in synergy with erc
IN TIUM
funded from ERC in Horizon 2020 program (grant agreement 818744)

The CYGNO experiment for directional dark matter searches

33rd Rencontres de Blois, 22-27 May 2022

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on behalf of:

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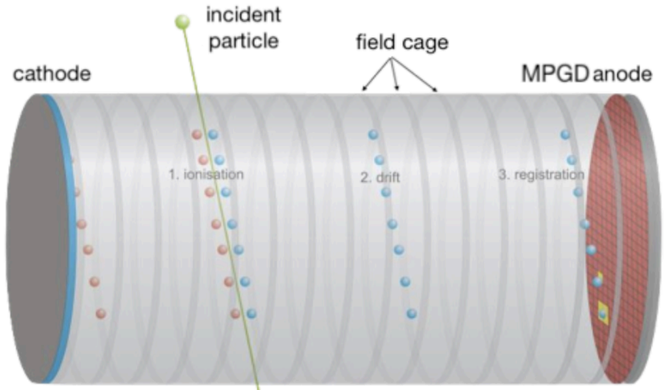
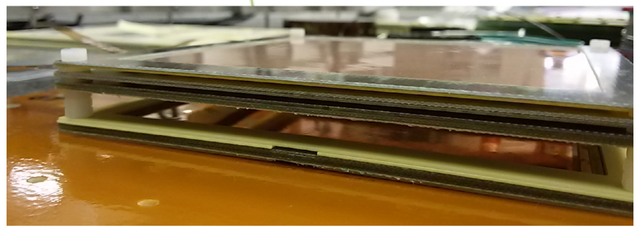
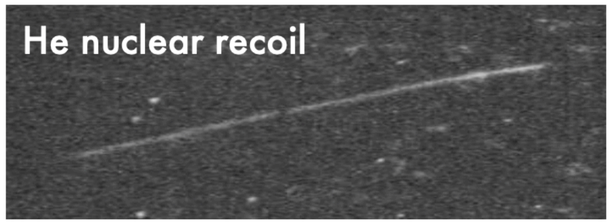
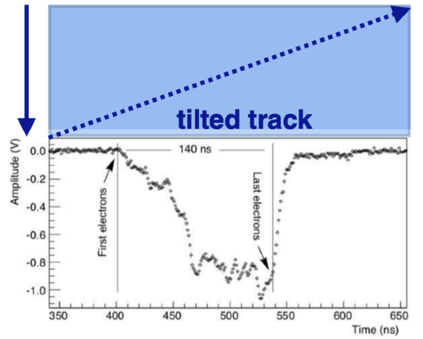
The CYGNO project:

- **Aiming at** a large detector for high precision **3D tracking of rare low energy nuclear recoils (keV)**
- **Experimental challenges**: rate O(evt/kg/y), background rejection, and energy threshold (keV)
- **Strategy**: **photograph nuclear recoil** in a He:CF_4 (1 atm) TPC with a GEM amplification stage
  - **Low density material**: “visible” track for low energy ER/NR
  - **3D tracking**: position, direction, and fiducialization, total released energy, dE/dx (head/tail), particle identification
  - **Optical sensors**: high granularity, very low noise, and high sensitivity
  - **Optical coupling**: sensors outside the sensitive volume, acquire large surfaces with small sensors





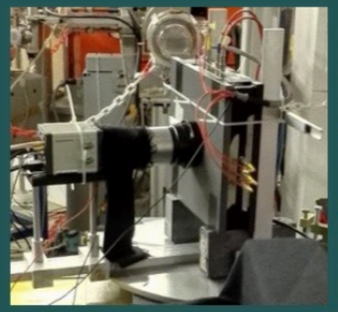




CYGNO timeline

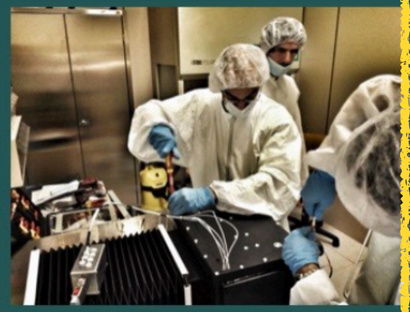
PHASE 0: R&D and prototypes

2015/16 ROMA1 → ORANGE



- 1 cm drift

2017/18 LNF → LEMON



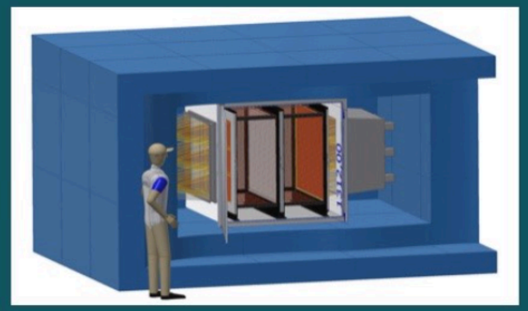
- 3D printing
- 20 cm drift

2019/21 LNF/LNGS → LIME

- 50 cm drift
- underground tests
- shielding

PHASE 1: 1 m³ Demonstrator

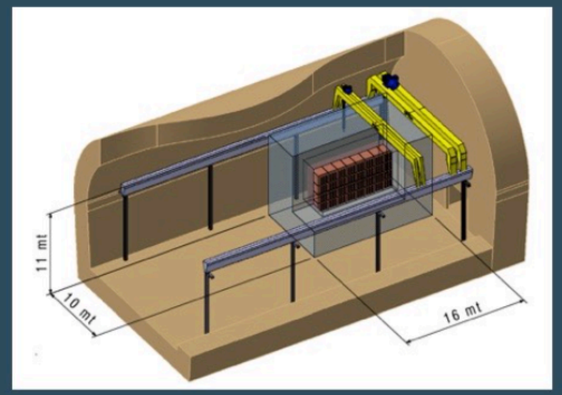
2022/25 LNF/LNGS → CYGNO_01



- background
- materials test, gas purification
- scalability

PHASE 2: 30 m³ Experiment

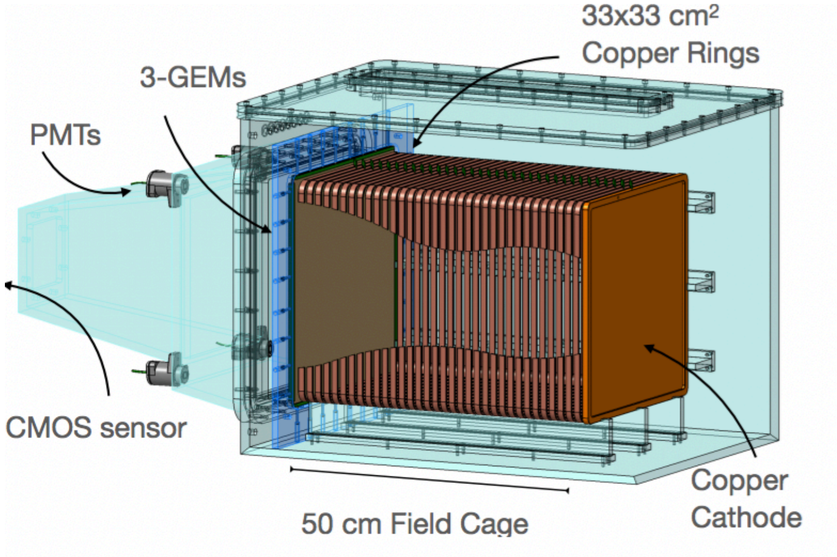
2026.. LNGS → CYGNO_30

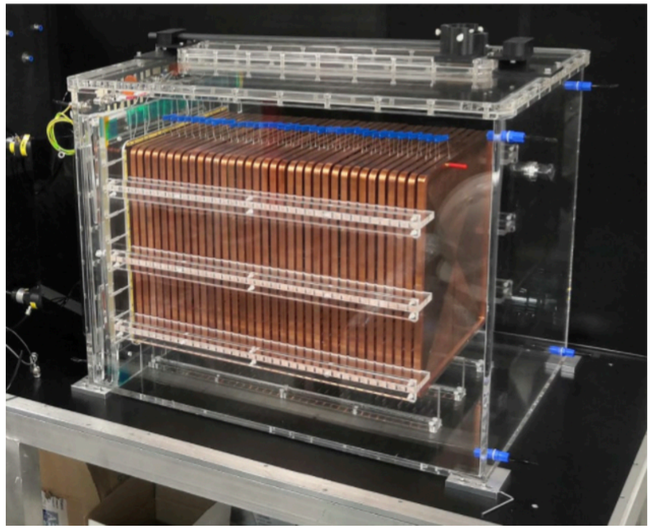


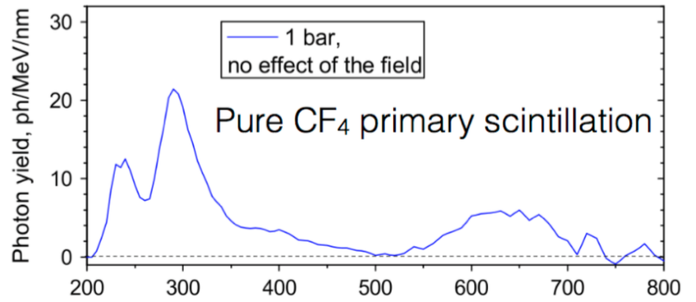
- Physics research

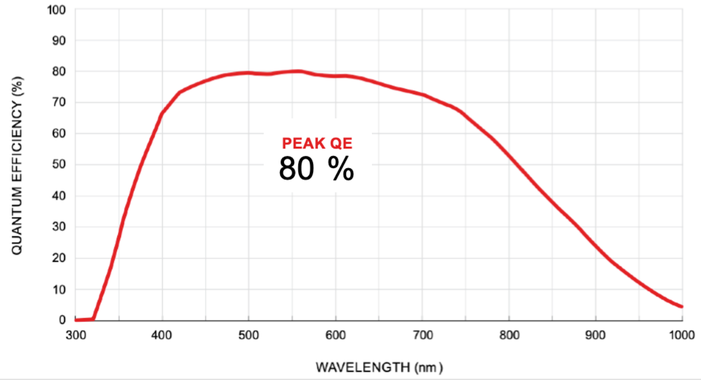
Instruments 6 (2022) 1, 6 JINST 15 (2020) P10001 JINST 15 (2020) 12, T12003
2019 JINST 14 P07011 JINST 15 (2020) P08018
NIM A 999 (2021) 165209 Measur.Sci.Tech. 32 (2021) 2, 025902

CYGNO PHASE 0: Lime prototype

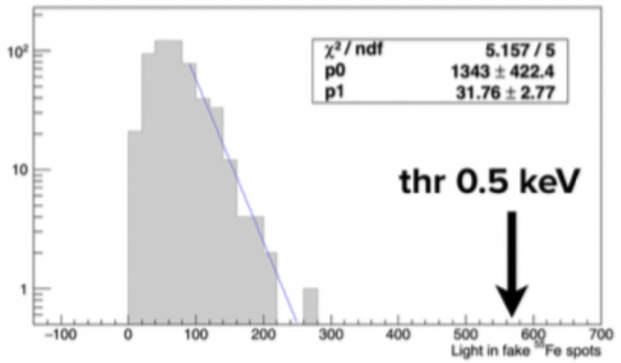




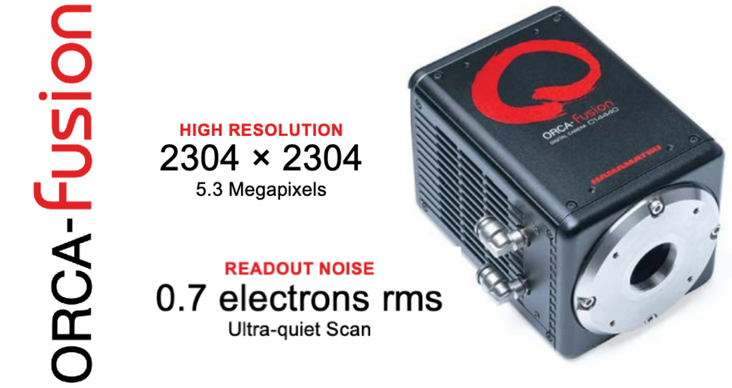




- He:CF_4 (1 atm)
- copper ring field cage, 50 cm drift
- 3 GEMs for a 33 x 33 cm² sensitive area
- 1 sCMOS sensor + 4 PMT
- acrylic vessel, aluminium faraday cage

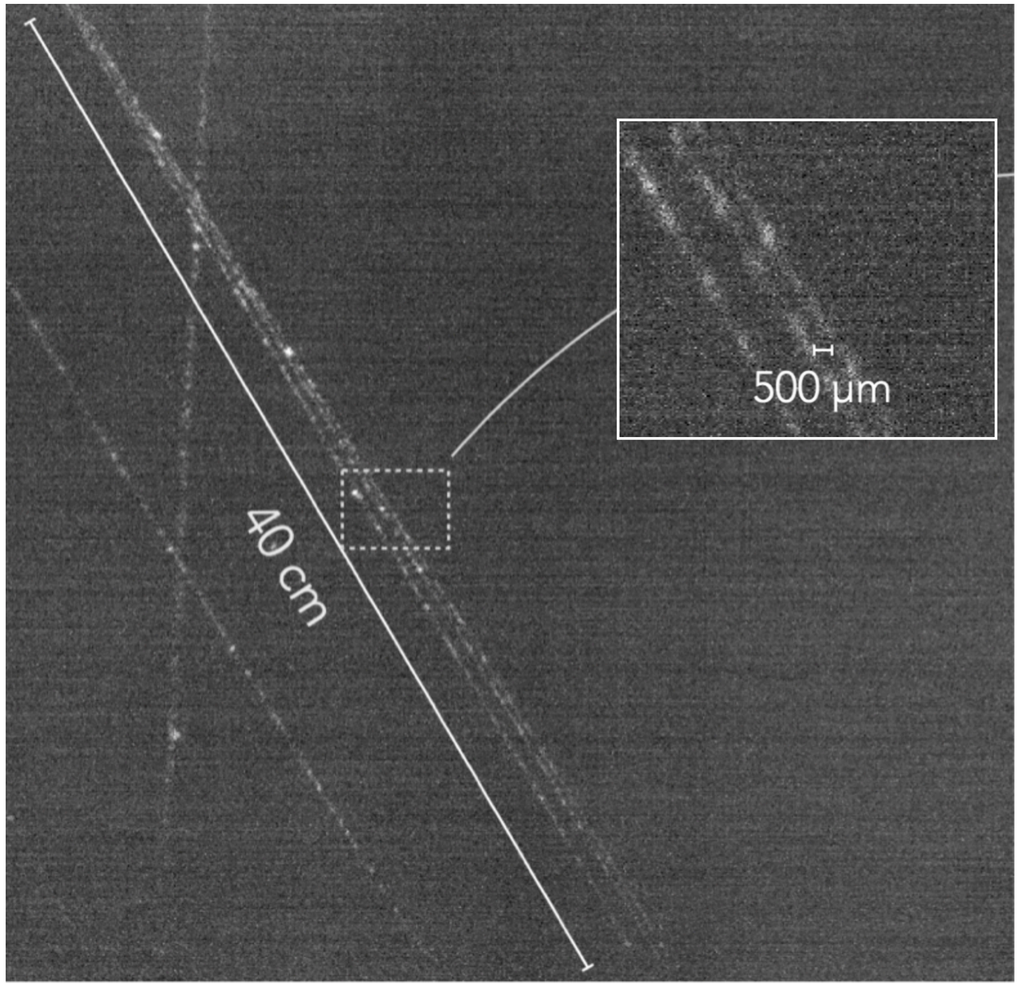


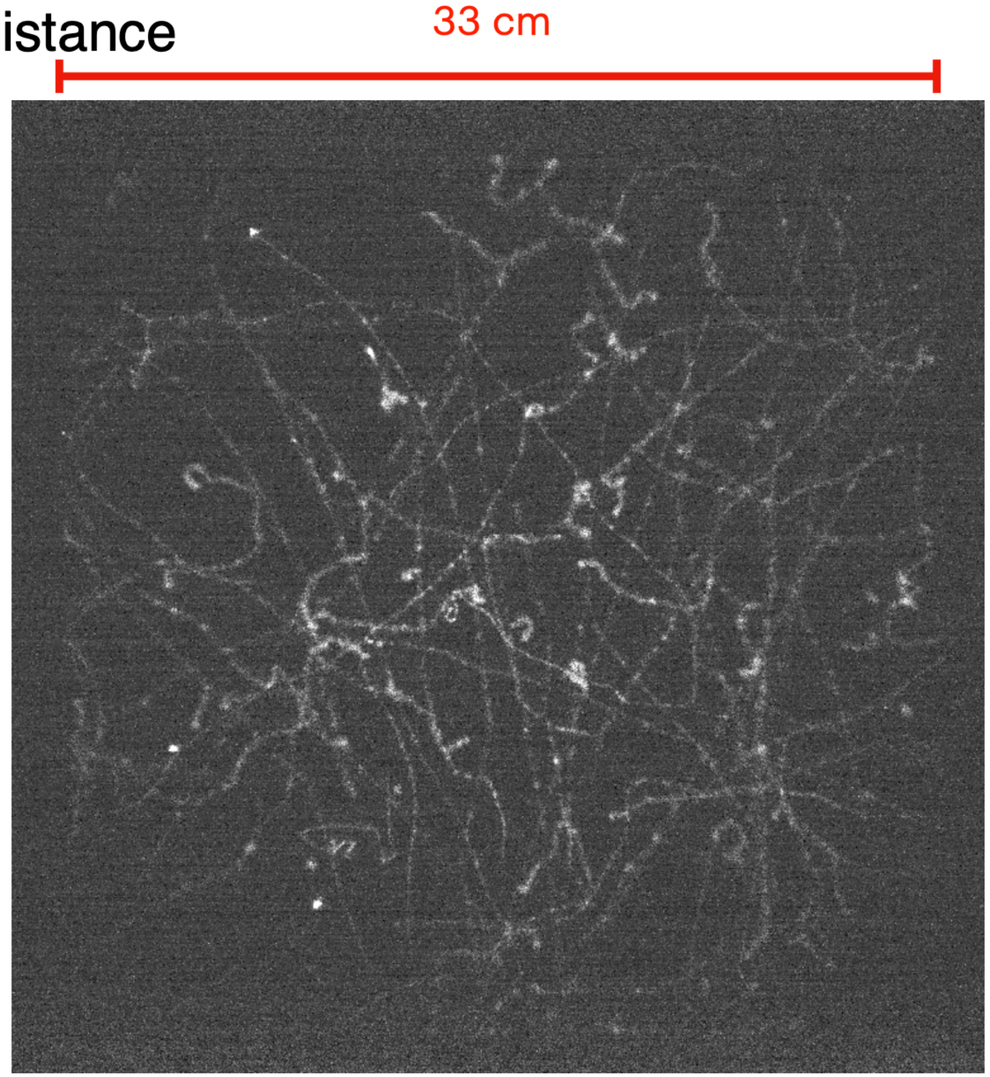
1 keV = 1200 photons



Overground images

- 2D projection of over the 50 cm drift distance

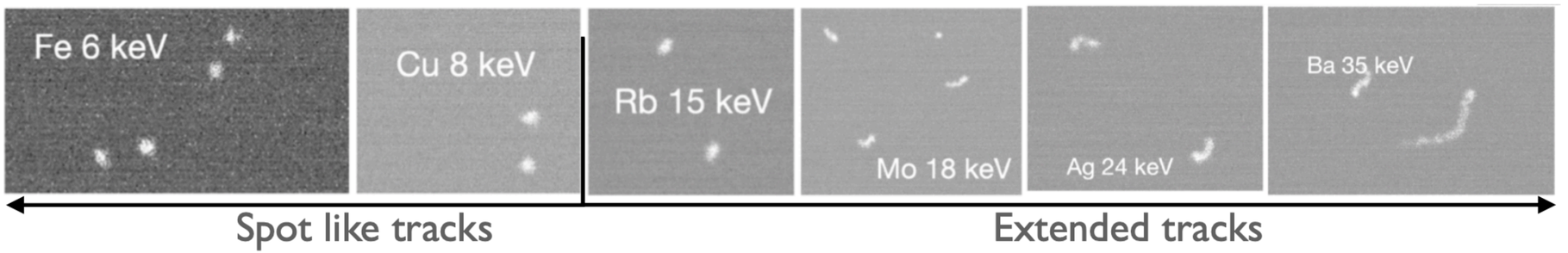




- Cosmic ray and radioactivity clearly visible (no shielding)

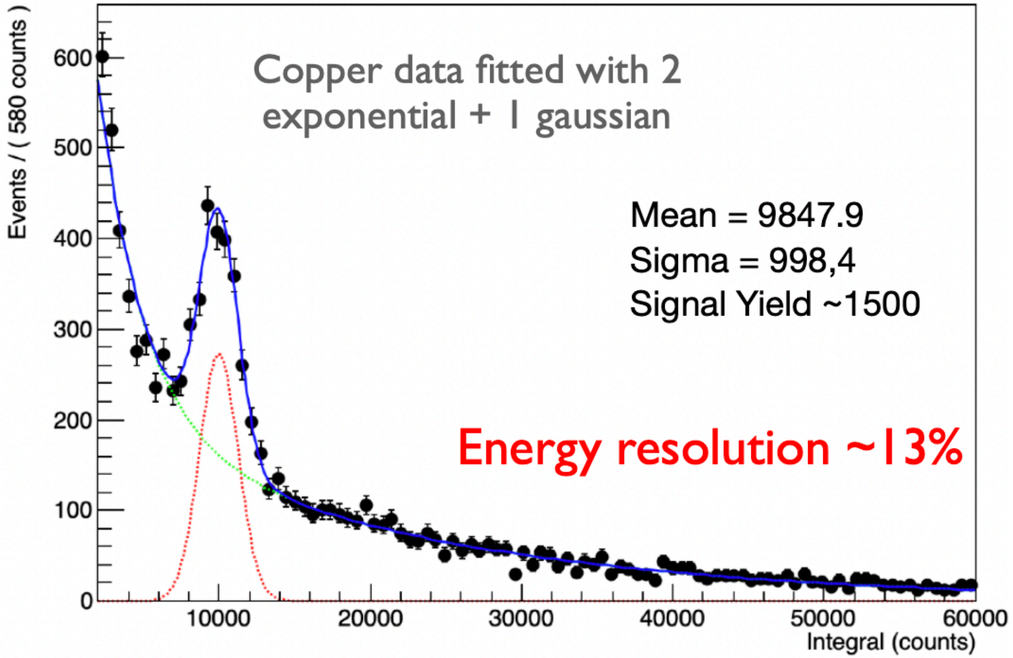
Energy response

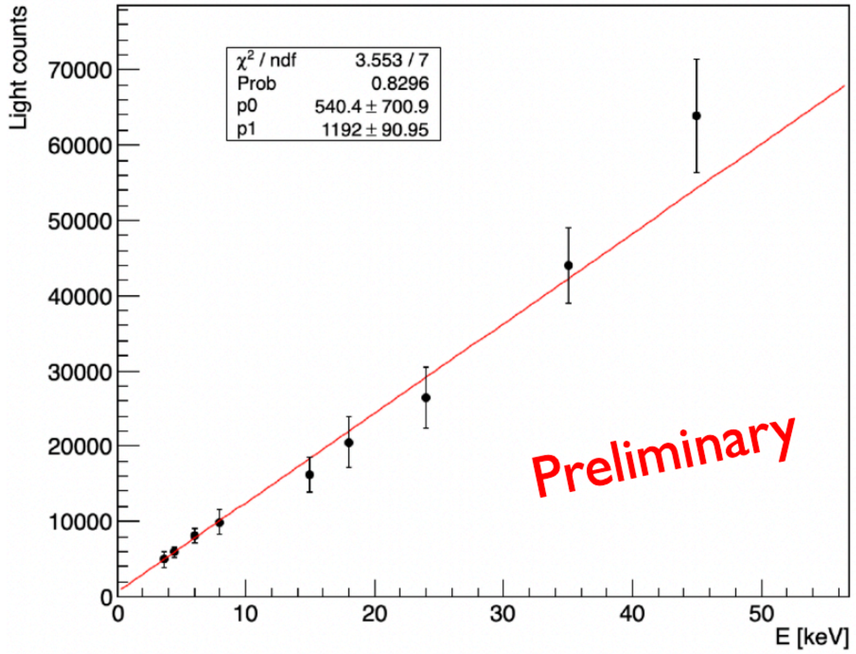
Study of linearity and energy resolution performed with different X-ray sources



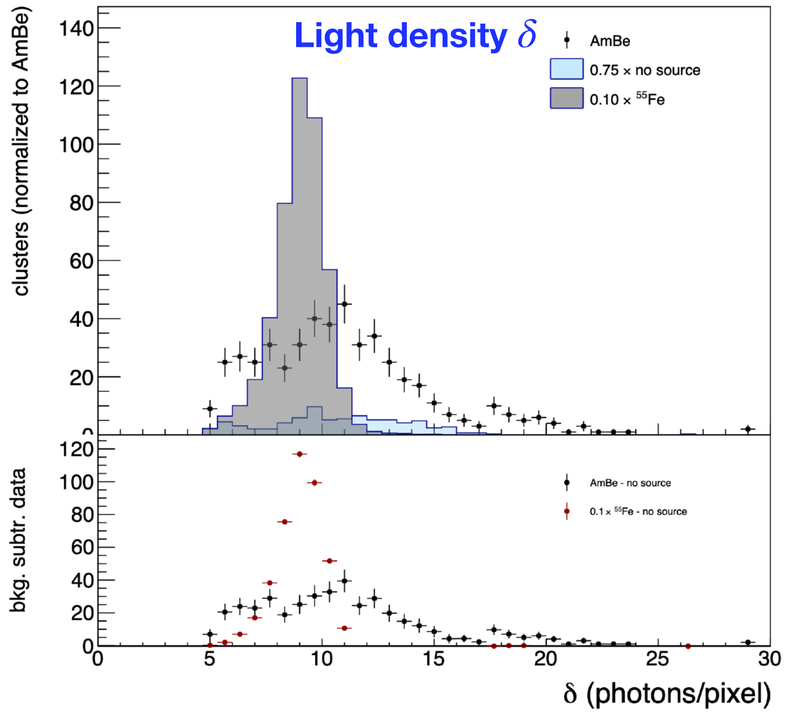
Data taken overground at LNF

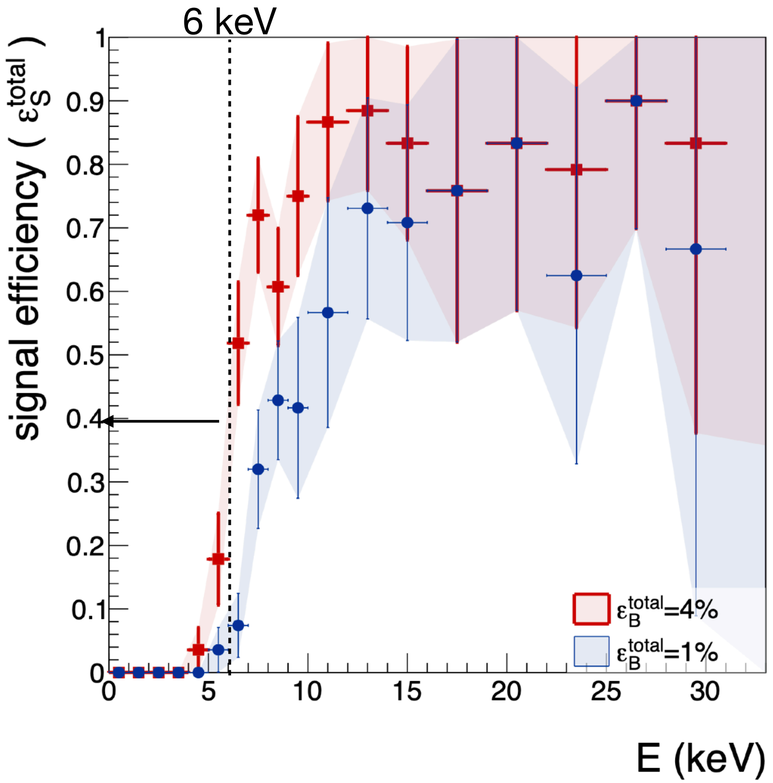
PRELIMINARY

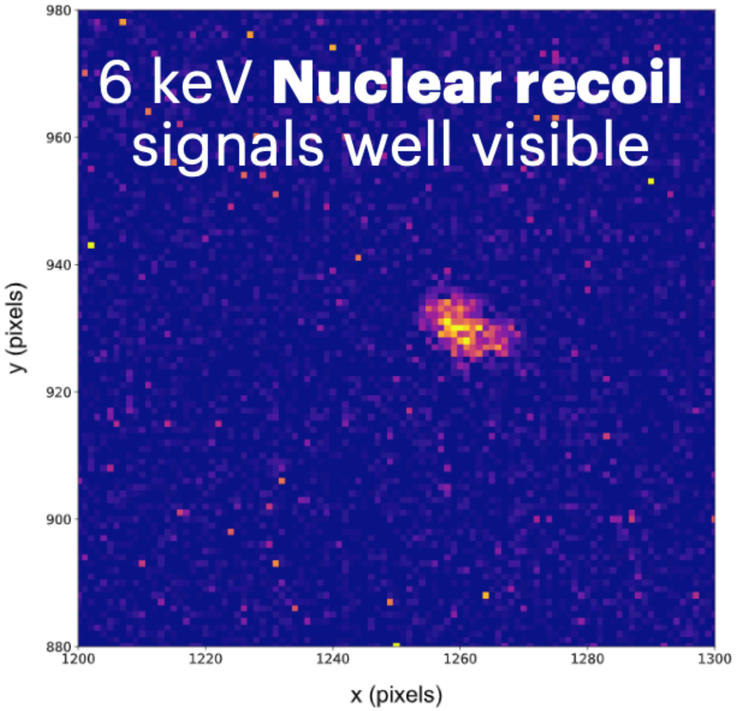




Response to low energy nuclear recoils







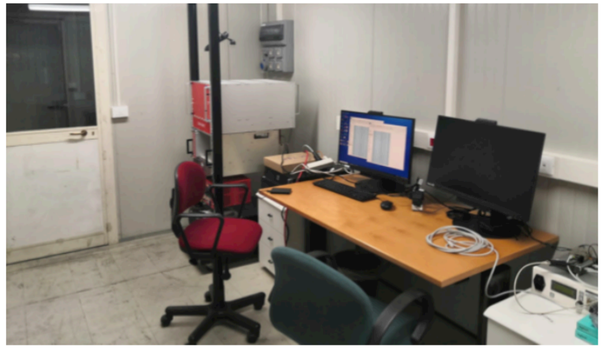
40% nuclear recoil efficiency at 6 keV_{ee} with 96% rejection against ^{55}Fe

CYGNO PHASE 0: LIME underground installation

- After the initial phase of tests overground, LIME is currently being installed at Laboratori Nazionali del Gran Sasso (LNGS) - INFN

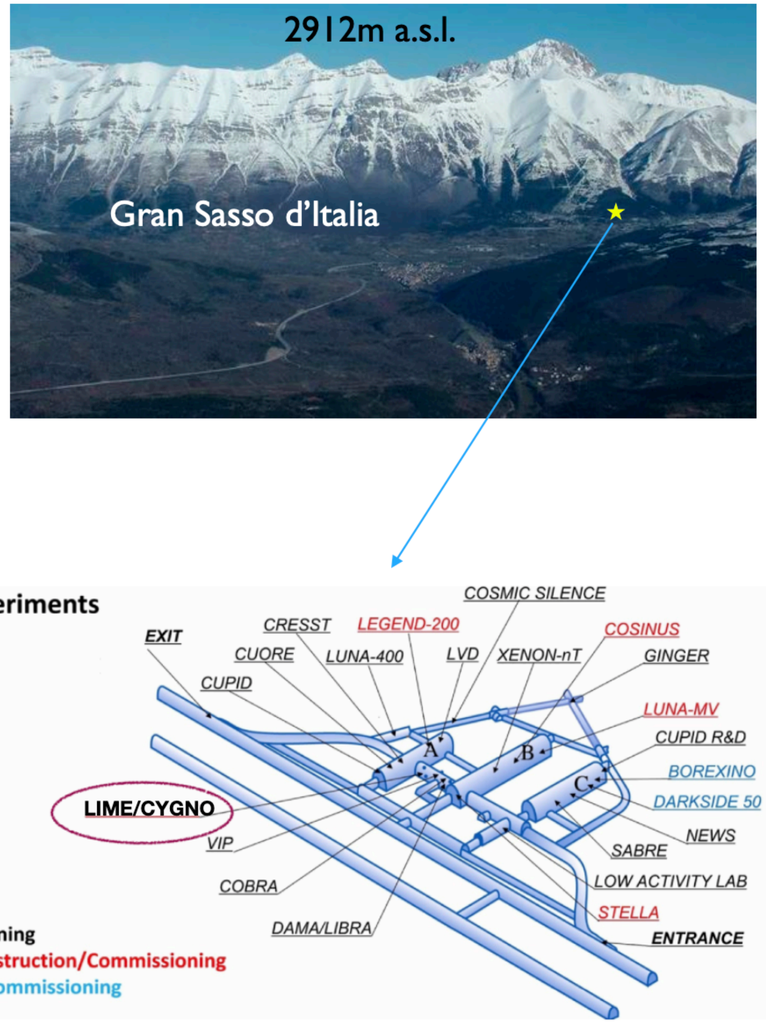
HV, VME, NIM crates

LIME inside the faraday cage



DAQ

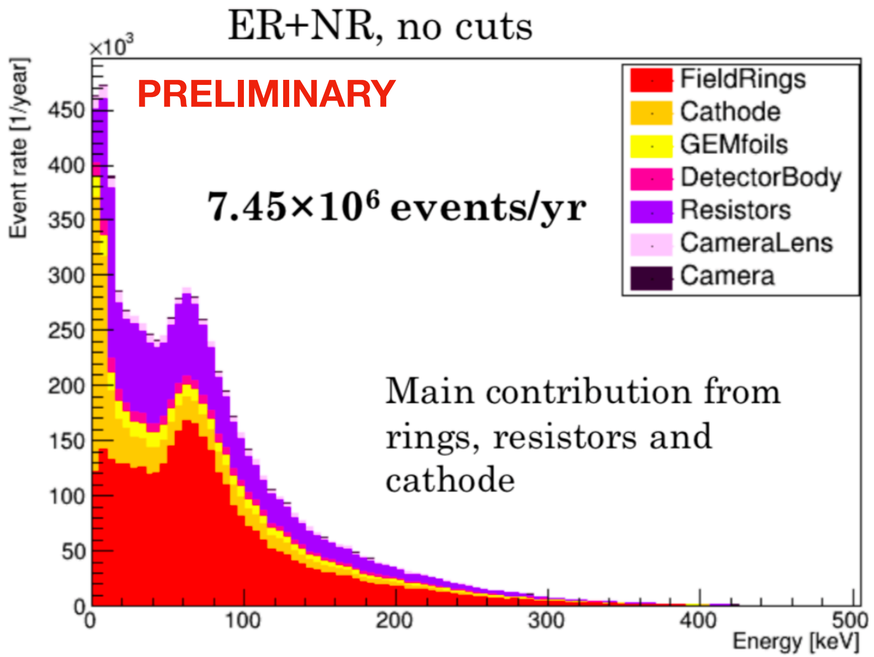
Gas System

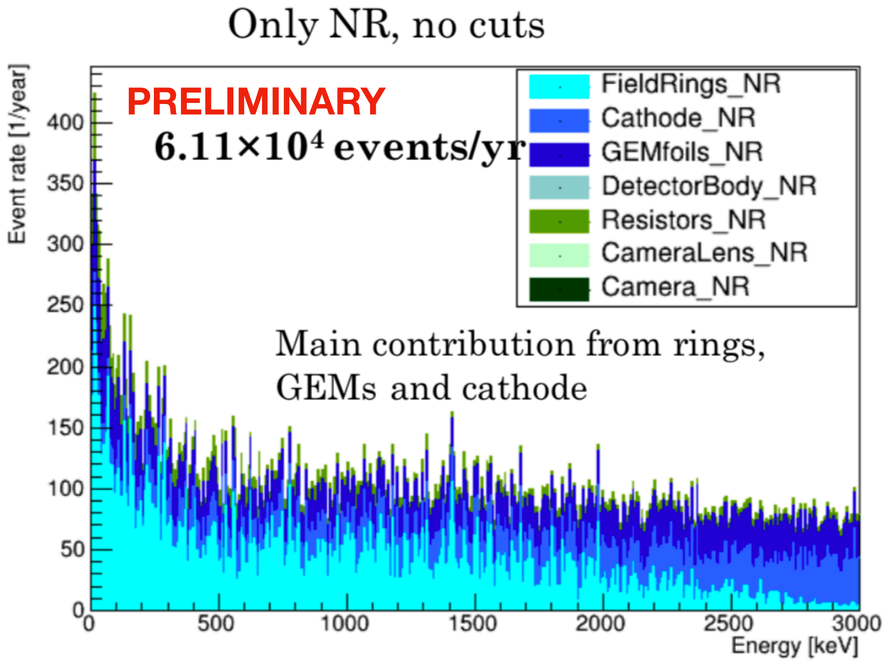


LIME Internal background

- **Activity** of all the main components of LIME was **measured underground** @ LNGS
- Natural radioactivity coming mainly from **decay chains of ^{232}Th, ^{238}U, ^{235}U, but also ^{40}K**
- Main contribution from **rings, resistors, GEM/cathode**
- Internal bkg can be **reduced** by 96% (99%) for ER (NR) with f**iducial cuts**

camera's components

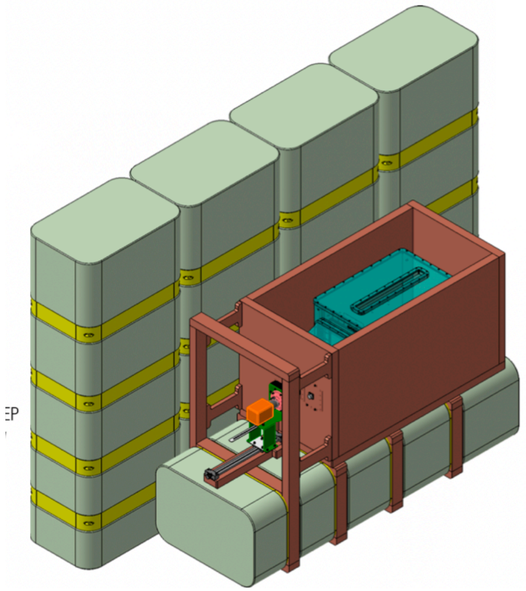


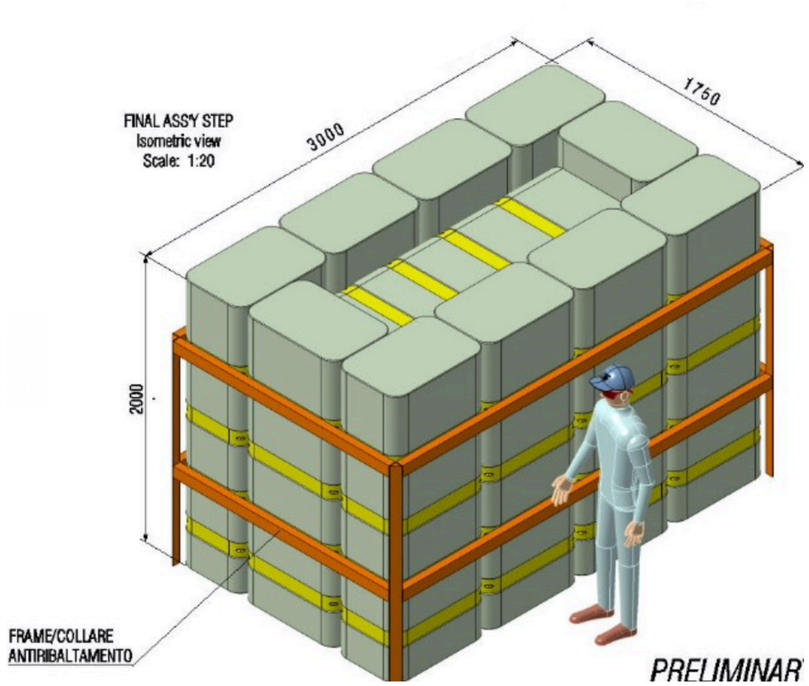


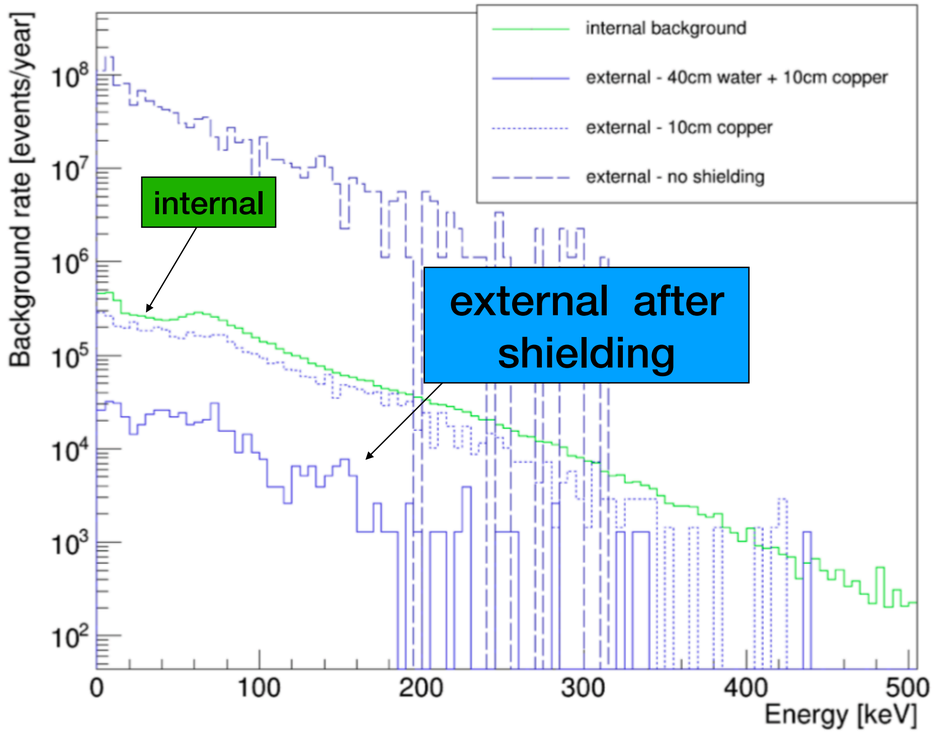
CYGNO PHASE 0: underground campaign

- Shielding: **10 cm of copper and 40 cm of water**
- Validation of Monte Carlo simulation and shielding
- Measure neutron flux in the 1-100 keV range (expect 200 NR from neutron in 4 months)

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	$1.5344(7)\times10^{6}$	$2.46(1)\times10^{5}$

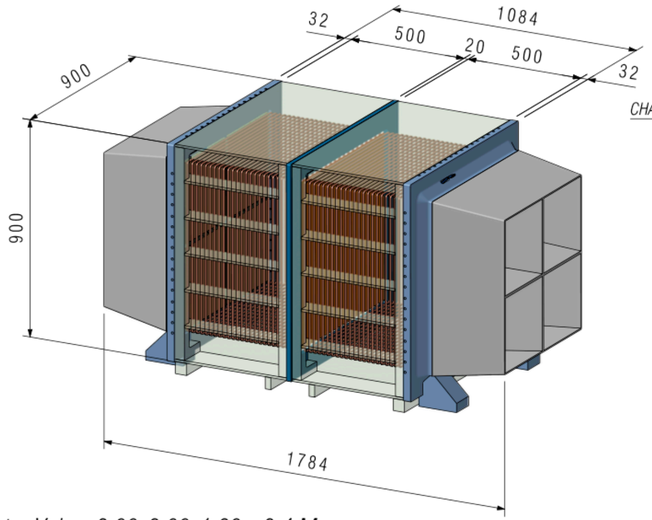


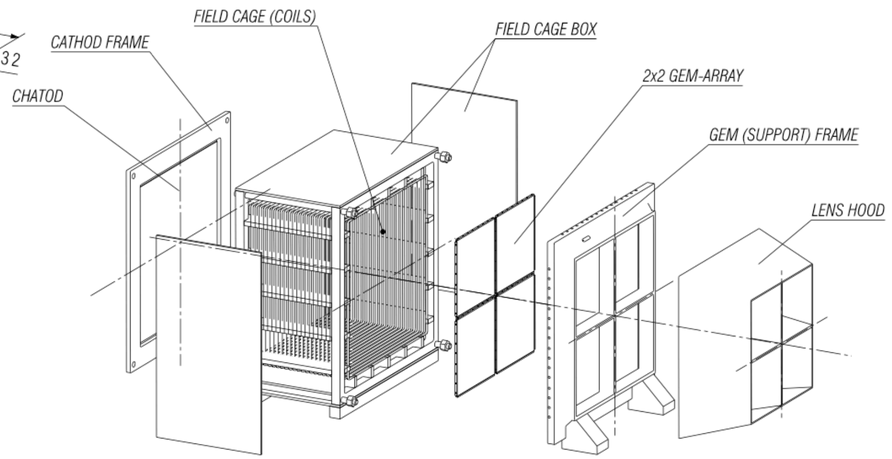




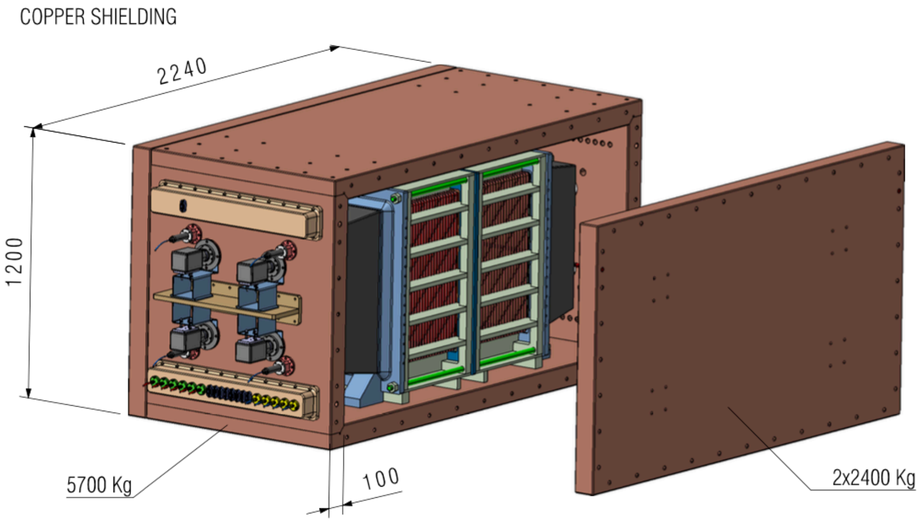
PHASE 1: CYGNO_04 preliminary design

- 2 field cages with a common cathode closed by 2 matrices of **2x2 triple GEMs.**
- Each GEM is readout by a **module identical to LIME**.
- low radioactivity PMMA vessel.
- Enclosed by 10 cm Cu + 110 cm water.





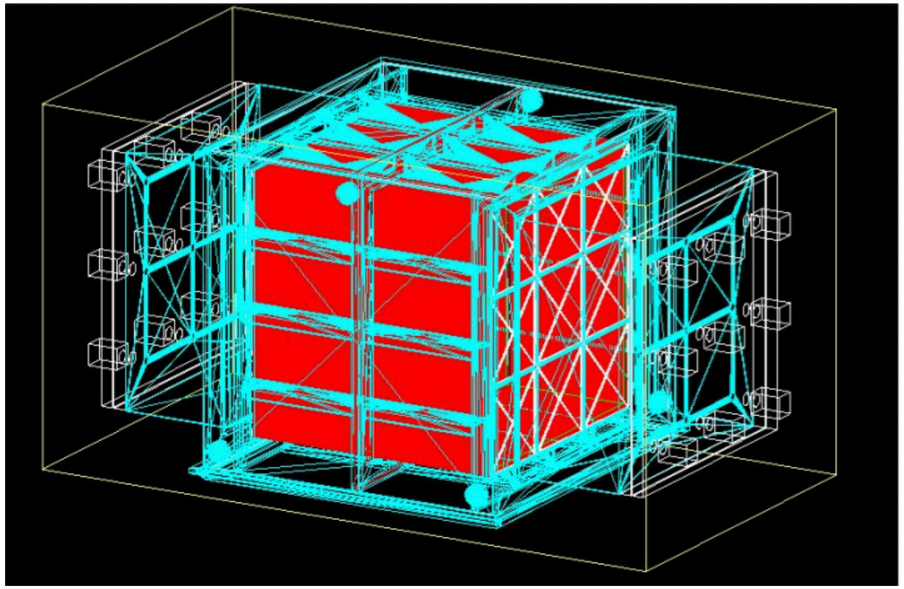
Detector Vol = 0.66x0.66x1.03=0.4 Mc



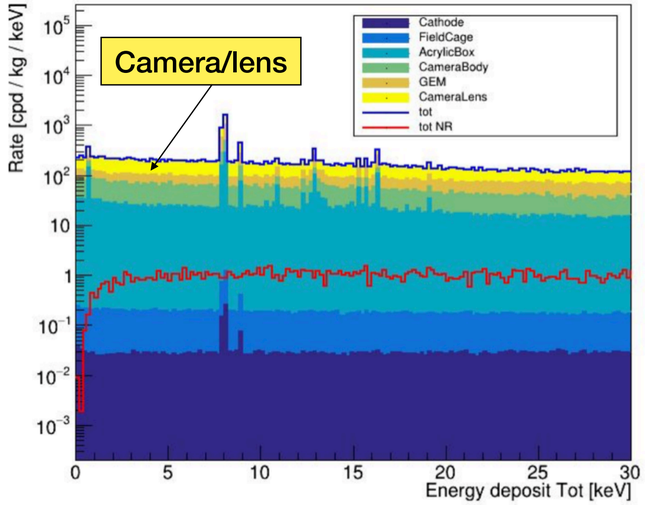
Detector has been funded
Designed at LNF and to be installed at LNGS

PHASE 1: CYGNO_04 backgrounds

Full background simulation for 1 m3 detector

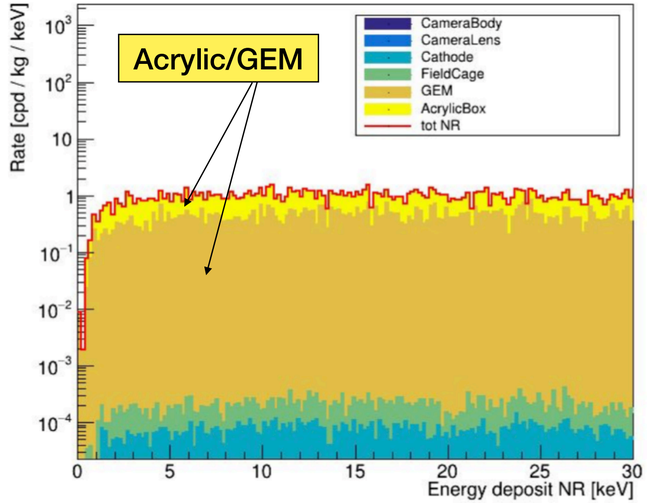


- CYGNO_04: ER rate [1-20] keV = 4.9×10^5 cts/yr



Internal ER background

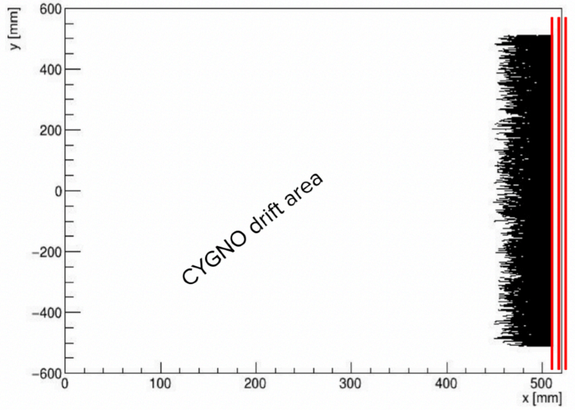
- CYGNO_04: NR rate [1-20] keV = 2.6×10^3 cts/y



Internal NR background

- **NR**: mostly from **GEMs [0.5 Bq/kg]** / **vessel [0.03 Bq/kg]** reducible with fiduacal cuts
  - Low radioactivity GEMs at CERN following T-Rex R&D
- **ER:** mostly form **lens [55 Bq/kg]** / **camera [3.2 Bq/kg]**
  - working with producing companies to reduce the radioactivity of the sensor and lens [<50 mBq/kg]

GEMs are here

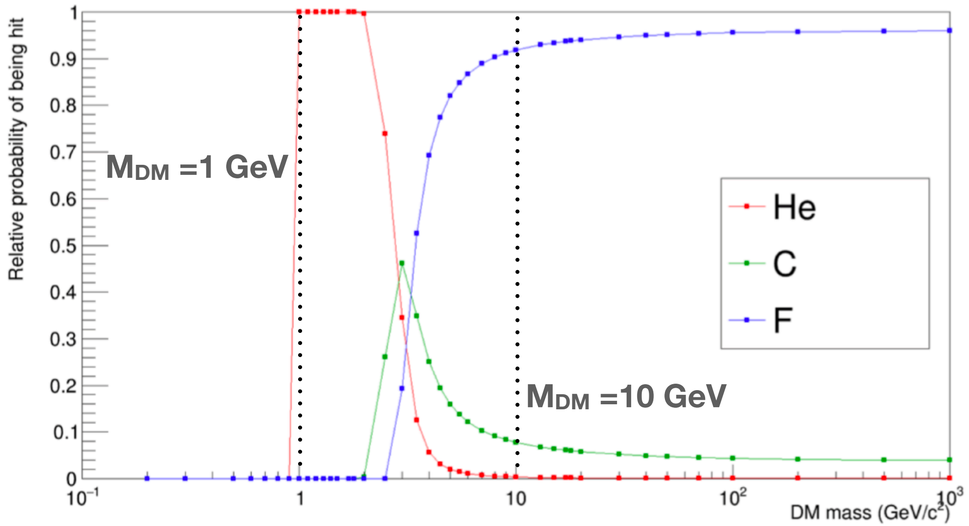


PHASE 2: The CYGNO experiment 30 m³

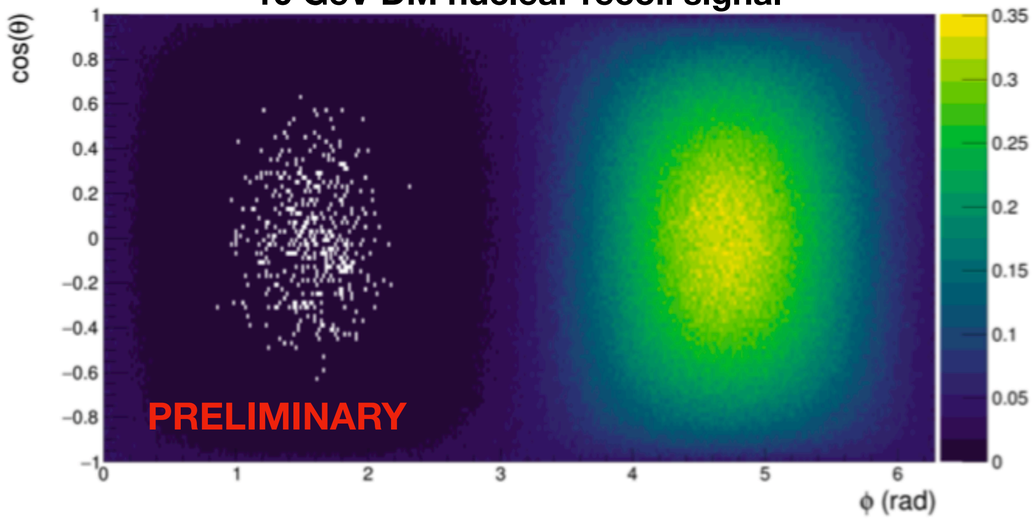
Searching for low mass DM

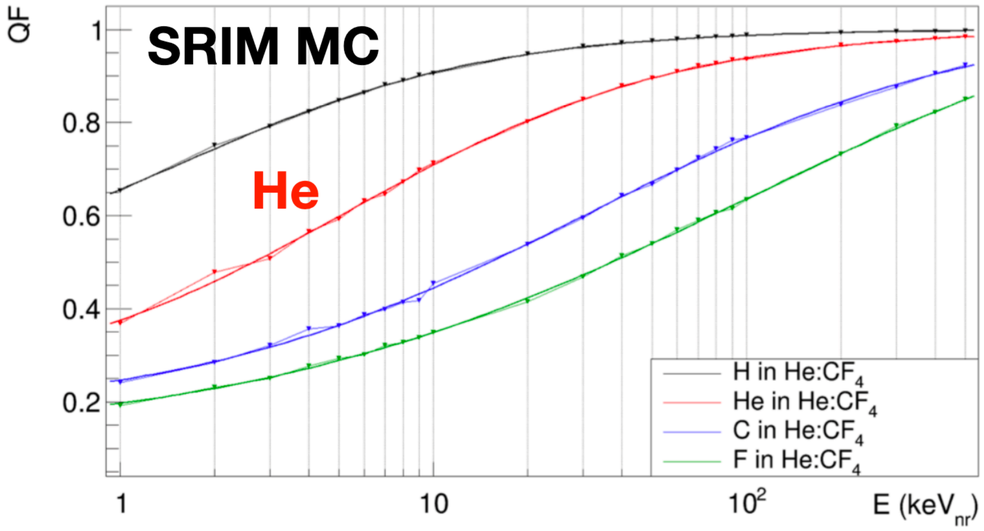
- **Use 1(0.5) keVee threshold**
- **QF evaluated with SRIM**
- **Angular distribution as discriminating information**
  - full head/tail recognition
  - 30 deg. resolution
- **Various scenarios with different background levels**
  - isotropic distribution

relative probability to detect a NR at 1 keV



10 GeV DM nuclear recoil signal

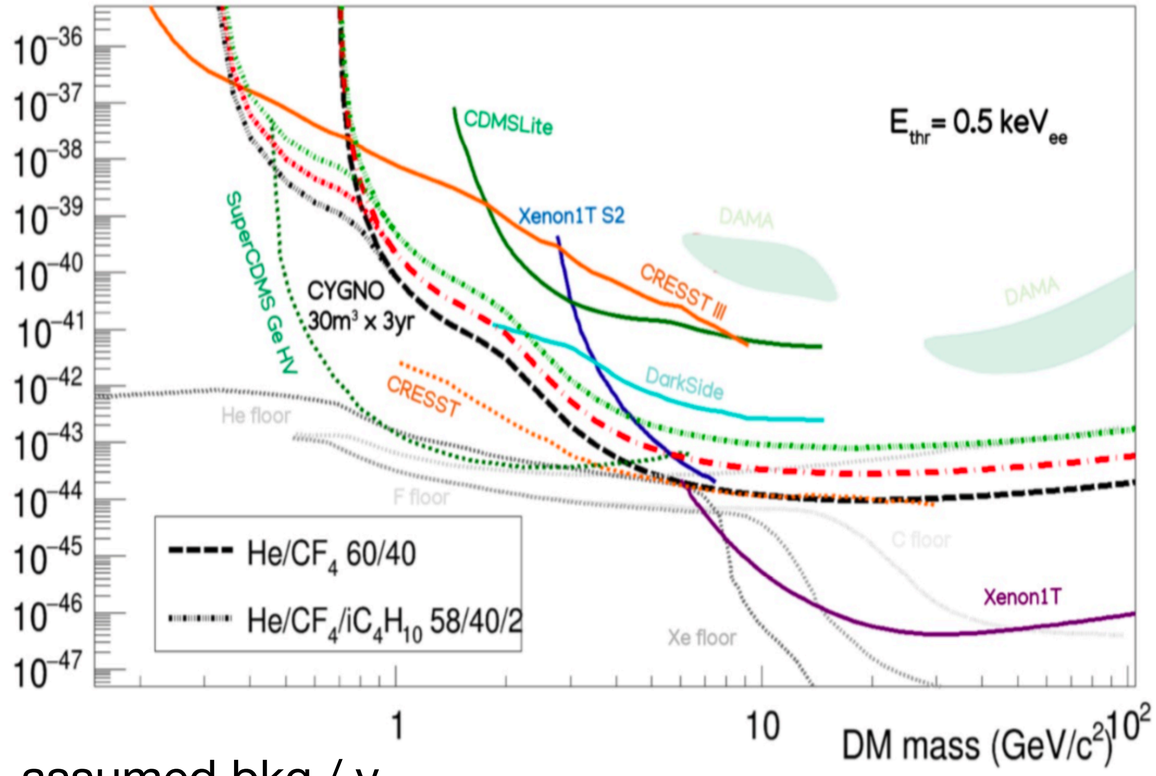




PHASE 2: The CYGNO experiment 30 m³

Searching for low mass DM

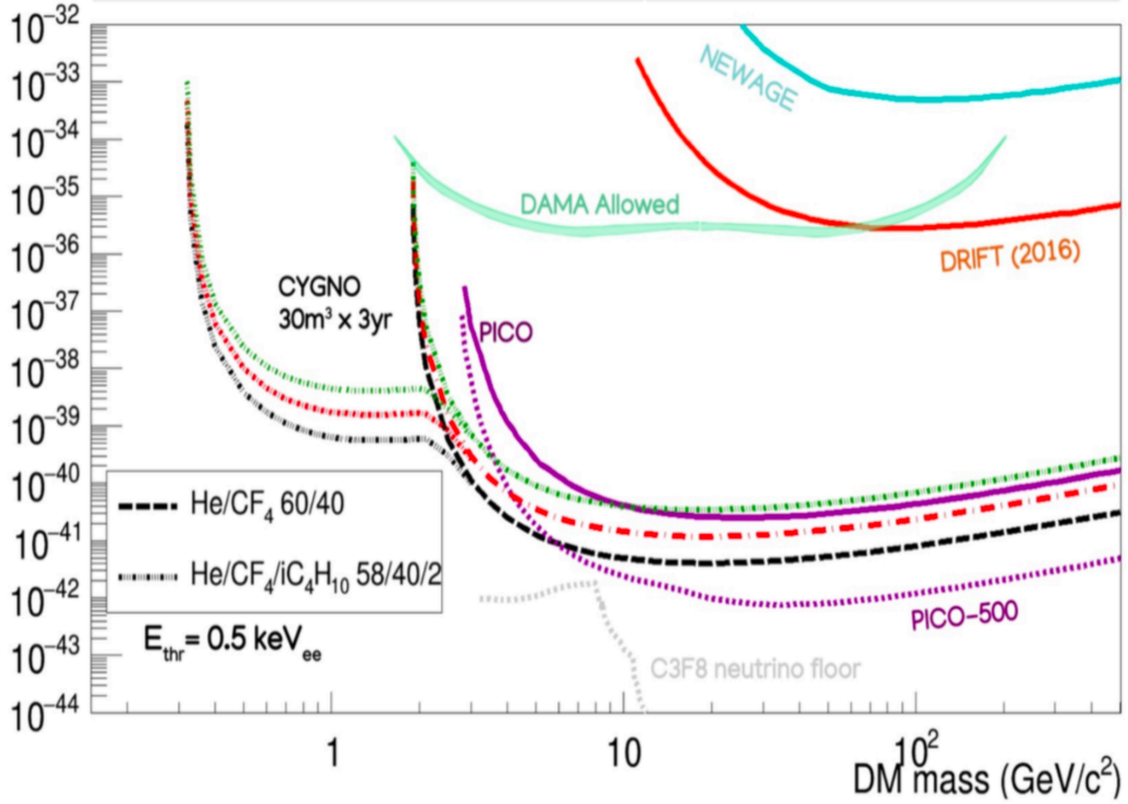
Spin Independent



assumed bkg / y

- $n_{BKG} = 10^2$
- $n_{BKG} = 10^3$
- $n_{BKG} = 10^4$

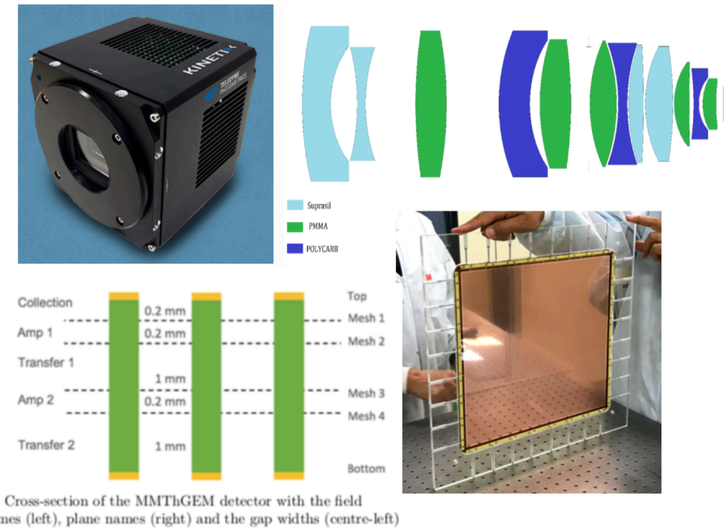
Spin Dependent



New R&D activities

Minimise internal radioactivity

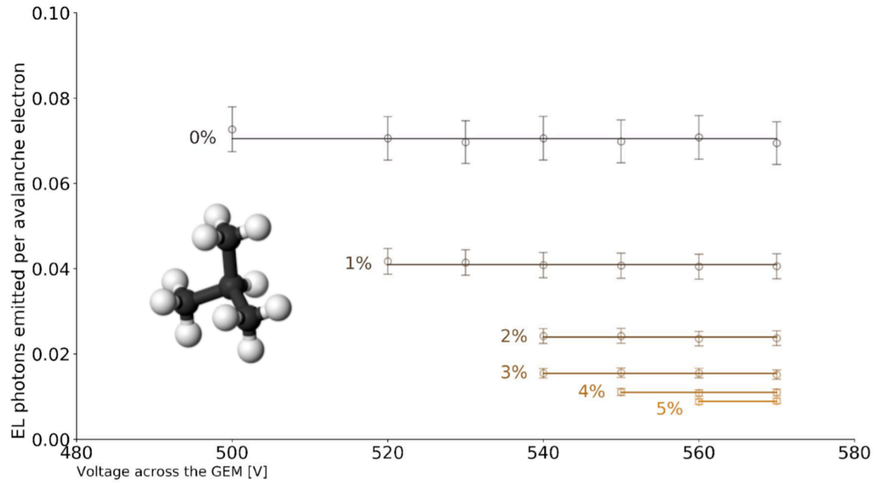
- Develop **custom sCMOS** sensor
- Realisation of **custom lens** with large aperture & low radioactivity



(a) Cross-section of the MMThGEM detector with the field names (left), plane names (right) and the gap widths (centre-left)

Gas studies

- adding **hydrogenated gas** (CH_4)
- First demonstration of a **very good light** yield from with hydrocarbons
- Work on eco-friendly gas mixture as substitute for CF_4

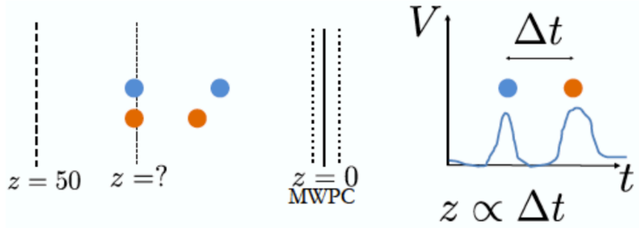


Negative ion drift

(financed by ERC INITIUM GA 818744)

- Add SF_6 to produce **negative ions** drift resulting in **better fiducialization**
- First encouraging results at nearly **atmospheric pressure**

JINST 13 (2018) 04, P04022



Summary

- The CYGNO collaboration is developing a **He:CF_4 TPC with optical readout**
  - **CYGNO PHASE 0 commissioned overground**: very good detector stability, energy and position resolution;
  - **CYGNO PHASE 0 installed underground at LNGS:** measure neutron flux, validate the background model, shielding configuration;
  - **CYGNO PHASE 1:** construct and operate a **CYGNO demonstrator** to pave the road for a larger apparatus for Dark Matter search.
- A 30-100 m^3 CYGNO detector might connect to a multi-site **CYGNUS observatory** for rare events

Acknowledgements

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CYGNO Project is funded by INFN.

Thank you!

The CYGNO collaboration:

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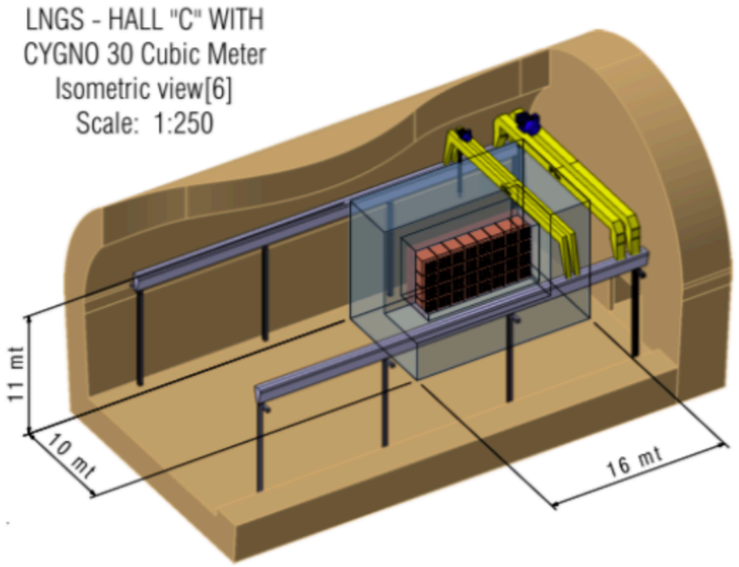
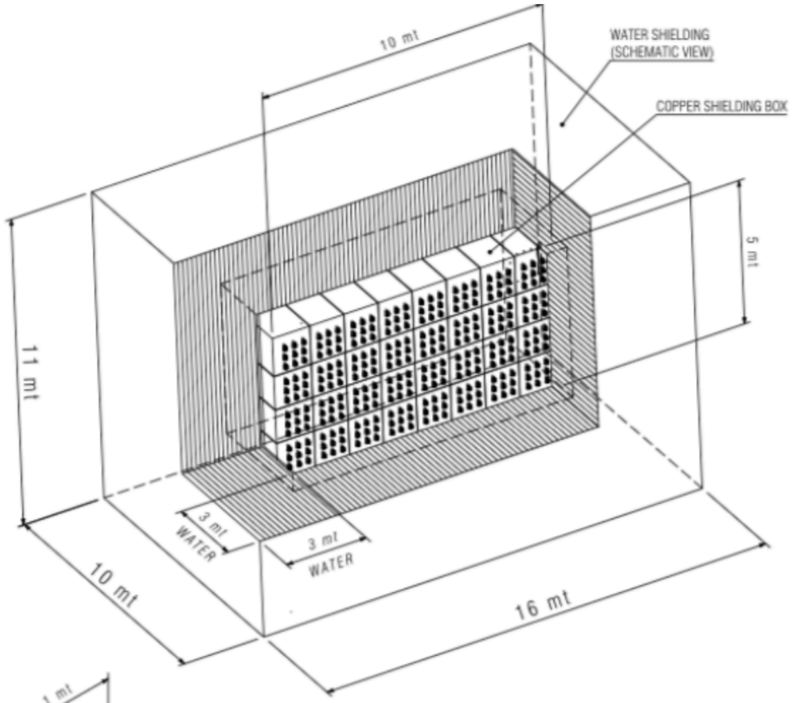
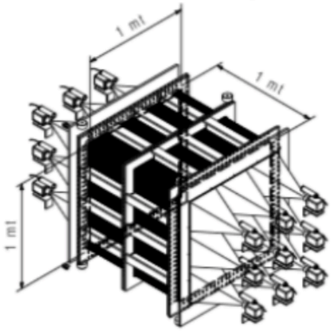
Phase2 CYGNO 30

- Modularity of the detector: it will be composed by many identical CYGNO phase1 detectors

- It will be used for the physics research:
  - Dark matter
  - Solar neutrinos
  - …







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

REVISIONS			
-	DATE: -	NAME: -
-	DATE: -	NAME: -
-	DATE: -	NAME: -
TOTAL WEIGHT (kg)	DATE	DRAWN
	23/11/2020	C.Capoccia
SCALE	DATE	CHECKED
1:1	-	-
SHEET	DATE	APPROVED
1/1	-	-

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

CYGNO 30 Mc

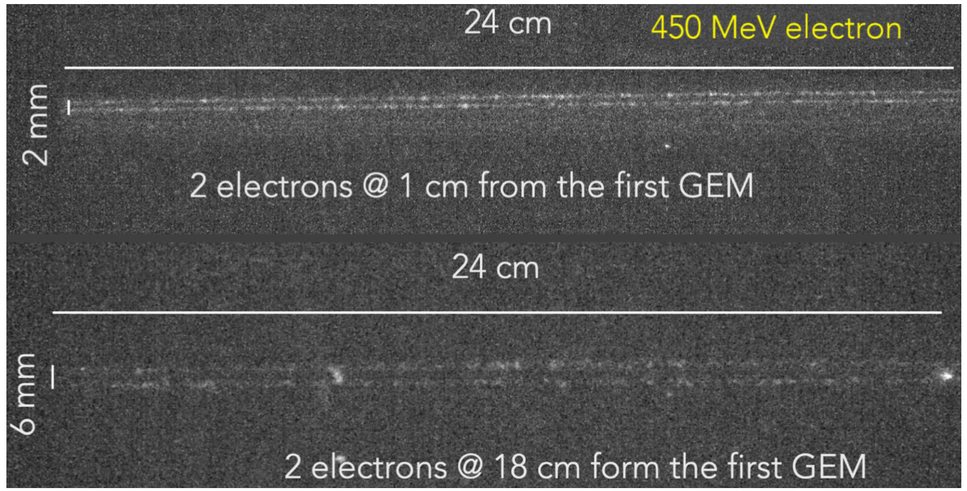
Response high energy electrons: tracking and fiducalization

NIM A 999 (2021) 165209

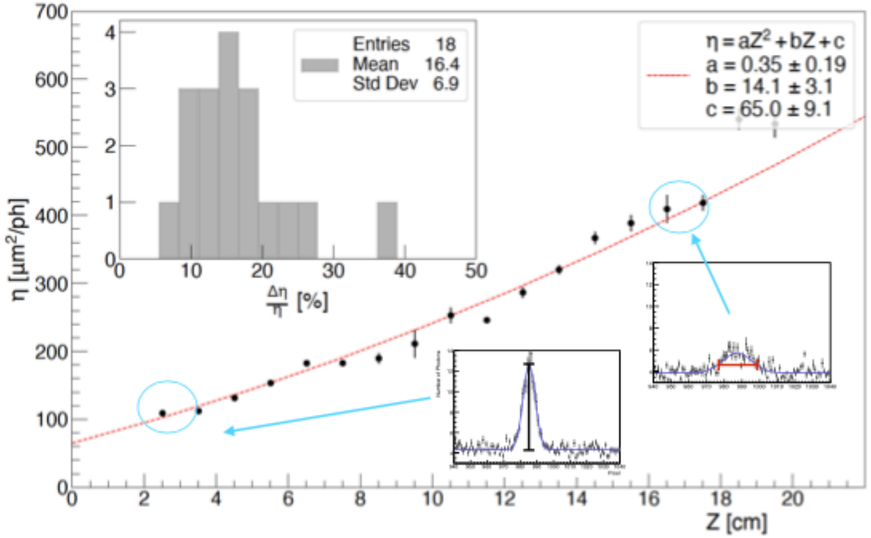
The diffusion can be exploited to estimate the z position of the event.

The width (S) and amplitude (A) of the transverse light profile and PMT waveform become larger and smaller respectively with increasing distance from the GEM (z position).

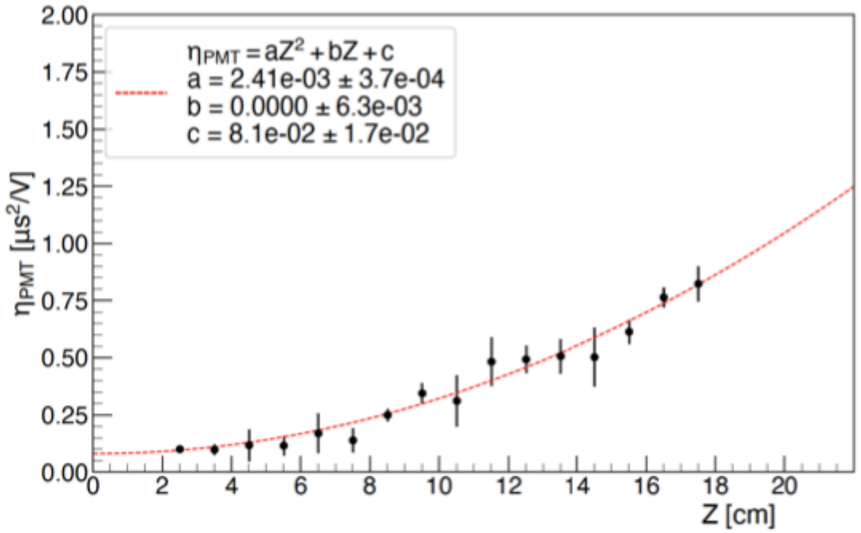
Thus $\eta = \frac{S}{A}$ increases



sCMOS

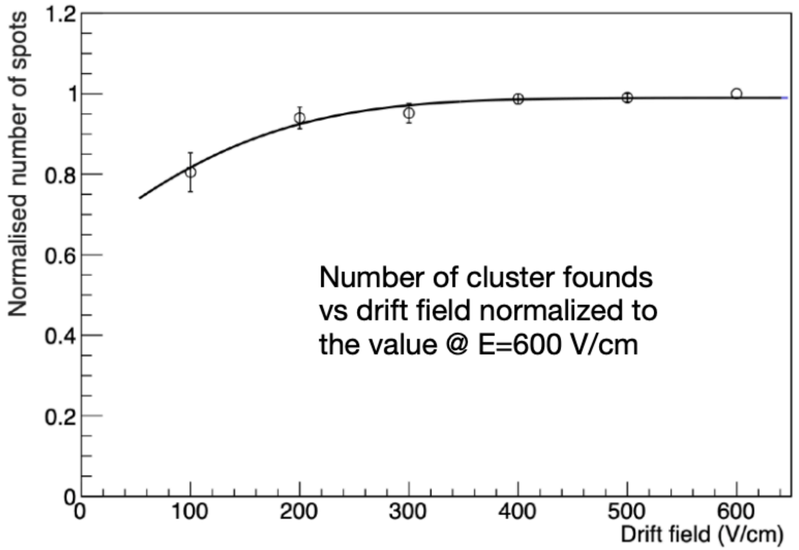


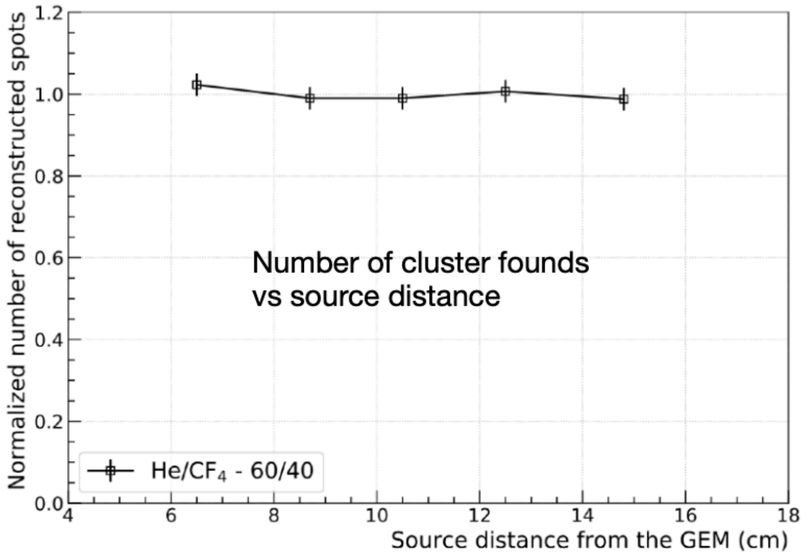
PMT

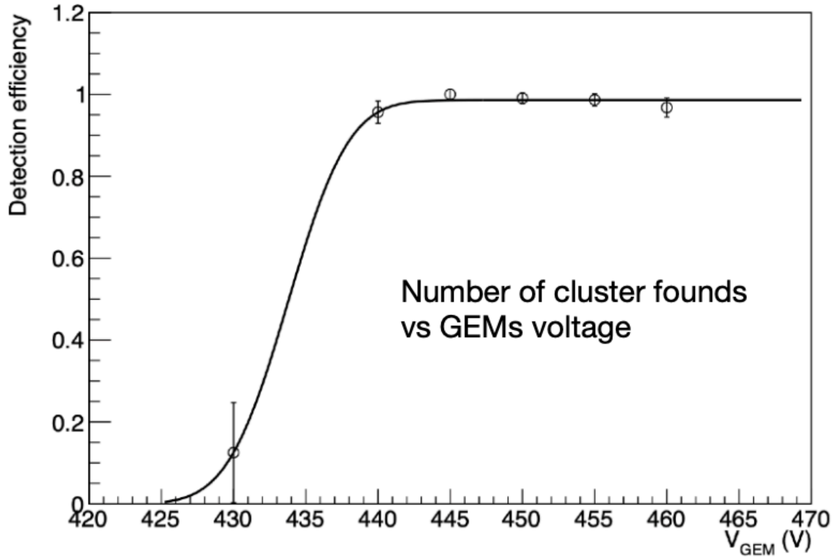


Both with light and charge 15% z position resolution (y evaluated with 100-300 μm resolution)

Detector efficiency

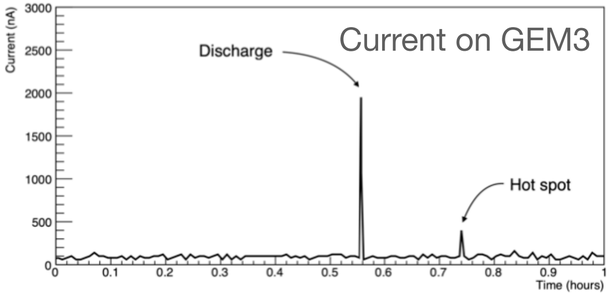


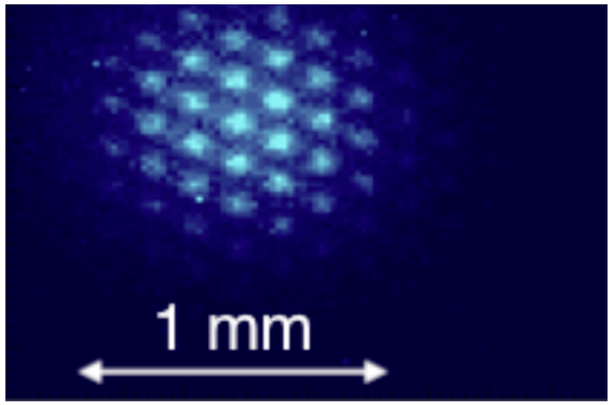




Large prototypes stability tests

JINST 15 (2020) P10001



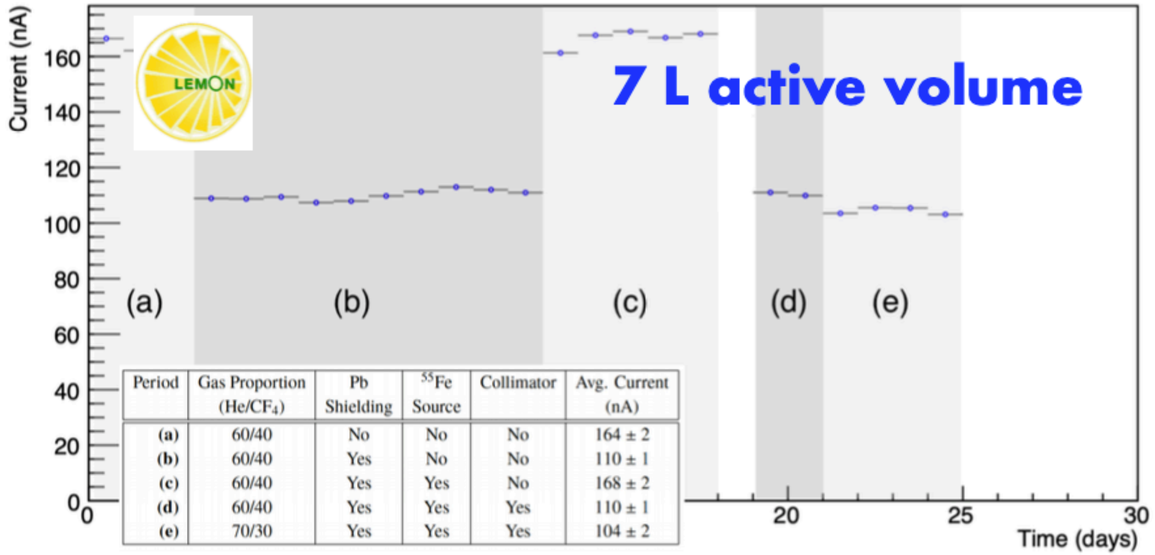


Hot spots and **Discharges:** dumped by lowering GEMs voltage to 100 V and raising it again (3 min deadtime)

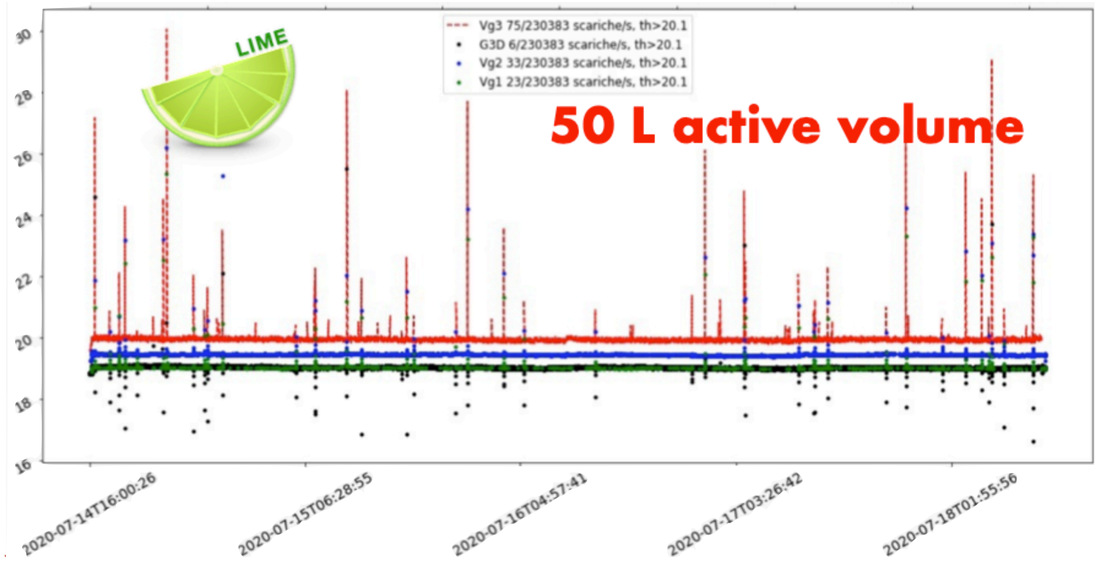
He:CF4 60:40% 1 atm

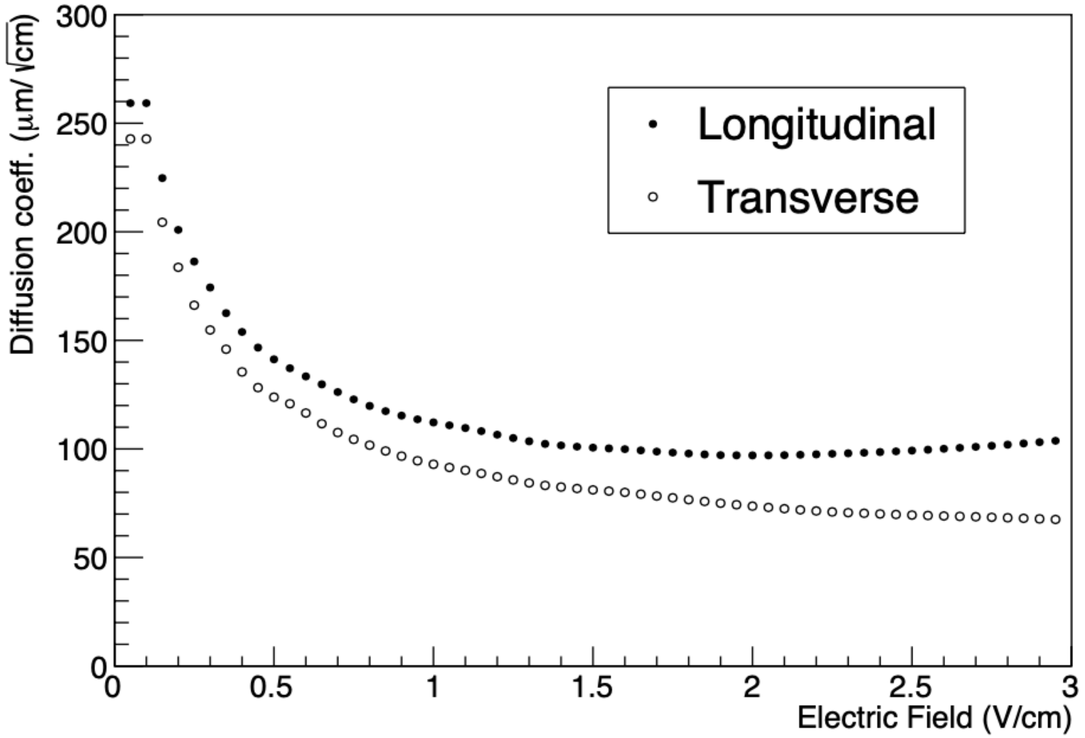
LEMOn successfully operated for 25 consecutive days with automatic GEM hot spots recovery procedure

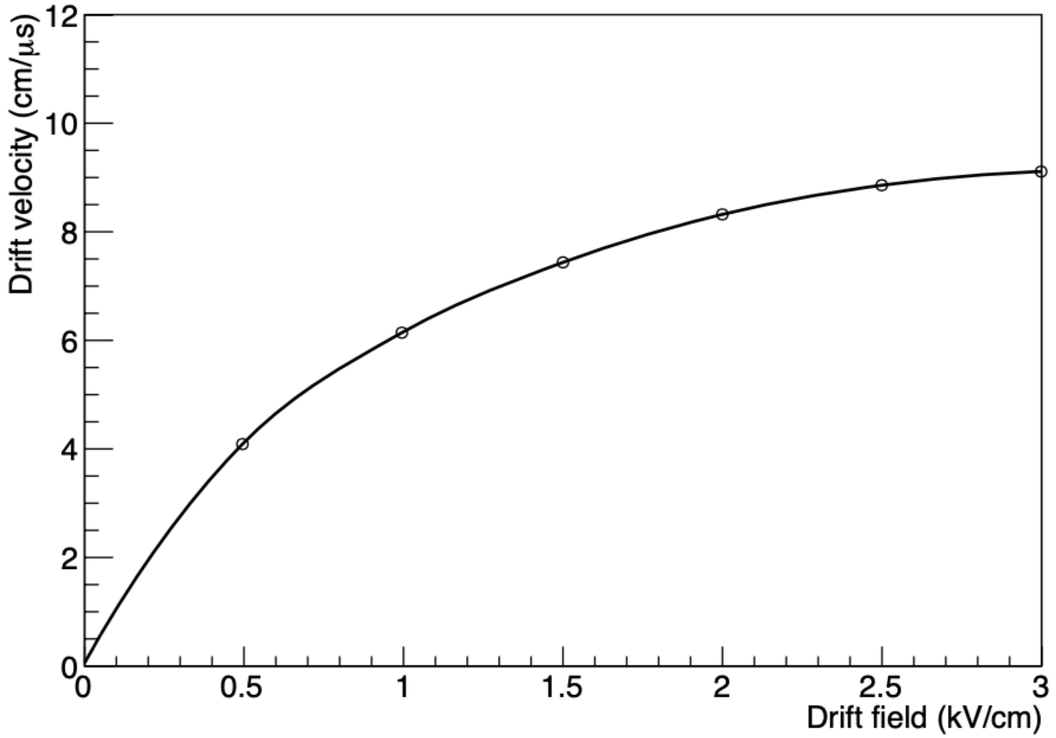
Similar stability with LIME: (less than 1 evt/hour) in agreement with a factor of 2 larger GEMs



Period	Gas Proportion (He/CF_4)	Pb Shielding	^{55}Fe Source	Collimator	Avg. Current (nA)
(a)	60/40	No	No	No	164 ± 2
(b)	60/40	Yes	No	No	110 ± 1
(c)	60/40	Yes	Yes	No	168 ± 2
(d)	60/40	Yes	Yes	Yes	110 ± 1
(e)	70/30	Yes	Yes	Yes	104 ± 2




Diffusion coeff. (μm/√cm)
300
250
200
150
100
50
0
0
0.5
1
1.5
2
2.5
3
Electric Field (V/cm)
Longitudinal
Transverse


Drift velocity (cm/μs)
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
3
Drift field (kV/cm)