Status of Scintillating Bolometer R&D towards a 0νββ Experiment at CJPL

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On behalf of the **CUPID-China Collaboration**

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OUTLINE

01 / Neutrinoless Double Beta Decay

02 / Cryogenic Bolometer Experiment

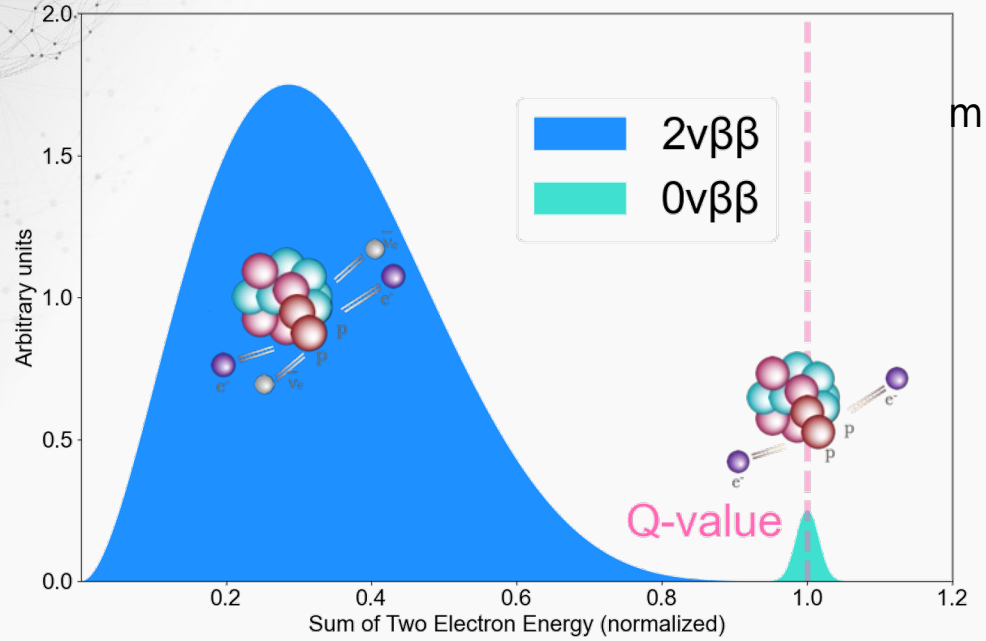
03 / R&D Progress for CUPID-CJPL Experiment

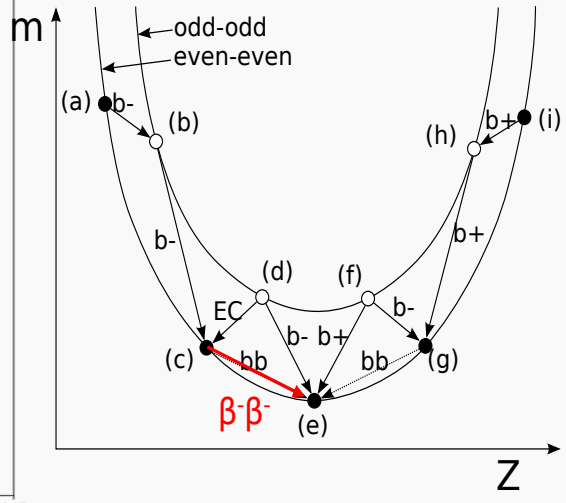
04 / Summary & Outlook

01

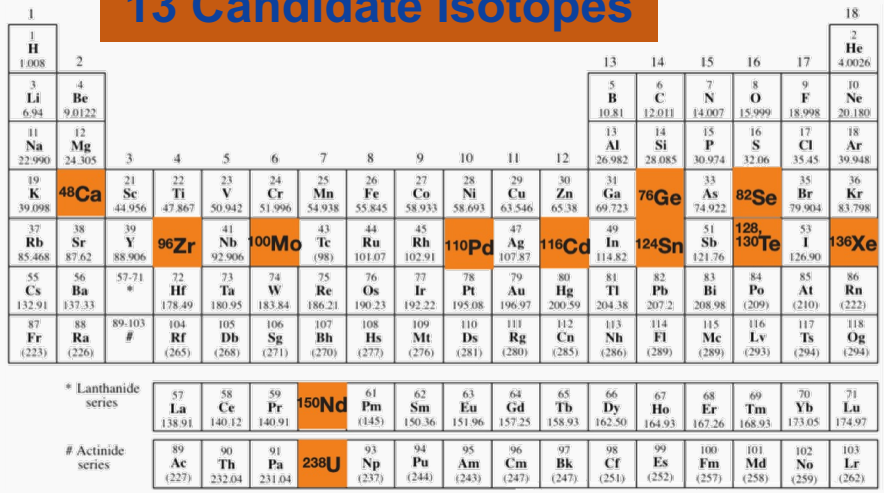
Neutrinoless Double Beta Decay

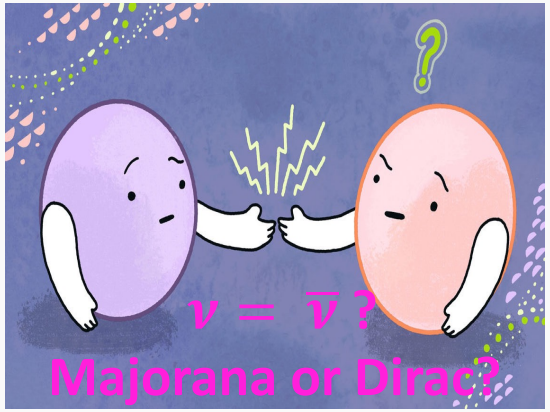
Neutrinoless Double Beta Decay (0νββ)





13 Candidate Isotopes





Forbidden in the Standard Model

Predicted $T_{1/2} > 10^{26}$ years

Δ L = 2, lepton number violation

Only if ν=ν̄: Majorana neutrino

$1/T_{1/2} \propto$ effective mass of neutrino

Experiment Design Consideration

The expected half-life sensitivity of 0ν2β decay experiment:

$$T_{1/2}^{0\nu}\ \text{limit} \propto \left(\frac{\varepsilon a}{A}\right)\sqrt{\frac{Mt}{N_B}}$$

Detection efficiency

ββ isotopic abundance

Mass of the source material

Time of running

Mass number of the source isotope

Number of background events in ROI

Mt is also called the **exposure**

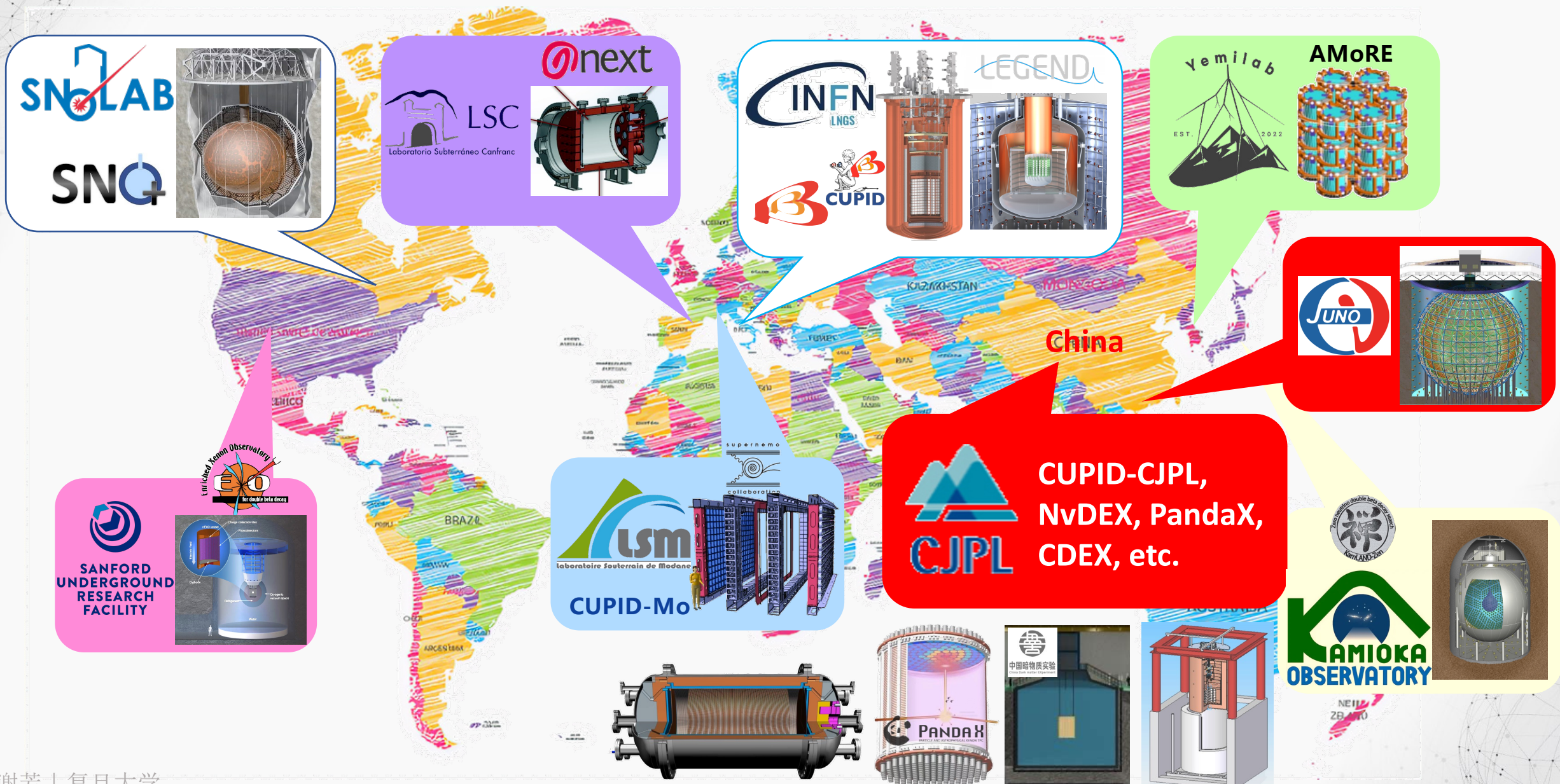
Energy Resolution ↑

Background ↓

For **zero background** experiment, it is **proportional to Mt**:

$$T_{1/2}^{0\nu}\ \text{limit} \propto \frac{\varepsilon a}{A} Mt$$

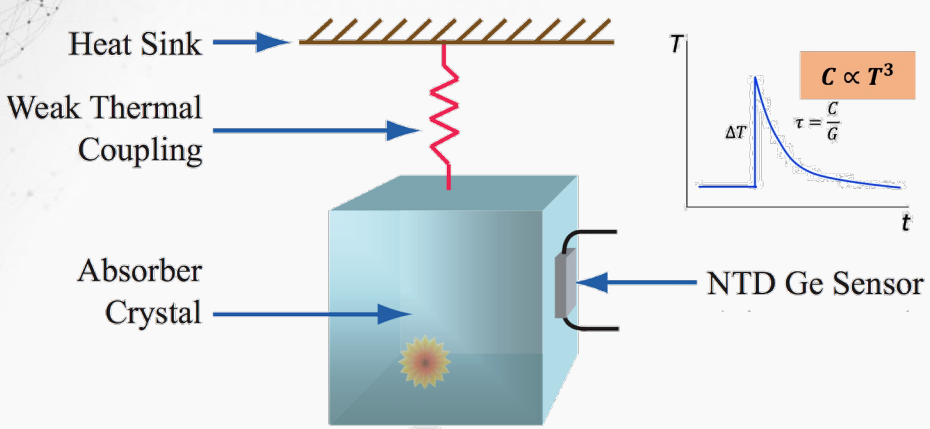
Worldwide 0νββ Experiments in Underground Labs

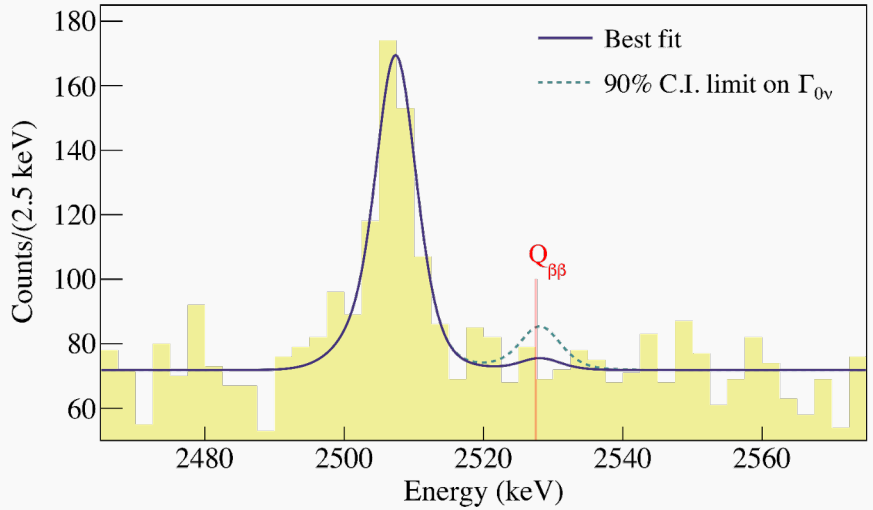


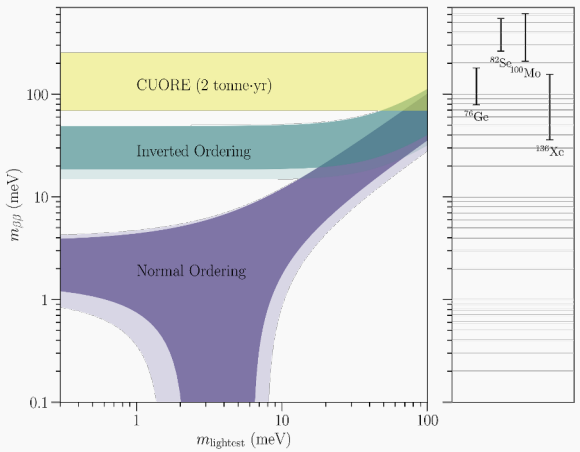
02

Cryogenic Bolometer

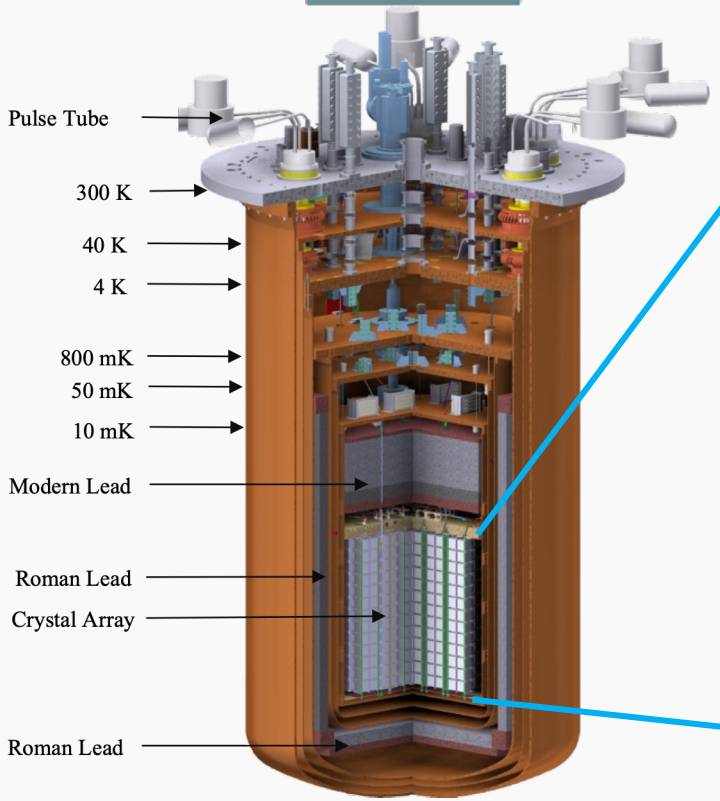
CUORE Experiment

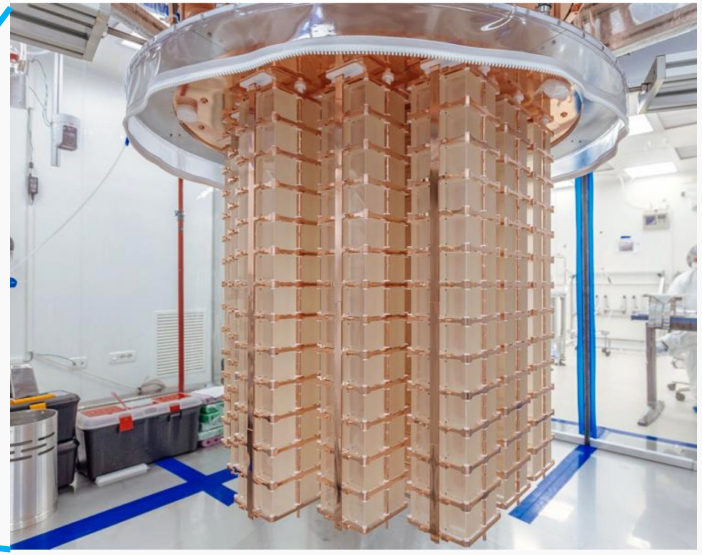






CUORE 2-ton yr result Science10.1126/science.adp6474 (2025)





Best limit on ^{130}Te

TeO_2 ~ 206 kg of ^{130}Te

$Q_{\beta\beta}$: 2727 keV

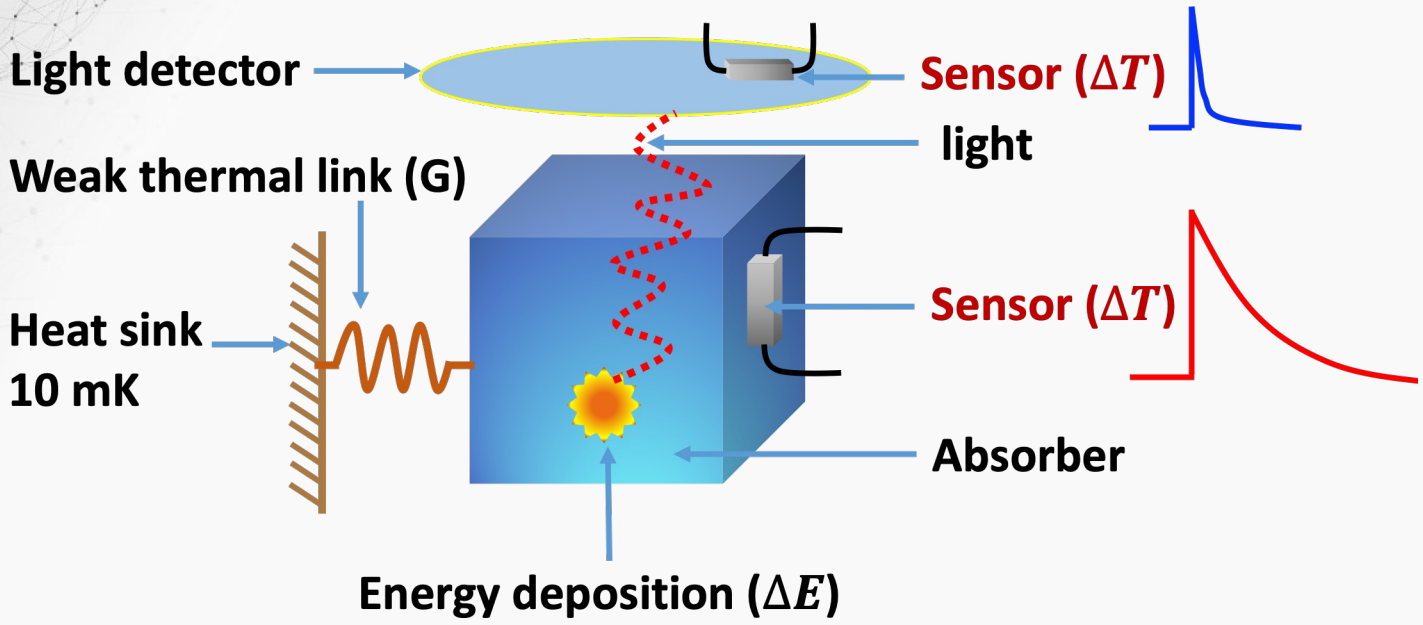
$T_{1/2} > 3.5 \times 10^{25}$ yr

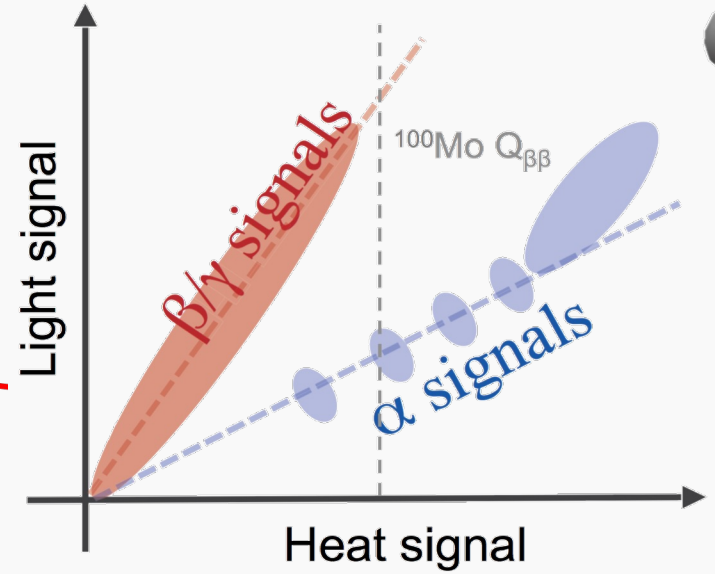
$m_{\beta\beta} < 70 - 250$ meV

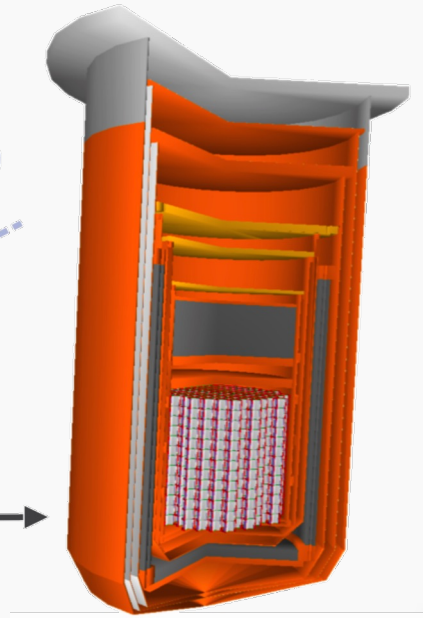
BI: 3×10^{-3} ckky in ROI

Energy resolution: ~ 0.3% FWHM @2.6 MeV

CUPID (CUORE Upgrade with Particle IDentification)







Scintillating bolometer:

- ✓ Source = Detector: High Eff_{det}
- ✓ Flexible isotope choices
- ✓ Energy deposition -> Phonons & Light
- ✓ Particle Identification (PID): reduce background
- ✓ NTD or TES sensor

CUPID

Aim to do:

Li_2MoO_4 ~ 240 kg ^{100}Mo

$Q_{\beta\beta}$: 3034 keV

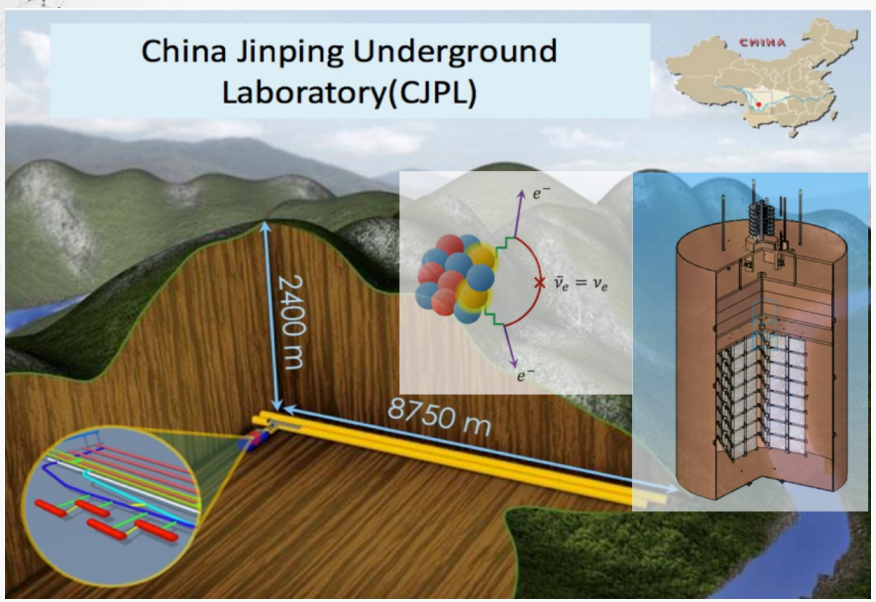
$T_{1/2} > 1 \times 10^{27}$ yr

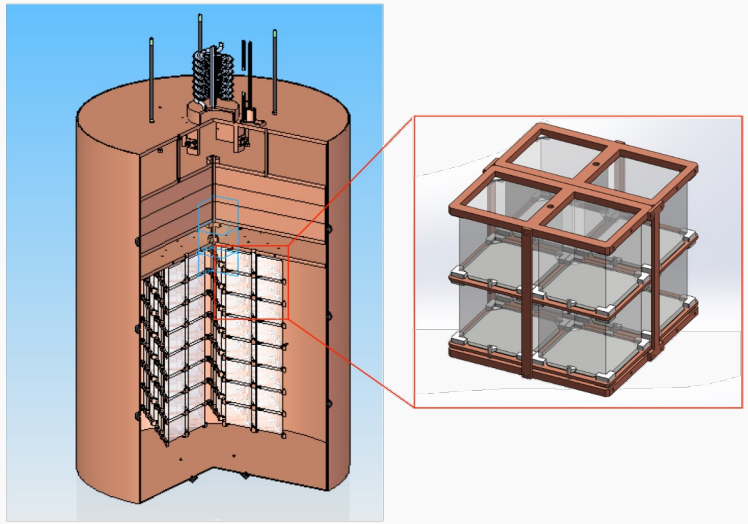
$m_{\beta\beta} < 12 - 20$ meV

BI: $< 10^{-4}$ ckky in ROI

Heat – Light dual readout

Bolometric 0νββ Experiment at CJPL





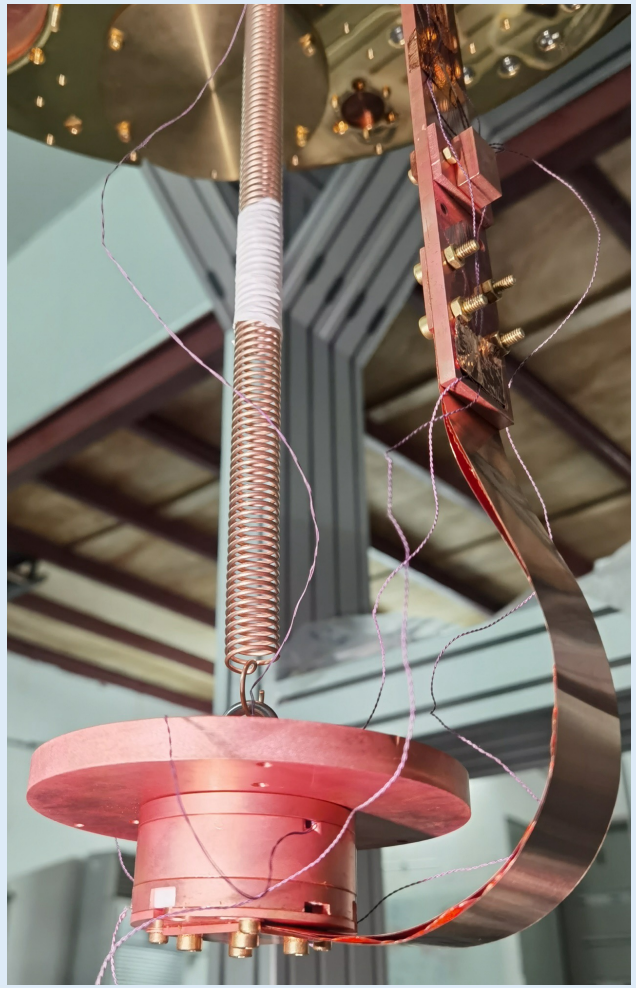
Isotope	i.a.(%)	Q [MeV]
^{48}Ca	0.187	4.263
^{76}Ge	7.8	2.039
^{82}Se	9.2	2.998
^{96}Zr	2.8	3.348
^{100}Mo	9.6	3.035
^{116}Cd	7.6	2.813
^{130}Te	34.1	2.527
^{136}Xe	8.9	2.459
^{150}Nd	5.6	3.371

- Bolometer for 0νββ search
- ^{100}Mo based bolometer for 0νββ search
- Scintillating LMO crystals ➔ light-heat dual readout (PID)
- Based in China Jinping underground Lab (CJPL) ➔ the deepest lab

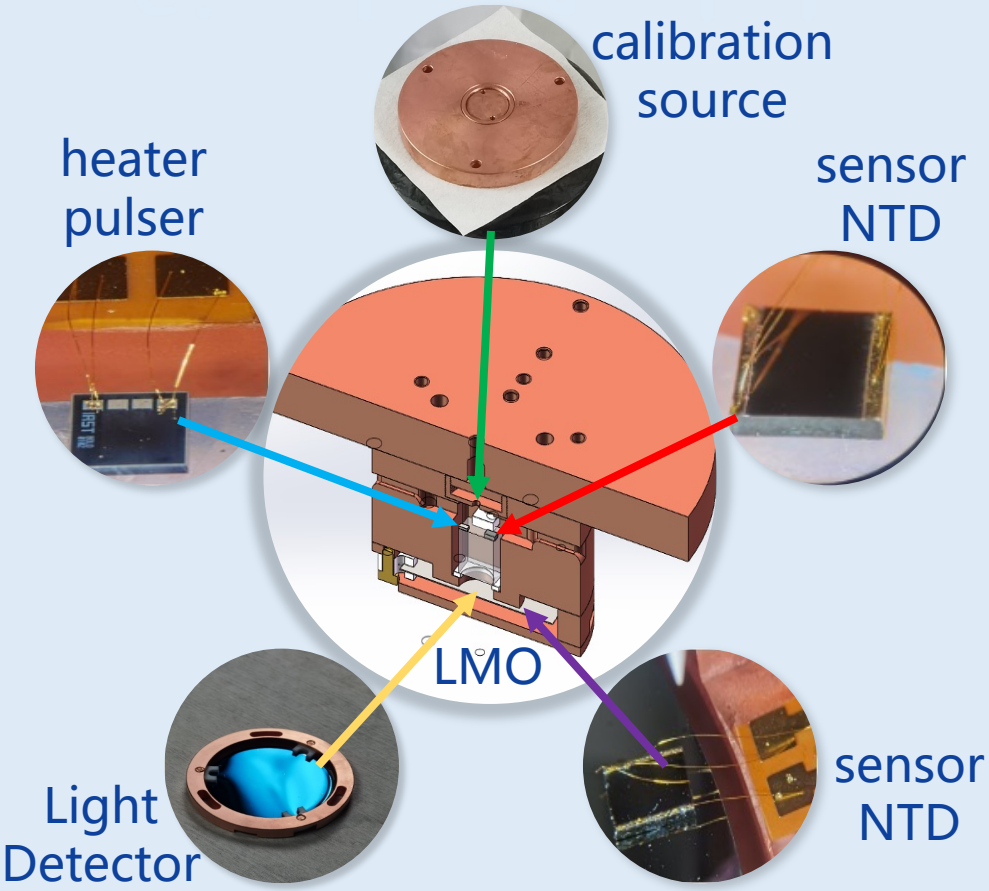
03

R&D Progress

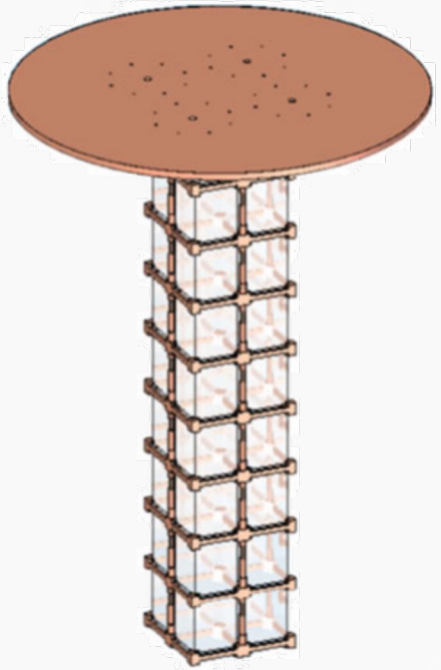
Detector Module Design

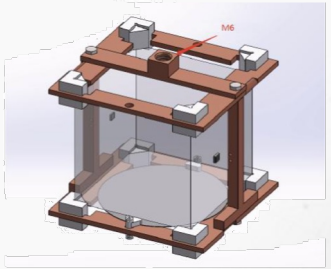


Single Module



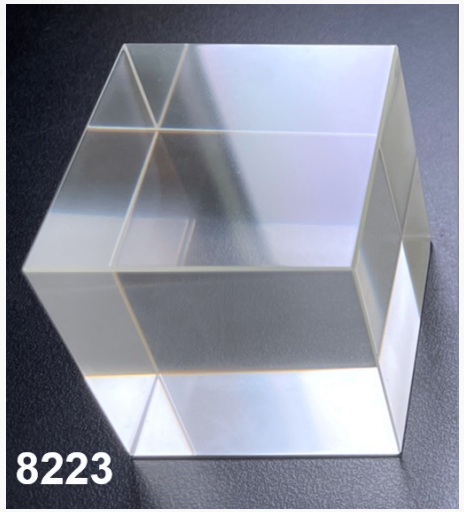
Array



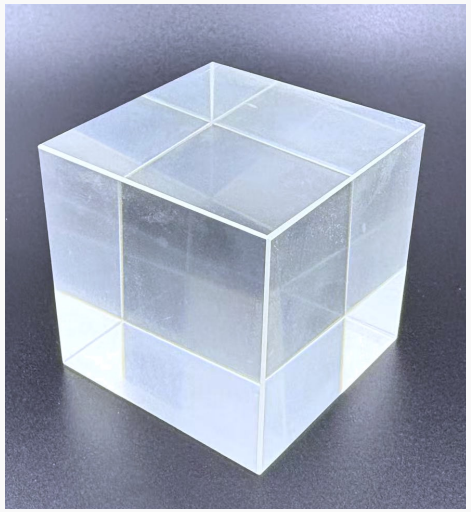


$Li_2{}^{100}MoO_4$ (LMO) Crystal Production

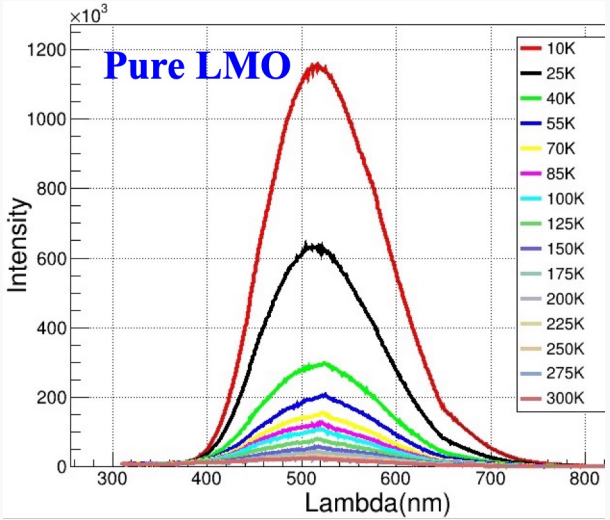
Natural LMO



Enriched $L^{100}MO$

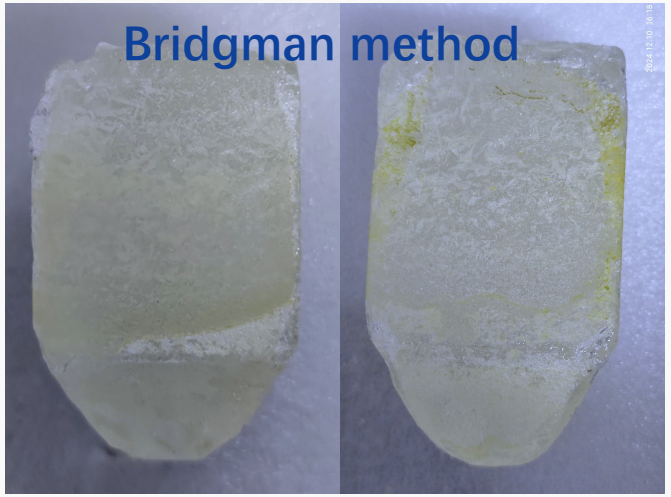


Fluorescence Emission Spectrum



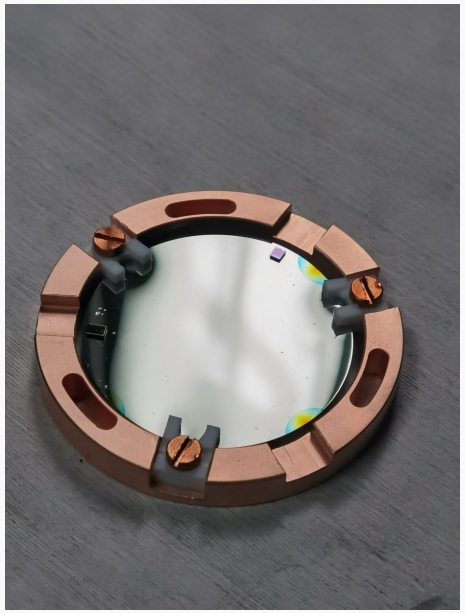
Enriched ^{100}Mo

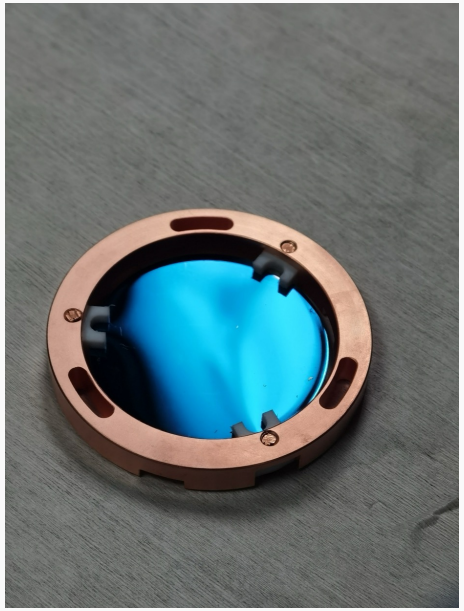
$L^{100}MO$ to be cut and polished

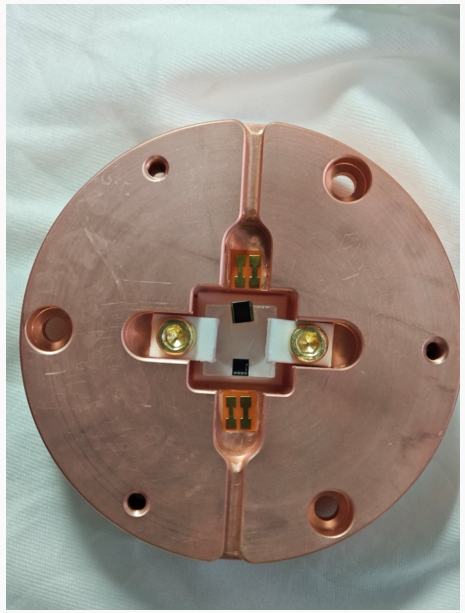


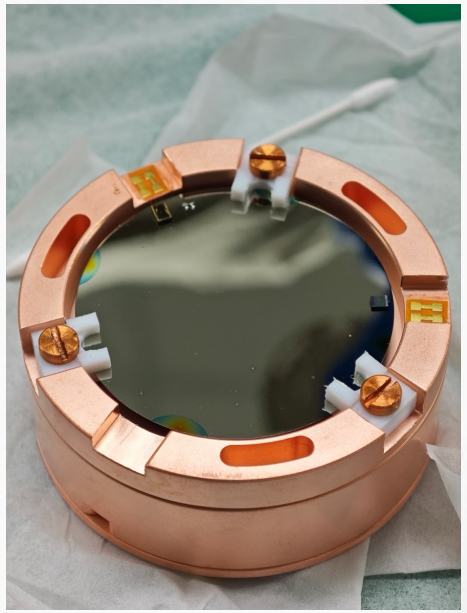
Light Detector

- High purity Ge thin wafer used for scintillation light collection
- Convert energy into thermal signal
- Coating is applied to enhance transmission
- Fabrication procedure well established









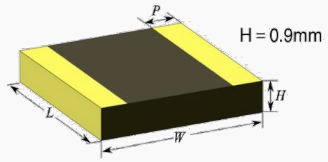
The Sensors

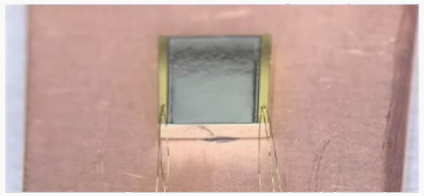
Neutron Transmutation Doped Germanium (NTD-Ge)

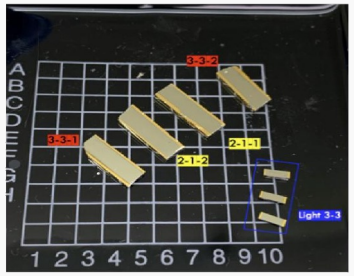
- Principle: variable range hopping mechanism
- Resistance follows Mott' s law:

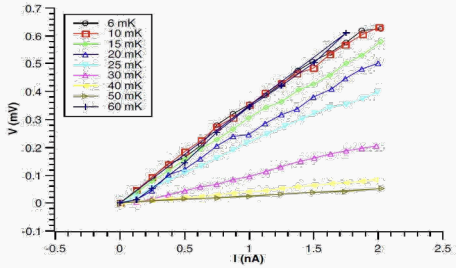
$$R = R_0 \, exp\left(\frac{T_0}{T}\right)^{\alpha}$$

- Advantages: high sensitivity, wide dynamic range, suitable for mass production, relatively simple readout electronics
- Full production chain established



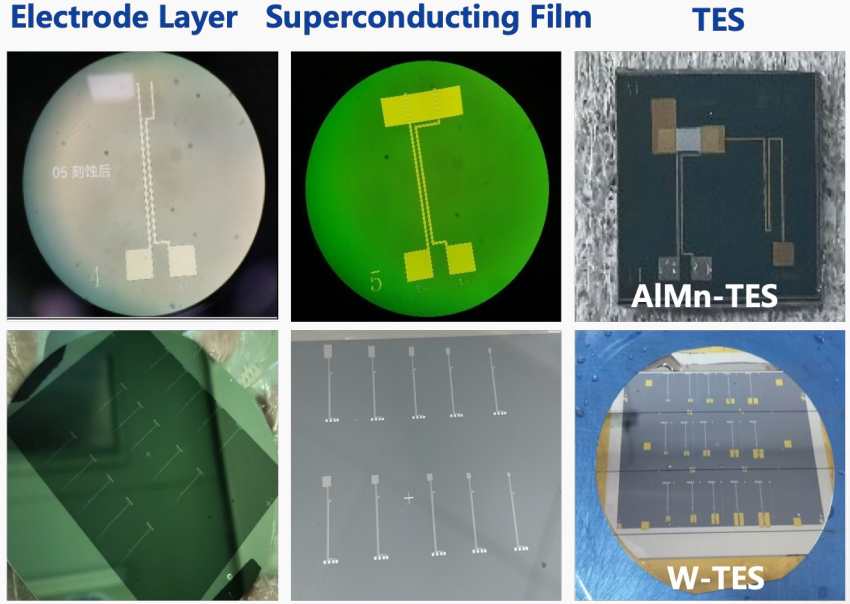






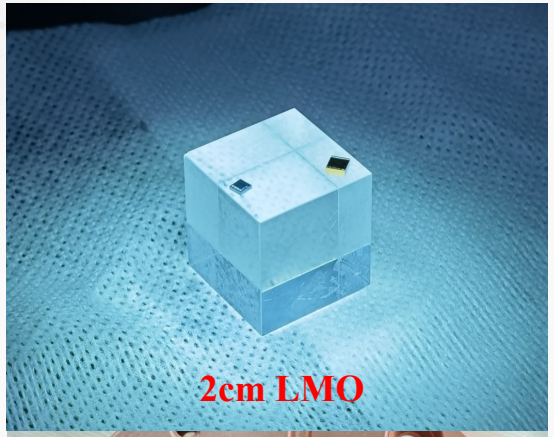
Transition Edge Sensor (TES)

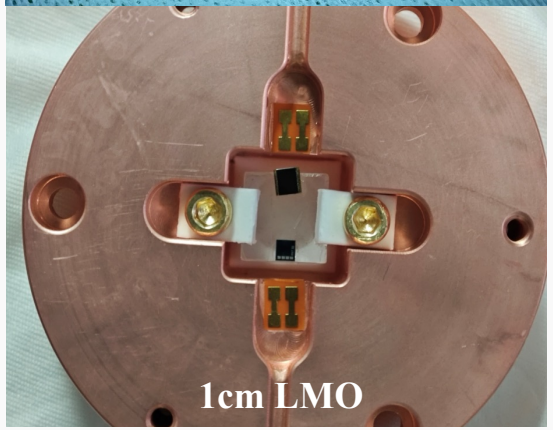
- Principle: sharp change in resistance of a superconducting thin film near **critical transition temperature (T_C)**
- Advantages: very high sensitivity, tunable T_C, scalable fabrication, fast readout
- Full production chain established, T_C controlled down to ~20mK.



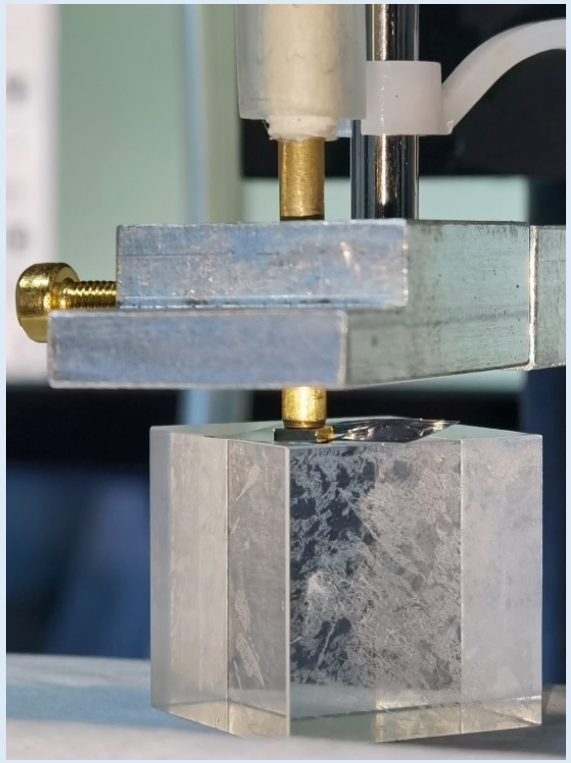
Ground Lab Test - Bolometer Module Assembling

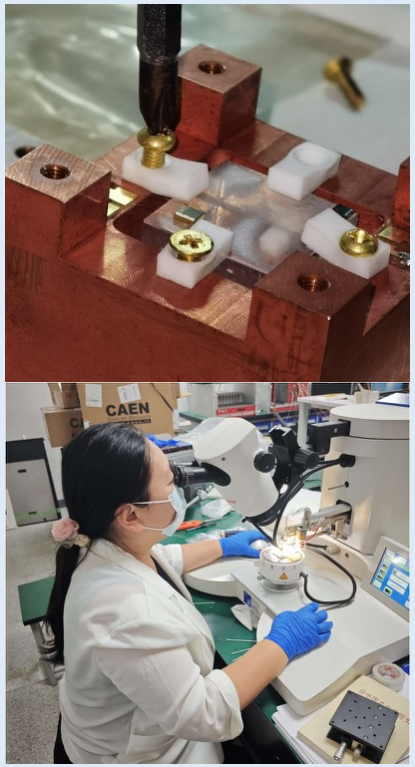
- Assembly process well established
- Small LMO crystal (2x2x2 / 1x1x1 cm^3) in ground lab test to reduce BKG pile-up

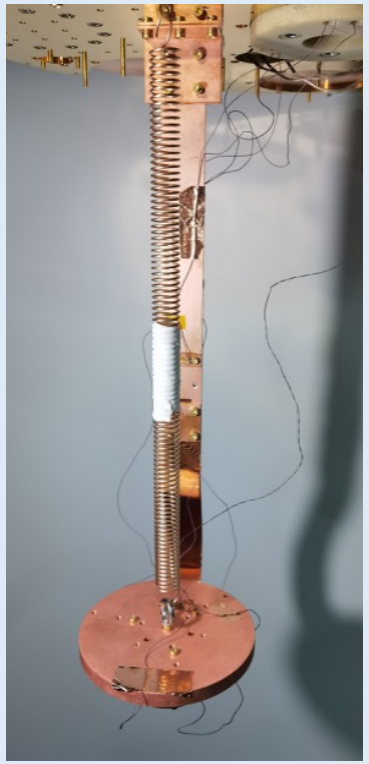




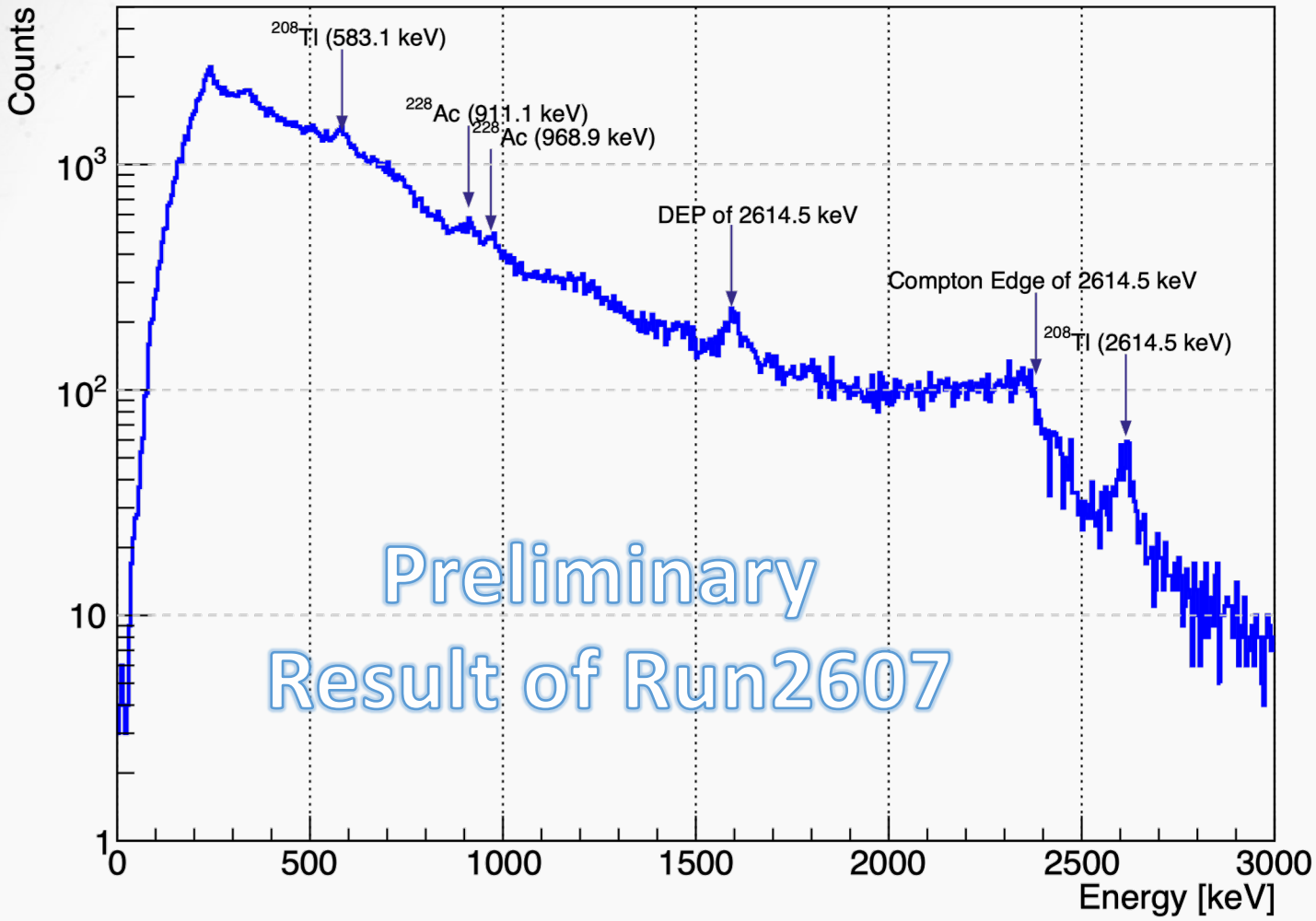
Cleaning & Drying → Gluing → Assembly & Bonding → Installation

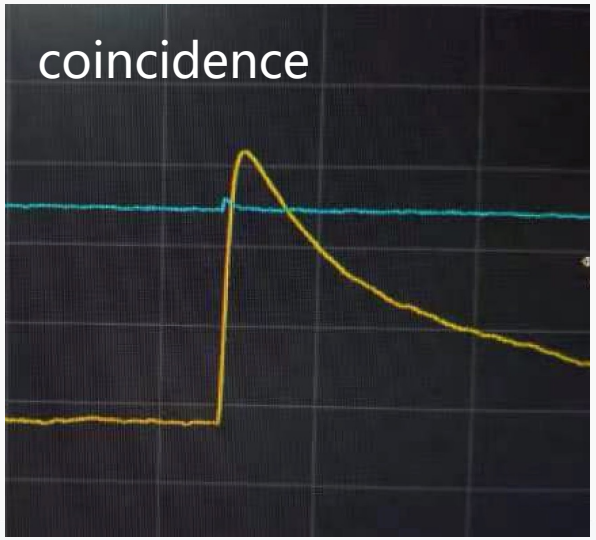


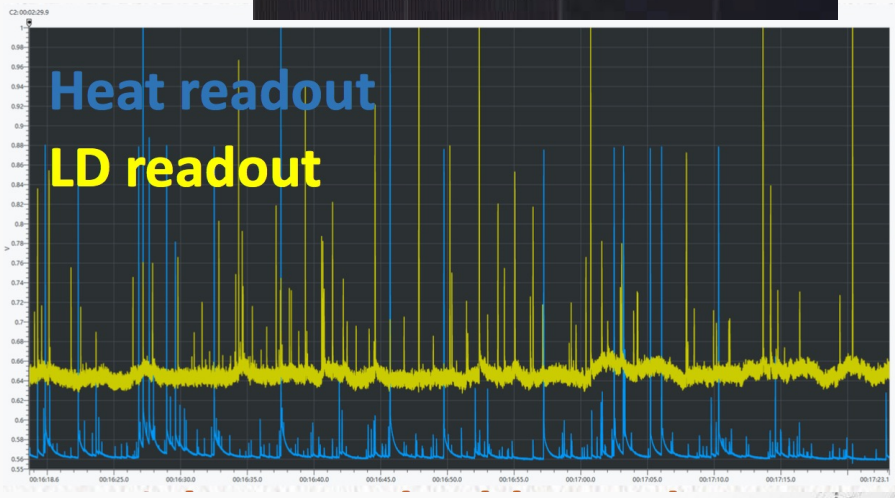




Ground Lab Test

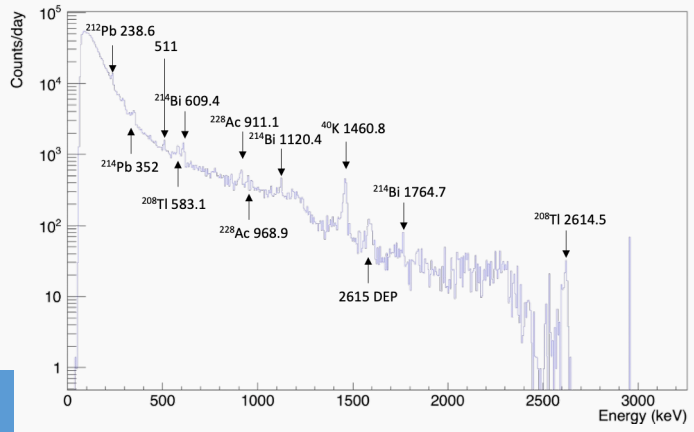


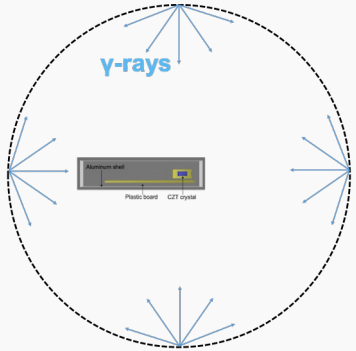




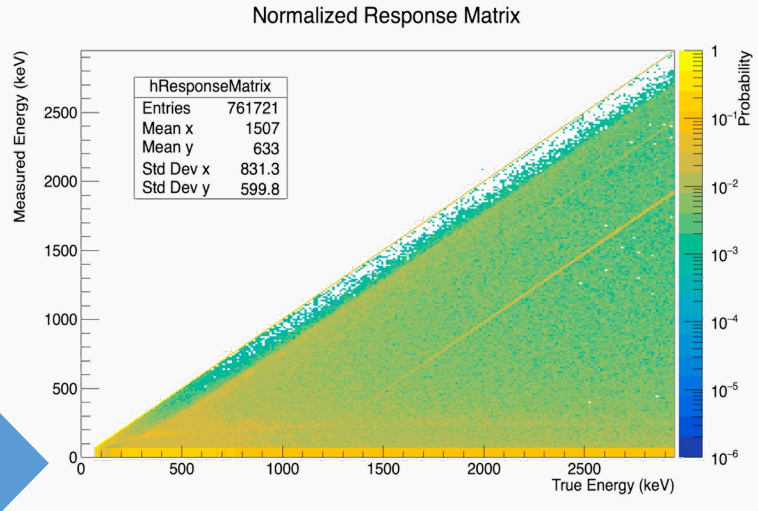
Towards the Underground - Background & Vibration Tests

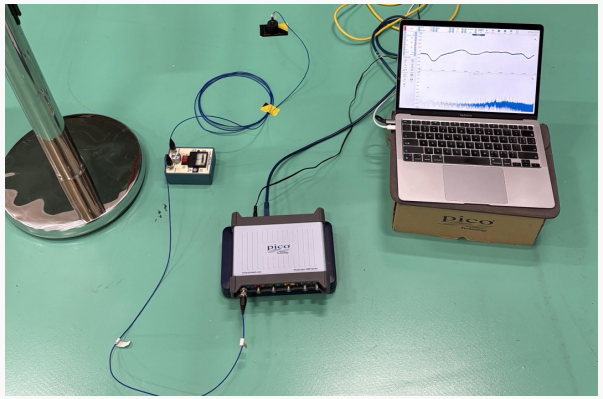
on-site BKG measurement



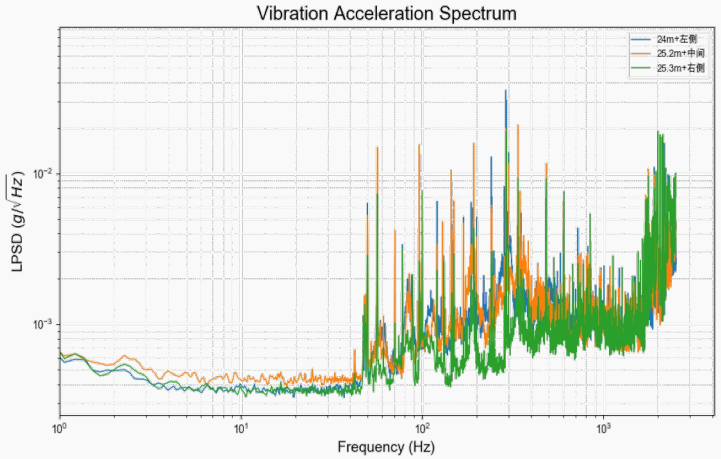


unfolding gamma flux

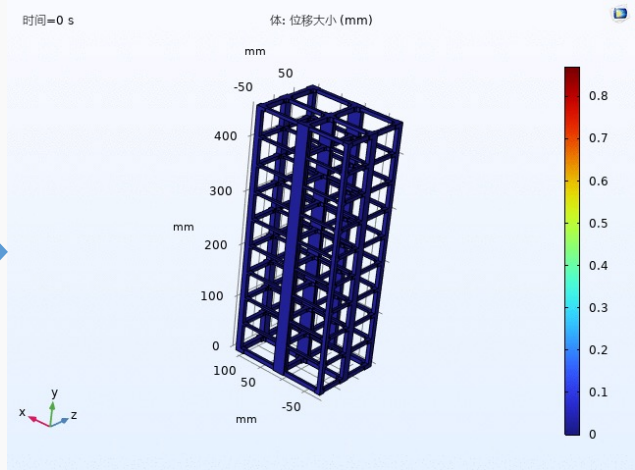




on-site vibration test



simulating effects



Simulation Framework

Simulation Tool

Configurator

Generator Factory

Calibration Sources
Background
Double Beta Decay

Geomatry Manager

Facilities
Detectors
SD

User Actions

Run Event
Track Step

Physics List

EMPhysics
RadioactiveDecay ...

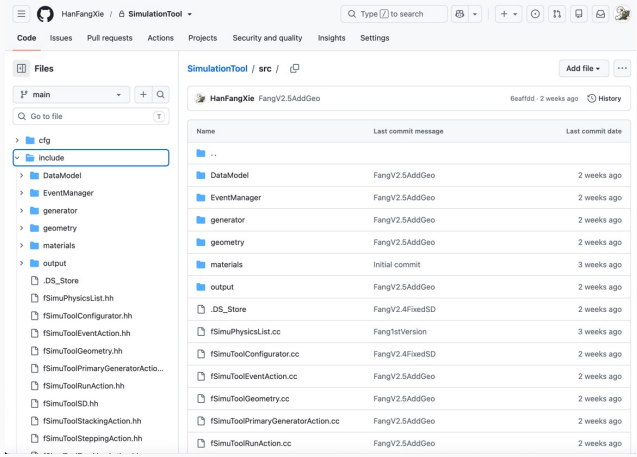
ROOT File Writer

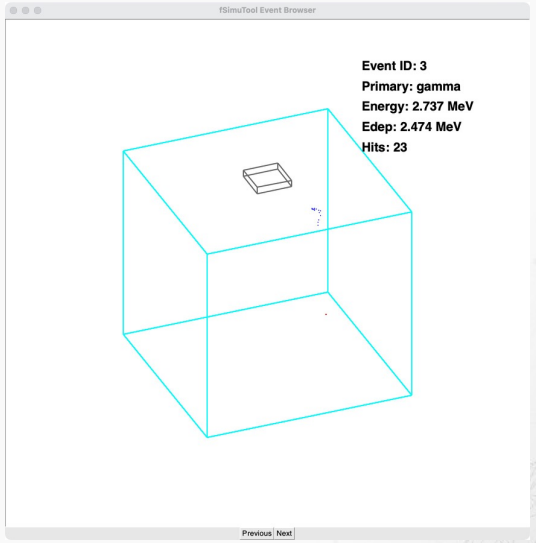
ROOT TTree Output

Simulation Viewer

- ROOT File Reader
- Geometry Re-Use
- Event Display
- Interactive Control

Further Analysis





Config-Driven | **Modular Design** | **Reproducible Analysis** | **Step Level Visualisation**

04

Summery & Outlook

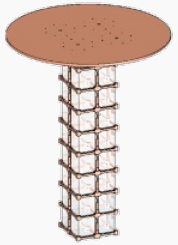
Roadmap

Module test

6-12 natural crystals
(2023-2026)

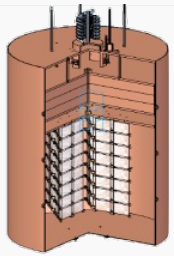
Module test

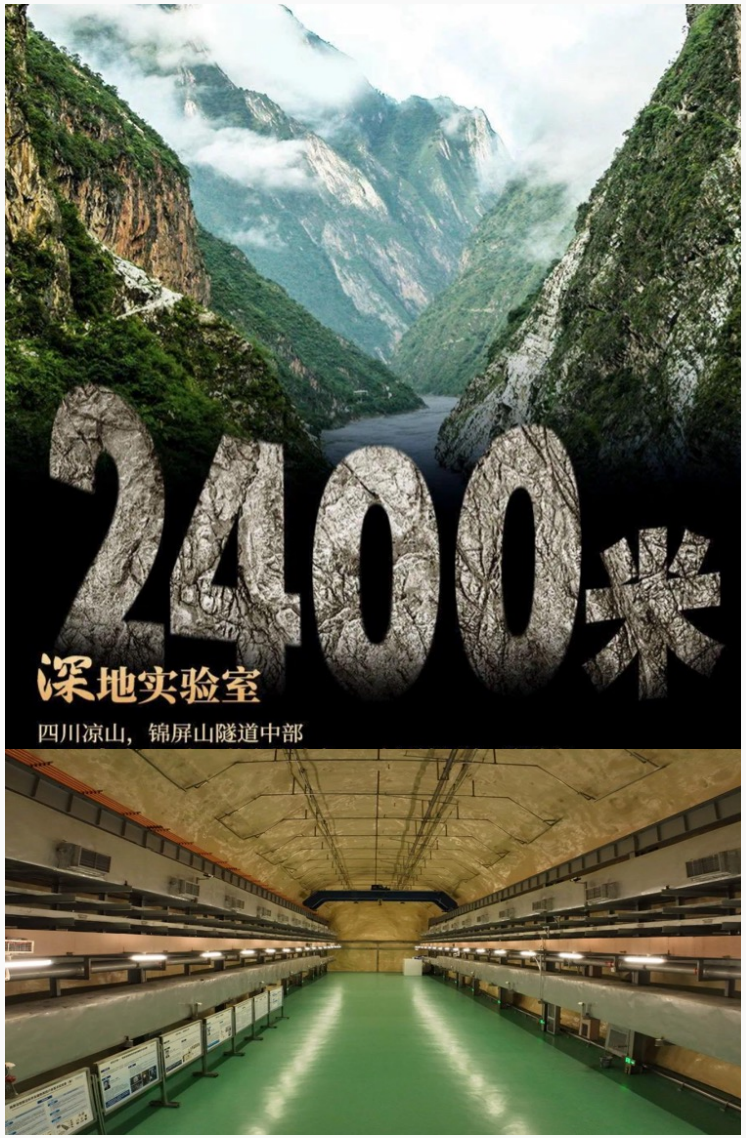
10 kg enriched
crystals
(2026-2028)



CUPID-CJPL 200

200 kg enriched
crystals
(2028+)





Summary

- ✓ A ^{100}Mo-based scintillating bolometer based at CJPL => prospective for high sensitivity 0νββ search
- ✓ Key technologies are demonstrated => essential for the development of 100 kg / ton-scale experiment
- ✓ Progresses have been made in crystal growth, low noise read-out electronics and bolometer module test
- ✓ R&D in progress:

  ^{100}Mo-enriched crystal testing

  light channel optimisation

THANKS

CUPID-China Collaboration

Backups

CUPID collaboration

International Collaboration
CUPID – Italy
CUPID – US
CUPID – France
CUPID – China
~ 30 institutes, >150 collaborators

CUPID-China

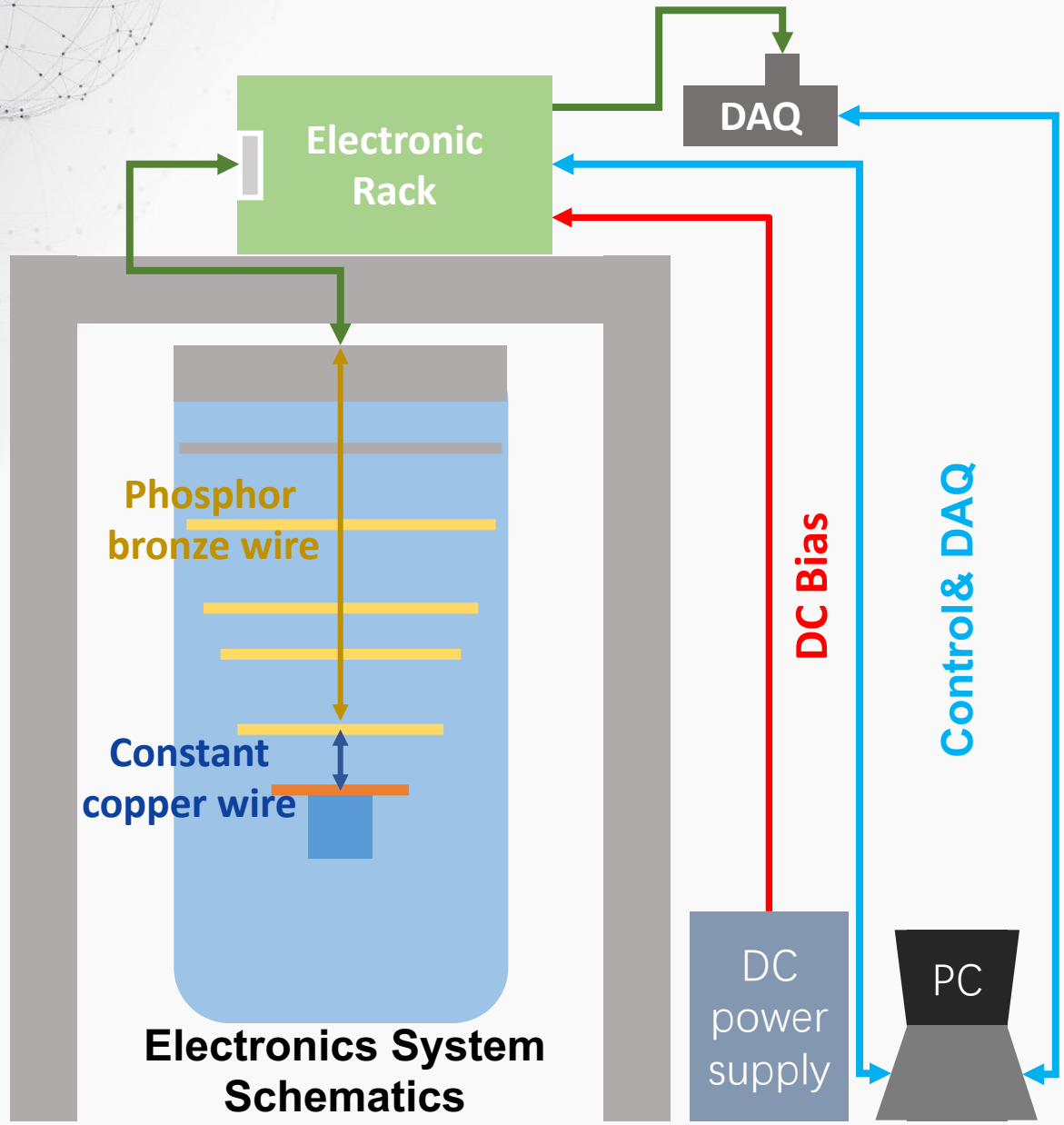
- Beijing Normal University*
- Fudan University*
- Ningbo University
- Shanghai Jiao Tong University*
- Shanghai Institute of Applied Physics
- Shanghai Institute of Ceramics
- Tsinghua University
- University of Science and Technology of China*

*(*Officially in the international CUPID collaboration)*

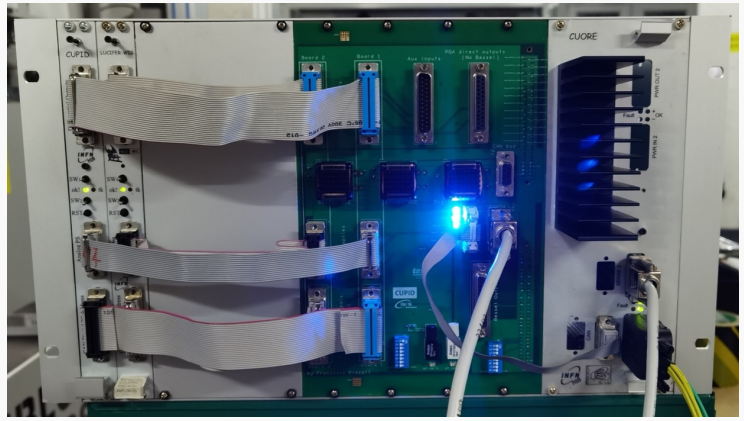
~ 8 institutes, > 40 collaborators

CUPID-China is actively collaborating with the international collaboration

Electronics



Electronics System Schematics



Electronic rack

NI 9239 DAQ

We thank MiB group from Italy for the electronics rack

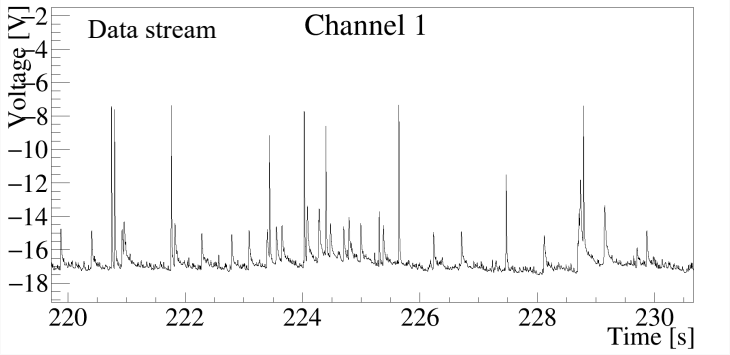
- ✓ Constant copper wire: poor thermal conductivity resistance almost unaffected by temperature
- ✓ Heat sinks on each plate: prevent heat leakage

Data Analysis Tool

OCTOPUS Data Process & Analysis Framework

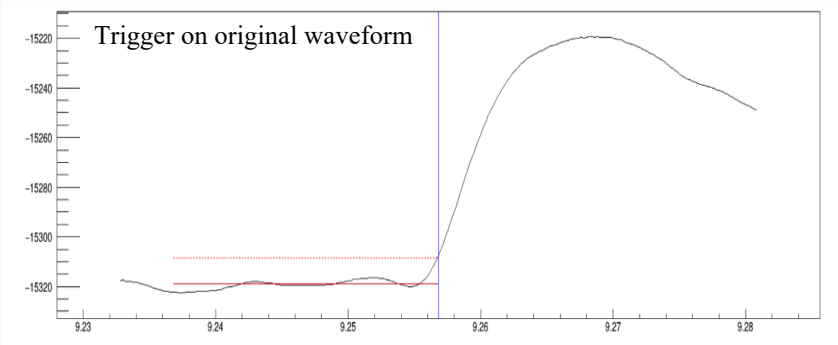
Plot Data Stream

- Plots data stream
- Check waveforms and decide trigger parameters



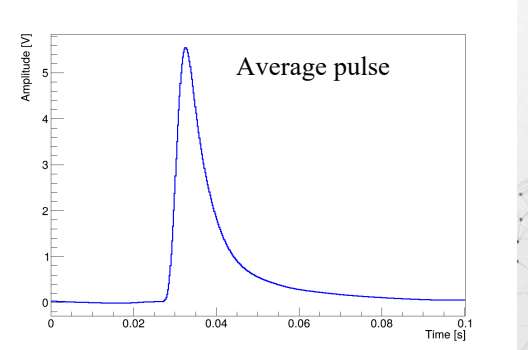
Trigger

- Threshold trigger on original or differentiated waveform
- Writes triggered flags into ROOT file



Octopus

- Read raw data and trigger
- Filter data
- Reconstruct event-based quantities and write data into .root

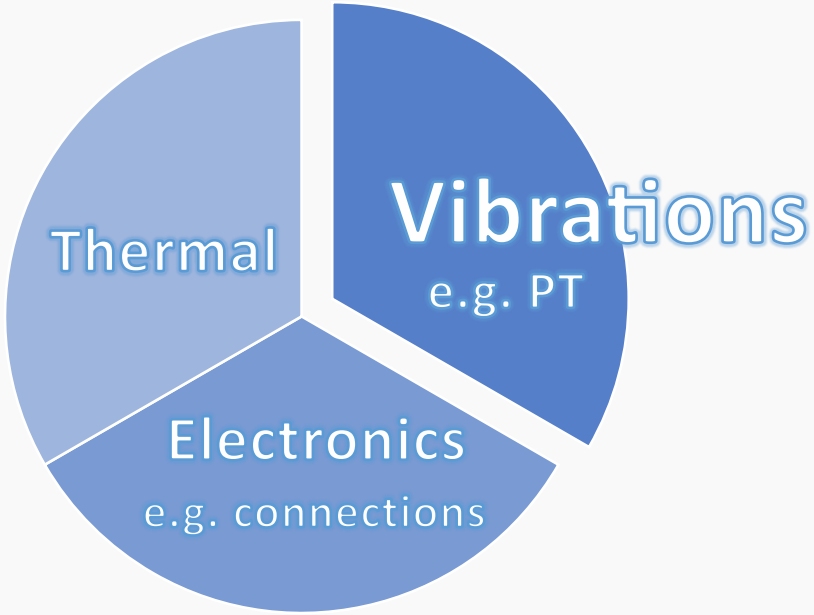


We thank Prof. Giovanni Benato for developing the OCTOPUS framework

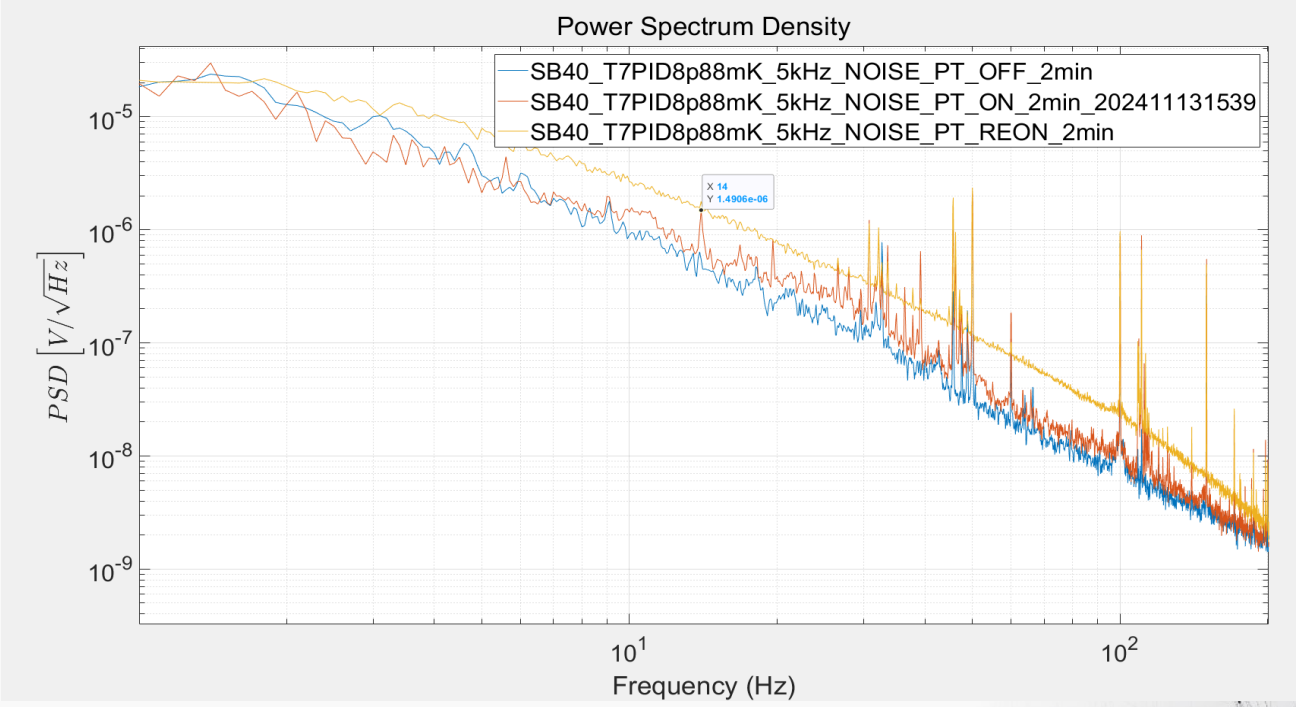
Investigation on sources of noise sources

Motivation to suppress noises

- Energy resolution
- Lower energy threshold
- Baseline resolution
- Maximise s/n



This study uses bolometer data collected at cryogenic temperatures during operation.



About myself

学习与工作经历

2015.9 – 2021.3	英国伦敦大学学院	Ph.D.	双贝塔衰变、低本底
2017.11 - 2017.12	法国马赛粒子物理研究中心	Visiting Scholar	低本底
2020.1 - 2022.12	英国苏塞克斯大学	Research Fellow	中微子探测、低本底
2023.6 至今	复旦大学	博士后	双贝塔衰变、低温量热器

supernemo collaboration

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE CPPM

UCL

DUNE

UNIVERSITY OF SUSSEX

CUPID

FUDAN UNIVERSITY 1905

2024入选优秀博士后“海外引才”计划，上海市白玉兰人才计划浦江项目，

主持国自然青年基金C，博士后面上项目