RICOCHET First Light & Experiment Progress

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University of Toronto

on behalf of the RICOCHET Collaboration

CAP Congress
June 10th 2025

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)

- Proposed by Freedman in 1974
  D.Z. Freedman, Phys. Rev. D 9, 1389 ***(1974)***
- At neutrino energies <50 MeV, interactions coherent, nucleus recoils as a whole
- Cross section scales with N^2, favours heavy nuclei detectors

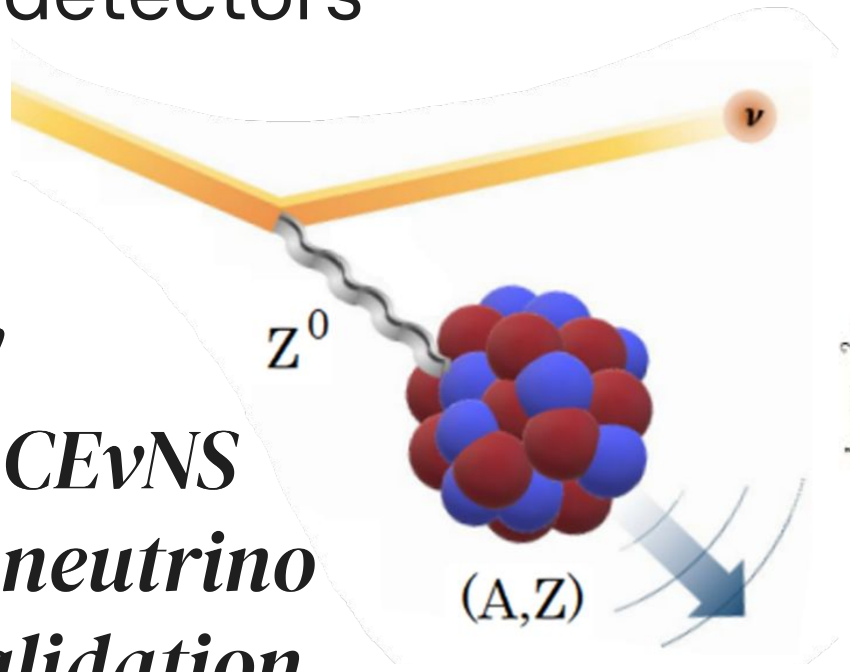
Weak Charge component $\propto N^2$

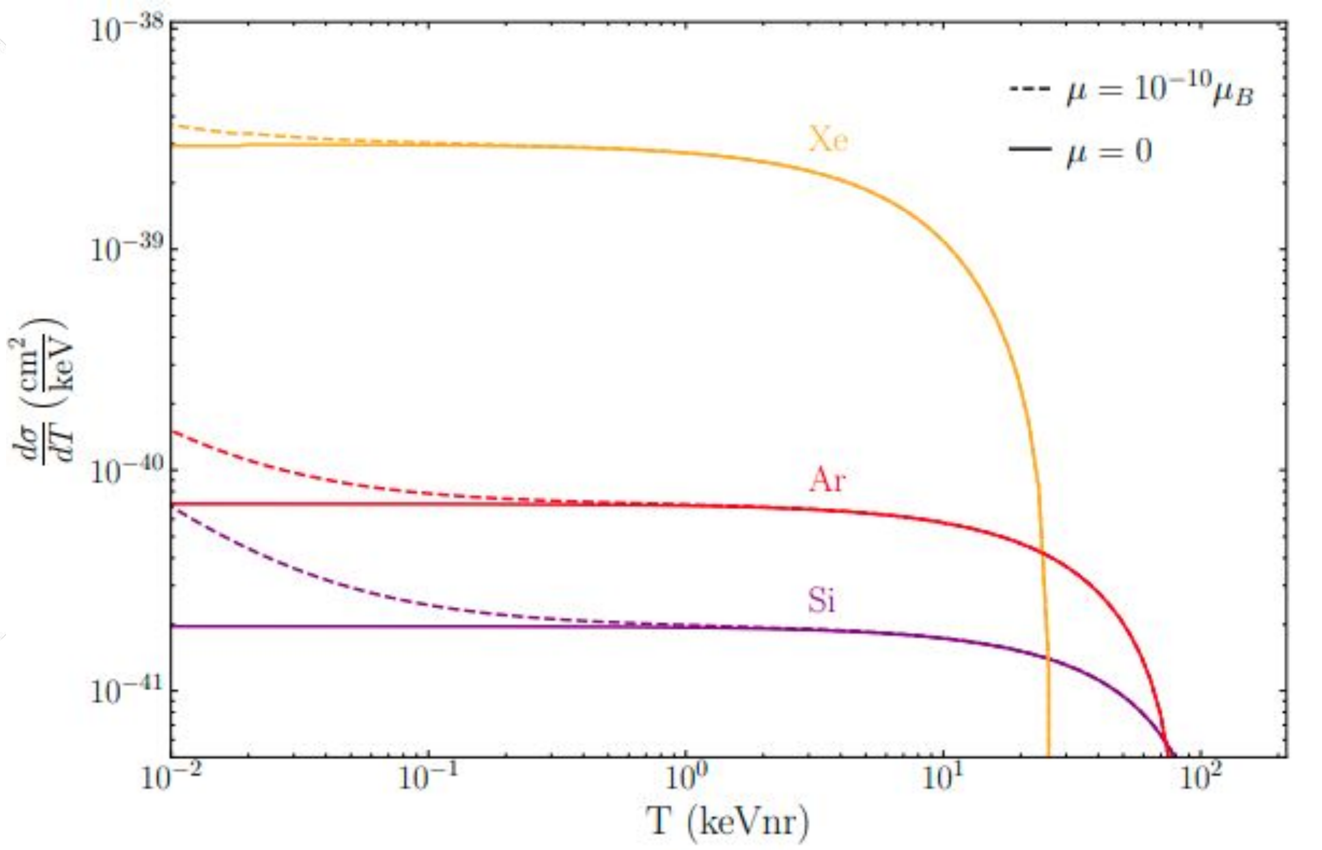
Nuclear Form Factor

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

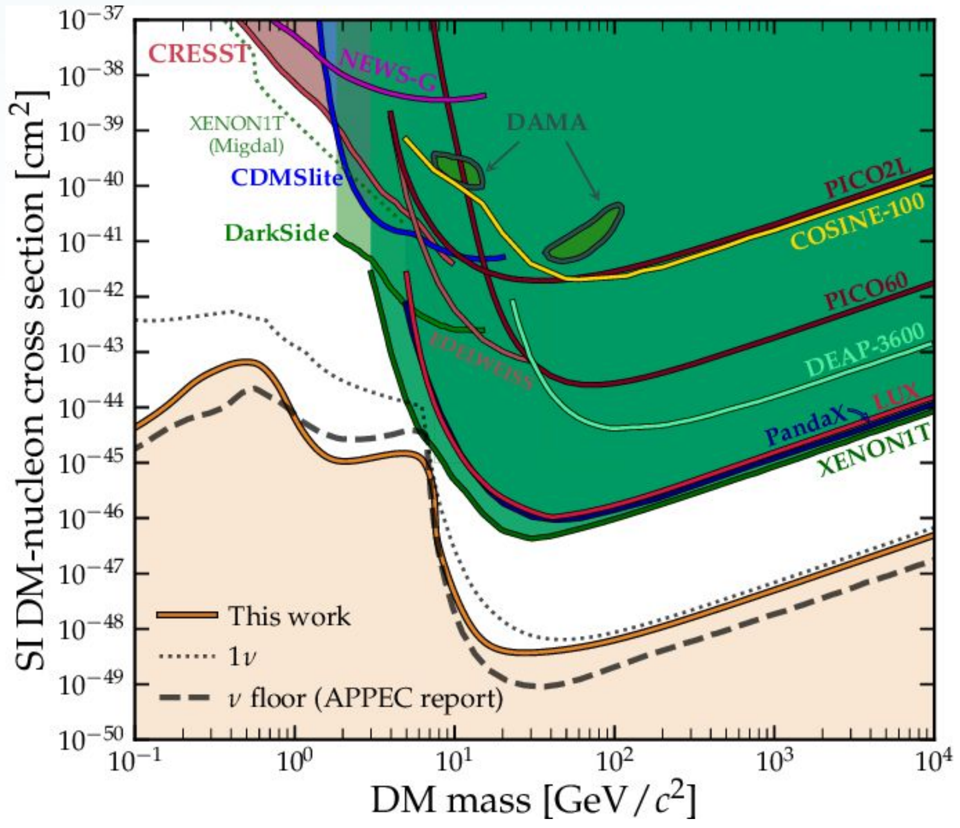
Motivation:

1. ***Detection!***
2. ***Studies of CEνNS x section: neutrino fog, SM validation, and more…***





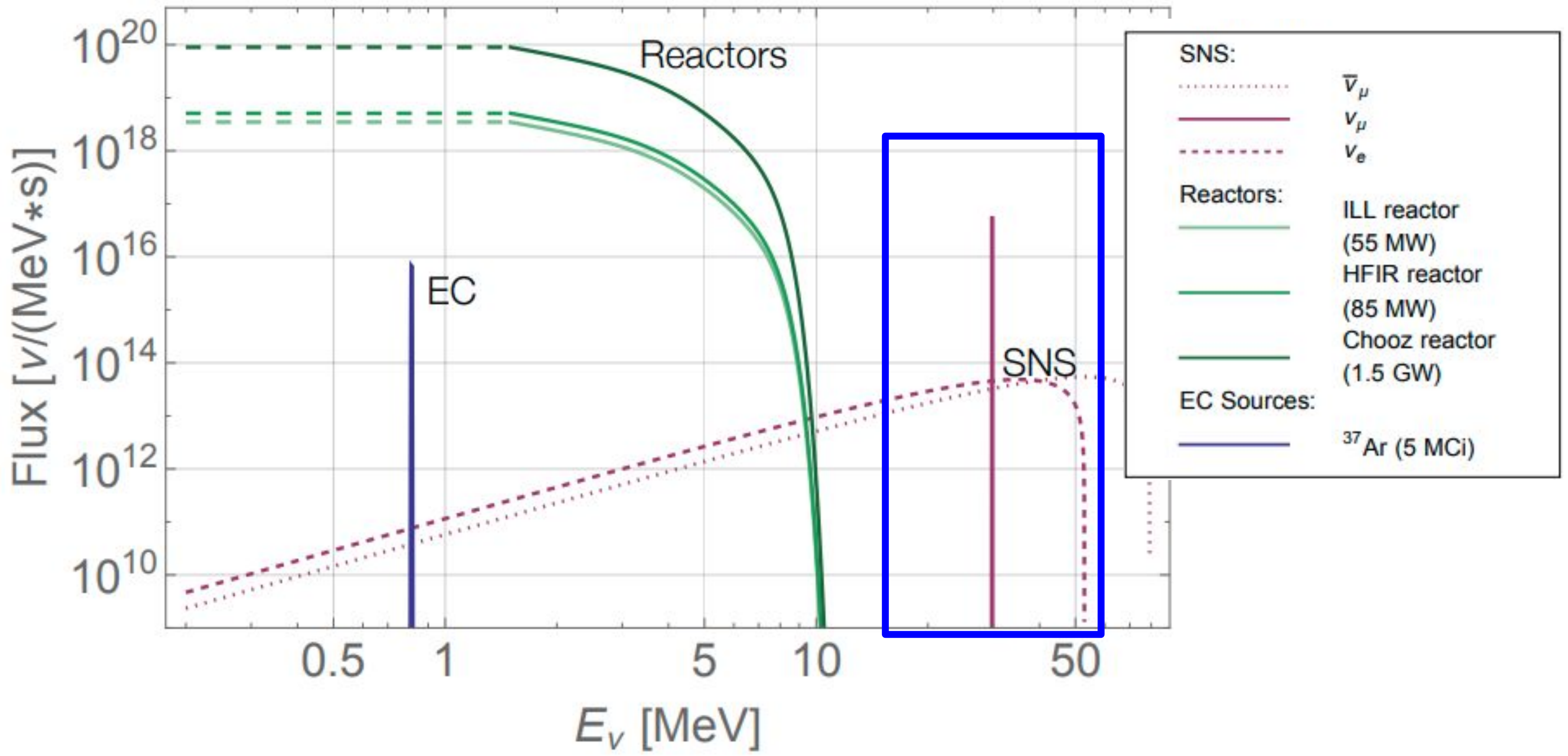
D. Baxter et al., JHEP 02 123 (2020)

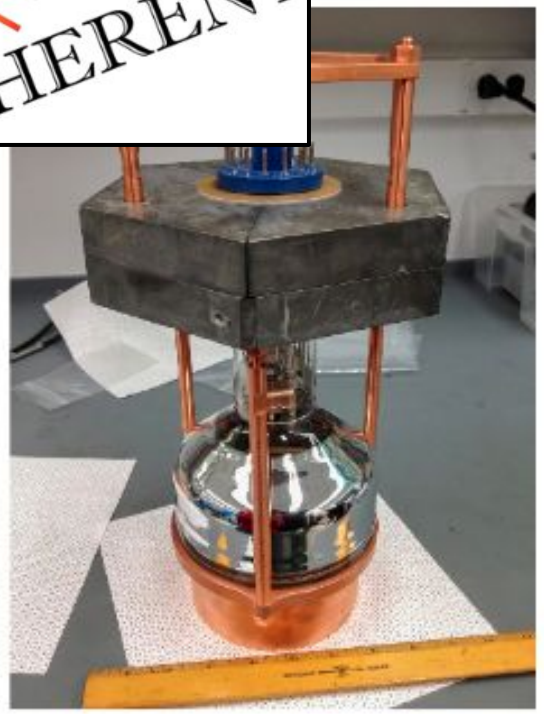


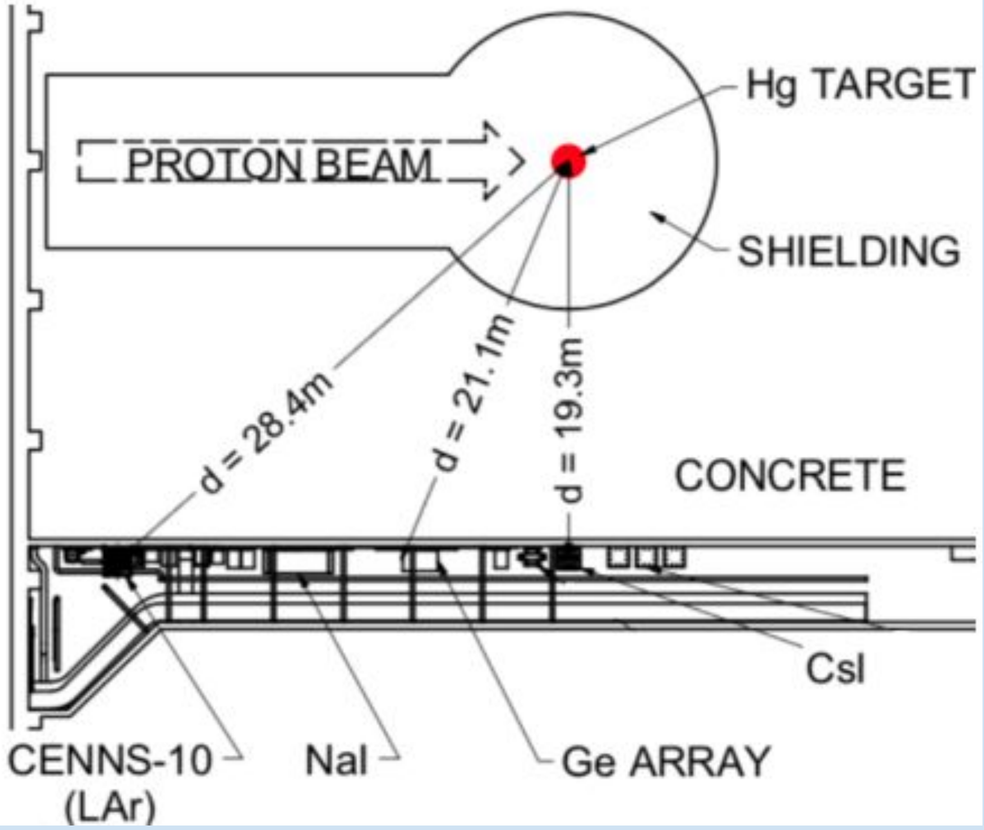
C. O'Hare, Phys. Rev. Lett. 127, 251802 (2021)

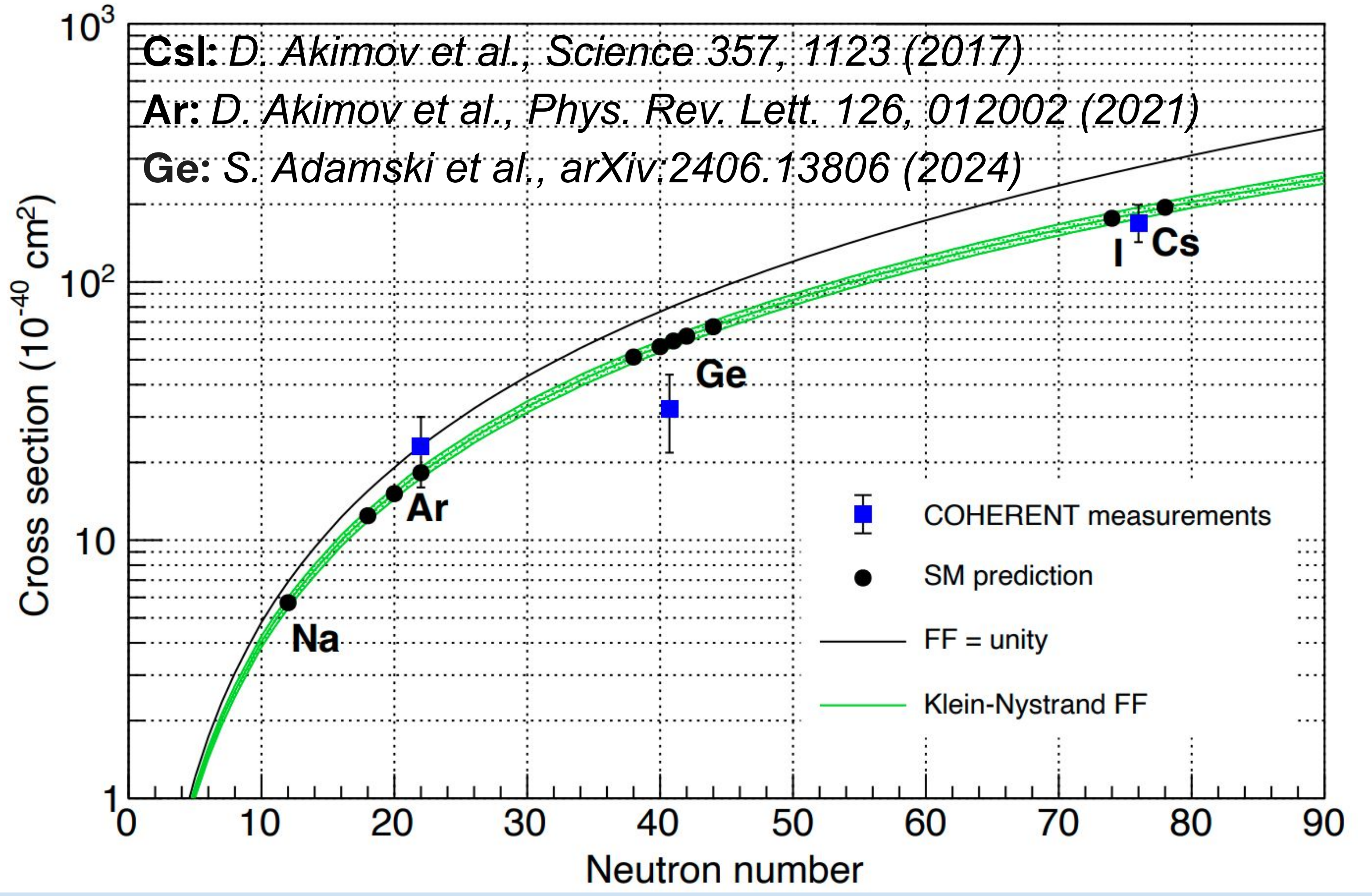
The Search for CEvNS

- Requires:
  - Well-understood high-flux neutrino source
  - Detectors tailored to CEvNS recoil energies
  - ON/OFF capabilities
- **First experimentally observed in 2017 by the COHERENT Collaboration**



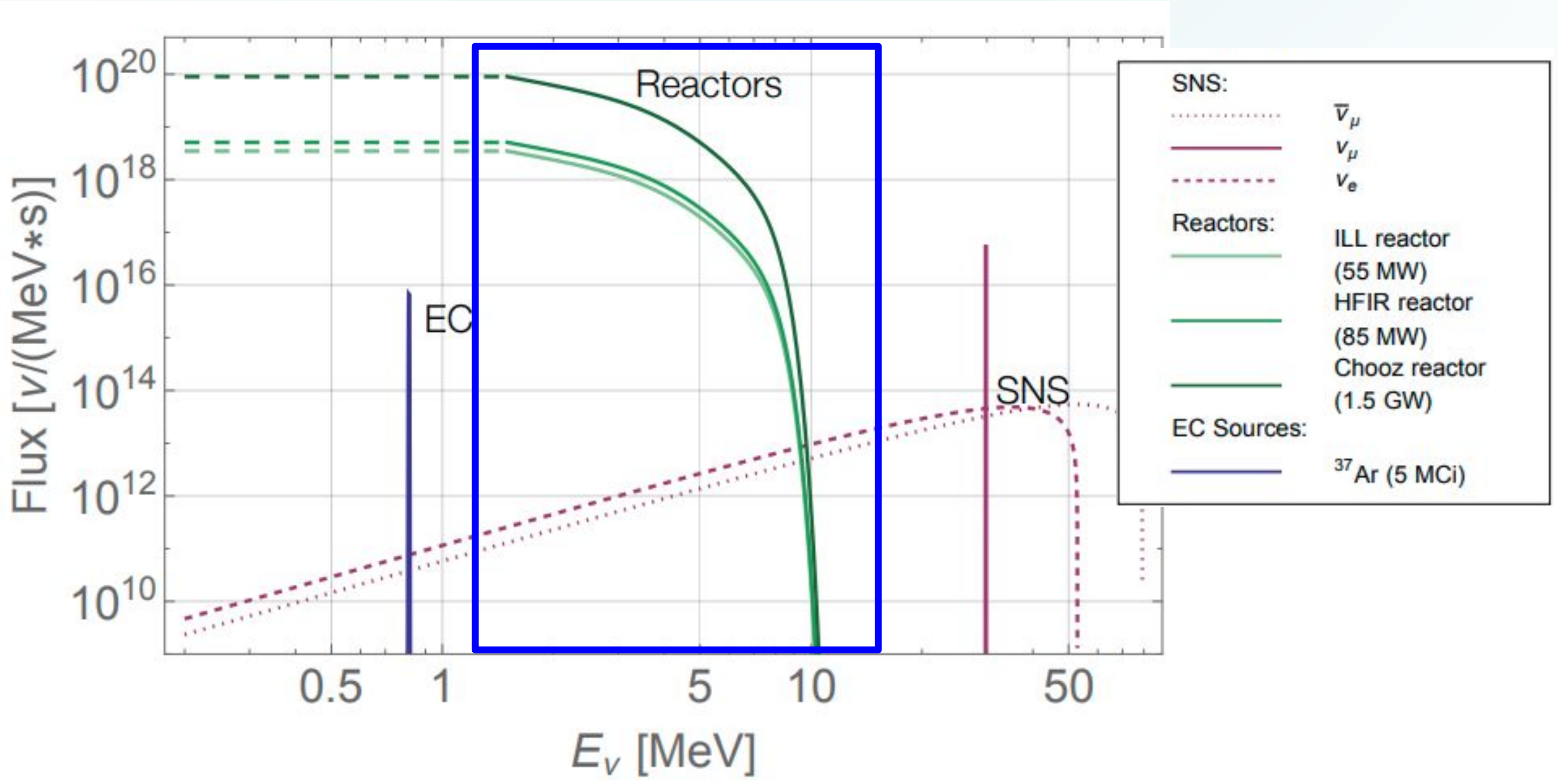






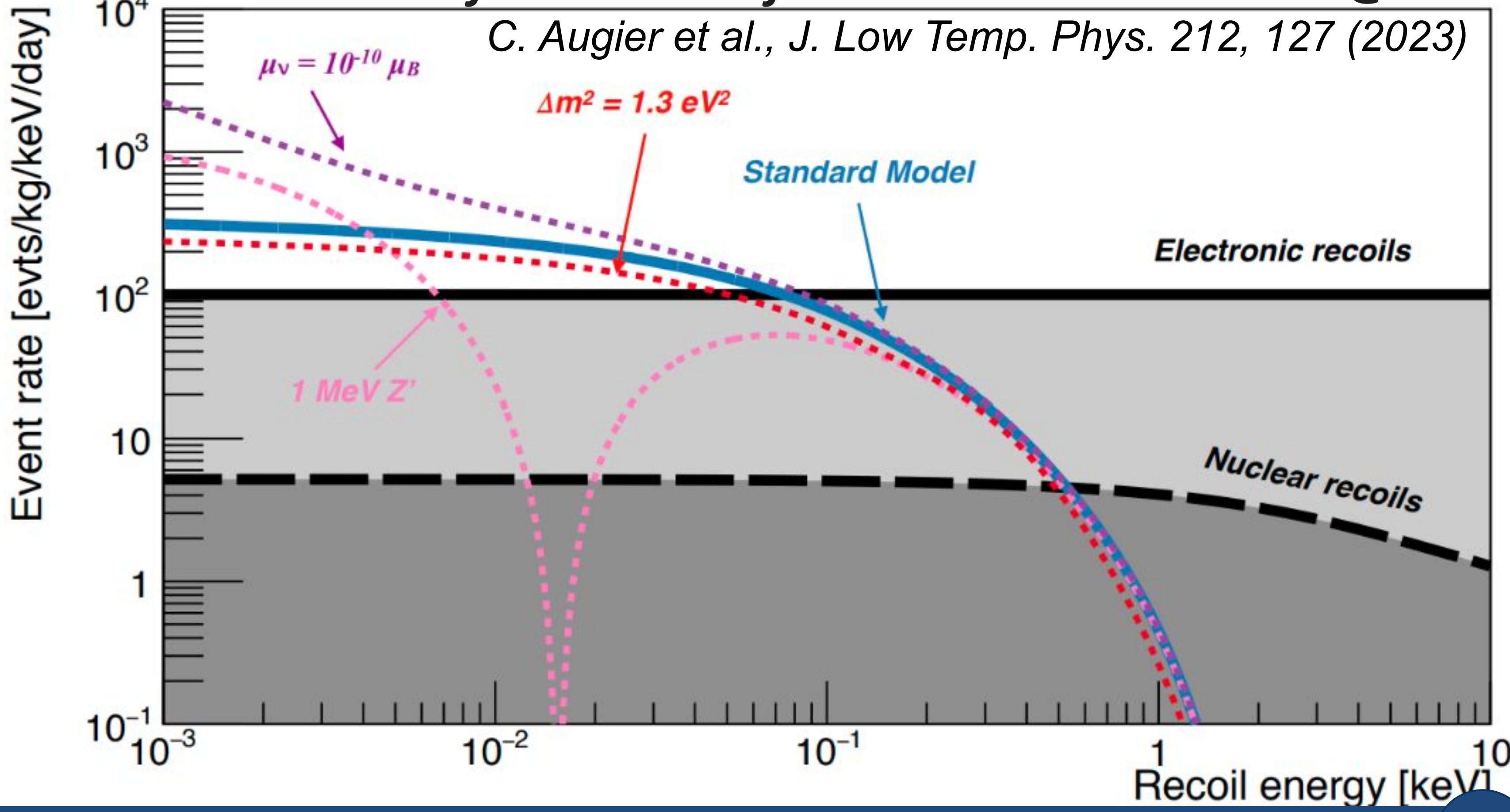
Pushing to lower recoil energies: Reactor Neutrinos

- Fully coherent <<50 MeV, little form-factor dependence
- **The Challenge:** E_v < 10 MeV → CEvNS recoil energy typ. < 1.5 keV
  - Hidden by ERs if recoil > 100 eV, particle ID essential
- **The Potential:** more space to explore CEvNS cross section
  - Increasing sensitivity to SM deviation at low recoil E



Estimation of CEvNS Rate for Ge Ricochet Detectors @ ILL

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

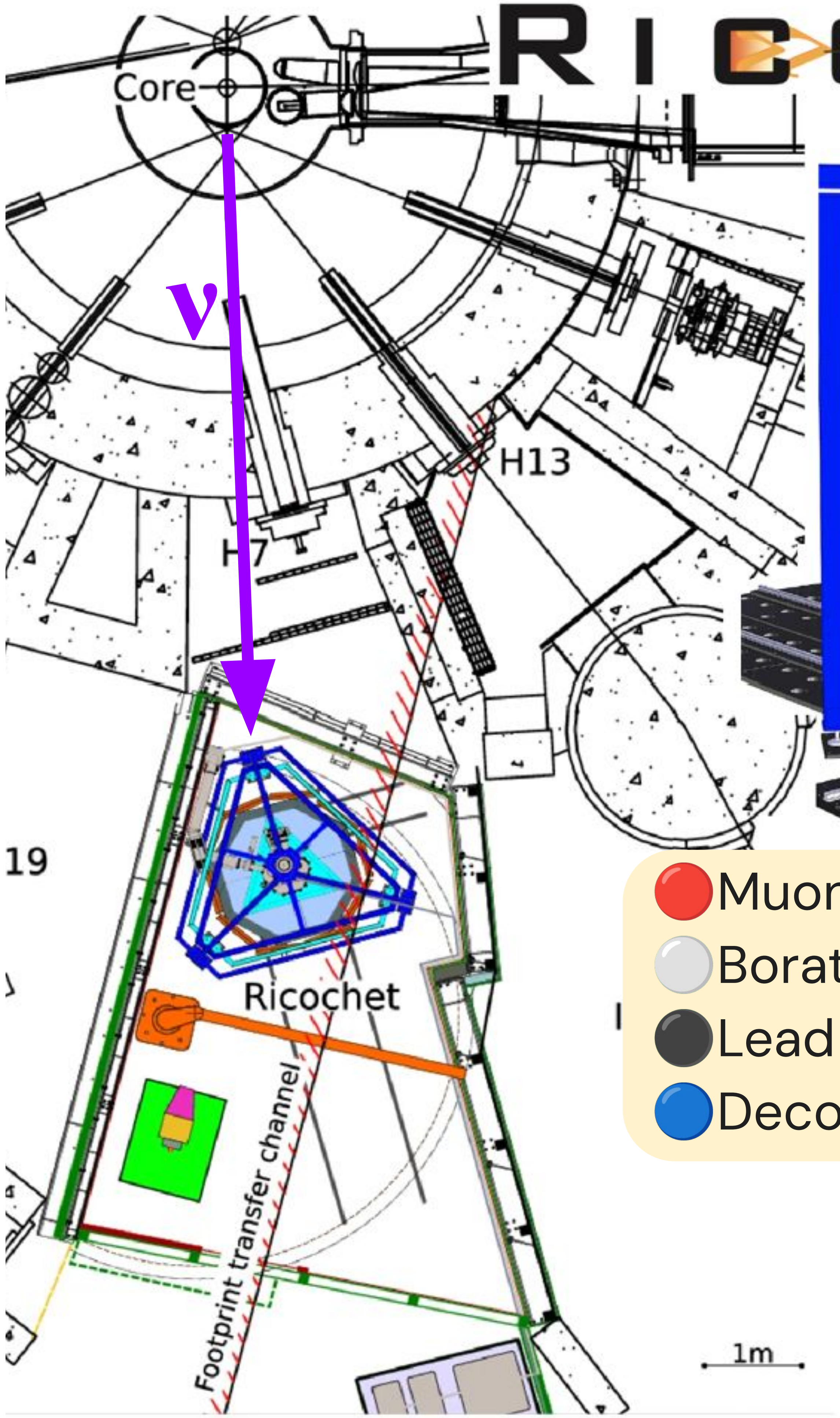


RICOCHET @ ILL

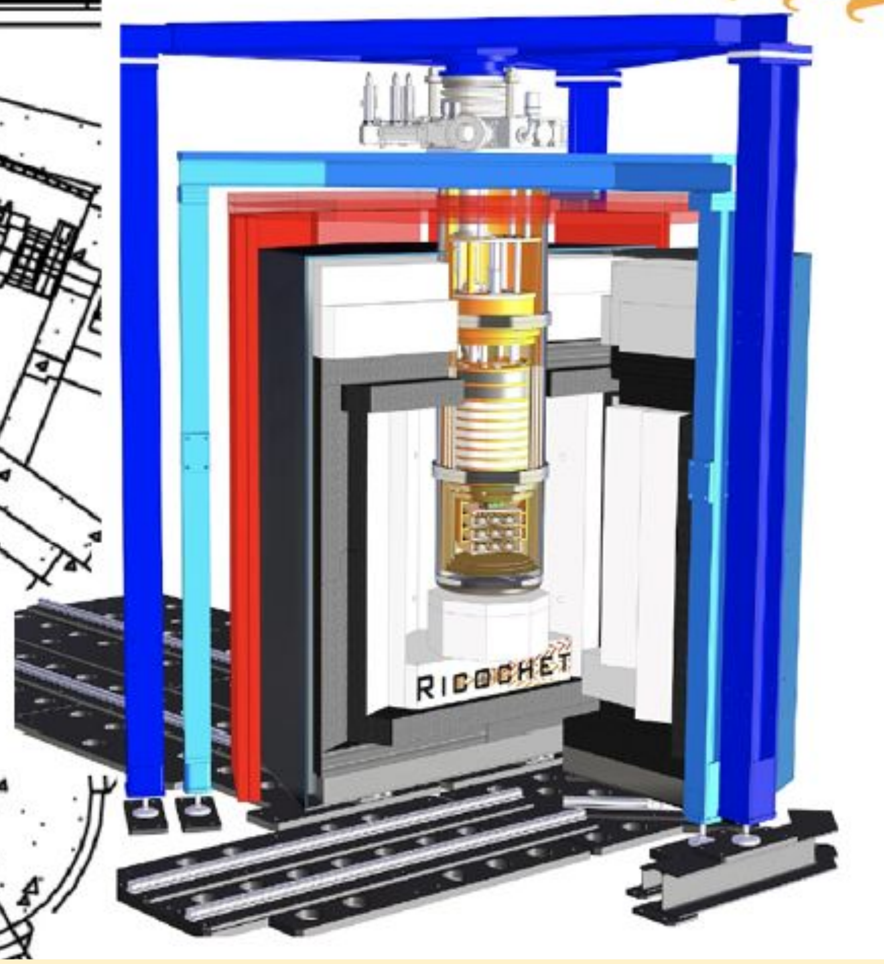
Searching for Reactor-induced CEvNS with cryogenic bolometers at the Institut Laue-Langevin (ILL) in Grenoble, France

- International collaboration, with European and North American groups
- 2023-2026 program, 7 reactor on periods, possible extension at ILL

👍8.8 m from high-flux 55 MW reactor
👍100-150 days/yr with Reactor ON
👎Background limitations (cosmo + reactogenic)



RICOCHET



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

Detection Strategy

For reactor CEvNS detection, need ER/NR discrimination ~ O(10) eV scale recoils:

CryoCube: Array of **18** Ge crystals (42 g ea.)

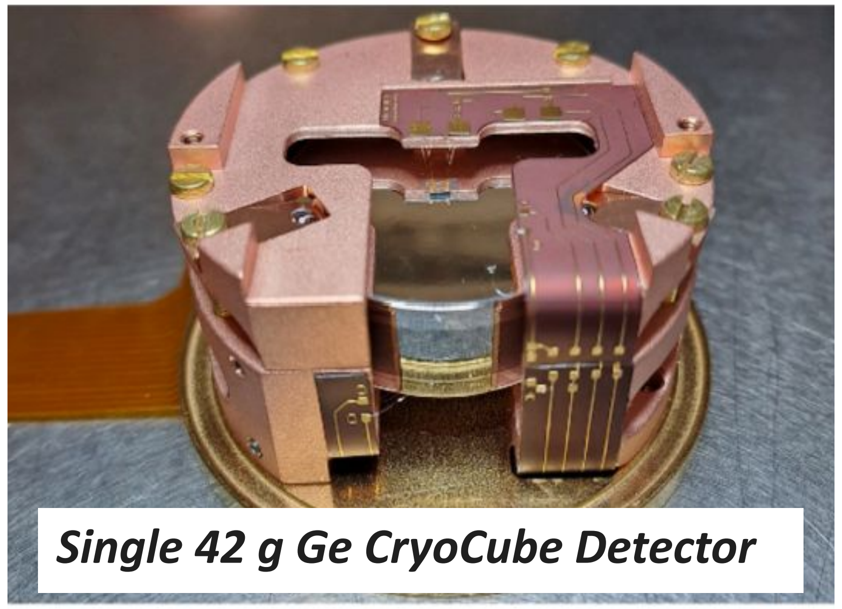
- Neutron transmutation doped sensors (NTDs) for phonon channel readout
- HEMT-based charge readout

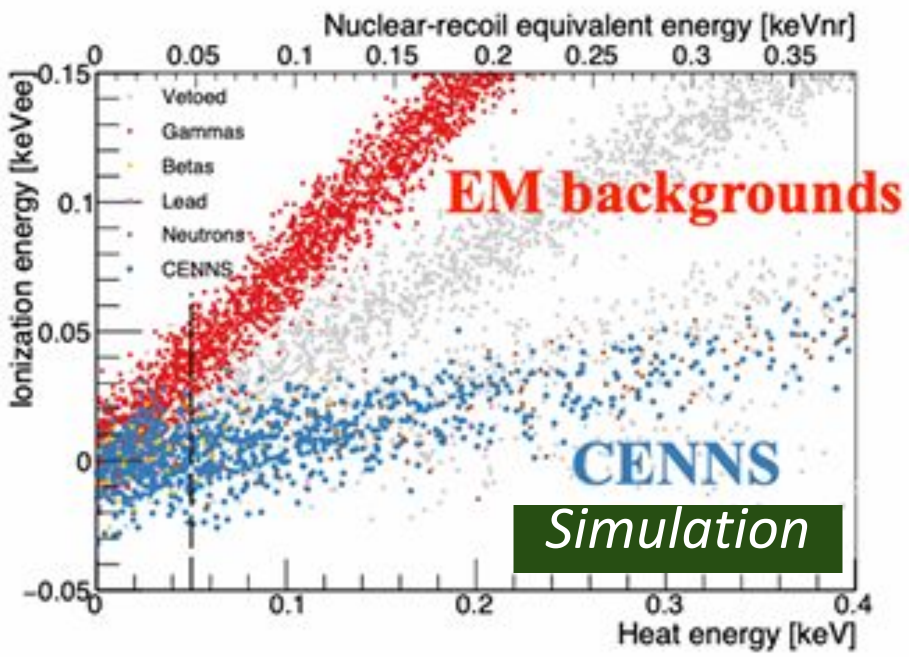
  → Heat/Ion Particle ID, Surf. rejection

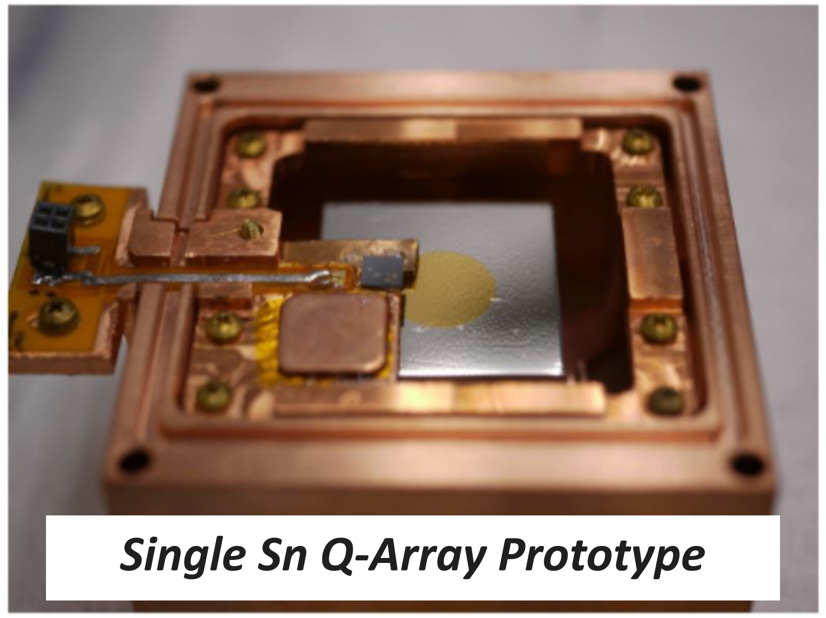
Q-Array: Array of superconducting crystals

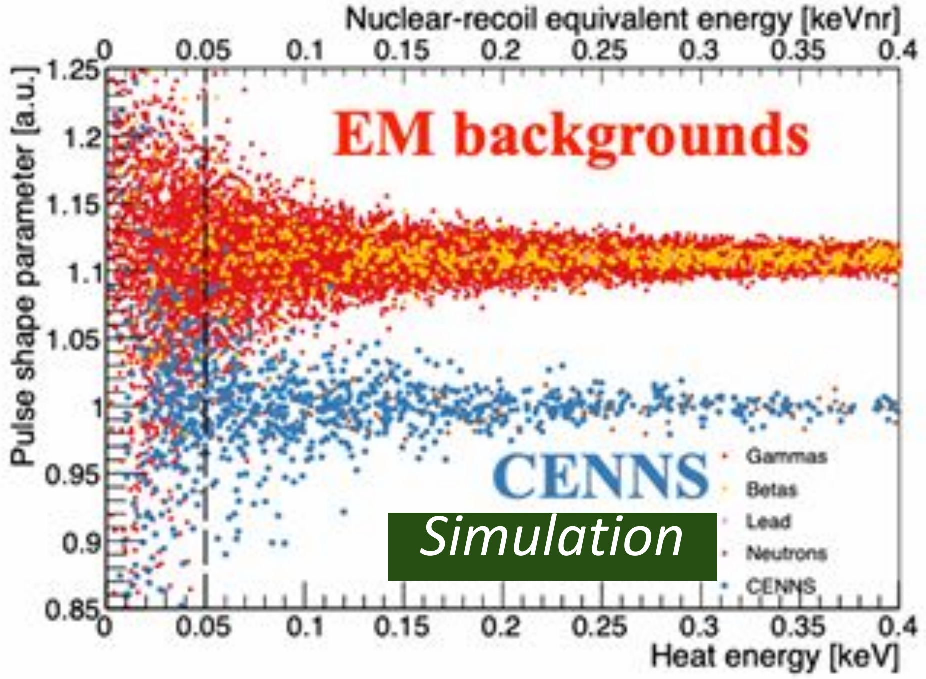
- Transition-Edge Sensor (TES) phonon channel readout, RF SQUID multiplexing

  → Particle ID from pulse shape


Single 42 g Ge CryoCube Detector




Single Sn Q-Array Prototype



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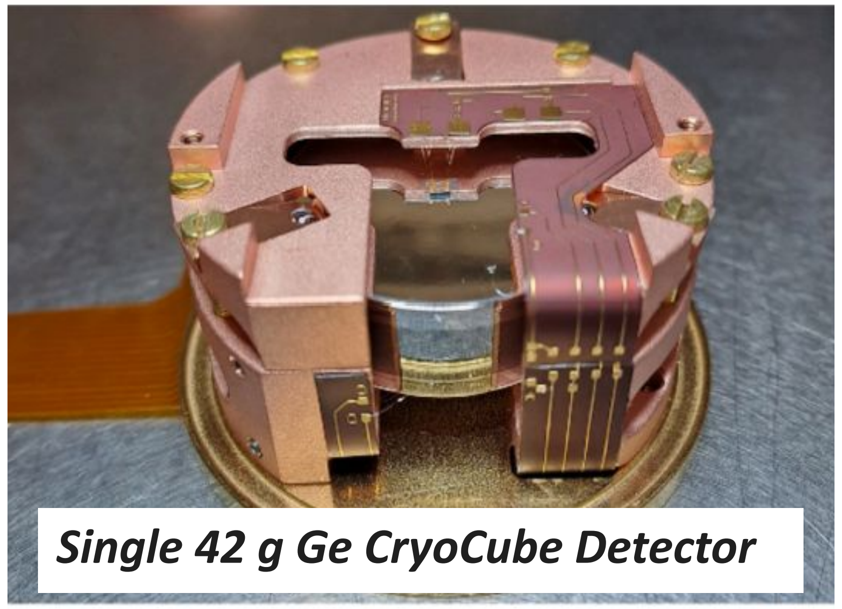
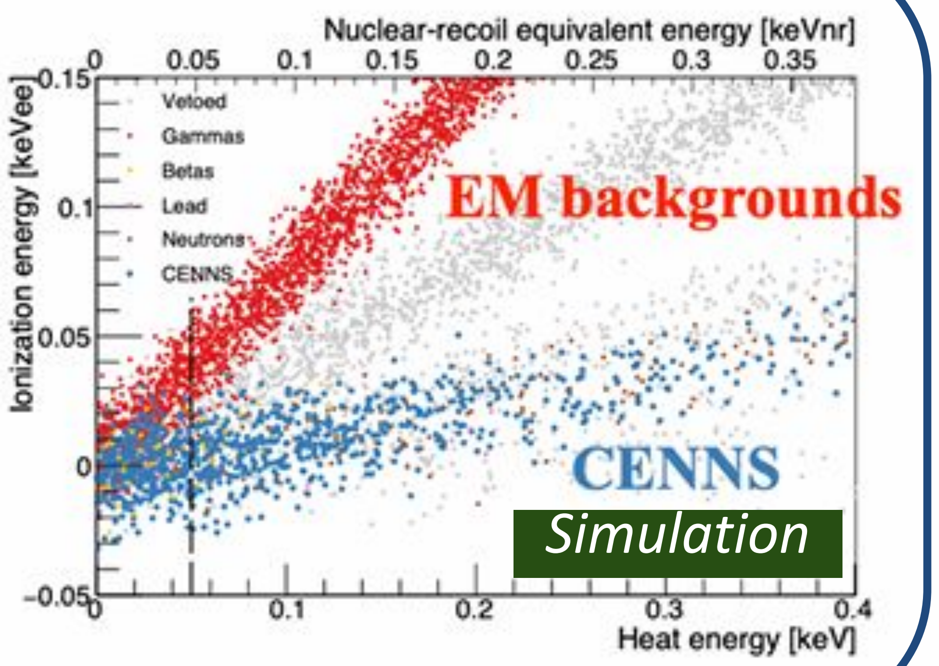
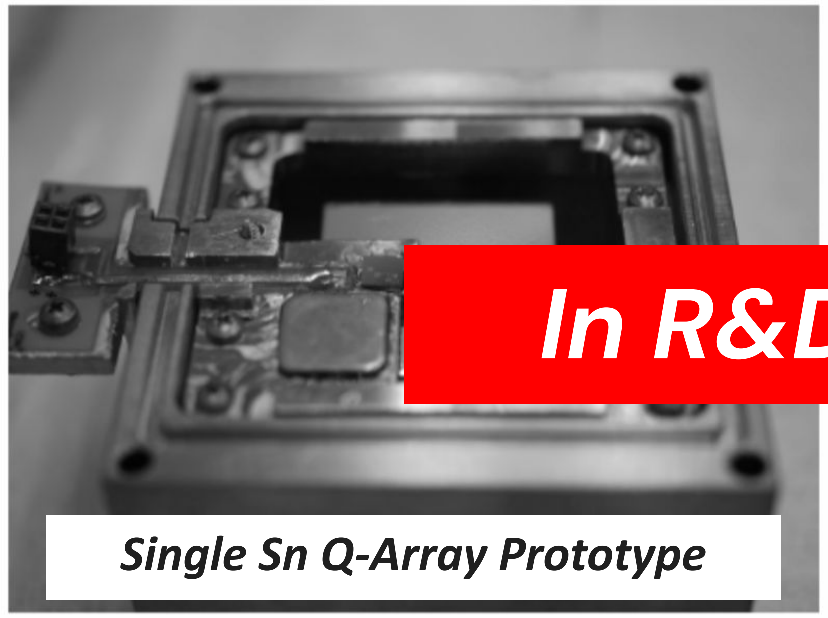


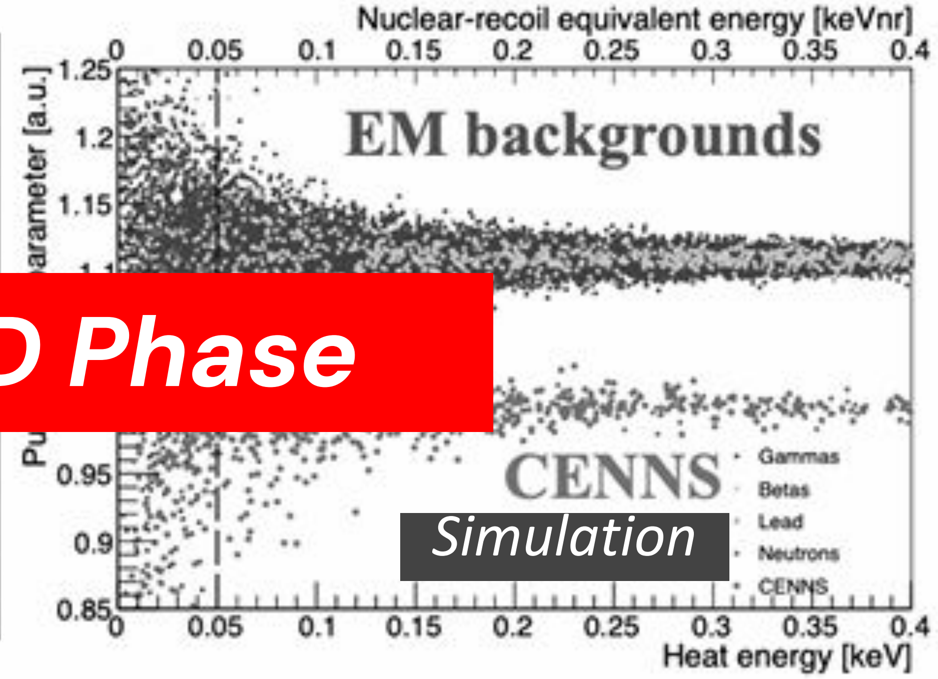
Single 42 g Ge CryoCube Detector





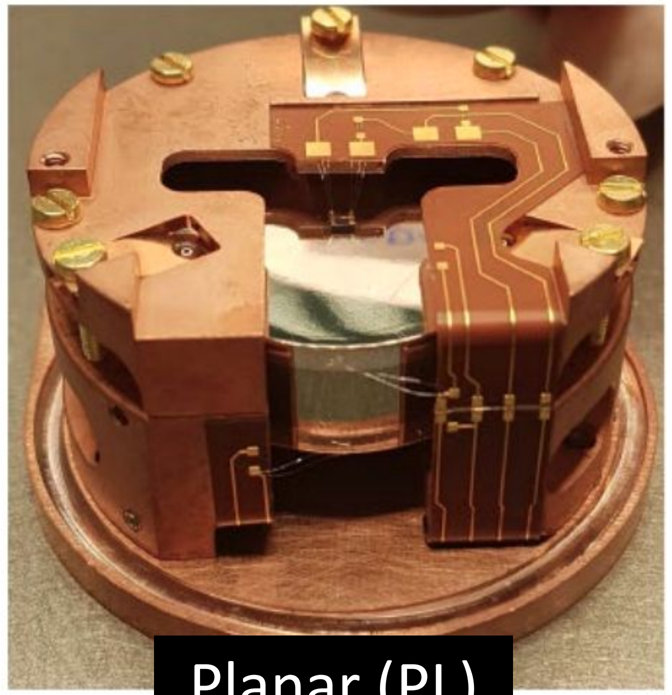
Single Sn Q-Array Prototype

In R&D Phase

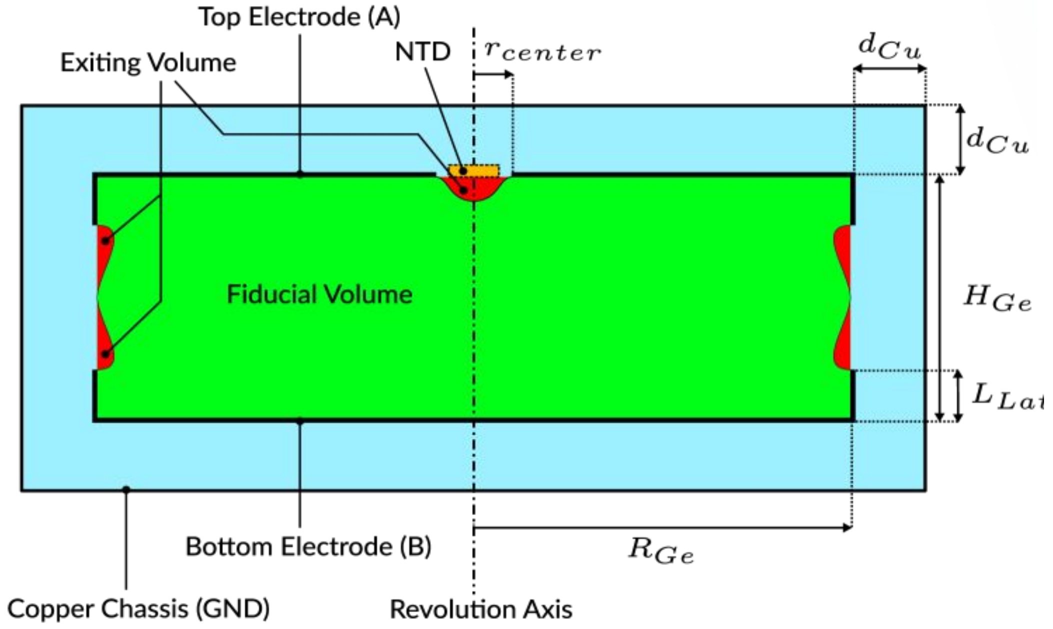


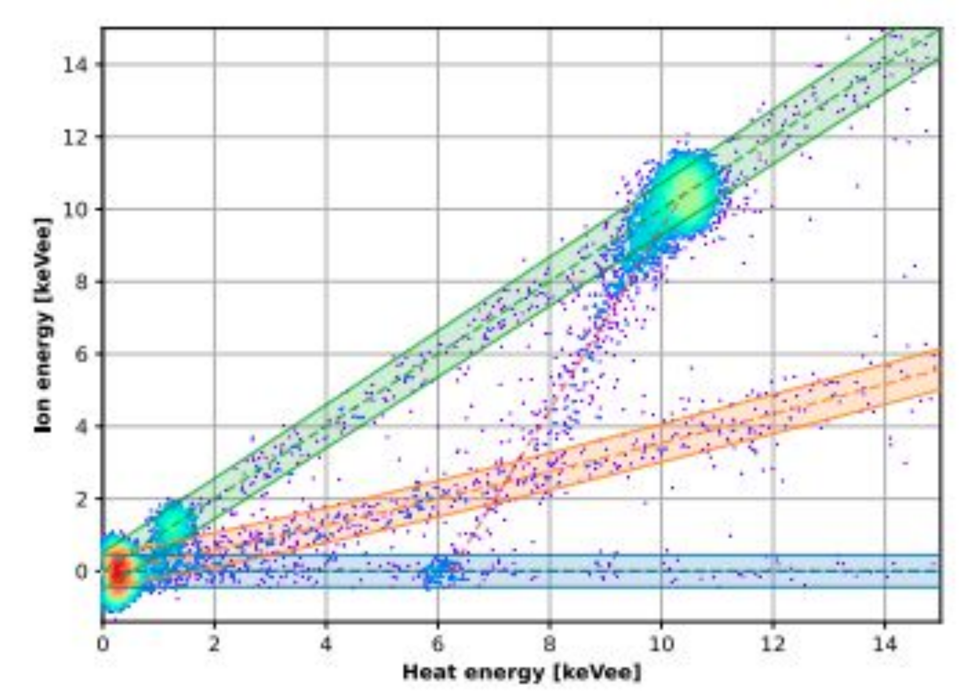
Goals: 20 eVee ion, 10eVph resolution, Particle discrimination to 50 eV

Detection Strategy: CryoCube



Planar (PL)



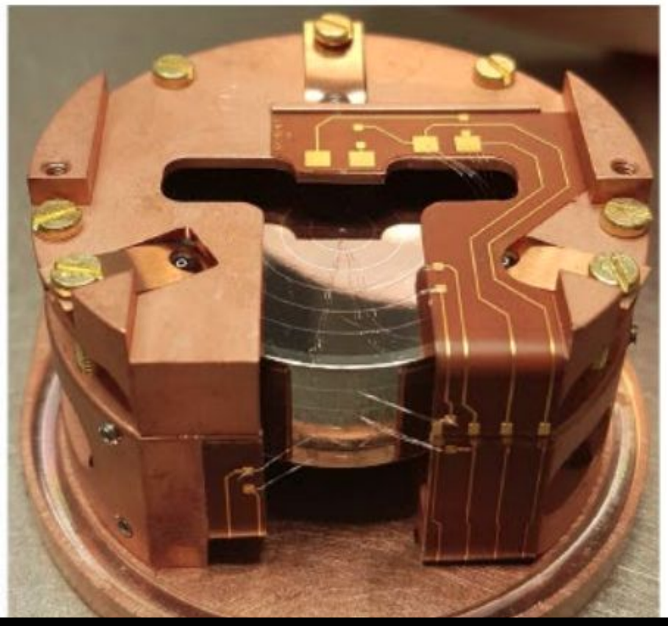


Fiducial volume ~99%

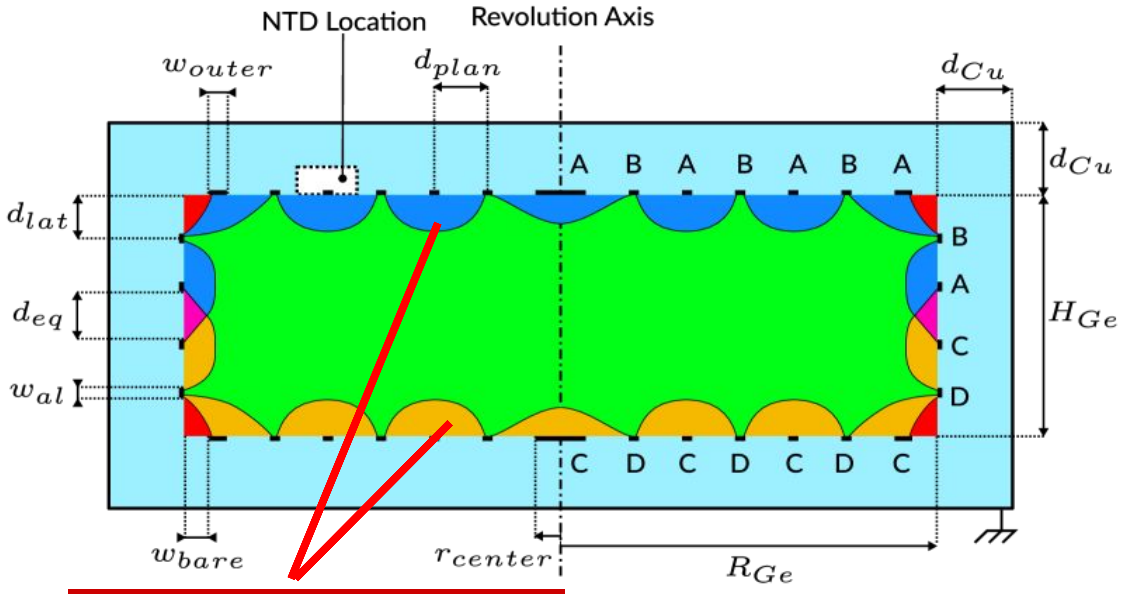
Surface Rejection ❌

First demo of 30 eVee PL ion resolution in *C. Augier et al., Eur. Phys. J. C 84, 186 (2024)*

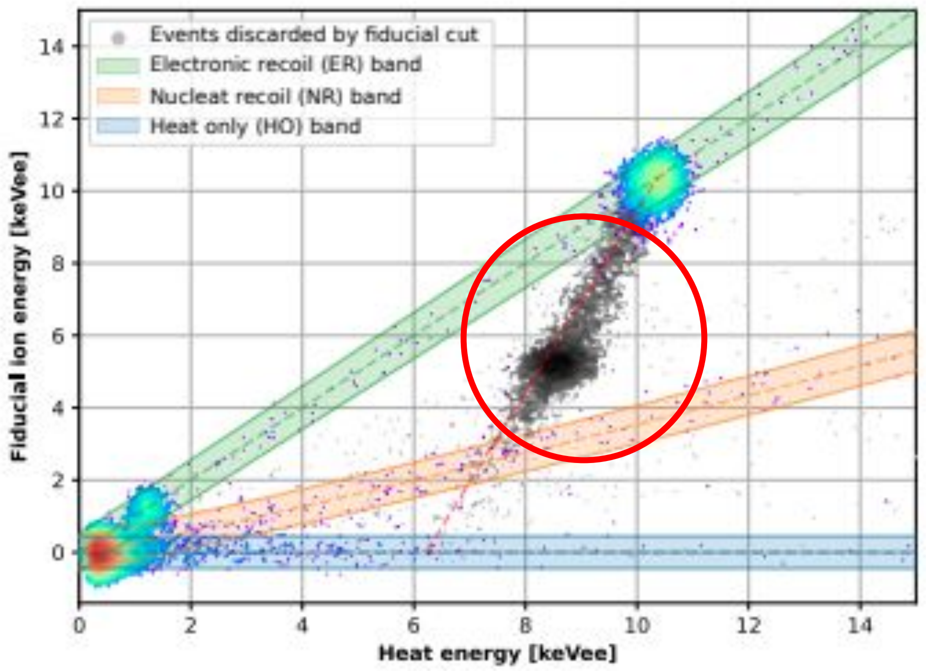
T. Salagnac et al., J. Low Temp. Phys. 211, 398 (2023)



Fully inter-digitized (FID)



Veto Electrodes

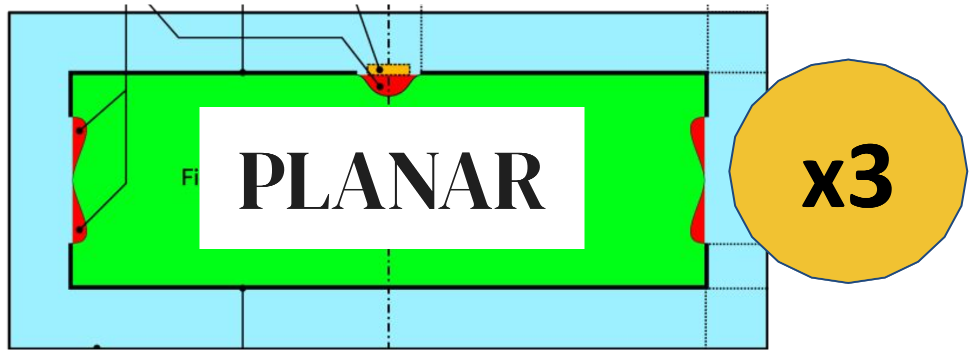


Fiducial volume **~70%**

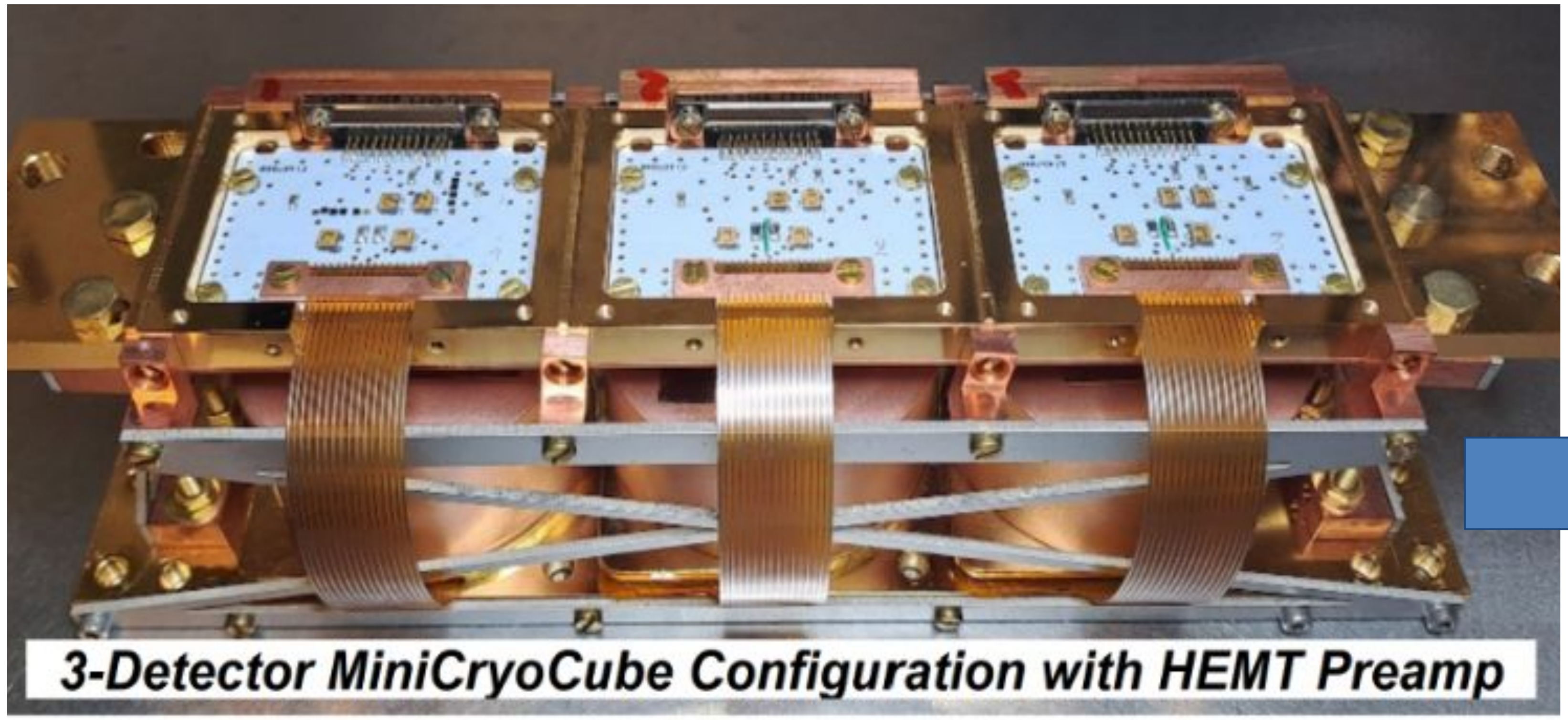
Surface Rejection ✅

RICOCHET @ ILL Status

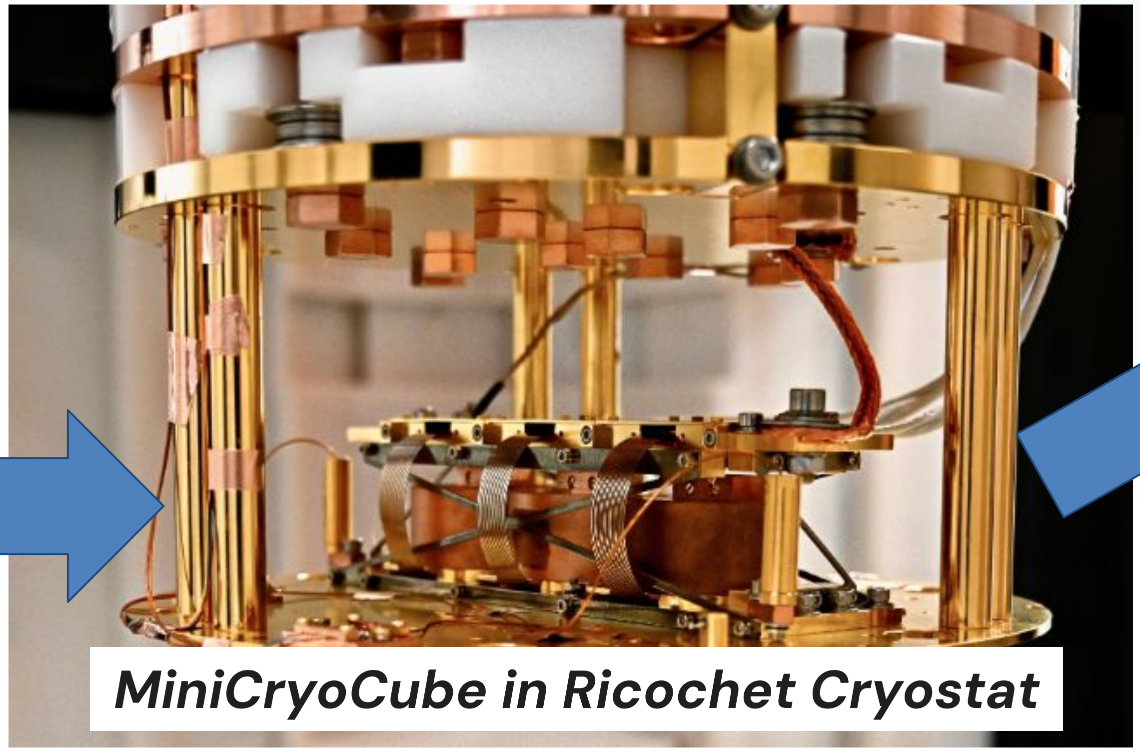
- ✅ Installation of Cryostat in Fall 2023, first cryogenic run (RUN012)
- ✅ First detector run Feb-April 2024 - 3 Detectors (RUN013)
- ✅ **Second Detector run May-October 2024 – 3 Detectors (RUN014)**



- **+ Inner shielding**
- **+ Outer Muon Veto**
- **+ Laser**



3-Detector MiniCryoCube Configuration with HEMT Preamp



MiniCryoCube in Ricochet Cryostat

Full Ricochet Cryostat with inner PE shielding

Paper on first commissioning runs coming soon!

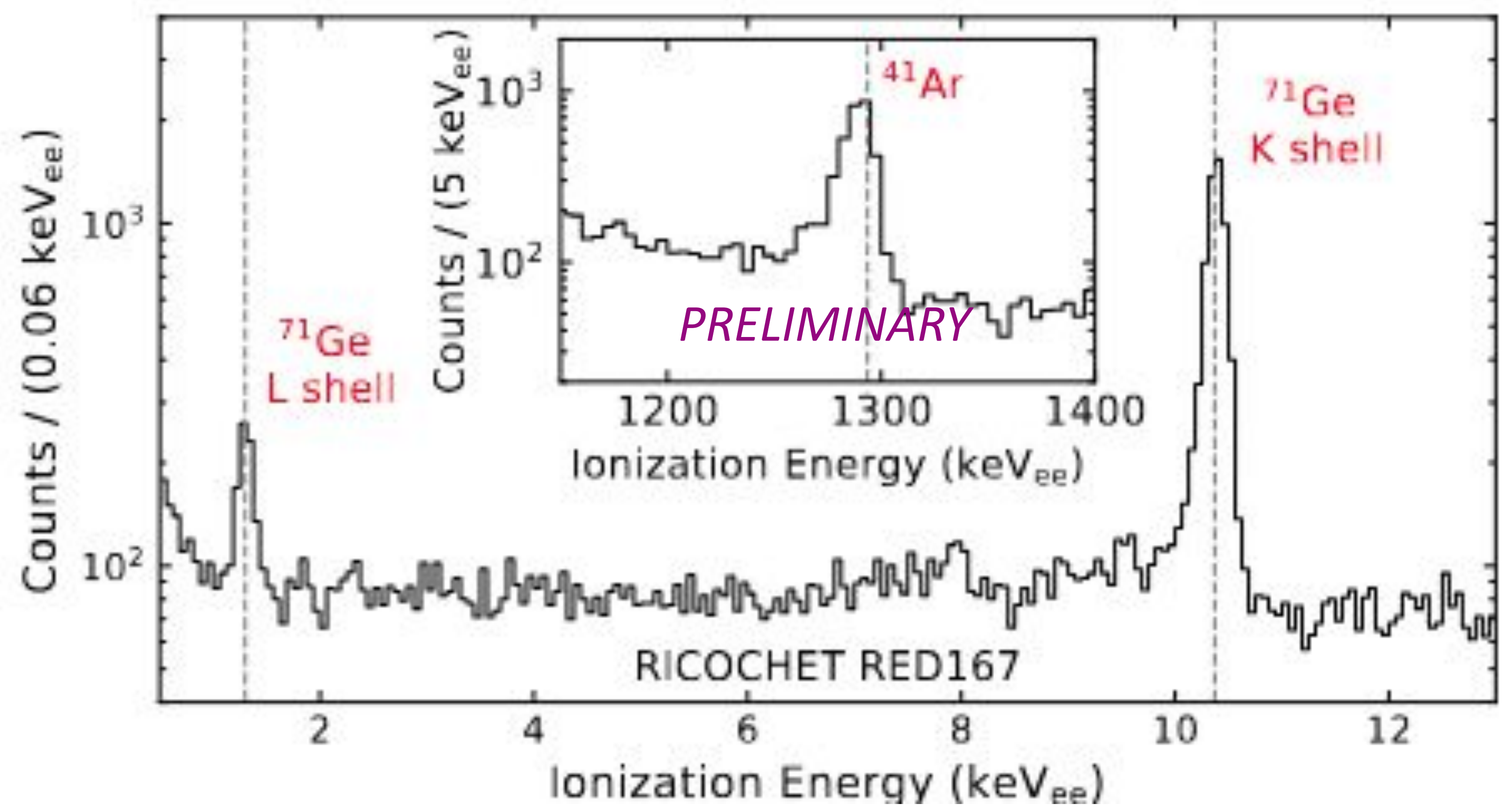
Results from First Commissioning Runs @ ILL

RUN014: *577 h (564 h) of* ***reactor-on*** *data, and 1438 h (1309 h) of* ***reactor-off*** *data for for RED167 (RED237)*

Detector Performance

- Optimizing detector performance at Reactor site
  - Regenerations, vibration damping, electronics tests
- **40 eVee, 50 eVph achieved for RED167 in RUN014**

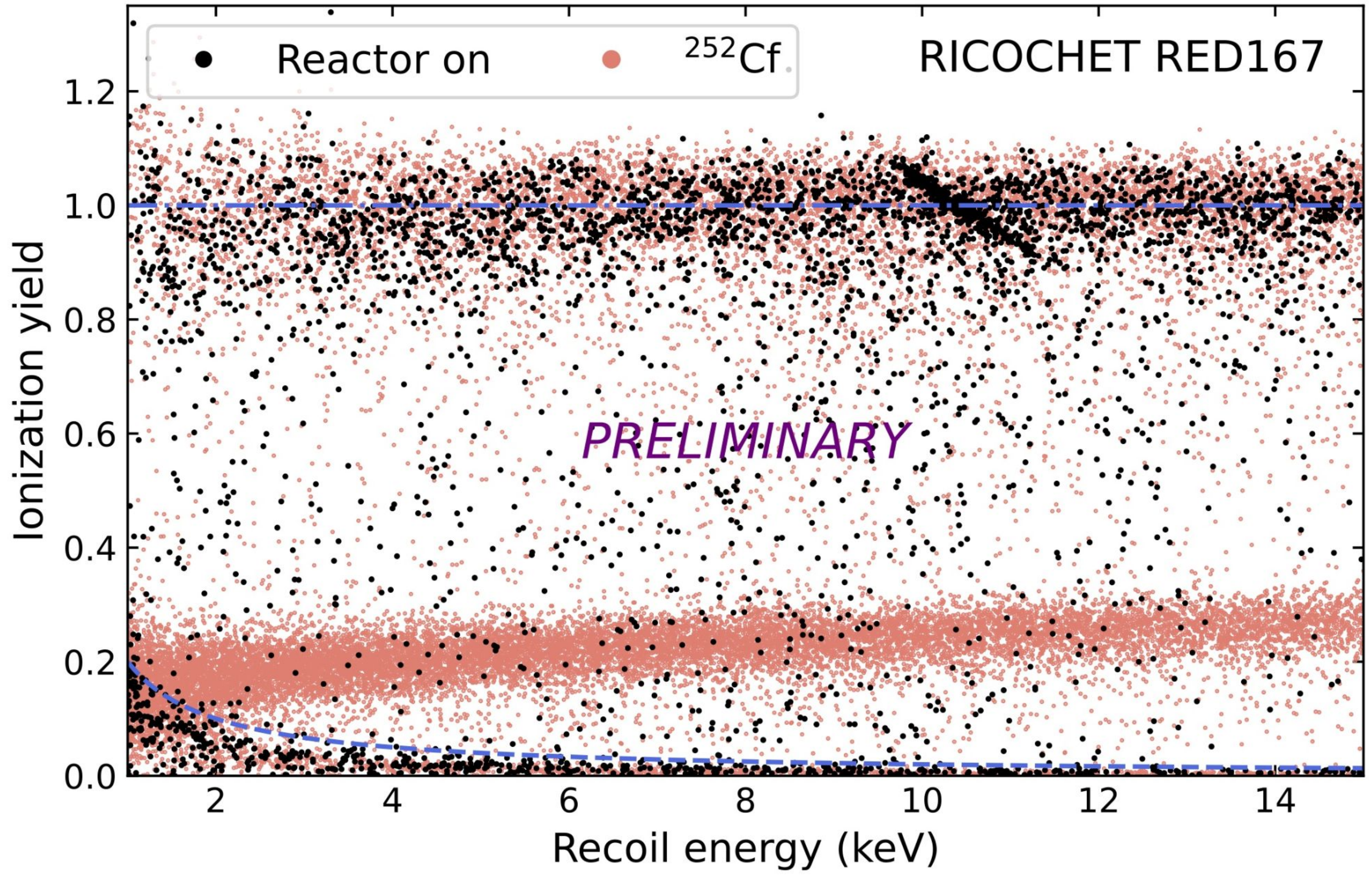
Ge activation + Ar peaks in RED167 ionization, with Reactor ON data



ER/NR Discrimination

- Clear separation of ERs/NRs to 1 keV
- Surface event population ~uniform 0 < Q < 1

Reactor ON vs. OFF Q-plot, with Cf source, Muon Veto



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Results from First Commissioning Runs @ ILL

RUN014: *577 h (564 h) of* ***reactor-on*** *data, and 1438 h (1309 h) of* ***reactor-off*** *data for for RED167 (RED237)*

Background Assessment (2 – 7 keV)

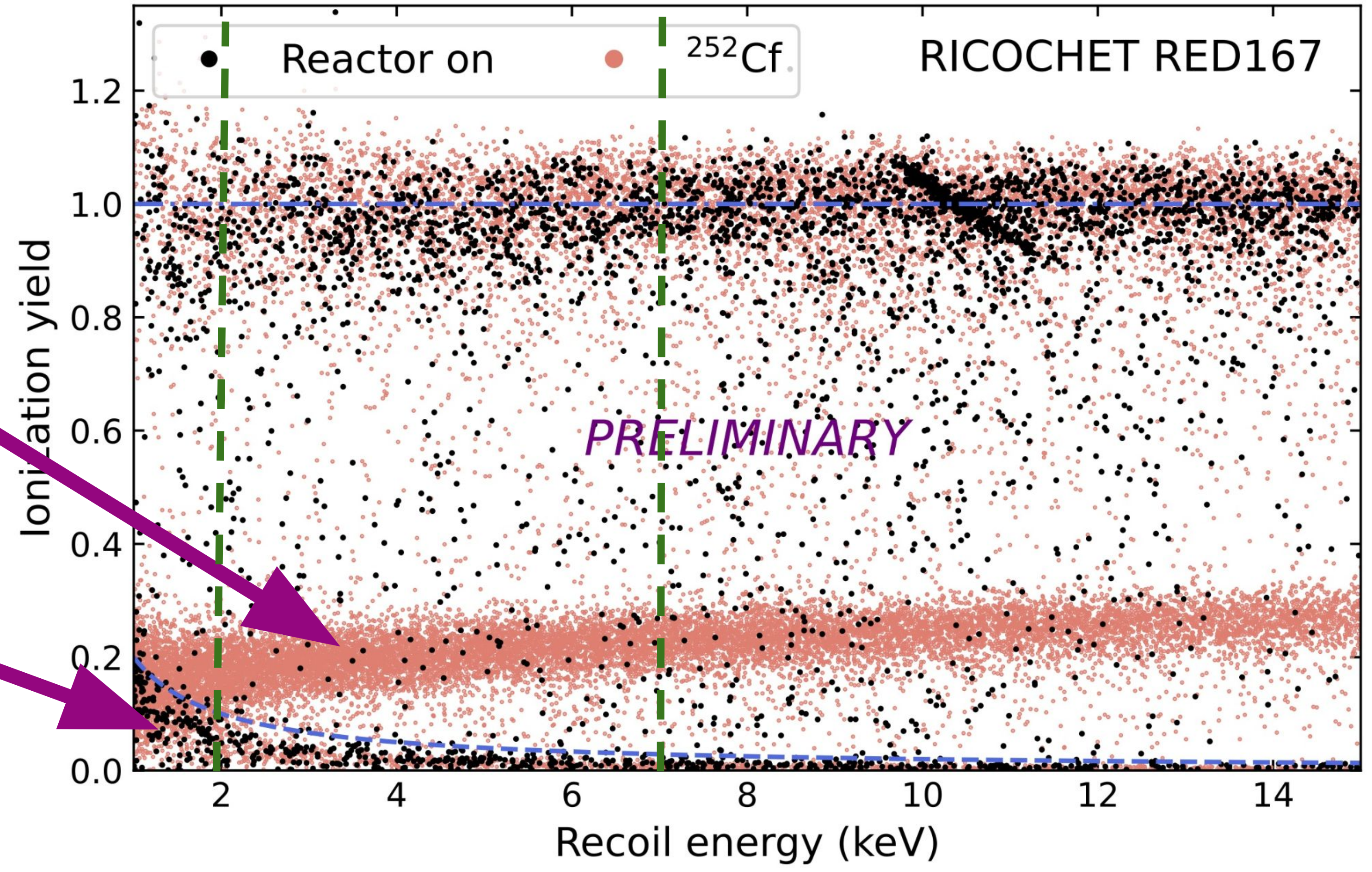
- Muon-induced ER (NR) rate ~ 330 (14) DRU during Reactor OFF → reject by veto
  Verifies G4 simulation efforts, ~ 310 (15) DRU.
- Difficult to differentiate non-muon NRs vs. surf. → Surf. rejection/treatment of Cu Imperative
- Rate of heat events with < 0.2 keVee challenging as we reach < 1 keV (600-700 DRU), but proven to be stable

Note: commissioning aim is to quantify background in stable, well-understood (Q, Eff.) energy range, i.e. 2 – 7 keV

ER/NR Discrimination

- Clear separation of ERs/NRs to 1 keV
- Surface event population ~uniform 0 < Q < 1

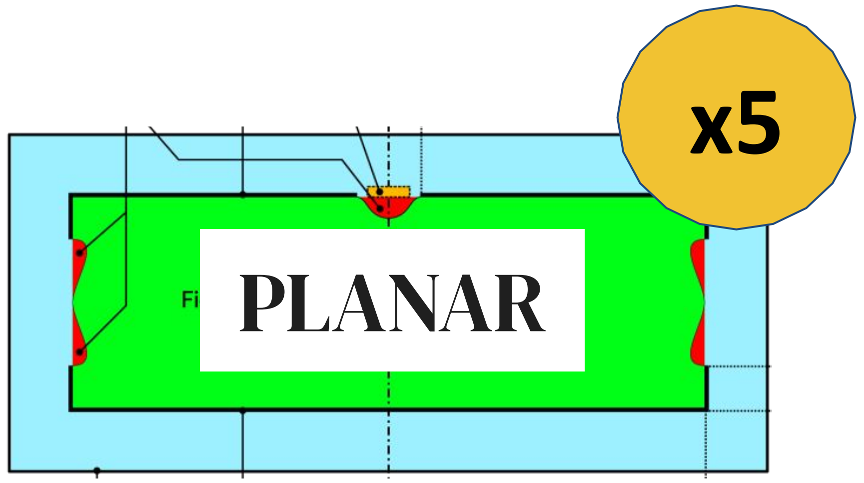
Reactor ON vs. OFF Q-plot, with Cf source, Muon Veto

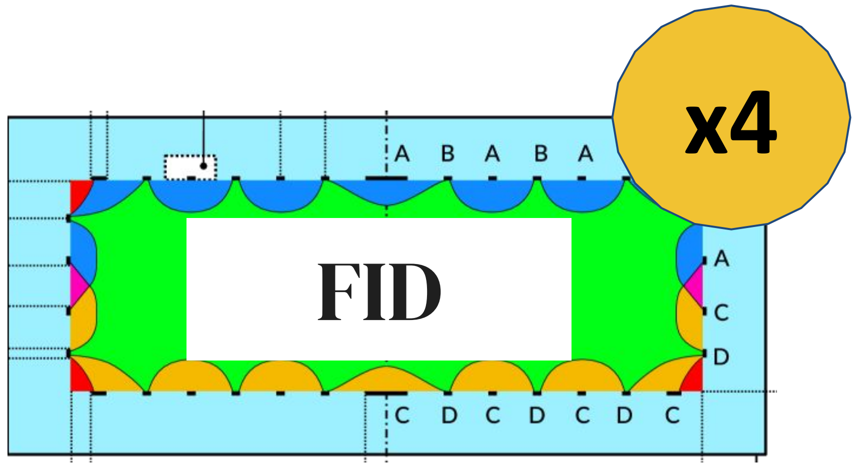


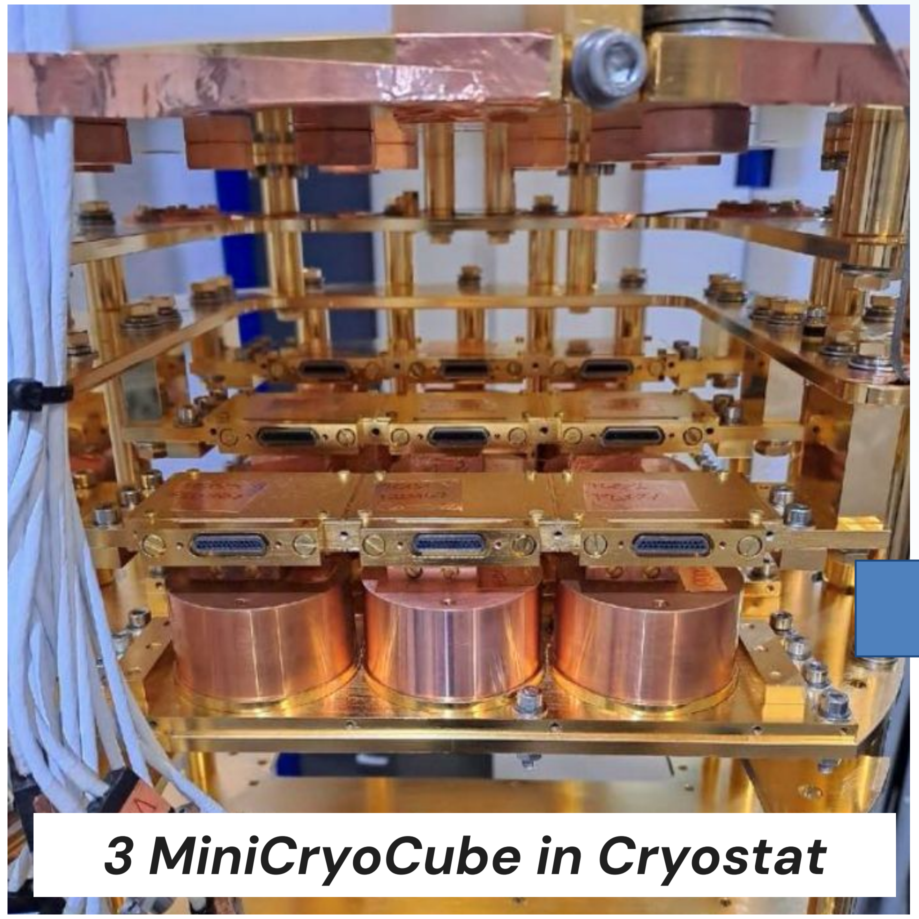
RICOCHET @ ILL Status

✅ Installation of Cryostat in Fall 2023, first cryogenic run (RUN012)
✅ First detector run Feb-April 2024 - 3 Detectors (RUN013)
✅ Second Detector run May-October 2024 - 3 Detectors (RUN014)
✅ **Third Detector run Jan-June 2025 - 9 Detectors (RUN015)**

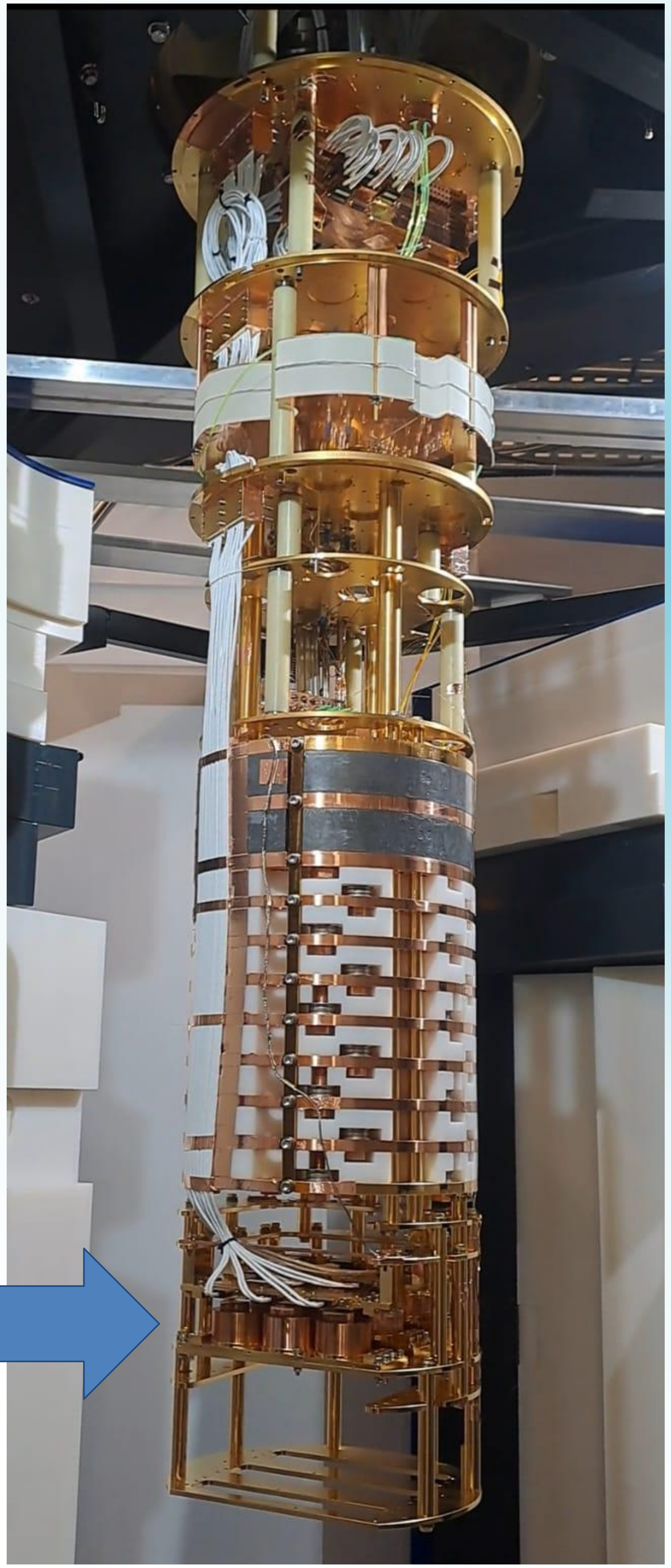
- **First FID installation @ ILL**
- **Cryo-muon veto installation**
- **Decoupling of 1 K HEMT stage from 10 mk detector stage**







3 MiniCryoCube in Cryostat

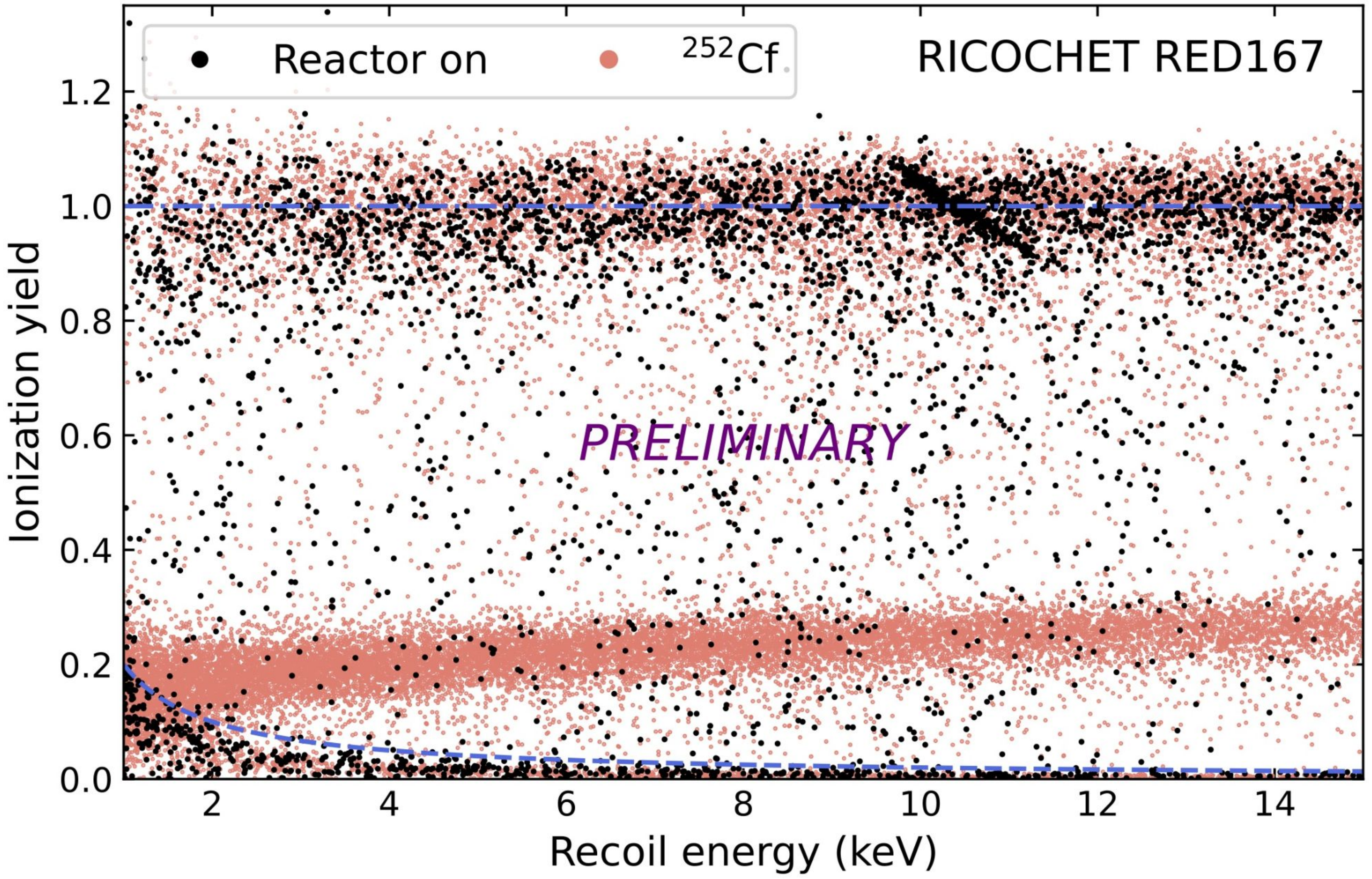


PRELIMINARY

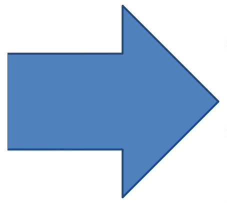
From RUN015: First look at FID performance

- FID veto electrodes → rejection of surface events → can see NRs!

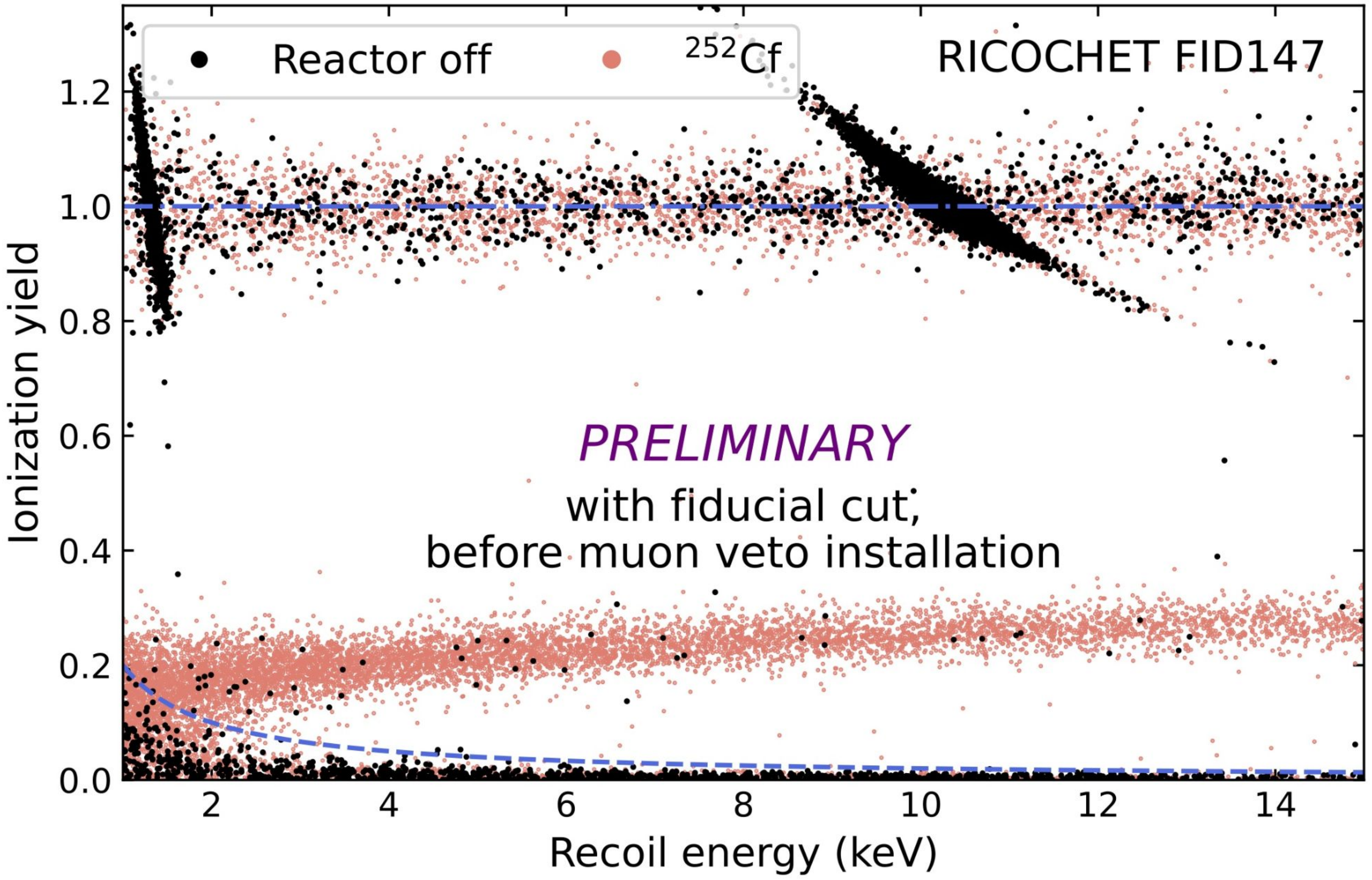
RED167 in RUN014: 40 eVee, 50 eVph



155h Reactor ON, 253h Cf Reactor OFF, muon veto cut



FID147 in RUN014: 40 eVee, 30 eVph

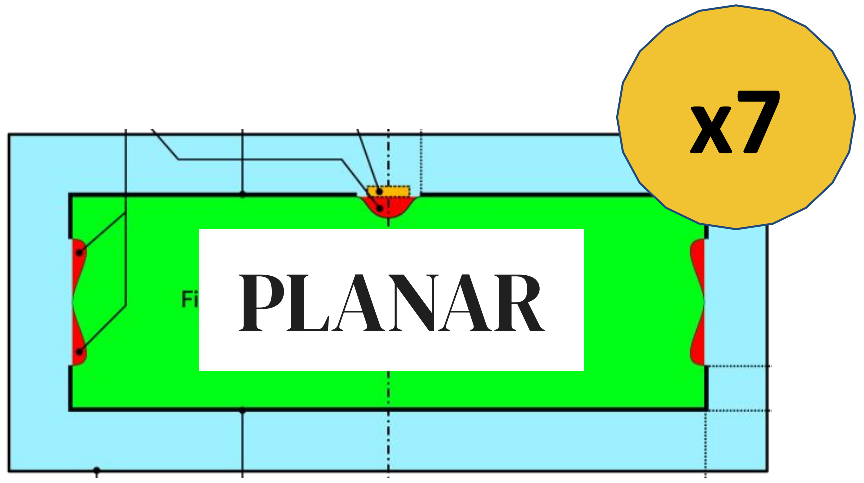


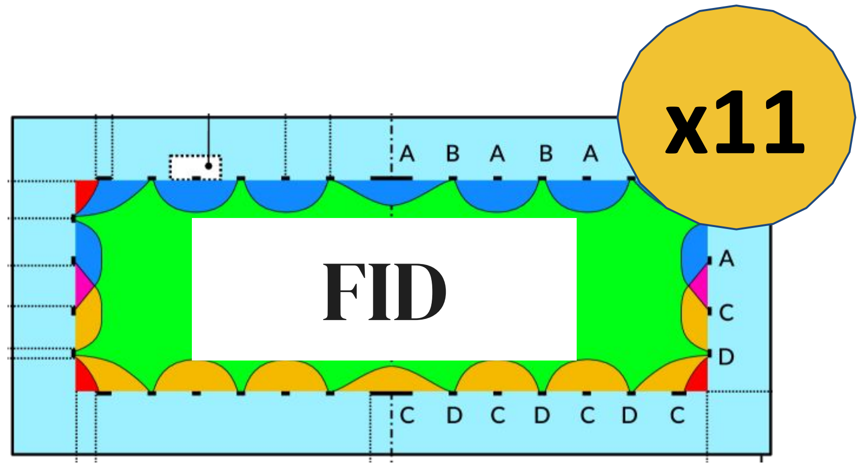
FID147: 277h Reactor OFF, 102h Cf Reactor OFF

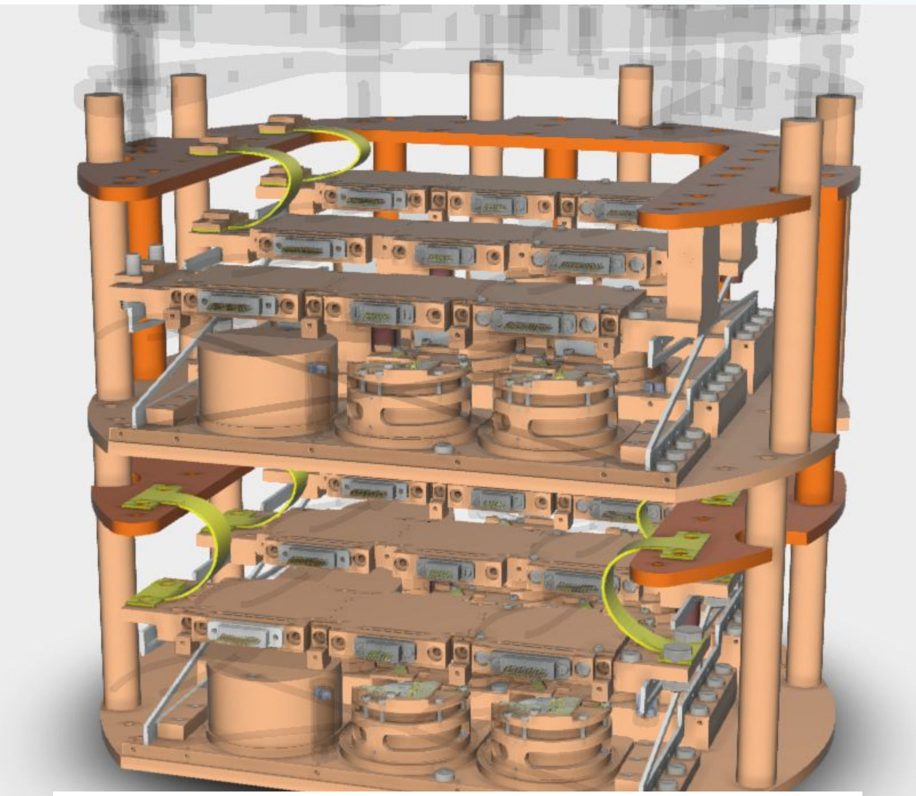
RICOCHET @ ILL Status: Next Steps

✅ Installation of Cryostat in Fall 2023, first cryogenic run (RUN012)
✅ First detector run Feb-April 2024 - 3 Detectors (RUN013)
✅ Second Detector run May-October 2024 - 3 Detectors (RUN014)
✅ Third Detector run Jan-June 2025 - 9 Detectors (RUN015)
⬜ **Installation of 18-detector Array (now!)**

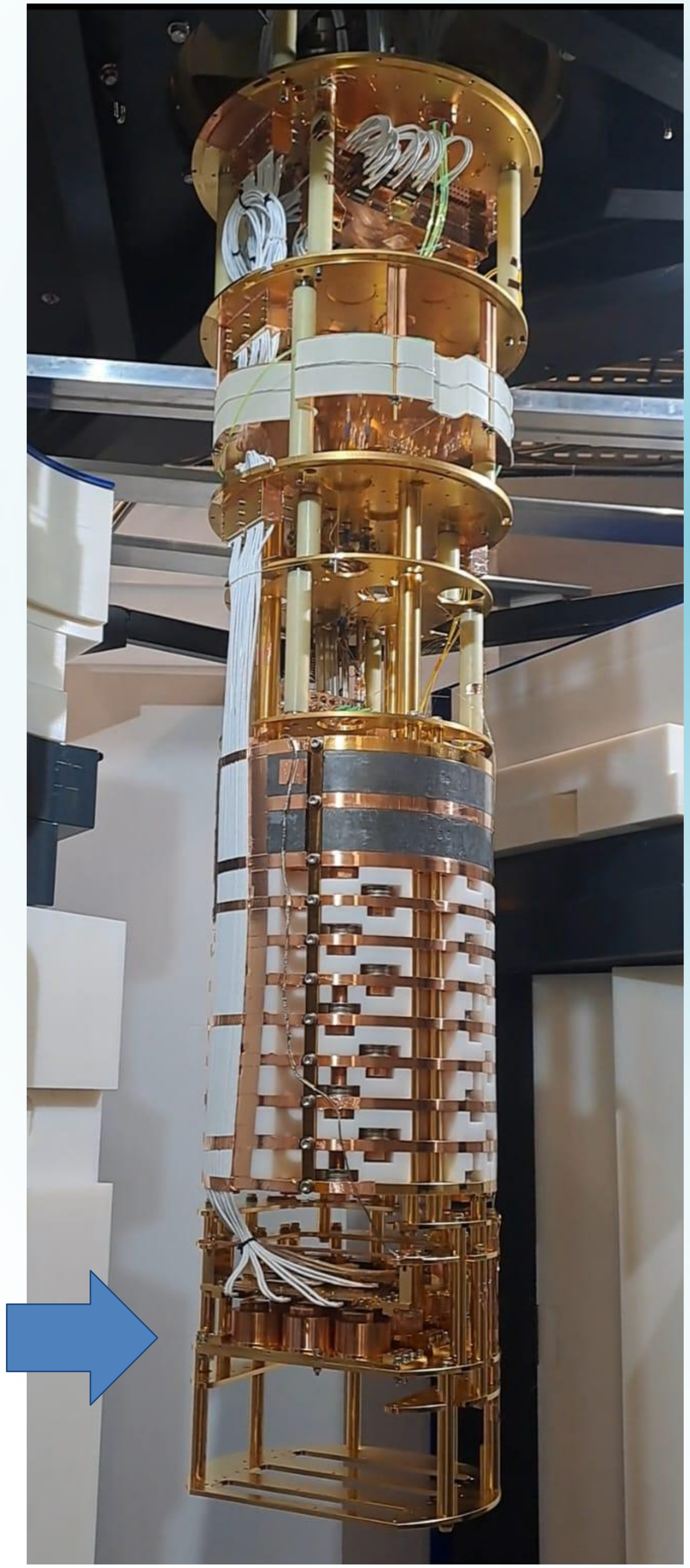
- **Cryo Muon Veto**
- **Etched Copper detector holders**



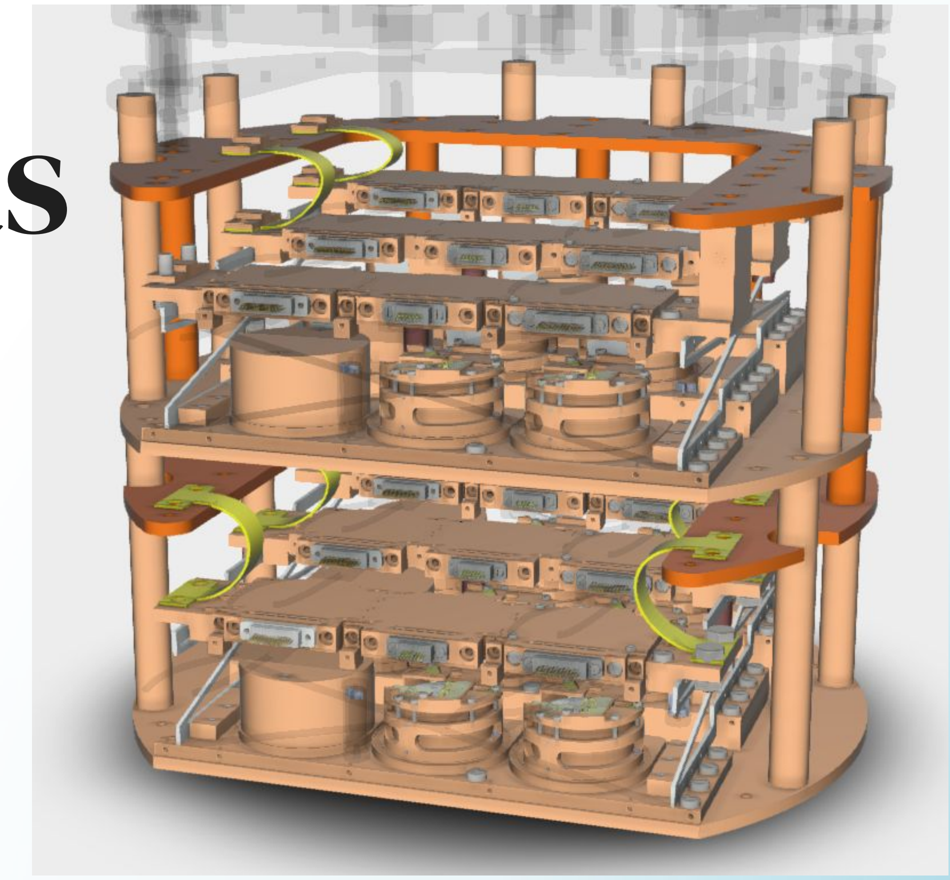




Full 750g Ricochet Payload



Towards CEvNS detection + More ideas



- Demonstration of detector performance, confirmation of background rates at ILL site in **RUN014**
- Continuation of background characterization + FID characterization with **RUN015**

The Future:

- **RUN016**: Full 18-detector payload
  - July 2025 will run for the next year+
    → ***CEvNS is on the horizon!***
- Future payloads: Mapping N^2 dependence of X-section → Si Ricochet, Q-Array?

Reactor Cycles | We are here | Start of RUN016

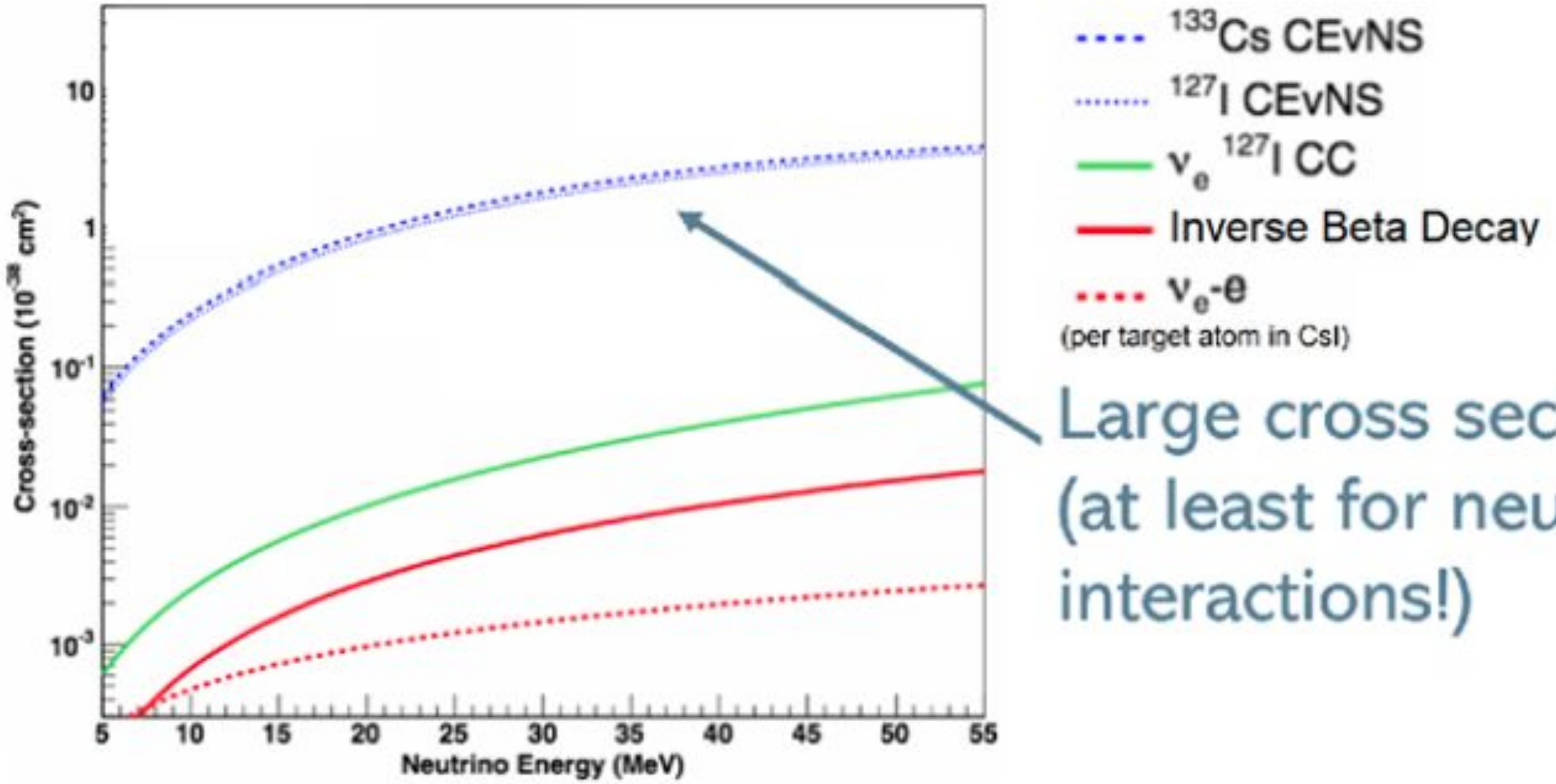
Year	Q1	Q2	Q3	Q4	Reactor ON Days
2024					105
2025					150/160
2026					160

Thank you!

Any Questions?

Backup: Cross section

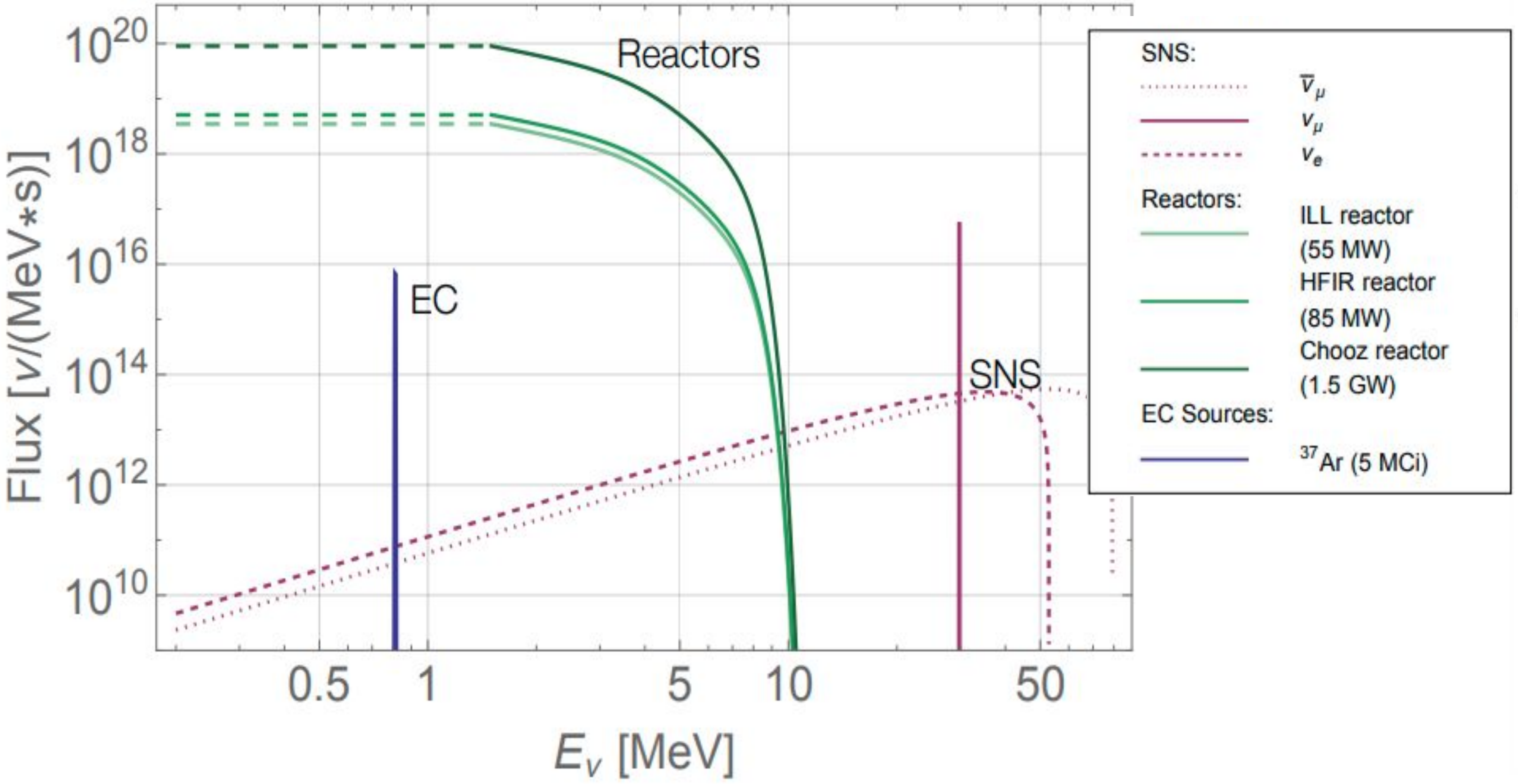
$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M_A \left(1 - \frac{M_A T}{2E_\nu^2}\right) F(Q^2)^2$$

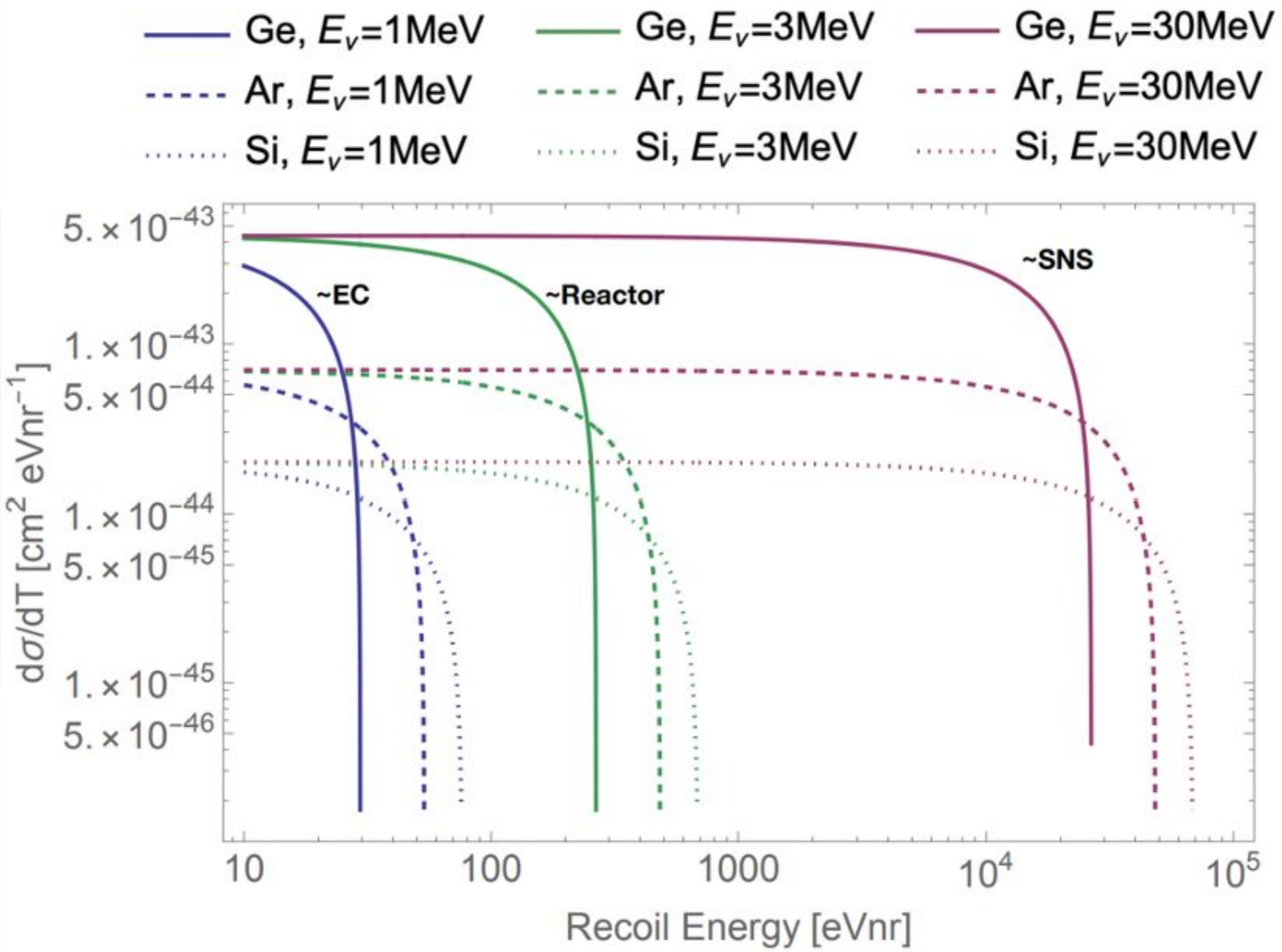


Large cross section, (at least for neutrino interactions!)

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

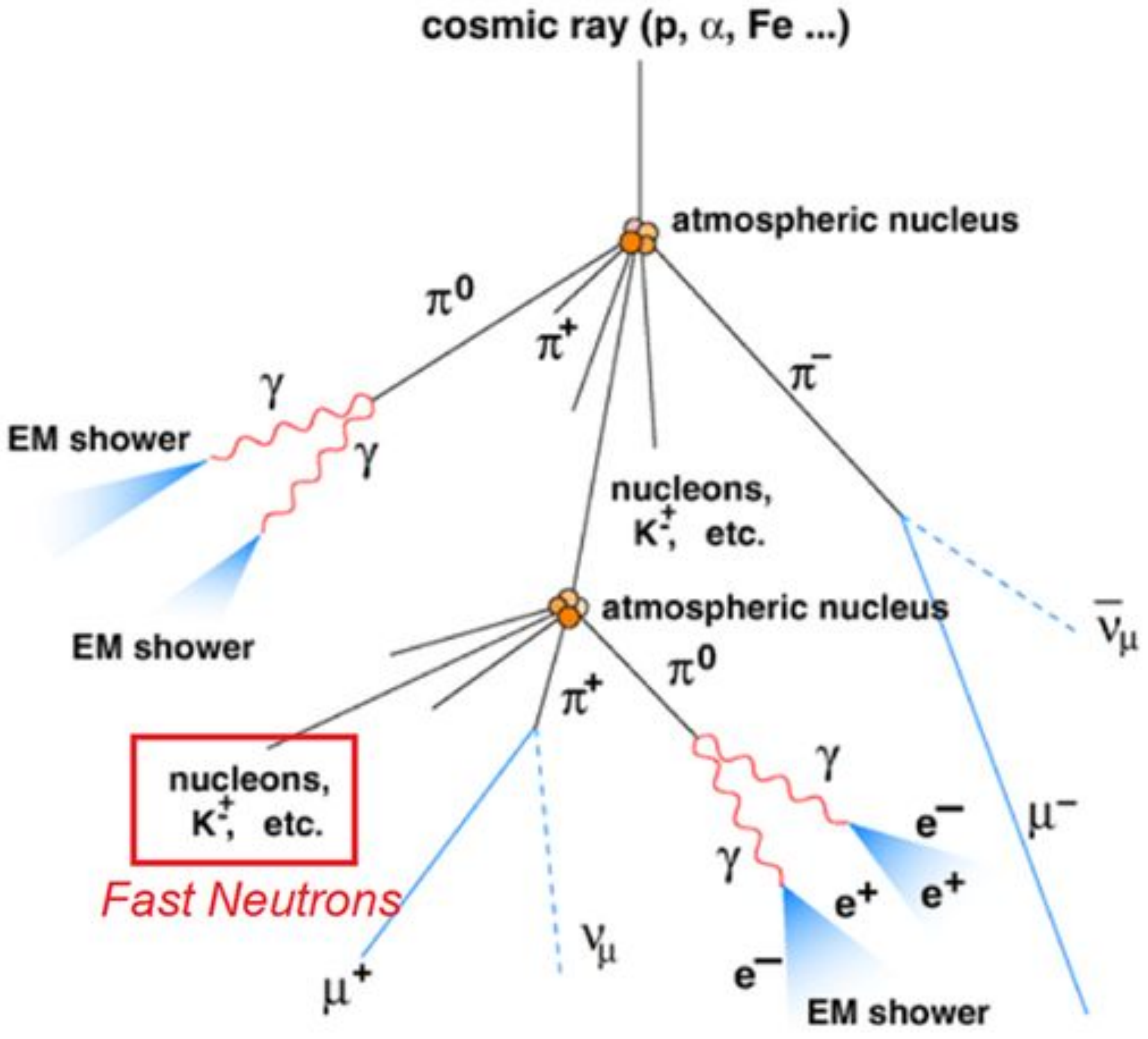
Backup: Neutrino and Recoil energies





Backup: Cosmogenic Estimates

		Cosmogenic
Electronic recoils	No Shielding (I)	260 ± 5
[50 eV, 1 keV]	Passive Shielding (II)	183 ± 6
(evts/day/kg)	Passive + μ-veto (III)	1.6 ± 0.6
Neutron recoils	No Shielding (I)	1554 ± 12
[50 eV, 1 keV]	Passive Shielding (II)	42 ± 3
(evts/day/kg)	Passive + μ-veto (III)	7 ± 2
CEνNS		**12.8**



[RICOCHET Collaboration: arXiv:2111.06745]

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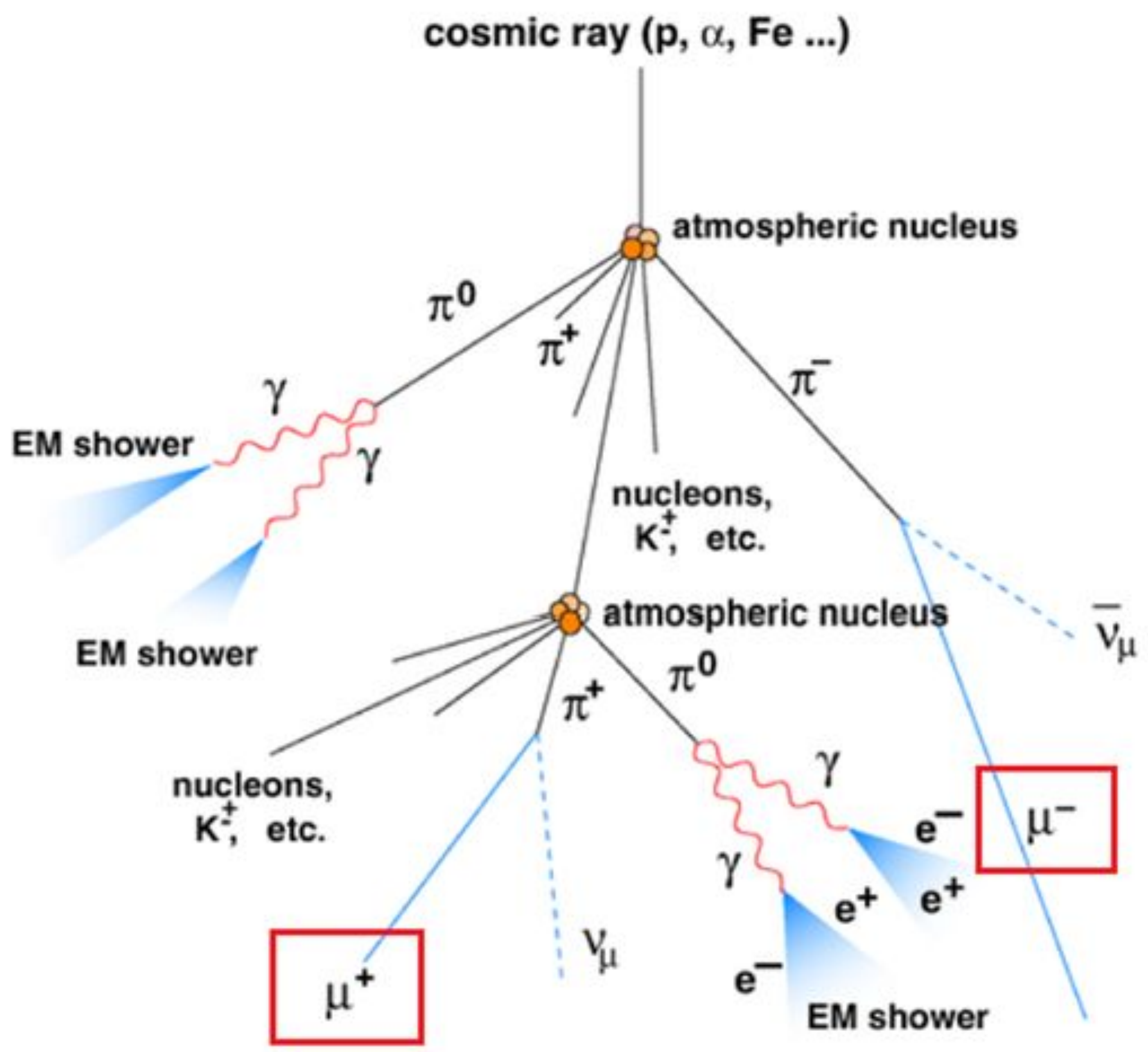
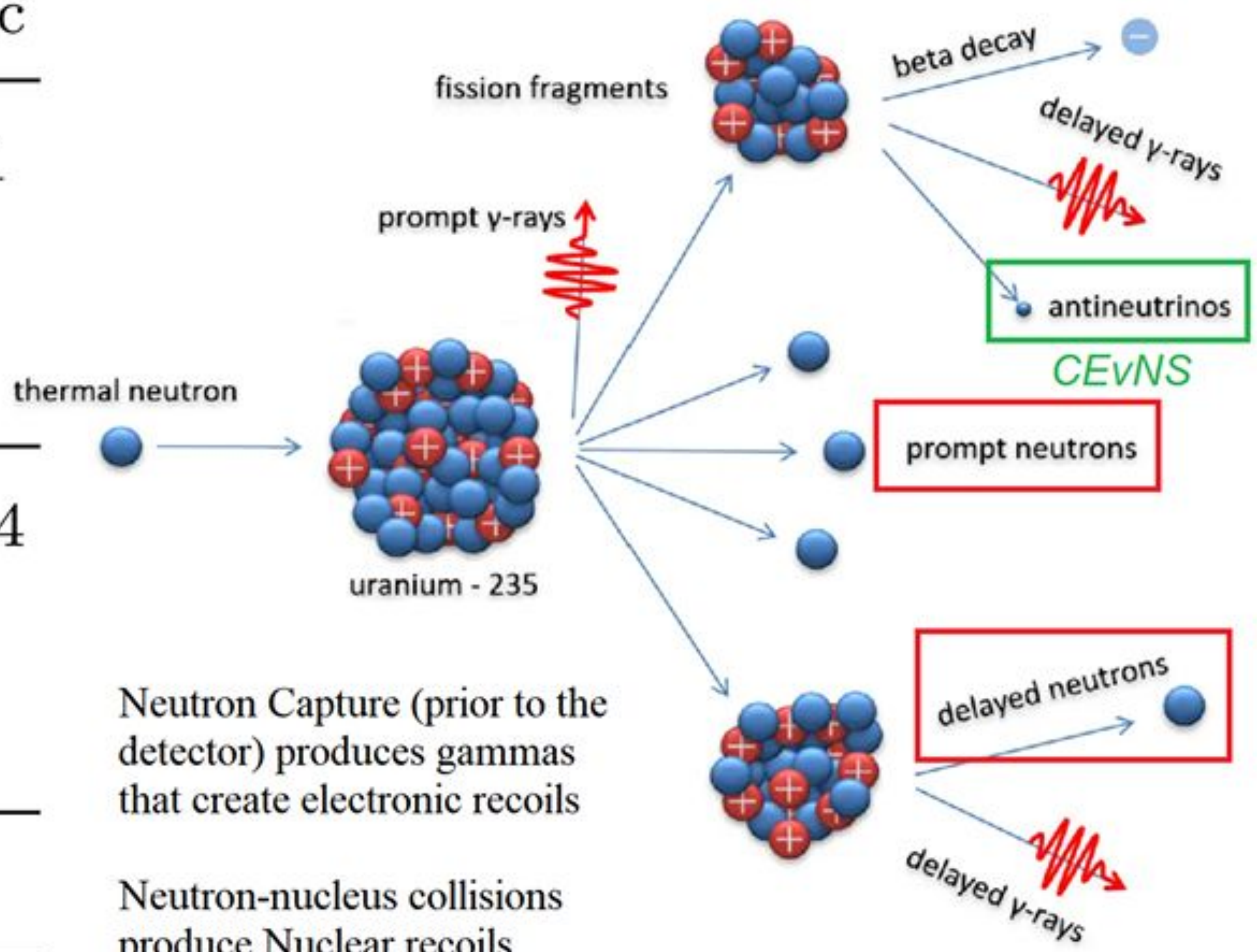


[RICOCHET Collaboration: arXiv:2111.06745]

Backup: Reactogenic Estimates

		Reactogenic
Electronic recoils	No Shielding (I)	4365 ± 301
[50 eV, 1 keV]	Passive Shielding (II)	18 ± 2
(evts/day/kg)	Passive + μ-veto (III)	
Neutron recoils	No Shielding (I)	53853 ± 544
[50 eV, 1 keV]	Passive Shielding (II)	2.4 ± 0.3
(evts/day/kg)	Passive + μ-veto (III)	
CEνNS		**12.8**



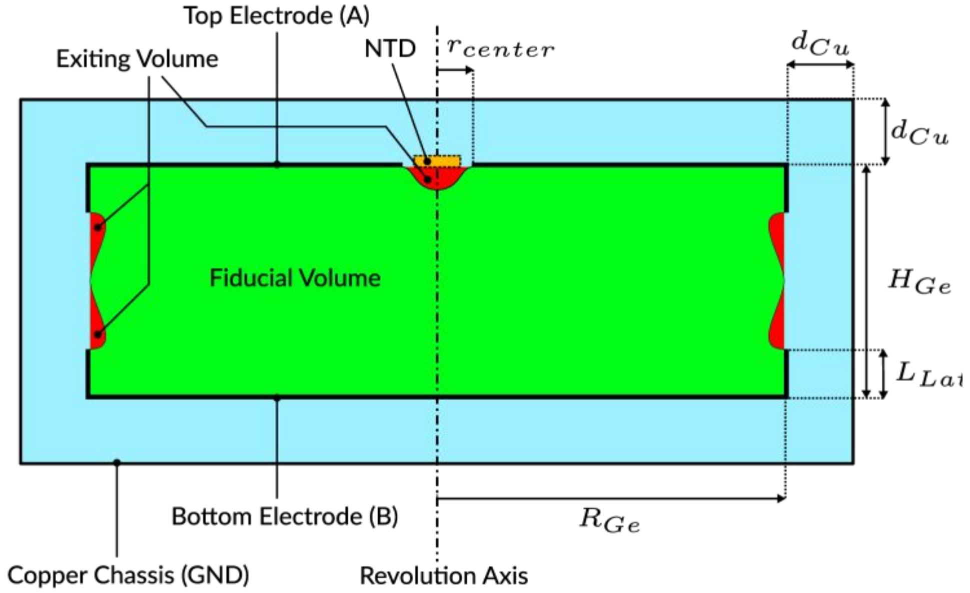
Neutron Capture (prior to the detector) produces gammas that create electronic recoils

Neutron-nucleus collisions produce Nuclear recoils

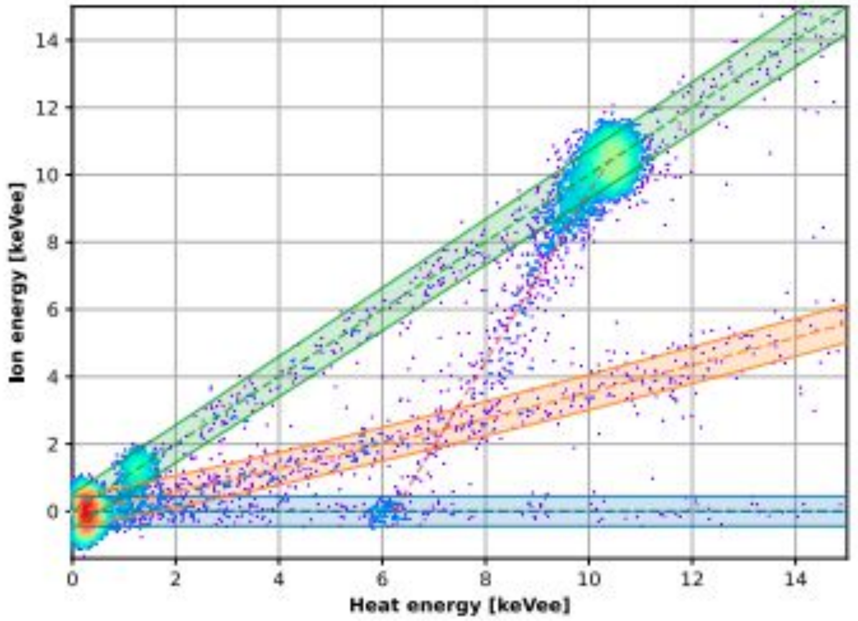
[RICOCHET Collaboration: arXiv:2111.06745]

Detection Strategy: CryoCube

Planar (PL)



T. Salagnac et al., J. Low Temp. Phys. 211, 398 (2023)



Fiducial volume ~99%

Surface Rejection ❌

CryoCube Detector Performance Goals

- 20 eVee ion resolution
- 10 eV phonon resolution
- Particle discrimination to 50 eV
- Scalable to ~kg payload mass

~30 eV$_{ee}$ baseline resolution achieved in ionization channel for 3 detectors tested at IP2I Lyon

C. Augier et al., Eur. Phys. J. C 84, 186 (2024)