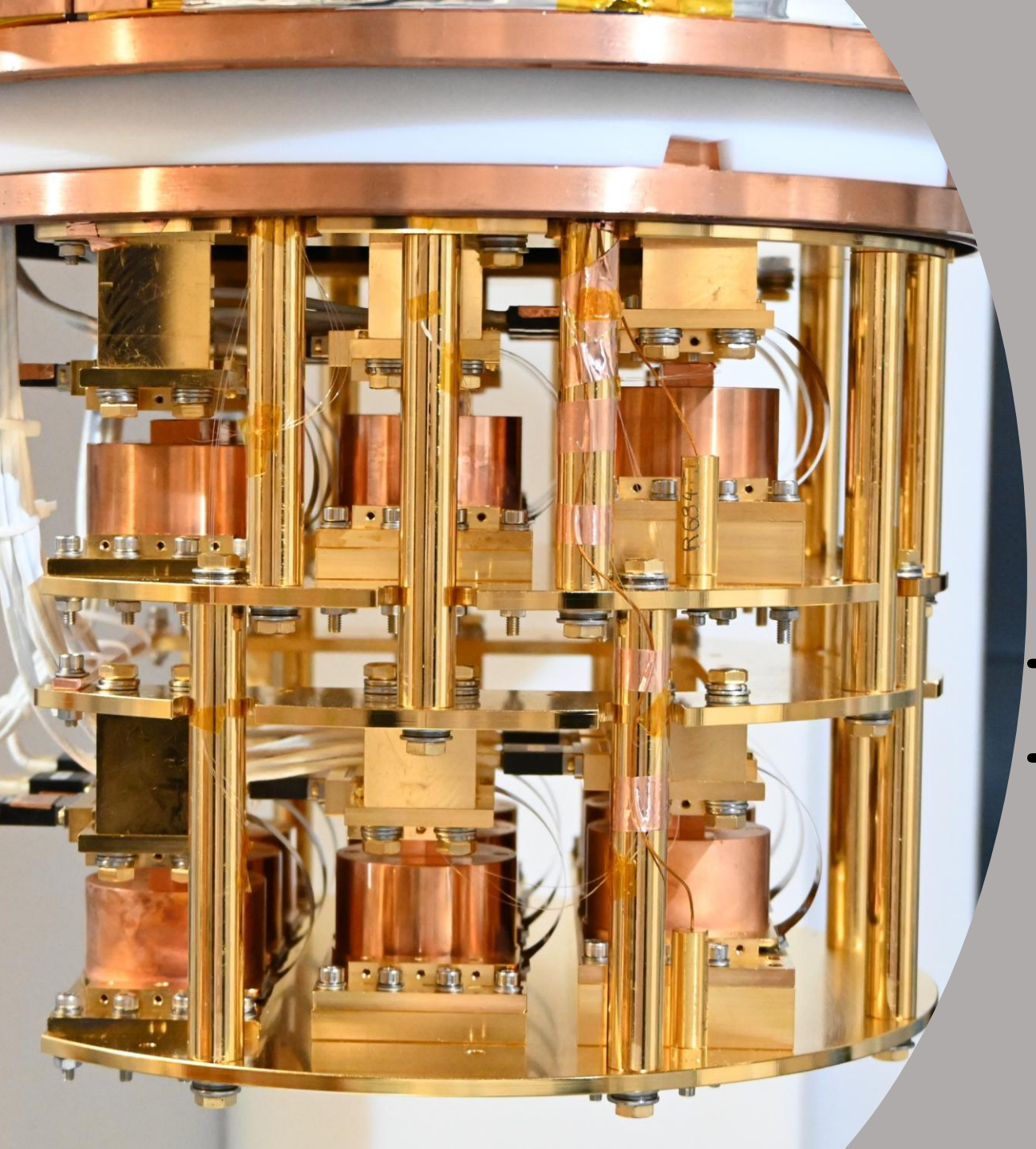


RICOCHET

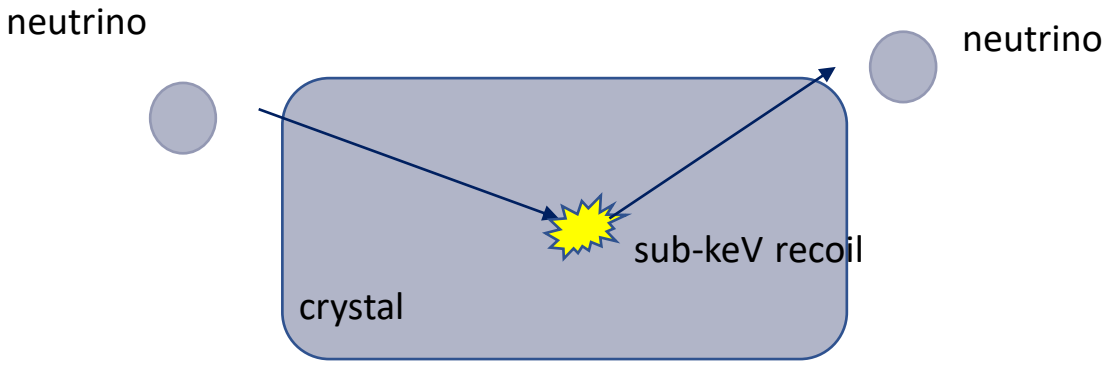
A Coherent Neutrino Scattering Program

The Ricochet's Cryocube: Technology & First Results

Juliette Blé, LPSC Grenoble

GDR DI2I, 18/06/26

Coherent Elastic Neutrino-Nucleus Scattering (CENNS)



- Predicted since 1974 by Freedman
- Measured for the 1st time only in 2017 by the COHERENT Collaboration

$$\frac{d\sigma^{\mathrm{CE\nu NS}}(E_\nu, E_r)}{dE_r} \cong \frac{G_F^2\, m_N}{\pi}\left(1 - \frac{m_N E_r}{2E_\nu^2}\right)\left[g_V^p\left(\sin^2(\vartheta_W)\right) Z F_Z(|\vec{q}|^2) + g_V^n N F_N(|\vec{q}|^2)\right]^2$$

Neutrino energy; Mass of the nucleus; **SM vector proton coupling**; SM vector neutron coupling; Nuclear recoil energy; Weinberg angle; Proton Form Factor; **Neutron Form Factor**

Precise measurement of the Standard Model through **Weinberg angle**
Test of **new physics** beyond the Standard Model
Irreducible background for **direct dark matter search** (same signature)

D. Z. Freedman, Phys. Rev. D 9, 1389 (1974)
D. Akimov et al. (COHERENT Collaboration), Science 357, 1123, (2017) - ArXiv:1708.01294

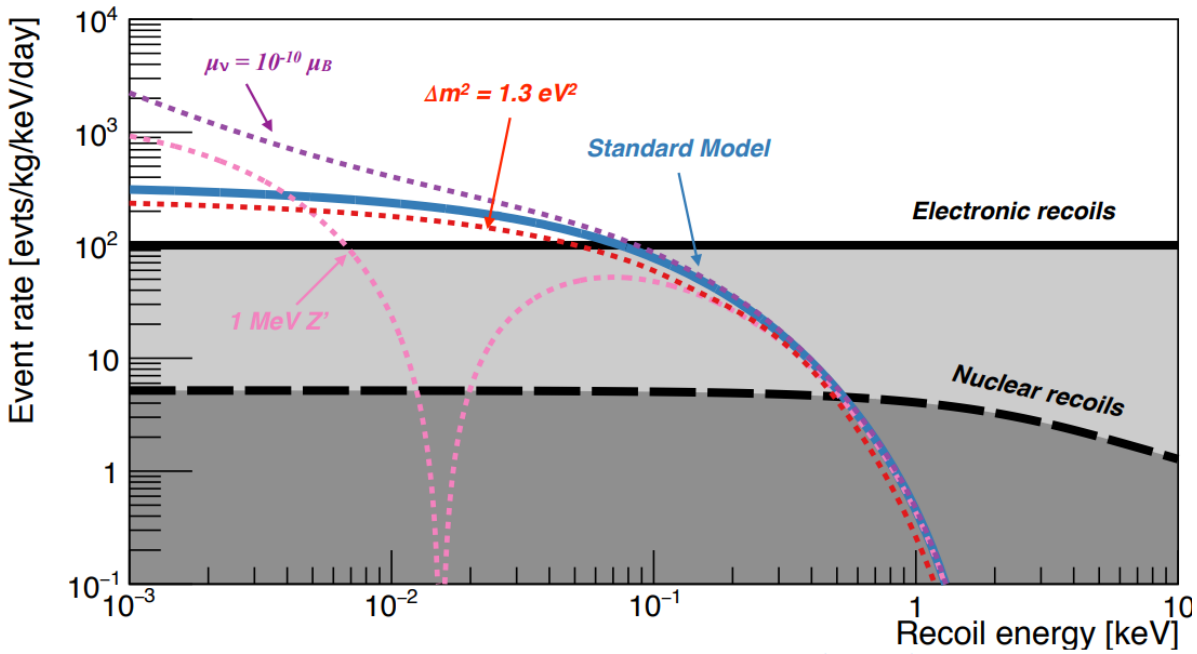
CENNS Measurement Wishlist for Ricochet

- **Low energy threshold detectors (recoil energy sub-keV)**
  → Cryogenic calorimeters

- **Low and Controlled Background**
  → Passive & Active Shielding

- **Discrimination between signal and background**
  → Simultaneous readout of signals induced from energy deposition to distinguish Nuclear Recoils (NR) and Electronic Recoils (ER)

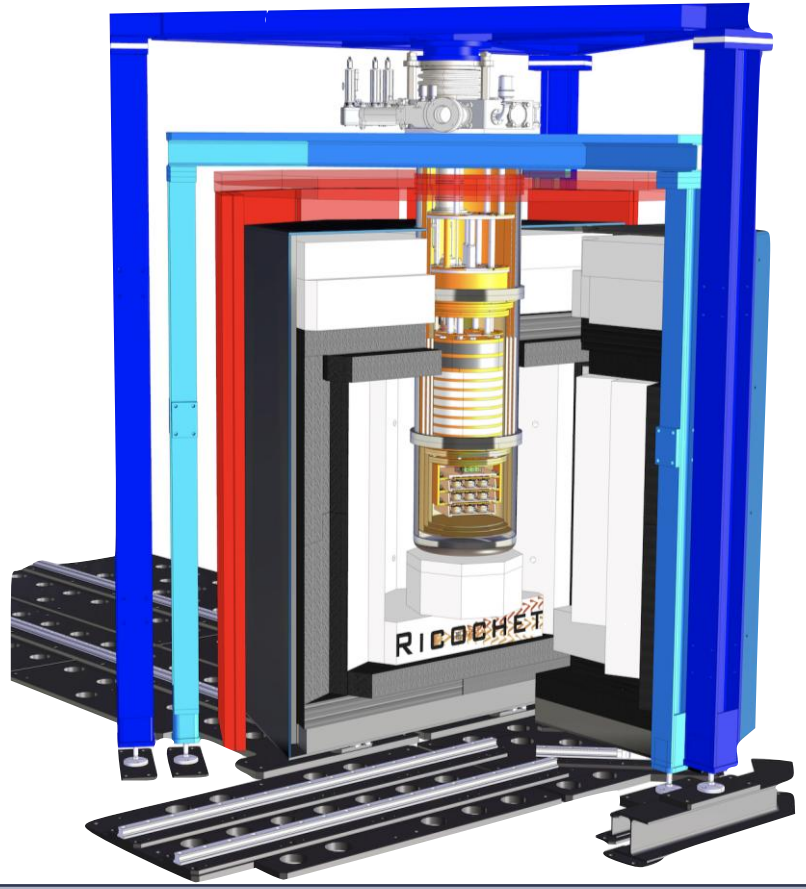
  → Fiducialization of detectors for background rejection



C.Augier et al., J.Low Temp. Phys. 212, 127 (2023)

The Ricochet Experiment

- International (USA/Canada/Russia/France) collaboration
- Located in Grenoble at the Institut Laue Langevin (ILL), 8.8m from reactor core: $\varphi \approx 10^{12}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Expected 11 events/kg/day in [50 eV – 1 keV]



- **Passive & active shielding:**

Borated PE, Lead, Soft iron
Muon veto

- **Background substraction:**

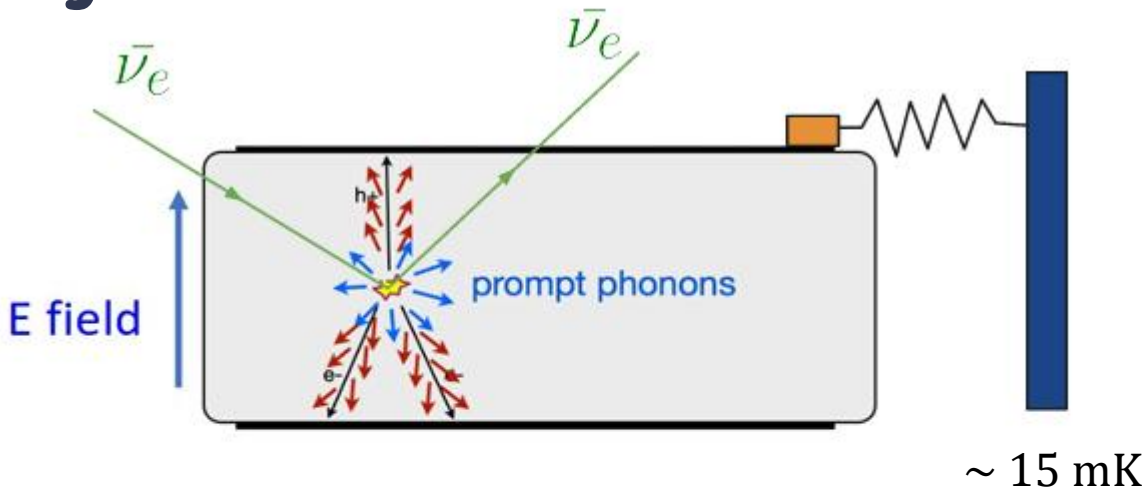
Reactor ON & ROFF cycles: allow for ON – OFF substraction !

- **2 technologies:**

Cryocube : 42g Ge semiconductor **Focus of this talk**

Q-Array: 32-g superconducting Zinc target

Cryocube Detector Technology



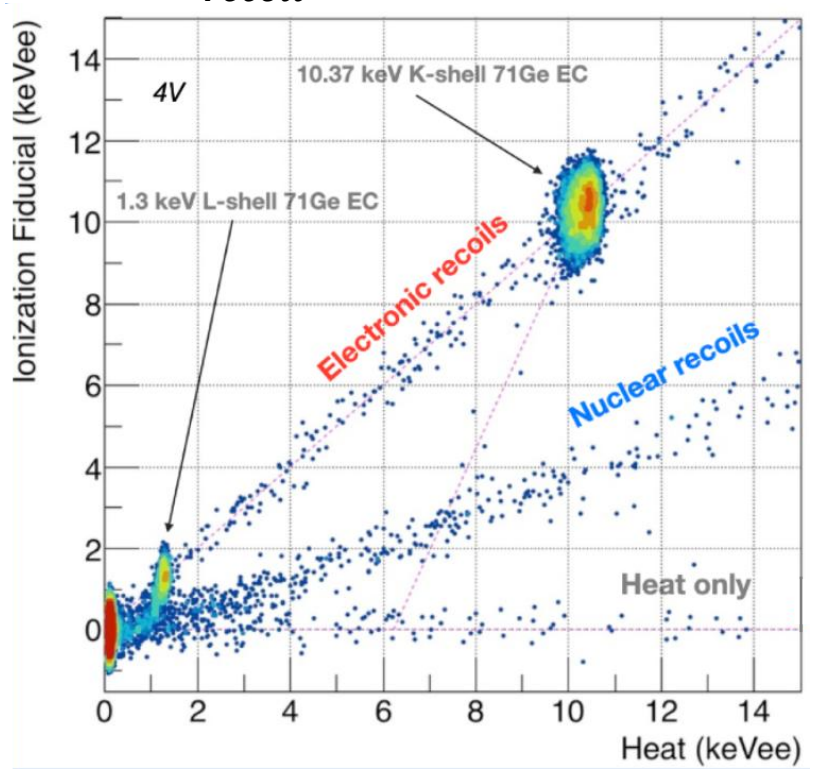
- High – purity Ge crystal
- Thermal sensor (ex: NTD-Ge → R = $R_0 \cdot \exp\left(\sqrt{\frac{T_0}{T}}\right)$)
- Thermal bath (~ 15mK)
- Al electrodes, for the charge collection AND readout

$$E_{total} = E_{recoil} + E_{NTL} = E_{recoil} + \frac{1}{\varepsilon_{Ge}} E_{ion} \Delta V$$

B. S. Neganov and V. N. Trofimov, Otkryt. Izobret., 146, 215 (1985)
P. N. Luke, J. Applied Phys. 64,6858 (1988)

Discrimination of Nuclear/Electronic Recoils

Quenching $\mathbf{Q} = \frac{E_{ion}}{E_{recoil}}$

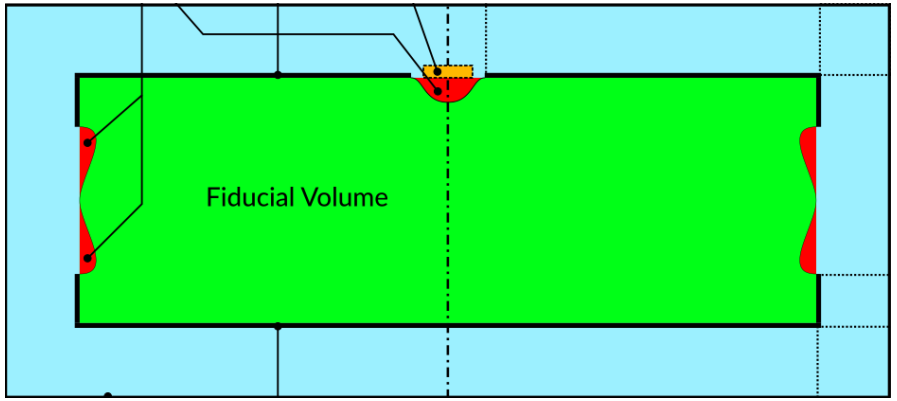


ER (γ/e^-) : Q = 1
NR (n/ν/DM) : Q ~ 0.2 – 0.3

Electrodes Geometry

Two electrode geometries

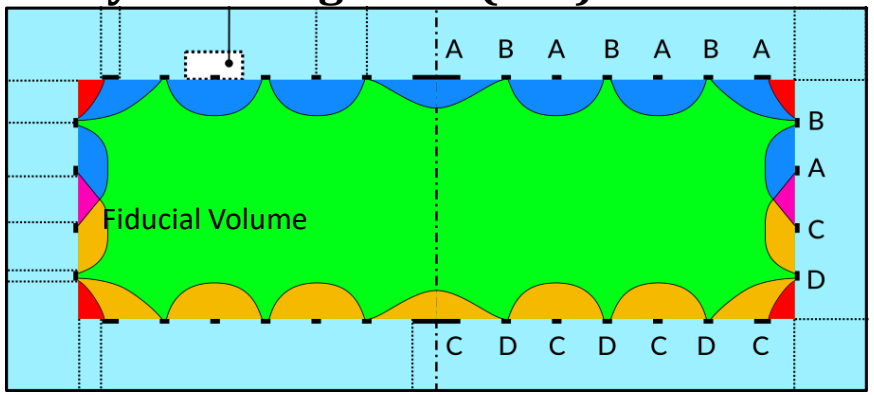
Planar



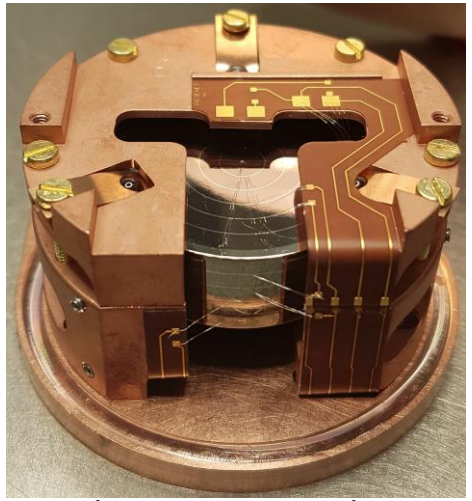
- **No surface** event **rejection**
- 2 fiducial electrodes
- Maximum fiducial volume (~ 100%)

Planar detector in Ricochet

Fully Inter-Digitized (FID)

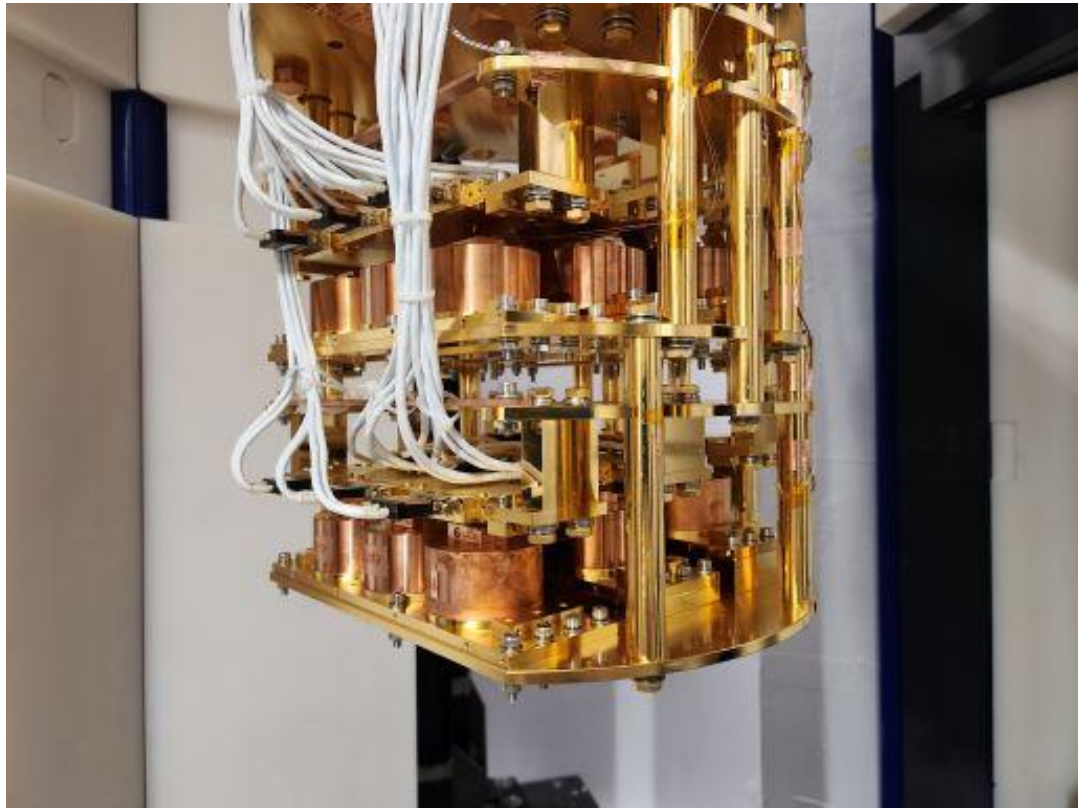


- **Surface event rejection** possible
- 2 veto electrodes + 2 fiducial electrodes
- Reduced fiducial volume

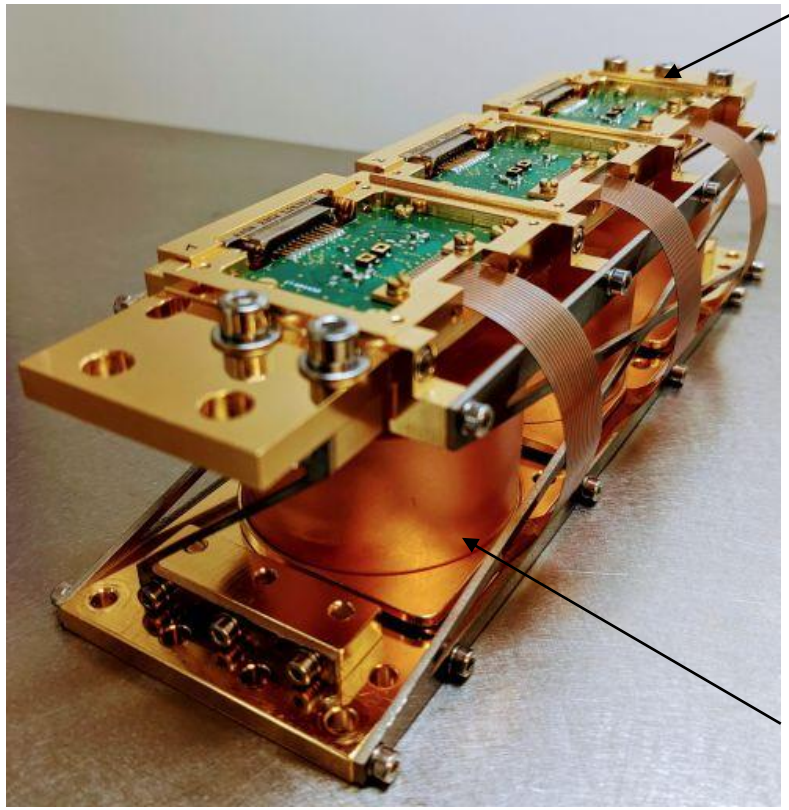


FID detector in Ricochet

The Cryocube



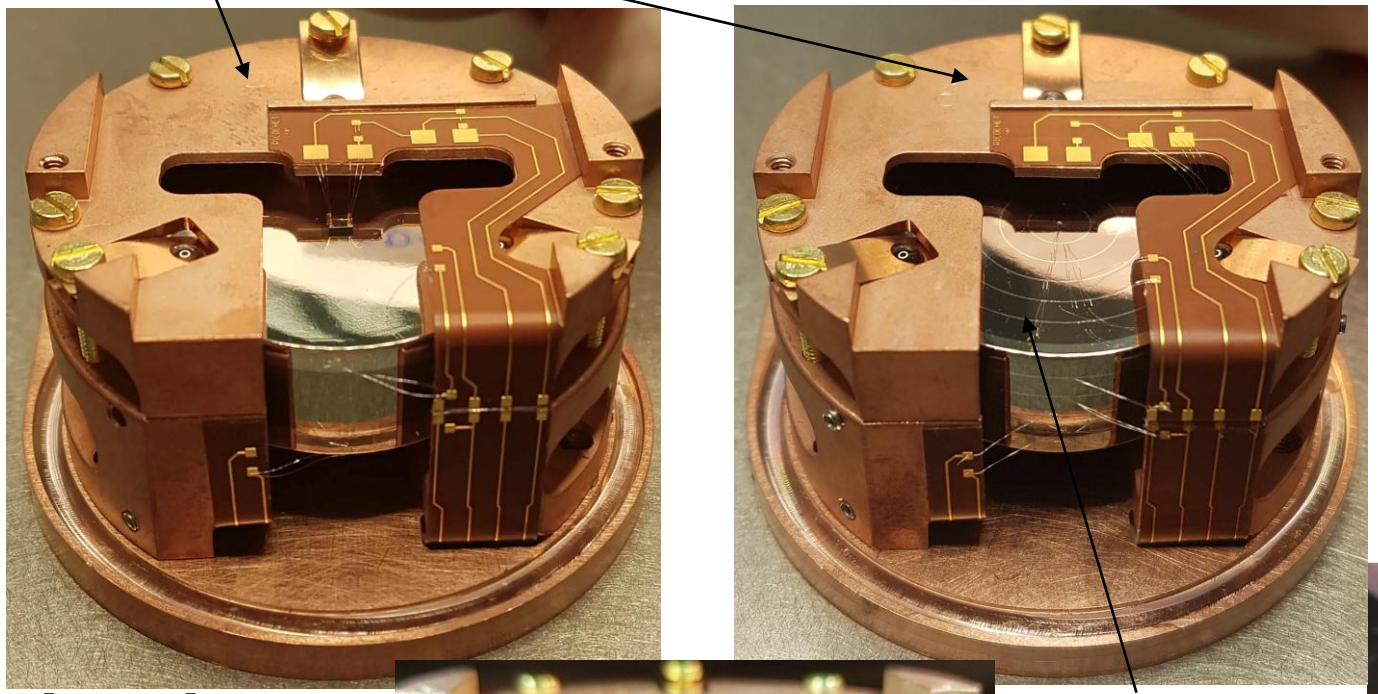
One mini-cryocube



Full Ricochet payload :
18 x 42 g Germanium detectors @ 15mK → Total payload of 750g
6 x Minicryocubes (= array of 3 Germanium)

A Closer Look at the Detectors

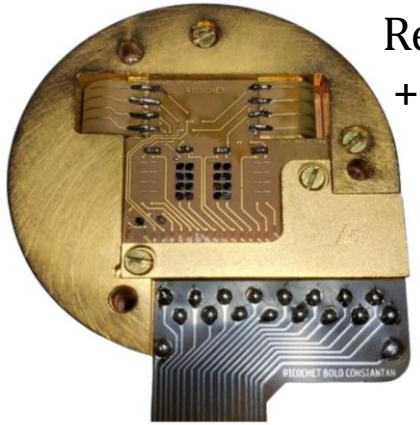
Copper holder

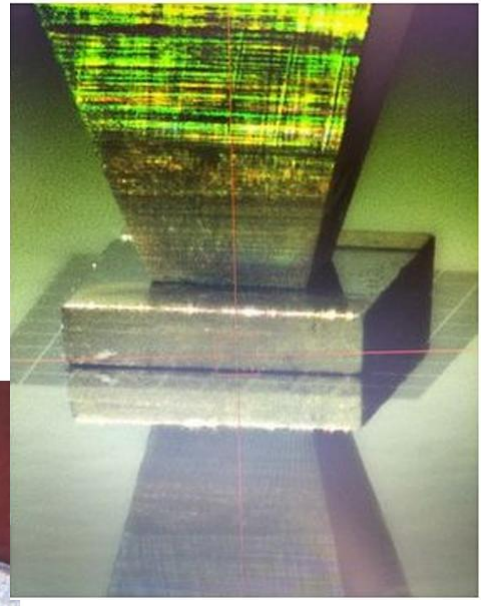


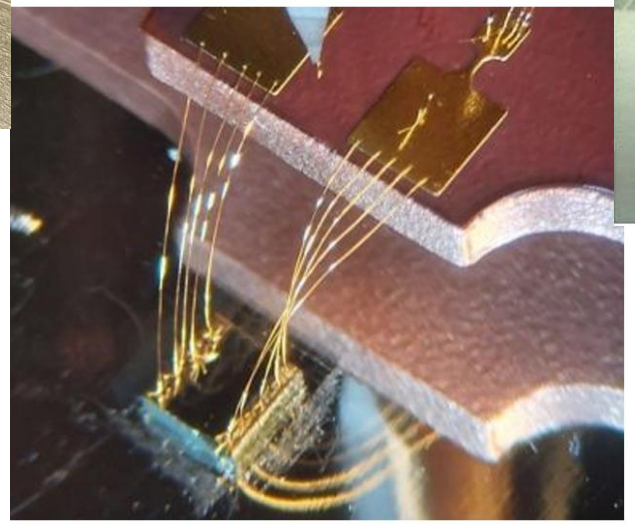
Planar detector

FID detector:
electrodes rings

« Goutte d'eau »
Resistors for NTD
+ electrodes polarization



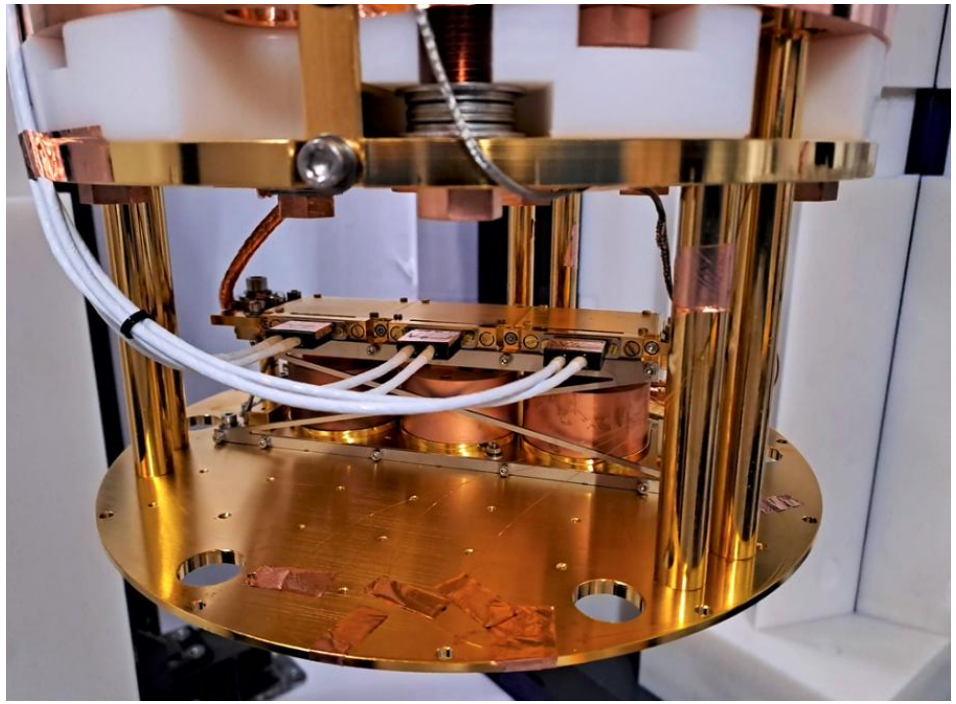




Aluminium electrodes evaporated @ IJCLab

NTD glued on Ge surface @ IP2I

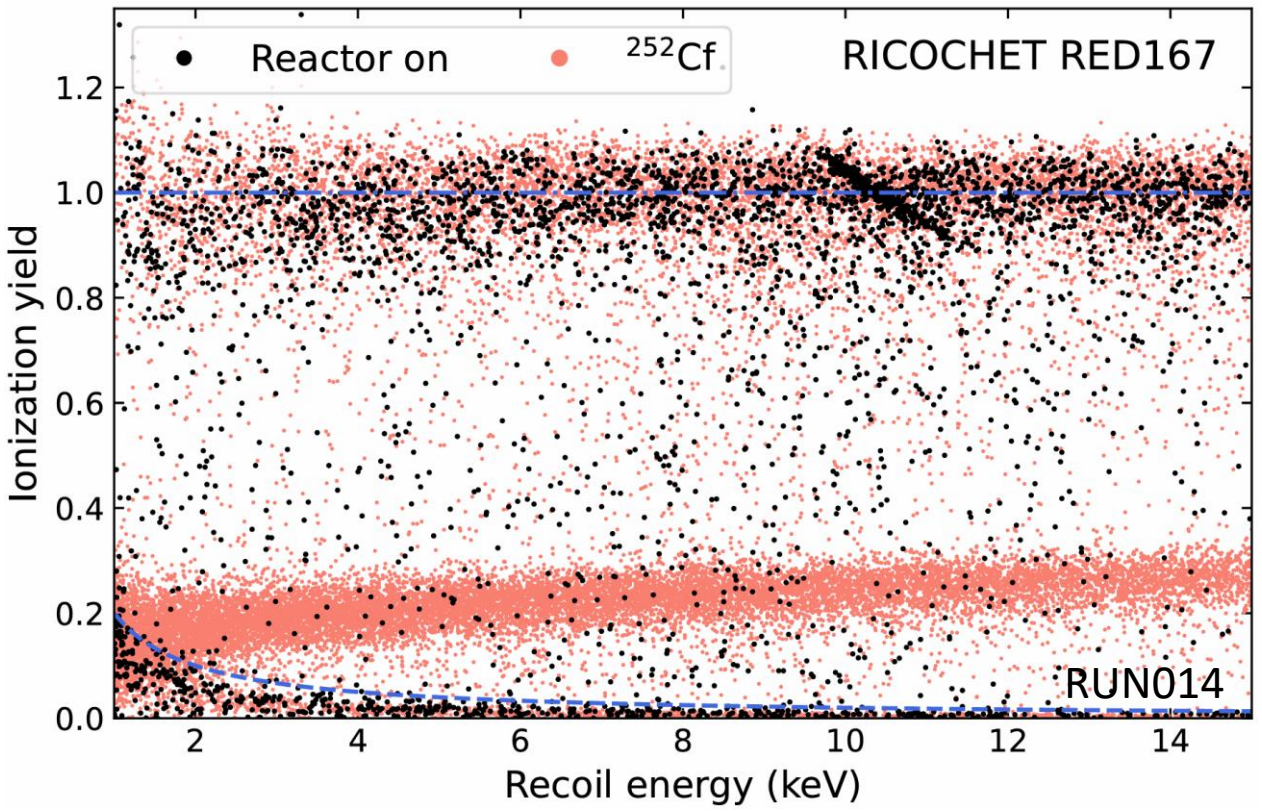
Commissioning Results



RUN013/RUN014: Commissioning with 1 minicryocube (3 planar Ge detectors)

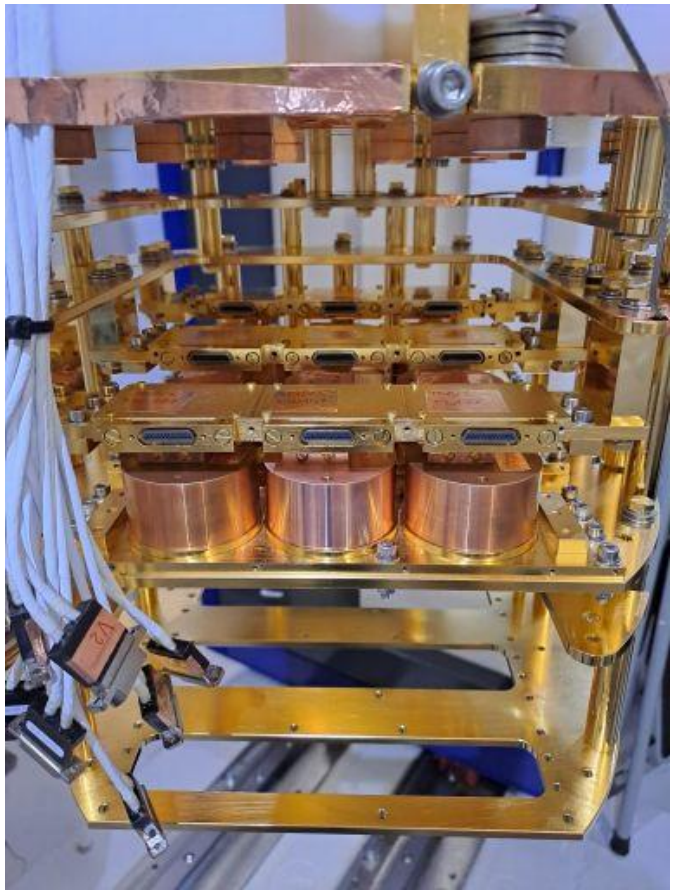
2024

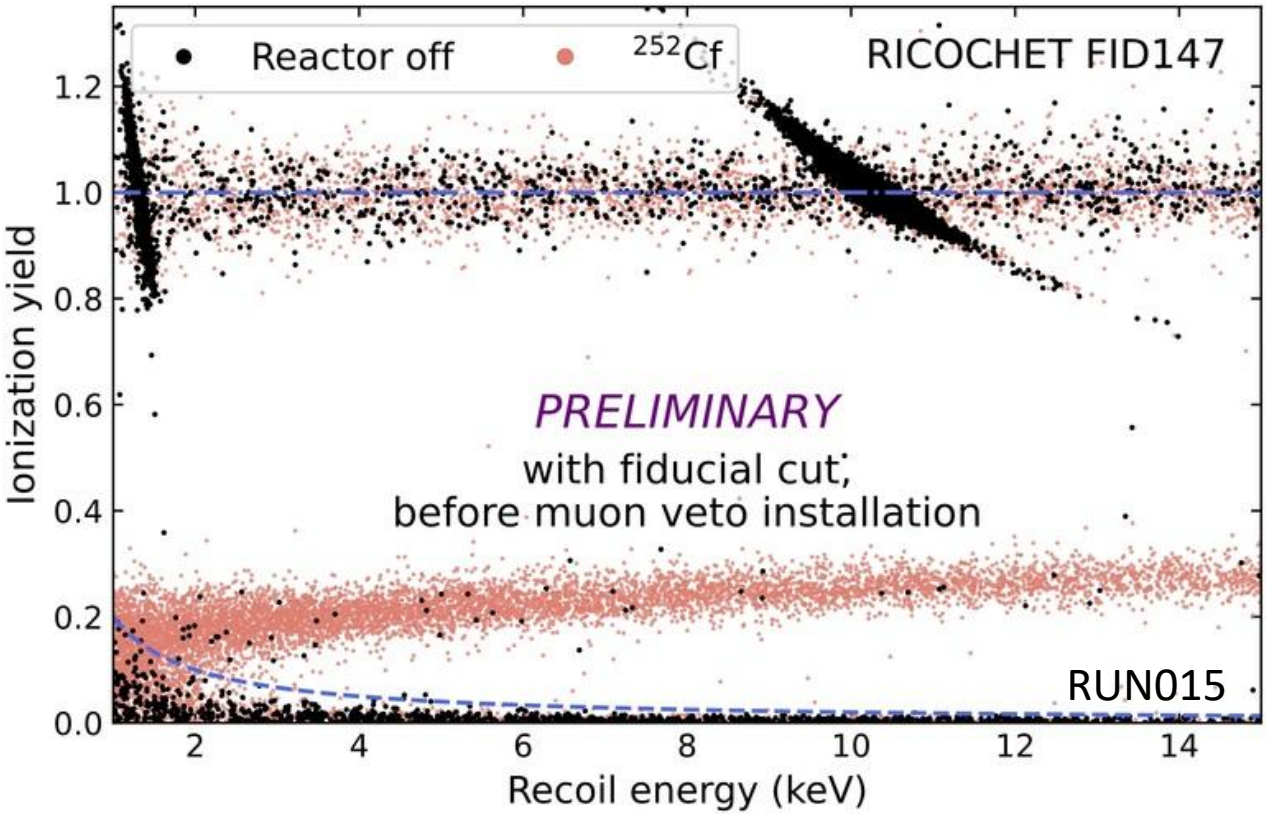
Phys. Rev. D 112, 112019



- NR rates from cosmogenic muons in agreement with G4 simulations
- Resolutions achieved: ion ~ 40 eVee, phonon 50 - 80 eVph
- Observation of surface events between ER and NR

Commissioning Results





- Surface events rejected with FID technology
- Improved resolutions: ion ~ 40 eVee, phonon ~ 30 eVph
- Ongoing studies for CENNS sensitivity estimates

RUN013/RUN014 — **RUN015: 4 FID + 5 PL detectors**

2024 — **01/25 – 06/25**

Science Runs

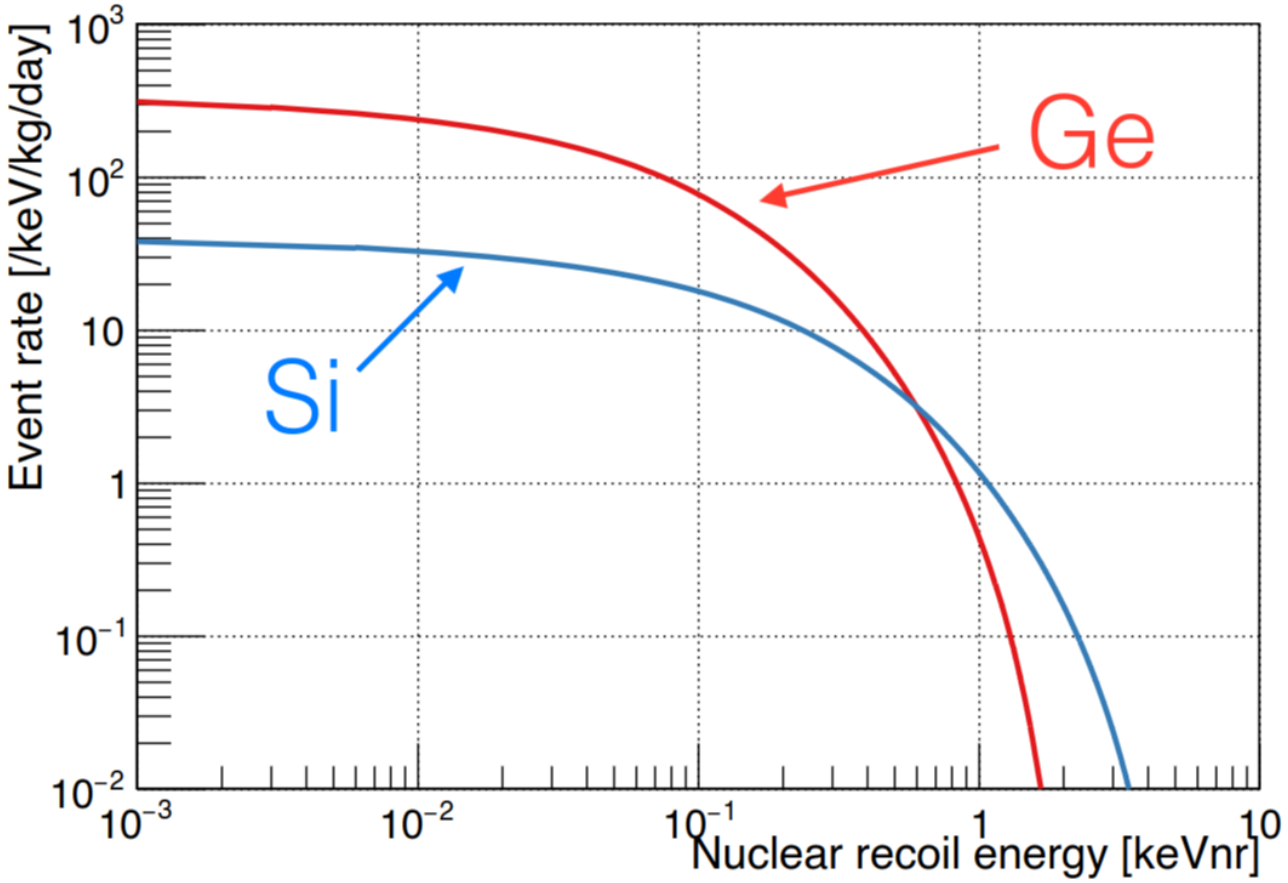
- Successfull operation of 18 detectors (11FID + 7PL) simultanenously
- Science runs with blinded analysis started in Summer 2025
- More analysis to come!

RUN013/RUN014 — **2024**

RUN015 — **01/25 – 06/25**

RUN016/RUN017: First science data taking — **Since 07/25**

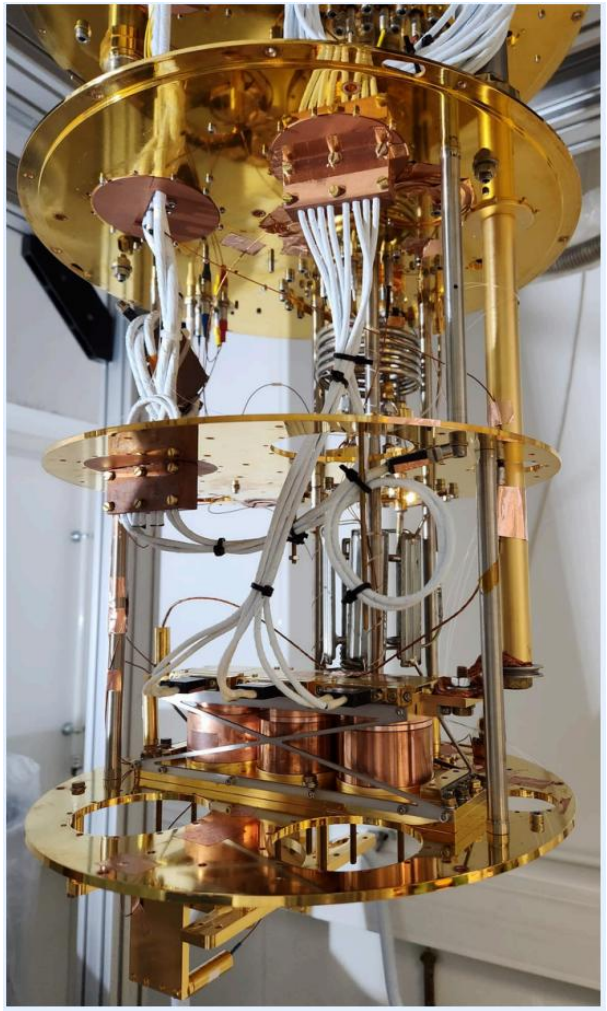
Next : Silicon detectors

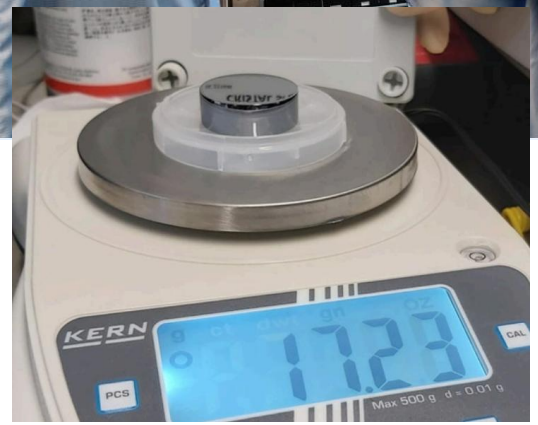


- Lower rate for Si than Ge, but **higher nuclear recoil energy**
- Good complementarity: comparison of Si/Ge results and test of $\sigma \propto N^2$
- $d_{Si} < d_{Ge}$: need bigger Si crystals to have the same mass (42g)

RUN013/RUN014	RUN015	RUN016/RUN017	**Next phase**
2024	**01/25 – 06/25**	**Since 07/25**	**2026 +**

Next : Silicon detectors





Intense ongoing R&D in Lyon!

First 2 Si planar detectors tested:

- Stable heat and ionisation over time
- Calibration with Am241 source (60 keV) + Fe55 source (5.89 keV, 6.4 keV)

More detectors with FID technology will be tested soon!

RUN013/RUN014 — **2024**

RUN015 — **01/25 – 06/25**

RUN016/RUN017 — **Since 07/25**

Next phase — **2026 +**

Conclusion

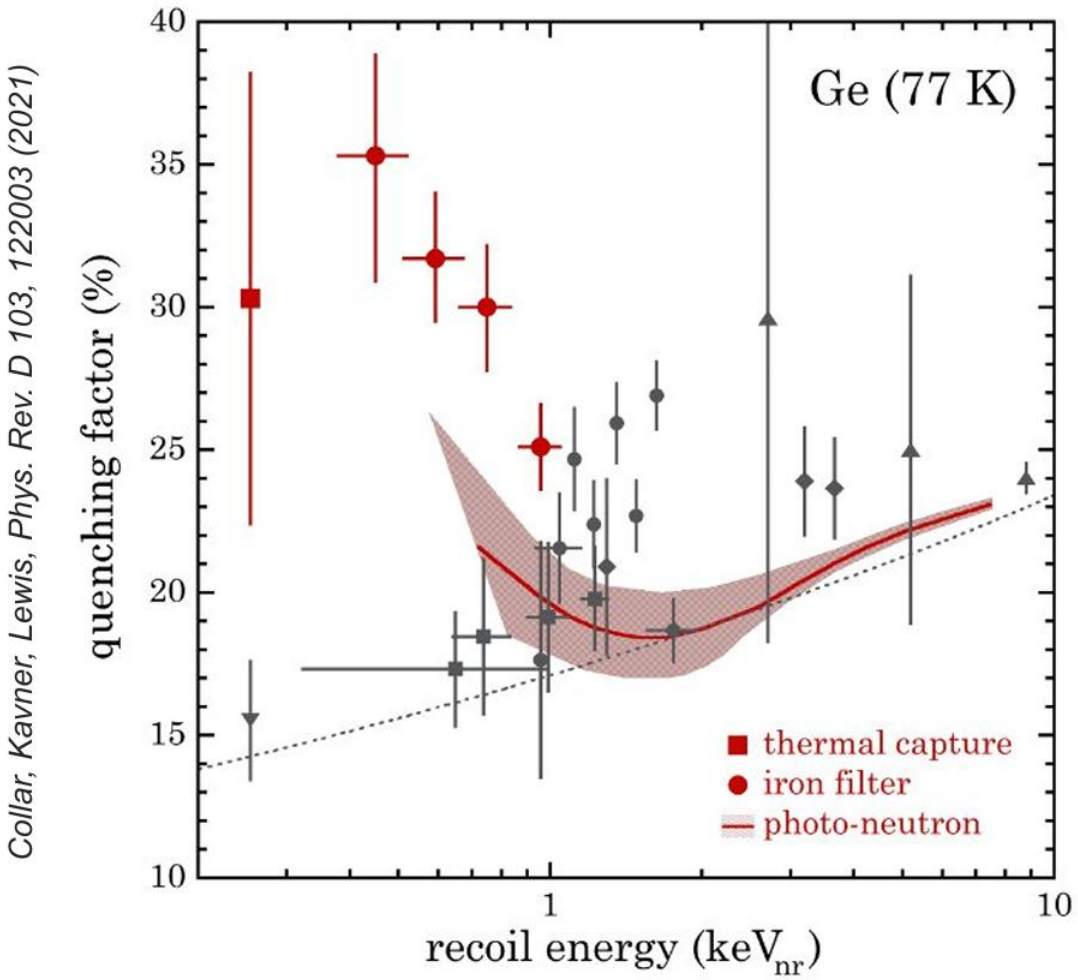
- Ricochet commissioning succesfully achieved
- Science phase started Summer 2025 with 18 Ge detectors for first CENNS physics
- Next phase to come with Si target

RICOCHET
A Coherent Neutrino Scattering Program

Thank you !

BACKUP SLIDES

Quenching



Collar, Kavner, Lewis, Phys. Rev. D 103, 122003 (2021)

Recent measurement of quenching factor at low energy seem to be incompatible with Lindhard model

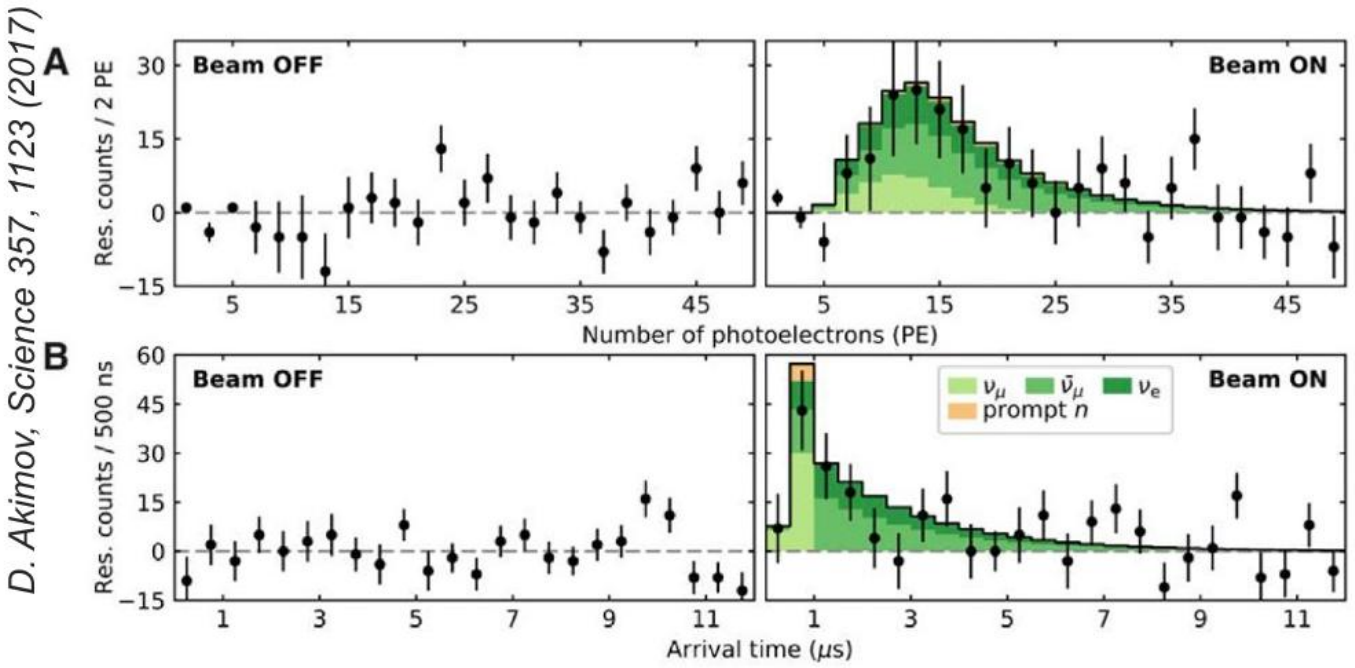
→ Necessity of our own quenching measurement onsite

→ Use a Californium source to have nuclear recoils

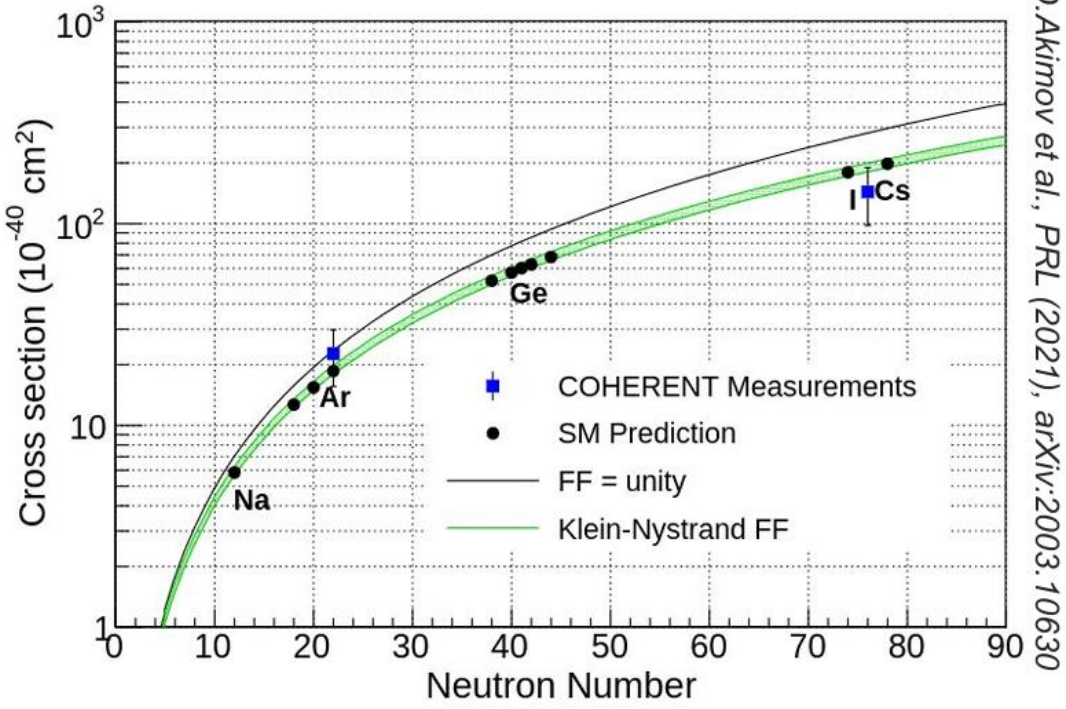
→ Data analysis of RUN014 Cf data ongoing

First CENNS measurement by COHERENT

First measurement by the COHERENT collaboration in 2017 with accelerator neutrinos
Using different targets to measure the CENNS cross-section dependency with N^2

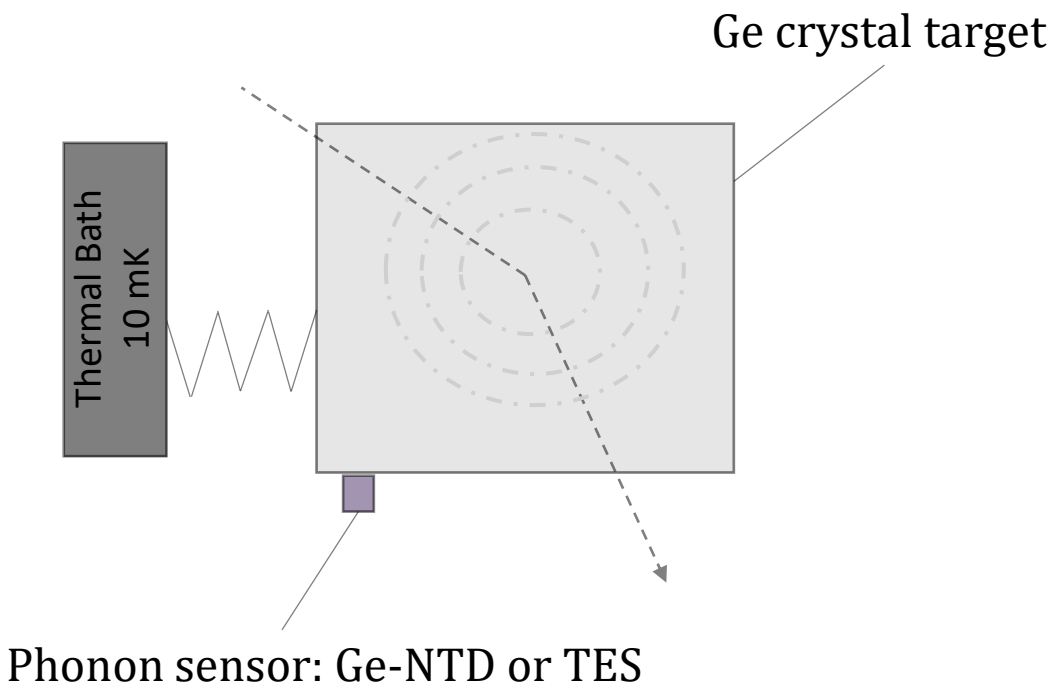


D. Akimov, Science 357, 1123 (2017)



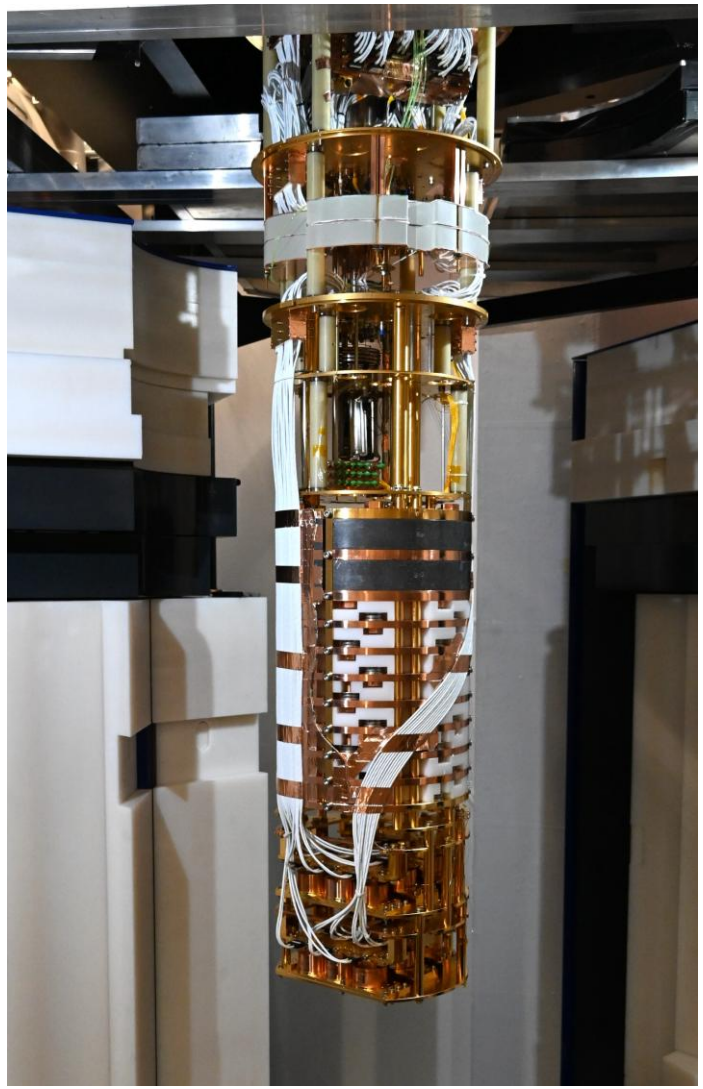
D.Akimov et al., PRL (2021), arXiv:2003.10630

Cryogenic Calorimeter



$$\Delta T \propto \frac{\Delta E}{T^3} \rightarrow \text{Calorimeters cool down to} \sim 15\ \text{mK}$$

$$\text{Ge-NTD: } R(T) = R_0 \exp\left(\sqrt{\frac{T_0}{T}}\right)$$



- **Exquisite energy resolutions**
- **Low energy threshold**