Identification of Dark Matter
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An innovative encapsulation technique for NaI(Tl) scintillating crystals

Valerio Toso[1,2], for the ASTAROTH collaboration

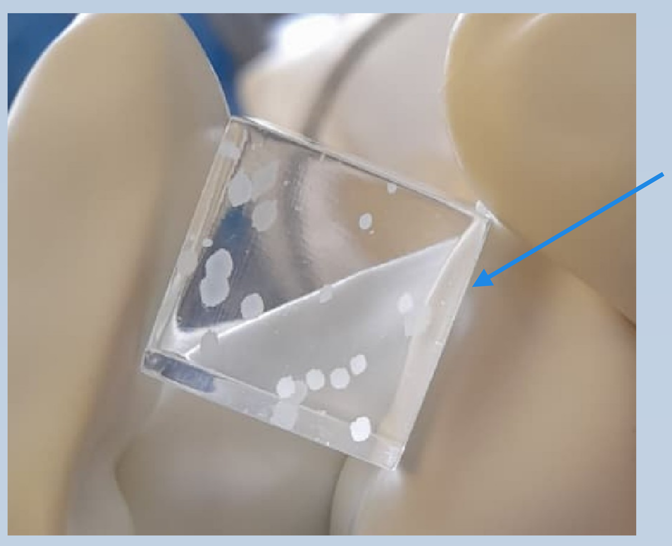
[1]INFN Milano; [2]Università degli Studi di Milano

INTRODUCTION

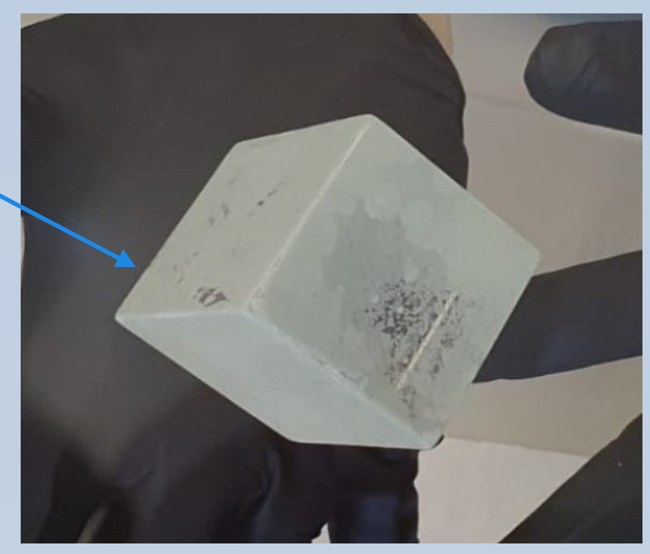
Scintillating crystals are among the most widely used particle detectors in research laboratories, industry, nuclear medicine, and physics experiments. Some of these **tend to degrade** when exposed to environmental **humidity**, such as **NaI(Tl)**. This makes the crystals difficult to handle, can limit their use in specific applications or forces the selection of alternative materials with suboptimal properties.
In the long-standing **search for dark matter**, NaI(Tl) crystals are widely used following the results of the DAMA/LIBRA experiment at the Gran Sasso National Laboratories. Several experiments worldwide (e.g. ANAIS, COSINE, SABRE, PICOLON) employ NaI(Tl) crystals enclosed in metal housings and read out by photomultiplier tubes through optical windows.
New projects such as ASTAROTH are developing next-generation detectors by coupling these crystals to Silicon Photomultiplier arrays. Operating at cryogenic temperatures improves the signal-to-noise ratio in the keV region and lowers the detection threshold below 1 keV.
Within ASTAROTH, an innovative epoxy-resin encapsulation technique for 5-cm cubic NaI(Tl) crystals has been developed. Compared to current solutions, it provides mechanical robustness, environmental protection, full optical transparency, compatibility with vacuum and cryogenic operation, and a low radioactive background.

I. MOTIVATION

NaI(Tl) crystals are highly hygroscopic and degrade when exposed to environmental humidity.

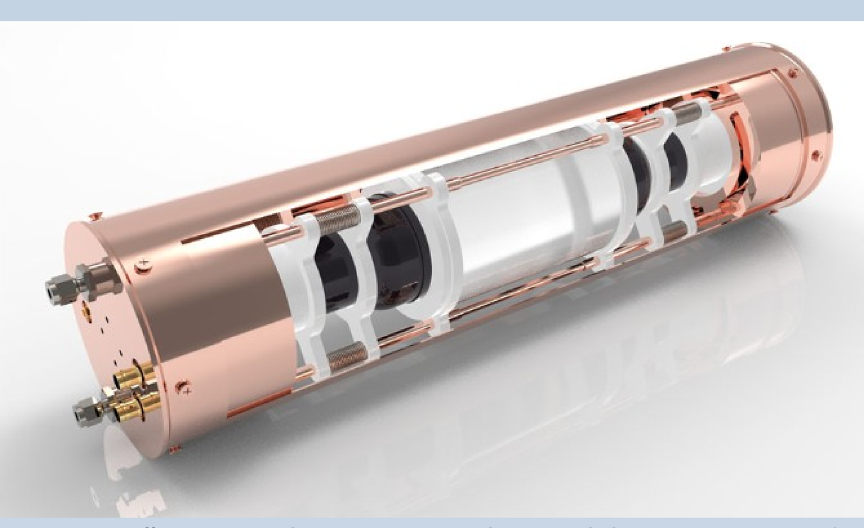


Cubic NaI(Tl) crystals exposed to environmental humidity (packaging issues)



Both research and commercial applications presents operational challenges and technological limitations:

Commercial solutions involve the use of encapsulation systems based on metal enclosures equipped with optical windows.



M. Antonello et a., "*The SABRE project and the SABRE Proof-of-Principle*" Eur. Phys. J. C (2019) 79:363

Limitations:

1) **Light collection is limited to the surface of the optical windows**
2) **Generally suitable only for operation at atmospheric temperature and pressure**
3) **Not easily adaptable to complex geometries**

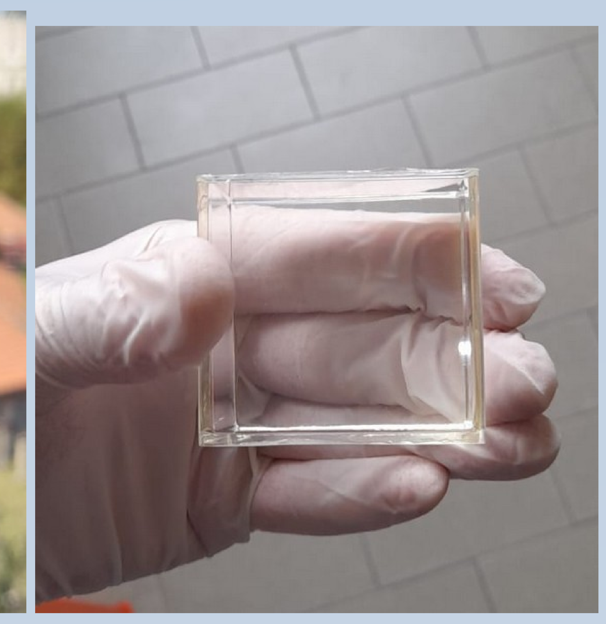
II. INNOVATION

ASTAROTH's Breakthrough

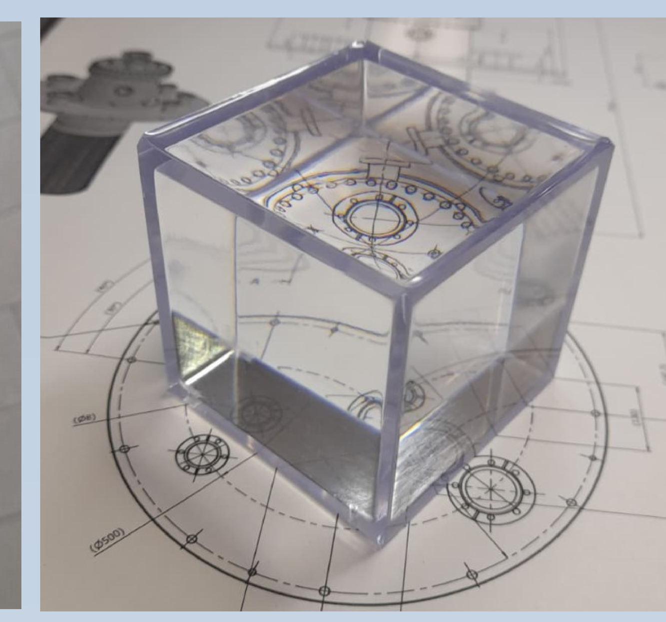
The solution developed within the ASTAROTH experiment consists of encapsulating the crystals in a bicomponent epoxy resin (Stycast 1266)

- Protection from environmental humidity while allowing free handling
- Mechanical strength and maximum transparency on all surfaces.
- Operation in vacuum and in cryogenic environments (already tested down to 80 K).

21 mm cubic crystal



45 mm cubic crystal

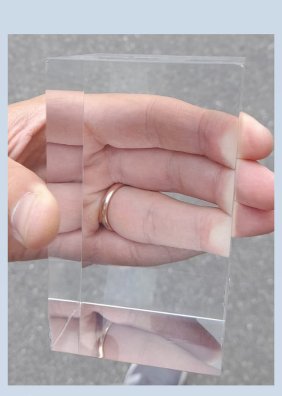


50 mm cubic crystal

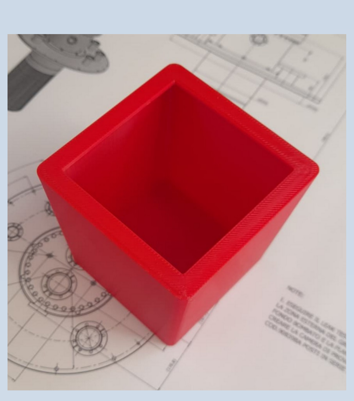
III. A "cooking recipe"

The encapsulation procedure was developed and scaled from small cubic NaI(Tl) crystals with a 21 mm side length up to 50 mm, addressing several issues related to outgassing, transparency on all sides, impermeability, and optical clarity. The procedure used is described below in three steps:

Step 1: making the silicone mold

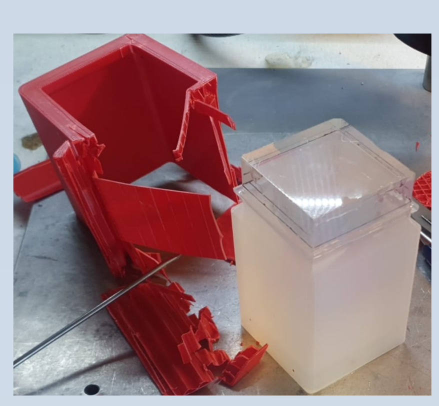


1) Create a plexiglass cube with polished surfaces



2) 3D print an external shell

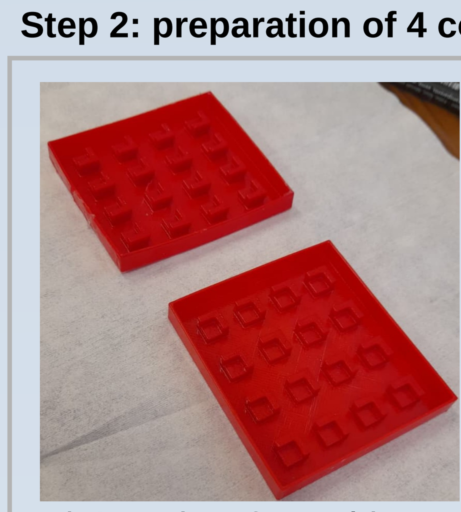
3) Fill the mold with a bi-component silicone and degas in vacuum



4) Break the outer 3D printed shell and remove the silicon and plexiglass

5) Remove the inner plexiglass cube

Step 2: preparation of 4 corner supports:



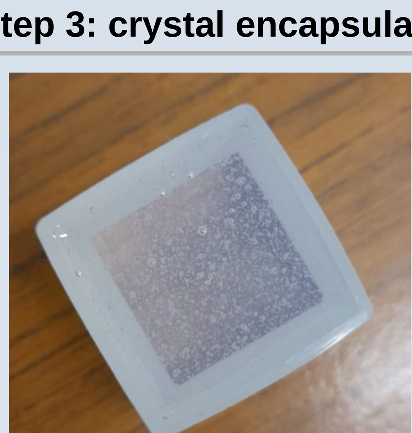
1) 3D print of a mold with the corners.(The surface of the 3D print can be smoothed with acetone vapors)

2) Pour the silicone to create a negative mold of the corners

3) Pour the epoxy resin into the silicone mold

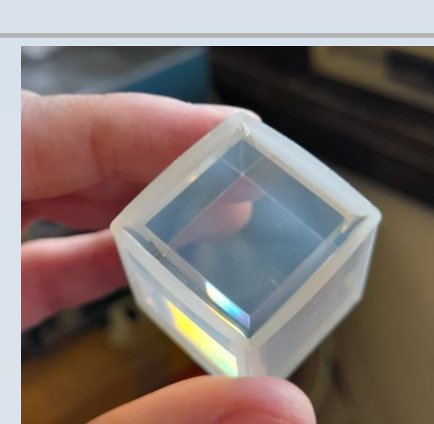
4) Remove the resin corners

Step 3: crystal encapsulation

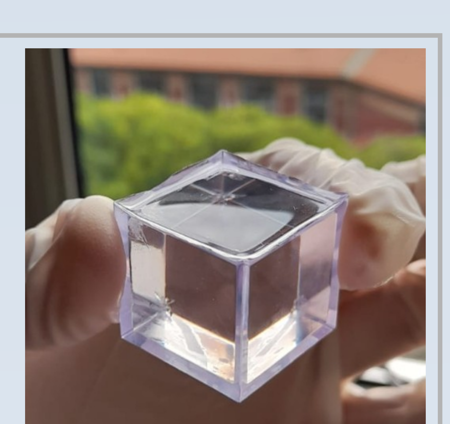


1) place the crystal into the mold over the corners and pour the epoxy resin

2) degas the resin under vacuum to remove bubbles



3) cure the resin in an oven

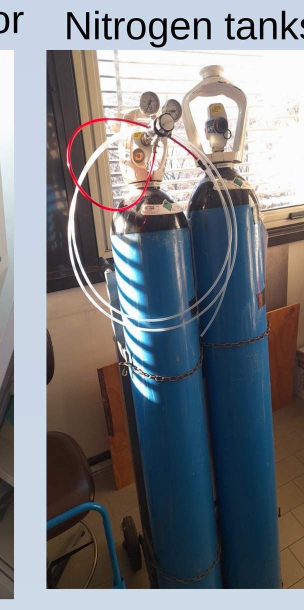


4) remove the silicone mold

IV. Glove-box for crystal handling

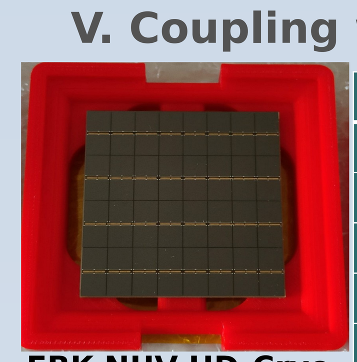
Purged with nitrogen gas to keep R.H. < 5%
- Dual side acrylic glove box (35" W x 35" D x 25" H)
- 4 glove ports
- Dual gasketed side doors
- Positive pressure operation
- Air Lock prechamber

Nitrogen generator



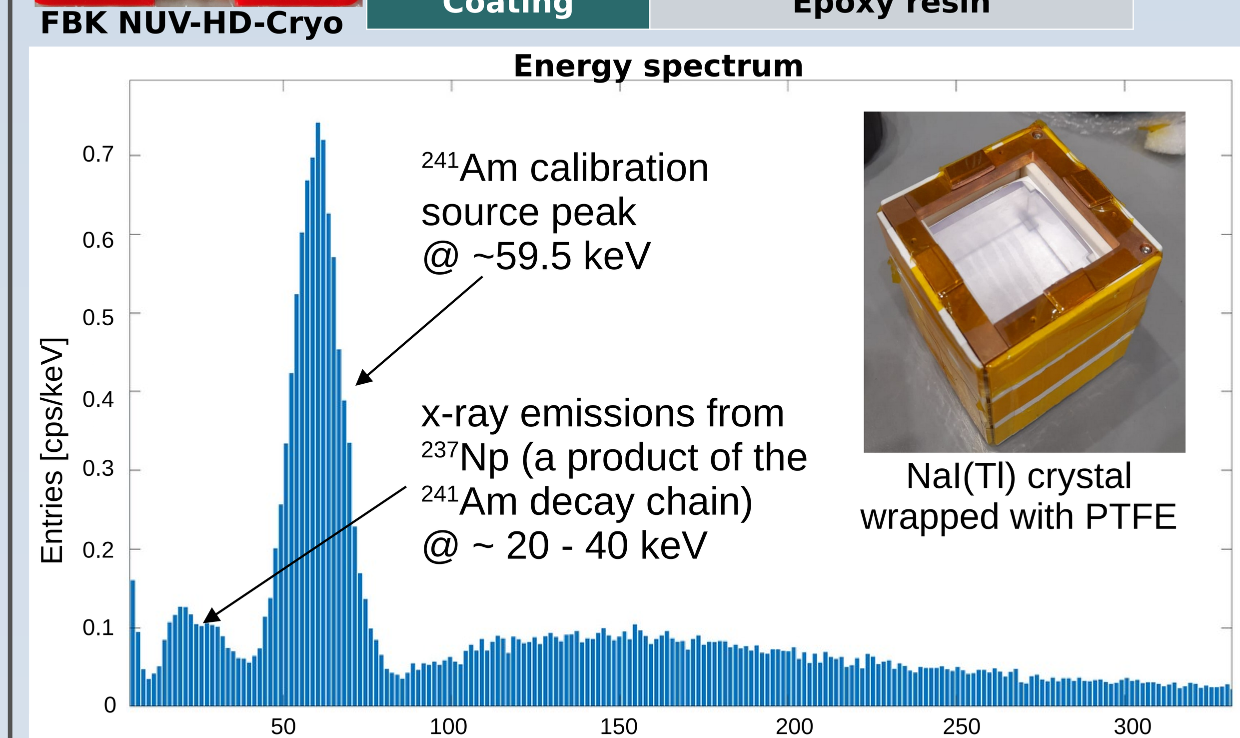
Nitrogen tanks

V. Coupling with SiPMs and low-energy spectrum measurement @ 80 K

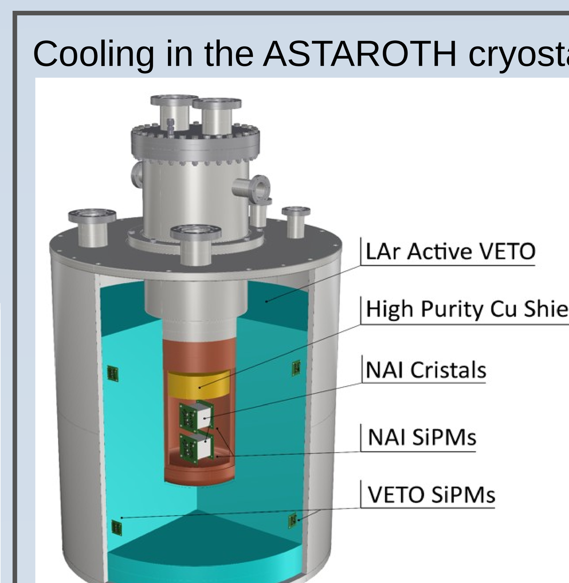


FBK NUV-HD-Cryo

Size	50 x 50 mm²
Devices	64
D. Area	6 x 6 mm²
Pitch	30 µm
PDE @420nm	65 %
Coating	Epoxy resin



Cooling in the ASTAROTH cryostat



Cooling power (LN2)

Heating power (tunable heater)

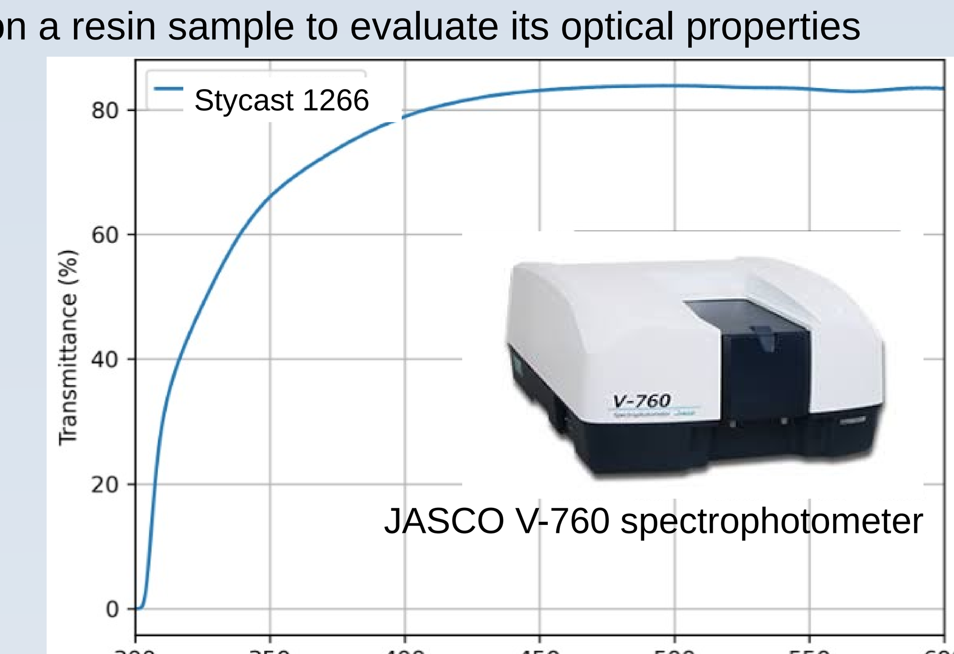
Dynamic equilibrium

77 K < *tunable* working temp. < 150 K

VI. Transmittance measurements:

We performed a transmittance measurement on a resin sample to evaluate its optical properties (at room temperature)

The thickness of the resin sample is comparable to the actual coating thickness of the crystals: ~2.5 mm



JASCO V-760 spectrophotometer