The AMoRE- Ⅱ Cryostat

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on behalf of AMoRE collaboration

Center for Underground Physics
Institute for Basic Science

AMoRE collaboration

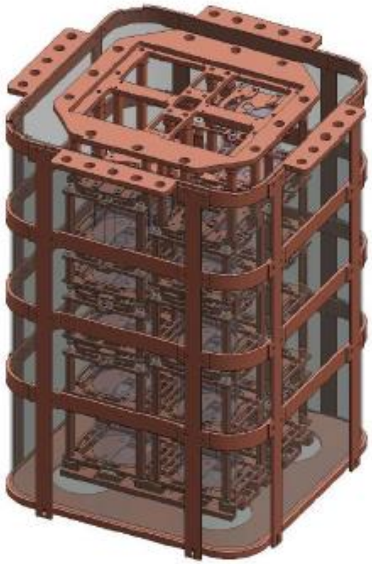
Advanced Mo-based Rare process Experiment

Neutrinoless Double Beta Decay

Phase of AMoRE Experiment

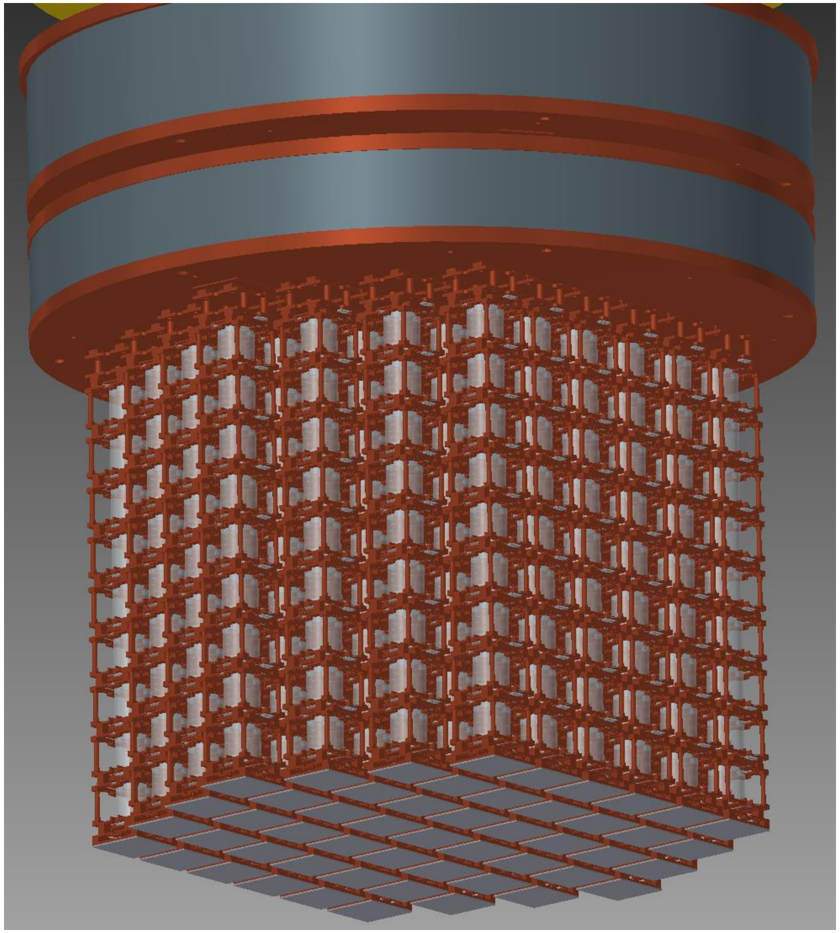
AMoRE pilot

finished



AMoRE- Ⅰ

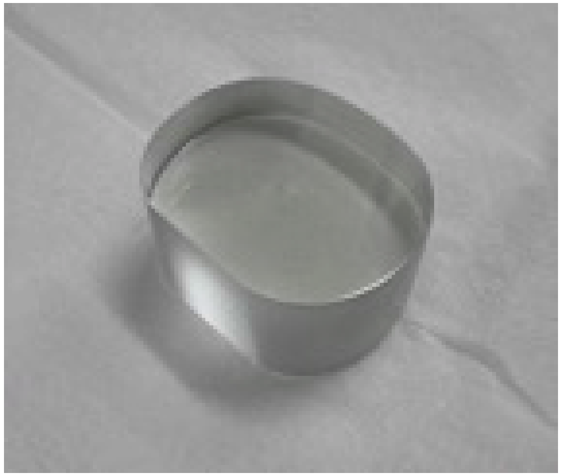
preparing

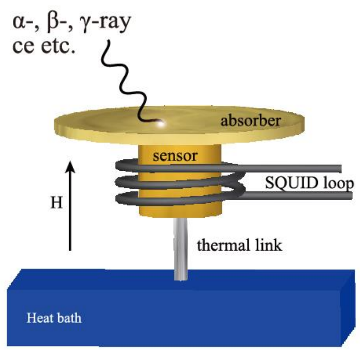


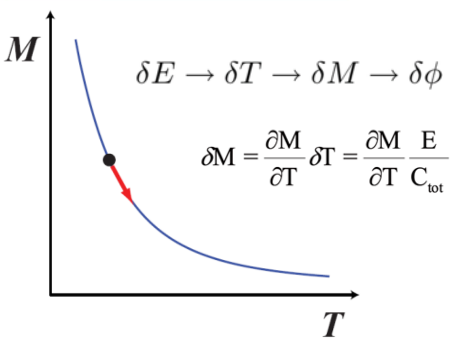
AMoRE-Ⅱ

Final goal

Detector : scintillating crystals and MMC







Scintillating Crystal ($^{40}Ca^{100}MoO_4$)

- enrichment of ^{100}Mo >96%, 3 MeV Q-value
- depleted of ^{48}Ca < 0.001%
- detection of heat & light signal

→ discrimination of alpha and beta/gamma

$$T_{1/2}^{0\nu}(\exp) = (\ln 2) N_a \frac{a}{A} \varepsilon \sqrt{\frac{MT}{b\Delta E}}$$

b = background index in cts/(keV kg y)
ΔE = FWHM energy resolution at $Q_{\beta\beta}$ in keV
M = mass of detector in kg,
A = mass number of candidate material
ε = detection efficiency at $Q_{\beta\beta}$,
a = ββ isotope fraction (Enrichment),
T = measured time in years

Metallic Magnetic Calorimeter (MMC)

Temperature sensor : paramagnetic (Au:Er) + SQUID

Energy (ΔE) → Temperature (ΔT) → Magnetization (ΔM) → Magnetic flux(ΔΦ) → Voltage

deposited energy → increase of temperature

γ : 0.3 keV (FWHM) @ 60 keV
α: 0.9 keV (FWHM) @ 5.5 MeV

superior performance

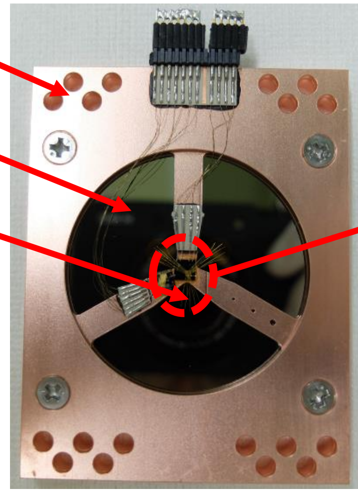
AMoRE detector

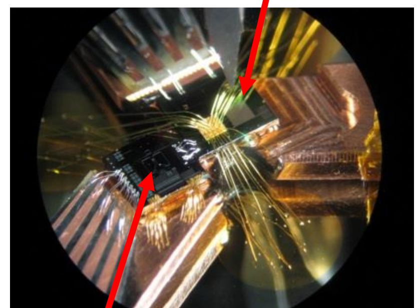
Detector module : $^{40}Ca^{100}MoO_4$ + MMC + SQUID + support

Wafer holder
(Cu, heat bath)

Light absorber
(Ge wafer)

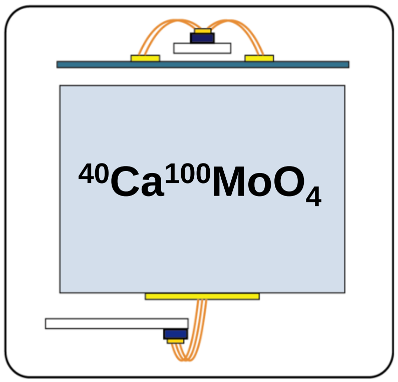
Phonon collector
(Gold films)



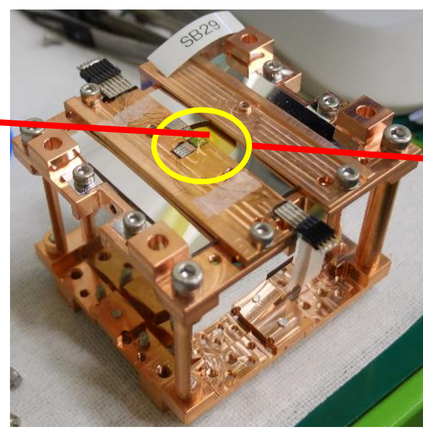


MMC

SQUID



Phonon collector
Patterned gold film

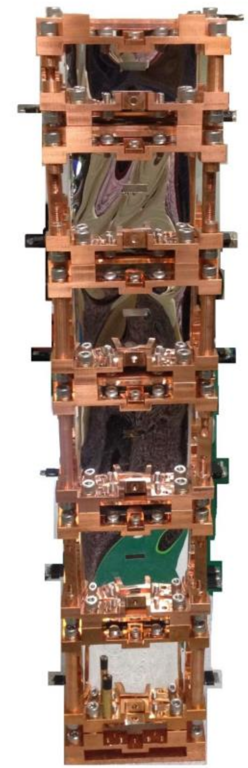


MMC

SQUID

Gold film

Gold wires
(thermal connection)



AMoRE-pilot detector

6 detector modules

Crystal : 1.9 kg

AMoRE detector and refrigerator

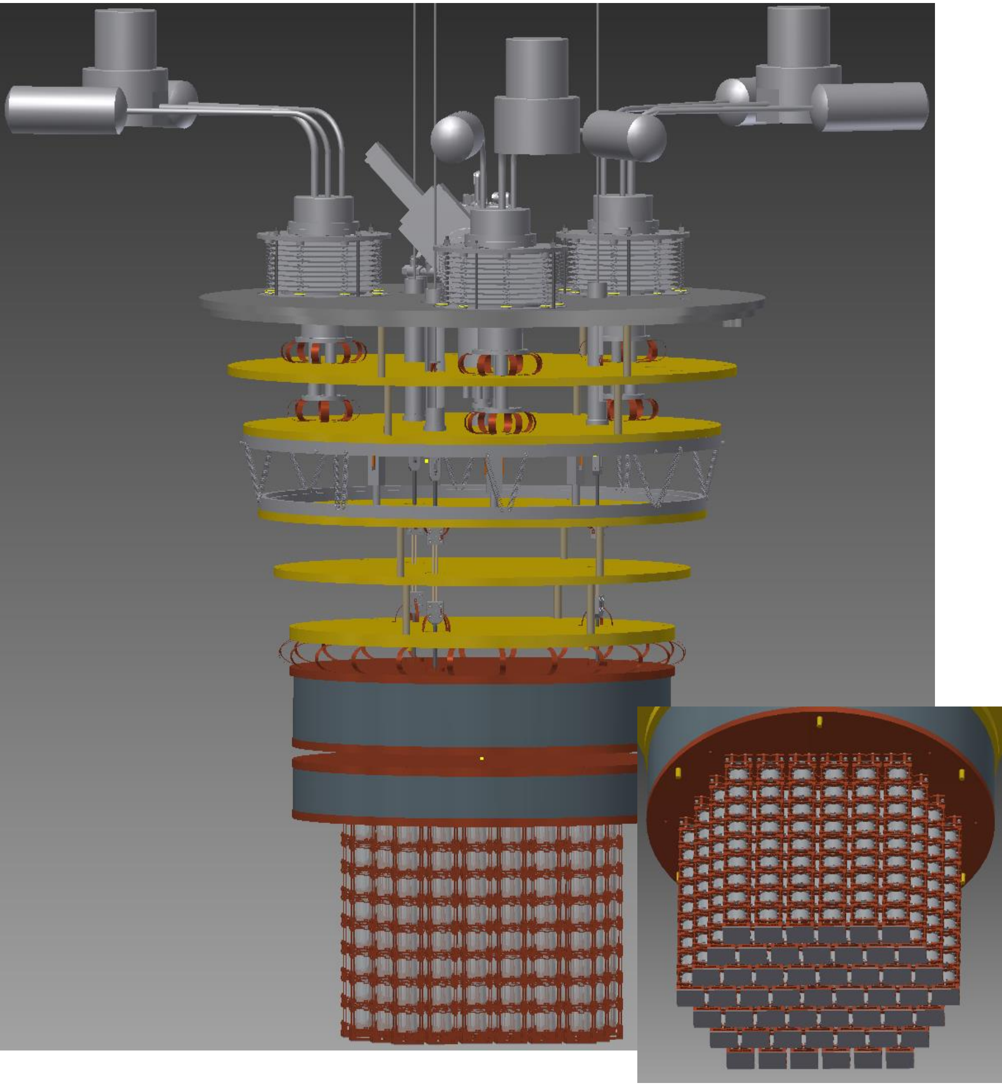
Present experimental set up

- Single detector module : 80 X 80 X 80 mm
- Detector tower : 6 single detector modules (4.2 kg)
- Internal radioactive shield : lead shield (172 kg) + copper support (39 kg)
- Superconducting shield : lead cylinder with copper frame (5.76 kg)
- Vibration damper : copper plate and supports (29 kg)
- Total mass for experiment : 250 kg

Present refrigerator

- Refrigerator : Leiden cryogenics, 1.4 mW @ 120 mK with 1 PTR (PT415)
- Experimental space : 408 mm (D) X 690 mm (H)
- AMoRE-Ⅰ : ~ 5.8 kg of crystal, 3 ~ 4 detector towers
- Enough size and cooling power for AMoRE-Ⅰ

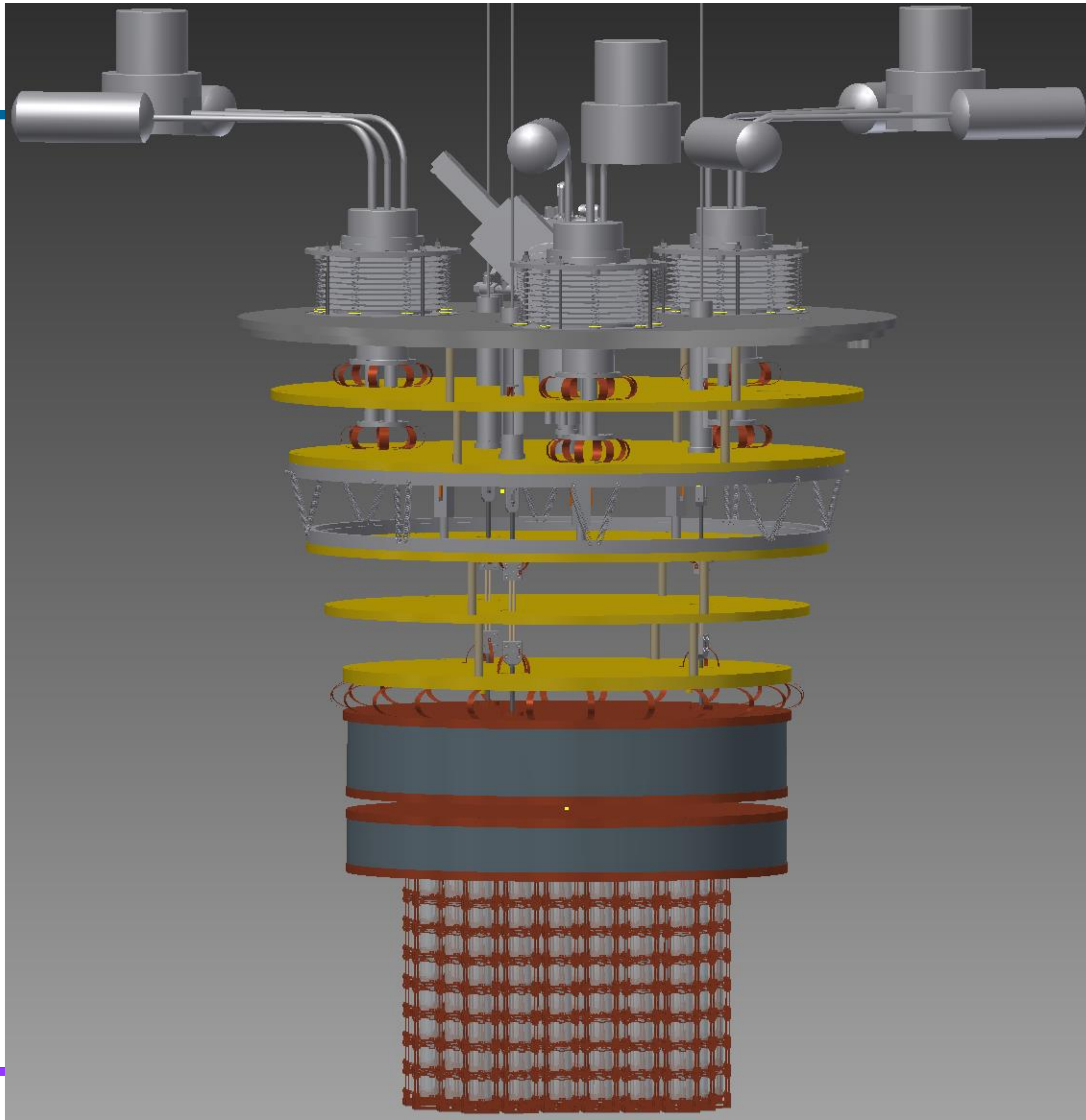
AMoRE-Ⅱ detector and refrigerator



AMoRE-Ⅱ set up

- 100Mo base crystals : CMO, LMO, …, etc, total 200 kg
  net mass of ^{100}Mo is 100 kg
- Detector module : 80 X 80 X 80 mm with ~400 g of crystal
- Detector tower : 8 detector modules
- Detector array : 64 detector towers
- Long S.C shield to get shielding efficiency
- Experimental space : 1000 mm (D) X 1950 mm (H)
- Detector temperature : < 10 mK

- Big and powerful dilution Refrigerator
- Three PTR (PT420 RM)
- 2.4 mW @ 120 mK, > 5 uW @ 10 mK



Mass for overall system

1. Dilution fridge

Temperature	Plate (mm) (OD X T)	Mass of plate (kg)	Shield can size (OD X L X T)	Mass of shield cans (kg)
300 K	1,420 X 40	500	1370 X 3098 X 4	680 for STS
50 K	1,320 X 30	350	1288 X 2874 X 4	500
4 K	1,240 X 30	320	1200 X 2650 X 8	750
Still	1,160 X 30	280	1165 X 2422 X 1	100
50 mK	1,080 X 30	240	1085 X 2171 X 1	85
M.C	1,000 X 30	210	--	--
Total		1,900		2,115

2. Experimental setup

Set up	material	Dimension (mm)	Mass (kg)	total
Radiation shield	lead	996 X 250	2200	~ 3.6 ton
shield support	Copper	998 X 20	140 X 4	
Detector	crystal	60 X 60	200	
	Copper	80 X 80 X 80	~ 500	
Superconducting shield	lead	980 X 1200 X 2	~ 100	
	Copper	985 X 1205 X 4	~ 50	

Mass for overall system

1. Dilution fridge

Temperature	Plate (mm) (OD X T)	Mass of plate (kg)	Shield can size (OD X L X T)	Mass of shield cans (kg)
300 K	1,420 X 40	500	1370 X 3098 X 4	680 for STS
50 K	1,320 X 30	350	1288 X 2874 X 4	500

Physically and thermally too heavy and massive

shield support	Copper	998 X 20	140	~ 3.6 ton
Detector	crystal	60 X 60	200	
	Copper	--	~ 500	
Superconducting shield	lead	980 X 1200 X 2	100	
	Copper	--	50	

Mass for overall system

1. Dilution fridge

Temperature	Plate (mm) (OD X T)	Mass of plate (kg)	Shield can size (OD X L X T)	Mass of shield cans (kg)
300 K	1,420 X 40	500	1370 X 3098 X 4	680 for STS
50 K	1,320 X 30	350	1288 X 2874 X 4	500

Special holding structure and precooling system

shield support	Copper	998 X 20	140	~ 3.6 ton
Detector	crystal	60 X 60	200	
	Copper	--	~ 500	
Superconducting shield	lead	980 X 1200 X 2	100	
	Copper	--	50	

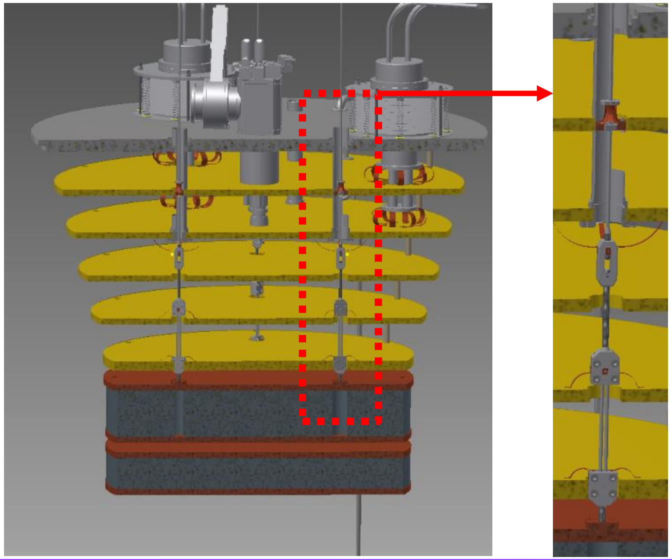
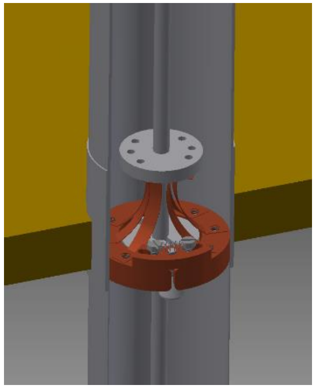
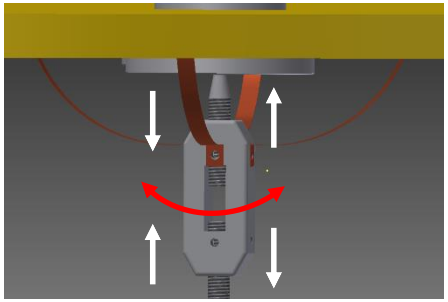
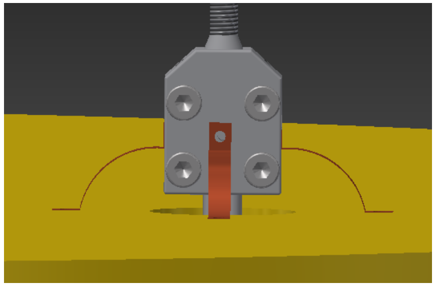
Holding structure for heavy mass

1. 300 K – Still (~ 100 mK)

- STS 316 rod : 6 mm (dia), tensile strength > 1.47 ton, 8 mm(dia), tensile strength > 2.62 ton
- STS rod connected with vibration damper at 300 K and go into fridge via clear shot
- STS rod thermally linked at each temperature plates, 50 K, 4 K, Still

2. Still – experimental setup

- 6 mm Kevlar rope : strong enough, tensile strength > 4.31 ton
- Very low thermal conductivity at low temperature : ~ 4 X 10^{-2} W/mK @ 4 K, ~ 4 X10^{-3} W/mK@ 1 K
- connected with STS rod at 4 K and hold all experimental setup

Heat load by structures

1. Thermal radiation

Stage	Material	Diameter (cm)	Length (cm)	Radiation (plate)	Radiation (can)	Total Radiation
300 K	STS (316)	176.8	3.98			
50 K	OFHC	128.8	145.7	41.2 W	228.2 W	310 W → 30 ~ 78 W
4 K	OFHC	123	128.7	0.005 W	0.0435 W	0.054 W

emissivity → 30 layers of superinsulation (MLI)

2. Heat load by wire and SQUID

- CuNi (alloy 30, Cu 70% + Ni 30%), D = 100 um, L = 2 m, 10,000 strands
- Assumed the SQUID bias current with 15 uA (1,000 SQUID's)

Stage	source	Thermal conductivity (W/K·m)	Electrical resistivity (Ω·m)	Conduction Heat load (mW)	Electrical Heat load
300 K	CuNi	30	5.0×10^{-6}	-	
50 K	CuNi	< 30	3×10^{-7}	< 1,324	
4 K	CuNi	0.52	3×10^{-7}	4.143	0.15 mW
Still	S.C wire	-	-	-	-
50 mK	S.C wire	-	-	-	-
M.C	SQUID	-	-	-	5 nW

Heat load by structures

3. Conduction by feedthrough (lead wires and supporting structure)

Stage	Surface area (mm^2)	Length (mm)	Heat load (mW)
50 K	260	199	< 3.90 X 5
4 K	4260	161.2	< 7.06 X 5

- 81 mm diameter clear shot : STS tube and copper flange

4. Conduction by holding structure

Temperature	material	Diameter (mm)	Length (cm)	Heat road
300 → 50 K	STS 316 LN	8	15	3.95 W X 3
50 K → 4K	STS 316 LN	8	15	0.32 W X 3
4 K → Still	STS 316 LN	6 or 8	15	522 uW X 3 or 928 uW X 3
	G11	8 or 10	15	304 uW X 3 or 475 uW X 3
Still → 50 mK	Kevlar	6	15	6.4 nW X 6
50 mK → M.C	Kevlar	6	12	N/A

Heat load by structures

Total expected heat load

Temp	radiation	conduction	Wire	3He -circulation	Total
300 → 50 K	78 W	~ 11.9 W	1.30 W		91.2 W
50 K → 4K	0.054 W	~ 0.995 W	4.14 mW	Nor 1.43	2.48 W
				Cond 4.3	5.35 W
4 K → Still	-	0.912 ~ 2.78 mW	S.C wire	-	0.912 ~ 2.78 mW
Still → 50 mK	-	38.4 nW	S.C wire	-	38.4 nW

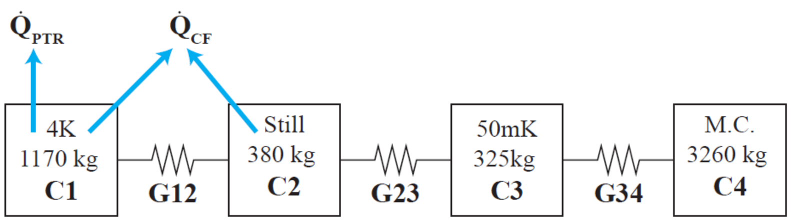
Heat load and cooling power

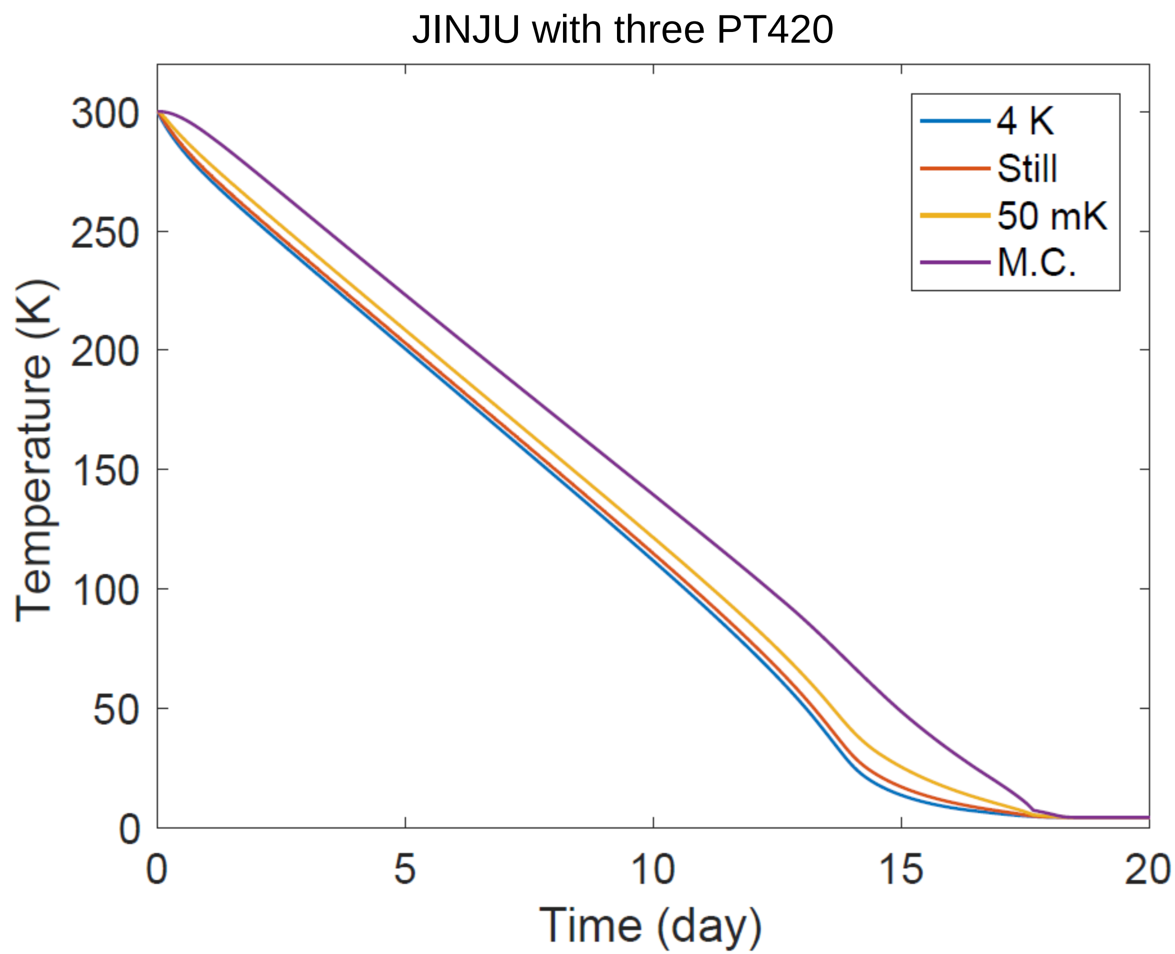
Temp	Cooling source	Cooling power	Total Heat load	
50 K	3 ea PTR	~ 150 W	~ 91.2 W	
4 K	3 ea PTR	5.4 W	Nor 2.48 W	
			Cond 5.35 W	
Still	DR	2.4 mW	0.912 ~ 2.78 mW	
50 mK	DR	--	Several tens mW	
M.C	DR	>5 uW	~ 5 nW	

Pre-cooling system

1. Expected Cool down time with 3 PT420 RM

- Cooling power : 55 W @ 45 K, 2.0 W @ 4K
- With remote motor : 1.8 W @ 4K
- Soft contact with copper braids
- Total mass of experimental setup : ~ 3.6 tons





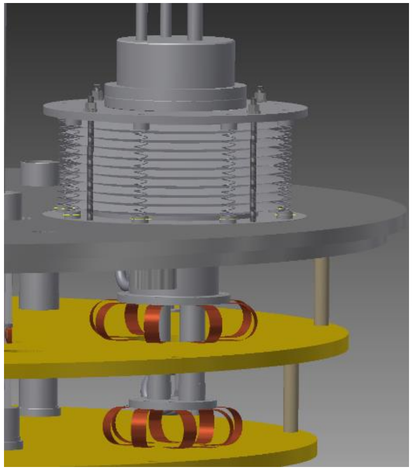
Approximately 20 days to reach 4 K from 300 K without LN_2 cooling

Vibration

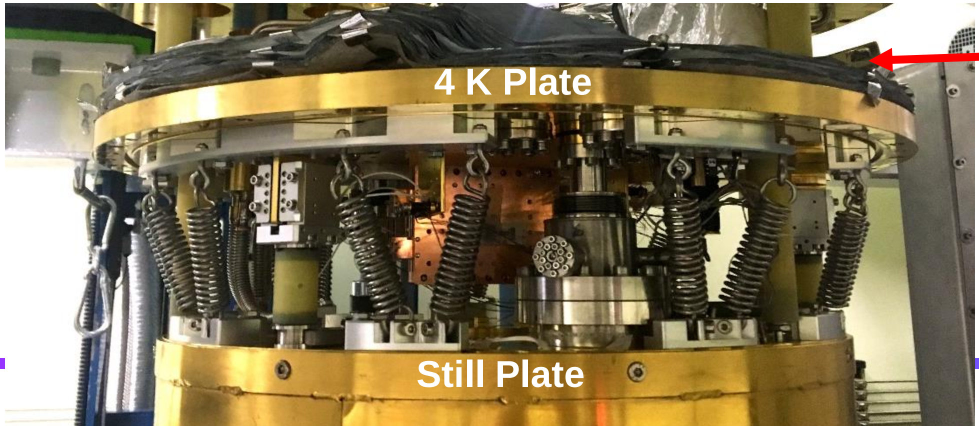
1. Isolation of detector system with vibration source by using special holding system
   - Connecting holding structure with damping system on room temperature

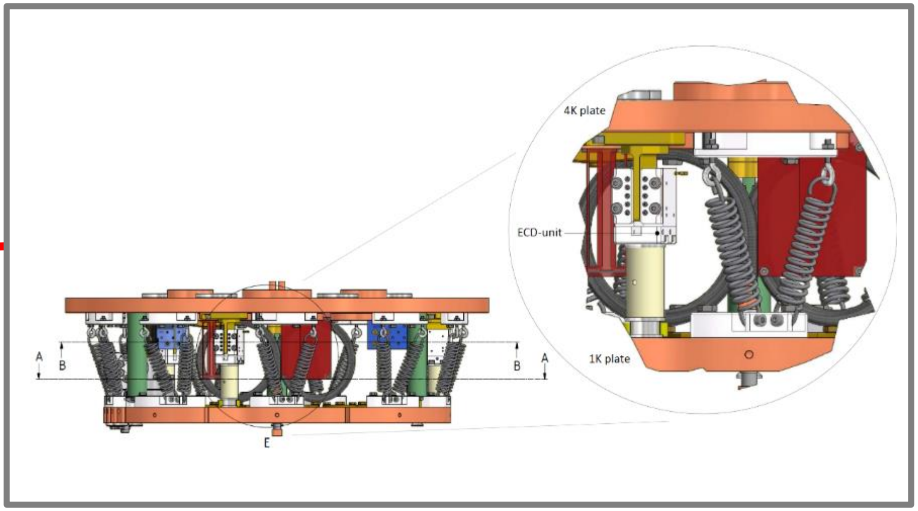
2. PTRs
   - Mechanically decouple with dilution fridge : super bellows and copper braids
   - Synchronization of PTR unit, linear driver

3. Additional damping system : Spring Suspended Still (SSS)
   - mechanically decouple between 4 K plate and still with spring and eddy current damper



4. Soft connection the detector array with Dilution refrigerator
   - 4 steps of vibration damping

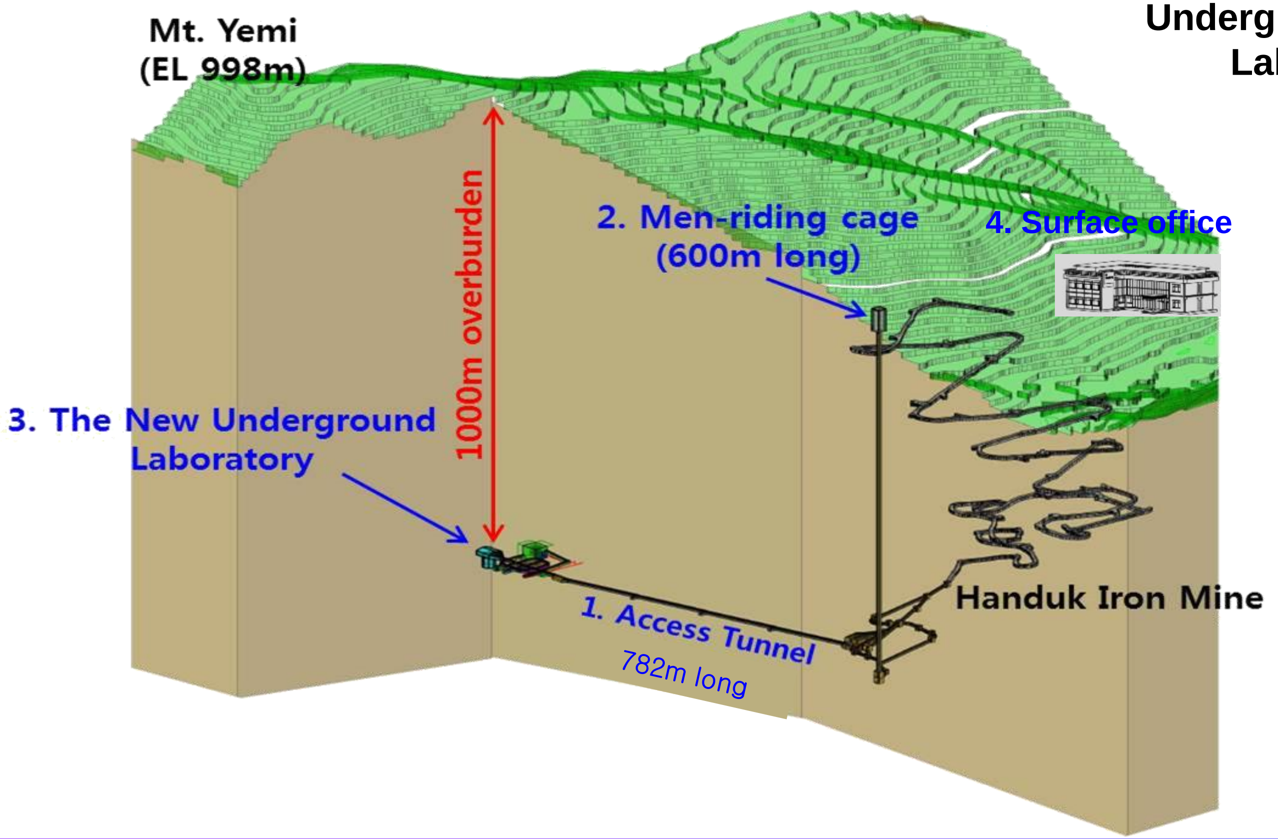


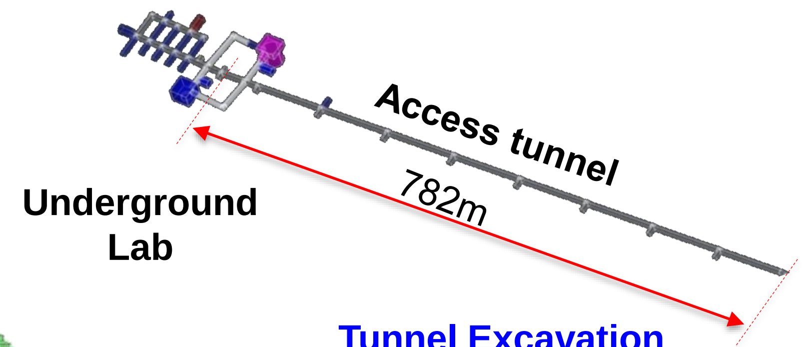


New Underground lab

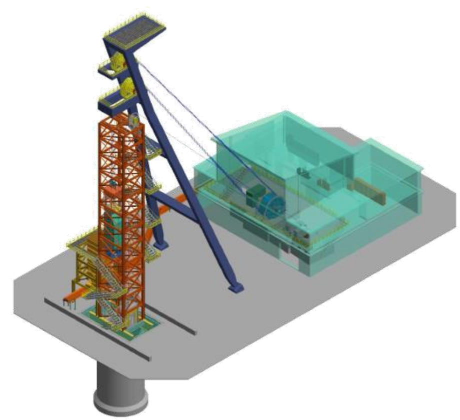
- The 3 major sub-constructions
  1. Tunnel & UL excavation(on going)
  2. Cage for passengers(done)
  3. Surface office/lab(on going)

Test operation : Oct. 2020



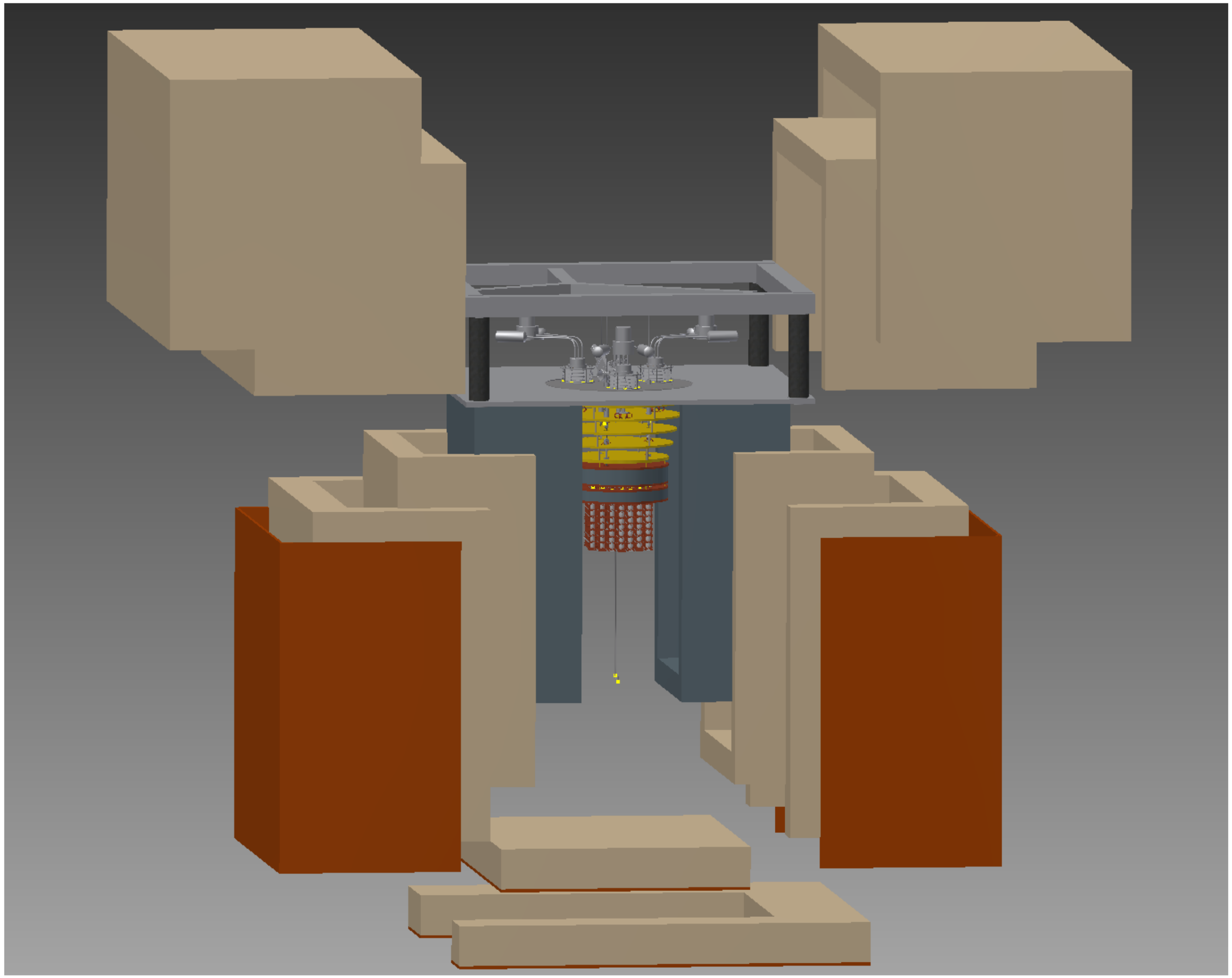


Tunnel Excavation



Shaft cage

Overall experimental structure



- lead : 25 cm thickness, 73.2 tons
- 1st side PE : 30 cm thickness, 10.7 tons
- 2nd side PE : 40 cm thickness, 16 tons
- Bottom PE : 40 cm thickness, 7.4 tons
- 1st top PE : 30 cm thickness, 14 tons
- 2nd top PE : 40 cm thickness, 25.8 tons
- Borated PE : 3 cm thickness, 3 tons
- Totally 150 tons
- 10^{-5} counts/KeV/kg/yr @ 3 MeV

Thanks to

Carlo Bucci

Matthias Buehler

Antonio D’Addabbo

Paolo Golar

Andreas Reiser

Posters about AMoRE experiment

- **Poster No 103 : 23rd. July.**
  Low temperature measurement on directional dependence of phonon-scintillation signals from a Zinc tungstate crystal, JA, Jeon

- **Poster No 104 : 23rd. July.**
  Development of Neganov-Luke light detectors for a rare event experiment, JA, Jeon

- **Poster No 111 : 23rd. July.**
  MMC critical temperature switch development with an integrated heater, Sora Kim

- **Poster No 218 : 23rd. July.**
  Development of low threshold detectors for light dark matter detection, Hyelim KIM

- **Poster No 264: 23rd. July.**
  The AMoRE Pilot experiment, Kyung Rae Woo

- **Poster No 278 : 23rd. July.**
  Stabilization heater for AMoRE, Do Hyung Kwon

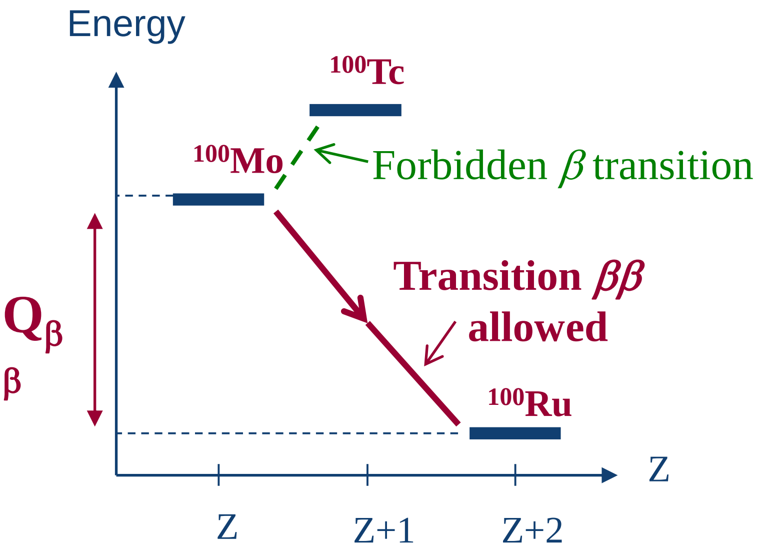
- **Poster No 216 : 25th. July.**
  Li2MoO4 phonon-scintillation detection system with MMC readout, Hyelim KIM

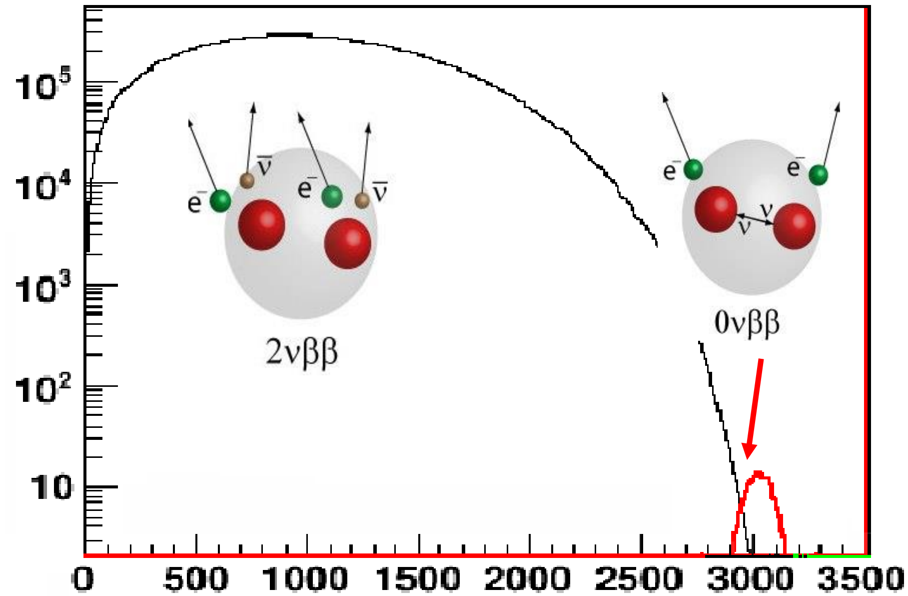
- **Poster No 245 : 25th. July.**
  Detector Design for AMoRE-I, HAN BEOM KIM

- **Poster No 268: 25th. July.**
  MMC development for the AMoRE project, Sang Goon Kim

Back up

Neutrinoless Double Beta Decay



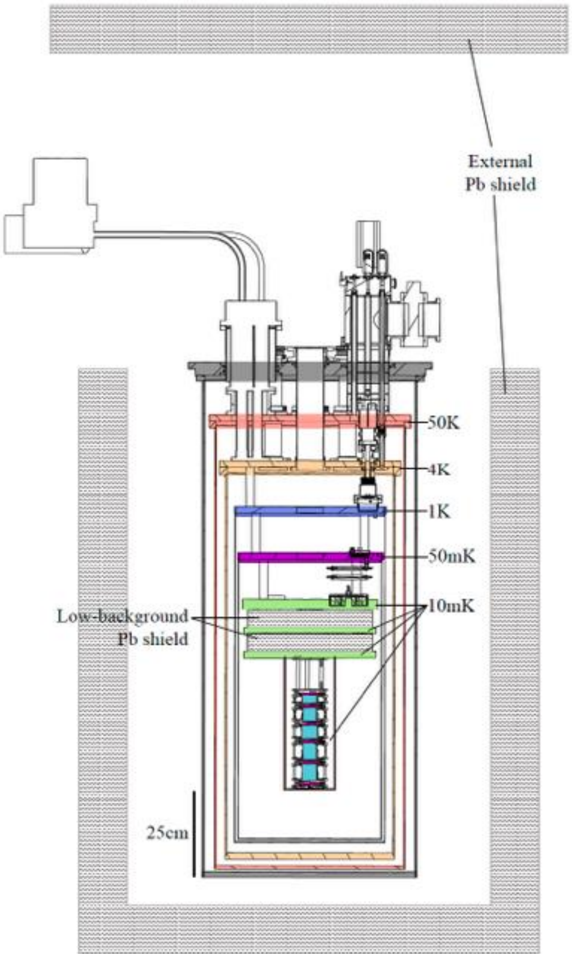


(Z, A) → (Z+2, A) + 2e$^-$ + 2anti-n_e (DL = 0, conserved)

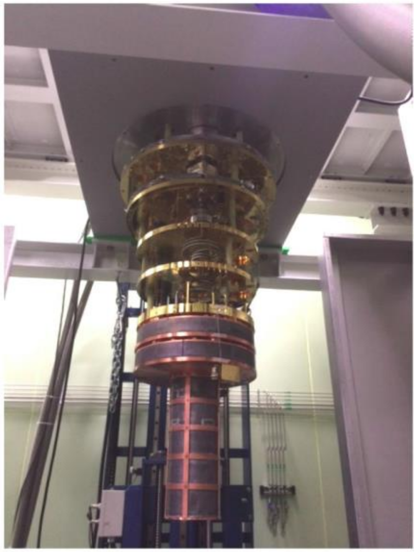
(Z, A) → (Z+2, A) + 2e$^-$ (DL = 2, violated)

- **0*n* DBD is forbidden by Standard Model for lepton number violation.**
- **If neutrino is a majorana particle, 0*n* DBD is possible.**
- **We will be able to define the neutrino type and absolute mass.**

AMoRE-pilot experiment : shielding

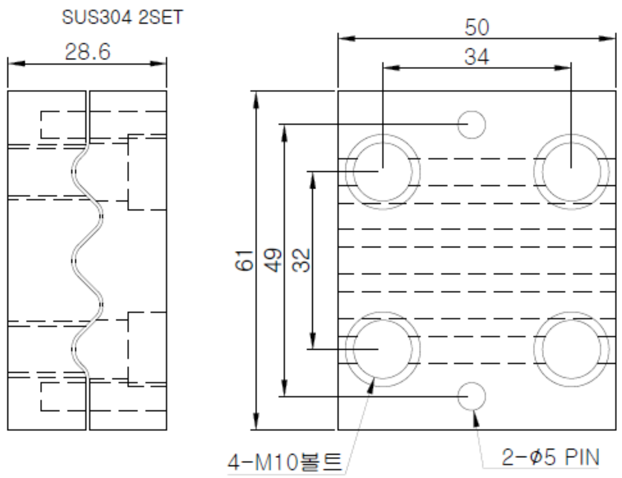


Overall structure of AMoRE-pilot



- first shield : normal lead ~ 50 Bq/kg, ~ 1 ppt for U/Th
  surround a refrigerator system including
  AMoRe-pilot detector
  weight 16 tons
- second shield : μ-metal can to prevent magnetic
  noise
- third shield : thick STS can and Cu can (OFE)
  inside a refrigerator system
  weight ~ 580 kg
- fourth shield : low background lead and Cu (NOSV)
  < 0.3 Bq/kg for Pb 210
  ~ 1 ppt for U/Th
  weight ~ 160 kg (lead), ~ 30 kg (Cu)
- fifth shield : superconducting shield
  low background lead

Tensile force experiment



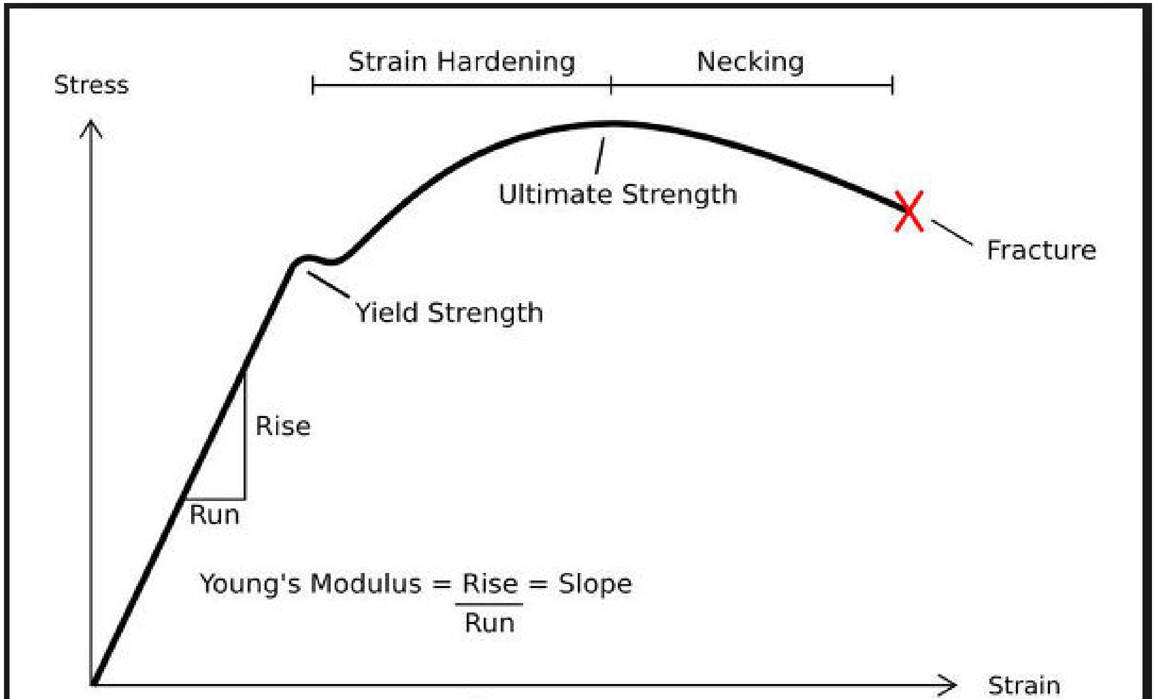


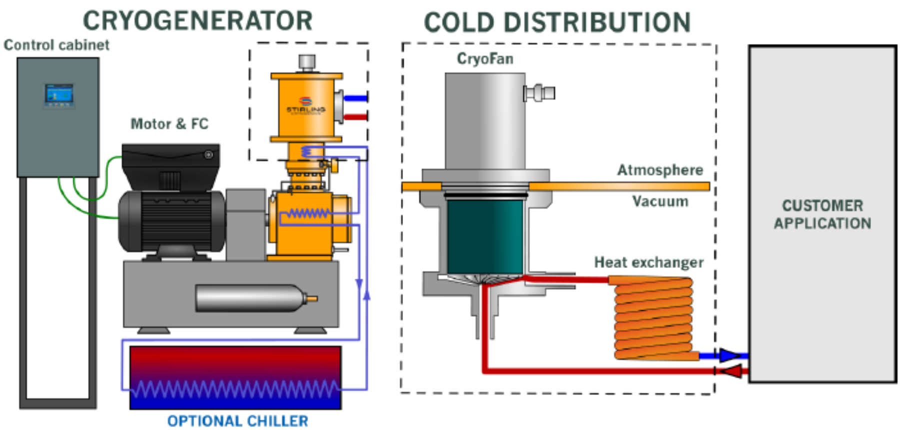
Figure 1

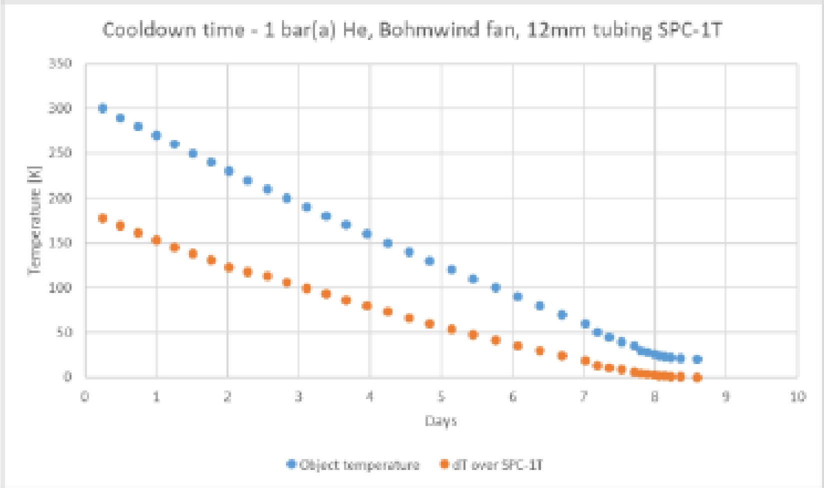
Pre-cooling system

2. Expected Cool down time with Stirling cooler

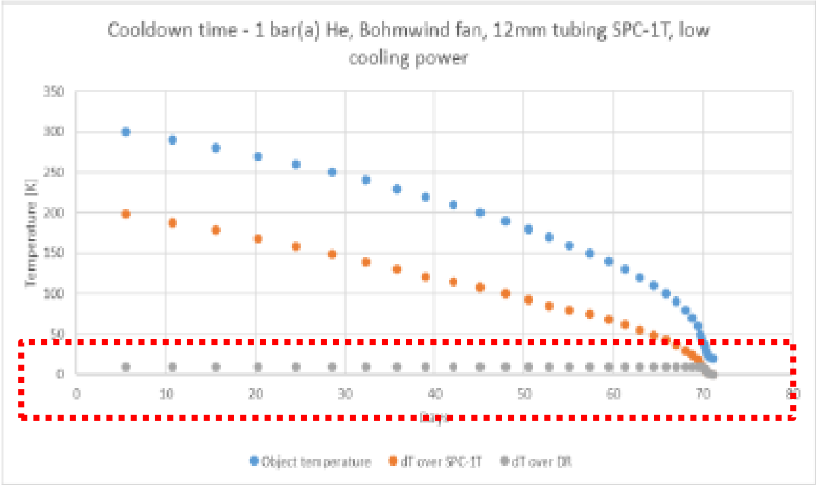
- Stirling cooler (SPC-1T)
- cooling with cold Helium gas and cryofan
- 80 W @ 15 K cooling power

- Pressure of system : 1 bar
- Around 3 ton @ 10 mK region





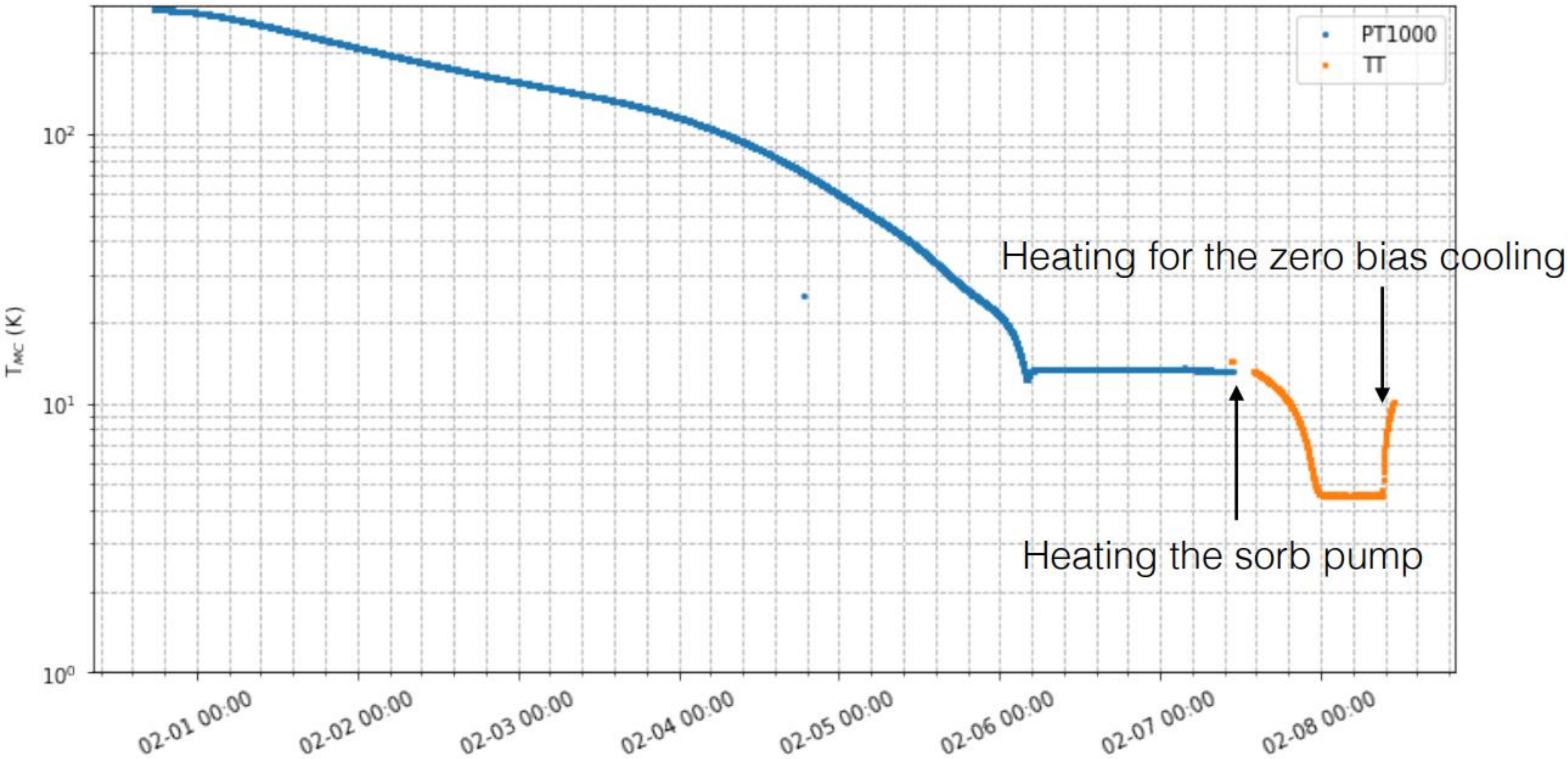
Direct cooling with cold gas



ΔT between crystal and cold gas : 10 K

Cool down time of present setup

5 ~ 6 day with one PTR from 300 to 15 K



Mass : around 3.5 times

Heat road : around 12 times

300 K → 50 K

Present setup