

At the 100 eV Frontier: Calibrating Nuclear Recoils with CRAB

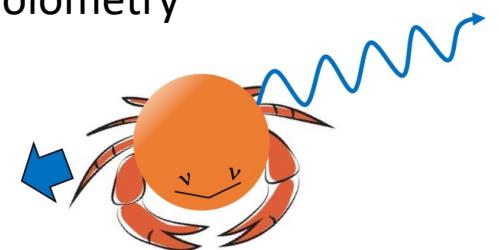
Victoria Wagner
on behalf of the CRAB Collaboration

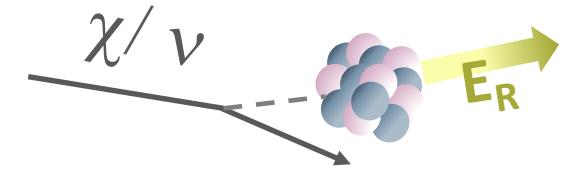
XVII International Conference on Topics in Astroparticle
and Underground Physics

August 29th, 2023

University of Vienna

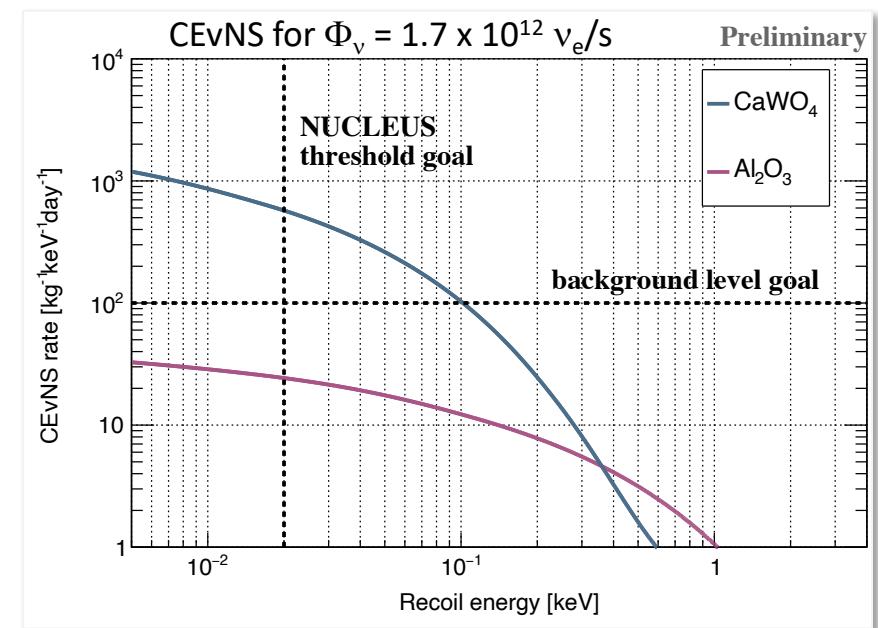
Calibrated Recoils for
Accurate Bolometry



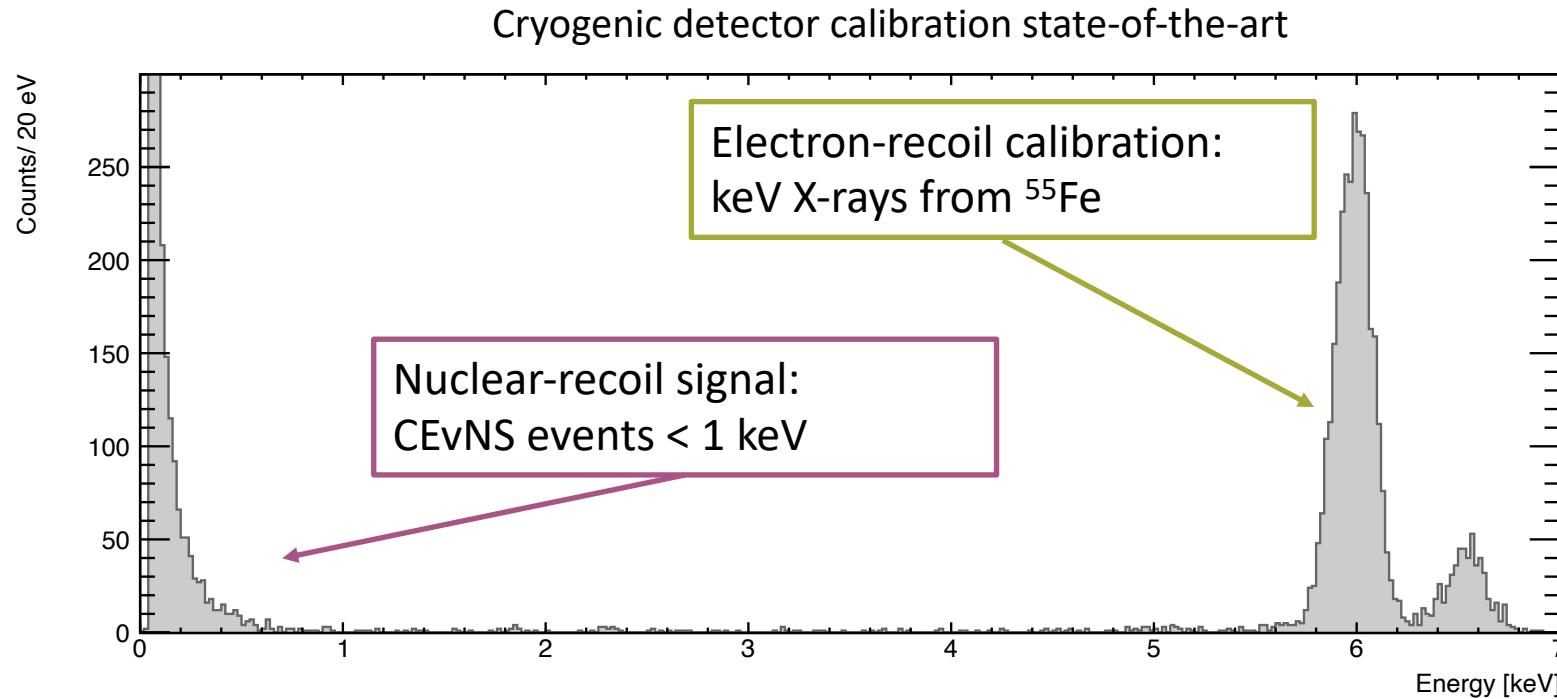


Sub-keV Nuclear Recoils in CEvNS & DM Studies

- CEvNS/ Dark Matter signature is a (sub)-keV nuclear recoil
- Solid-state cryogenic detectors reach **O(few 10 eV thresholds)** to
 - search for CEvNS of reactor neutrinos
 - probe DM masses down to 0.2 GeV
- Understanding of **energy scale is** crucial to find & interpret **new physics**



Low-Energy Calibration



Limitations

- Detector linearity
- ER/ NR differences

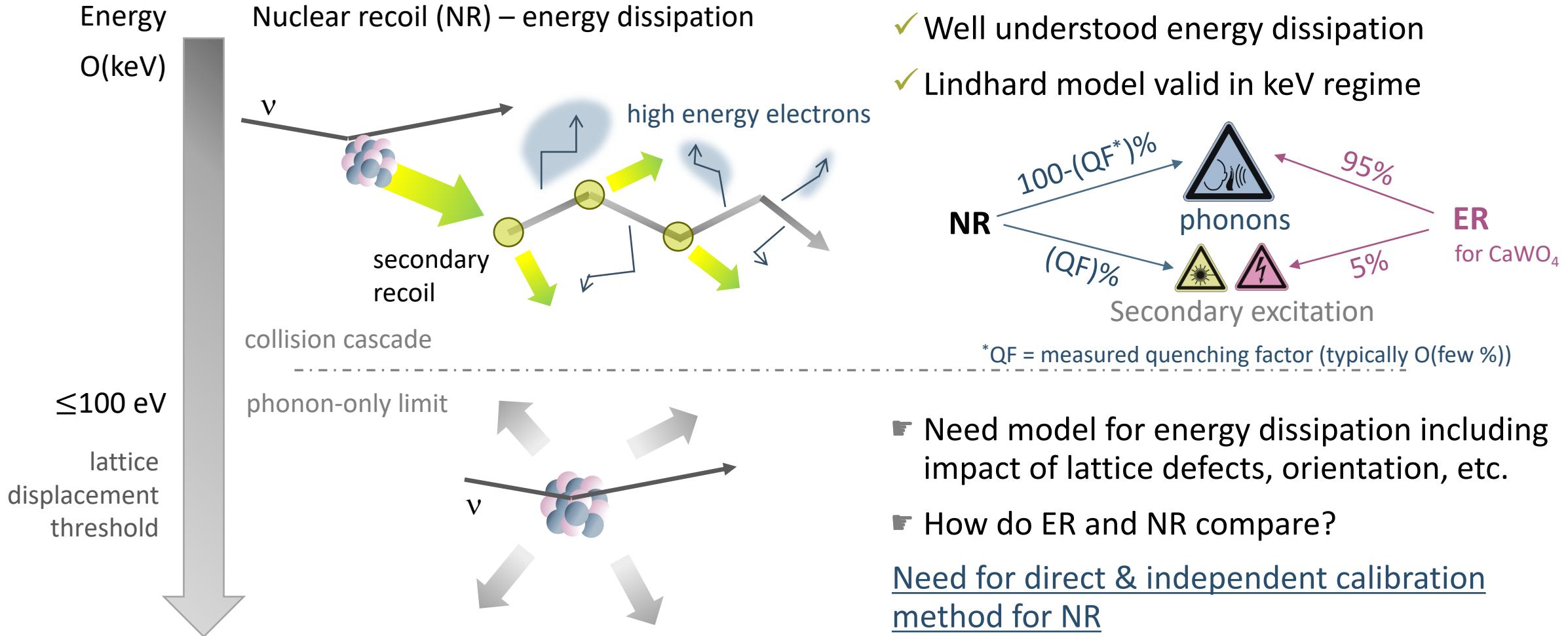


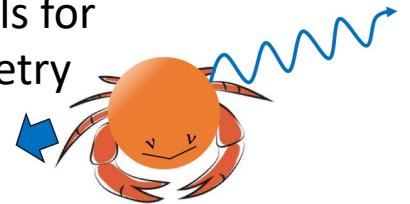
- Push electron-recoil calibration below 1keV: X-ray fluorescence sources
- Novel sub-keV nuclear-recoil calibration: **CRAB-method**

see T. Lasserre's talk

This talk

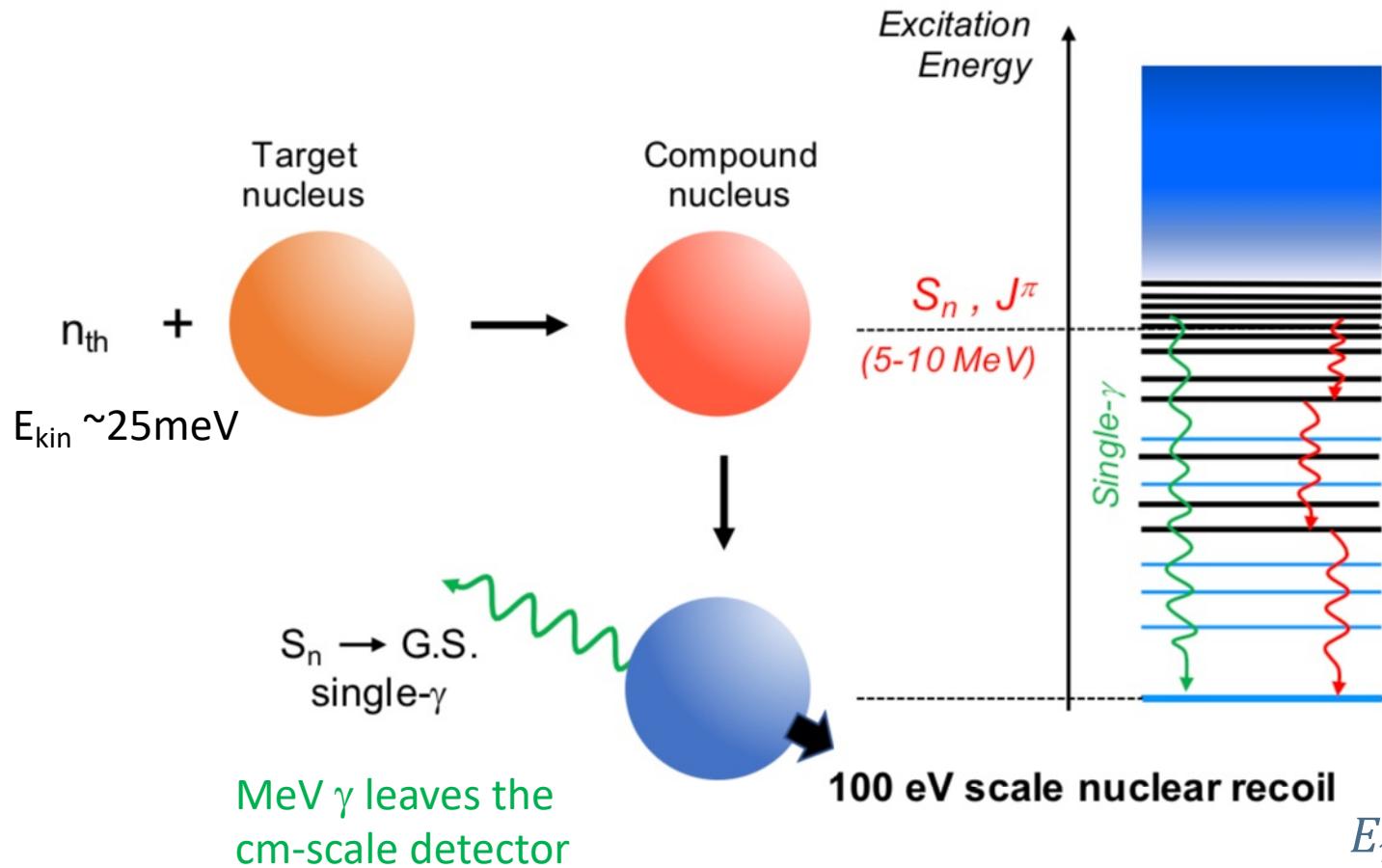
The Need for Nuclear Recoil Calibration at 100 eV





Calibration of Sub-keV NR

based on L. Thulliez, D. Lhuillier *et al* 2021 JINST 16



Key ingredient: simulation code FIFRELIN* for prediction of

- ✓ signal nuclear recoils induced by single- γ emission
- ✓ background induced by multi- γ cascades
- ✓ Recently: timing effects

*O. Litaize et al., Eur. Phys. J. A 51, 1 (2015)

$$E_{nr} = \frac{E_\gamma^2}{2M} \sim O(100\text{ eV} - 1\text{ keV})$$



The CRAB Collaboration: Calibrated Recoils for Accurate Bolometry



Strong collaboration with



CRAB (V. Wagner, TUM)

See talk by T. Lasserre



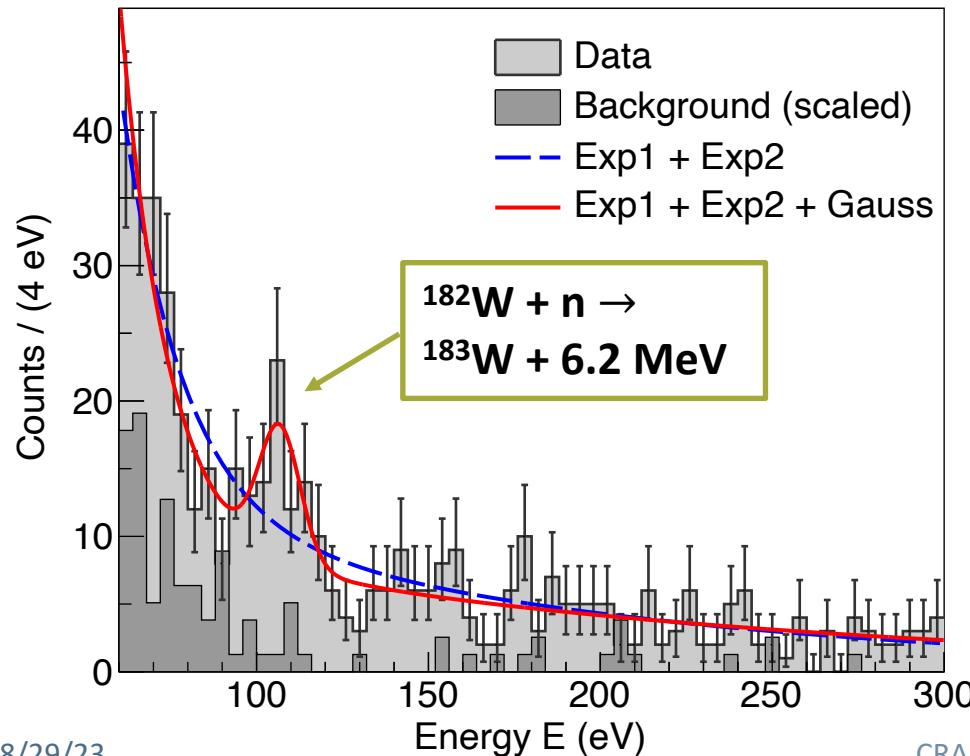
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Observation of a NR Peak at the 100 eV Scale Induced by Neutron Capture

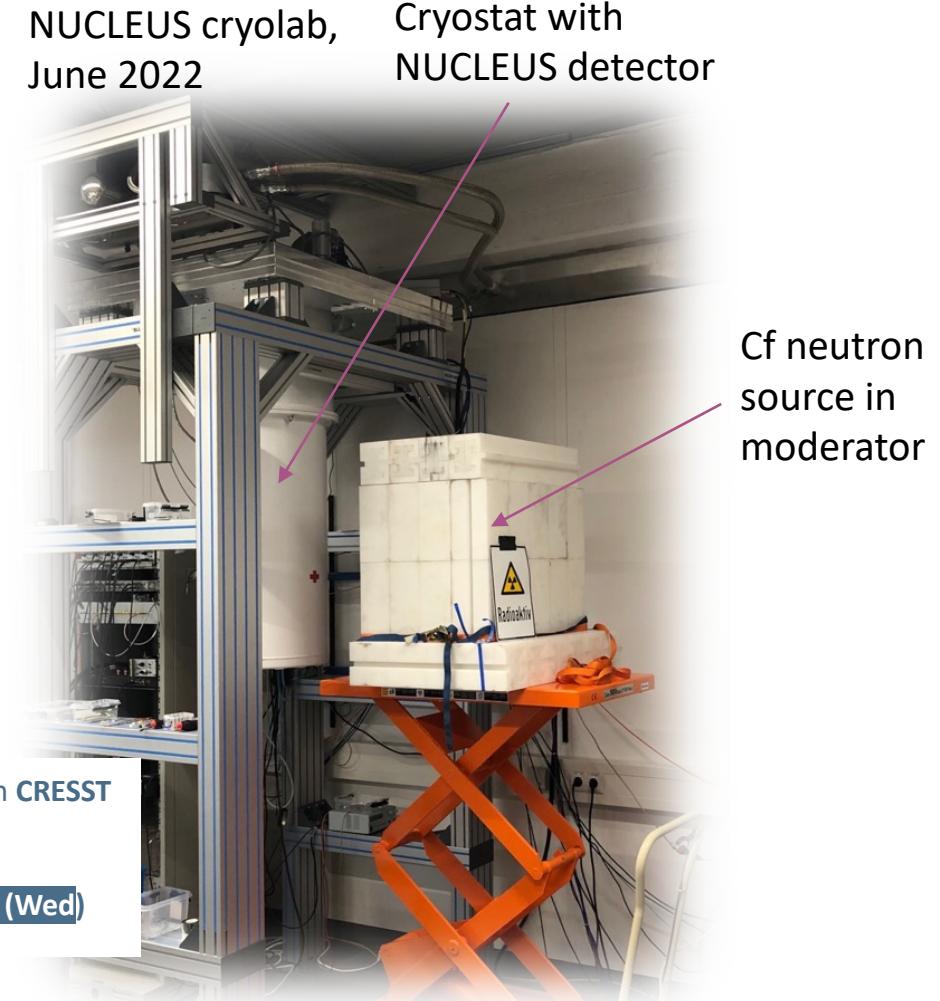
See poster by G. Del Castello (Wed)

- Stable operation with 6 eV resolution over 60 h
- Nuclear recoil peak at 112 eV observed with more than 3σ significance

Phys. Rev. Lett. 130, 211802 (2023)



Observation of this process in CRESST
recently published:
Phys. Rev. D 108, 022005
See talk by M. Kaznacheeva (Wed)

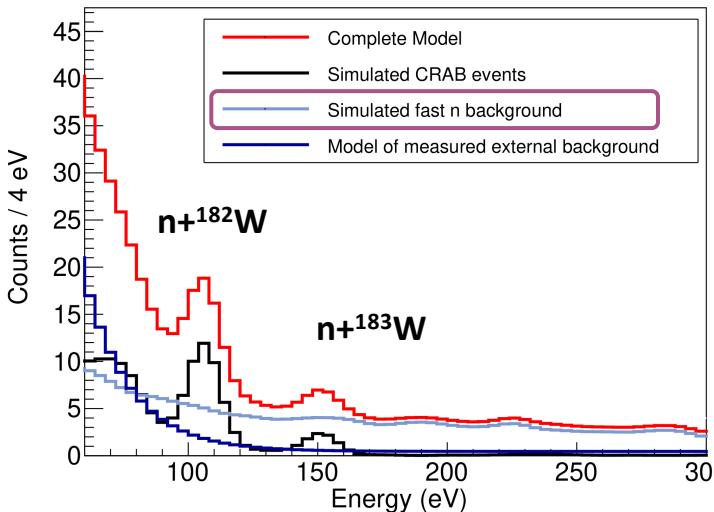


Next Steps

Towards a precision calibration of CaWO₄

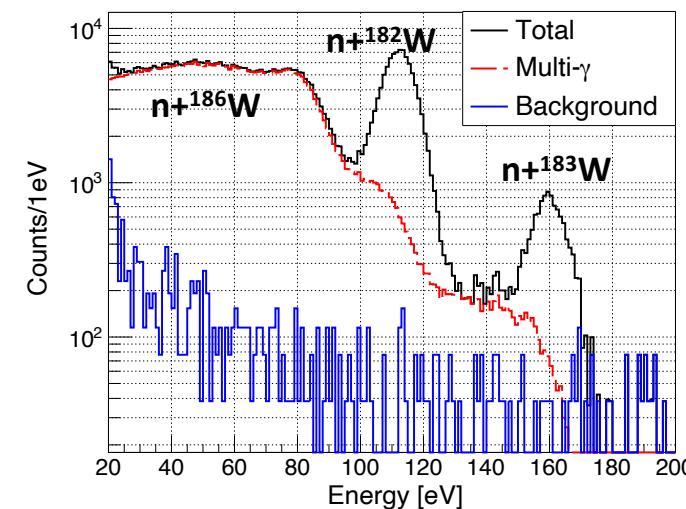
✓ Radiogenic source

Limited by fast neutron background



⚙ Thermal neutron beam

Limited by multi- γ background



08/29/23

CRAB (V. Wagner, TUM)

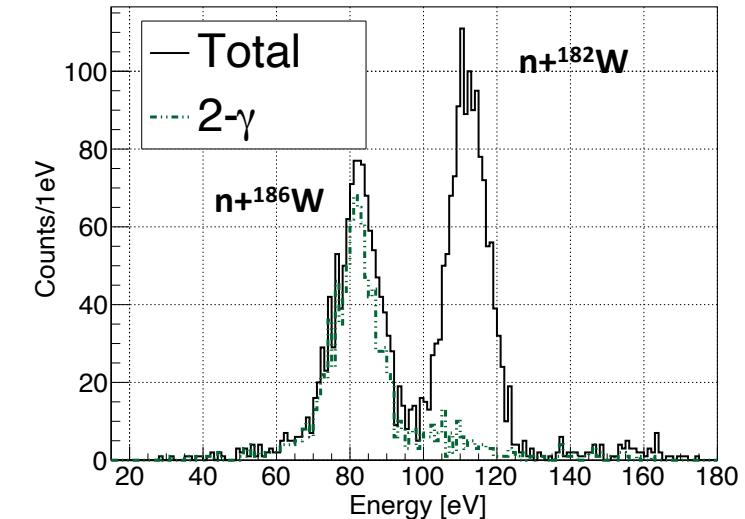
Target material	Target Isotope	Nuclear Recoil [eV]	F.O.M.*
CaWO ₄	¹⁸² W	112.5	7506
	¹⁸³ W	160.3	823
	¹⁸⁶ W	85.8	281

* F.O.M. = nat. abundance * σ * BR

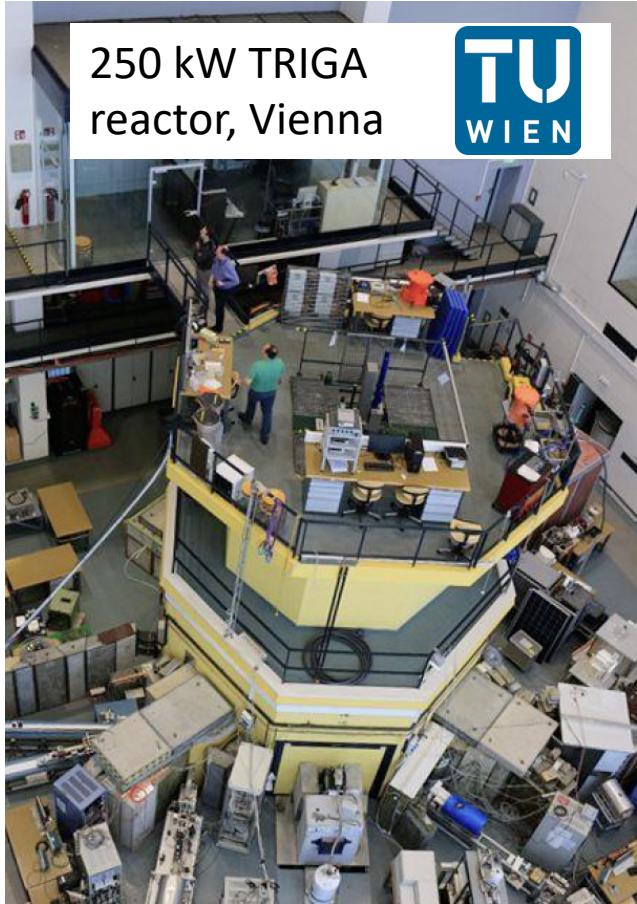
⚙ Coincident γ -tagging

Quasi background-free,
Relaxing E-resolution constraints

(5.47 ± 0.2) MeV

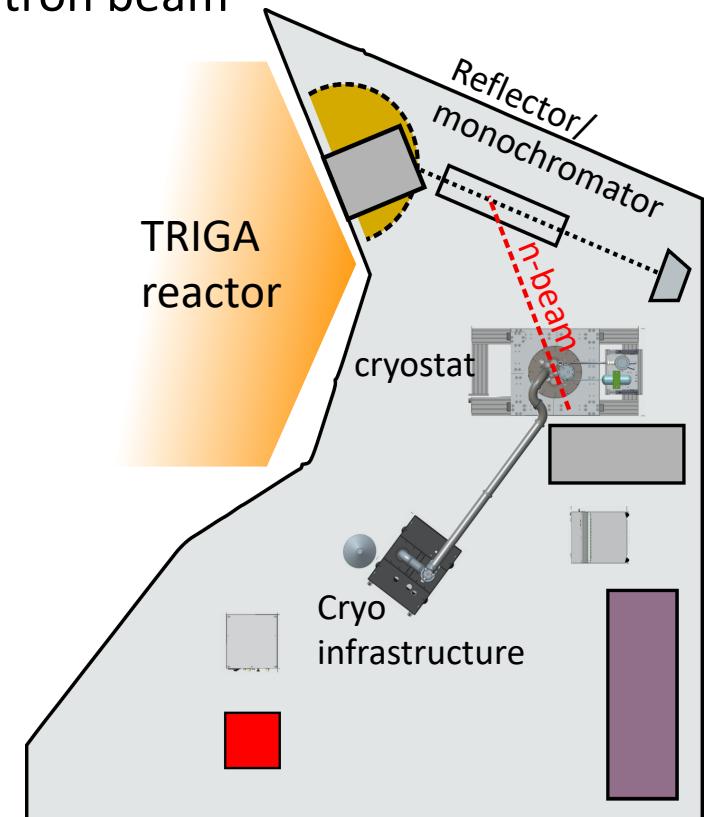
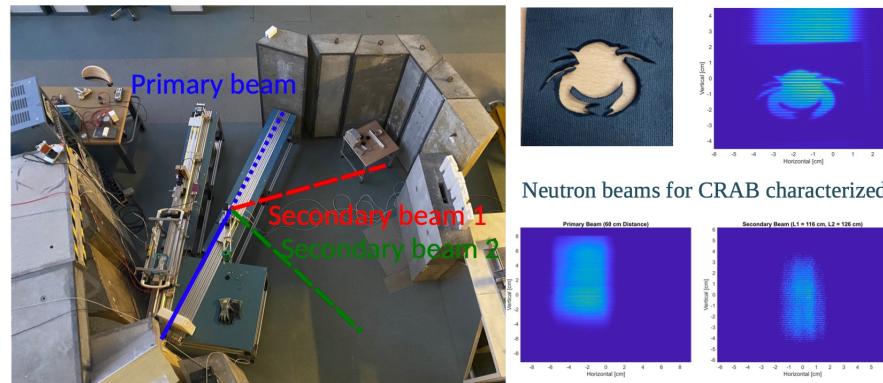


CRAB Beamlne



- ✓ Low power TRIGA reactor in Vienna provides optimal conditions: monochromatic thermal neutron beam with $1-100 \text{ n/cm}^2/\text{s}$
- ✓ negligible background of fast neutrons and γ -rays

⌚ On-going beamline construction



Other Materials & Physics Potential

Target material	Target Isotope	Nuclear Recoil [eV]	F.O.M.*
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	¹⁸⁶ W	85.8	281
Al ₂ O ₃	²⁷ Al	1145	616
Si	²⁸ Si	1330	36
	²⁸ Si	989.9	118
Ge	⁷⁰ Ge	416.2	122
	⁷⁴ Ge	303.2	54

Linearity Study with
three NR peaks

Strong single- γ
transition

Interesting double- γ
transition for **timing studies**

Long-lived nuclear levels for
timing studies

Quenching factor measurements
for ionization and NTL-detectors

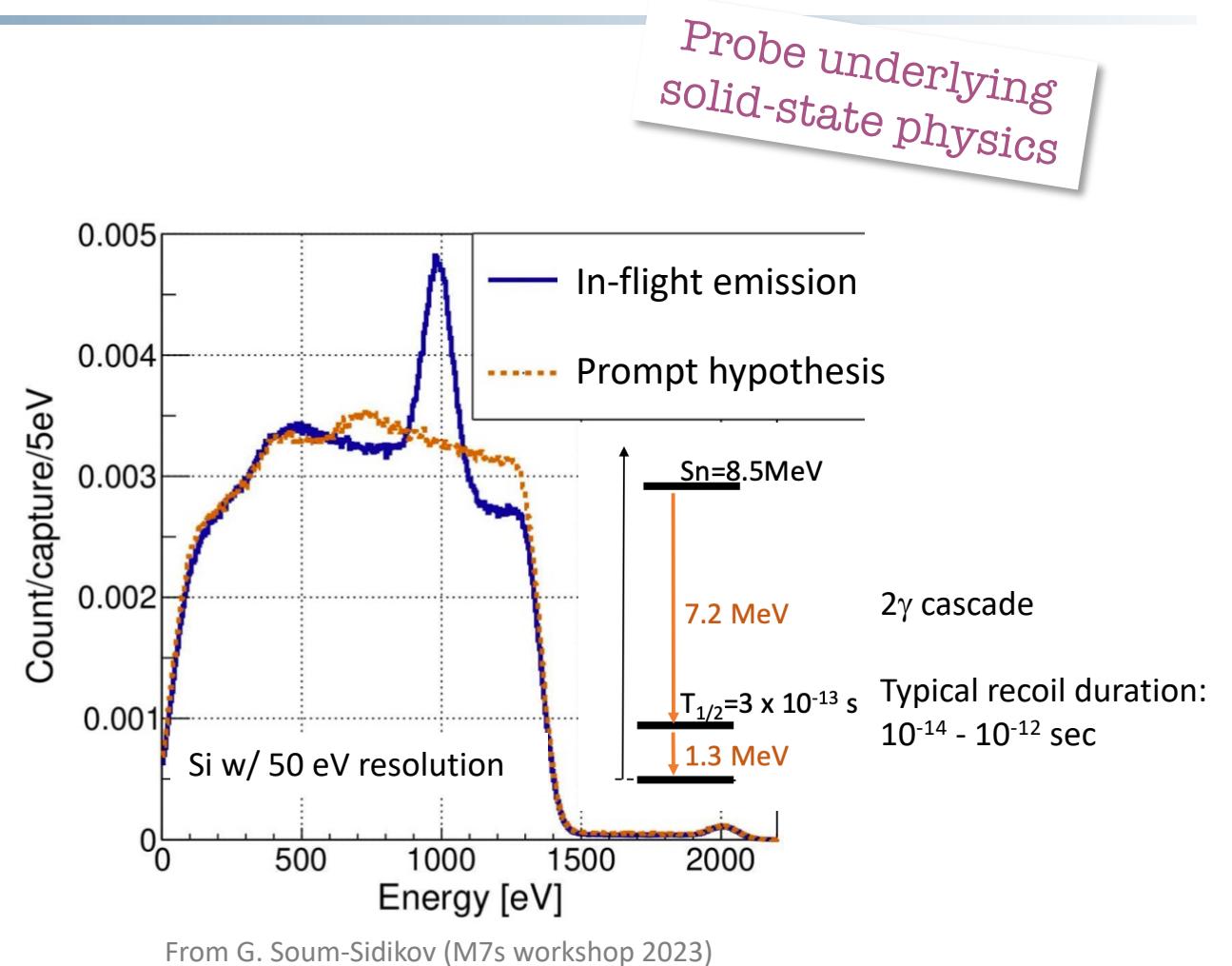
* F.O.M. = nat. abundance * σ * BR

Timing Effects -Si

G. Soum-Sidikov, arXiv:2305.10139

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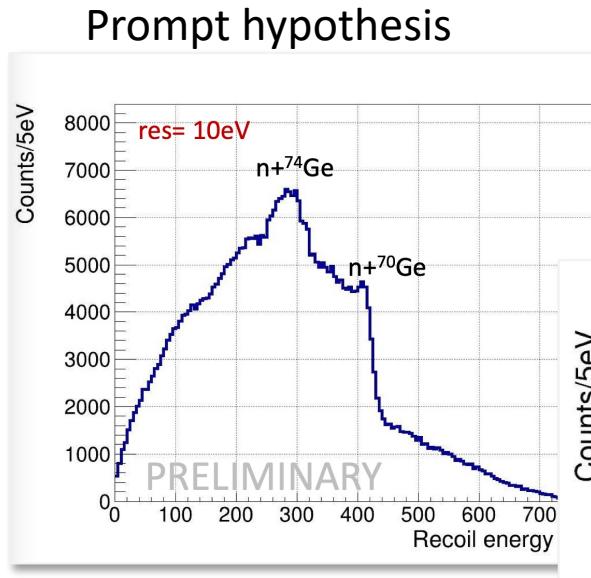


Timing Effects - Ge

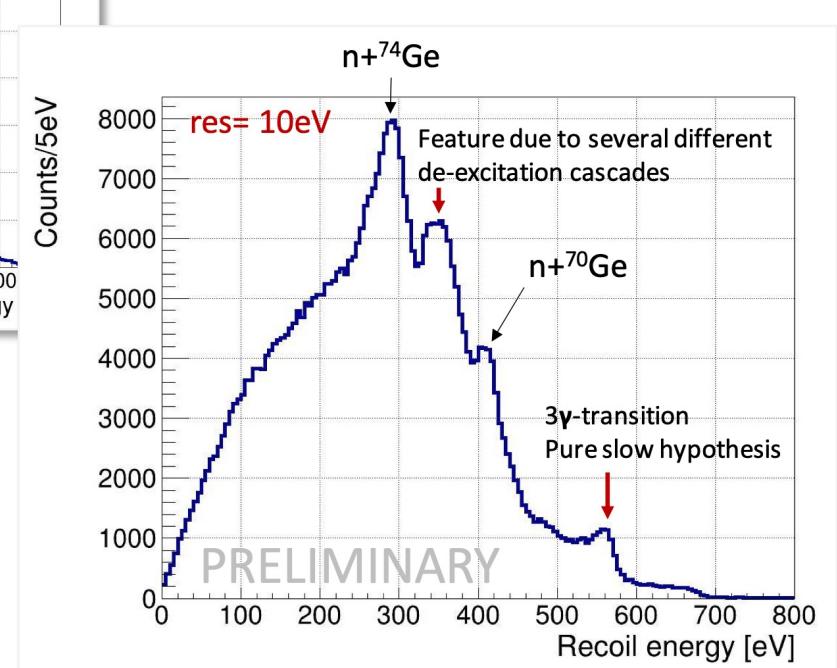
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Calibration peak selection with γ -tagging



From G. Soum-Sidikov (M7s workshop 2023)

Further calibration features from long-lived nuclear levels -> Quenching factor measurement(s)

CRAB: Towards a Precision Calibration Facility for the DM and CEvNS Community

2023



- ✓ Calibration of NUCLEUS detectors (CaWO_4)

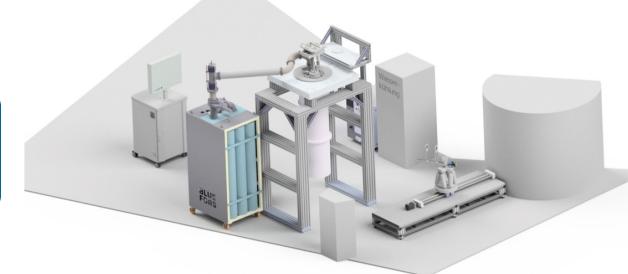


Proof of principle

Installation &
first measurements
@TU Wien



end of 2023

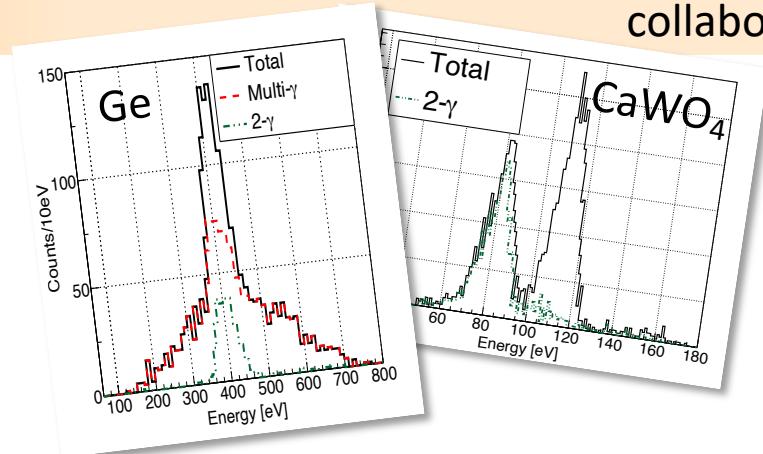


2024

- Study **linearity**
- Application to **other materials** beyond CaWO_4
- Measurement of **quenching factor at sub-keV**

Upgrade: γ -tagging

Calibration facility
Open for new
collaborators

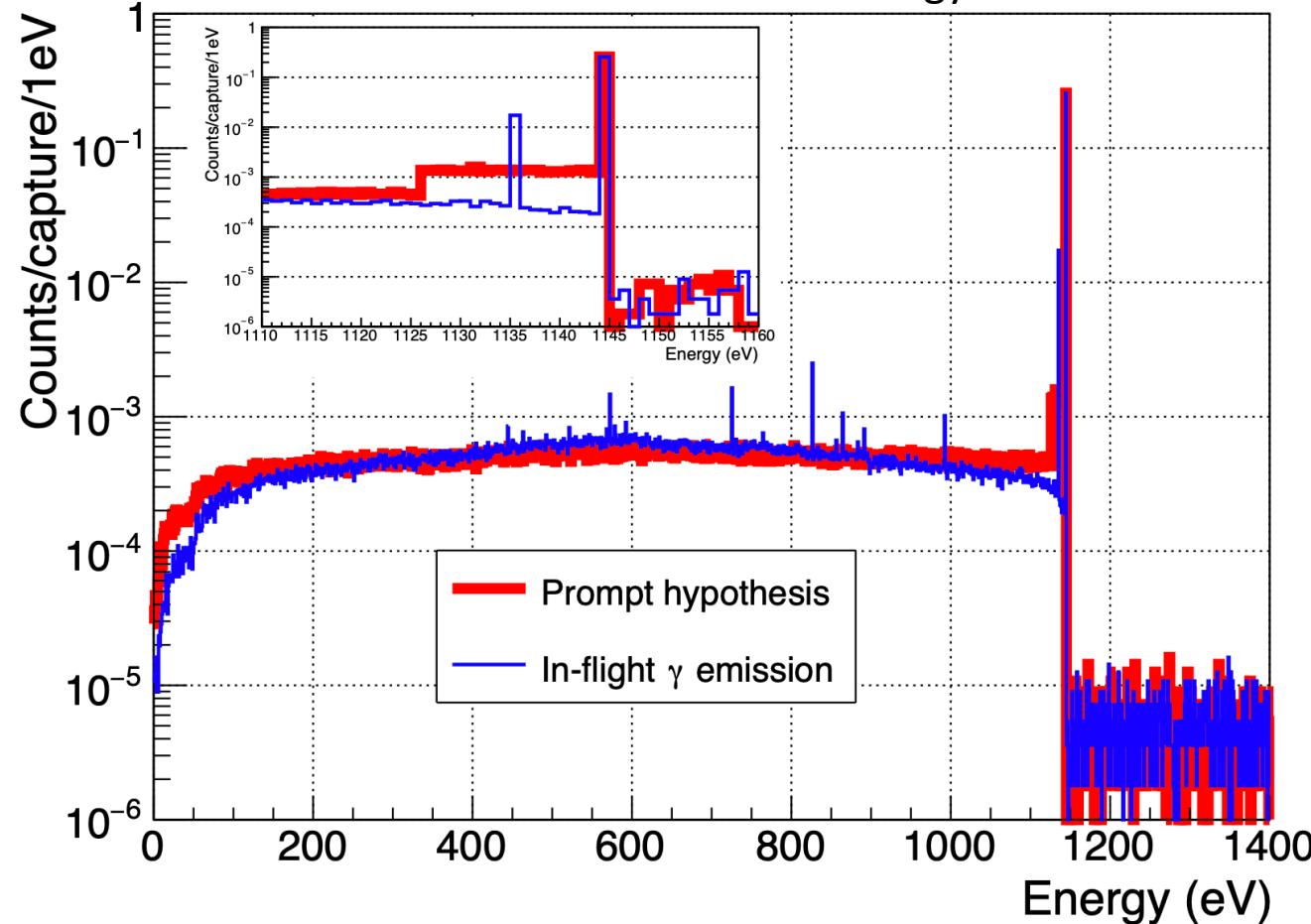


BONUS SLIDES

Al_2O_3 Transition Spectrum

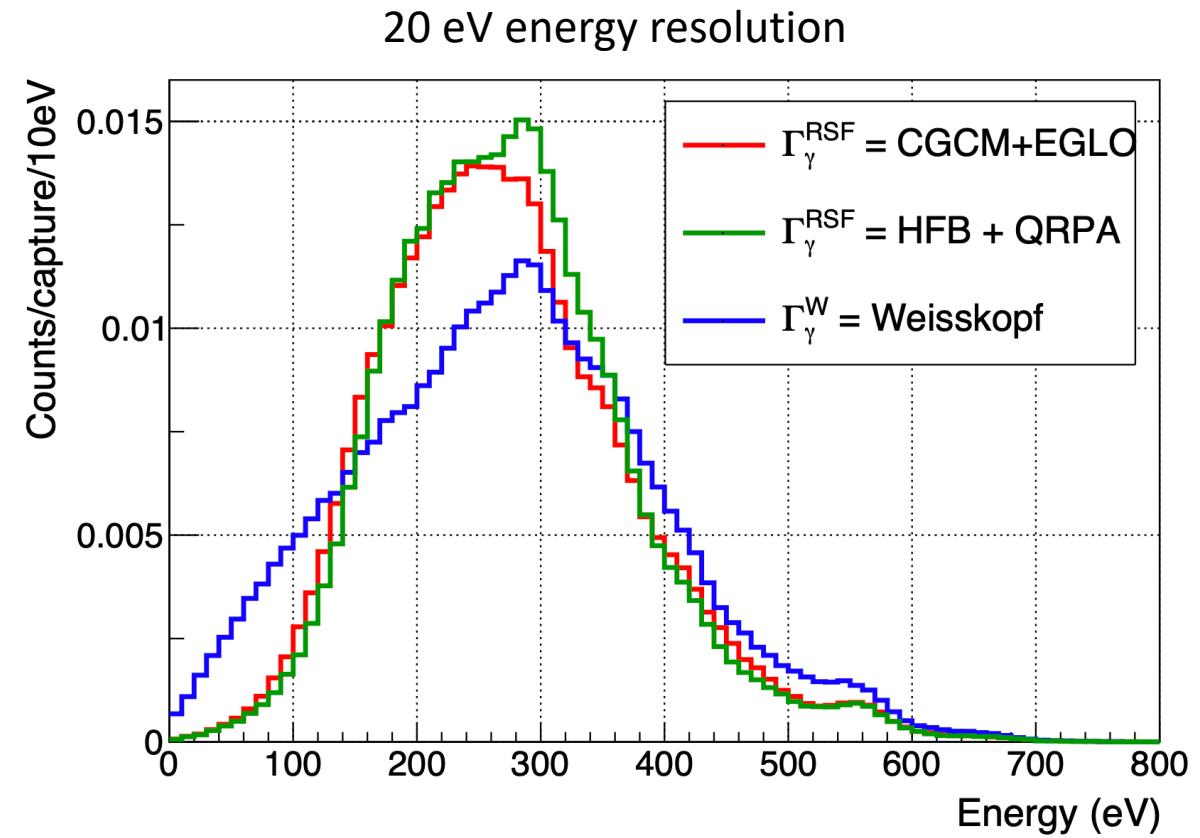
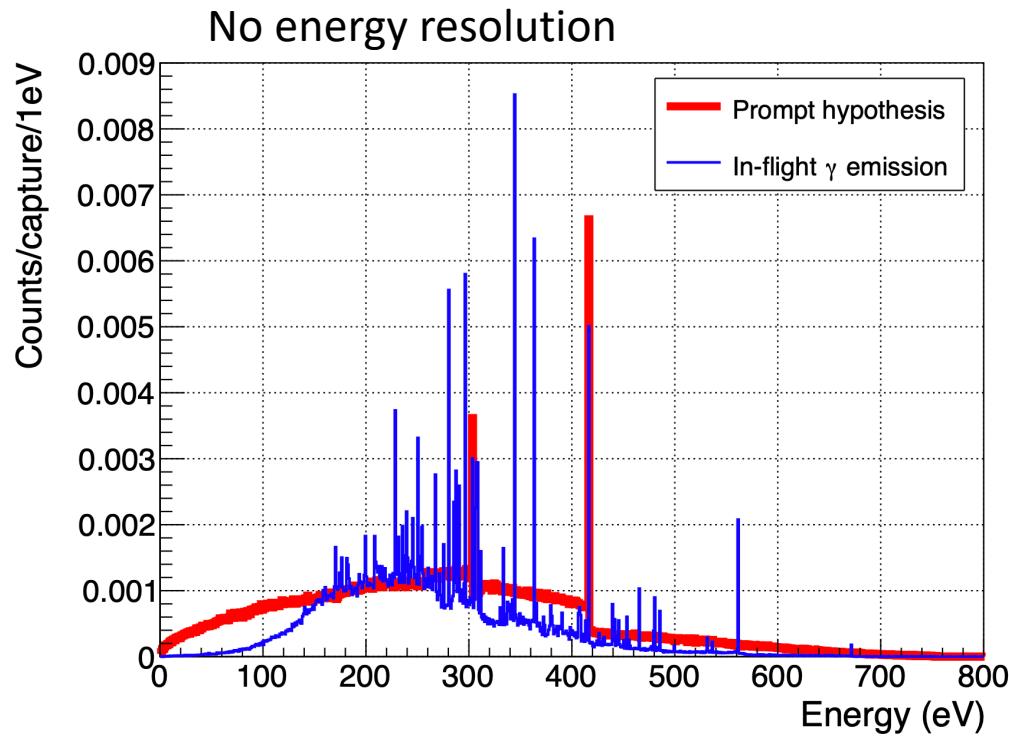
arXiv:2305.10139

No energy resolution

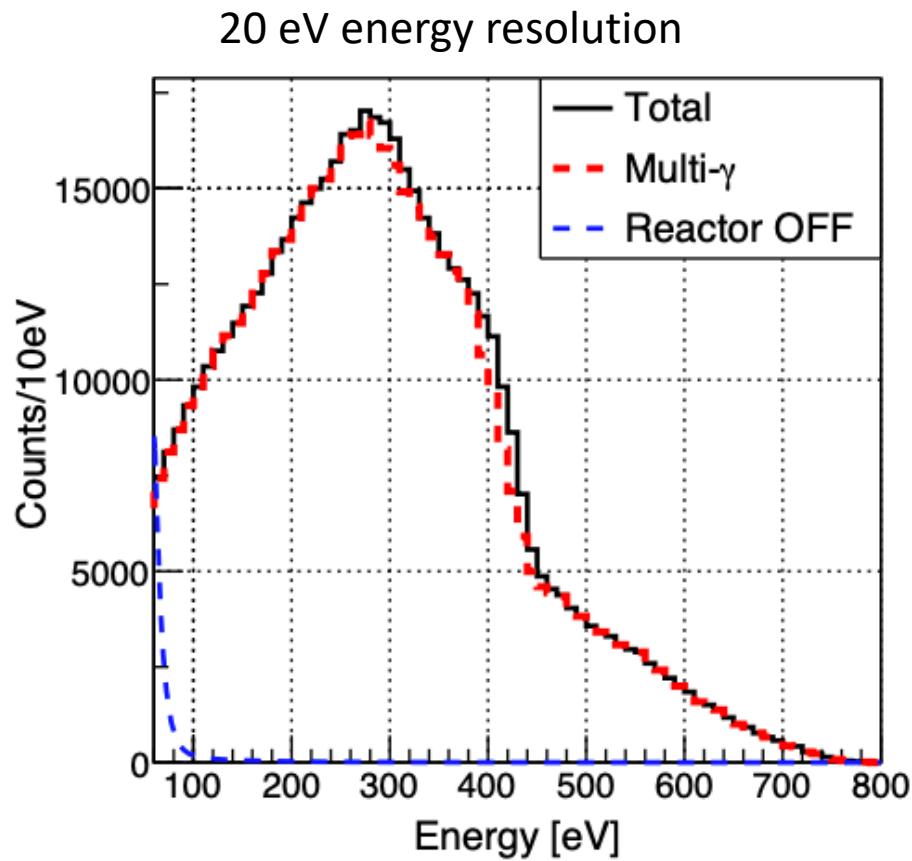


Germanium Transition Spectrum

arXiv:2305.10139



Germanium Gamma-Tagging



No timing effect: L. Thulliez, D. Lhuillier *et al* 2021 JINST 16

