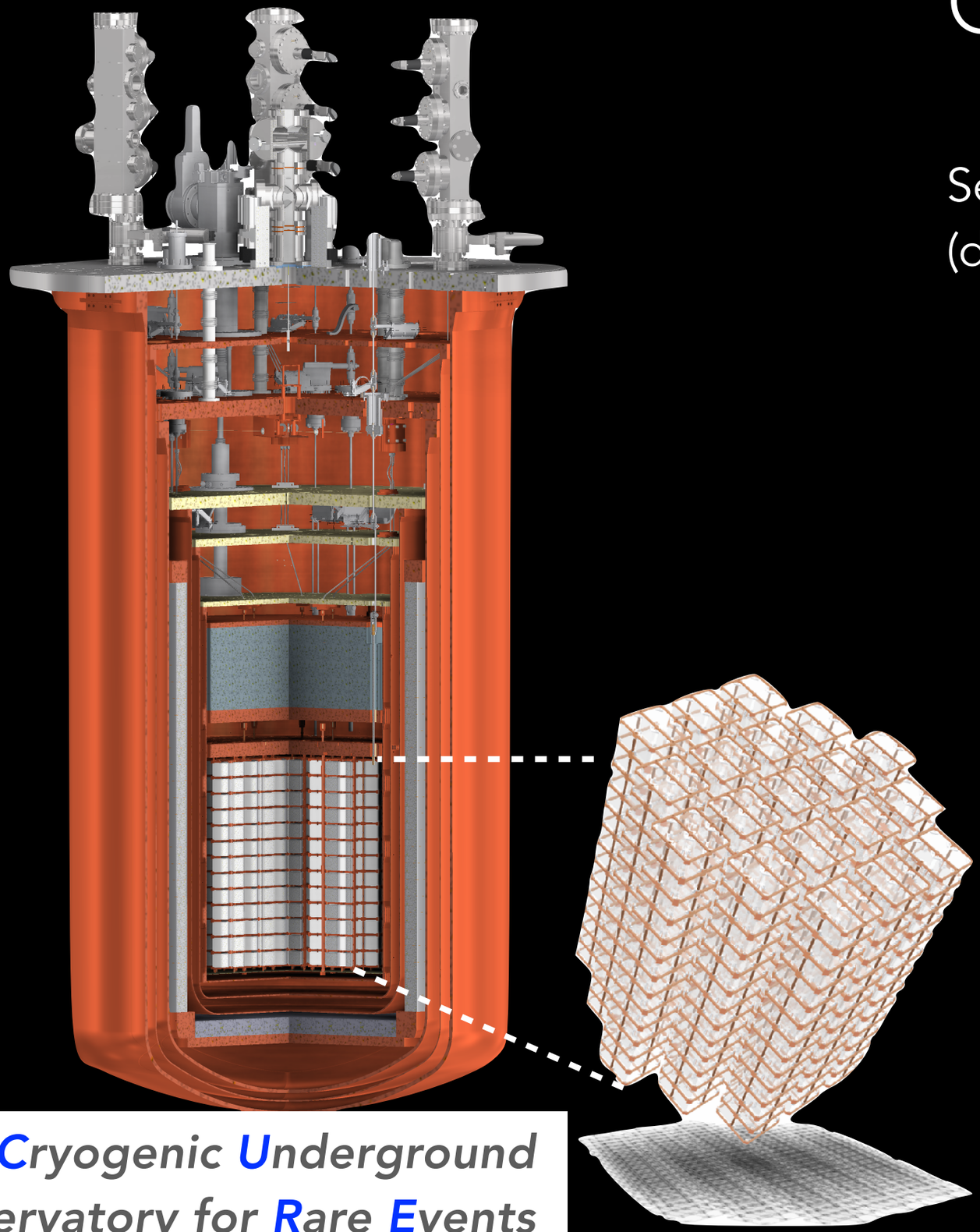
# THE CUORE CRYOSTAT:

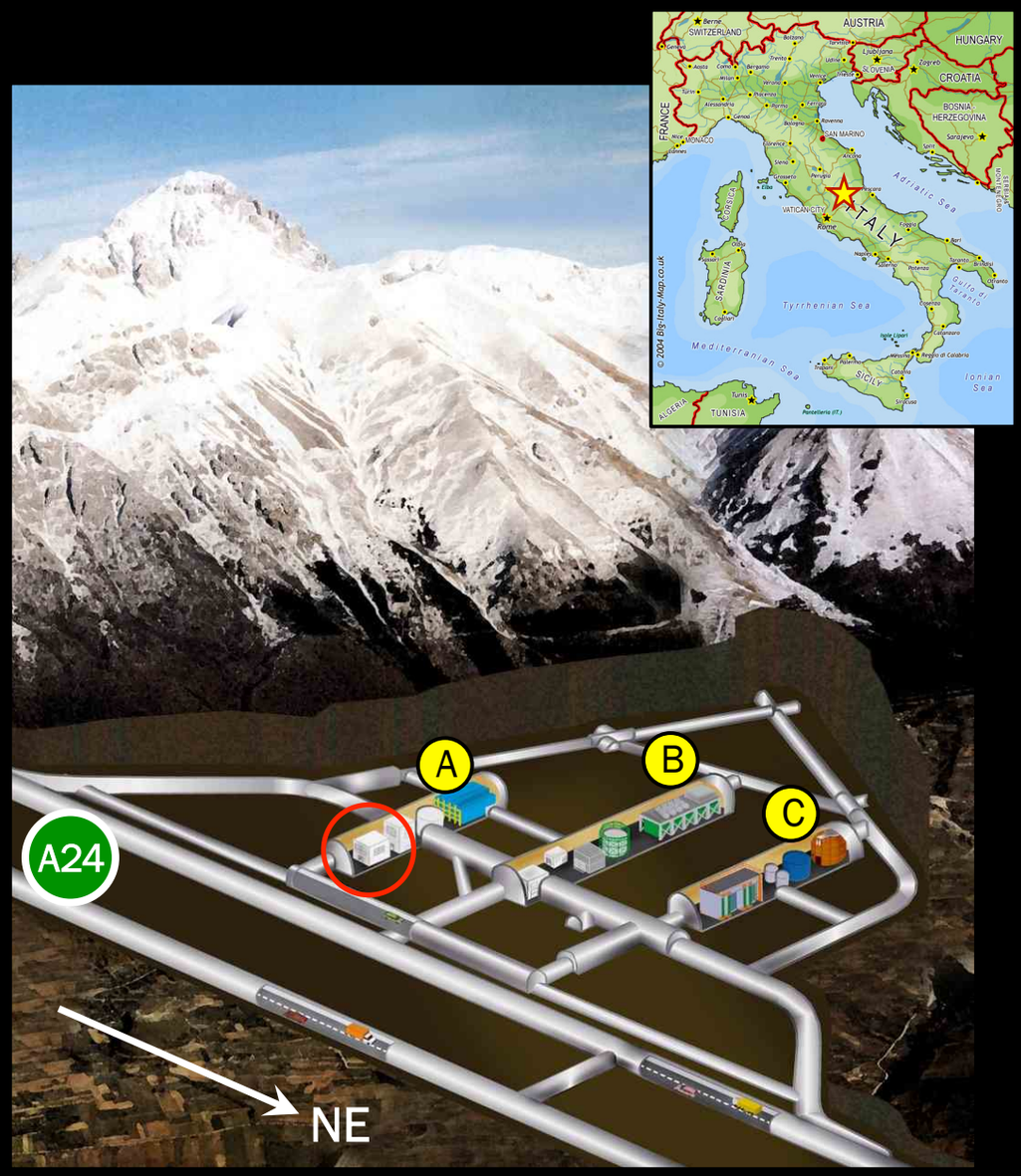
The first sub 10 mK , tonne-scale infrastructure for  low temperature detectors.

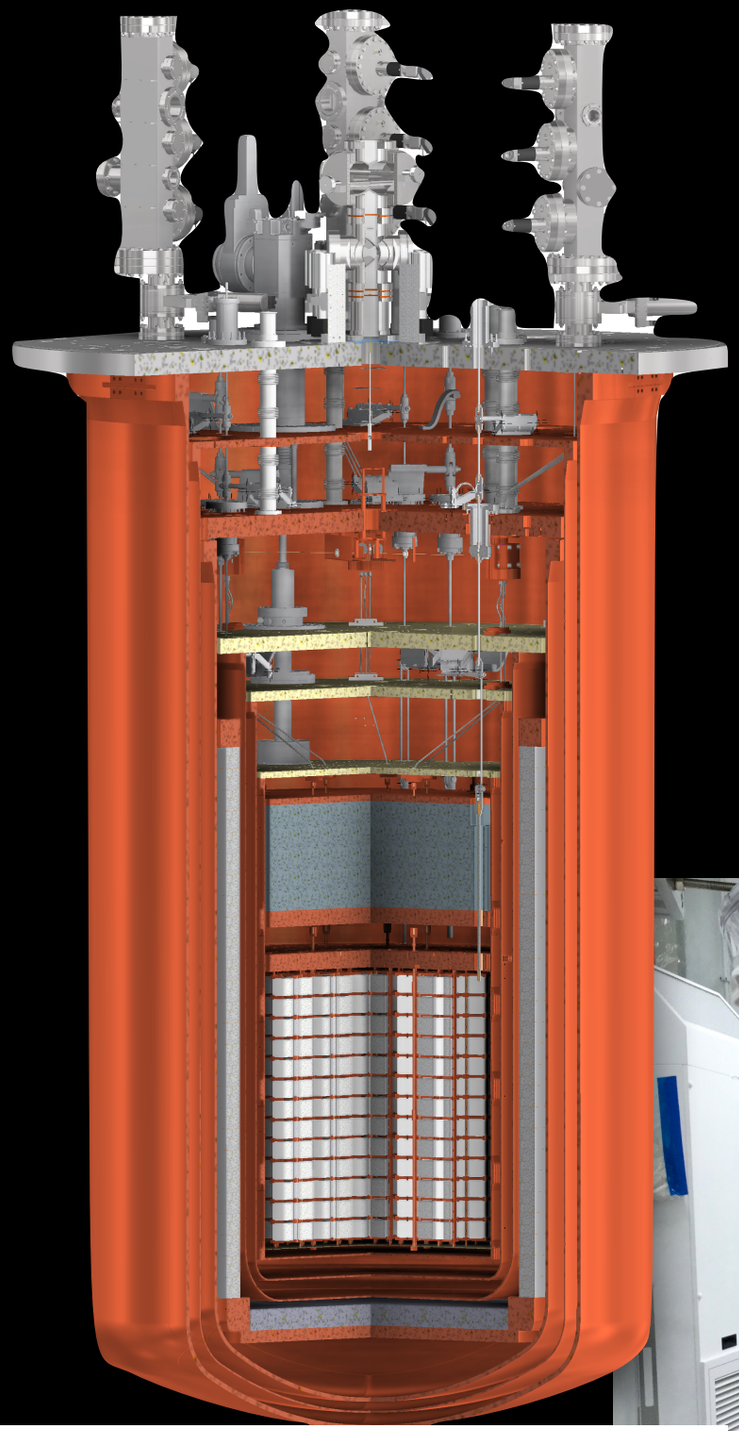
# CUORE

Search for 0νββ in $^{130}$Te at LNGS, Italy
(depth ~ 3600 m.w.e )

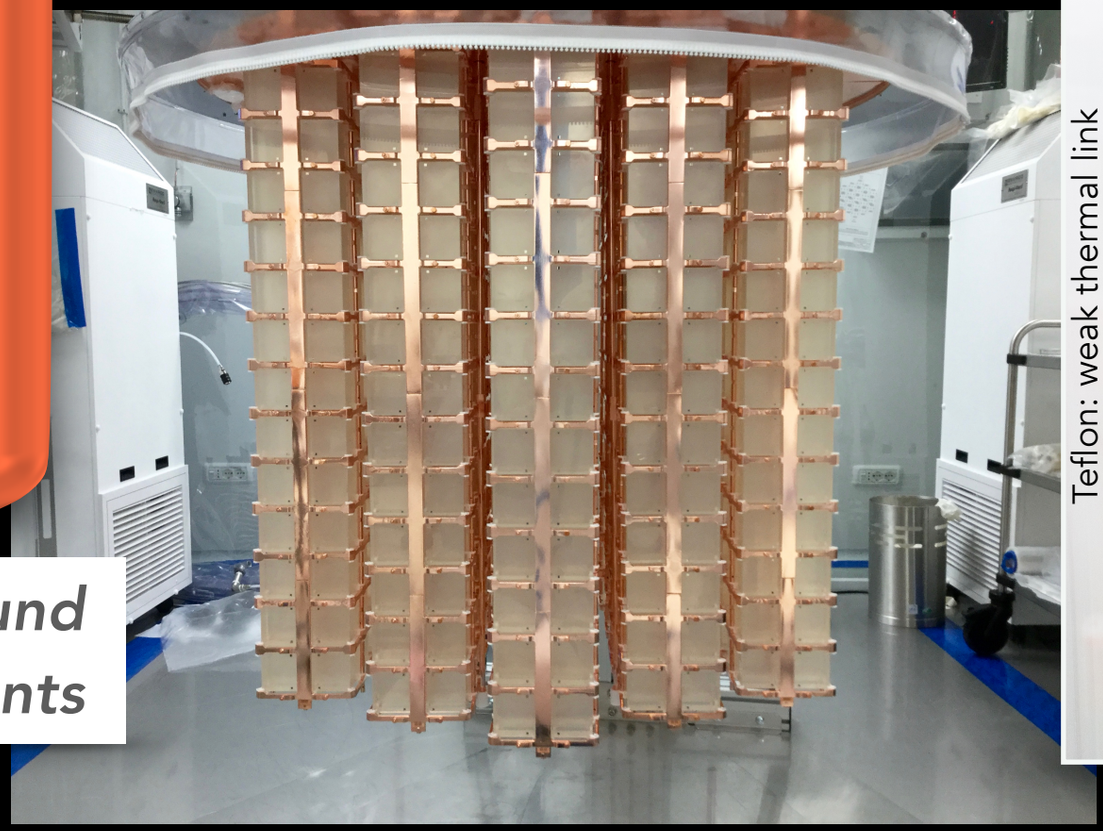


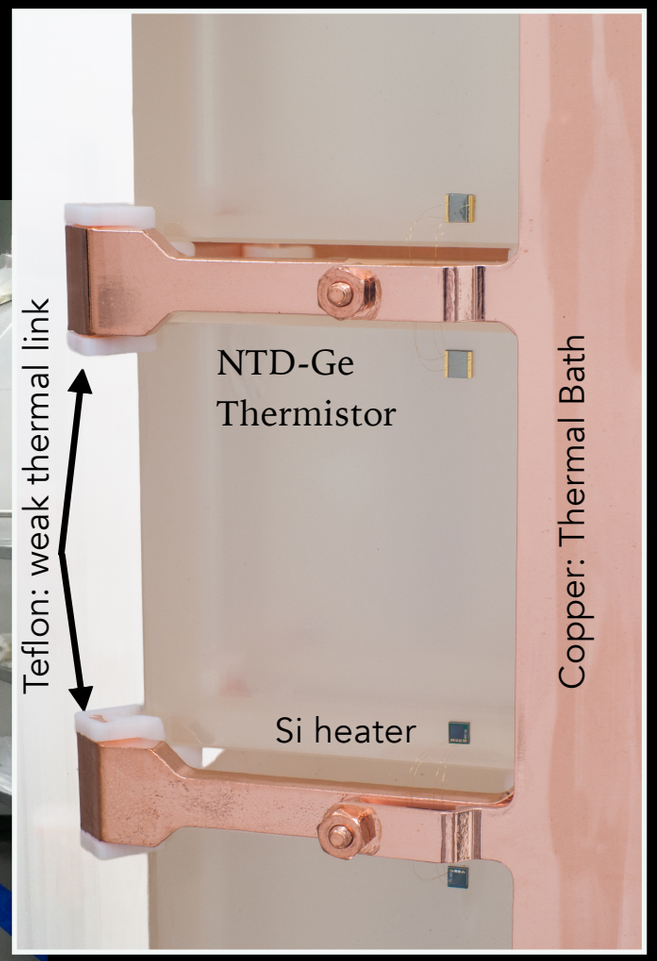
***The Cryogenic Underground Observatory for Rare Events***





- 988 $TeO_2$ crystals (arranged in 19 towers with 13 floors each)
- Isotopic mass of $^{130}Te$ : 206 kg
- Massive thermal calorimeters operated at ~10 mK
- Goal:
  - $\triangle E_{FWHM} \leq 5$ keV @ 2615 keV
  - B = 0.010 cnts/(keV·kg·yr)
  - $T_{1/2}$ (90% C.L.) > 9 x $10^{25}$ y
    5 yrs of live time ;
    Effective Majorana neutrino mass $\langle m_{\beta\beta} \rangle$ ~ 45 - 210 meV.






***The Cryogenic Underground Observatory for Rare Events***

# Goals

988 $TeO_2$ crystals
(arranged in 19 towers with 13 floors each)

Massive thermal calorimeters
operated at ~10 mK

$\triangle E_{FWHM} \leq 5$ keV @ 2615 keV

B = 0.010 cnts/(keV·kg·yr)

$T_{1/2}$ (90% C.L.) > 9 x $10^{25}$ y
5 yrs of live time ;
Effective Majorana neutrino mass
$\langle m_{\beta\beta} \rangle$ ~ 45 - 210 meV.

# Constraints

} Mechanical stability:
Cryostat should support tonnes of mass
(detector + vessels + internal shielding)

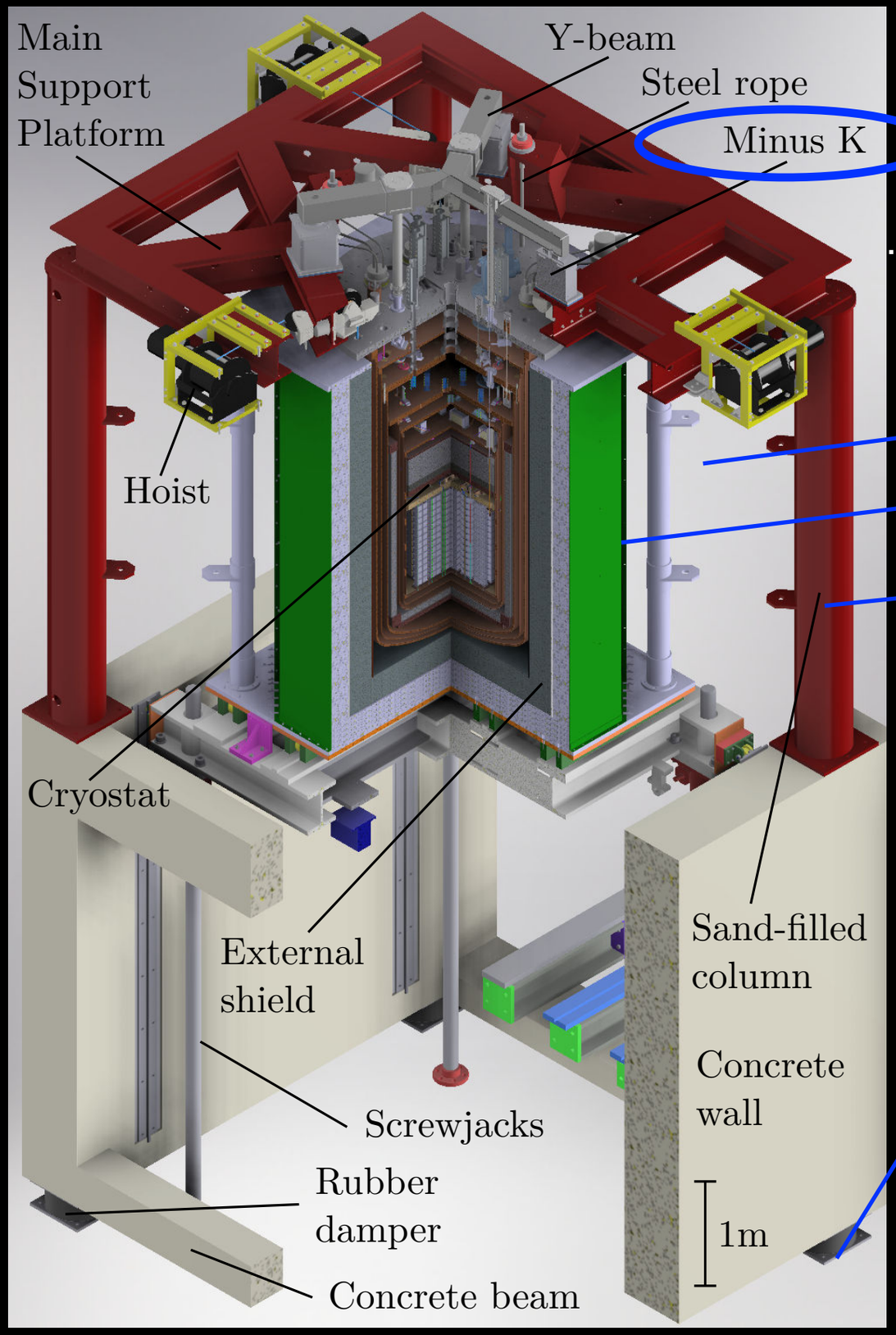
} Temperature stability:
Base temperature below 10 mK

} Minimize vibrational and electrical noise

} Stringent radio-purity criteria on materials
used for cryostat construction

} Long livetime

# CRYOSTAT SUPPORT STRUCTURES




Detectors on three Minus-K® vibration isolator.
Cutoff frequency of 0.5 Hz

2nd Floor level

Clean room access for detector installation

External lead shield lifted on screw-jacks

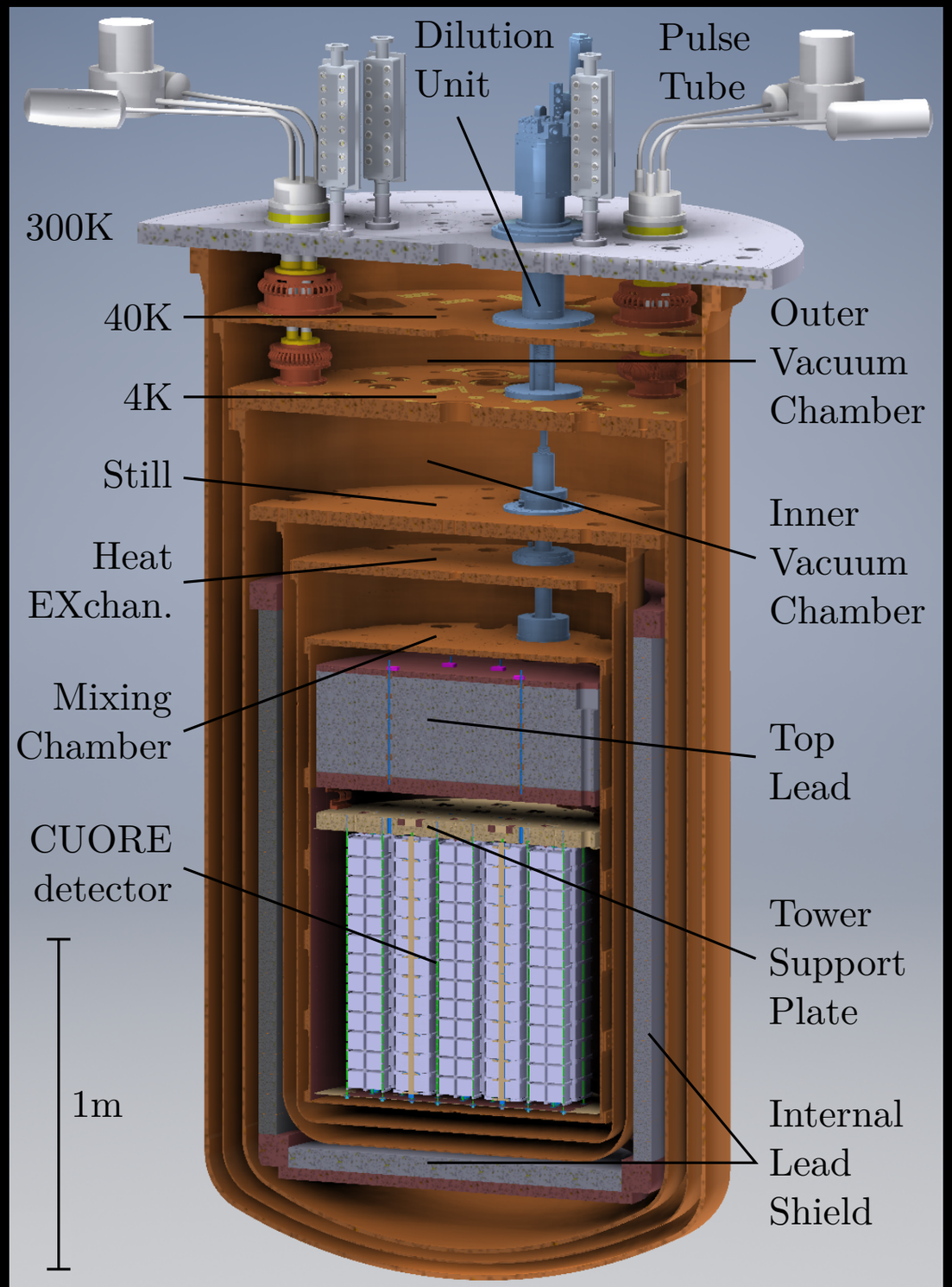
Column filled with sand to reduce resonance

1st Floor level

Rubber dampers for seismic isolation

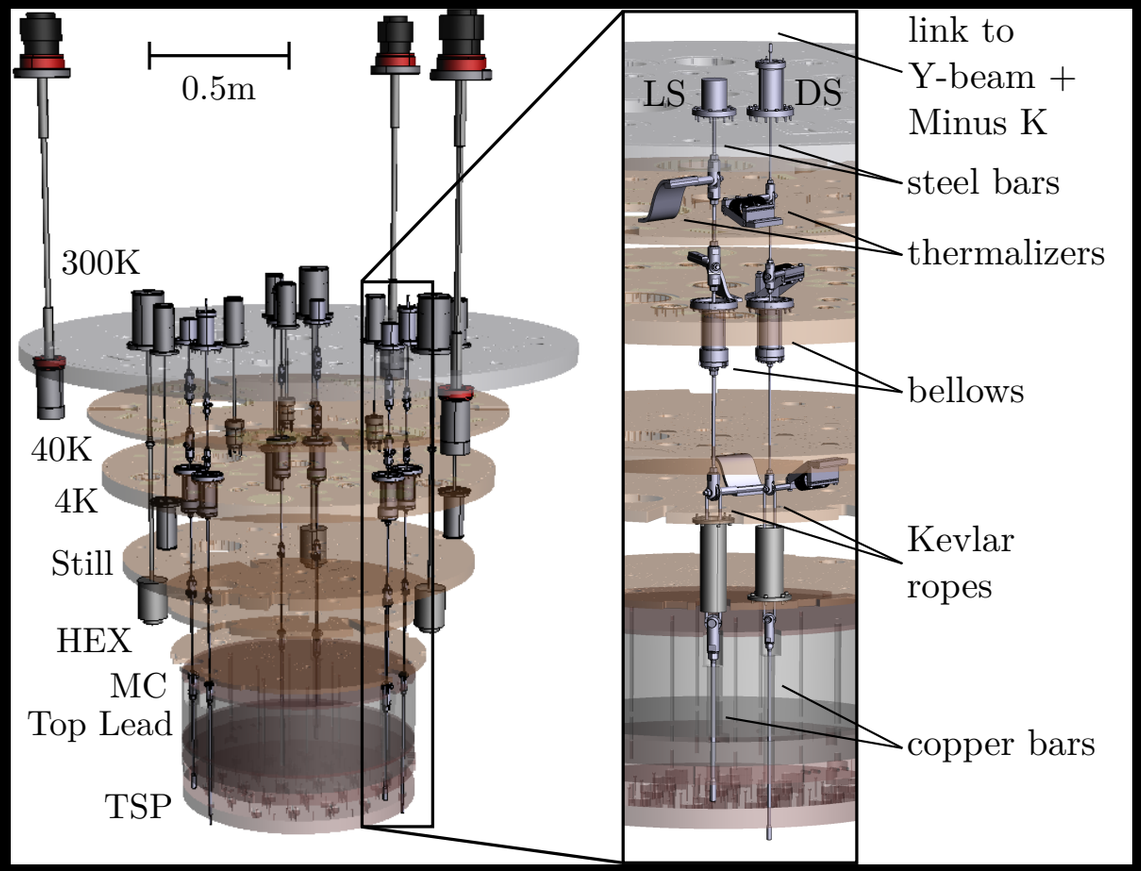
- Cryostat suspended from Main Support Platform
- Can withstand the strongest of earthquakes (peak-ground-acceleration< 0.26 g)

# CRYOSTAT



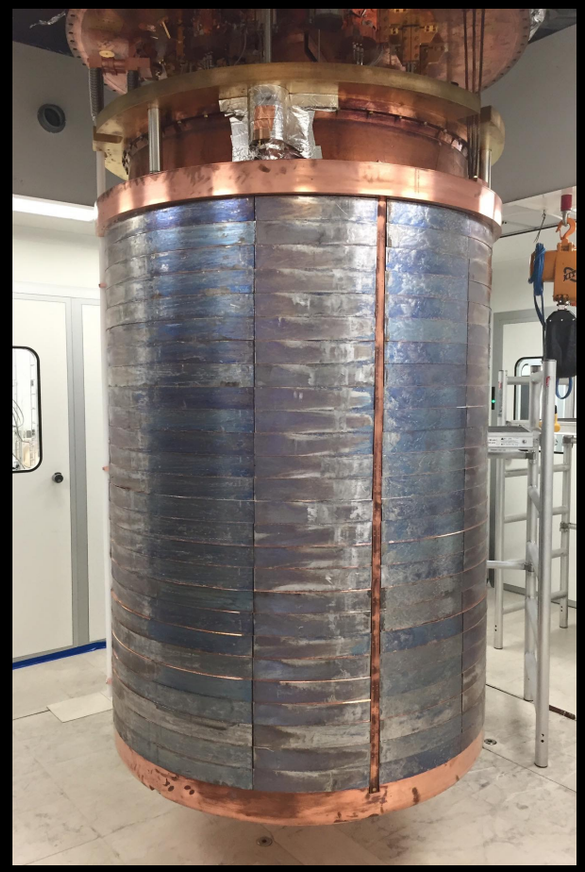

- 6 nested vessels
  - 300K (SS/Cu OFE)
  - 40 K @ PT 1st stage (Cu OFE)
  - 4 K @ PT 2nd stage (Cu OFE)
  - Still @ 800 mK (Cu OFE)
  - HEX @ 50 mK (Cu OFE)
  - MC @ 10 mK (Cu NOSV)
- 2 vacuum chambers
  - OVC (3.5 $m^3$)
  - IVC (2.5 $m^3$)
- 2 internal lead shields
  - Top Lead @ 50 mK (2.5 tonnes)
  - Lateral+bottom @ 4K (5.5 tonnes)
- Cooling systems
  - Pulse Tubes (PT)
  - Dilution Unit (DU)
- All the copper parts @ 10 mK fabricated with NOSV-Cu
  - Selected for radiopurity, RRR, $H_2$ content
- Cu freshly made
- All welding performed with electron beam

# INTERNAL SHIELDING

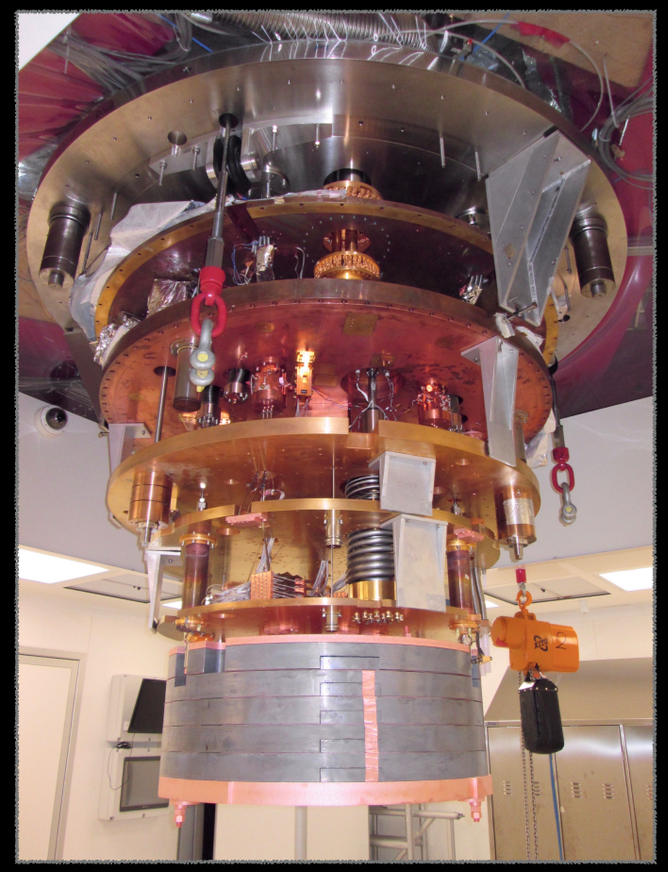



Total mass cooled ~ 14 tons

Mass cooled below 4K ~ 13 tons

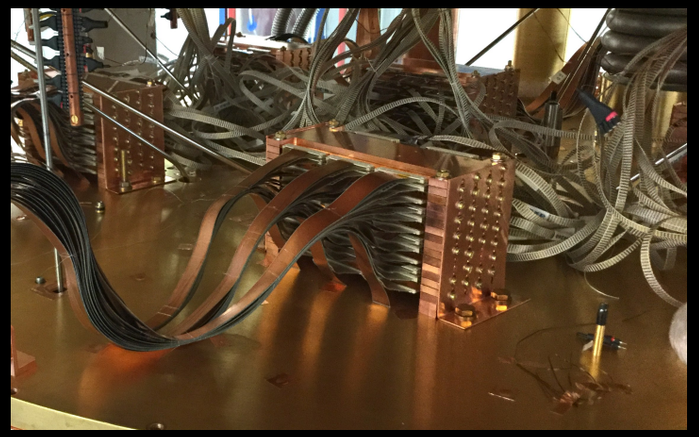


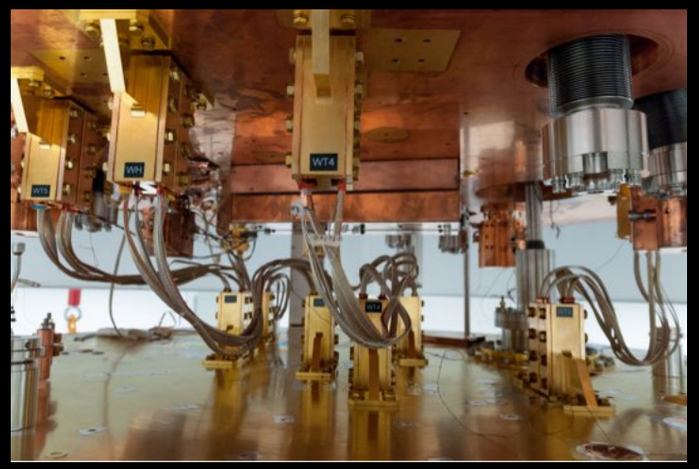
6 cm Roman Pb Shield
(5 tons@4K)

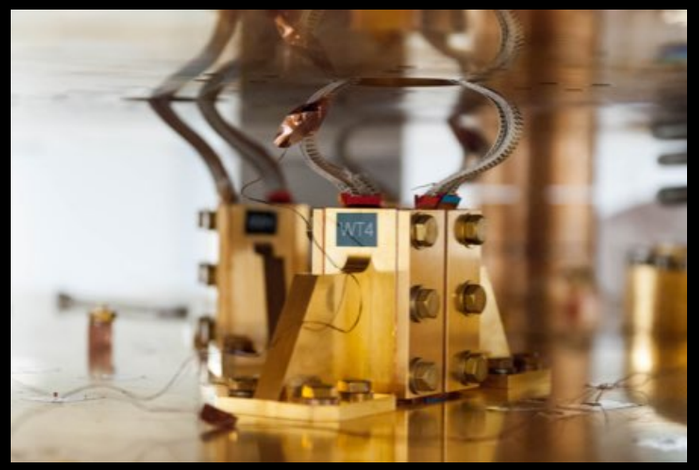


30 cm of Pb Top Shield
(2.5 tons@50 mK)

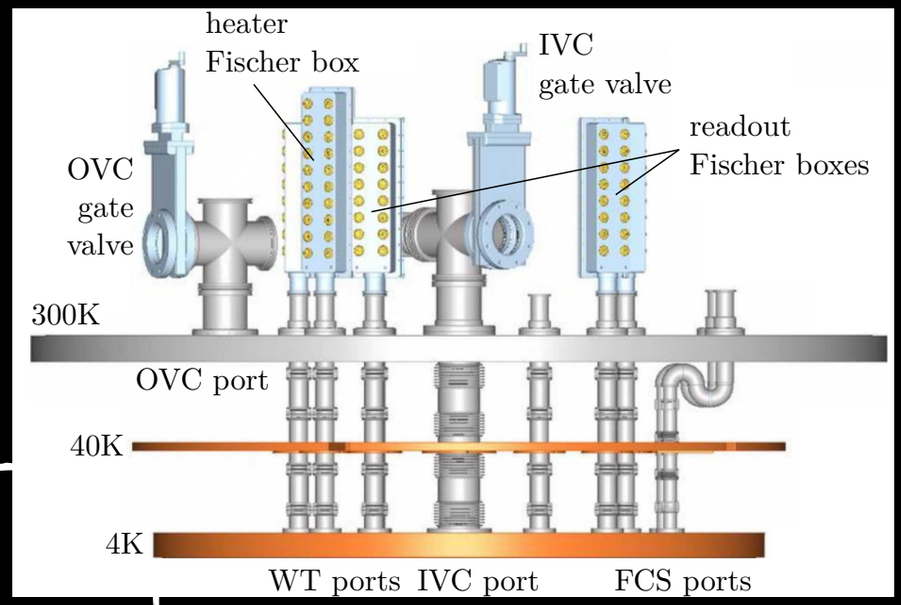
# SIGNAL READOUT WIRING

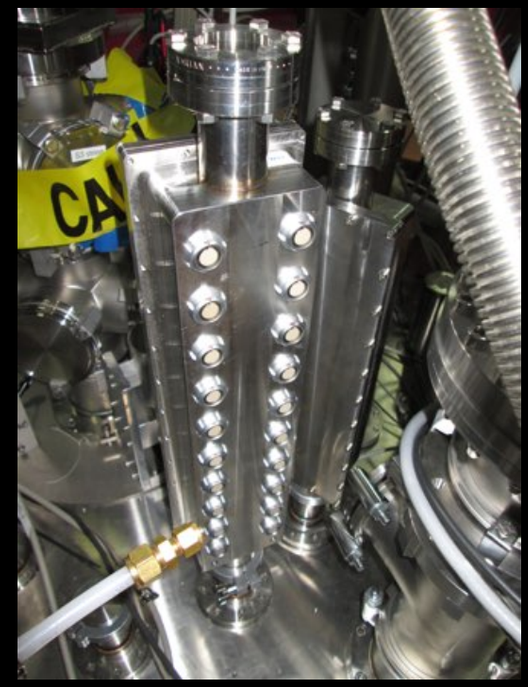






- From Mixing Chamber to the detector
  - 152 Cu-PEN tapes (2.3 meters long, 80 μm thick), with a pattern of etched copper tracks
- 2600 wires from 300 K to Mixing Chamber
  - 100 woven ribbon cables (~ 2.5 meters long) with 13 twisted pairs of NbTi wires (100 μm diameter), CuNi coating (5 μm thickness) and a NOMEX texture
  - thermalized at every stage of the cryostat



*Fischer connectors at top of the cryostat at room temperature.*

# CRYOSTAT CLOSURE

*10 mK*

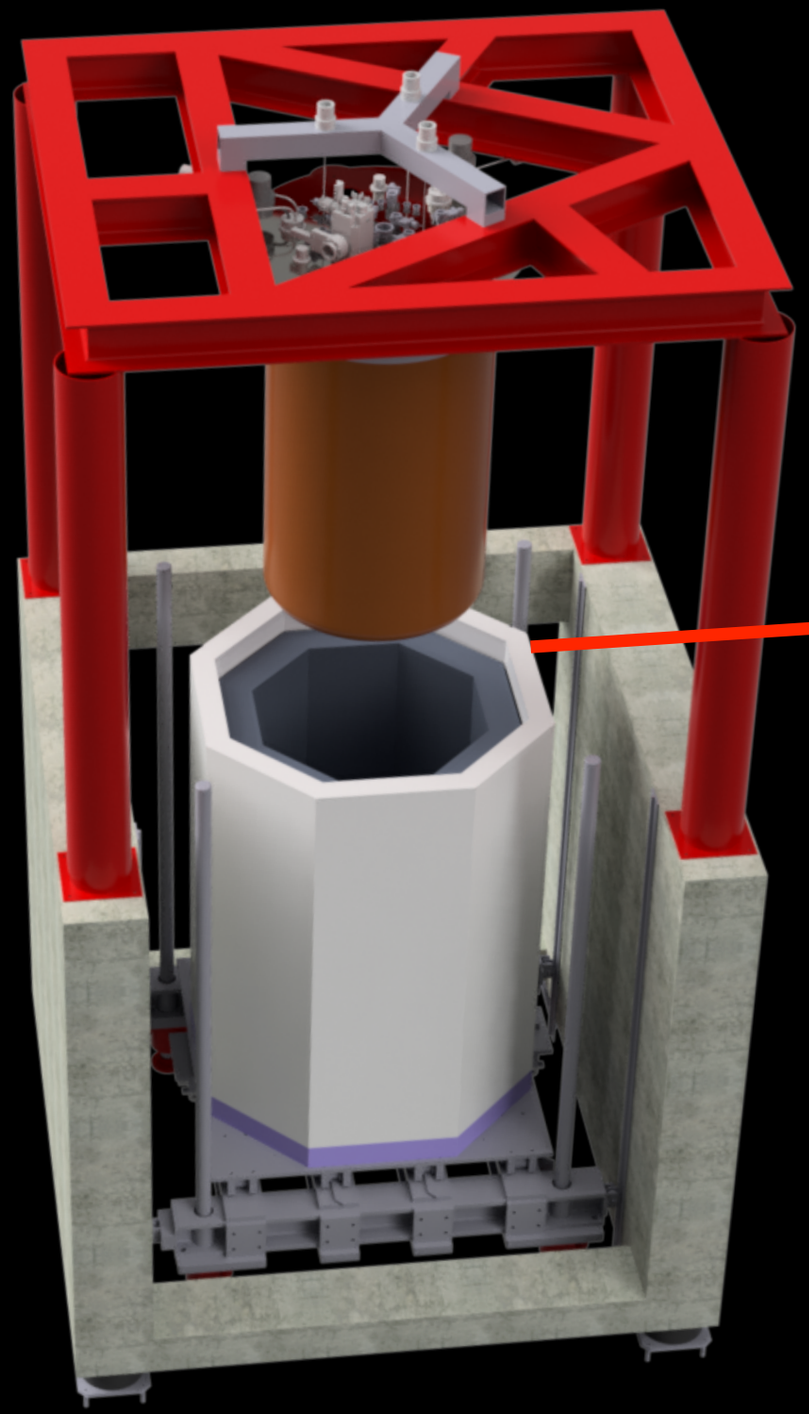
*Roman Lead*

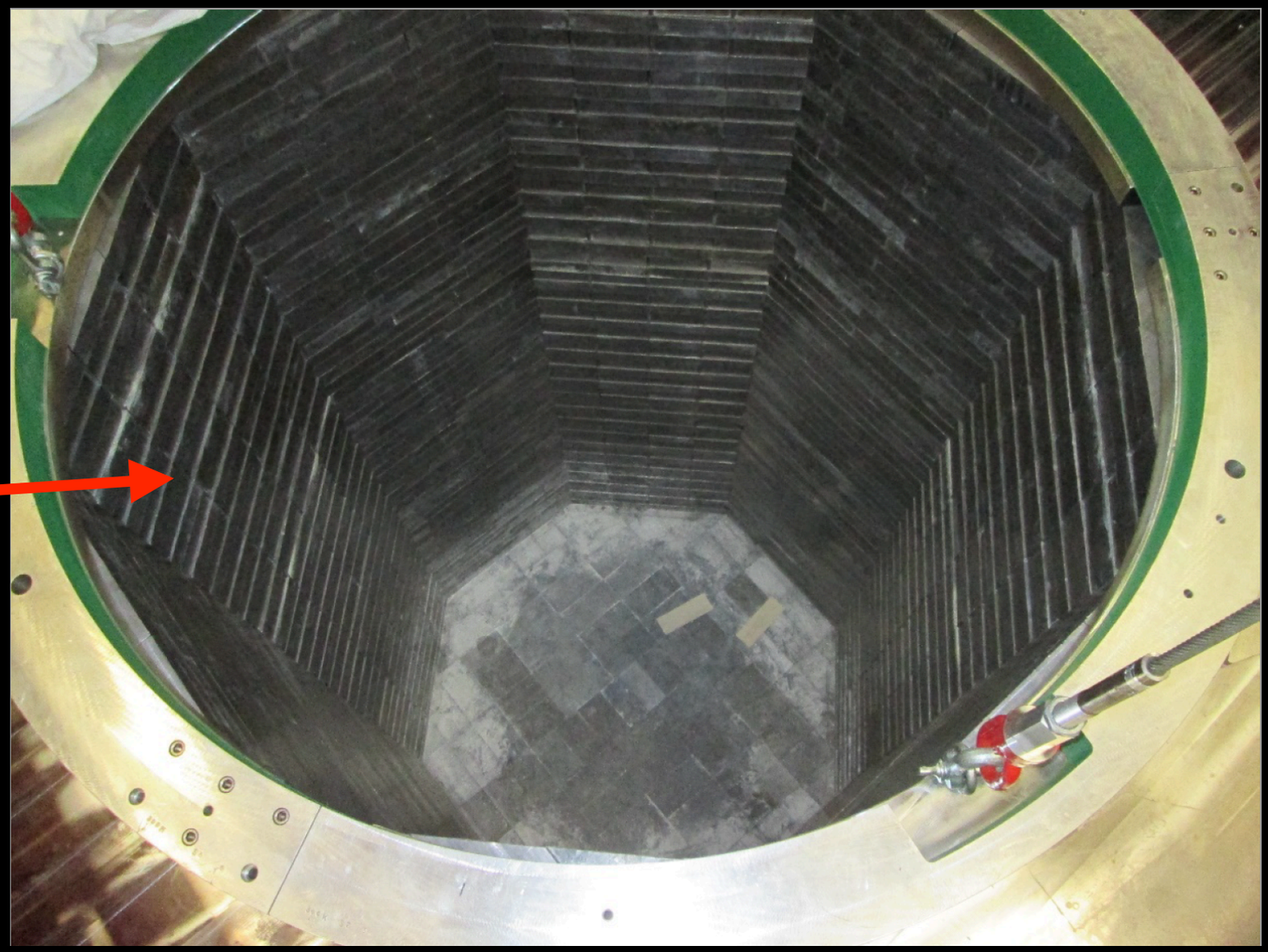
*300 K*

*Still*

*4K with super insulation*

# EXTERNAL SHIELDING



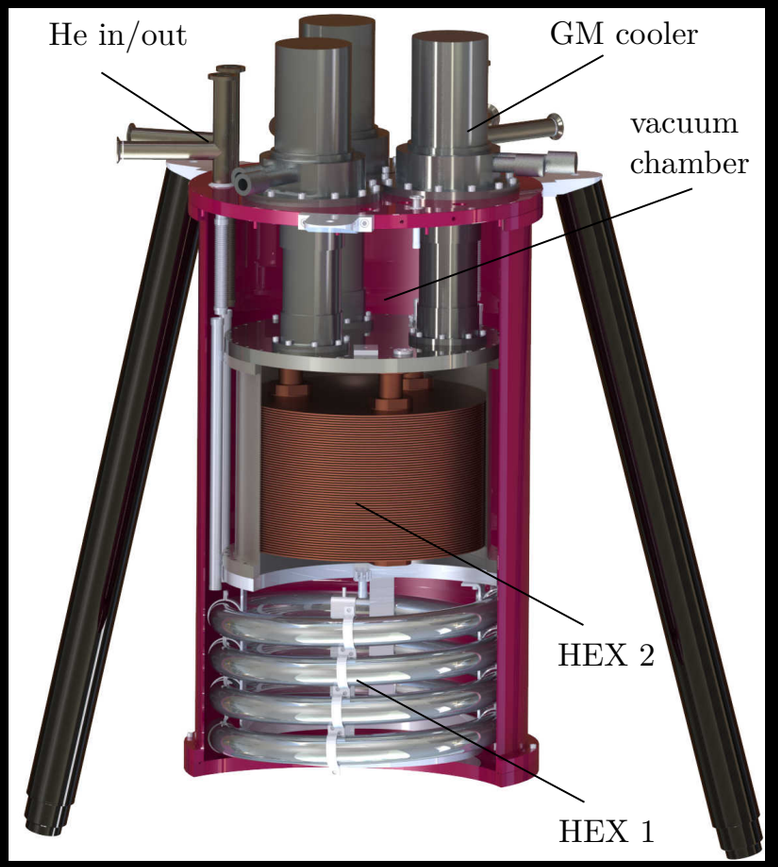


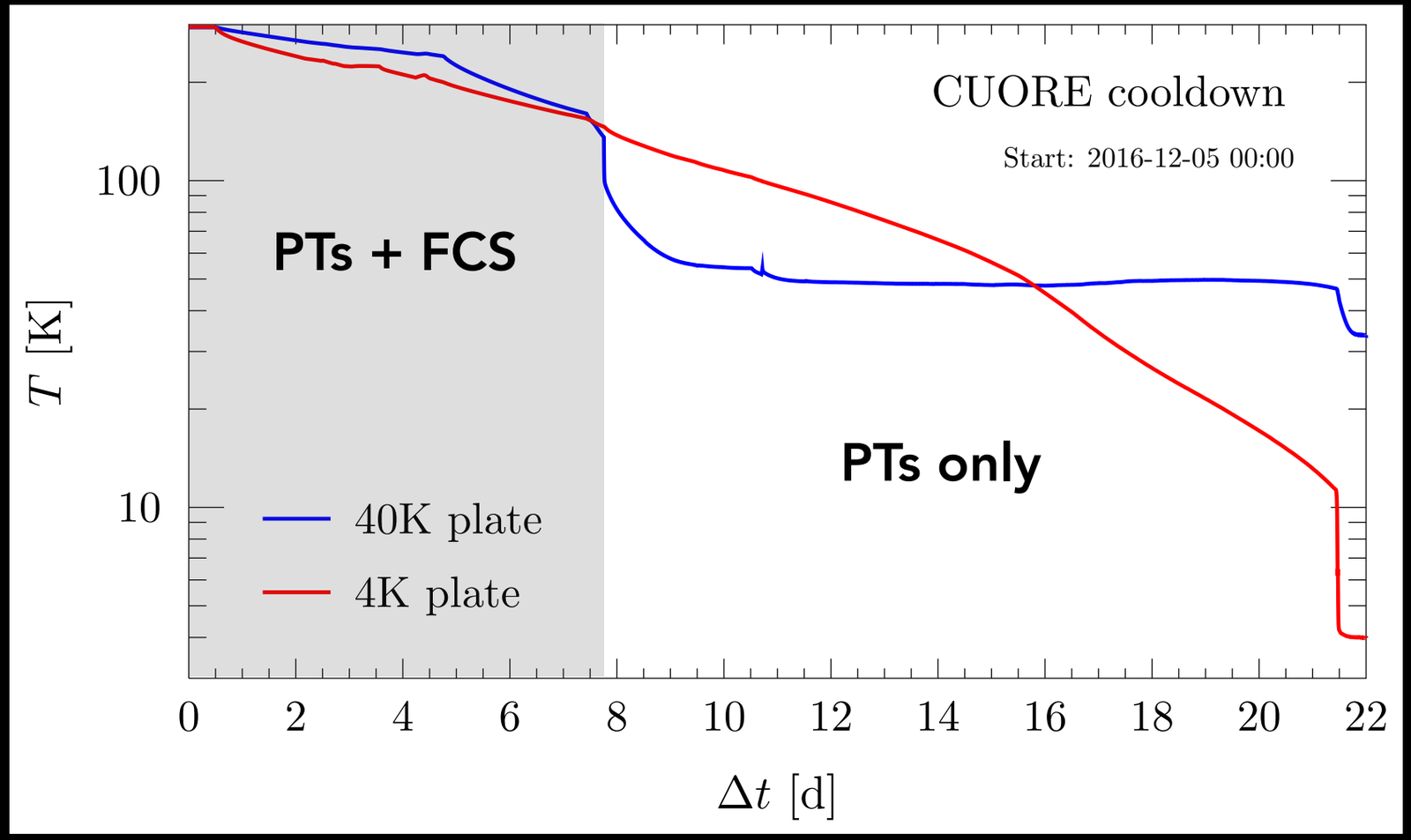
External lead: 25 cm thick

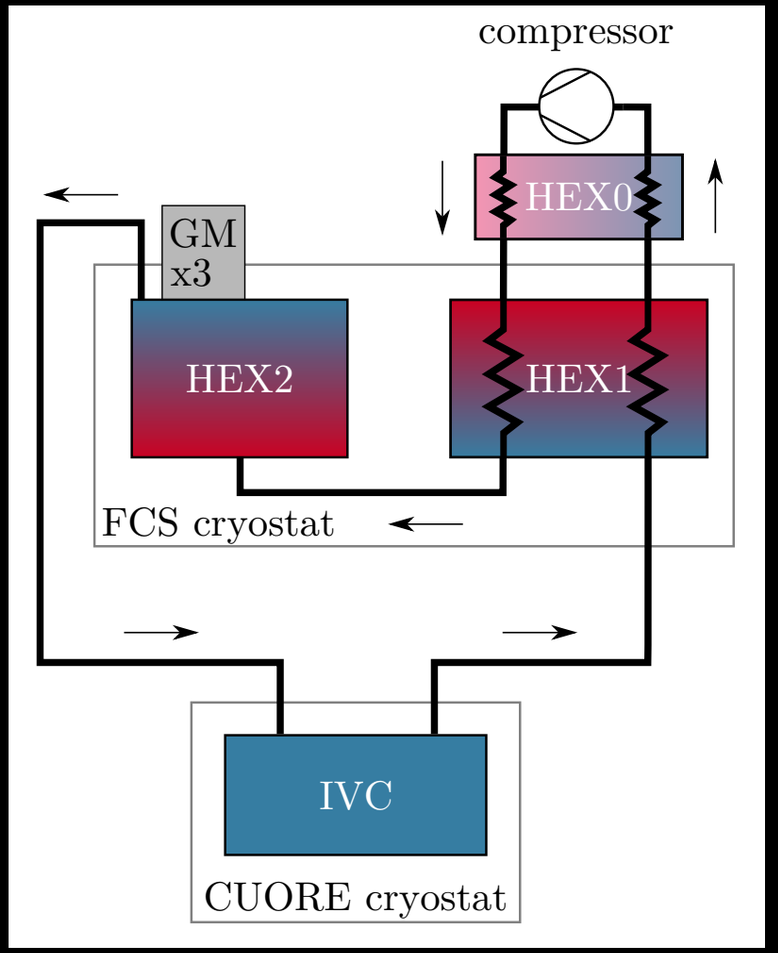
Neutron shield: 20 cm borated polyethylene

# FAST COOLING SYSTEM

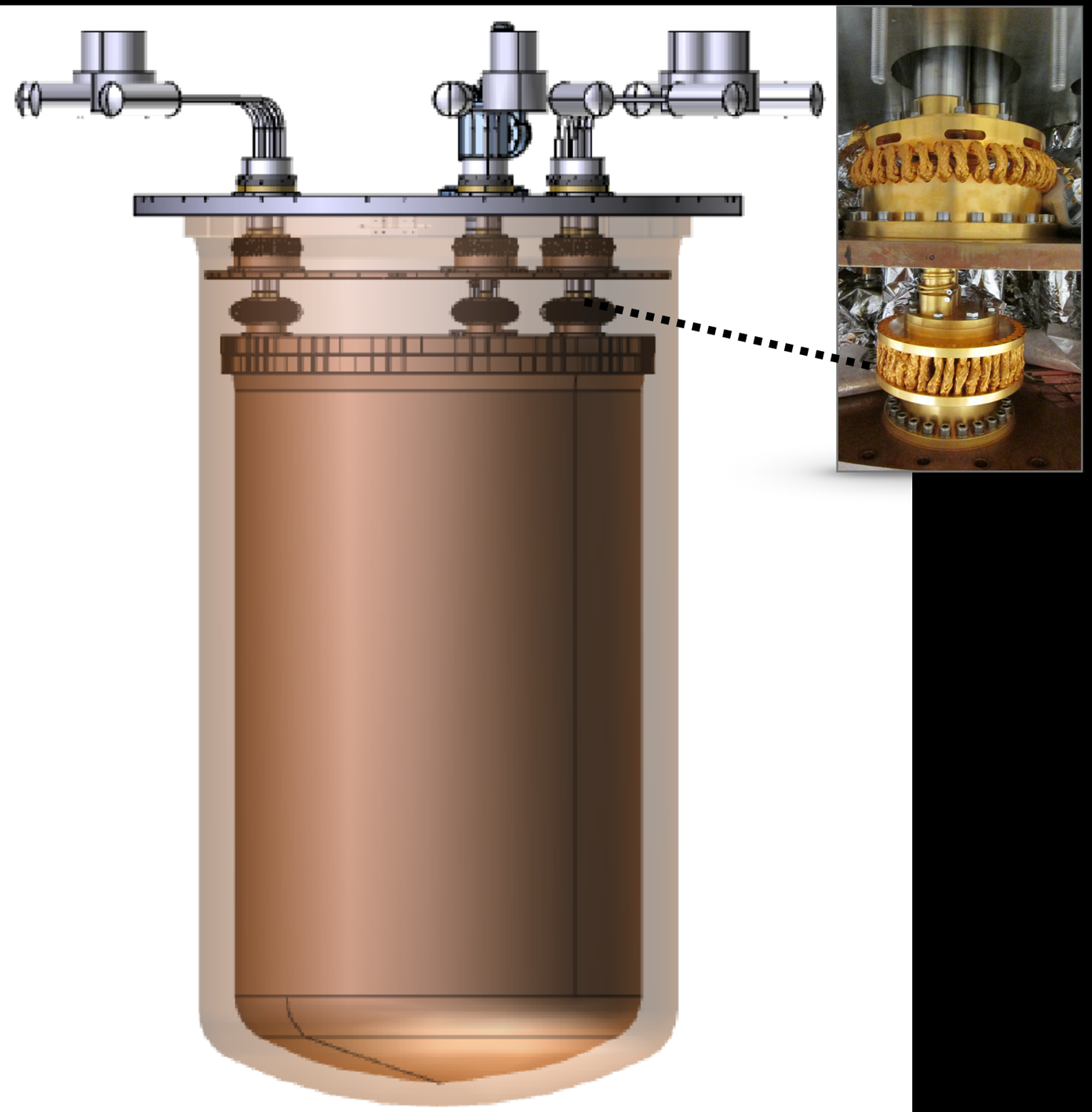
- Between 300 K and 40 K, the cooling system must remove ~ 7 Giga-Joules of enthalpy.
- This is over 95% of the total enthalpy of the system.
- FCS circulates cold He has through a dedicated circuit that uses 3 GM cryocoolers from Cryomech.



# PULSE TUBE COOLERS (CONTINUOUS COOLING AT 4K)

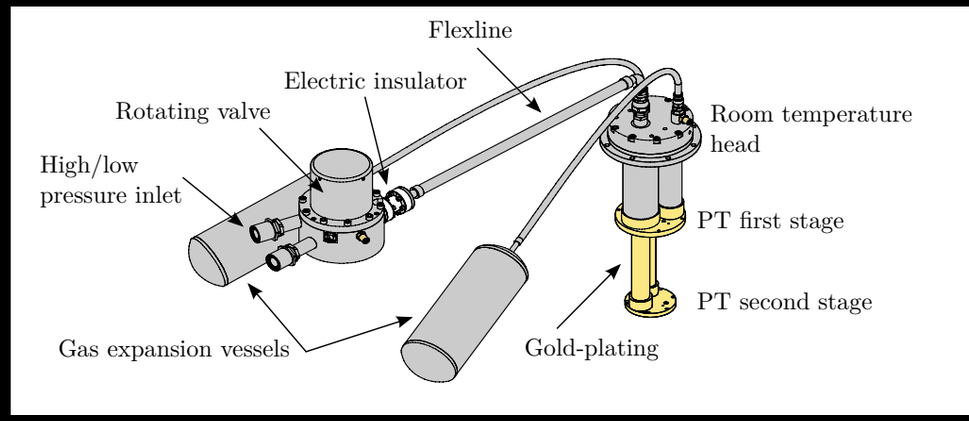


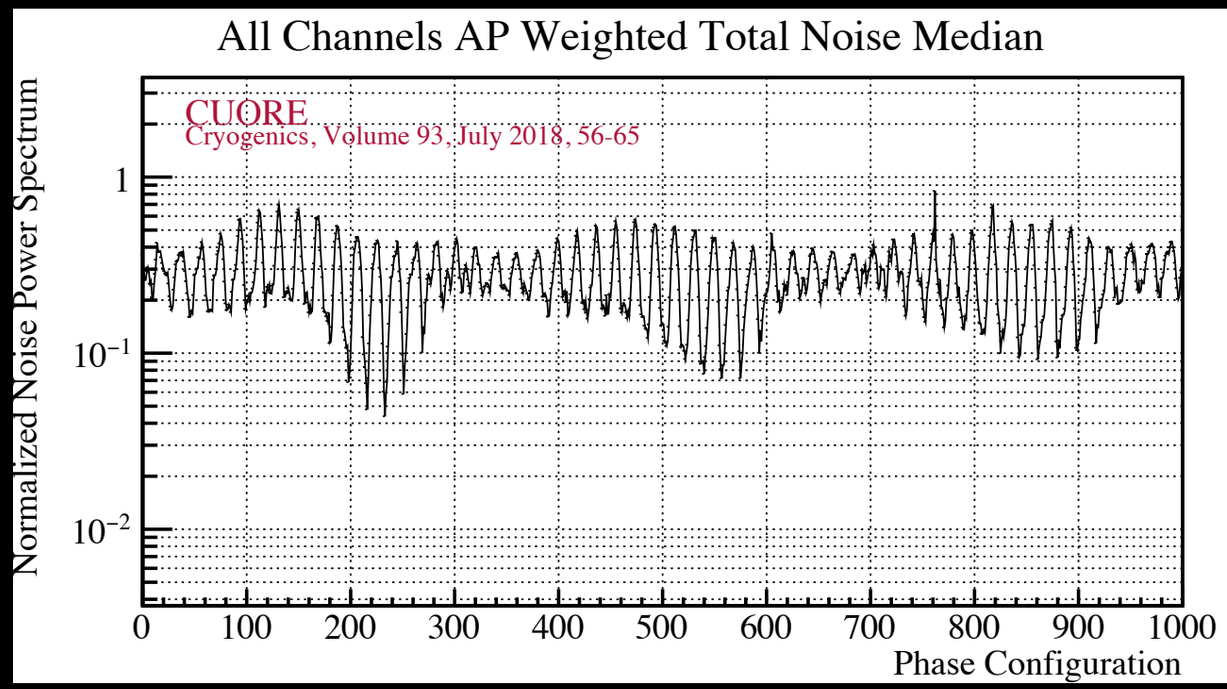


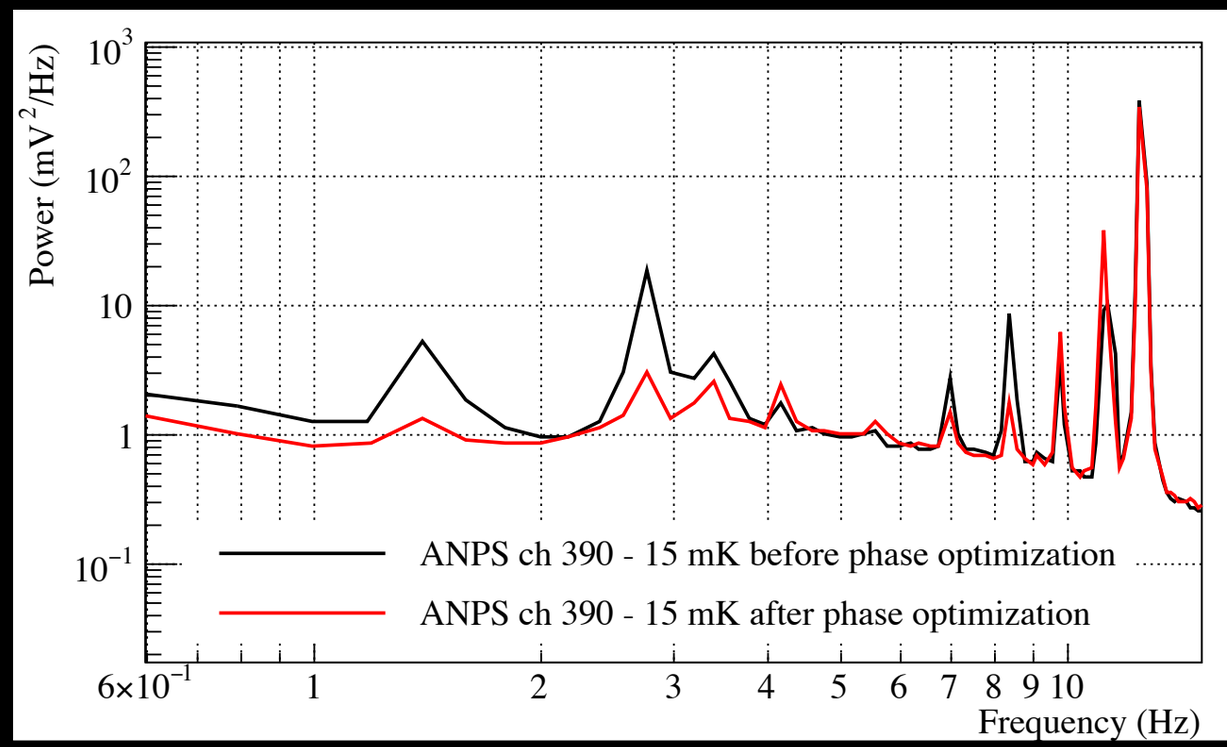
- 5 Cryomech PT415 with remote motor option
- 1.2 W @ 4.2K and 32 W @ 40K
- 3 PTs strictly needed for the operation
  + 2 PTs for redundancy
- 2 PTs have a condensing line of the DU soldered between the 1st and 2nd stage
- Custom thermalizations to the plates realized with high RRR copper
- Sliding seal on the 300 K plate to compensate for thermal expansion

# OPTIMIZATION OF PT PHASES

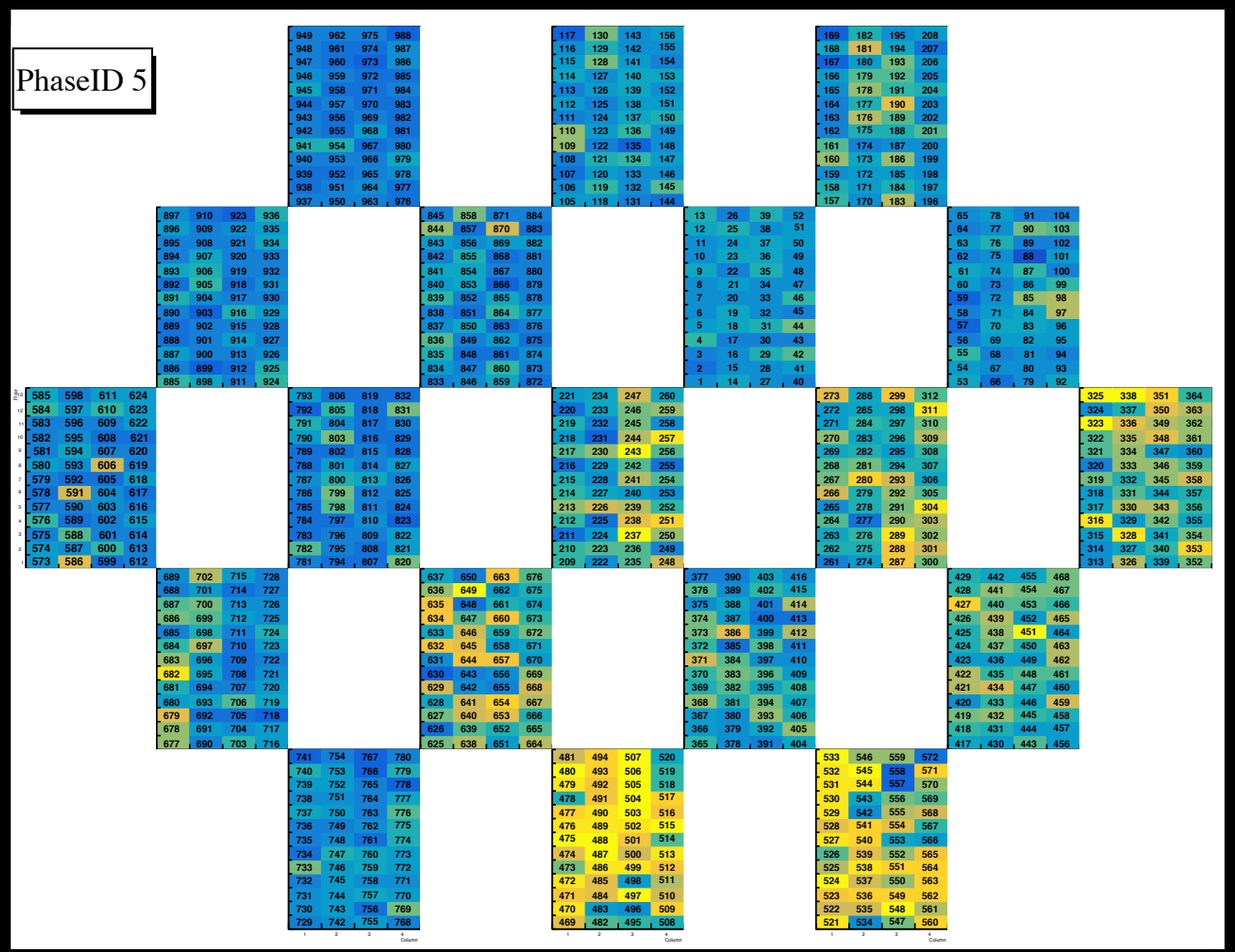
- Signal bandwidth of CUORE includes 1.4 Hz
- Passive vibration dampening is implemented
  - Suspended rotary valves, soft bellows, Cu braids
- Active vibration dampening possible
  - Relative phases of PT rotary valves measured
  - Discretize space of all possible relative phases into distinct phase configurations and scan
  - Tune relative phase of vibrations to cause maximal destructive interference

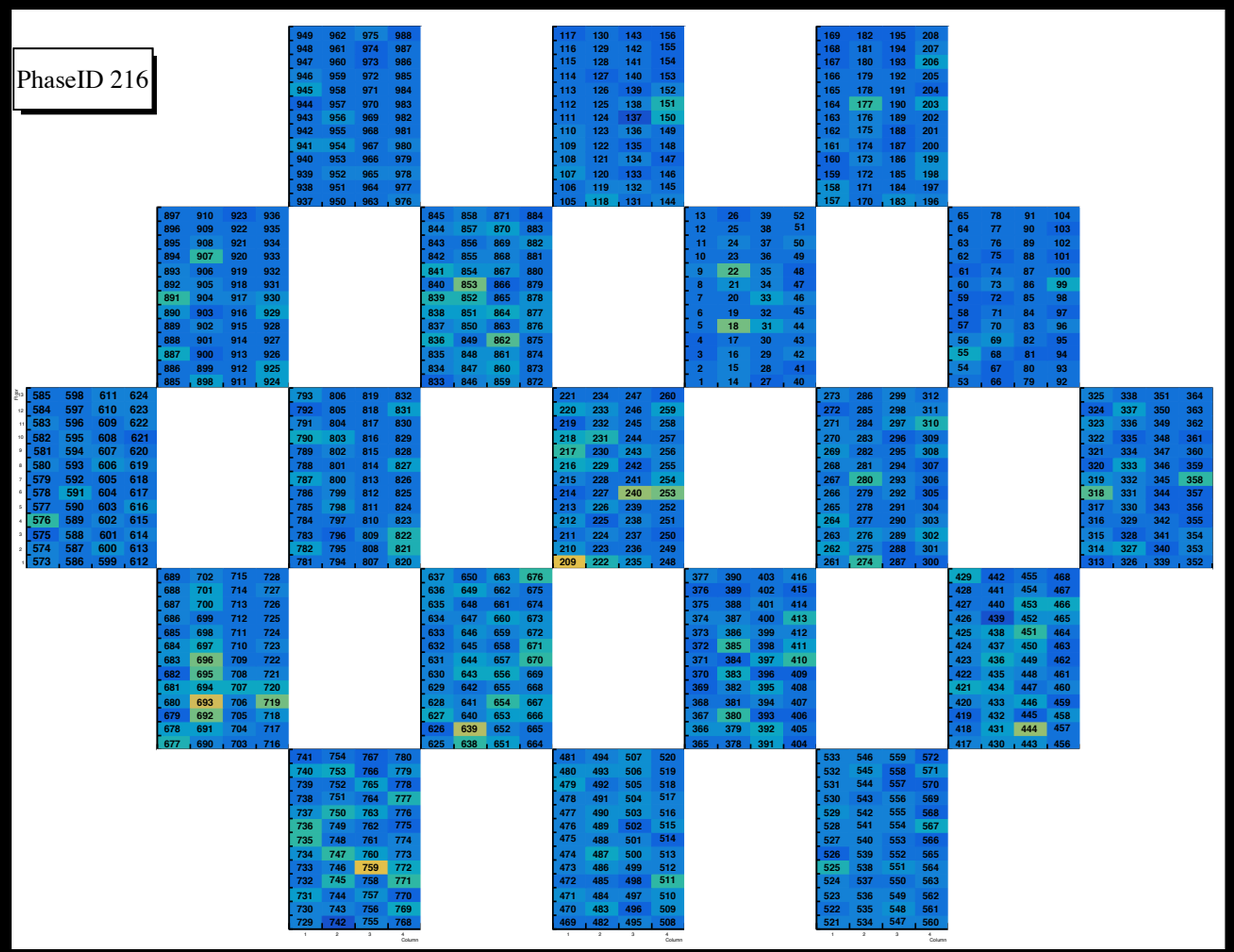


# PT PHASE ID

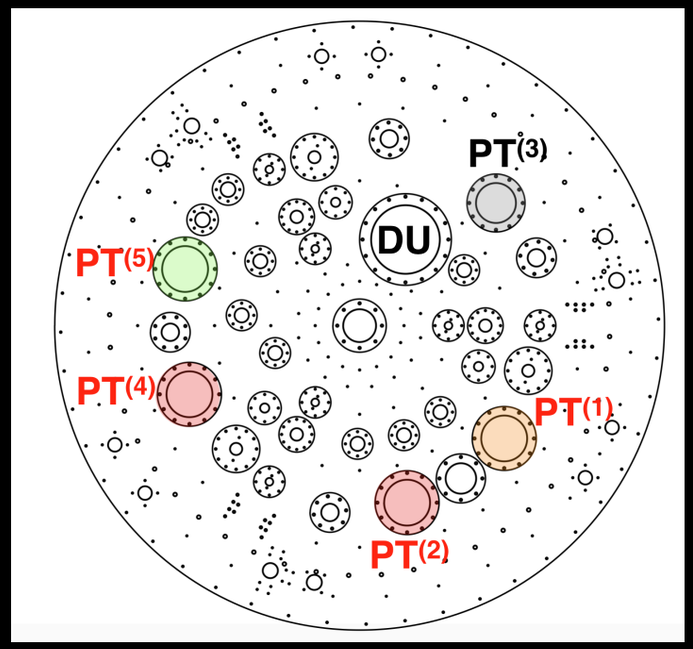


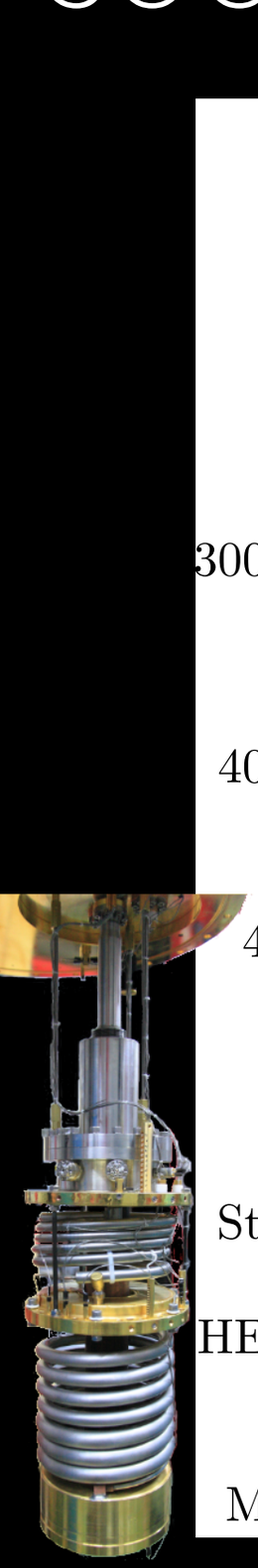

Different phase configurations excite different parts of detector

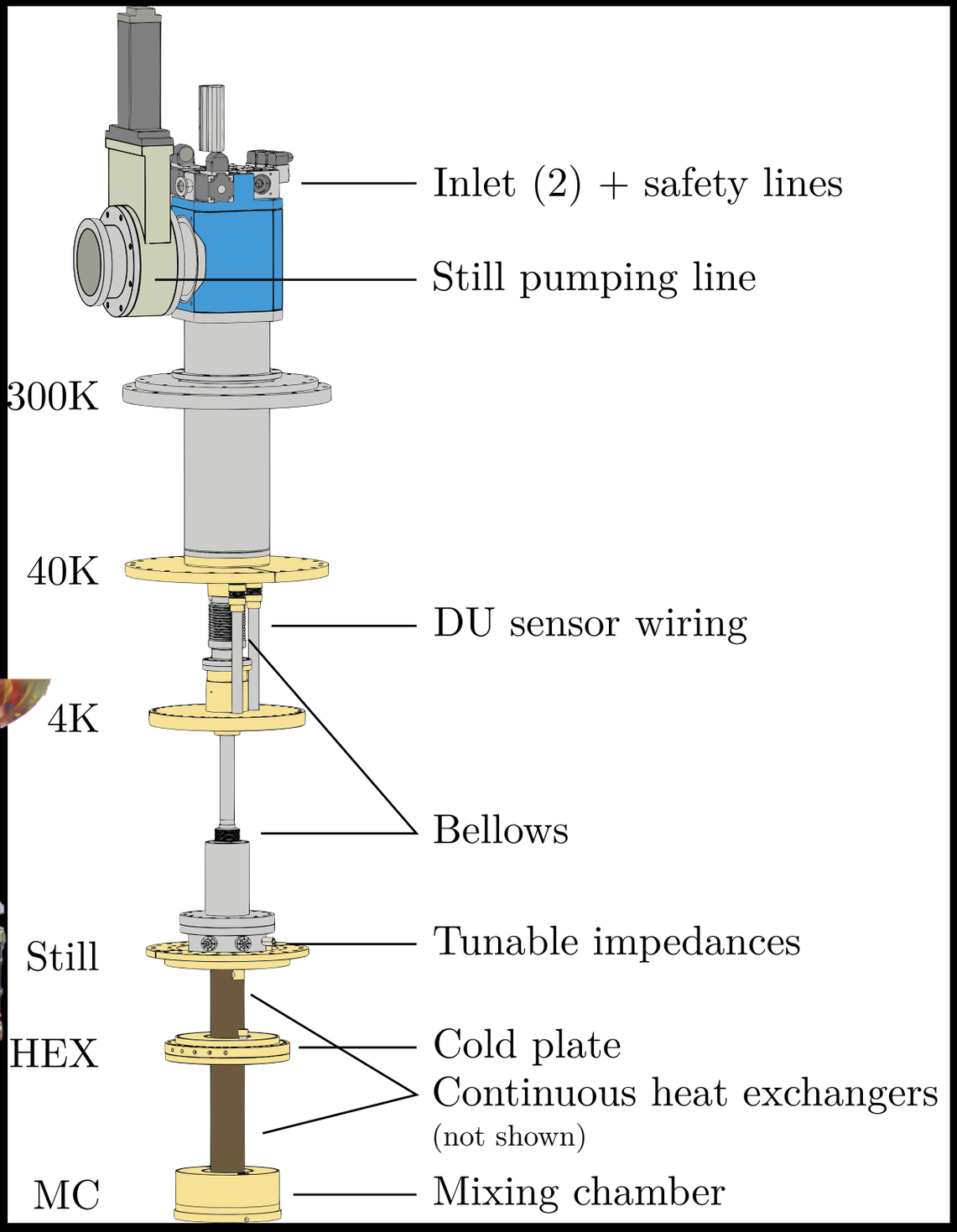
***Poster: The CUORE pulse tubes noise cancellation technique***

***Valentina Dompe, 23rd July 2019, 5:45 PM***

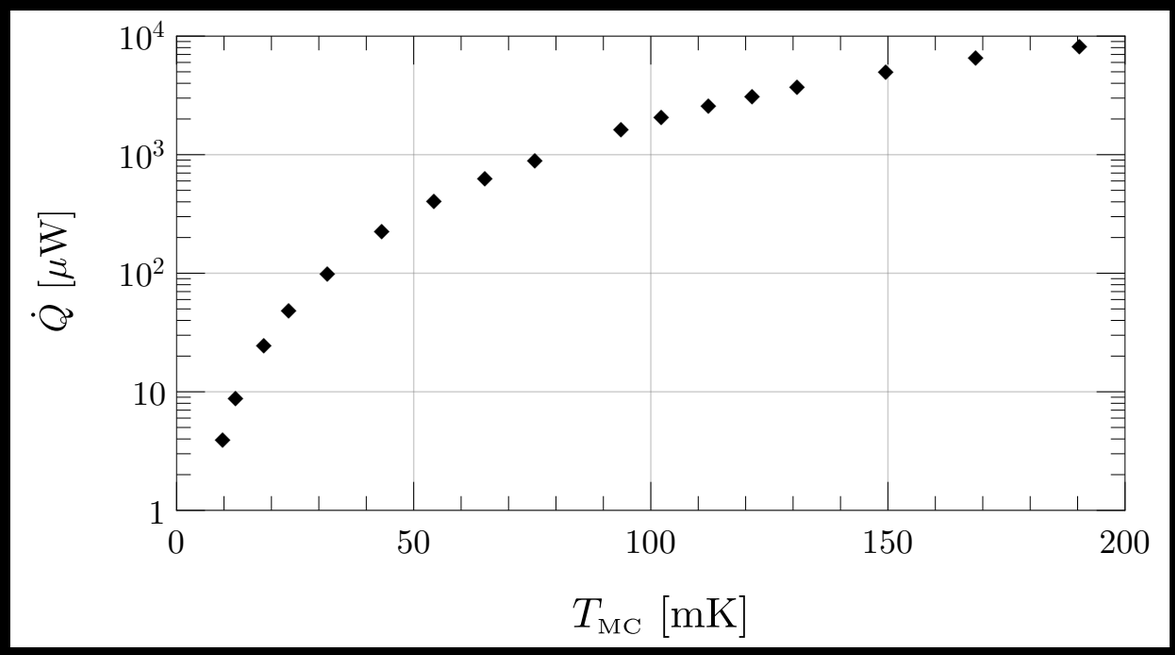


# DILUTION UNIT (CONTINUOUS COOLING AT BASE TEMPERATURE)



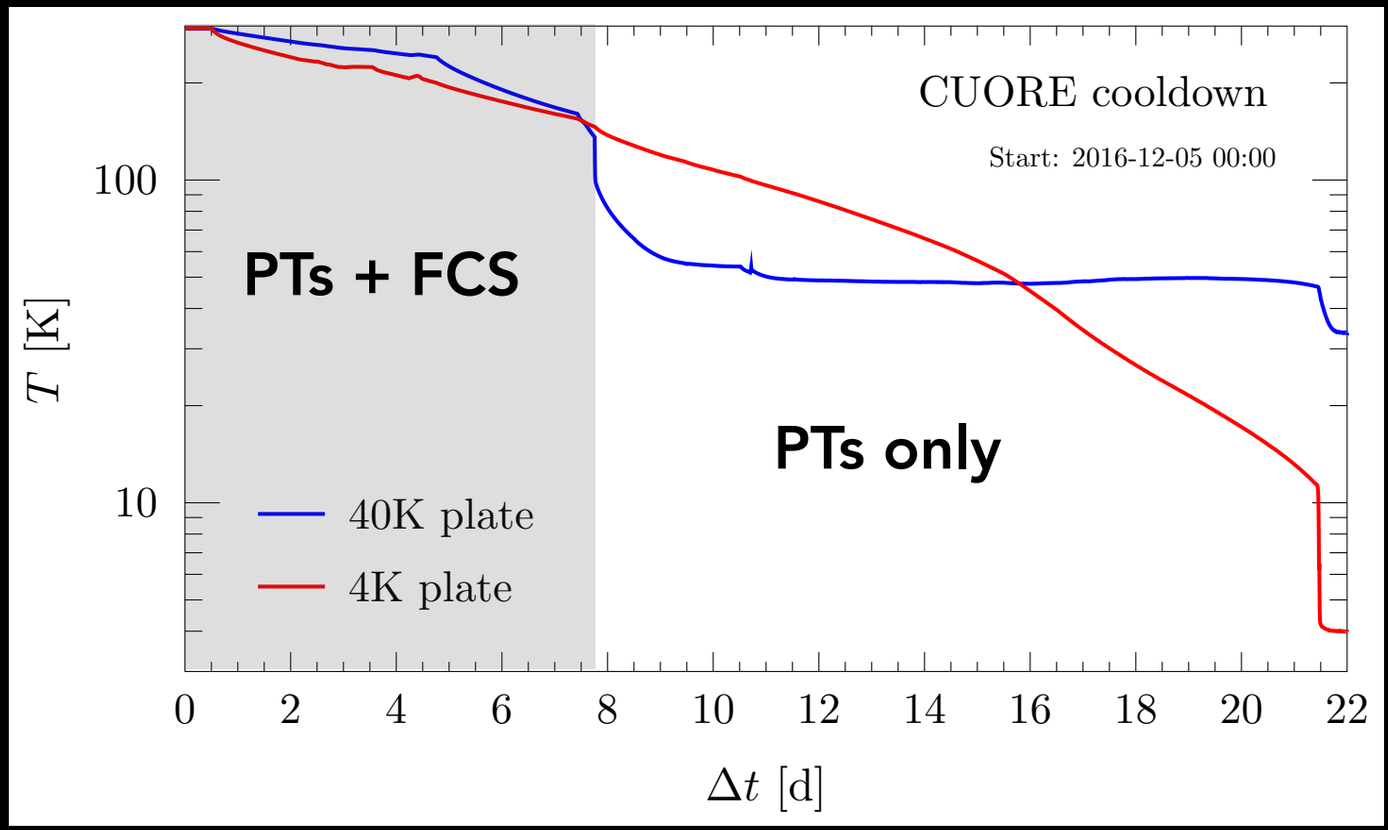


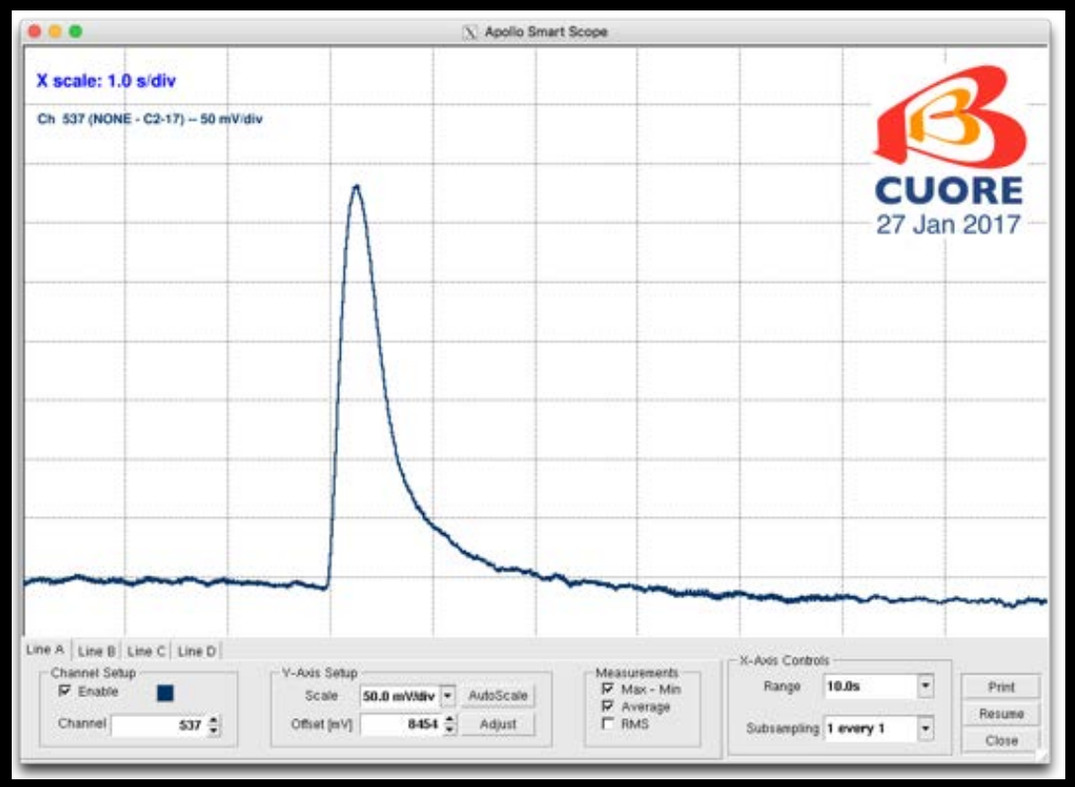

- Custom built DU by Leiden Cryogenics
- Cooling power:
  - > 4 μW @ 10 mK;
  - >1.5 mW @ 120 mK
- Cryogen-free DU with the largest cooling power ever built!

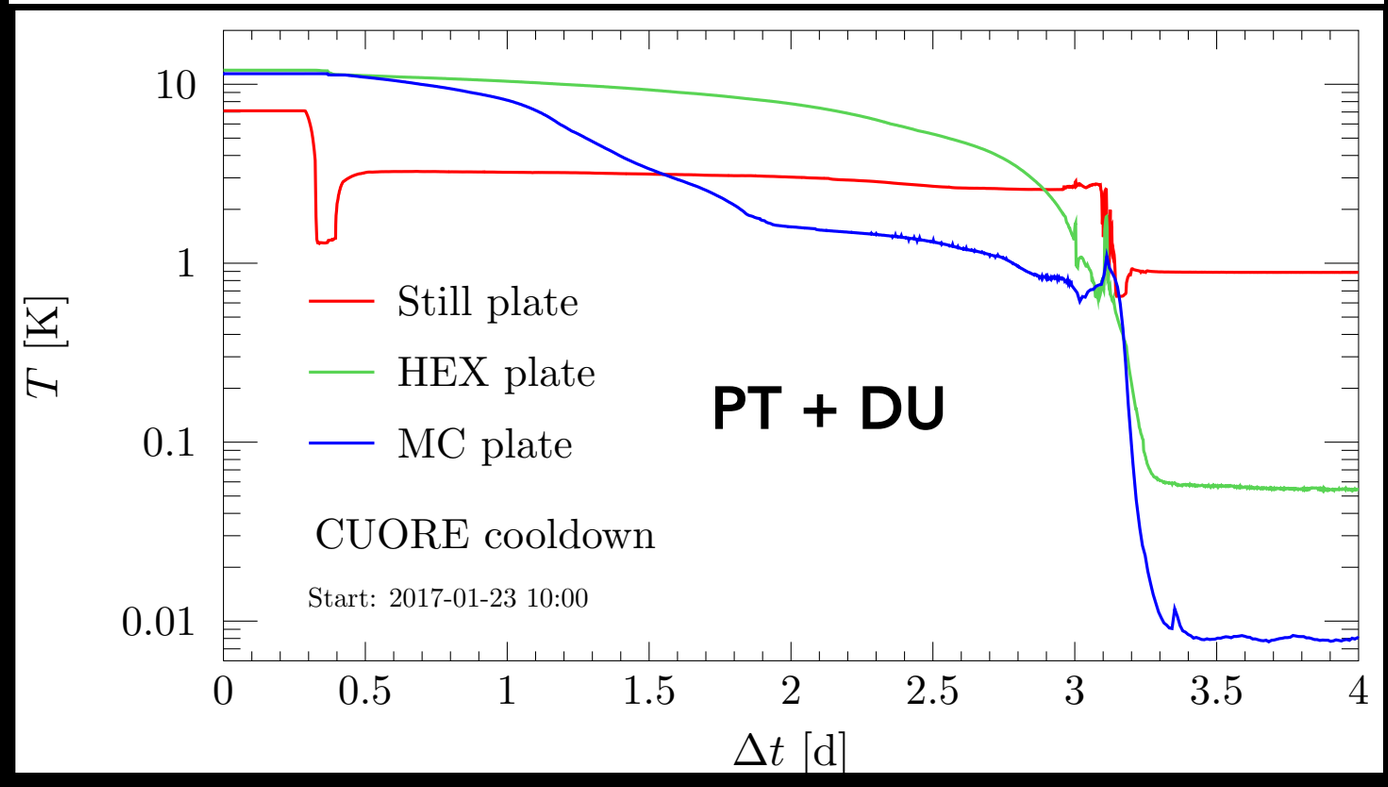


# CUORE COOLDOWN

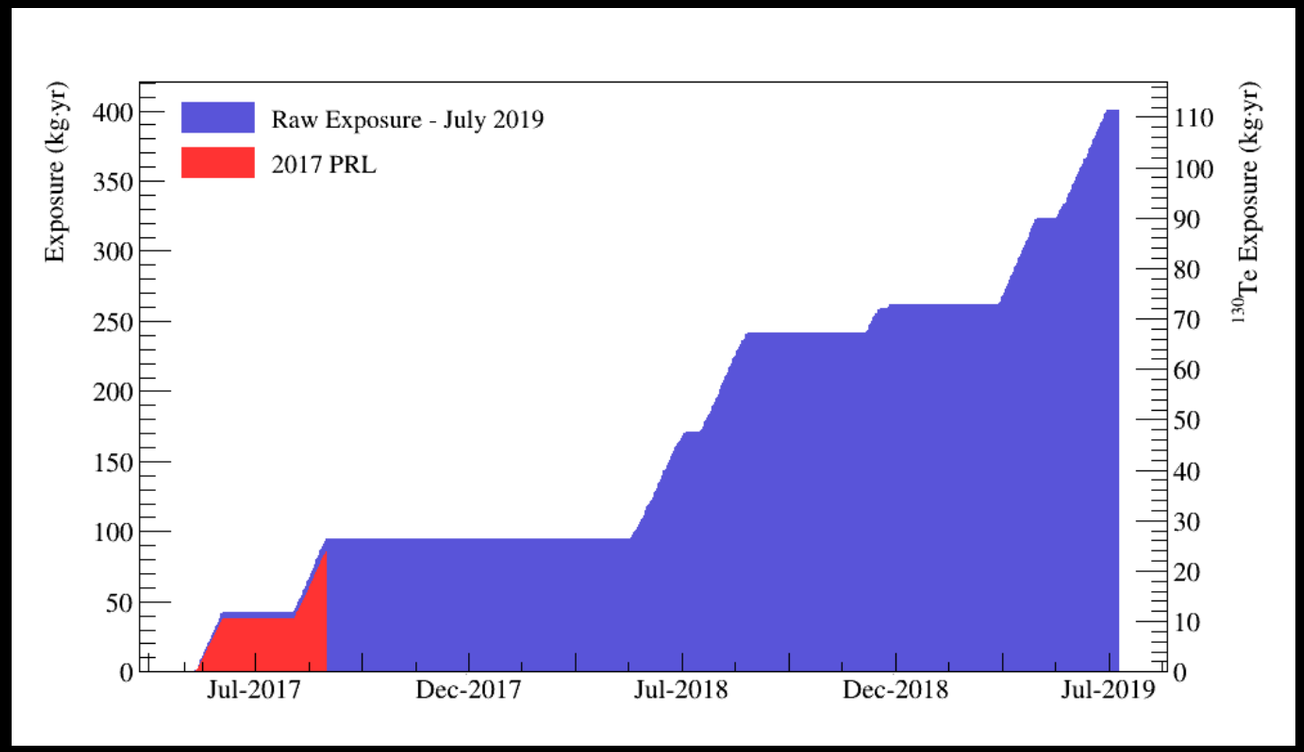
- Dec 2016: Cooldown to 4K: 22 days
- Jan 2017: cooldown to base: 3 days
- Lowest temperature reached: 6.7 mK
- First detector pulses: Jan 27, 2017

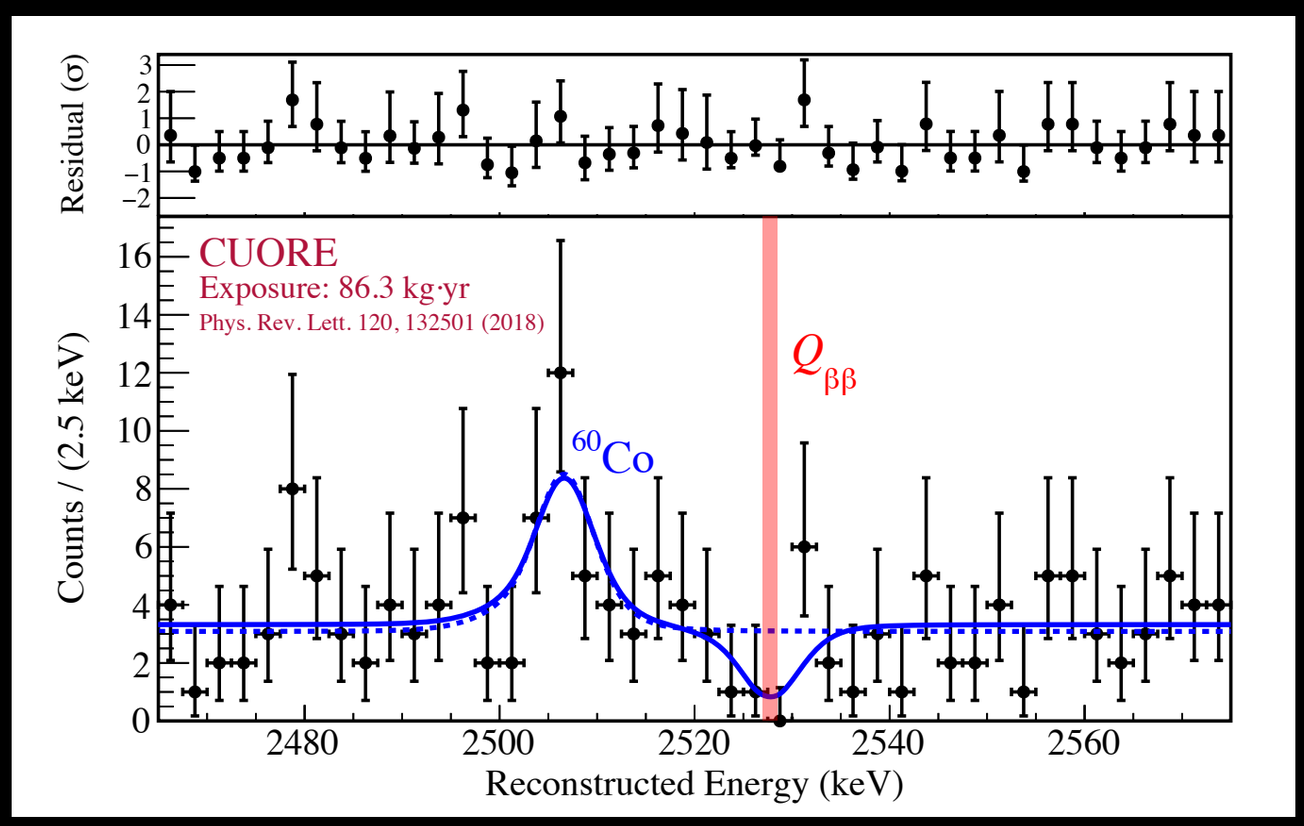


# STATUS




Currently taking data.
Upcoming physics results at TAUP 2019.

Limits combining CUORE with CUORE-0 and Cuoricino:

- Bayesian limit @ 90% c.i. (flat prior for $\Gamma_{\beta\beta}>0$):
  **$T_{1/2} > 1.5 \times 10^{25}$ yr**
- Profile likelihood ("frequentist") limit @ 90% CL:
  **$T_{1/2} > 2.2 \times 10^{25}$ yr**

- *Talk: The CUORE detector and results.*
  *Irene Nutini, 25th July 2019, 11:15 AM*
- *Poster: Lowering the energy threshold for the CUORE experiment.*
  *Alice Campani, 23rd July 2019, 5:45 PM*
- *Poster: Noise reduction techniques for the CUORE experiment.*
  *Guido Fantini, 23rd July 2019, 5:45 PM*
- *Poster: The CUORE data acquisition system.*
  *Simone Copello, 25th July 2019, 5:45 PM*
- *Poster: The CUORE bolometric detectors: pulse shape analysis of the thermal signals.*
  *Irene Nutini, 25th July 2019, 5:45 PM*

# WHAT NEXT?

- CUORE : a ton scale cryogenic experiment will be able to probe $\langle m_{\beta\beta} \rangle$ ~ 45 - 210 meV
- CUORE → Limited by the surface $\alpha$ background near the detector.
- Natural successor → CUPID, one tonne experiment with particle identification
  - B = 0.1 cnt/ton/y in ROI
  - $\langle m_{\beta\beta} \rangle$ ~ 10 meV discovery sensitivity (covers Inverted Hierarchy)
- Heat + Light channel most favorable technique for particle ID.
- Use CUORE cryostat when CUPID is ready to be deployed.

# THANKS

Yale

INFN

BERKELEY LAB

CAL POLY
SAN LUIS OBISPO

Massachusetts Institute of Technology

VirginiaTech
Invent the Future®

Lawrence Livermore National Laboratory

SAPIENZA
UNIVERSITÀ DI ROMA

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

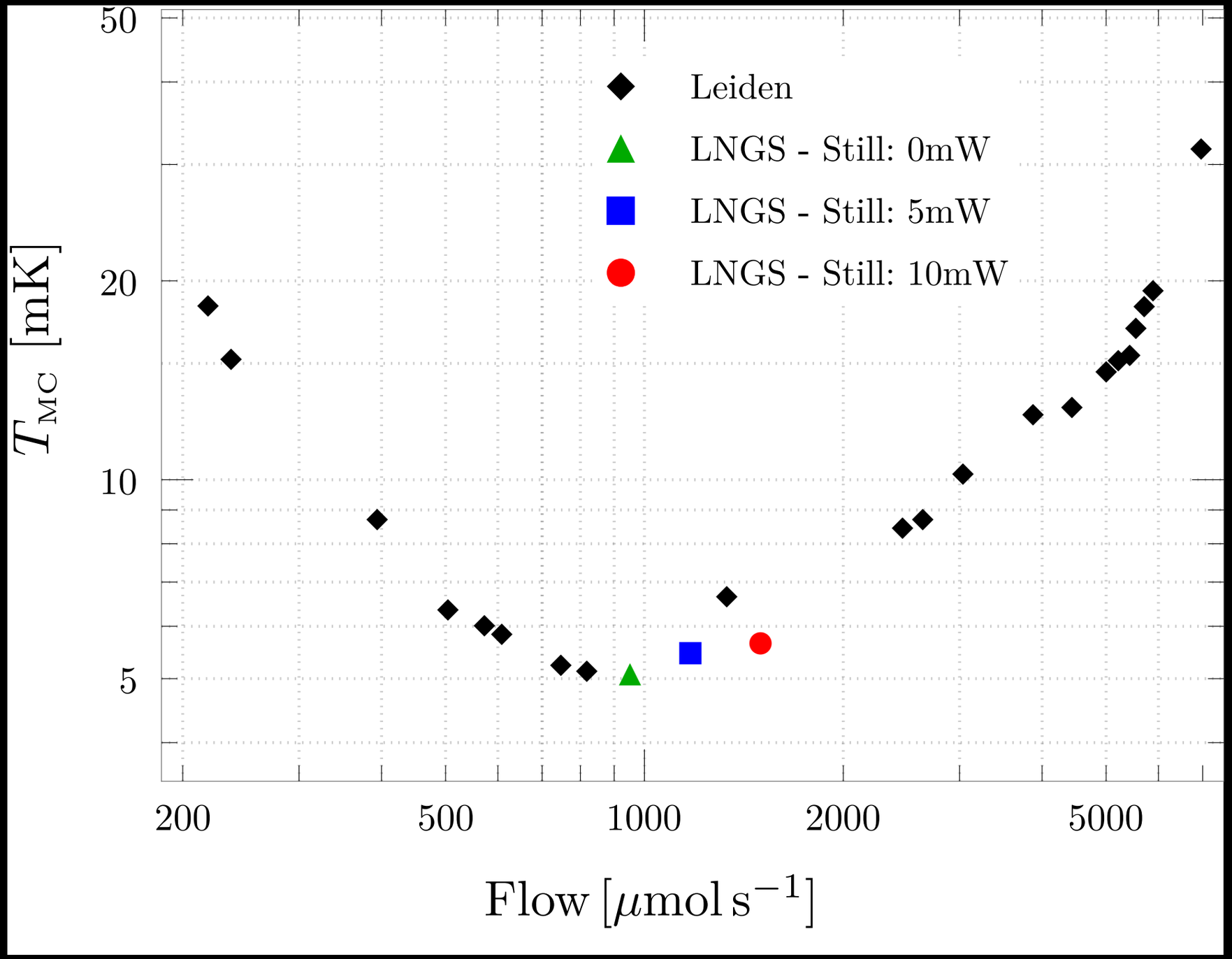
UCLA

UNIVERSITY OF SOUTH CAROLINA

CUORE

# BACK UP

# MOLAR FLOW


50
20
10
5
$T_{\mathrm{MC}}$ [mK]
Leiden
LNGS - Still: 0mW
LNGS - Still: 5mW
LNGS - Still: 10mW
200
500
1000
2000
5000
Flow [$\mu$mol s$^{-1}$]