CYGNO status and plans
Feb 2025

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

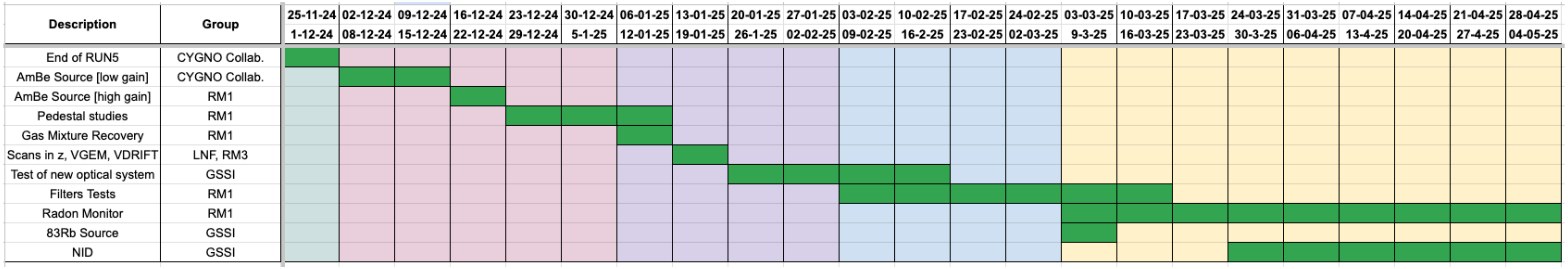
From **January 2025** we have taken **technical runs** intended as **pre-commissioning** of sub-parts of **CYGNO04:**

- new camera + lens;

- gas filters lifetime and efficiency;

- gas mixture quality check;

- data taking with the 83Rb calibration source;

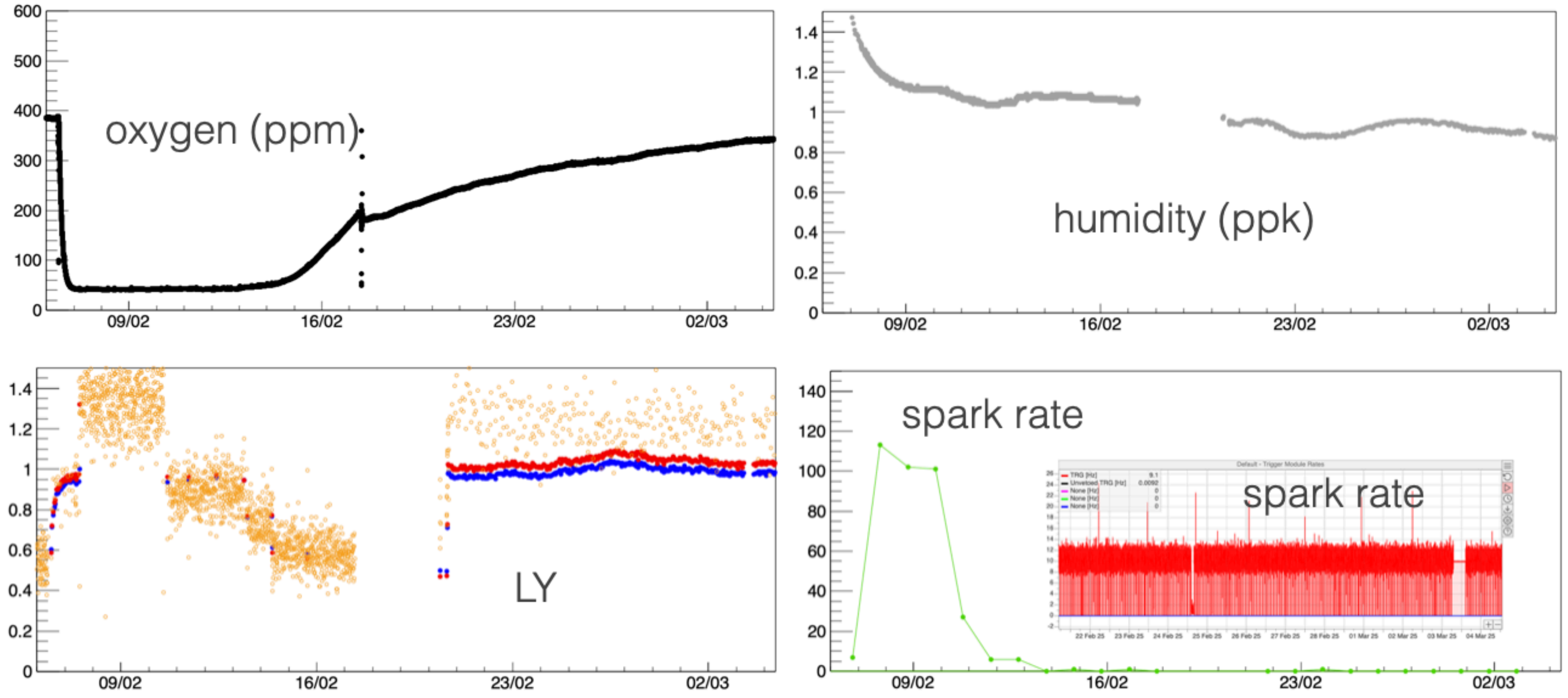


A **Negative Ion Drift** run take before the closure**;**

LIME Technical-Runs: new optics system

LIME Technical-Runs: gas system study

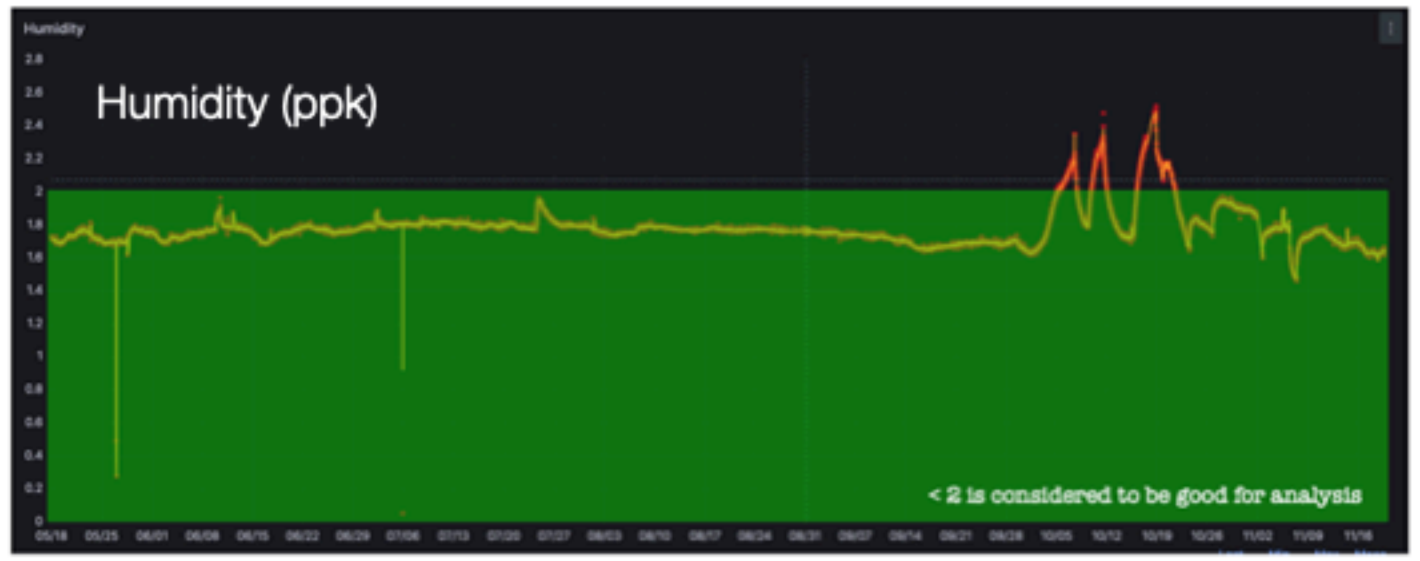
By means of a CF_4 analyser and calibrated pre-mix bottles, we cross-checked that the gas-mixture percentages were correct within 1%;

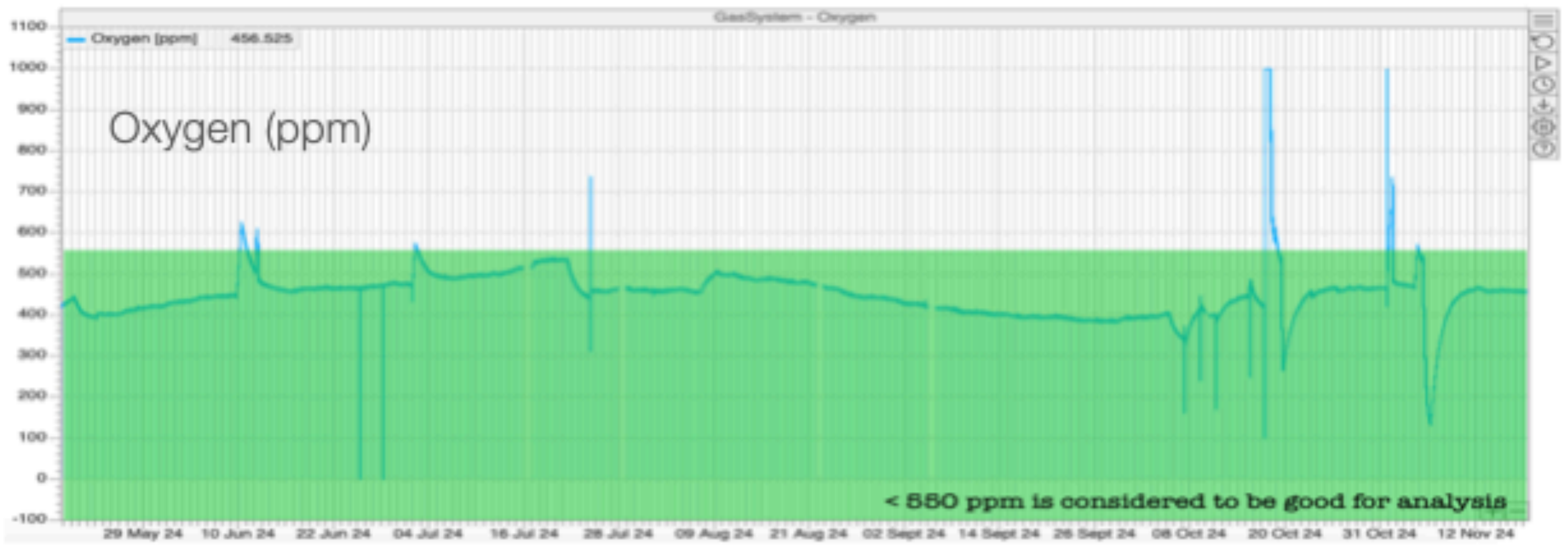


A study on filters effect, showed that a too low oxygen content, makes gas mixture unstable while high humidity has impact on the light yield;

The level of humidity and oxygen optimised on LIME and now provided by the usual gas system behavior are the "optimal" ones

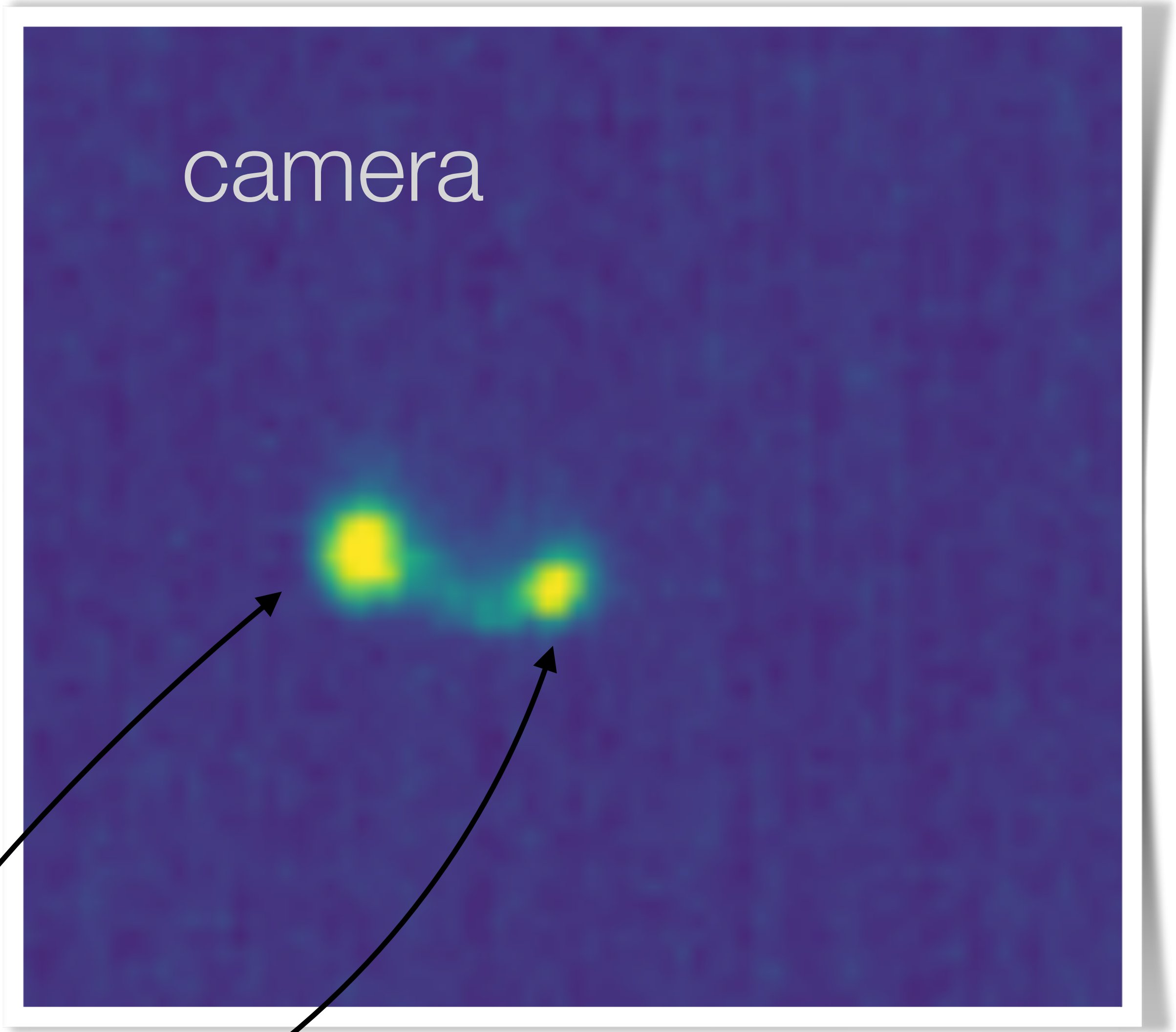
No need to modify the gas recirculation system

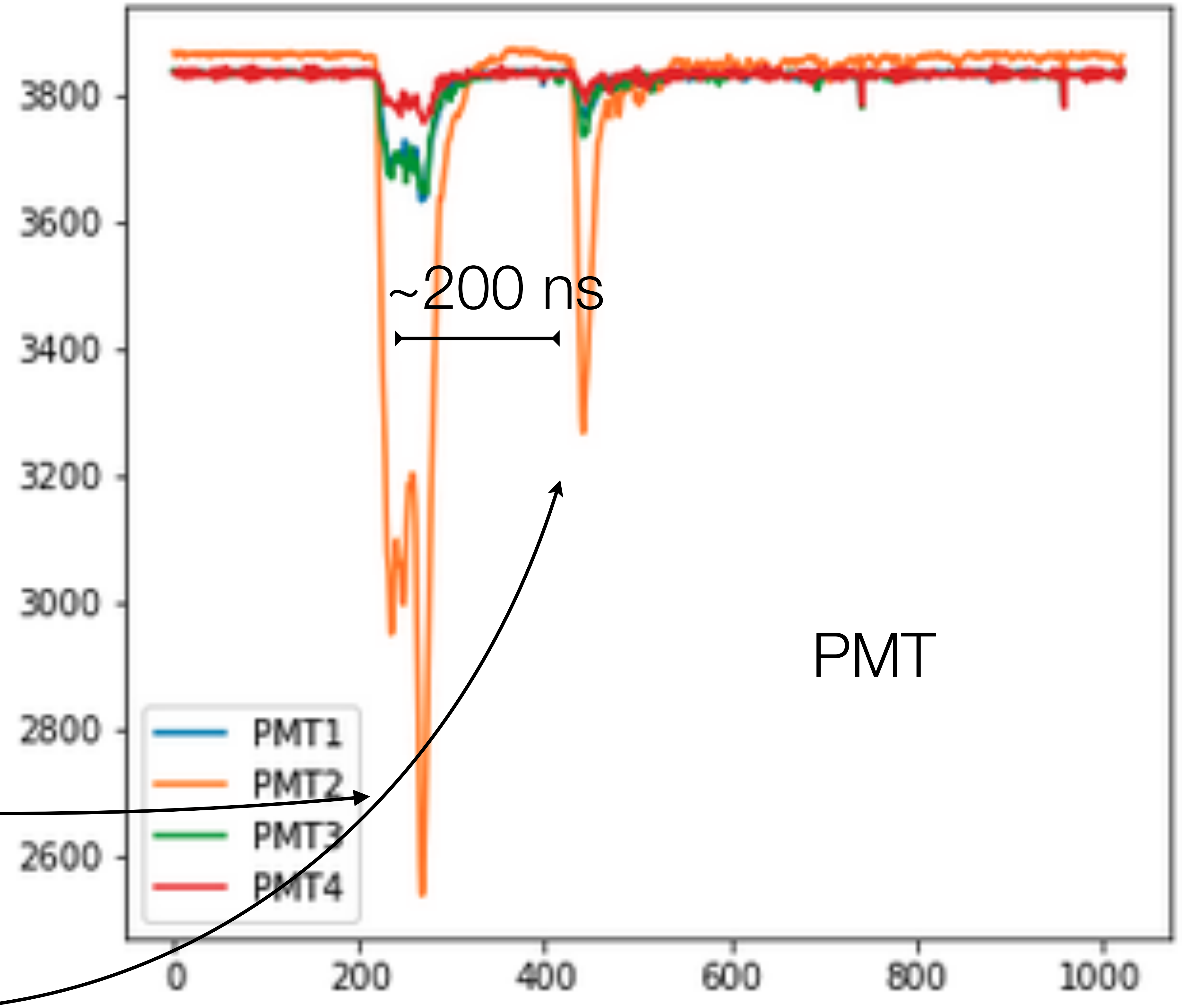




LIME Technical-Runs: test with Rb and ^{83}Kr

It allows to test uniformly
the sensitive volume





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

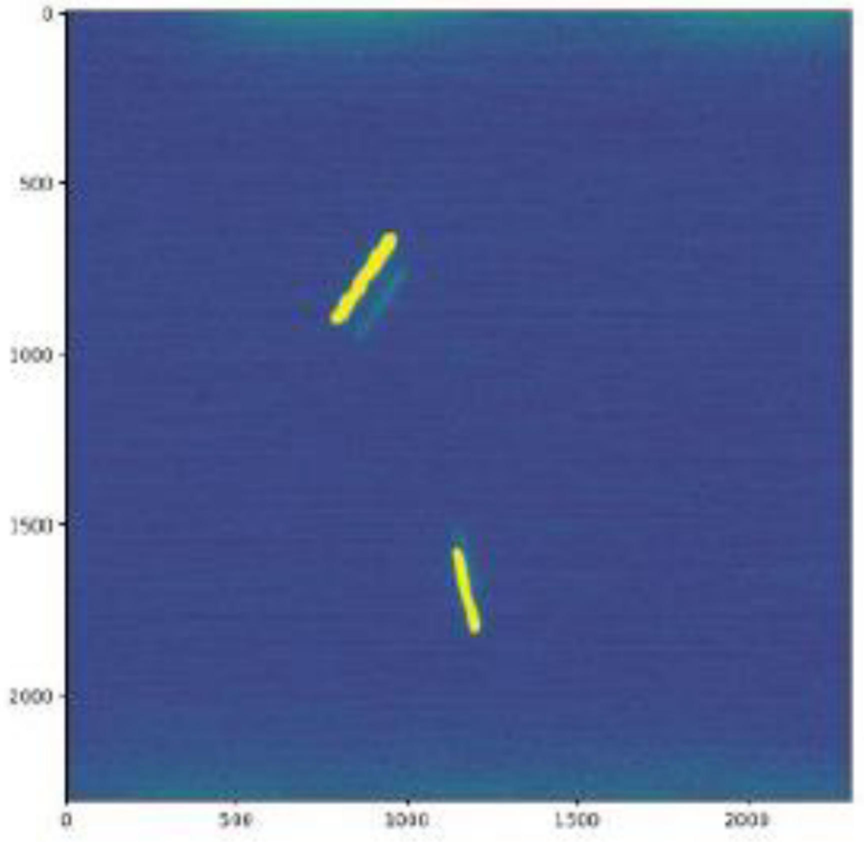
of about 2 hours

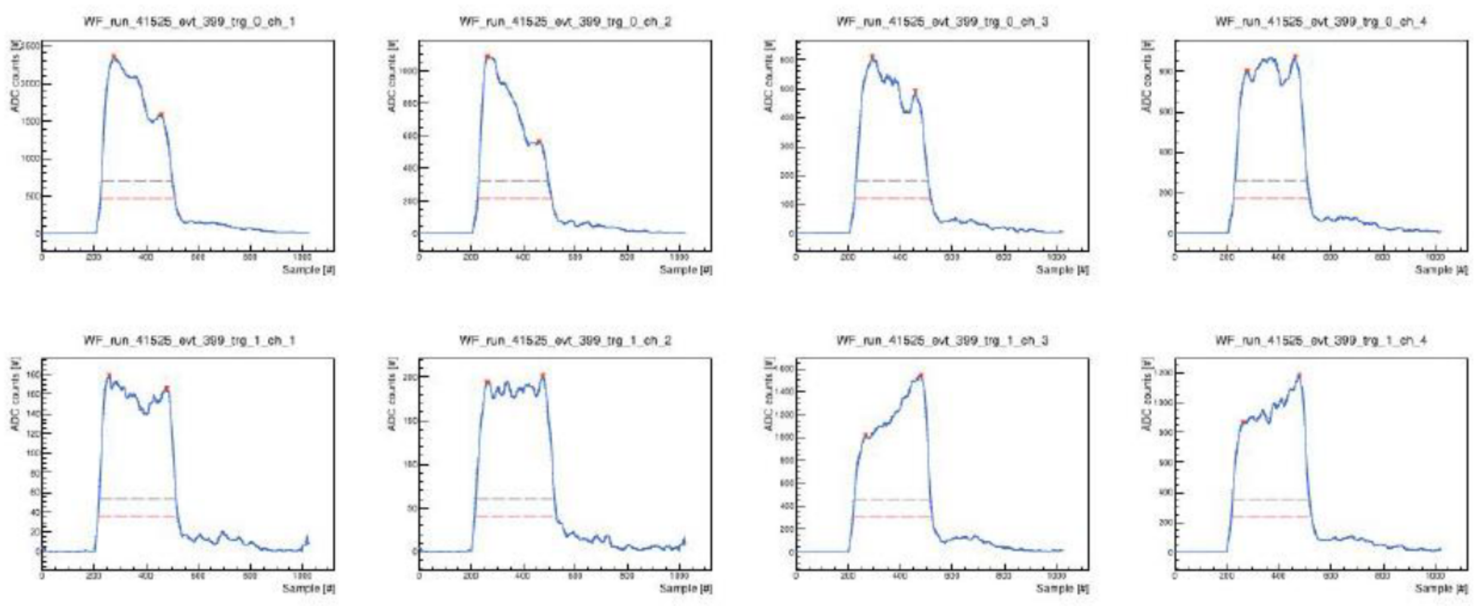
By Internal Conversion, these will produce electrons

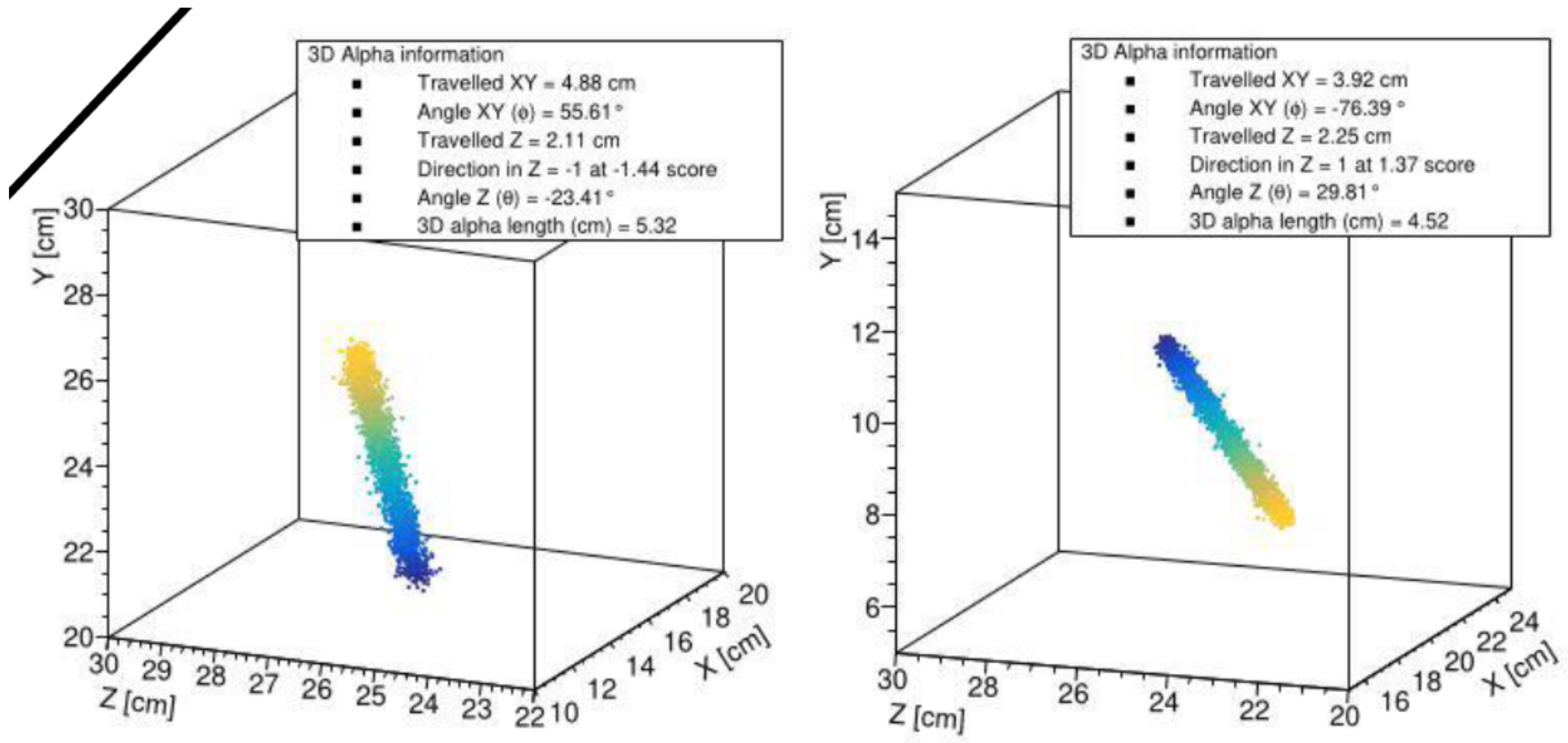
The 9.4 keV photon provides mainly a 7.5 electron (90%) and electrons of 9.1 keV (10%), while the other makes 17.8 keV (25%) and around 30 keV (75%)

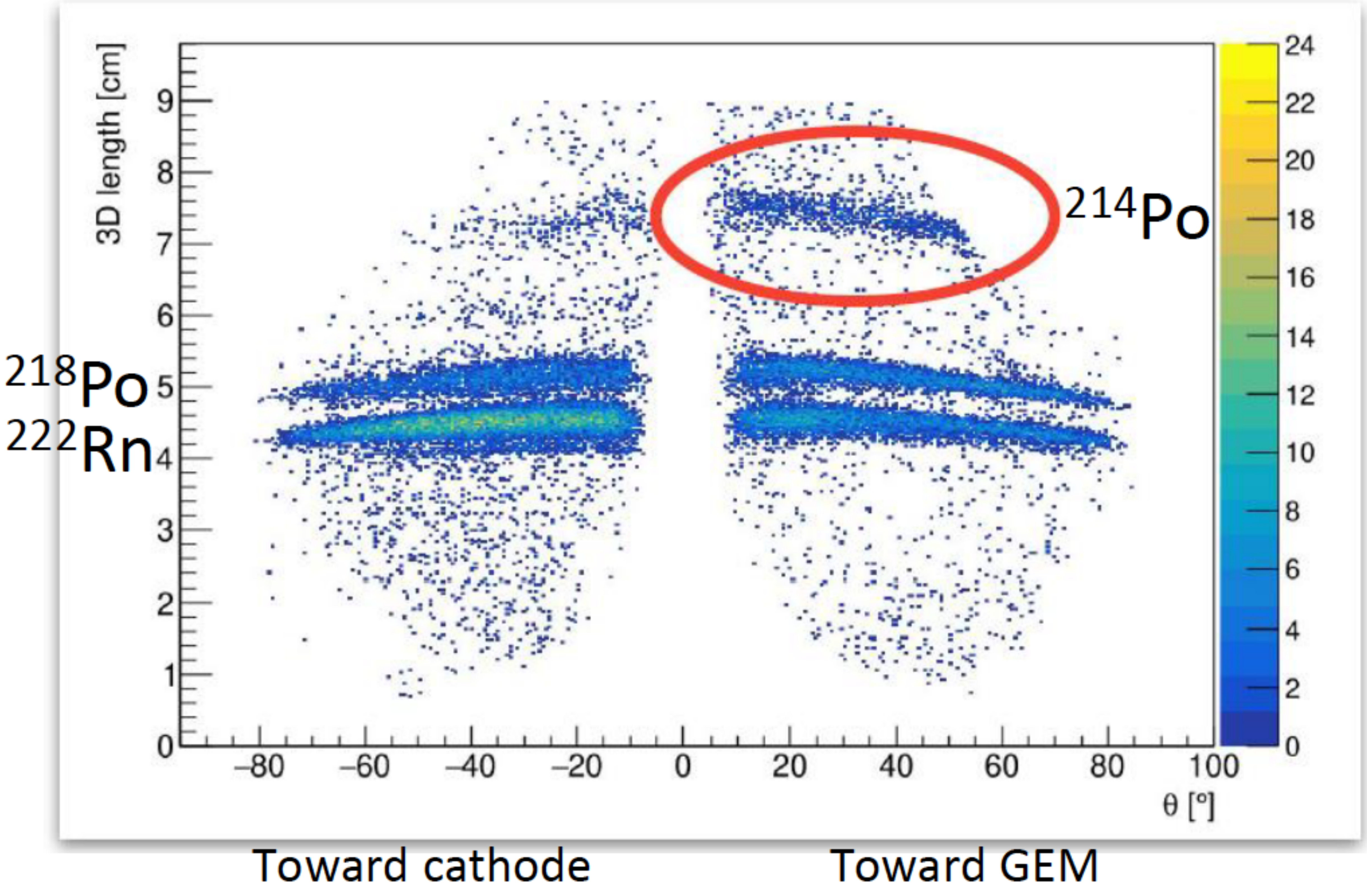
Main LIME performance: 3D and directionality NR

- By merging together info from camera and PMT with a multi-variate Bayesian fit procedure, the direction and head-tail are reconstructed for alpha particles





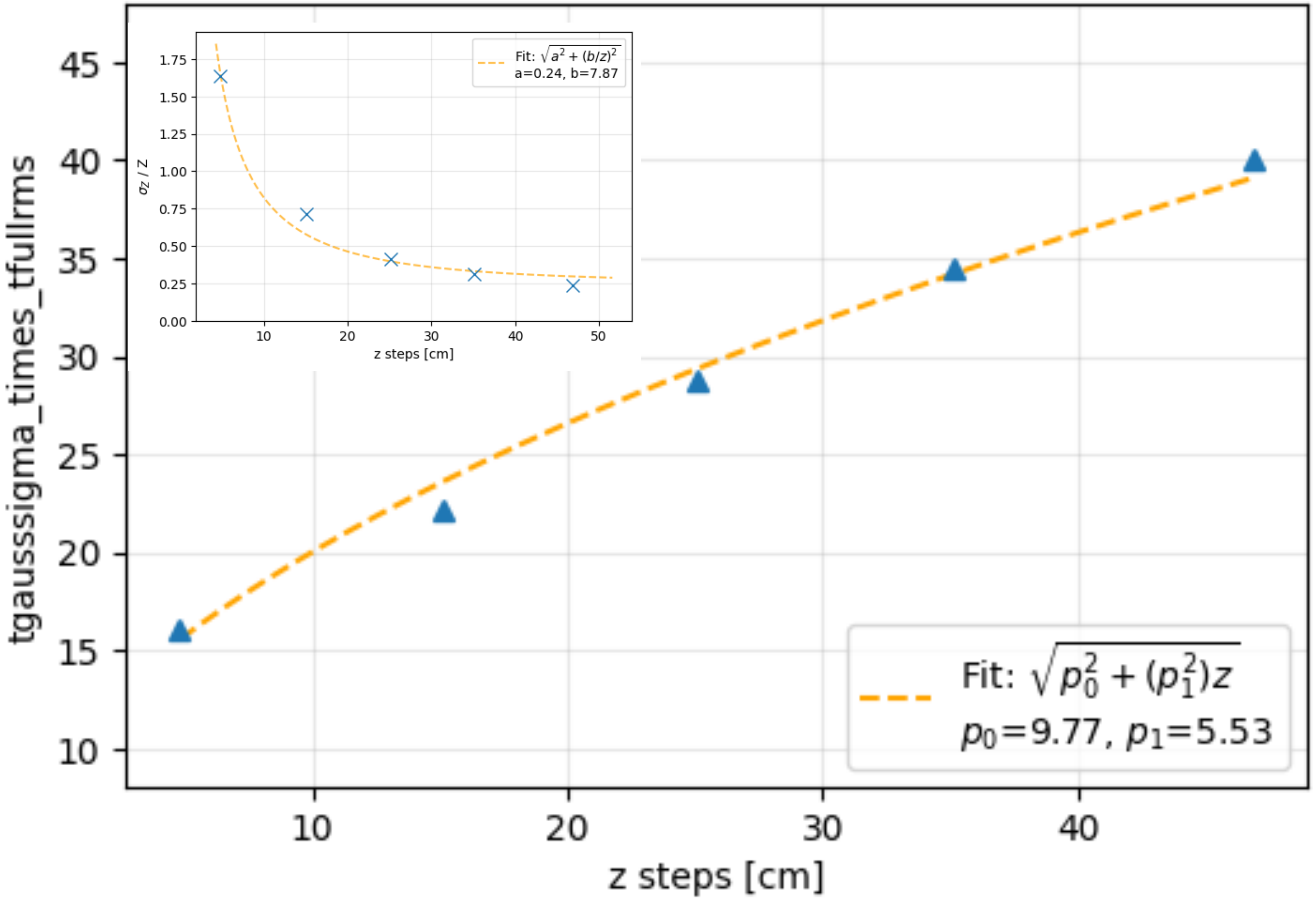


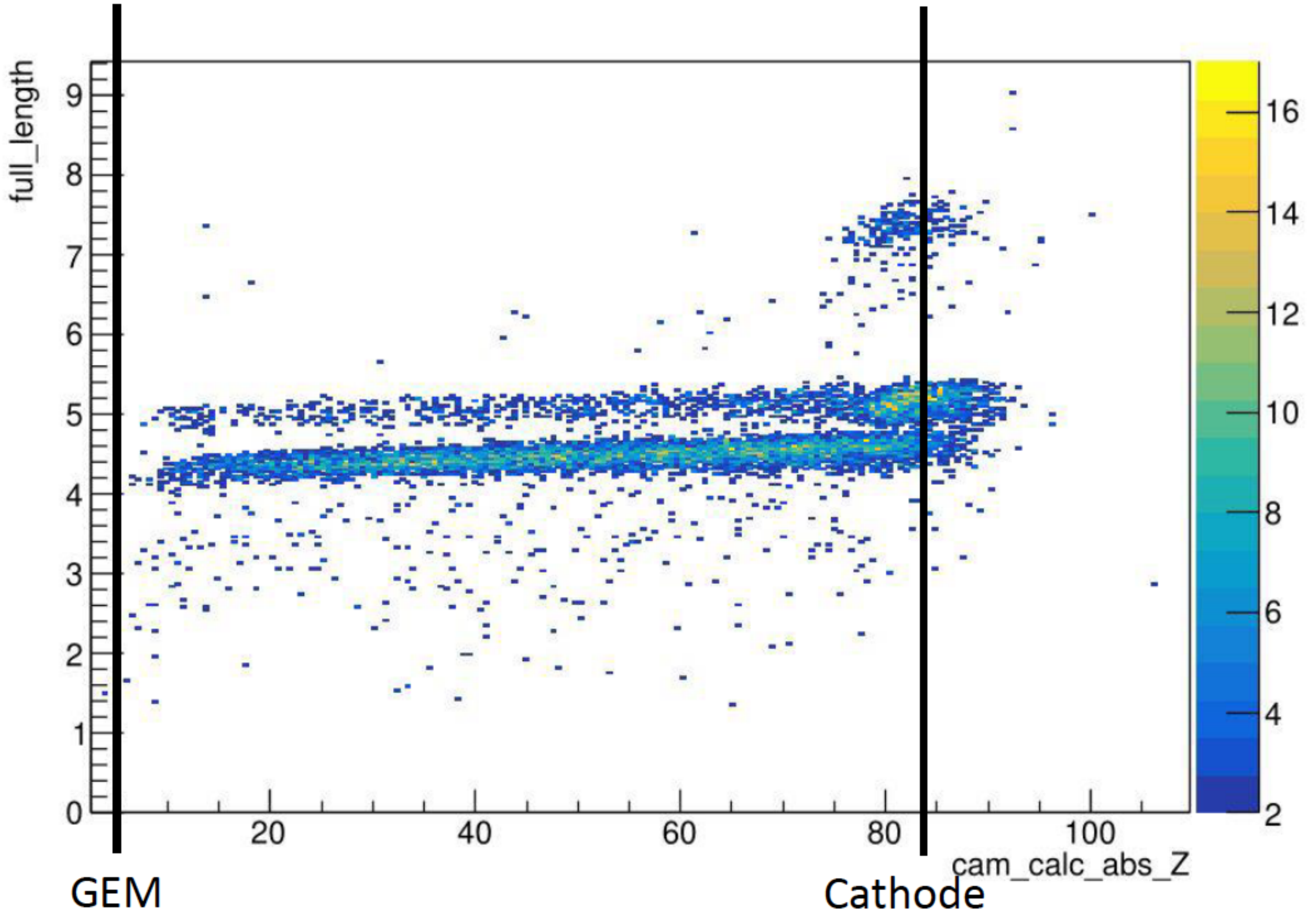


Main LIME performance: z reconstruction

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).

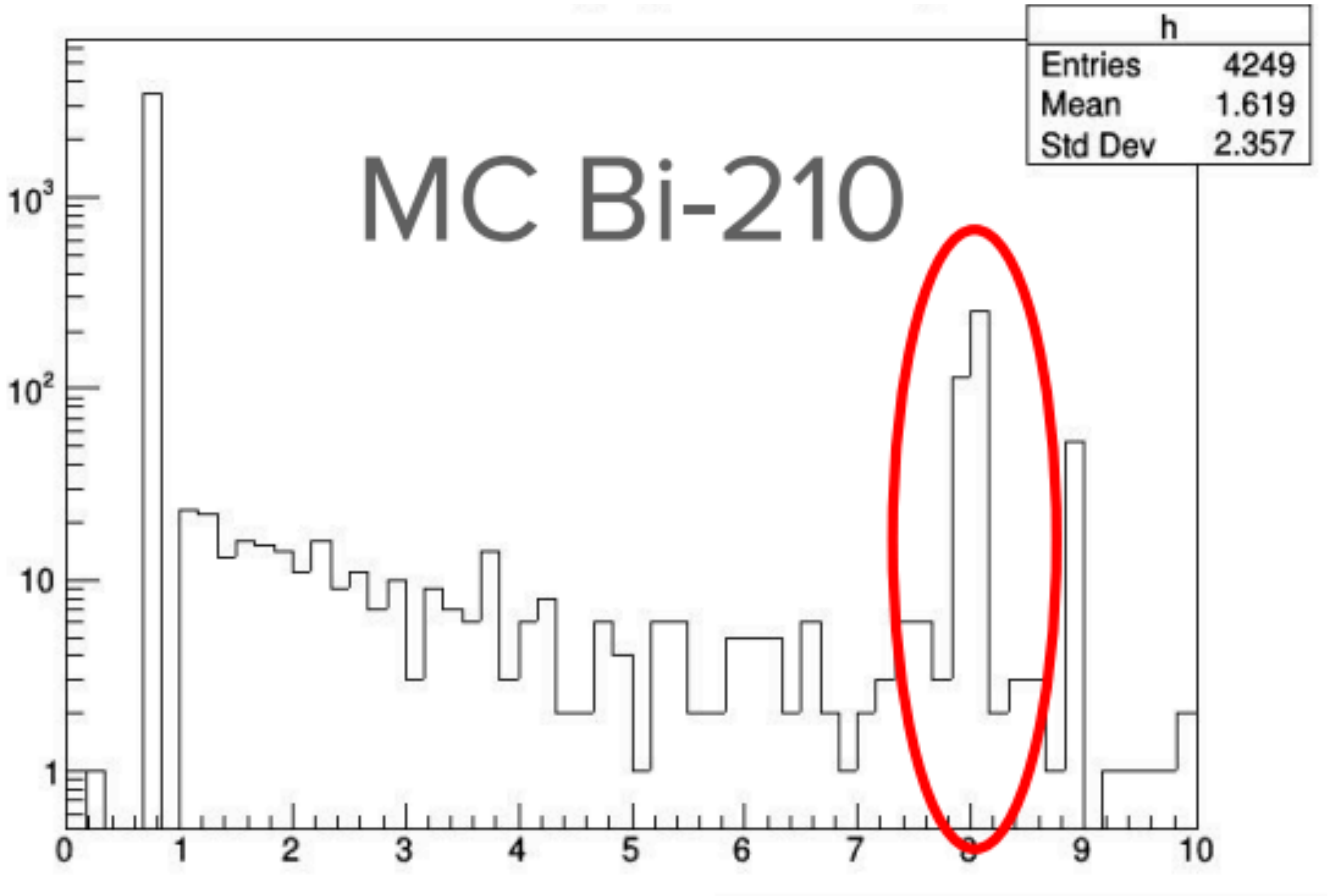


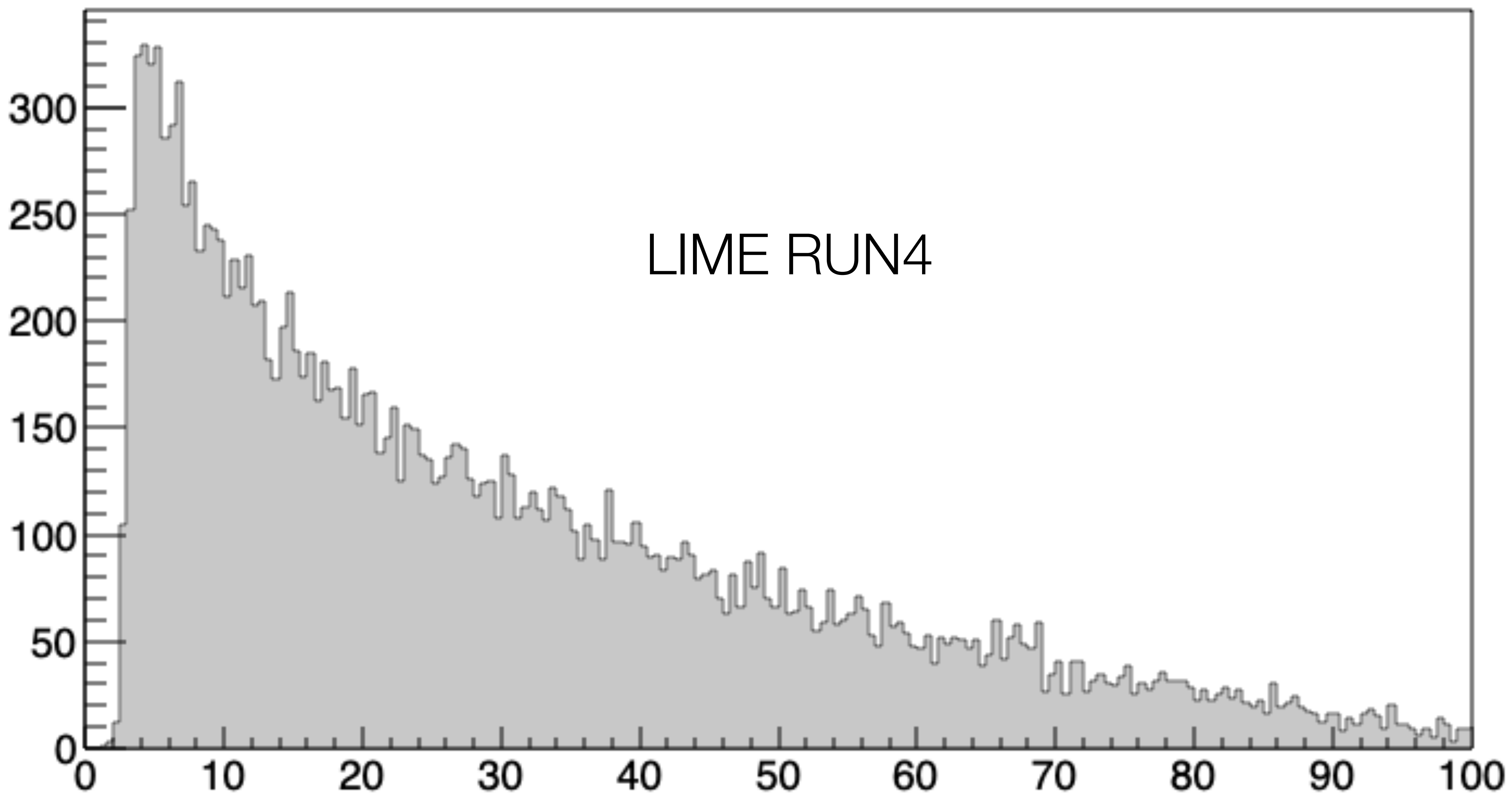


Main LIME performance: z reconstruction ER

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



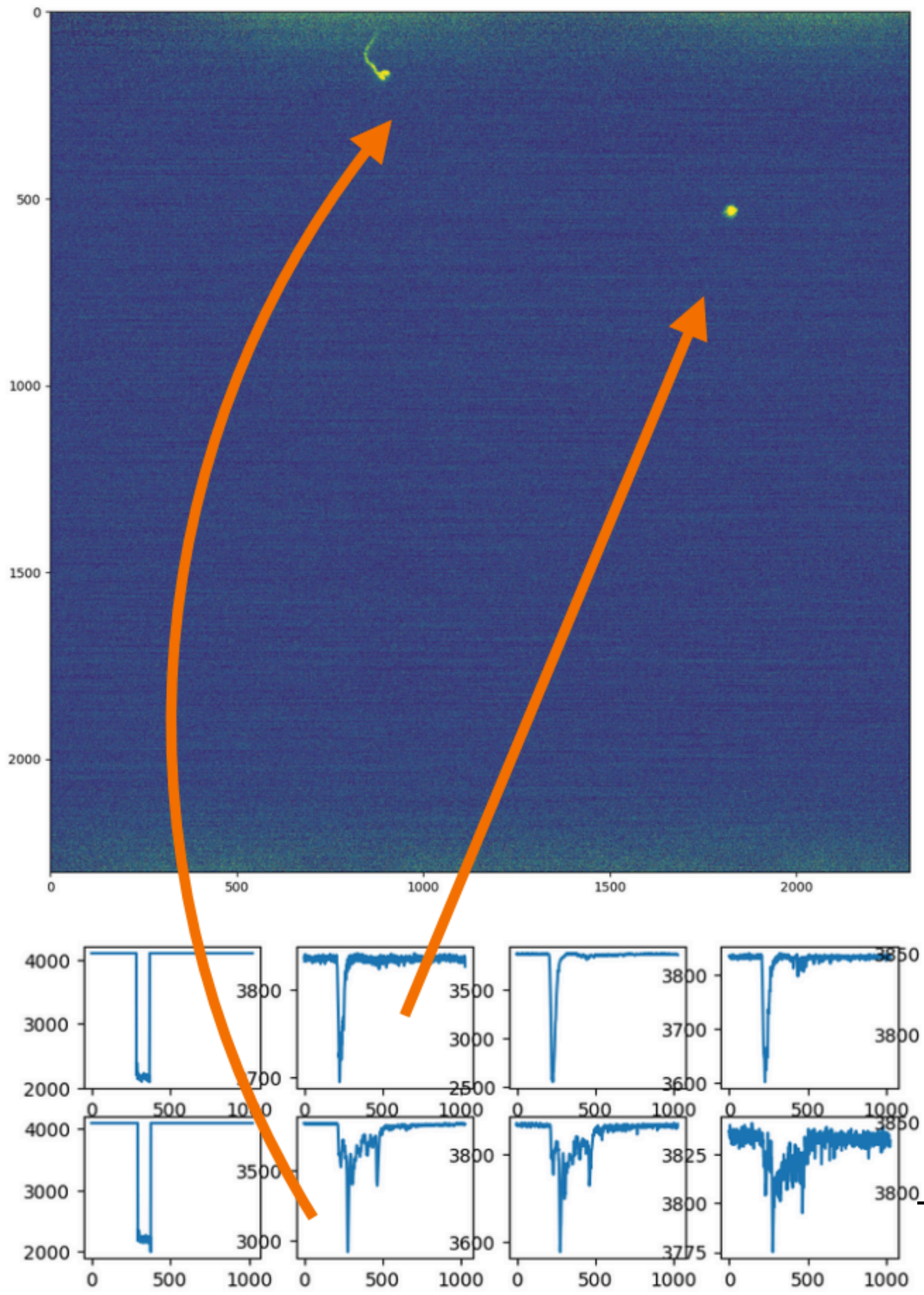


To compare the results, we need to digitize and reconstruct the MC-Truth

Main LIME performance: z reconstruction NR

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

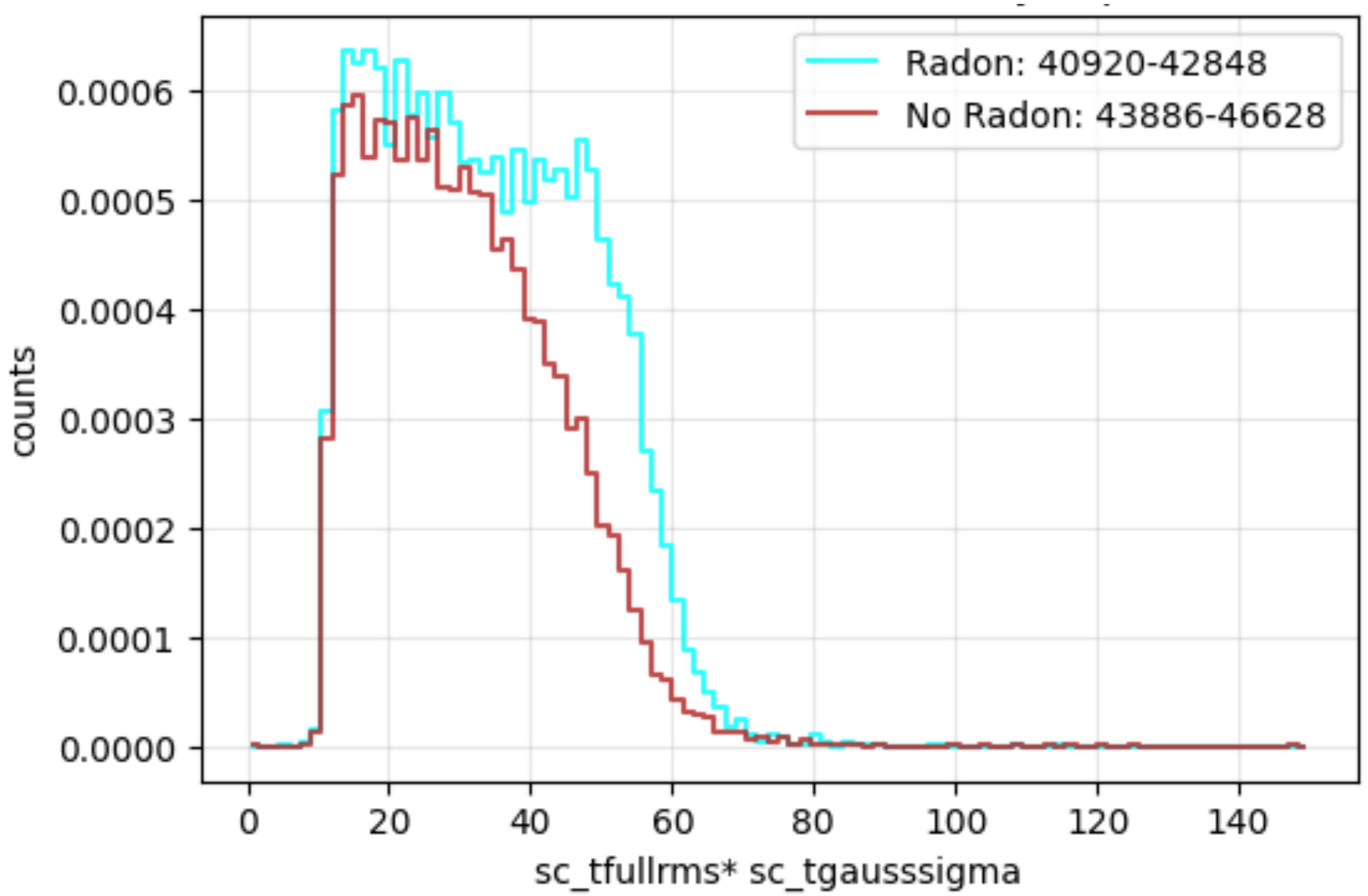
- Is likely due NR in gas;
- Has a reconstructed energy of the order of 20-30 keV_{ee};
- Is reconstructed at very high Z, at the cathode level;



PMT waveforms

Typical wfms for a NR

Typical wfms for an ER



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

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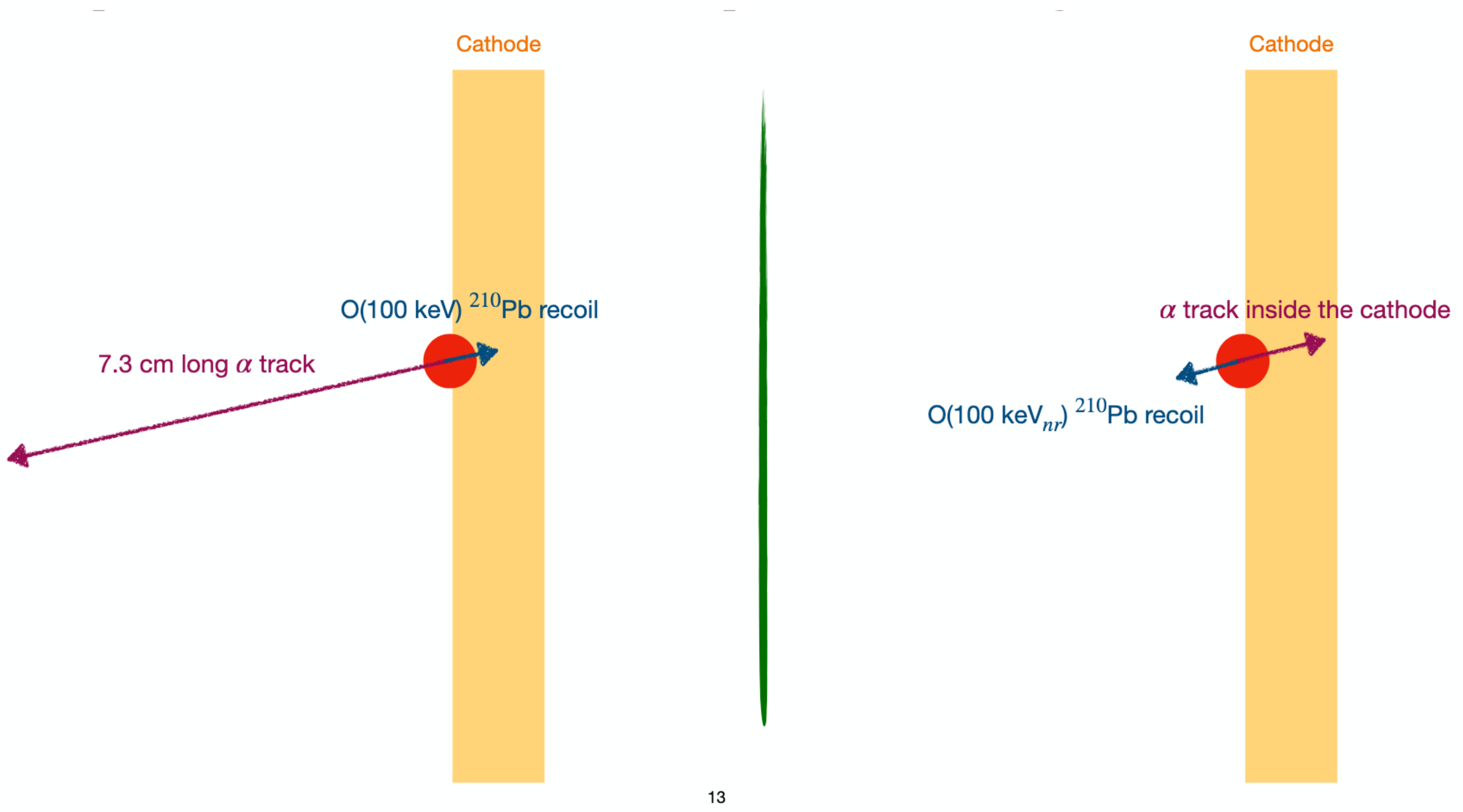
Journal of Instrumentation, Volume 12, June 2017
Citation Q. Riffard *et al* 2017 *JINST* **12** P06021
DOI 10.1088/1748-0221/12/06/P06021

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% for lead at the 100 keV energy, we should expect 15-30 keV$_{ee}$

The identification of this very 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

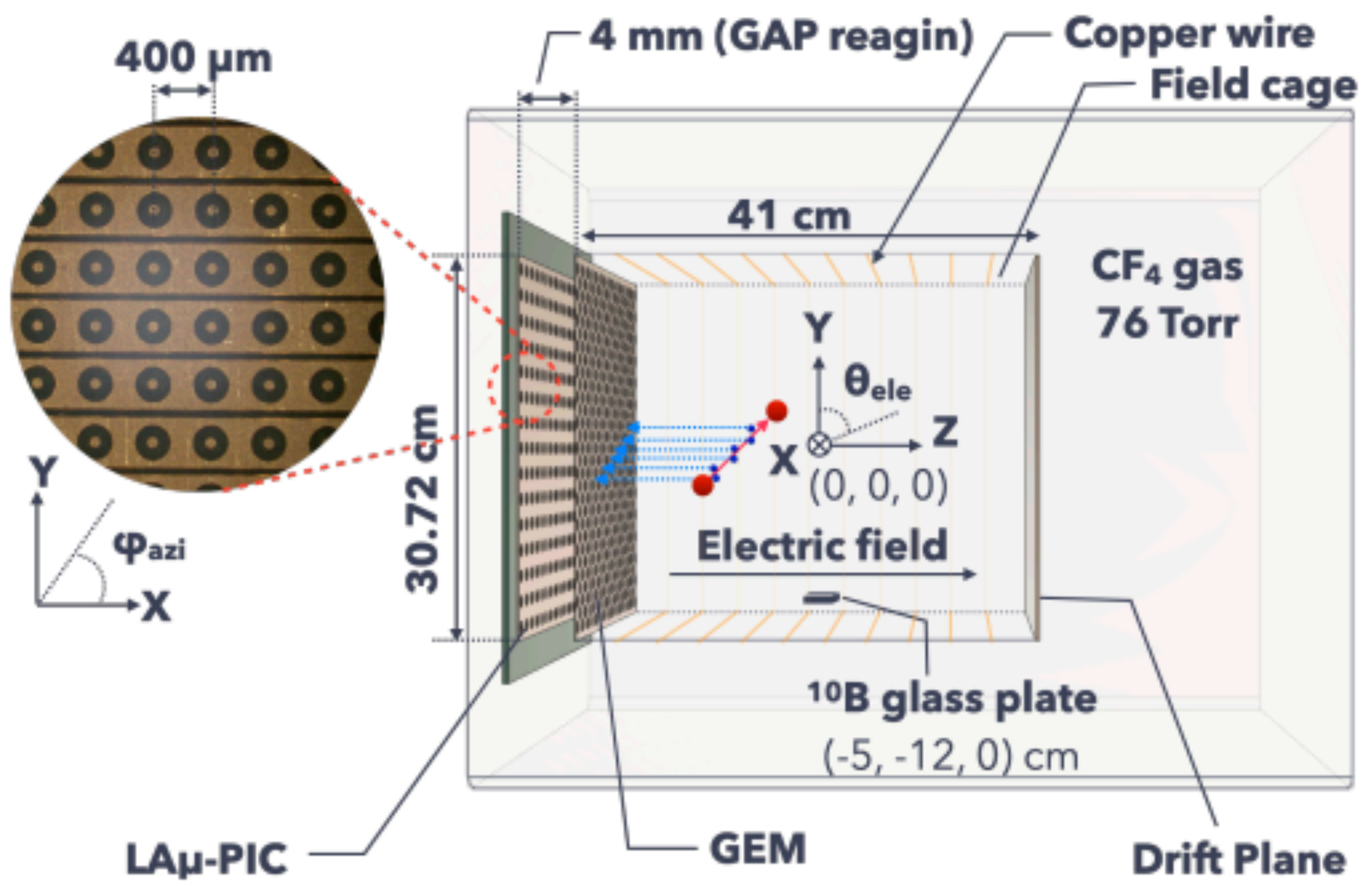
Direction-sensitive dark matter search with three-dimensional vector-type tracking in NEWAGE

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

LIME-like prototype operated at 0.1 bar CF_4

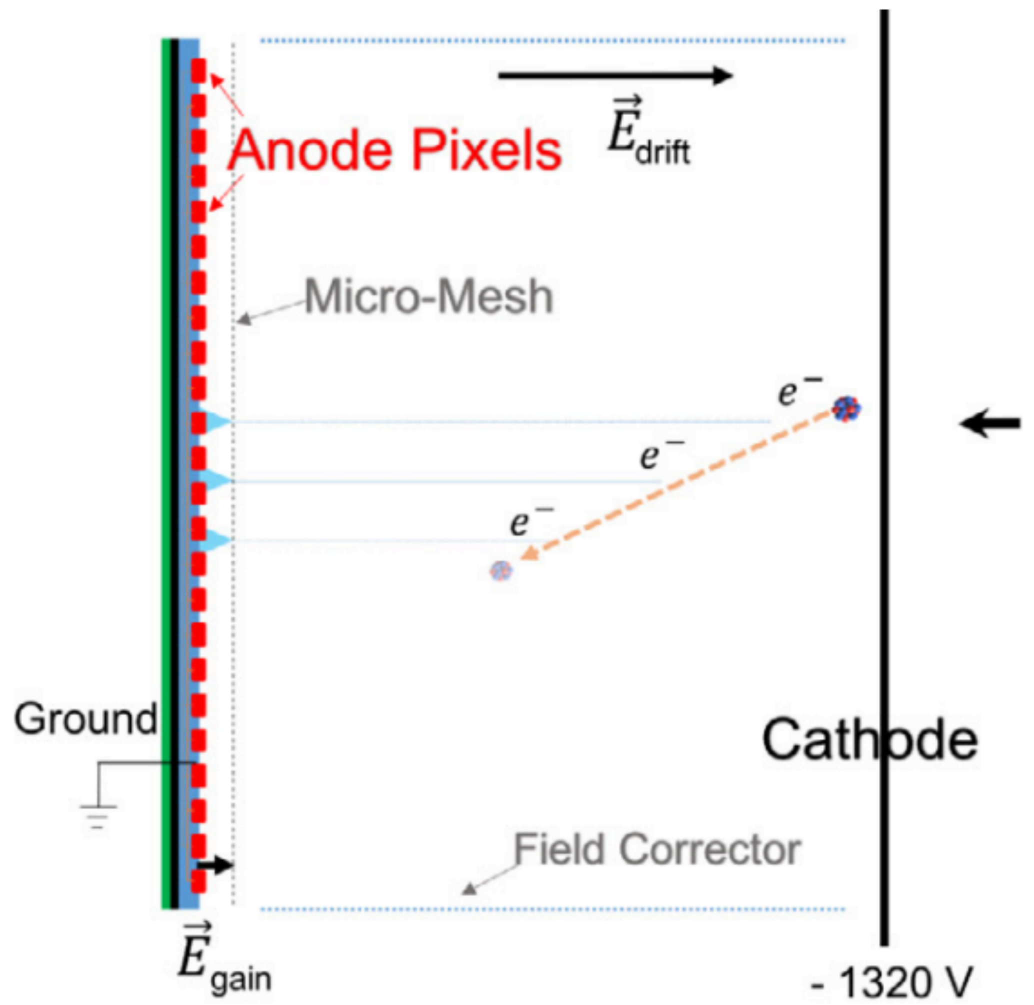
Angle resolution 58° at 50-100 keV_{ee} energy range

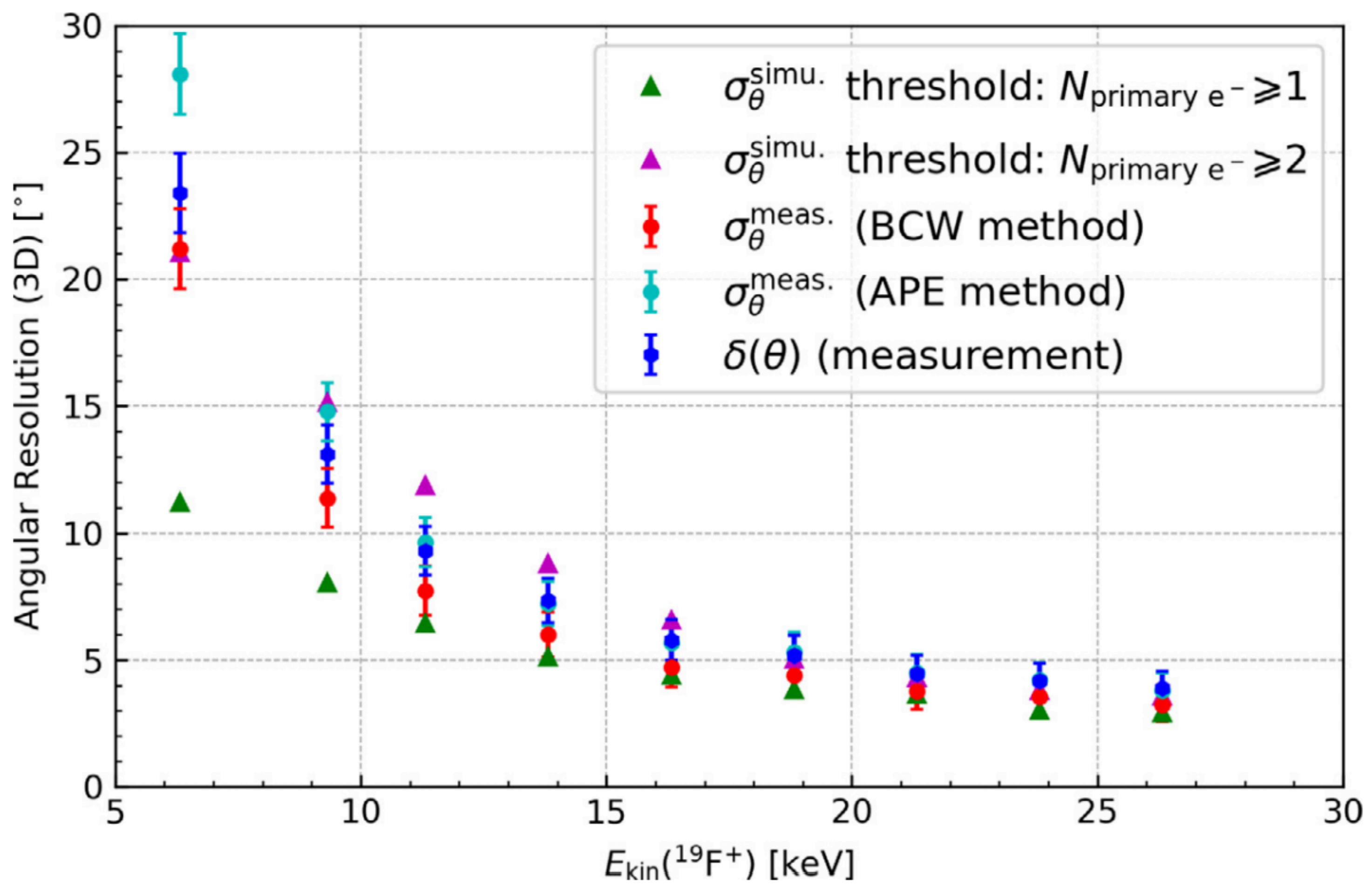
(Note that the energy released from neutrons to C and F is 43% and 30% w.r.t. He)



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

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

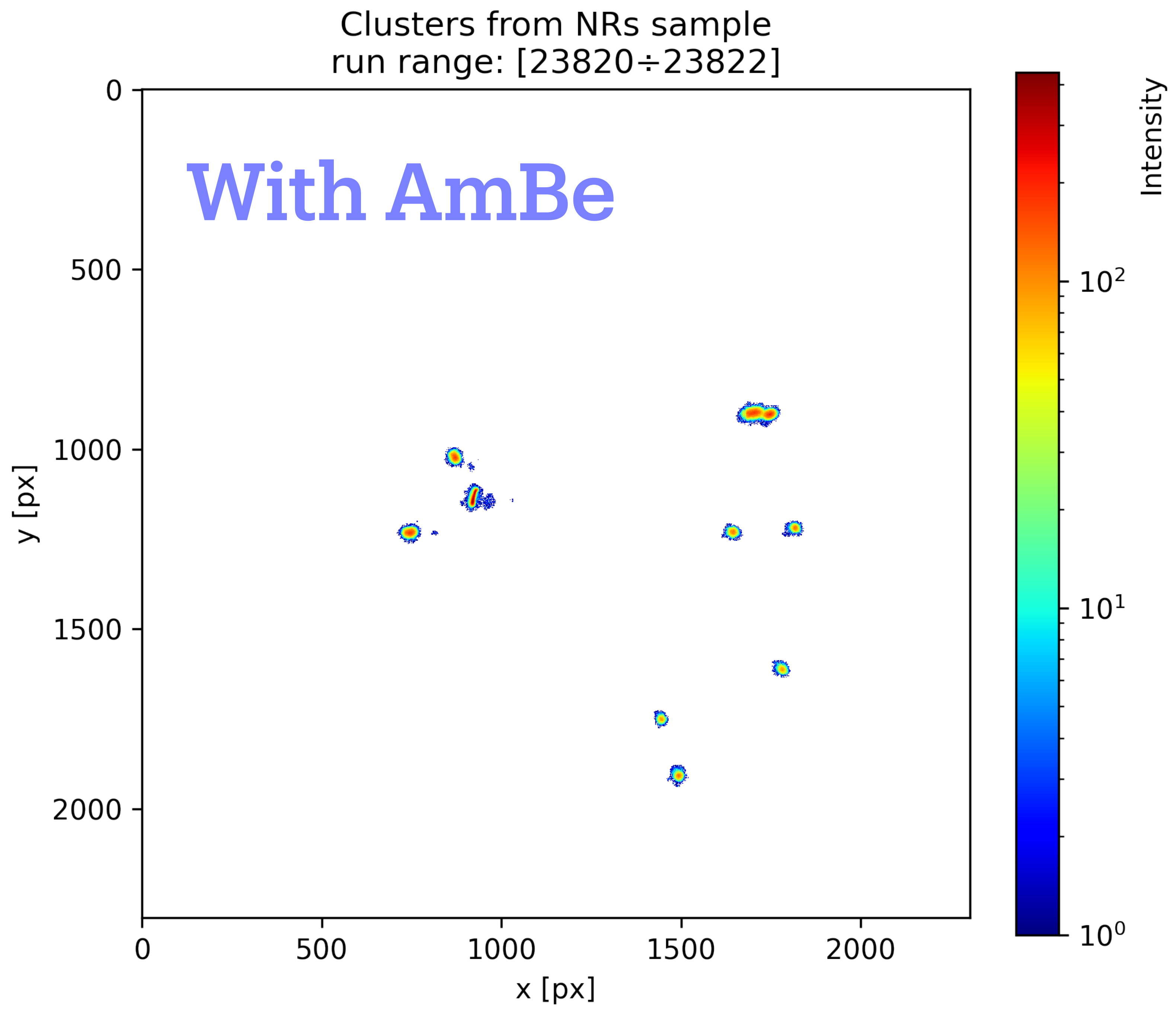




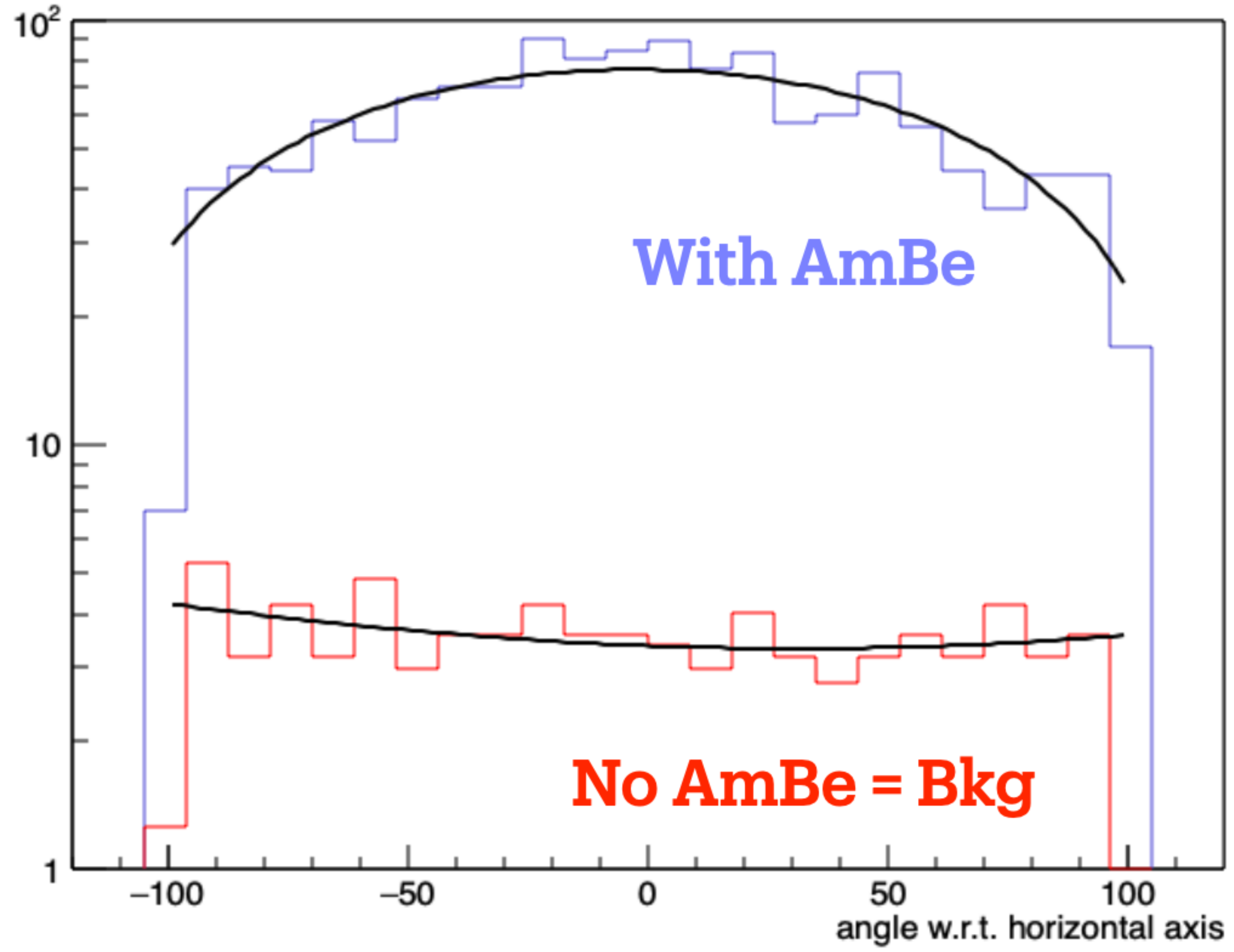
10x10x5 cm^3 prototype (1% of LIME volume) operated at 0.05 bar CF_4 /CHF_3/C_4H_{10}

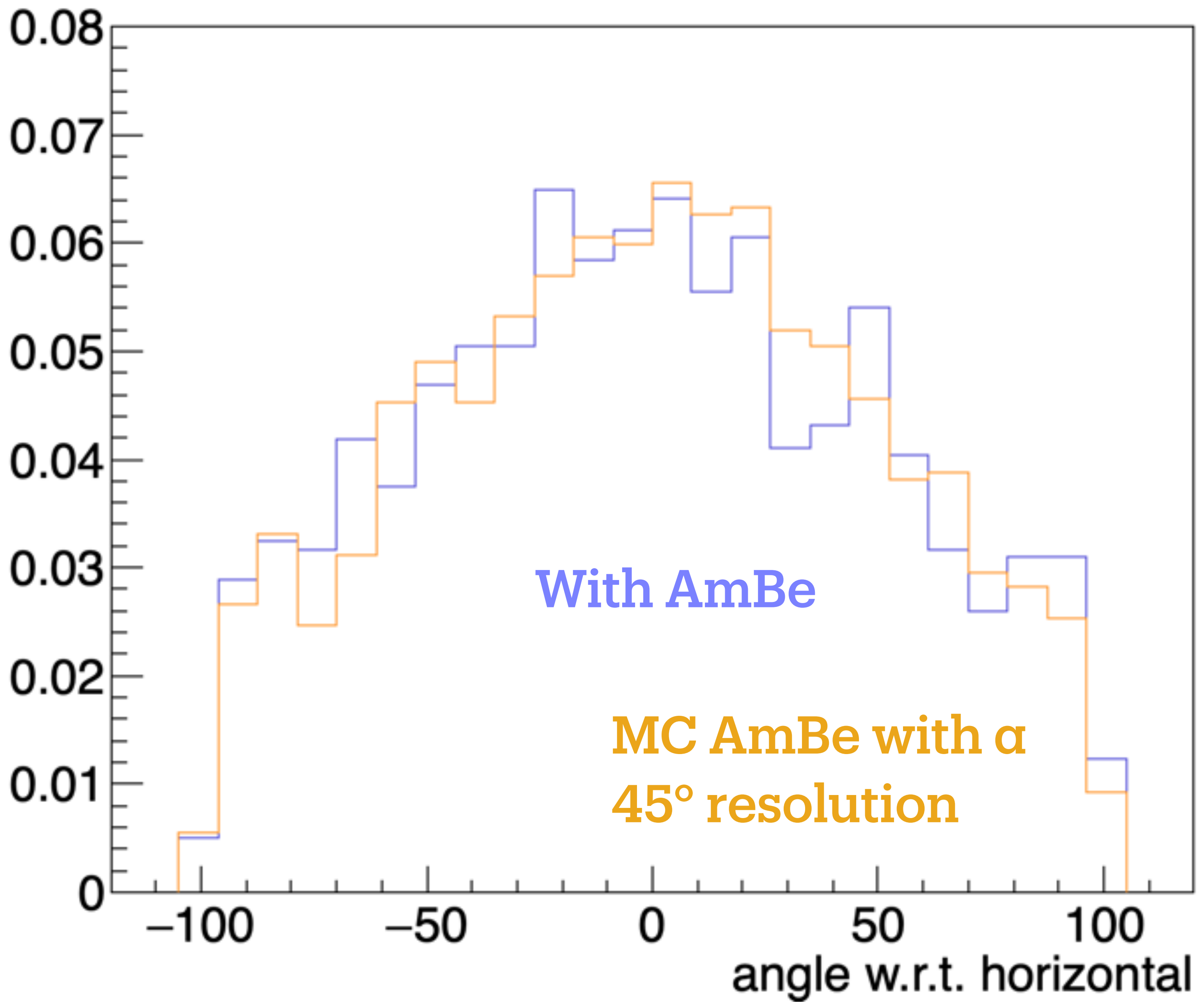
Good resolution in reconstructing the F angle arriving perpendicular to readout plane

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

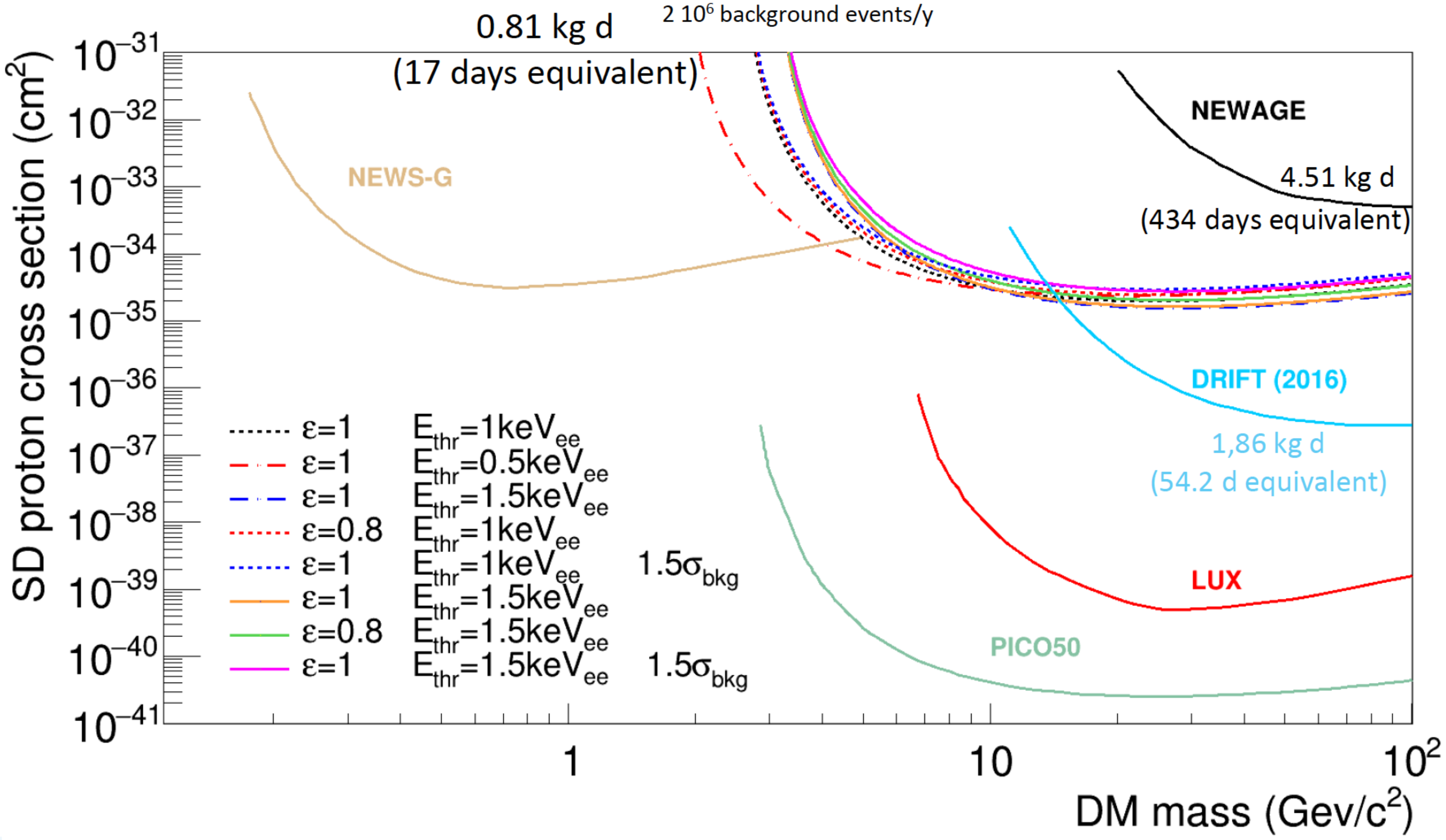
Room for large improvements with more sophisticated directional and rejection algorithms under development

Main LIME performance: evaluation of DM sensitivity

CYGNO Experiment

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)

LIME is not able to provide limits yet: no solid background model (LIME was not meant for this), however, it can be used to estimate where the exposure of the detector can lead and 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],
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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

Fernando Domingues Amaro[1], Rita Antonietti[2,3], Elisabetta Baracchini[4,5], Luigi Benussi[6], Stefano Bianco[6], Francesco Borra[2,3a], 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 Giambattista[4,5], Emanuele Di Marco[7], Giulia D'Imperio[7], Matteo Folcarelli[7,8b], Joaquim Marques Ferreira dos Santos[1], Davide Fiorina[4,5], Francesco Iacoangeli[7], Zahoor Ul Islam[4,5], Herman Pessoa Lima Júnior[4,5], Ernesto Kemp[10], Giovanni Maccarrone[6], Rui Daniel Passos Mano[1], David José Gaspar Marques[4,5c], Luan Gomes Mattosinhos de Carvalho[12], Giovanni Mazzitelli[6], Alasdair Gregor McLean[11], Pietro Meloni[2,3], Andrea Messina[7,8], Cristina Maria Bernardes Monteiro[1], Rafael Antunes Nobrega[12], Igor Fonseca Pains[12], Emiliano Paoletti[6], Luciano Passamonti[6], Fabrizio Petrucci[2,3], Stefano Piacentini[4,5], Davide Piccolo[6], Daniele Pierluigi[6], Davide Pinci[7], Atul Prajapati[4,5d], Francesco Renga[7], Rita Joana Cruz Roque[1], Filippo Rosatelli[6], Alessandro Russo[6], Giovanna Saviano[6,13], Pedro Alberto Oliveira Costa Silva[1], Neil John Curwen Spooner[11], Roberto Tesauro[6], Sandro Tomassini[6], Samuele Torelli[4,5e], and Donatella Tozzi[7,8]

t] 5 Jun 2025

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