

DIRECTIONAL DARK MATTER SEARCHES WITH CYGNO/INITIUM

G. Dho for CYGNO coll:

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M. Marafini, G. Mazzitelli, A. Messina, R. A. Nobrega, A. Orlandi, E. Paoletti,
L. Passamonti, F. Petrucci, D. Piccolo, D. Pierluigi, D. Pinci, A. Prajapati, F. Renga,
F. Rosatelli, A. Russo, G. Saviano, R. Tesauero, S. Tomassini, S. Torelli

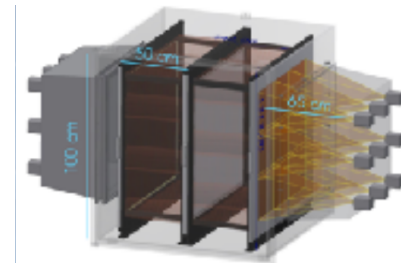


Part of this project has been funded by the European Union's Horizon
2020 research and innovation programme under the ERC Consolidator
Grant Agreement No 818744



CYGNO EXPERIMENT

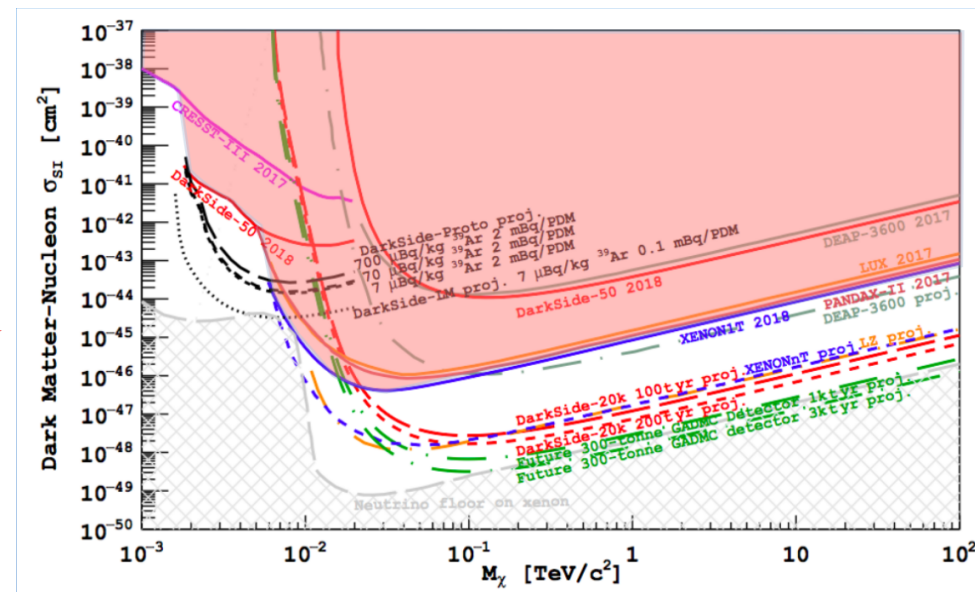
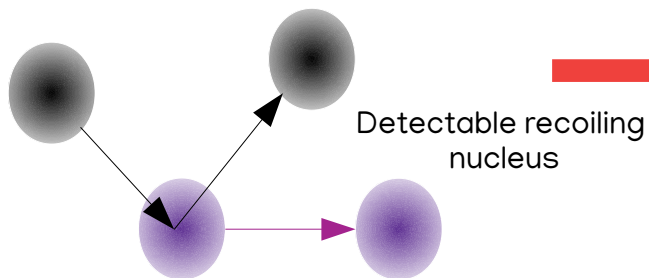
- CYGNO is the project of a directional detector, whose main goal is the direct detection of Dark Matter



He:CF₄ gas mixture as target

looking at its nuclear
(electron) recoils

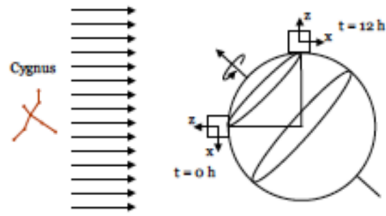
Dark Matter
particle



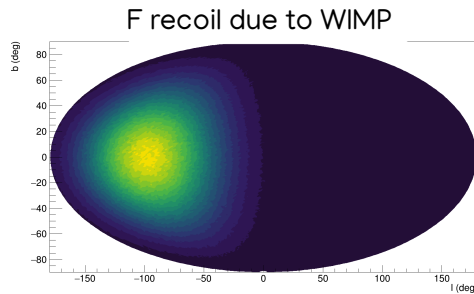
DIRECTIONALITY

- The addition of directional information to the energetic one boosts the capabilities of the search

High potential for positive discovery



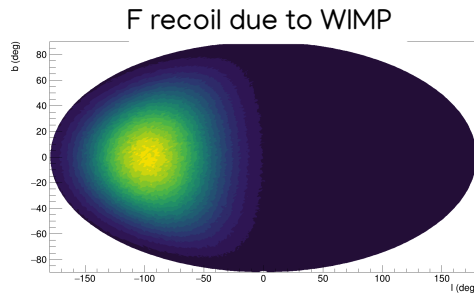
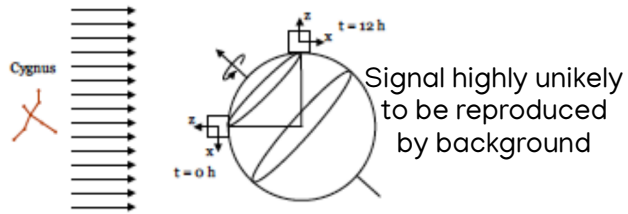
Signal highly unlikely to be reproduced by background



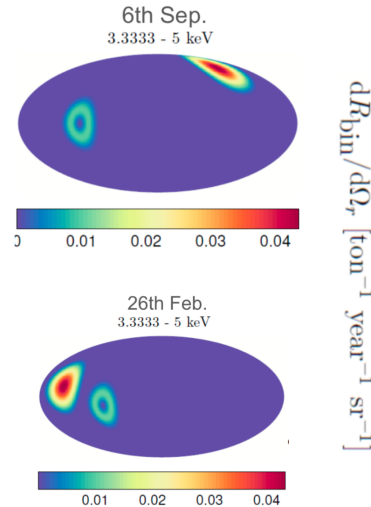
DIRECTIONALITY

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High potential for positive discovery



What is now considered background can become signal

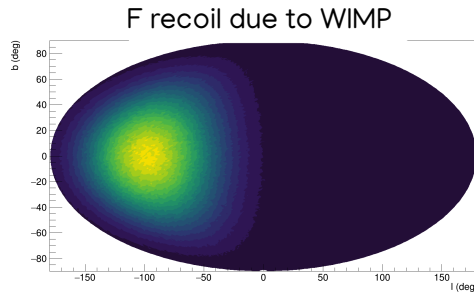
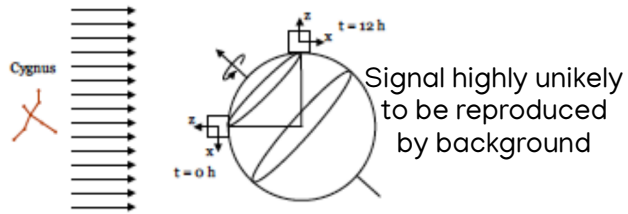


Recoils from coming from Solar neutrinos will not overlap with DM ones

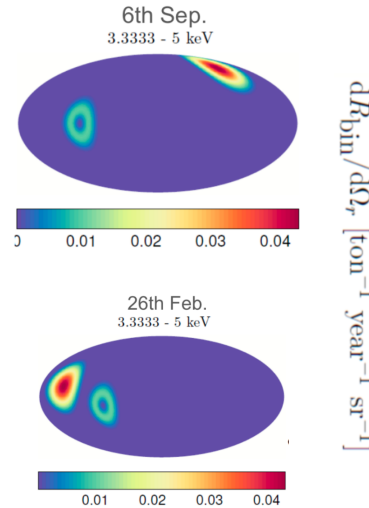
DIRECTIONALITY

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Recoils from coming from Solar neutrinos will not overlap with DM ones

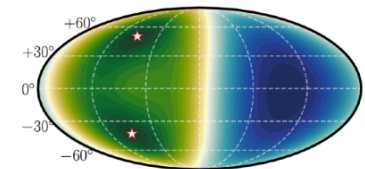
Capability to probe DM nature

Capability to probe DM nature

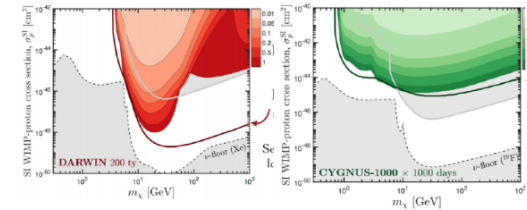
The Gaia Sausage gives rise to peaks off center from Cygnus

Phys.Rev. D99 (2019) no.2, 023012

5 - 10 keV



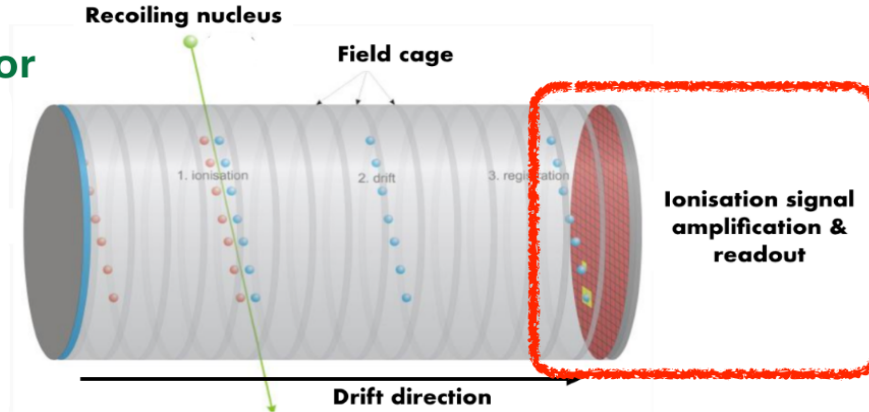
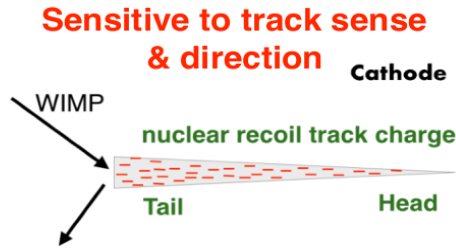
Distribution for 5-10 keV Fluorine recoils with a 100 GeV WIMP
Halo model = SHM + Sausage



Phys.Rev. D98 (2018) no.10, 103006

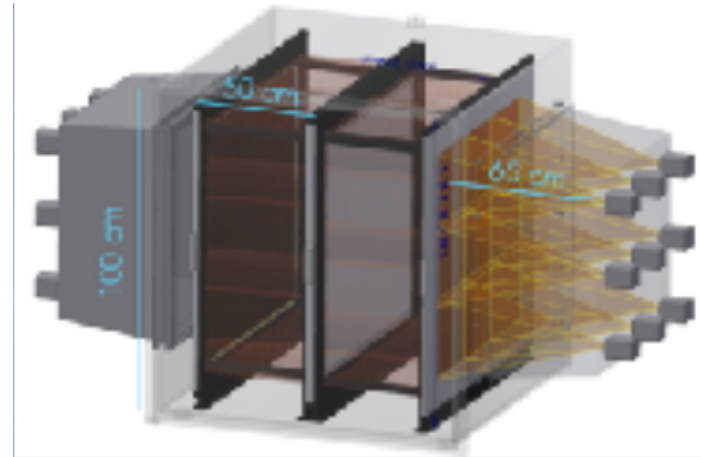
TPC

Inherently a 3D detector

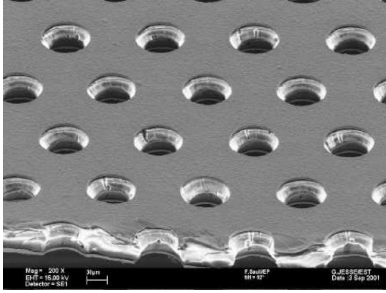


- Advantages:
 - Axial Directionality
 - **Head/tail**
 - Background rejection
 - Particle ID
 - 3D fiducialization
- Technologically challenging, but now achievable via multiple technologies

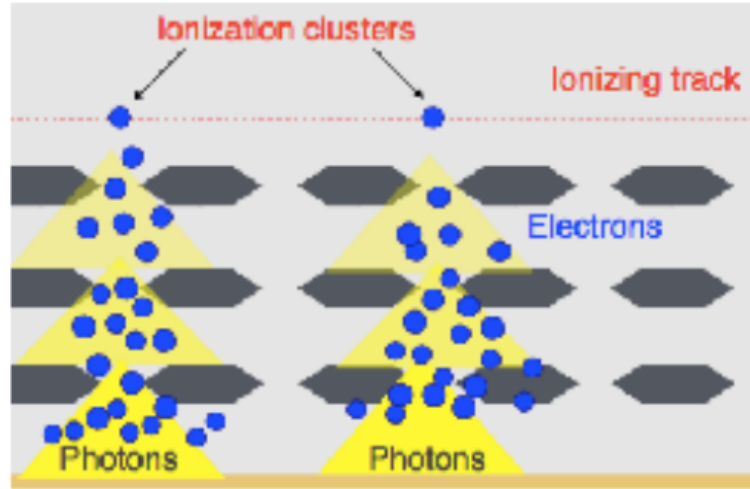
- The one conceived for CYGNO will have two back to back 50 cm drift regions with 1 m² of readout area
- Main gas mixture He:CF₄
- Room temperature and atmospheric pressure



READOUT

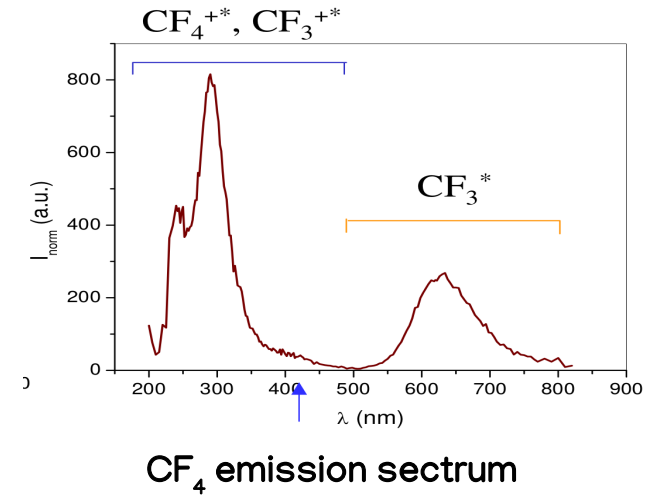


Triple GEM

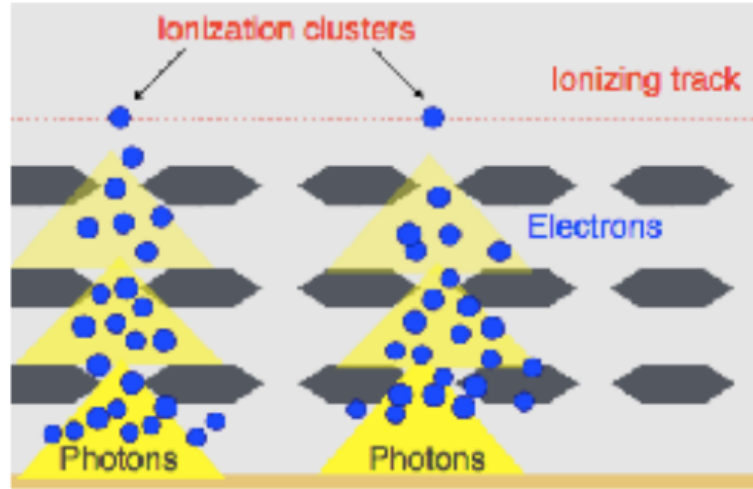


Triple GEM structure

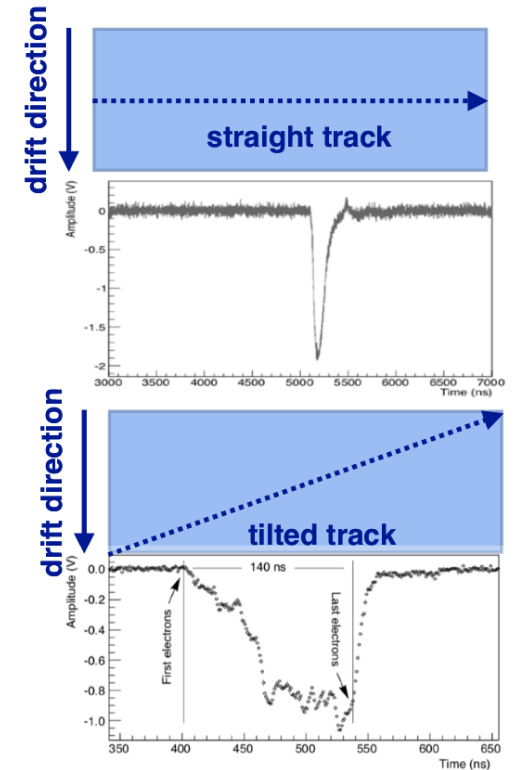
for charge amplification
and light production



Triple GEM



PMT

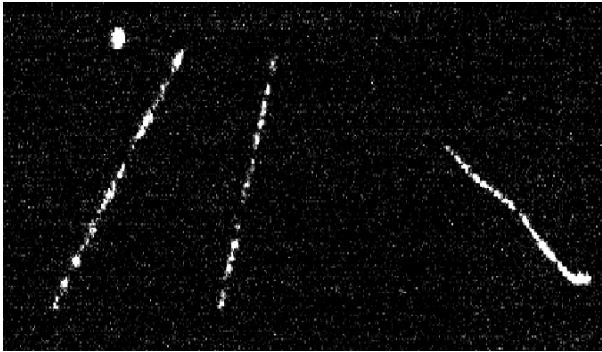


Energy
z coordinate

READOUT

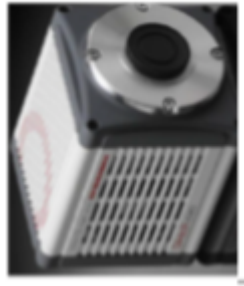
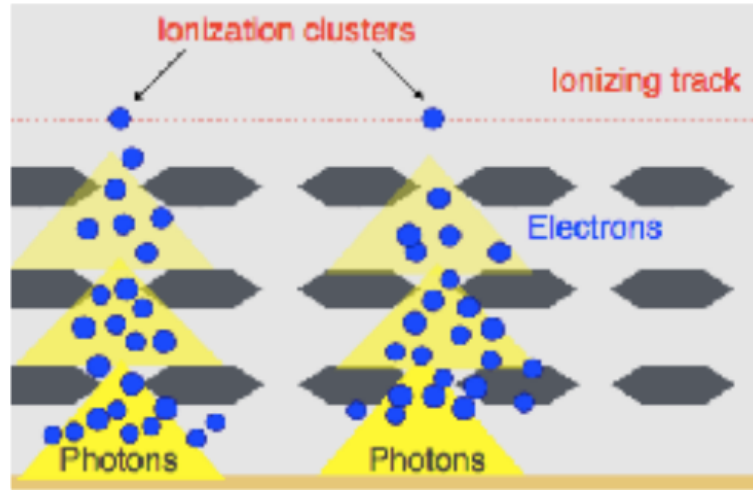
sCMOS camera

- Single photon sensitivity
- High granularity (2304x2304 pixels)
- Market pulled
- Large areas of detection

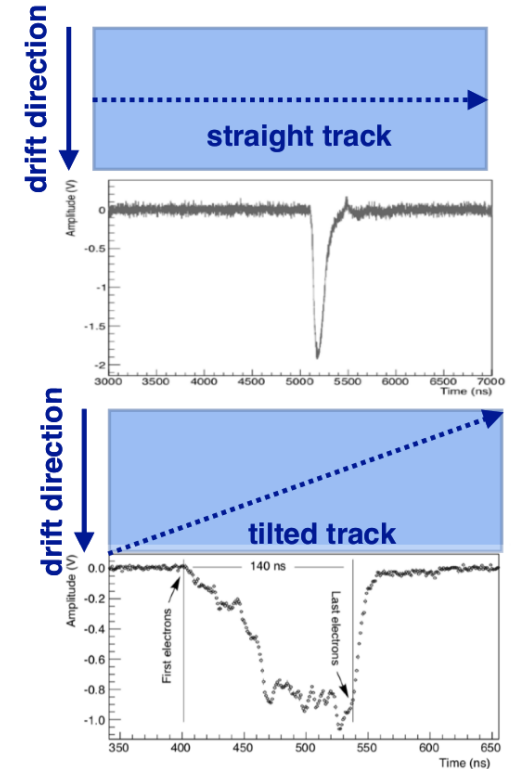


Energy
x-y coordinate

Triple GEM



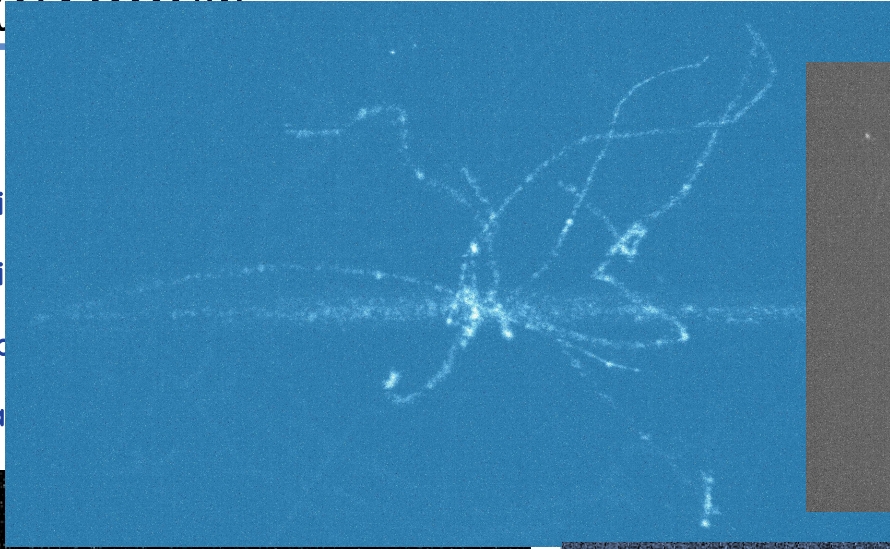
PMT



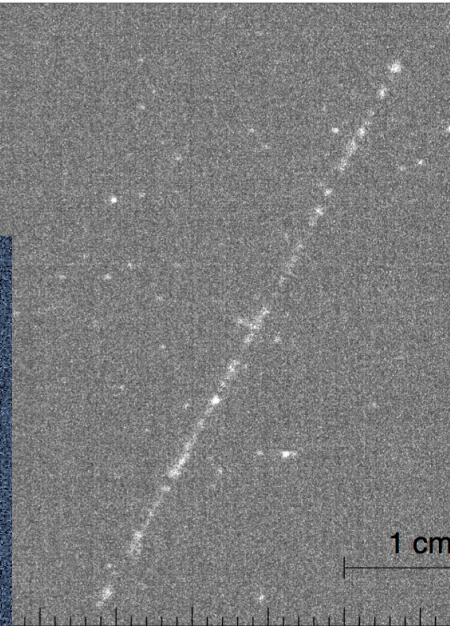
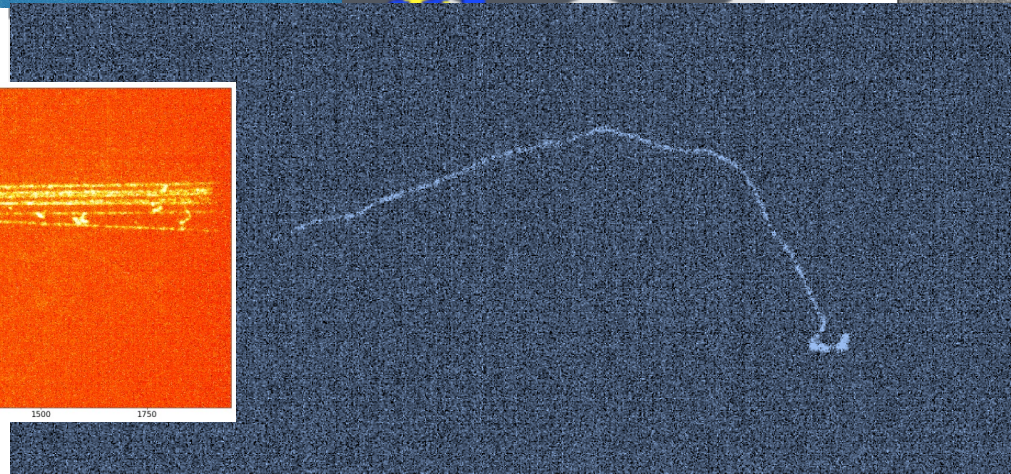
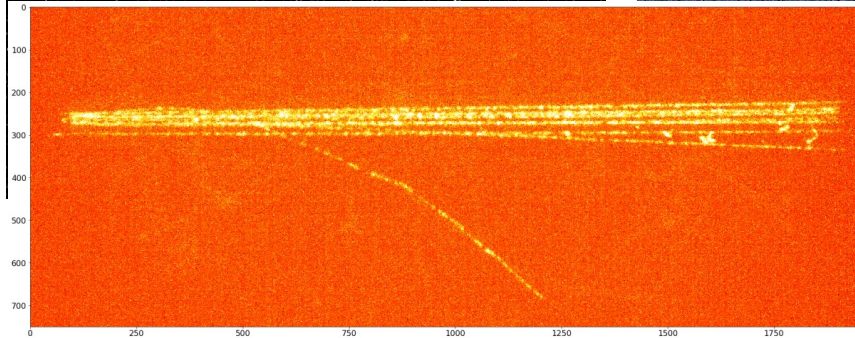
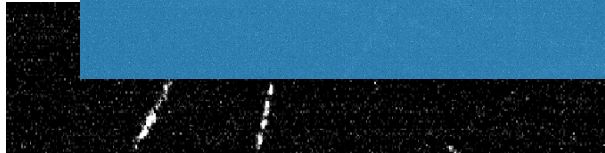
Energy
z coordinate

REPORT

- Si
- Hi
- Mo
- La



PMT

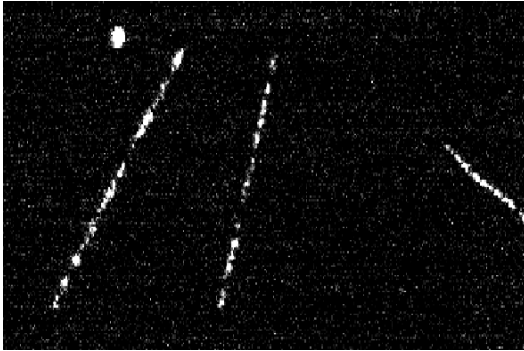


Energy
z coordinate

READOUT

sCMOS camera

- Single photon sensitivity
- High granularity (2304x2304 pixels)
- Market pulled
- Large areas of detection



Energy
x-y coordinate

Triple GEM



+ SF_6 for negative ion drift

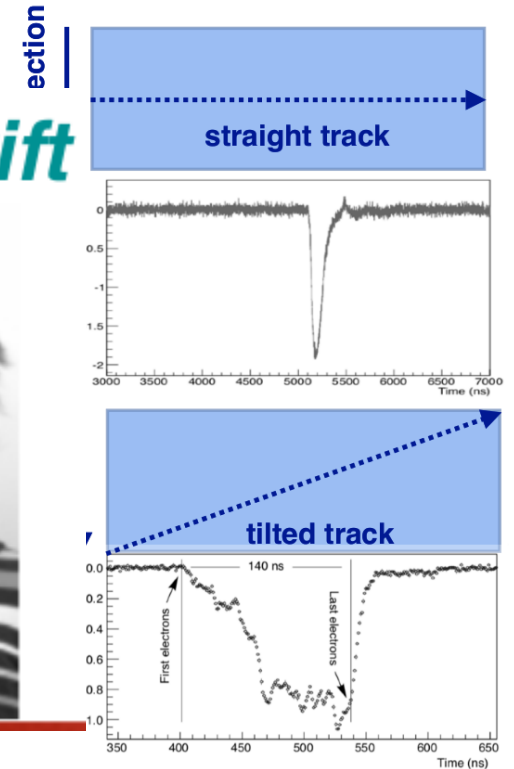


European Research Council

IN TIUM



PMT



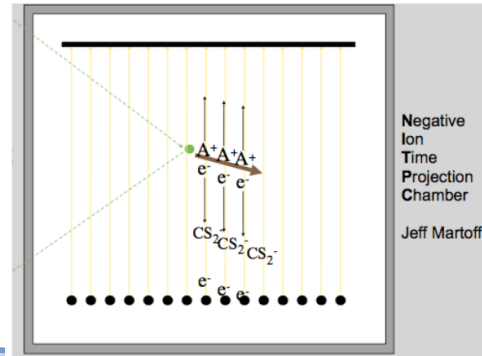
Energy
z coordinate

NEGATIVE IONS

- It consists in the addition of a high electronegative dopant to the gas (CS_2 , SF_6)

Improved track resolution thanks to limited diffusion

- electrons get attached to the dopant close to the ionization position $\sim 100 \mu\text{m}$
- Anions drift acting as the image carrier but with a longitudinal and transverse diffusion reduced to the thermal limit

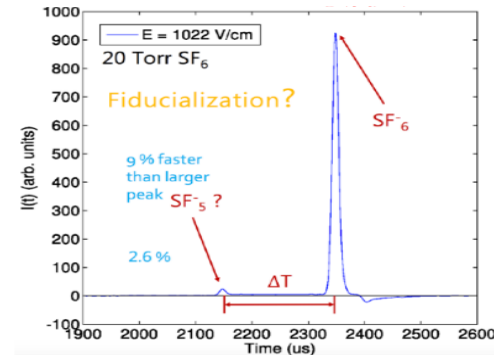
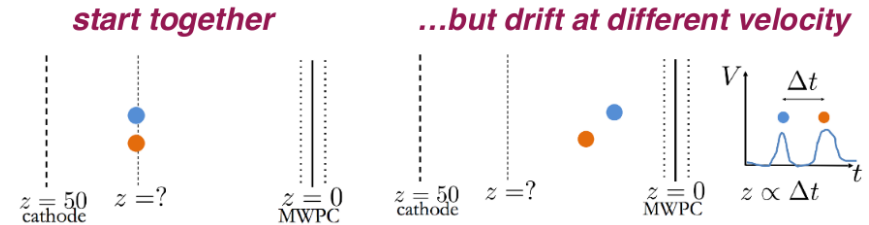


T. Ohnuki et al.,
J. Martoff et al.,
NIM A 463

J. Martoff et al.,
NIM A 440 355

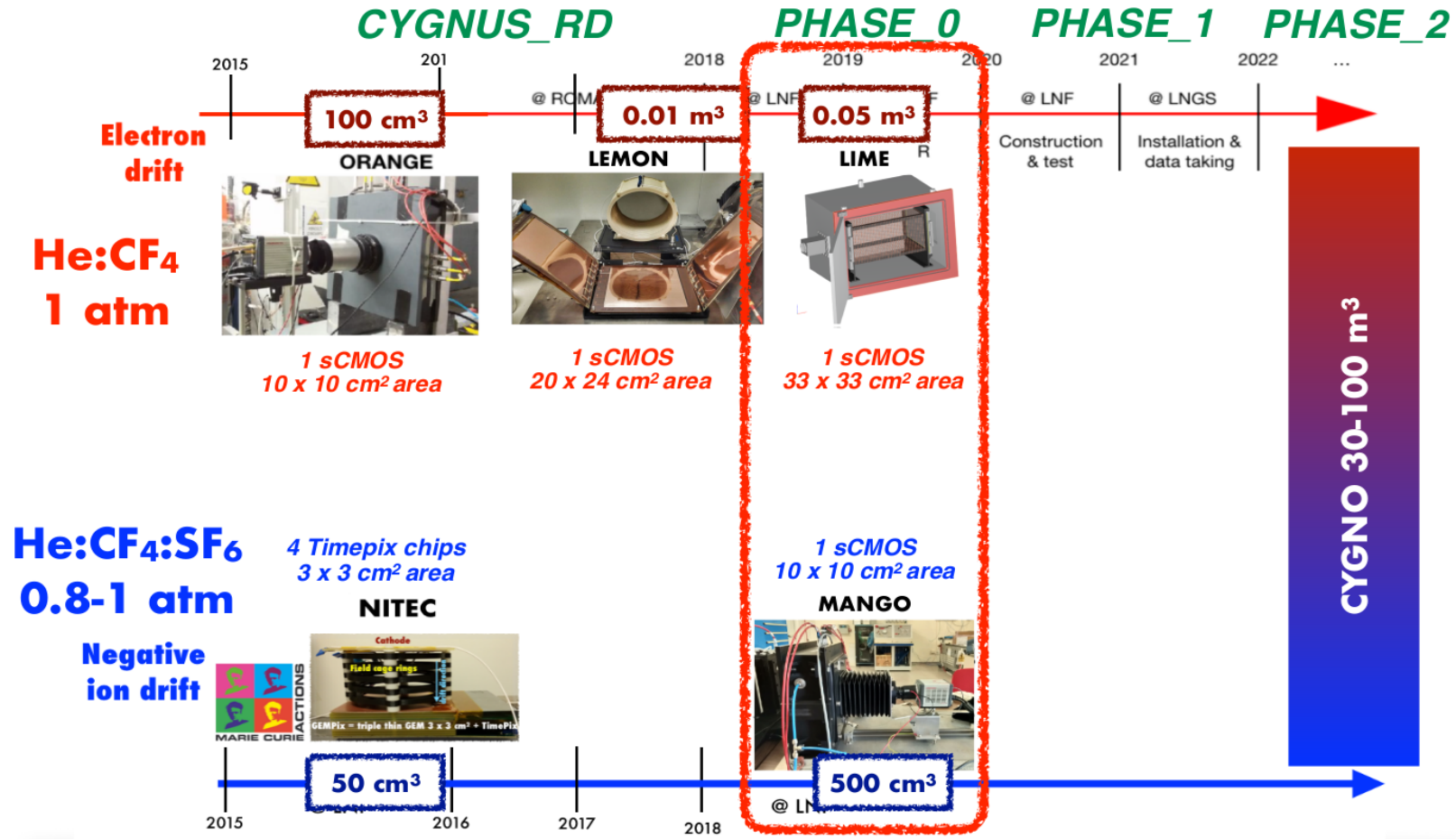
Full 3D fiducialization

- Thanks to multiple charge carriers, the difference in mass induces a difference in arrival time



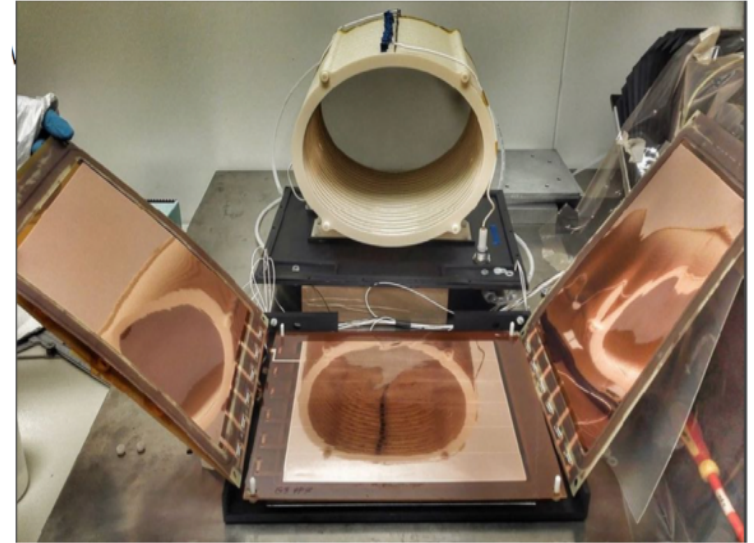
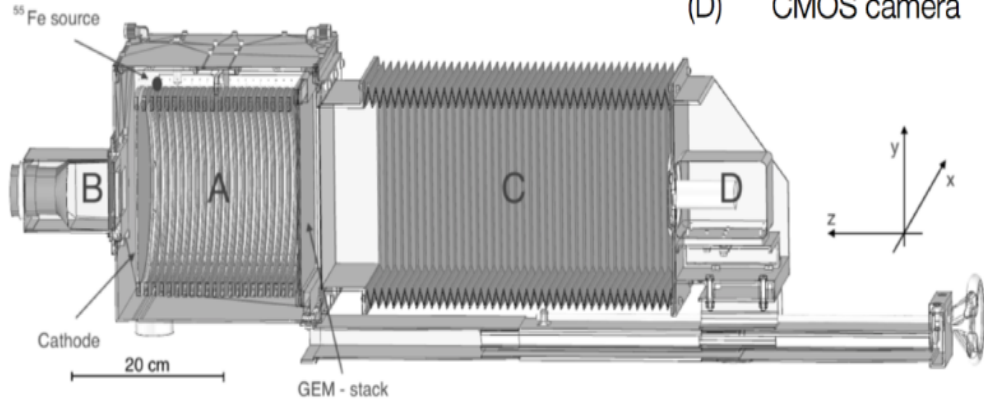
N.S.Phan et al., JINST 12
(2017) no.02, P02012

STATE OF THE ART



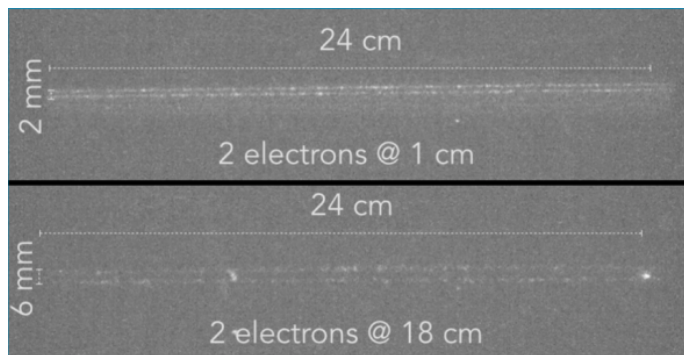
LEMON

1 sCMOS + 1 PMT
20 x 24 cm² readout area
20 cm drift
7 L active volume



LEMON

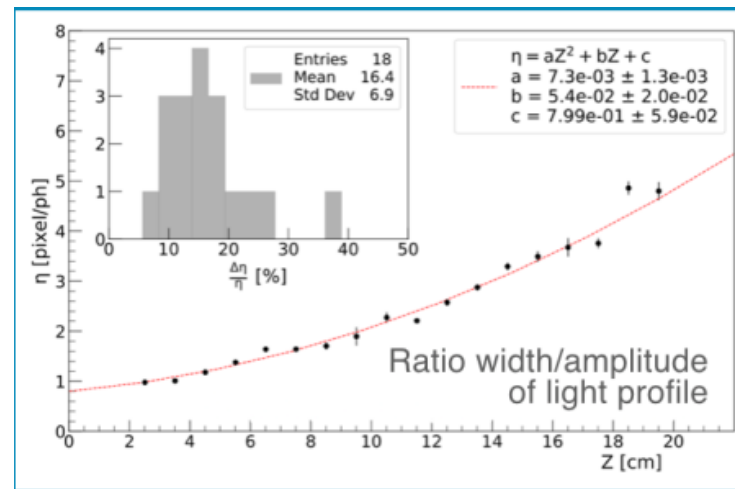
- Tracking and fiducialization assessments



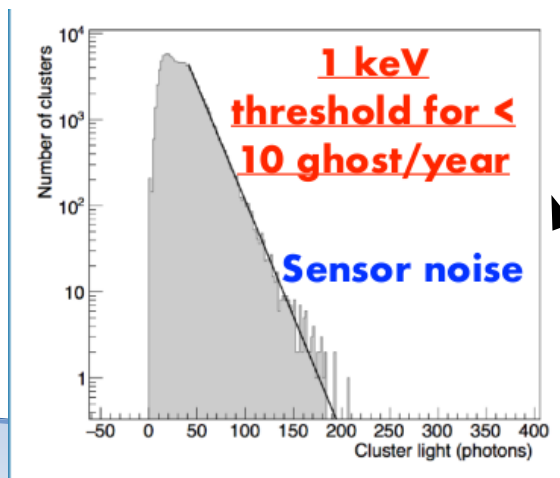
Energy density and diffusion used to reconstruct absolute Z

(~15% res)

E. Baracchini et al.
NIM A 936 (2019) 453–455



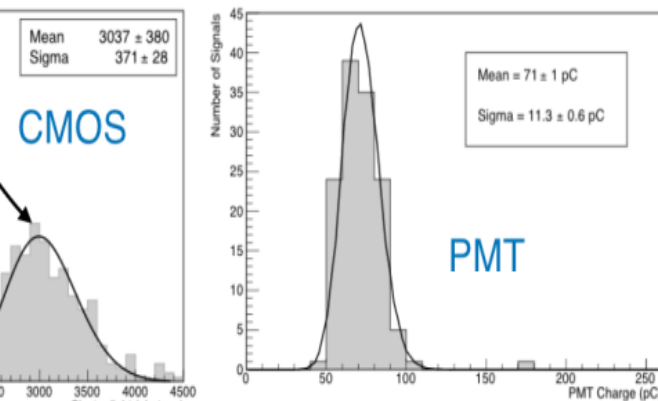
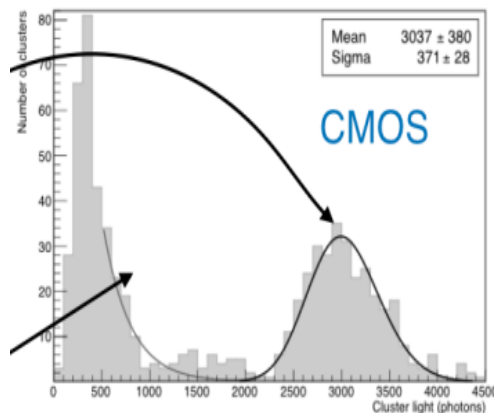
- Tested performances with a 5.9 keV iron source



Energy resolution

15% @ 5,9 keV

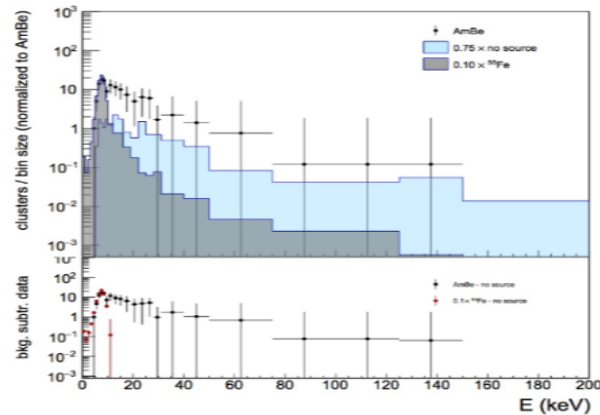
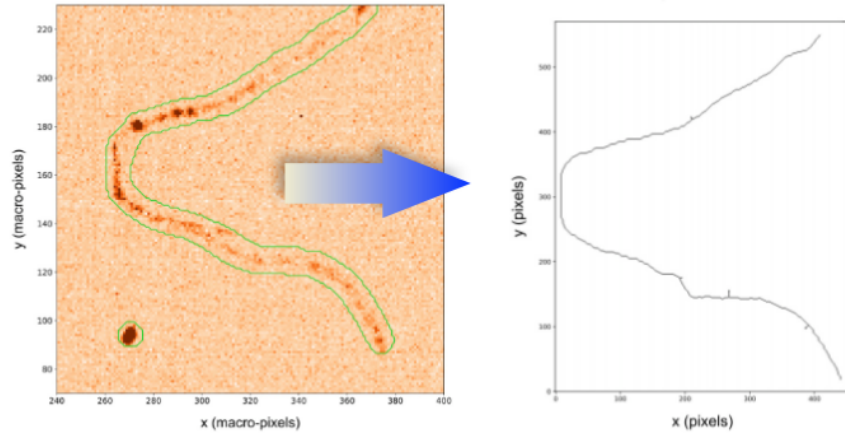
Low noise and ghost clusters



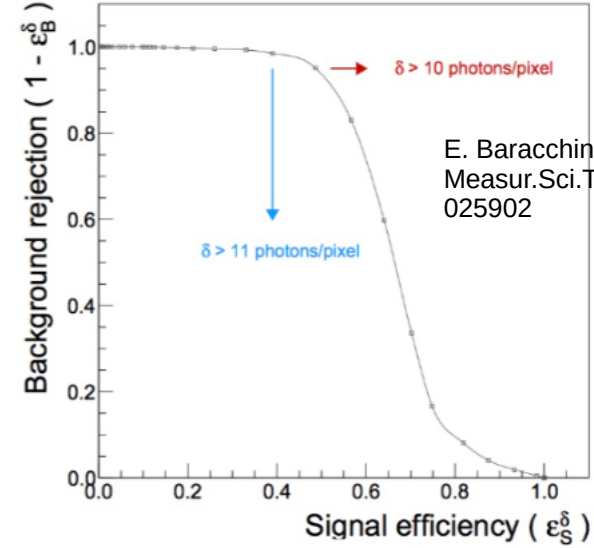
E. Baracchini et al.
JINST 15 (2020) 10, P10001

LEMON

• Particle ID and background rejection tests



Nuclear recoils
down to few keV

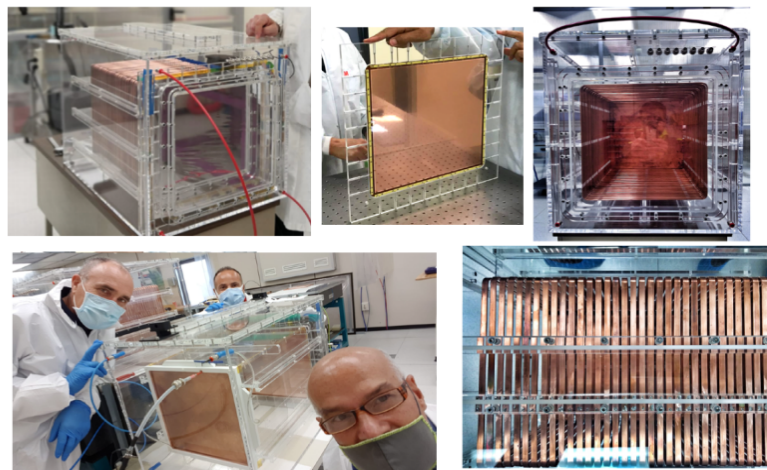
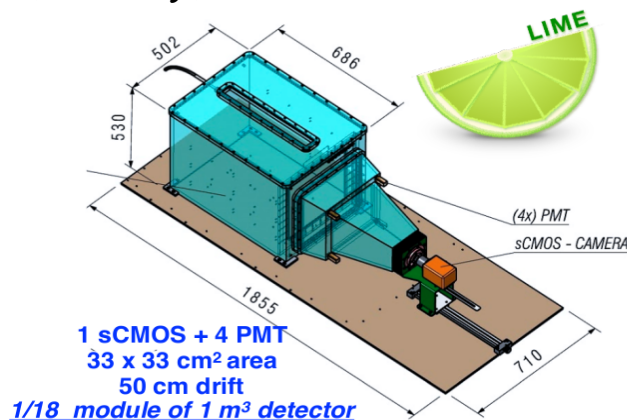


E. Baracchini et al.
Measur.Sci.Tech. 32 (2021) 2,
025902

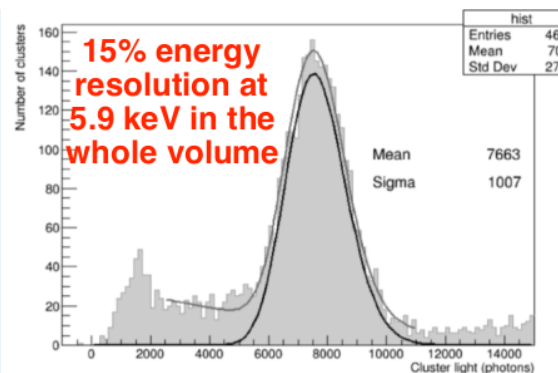
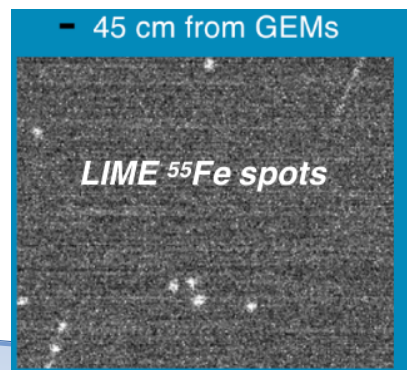
working point	Signal efficiency			Background efficiency		
	ϵ_S^{presel}	ϵ_S^δ	ϵ_S^{total}	ϵ_B^{presel}	ϵ_B^δ	ϵ_B^{total}
WP ₅₀	0.98	0.51	0.50	0.70	0.050	0.035
WP ₄₀	0.98	0.41	0.40	0.70	0.012	0.008

LIME

- It is a large 50 L prototype with 50 cm drift. Exactly **one of the 18** modules that will build CYGNO



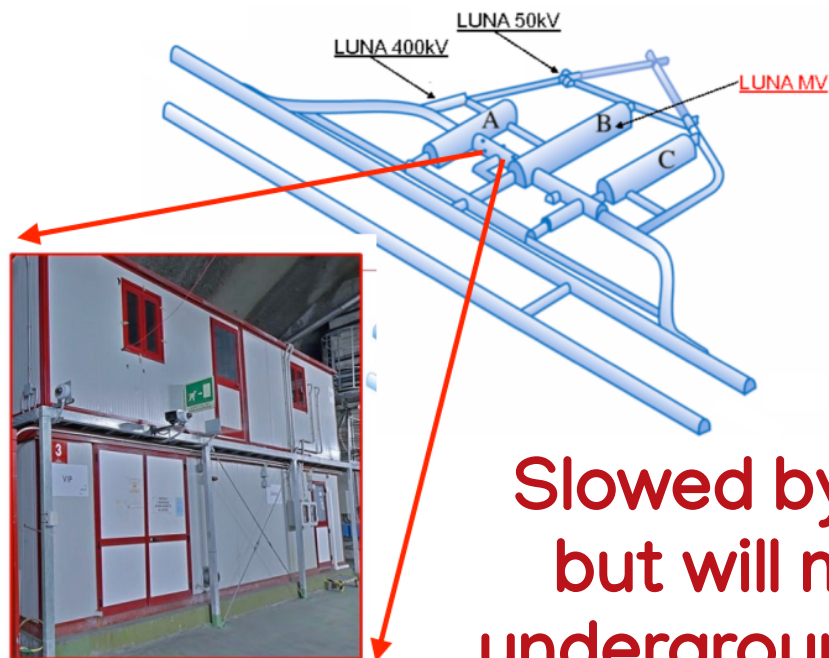
- Already operational and stable



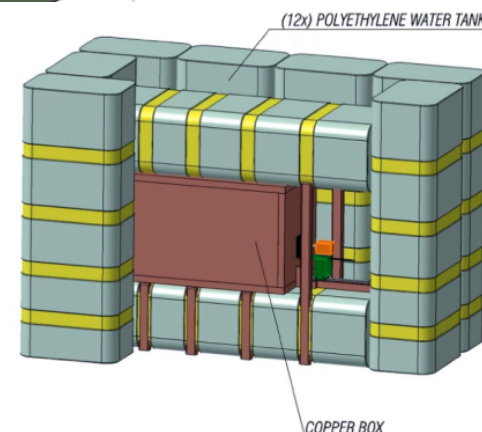
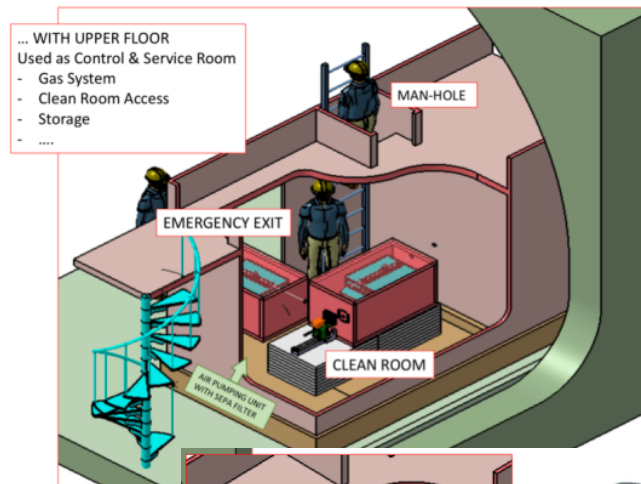
LIME

- It will provide the **first directional** measurement of the neutron flux in the underground

laboratories at LNGS



Slowed by COVID
but will move to
underground LNGS
in summer 2021



MANGO

A Multipurpose Apparatus for
Negative ion studies with GEM
Optically readout

Lenses

17mm FL, f/0.95 Fast C Mount
<https://www.schneideroptics.com>

3 GEMs:

50 μm thick

140 μm pitch

70 μm holes diameter

sCMOS Camera
Orca fusion

www.hamamatsu.com.

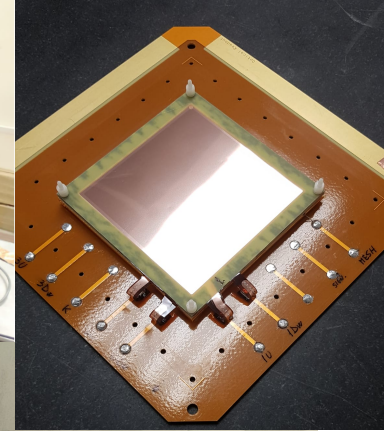
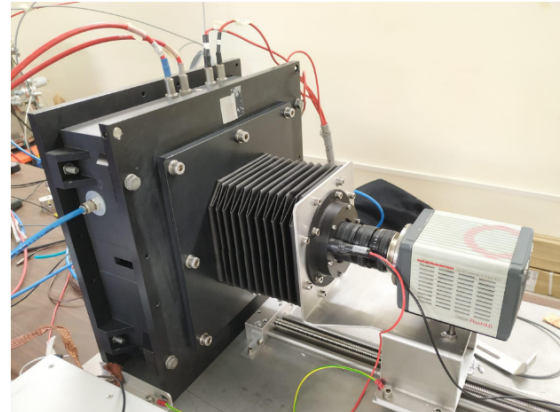
TPC volume:

Max volume 500 cm^3
(10x10 cm^2) area

He:CF₄ mixture 60/40

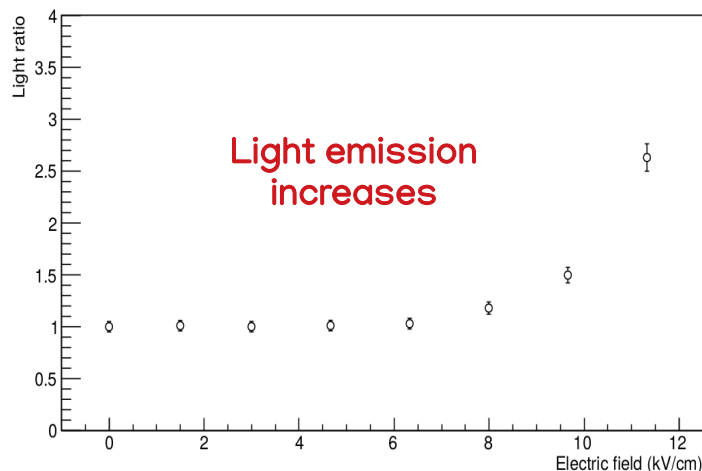
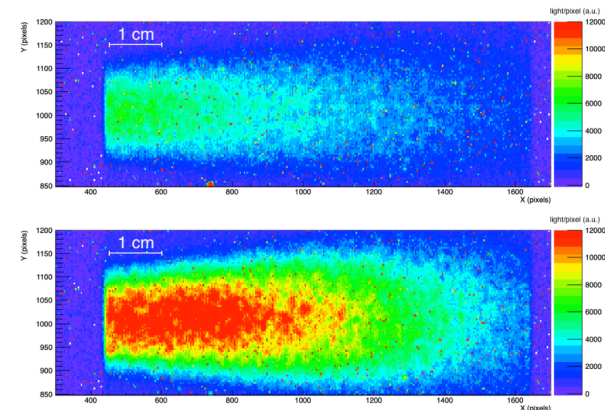
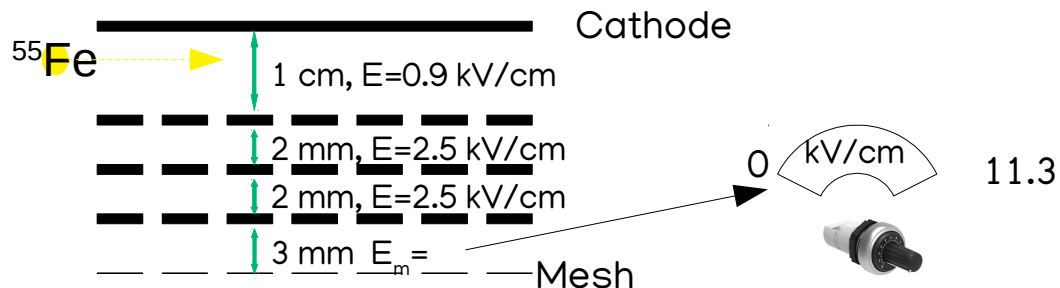
1 atm

Plastic
gas-tight
box



MANGO

- Electroluminescence studies produced results

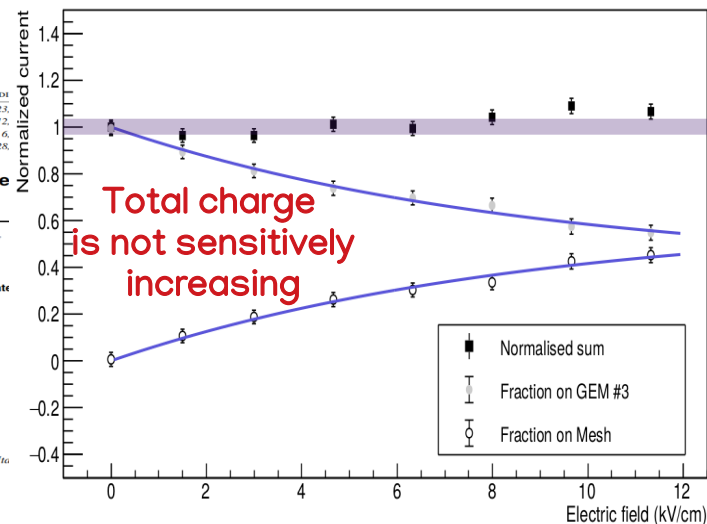


Jinst PUBLISHED BY IOP PUBLISHING FOR SISSA MEDA
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First evidence of luminescence in a He/CF₄ gas mixture induced by non-ionizing electrons

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^jDipartimento di Ingegneria Chimica, Materiali e Ambiente, Sapienza Università di Roma, Roma, Ita



MANGO

- MANGO is a multipurpose prototype for R&D

Electroluminescence

E_{GAP} scan in He:CF₄

Varying He:CF₄
fractions

Try Fluoromethanes
for EL

Fluoromethanes

He:CF₄:CHF₃ /
He:CHF₃

He:CF₄:CH₂F₂ /
He:CH₂F₂

He:CF₄:CH₃F /
He:CH₃F

GEM thickness/
staging options

125 μm

400 μm

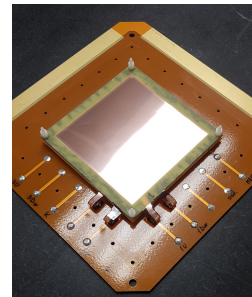
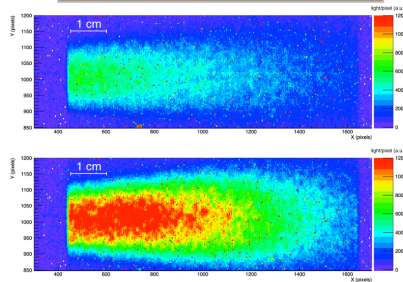
50 μm , 125 μm and
400 μm stacking

Negative ion drift

He:CF₄:SF₆ at 1
atm

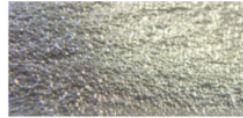
He:CF₄:SF₆ <1
atm

He:CH_xF_x:SF₆

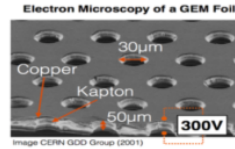


FUNDED!

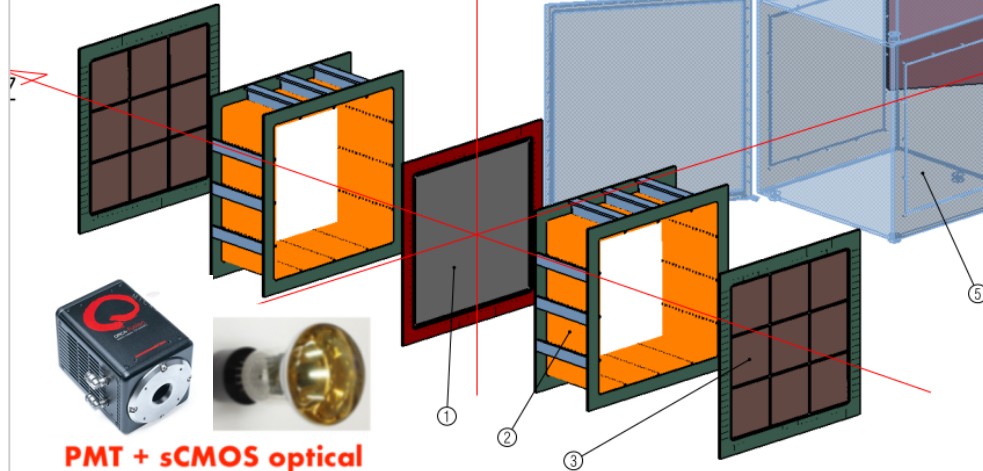
Transparent texturised
mylar cathode a'la DRIFT



Gas Electron Multipliers
(GEMs) amplification



Atmospheric pressure &
room temperature:



PMT + sCMOS optical
readout decoupled
from target volume

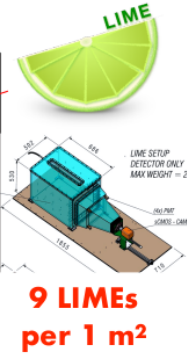
He:CF₄:(SF₆) 1.5 kg mass, 1 m³ volume

Isometric view
Scale: 1:15

9 cameras/m²

A total of 72 10⁶ readout
165 x 165 μm² pixels

18 cameras monitoring
330*330 mm each
with 160 μm resolution



9 LIMES
per 1 m²

Installed and
commissioned
by 2023

CYGNUS



👤 About 70 members

👤 Steering group:

👤 Elisabetta Baracchini (GSSI/INFN, Italy)

👤 Greg Lane (Canberra, Australia)

👤 Kentaro Miuchi (Kobe, Japan)

👤 Neil Spooner (Sheffield, UK)

👤 Sven Vahsen (Hawaii, USA)



*A multi-site, multi-target Galactic Recoil Observatory at the **ton-scale** to probe Dark Matter below the Neutrino Floor and measure solar Neutrinos with directionality*

👤 **Helium/Fluorine gas mixtures at 1 bar**

👤 Sensitivity to O(GeV) WIMP for both SI & SD couplings

👤 Possibility of switching between higher (search mode) and lower gas densities (improved directionality) for signal confirmation

👤 **Reduced diffusion**

👤 Through negative ion drift or “cold” gases

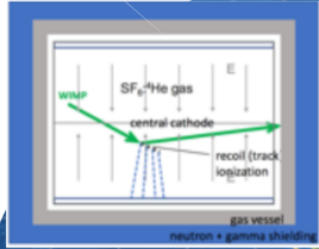
👤 **3D fiducialization**

👤 Through minority carriers or fit to diffusion

👤 **Directional threshold at O(keV)**

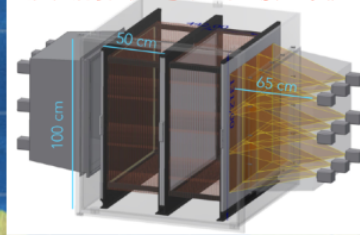
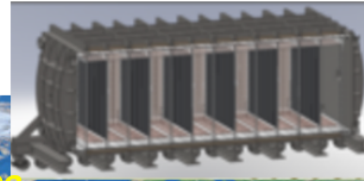
👤 **Full background rejection at O(keV)**

CYGNUS



CYGNUS-HD10
GEMs + 2D strips
He:CF₄:C₄H₁₀
1 m³ under construction
towards 10 m³
experiment

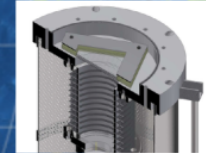
CYGNUS-10
10 m³, GEMs + wires
He:SF₆
Boulby, UK
R&D ongoing on 1 m³



CYGNO/INITIUM
GEMs + sCMOS + PMT
He:CF₄ (:SF₆)
LNGS, Italy
1 m³ demonstrator
funded towards 30 m³
experiment



CYGNUS-KM
1 m³, GEMs + 2D strips
SF₆/CF₄
Kamioka, Japan
R&D ongoing on 1 m³



CYGNUS-OZ
Stawell, Australia
GEMs + CCDs for gas studies
Plans for 1 m³
demonstrator



CYGNO AT GSSI

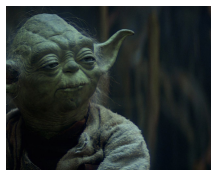
Professor/boss

Post-doc



All GSSI people
You can find us anytime!!

G.Dho, *GSSI Science fair*



E. Baracchini



A. Cortez



G. Dho



F. Di Giambattista



A. Prajapati



S. Torelli



D. Marques

- LIME background simulation
- PMT signal reconstruction
- CYGNO sensitivity
- EL and NID with MANGO
- Neutron simulation
- Analysis of LIME data underground
- Noise simulation
- Machine learning for PI
- Study of directionality
- Neutrino case
- Exams

