nucleus EXPERIMENT

Detecting reactor CEvNS with the NUCLEUS experiment

Mayorana Summer School 2025

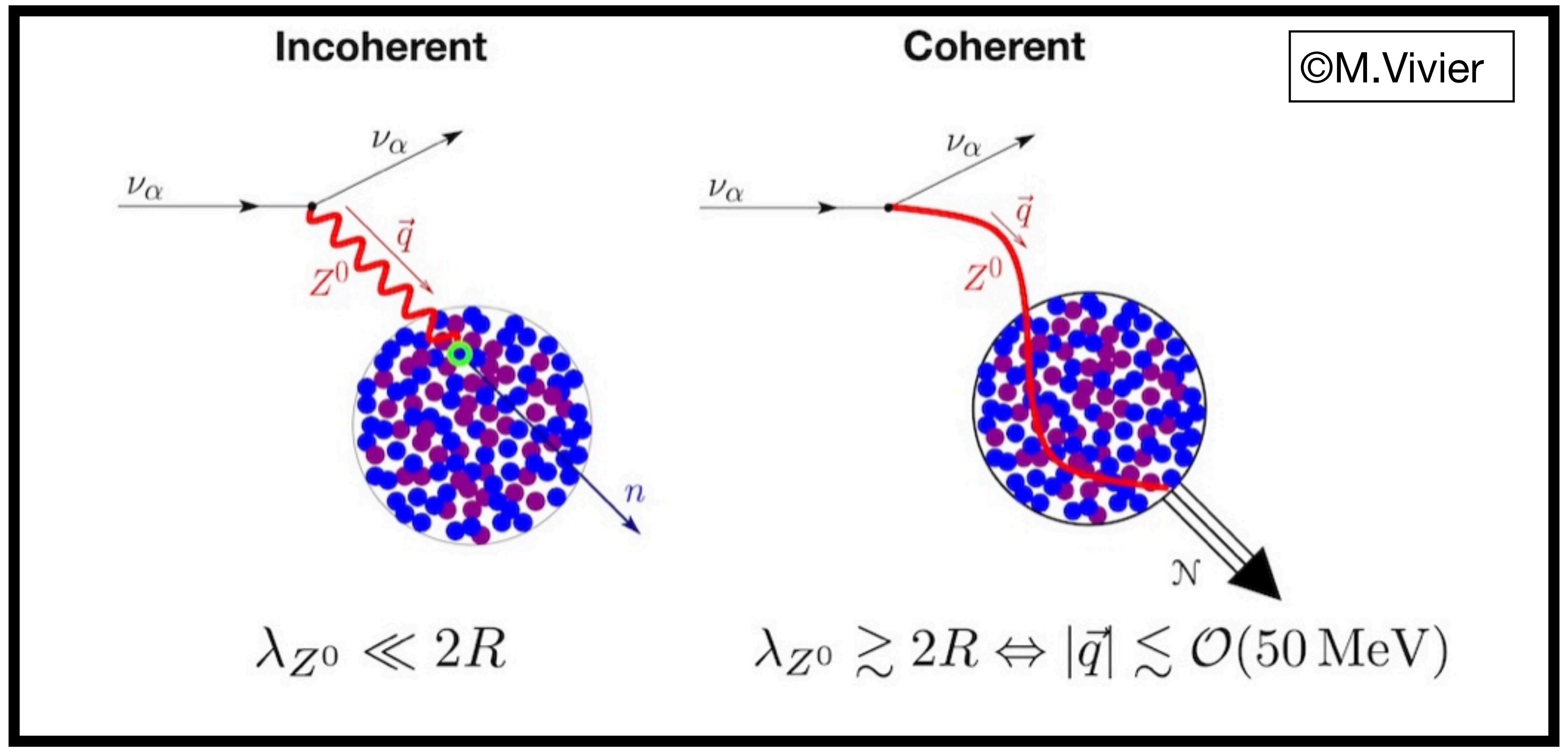
CEA Irfu · EDF · Sapienza Università di Roma · Max-Planck-Institut für Physik · TUM · HEPHY Institute of High Energy Physics · INFN · TU Wien

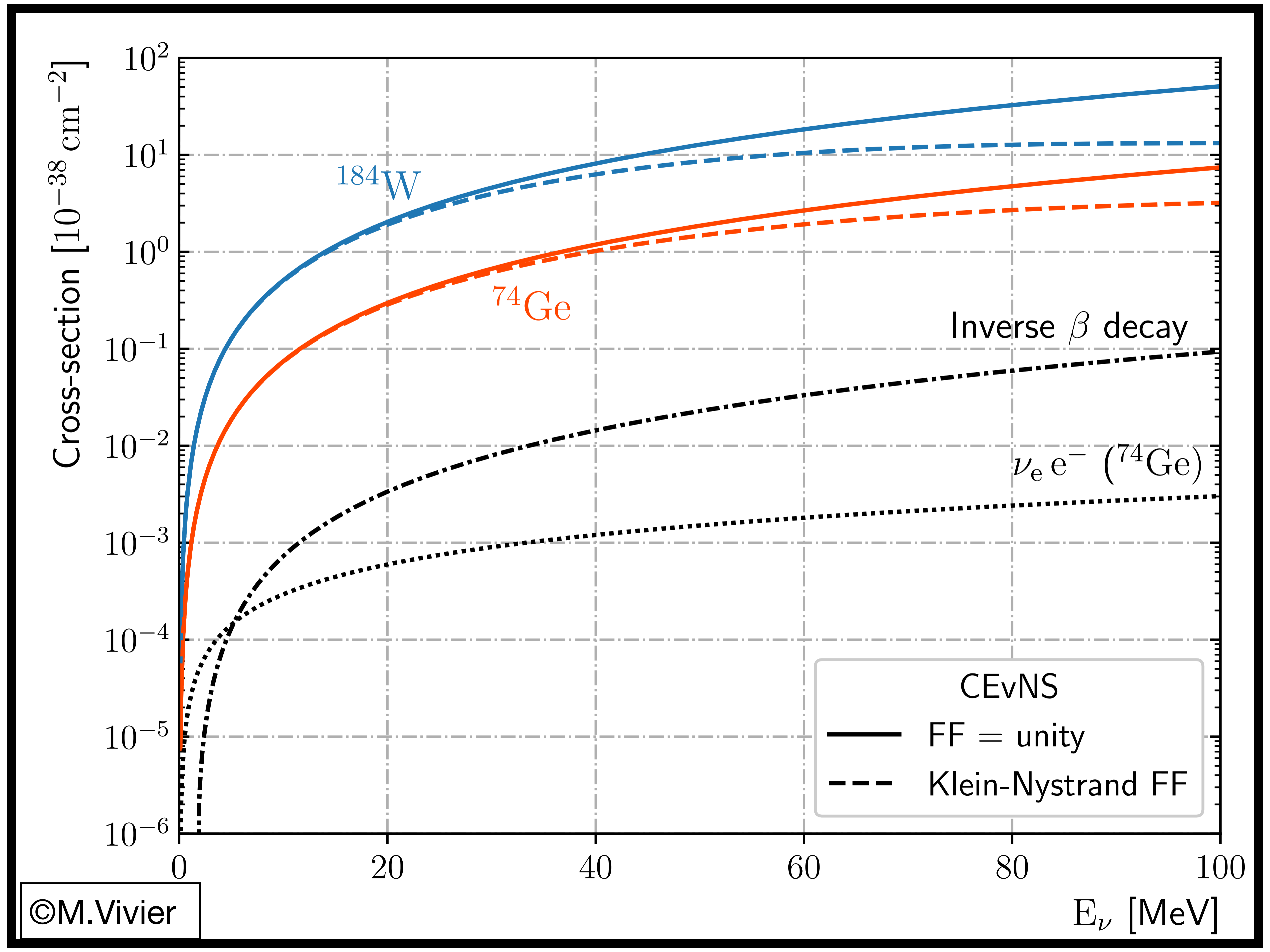
Liliane McCallin, on behalf of the NUCLEUS experiment - 24th of July 2025

What is CEvNS?

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{4\pi(\hbar c)^4}\left(1 - \frac{MT}{2E_\nu^2}\right)(Z(1-4sin^2(\theta_W)) - N)^2(F_W^2(q^2))$$

- Cross section scales with N^2 —> 10-1000>larger than IBD
- Good probe of θ_W and BSM physics at low energies
- Signature is a very low energy nuclear recoil



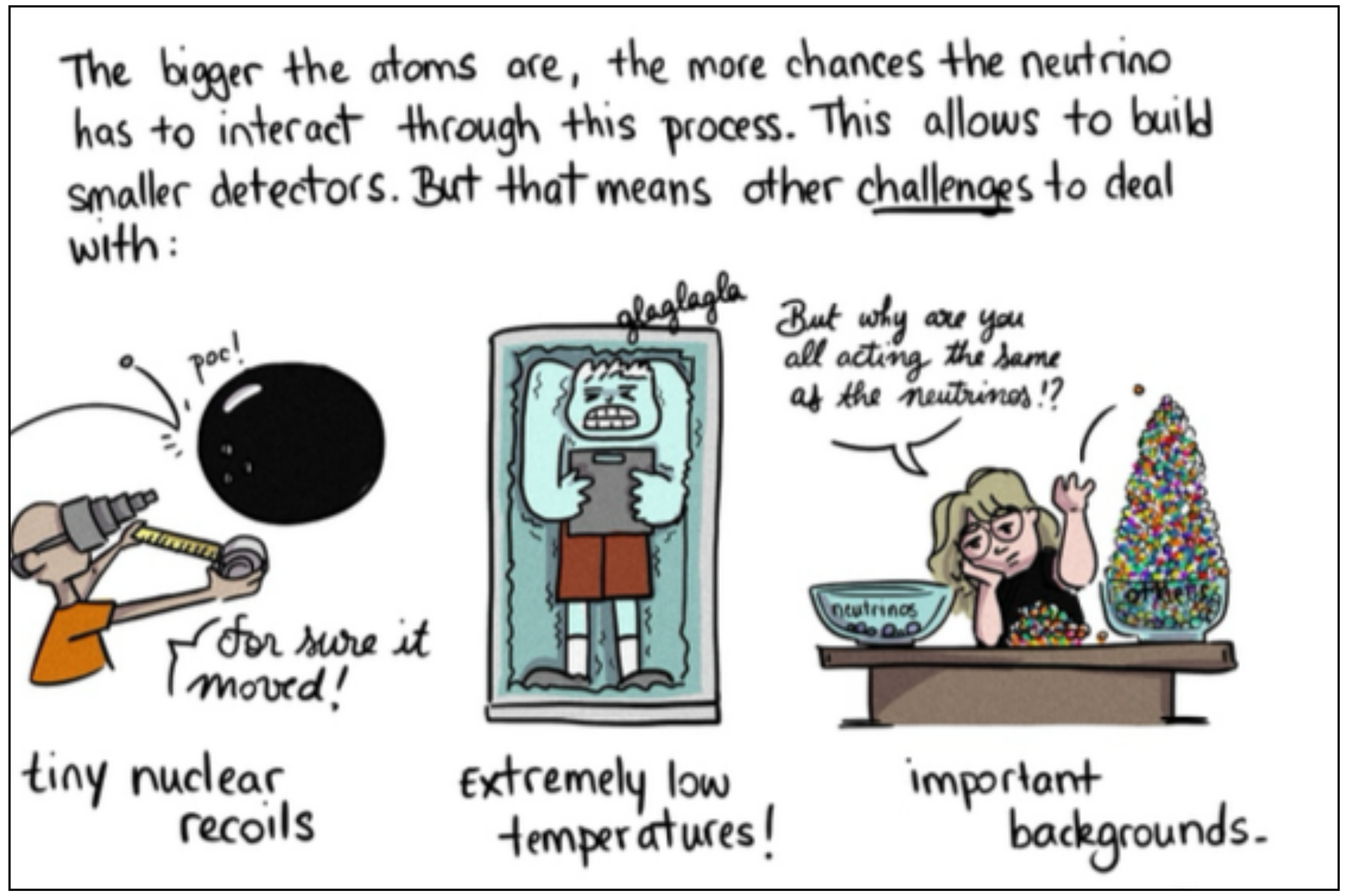


How do we measure CEνNS?

2 experimental issues arise when trying to measure CEνNS:

1. **How do I detect them ?**
   —> Using a neutrino source, going to cryogenic temperatures, ultra low threshold detectors

2. How do I make sure what I detect is actually a neutrino?
   —> Passive shielding and multiple particle vetoes



Comic by C.Goupy

How do we measure CEvNS with NUCLEUS?

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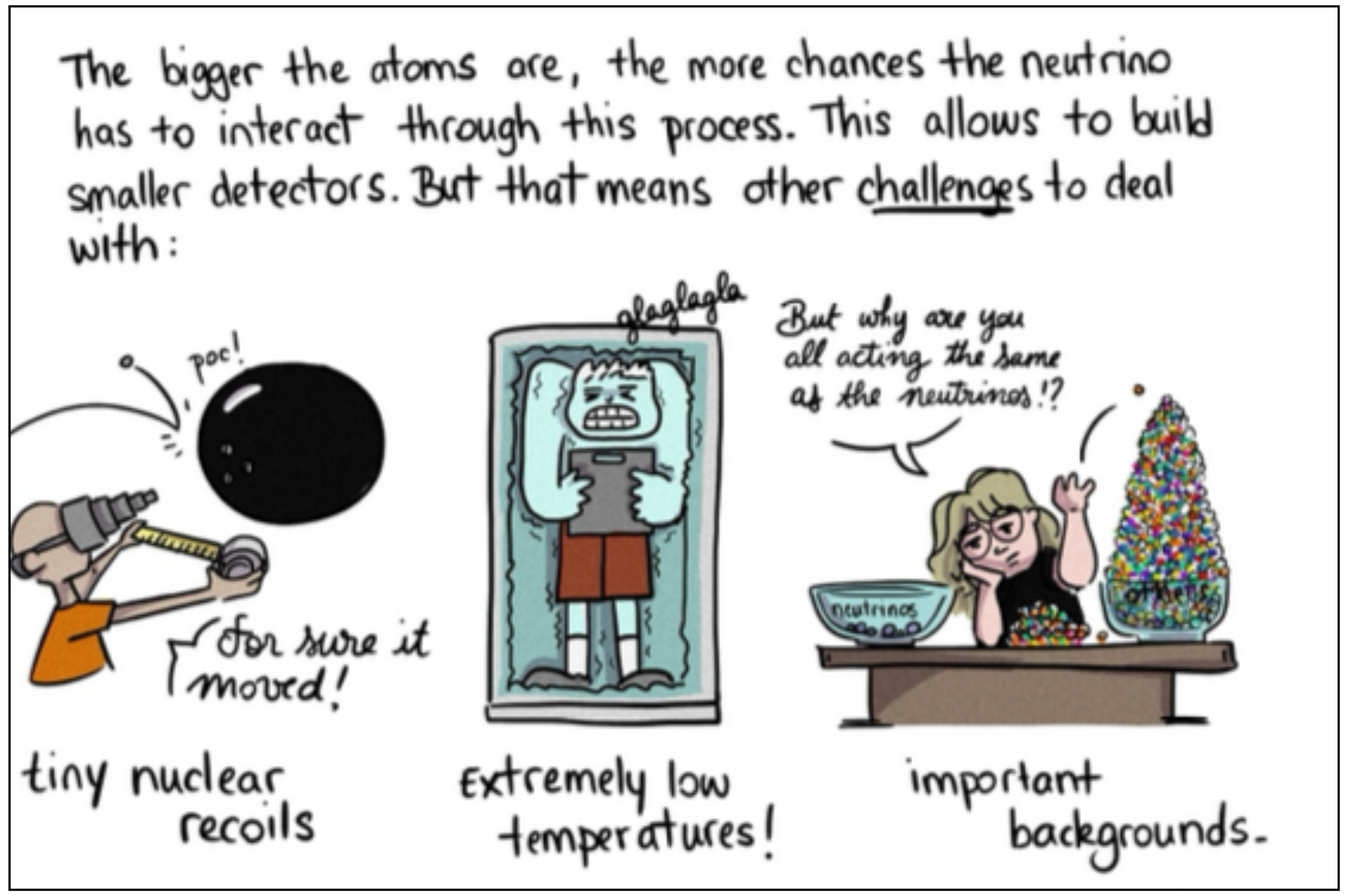

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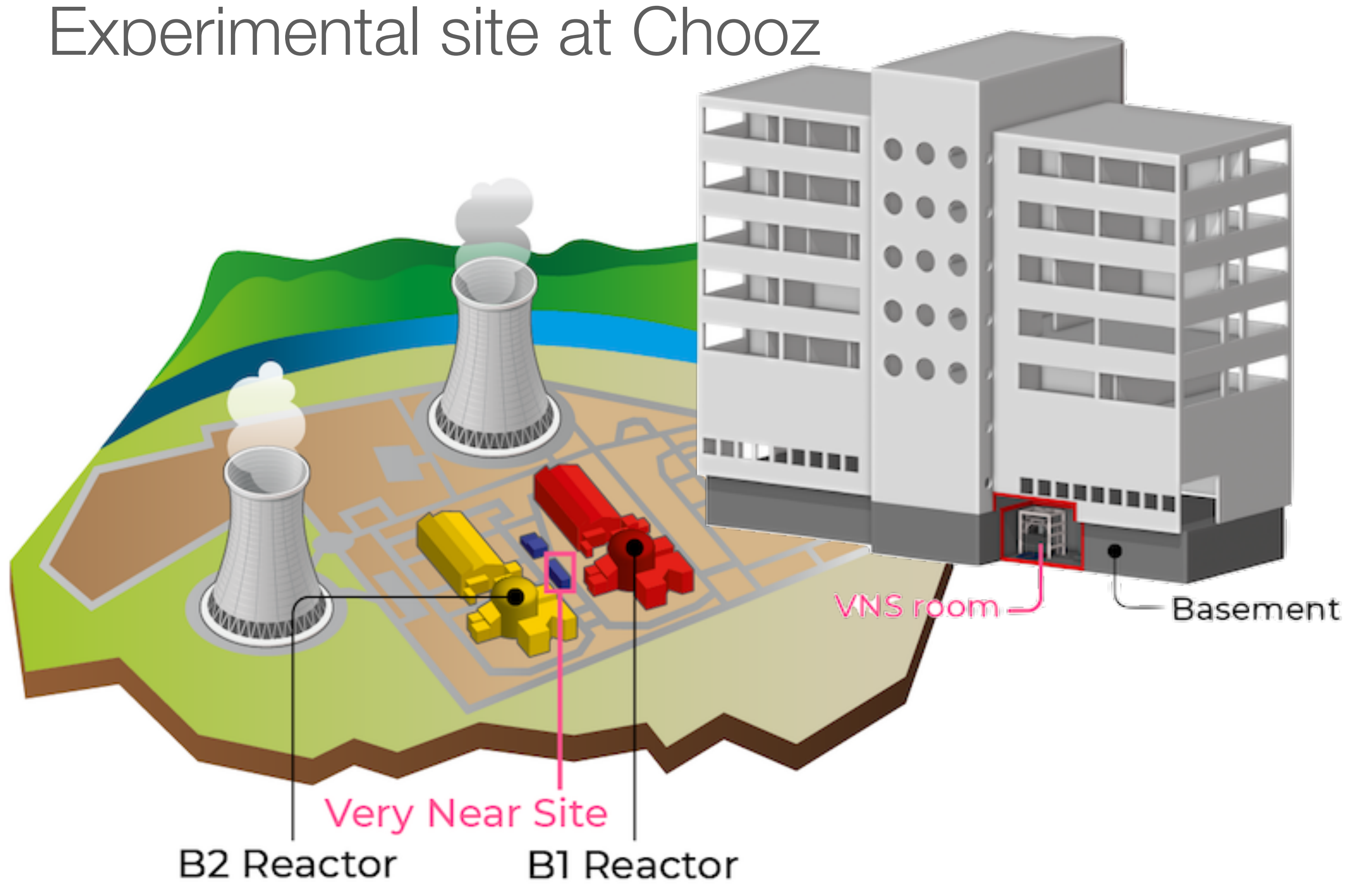
How do I detect CEvNS with NUCLEUS?

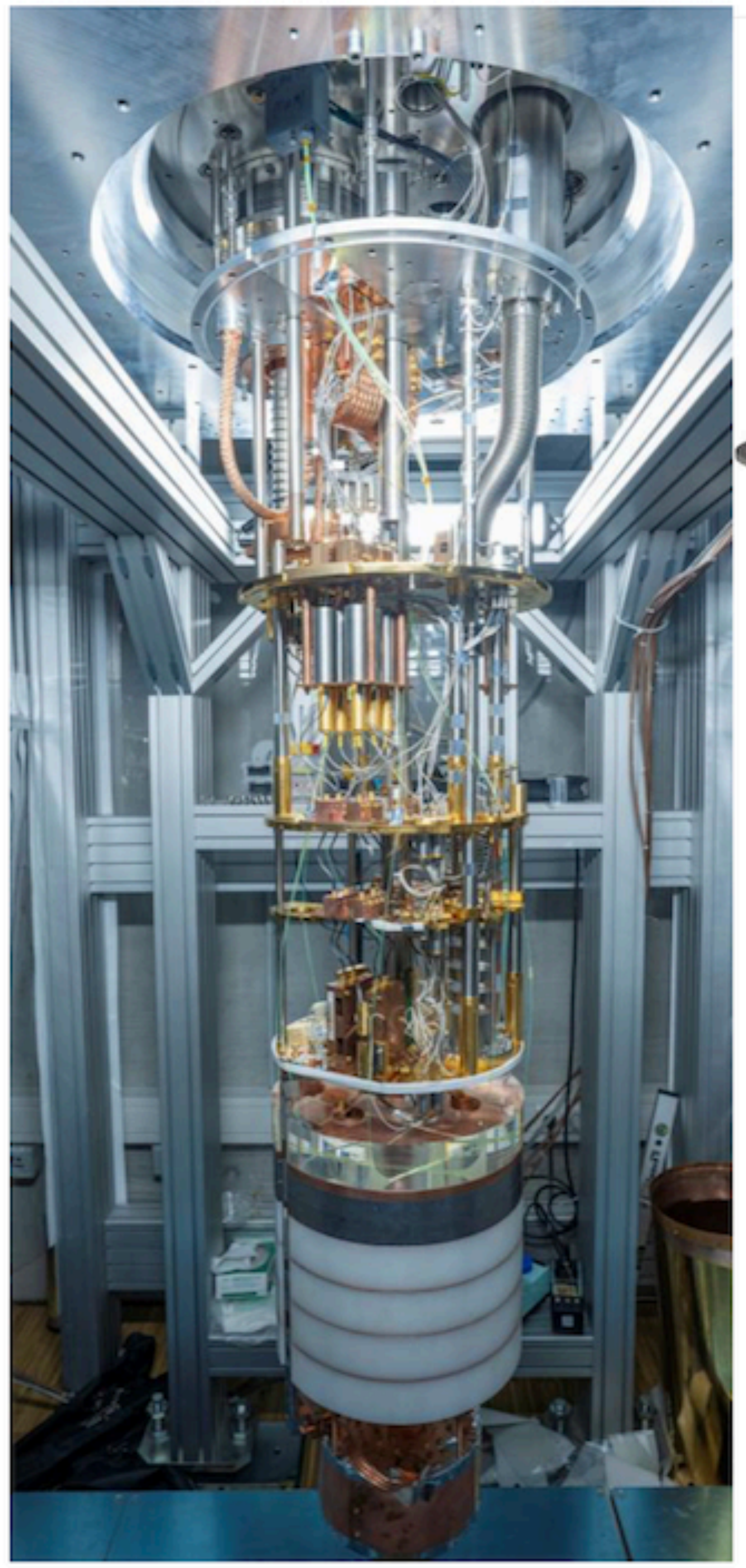
<u>1st step:</u> Find a source with high neutrino flux

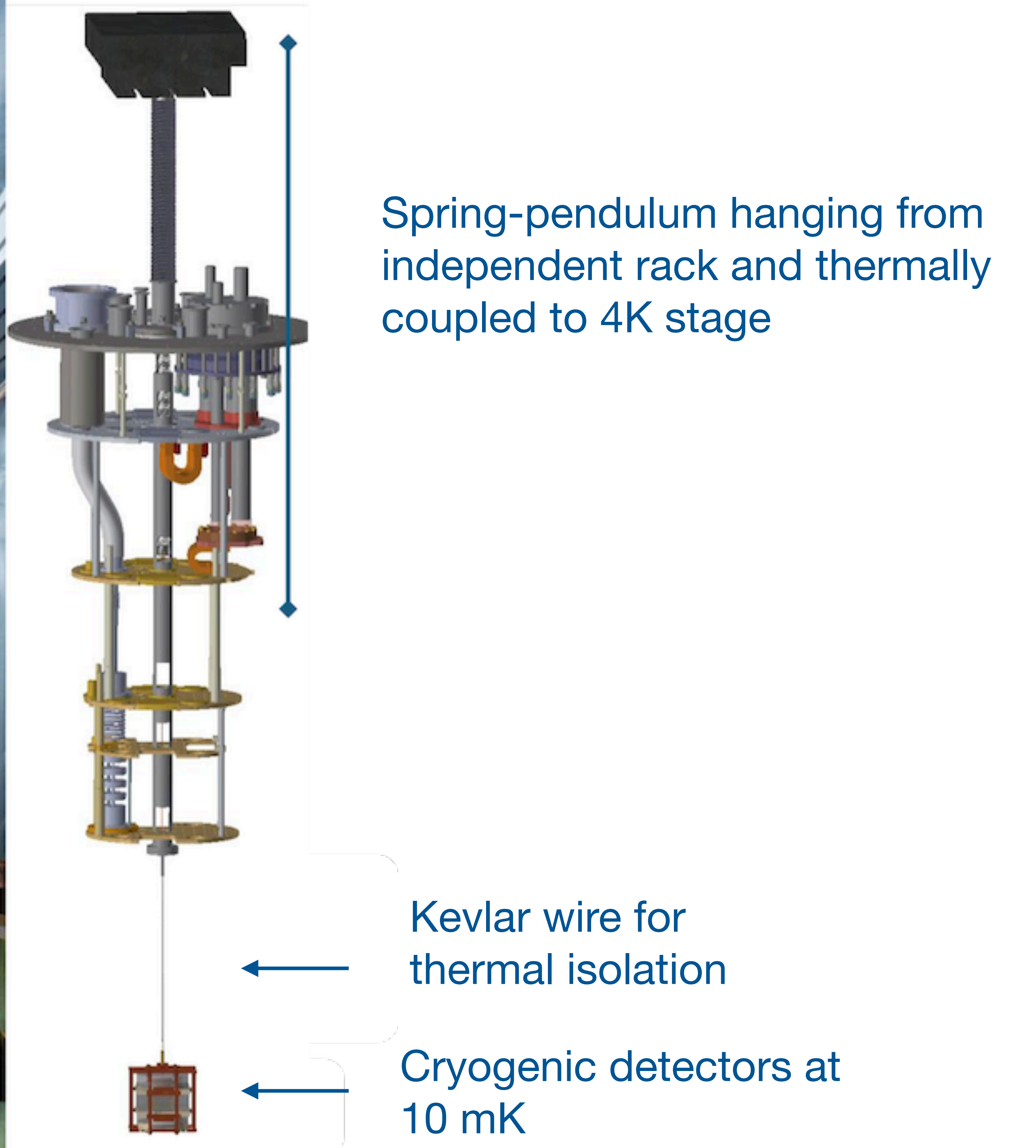
Experimental site at Chooz



- Located in between 2 reactors
- Small overburden of 3 m.w.e
- Neutrino flux ~1.7 10^{12} cm^{-2} s^{-1}
- Produces antineutrino of ~10MeV and under —> nuclear recoil O(1keV)

<u>2nd step:</u> Go to cryogenic temperatures





- NUCLEUS cryostat goes down to 10mK, which makes it sensitive to the very small temperature variations induced by nuclear recoils

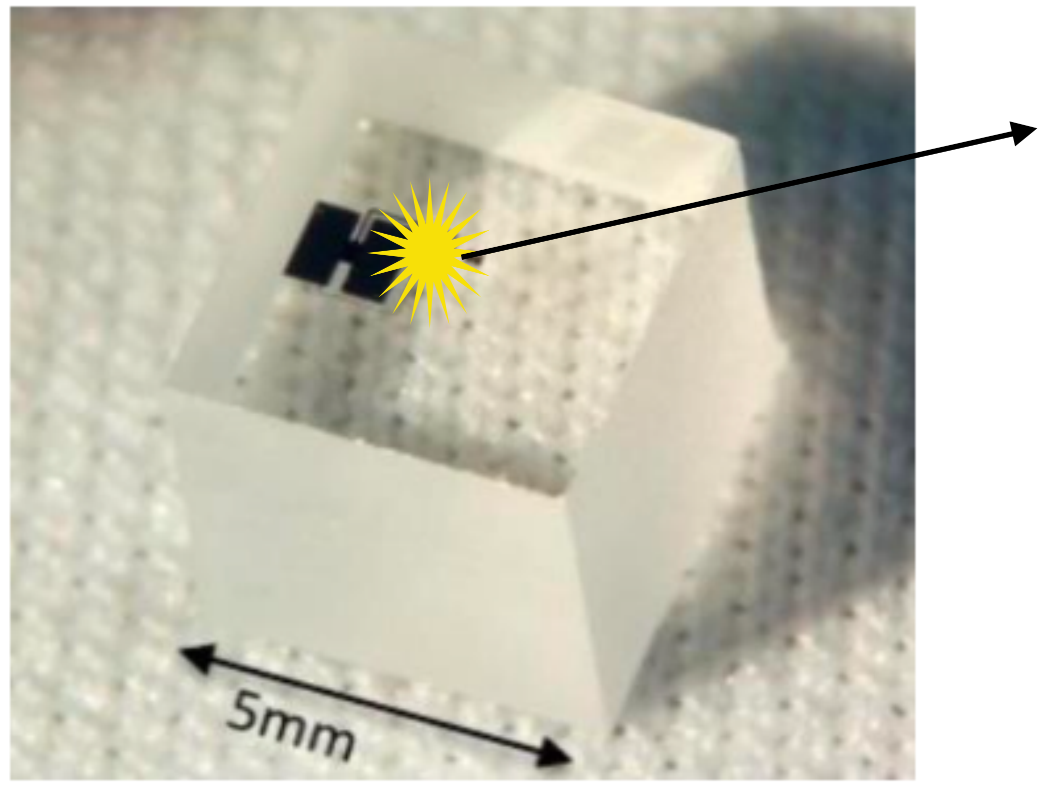
How do I detect CEνNS with NUCLEUS?

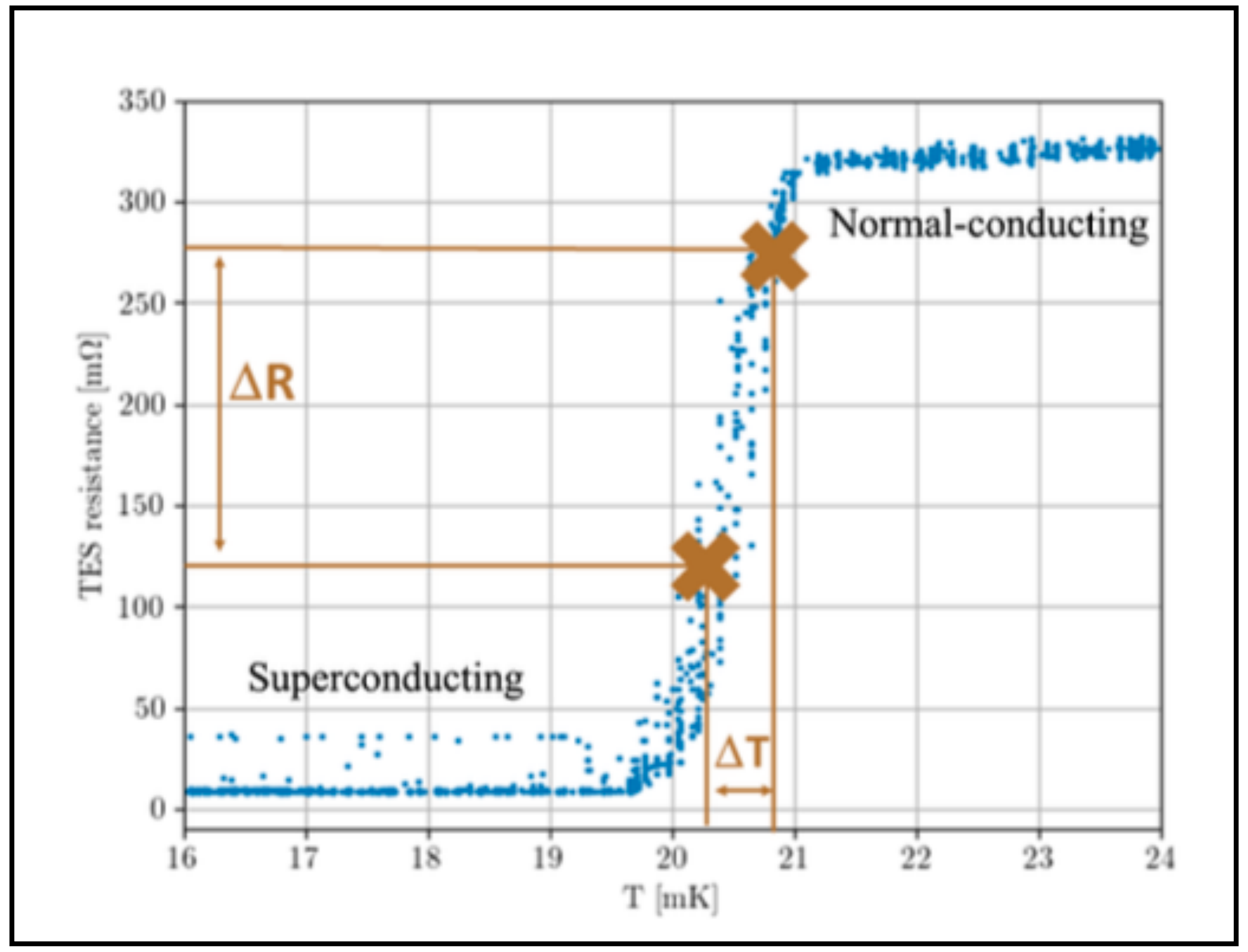
<u>3rd step:</u> Use ultra low threshold cryogenic detectors

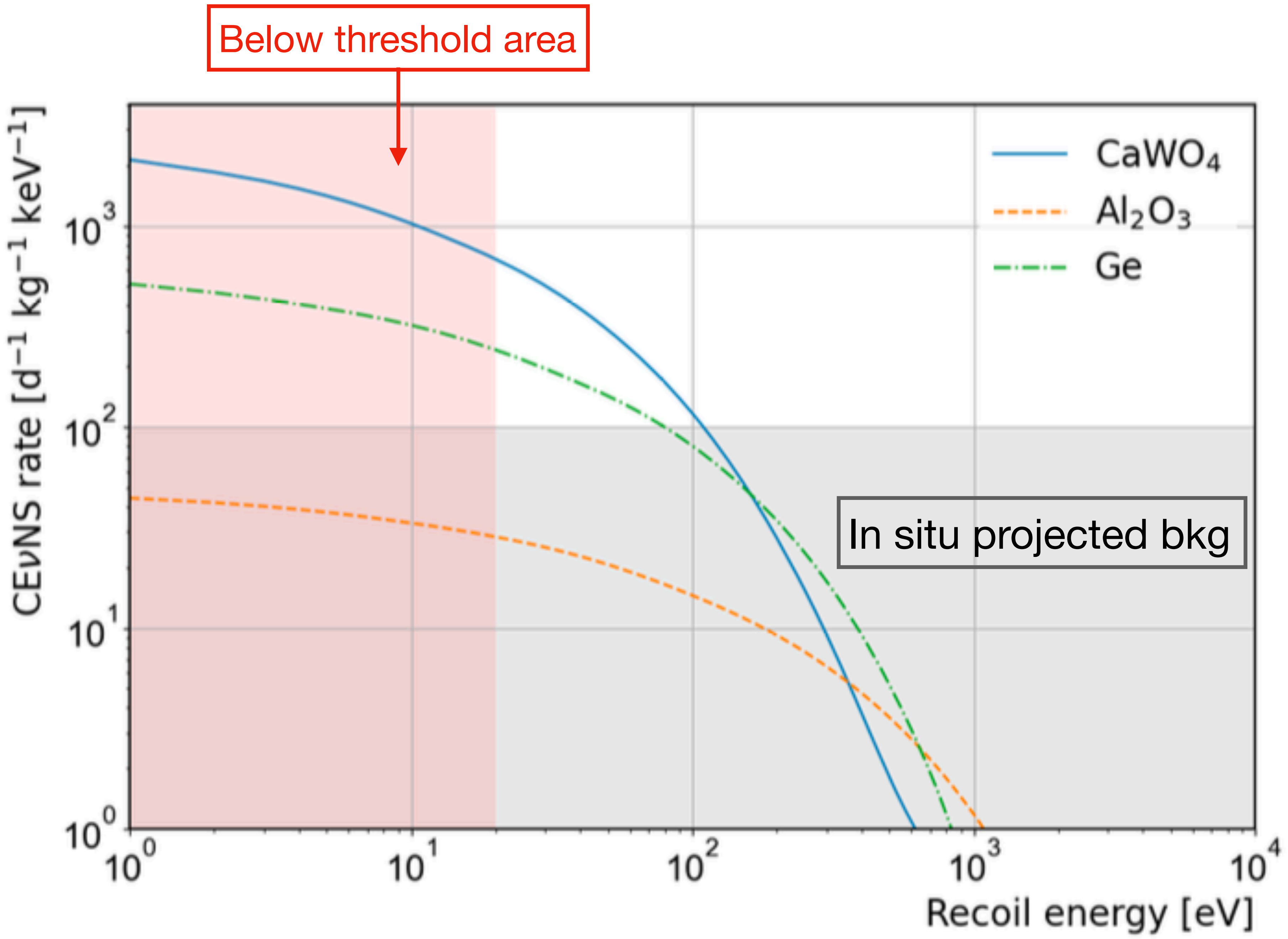
—> 2 arrays of 9 cubic $CaWO_4$ and Al_2O_3 calorimeters

—> Read out using Transition Edge Sensors (TES)

—> Stable noise RMS $5.5 \pm 0.2\ eV$ $Al_2O_3$and $6.2 \pm 0.3 eV$ for $CaWO_4$ demonstrated (paper in preparation)





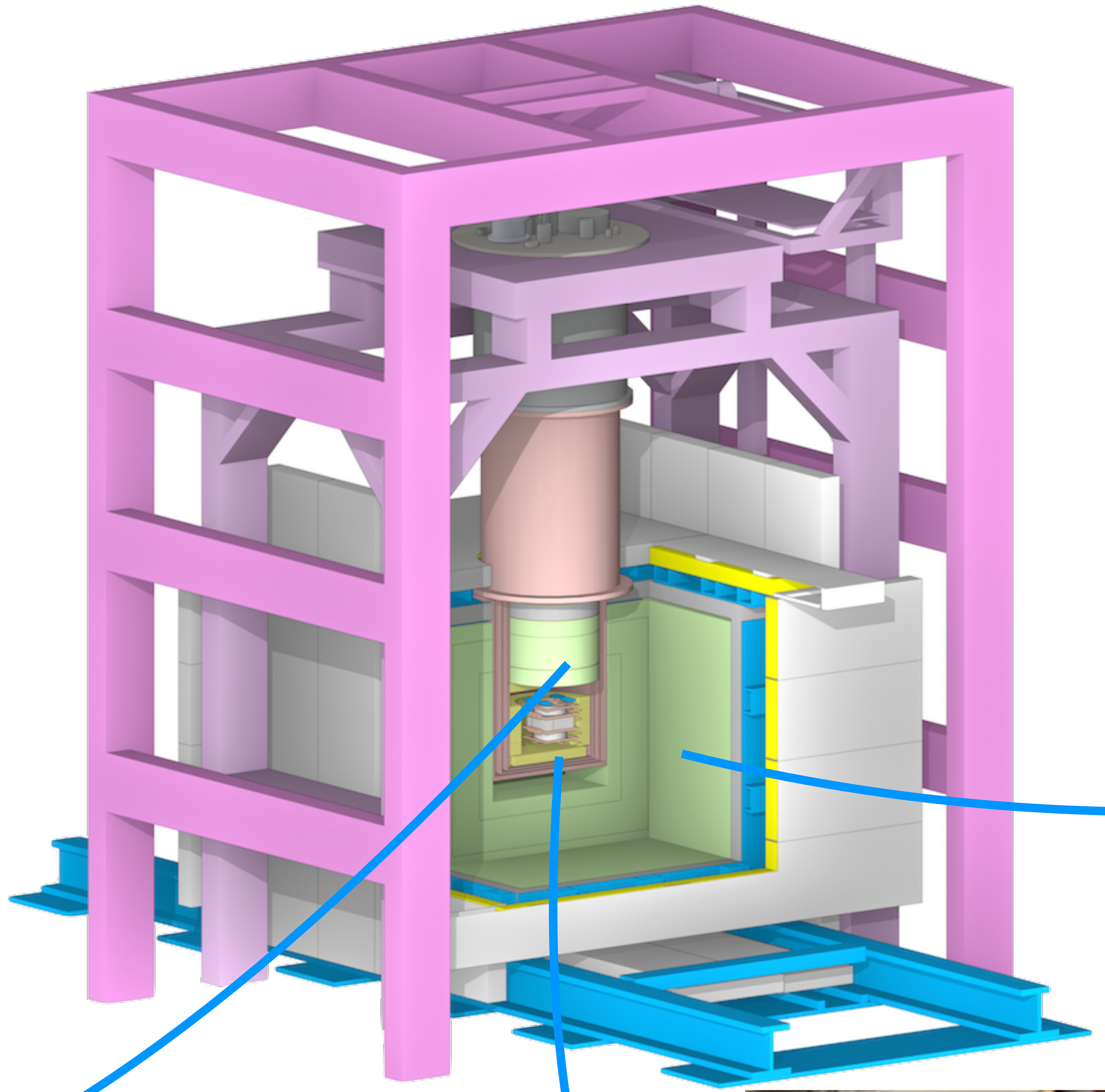


Background rejection strategy - Passive shielding

Shielding systems

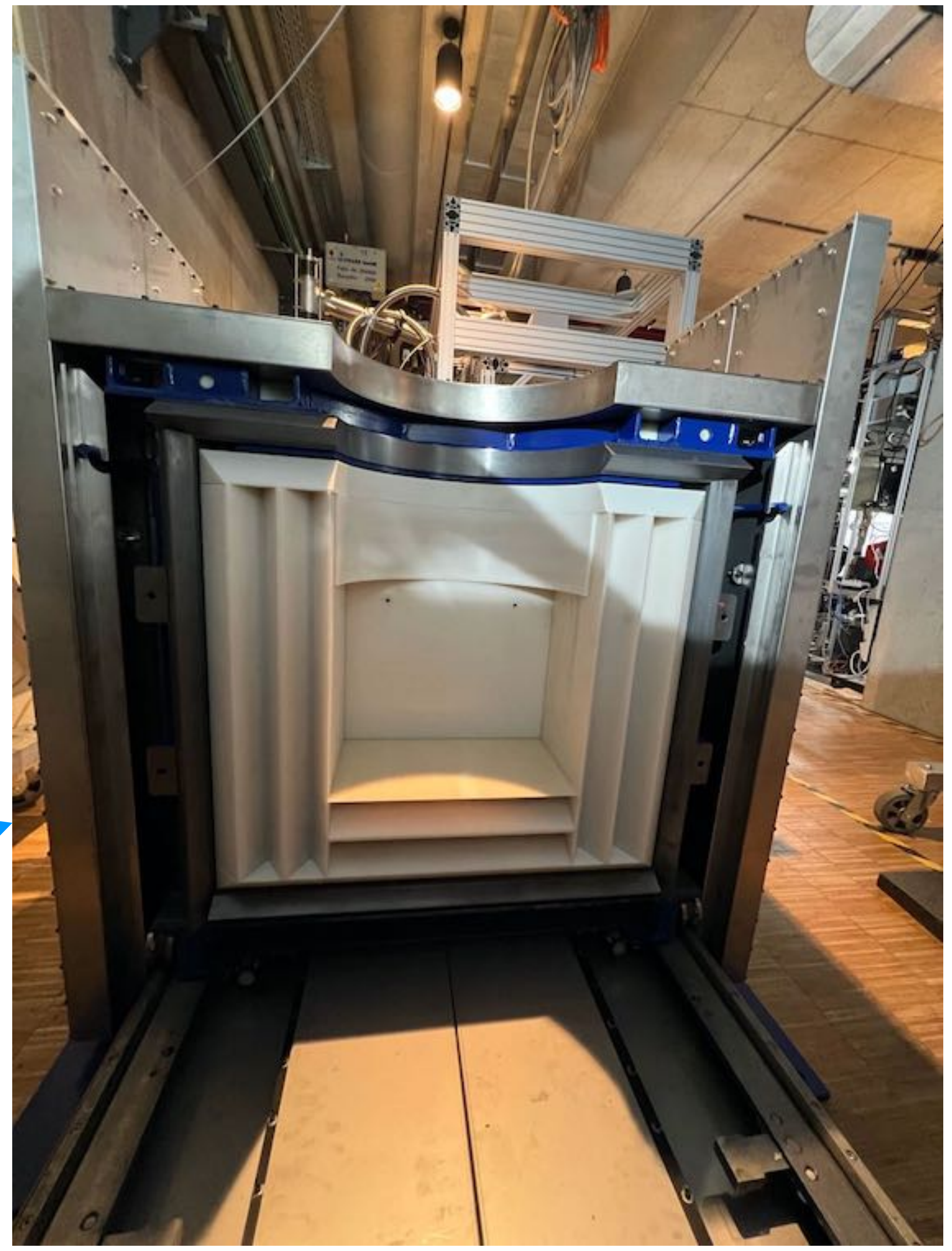
Internal passive shields at cryogenic temperatures

- Extension of the external shield inside the cryostat (Pb, HDPE + muon veto)
- Thermalized by copper disks



External passive shields

- 5-cm Pb + 20-cm borated HDPE installed in mechanical structure



B_4C internal shield (not present)

- Additional neutron rejection
- Concept under validation, to be integrated at Chooz

Commissioning results:

External shielding fully commissioned

Thermalization of internal shielding (~ 50 kg of HDPE + Pb + Cu) achieved within 11 days

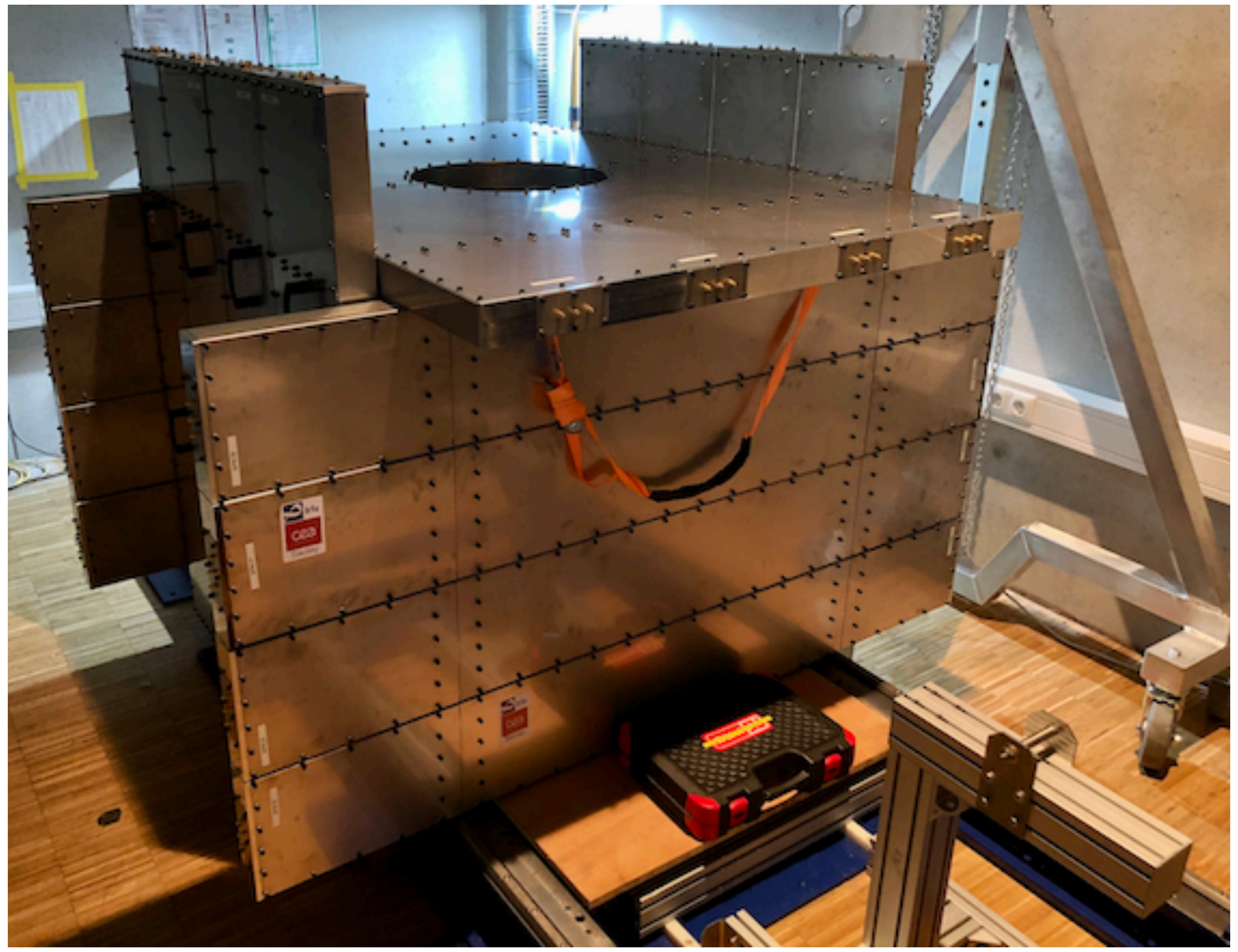
Background rejection strategy - Active shielding

Cryogenic and external muon veto:

- 28 x 5-cm thick plastic scintillator modules with WLS and Si-PM readout

- Demonstrated with ~98.5 % efficiency

- Operated in anti coincidence with target detector



Cryogenic Outer Veto (COV):

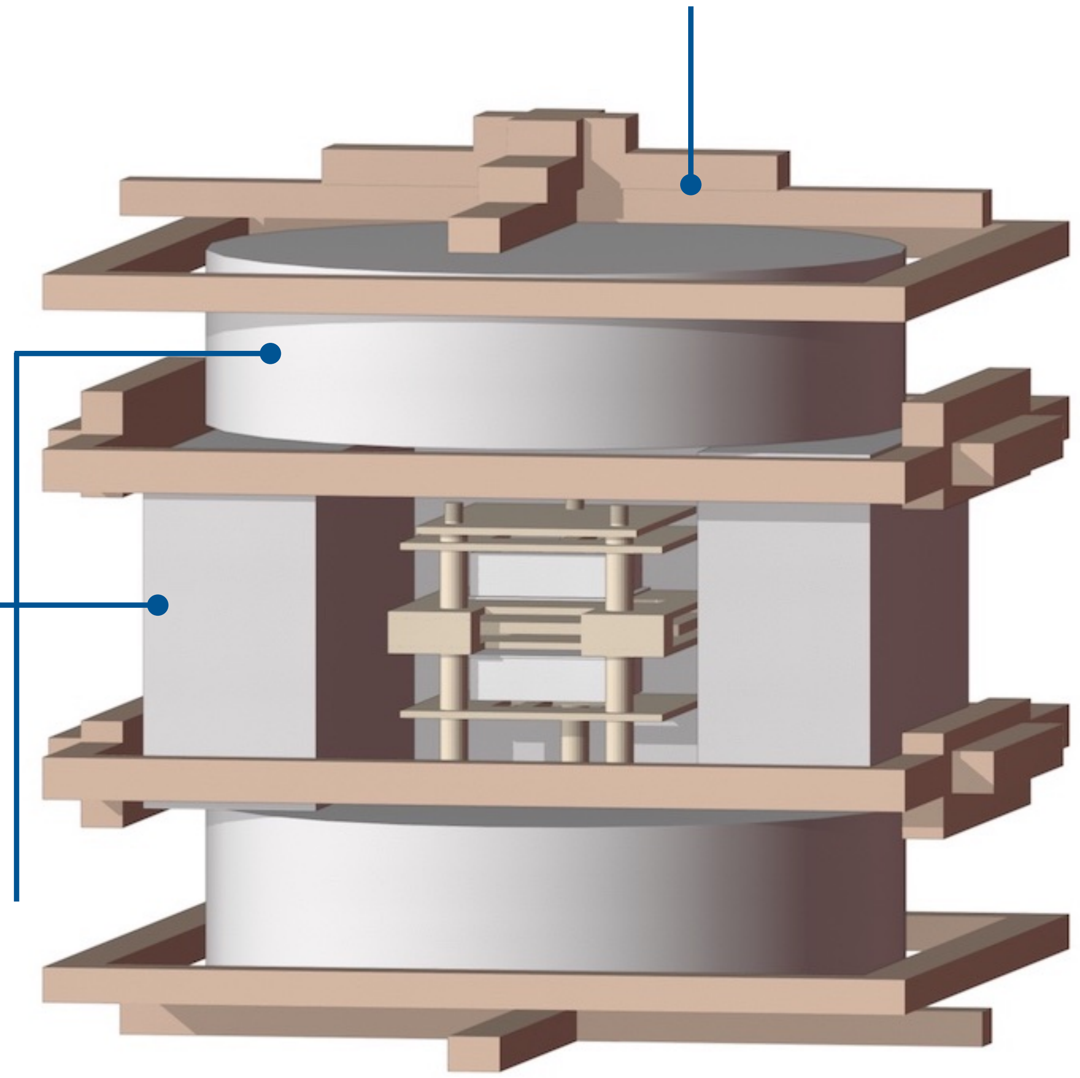
- 6 HPGe crystals with near 4π coverage

- External γ-ray veto (+neutron)

- Read out in ionisation channel

- Operated in anti coincidence with target detector

- O(10keV) energy threshold



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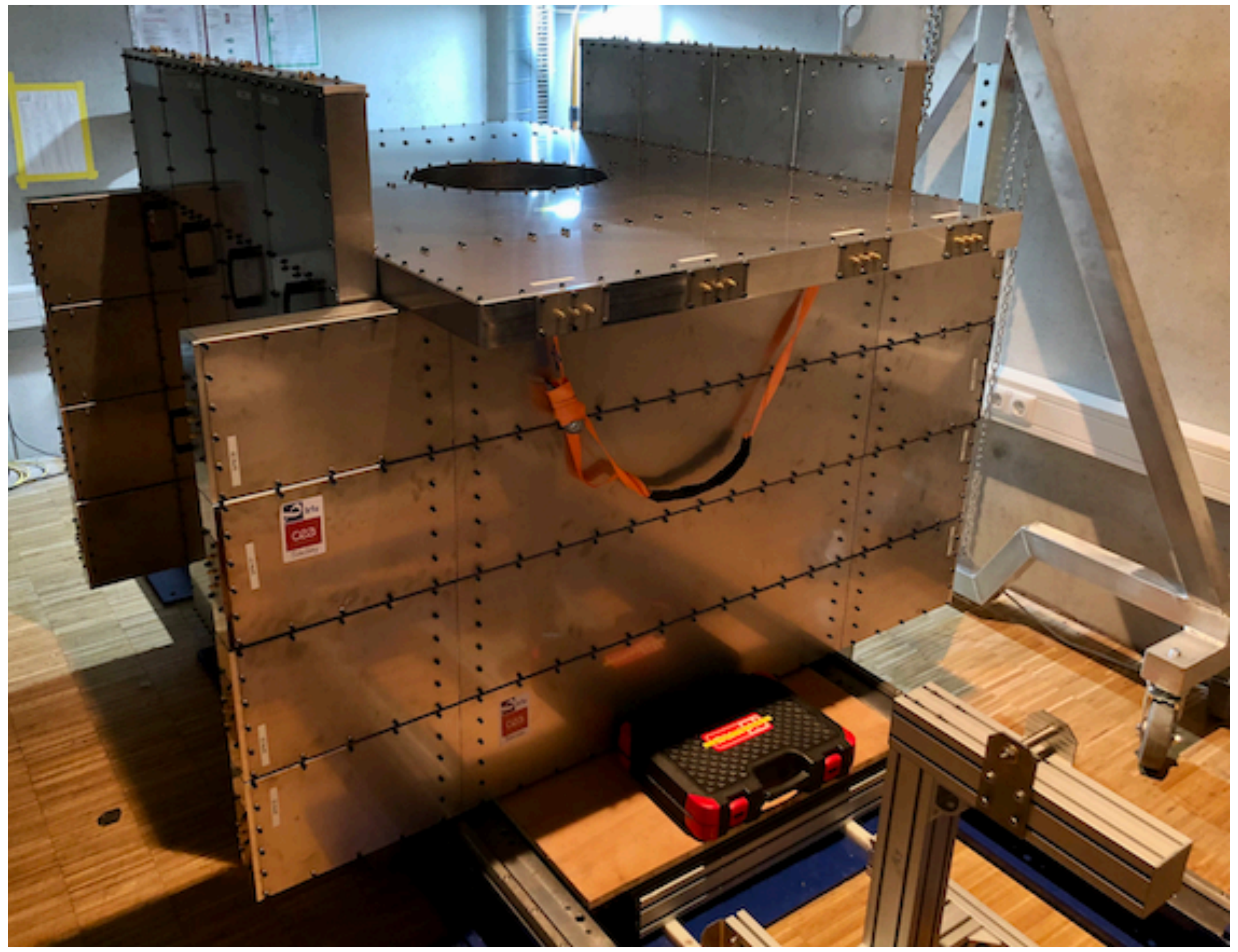

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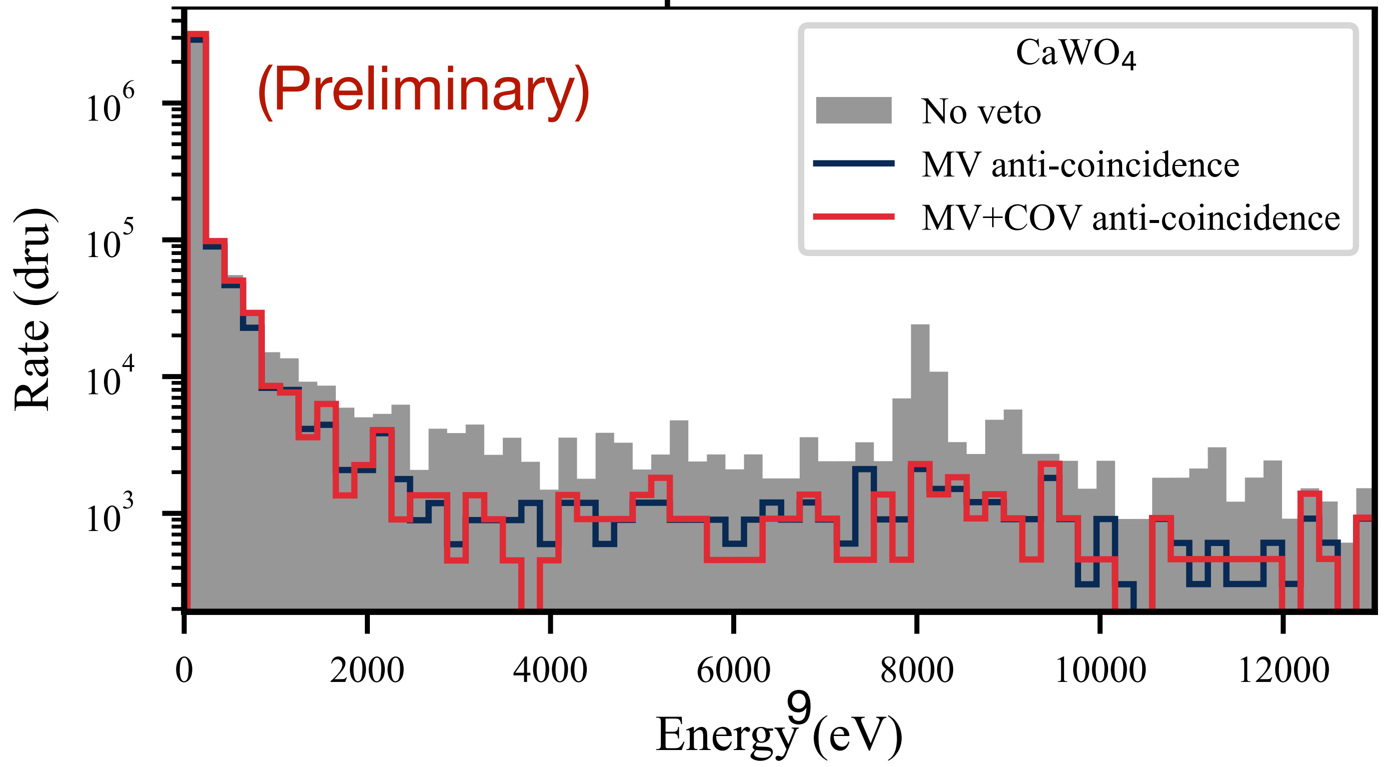

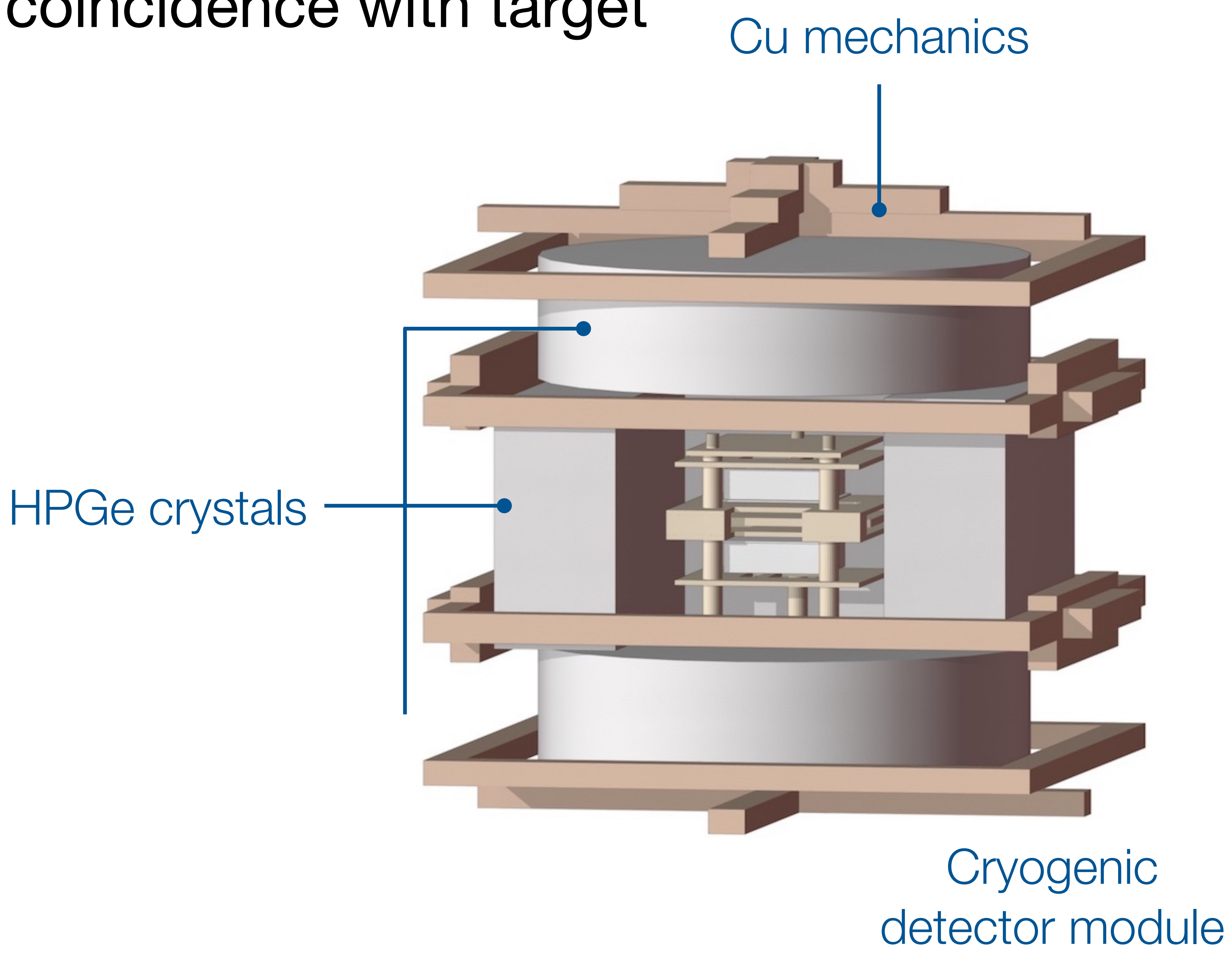

Thank you for listening!

Contact: liliane.mccallin@cea.fr
Read about us at: nucleus-experiment.org

Sources:

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