CYGNO status and plans
June 2024

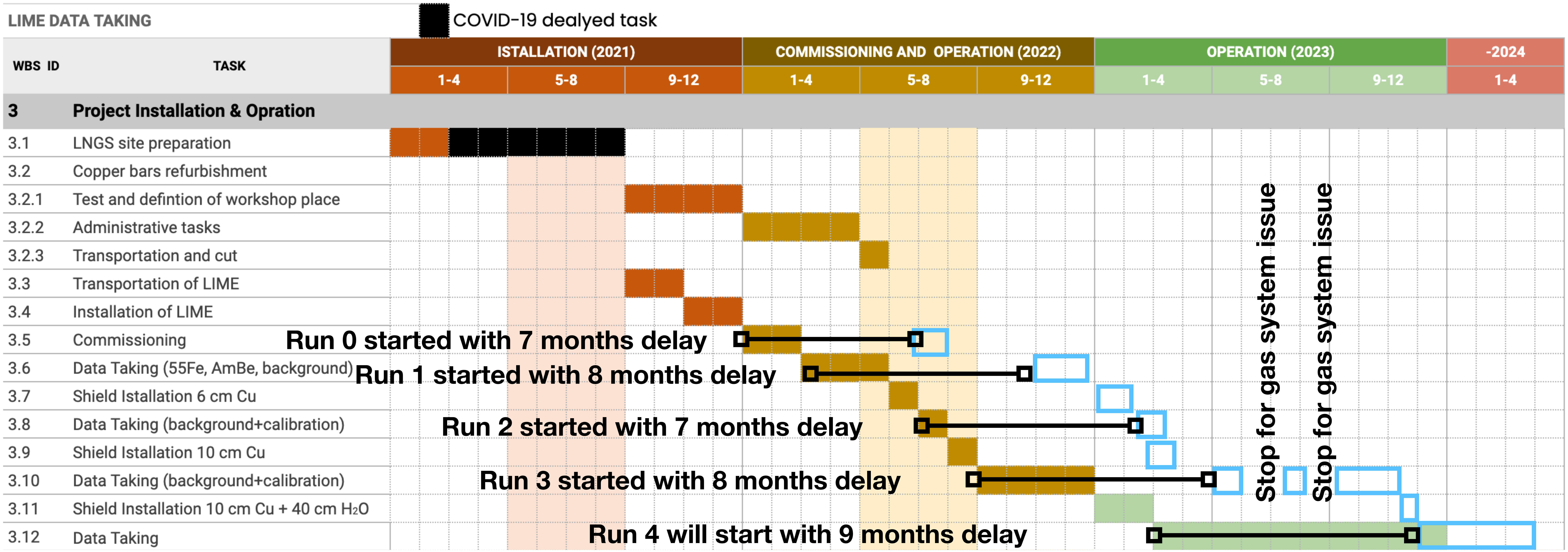
LIME: Runs 1-4

	Time slot	Number of pictures	Event rate	Number of events
RUN 1: No-shielding	3 November - 15 December	$4\ 10^5$	35 Hz	$4\ 10^6$
RUN 2: 4 cm Cu shielding	15 Feb - 15 March	$4.5\ 10^5$	3.5 Hz	$5\ 10^5$
RUN 3: 10 cm Cu shielding	5 May - 16 November	$1.6\ 10^6$	1.5 Hz	$7.3\ 10^5$
RUN 4: 10 cm Cu + 40 cm water shielding	30 November - 31 March	$2\ 10^6$	1.0 Hz	$6\ 10^5$

Special data takings

AmBe for Nuclear Recoils	2-6 August	$2\ 10^5$	0.04 Hz of NR	$2.5\ 10^3$ NR
^{241}Am for Electron Recoils	7-16 November	$7\ 10^5$	50 Hz	10^6

PHASE 0: GANTT



Run4 started 9 months later than it was expected in 2020;

W.r.t. the real t0 (due to the civil works in the experimental site) so far **2 months** of delay were accumulated in about **20 months of operations**;

LIME PLANS

With the **end of RUN4** in March 2024, LIME data taking for **PHASE_0 is considered closed**;

Several different **analyses are ongoing**: radon contamination, NR sensitivity from AmBe events, low energy ER sensitivity, 3D reconstruction of events, muons counting;

In **April 2024** we took some **"technical runs"** to study the effects of gas **filters**, **gas gain**, **drift fields**;

The water shielding was then removed and in **May 2024** a new run (**RUN5**) has started:

- this data taking is intended to measure the **flux of underground neutrons**, in the framework of **PRIN** "Zero Radioactivity"
- very **preliminary simulation** demonstrated a **promising sensitivity of LIME** to them with the possibility of detecting few **tens of neutrons per months**, allowing the perform a **competitive measurement** in 6 months;
- a more **effective evaluation** of the **sensitivity** based on the measurement in **RUN3** in **RUN4** is now starting;
- good exercise to **tune and test simulation and analysis algorithms** for **NR**, propaedeutic to DM search…

Updated collaboration structure

WP1 **Physics**, E. Baracchini GSSI, is in charge of studying the discovery potential and physics cases of the project

WP2 **Data Analysis**, G. Dho INFN-LNF: is in charge of developing reconstruction software and analyzing data

WP3 **Detector Simulation**, G. D'Imperio INFN-RM1: is in charge to develop fast and full simulation of the detector background and to evaluate detector systematics and uncertainty

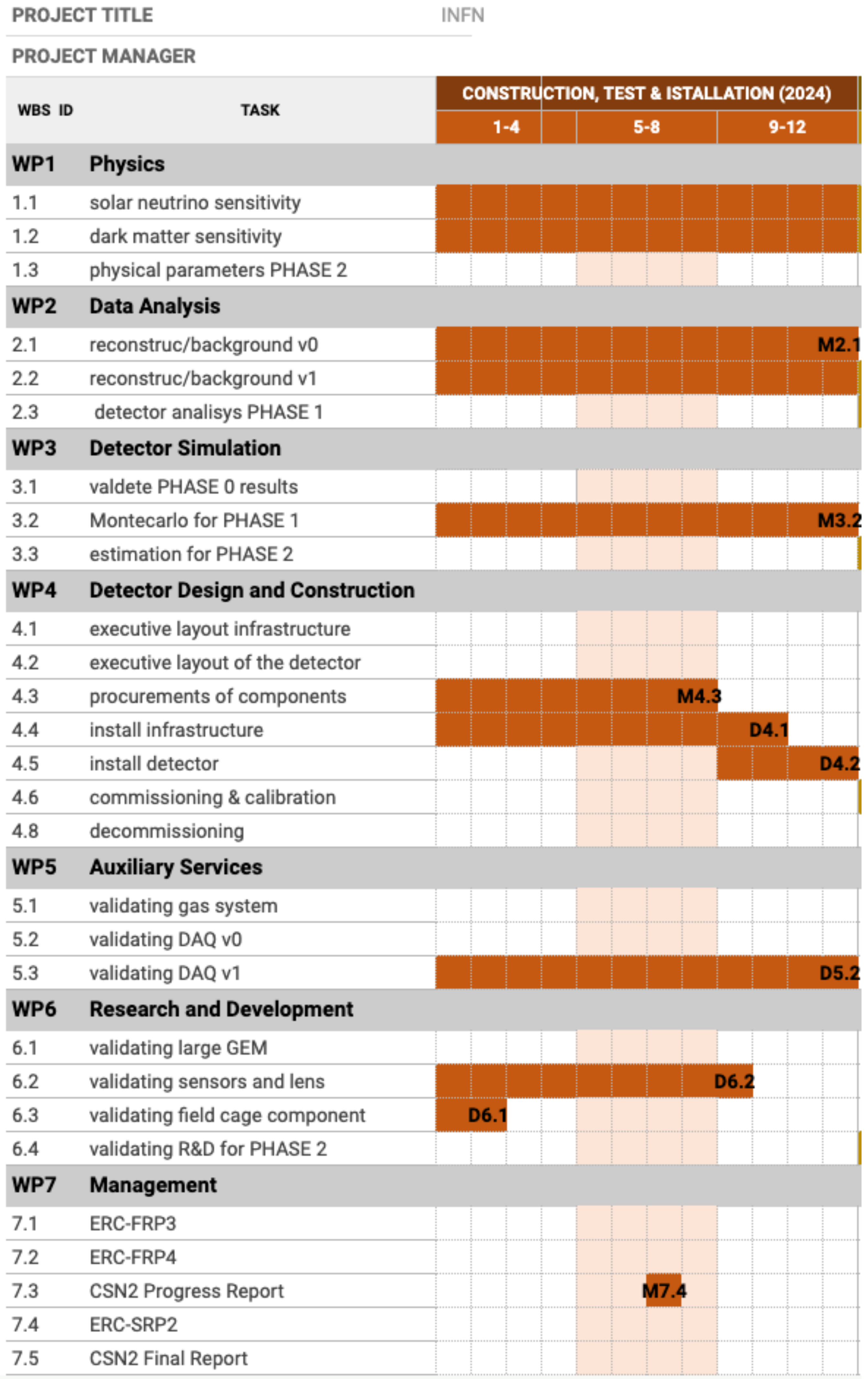
WP4 **Detector Design and Construction**, G. Mazzitelli INFN-LNF: is in charge of the design, construction and implementation of the detector, the shielding and infrastructures.

WP5 **Auxiliary Services**, A. Messina INFN-ROMA1: is in charge of all Axillary System: Gas System, HV and LV, DAQ and computing.

WP6 **Research and Development**, D. Pinci INFN-ROMA1: in charge of the development ongoing for PHASE 1 and the study needed to enhance the performance for PHASE 2

WP7 **Management**: management of the project and interactions with CSN2, LNGS, ERC

Plans for 2024



In general, the **running of LIME is** now way **less demanding** than in the past, requiring a **lighter shifts sharing scheme**

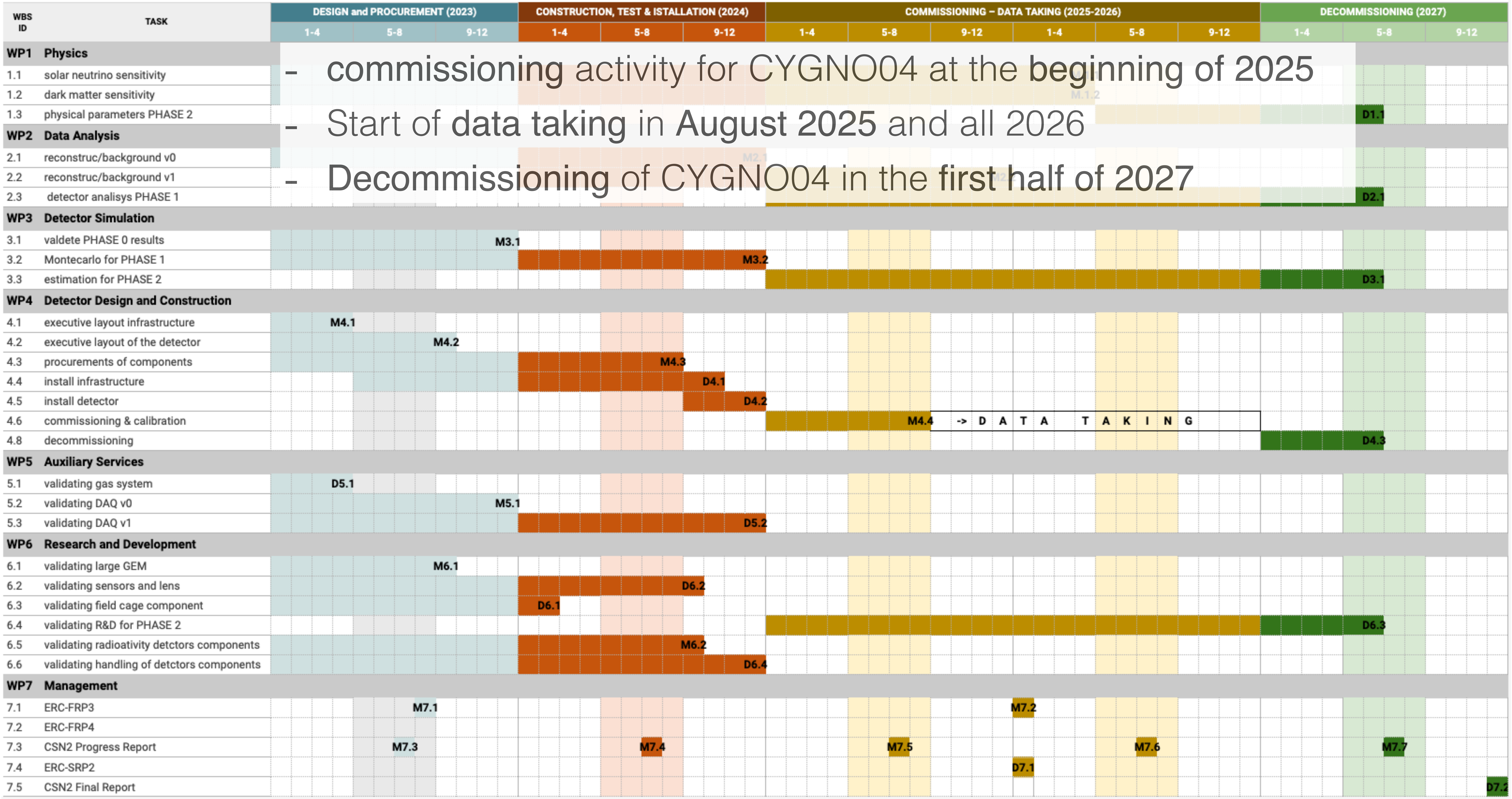
Main part of the **person-power moved** to data analysis and simulation and **studies** for the **CYGNO04 realisation**.

Activities foreseen:

- Full **LIME data analysis** (M2.1 - 31/12)
- Full **GEANT4 simulation** of CYGNO-04 (M3.2 - 31/12);
- **Tenders** for CYGNO-04 realisation (M4.3 - 31/08);
- Installation of the **infrastructure** (D4.1 - 30/10) and then of the **detector** (D4.2- 31/12);
- **Validation** of last components and ancillaries: **field cage** (D6.1 - 28/02), **new optics** (D6.2 - 30/09) and **DAQ V1** (D5.2 - 31/12)

TDR CYGNO04 GANNT

- commissioning activity for CYGNO04 at the **beginning of 2025**
- Start of **data taking** in **August 2025** and all 2026
- **Decommissioning** of CYGNO04 in the **first half of 2027**



TDR CYGNO financial plan and CSN2 proposal

CYGNO Experiment

In **2022**, according to the operation schedule presented in the **TDR**, we presented the financial plans for the **quinquennium 23-27**

A total of **525 k€** in 5 years, including 200 k€ for travels

INFN - CSN2	2023	2024	2025	2026	2027
Gas Bottle	10	5	15	15	0
Gas Recovery	10	0	20	20	0
Consumables	10	20	20	10	20
R&D	50	50	30	20	0
Tot w/o Travels (k€)	80	75	85	65	20
Travels - Shift	30	20	20	30	0
Travels - Installation	10	30	30	0	30
Tot Travels (k€)	40	50	50	30	30
Tot (k€)	**120**	**125**	**135**	**95**	**50**

La commissione giudica positivamente il TDR di Cygno-04 notando che, in quanto progetto finanziato ERC, ha un profilo di rischio più alto di quello normalmente accettato per un progetto di commissione 2. Richiede che il TDR venga aggiornato appena siano disponibili i risultati ottenuti dal run underground del prototipo LIME (performance, stabilità temporale, background model) e dai test previsti per il prossimo anno su catodo, field cage, ecc.

La commissione approva il piano finanziario proposto dalla collaborazione CYGNO che prevede, da parte della Commissione, un contributo massimo di 120 k€/anno (inclusivo di ogni voce di spesa). L'approvazione si riferisce per il momento ai due anni previsti per la costruzione: 2023 e 2024. Quando sarà disponibile il TDR aggiornato secondo le richieste sopra menzionate, la Commissione procederà alla discussione del piano di spesa previsto per gli anni 2025-2027 che servirebbe a sostenere i costi di operazione del dimostratore.

WP1: Physics

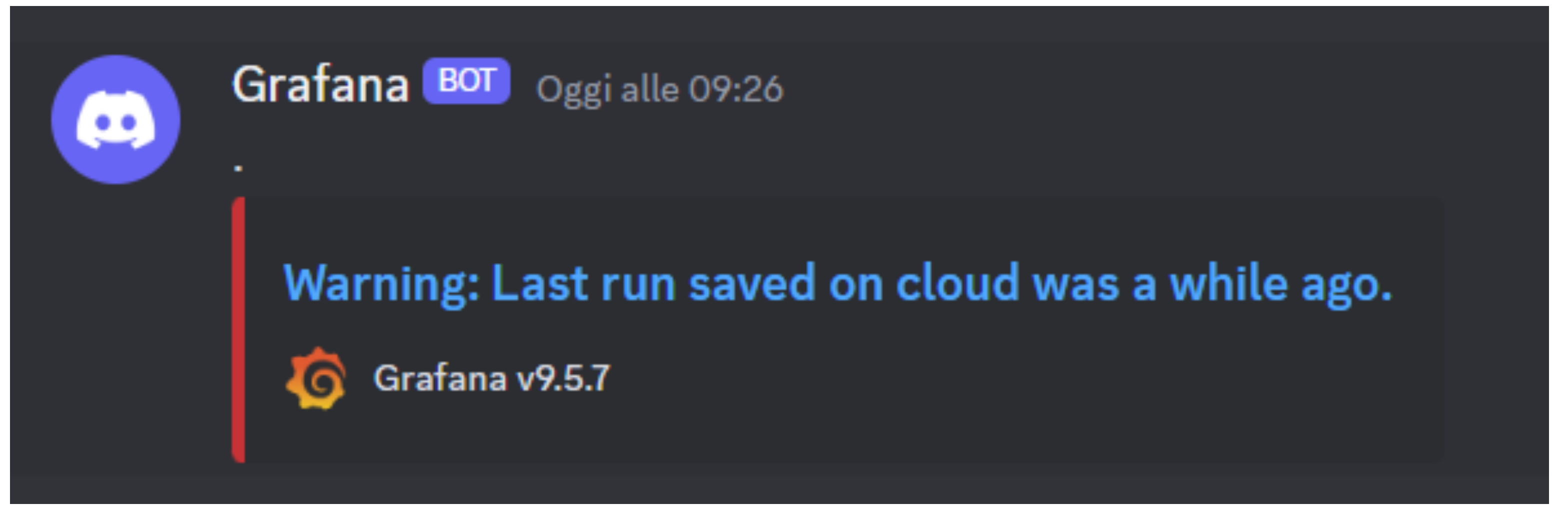
WP2: What we Learnt I: Stability of Operation and Monitor

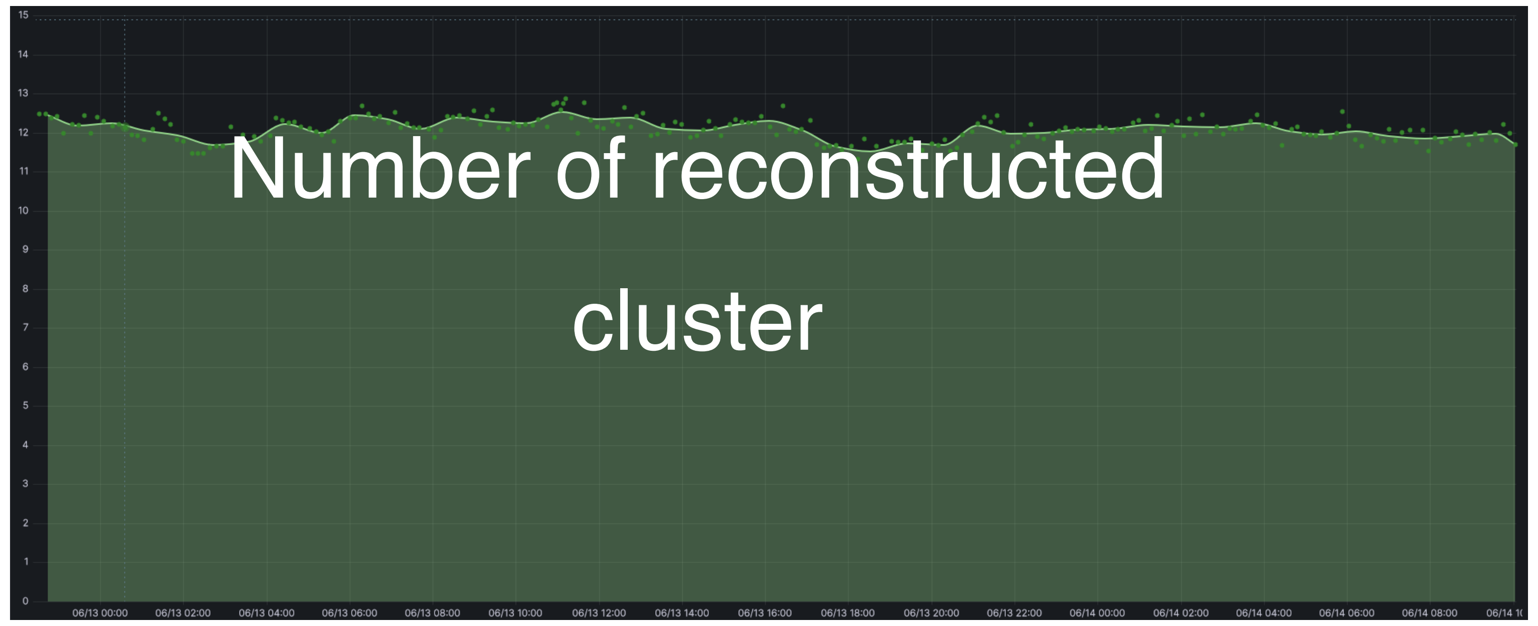
- LIME underground data proved to be fundamental to test our understanding of the detector in a realistic environment for rare event searches

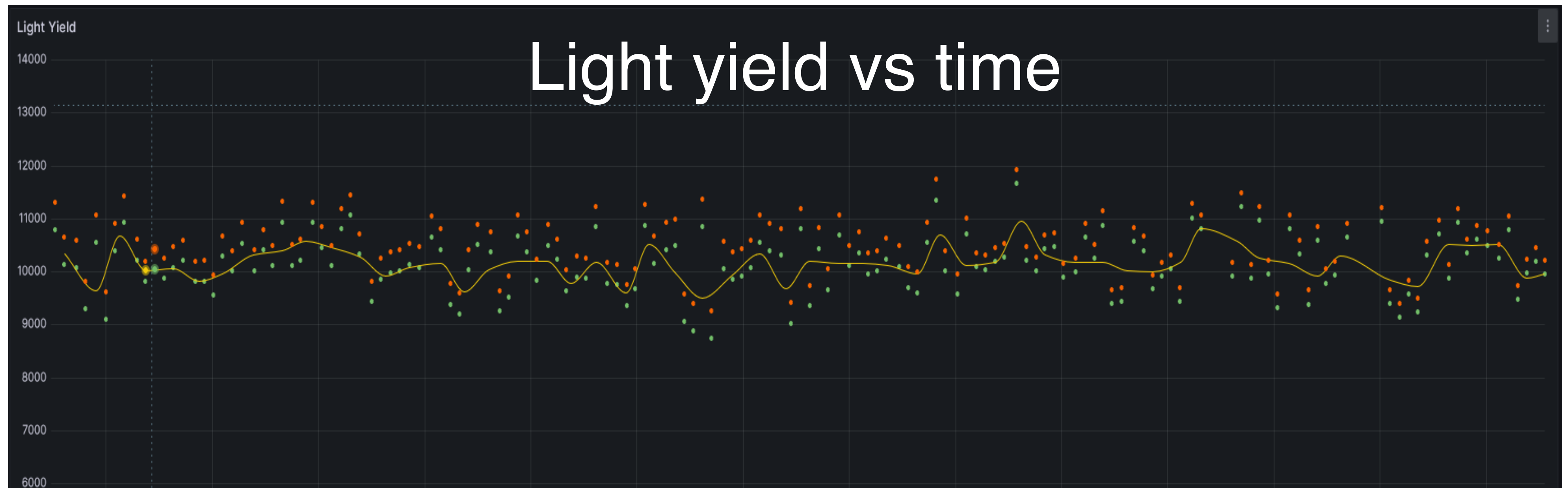
No in person shifter was required anymore

(except for gas bottle changes)

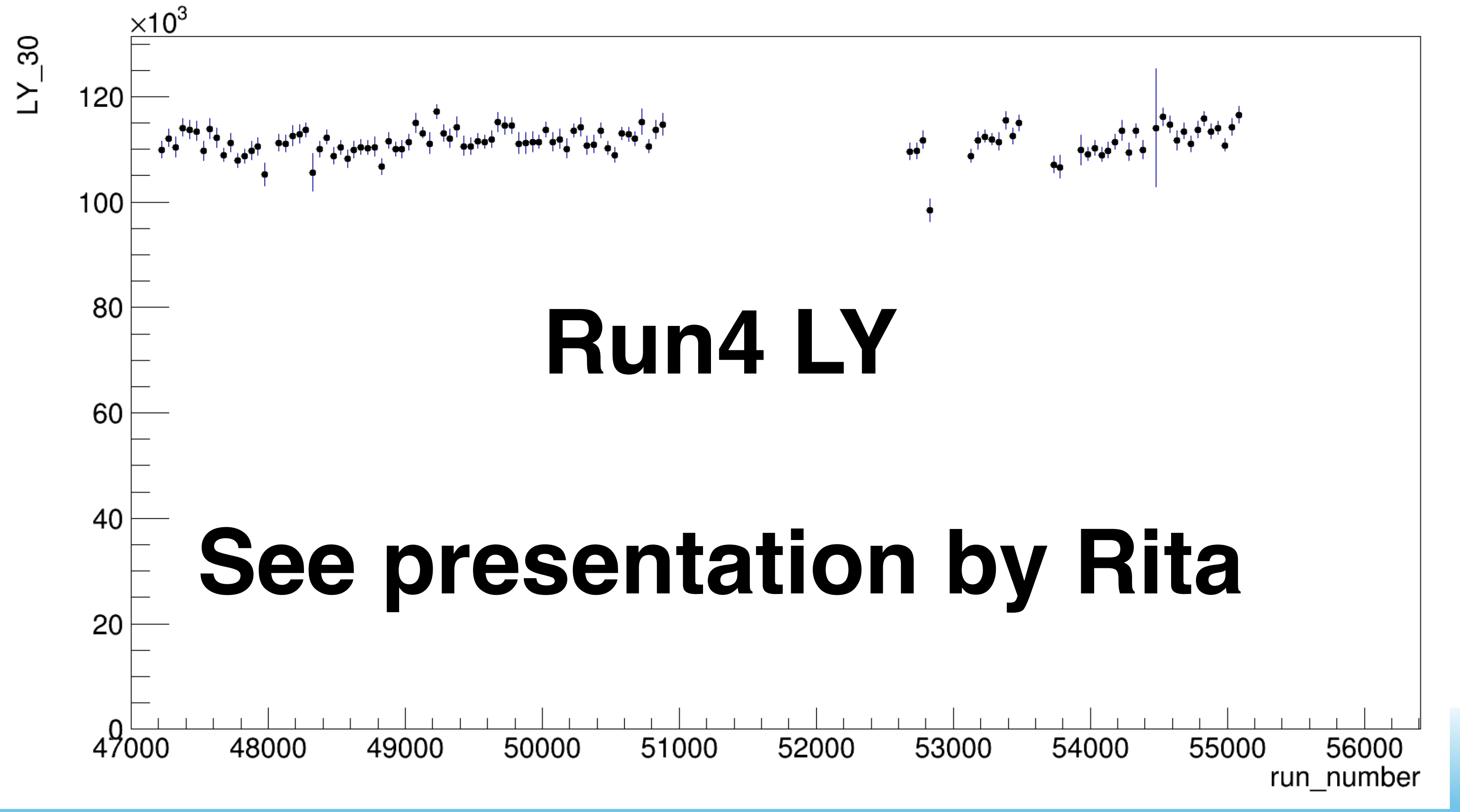
- Automation of reconstruction algorithm allows continuous monitoring of various variables in close-to real time and check quality of data (Run4 had 95% duty cycle)







- Correction for light yield variation with time allowed to estimate the stability of the detector and performing first physics analyses



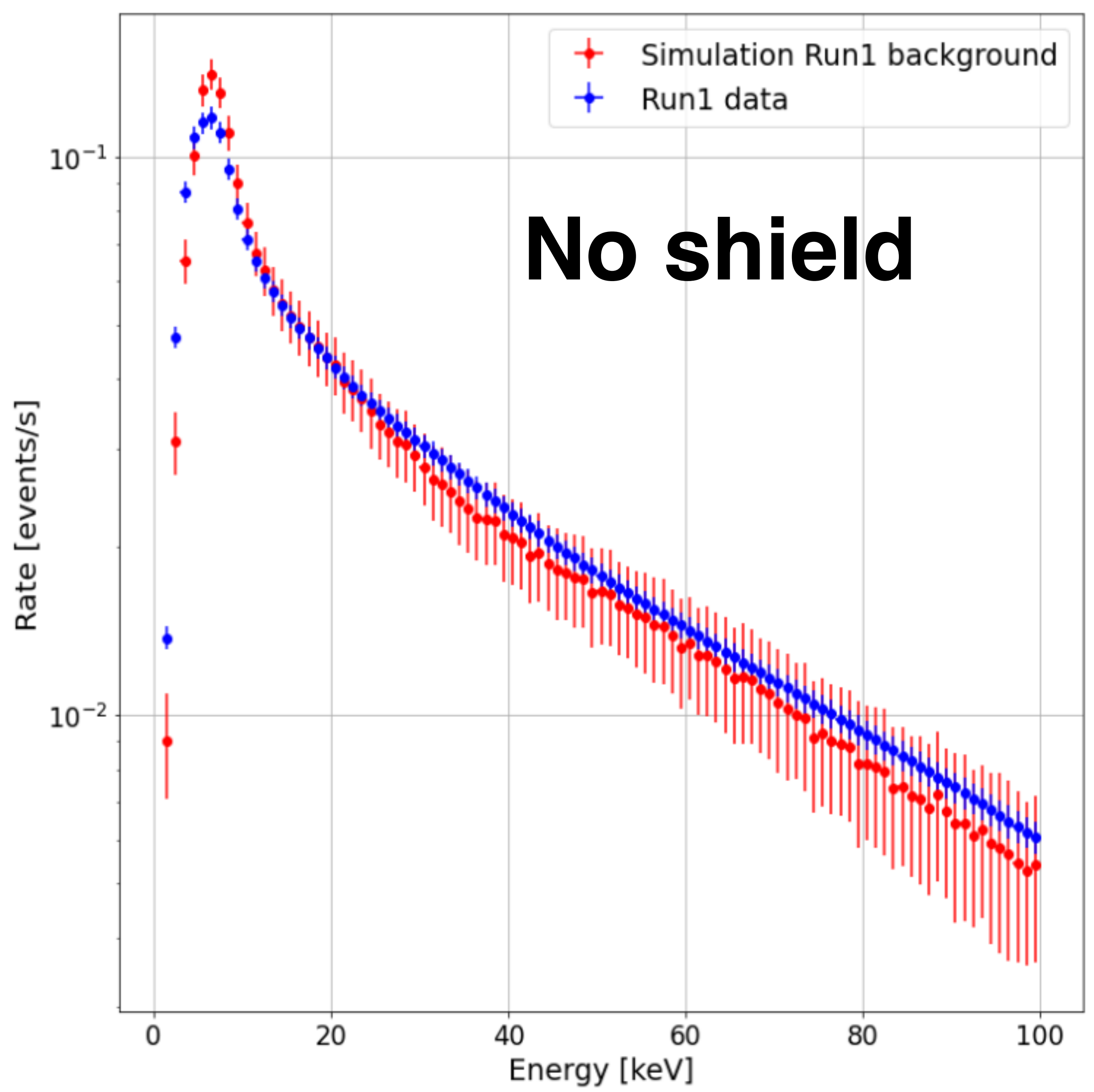
WP2:2.1 The data of background is coherently and continuously reconstructed

G.Dho

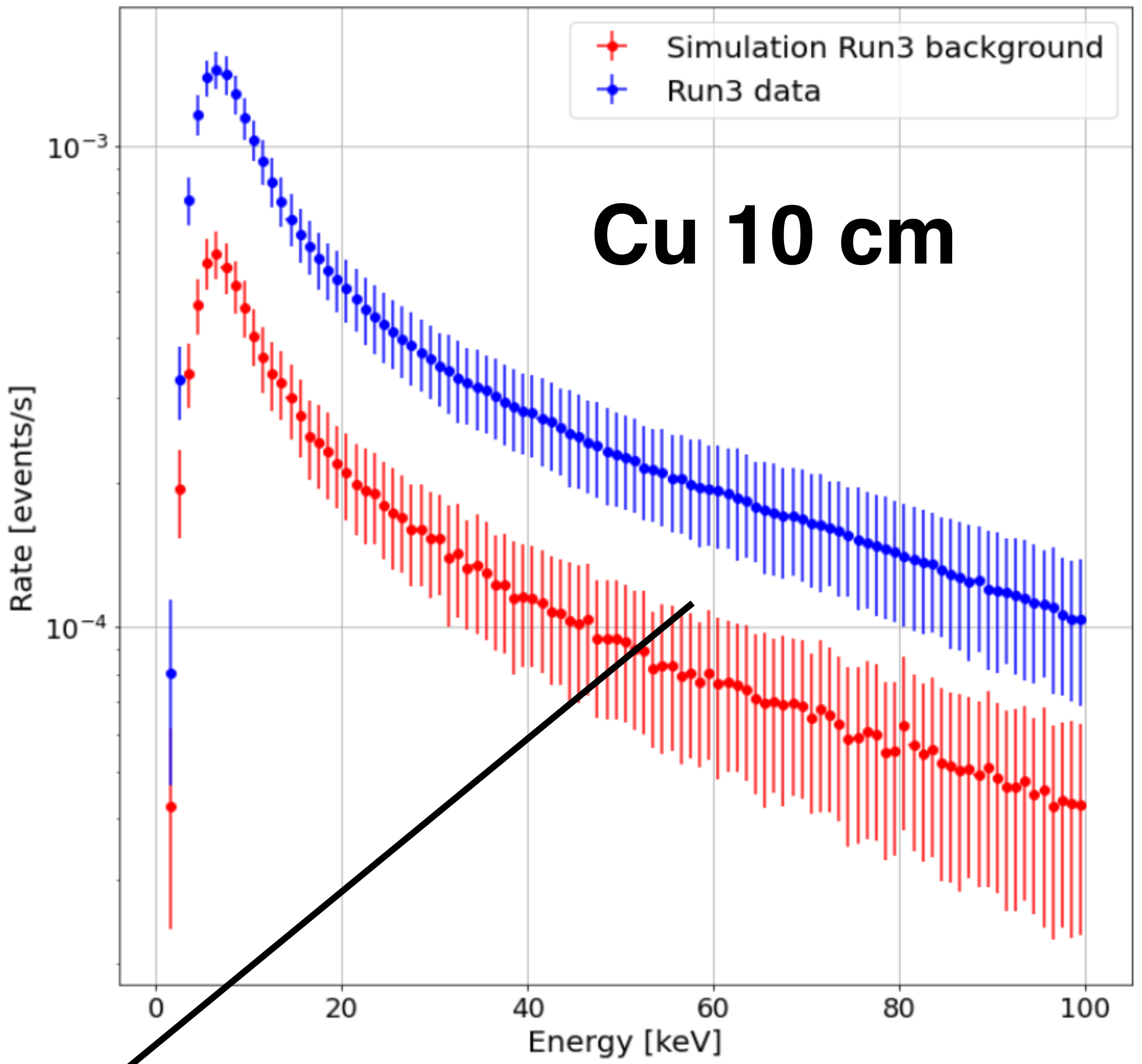
WP2: What we Learnt II: Simulation + Analysis works

- The analysis and study of the data-MC comparison showed extremely good results

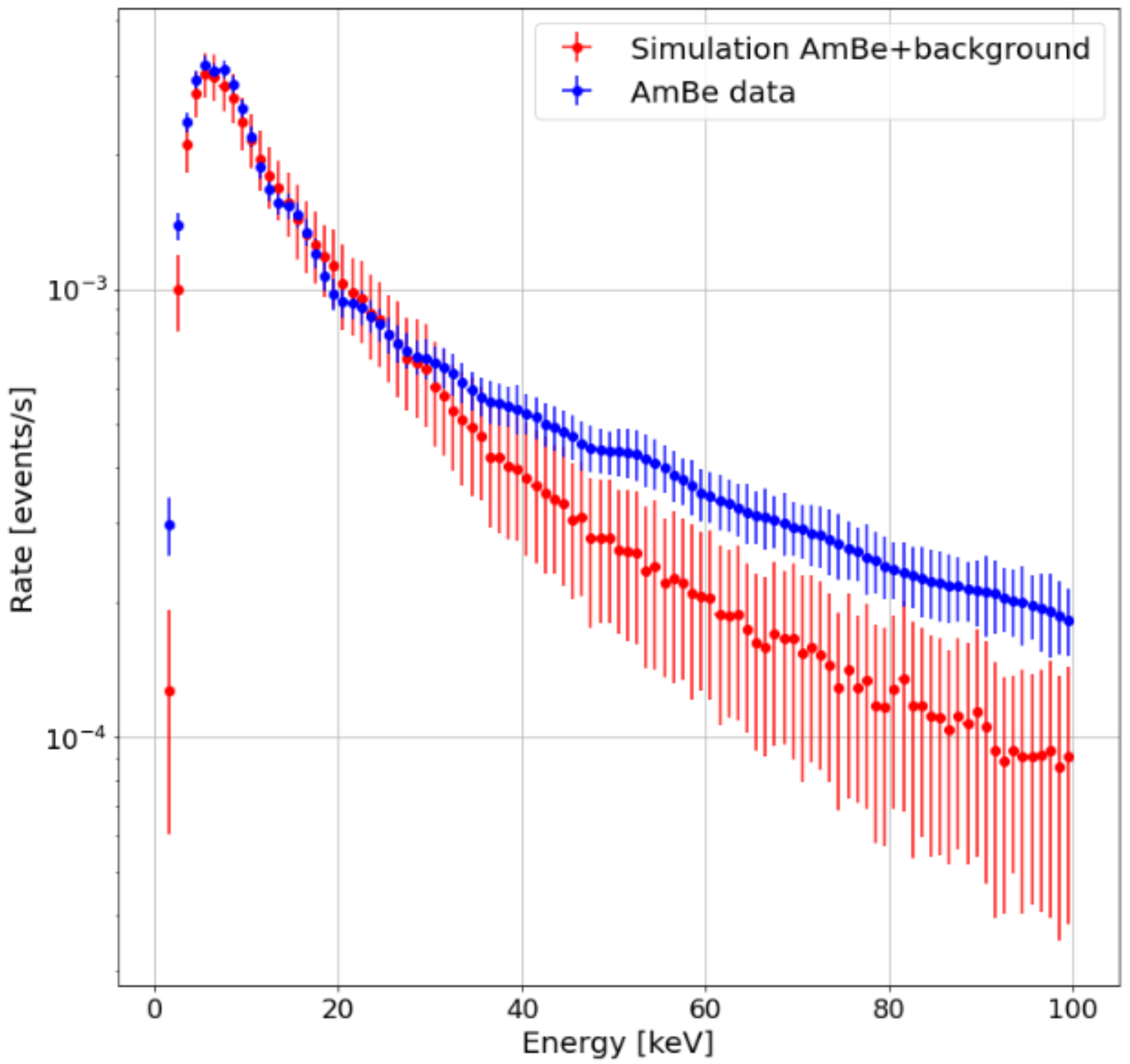
Run1



Run3

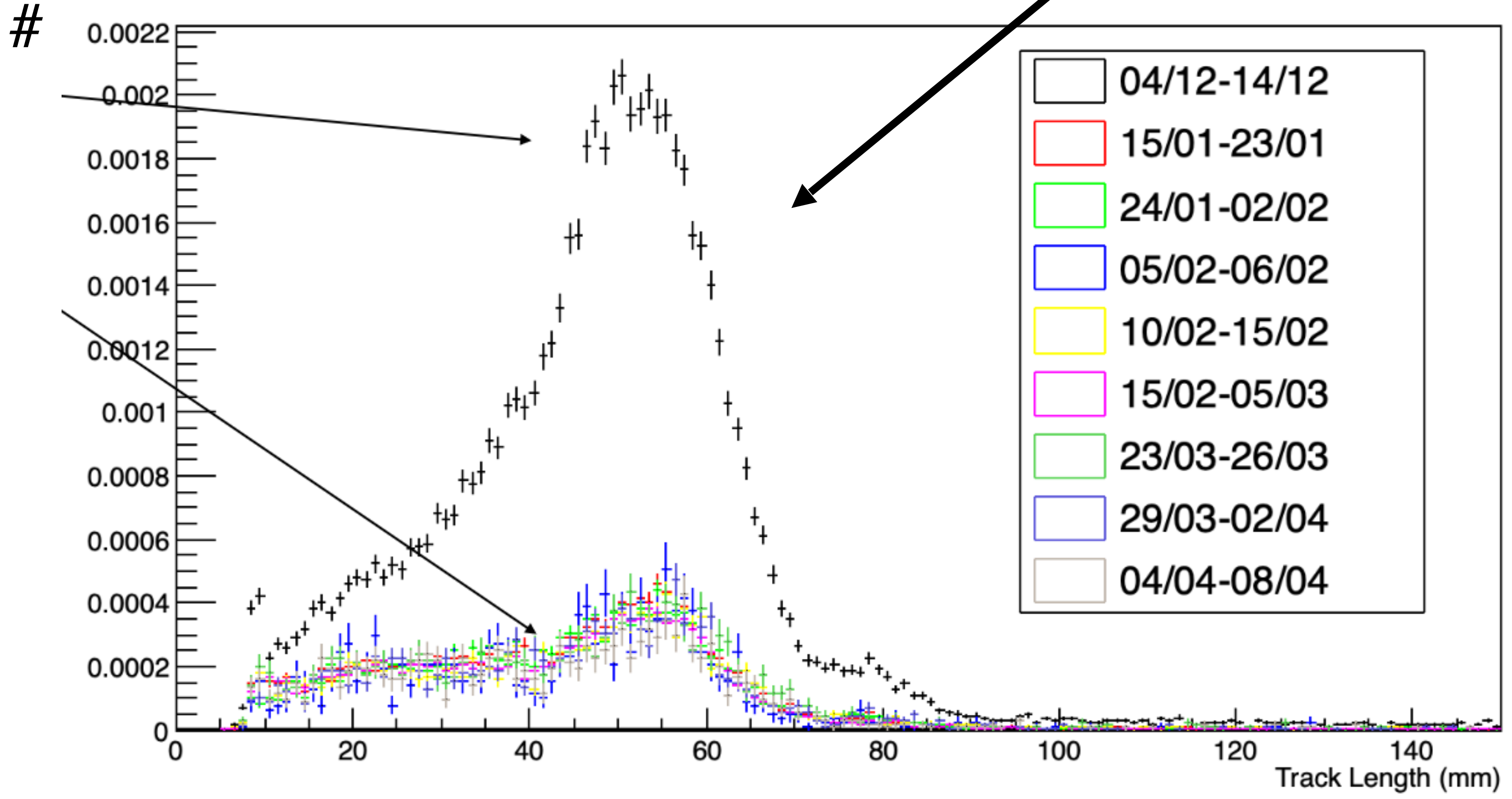


AmBe



Run4 undergoing

AmBe simulation excellently matches data when AmBe contribution dominates



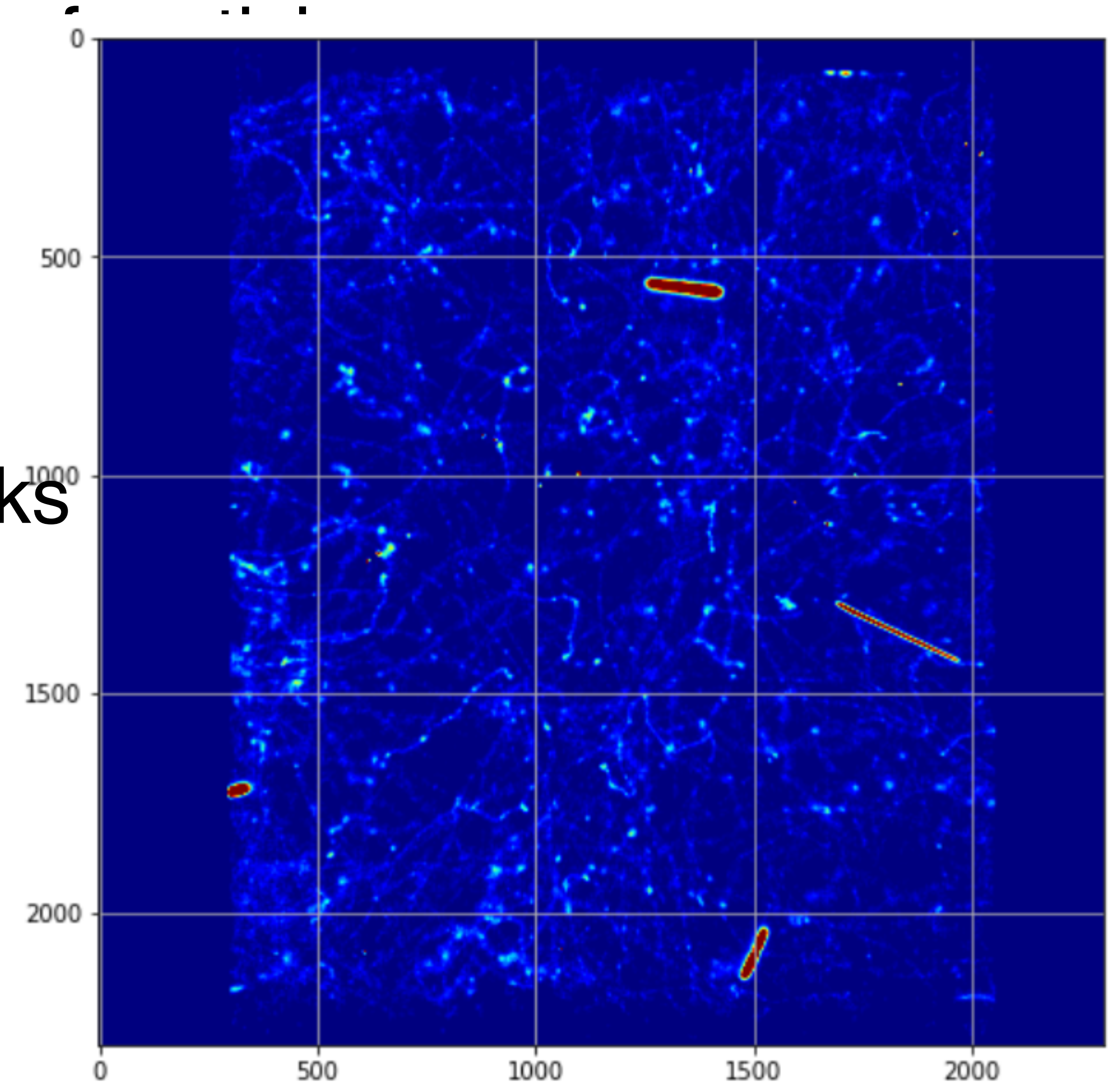
Contamination found (Rn suspects under analysis)

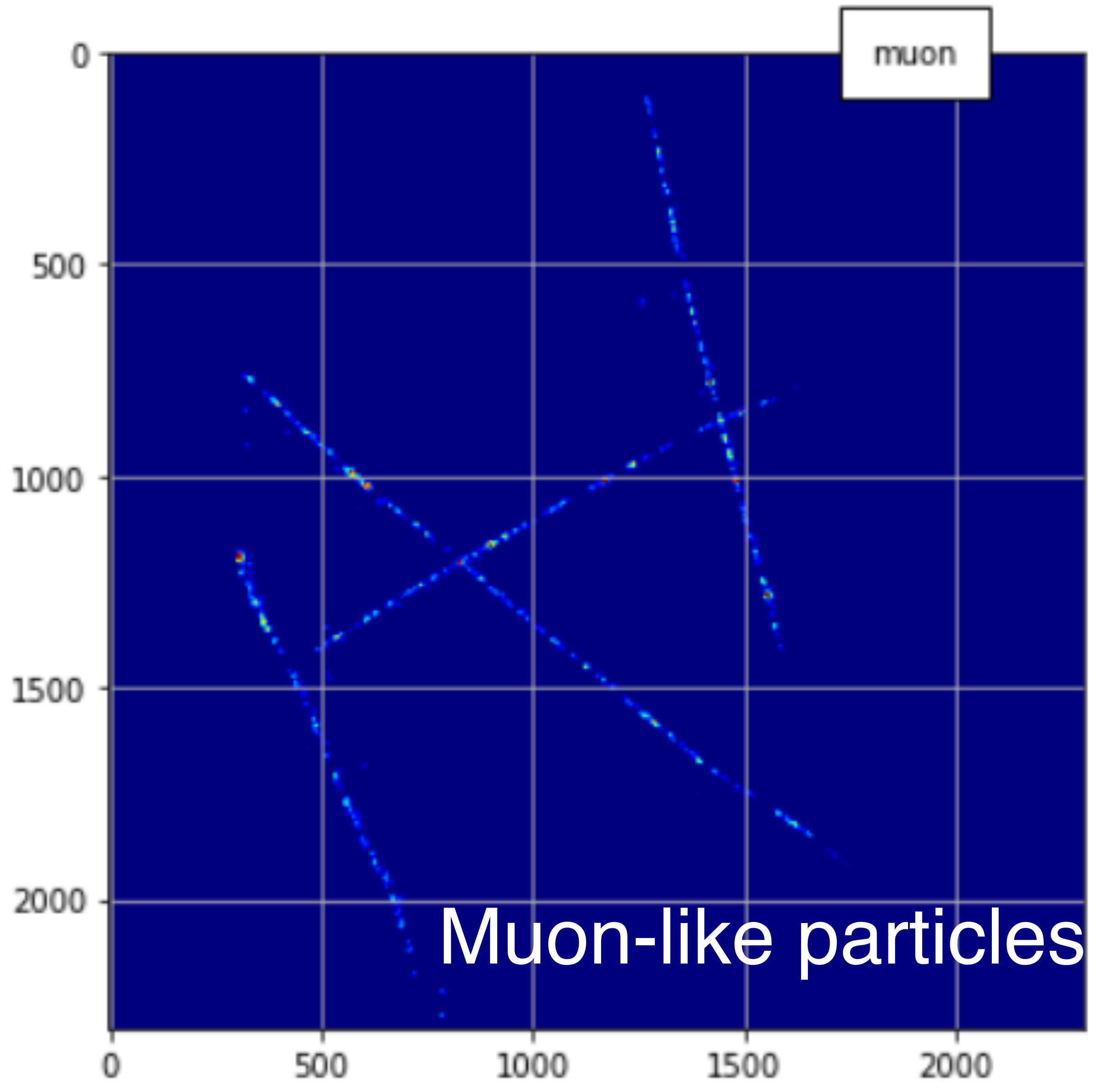
WP3:3.1 MC can be considered validated by the simulation and the analysis comparison (see WP3 section)

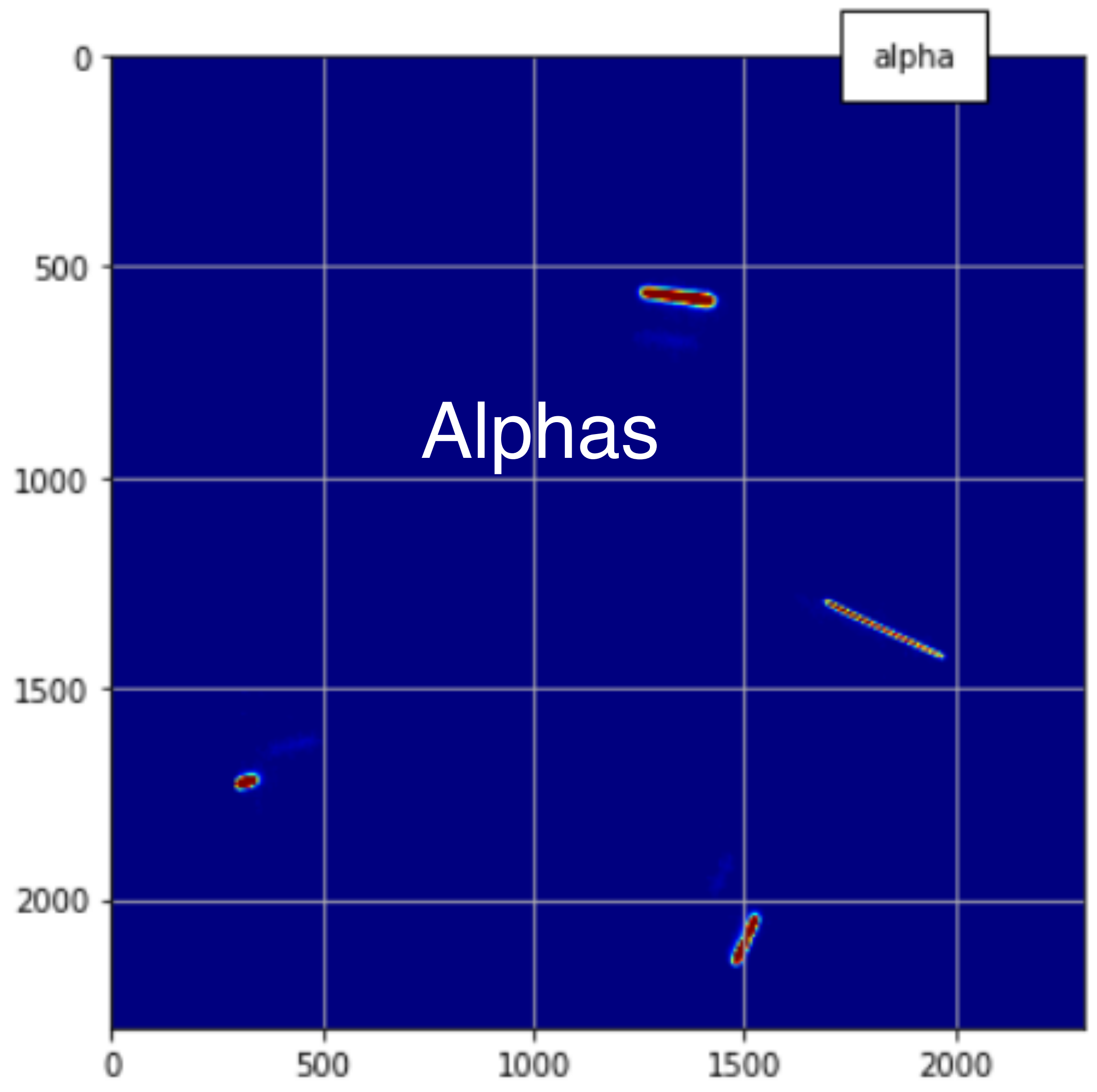
WP2: What we Are Learning I: Particle Discrimination

- Large statistics and low occupancy provided by LIME, simple variables of clusters (density, length..) can be used to discriminate wide types

All reconstructed tracks in 400 images

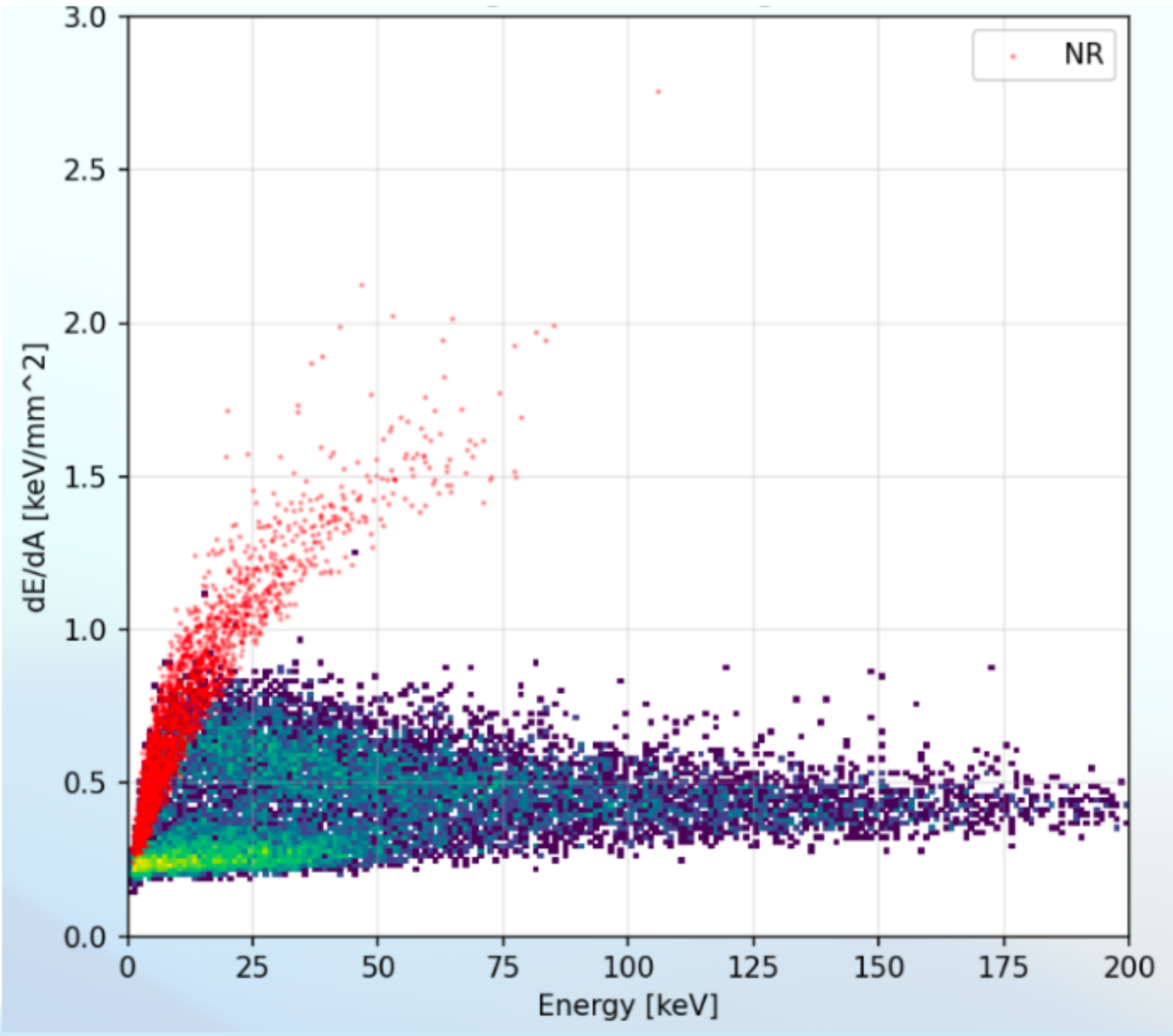






- Machine Learning techr ... ria ... tion samples to get NR-ER discrimination

Trained only on simulated pool of data



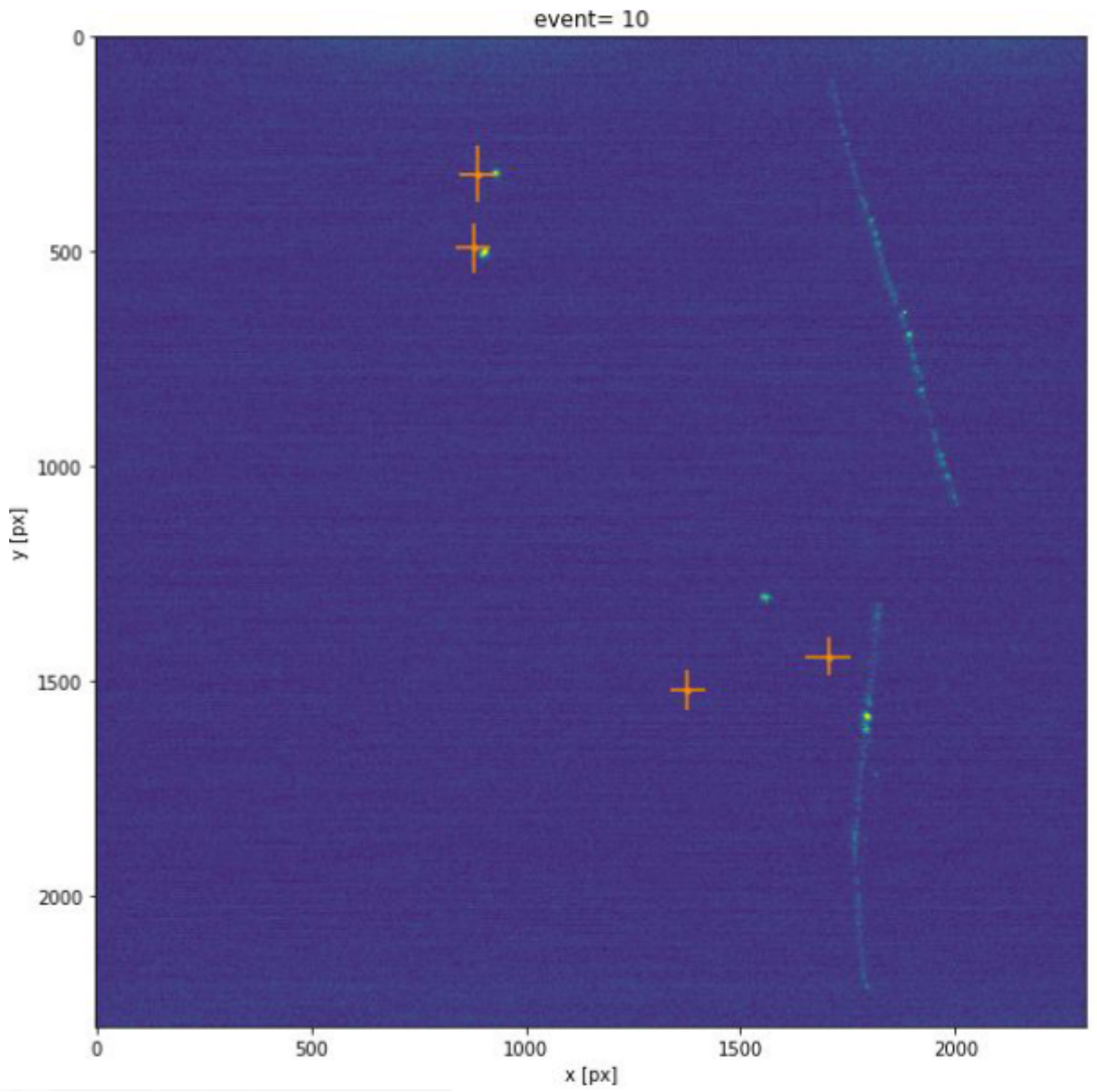
Parameters and ML structure selection on going

WP2:2.1 Towards ER and NR discrimination

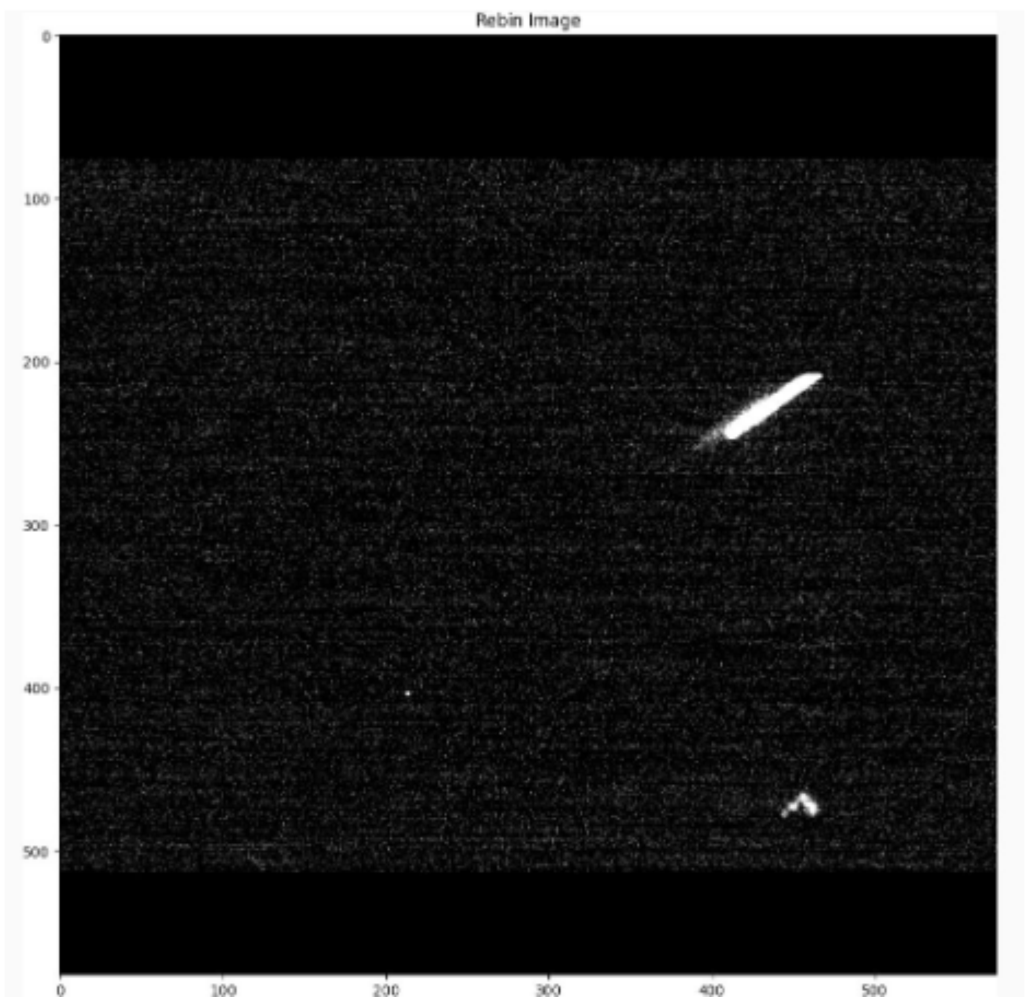
WP2: What we Are Learning II: 3D Reconstruction

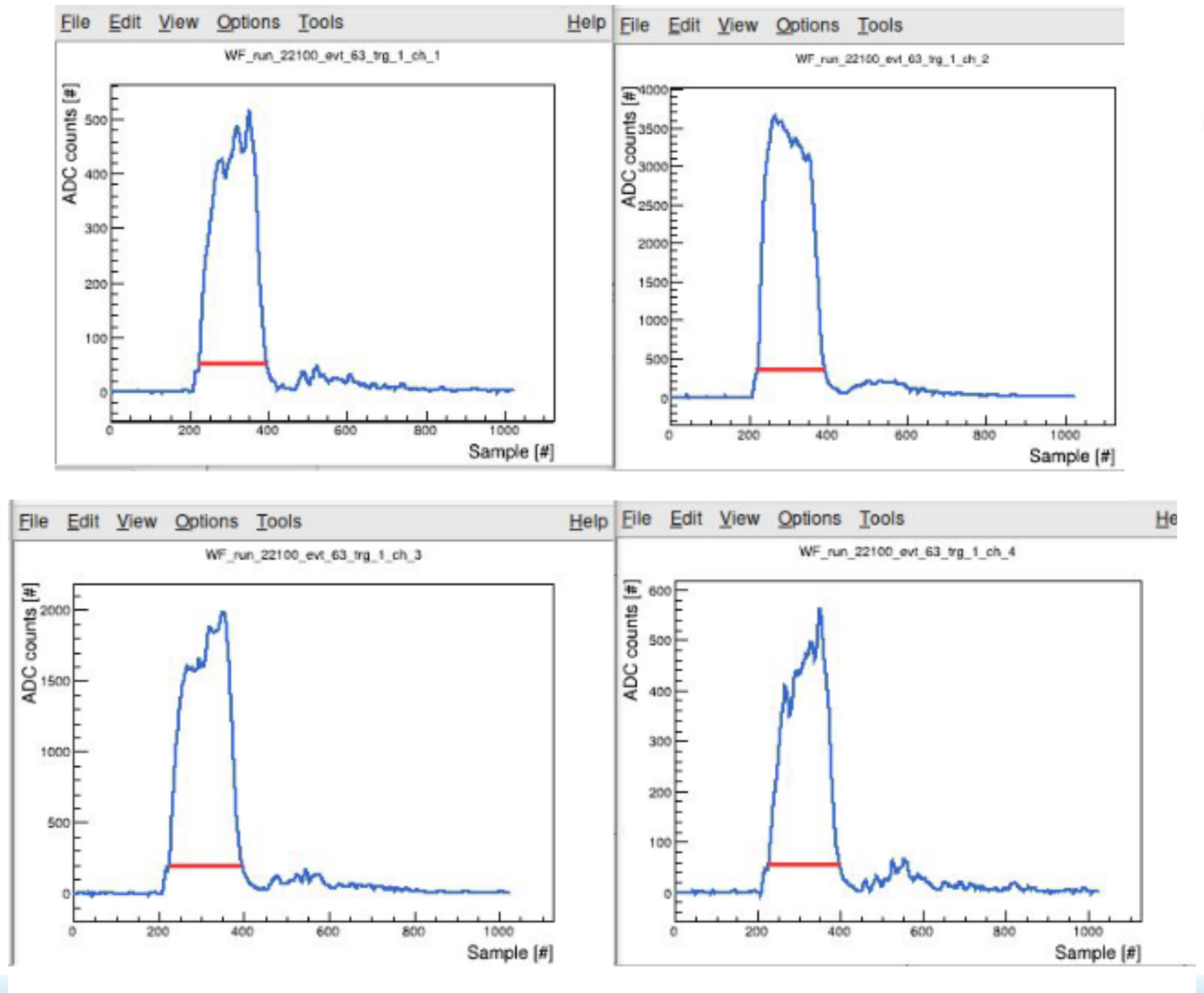
- Bayesian fit technique allows to link PMT waveforms to camera cluster O(cm) precision

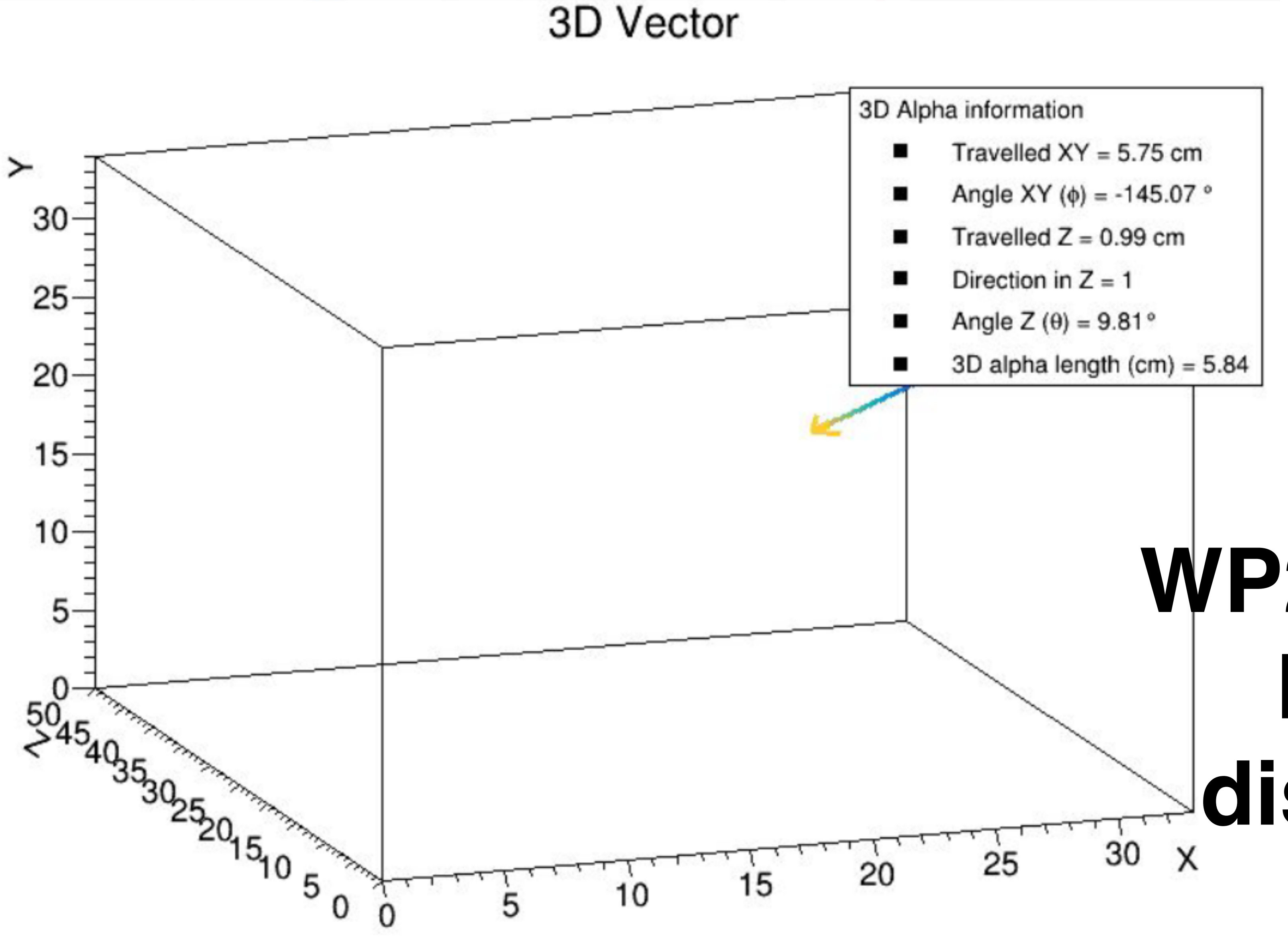
Crosses are positions x-y positions estimated by PMT



- The topology of camera and PMT waveforms can be joined to reconstruct
  3D orientation of tracks (under test on data alpha tracks)



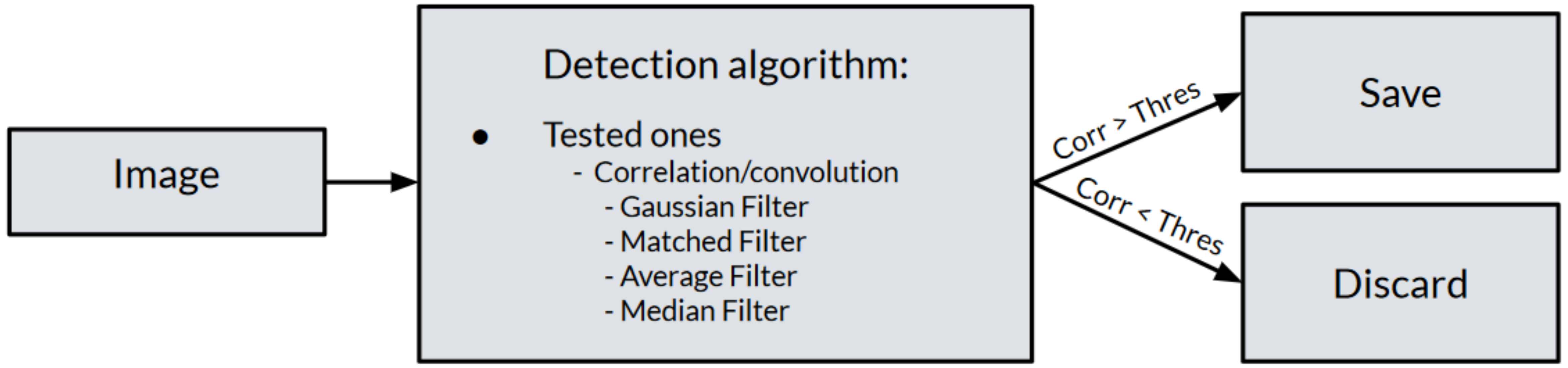




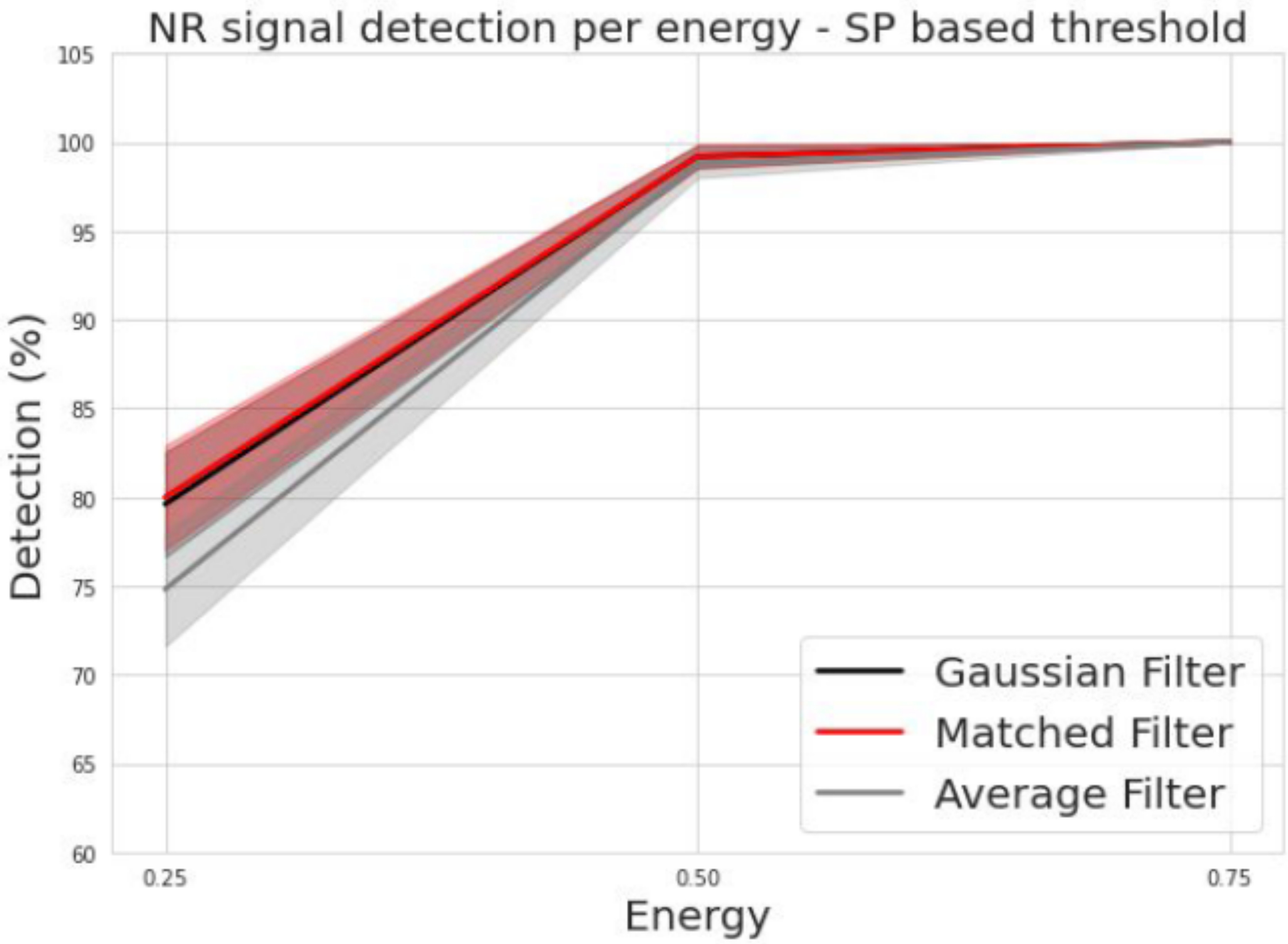
WP2:2.1 Towards ER and NR discrimination

WP2 Looking Forward: Image and Signal Selection

- Machine learning techniques are under study on simulated data to improve image selection (when an image has signal) and which pixels contain relevant information



Above 80% efficiency in selecting signal images with E=0.25 keV_{ee}



WP2:2.2 Towards Multicamera analysis

WP3: Detector simulation

Milestone M3.1 Dec 2023: **validation of the PHASE_0 results**

Software able to r**eproduce detector response** and main **background components**. Still under **evaluation** the contribution of **Radon** in order to properly quantify it;

Milestone M4.1 Dec 2024: **Montecarlo for PHASE_1**

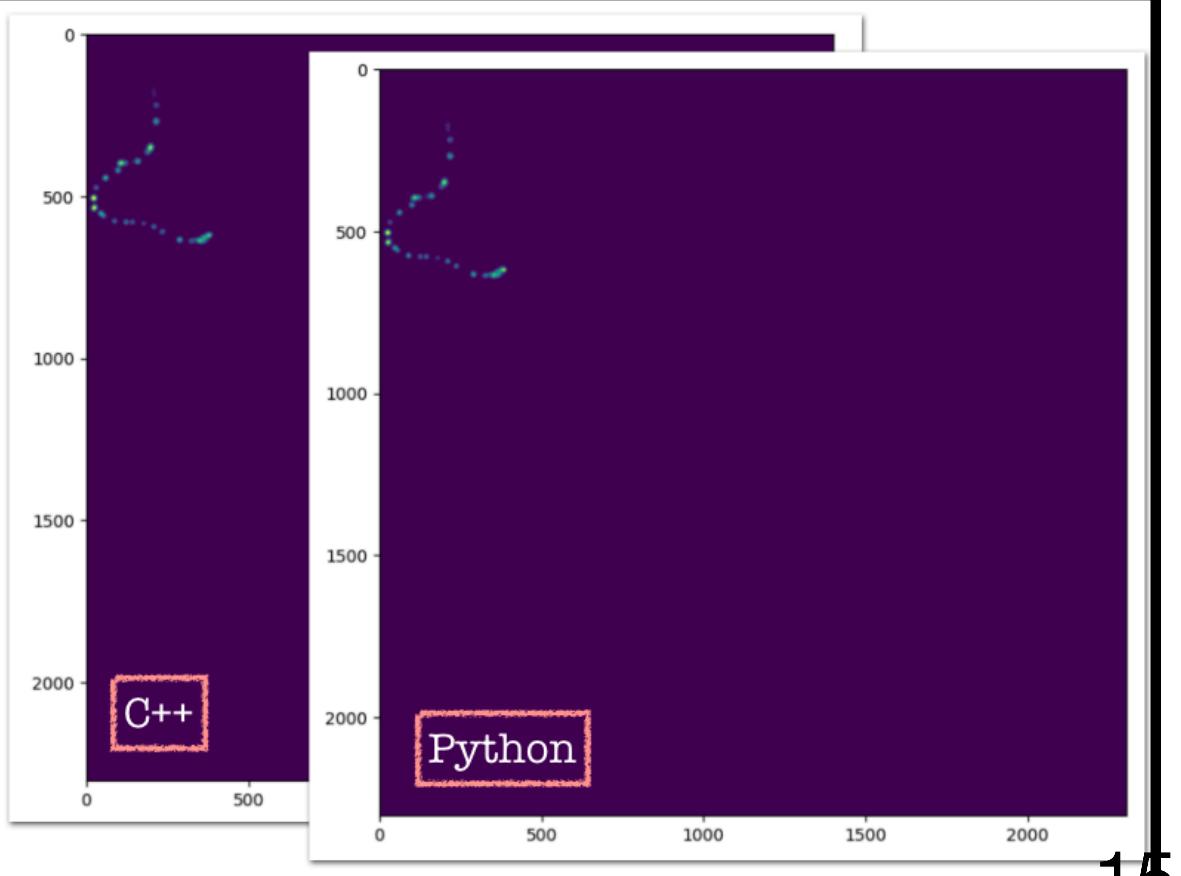
Simulation and **digitisation** underwent several optimisation to s**peed them up by a factor 10**;

the full simulation of radioactivity background in the apparatus is about 5 times faster

Montecarlo

- Total time to digitize 9 tracks:
  - ➡ Traditional voxels, Python: 178 s
  - ➡ Traditional voxels, C++: 25 s
  - ➡ New map algorithm on long tracks, C++: 19 s

Digitisation



WP3: Detector simulation

Milestone M4.1 Dec 2024: **Montecarlo for PHASE_1**

A first **estimation** of **background** in **CYGNO04** was done with preliminary designs in the past years;

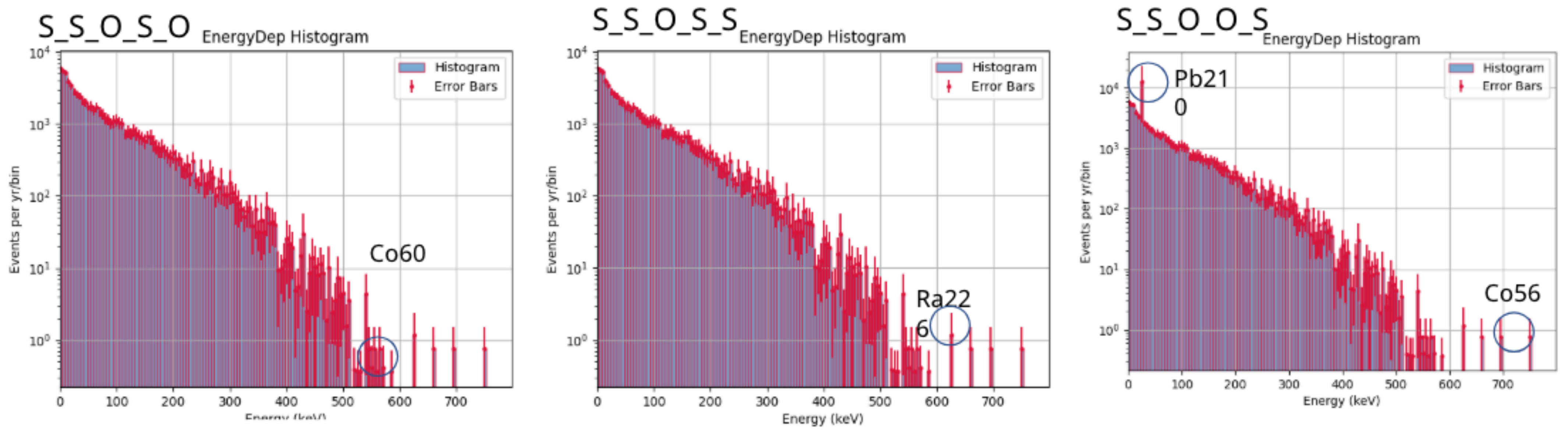
- **optimised** detector **copper** shielding configuration;

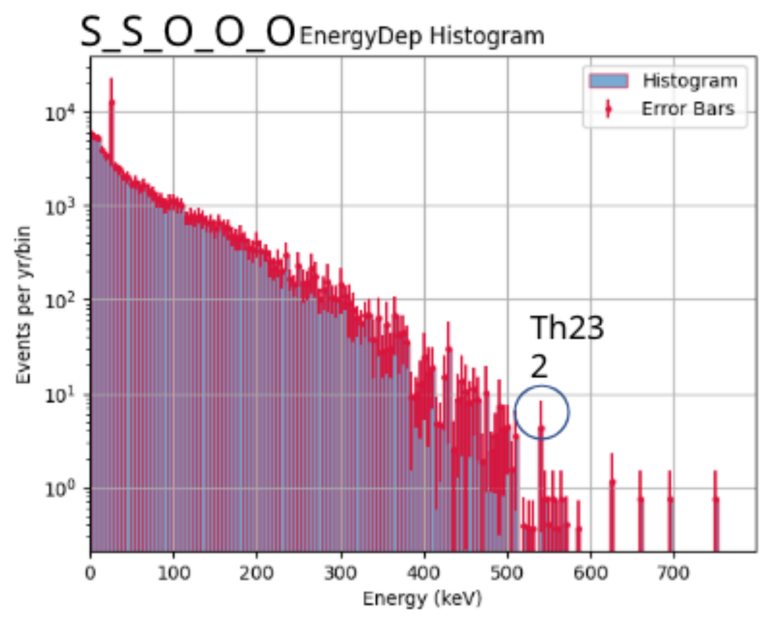
- the **contribution** of **external background**, **copper** shielding already **fully simulated**;

- as soon as **CYGNO04 design is frozen**, the detector CAD will be **imported in GEANT4** and the contribution of each part will be **evaluated**.

- One **month** of computing time should be enough;

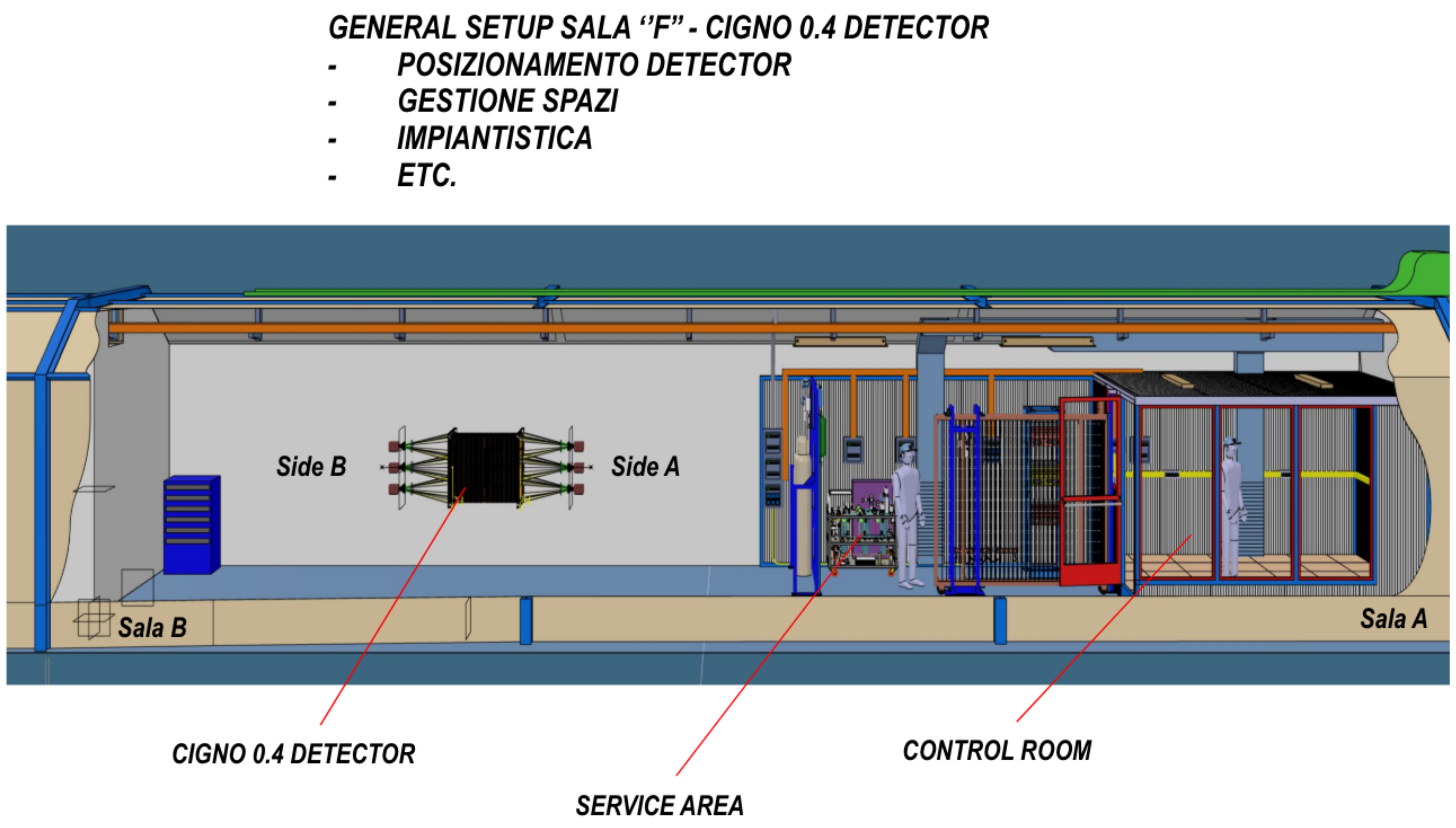
- new C++ code will allow to digitise also alphas and high energy releases and thus provide info about the effect of **radon contamination** in the sensitive volume;





Combination	Events per year with uncertainty	Dominant Isotope
S_S_O_S_O	96132.25 ± 2142.6	U238: 28773 ± 1787
S_S_O_S_S	96349.5 ± 2152.7	U238: 28773 ± 1787
S_S_O_O_O	96422.5 ± 2145.2	U238: 28773 ± 1787
S_S_O_O_S	96639.86 ± 2155.4	U238: 28773 ±

WP4: Detector Design and Construction



Infrastructure installation (D4.1)

- Final **designs** produced in **November 23**

- (Very) long **iteration** between GSSI (commissioner of works) and LNGS lead to an **official agreement in March 24**;

- Final designs translated in **executive designs in the meanwhile** and tender expected to be **issues in the next weeks**;

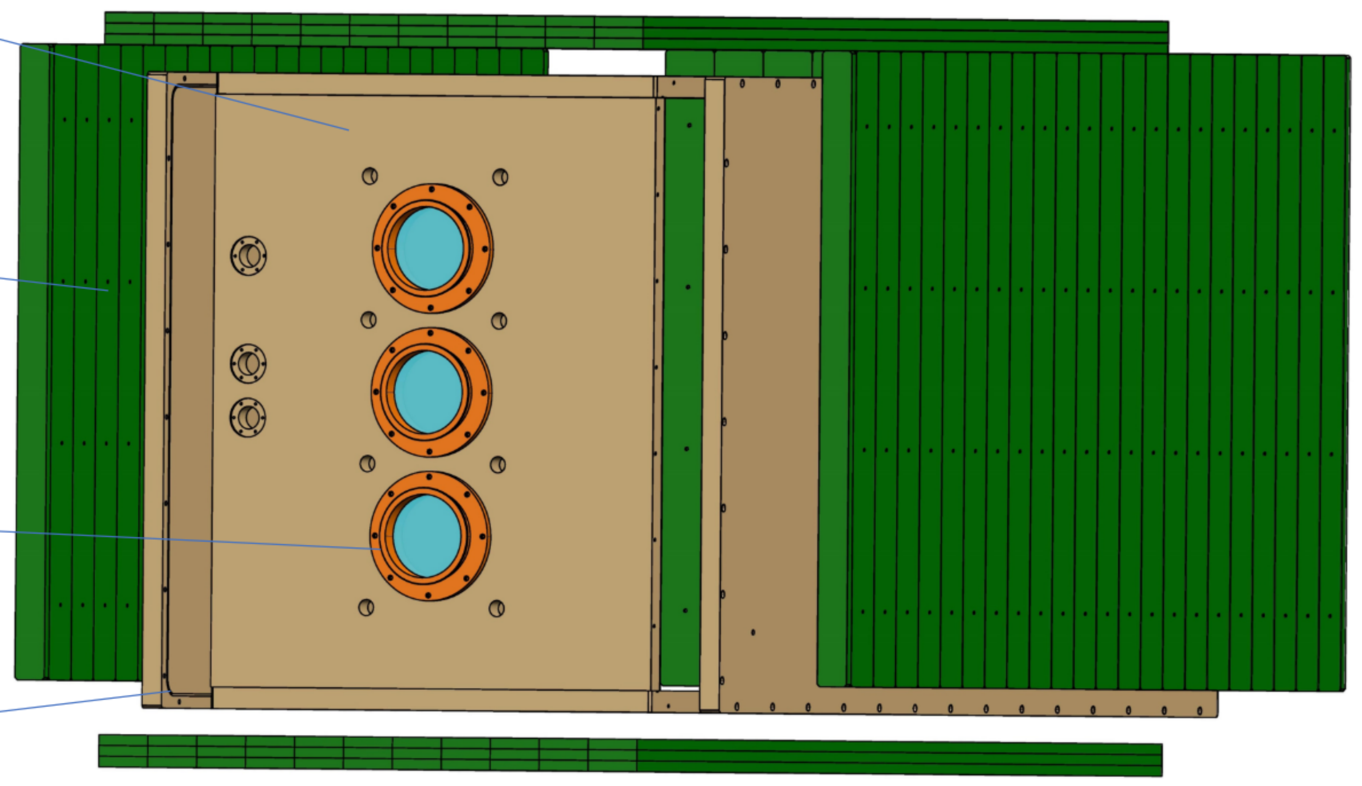
Material procurement and preparation by the **company in July**;

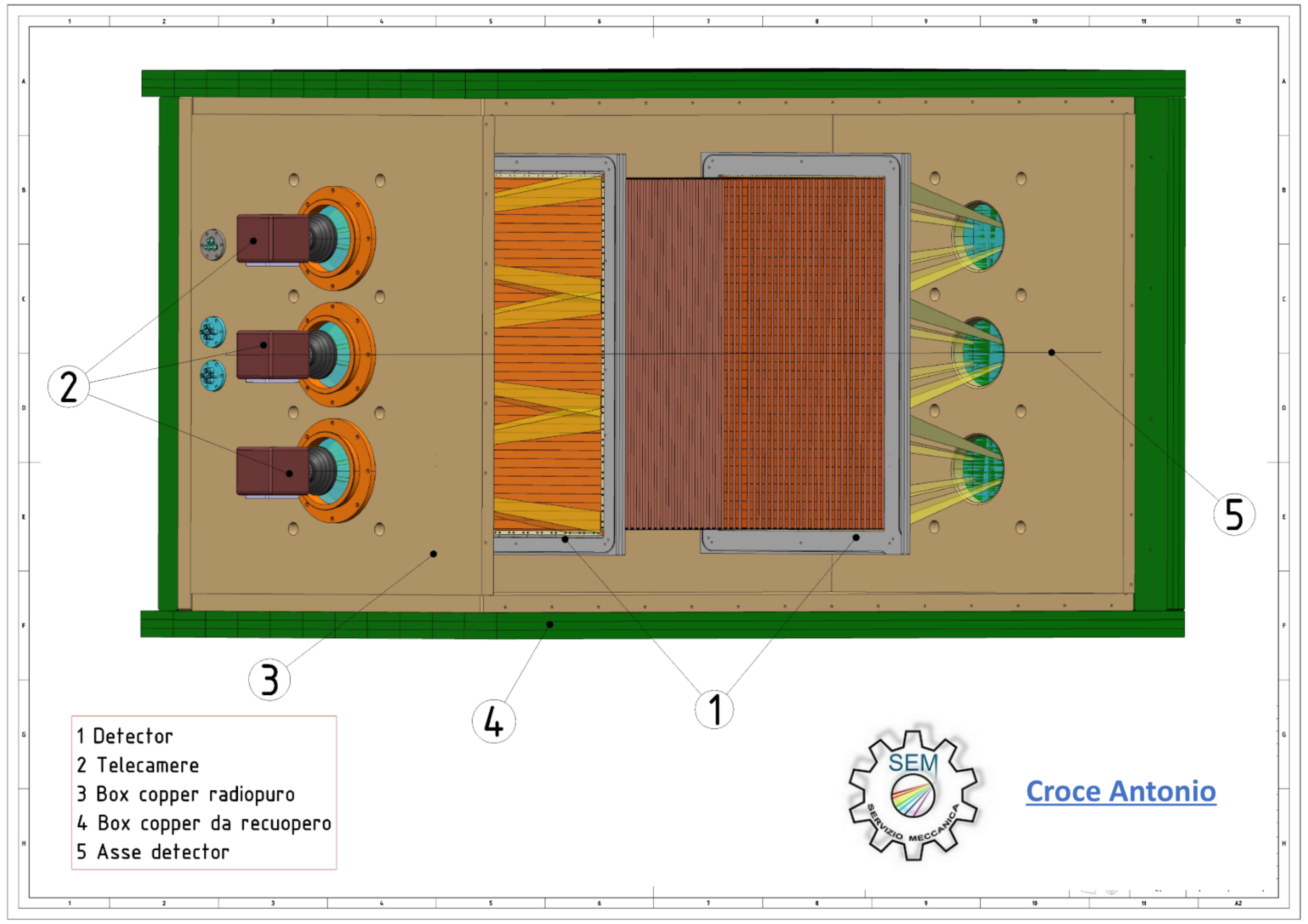
Works are then expected to **start after the summer** with a duration of **1-2 months**;

Hall-F is then expected to be **ready by the end of 2024**;

WP4: Detector Design and Construction

- Box clean Cu (2260x900x1100)
- Box of Cu refurbished (OPERA).
- CAMERAs pass through
- O-Ring Cu for tightness





Detector Design (M4.2)

- Based on the optimisation of copper shielding scheme, the demonstrator designs are being developed: **4 tons of radio-pure** copper for the **internal** layer and **7 tons for the external one**;

- Feed through and optical windows still under study;

- **Cathode** and **field cage almost finalised** (Giorgio and Alex slides);

- Internal **PMMA gas vessel still to be finalised**;

- **Final layout** of the detector foreseen **after the summer** (October 24);

Item	Cost (k€)
4 Ton of radiopure Copper	120
Copper precision machining	10
7 Ton of "OPERA" Copper refurbishing	30
High Voltage Feed Through	10
Optical windows	10
Total	180

WP5 Auxiliary Services

DAQ

- Finalise **automatic procedure** to handle **calibration** runs
- Develop a **custom module** to handle **timing**, **trigger**, and **busy** signals, and to monitor rates and deadtime. **First version** used **successfully** in **LIME;**
- Acquiring and testing USB3 PCIe cards to **readout 6 cameras** and **additional digitizers**
- Working on a new **DAQ** software to **readout** the cameras in **continuum mode.** This should **reduce** by a **factor 10 the dead time** of the camera readout;

Gas system

- From LIME data we evaluated **an efficiency larger than 90%** of the recirculation system **in filtering radon from gas;**
- From this number, the **activity** expected to be produced by **external radon** entering through a **gas leak to be 1300 ev/y/sccm** in **CYGNO04**;

WP6: R&D for PHASE1

Material scrutiny

A new PhD student is working with **Special Technics Services** (STS) for the data analysis to **speed up** the test **procedure**;

In the **past** years, **several materials** were **scrutinised**: LIME-copper, LIME-PMMA, different cameras, sensors, PMT, lenses;

Recently we tested (we are testing): different **Field Cages foils** and **ultra-clean GEM**;

As soon as CYGNO04 design is frozen, we'll contact companies for the final purchase and for **material samples** for radioactivity measurements;

Cleaning the **handling** procedures to be used are discussed with **STS team** and colleagues from **other experiments**;

WP6: R&D for PHASE1

Large area GEM

- The 50x80 cm^2 GEM were bought at CERN and underwent an **high voltage validation at LNF (M6.1)**;
- All of them resulted to be **good**;
- A similar **GEM**, is going to be tested by **STS for the radioactivity measurements (M6.2);**

Field cage and Cathode (D6.2)

- Different **field cage structures** were tested at **LNF** on the **GIN prototype** (see Giorgio’s slides);
- **One** of them was already **tested** by TST and **another** is **under test**;

Low radioactive optics (D6.3)

- The **mechanical design** and **tolerance analysis** is **completed**;
- By **July** we will have the **final report** and **samples of semi-finished materia**l for **radioactivity** test

WP7: Management

Since **July 2023**, the **Steering Committee** composed by the leaders of the different Working Packages and Local Responsible started to operate with the **goal of overseeing to the smooth progress in the work** of the **CYGNO collaboration** through its goals;

In April, **Giovanni Mazzitelli resigned** from his roles of **Technical Coordinator, RAE** and **GLIMOS** because of an **irreconcilable** difference of opinion about the project management

Since April 2024, **Fabrizio Petrucci** (RomaTRE University) is the new **Project Coordinator** of the CYGNO

With this role he is **coordinating** the **steering committee** operation, working in close contact with the SPs, and the coordinators of the WPs, acting as an **interface** to ensure a **smooth communication** among the different coordinators;

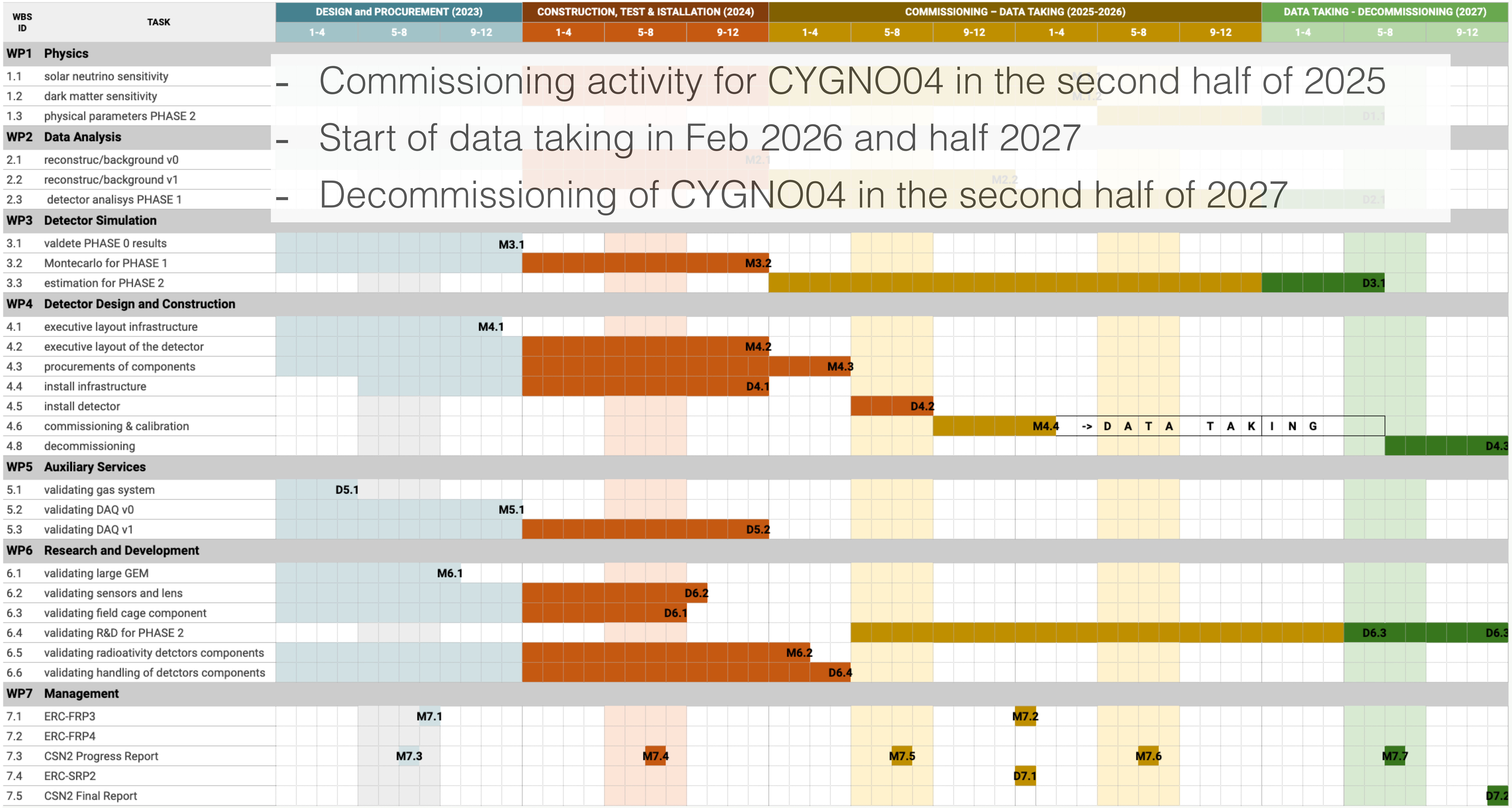
A separate role for a **SC Coordinator** can be **foreseen** in the future;

Andrea Messina is the new **coordinator** of the **Publication** Committee;

D. Pinci is the **resource manager**;

Tentative updated CYGNO04 GANNT

- Commissioning activity for CYGNO04 in the second half of 2025
- Start of data taking in Feb 2026 and half 2027
- Decommissioning of CYGNO04 in the second half of 2027



Davide Pinci, INFN - Roma

Richieste 2025

Task	Section	Item	Cost [k€]
Travels	LNF	shifts (TDR-M2.1/M3.1)	3
		meeting di analisi e di collaborazione	6
		installazione infrastruttura e detector CYGNO04 e coordinamento ai LNGS. TDR-D4.1/D4.2 e commissioning (2 persone, 5 volte al mese)	20
	RM1	shifts (TDR-M2.1/M3.1)	4
		CYGNO04 commissioning (2 persone, 2 volte al mese)	5
		meeting di analisi e di collaborazione	6
	RM3	CYGNO04 commissioning (1 persona, 2 volte al mese)	3
		meeting di analisi e di collaborazione	4
	LNGS	meeting analisi e meeting di collaborazione	5
		Tot	**56**
Consumo	LNF	manutenzione apparati ai LNF/LNGS (sistema di gas, sensori ausiliari, tubi gas, connettori, ecc)	5
		consumo necessario per l'assemblaggio di CYGNO-04 ai LNF (TDR-D4.1/D4.2)	15
	RM1	studio e realizzazione ottica a bassa radioattività (TDR-D6.2)	30
		materiale per realizzazione e test sistema purificazione radon (TDR-D5.1)	5
		Tot	**55**
Altri Consumi	LNGS	acquisto gas per test overground e underground (TDR-M2.1/M3.1)	5
		gas recovery per commissioning CYGNO04	10
		attività manutenzione e facchinaggio CYGNO04 (TDR-M2.1/M3.1)	5
	LNF	acquisto gas per test e commissioning CYGNO04	5
		Tot	**25**
		Gran-Tot	**136**

Updated CYGNO04 Costs for CSN2

Based on the experience gained with the on-going R&D and the construction, commissioning and running of LIME, we expect:

- 10-20 k€/year of consumable for detector maintenance or construction;
- 50 k€/year of R&D before CYGNO-04 installation and 20/30 k€/year for the last R&Ds toward PHASE 2;
- 30 k€/year of travels for the technical operation (installation, commissioning and decommissioning);
- 20 k€/year of gas bottles for CYGNO-04;
- 20 k€/year of gas recovery for CYGNO-04;
- 20 k€/year for shifts and commissioning;

INFN - CSN2	2025	2026	2027
Gas Bottles	10	20	10
Gas Recovery	10	20	10
Consumables	30	10	20
R&D	30	20	0
Tot w/o Travels (k€)	80	70	40
Travels - Shift	28	20	10
Travels - Installation	28	10	30
Tot Travels (k€)	56	30	40
Tot (k€)	**136**	**100**	**80**

Summed to the **185 k€ funded** in the past two years would provide **501 k€** in total for **5 years 2023-2027**

Economic sustainability

Currently, from the ERC fundings, to cover the core costs of CYGNO04, there are **119 k€** available at **INFN** and **490 k€ at GSSI** for a t**otal of 609 k€**

Part of the equipment needed for CYGNO04 was already bought and is currently being used and validated on LIME:

- high voltage system;
- gas system;
- DAQ and trigger;

Item	Cost (k€)
Gas Vessel	35
Readout: GEM. cameras, PMT	146
Cathode	17
Field Cage	13
Calibration	10
Copper Shielding	180
Water Shielding	85
Polietilene Base	20
DAQ	11
Electric Services	20
Cooling and Conditioning	25
Safety: fire detection, gas monitors	35
Total	597

According to the latest quotations received, the **other costs** expected for the **construction** of CYGNO04 is of **597 k€**, therefore an expense that can **be fully covered with ERC funds**

The **total value** of **CYGNO04** is of about **910 k€.**

Summary of CYGNO04 Costs

CYGNO Experiment

Year	INITIUM/ERC	CYGNO/INFN
2019	20	54
2020	201	44
2021	71	96
2022	40	96
2023	164	90
2024	528	90
2025	75	136
2026	0	90
2027	0	80
Tot 23-27	767	486
Tot	**1099**	**776**

With the projections foreseen

- the total INFN-CSN2 contribution to CYGNO/INITIUM activity in **9 years of operations**, from the R&D phase to the demonstrator decommissioning will be **776 k€** (of these, 255 k€ for travels);

- an average of 86 k€/year;

- the contribution mainly for **material** and **instrumentation** and the realisation of the site and the **demonstrator** from **ERC is 1099 k€**.

Conclusion

- 2024 is the year of **transition** from PHASE_0 to PHASE_1;

- activities on **LIME** are mostly **ordinary maintenance** of gas bottle and filters and light shifts;

- a lot of effort moved to **data analysis** and **simulation** to extract as more information as possible from the LIME data;

- focused **R&D** on GIN are leading the **final choice** about the detector **field cage** and **cathode**;

- we are converging on the **final designs** for CYGNO04: **shielding** first, then the **gas vessel** and **field cage** and **cathode**;

- by the end of **2024** the **site will be ready** and we plan to start the **commissioning** of **CYGNO04** in **2025;**

- we formally ask to **CSN2** the **approval** of the **financial plan** presented for the **triennium 2025-27;**

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Letter

Secondary scintillation yield from GEM electron avalanches in He-CF_4 and He-CF_4-isobutane for CYGNO — Directional Dark Matter search with an optical TPC

F.D. Amaro [a], E. Baracchini [b,c], L. Benussi [d], S. Bianco [d], C. Capoccia [d], M. Caponero [d,e], D.S. Cardoso [f], G. Cavoto [g,h], A. Cortez [b,c], I.A. Costa [i,j], G. D'Imperio [h], E. Dané [d], G. Dho [b,c], F. Di Giambattista [b,c], E. Di Marco [h], F. Iacoangeli [h], H.P. Lima Júnior [f], G.S.P. Lopes [k], G. Maccarrone [d], R.D.P. Mano [a], R.R. Marcelo Gregorio [l], D.J.G. Marques [b,c], G. Mazzitelli [d], A.G. McLean [l], A. Messina [g,h], C.M.B. Monteiro [a,*], R.A. Nobrega [k], I.F. Pains [k], E. Paoletti [d], L. Passamonti [d], F. Petrucci [i,j], S. Piacentini [g,h], D. Piccolo [d], D. Pierluigi [d], D. Pinci [h], A. Prajapati [b,c], F. Renga [h], R. J.d.C. Roque [a,*], F. Rosatelli [d], A. Russo [d], G. Saviano [d,m], N.J.C. Spooner [l], R. Tesauro [d], S. Tomassini [d], S. Torelli [b,c], J.M.F. dos Santos [a]

[a] *LIBPhys, Department of Physics, University of Coimbra, 3004-516 Coimbra, Portugal*
[b] *Gran Sasso Science Institute, 67100, L'Aquila, Italy*
[c] *Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Gran Sasso, 67100, Assergi, Italy*
[d] *Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, 00044, Frascati, Italy*
[e] *ENEA Centro Ricerche Frascati, 00044, Frascati, Italy*
[f] *Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro 22290-180, RJ, Brazil*
[g] *Dipartimento di Fisica, Universitá La Sapienza di Roma, 00185, Roma, Italy*
[h] *Istituto Nazionale di Fisica Nucleare, Sezione di Roma, 00185, Rome, Italy*
[i] *Dipartimento di Matematica e Fisica, Universitá Roma TRE, 00146, Roma, Italy*
[j] *Istituto Nazionale di Fisica Nucleare, Sezione di Roma Tre, 00146, Rome, Italy*
[k] *Universidade Federal de Juiz de Fora, Faculdade de Engenharia, 36036-900, Juiz de Fora, MG, Brazil*
[l] *Department of Physics and Astronomy, University of Sheffield, Sheffield, S3 7RH, UK*
[m] *Dipartimento di Ingegneria Chimica, Materiali e Ambiente, Sapienza Università di Roma, 00185, Roma, Italy*

Our paper on the use of hydrogenated has mixtures for the search of light DM was published on Physics Letter B

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ABSTRACT

CYGNO is an international collaboration with the aim of operating a 1 m^3 optical time projection chamber (TPC) for directional Dark Matter (DM) searches and solar neutrino spectroscopy, to be deployed at the Laboratori Nazionali del Gran Sasso (LNGS). A He/CF_4 (60/40) mixture is used, along with a triple Gas Electron Multiplier (GEM) cascade to amplify the ionisation signal. The scintillation produced in the electron avalanches is read out using a scientific complementary metal–oxide–semiconductor (sCMOS) camera. This solution has proven to provide very high sensitivity to interactions in the few keV energy range. The inclusion of a hydrogen-based gas will offer an even lighter target, resulting in a more efficient energy transfer in a DM particle collision, and consequently, a lower detection threshold. Additionally, longer track lengths of light nuclear recoils are easier to detect with a clearer direction. However, the addition of such gas will contribute to quenching the scintillation, jeopardizing the TPC performance. In this work, we demonstrate the feasibility of adding 1% to 5% isobutane to the He/CF_4 (60/40) mixture by measuring the respective absolute scintillation yield output. The overall scintillation produced in the charge avalanches is not drastically suppressed by quenching due to the isobutane addition. The presence of Penning transfer from excited He atoms to isobutane molecules increases the number of electrons in the avalanches, partially compensating for the loss of scintillation due to quenching. For the highest applied GEM voltage, the total number of photons produced in the avalanche per keV deposited in the absorption region presents a decrease of only a factor of about three, from $2.30(20) \times 10^4$ to $8.2(4) \times 10^3$

* Corresponding authors.
E-mail addresses: cristinam@uc.pt (C.M.B. Monteiro), ritaroque@fis.uc.pt (R. J.d.C. Roque).

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