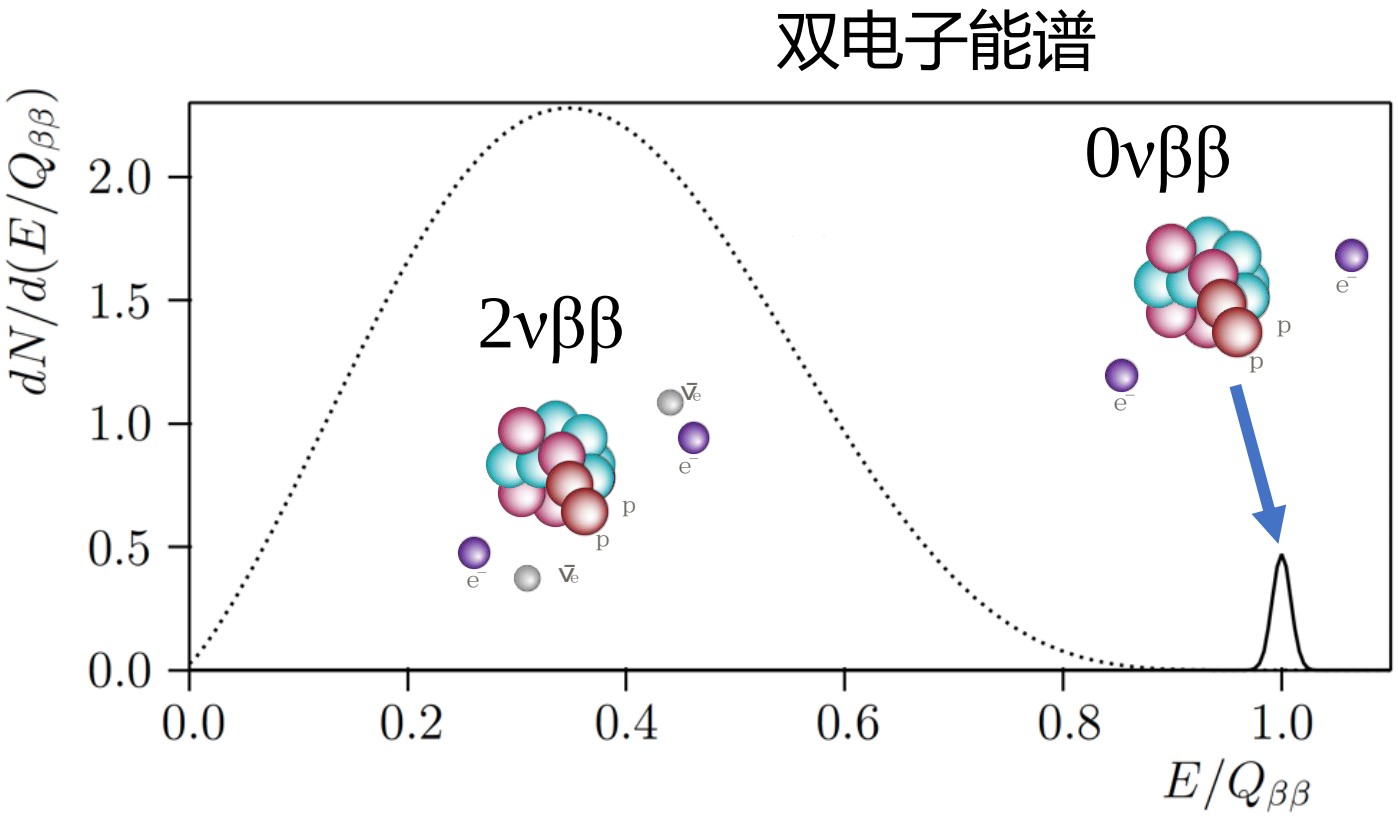
CUPID-China实验进展与计划

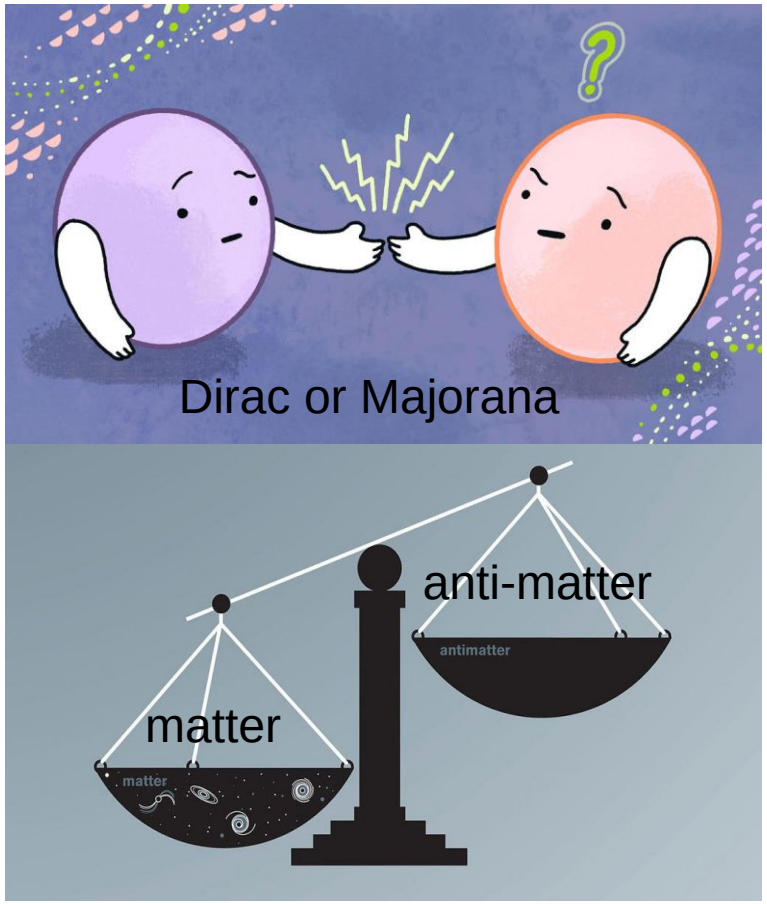
陈昊 复旦大学现代物理研究所

CUPID-China合作组

第十四届全国粒子物理学术会议@青岛
2024年8月15日

无中微子双贝塔衰变(0νββ)--> 新物理?

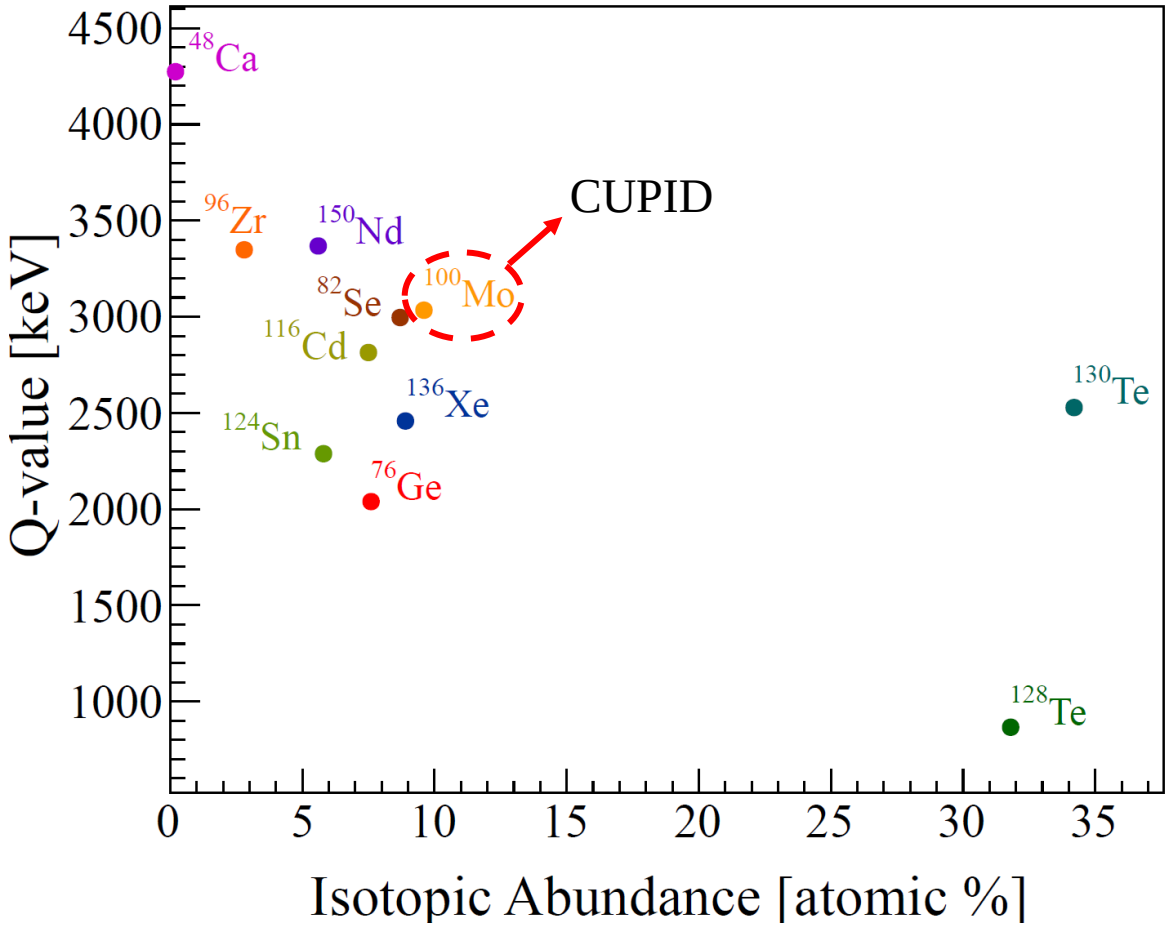


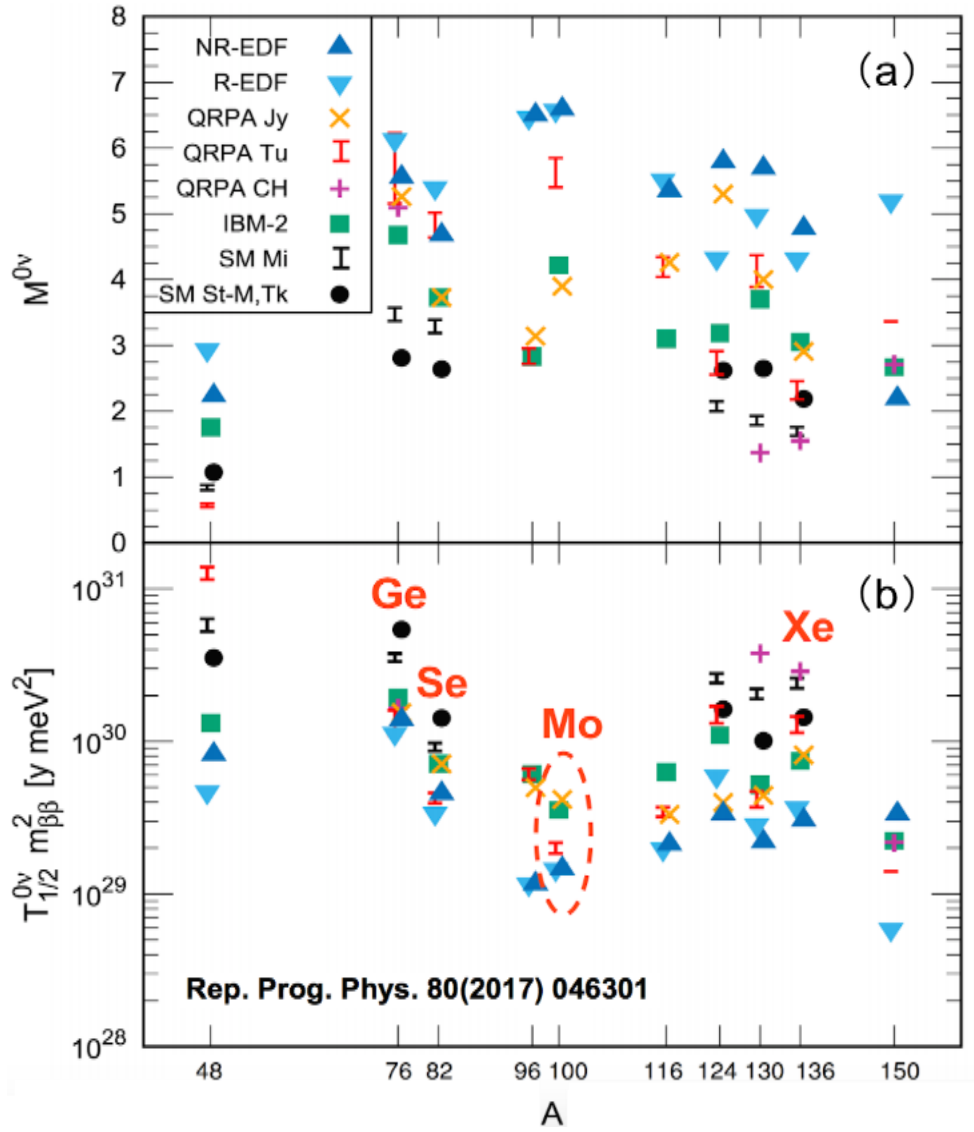


非常明确的实验观测目标

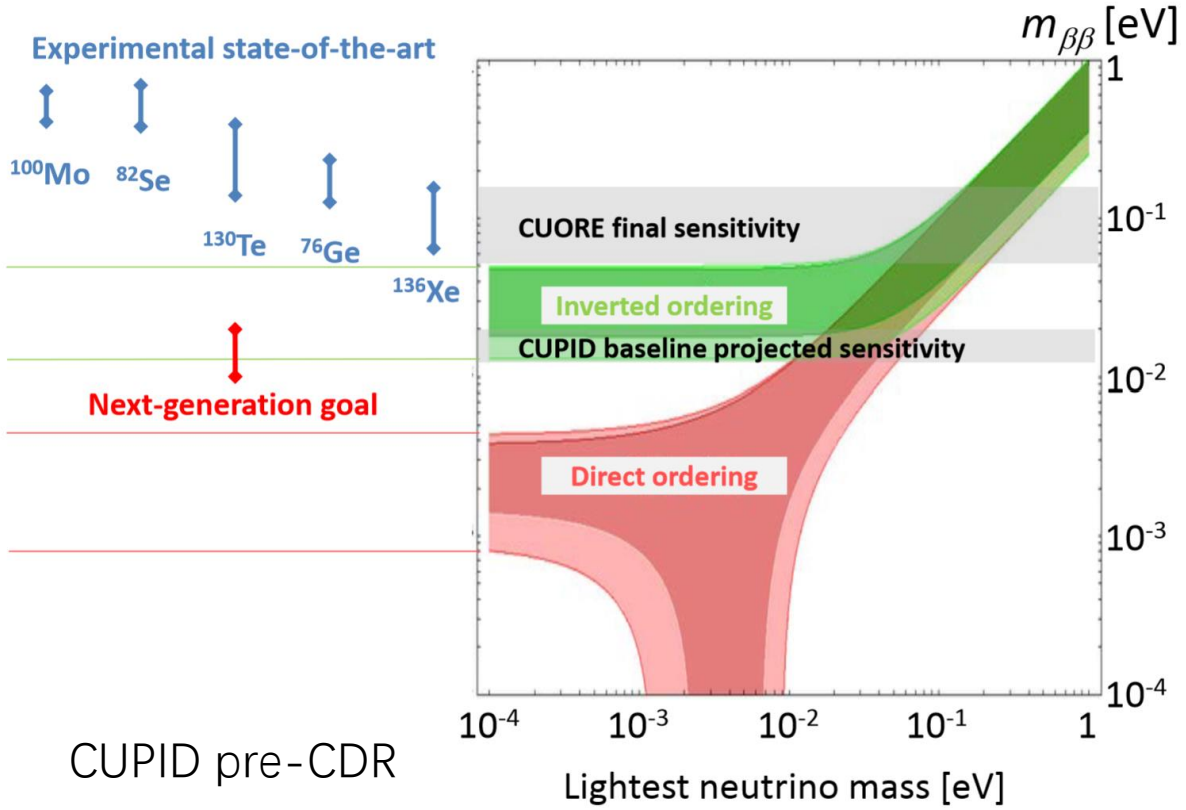
丰富而重要的物理意义

0νββ实验可用的同位素

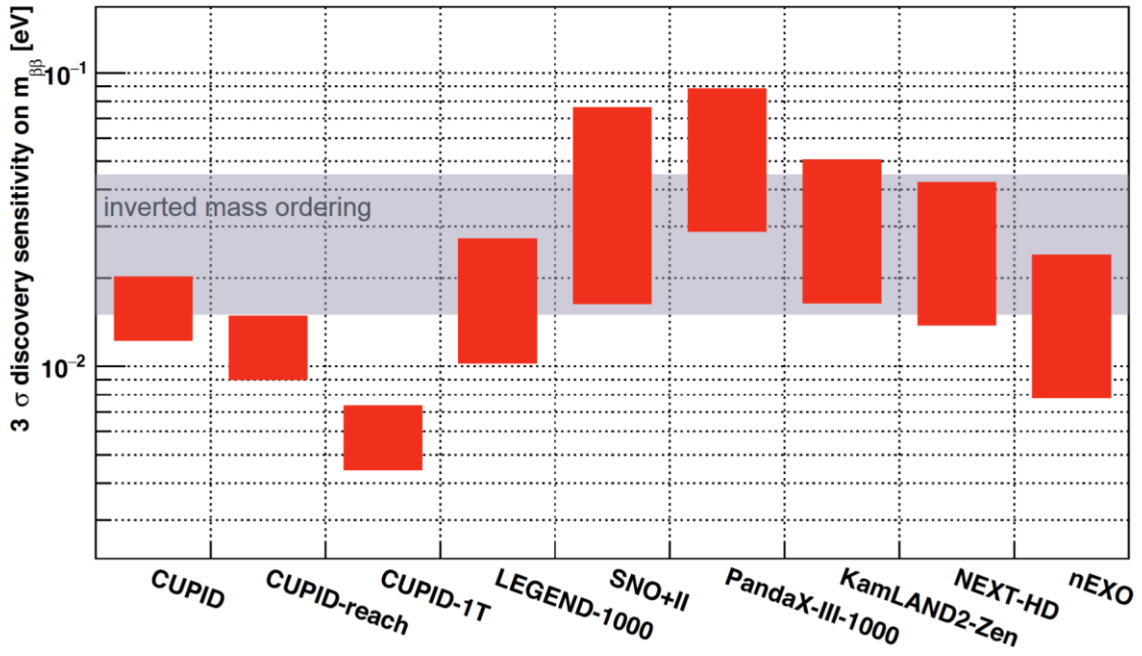




下一代0νββ实验目标



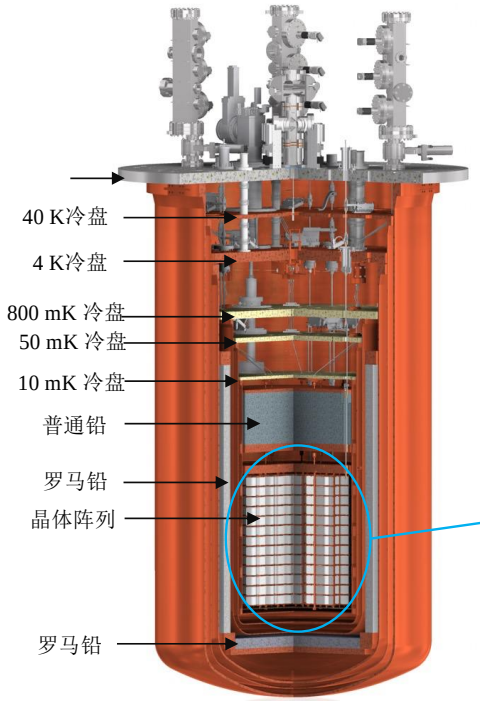
CUPID pre-CDR

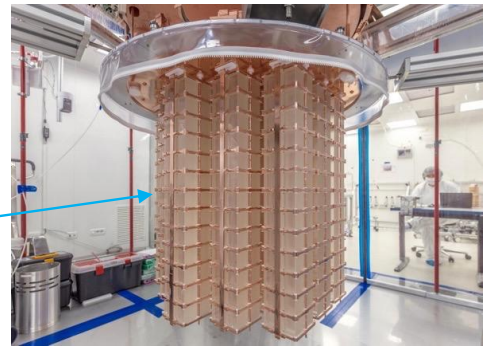


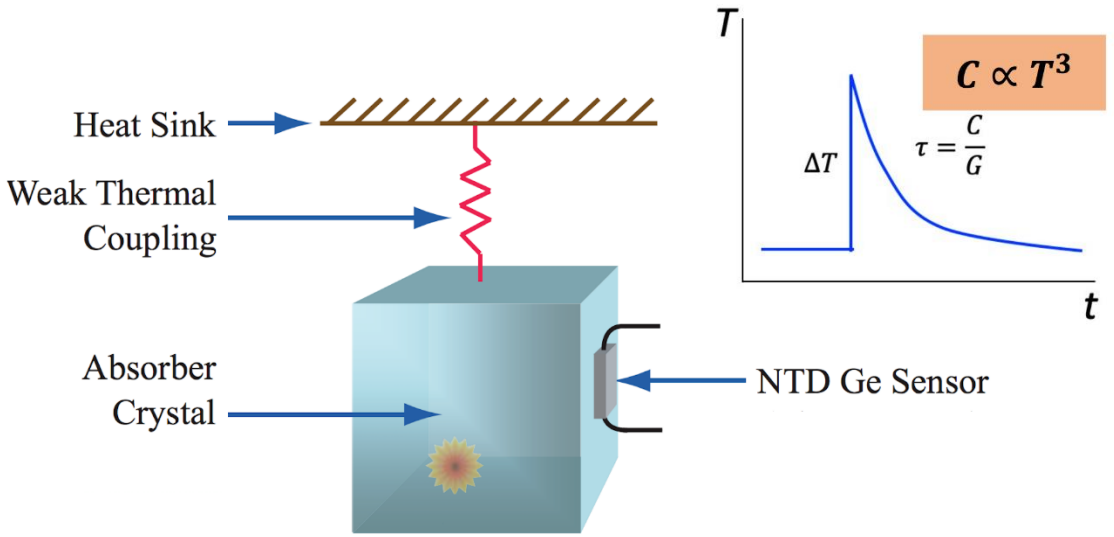
CUPID baseline: 472 kg晶体，253 kg ^{100}Mo

下一代实验目标：覆盖质量反常序对应的参数空间

低温晶体量热器实验CUORE

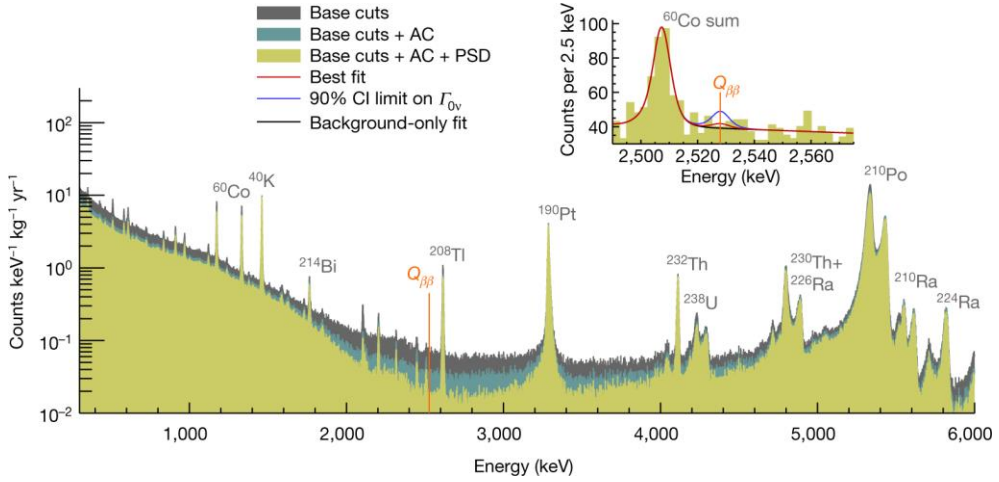




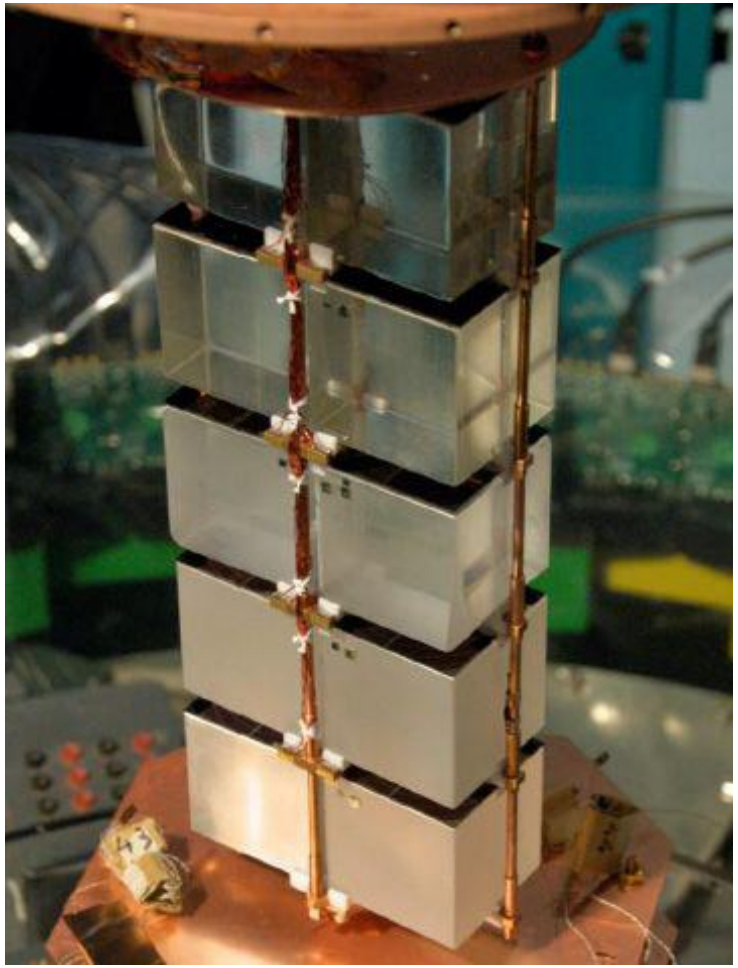


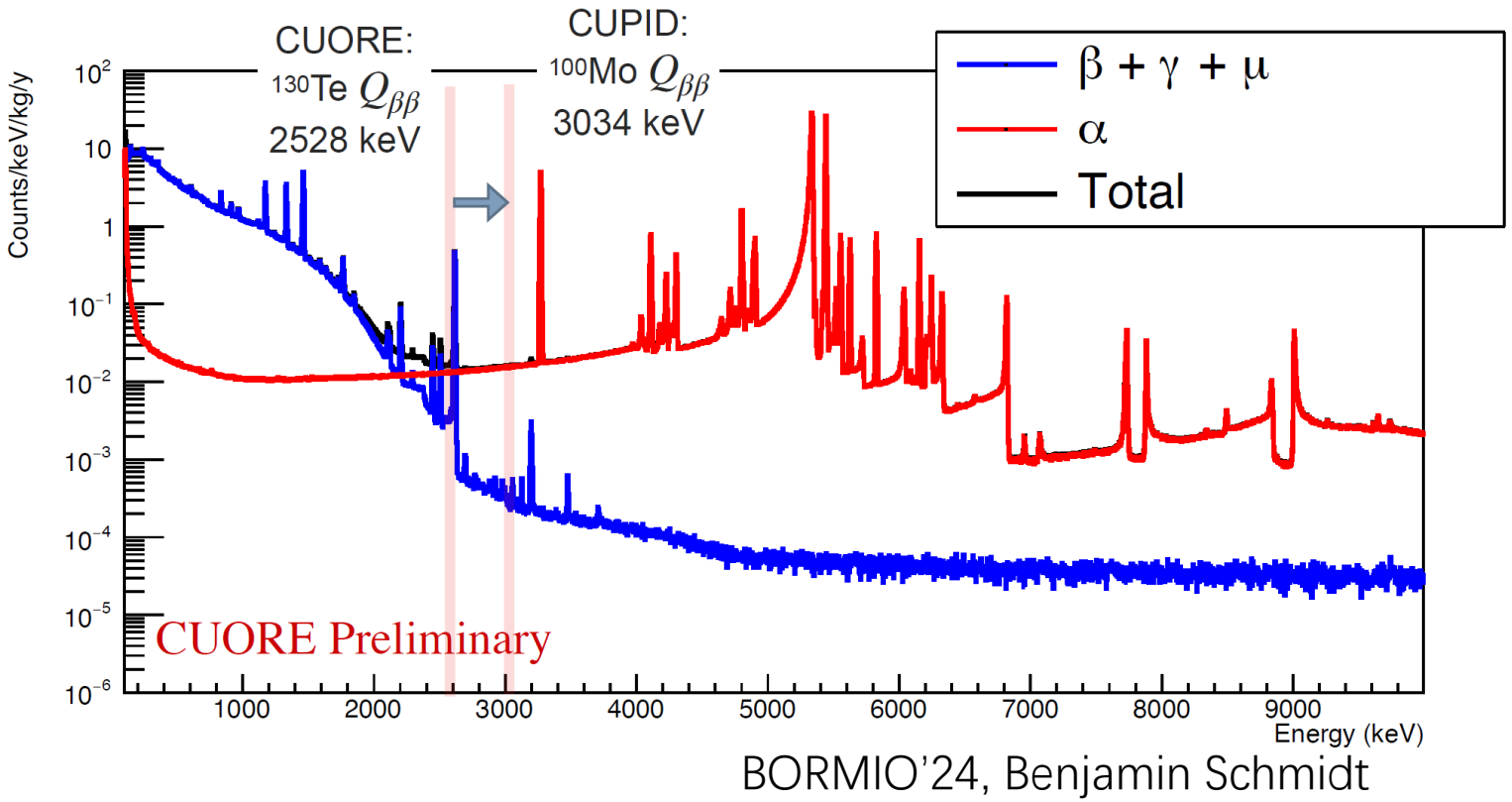
~10 mK → 高能量分辨率~0.3% (FWHM)
衰变源=探测器→ 探测效率高(>85%) :

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



CUPID：更低本底—^{100}Mo





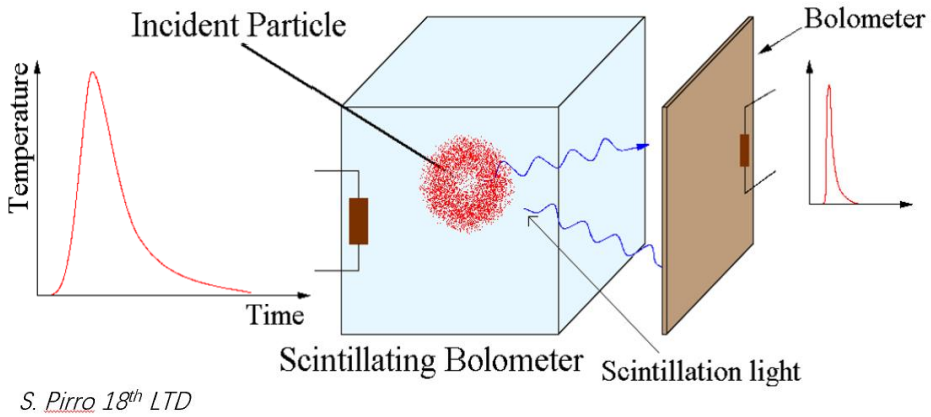
BORMIO'24, Benjamin Schmidt

^{100}Mo高$Q_{\beta\beta}$ (~3.034 MeV)

避开自然界中大多Gamma本底

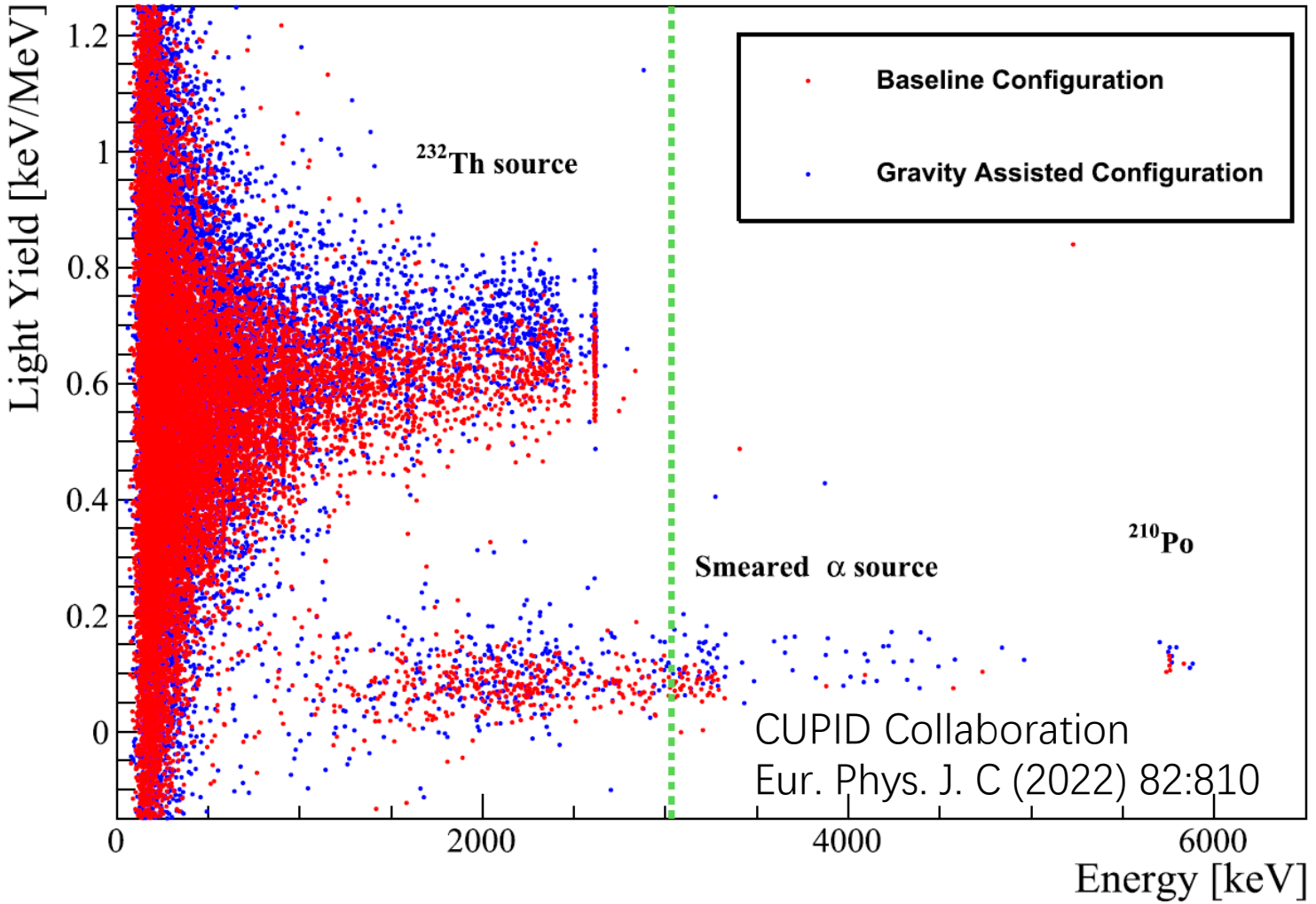
富集^{100}Mo的 Li_2MoO_4 晶体

CUPID：更低本底—光热双信号读出



S. Pirro 18th LTD

同时读出光信号和热信号
去除Alpha本底



ROI内排除>99.9% 的α 本底 (超过CUORE灵敏度，实现CUPID灵敏度)

CUPID合作组

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

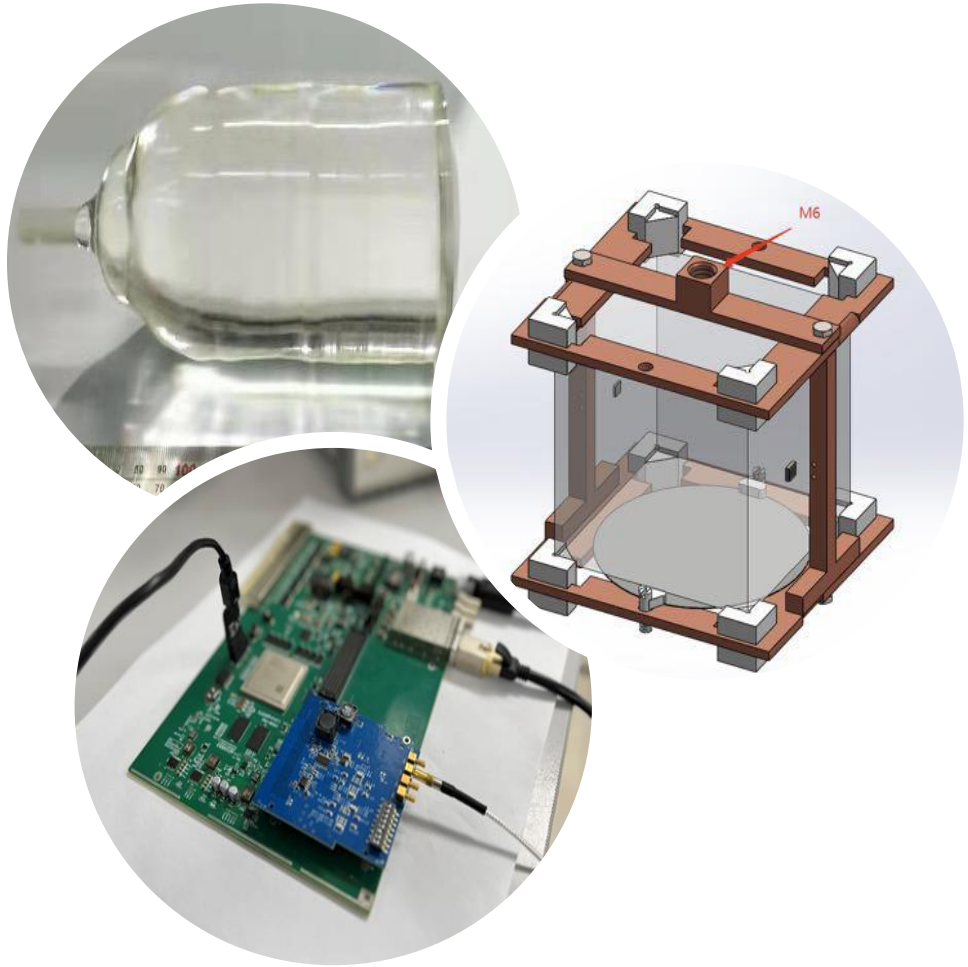
CUPID-China

- 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关键技术



晶体生长

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

电子学

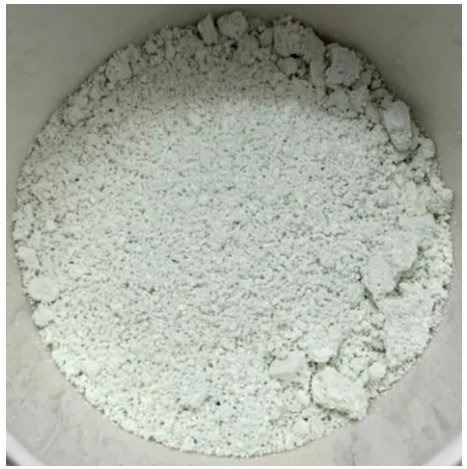
- NTD/TES thermistor fabrication and performance study
- Front-end / DAQ system development and test

探测器系统

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

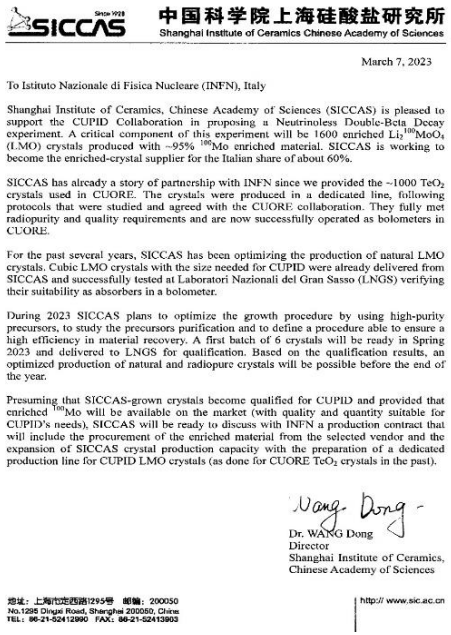
^{100}Mo同位素富集

核工业理化工程研究院



^{100}Mo富集丰度达到：>95%

- 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



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。

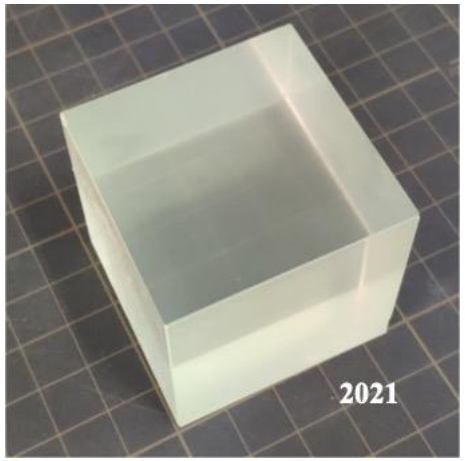
二、产品质量标准：按甲乙双方约定执行。

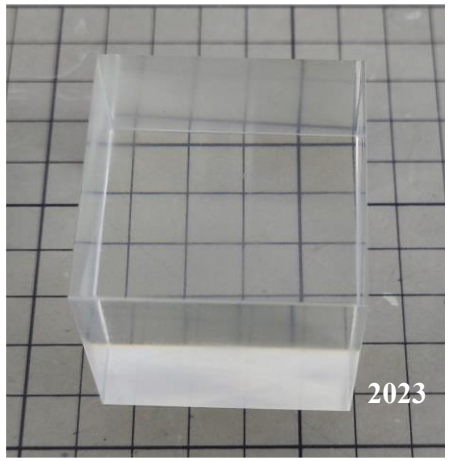
三、包装方式：本产品容器由乙方提供，但需双方对容器要求协商一致，密封存储。

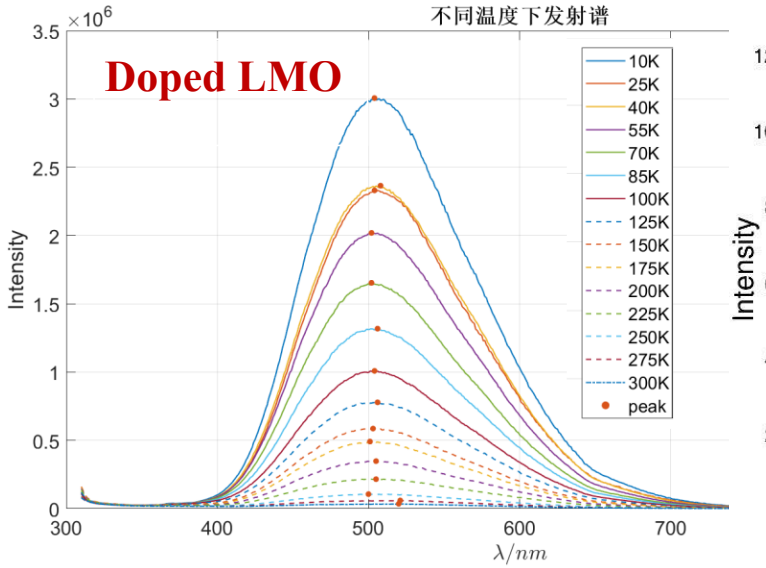
四、交货

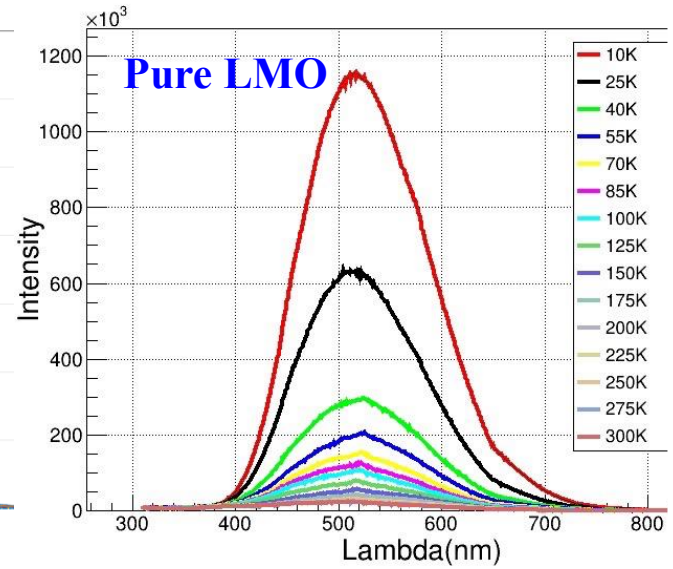
晶体制备

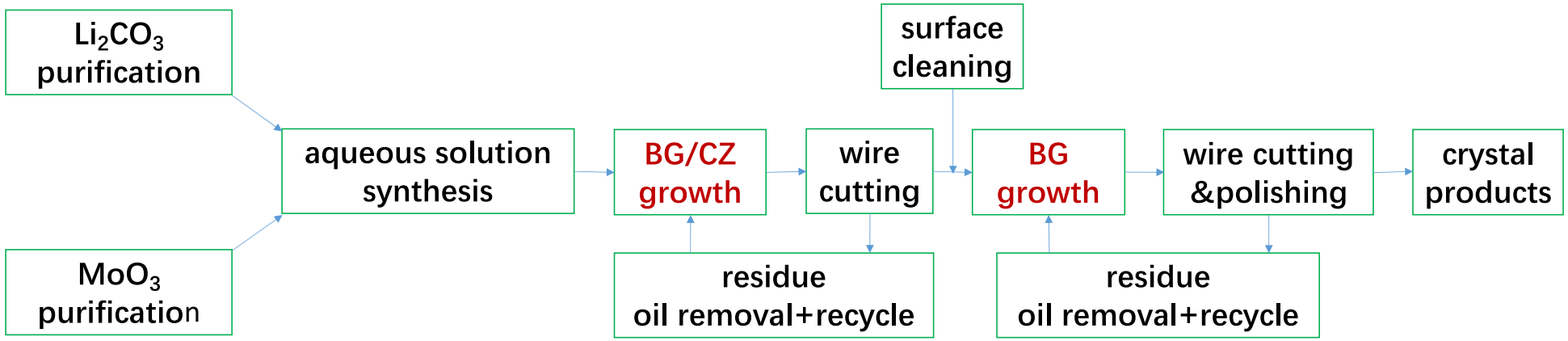
袁晖，陈良等，上海硅酸盐所







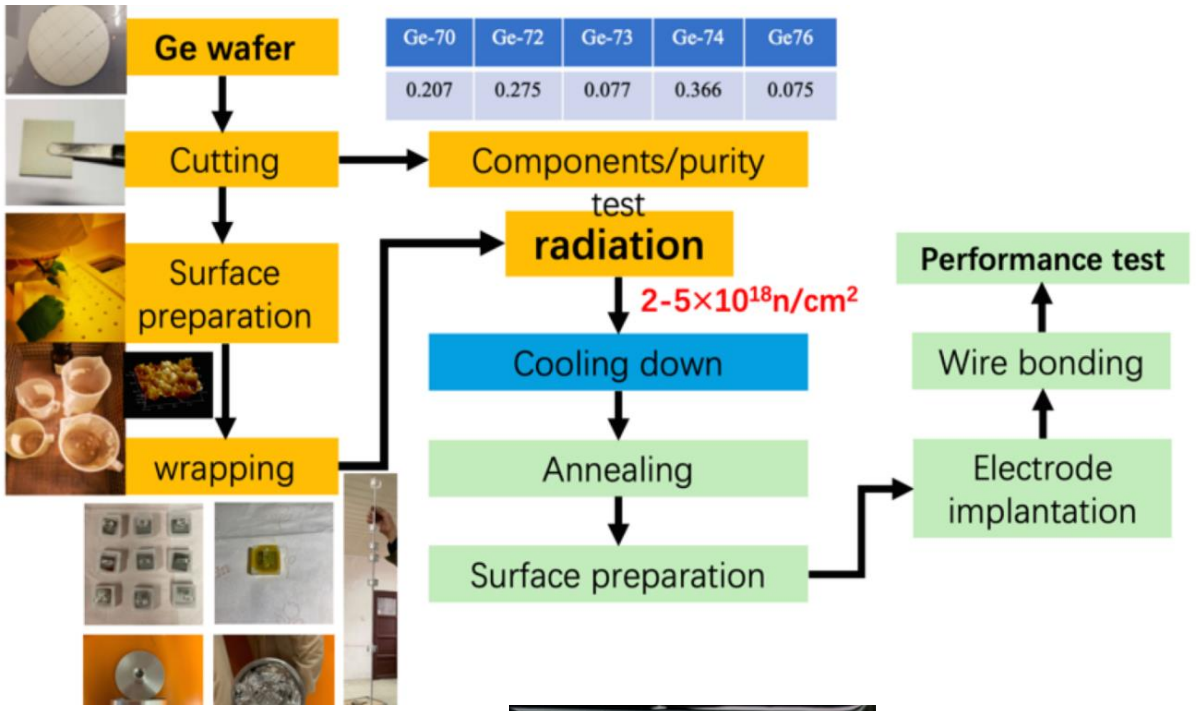




钼酸锂晶体在意大利INFN LNGS测试→能量分辨率良好，光信号可测，粒子甄别良好

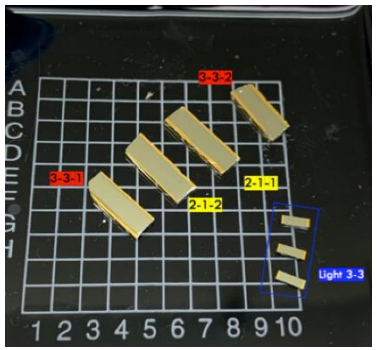
NTD-Ge：热信号读出的关键设备

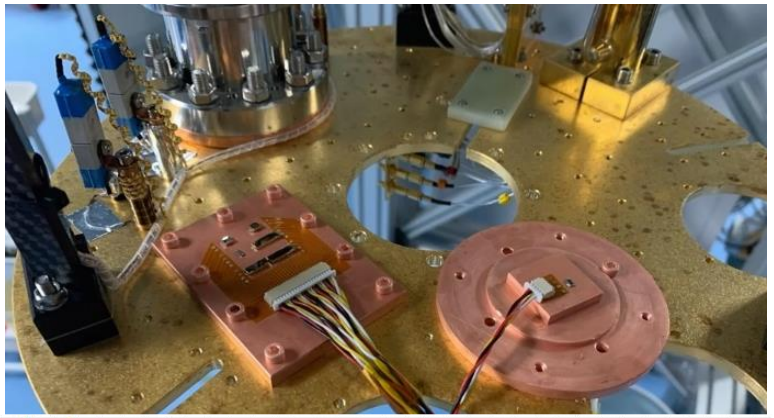
薛明萱，赵康康等, (中科大)

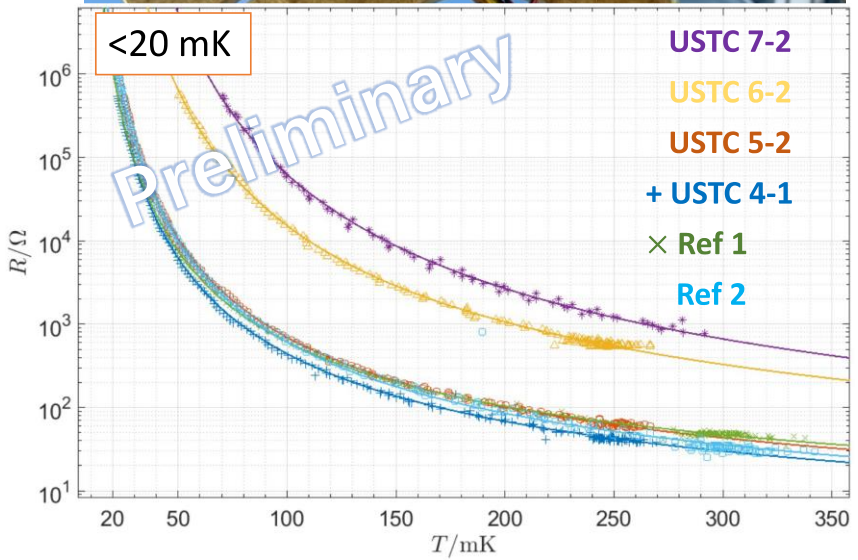


Ge-70	Ge-72	Ge-73	Ge-74	Ge76
0.207	0.275	0.077	0.366	0.075

制作工艺不断提升



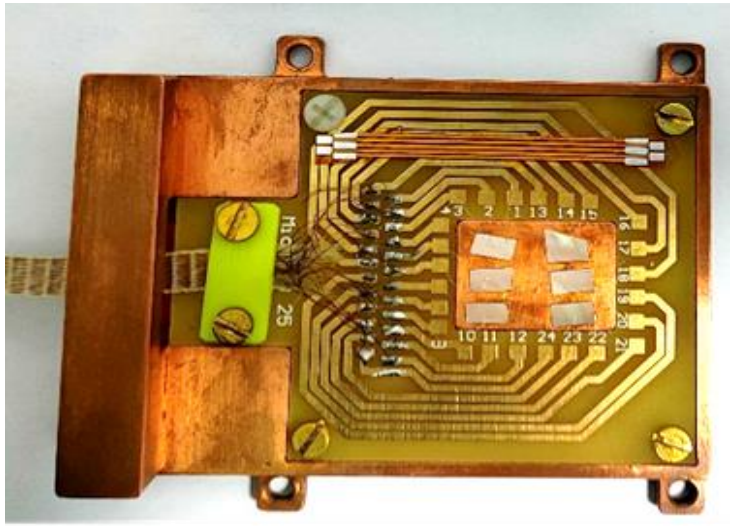


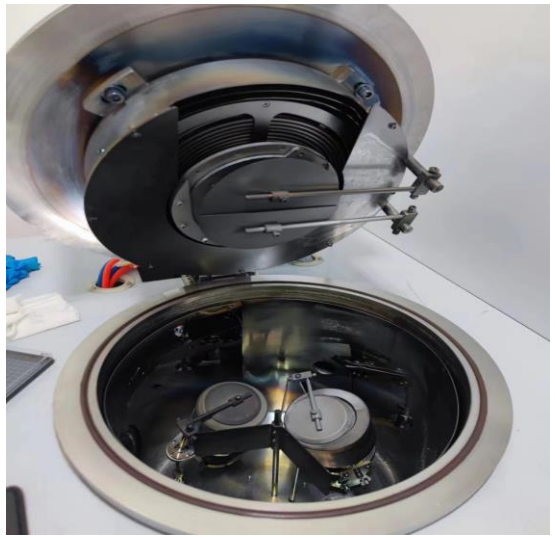


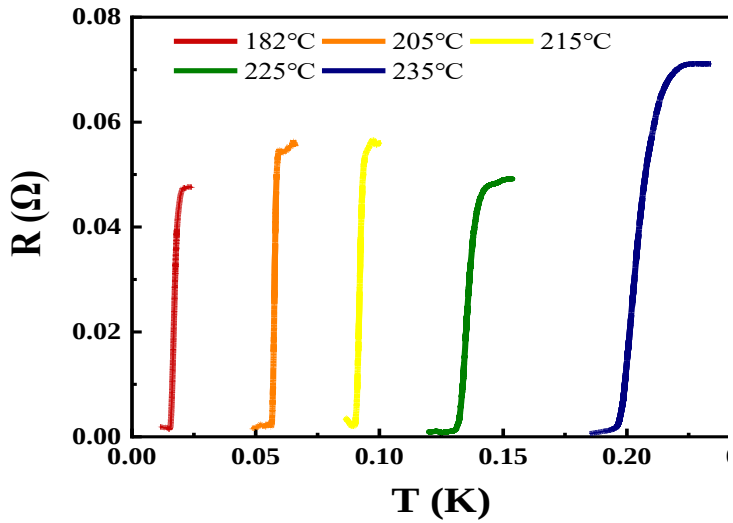
性能测试：I-V，R-T 曲线: R >10MΩ @ T<20 mK

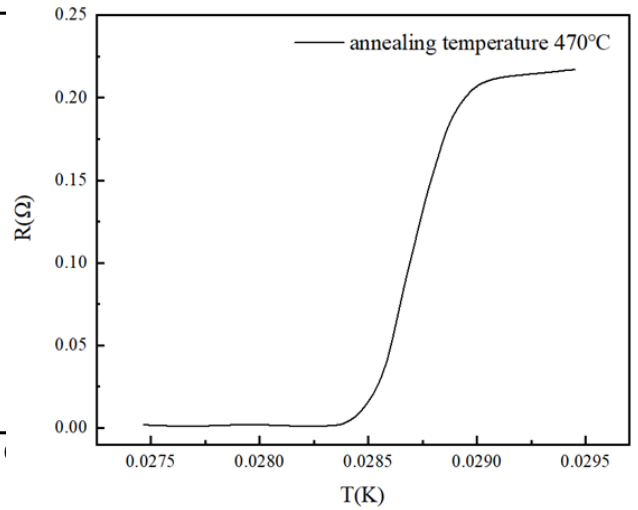
Transition-Edge-Sensor (TES) R&D

刘圆圆，王宇，刘舟慧等
(北师大/高能所)









AlMn/W superconducting

优势:

信号响应快，信噪比高

目标:

优化工艺使超导转变温度达到 < 20 mK

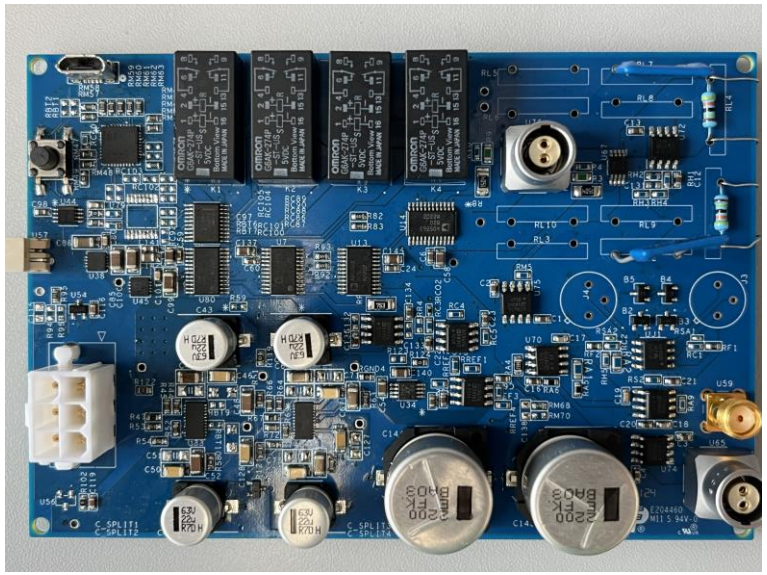
进展:

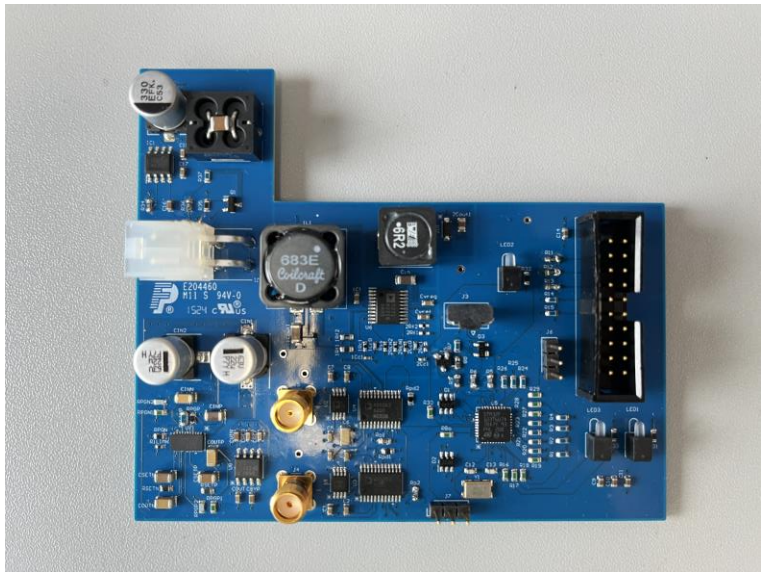
优化材料和工艺（薄膜厚度，退火温度等）

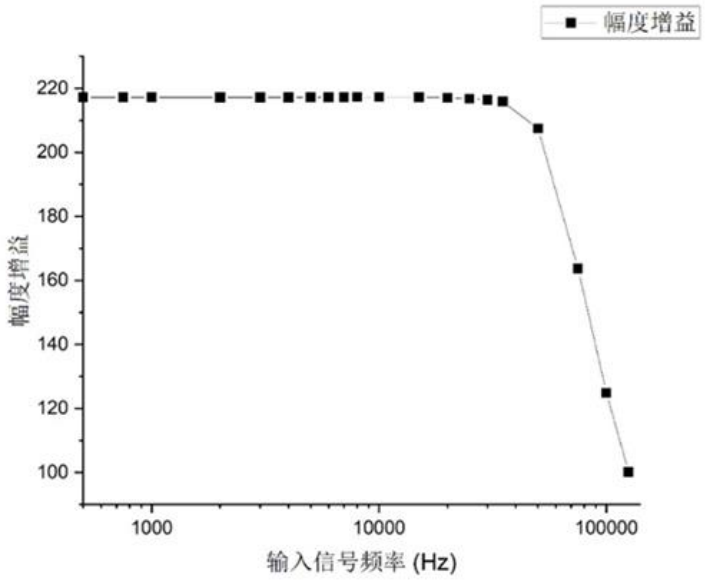
通过模拟探索光信号收集

电子学读出

杨俊峰，李毅 (中科大)

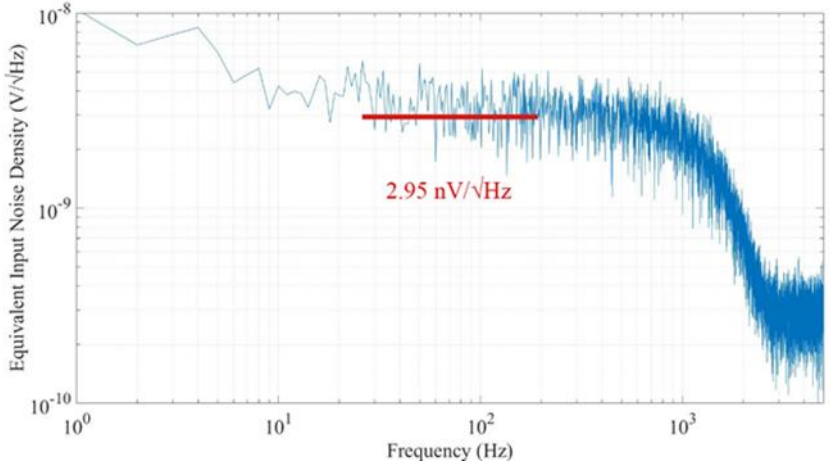




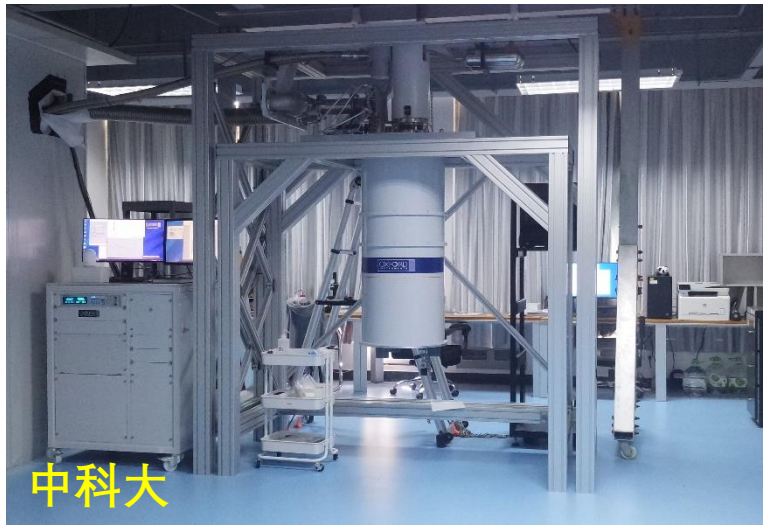


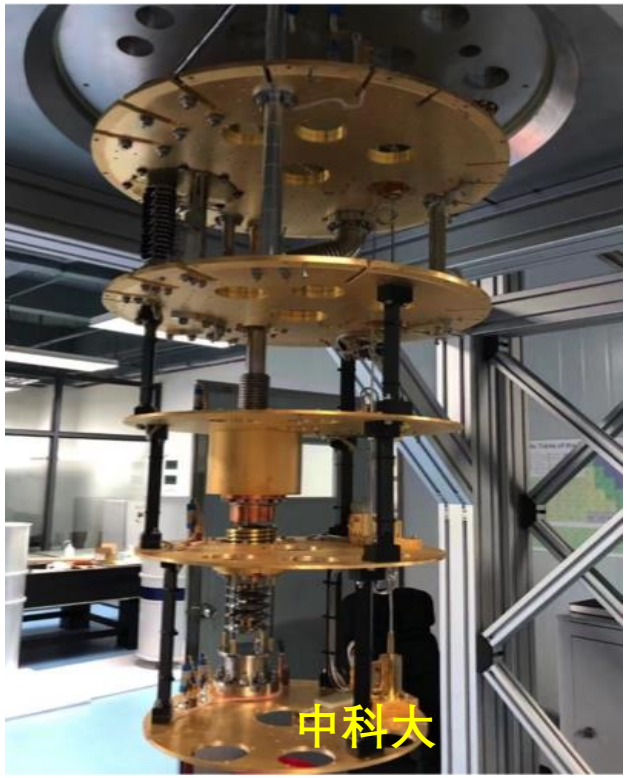
低噪声电子学前端R&D

- 改进NTD-Ge Front-End board
- 测量等效输入噪声谱⇒ competitive low level



制冷机

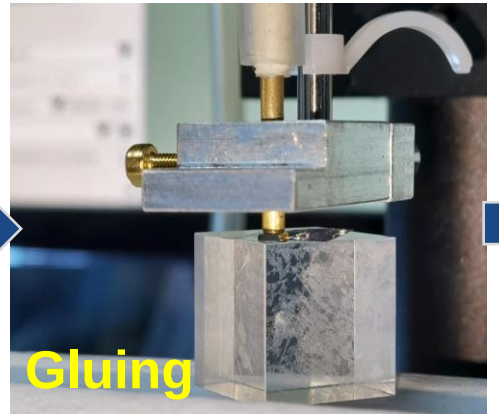


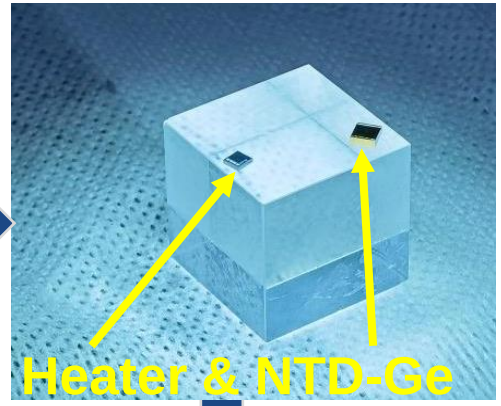


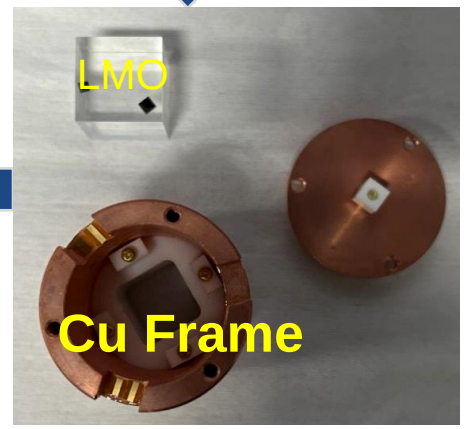
USTC-DR: 商业系统用于地面晶体测试
FDU-DR: 定制系统，可承重300 kg, 用于地下低本底实验

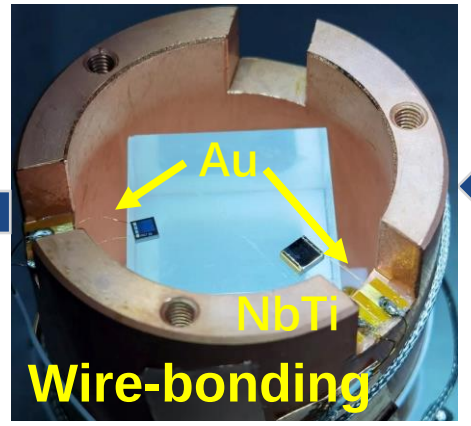
探测器系统安装

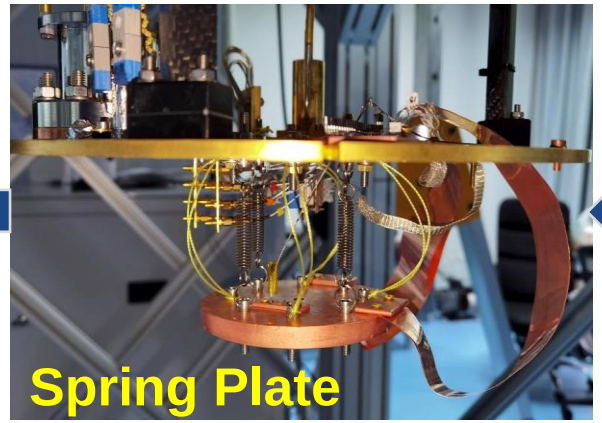
目前测试使用小晶体 $2x2x2cm^3$ /$1x1x1\ cm^3$

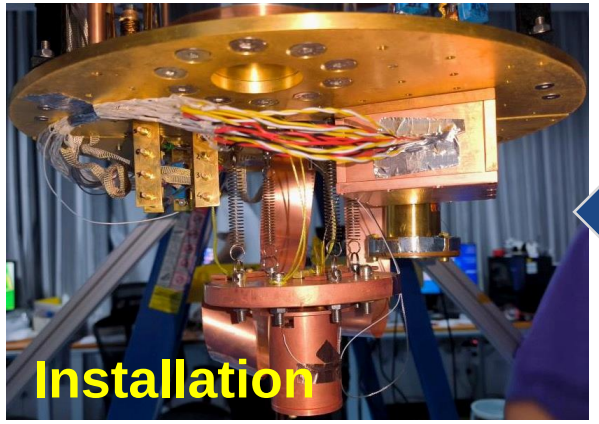






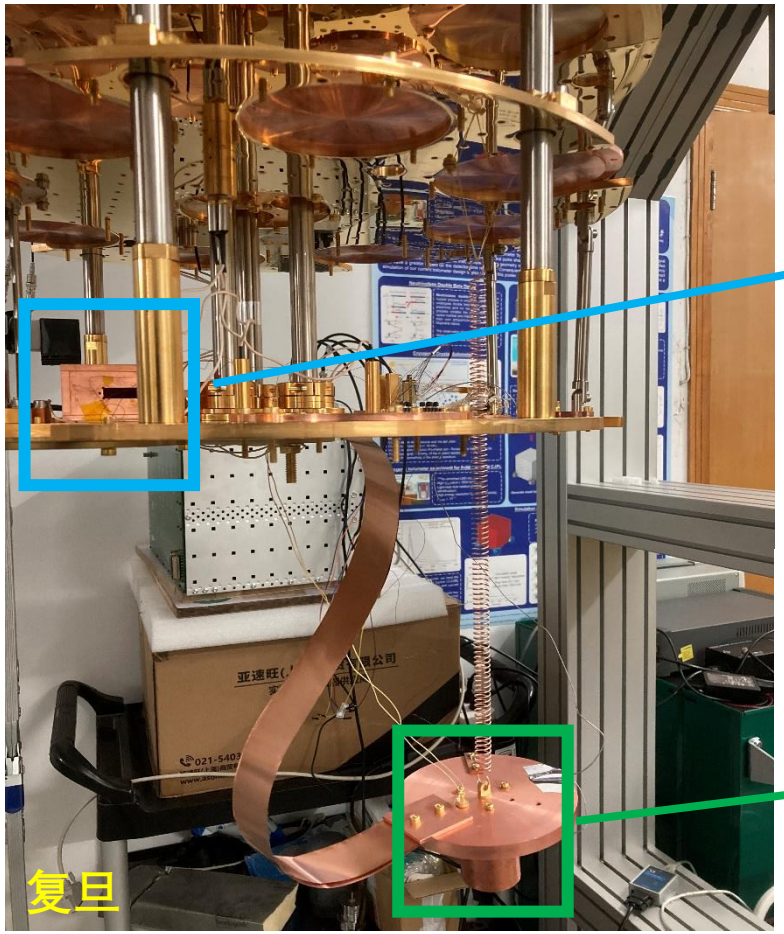


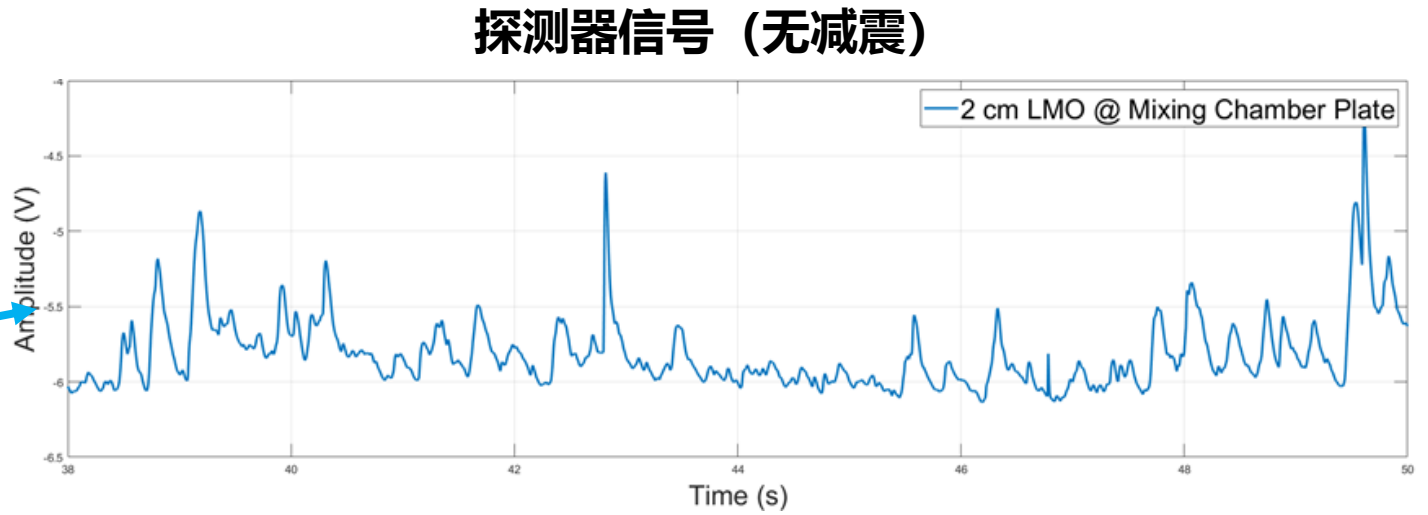


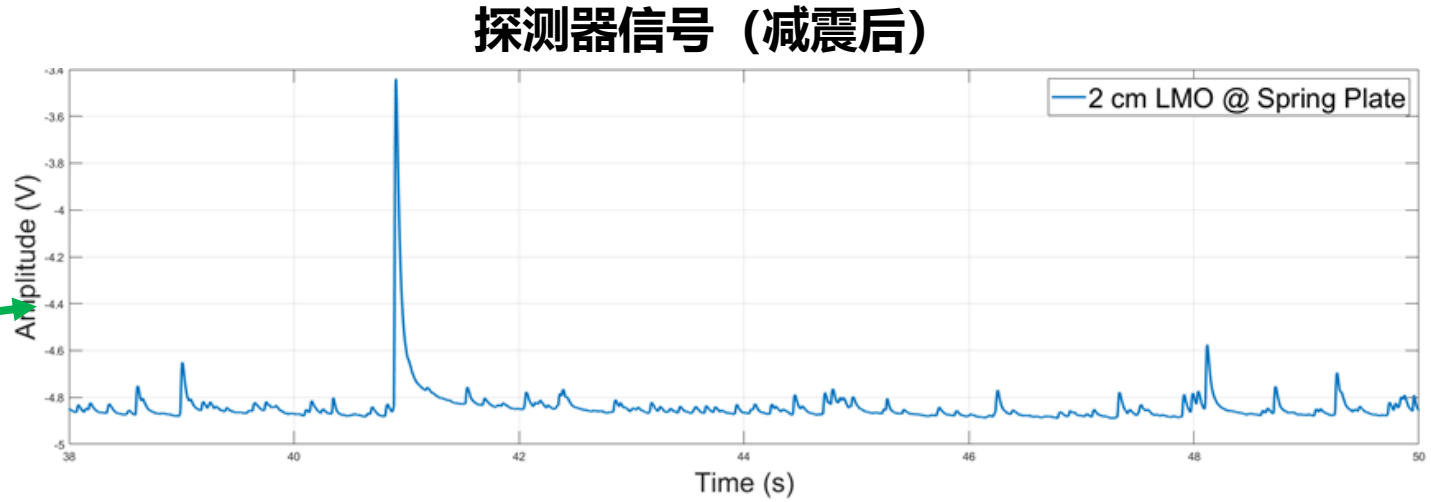


弹簧减震

马龙，曹嘉璇(复旦)，段德勇(中科大)





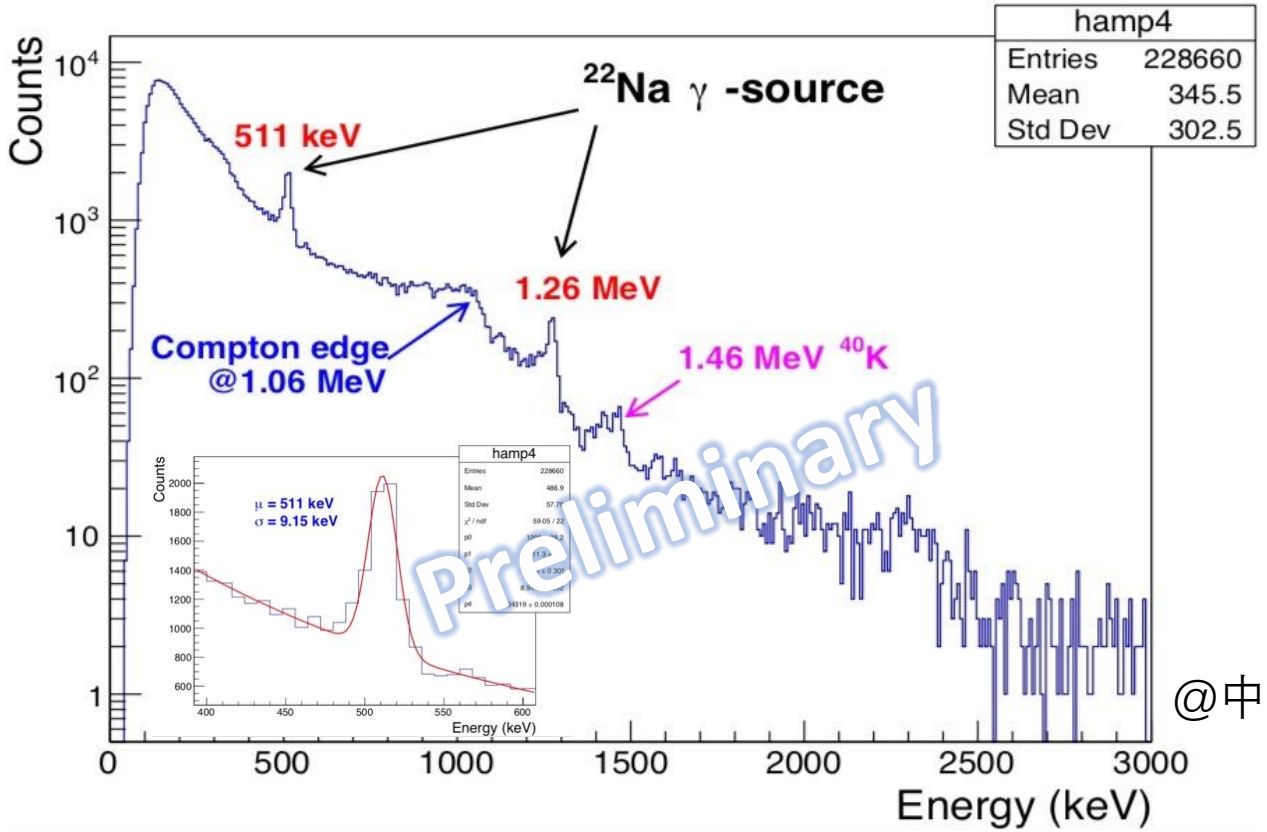


数据处理与测试结果

赵康康(中科大)、谢芳(复旦)

Data Processing

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

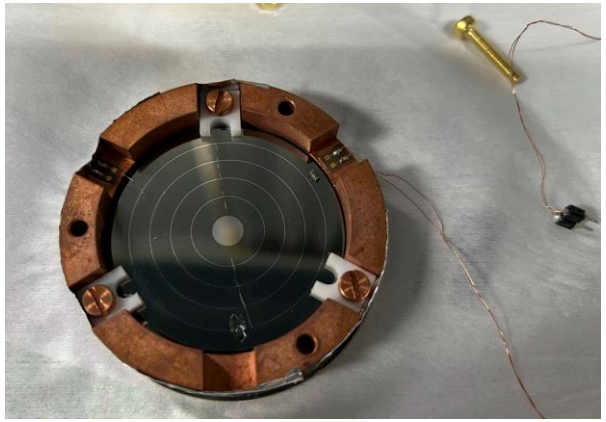


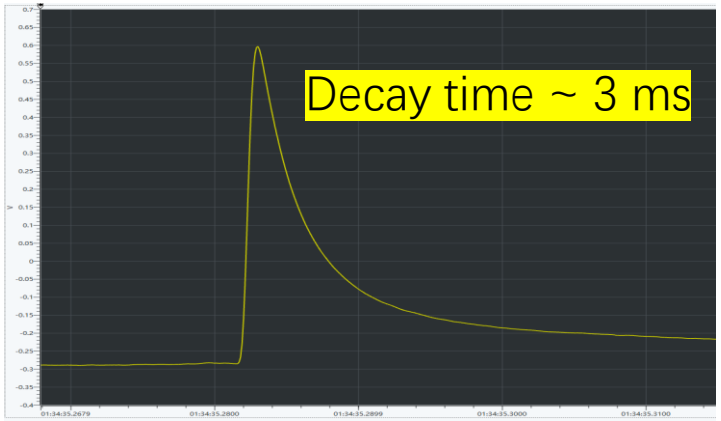
@中科大

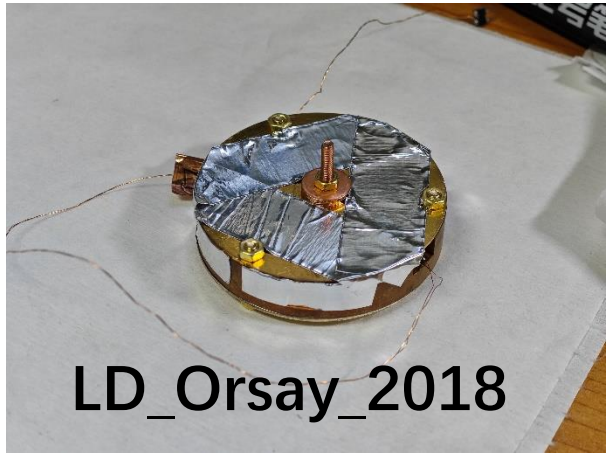
热信号刻度： ^{22}Na: 511 keV, 1.27 MeV; ^{40}K: 1.46 MeV

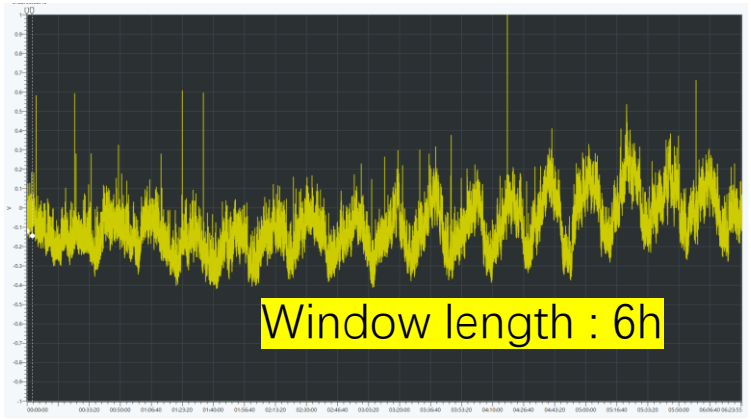
能量分辨率： FWHM 21.5 keV@511 keV, 28.9 keV@1.27 MeV

光探测器R&D

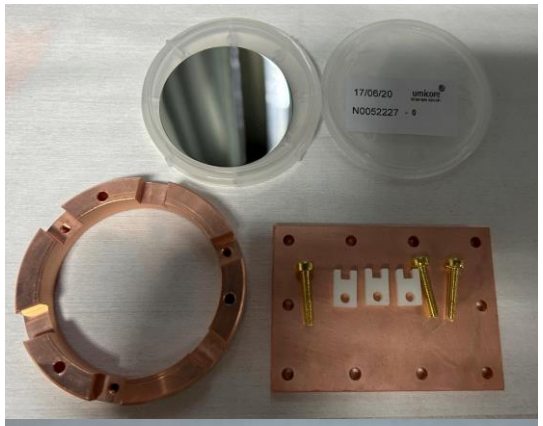


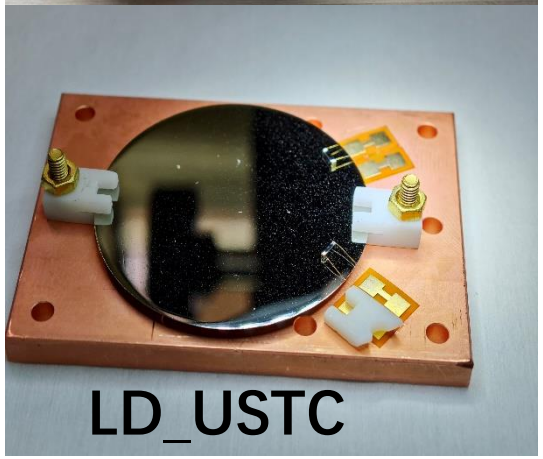






Orsay_2018光探测器, 固定在MC冷盘上
测试其对宇宙线，振动的反应





中科大自制光探测器，
预研中

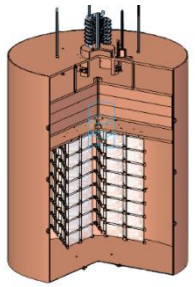
CUPID-CJPL Roadmap

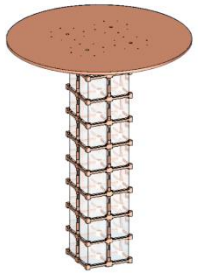
Module test

6-12 natural crystals
(2023-2025)

CUPID-CJPL 200

200 kg enriched crystals
(2028+)



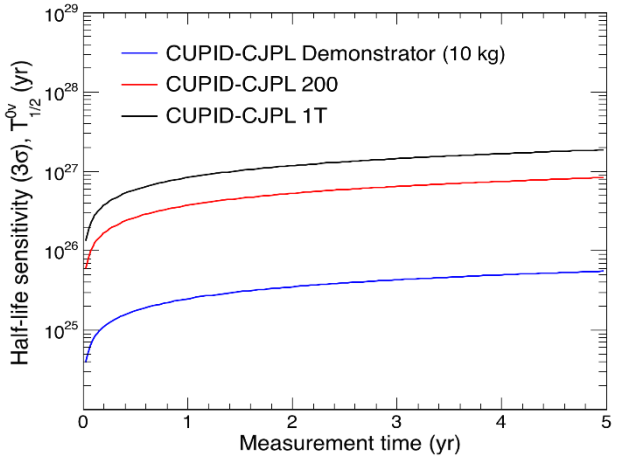


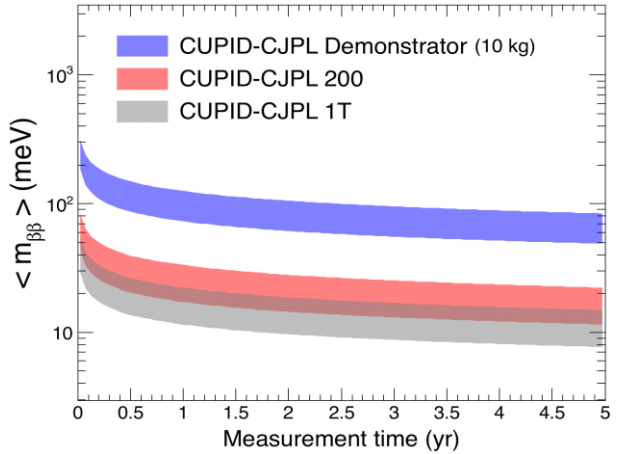
10 kg enriched crystals
(2025-2028)

CUPID-CJPL Demo

ton-scale experiment

CUPID-CJPL 1T





总结

- CUPID是下一代无中微子双贝塔衰变实验中最有竞争力的技术之一。
- CUPID-China合作组对实验的所有关键技术进行了预研工作，目前取得的进展有
  - 超纯晶体生长
  - 低噪声电子学系统研发
  - 低温量热器测试
- 其它方面的预研工作也在积极推进中，包括
  - 富集^{100}Mo低本底晶体生长
  - 光探测器测试和优化
  - 数据处理优化

合作组将致力于利用锦屏地下实验室领先世界的低本底条件，建立地下低温量热器平台，寻找无中微子双贝塔衰变这一重要的物理过程。

CUPID-China相关报告：

$Li_2MoO_4/Na_2Mo_2O_7$ Cryogenic Phonon Scintillating Bolometer（8.15上午，薛明萱）

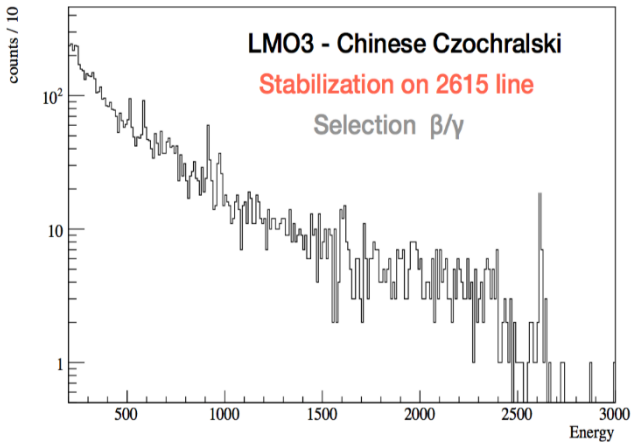
墙报 ***5-30***：低温晶体量热器中***NTD-Ge***热传感器的制备和特性研究，赵康康，薛明萱，彭海平等

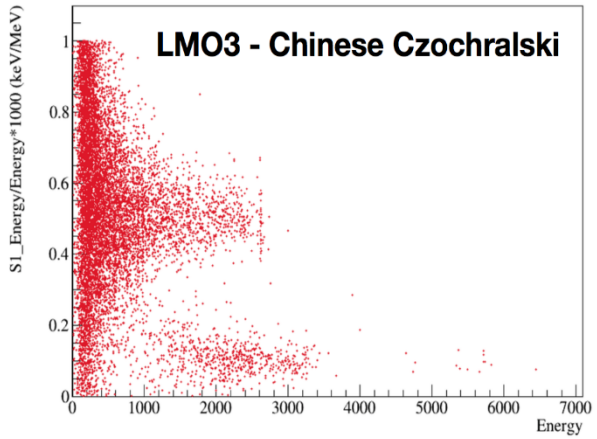
墙报 ***5-20***：Measurement of alpha contamination of Po-210 using a BGO cryogenic bolometer，段德勇，薛明萱，彭海平等

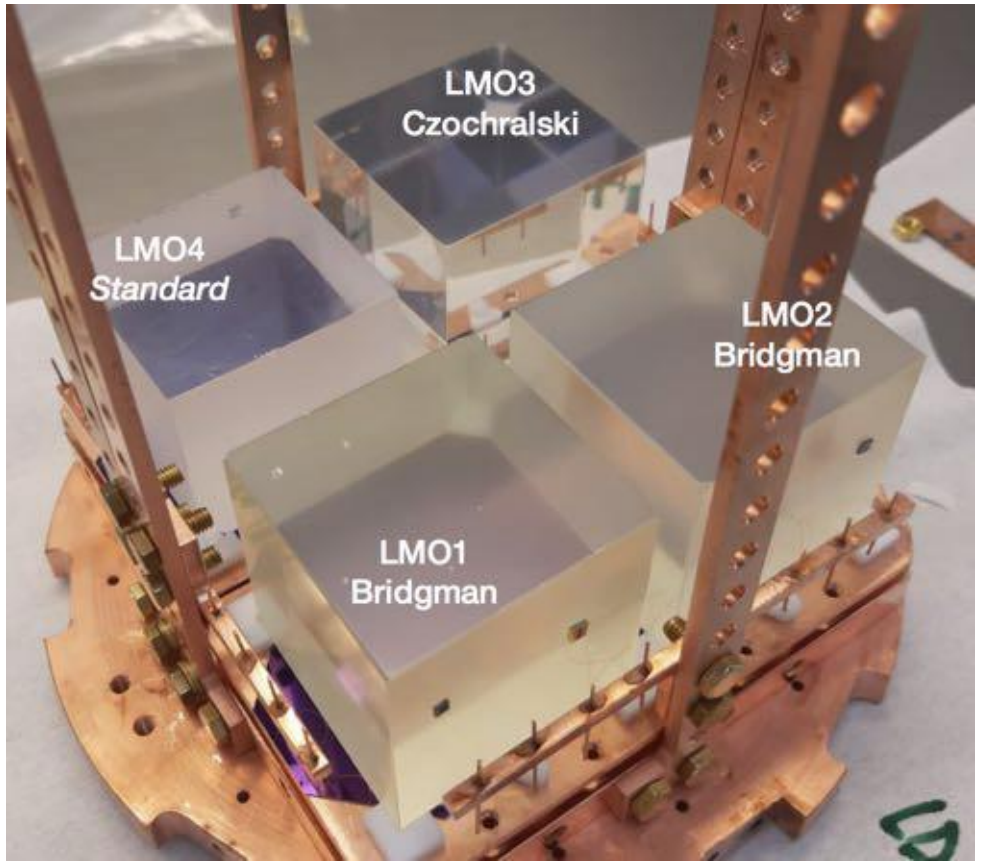
backup

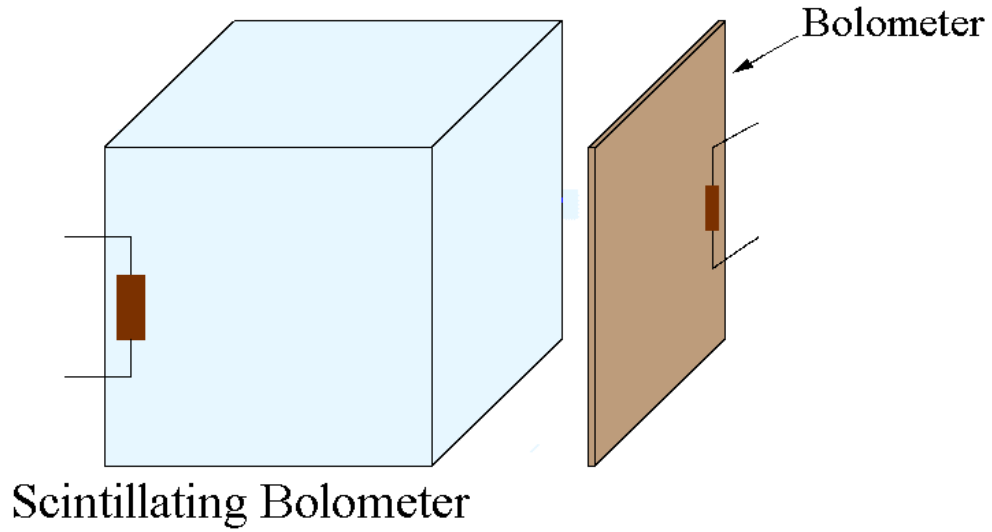
LMO晶体测试@ INFN LNGS

- 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

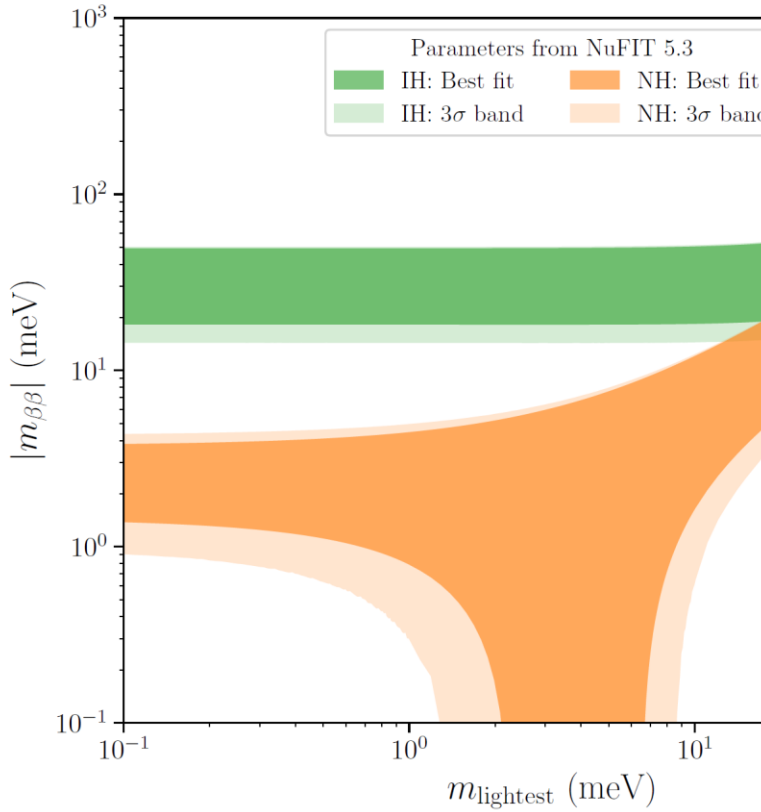








S. Pirro 18th LTD



https://toej93.github.io/LobsterPlot/