CUPID-CJPL: a cryogenic bolometer testbed

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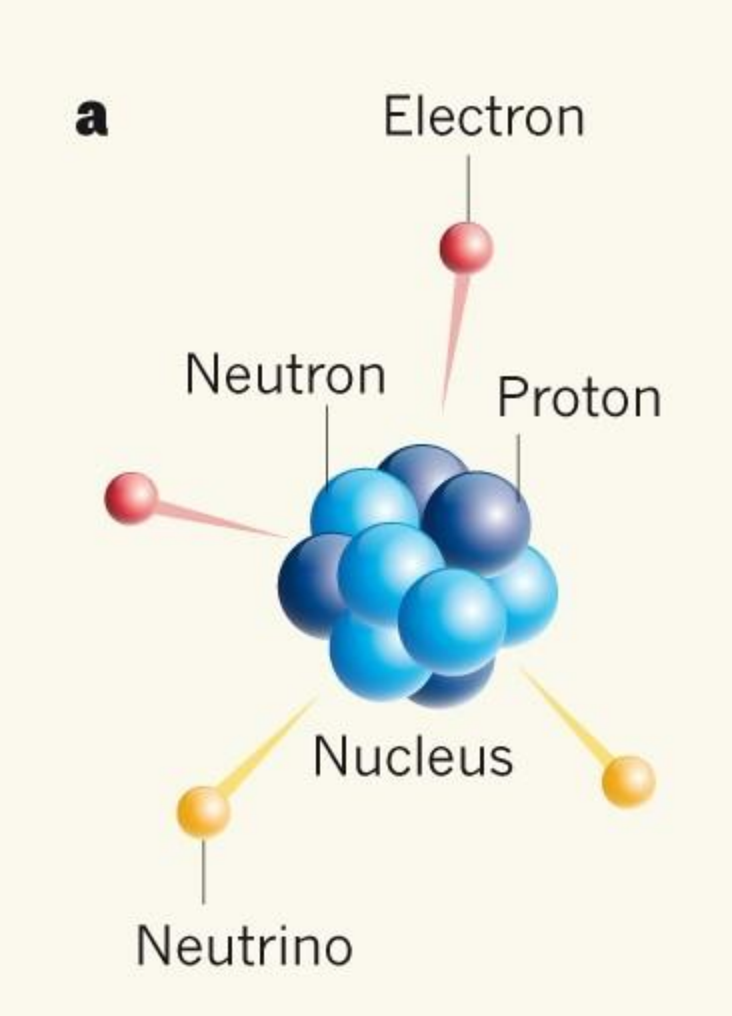
On behalf of the CUPID collaboration

@Xichang 2025/8/26

2νββ ✓ 0νββ ?

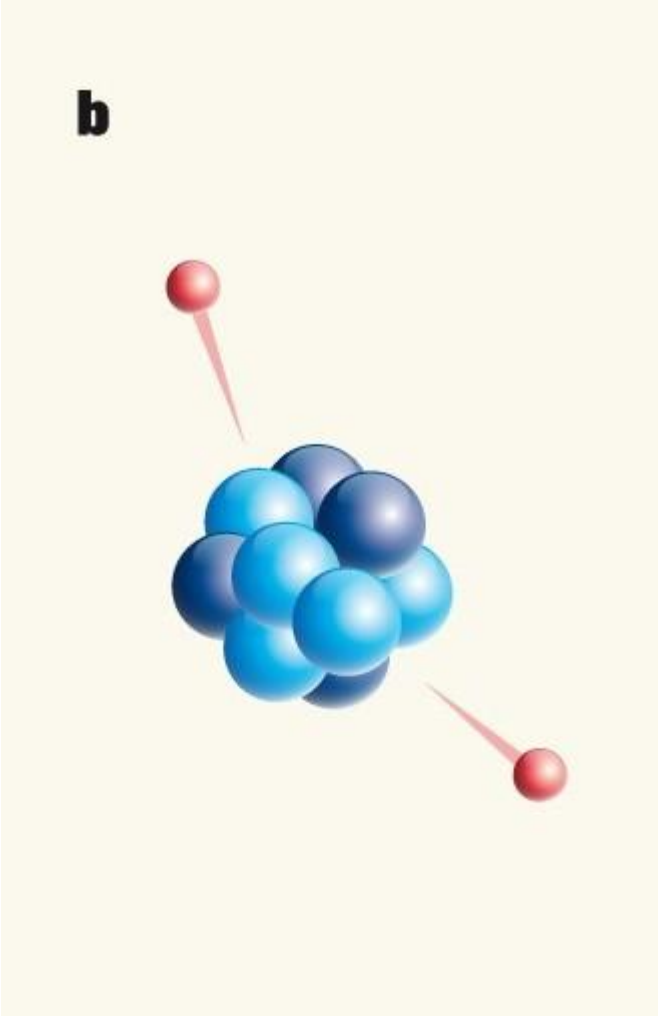


2νββ: 35 isotopes could produce

Observed in many experiments

0νββ: can these isotope also produce?

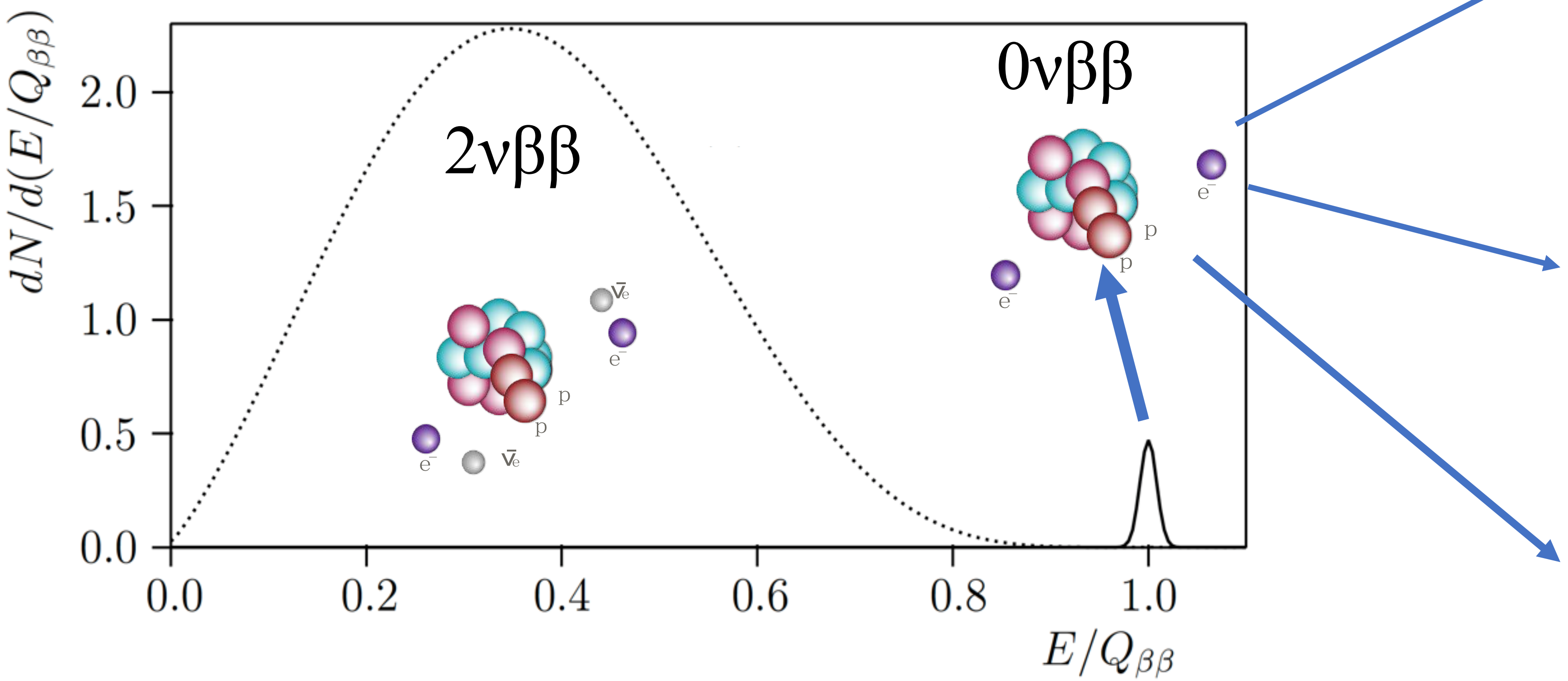
We are trying very hard

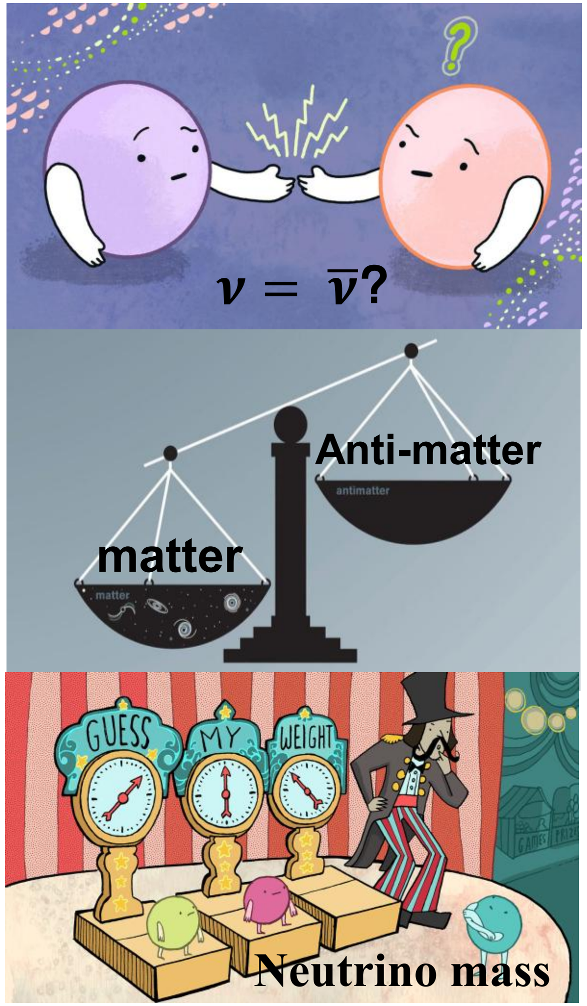


Nature, 538, 48–49 (2016)

Search for 0νββ

Energy spectrum of double electrons



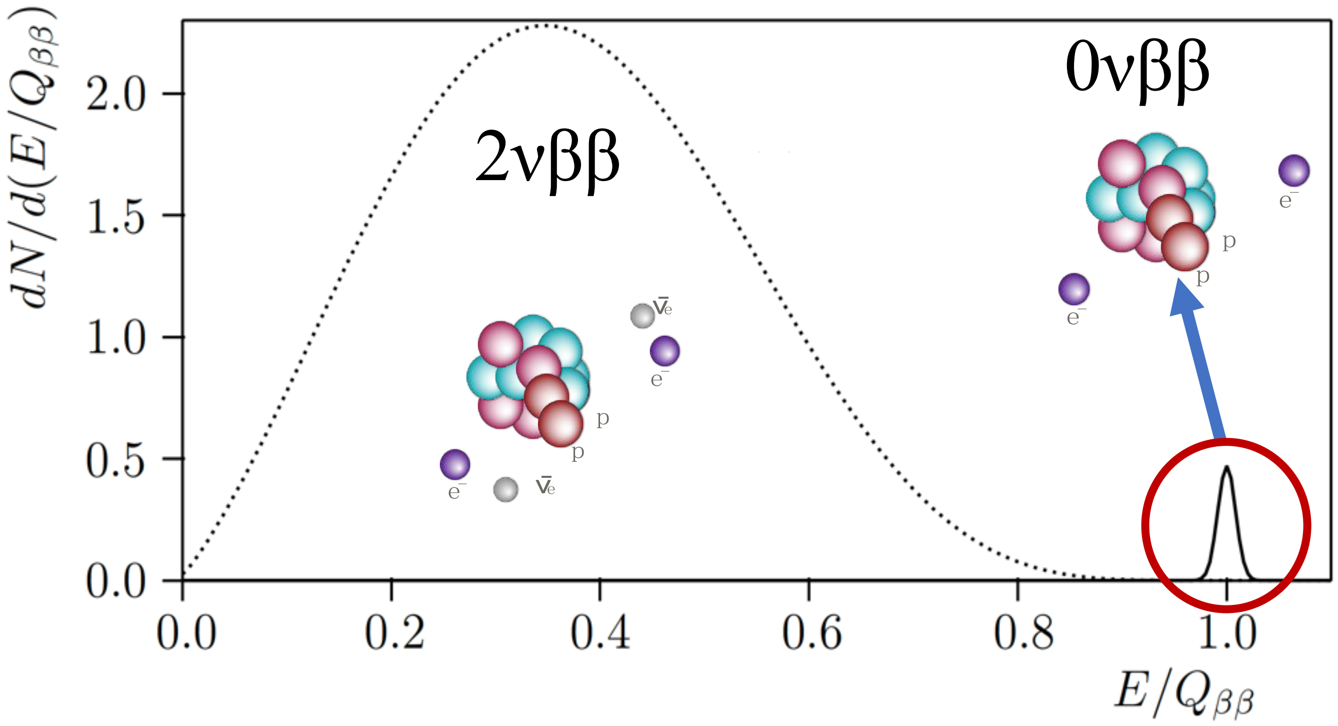


Clear observables

Rich physics

Key for the search

Energy spectrum of double electrons



Simply, when there is background…

$$T_{1/2}^{0\nu}\ sensitivity \propto a\epsilon\sqrt{\frac{Mt}{B\Delta E}}$$

a = abundance

ϵ = detection efficiency

Mt = exposure

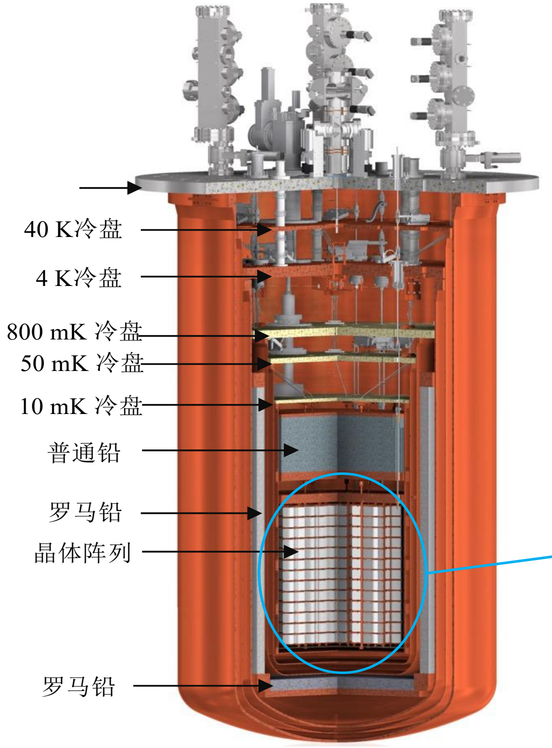
B = background index @ Q value

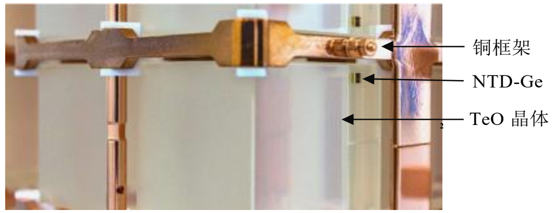
ΔE = energy resolution @ Q value

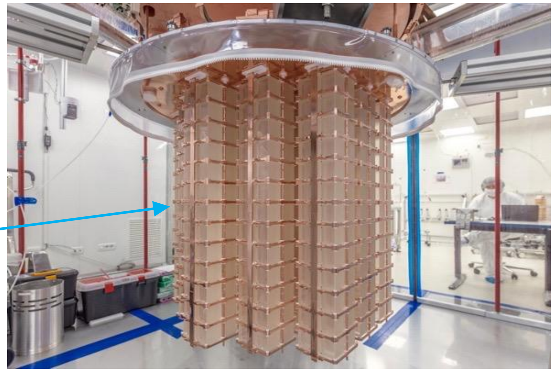
So, we want to have:

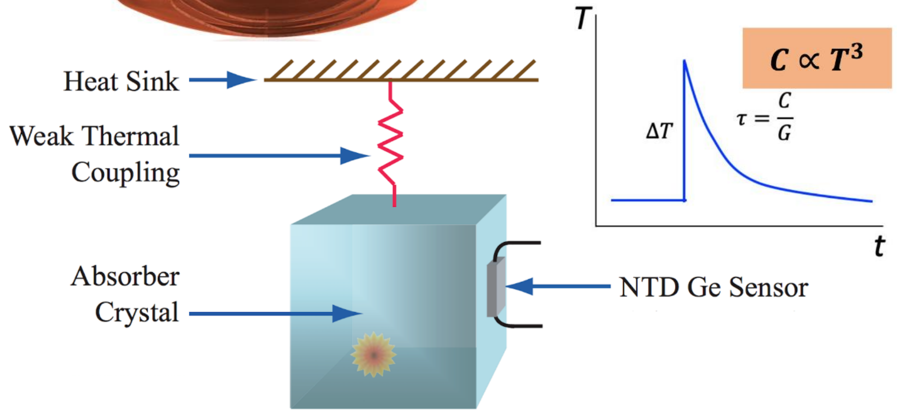
Lower background **Better energy resolution** **Detector scale-up….**

Cryogenic crystal bolometer—CUORE on duty









CUORE basics:

Location: Italy LNGS (underground)

Energy resolution: 0.3% @ $Q_{\beta\beta}$

Mass: 988 TeO_2 crystals (~750 kg)

CUORE is good for:

Most stringent ^{130}Te 0νββ half-life limit!

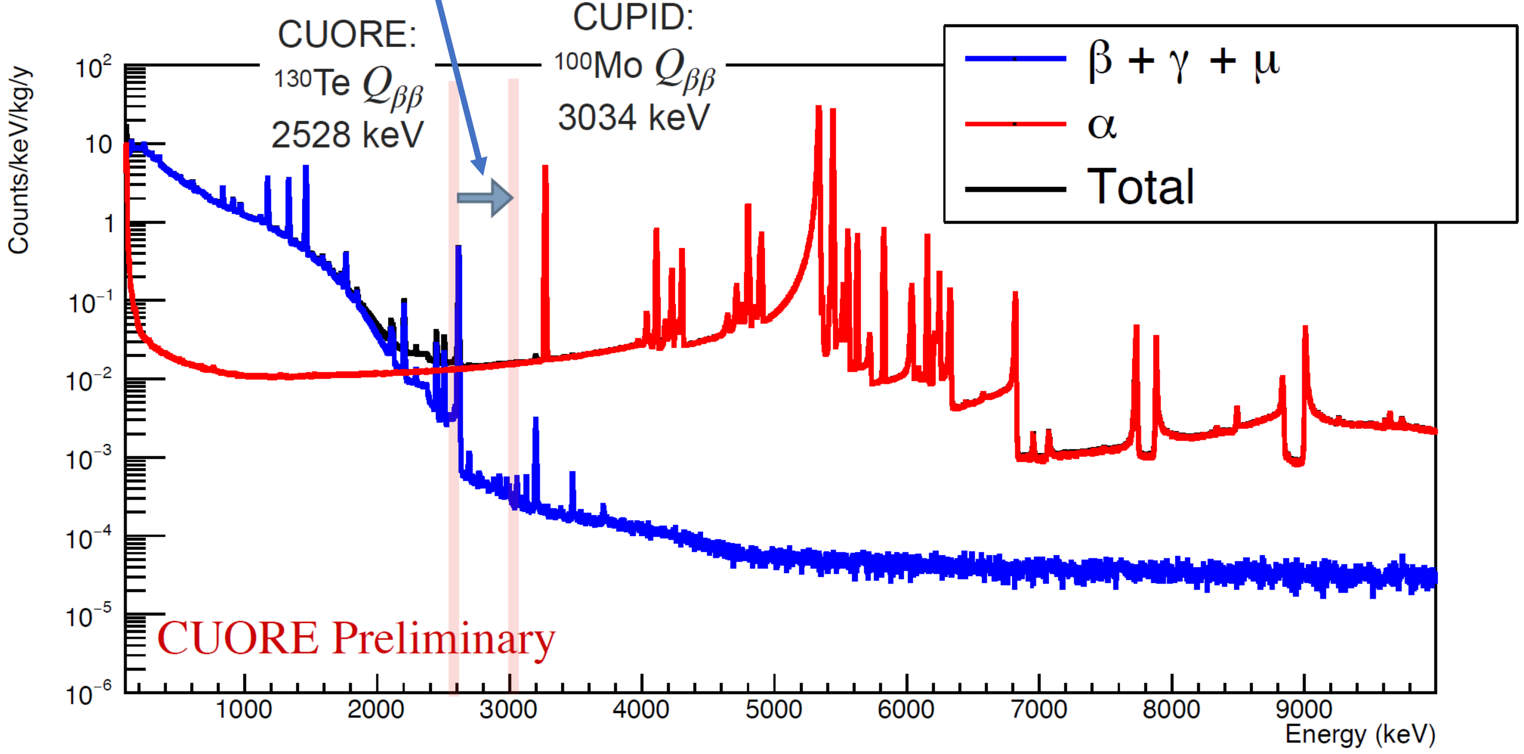
Demenstrate feasibility of operating 750 kg of crystals at ~10 mK + two ton-years of exposure so far

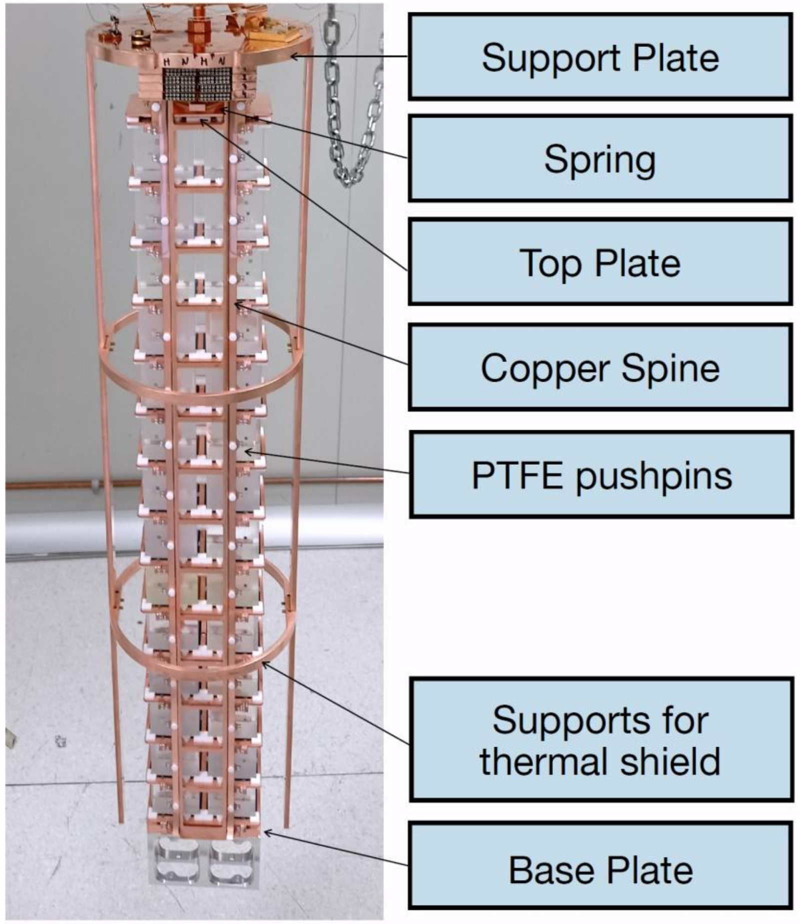
Background model build

Future experiment

CUPID: lower background—^{100}Mo

High $Q_{\beta\beta}$ of ^{100}Mo to Avoid most of the environmental gamma

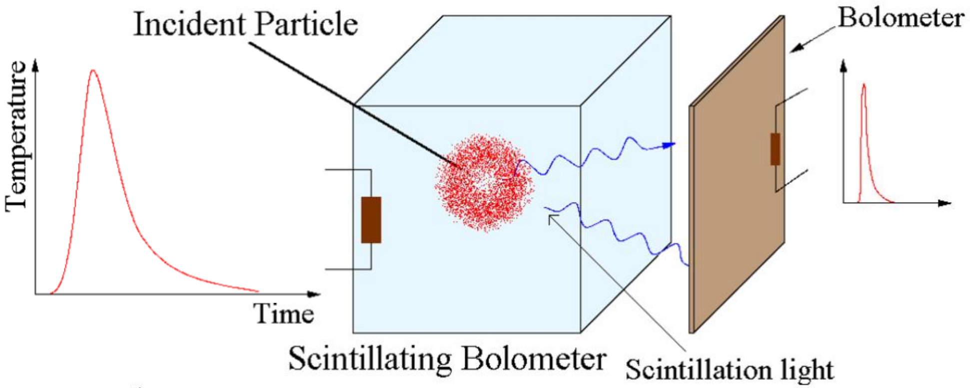




arXiv:2503.04481

CUPID：lower background—dual-readout

LMO crystals are scintillators

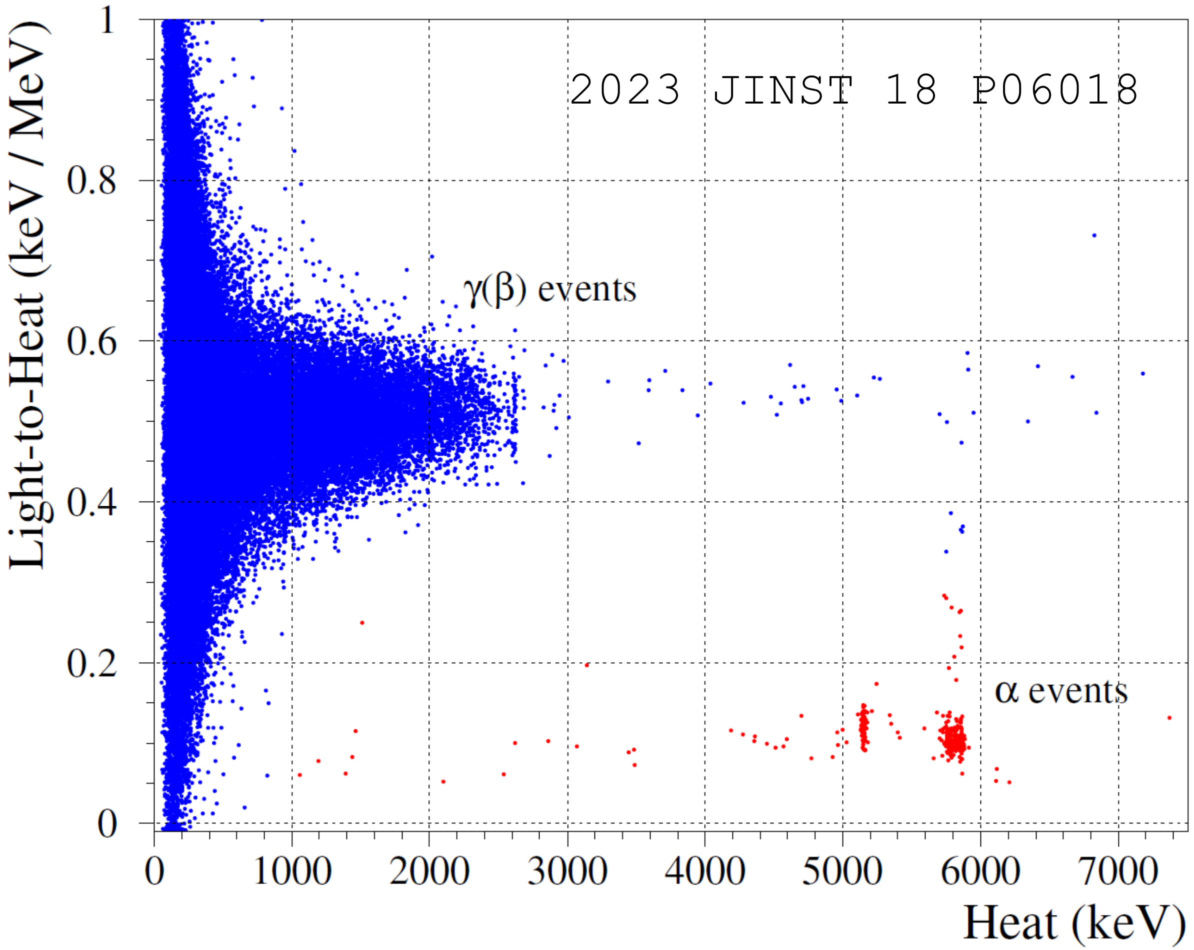


S. Pirro 18th LTD

Dual-readout

↓

Particle Identification

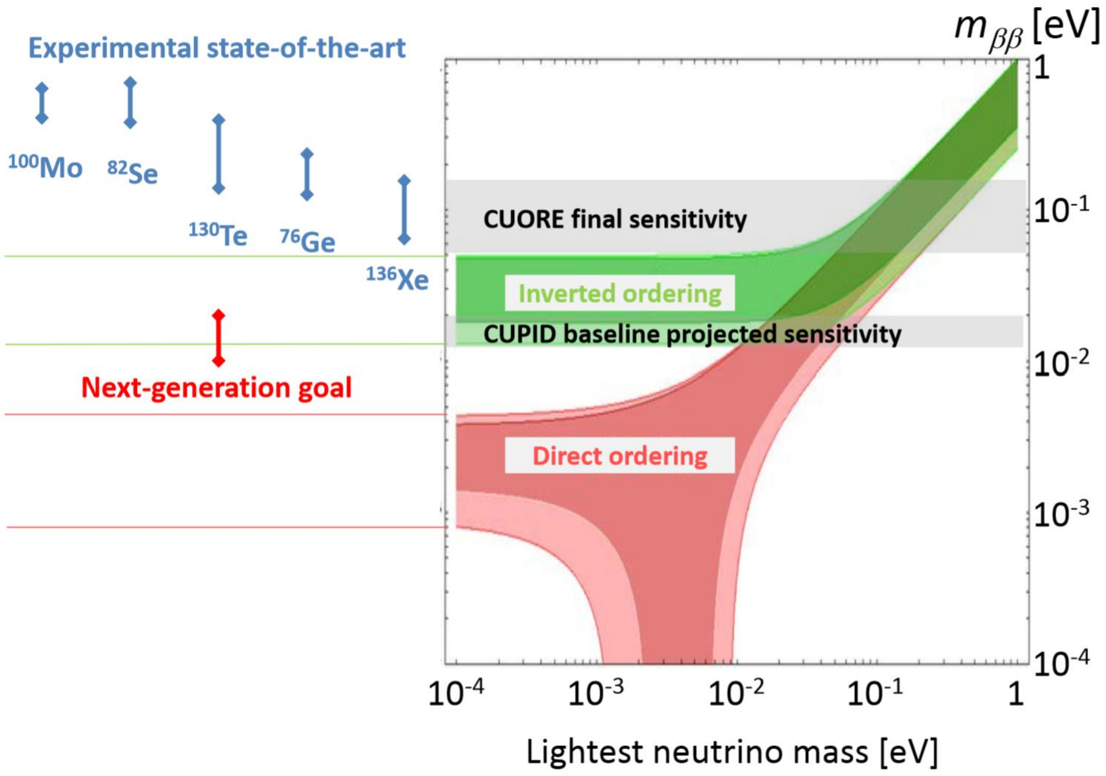


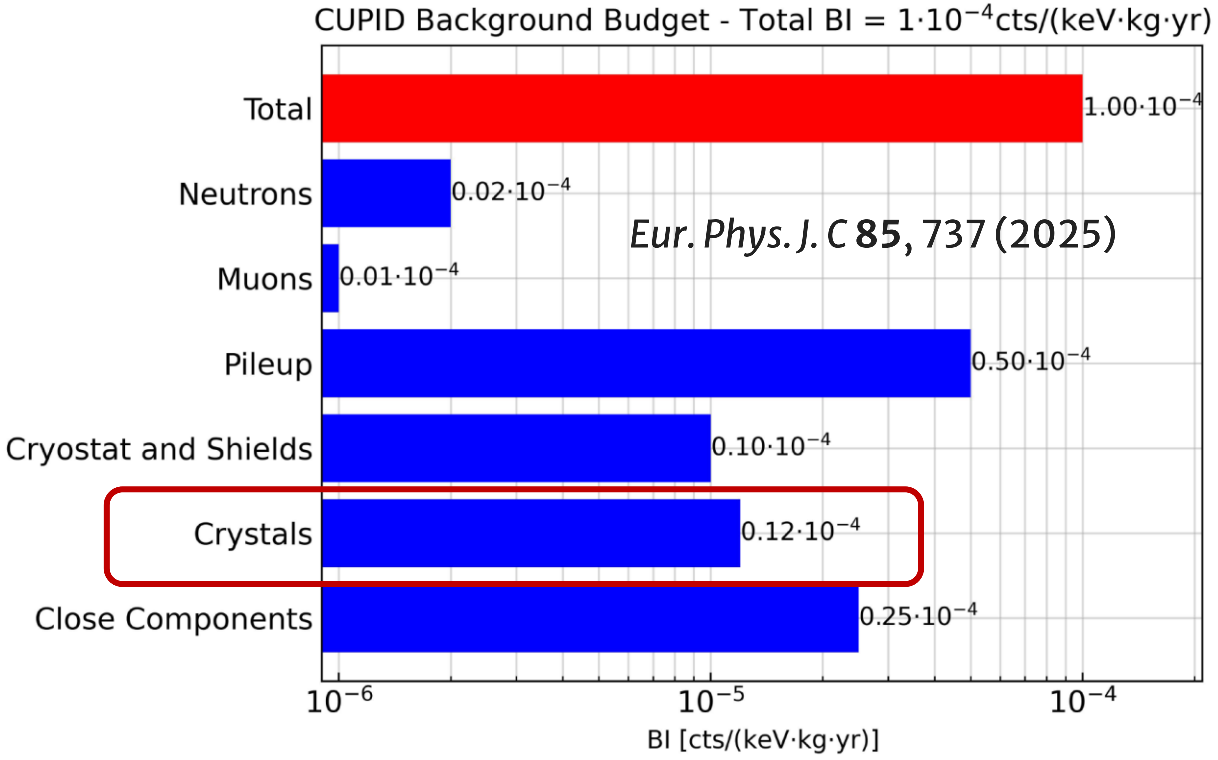
CUPID-0 and CUPID-Mo demonstrate the power of dual-readout: remove 99.9% α background

The background is expected to be **reduced by a factor 100 with respect to CUORE**

CUPID background budget

To cover the whole region of inverted ordering, CUPID set the background index goal at 10^{-4} cts/(keV kg yr)



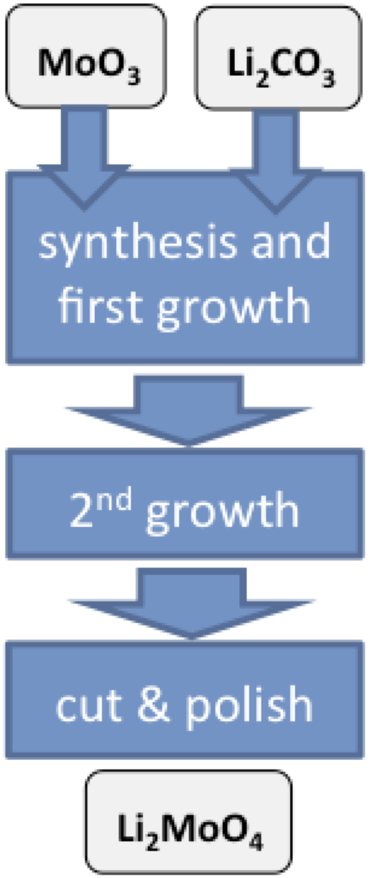


Quality control of the crystals is very important:

- Radioactive impurities in crystals
- Energy resolution
- Light yield for better discrimination

Crystals production

SICCAS/NBU



Preparation of ^{100}Mo-enriched Li_2MoO_4 crystals

- Agreement made with INFN on the pre-production of enriched LMO crystals
- ^{100}Mo-enriched (98%) LMOs have been produced and is undergoing QA testing
- Twice growth technique with BG+BG method - higher production efficiency
- SICCAS and IPC working closely to produce 100Mo-enriched LMO powder with qualified chemical/radioactive purity

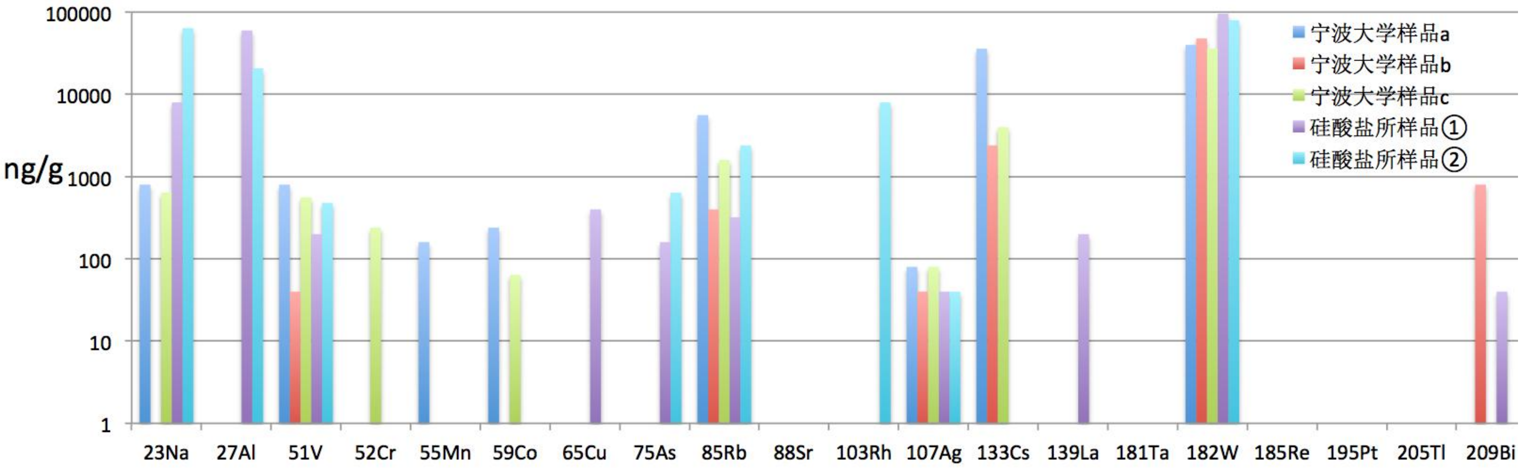
Radio-purity assessment

Tasks:

- Assay of the sample of the raw material (Li_2CO_3,Mo_2O_3 powder)
- Quick radio-purity assessment of LMO samples

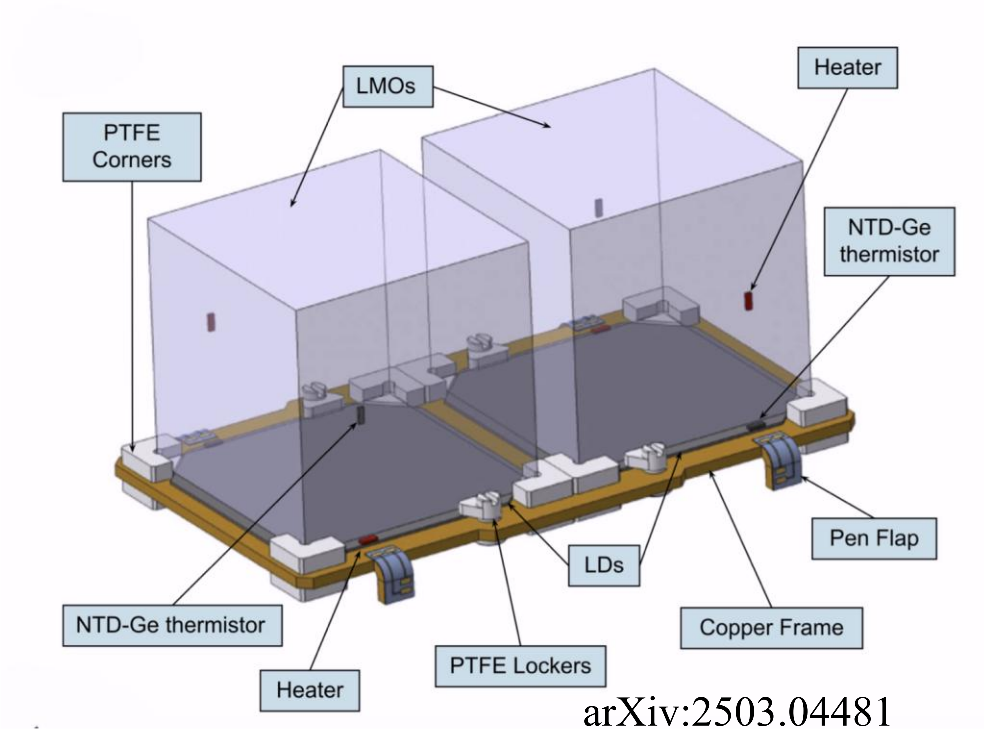
Method: High sensitivity ICP-MS measurement

- Quick (~1 week), economical
- Require only small amount of sample

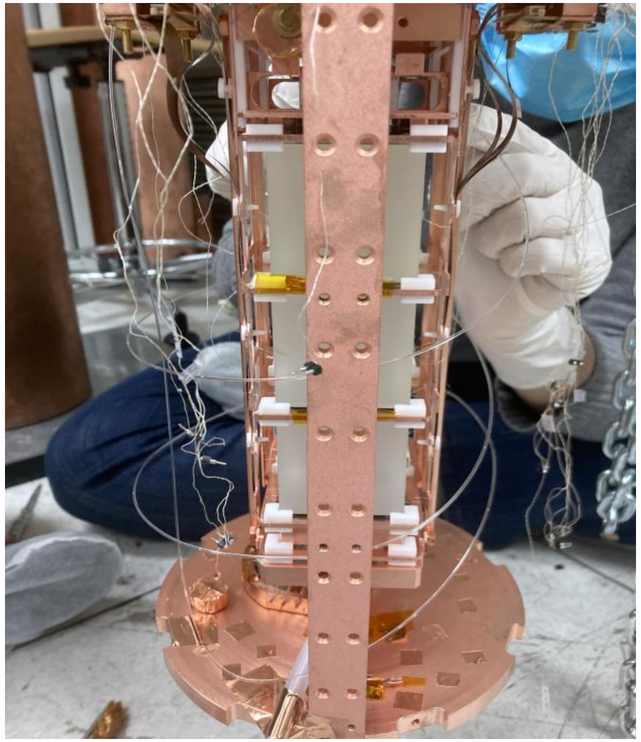


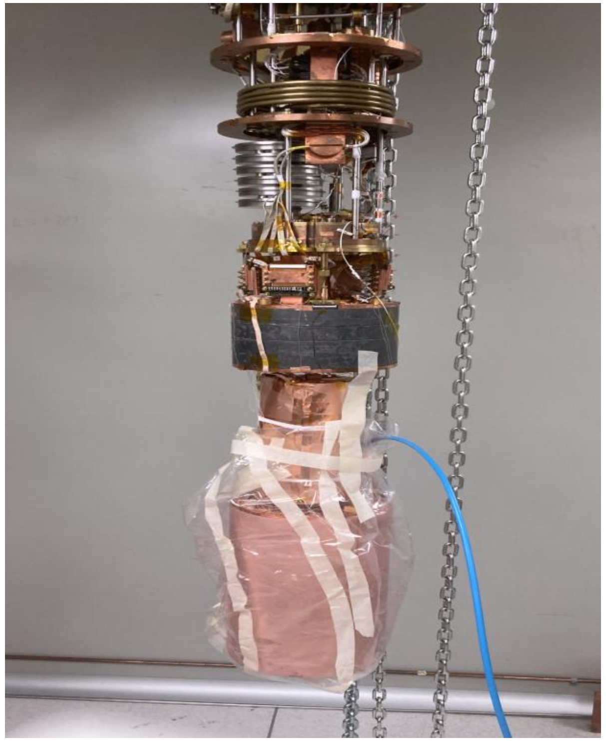
Underground crystal test

Sensitive crystal quality evaluation through bolometric run (CCVR) @Italy LNGS



arXiv:2503.04481



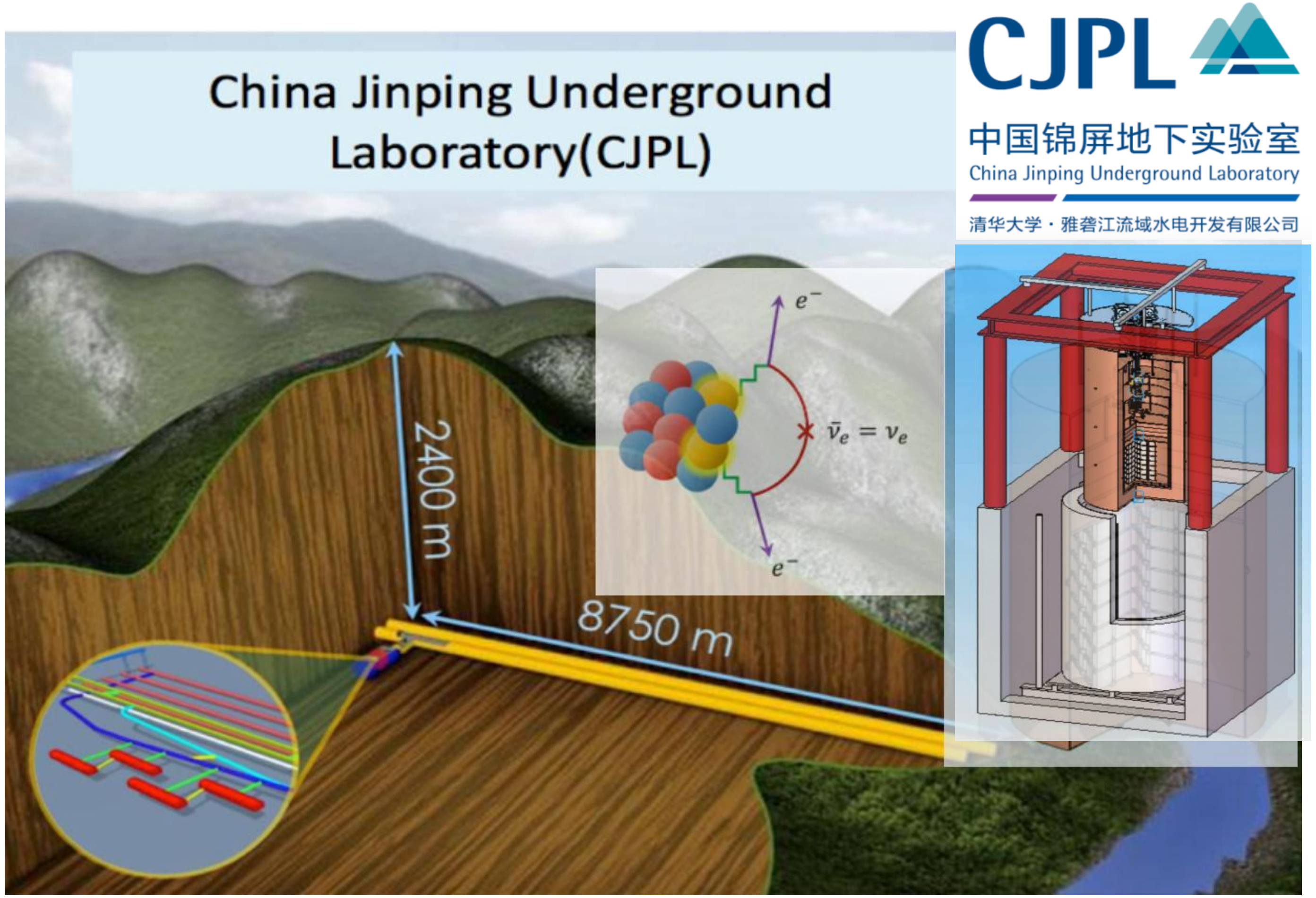


Necessary to assess:

- Radioactive impurities in crystals (more accurate, in-situ)
- Energy resolution
- Light yield

See Massimo Girola's talk "Validation of LMO crystals for the CUPID Experiment"

CUPID-CJPL: a cryogenic bolometer testbed



Technical and scientific goals:

Supporting CUPID as a test facility

CUPID-CJPL prototype:

Set up a complete cryogenic bolometer facility, demonstrate the performance

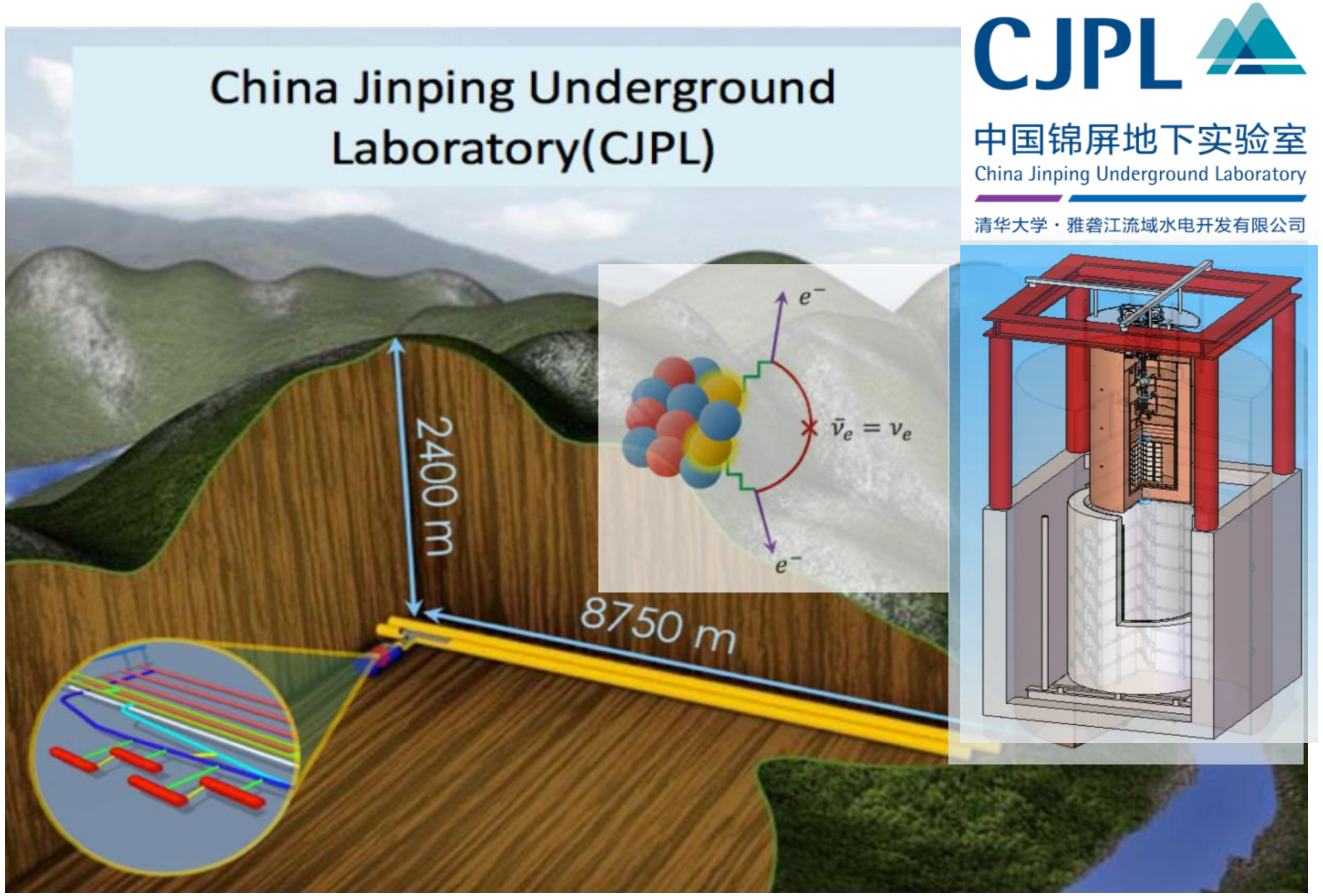
R&D development:

Background mitigation

Vibration isolation

Alternative temperature sensor (TES)

CUPID-CJPL: a cryogenic bolometer testbed



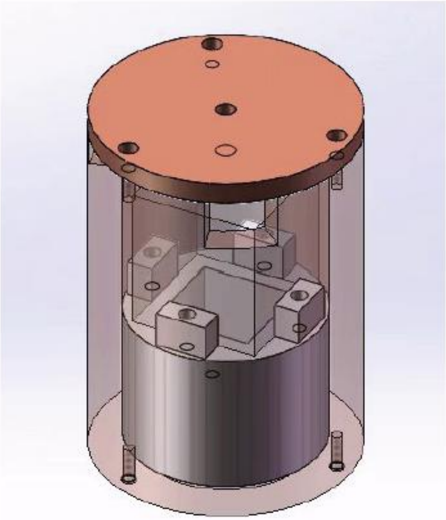
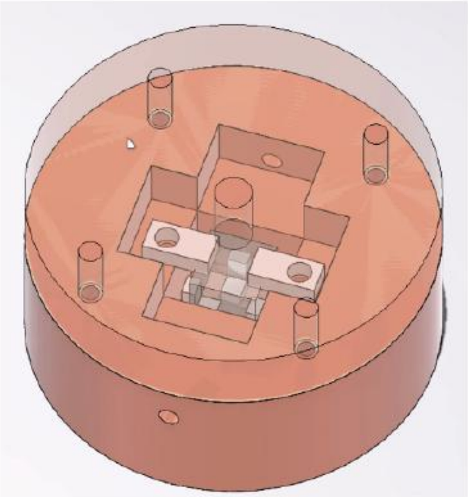
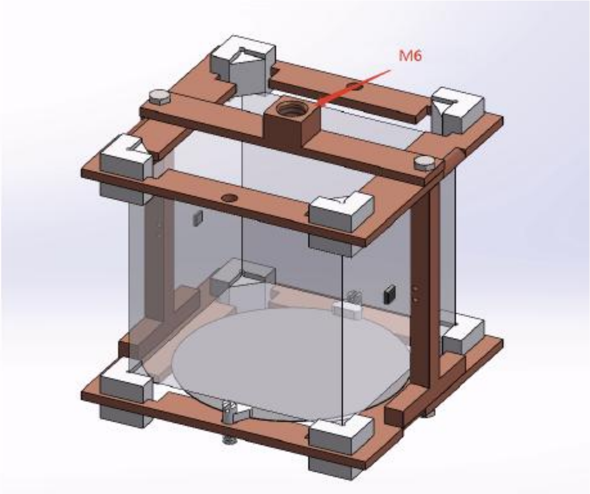
Planned technical specifications:

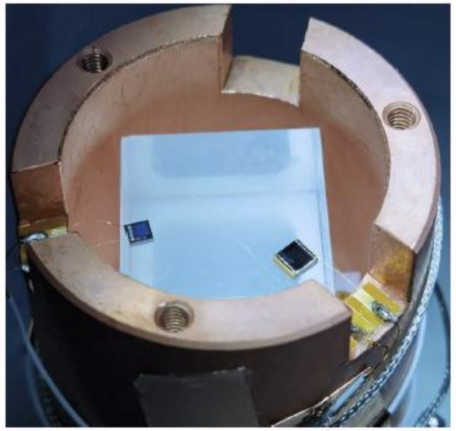
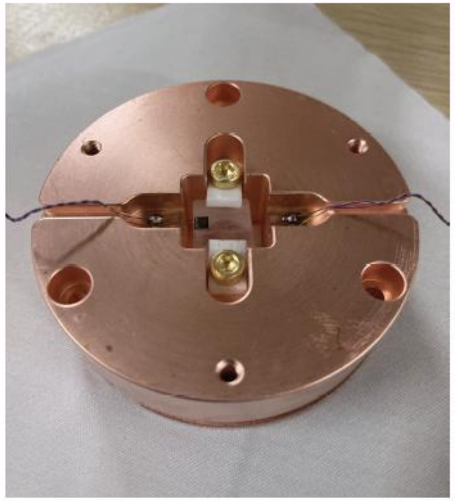
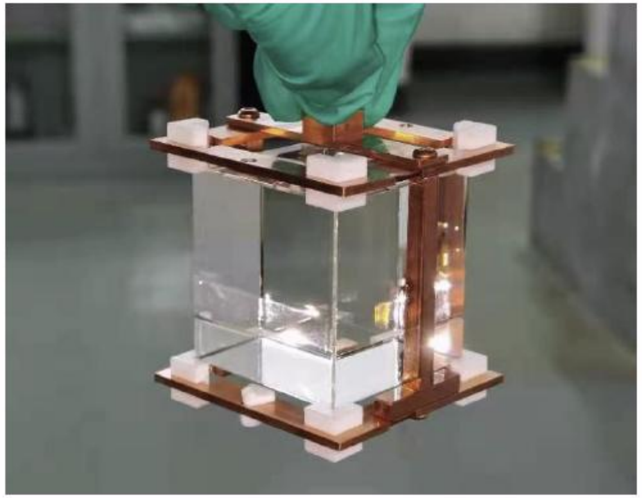
- ~10 mK
- Capable of holding up to 10 kg of crystals
- Cryogenic scintillating crystal bolometer with CUPID technology

Facility duties:

- Quality assessment of CUPID LMO crystals
- Quality assessment of new readout electronics made for CUPID
- Assessment of background level of cryogenic bolometers in CJPL

Preparation: Detector module design

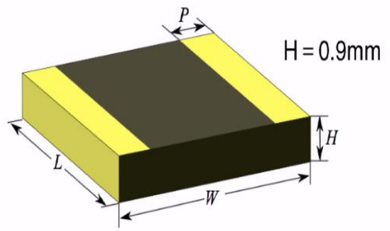




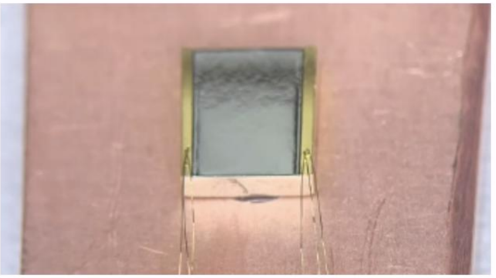




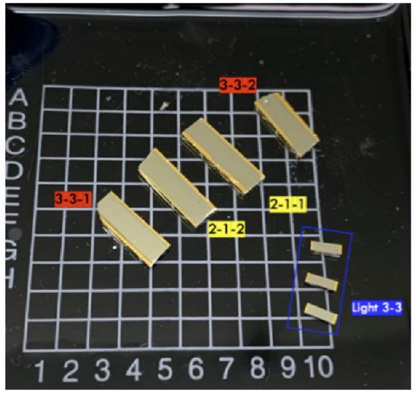
Module design for different sizes of LMO crystals

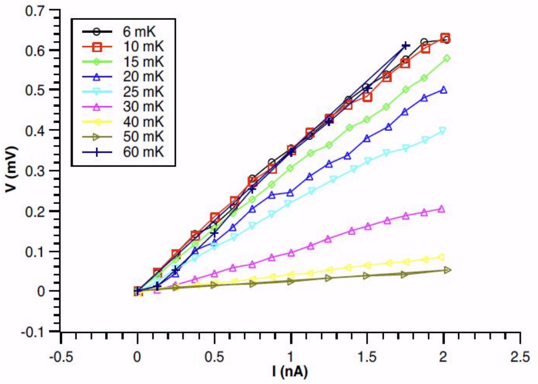
- PTFE is used to hold the crystals
- Minimum supporting materials to reduce backgound
- Extra copper shielding for smaller (1 cm) crystals
- Stackable

R&D progress - Thermistor





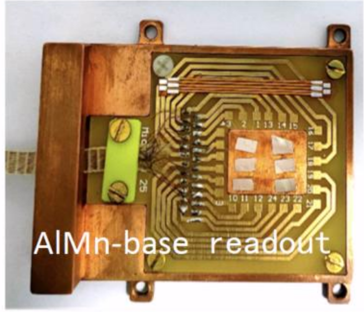


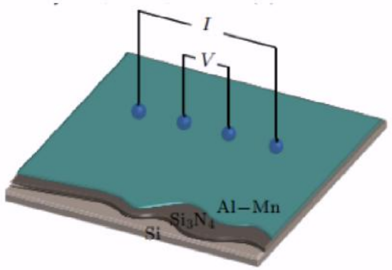


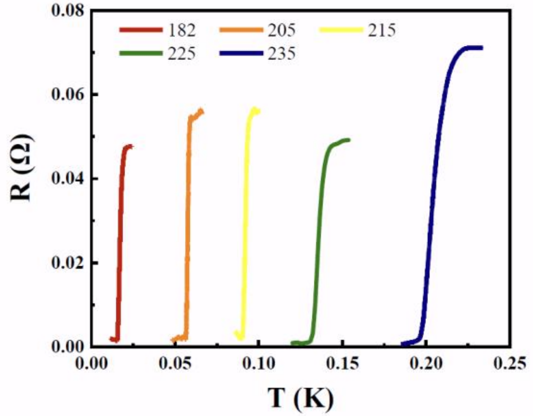
NTD-Ge (Neutron Transmutation Doped germanium thermistor)

- Fabrication process is well established
- Performance study: I-V and R-T curve: R>10MΩ @ T<20 mK
- Continuous optimization

@USTC







Aiming For future CUPID experiment

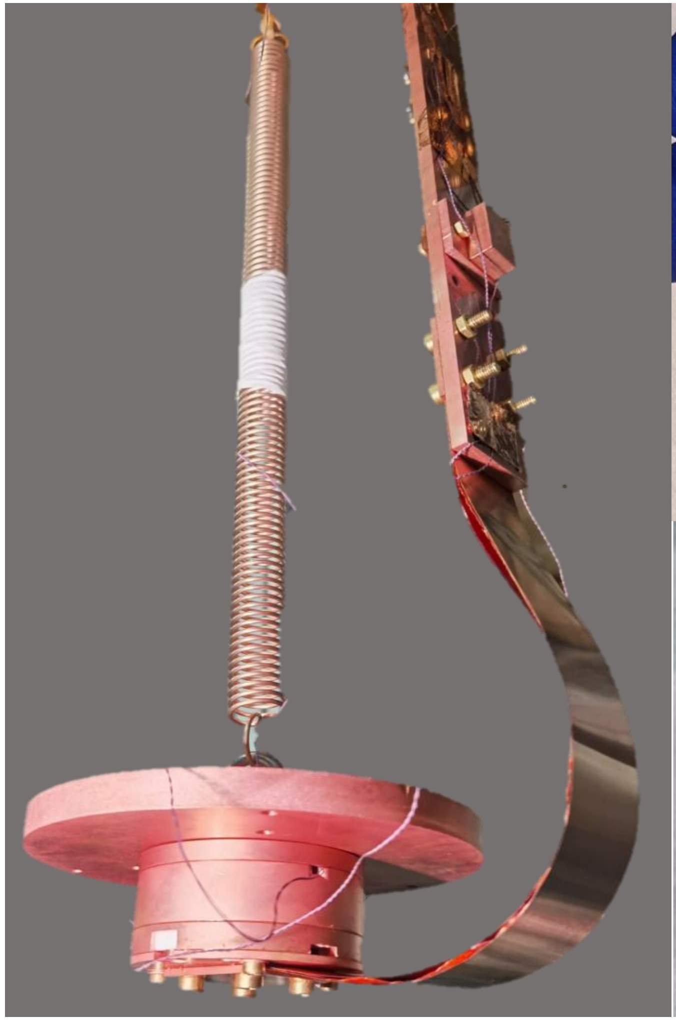
@BNU

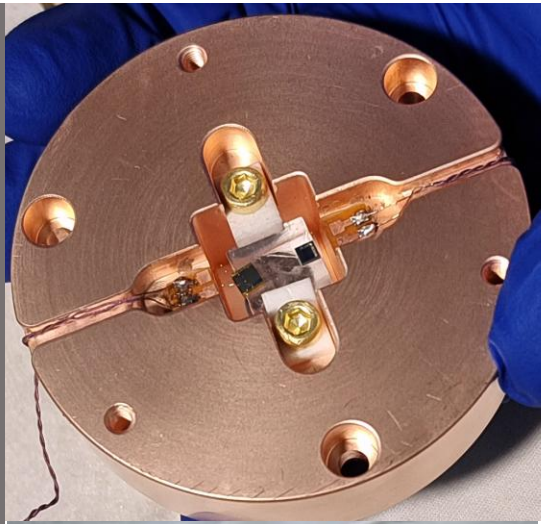
TES (Transition-Edge-Sensor)

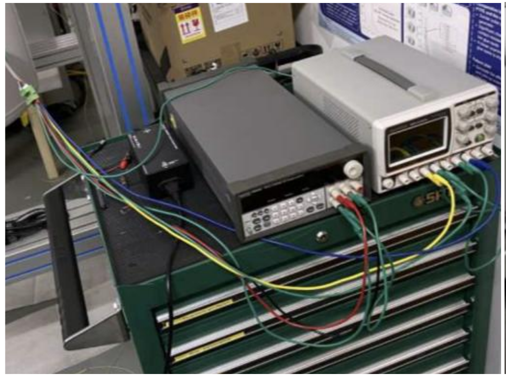
- AlMn/W superconducting film preparation and performance study
- Optimization towards goal of Tc < 20 mK

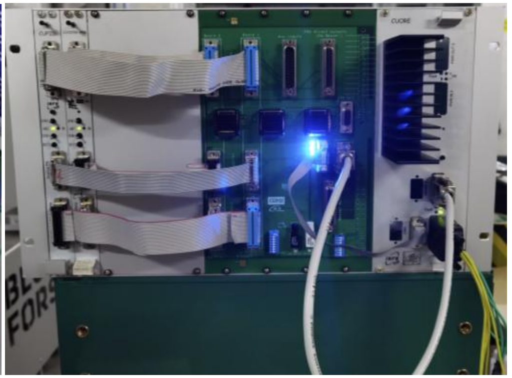
See Yu Wang's talk "The Study of Tungsten Thin Films for Ultra-low Tc Superconducting Transition Edge Sensors for 0νββ Experiment"

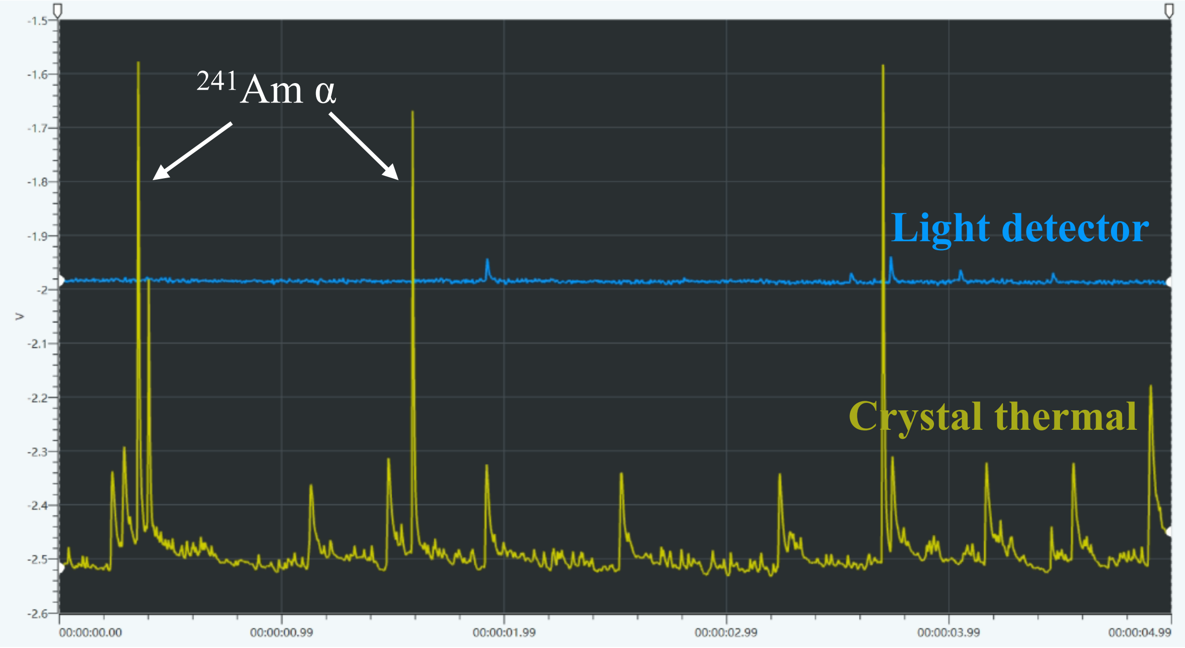
Ground test











^{241}Am α
Light detector
Crystal thermal
V
00:00:00.00
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00:00:01.99
00:00:02.99
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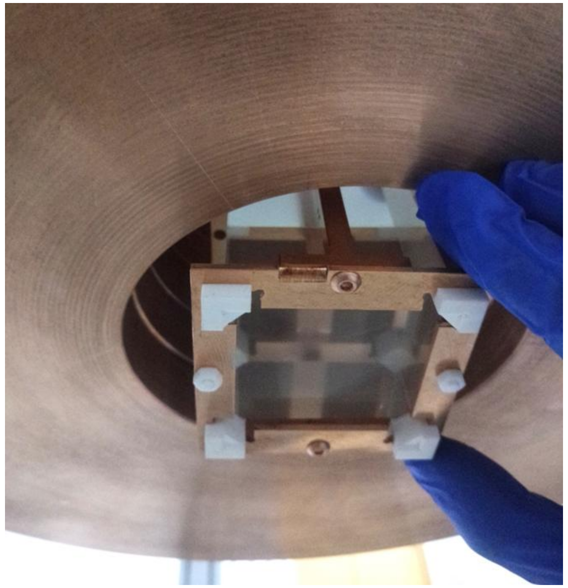
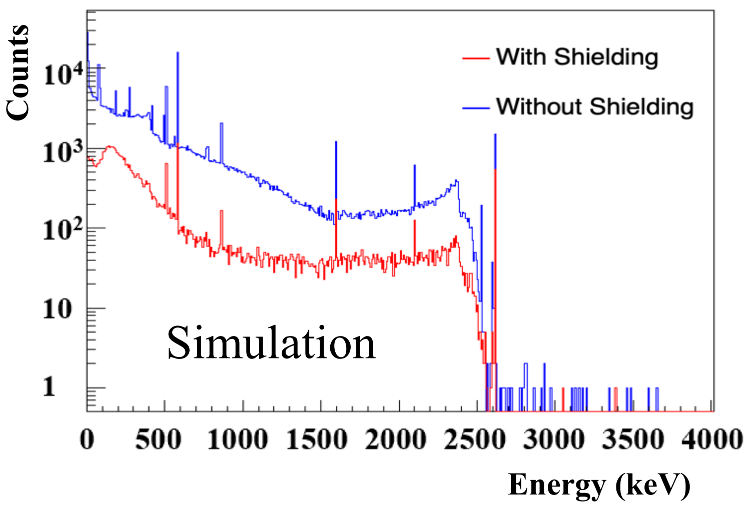
Ground test: inner shielding

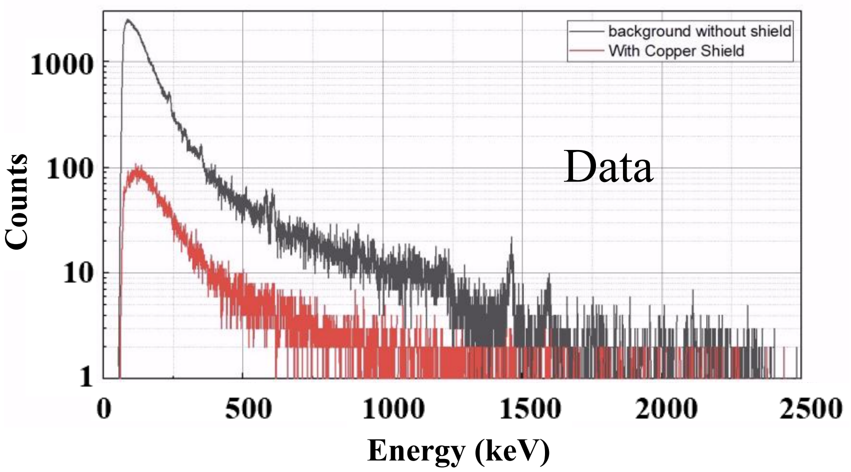
To suppress γ-rays, especially those from close components

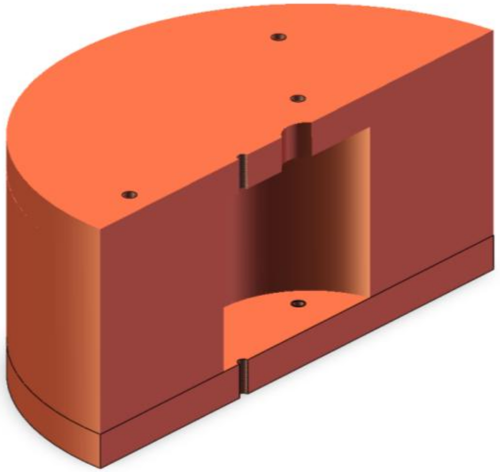
Utilizing the customized cryogenic system: load capacity of **300 kg**



Energy spectrum, 10^8 events simulated

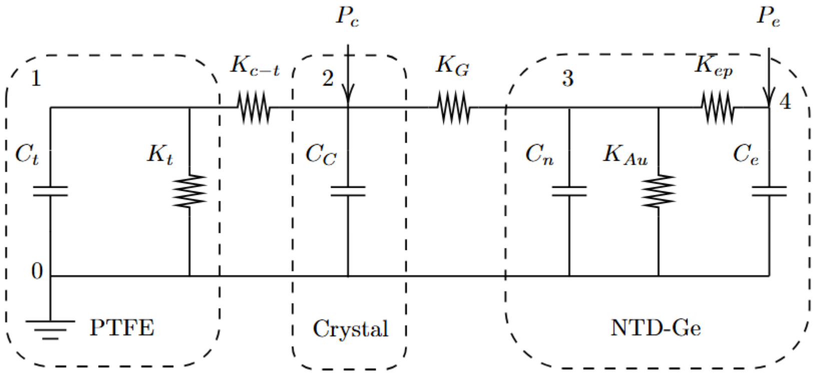




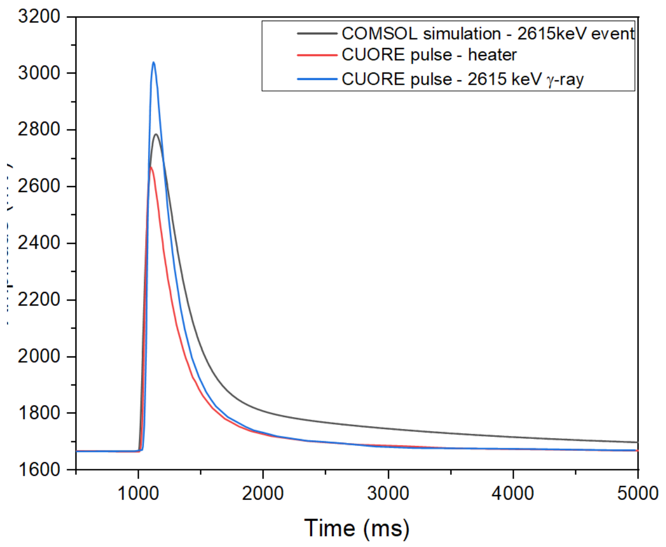


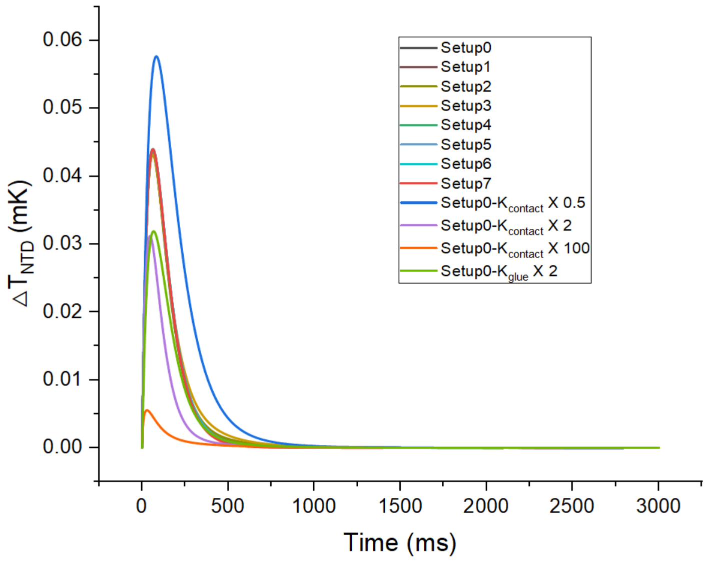
Both simulation and measuring data demonstrate effective environmental gamma shielding

Simulation of pulse shape

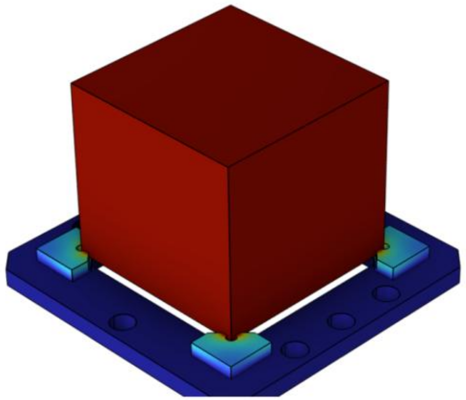


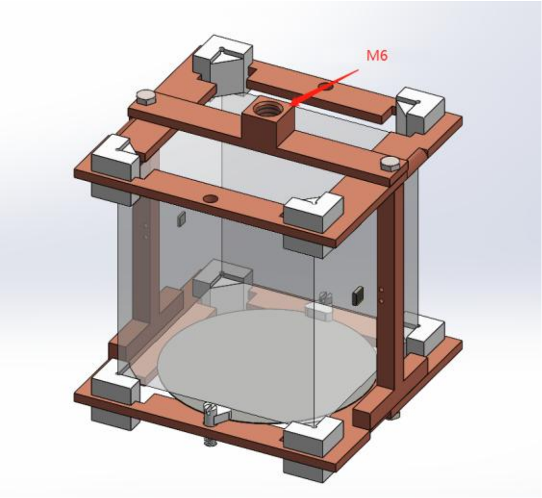
Thermal circuit of a bolometer





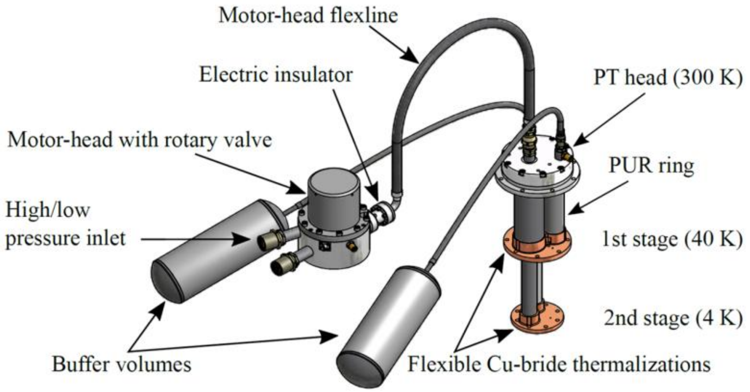
COMSOL modeling
(courtesy of Jiaxuan Cao)





Pulse shape study and optimization:
reduce pile-up, study pulse shape discrimination

Vibration reduction



Pulse-Tube vibration

~25 µm p–p at 1.4 Hz & harmonics.

↓

lower energy resolution.

- ◆ **Design a spring pendulum (~55cm)**
- ➢ Mount on the Still plate
- ➢ Tower Mass: ~12.6 kg
- ➢ **PTFE**-supported on copper frame

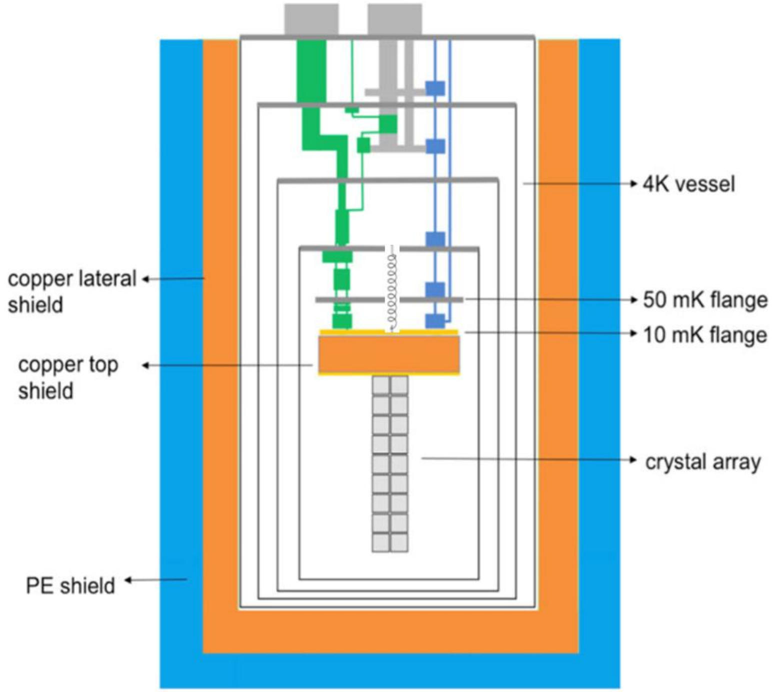
Restrictions

- ➢ **Outer Diameter of the Spring**
  $d\_out \leq 100$ mm
- ➢ **Equilibrium Length**
  $L\_eq \leq 350$ mm
- ➢ **Fatigue Limit**
  - ✓ Shear Stress (τ)
    $\tau\_max \leq 0.45\,\sigma\_b$
  - ✓ Normal Stress (σ)
    $\sigma\_max < 0.7\,\sigma\_b$

- ➢ Optimal Resonance Frequencies

  Vertical ~1.05 Hz

  Radial ~0.66 Hz

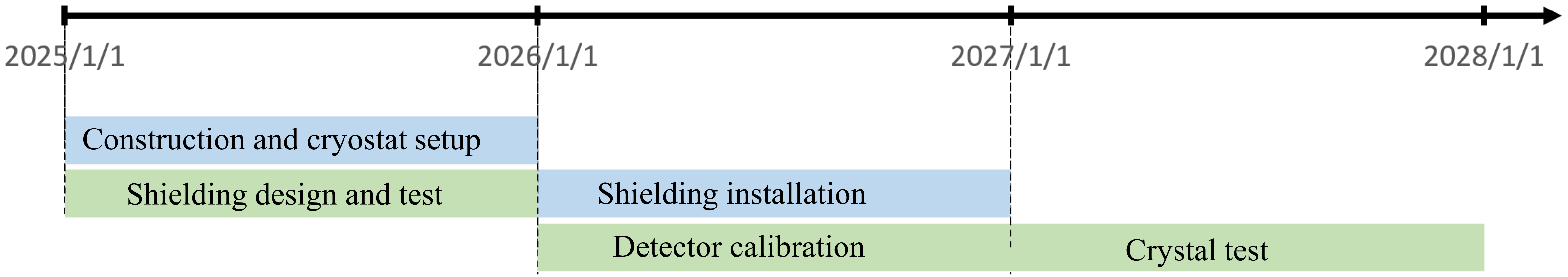


Other plans to reduce vibration:

- Active vibration cancellation instrument will be added

See Huaqi Cao's poster "Development of a spring-mass vibration damping system for a Jinping bolometric demonstrator experiment"

CUPID-CJPL schedule



- CUPID will use 1596 LMO crystals, multiple underground crystal test facilities are neccessory
- Data from CUPID-CJPL bolometer would build a background model, MIGHT make CJPL an option for ton-scale search experiment.

Summary

1. Discovery opportunities are there in the next generation of 0νββ search, and CUPID is on the way to operate.
2. Background level and detector performance are both crucial for CUPID, thus making the quality assessment of the LMO crystals necessary.
3. CUPID CJPL may be able to assist with crystal testing in the future.
4. The operation of CUPID-CJPL could also pave the road to search for 0νββ with cryogenic bolometer in CJPL in future.

Related talks&posters

- The CUPID neutrinoless double-beta decay experiment, I. Nutini, 25/08/25 - parallel 1A
- Toward a background-free ton-scale 0νββ bolometric experiment: status and prospects of BINGO, C. Nones, 25/08/25 - parallel 2A
- Detector response study of cryogenic scintillating Li_2MoO_4 detectors for next generation 0νββ search, B. Schmidt, 26/08/25 - parallel 3A
- Sensitivity of the CUPID experiment to 0νββ decay of ^{100}Mo, P. Loaiza, 26/08/25 - parallel 4A
- Validation of LMO crystals for the CUPID experiment, M. Girola, 27/08/25 - parallel 5
- Opossum - Optimal Particle Identification Of Single Site events with Underground MKIDs detectors, A. Puiu, 27/08/25 - parallel 6B
- Performance validation of the VSTT: An Upgraded CUPID Prototype Tower with Neganov-Luke Enhanced Light Detectors, I. Nutini, 27/08/25 (poster)
- Recent R&D Progress Towards a Bolometric 0νββ Experiment at China Jinping Underground Laboratory, Keyu Shang, Fang Xie, 27/08/25 (poster)
- Development of a spring-mass vibration damping system for a Jinping bolometric demonstrator experiment, Huaqi, Cao, 27/08/25 (poster)
- The Study of Tungsten Thin Films for Ultra-low Tc Superconducting Transition Edge Sensors for 0νββ Experiment, Yu, Wang, 27/08/25