# Status of the Ricochet experiment

**Thomas Salagnac**
On the behalf of the Ricochet collaboration

**GDR Neutrino 2020**

**24/11/2020**

# Coherent Elastic Neutrino-Nucleus Scattering

**CEνNS**: **C**oherent **E**lastic **N**eutrino-**N**ucleus **S**cattering

- First detection in 2017 by the COHERENT experiment

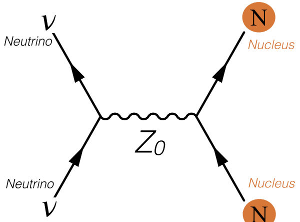
- Cross-section scale as $N^2$ ($N$: number of neutrons)

$$\frac{d\sigma}{d\cos\theta} = \frac{G^2}{8\pi}[Z(4\sin^2\theta_w - 1) + N^2]E^2(1+\cos\theta)$$

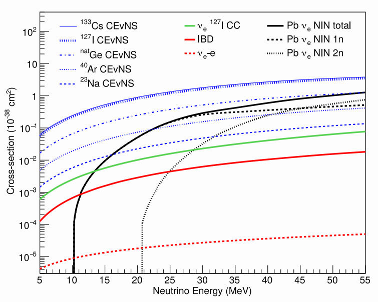
  → Allow small target of heavy elements

- Small nuclear recoil energy: sub-keV

  → Hard to detect in practice

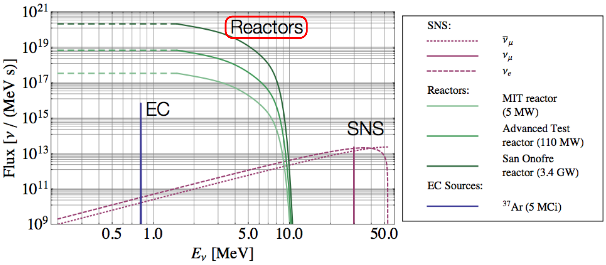



**arXiv: 1708.01294**

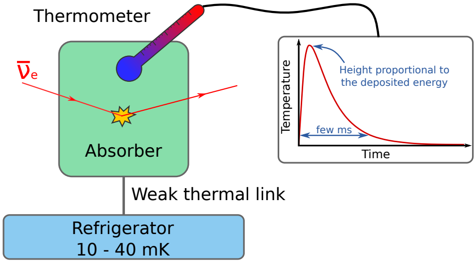


# One way to study CEνNS

## A source:




## A detector:




**Nuclear reactor** are very interesting neutrino source:

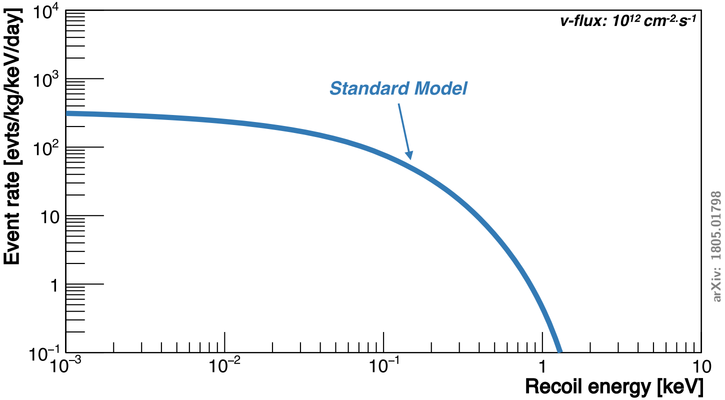
- High flux: $1\,\mathrm{GW_{th}} \rightarrow 2 \times 10^{20}\ \nu/s$
- Neutrino energy $< 10\,\mathrm{MeV}$: almost fully coherent

**Advantage of a phonon readout:**

- Direct measurement of the recoil energy, no quenching
- $\sim 100\%$ of the recoil energy is sensed, allowing for low thresholds
- No intrinsic threshold (meV)
- From thermodynamics, ultimate energy resolution is: **$\sim$eV (RMS) for 10 g detectors**

# Probing new physics with CEνNS and reactor neutrinos

**Example:** Nuclear recoil spectrum inside 1kg Ge target at $\sim 8$ m of the 58 MWth ILL reactor



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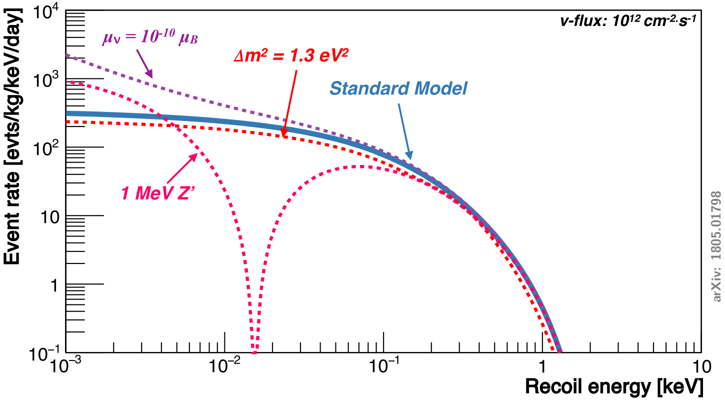


**Looking for physics beyond the Standard Model in the electro-weak sector:**

- Anomalous large neutrino magnetic moment (NMM)
- New massive mediator: Z' boson
- Non standard neutrino interactions (NSI) at low energy
- Light sterile neutrino oscillation

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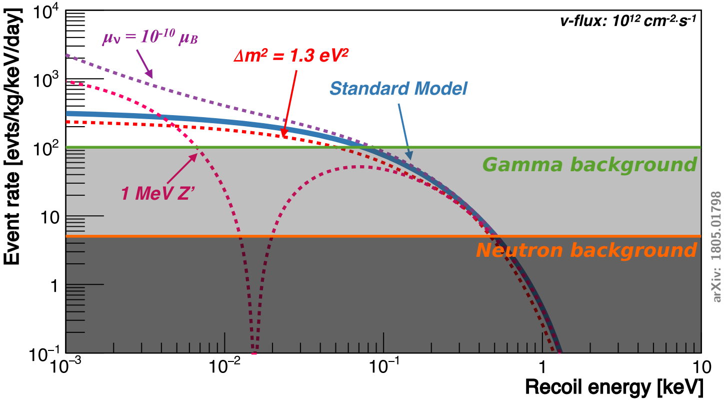


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- New massive mediator: Z' boson
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# Projection for new physics using CEνNS

**Detector wish list:**

- Low energy threshold $\sim 50\,eV$
- Low energy resolution $\sim 10\,eV$
- EM background rejection of $> 10^3$

**Source wish list:**

- Decent neutrino flux: $10^{12}$ ν/cm$^2$/s

**Assume 1kg detector $\Rightarrow \sim$ 20 ν/day**

**Background wish list:**

- 100 DRU of electronic recoils (ER)
- 5 DRU of nuclear recoils (NR)

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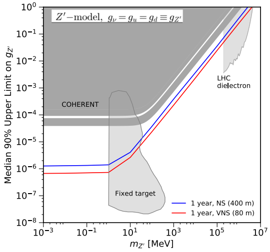
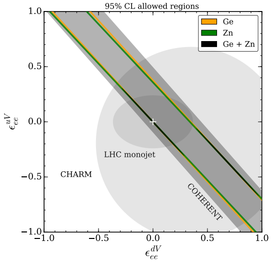
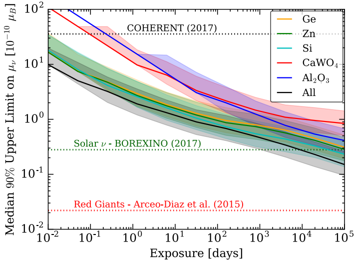
arXiv: 1805.01798



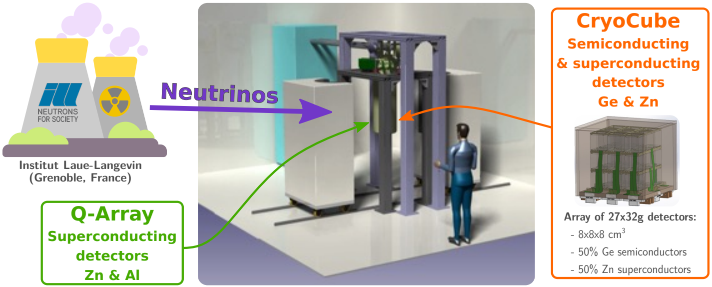




- Weinberg angle Measure at %-precision from 1 to 10 MeV in momentum transfer
- Search for new bosons with competitive sensitivity
- Further constrain the existence of NSI $\Rightarrow$ **need different targets**
- Competitive CEνNS-based NMM limit of $\mu_\nu \sim 10^{-11}\,\mu_B$ at the 90% C.L.

# The Ricochet experiment

RICOCHET
A Coherent Neutrino Scattering Program




**Proposal paper:** arXiv: 1612.09035

"The first low-energy kg-scale CEνNS neutrino observatory combining multi-target and multi-technology cryogenic detectors", J. Billard et al., J. Phys. G (2017)

# ILL reactor site

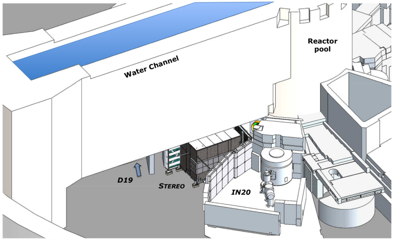
**ILL:** ⇒ **Ricochet proposal accepted by ILL**

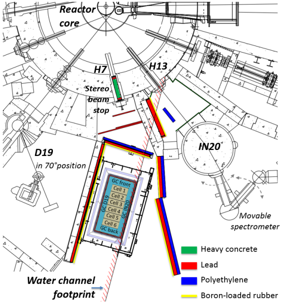
- Use STEREO casemate
  → Benefit from Stereo experience and background characterization **STEREO Collab., JINST 2018**
- 8 m from 58 MWth core
  → $1.6 \times 10^{12}$ $\nu/\mathrm{cm}^2/\mathrm{s}$ at the detector
- 3 or 4 cycles of $\sim 50$ days per year
  → good ON / OFF ratio
- 15 m.w.e overburden :
  → reduction factor 2 to 3 of muon flux
- Close to reactor and neighboring experiments
  → High level of reactor correlated background

**Expect 20 CEνNS events/day**

⇒ 5 σ CEνNS detection in a couple of days !

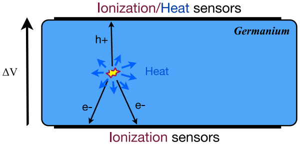
⇒ 1 % precision measurement after one year



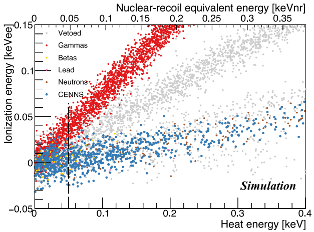



# Particle identification

## Germanium (and silicon ?) semiconductors:

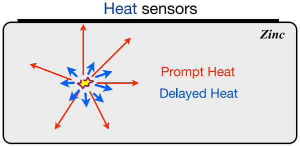



- Ionization/Heat ratio depends on the particle type
- Need to achieve an unprecedented ∼10 eV ionization resolution

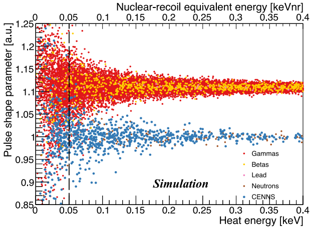



**Inspired from the FID800 success of EDELWEISS-III**

## Zinc (and aluminum ?) superconducting metals:




- Prompt / delayed heat signals depend on the particle type
- High risk / high reward

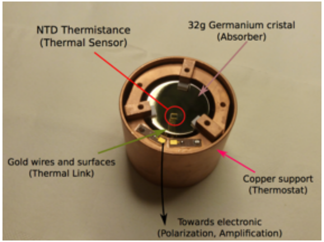


# Toward a heat baseline resolution of 10 eV

**From EDELWEISS R&D:** Armengaud, E. *et al.*, Phys. Rev. D 2019

**Major accomplishments:** with 32 g Ge detector

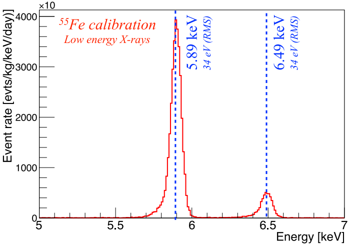
- 18 eV baseline energy resolution (RMS)
- 55 eV energy threshold
- %-level stability over a week

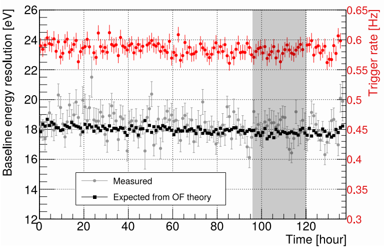



**Reproducible:** similar results on 6 other $\sim 30$ g bolometers

$\Rightarrow$ **Validates the choice of 30 g crystals as individual detectors for the CryoCube array**

$\rightarrow$ **Expect a factor 2 of improvement with HEMT**



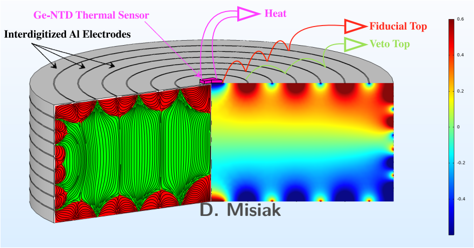
# Improving resolution and particle discrimination

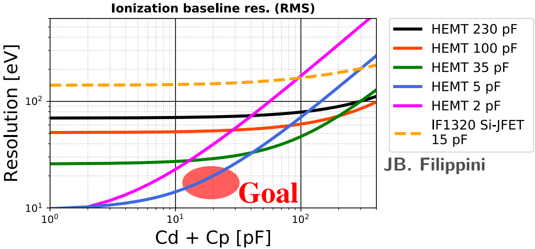
Particle discrimination is right now limited by the ionization resolution (200 eV)

**Goal:** reach a ionization resolution below 20 eV

**HEMT preamplifier:** High Molity Electron Transistor

- Lower intrinsic noise than JFET (Junction Field Effect Transistor)
- HEMT Noise Model: goal implies a 20 pF total capacitance (detector & cabling)
- Low temperature threshold ∼4 K, closer to detector, less cable capacitance
- R&D ongoing, HEMT are being characterized




**New electrode design:**

- Good charge collection, for event reconstruction
- Large fiducial volume (75%)
- High surface event rejection efficiency (FID)
- Minimized capacitance: Cdet ∼ 10 pF
- Studies ongoing : multiple design simulated with COMSOL and data driven model

# Neutron background characterization

## 3He detectors measurements at ILL and R&D lab.:

**Two 3He detectors, two modes:**

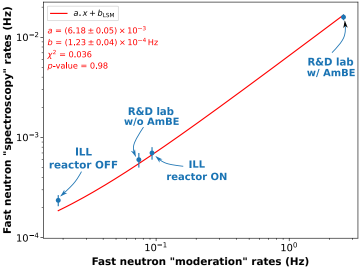
- Fast neutron "moderation":

  poly. shielding and

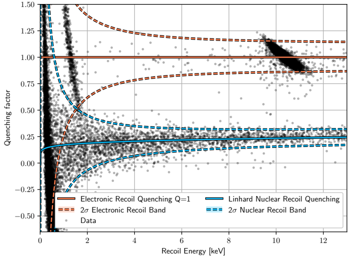
  $$n + {}^3\text{He} \rightarrow \underbrace{{}^3\text{H} + p}_{764\ \text{keV}}$$

- Fast neutron "spectroscopy":

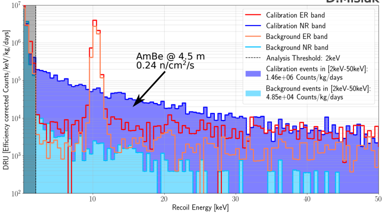
  $$n + {}^3\text{He} \rightarrow \underbrace{{}^3\text{H} + p}_{764\ \text{keV} + E_n^{kin}}$$




## Particle identification with Ge detectors at R&D lab.:




D.Misiak




- Ratio with/without AmBe source: $\sim 30 \Rightarrow$ Ge detector in agreement with He3 counters
- At the upper edge of the CENNS ROI (2 keV), neutron backgrounds **inside Ge detectors with no shielding** can be inferred at:
  - R&D lab. (no source): $\sim 10\,000$ DRU (measurement)
  - ILL reactor ON: $\sim 12\,500$ DRU (extrapolation)
  - ILL reactor OFF: $\sim 2\,500$ DRU (extrapolation)
- Neutron background level reduction goal: $\sim 4$ orders of magnitude

  $\Rightarrow$ **manageable with shielding according to Geant4 simulation !**

# Background simulations and shielding design

**Geant4 background simulation:**

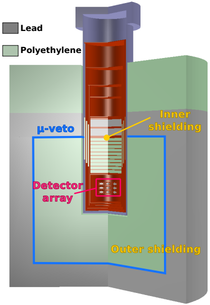
- Reactogenics: gamma and neutron backgrounds from HPGe measurements and MCNP sim. from STEREO
- Cosmogenics: use CRY generator, validated with STEREO muon-flux measurements and simulations

**External shielding design:**

- 20 cm of lead
- 40 cm of borated-polyethylene (PE)
- Muon-veto

**Internal shielding design:**

- 15 cm of lead/copper
- 30 cm of PE/copper



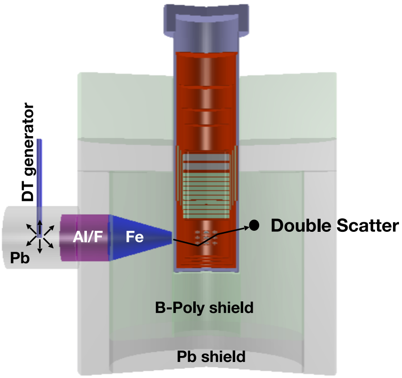

| Electronic recoil rates in [50 eV, 1 keV] energy range (in evts/day/kg) | | | | |
|---|---|---|---|---|
| | Cosmogenic | Reactogenic | Total | Goal |
| (I) No shielding | $260 \pm 5$ | $4365 \pm 301$ | $4625 \pm 301$ | – |
| (II) Shielding | $175 \pm 4$ | $26 \pm 2$ | $201 \pm 5$ | – |
| (III) Shielding + μ-veto | $7 \pm 1$ | | $33 \pm 2$ | 100 |
| (IV) Shielding + full cover. μ-veto | $0.6 \pm 0.2$ | | $27 \pm 2$ | 100 |

| Nuclear recoil rates in [50 eV, 1 keV] energy range (in evts/day/kg) | | | | |
|---|---|---|---|---|
| | Cosmogenic | Reactogenic | Total | Goal |
| (I) No shielding | $1554 \pm 12$ | $53853 \pm 544$ | $55407 \pm 545$ | – |
| (II) Shielding | $37 \pm 2$ | $0.8 \pm 1$ | $38 \pm 2$ | – |
| (III) Shielding + μ-veto | $12 \pm 1$ | | $13 \pm 1$ | 5 |
| (IV) Shielding + full cover. μ-veto | $4 \pm 1$ | | $5 \pm 1$ | 5 |

**Results:**

- ER better than goals but NR 2.5 times larger (config. III) or equivalent (config. IV) $\Rightarrow$ reachable
- Muon veto is essential, estimated dead time: 9-14% (config. III) and 20-30% (config. IV) $\Rightarrow$ manageable
- With S = 15 evt/kg/day and PID, we expect S/B = 1 (config. III) or 3 (config. IV) $\Rightarrow$ promising
- Correlated reactogenic neutrons reduced by $\sim 5 \times 10^4$ thanks to shielding $\Rightarrow$ 0.8 evt/kg/day

# Calibration setup

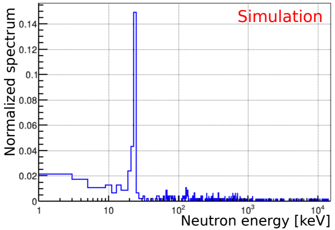



**DT generator:** allow for pulsated neutron calibration $\Rightarrow$ background free

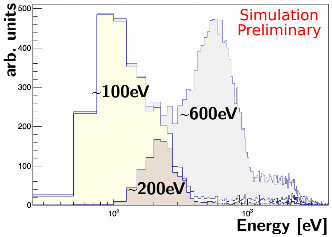
**Mono-energetic neutron production steps:**

1) $n \to 2n$ process in Pb, neutrons $< 1$ MeV
2) Moderator Al/F, neutrons $< 100$ keV
3) Filter Fe, neutrons $= 24$ keV

**Neutron Striking the CryoCube:**

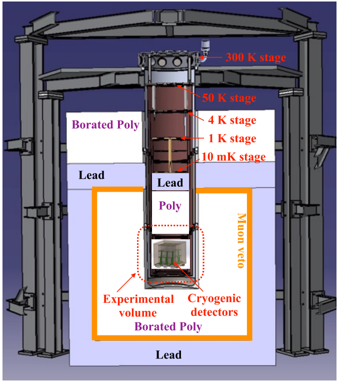



**Calibration spectra for a few pairs of detectors:**




P.Patel's talk @ Magnificent CEvNS 2020 workshop

# Experimental setup



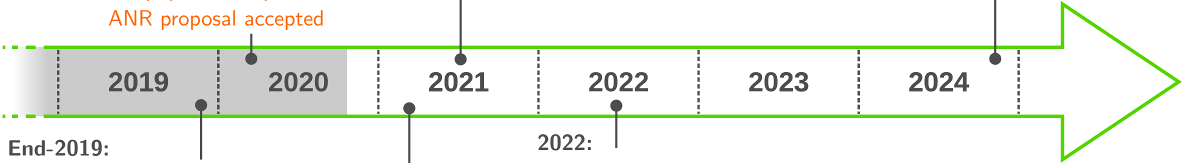

- Setup optimization, design and drawings ongoing:
  - Must comply with safety regulations
  - Must be compatible with dedicated neutron source
  - Supported thanks to RICOCHET-ANR (2020)
- Anticipated load of $\sim 15$ tons over $4\,\mathrm{m}^2$
- Cryostat to be delivered at IP2I early 2021
- Blank assembly at IP2I prior to ILL deployment

**Funded by:**

AGENCE NATIONALE DE LA RECHERCHE ANR

- J. Lamblin (LPSC) - PI
- A. Juillard (IP2I)
- S. Marnieros (IJCLab)
- A. Monfardini (I. Neel)

# Ricochet timeline




**End-2019:**
Nuclear site decision and first version of Ricochet's experimental setup

**2020:**
ILL poposal accepted
ANR proposal accepted

**Early-2021:**
Cryostat delivery, start of blank assembly and Ge detector design finalized

**2021:**
Ricochet's technical design completed (shielding, mechanics, cryostat, cabling, and warm elec.)

**2022:**
Deployment of the Ricochet experiment at the chosen nuclear reactor site

**2024:**
Deliver the first low-energy (sub-100 eV) high-precision (%-level) CEνNS measurement after 1 year of data taking

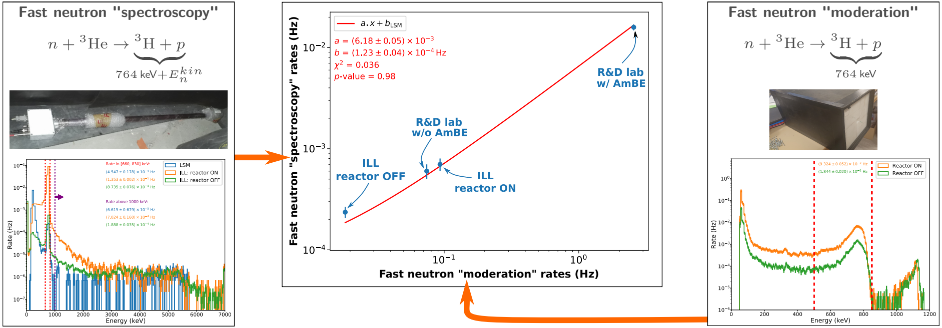
# Conclusion

- Strong interest in CEvNS physics from the Neutrino and DM communities ⇒ Magnificent CEvNS 2020 workshop last week (link)
- Ricochet detector key feature: particle identification down to 50 eV
- R&D phase on track:
  - Sub-100 eV heat energy threshold secured on 33.4 g Ge crystal,
  - HEMT-based preamplifier expected for end-2020 ⇒ ionization resolution down to 100 eV
- Background studies: simulations and measurements
  - According to simulations and neutron measurements, background seems be manageable
  - 1st shielding design: should allow Ricochet to reach its specifications
- Ricochet experimental setup and integration at ILL funded thanks to recently awarded ANR (2020)
- Ricochet has been accepted at ILL by Scientific Council and directorate for onsite integration in 2022/2023

**Thanks for your attention !**

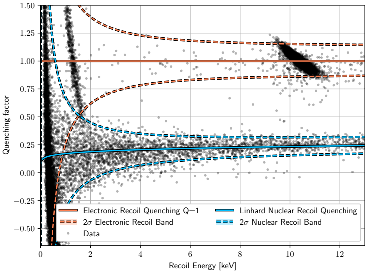
# Backup

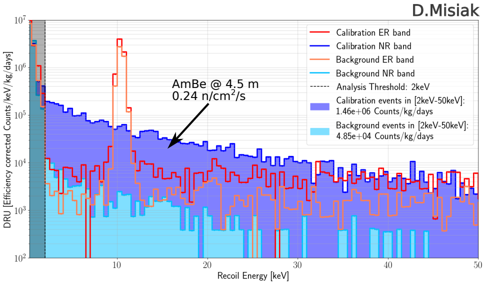
# Neutron background characterization (1/2): ILL vs R&D lab




- Excellent relative flux measurements (correlation) between the two apparatus
  - Includes the very low alpha background from « Dubna detector » ($b_{\mathrm{LSM}}$)
  - Ongoing studies to extract neutron energy spectrum from Dubna He3 detector
- Fast neutron flux at ILL reactor ON $\sim 5$ times larger than reactor OFF
- ILL reactor ON only 25% higher than the fast neutron flux at IP2I (inside Pb shield)

# Neutron background characterization (2/2): bolometer at R&D lab




- Clear separation between electronic and nuclear recoils down to $\sim 1$ keV (limited by current J-FET electronics)
- Ratio with/without AmBe source: $\sim 30 \Rightarrow$ in agreement among the Ge bolometers and He3 counters
- At the upper edge of the CENNS ROI (2 keV), neutron backgrounds **with no shielding** can be inferred at:
  - R&D lab. (no source): $\sim 10\,000$ DRU (measurement)
  - ILL reactor ON: $\sim 12\,500$ DRU (extrapolation)
  - ILL reactor OFF: $\sim 2\,500$ DRU (extrapolation)
- Data driven extrapolations consistent with preliminary Ricochet Geant4 simulations
- Neutron background level reduction goal: $\sim 4$ orders of magnitude $\rightarrow$ manageable with shielding according to Geant4 simulation !

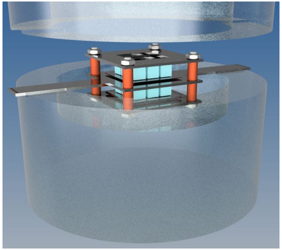
# Other experiments probing CEνNS in the sub-100 eV region

## MINER

- At the Mitchell Insti. research reactor(1 MW) with movable core
- Use of SuperCDMS Soudan detectors iZIP (625 g Ge) in HV mode
- Background reduction with passive and active shielding - No particle identification < 1 keV
- Science run started, Phase 2 in  1 year

R. Mahapatra *et al.*, NIMA 853 (2017) 53

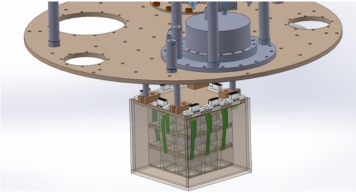
## NuCLEUS



- 80 meters away from Chooz reactors (2 x 4.25 GW)
- Phase 1: total target mass of 10 g - 9 x 0.8 g CaWO 4 and 9 x 0.5 g Al2O 3
- Background reduction with passive and active shielding (w. bolometers) - no particle identification
- Phase 1 start in 2020, then switch to phase 2 with 10 kg (2000 crystals)

G. Angloher *et al.*, arXiv:1905.10258 (2019)

## Ricochet - CryoCube



- Nuclear site to be finalized by end-2019
- Two detector technologies:
  - CryoCube: 1 kg array of detectors 30g (Ge & Zn)
  - Q-Array: 100 g (Zn & Al)
- Background reduction with passive and active shielding + particle identification
- First science data taking planned for 2023

J. Billard *et al.*, JPG 44 (2017) 10