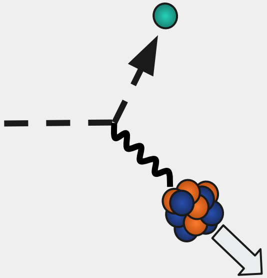
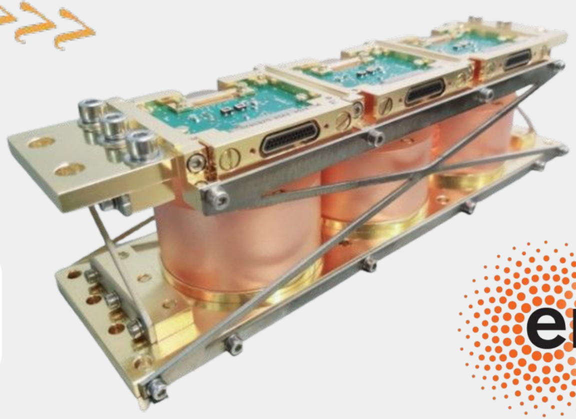
# CryoCube detector technology for RICOCHET



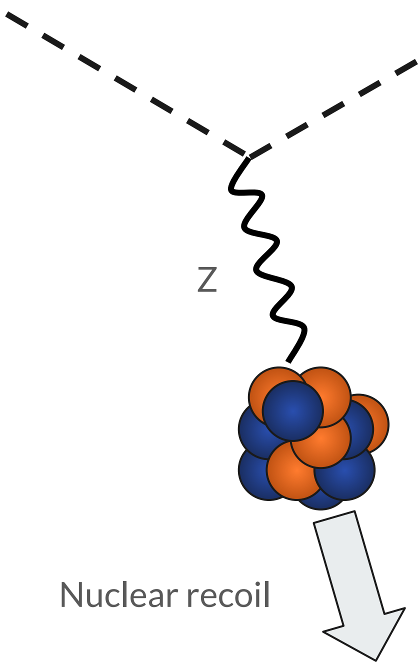
GDR DI2I 2025 - 19/06/2025

A. Armatol on behalf of the RICOCHET collaboration

GDR-DI2I
Groupement De Recherche
Détecteurs et Instrumentation pour les 2 Infinis



# The Coherent Elastic Neutrino-Nucleus Scattering



**The Coherent Elastic Neutrino-Nucleus Scattering (CE$\nu$NS)** is possible for low energy neutrinos (< ~50 MeV)

The neutrino interacts with the nucleus as a whole
Dominant low energy neutrino interaction!

Predicted 1974 and detected for the 1st time in 2017* with CsI[Na] detectors and in 2024** on Ge by COHERENT

*doi.org/10.1126/science.aao0990 **https://arxiv.org/abs/2406.13806

**Experimental signature:** Nuclear recoil energy

$$E_r^{\max} \sim \frac{2E_\nu^2}{M}$$

If $E_\nu$=1 MeV, $E_r^{max}$ ~ 30 eV in Ge

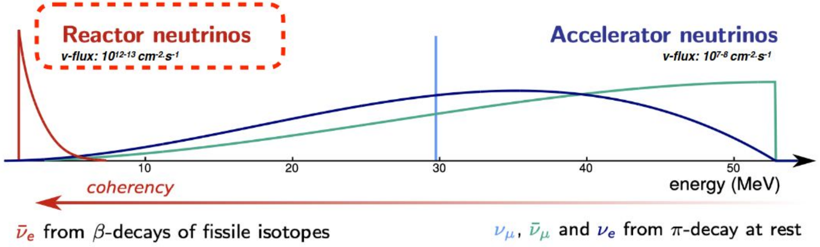
But a really tiny signal...

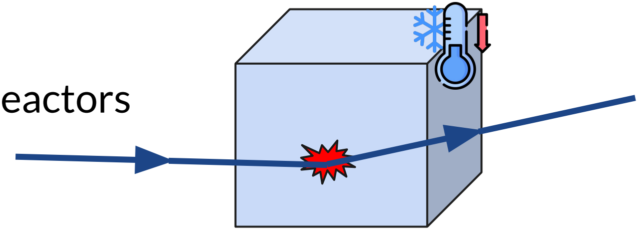
# How to observe it?

**Needs :**

- A large low energy neutrino flux
- A background under control
- Low energy threshold detectors

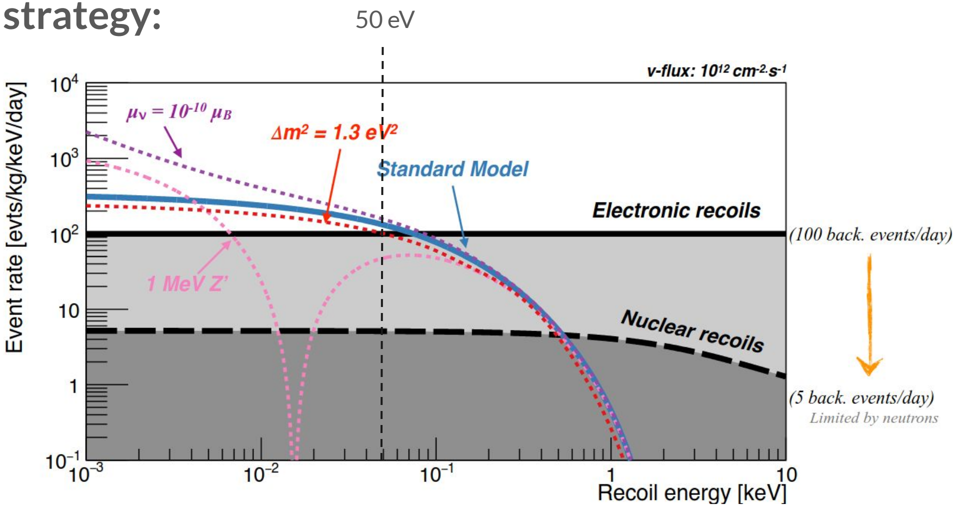
RICOCHET strategy:





ν from reactors

Cryogenic target



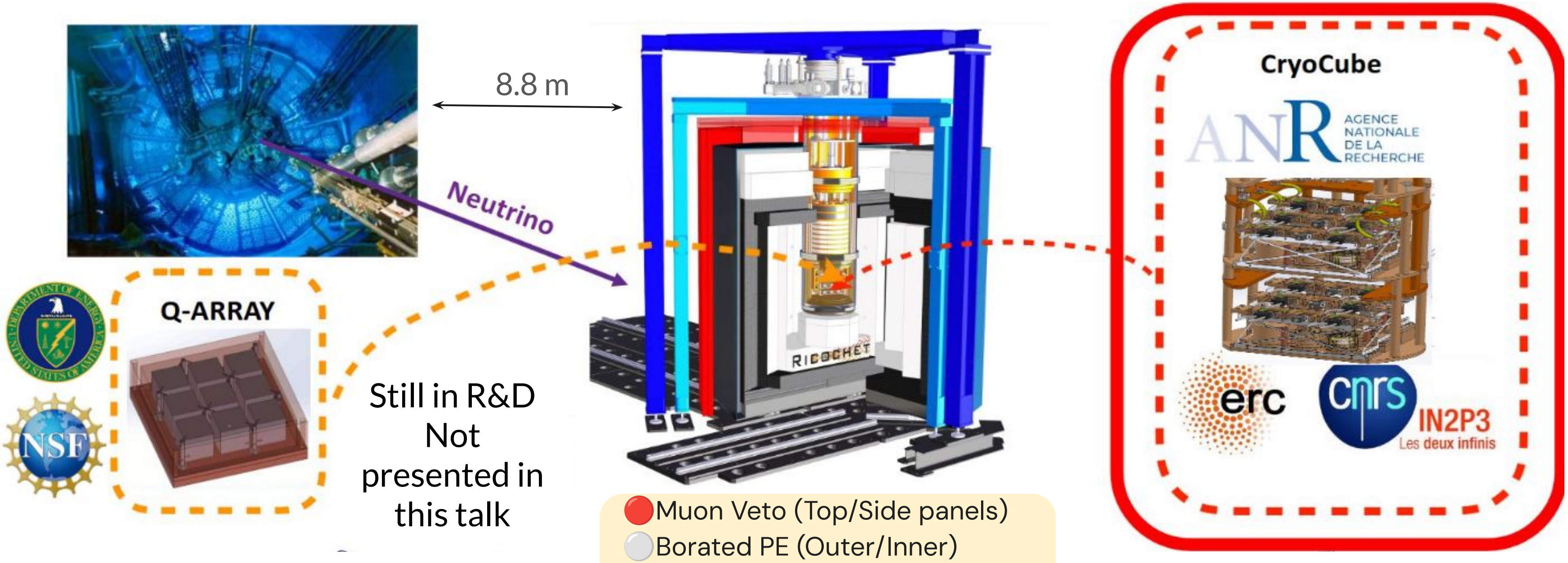
***Estimation of CEvNS Rate for Ge Ricochet Detectors @ ILL***

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

# The RICOCHET experiment

RICOCHET is a France, USA, Canada and Russia wide collaboration

**@ ILL in Grenoble, FR** 58 MW → $1.2\text{x}10^{12}\ \nu/(\text{s.cm}^2)$ so a CEvNS rate of ~ 11 events/day/kg with a 50 eV threshold

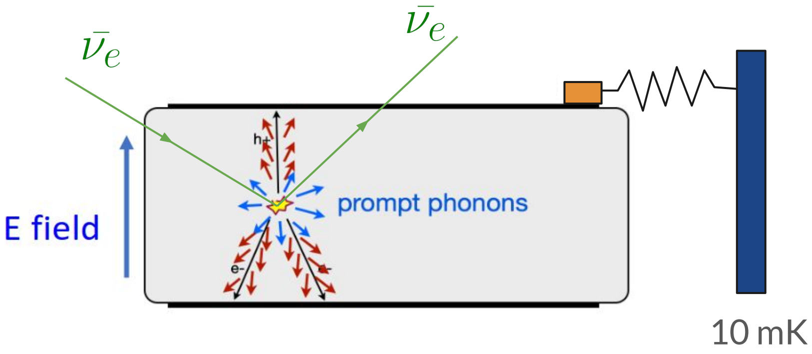


Still in R&D
Not presented in this talk

- 🔴 Muon Veto (Top/Side panels)
- ⚪ Borated PE (Outer/Inner)
- ⚫ Lead Shielding
- 🔵 Decoupled Frame

Ready to take Physics data!

# Detector technology



- **Cryogenic detectors** operated around 10 mK

- High-purity Ge crystal with Al electrodes evaporated on the surface

- **Double readout: heat + charges**
  **→ Electron recoil discrimination**

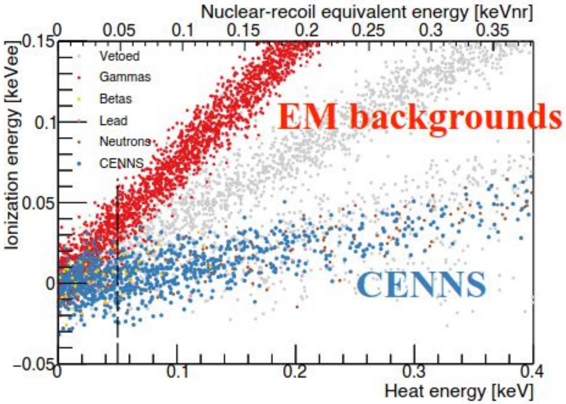
⬜ High-purity Ge crystal

🟧 Thermal sensor (ex: NTD-Ge → $R = R_0 \cdot \exp\left(\sqrt{T_0/T}\right)$ )

🟦 Thermal bath (around 10 mK)

⬛ Al electrodes, for the charge collection AND readout

$$E_{total} = E_{recoil} + E_{luke}$$
$$= E_{recoil} + \frac{1}{3\ eV} E_{ion} \Delta V$$



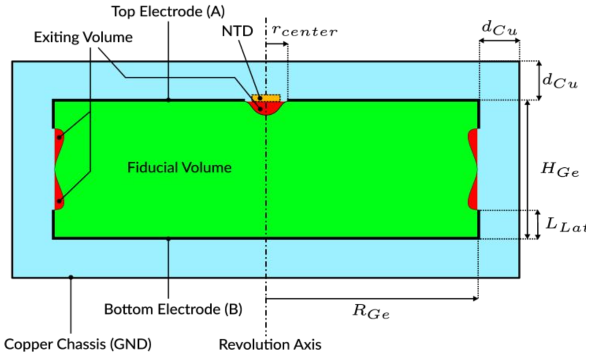
$$Q = \frac{E_{\text{ion}}}{E_{\text{recoil}}}$$

Q=1 for ER (ɣ,β)

Q~0.3 for NR
(Neutrons, CE$\nu$NS, WIMPS)

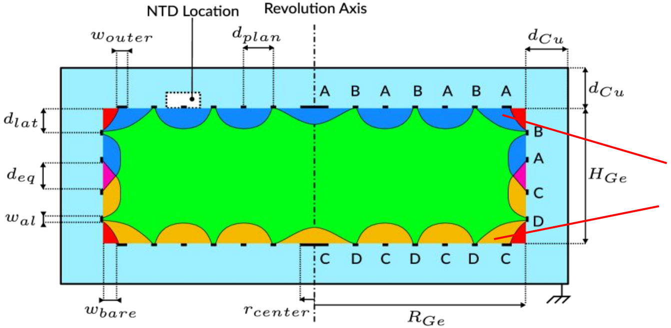
# Electrode designs

## Planar (PL)

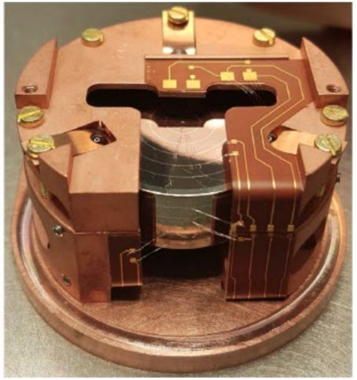


2 ionisation channels
Fiducial volume ~99%

## Fully Inter-Digitized (FID)



Veto electrodes



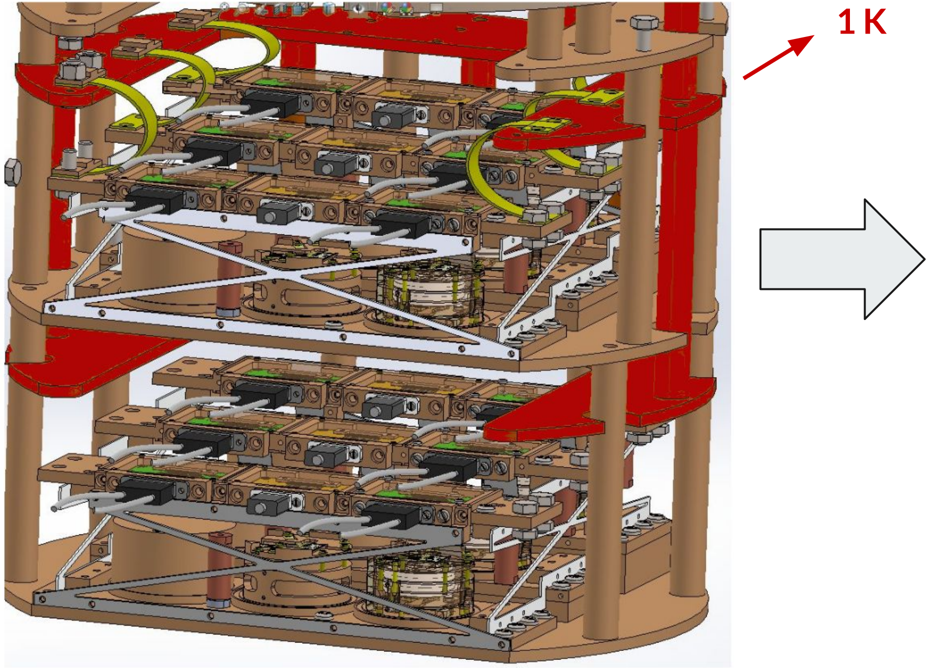
4 ionisation channels
Fiducial volume ~70%

Surface events rejection!

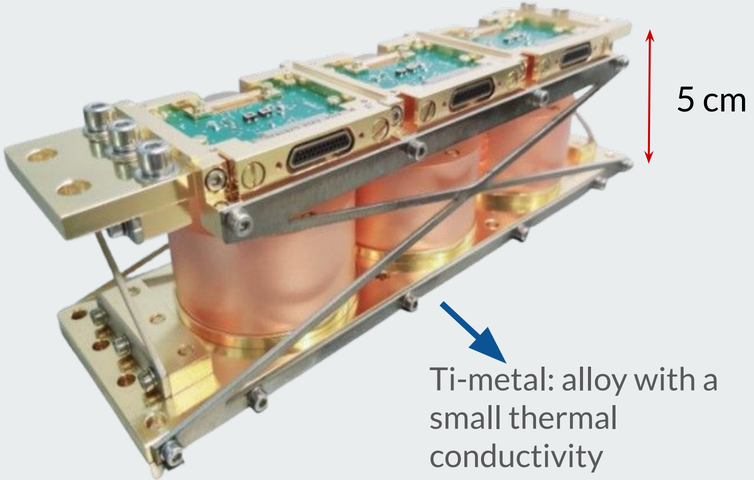
# The CryoCube

**18 detectors** of 42 g each @ 10 mK → **Total payload: 750g**

Assembled per 3 in a sub structure called “Mini-CryoCube”



## MINI-CryoCube



1 K stage: charge preamplification

10 mK stage: detectors

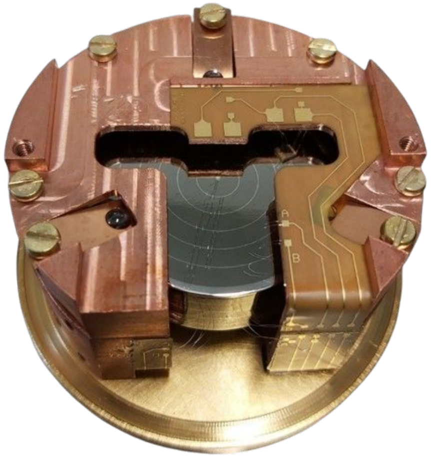
Ti-metal: alloy with a small thermal conductivity for mechanical support **NOT NEEDED IN THE CRYOCUBE**

Power dissipated between the two stages: 1 μW

# MINI-CRYOCUBE: Main ingredients

10 mK

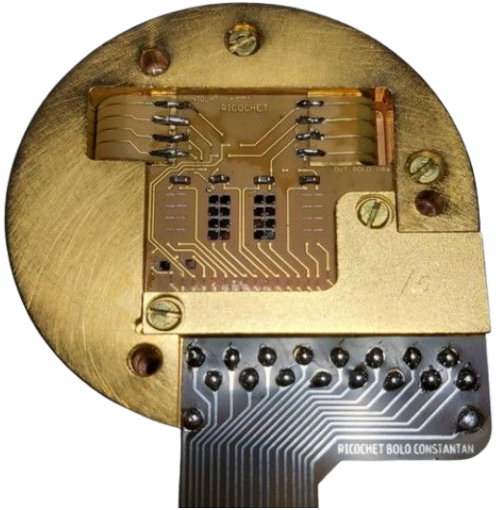
Detector support x3



- Host the Ge crystal
- Bondings from electrodes/NTD to Au traces

+

“Goutte d’eau” x3
(Water drop or tear)

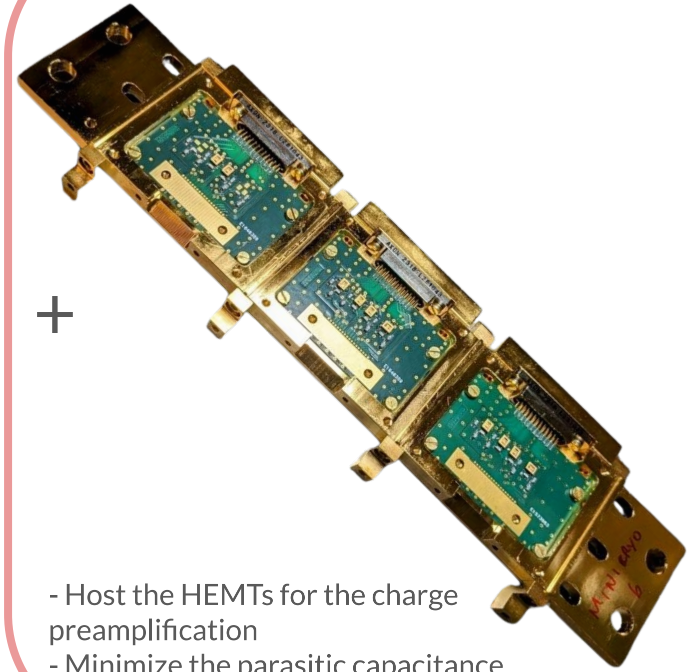


- Where the resistors for NTD and electrodes polarization are
- Host also the decoupling capacitors

+

1 K

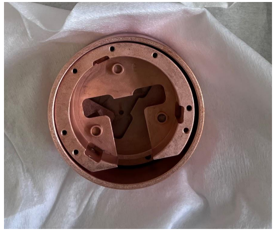
1K stage



- Host the HEMTs for the charge preamplification
- Minimize the parasitic capacitance

# Detector support

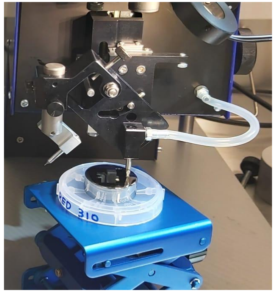
## Support preparation

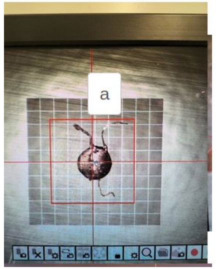

Cleaning with US bath and acidic soap
(some were also chemically etched before)

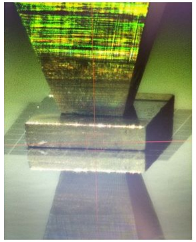

Gluing of the kapton with the Au/Cu traces using Epoxy

## Crystal preparation

- Al electrodes evaporated @ IJCLAB
- Gluing of the NTD done in Lyon

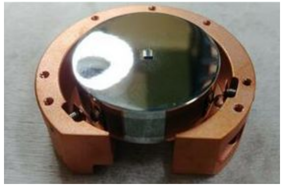


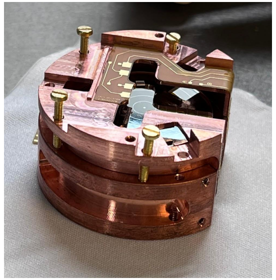




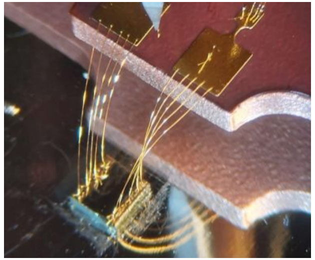
## Mounting in the support

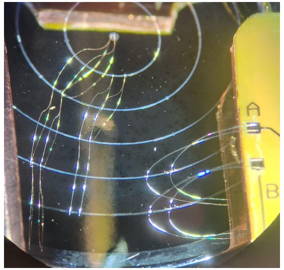
The crystal is resting on 3 sapphire balls and held by 3 others on the side and 3 on the top





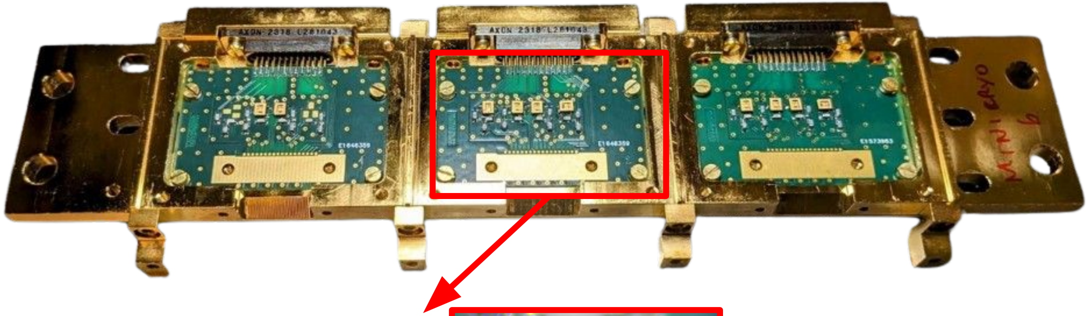
## Finally… bondings!

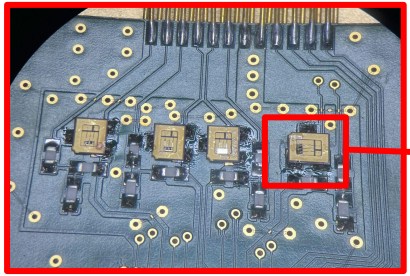

Au wires for the NTD

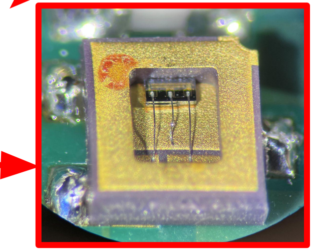


Al wires for the electrodes

# 1K stage





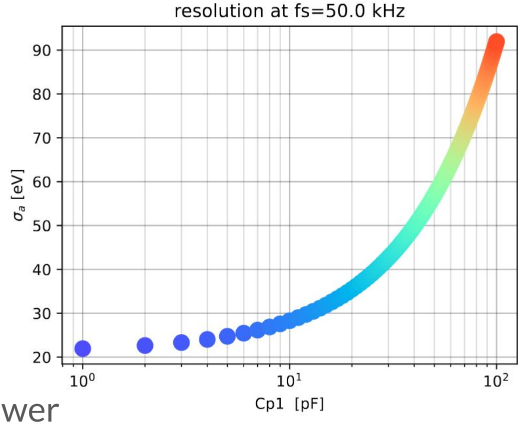


Produced by CryoHEMT
*https://cryohemt.com/*

- Unlike Si-JFETs used for the heat channel, **HEMTs can be operated at temperatures <50K**

- Having them the closest possible to the detectors allows the **minimization of the parasitic capacitance**

- **Better energy resolution!**

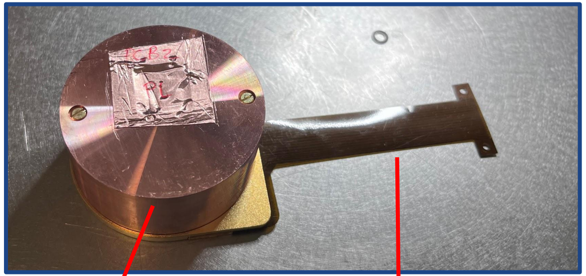


Currently, Cp~25pF

*J. Colas's thesis*
*NT : 2023LYO10238.*
*tel-04682128*

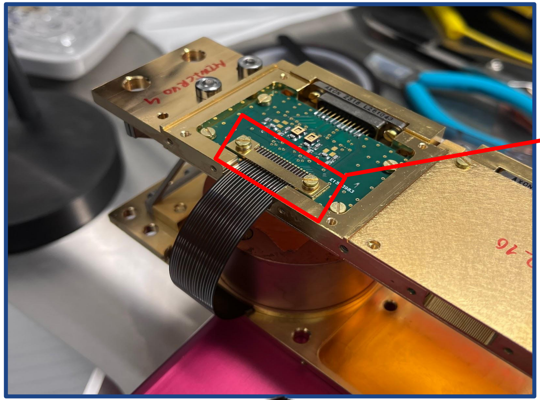
~ 20 uW dissipated per HEMT,
→ Total for the full RICOCHET payload: ~1.2 mW
Needs to be operated at 1K where there is more cooling power

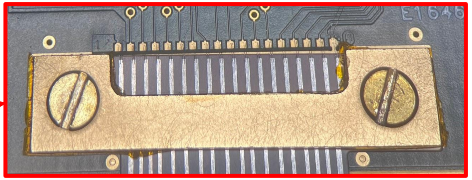
# Detector integration in the MINI-CryoCube



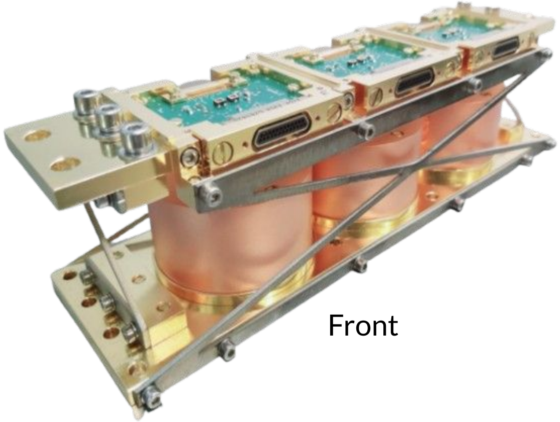
Anti-IR cap

10mK to 1K kapton
(Polyimide +Constantan leads)





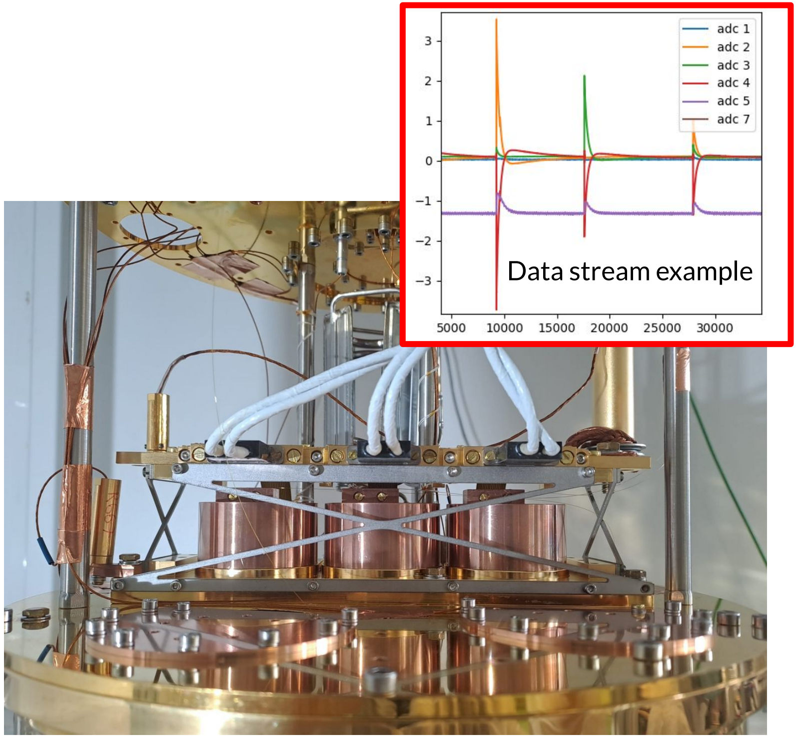
**And… more Al bondings!!**



Front

Back

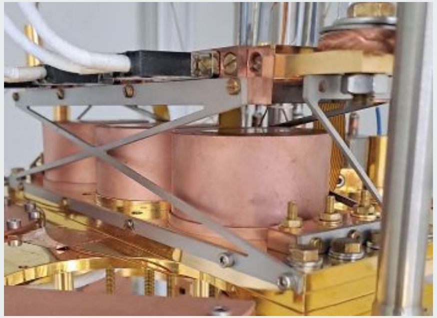
# Detector testing in LYON



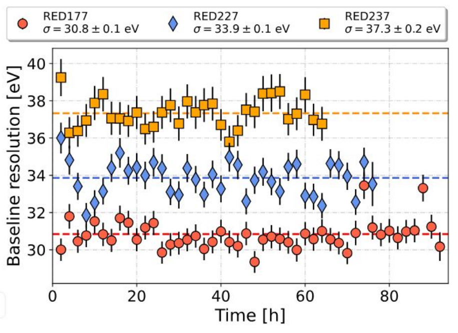
Data stream example

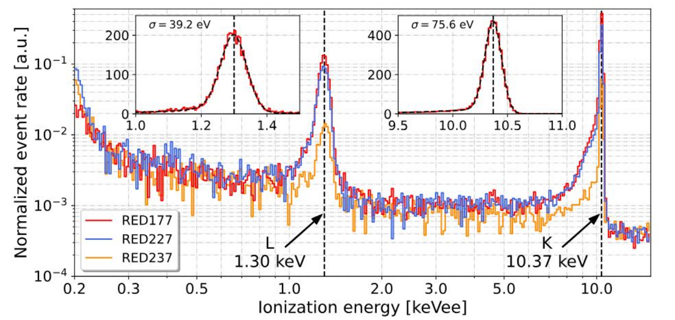
## Major results

30 eV ionisation energy resolution obtained in 2023 !!



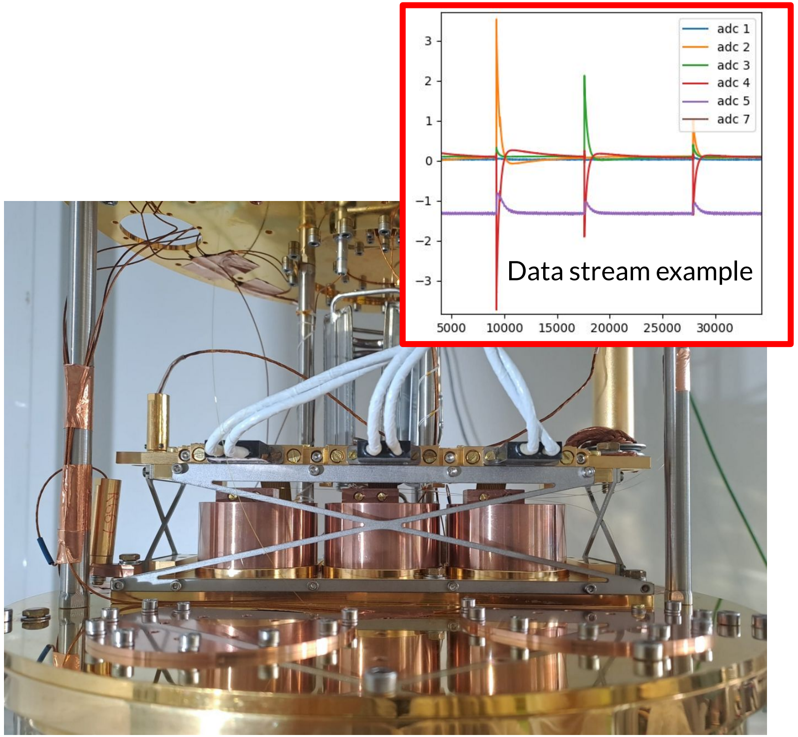
Three PL detectors





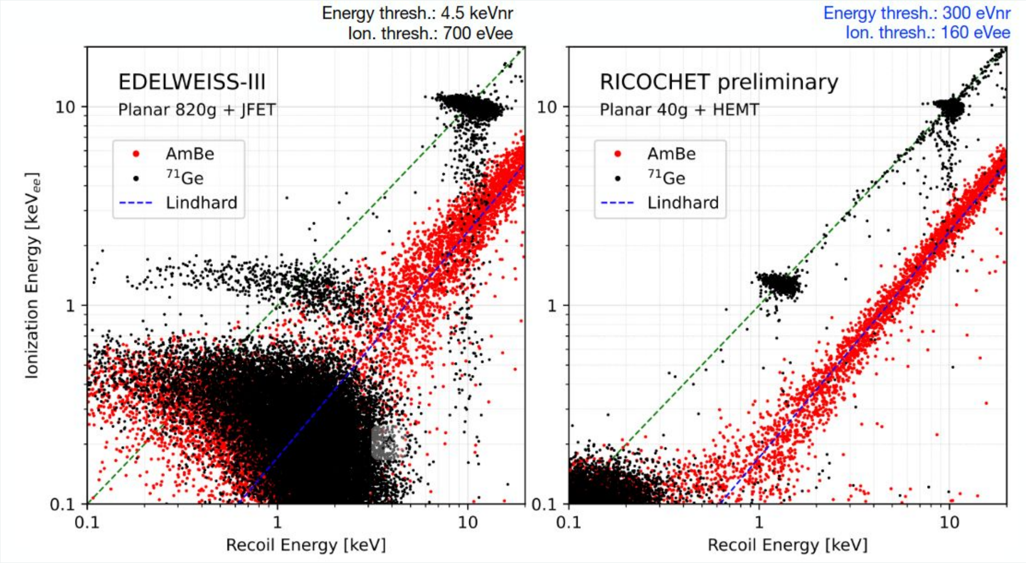
*Eur.Phys.J.C 84 (2024) 2, 186 | arxiv:2306.00166*

# Detector testing in LYON



Data stream example

## Major results



**EDELWEISS-III**
820 g Ge crystal
JFET-based charge preamplifier

**RICOCHET**
40 g Ge crystal
HEMT-based charge preamplifier

# Commissioning runs @ ILL

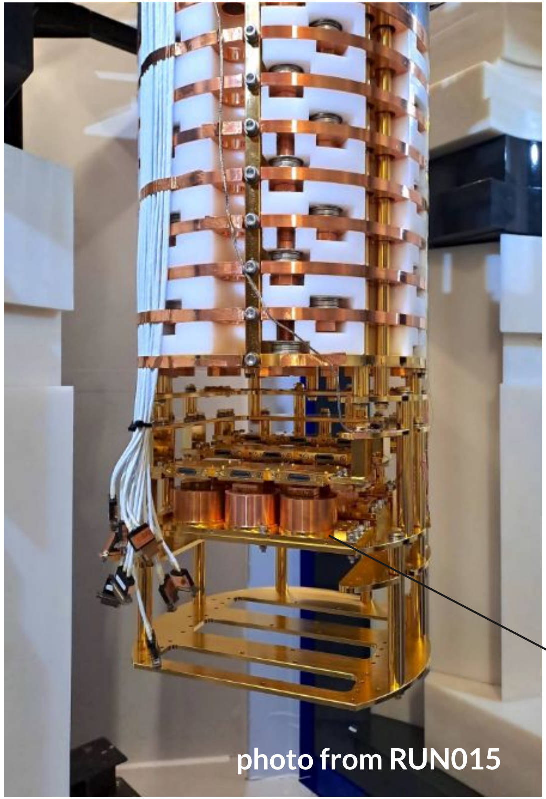
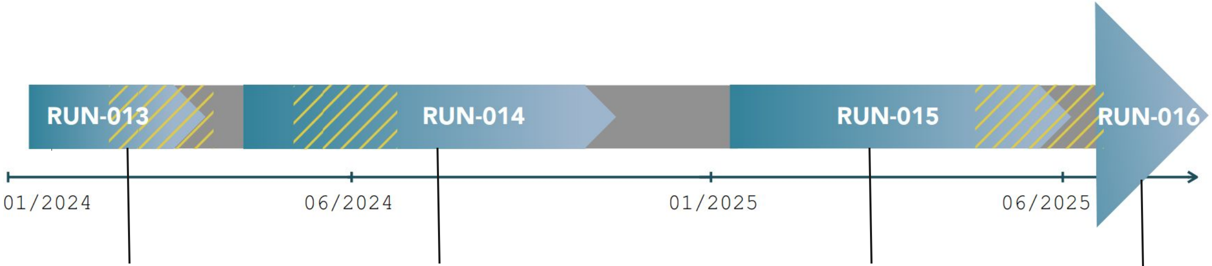


photo from RUN015

- **RICOCHET's cryostat installed @ ILL since end of 2023**
- Several commisionning runs since then to test and optimize the detector performance before the physics data taking



3 PL detectors

3 PL detectors
+ outer muon veto
+ lasers added

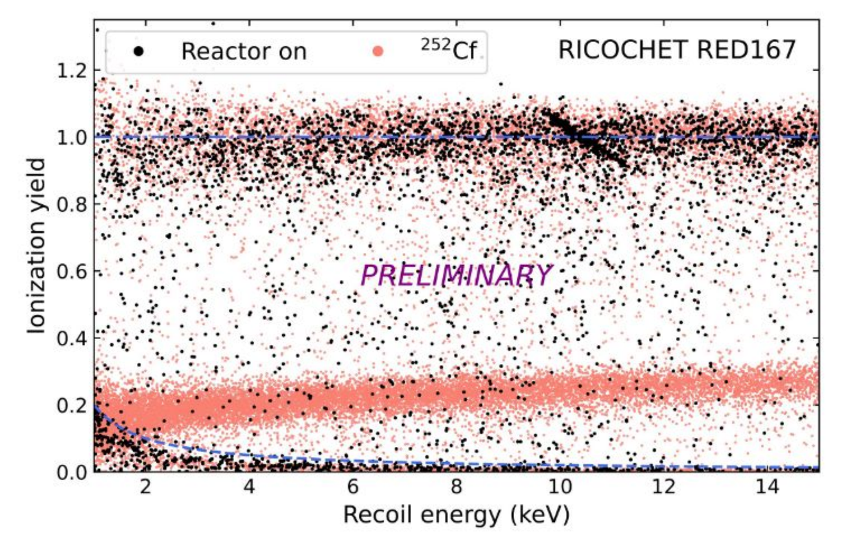
CryoCube structure installed
w/ 9 detectors (6 FID and 3 PL)

No more Ti-metal!

Science run w/ 18 detectors
now in preparation!!
11 FID and 7 PL

# Some recent results…

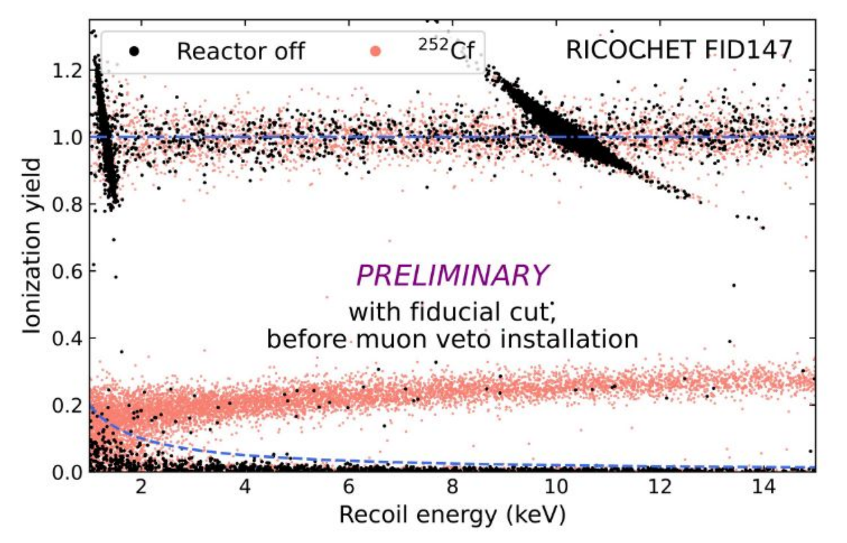
## PL167 during RUN014



$\sigma_{ion}$ ~ 40 eVee $\sigma_{ph}$ ~ 50 eVph

*A paper is under collaboration review*

## FID147 during RUN015



$\sigma_{ion}$ ~ 30 eVee $\sigma_{ph}$ ~ 40 eVph

*Analysis effort still ongoing*

# Thanks for your attention

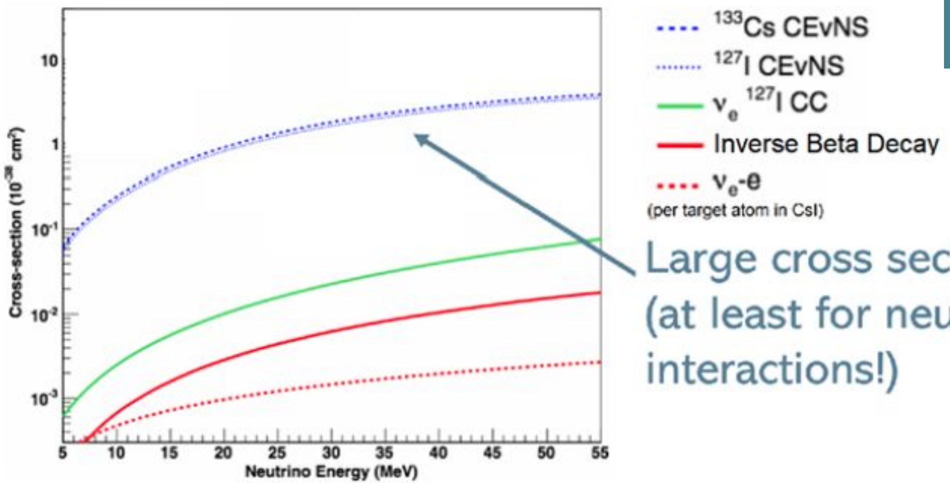
# Back-up

# CEvNS cross section

$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi}\boxed{Q_W^2}M_A\left(1-\frac{M_A T}{2E_\nu^2}\right)\boxed{F(Q^2)^2}$$

Weak Charge component $\propto N^2$

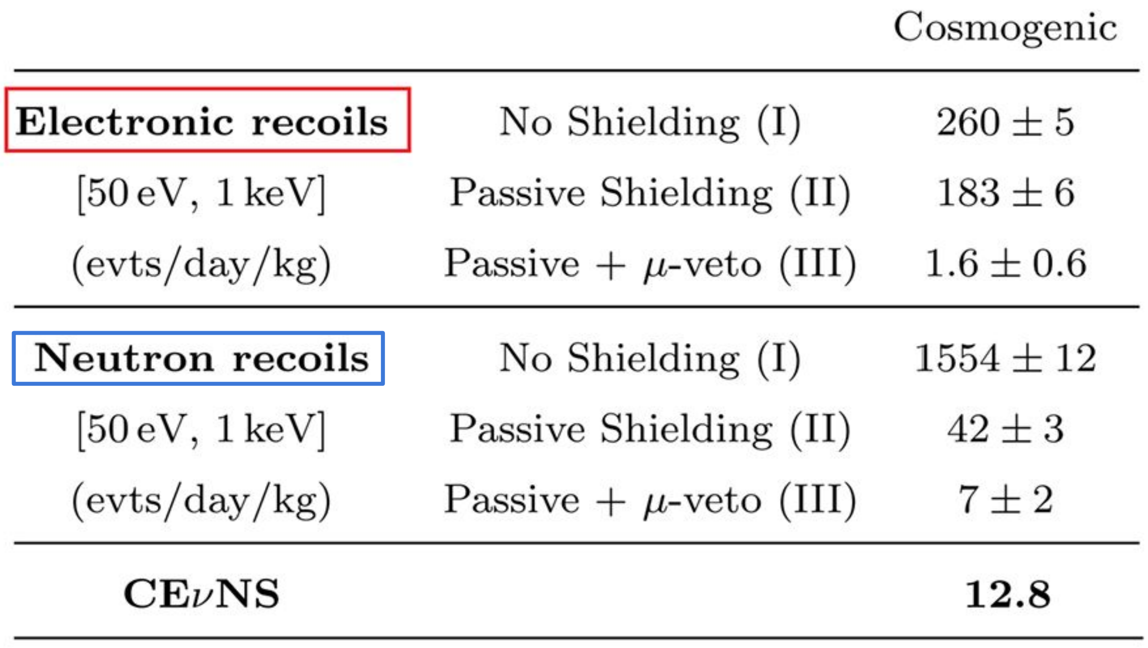
Nuclear Form Factor



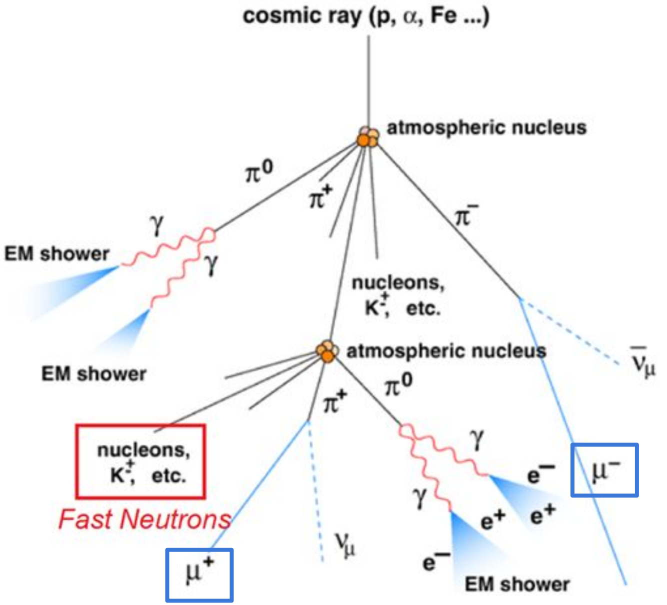
Large cross section, (at least for neutrino interactions!)

$G_F$ = Fermi Constant
$Q_W$ = Weak Charge
$M_A$ = Atomic mass of target
$T$ = Nuclear Recoil Energy
$E_\nu$ = Neutrino Energy
$F(Q)$ = Nuclear Form Factor
$Q = \sqrt{2M_A T}$

# Cosmogenic estimates



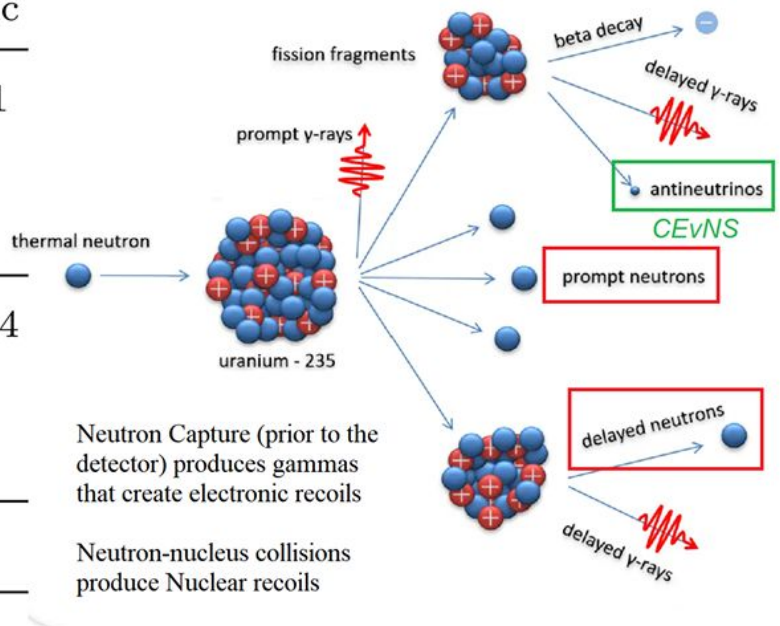
| | | Cosmogenic |
|---|---|---|
| **Electronic recoils** | No Shielding (I) | $260 \pm 5$ |
| [50 eV, 1 keV] | Passive Shielding (II) | $183 \pm 6$ |
| (evts/day/kg) | Passive + $\mu$-veto (III) | $1.6 \pm 0.6$ |
| **Neutron recoils** | No Shielding (I) | $1554 \pm 12$ |
| [50 eV, 1 keV] | Passive Shielding (II) | $42 \pm 3$ |
| (evts/day/kg) | Passive + $\mu$-veto (III) | $7 \pm 2$ |
| **CE$\nu$NS** | | **12.8** |



[RICOCHET Collaboration: arXiv:2111.06745]

# Reactogenic estimates

| | | Reactogenic |
|---|---|---|
| **Electronic recoils** | No Shielding (I) | $4365 \pm 301$ |
| [50 eV, 1 keV] | Passive Shielding (II) | $18 \pm 2$ |
| (evts/day/kg) | Passive + $\mu$-veto (III) | |
| **Neutron recoils** | No Shielding (I) | $53853 \pm 544$ |
| [50 eV, 1 keV] | Passive Shielding (II) | $2.4 \pm 0.3$ |
| (evts/day/kg) | Passive + $\mu$-veto (III) | |
| **CE$\nu$NS** | | **12.8** |

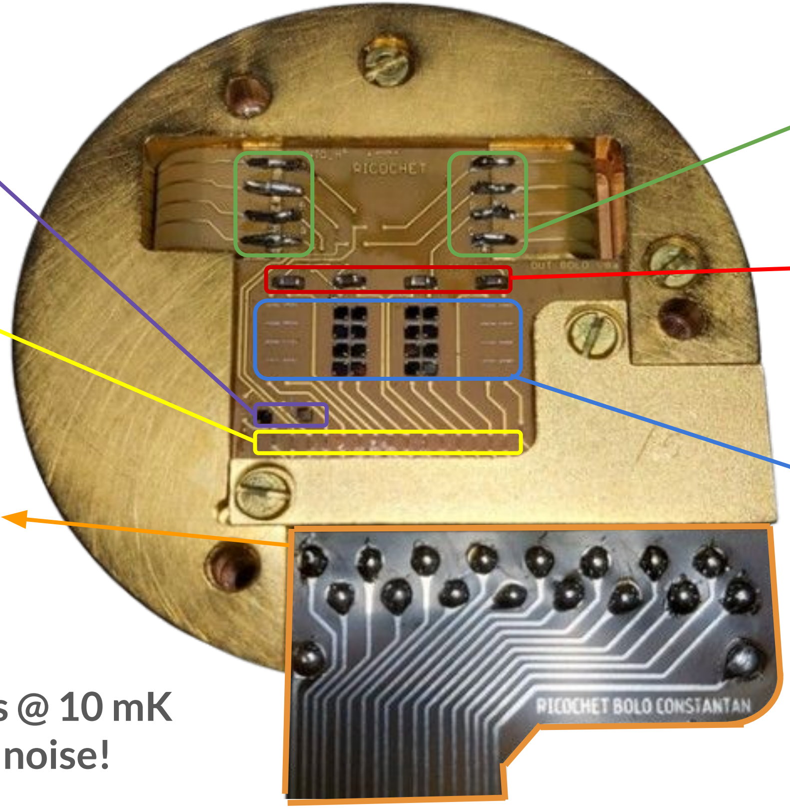


Neutron Capture (prior to the detector) produces gammas that create electronic recoils

Neutron-nucleus collisions produce Nuclear recoils

[RICOCHET Collaboration: arXiv:2111.06745]

# Goutte d'eau



Resistors for the NTD polarization

Al wires: it is an extra precaution to thermally decouple the 1K stage and the 10 mK stage

10 mK to 1K kapton.
It is soldered to the goutte d'eau.

Kapton from the detector support soldered to the goutte d'eau

Electrode decoupling capacitors to separate the polarization circuit from the charge readout

Resistors for the electrode polarization and the passive feedback. Each is ~150 MΩ
Here it is for a planar detector

**Keeping all the resistors @ 10 mK minimize their Johnson noise!**