STATUS OF THE CYGNO EXPERIMENT

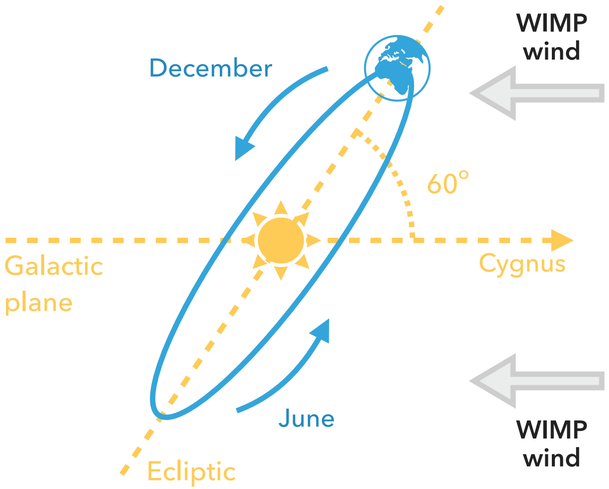
MELBA D'ASTOLFO

On behalf of the CYGNO collaboration

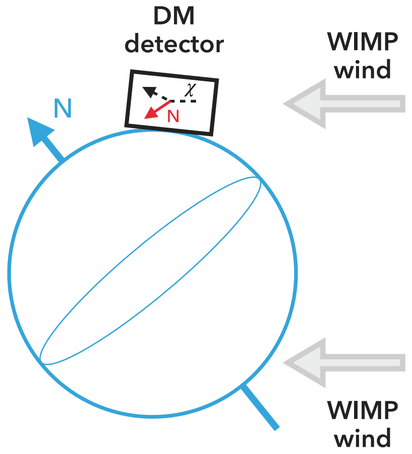
Gran Sasso Science Institute

melba.dastolfo@gssi.it

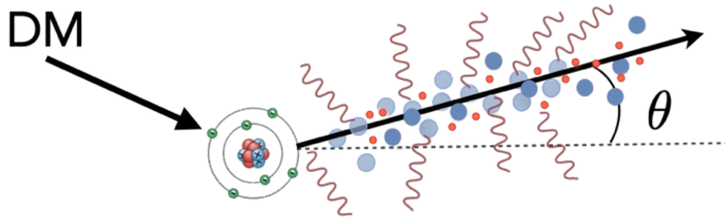
Our galaxy



Solar System



Earth



DM Detector

Gaseous TPC

- He:CF_4 (60:40)
- Room temperature
- Atm pressure

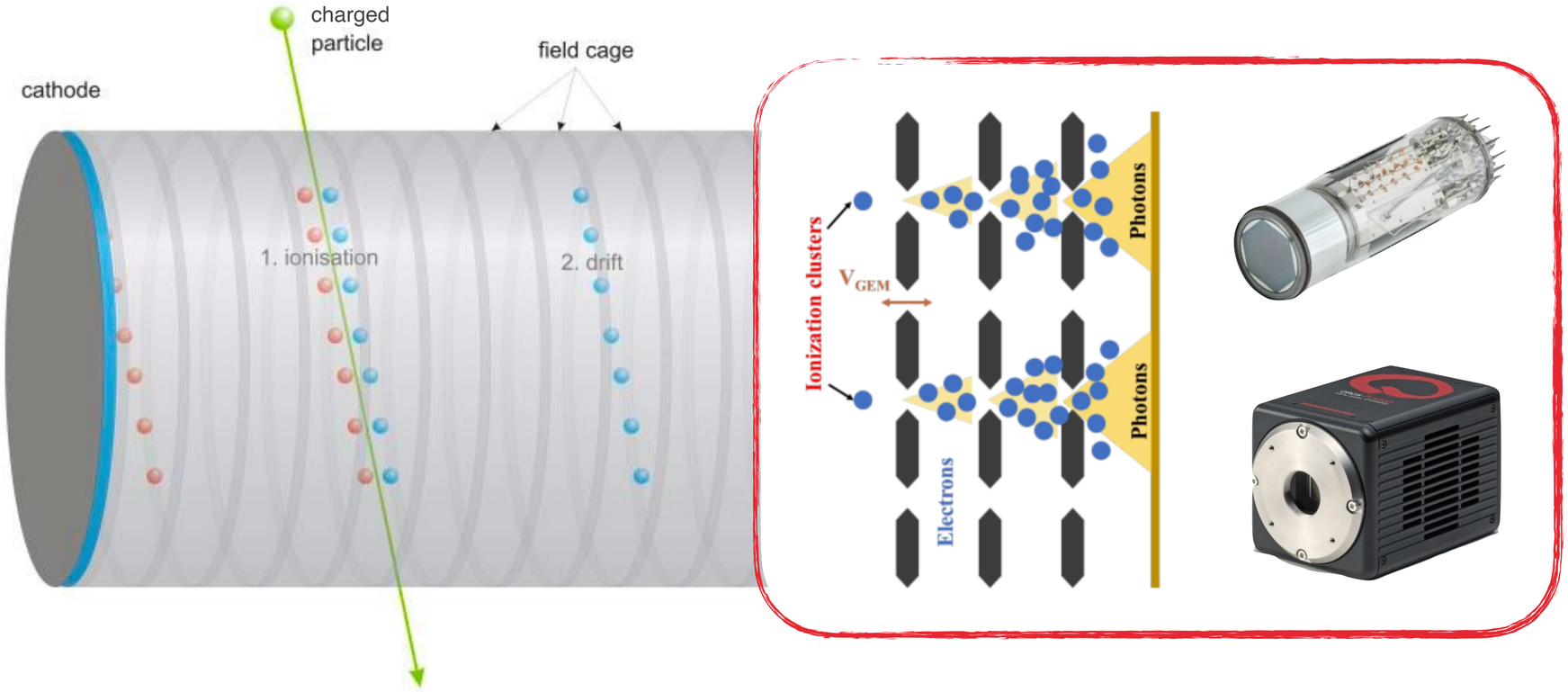
Triple GEM

Charge multiplication

Scintillation photons

Camera + PMT

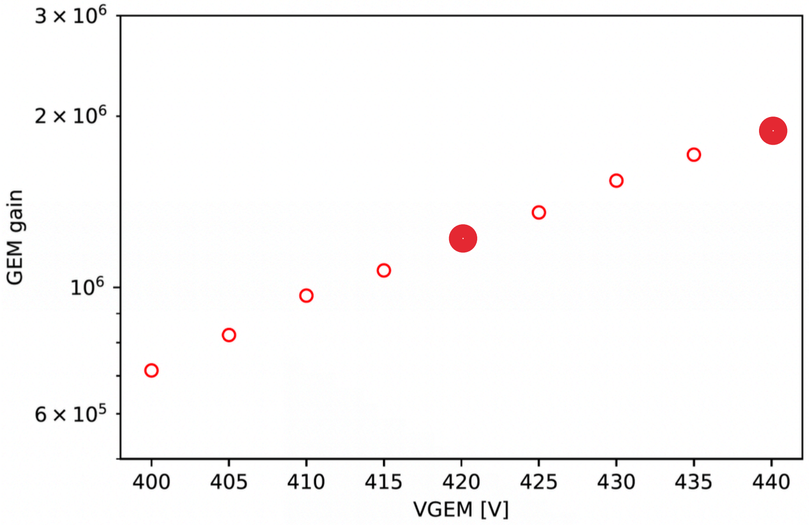
Light from gas scintillation during electron avalanche



GEM AMPLIFICATION

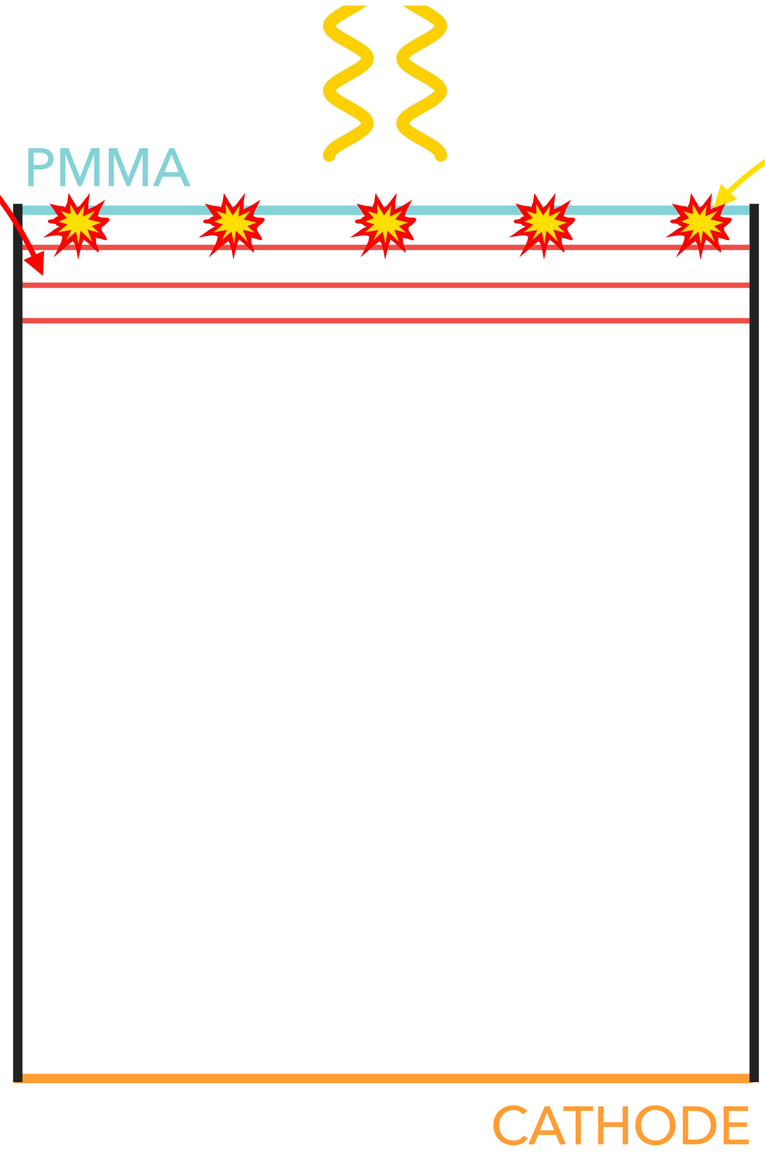
We operated our detector setting the **GEM HV** to two different configurations:

- ➡ High gain: 440 V
- ➡ Low gain: 420 V



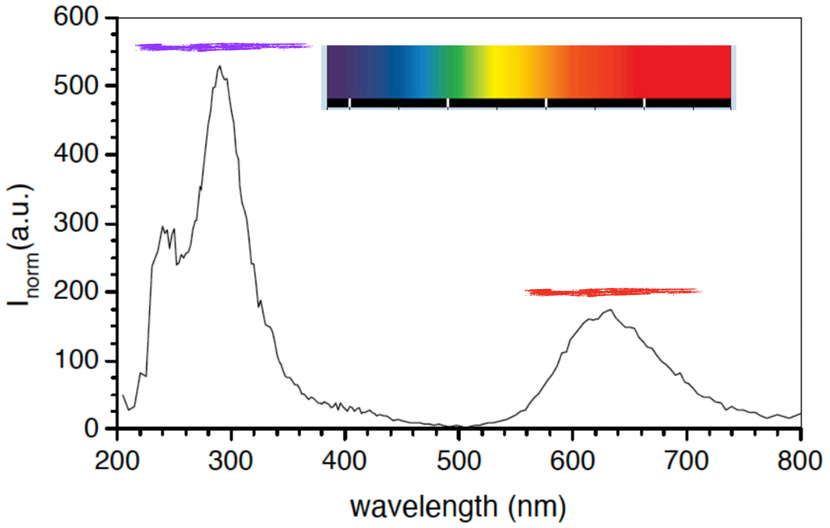
GEM stability: 2 years of data taking with gain 10^6 without showing any damage

Estimated spark rate: 0.3/day



LIGHT EMISSION

$$e^- + CF_4 \rightarrow CF_3^* + F + e^-$$



Two main lines, excited by accelerated electrons:

- ➡ Visible: 620 nm
- ➡ UV light: 265 nm

Relative light production **independent** from the voltage

PMT

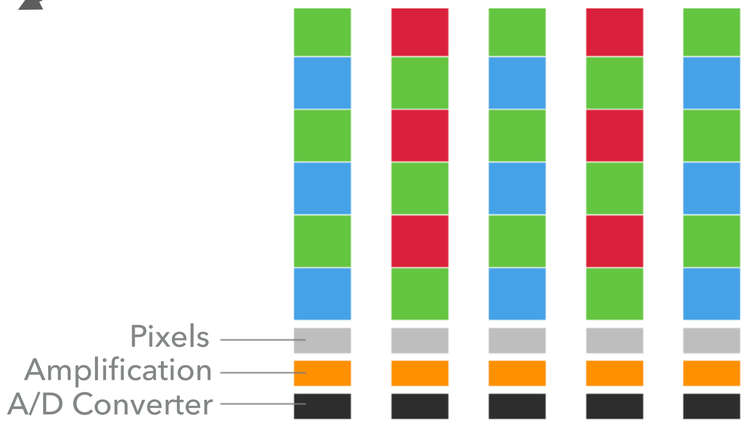
Camera

Hamamatsu R7378 PMTs

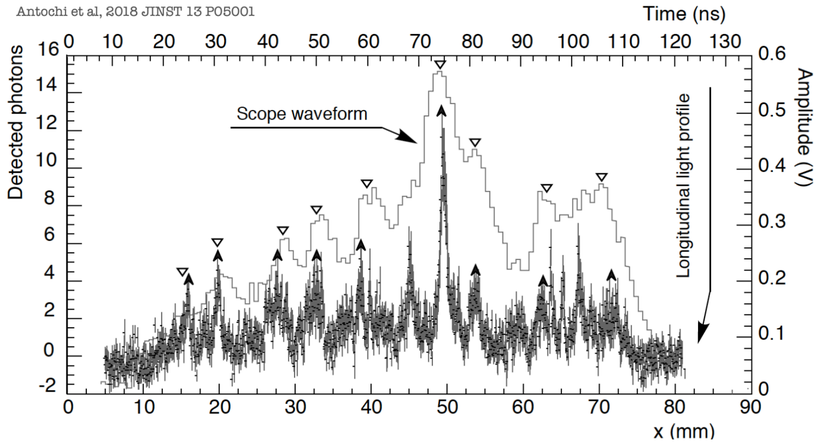
$\Longrightarrow$ 22 mm diameter

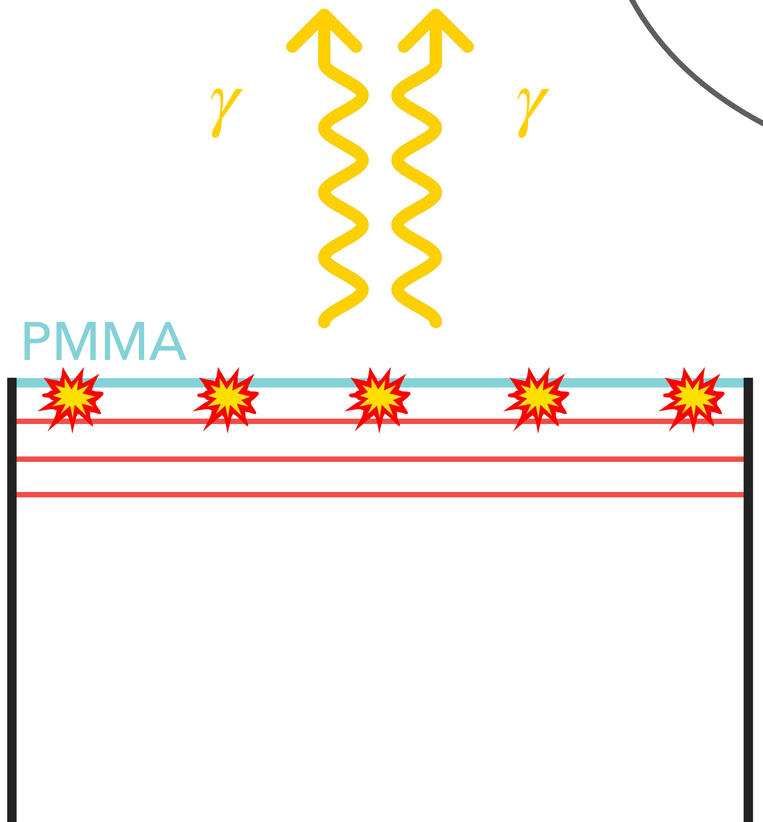
$\Longrightarrow$ ~ns time response

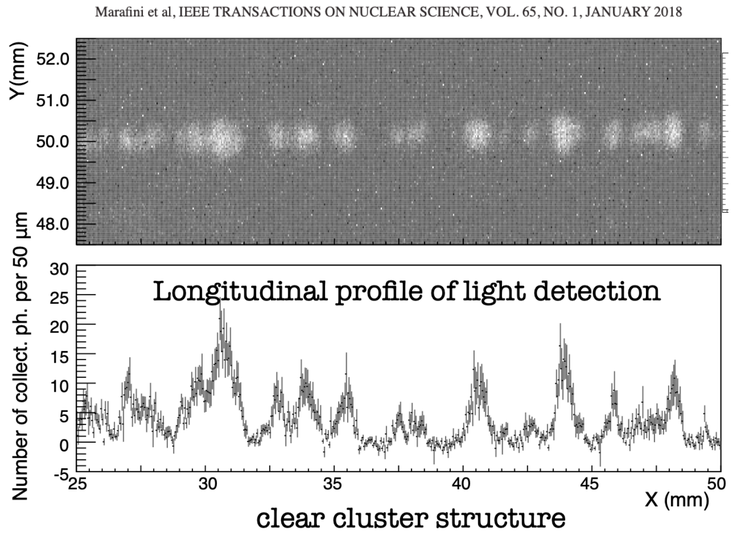
CMOS sensor



Hamamatsu ORCA

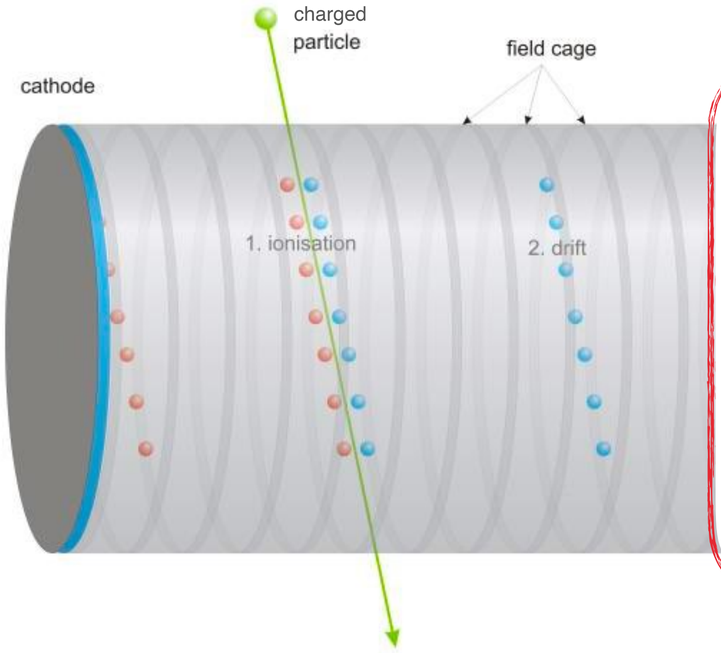


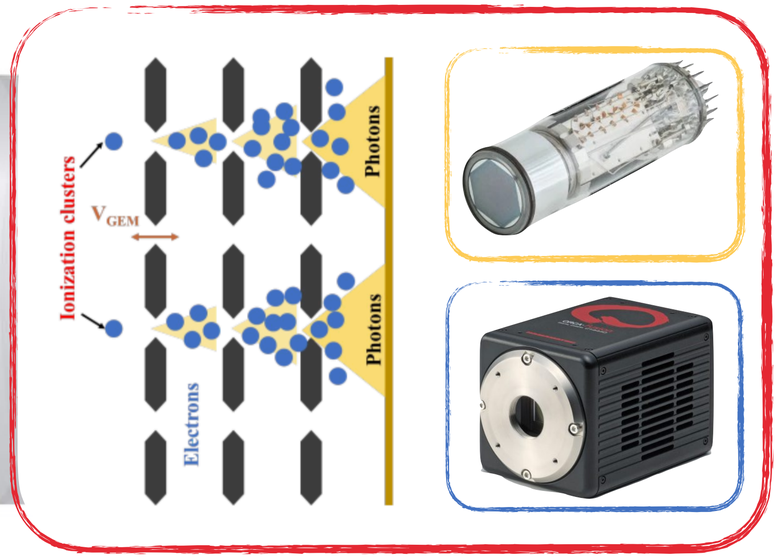




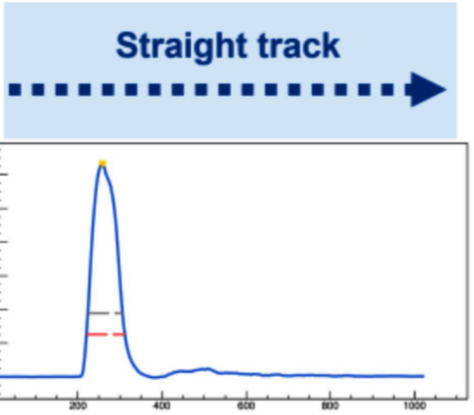
Fast photosensors to get the **time** information

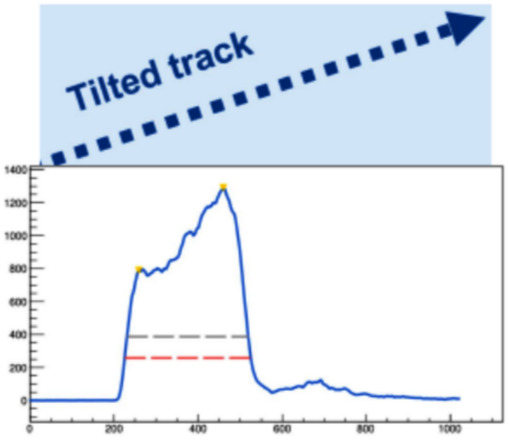
⇒ reconstruct **z inclination**



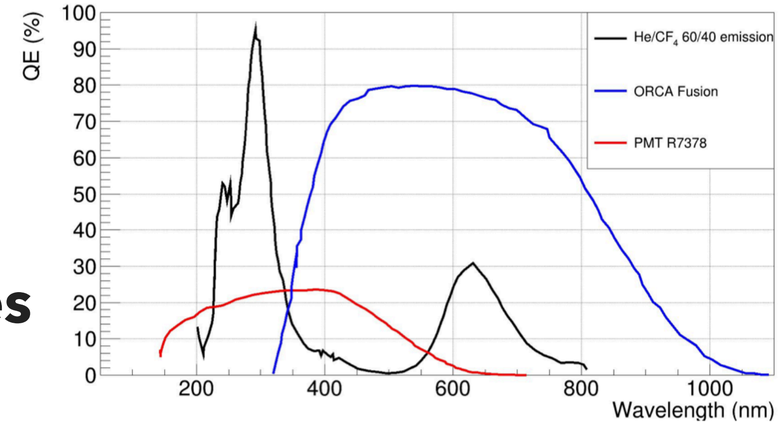


Integrated z + Energy

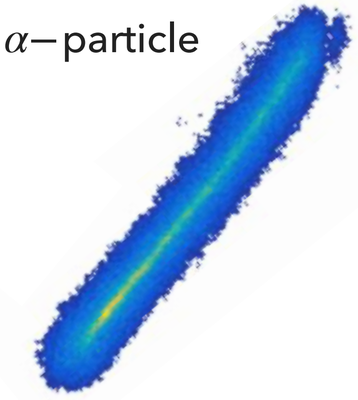




Energy + X & Y coordinates



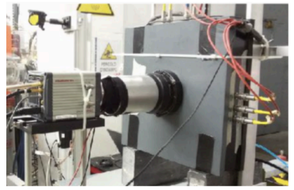
$\alpha-$particle



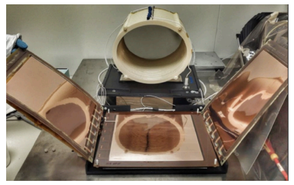
PHASE 0 - R&D and prototypes | PHASE 1 | PHASE 2

2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

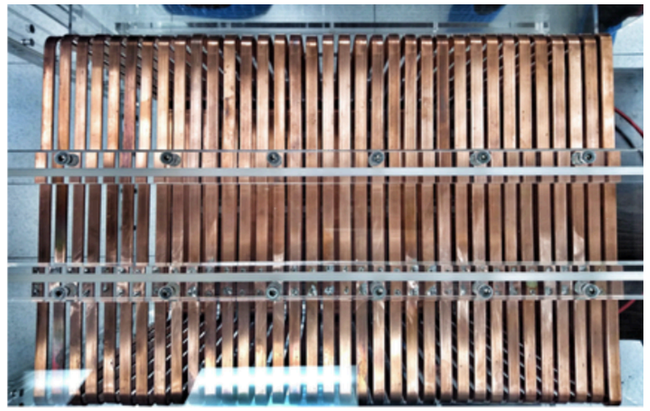
ORANGE | LEMON | LIME | CYGNO_04 | CYGNO_30



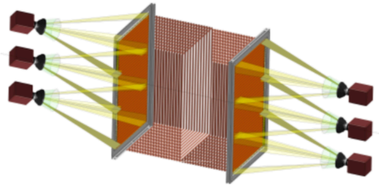
- 1 cm drift



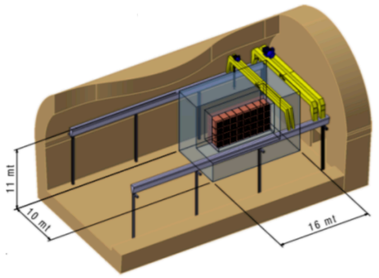
- 3D printing
- 20 cm drift



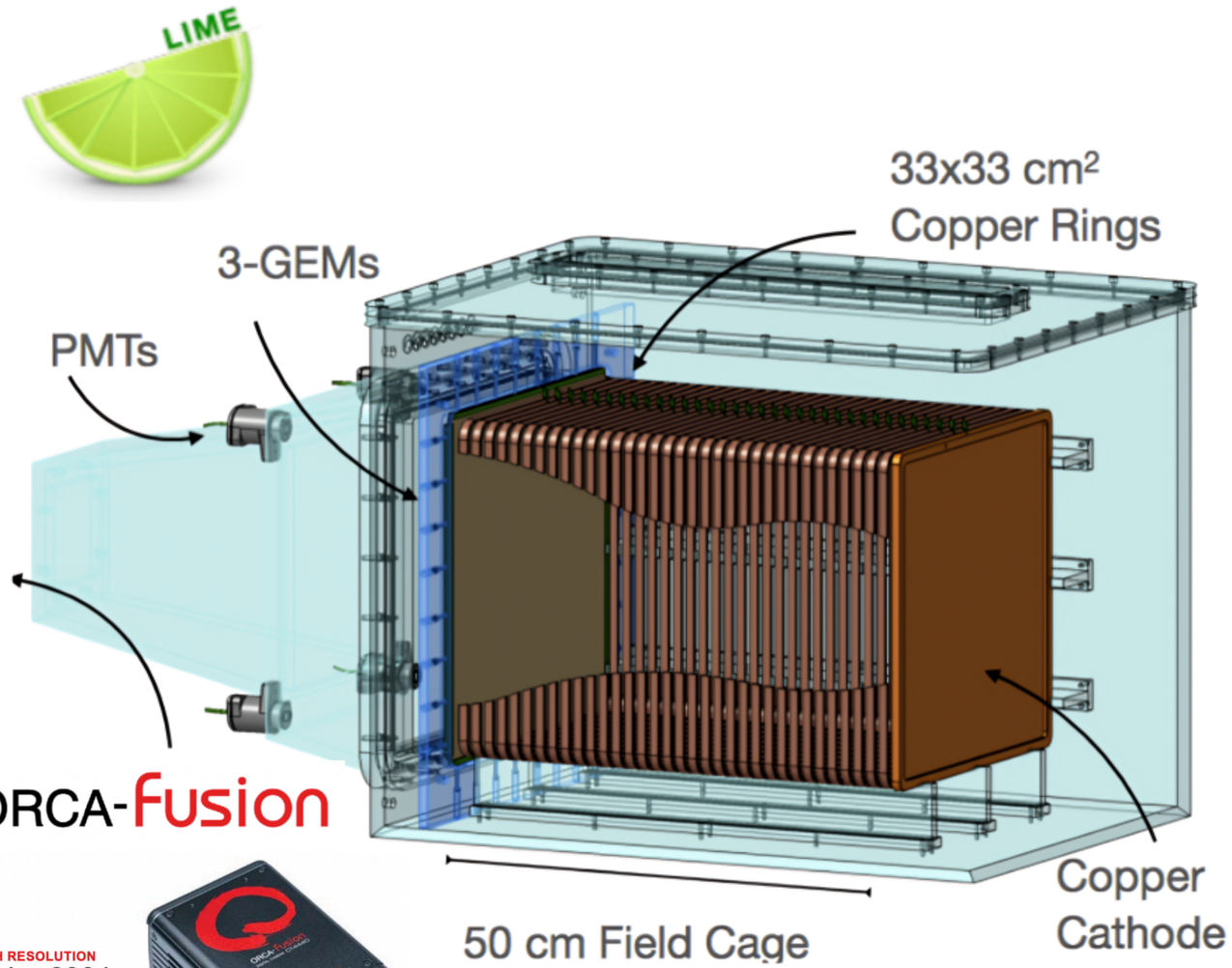
- 50 cm drift
- Underground tests
- MC validation



- Background
- Material tests
- Gas purification
- Scalability



- Physics research



50 L active volume of $He:CF_4$ (60:40)

Atmospheric pressure and room temperature

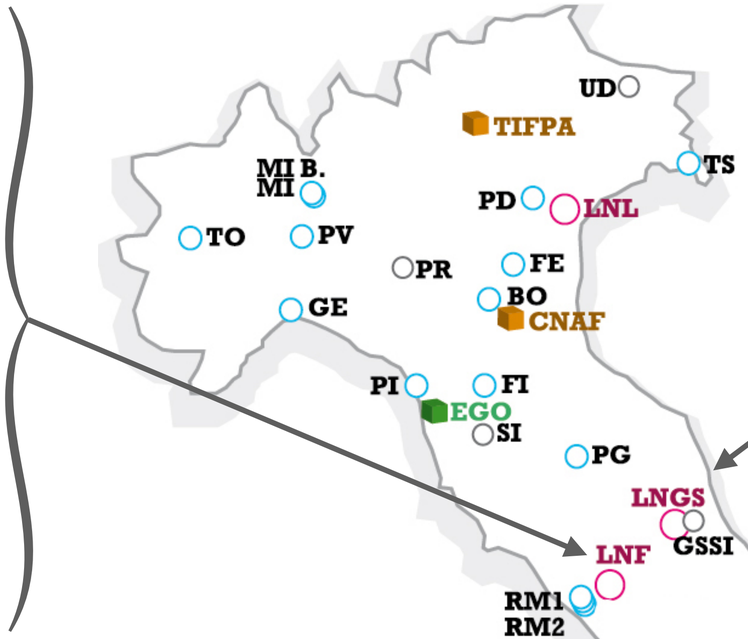
Triple 33x33 cm^2 GEM stack for amplification

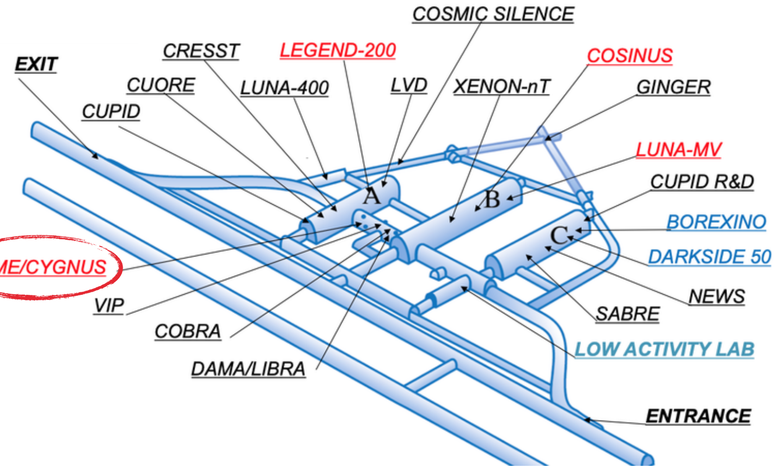
Optical readout → 4 PMTs + 1 sCMOS camera (ORCA fusion)

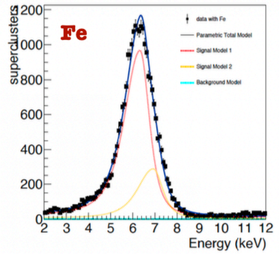
Light yield and saturation

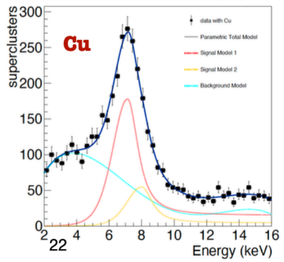
Energy threshold and resolution

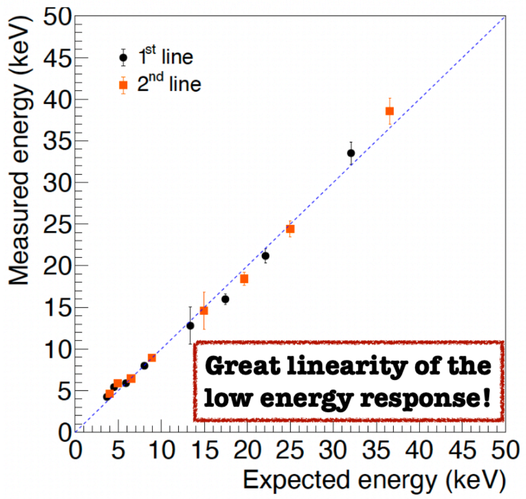
Linearity of the energy response









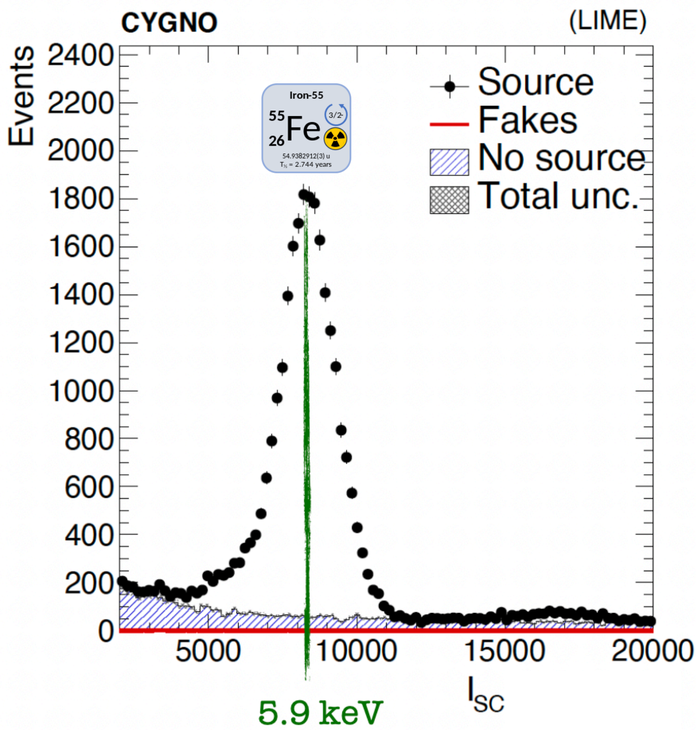


Initial tests: DAQ, remote control, slow control, gas quality, detector operation optimization

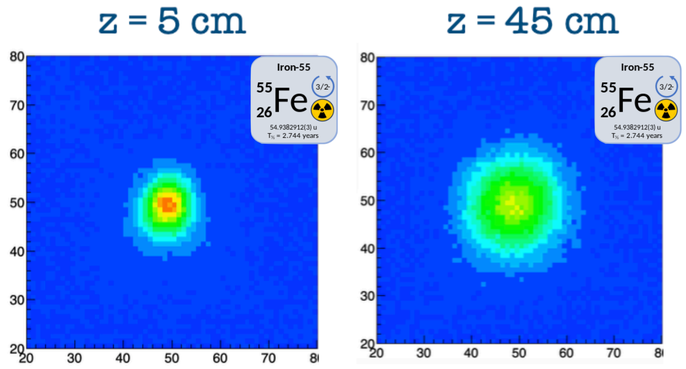
- Laboratori Nazionali
- Sezioni
- Gruppi collegati
- Centri Nazionali e Scuole
- Consorzi

LIGHT YIELD

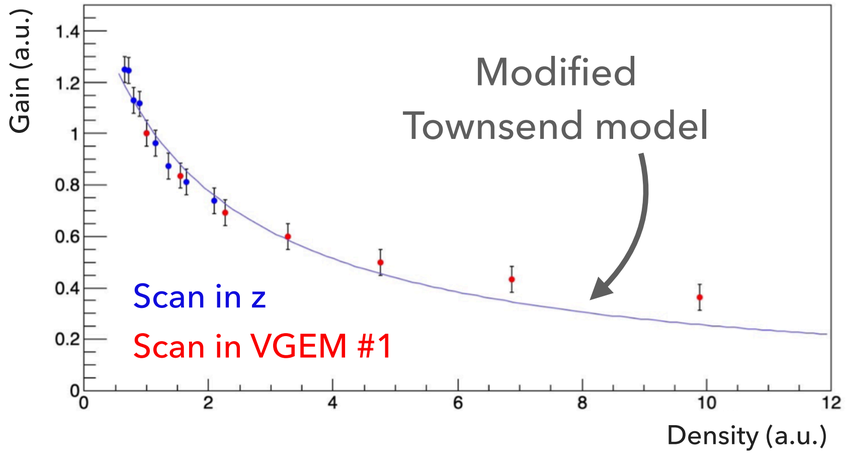
Total light integral proportional to the **energy**, and **dependent on z** due to the saturation of GEM gain



SATURATION

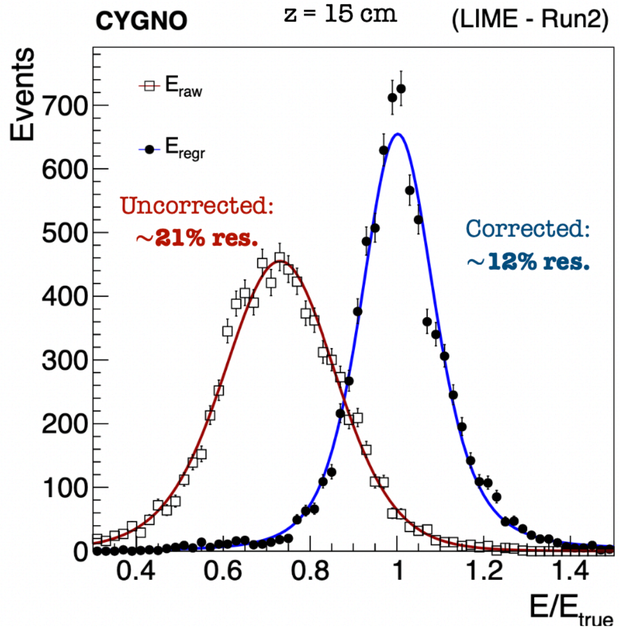


Saturation of GEM gain due to **avalanche local space charge**



ENERGY RESOLUTION

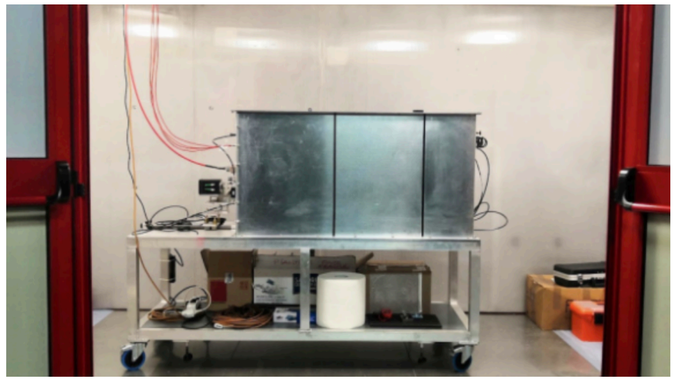
Multivariate regression algorithm to correct for x-y non uniformity of the light yield, and partially the saturation effect



Spr/Sum 2022	Autumn 2022	Winter 2023	Spr/Sum 2023	Win/Spr 2023	Sum/Aut 2023
RUN 0	**RUN 1**	**RUN 2**	**RUN 3**	**RUN 4**	**RUN 5**
Commissioning	No shielding	4 cm Cu	10 cm Cu	10 cm Cu + 40 cm H_2O	10 cm Cu
	R_{PMT} = 30 Hz	R_{PMT} = 3.5 Hz	R_{PMT} = 1.6 Hz	R_{PMT} = 1.0 Hz	R_{PMT} = 1.5 Hz
	V_{GEM} = 420 V	V_{GEM} = 440 V	V_{GEM} = 440 V	V_{GEM} = 420 V - 440 V	V_{GEM} = 420 V
			AmBe ^{241}Am		Neutron flux AmBe

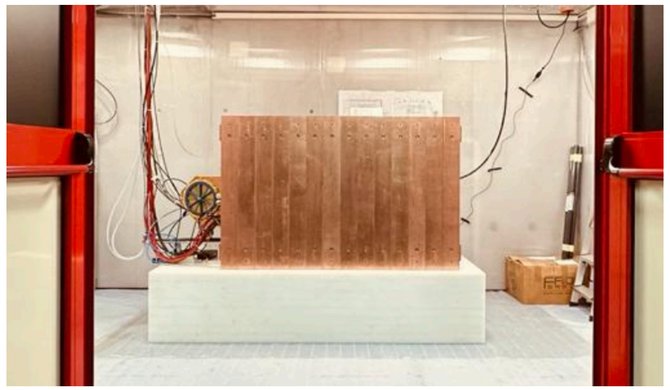
RUN 1

Background dominated by the external sources



RUN 2-3-5

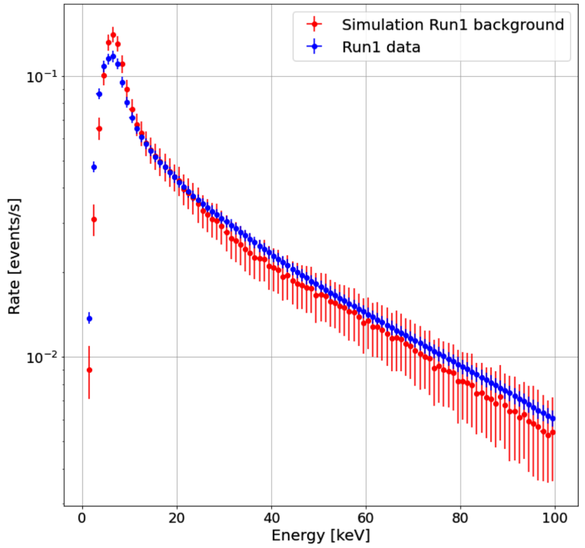
External background suppressed by a factor ~40-600

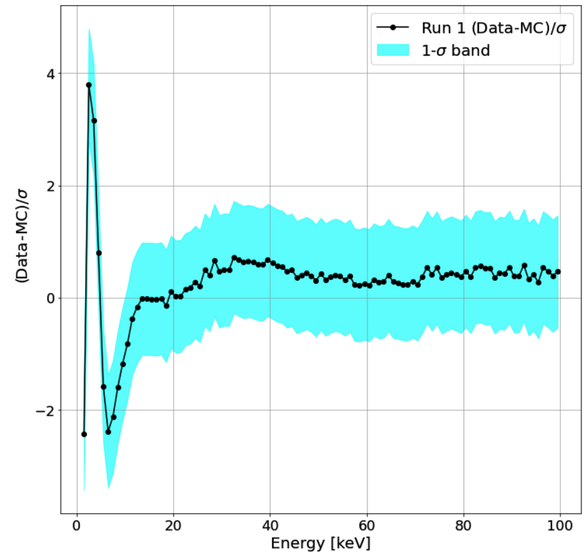


RUN 4

Residual external neutron background suppression

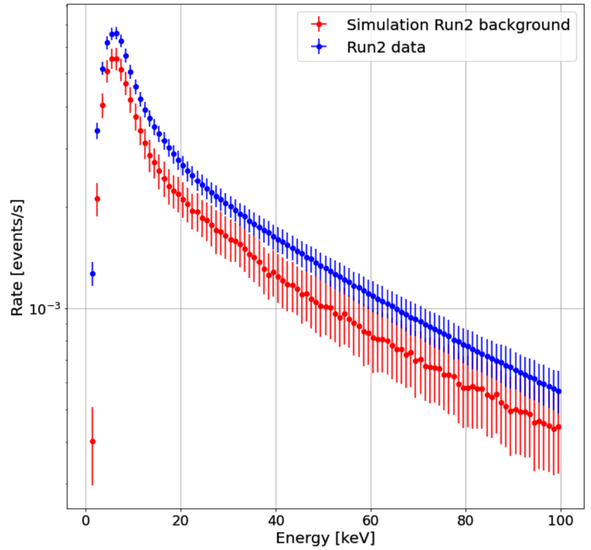
RUN 1

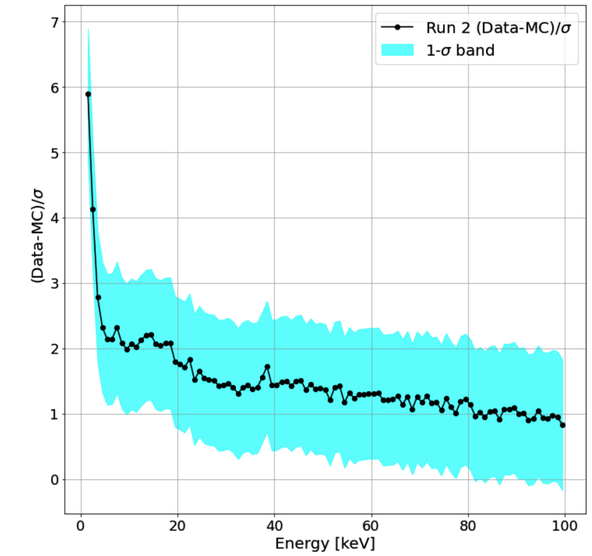




Agreement → capability of simulating external background

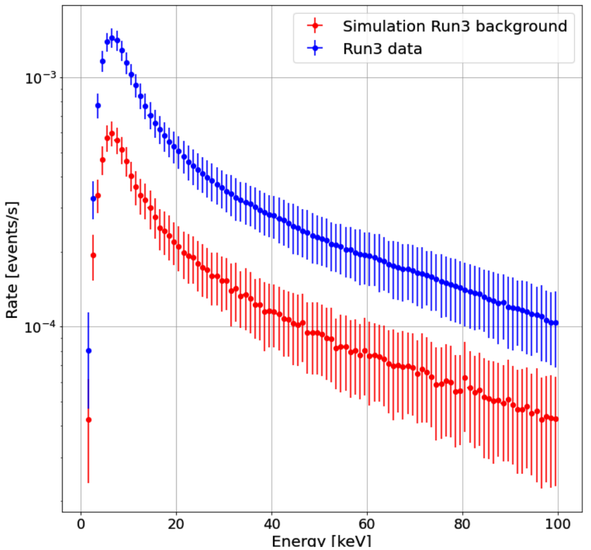
RUN 2

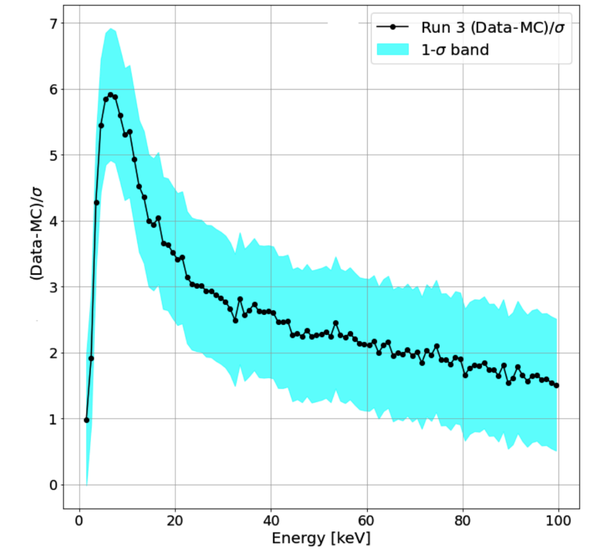




Difference ±22% → internal component missing

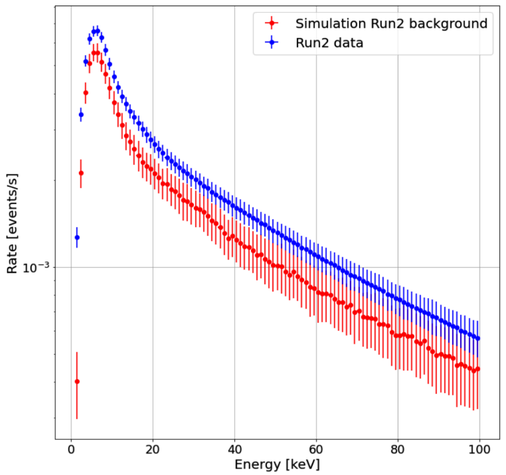
RUN 3

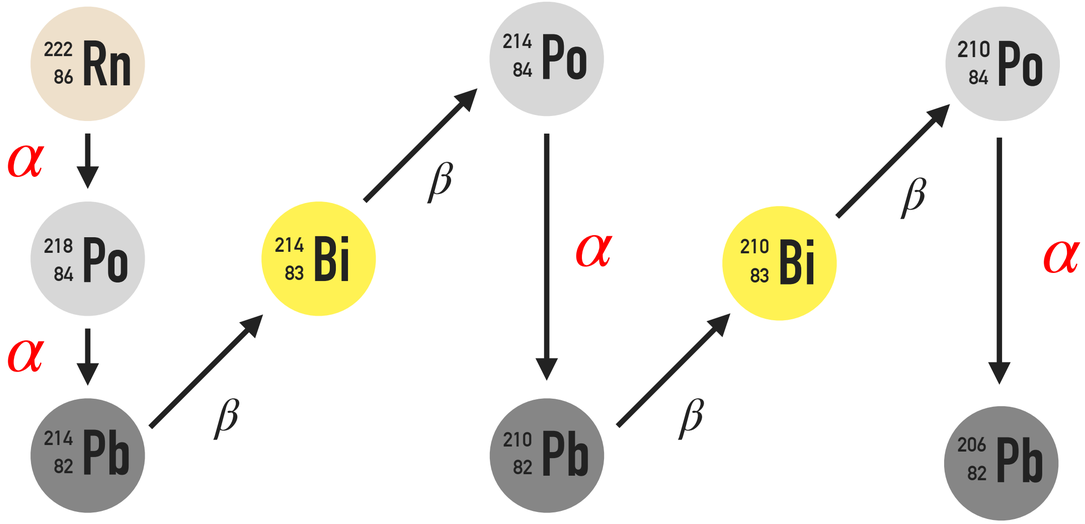




Difference ±60% → internal component missing

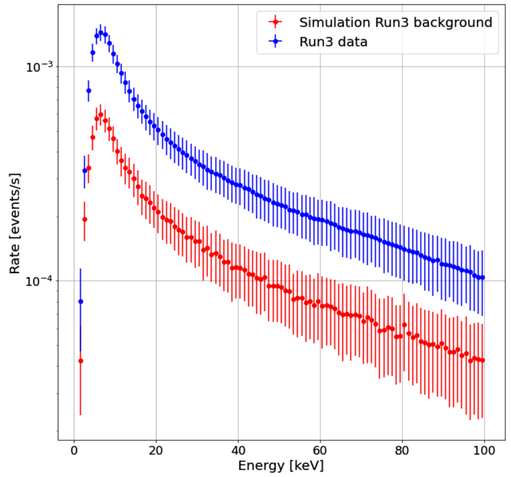
RUN2

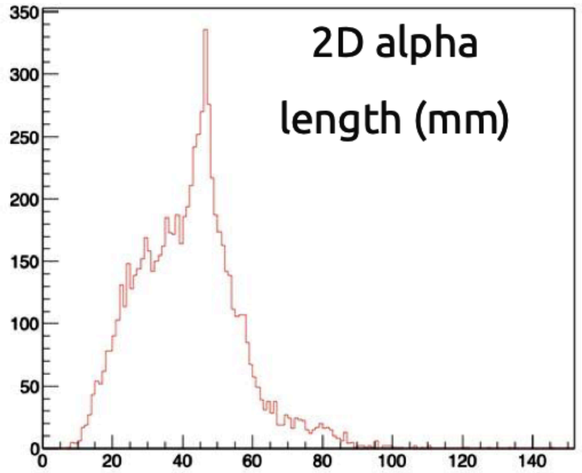




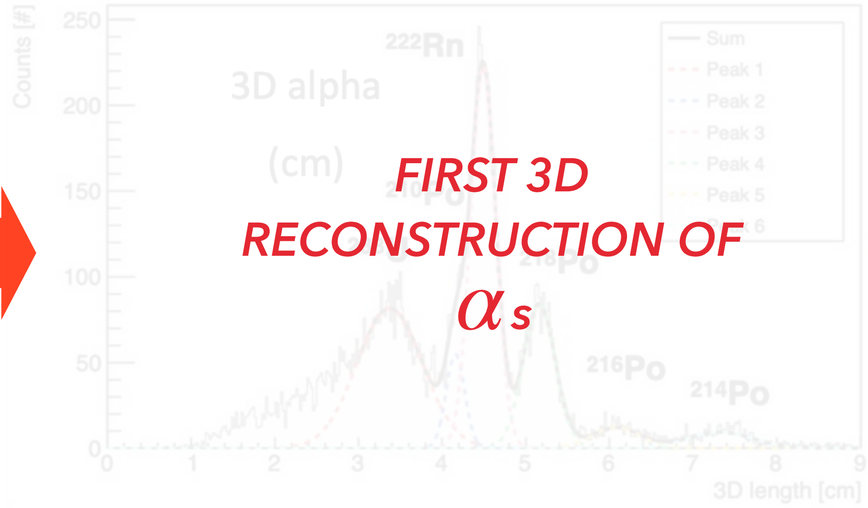
A deeper analysis confirmed ***Radon contamination,*** that could explain the discrepancy

RUN3





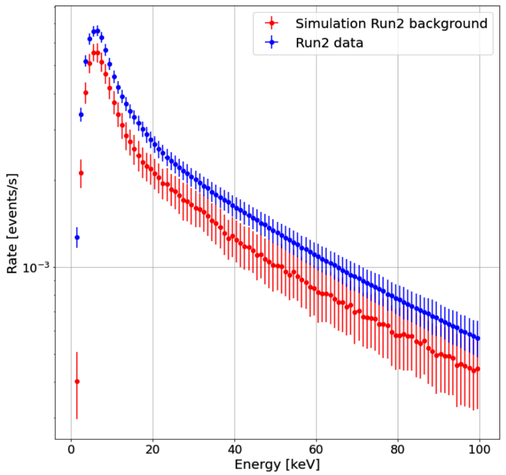
CAMERA

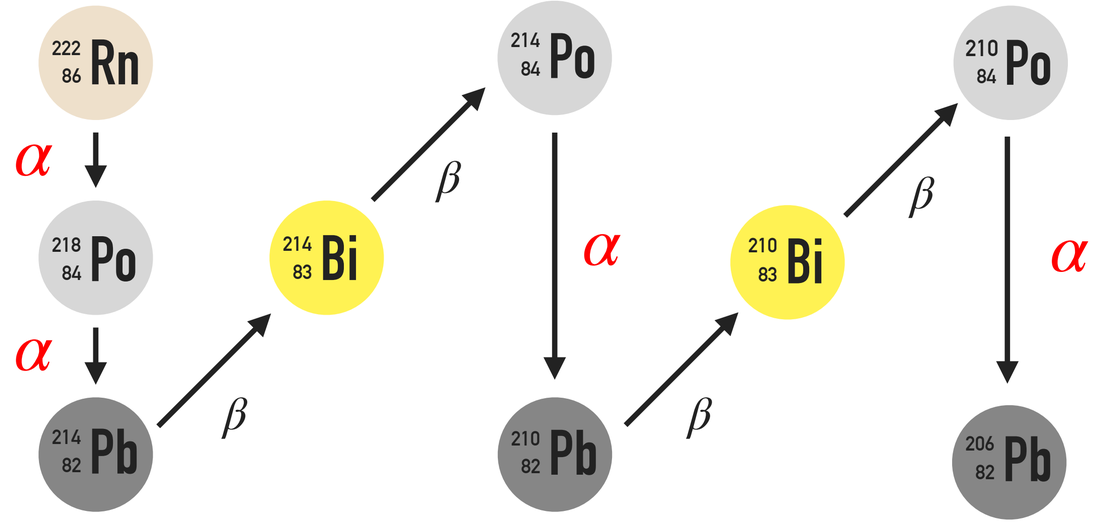


FIRST 3D RECONSTRUCTION OF αs

CAMERA + PMTs

RUN 2

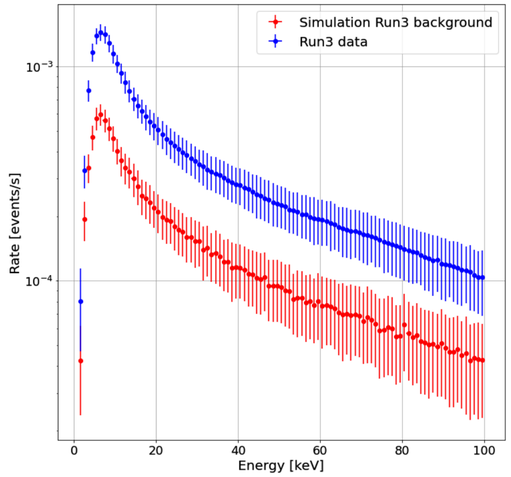


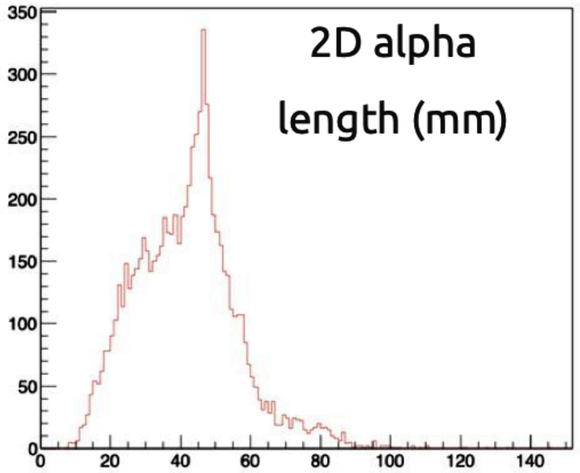


A deeper analysis confirmed ***Radon contamination,*** that could explain the discrepancy

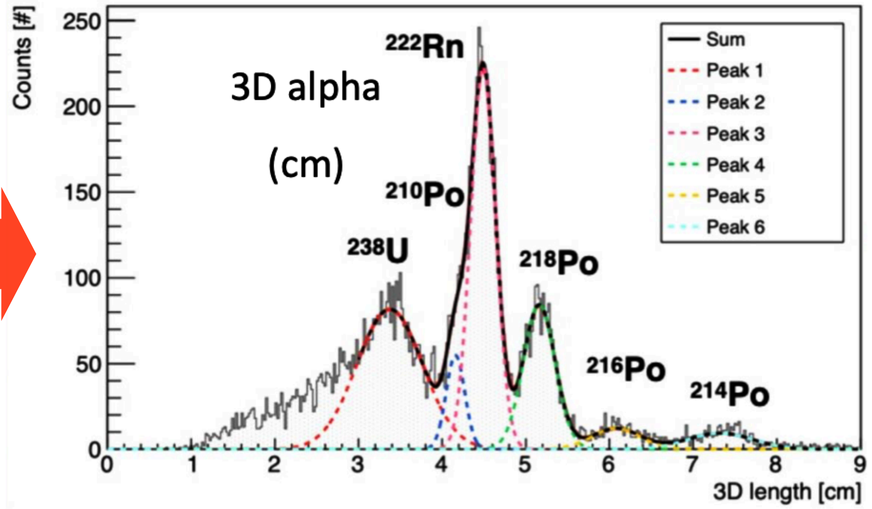
David J. G. Marques' thesis

RUN 3





CAMERA

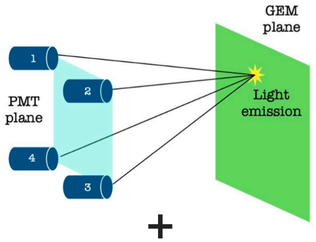


CAMERA + PMTs

David J. G. Marques' thesis

PMT Analysis

Charge integral

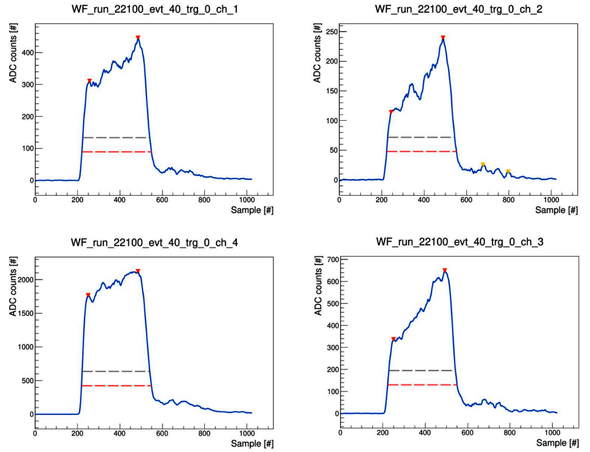


+

BAT
BAYESIAN ANALYSIS TOOLKIT

Multi-variable Bayesian fit

Waveforms analysis

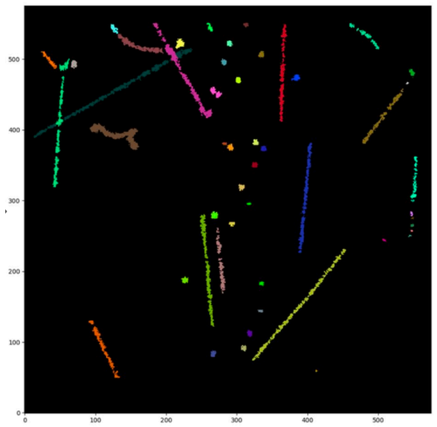


Time-over-Threshold ⇒ ΔZ

Bragg peak position ⇒ Z angle

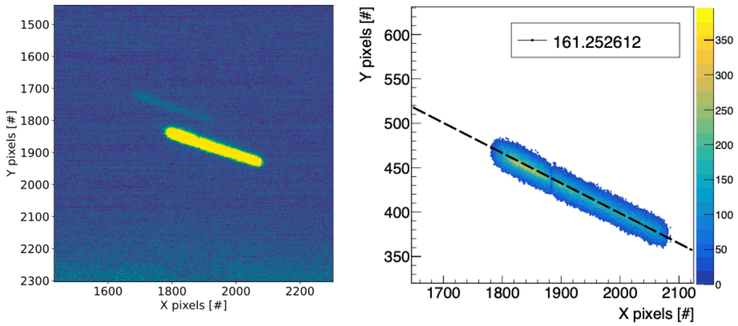
ONE-TO-ONE CLUSTER ASSOCIATION

CMOS Analysis



Reconstruction algorithm

Directionality algorithm



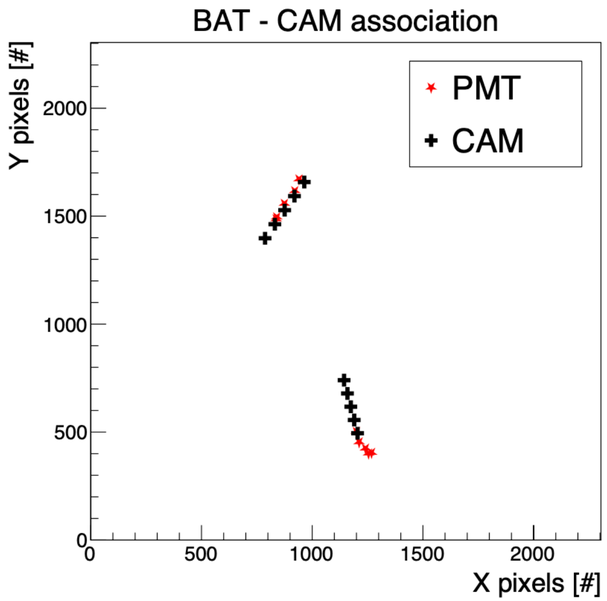
⇒ ΔXY + X-Y angle + 2D direction

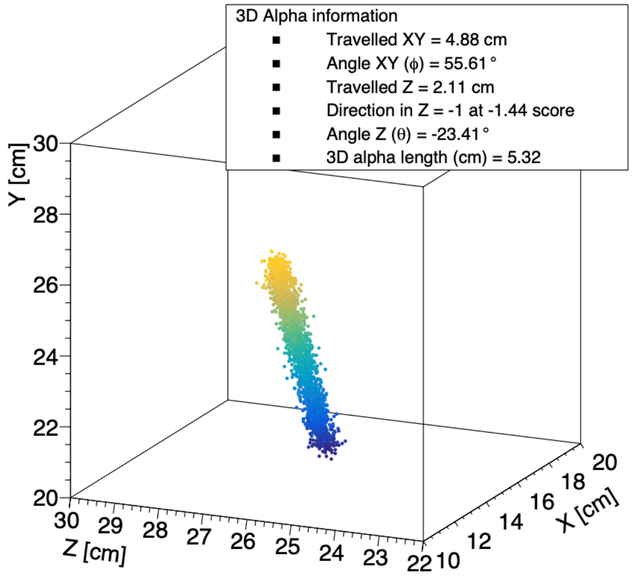
David J. G. Marques' thesis

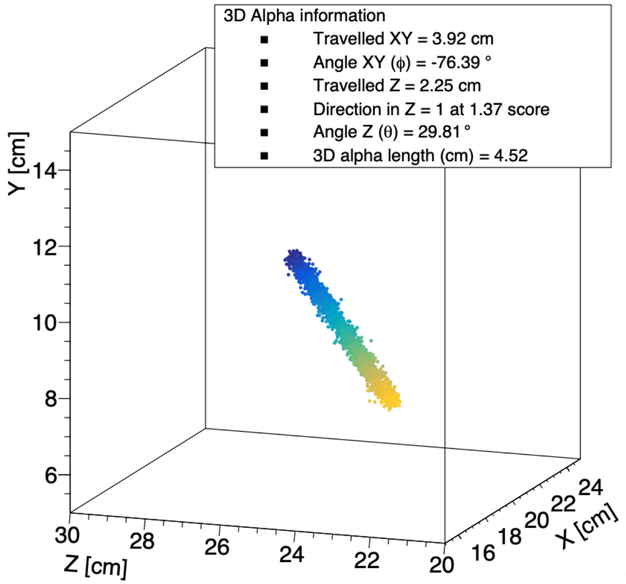
PMT Analysis

+

CMOS Analysis



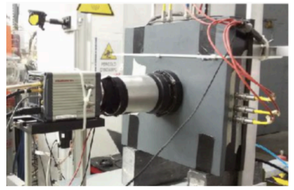




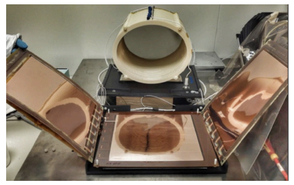
PHASE 0 - R&D and prototypes | PHASE 1 | PHASE 2

2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

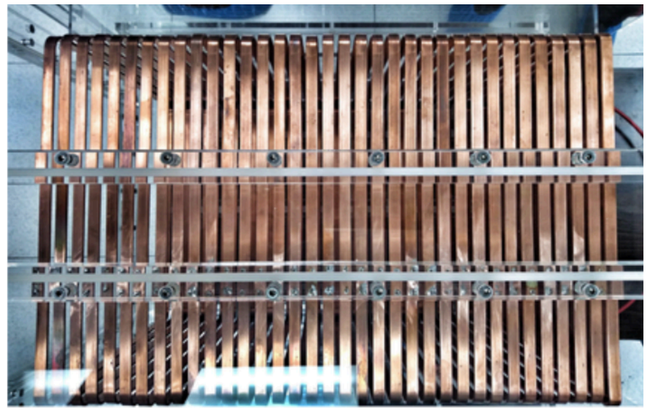
ORANGE | LEMON | LIME | CYGNO_04 | CYGNO_30



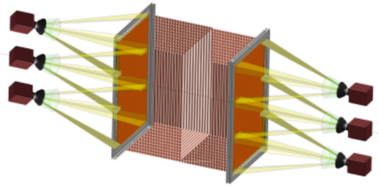
- 1 cm drift



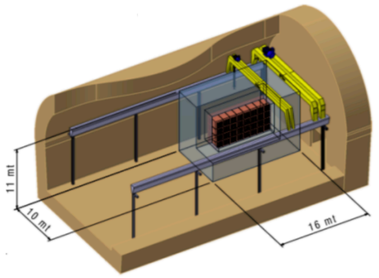
- 3D printing
- 20 cm drift



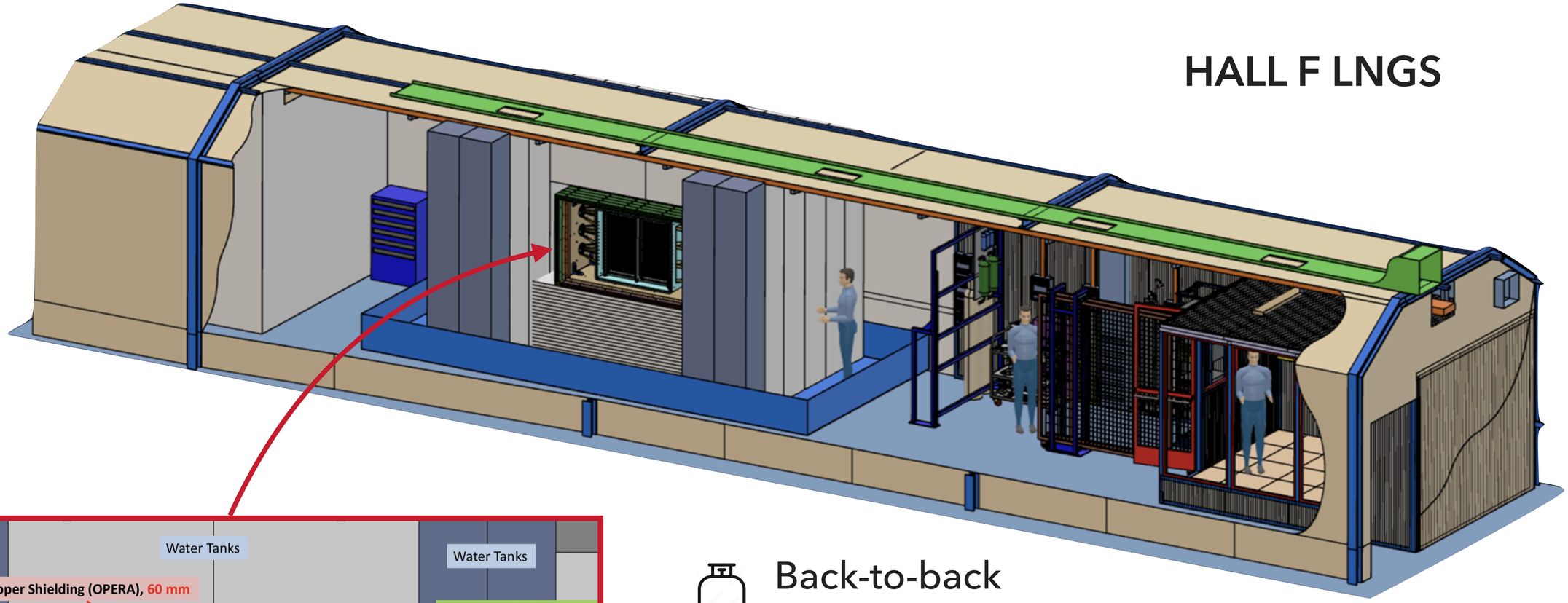
- 50 cm drift
- Underground tests
- MC validation

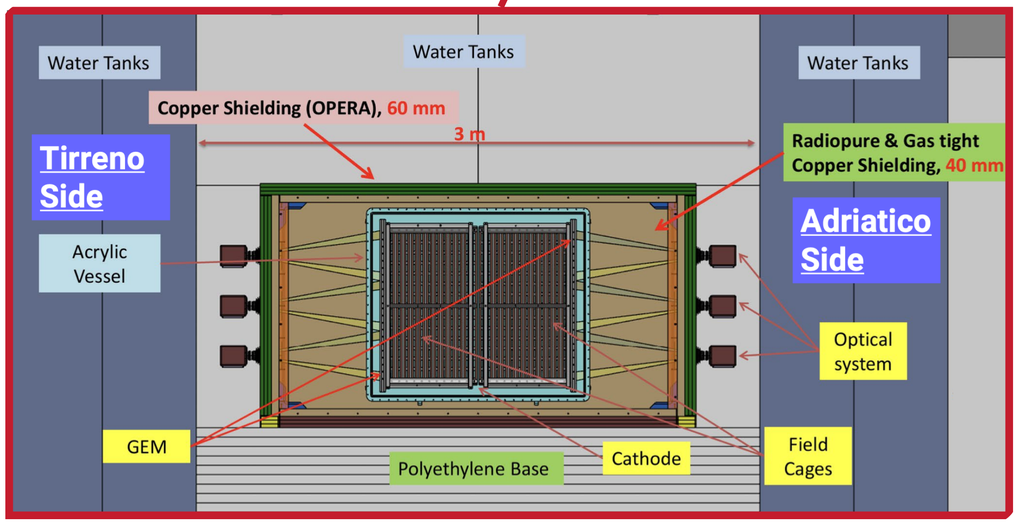


- Background
- Material tests
- Gas purification
- Scalability



- Physics research



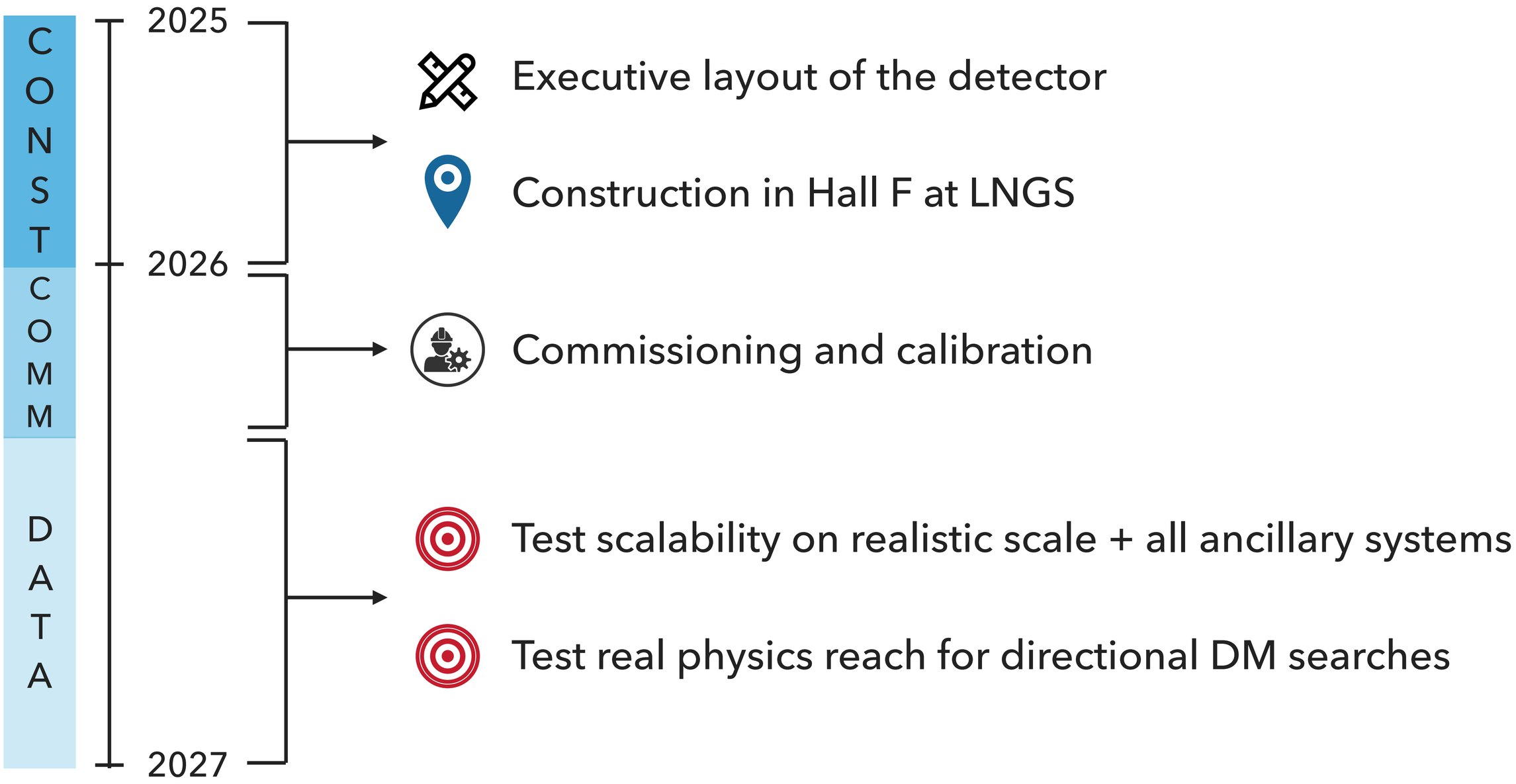


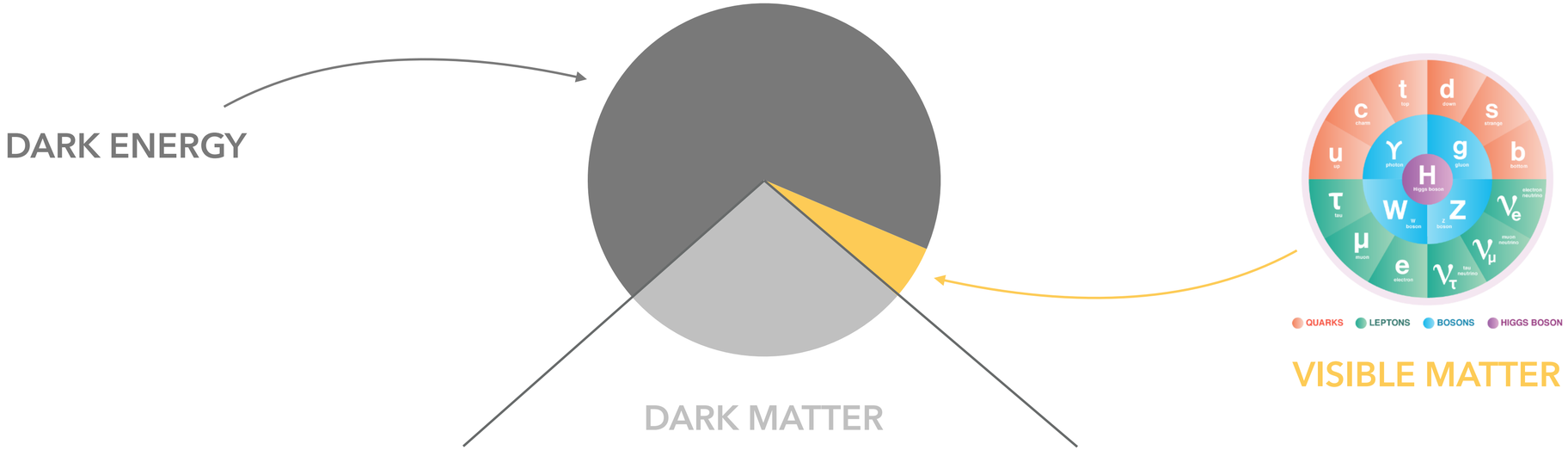
Back-to-back
0.4 m³ TPC, with central cathode

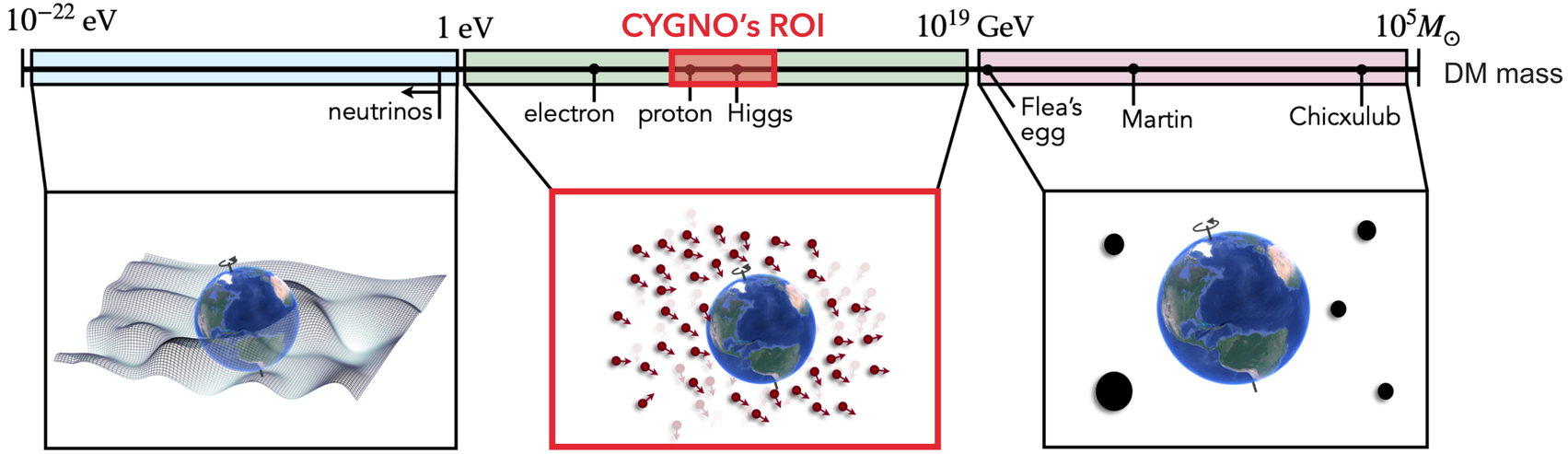
3 sCMOS ORCA Quest per side + PMTs (# TBD)

29
Cu
H_2O

Projected shielding composed of 10 cm Cu + 100 cm H_2O


CONST
COMM
DATA
2025
2026
2027
Executive layout of the detector
Construction in Hall F at LNGS
Commissioning and calibration
Test scalability on realistic scale + all ancillary systems
Test real physics reach for directional DM searches



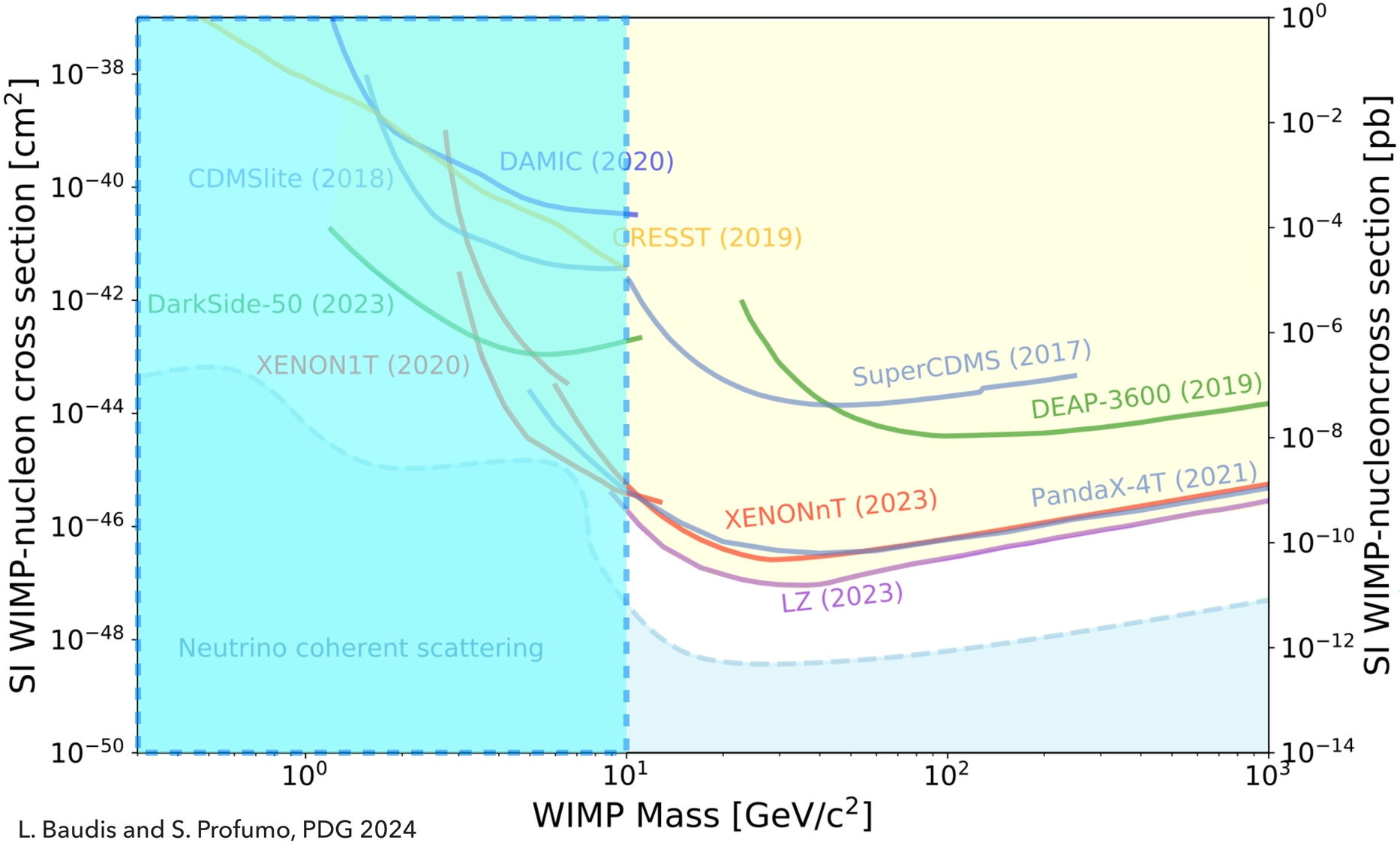


Dark matter acts like a wave*

Dark matter acts like particles

Dark matter acts like objects

CYGNO Dark Matter exploration region



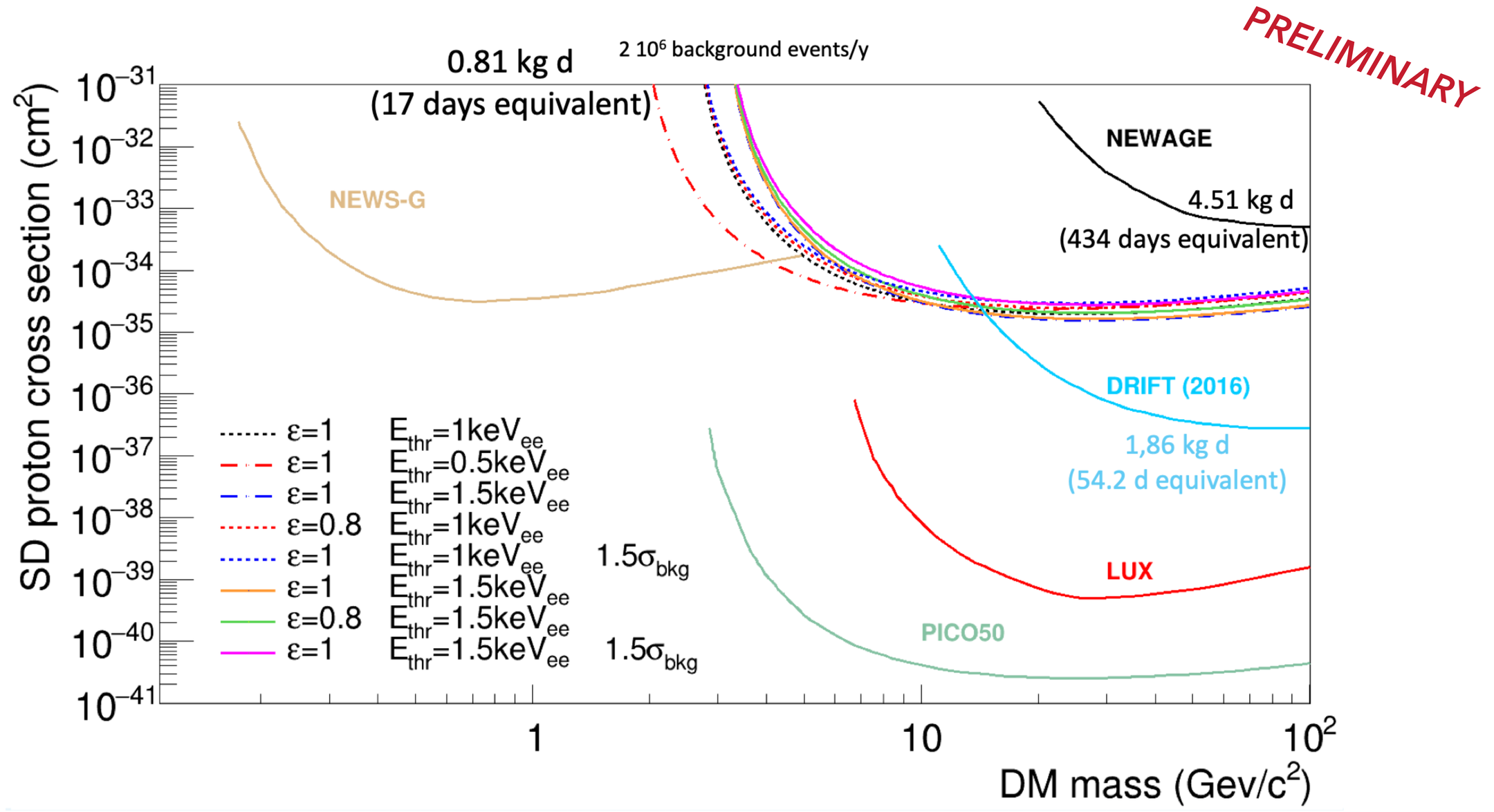
L. Baudis and S. Profumo, PDG 2024

2
He

- ***Light*** target for low mass WIMPs
- Sensitive to ***SI*** couplings

9
F

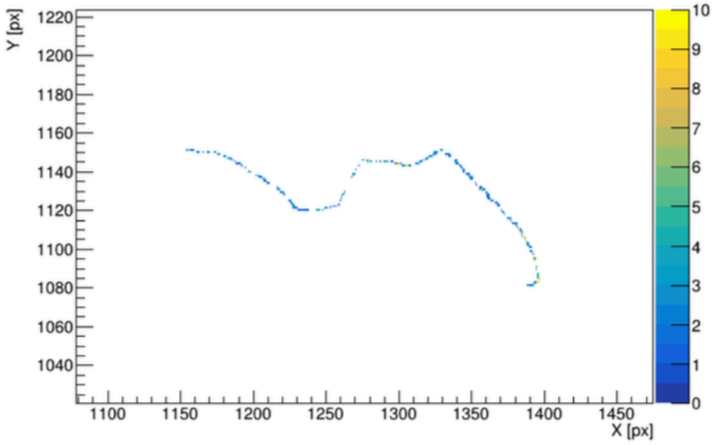
- ***Heavier*** target for intermediate masses
- Sensitive to ***SD*** couplings


PRELIMINARY
0.81 kg d
(17 days equivalent)
2 10⁶ background events/y
NEWS-G
NEWAGE
4.51 kg d
(434 days equivalent)
DRIFT (2016)
1,86 kg d
(54.2 d equivalent)
LUX
PICO50
ε=1 E_thr=1keV_ee
ε=1 E_thr=0.5keV_ee
ε=1 E_thr=1.5keV_ee
ε=0.8 E_thr=1keV_ee
ε=1 E_thr=1keV_ee 1.5σ_bkg
ε=1 E_thr=1.5keV_ee
ε=0.8 E_thr=1.5keV_ee
ε=1 E_thr=1.5keV_ee 1.5σ_bkg
SD proton cross section (cm²)
DM mass (Gev/c²)
10⁻³¹
10⁻³²
10⁻³³
10⁻³⁴
10⁻³⁵
10⁻³⁶
10⁻³⁷
10⁻³⁸
10⁻³⁹
10⁻⁴⁰
10⁻⁴¹
1
10
10²

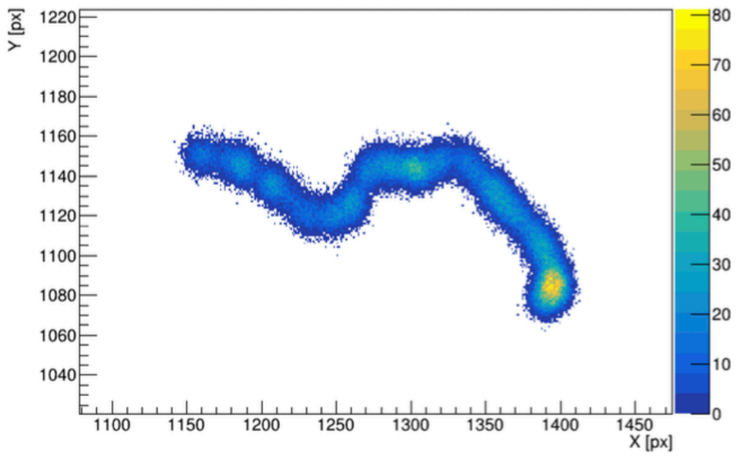
Simulation

- **Energy deposit** simulation with **GEANT 4** and **SRIM**
- **Charge transport** (diffusion, electron attachment) with **Garfield**
- **Gain** with a **dedicated MC** simulation based on the modified Townsend model
- **Digitization** to reproduce the noise of the camera sensor

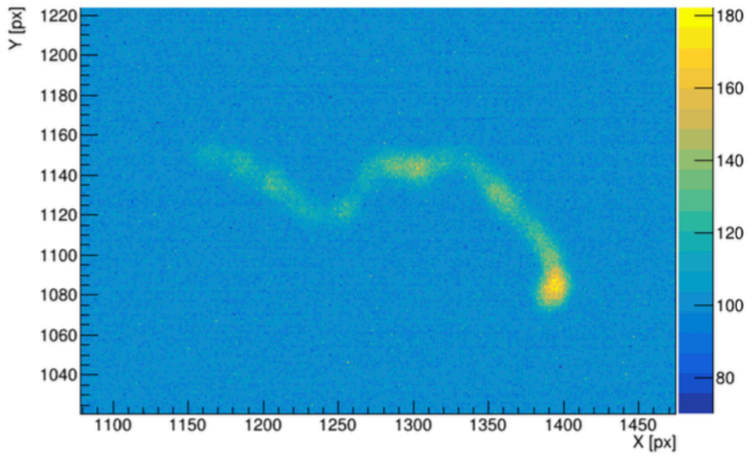
Tracks



Charge transport



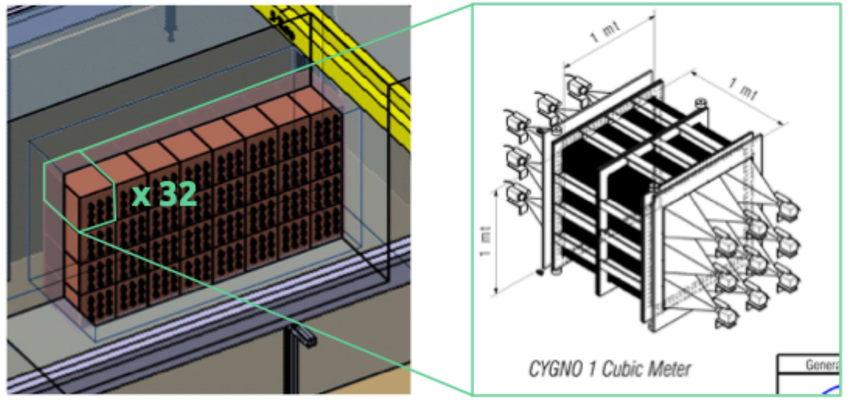
Gain + Digitization



Slide courtesy of Stefano Piacentini

CYGNO-30 - Prospects

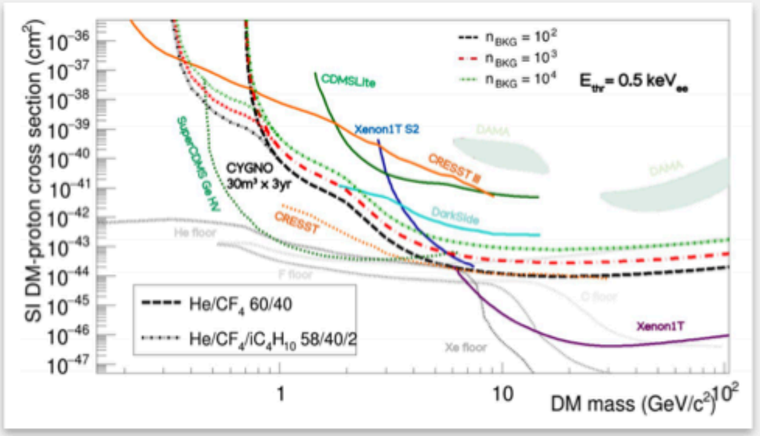
- **Low mass (0.5 - 10 GeV) directional DM searches**
- > 2027
- **30 - 100 m3** detector
- **0.5 - 1 keV_{ee}** energy threshold
- **30°** angular resolution

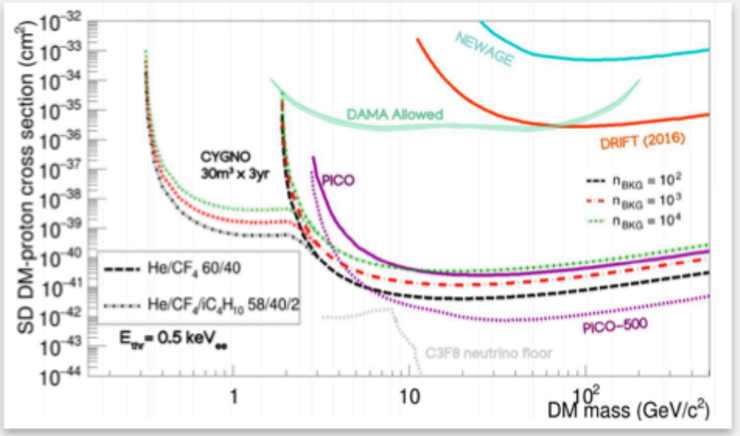


Expected **SI** and **SD** (90% CL)
interaction cross-section exclusion

Quenching factor simulated with **SRIM** → Direct measurement incoming!

He / (eventually H) allows us to explore very low DM masses!





Slide courtesy of David J. G. Marques