The C*GNO Experiment: A Directional Dark Matter Detector with Optical Readout

INITIUM: Innovative Negative Ion TIme projection chamber for Underground dark Matter searches

A. Prajapati* on behalf of CYGNO collaboration

*Gran Sasso Science Institute, L'Aquila, Italy / Ph.D. student / Email: atul.prajapati@gssi.it

F. Amaro, R. Antonietti, E. Baracchini, L. Benussi, D. S. Cardoso, C. M. B. Monteiro, S. Bianco, C. Capoccia, M. Caponero, G. Cavoto, R. J. C. Roque, I. A. Costa, E. Di Marco, G. D'Imperio, G. Dho, F. Di Giambattista, R. R. M. Gregorio, F. Iacoangeli, H. P. L. Júnior, G. S. P. Lopes, G. Maccarrone, R. D. P. Mano, D. J. G. Marques, G. Mazzitelli, A.G. McLean, A. Messina, R. A. Nobrega, I. Pains, E. Paoletti, L. Passamonti, S. Pelosi, F. Petrucci, S. Piacentini, D. Piccolo, D. Pierluigi, D. Pinci, F. Renga, **A. Prajapati***, F. Rosatelli, A. Russo, G. Saviano, N. Spooner, R. Tesauro, S. Tomassini, S. Torelli, J. M. F. dos Santos
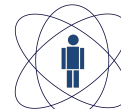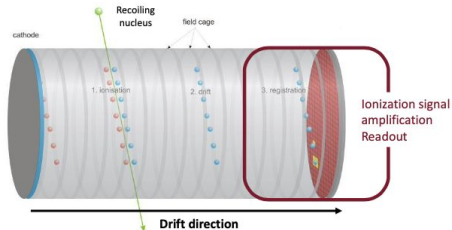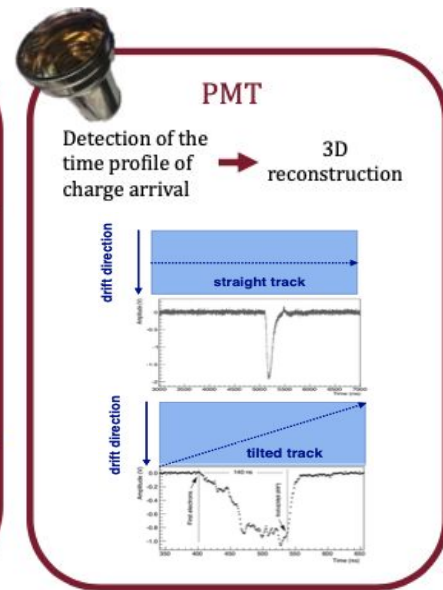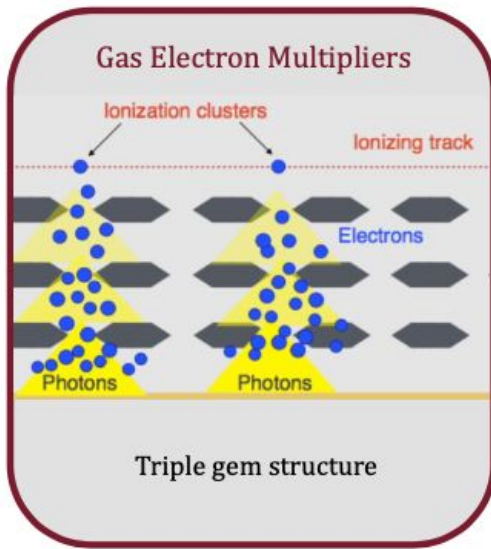
Triple GEM
Charge amplification & light production

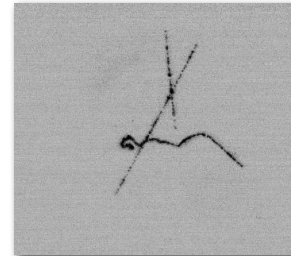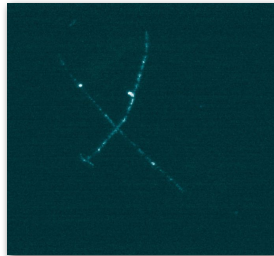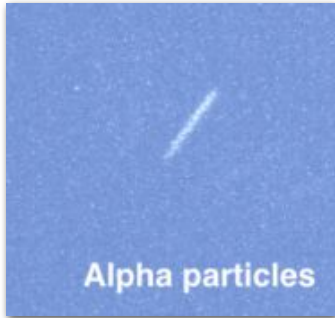**Camera & PMT**
Light produced by the de-excitation of the gas molecules during electron multiplication is optically read by sCMOS and PMT

sCMOS cameras
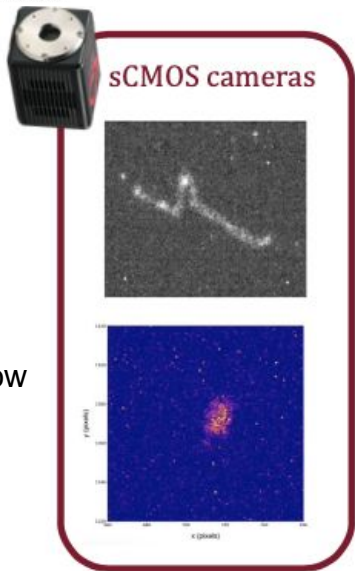
We can measure energy and X-Y coordinate using sCMOS's high granularity and low readout noise.

X-Y + Energy

Gas Electron Multipliers

Ionization clusters
Ionizing track
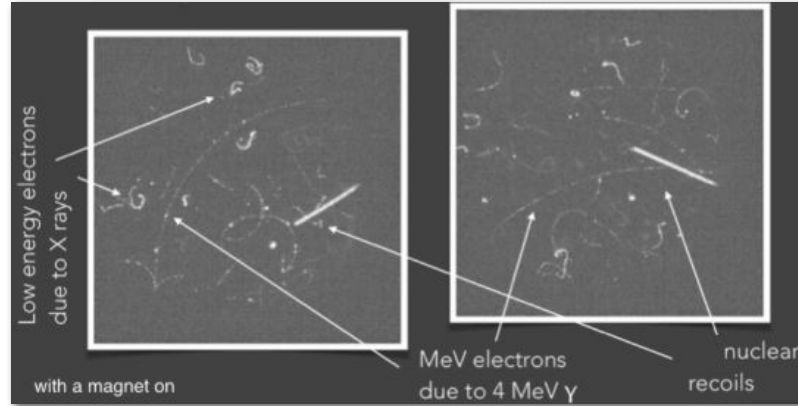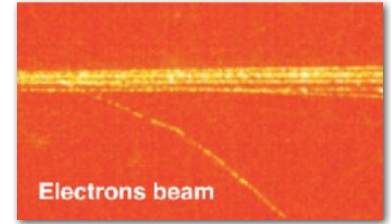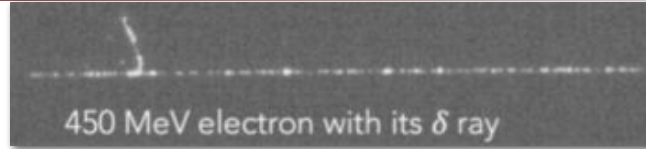Electrons
Photons   Photons

Triple gem structure

PMT

Detection of the time profile of charge arrival → 3D reconstruction

drift direction — straight track

drift direction — tilted track

PMT measures the integrated energy and time of arrival (dZ) of charge carriers with high sampling rates.

Z + Energy

450 MeV electron with its δ ray

Electrons beam

Low energy electrons due to X rays

MeV electrons due to 4 MeV γ

nuclear recoils

with a magnet on

Alpha particles

Proton
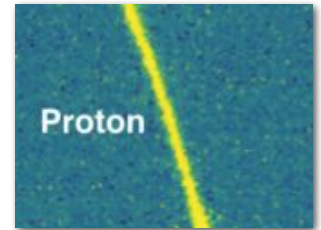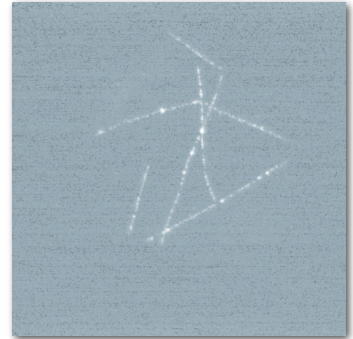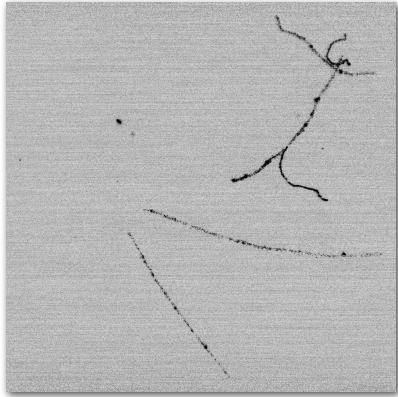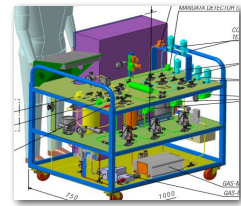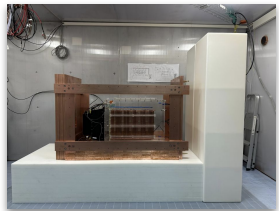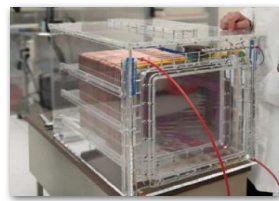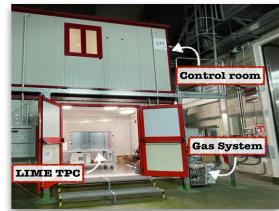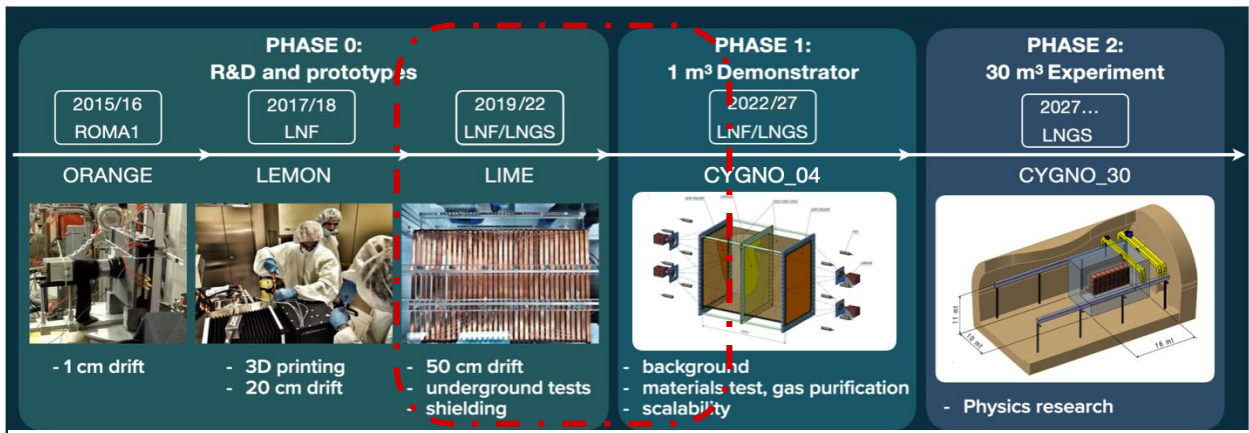
Ongoing studies:

❖ Performance and stability test

❖ 3D reconstruction

❖ Directionality

❖ ER vs. NR discrimination

❖ Shielding materials

❖ Data/MC comparison

❖ Parallel research with MANGO detector for studying different GEM configuration, gas mixtures and Negative Ion Drift.

E. Baracchini et. al, JINST 13(2018) no.04, P04022
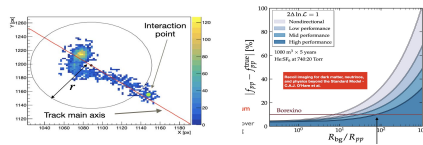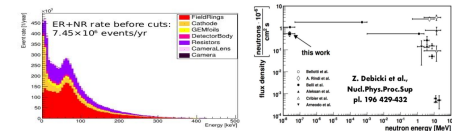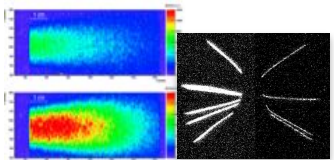
- Directionality
- Neutrino feasibility study

S.Torelli

- Neutron Simulation
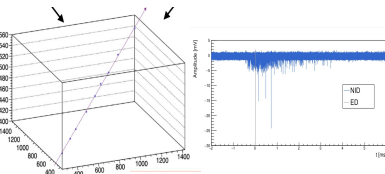- Background Simulation and Shielding

F. Di Giambattista

- CYGNO Sensitivity
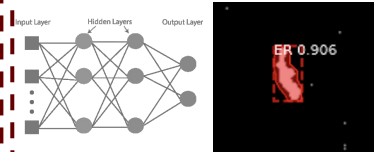- EL and NID studies with MANGO

G. Dho

- PMT Signal
- 3D Reconstruction

D. Marques

- Track Reconstruction
- PID with ML

A. Prajapati

E. Baracchini

E. Baracchini

- Directionalit...
- Neutrino fea... study
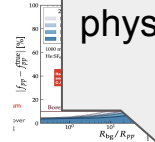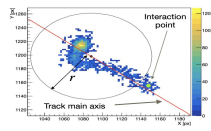
If CYGNO_30 is funded then it becomes a physics case.

- Neutron Simu...
- Background S... and Shielding...
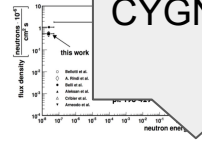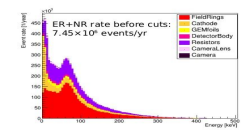
Measurement of annual variation of neutron with CYGNO_04.

- CY...
- EL... wi...

1) Use of NID to reduce diffusion
2) Study of EL and Gas mixture to amplify light output.

- PMT...
- 3D...
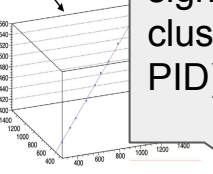
Study of NID with PMT, which is showing the signs of single ionization cluster (best way to do PID).

- Tra...
- PID...
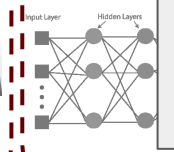
Improvement in simulation and use of different algorithm to improve Reconstruction and PID.
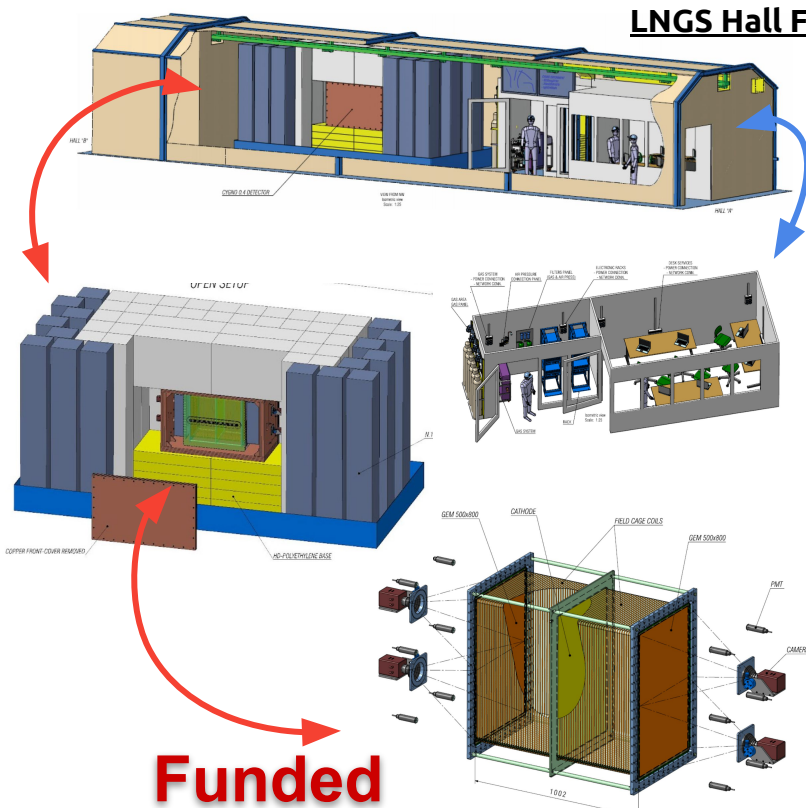
Funded

- Setting limits with **CYGNO_04**
- **CYGNO_04** data analysis
- Minimisation of radioactivity for **CYGNO_04** and **CYGNO_30**

X-ray polarimetry in space

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

HypeX (X-Ray Polarimetry) -> **Funded**
- Process of hiring a PostDoc (There's a dedicated poster)

FINEM (Migdal measurement) -> **Funded**

Measurement of Migdal effect

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

Directional neutron detection

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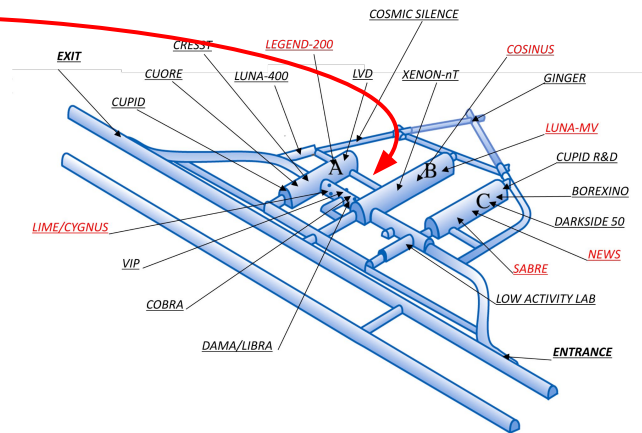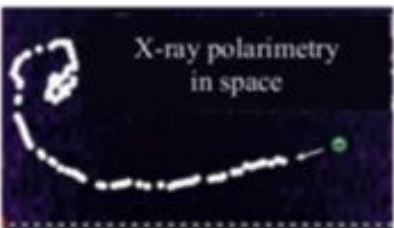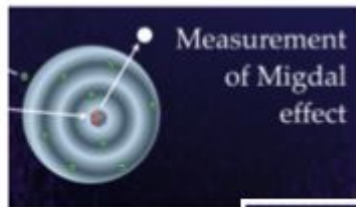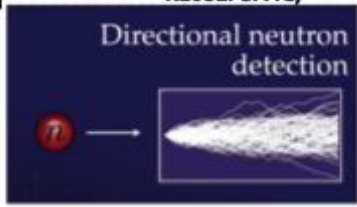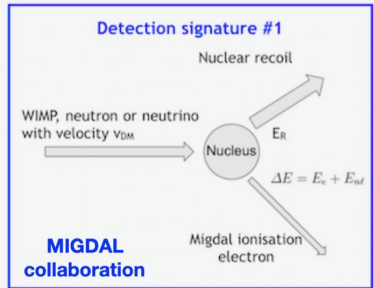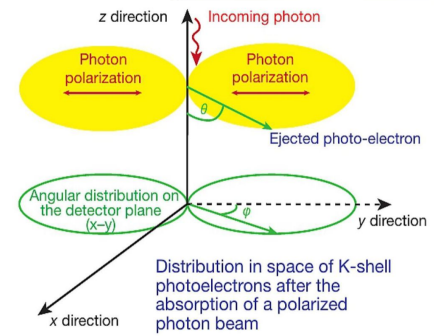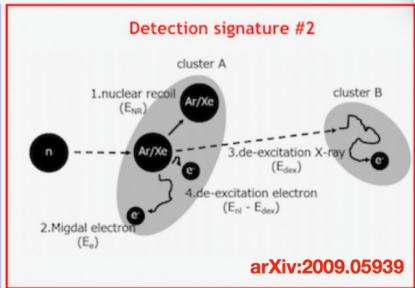(PRIN 2017 Prot. 2017T54J9J)

PLEASE NOTE: signature #1 is ALWAYS present (no X-ray needed) but might be difficult to distinguish ER + NR from same vertex

PLEASE NOTE: signature #2 is required for high density mixtures/low granularity readout BUT need an atom that makes X-ray

Detection signature #1

Nuclear recoil

WIMP, neutron or neutrino with velocity v_{DM}

Nucleus

E_R

$\Delta E = E_e + E_{nl}$

Migdal ionisation electron

MIGDAL collaboration

Detection signature #2

cluster A

1.nuclear recoil (E_{NR})

cluster B

n

Ar/Xe

Ar/Xe

3.de-excitation X-ray (E_{dex})

e⁻

2.Migdal electron (E_e)

4.de-excitation electron $(E_{nl} - E_{dex})$

e⁻

arXiv:2009.05939

z direction — Incoming photon

Photon polarization — Photon polarization

θ

Ejected photo-electron

Angular distribution on the detector plane (x–y)

ϕ

y direction

x direction

Distribution in space of K-shell photoelectrons after the absorption of a polarized photon beam

$$\frac{d\sigma_{ph}}{d\Omega} = \frac{\sigma_{ph}^{tot}}{4\pi}\left[1 + \frac{b}{2}\left(\frac{3\sin^2\theta\cos^2\phi}{(1+\beta\cos\theta)^4} - 1\right)\right]$$

THANKS!

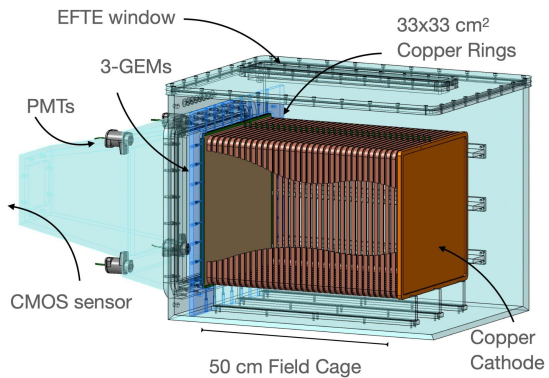# Backup

LIME: the Long Imaging ModulE

- ❖ **50 L** gaseous TPC with **50 cm drift**
- ❖ **He:CF$_4$ (60:40)** gas mixture at room temperature and atm pressure
- ❖ **Triple 33x33 cm^2 GEM** stack for amplification
- ❖ **Optical readout**
  - ➢ 4 PMTs
  - ➢ 1 sCMOS camera (Orca Fusion)
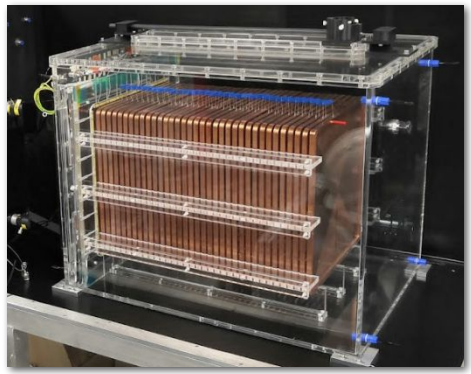
ORCA-Fusion
CAMERA SPECS

LOW NOISE AND EXCEPTIONAL READOUT NOISE UNIFORMITY

READOUT NOISE
0.7 electrons rms
Ultra-quiet Scan

DSNU
0.3 electrons rms

PRNU
0.06 % rms
At 7500 electrons

HIGH SPEED
100 frames/s
At 2304 × 2048 ROI

HIGH RESOLUTION
2304 × 2304
5.3 Megapixels

PIXEL SIZE
6.5 µm × 6.5 µm

DYNAMIC RANGE
21 400:1

PEAK QE
80 %

Carbon tetrafluoride (CF4)

- Significant light yield at the camera's QE peak

QE and He:CF$_4$ emission