Integrating a Liquid Argon Active Veto in ASTAROTH: a Cryogenic SiPM Based Experiment for Low-Threshold NaI(Tl) Dark Matter Searches

Edoardo Martinenghi[1], for the ASTAROTH collaboration

[1]*Istituto Nazionale di Fisica Nucleare (INFN) sezione di Milano, Via Celoria 16, 20133 Milano (Italy)*

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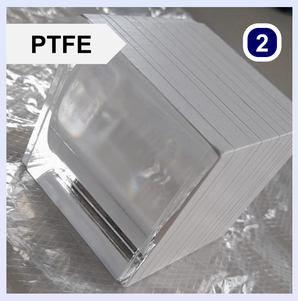
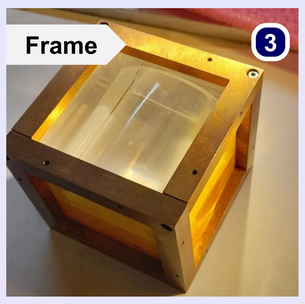
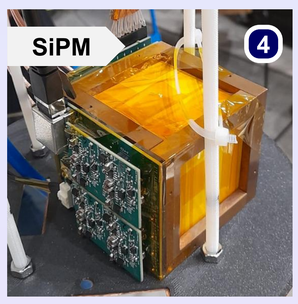
INTRODUCTION & MOTIVATION

ASTAROTH (**A**ll **S**ensitive crys**T**al **AR**ray with l**O**w **TH**reshold) is an R&D project aimed at developing a new generation of NaI(TI)-based detectors for dark matter direct detection with sub keV threshold. Achieving sensitivity at low-energy requires not only high light yield and low-noise photosensors, but also suppression of both environmental and internal backgrounds. To avoid the photodetector noise, ASTAROTH exploits Silicon Photomultiplier (SiPMs) arrays operated at cryogenic temperature, where their dark noise is nearly two orders of magnitude lower than conventional photomultiplier tubes (PMTs). The detector is housed in a dedicated cryostat cooled by a cryogenic bath, enabling stable operation down to about 80 K. The dominant contribution to the measure background arises from environmental and internal gamma radioactivity, to mitigate this contribution, a dedicated passive shielding system and an active veto detector have been designed.

DETECTOR

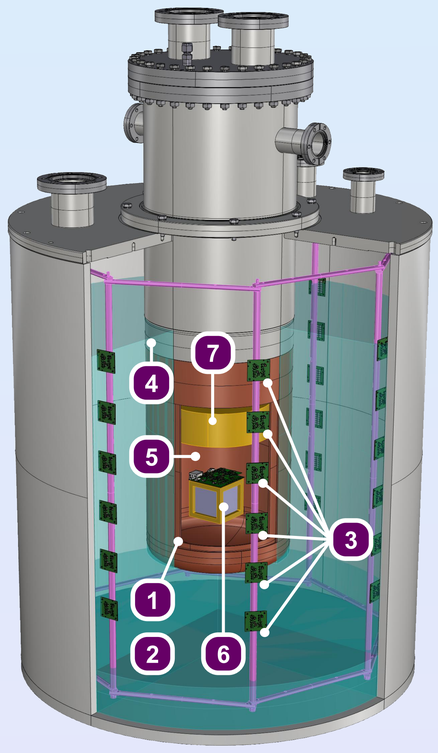


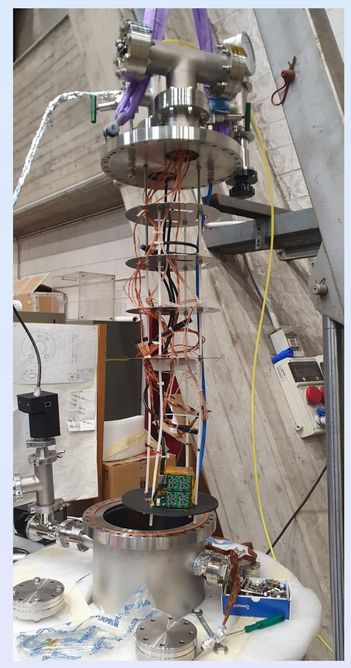




The **detector** 1 is a cylindrical **NaI(Tl)** crystal (**~ 360 g**). To prevent degradation, the crystal is enclosed in a **hermetic quartz** housing and wrapped with **PTFE** 2 to enhance light collection. The scintillation light is read out by a **SiPM matrix** 4 , coupled to the crystal through a dedicated copper frame 3 , which also hosts the front-end electronics for cryogenic signal amplification.

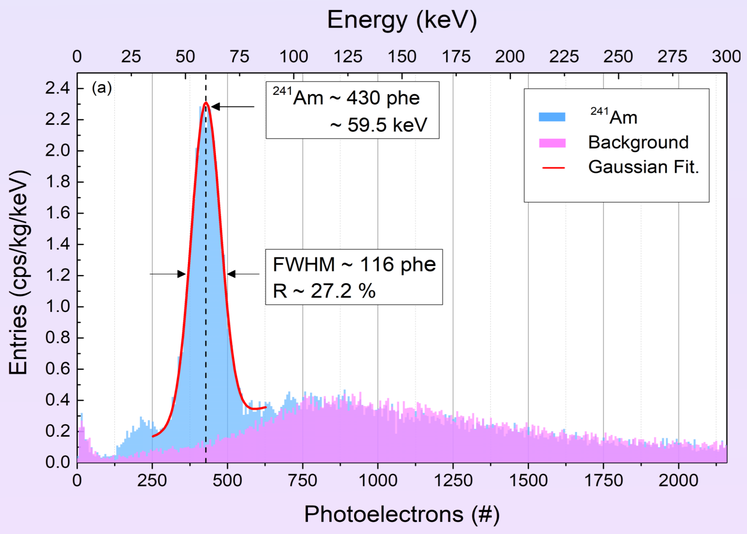
CRYOGENIC SET-UP





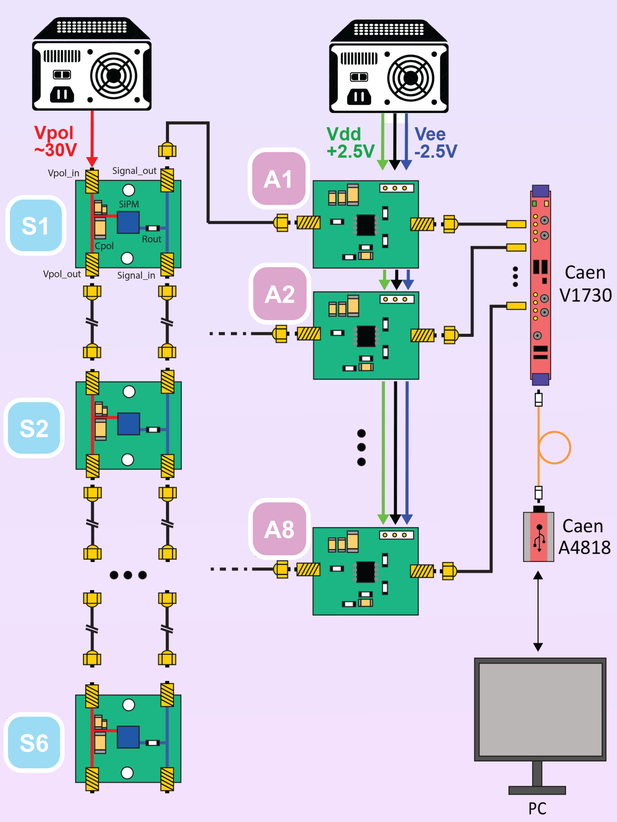
ASTAROTH employs a cryogenic setup based on a **double-walled vacuum-insulated copper chamber** 1 immersed in a **cryogenic bath** (LN_2 or LAr) 2 . The **detector** 6 is housed in an **inner chamber** filled with helium gas 5 , which acts as a thermal exchange medium, while cooling is provided through a dedicated **thermal bridge** 4 designed for controlled and **safe temperature variation**. A 10 cm thick **copper shield** 7 reduces external background contributions. When operated in liquid argon, the cryogenic bath can also be instrumented with additional SiPM arrays 3 and used as an **active veto** detector for **background rejection**. Details at: F. Alessandria *et al* 2026 *JINST* **21** P01038

PERFORMANCES



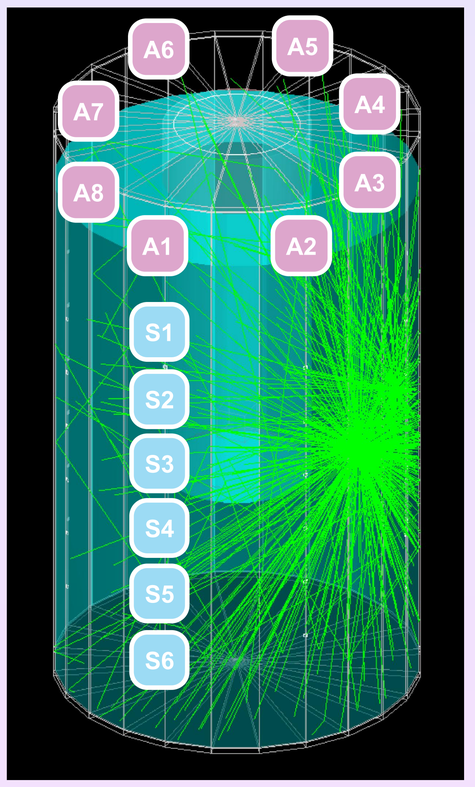
A **^{241}Am source** was used to characterize the detector by comparing spectra acquired with and without the source. By fitting the 59.5 keV gamma peak, a gross photoelectron yield of **7.2 ph/keV** was obtained, (**4.5 ph/keV** after **crosstalk correction**). External and internal backgrounds can be mitigated by **passive shielding** and **the outer veto** detector, as described in the **dedicated sections**.

OUTER VETO DETECTOR

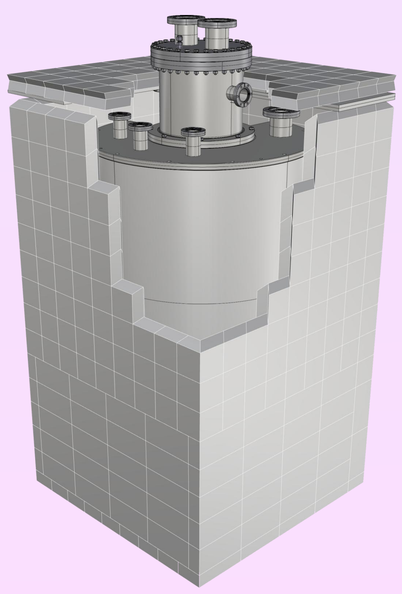


The **veto detector** consists of **48 SiPMs** (6 × 6 mm²), arranged in 8 branches of **6 sensors**. Individual boards (**S1–S8**) provide SiPM support and bias, while **8 amplification** stages (**A1–A8**) sum the signals. DAQ acquisition is performed with a **14-bit digitizer** .

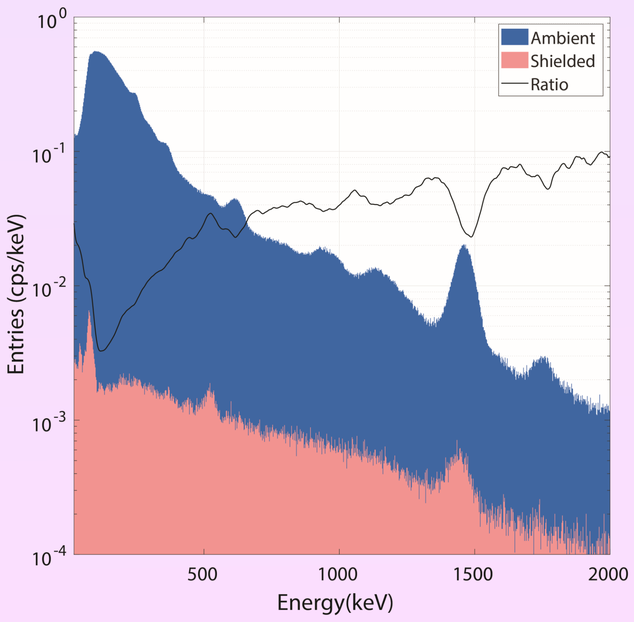
Low-energy background arises from radioactive decays within the crystal, often in coincidence with **high energy emissions** escaping the chamber. The veto can tag these events, improving **rejection at low energies**. MC simulations show a **tagging efficiency** of **~70%** at **1.5MeV**, which stand for ^{40}K, a predominant contaminant in NaI(Tl).



PASSIVE SHIELDING



External radioactivity dominates the setup **background**, making passive shielding essential. A preliminary **10 cm lead shield**, composed of **~144 bricks**, has been designed and is currently under construction. A **scaled-down prototype** was tested at the experimental site using a **commercial ORTEC® NaI** detector, showing a background reduction of more than **one order of magnitude**. Further improvements are expected with the use of **radiopure materials** in the full cryogenic setup.



REFERENCES

Martinenghi, E. *et al.* First use of large area SiPM matrices coupled with NaI(Tl) scintillating crystal for low energy dark matter search. *Eur. Phys. J. C* **85**, 1444 (2025). https://doi.org/10.1140/epjc/s10052-025-15197-4

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