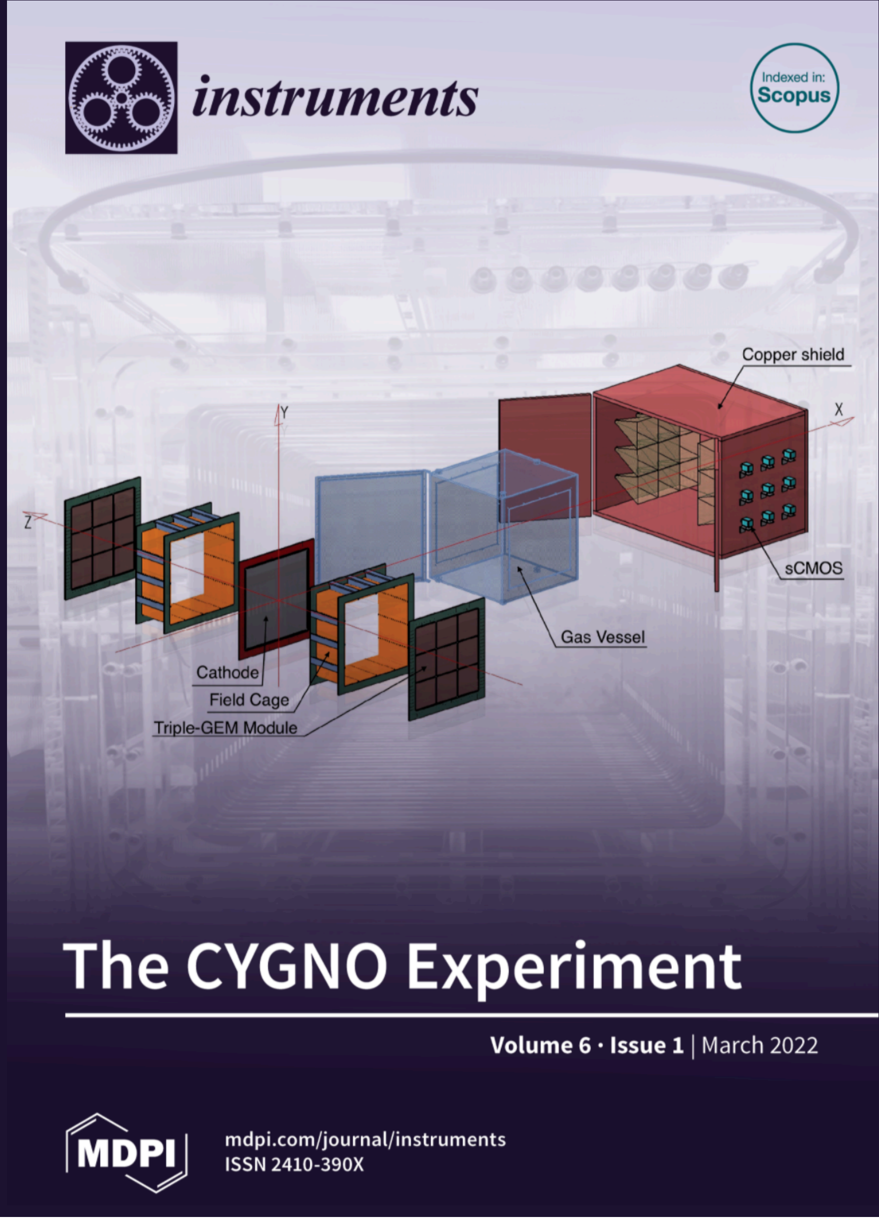


Fernando Domingues Amaro [1], Elisabetta Baracchini [2,3], Luigi Benussi [4], Stefano Bianco [4], Cesidio Capoccia [4], Michele Caponero [4,5], Danilo Santos Cardoso [6], Gianluca Cavoto [7,8], André Cortez [2,3], Igor Abritta Costa [9], Rita Joanna da Cruz Roque [1], Emiliano Dané [4], Giorgio Dho [2,3], Flaminia Di Giambattista [2,3], Emanuele Di Marco [7], Giovanni Grilli di Cortona [4], Giulia D'Imperio [7], Francesco Iacoangeli [7], Herman Pessoa Lima Júnior [6], Guilherme Sebastiao Pinheiro Lopes [9], Amaro da Silva Lopes Júnior [9], Giovanni Maccarrone [4], Rui Daniel Passos Mano [1], Michela Marafini [10], Robert Renz Marcelo Gregorio [11], David José Gaspar Marques [2,3], Giovanni Mazzitelli [4], Alasdair Gregor McLean [11], Andrea Messina [7,8], Cristina Maria Bernardes Monteiro [1], Rafael Antunes Nobrega [9], Igor Fonseca Pains [9], Emiliano Paoletti [4], Luciano Passamonti [4], Sandro Pelosi [7], Fabrizio Petrucci [12,13], Stefano Piacentini [7,8], Davide Piccolo [4], Daniele Pierluigi [4], Davide Pinci [7,*], Atul Prajapati [2,3], Francesco Renga [7], Filippo Rosatelli [4], Alessandro Russo [4], Joaquim Marques Ferreira dos Santos [1], Giovanna Saviano [4,14], Neil John Curwen Spooner [11], Roberto Tesauro [4], Sandro Tomassini [4] and Samuele Torelli [2,3] **B. P. Gelli, E. Kemp**

CYGNO timeline

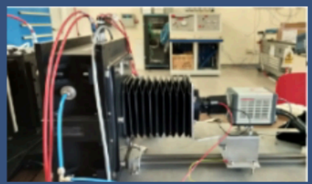
Instruments 6 (2022) 1, 6
JINST 15 (2020) 12, T12003
JINST 15 (2020) P08018
Measur.Sci.Tech. 32 (2021) 2, 025902

JINST 15 (2020) P10001
2019 JINST 14 P07011
NIM A 999 (2021) 165209

INITIUM: NID studies

Currently at LNGS

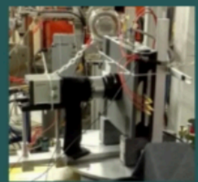
MANGO



- up to 5 cm drift
- for gas studies

PHASE 0: R&D and prototypes

2015/16 ROMA1 — ORANGE



- 1 cm drift

2017/18 LNF — LEMON

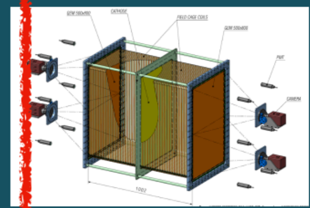
- 3D printing
- 20 cm drift

2019/2024 LNF/LNGS — LIME

- 50 cm drift
- underground tests
- MC validation

PHASE 1: O(1) m^3 demonstrator

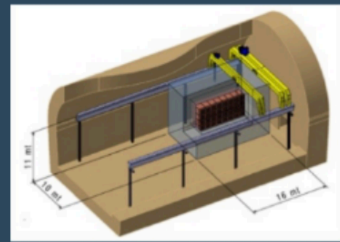
2024/2026 LNF/LNGS — CYGNO_04



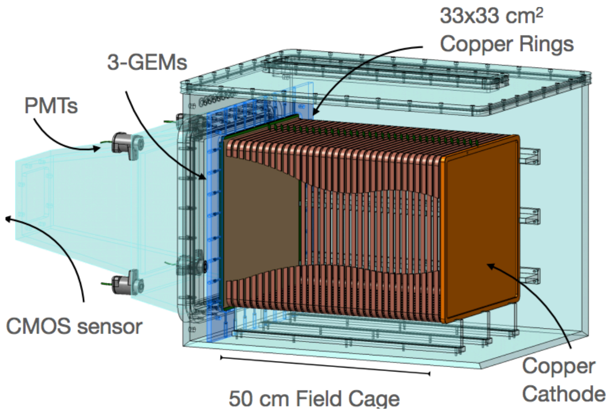
- background
- material tests, gas purification
- scalability

PHASE 2: 30 m^3 experiment

2026 ... LNGS — CYGNO_30



- Physics research



LIME

1 sCMOS + 4 PMT + 3 GEMs
33 x 33 cm² readout area
50 cm drift length
50 L active volume

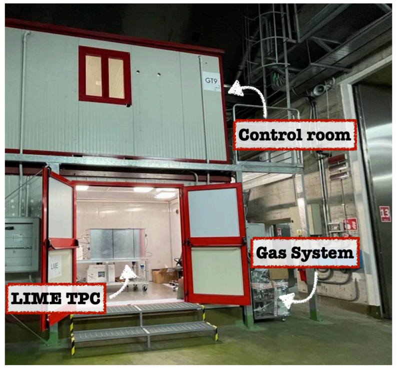
LIME underground campaign

LIME staged shielding underground campaign concludes <u>today</u>

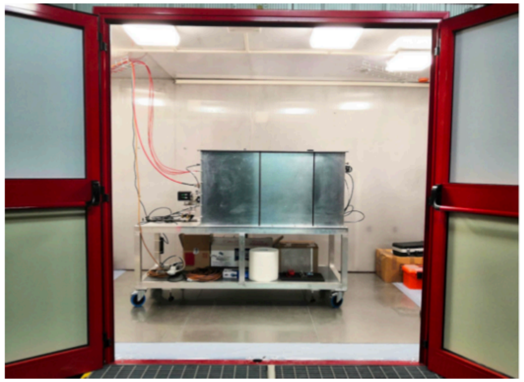
Water shielding being dismounted to perform extended Run5 with 10 cm Cu only for underground neutron flux measurement (PRIN 2017)

	Shielding	Number of bkg pictures	Event rate	Period
Run1	none	4×10^5	35 Hz	Oct 2022
Run2	4 cm Cu	4.5×10^5	3.5 Hz	Jan-Mar 2023
Run3	10 cm Cu	2.7×10^6	1.3 Hz	May-Nov 2023
Run4	10 cm Cu + 40 cm H_2O	2.8×10^6	0.9 Hz	Dec 2023-Apr 2024

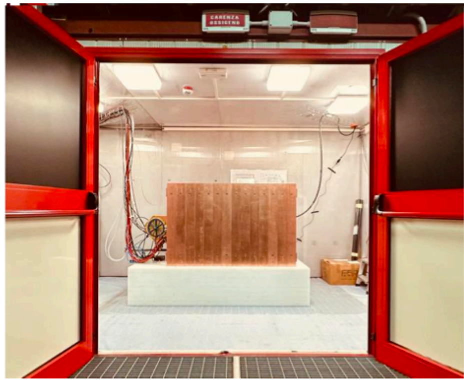
+ periodic calibrations with ^{55}Fe (as a function of distance from GEM from Run2)
+ AmBe measurement during Run3
+ ^{133}Ba, ^{152}Eu, ^{241}Am calibrations during Run3



Underground installation with full axuliary systems



Run1

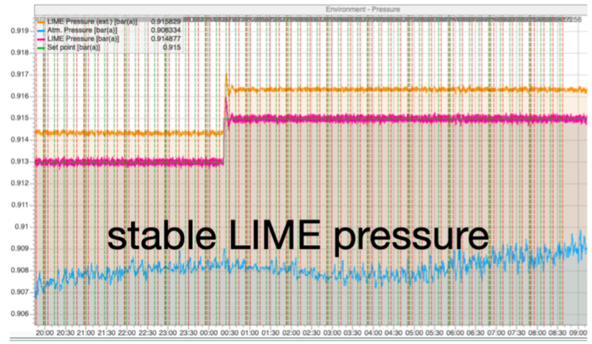


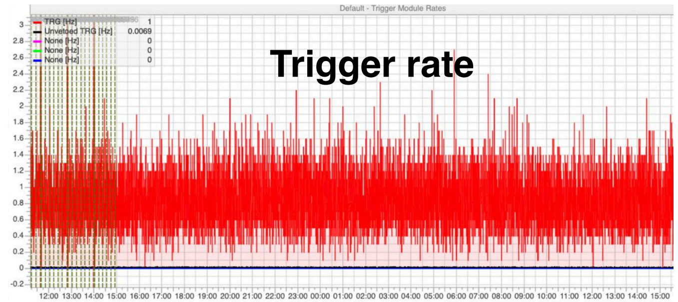
Run2 - Run3

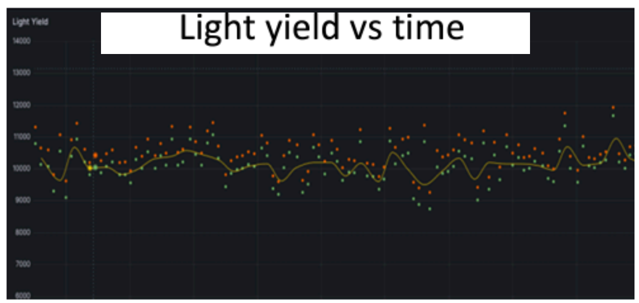
Run4

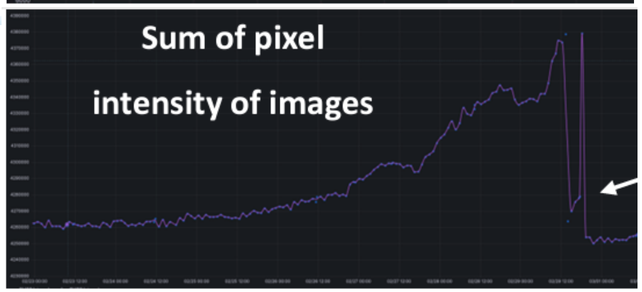
LIME underground operation with full auxiliary system configuration

- Automated system developed to control and monitor remotely HV, gas system, environmental parameters, DAQ, trigger rate, ^{55}Fe calibrations, detector conditions and data taking
- Automatic data reconstruction implemented
- Complementary Grafana online monitor for fast interventions to critical issues
- Fully remote shifts 24/7 from Run4



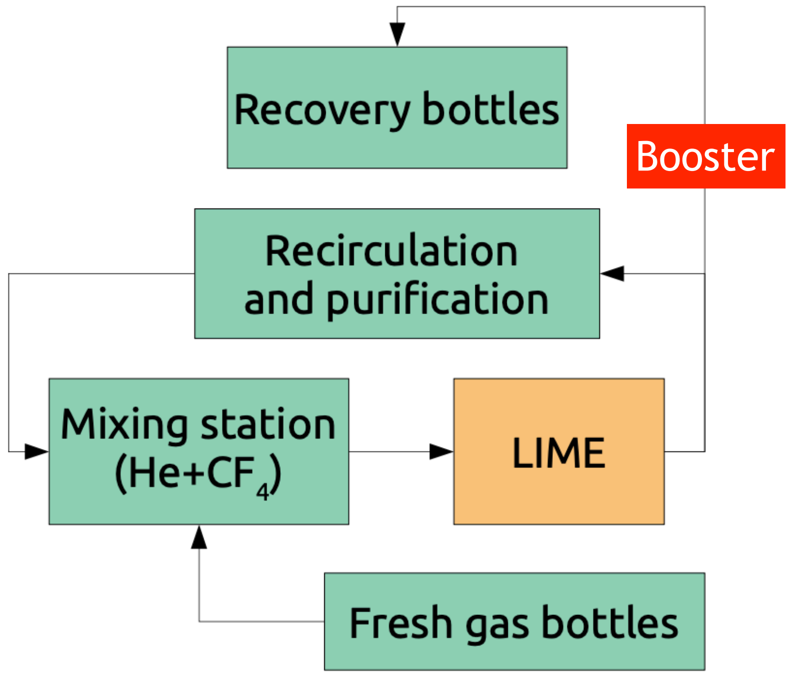






LIME gas system operations optimisation

- **Operations started without recirculation to assess detector conditions independently from it (Run1 & Run2)**
- **Recirculation introduced at end of Run3**
  - **Leakages in the line induced LY instabilities due to humidity in the gas**
  - **Pump electronic board failures required periodic halts to data taking and interventions**
  - **Booster failures additionally prevented regular operations**



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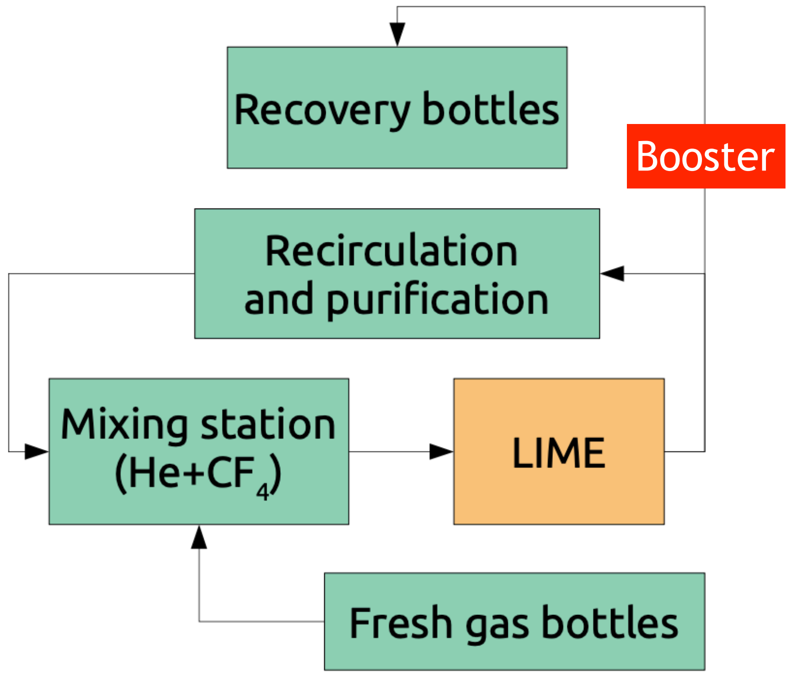
- Recirculation introduced at end of Run3
  - Leakages in the line induced LY instabilities due to humidity in the gas
  - Pump electronic board failures required periodic halts to data taking and interventions
  - Booster failures additionally prevented regular operations
- Interventions in September 2023 allowed to fix all pump and booster instabilities and main leaks down to:
  - 0.5 cc/min leak in LIME
  - < 3 cc/min in the rest of the system
- Thanks to stability and improved gas system operations, optimisation of recirculation configuration performed in Oct-Nov 2023
- **Stable operation and high quality operations achieved in full gas system configuration from December 2023**



LIME operations in Run4

Uptime

Thanks to the interventions on the gas system, an uptime > 95% was achieved for nearly 4 consecutive months in Run4

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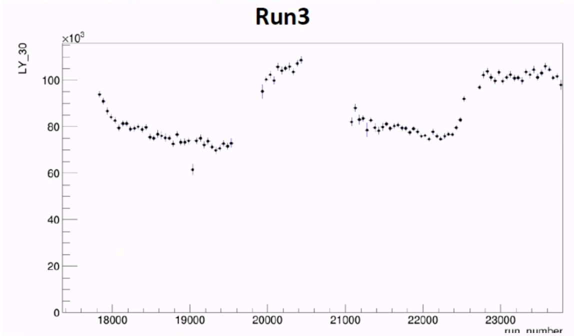
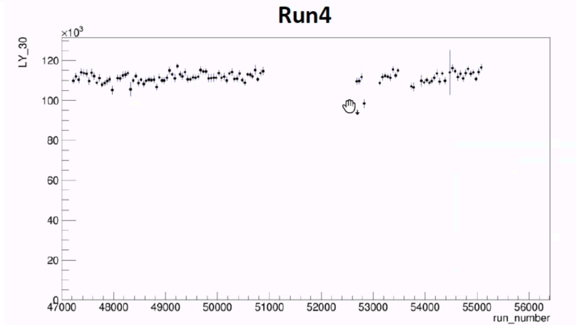
Light Yield





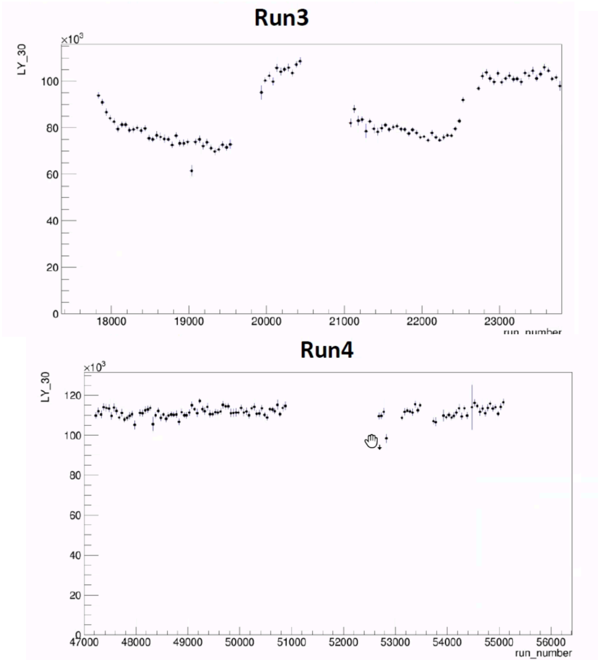
Thanks to the tests and optimisation of recirculation and filtering at the end of Run3, in Run4 we achieved a stable (within 5%) and high (2 counts/eV) LY

LIME operations in Run4

Uptime

Thanks to the interventions on the gas system, an uptime > 95% was achieved for nearly 4 consecutive months in Run4

Light Yield



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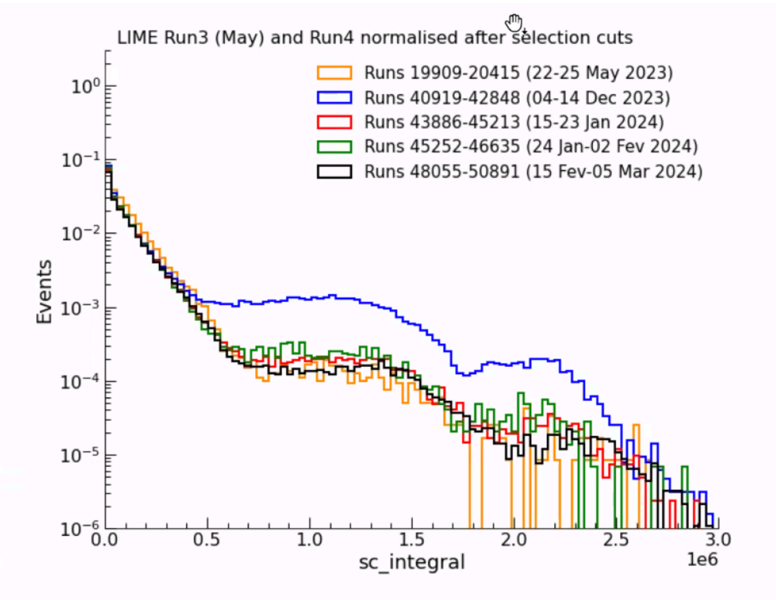
Alpha rate



Thanks to the tests and optimisation of recirculation and filtering at the end of Run3, in Run4 the alpha rate (likely related to Rn contamination in the gas, see later) was reduced to the same level of no recirculation

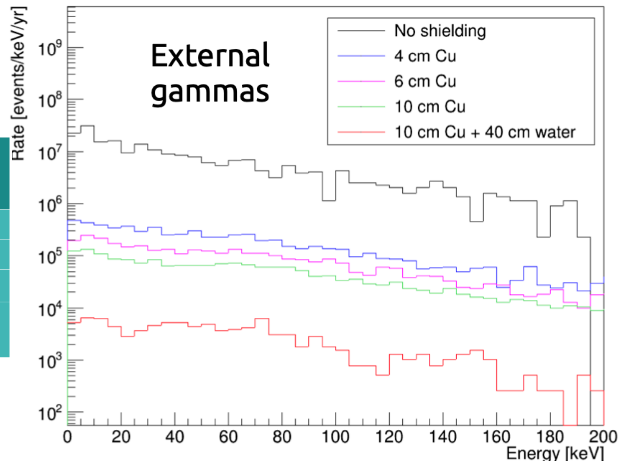
LIME underground background data analysis and comparison with MC prediction

Run4 is not discussed in this presentation since data analysis still ongoing

LIME expected backgrounds from MC simulation

External backgrounds

Shielding	Gamma background [10^6 ER yr^{-1}]	Neutron background [NR yr^{-1}]
Unshielded	(1140±30)	(1480±90)
4 cm Cu	(26.2±0.6)	(870±10)
6 cm Cu	(9.4±0.3)	(1000±30)
10 cm Cu + 40 cm H_2O	(0.5±0.2)	(2.0±0.2)



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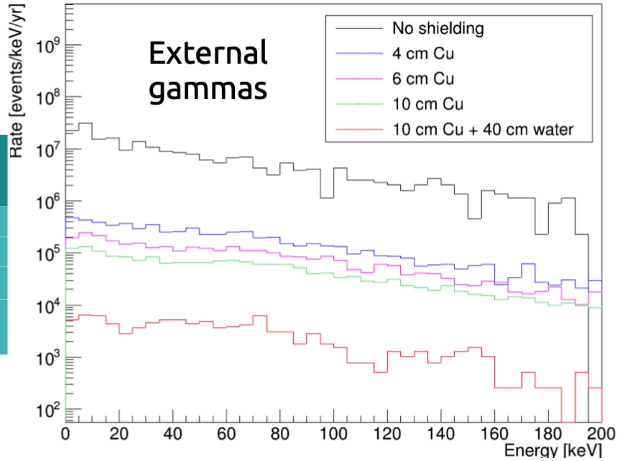
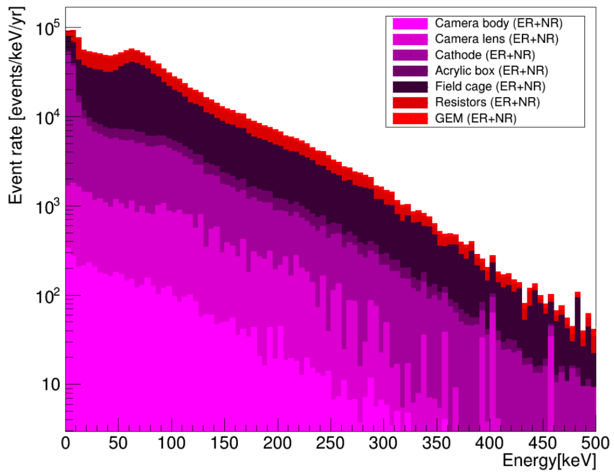


Internal backgrounds



Source	Event rate [10^6 yr^{-1}]
Field cage	(3.57±0.01)
Resistors	(1.873±0.006)
Cathode	(1.095±0.001)
GEMs	(0.3891±0.0002)
Vessel	(0.268±0.001)
Camera lens	(0.151±0.004)
Camera body	(0.0242±0.0005)
TOTAL	**(7.34±0.01)**

Please note LIME was NOT built with radioactive pure components

LIME expected backgrounds from MC simulation

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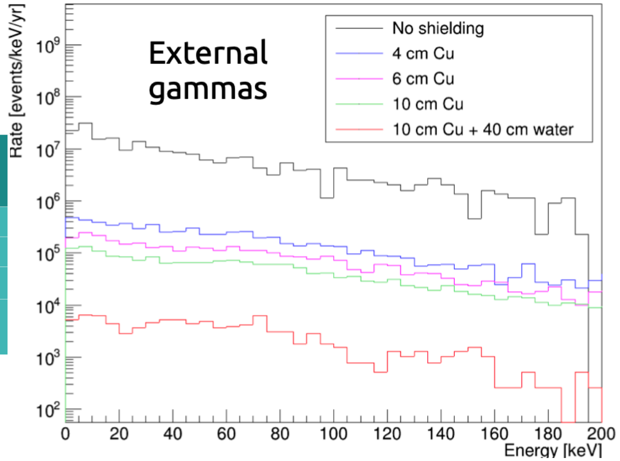
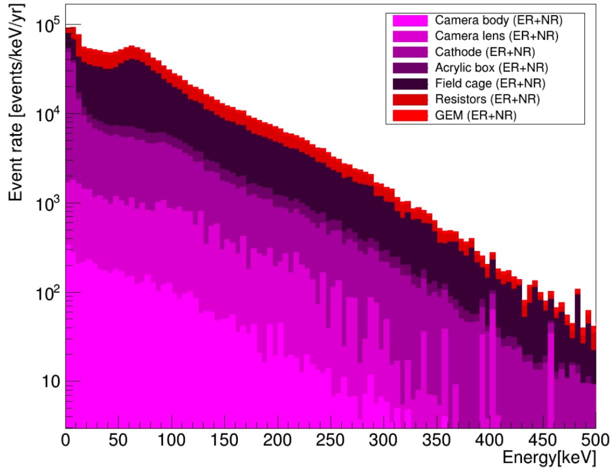


Internal backgrounds



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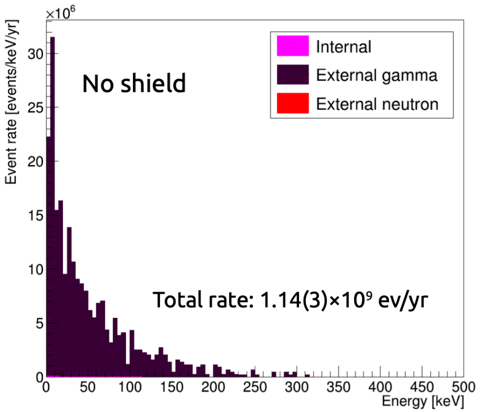
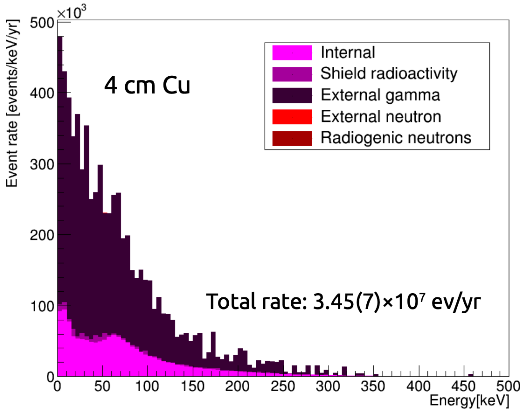
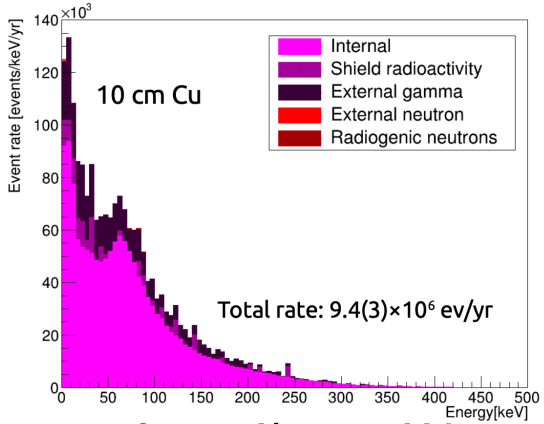
Total backgrounds



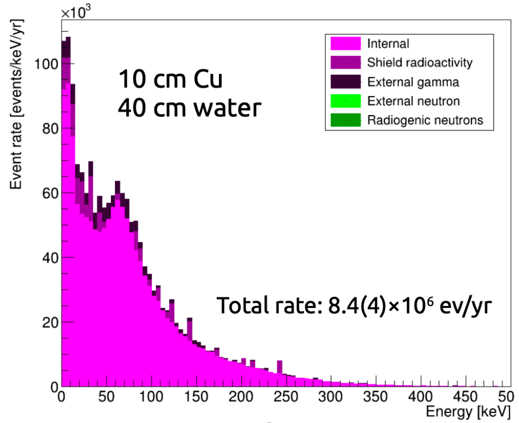
internal/external bkg
0.6%



internal/external bkg
20%



internal/external bkg
78%



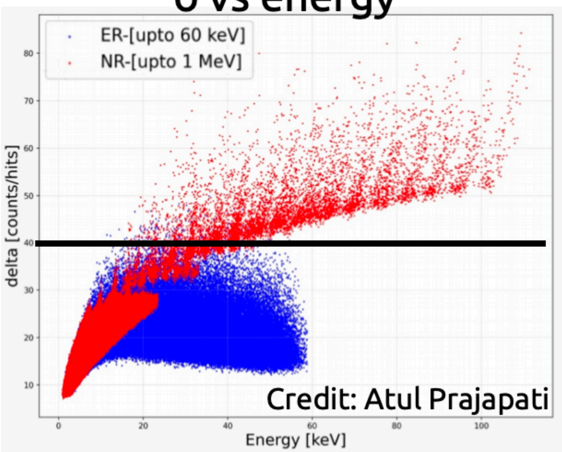
internal/external bkg
87%

Data/MC analysis: quality and selection cuts

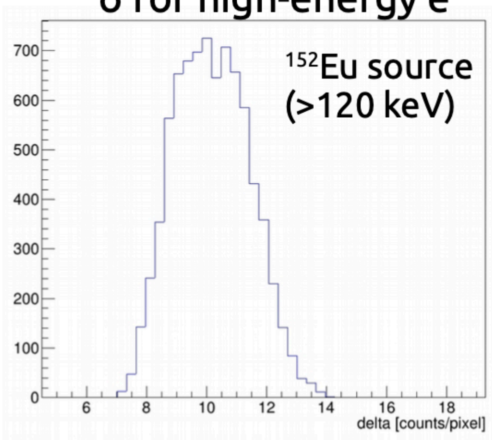
Goal: maximise consistency between data and MC samples for proper data/MC comparison (rather than efficiency)

- **Fiducial cuts to exclude sCMOS sensor noisy borders**
  - **A central square of 23 x 23 cm^2**
- **Quality cuts to remove fake clusters from residual sensor noise**
  - **Remove uniform, compact and sharp-edged clusters from pedestal study**
- **Track selection cuts based on delta = # of counts/# of pixels (i.e. uncalibrated dE/dx)**
  - **To remove alphas (energy > 800 keV, not digitised, not of interest for DM searches)**
  - **To exclude MIP-like particles (not of interest for DM searches) whose reconstruction highly depends on LY and that might end up splitted in the reconstruction**

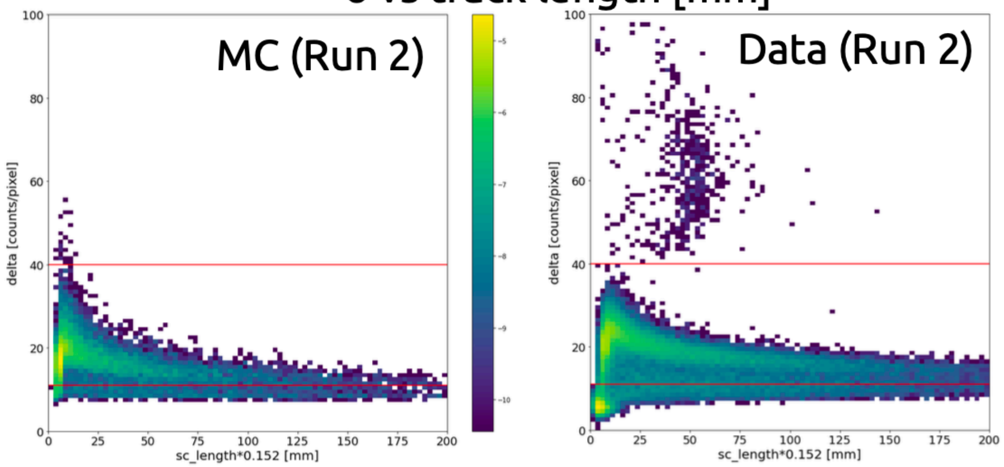
δ vs energy



δ for high-energy e⁻

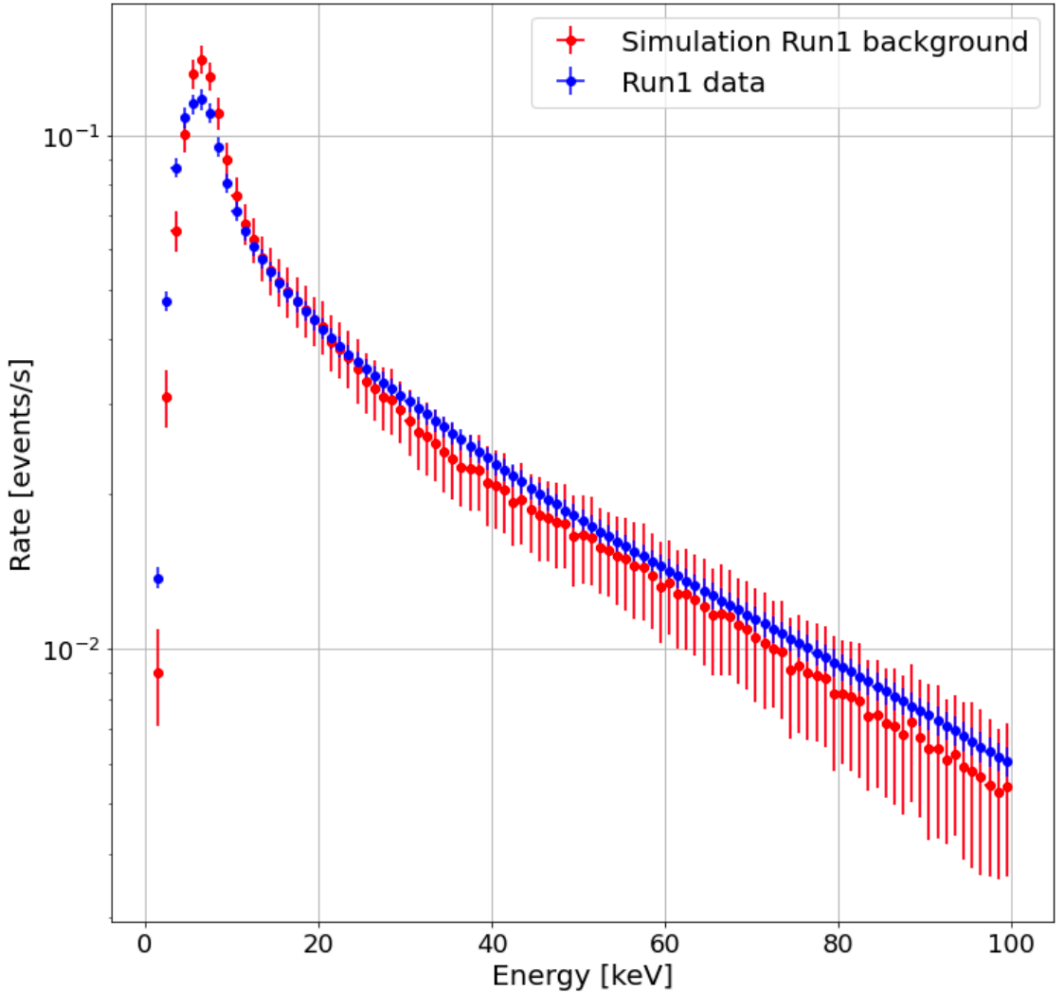


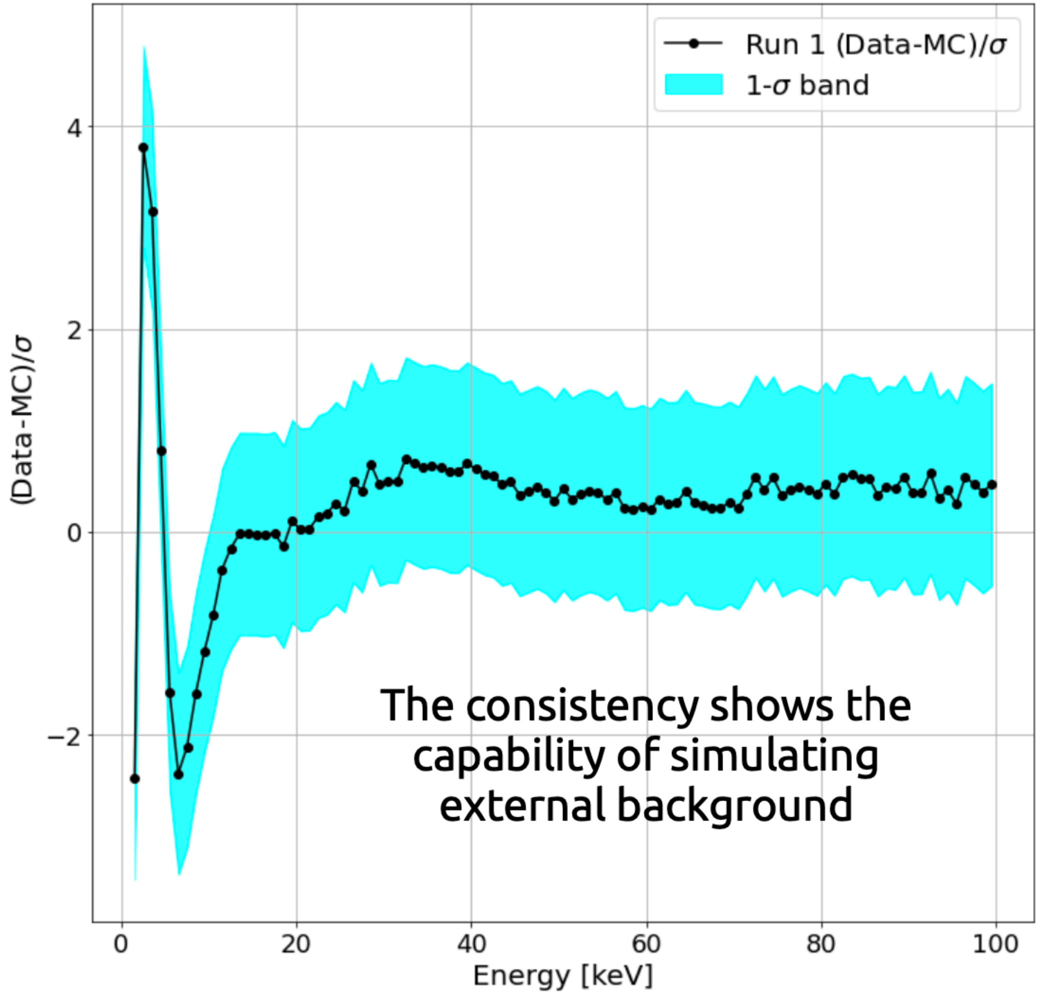
δ vs track length [mm]



LIME underground data/MC comparison results

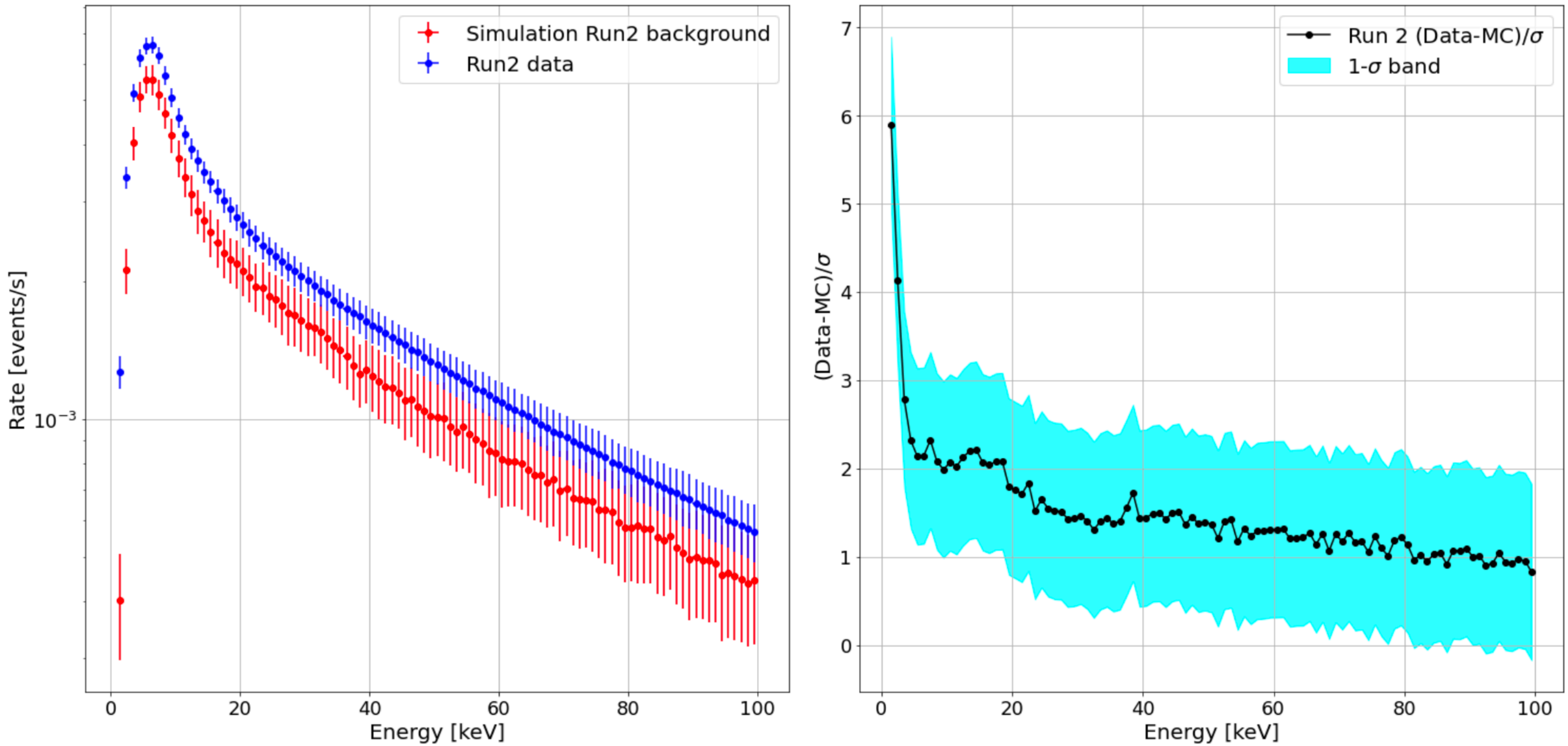
Run1: dominated by external gamma background (internal 0.6%)





LIME underground data/MC comparison results

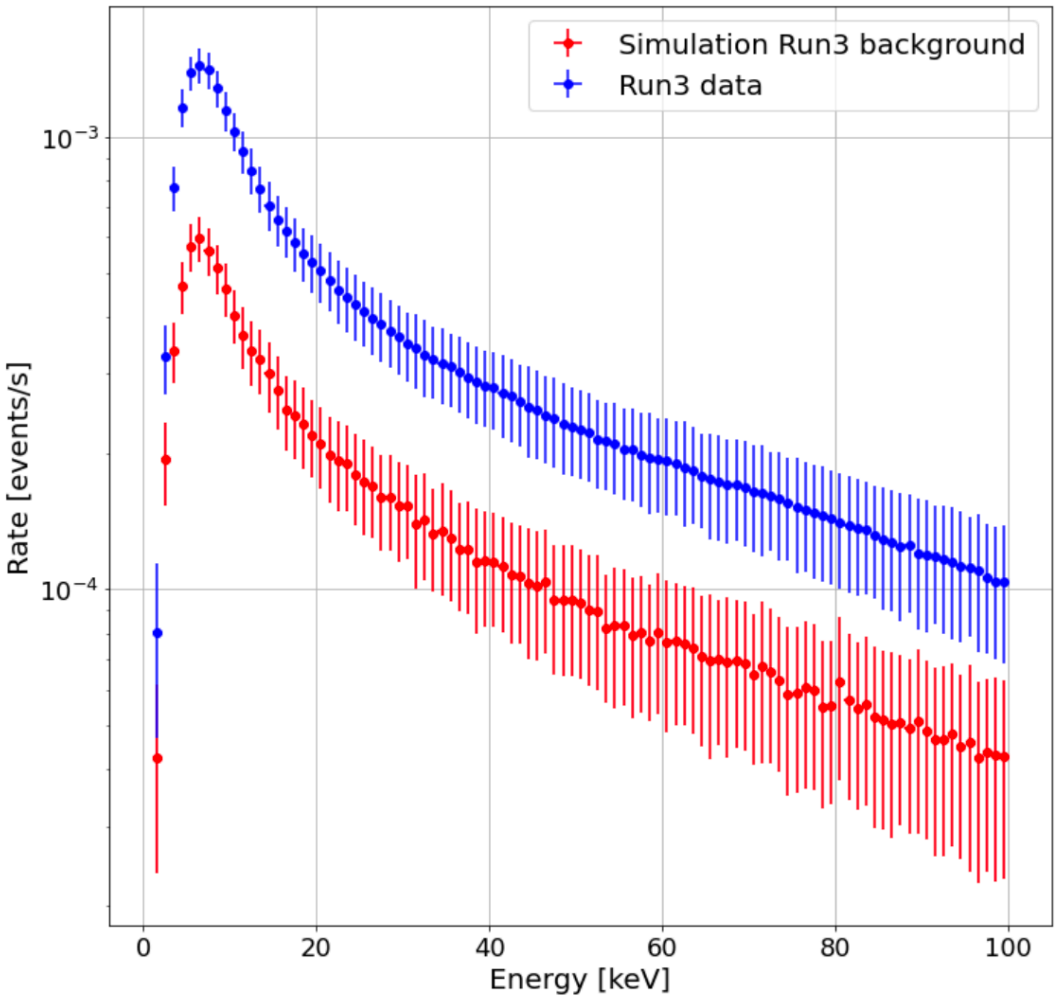
Run2: start probing internal gamma background (internal 20%)

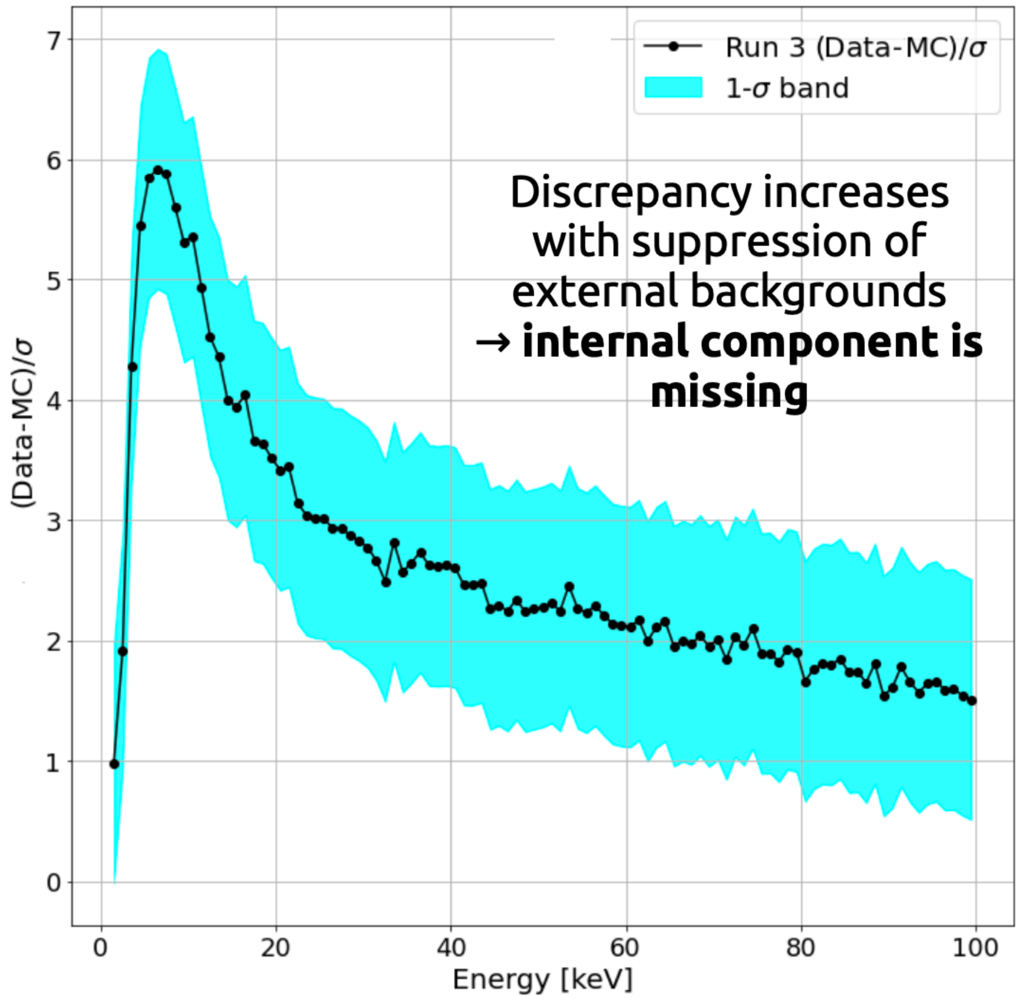


Data/MC difference ± 22%

LIME underground data/MC comparison results

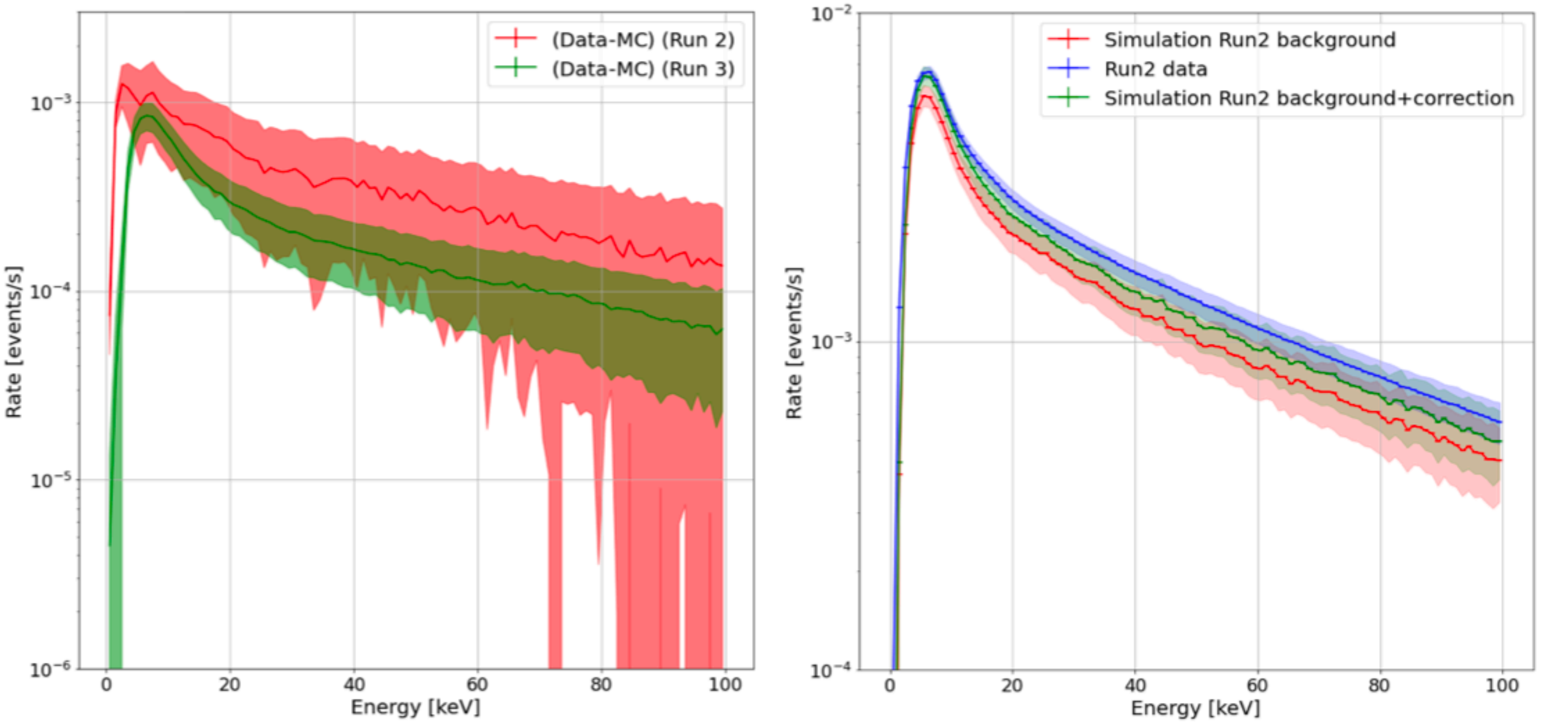
Run3: dominated by internal gamma background (internal 86%)





Data/MC difference ± 60%

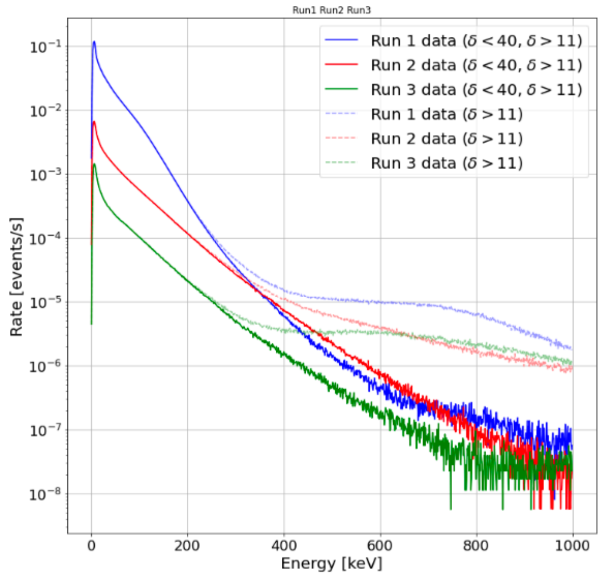
The missing component



- Data/MC difference increasing with increasing shielding thickness/increasing suppression of external backgrounds
- Data/MC difference consistent between Run2 and Run3 even with an order of magnitude difference of overall rate
- Indicating an internal component not considered in the MC simulation
- Missing component of $O(10^{-2})$ events/s

A closer look into the missing component

- **Excess of α** events in all runs (long, dense tracks)
  - Alphas from GEANT4 (not digitized) are not enough to explain the excess
- Due to varying gas conditions (charge gain saturation) energy measurement not feasible



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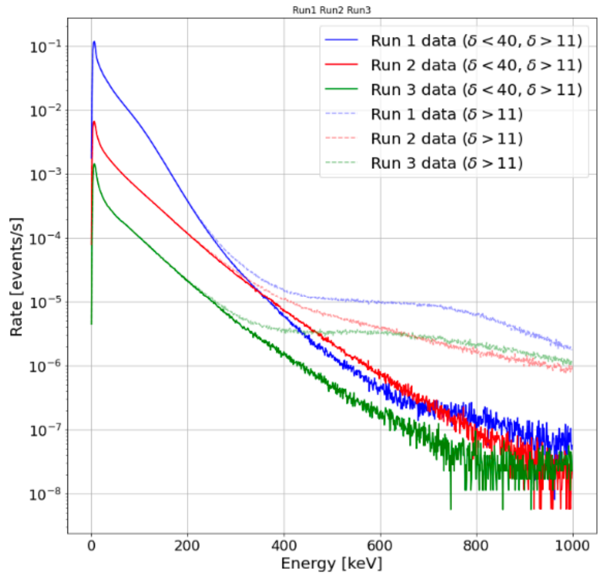
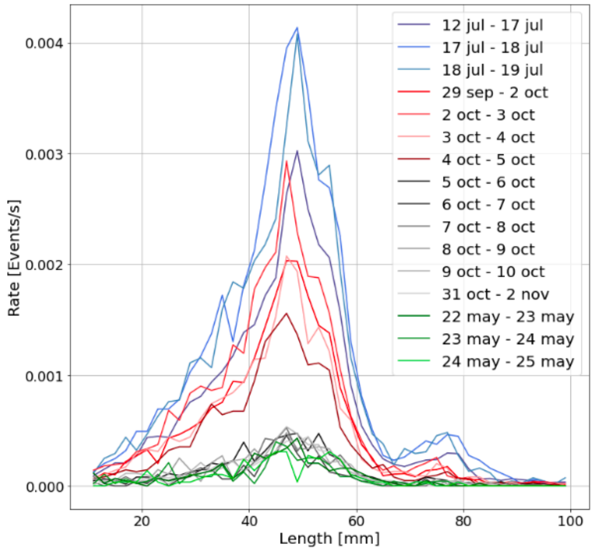
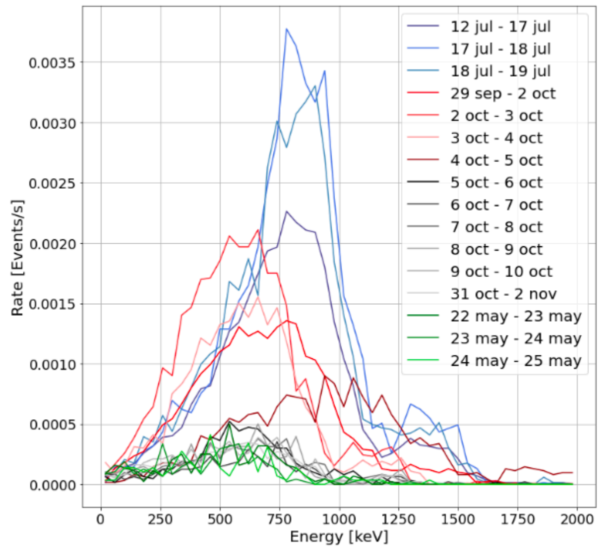


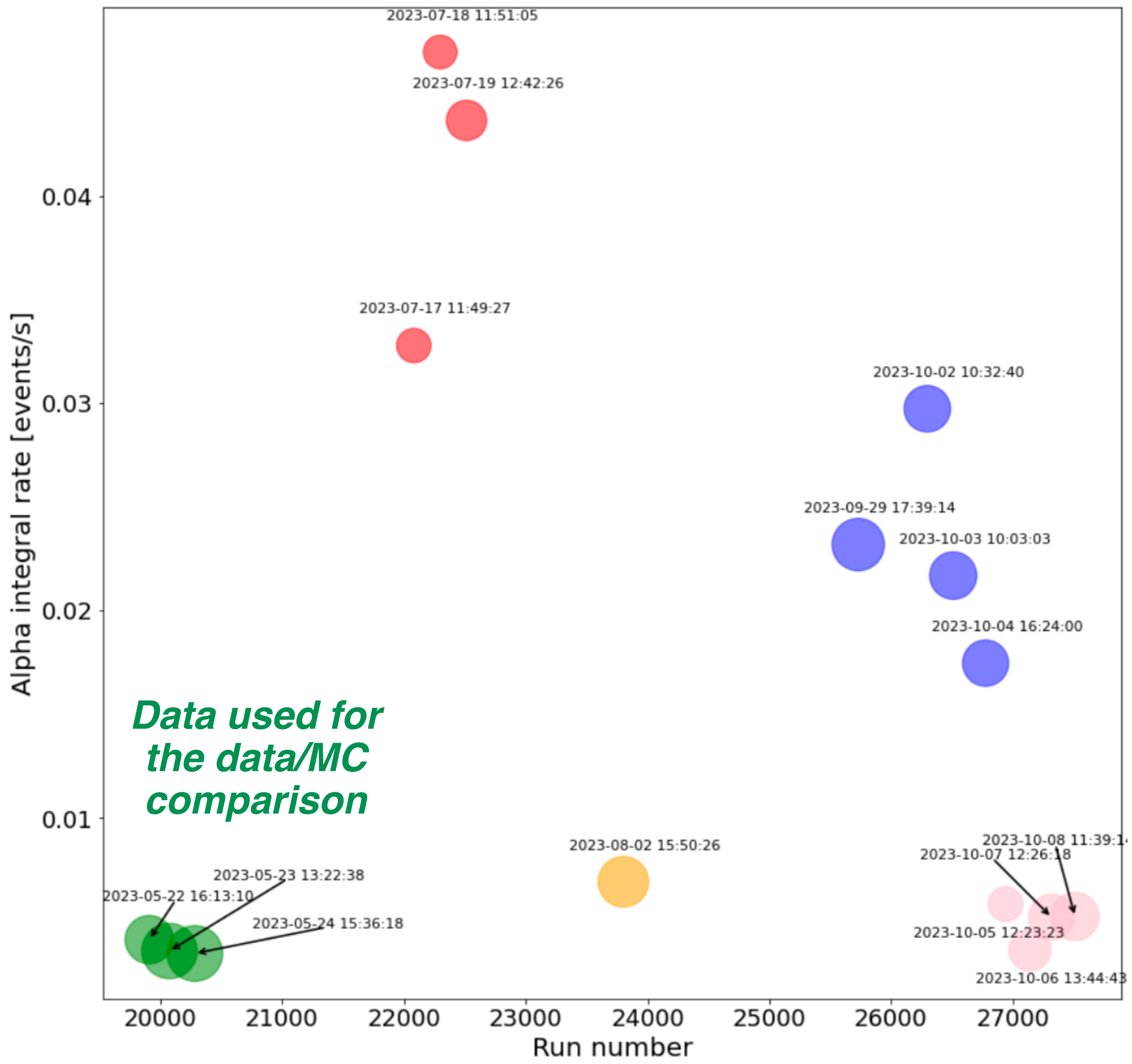
- **Length** distribution indicates peaks around 5.9 MeV, 6.6 MeV, 8.1 MeV peaks (might be ^{222}Rn)
- Radioactive contamination might also induce beta and gamma events, populating the **low energy region**
- Further studies to identify the source (ongoing)





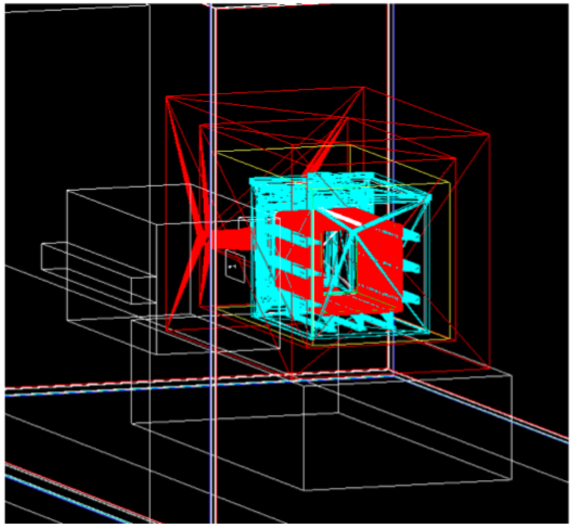
Intervention on gas system and alpha rate

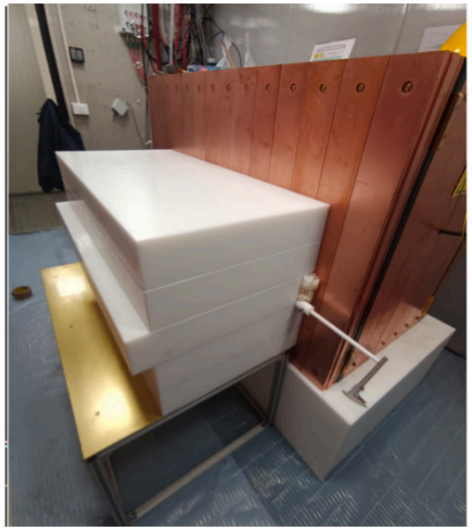
- Alpha event rate change over time, related to **gas system conditions**
  - May: no recirculation
  - July: start of recirculation
  - August (AmBe): filter change
    - Gas system failure
  - October: filter change
- Gas system interventions introduce **radioactive contaminants** (not expected, not simulated)
- Alpha contamination level O(0.1-1) Bq/m^3

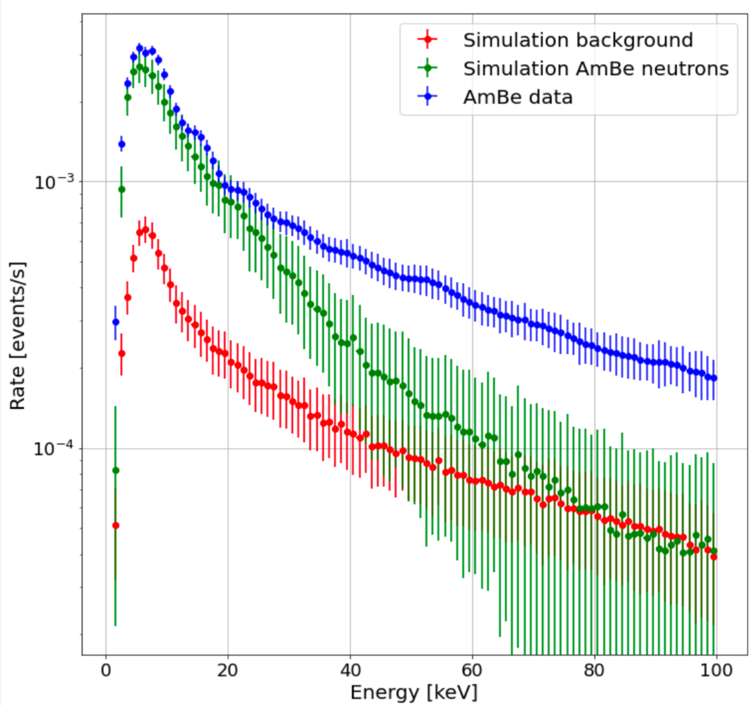


The size of the circle is proportional to the measured LY

AmBe data taking campaign during Run3

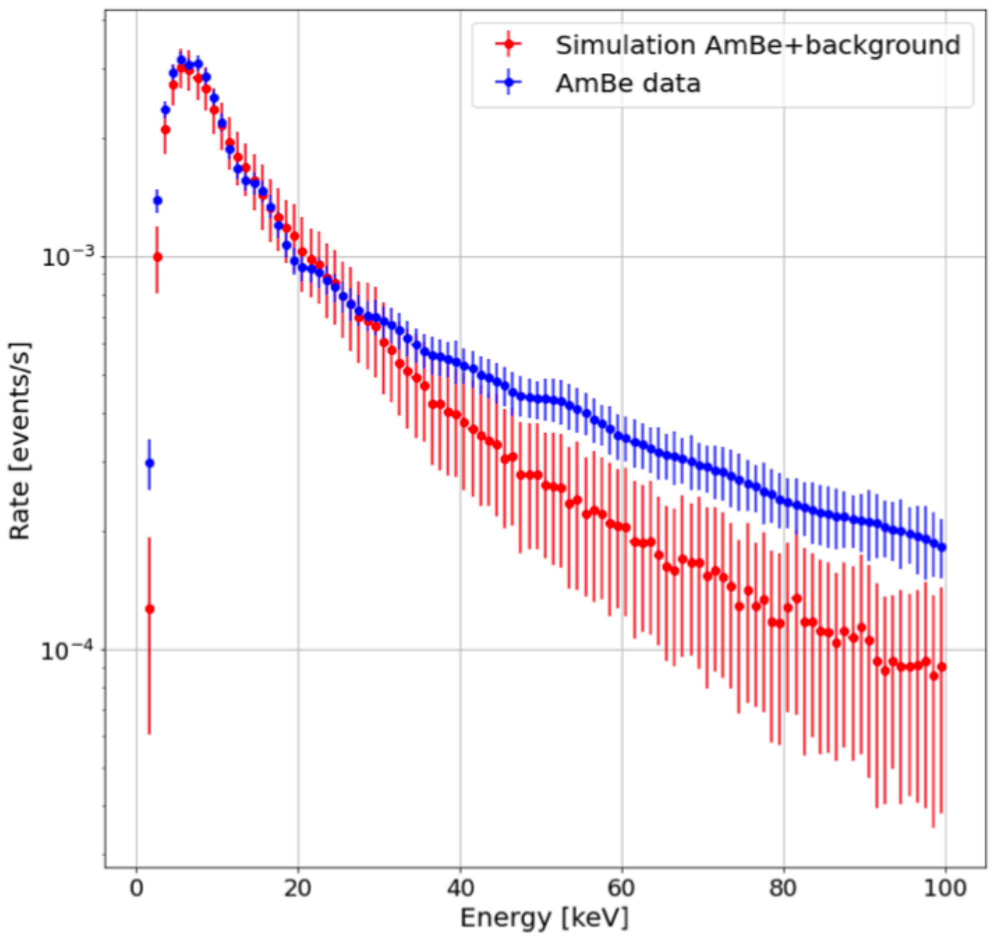


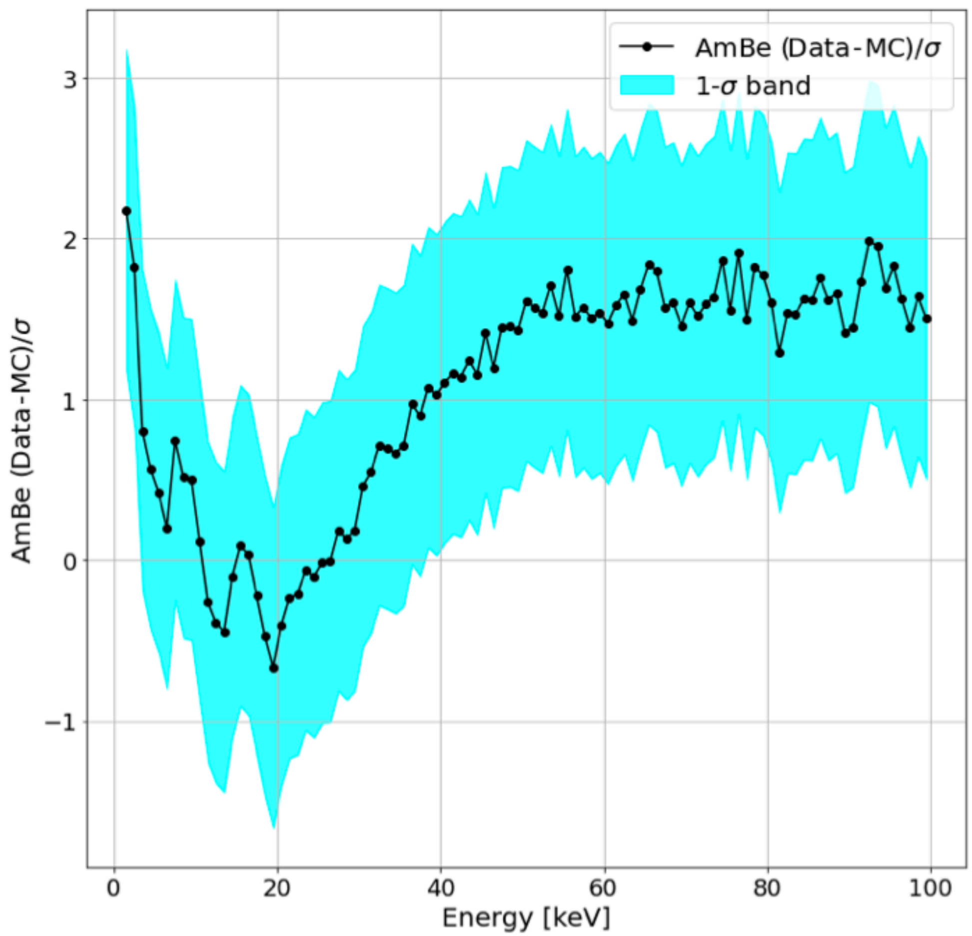




- **During AmBe ^{55}Fe calibrations only at the center of detector to minimise human intervention**
- **Same energy calibration, time normalisation and quality and selection cuts as background analysis**
  - **Except for delta < 40 to not remove NR**
- **AmBe induced events dominate backgrounds of 1 order of magnitude <20 keV**
- **AmBe induced events comparable to backgrounds between 20 and 50 keV**
- **Backgrounds dominating > 50 keV**

AmBe data/MC comparison





- **Missing component consistent between AmBe data and Run2/Run3, further validating our hypothesis of an internal common (likely gas-related) unforseen radioactive contamination**

Conclusions from LIME Run1,Run2, Run3 and AmBe data analysis and MC comparison

- Consistency of AmBe data and simulation below 20 keV where the Ambe contribution dominates over the backgrounds
    - correct relative normalisation of data and MC and of the energy calibration

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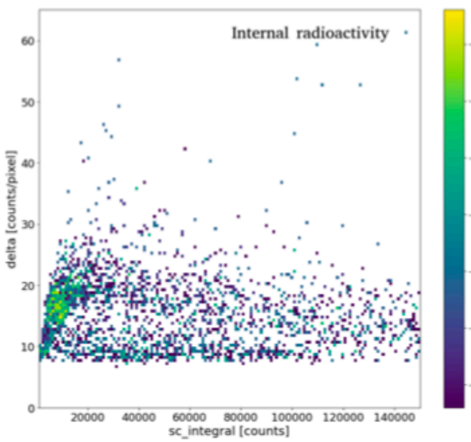
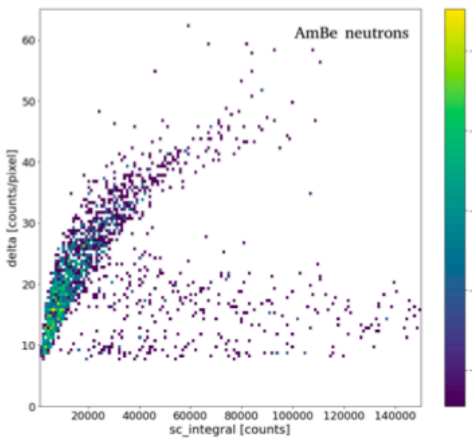
- Low radioactivity Radon filter installed at the end of March 2024, Radon monitor to be installed soon

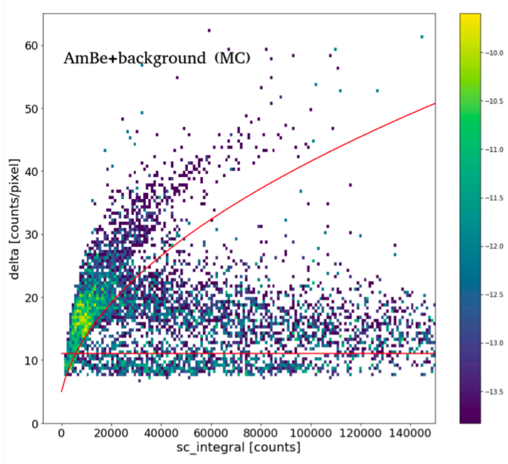
Preliminary estimate of ER/NR discrimination on LIME data

AmBe data: NR identification/ER rejection with classical approach

Same energy calibration, time normalisation and quality and selection cuts as background analysis, except for delta < 40 to not remove NR

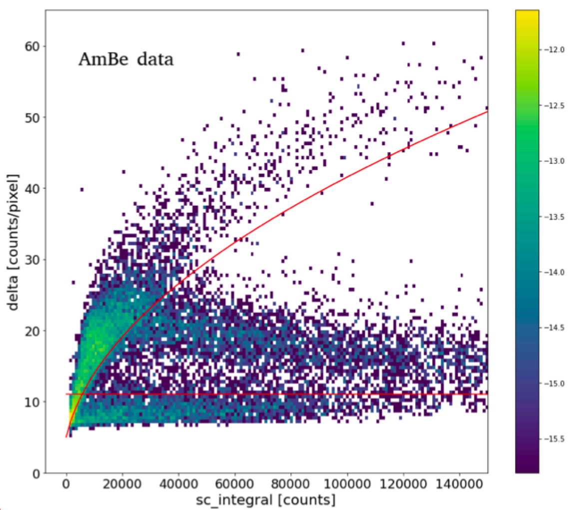


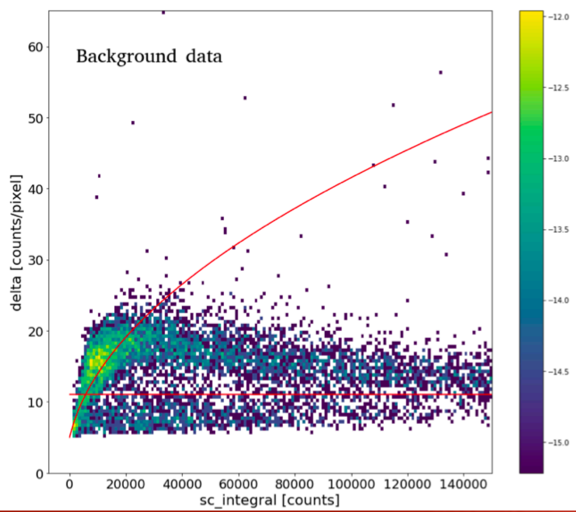




MC simulation

uncalibrated dE/dx versus uncalibrated E





LIME AmBe/ background data

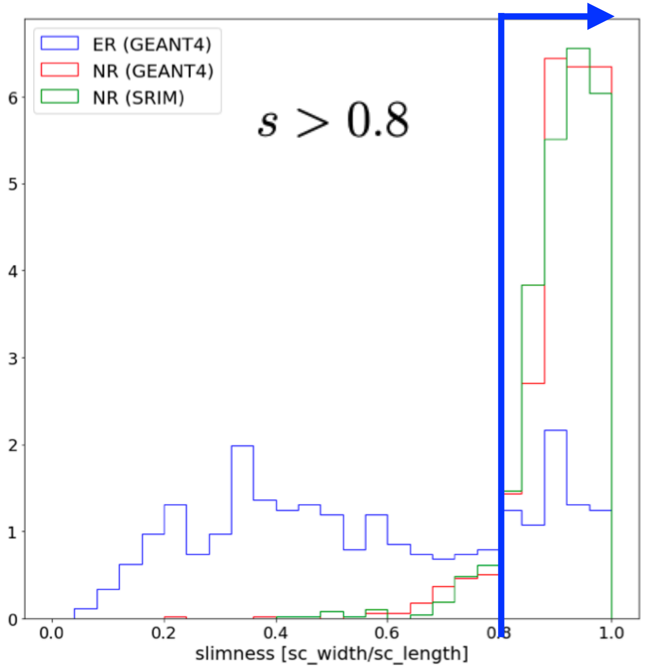
$$\delta > \sqrt{a + bI}$$

$$a = 25 \text{ and } b = 0.017$$

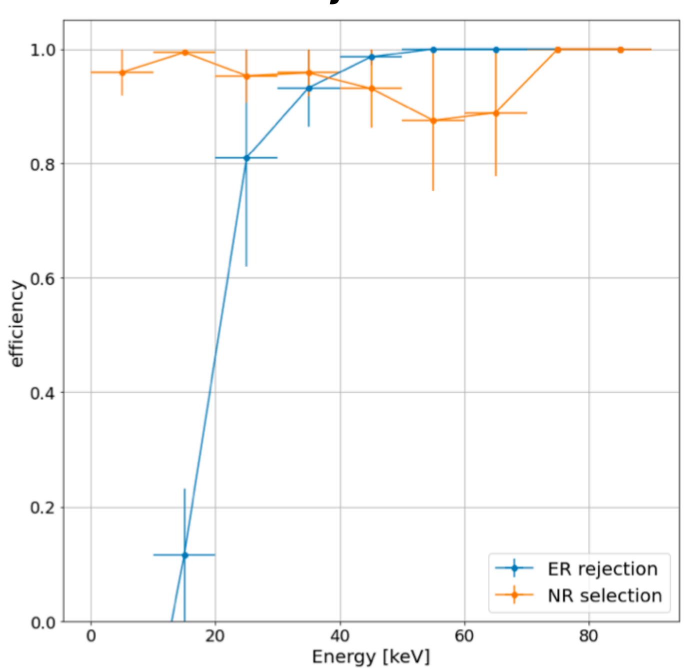
NR selection cut optimised on MC simulation

AmBe data: NR identification/ER rejection with classical approach

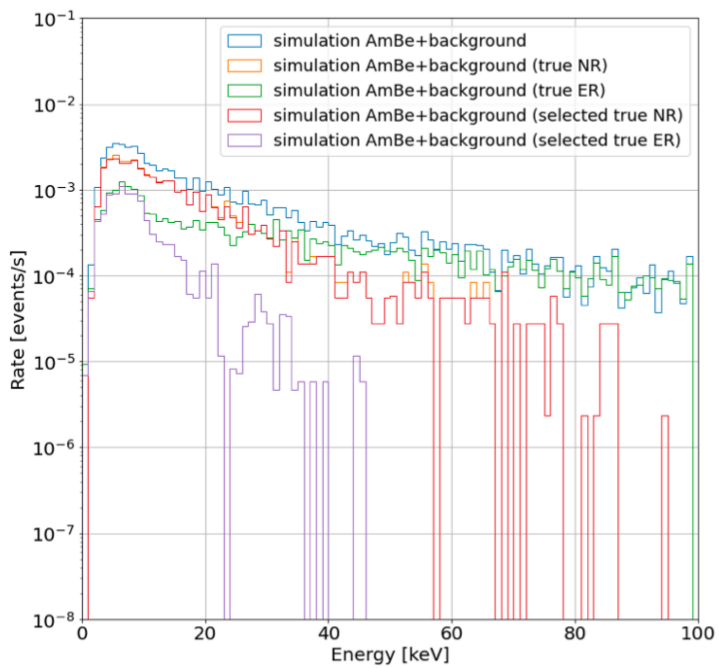
Ratio minor/major track axis



NR efficiency/ER rejection



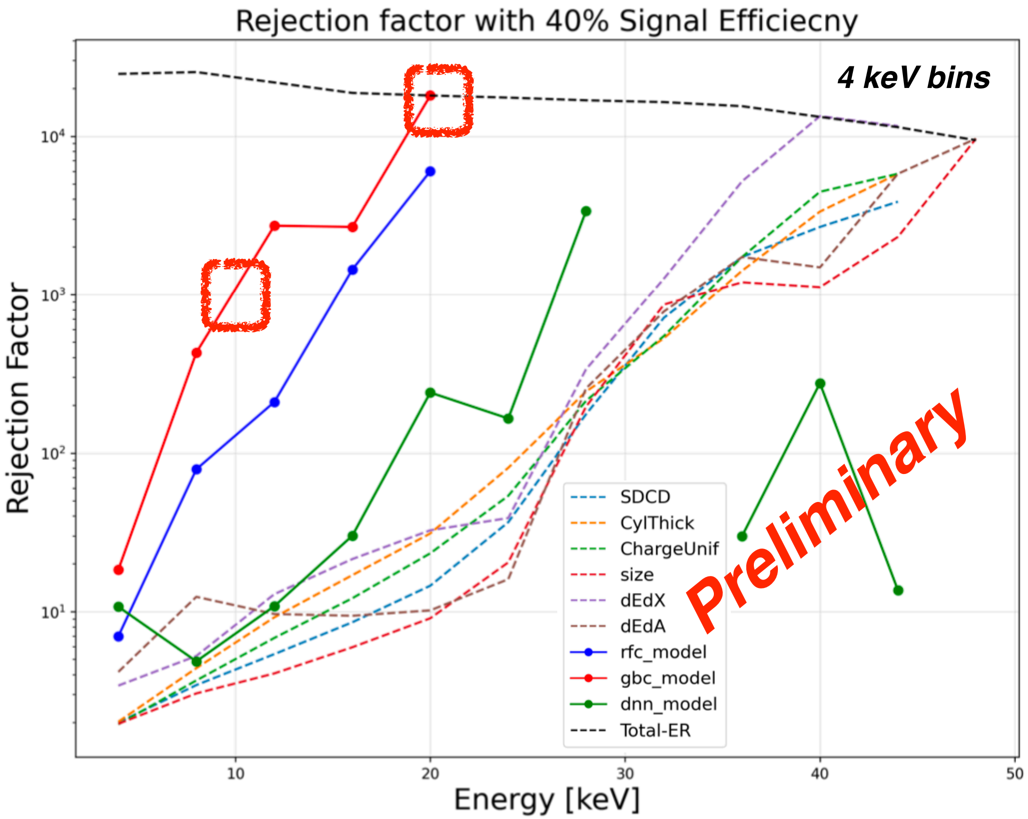
AmBe spectrum after selection



- Simple selection optimized on MC, cut on **track energy density** and **slimness** yields good **ER rejection** (>80% at 20 keV)
- Preliminary demonstration of feasibility of neutron flux measurement (Run 5)
- ML algorithm developments ongoing for ER/NR discrimination

Preliminary results from ML techniques

Rejection factor on MC full simulation



3 deep lerning models developed and compare with classical analysis on track shape variable

indication of background rejection > 10^4 @ 20 keV

CYGNO near future

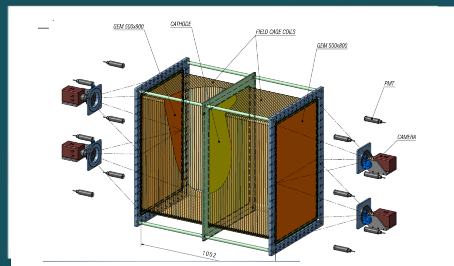
PHASE 1:

O(1) m^3 Demonstrator

2024/26

LNF/LNGS

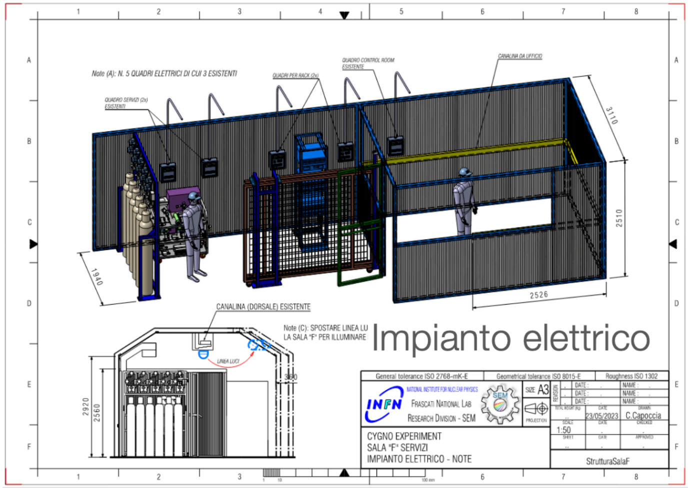
CYGNO_04



- background
- materials test, gas purification
- scalability

Towards CYGNO-04 realisation

- **An (unforeen necessary) formal agreement between GSSI and LNGS for the realisation of infrastructure works was signed by end of March 2024**
- **Technical design validation by the company to be completed by mid May 2024 will be immediately followed by formal awarding of the contract**



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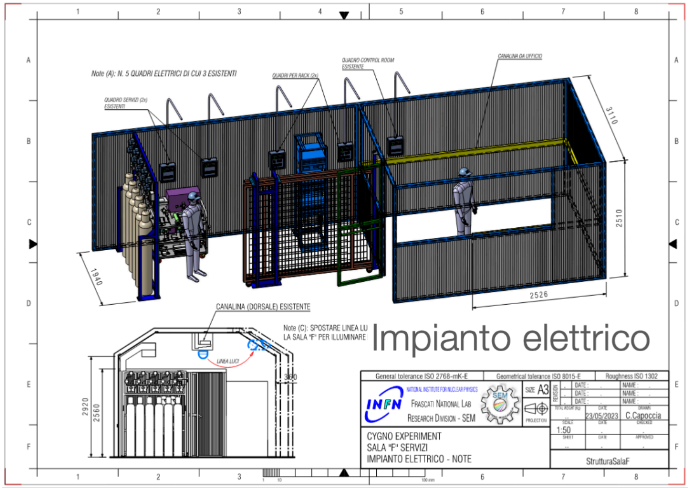

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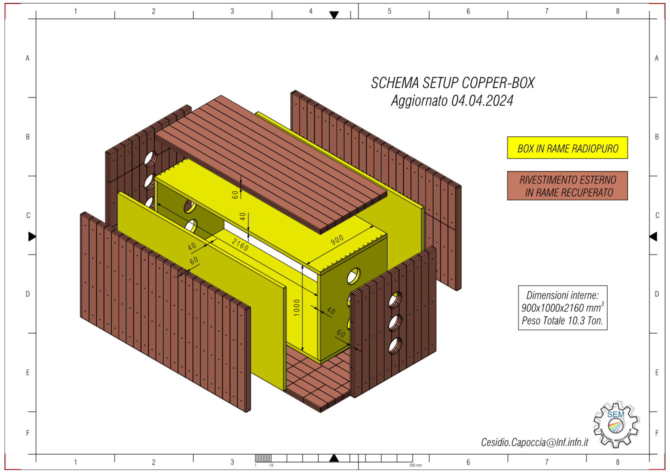

- **Detector and shielding design under finalisation**
- **Main detectors materials and components identified and construction procedures under test and validation**

Towards CYGNO-04 realisation

More details in the closed session

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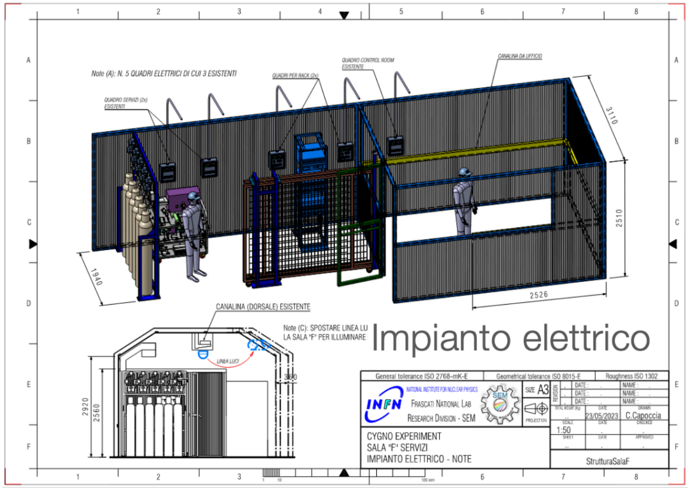

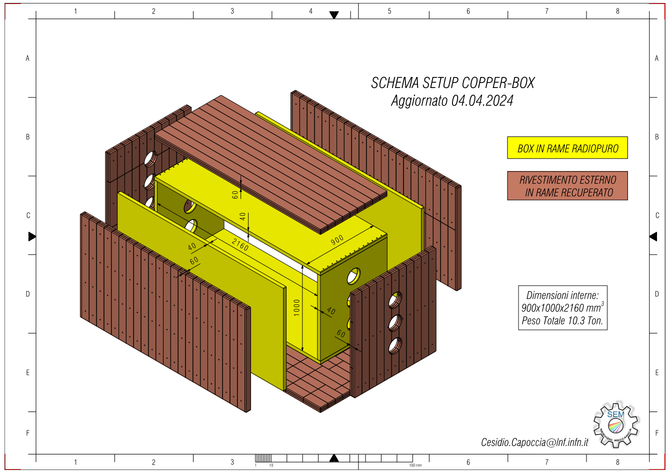

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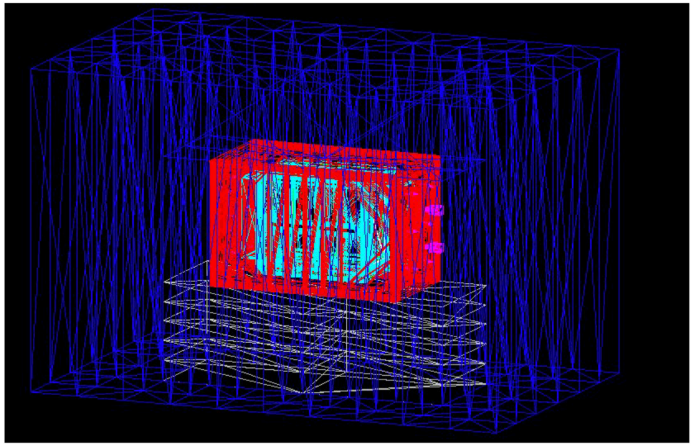
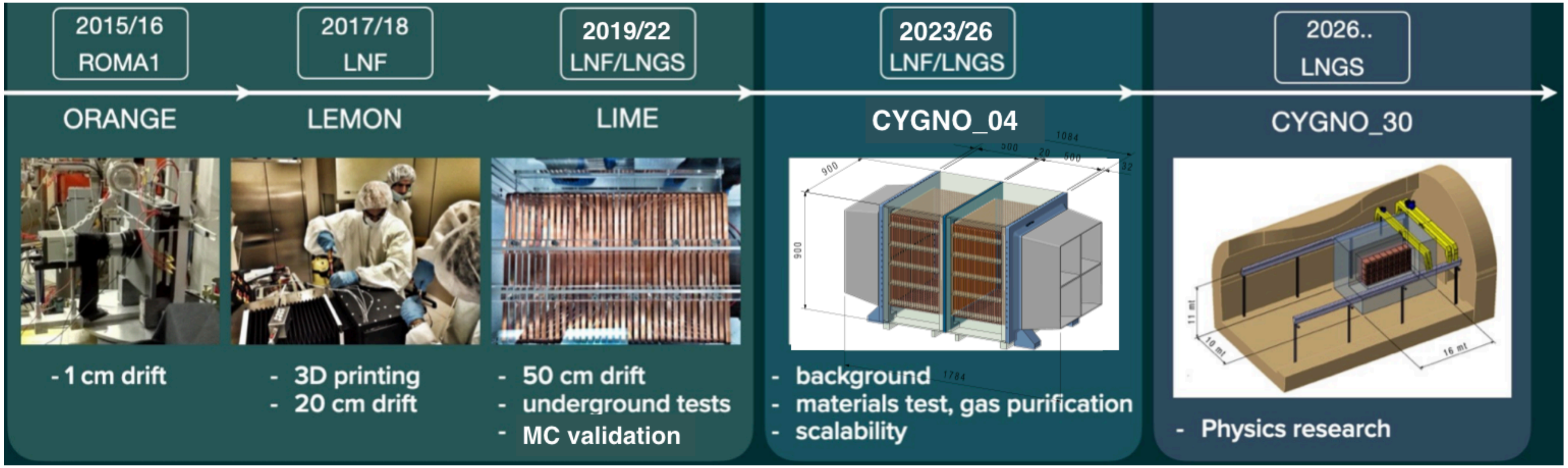


- Nearly final design implemented in GEANT-4
- Preliminary evaluation of external gammas in full shielding configuration performed
- Full simulation of internal and external backgrounds ongoing

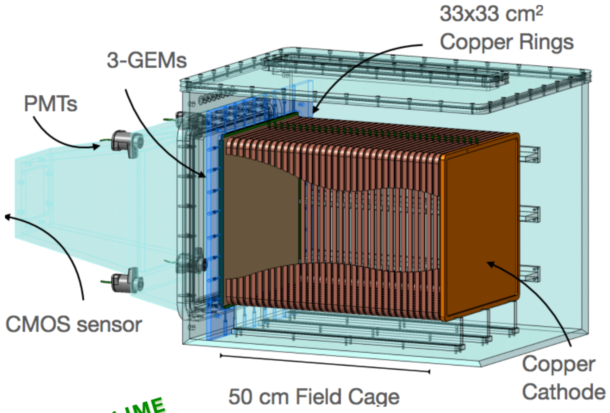
Conclusions & Outlook

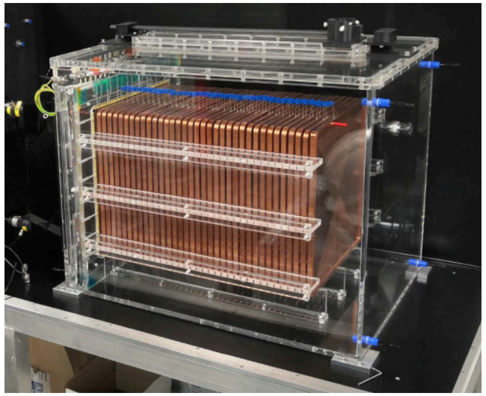
- PHASE 0 has been successful in realising its goals
  - LIME underground operation proceeding since > 1 year
  - Auxiliary systems improved and validated
  - Computing infrastructure realised and validated
  - External shielding effect on backgrounds validated
  - MC simulation validated and unforeen background contamination likely identified
  - Stable and high quality detector operation achieved with full auxiliary systems configuration
- Development towards CYGNO-04 realisation advancing
  - Infrastructures to be completed in a couple of months
  - Detector and shielding design under finalisation
  - Main detector materials and components identified and construction procedures under test
  - Full background simulation ongoing



BACKUP

CYGNO PHASE 0: overground commissioning

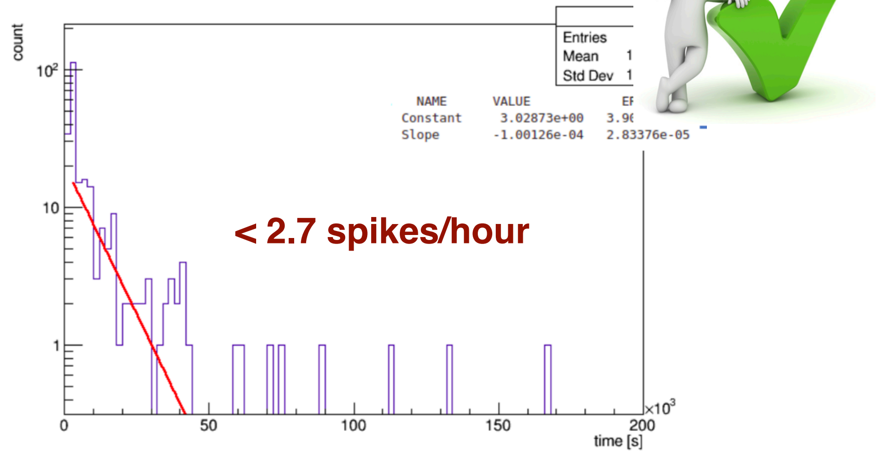




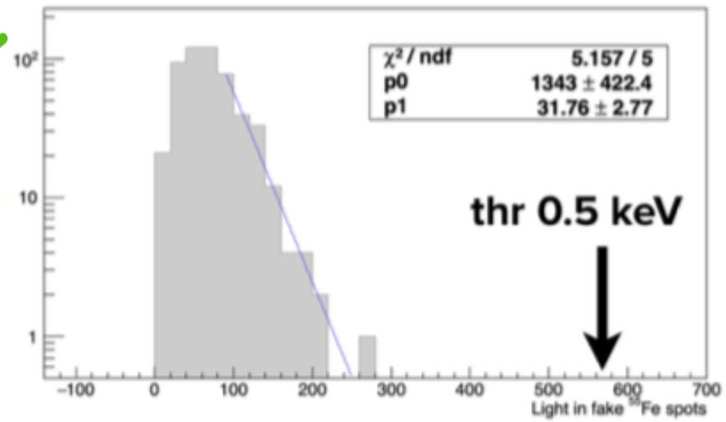
He:CF4 @ 1 atm

1 sCMOS + 4 PMT + 3 GEMs
33 x 33 cm² area
50 cm drift, 50 L active volume
Base module of PHASE 1 design

Stability



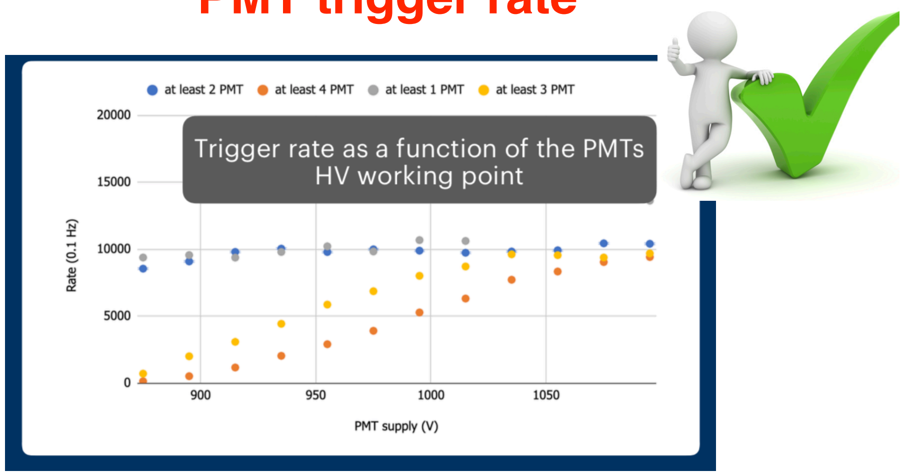
sCMOS fake clusters threshold



ORCA-Fusion

1 keV = 1200 photons

PMT trigger rate

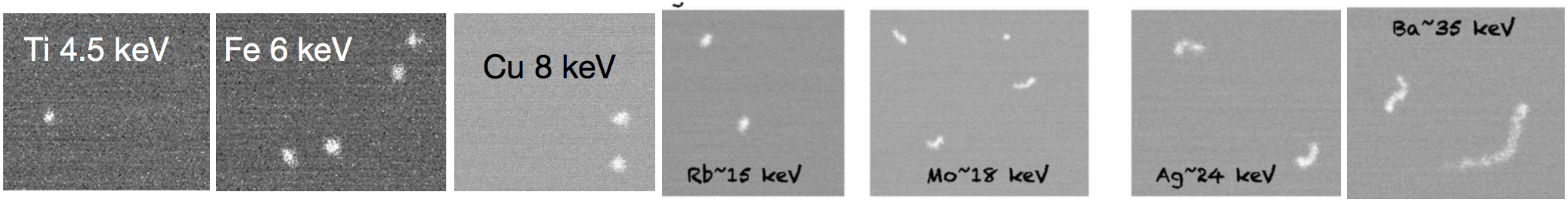


Different Trigger logics were tested with ^{55}Fe;
All of them converge to the same rate of 1 kHz

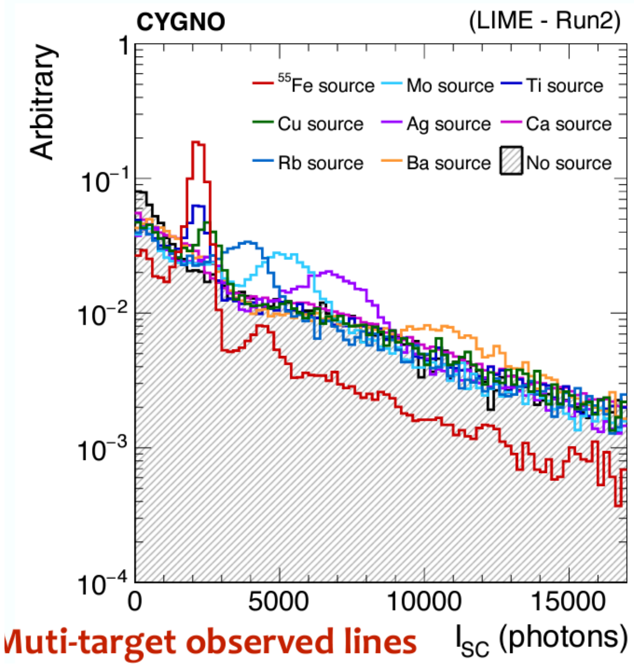
Eur. Phys. J. C 83 (2023) 10, 946

LIME overground commisioning @ LNF

Electron recoils calibration

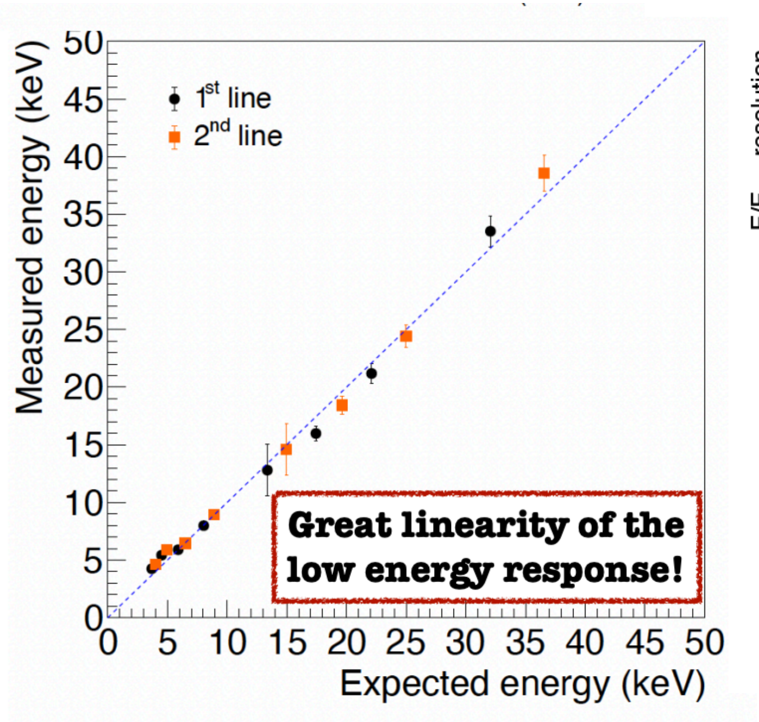


Multi-source + bkg spectrum

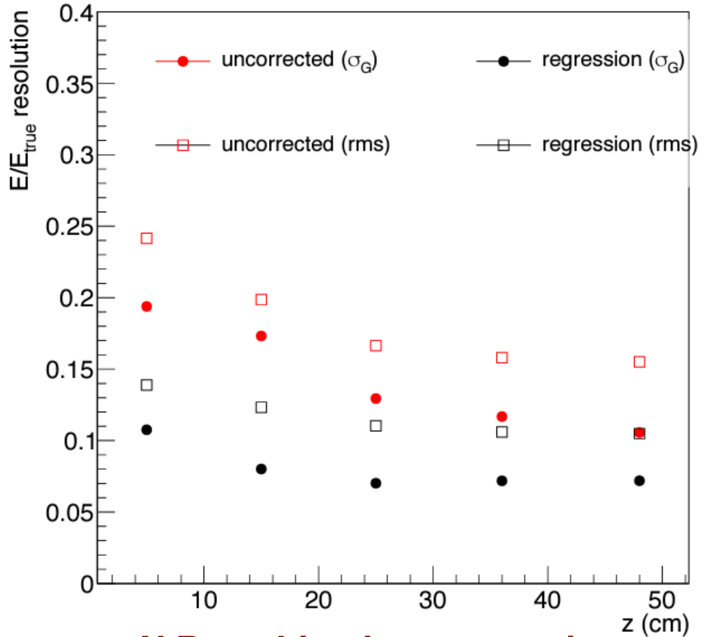


Muti-target observed lines

Energy response linearity



Energy resolution

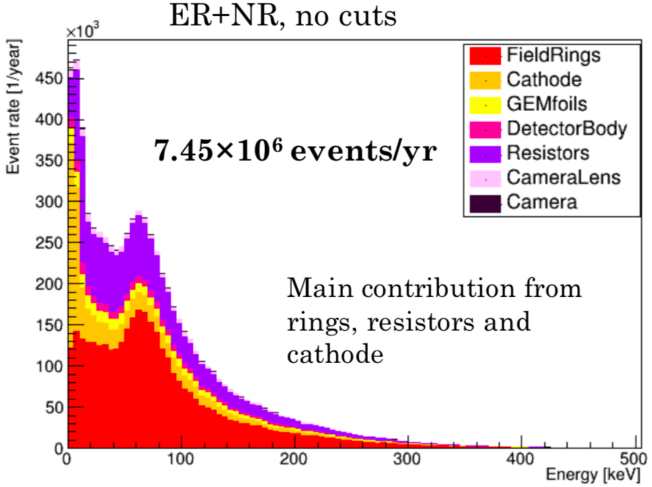


N.B. multivariate regression to correct for detector response disuniformities

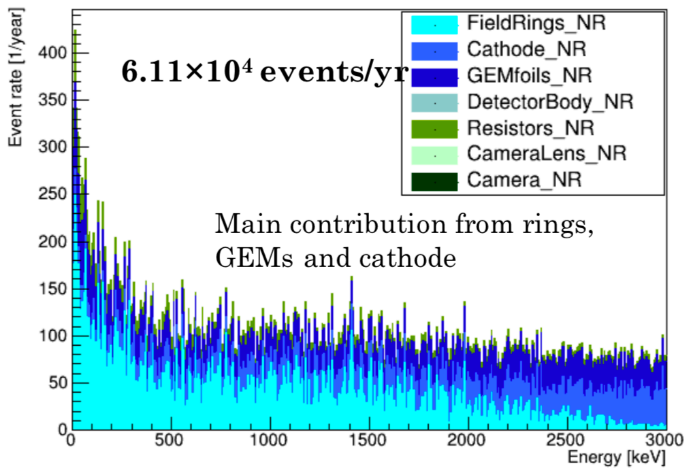
PHASE 0 internal backgrounds simulation

- **Radioactivity** from natural radioactive decay chains ^{232}Th, ^{238}U, ^{235}U and other contaminants
- Activity of all main components of LIME were measured underground by M.Laubestein:
  - Acrylic box
  - Field rings
  - Cathode
  - Resistors
  - GEMs
  - Camera (body + lens)

ER+NR, no cuts



Only NR, no cuts



	Radionuclide	FieldRings	Cathode	Resistors	GEM	Acrylic	Camera body	Camera lens
^{238}U chain	234Th	<2,10E-01	<2,10E-01	1,99E+01	1,63E-01	-	3,16E+00	4,22E+00
	234mPa	<7,70E-02	<7,70E-02	2,19E+01	-	-	-	-
	226Ra	<1,30E-03	<1,30E-03	2,16E+00	3,25E-02	<3,50E-03	8,13E-01	1,92E+00
	210Pb	-	-	5,94E+02	-	-	-	-
^{232}Th chain	228Ra	<1,10E-03	<1,10E-03	3,50E+00	<3,09E-02	<5,00E-03	9,49E-01	3,61E-01
	228Th	<1,30E-03	<1,30E-03	3,36E+00	<1,56E-02	<4,50E-03	9,49E-01	3,65E-01
^{235}U chain	235U	<1,60E-03	<1,60E-03	3,37E-01	<1,58E-02	-	1,81E-01	1,45E-01
Other	40K	<6,00E-03	<6,00E-03	<1,78E+00	<3,58E-01	<3,50E-02	8,59E-01	5,15E+01
	137Cs	<4,70E-04	<4,70E-04	<7,35E-02	<8,13E-03	-	4,07E-02	<2,67E-02
	60Co	<5,70E-04	<5,70E-04	<7,73E-03	<7,48E-03	-	<5,42E-03	<4,64E-02
	58Co	9,00E-04	9,00E-04	<3,10E-03	-	-	-	-
	Mn54	<4,30E-04	<4,30E-04	<3,27E-03	-	-	-	-
	La138	-	-	-	-	-	-	2,44E+00

Thanks to LNGS Services

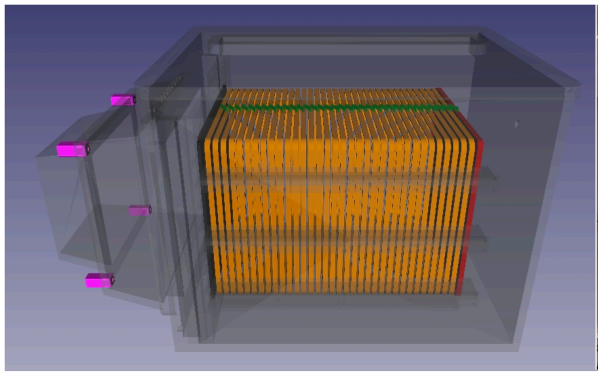
Simulation performed including both measurements and limits

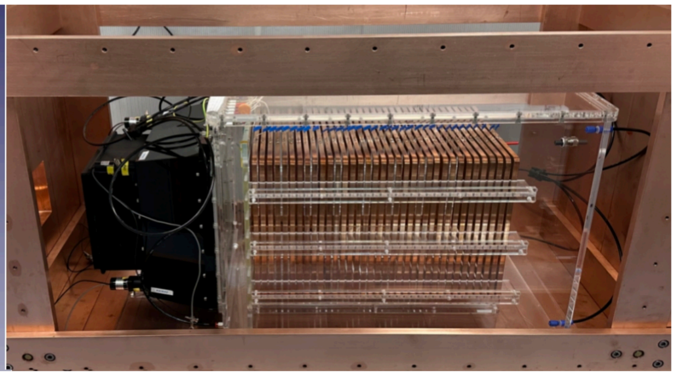
NOTE: internal background can be reduced of 96% (99% for NR) with fiducial cuts

LIME backgrounds Geant4 simulation

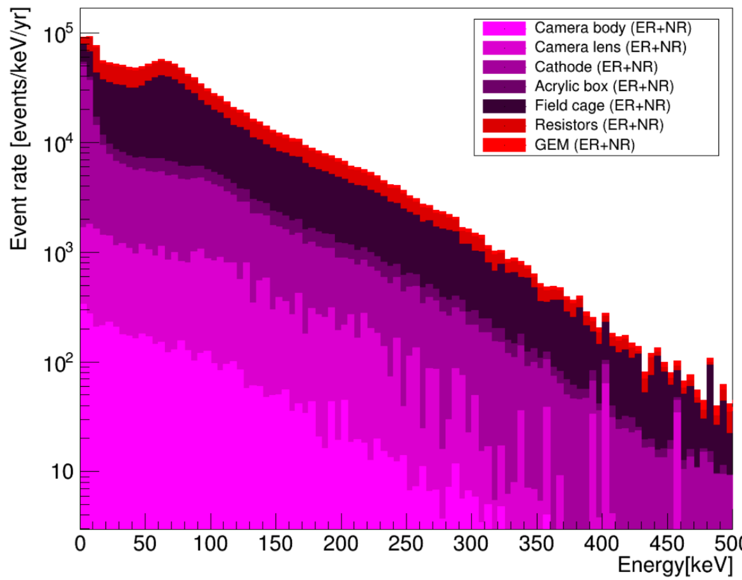
- **LIME components and shielding imported from technical CAD design**
- **Intrinsic radioactivity of main LIME materials as measured by LNGS Special Techniques Division**
  - **Cu field cage rings, field cage resistors, Cu cathode, GEMs, acrylic vessel, camera body, camera lens**
  - **camera body and lens results <u>subdominant w.r.t. others</u>**
- **Cu shielding radioactivity as measured by LNGS Special Techniques Division**
  - **From Opera dismissed Cu bars**
  - **<u>Subdominant</u> w.r.t. internal backgrounds**
- **Radiogenic and cosmogenic neutrons from shielding**
  - **<u>Subdominant</u> w.r.t. internal backgrounds**

Many thanks to LNGS Special Techniques Division





Field cage Cu bars, resistors and Cu cathode dominate total background



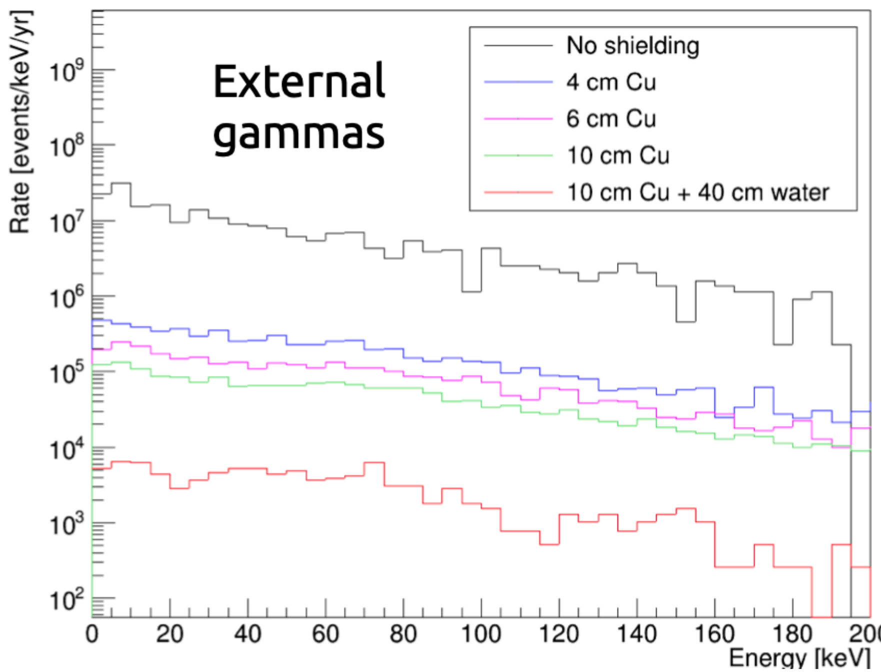
Source	Event rate [10^6 yr^{-1}]
Field cage	(3.57±0.01)
Resistors	(1.873±0.006)
Cathode	(1.095±0.001)
GEMs	(0.3891±0.0002)
Vessel	(0.268±0.001)
Camera lens	(0.151±0.004)
Camera body	(0.0242±0.0005)
TOTAL	**(7.34±0.01)**

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

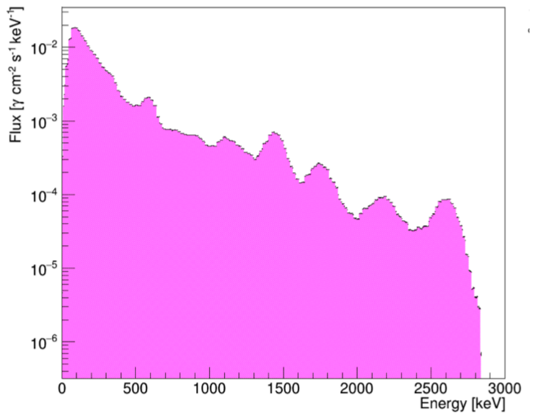
Please note LIME was NOT built with radioactive pure components

LIME backgrounds Geant4 simulation

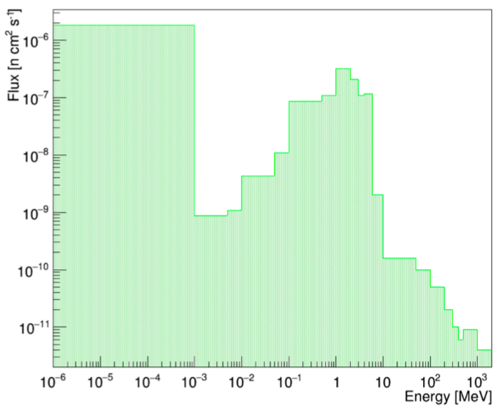
- **External gammas and neutron fluxes from previous measurements**
- **A staged shielding approach was devised to better:**
  - measure and validate neutrons and gamma shielding capability to suppress external backgrounds
  - validate MC simulation of internal and external components
- **After optimisation, four stages were chosen**
  - No shield (Run1)
  - 4 cm Cu shield (Run2)
  - 10 cm Cu shield (Run3)
  - 10 cm Cu + 40 cm H_2O shield (Run4)



Input gamma (left) and neutron (right) fluxes for the simulation



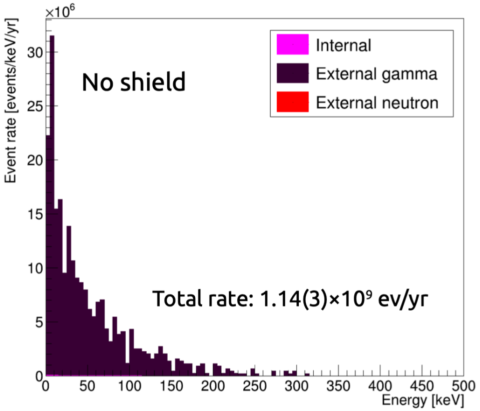
SABRE collaboration



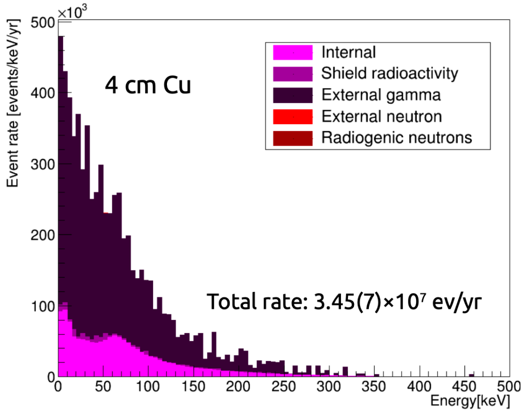
Phys.Rev. D73 053004 (2006)
Il Nuovo Cimento A 101 (1989)
Il Nuovo Cimento A 112.A (1999)

Shielding	Gamma background [10^6 ER yr^{-1}]	Neutron background [NR yr^{-1}]
Unshielded	(1140±30)	(1480±90)
4 cm Cu	(26.2±0.6)	(870±10)
6 cm Cu	(9.4±0.3)	(1000±30)
10 cm Cu + 40 cm H_2O	(0.5±0.2)	(2.0±0.2)

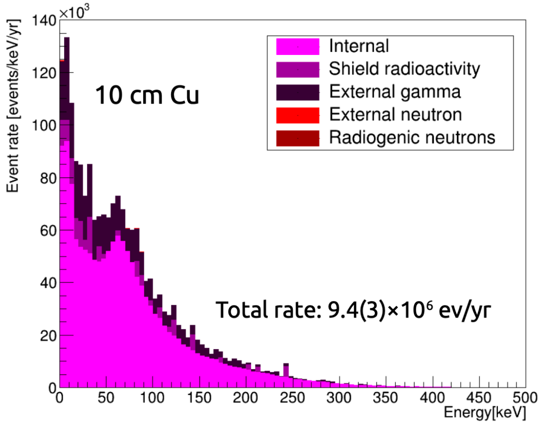
Total LIME expected backgrounds



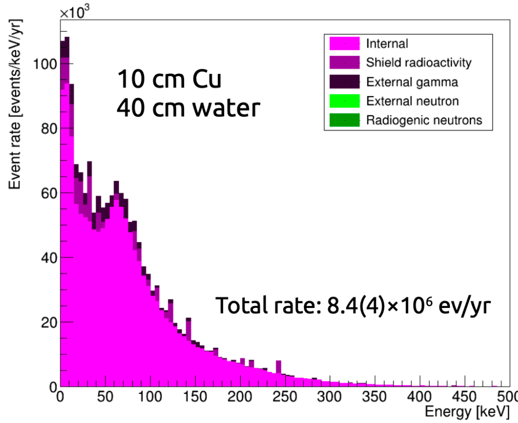
Completely dominated by external gammas
(internal is 0.6% of total)



Starting to probe internal background
(internal is 20% of total)



Internal background gives major contribution
(internal is 78% of total)



Largely dominated by internal background
(internal is 87% of total)

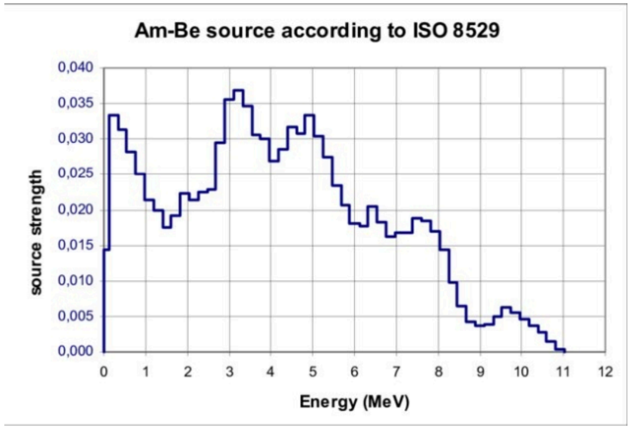
Phase	External		Internal		Total		internal/external
	ER [10^6 yr^{-1}]	NR [yr^{-1}]	ER [10^6 yr^{-1}]	NR [yr^{-1}]	ER [10^6 yr^{-1}]	NR [yr^{-1}]	
Run 1	1140 ± 35	1480 ± 90	7.34 ± 0.01	79000 ± 470	1140 ± 35	80480 ± 480	0.6%
Run 2	26.6 ± 0.6	870 ± 10	7.87 ± 0.3	79000 ± 470	34.5 ± 0.7	79870 ± 470	20%
Run 3	1.49 ± 0.04	930 ± 25	7.88 ± 0.3	79000 ± 470	9.37 ± 0.3	79930 ± 470	78%
Run 4	0.5 ± 0.2	2.0 ± 0.2	7.88 ± 0.3	79000 ± 470	8.38 ± 0.4	79000 ± 470	87%

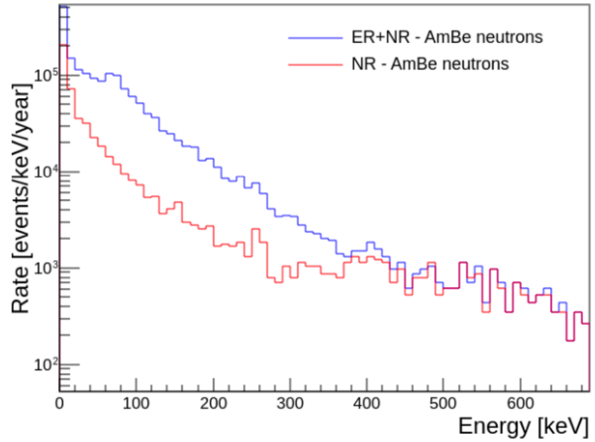
AmBe setup & simulation

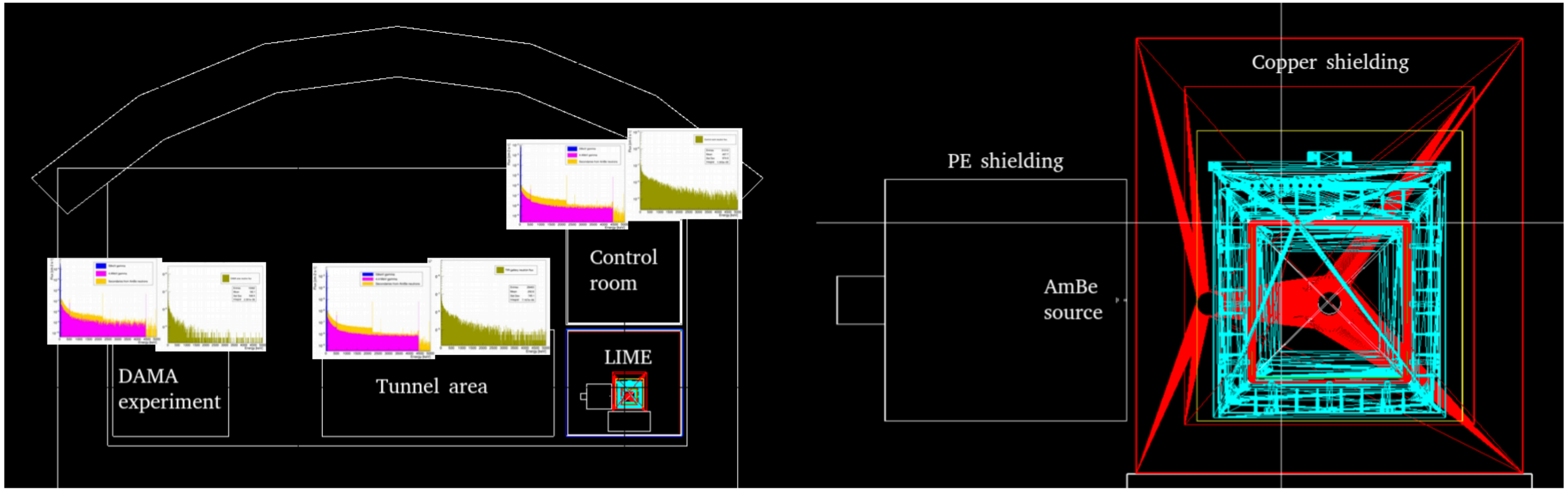
- AmBe neutrons*, 4.43 MeV gamma, 59 keV gamma isotropically emitted

$$\alpha + {}^{9}Be \longrightarrow n + {}^{12}C^{*}$$

- Neutron-induced events dominate over gamma, expected event rate (0.472 ± 0.004) ev/s (ER+NR), (0.146 ± 0.002) NR/s

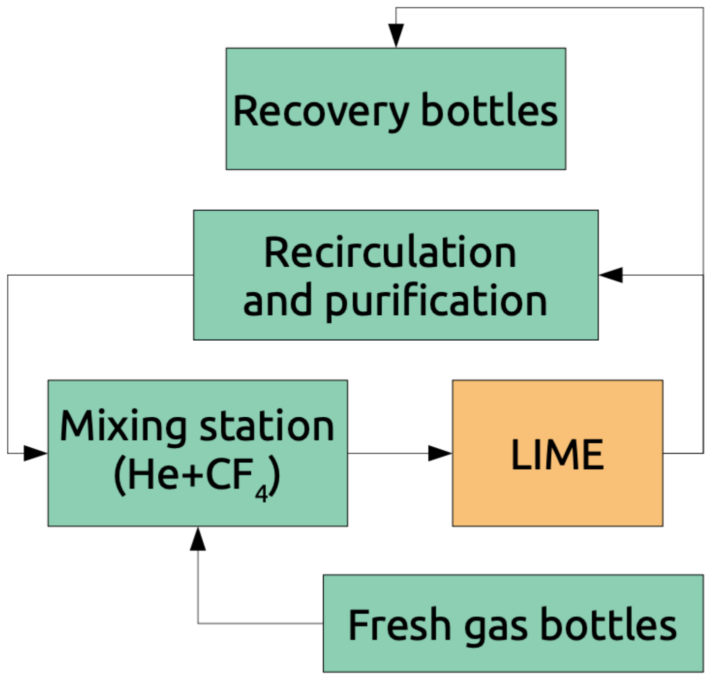






LIME underground operational parameters

- **GEM voltage** at 420 V (440 V) on each GEM in Run 1 (2, 3, 4)
- **Drift field** 800 V/cm
- **Gas system**:
  - Fresh gas flux: between 1 and 20 L/h (to study LY)
  - Recirculation system activated for part of Run 3 (to reduce gas consumption)
- **DAQ**:
  - 300 ms camera exposure
  - Periodic pedestal runs
  - Acquisition trigger on coincidence of 2 out of 4 PMTs



Time normalisation of energy spectra

- MC energy spectra normalized to equivalent time of simulation
- Data normalized to total live time of runs, corrected for dead time

$$\tau = T_{cam} + N_{wf} \cdot t_{wf}$$

Dead time: time for readout of camera and PMT waveforms

$$r_{true} = \frac{k+m}{T_{run}}$$

True event rate: measured rate + rate of events missed during dead time

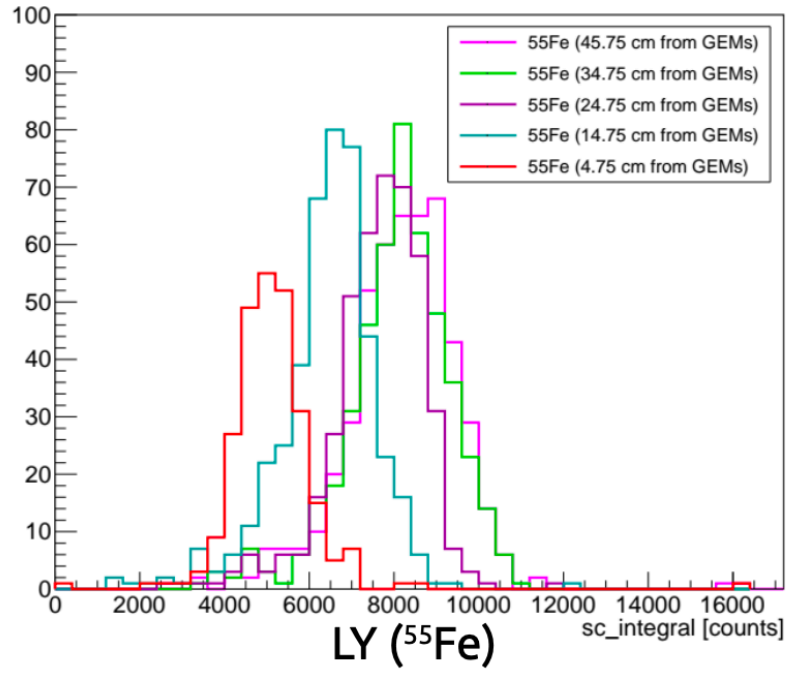
$$D = 1 + \frac{m}{k} = 1 + \frac{T_{cam} + R_{PMT} \cdot T_{window} \cdot t_{wf}}{T_{window}}$$

Correction mainly depends on total trigger rate

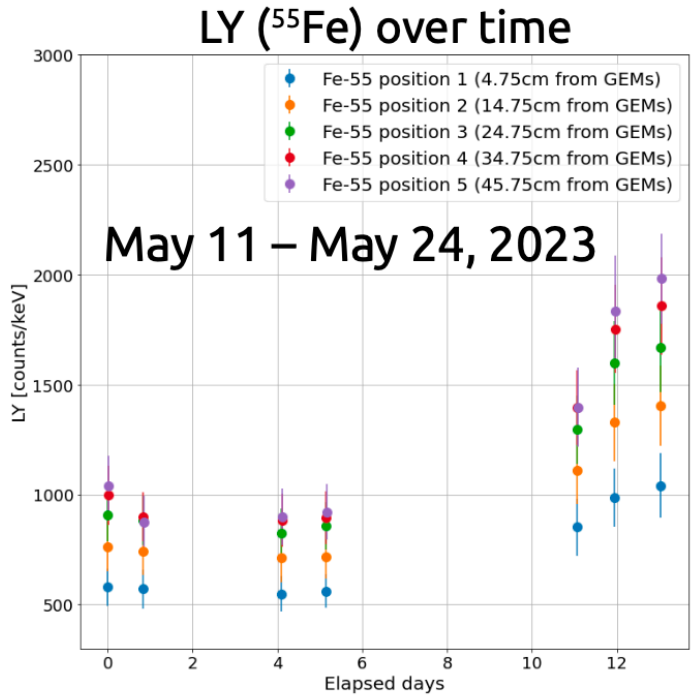
Run 1	Run 2	Run 3
(R_{PMT}~30 Hz)	(R_{PMT}~3.5 Hz)	(R_{PMT}~1.6 Hz)
D = 1.42±0.06	D = 1.104±0.009	D = 1.081±0.007

^{55}Fe calibration & LY monitoring

- 5.9 keV X-ray ^{55}Fe source on top face of LIME, pointing towards gas
- **Daily dataset** taken in 5 positions (only Run 2,3)



Standard candle for **energy calibration**



LY monitoring over time

LIME background datasets considered

In order to maximise consistency among runs, Run3 data analysed are before the introduction of recirculation, i.e. fresh gas flux

A subset of runs were analysed for MC comparison (good LY, stability, gas system operation)

Run 1 (no shield)
Oct 8 - Dec 6 2022

285665 images
~49 hr, Dec 2–6 2022
10 L/h flux

Run 2 (4 cm Cu)
Feb 15 - Mar 9 2023

297992 images
~53 hr, Mar 6–9 2023
20 L/h flux

Run 3 (10 cm Cu)
May 5 - Nov 7 2023

171579 images
~53 hr, May 22–25 2023
20 L/h flux

Run4 is not discussed in this presentation since still on-going to these days

LIME background MC dataset

- From GEANT4 output, only main contributors were digitized and reconstructed: **external gammas**, **intrinsic radioactivity** of field cage rings, resistors, cathode, GEMs, acrylic box

Digitised with standard CYGNO detector response simulation (see backup for details) with:

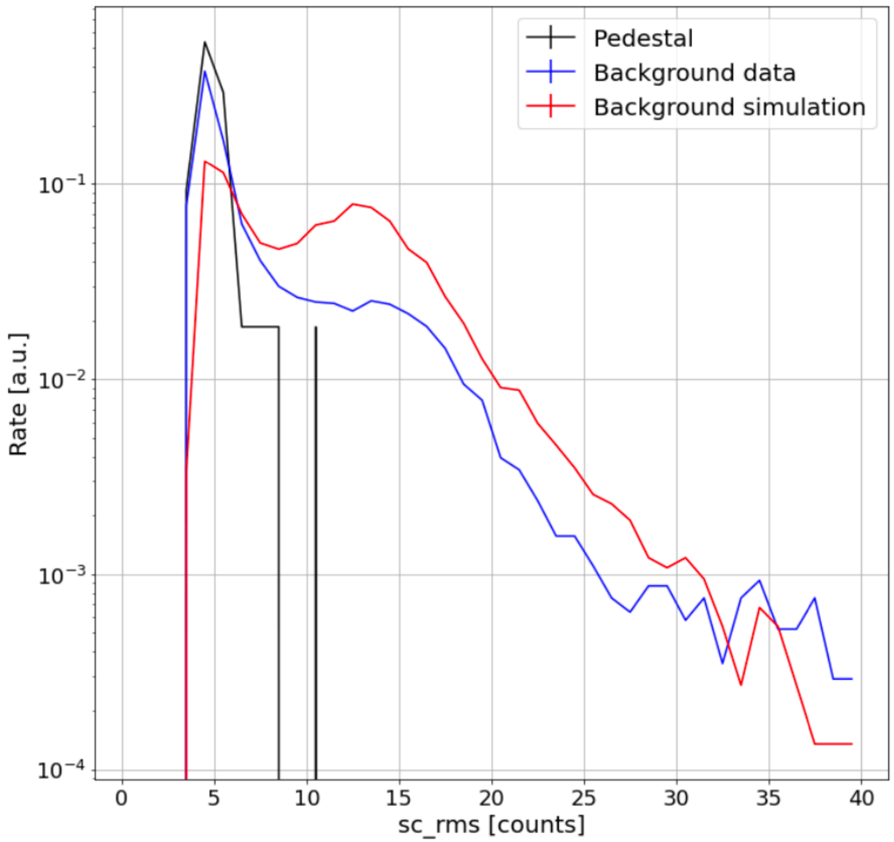
- Sensor noise added from real pedestal images *from underground data*
- Only events with energy deposits <800 keV digitized
- Diffusion parameters

$$\sigma_{0T} = 350\,\mu m, \qquad \sigma_T = 115\,\mu m/\sqrt{cm}, \qquad \sigma_{0L} = 260\,\mu m, \qquad \sigma_L = 100\,\mu m/\sqrt{cm}$$

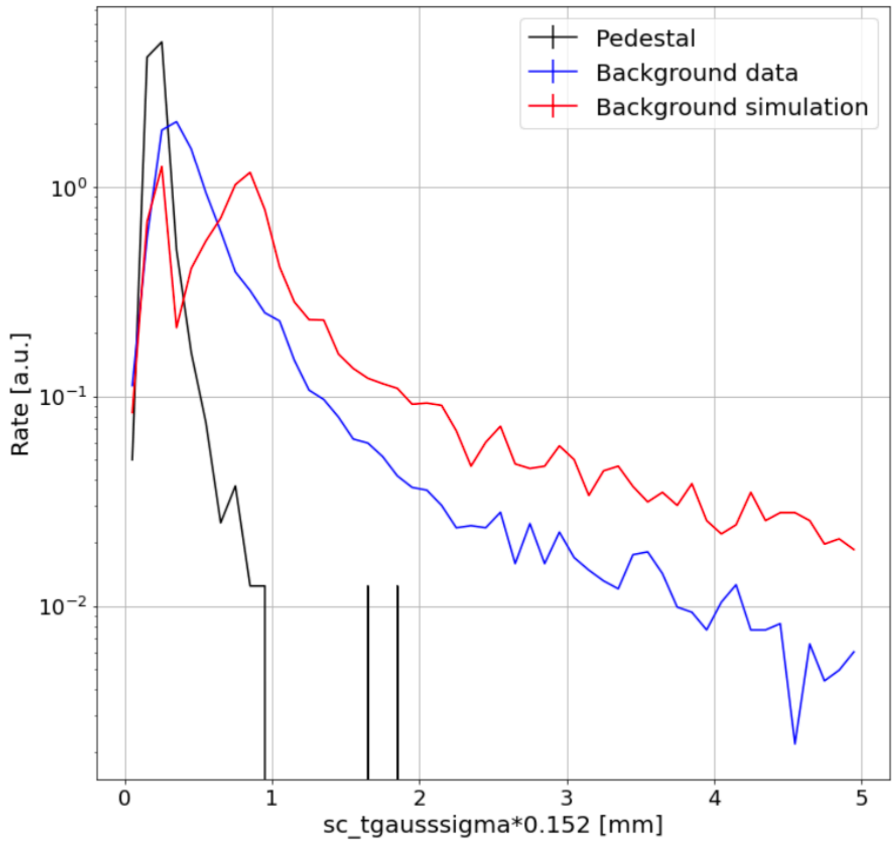
- Images reconstructed with same reconstruction parameters as corresponding data

Corresponding phase	Shielding	V_{GEM} [V]	Background source	Equivalent time [s]
Run 1	None	420	Gammas	3129
			Radioactivity	432000
Run 2	4 cm Cu	440	Gammas	57813
			Radioactivity	432000
Run 3	10 cm Cu	440	Gammas	172700
			Radioactivity	432000

Data/MC quality cuts



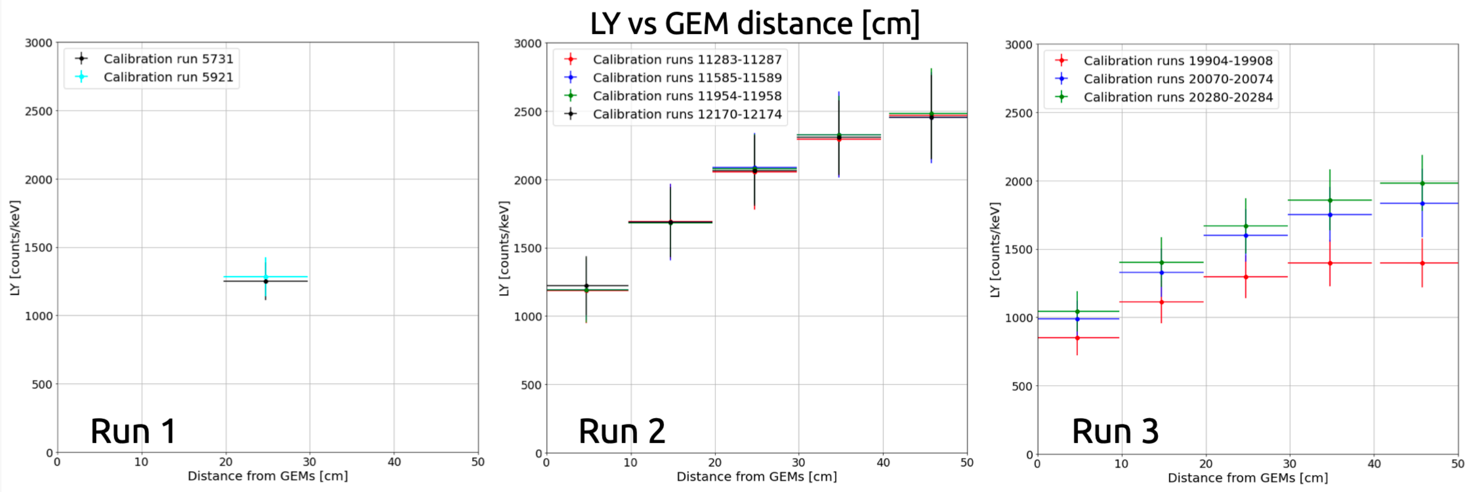
Standard deviation of the counts of all the pixels in a cluster. The lower it is, the more uniform the pixel intensity (and therefore the dE/dx) of the track is



Sigma of the Gaussian transverse profile. It is a measurement of the spread of the energy deposit wrt the original path of the event in the gas

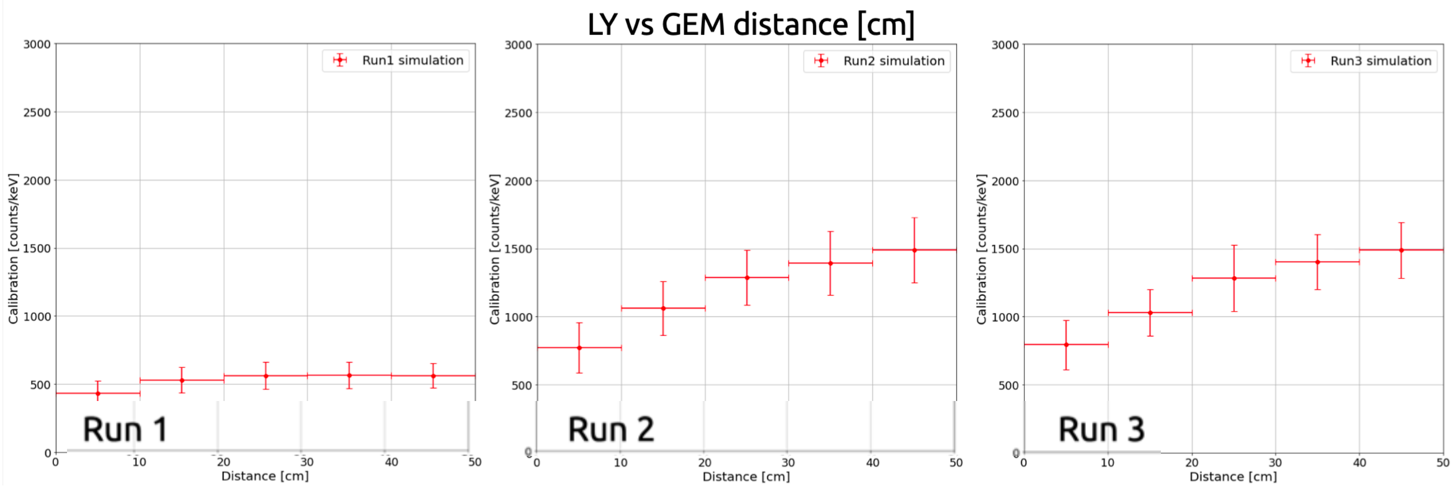
Energy calibration with ^{55}Fe

Run1, Run2 and Run3 data energy calibration



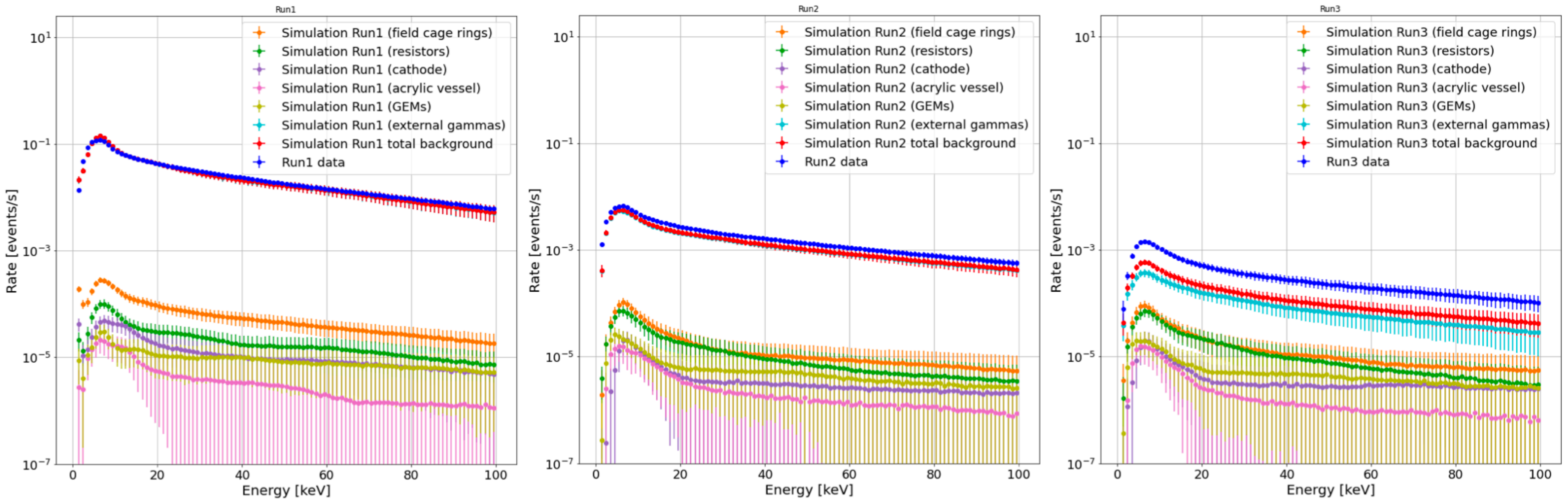
- **LY depends on distance from GEM (Z)**
- **Event Z position evaluation still preliminary and not precise enough yet (about 10 cm resolution) to correct data**
- **Random uniform Z extraction, random Gaussian LY extraction, bootstrap sampling**

Run1, Run2 and Run3 MC energy calibration



- **LY from MC sample with energy between 2 and 10 keV**
- **Same method used for data, except for LY variation over time**
- **Lower LY observed in MC (optimised on overground data), strongly dependent on specific data conditions**

Data/MC comparison by background component



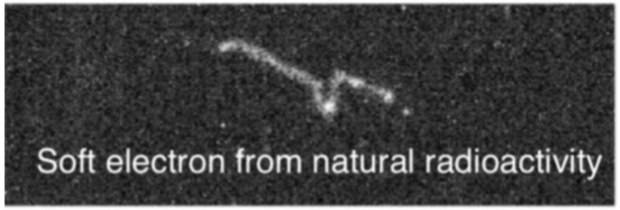
He:CF_4 @ 1 atm

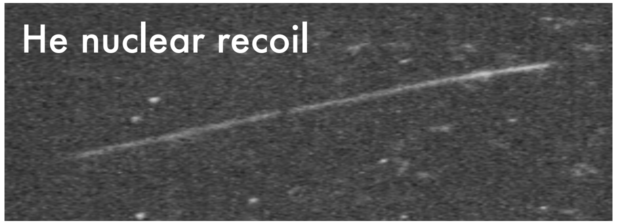
CYGNO: 3D optical readout with sCMOS & PMT

JINST 13 (2018) no.05, P05001

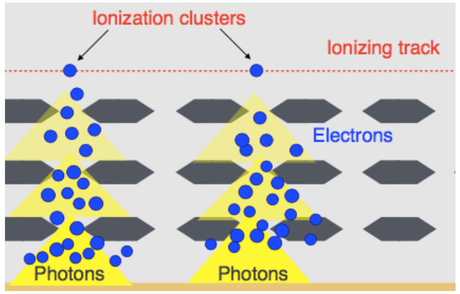
sCMOS:

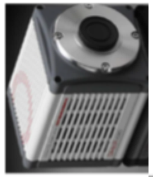
high granularity
X-Y + energy measurements

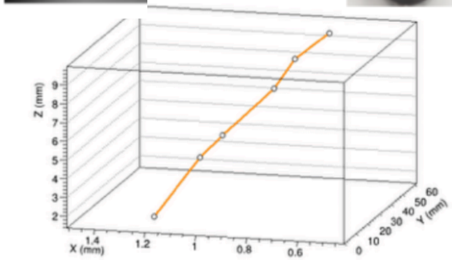




- **1/3 noise w.r.t. CCDs**
- Market pulled
- Single photon sensitivity
- Decoupled from target
- Large areas with proper optics



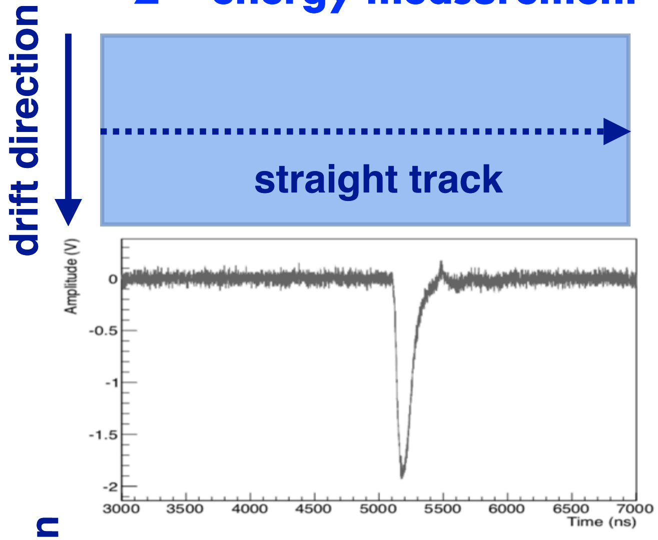


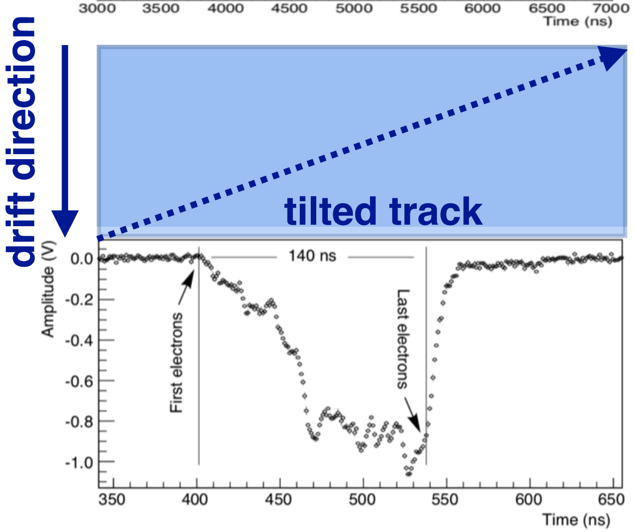


+ SF_6 for negative ion drift

PMT:

integrated
Z + energy measurement

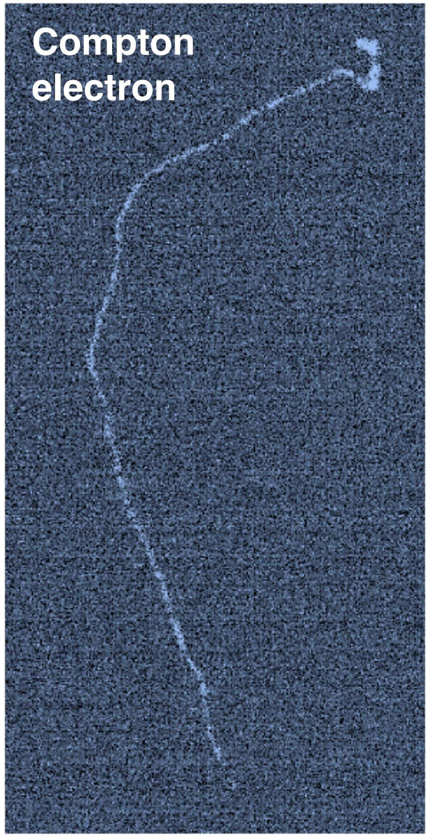


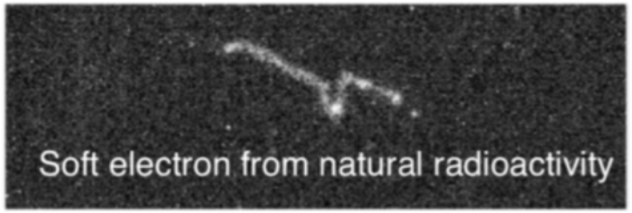


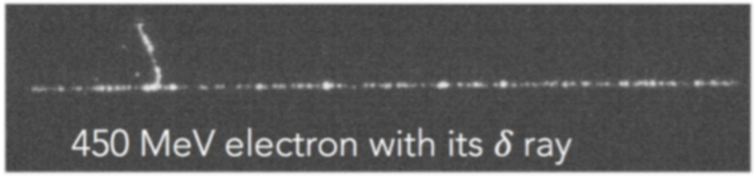
CYGNO: photographing tracks

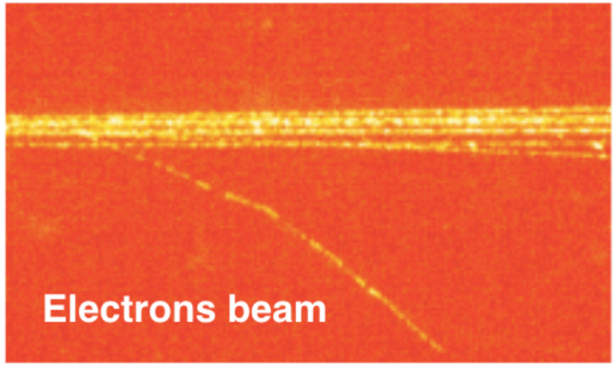
https://web.infn.it/cygnus/

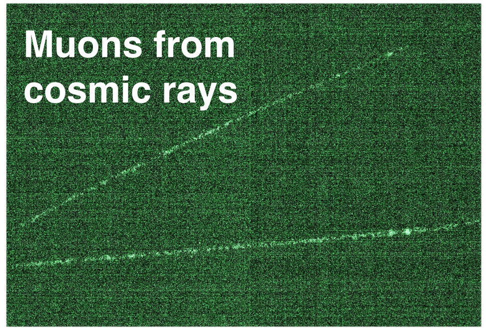
He:CF_4 @ 1 atm

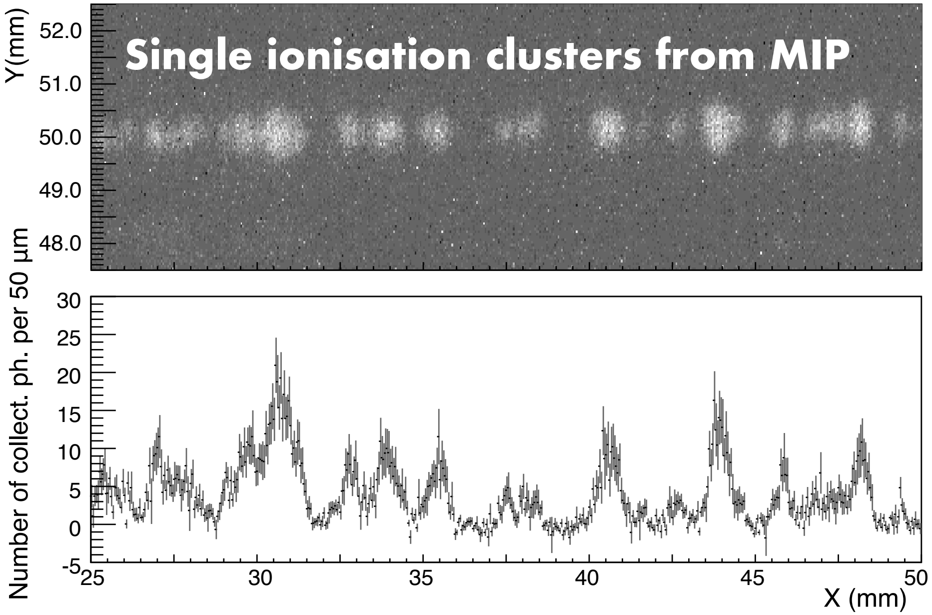


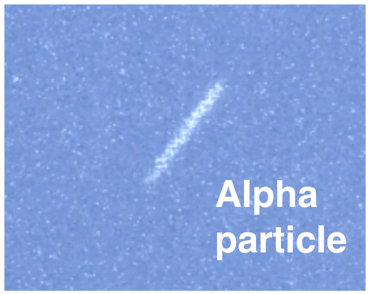


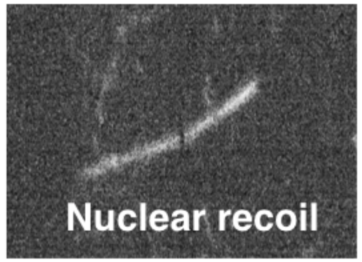




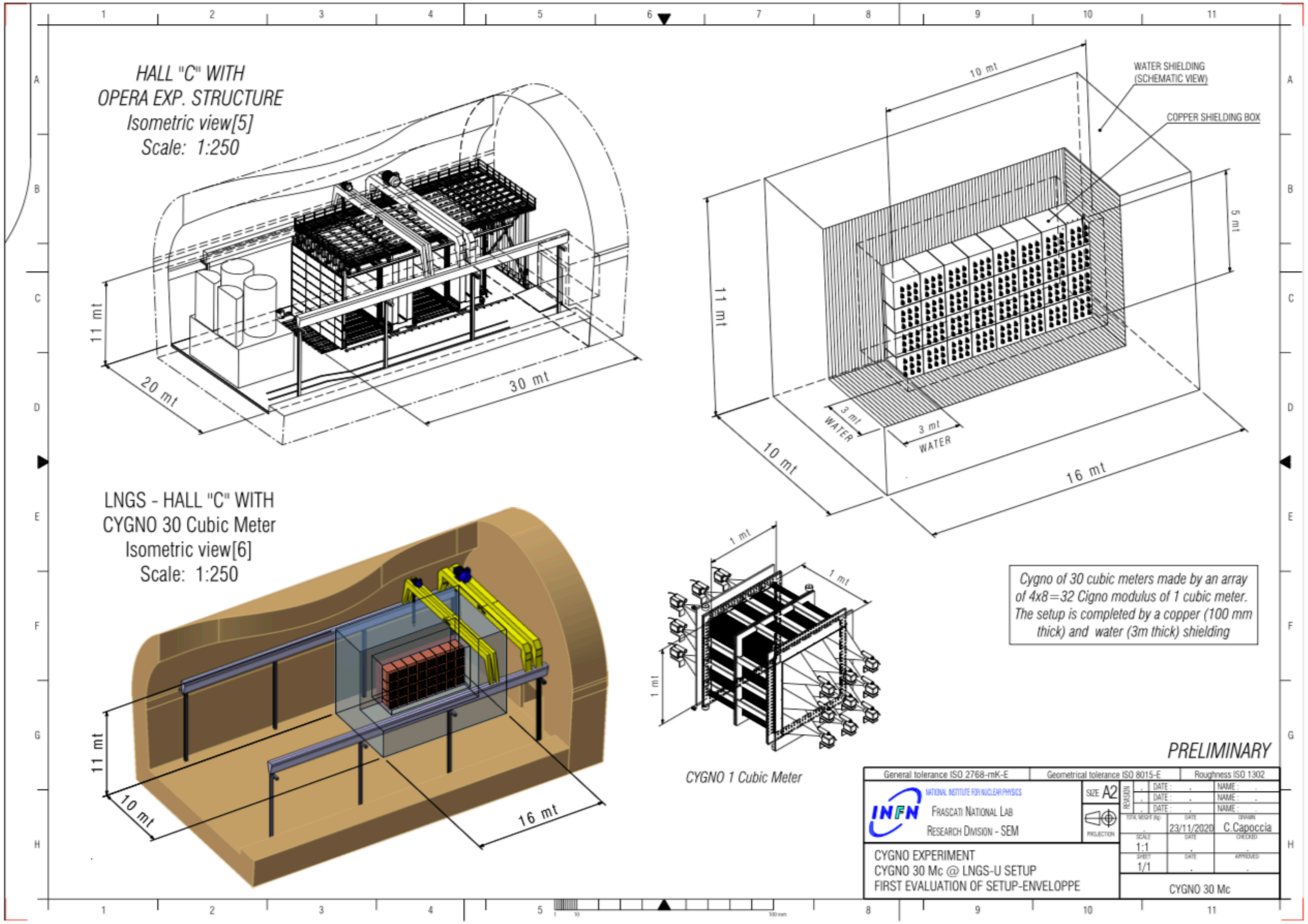








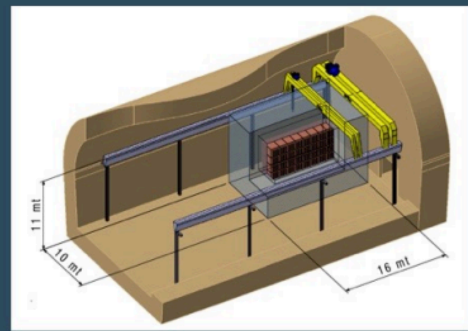
CYGNO future



PHASE 2:
30 m³ Experiment

2026..
LNGS

CYGNO_30

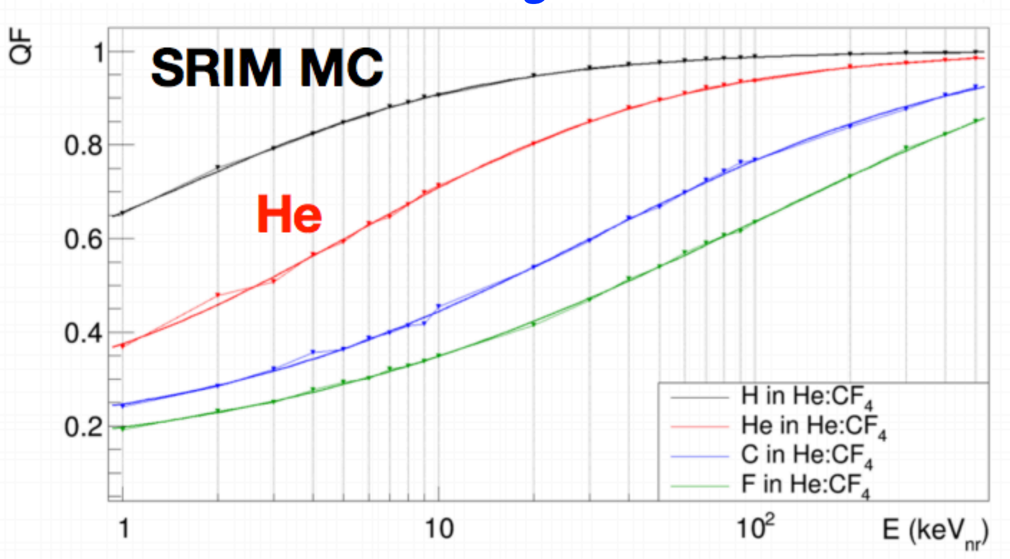


- **Physics research**

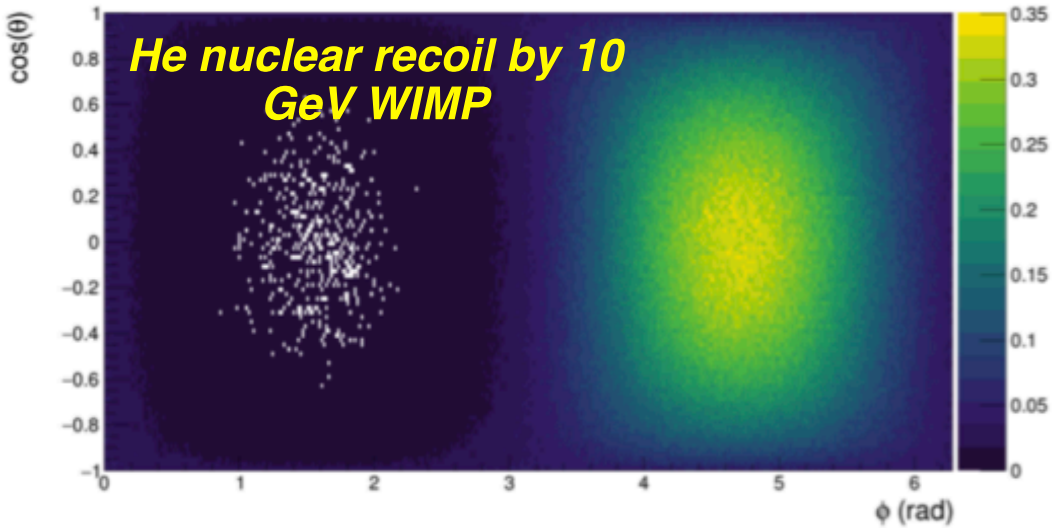
CYGNO PHASE 2 sensitivity evaluation

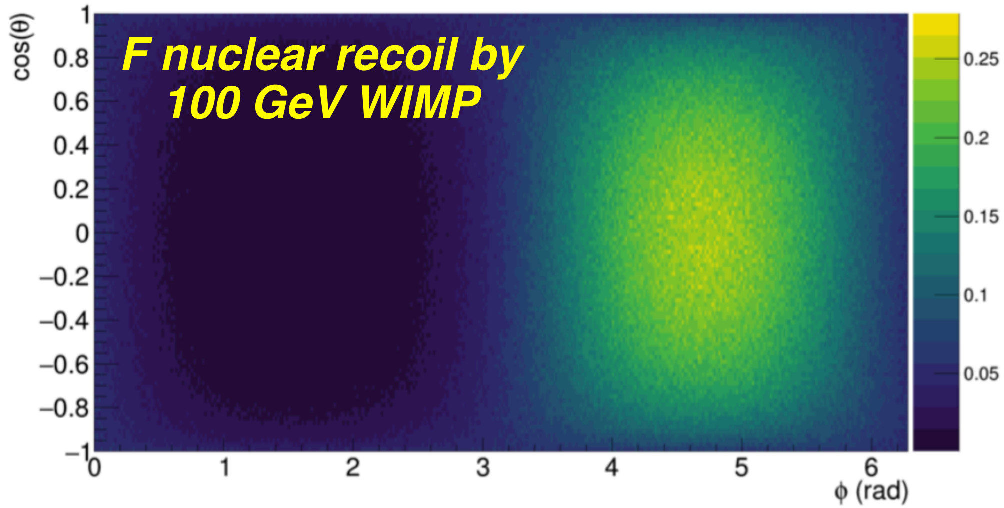
- Use 1 keV_{ee} threshold
- Evaluate QF with SRIM
- Introducing **angular distribution** as discriminating
- Full head/tail recognition
- Using a 30 deg resolution

Quenching Factor



Examples of expected measured angular distribution in Galactic coordinates



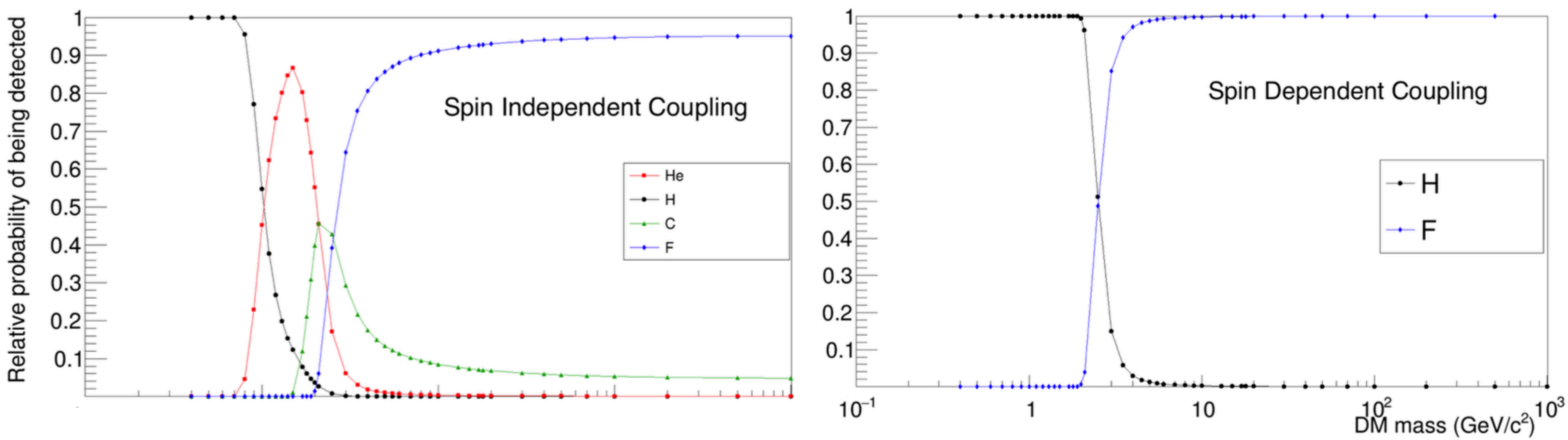


CYGNO PHASE 2 sensitivity evaluation

- **Since CYGNO is a multi-target DM experiment, both the kinematics of the expected DM-nucleus interaction and the expected rate calculation influence the probability of each element to be detected differently as a function of the DM mass**

- **The region of the DM velocity distribution accessible to detection is limited at lower values by the energy threshold and at higher values by the local escape velocity (here taken as 544 km/s)**

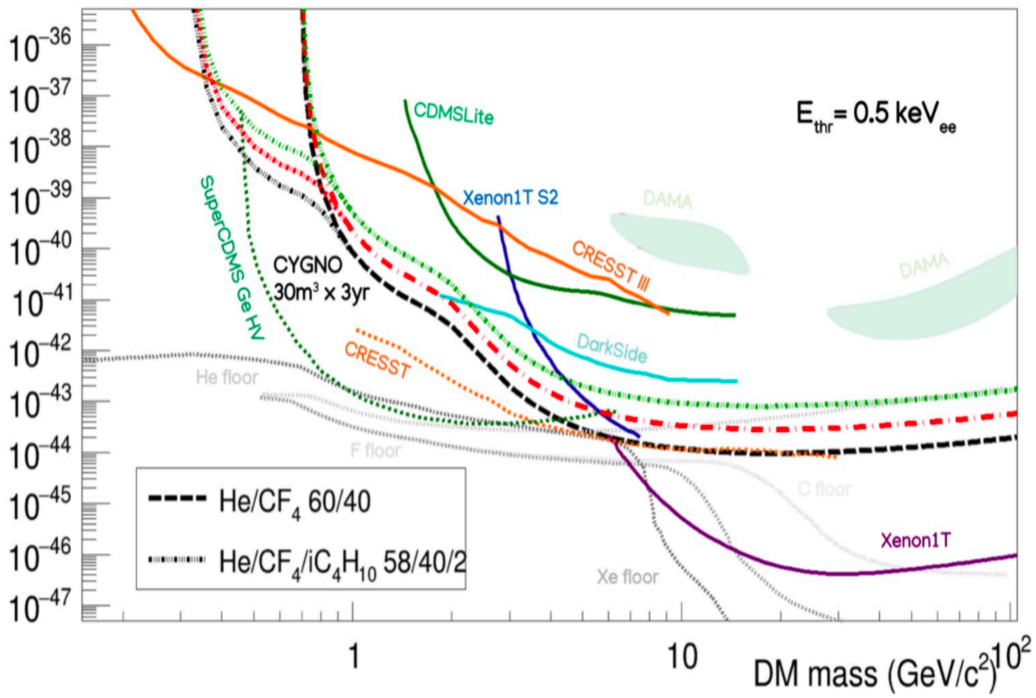
	Minimum detectable DM mass for 0.5 keV_{ee} energy threshold	Minimum detectable DM mass for 1 keV_{ee} energy threshold
H	300 MeV/c^2	500 MeV/c^2
He	700 MeV/c^2	1 GeV/c^2
C	1.4 GeV/c^2	1.9 GeV/c^2
F	1.9 GeV/c^2	2.5 GeV/c^2



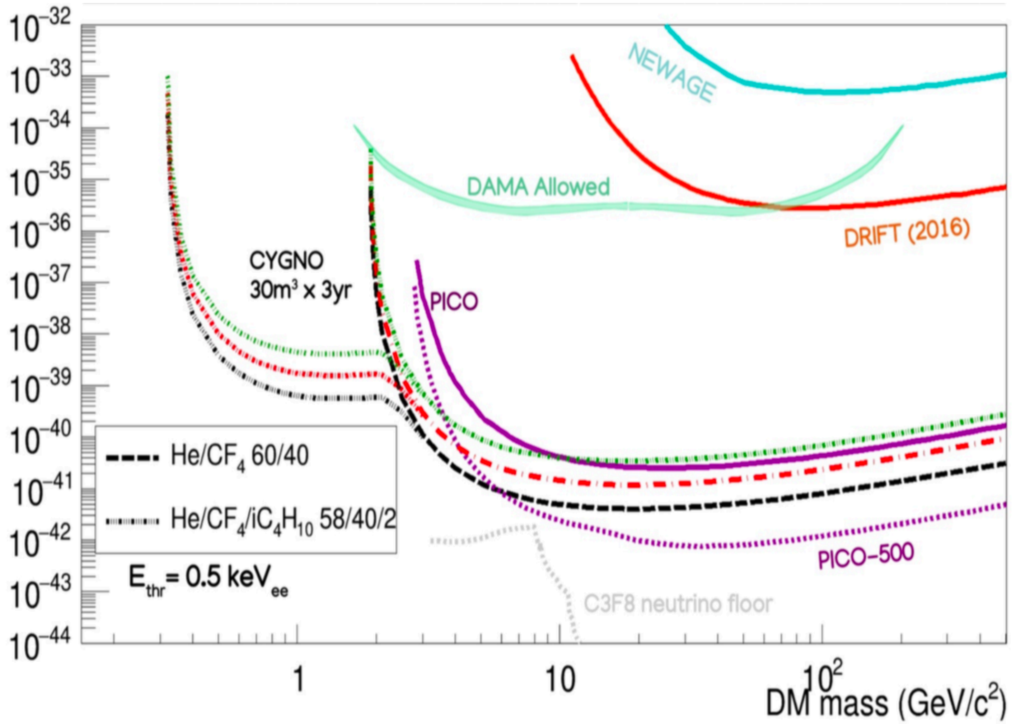
Target nuclei relative probability of being detected for 1 keV_{ee} energy threshold

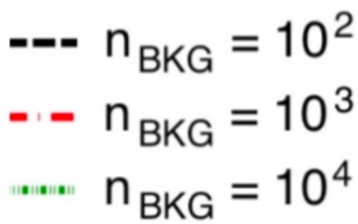
CYGNO 30 m³ preliminary sensitivity studies

Spin Independent



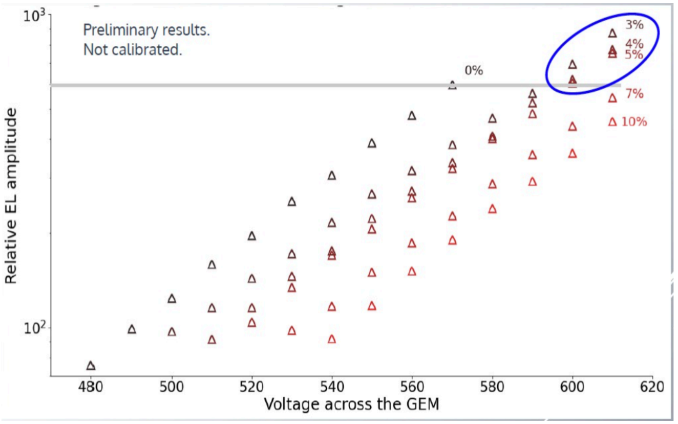
Spin Dependent





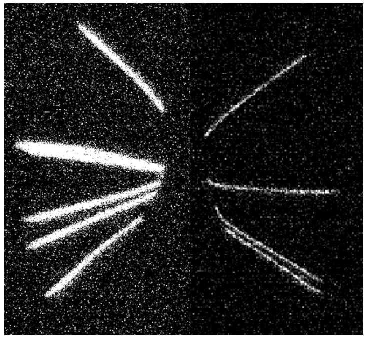
R&D developments towards CYGNO 30 m^3

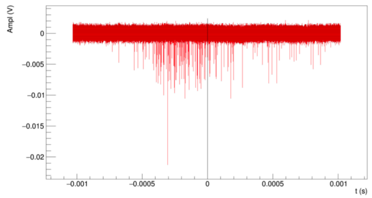
Improve sensitivity at low < 1 GeV WIMP masses by means of Hydrogen target



- R&D with iC_4H_{10} and CH_4 demostrated good light yield achievable
- Future studies on Fluorine-based molecule with H (CHF_3, CH_2F_2)
- R&D work on eco-friendly gas mixture as substitute to CF_4 (doi: 10.1109/NSS/MIC42101.2019.9059721)

Improve tracking by means of Negative Ion Drift operation



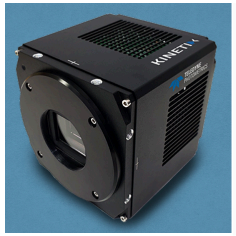


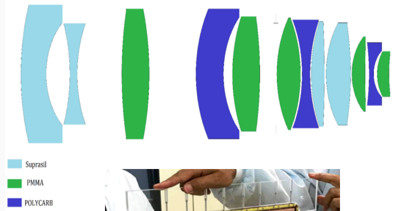
$He:CF_4:SF_6$
59:39.4:1.6

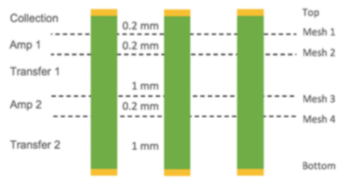
erc
European Research Council
INITIUM

- First ever demonstration of NID operation at atmospheric pressure with optical readout of both sCMOS and PMT
- 5 MeV alpha particles and possibly Ba133 observed
- Opens a completely new window of possibility of optimisation of the gas mixtures
- Systematics studies ongoing

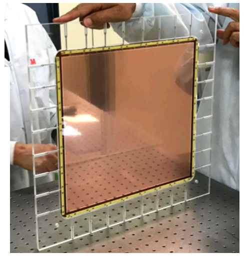
Minimise internal radioactivity and optimise optical system & amplification







(a) Cross-section of the MMThGEM detector with the field names (left), plane names (right) and the gap widths (centre-left)



- Develop custom sCMOS sensor with photon sensitivity & radioactivity budget optimised for CYGNO
- Realisation of custom lens with large aperture & low radioacitivity
- Optimisation of amplification structures in terms of gain and radioacitivty budget