Performance Validation of the VSTT: An Upgraded CUPID Prototype Tower with Neganov-Luke Enhanced Light Detectors

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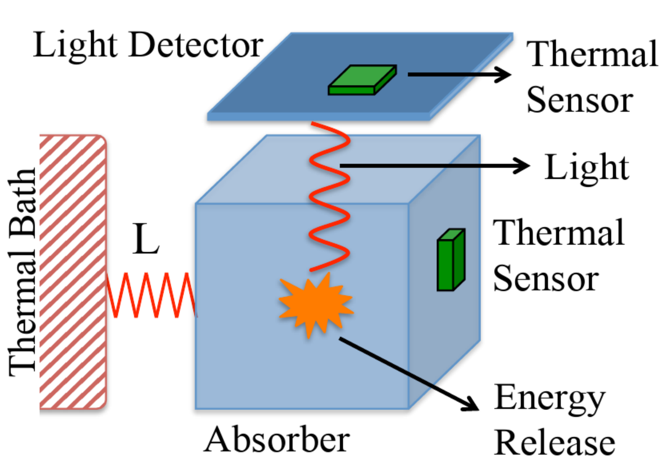
The CUPID experiment

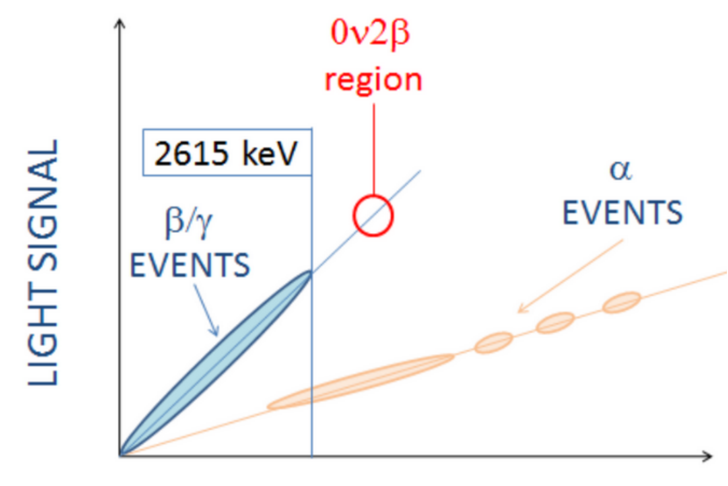
Cryogenic detectors have been widely utilised for the last 50 years for the search of neutrinoless double beta decay (CUORE, CUPID-0, CUPID-Mo, CUPID, AMoRE,..), demonstrating reproducible and stable performances at 10mK, in particular an optimal energy resolution in keV-MeV range.

The CUPID collaboration is advancing toward a next-generation cryogenic experiment for neutrinoless double beta decay searches, based on 100Mo-enriched scintillating crystals. The scintillation light is used to obtain both the particle discrimination and a temporal information for each event.

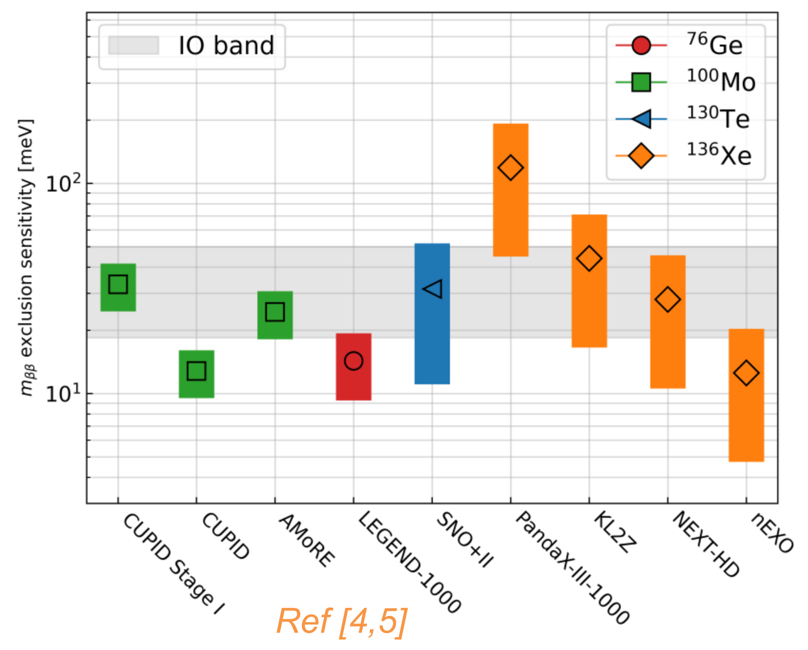
CUPID and the next generation $\beta\beta$ experiments aim to probe the full IH region for $m_{\beta\beta}$, exploiting ton-scale active masses and zero background conditions



Refs. [1-3]



CUPID Sensitivity goal:
$T^{0\nu}_{1/2}$ = 1 x 10^{27} yr
$m_{\beta\beta}$ = 12-20 meV



Ref [4,5]

CUPID detector design status and goals

The CUPID detector array will consist of:

- 57 towers
- Each tower hosts Li_2MoO_4 (LMO) crystals enriched in 100Mo (95%) distributed in 14 floors and 2 columns
- Each LMO crystal has top and bottom Ge Light Detectors (LD)
- LMO crystals and light detectors are both read with Ge-NTD sensors

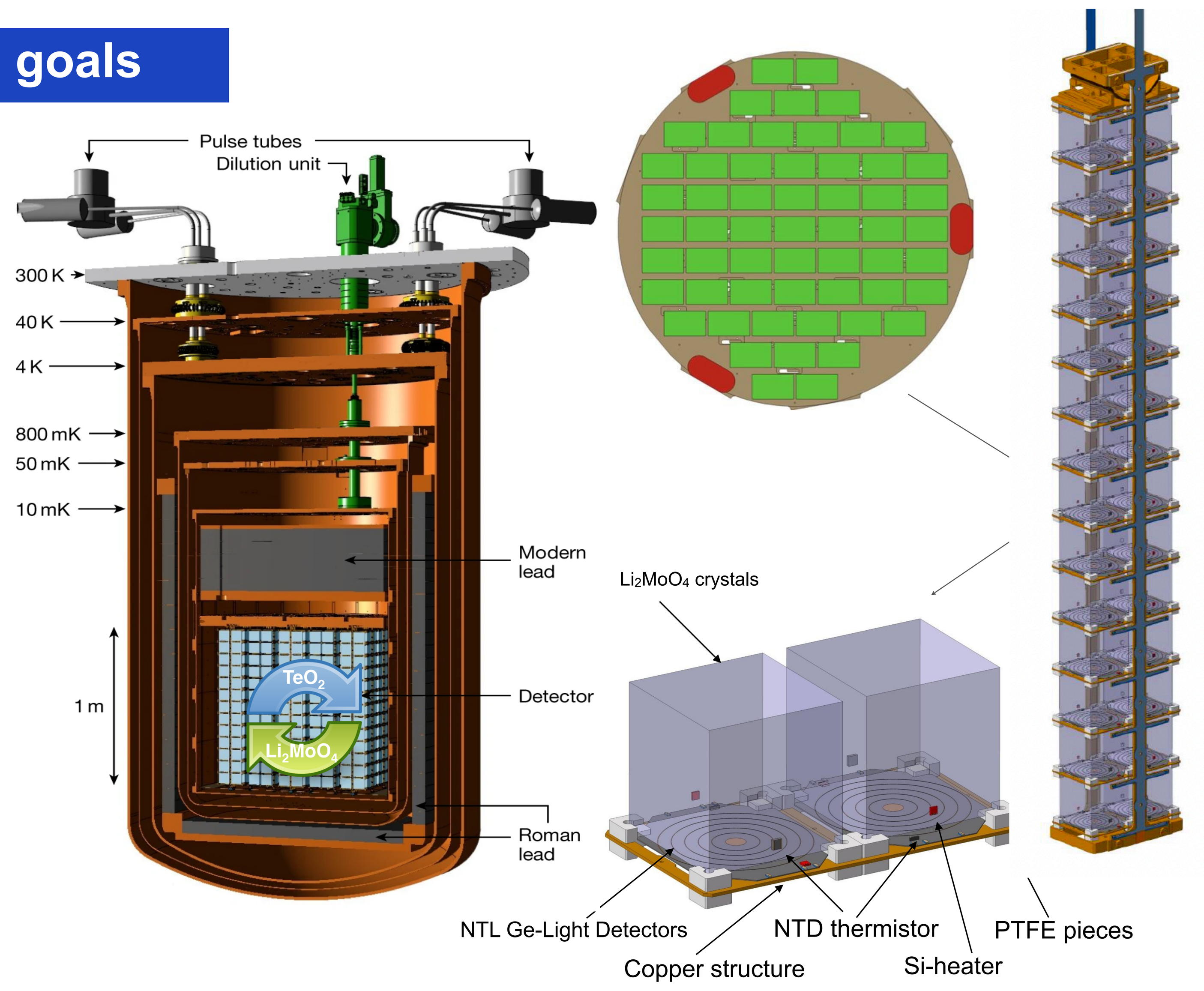
For a total of:

- 1596 LMO scintillating crystals (4.5x4.5x4.5 cm^3, 280 g each)
- 1700 Ge light detectors, of 500um thickness

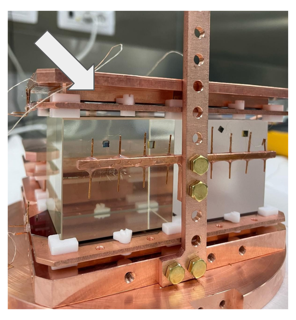
Active mass:
450 kg (240 kg) $Li_2{}^{100}MoO_4$ (^{100}Mo)

The detector will be hosted in the upgraded CUORE cryostat.

Ref [6,7]

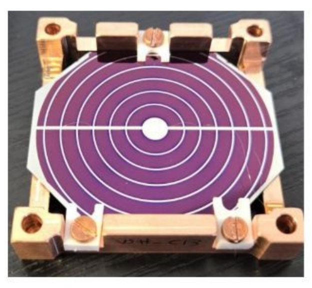


Crystals with masses of ~ tens-hundreds g read by Ge-NTDs thermistors are slow detectors (~1ms-1s), still suitable for rare event physics searches



$Li_2{}^{100}MoO_4$ crystals
- Controlled crystals production chains (SICCAS)
- CCVR runs at LNGS to assess crystals performances and analyse residual radioactivity

Background of enriched LMO crystals operated at 10mK will be dominated by $2\nu\beta\beta$ rate



NTL Ge-Light Detectors
Exploit Neganov-Trofimov-Luke effect. Improve SNR for LDs

Signal amplification allows the use of light detectors for efficient $2\nu\beta\beta$ pile-up rejection

Ref [8,9]

CUPID VSTT - Vertical Slice Tower Test

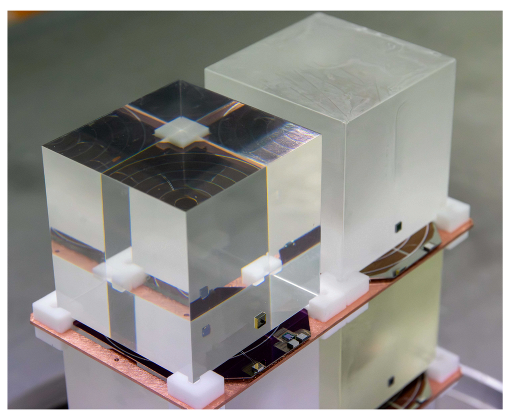
Building on the experience of the first prototype (GDPT), a new upgraded tower has been developed. The Vertical Slice Tower Test (VSTT) features an upgraded mechanical structure designed to improve the uniformity of thermalization across the array and to suppress correlated noise among the light detectors (LDs).

- Mechanical assembly with upgraded tower design
- Test of the assembly-line (glueing, mounting, bonding,…)
- NTL light detectors
- Optical fibers along the tower
- New electronics and DAQ

VSTT has been installed in the CUPID wet cryostat at LNGS Hall A.
The tower has ben cooled down in **early August 2025,** reaching Tbase~7mK. We are currently working in optimising the cryogenic conditions and starting operating the detectors.

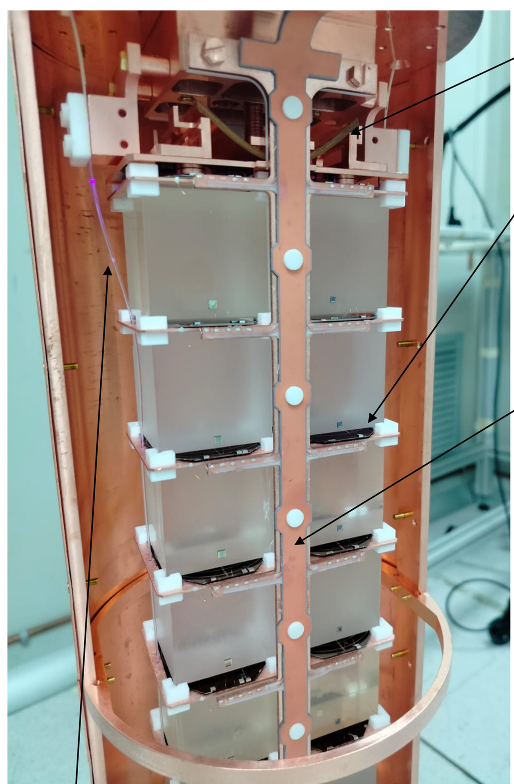
The plan is to perform a full characterization of thermal behaviour, optical performance, LD signal amplification, and vibrational noise of the VSTT during the next months.

The VSTT results will be pivotal in validating the technological solutions for the final CUPID detector design.



NTDs:
- 3x3x1 mm3 glued with Araldite/UV-glue for LMOs
- 3x1x0.5 mm3 glued with Araldite for LDs

Bonding:
- 25um Au bonding from NTD/heater to Cu-Pen pads (assisted by In)
- Transition pieces to ease the bonding of NTD/heaters of LDs



Two optical fibers routed along the tower, with diffusive points at the height of each LD

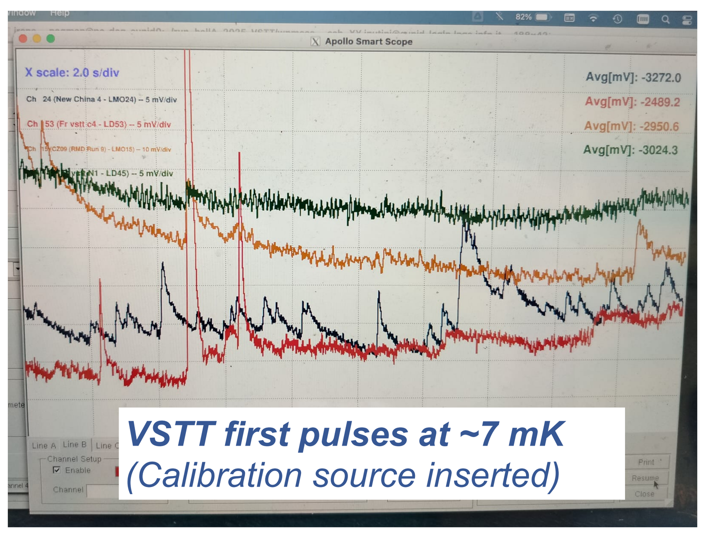
Top-spring to regulate the strength for holding the tower

Gravity assisted LMOs (as in GDPT)

Ge-LDs with NTL electrodes

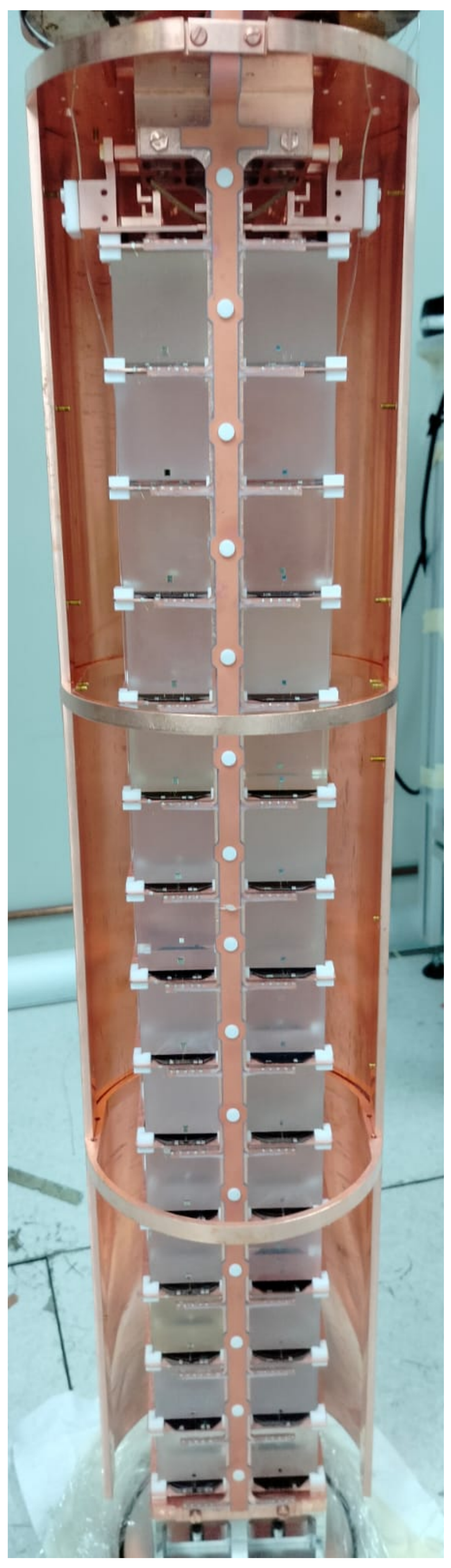
Single central copper column (on both sides) to host and thermalise the Cu-Pen wiring

Cu-Pen wiring:
- NTD-LMO & Heater-LD on same strip
- NTD-LD & Heater-LMO on same strip
to reduce crosstalk
- NTL electrodes HV has its own Cu-PEN strip (HV 50-150V)

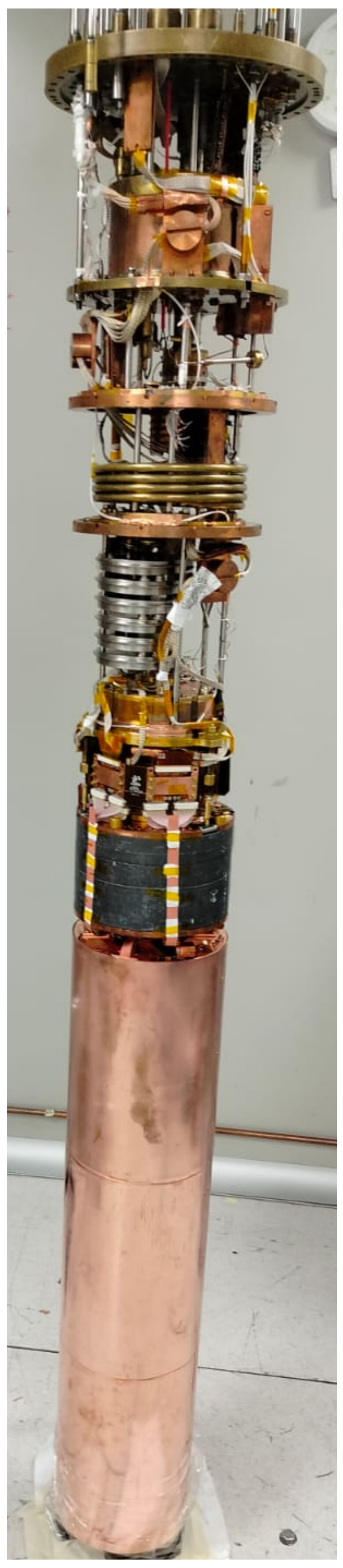


VSTT first pulses at ~7 mK
(Calibration source inserted)

VSTT assembled, kept under N2 flux



VSTT : all NTDs/heaters bonded to the Cu-Pen wiring and tower installed in the cryostat



VSTT installed in the cryostat.
10mK shield closed and wiring completed

References

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