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

Giorgio Dho on behalf of CYGNO coll.

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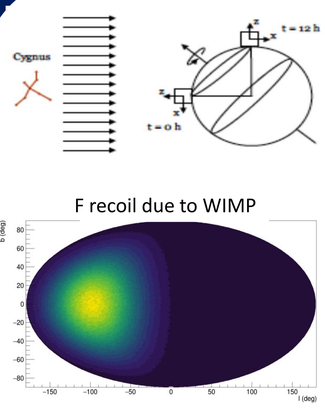
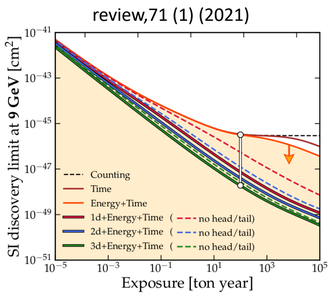
Physics case



Strong anisotropical angular distribution imprinted in WIMP case

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



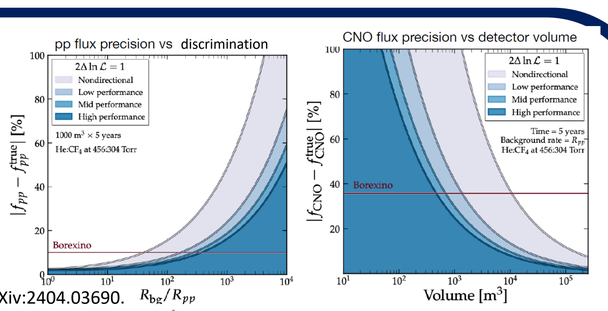
Directional Dark Matter (DM)

- 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
- Requires: imaging of nuclear recoils (NRs)

But not only

Neutrinos can become signal

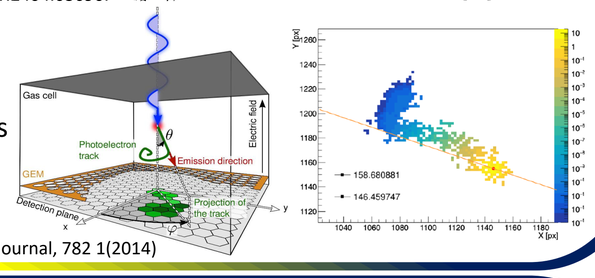
- Requires: imaging of electron recoils (ERs)



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

Polarization of X-ray from space And Migdal effect

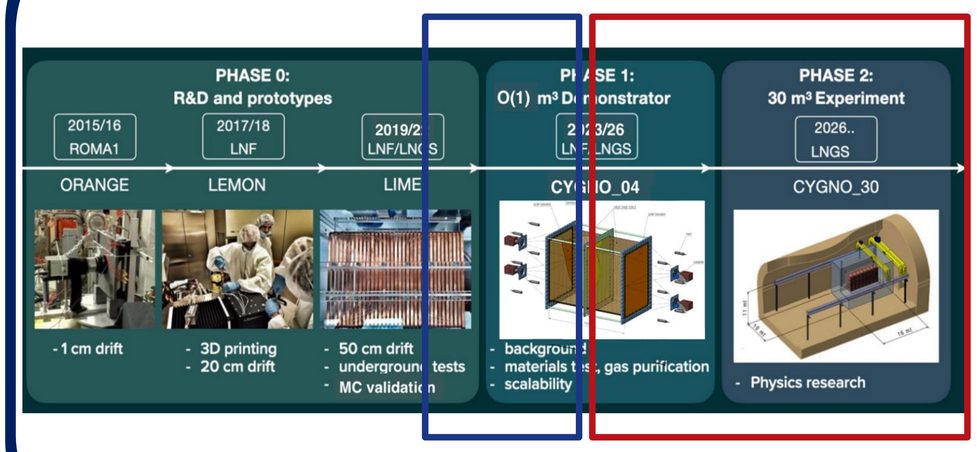
- Requires: imaging of ERs and NRs
- New frontiers in fundamental Physics and Astrophysics



Muleri, Astrophysical Journal, 782 1(2014)

The Detector

Gaseous Time Projection Chamber



See D. Marques presentation
Thursday direct directional session

Future

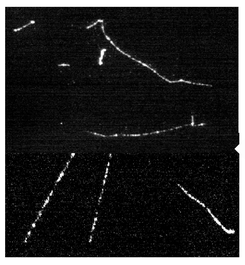
Main Features

- 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

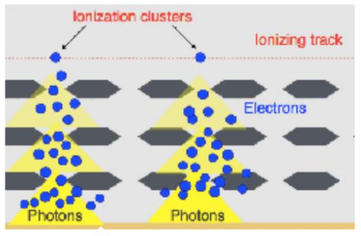
Optical Readout

sCMOS camera

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



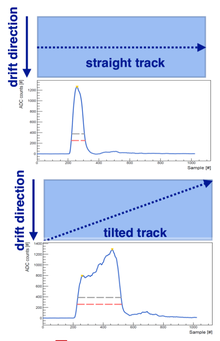
Energy x-y coordinate



Full 3D reconstruction

PMT

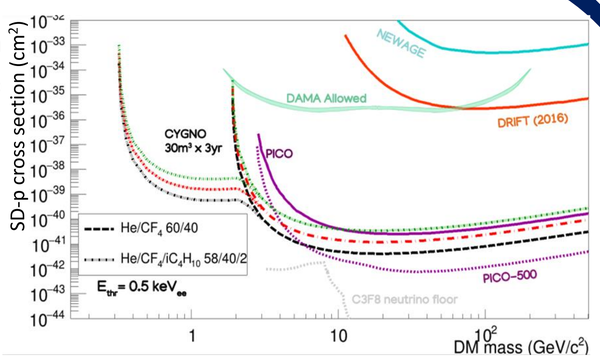
- Fast detector



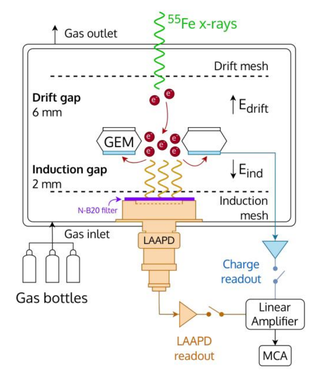
Energy z coordinate

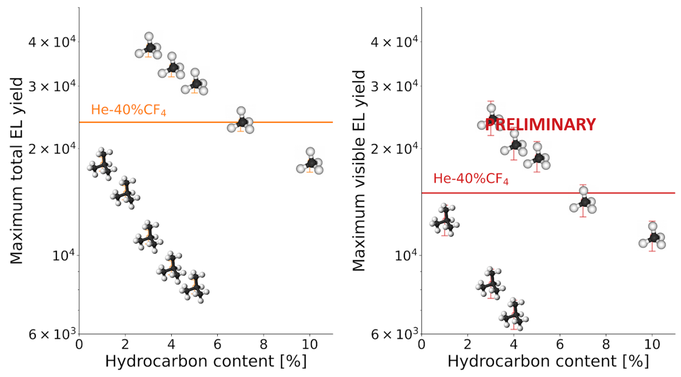
H-rich gases

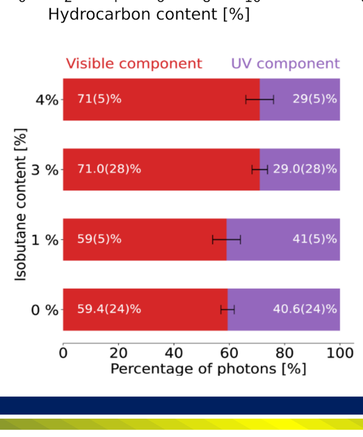
- The possibility of adding hydrogen rich gas is under study to gain sensitivity to lower DM masses
- Limit estimation with 2% isobutane or 5% methane



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







- Methane gave larger stability

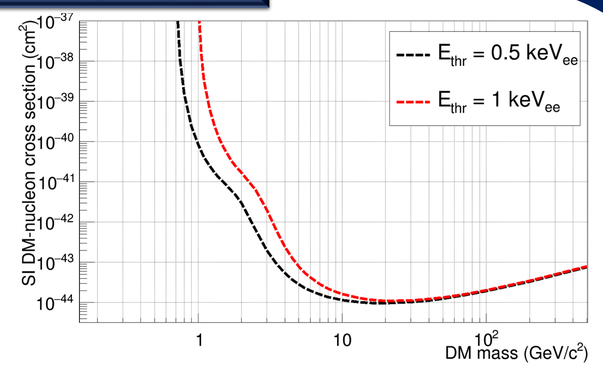
Larger gain achieved than He:CF_4 alone

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

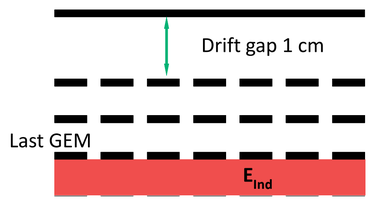
Amaro et al.,PLB 855 (2024) https://doi.org/10.1016/j.physletb.2024.138759

Enhanced light yield

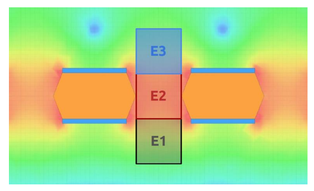
- Increasing the light yield produced in the amplification stage allows to:
  - Lower the energy threshold
  - Improve signal to noise ratio



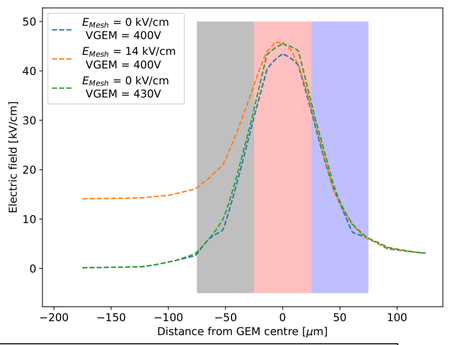
- Concept: add a strong electric field (10- 15 kV/cm) below the last GEM of amplification



ITO glass



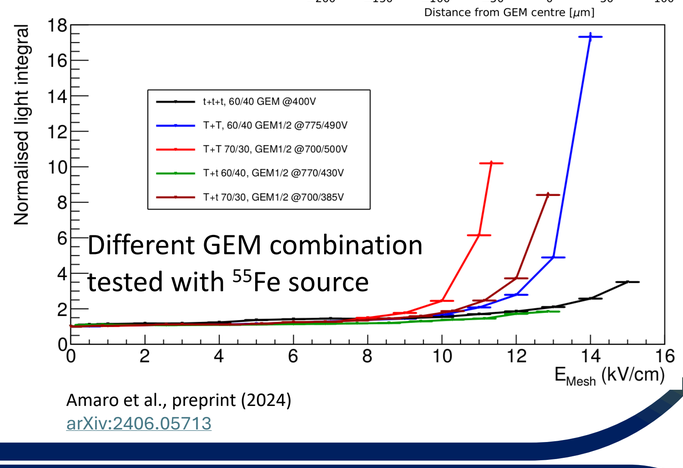
Distortion of E field below GEM



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)



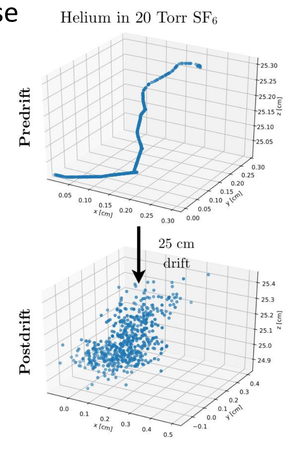
Amaro et al., preprint (2024) arXiv:2406.05713

Negative ion Drift

Principle

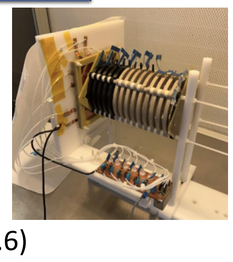
- Diffusion in gas limits the amount of information retrievable to characterise the topology of the tracks
- Electronegative gases can capture primary electron and generate negative ions
- Diffusion can be reduced to thermal limit (maybe below?)

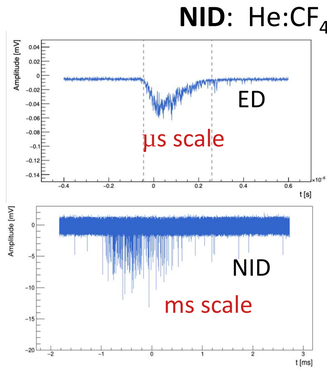
CYGNUS white paper: https://arxiv.org/abs/2008.12587



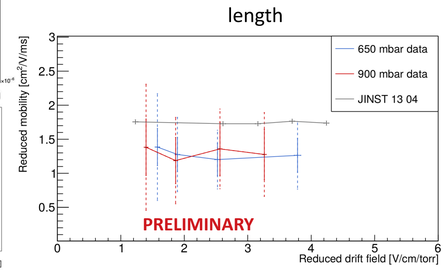
Experimental realisation

- 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)





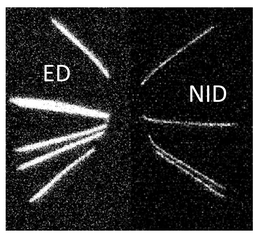
Ion mobility estimated by PMT signal length

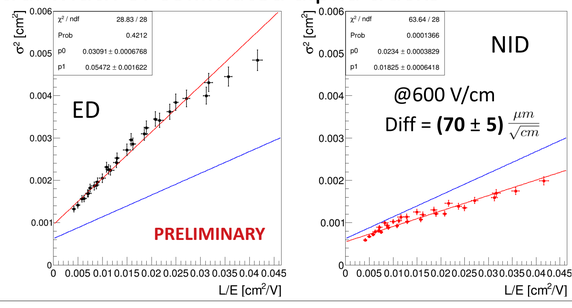


Diffusion measurement

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

- Exploiting the central width of collimated alpha tracks





Extremely low transverse diffusion achieved

Gas	Trans Diffusion @1 kV/cm [$\frac{\mu m}{\sqrt{cm}}$]	
Ar:CH_4 (90/10):	600	PDG
He:CF_4 (60/40):	110	PDG
He:CF_4:SF_6 (59:39.4:1.6):	**55 (estimated)**	

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