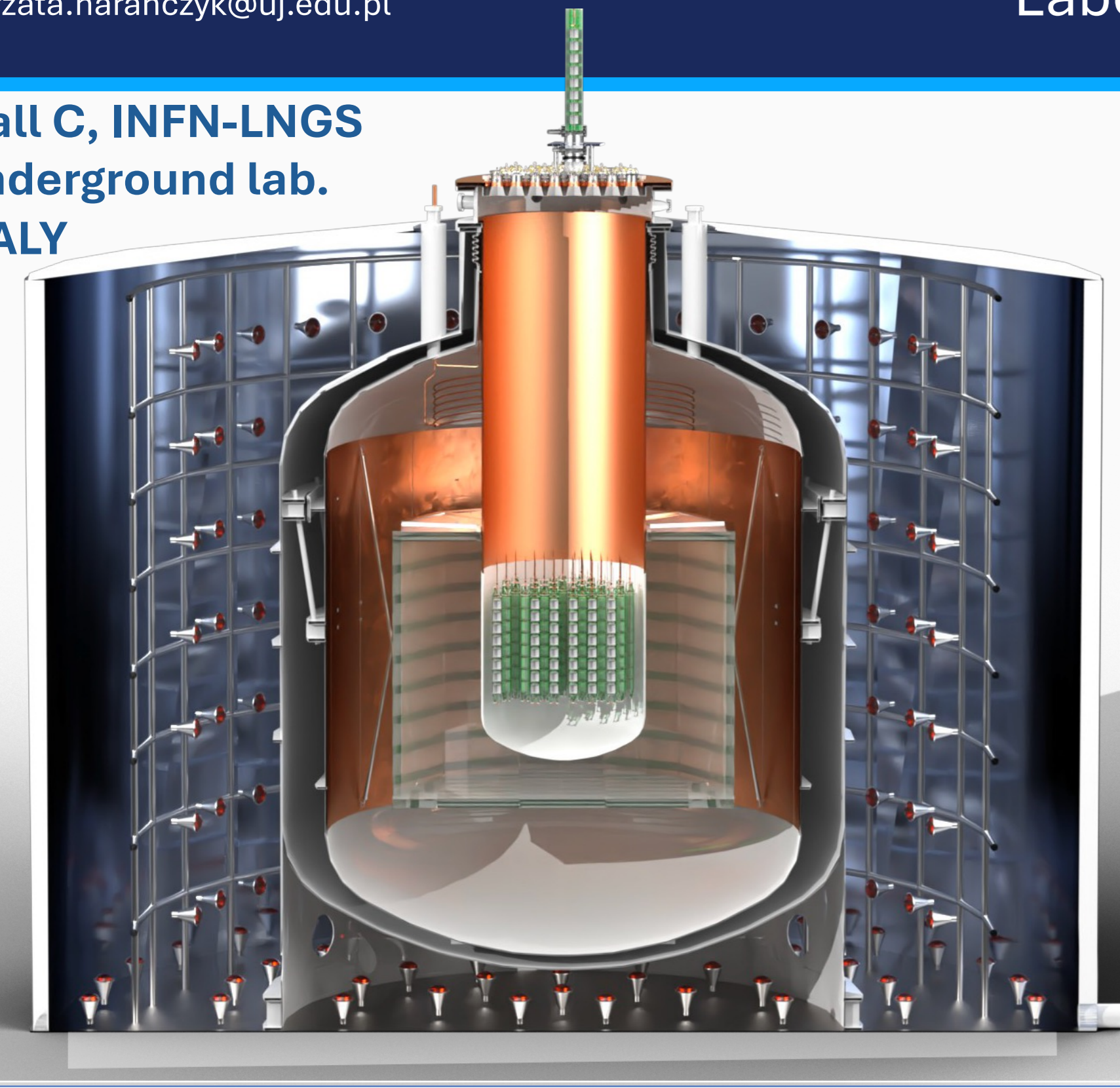




Hall C, INFN-LNGS underground lab. ITALY



LEGEND-1000 future of search for $0\nu\beta\beta$ decay with High Purity Germanium crystals:



Background Index Goal: $1 \times 10^{-5} \text{ cts}/(\text{keV kg yr})$

$T_{1/2} > 10^{28} \text{ yr}$ after 10 years of data

L-1000 posters:

331. LEGEND-1000 Progress and Status;

202. The LEGEND-1000 Water Instrumentation and Neutron Tagger

Cosmogenic background problem:

${}^{77}\text{Ge}$ and ${}^{77m}\text{Ge}$ are produced by fast-neutron capture on ${}^{76}\text{Ge}$.

${}^{77m}\text{Ge}$ β decay can mimic $\beta\beta$ -like events near $Q_{\beta\beta}$ making it a dangerous cosmogenic background!

Solution: Outer Liquid Argon volume instrumentation with:

- **Passive shield** - radiopure *Polymethyl methacrylate* (PMMA) - based neutron moderator

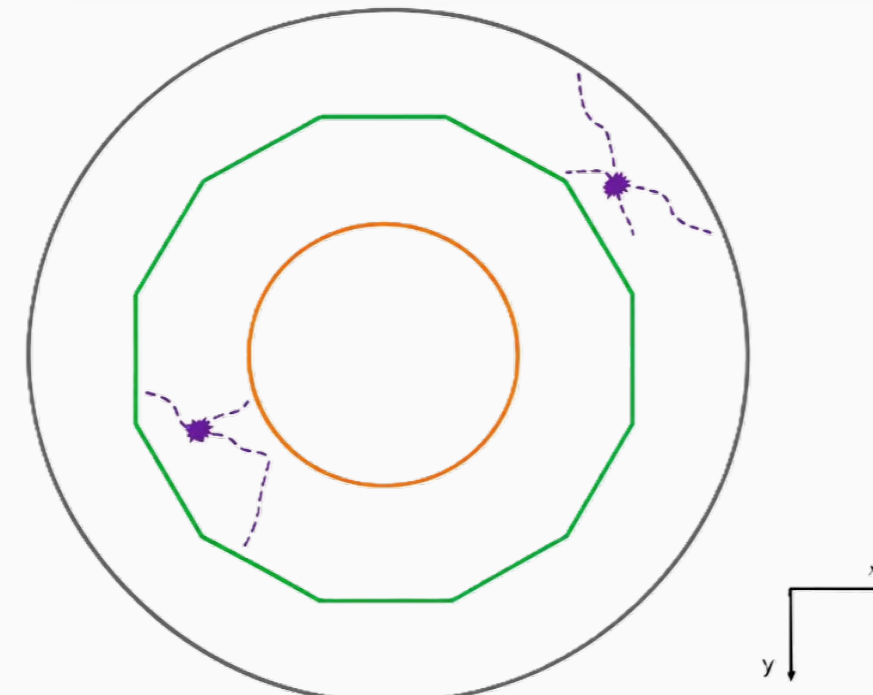
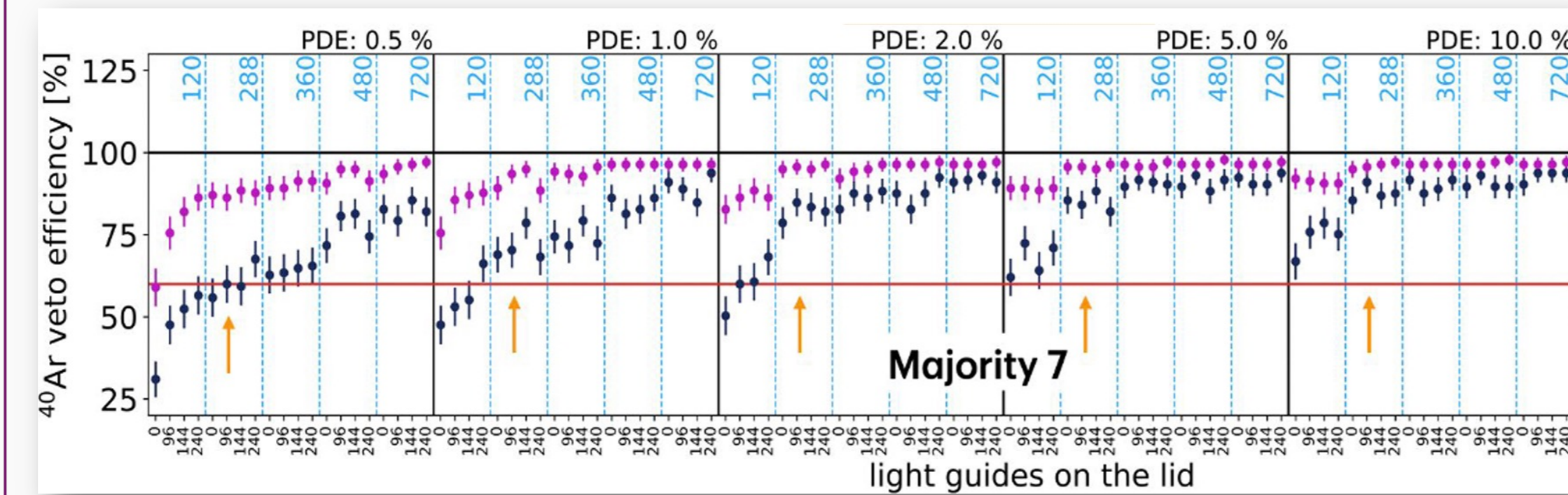
A layer of a hydrogen-rich material to reduce neutron captures in germanium.

- **Active shield** - LAr scintillation Light Detection Modules (LDM) *LAr Scintillation detectors designed to tag neutrons captured by ${}^{40}\text{Ar}$ in atmospheric argon volume as proxy for muon-induced production of ${}^{77m}\text{Ge}$.*

Simulations with Geant4 to investigate different scenarios:

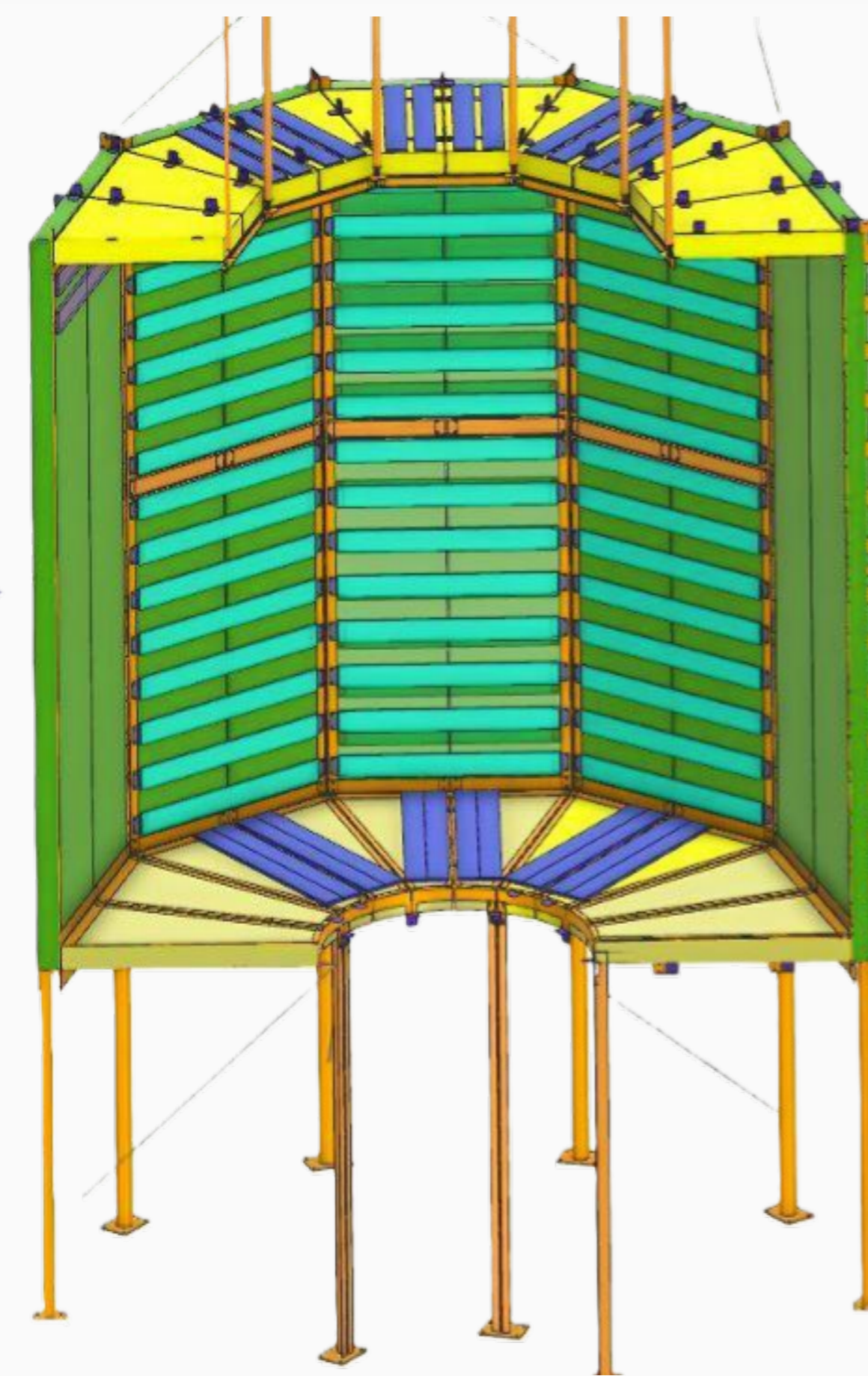
(for details: [1])

- PMMA panels: geometry, material
- LAr properties affecting scintillation: LAr purity and Xe doping,
- Photon Detection Efficiency (PDE) expected from active LDM



Neutrons can be generated "outside" and "inside" moderator

- active LDMs are offering background mitigation option for both situations.



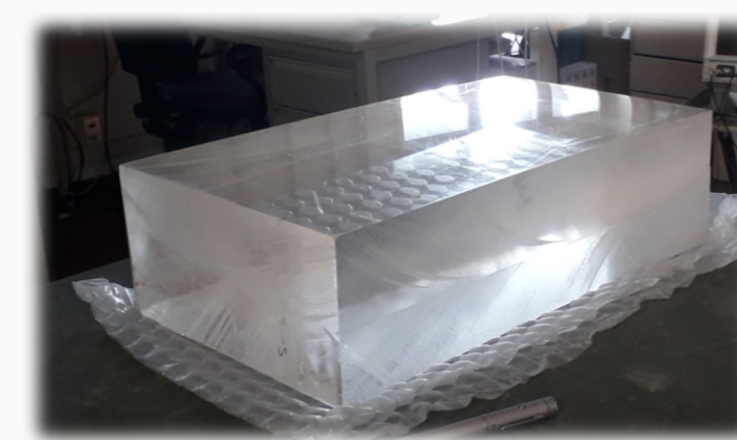
Neutron Moderator - preliminary design

- Height: 300 cm
- Diameter: 360 cm
- Panel thickness: 10 cm
- Material: PMMA
- Radio-pure copper for the mechanical support

Radioactivity measurements and budget estimations including:

- Copper structure, - PMMA 5.6 ton, - Electronic components

- **Expected to maintain the background budget within 5% of the LEGEND-1000 goal!**

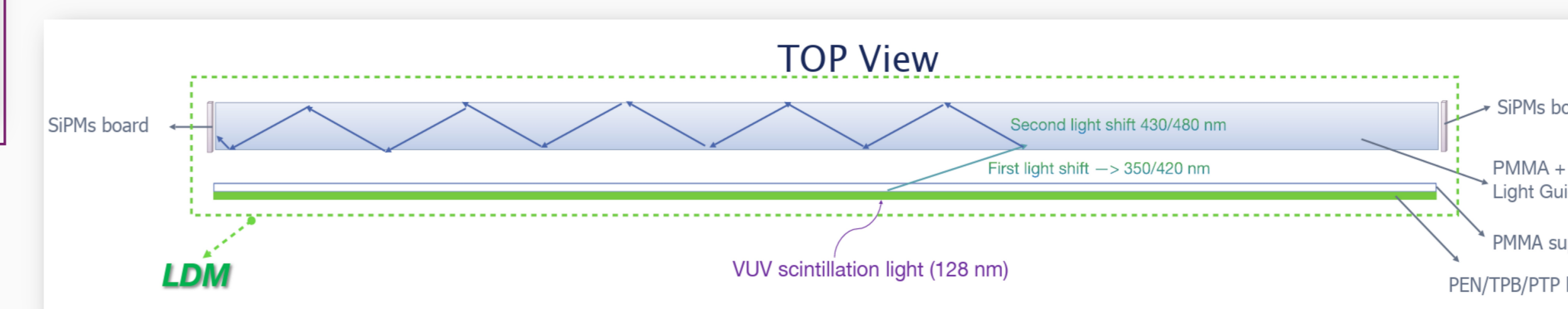


R&D for Active Instrumentation

Reference Design of single module:

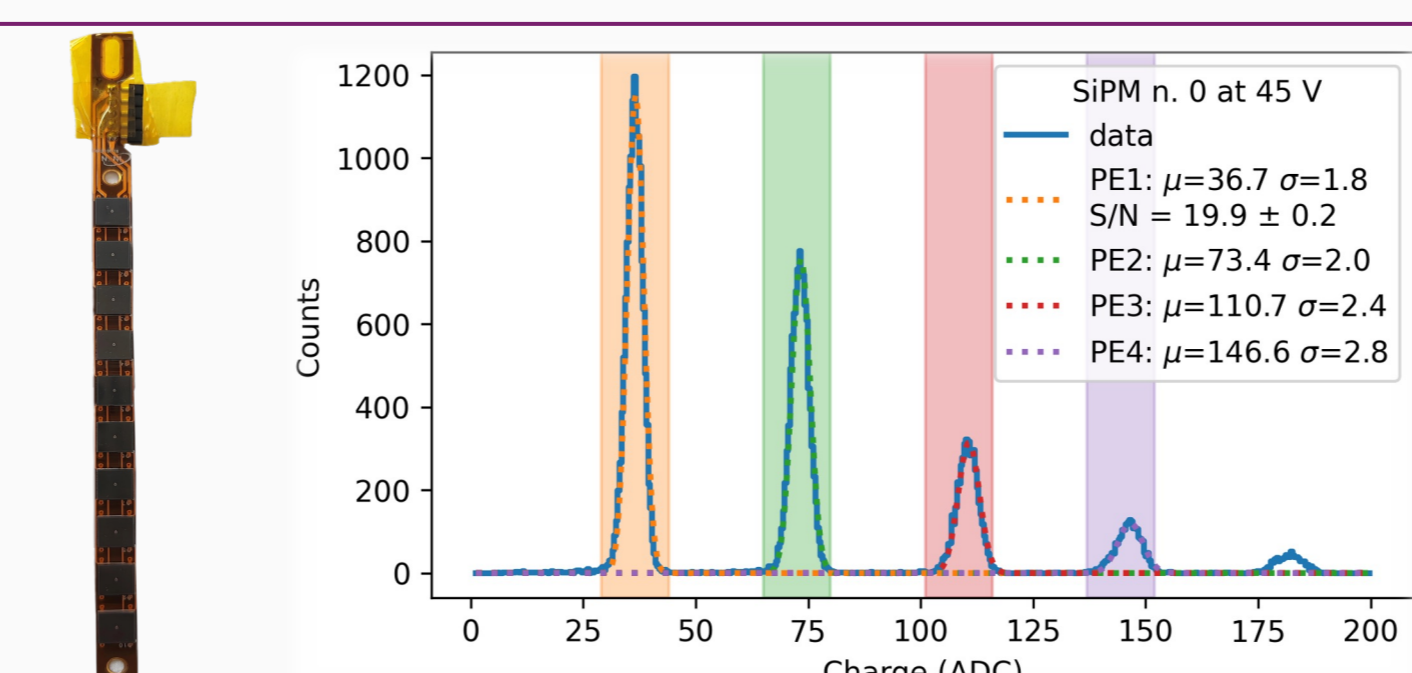
100 x 10 x 0.6 cm² Light Detection Modules (LDM)

1. Wavelength shifter (WLS) for the 128 nm Ar light (175 nm of Xe-doped) realized by layer of PEN foil or coating with TPB or pTP
2. WLS doped PMMA light guide
3. The readout is realized by two arrays consisting of 6x6 mm² SiPMs. (Dark Count Rate << Ar³⁹ rate)



LEGENDArYNO R&D cryogenic setup at LNGS Testing and prototyping of LDM in realistic LAr volume

- Optical properties, geometry, materials, wavelength shifting
- Mechanical resistance and robustness to low temperatures
 - Resilience to thermal cycles
- Comparison study of Photo Detection Efficiency (PDE)



- Prototype of the SiPM array on the thin, flexible substrate. Use of Hamamatsu 6x6 mm²,
- Single Photo-Electron resolution and calibration done with blue LED.

Signal/Noise ratio ~ 20, 1PE ~ 36 ADC

PDE estimation includes many terms ... (as described in [4]):

$$\text{PDE} = N_{\text{Detected}} / N_{\text{Incident}}$$

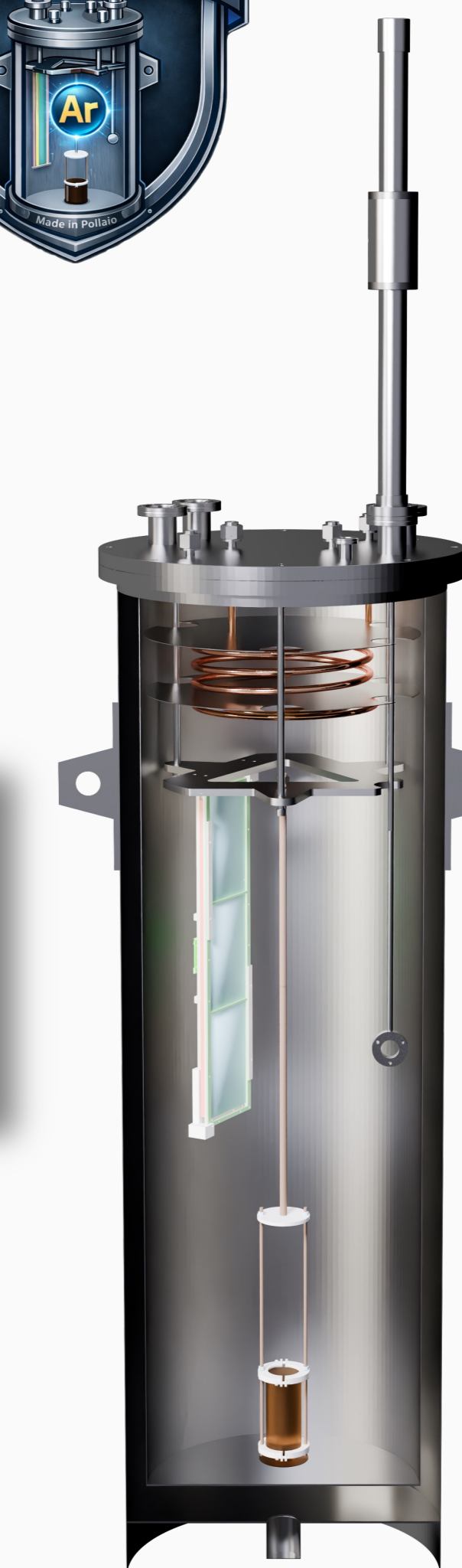
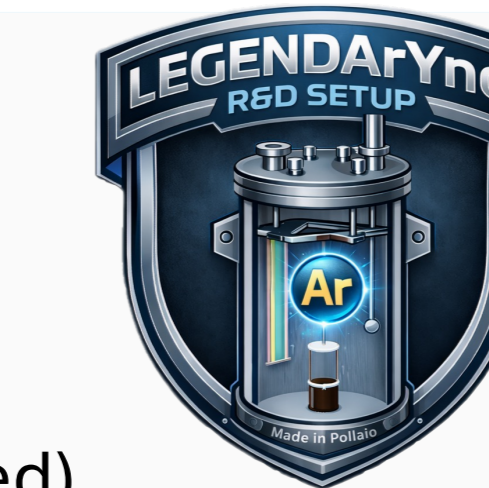
For LDM_v0 test:

PDE_min = 0.8 % and PDE_max = 4%

$N_{\text{Det}} \sim 250 \text{ pe.}$

$N_{\text{Inc/Min}} \sim 32k \text{ pe.}$

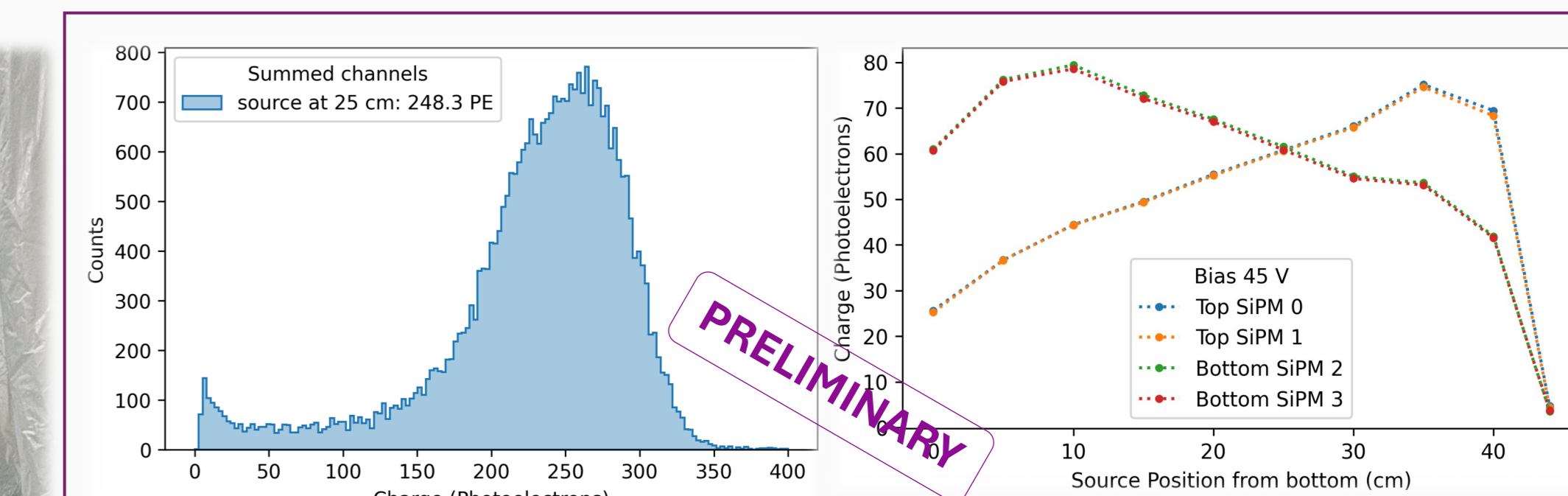
Assuming α, γ quenching and transport effects in LAr



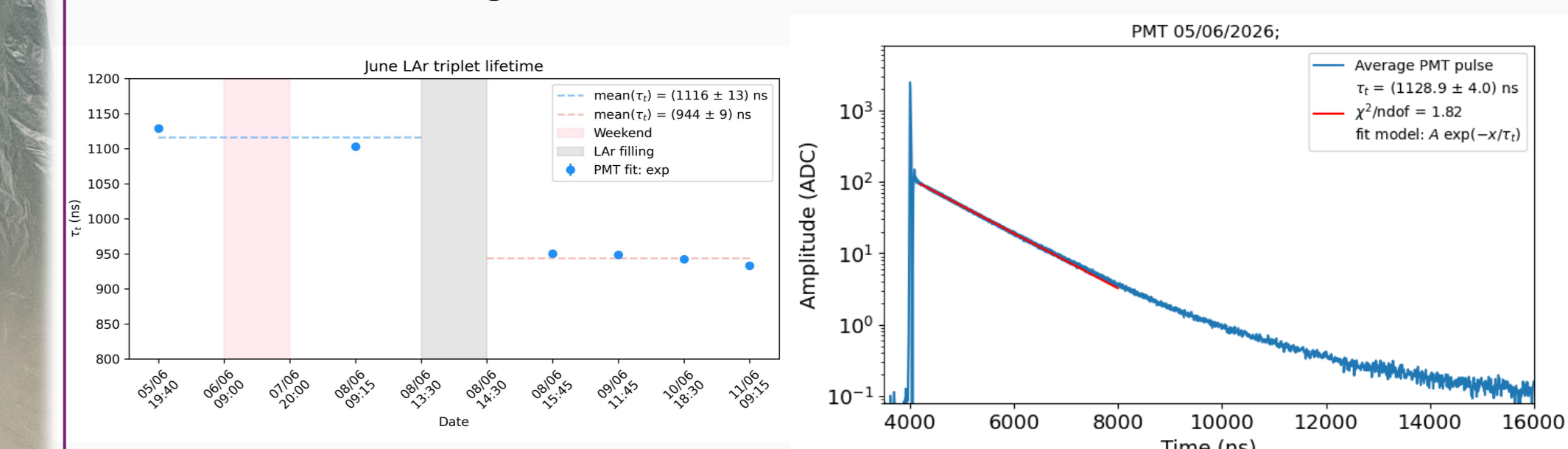
- Vacuum insulated double wall cryostat for Liquid Argon (40 cm diameter, 135 cm height)
- Heat shields with Liquid Nitrogen active cooling
- Purification system installed on the LAr line (inspired by [2])

Instrumentation:

- ${}^{241}\text{Am}$ α source (1kBq) at 9 cm distance ($E_{\alpha} = 5.4 \text{ MeV}$)
- SiPM arrays read out by 4 ch. with custom made Front-End electronic board (for details [3]) coupled with CAEN digitizer
- TPB covered 2" PMT for independent LAr purity monitoring



- α PE spectrum registered by the LDM_v0. This version consists of "blue" PMMA and pTP coating serving as WLS. Module is 50cm long.
- Charge registered by top and bottom SiPM array, for different source position along LDM_v0.



LAr purity monitoring is performed by estimating: the effective triplet state lifetime (so called slow component) for each data taking run. The averaged pulse registered by PMT is fitted with an exponential function. The >900 ns value corresponds with the use of LAr 5.0 quality (99.999%).

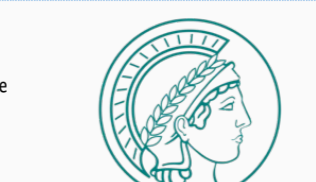
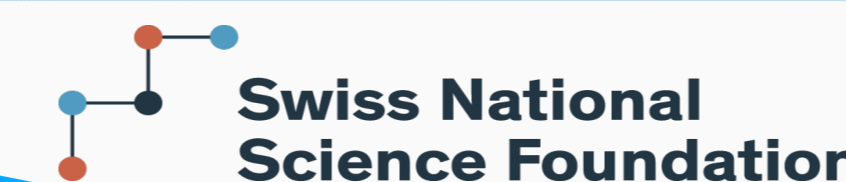
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References:

- 1) Morella, M. (2025). Doctoral dissertation, GSSI, (Publication No. 36425).
- 2) Harańczyk, M. et al., 2026, arXiv:2605.20507
- 3) Abritta Costa, I. et al 2023 JINST 18 P09007
- 4) Álvarez-Garrote, R. et al., 2024, arXiv:2405.12014