Elisabetta Baracchini
Gran Sasso Science Institute & INFN

CYGNO & INITIUM

Directional Dark Matter searches with optical sCMOS readout

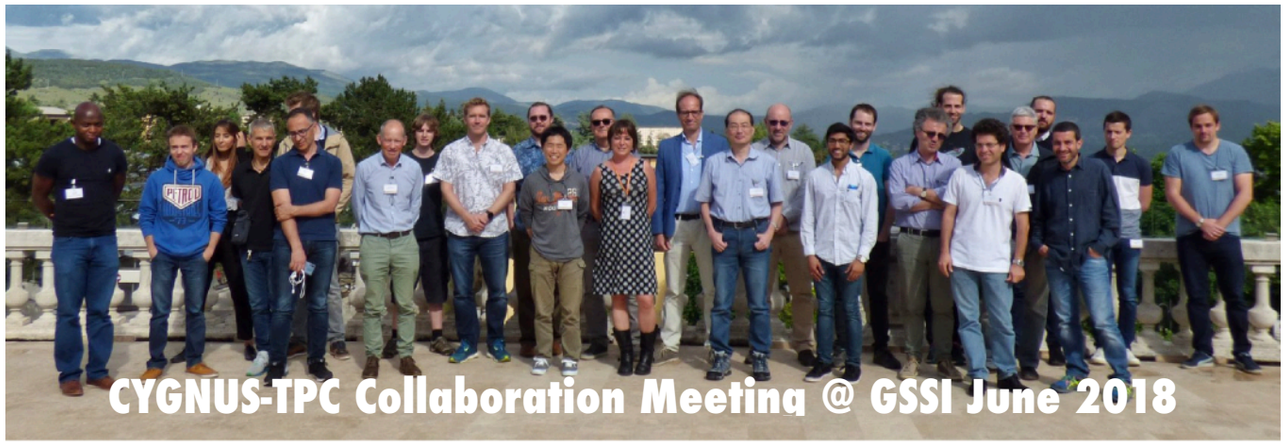
On behalf of the CYGNO collaboration

Part of this project has received fundings under the European Union's Horizon 2020 research and innovation programme from the Marie Sklodowska-Curie grant agreement No 657751 and from the European Research Council (ERC) grant agreement No 818744

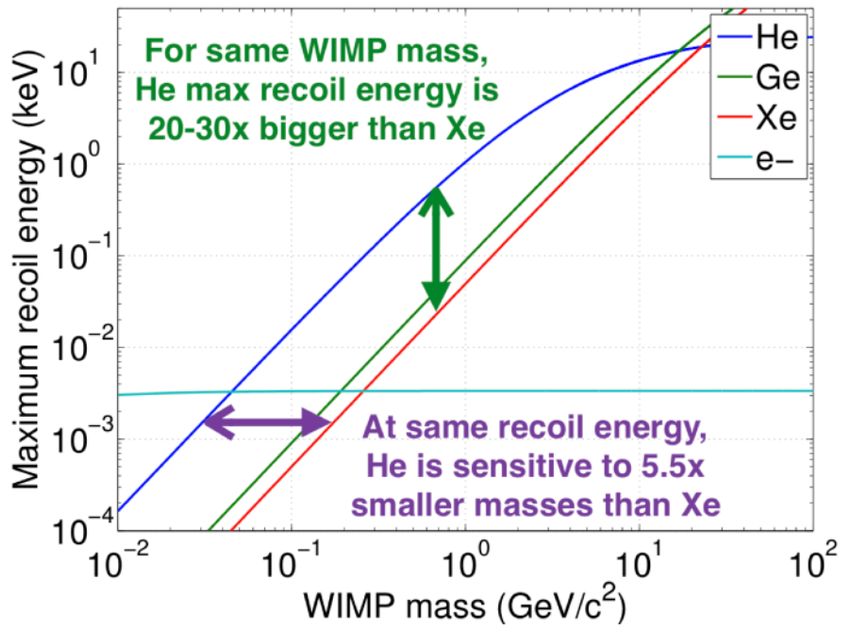
CYGNUS-TPC vision

See S. Vahsen talk

Since fall 2016



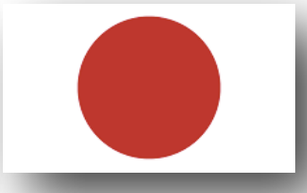
A multi-site Galactic Nuclear Recoil Observatory at the ton-scale to probe Dark Matter below the Neutrino Floor and measure ^{8}B solar Neutrinos with directionality



He-F target for simultaneous SI & SD sensitivity to O(GeV) WIMPs

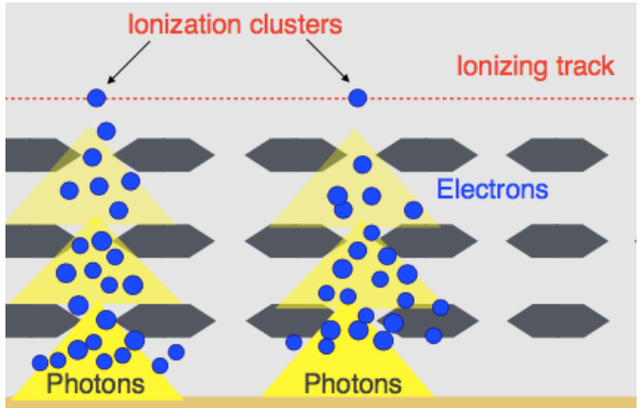
- Helium/Fluorine-based gaseous TPC for sensitivity to low mass WIMP region for both SI and SD couplings
- Goal of zero background operation after electron/gamma rejection and fiducialization at O(keV)
- Directional and gamma/electron rejection thresholds at O(keV)




3D optical readout

CYGNO: GEMs + sCMOS + PMT



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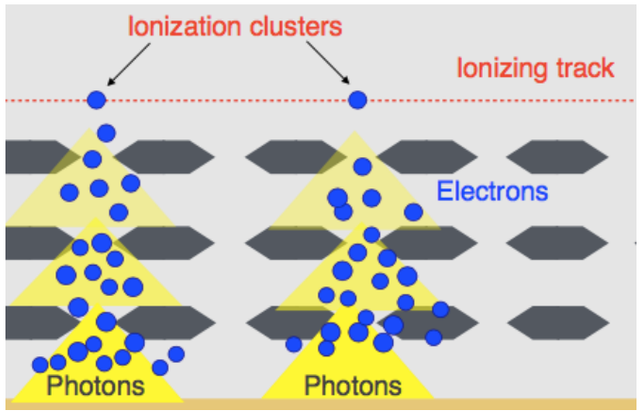
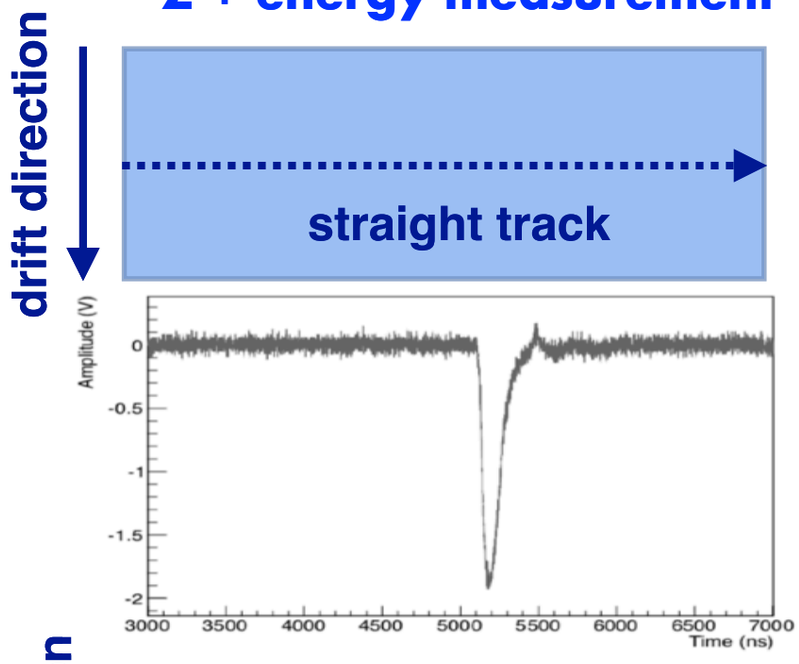
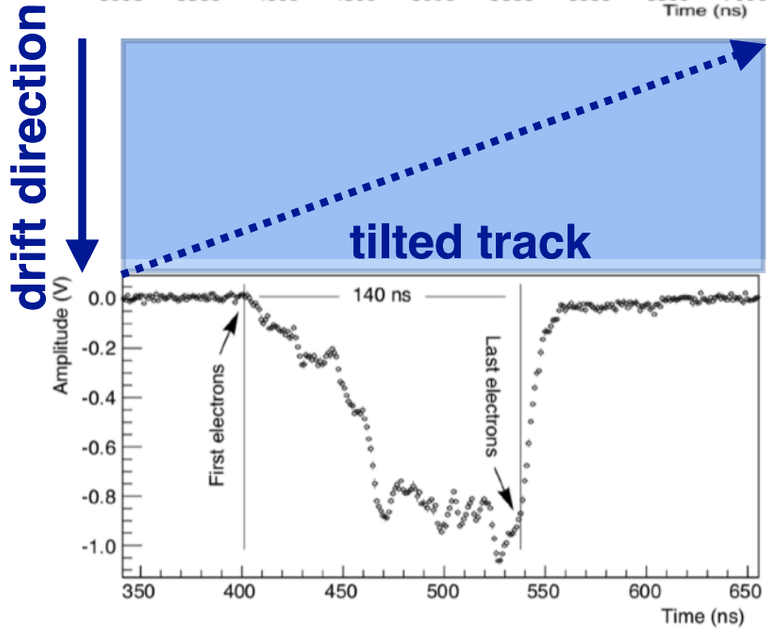


PMT:

integrated

Z + energy measurement





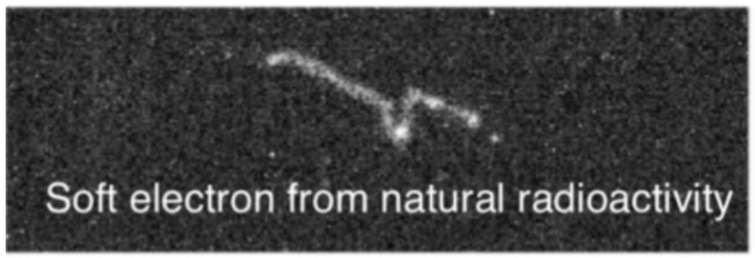
3D optical readout

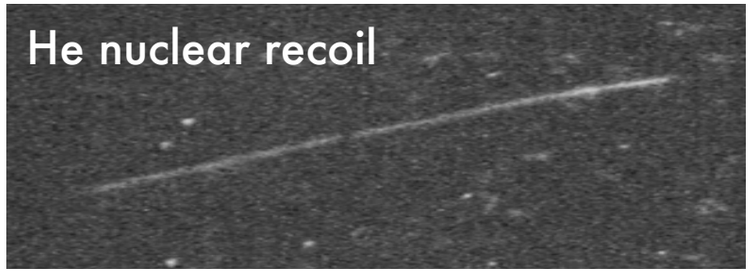
CYGNO : GEMs + sCMOS + PMT

sCMOS:

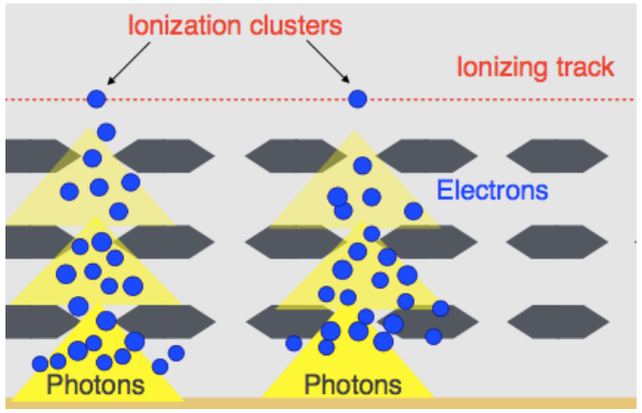
high granularity

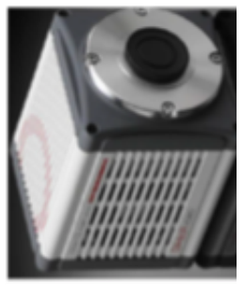
X-Y + energy measurements





- **1/3 noise w.r.t. CCDs**
- **Market pulled**
- **Single photon sensitivity**
- **Decoupled from target**
- **Large areas with proper optics**





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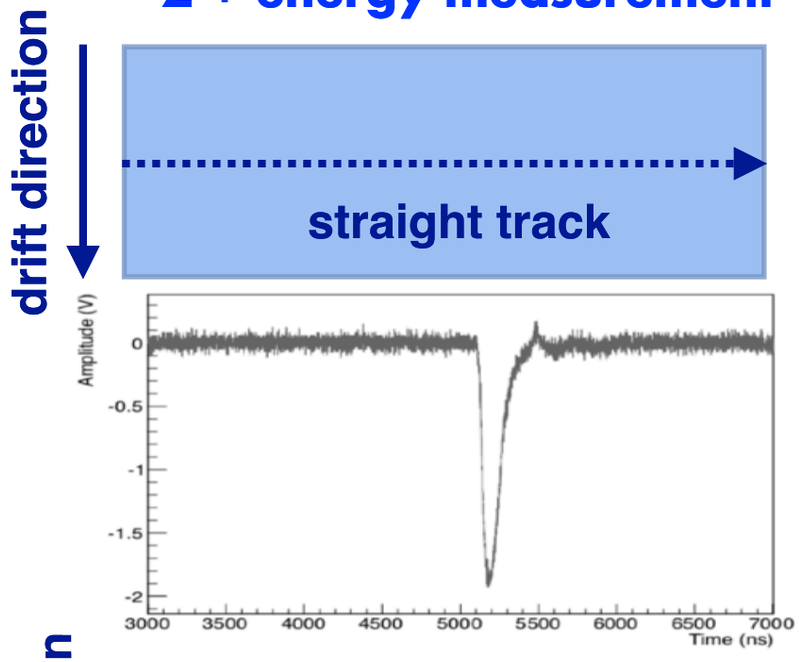

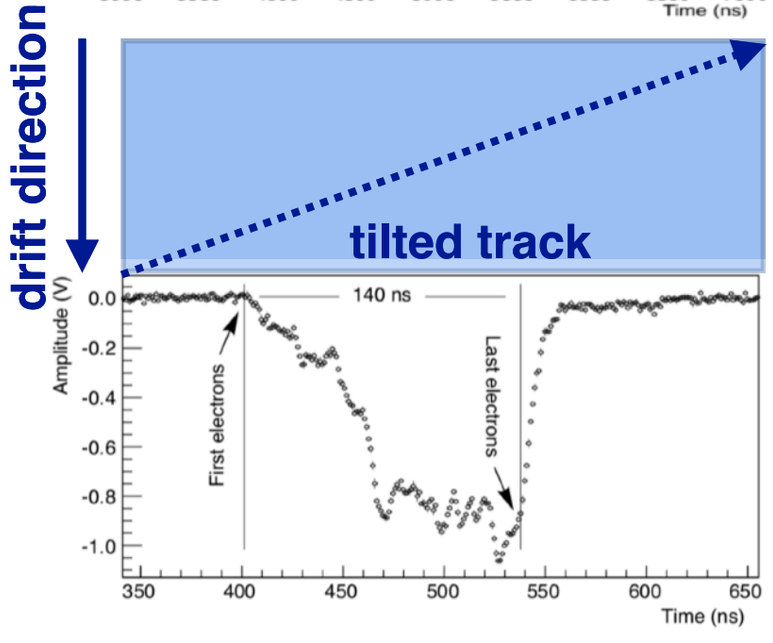

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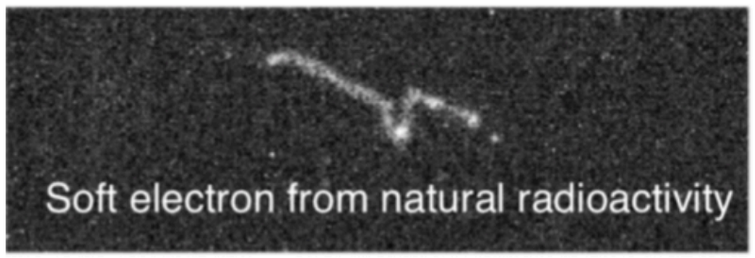

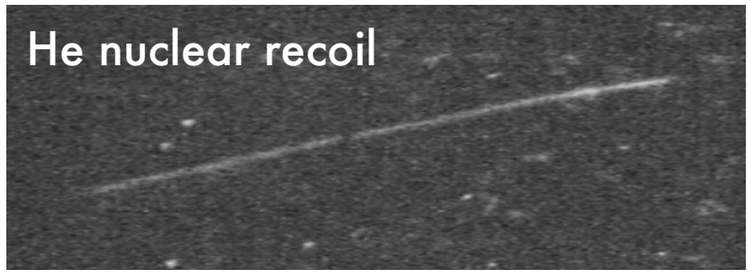

- **1/3 noise w.r.t. CCDs**
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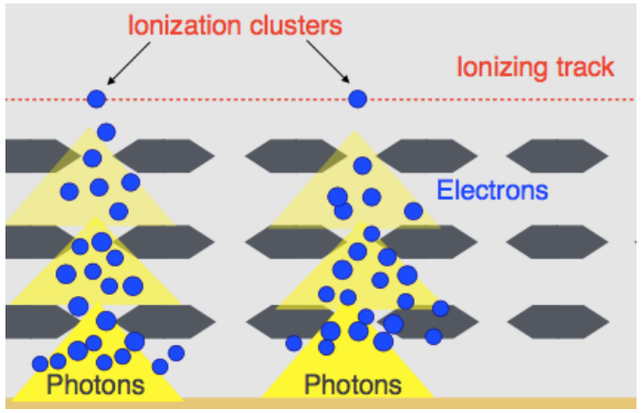
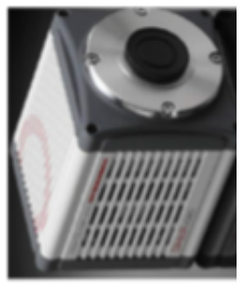
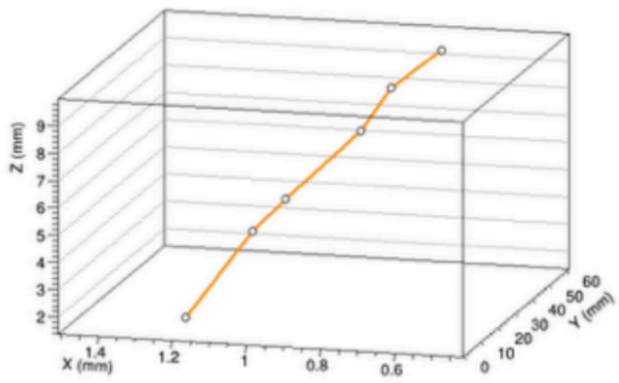
JINST 13 (2018) no.05, P05001







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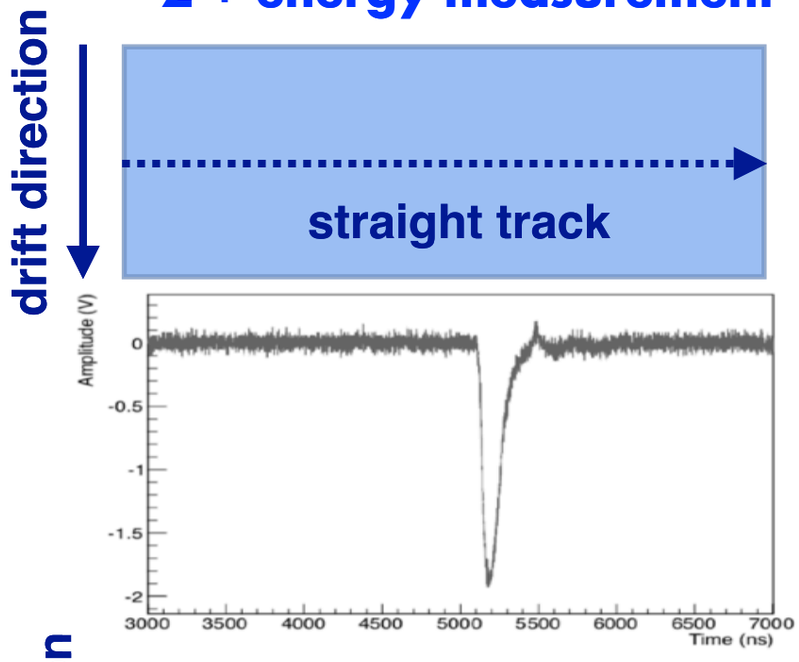
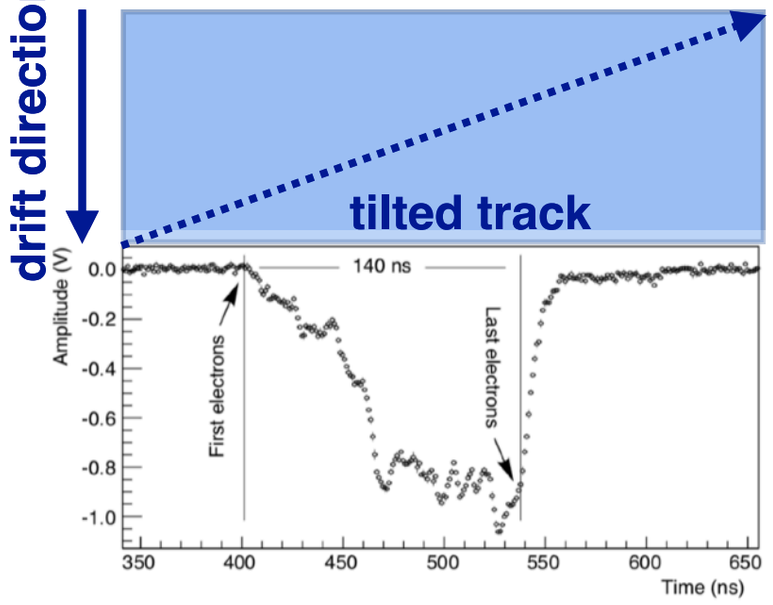
integrated

Z + energy measurement



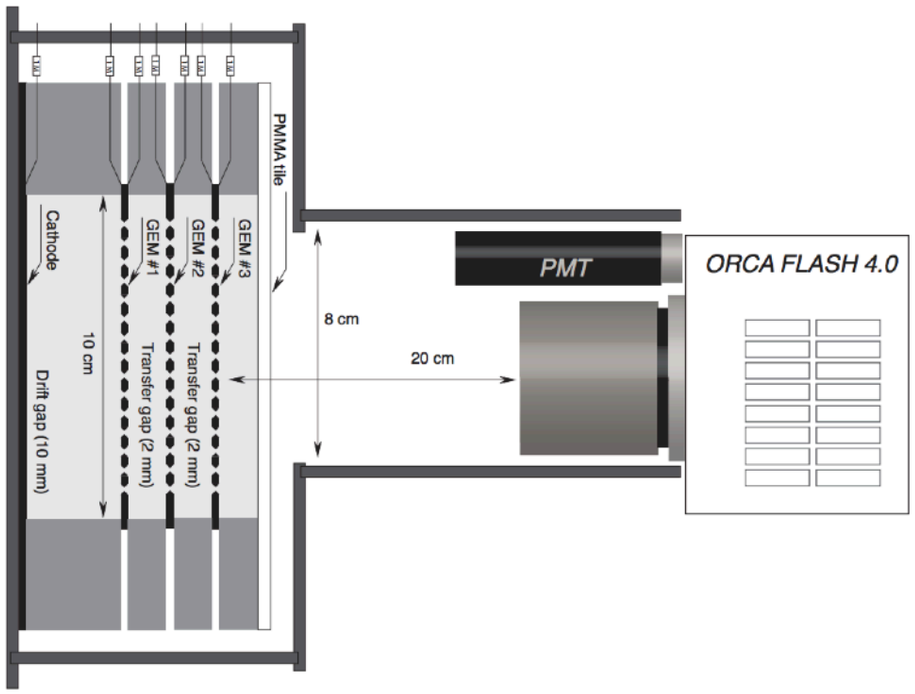


O(100) um 3D tracking with high quality particle identification (PID)

CYGNUS-RD project (2016-2018)

JINST 13 (2018) no.05, P05001

10 x 10 x 1 cm³
0.1 Liters
Triple thin GEMs
CMOS & PMT on same side



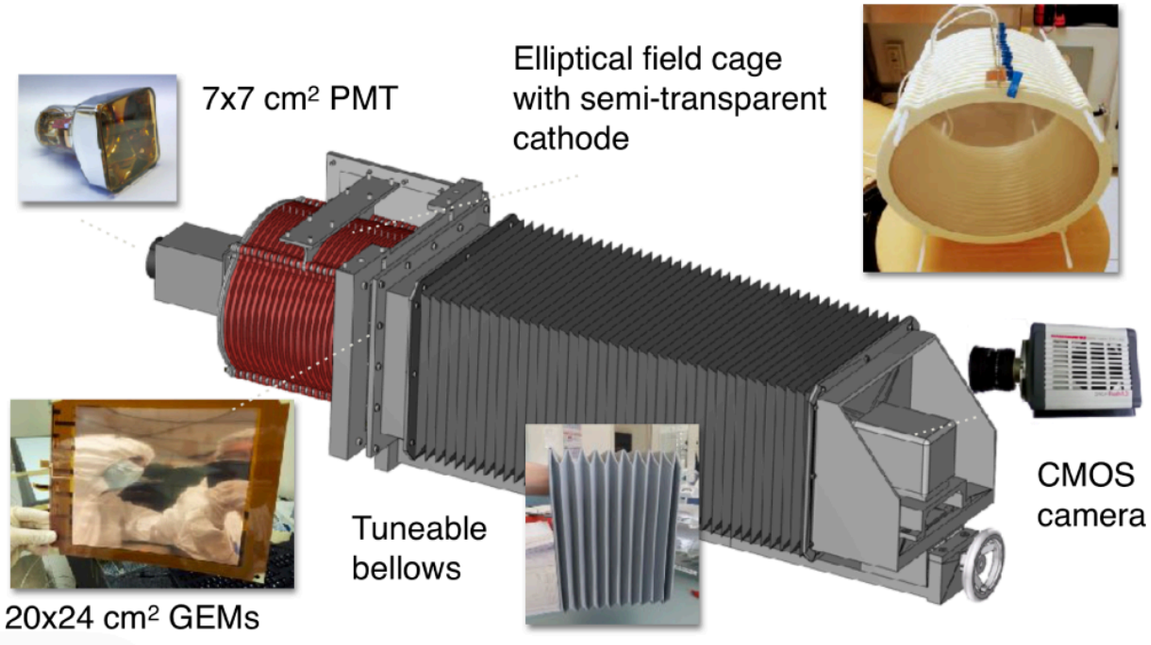
ORANGE: small prototype

Optically ReAdout GEms

Camera distance ± 18 cm

PoS EPS-HEP2017 (2017) 077

24 x 20 x 20 cm³
9.6 Liters
Triple thin GEMs
CMOS & PMT on opposite sides



LEMOn: large prototype

Large Elliptical Module Optically readout

Camera distance ± 53 cm

Equipped with a suitable large aperture (f/0.95) and a short focal length (25 mm) lens

CYGNUS-RD project (2016-2018)

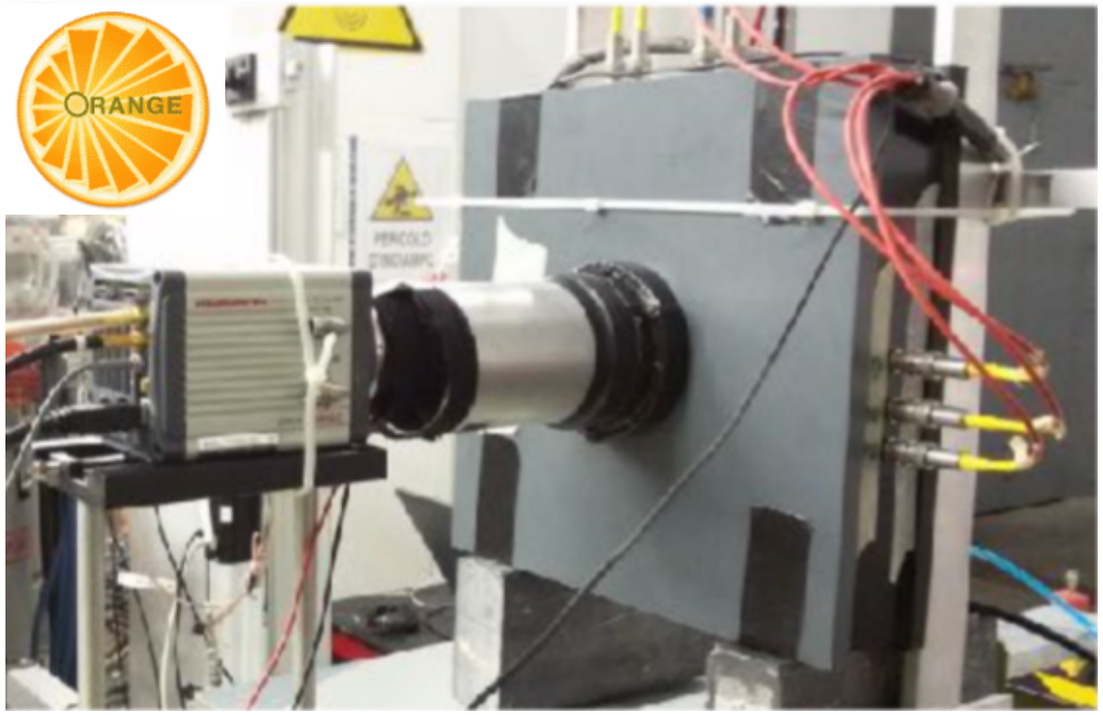
JINST 13 (2018) no.05, P05001

10 x 10 x 1 cm³

0.1 Liters

Triple thin GEMs

CMOS & PMT on same side



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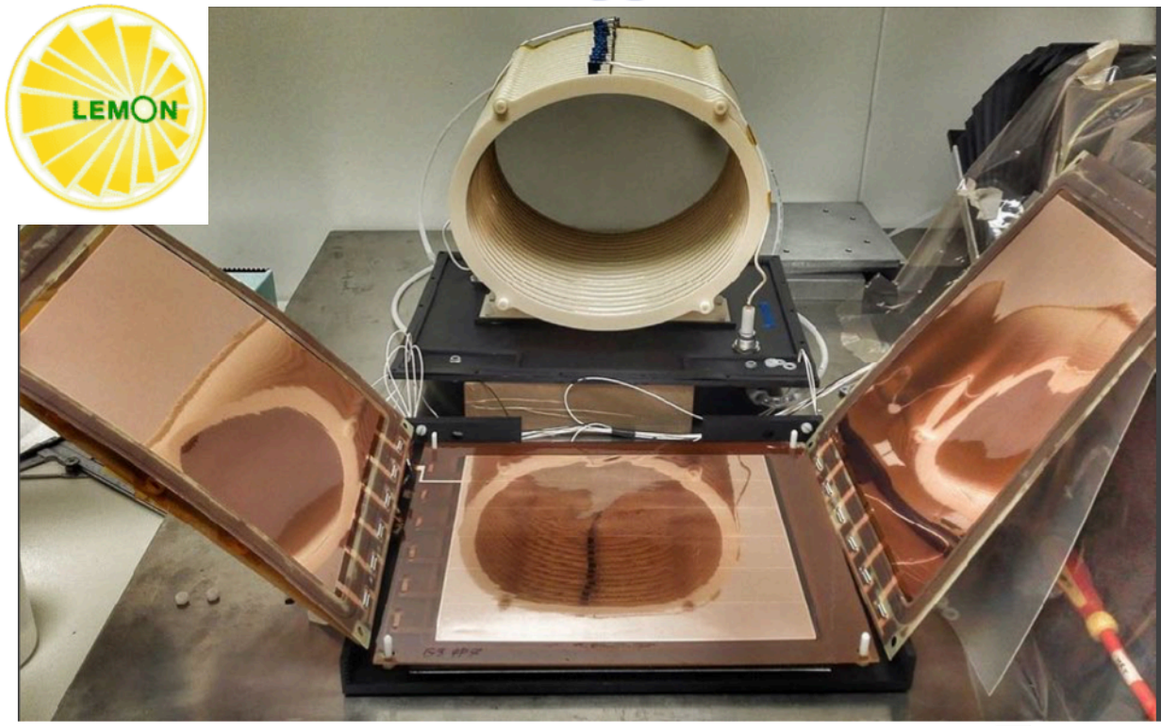

LEMOn: large prototype

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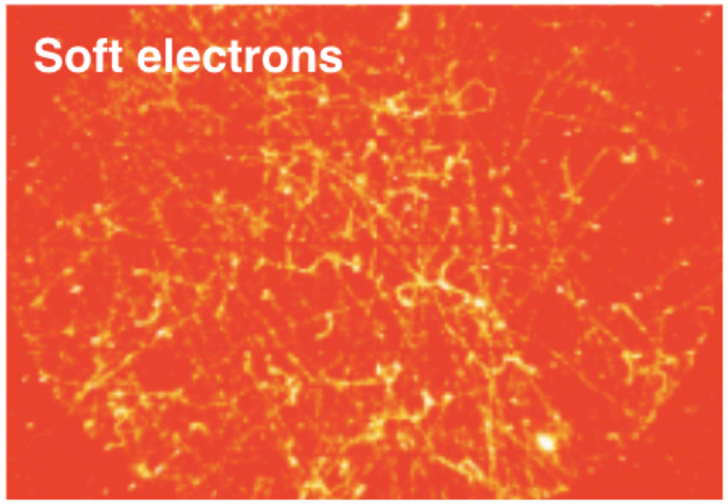
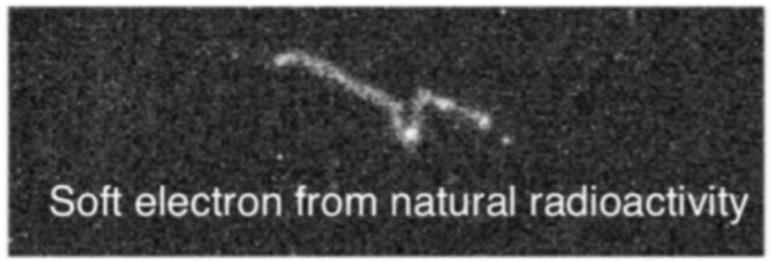
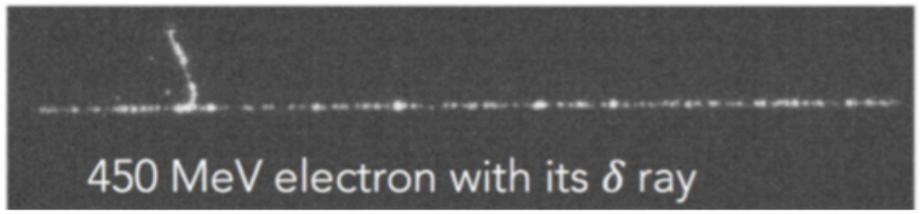
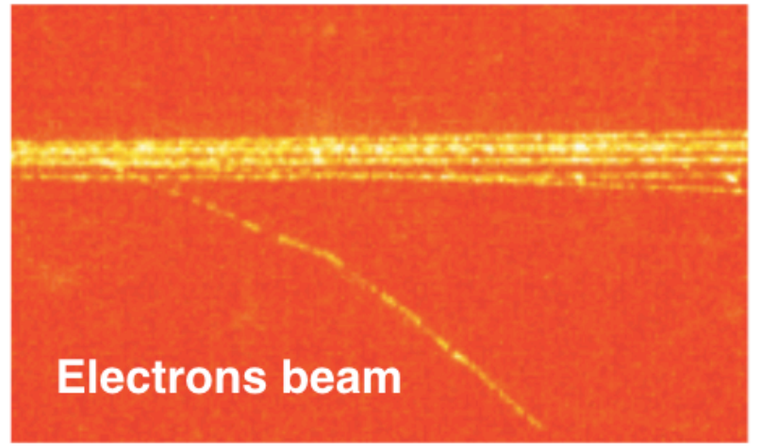
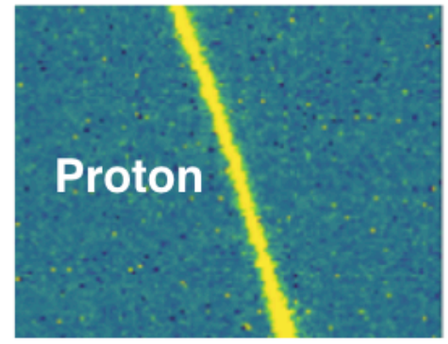
CYGNO:photographing tracks

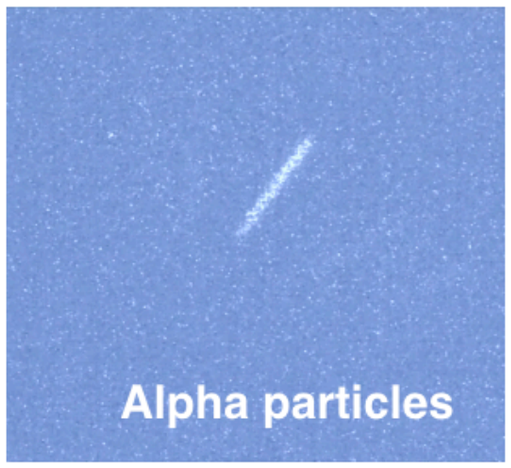


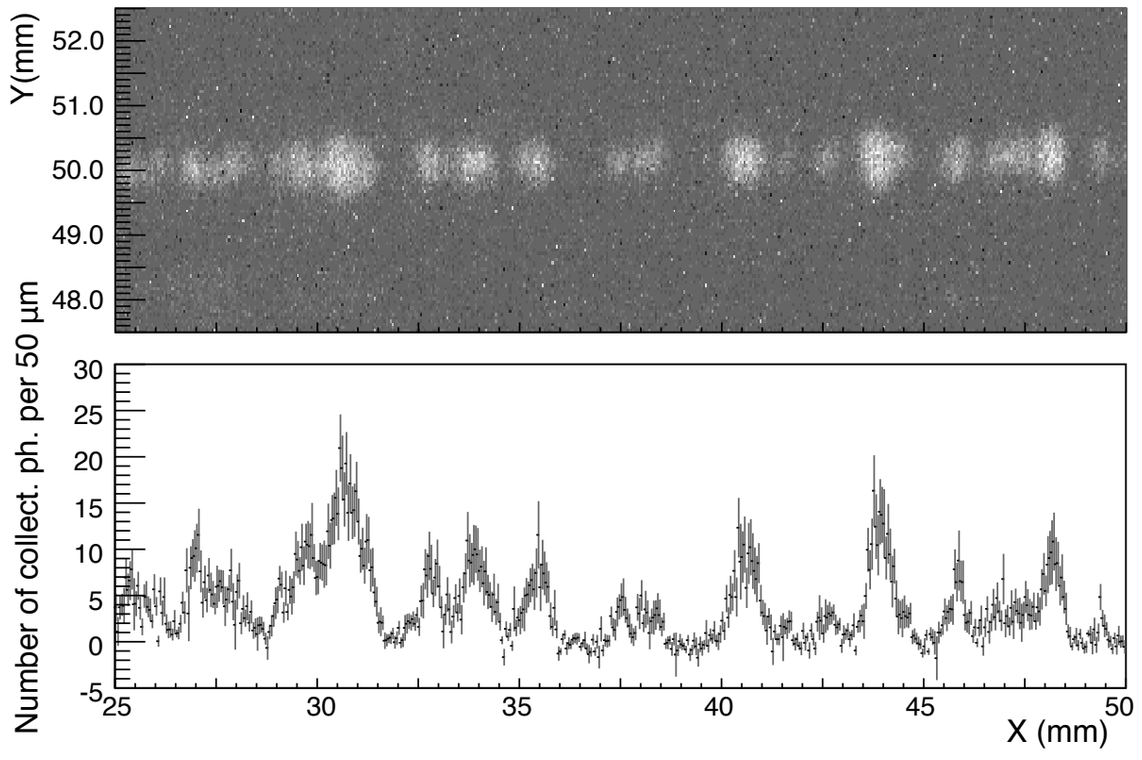


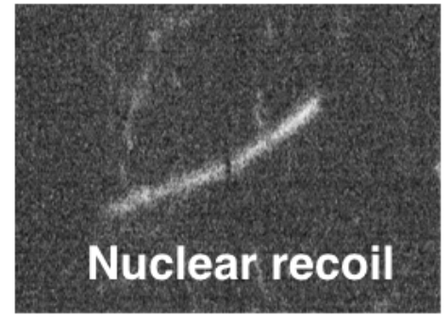








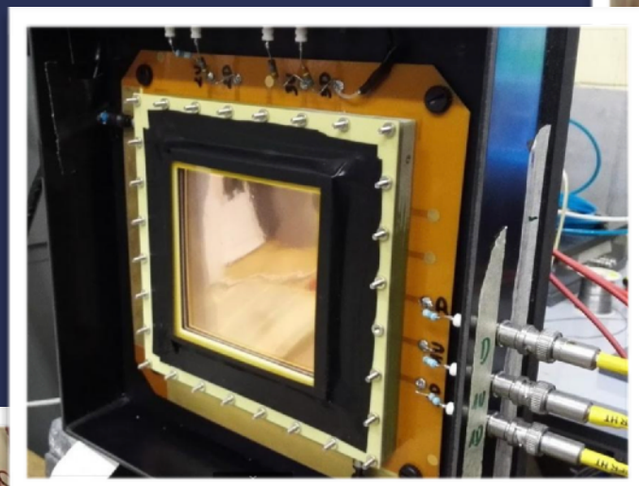


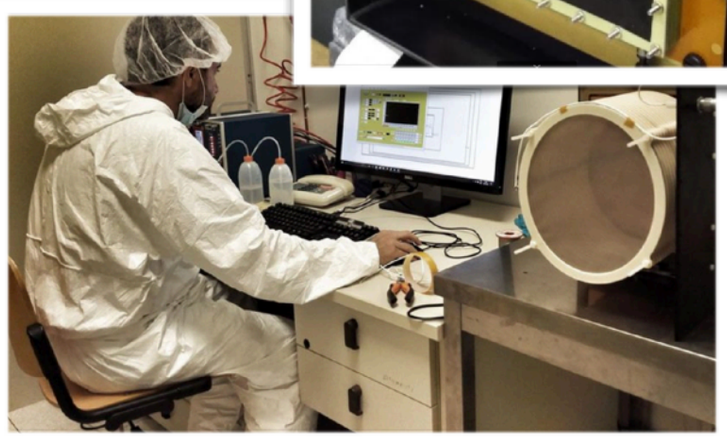


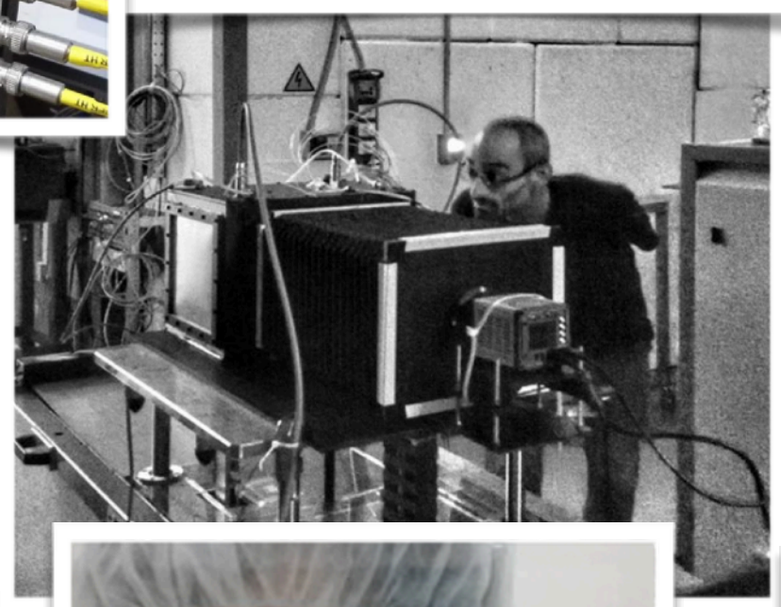
CYGNO: photographing ourselves

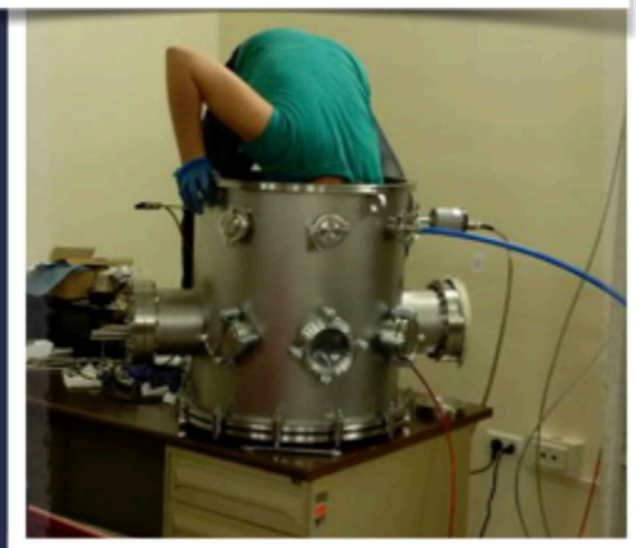
#socialdetector #infn

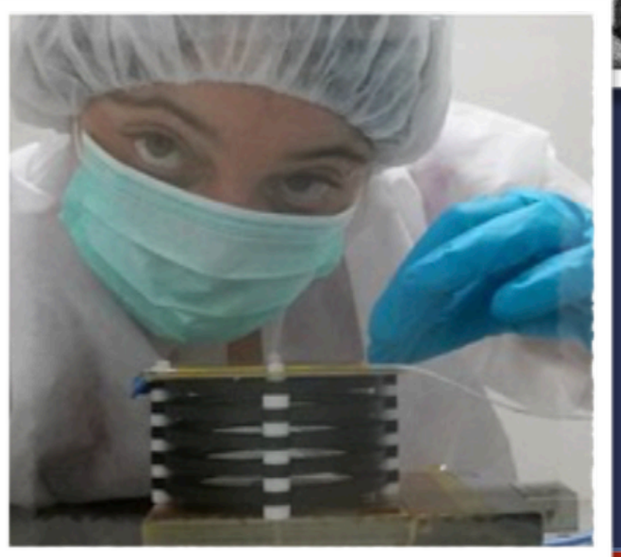
https://web.infn.it/cygnus

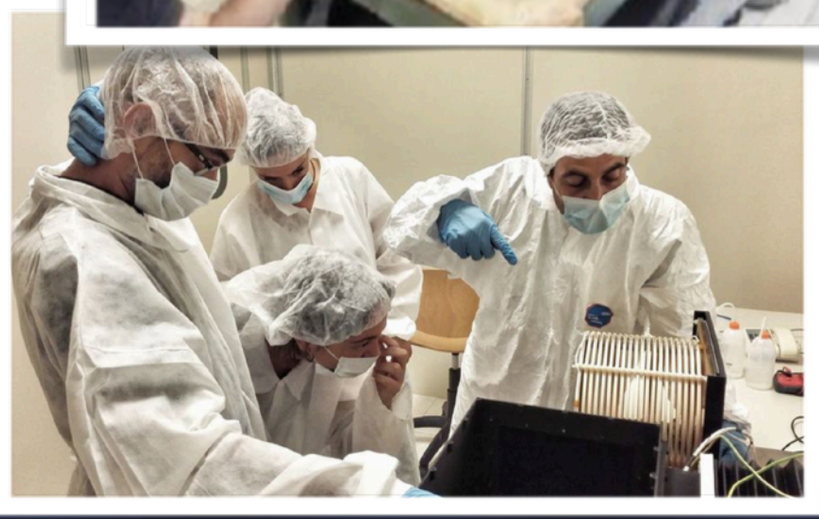












3D optical readout
CYGNO roadmap

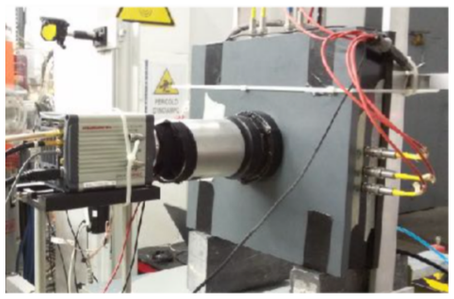
CYGNUS_RD | PHASE_0 | PHASE_1 | PHASE_2

2015 | 201 | 2018 | 2019 | 2020 | 2021 | 2022 | …

Electron drift

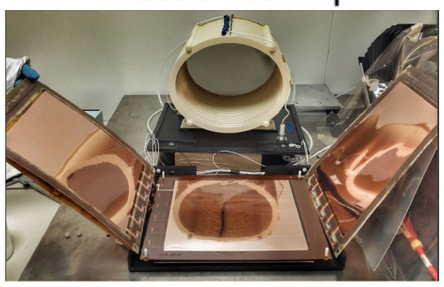
He:CF$_4$
1 atm

100 cm³ — ORANGE



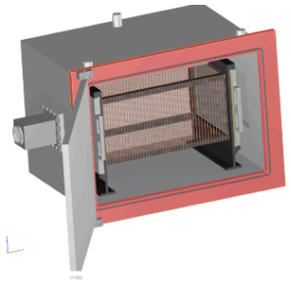
1 sCMOS
10 x 10 cm² area

@ RO… — **0.01 m³** — LEMON



1 sCMOS
20 x 24 cm² area

@ LNF — **0.05 m³** — LIME — R



1 sCMOS
33 x 33 cm² area

@ LNF — Construction & test

@ LNGS — Installation & data taking

…

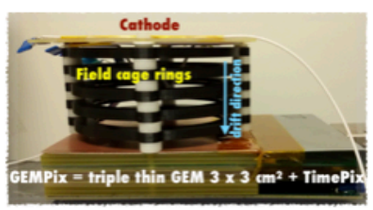
PHASE_0 funded by INFN

He:CF$_4$:SF$_6$
0.8-1 atm

Negative ion drift

4 Timepix chips
3 x 3 cm² area

NITEC

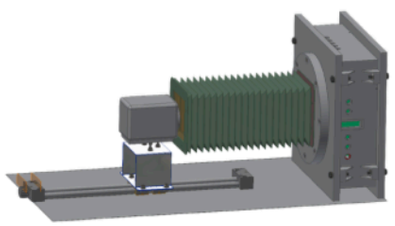


50 cm³

2015 | 2016 | 2017 | 2018

1 sCMOS
10 x 10 cm² area

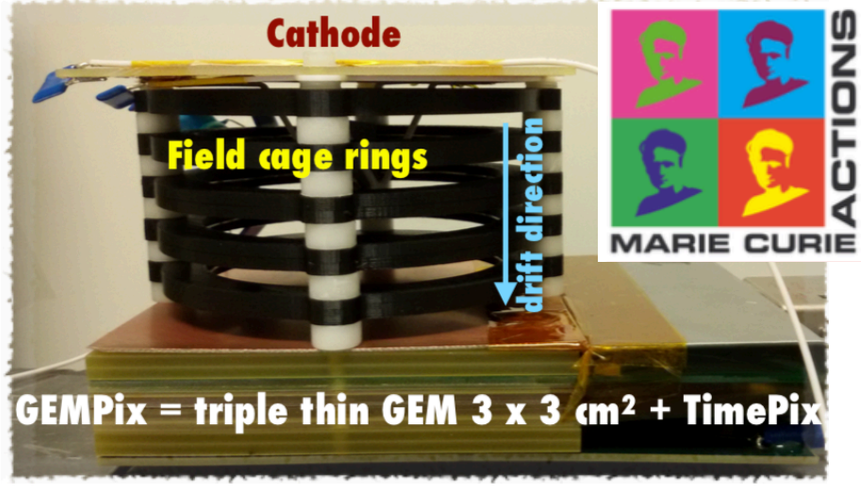
MANGO

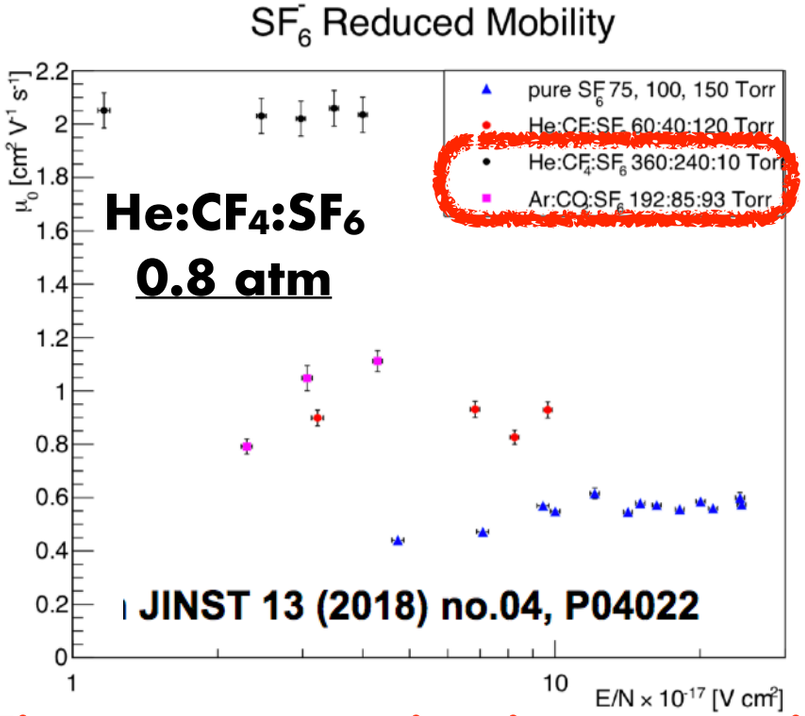


500 cm³ — @ LN…

Part of this project has received fundings under the European Union's Horizon 2020 research and innovation programme from the Marie Sklodowska-Curie grant agreement No 657751

NITEC: a Negative Ion Time Expansion Chamber (2015-2016)





Opened the doors for a realistic development of NITPC at 1 bar with SF_6

First ever negative ion operation at nearly atmospheric pressure with SF_6

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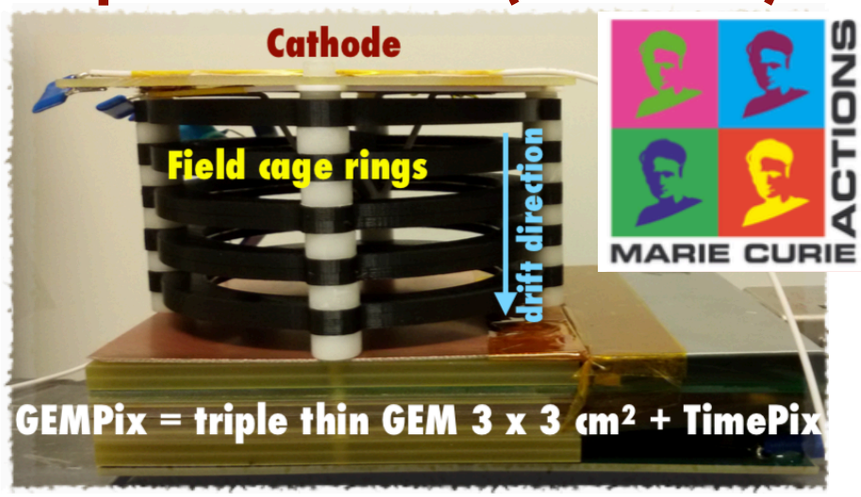
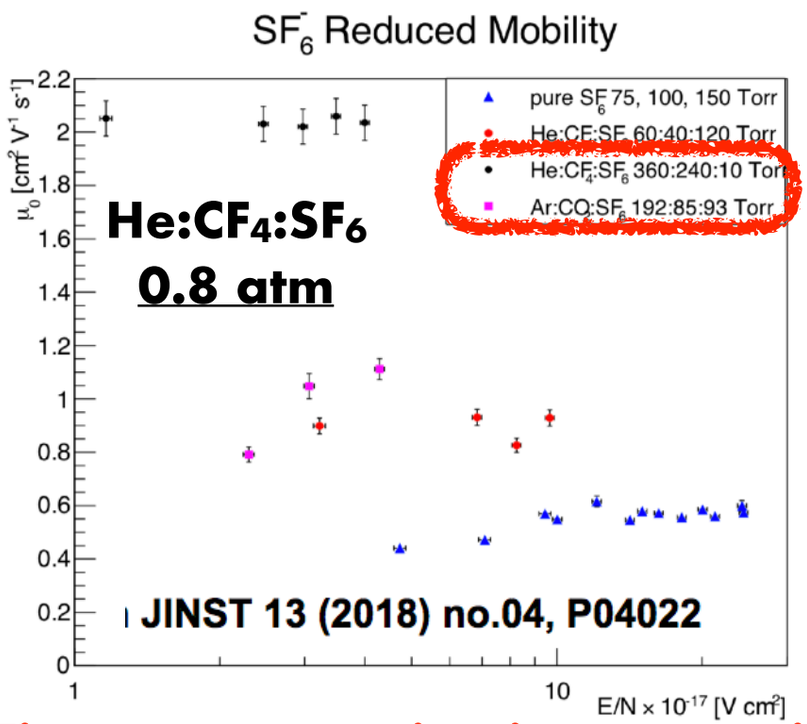
CYGNO IN TIUM synergy

NITEC: a Negative Ion Time Expansion Chamber (2015-2016)





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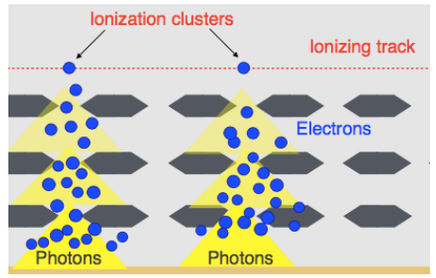
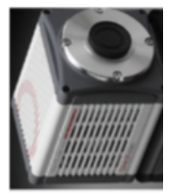
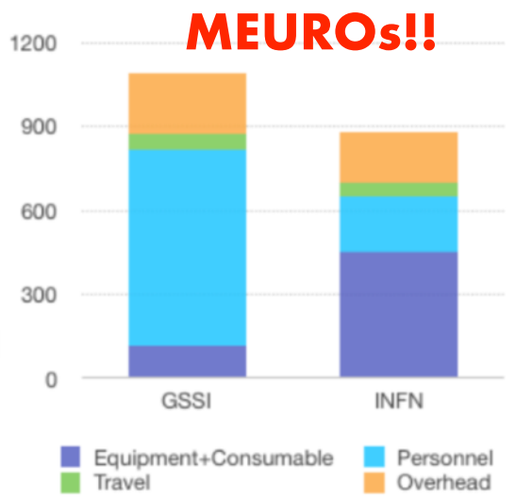




3D optical readout with negative ion drift demonstrator towards the development of 100-1000 m³ directional DM detector (i.e. CYGNO PHASE_2)

±80% He ±19% CF_4 ±1% SF_6

Funded with 2 MEUROs!!



European Research Council

Supporting top researchers from anywhere in the world

This project has received fundings under the European Union's Horizon 2020 research and innovation programme from the Marie Sklodowska-Curie grant agreement No 657751 and from the European Research Council (ERC) grant agreement No 818744

3D optical readout with negative ion drift

CYGNO roadmap & synergy with INTIUM

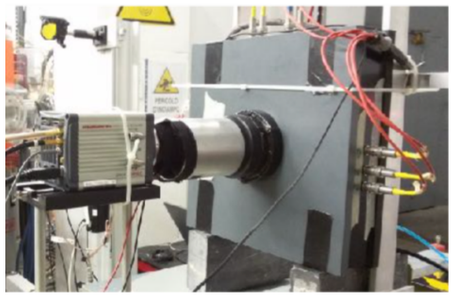
CYGNUS_RD — PHASE_0 — PHASE_1 — PHASE_2

2015 — 2016 — 2017 — 2018 — 2019 — 2020 — 2021 — 2022 — …

Electron drift

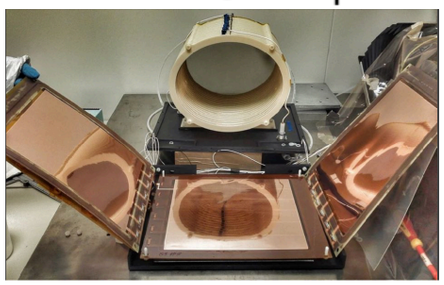
He:CF$_4$
1 atm

100 cm³ — ORANGE



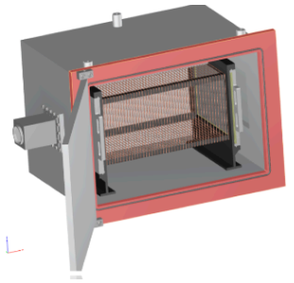
1 sCMOS
10 x 10 cm² area

0.01 m³ — LEMON



1 sCMOS
20 x 24 cm² area

0.05 m³ — LIME

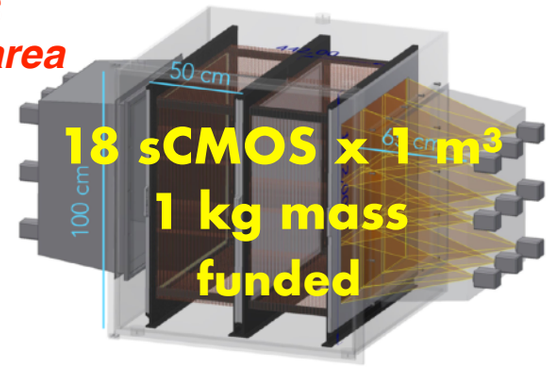


1 sCMOS
33 x 33 cm² area

@ LNF — Construction & test

@ LNGS — Installation & data taking

CYGNO Demonstrator



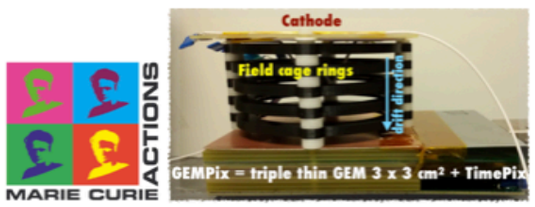
PHASE_0 funded by INFN

He:CF$_4$:SF$_6$
0.8-1 atm

4 Timepix chips
3 x 3 cm² area

NITEC

Negative ion drift

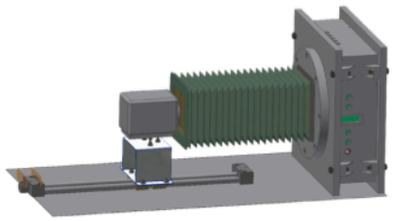


50 cm³

@ LNF

1 sCMOS
10 x 10 cm² area

MANGO



500 cm³

@ LNF

CYGNO 30-100 m³

INTIUM

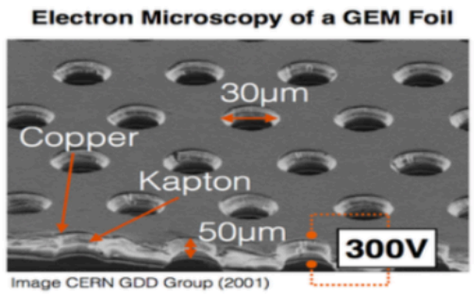
erc

2015 — 2016 — 2017 — 2018

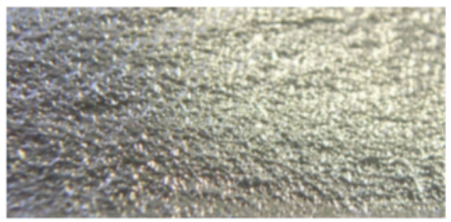
Part of this project has received fundings under the European Union's Horizon 2020 research and innovation programme from the Marie Sklodowska-Curie grant agreement No 657751 and from the European Research Council (ERC) grant agreement No 818744

PHASE_1: detector concept

Gas Electron Multipliers (GEMs) amplification



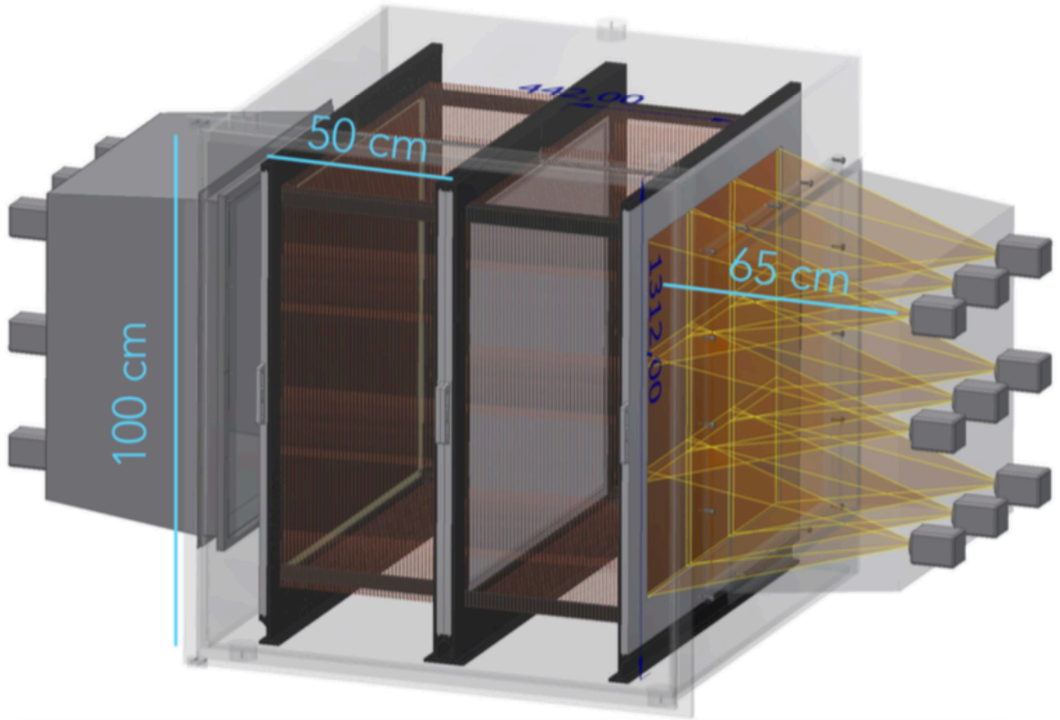
Transparent texturised mylar cathode a'la DRIFT



Full background simulation on going with sCMOS camera & GEMs activities recently measured @ LNGS

Active contribution from several CYGNUS-TPC members

*gammas & neutrons shielding not shown but present

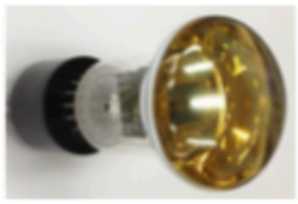


He:CF_4(:SF_6) 1 kg mass, 1 m^3 volume

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

9 cameras/m^2

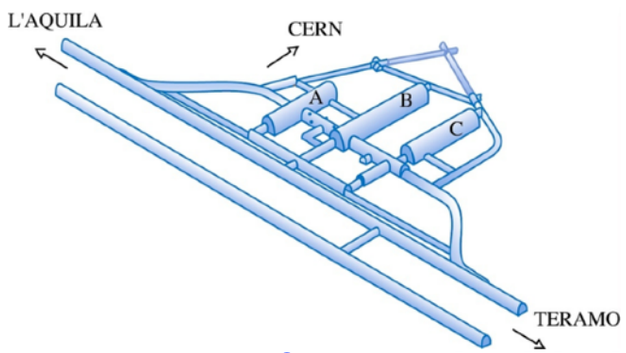
A total of 72 10^6 readout
165 x 165 μm^2 pixels



PMT + sCMOS optical readout decoupled from target volume

Atmospheric pressure & room temperature: minimal infrastructure

To be installed @ LNGS



IMPORTANT: first unshielded run will provide seasonal, spectral & directional ambient neutron flux measurement

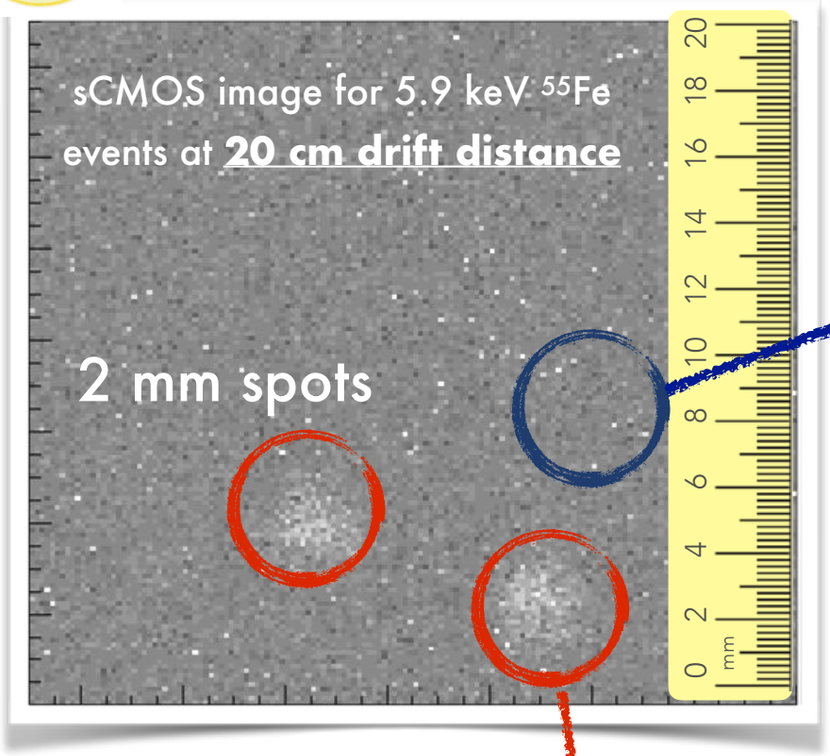
CYGNUS-RD developments towards

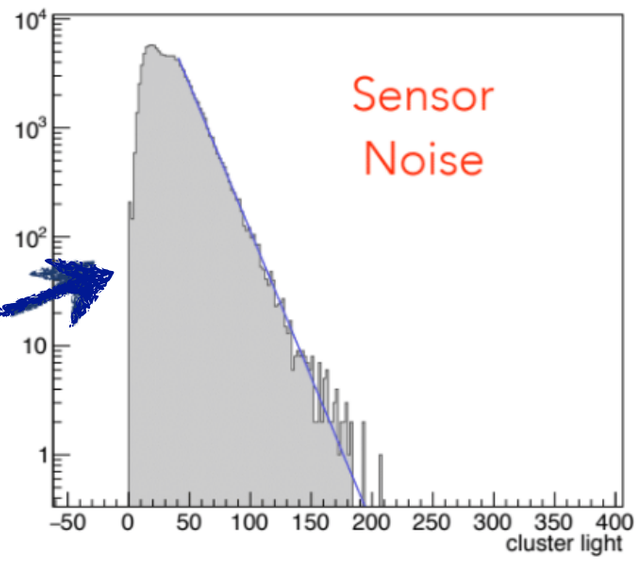
CYGNO & INITIUM

He:CF_4 1 atm

Energy threshold (conservative) & energy resolution

arXiv:1905.04066 [physics.ins-det]

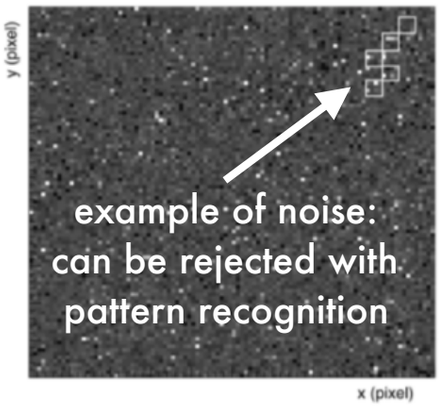


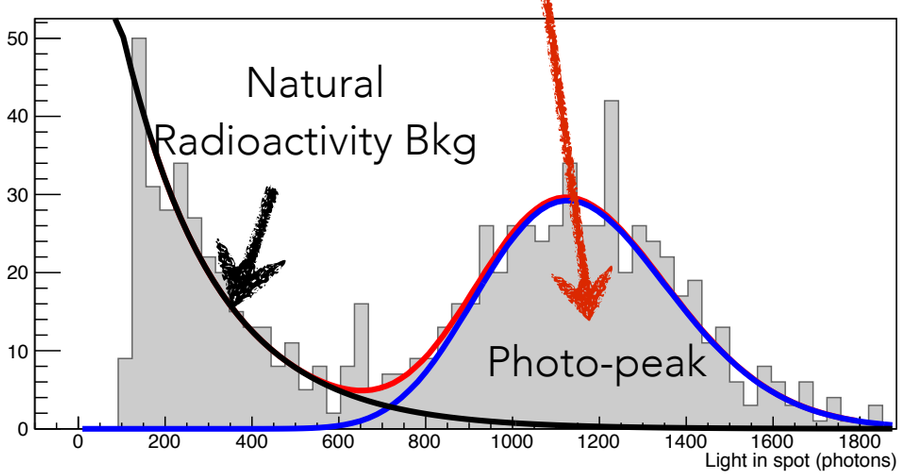


Exponential distribution for noise (slope ~ 16 photons).

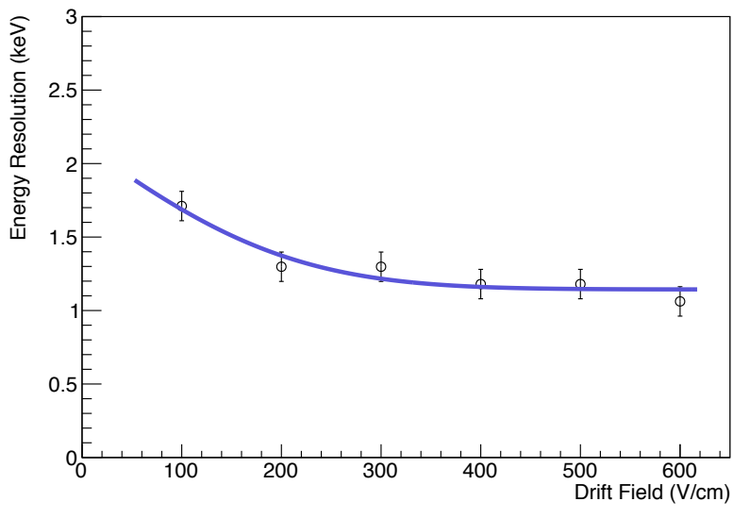
With 400 ph. threshold (2 keV) :
fake rate 10 events/year per sCMOS sensor

LEMON: 20 x 24 cm² readout area, with 20 cm drift

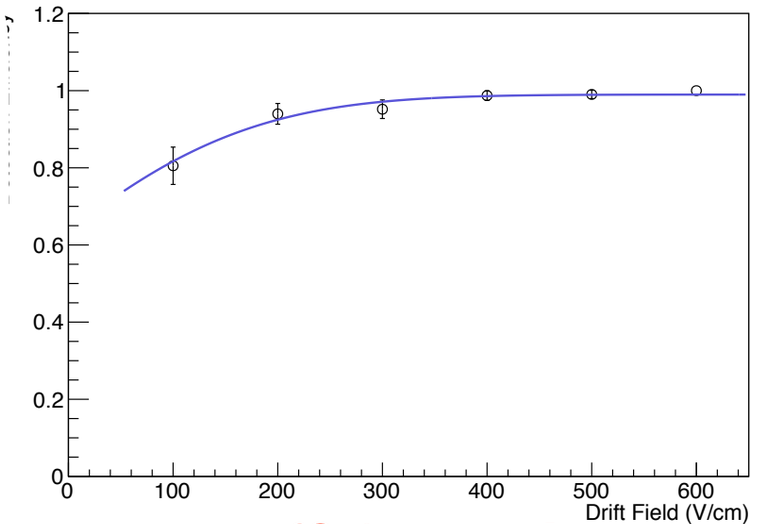




1 photon detected every 5 eV



18% energy resolution @ 5.9 keV



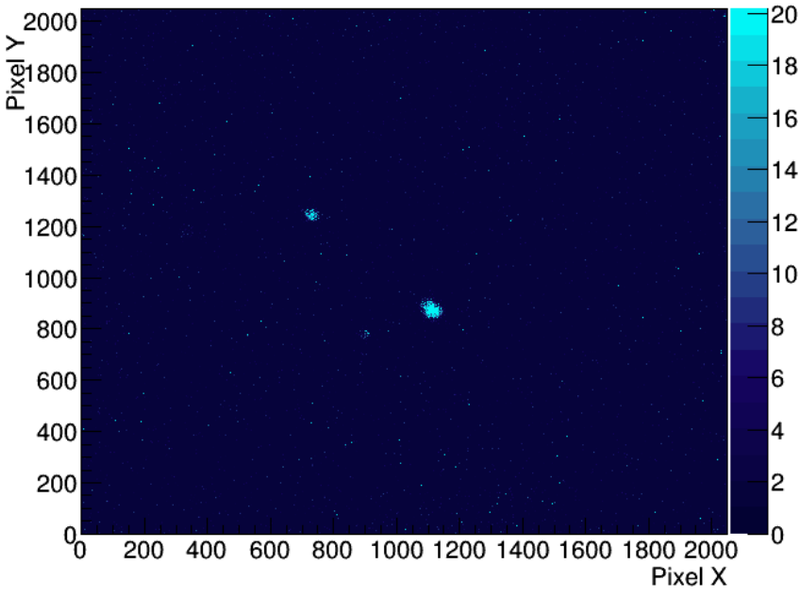
100% efficiency above 300 V/cm drift field

Stability test

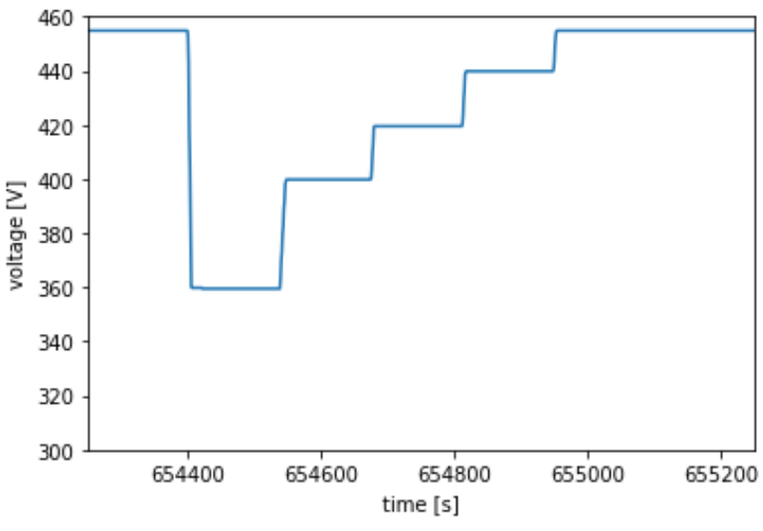
He:CF_4 1 atm

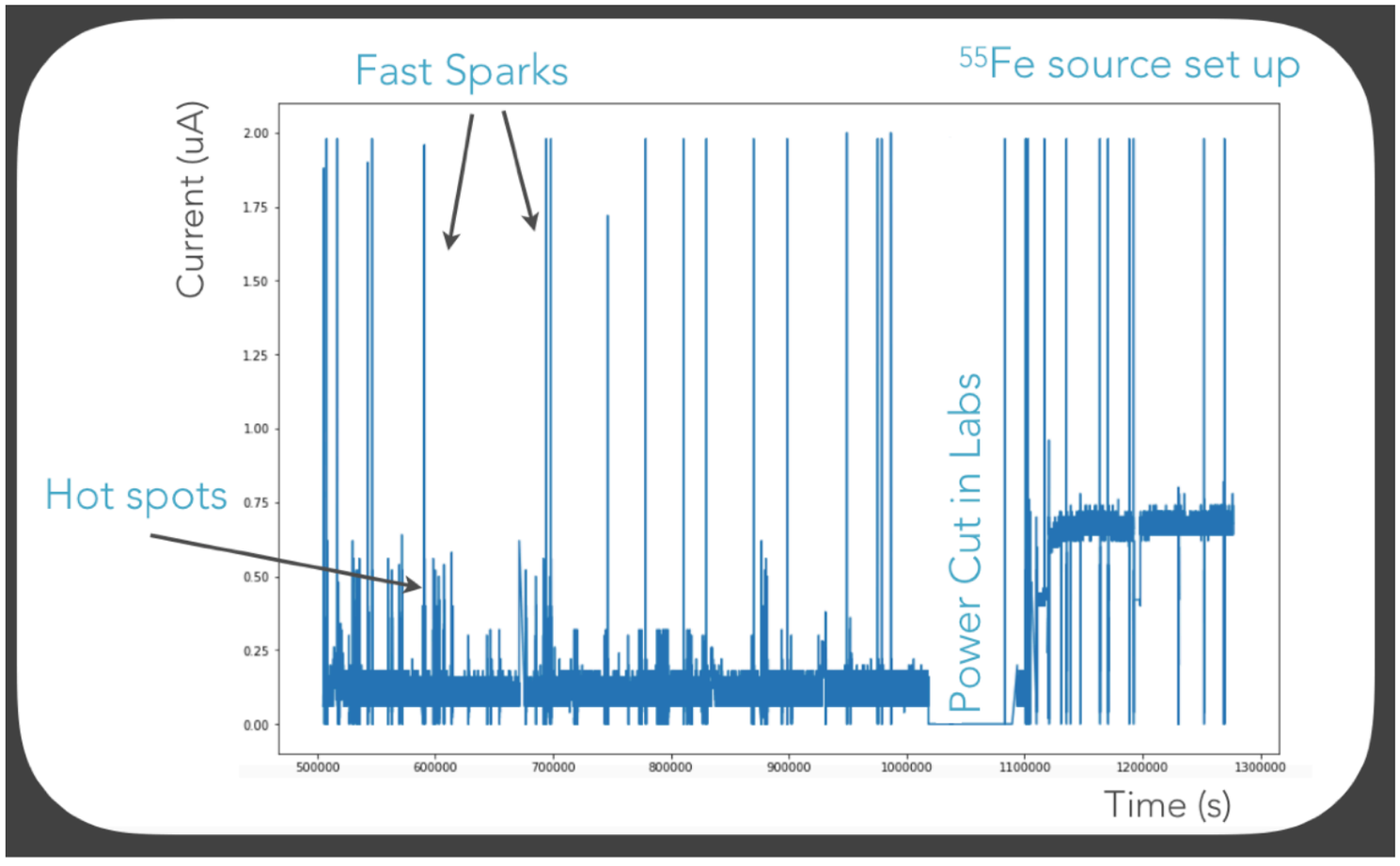
With 60:40, 70:30 and 80:20 gas mixture ratios

Details & results in F. Renga talk on Thursday afternoon



A typical hot spot, easily cured lowering GEM voltages of 100 V and then raising it again to nominal





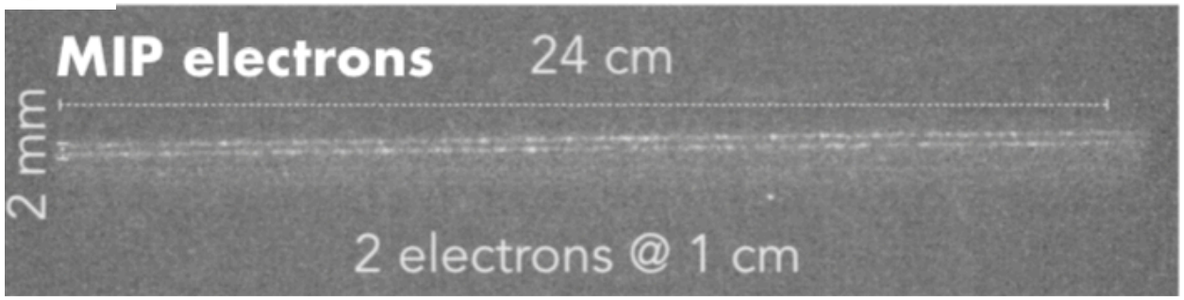
With He:CF_4 @ 60:40 we had 28 discharges (3/day), 72 hotspots (8/day) for a total of about 7% dead time due to GEM recovery over 9 days

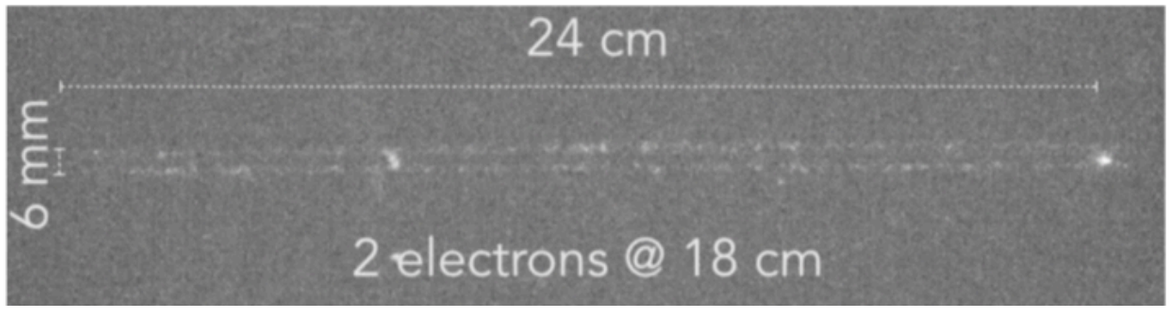
LEMOn detector (20 x 20 x 24 cm³) successfully operated for 15 consecutive days, with automatic GEM hot spots + trips recovery

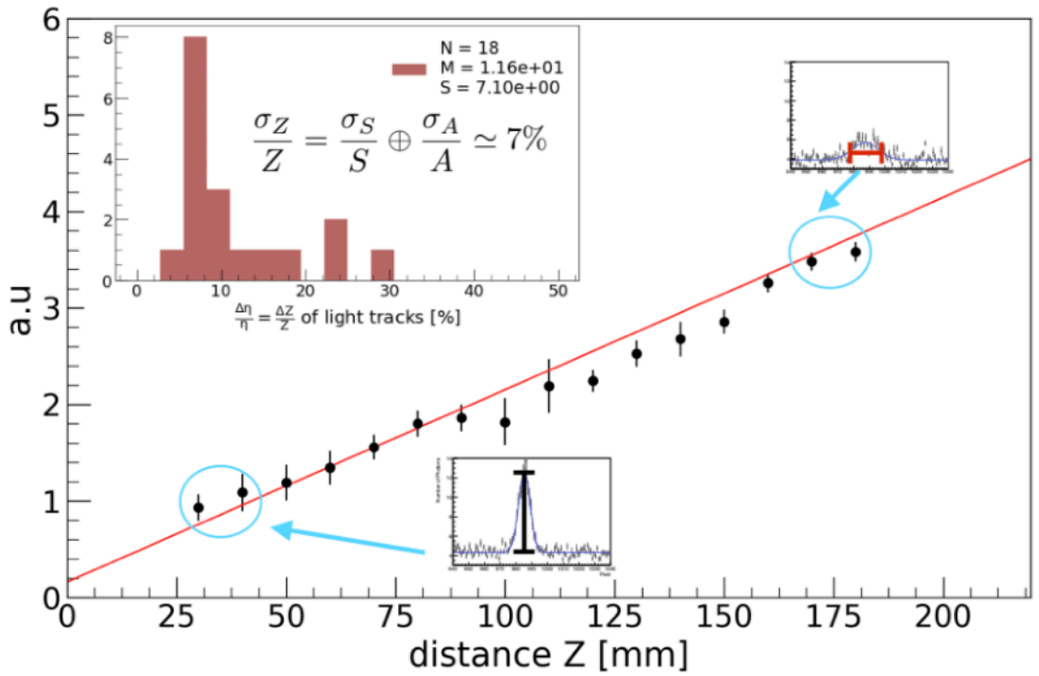
He:CF_4 1 atm

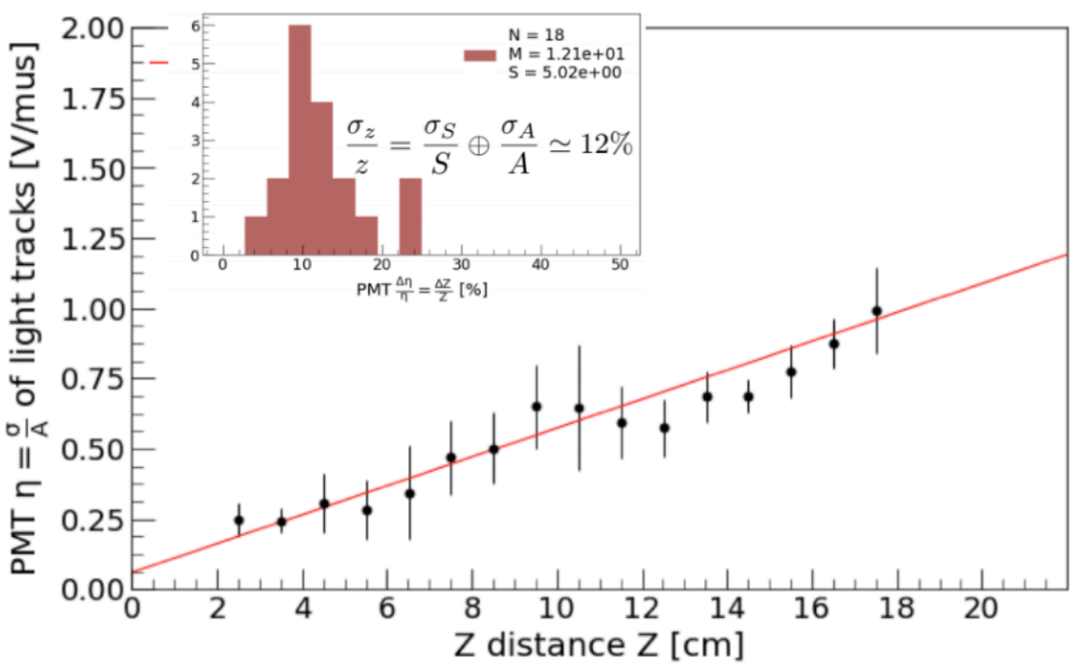
Fiducialization in the drift direction exploiting diffusion

The high readout granularity and position resolution allows to to measure coordinate along drift direction fitting for the diffusion









Light transverse profile of both sCMOS images and PMT waveforms sensitive to absolute Z position via fit to diffusion

Conference Record of 2018 IEEE NSS/MIC/RTSD

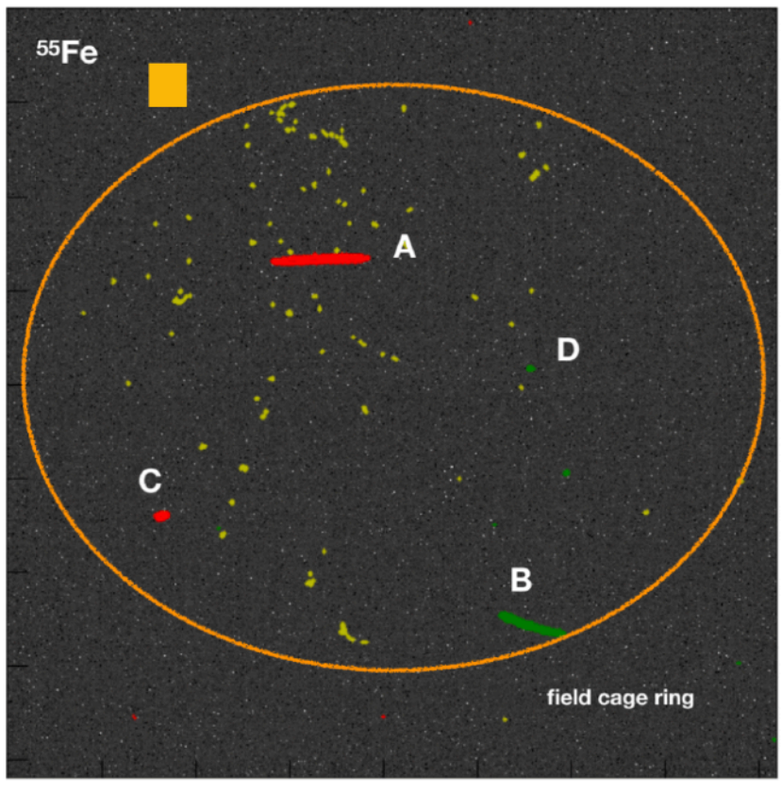
arXiv:1901.04192 [physics.ins-det]

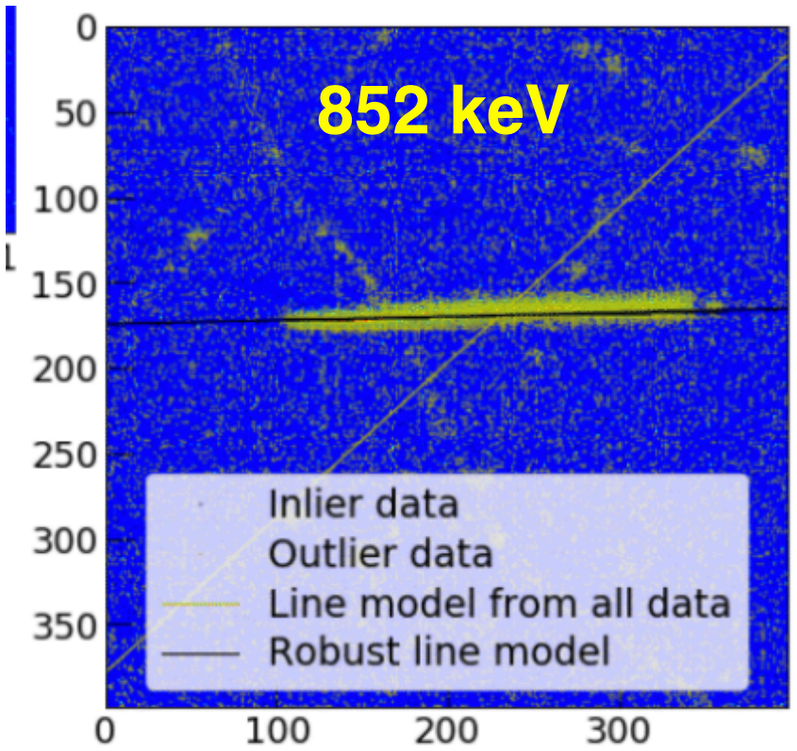
Measurement to be soon repeated and verified on nuclear recoils

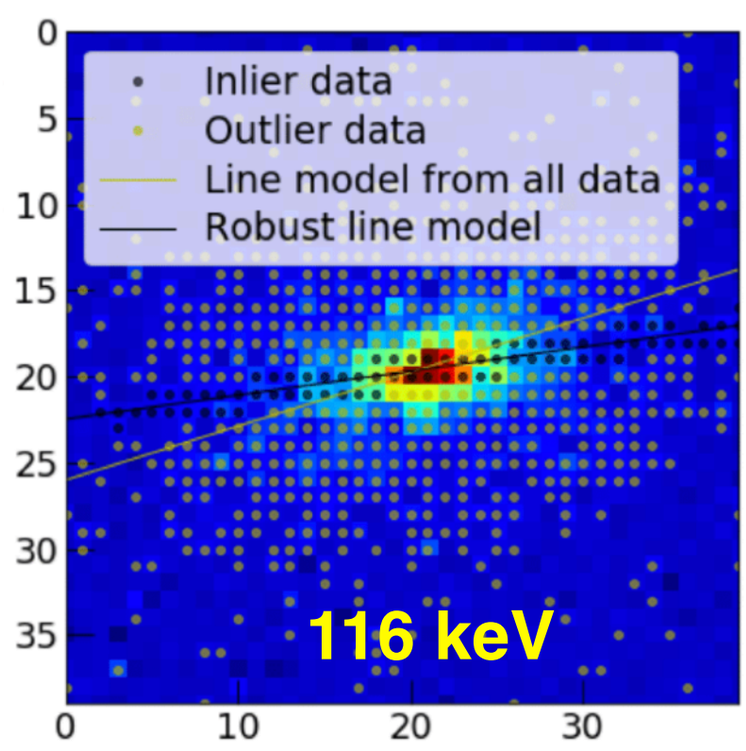
He:CF_4 1 atm

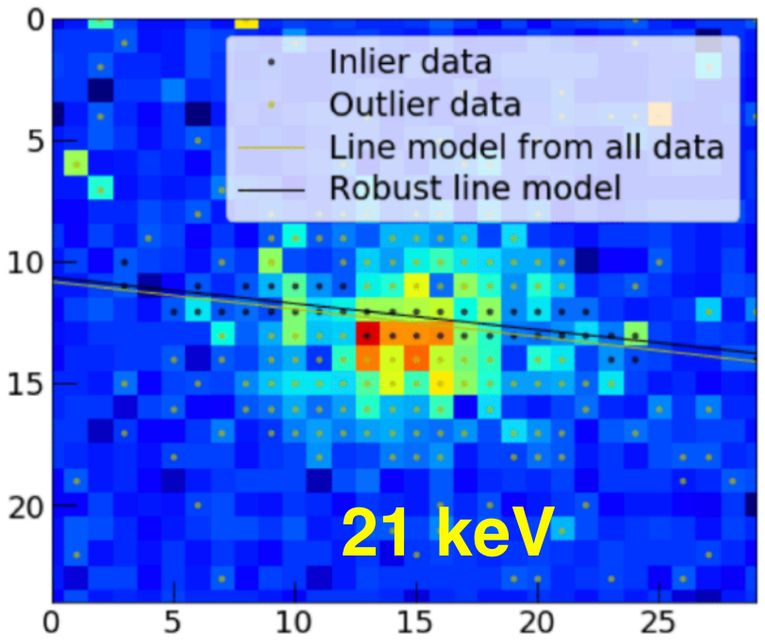
Nuclear recoils from AmBe with directionality

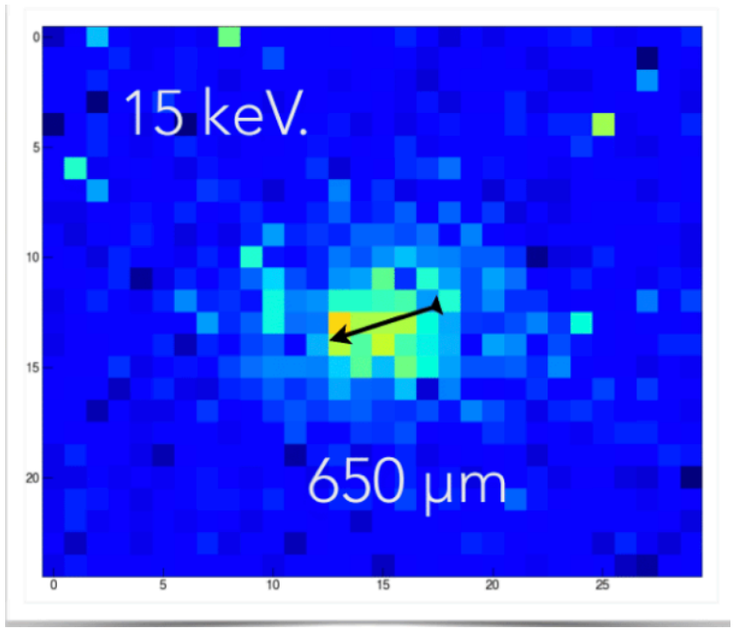
Hint of directionality down to low thresholds!







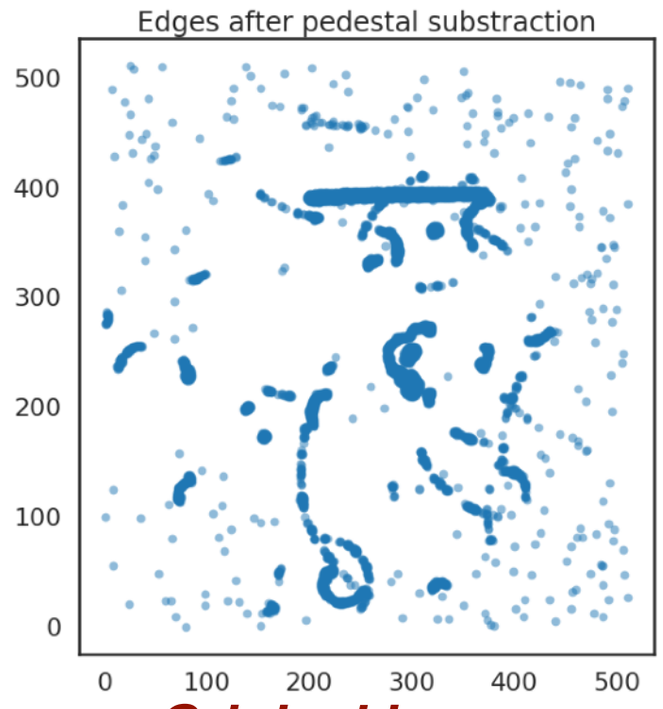




New work just started to quantitatively estimate Head-Tail & directionality performance on these + FNG data (G. Dho, GSSI PhD)

Cluster reconstruction and particle identification

PRELIMINARY

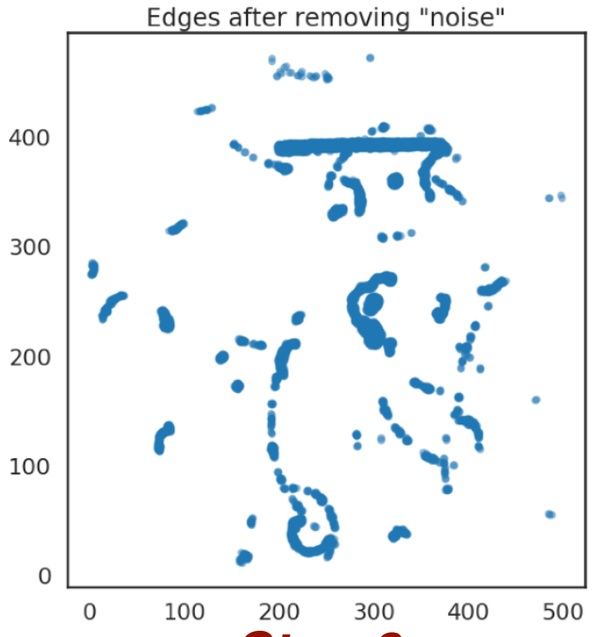


Original image

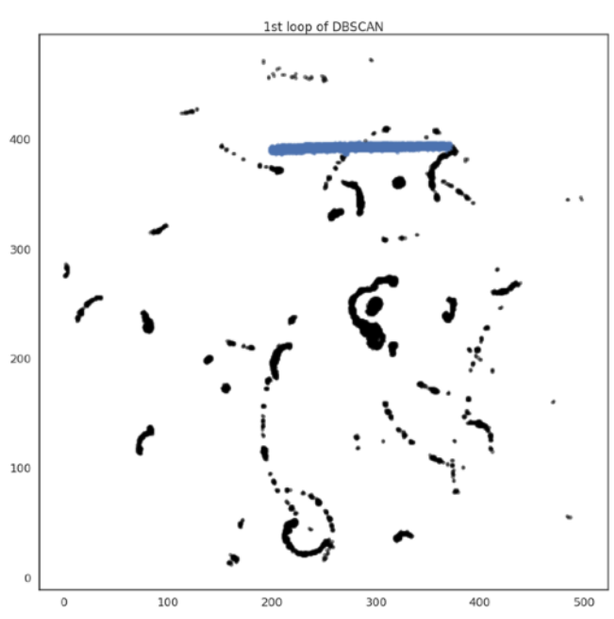
Details & results in I. Abritta Costa talk on Thursday afternoon

- Step 0: remove noise clusters (no nearest neighbours)
- Step 1: cluster high density pixels
- Step 2: cluster medium density pixels
- Step 3: cluster low density pixels

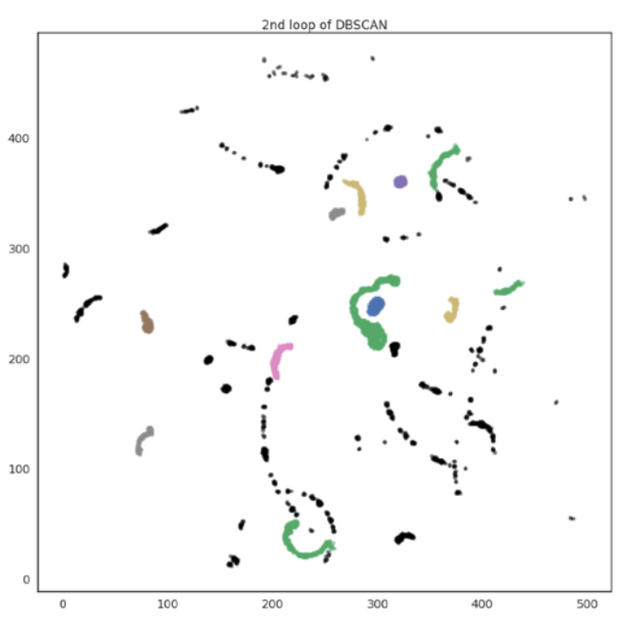
Based on an improved DBSCAN algorithm



Step 0



Step 1



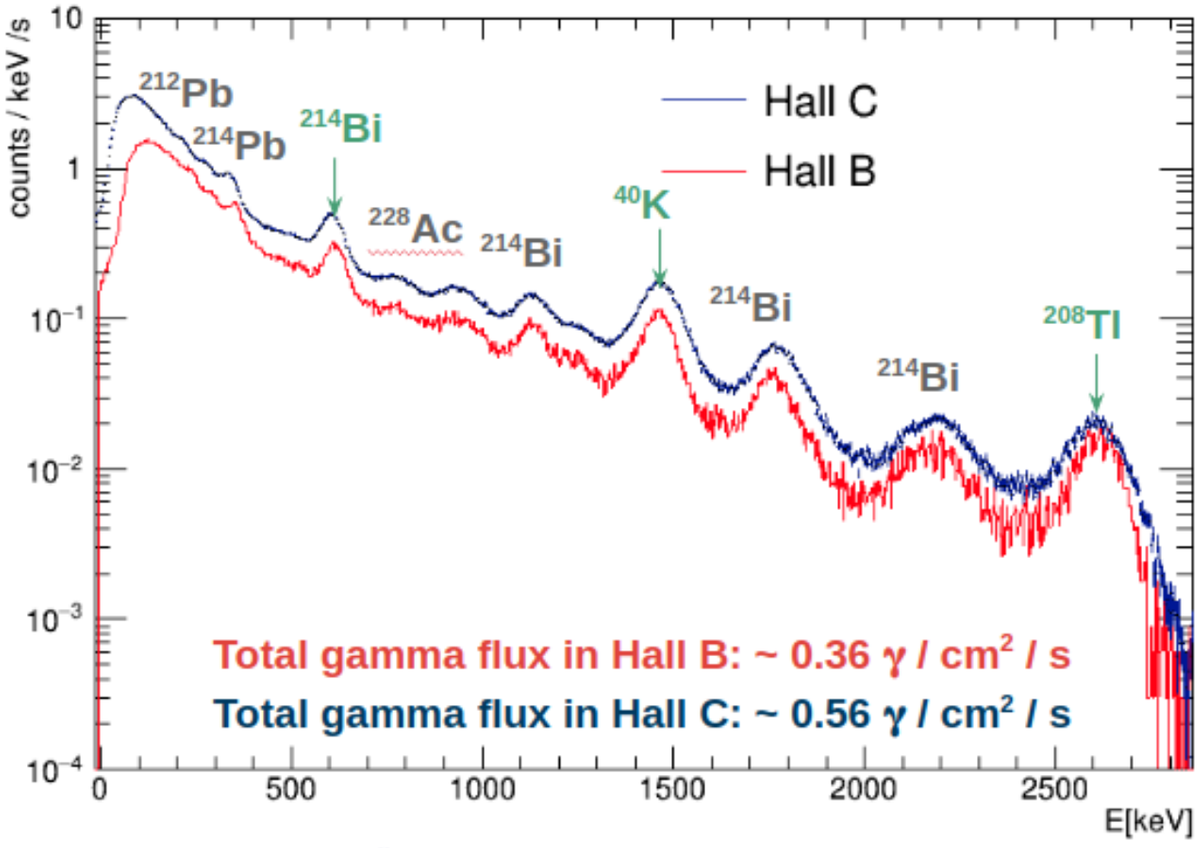
Step 2

Step 3

Background simulation

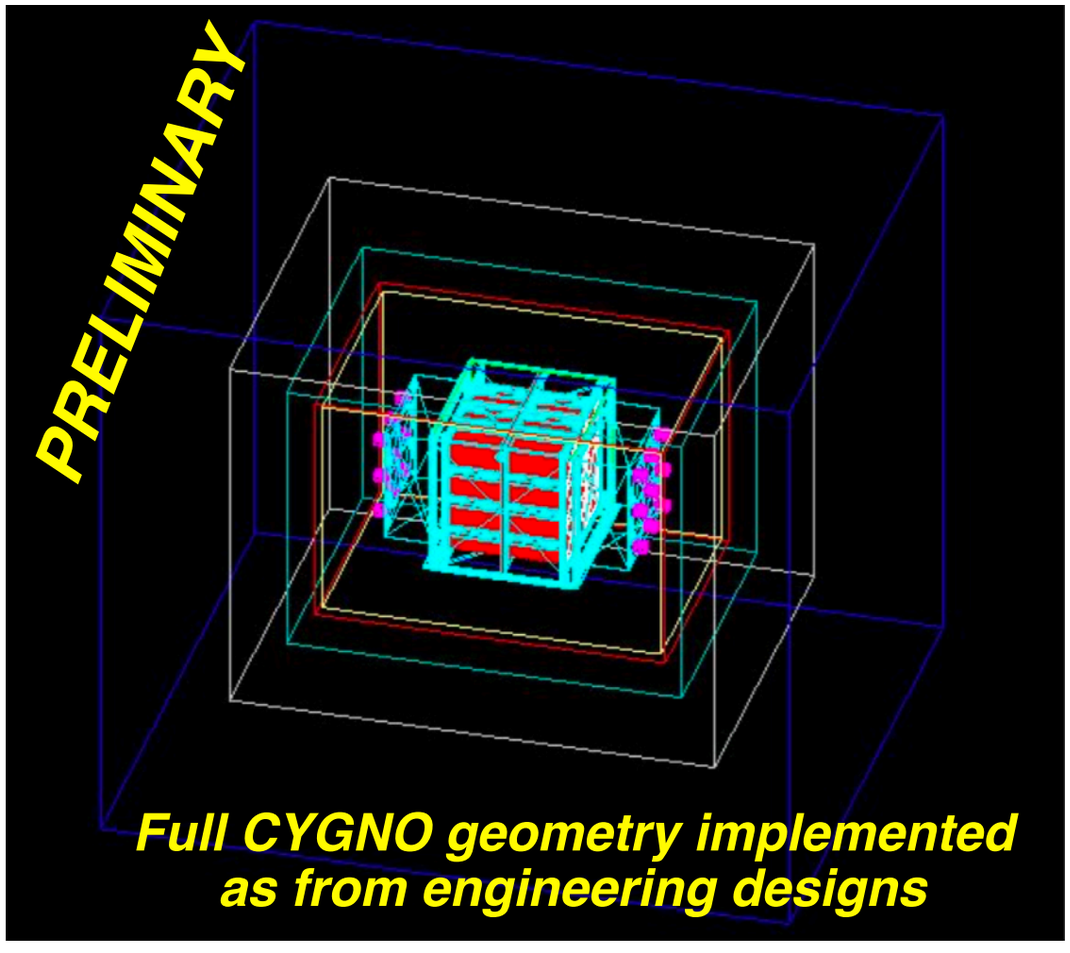
F. Bellini, G. Cavoto, G. D'Imperio, A. Messina

Under development



From SABRE measurements

Various shielding options under study



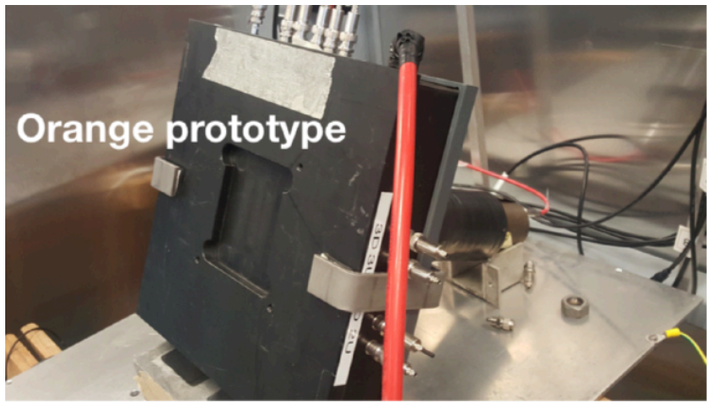
Full CYGNO geometry implemented as from engineering designs

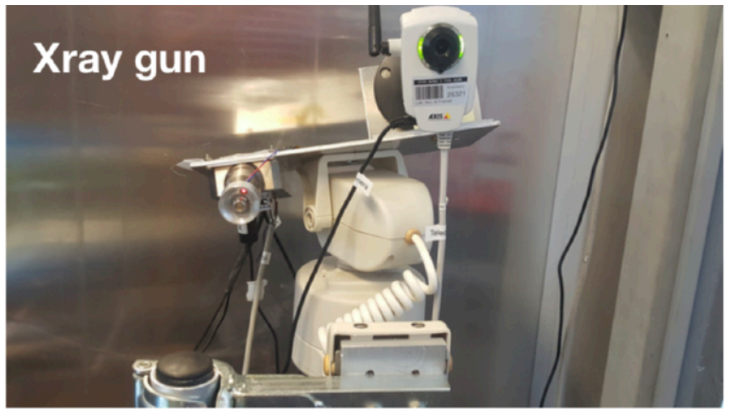
New R&D gas studies to go green

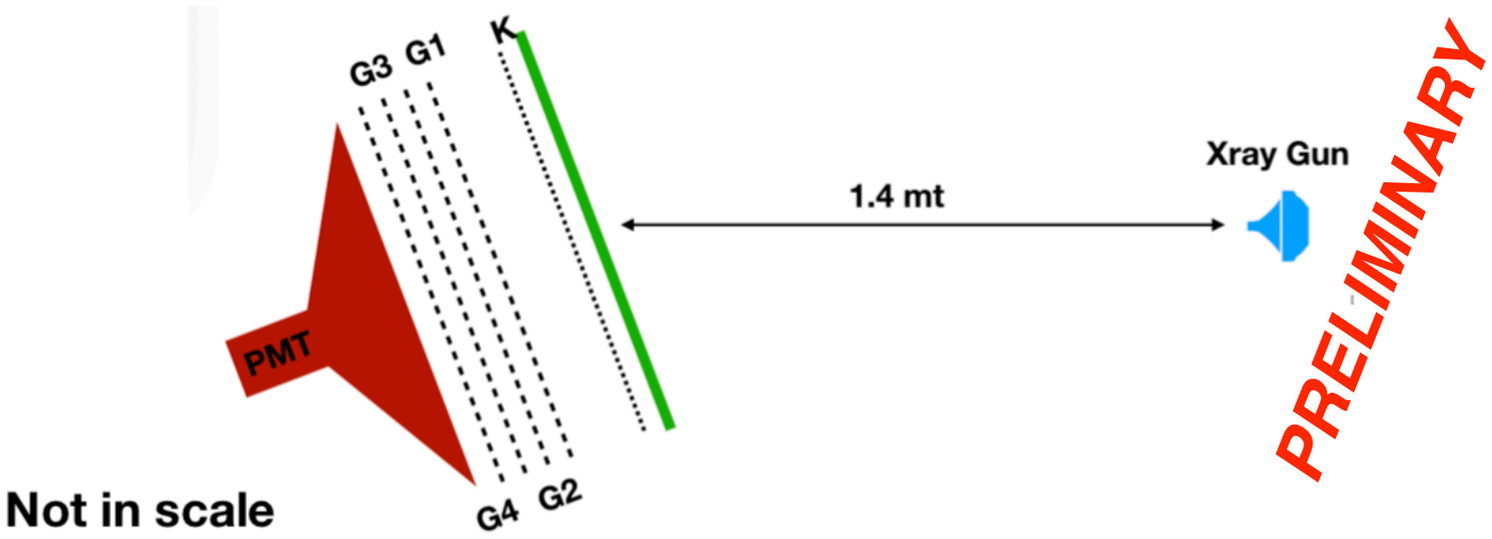
Details & results in D. Piccolo talk on Thursday afternoon

CF_4 for quenching + scintillation
GWP = 6500

R&D undergoing to possibly substitute CF_4 with HFO
GWP = 6







Gas mixtures tested

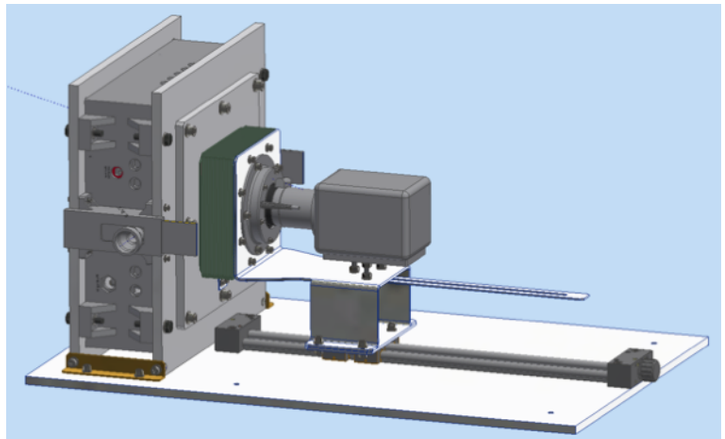
Mix	HV GEM
He-CF4 (60-40)	340
He-CF4 (60-40)	350
He-CF4 (70-30)	320
He-CF4 (70-30)	330
He-CF4-HFO(70-30-10)	360
He-CF4-HFO(70-30-10)	370
He-CF4 (80-20)	380

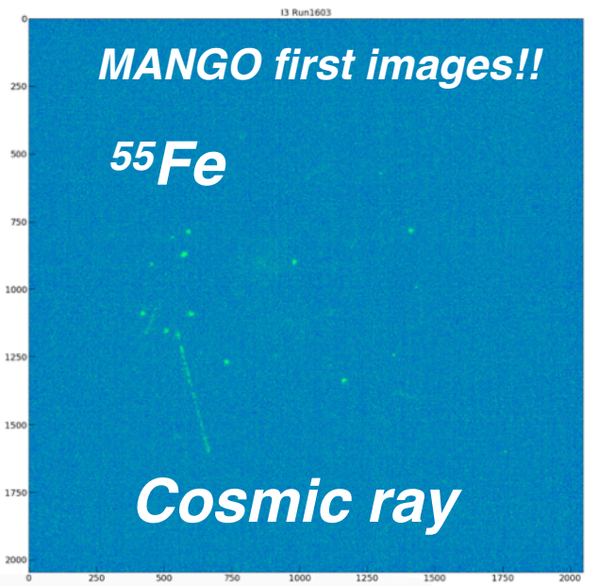
New prototypes

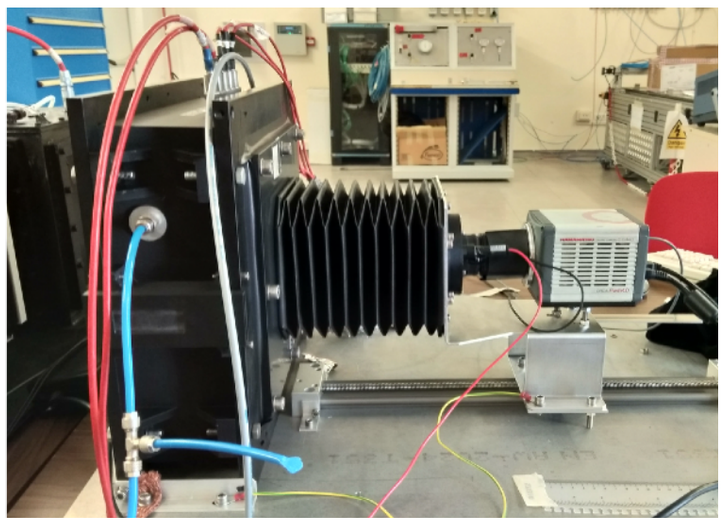
C. Capoccia, A. Pelosi, F. Rosatelli, S. Tomassini A. Orlandi, E. Paoletti, L. Passamonti, D. Pierluigi, A. Russo

MANGO: a Multipurpose Apparatus for Negative ion studies with GEM Optically readout

1 sCMOS + 1 PMT
10 x 10 cm²
readout area
1-5 cm drift

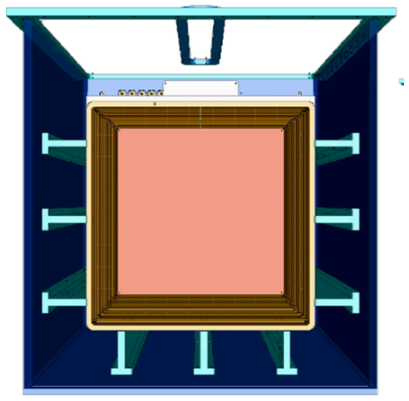


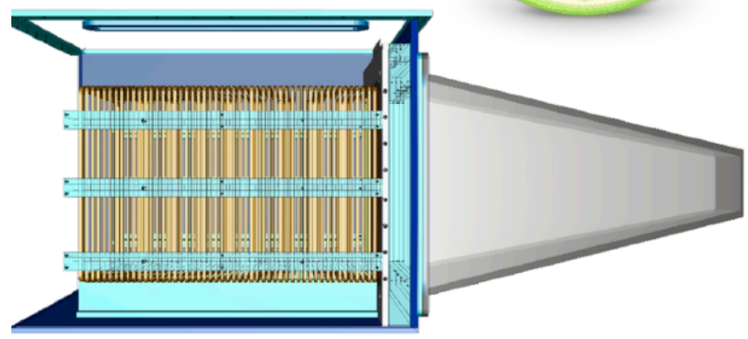




Installed at LNF July 2019: light vs gain studies, negative ions, CYGNO field cage tests, HFO

LIME: Long Imaging ModulE





1 sCMOS + 4 PMT
33 x 33 cm² readout area
50 cm drift
1/18 of CYGNO

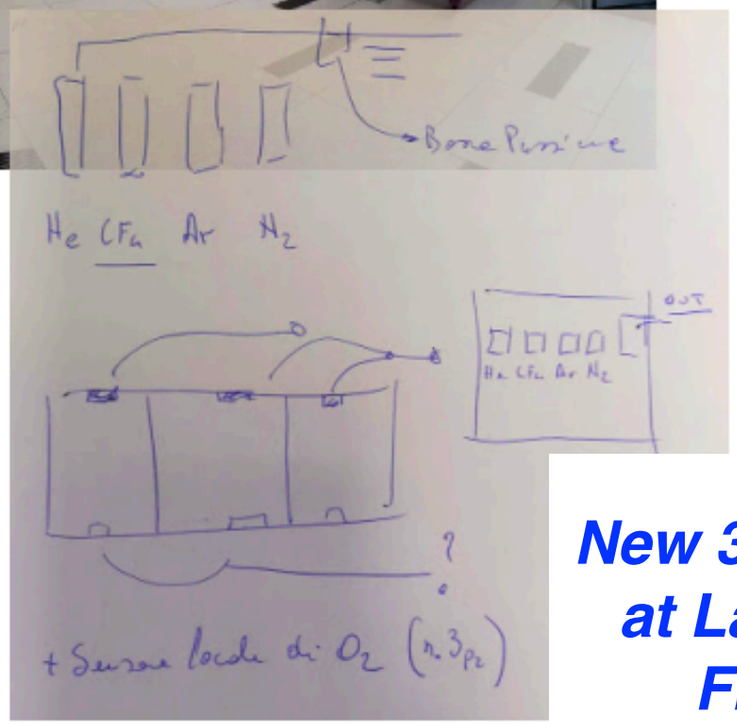
50 L volume under manufacturing

10mm PMMA
3 mm Cu

shielding

- studying materials
- performing a detailed study, minimisation and simulation of radioactive background;
- gas re-circulation and purification.
- optimisation of PMT/SiPM readout and trigger.
- HV Test

New infrastructures @ LNF



A. Mengucci,
L. Passamonti

many thanks to MU2E group and in particular to E. Paoletti and F. Marino

Reuse, Recicle

New 30 m² ISO-7 clean room at Laboratori Nazionali di Frascati, to be soon equipped with a gas system

G. Mazzitelli, CL preventivi 09-07-2019

TDR, working plan & new members

Technical Design Report

Esperimento XXX

In questo documento sono descritte le linee guida principali che necessariamente devono essere presenti nella redazione di un Technical Design Report (TDR).

Questo documento è derivato dal template redatto e approvato dal Gruppo di Lavoro "Project Management" dell'Istituto Nazionale di Fisica Nucleare (INFN) ed è declinato tenendo conto delle peculiarità dei Laboratori Nazionali del Gran Sasso (LNGS).

Autore	Verificato da	Approvato da

Summary

Preliminary Risk Analysis (PRA) under development for TDR, towards Quantitative Risk Analysis (QRA)

Details in G. Mazzitelli talk on Thursday afternoon

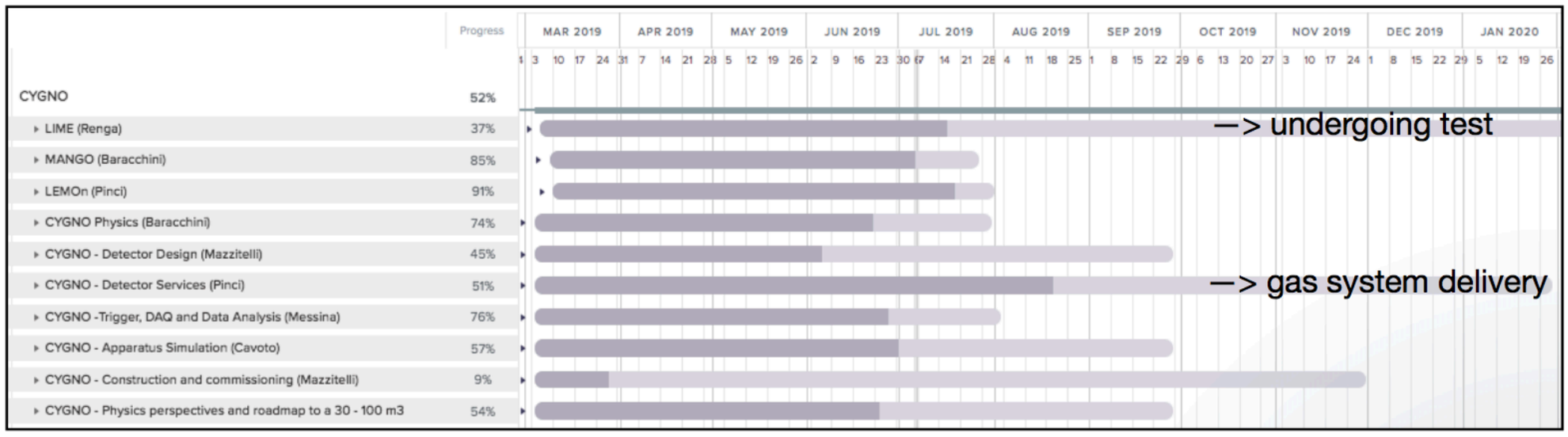
	FTE 2019	FTE 2020
CYGNO + INITIUM	4.5	10

TDR preparation to be submitted to October 2019 Scientific Committee, with the help of LNGS services

Thanks to new members + PhDs & Postdocs hired with ERC

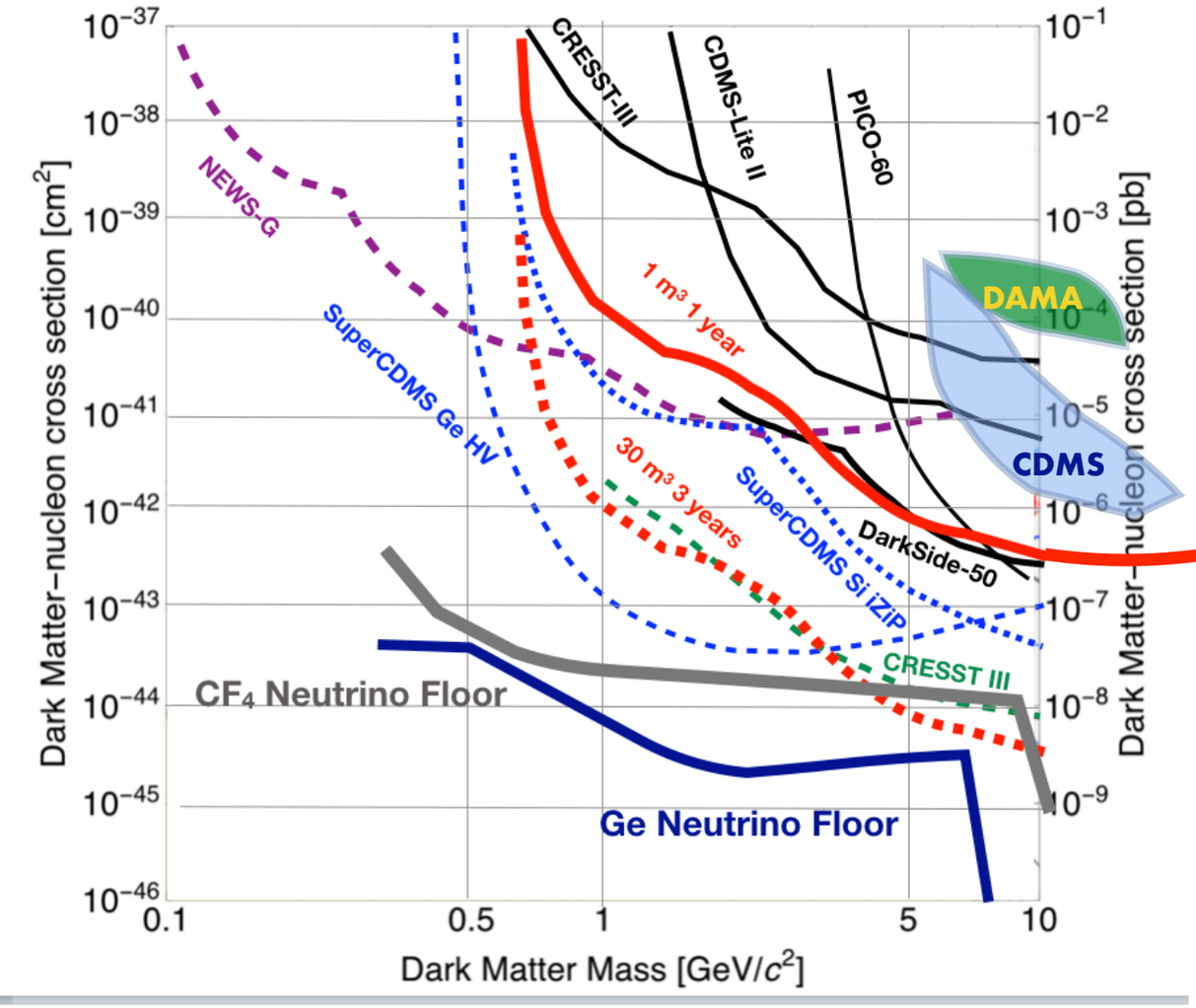
- GLIMO-S&E: to be define

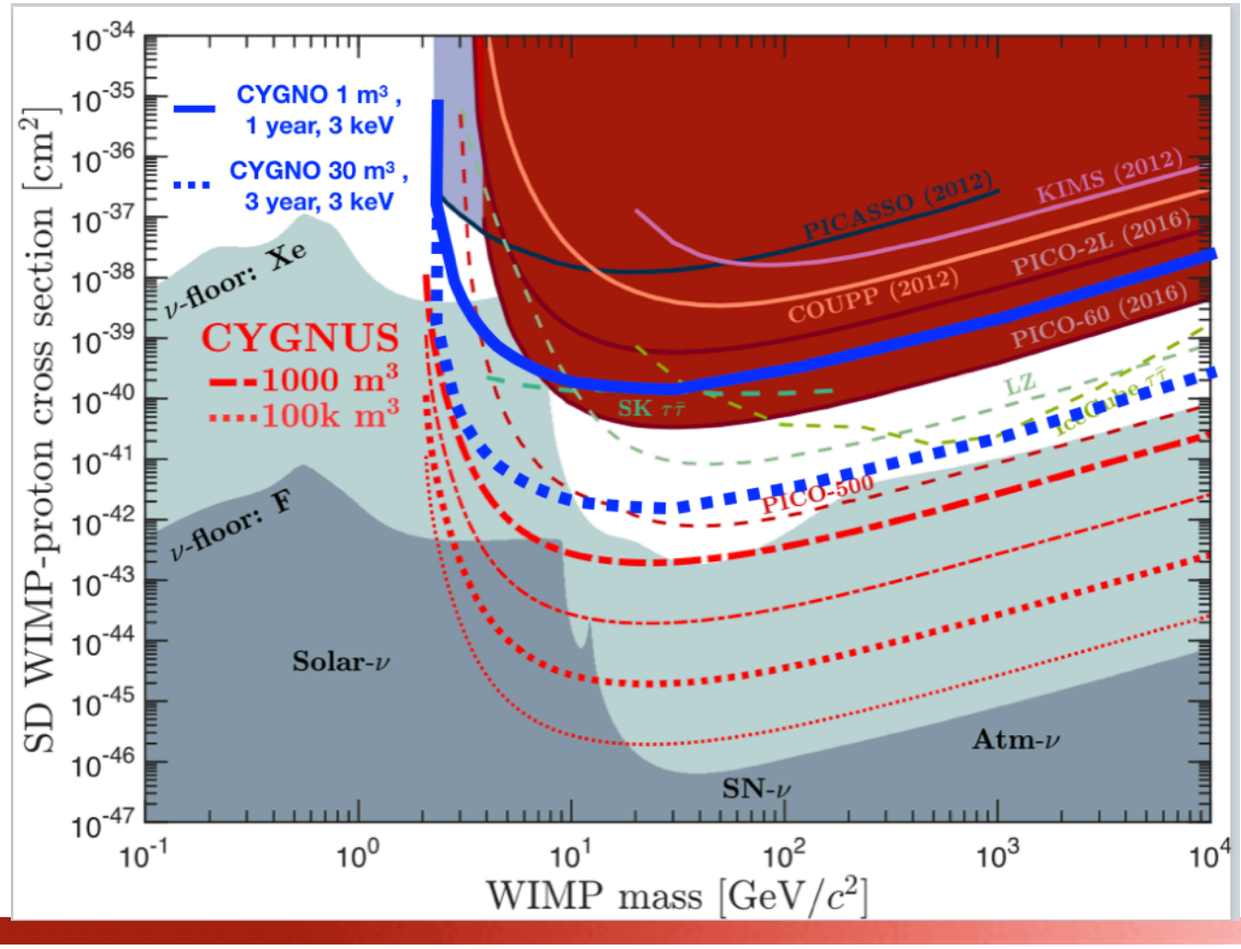
TDR and R&D 2019 GANTT



CYGNO prospects sensitivity at low WIMP masses

Zero background assumed





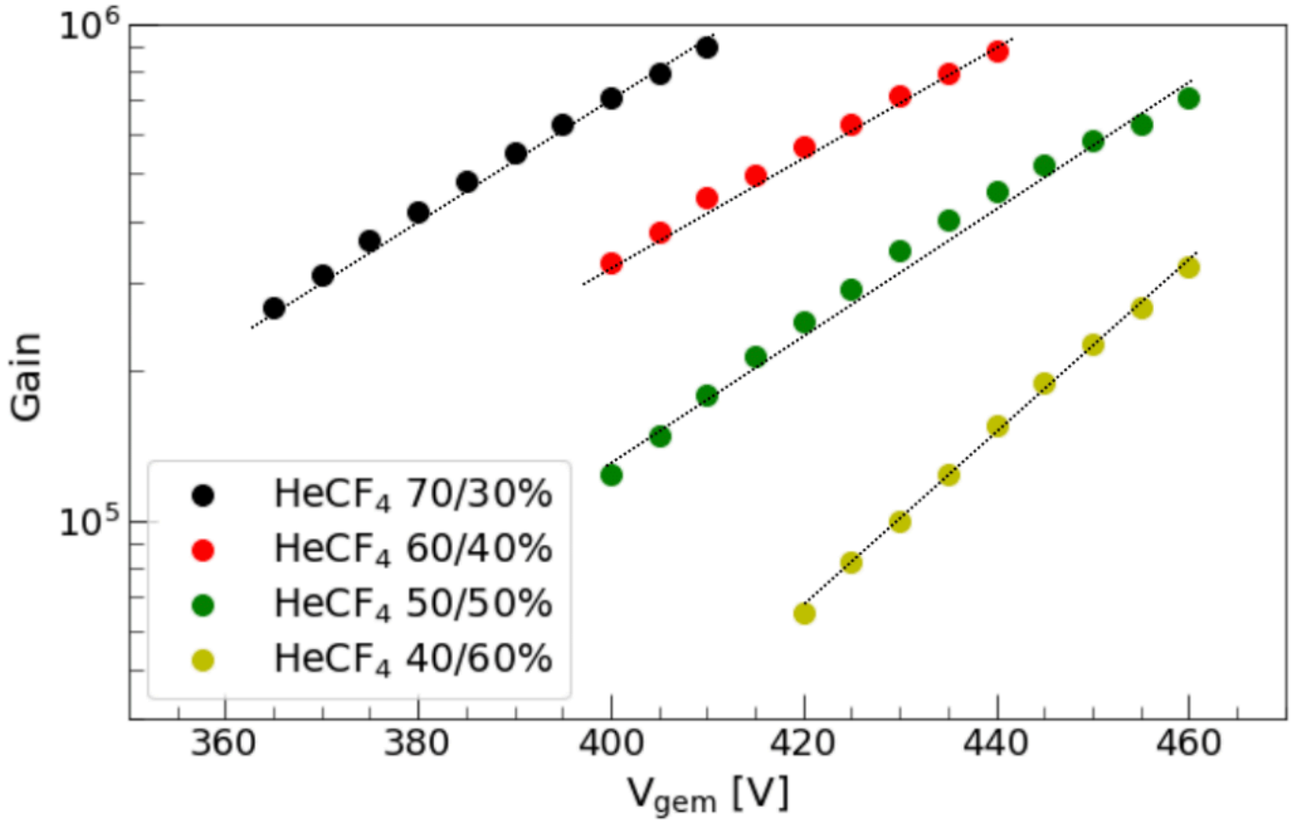
Stay tuned for CYGNO birth!

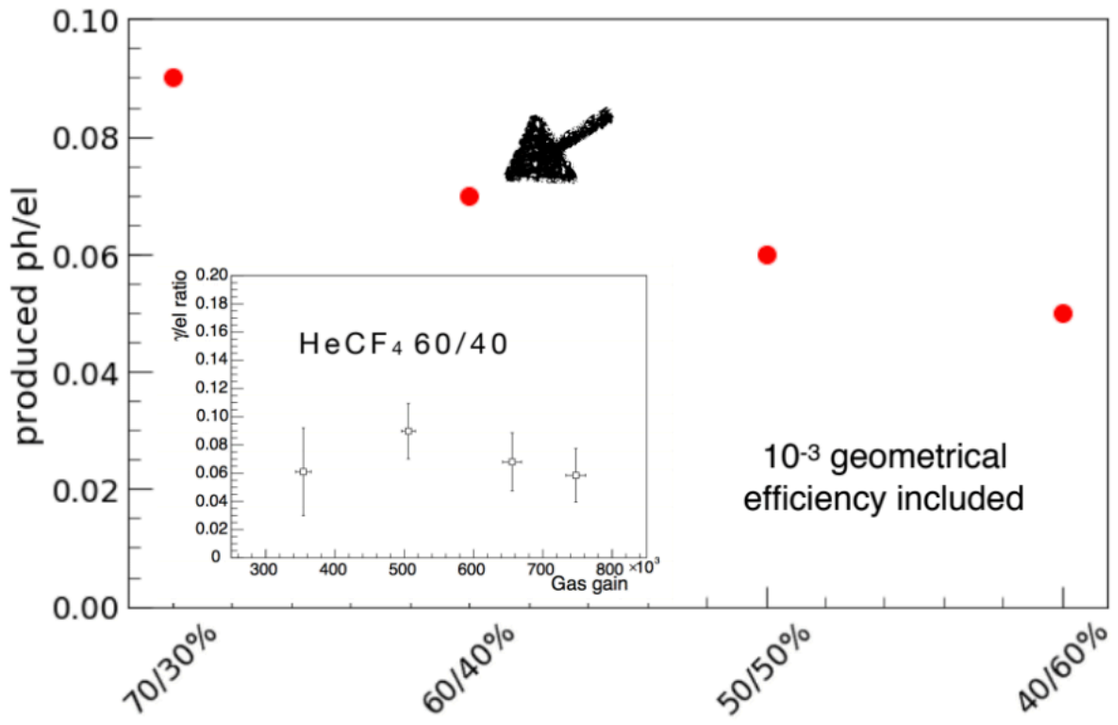
https://web.infn.it/cygnus/

Backup slides

CYGNO gas mixture

$HeCF_4$ Gain and photons efficiency

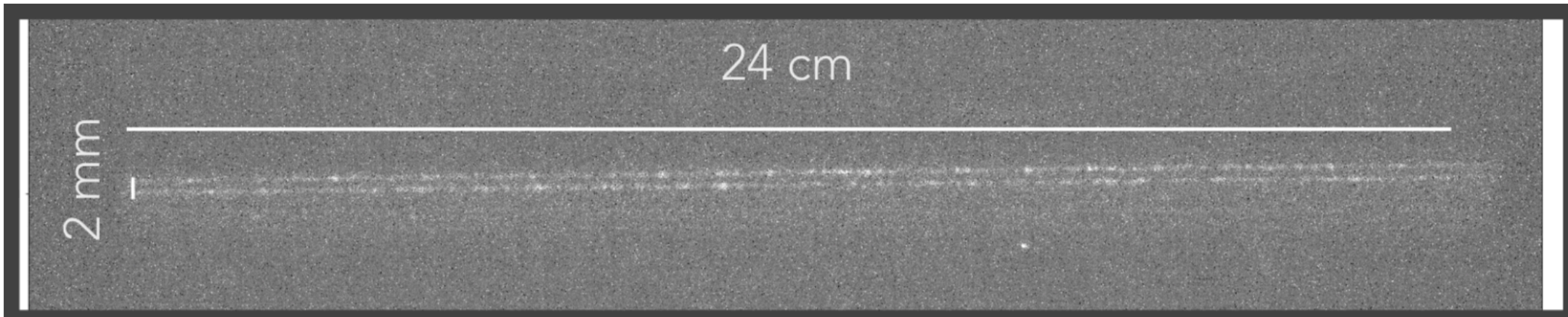


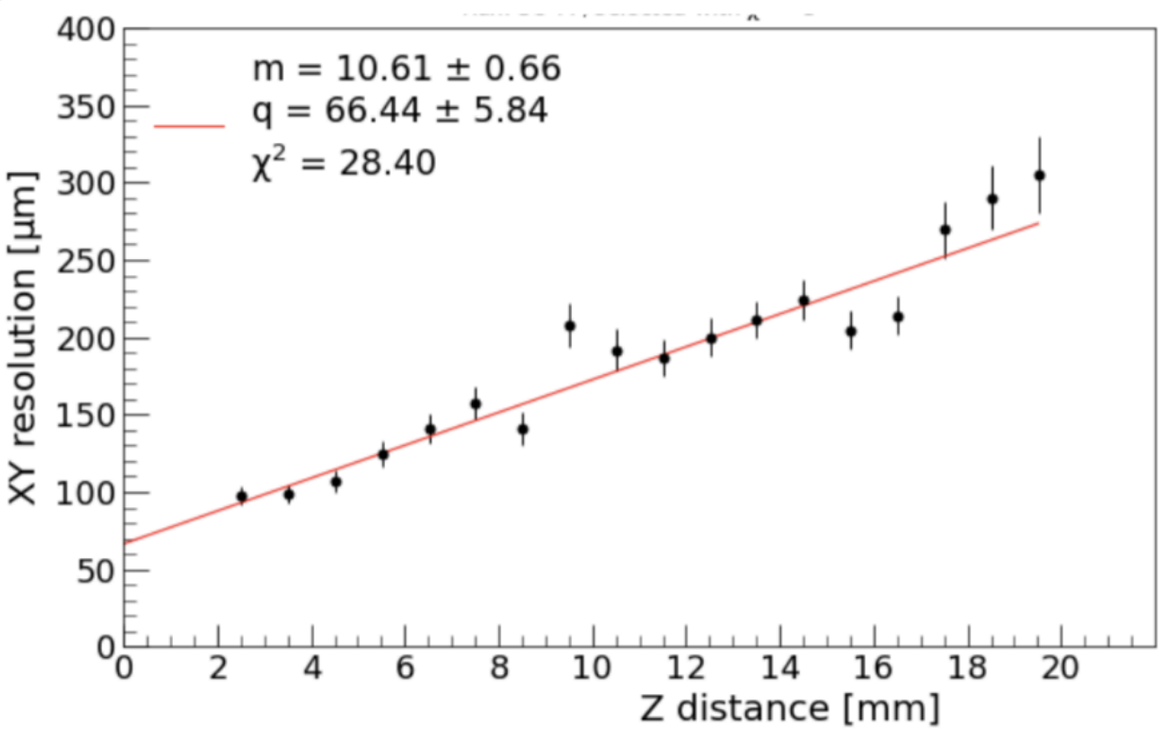


about 0.07 photons produced by secondary electron in the GEM shower

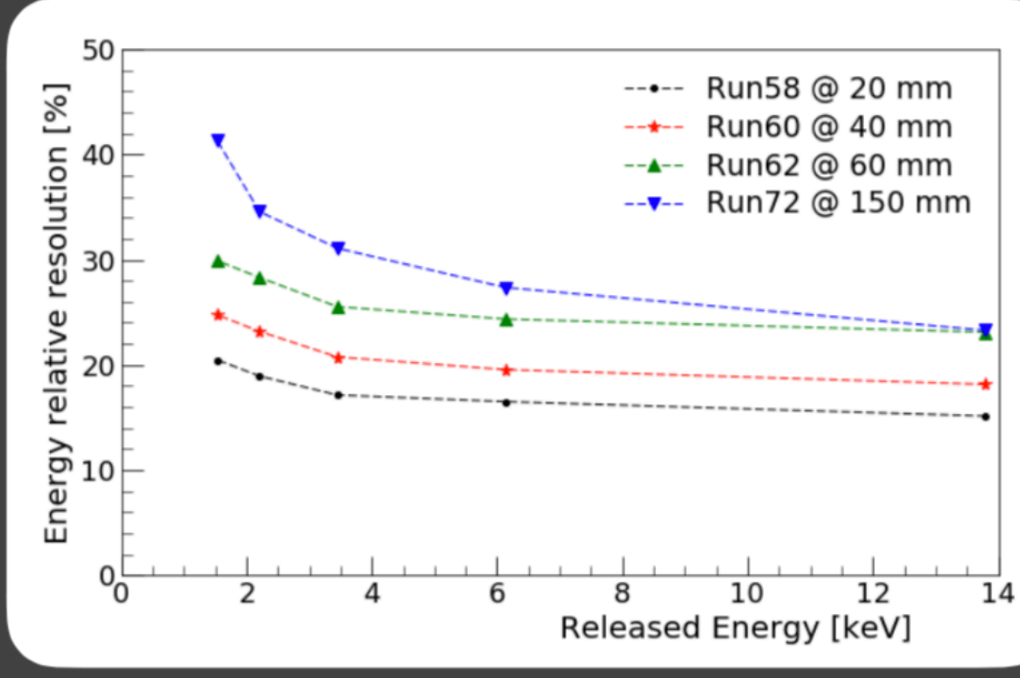
LEMOn tracking performances

He:CF_4 1 atm





Energy resolution was studied at different depths (Z).



In the few keV region a relative resolution of 20%-30% is achieved