# Directional Dark Matter searches with CYGNO experiment

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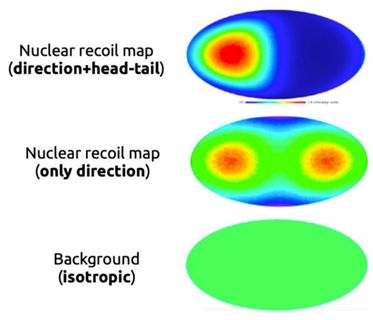
## Introduction

The presence in the Universe of a large amount of non-luminous matter, **Dark Matter** (DM), is nowaday a paradigm. One of the DM particle candidate are the **WIMPs** (Weakly Interactive Massive Particles)

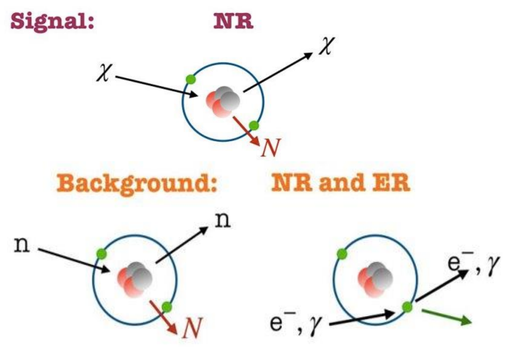
- Dark Matter forms a halo around Our Galaxy;
- Our Solar system rotates around the Galactic center apparently in the direction of the Cygnus constellation;
- Motion of Our Galaxy creates an apparent wind of DM coming from Cygnus constellation towards Earth.

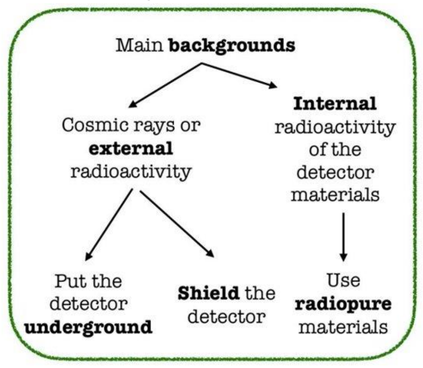
WIMP recoil distribution is expected highly anisotropical thanks to Sun and Earth's motion




## Signal & Background

At not relativistic speed, WIMPs are expected to interact with ordinary matter mainly via elastic scattering with nuclei.
Challenge -> to discriminate the low energy nuclear recoil induced by dark matter




## The CYGNO experiment

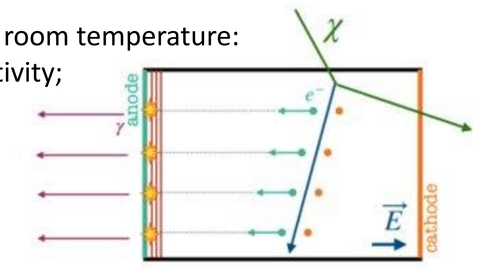
The CYGNO project goal is to deploy underground at the Laboratori Nazionali del Gran Sasso a high resolution Time Projection Chamber (**TPC**) with Optical readout for the study of rare events such as the interaction of low mass DM particles.
Strategy:

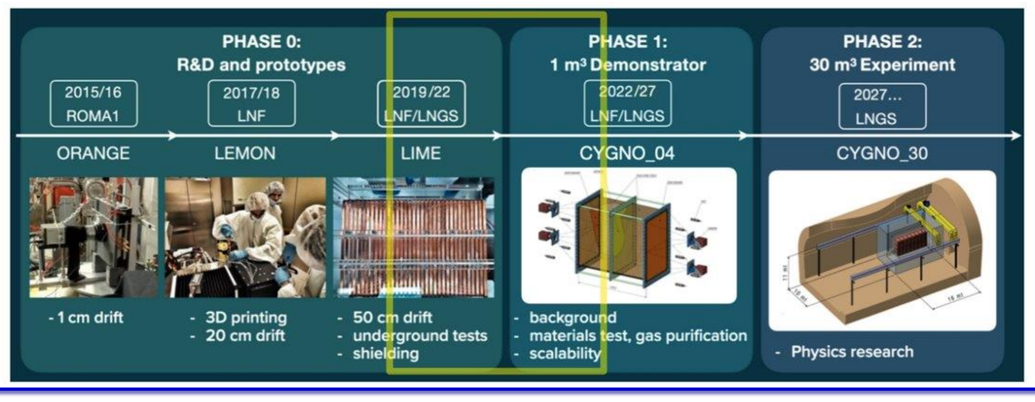
- **He:$CF_4$** (60:40) gas mixture at atmospheric pressure and room temperature:
  - Helium -> light, O(GeV) dark matter sensitivity;
  - Fluorine -> Spin dipendent sensitivity;

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 down O(1) keV;

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



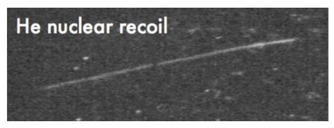




## The Optical Readout

**3D reconstruction** of the tracks thanks to the combined use of:

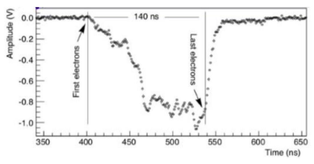
--> sCMOS camera

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




--> PMT

- Fast light sensor;
- for Δz component.



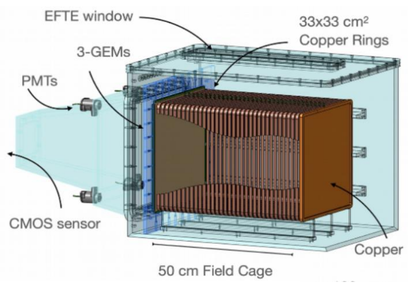

**Both sensors measure the energy**

## PHASE_0: LIME PROTOTYPE

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

- 33 x 33 $cm^2$ readout area, 50 cm drift distance (50 L volume);
- 4 PMTs (Hamamatsu R7378 PMT);
- 1 sCMOS camera (Hamamatsu ORCA Fusion):
- The fieldcage is composed by copper rings, roundly shaped to avoid discharges

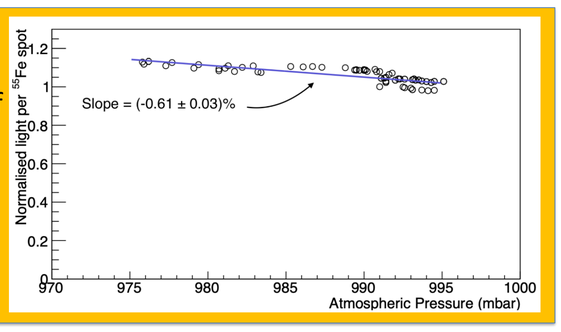
The tracks are reconstructed with an algorith based on **DBSCAN**




## LIME @ LNF

A DM search detector must guarantee uninterrupted, reliable and very long data taking periods
-->LIME operated for several months overground at LNF
The $^{55}$Fe source was placed 25 cm far from the GEMs and data was recorded for two weeks.
The room temperature ~ 298.7 K

A light yield decrease of about 0.6 % per mBar is found




$^{55}$Fe spot example

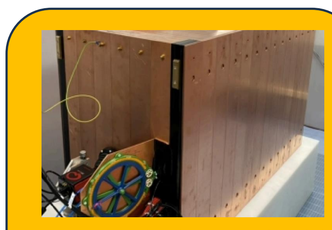

## LIME @ LNGS

The LIME prototype has been installed underground at **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.

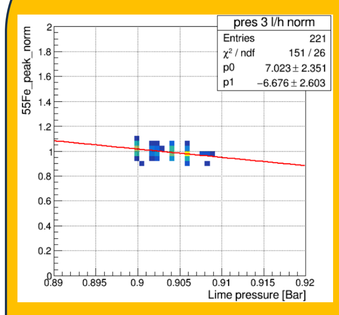
The temperature is kept constant ~290K

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

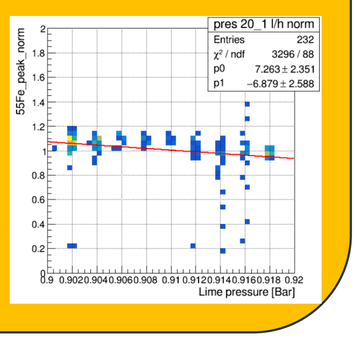


LIME with the Cu shield

### Run1



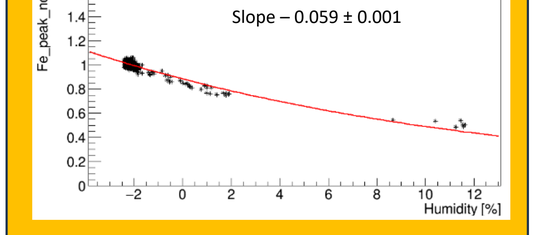

| Gas flow [l/h] | Decrease %/[mBar] |
|---|---|
| 3 | 0.67 |
| 20 | 0.69 |




The obtained results are compatible with the measuraments at LNF

### Run3

A humidity sensor has been installed




Increasing the humidity --> the $^{55}$Fe peak decreases

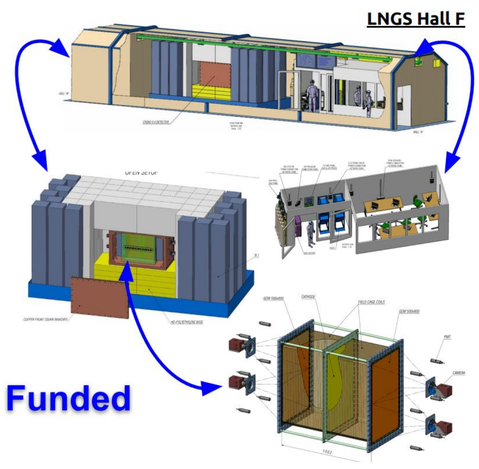
## CYGNO_04

Next phase will show achievability of CYGNO_30 physics performances

- Study and minimize radioactivity
- Develop modular readout and DAQ
- 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
➔ Foreseen 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).

- The LIME prototype is currently under study and the current results on detector stability are promising for the next step towards the realisation of a large scale experiment.

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

## References

[1] CYGNO Collaboration, Instruments 6(1), 6 (2022)
[2] E. Baracchini et al., JINST 15 no.12, T12003 (2020)
[3] E. Baracchini et al., JINST 15 (2020) 12, T12003
[4] Instruments 2022, 6(1), 6

Web page: https://web.infn.it/cygnus/cygno/
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