



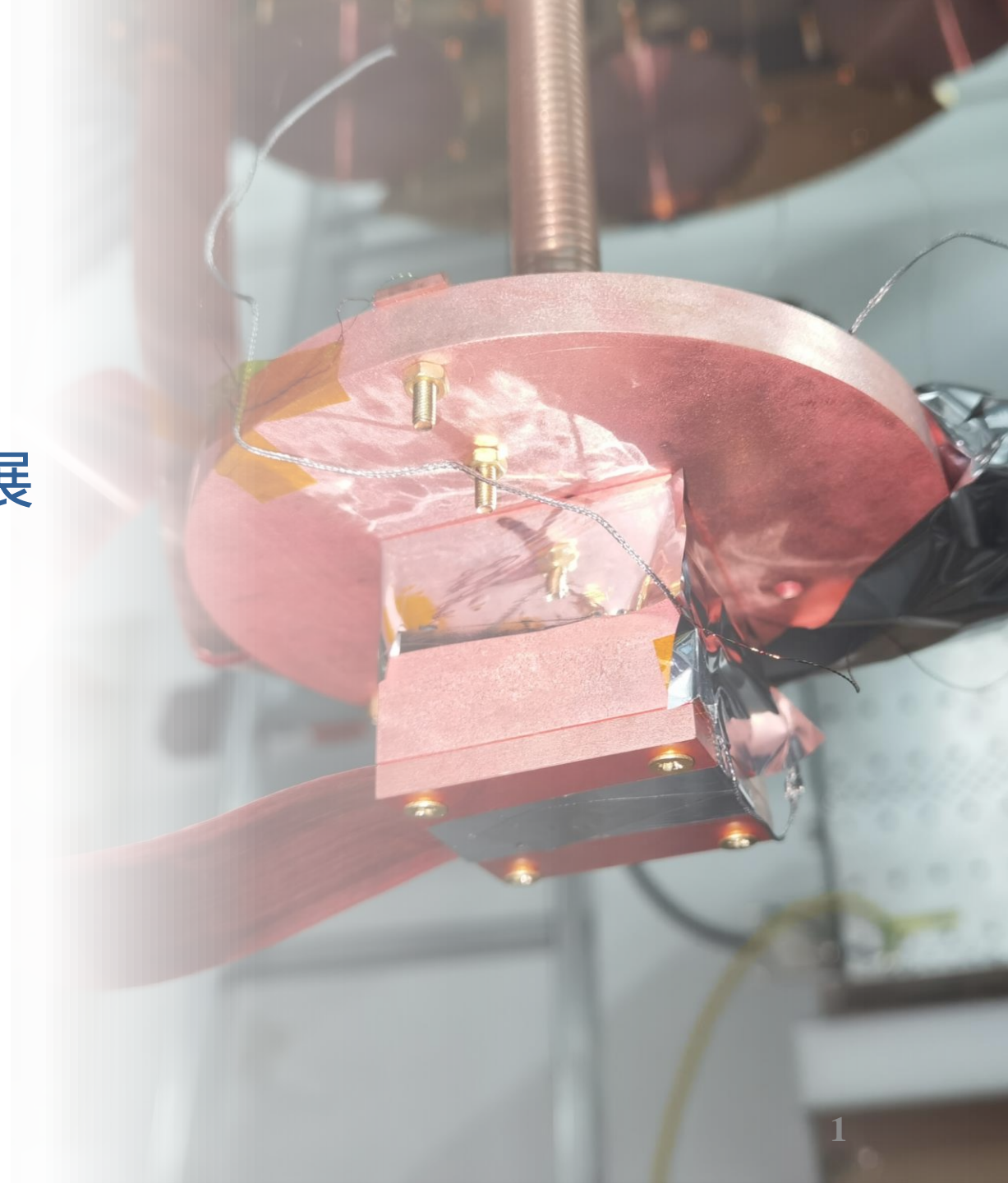
# CUPID-CJPL实验地面晶体测试平台进展

第三届地下和空间粒子物理与宇宙物理前沿问题研讨会

汇报人：曹嘉璇 复旦大学

代表CUPID-CJPL合作组

2024年05月10日 西昌





# 目录

## 一、实验背景

- 无中微子双贝塔衰变
- 低温晶体量热器技术
- CUPID-CJPL实验

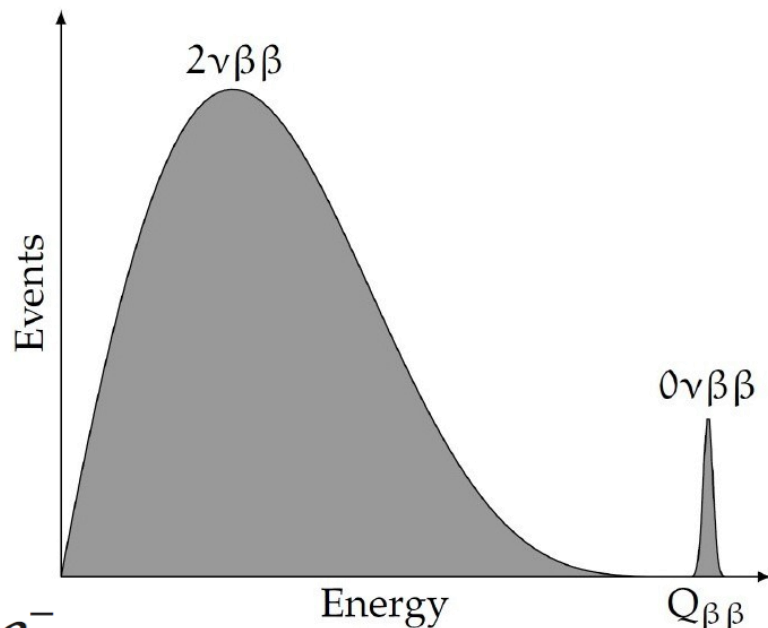
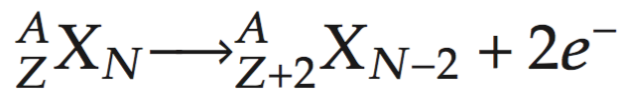
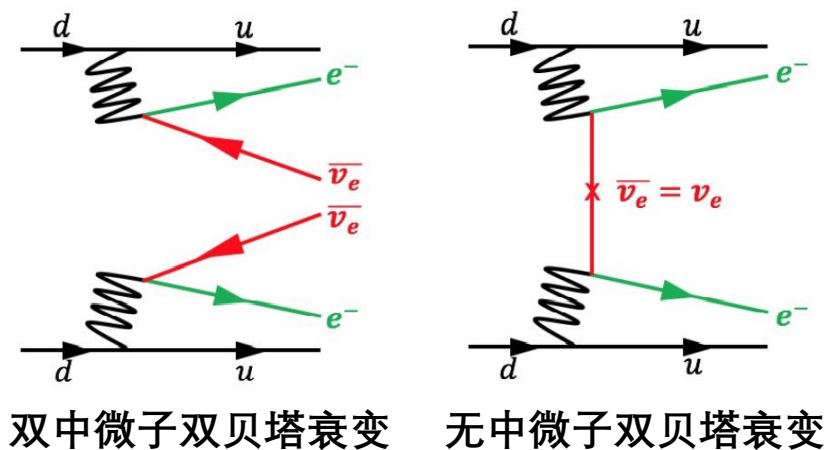
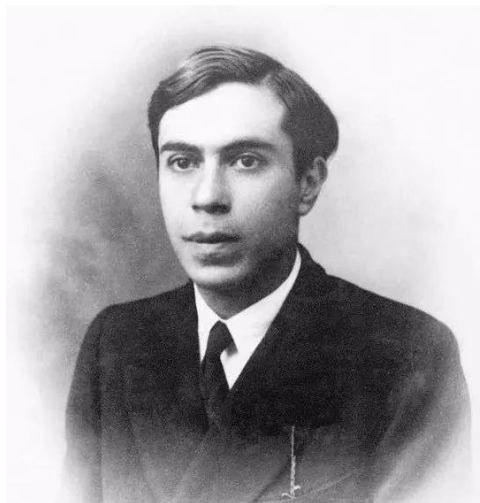
## 二、实验设置与进展

- 稀释制冷机介绍
- 电子学读出
- NTD-Ge参数标定
- 减振系统设计
- 晶体装配
- 数据处理流程

## 三、总结展望

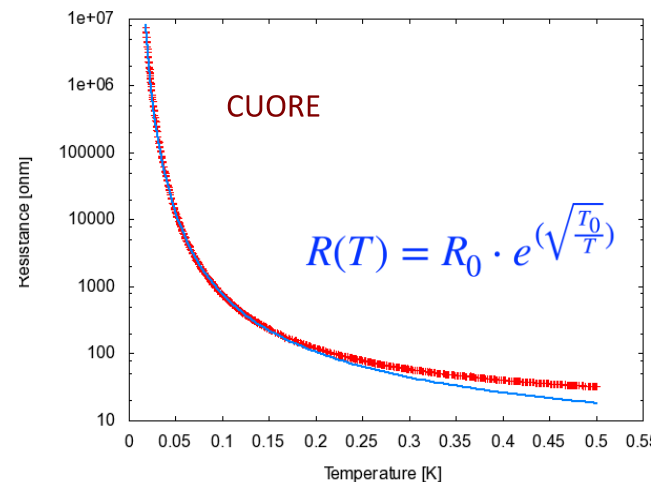
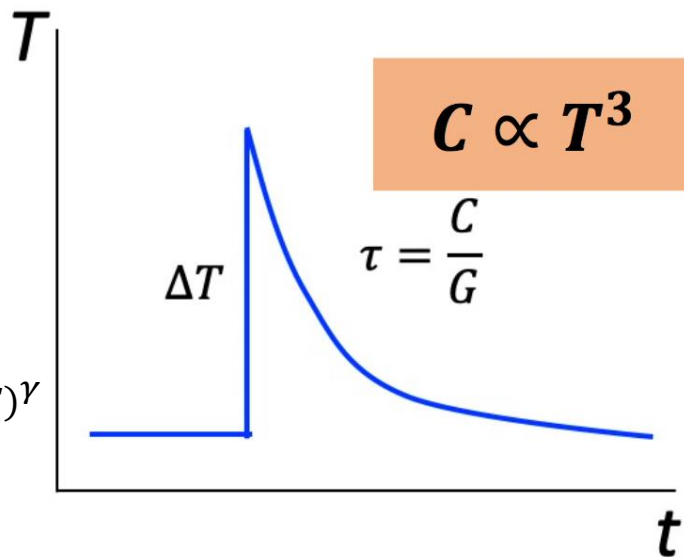
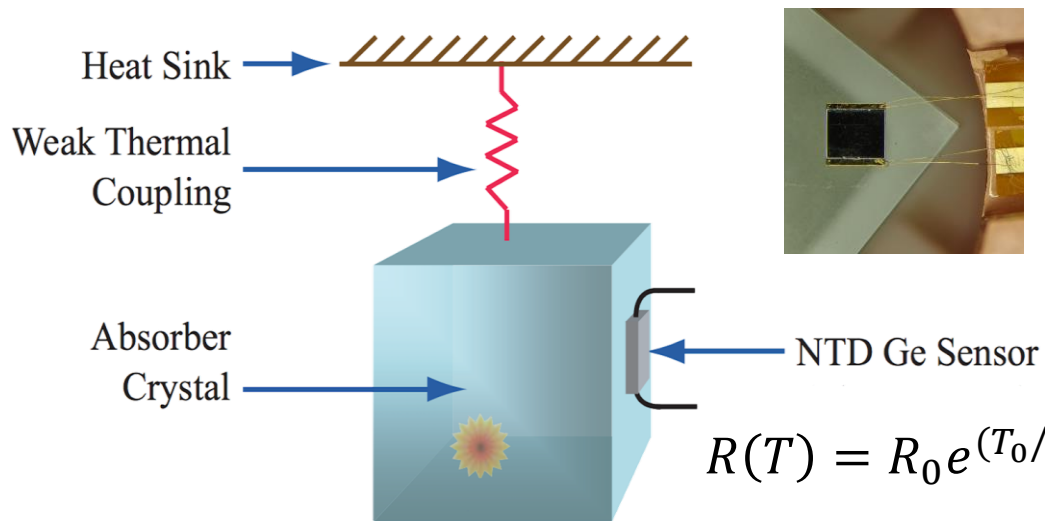
- 现阶段总结
- 后续改进计划

## 无中微子双贝塔衰变过程



- 若无中微子双贝塔衰变能够被观测到，则证明了中微子的马约拉纳属性
- 是轻子数破缺的直接证据
- 有助于确定中微子绝对质量标度

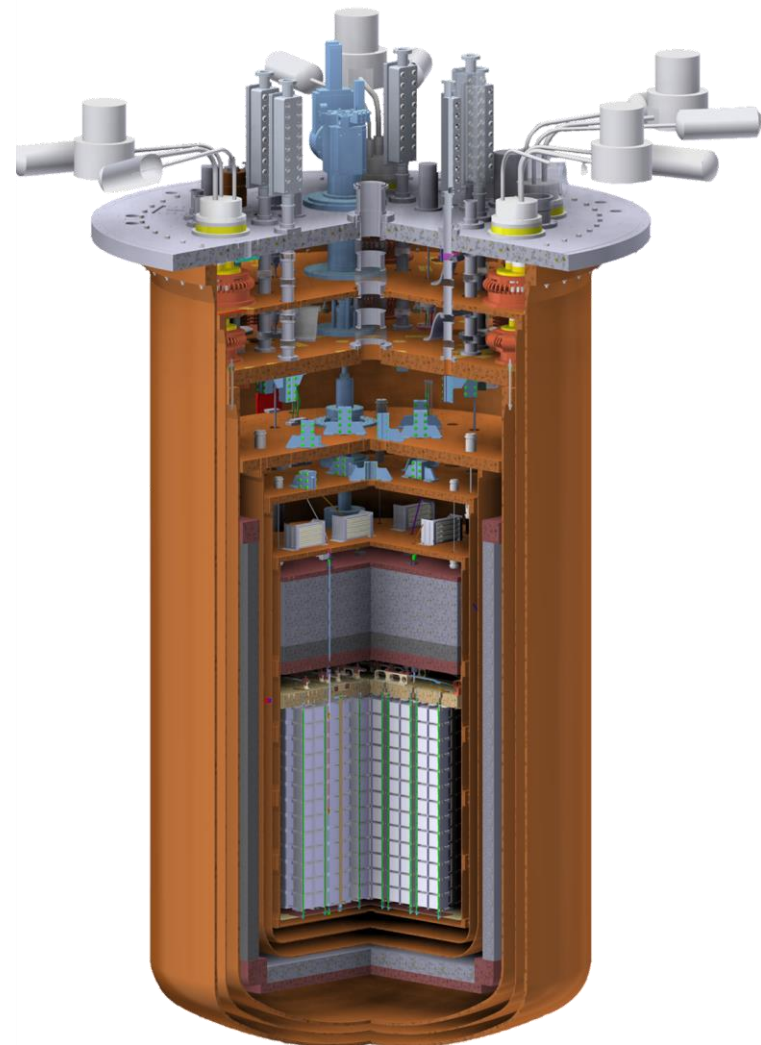
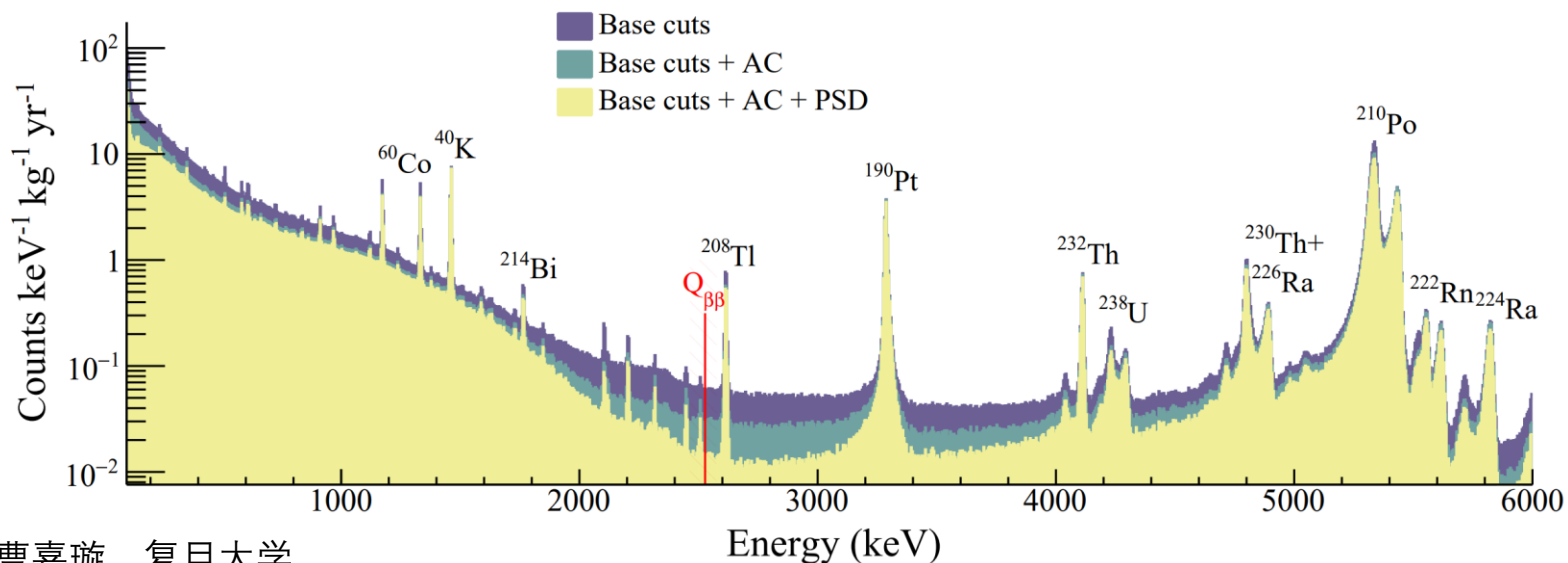
## NTD-Ge: 中子核嬗变掺杂锗传感器

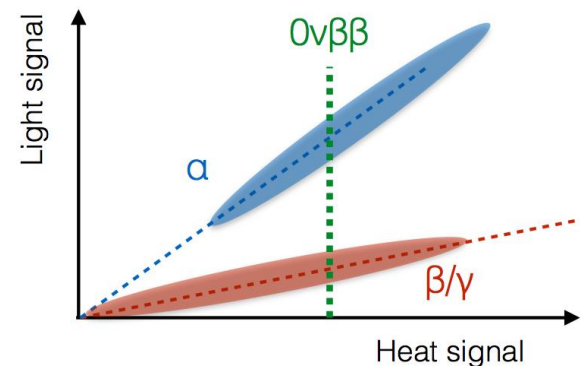
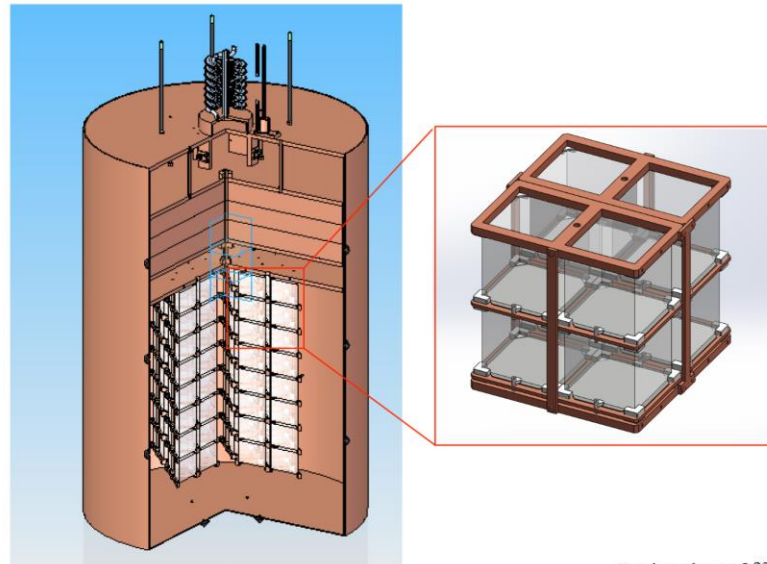
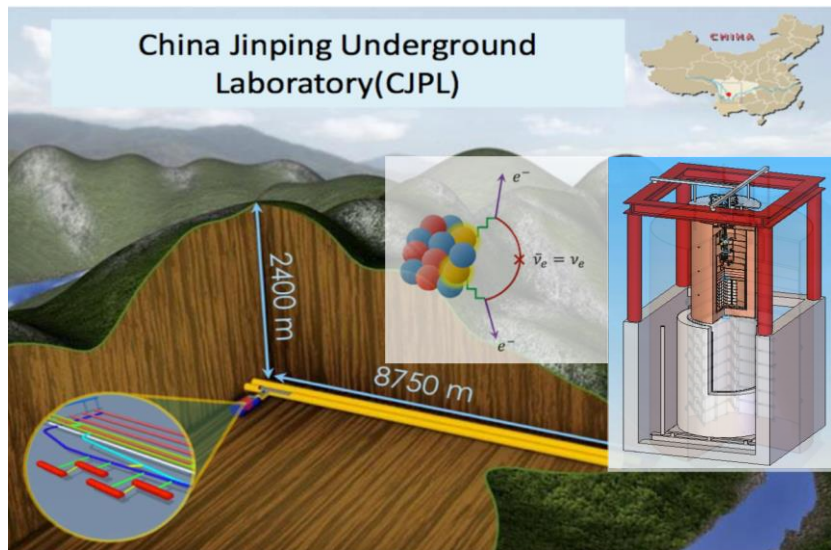


- 极低的工作温度 (~10 mK)
- 高效率 (>85%) : 双贝塔源即是吸收体
- 高能量灵敏度
  - 低温下遵循莫特定律
  - 可以实现μK量级温度测量
- 高能能量分辨率 (~0.2% FWHM)

## CUORE: Cryogenic Underground Observatory for Rare Events

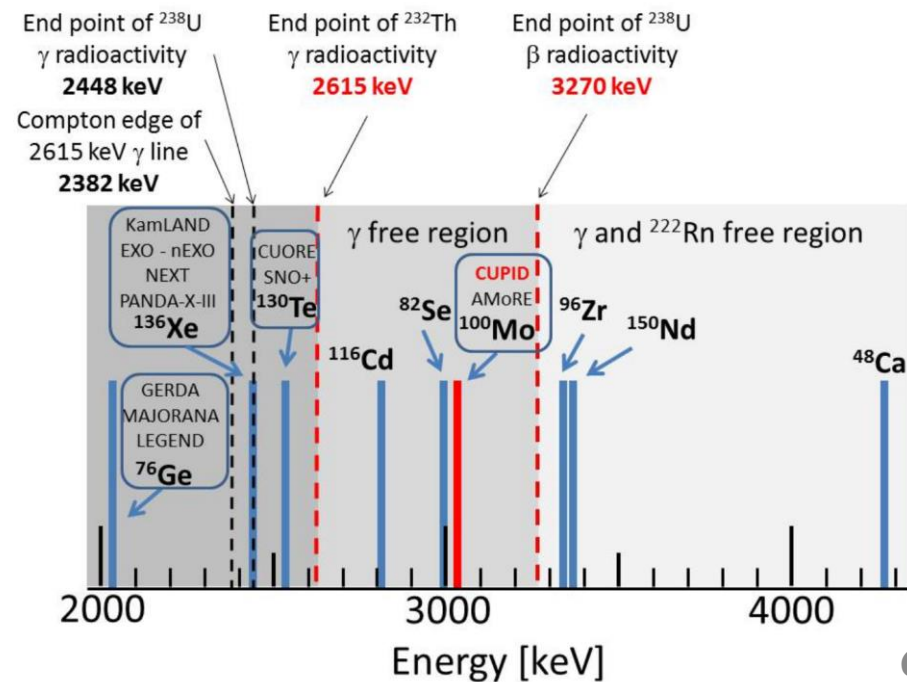
- 988块5 cm边长 $\text{TeO}_2$ 立方晶体
- 总质量 742 kg (206 kg  $^{130}\text{Te}$ )
- $T @ \sim 10 \text{ mK}$
- 寻找 $^{130}\text{Te}$ 的 $0\nu\beta\beta$
- $T_{1/2} > 3.8 \times 10^{25} \text{ years (90\% C.I.)}$





## CUPID-CJPL: A scintillating bolometer experiment for $0\nu\beta\beta$ search at CJPL

- $^{100}\text{Mo}$  钼酸锂晶体, 高  $Q_{\beta\beta}$  值 ( $\sim 3034$  keV)
- 光热双读出 (实现粒子鉴别)





# 目录

## 一、实验背景

- 无中微子双贝塔衰变
- 低温晶体量热器技术
- CUPID-CJPL实验

## 二、实验设置与进展

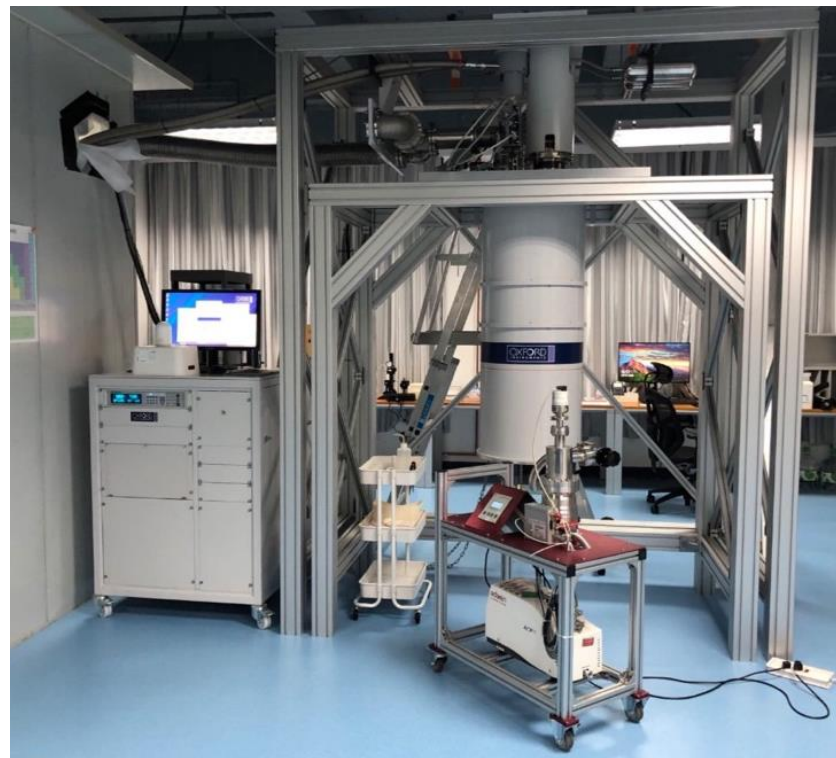
- 稀释制冷机介绍
- 电子学读出
- NTD-Ge参数标定
- 减振系统设计
- 晶体装配
- 数据处理流程

## 三、总结展望

- 现阶段总结
- 后续改进计划



**BlueFors XLD-400 @ Fudan**

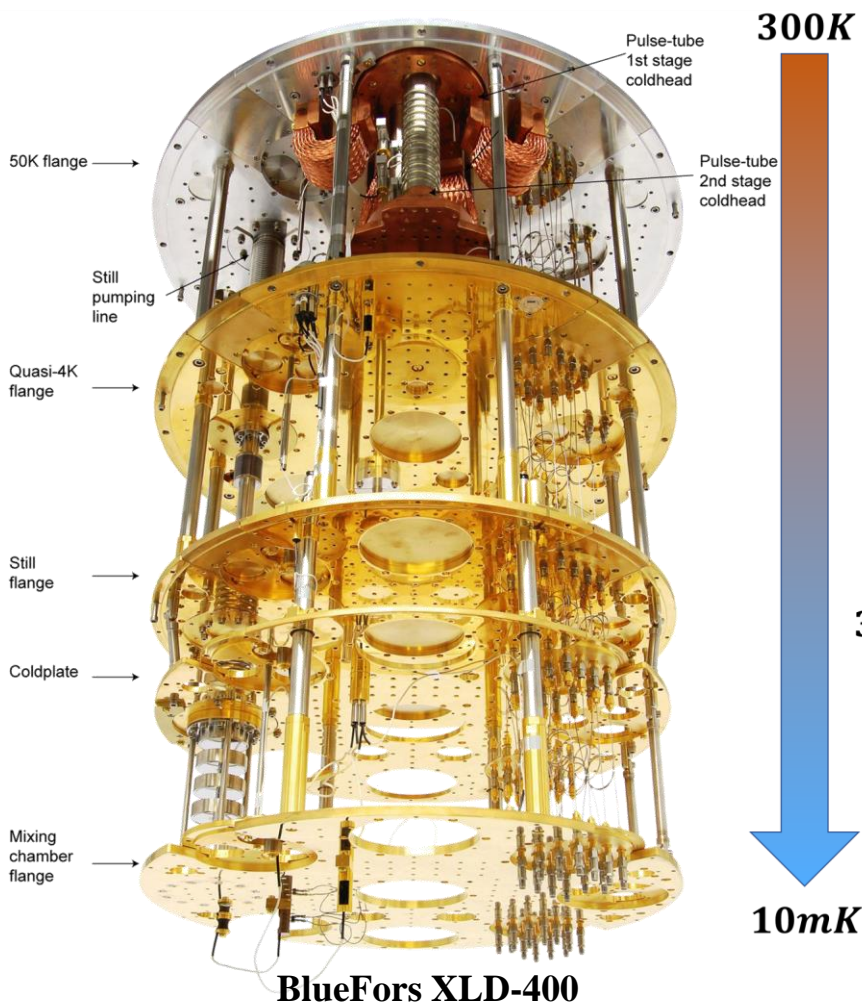


**Oxford Triton 500 @ USTC**

见李毅5月10日下午报告@二楼三会



## 降温过程

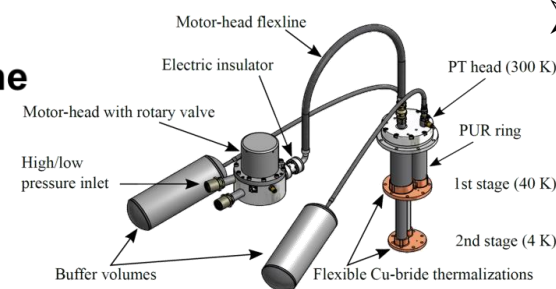


### Cooling Time

PTs  
~ 2 days

Start mixture gas  
condensing

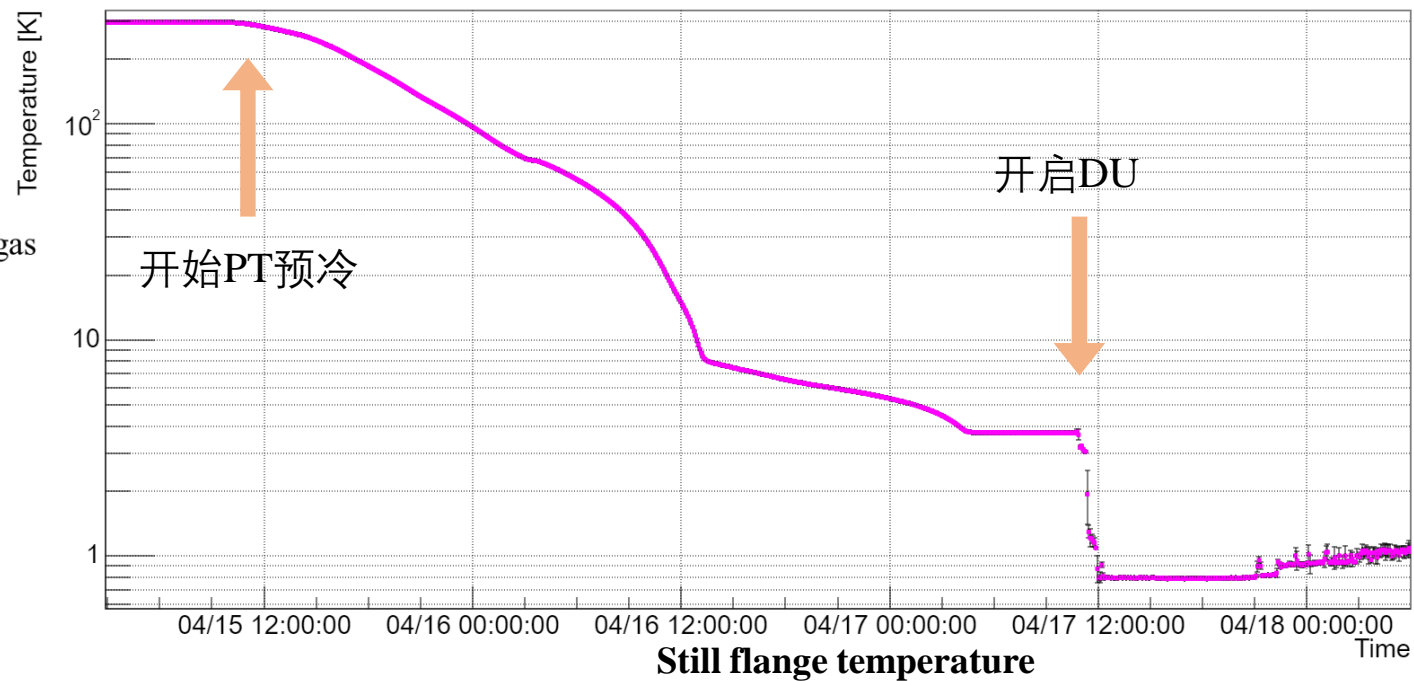
DU  
~ 4 days



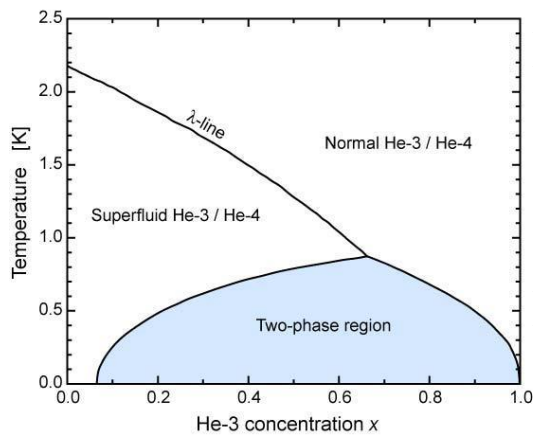
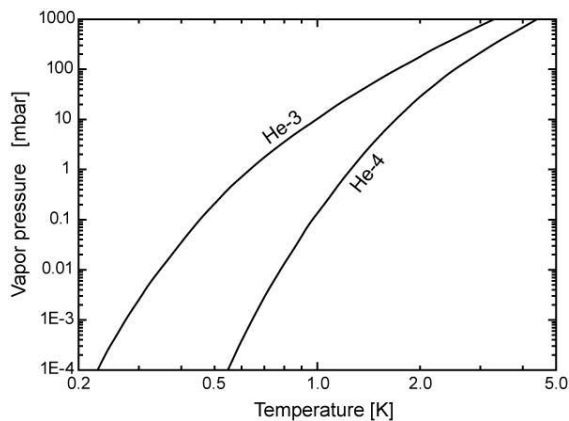
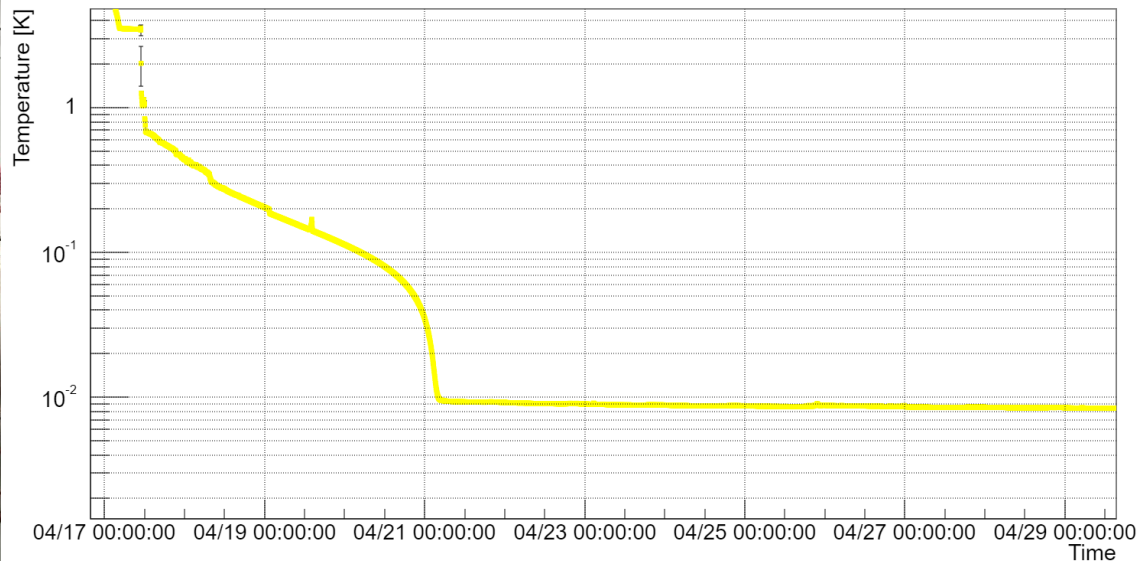
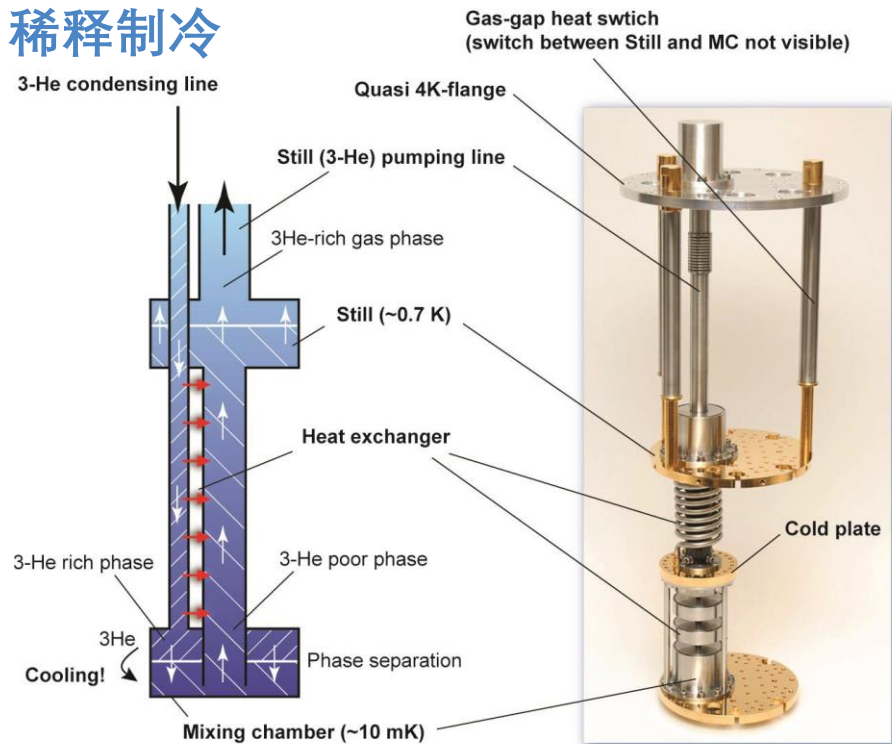
➤ 首先进行脉管 (Pulse Tube) 的预降温

➤ 为稀释制冷模块预冷

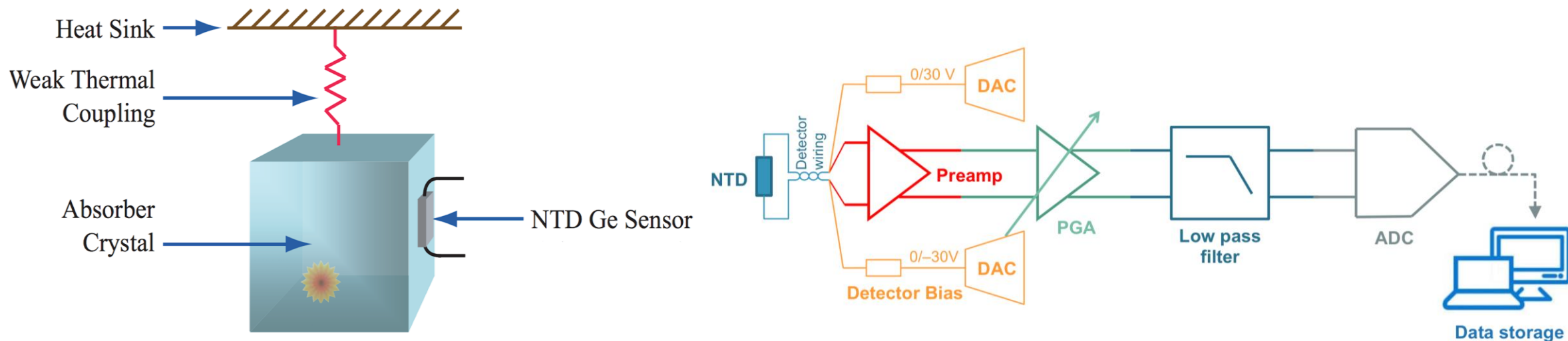
➤ Still 盘降温到3 K左右



## 稀释制冷

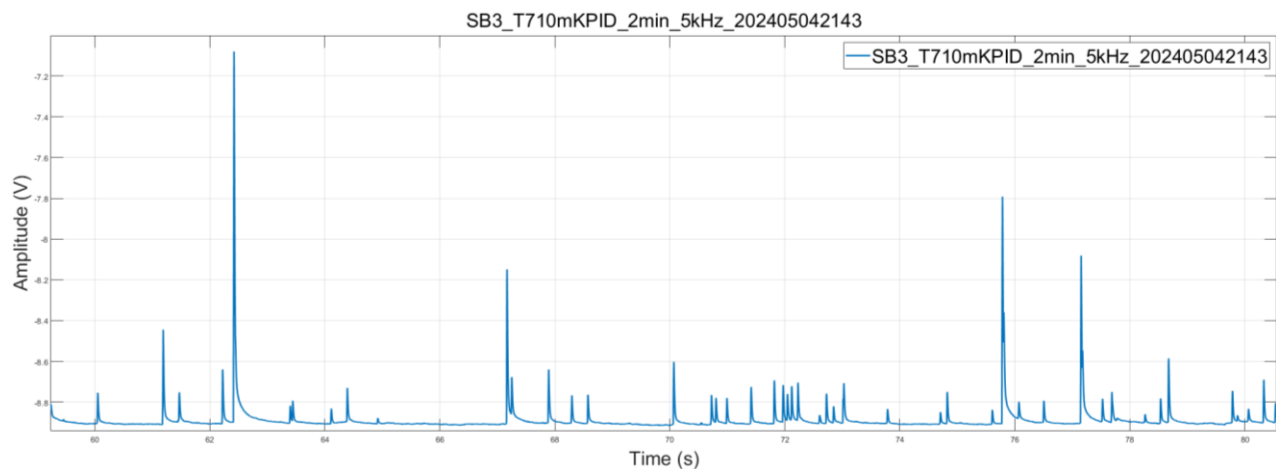
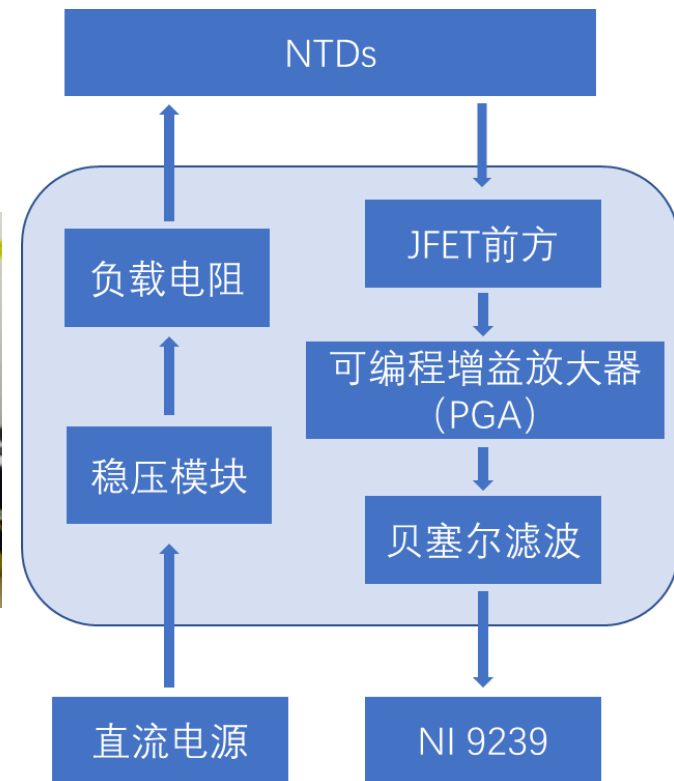
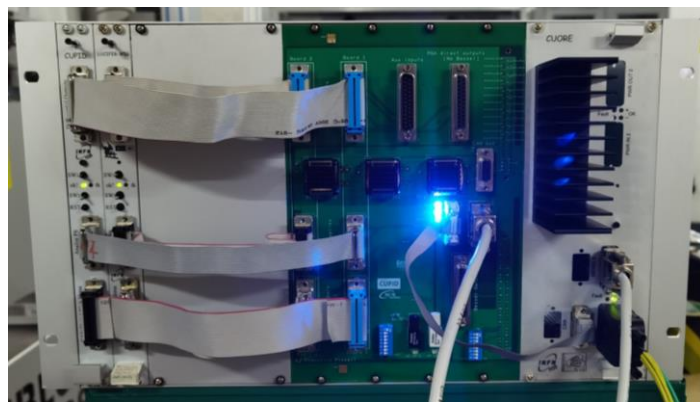
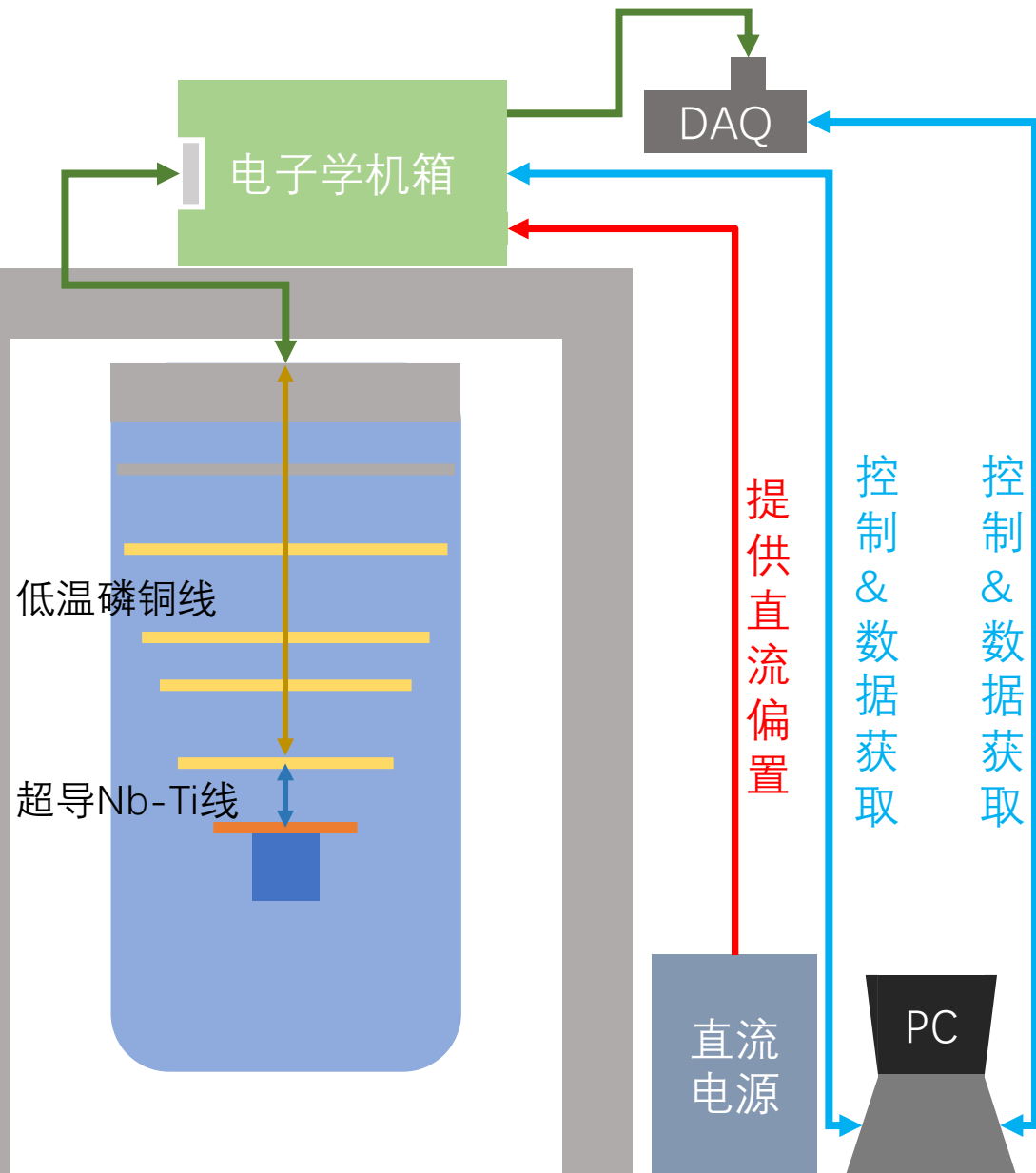


- 低温下3-He、4-He混合气体分为3-He的浓相和稀相
  - 3-He被不断从稀相中抽出
    - 浓相中的3-He向稀相转移，吸收热量
- 单次可持续运行 > 1 month
  - 补充冷阱液氮后，可继续运行



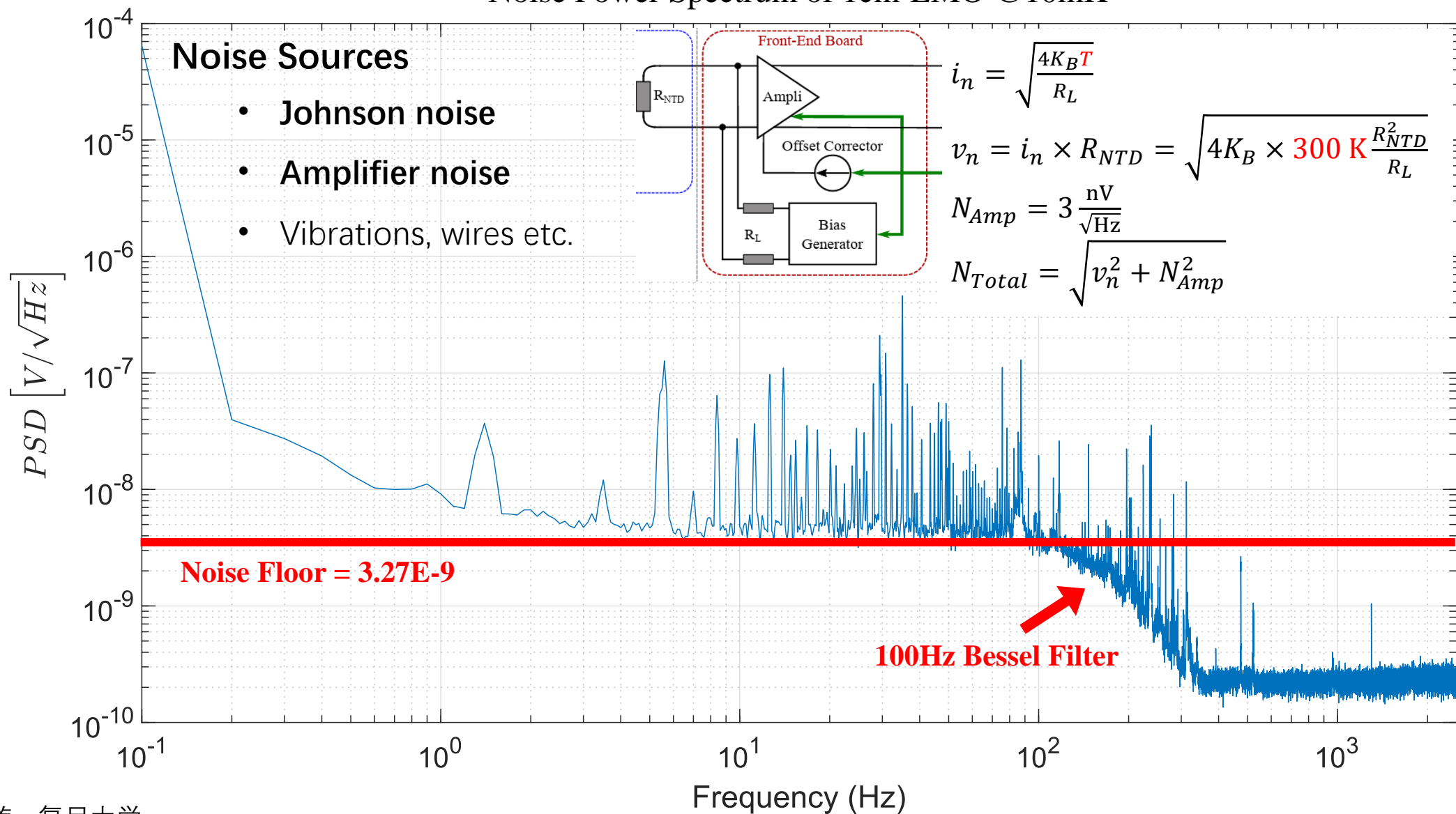
## NTD-Ge读出电子学原理

- 选择 $G\Omega$ 量级的负载电阻，提供 $pA$ 量级的直流偏置，减弱加热效应
- NTD两端的电压信号，经JFET前放以及可编程增益放大器放大
- 放大后的信号经由贝塞尔滤波，消除高频噪声
- 经模数转换后存储



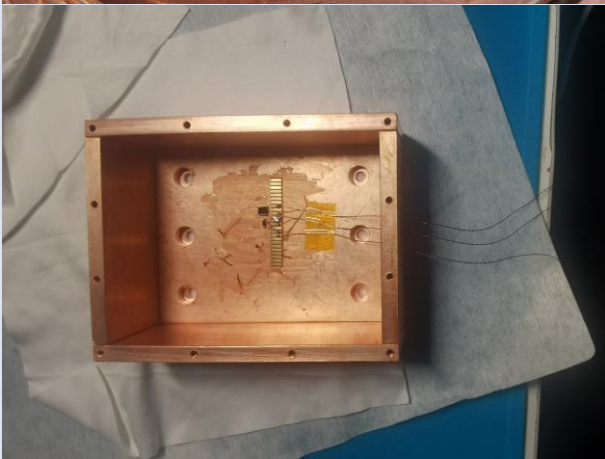
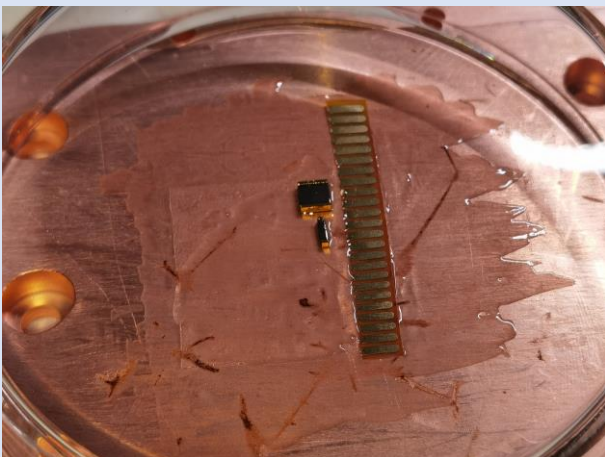
## 电子学读出噪声表现

Noise Power Spectrum of 1cm-LMO @ 10mK

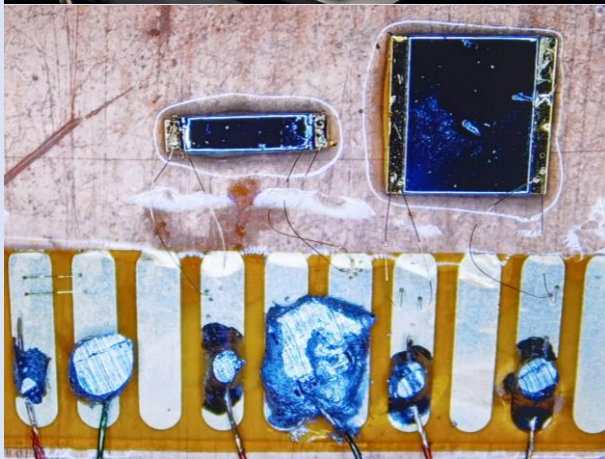
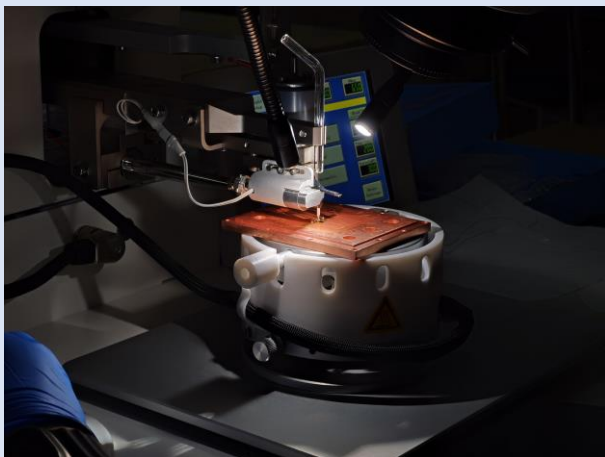


## NTD-Ge R-T关系标定

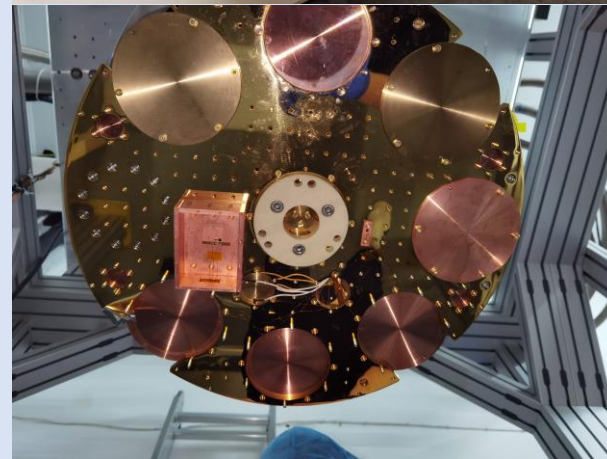
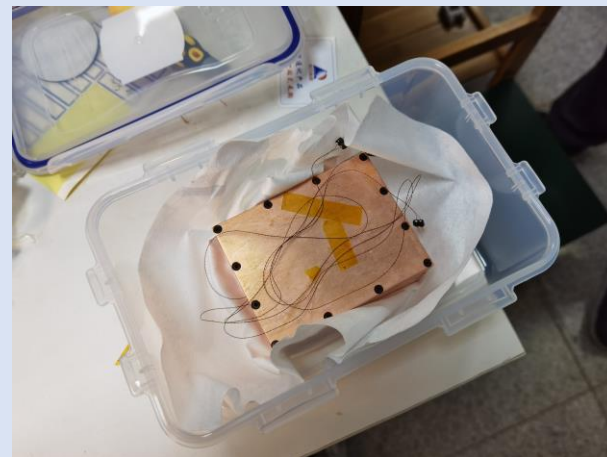
NTD与屏蔽罩耦合



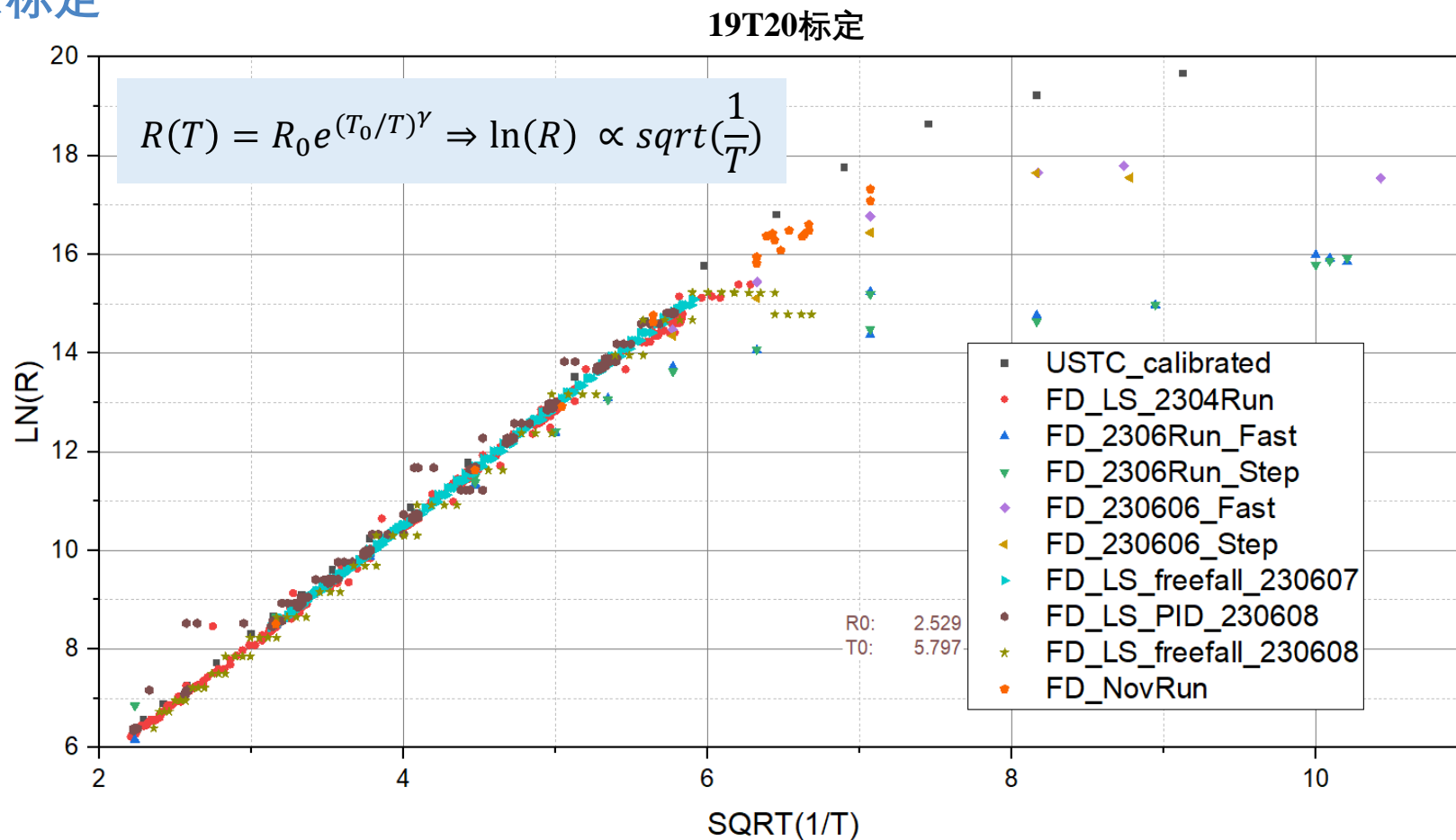
引线键合至测试电极



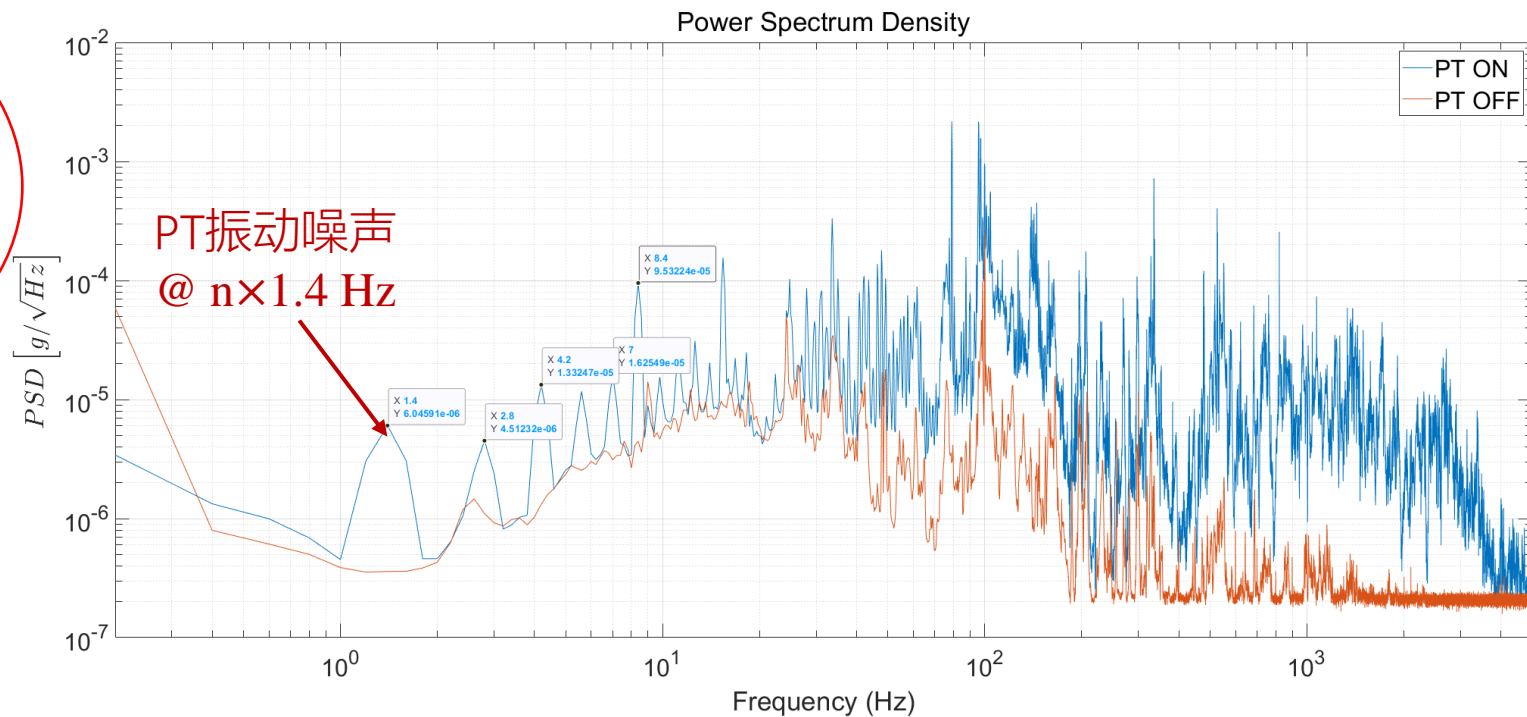
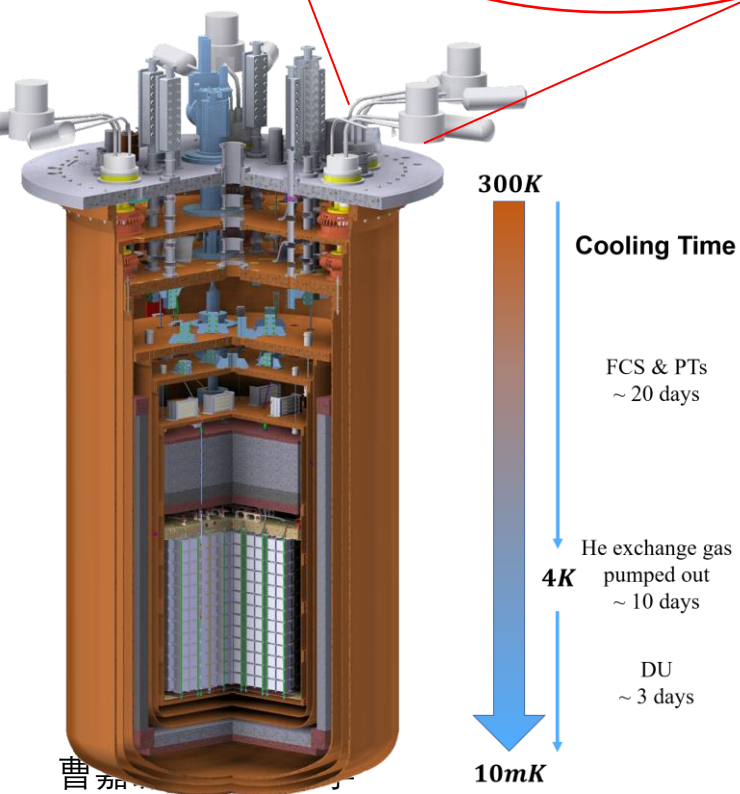
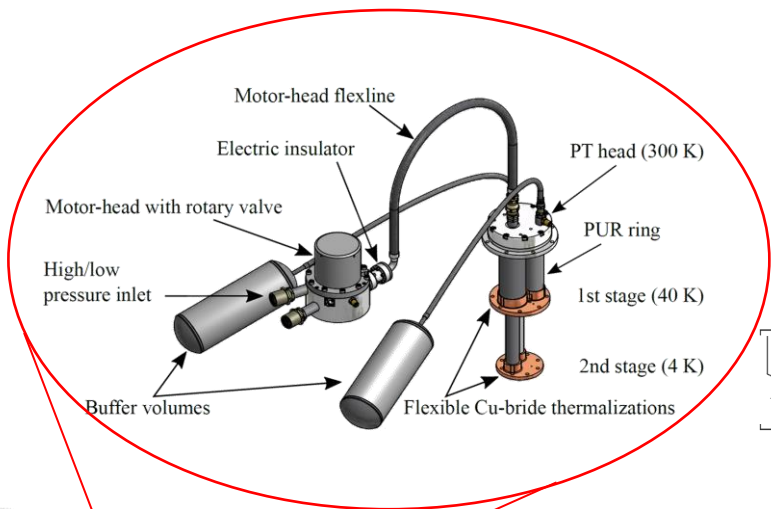
制冷机内安装



## NTD-Ge R-T关系标定



NTDs	19T20	3x3	3x1	5T6
R0	2.53	2.57	33.35	2.38
T0	5.80	6.02	4.36	6.05



➤ 干式稀释制冷机需要利用脉管（PT）进行初步的降温

➤ PT的运转会引入明显的振动噪声



## 减振结构



PCB 393B04  
振动探测器



PCB 480E09  
信号调制器



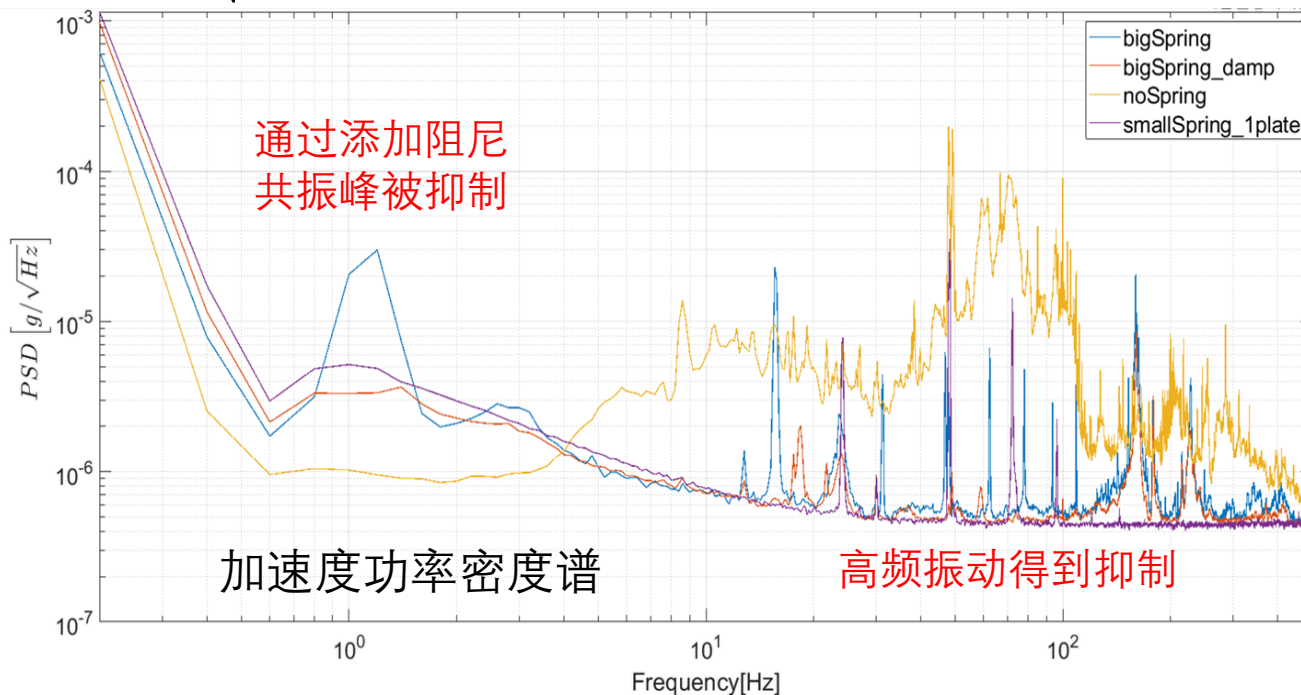
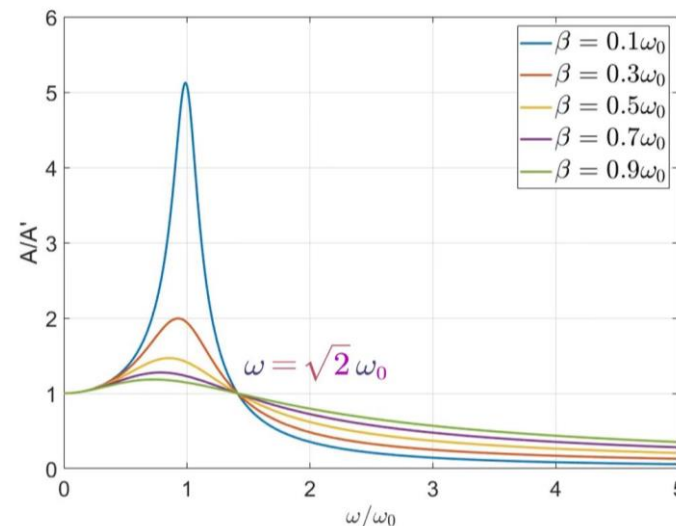
NI 6218  
16bit DAQ

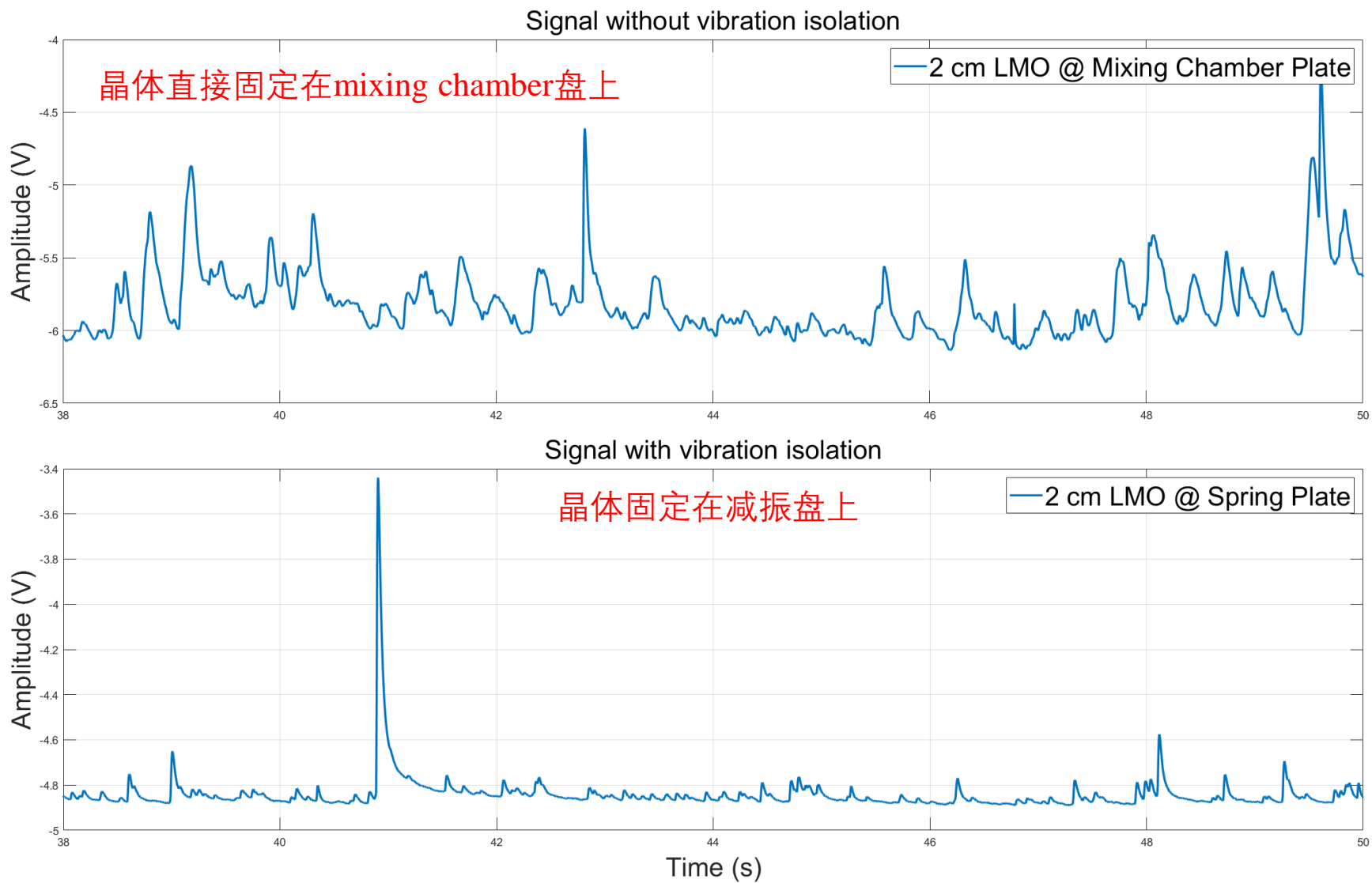
振动传递函数:

$$\frac{x}{X_0} = \frac{1}{\sqrt{(1 - (\frac{\omega}{\omega_0})^2)^2 + (2\beta \frac{\omega}{\omega_0})^2}}$$

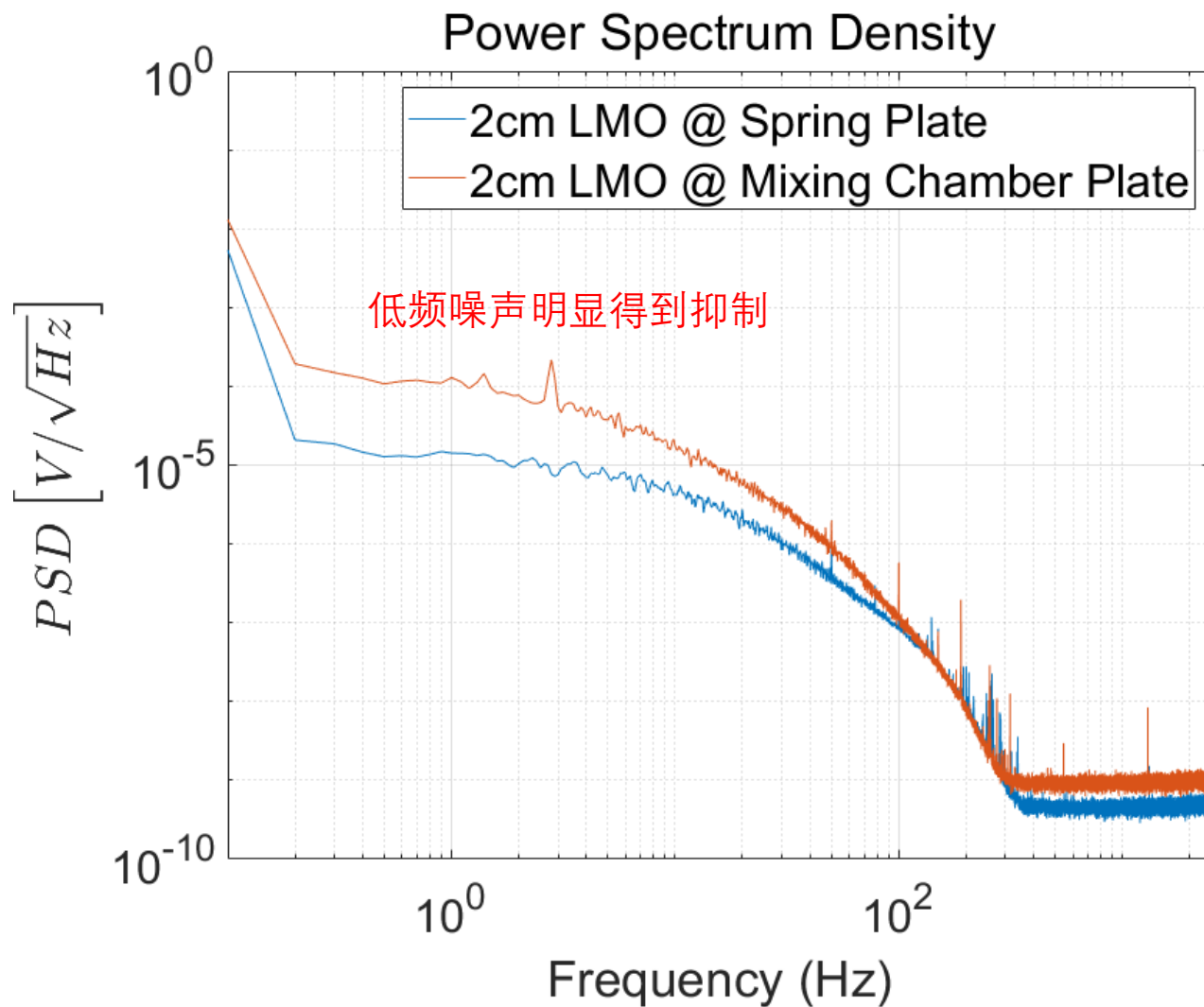
其中,

$$\omega_0 = \sqrt{\frac{k}{m}}$$



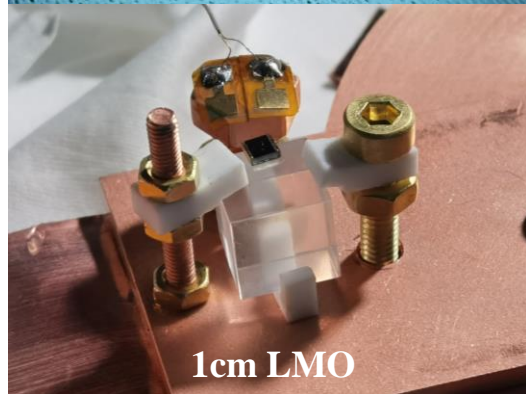
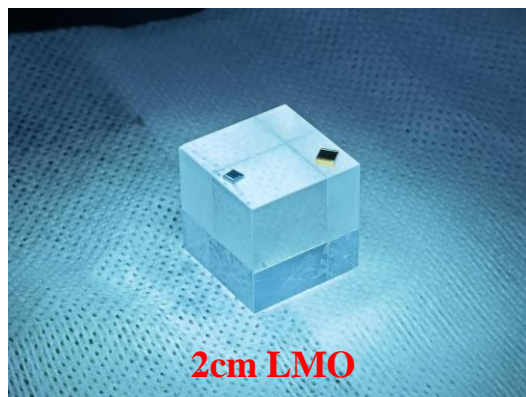


减振前后2cm晶体时域信号对比

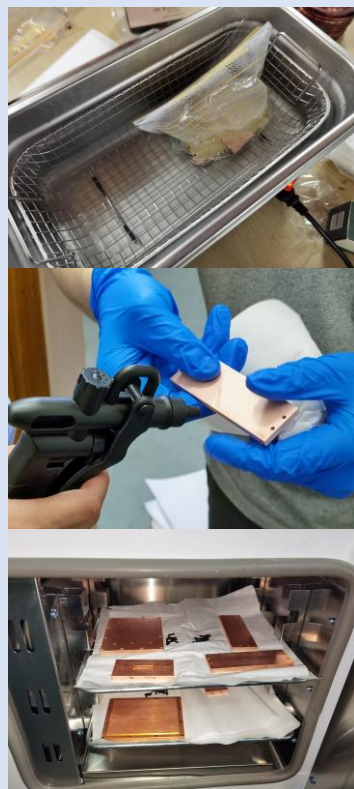


减振前后2cm晶体信号频域对比

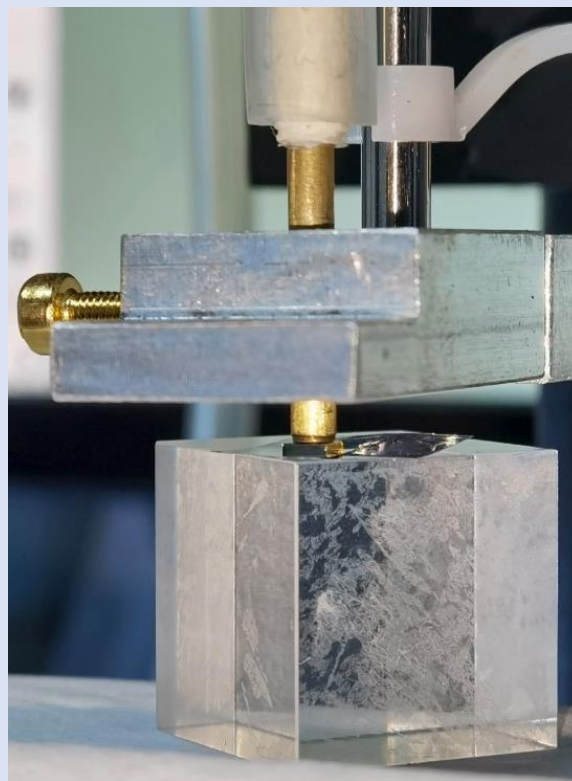
## LMO晶体及装配流程



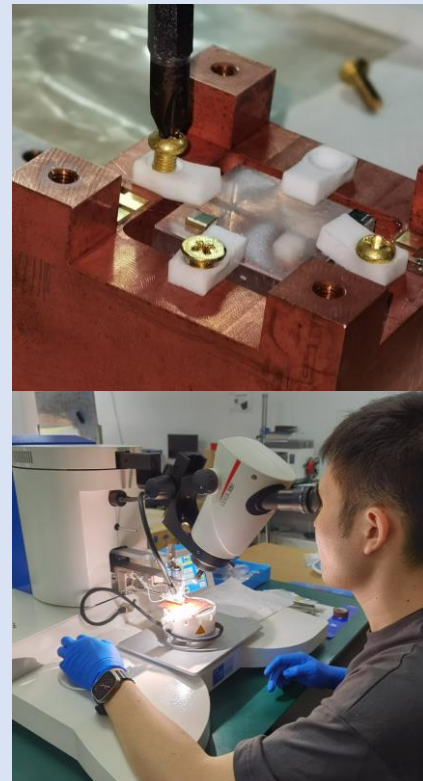
### 清洗铜框架



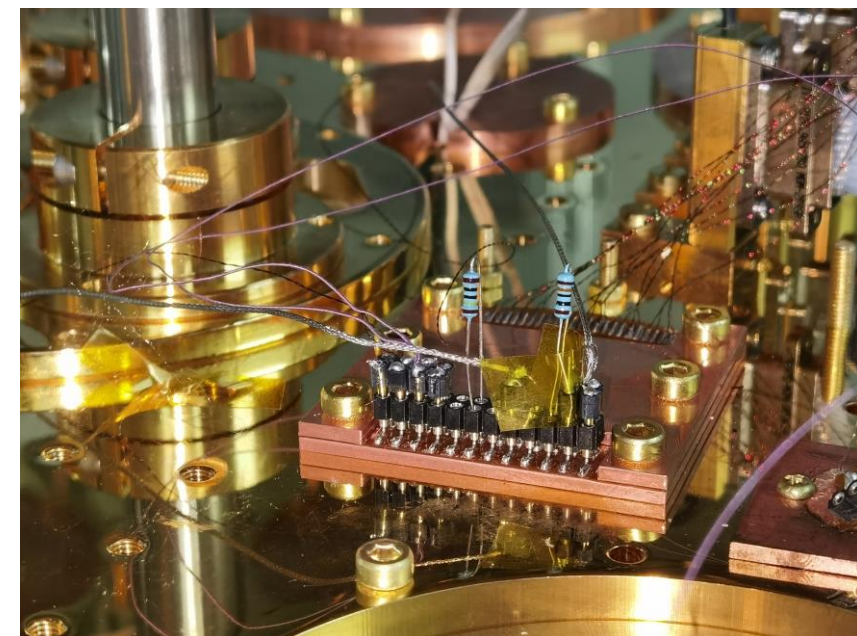
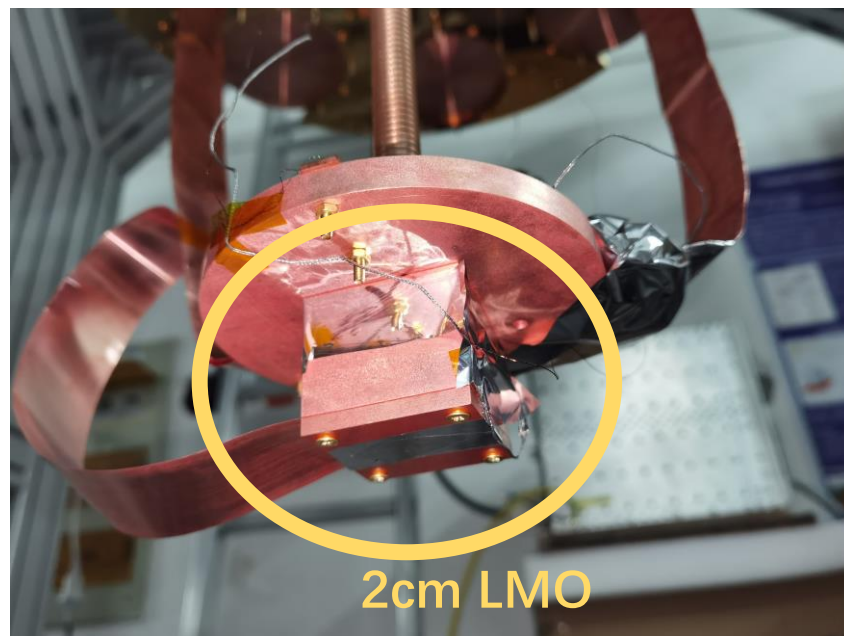
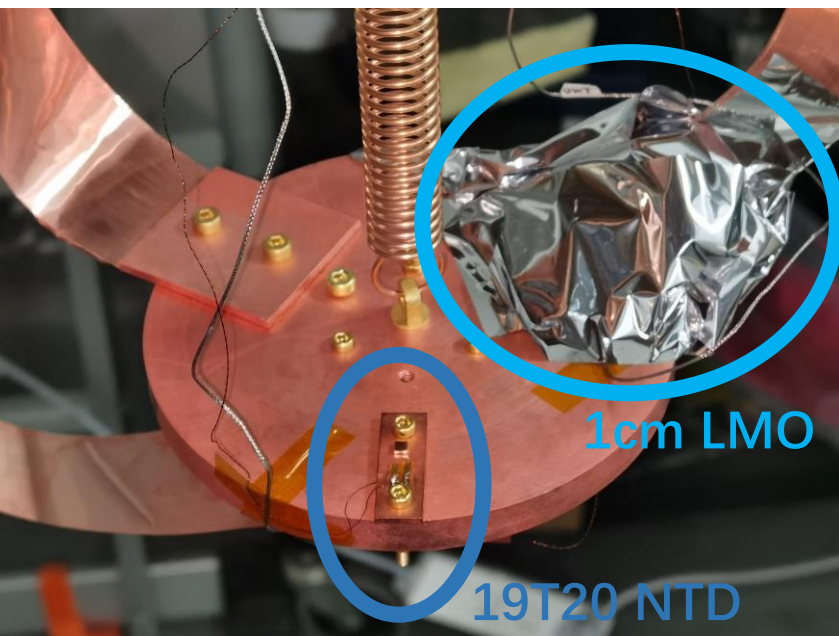
### 晶体耦合NTD-Ge



### 装配晶体&引线键合



- 目前测试晶体：
  - 1cm、2cm边长自然丰度钼酸锂 (LMO) 晶体
- 晶体来源
  - 硅酸盐所&宁波大学



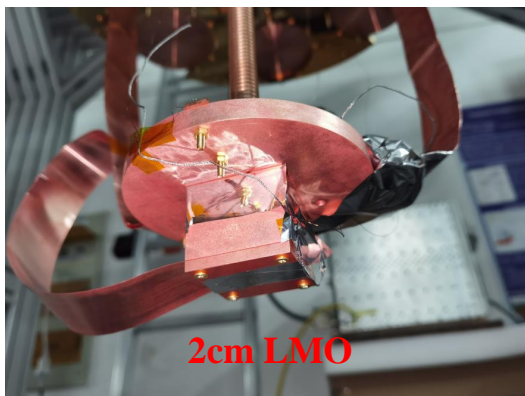
CH1	CH3	CH5	CH7	CH9	CH11
1cm LMO	100kOhm	2cm LMO	1MOhm	3×1 NTD	19T20

减振板上

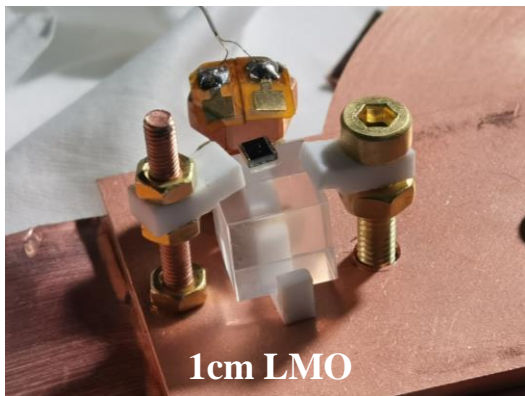
直接固定在MXC上

CH2	CH4	CH6	CH8	CH10	CH12
短接	\	\	\	200μm康铜	20μm康铜

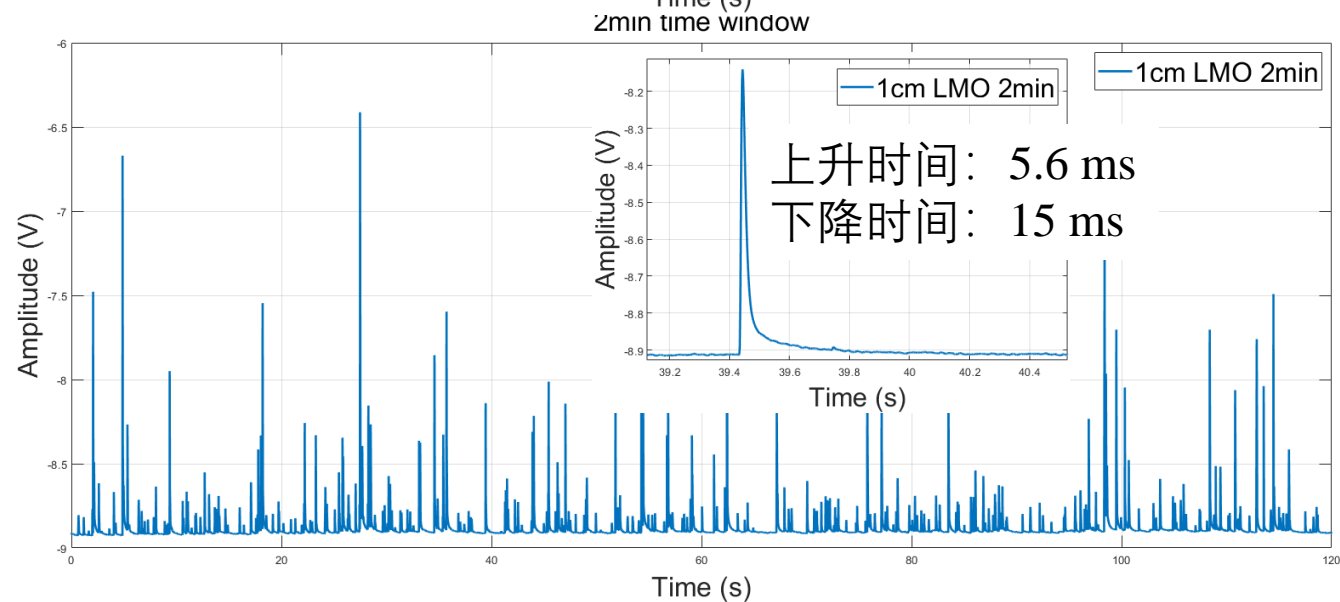
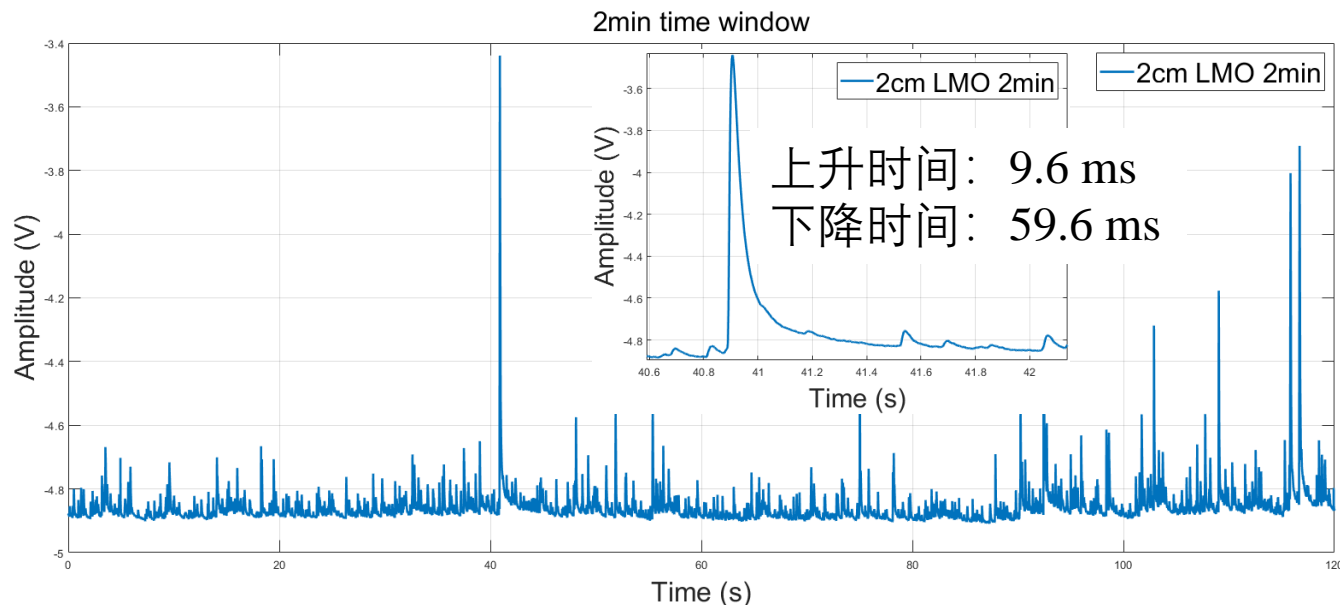
## 输出信号



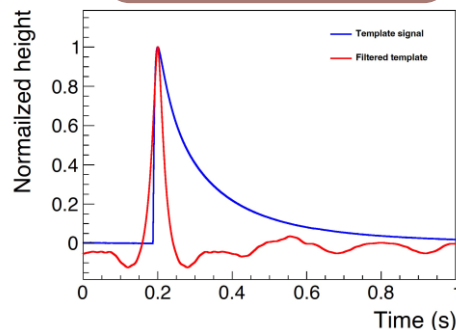
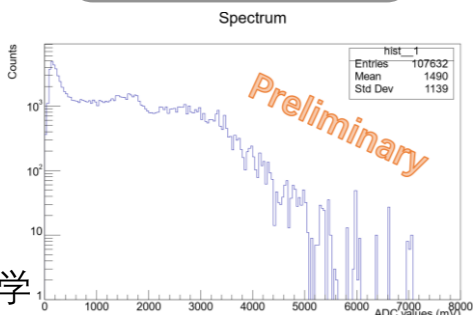
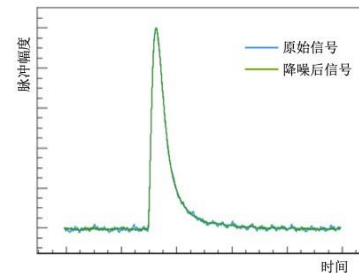
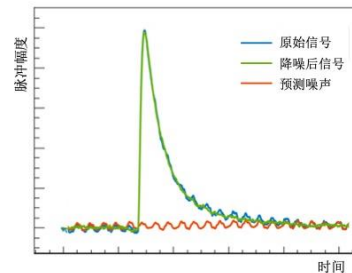
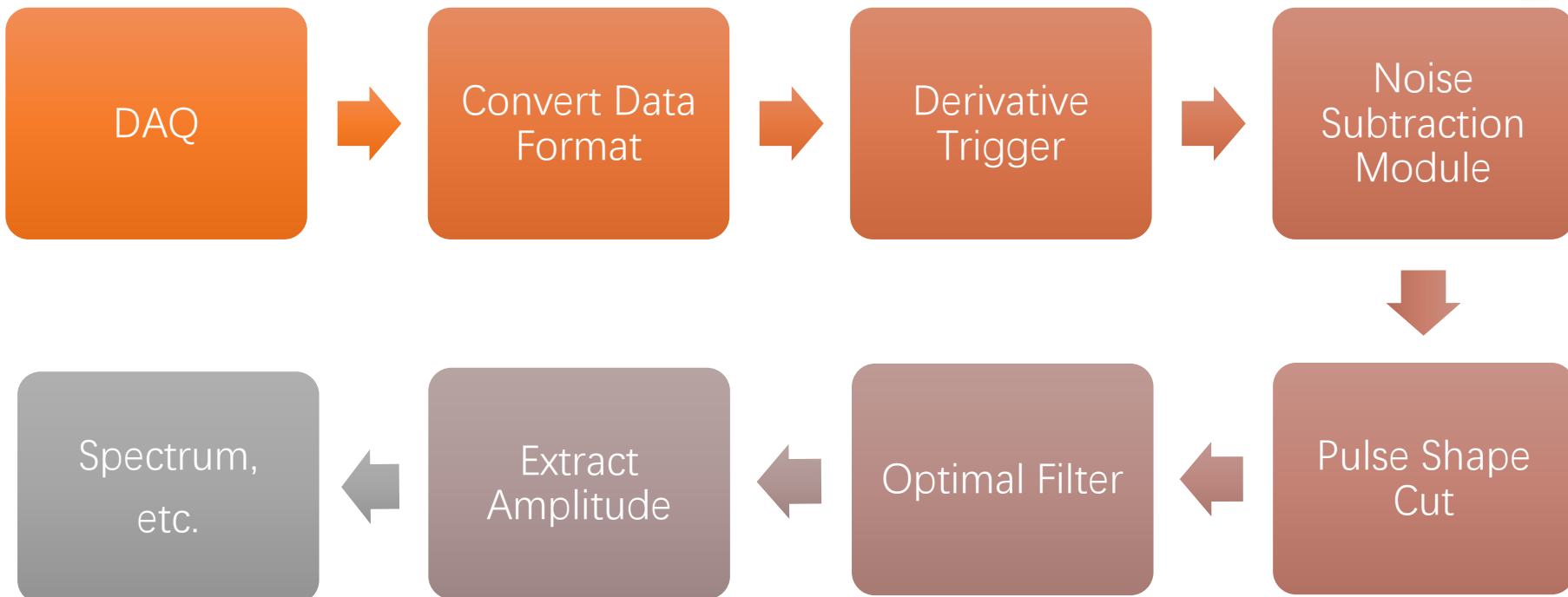
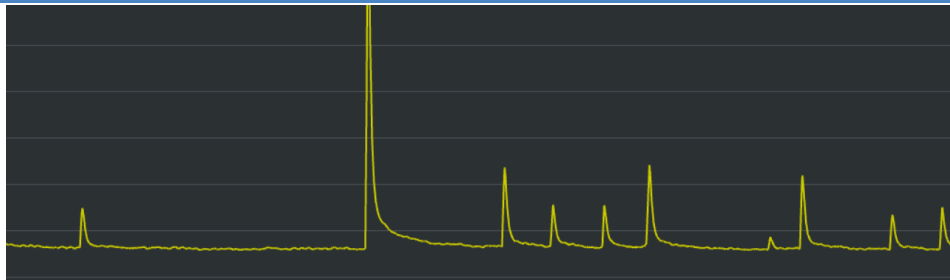
- 减振盘温度: 20.11 mK
- NTD @ 2 cm LMO阻值: 2.1 M $\Omega$



- NTD @ 1 cm LMO阻值: 777 k $\Omega$



# 数据处理流程



By 谢芳&符士洪



# 目录

## 一、实验背景

- 无中微子双贝塔衰变
- 低温晶体量热器技术
- CUPID-CJPL实验

## 二、实验设置与进展

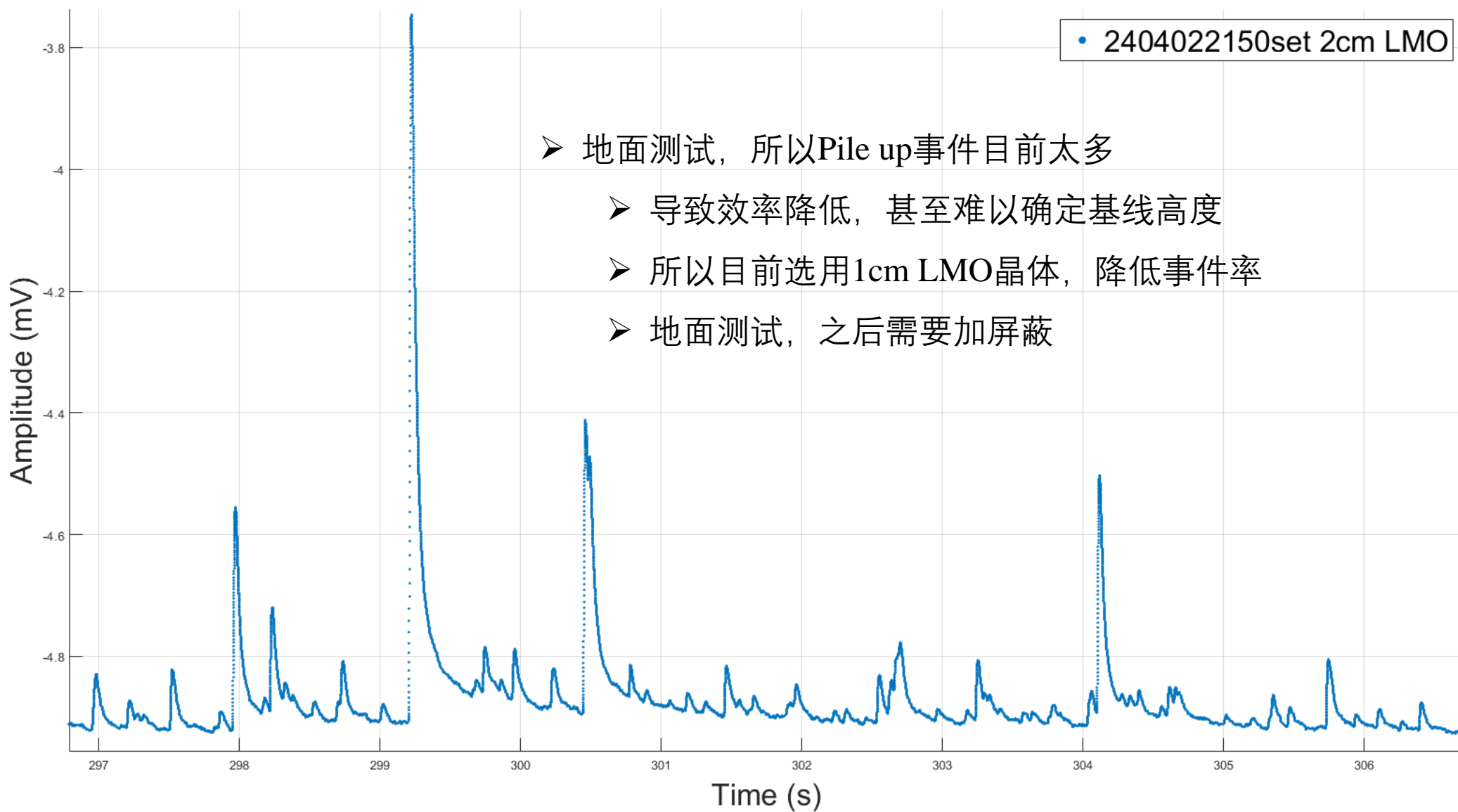
- 稀释制冷机介绍
- 电子学读出
- NTD-Ge参数标定
- 减振系统设计
- 晶体装配
- 数据处理流程

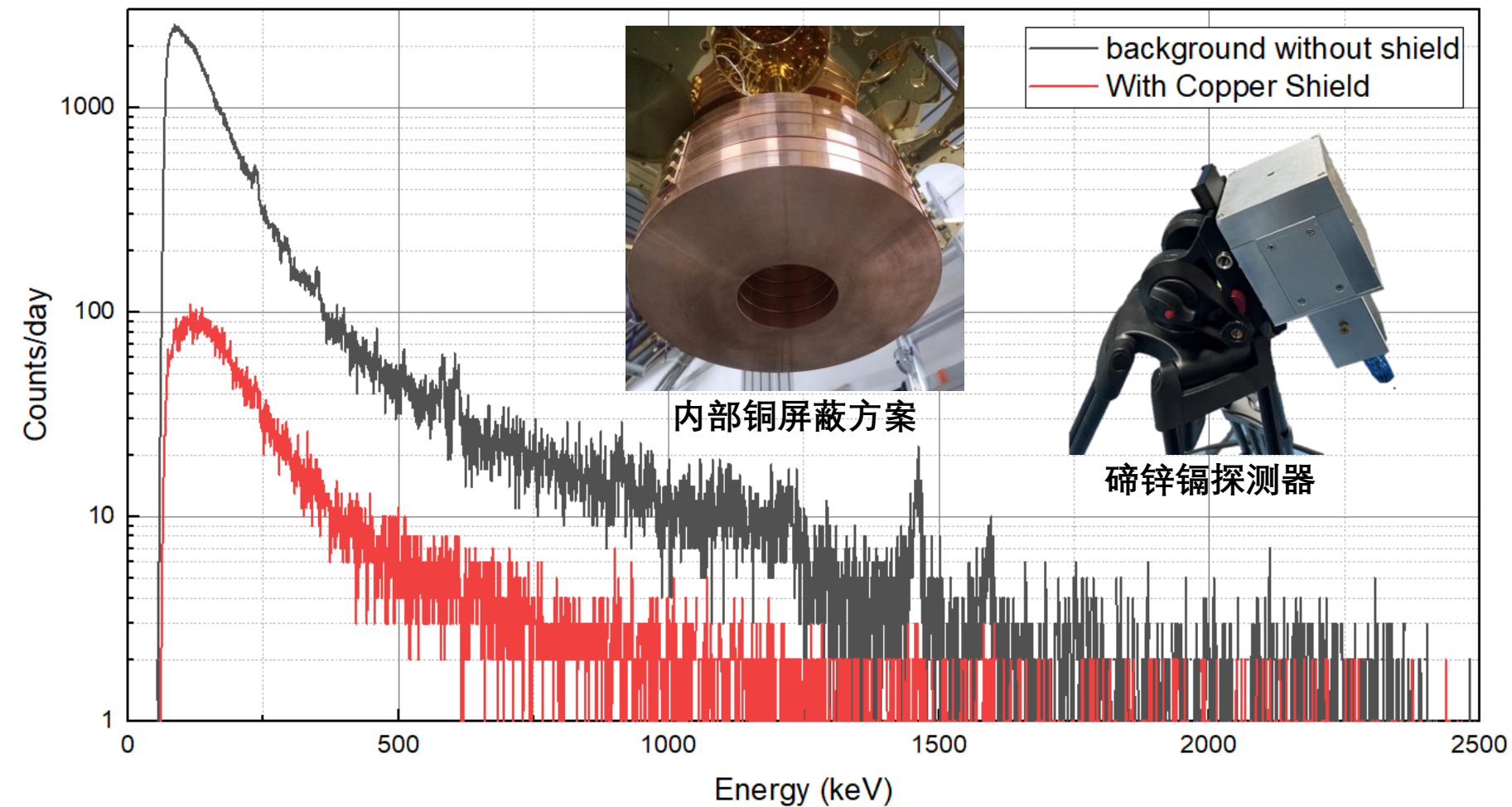
## 三、总结展望

- 现阶段总结
- 后续改进计划



- 制冷机稳定运行，可长期维持在10mK温区，进行相应的R&D工作
- 读出电子学系统稳定运行，有良好的基线表现及噪声水平
- 能谱分析软件开发稳步推进
- 拥有进行进一步地面晶体测试的条件





碲锌镉探测器实验室本底计数

- 低本底铜内部屏蔽
- 外部铅屏蔽



- 对现有能谱进一步分析
- 使用源，对量热器进行定标
- 开展光热双读出测试

Thanks