



Search for Neutrinoless Double Beta Decay with Cryogenic Bolometer

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OUTLINE



01 Neutrinoless double beta decay

02 Bolometer for $0\nu\beta\beta$

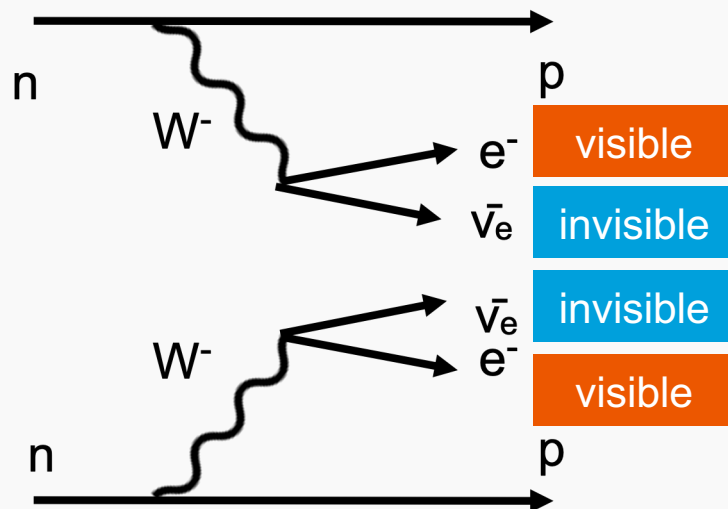
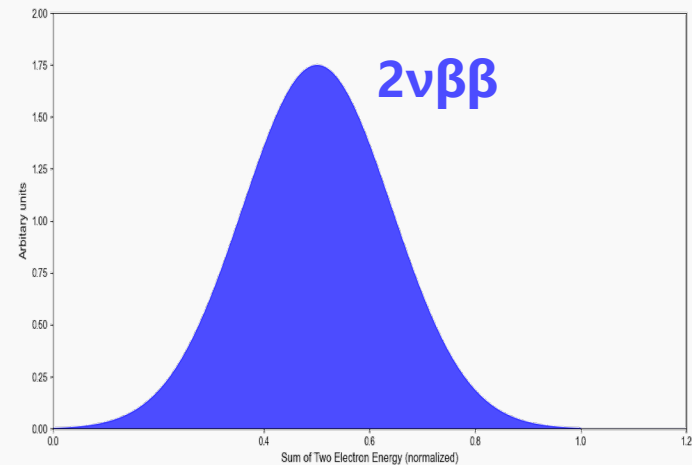
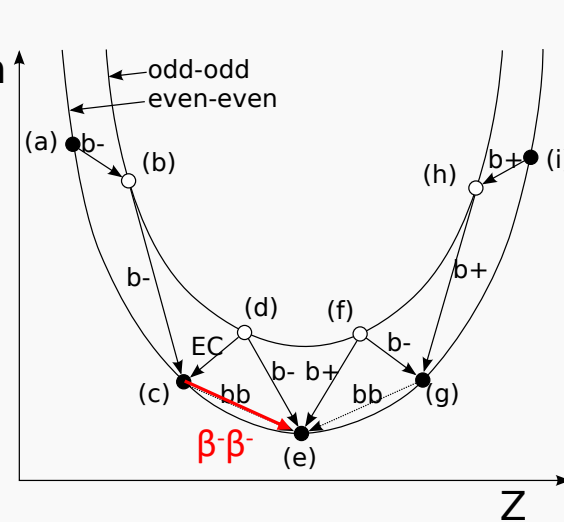
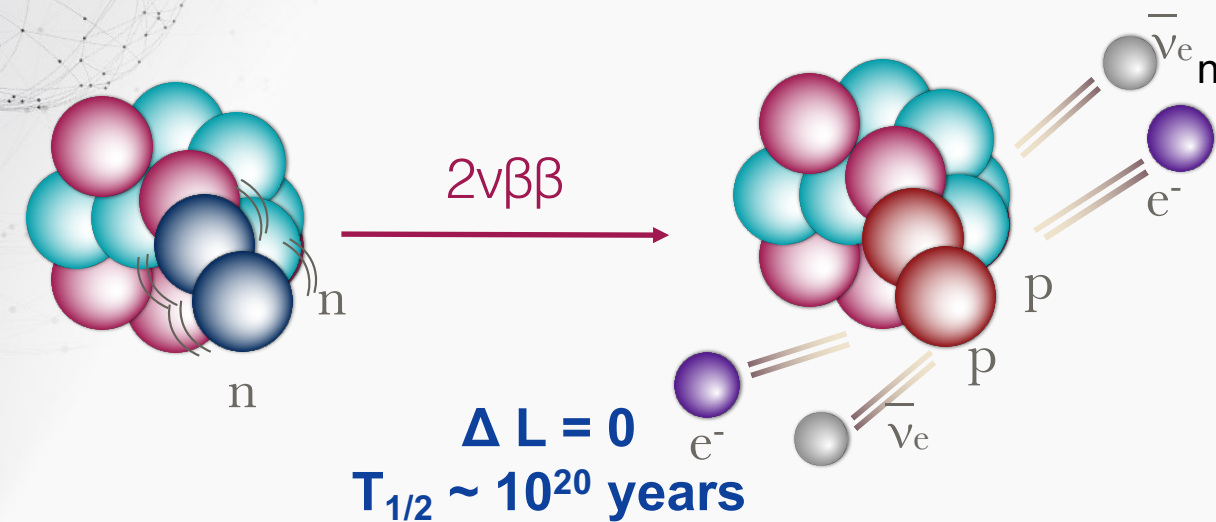
03 CUPID-CJPL experiment

04 Summary & outlook



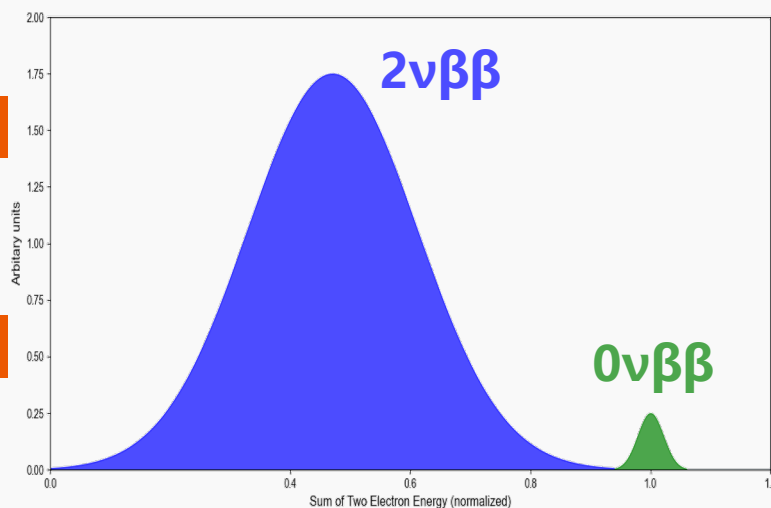
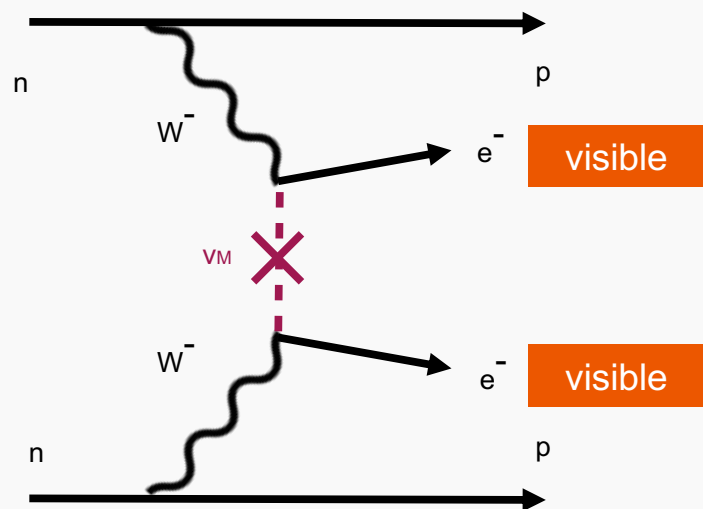
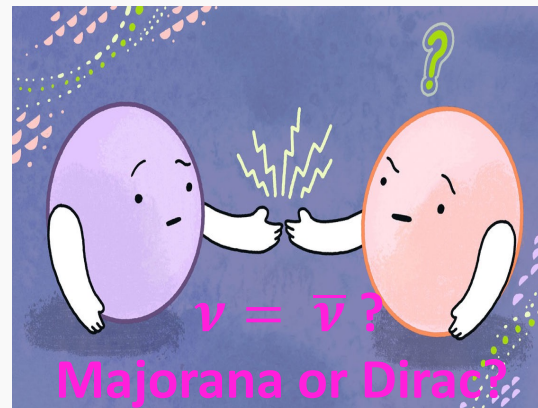
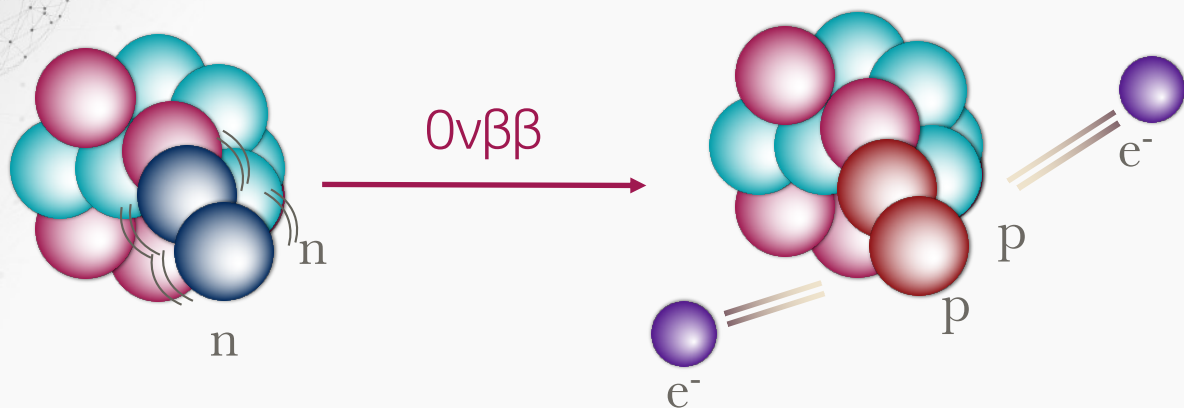
$0\nu 1$ Neutrinoless Double Beta Decay

Two Neutrino Double Beta Decay



1	2																18
1 H 1.008																	2 He 4.0026
3 Li 6.94	4 Be 9.0122																10 Ne 20.180
11 Na 22.990	12 Mg 24.305																18 Ar 39.948
19 K 39.098	48Ca	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	76Ge	33 As 74.922	82Se	35 Br 79.904	36 Kr 83.798
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	96Zr	41 Nb 92.906	100Mo	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	110Pd	47 Ag 107.87	116Cd	49 In 114.82	124Sn	51 Sb 121.76	128, 130Te	53 I 126.90	136Xe
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 (261)	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 # Actinide series																	
57 La 138.91	58 Ce 140.12	59 Pr 140.91	150Nd	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			
89 Ac (227)	90 Th 232.04	91 Pa 231.04	238U	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)			

Neutrinoless Double Beta Decay ($0\nu\beta\beta$)



Forbidden in the Standard Model

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

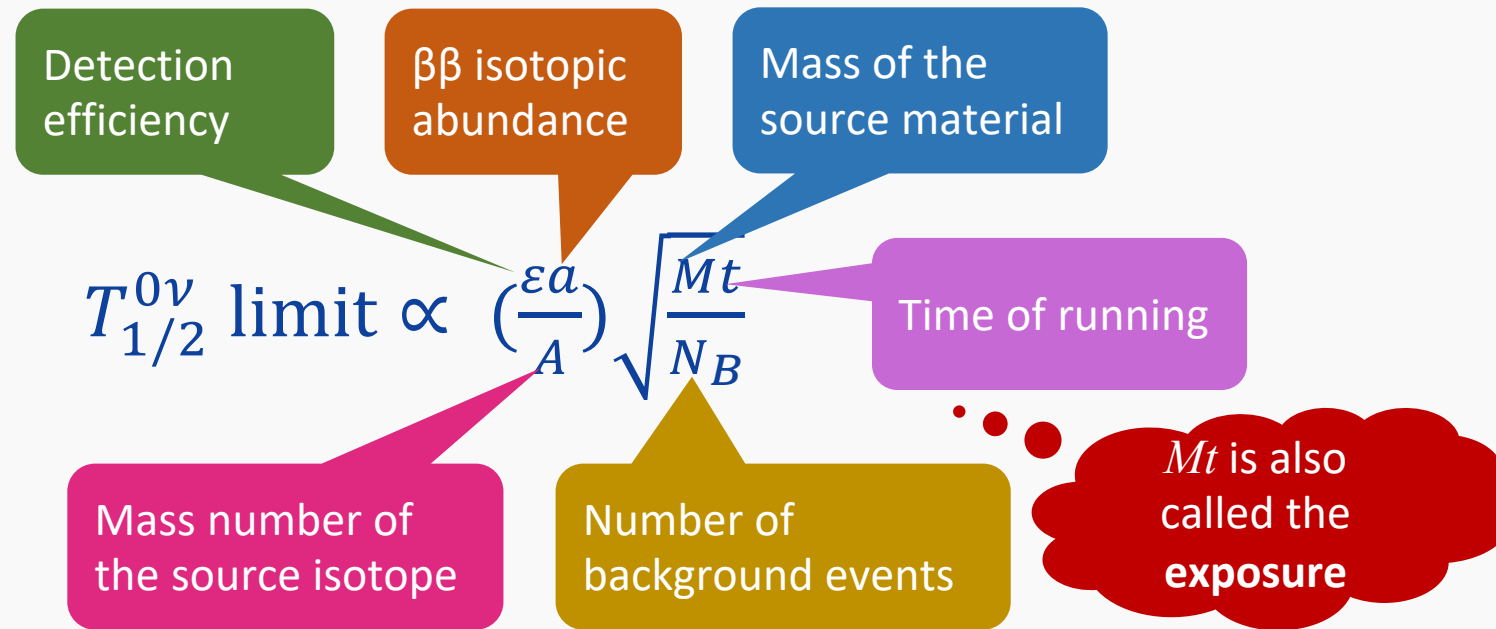
$$\Delta L = 2$$

Only if $\nu=\bar{\nu}$: Majorana neutrino

All $2\nu 2\beta$ isotopes are candidate of $0\nu 2\beta$ decays.

Experiment Design Consideration

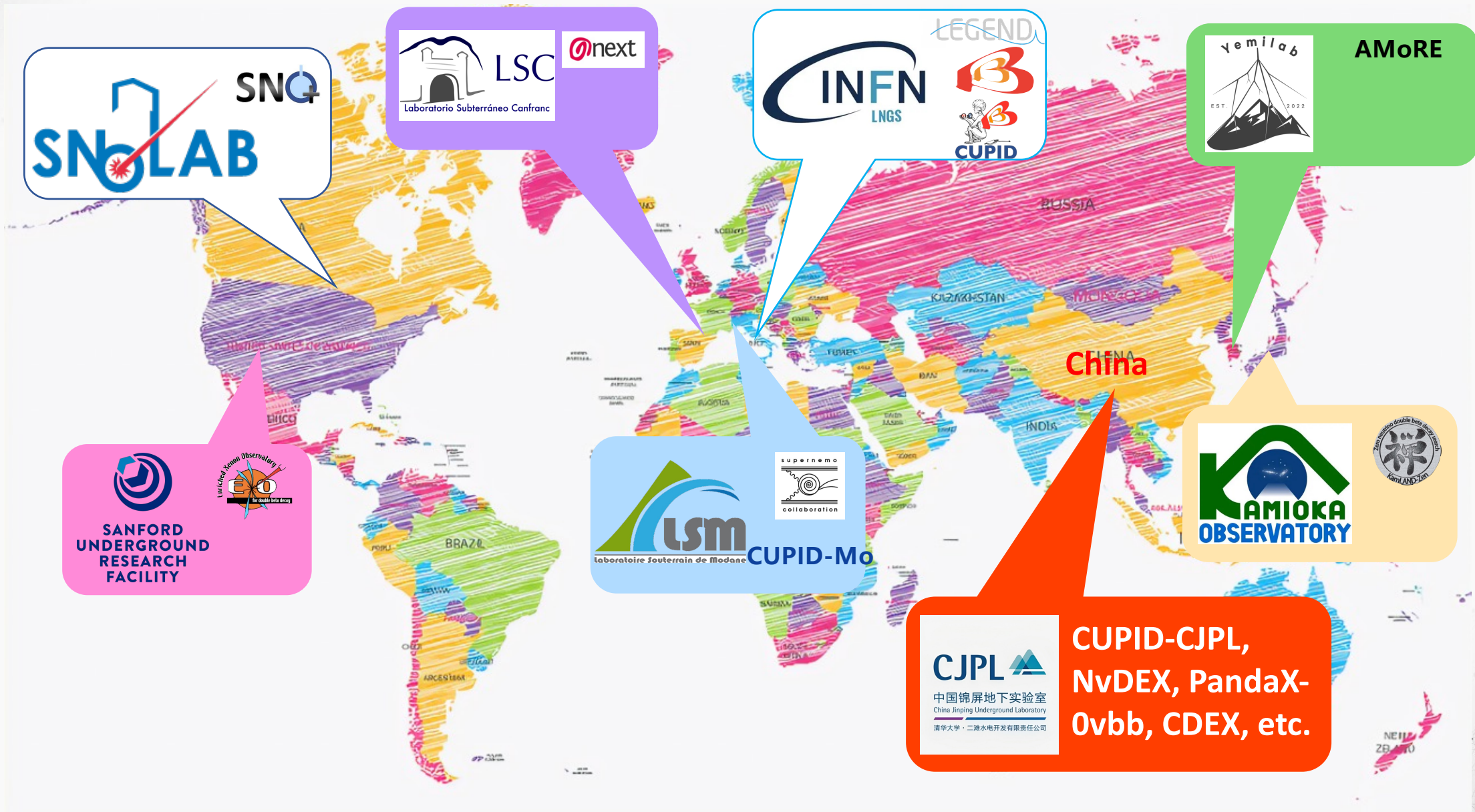
The expected half-life sensitivity of $0\nu 2\beta$ decay experiment:



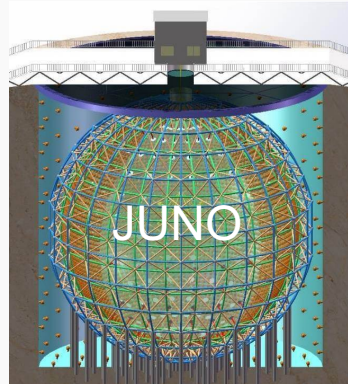
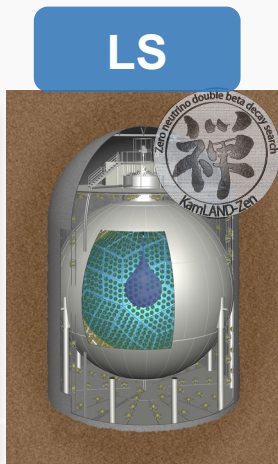
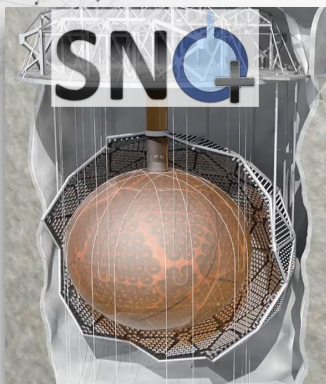
For **zero background** experiment, it is **proportional to Mt** :

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

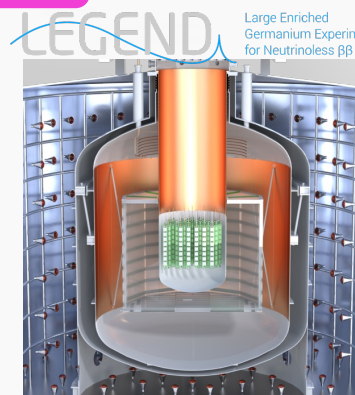
Worldwide $0\nu\beta\beta$ Experiments in Underground Labs



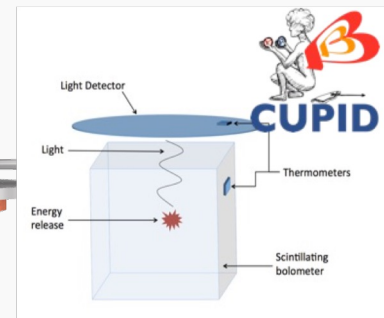
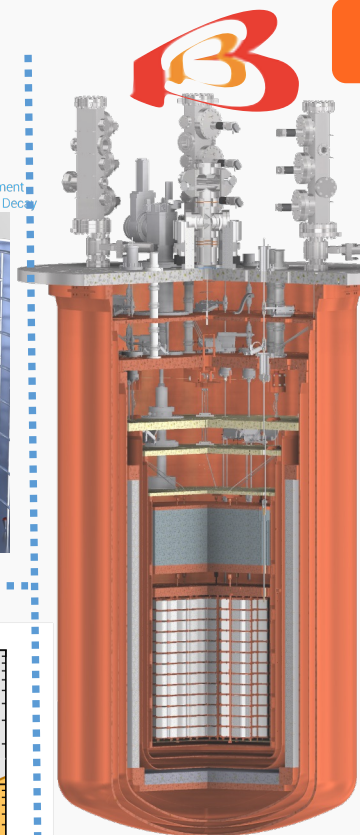
$0\nu\beta\beta$ Experiments



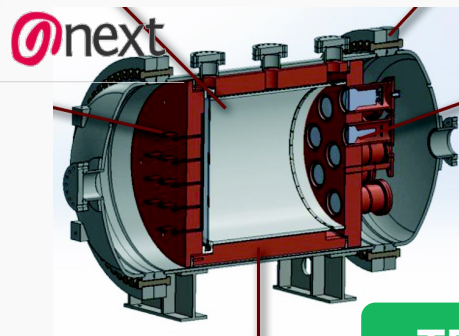
HPGe



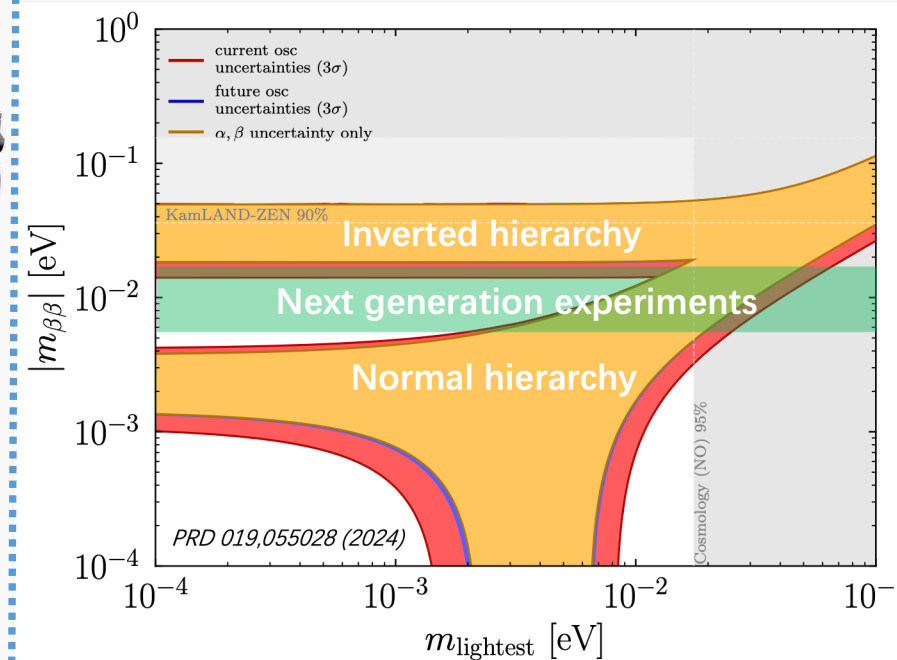
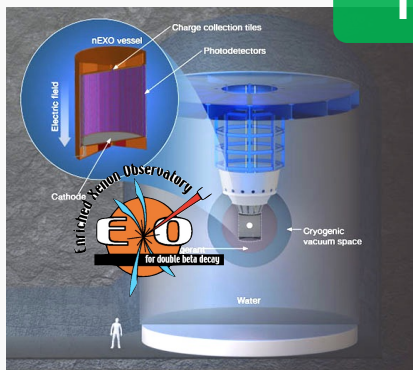
Bolometer



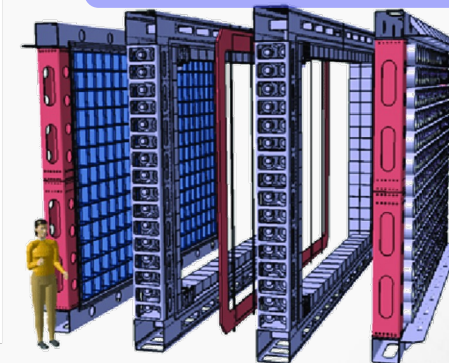
AMoRE



TPC



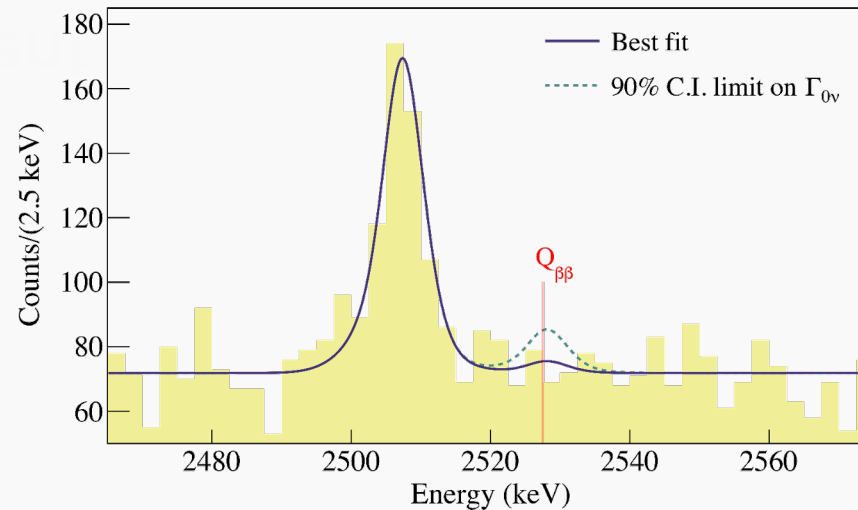
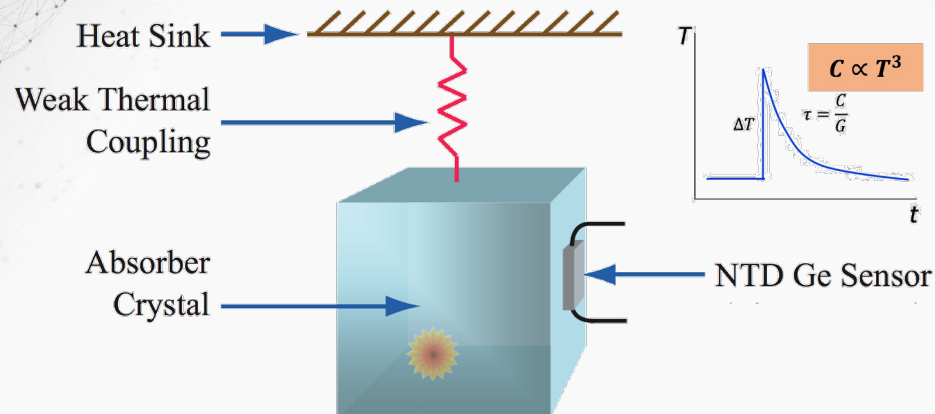
Tracker + calorimeter



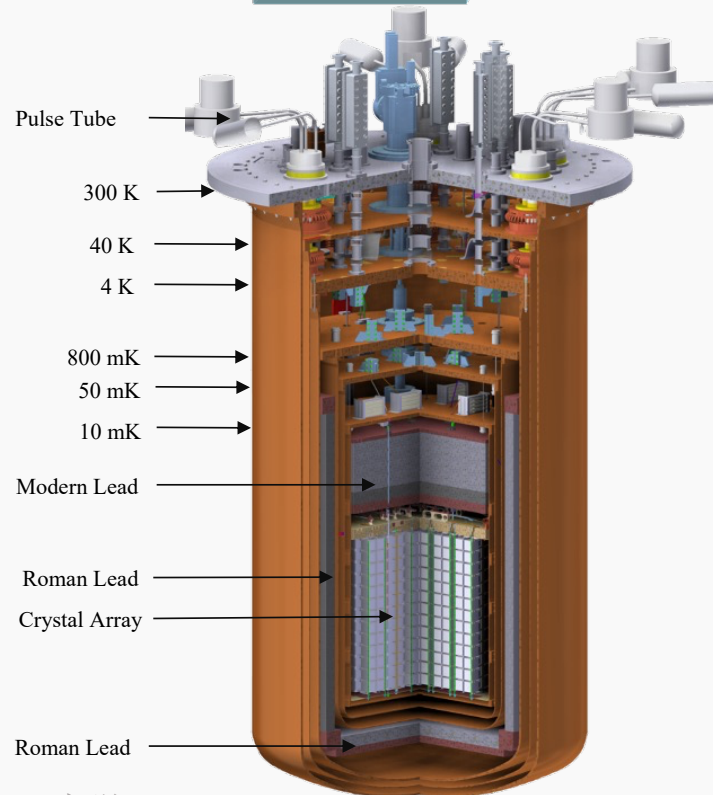
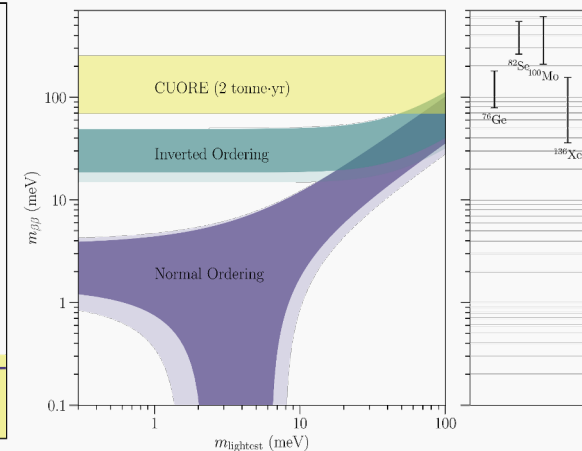


Bolometer for $0\nu\beta\beta$

From CUORE to CUPID Experiment



CUORE 2-ton yr result [Science 10.1126/science.adp6474](https://doi.org/10.1126/science.adp6474) (2025)

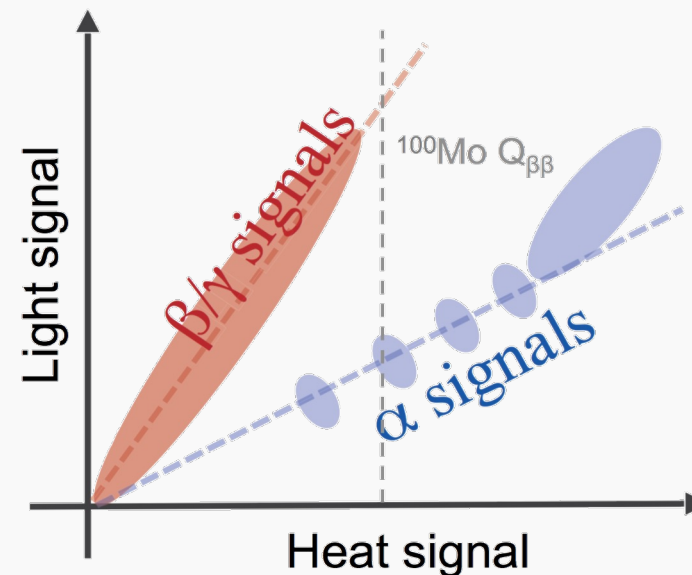
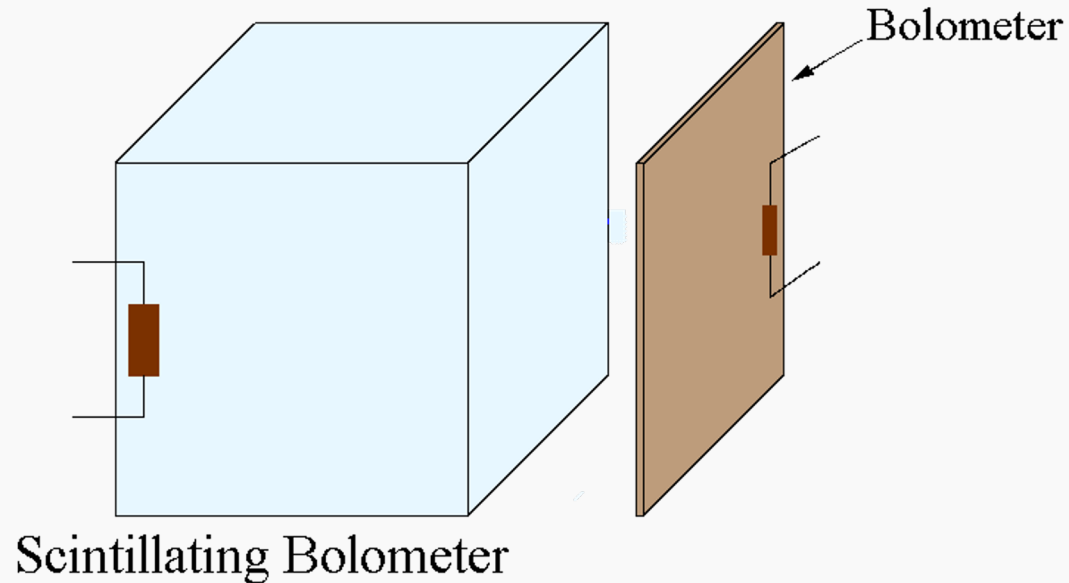


Best limit on ^{130}Te
 $\text{TeO}_2 \sim 206 \text{ kg of } ^{130}\text{Te}$
 $Q_{\beta\beta} : 2727 \text{ keV}$
 $T_{1/2} > 3.5 \times 10^{25} \text{ yr}$
 $m_{\beta\beta} < 70 - 250 \text{ meV}$
 $\text{BI} : 3 \times 10^{-3} \text{ ckky in ROI}$
Heat signal only



Aim to do:
 $\text{Li}_2\text{MoO}_4 \sim 240 \text{ kg } ^{100}\text{Mo}$
 $Q_{\beta\beta} : 3034 \text{ keV}$
 $T_{1/2} > 1 \times 10^{27} \text{ yr}$
 $m_{\beta\beta} < 12 - 20 \text{ meV}$
 $\text{BI} : < 10^{-4} \text{ ckky in ROI}$
Heat – Light dual readout

CUPID (CUORE Upgrade with Particle IDentification)



Bolometer:

- ✓ **Source = Detector:** High Eff_{det}
- ✓ **Energy deposition $\rightarrow$ Phonons**
- ✓ **Flexible isotope choices**
- ✓ **Ultra-low detection threshold (~ 15 eV)**
- ✓ **Exceptional energy resolution ($\sim 0.3\%$ FWHM @2.6 MeV)**

Scintillating bolometer:

- ✓ **Light-Heat Signal Dual Readout**
- ✓ **Particle Identification**
- ✓ **Further reduce background**
- ✓ **NTD or TES sensor**

The background features a complex network diagram with numerous nodes (represented by small grey and black dots) connected by thin grey lines, forming a web-like structure that spans the entire slide.

nr

CUPID-CJPL

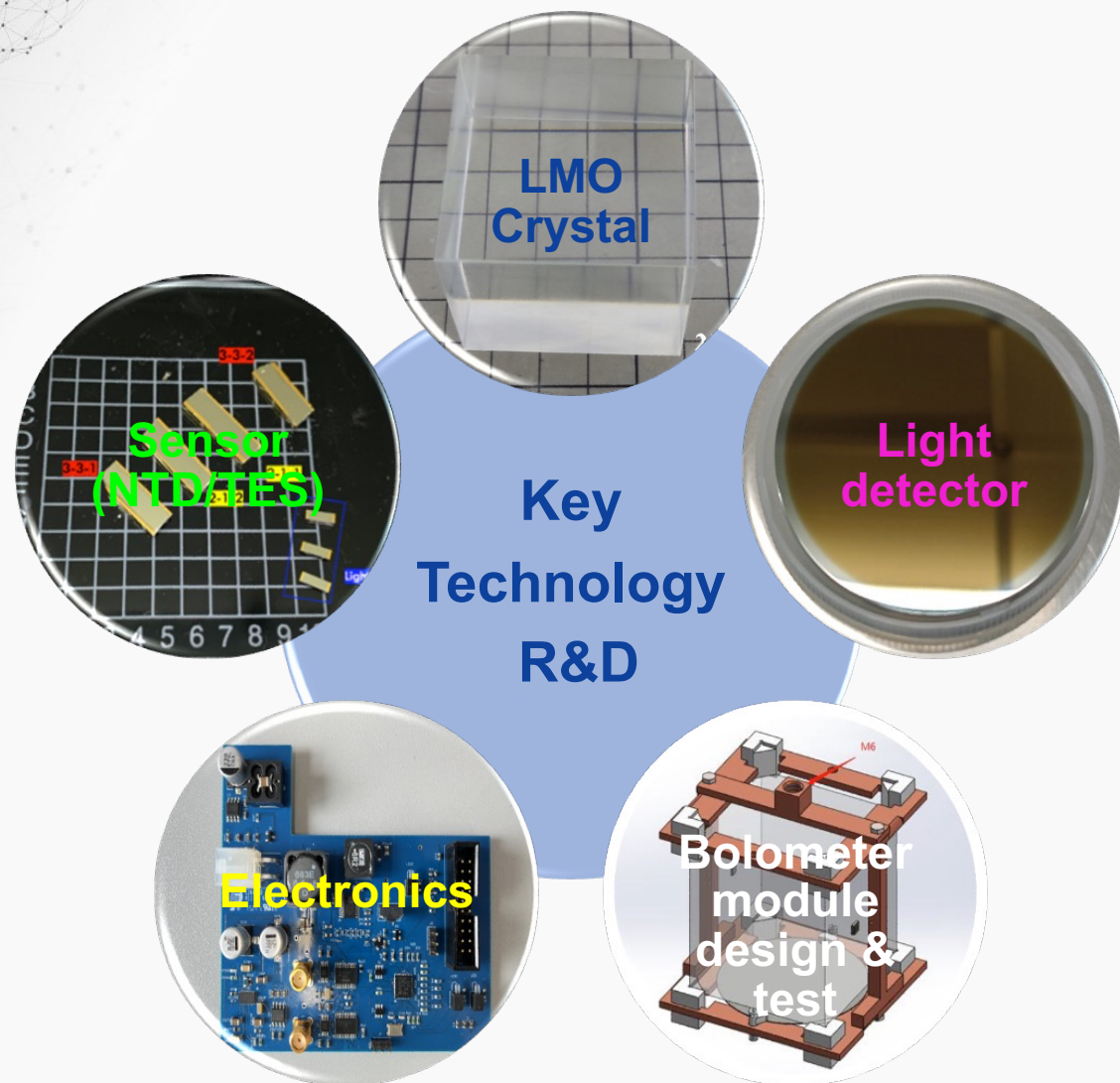
CUPID

Bel

-
- The image displays a 3D CAD model of a cylindrical container. The container is shown in a cutaway view, revealing a grid of internal components, likely a heat exchanger or a similar structure. A red rectangular box highlights a specific corner joint of the grid. An inset image to the right provides a detailed view of this corner joint, showing the intersection of the grid's structural members and the internal components, which are held together by a complex assembly of bolts and plates.



CUPID-CJPL R&D in China



CUPID-CJPL

- 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*
- Institute of High Energy Physics

(*Officially in the international CUPID collaboration)

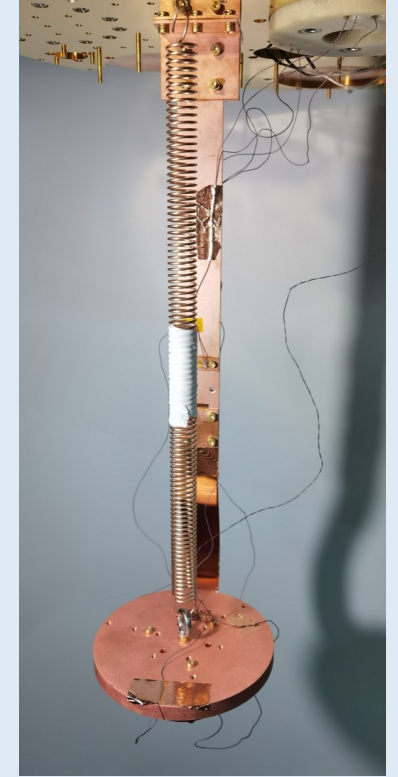
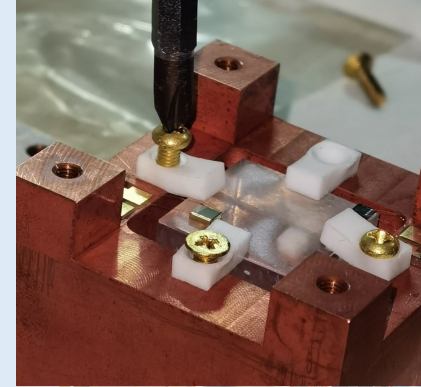
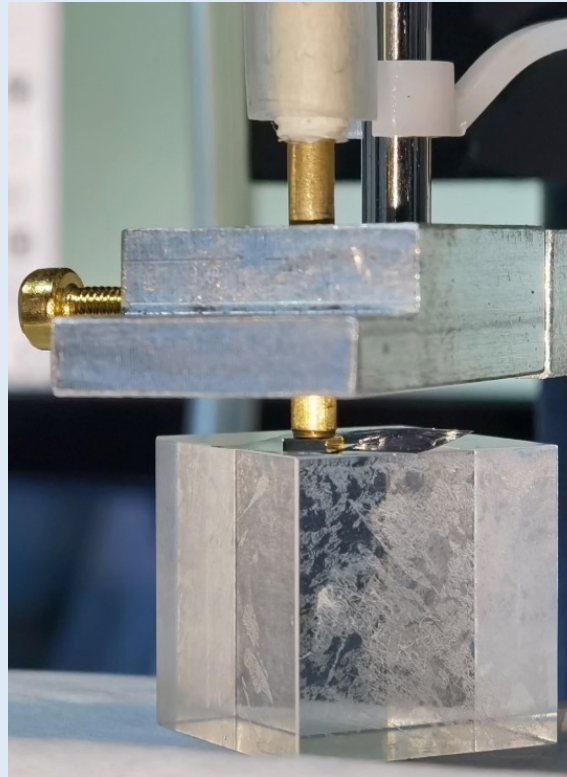
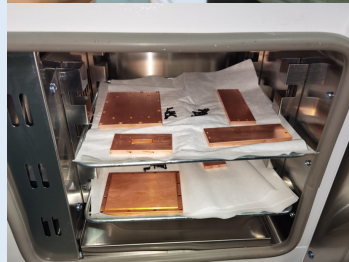
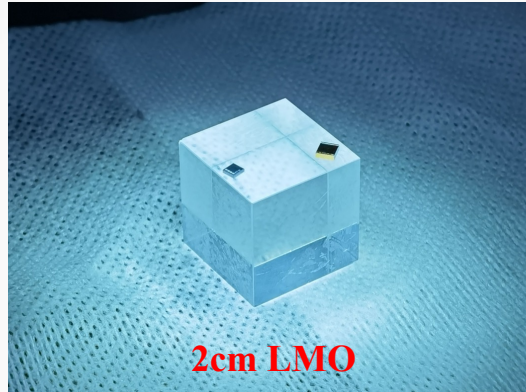


~ 9 institutes, > 40 collaborators

Bolometer Module Assembling @ Fudan

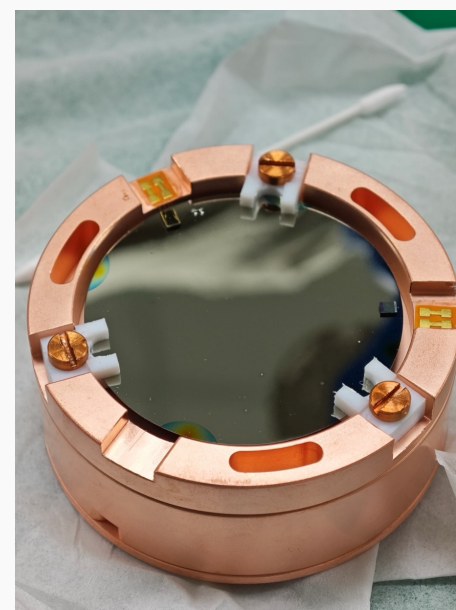
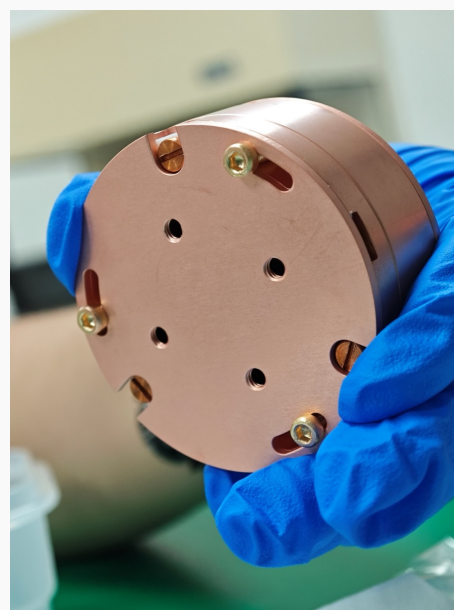
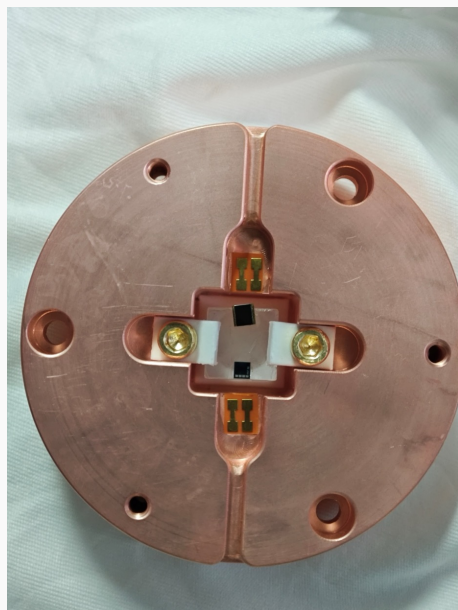
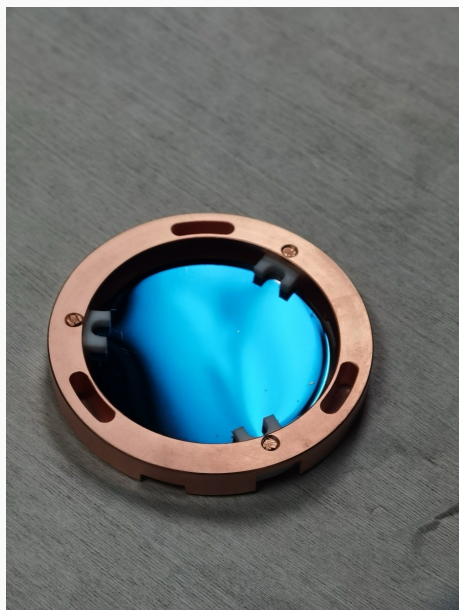
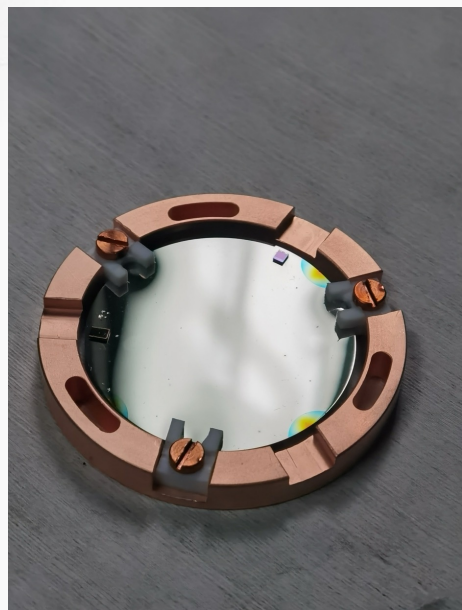
- ✓ Testing of the small size LMO crystal ($2 \times 2 \times 2 \text{ cm}^3$ / $1 \times 1 \times 1 \text{ cm}^3$, BG/CZ) in ground lab
- ✓ Module components: LMO crystal, NTD-Ge, heater, PTFE/Cu holder
- ✓ Assembly process well established

Cleaning & Drying → Gluing → Assembly & Bonding → Installation

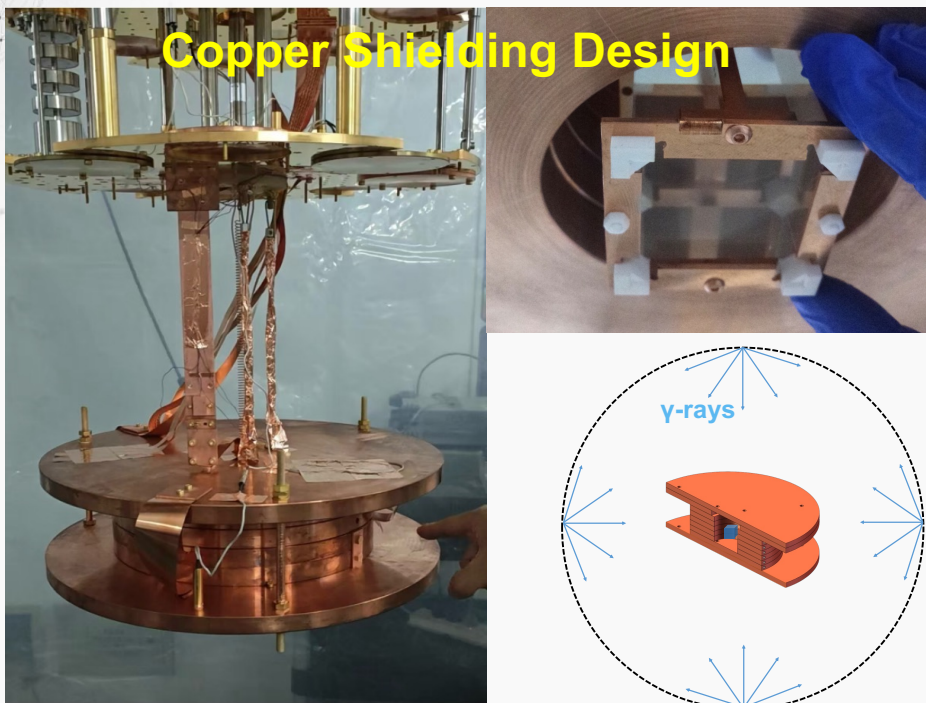


Light Detector R&D and Tests @ Fudan

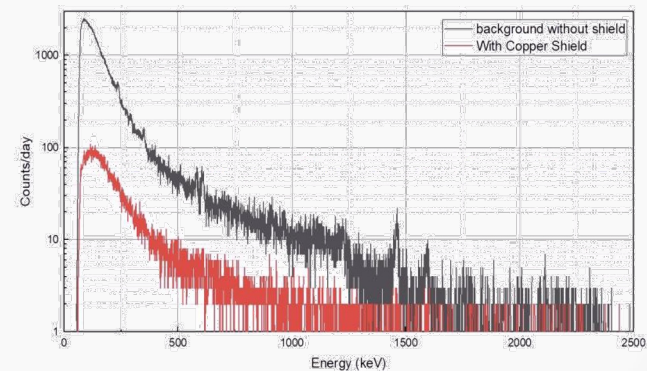
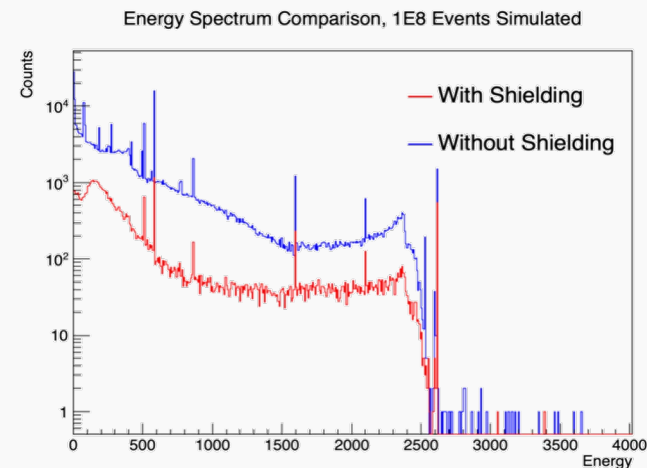
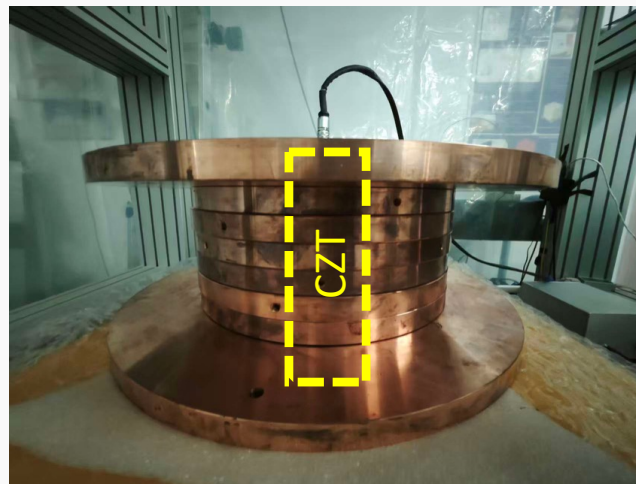
- ✓ Light detector, ϕ 44, is assembled together with 1cm LMO on the spring plate
- ✓ Sensitive to cosmic ray, vibration, and other background events.



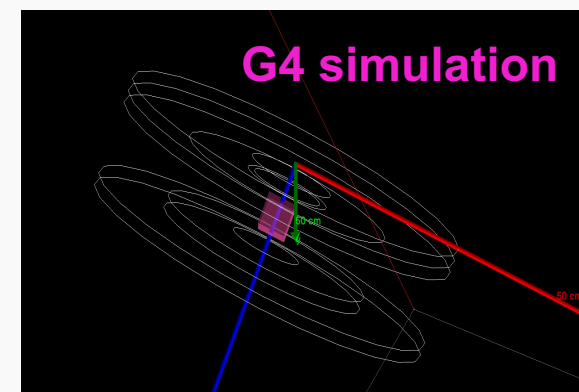
Background study & Internal Shielding Design @ Fudan



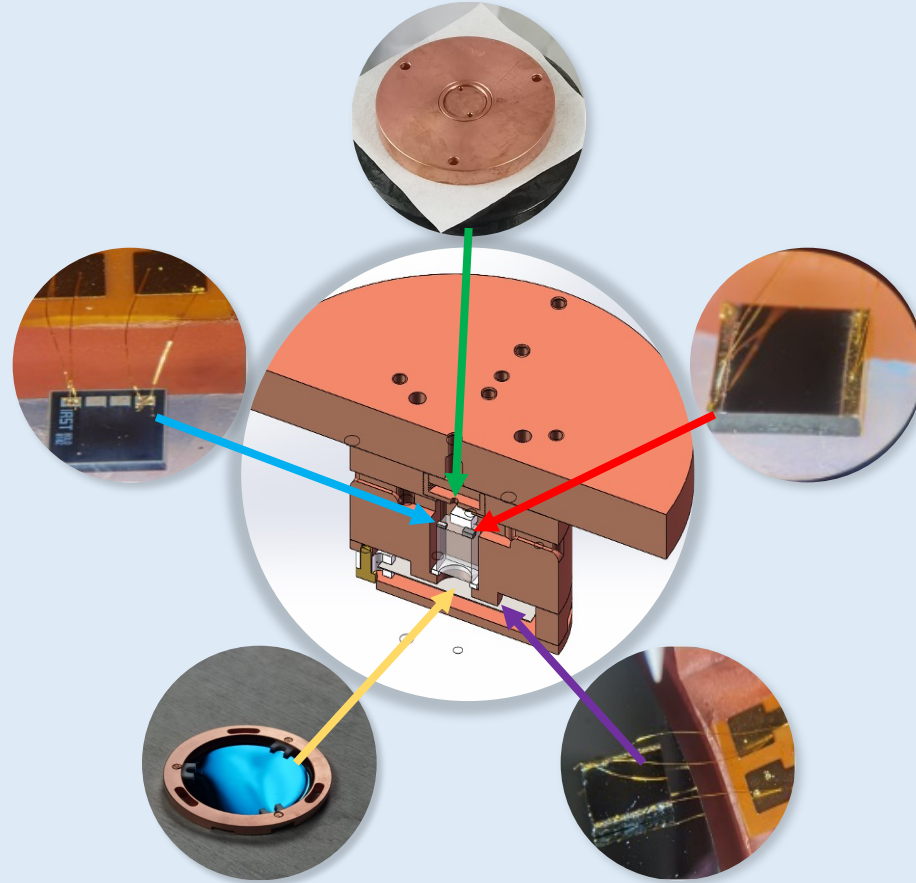
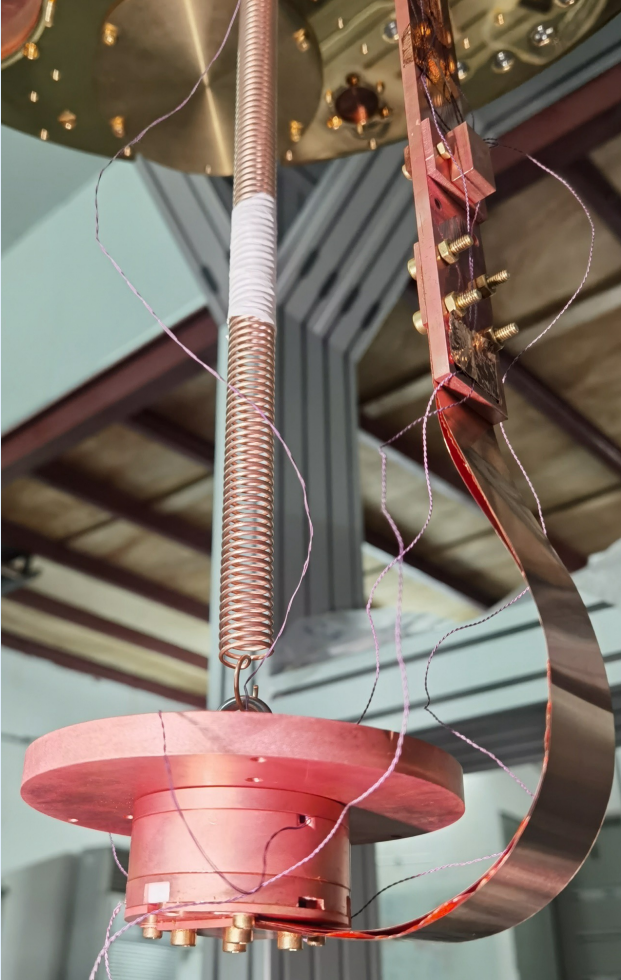
Validating shielding capability



- ❑ Main background: cosmic ray & environmental radiation
- ❑ Typical decay time **10 ~100 ms** for heat channel
- ❑ Heavy pile-up issue ⇒ **shielding**
- ❑ Shielding designed using Geant4 simulation
- ❑ Shielding capability validated by CZT & HPGe detector

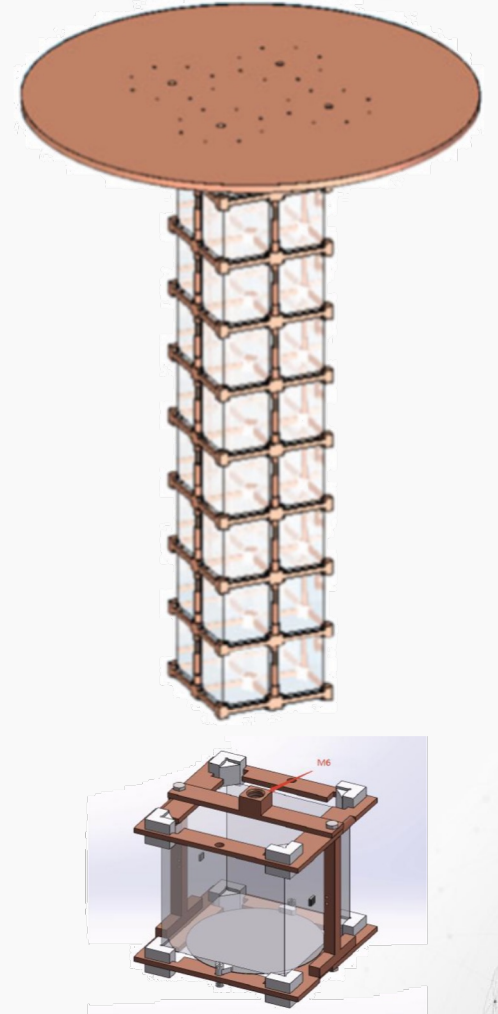


Detector Module Design @ Fudan



Single Module

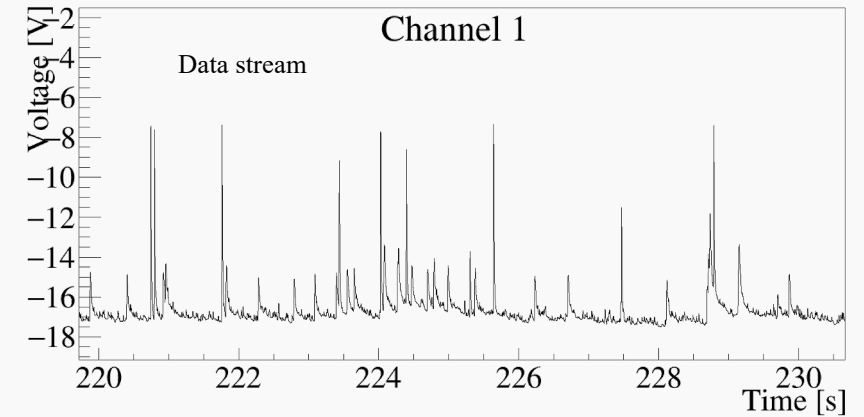
Array



Data process workflow @ Fudan

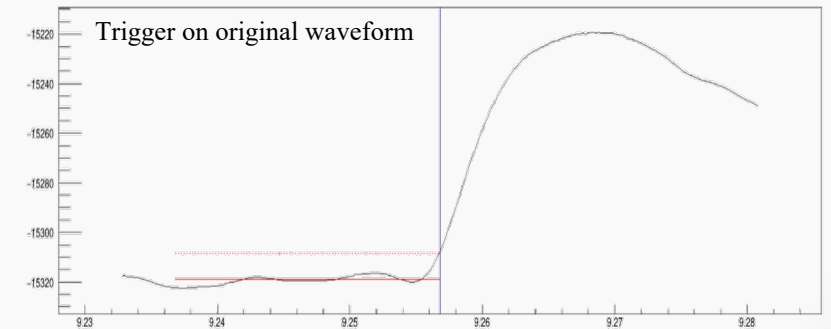
Plot Data Stream

- Plots data stream
- Check waveforms and decide trigger parameters



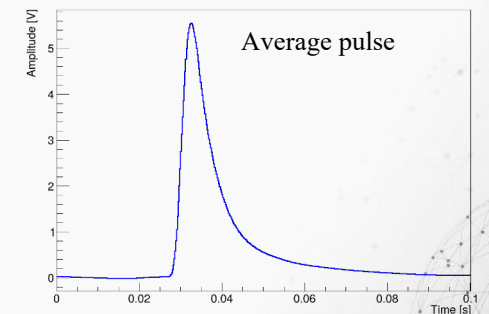
Trigger

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



Filter & Recon.

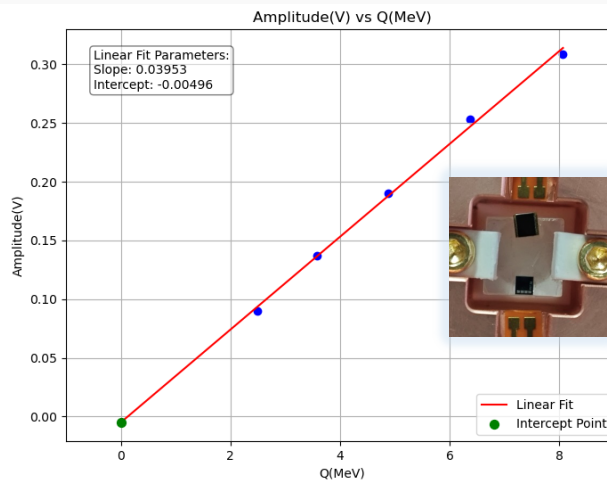
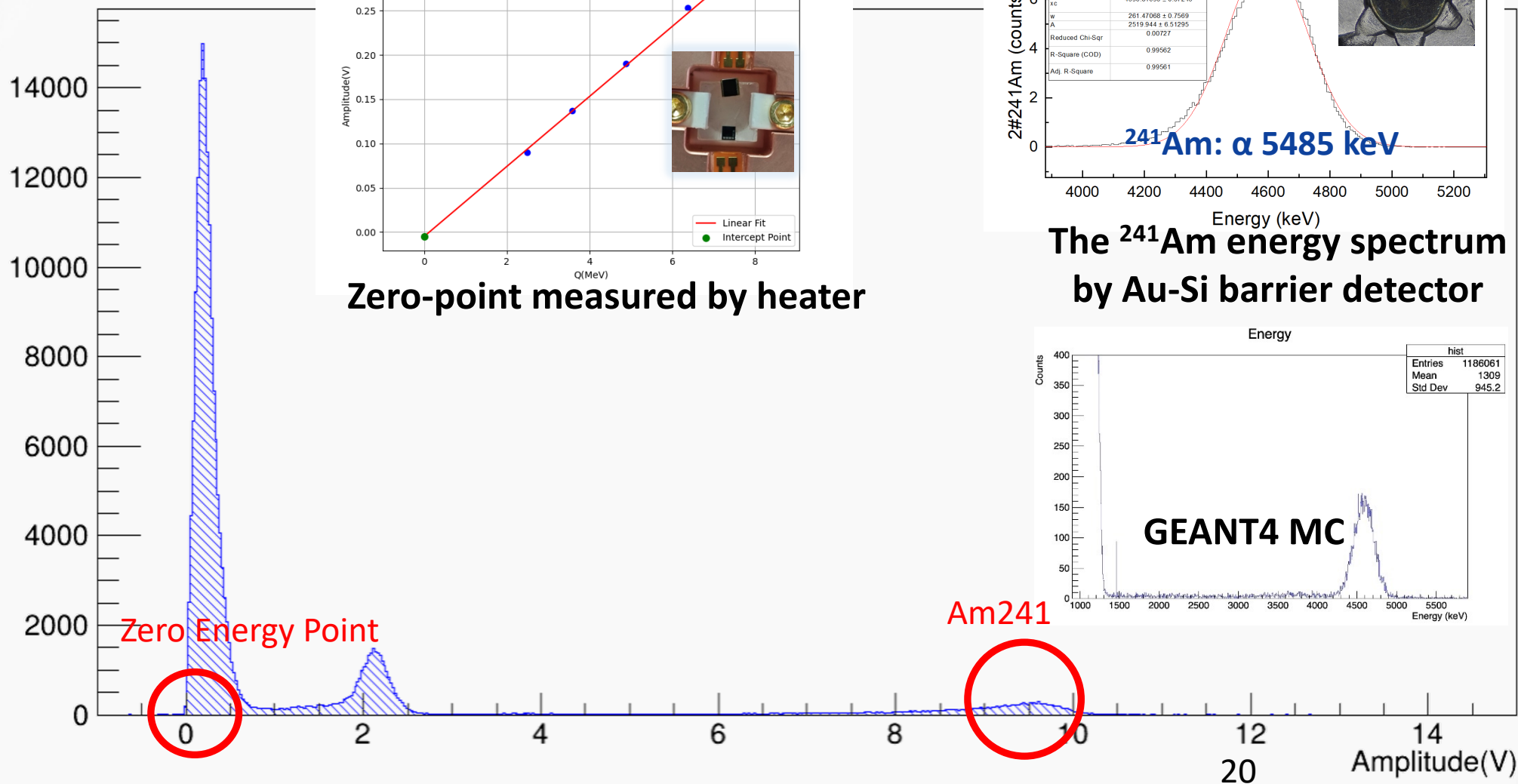
- Read raw data and trigger
- Filter data
- Reconstruct event-based quantities and write data into .root



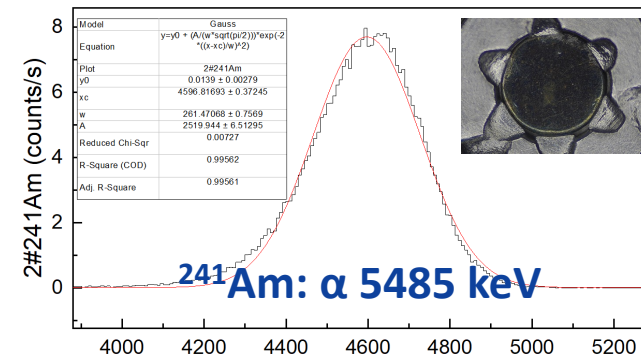
Customised modules can be added to the framework.

Joint calibration with heater & ^{241}Am @ Fudan

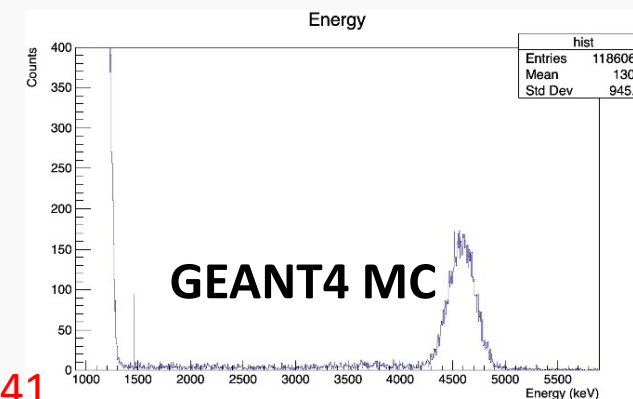
Event



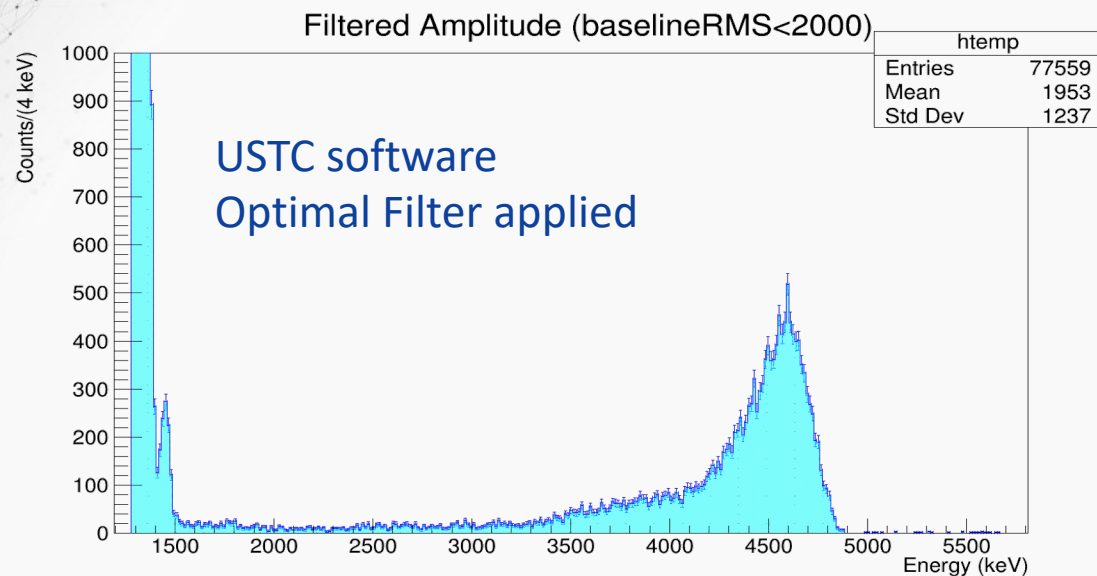
Zero-point measured by heater



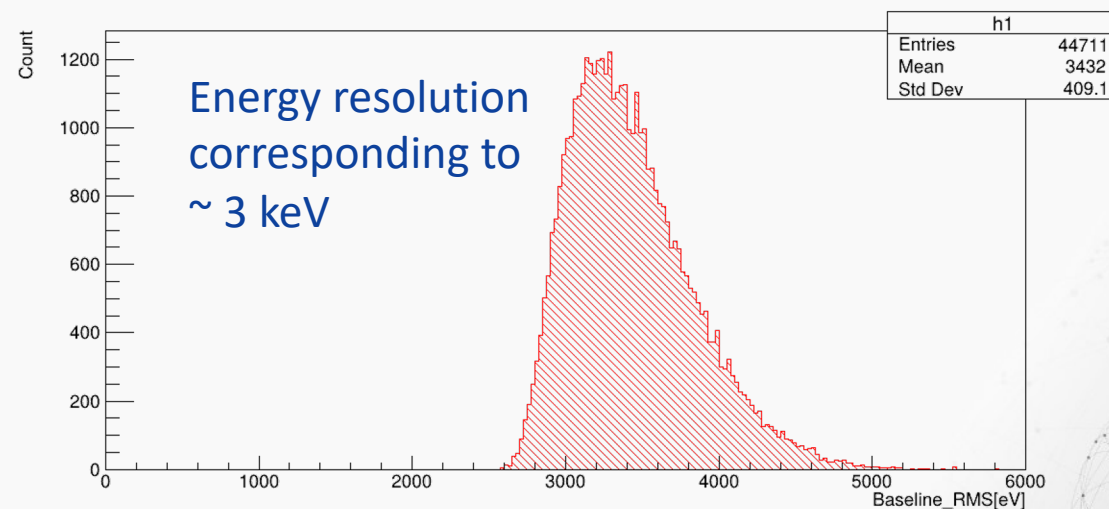
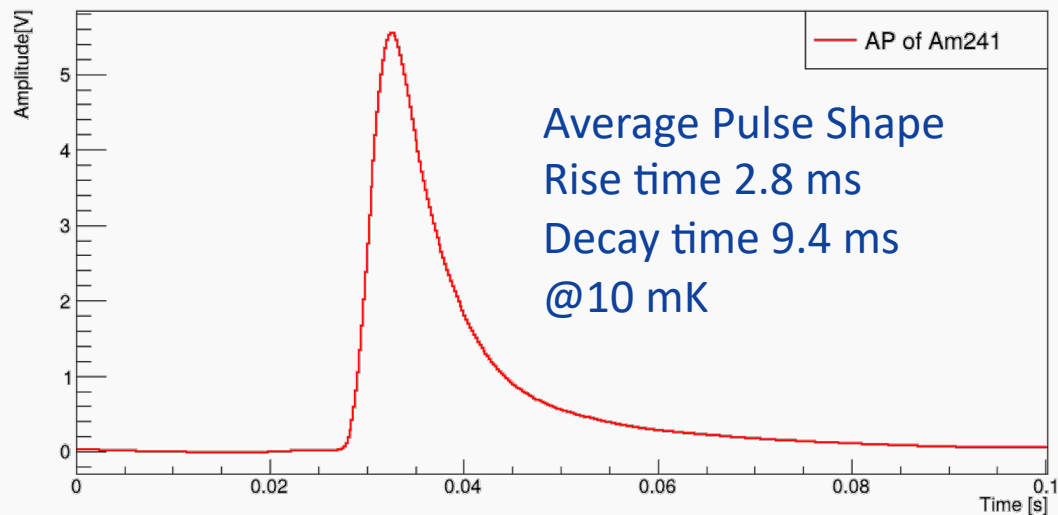
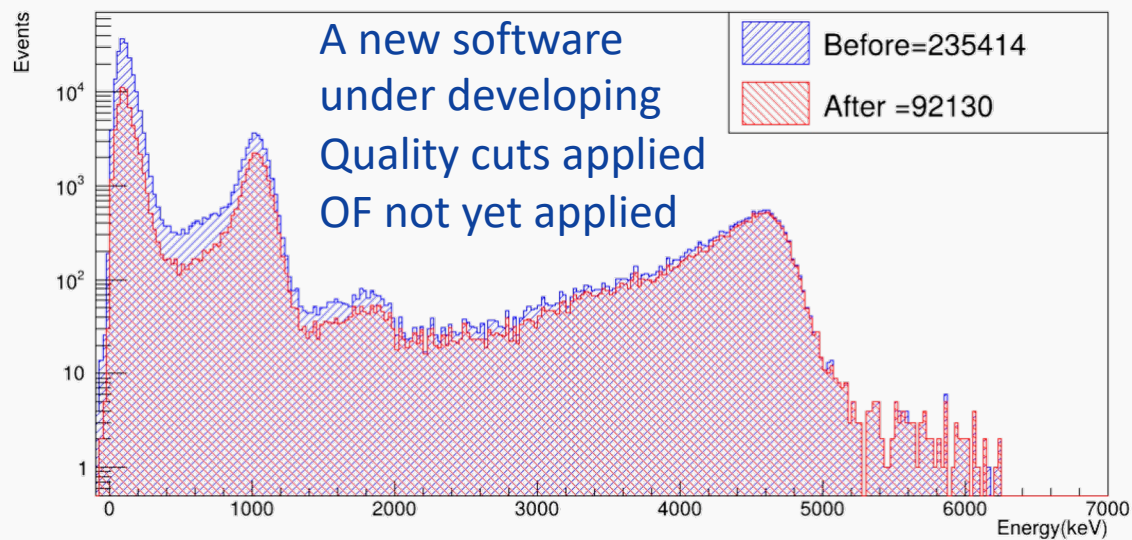
The ^{241}Am energy spectrum
by Au-Si barrier detector



Preliminary Spectrum @ Fudan



Preliminary results



Investigation on sources of noise sources @ Fudan



Motivation to
suppress noises

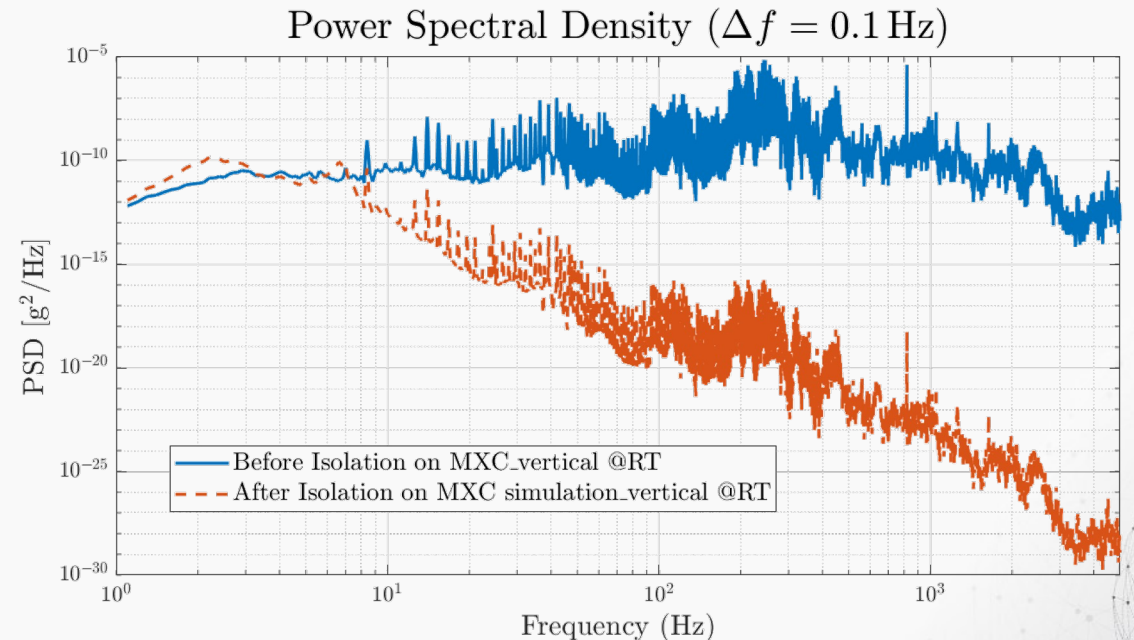
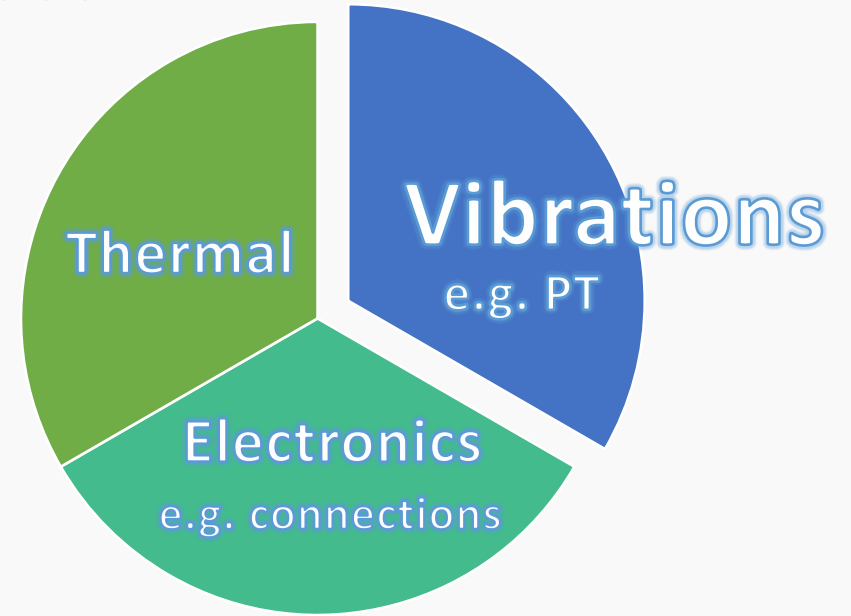
Energy resolution

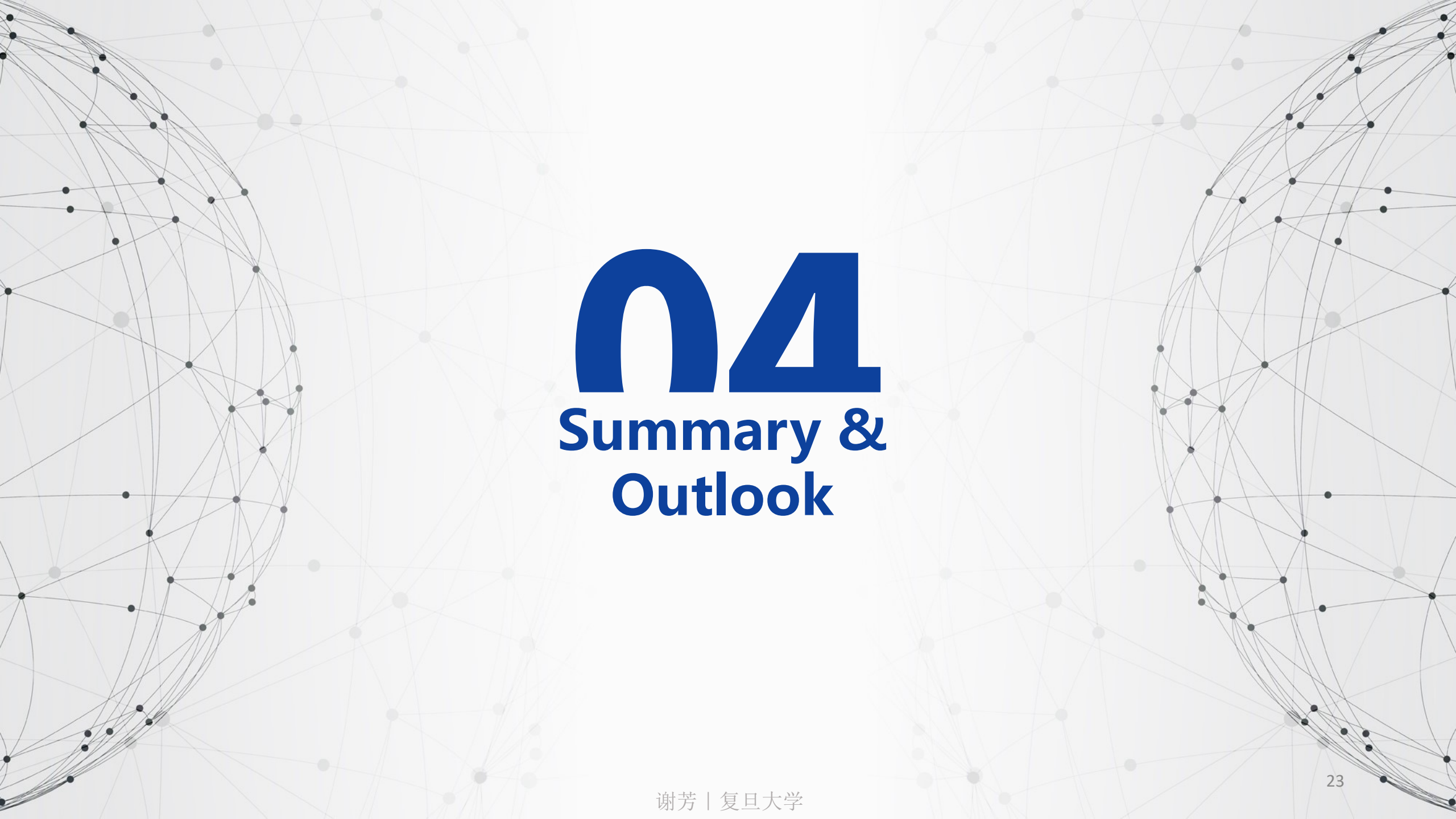
Lower energy threshold

Baseline resolution

Maximise s/n

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

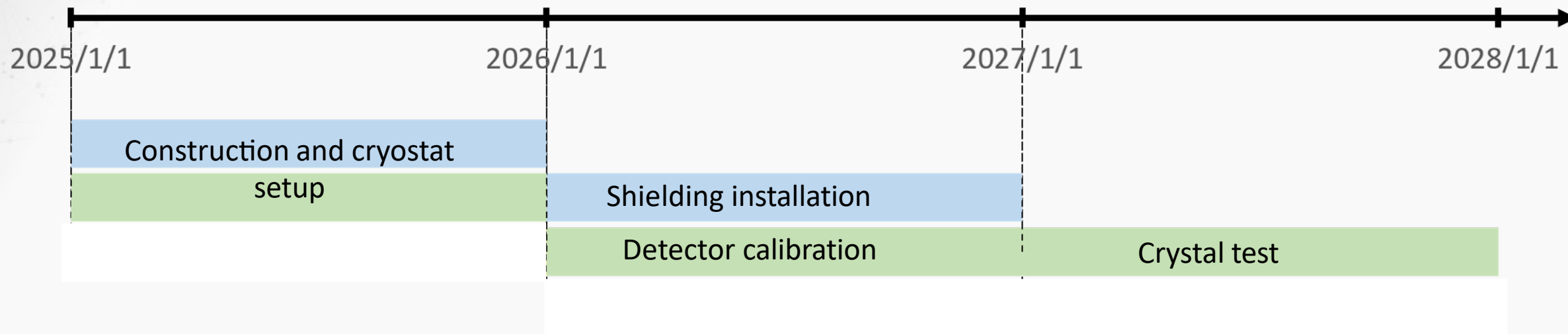


The background features a complex network diagram with numerous nodes (represented by small grey and black dots) connected by thin, light grey lines. These connections form a dense web that fills the entire slide, with some lines curving around the central text area.

N4

Summary & Outlook

CUPID-CJPL schedule



- **CUPID will use 1596 LMO crystals, multiple underground crystal test facilities are necessary**
- **Data from CUPID-CJPL bolometer would build a background model, MIGHT make CJPL an option for ton- scale search experiment.**

Summary and Outlook

- ❑ CUPID Experiment
 - ✓ search for $0\nu\beta\beta$ of ^{100}Mo
 - ✓ cryogenic scintillating bolometer
- ❑ CUPID-CJPL Demonstrator lead by CUPID-China collaboration
 - ✓ demonstration of key technologies for ton-scale experiment at CJPL
- ❑ R&D in progress
 - ✓ ^{100}Mo -enriched radio-pure crystal growth
 - ✓ bolometer module test & calibration
 - ✓ light detector fabrication & tests
 - ✓ thermal sensor test (NTD & TES)
 - ✓ vibration dumping system
 - ✓ simulation framework
 - ✓ data processing & denoise algorithm
- 👉 Next: Go underground!

Thanks!



CUPID-China Collaboration

