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SFB 1258



Status and recent developments of the NUCLEUS experiment

Lorenzo Valla, on behalf of the NUCLEUS collaboration

ÖPG-CMD-Graz2026

22.09.2026

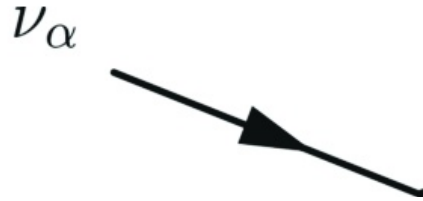
What is Coherent Elastic neutrino-Nucleus Scattering (CEvNS)?

CEvNS

CE ν NS

Neutrino

CE ν NS



Neutrino

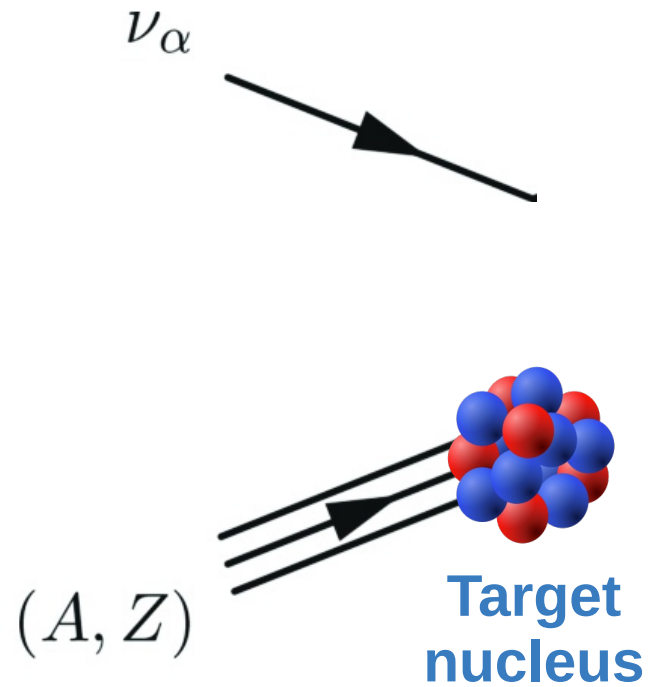
CE ν NS



Neutrino

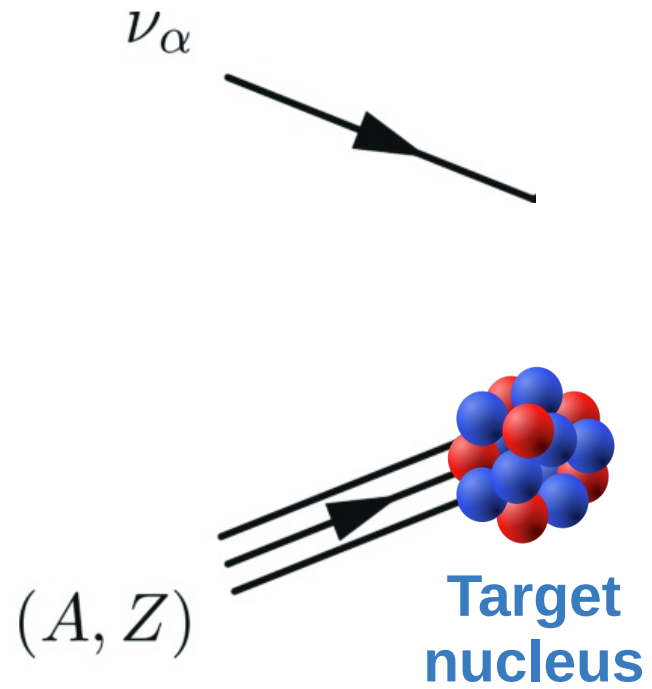
Nucleus

CEvNS



Neutrino
Nucleus

CEvNS

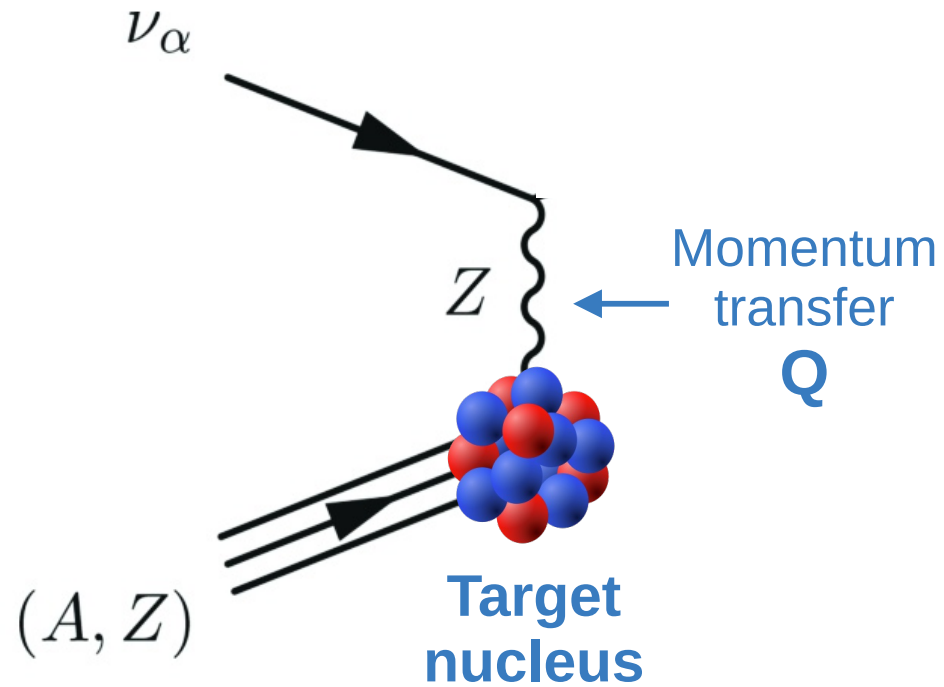


Neutrino

Nucleus

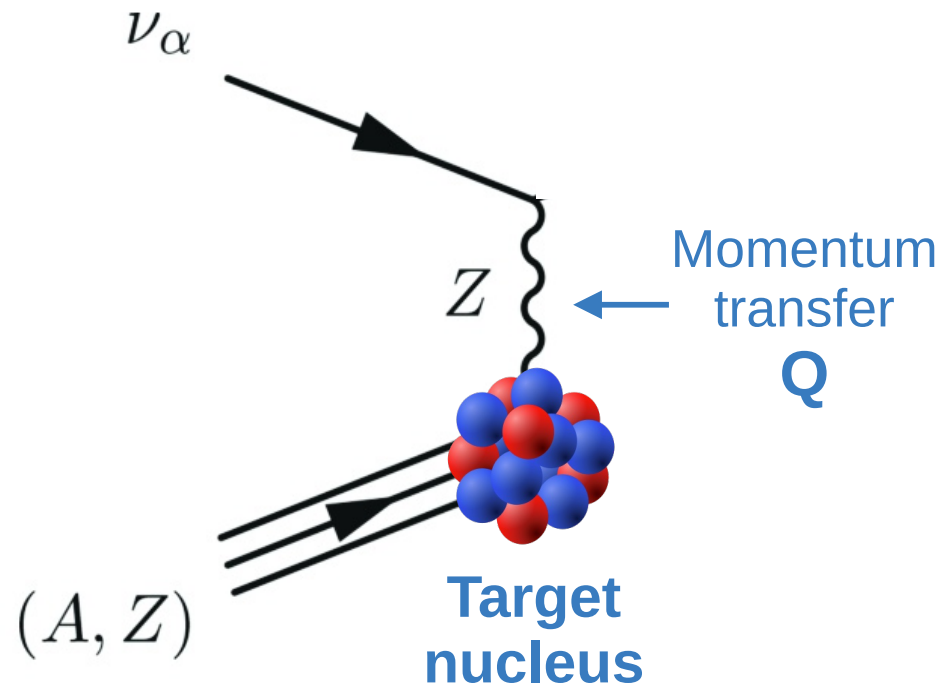
Scattering

CEvNS



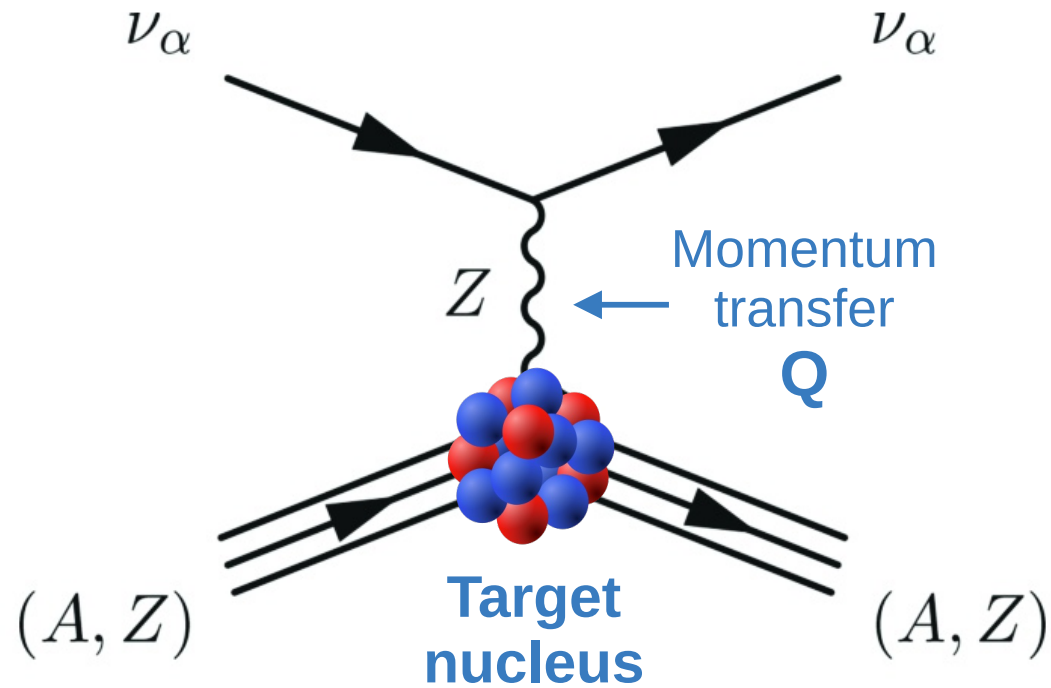
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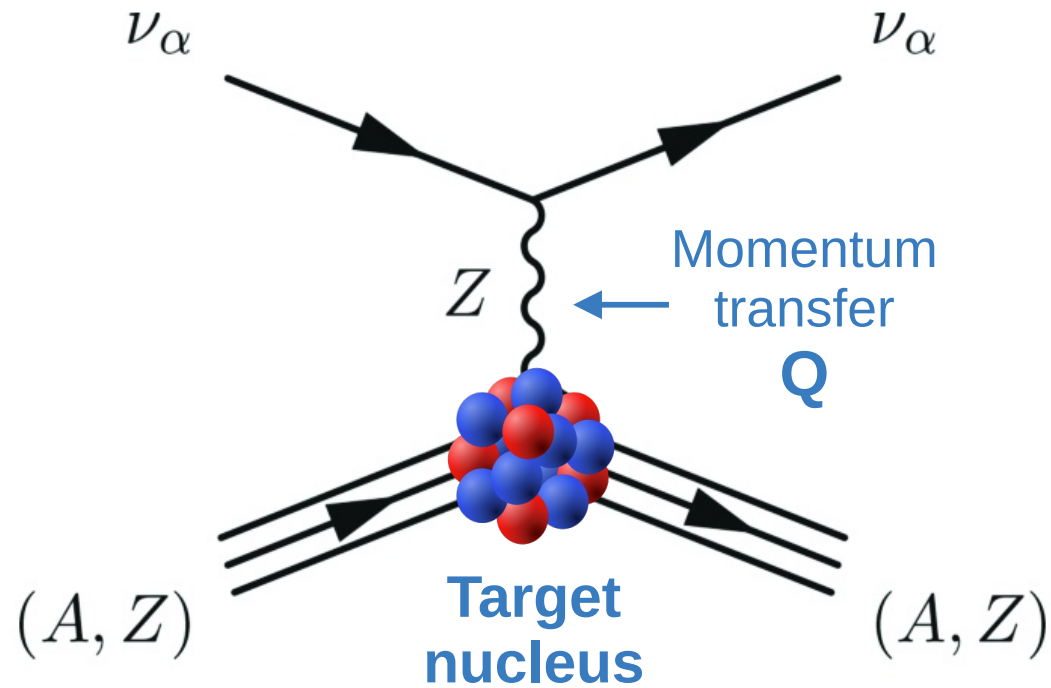
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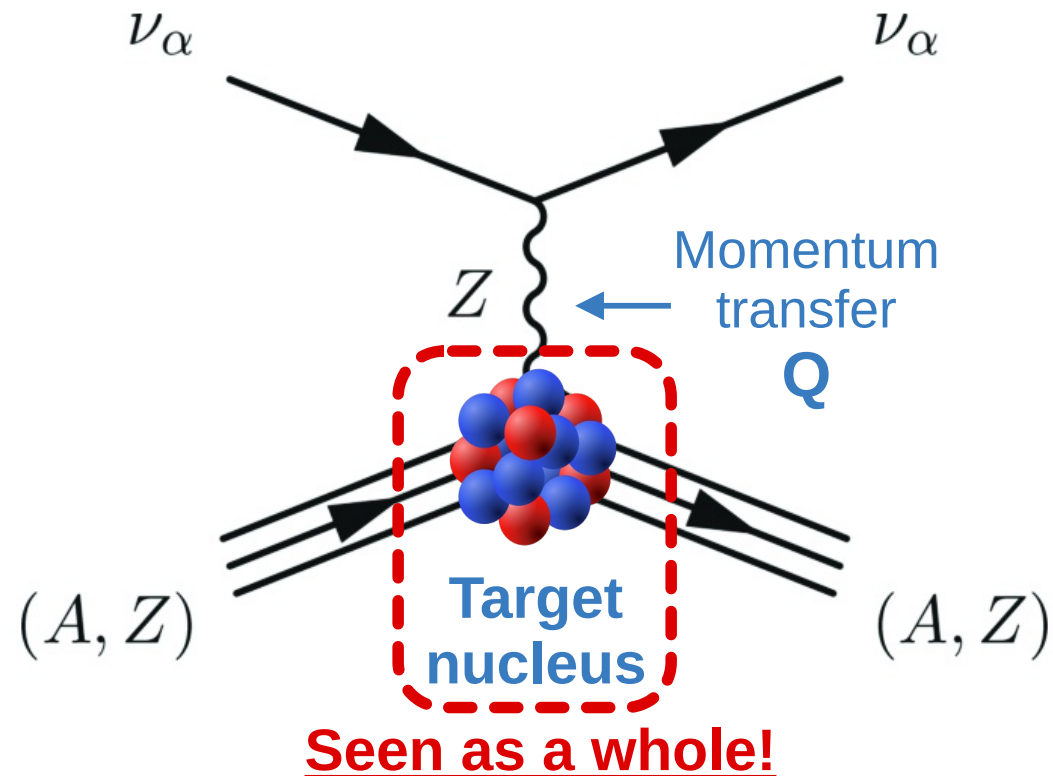
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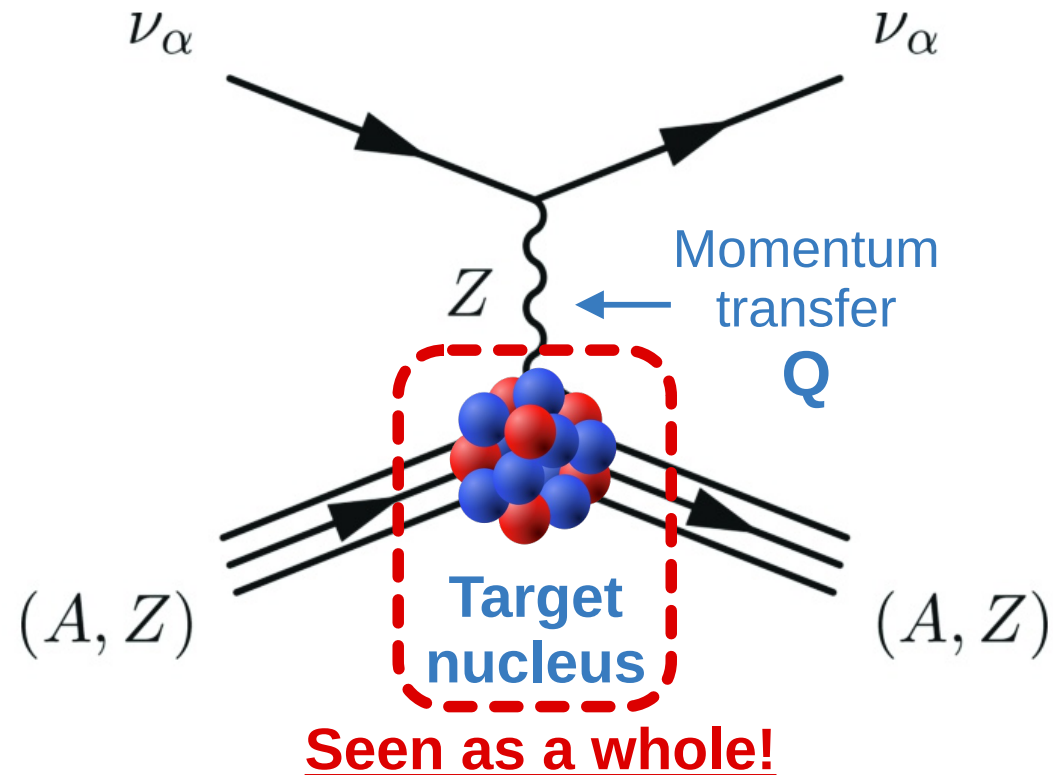
Coherent
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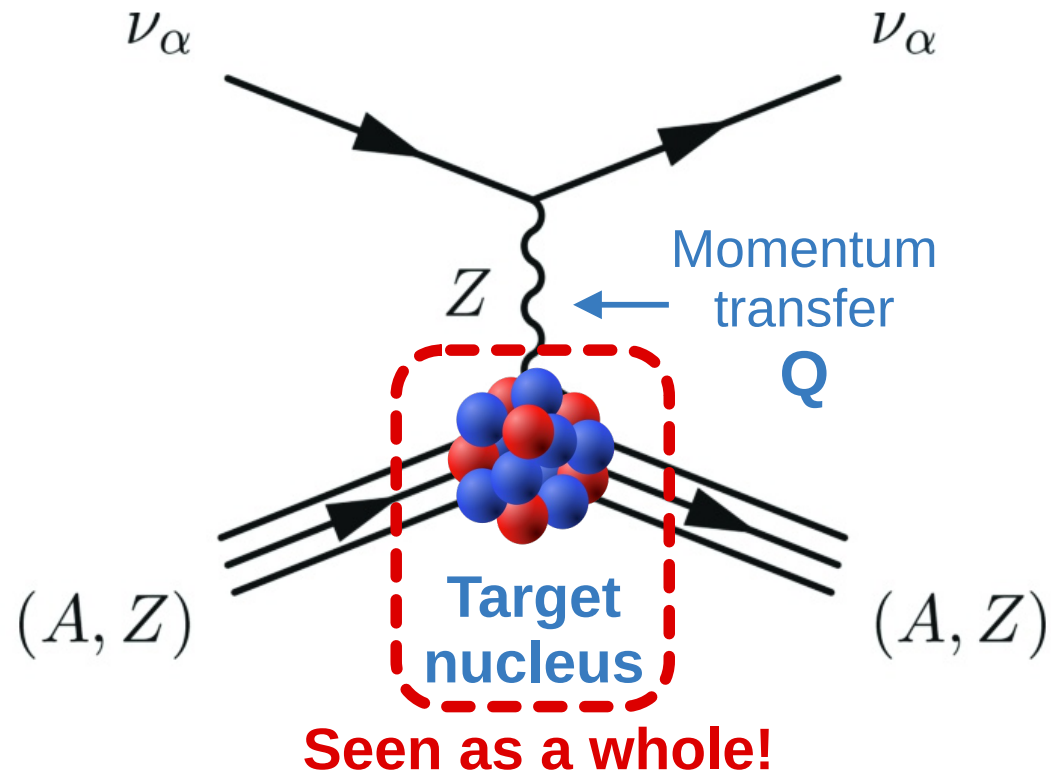


Coherent
Elastic
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Nucleus
Scattering

- ❖ Standard Model weak neutral current, flavor-blind process



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Coherence condition

$$\lambda(Q) \gtrsim 2R$$

Z-boson
wavelength

Nucleus'
size

i.e. **$E_\nu \lesssim 50 \text{ MeV}$**

I. CEvNS properties



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❖ Signature: **nuclear recoil**

I. CEvNS properties



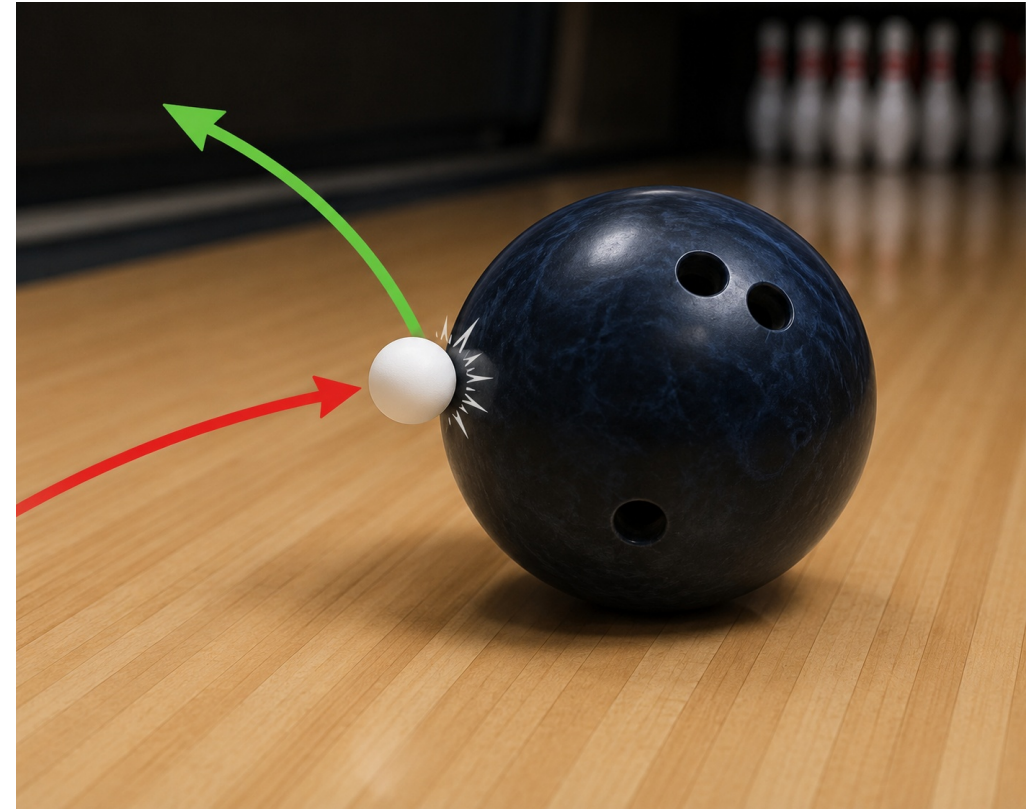
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$$T_{max} \approx 2E_\nu^2/M$$

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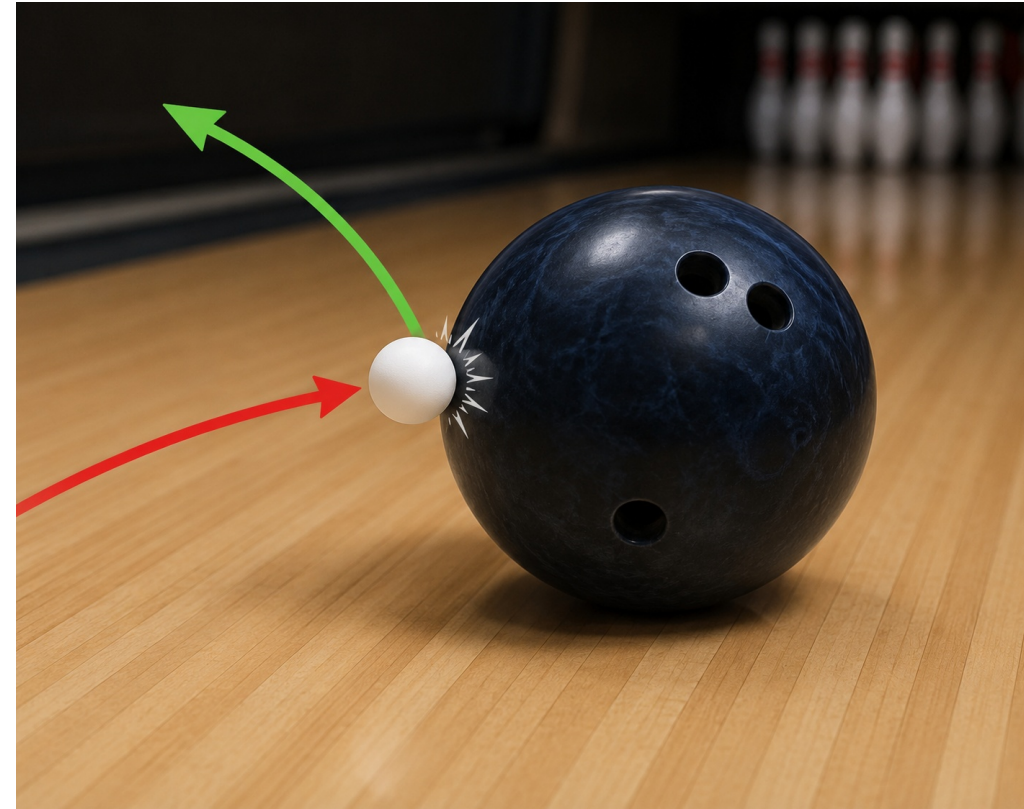


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eV-keV recoils!



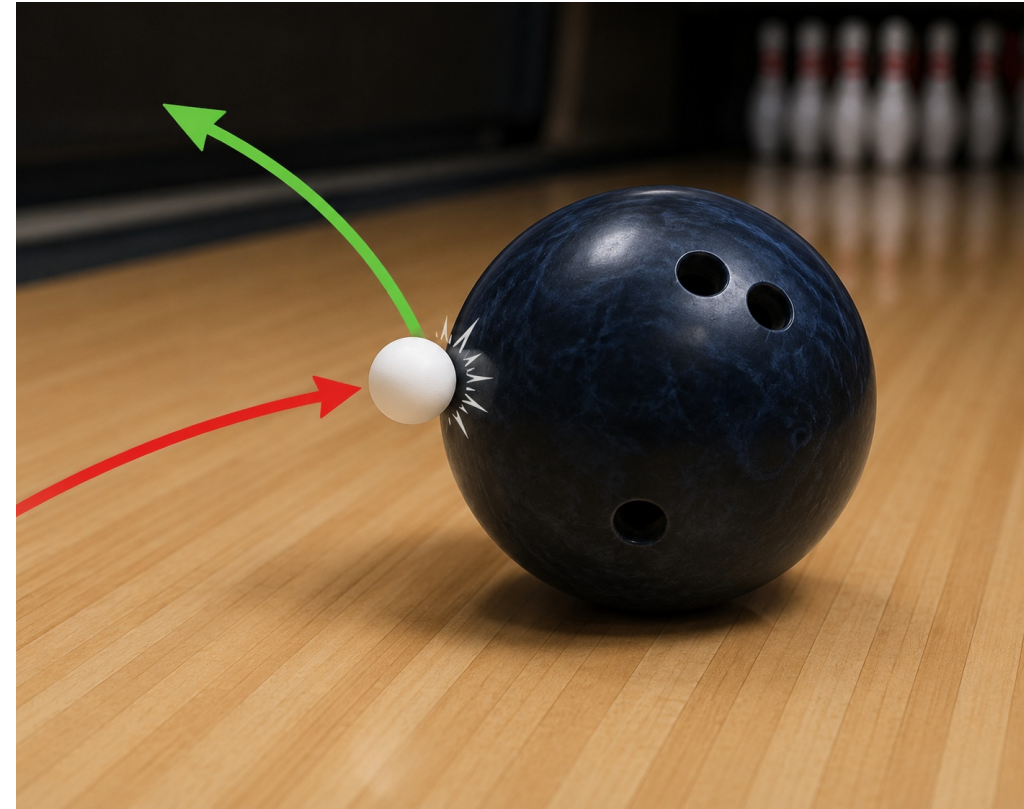
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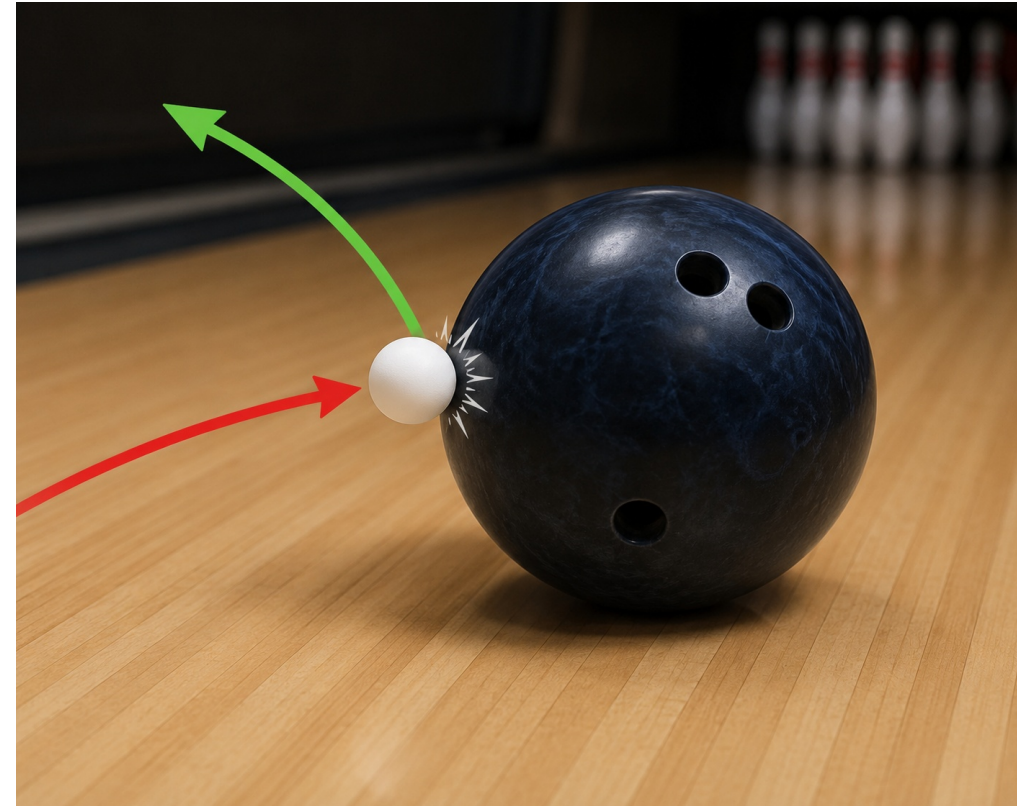
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- ❖ No energy threshold



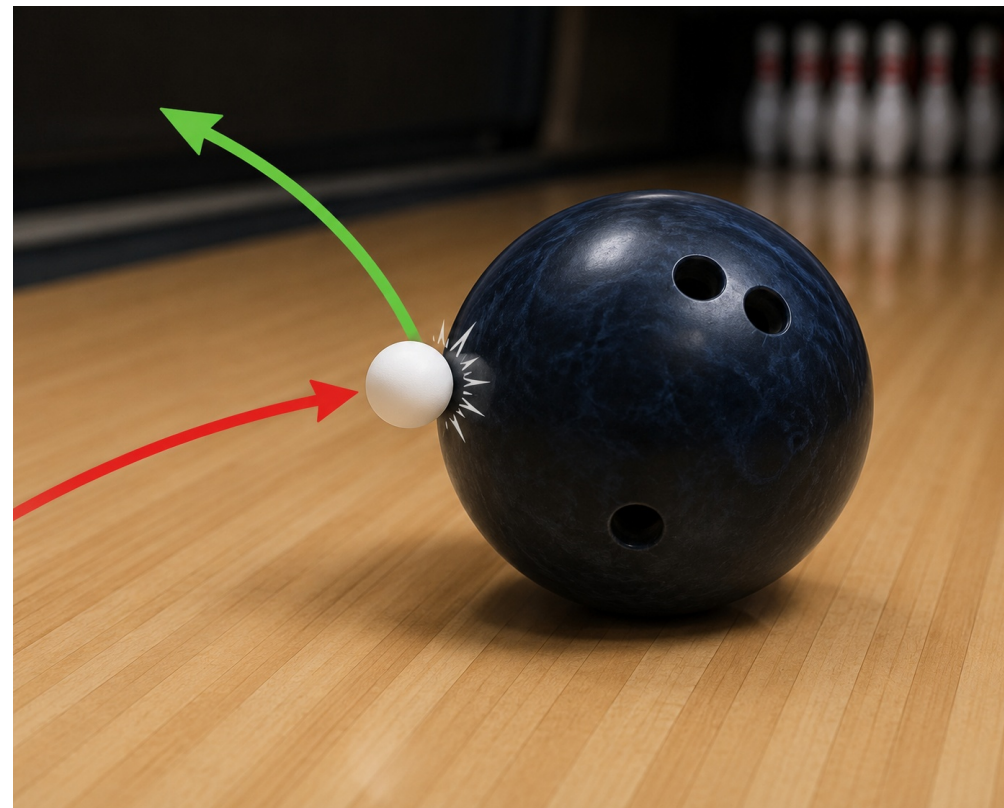
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eV-keV recoils!

But...

- ❖ No energy threshold
- ❖ Cross section **orders of magnitude larger** than other neutrino interactions!



I. CEvNS - Experimental detection status



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Neutrino source	Energy
π DAR	Up to 50 MeV
Solar	< 10 MeV
Reactor	< 10 MeV

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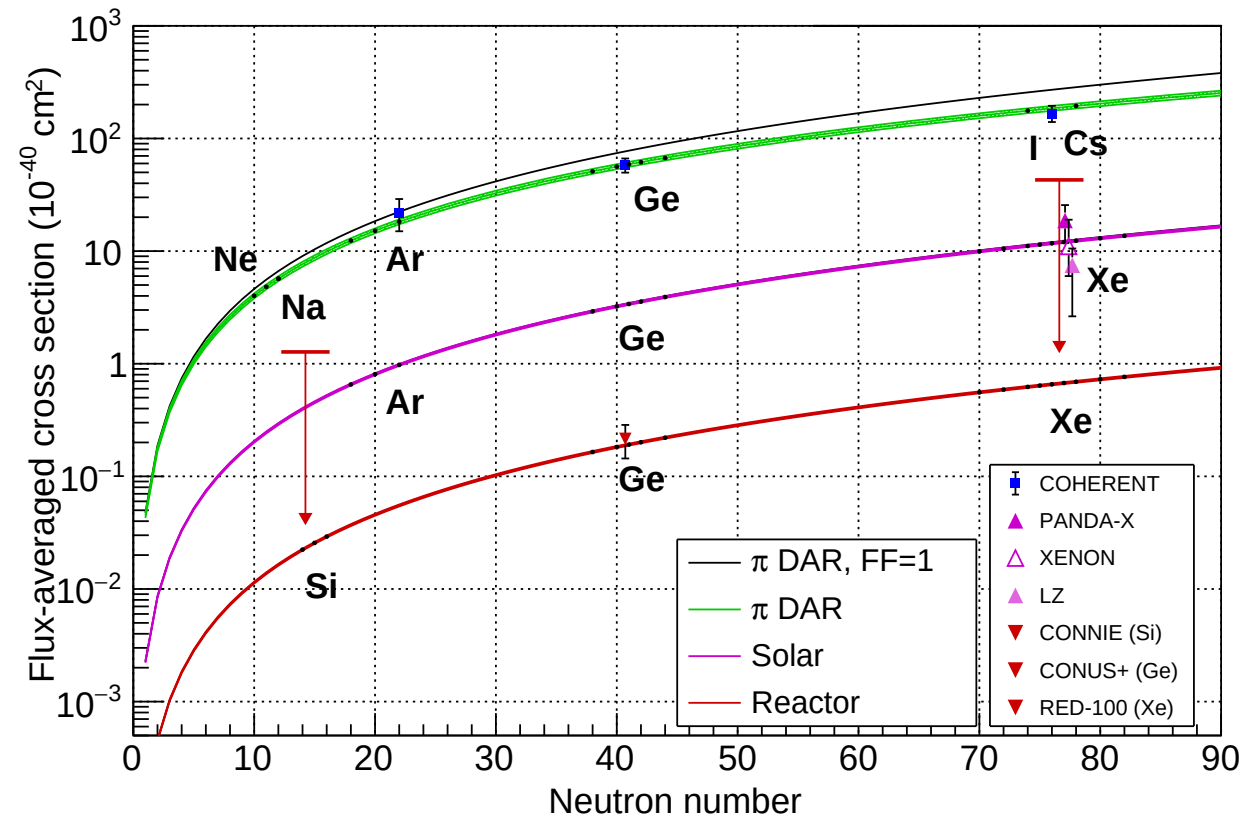
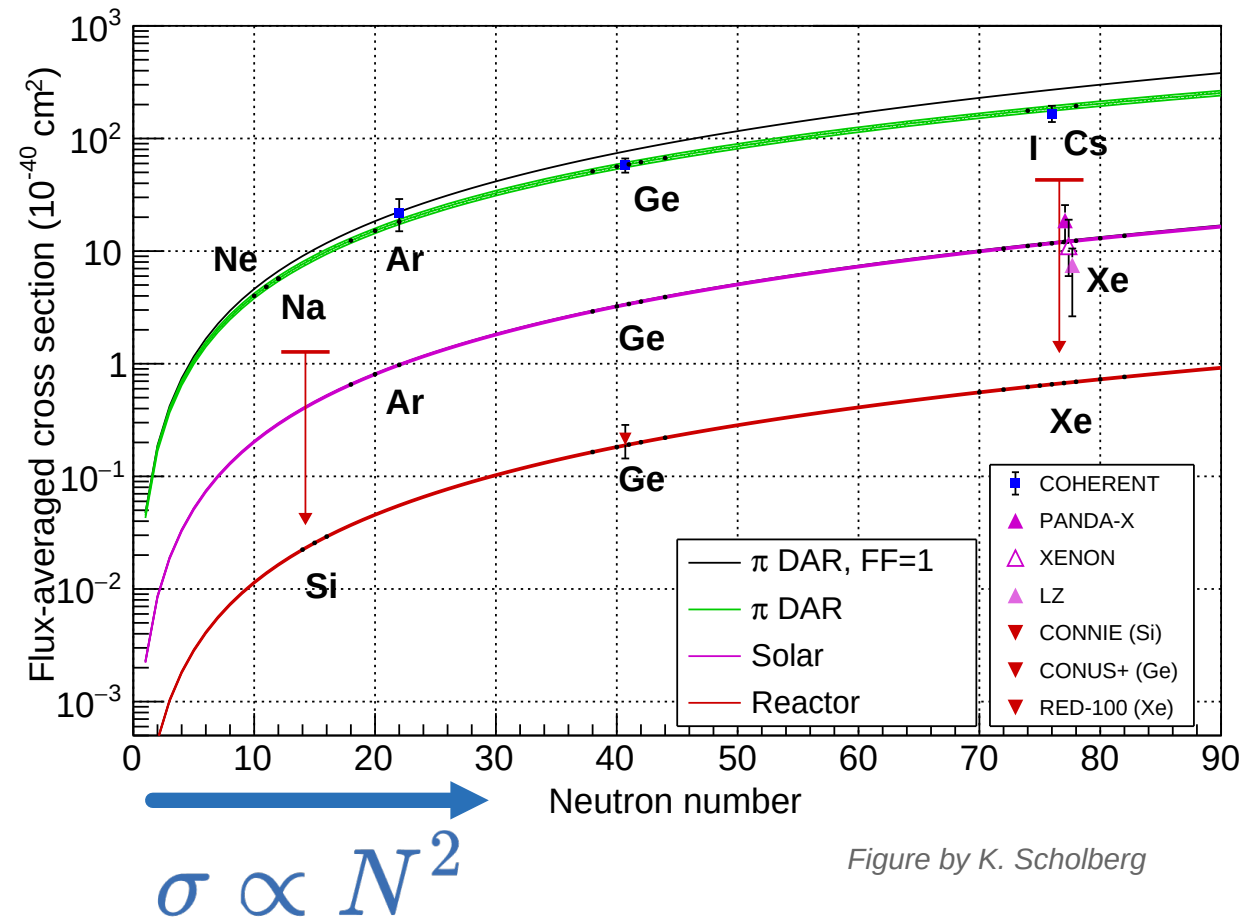


Figure by K. Scholberg

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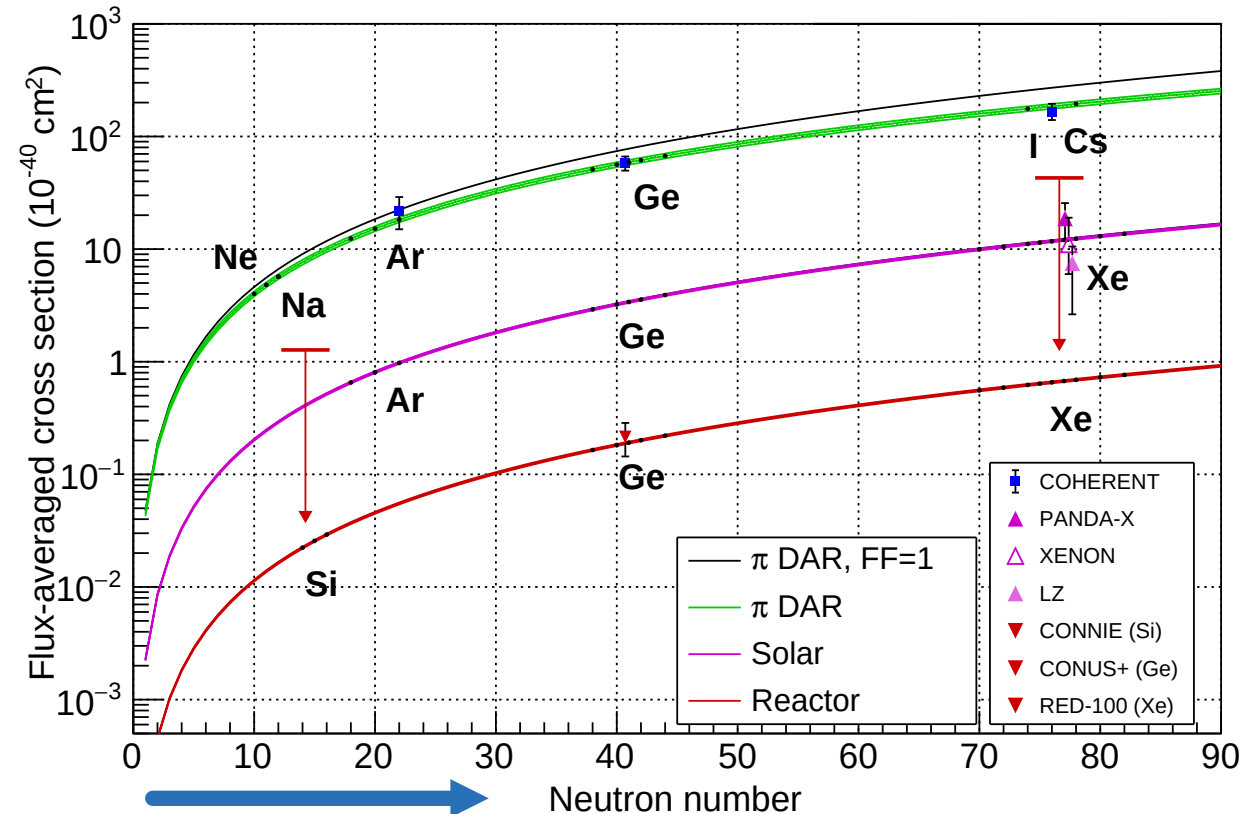
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$$\sigma \propto E_\nu^2$$



$$\sigma \propto N^2$$

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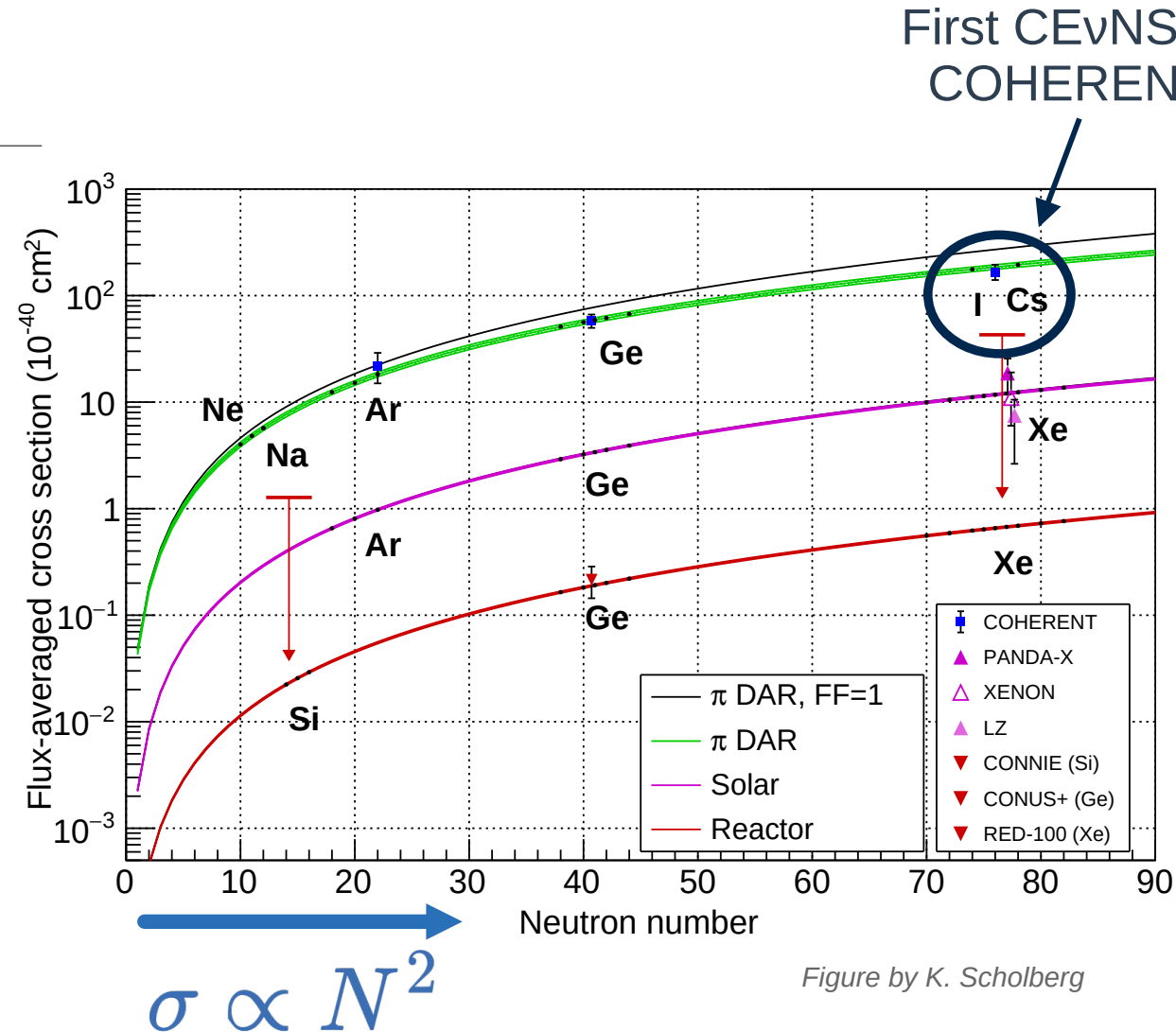
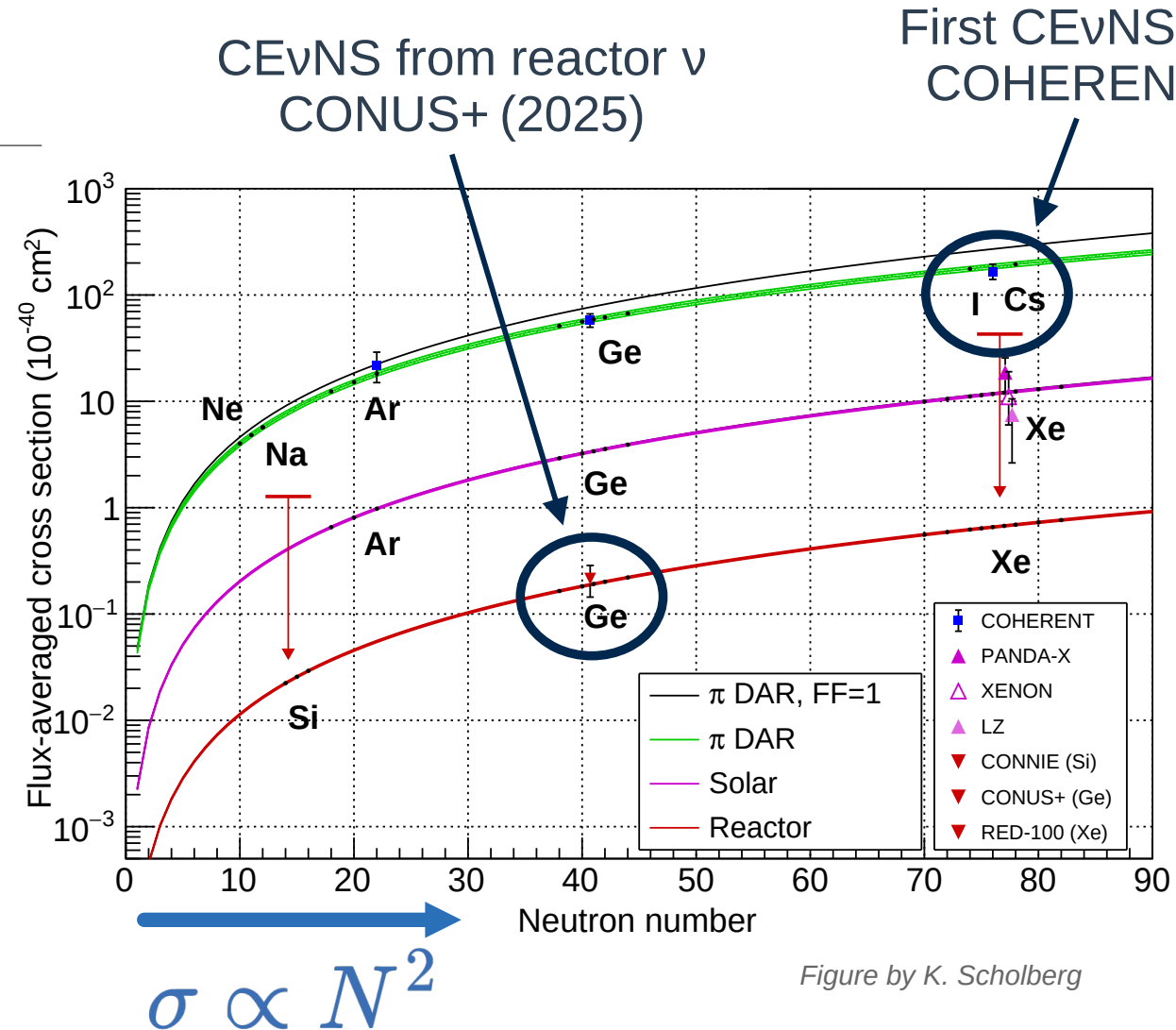


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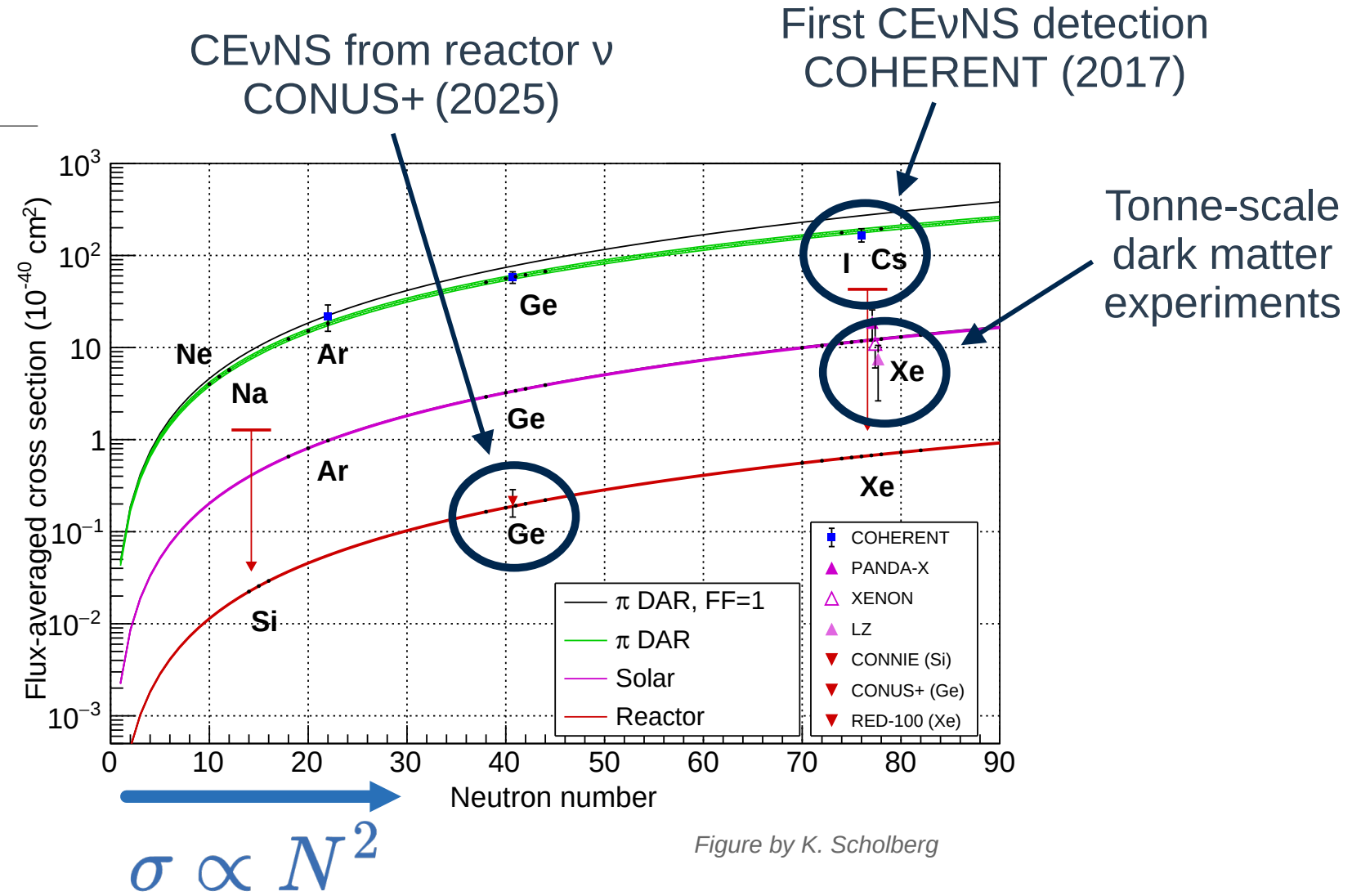
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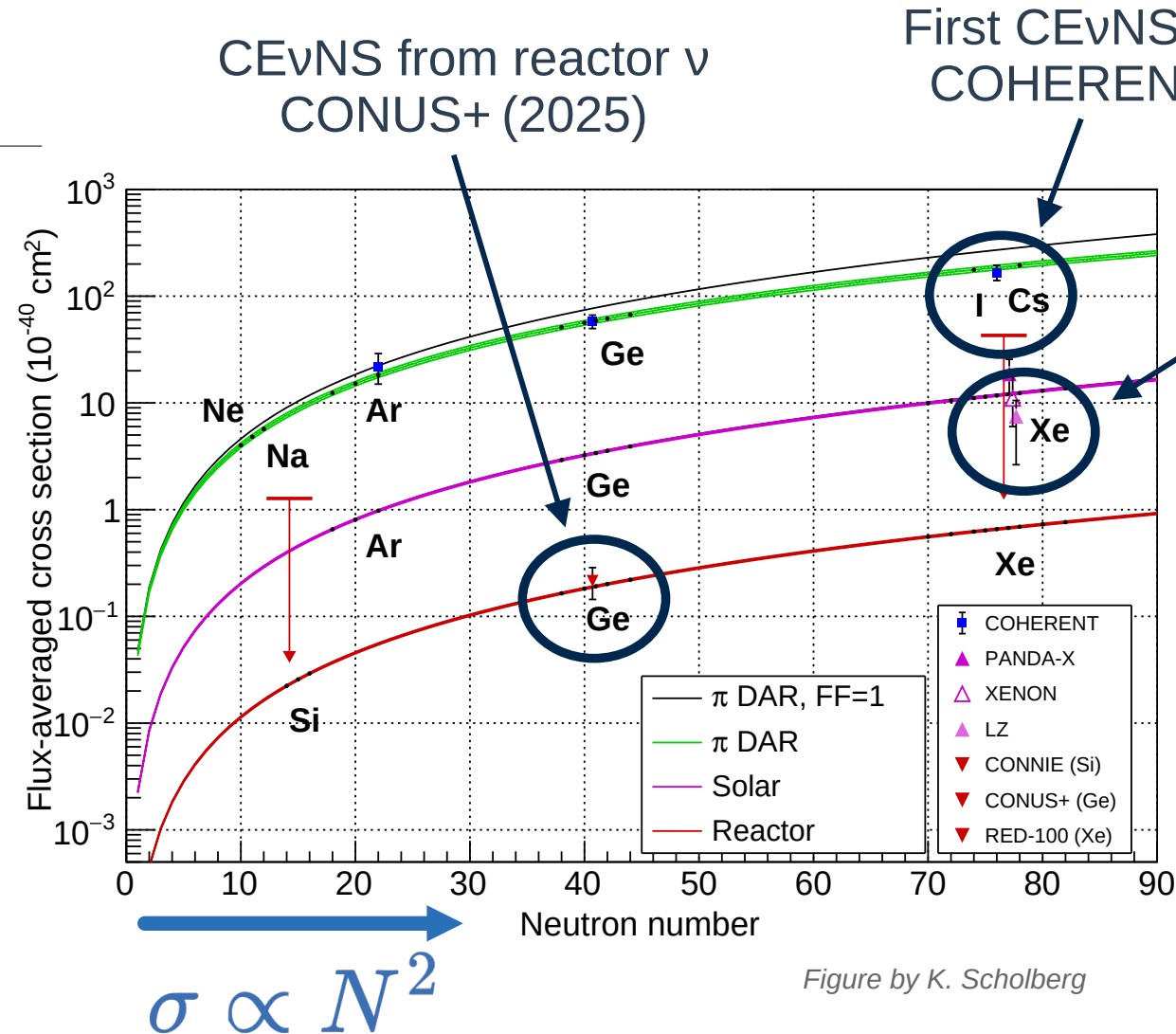
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First CEvNS detection
COHERENT (2017)

Tonne-scale
dark matter
experiments

.W

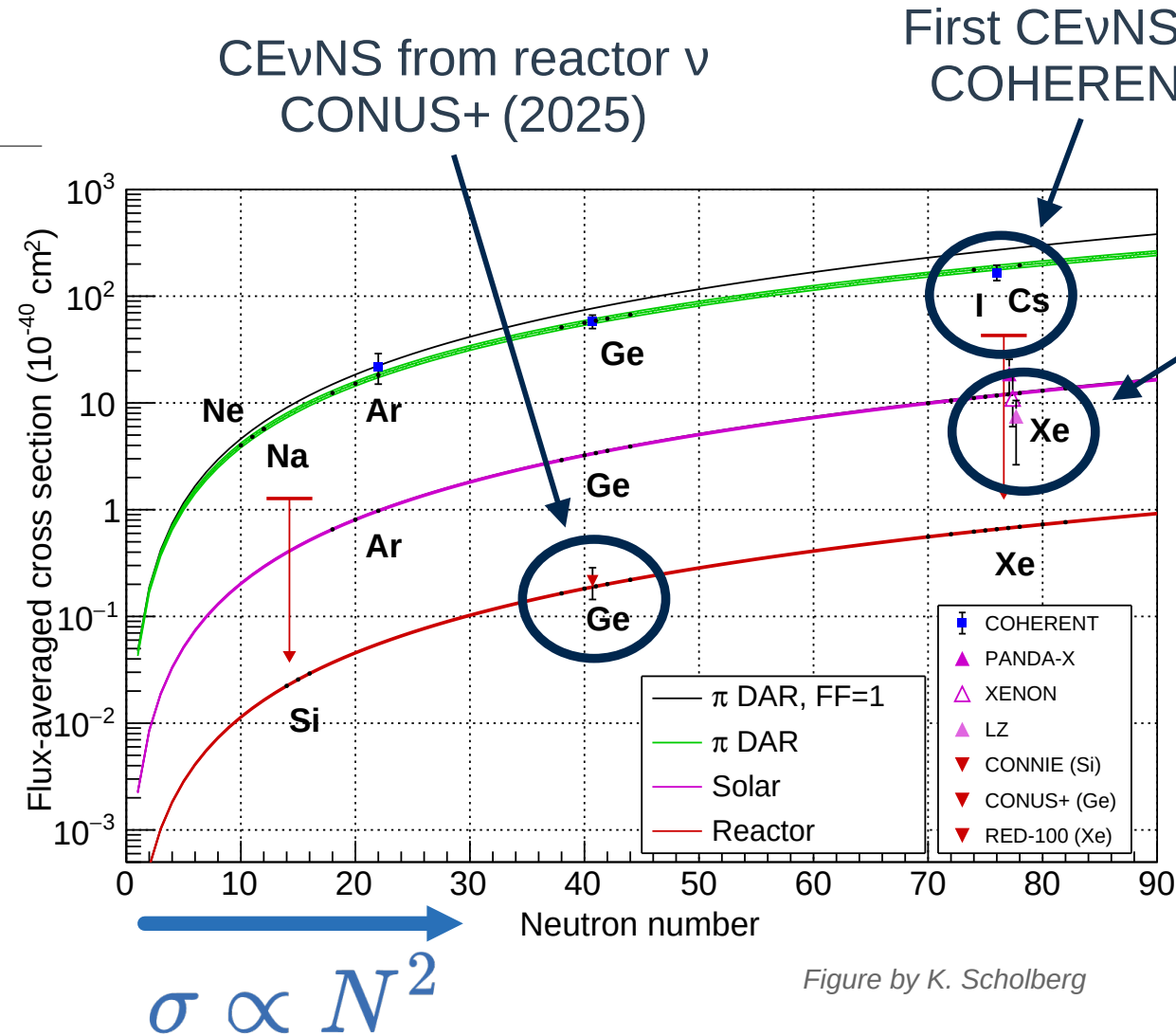
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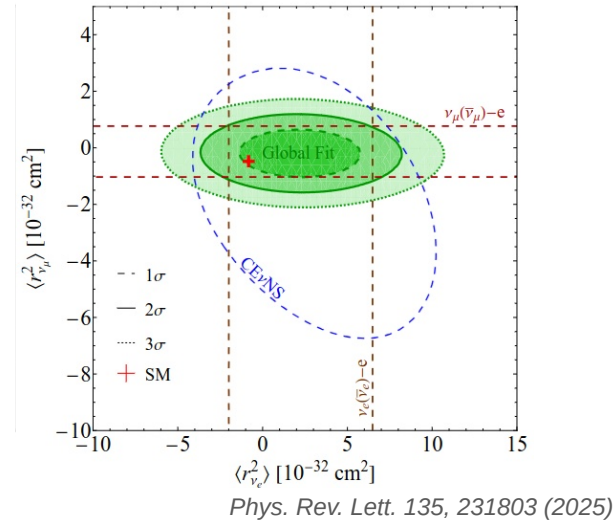
I. CEvNS motivation



I. CEvNS motivation

Test SM

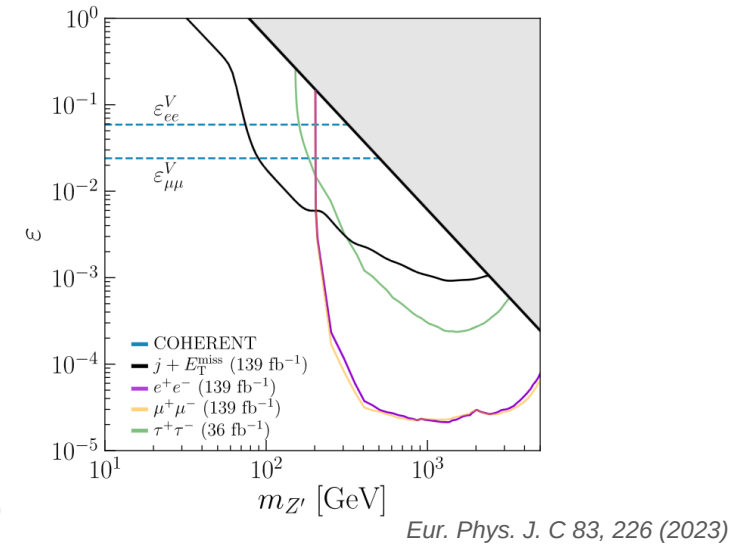
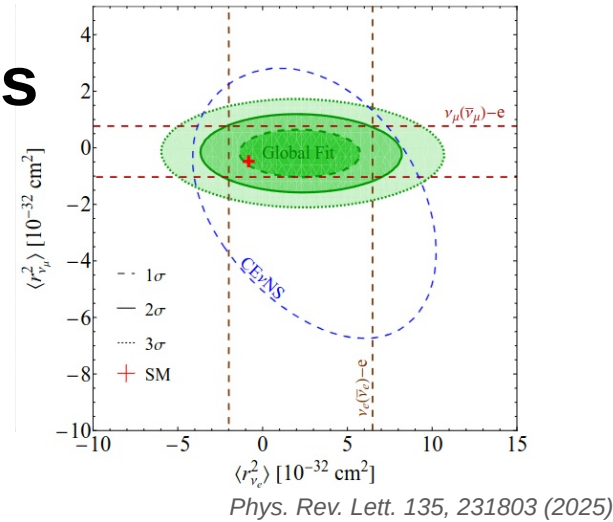
- Θ_W , ν charge radius...



I. CEvNS motivation

Test SM and **look for new physics**

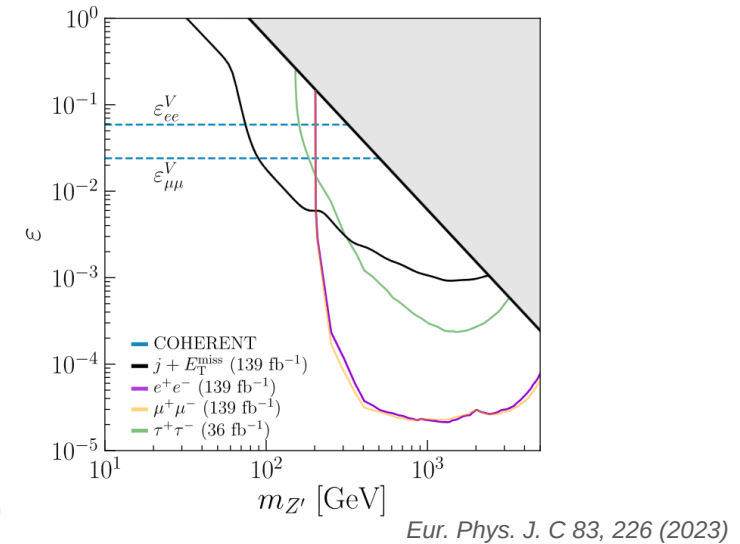
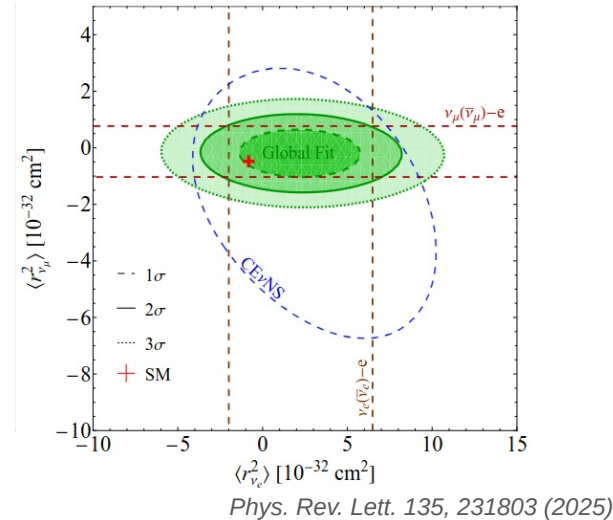
- Θ_W , ν charge radius...
- Non-standard interactions
- Light mediators



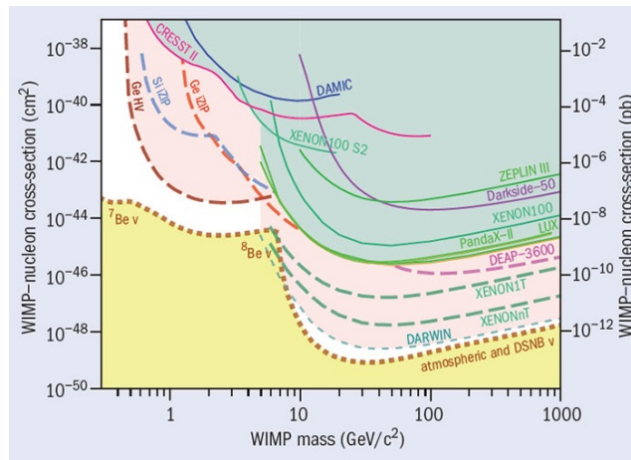
I. CEvNS motivation

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Neutrino floor

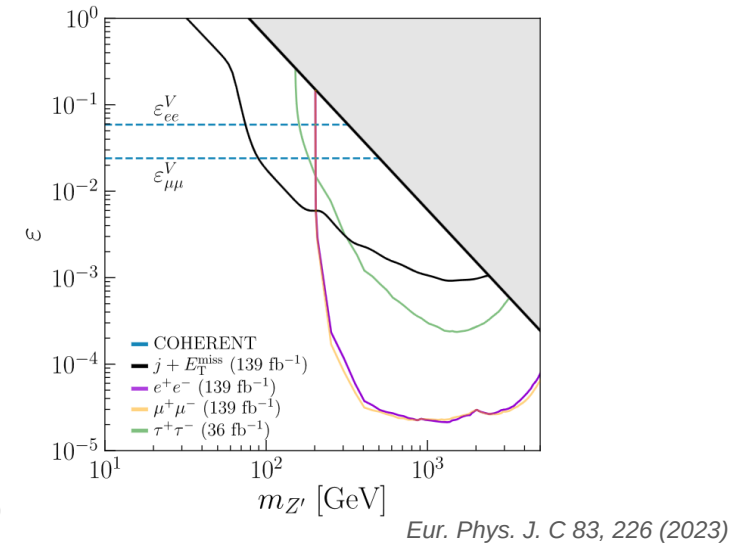
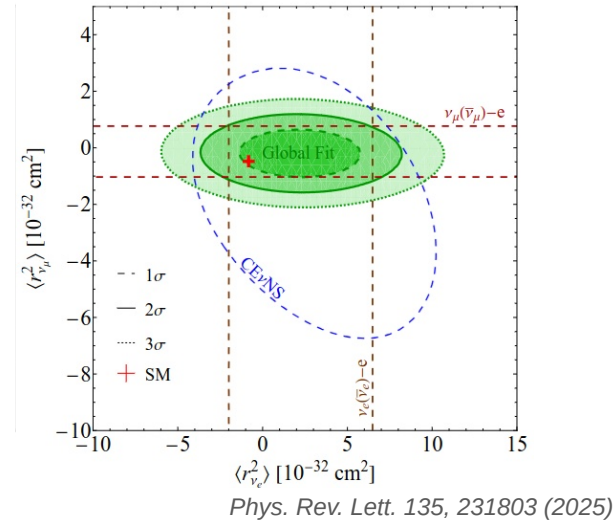


<https://cerncourier.com/a/testing-wimps-to-the-limit/>

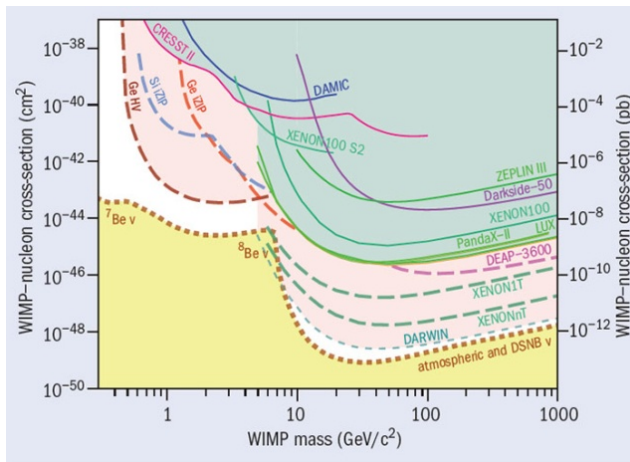
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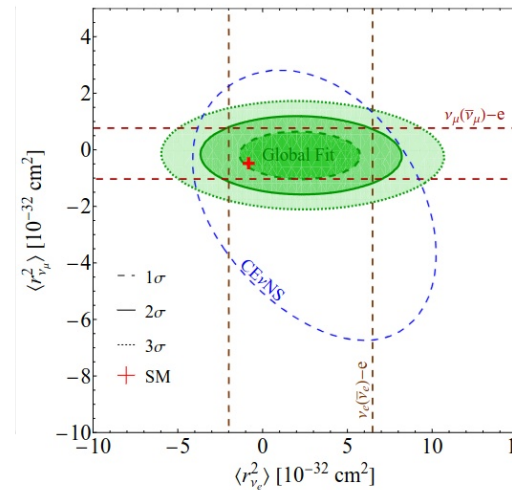
Supernovae ν 's



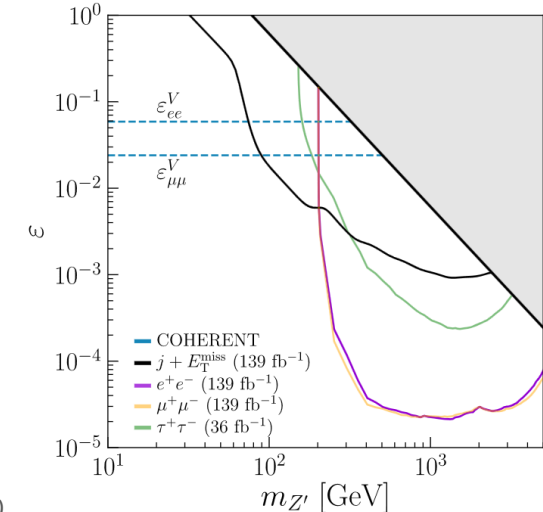
James Webb's SN 1987A picture

I. CEvNS motivation

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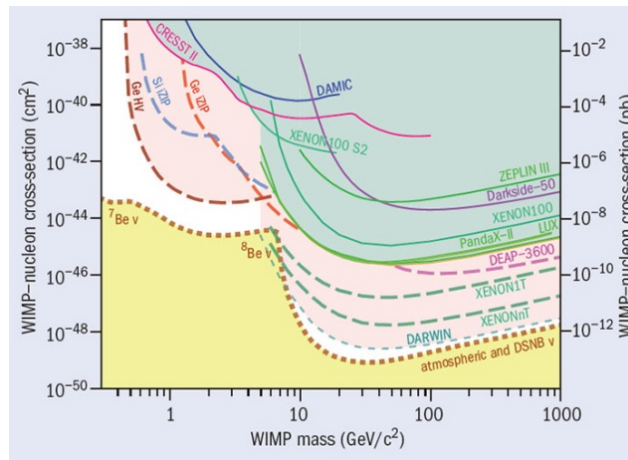


Phys. Rev. Lett. 135, 231803 (2025)



Eur. Phys. J. C 83, 226 (2023)

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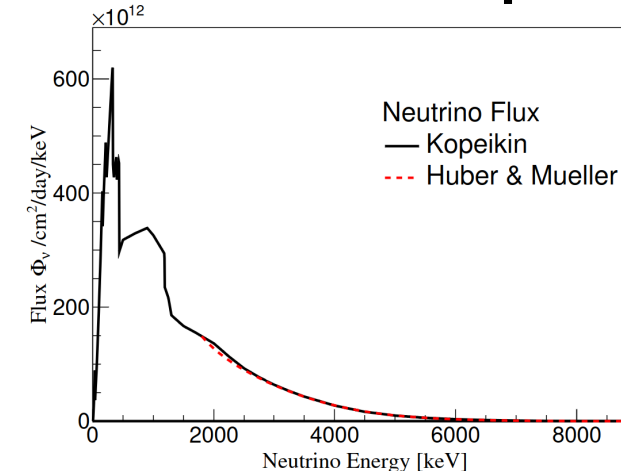
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Supernovae ν 's



James Webb's SN 1987A picture

Reactor anti- ν spectrum



Phys. Rev. Lett. 135, 231803

NUCLEUS: CE ν NS detection with CaWO₄ cryogenic calorimeters



II. The Location



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❖ Chooz (FR) nuclear power plant



II. The Location

- ❖ Chooz (FR) nuclear power plant
- ❖ $2 \times 4.25 \text{ GW}_{\text{th}}$ cores
- ❖ Very Near Site (VNS):
72 & 102m from the cores

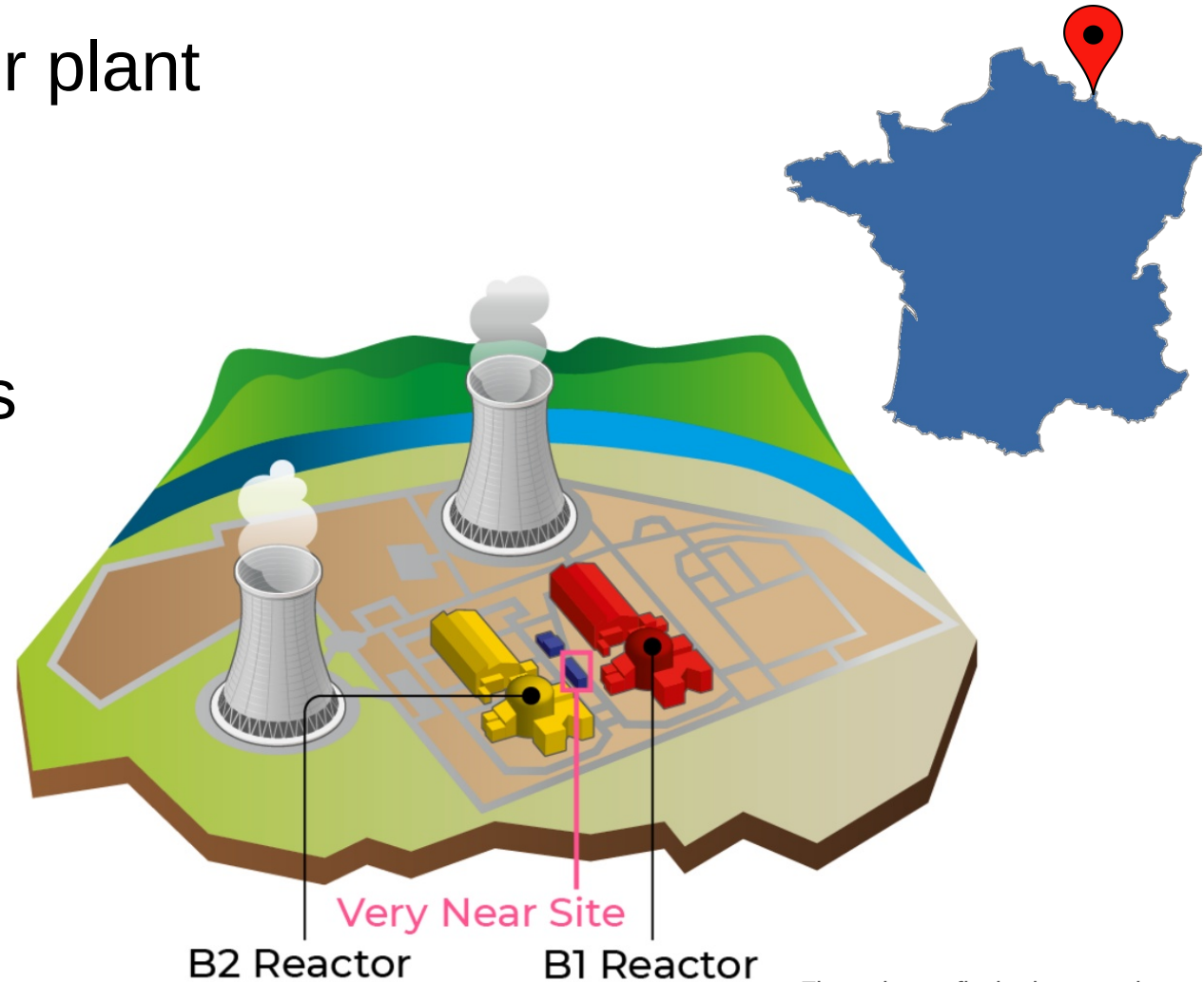


Figure by grafische kooperative

II. The Location

- ❖ Chooz (FR) nuclear power plant
- ❖ $2 \times 4.25 \text{ GW}_{\text{th}}$ cores
- ❖ Very Near Site (VNS):
72 & 102m from the cores
- ❖ Flux: $1.2 \cdot 10^{12} \bar{\nu}_e \cdot \text{cm}^{-2} \text{ s}^{-1}$
- ❖ $E_\nu \sim \text{MeV}$

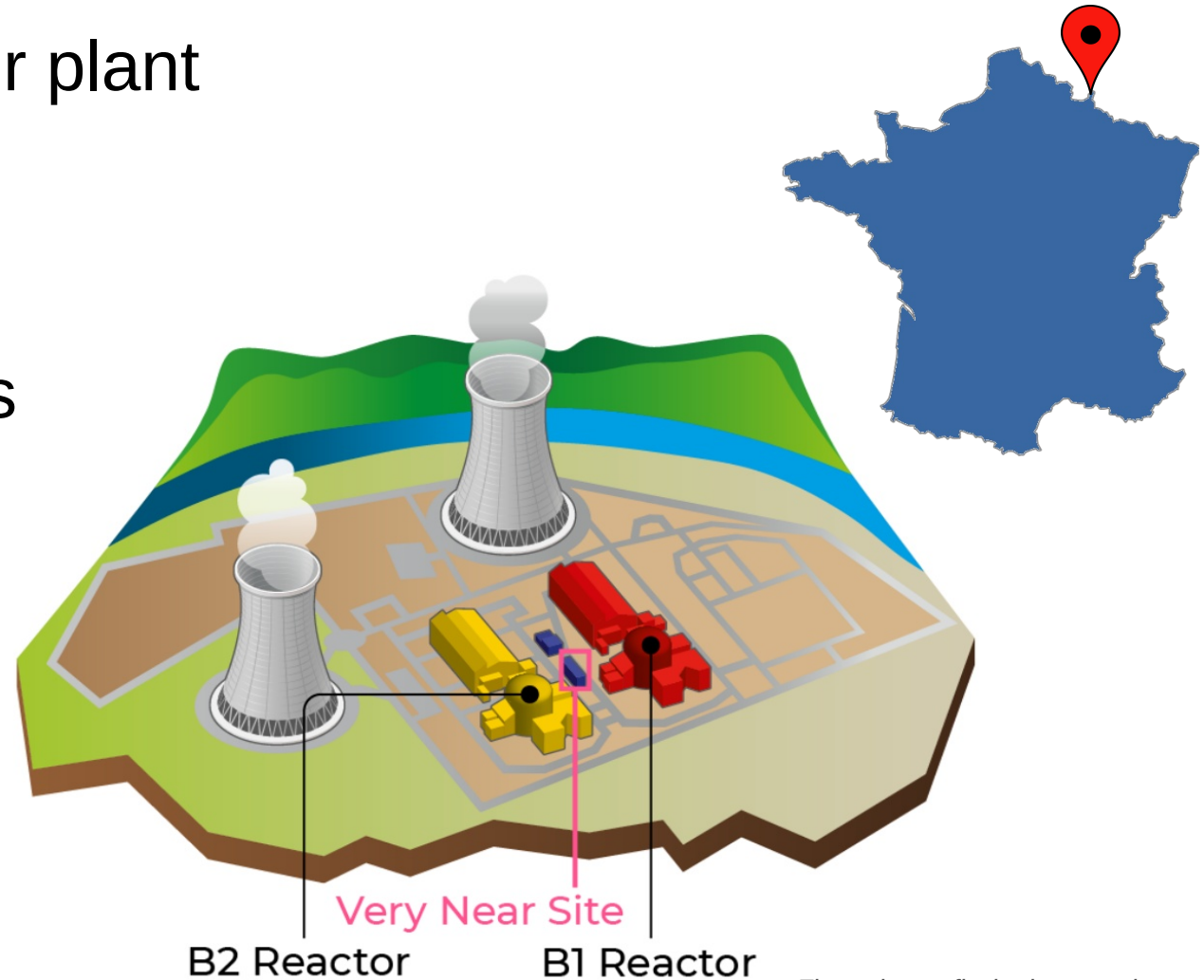


Figure by grafische kooperative

II. Experimental Setup



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- ❖ Expected CEvNS rate: ~ 2 events/week
- ❖ VNS overburden: 3 m.w.e.

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**Active + passive
shielding required**

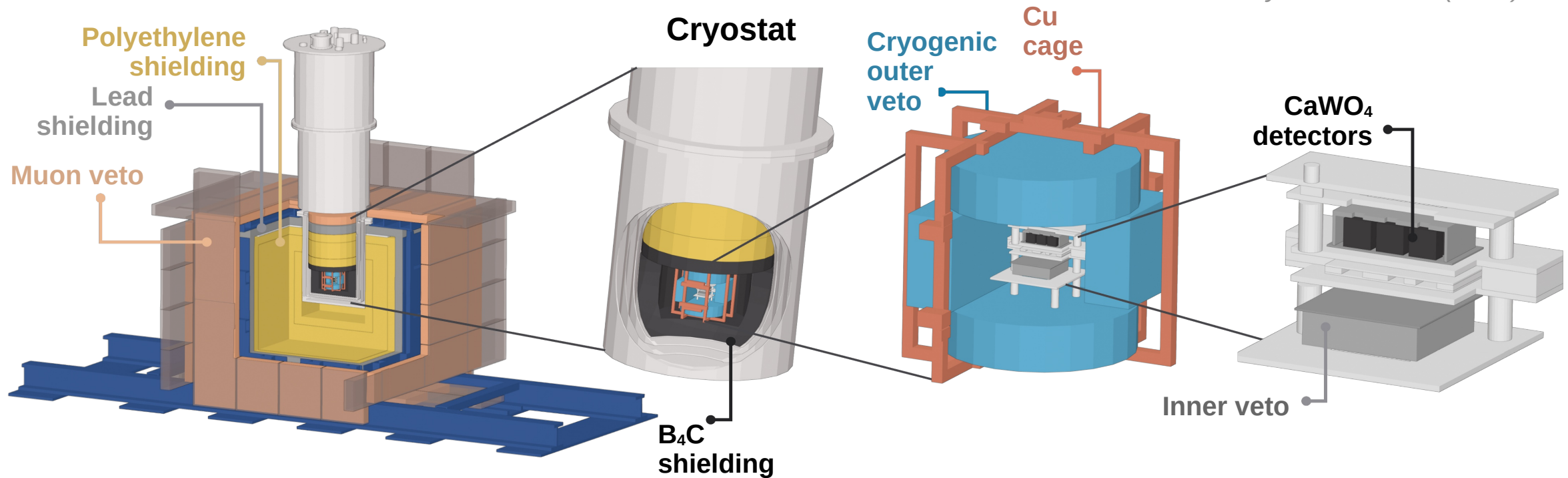
Eur. Phys. J. C 86, 29 (2026)

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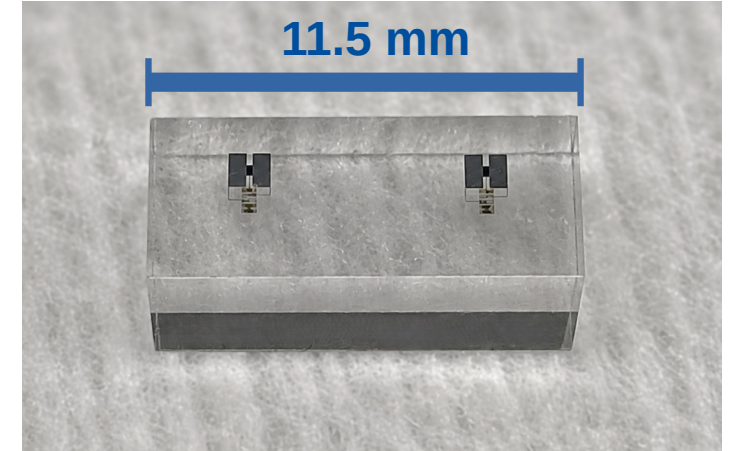
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II. Target Detectors



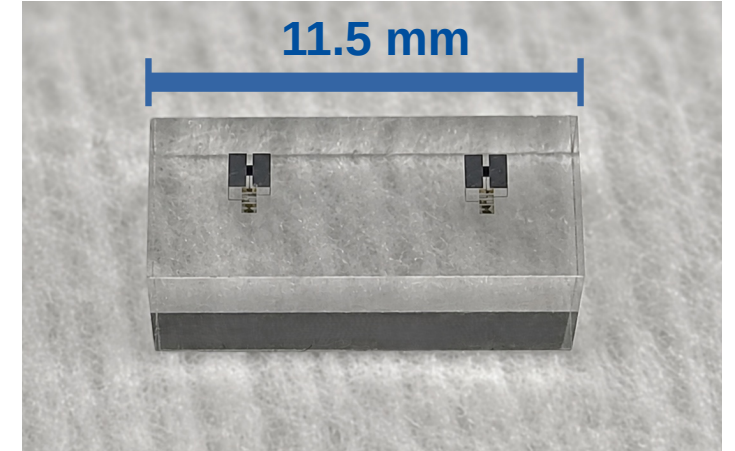
❖ CaWO_4 cryogenic calorimeters



II. Target Detectors



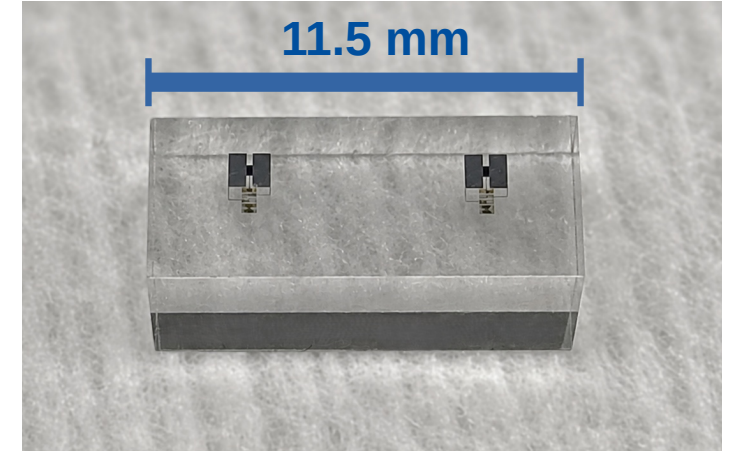
- ❖ **CaWO_4 cryogenic calorimeters**
- ❖ Operation at **$\sim 10 \text{ mK}$** (dry dilution refrigerator)



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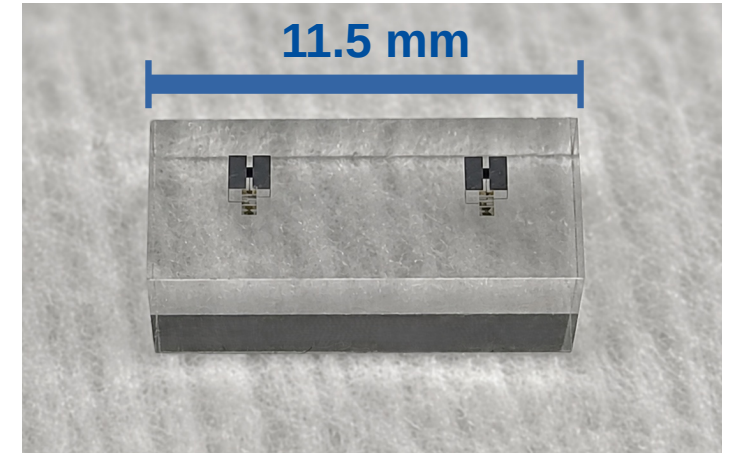
- ❖ **CaWO₄ cryogenic calorimeters**
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II. Target Detectors



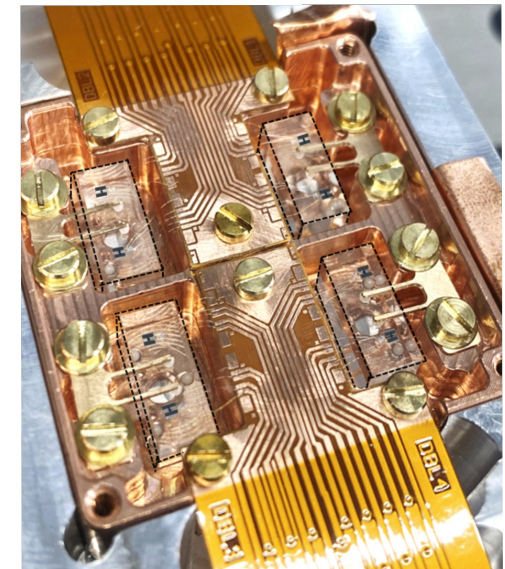
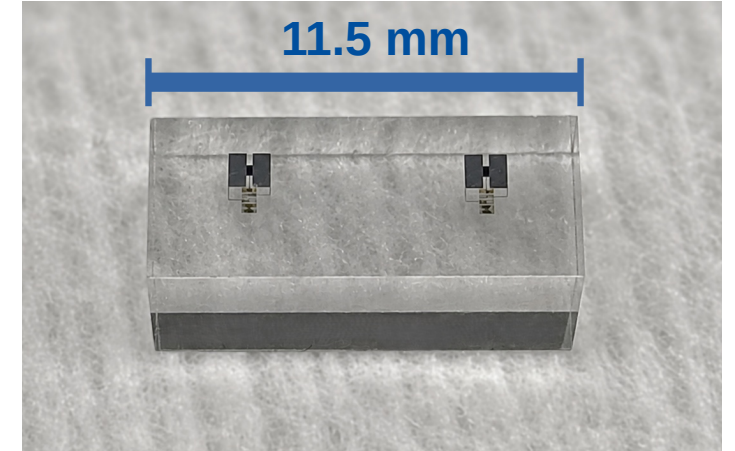
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- ❖ DAQ system: **VDAQ3 (developed @ MBI)**



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- ❖ **CaWO₄ cryogenic calorimeters**
- ❖ Operation at **~10 mK** (dry dilution refrigerator)
- ❖ Readout with **Transition Edge Sensors**
- ❖ DAQ system: **VDAQ3 (developed @ MBI)**
- ❖ Minimal detector module (MDM): 4 crystals, **~7 g**

arXiv:2608.25595 [physics.ins-det]

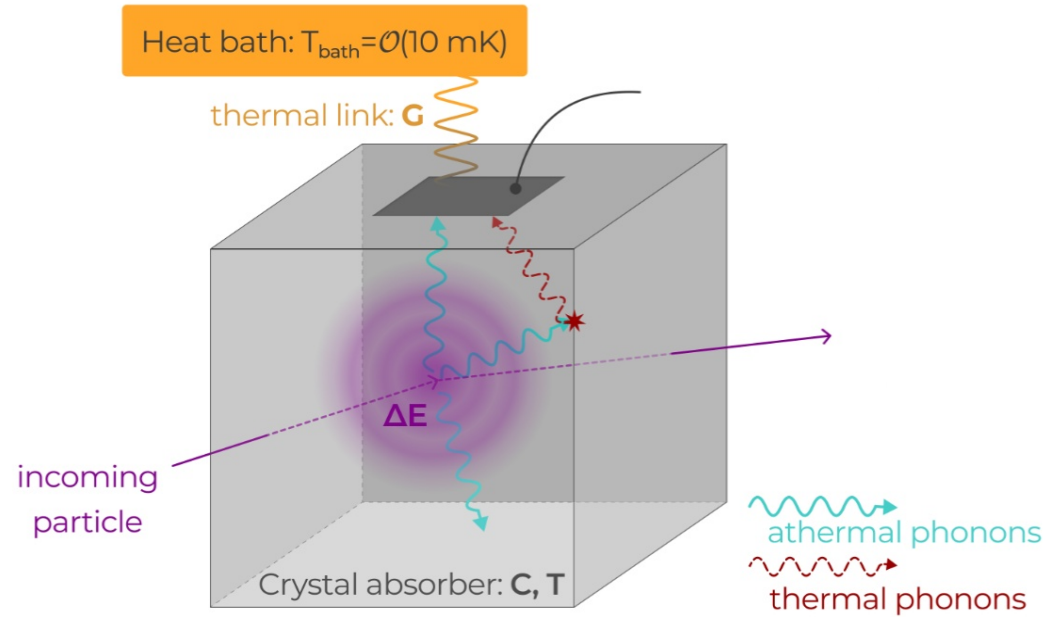


II. Transition Edge Sensors (TES)



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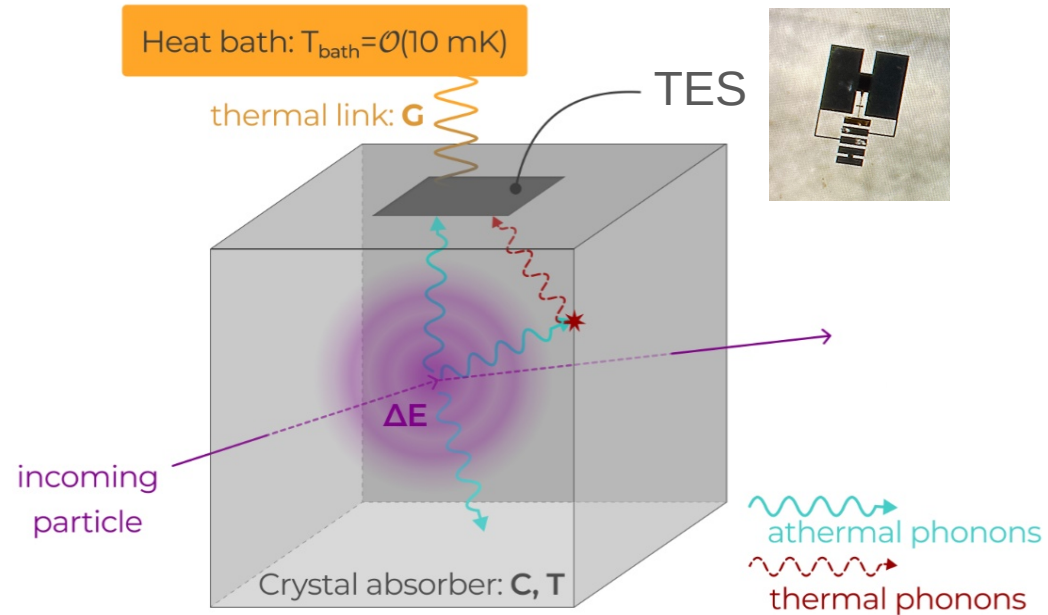
Cryogenic calorimeter



From M. Kaznacheeva's PhD thesis

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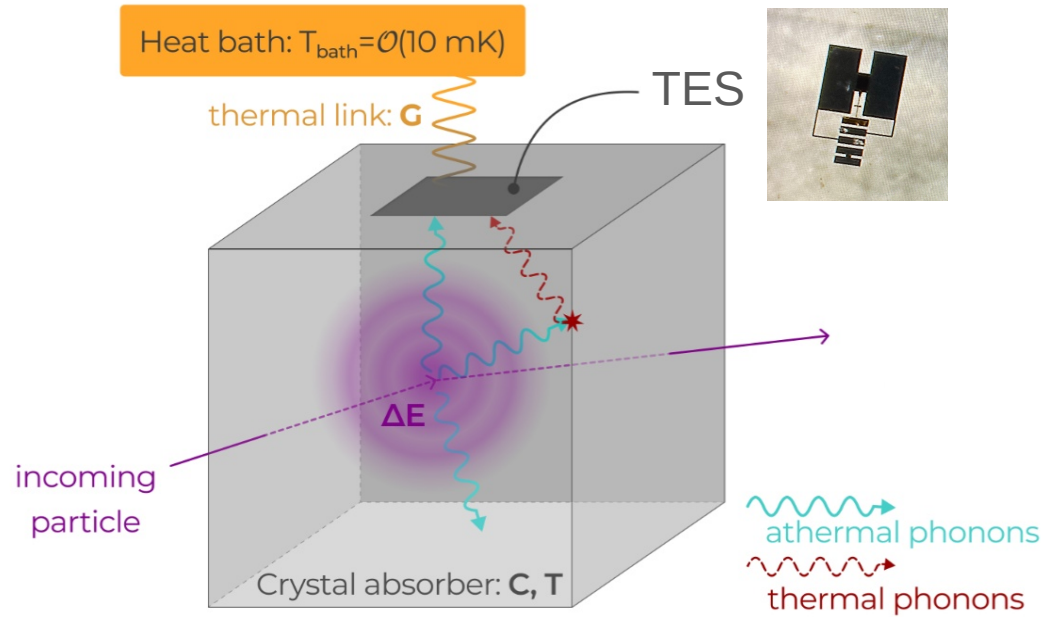


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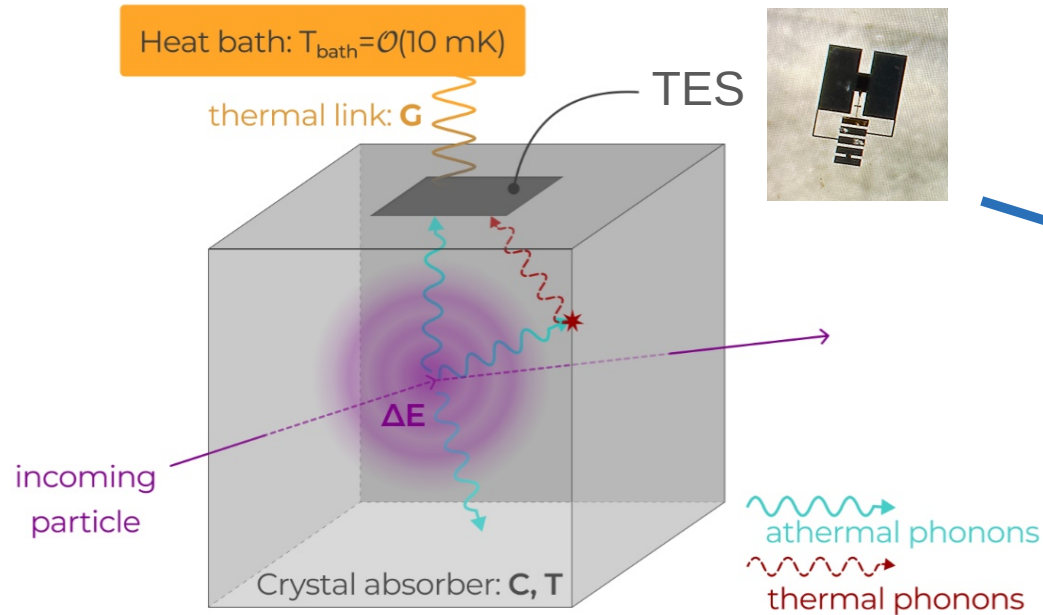


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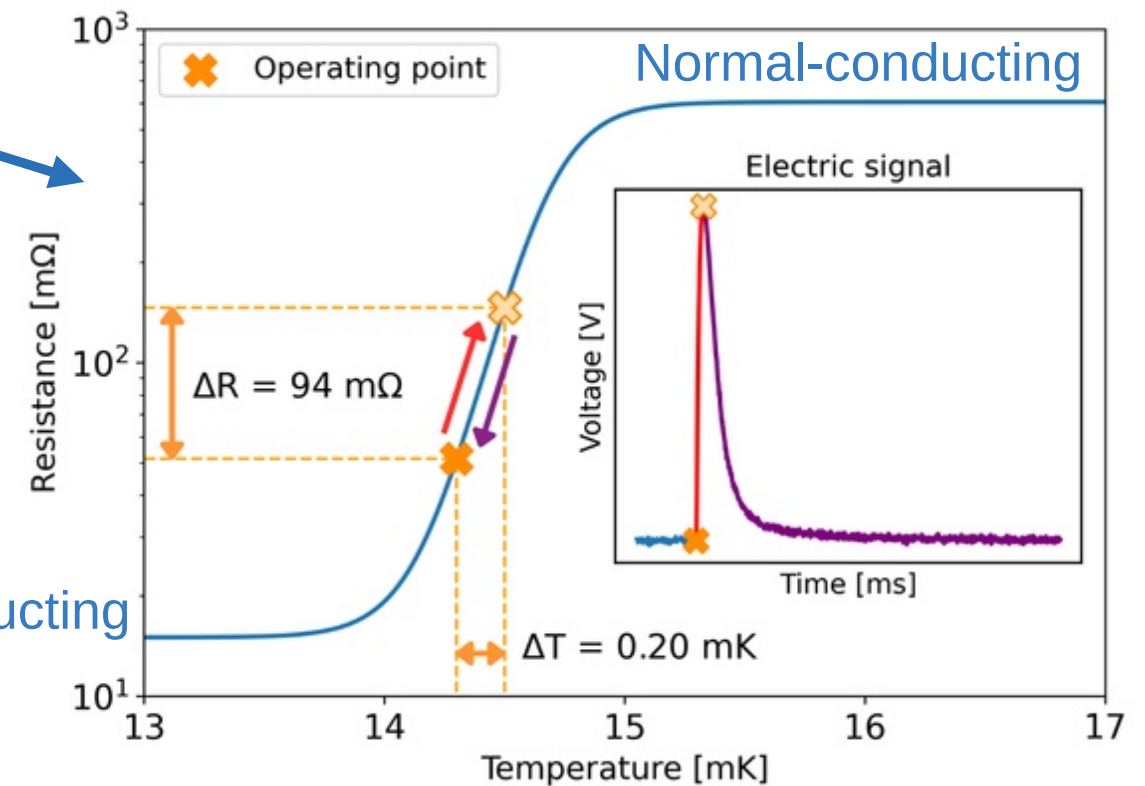
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Energy deposition
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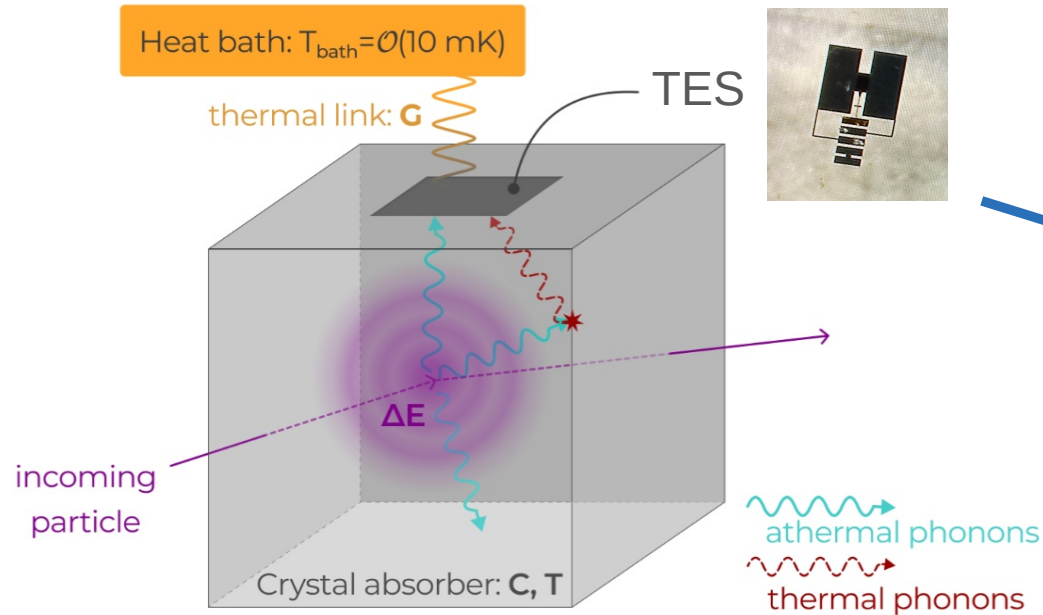
Superconducting



Adapted from M. Kellermann's PhD thesis

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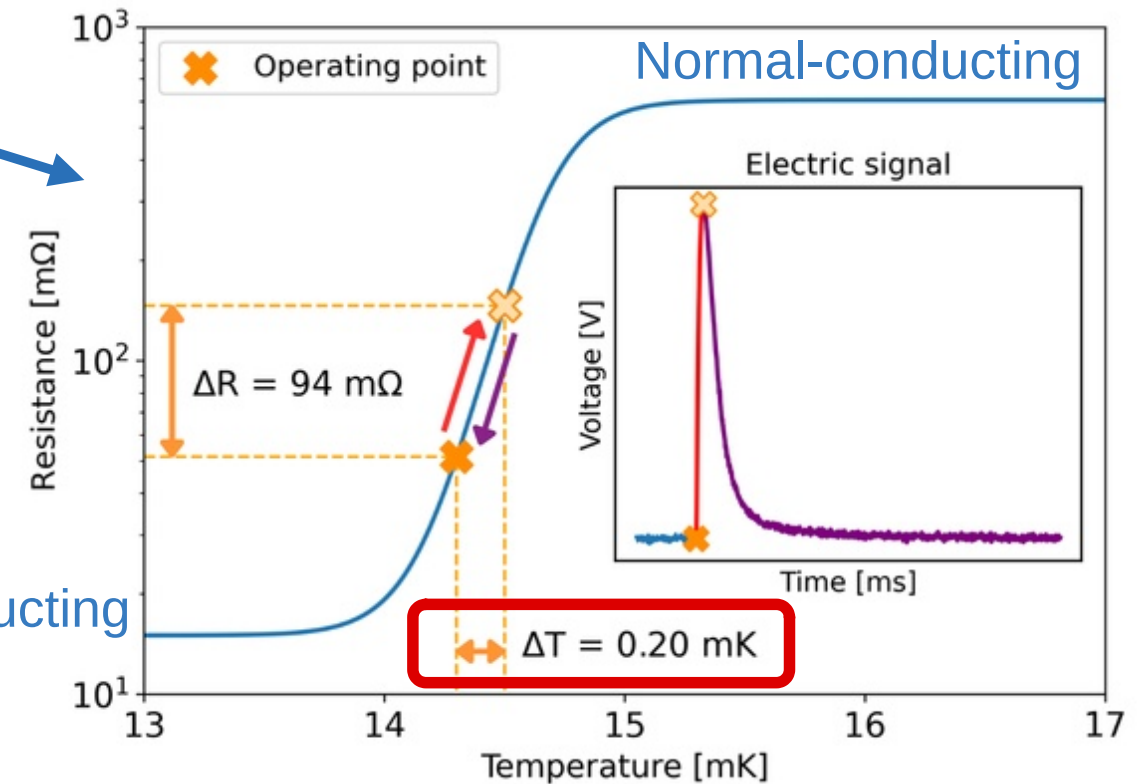
Cryogenic calorimeter



From M. Kaznacheeva's PhD thesis

Energy deposition
(phonons) $\rightarrow \Delta T$

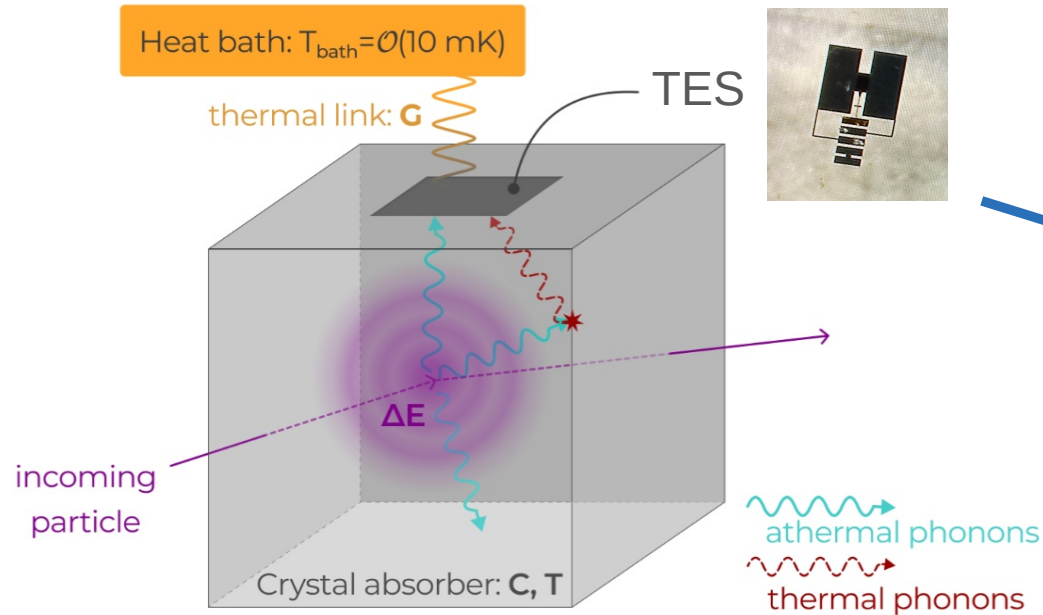
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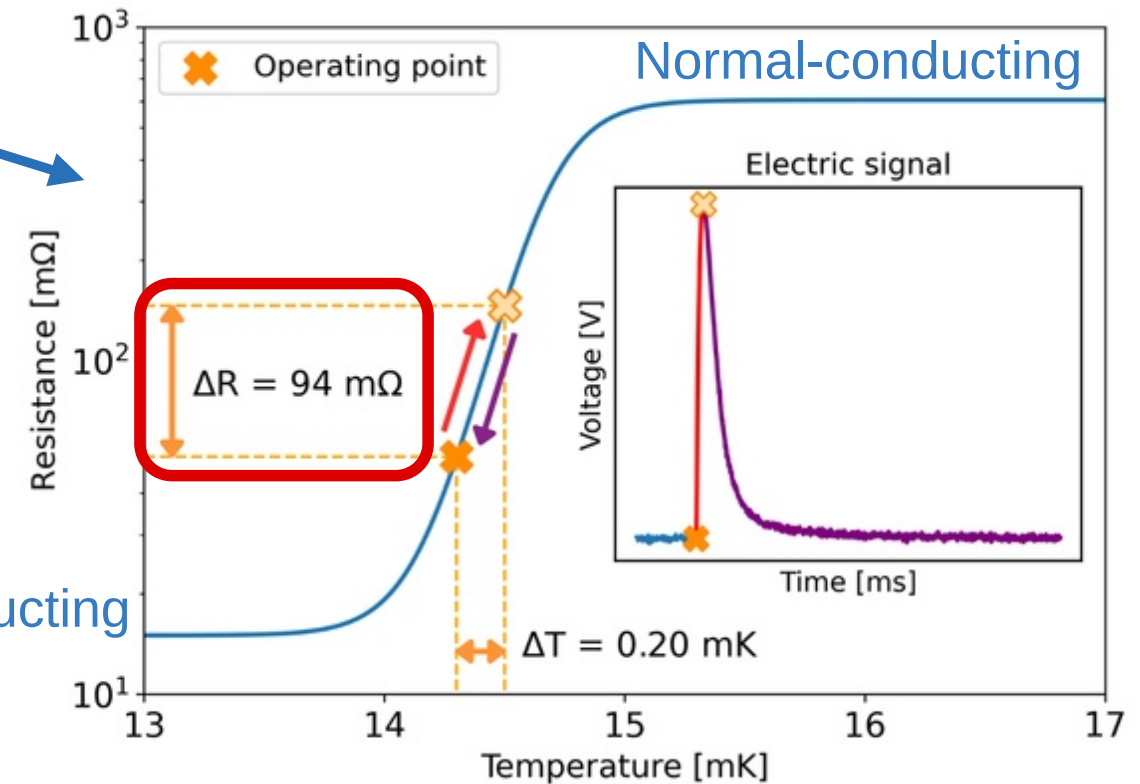
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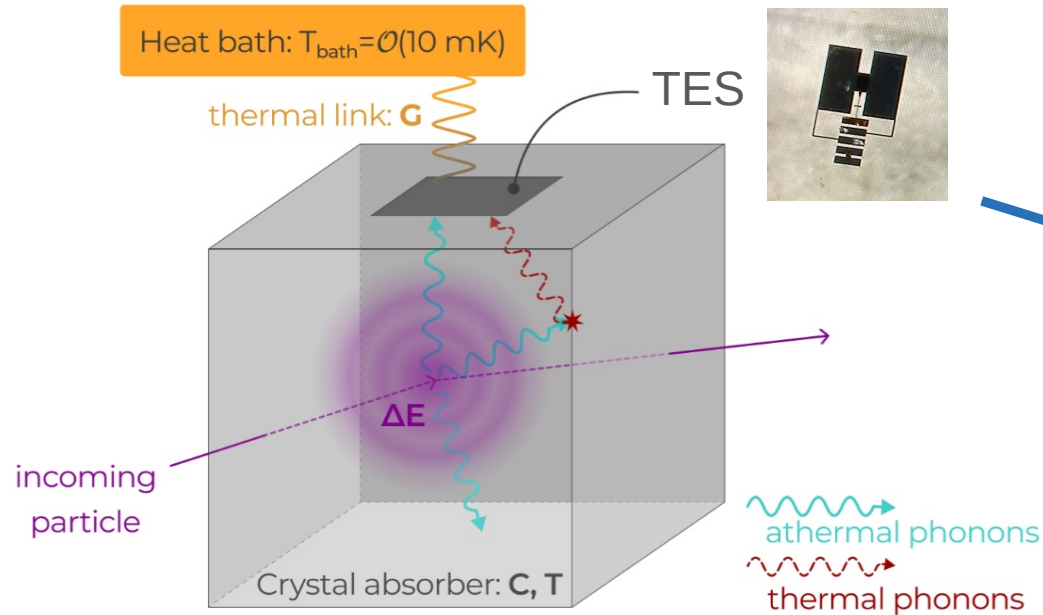
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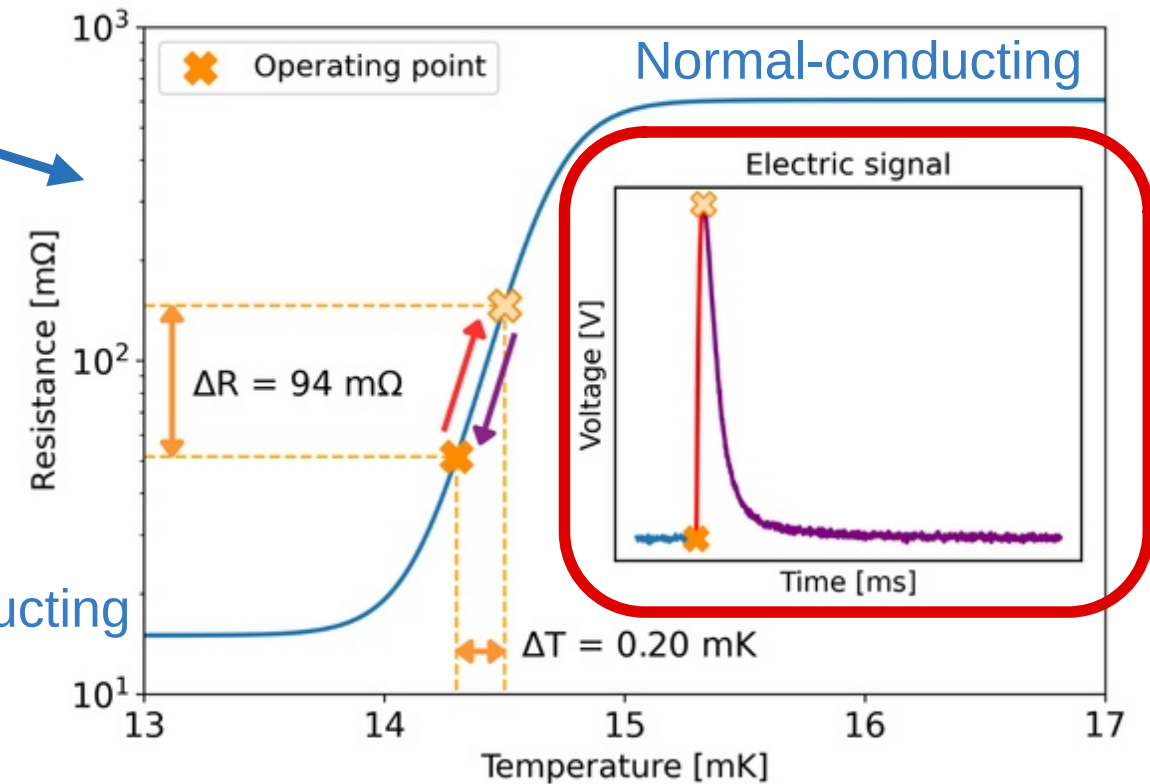
Cryogenic calorimeter



From M. Kaznatcheeva's PhD thesis

Energy deposition (phonons) $\rightarrow \Delta T \rightarrow \Delta R \rightarrow \Delta V$

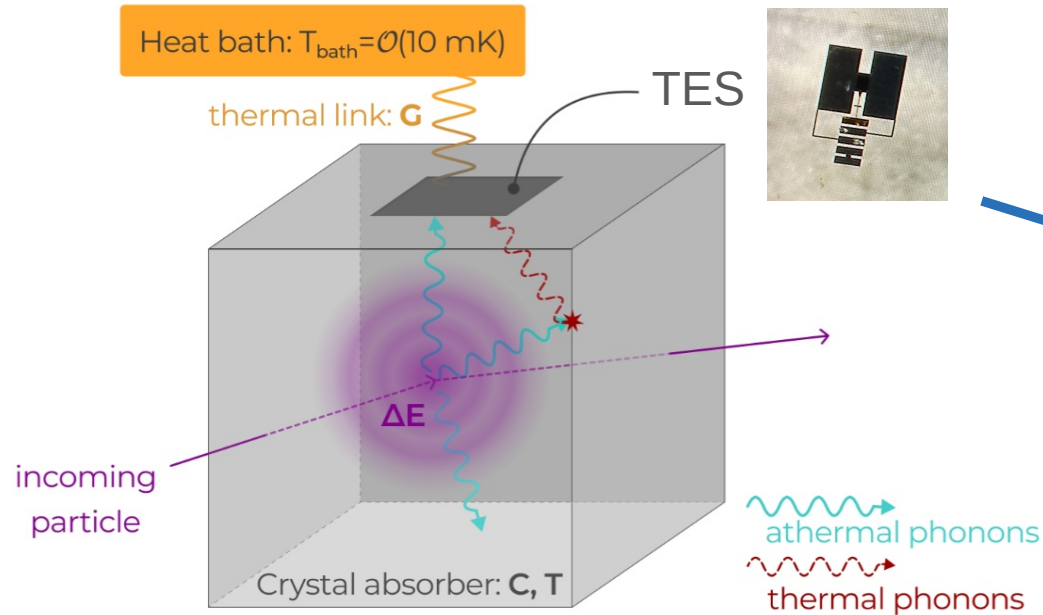
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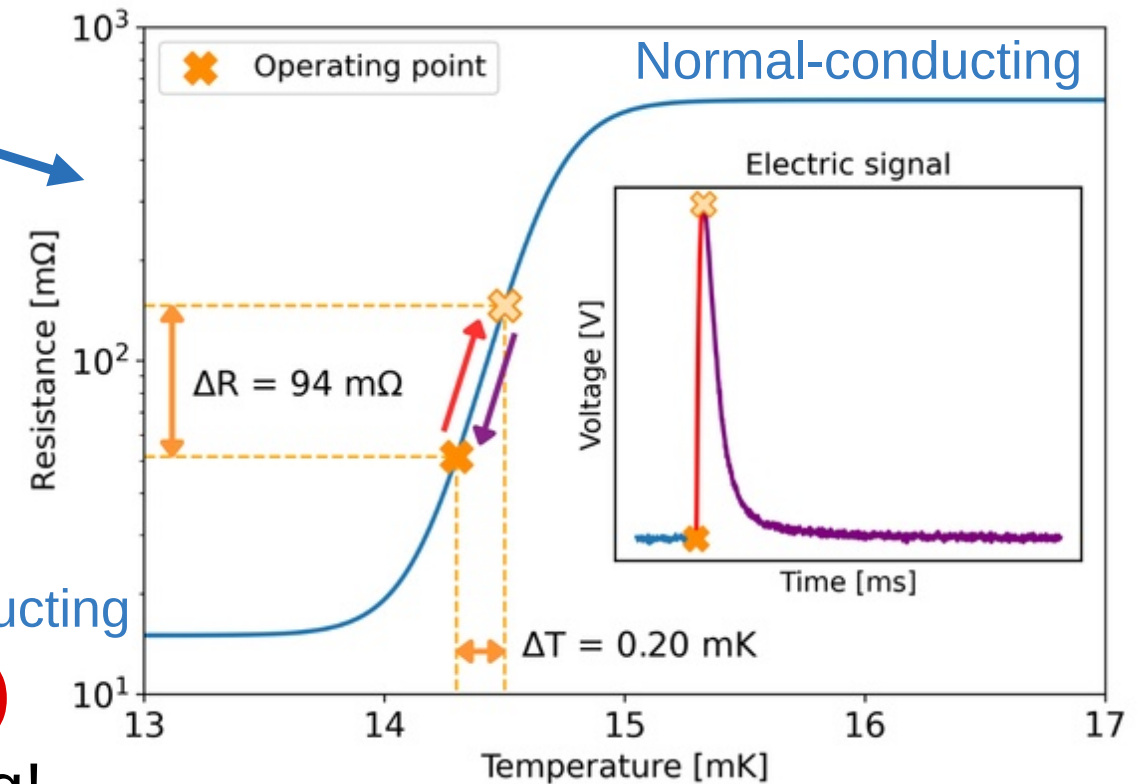
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Adapted from M. Kellermann's PhD thesis

- ❖ Ultra-low energy threshold: $\sim \mathbf{O(10\ eV)}$
- ❖ Direct **phonon readout**, no quenching!

II. Detector Characterization at TUM



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"Christmas Run" (Dec '25 – Jan '26)

II. Detector Characterization at TU



"Christmas Run" (Dec '25 – Jan '26)

- ❖ 21-day data-taking campaign at TU Munich
- ❖ Goal -
- ❖ Result -

II. Detector Characterization at TUM



"Christmas Run" (Dec '25 – Jan '26)

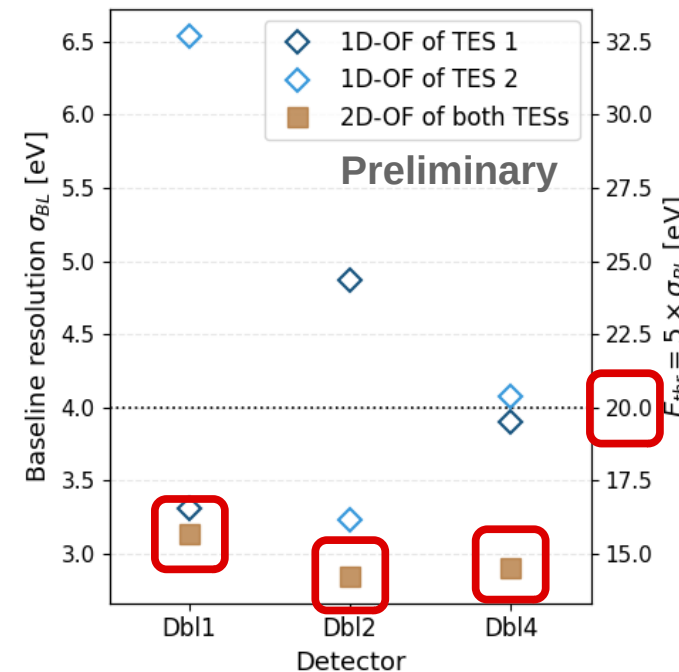
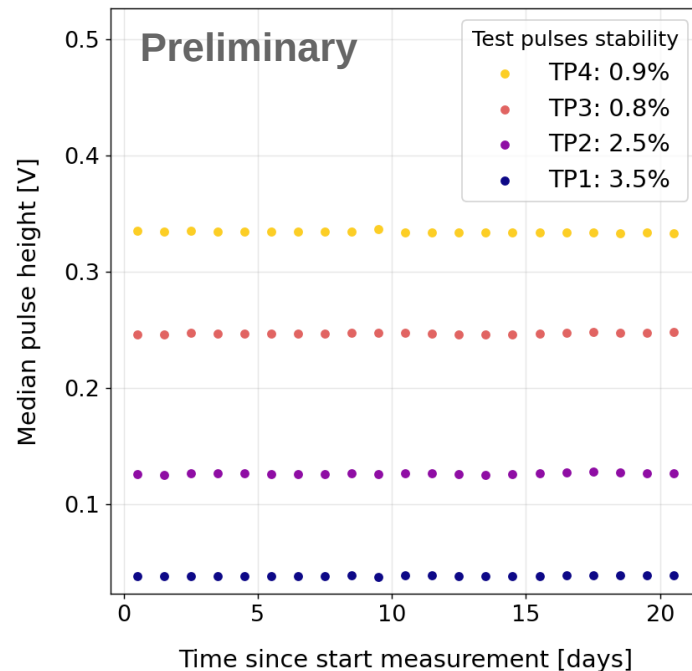
- ❖ 21-day data-taking campaign at TU Munich
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- ❖ Result -

II. Detector Characterization at TUM



"Christmas Run" (Dec '25 – Jan '26)

- ❖ 21-day data-taking campaign at TU Munich
- ❖ Goal - Detector (MDM) performance & stability assessment
- ❖ Result - **3 weeks of stable operation with energy threshold $\lesssim 20$ eV!**



II. Detector Characterization at TUM

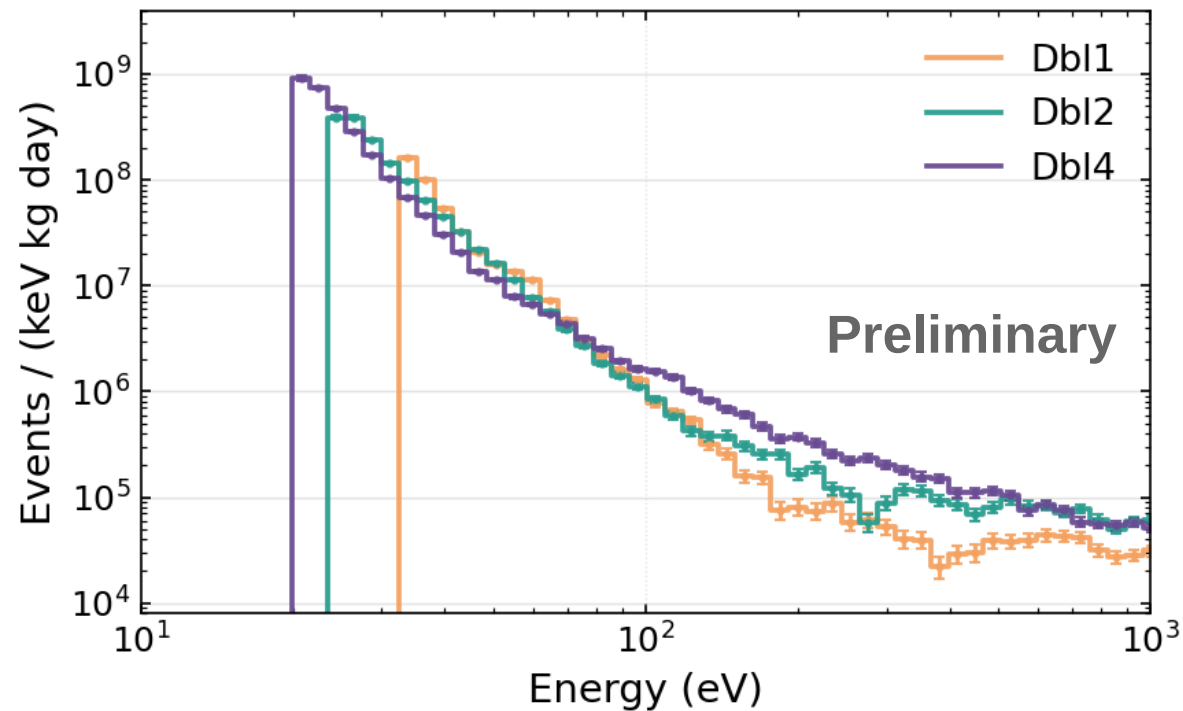


Energy spectra

II. Detector Characterization at TUM



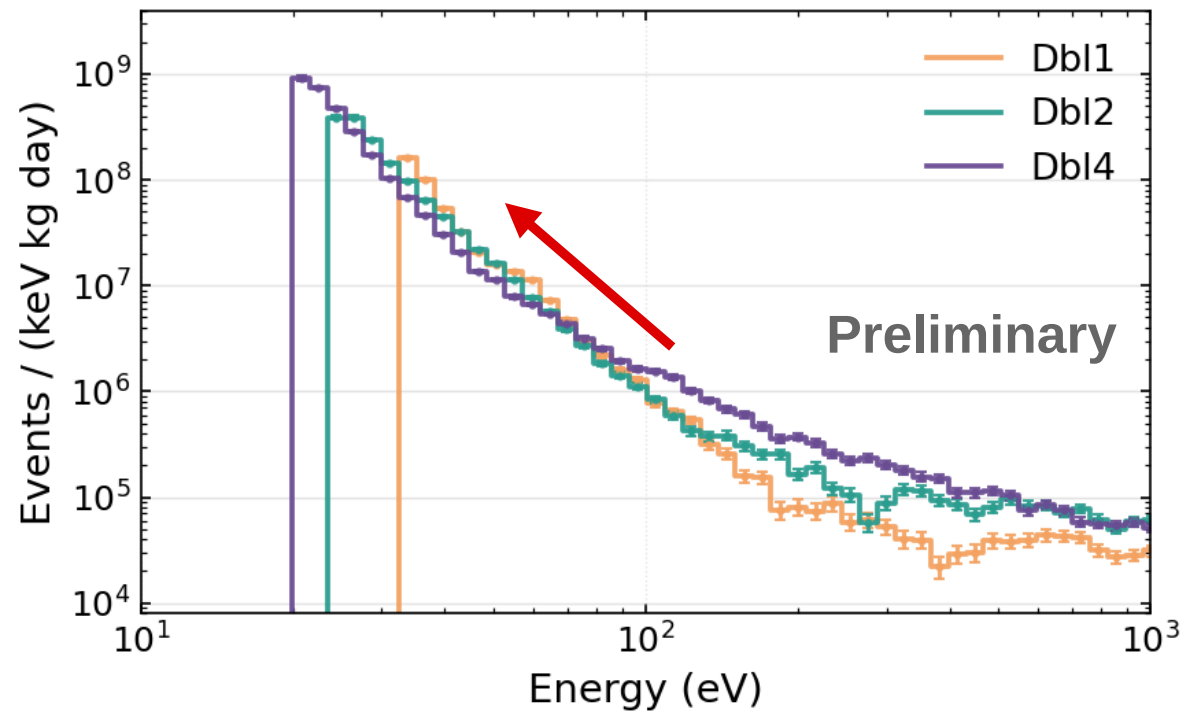
Energy spectra



II. Detector Characterization at TUM



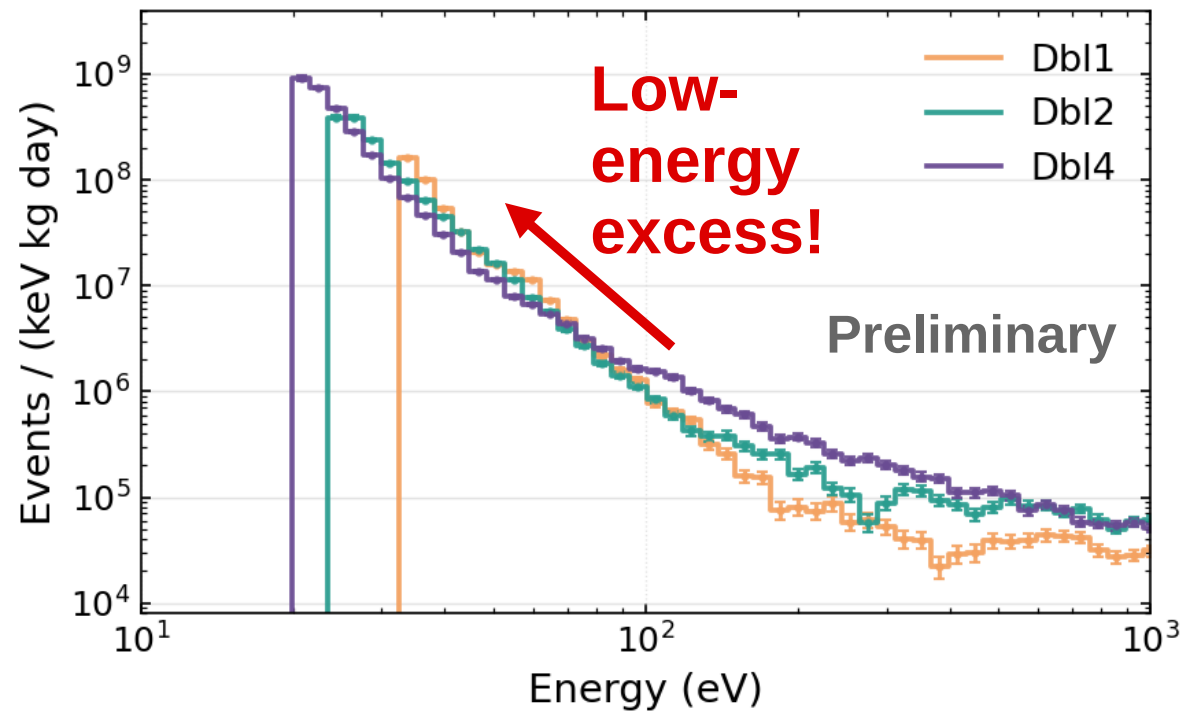
Energy spectra



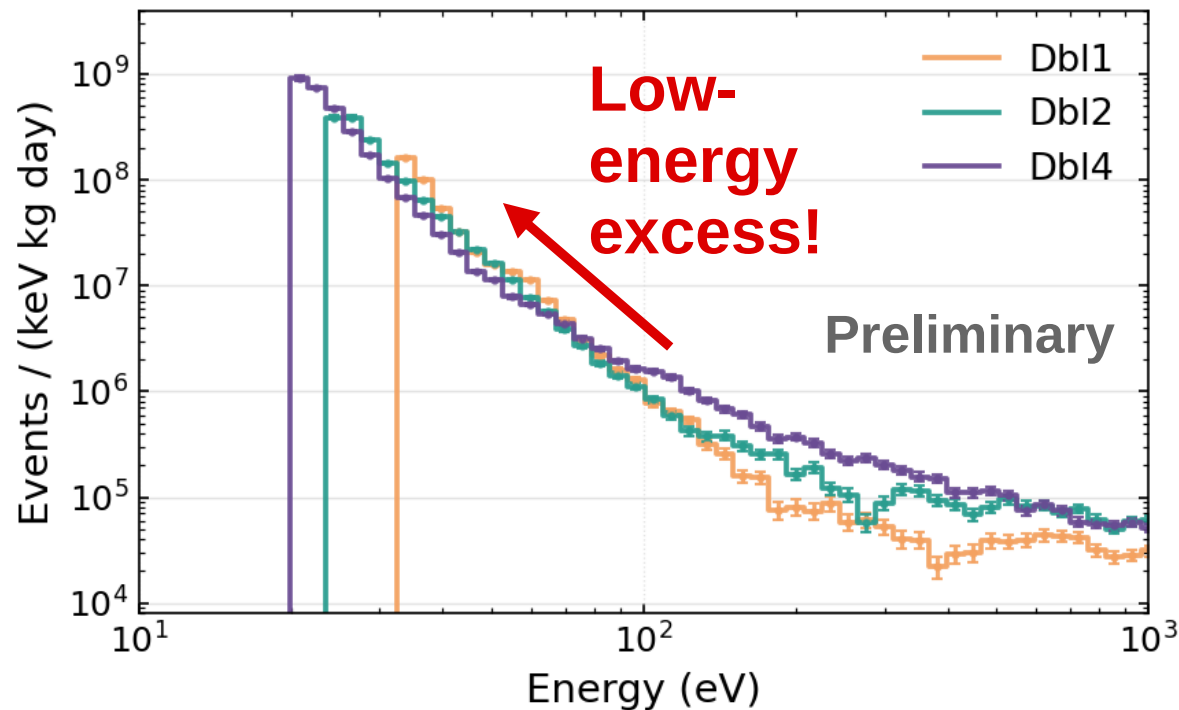
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Energy spectra



Energy spectra



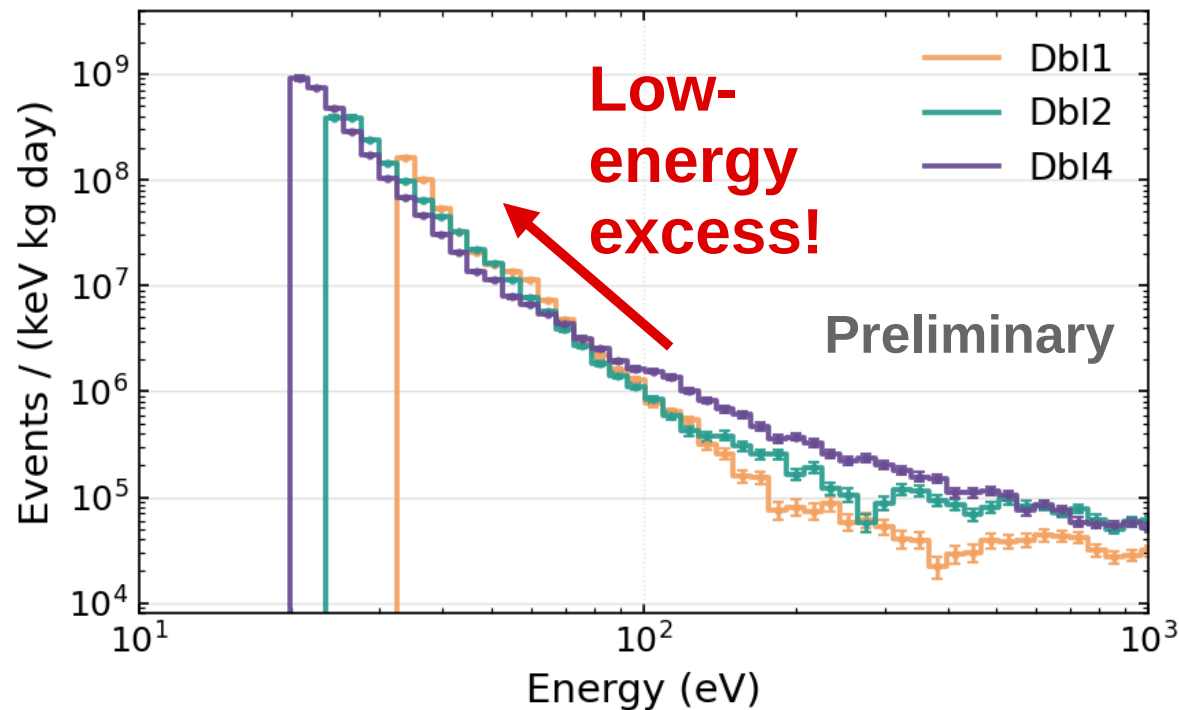
Low-energy excess (LEE)

- ❖ Rise of background events of unknown origin at low energies

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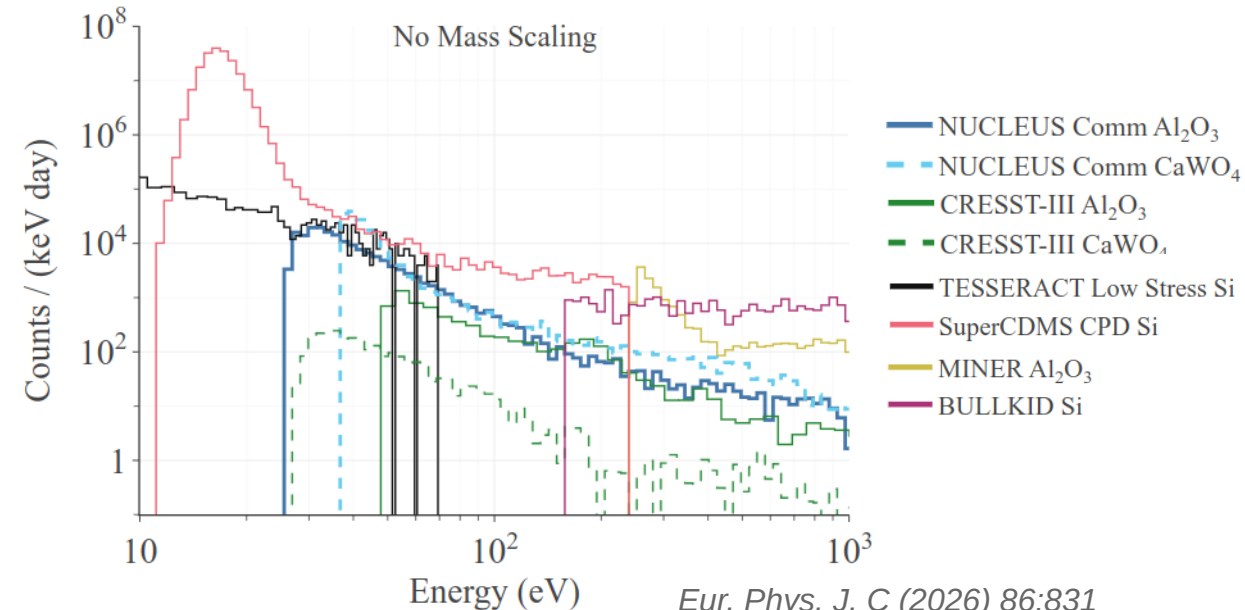


Energy spectra



Low-energy excess (LEE)

- ❖ Rise of background events of unknown origin at low energies
- ❖ Observed in many solid state detectors

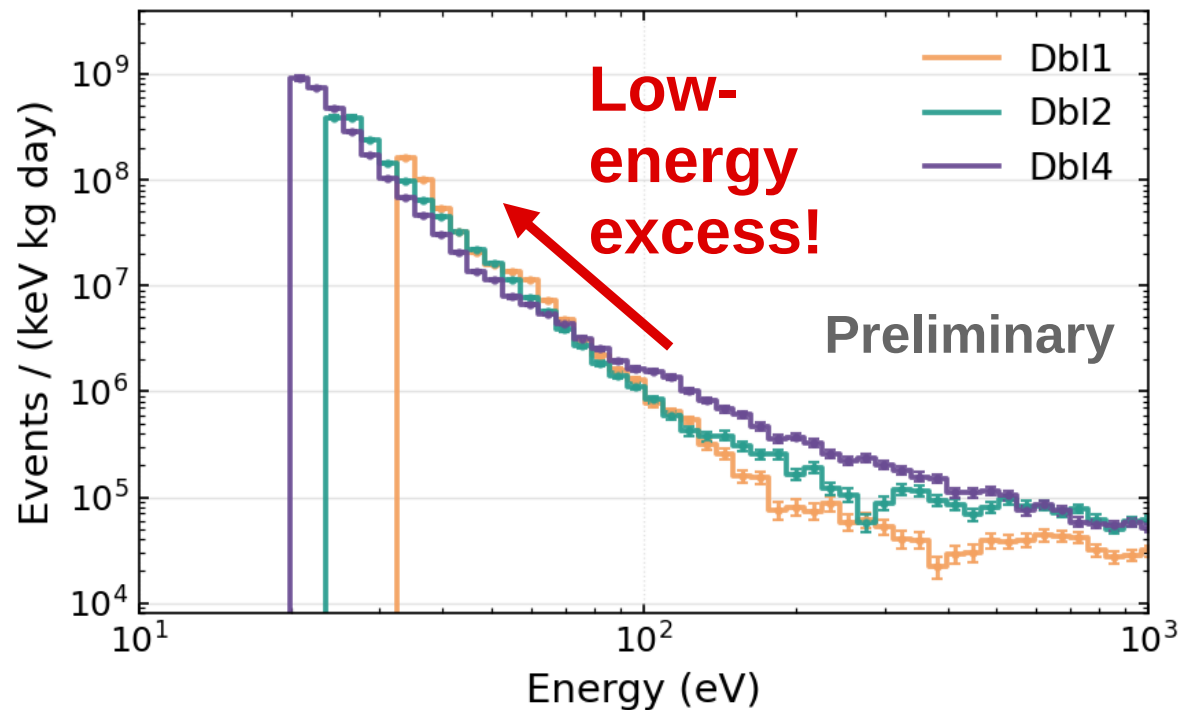


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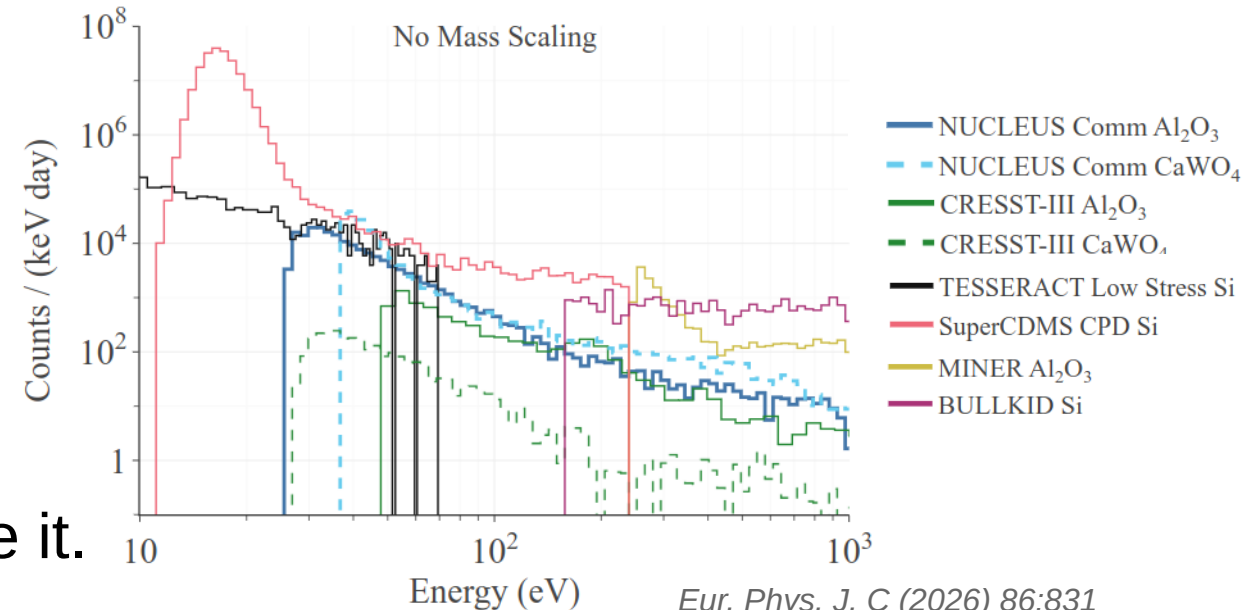
Energy spectra



Ongoing efforts to understand and mitigate it.

Low-energy excess (LEE)

- ❖ Rise of background events of unknown origin at low energies
- ❖ Observed in many solid state detectors



Eur. Phys. J. C (2026) 86:831

NUCLEUS: current status and outlook



III. Towards the Technical Run



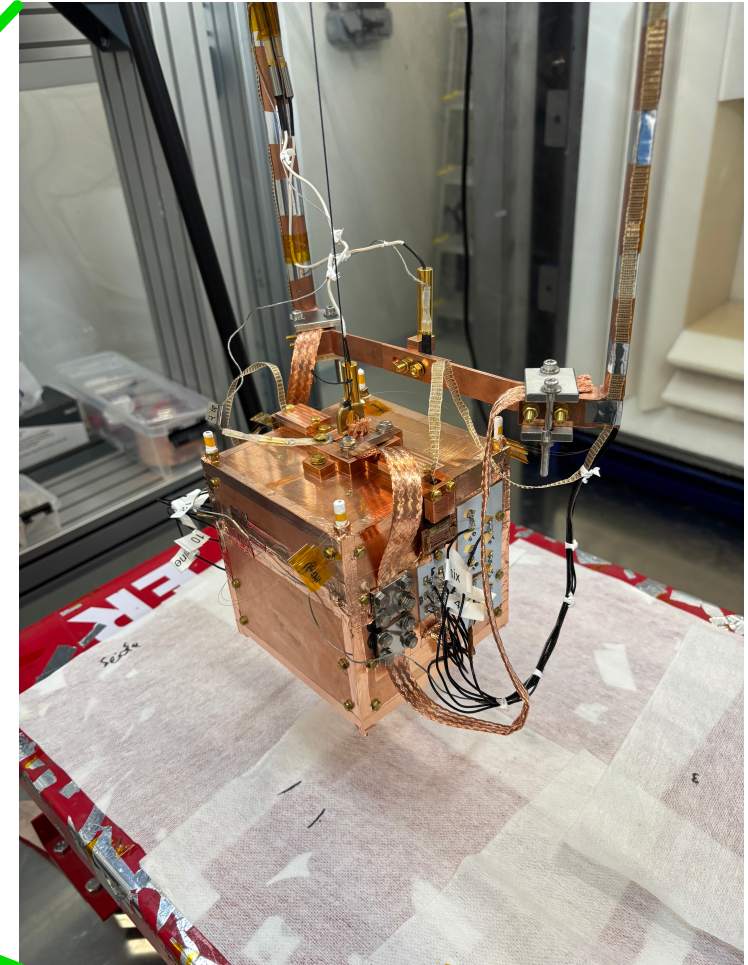
III. Towards the Technical Run

❖ TUM → Chooz relocation completed in April 2026



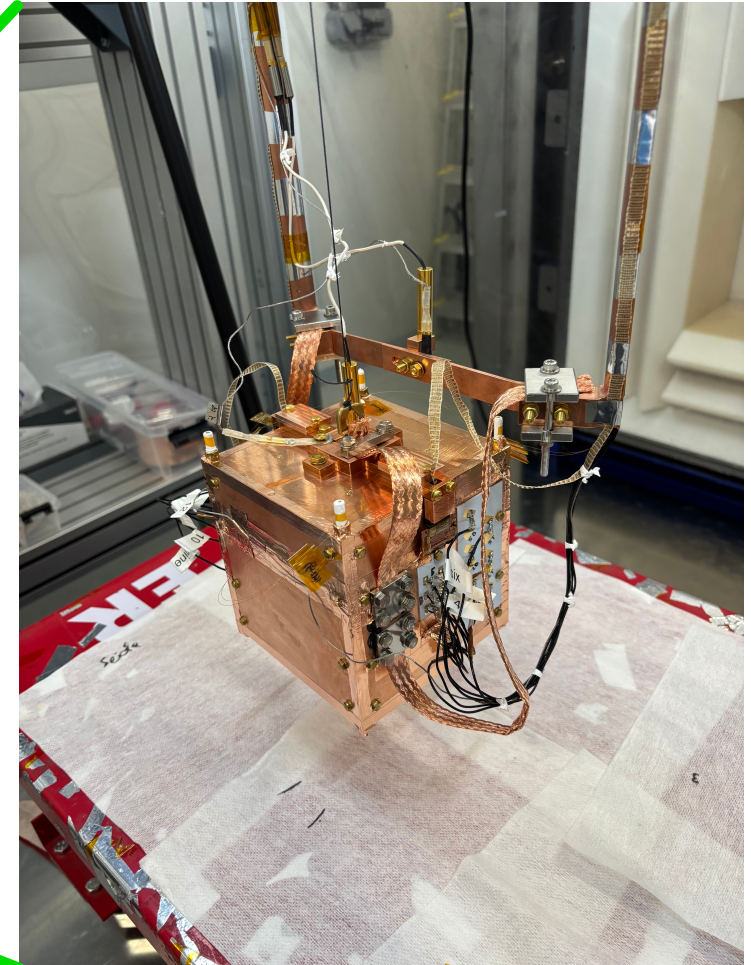
III. Towards the Technical Run

- ❖ TUM → Chooz relocation completed in April 2026
- ❖ Successful cooldown of the detectors 2 weeks ago!



III. Towards the Technical Run

- ❖ TUM → Chooz relocation completed in April 2026
- ❖ Successful cooldown of the detectors 2 weeks ago!
- ❖ **Technical run starting soon** (noise & detectors' characterization, demonstrate stable operation)



III. NUCLEUS timeline

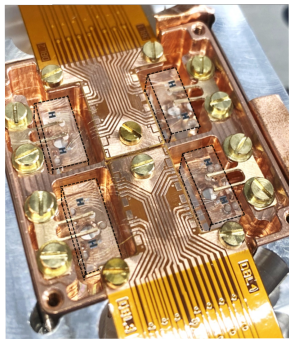


III. NUCLEUS timeline



**Commissioning
and R&D at TUM
(Munich)**

2024-25



III. NUCLEUS timeline



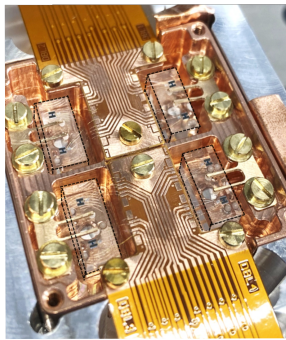
**Commissioning
and R&D at TUM
(Munich)**

2024-25



Jan – Apr
2026

Relocation to Chooz



III. NUCLEUS timeline



**Commissioning
and R&D at TUM
(Munich)**

2024-25

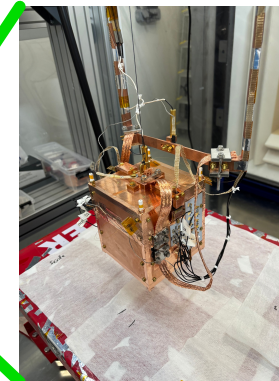
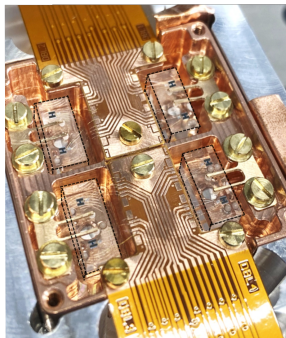


**Technical run
Starting soon!**

2026-27

Jan – Apr
2026

Relocation to Chooz



III. NUCLEUS timeline

**Commissioning
and R&D at TUM
(Munich)**

2024-25

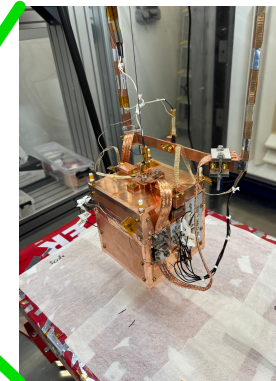


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2026

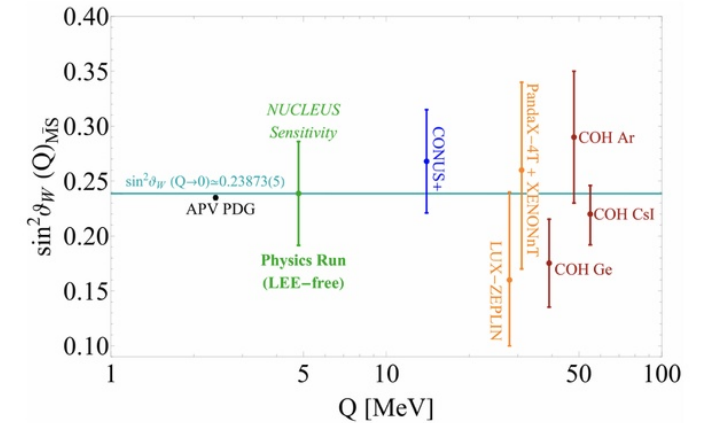
Relocation to Chooz



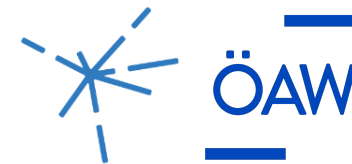
2027

Physics run

Phys. Rev. D 112, 072013 (2025)



The NUCLEUS Collaboration



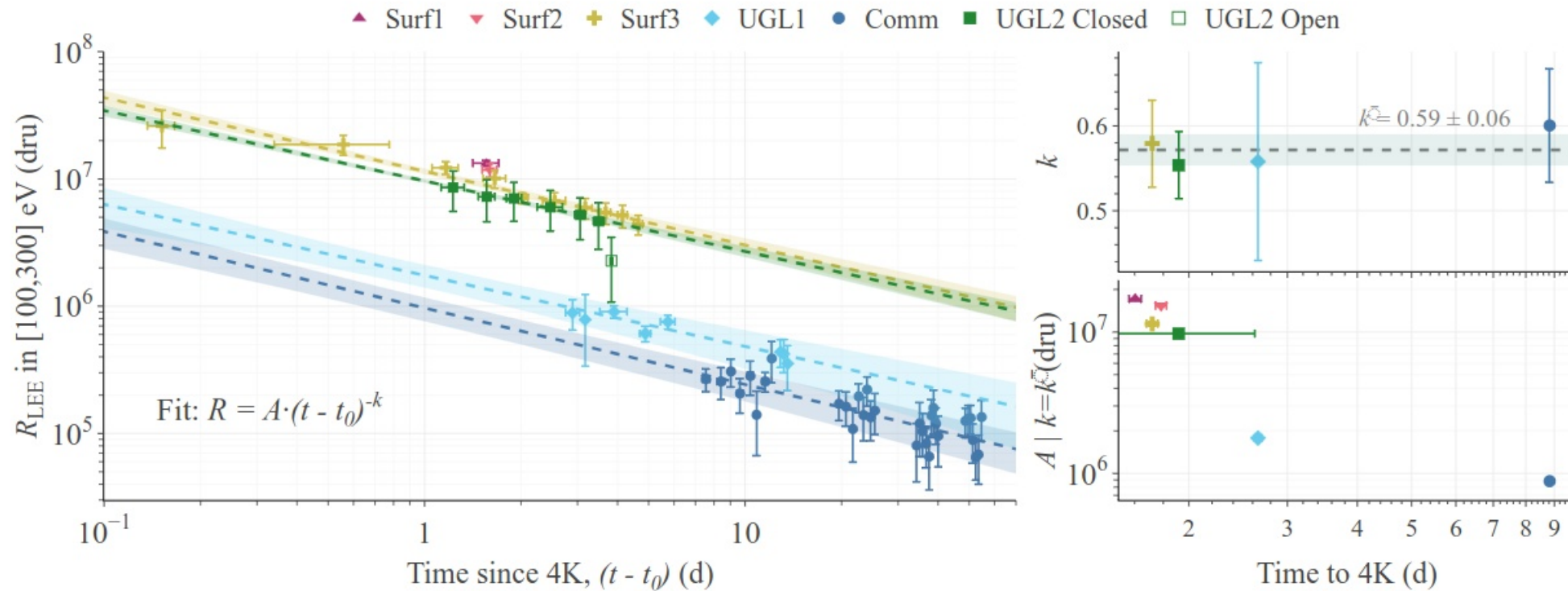
That's it (for now).
Stay tuned for the upcoming (exciting)
developments through our blog!



nucleus-experiment.org/blog

LEE time dependence

$$R_{LEE}(t) = A \cdot (t - t_0)^{-k}$$

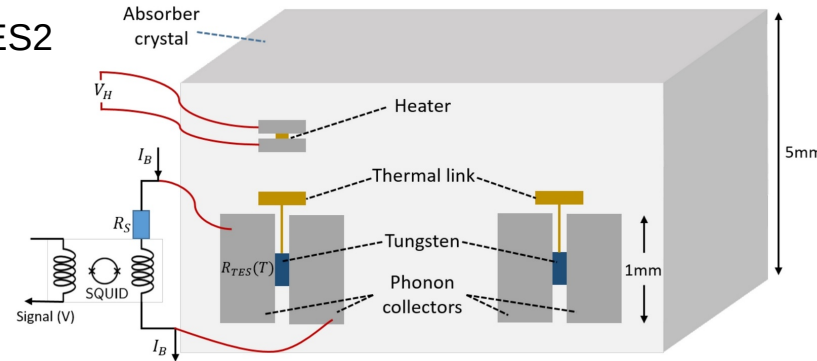


Eur. Phys. J. C 86, 831 (2026)

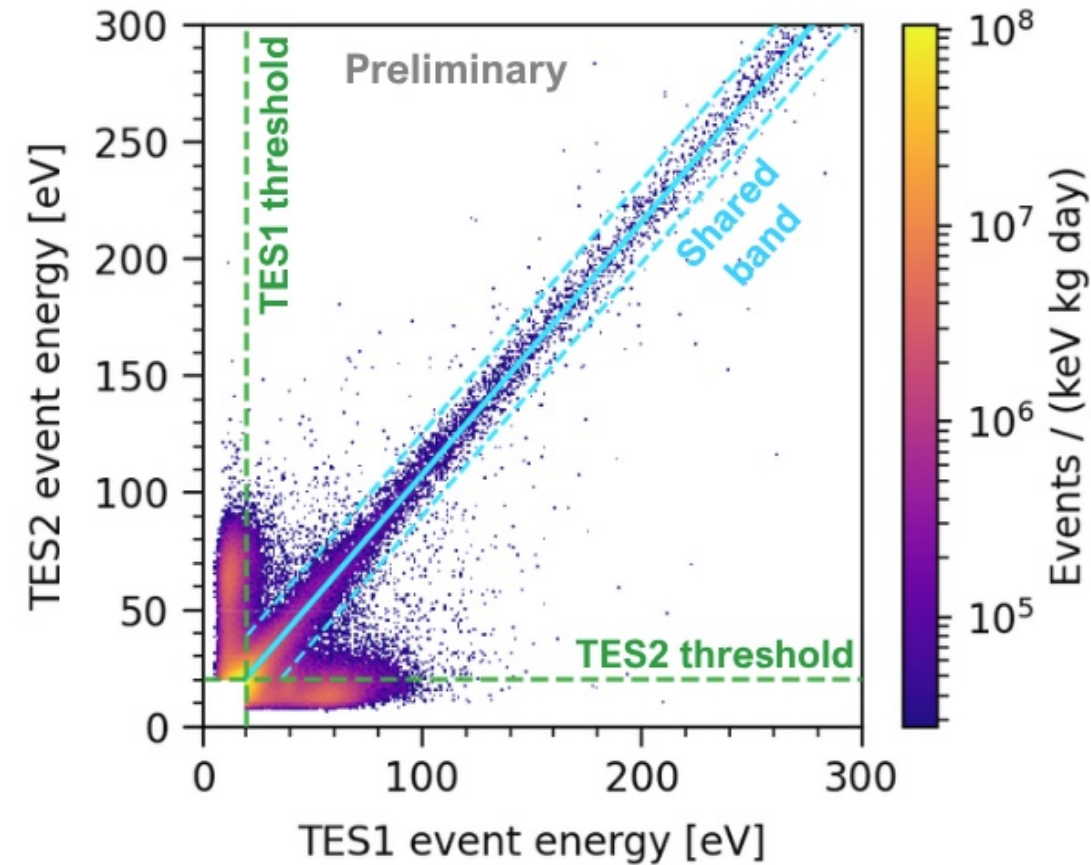
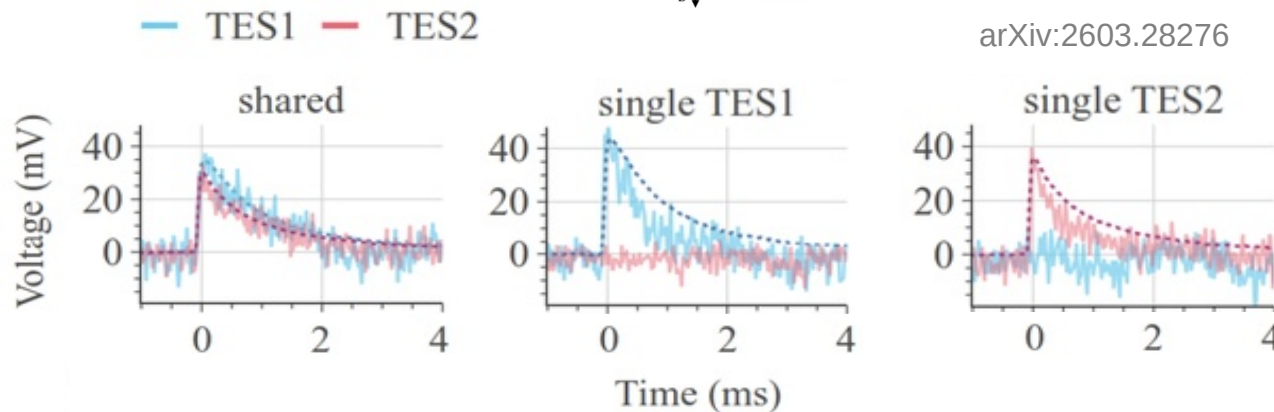
LEE mitigation with Double-TES detectors

Hypothesis: sensor-related stress relaxation?

- ❖ **Double-TES detectors**
- ❖ Events in the crystal bulk are expected to have $E_{\text{TES1}} \approx E_{\text{TES2}}$



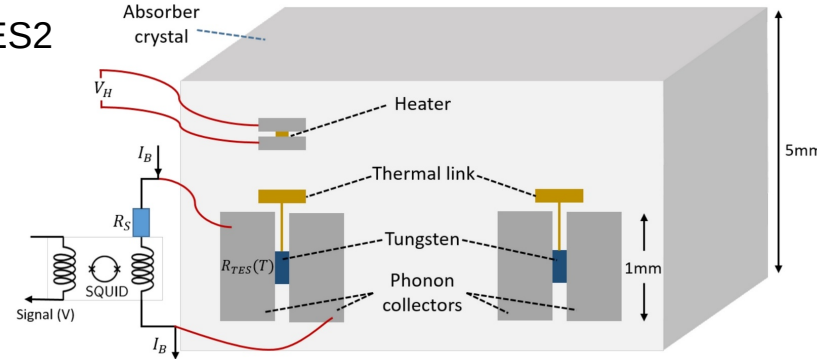
arXiv:2603.28276



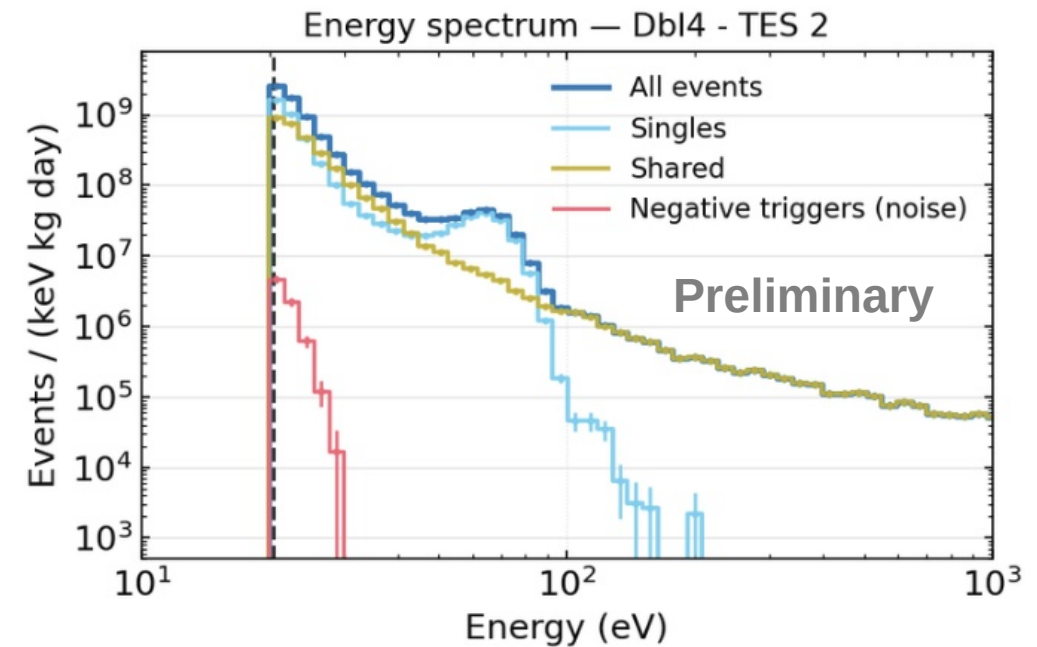
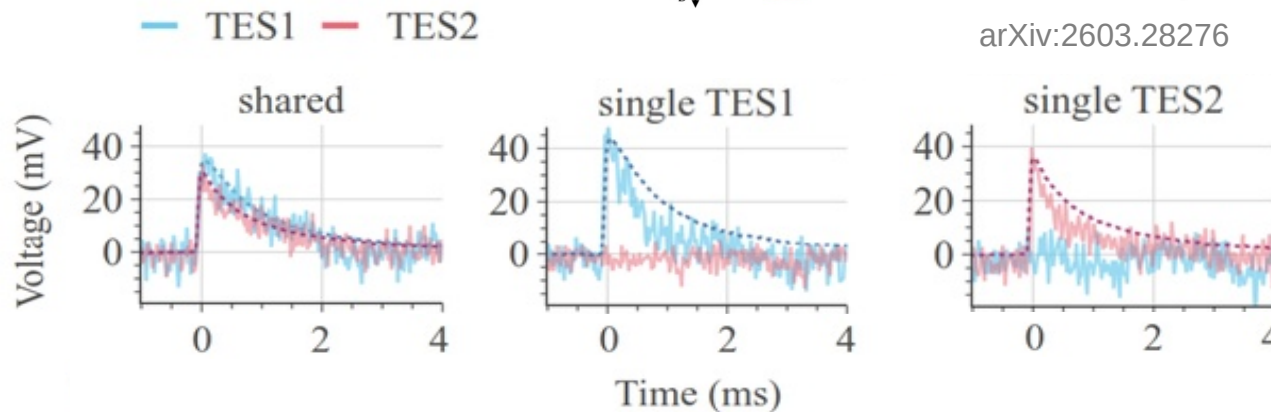
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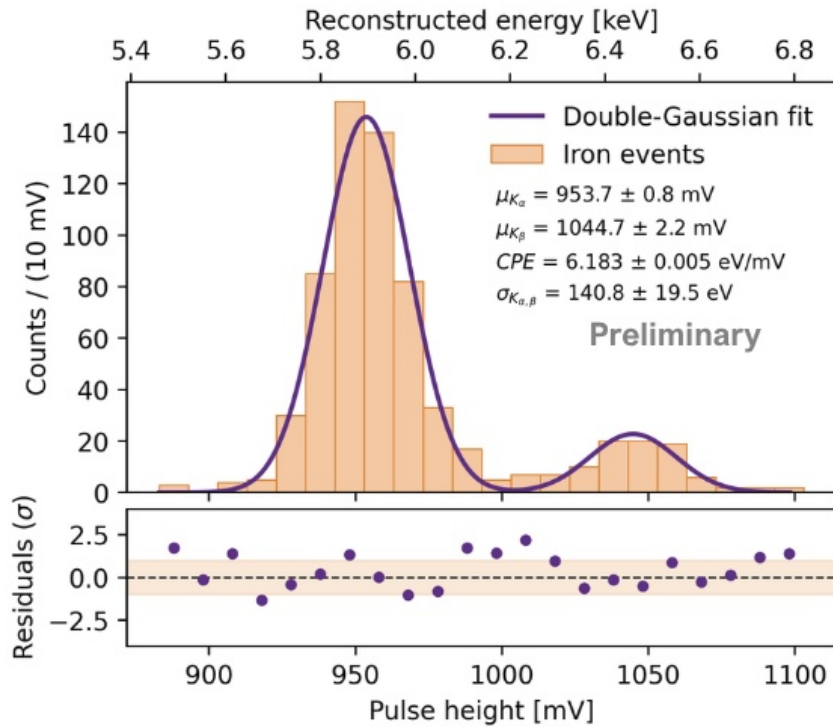
arXiv:2603.28276



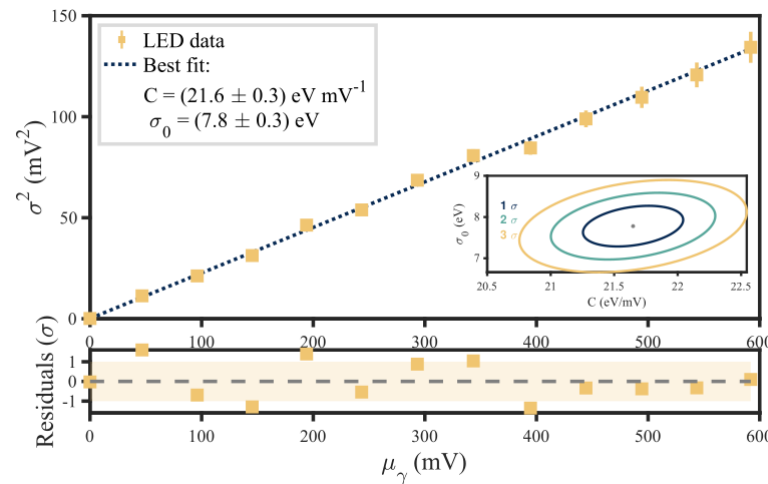
Detector calibration



Calibration with ^{55}Fe source lines (Christmas Run)



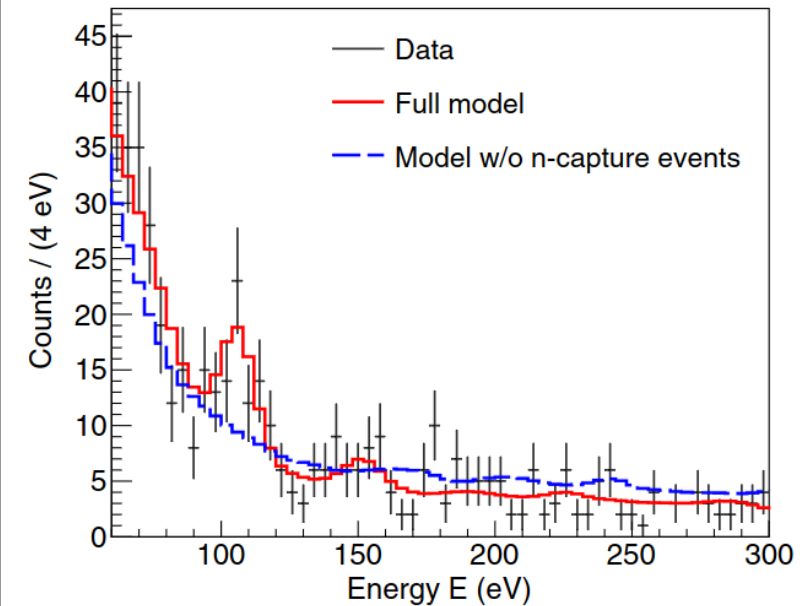
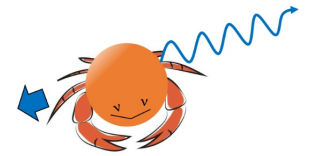
Calibration with LED pulses (TUM commissioning run)



$$\sigma^2 = \frac{1}{C} \cdot \epsilon_\gamma \cdot \mu_\gamma + \sigma_0^2$$

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Future: CRAB calibration (low-E nuclear recoils)

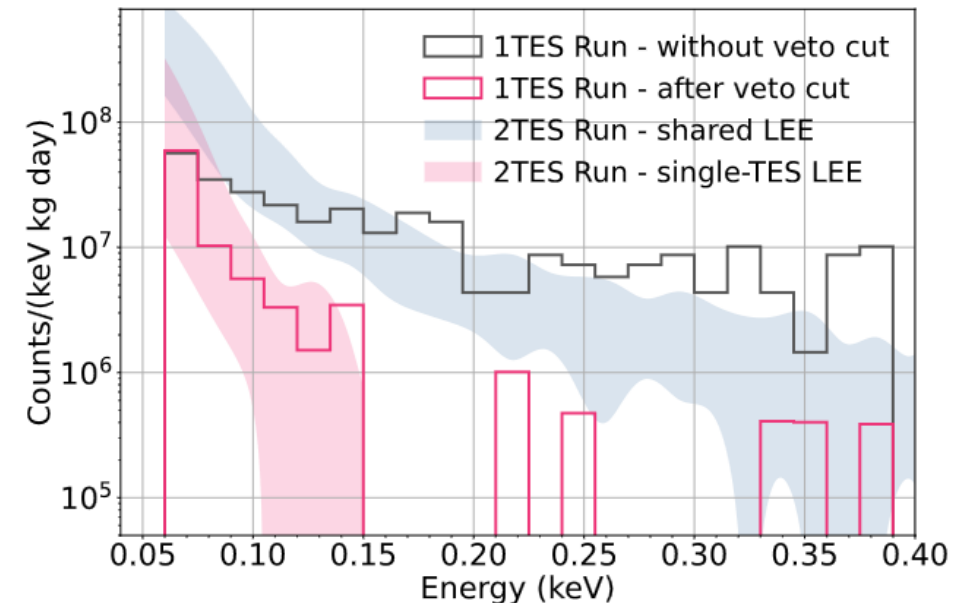
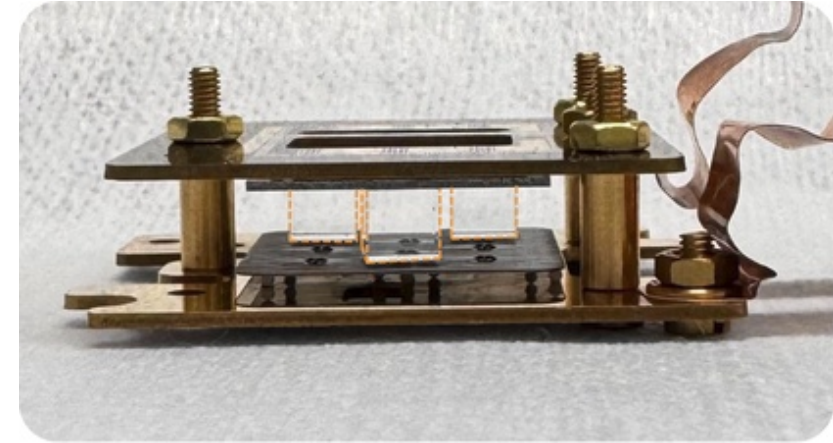


Phys. Rev. Lett. 130, 211802

LEE mitigation with an Inner Veto

Hypothesis: holder-related stress relaxation?

- ❖ Si detector holder (2 wafers)
- ❖ Instrumented with TES
- ❖ LEE mitigation: reject stress-related events originating at the interface between the holder and the crystal

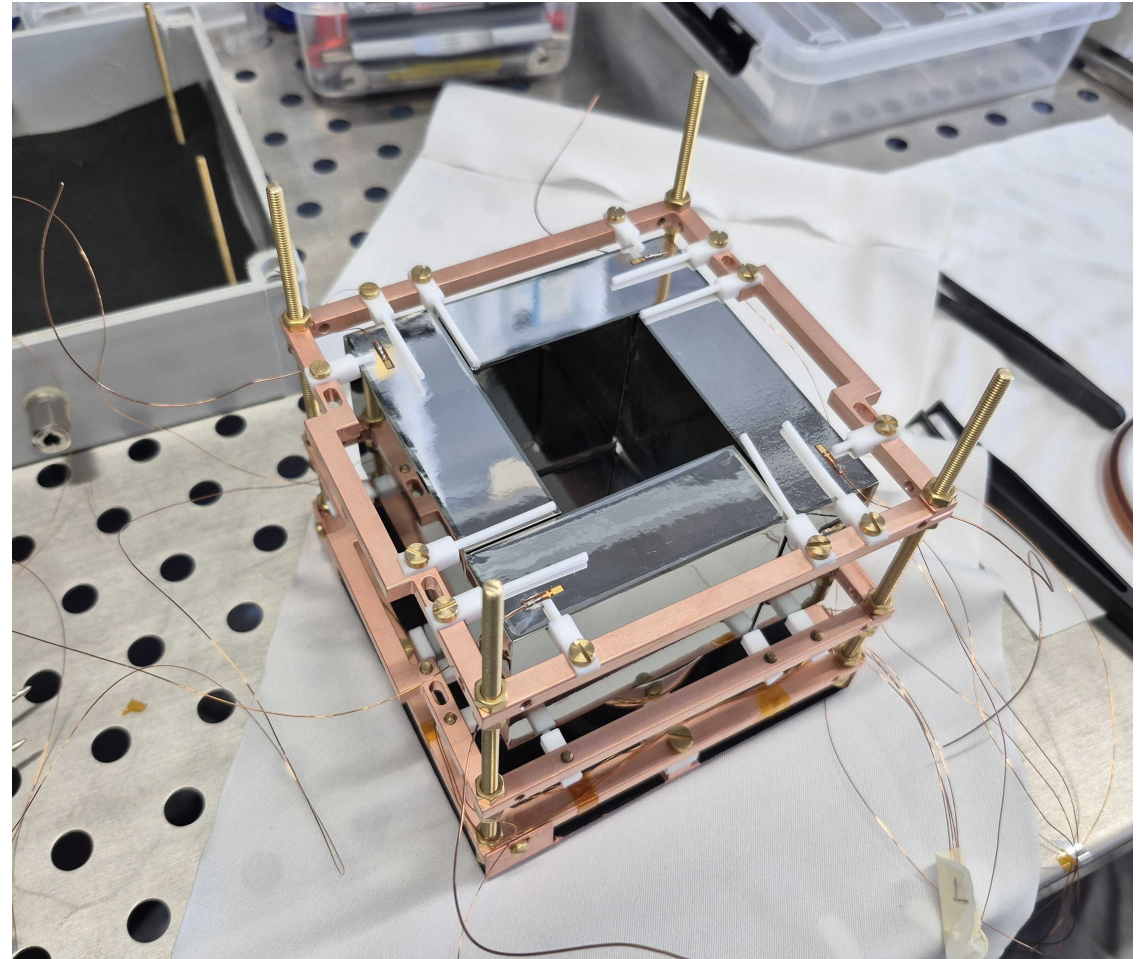


<https://mediatum.ub.tum.de/?id=1759370>

Cryogenic Outer Veto



- ❖ 6 HPGe crystals
- ❖ Ionization mode readout
- ❖ 4π coverage
- ❖ γ , n , μ rejection
- ❖ ~ 10 keV energy threshold

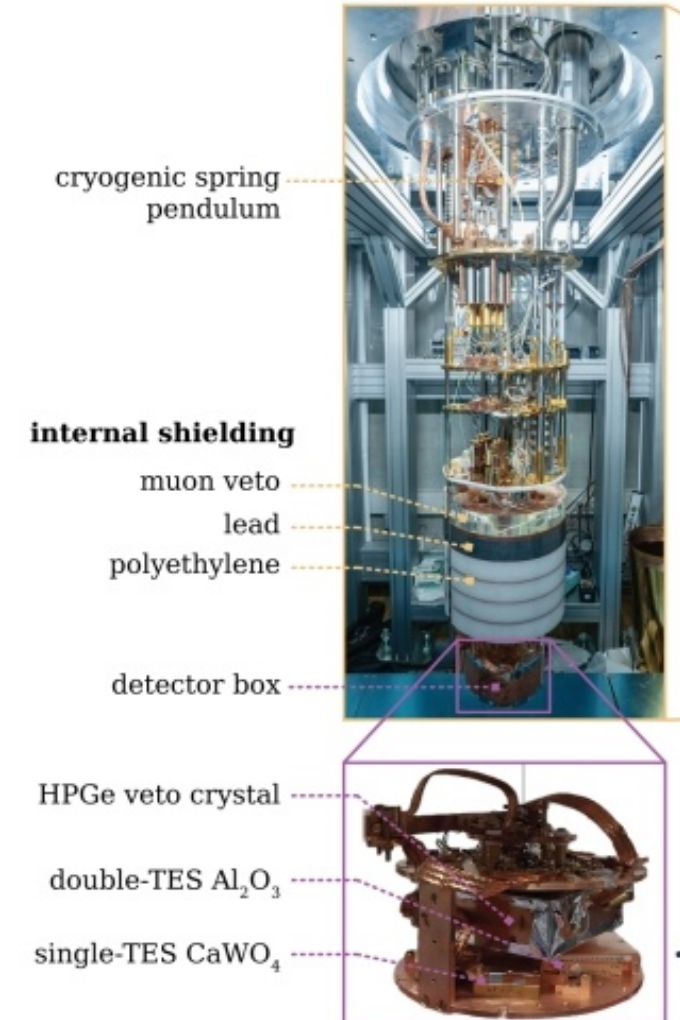


Commissioning at TUM



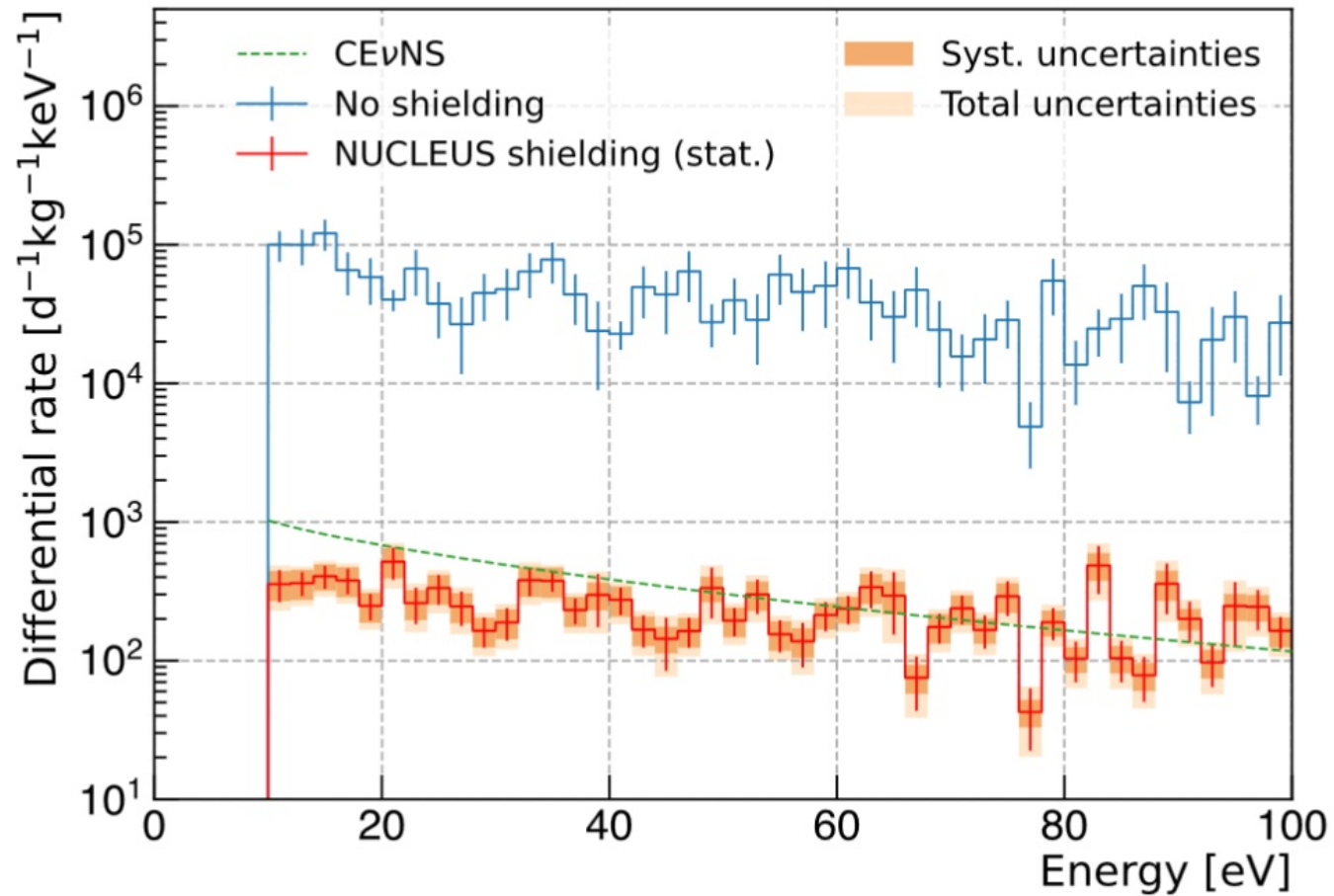
Long Background Run (Summer 2024)

- ❖ **Detector crystal + COV crystal + Muon Veto simultaneous operation**
- ❖ Polyethylene and lead shielding (warm and cold) deployed
- ❖ Data-MC agreement within a factor of 2
- ❖ Crucial milestone for the experiment!



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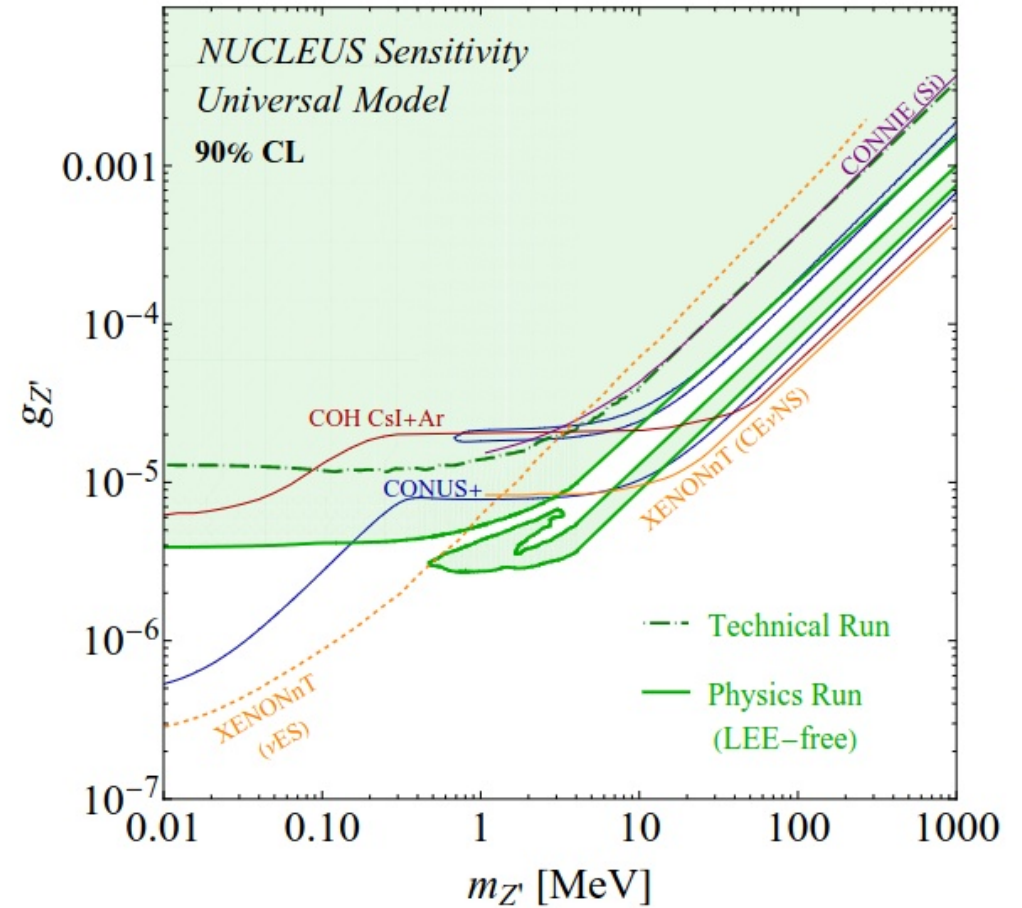
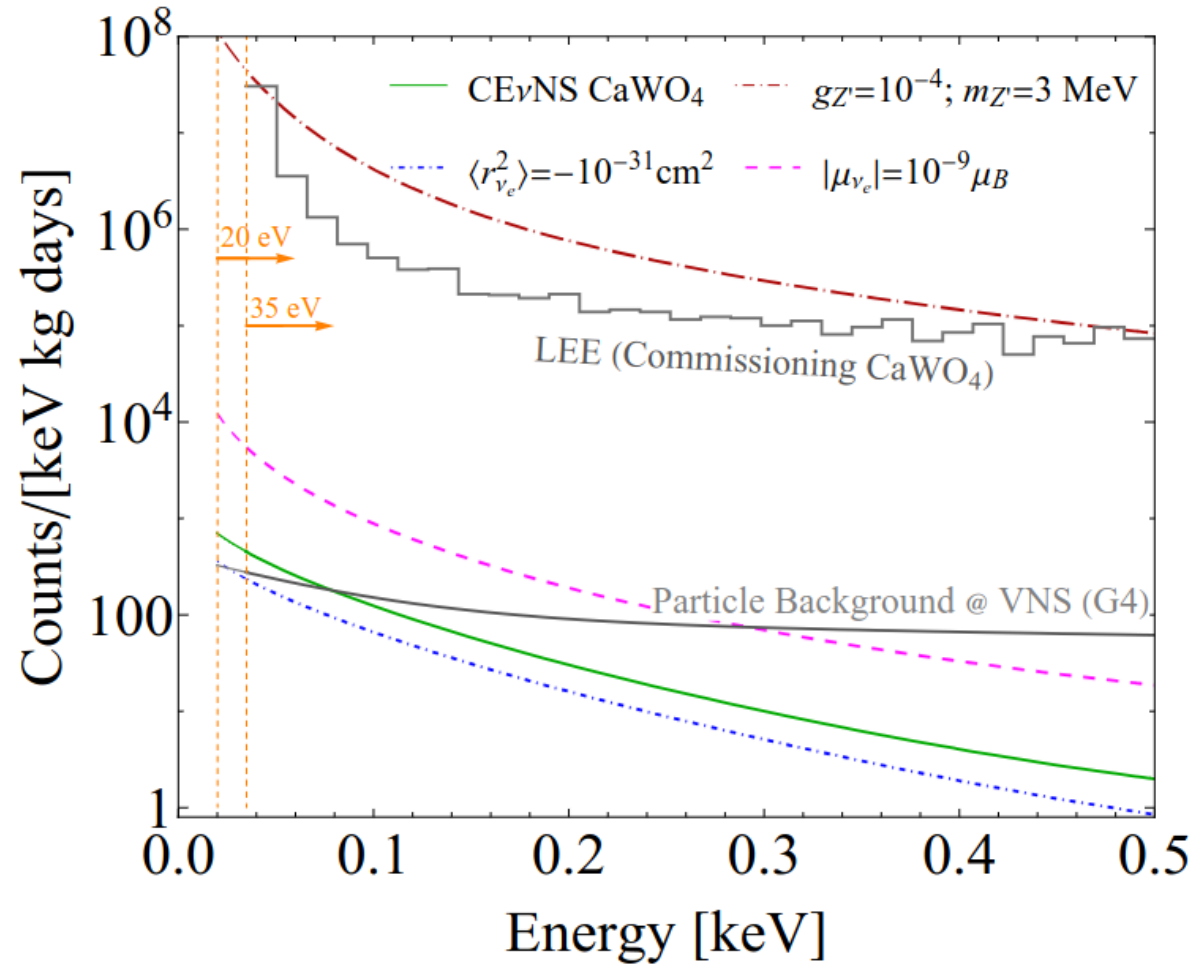
NUCLEUS Physics Sensitivity



Hypothesis of no LEE!

Eur. Phys. J. C 86, 29 (2026)

NUCLEUS Physics Sensitivity



Phys. Rev. D 112, 072013 (2025)

I. CEvNS properties



Differential cross-section

$$\frac{d\sigma}{d\Omega} = \frac{\overset{\text{Fermi constant}}{G_F^2}}{16\pi^2} \underset{\substack{\text{Weak nuclear charge}}}{Q_W^2} \overset{\text{Neutrino energy}}{E_\nu^2} (1 + \underset{\substack{\text{Scattering angle}}}{\cos \theta}) \overset{\substack{\text{Form factor} \\ \text{(accounts for non-coherence)}}}{F(Q^2)}$$

$$\overset{\text{\# neutrons}}{Q_W^2} = (N - (1 - 4 \sin^2 \theta_W)Z)^2 \approx N^2$$

$$F(Q^2) \approx 1 \quad (\text{for } \sim \text{MeV neutrinos})$$

NUCLEUS specificities

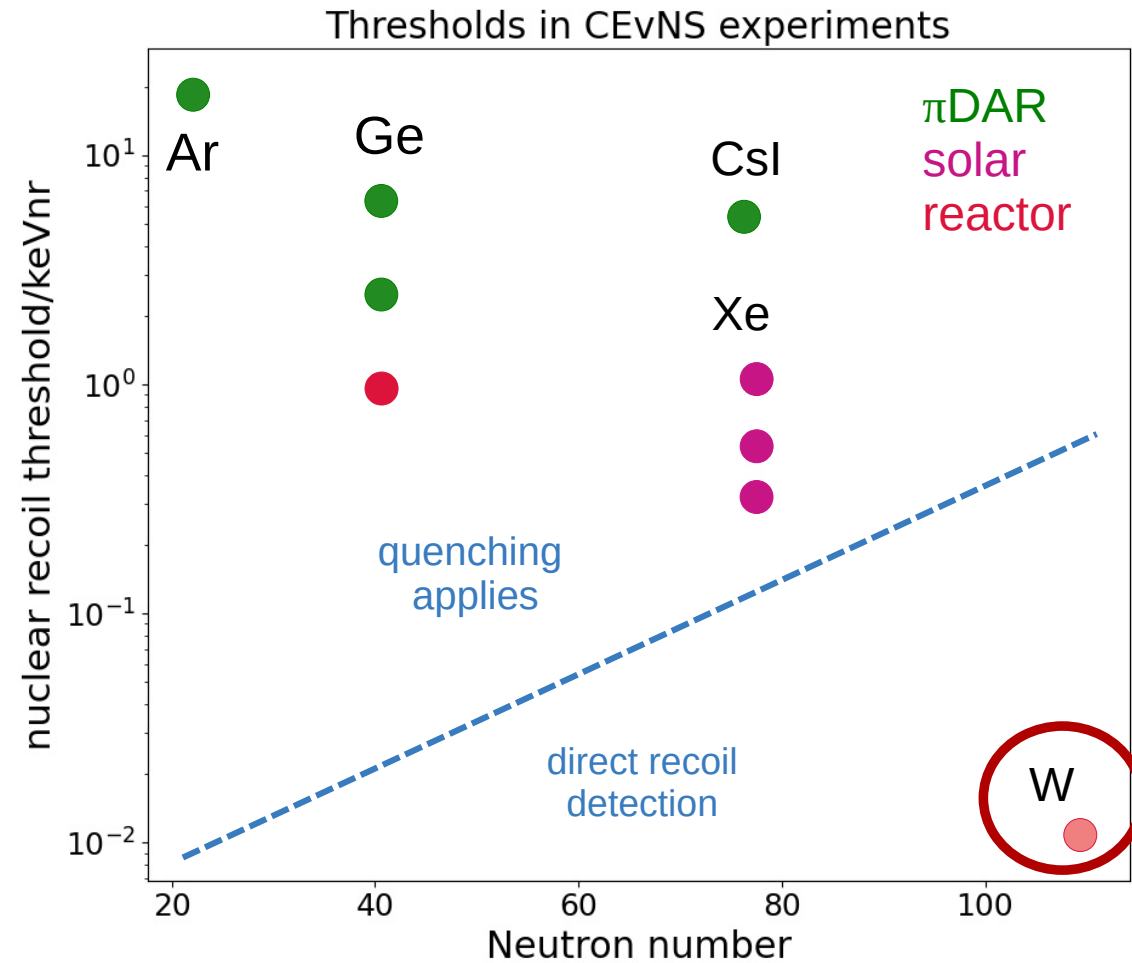


Figure by J. Hakenmüller