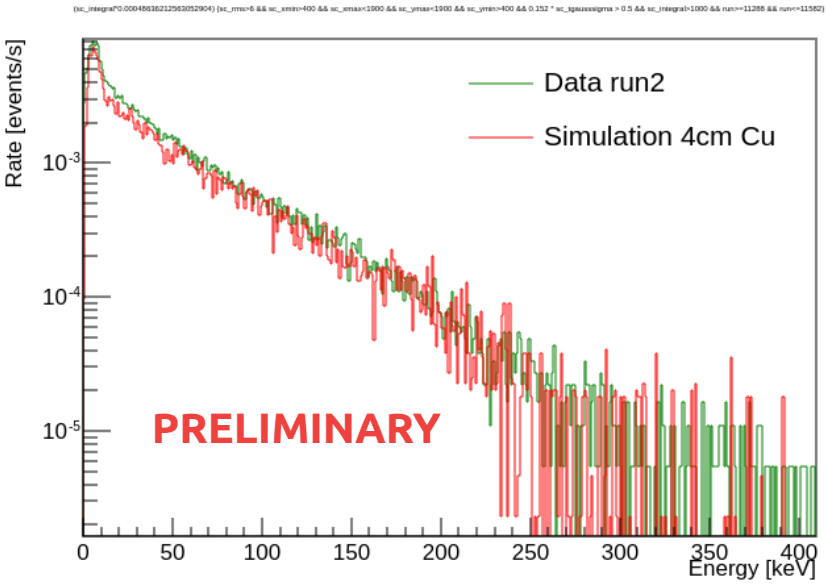


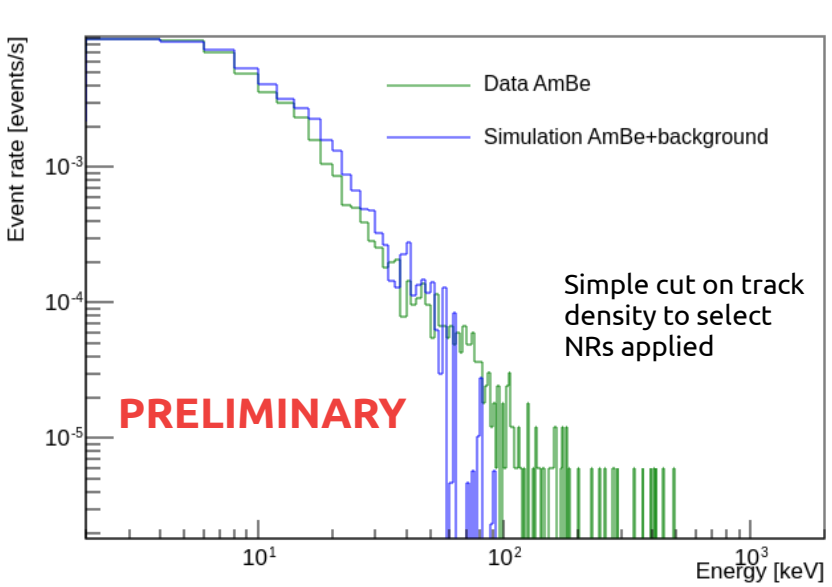


- GEANT4 simulation of detector geometry for different data taking configurations (run1,run2,run3 and AmBe)
- Main sources:
  - Environmental **gammas** (flux measured with NaI)
  - **Radioactivity** of materials (GEMs, acrylic vessel, copper rings, resistors and camera (sensor and lens) were measured underground)
- From simulated 3D energy deposit we generate **sCMOS images** to compare with data – including charge amplification, light yield, diffusion of electrons, sensor noise, and other effects of the detector

Data/MC comparison

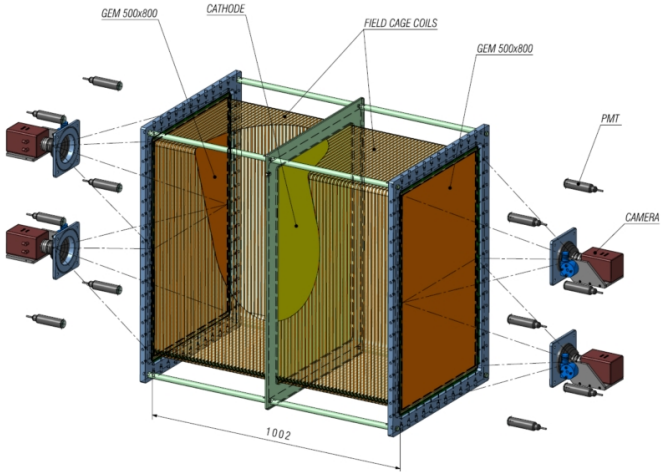
- Data are corrected for the **dead time**
- Quality cuts and **fiducial cuts** in x-y plane are applied to exclude **fake events** from sensor noise





Analysis of Run3 (10cm copper shielding) is ongoing (and we are still taking data!)

PHASE 1: CYGNO_04

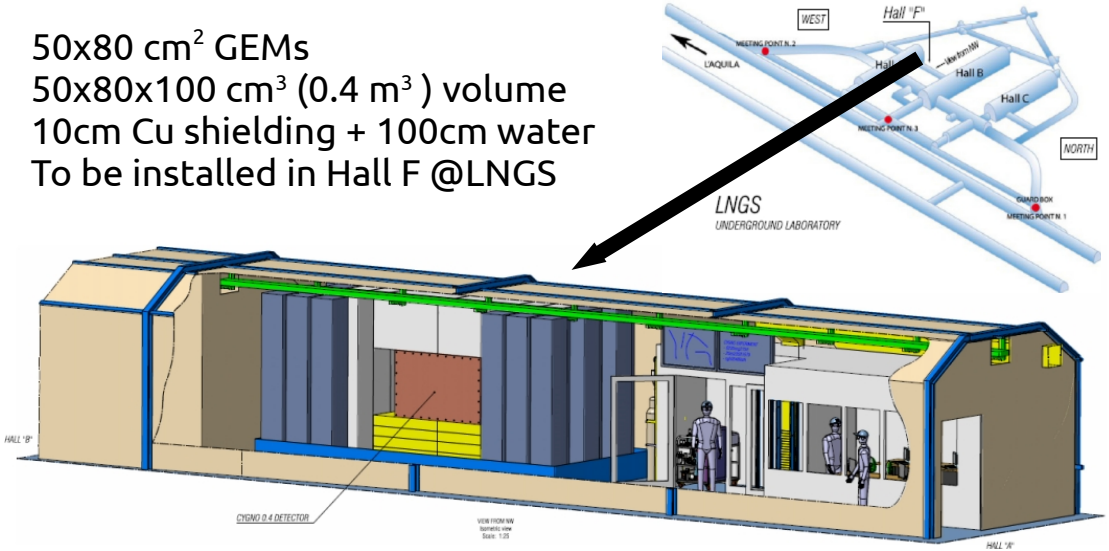


Next phase will show achievability of CYGNO_30 physics performances

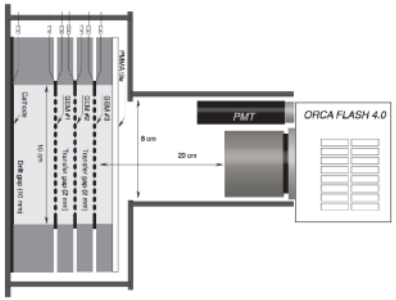
- Study and minimize radioactivity
  - Already developing a **custom lens** with LOBRE s.r.l. with **low radioactivity** materials (Suprasil, PMMA, polycarbonate)
- Develop **modular** readout and DAQ
  - To test **scalability** to m^3 volumes

Multiple sensors acquisition:
4 qCMOS cameras (Hamamatsu ORCA Quest)
+ 12 PMTs

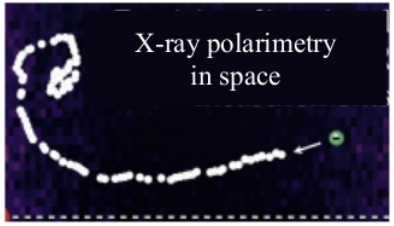
- 50x80 cm^2 GEMs
- 50x80x100 cm^3 (0.4 m^3) volume
- 10cm Cu shielding + 100cm water
- To be installed in Hall F @LNGS



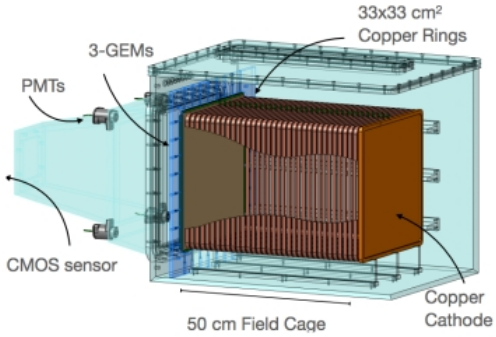
Beyond Dark Matter



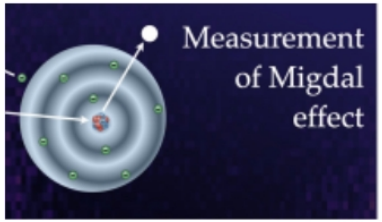
Small O(1L)



Funded!
"HypeX: High Yield Polarimetry Experiment in X-rays"
(PRIN 2020 Prot. 2020MZ884C)

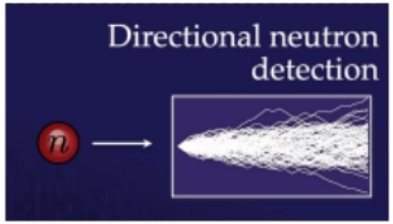


Medium O(50L)

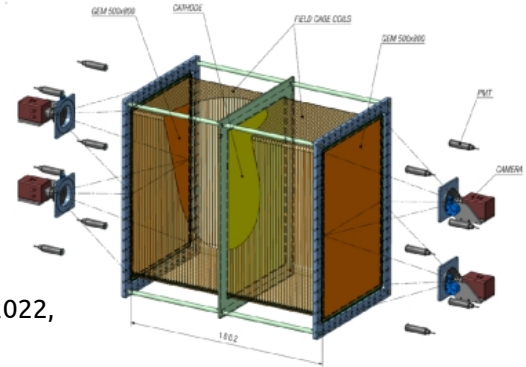


Funded!
"FINEM: Full Imaging of Nuclear recoils for Experimental Migdal measurement"
(FARE 2020 Prot. R208LP3A4C)

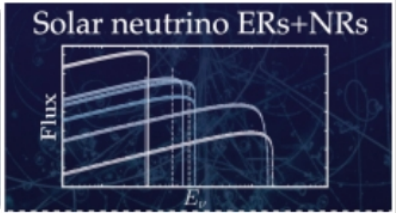
Funded!
"Zero Radioactivity for Future Experiments"
(PRIN 2017 Prot. 2017T54J9J)

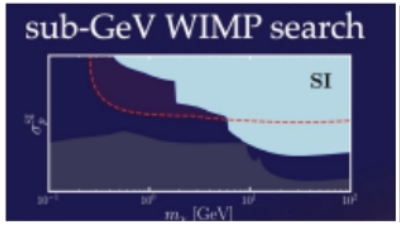


"The CYGNO experiment", Instruments 2022, 6(1), 6



Large O(30-1000 m^3)





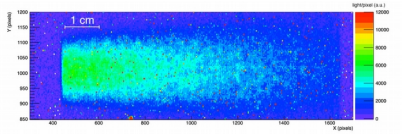
C. A. J. O'Hare et al., 2022 Snowmass Summer Study, arXiv:2203.05914
S.E.Vahsen et al., arXiv:2008.12587

R&D activities

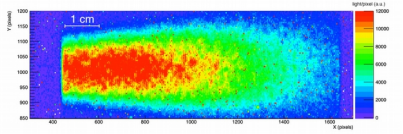
Enhanced light yield

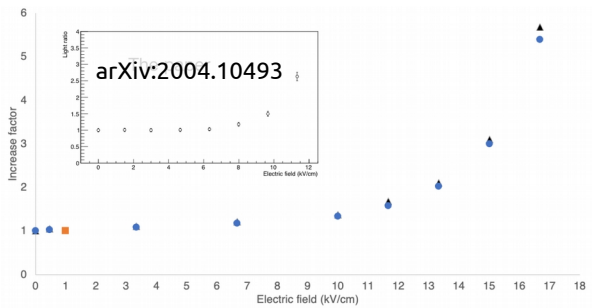
- Strong electric field after GEMs
- Enhanced LY (x7 light, x1.7 charge)

0 kV/cm



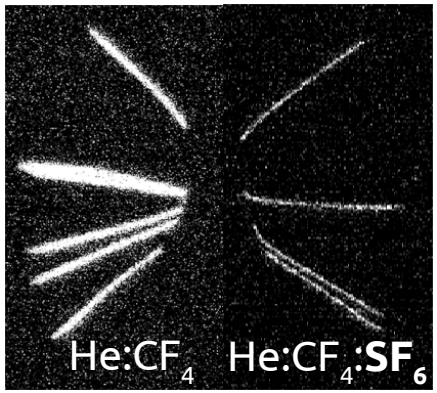
11.3 kV/cm





Negative ion drift

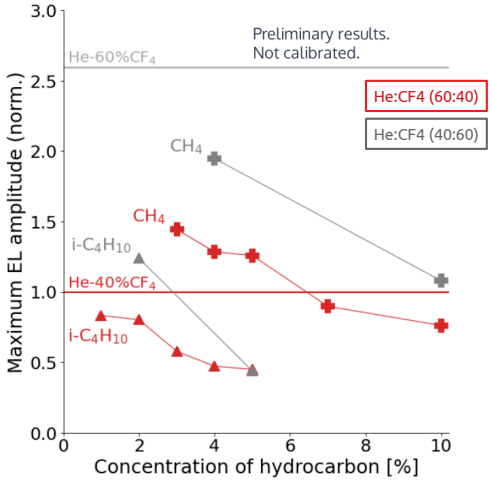
- Electronegative dopants to reduce diffusion
- Improved **spatial resolution**
- **Absolute z position** from drift time of different species
- Good results at **atmospheric pressure**



E. Baracchini et al., 2018, JINST 13 P04022

Hydrocarbons

- Adding hydrocarbons (isobutane and methane tested) to enhance sensitivity to low mass DM and improve LY



Conclusions

- The CYGNO collaboration is developing a **high-precision gaseous TPC at atmospheric pressure with optical readout,** 50L volume **LIME** detector is taking data in underground LNGS laboratories
- **Analysis of underground data** is ongoing, with promising results from background and AmBe measurements
- Design of **next phase** CYGNO_04 is ongoing, already funded and with a TDR submitted
- Several **R&D projects** are ongoing in order to find optimal means of TPC operation
- *What is next:*
  - Spectral (and directional) **neutron flux** measurement underground at LNGS
  - Water shielding installation and final test of LIME operation

Thank you for your attention!