Gamma background characterization and modeling for the Ricochet Experiment

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The Ricochet experiment

Ricochet is an international collaboration involving more than 15 research institutes and about 50 scientists. This cryogenic experiment aims at detecting the **CEνNS** process (**C**oherent **E**lastic ν-**N**ucleus **S**cattering) in the sub-keV range at the ILL (Institut Laue-Langevin) research nuclear reactor (Fig. 1).

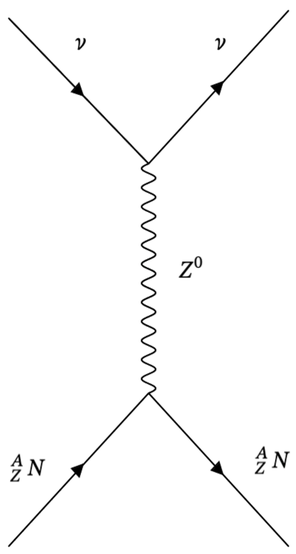

Figure 1: Diagram of CEνNS

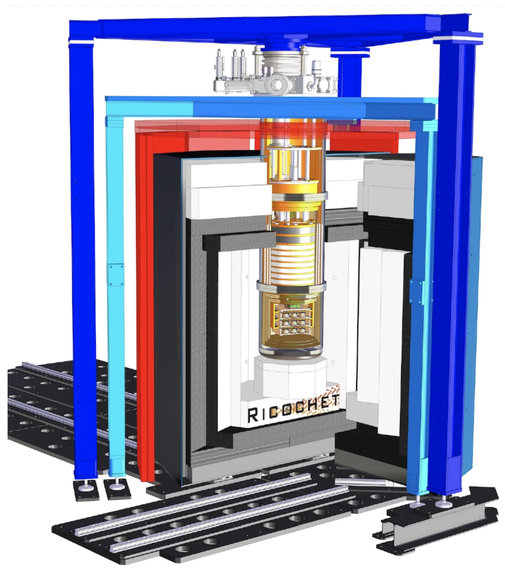

Figure 2: Ricochet shielding & cryostat [1]

CEνNS = rare event physics { theorized in 1974 by D. Z. Freedman [2]; first measured in 2017 by COHERENT [3]

Cross section predicted by the Standard Model (Eq. 1) and proportional to neutron number squared of target nuclei but brings into play low recoil energy:

$$\frac{d\sigma_{\nu/\mathrm{N}}}{dE_{\mathrm{recoil}}} = \frac{G_{\mathrm{f}}^2}{4\pi}\, Q_{\mathrm{w}}^2\, m_{\mathrm{N}} \left(1 - \frac{m_{\mathrm{N}}\, E_{\mathrm{recoil}}}{2\, E_{\nu}^2}\right) F^2(E_{\mathrm{recoil}}) \sim N^2 \qquad (1)$$

Sensitive to new physics (Fig. 3):

- non-standard ν-q interaction
- neutrino magnetic moment μ_ν
- new mediator boson Z'

Background for Dark Matter:

- solar neutrinos
- same signature as DM
- threshold "ν-floor"

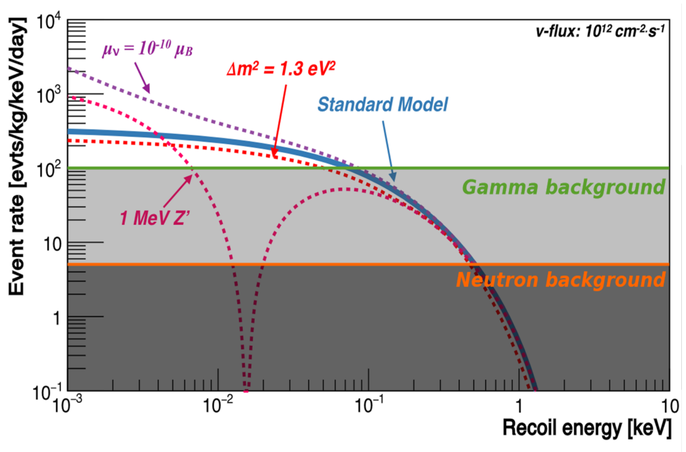

Figure 3: Theoretical expected event rate [4]

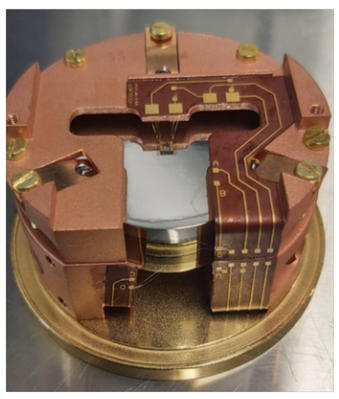

Figure 4: Ricochet bolometer [5]

Ricochet is composed of 18 cryogenic detectors (Fig. 4) cooled down to 10 mK and forming the **CryoCube**. The NTD sensor and aluminum electrodes provide a dual measurement of heat (E_{heat}) and ionization (E_{ion}) energies:

- **goal**: 20 eV resolution in ionization & heat channels
- signal discrimination with ionization yield or **quenching** factor (Eq. 2)

$$Q = \frac{E_{\mathrm{ion}}}{E_{\mathrm{recoil}}} = \frac{E_{\mathrm{ion}}}{E_{\mathrm{heat}} - q \times \frac{E_{\mathrm{ion}}\ \Delta V}{\epsilon}} \quad \begin{cases} = 1 \text{ for electronic recoil (ER)} \\ < 1 \text{ for nuclear recoil (NR)} \end{cases} \qquad (2)$$

Background sources and shielding

The Ricochet experiment is subject to three types of background (Fig. 2):

- **cosmogenic**: cosmic particles (muons) $\Leftrightarrow$ veto panels & 15 m.w.e
- **reactogenic**: fast neutrons & capture gammas
- **radiogenic**: natural radioactivity of the environment

} 20 t of lead, 2 t of HDPE

Analysis and GEANT4 simulations

Radiogenic: from shielding (HDPE & Pb) and concrete transfert channel with 5 identified sources (^{232}Th & $^{235/238}$U chains, and ^{40}K & ^{60}Co isotopes). Characterized using an ORTEC-GEM60 [6] HPGe (High Purity Germanium) detector (Fig. 6) and the Cubix spectroscopy software [7].

$$\chi^2 = \sum_{i=1}^{N_{\mathrm{bin}}} \left[\frac{S_i^{\mathrm{exp.}} - f \times S_i^{\mathrm{sim.\ stat.}}\left(s_k^{\mathrm{mat.}}, a_k\right)}{\sqrt{\sigma_{i^{\mathrm{exp.}}}^2 + \sigma_{i^{\mathrm{sim.\ stat.}}}^2}} \right]^2 + \left(\frac{f-1}{\sigma_f^{\mathrm{sim.\ sys.}}} \right)^2 \qquad (3)$$

The aim is to find the a_k coefficients by combining the GEANT4 [8] simulated spectra to reproduce experimental data of the radiogenic background using a χ^2 algorithm with a tuning factor f and a simulation uncertainty σ_f (Eq. 3).

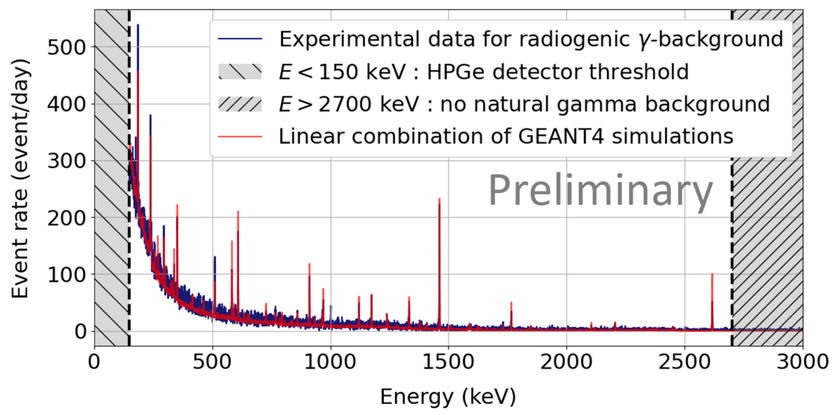

Figure 5: Radiogenic γ-background

Figure 6: HPGe detector

Reactogenic: from the neutron capture on ^{41}Ar in the ambient air and diffusion in the HDPE shielding. Characterized during the commissionning phase RUN014 using two Ricochet bolometers: RED167 & RED237. The aim is to predict the experimental event rate in the energy range from 2 to 7 keV, in event per kg, day and keV (DRU).

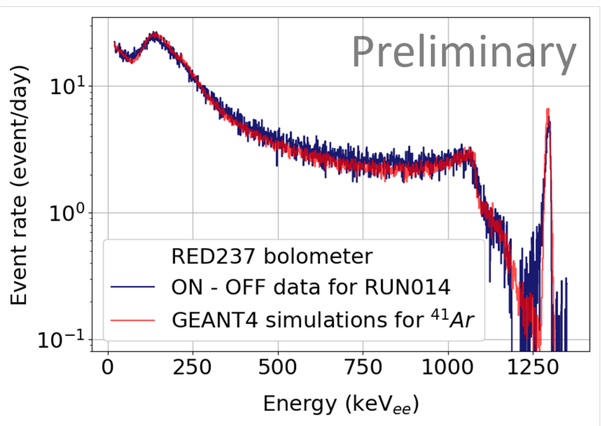

Figure 7: Reactogenic γ-background

	RED167	RED237
RUN014 reactor ON data	985 $\pm$ 152	1096 $\pm$ 168
RUN014 reactor OFF data	137 $\pm$ 21	129 $\pm$ 20
^{41}Ar simulation (stat. error)	787 $\pm$ 39	711 $\pm$ 33

Table 1: RUN014 and GEANT4 event rates in DRU

Conclusion

Radiogenic: adjusting individual simulated spectra and using existing radiopurity measurements, the radiogenic spectrum is well reproducted (Fig. 5).

Reactogenic: event rates (Fig. 7 & Tab. 1) compatible with experimental data [9] but improvements needed to take into account other sources (capture γ).

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Ricochet COLLABORATION

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