Optical Readout TPC for low energy event tracking

F.D.Amaro, E.Baracchini, L.Benussi, S.Bianco, C.Capoccia, M.Caponero, D.S.Cardoso, G.Cavoto, A.Cortez, I.A.Costa, R.J.d.C.Roque, E.Dané, G.Dho, F.Di Giambattista, E.Di Marco, G.Grilli di Cortona, G.D'Imperio, F.Iacoangeli, H.P.Lima Júnior, G.S.Pinheiro Lopes, A.d.S.Lopes Júnior, G.Maccarrone, R.D.P.Mano, M.Marafini, R.R.Marcelo Gregorio, D.J.G.Marques, G.Mazzitelli, A.G.McLean, A.Messina, C.M.Bernardes Monteiro, R.A.Nobrega, I.F.Pains, E.Paoletti, L.Passamonti, S.Pelosi, F.Petrucci, S.Piacentini, D.Piccolo, D.Pierluigi, D.Pinci, A.Prajapati, F.Renga, F.Rosatelli, A.Russo, J.M.F.dos Santos, G.Saviano, N.J.C.Spooner, R.Tesauro, S.Tomassini, S.Torelli

18 October 2022, Bari, IFD2022

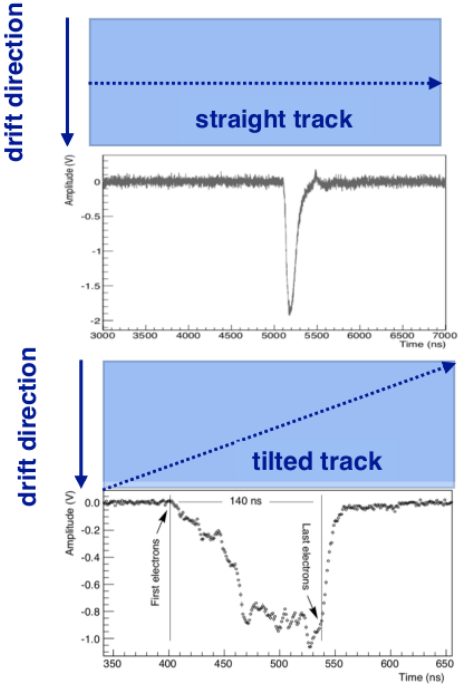
The CYGNO* approach: gaseous TPC with optical readout

*Instruments 2022, 6(1), 6

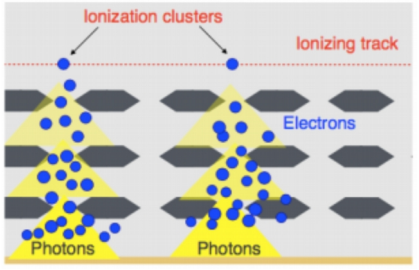
- Gaseous TPC for **directional** Dark Matter search, He:CF_4 60:40
- Triple GEM amplification + optical readout (sCMOS cameras + PMT)
- **3D track reconstruction**
  - Directionality (axial+sense)
  - Background rejection
  - Particle identification
  - Fiducialization

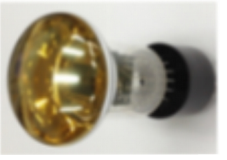
Optical readout:

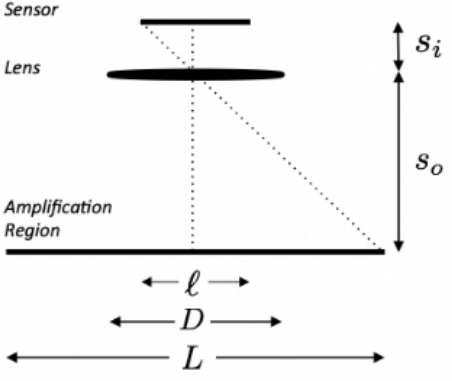
- With suitable lenses we can image **large areas** O(1m^2) **with single sensor**, with O(100 μm) effective pixel size
- **sCMOS**: high granularity, low noise, single photon sensitivity (energy + **xy** position)
- **PMT**: energy + **z** component



JINST 13 (2018) 05, P05001

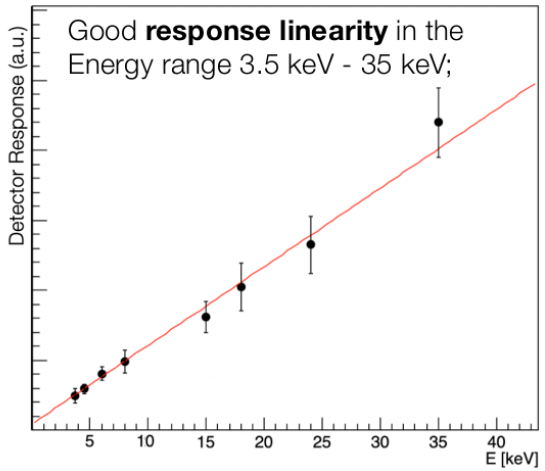


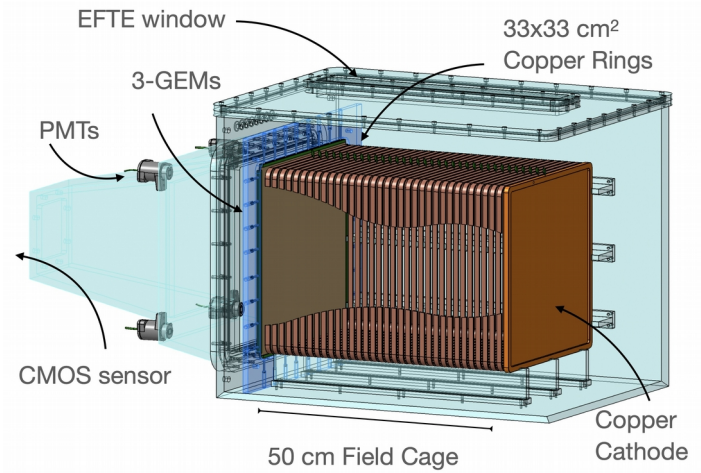


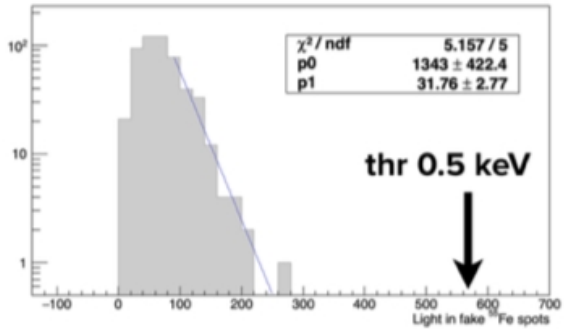


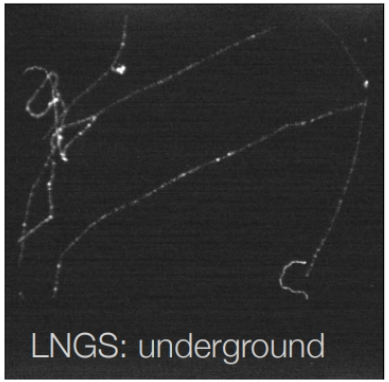
LIME (Long Imaging ModulE)

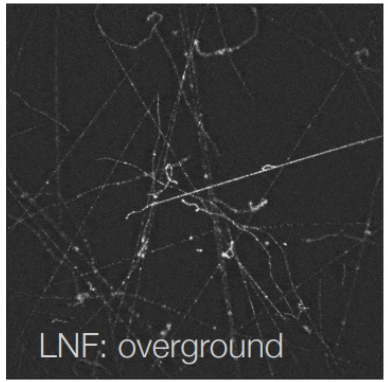
- 50 liters sensitive volume
- He:CF_4 60/40, atm.pressure
- Triple GEM amplification
- 33x33 cm^2 readout area, 50cm drift
- 1sCMOS camera + 4 PMTs
- Now installed underground at LNGS







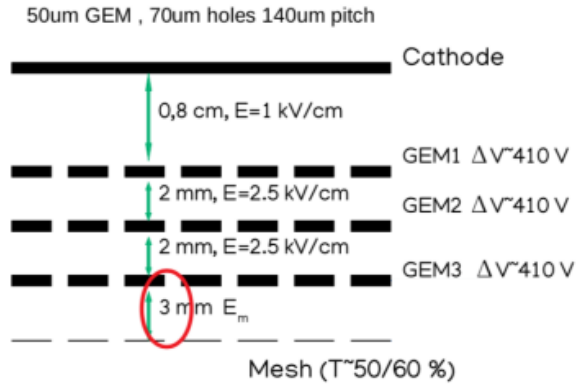


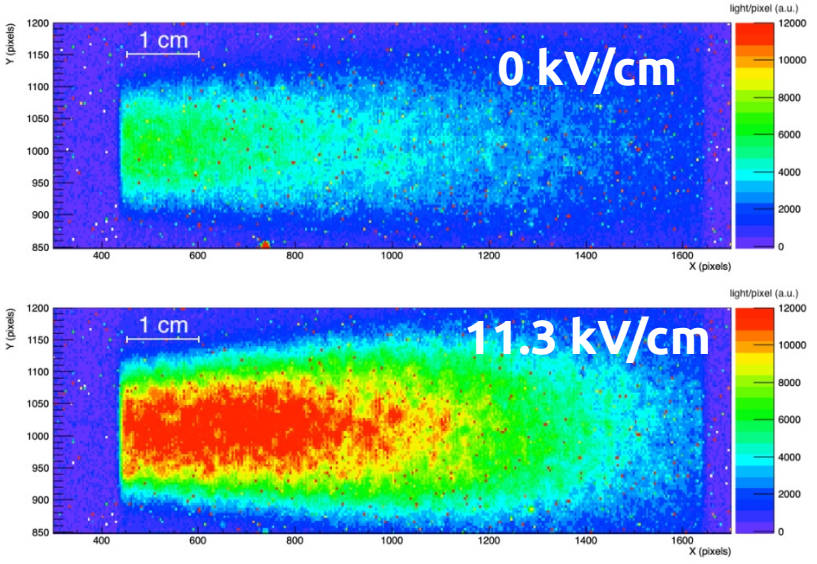


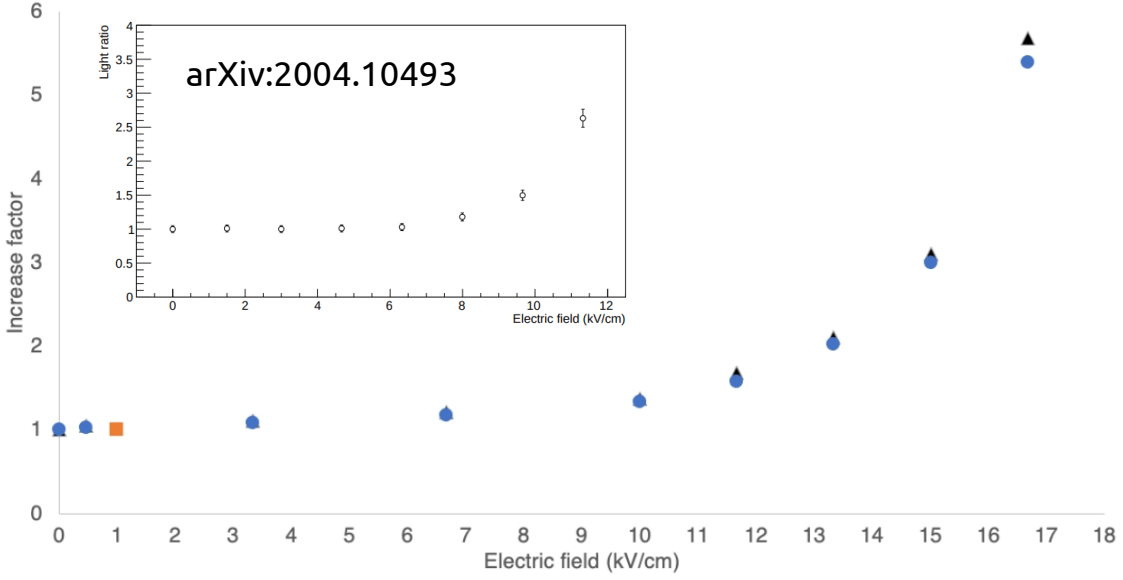
Electroluminescence studies

JINST 15 (2020) 08, P08018

- Add a mesh (or ITO glass) 3 mm after last GEM
- Apply drift field between GEM and mesh
- Electrons travelling in the GEM-mesh gap produce additional light with no (or relatively low) further ionisation
  - More light without degrading resolution (lower threshold)



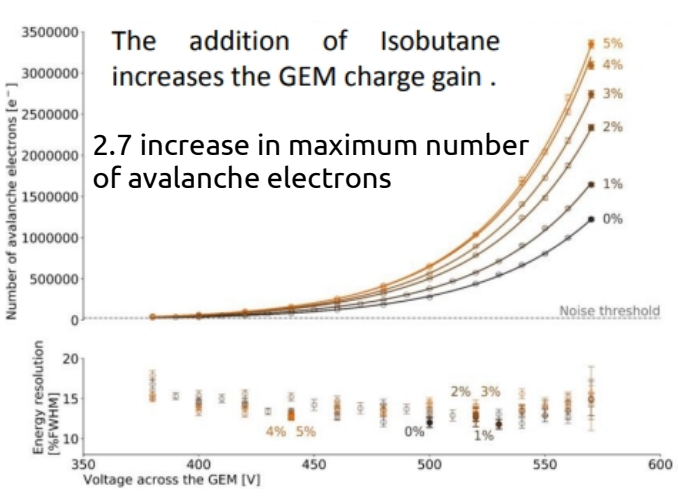


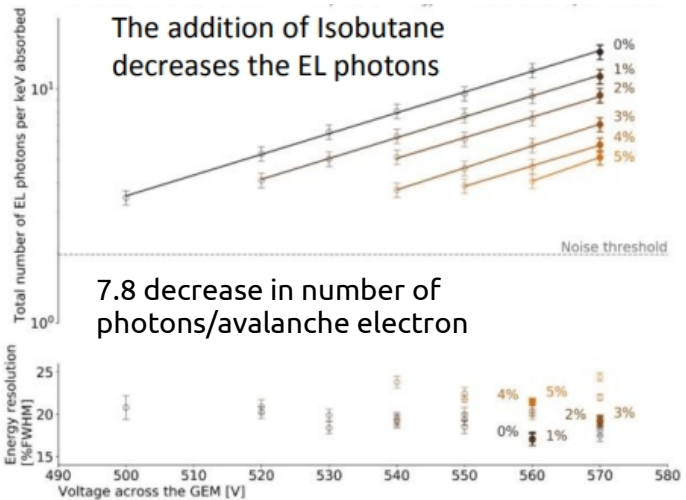


Hydrocarbons studies

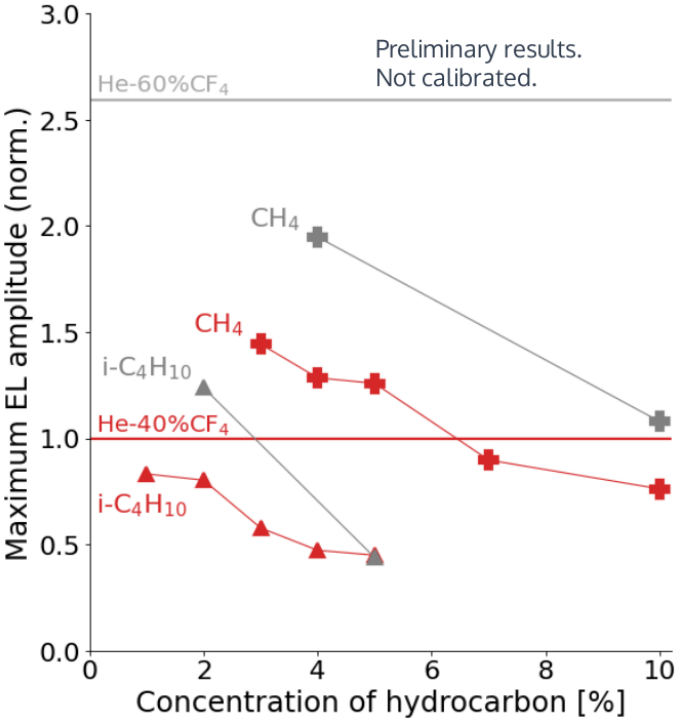
High hydrogen content extends sensitivity to lower WIMP masses
We studied for the first time the light yield of hydrocarbons gas mixtures
Adding between 0% and 5% of **iC_4H_{10}** to He:CF_4 mix:

- Overall only 2.8 decrease in photons/keV
- Energy resolution independent from iC_4H_{10} content

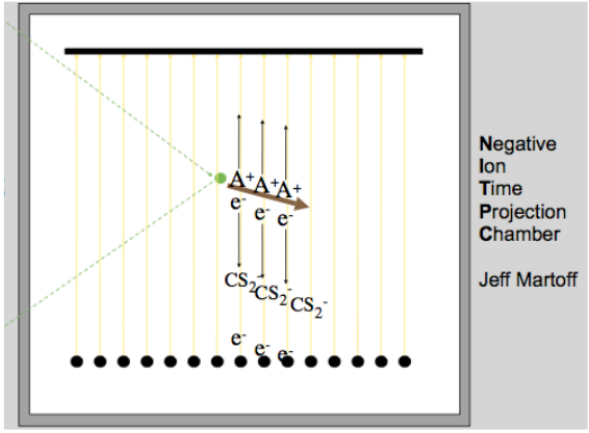




Adding between 3% and 5% of **CH_4** increases the light yield without degrading the energy resolution (ongoing)



Negative ion drift operation

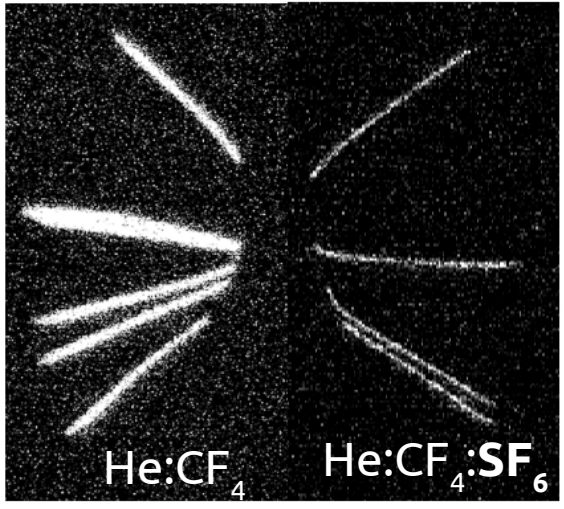


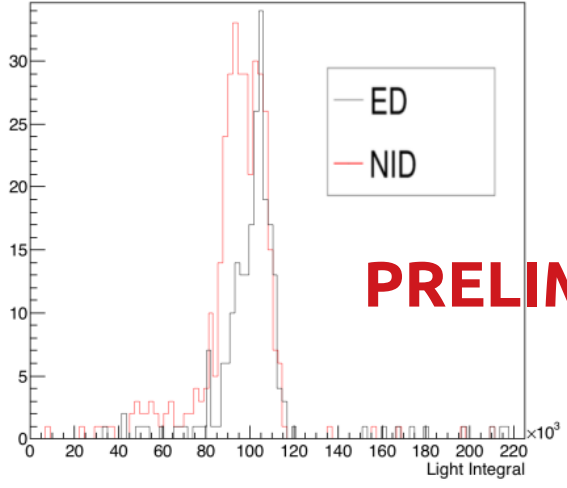
- **Electronegative** dopants added to the gas mixture
- Primary ionization electrons captured by electronegative gas molecules at O(100) um
- Negative ions act as image carriers instead of electrons – **reduced diffusion** allows larger volume TPCs with same (or better) tracking
- Tests ongoing on small prototype with SF_6 – promising results!

J. Martoff et al., NIM A 440 355

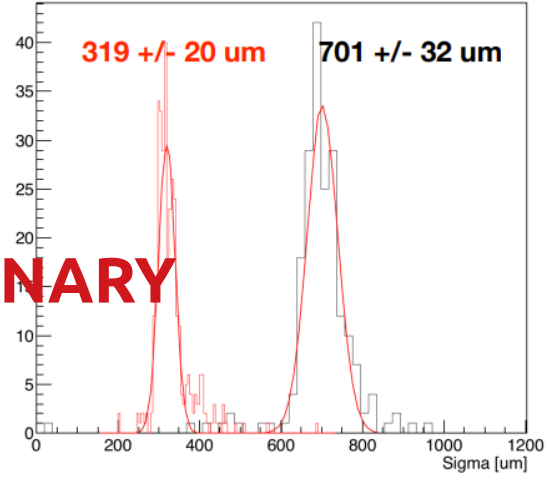
T. Ohnuki et al., NIM A 463

E. Baracchini et al., 2018, JINST 13 P04022



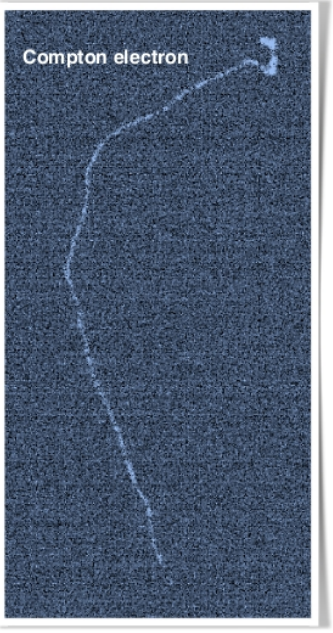


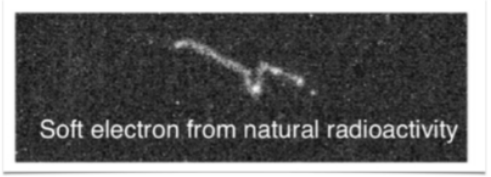
PRELIMINARY

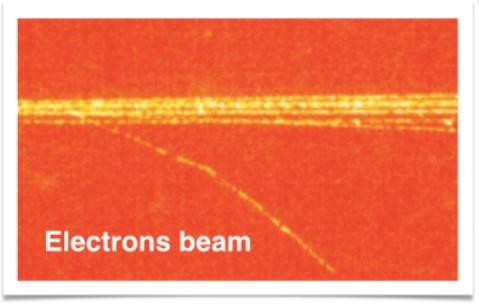


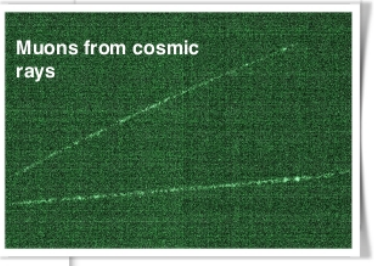
Photographing tracks

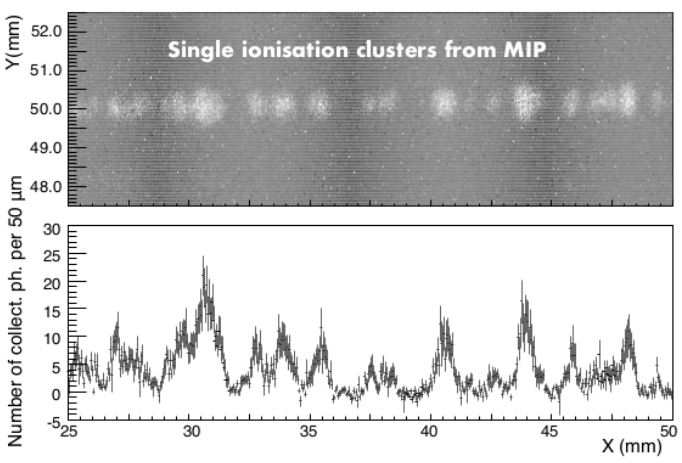
https://www.facebook.com/cygno.experiment
https://web.infn.it/cygnus/cygno

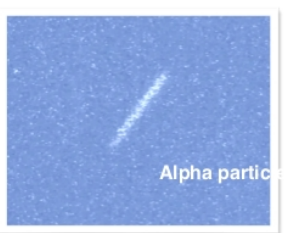


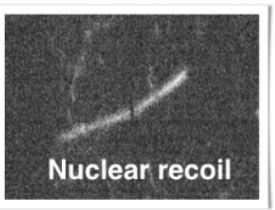




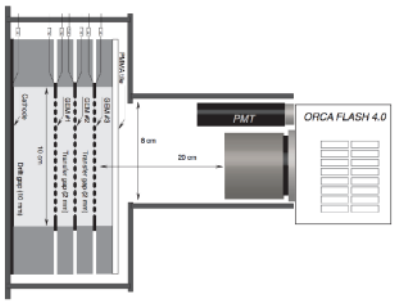




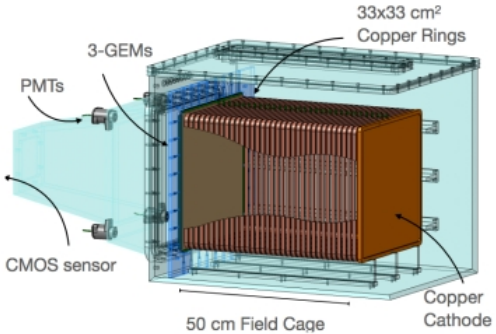




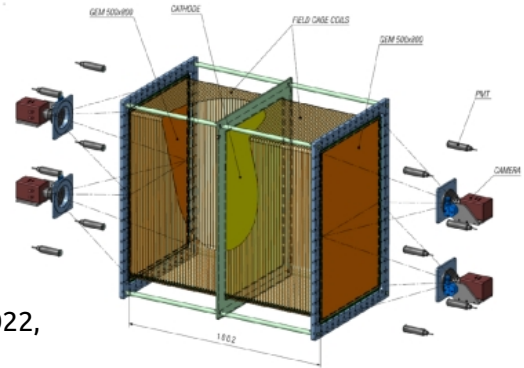
Beyond Dark Matter



Small O(1L)



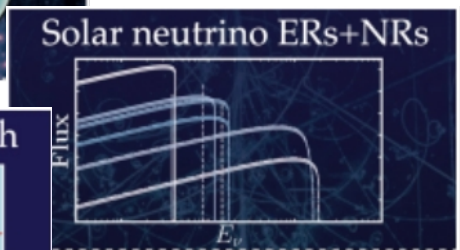
Medium O(50L)

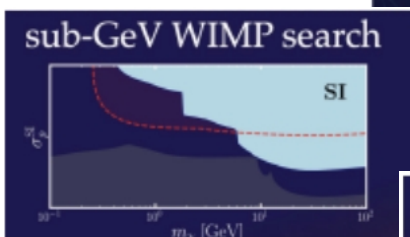


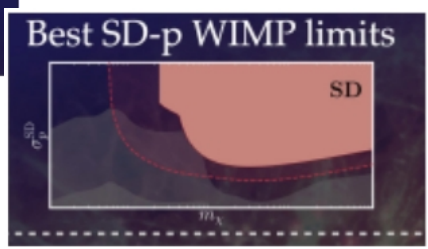
"The CYGNO experiment", Instruments 2022, 6(1), 6

Large O(30-1000 m³)

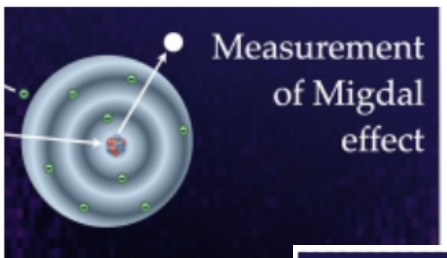
S.E.Vahsen et al., arXiv:2008.12587



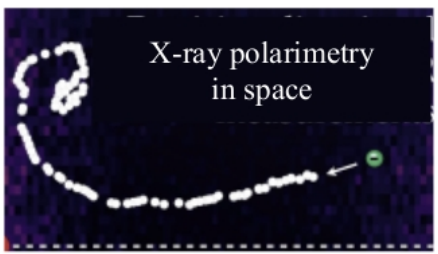




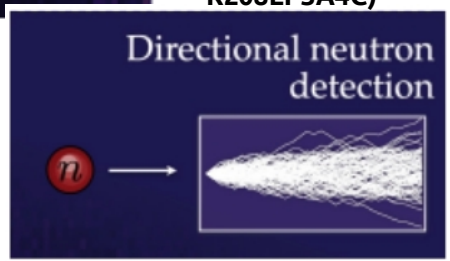
C. A. J. O'Hare et al., 2022 Snowmass Summer Study, arXiv:2203.05914



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



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



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

Beyond Dark Matter

MIGDAL

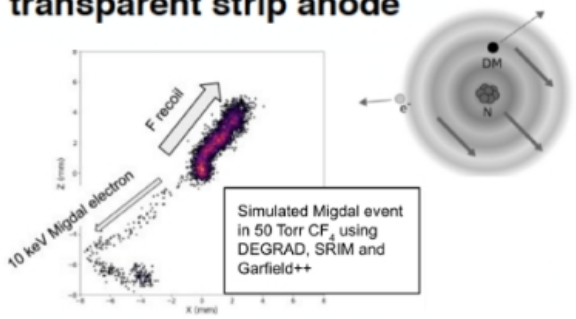
Migdal In Galactic Dark mAtter expLoration

CERN 2020

Low-pressure TPC with optical+electronic readout

Migdal effect search in low-pressure CF_4 for DM searches in

CMOS + electronic readout of **transparent strip anode**



P. Majewski, RD51 Mini-Week 2020, https://indico.cern.ch/event/872501/contributions/3730586/attachments/1985262/3307758/RD51_mini_week_Pawel_Majewski_ver2.pdf

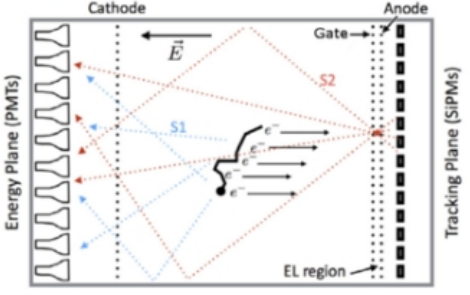
next

CANFRANC 2019

High Pressure Xe gas TPC with electroluminescent amplification

Neutrinoless double beta decay searches in ^{136}Xe

PMTs for energy measurement & t_0 from S1, **SiPM-based tracking** plane recording electroluminescence



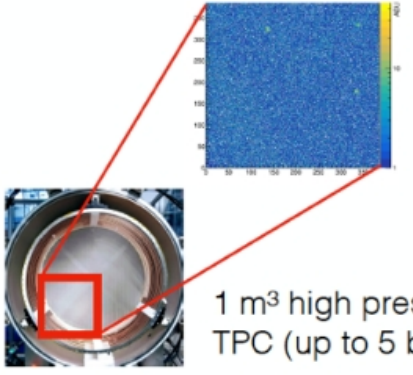
https://next.ific.uv.es/next/experiment/detector.html
L. Arazi, Status of the NEXT project, https://doi.org/10.1016/j.nima.2019.04.080

High Pressure TPC

DUNE COLLABORATION 2021

Towards a neutrino-nucleus cross section experiments

Stitched optical readout (4 CCD cameras) + **electronic signals** from meshes used for amplification



1 m^3 high pressure TPC (up to 5 bar)

A. Deisting, HPTPC, https://arxiv.org/pdf/2102.06643.pdf

Thank you