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RICOCHET

Search for Coherent Elastic Neutrino-Nucleus Scattering with the Ricochet Experiment

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On behalf of the RICOCHET collaboration

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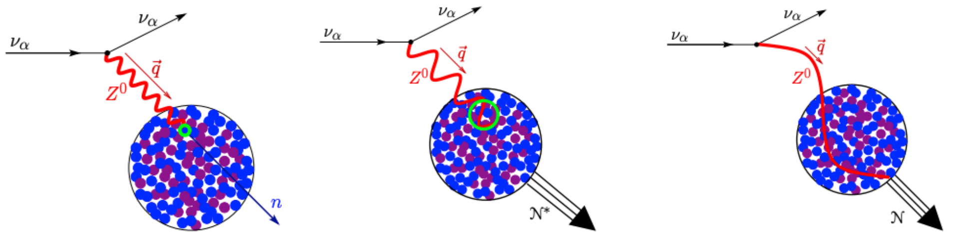
The coherent elastic neutrino-nucleus scattering (CEνNS)

- Originally proposed in 1974 by Daniel Friedman
- Neutrinos interact coherently with all neutrons in the nuclei when the momentum exchanged is smaller than the inverse of the nuclear size
- First observation in 2017 by the COHERENT collaboration



Inelastic incoherent $\lambda_{Z^0} \ll 2R$ | Elastic incoherent $\lambda_{Z^0} \lesssim 2R$ | Elastic coherent (CEνNS) $\lambda_{Z^0} \gtrsim 2R$

CEvNS: Differential cross section

E_ν: neutrino energy
E_r: nuclear recoil energy

m_N: nuclear mass
G_F: Fermi constant

$$\frac{d\sigma}{dE_r}(E_r, E_\nu) = \frac{G_F^2}{4\pi} Q_W^2 m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) \boxed{F^2(E_r)} \longrightarrow$$

Form factor: depends on the neutrons and protons distributions in the nucleus

$F^2(E_r) = 1 \rightarrow$ full coherence

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Form factor

Kinematics: $E_r^{max} = \dfrac{2E_\nu^2}{m_N}$

CEvNS: Differential cross section

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Form factor

$$\boxed{Q_W = N - Z\left(1 - 4\sin^2\theta_W\right)}$$

Weak nuclear charge

Kinematics: $E_r^{max} = \dfrac{2E_\nu^2}{m_N}$

N: neutron number
Z: atomic number

$\sin^2\theta_W = 0.231$
is small

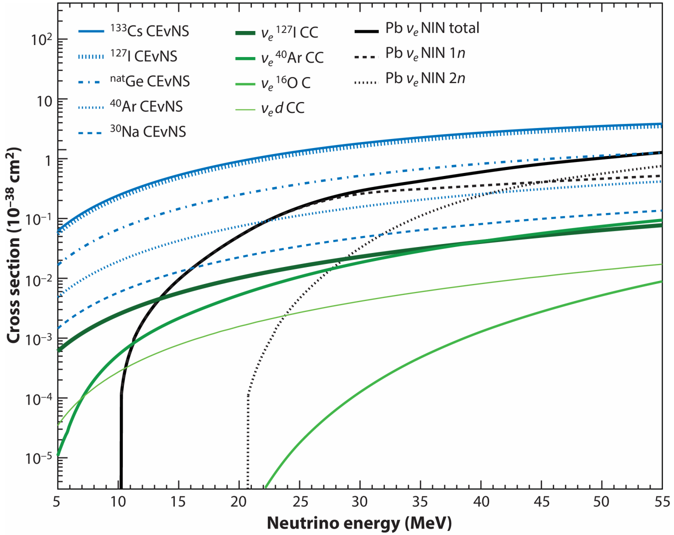
$\longrightarrow$ $Q_W \propto N$

CEvNS: Differential cross section

$$\frac{d\sigma}{dE_r}\left(E_r, E_\nu\right) = \frac{G_F^2}{4\pi}\boxed{Q_W^2}\, m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) F^2\left(E_r\right)$$

$$\boxed{Q_W = N - Z\left(1 - 4\sin^2\theta_W\right)}$$

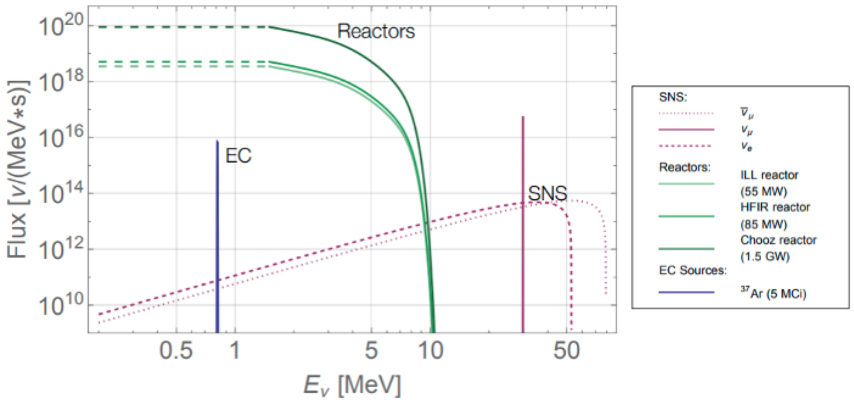
$$\longrightarrow \quad \sigma \propto N^2$$



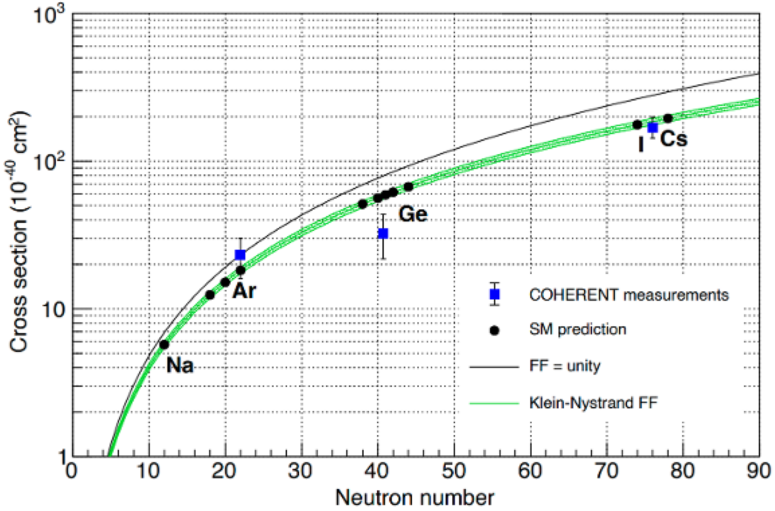
- Higher cross section compared to the other neutrino detection channels
- Sensitive to all neutrino flavors

The search for CEνNS

- Requirements:
  - High-flux neutrino source
  - Detectors tailored to recoil energies
  - Possibility to turn ON/OFF neutrinos flux



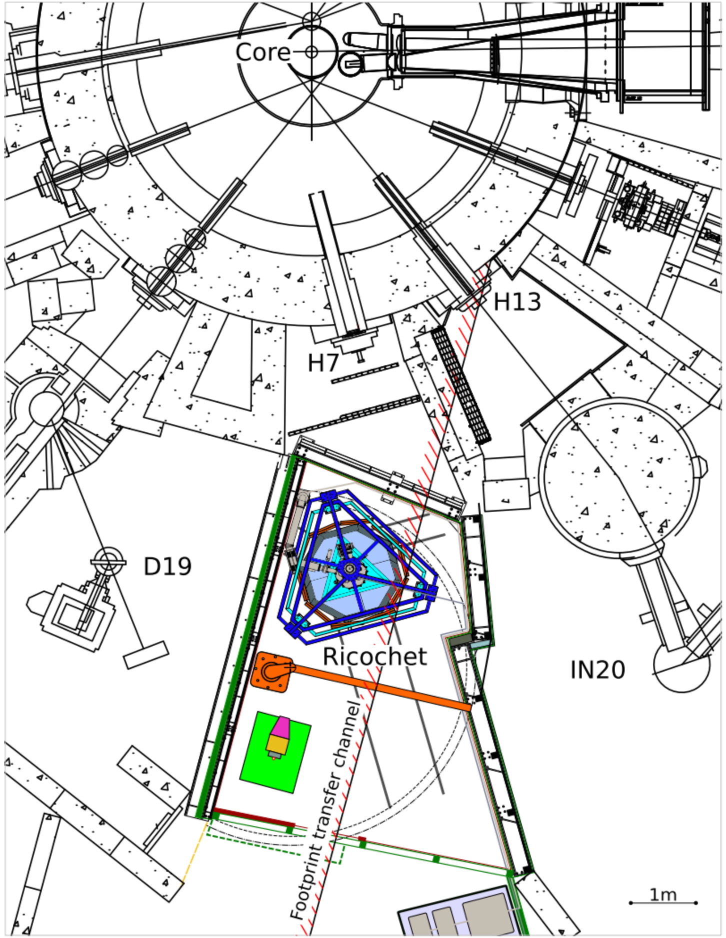
CsI: D. Akimov et al., Science 357, 1123 (2017)
Ar: D. Akimov et al., Phys. Rev. Lett. 126, 012002 (2021)
Ge: S. Adamski et al., arXiv:2406.13806 (2024)



The RICOCHET experiment

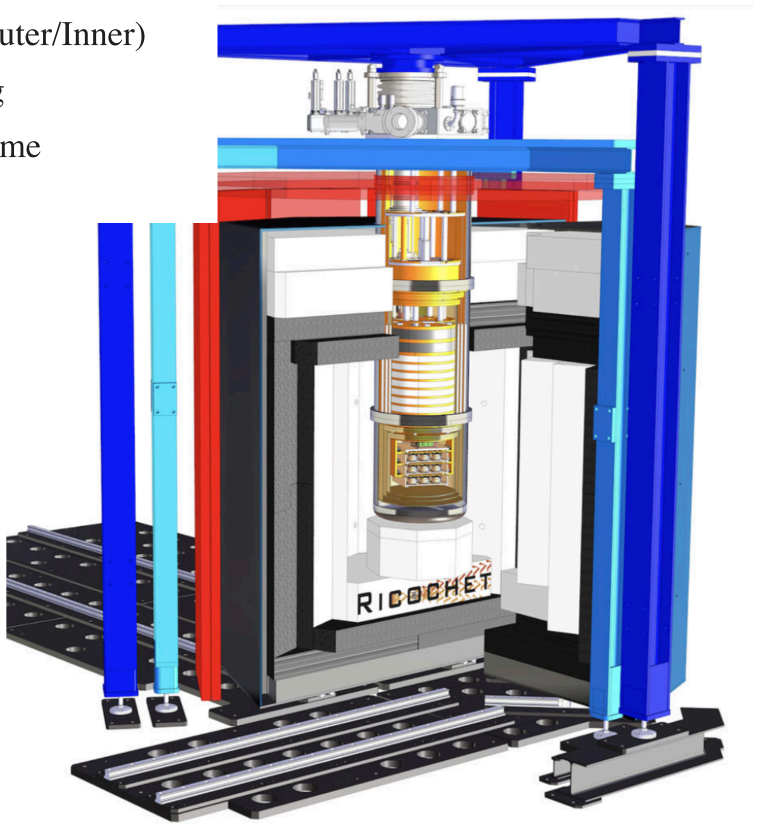
aims to measure the CEνNS with antineutrinos from nuclear reactor hosted at the Institut Laue Langevin (ILL) in Grenoble (France) with cryogenic particle detectors

- 8.8 m from high-flux 55 MW reactor
- 2023—2026 program with 7 reactor ON/OFF cycles (+ possible extension)



The RICOCHET experiment

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



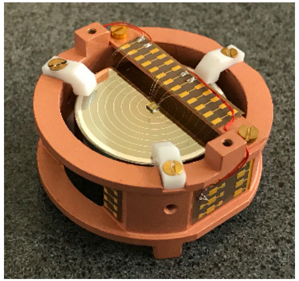
aims to measure the CEνNS with antineutrinos from nuclear reactor hosted at the Institut Laue Langevin (ILL) in Grenoble (France) with cryogenic particle detectors

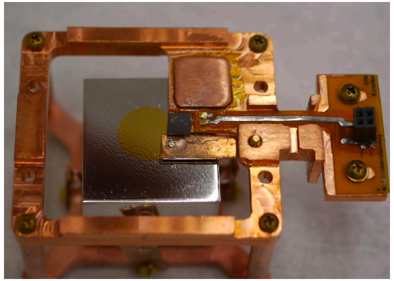
- Cryostat equipped with Ultra Quiet Technology to reduce environmental vibrations
- Optimized shielding design:
  - 35-cm-thick inner layer of borated high-density polyethylene (HDPE)
  - 20-cm-thick outer layer of lead
  - 35-cm-high top layer of HDPE

CryoCube

Q-Array

Cryogenic
Germanium
detectors
GeNTD/HEMT
readout





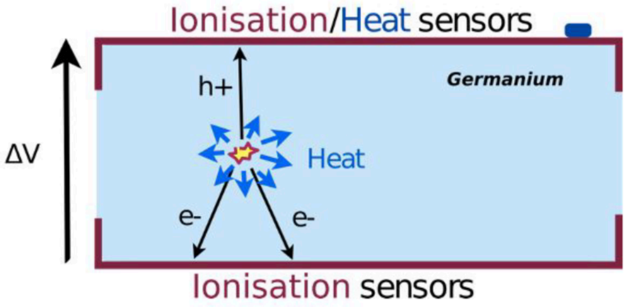
R&D phase

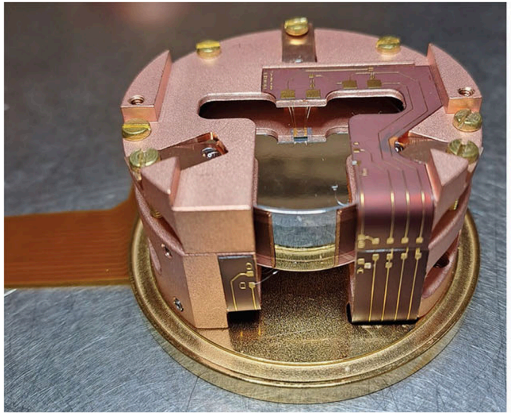
Cryogenic
supercondutor
TES readout

CryoCube technology

- Dual readout heat-ionization cryogenic calorimeters operating at O(10 mK)
- Detector module: 42 g Ge crystal
- Well established technology from dark matter searches
- Phonon energy is boosted by the Neganov-Trofimov-Luke (NTL) effect
- Operating voltage ± 4V

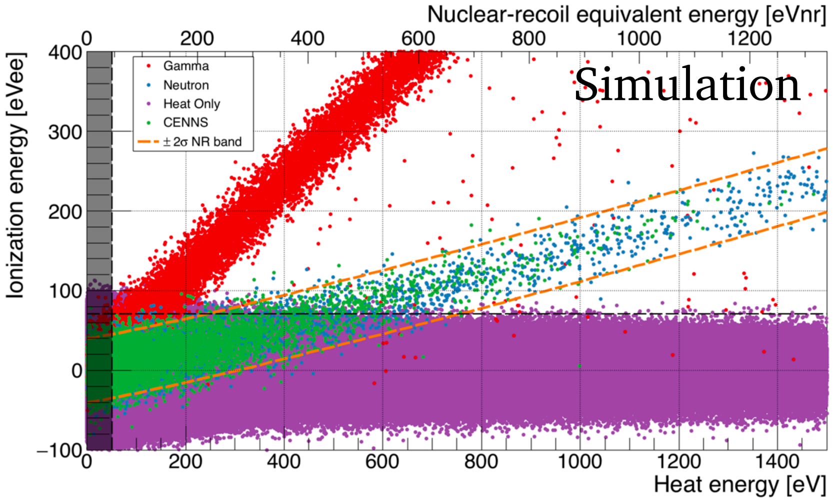
$$E_{ph} = E_r + E_{NTL} = E_r + E_r \cdot \mathcal{Q}\frac{q \cdot V}{\epsilon}$$

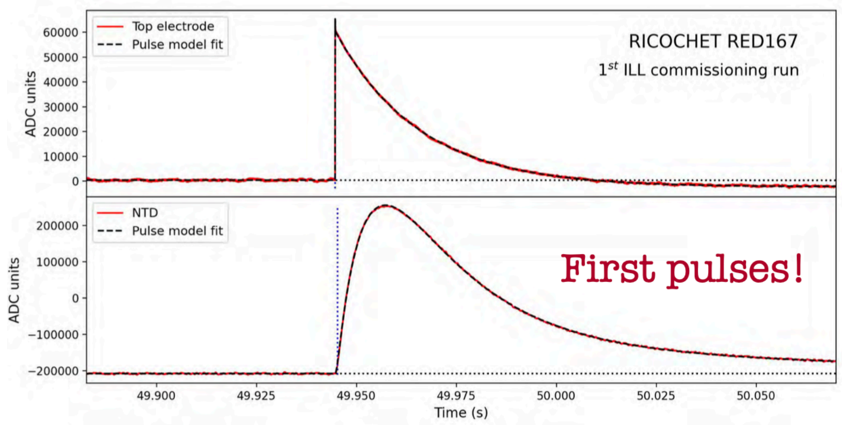




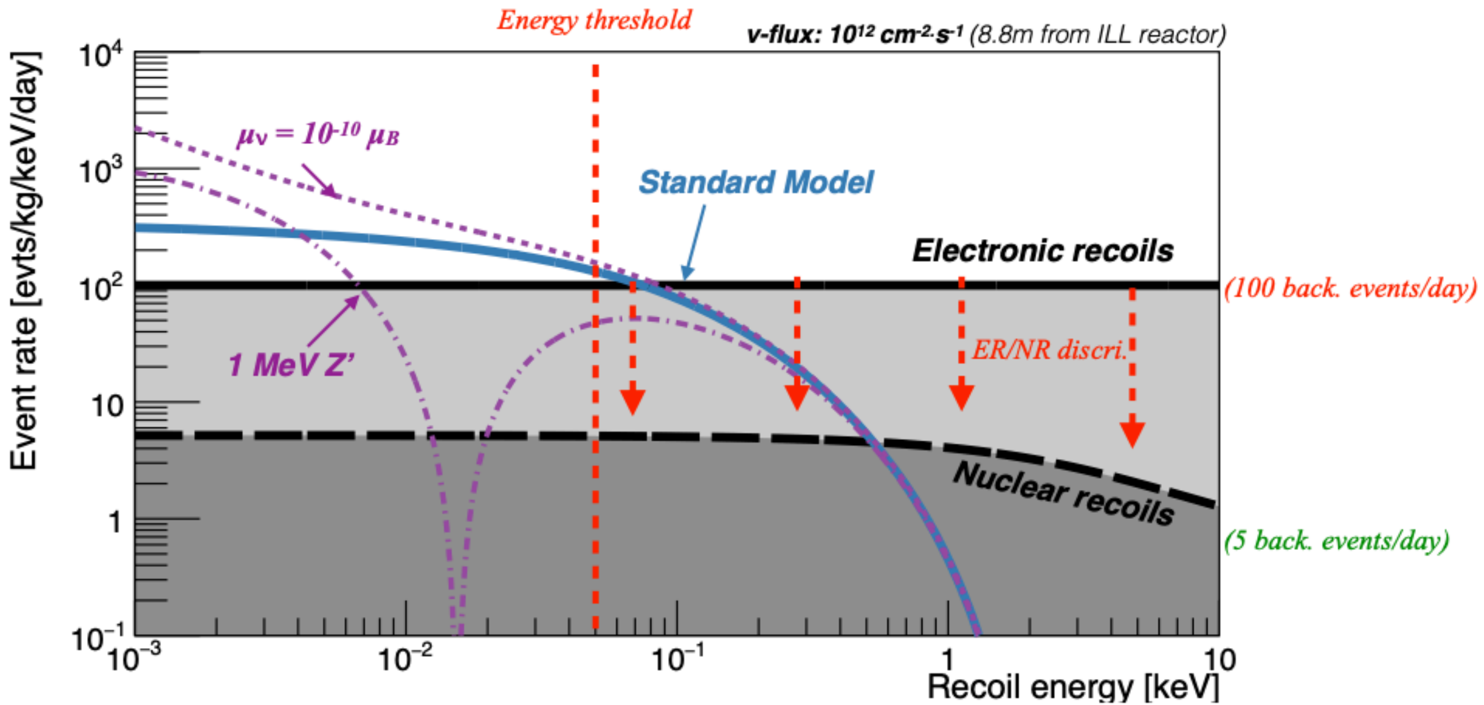
CryoCube technology - Particle identification

Particle identification allows to separate electronic (ER) from nuclear recoils (NR)





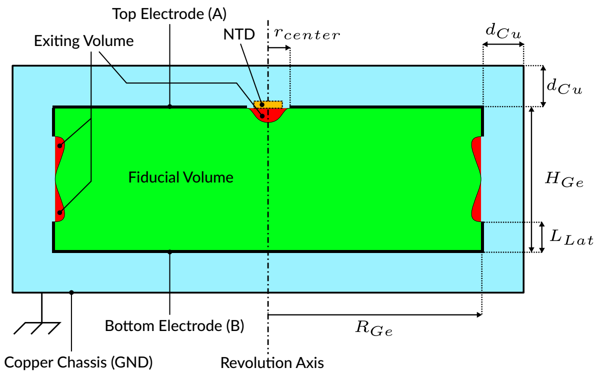
Why PID?



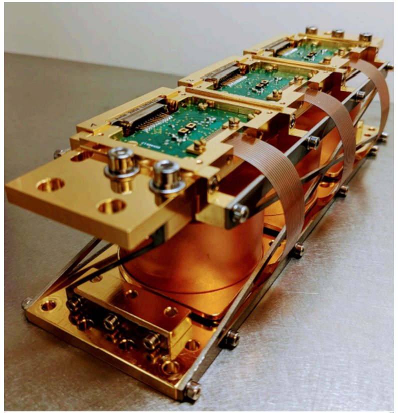
Energy threshold
ν-flux: 10^12 cm^-2 s^-1 (8.8m from ILL reactor)
μν = 10^-10 μB
Standard Model
Electronic recoils
(100 back. events/day)
1 MeV Z'
ER/NR discri.
Nuclear recoils
(5 back. events/day)
Event rate [evts/kg/keV/day]
Recoil energy [keV]
10^4
10^3
10^2
10
1
10^-1
10^-3
10^-2
10^-1
1
10

First commissioning @ ILL

- First commissioning run successfully conducted from May to October 2024
- MiniCryoCube: array of 3 “planar” detectors
- ~577 h of **reactor-on** data, and ~1400 h of **reactor-off** data

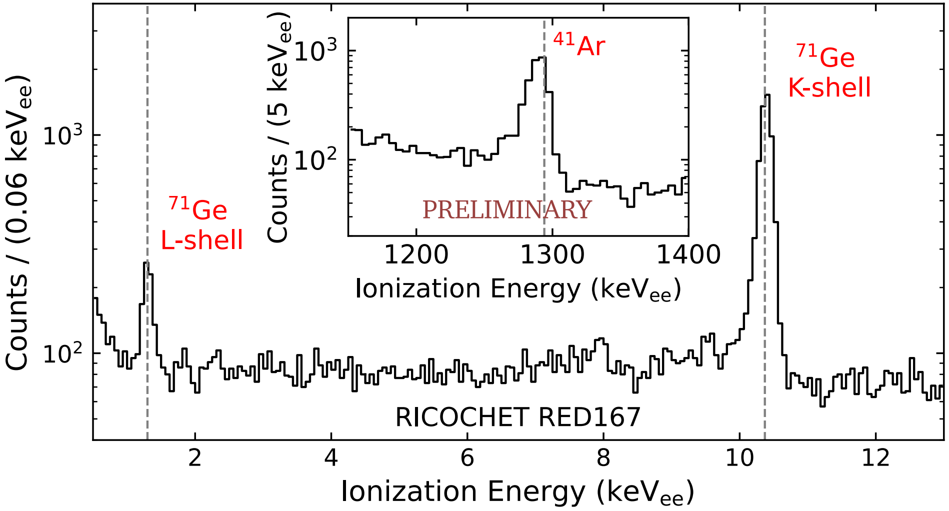


+Inner shielding
+Outer Muon Veto
+Laser



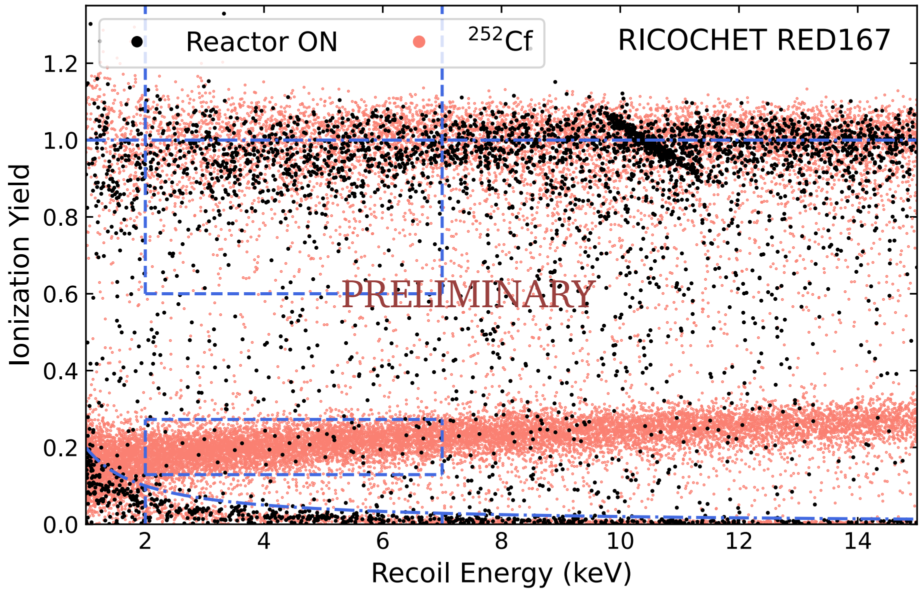
Results from the first commissioning @ ILL

- Activation of ^{71}Ge before the run to use the 10.3 keV X-ray for calibration
- ^{41}Ar from the activation of Ar in the air surrounding the cryostat when reactor is ON
- ~40 eVee, ~50 eVph baseline resolution achieved on ionization and heat (respectively)
- Optical fiber coupled to each detector to inject artificial pulses



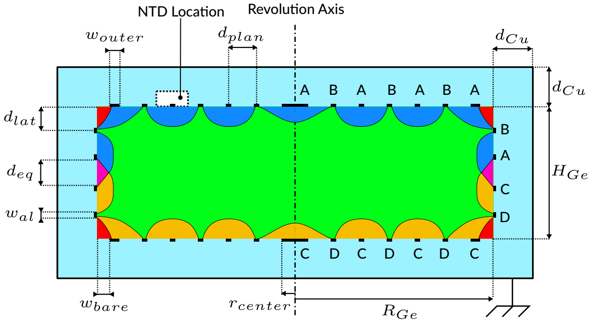
Results from the first commissioning @ ILL

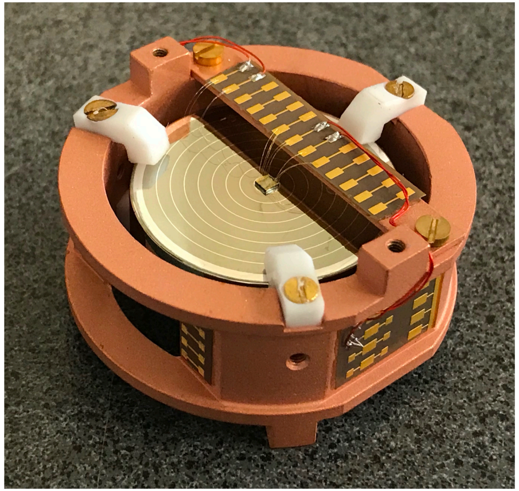
- Clear separation between ER and NR
- Background sources:
  - Reactogenic neutrons → Shielded
  - Cosmogenic neutrons → Vetoed
  - Surface β-decays
- Muon-induced NR rate ~ 14 counts/kg/day during Reactor OFF → reject by veto

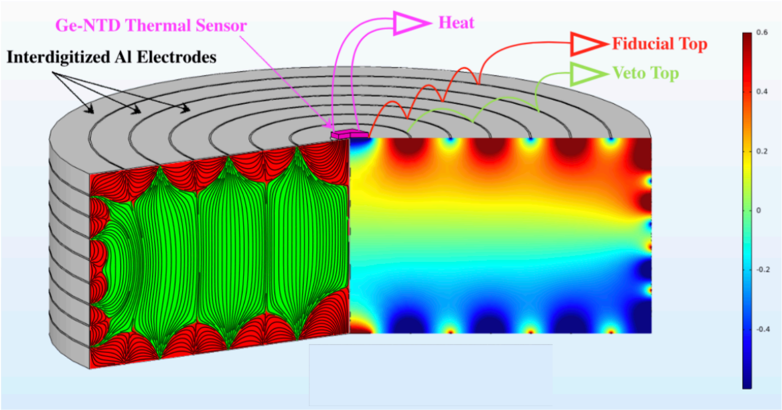


FID detectors

Fully Inter-Digitized (FID) → re-optimized electrodes geometry to differentiate bulk from surface events (∼70% fiducial volume)

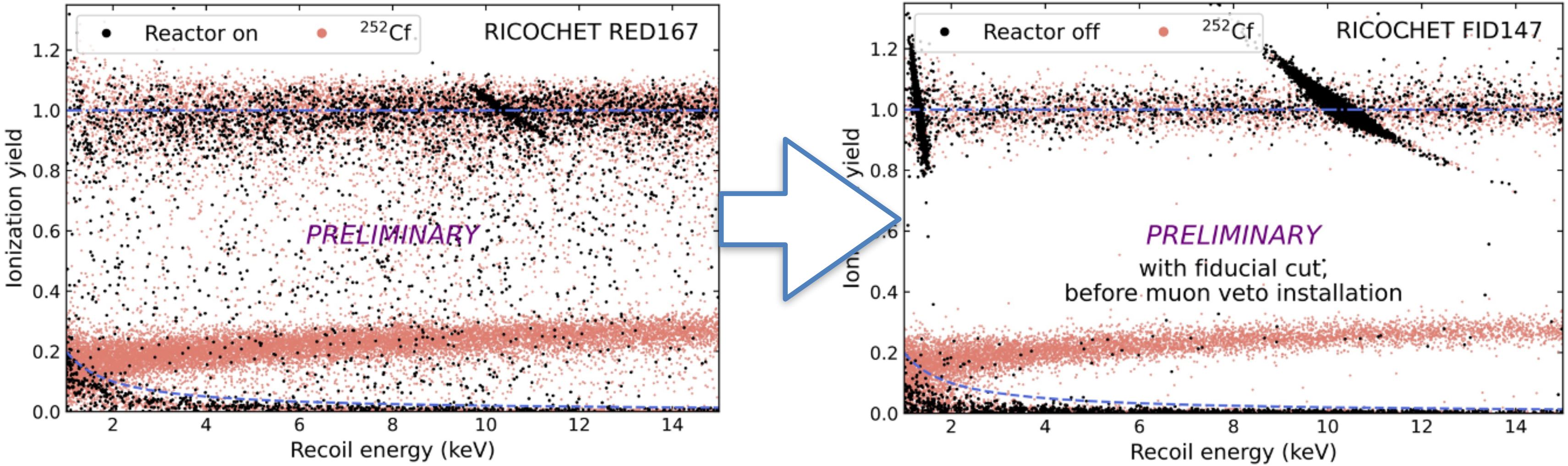






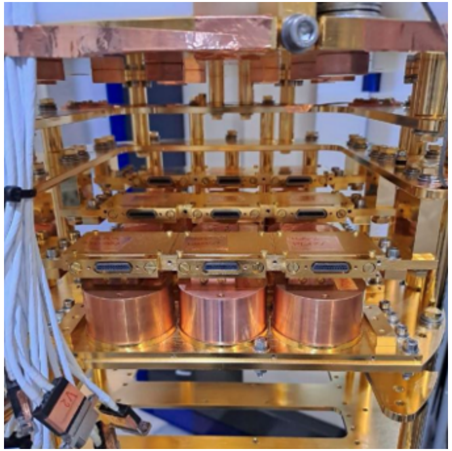
FID performances

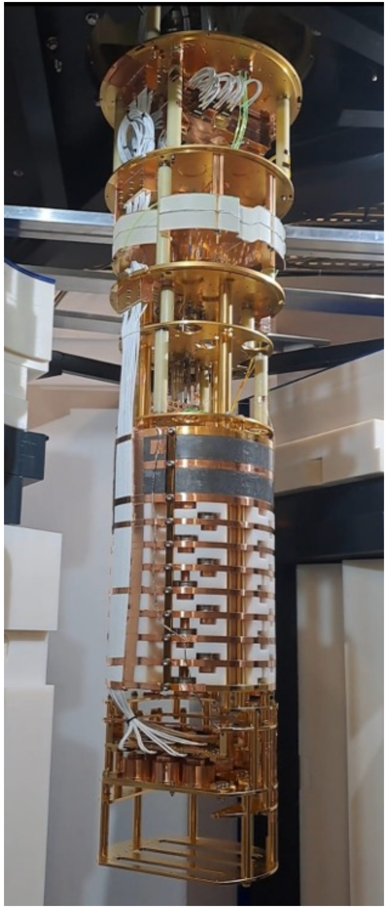
Rejection of the majority of surface events



Status of RICOCHET @ ILL

- Third Detector run from January to June 2025 in preparation for the physics run
- First FID installation @ ILL
- 9 Detectors (5 planar + 4 FID)
- Cryo-muon veto installation
- Improving ionization noise conditions decoupling of 1 K HEMT stage from 10 mK detector stage





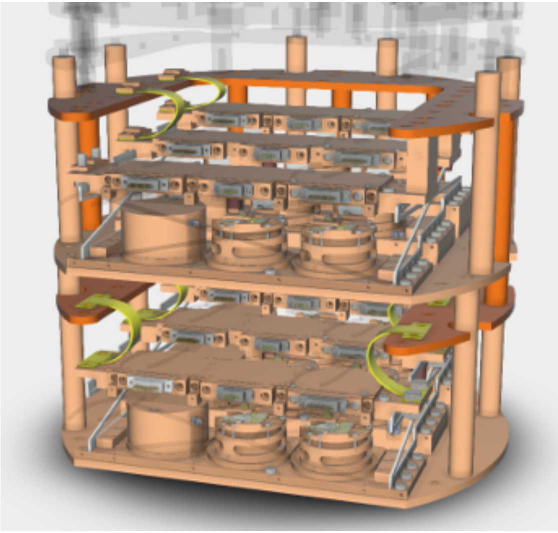
Whats next?

Summer 2025:

- Installation of 18-detector Array (7 planar + 11 FID)
- Commissioning paper will be submitted soon
- Analysis of science run with 9 detectors

2026++:

- CEνNS from 18 payload detectors
- New detector technologies (superconductors, Si and Ge detectors)



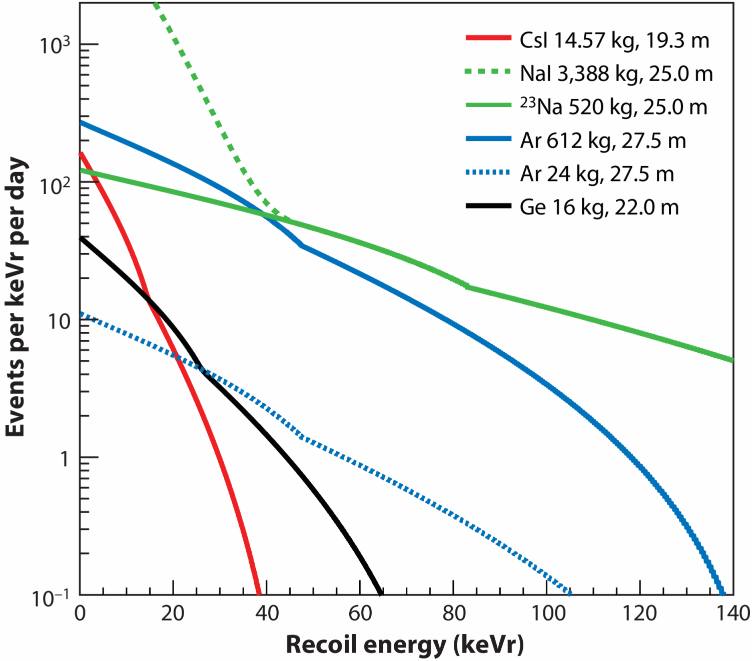
Thanks for the attention

Backup

How to detect CEνNS

Requirements:

- Low energy neutrinos $E_\nu \lesssim 30\text{MeV}$
- Intense neutrino source:
  - Spallation neutron sources
  - Nuclear reactors
- Technology able to detect nuclear recoils $E_r^{max} \sim 20 - 100$ keV

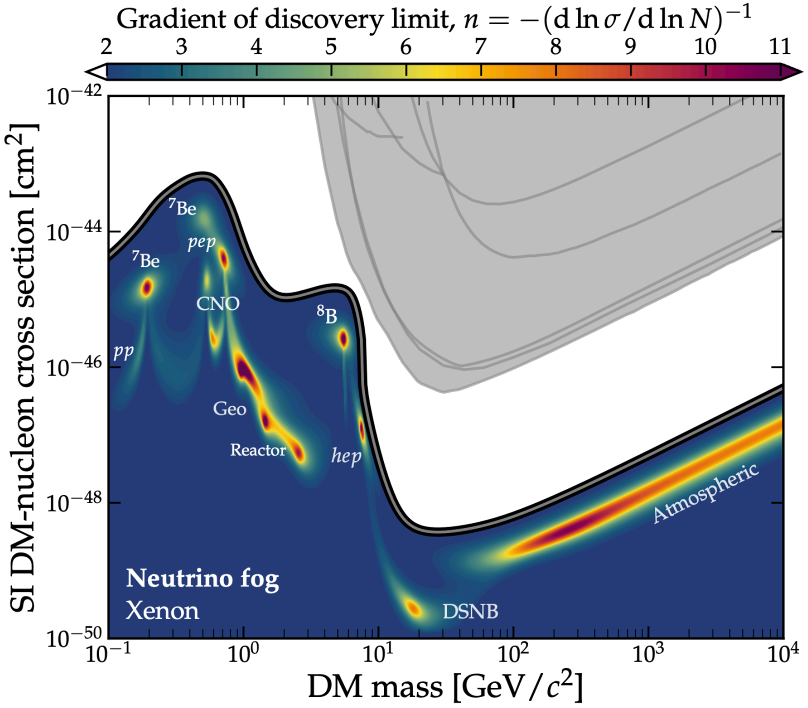


Barbeau PS, et al. 2023
Annu. Rev. Nucl. Part. Sci. 73:41–68

Background in next generation dark matter experiments

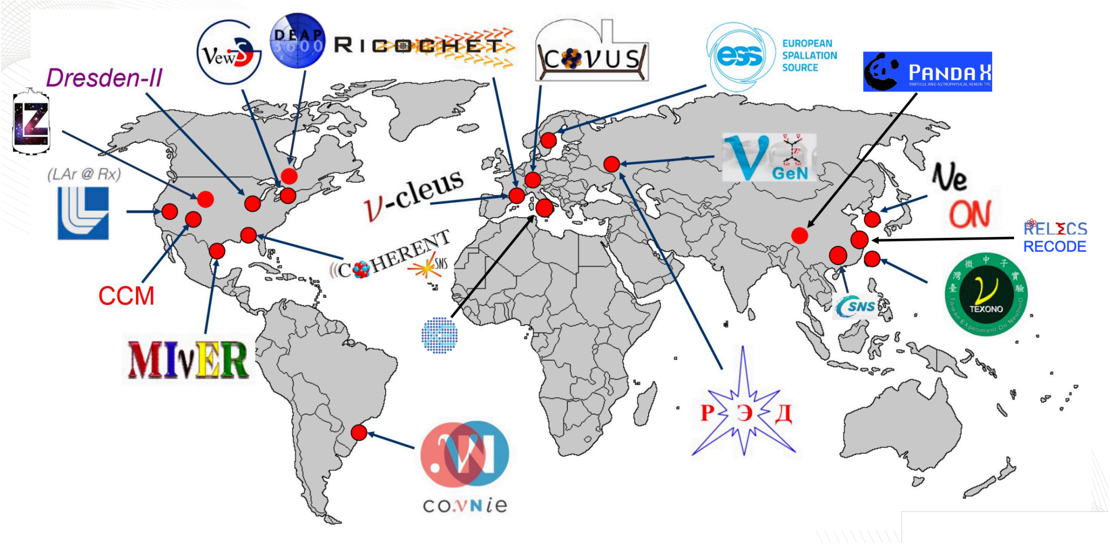
- CEvNS shows the same signature (nuclear recoils) of the expected WIMP dark matter signal
- CEvNS from solar and atmospheric neutrinos represents an irreducible background for future dark matter searches (**neutrino fog**)

→ precise CEvNS measurements can constrain this background contribution

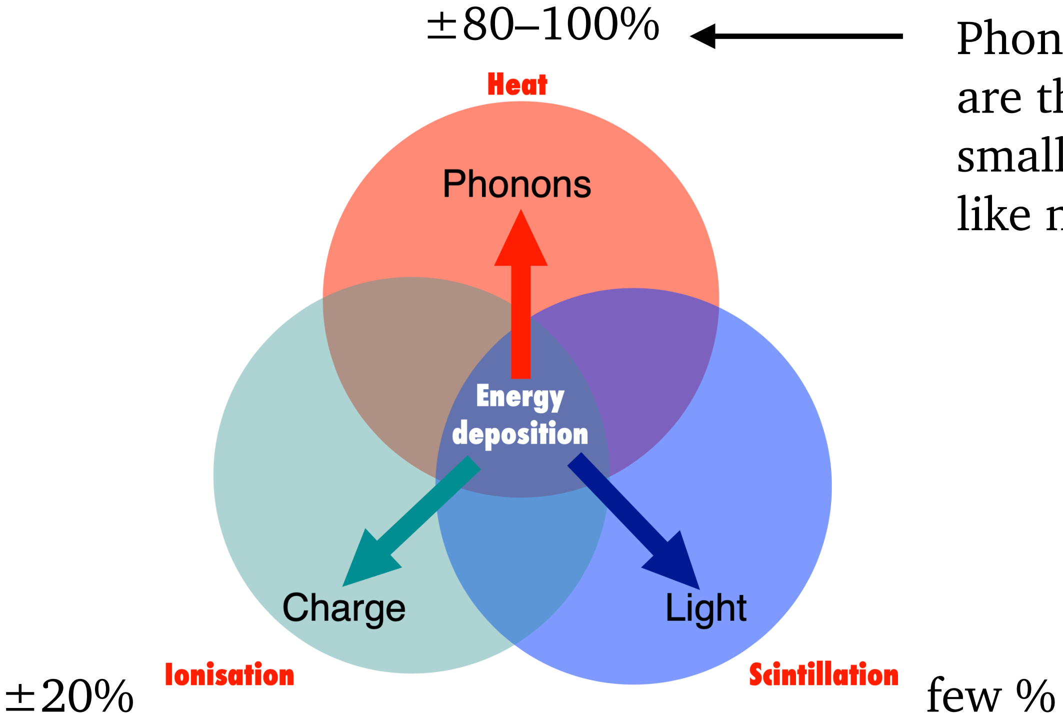


Many experiments…

Experiment	Detetctor Type	Location	Source
COHERENT	CsI, Ar, Ge, NaI	USA	πDAR
CCM	Ar	USA	πDAR
JSNS²	TBD	Japan	πDAR
ESS	CsI, Si, Ge, Xe	Sweden	πDAR
BULLKID	Si/Ge	Italy	Reactor
CHILLAX	Ar	TBD	Reactor
CONNIE	Si CCDs	Brazil	Reactor
CONUS	HPGe	Germany	Reactor
DRESDEN II	PCGe	USA	Reactor
NEWS-G	Ar+CH4	Canada	Reactor
MINER	Ge/Si cryogenic	USA	Reactor
NEON	NaI(Tl)	Korea	Reactor
NUCLEUS	Cryogenic $CaWO_4$, Al_2O_3	Europe	Reactor
NUXE	Xe		Reactor
νGEN	Ge PPC	Russia	Reactor
RED-100	LXe dual phase	Russia	Reactor
Ricochet	Ge, Zn bolometers	France	Reactor
TEXONO	p-PCGe	Taiwan	Reactor
SBC	Scint. Bubble Chamber	USA	Reactor



Detector energy deposition



Phonons-based detectors are the most sensitive to small energy depositions like nuclear recoils

Cryogenic particle detectors

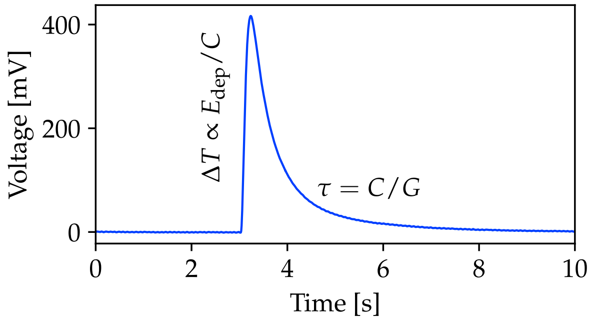
C = heat capacity

G = thermal conductance

Highly sensitive calorimeters operated at cryogenic temperature (~10 mK)

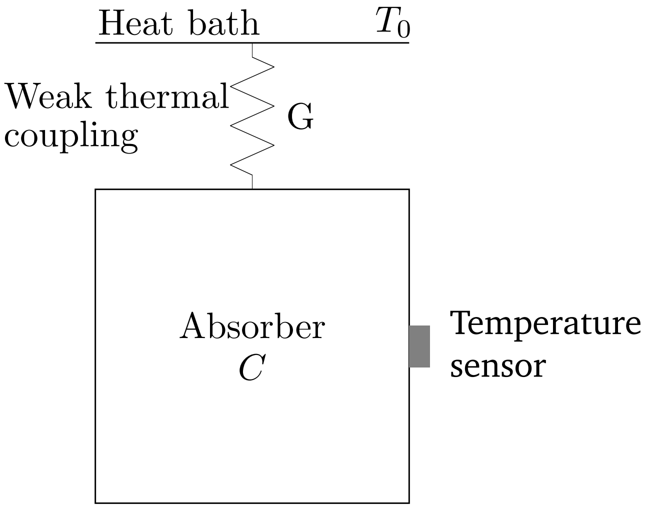
$$\Delta T(t) = \frac{\Delta E}{C} \exp\left(-\frac{t}{\tau}\right) \quad \text{where} \quad \tau = \frac{C}{G}$$

From Debye law $C \propto T^3$



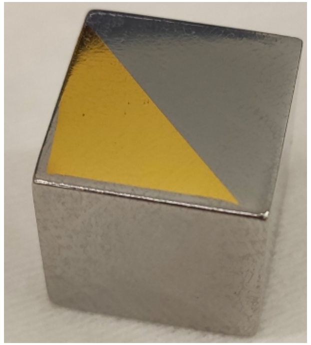
Example pulse

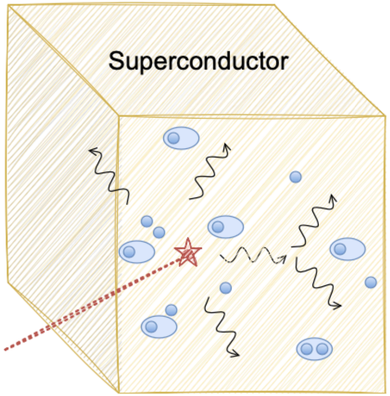
Pulse shape depends on the low temperature detector used

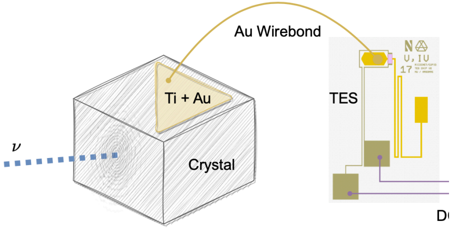


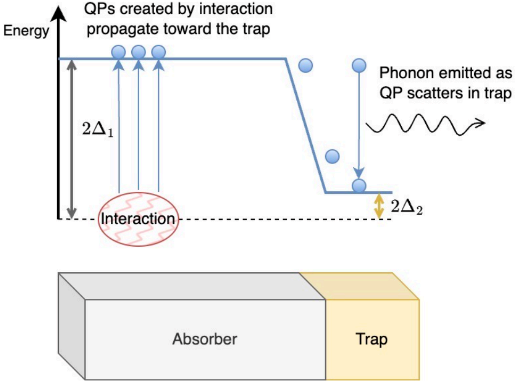
Q-Array technology

- Dielectrics (like Si and Ge):
  - Ionisation with energy gap of O(1 eV)
  - Detection of long living thermal phonons
- Superconductors:
  - Debye energy > $2\Delta_{gap}$ [O(100 μeV)]
  - Athermal phonons above the gap create quasi-particles, these are trapped and emit phonons









Q-Array status

- Testing different crystals (Zn, Sn, Al) with TES readout
- The final setup is composed of 9 Q-Array detectors with a multiplexed readout
- Possibility of particle identification through pulse shape discrimination