Jinping bolometric experiment for double beta decay study

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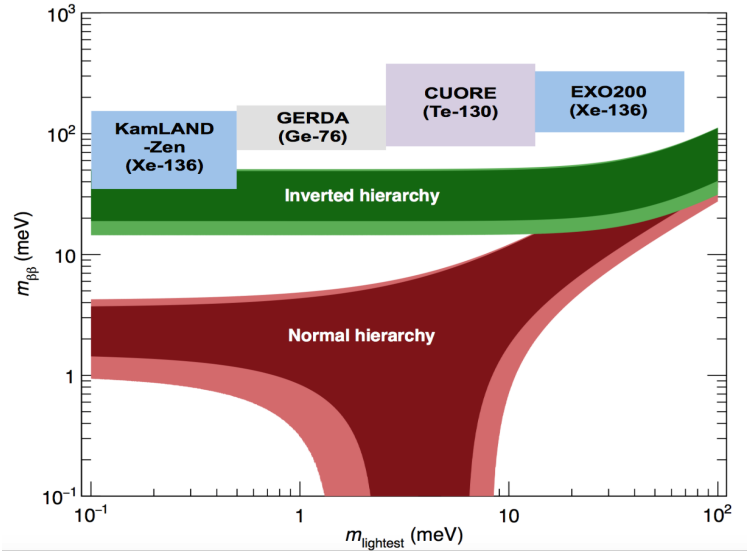
(on behalf of the CUPID-China collaboration)

Outline

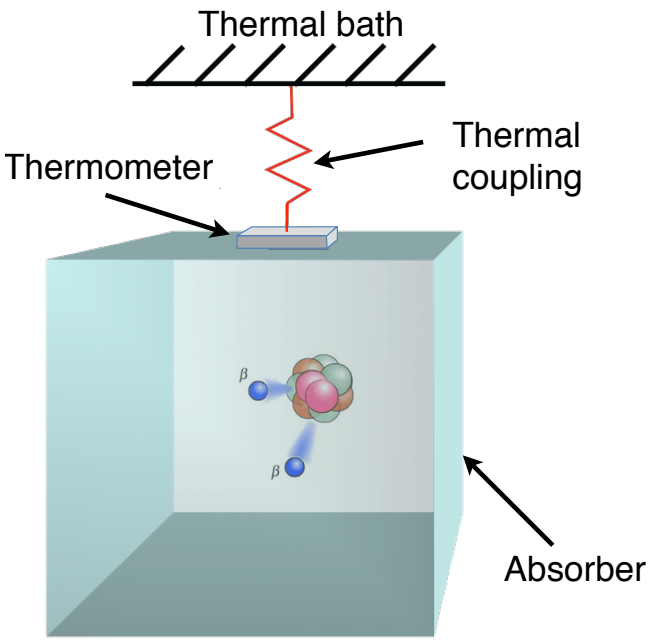
- ❑ Cryogenic bolometer
- ❑ Jinping bolometric experiment
- ❑ Recent R&D progresses
- ❑ Challenges
- ❑ Roadmap
- ❑ Summary

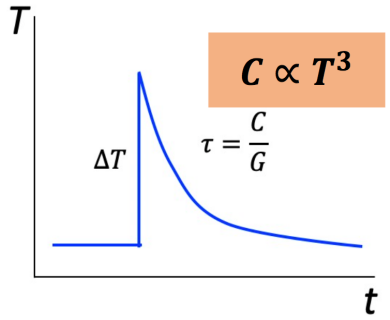
International efforts for 0νββ search

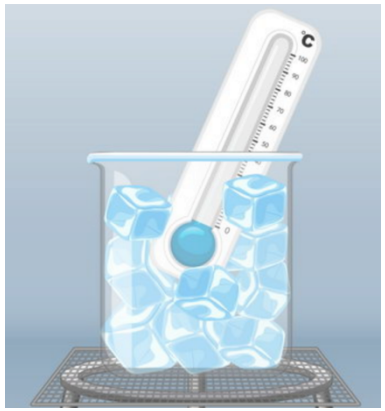
- Multiple technologies have been applied for 0νββ search
- Current experiments based on different technologies and isotopes have achieved comparable measurement sensitivity

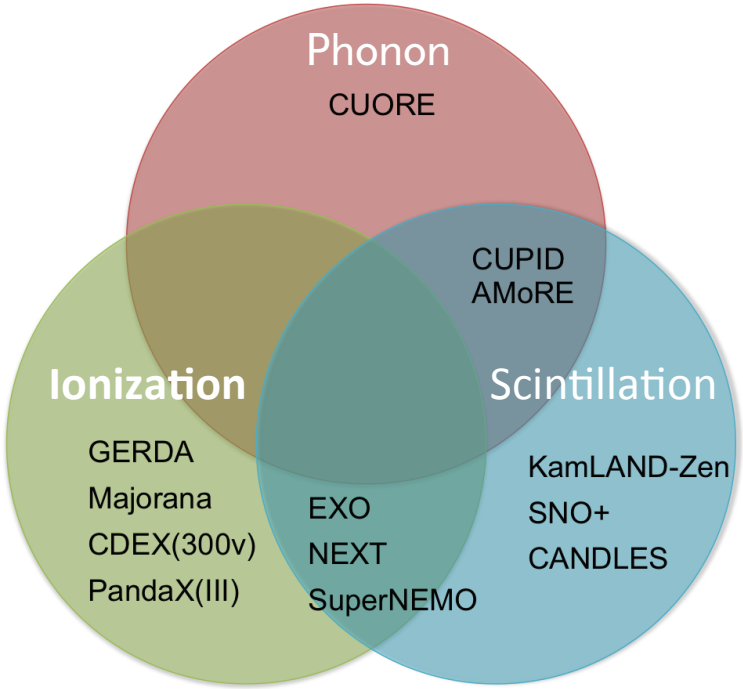


Cryogenic bolometer



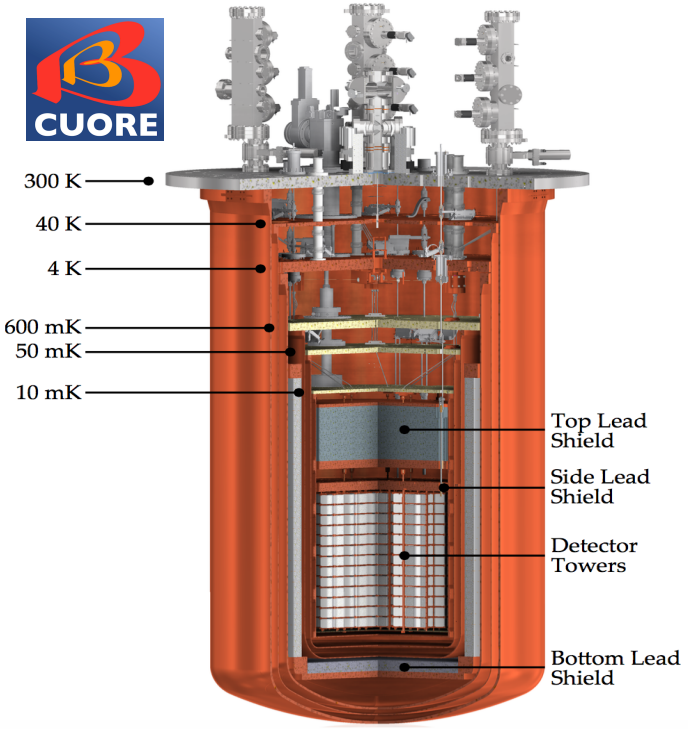


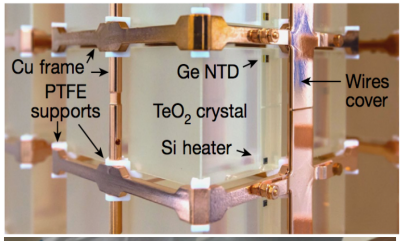


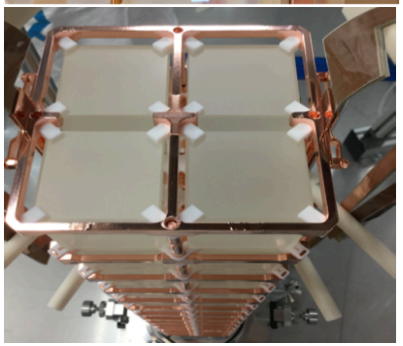


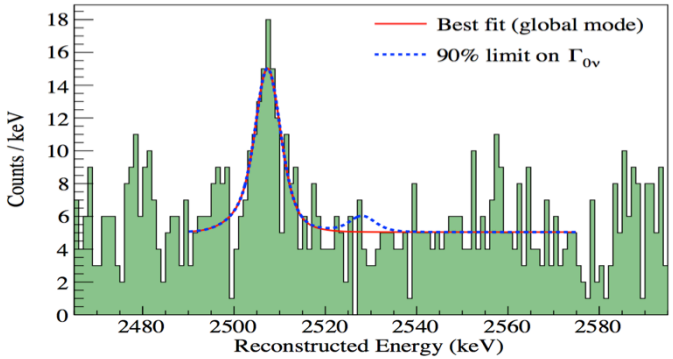
- ➢ Crystal micro-calorimeter operating at extremely low T (~10 mK)
- ➢ High sensitivity E_{dep} measurement (phonon)
- ✓ High efficiency: source = absorber
- ✓ High energy resolution: ~0.25% (FWHM)

CUORE









$T_{1/2}^{0\nu} > 2.2 \times 10^{25}$ yr (90% C.L)
$m_{\beta\beta} < 90 - 305$ meV

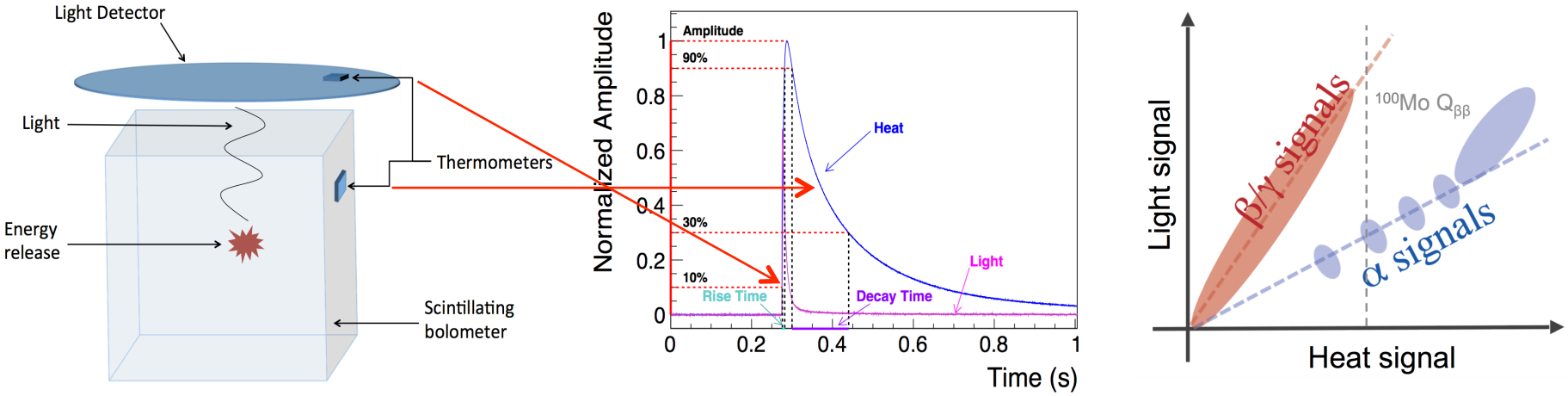
Nature 604, 53 (2022)

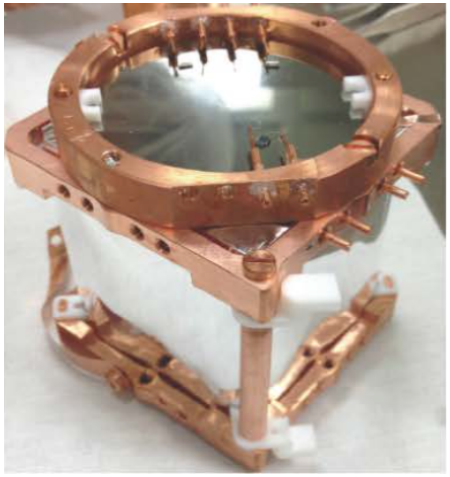
- **CUORE: world's largest bolometric 0νββ experiment**

- Location: Italy LNGS
- 988 TeO_2 crystals (~750 kg)
- ~3 ton @ T < 50 mK
- ~15 ton @ T < 4K

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

CUPID



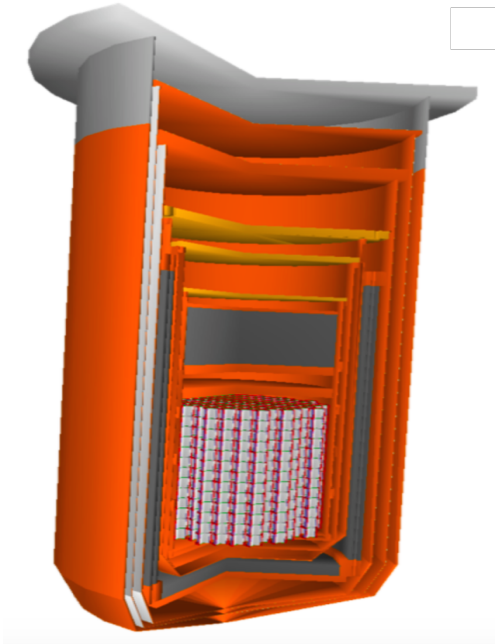


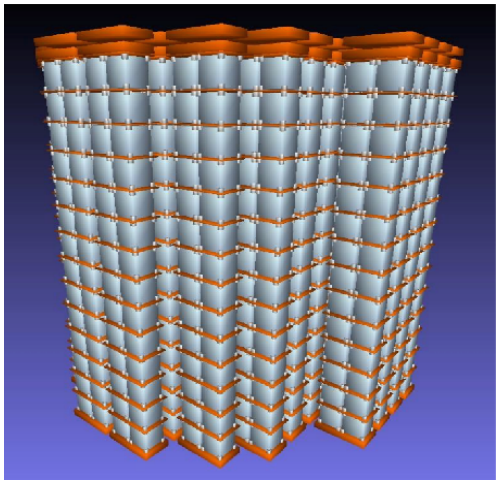
- **CUPID (CUORE Upgrade with Particle IDentification)**

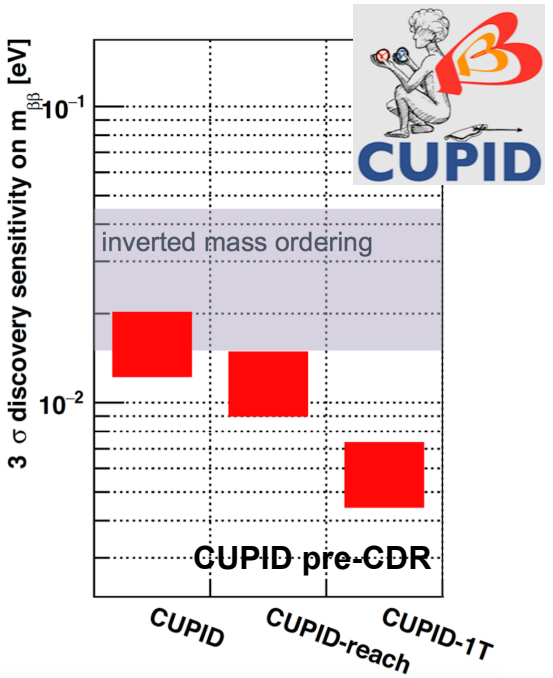
- CUORE infrastructure with detector upgrades

- Scintillating bolometer technology => PID by simultaneously measuring heat and light:
  > 99.9% **α** discrimination power @ $Q_{\beta\beta}$

CUPID

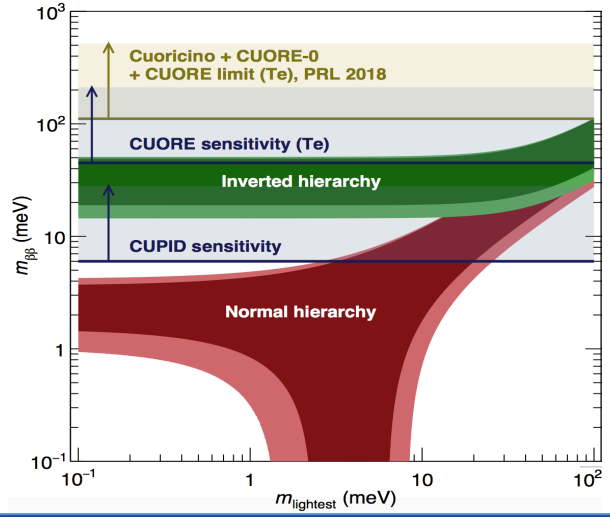




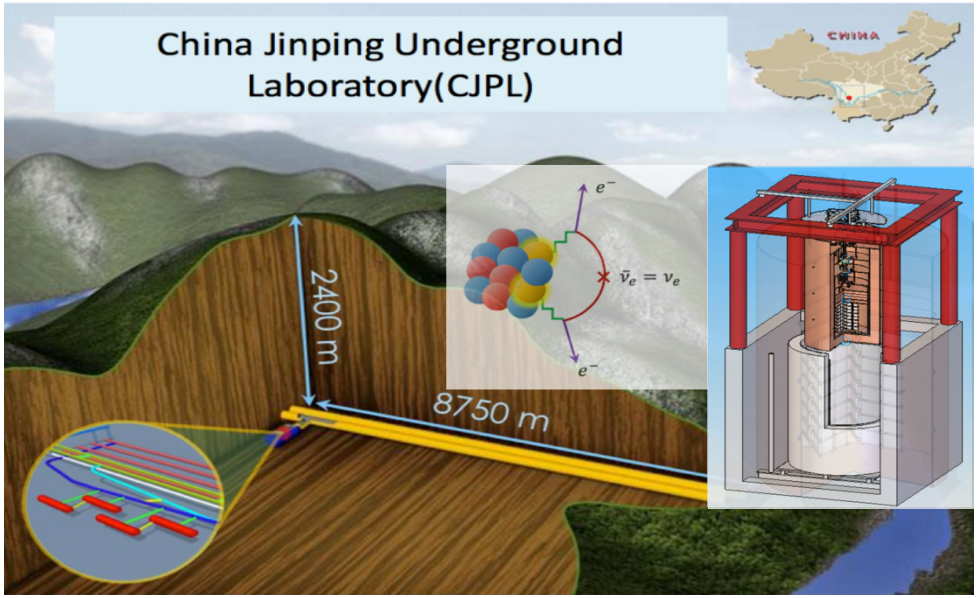


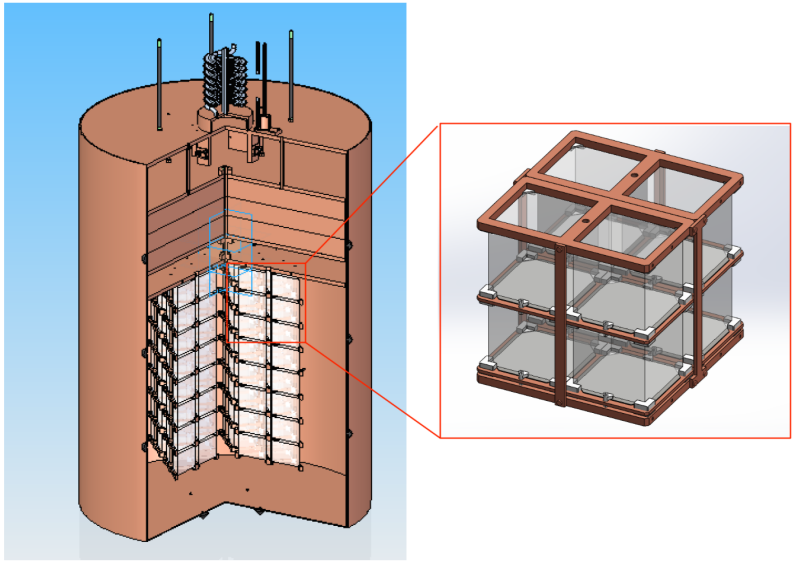
➢ **International CUPID roadmap：**

- CUPID-baseline (@LNGS): enriched crystal
- CUPID-reach: enriched crystal + lower Bkg
- CUPID-1T： enriched crystal + lower Bkg + larger exposure



Jinping bolometric experiment





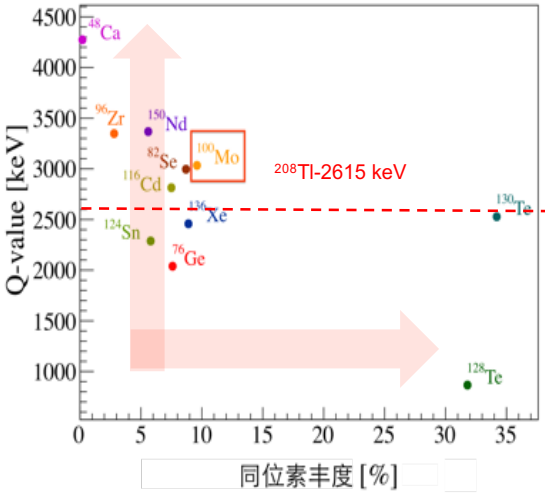
Jinping bolometric experiment:
a ^{100}Mo-based bolometer for 0νββ search at CJPL

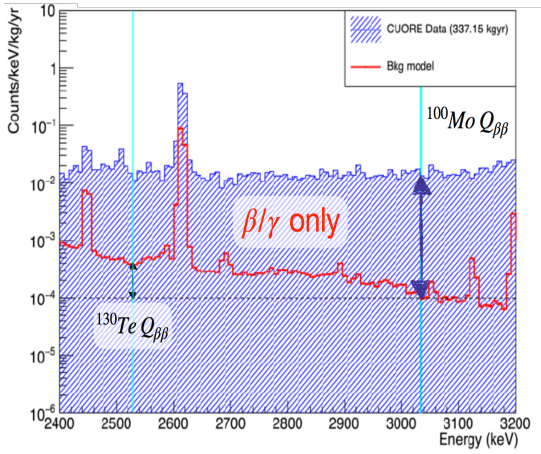
- ^{100}Mo-enriched crystals (Q~3034 keV)
- light-heat dual channel readout
- **aiming for CUPID-reach sensitivity**

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

Jinping bolometric experiment

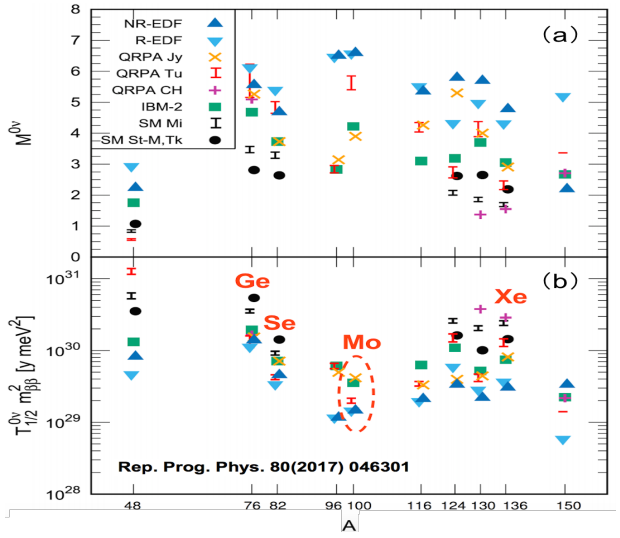
- **Isotope Q-value and natural abundance**
  - high $Q_{\beta\beta}$ => reduced γ Bkg
  - high abundance => easier enrichment



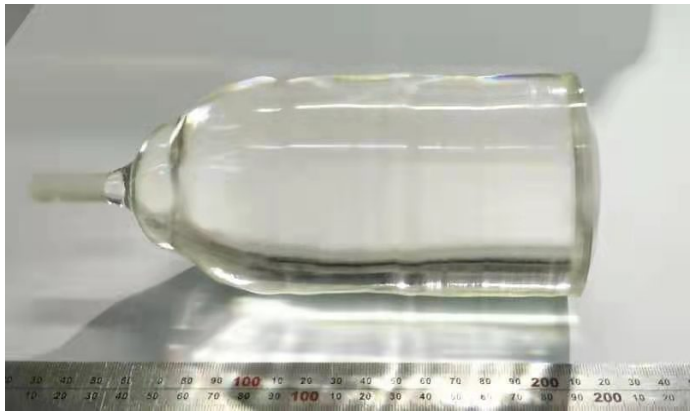


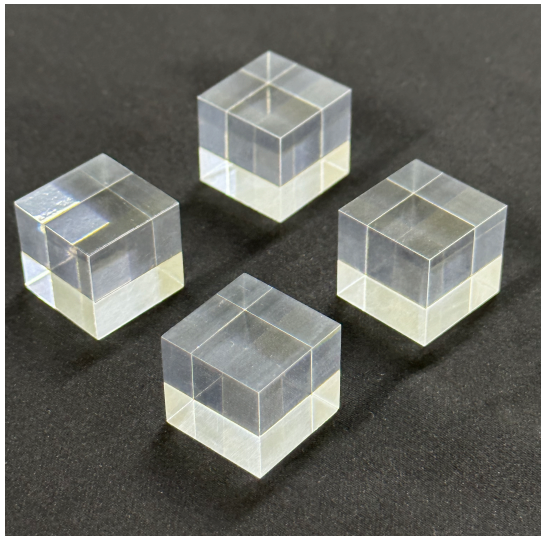
- **Event rate – signal expectation**

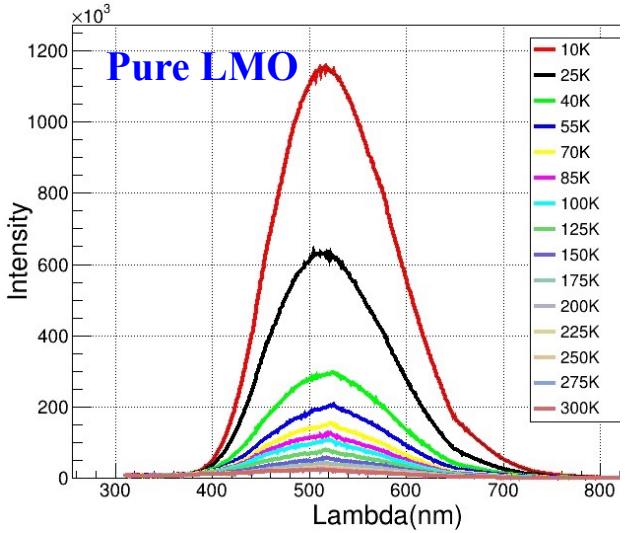
$$r^{0\nu} = 1/T_{1/2}^{0\nu} = \frac{|m_{\beta\beta}|^2}{m_e^2} \times G^{0\nu} \times |M^{0\nu}|^2$$

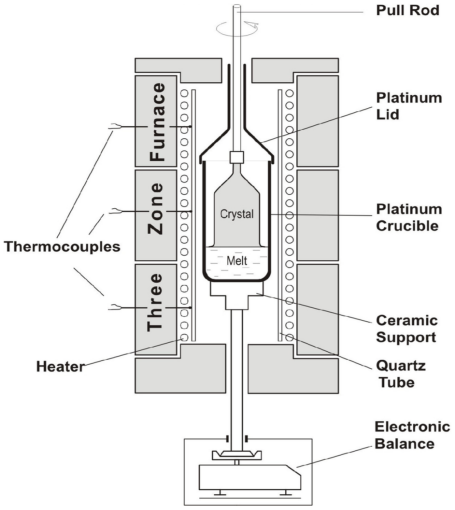


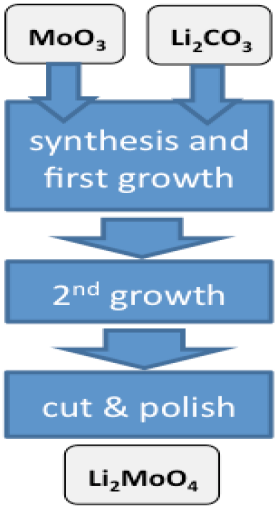
R&D progress - Crystal









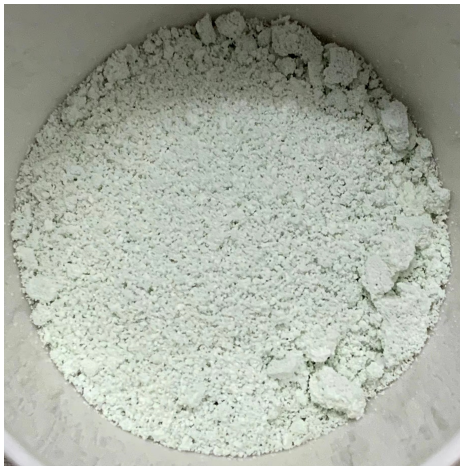


- **Bridgeman and Czochralski preparation of radiopure natural Li_2MoO_4 crystals**

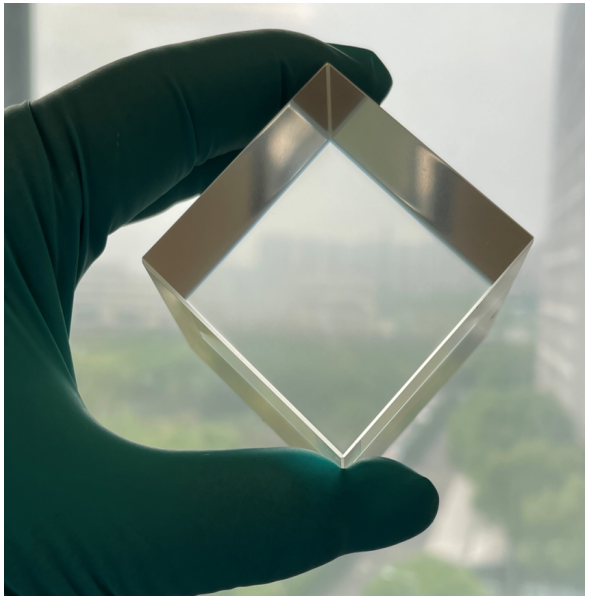
- desirable optical quality at low T
- further efforts to improve transparency and mitigate radioactive impurities

SICCAS/NBU

R&D progress - Crystal



Enriched Mo-100 powder



Crystal Powder

↓

Low Enrichment

↓

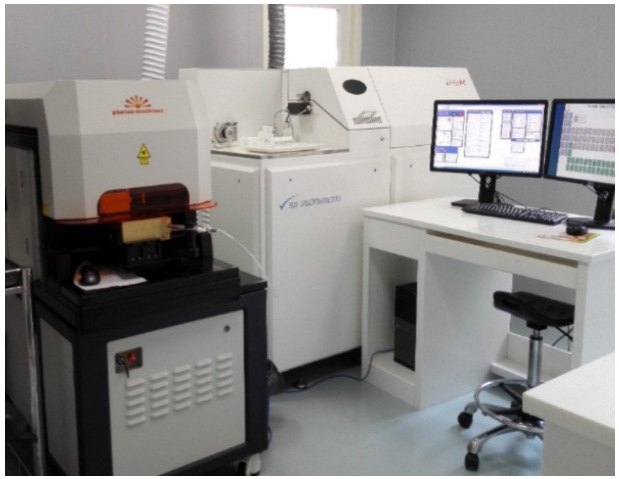
High Enrichment

➢ **Preparation of ^{100}Mo-enriched Li_2MoO_4 crystals**

- agreement made with INFN on the pre-production of enriched LMO crystals
- first batch of ^{100}Mo-enriched (98%) LMOs has been produced and is undergoing QA testing
- exploration of the twice growth technique with BG+CZ method - higher production efficiency

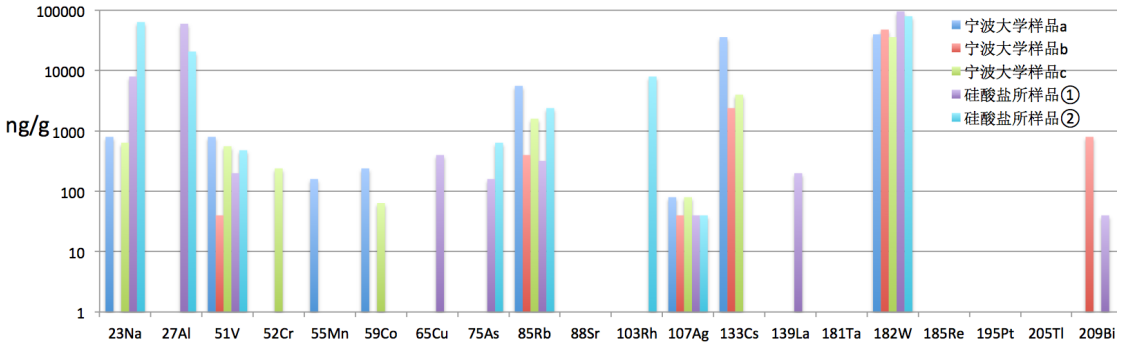
SICCAS

R&D progress - Radiopurity assessment



Sample	Na	Mg	Al	Ca	V	Cr	Mn	Fe	Co	Ni	Cu	Ga	Rb	Ag
	μg/kg													
LMO	< 33	< 7	< 11	< 83	60.3	15.7	< 2.4	< 1161	0.097	< 28	< 4.5	0.193	1.35	3.87

Sample	Sn	Te	Cs	Ba	Pt	Tl	Pb	Bi	K	W	^{232}Th	^{238}U
	μg/kg									mg/kg	ng/kg	
LMO	5.71	118	32.5	109	< 0.1	109	< 0.1	< 0.3	< 100	256	73.1	331

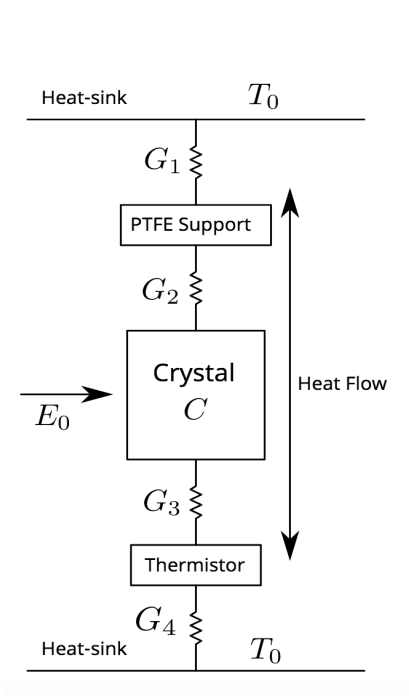


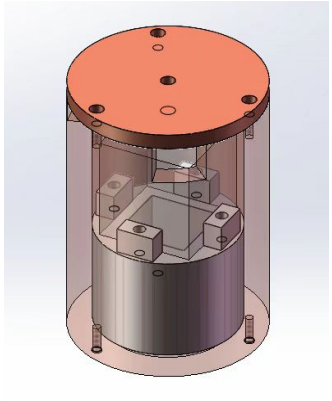
➢ **High sensitivity ICP-MS measurement**

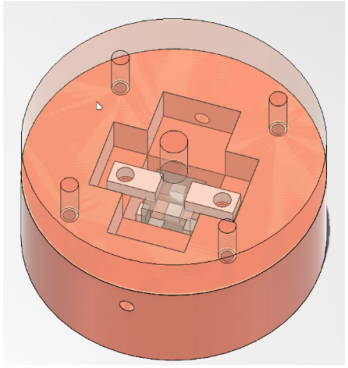
- quick QA for sample radio-purity assessment (Li_2CO_3, Mo_2O_3 and LMO)

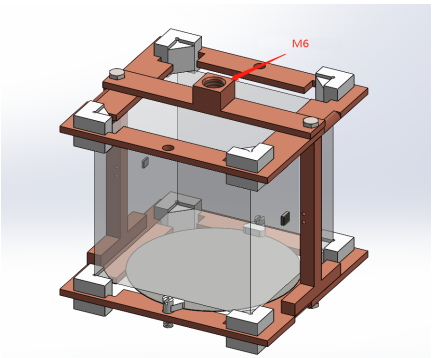
SINAP

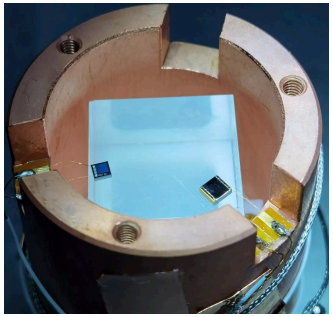
R&D progress - Detector module design

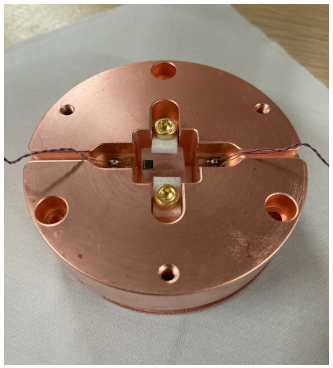


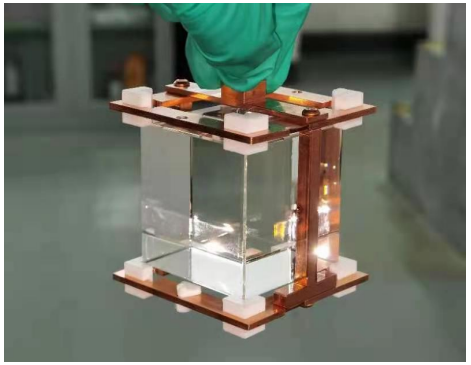








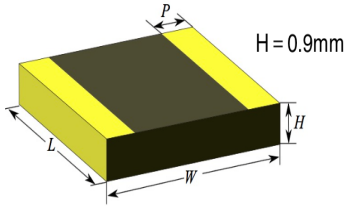


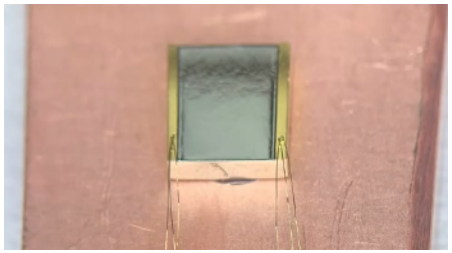


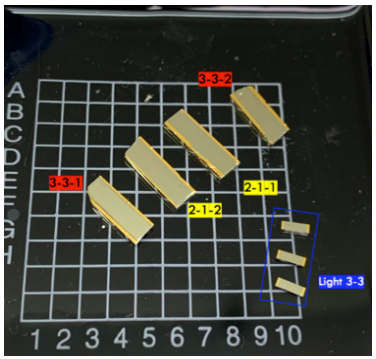
- Module design based on multi-physics simulation
- Thermal-electric response and thermal coupling optimization

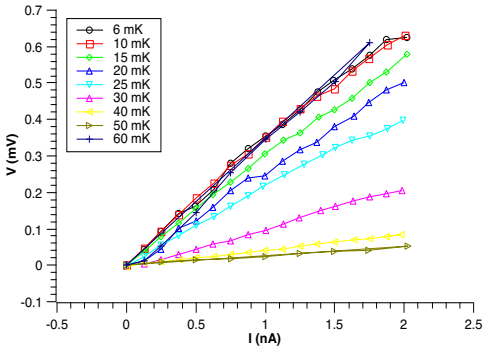
FDU

R&D progress - Thermistor



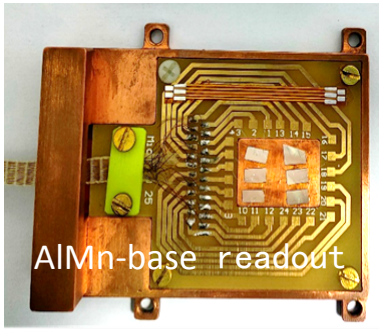


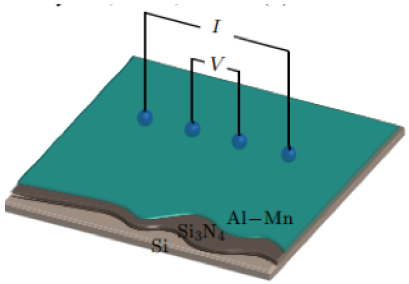


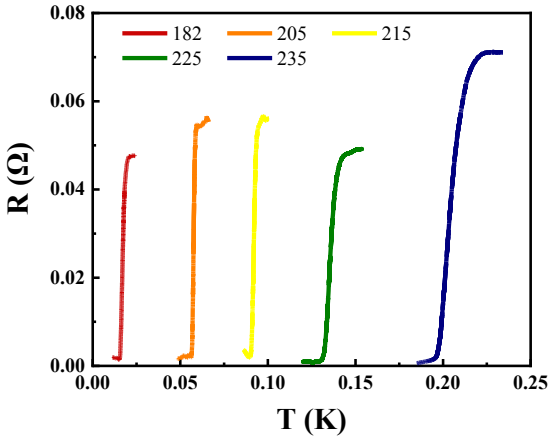


- **NTD-Ge (Neutron Transmutation Doped germanium thermistor)**
- Fabrication process is well established
- Performance study: I-V and R-T curve: R >10MΩ @ T<20 mK
- Continuous optimization

USTC



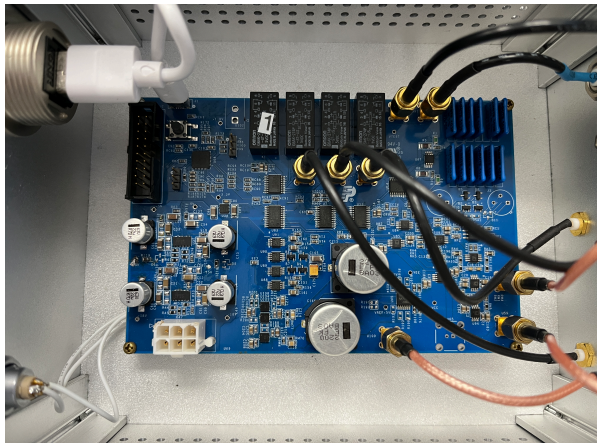


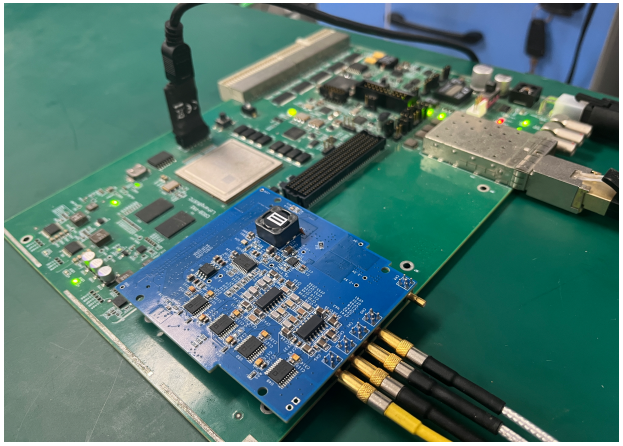


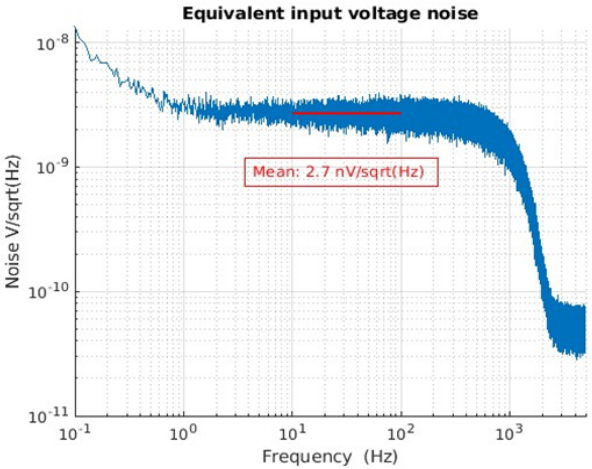
- **TES (Transition-Edge-Sensor)**
- AlMn/W superconducting film preparation and performance study
- Optimization towards goal of Tc < 20 mK

BNU

R&D progress - Readout electronics







➢ **Low noise Front-End electronics**

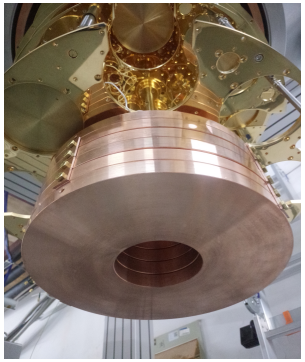
- improved design of the board and connectors
- noise level: EIN~10 nV/√Hz@1 Hz，white noise ～2.7 nV/√Hz

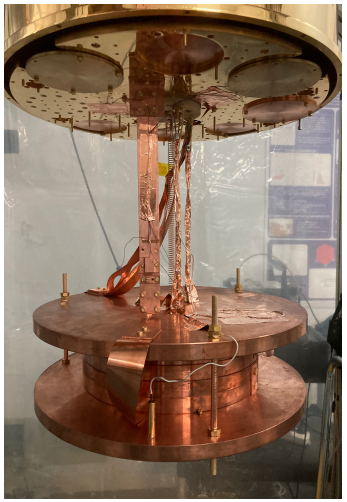
➢ **DAQ board**

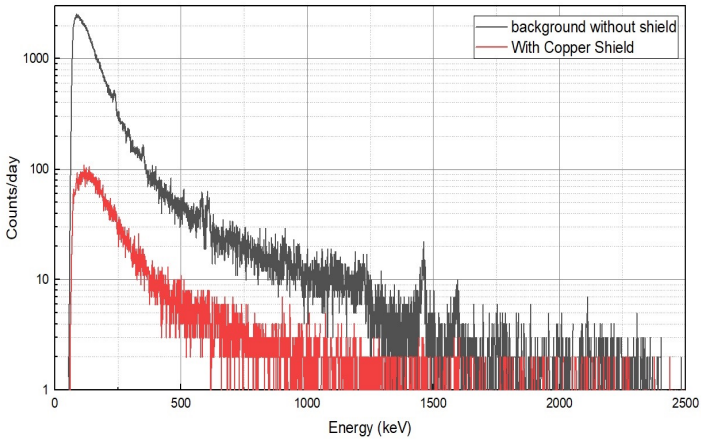
- design and test of a multi-channel digital board with Bessel filter
- sampling rate: 10 ksps/channel

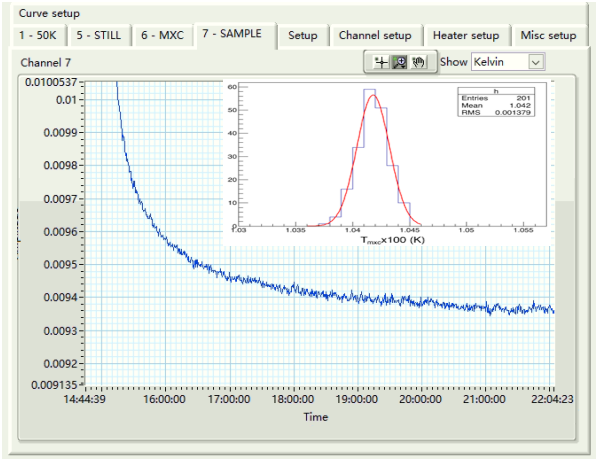
USTC

R&D progress - Ground crystal test



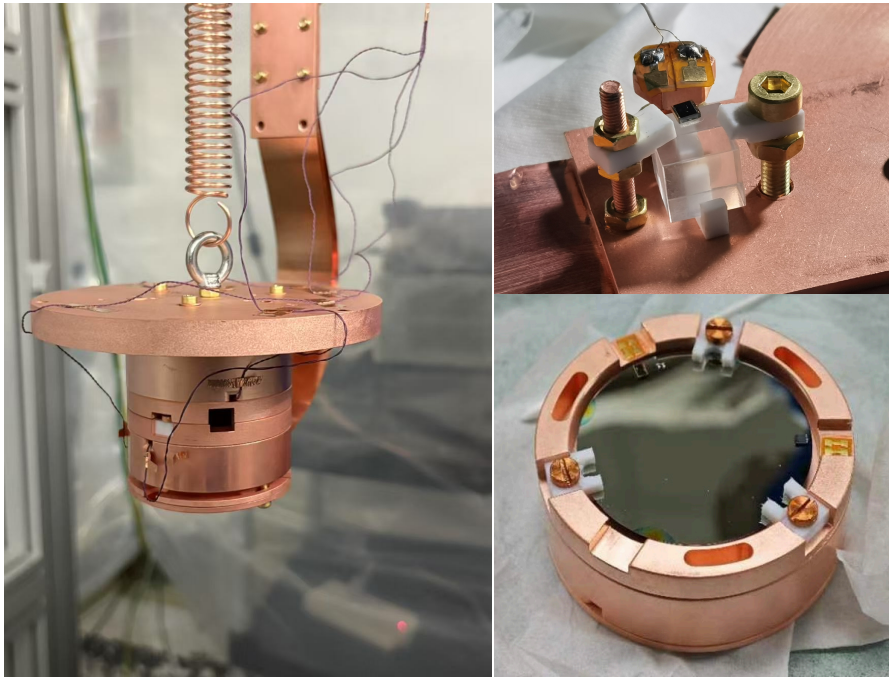


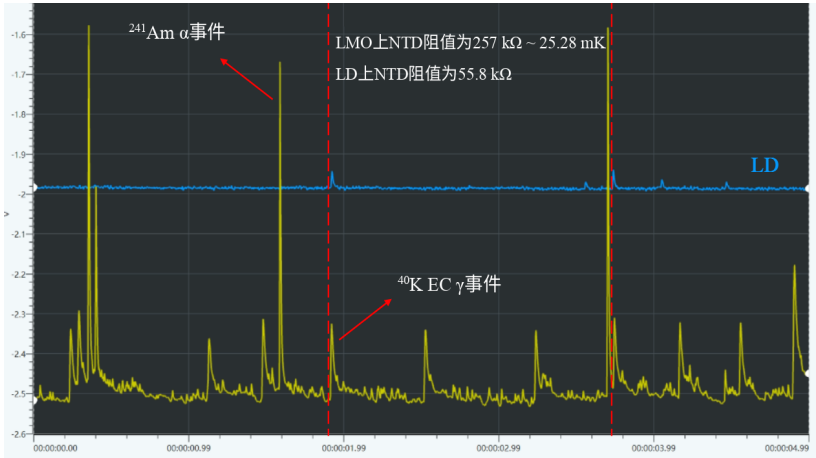


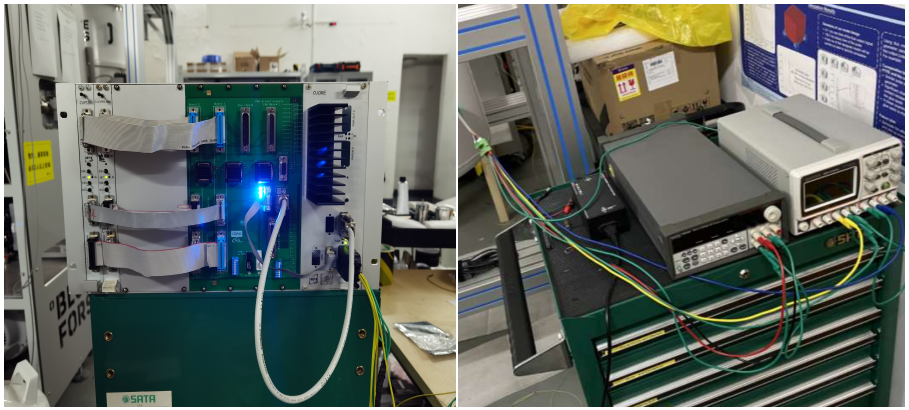


- **Crystal testing platform (FDU)**
  - Customized cryogenic system
  - T_{min} : 9.2 mK, σ_T : ±0.02 mK
- **Inner copper shield**
  - effective environmental gamma shielding by more than one order of magnitude

R&D progress - Ground crystal test



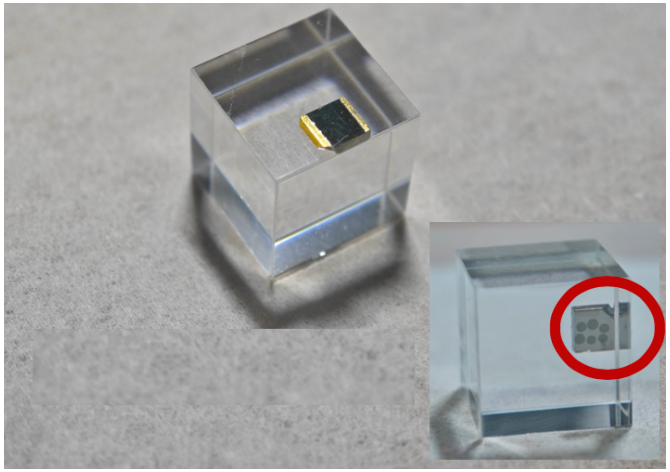


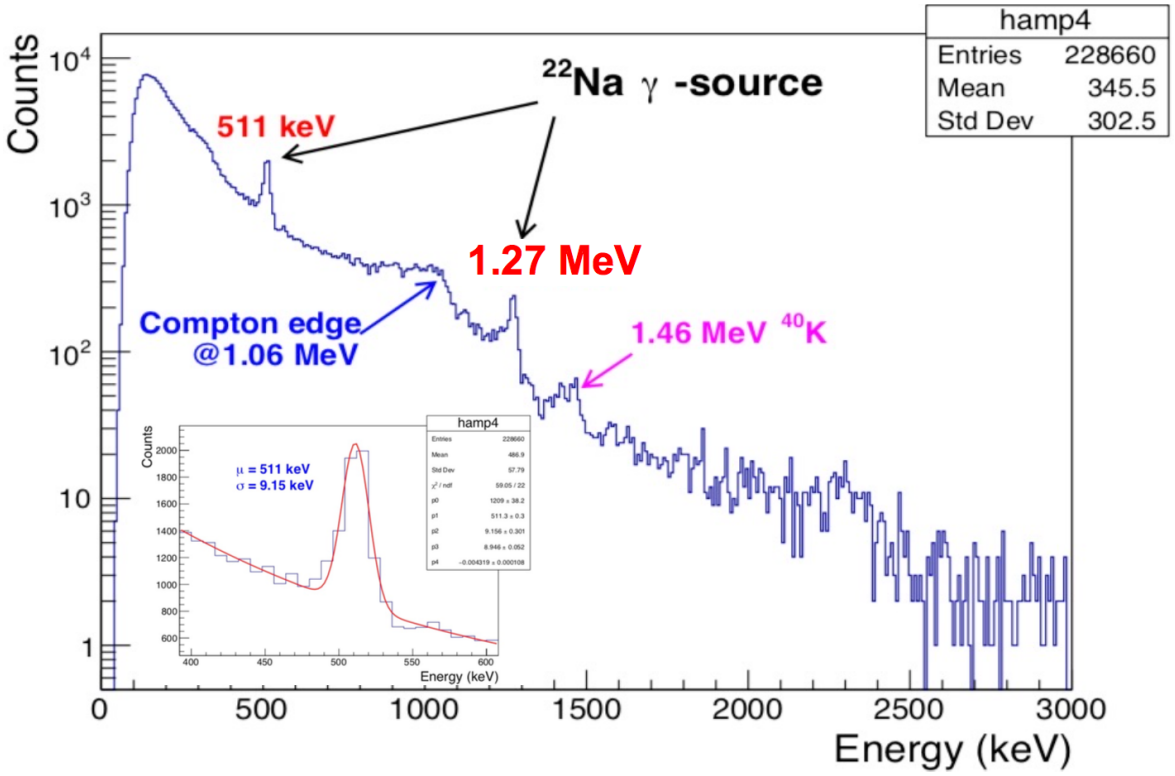


- ground tests of the natural LMO are performed
- heat (phonon) and light channel readouts are achieved

FDU

R&D progress - Ground crystal test

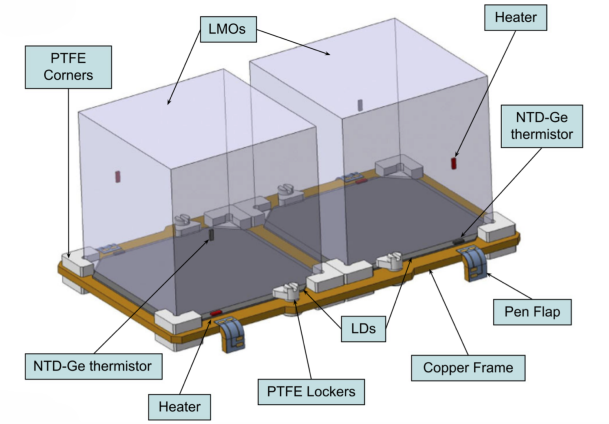


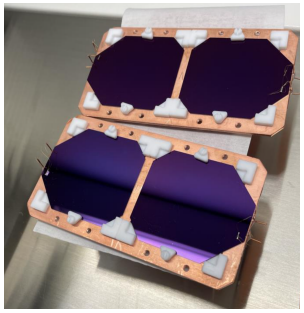


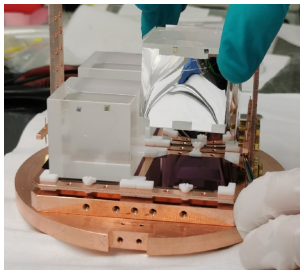
- calibration run performed with Na-22 source
- raw spectrum obtained

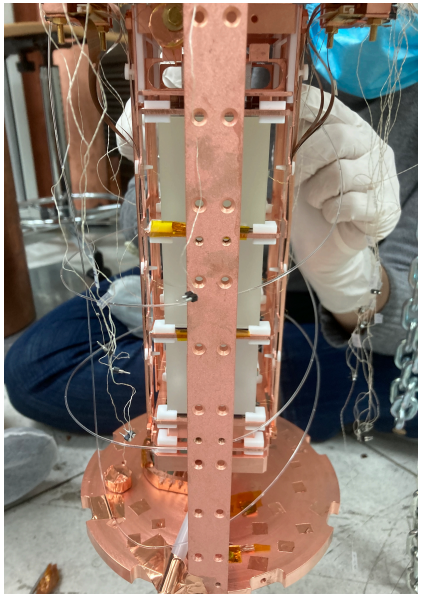
FDU/USTC

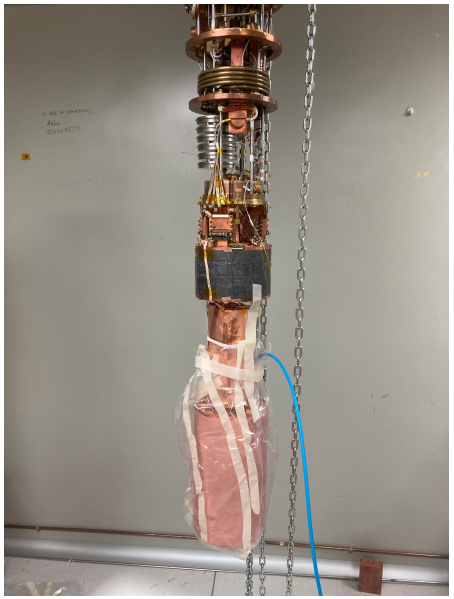
R&D progress - Underground crystal test









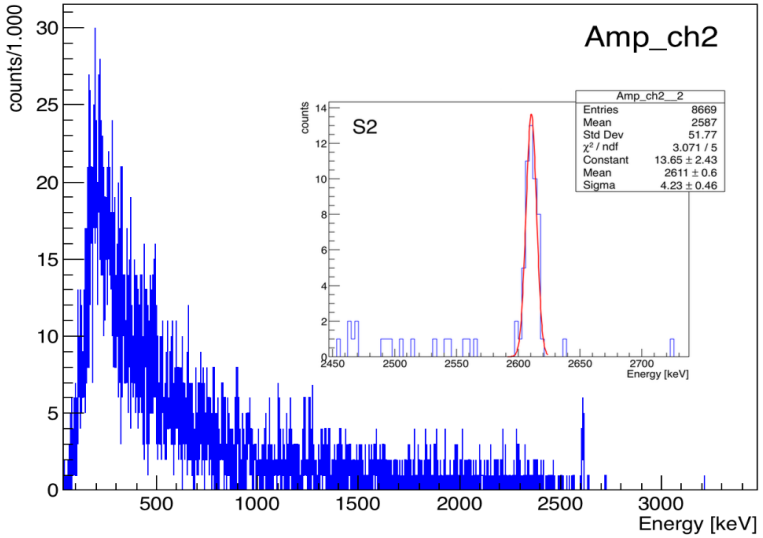


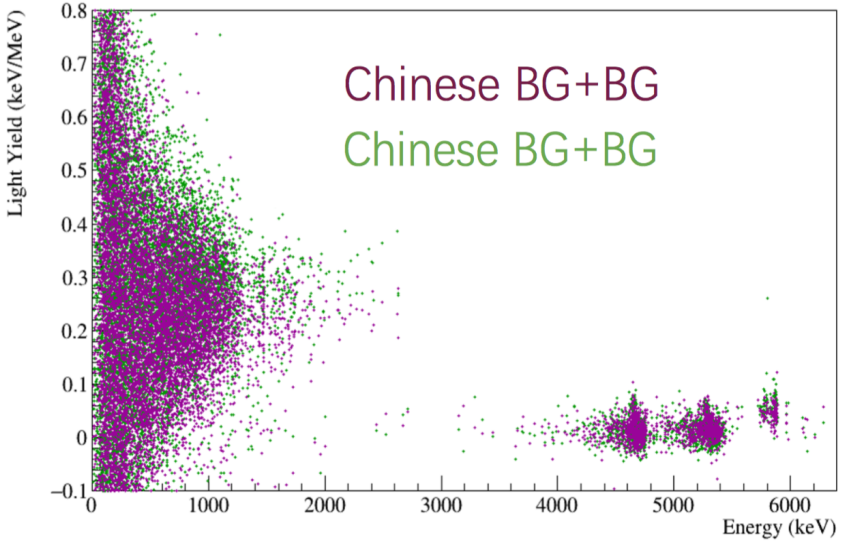
➢ **Underground testing of CUPID-China crystals**

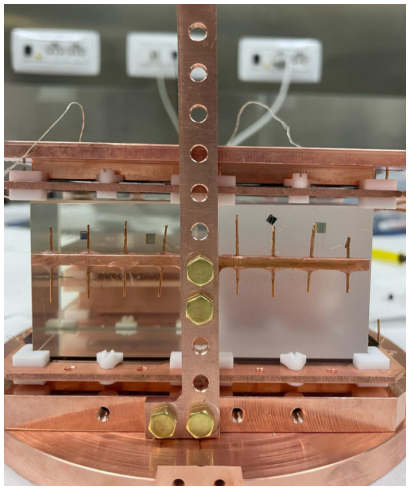
- Location: Italy LNGS，2023/11-12 (Run1 11d)，2024/3-4 (Run2 20d)
- Sensitive crystal quality evaluation through bolometric run (CCVR)

FDU/LNGS

R&D progress - Underground crystal test



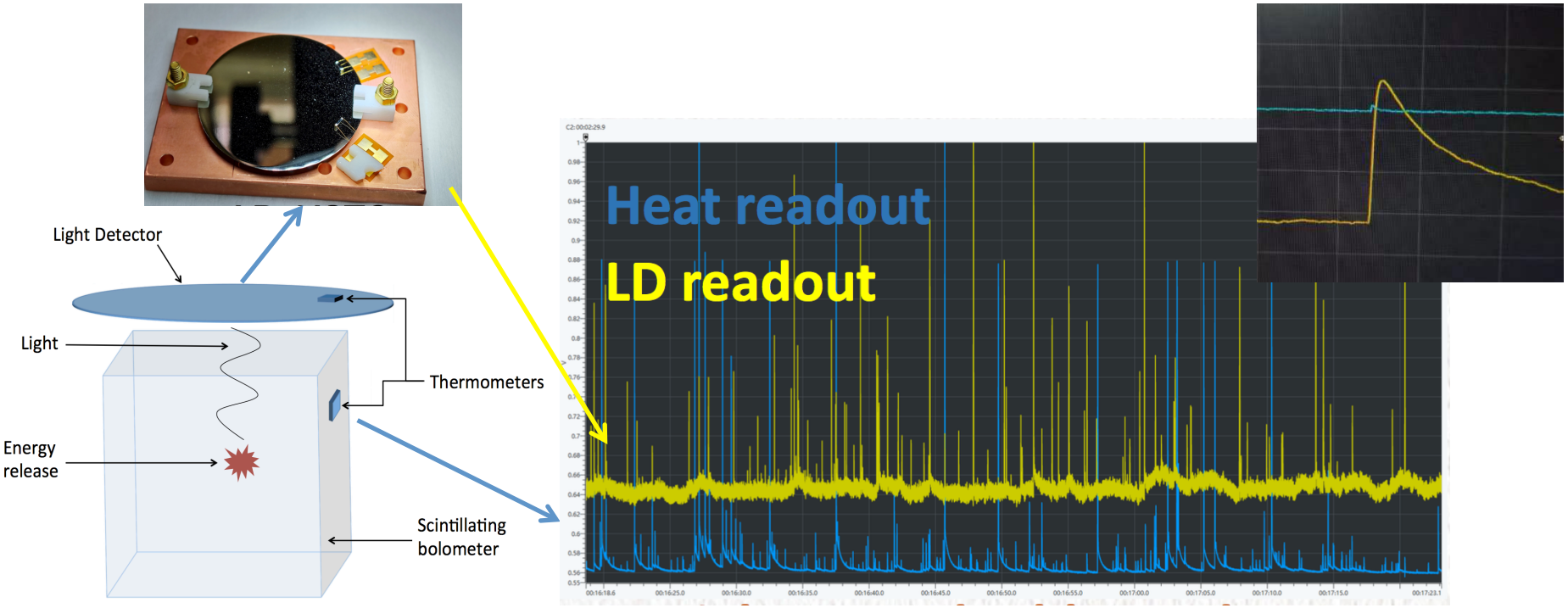




- Performance of natural LMO module:
  - good energy resolution: 9.9±1.2 keV(FWHM)@2615keV
  - U/Th contamination: ^{238}U< 48.2±25.0 μBq/kg, ^{232}Th< 42.2±21.1 μBq/kg
  - good light yield performance => clear alpha discrimination
- Ongoing test for the enriched LMOs

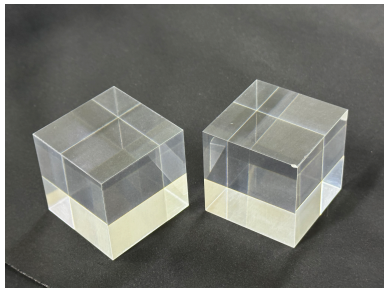
FDU/LNGS

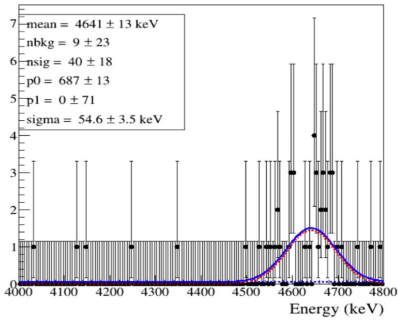
Challenge - Light-heat coincidence

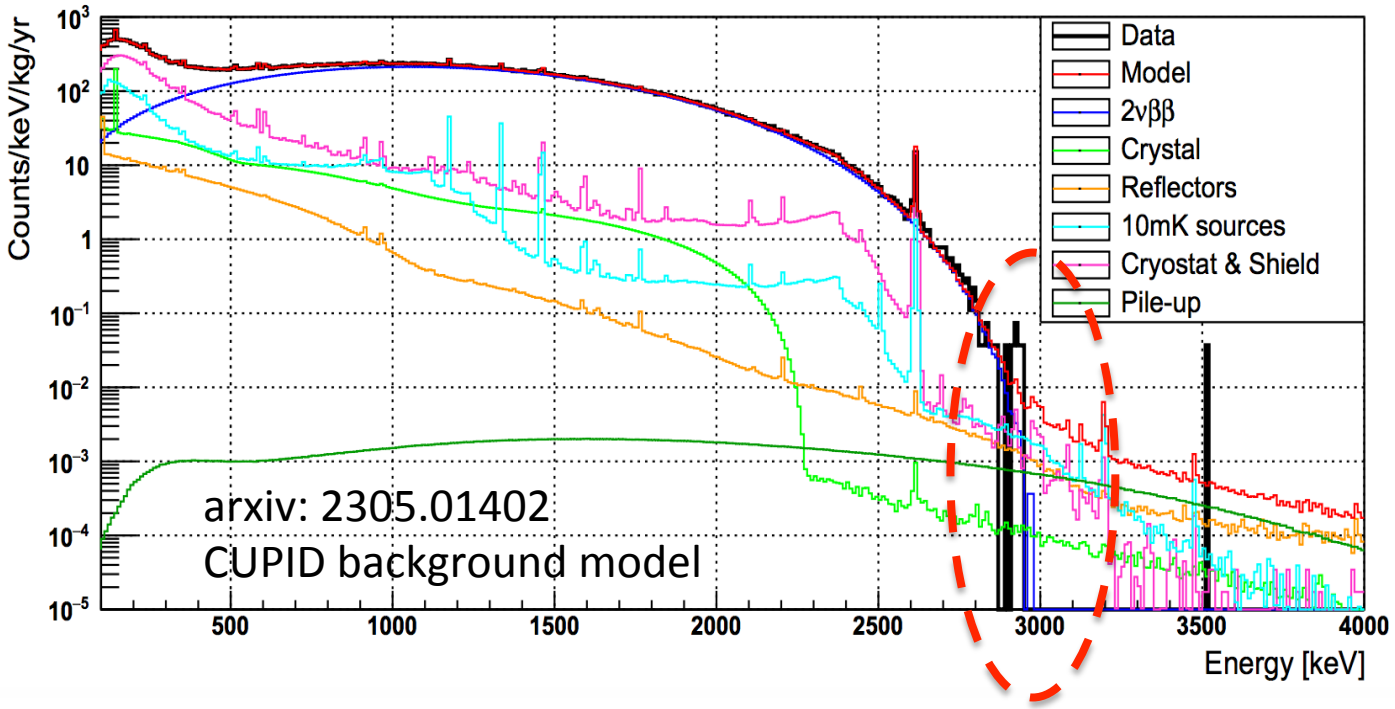


- Relative low light yield (LY~0.3keV/MeV) and narrow signal window => difficult for coincidence measurement
- Possible solutions: reduce the light channel noise; optimize chip fabrication, absorber coupling and light collection;

Challenge - Background





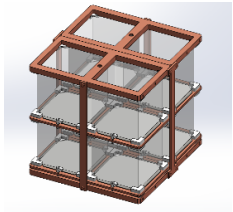


- clear alpha contamination (U/Th chain) observed in crystal testing
- material radioactivity mitigation and development of ultra-cleaning process for crystal machining are necessary

The roadmap

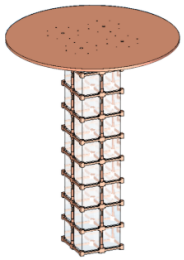
Crystal test

6-12 natural LMO
(2024-2026)



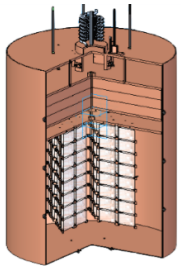
Demonstrator

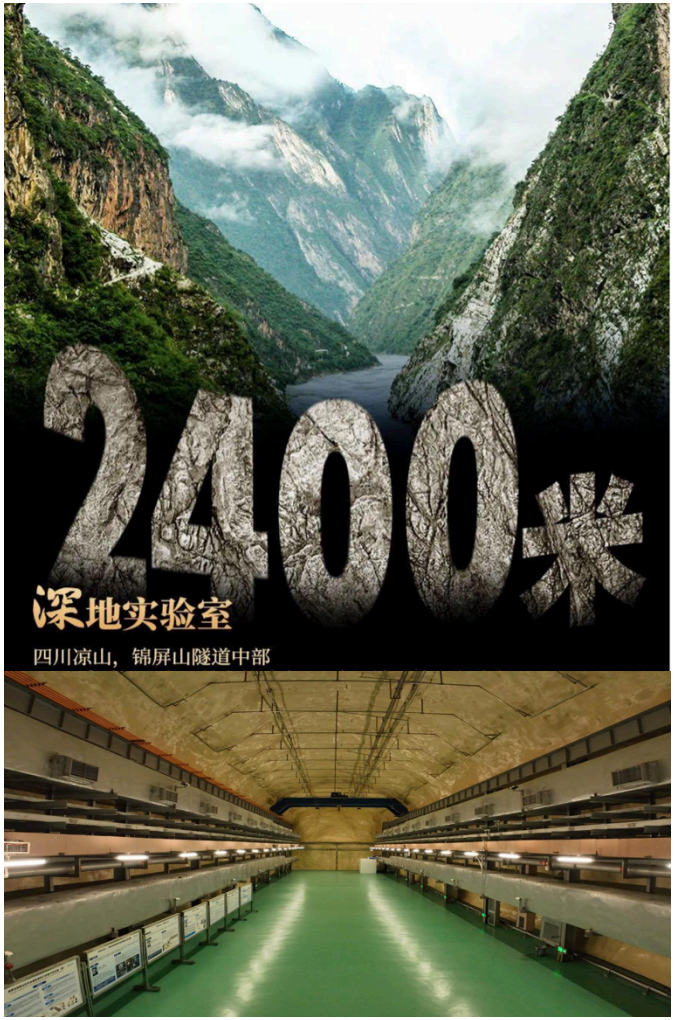
10 kg enriched LMO
(2026-2028)



200kg/1T experiment

200/1000 kg enriched LMO
(2028+)





Summary

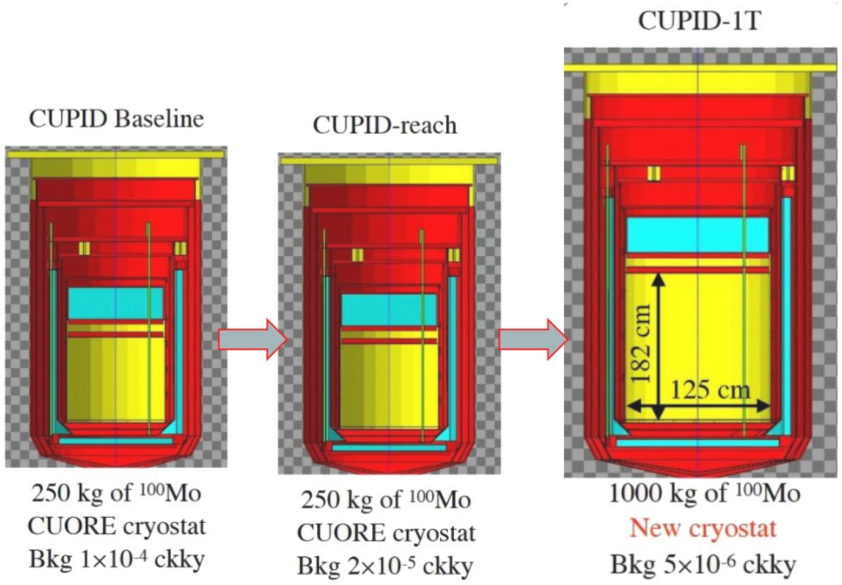
- A ^{100}Mo-based scintillating bolometer based at CJPL => prospective for high sensitivity 0νββ search

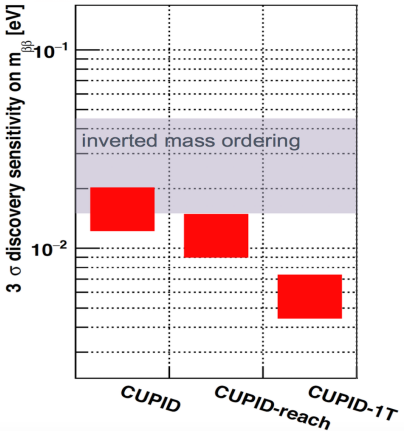
- Key technologies are demonstrated => essential for the development of hundred-kg / ton-scale experiment

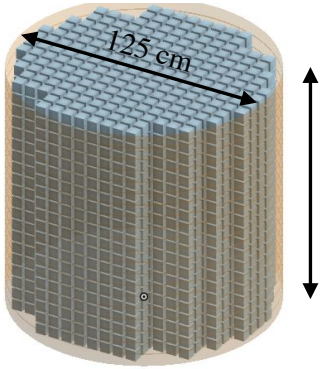
- Progresses have been made in crystal growth, low noise read-out electronics and bolometer module test

- R&D in progress
  - ^{100}Mo-enriched crystal testing
  - light channel optimization

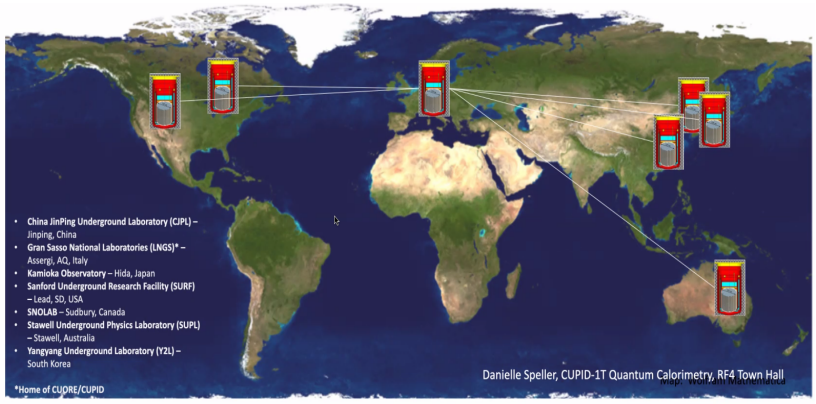
backup: international roadmap







arXiv:2203.08386



Snowmass 2021 Planning workshop

➢ **CUPID-Baseline**
- High enrichment LMO (240 kg ^{100}Mo)
- Sensitivity (3σ): $T_{1/2} > 10^{27}$ yr , $m_{\beta\beta} < 12\text{-}20$ meV

➢ **CUPID-Reach**
- further background reduction
- Sensitivity (3σ): $T_{1/2} > 2\times10^{27}$ yr , $m_{\beta\beta} < 9\text{-}15$ meV

➢ **CUPID-1T**
- 1000 kg of ^{100}Mo (~1500 kg of LMO)
- Sensitivity(3σ): **$T_{1/2} > 8\times10^{27}$ years, $m_{\beta\beta}$<4-7 meV**

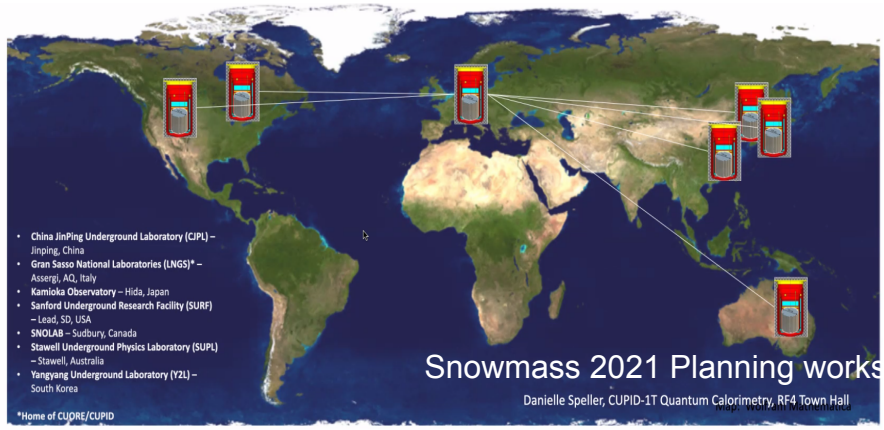
Potential options (CUPID-1T@2030+)

➢ **single detector (new cryostat)**

➢ **multiple facilities world wide**

backup: CUPID-China

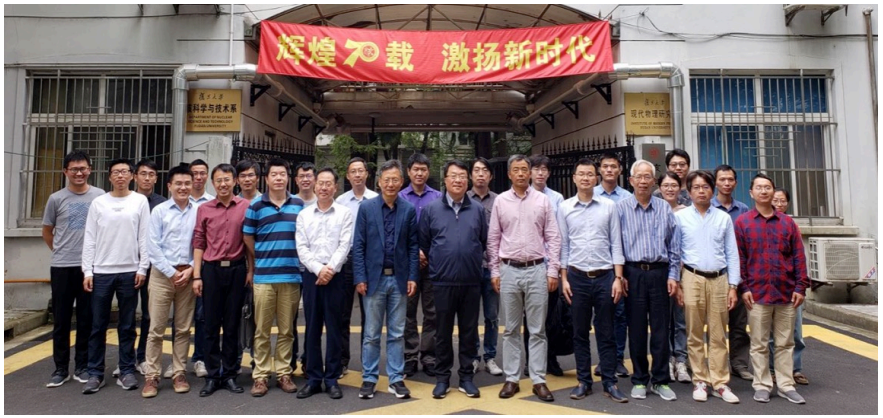
International CUPID collaboration



International Collaboration:
CUPID – Italy
CUPID – US
CUPID – France
CUPID – China

~ 30 institutes, >150 collaborators

CUPID-China collaboration



~ 8 institutes, > 40 collaborators

CUPID-China is actively collaborating with CUPID- France, Italy and US.