Status of the future Ricochet experiment

J. Billard,

on behalf of the Ricochet collaboration

Institut de Physique Nucléaire de Lyon / CNRS / Université Lyon 1

Magnificent CENNS, Munich, 23rd of March 2023

RICOCHET: *A future low-energy neutrino observatory*

RICOCHET is a **France, USA and Russia** wide collaboration accounting for about 60 physicists, engineers, and technicians, aiming at building a **low-energy neutrino observatory**

Ricochet coll. meeting March 2023 (ILL)

RICOCHET: *A future low-energy neutrino observatory*

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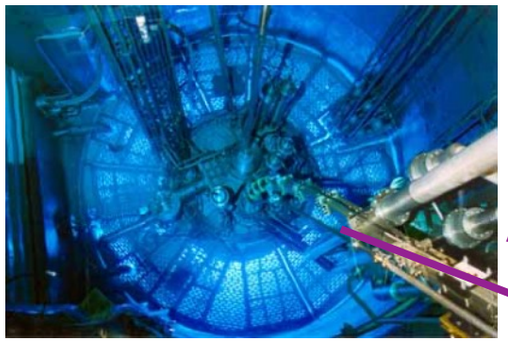
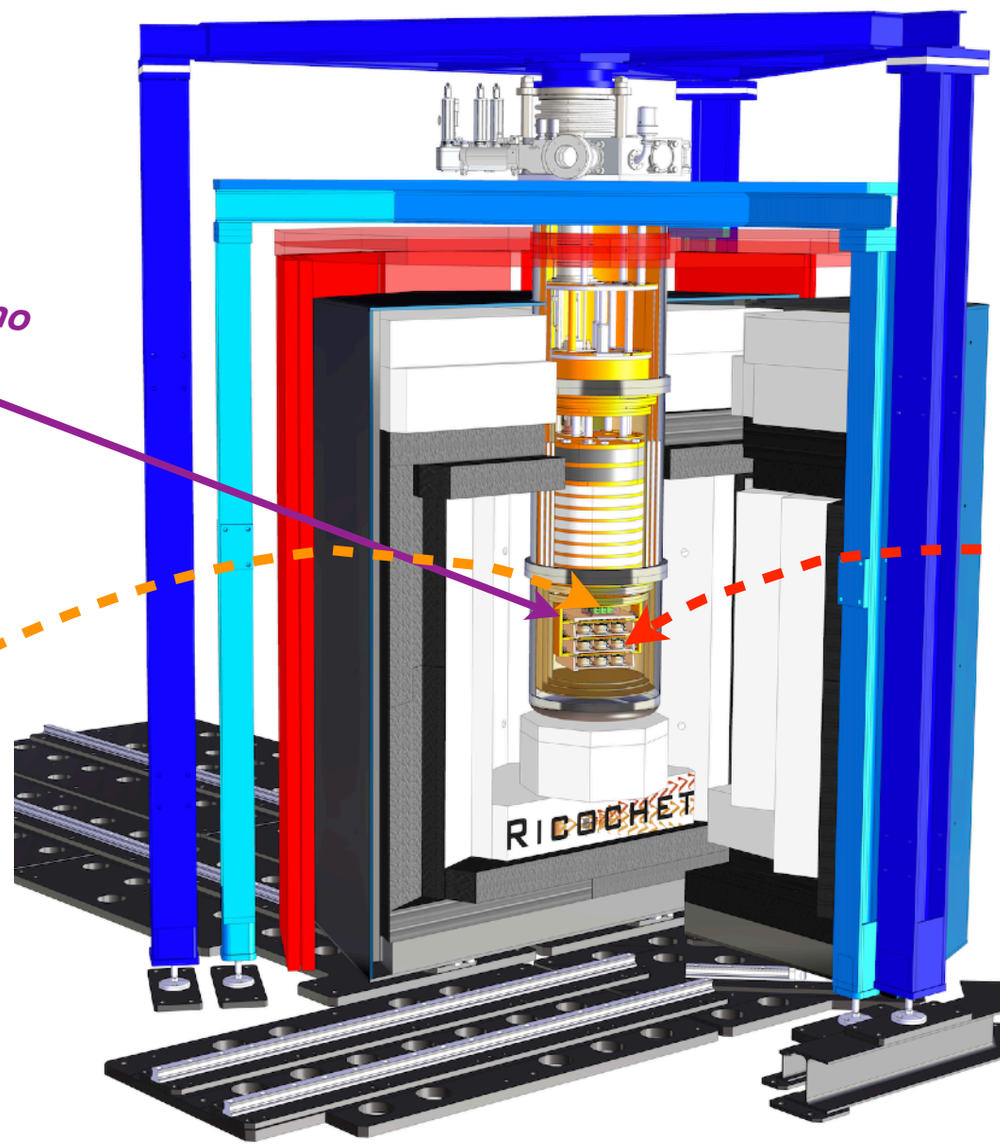
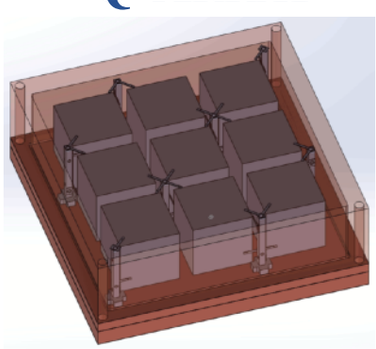


Neutrino

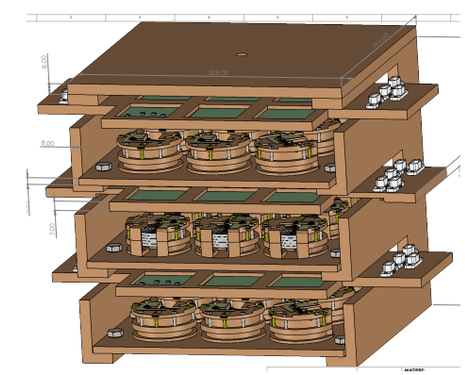


Q-ARRAY



CRYOCUBE

Ge (& Si?)



ANR AGENCE NATIONALE DE LA RECHERCHE

erc

cnrs IN2P3 Les deux infinis

Northwestern University

LPSC Grenoble

IJCLab Irène Joliot-Curie

iP2i LES 2 INFINIS LYON

MIT

NÉEL

THE UNIVERSITY of WISCONSIN MADISON

UMASS AMHERST

UNIVERSITY OF TORONTO

RICOCHET: *ILL-H7 nuclear reactor site*

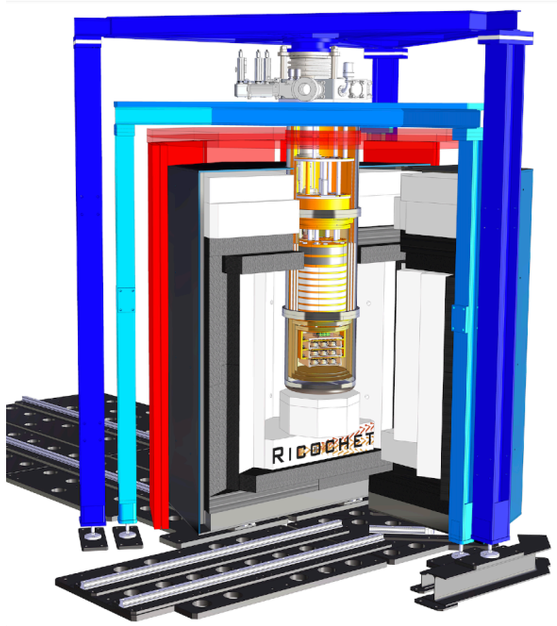
- 58 MW nominal thermal power
- ~11 evts/day/kg (50 eV threshold)
  - *Evaluation using STEREO measurement [Nature 2023]*
- 3 to 4 cycles per year: ***excellent ON/OFF modulation to subtract uncorrelated backgrounds***
- **Ricochet @ ILL design finalised**
- Fast and thermal neutron flux characterised

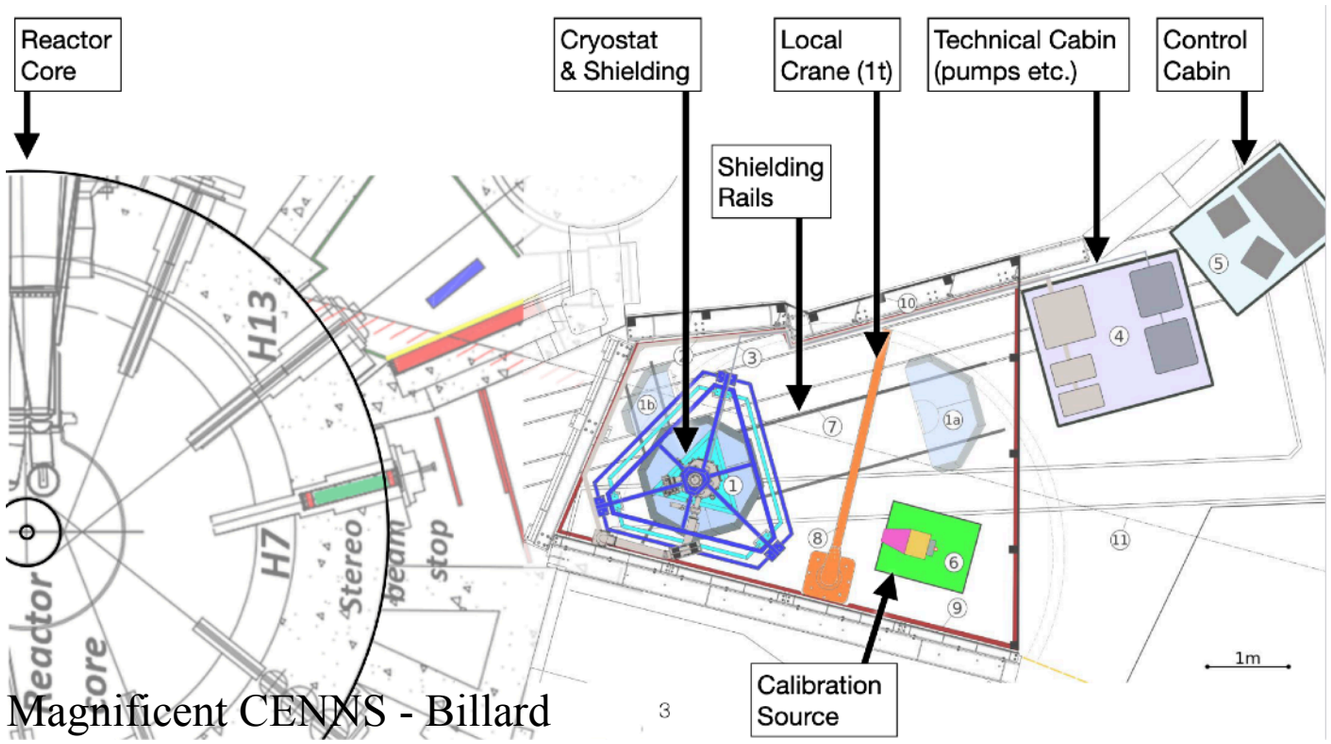
*Ricochet coll., Eur. Phys. J. C **83** (2023) 1, 20*

- Significant overburden (~15 m.w.e) to reduce cosmics
- **Ricochet integration started !**
  - ***First neutrino data mid-2024***

Inner shielding:
- PE/Cu: 30 cm
- Pb/Cu: 15 cm
- Cryogenic Muon Veto
- Mu-Metal

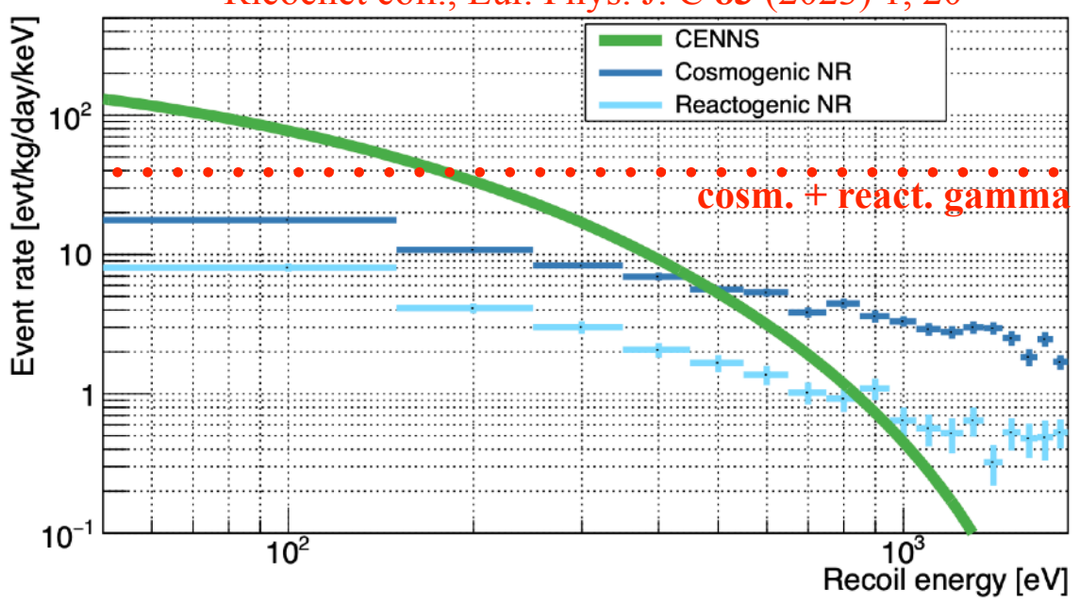
Outer shielding:
- PE: 35 cm
- Pb: 20 cm
- Muon veto
- Soft iron





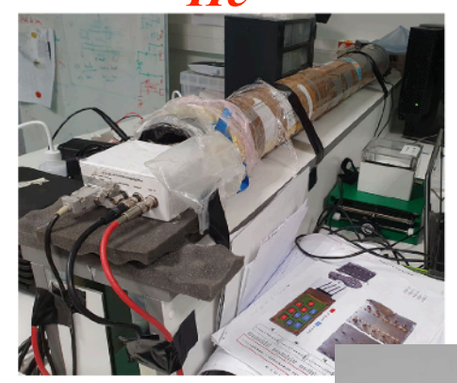
RICOCHET: *Expected backgrounds and monitoring*

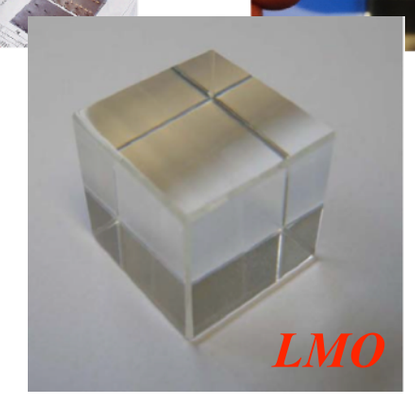
Ricochet coll., Eur. Phys. J. C **83** (2023) 1, 20



Recoil type rate	Cosmogenic	Reactogenic	Total
R_{ER} (evts/d/kg)	9.5 ± 0.5	23.0 ± 1.6	32.5 ± 1.7
R_{NR} (evts/d/kg)	8.4 ± 0.4	1.0 ± 0.2	9.4 ± 0.5

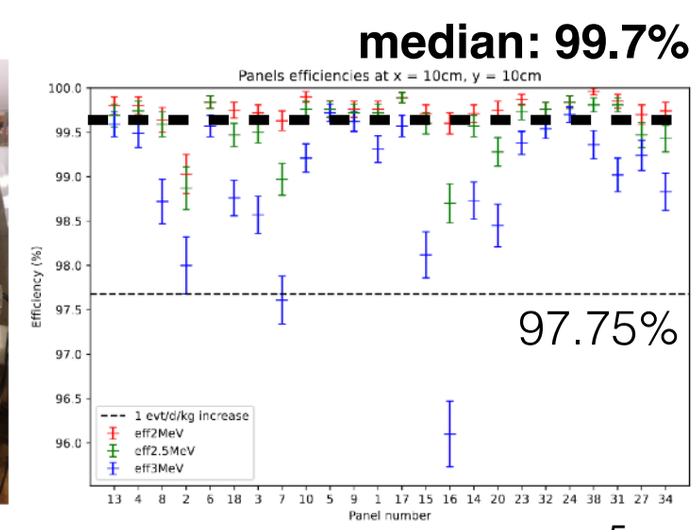
Background model





In-situ neutron monitoring detectors

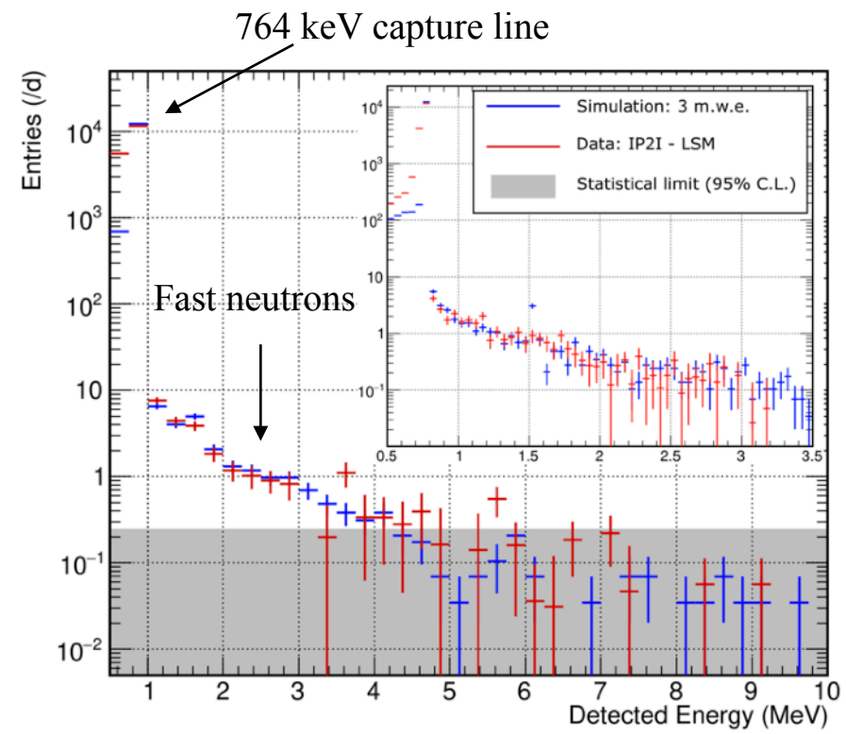
- ***Targeted neutron background levels achievable to reach S/B ~ 1***
- Muon veto under commissioning
- Reactogenic neutrons negligible (~ 10%)
- Reactogenic + cosmogenic gamma around 30 DRU but radiogenic not yet accounted for (screening ongoing)
- In-situ neutron detectors for accurate background subtraction: ^{3}He, H, and cryogenic LMO



See G. Chemin's talk

RICOCHET: *Blank assembly at IP2I (Lyon)*

Outer shielding:
- PE: 30 cm (1 ton)
- Pb: 10 cm (9 tons)



Ricochet coll., Eur. Phys. J. C **83** (2023) 1, 20

Cosmogenic neutron characterisation

Use of 3He and muon scintillating panels

Expect 200 DRU NR in blank assembly

- **Goal**: Validation of the Ricochet setup and detectors' sensitivity from a **3 m.w.e low-background installation**

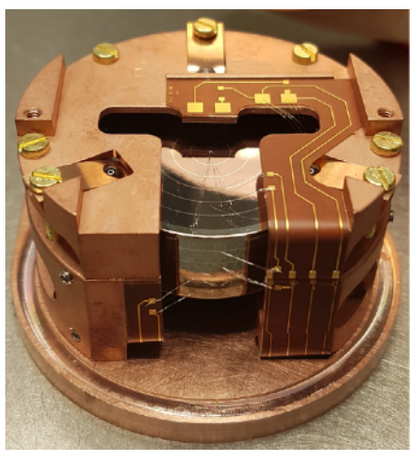
- Validation of the Ricochet cryostat: cryogenic and vibration performances (**done**)
- Validation of the cold inner shielding: Pb, PE, and Cu layers + cryogenic muon veto (**ongoing**)
- Integration of the cold cabling, electronics and cryogenic detectors (**upcoming**)

- Validation of the DAQ readout, database and processing/analysis pipeline (*see J. Colas' poster*)
- **Getting ready for ILL deployment by end-2023**

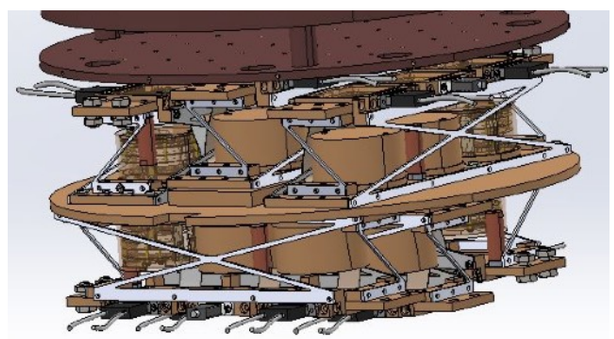
Ricochet: *Detector technology innovation*

Technological key features of RICOCHET: Particle Identification down to sub-100 eV

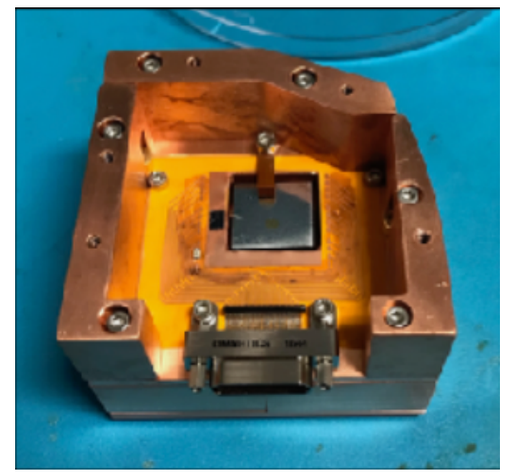
Germanium semiconductor



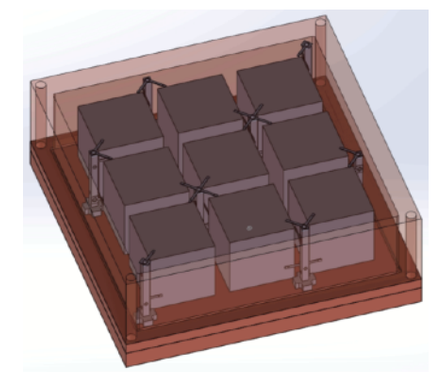
Array of 18-to-27 42-g Ge detectors

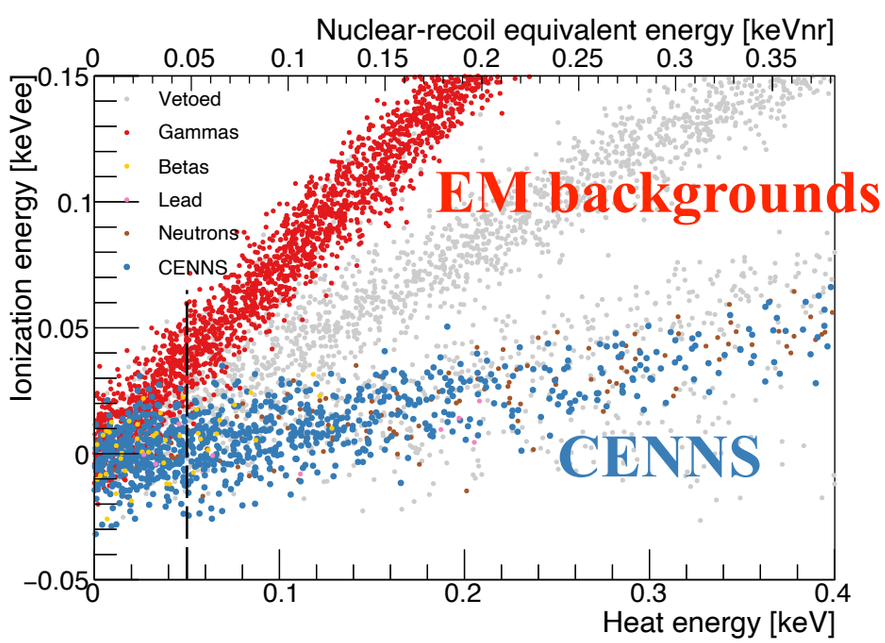


Zinc superconducting metal

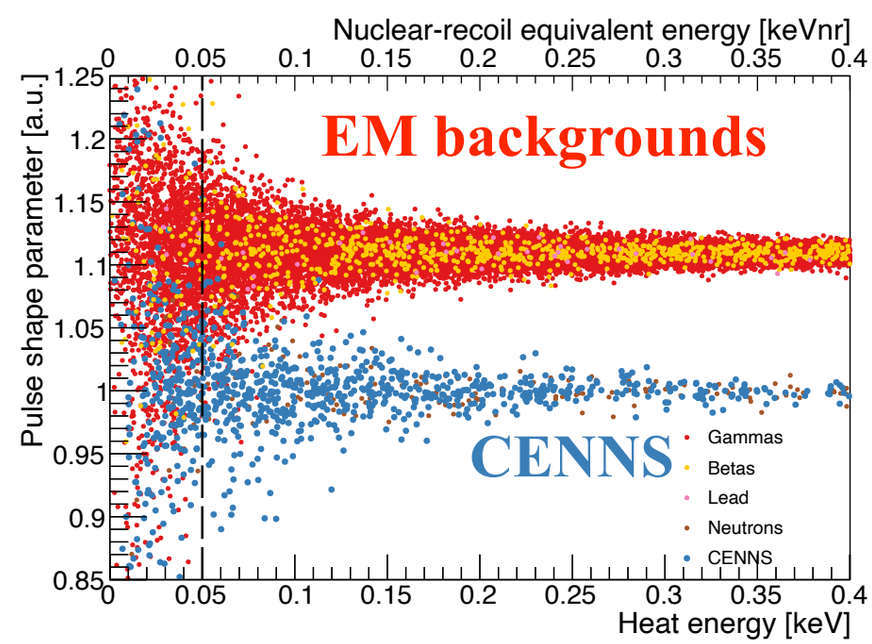


Array of 9 32-g Zn detectors





Particle ID based on **Ionization / heat** ratio

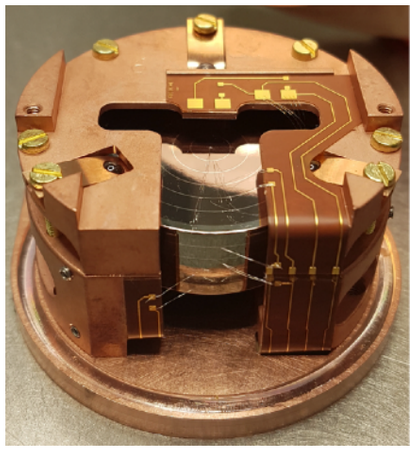


Particle ID based on **Prompt / delayed** heat signals

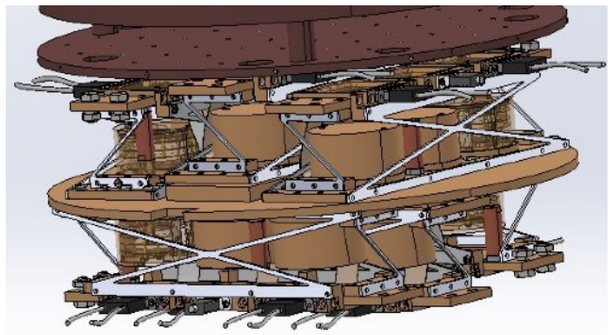
Ricochet: *Detector technology innovation*

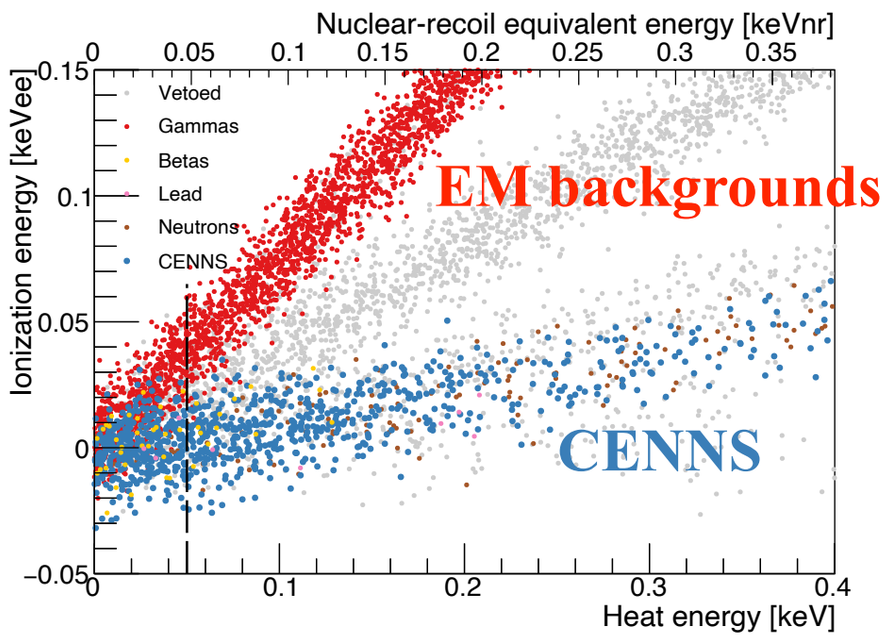
Technological key features of RICOCHET: Particle Identification down to sub-100 eV

Germanium semiconductor



Array of 18-to-27 42-g Ge detectors





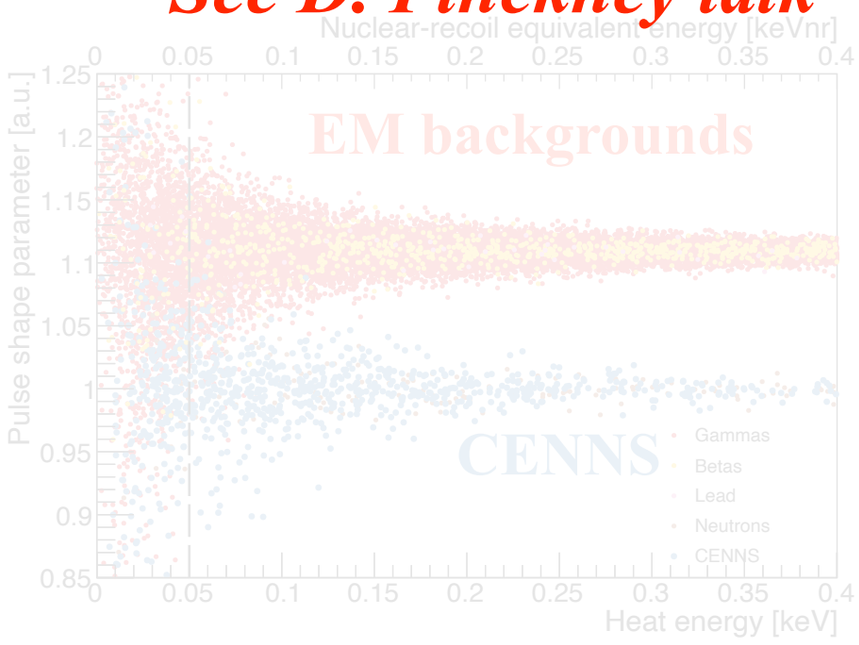
Particle ID based on **Ionization / heat** ratio

Magnificent CENNS - Billard

Zinc superconducting metal

Array of 9 32-g Zn detectors

See D. Pinckney talk



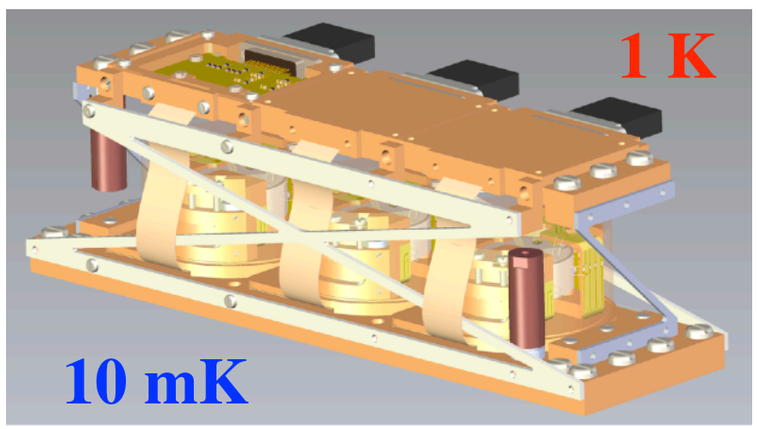
Particle ID based on **Prompt / delayed** heat signals

Ricochet: *Detector technology innovation (CryoCube)*

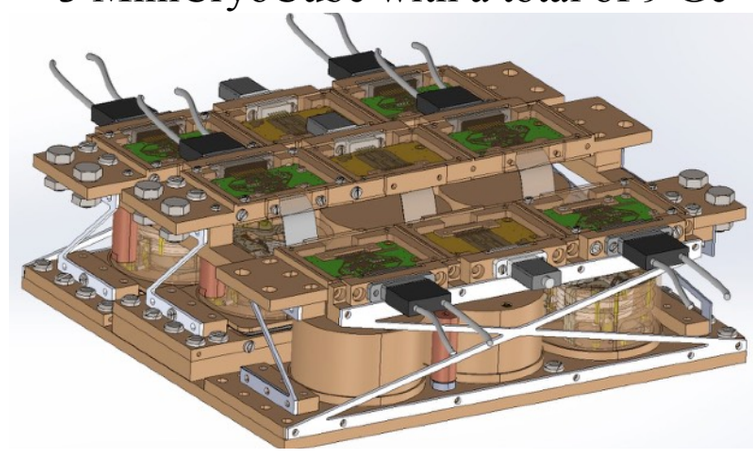
CryoCube specifications:	1) Heat energy resolution:	**10 eV (RMS)**
	2) Ionization resolution:	**20 eVee (RMS)**
	3) Optimized electrodes:	**fid. V >70% + surf. rej. ?**
	4) Timing resolution:	**~100 us @ 100 eV**
	5) Detector payload:	**1 kg —> 750 g**

*<u>Key feature</u>: Achieve **Particle Identification** down to O(10) eV with a ER rejection >10^3*

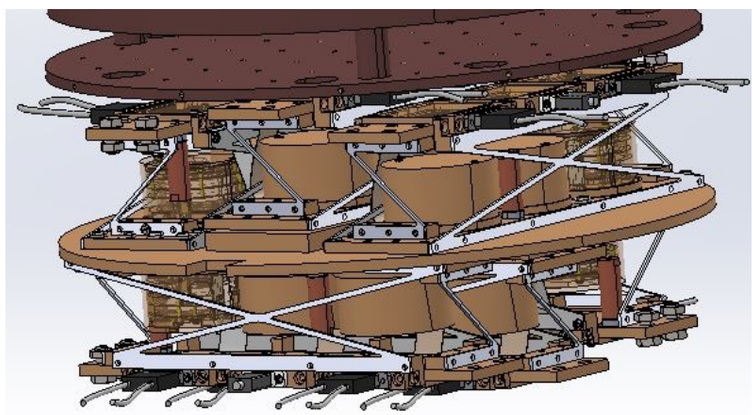
MiniCryoCube
3 Ge detectors (10 mK) with their elec. (1K)



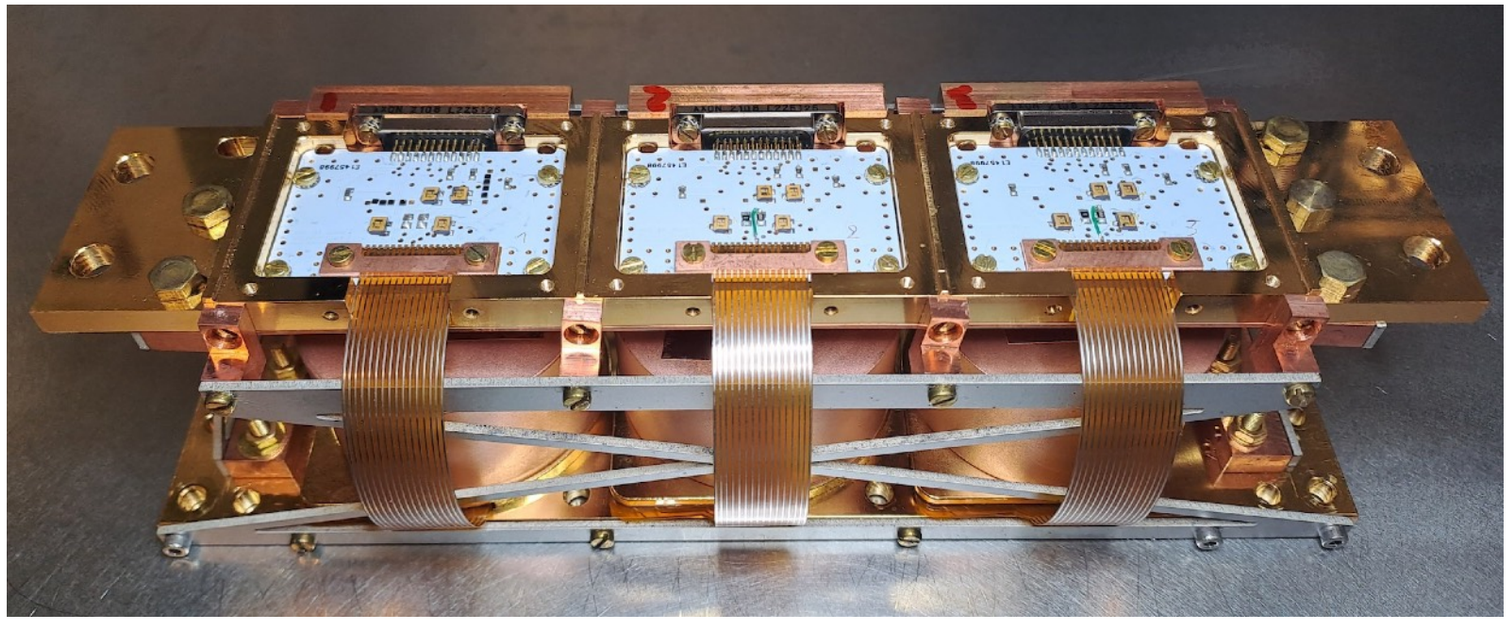
MiniCryoCube assembly
3 MiniCryoCube with a total of 9 Ge

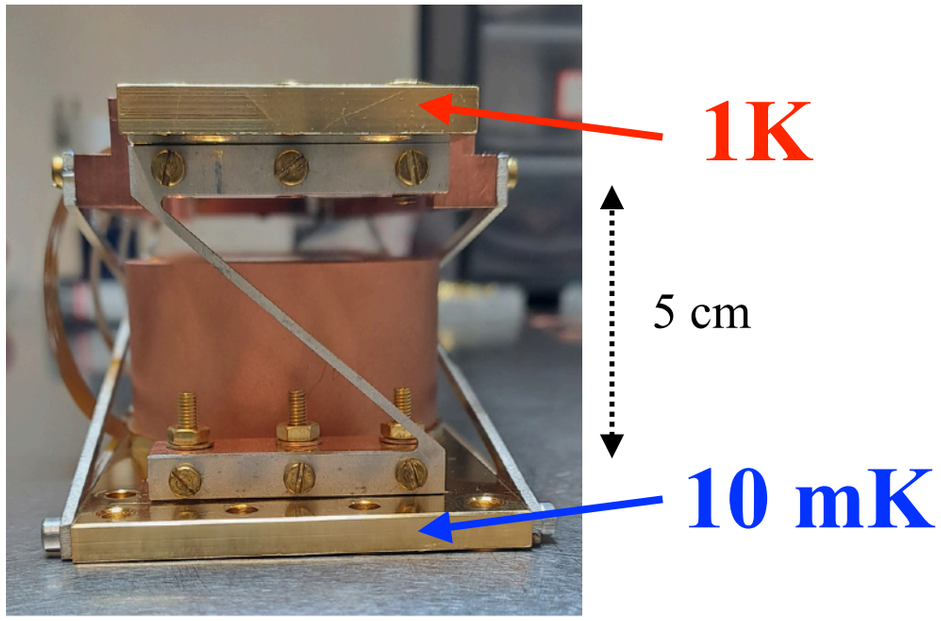


CryoCube array
2/3 MiniCryoCube assembly: 18/27 Ge

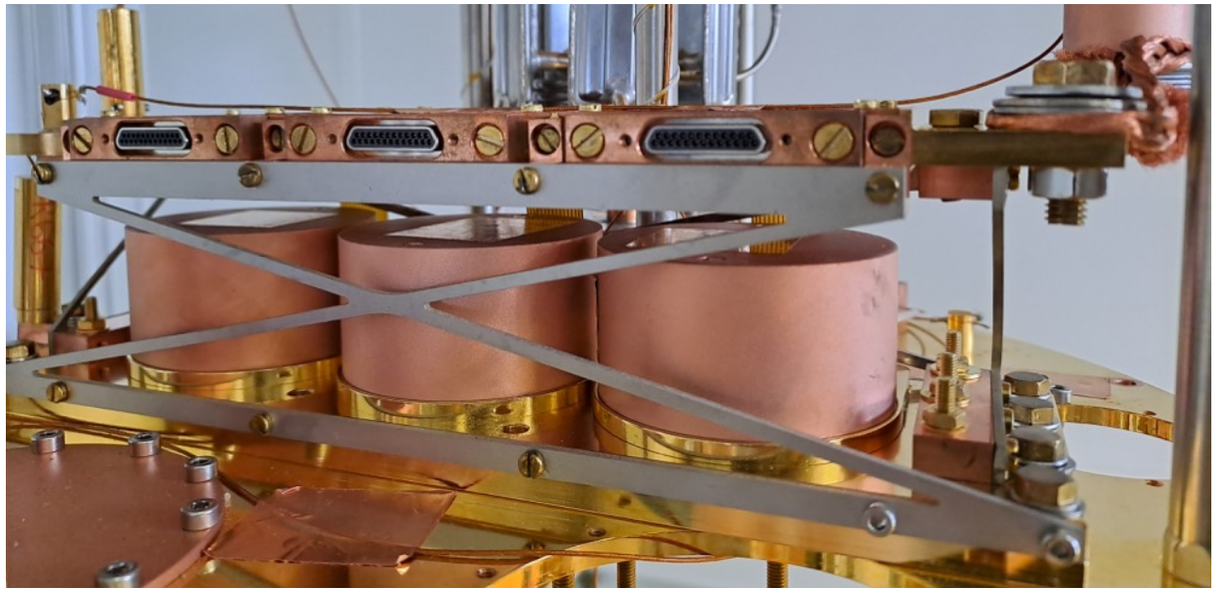


CRYOCUBE: *Scaling up to the kg-scale payload*



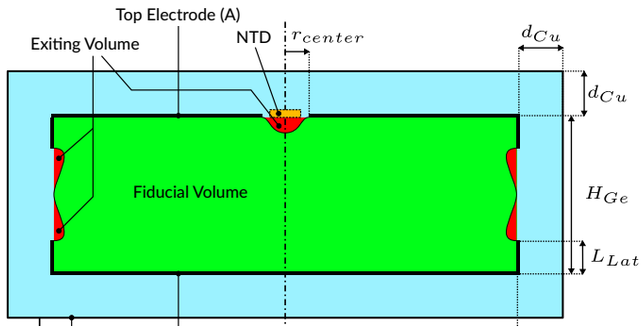


- **Mini-CryoCube:** 3 bolometers @ 10 mK with their HEMT preamplifiers @ 1 K only 5 cm above
- Total heat load budget of the CryoCube array 1K-to-10mK stages of **4 uW**
- First 3x MiniCryoCube assembly tests to begin in Ricochet cryostat @ Lyon summer 2023
- **Validation of the full CryoCube array planned over the fall of 2023**



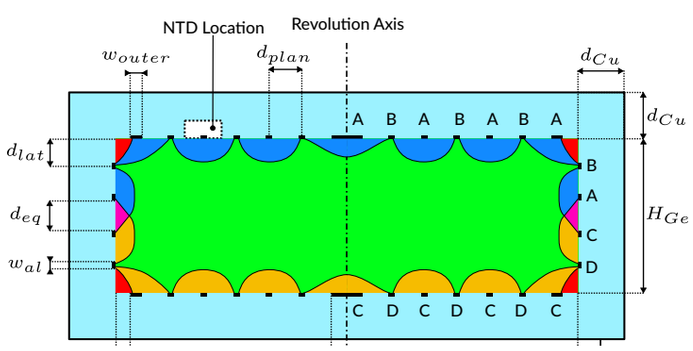
CRYOCUBE: *Individual detector design*

PL 38



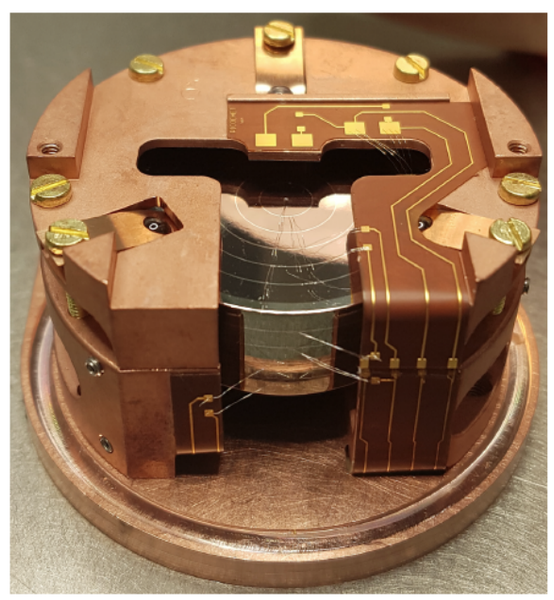
- Incomplete charge coll. **< 10%**
- Fiducial volume: **98.6 %**
- Surface event rejection: **NO**
- Total capacitance: **15 pF**

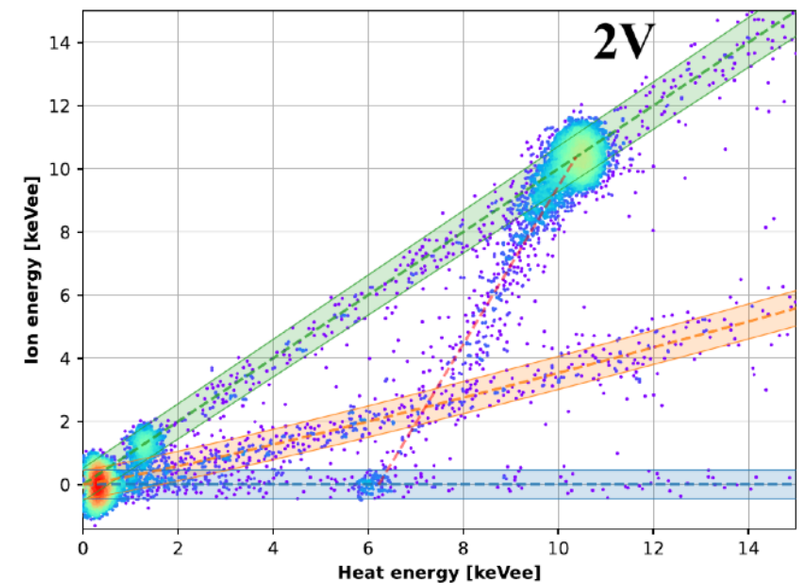
FID 38

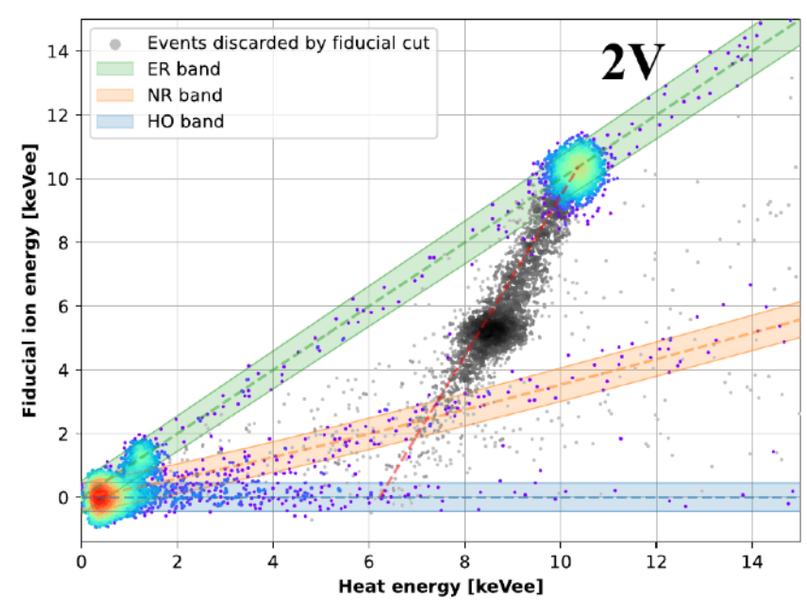


- Incomplete charge coll. **< 1%**
- Fiducial volume: **62 %**
- Surface event rejection: **YES**
- Total capacitance: **18 pF**

Salagnac & al: arXiv:2111.12438





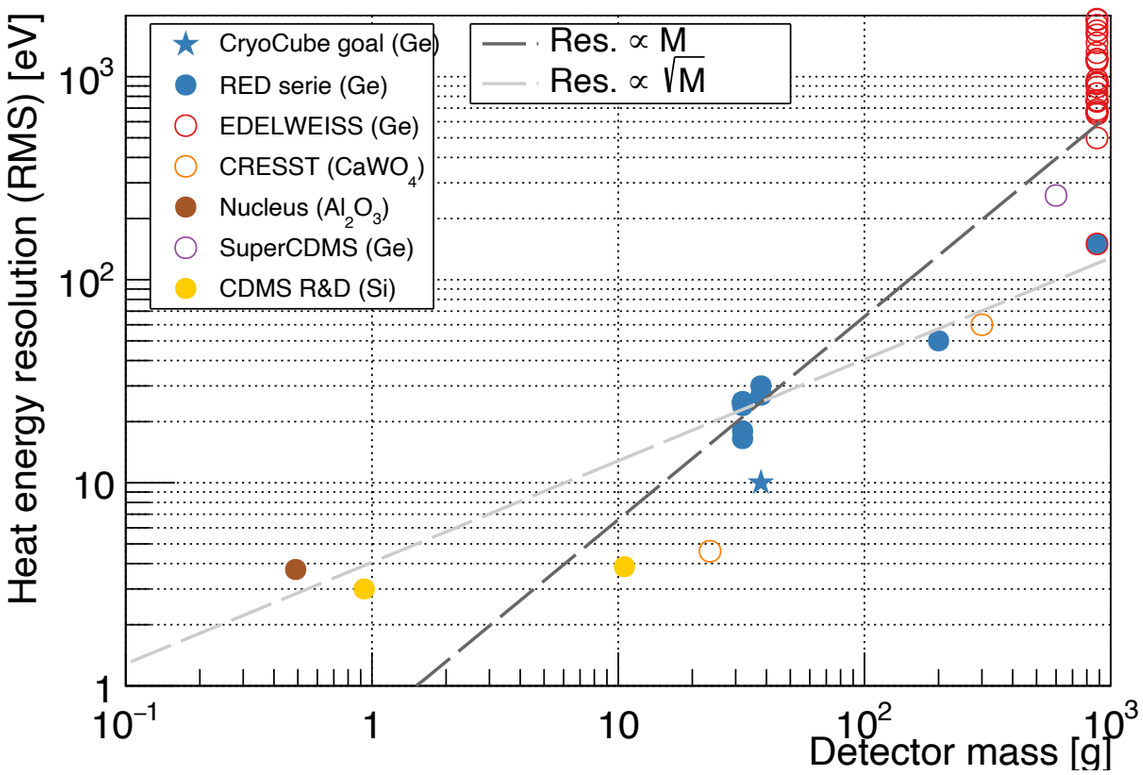


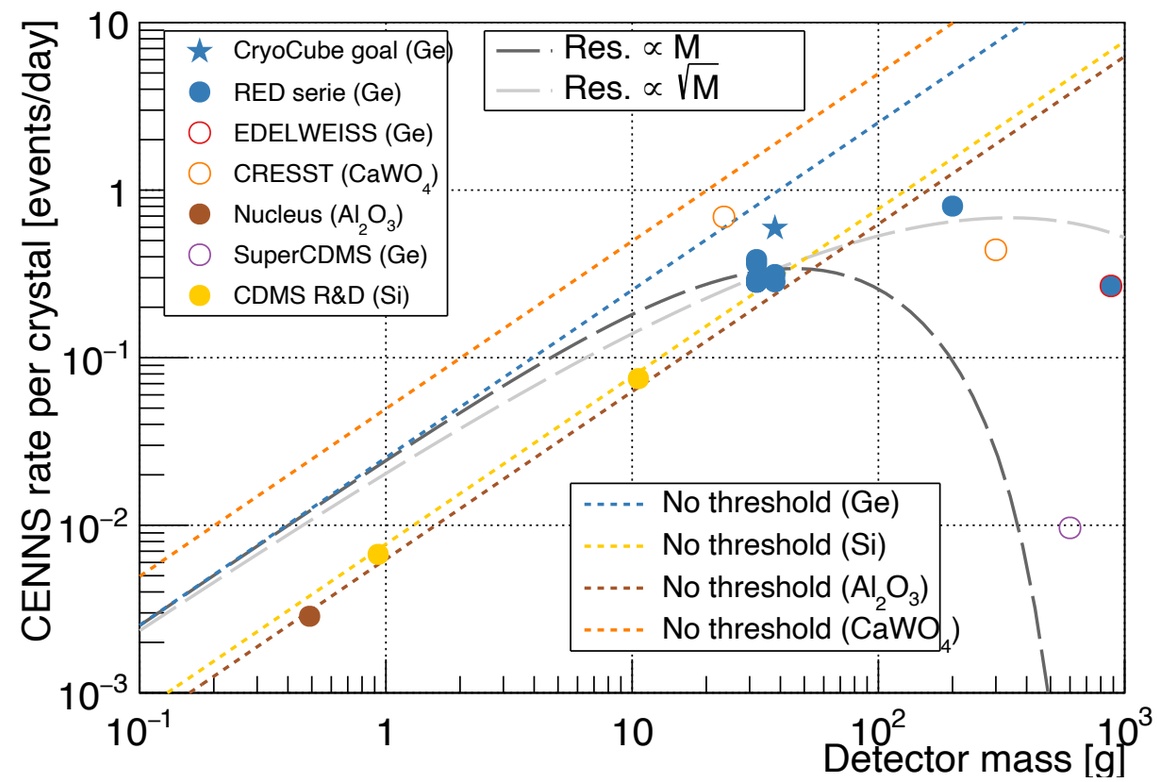
- **Total of 16 Ge detectors (PL and FID) already produced,** validation ongoing…
- *The results presented here are from using the 100K JFET-based EDELWEISS electronics*
- ***First results with Ricochet-CryoCube HEMT-based electronics upcoming…***

CRYOCUBE: *Heat channel optimization*

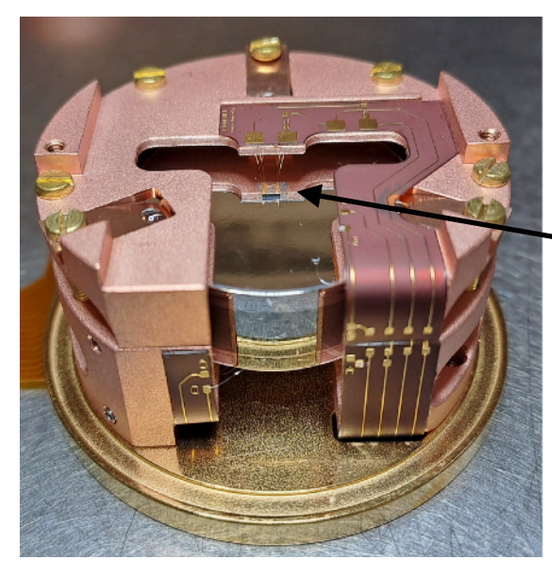
Salagnac & al: **arXiv:2111.12438**

Threshold defined for all experiments as 5σ





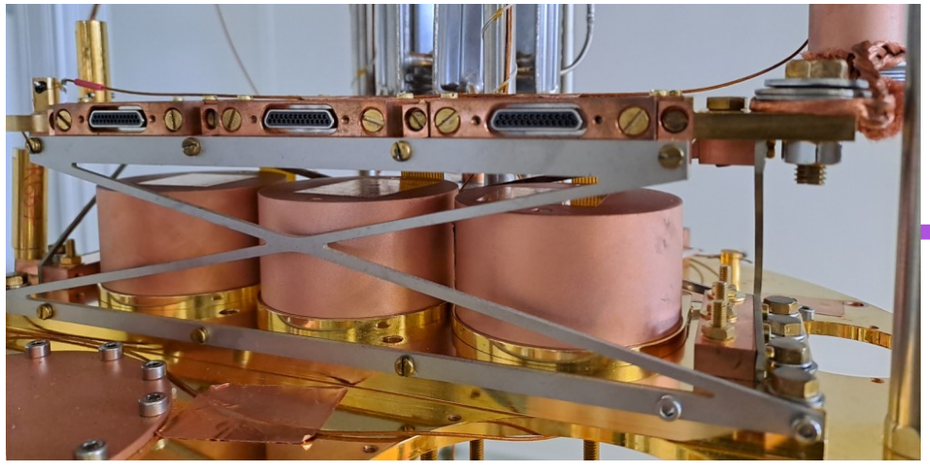
- Achieved an averaged 25 eV resolution on 10 Ge detectors with JFET electronics
- Among the **best resolution-to-mass ratio** from **above ground operation**
- Exhibit the **largest CENNS signal strength per crystal** of about 0.3 evt/day
  - *Goal: 0.6 evt/day 8.8m away from the ILL reactor.*
- Targeted 10 eV resolution expected with *new CryoCube JFET-based electronics.*

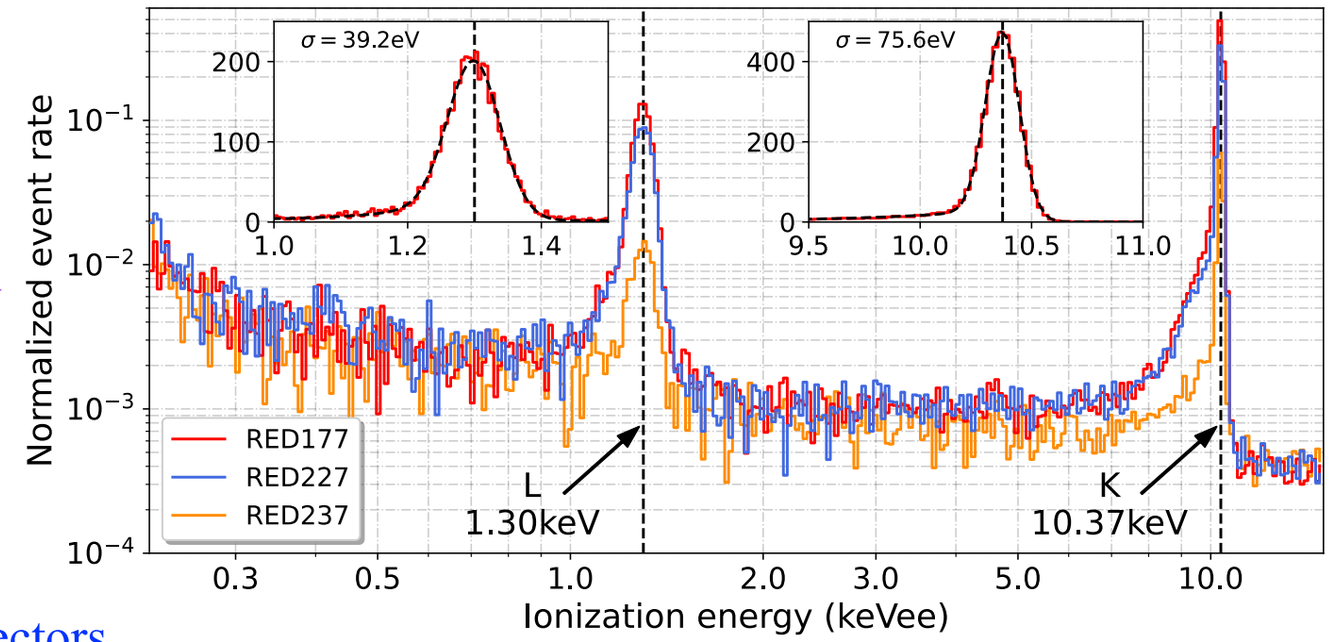


NTD
Heat sensor

CRYOCUBE: *HEMT-based ionisation preamplifiers*

Ricochet coll., *paper in preparation (2023)*





- 30 eVee ionisation resolution achieved on all three detectors operated in a MiniCryoCube in R&D cryostat
- Factor of 7 and 11 improvement w.r.t to previously achieved resolution in EDW/CDMS and similar to best HPGe @ 77K

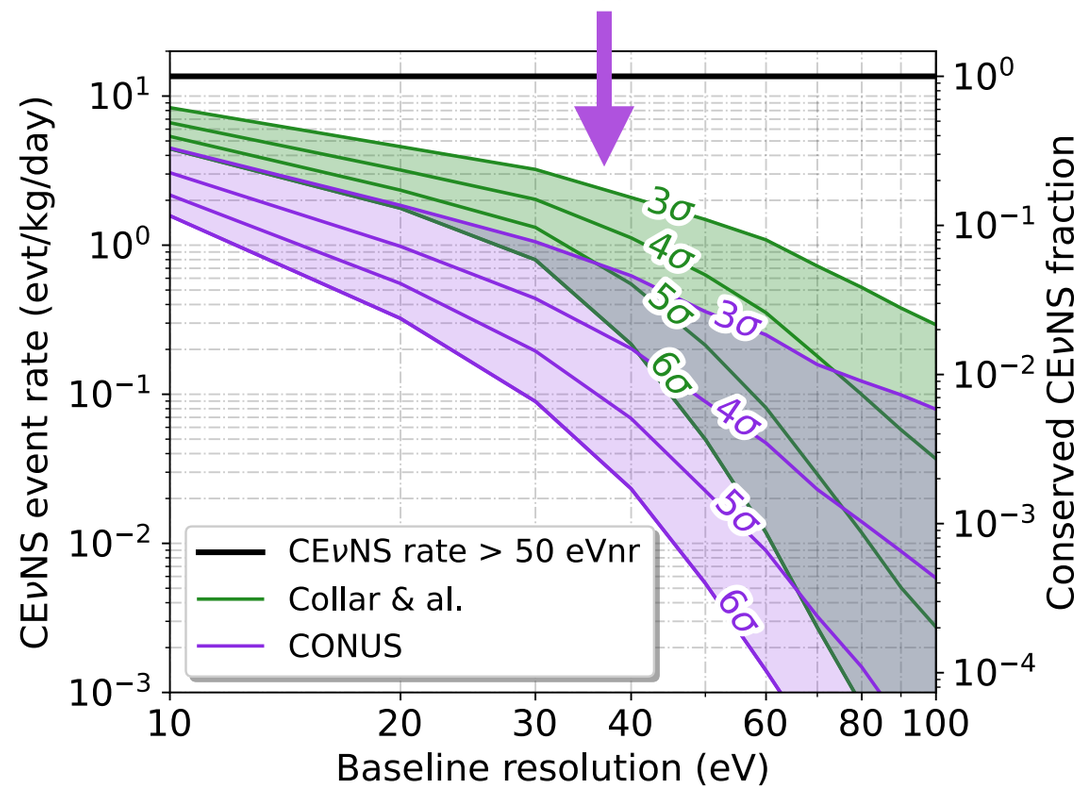
Reaching over the Heat Only wall ! *(see F. Reindl LEE talk)*

Rejection of 10^5 HO while keeping ~10/20% CENNS signal

Need a precise NR ionisation yield measurement at 10 mK

=> *Ricochet's DT in-situ calibration source*

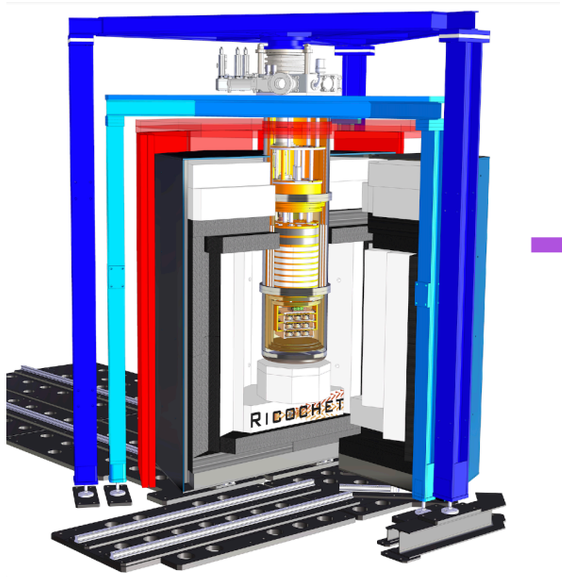
Coming soon: dual heat-ionisation measurement !



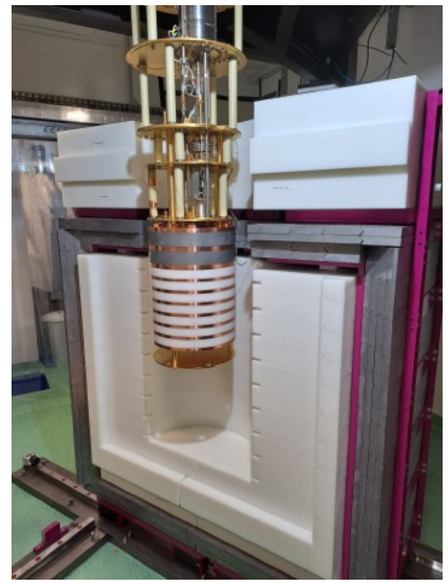
See N. Martini's poster

Conclusion

Design phase: ***done***



Commisioning: ***ongoing***



Ricochet @ ILL: ***in construction***

Data Vs Monte Carlo studies suggest a signal-to-noise ratio ~1, *provided that the gamma and heat only backgrounds can be efficiently rejected with PID*

The CryoCube Ge detector technology is nearing its targeted performance *and will be ready for its deployment in the Ricochet experiment at ILL by early-2024*

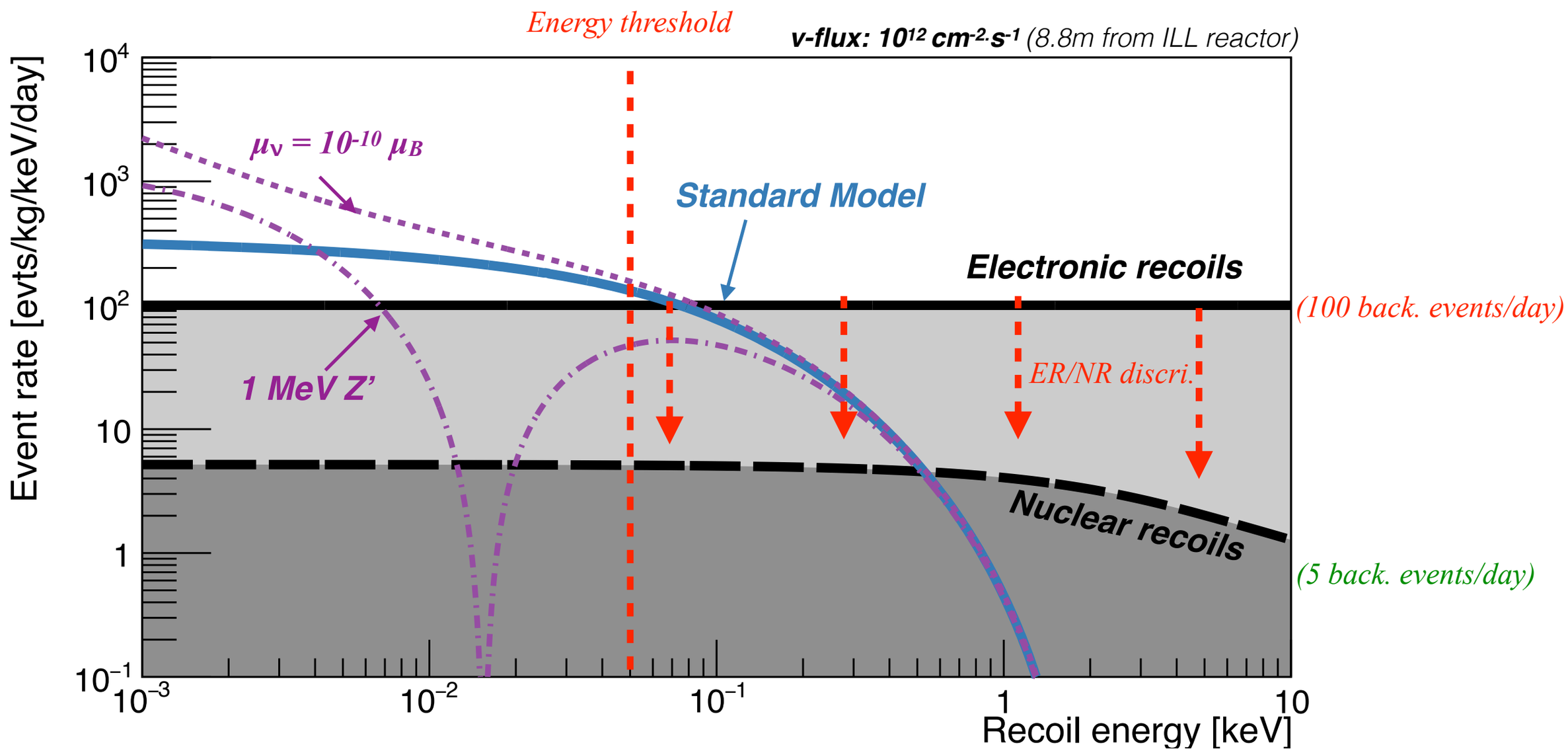
Exciting new updates from the Ricochet Q-Array Zn detector technology *(see D. Pinckney's talk)*

First neutrino data to begin over the summer 2024

Backup

Ricochet: *searching for new physics*

Technological key features of RICOCHET: Particle Identification down to sub-100 eV

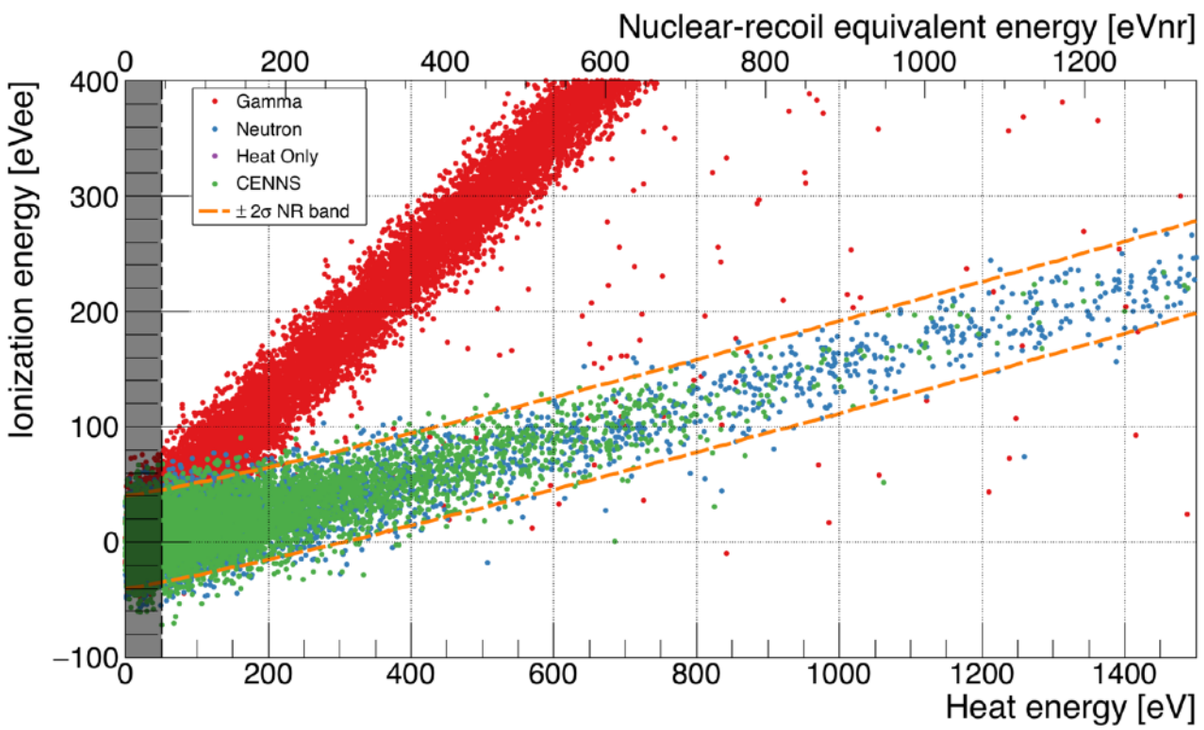


11 CENNS events/day and a 10^3 CENNS-spectrum averaged ER rejection

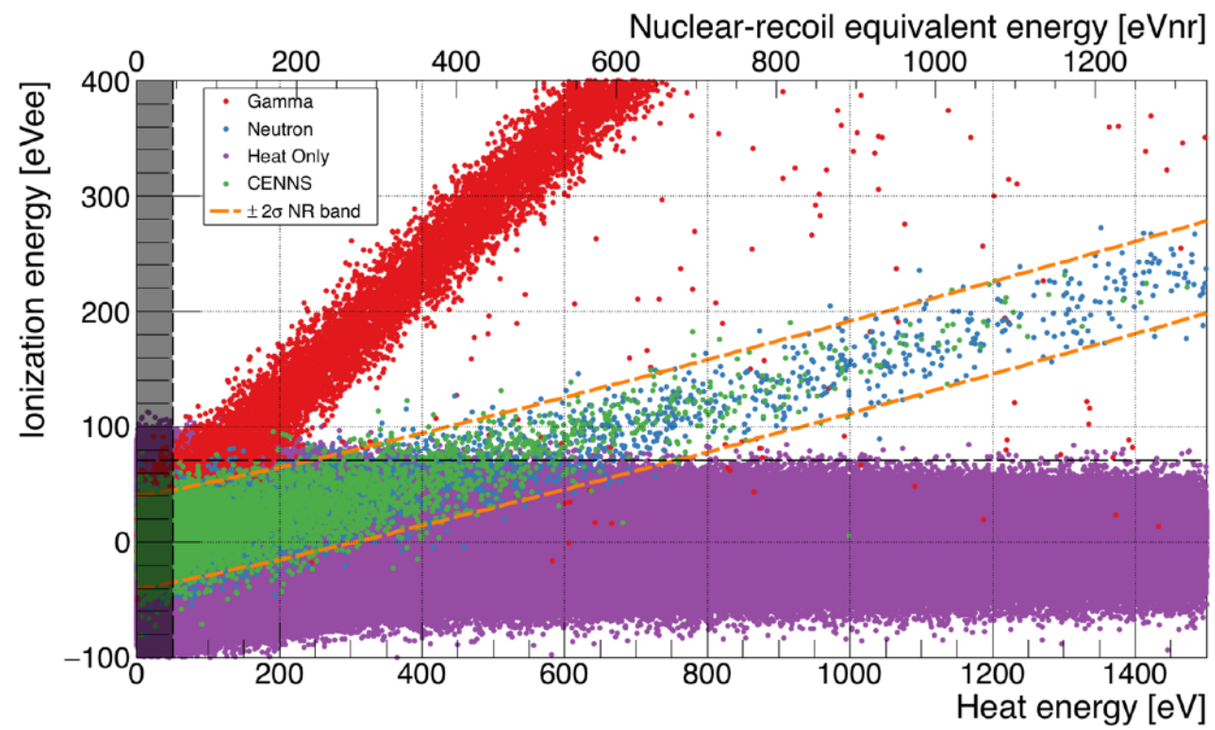
~4-to-20 sigma CENNS detection after one reactor cycle including LEE or not (not shown)

CRYOCUBE: *Expected CENNS sensitivity at ILL*

Baseline scenario



Worst case scenario

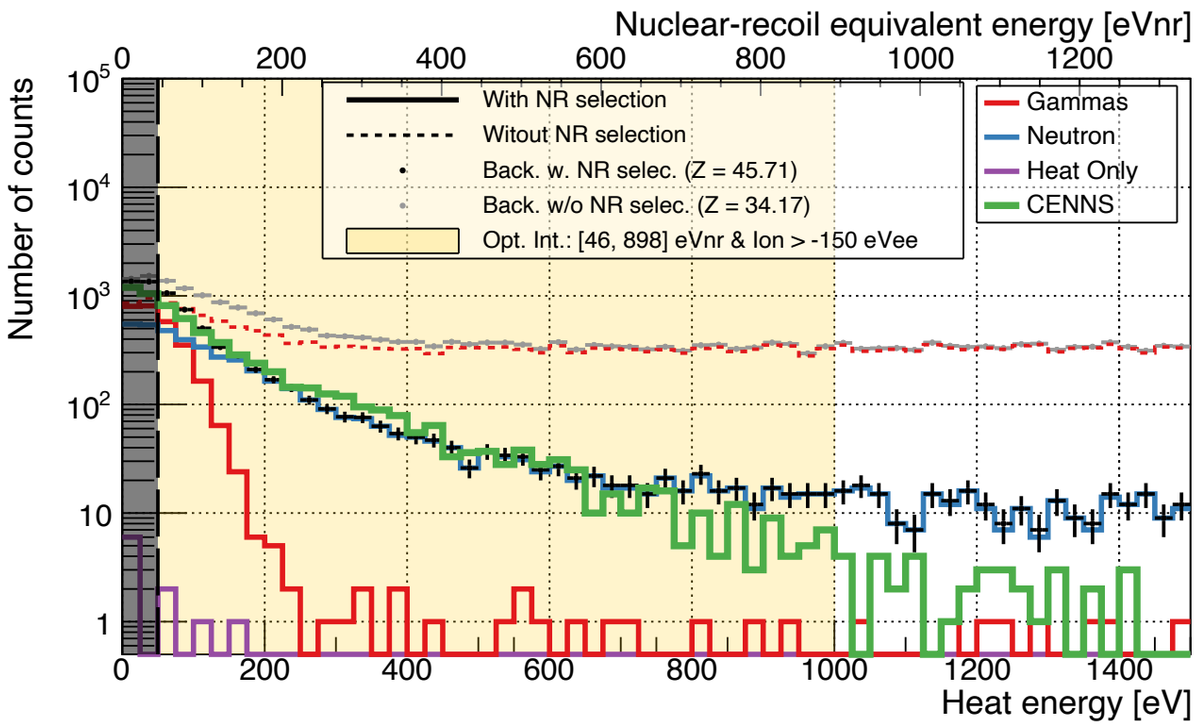


- CENNS sensitivity estimation considering:
  - The Ricochet at ILL background model
  - An outer muon veto with a time coincidence window of 350 us
  - The CryoCube anticipated performance (PL38)
  - 7 reactor cycles (~ 2 years)
  - Lindhard Ge ionization yield model

- Similar condition as baseline scenario but with the addition of a strong Heat Only background inducing a low-energy excess as observed in all low-threshold cryogenic experiments:
  - EDELWEISS-Surf: 1e6 DRU at 50 eV
  - CRESST/NuCLEUS: 1e8 DRU at 20 eV
  - CDMS/Si-PD: 1e9 DRU at 20 eV

CRYOCUBE: *Expected CENNS sensitivity at ILL*

Baseline scenario



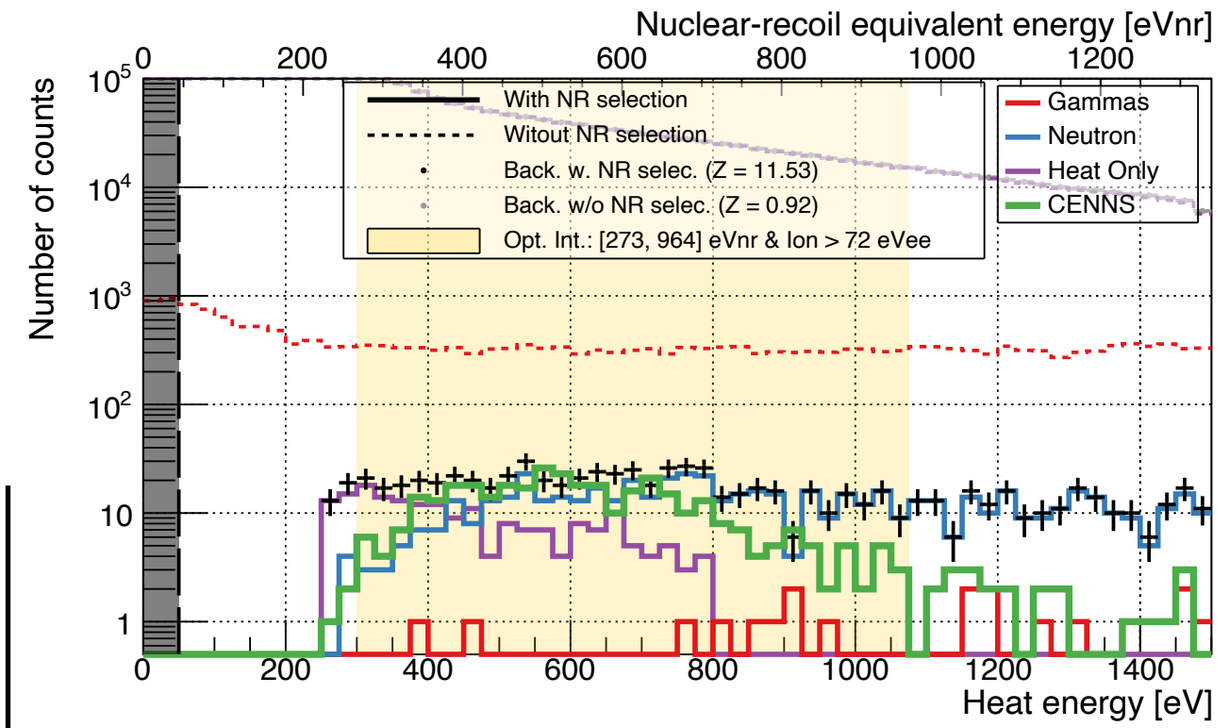
CENNS signal significance (after one cycle): **17.3 sigma**

Final CENNS precision measurement: **<2% (stat.)**

Effective CENNS threshold: **50 eV**

Full accomplishment of Ricochet's scientific goals, orders of magnitude improved sensitivity w.r.t current constraints

Worst case scenario



CENNS signal significance (after one cycle): **4.2 sigma**

Final CENNS precision measurement: **<8% (stat.)**

Effective CENNS threshold: **250 eV**

Partial accomplishment of Ricochet's scientific goals:

- Full sensitivity to: NSI, heavy bosons, and sterile-ν
- Reduced sensitivity to light bosons

Particle identification is key to mitigate efficiently this yet-to-be-understood overwhelming background

RICOCHET: *Controlling the signal systematics*

We anticipate our final CENNS measurement to be limited by the following dominating systematics:

1. The anti-neutrino reactor predictions:

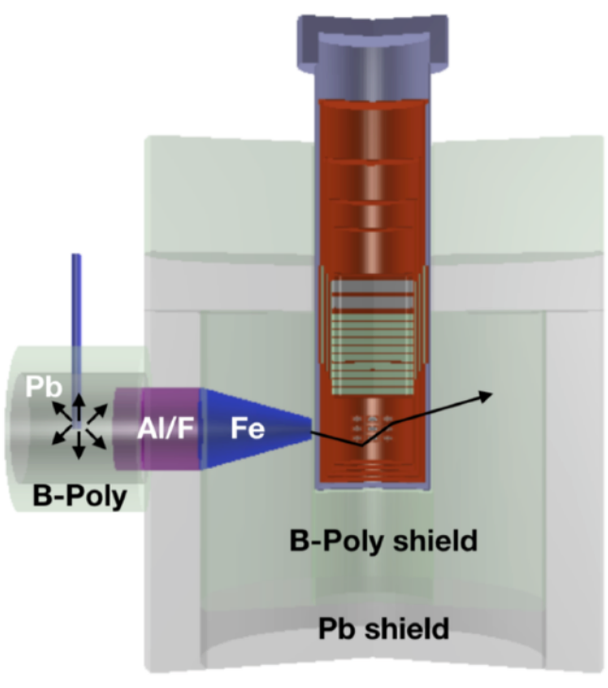
   Expected to be at the level of 3% despite of the large unknown below the IBD threshold

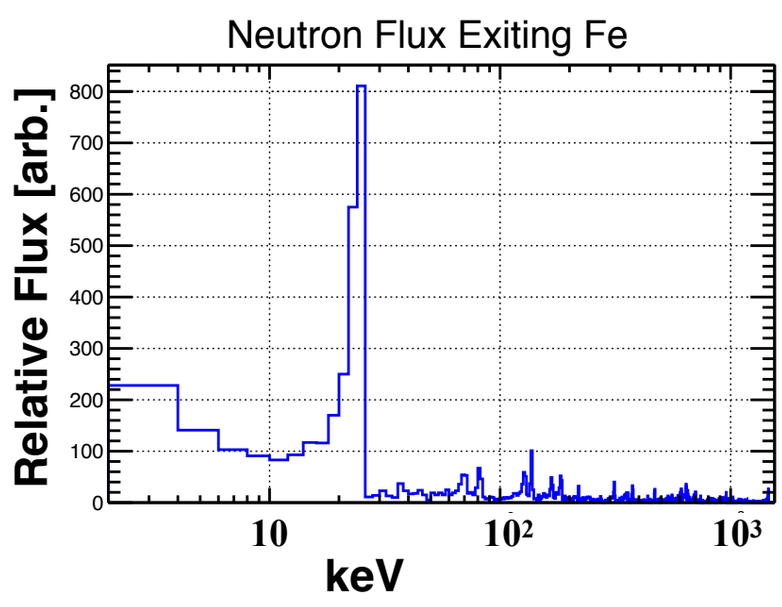
2. The neutron background in the CENNS region of interest:

   Considering the use of lithiated, He3 and H proportional counters to monitor the in-situ fast neutron flux to subtract it from Ge and Zn data with reduced systematics

3. Low-energy nuclear recoil calibrations:

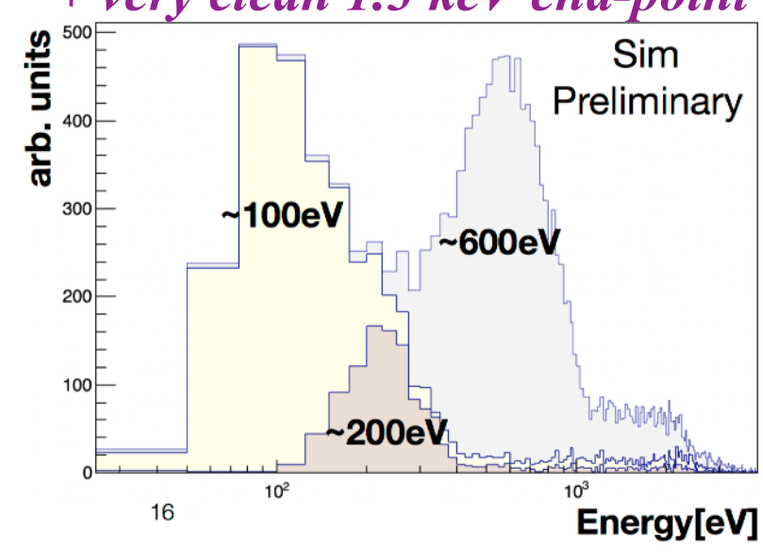
   Dedicated low-energy, mono-energetic (24.4 keV), and pulsed neutron source from a DT generator





See Pratyush presentation

+ very clean 1.3 keV end-point



Ricochet: *Appreciating the CENNS challenge*

Neutrino-WIMP equivalent model ***independent of target material***

CENNS signal from reactor neutrino is similar to a 2.7 GeV WIMP with a cross section depending on the flux

Ricochet needs to be as sensitive as DM experiments but from above ground !