Optimisation of gas composition and amplification stage for the CYGNO/INITIUM experiment

Giorgio Dho on behalf of CYGNO coll.

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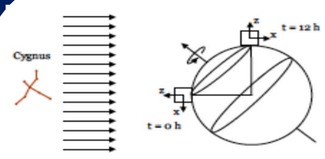
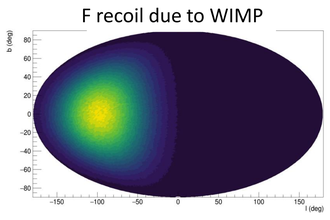
Part of this project has been funded by the European Union's Horizon 2020 research and innovation programme under the ERC Consolidator Grant Agreement No 818744

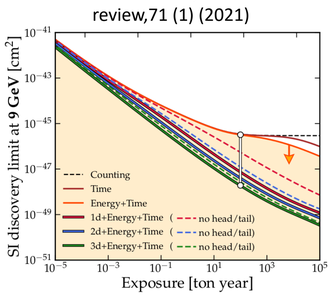
Physics case





Strong anisotropical angular distribution imprinted in WIMP case

Vahsen et al., Annual review,71 (1) (2021)



Directional Dark Matter (DM)

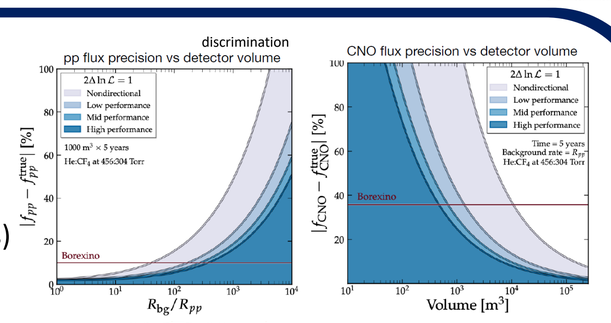
- Assuming DM model detectable by scattering (WIMPs..)
- Directional information crucial for direct detection:
  - Better statistical rejection of background
  - Sidesteps the neutrino fog problem (especially for Solar neutrinos)
  - Will allow 3D astronomy of DM
- Imaging of nuclear recoils (NRs)

But not only

Neutrinos can become signal

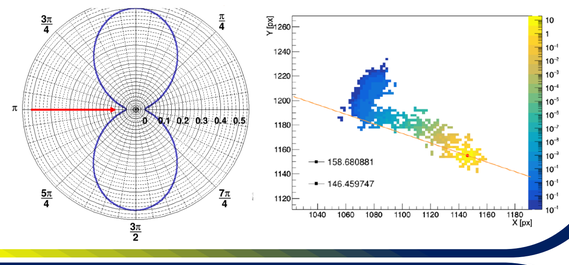
- Imaging of electron recoils (ERs)

Lisotti et al. (2024). arXiv:2404.03690.



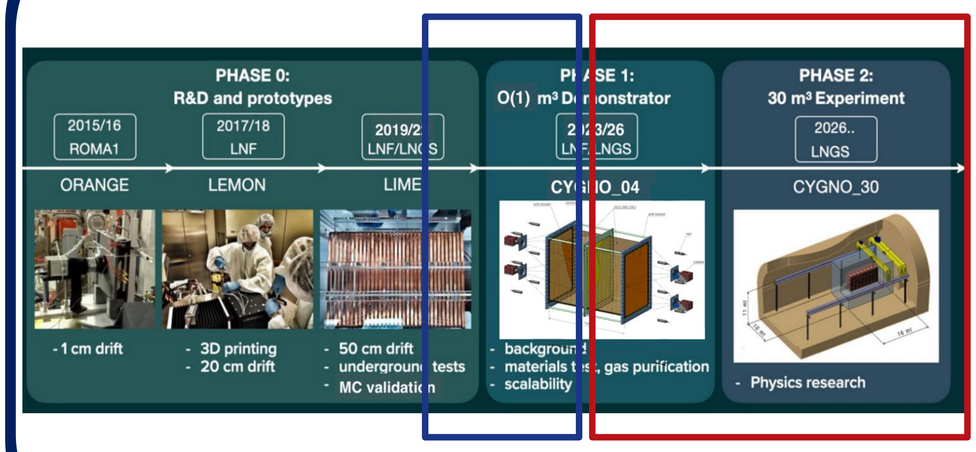
Polarization of X-ray from space

- Imaging of electron recoils (ERs)
- Opens new knowledge on large



The Detector

Gaseous Time Projection Chamber based detector



See D. Marques presentation

Future

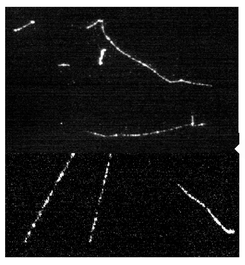
Main Features

- Imaging detector of low energy Ers and NRs (E_{th}~ 1 keV_{ee})
- Operated at atmospheric pressure and room temperature with mixture of He:CF_4 (60/40)
- Sensitivity to SI and SD for WIMP mass range of 0.7-50 GeV/c^2
- Triple Gas Electron Multiplier (GEM) stack for signal amplification
- 3D reconstruction with combined use of the camera and PMTs

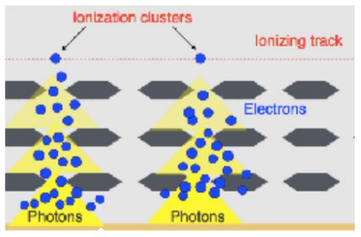
Optical Readout

sCMOS camera

- Single photon sensitivity
- High granularity (2304x2304 pixels)



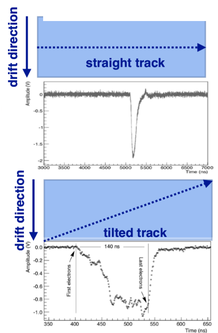
Energy x-y coordinate



Full 3D reconstruction

PMT

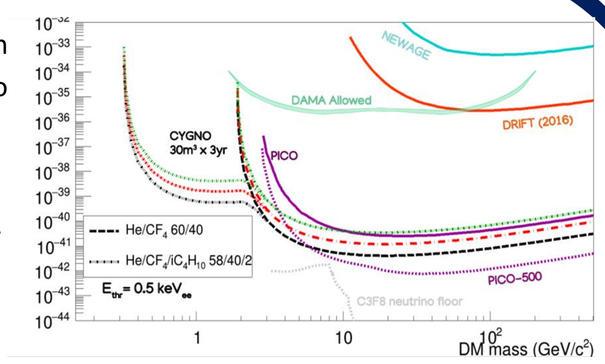
- Fast detector



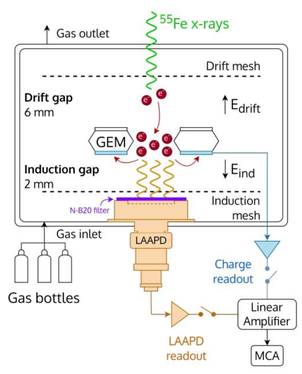
Energy z coordinate

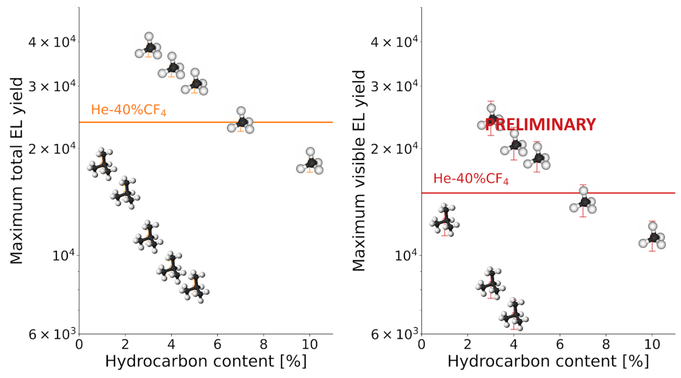
H-rich gases

- The possibility of adding hydrogen rich gas is under study to gain sensitivity to lower DM masses
- Limit estimation with 2% isobutane or 5% methane



- Both isobutane and methane in <10% concentration were tested

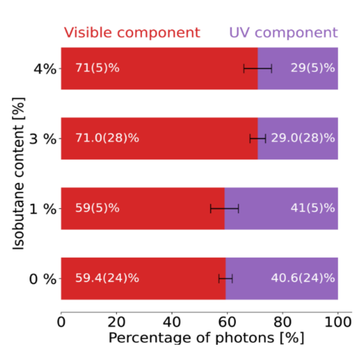




- Methane gave larger stability

Larger gain achieved than He:CF_4 alone

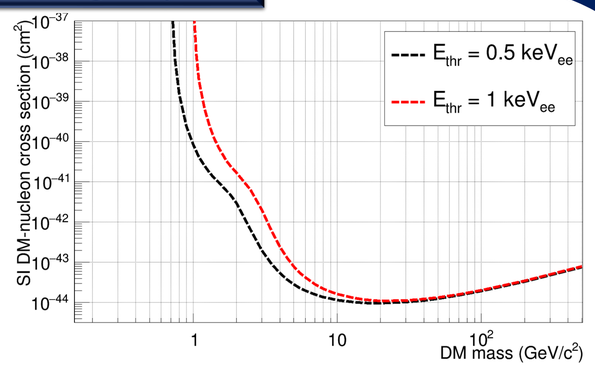
- Level of visible to UV light quenching estimated with filters (pass >300 nm)



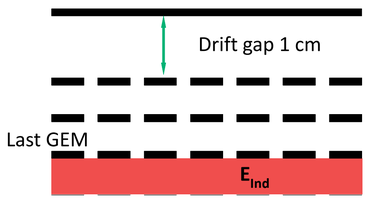
Amaro et al.,PLB 855 (2024) https://doi.org/10.1016/j.physletb.2024.138759

Enhanced light yield

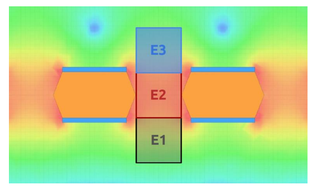
- Increasing the light yield produced in the amplification stage allows to:
  - lower the energy thresold
  - Improve signal to noise ratio



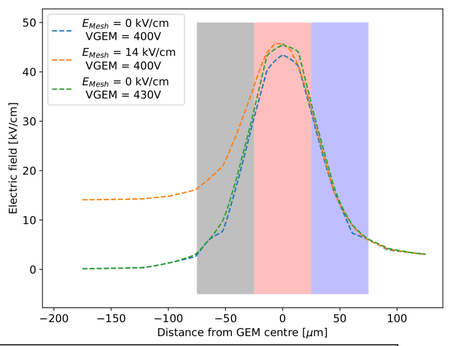
- Concept: add a strong electric field (10- 15 kV/cm) below the last GEM of amplification



ITO glass



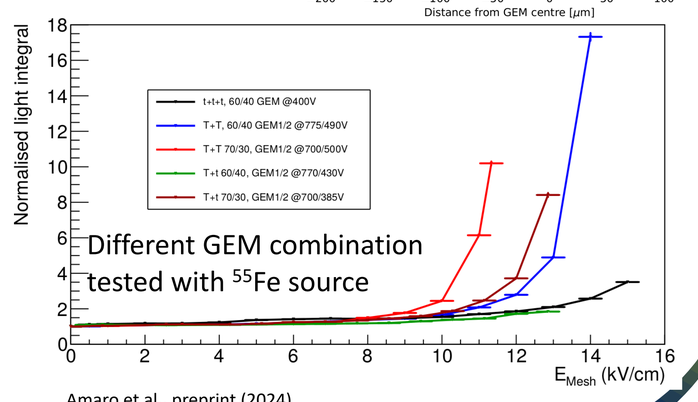
Distortion of E field below GEM



Advantages:

- Large increment in light yield
- Light yield surpassed regular GEM operation
- Intrinsic diffusion stable

Allows the use of 2 GEM stack with reduced intrinsic diffusion (~ 25% less) and comparable light yield (~ factor 2 less)



Different GEM combination tested with ^{55}Fe source

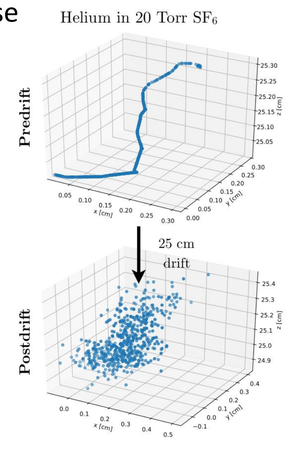
Amaro et al., preprint (2024) arXiv:2406.05713

Negative ion Drift

Principle

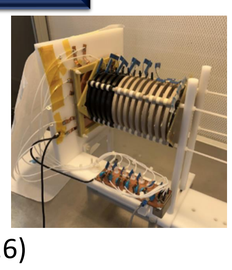
- Diffusion in gas limits the amount of information retrievable to characterise the topology of the tracks
- Electronegative gases can capture primary electron and generate negative ions
- Diffusion can be reduced to thermal limit (maybe below?)

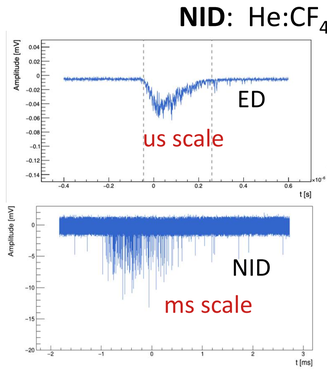
CYGNUS white paper: https://arxiv.org/abs/2008.12587



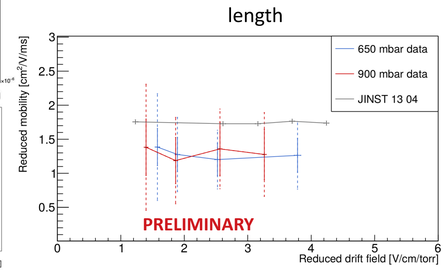
Experimental realisation

- TPC 10x10 cm^2 15 cm drift length, ^{241}Am source, 900 and 650 mbar
- Gas mixture **ED**: He:CF_4 (60/40)
  NID: He:CF_4:SF_6 (59/39.4/1.6)





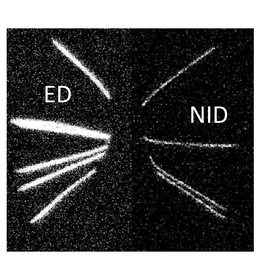
Ion mobility estimated by PMT signal length

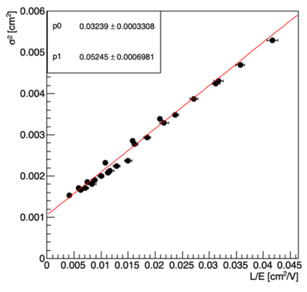


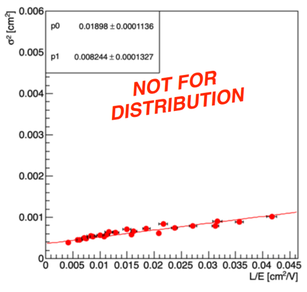
Diffusion measurement

$$\sigma^2_{meas} = \sigma^2_0 + \frac{2kT_{eff}}{e}\frac{L}{E} = p_0^2 + 2p_1\frac{L}{E}$$

- Exploiting the central width of collimated alpha tracks







Extremely low transverse diffusion achieved

Gas	Diffusion @1 kV/cm [$\frac{\mu m}{\sqrt{cm}}$]
Ar:CH_4 (90/10):	600
He:CF_4 (60/40):	140
He:CF_4:SF_6 (59:39.4:1.6):	**35**

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