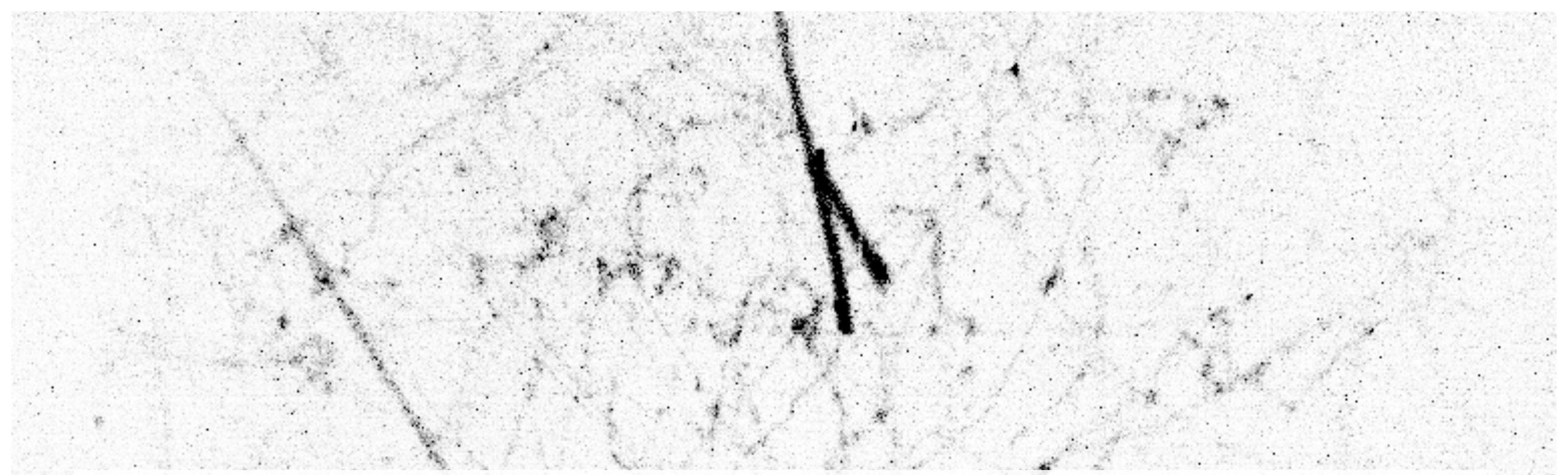


CYGNO Experiment

CYGNO status and plans
Feb 2025

INFN · Sapienza Università di Roma · GSSI · Roma Tre Università degli Studi · ENEA · The University Of Sheffield. · UFJF Universidade Federal de Juiz de Fora · UNICAMP · Universidade de Coimbra · CBPF · European Research Council Established by the European Commission

LIME

LIME: RUNs 1-5

	Time slot	Number of pictures	Event rate	Number of events
RUN 1: No-shielding	3 Nov 2022 - 15 Dec 2022	$4\ 10^5$	35 Hz	$4\ 10^6$
RUN 2: 4 cm Cu shielding	15 Feb 2023 - 15 March 2023	$4.5\ 10^5$	3.5 Hz	$5\ 10^5$
RUN 3: 10 cm Cu shielding	5 May 2023 - 16 Nov 2023	$1.6\ 10^6$	1.5 Hz	$7.3\ 10^5$
RUN 4: 10 cm Cu + 40 cm water shielding	30 Nov 2023 - 31 March 2024	$2\ 10^6$	1.0 Hz	$6\ 10^5$
RUN 5: 10 cm Cu shielding (neutron flux measurements)	17 May 2024 - 1 Dec 2024	$12\ 10^6$	1.5 Hz	$5.4\ 10^6$

Special data takings

AmBe for Nuclear Recoils	2-4 Aug 2023	$2\ 10^5$	0.04 Hz of NR	$2.5\ 10^3$ NR
^{241}Am for Electron Recoils	7-16 Nov 2023	$7\ 10^5$	50 Hz	10^6
AmBe for Nuclear Recoils	5-15 Dec 2024	$6\ 10^5$	0.04 Hz of NR	$7.0\ 10^3$ NR

LIME STATUS

LIME was shut down on the 5th of May (Ei fu);

After 27 months of operation, 5 Scientific Runs, 2 AmBe campaigns and extensive tests with Eu, Ba and Am sources

From **January 2025** we have taken **technical runs** intended as **pre-commissioning** of sub-parts of **CYGNO04:**

- new camera + lens;

- gas filters lifetime and efficiency;

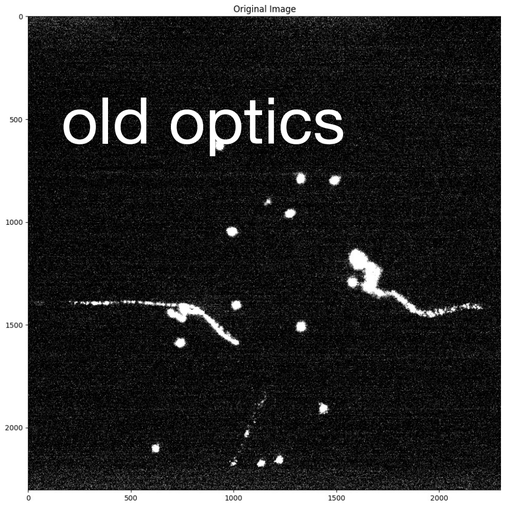
- gas mixture quality check;

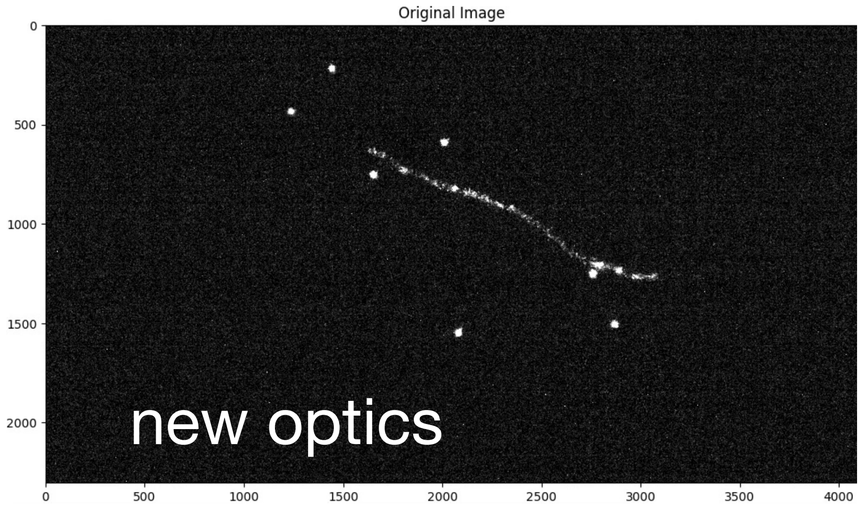
- data taking with the 83Rb calibration source;

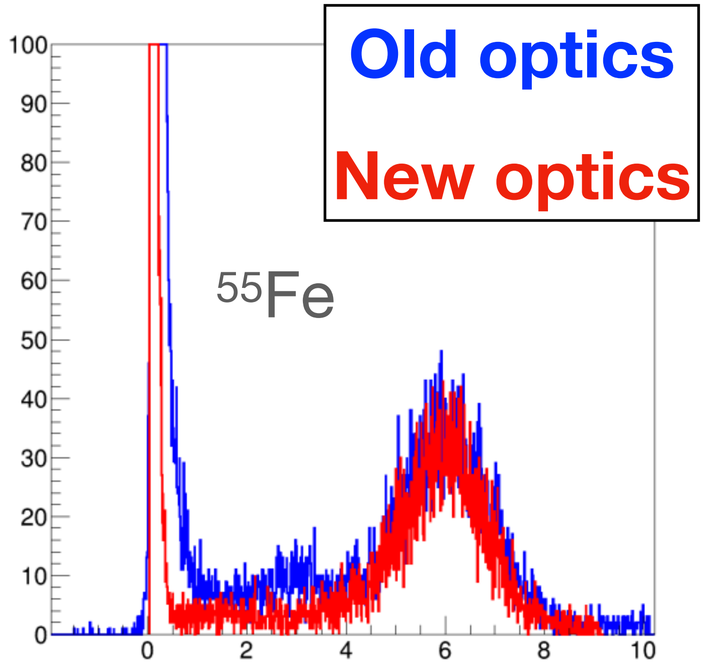
Description	Group	25-11-24 1-12-24	02-12-24 08-12-24	09-12-24 15-12-24	16-12-24 22-12-24	23-12-24 29-12-24	30-12-24 5-1-25	06-01-25 12-01-25	13-01-25 19-01-25	20-01-25 26-1-25	27-01-25 02-02-25	03-02-25 09-02-25	10-02-25 16-2-25	17-02-25 23-02-25	24-02-25 02-03-25	03-03-25 9-3-25	10-03-25 16-03-25	17-03-25 23-03-25	24-03-25 30-3-25	31-03-25 06-04-25	07-04-25 13-4-25	14-04-25 20-04-25	21-04-25 27-4-25	28-04-25 04-05-25
End of RUN5	CYGNO Collab.																							
AmBe Source [low gain]	CYGNO Collab.																							
AmBe Source [high gain]	RM1																							
Pedestal studies	RM1																							
Gas Mixture Recovery	RM1																							
Scans in z, VGEM, VDRIFT	LNF, RM3																							
Test of new optical system	GSSI																							
Filters Tests	RM1																							
Radon Monitor	RM1																							
83Rb Source	GSSI																							
NID	GSSI																							

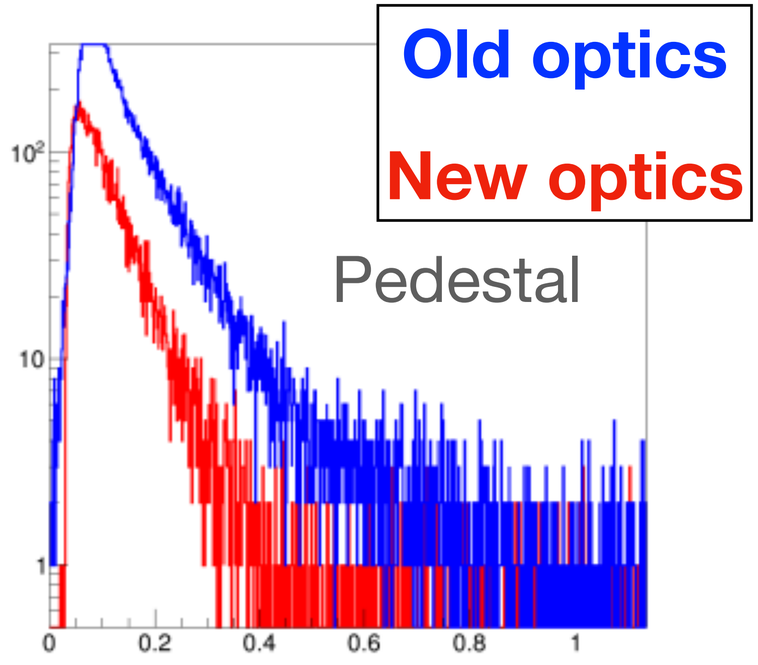
A **Negative Ion Drift** run take before the closure**;**

LIME Technical-Runs: new optics system





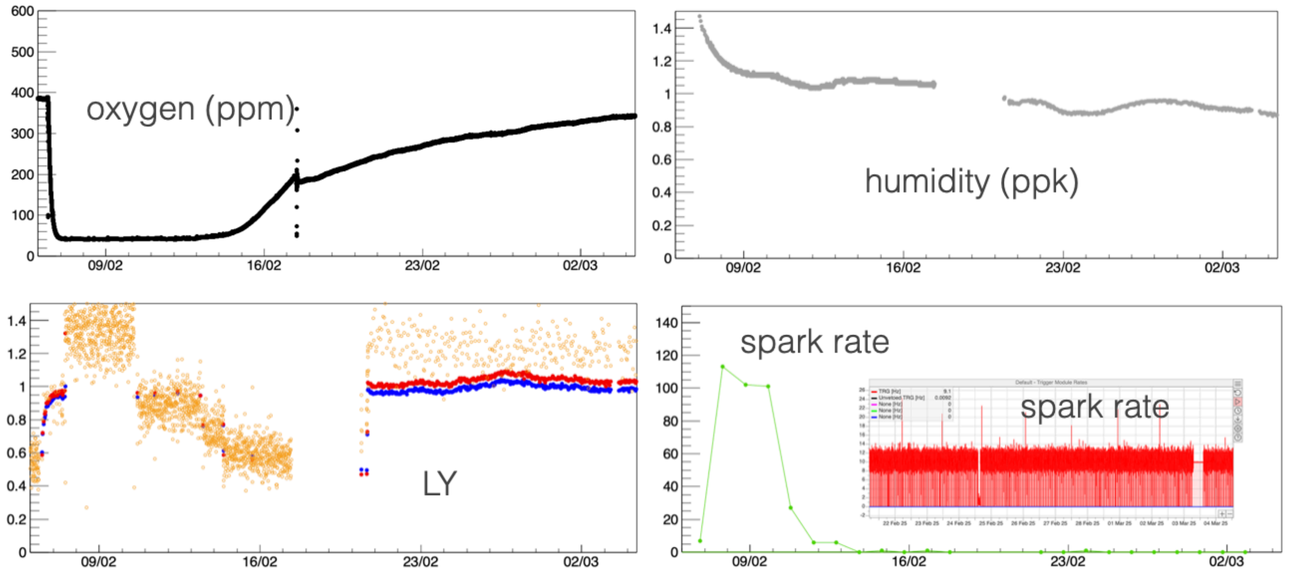




- **New camera+lens system** is definitely better in terms of noise RMS (and also granularity)
- Almost **factor 2 in RMS** value
- We demonstrated that the **energy threshold can be 15-20%** less than old one in the same configuration

LIME Technical-Runs: gas system study

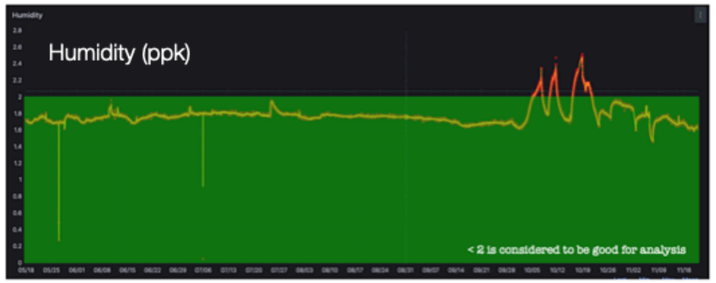
By means of a **CF_4 analyser** and **calibrated pre-mix bottles**, we cross-checked that the **gas-mixture percentages were correct within 1%;**

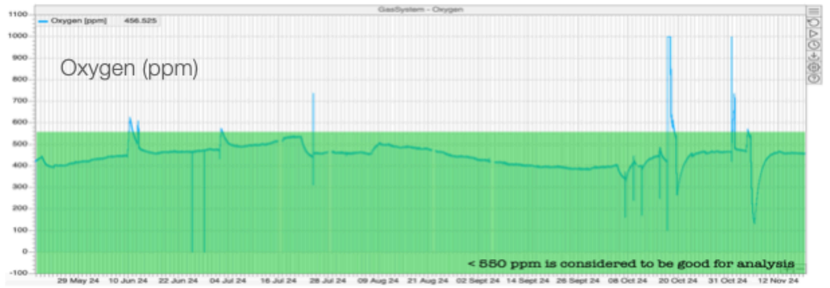


A study on filters effect, showed that:

- **too low oxygen content**, makes gas **mixture unstable;**
- **high humidity** has impact on the light yield;

Current filter setup was able to keep **humidity under control** on LIME

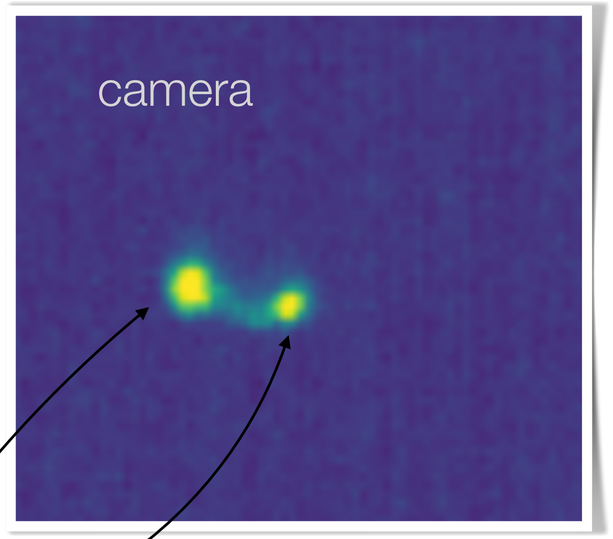


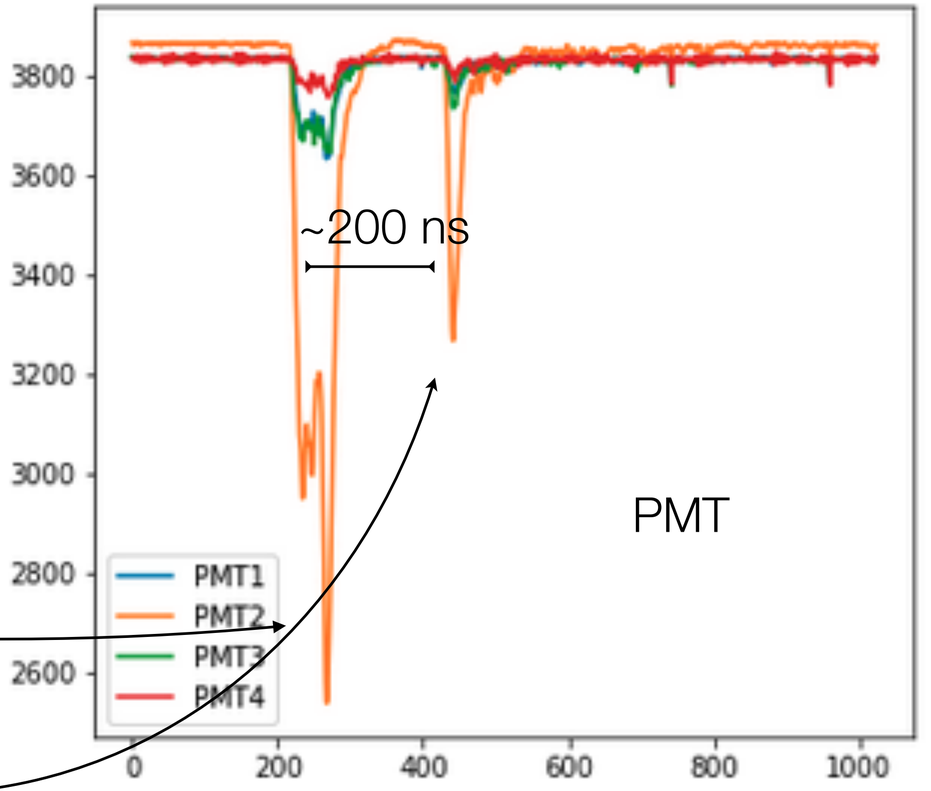


No need to **modify** the gas recirculation **system**

LIME Technical-Runs: test with Rb and ^{83}Kr

It allows to test **uniformly** the **sensitive volume** and to study and **calibrate camera** and **PMT** in the few keV region





Rb has an half life of 3 months

Produces 83Kr that emits 32 keV and 9.4 keV

photons 155 ns apart with an half life

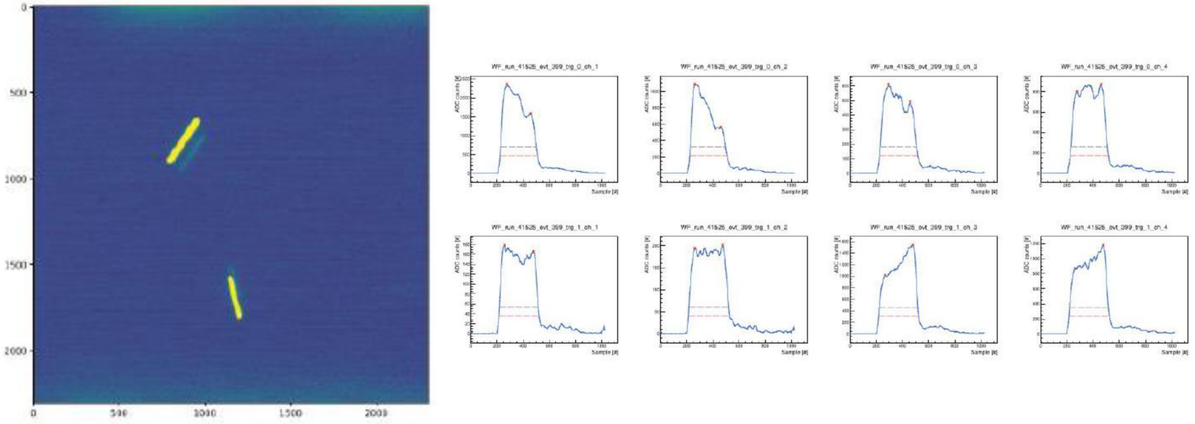
of about 2 hours

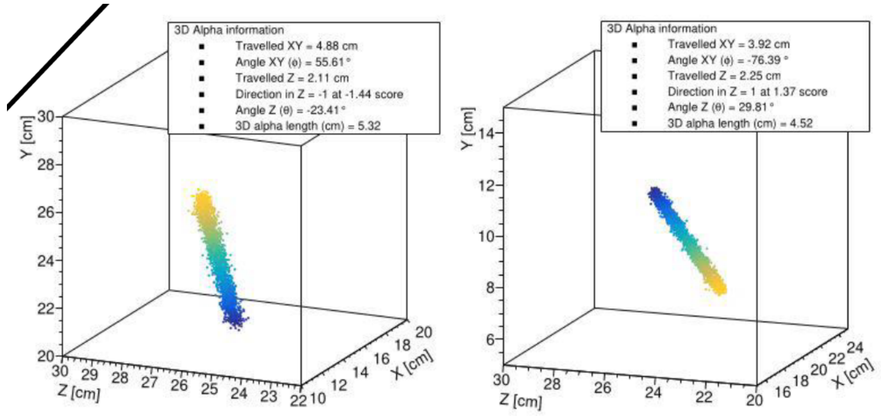
By Internal Conversion, these will produce electrons

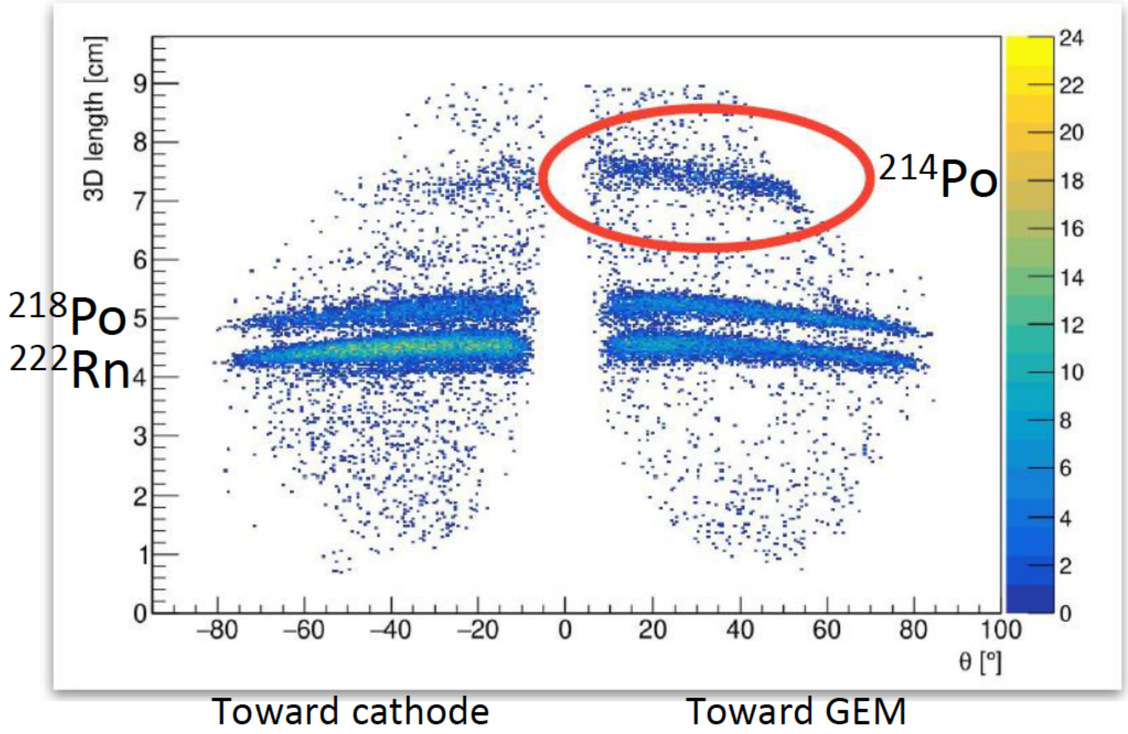
The 9.4 keV photon provides mainly a 7.5 electron (90%) and electrons of 9.1 keV (10%), while the other makes 17.8 keV (25%) and around 30 keV (75%)

Main LIME performance: 3D and directionality NR

- By **merging** together **info from camera and PMT** with a **multi-variate Bayesian fit** procedure, the **3D position** and **direction** and **head-tail** are reconstructed for **alpha particles** within LIME volume



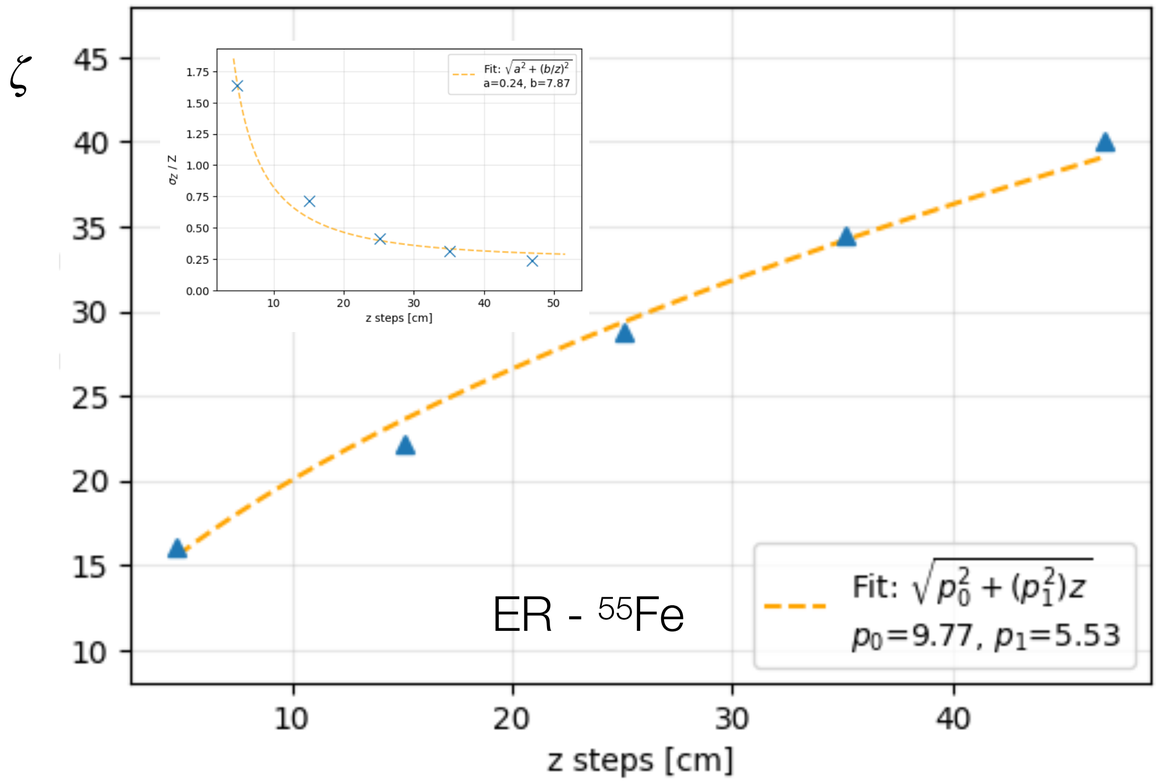


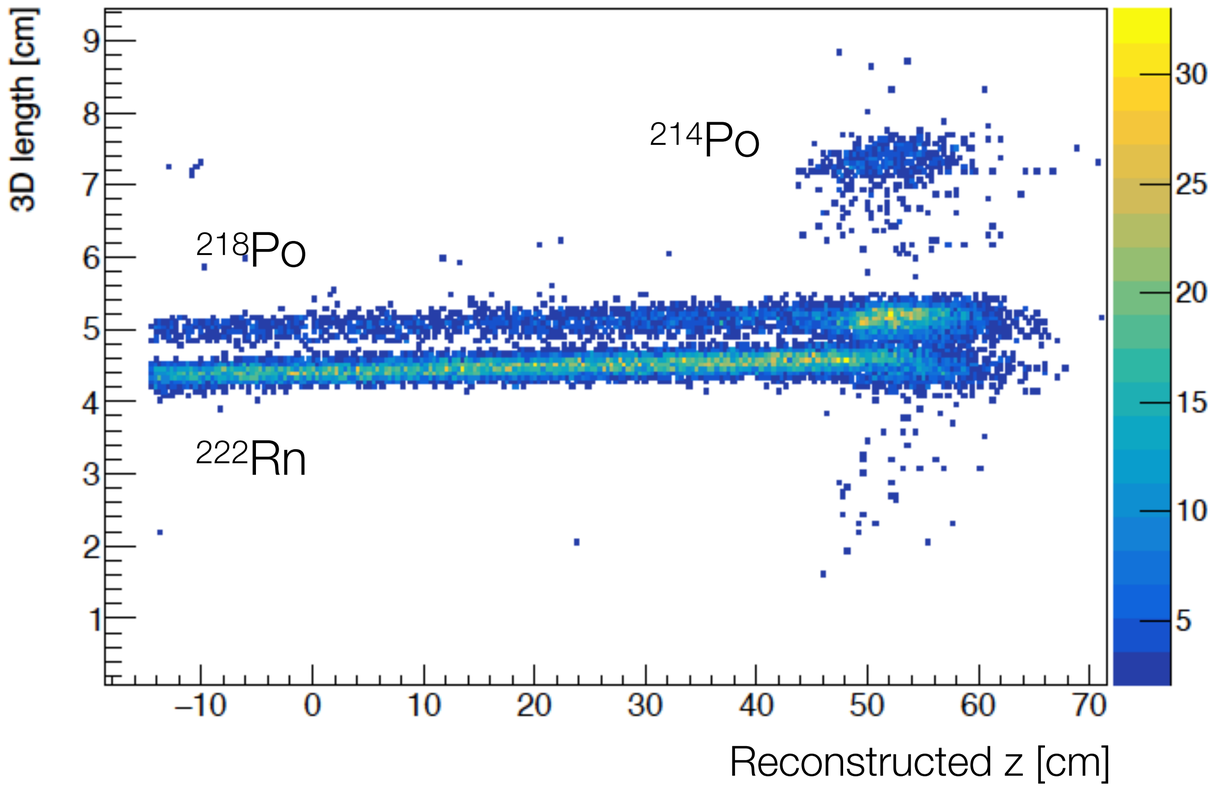


Main LIME performance: z reconstruction

To develop tools to evaluate **the absolute z** of low energy ER, we use **^{55}Fe events**;

Several variables spot-shape were studied and the **most effective resulted** ζ that takes into account the distribution of the hits within the spot.

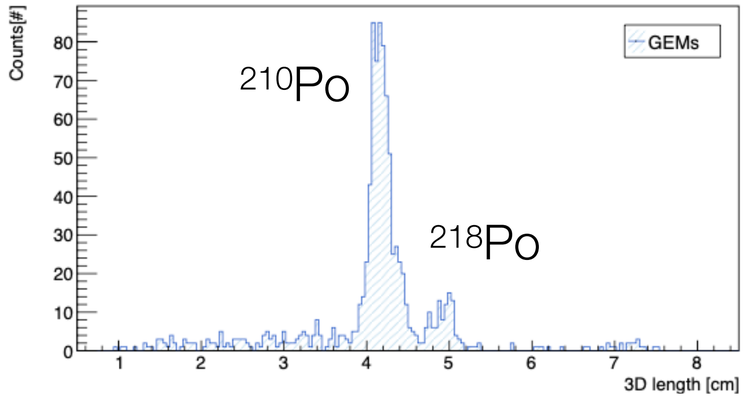


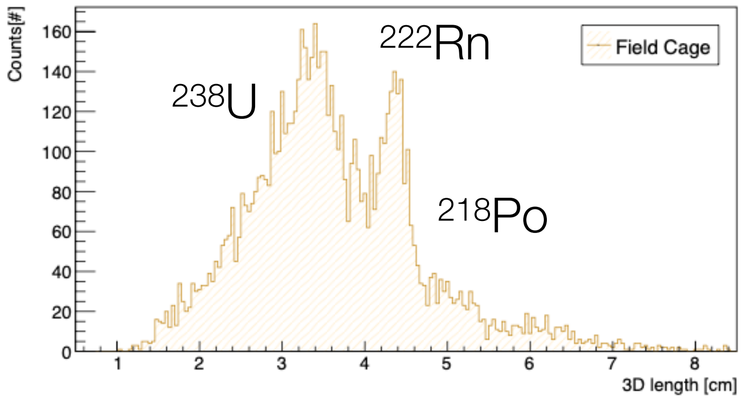


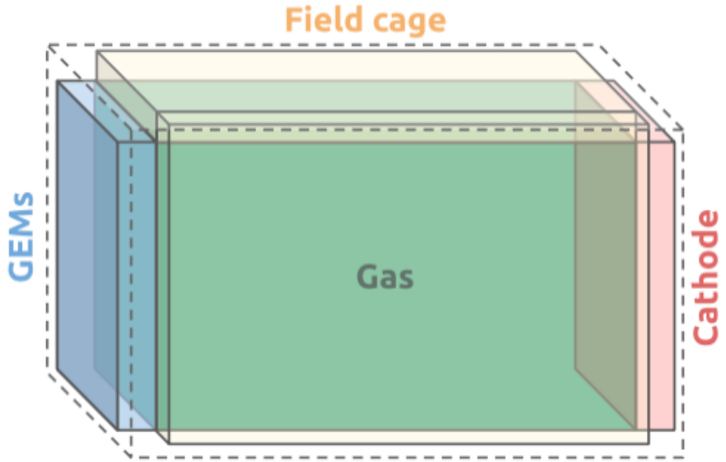
Main LIME performance: 3D and directionality NR

By reconstructing the **3D positions** of the alphas, we can **separate the contributions** of **^{232}Rn chain** (gas and cathode) and **^{238}U and ^{232}Th chains** as found in the GEM and Field Cage copper by Matthias

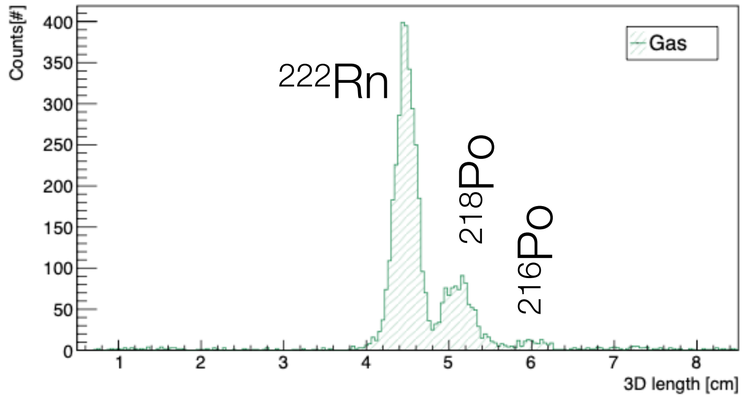
^{238}U and ^{232}Th chains

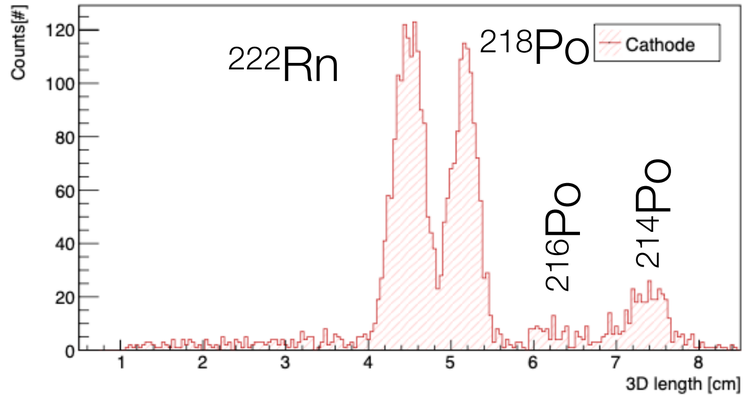






^{232}Rn chain

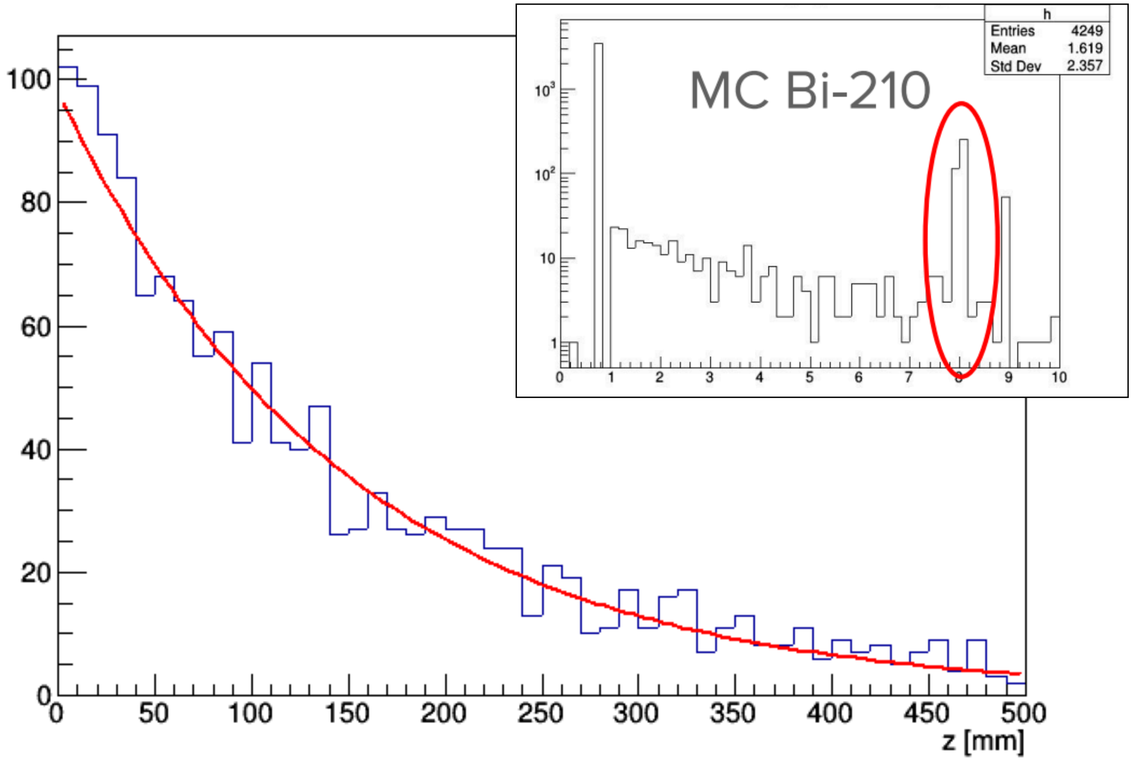


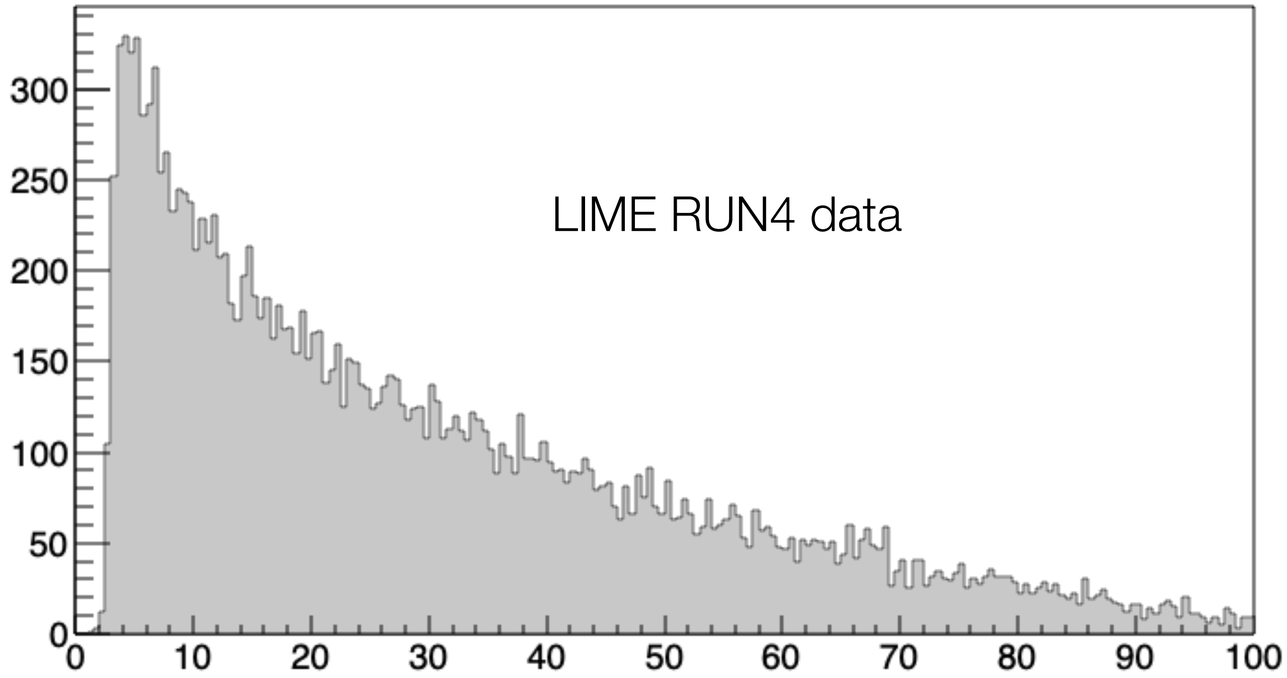


Main LIME performance: z reconstruction ER

To test this tool on another energy value ER, we use the presence of **X-ray fluorescence** induced on the **GEM - copper** by the internal decays of the 210Bi;

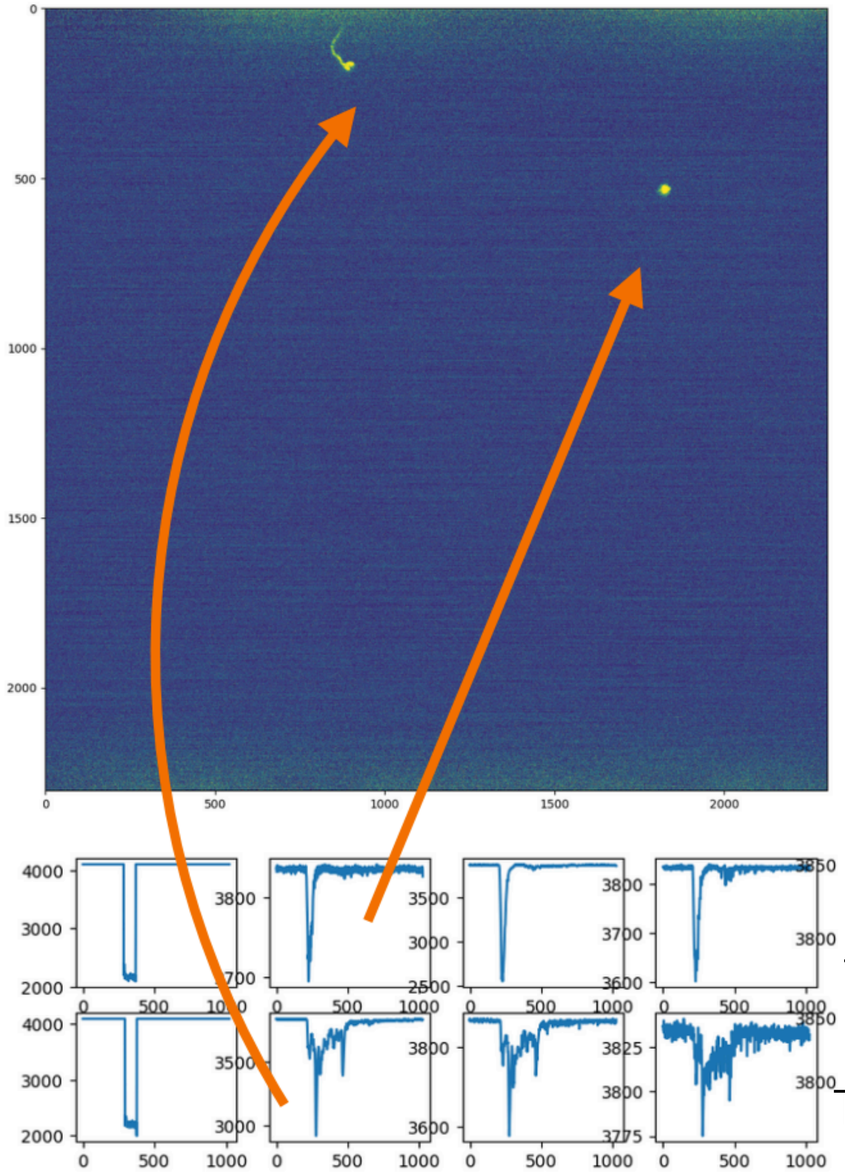
From the MC we expect these to produce **8-9 keV ER** with a z exponentially decaying from the GEM side





To compare the results, we need to **digitize** and **reconstruct** the MC-Truth

Main LIME performance: z reconstruction NR



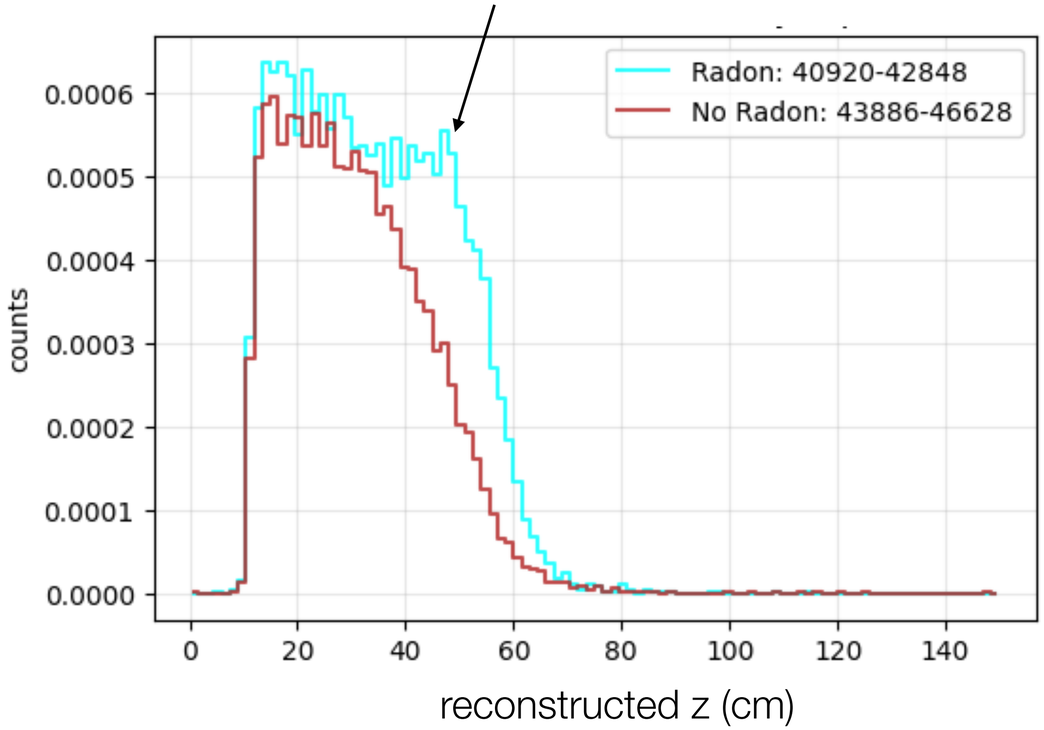
PMT waveforms

Typical **wfms** for a **NR**

Typical **wfms** for an **ER**

In the LIME data we observe a **background component** present only in runs with high **Radon contamination**;

- Is likely due **NR** in gas;
- Has a reconstructed energy of the order of **20-30 keV$_{ee}$**;
- Is reconstructed at very high Z, **at the cathode level**;



Main LIME performance: z reconstruction ER

First detection of radon progeny recoil tracks by MIMAC

Q. Riffard, D. Santos, O. Guillaudin, G. Bosson, O. Bourrion, J. Bouvier, T. Descombes, C. Fourel, J.-F. Muraz, L. Lebreton Show full author list

Published 30 June 2017 • © 2017 IOP Publishing Ltd and Sissa Medialab

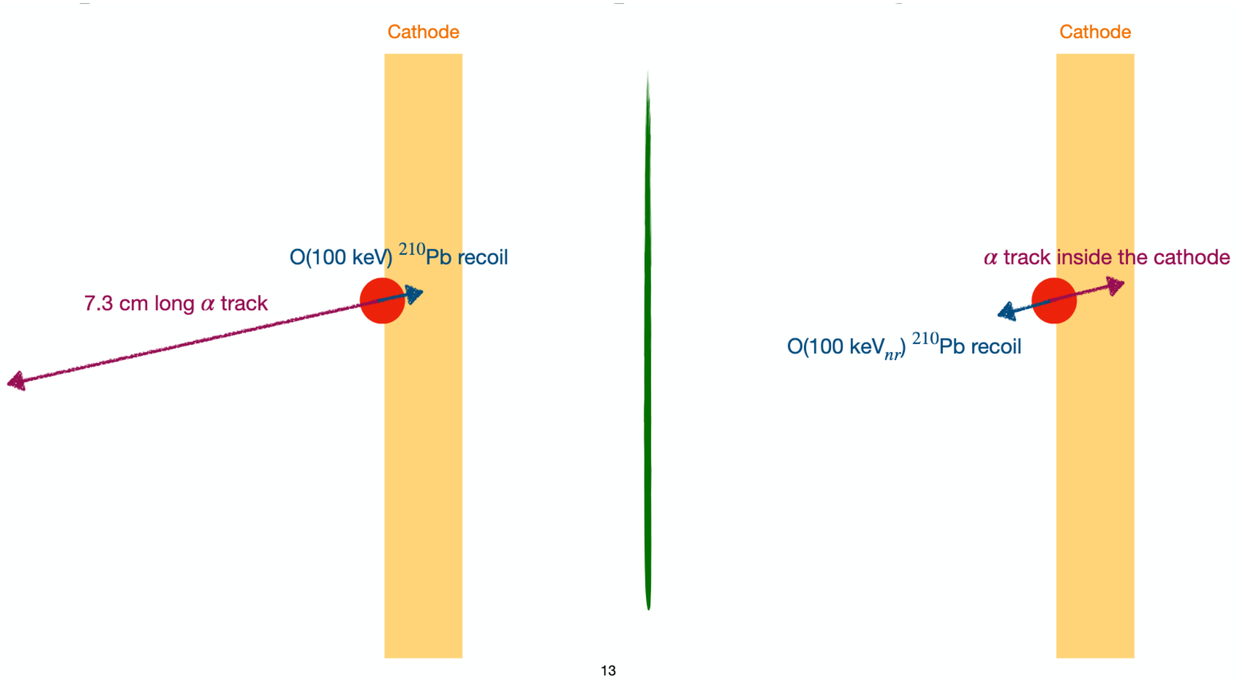
Journal of Instrumentation, Volume 12, June 2017

Citation Q. Riffard *et al* 2017 *JINST* **12** P06021

DOI 10.1088/1748-0221/12/06/P06021

MIMAC paper: 10.1088/1748-0221/12/06/P06021

Parent	$T_{1/2}$	Mode	$E^{kin}_{\alpha/\beta\,max}$ [MeV]	Daughter	E^{kin}_{recoil} [keV]	E^{ioni}_{recoil} [keVee]
From ^{222}Rn						
^{222}Rn	3.8 days	α	5.489	^{218}Po	100.8	38.23
^{218}Po	3.1 min	α	6.002	^{214}Pb	112.3	43.90
^{214}Pb	27 min	β^-	1.024	^{214}Bi	-	-
^{214}Bi	20 min	β^-	3.272	^{214}Po	-	-
^{214}Po	164 µs	α	7.687	^{210}Pb	146.5	58.78
^{210}Pb	22 years	β^-	0.064	^{210}Bi	-	-
^{210}Bi	5 days	β^-	1.163	^{210}Po	-	-
^{210}Po	138 days	α	5.304	^{206}Pb (stable)	103.7	40.28



If we consider a **10%-20% Quenching Factor** for **Pb** at the **150 keV** energy, we should expect 15-30 keV$_{ee}$

The **identification** of this dangerous **background component** will allow to reject it

Directional experiments

"Going beyond the coherent neutrino-scattering wall will require direction-sensitive detectors. As long as convincing Dark Matter signals are found, such detectors will almost certainly be crucial to assessing the detailed nature as well as the astrophysical origin of Dark Matter. Anticipating this, detector R&D in this sphere has already begun"

- **Directional detectors**, which measure the directions of nuclear recoils as well as their energies, in principle offer a powerful way of confirming the Galactic origin of a WIMP signal
- An ideal directional detector could **discriminate a WIMP signal from isotropic backgrounds** with only of order 10 events.
- Directional experiments can in principle probe cross sections **below the neutrino floor** with **smaller exposures** than conventional direct detection experiments

Gaseous TPC, provide the possibility of reconstruct the **track direction**;

Several groups, in the framework of the CYGNUS-TPC pseudo-collaboration, are developing this technology for a world wide Nuclear Recoil observatory network

Experiment	Where	Amplification + Readout	Gas Pressure [mbar]	Volume [L]	Energy Thr [keV_{ee}]	Active Mass [gr]
DRIFT	UK	MWPC	55	800	20	33
NEWAGE	Japan	1 GEM +muPIC	100	37	20	11.5
MIMAC	France	Micromegas	50	5.8	2	1.2
D3	Australia	2 GEM + pixelated RO	1000	40	5	60
CYGNO	Italy	3 GEMs + sCMOS + PMT	900	400	1	600

NR directionality: current scenario

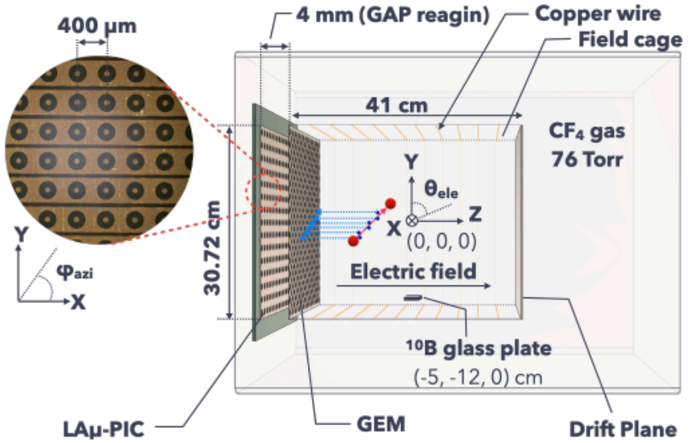
Direction-sensitive dark matter search with three-dimensional vector-type tracking in NEWAGE

arXiv:2301.04779v4 [hep-ex] 21 Sep 2023

LIME-like prototype operated at **0.1 bar CF_4**

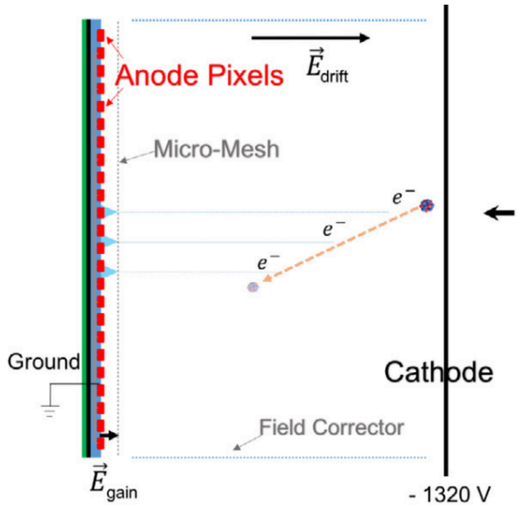
Angle resolution **58° at 50-100 keV_{ee}** energy range

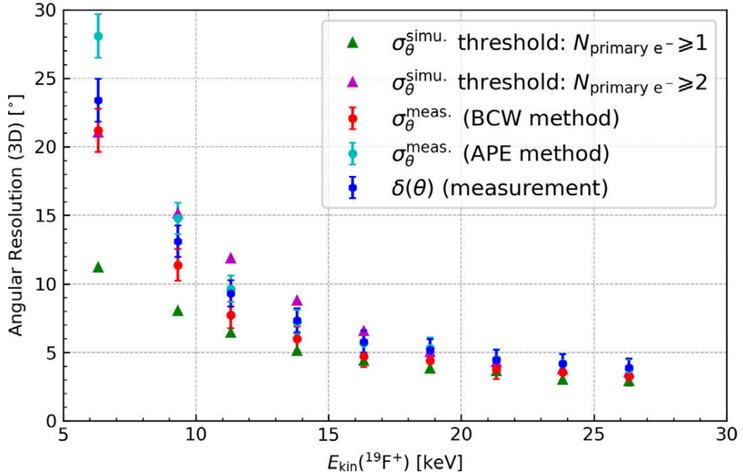
(Note that the energy released from neutrons to C and F is 43% and 30% w.r.t. He)



Nuclear Inst. and Methods in Physics Research, A 1021 (2022) 165412

Dark Matter Directionality Detection performance of the Micromegas-based μTPC-MIMAC detector

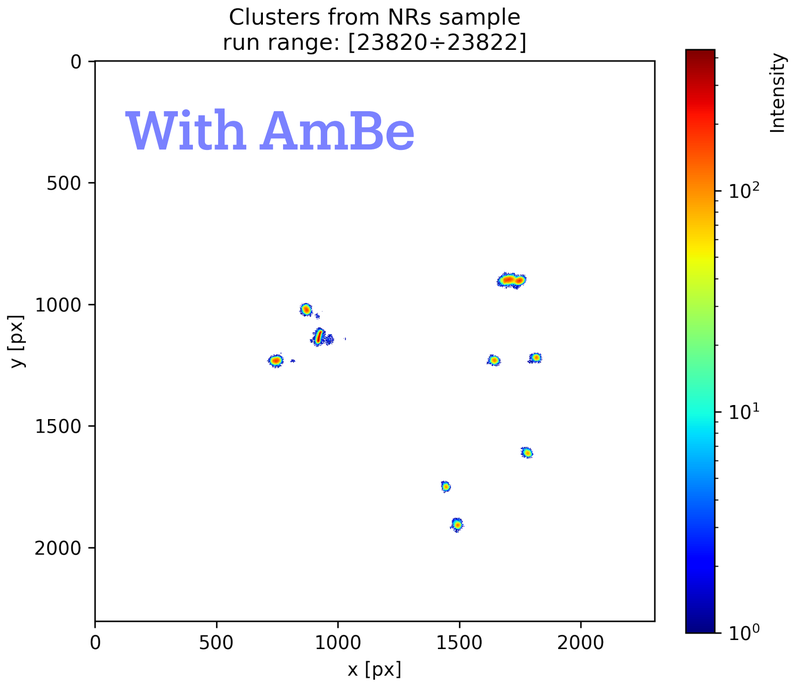




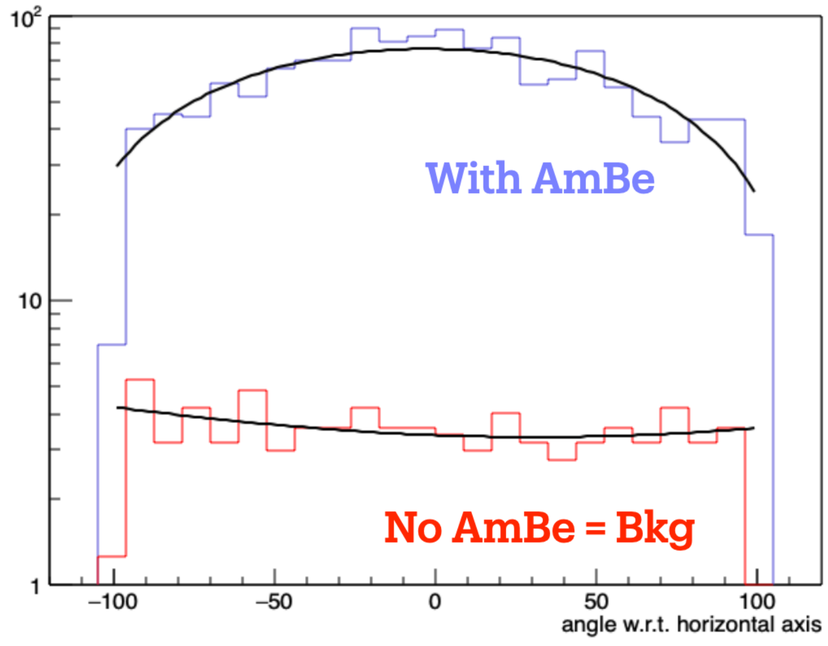
10x10x5 cm^3 prototype (**1% of LIME volume**) operated at **0.05 bar CF_4 /CHF_3/ C_4H_{10}**

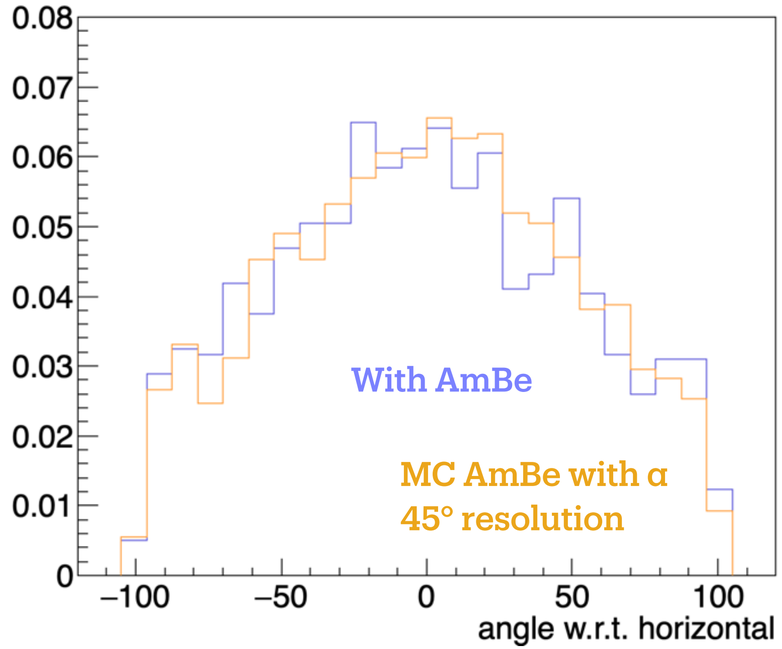
Good resolution in reconstructing the F angle arriving **perpendicular to readout plane**

Main LIME performance: NR directionality



The analysis of data taken with an AmBe calibration source shows a clear sensitivity to the direction of NR induced by neutron scattering with an evaluated **2D angular resolution of 45°**





Best results for a O(0.1 kg) mass target

Room for large improvements with more sophisticated directional and rejection algorithms under development

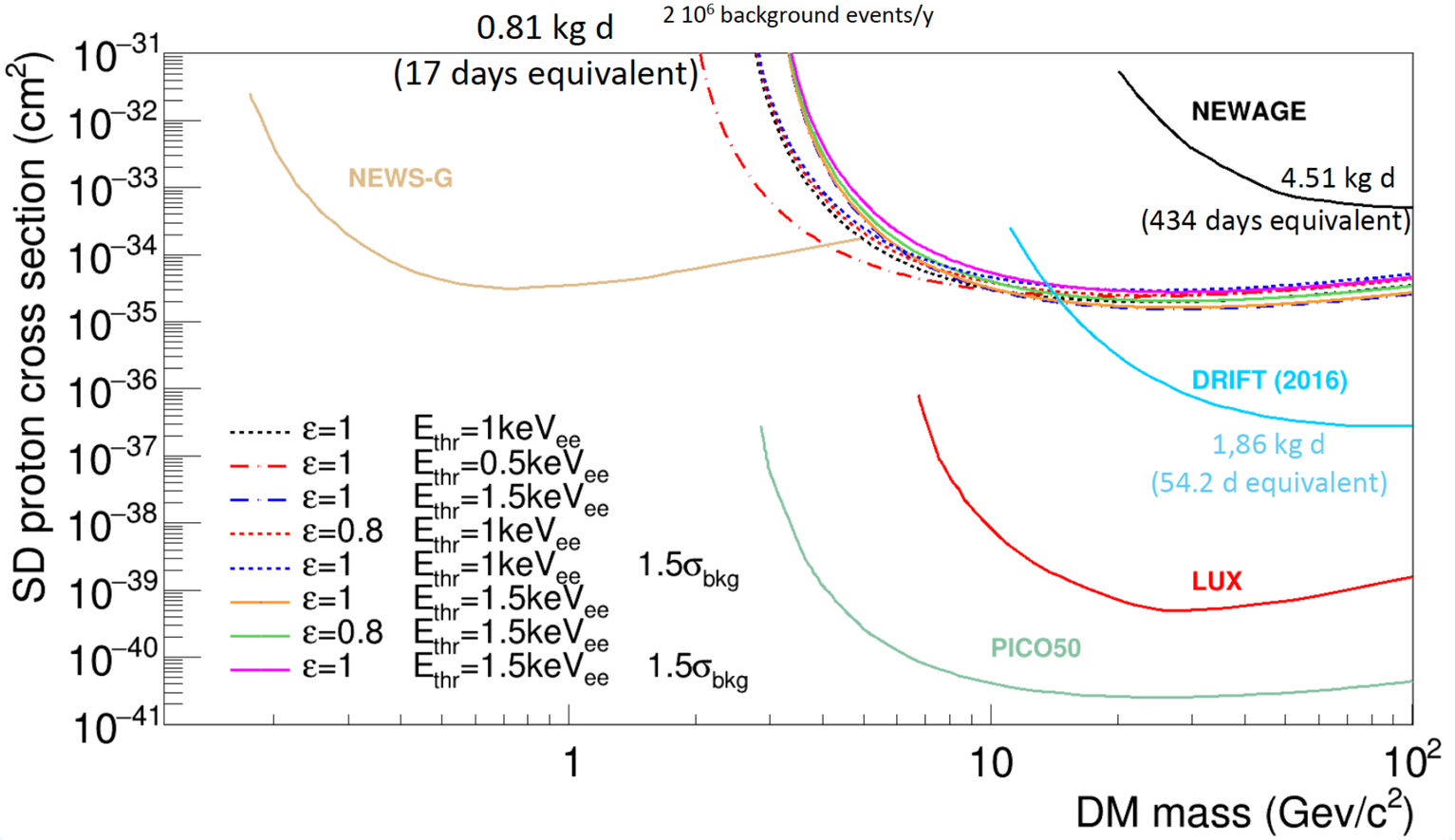
Higher statistics runs and **different gain configurations** tested in **RUN5** AmBe tests

Main LIME performance: evaluation of DM sensitivity

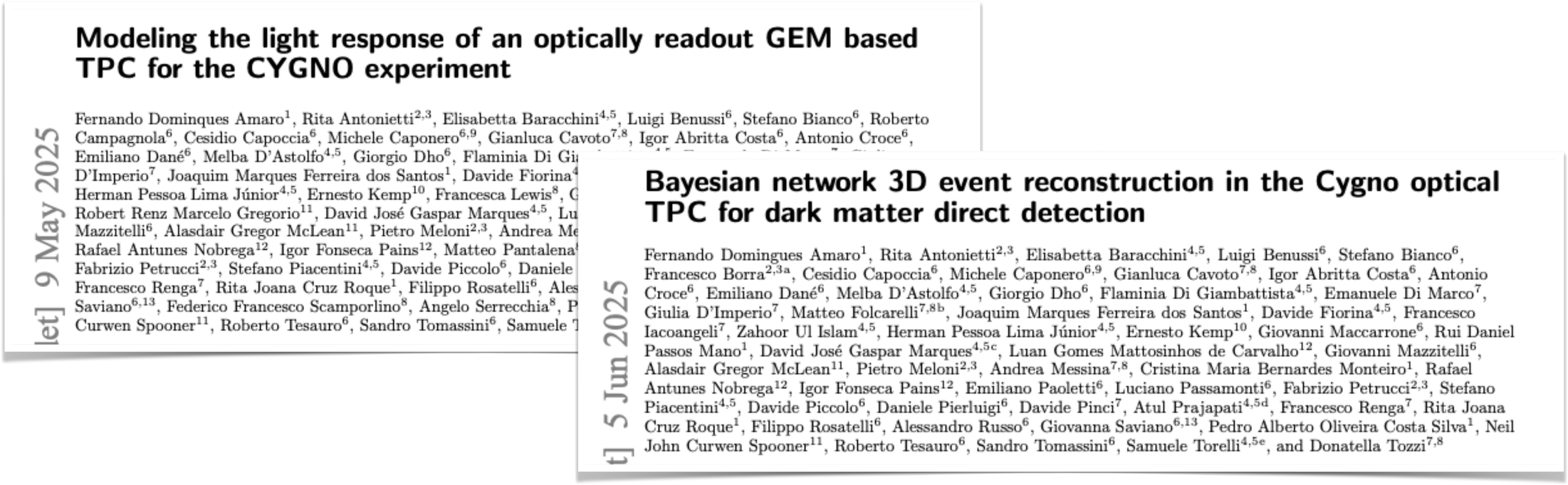
An exercise was performed to evaluate from a with a **subsample of 17 days**, the **DM sensitivity** with a **Bayesian fit** procedure to estimate Credible Interval Limit (BAT toolkit used)

Even if **no solid background model** (LIME was not meant for this) is available so far:

- it can be used to **estimate** where the **exposure** of the detector can lead;
- what are the **parameters** we need to evaluate to get the final results
- to **get practice with the analysis tools**;



Papers



Modeling the light response of an optically readout GEM based TPC for the CYGNO experiment

Fernando Dominques Amaro[1], Rita Antonietti[2,3], Elisabetta Baracchini[4,5], Luigi Benussi[6], Stefano Bianco[6], Roberto Campagnola[6], Cesidio Capoccia[6], Michele Caponero[6,9], Gianluca Cavoto[7,8], Igor Abritta Costa[6], Antonio Croce[6], Emiliano Dané[6], Melba D'Astolfo[4,5], Giorgio Dho[6], Flaminia Di Gi
D'Imperio[7], Joaquim Marques Ferreira dos Santos[1], Davide Fiorina[4]
Herman Pessoa Lima Júnior[4,5], Ernesto Kemp[10], Francesca Lewis[8], G
Robert Renz Marcelo Gregorio[11], David José Gaspar Marques[4,5], Lu
Mazzitelli[6], Alasdair Gregor McLean[11], Pietro Meloni[2,3], Andrea Me
Rafael Antunes Nobrega[12], Igor Fonseca Pains[12], Matteo Pantalena[
Fabrizio Petrucci[2,3], Stefano Piacentini[4,5], Davide Piccolo[6], Daniele
Francesco Renga[7], Rita Joana Cruz Roque[1], Filippo Rosatelli[6], Ales
Saviano[6,13], Federico Francesco Scamporlino[8], Angelo Serrecchia[8], P
Curwen Spooner[11], Roberto Tesauro[6], Sandro Tomassini[6], Samuele T

let] 9 May 2025

Bayesian network 3D event reconstruction in the Cygno optical TPC for dark matter direct detection

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Two new papers based on the development made with LIME were just submitted to EPJC