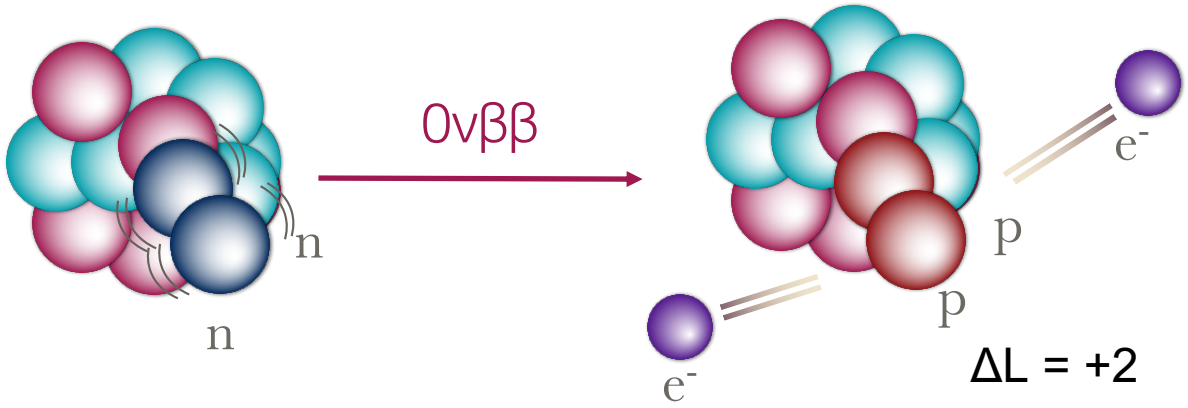
Recent progress of CUPID-CJPL Experiment

谢芳
on behalf of CUPID-China Collaboration
Institute of Modern Physics, Fudan University
COUSP2024, Xichang, 2024.5.7-11

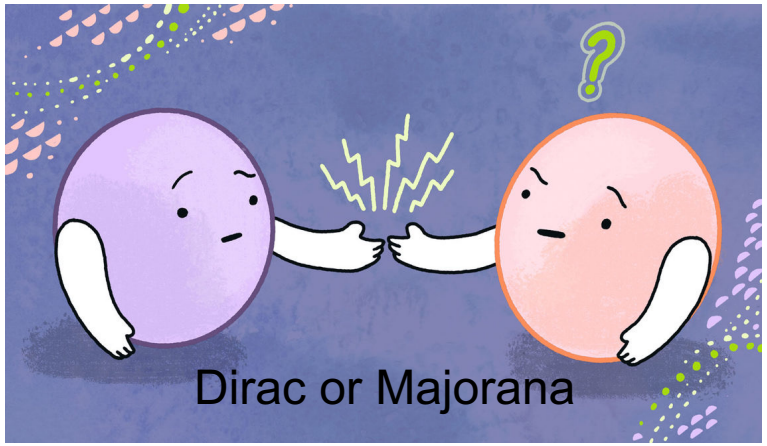
CONTENT

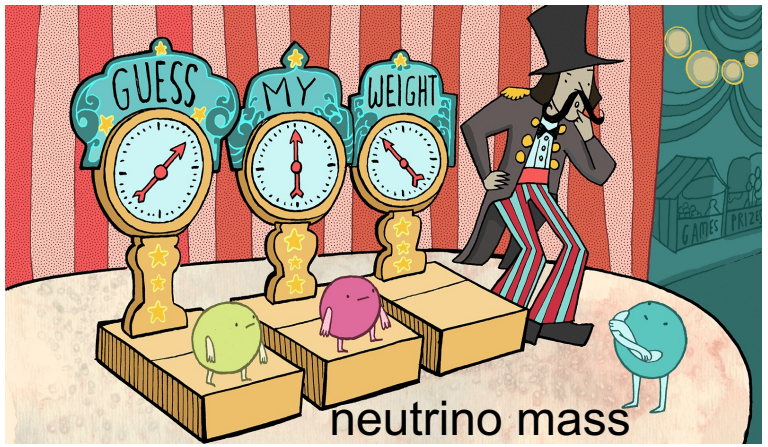
Double Beta Decay

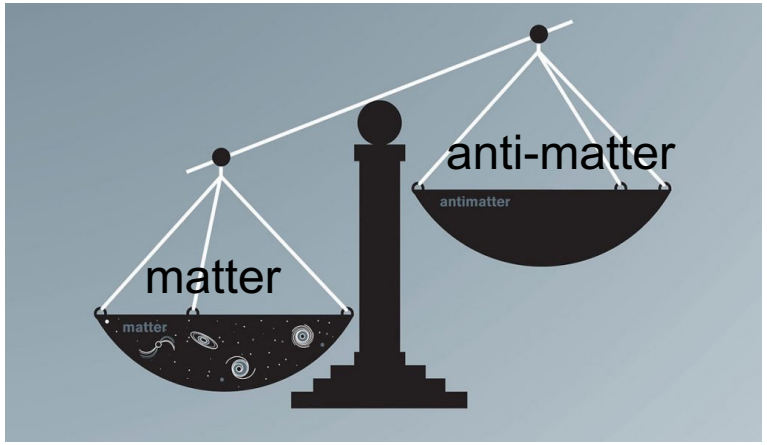
Double Beta Decay



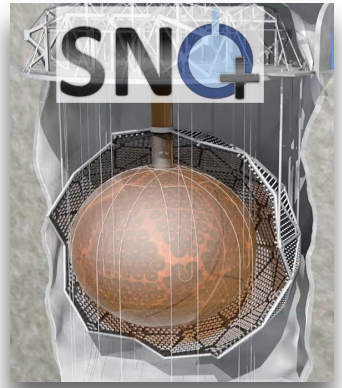
1 H 1.008												13	14	15	16	17	18 2 He 4.0026
3 Li 6.94	4 Be 9.0122											5 B 10.81	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305	3	4	5	6	7	8	9	10	11	12	13 Al 26.982	14 Si 28.085	15 P 30.974	16 S 32.06	17 Cl 35.45	18 Ar 39.948
19 K 39.098	^{48}Ca	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	^{76}Ge	33 As 74.922	^{82}Se	35 Br 79.904	36 Kr 83.798
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	^{96}Zr	41 Nb 92.906	^{100}Mo	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	^{110}Pd	47 Ag 107.87	^{116}Cd	49 In 114.82	^{124}Sn	51 Sb 121.76	^{128,130}Te	53 I 126.90	^{136}Xe
55 Cs 132.91	56 Ba 137.33	57-71 *	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89-103 #	104 Rf (265)	105 Db (268)	106 Sg (271)	107 Bh (270)	108 Hs (277)	109 Mt (276)	110 Ds (281)	111 Rg (280)	112 Cn (285)	113 Nh (286)	114 Fl (289)	115 Mc (289)	116 Lv (293)	117 Ts (294)	118 Og (294)
* Lanthanide series			57 La 138.91	58 Ce 140.12	59 Pr 140.91	^{150}Nd	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97
# Actinide series			89 Ac (227)	90 Th 232.04	91 Pa 231.04	^{238}U	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

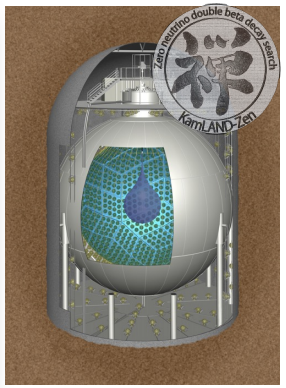


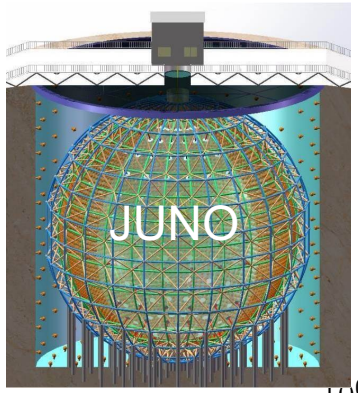


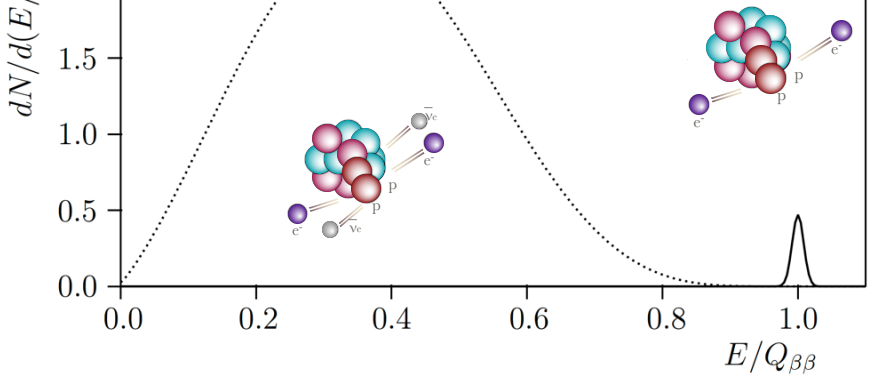


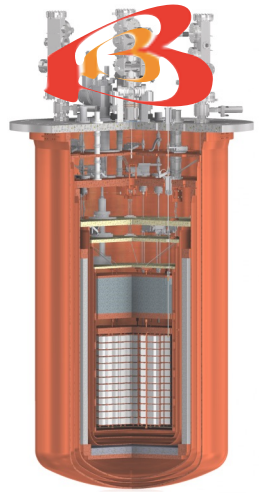
0νββ Experiments

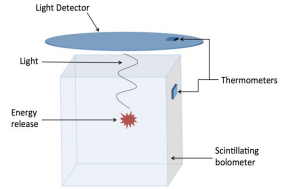






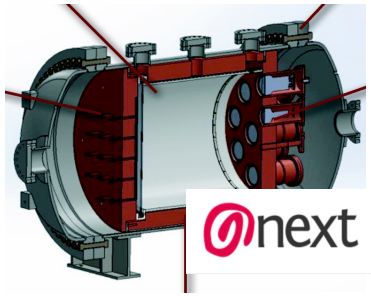


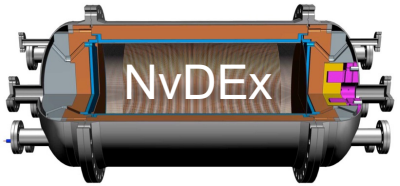


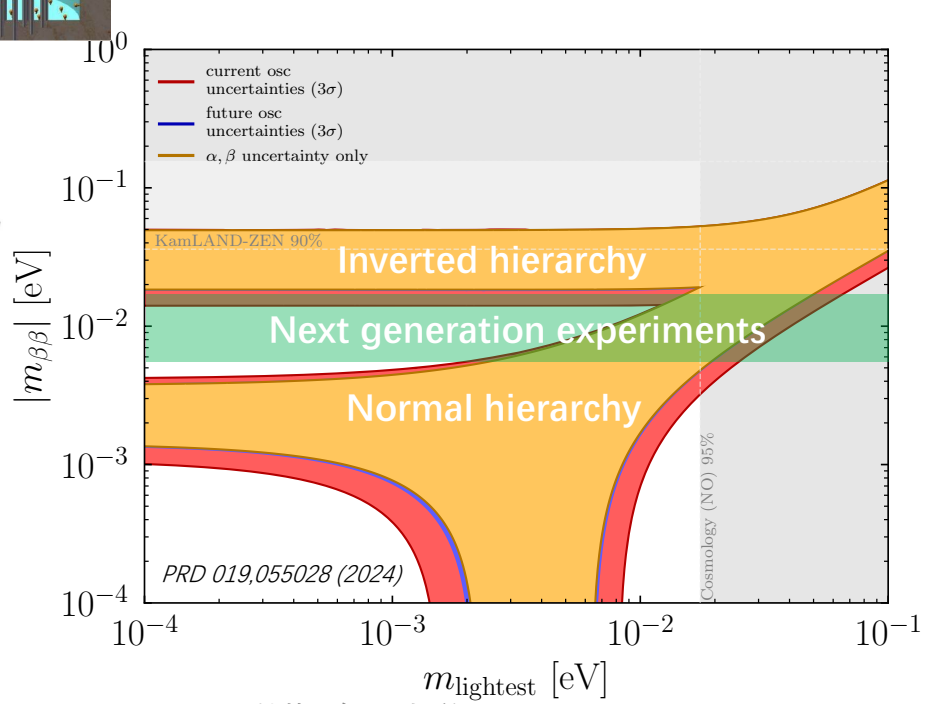


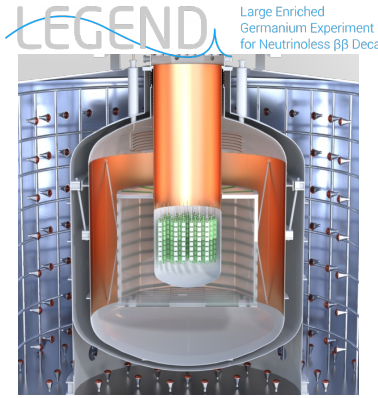
CUPID

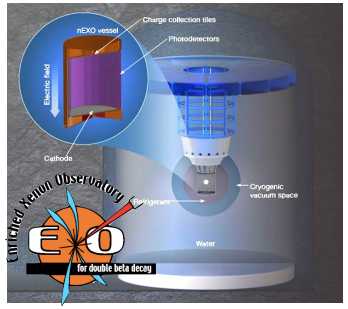
CUPID-CJPL

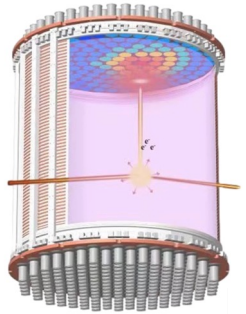




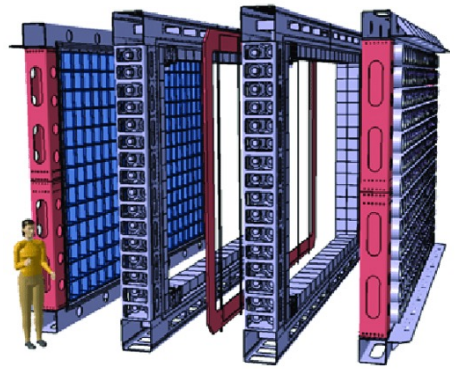








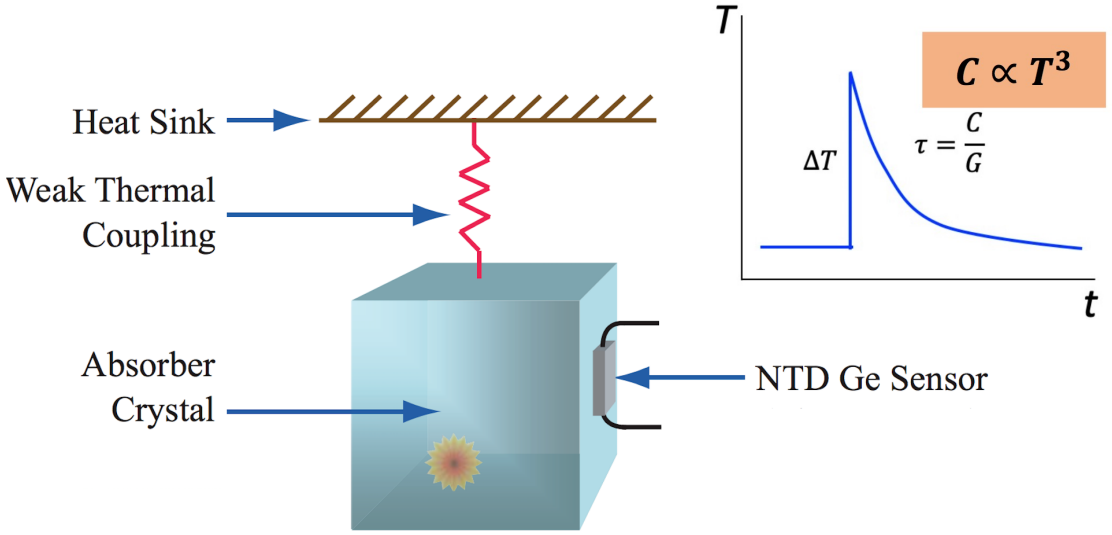
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

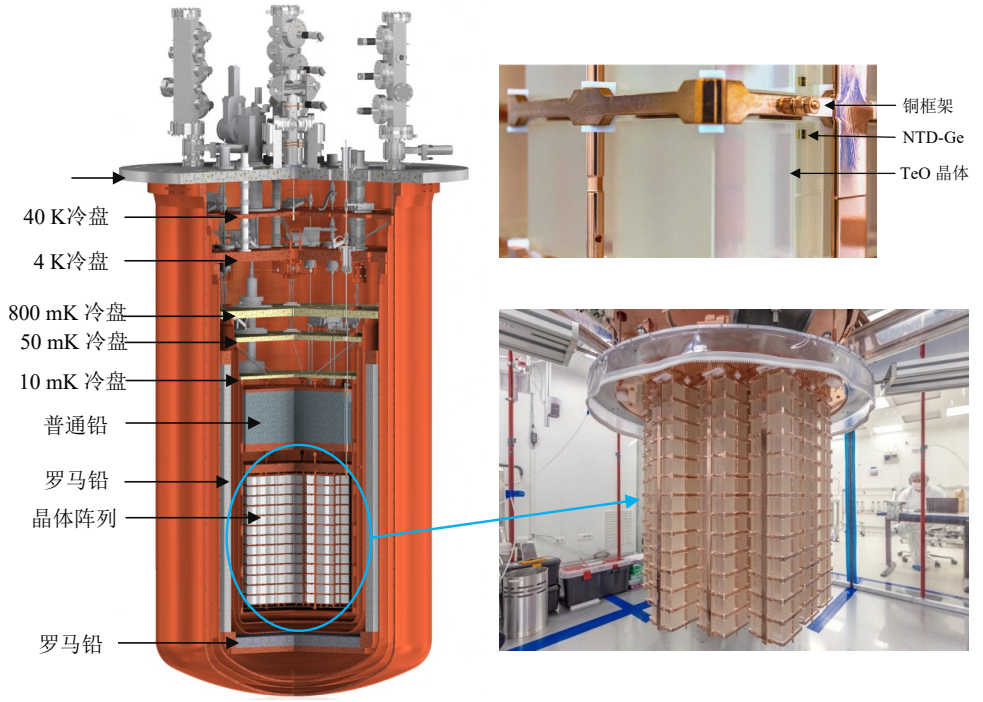


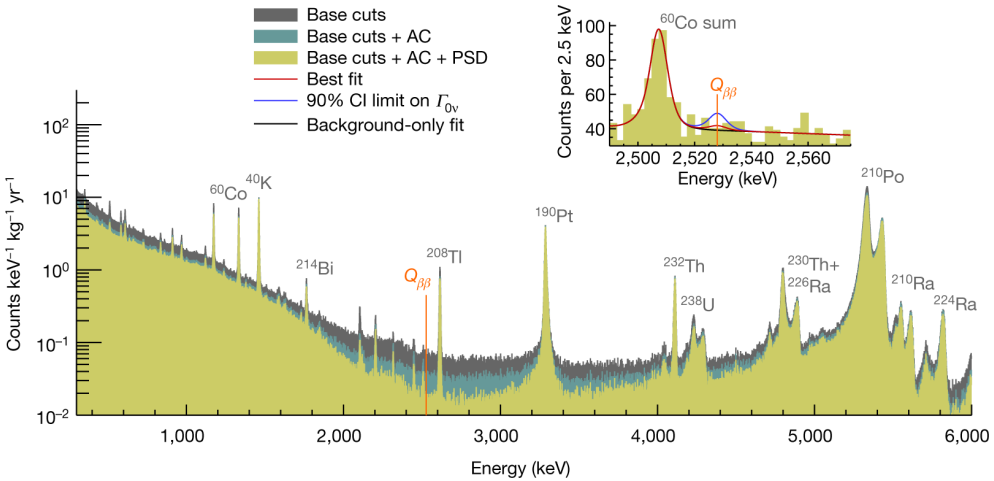
supernemo
collaboration

CUPID Experiment

CUORE Experiment





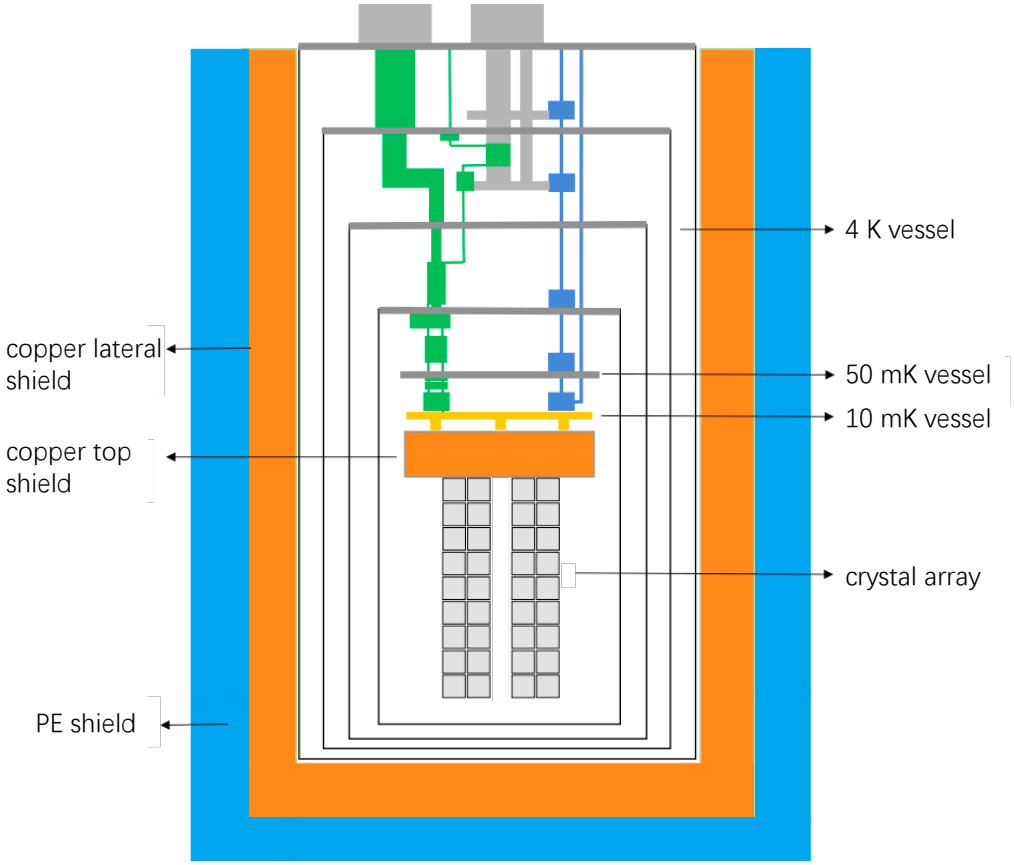


❒ **Cryogenic crystal bolometer**

- low temperature ~10 mK
- high sensitivity E measurement via ΔT
- low threshold： eV - keV
- high detection efficiency (>85%) : source=detector
- high energy resolution: ~0.3% (FWHM)

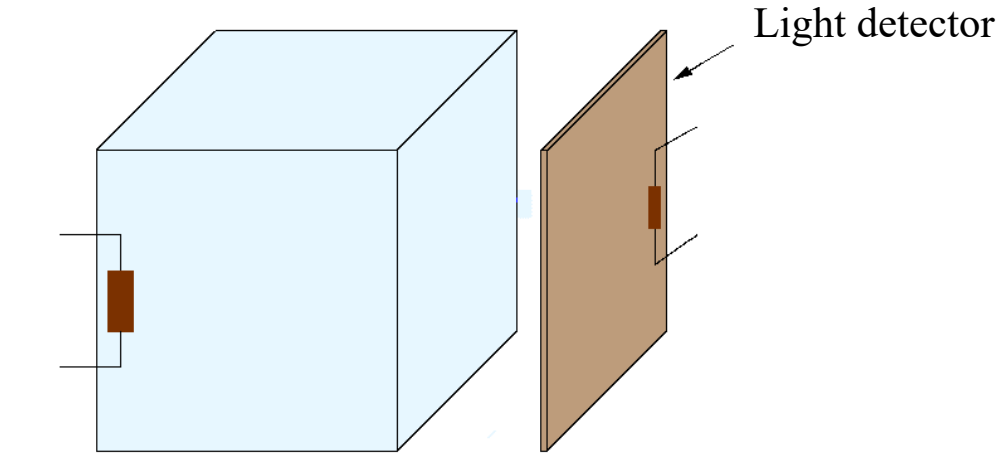
$T_{1/2} > 2.8 \times 10^{25}$ yr, $m_{\beta\beta} < 90\text{-}305$ meV
Best limit on ^{130}Te, *Nature 604,53 (2022)*

CUPID (CUORE Upgrade with Particle Identification)

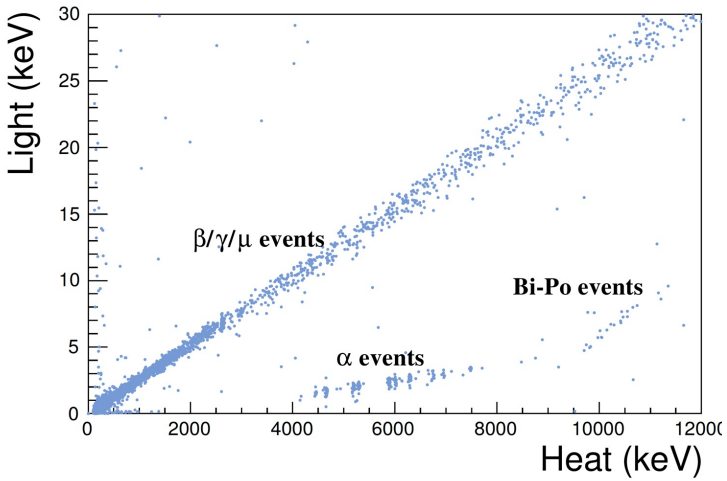


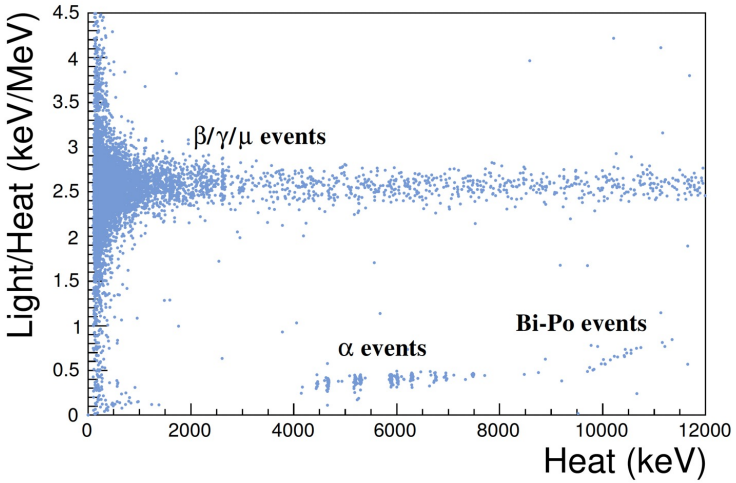
CUPID pre-CDR

S. Pirro 18th LTD

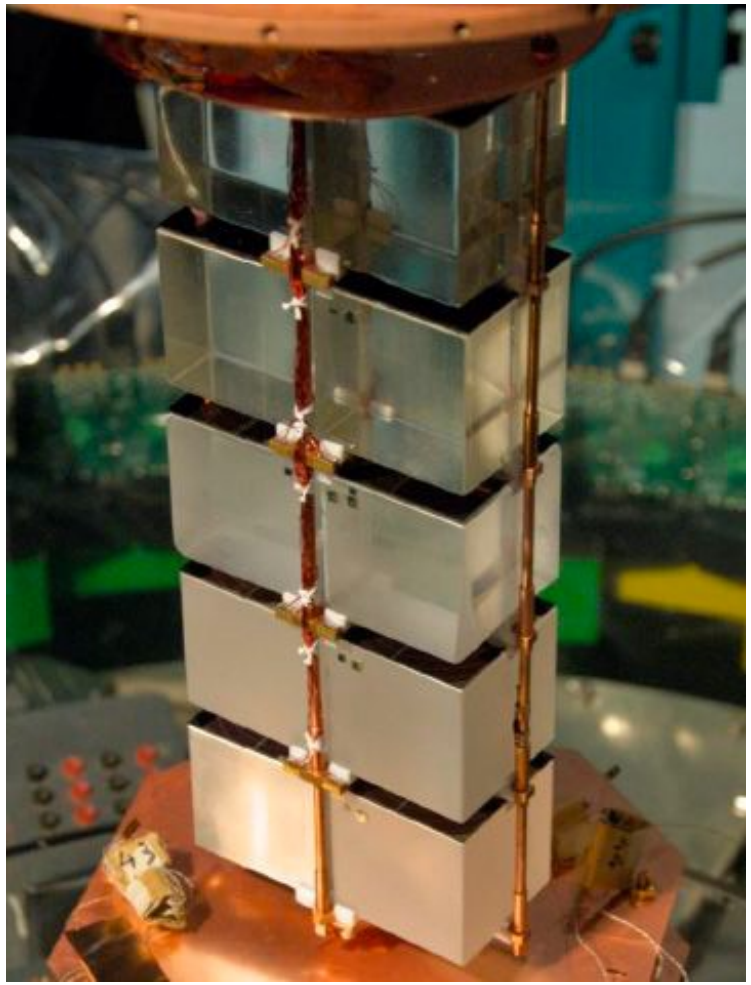


Scintillating Bolometer





CUPID Experiment



^{100}Mo-enriched Li_2MoO_4 crystals
^{100}Mo high $Q_{\beta\beta}$ (~3.034 MeV)

Scintillating bolometer technology
PID by heat & light dual readout
> 99.9% α discrimination @ 3 MeV

CUORE infrastructure with detector upgrades

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*

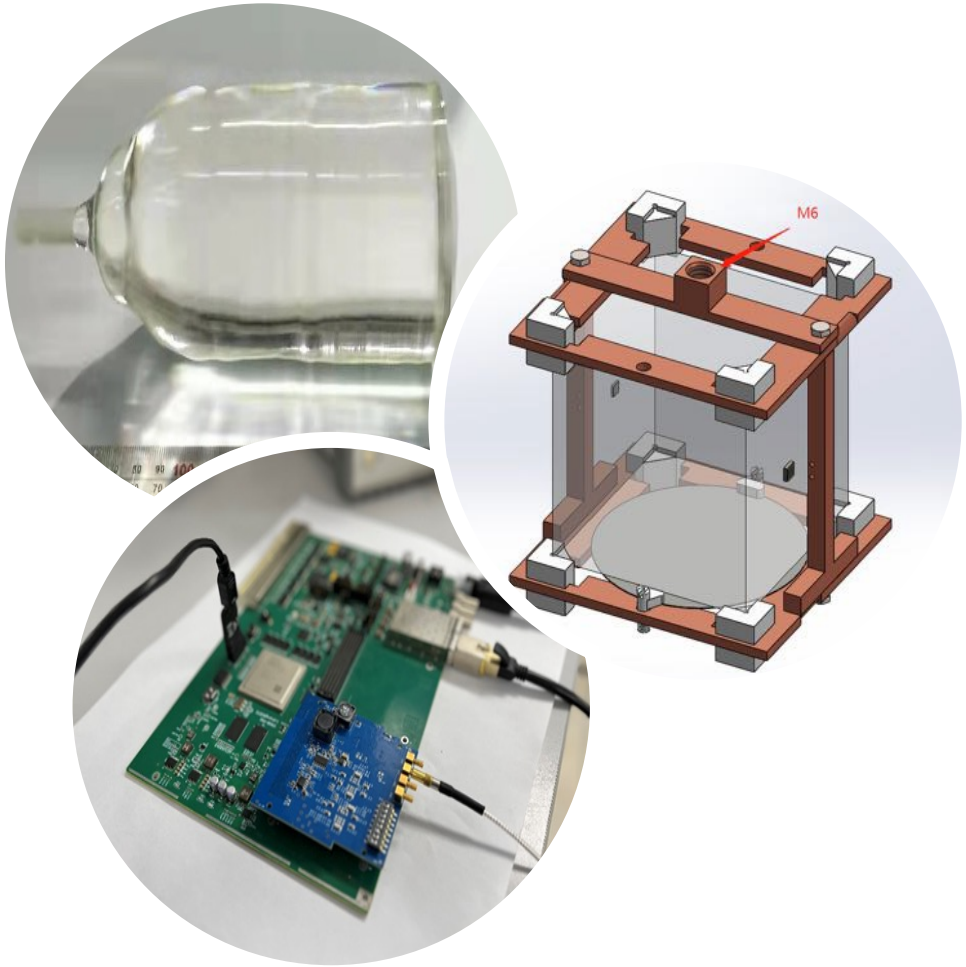
*(*Officially in the international CUPID collaboration)*

~ 8 institutes, > 40 collaborators

CUPID-China is actively collaborating with the international collaboration

CUPID-CJPL Recent Progress

Key Technology R&D



Crystal Production

- Growth of ultra-pure LMO crystal
- Pre-production of ^{100}Mo-enriched crystal

Readout Electronics

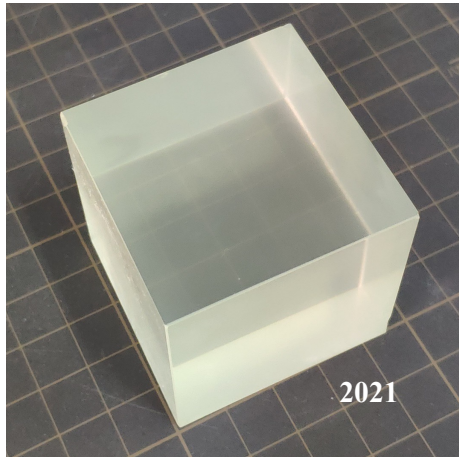
- NTD/TES thermistor fabrication and performance study
- Front-end / DAQ system development and test

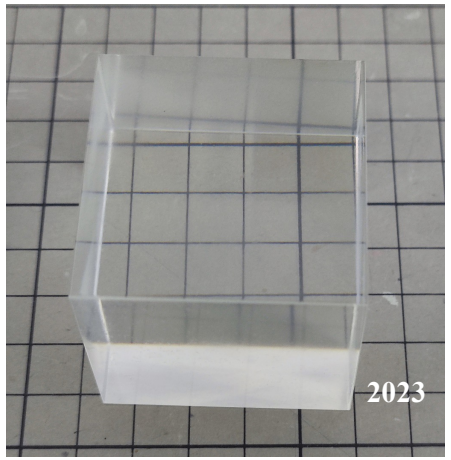
Single Module Bolometer

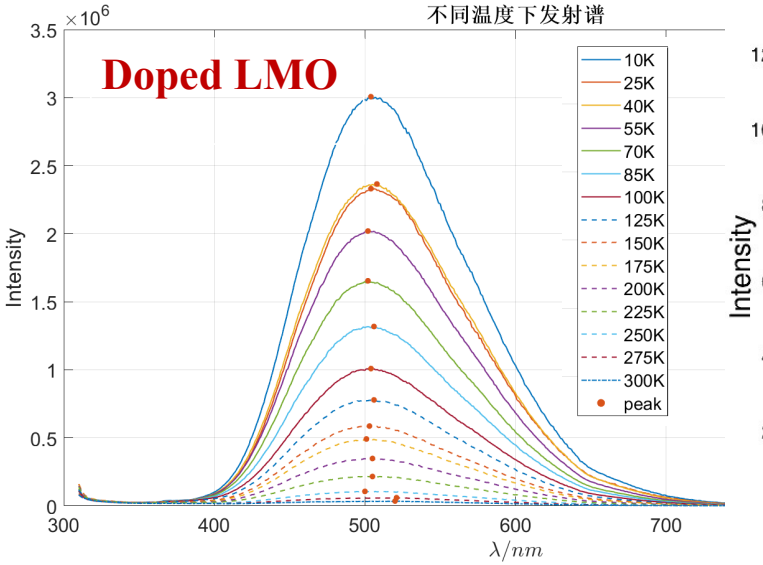
- Ground testing of small crystal
- Heat-light readout performance study

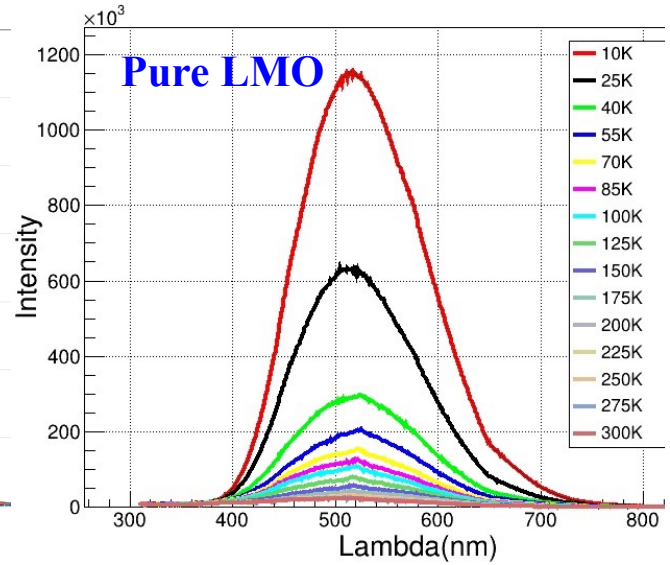
LMO Crystal Production

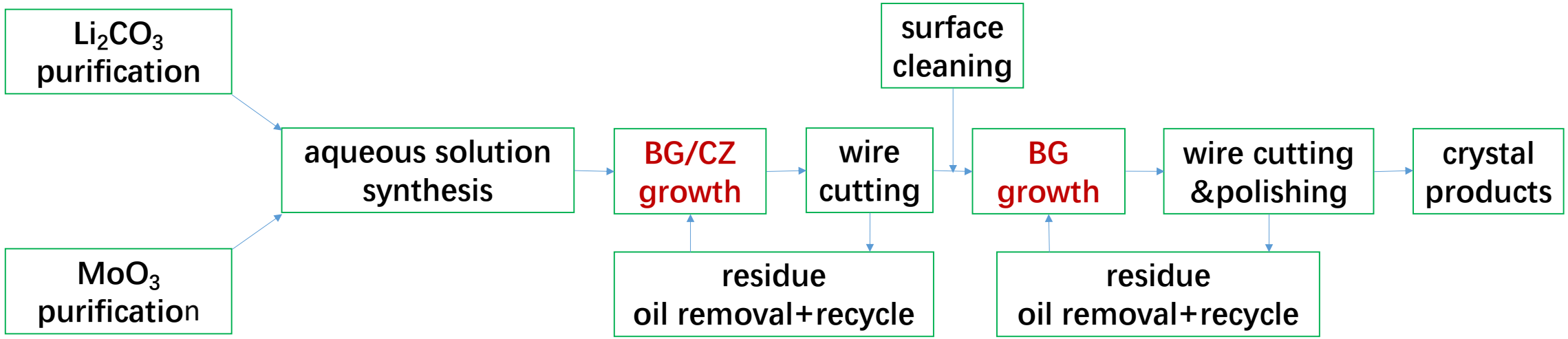
袁晖 et al, SICCAS











^{100}Mo enriched LMO

❒ R&D on the Mo-100 enriched LMO crystal

- Agreement made with INFN and CNRS on pre-production of enriched LMO crystal for CUPID
- Procurement of a few kg enriched raw material (MoO_3 powder) in process
- First sample of ^{100}Mo enriched MoO_3 powder has been produced and QA studied
- Pre-production starts from 2024

SICCAS 中国科学院上海硅酸盐研究所
Shanghai Institute of Ceramics Chinese Academy of Sciences

March 7, 2023

To Istituto Nazionale di Fisica Nucleare (INFN), Italy

Shanghai Institute of Ceramics, Chinese Academy of Sciences (SICCAS) is pleased to support the CUPID Collaboration in proposing a Neutrinoless Double-Beta Decay experiment. A critical component of this experiment will be 1600 enriched $Li_2{}^{100}MoO_4$ (LMO) crystals produced with ~95% ^{100}Mo enriched material. SICCAS is working to become the enriched-crystal supplier for the Italian share of about 60%.

SICCAS has already a story of partnership with INFN since we provided the ~1000 TeO_2 crystals used in CUORE. The crystals were produced in a dedicated line, following protocols that were studied and agreed with the CUORE collaboration. They fully met radiopurity and quality requirements and are now successfully operated as bolometers in CUORE.

For the past several years, SICCAS has been optimizing the production of natural LMO crystals. Cubic LMO crystals with the size needed for CUPID were already delivered from SICCAS and successfully tested at Laboratori Nazionali del Gran Sasso (LNGS) verifying their suitability as absorbers in a bolometer.

During 2023 SICCAS plans to optimize the growth procedure by using high-purity precursors, to study the precursors purification and to define a procedure able to ensure a high efficiency in material recovery. A first batch of 6 crystals will be ready in Spring 2023 and delivered to LNGS for qualification. Based on the qualification results, an optimized production of natural and radiopure crystals will be possible before the end of the year.

Presuming that SICCAS-grown crystals become qualified for CUPID and provided that enriched ^{100}Mo will be available on the market (with quality and quantity suitable for CUPID's needs), SICCAS will be ready to discuss with INFN a production contract that will include the procurement of the enriched material from the selected vendor and the expansion of SICCAS crystal production capacity with the preparation of a dedicated production line for CUPID LMO crystals (as done for CUORE TeO_2 crystals in the past).

Wang Dong

Dr. WANG Dong
Director
Shanghai Institute of Ceramics,
Chinese Academy of Sciences

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http:// www.sic.ac.cn

甲方合同编号：_____

乙方合同编号：_____

三氧化钼物资销售合同

买方：中国科学院上海硅酸盐研究所（下称甲方）

卖方：核工业理化工程研究院（下称乙方）

甲乙双方经过协商，本着自愿平等、互惠互利的原则，就甲方购买乙方本合同约定的产品事宜，达成协议如下：

一、产品名称、规格、数量、价款

产品名称	计量单位	规格型号	含税单价（元）	数量	含税总价（元）	不含税总价（元）
三氧化钼	克	钼-100 丰度≥95%	700.00	200	140,000.00	123,893.80
小写合计			-----	----	140,000.00	123,893.80
含税总价款（大写）	壹拾肆万元整					

1.1 随本合同交付，乙方另提供一份样品，用于甲方前期测试。

1.2 以上含税价的税率为 13 %，如遇国家税率调整，上述含税单价和含税总价按照以下原则计算：先付款后发货的，按照支付货款时的税率计算，支付预付款后发货的和货到验收合格后付款的，按照收到货物时的税率计算。甲、乙双方按照前述税率以及前述原则计算的价款进行开票、结算。

二、产品质量标准：按甲乙双方约定执行。

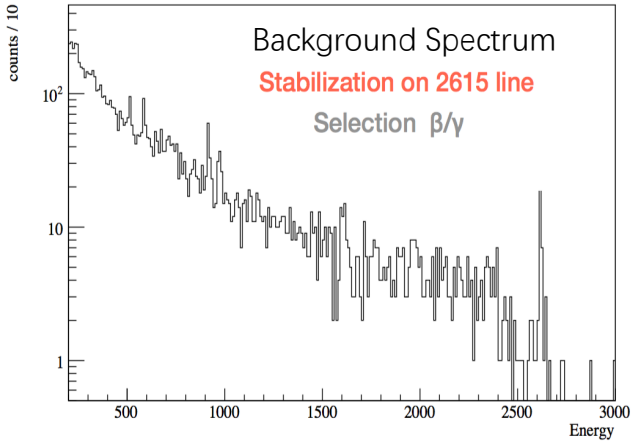
三、包装方式：本产品容器由乙方提供，但需双方对容器要求协商一致，密封存储。

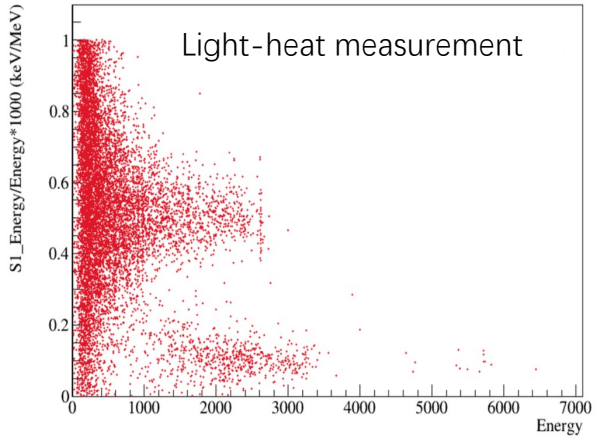
四、交货

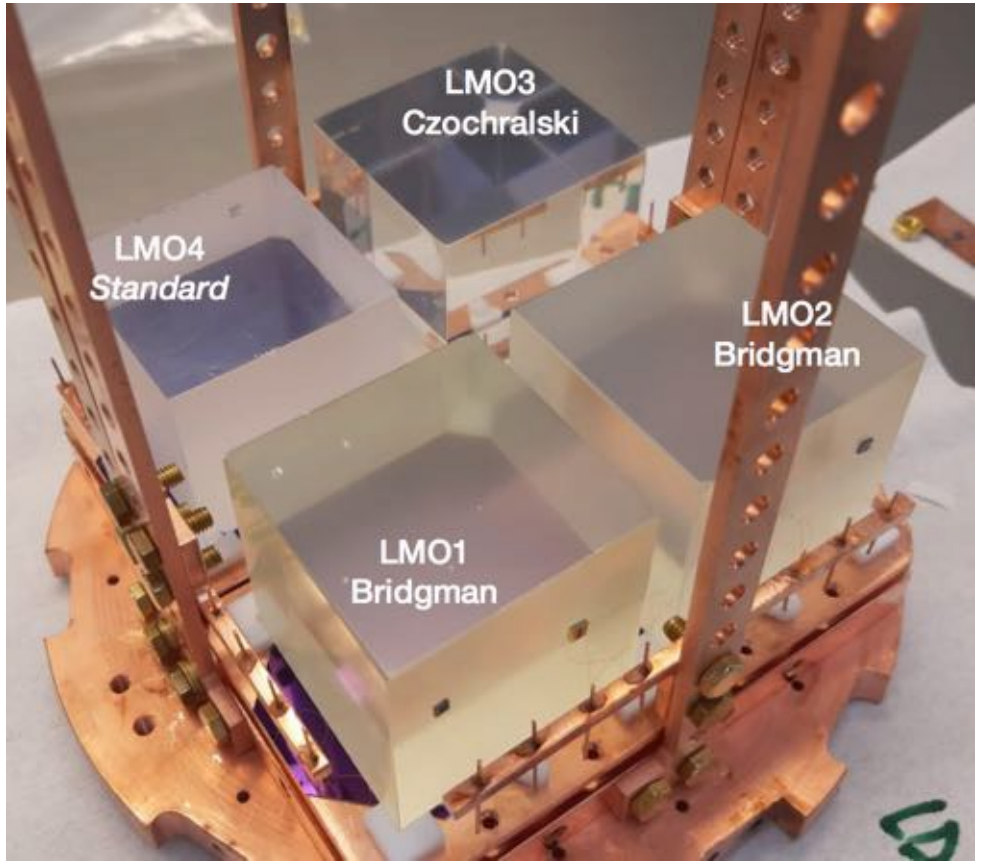
Meeting with INFN CUPID, Sep. 25, 2023 @ SICCAS

LMO Crystal test @ INFN LNGS

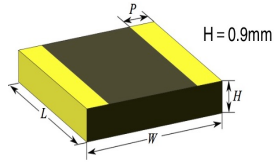
- Sensitive quality evaluation through bolometer run (CCVR/BDPT)
- Good energy resolution and light yield observed for all the crystal samples ⇒ clear alpha discrimination
- New LMOs (2023) produced with cleaner materials is being tested now at LNGS

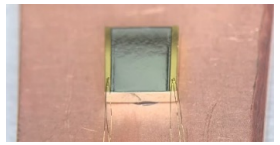


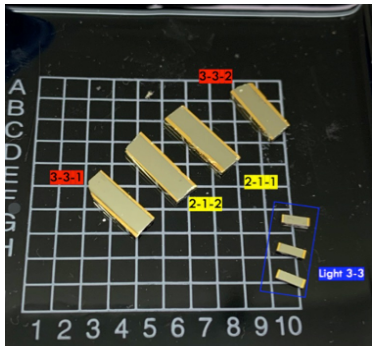


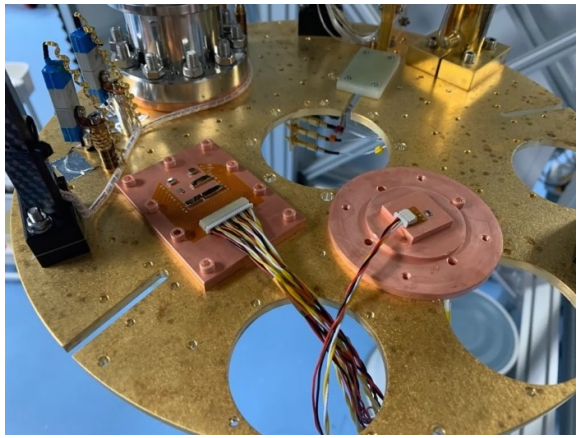


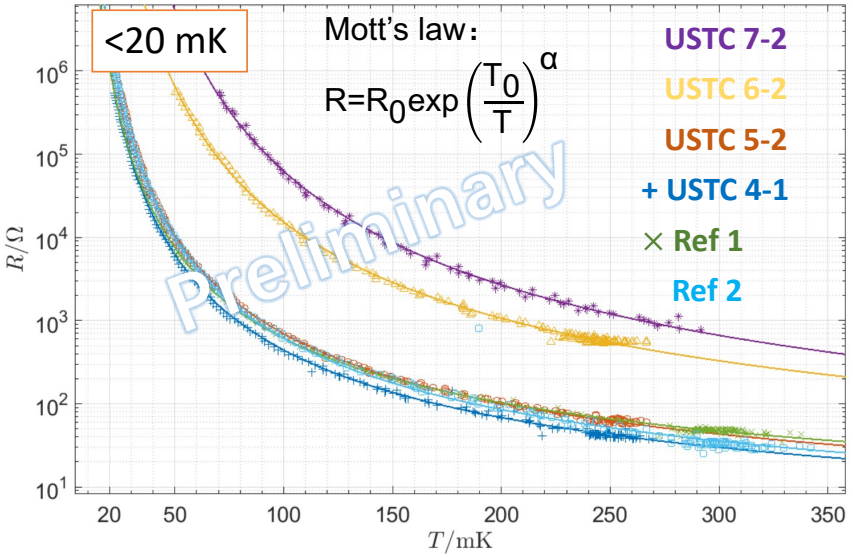
NTD-Ge thermometer

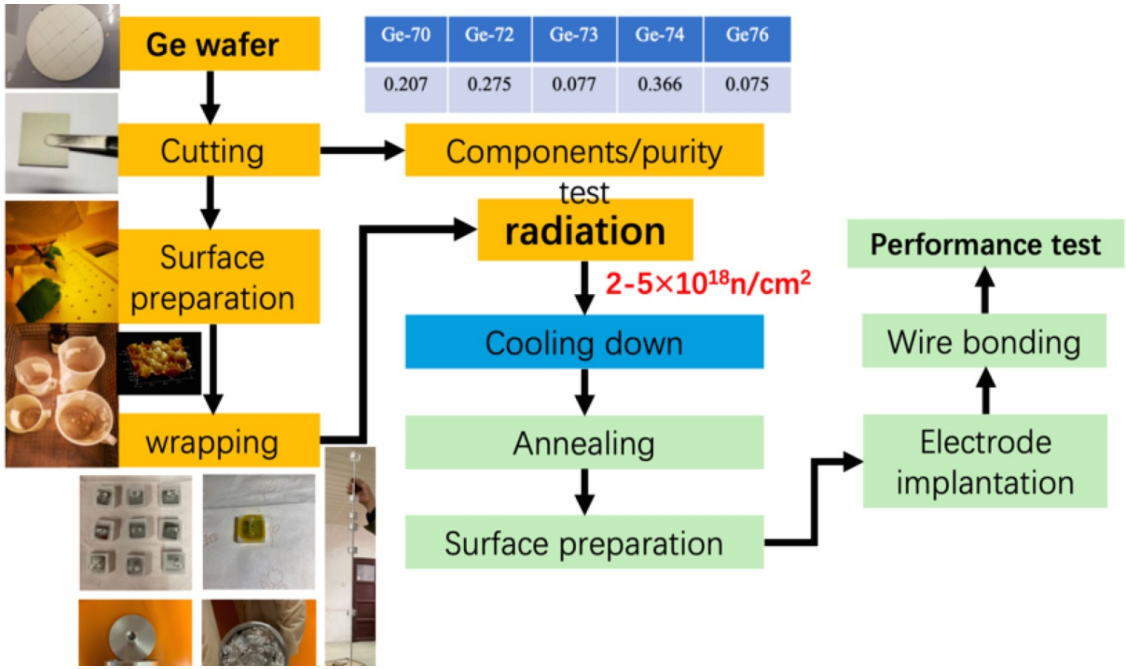












Ge-70	Ge-72	Ge-73	Ge-74	Ge76
0.207	0.275	0.077	0.366	0.075

❒ **NTD-Ge (Neutron Transmutation Doped germanium thermistor)**

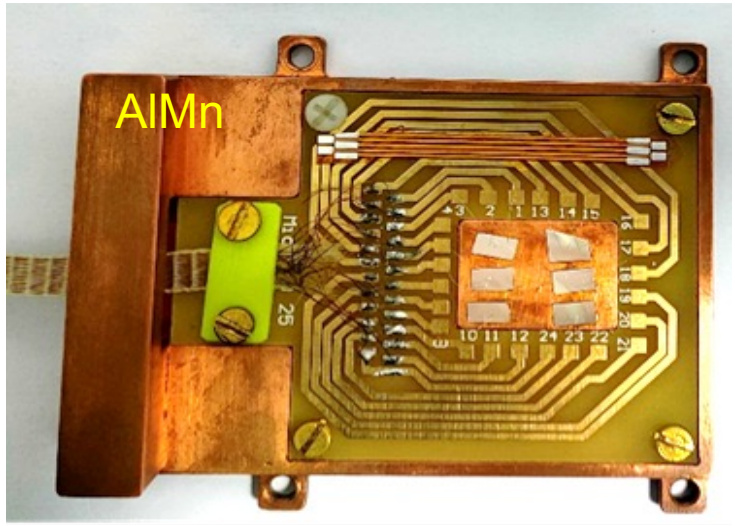
- key component for heat (phonon) signal readout
- well established fabrication process
- continuous optimization of the processing technique

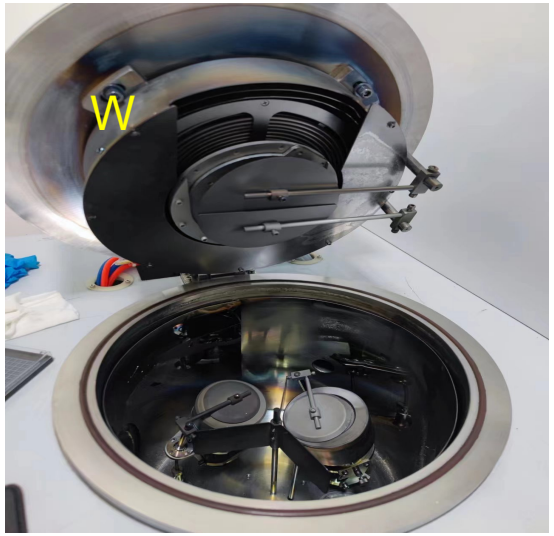
❒ **Performance study**

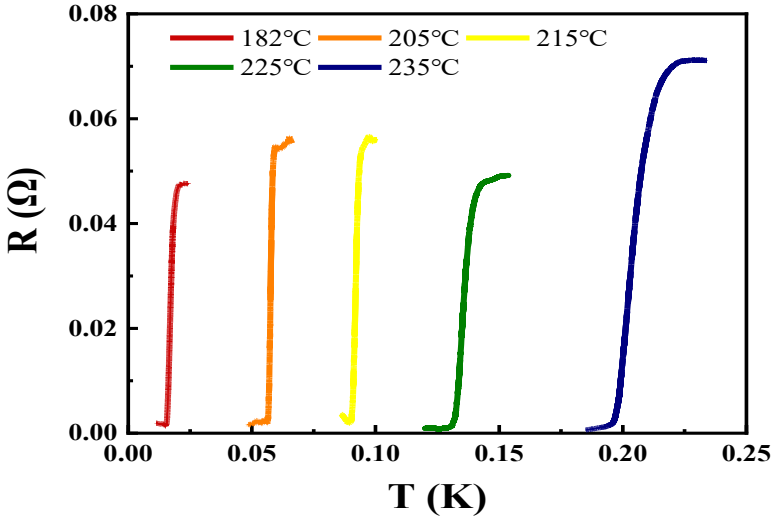
- I-V and R-T curve: R >10MΩ @ T<20 mK

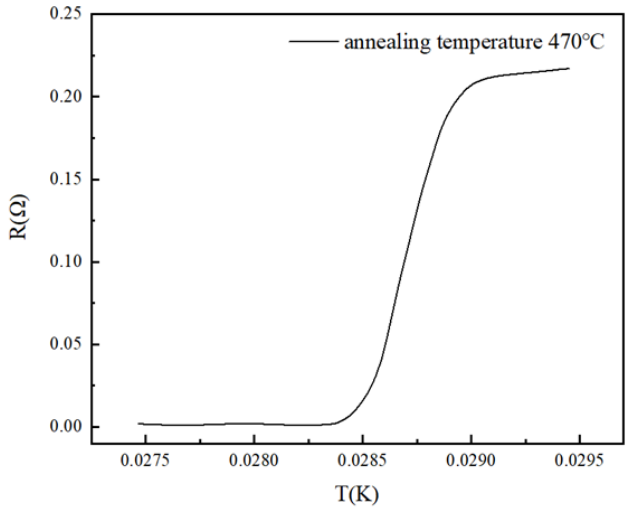
薛明萱／赵康康 et al, (USTC)

Transition-Edge-Sensor (TES)







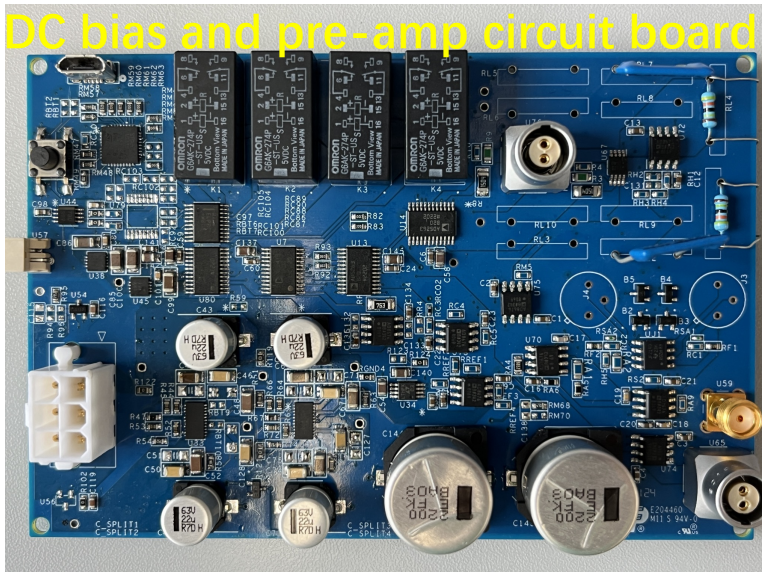


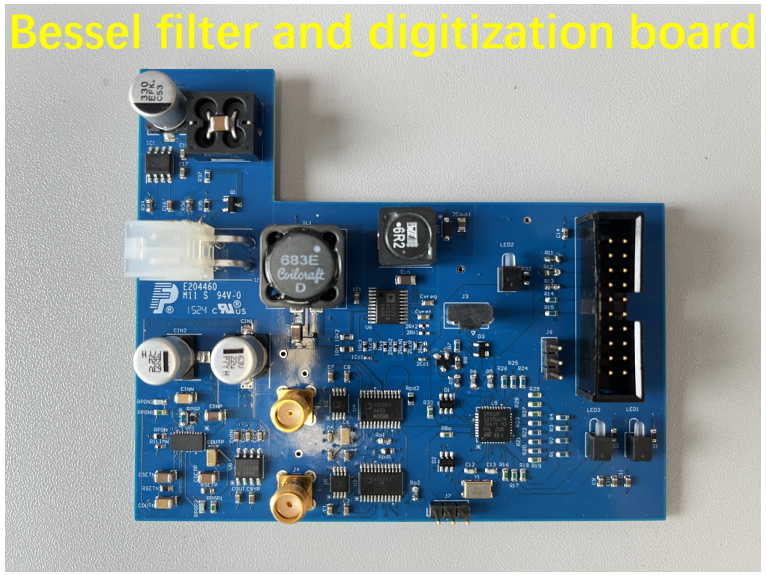
- TES for **faster** light readout
- Novel technique for the future experiment
- AlMn/W superconducting film preparation and performance study:

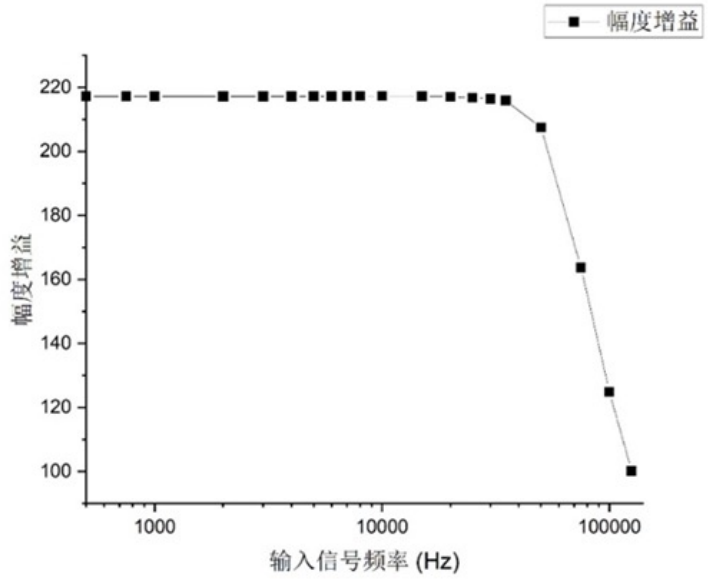
  material/thickness/coating
- Optimization towards the goal of Tc < 20 mK
- Progresses made in simulation for chip design

刘圆圆 / 王宇 / 刘舟慧 et al, (BNU / IHEP)

Electronics R&D



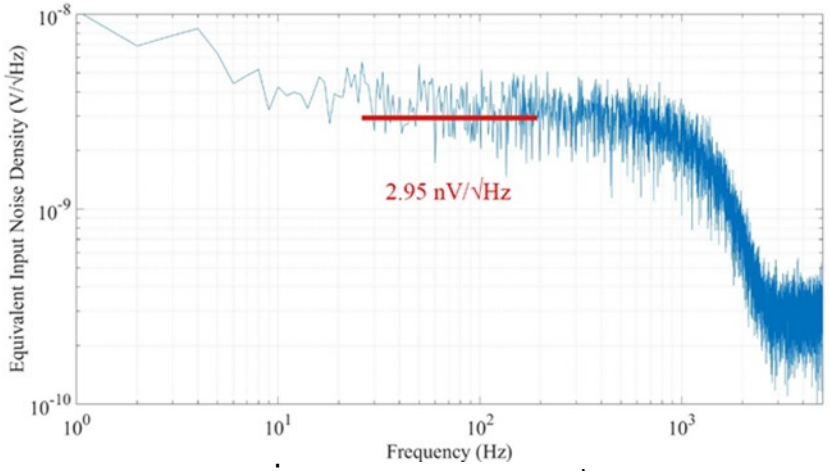




frequency response

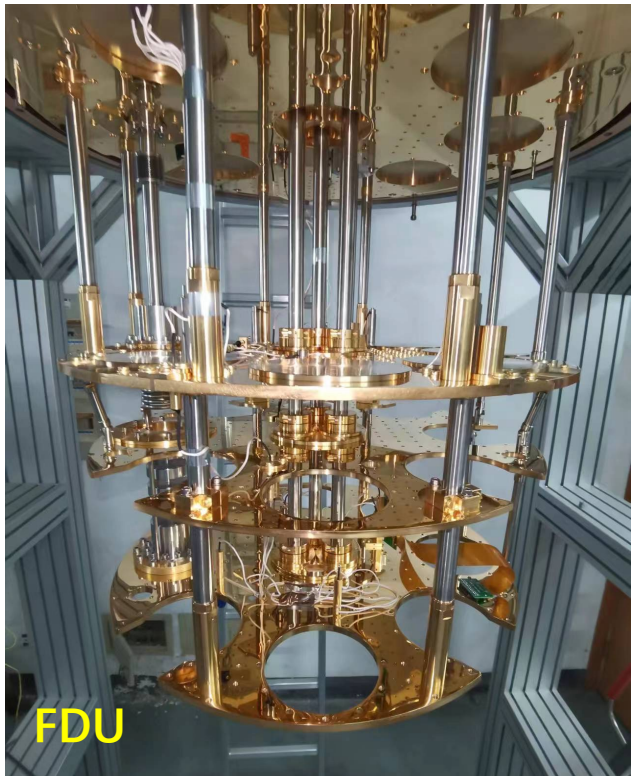
❒ **R&D on the low noise Front-End electronics**

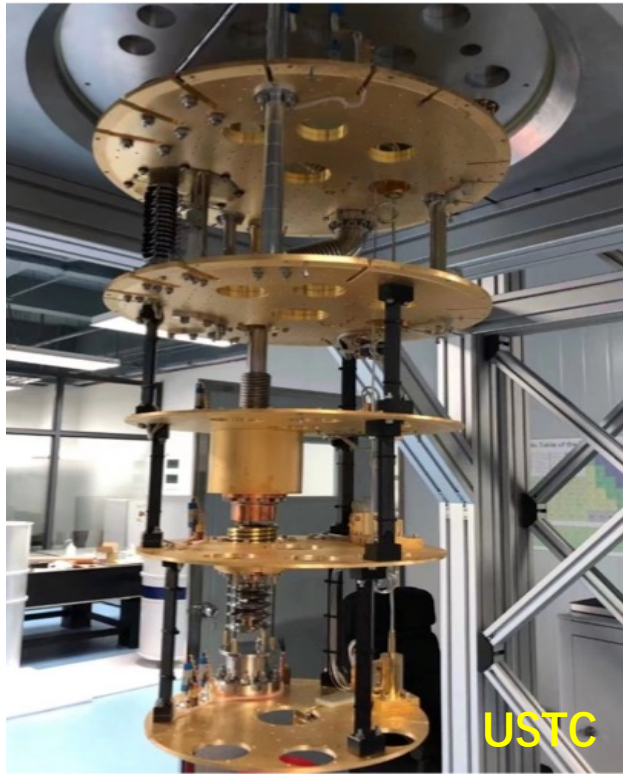
- improved design of the NTD-Ge Front-End board
- measurement of the equivalent input noise spectral density ⇒ competitive low level



noise power spectrum

Cryogenic

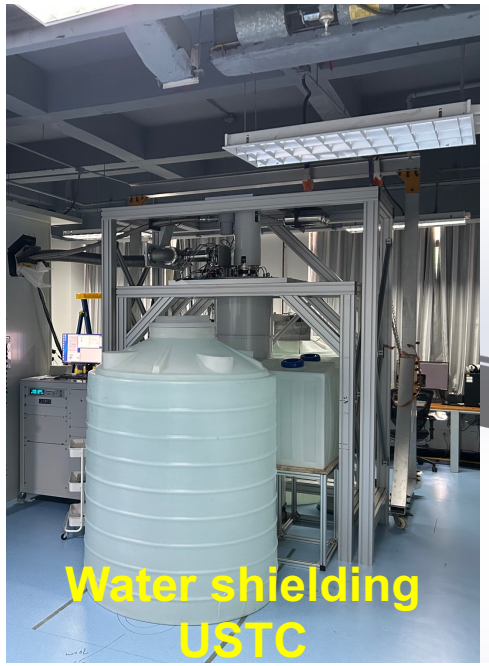


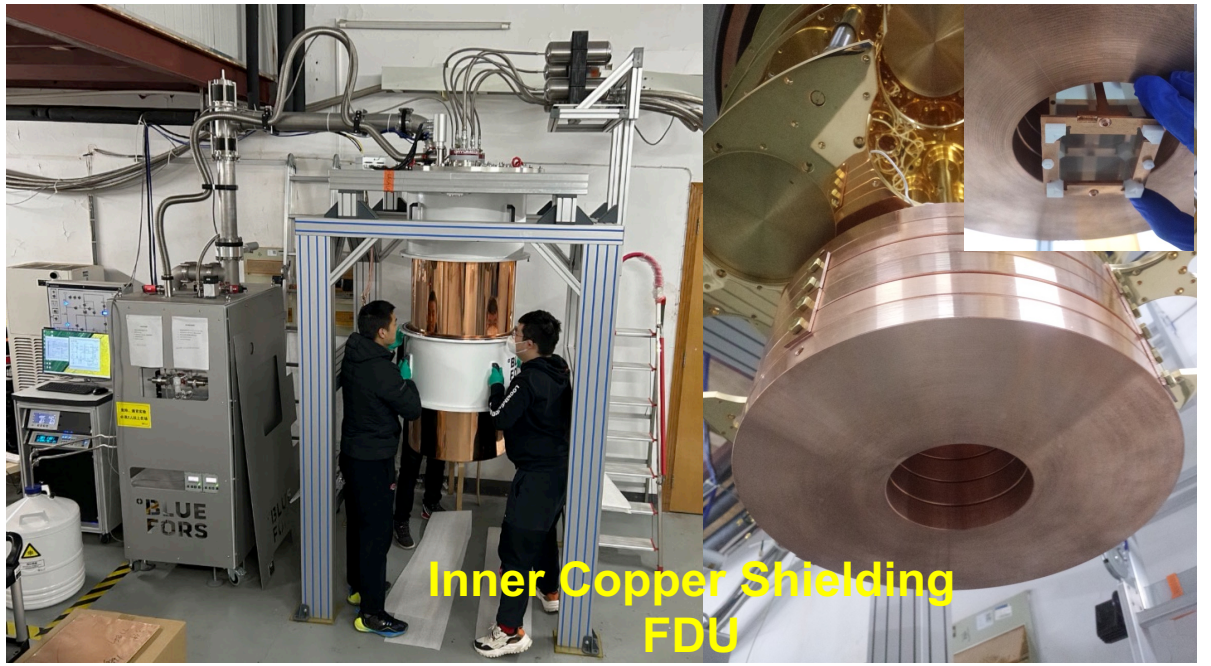


USTC-DR: commercial system for crystal test at ground
FDU-DR: customized system for underground experiment

Shielding

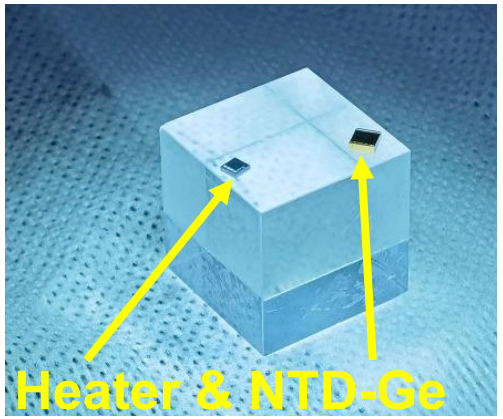
- ❒ Signals from cosmic ray & environmental radioactive background
- ❒ Typical decay time **~100 ms** for heat channel
- ❒ Heavy pile-up issue ⇒ use **smaller crystal** & **Pb/Cu/water shielding**

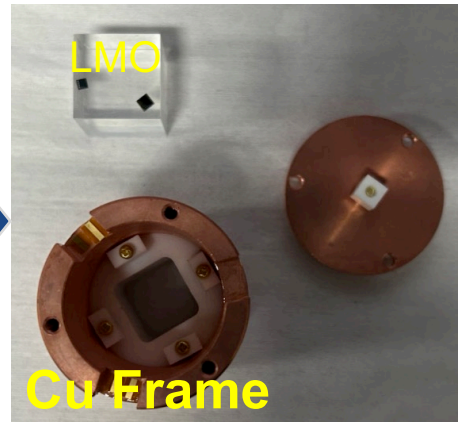


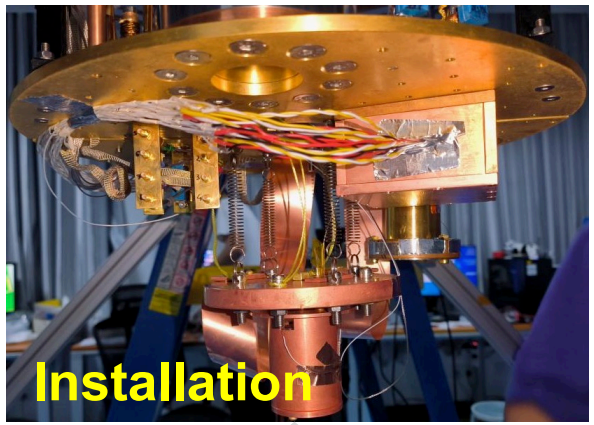


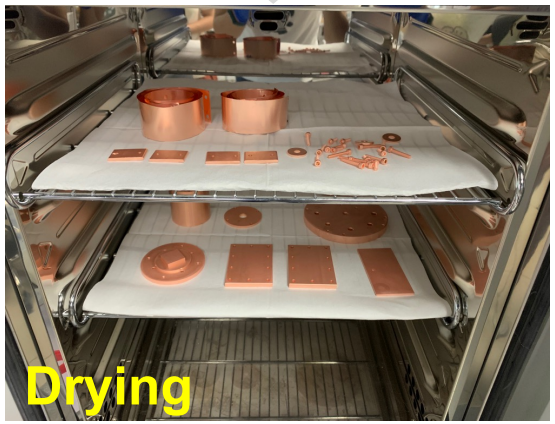
Bolometer Module Assembling

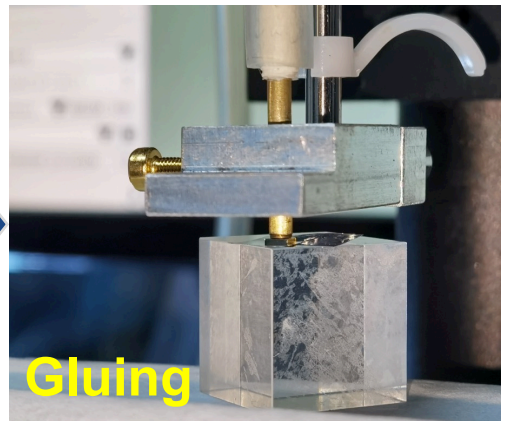
- Testing of the small size LMO crystal (2x2x2cm^3 /1x1x1 cm^3, BG/CZ)
- Module components: LMO crystal, NTD-Ge, heater, PTFE/Cu holder
- Assembly process well established

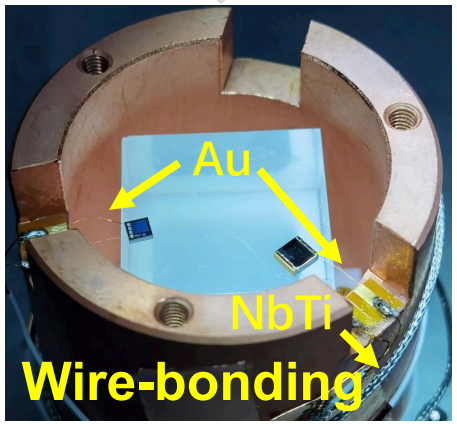


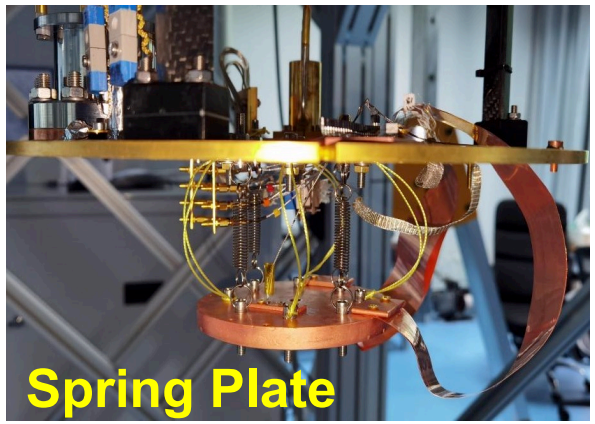




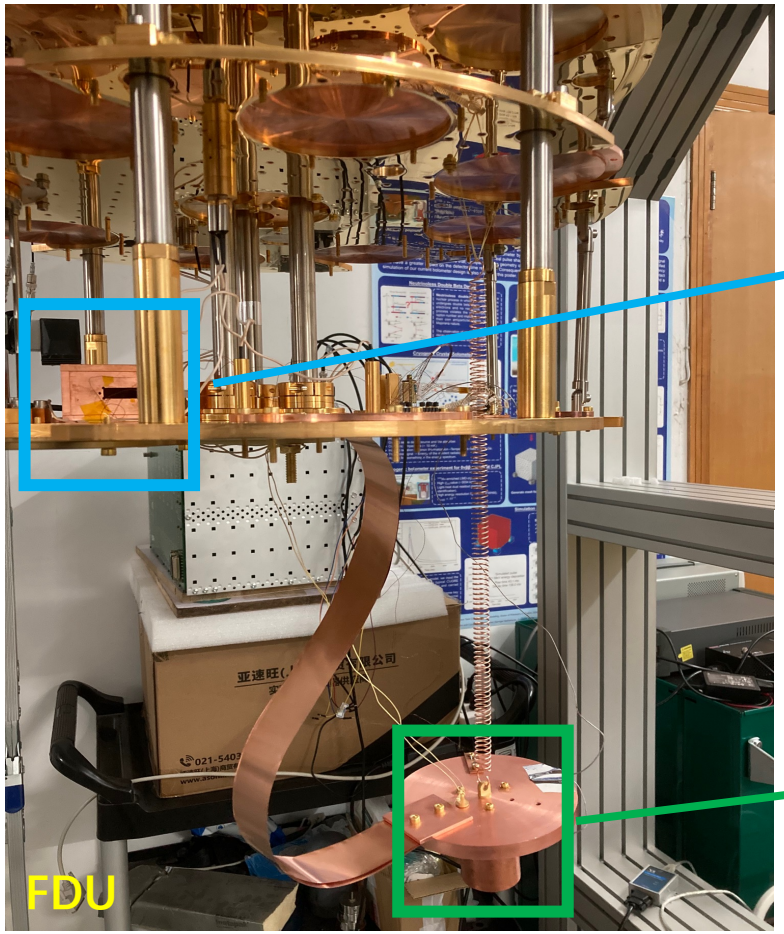


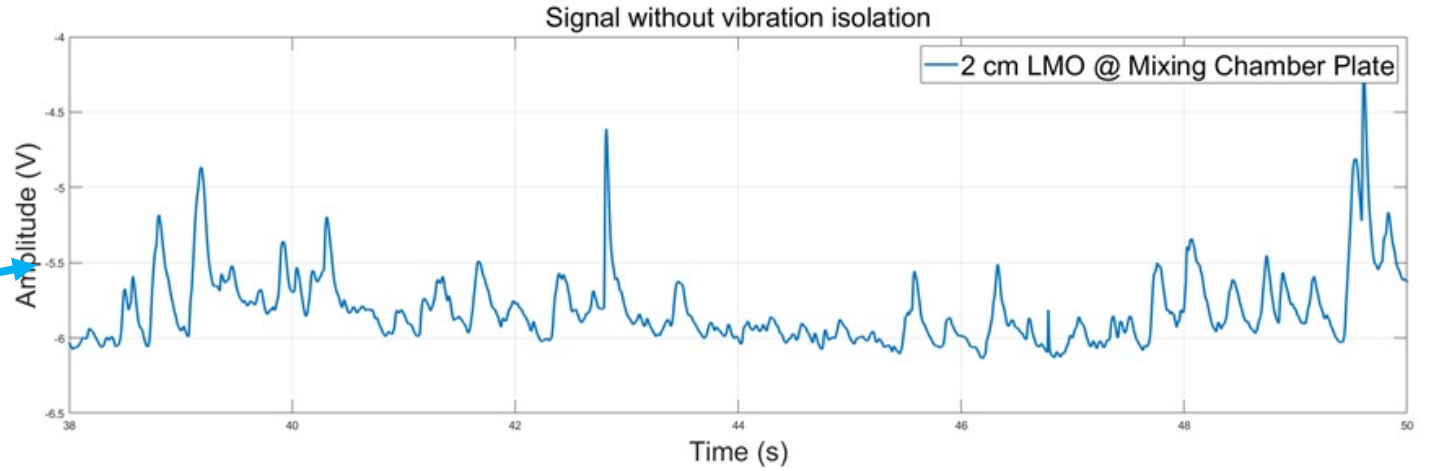


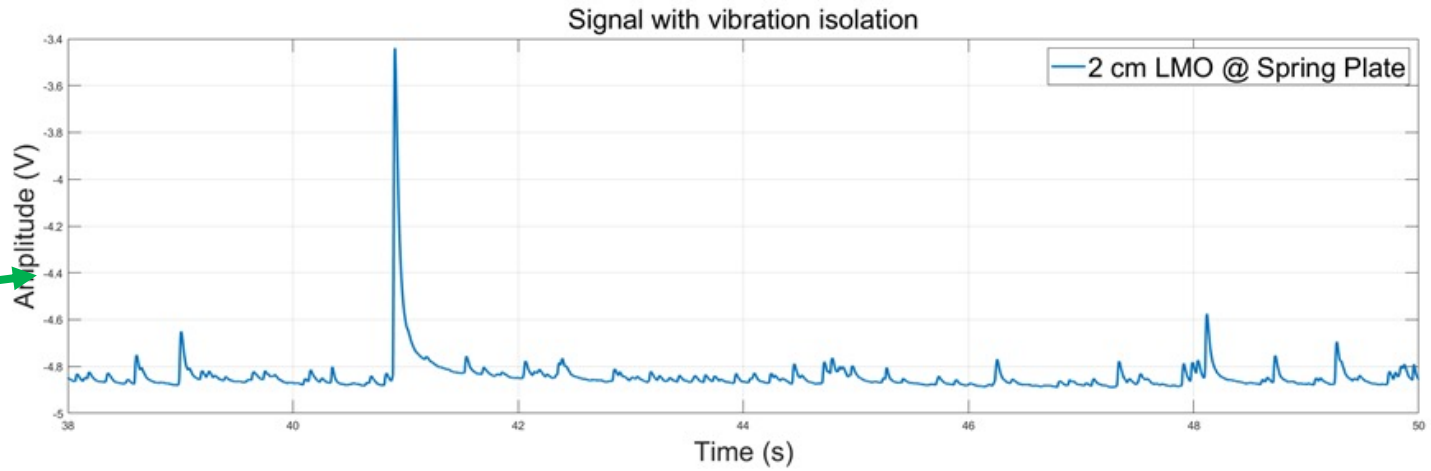




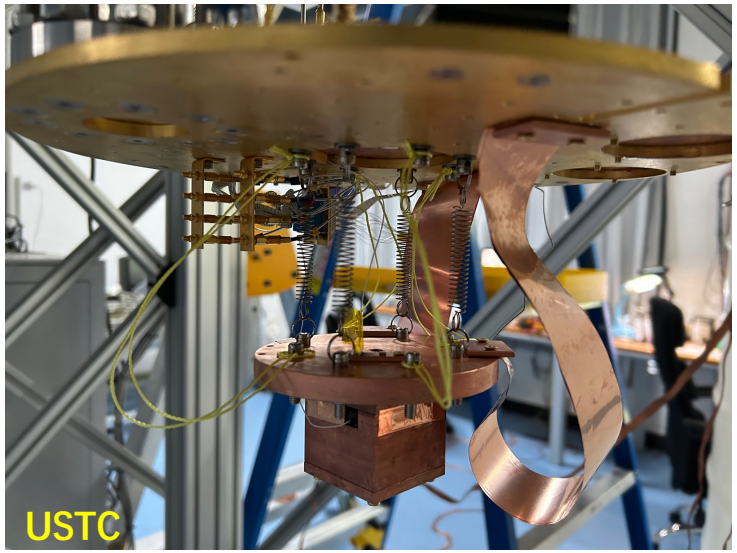
Spring Vibration Damping

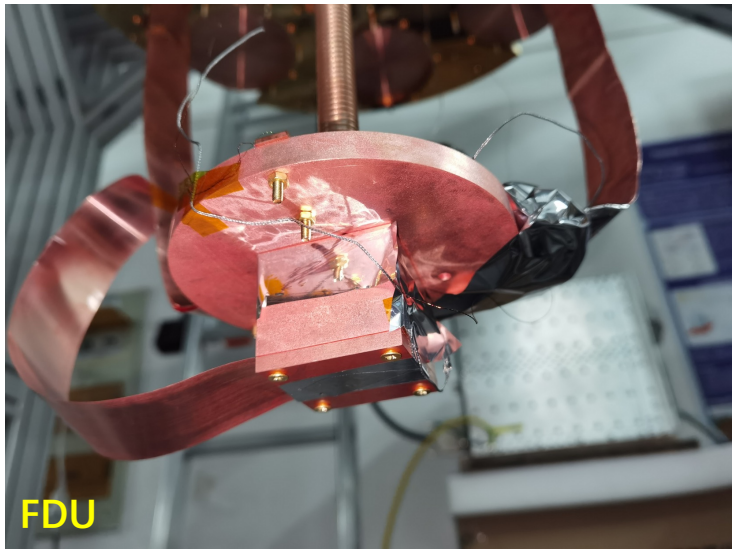


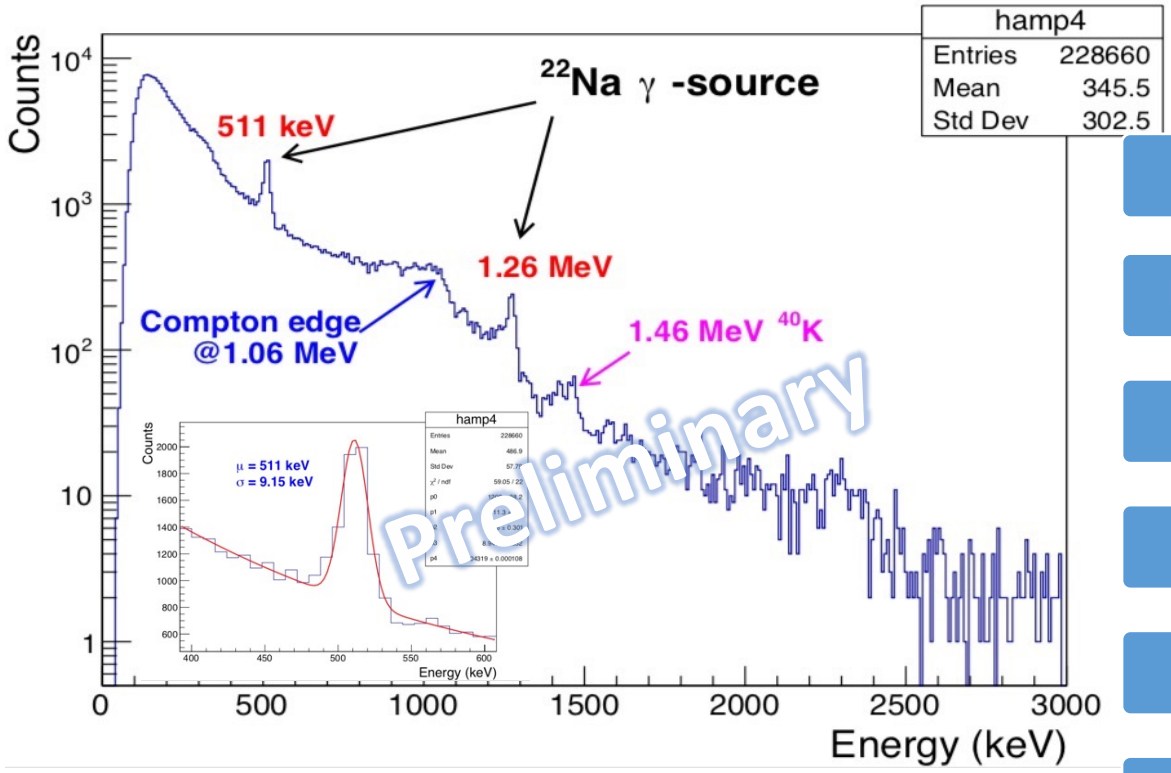




LMO Crystal Test in the Ground Lab







Data Processing

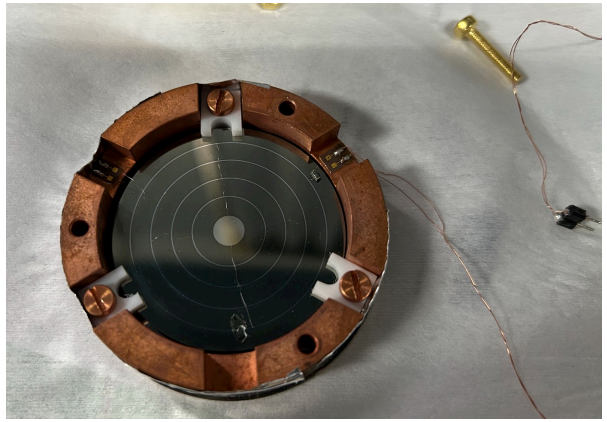
- Derivative Trigger
- Periodic Noise Subtraction
- Pulse Shape Cut
- Optimal Filter
- Extract Amplitude
- Temperature stability correction
- Spectrum

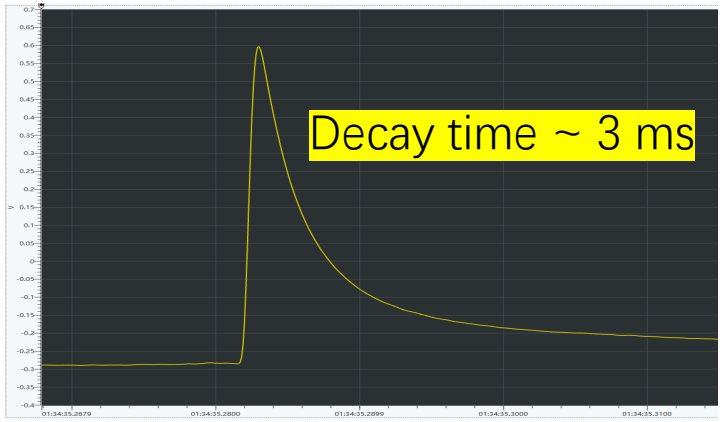
- ❒ Both heat & light channel are tested.
- ❒ Heat channel are calibrated by:

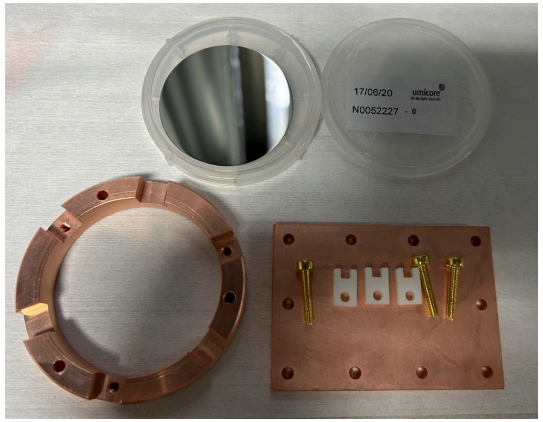
  ^{22}Na: 511 keV, 1.27 MeV; ^{40}K: 1.46 MeV
- ❒ FWHM 21.5 keV@511 keV, 28.9 keV@1.27 MeV

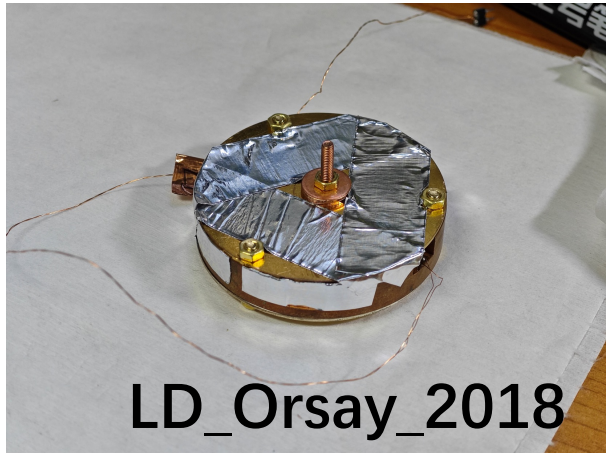
Light Detector R&D and Test in the Ground Lab

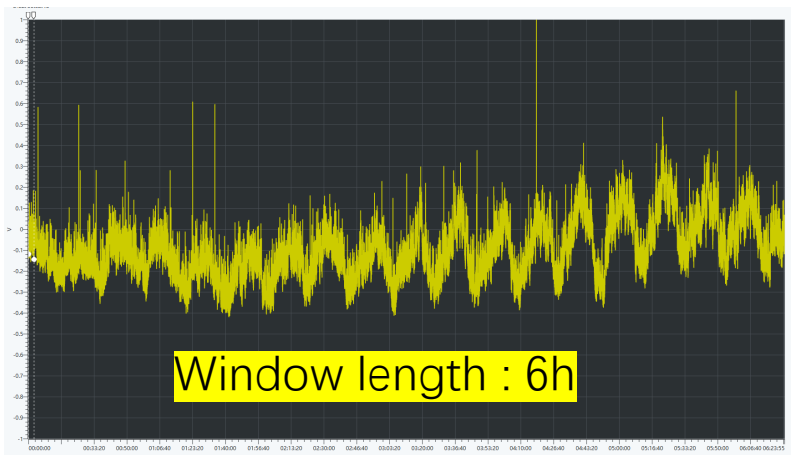
- ❒ Light detector from Orsay_2018, fixed on the MC plate, response to cosmic ray, vibration
- ❒ Light detector from USTC, bad thermal conductance, fixed on MC, ~60 mK

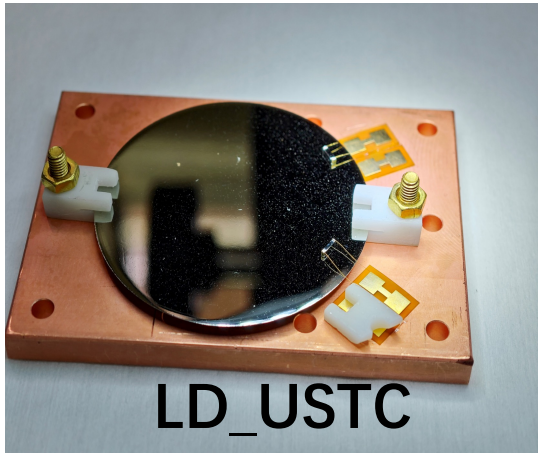










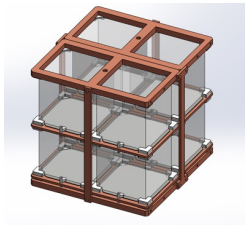


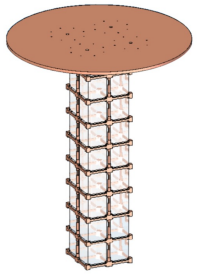
Summary and Plan

CUPID-CJPL Roadmap

Module test

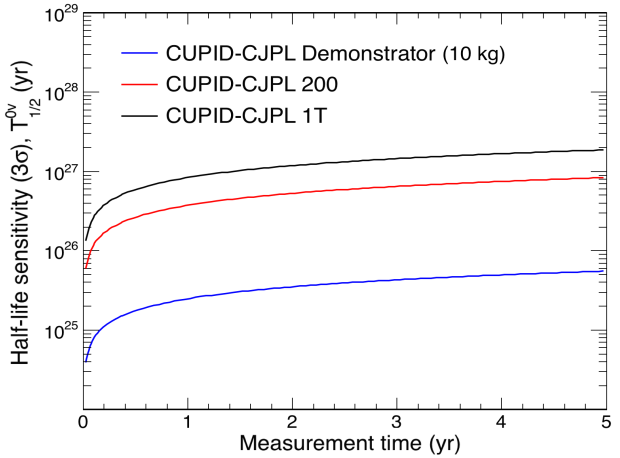
6-12 natural crystals
(2023-2025)





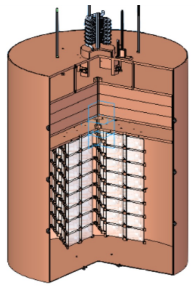
10 kg enriched crystals
(2025-2028)

CUPID-CJPL Demo



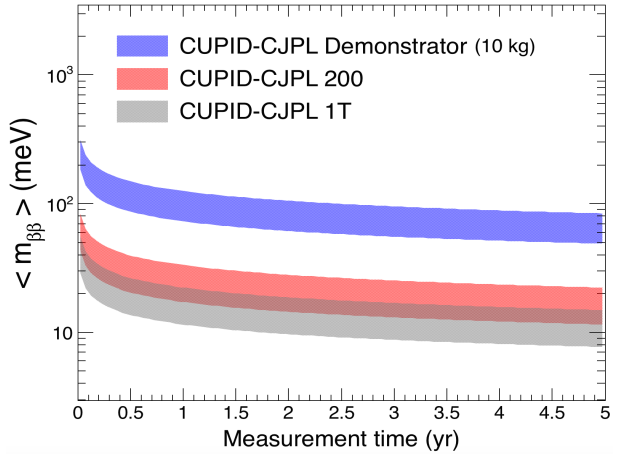
CUPID-CJPL 200

200 kg enriched
crystals
(2028+)



ton-scale experiment

CUPID-CJPL 1T



Summary

❒ **CUPID-CJPL**

- search for 0νββ of ^{100}Mo
- cryogenic scintillating bolometer

❒ **CUPID-CJPL Demonstrator**

- demonstration of key technologies for ton-scale experiment at CJPL

❒ **Progresses have been made**

- ultra-pure crystal growth
- low noise read-out system
- bolometer module test

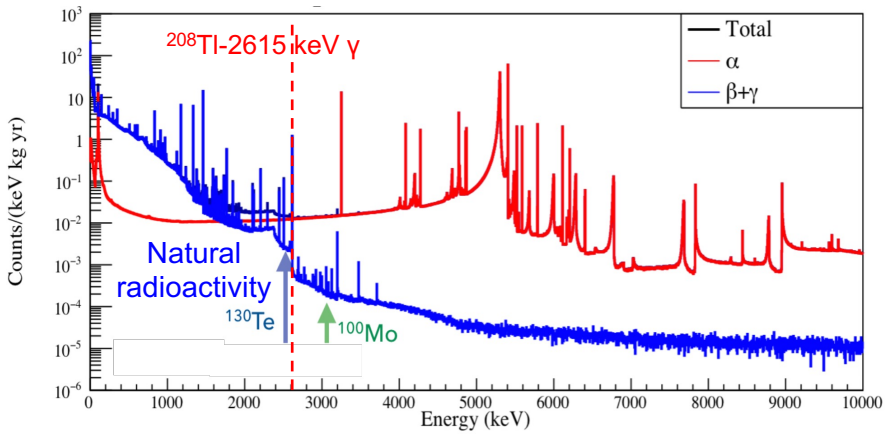
❒ **R&D in progress**

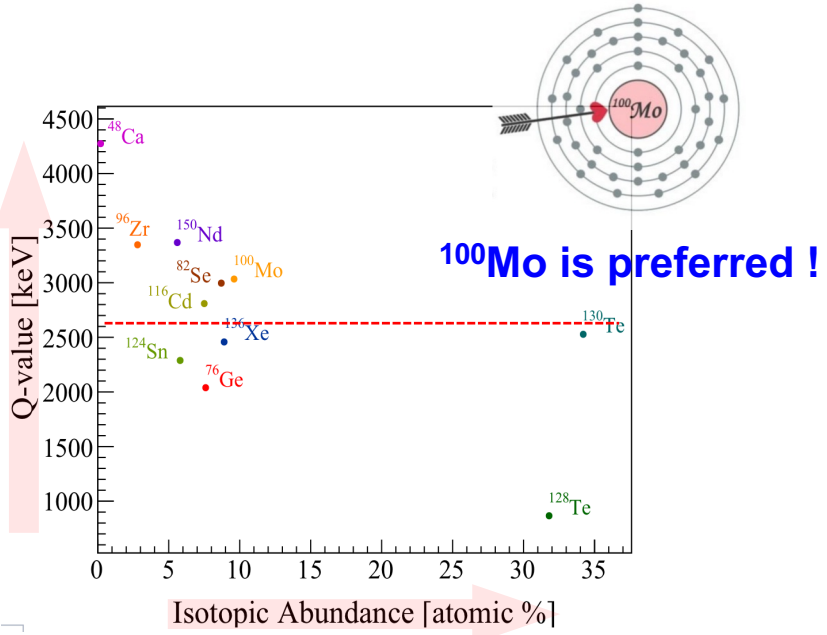
- ^{100}Mo-enriched radio-pure crystal growth
- light module test & optimization
- data processing & denoise method

Thanks

Why Mo-100 ?

- **Q-value and natural abundance**
- background level and enrichment cost

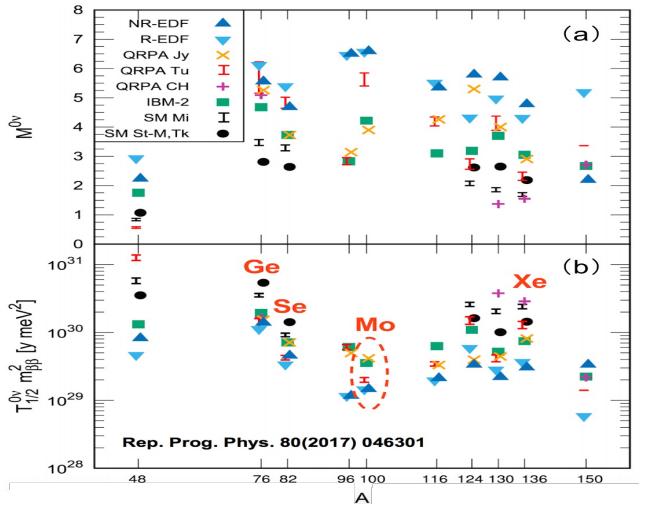




^{100}Mo is preferred !

- **Decay rate**
- for finite $m_{\beta\beta}$, the larger $|M^{0\nu}|^2 G^{0\nu}$ (or smaller $T^{0\nu}_{1/2} \mid m_{\beta\beta} \mid^2$), the larger 0νββ decay rate (event rate)

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



CUPID potential for multiple physics studies

0vDBD/2vDBD

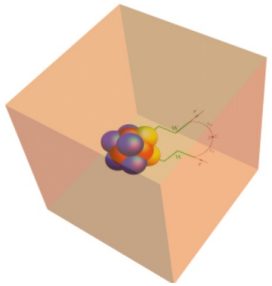
- Multiple isotopes

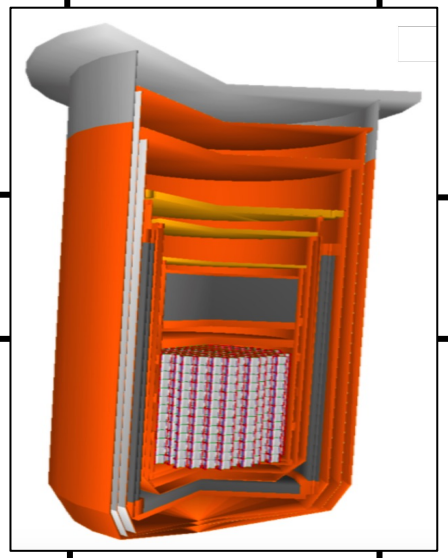
$Zn^{82}Se$

$Li_2{}^{100}MoO_4$

$Na_2{}^{100}MoO_4$

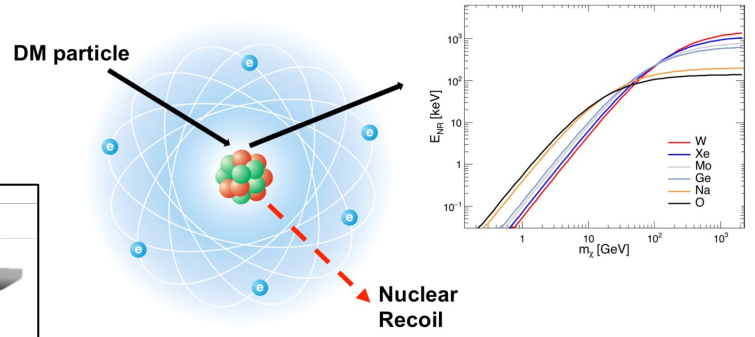
$Cd^{100}MoO_4$



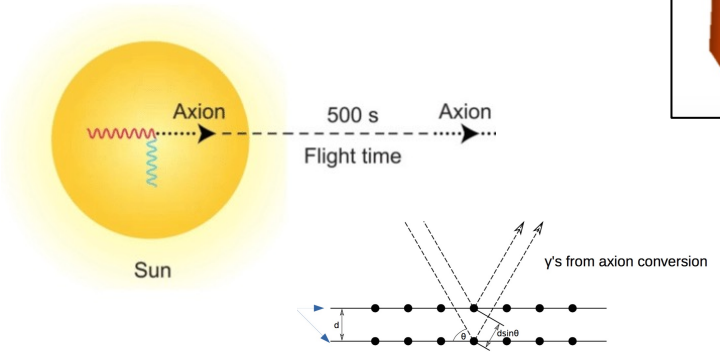


CEvNS
Supernova ν
…

Dark matter

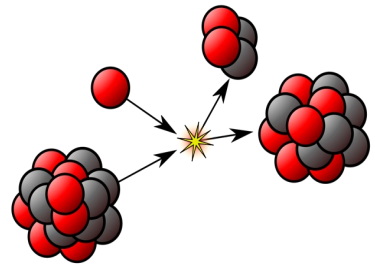


Solar axion



Rare nuclear decay

e. g. excited states/tri-nucleon



backups