3rd International Conference on

DETECTOR STABILITY AND AGING PHENOMENA IN GASEOUS DETECTORS

CYGNO Experiment

Study of long term stability of a 50 liters TPC, based on TRIPLE-GEM with optical readout, for the CYGNO experiment

RITA ANTONIETTI - UNIVERSITÀ DI ROMA TRE & INFN ROMA TRE

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ROMA TRE UNIVERSITÀ DEGLI STUDI

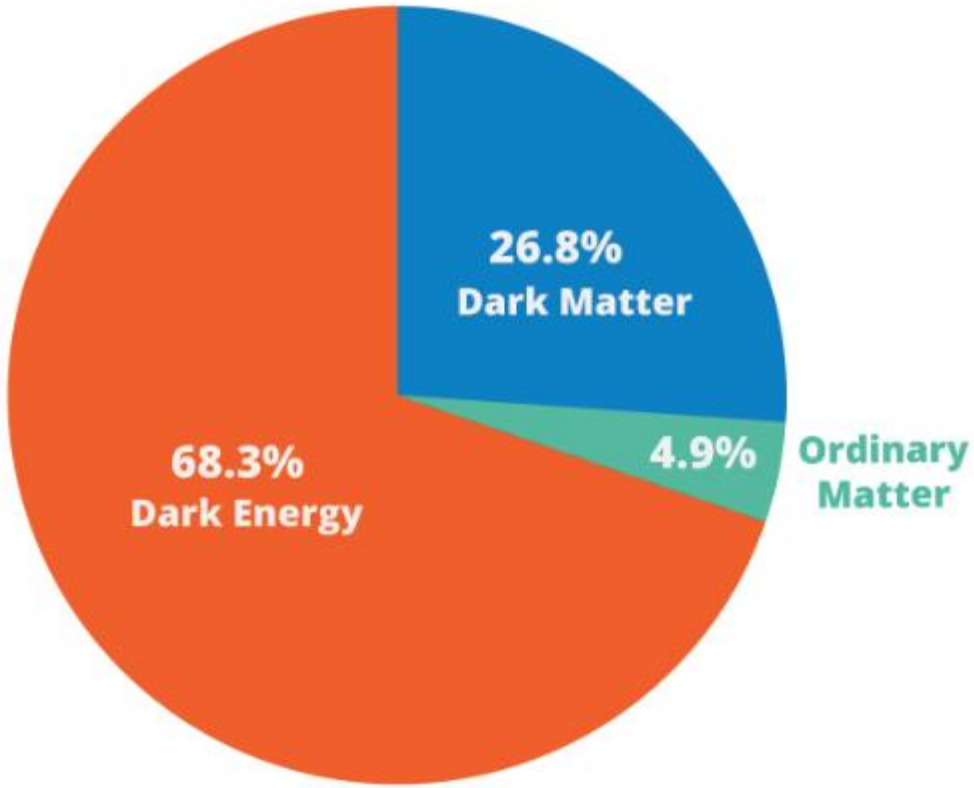
GSSI

ufjf Universidade Federal de Juiz de Fora

CBPF

INFN Istituto Nazionale di Fisica Nucleare

Physics motivation



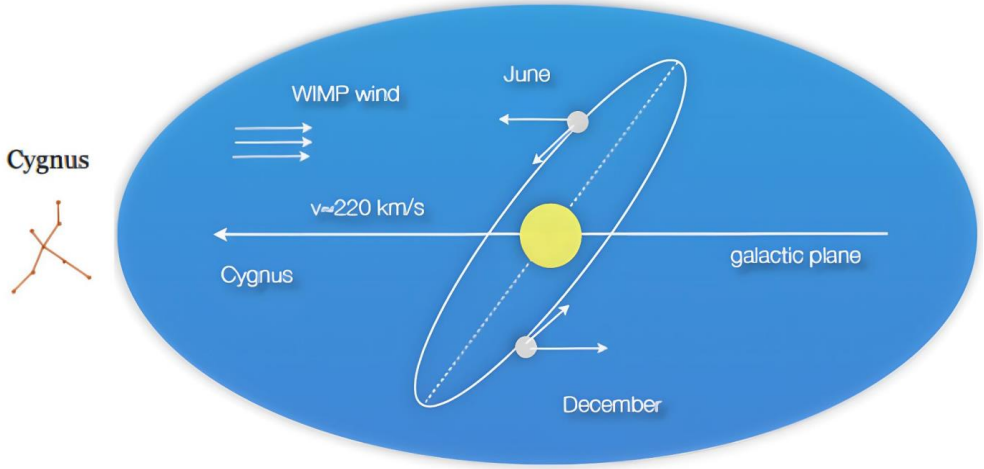
The presence in the Universe of large amount of non-luminous matter, **Dark Matter (DM)** is nowadays a paradigm

One of the DM particle candidates are the **WIMPs** (Weakly Interactive Massive Particles) :

- Electrically neutral;
- Very low interacting particles;
- Large mass range, CYGNO will look low mass range (0.5-10 GeV)

Travelling throught DM

- Dark Matter forms a halo around Our Galaxy;
- Our Solar system rotates around galaxy center apparently in the direction of the Cygnus constellation;
- Motion of our Galaxy creates an apparent wind of DM coming from Cygnus constellation towards Earth.

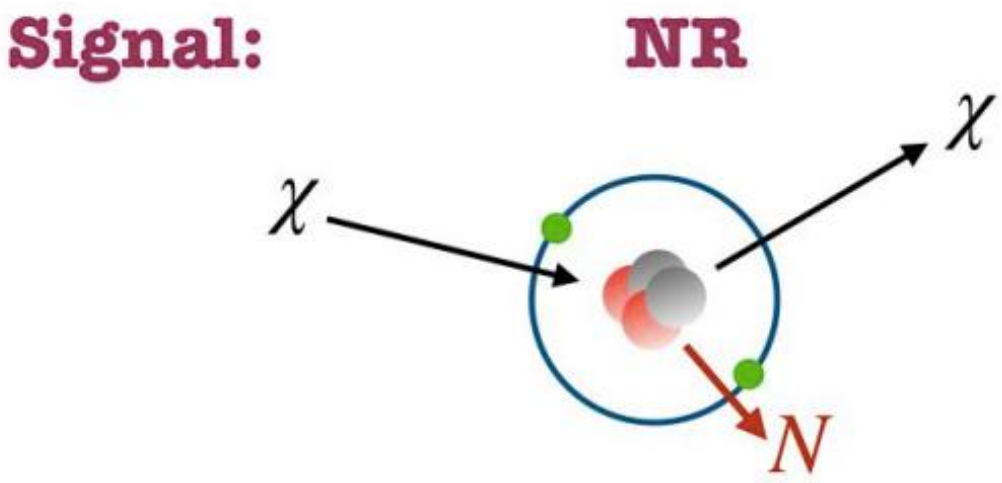


In the Earth rotation around the Sun: a seasonal modulation of few percent in the signal is expected;

Due to the Earth rotation around its axis, an observer on Earth would see the average DM incoming direction changing every 12 hours.

Signal

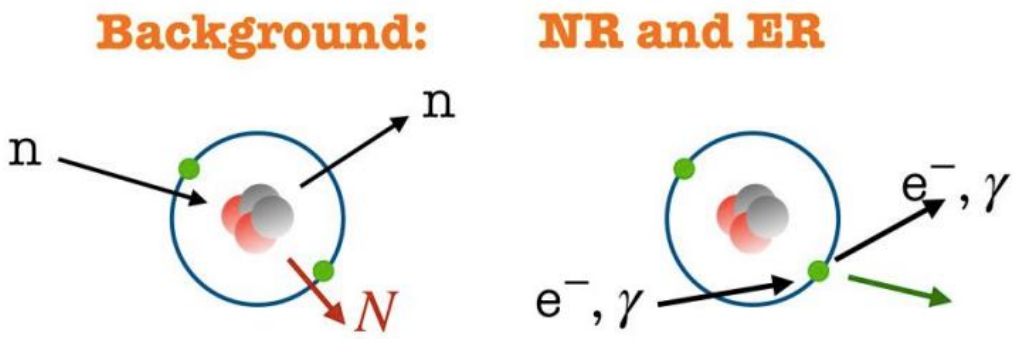
To not relativistic speed, elastic scattering with ordinary matter, are expected to be the most evidence of WIMP interactions.

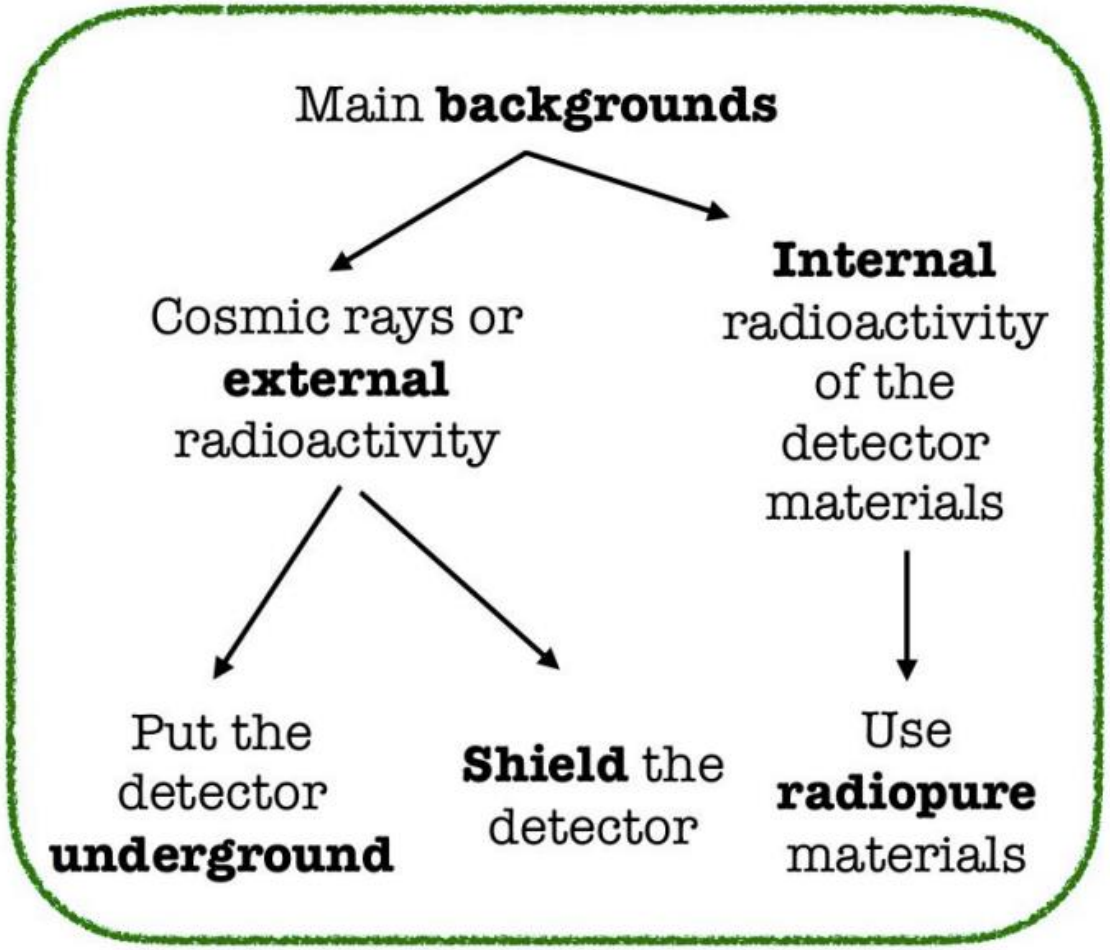


Directional discrimination is the only way to unambiguously identify a DM signal given the anisotropy in the angular distribution that no background can mimic.
Directional measuraments can discriminate between various DM halo models and provide constrints on WIMP properties, like no other non-directional detector.

Background

Challenge -> to discriminate the low energy nuclear recoil from interactions induced by other particles.





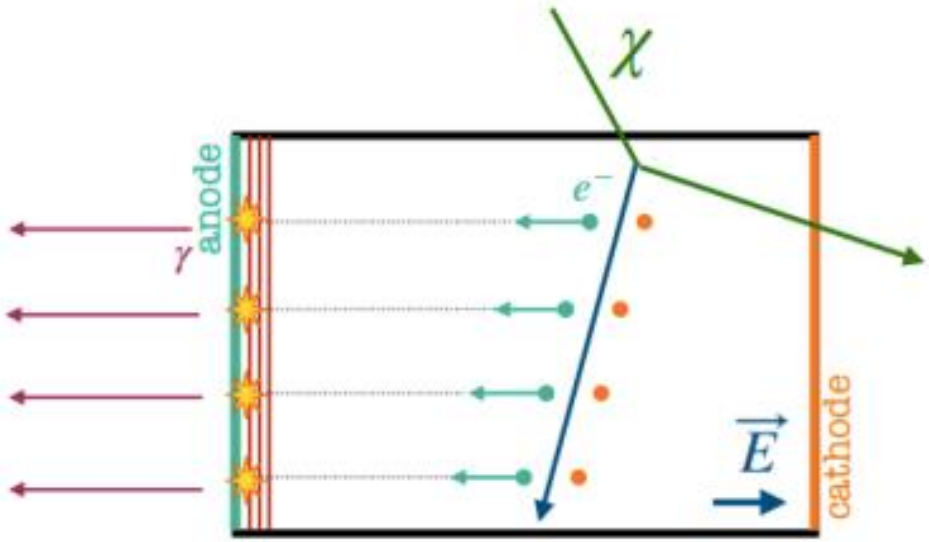
AIM

The CYGNO experiment goal is to deploy underground at the LNGS a high-resolution Time Projection Chamber (**TPC**) with Optical readout for the study of rare events as interaction of low mass DM particles.

Strategy:

- $He:CF_4$ (60:40) gas mixture at atmospheric pressure and room temperature:
  - Helium -> light, O(GeV) dark matter sensitivity;
  - Fluorine-> Spin dipendent sensitivity

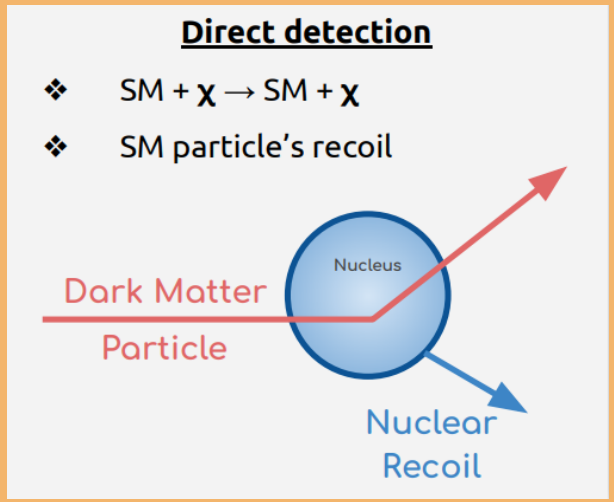
  The possibility of operation at atmospheric pressure guarantees a reasonable volume to target mass ratio
- Triple GEM amplification stage;
- 3D reconstruction of the track;
- NR/ER discrimination capability;



The results obtained with current prototypes are the basis for the $0.4m^3$ demonstrator

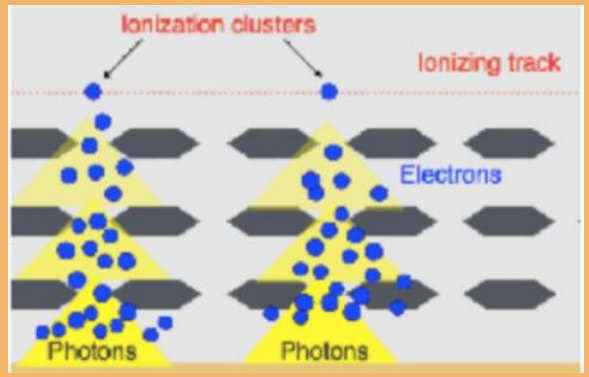
The optical readout

Ionization



Charged particles traveling in the gas can ionize atoms and molecules but can also excite them. During the de-excitation processes, photons are emitted.

Amplification

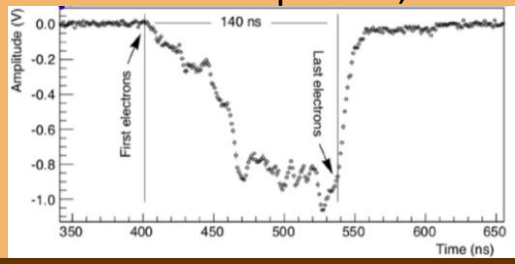


A Triple Gas Electron Multiplier (**GEM**) stack is used to multiply the signal, photons are produced during the amplification

Readout

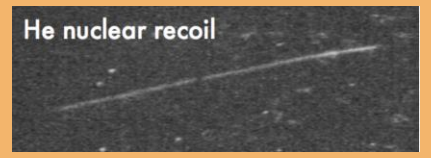
Hamamatsu R7378 PMT

- Fast light sensor;
- For Δz component;



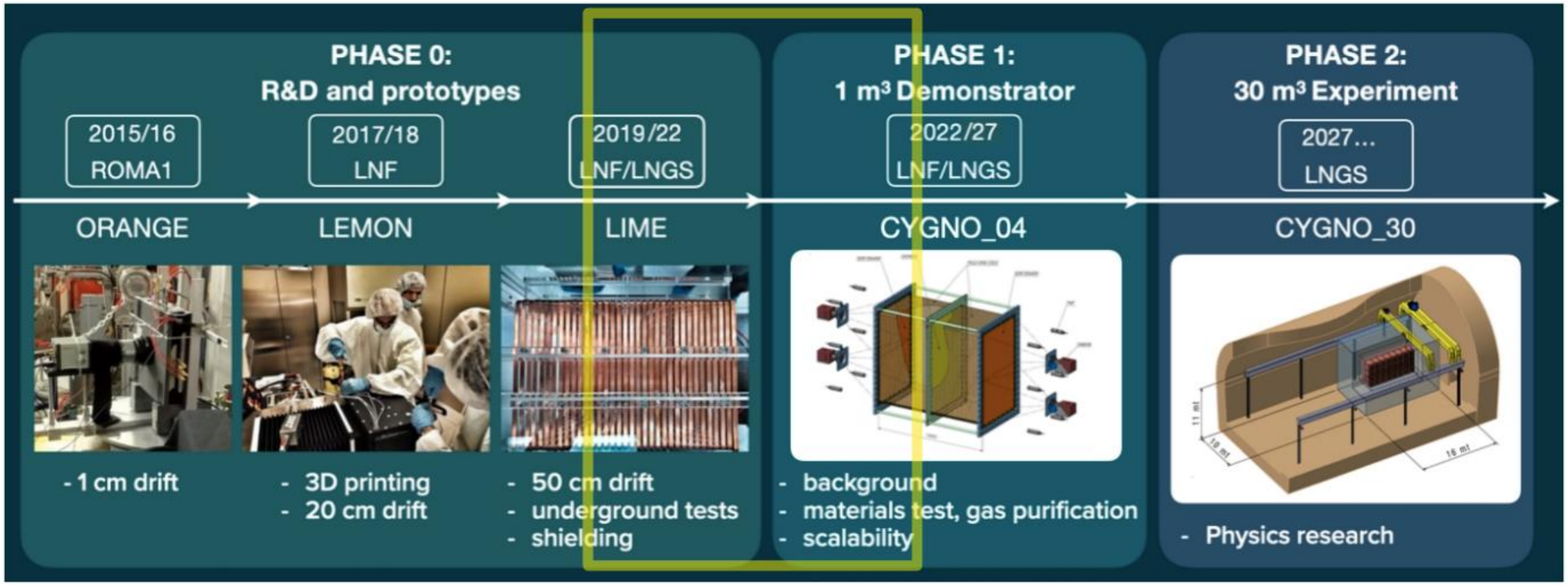
Hamamatsu Orca-Fusion camera

- Single photon sensitivity;
- High granularity;
- For x-y projection;



The CYGNO experiment - TIMELINE

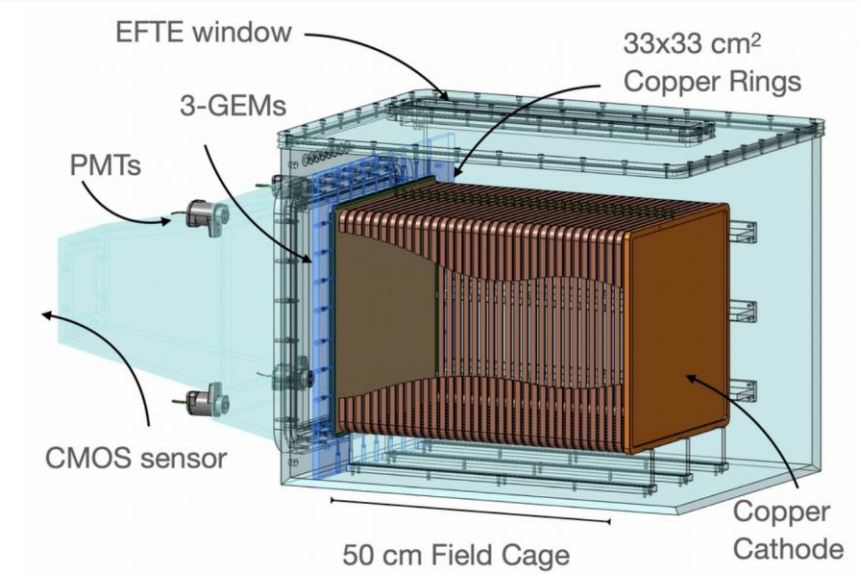
Instruments 2022, 6(1), 6



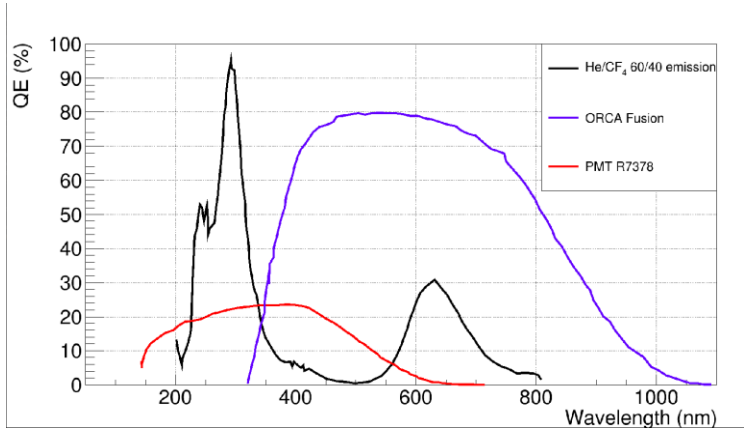
LIME: the Long Imaging ModulE

LIME (Long Imaging ModulE) is the largest prototype built which is currently installed underground at LNGS

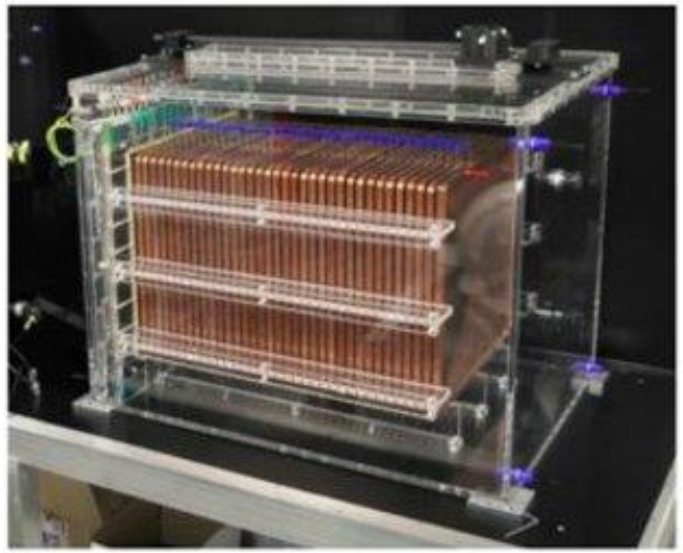
- Filled with He:CF_4 (60:40) gas mixture;
- 50 cm drift distance;
- A triple 33 x 33 cm^2 stack of thin GEMs;
- 1 sCMOS camera (Hamatsu ORCA Fusion):
  - 2304 x 2304 pixels;
  - Low noise (1 ph/pixel);
  - High granularity;
- 4 PMT
- The fieldcage is composed by copper rings, roundly shaped to avoid discharges



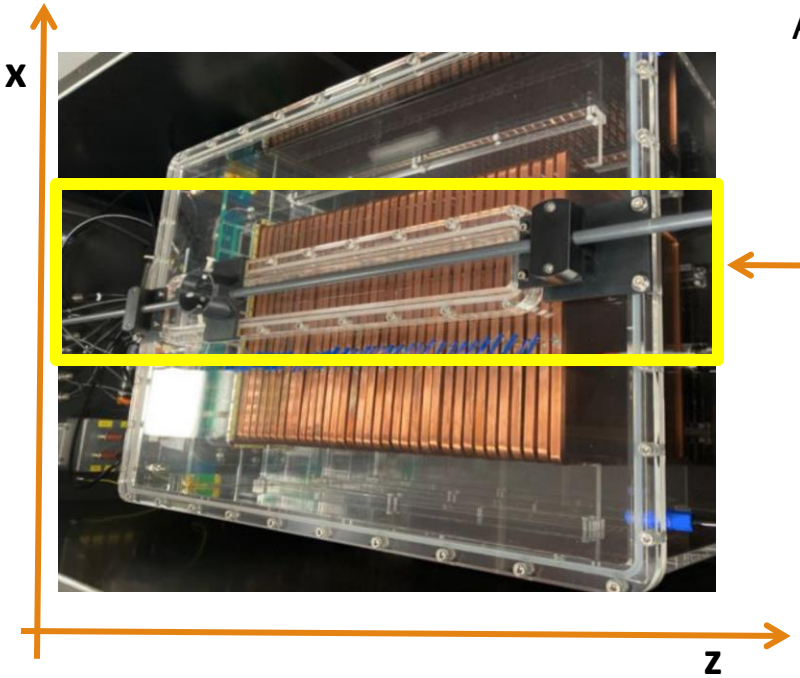
The Hamamtu ORCA_Fusion Camera
Has 80% QE at 600nm



The output gas is sent to an exhaust line connected to the external environment via a water bubbler ensuring the small (3 mBar) required overpressure



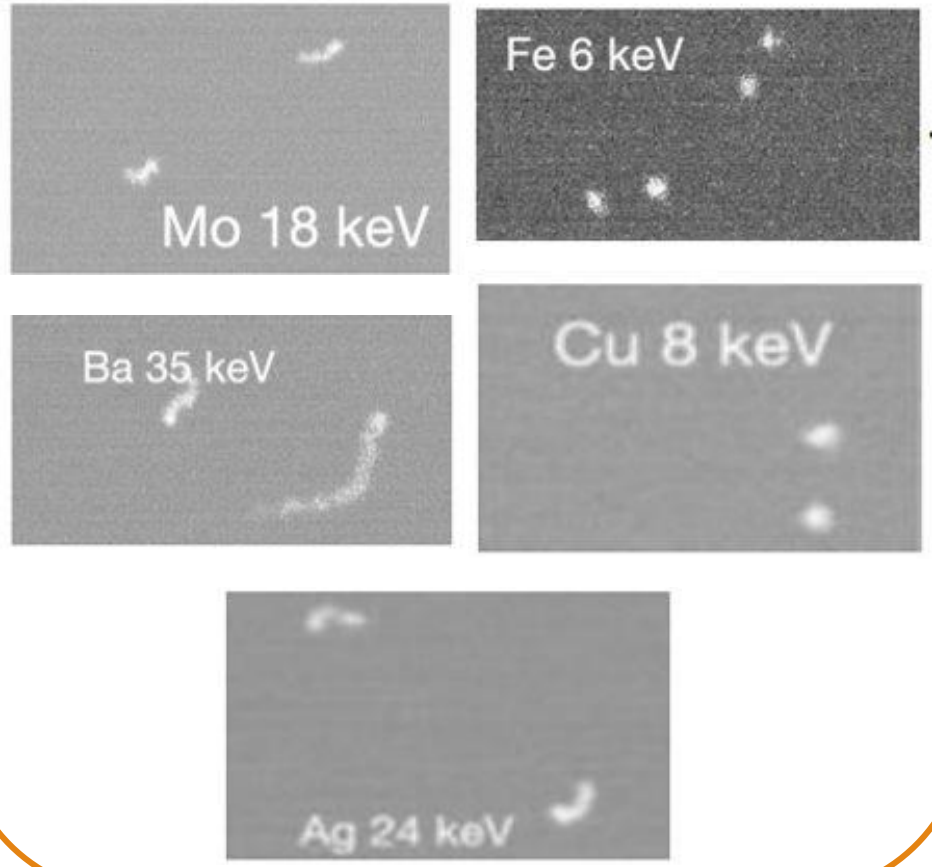
A photo of the LIME prototype



A trolley is mounted on the vessel to move an iron calibration source along the z axis from 5 cm to 45 cm far from the GEMs

Some tracks at different energies

The tracks are reconstructed using an algorithm based on DBSCAN

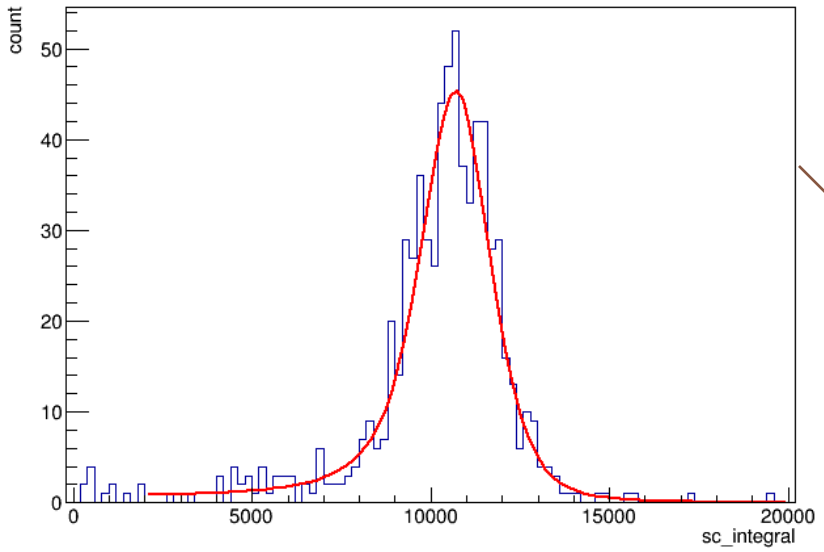


^{55}Fe signal

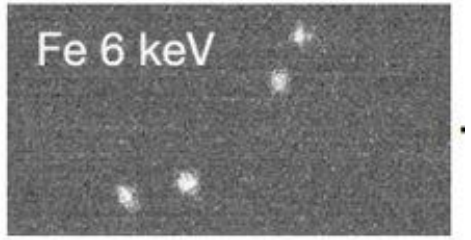
E. Baracchini et al. A density-based clustering algorithm for the CYGNO data analysis
JINST 15 (2020) 12, T12003
https://arxiv.org/abs/2007.01763

The ^{55}Fe source is used to calibrate the prototype.
It emits X-rays with an energy of about 5.9 keV, with an additional emission at around 6.4 keV.
The interactions of low energy photons with atoms in the gas mixtures create photo-electrons

The images acquired by the sCMOS are reconstructed and one of the most important information saved is the light of each cluster:



These events produce round-like spots on the CMOS sensor with diameters of 2-3 mm



Light distribution
A fit with the Cruijff function on the ^{55}Fe peak is performed to evaluate the mean value

$$f(x) = \exp\left(\frac{(x-m)^2}{2\sigma_{L,R}^2 + \alpha_{L,R}(x-m)^2}\right)$$

LIME Overground @ LNF

Long Term Stability Test

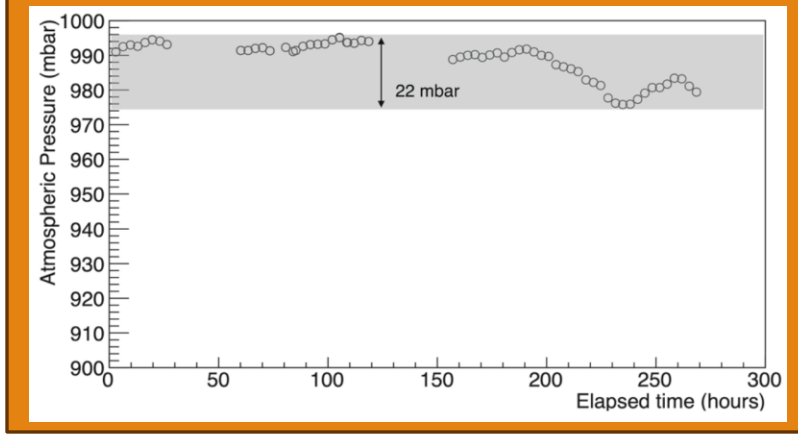
Amaro, F.D. et al. A 50 l CYGNO prototype overground characterization. Eur. Phys. J. C 83, 946 (2023)
https://arxiv.org/abs/2305.06168

A DM search detector must guarantee uninterrupted and reliable and very long data taking periods
---> LIME operated for several months overground at Frascati National Laboratories (LNF – INFN):

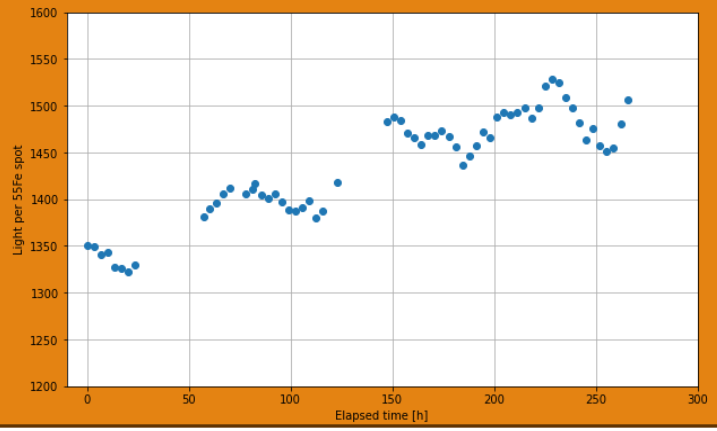
The ^{55}Fe source has been placed 25cm far from the GEMs and for two weeks recorded the data
The room temperature has been quite stable, with an average value of **298.7 K**

The analyses shown are made using the data taken by the sCMOS camera

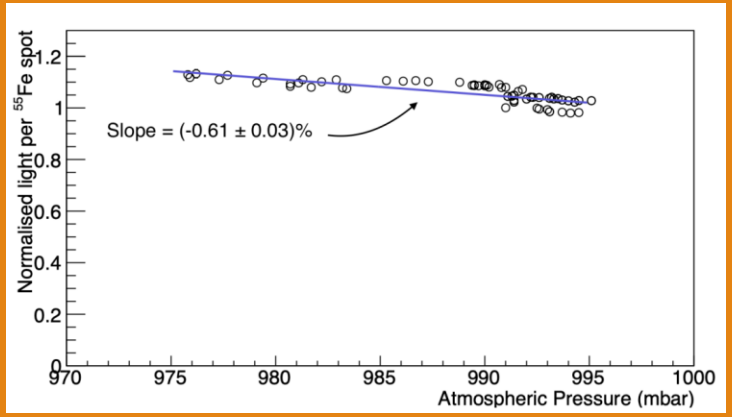
The pressure



The ^{55}Fe peak



The ^{55}Fe peak is normalised to the first acquired run, The ^{55}Fe peak vs the Pressure is plotted and a linear fit is performed and a light yeald decrease of about 0.6 % per mBar is found



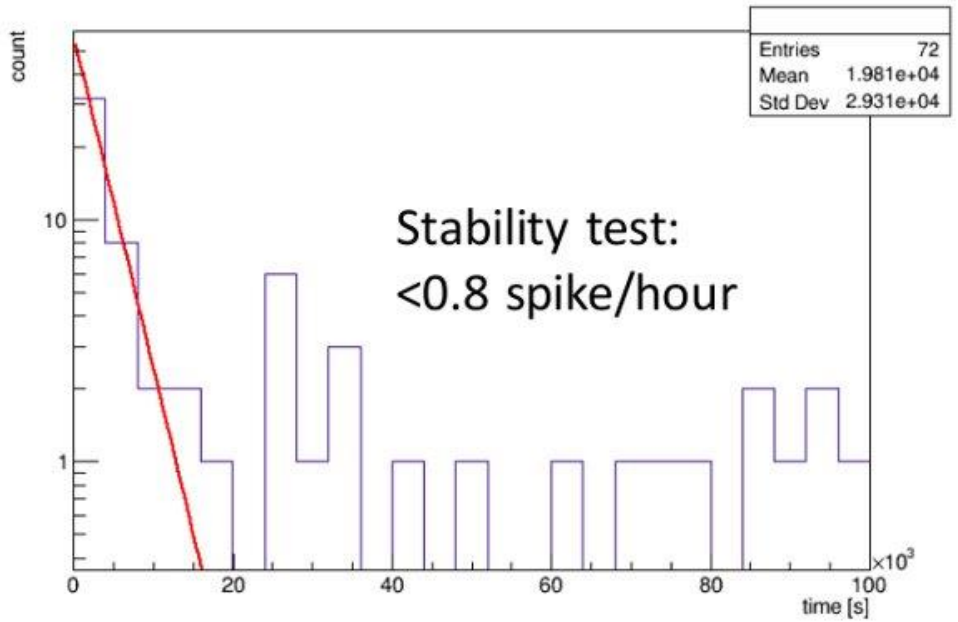
GEM's currents studies @ LNF

The GEM's currents are recorded.

To study the long term stability, the currents of the third GEM are studied in one month of operation.

If the GEM's HV is stable and the current value is higher than 1nA, it is counted like a spike. The time between two spikes has been evaluated.

An exponential fit on the time between two spikes distribution is performed

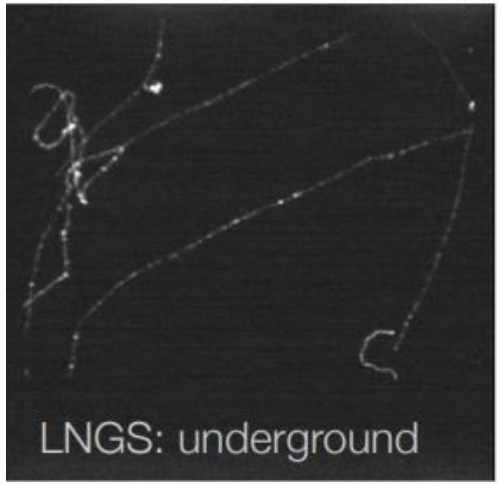


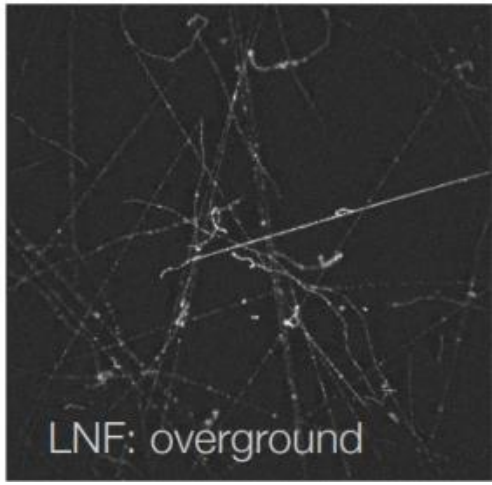
Time between sparks

LIME underground @ LNGS

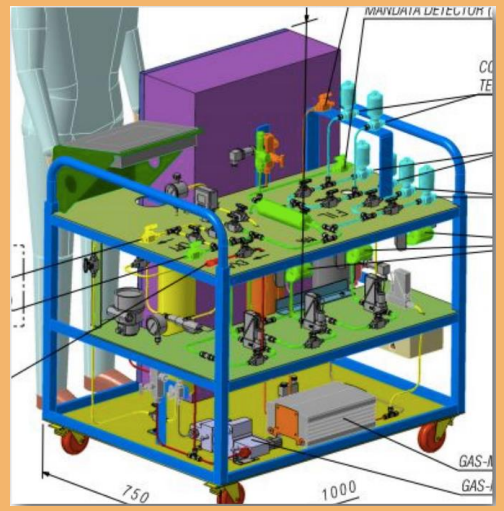
The LIME prototype has been installed underground at Gran Sasso National Laboratories (LNGS) at the beginning of 2022:

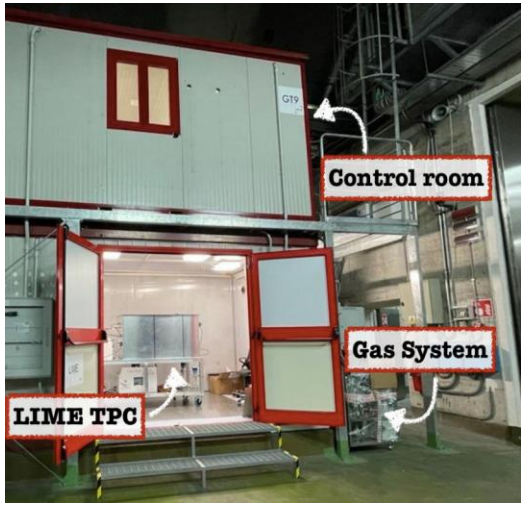
- To test the detector performance in low radioactivity and low pile-up configuration;
- To characterise the radioactive background present in the site and then to validate the GEANT4 simulation.

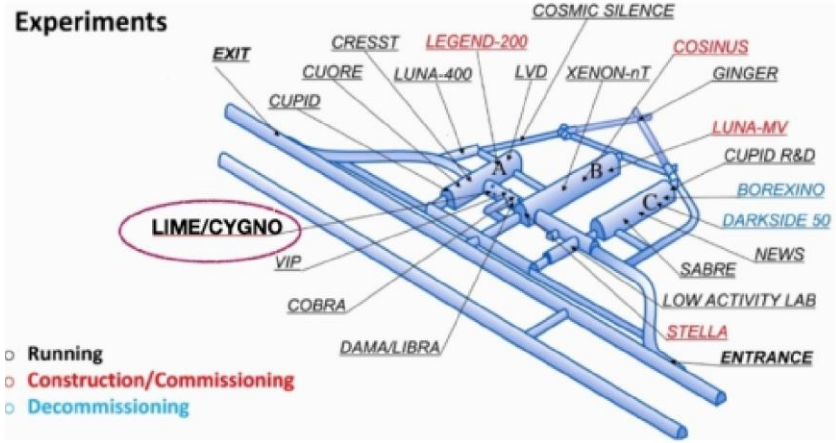




LIME has been equiped with the Gas-System, the same one which will be used for the demostrator





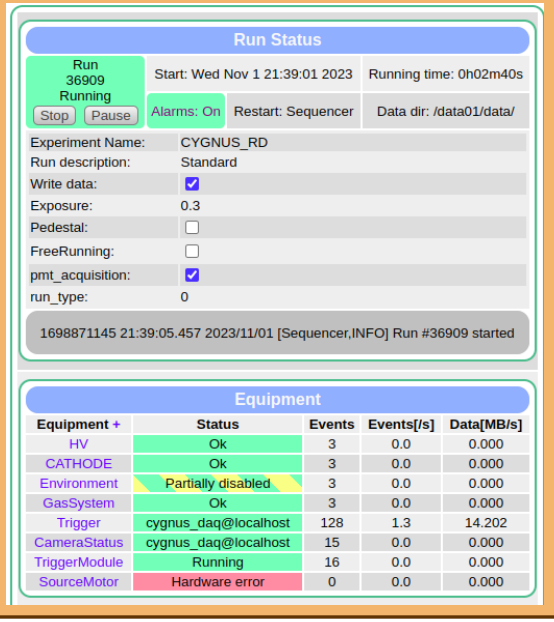


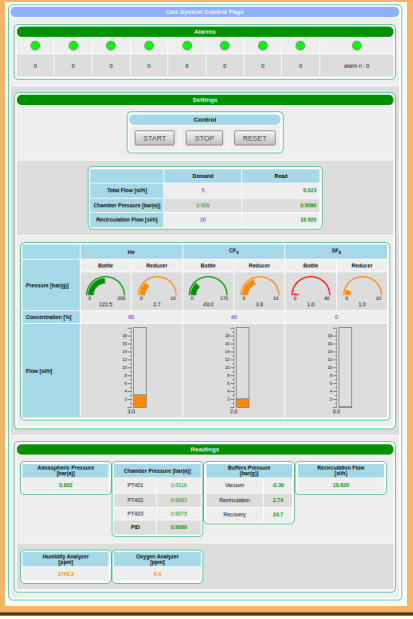
LIME underground @ LNGS - TIMELINE

Spring/Summer 2022	Autumn 2022	Winter 2023	Sping/Summer 2023	
Run0	**Run1**	**Run2**	**Run3**	**Run4**
Commissioning	No Shielding	4cm Cu shield	10cm Cu shield - AmBe measurement -Neutron flux measurement -Ba measurement -Eu measurement	10cm Cu shield 40cm water

We are here

The acquisition data and the control of the system is based on the MIDAS framework

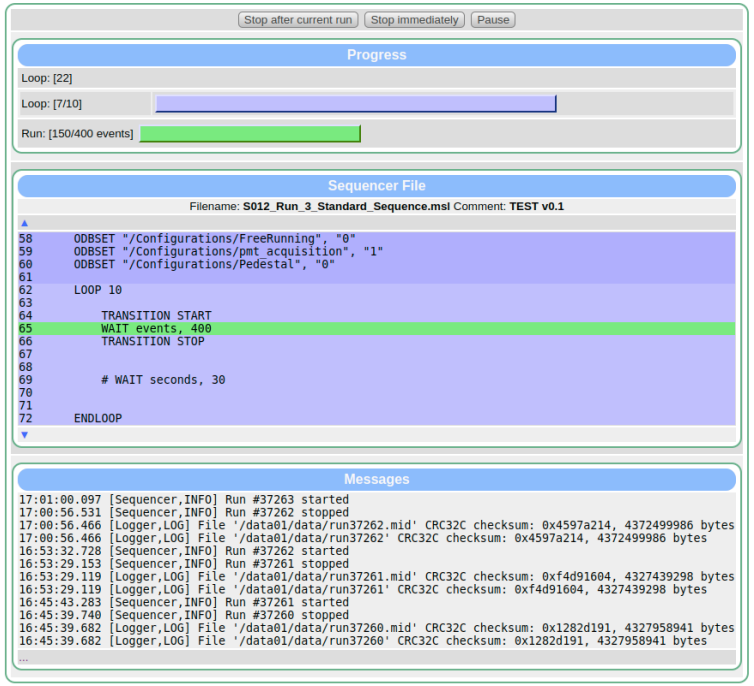




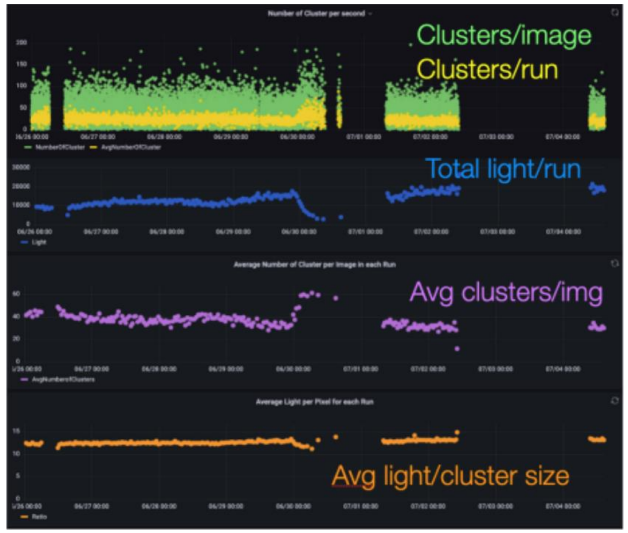
LIME with the Cu shield

Acquisition data & Monitoring

The detector needs to work for a long period, thanks to the control page we can acquire data automatically, without human intervantion.



Thaks to the the Graphana system, we can monitor the data quality



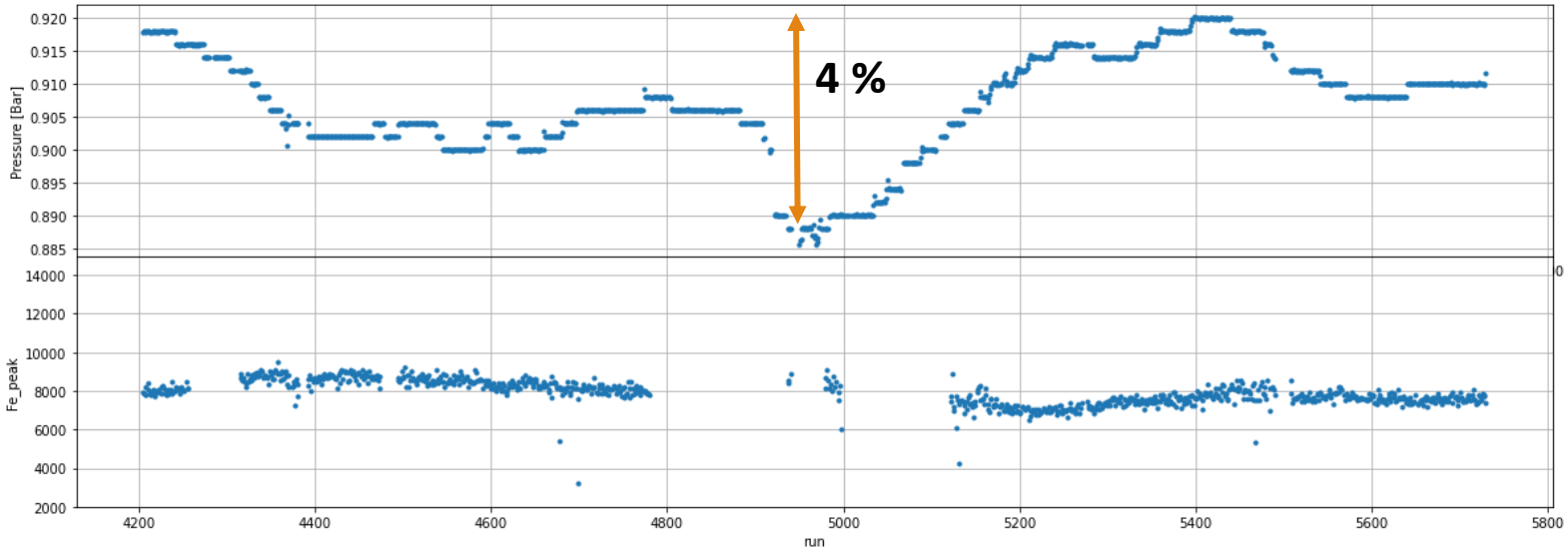
Long Term Stability Test @LNGS

Run 1

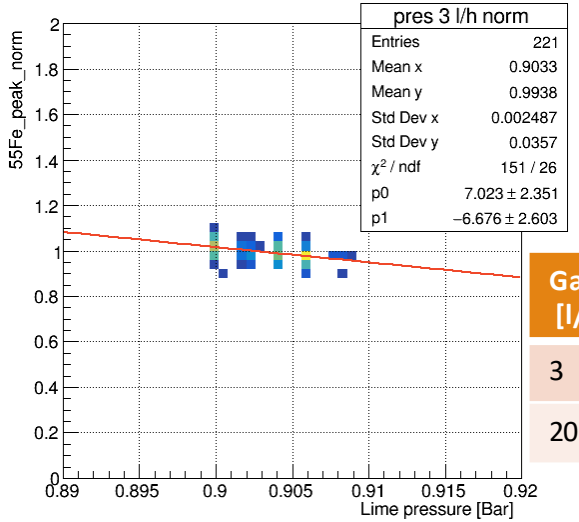
No shield

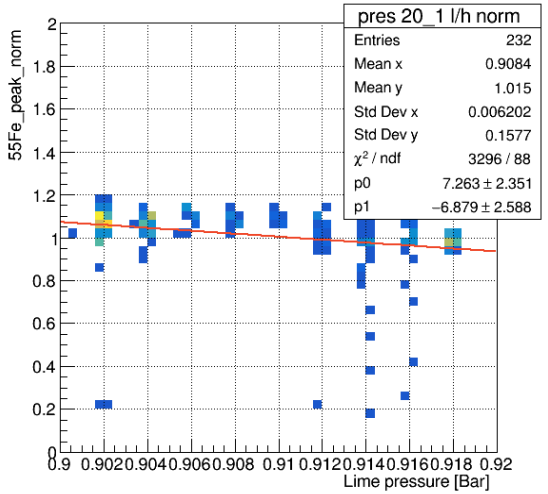
November – December 2022

The temperature is kept constant ~ 290 K by a heating system



2 different gas flows:



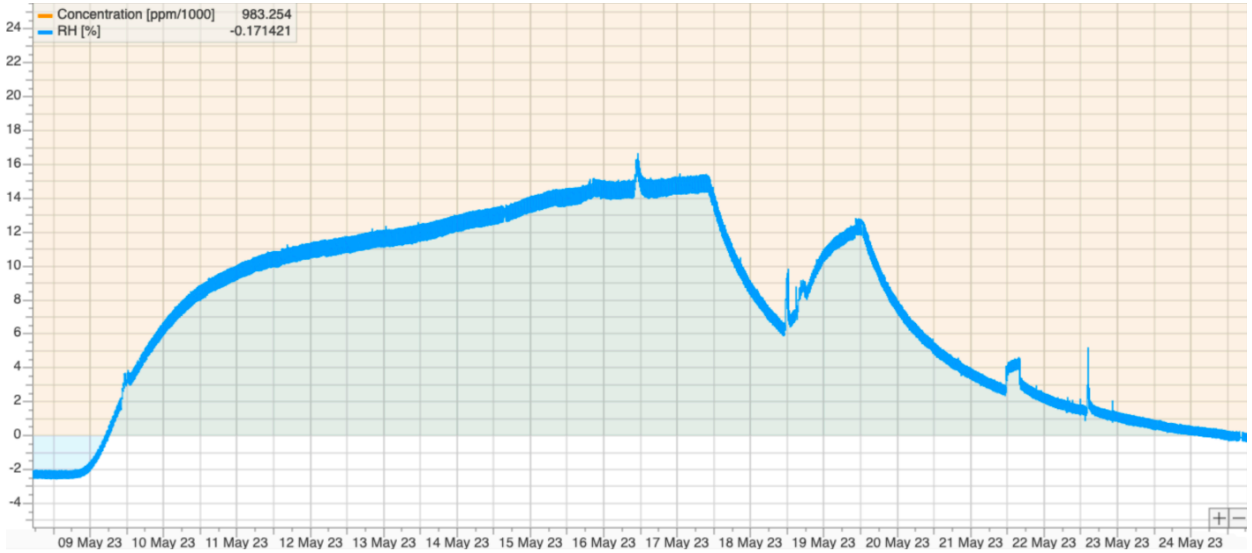


Gas flow [l/h]	Decrease %/[mBar]
3	0.67
20	0.69

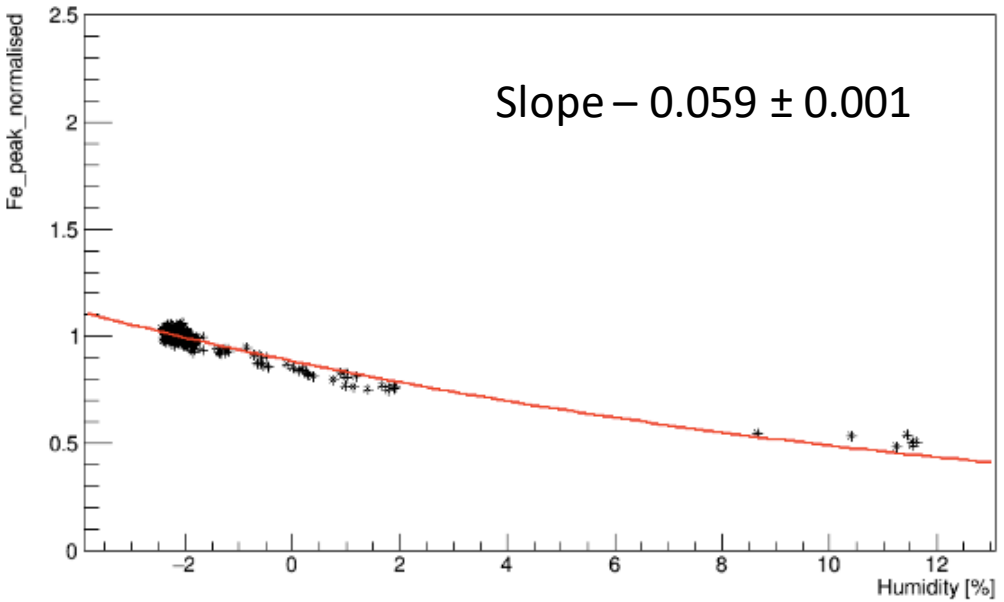
Compatible with LNF results

Long Term Stability Test @ LNGS

Run 3
10 cm Cu shield
May 2023
The temperature is kept constant ~293 K by a heating system
A humidity sensor has been installed



On the y axis the relative humidity is reported with an offset



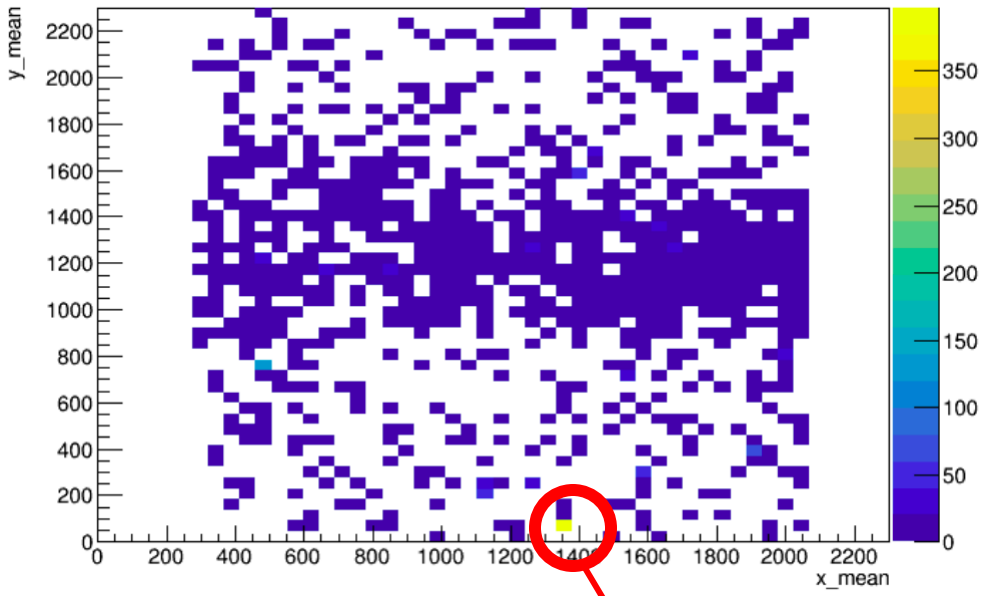
The ^{55}Fe peak is normalised to the first run and it is plotted vs the Humidity, an exponential fit is performed

Increasing the humidity --> The ^{55}Fe_Peak decreases

Hot-spots and noise studies @ LNGS

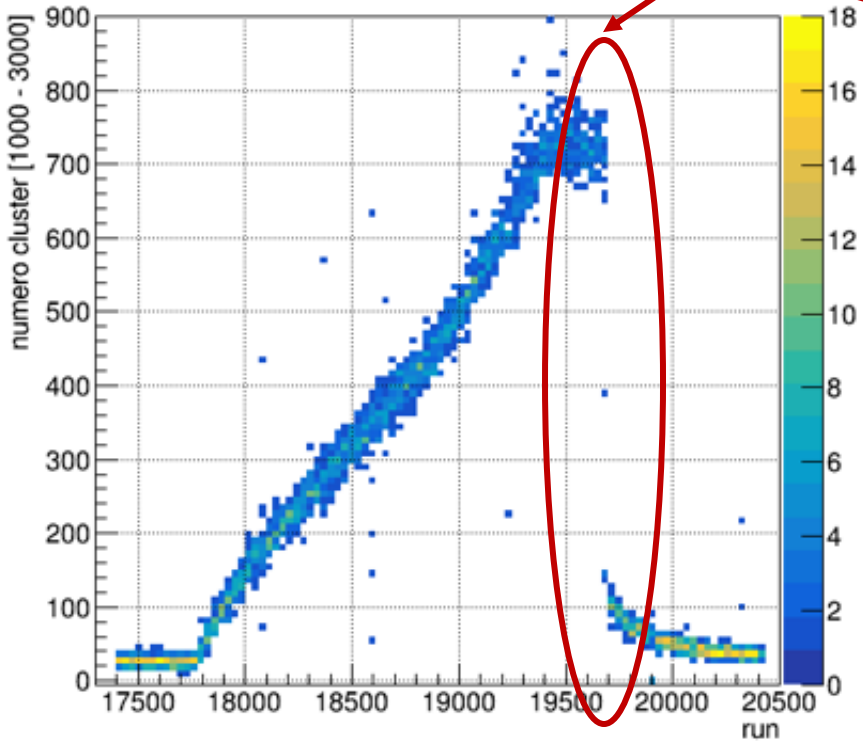
Hot-spots = Appearance of small luminous and low energy spots on the GEM surface which are not due to the particle's interaction with the gas.
Some of these spots fade out with the time

Mean position of each cluster taken in 400 images



There is a cluster in each image = hot-spot

Human intervantion



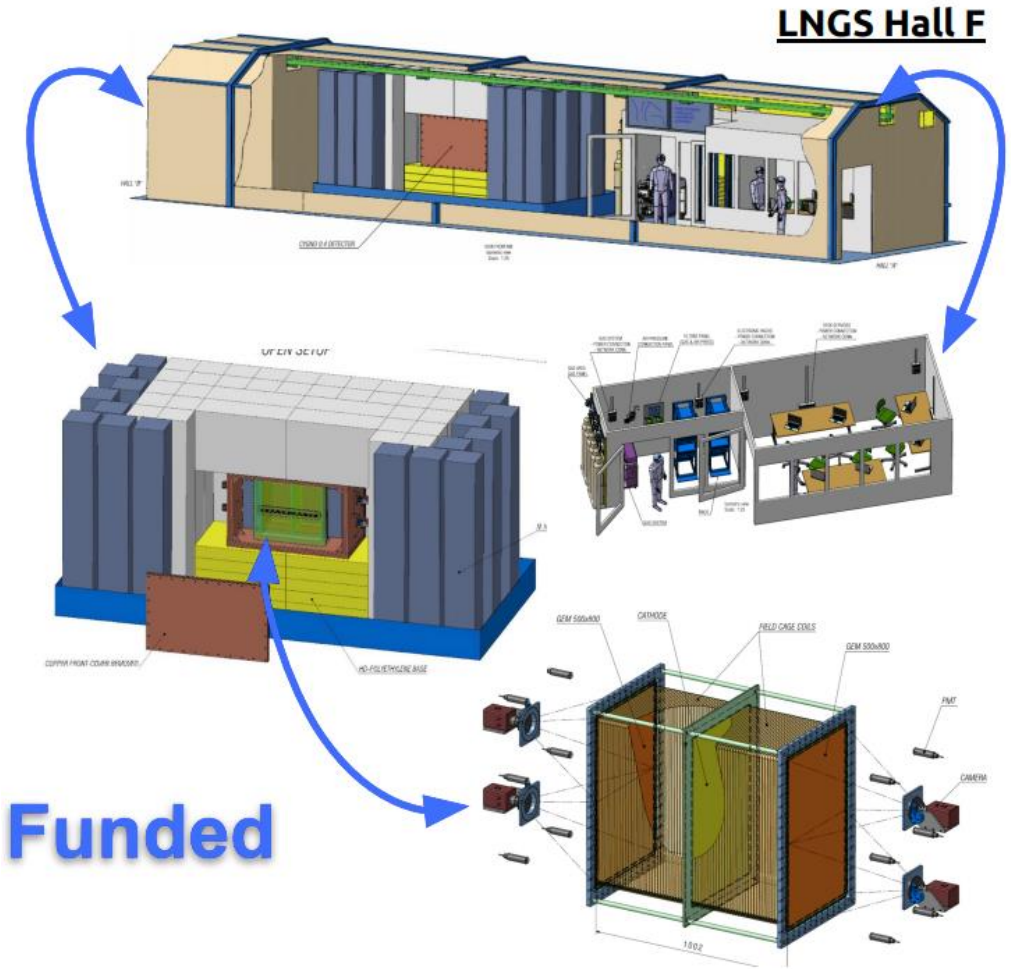
CYGNO_04

Next phase will show achievability of CYGNO_30 physics performances

- Study and minimize radioactivity
- Develope modular readout and DAQ
- To test scalability to m^3 volumes

➔ Back-to-back 0.4 m^3 gaseous TPC, with central cathode.
➔ At atm pressure, room temperature and He:CF_4
➔ Triple 50 x 80 cm^2 GEM stack for amplification
➔ Projected shielding composed of 10 cm Cu + 100 cm H_2O
➔ To be installed in Hall F @LNGS

Optical readout:
-4 qCMOS cameras (Hamamatsu ORCA Quest);
-12 PMTs;



Conclusions

-The CYGNO collaboration is developing a high-precision gaseous TPC at atmospheric pressure with optical readout.

-The main focus is the direct search of DM WIMP-like particles in the low mass range (0.5-10 GeV).

-Through directionality, solar neutrinos can be discriminated and unambiguous confirmation of DM is possible.

-The 50L LIME prototype is currently taking data at the underground LNGS facilities.

-Analysis of underground data is ongoing;

-CYGNO_04, already funded and with a TDR submitted, will allow us to test the experiments scalability.

-CYGNO_30 is under study, with its sensitivities looking promising.

-What is next:

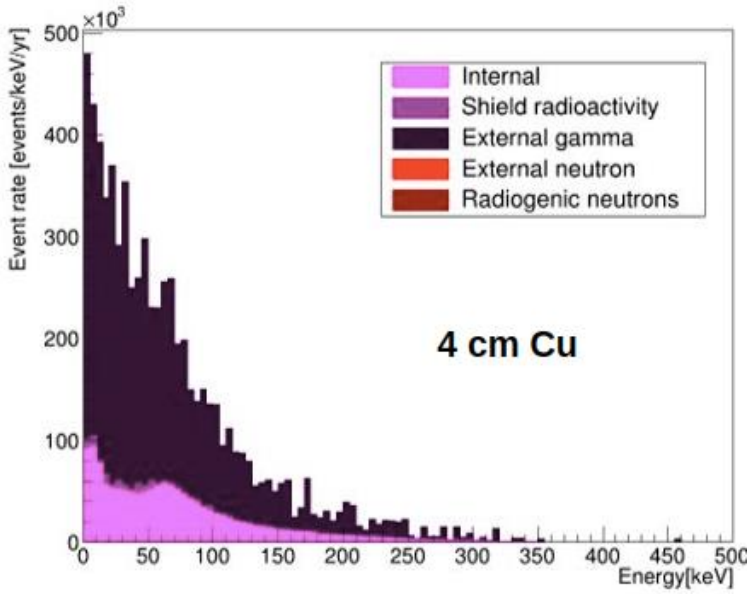
- Spectral (and directional) neutron flux measurement underground at LNGS
- Water shielding installation and final test of LIME operation

Backup

Background simulation

The detector and the shielding geometry has been simulated with GEANT4

Inputs:
- External radioactyvity measure on site;
- Activity of all main components measured underground@ LNGS (rings, resistors, cathode, GEMs, camera components)



Data/MC comparison