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LIME: a gaseous TPC with optical readout

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CYGNO Experiment

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

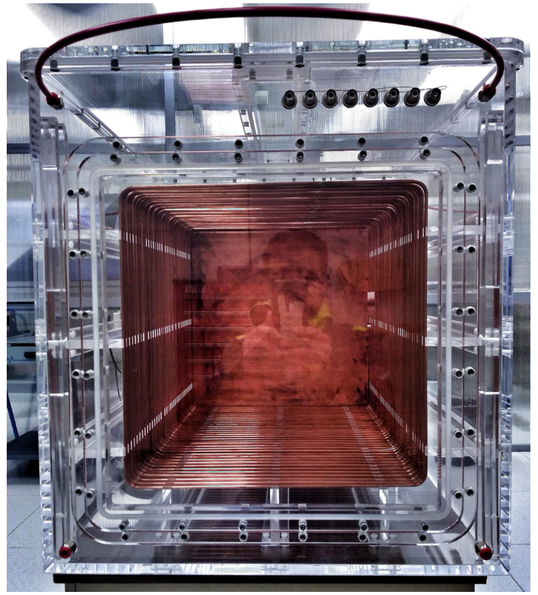
Istituto Nazionale di Fisica Nucleare

Introduction

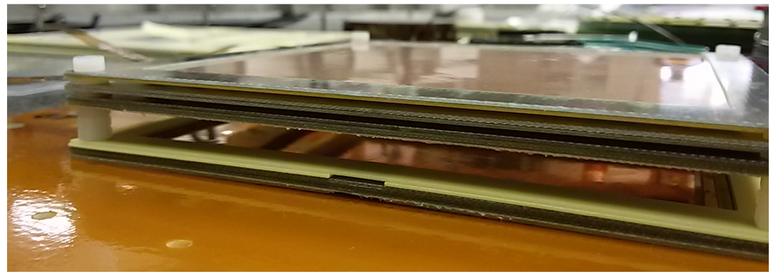
- In this contribution we present **LIME**, the latest 50 L prototype of the CYGNO project.
- The CYGNO experimental approach is based on a **gaseous** Time Projection Chamber (**TPC**) **with optical readout**.
- The **goal** of the collaboration is to contribute to the **direct search** for **dark matter** candidates with a detector with **directional capabilities**
- **LIME** has been **recently** installed **underground** at the Laboratori Nazionali del Gran Sasso (**LNGS**):
  - to assess the **performance** of the CYGNO experimental approach in a low background environment
  - to validate the **background model**, measure the **neutron flux** and determine the best **shielding configuration**

The CYGNO project

- **Aiming at** a large detector for high precision **3D tracking of rare low energy nuclear recoils (keV)** as for example WIMPs.
- **Experimental challenges:** rate O(evt/kg/day), background rejection, and energy threshold (keV)
- **Strategy:** **photograph nuclear recoils** in a (1 atm) He:CF_4 TPC with a GEM amplification stage
  - low energy events in 1 atm gas ⇒ visible tracks
  - Access to position, direction, total released energy, dE/dx (head/tail), PID
  - **optical sensors:** high granularity, very low noise, and high sensitivity
  - **optical coupling:** sensors outside the sensitive volume, acquire large surfaces with small sensors



TPC of the LIME prototype @ LNF

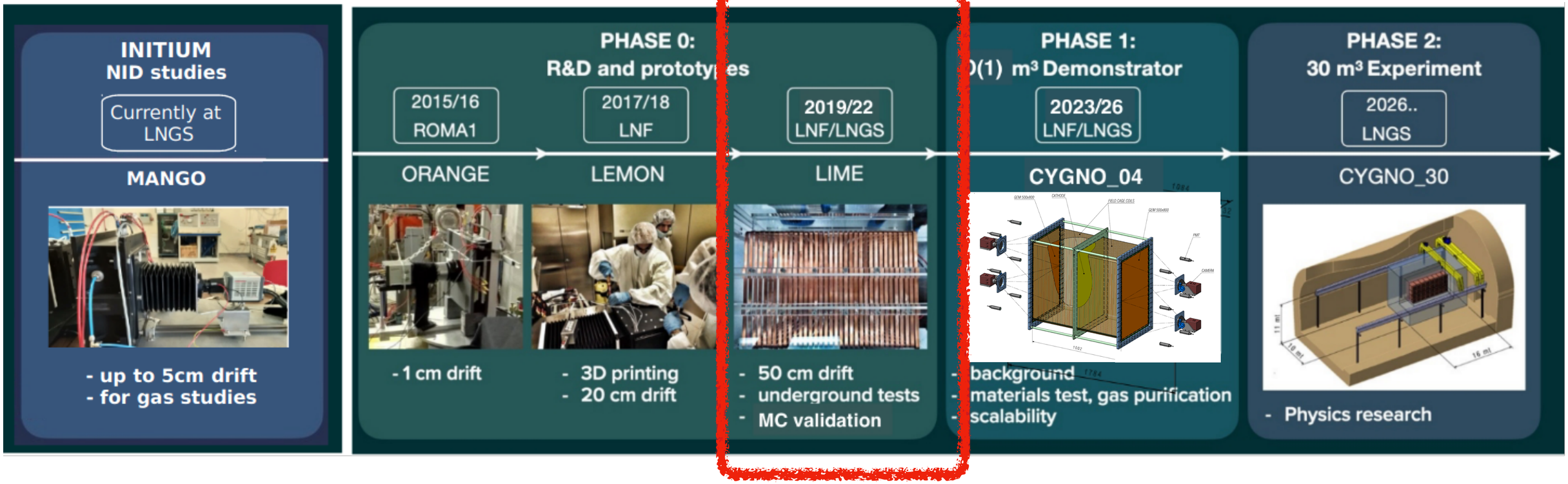


Amplification with GEMS

sCMOS camera [Hamamatsu Orca-Fusion]

4 PMTs [Hamamatsu R7378]

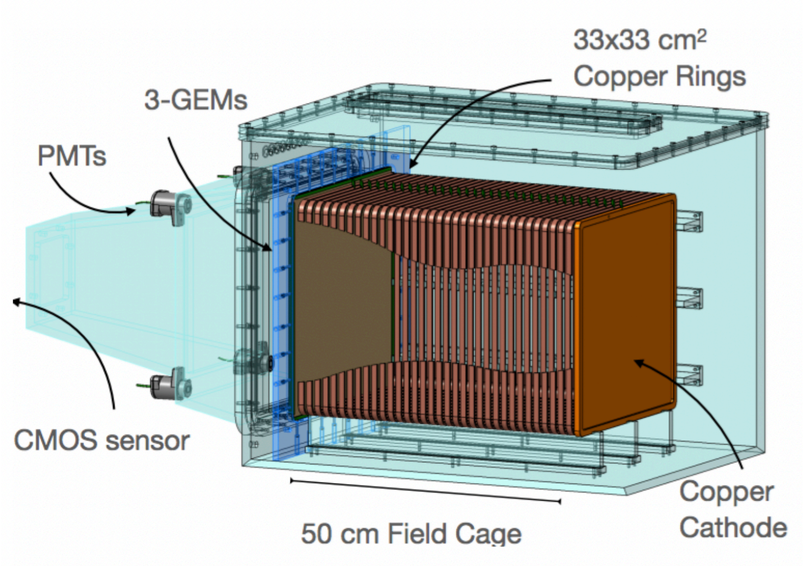
The CYGNO timeline

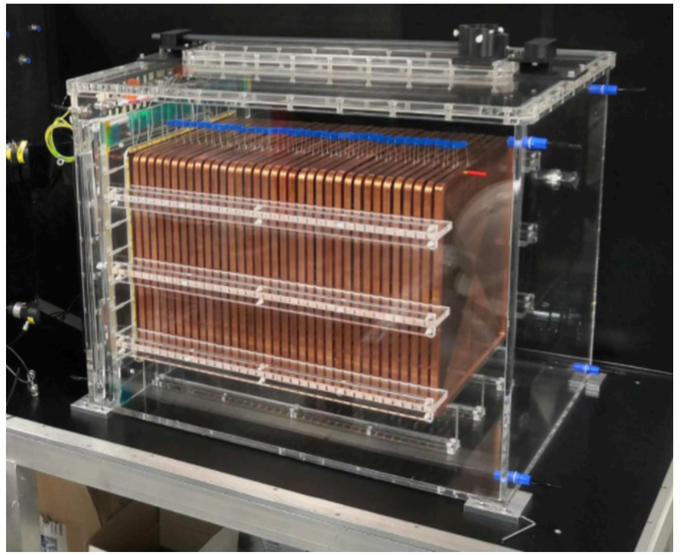


Instruments 6 (2022) 1, 6
JINST 15 (2020) 12, T12003
JINST 15 (2020) P08018
Measur.Sci.Tech. 32 (2021) 2, 025902

JINST 15 (2020) P10001
2019 JINST 14 P07011
NIM A 999 (2021) 165209

CYGNO PHASE 0: the LIME prototype





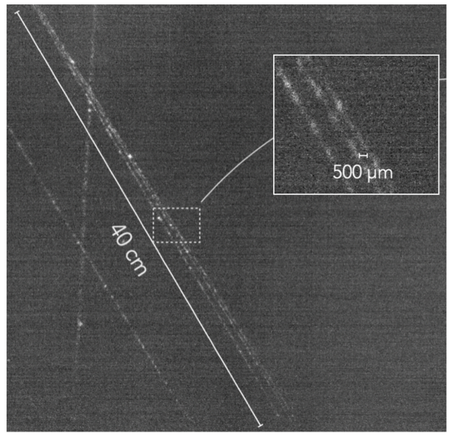
ORCA-Fusion

HIGH RESOLUTION
2304 × 2304
5.3 Megapixels

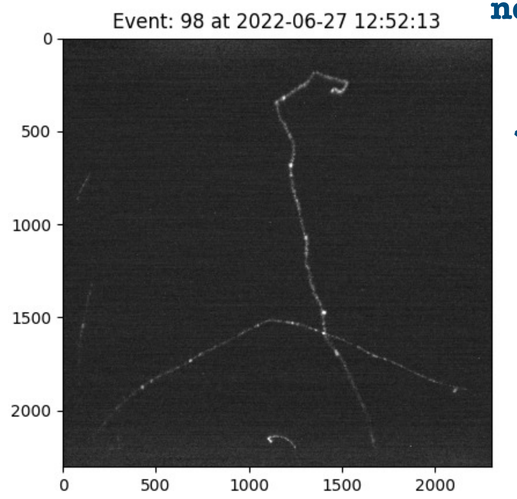
READOUT NOISE
0.7 electrons rms
Ultra-quiet Scan

- He:CF_4 @ 1 atm
- Copper ring field cage, 50 cm drift
- 1 sCMOS sensor + 4 PMT
- 3 GEMs for a 33 x 33 cm^2 sensitive area

Cosmic rays (overground, no shielding)

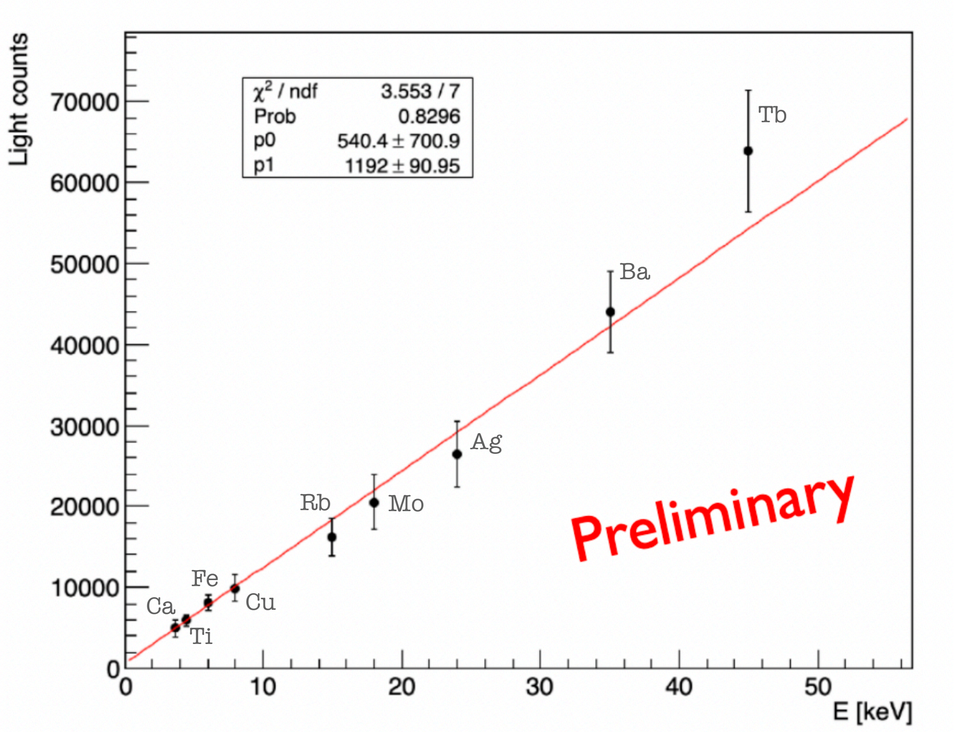


Natural radioactivity (underground, no shielding)



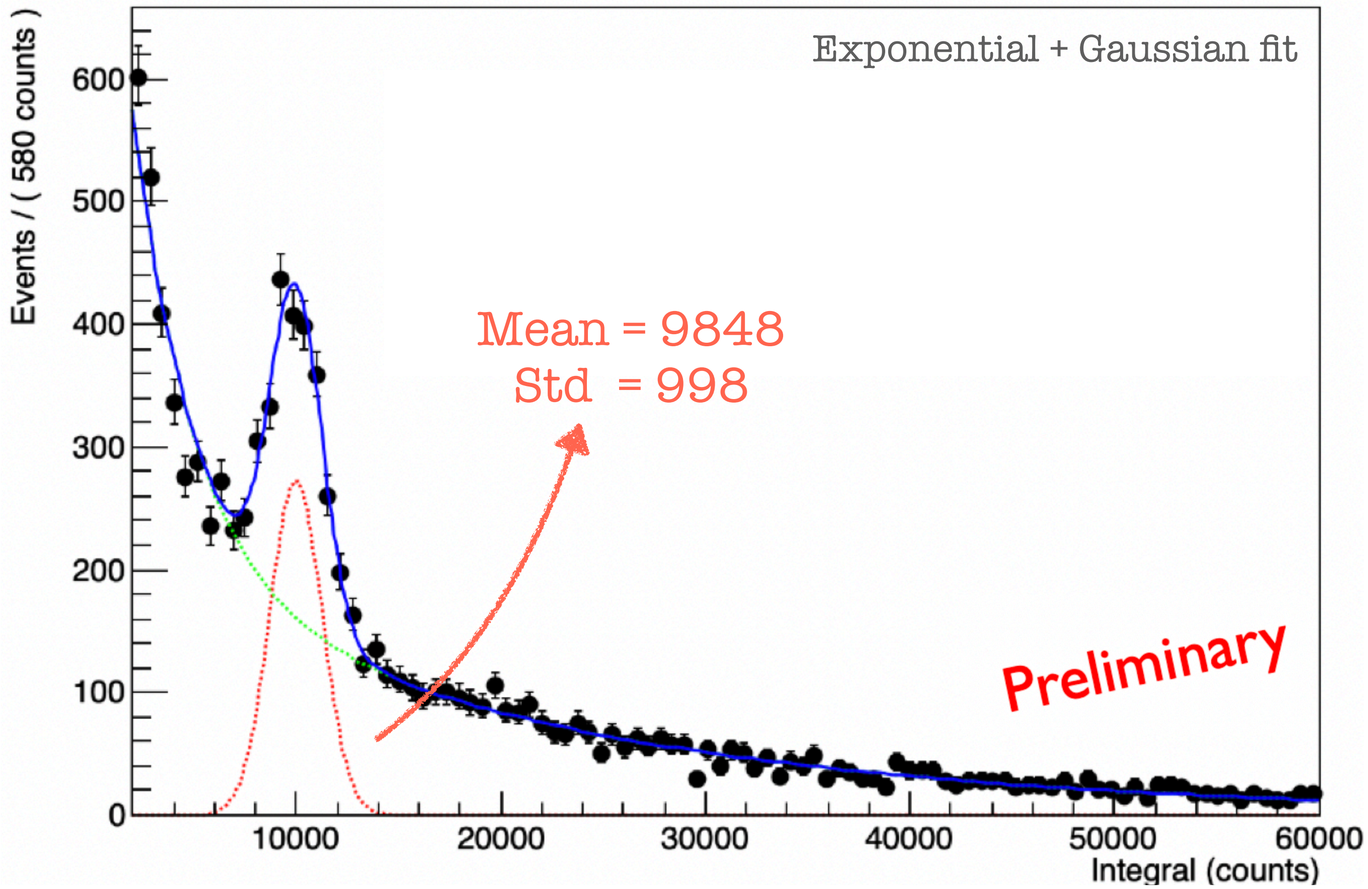
Overground tests: ER energy response

Electronic recoil (ER) calibration:



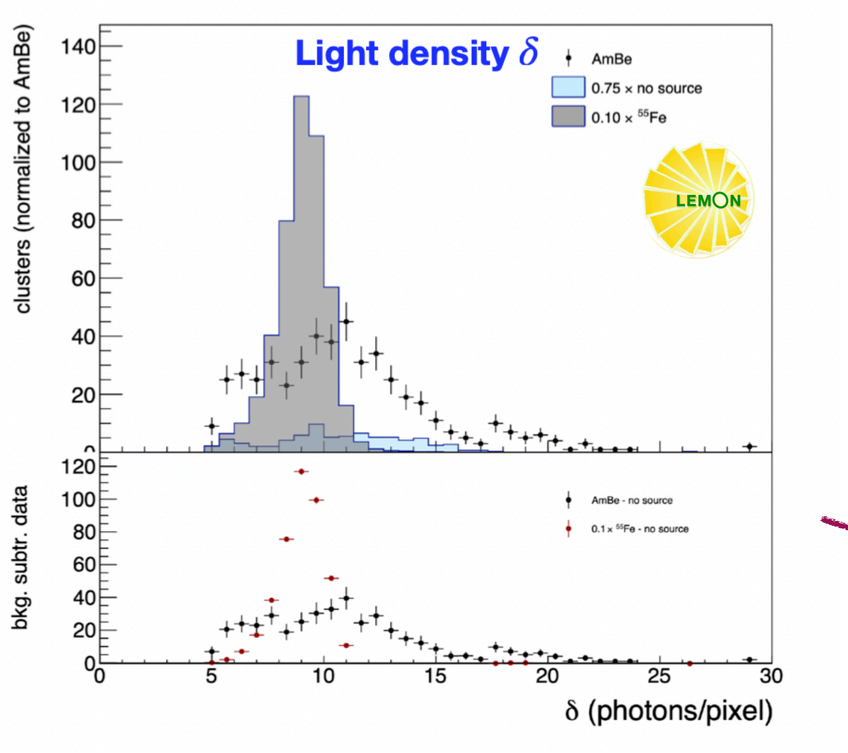
- ~ **13% energy resolution**
- **good linearity** in the response

Example: calibration with the 8 keV Cu X-rays

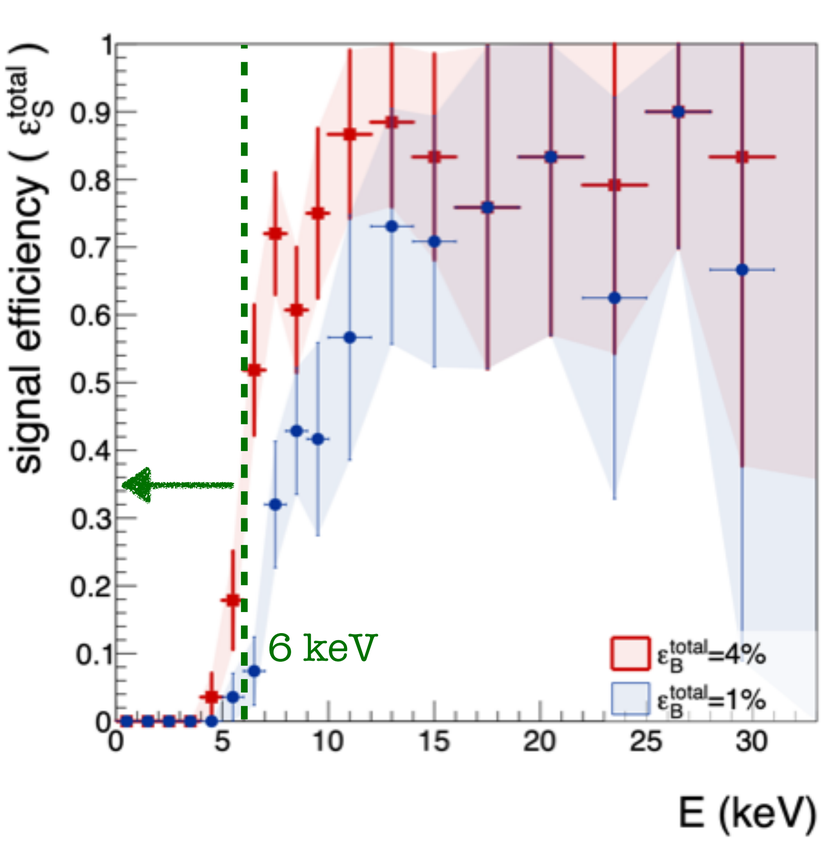


NR vs ER discrimination

- NR vs ER discrimination power: preliminarily assessed with the AmBe LEMOn campaign



A cut on δ

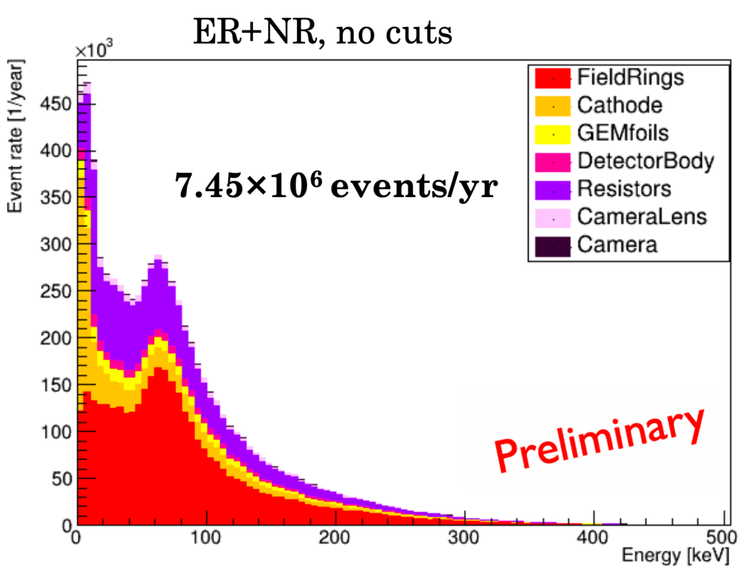


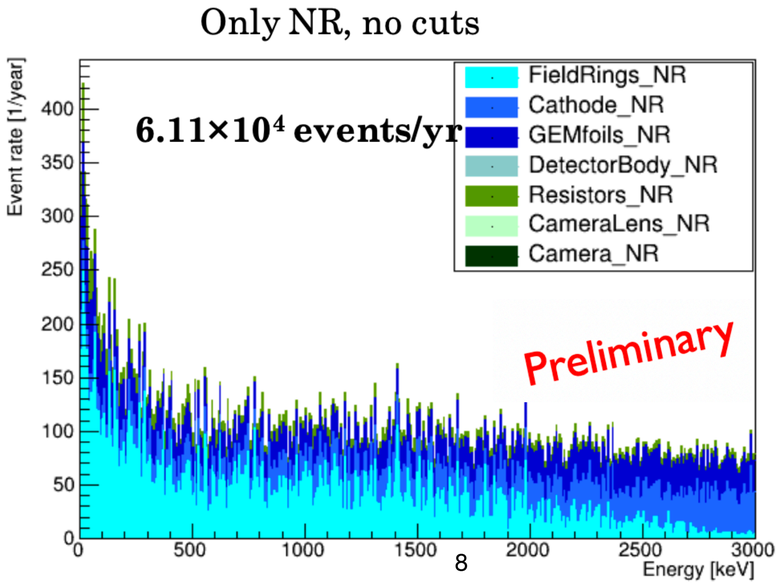
40% NR efficiency at 6 keV$_{ee}$ obtained with 96% rejection against ^{55}Fe

Background studies for LIME

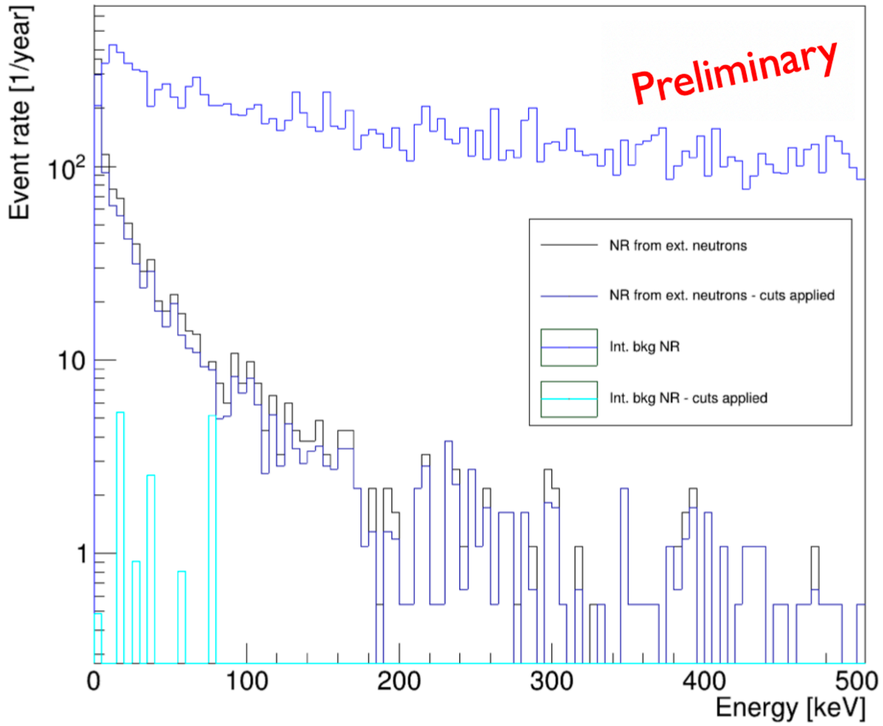
- **Activity** of the **components**: **measured** @ LNGS
- Main contribution to the **internal backgrounds**: copper rings, resistors, GEM/cathode
- 96% (99%) reduction of ER (NR) events with **fiducial cuts**
- **Studies** about the **shielding** are **ongoing** (10 cm copper + 40 cm water for the underground campaign)

ER and NR internal background





Neutron external background

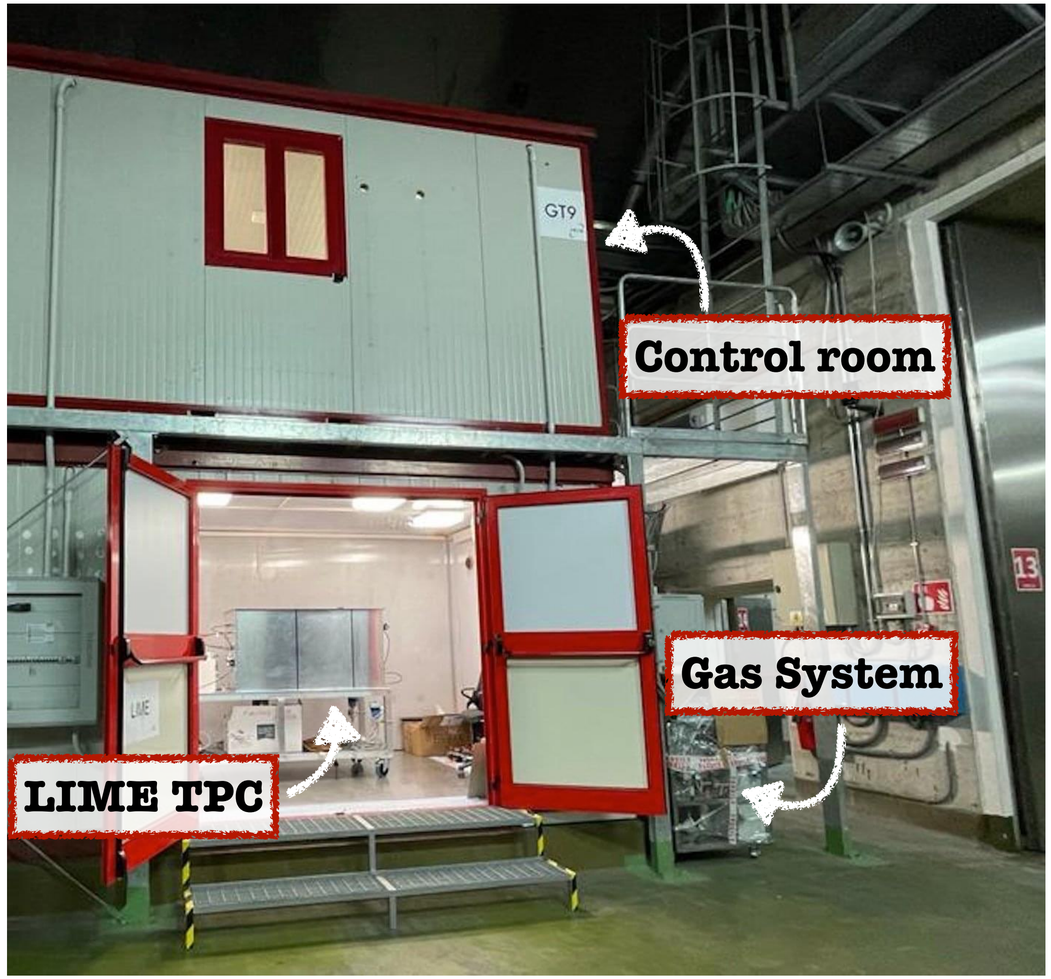


Underground installation

- The LIME prototype has been preliminarily assembled and **tested overground** at Laboratori Nazionali di Frascati (**LNF**)
- **Moved underground** at Laboratori Nazionali del Gran Sasso (**LNGS**) the beginning of 2022

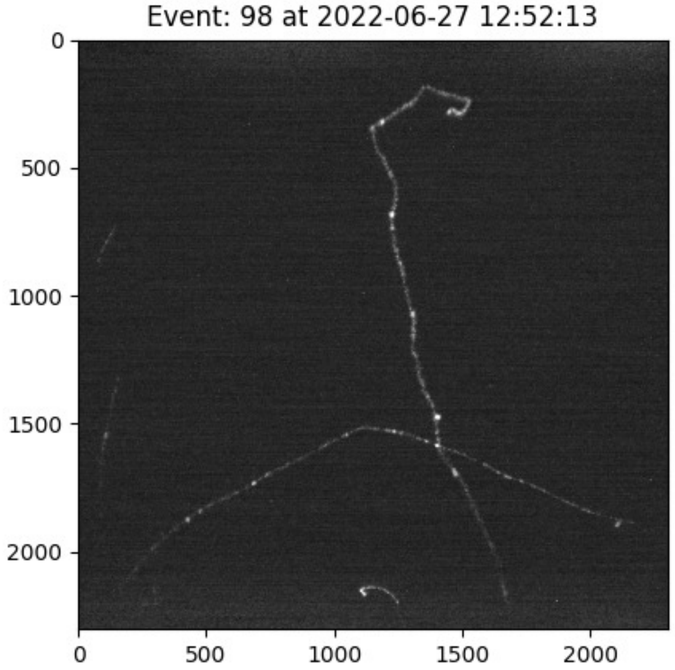
The TPC inside the Faraday cage

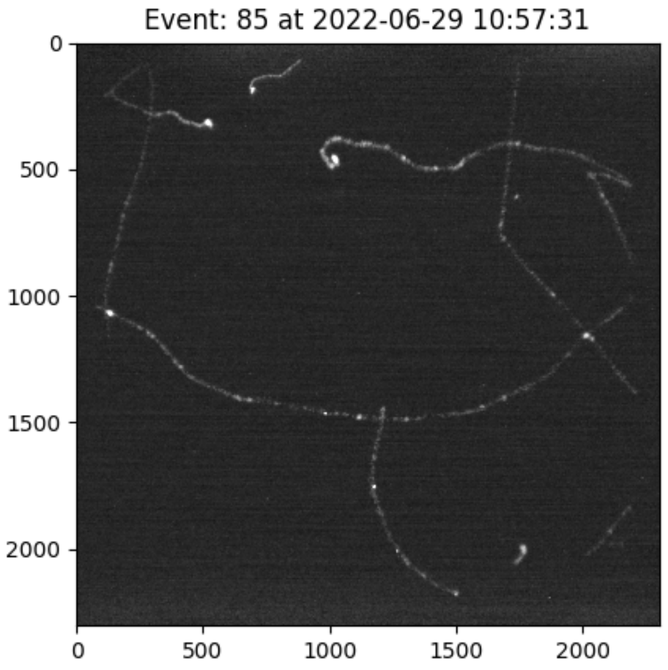
HV and DAQ crate



First images underground

- **LIME is currently collecting its first data** underground @ LNGS
- We are **testing** the **stability** of the chamber and the **gas system**
- In parallel, a clone of LIME, called **LIME2**, has been installed at **LNF** for the assessment and the setup of an **upgraded trigger and DAQ system**.

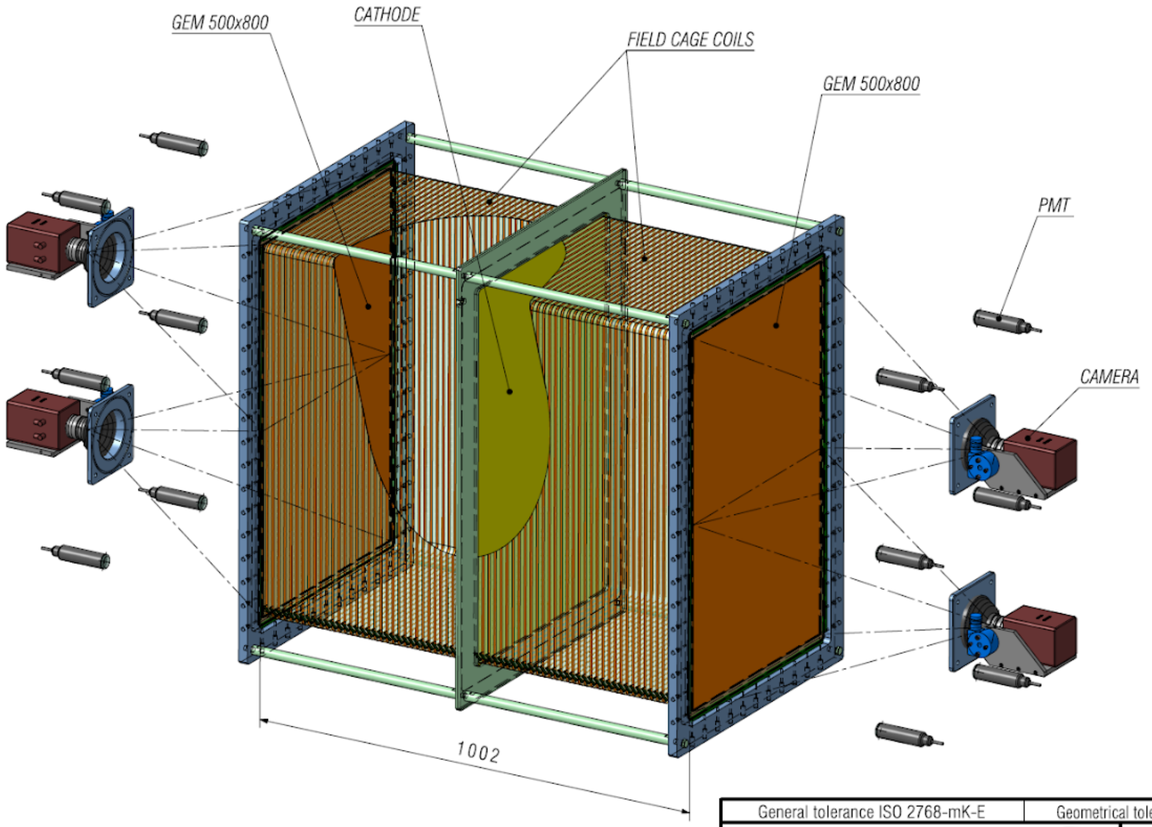




CYGNO PHASE 1: CYGNO_04

- **Preliminary 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: 2 cameras with rectangular sensors (ORCA Quest) + 6 PMTs
  - **Vessel:** low radioactivity PMMA
  - **Shielding:** 10 cm copper + 100 cm water with a polyethylene base

Designed at LNF and to be installed at LNGS



CYGNO 0.4 TPC
500x800x1000=0.4 m^3

General tolerance ISO 2768-mK-E	Geometrical tolerance ISO 8015-E	Roughness ISO 1302

NATIONAL INSTITUTE FOR NUCLEAR PHYSICS
INFN FRASCATI NATIONAL LAB
RESEARCH DIVISION - SEM

SIZE A3 | PROJECTION

REVISION		DATE	NAME
.	.	DATE : .	NAME : .
.	.	DATE : .	NAME : .
.	.	DATE : .	NAME : .

TOTAL WEIGHT (Kg)	DATE	DRAWN
.	11/06/2022	C.Capoccia
SCALE 1:8	DATE .	CHECKED .
SHEET 1/3	DATE .	APPROVED .

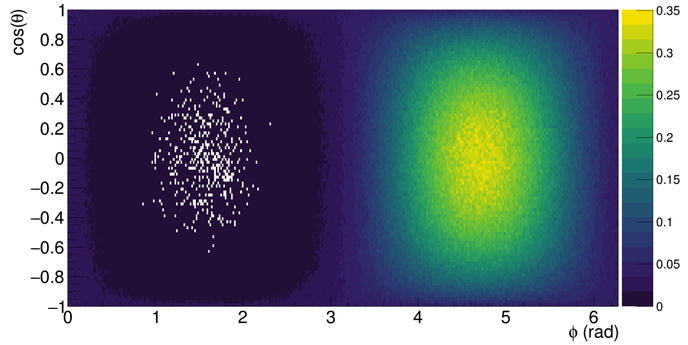
CYGNO EXPERIMENT
CYGNO 0.4 DETECTOR
TPC COMPONENTS SCHEME

CY4-01-P

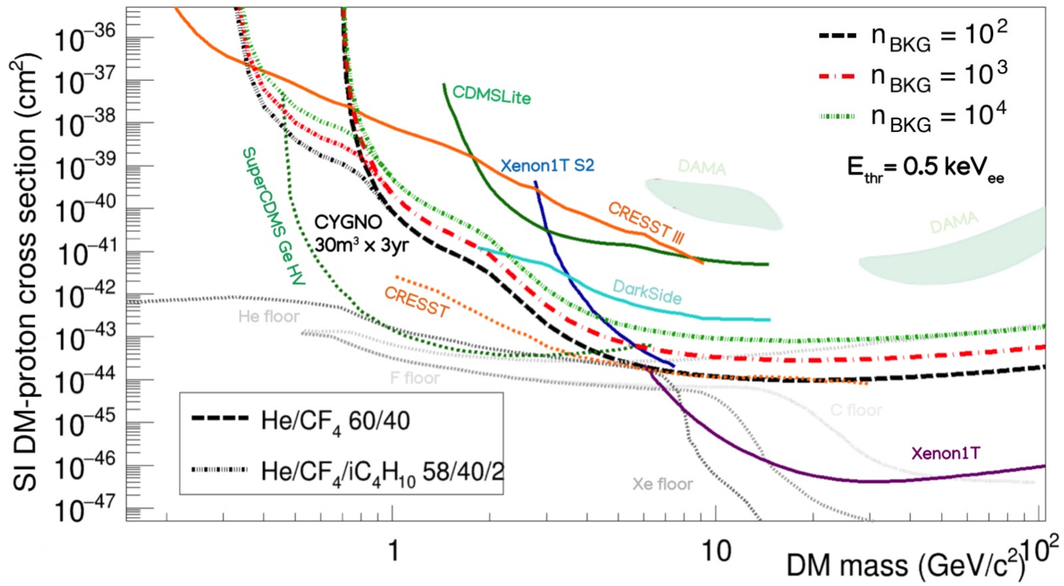
CYGNO PHASE 2: the 30 m^3 experiment for low mass DM searches

- $\mathcal{O}$(**30-100 m^3**) **detector** for directional dark matter (**DM**) **search** in the ~**GeV**/c^2 **mass region**.
- Preliminary sensitivity projections. **Assumptions**:
  - Low energy **threshold**: 1 keV (0.5 keV)
  - **Quenching Factor**: SRIM simulation
  - **Observable**: angular distribution
  - **Angular resolution**: 30°
  - **Background**: different scenarios (isotropic background)

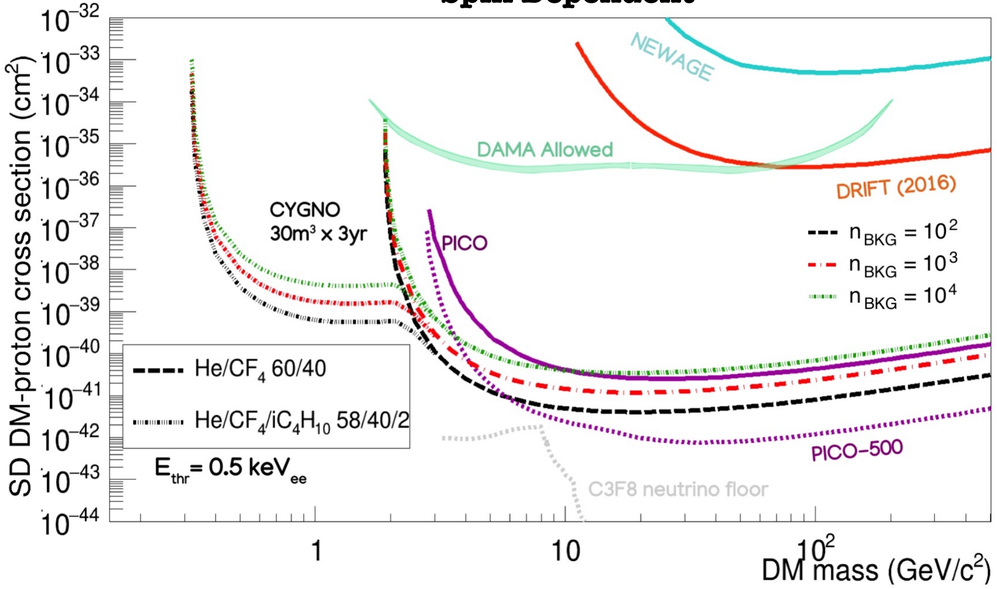
10 GeV/c^2 WIMP-like signal



Spin Independent



Spin Dependent



Conclusions

- The CYGNO collaboration is developing a **gaseous TPC with optical readout**
- **LIME**, a 50 L prototype, has recently been moved @ LNGS and is now taking data.
- This is just a step towards larger detectors for **directional dark matter search**
- **Other R&D activities:**
  - **Internal background reduction:** custom sCMOS sensor, custom lens
  - **Studies of the gas mixture:** addition of hydrogen-rich gas (CH_4), study of the light yield from hydrocarbons, possible eco-friendly gas mixture to substitute CF_4
  - **Negative ion drift:** negative ions with the addition of SF_6 for better fiducialization, 1 atm tests with encouraging results

Acknowledgements

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CYGNO Project is funded by INFN.

Thanks for the attention!

The CYGNO collaboration:

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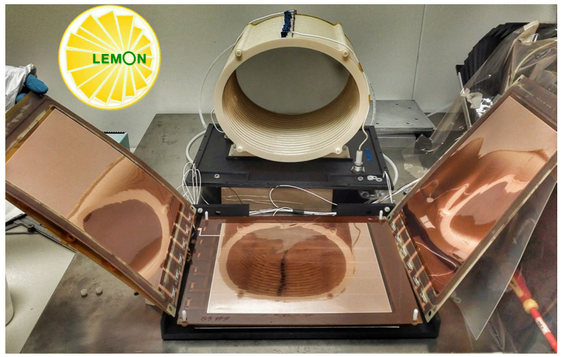
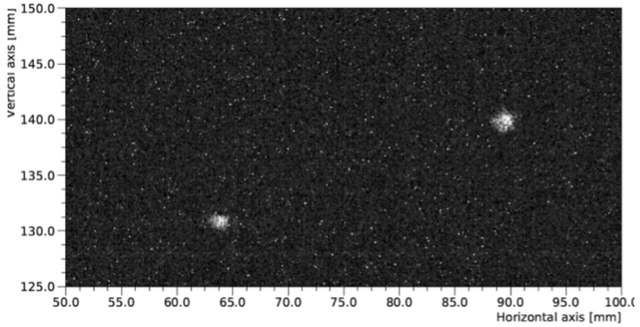
Backup

Detector performances: LEMOn

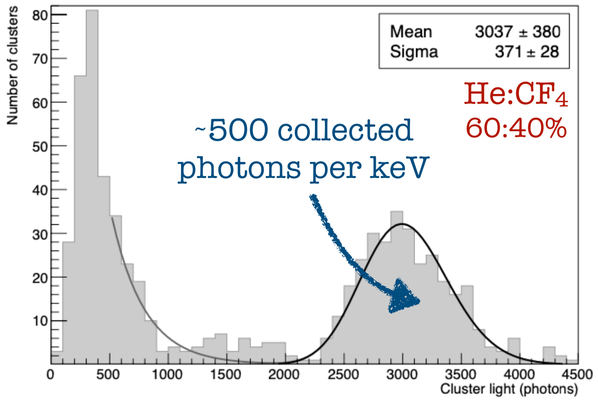
Energy resolution

^{55}Fe X-ray signal

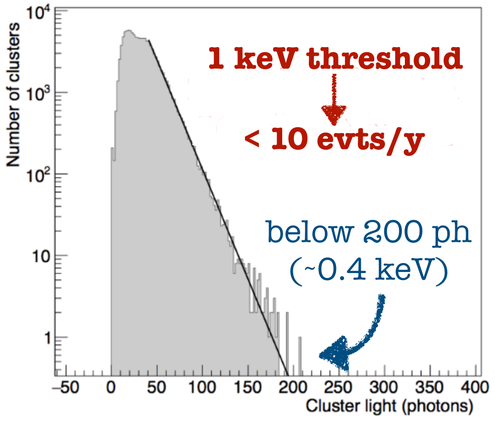




Energy resolution



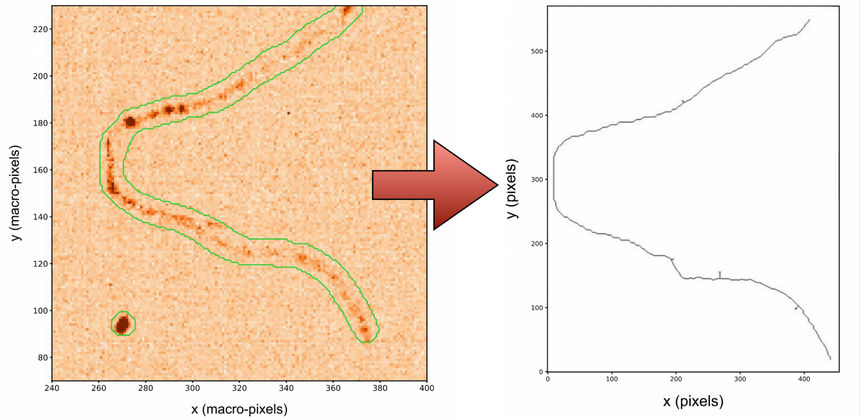
sCMOS sensor noise



Energy resolution of **15% at 5.9 keV$_{ee}$** with both sCMOS and PMT

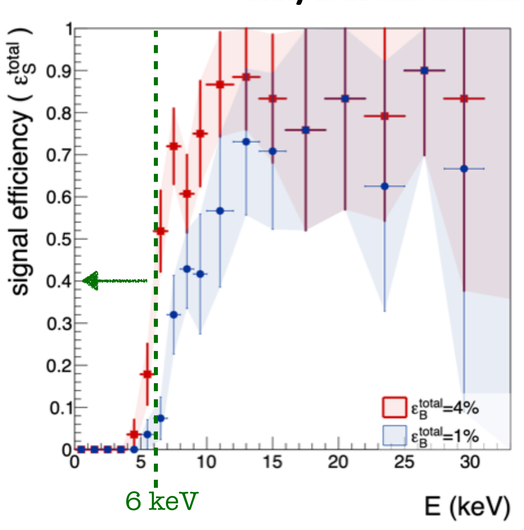
Reconstruction efficiency

Multiple DBSCAN + GAC* pattern recognition algorithm



*Geodesic Active Contour

ER/NR discrimination power



40% NR efficiency at 6 keV$_{ee}$ obtained with 96% rejection against ^{55}Fe

Detector performances: LEMOn

z position reconstruction

$$\eta = \frac{\sigma}{A}$$

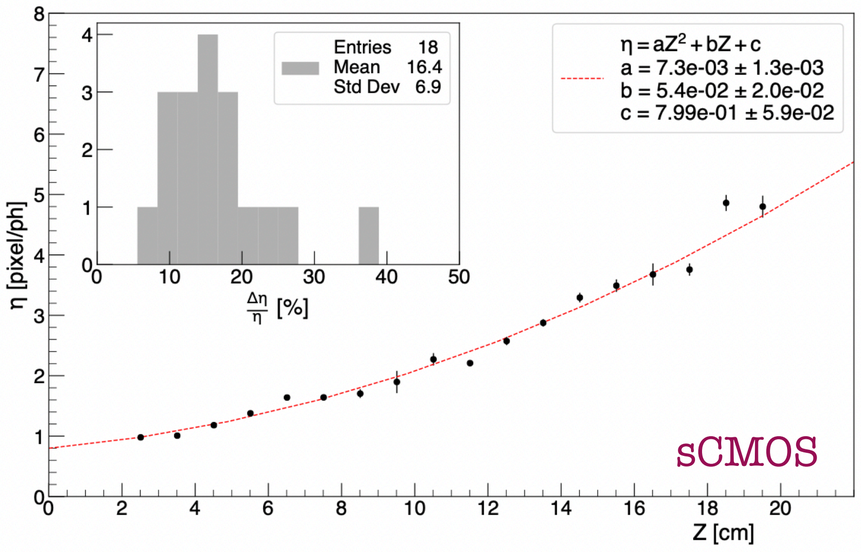
Width of the transverse light profile

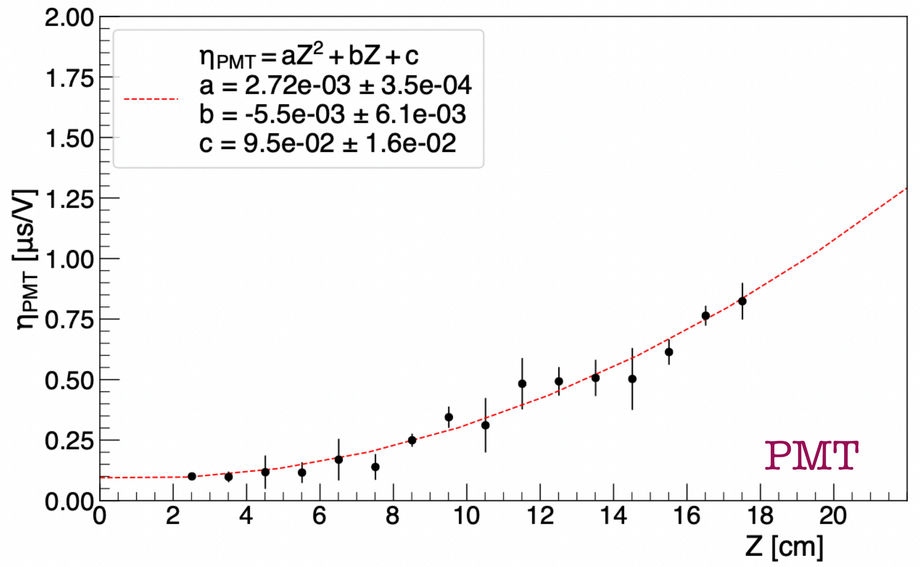
Amplitude of the transverse light profile

$$\eta_{PMT} = \frac{\sigma_{PMT}}{A_{PMT}}$$

Time width of the PMT signal

Amplitude of the PMT signal

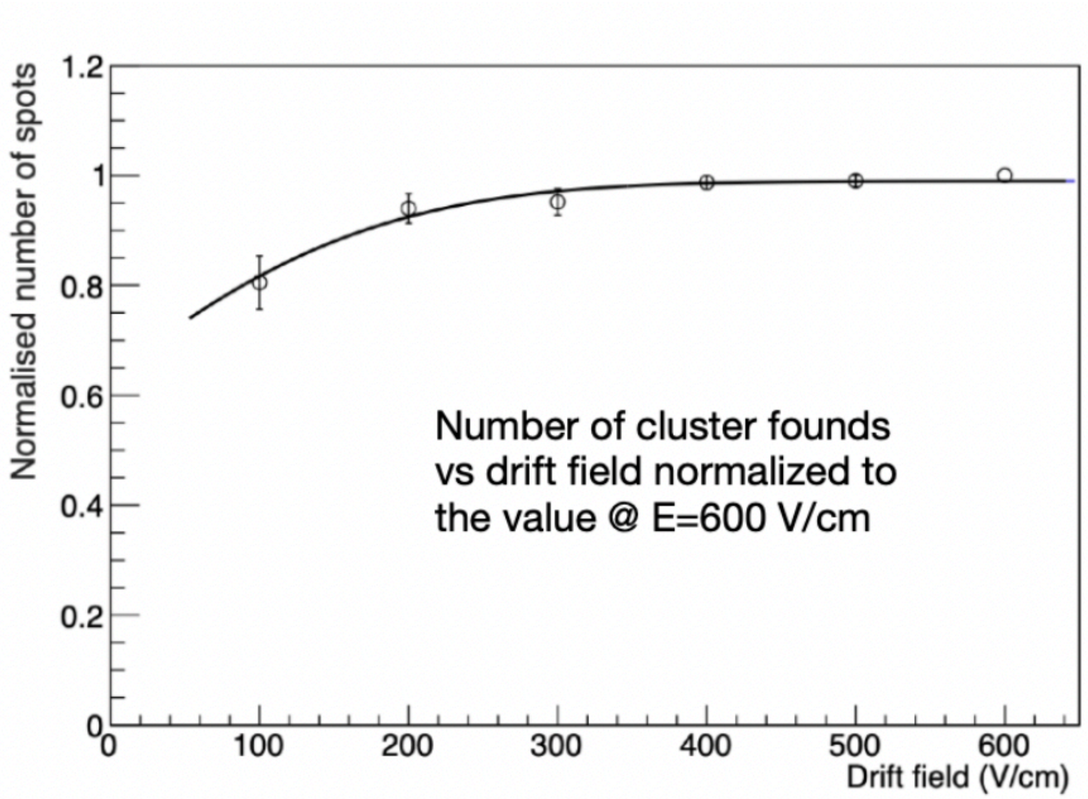


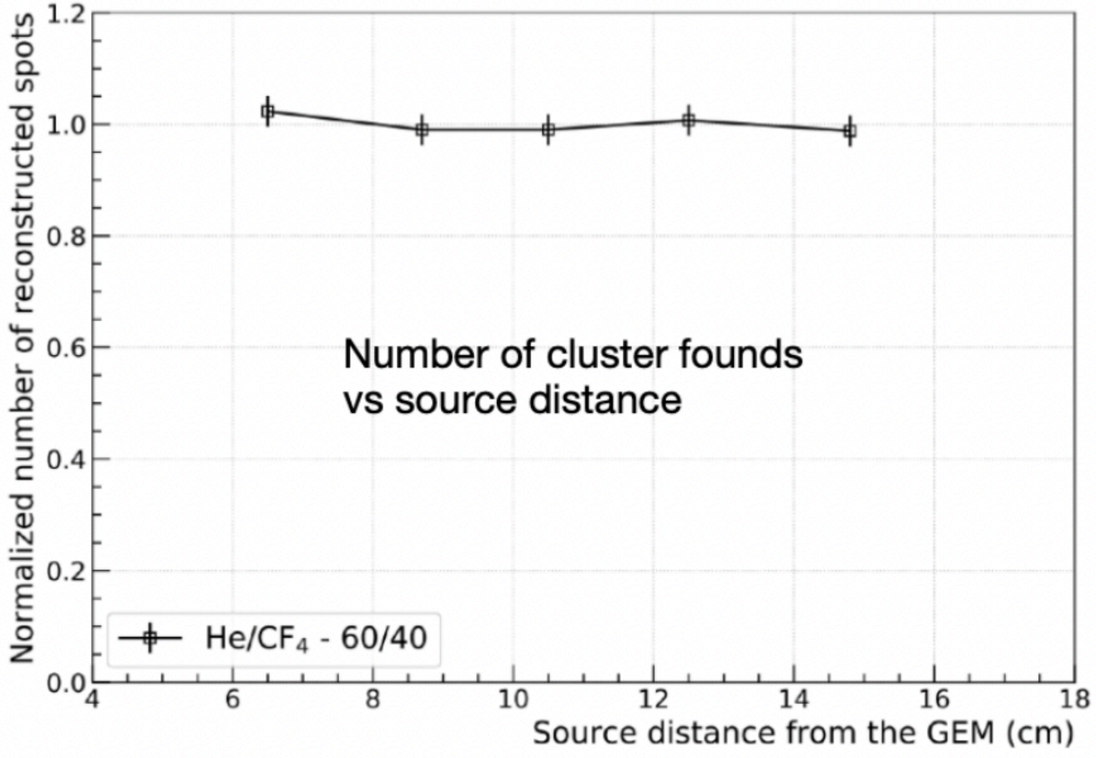


Using both sCMOS and PMT: 15% z resolution

Detector performances: LEMOn

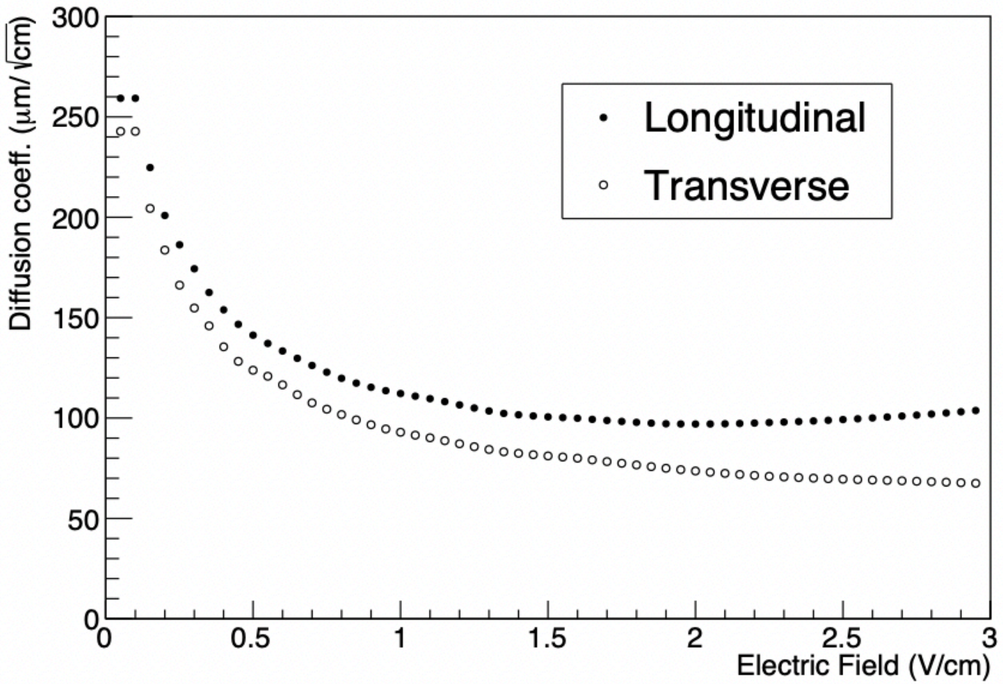
Detector efficiency

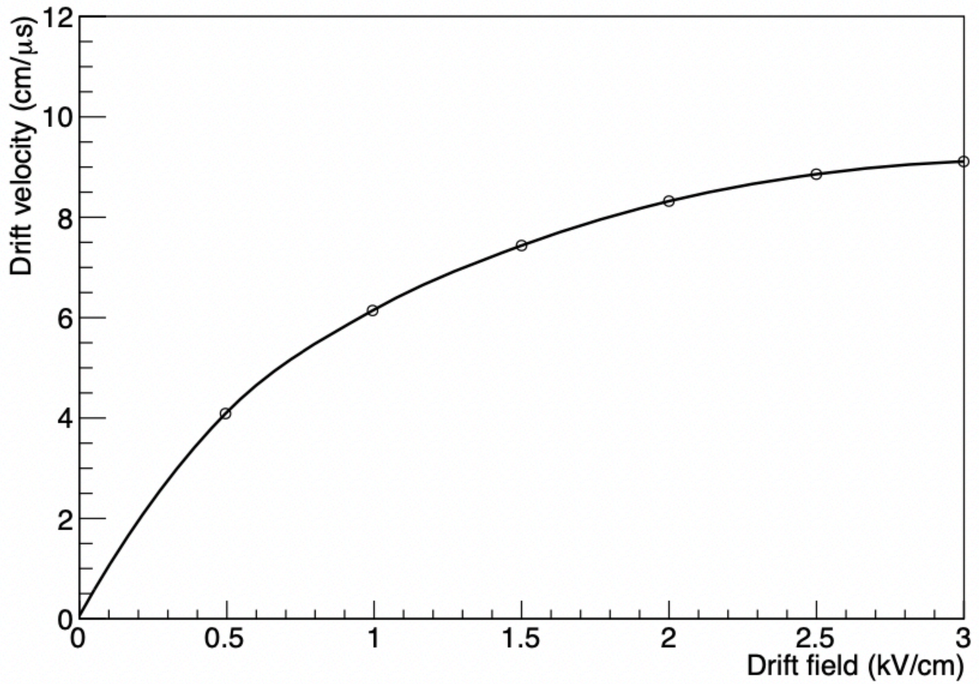




Detector performances: LEMOn

Diffusion

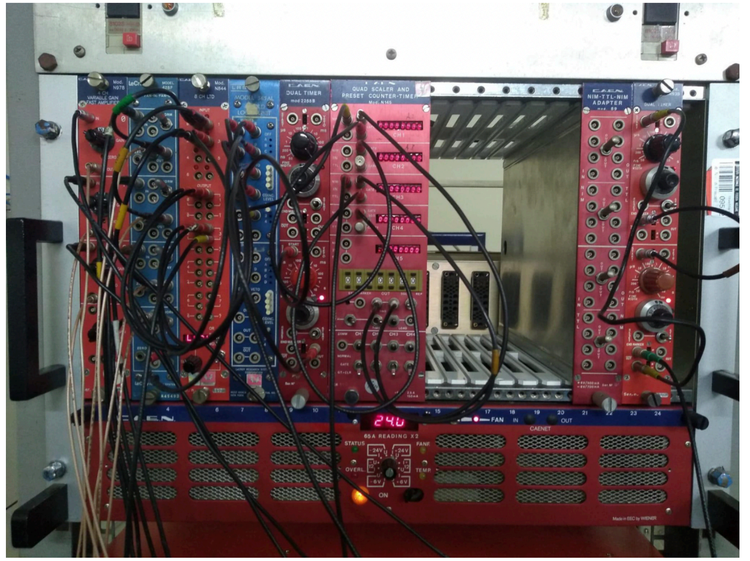


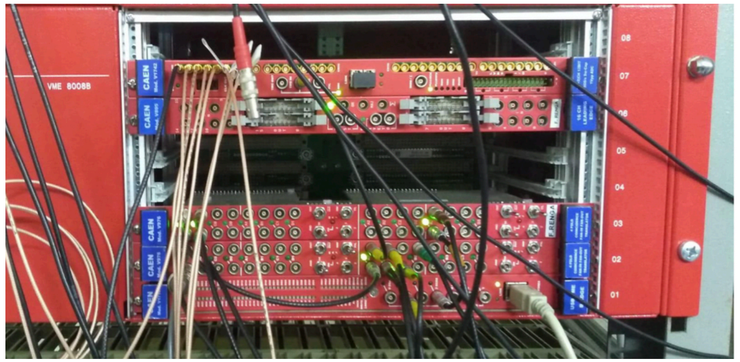


DAQ system for LIME underground

DAQ system based on USB for the camera + NIM and VME modules for analog signals:

- **NIM**: Splitting (N625), Discriminating (N840)
- **VME**: Fast digitization for PMT (V1742), slow digitization for GEMs (V1718, V3718), and logic (V976 or custom trigger module)
- **Two servers Xeon** 16 core 4216, 32 GB RAM+ 2x8 TB HD, NVIDIA RTX5000 24 GB

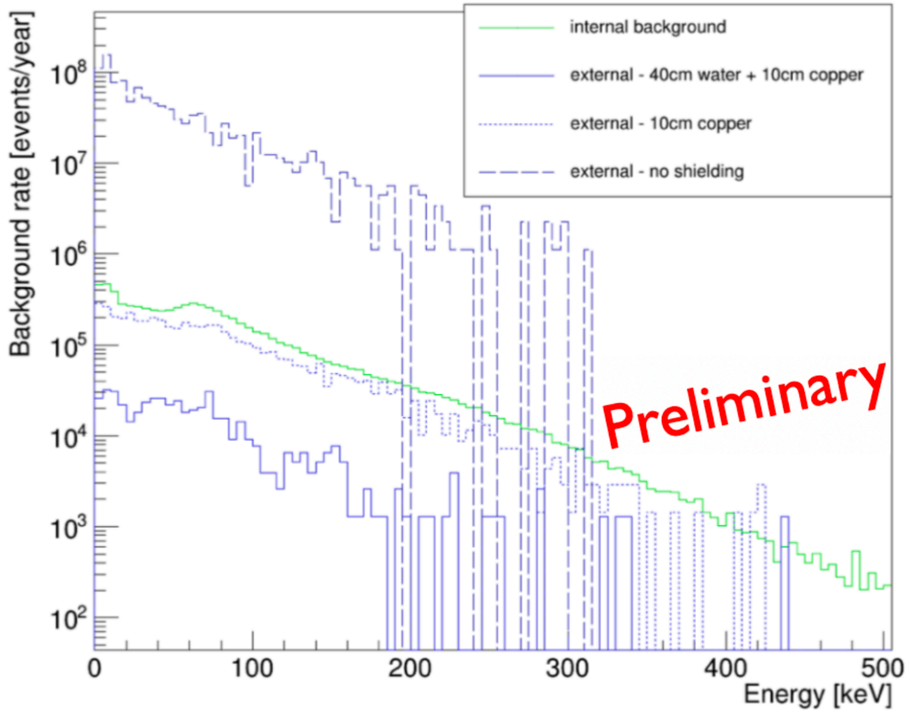


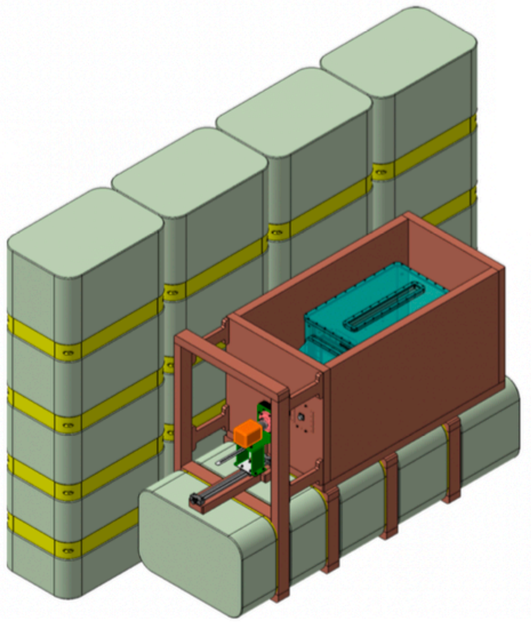


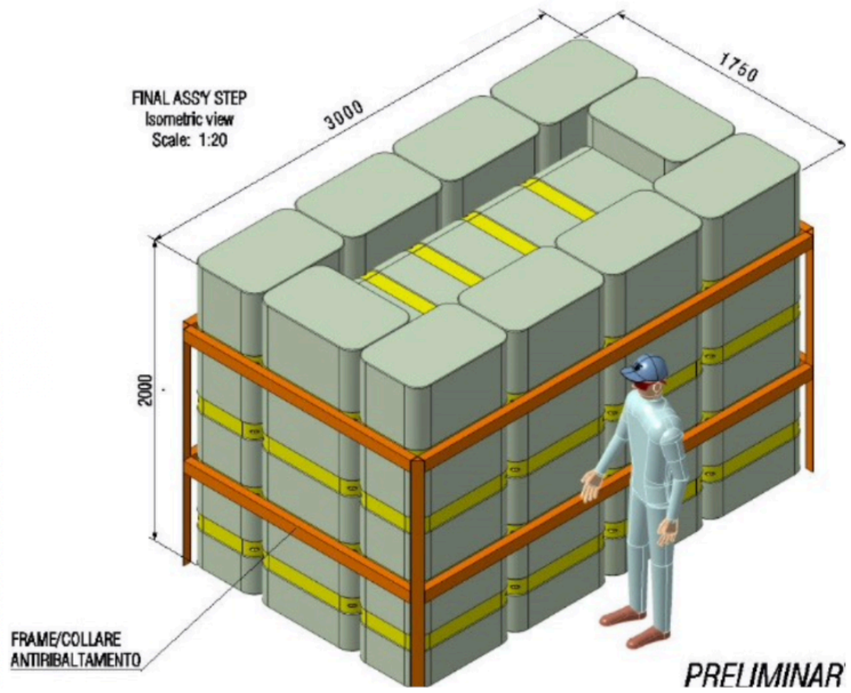
LIME: the underground campaign

Shielding	Internal [ev/yr] (1-20 keV)	External* [ev/yr] (1-20 keV)
No shield	$1.5344(7)\times10^{6}$	$4.061(8)\times10^{8}$
5cm copper	$1.5344(7)\times10^{6}$	$1.90(2)\times10^{7}$
10cm copper	$1.5344(7)\times10^{6}$	$1.024(2)\times10^{6}$
40cm water + 10cm copper	$1.5344(7)\times10^{6}$	$2.46(1)\times10^{5}$

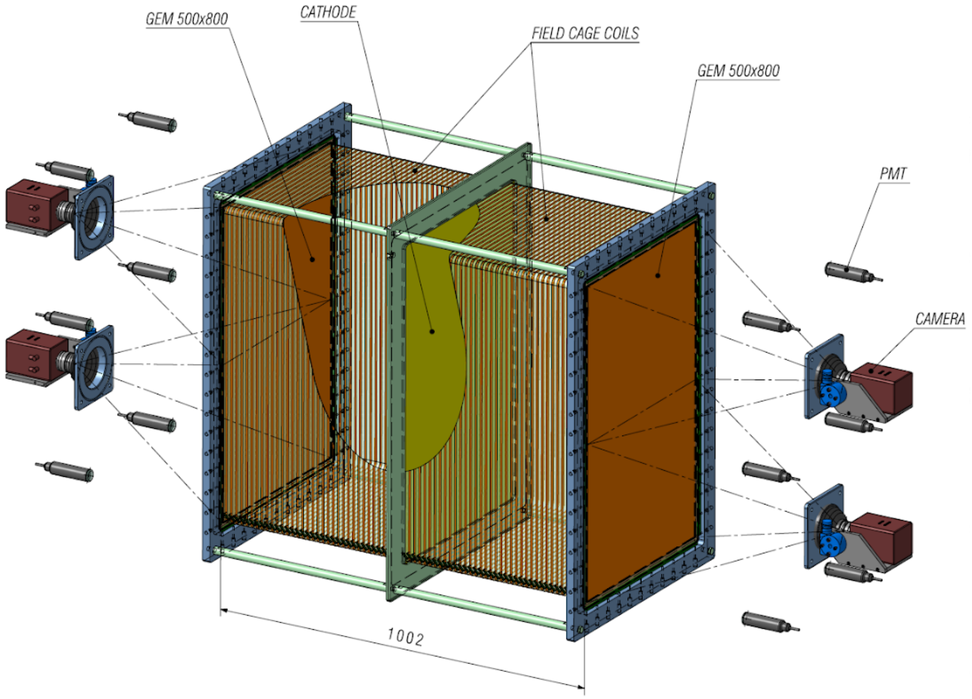
- Shielding: 10 cm of copper + 40 cm of water
- Validate detector MC simulation
- Measure the neutron flux (expected 200 NRs from neutrons in 4 months)





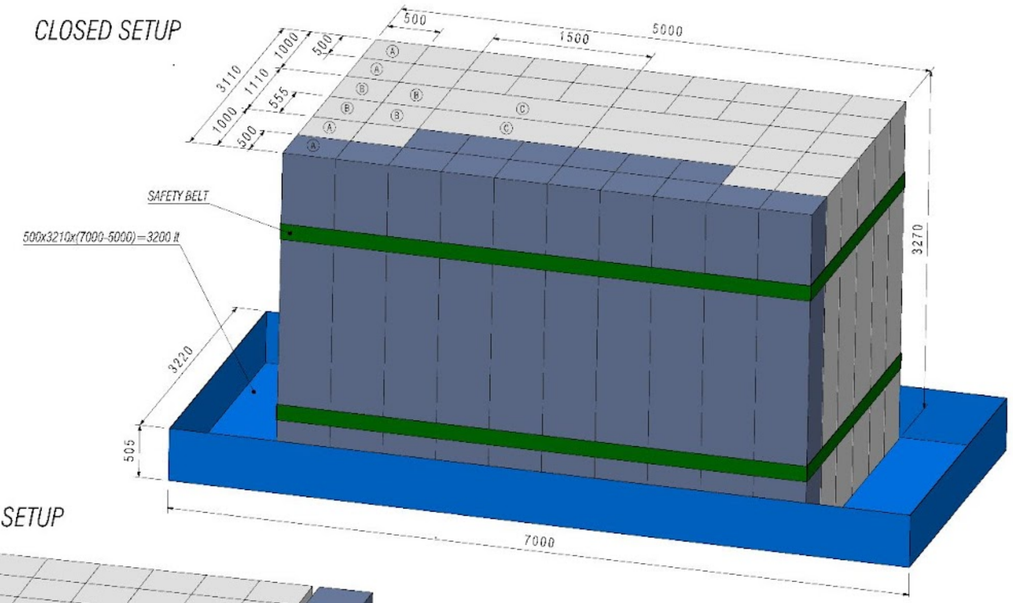


CYGNO PHASE 1: CYGNO_04

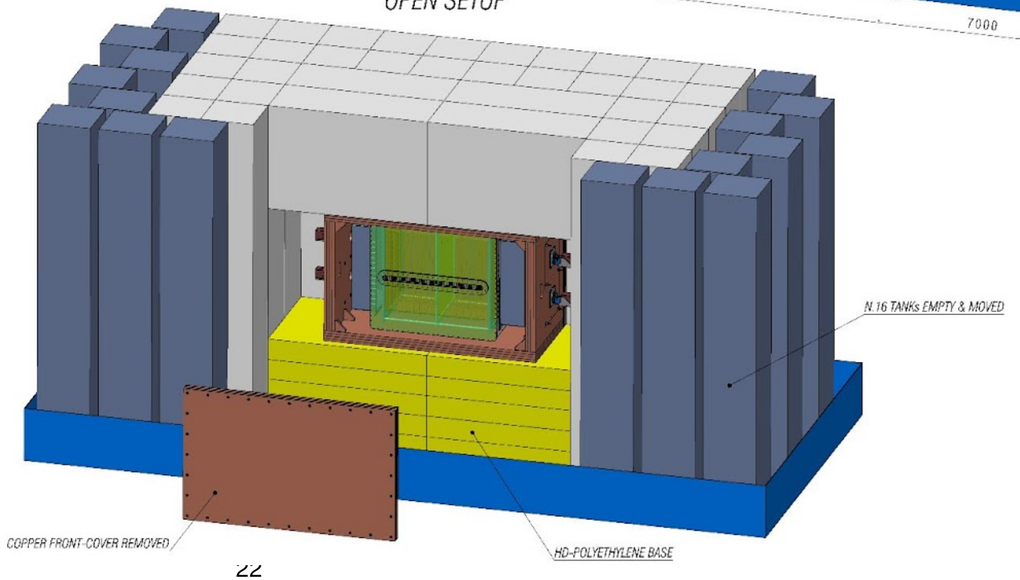


PRELIMINARY NEUTRON SHIELDING SETUP (1 METER THICKNESS)

CLOSED SETUP



OPEN SETUP

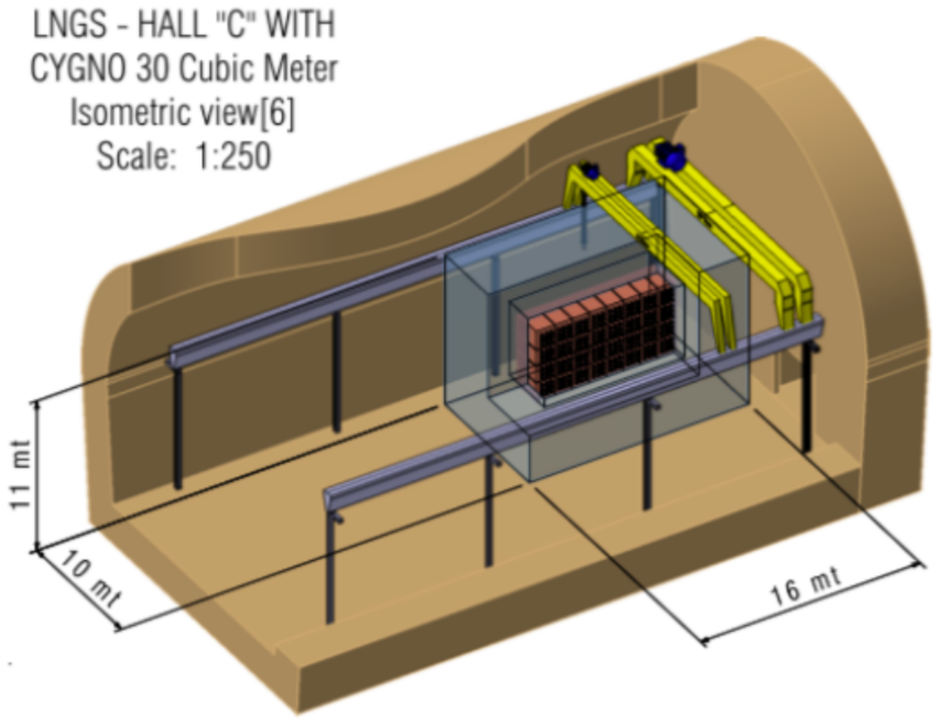


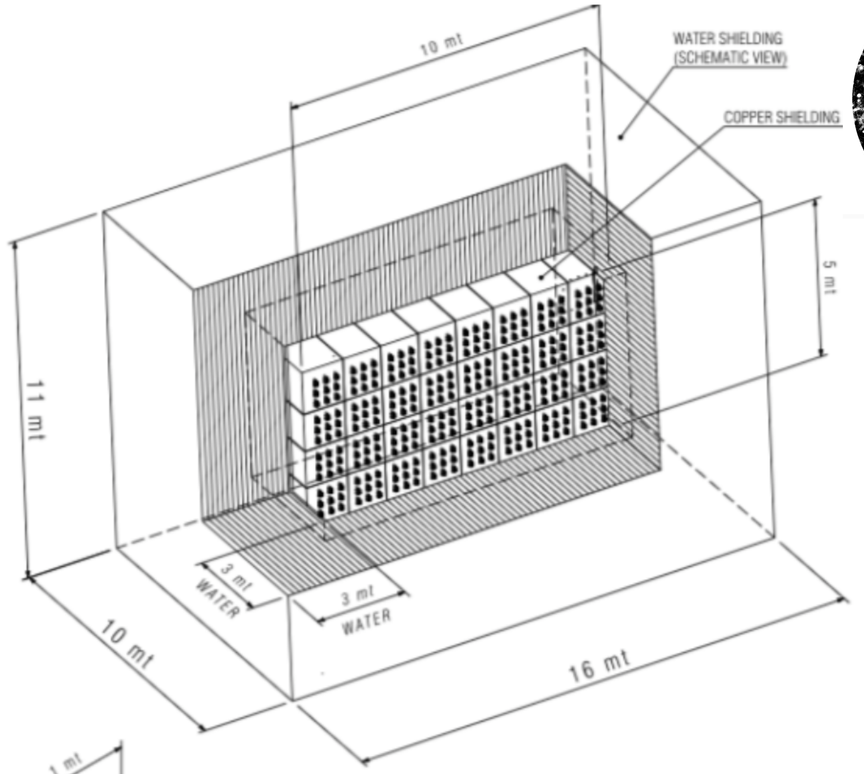
NEUTRON SHIELDING SETUP:
- 40 mc WATER
- 3.4 mc POLYETHYLENE

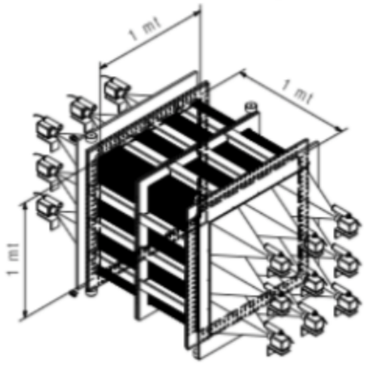
- N. 40 TANKs (A) -> 500x500x3270 -> 817 lt x 40 = 33 mc (WATER)
- N. 04 TANKs (B) -> 555x500x3270 -> 908 lt x 4 = 3.6 mc (WATER)
- N. 04 TANKs (C) -> 555x1500x1000 -> 833 lt x 4 = 3.4 mc (WATER)
- N. 01 BASE IN POLYETHYLENE -> 1110x3000x1000 = 3330 Kg

MAX WEIGHT OF EMPTY TANK IS 72 Kg

CYGNO PHASE 2: the 30 m^3 experiment







CYGNO 1 Cubic Meter

Cygno of 30 cubic meters made by an array of 4x8=32 Cigno modulus of 1 cubic meter. The setup is completed by a copper (100 mm thick) and water (3m thick) shielding

PRELIMINARY

General tolerance ISO 2768-mK-E	Geometrical tolerance ISO 8015-E	Roughness ISO 1302

INFN NATIONAL INSTITUTE FOR NUCLEAR PHYSICS
FRASCATI NATIONAL LAB
RESEARCH DIVISION - SEM

SIZE A2 | PROJECTION | REVISION | DATE | NAME | 23/11/2020 C.Capoccia | SCALE 1:1 | SHEET 1/1

CYGNO EXPERIMENT
CYGNO 30 Mc @ LNGS-U SETUP
FIRST EVALUATION OF SETUP-ENVELOPPE

CYGNO 30 Mc