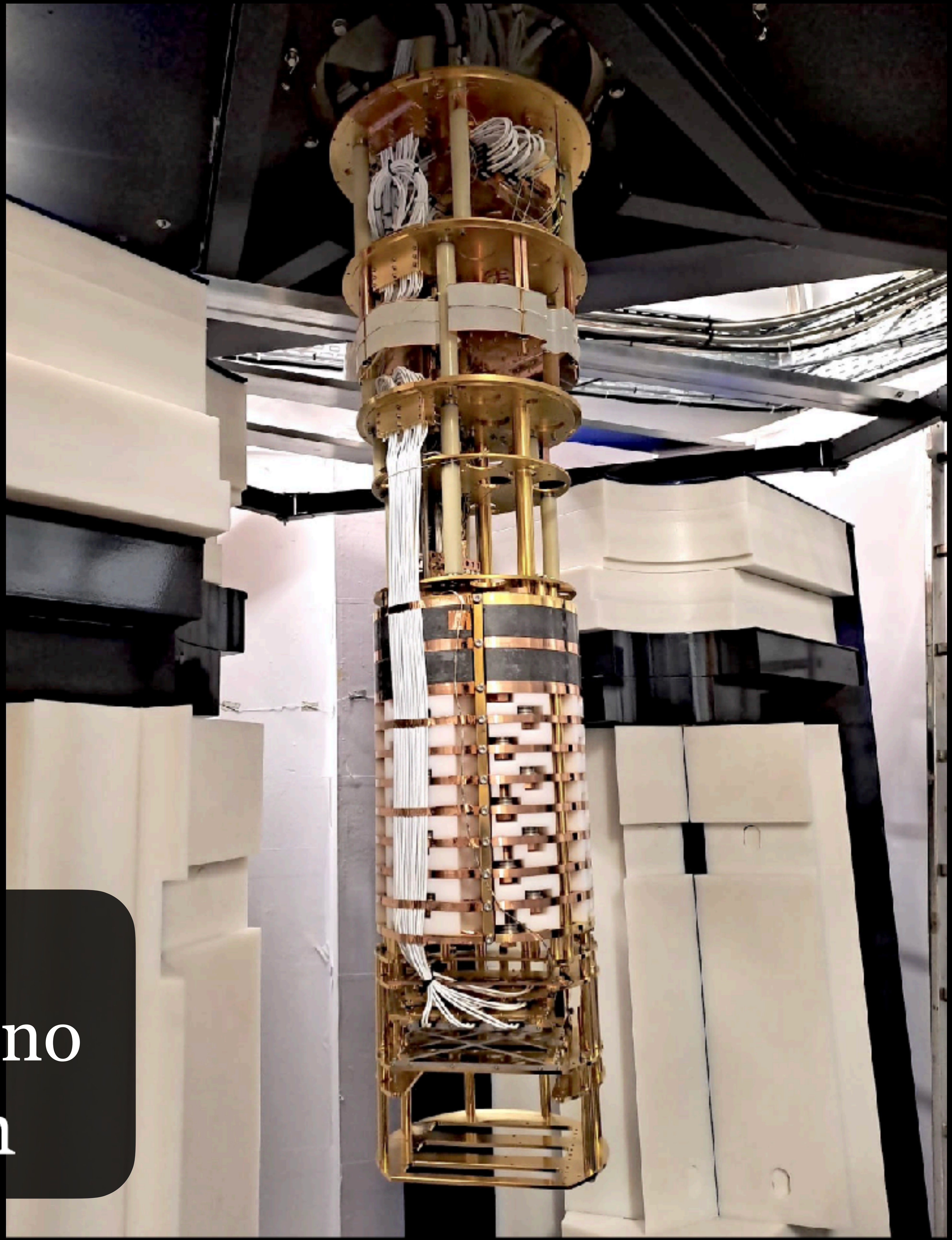
Very Cool Measurements of Very Hot Reactors:

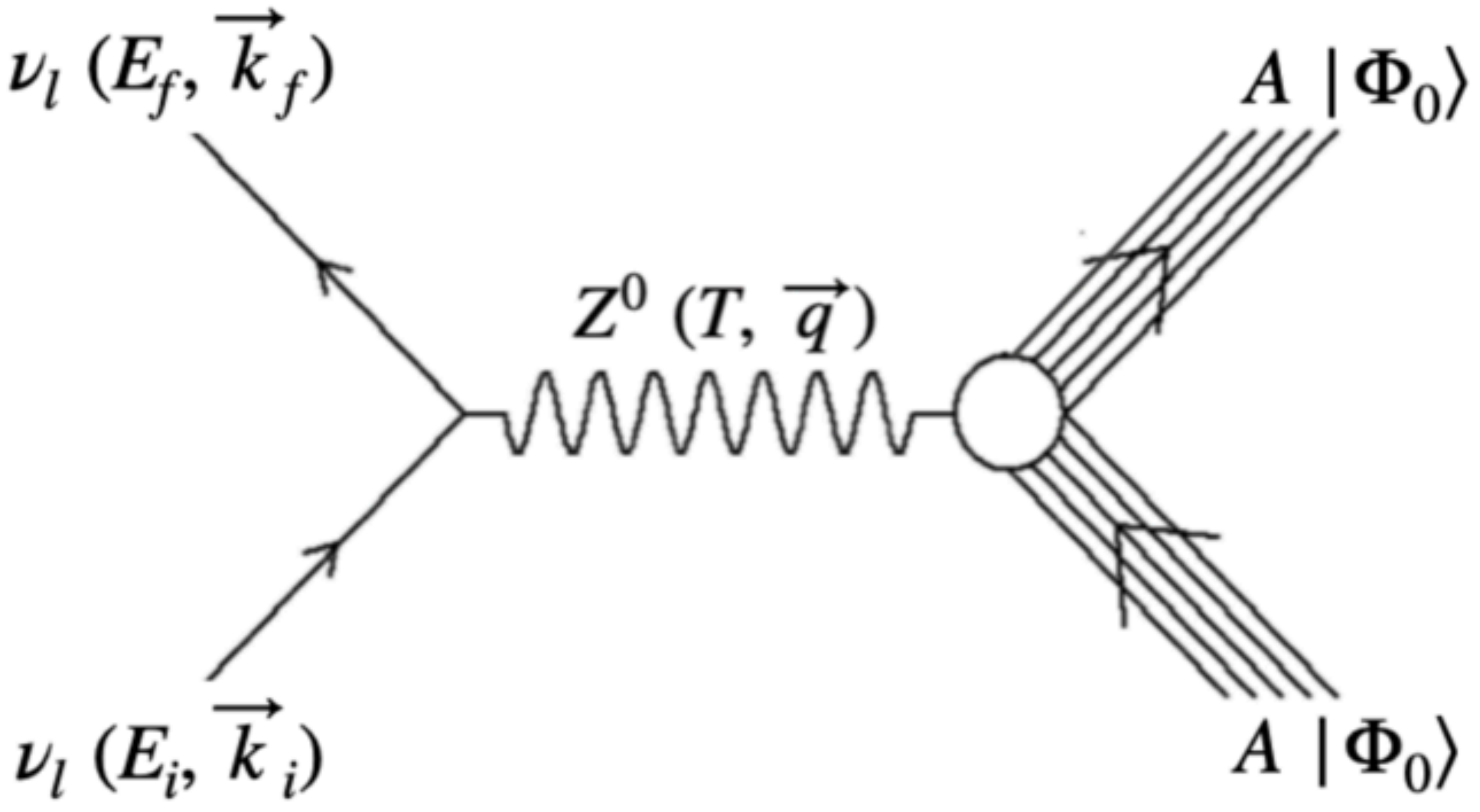
CEvNS goes **Nuclear!**



Enectalí
Figueroa-Feliciano
Northwestern

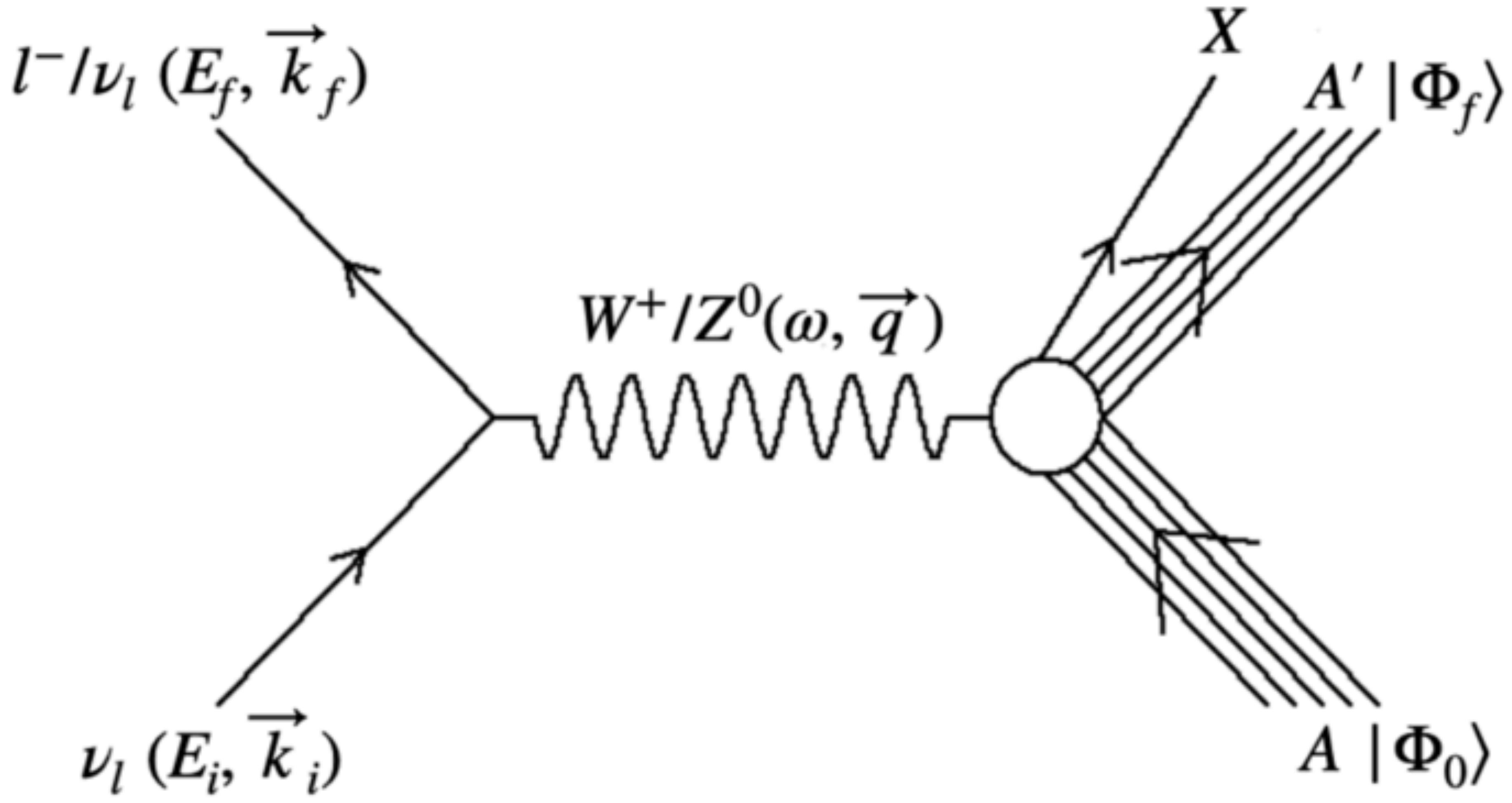
Life is simple at low energies

Elastic



$$\mathrm{CE}\nu\mathrm{NS}$$

Quasi-Elastic



$$\mathrm{CCQE, NCQE}$$

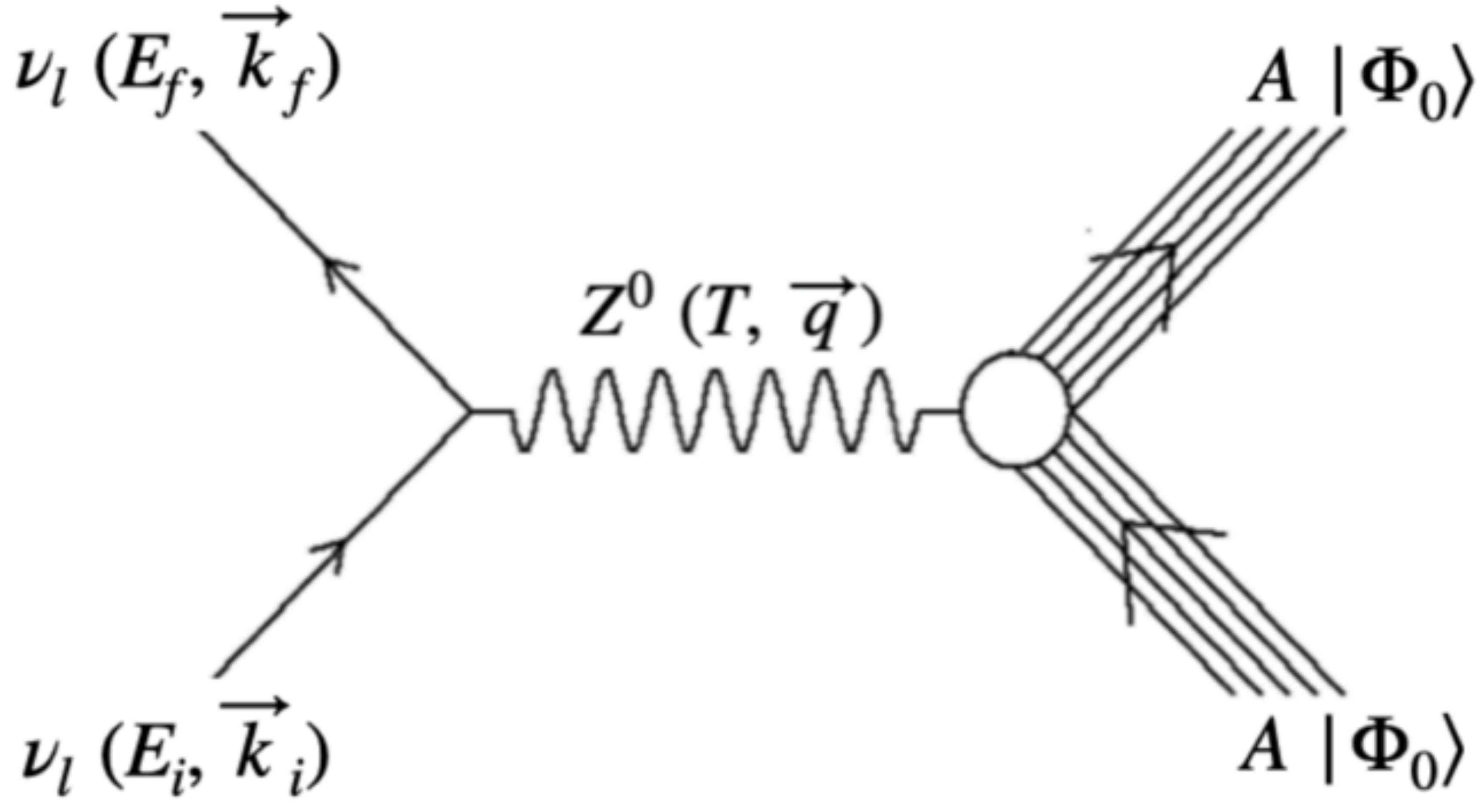
Dessel et al., *Universe* **2023**, *9*(5), 207; https://doi.org/10.3390/universe9050207

Coherent Elastic ν-Nucleus Scattering

CEνNS

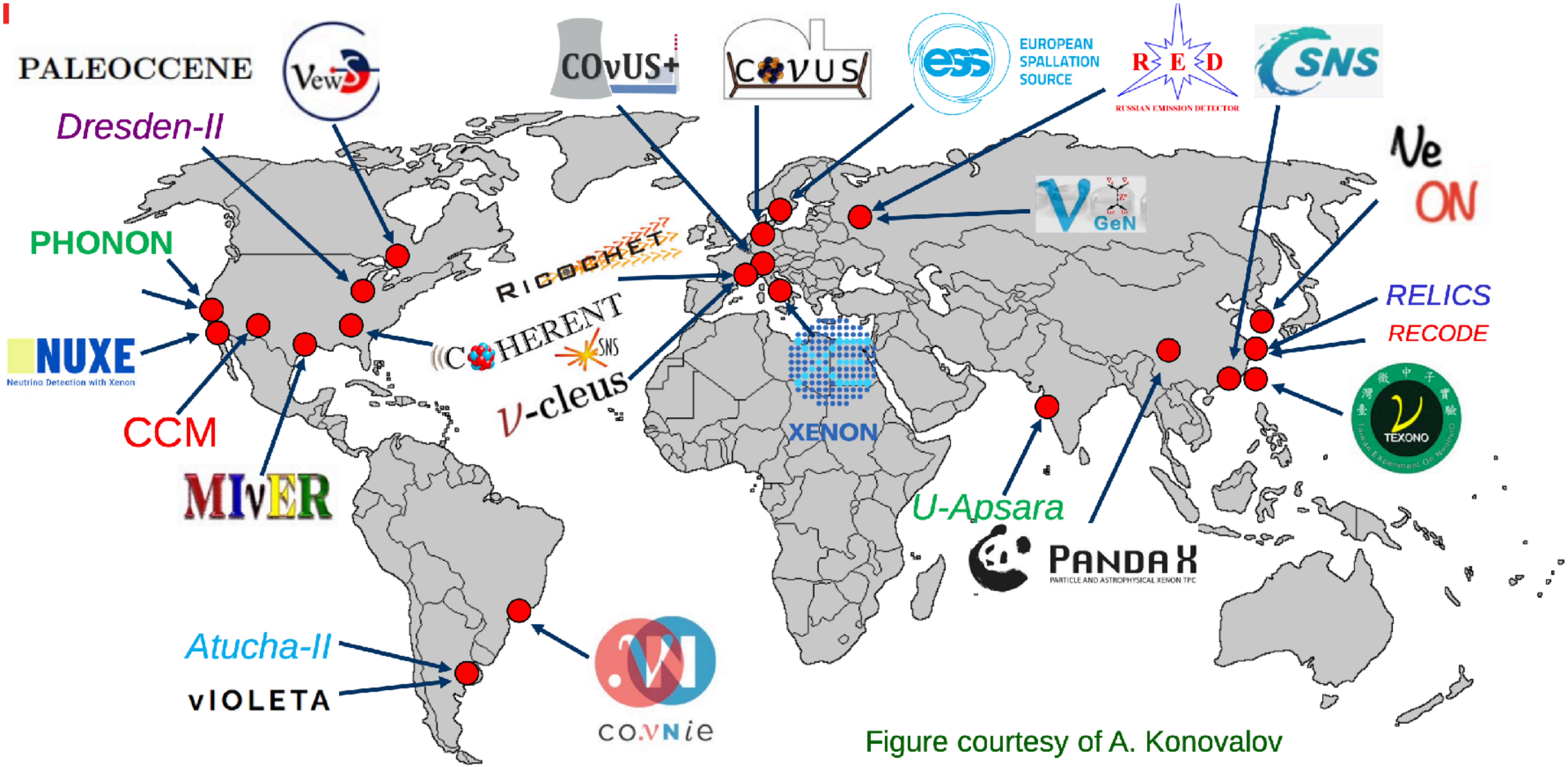
$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M_A \left(1 - \frac{T}{E_\nu} - \frac{M_A T}{2E_\nu^2}\right) F_W(q^2)^2$$

- σ: Cross Section
- T: Recoil Energy
- E_ν: Neutrino Energy
- G_F: Fermi Constant
- Q_W: Weak Charge
- M_A: Atomic Mass
- F_W: Form Factor

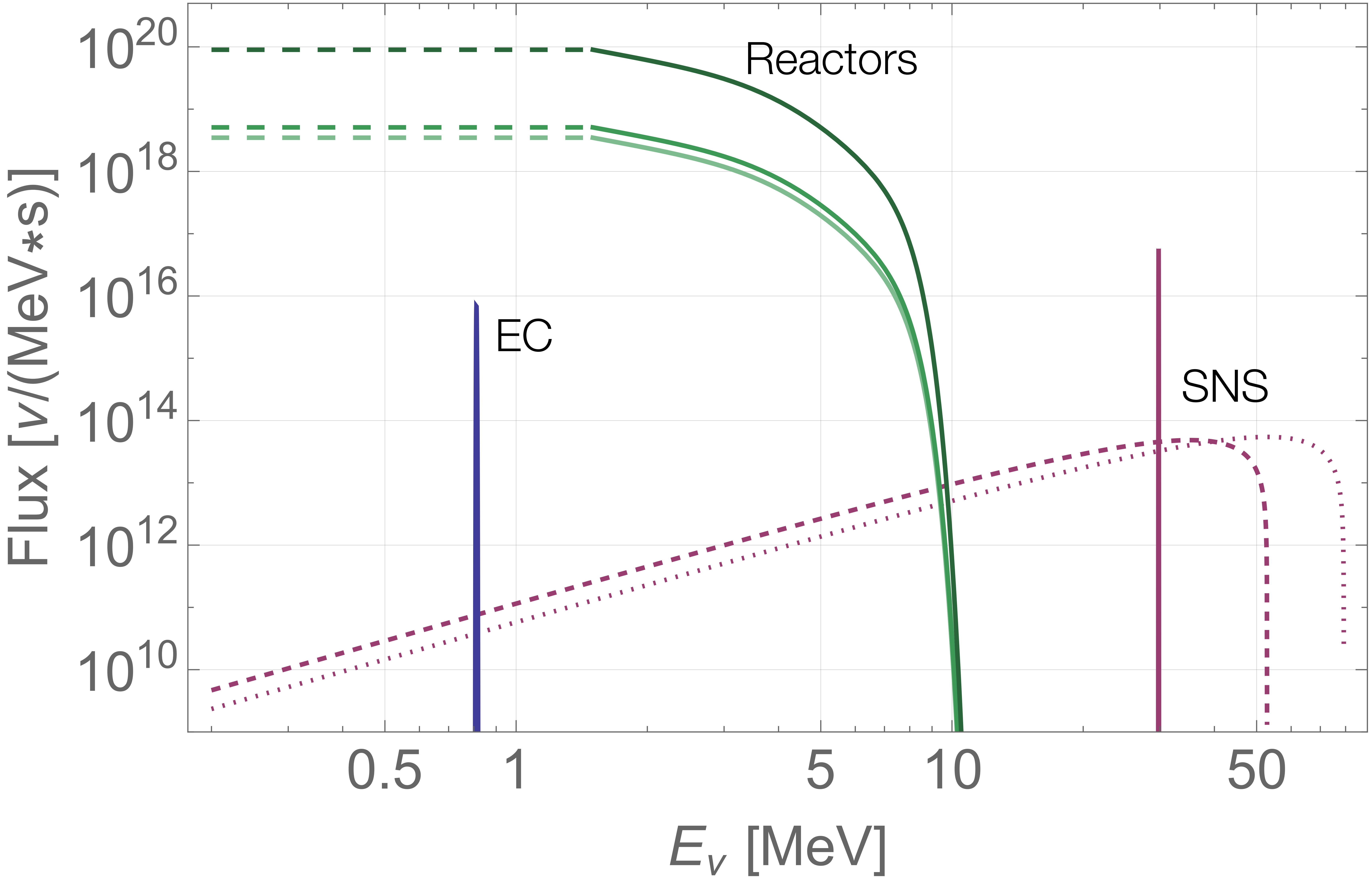


No flavor-specific terms!!!
Same rate for ν_e, ν_μ, and ν_τ

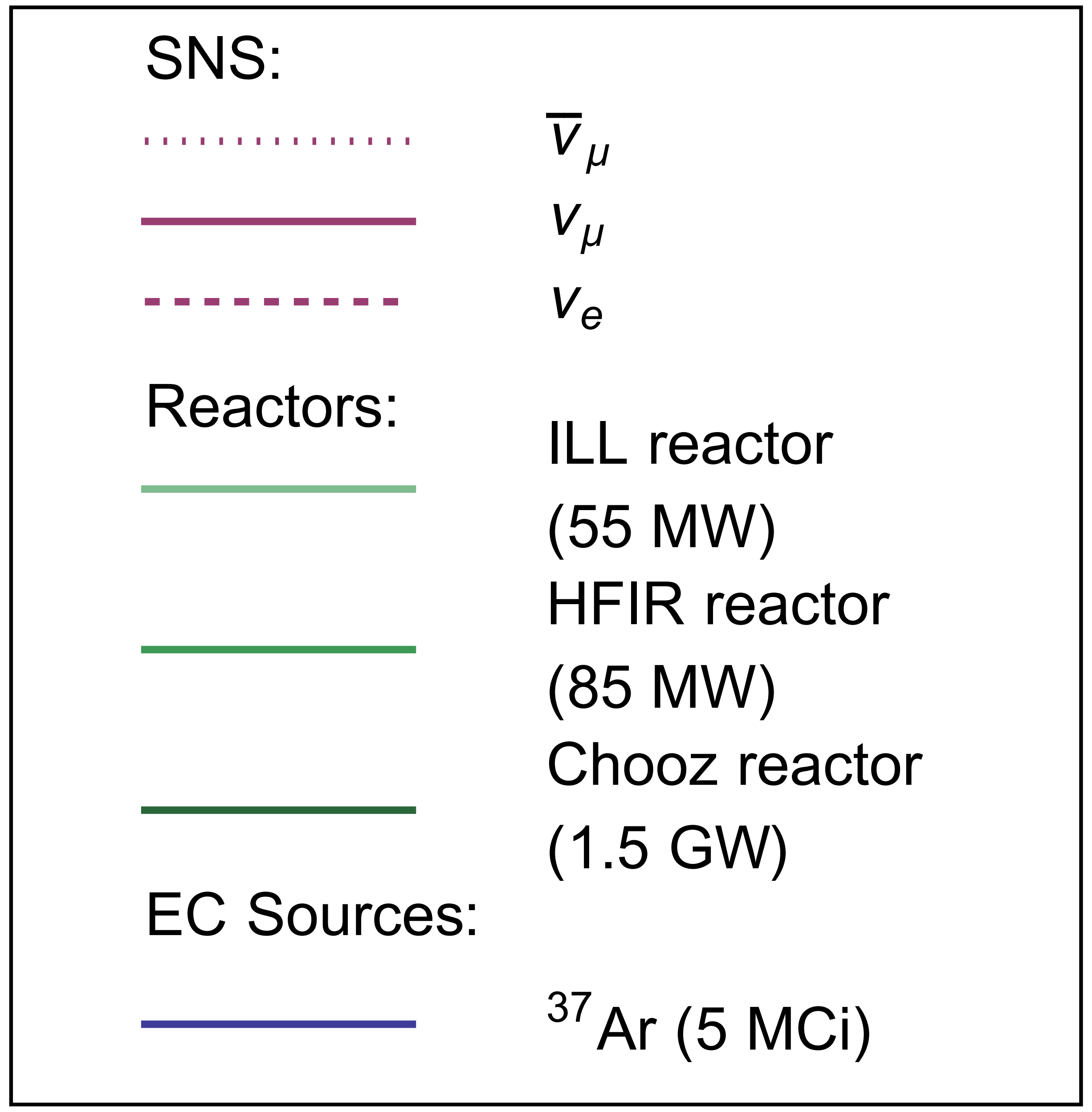
CEvNS Around the World (thanks Janina!)



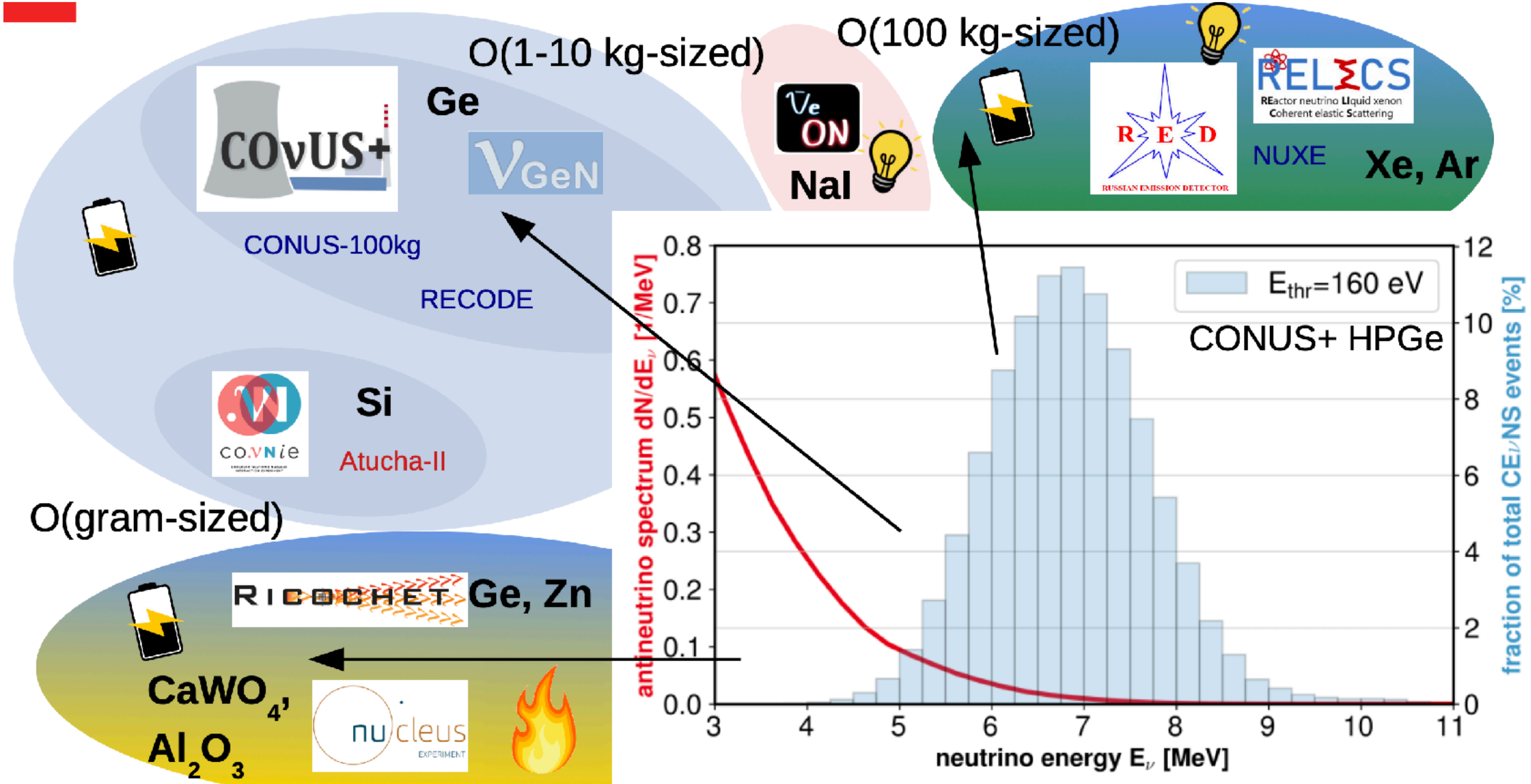
Neutrino Sources for CEνNS



- Electron-capture sources
- Reactors
- Decay-at-rest sources



Review of Reactor Experiments



R&D:
- SBC
- Paleoccene (color centers)
- spherical prop. counters

...

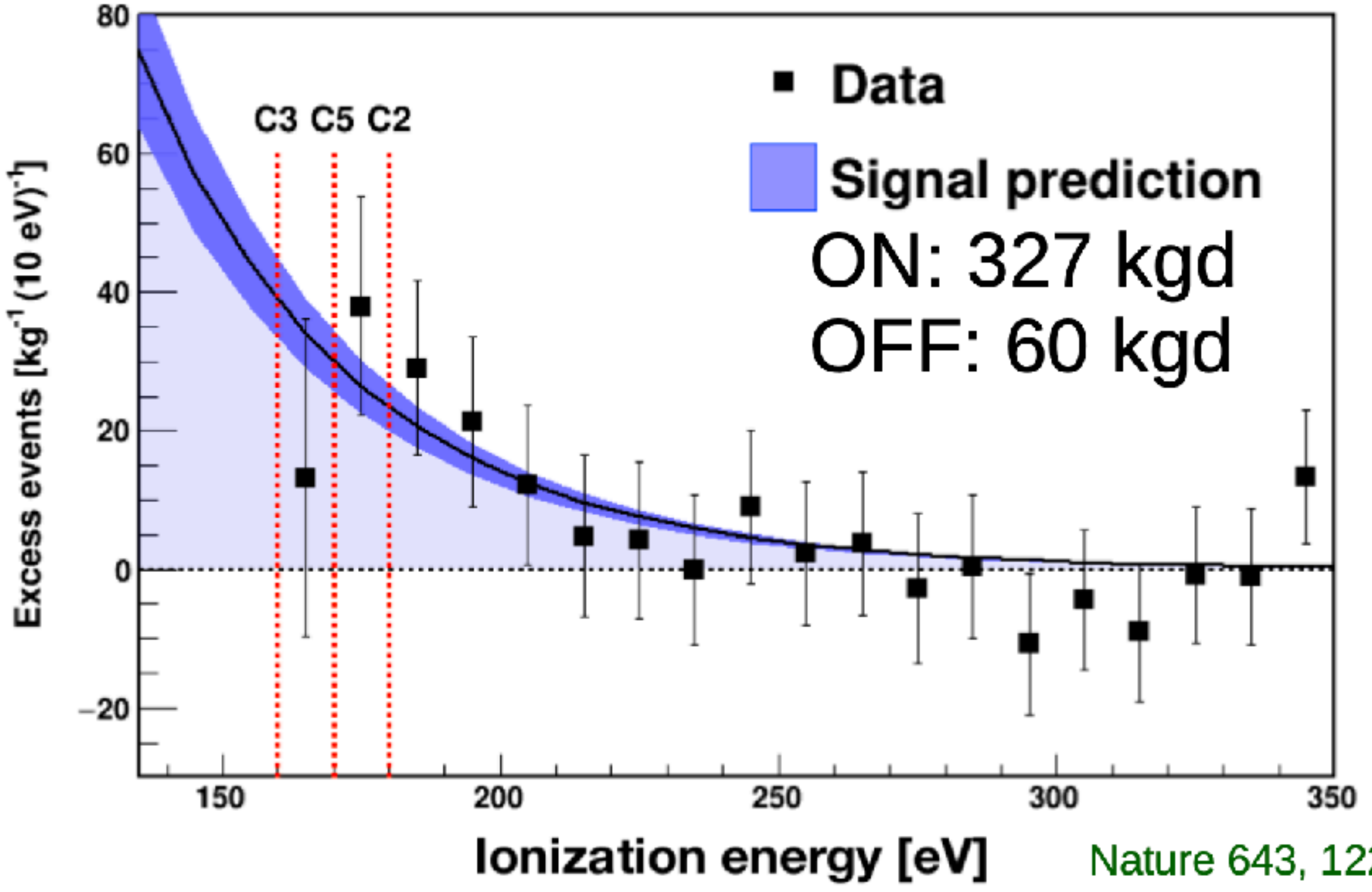
Nature 643, 1229–1233 (2025)

First detection of CEvNS at reactor site

Simultaneous binned log likelihood fit of:

reactor OFF (→ bkg model) and reactor ON data (→ bkg model + CEvNS)

Figure: bkg model subtracted



Nature 643, 1229–1233 (2025)

Quenching:

detectable with HPGe

recoil → ionization energy + phonons

=> Lindhard theory (confirmed in)

Total active mass: (2.83+-0.02) kg

Signal events data: **395+-106**

Signal predicted: 347+-59

Ratio to SM: 1.14+-0.36

3.7 σ significance!

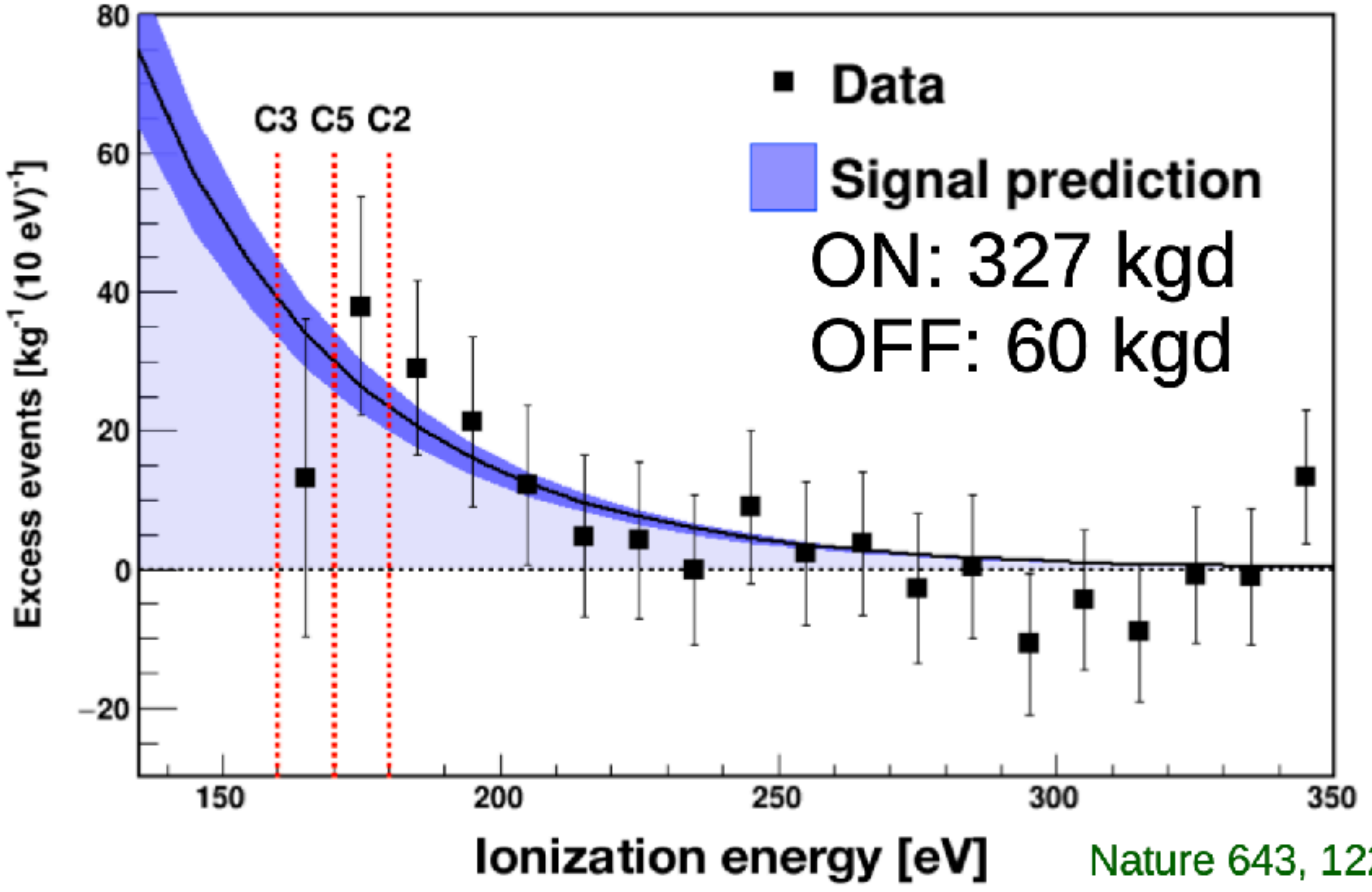
First detection of CEvNS at reactor side!

First detection of CEvNS at reactor site

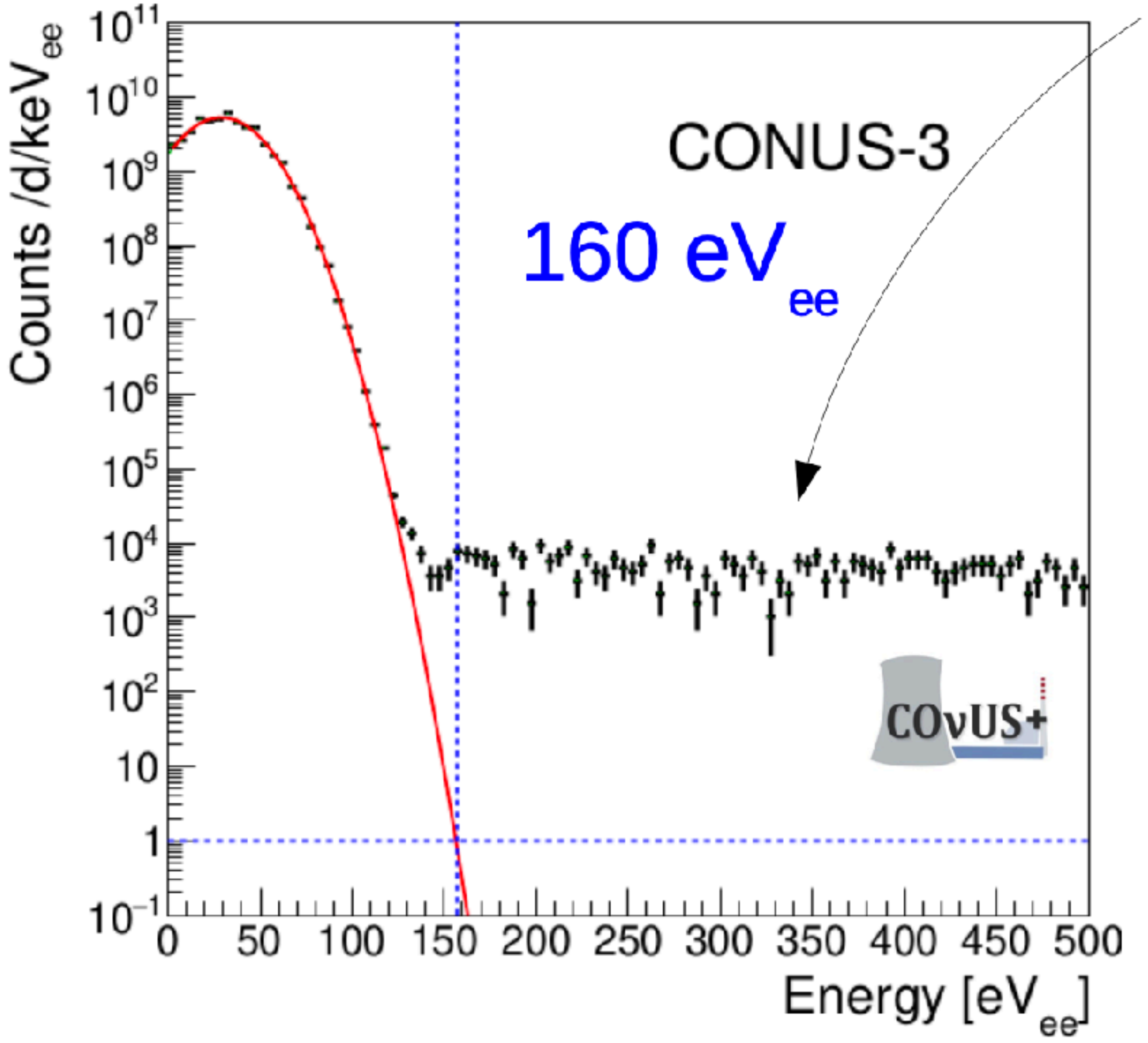
Simultaneous binned log likelihood fit of:

reactor OFF (→ bkg model) and reactor ON data (→ bkg model + CEvNS)

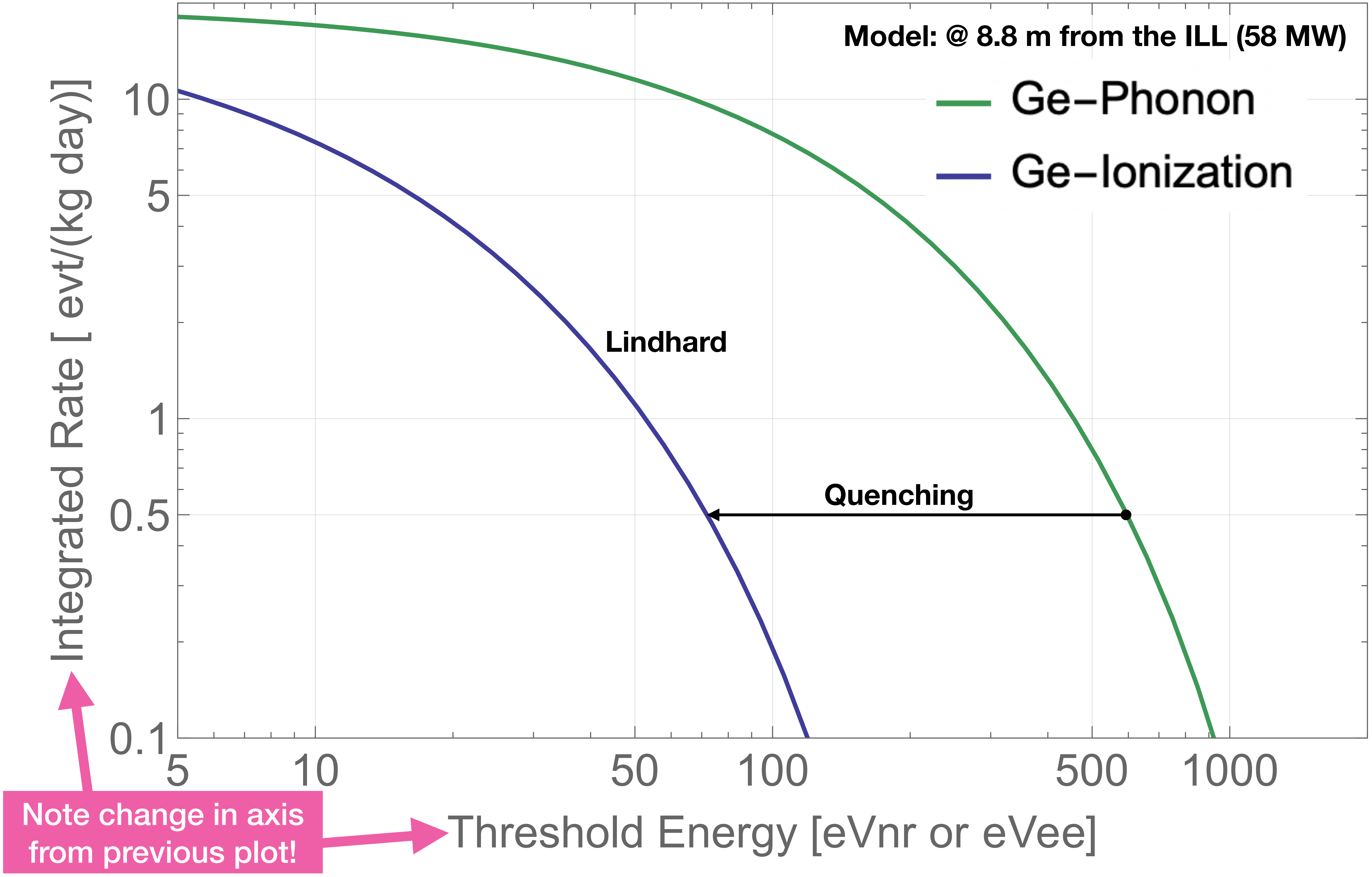
Figure: bkg model subtracted



Nature 643, 1229–1233 (2025)



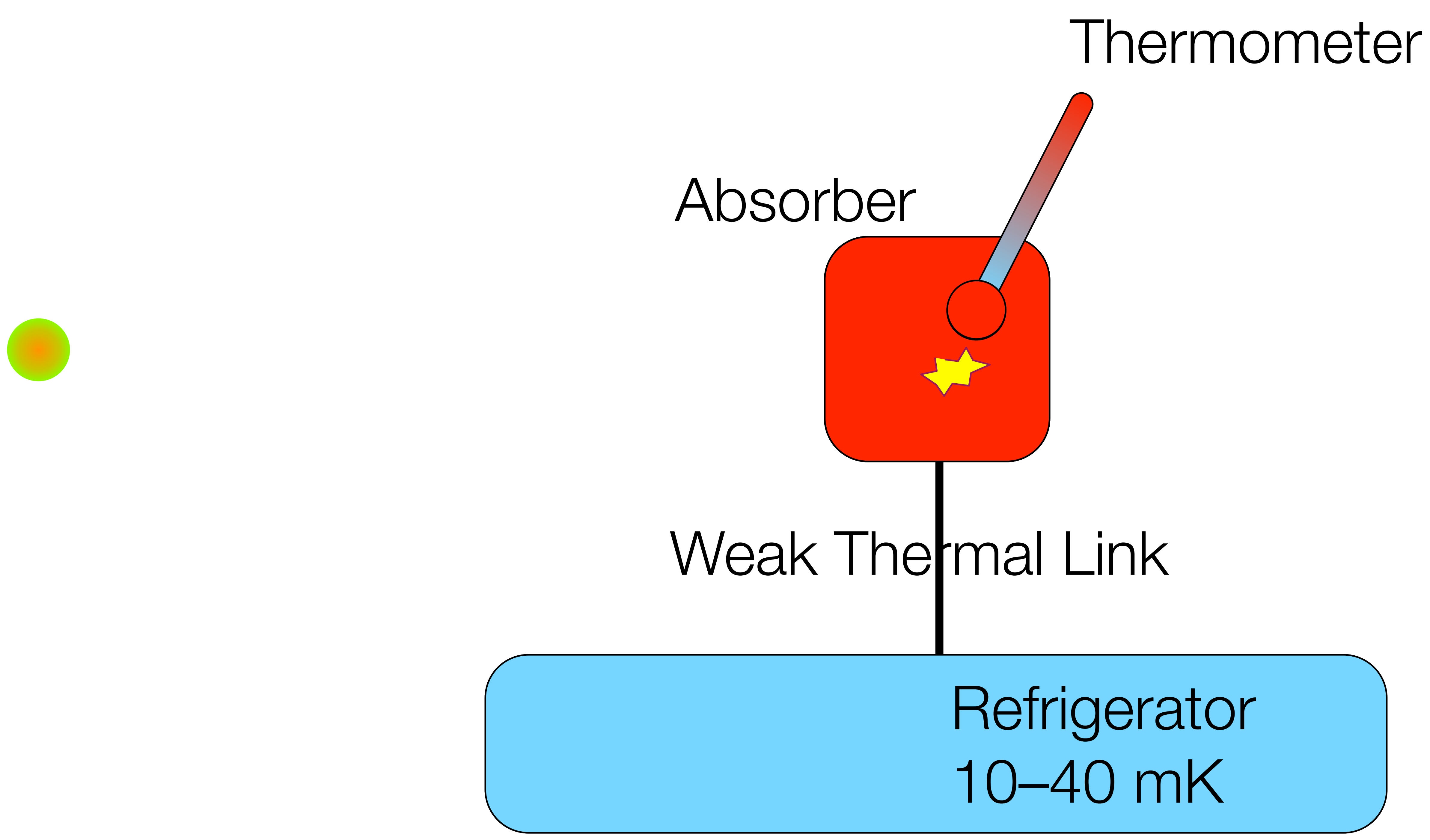
Ionization Measurements and Quenching

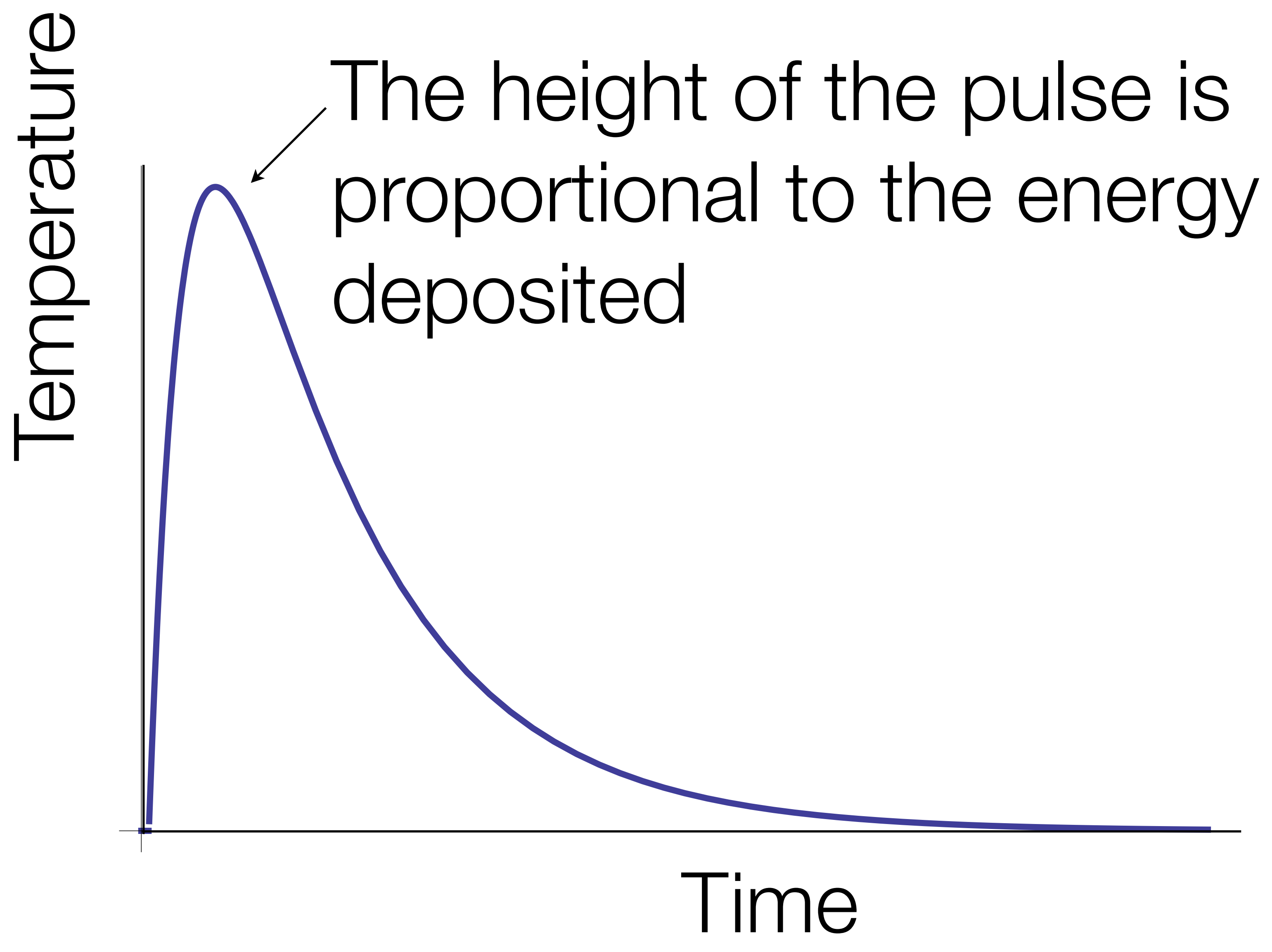


- Ionization measurements of CEvNS require lower thresholds to get the same rate due to the quenching factor
- The result depends heavily on the yield model you use!

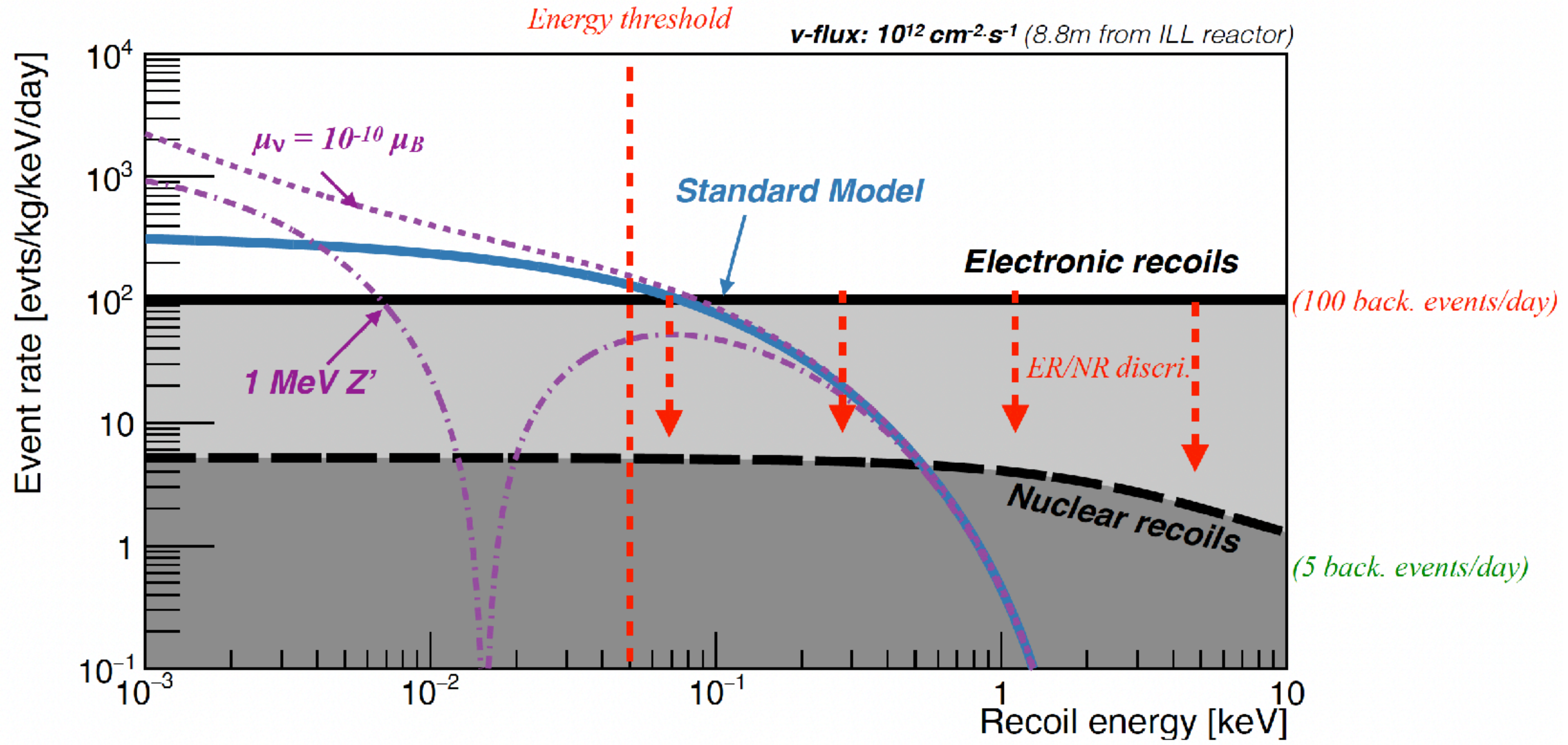
Cryogenic Phonon Detectors

$$\Delta E_{\mathrm{FWHM}} \approx 2.36\sqrt{4kTE_{\mathrm{max}}}$$



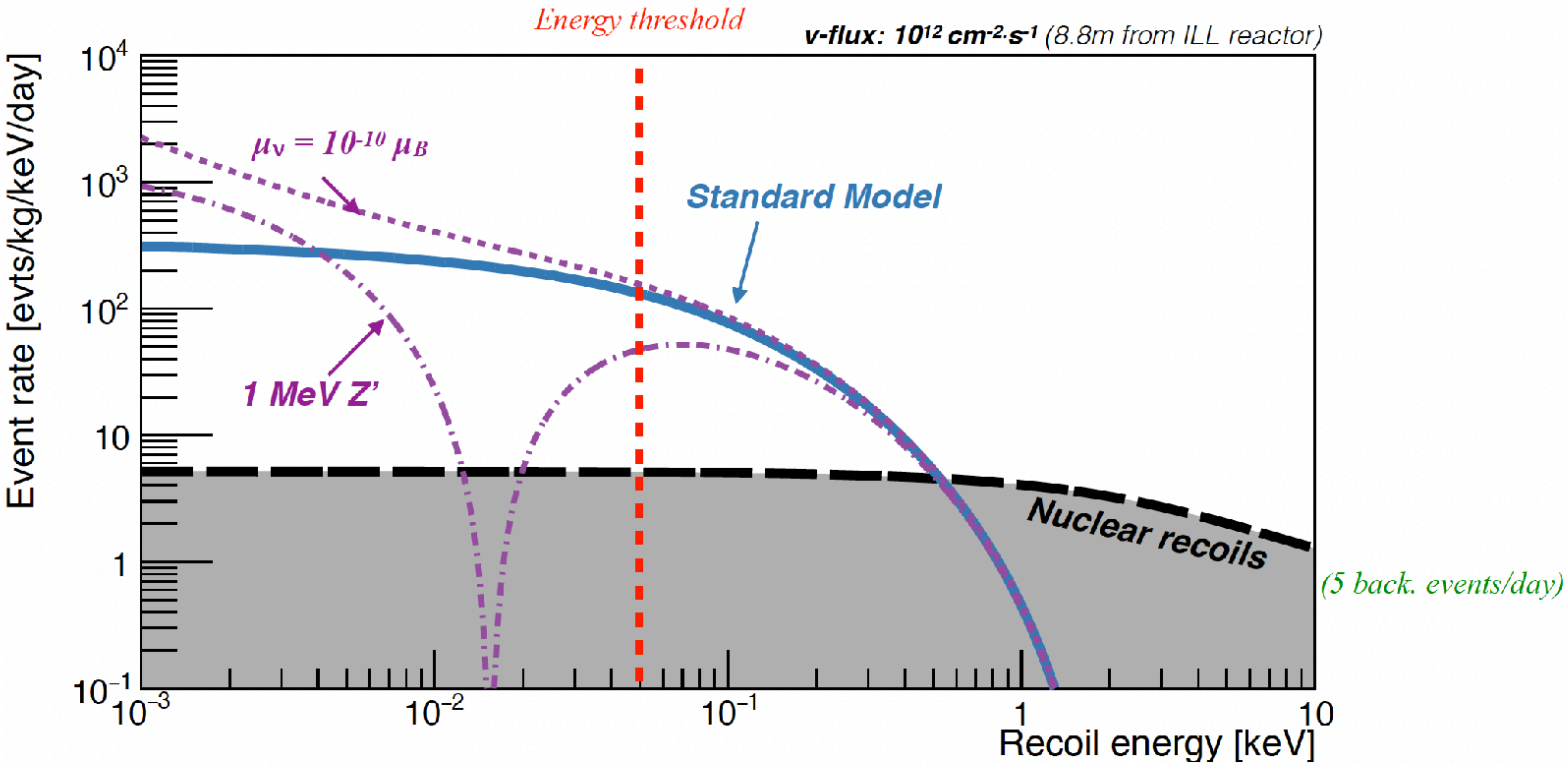


CEνNS Future Science Example: Ricochet



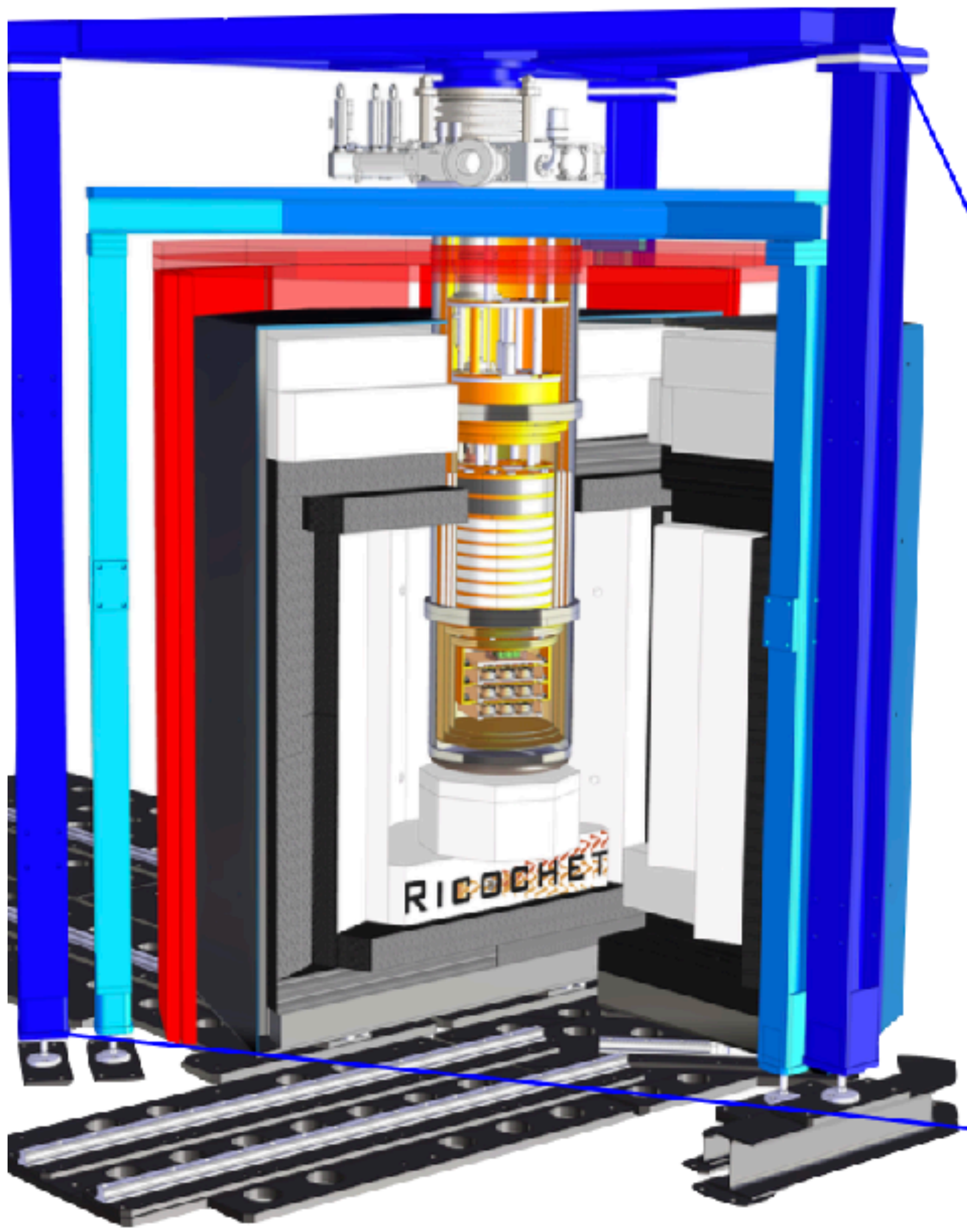
Spectral information improves searches for new physics!

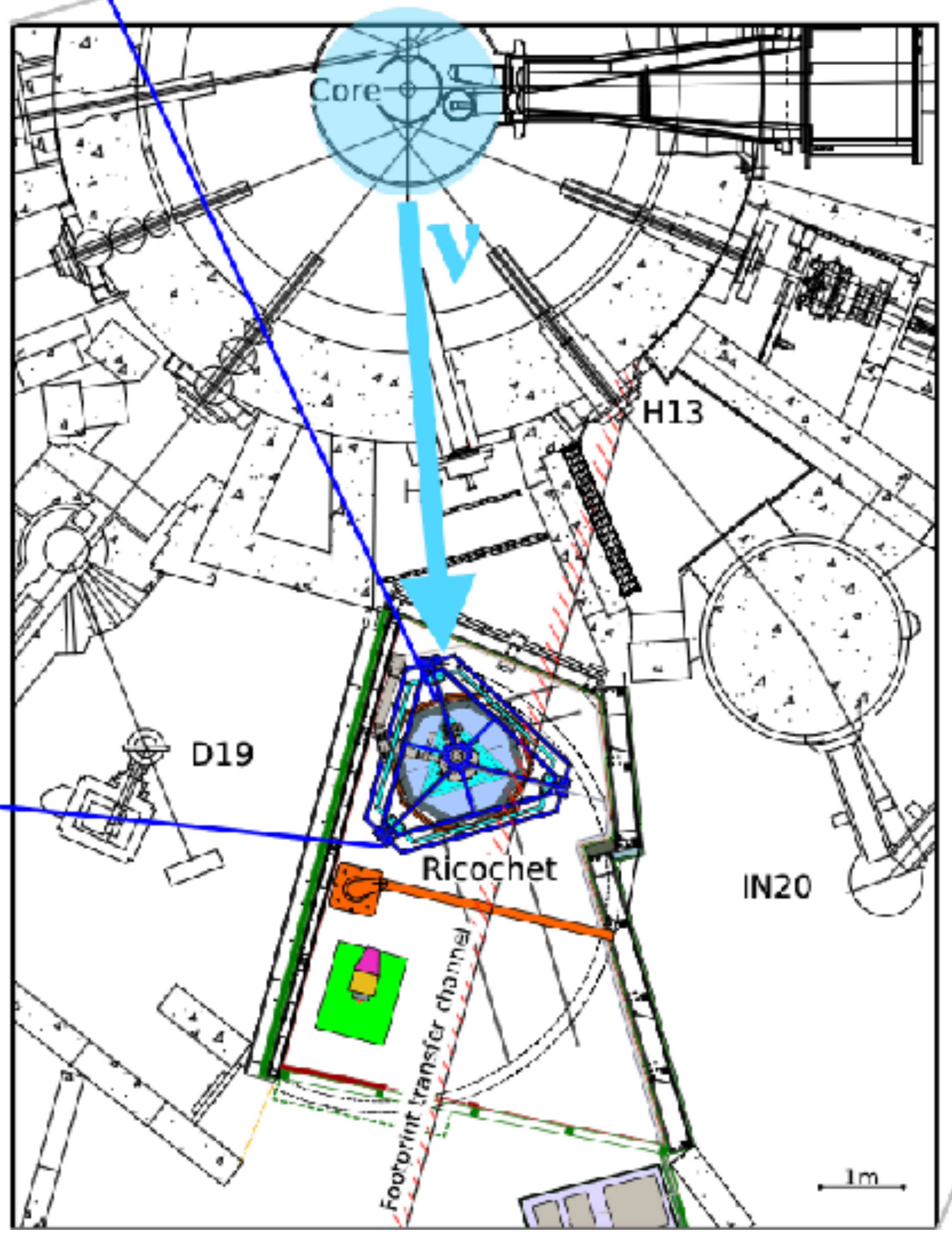
CEνNS Future Science Example: Ricochet



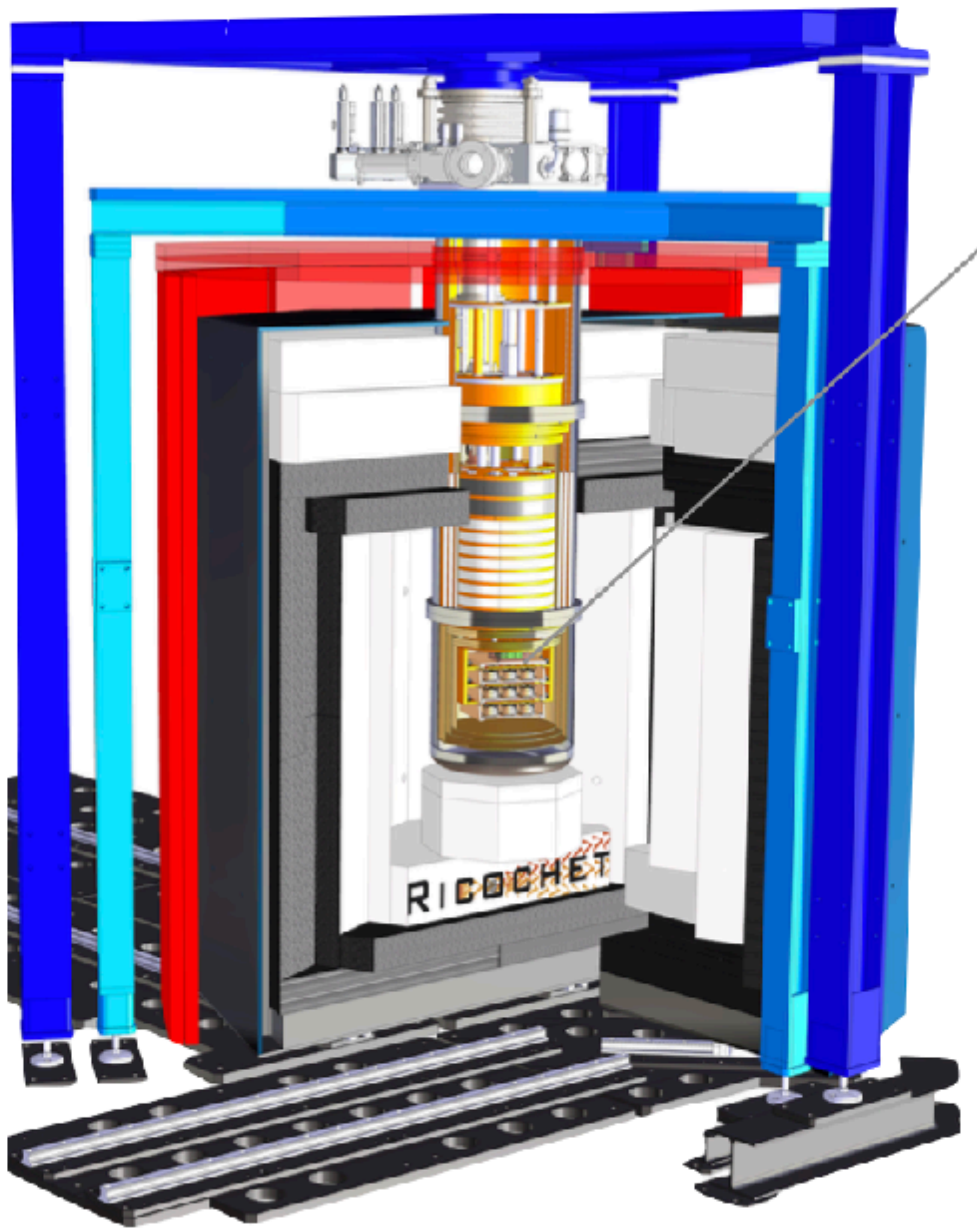
Spectral information improves searches for new physics!

THE RICOCHET EXPERIMENT

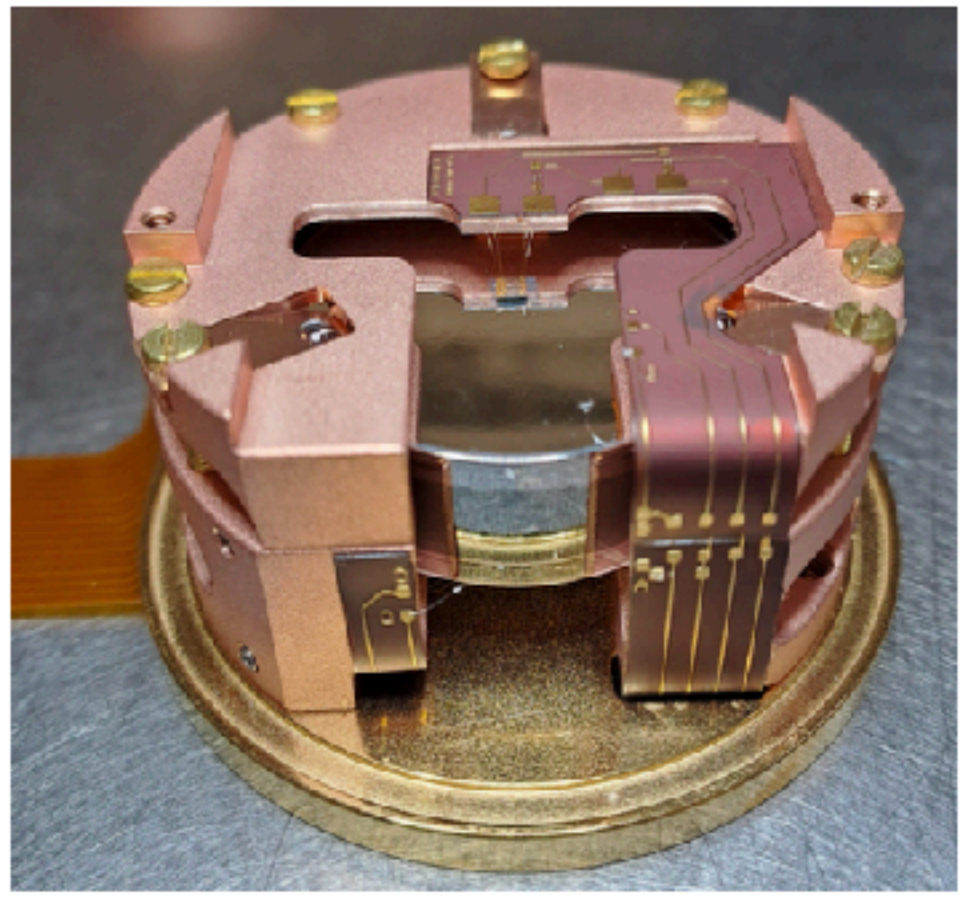


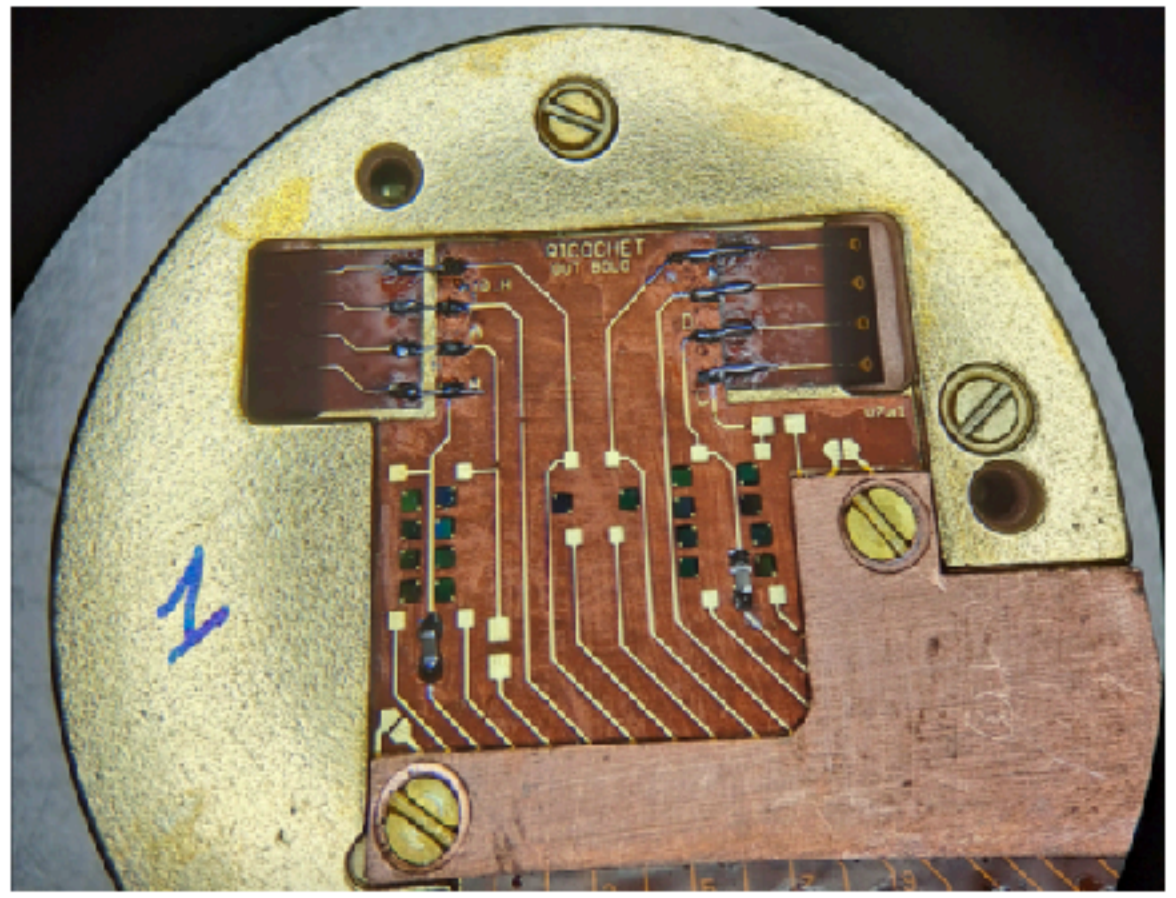


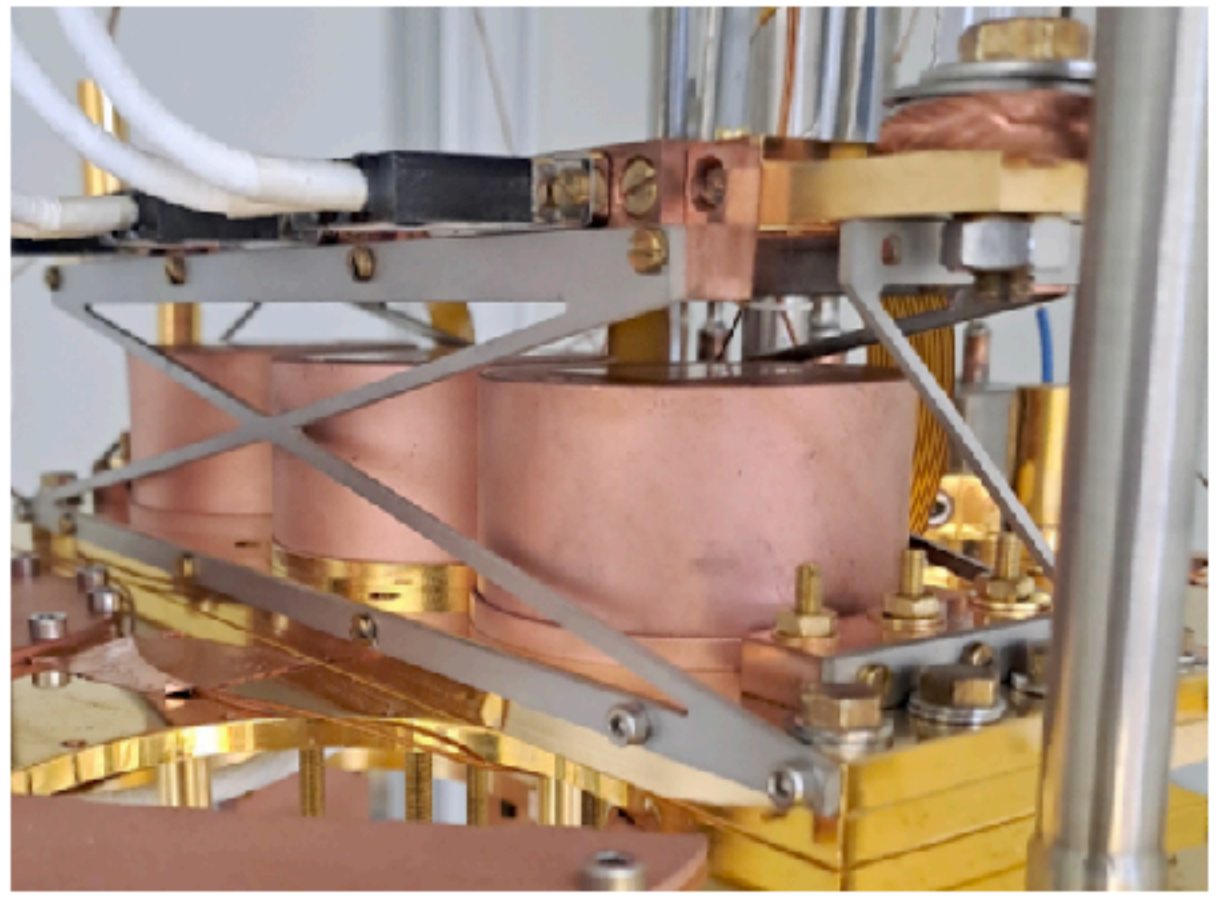
THE RICOCHET ANATOMY - DETECTORS



- 2 technologies planned for CEvNS detection
- Cryocubes:
  - 42-g semiconductor Germanium target
  - simultaneous detection of ionisation and heat
  - 9 detectors currently installed
  - 18 planned for July 2025 (full payload!)







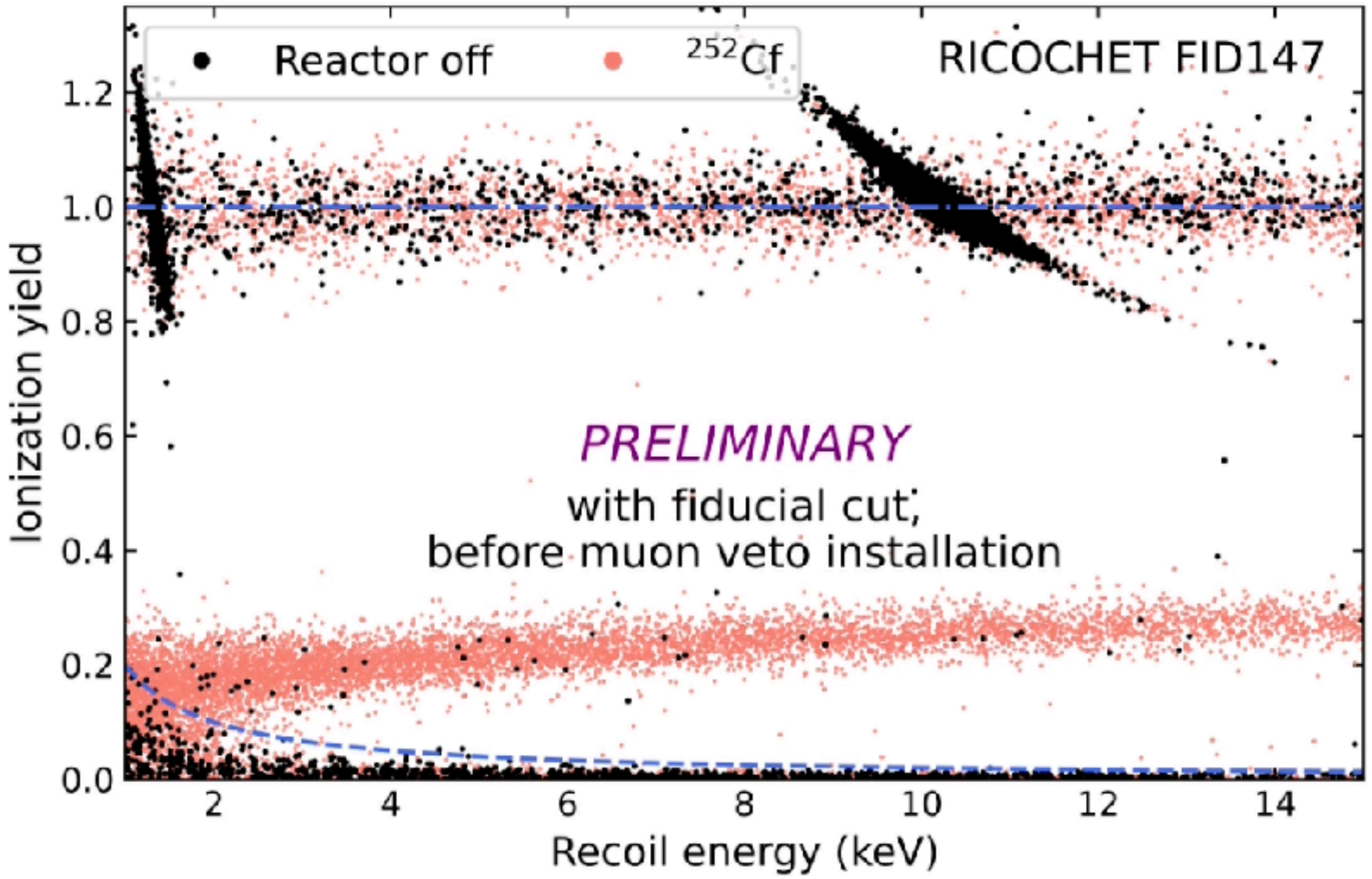
Eur.Phys.J.C 84 (2024) 2, 186 | arxiv:2306.00166

RESULTS FROM COMMISSIONING RUNS

Resolution on fiducial detector FID147 (preliminary)

- Ion channel < 40 eVee
- Heat channel < 30 eVph
- Difference reactor ON/OFF ~ few eV

- Events in FID147 during run-015
- 277h of reactor OFF with 102h of Cf-252 exposition
- **Strong background rejection!**
  Observation of nuclear recoils !



RUNS @ ILL

- RUN013 from February 19th to April 4th, 2024
- RUN014 from May 7th to October 14th, 2024
- RUN015 from January 22th to June 4th, 2025

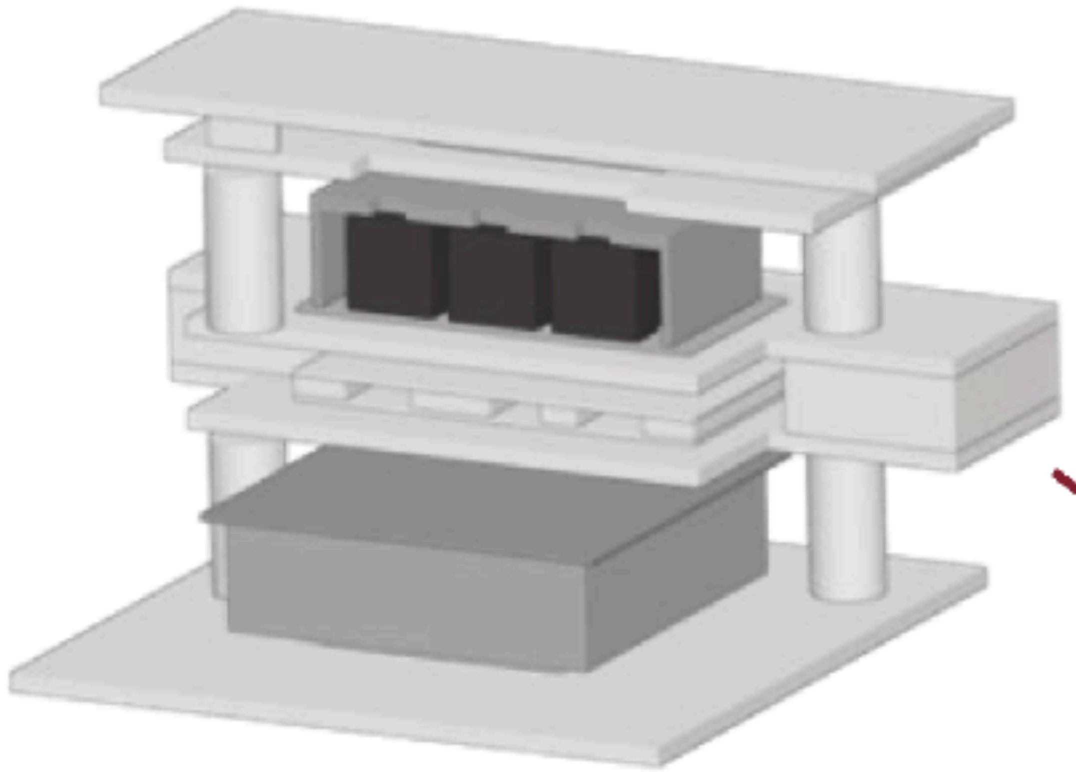
commissioning runs

- RUN016 from July 2025 to end of 2026

18 detectors (planar + FID)

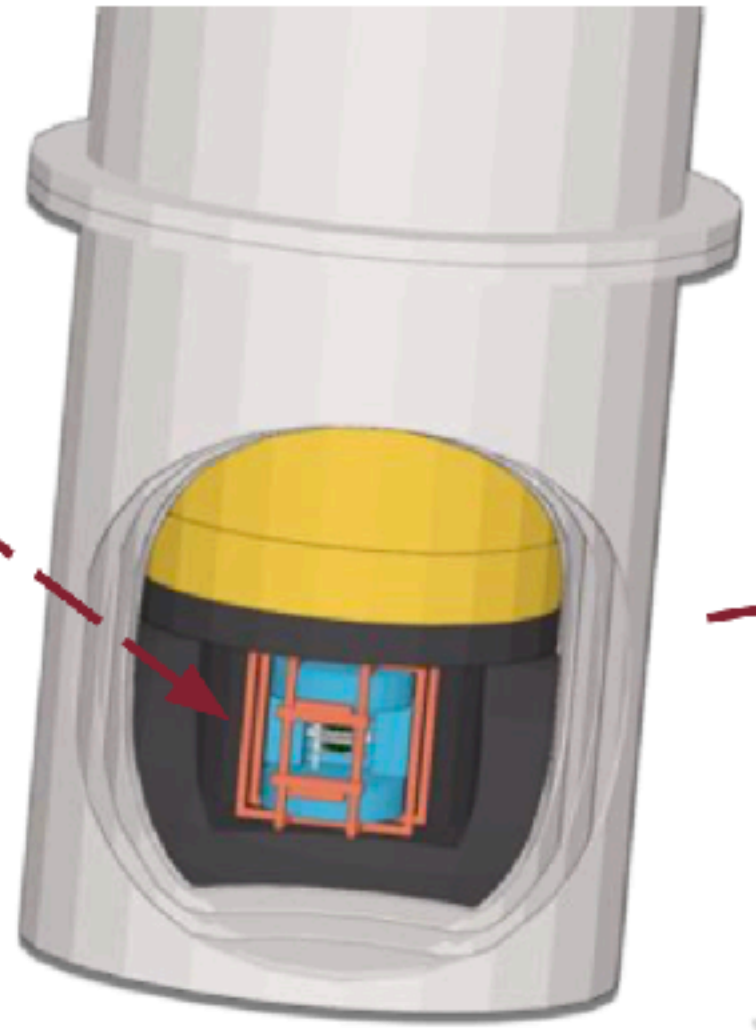
science run starting this Summer!

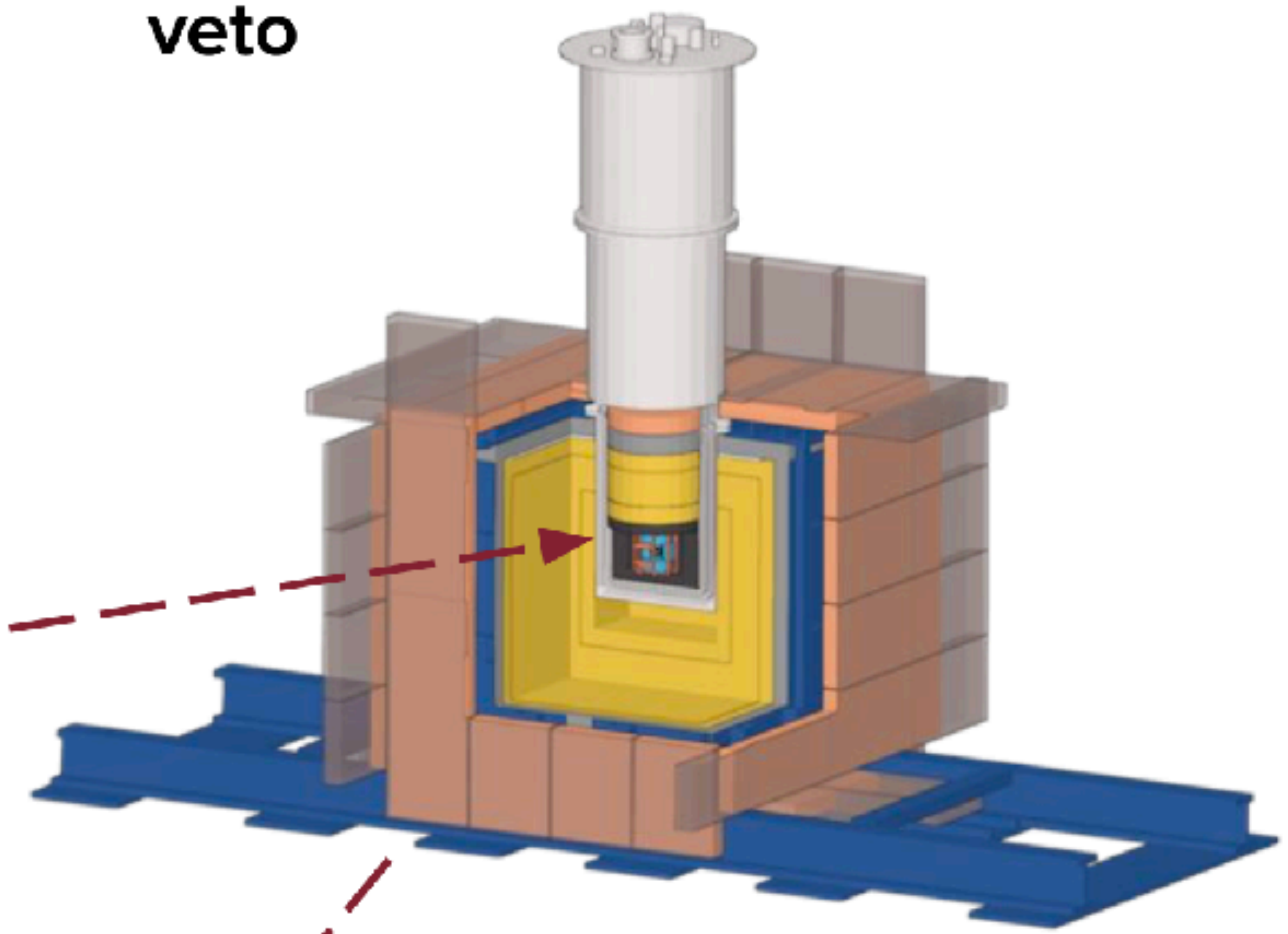
NUCLEUS



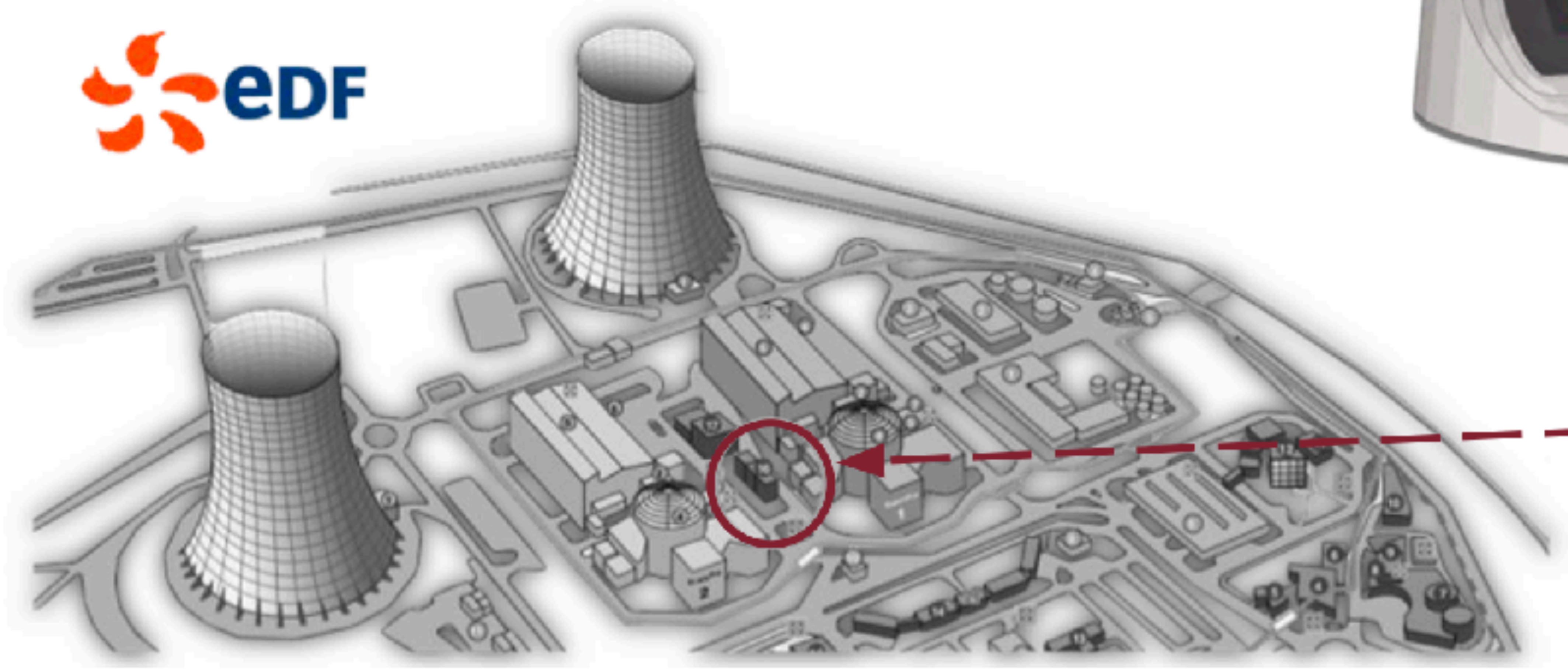
- Cryogenic shieldings of active germanium (COV), B_4C, borated polyethylene, lead and muon veto. Dry dilution refrigerator at O(10 mK)

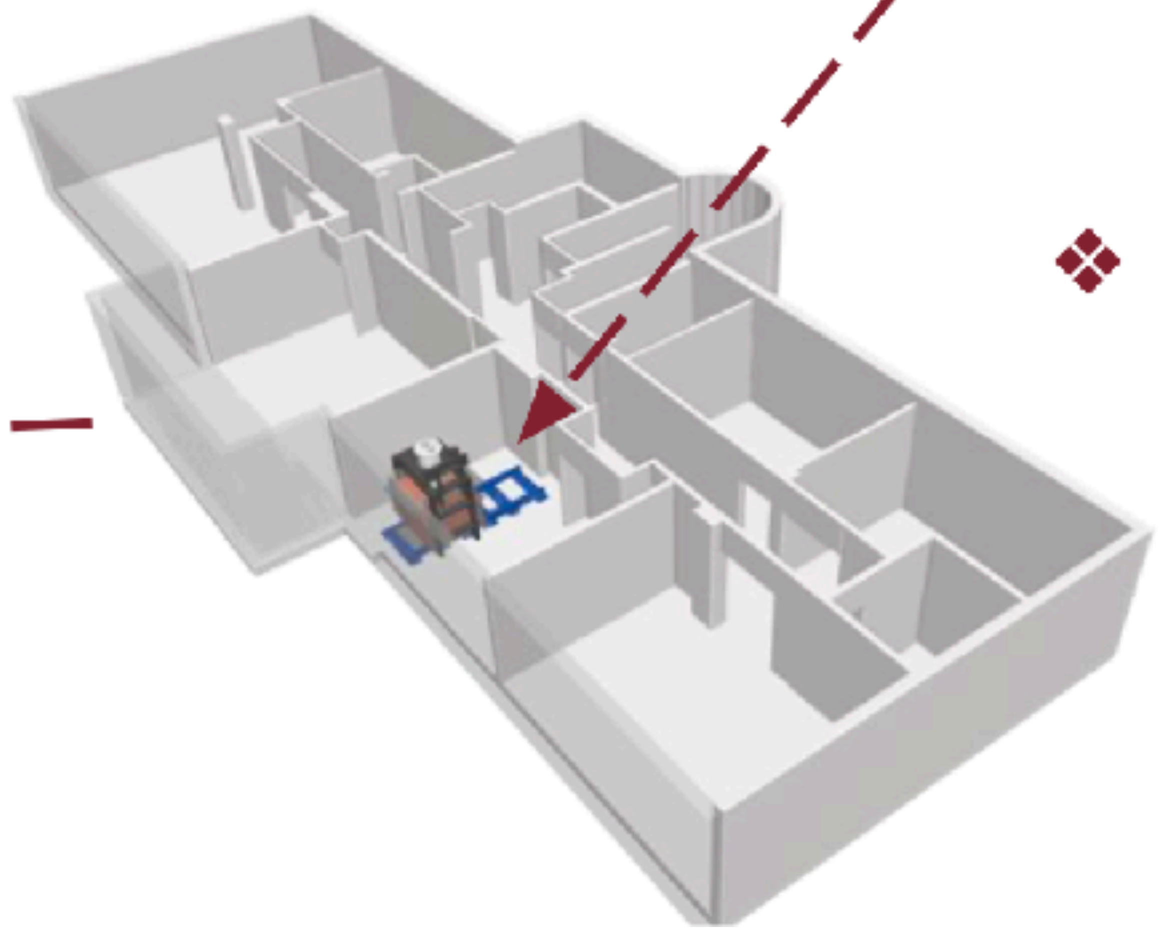
- External shieldings of borated polyethylene, lead and muon veto





- 10 g target detectors of $CaWO_4$ and Al_2O_3 with instrumented holders (inner veto)



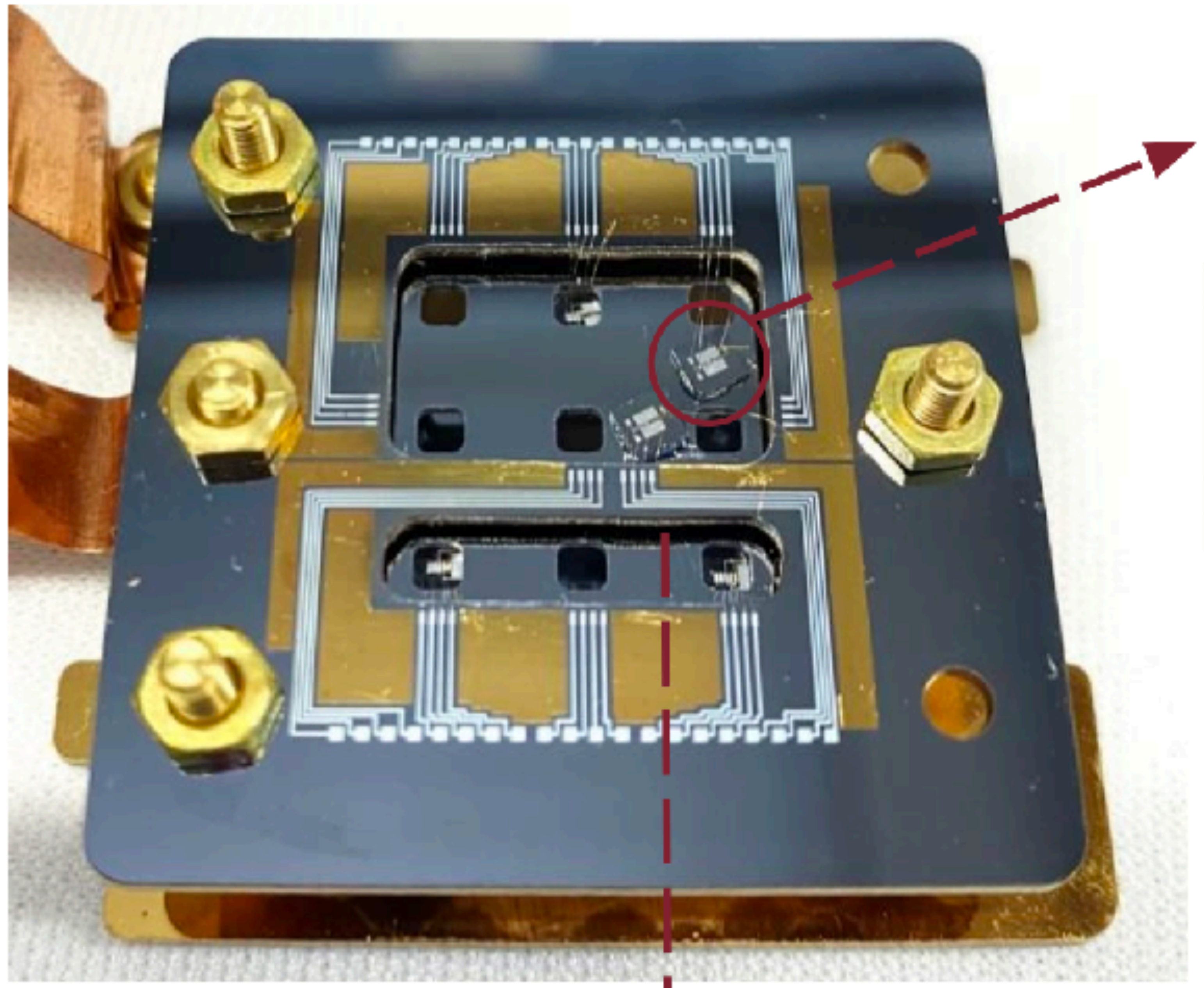


- All setup placed at the "very near site" (VNS) room at Chooz nuclear power plant in France

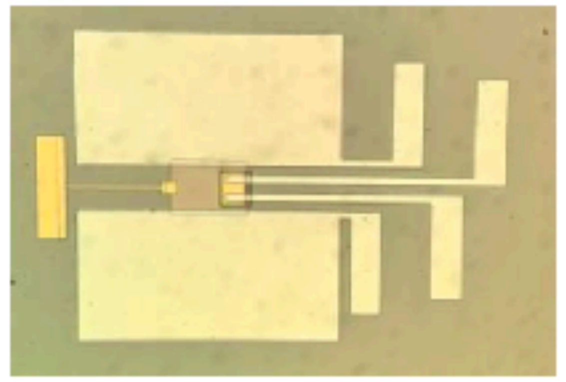
- Antineutrinos from reactor cores

NUCLEUS

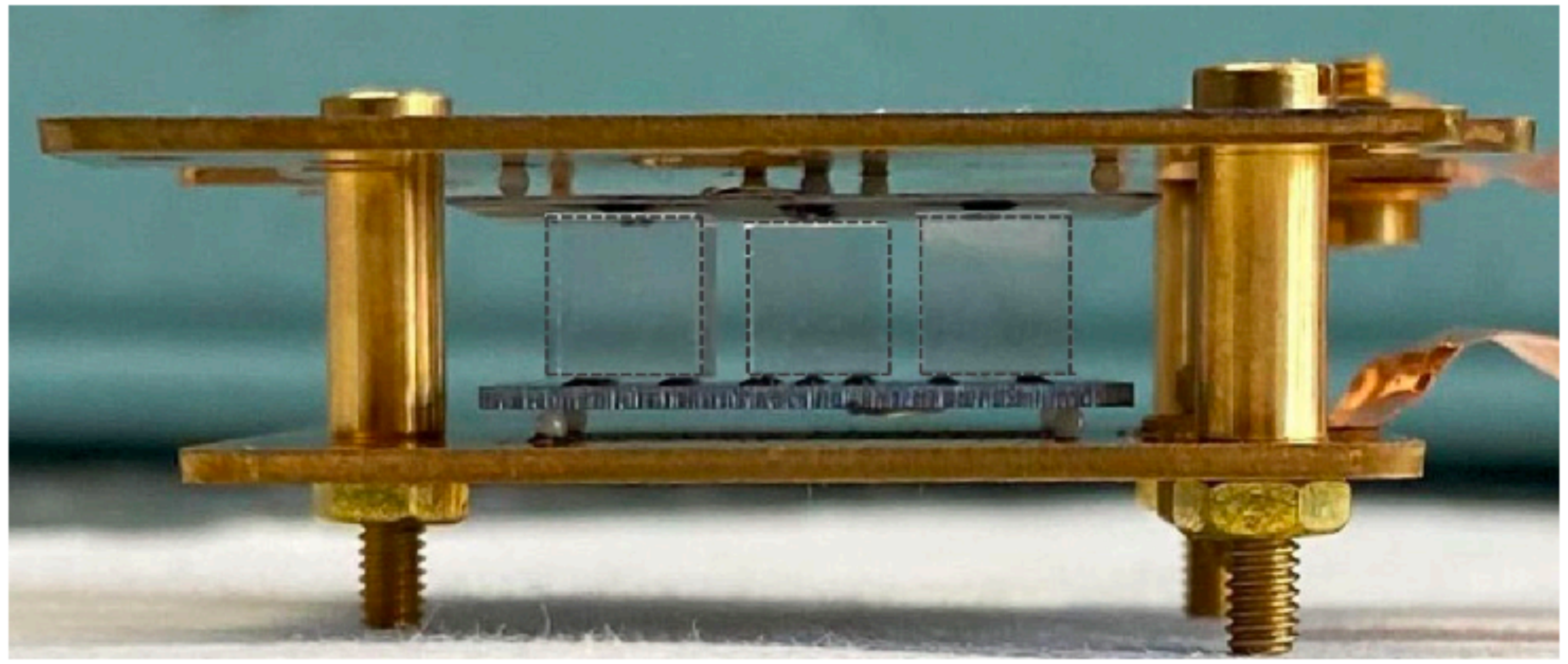
- Silicon wafers with TES detectors as instrumented holders for target crystals
- Reject surface events and mechanical stress induced events



Veto TES on Si carrier

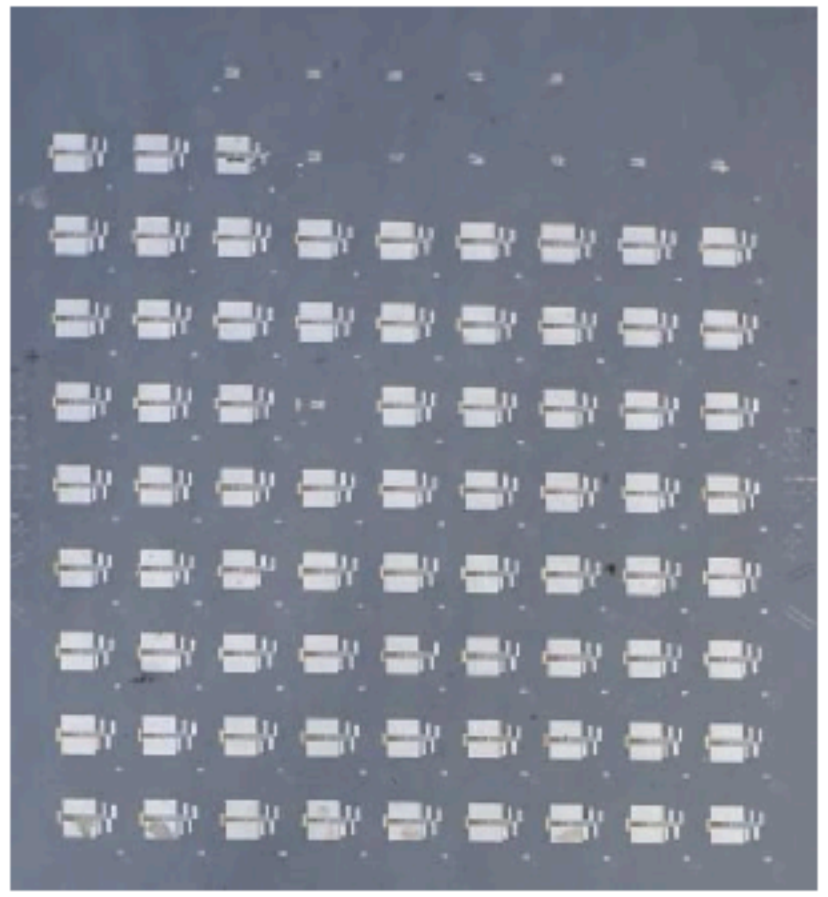


Thick inner veto wafer with pyramids for crystal-silicon interface (low phonon dispersion)

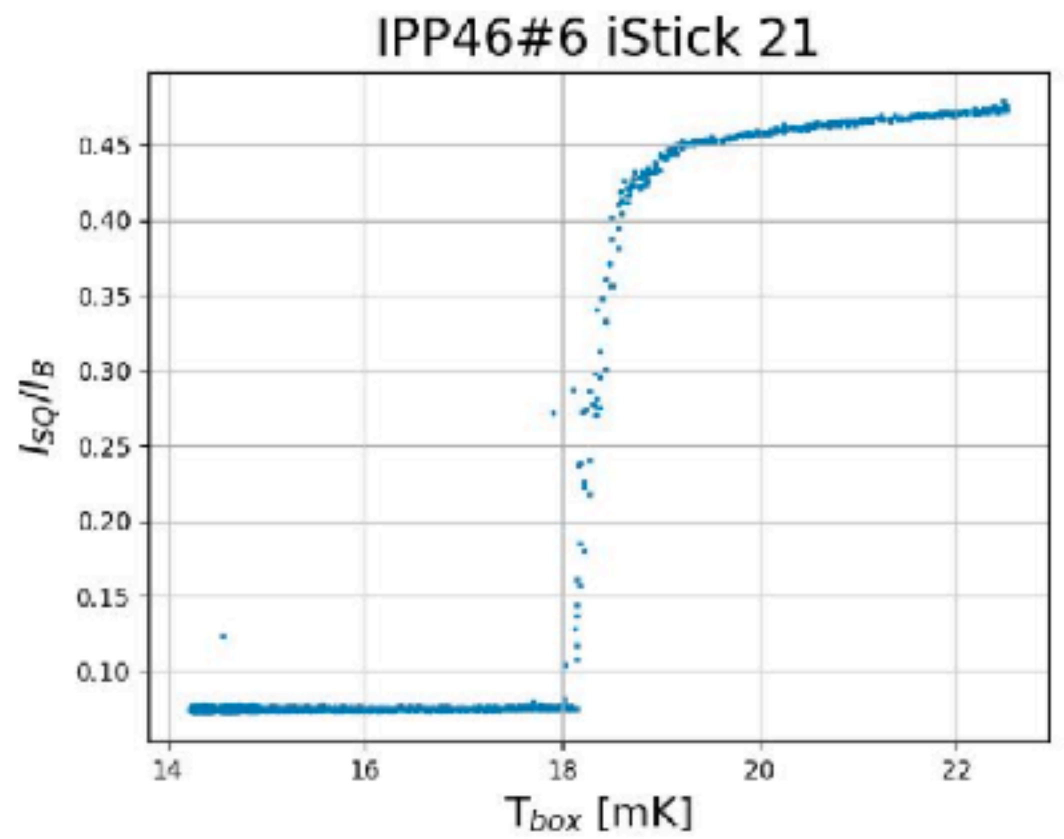


Cubes in inner veto module

- Operation of cubes in the inner veto module demonstrated, currently optimization of the veto TES



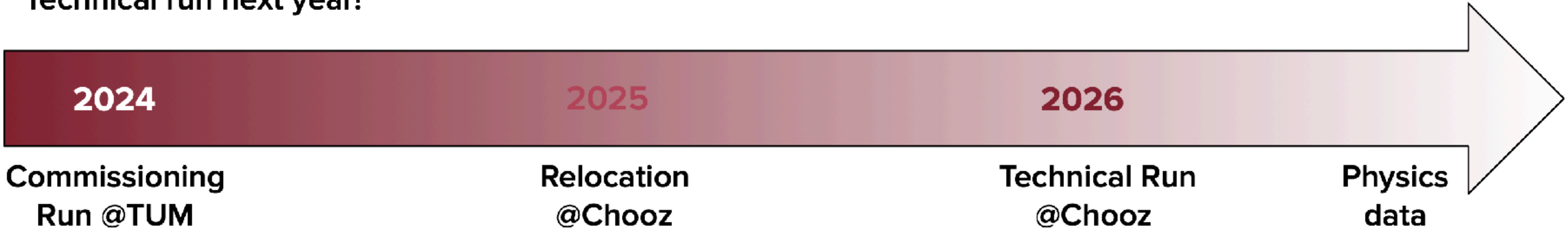
TES on Si wafer



TES transition curve (T_c ~18 mK)

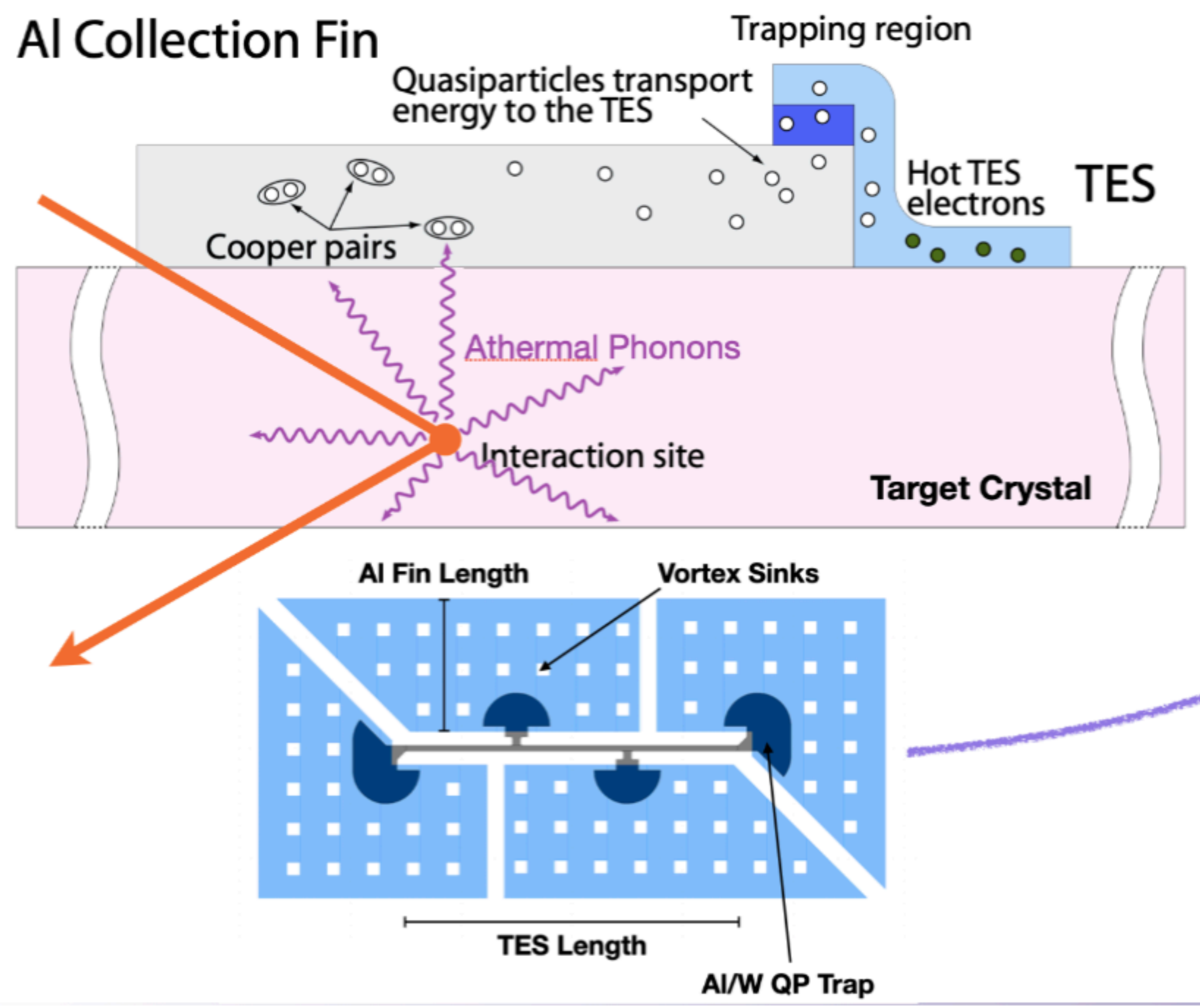
NUCLEUS

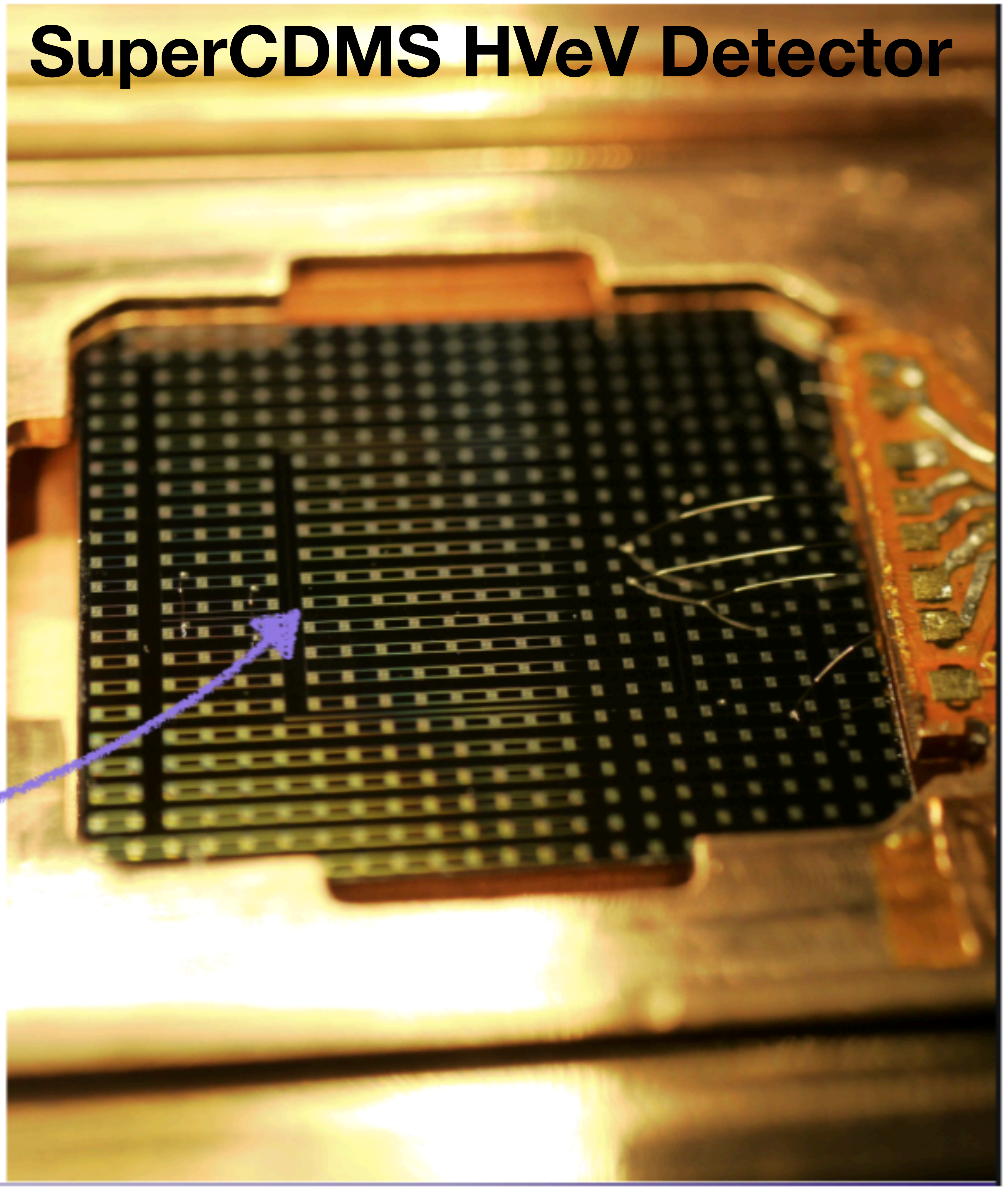
- NUCLEUS will exploit sensitive cryogenic calorimeters and extensive shielding techniques to measure CEνNS at reactors
- New Milestone: Commissioning Run @TUM proved the feasibility of the experiment and demonstrated stable operation over longer timescales
- New results on low energy excess and validation of simulation from the Commissioning Run
- Detector upgrade and relocation @Chooz right now!
- Technical run next year!



HONEYCOMB

The HOdoscopic Neutrino-EnergY CryOgenic Multiplexed Bolometer

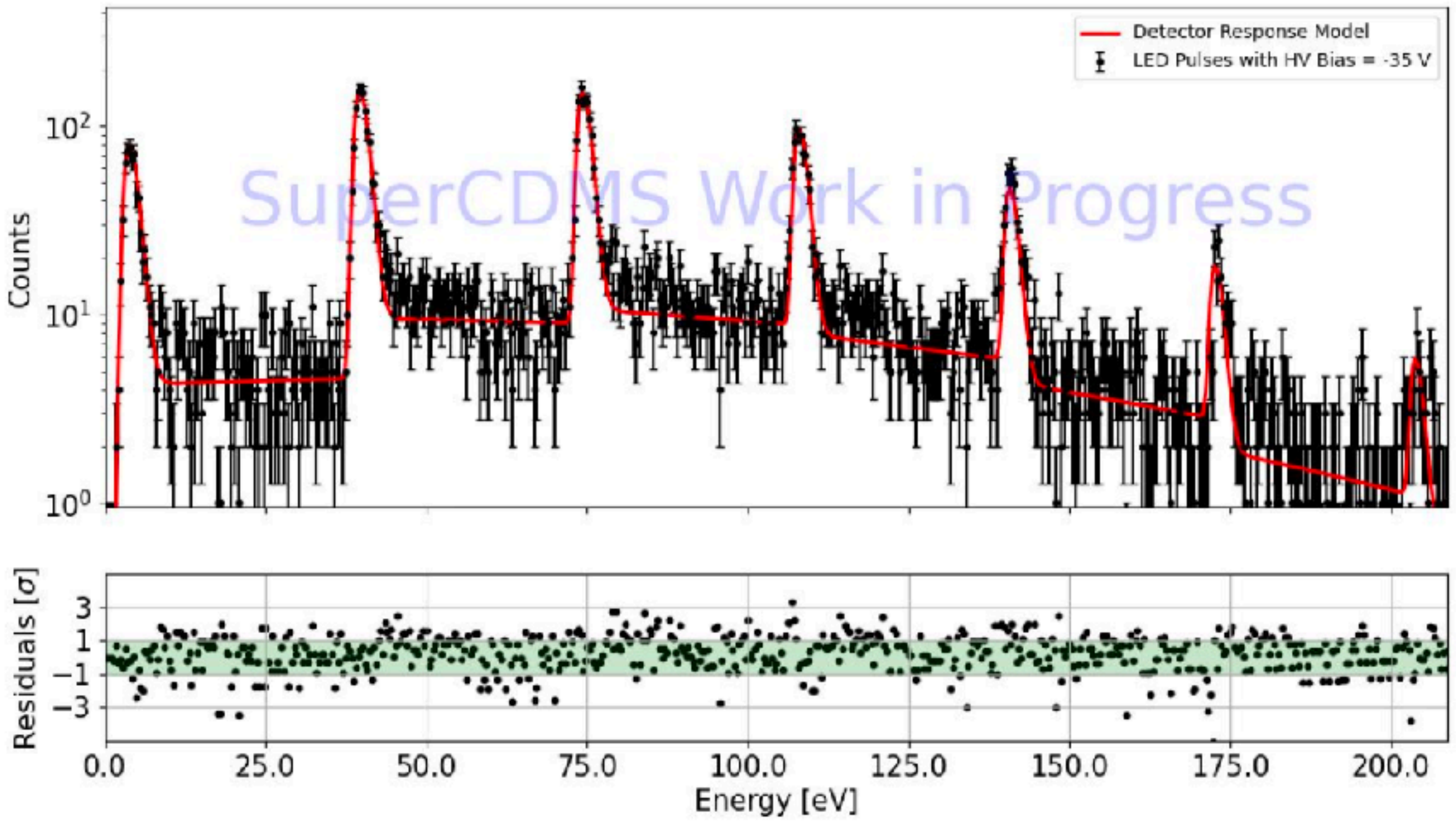




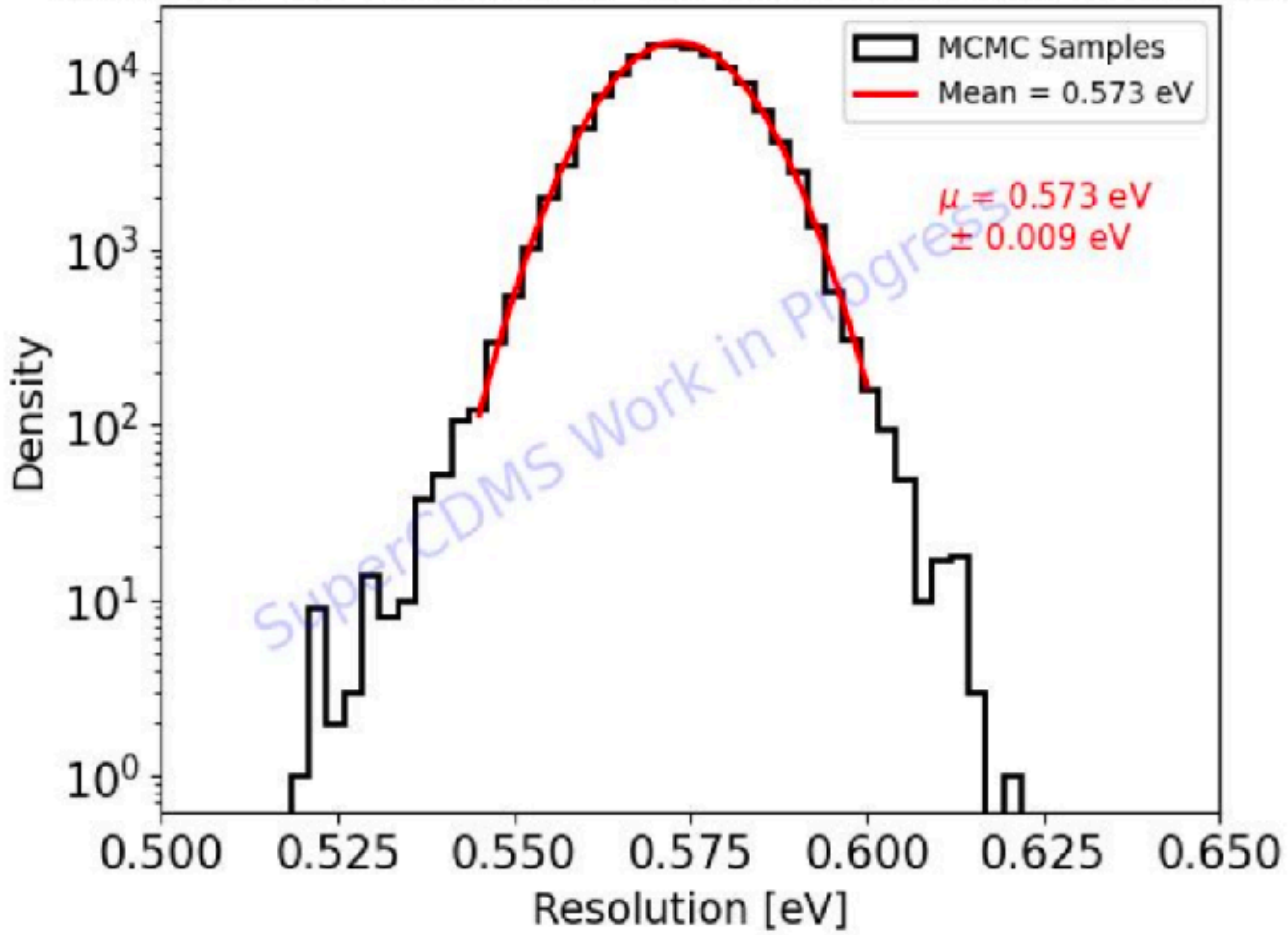
HONEYCOMB

SiO_2 HVeV achieved **0.573 eV baseline resolution!**

Detector response model fit to LED calibration data

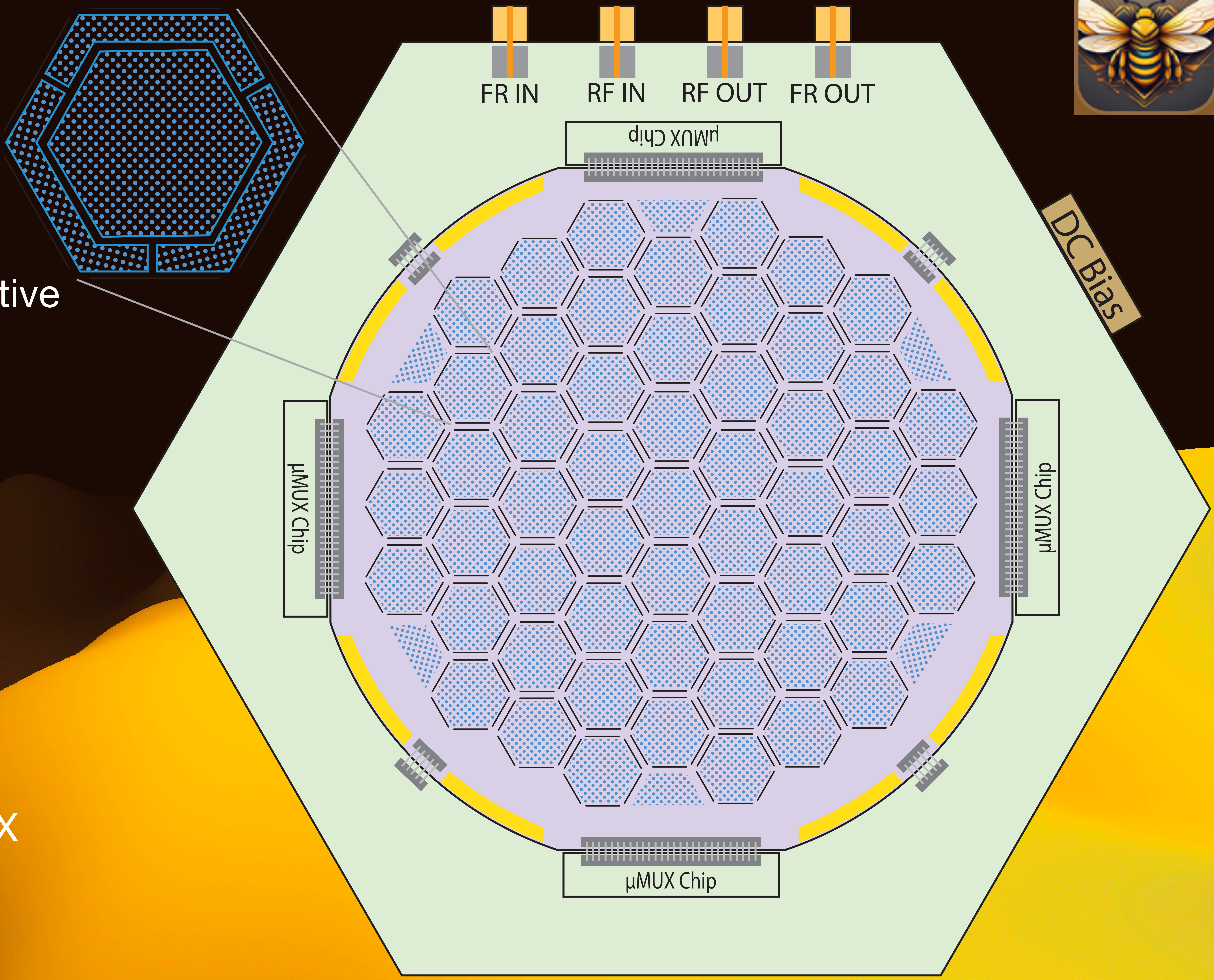


Sample of the posterior of the resolution from MCMC chain



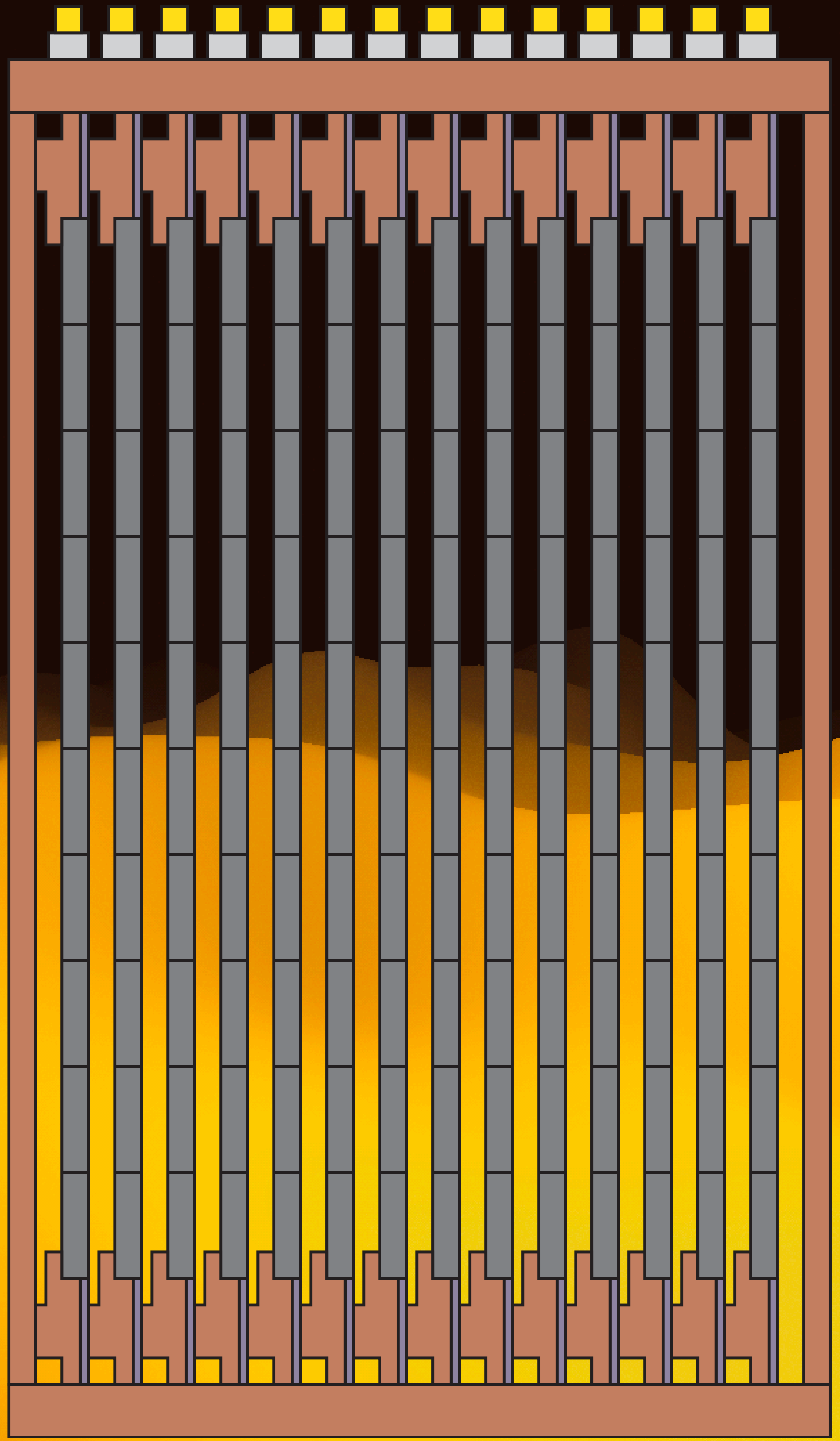
HONEYCOMB

- Scaling up HVeV concept
- A few grams each
- “Dicing” wafer with Deep Reactive Ion Etching trenches
- Leave a small “bridge” for thermal conduction
- Smooth dicing reduces sidewall charge injection
- Stress-free mounting, hope to reduce/remove low energy excess
- Multiplexing readout with uMUX
- With multi-stage cryogenic amplifiers



HONEYCOMB

- Stacking multiple wafers for 1 kg payload
- Aiming for eV level threshold for 10x improvement, access to full reactor spectrum
- Multiple chips serve as active veto for each other (Hodoscope)
- Multiplexed readout of 3000+ detectors



Conclusions

- Reactor experiments have finally put a point on the CEvNS board! (congrats CONUS+!)
- The next frontier is precision measurements of the CEvNS spectrum, and that requires < 100 eVnr thresholds
- Cryogenic phonon detectors are operating right now at reactors and science runs at Ricochet have begun.
- New technologies are being brought to bear, and we can look forward to future percent-precision measurements of CEvNS spectra and searches for new physics!