中国物理学会高能物理分会
HIGH ENERGY PHYSICS BRANCH OF CPS

Li_2MoO_4/$Na_2Mo_2O_7$ Cryogenic Phonon Scintillating Bolometer

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(on behalf of CUPID-CJPL)

State Key Laboratory of Particle Detection and Electronics (SKLPDE)
University of Science and Technology of China (USTC)

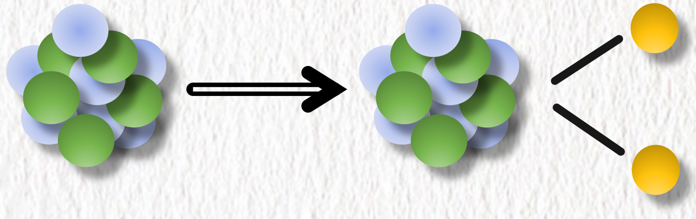
Qingdao, August 12-18, 2024

Outline

- **Motivation**
  - ✓ $0\nu\beta\beta$ and cryogenic phonon-scintillating bolometer
  - ✓ Molybdate crystals
- **LMO/NMO cryogenic phonon detector**
  - ✓ LMO/NMO crystal growth and low temperature properties
  - ✓ NTD-Ge sensors and electronics
  - ✓ LMO bolometers
  - ✓ Cryogenic lab status @USTC
- **Summary**

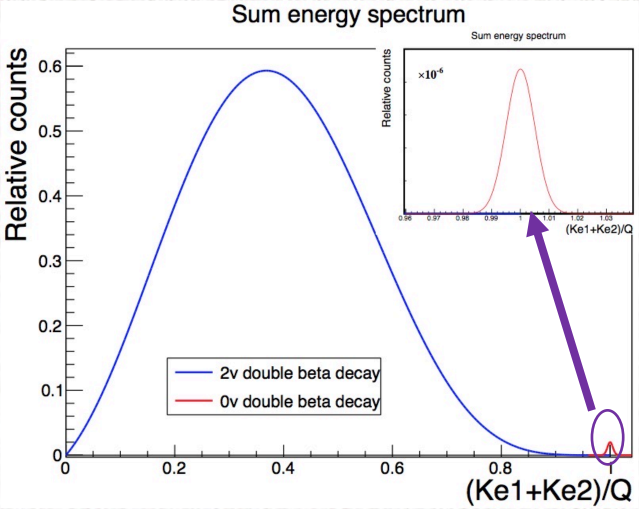
$0\nu\beta\beta$ and cryogenic phonon-scintillating bolometer

- Physics goal: neutrinoless double beat decay ($0\nu\beta\beta$)

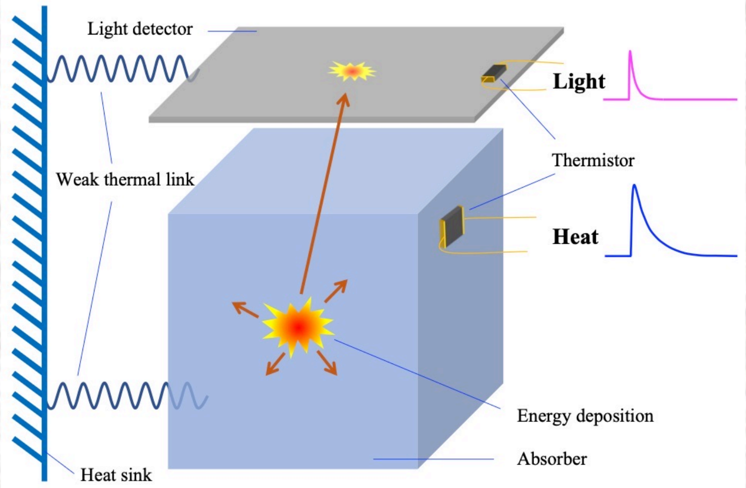


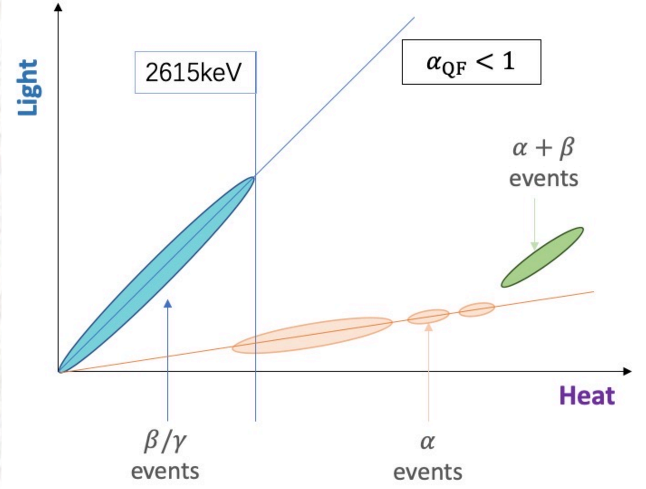
$(A, Z) \rightarrow (A, Z+2) + 2e^-$

- ✓ Lepton number violation
- ✓ Majorana or Dirac particles
- ✓ Neutrino mass
- ✓ Asymmetry of (anti-)matter…



- Light-heat dual-bolometer

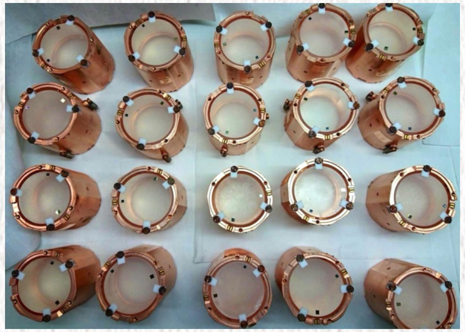




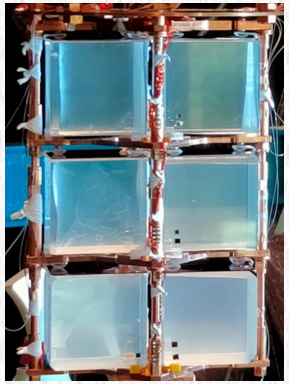
- ✓ **Absorber = Scintillating crystal**
- ✓ **Low energy threshold**
- ✓ **Good energy resolution**
- ✓ **Particle identification** (α vs. β/γ)

Why molybdate crystals → ^{100}Mo

CUPID-Mo
Li_2MoO_4
@Modane

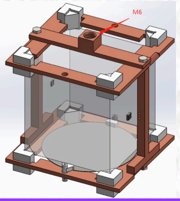


Li_2MoO_4
@Canfranc



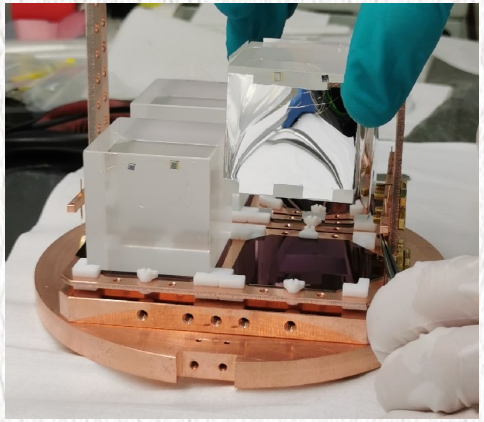
$ZnMoO_4$, $PbMoO_4$, $CdMoO_4$, $Na_2Mo_2O_7$ R&D

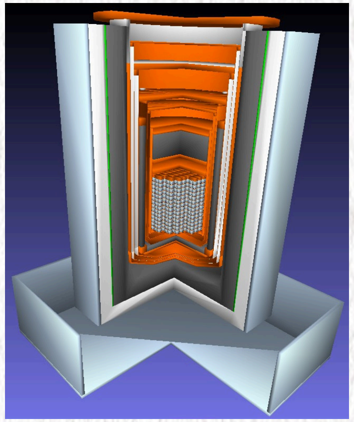
High Q value (3034 keV) & natural isotope abundance



Li_2MoO_4 @CJPL

Parameter	Value
Crystal	$Li_2{}^{100}MoO_4$
Size	45x45x45 mm³
Heat Channels	1596
Light Channels	1710
Detector mass	450 kg
Enrichment	95%
^{100}Mo mass	240 kg
E resolution	< 5 keV
Bk index	< e-4 ckky





CUPID
Li_2MoO_4 @LNGS

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- ✻ **LMO/NMO cryogenic phonon detector**
  - ✓ LMO/NMO crystal growth and low temperature properties
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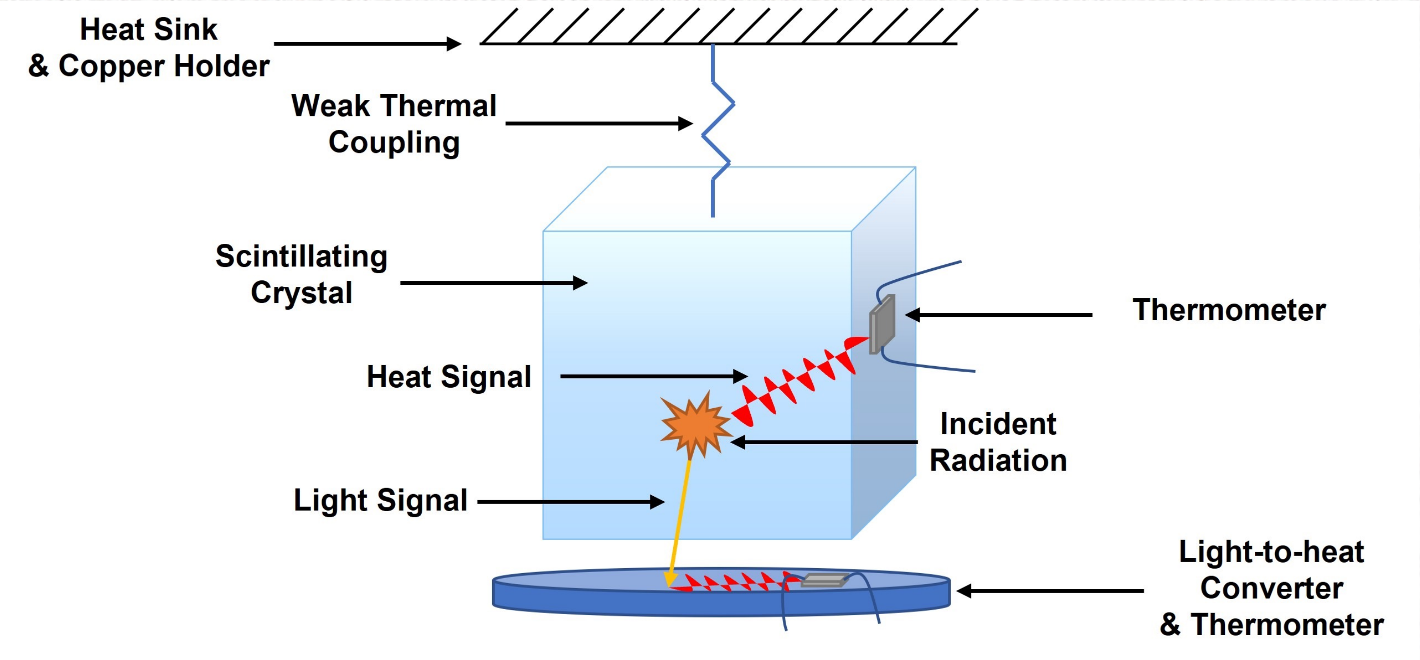
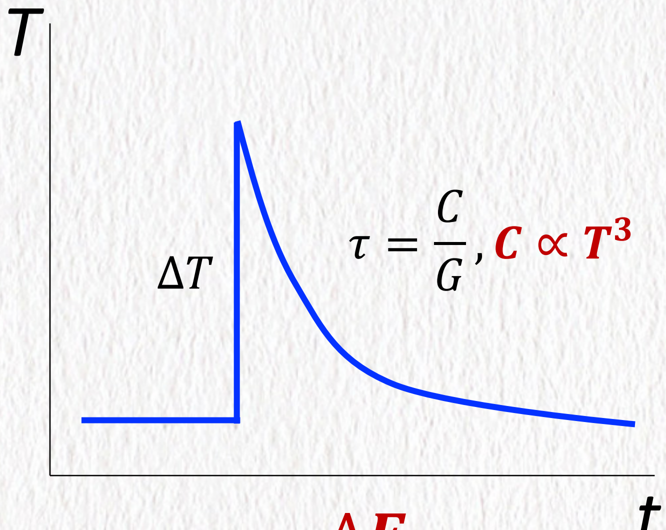
- ✻ **Summary**

Cryogenic Phonon-scintillating Detector

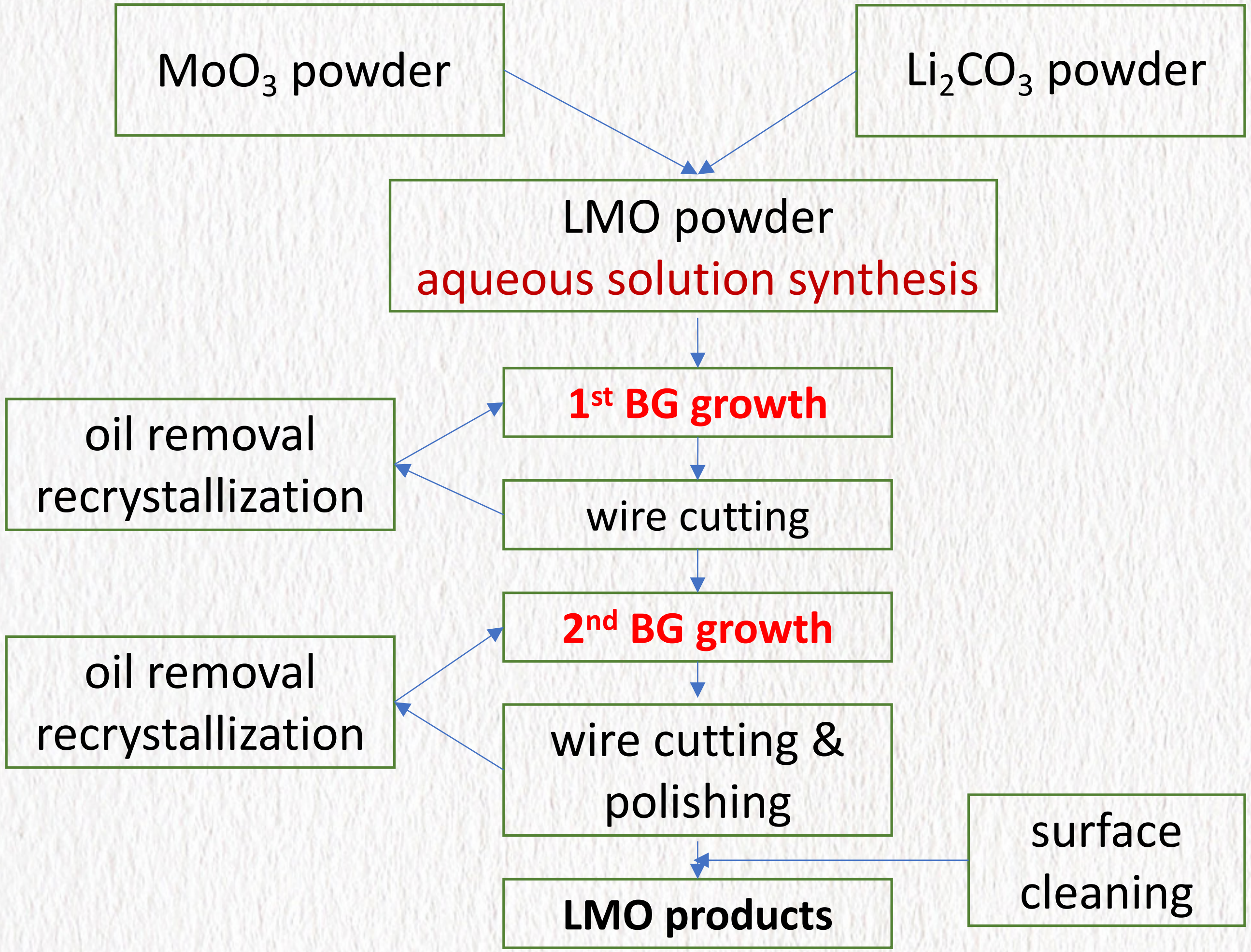
- **Absorber**, **scintillation light** → α **vs.** β/γ, small **heat capacity** **(C)** → **sensitive detector**
- **Sensor**, **crucial component**, sensitive to **μK-level changes** at very low temperatures
- **Heat sink and Weak thermal link**, provide stable low temperature and energy release
- **Light detector**, collect photons and convert to signal readout as light channel

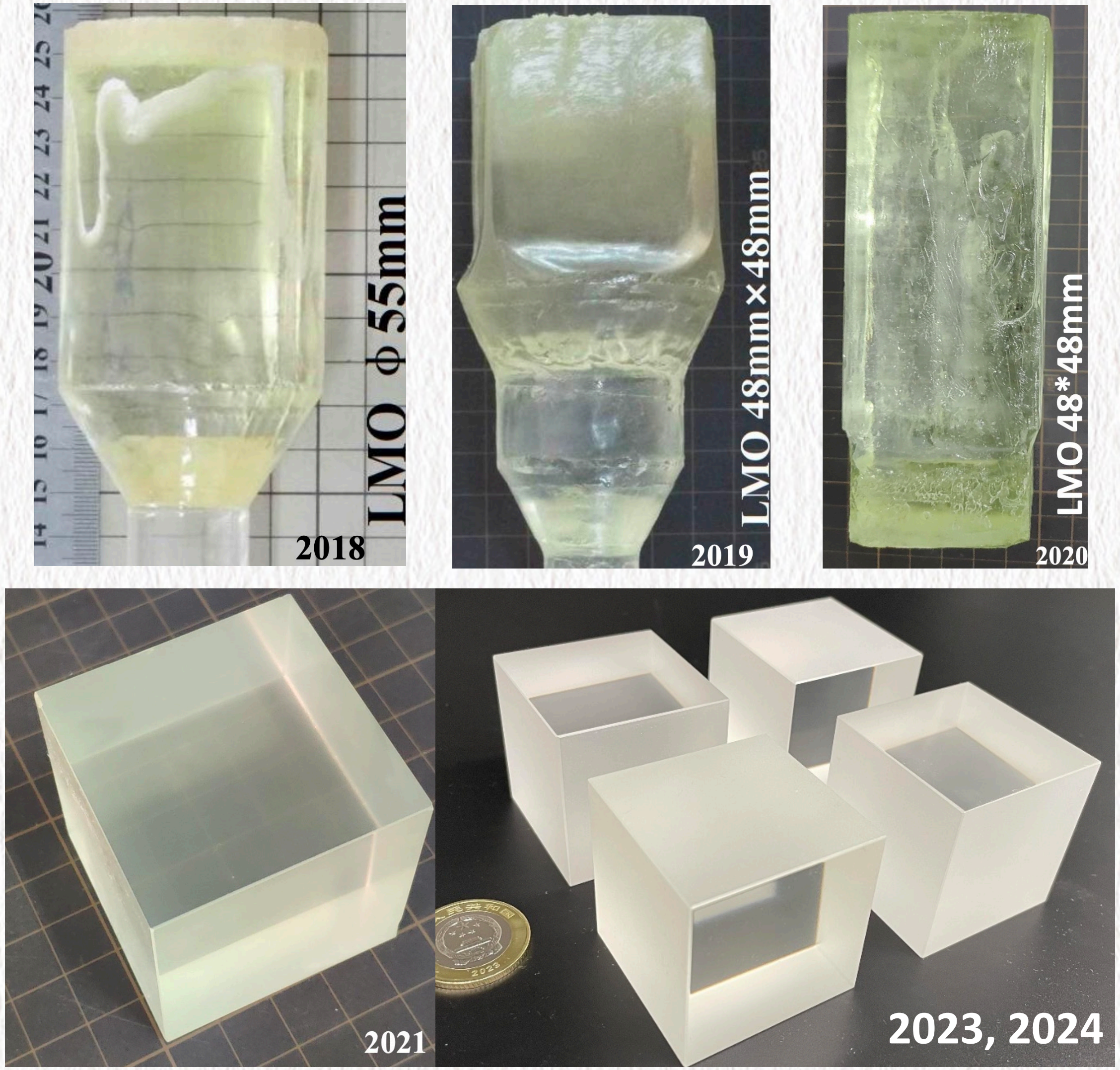




$$\Delta T(t) = \frac{\Delta E}{C} \cdot e^{-t/\tau}$$

LMO crystal growth

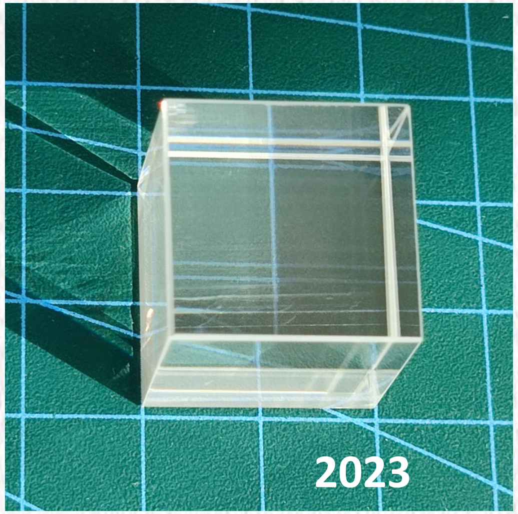




$L^{100}MO$ crystal growth would start from this September

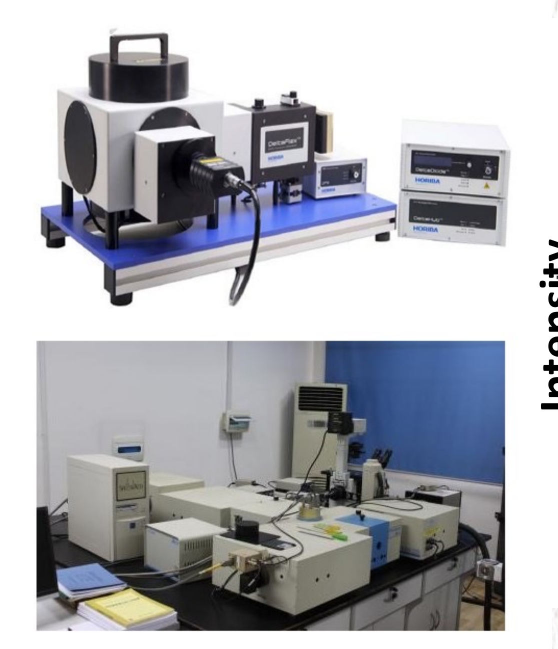
NMO crystal growth

- **LMO, very attractive, but deliquescent**
- **NMO, not deliquescent, high light yield, not easy to grow into large bulk at present**
- Bridgman growth method, similar process as LMO

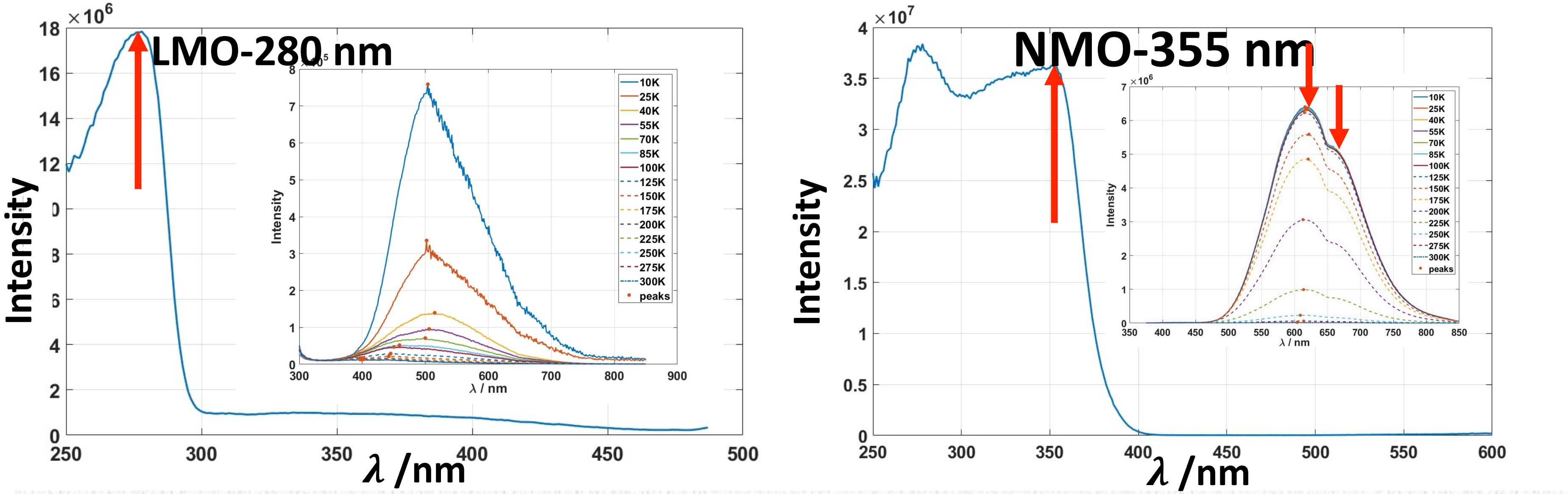


Scintillation light properties

- Low temperature test platforms with laser (**10-300 K**), laser 250-1700 nm
- LMO test with laser **280 nm**, peak at **510 nm**, lower temperature, higher light yield
- NMO test with laser **355 nm**, peak at **620 nm**, lower temperature, higher light yield



Test platforms

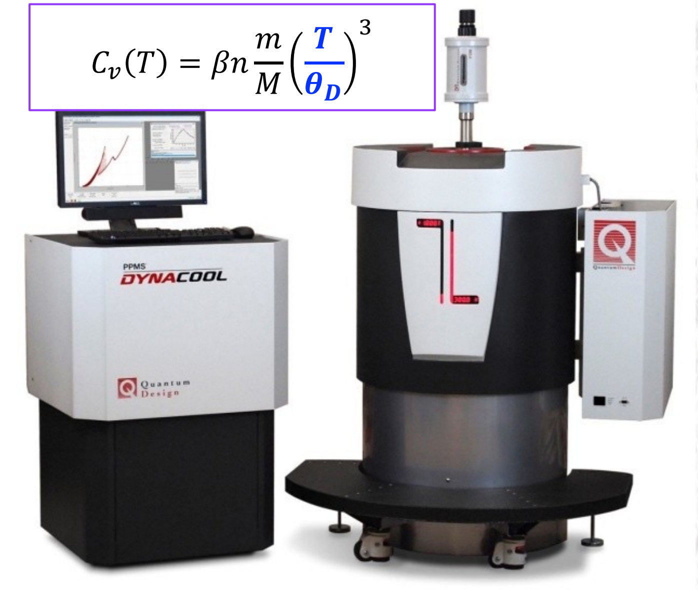


Excitation spectrum @10 K and emission spectrum

Heat capacity measurement

- PPMS (Physical Property Measurement System, Quantum Design), 50 mK -400 K
- Heat capacity measurements of LMO and NMO from 200 mK -2 K with PPMS, the results are **consistent with the Debye model**, $\boldsymbol{\theta_D(LMO) = 330 \pm 3\ \mathrm{K}, \theta_D(NMO) = 351 \pm 2\ \mathrm{K}}$

$$C_v(T) = \beta n \frac{m}{M}\left(\frac{\boldsymbol{T}}{\boldsymbol{\theta_D}}\right)^3$$



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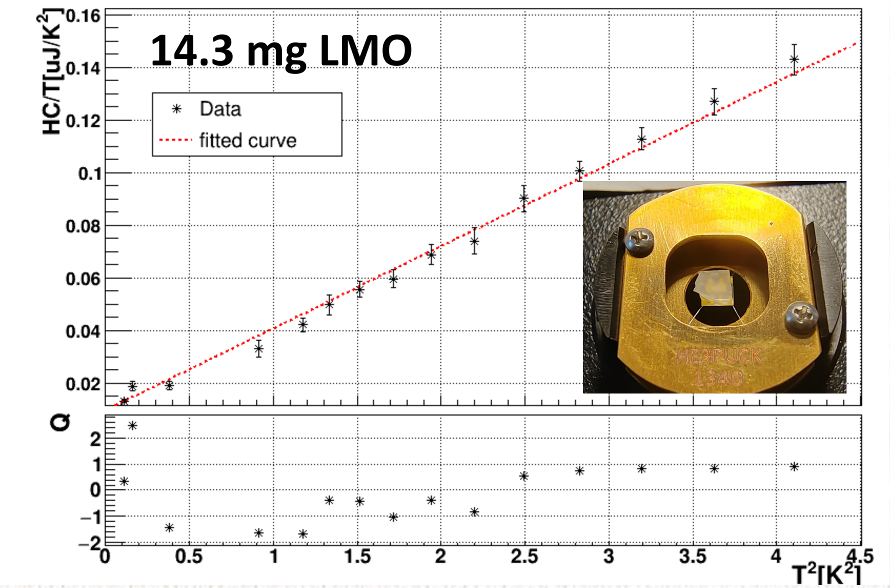

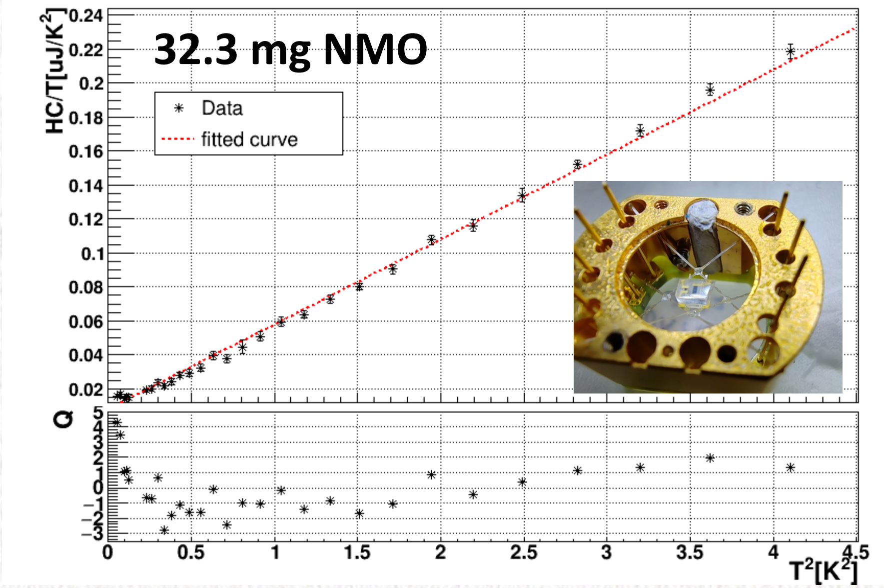

C/T as a function of T^2

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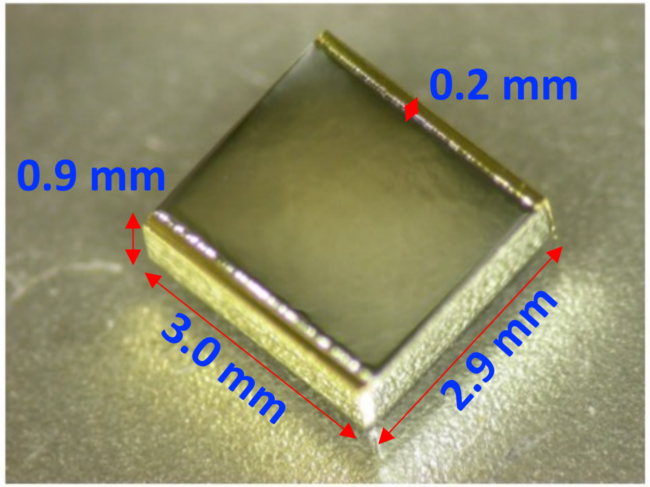
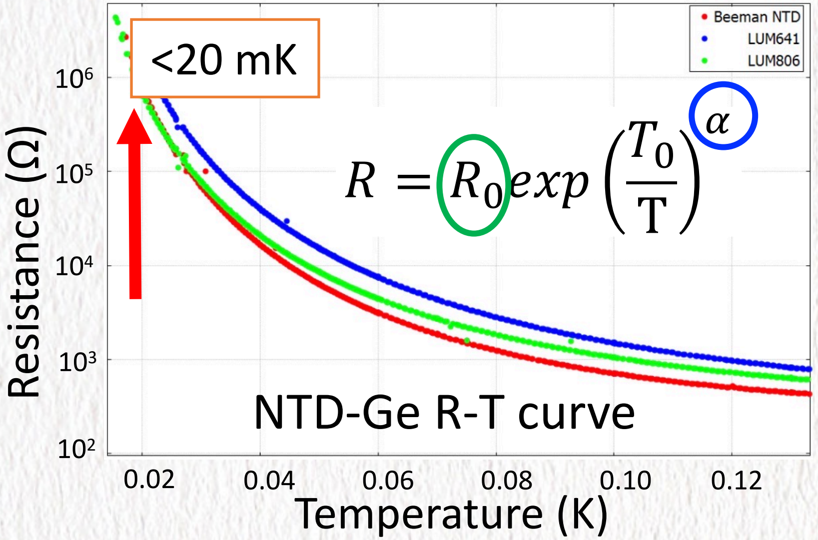
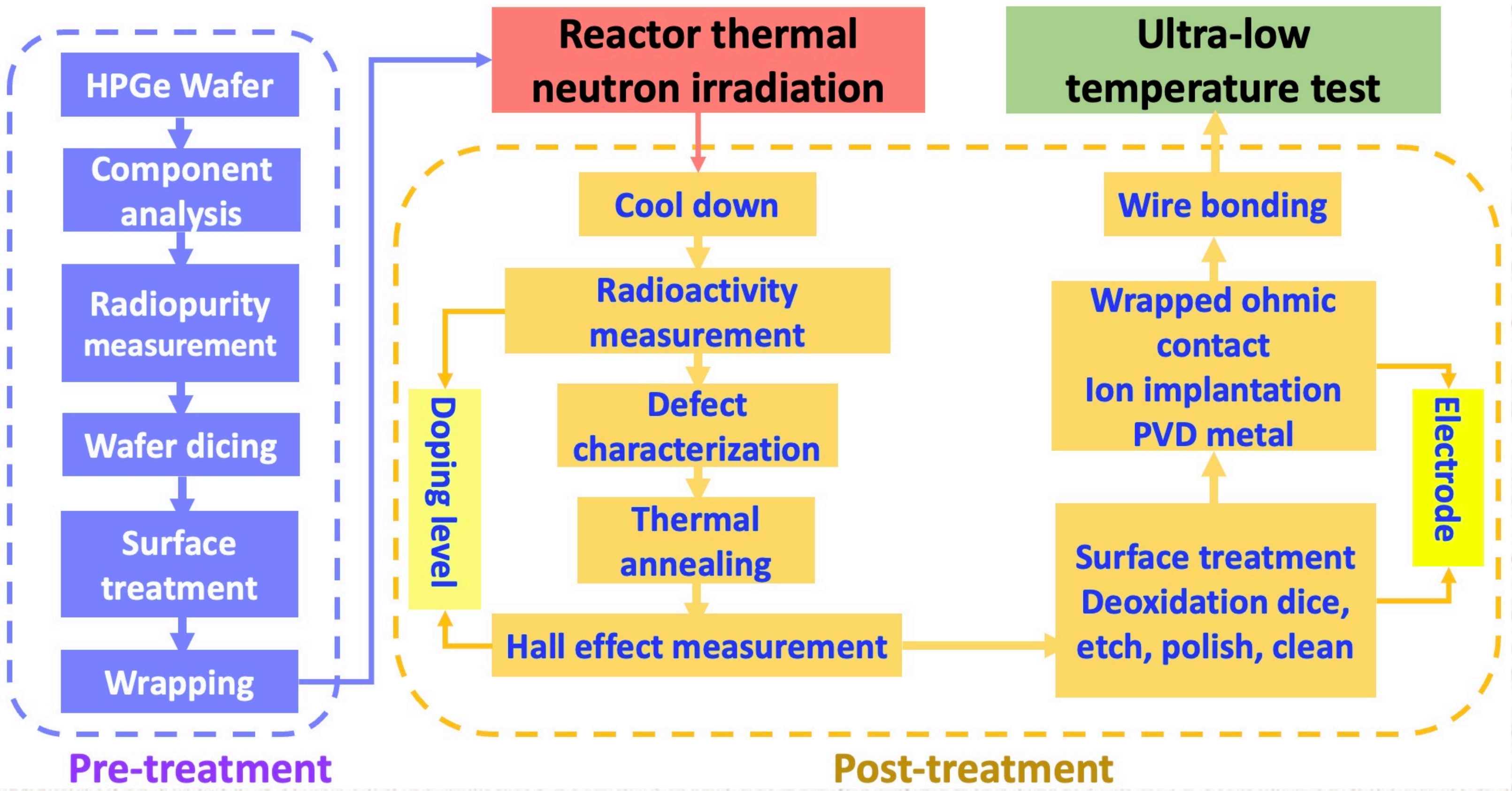
Neutron Transmutation Doped Germanium (NTD-Ge)





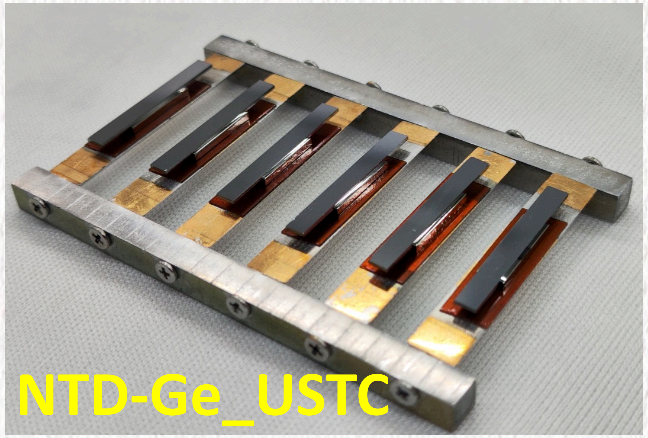
NTD-Ge R-T curve

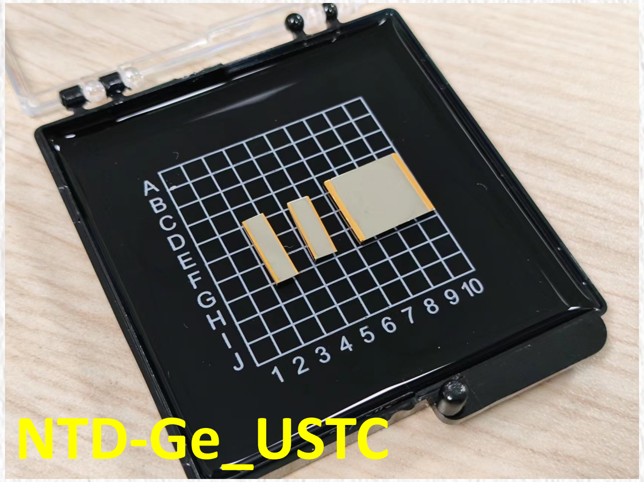


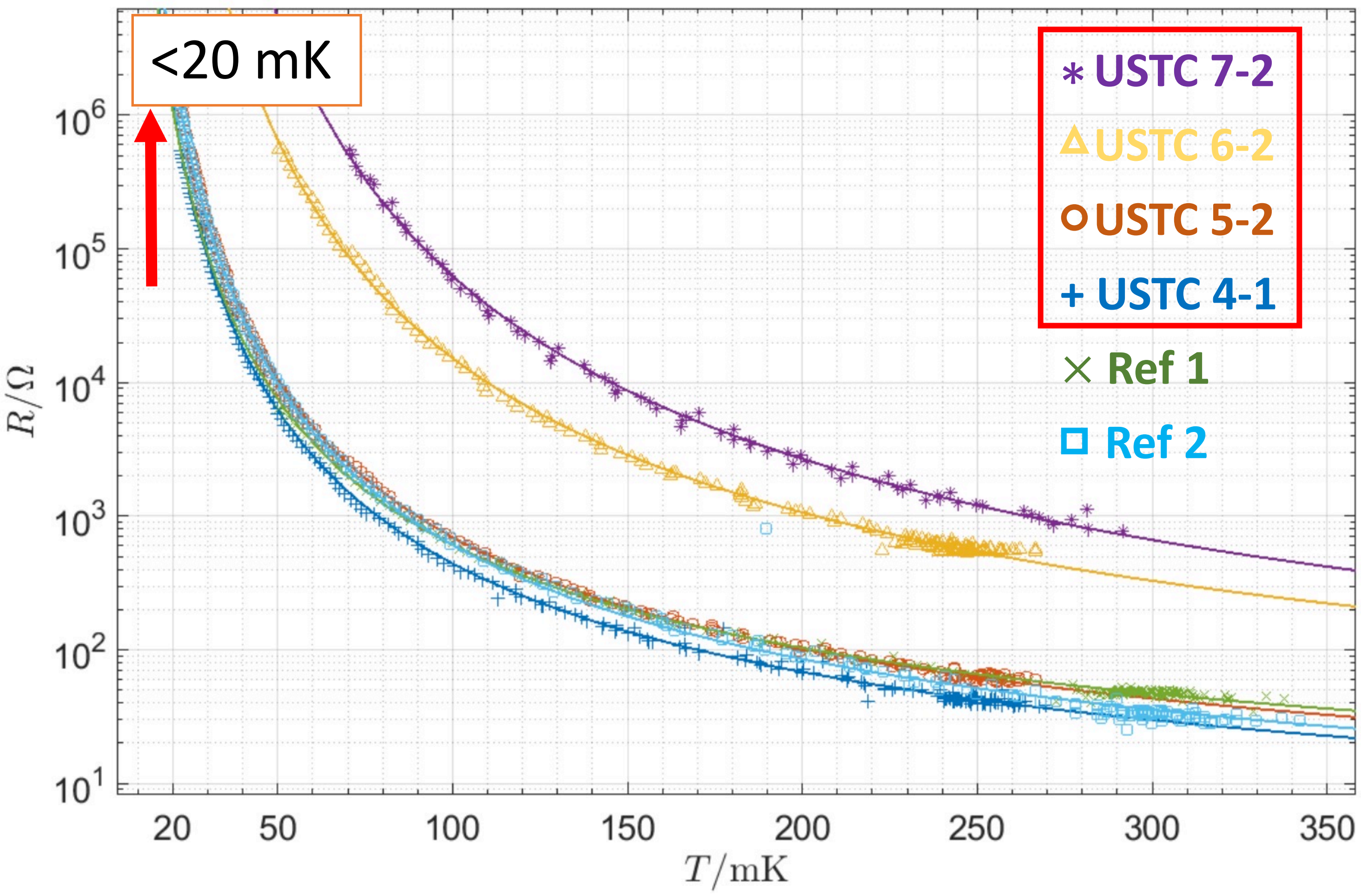
NTD-Ge fabrication roadmap

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

NTD-Ge_USTC (R-T) 20-350 mK

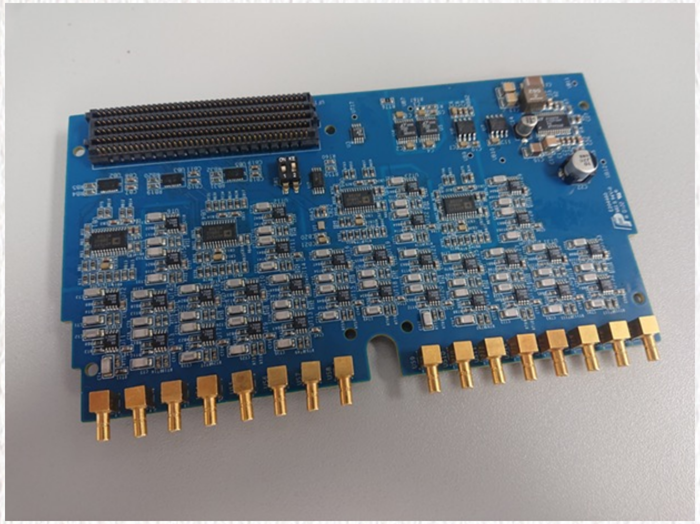
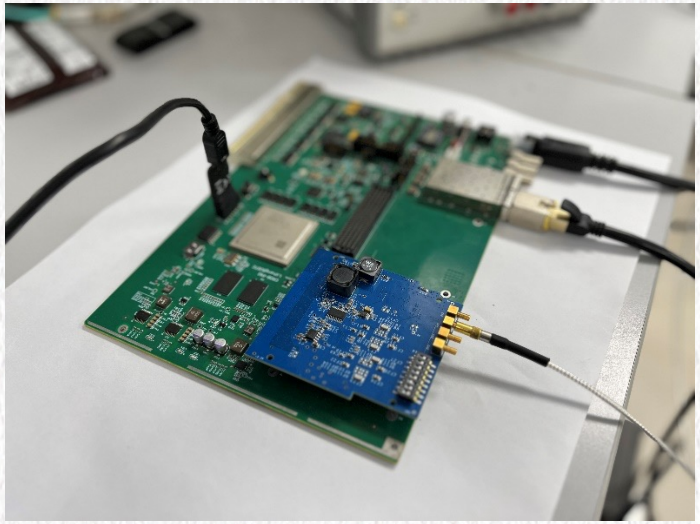






Low noise FEE and digital readout for NTD-Ge

- Produce four preamplifier boards that can work
- Design and test of a **16-channel digital board with Bessel filter** at 10 kHz sampling rate
- Develop a four-channel digital board with adjustable bandwidth that significantly improves the baseline performance

Readout electronics test with NTD-Ge, 16-channel digital board and four-channel adjustable bandwidth digital board

- Further reduce the noise of the preamplifier
- Low temperature electronics

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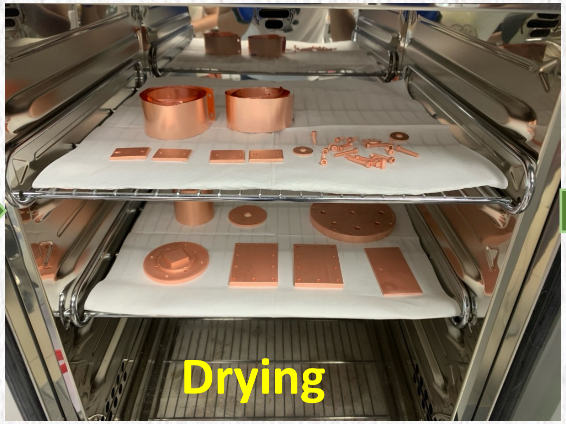
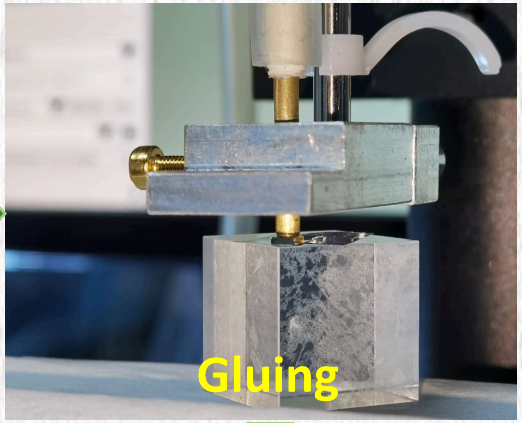
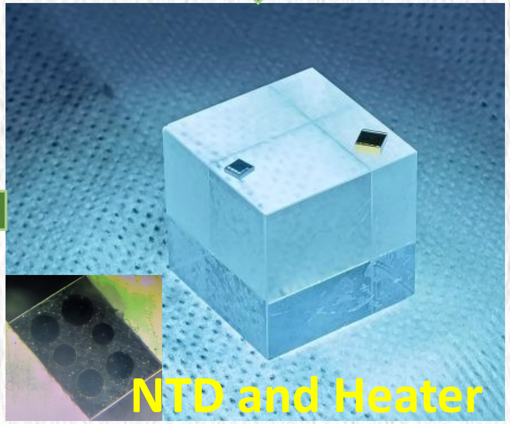
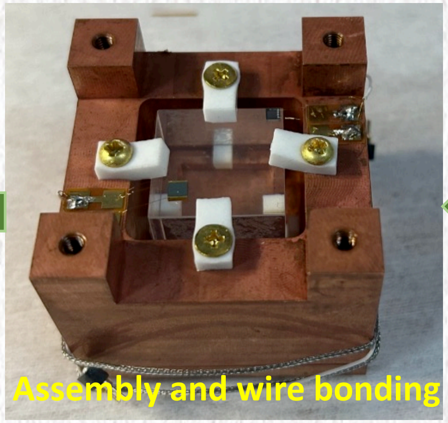
Small LMO ($2\times2\times2$ cm^3) bolometer I

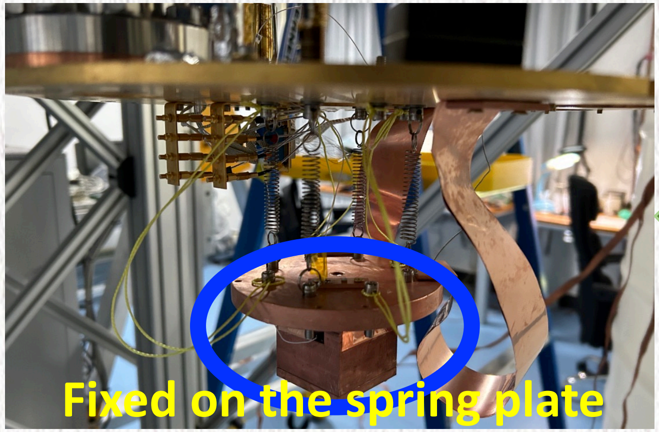
- LMO bolometer design
- ↓ Copper frame cleaning
- ↓ NTD/Heater gluing
- ↓ Kapton Pad gluing
- ↓ LMO bolometer assembly
- ↓ Wire bonding
- ↓ Fixed on the cryostat



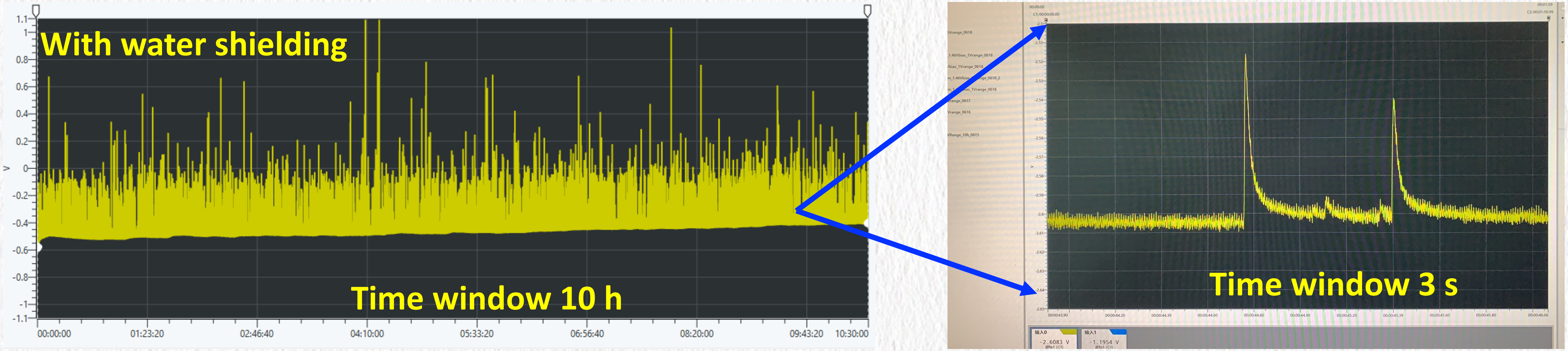


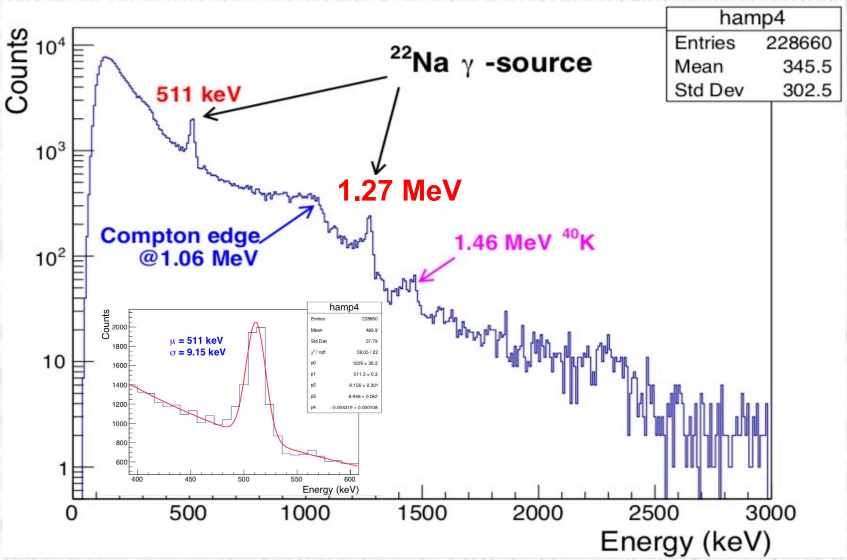






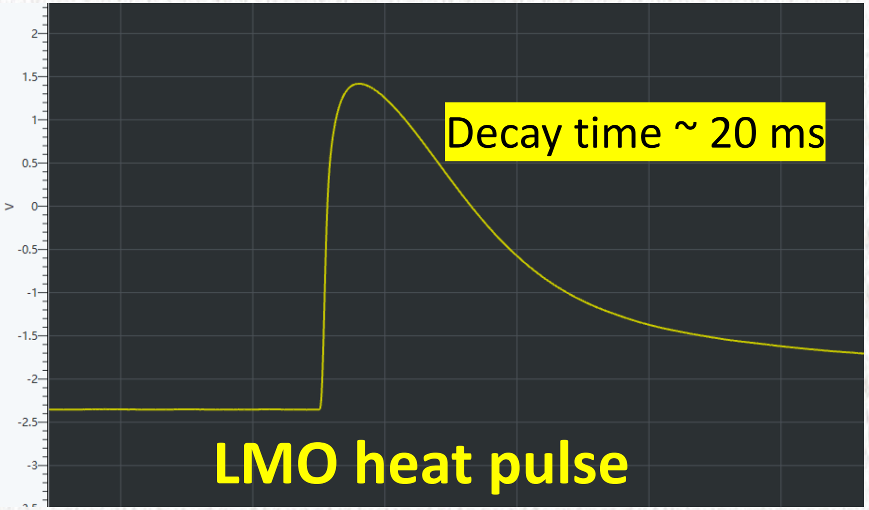
LMO ($2\times2\times2$ cm^3) bolometer test result

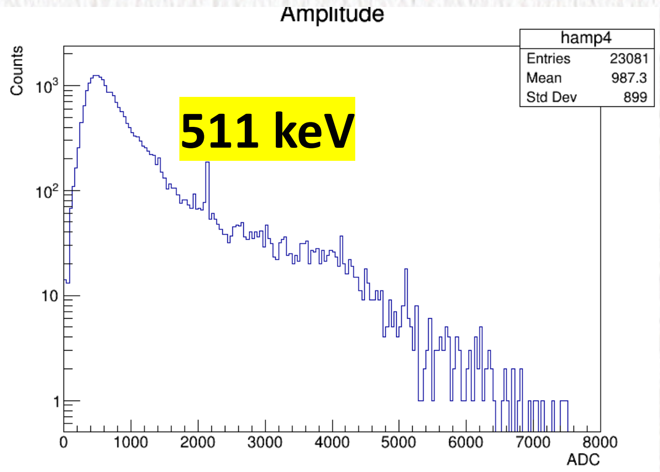


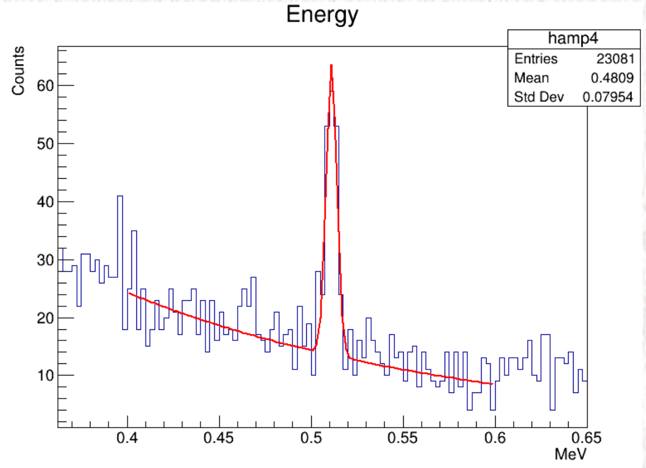


- Test at MC<**10 mK, Spring plate ~18 mK**
- NTD –Ge ~**300 kΩ**
- ^{22}Na: 511 keV, 1.27 MeV; ^{40}K: 1.46 MeV
- FWHM 21.5 keV@511 keV, 28.9 keV@1.27 MeV

Small LMO (1×1×1 cm³) bolometer II

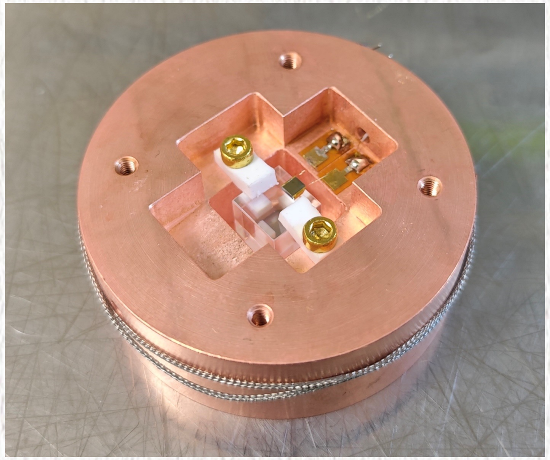


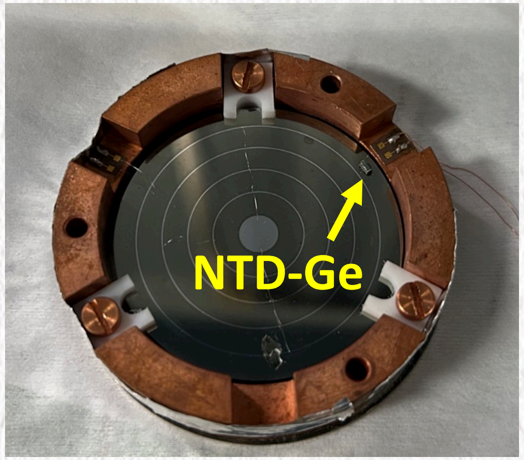


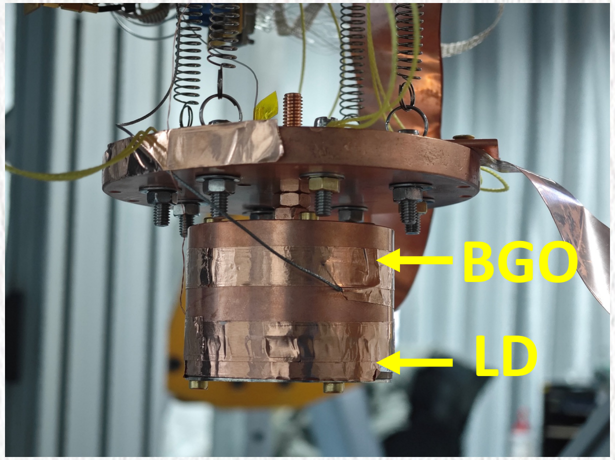


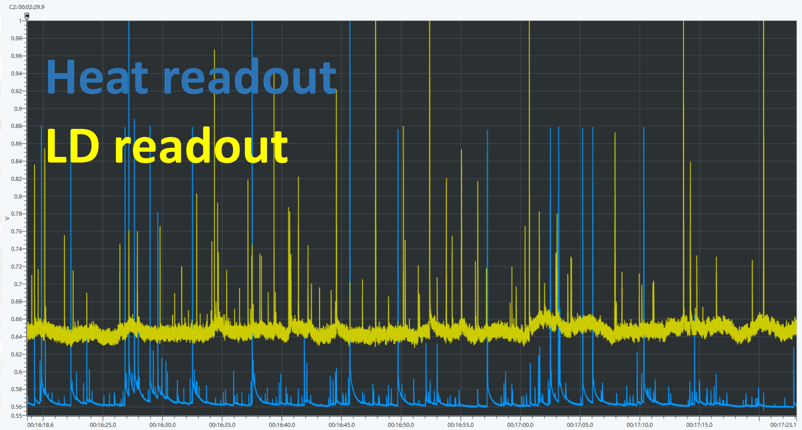
- Test at MC<**10 mK, Spring plate ~18 mK**
- $R_{NTD} \sim 2\ M\Omega, V_{bias} = 3.5\ V, R_{load} = 2G\Omega$
- FWHM 7 keV@511 keV
- Small crystal, low detection efficiency

Quick glance of a BGO L-H double-readout bolometer R&D @USTC

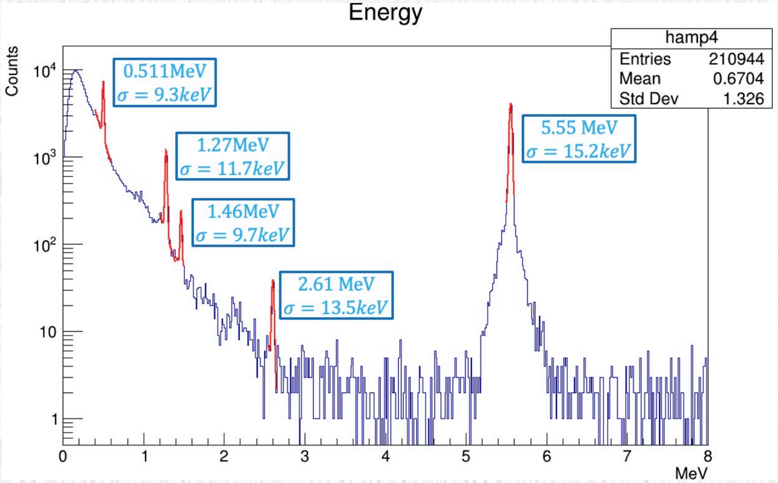


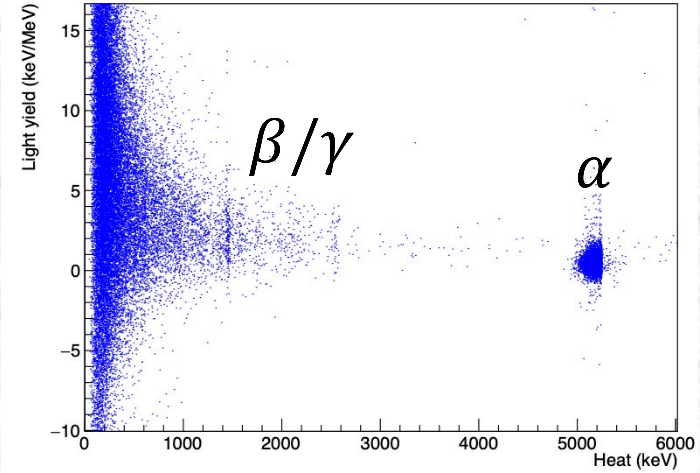






Light-Heat double readout

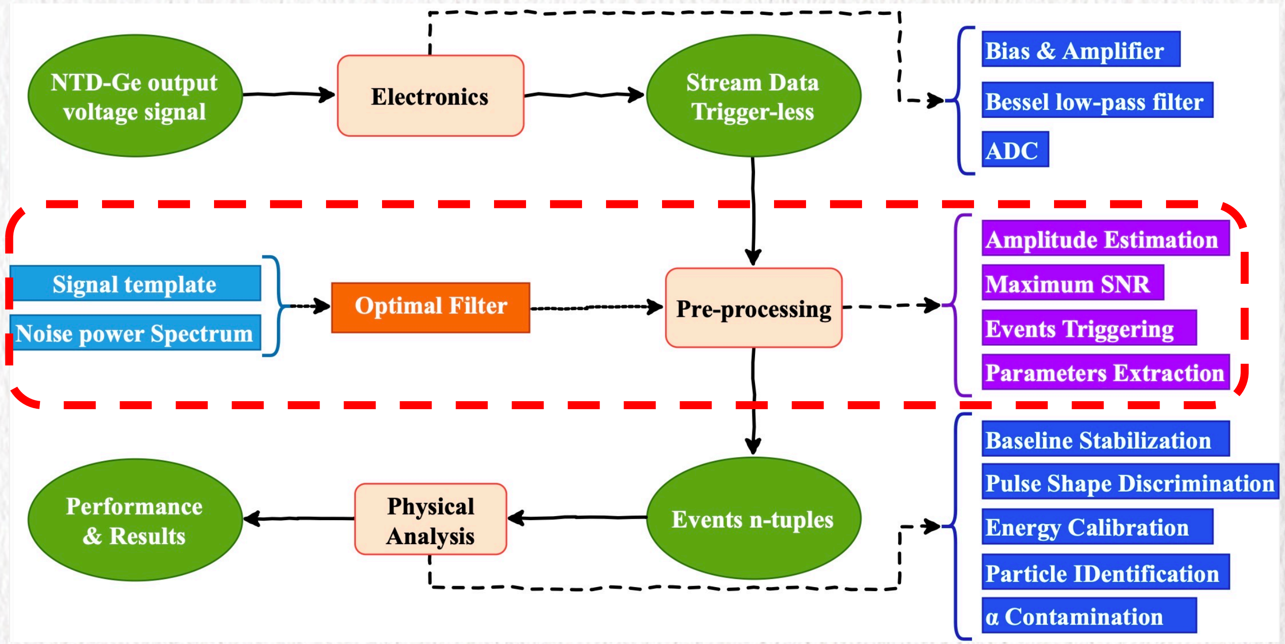


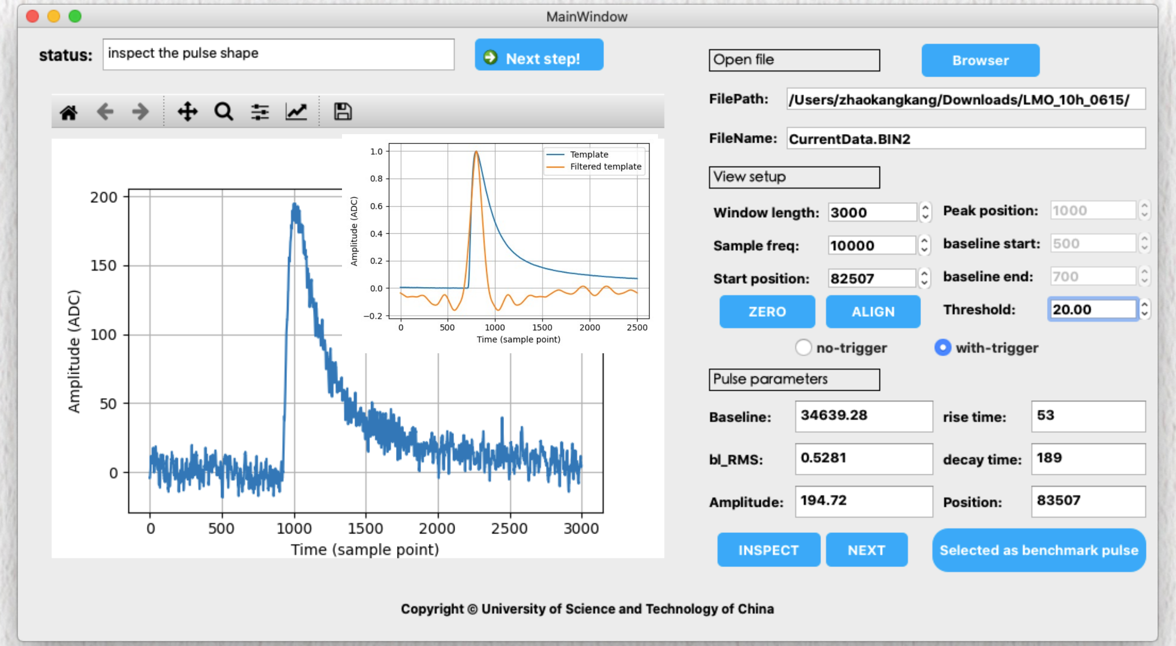


Poster 5-20: Measurement of alpha contamination of Po-210 using a BGO cryogenic bolometer, Deyong Duan, Mingxuan Xue, Haiping Peng

Stream data processing software

- Collect triggerless stream data, python-based visualization software
- Exploit a matched filter, the Gatti-Manfredi optimum filter, **to maximize the signal to noise (S/N)** and to get the information about the pulse-shape parameters
- Amplitude, decay time, rise time, baseline, correlation, et al.





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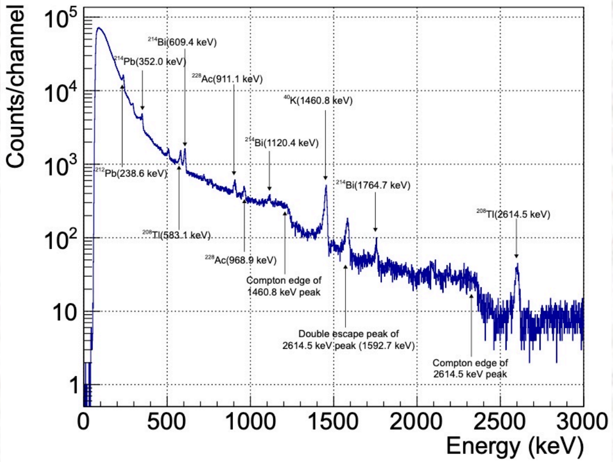
Ground cryogenic lab status

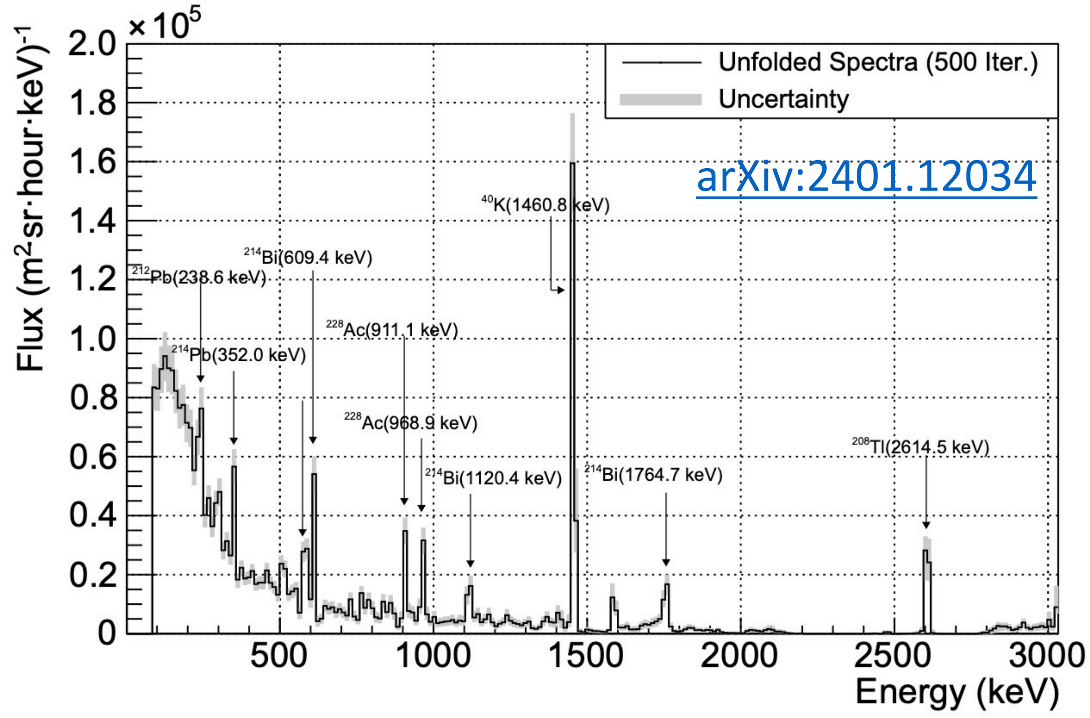
Oxford Triton 500@USTC, 2021

Running with water shielding, reduce pile-up

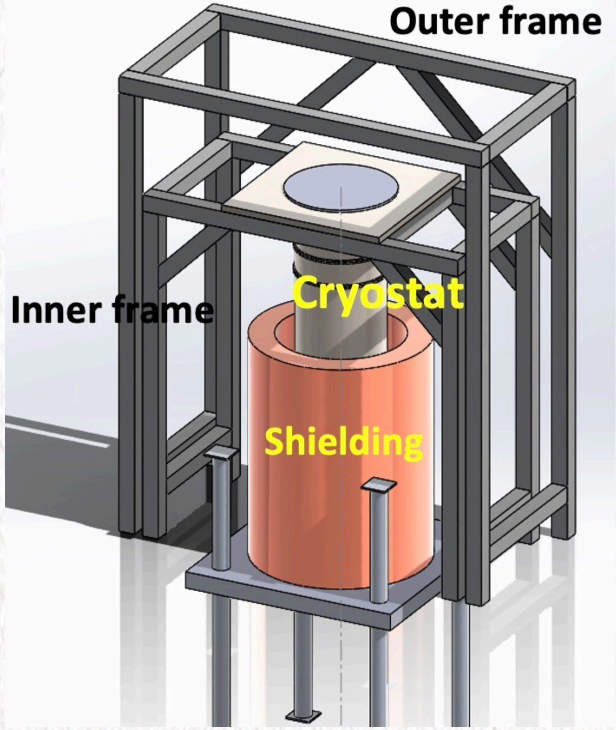
Ground lab gamma flux

- CZT(CdZnTe) detector + unfolding method → high gamma flux backgrounds
- Long decay time (hundreds ms)→ pile-up events →shielding





Surrounding gamma flux backgrounds



Pb+Cu shielding, 2024

Summary

- LMO and NMO are both very attractive crystals, especially for **$0\nu\beta\beta$ search** with **Cryogenic phonon scintillating detector**
- LMO/NMO crystal growth with high quality
- R&D work on **NTD-Ge fabrication and electronics**, scintillating crystals' low temperature characteristics, **bolometer design and mK running, radioactive shielding**
- Contribute to $0\nu\beta\beta$ experiments with CPD at **China Jinping Underground Lab**

CUPID-China实验进展与计划，陈昊老师

Summary

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谢谢！