25th International Workshop on Next Generation Nucleon Decay and Neutrino Detectors

# STATUS AND LATEST RESULTS OF THE CONUS+ EXPERIMENT

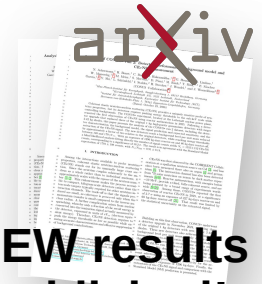
**Matthias Meier**
on behalf of the CONUS+ collaboration

MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK

# Outline

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

- CEνNS introduction
- CONUS+ setup
- Measurement campaigns
- Latest campaign (Run 2)
  - Data acquisition & stability
  - Calibration & Analysis
  - CEνNS results



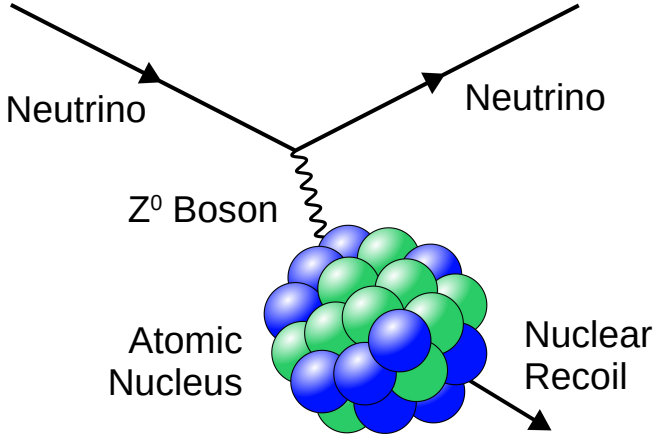

**NEW results published!**
(This morning)



# CEνNS

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

## Coherent Elastic Neutrino Nucleus Scattering



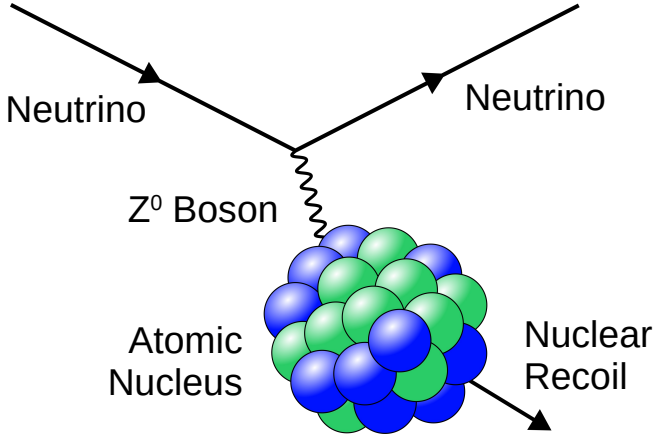

- Predicted by Freedman (1974)
- First detection by COHERENT (2017)
  Using a CsI detector at a pion-decay-at-rest source

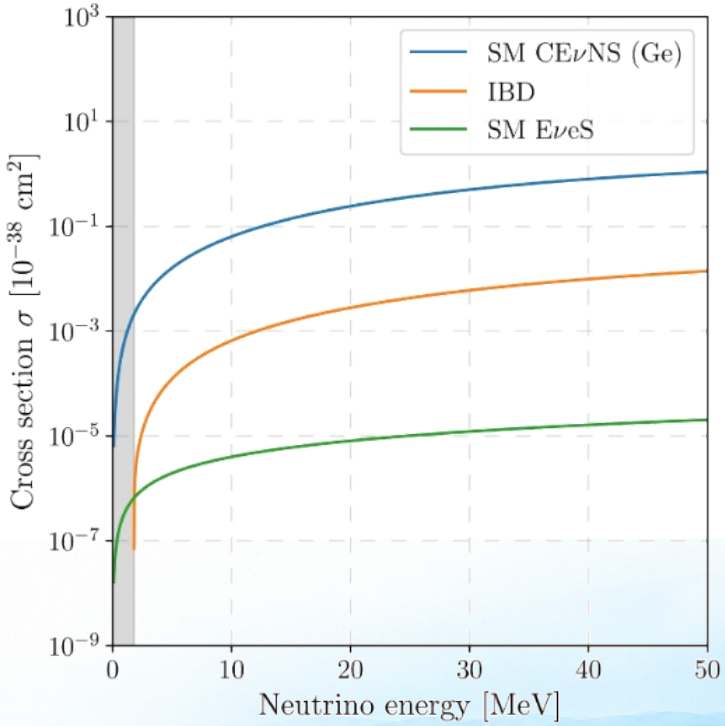


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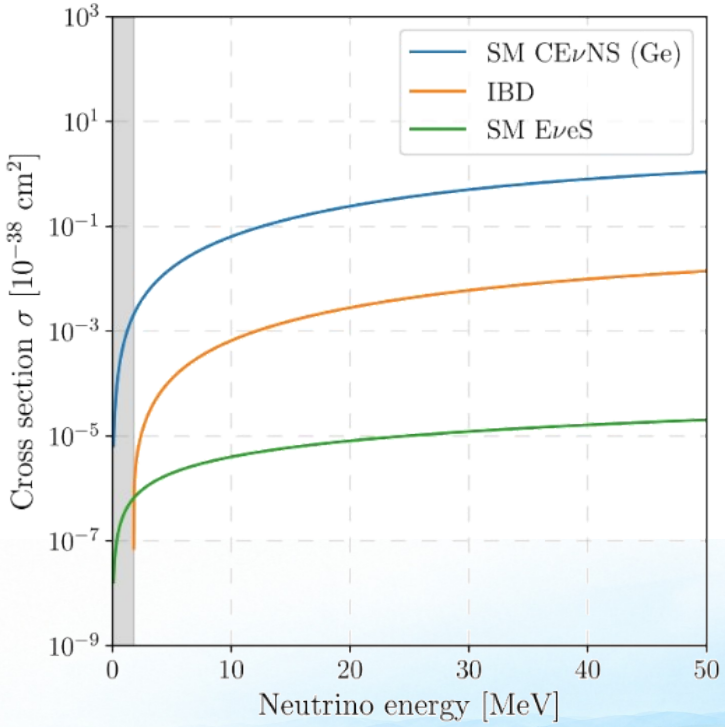
- Cross-section

Weak nuclear charge

Kinematics term

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi} \cdot \frac{Q_W^2}{4} \underbrace{F^2(Q)} \left(2 - \frac{MT}{E_\nu^2}\right)$$

Nuclear form factor (→1 as Q→0)



# CEνNS

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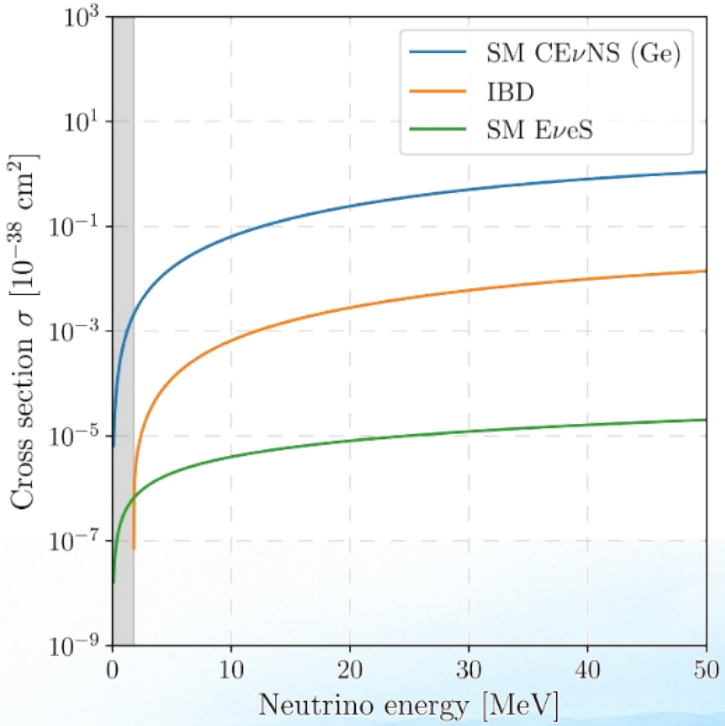
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Low neutrino energies → Fully coherent CEνNS

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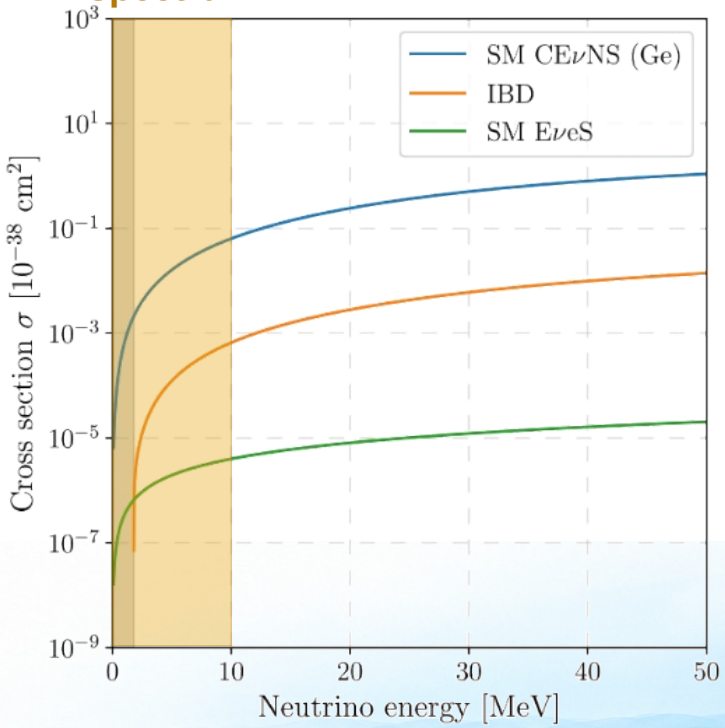
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Reactor spectrum




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# CEνNS

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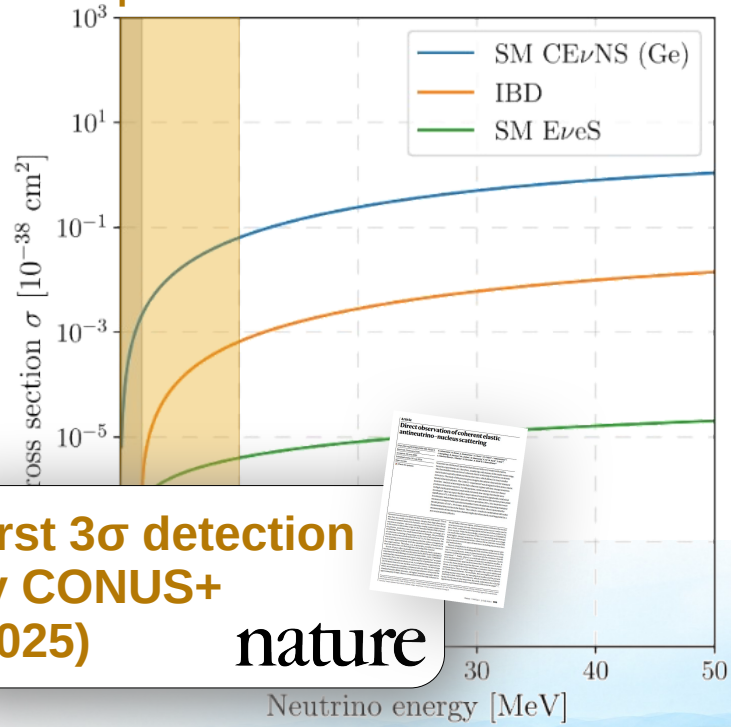
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Nuclear form factor (→1 as Q→0)

Reactor spectrum




First 3σ detection by CONUS+ (2025)

nature

Low neutrino energies → Fully coherent CEνNS

# CONUS+ Setup

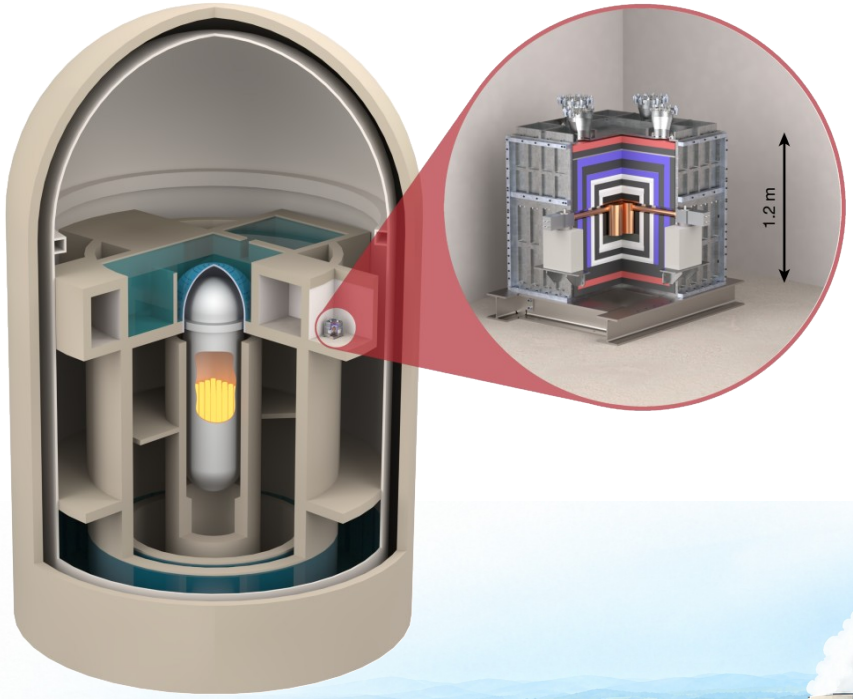
- **Located at the KKL power plant**
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  - Boiling water reactor
  - Thermal power: **3.6 GW**
  - Off-time: ~ 1 month/year



# CONUS+ Setup

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

- **Located at the KKL power plant**
  (Leibstadt, Switzerland)
  - Boiling water reactor
  - Thermal power: **3.6 GW**
  - Off-time: ~ 1 month/year
- **Measurement location**
  - Inside the reactor building
  - Distance to reactor core: **20.7 m**
  - High antineutrino flux: **1.45 x $10^{13}$ $s^{-1}cm^{-2}$**
  - Average overburden: 7.4 m w.e.

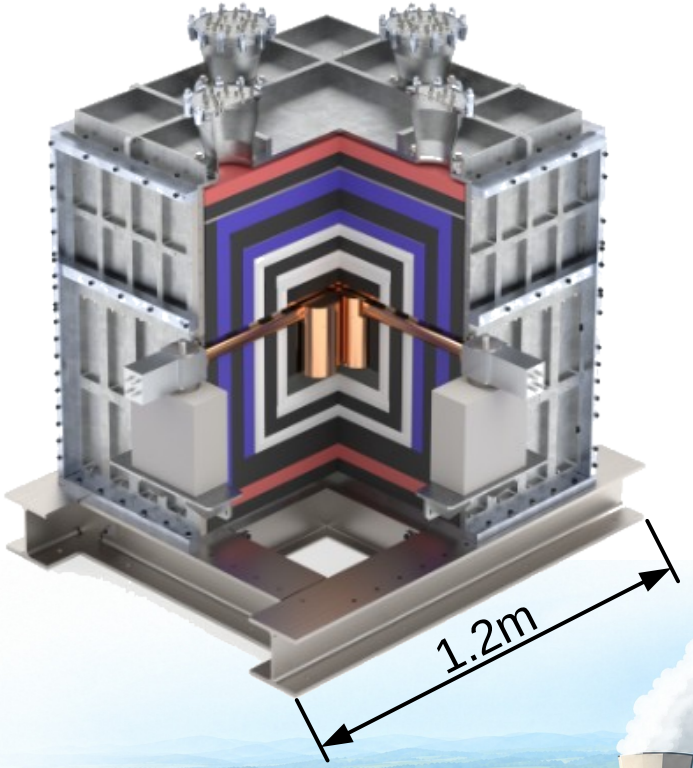





# CONUS+ Setup

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

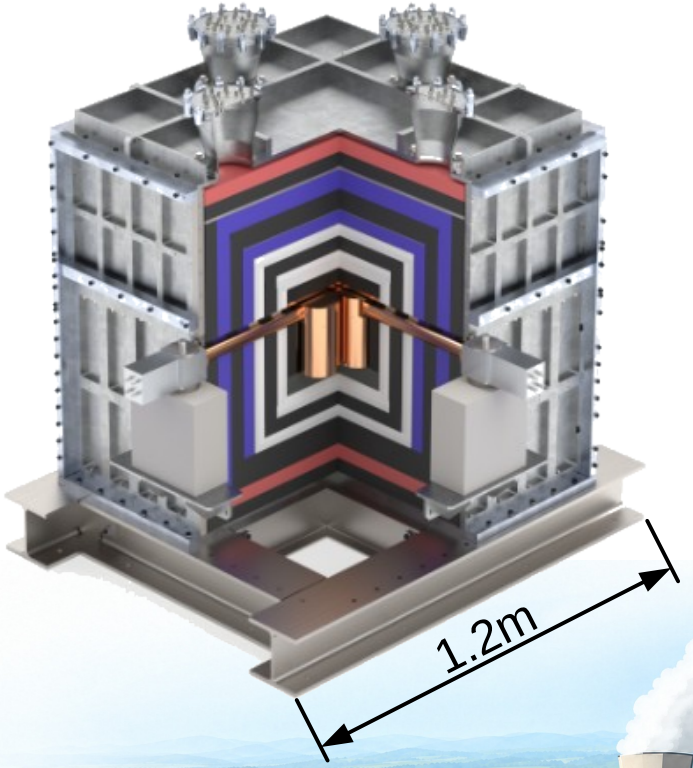
- **Neutrino detectors**
  - **4 High purity germanium** detectors
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# CONUS+ Setup

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

- **Neutrino detectors**
  - **4 High purity germanium** detectors
  - Electrically cryocooled
- **Shielding**
  - **Active muon veto**
    - Two layers of plastic scintillators
    - Photo Multiplier Tube readout
  - Multiple **lead** layers for gamma suppression
  - Multiple (borated) **polyethylen** layers for neutron reduction
  - Flushing of detector chamber with **radon-free air**

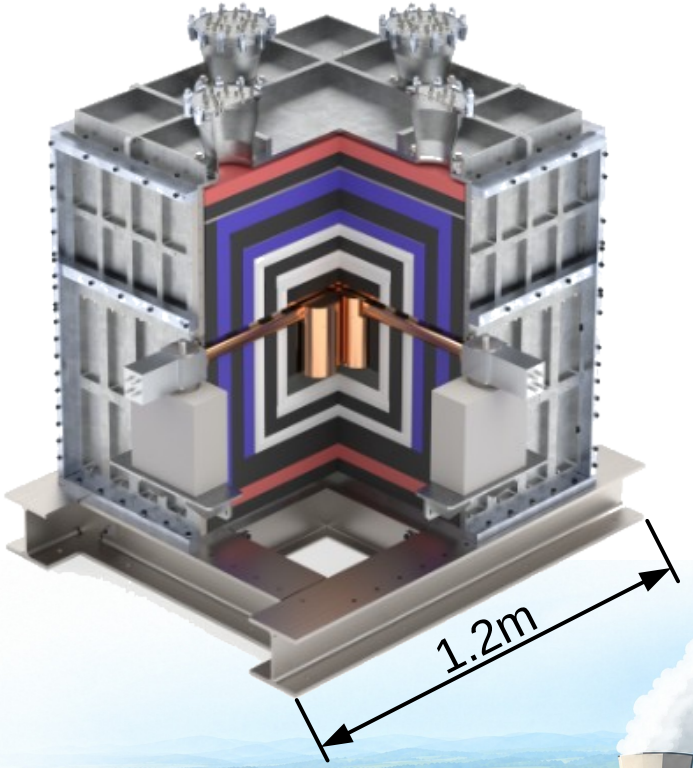


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**Background suppression by $10^{-4}$**



# Measurement campaigns

| | Run 1 | Run 2 |
|---|---|---|
| Individual mass (kg) | 4 x 0.94 | 1 x 0.94<br>3 x 2.45 |

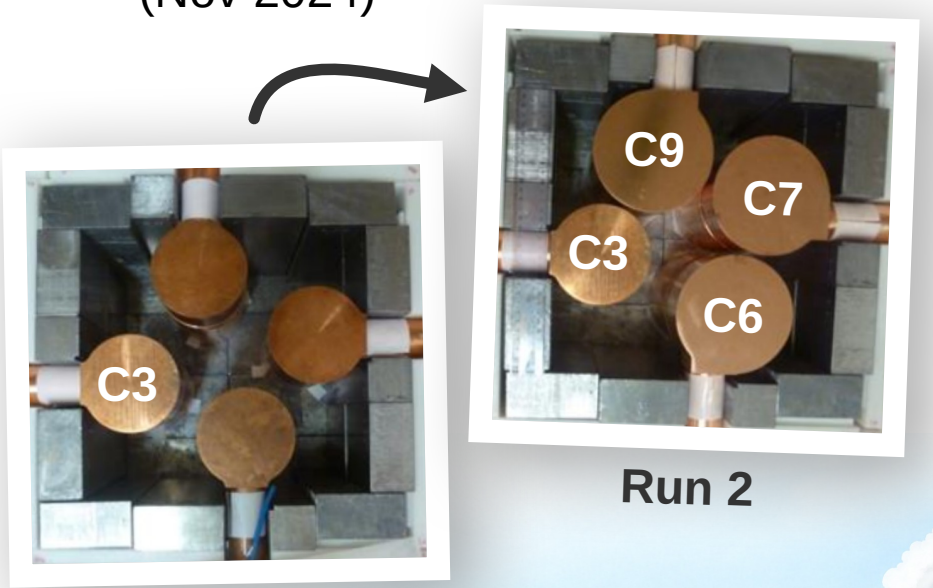


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## Detector upgrade

(Nov 2024)



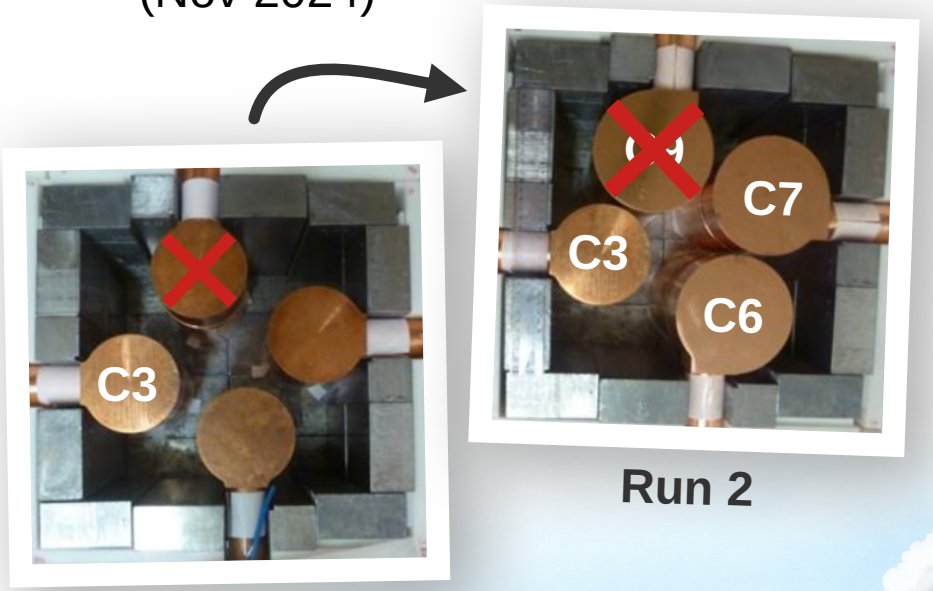
# Measurement campaigns

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

| | Run 1 | Run 2 |
|---|---|---|
| Individual mass (kg) | 4 x 0.94 | 1 x 0.94<br>3 x 2.45 |
| **Total active mass (kg)** | **2.8** | **5.6** |
| Energy threshold ($eV_{ee}$) | 160–180 | 140–170 |
| Electronic noise (FWHM in $eV_{ee}$) | ~50 | ~50 |
| **Exposure (kg day)** | **327** | **1296** |

## Detector upgrade

(Nov 2024)



# **Run 2**
# overview & results



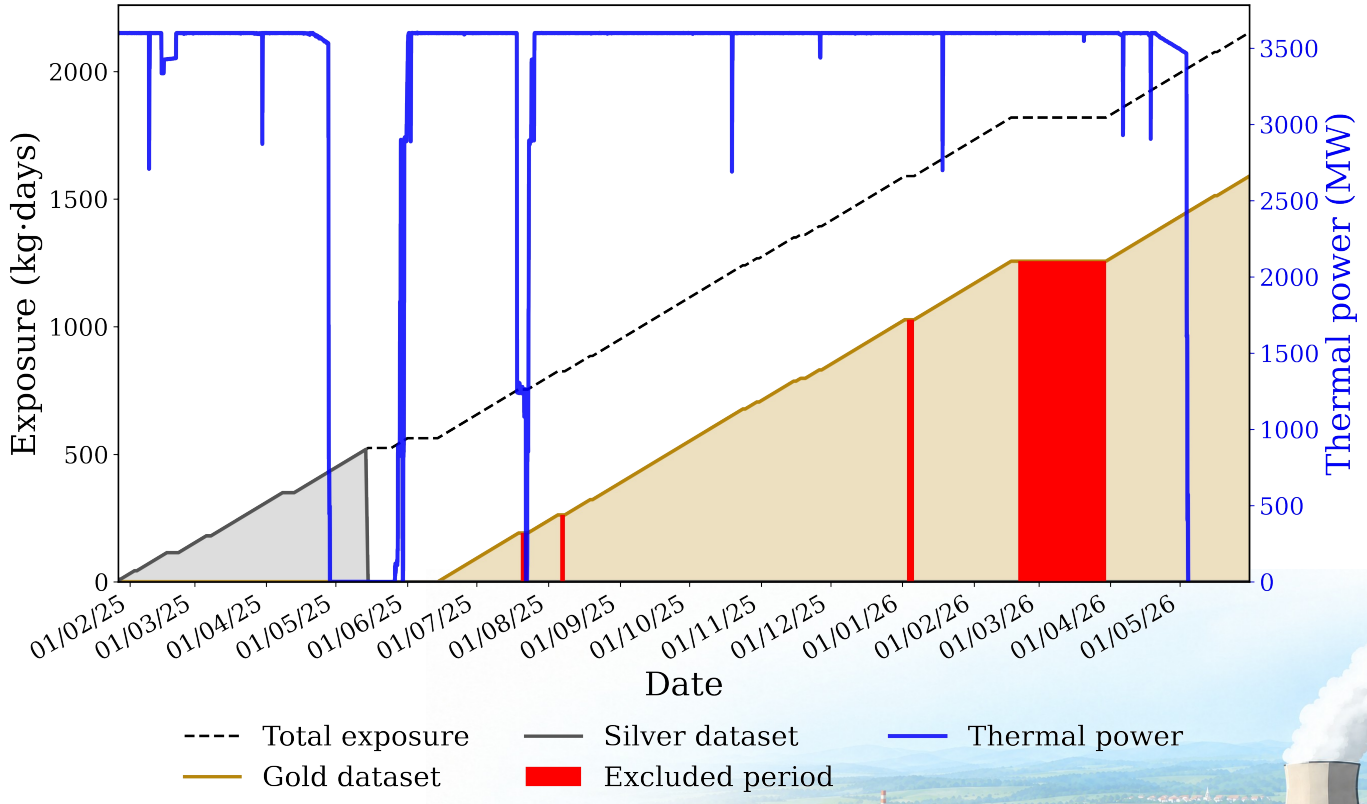
# Run 2 - Data acquisition

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

**Run 2**

Excluded instable periods due to:

- Air flushing system for radon-suppression
- Electrical grounding



# Run 2 - Data acquisition

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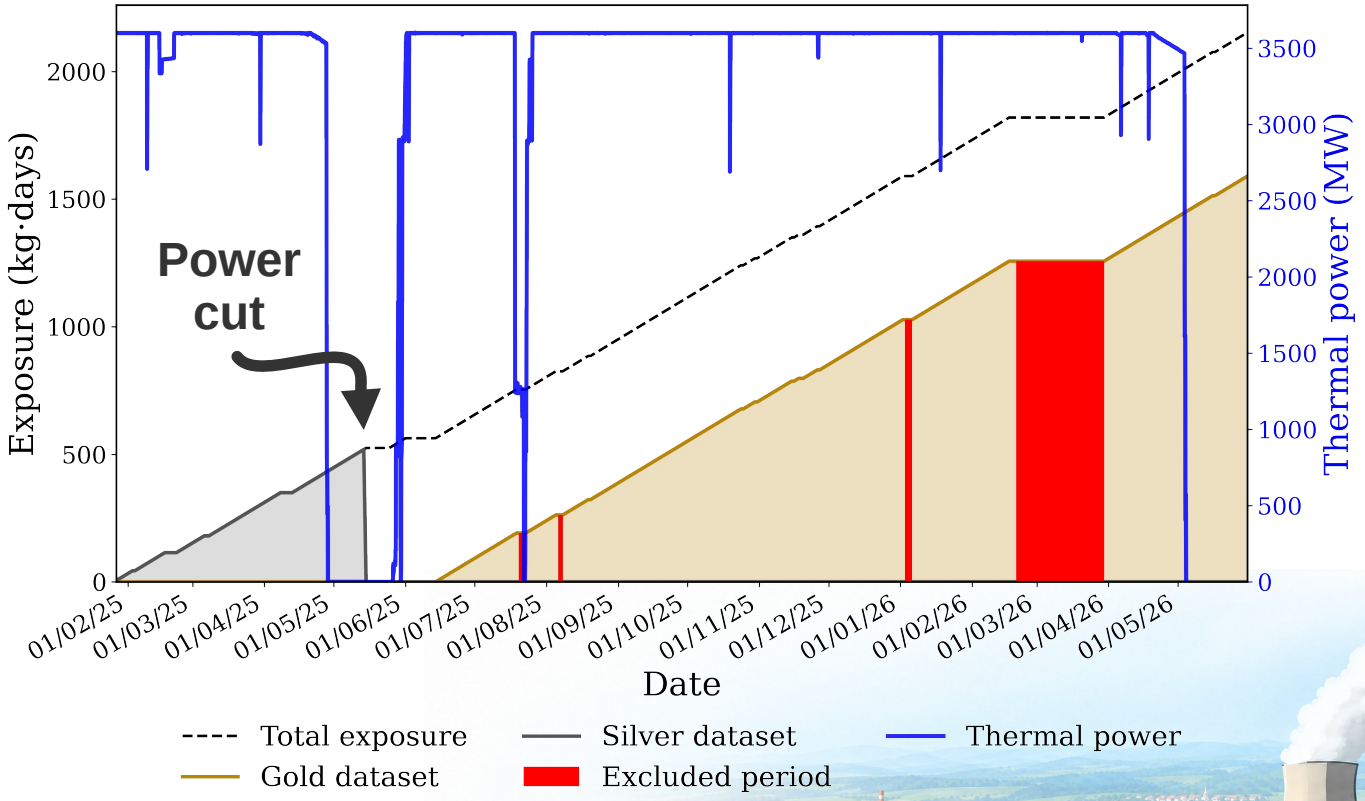
**Run 2**

Excluded instable periods due to:

- Air flushing system for radon-suppression
- Electrical grounding

Split into:

- **Silver dataset** (calibration, detector specific studies)
- **Gold dataset** (whole **CEvNS analysis**)

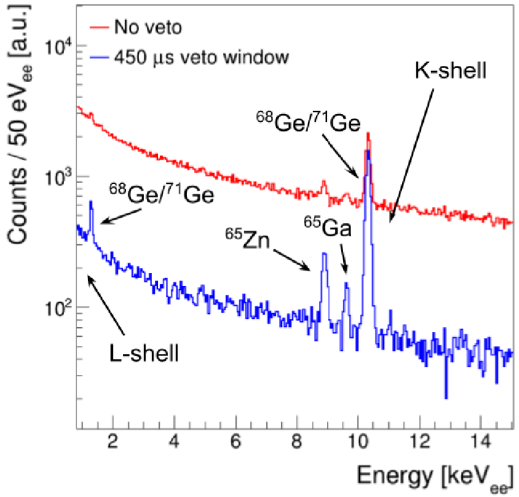


# Run 2 - Calibration

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

## Energy calibration

- Linear calibration
- Using atomic de-excitation lines
  (mainly cosmogenic $^{71}$Ge prod. in detectors)



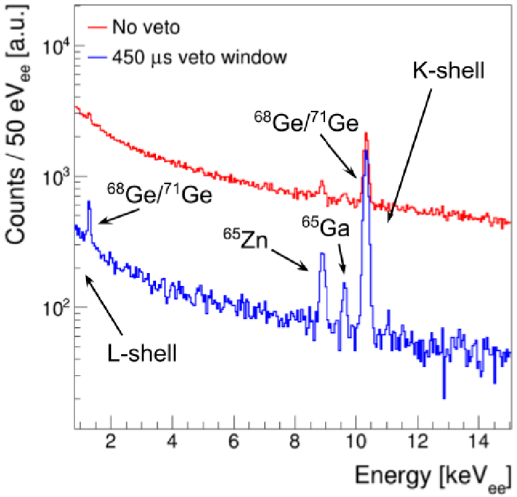



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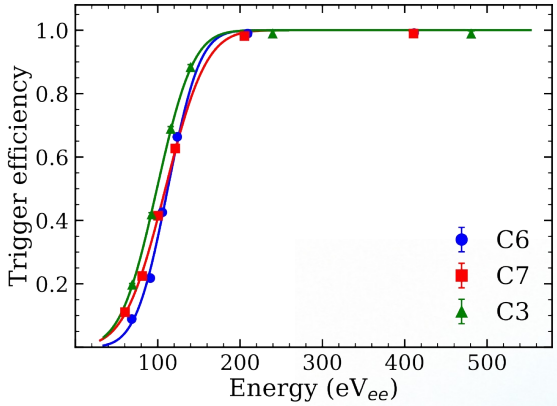
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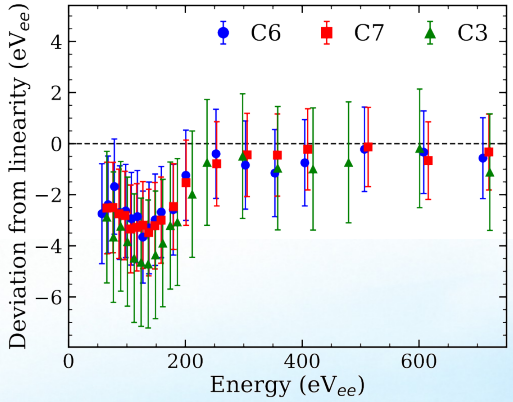
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## Pulser scan

- Characterization down to threshold
  - Trigger efficiency
  - Correct for non-linearities



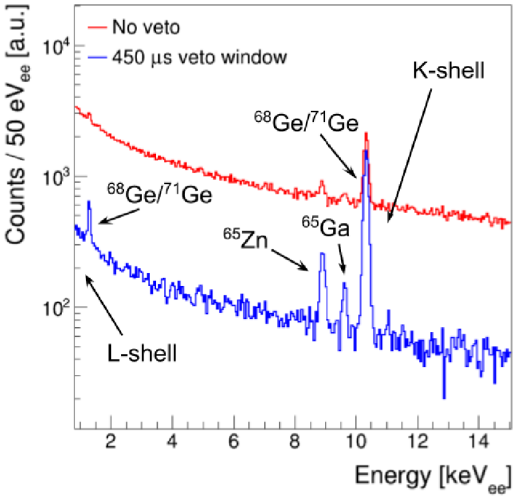



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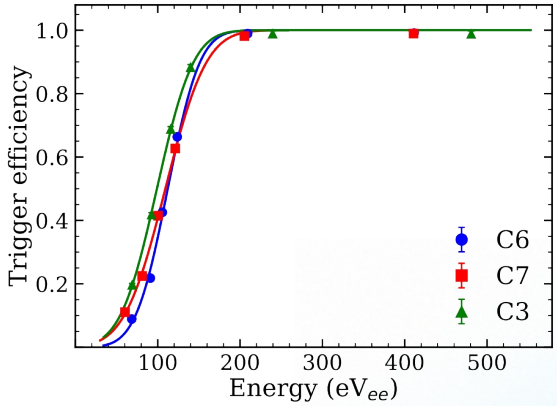
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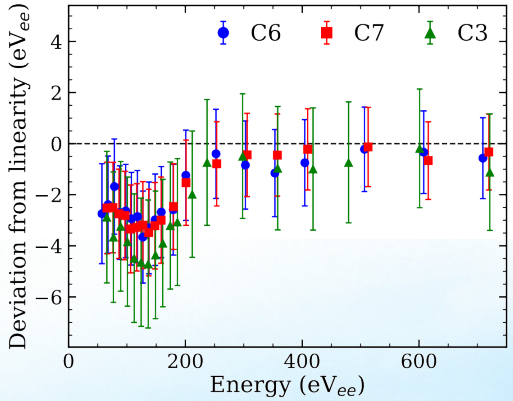
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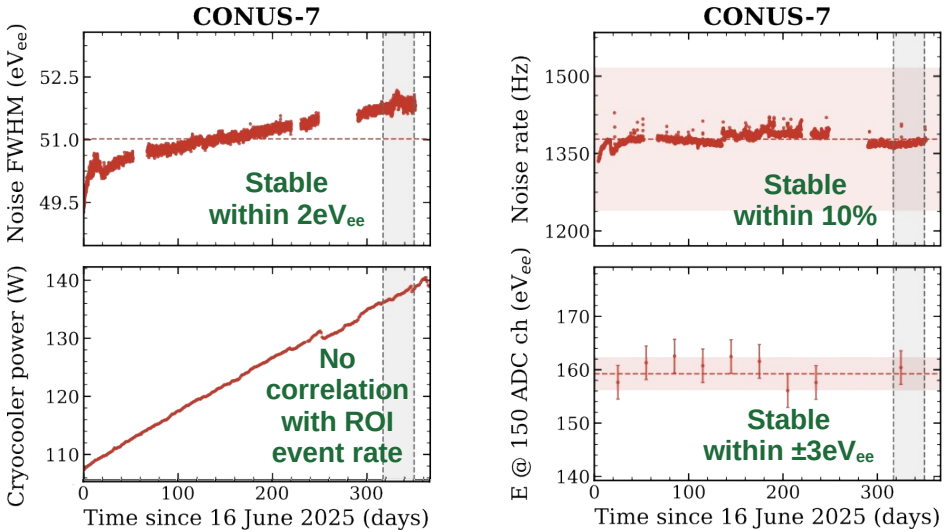
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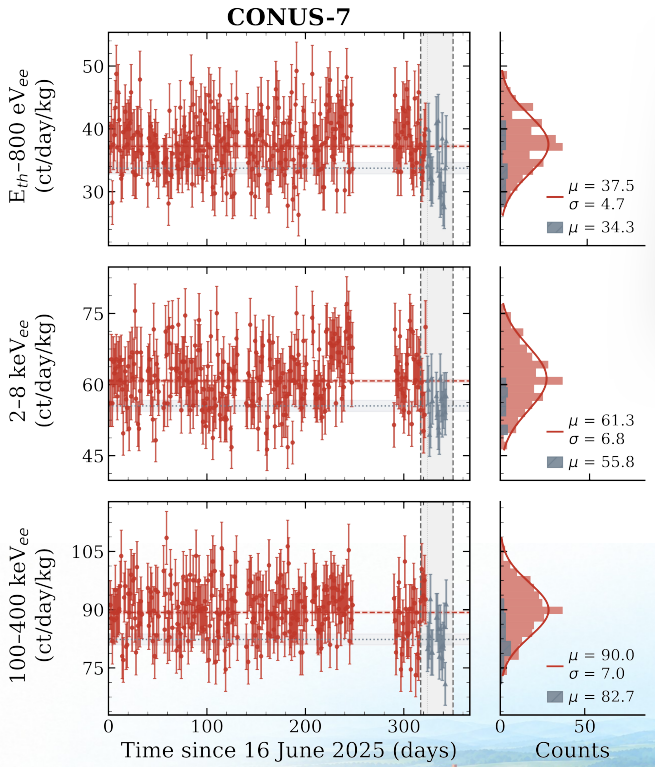

**Result: only 3 eV$_{ee}$ uncertainty at threshold**

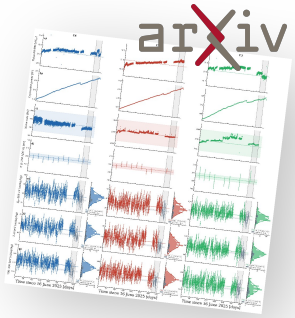
# Run 2 - Stability







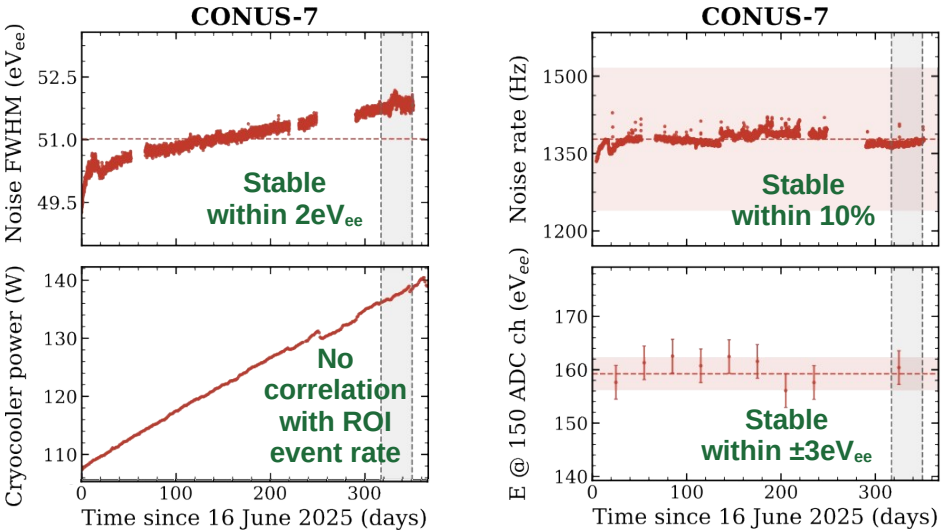


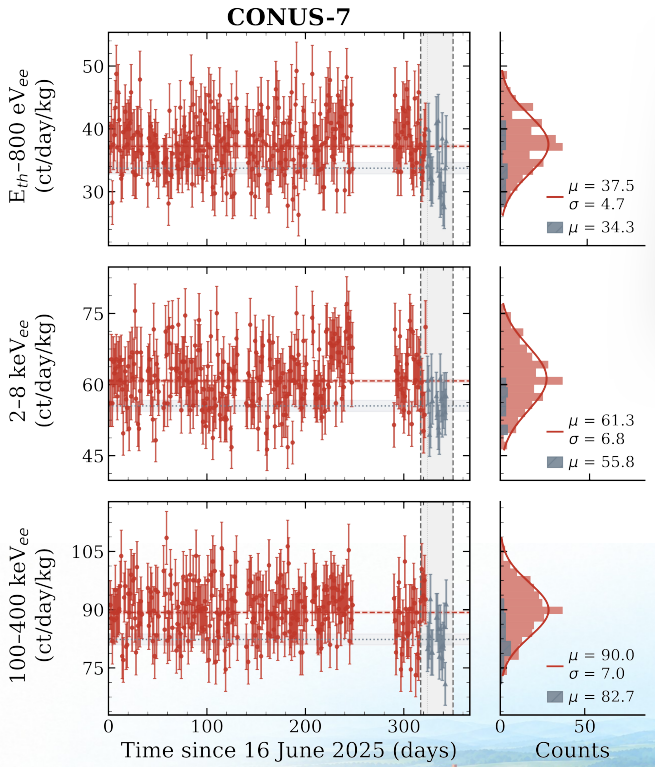



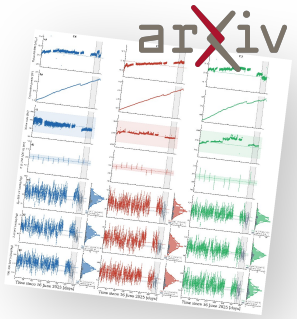

**For all detectors see analysis paper on arXiv**

# Run 2 - Stability

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK



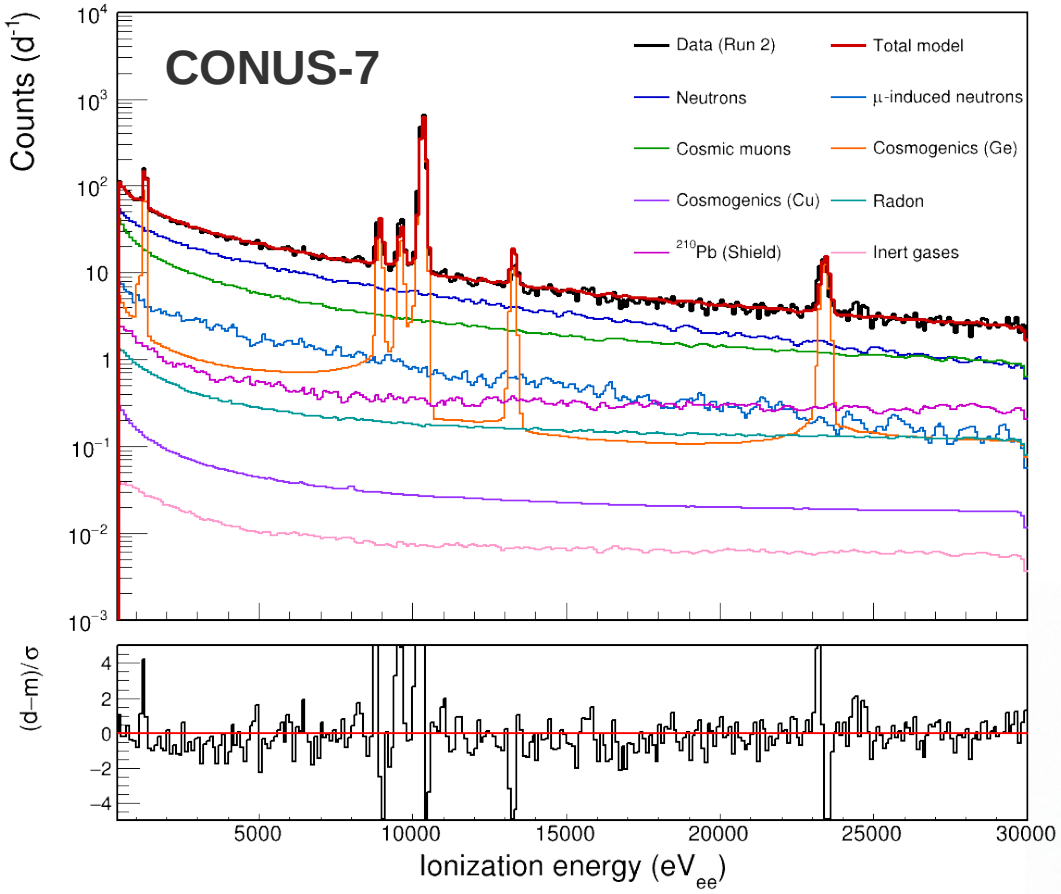



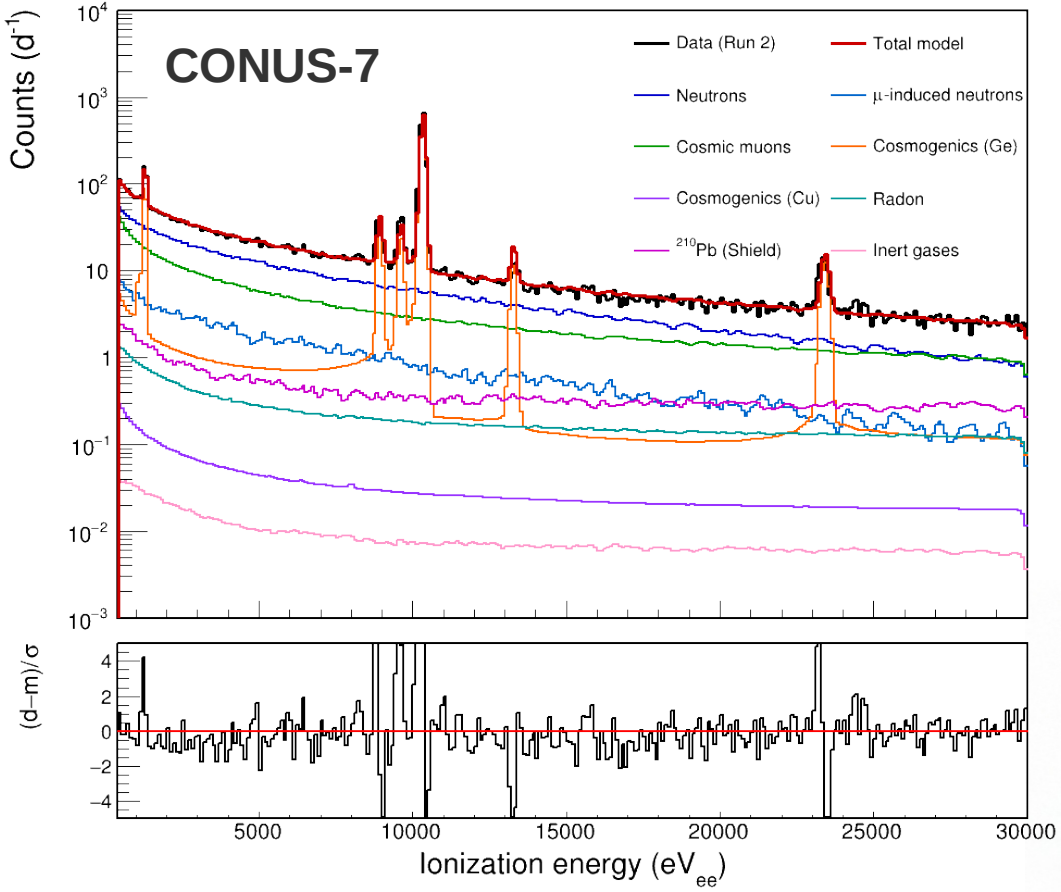

**For all detectors see analysis paper on arXiv**

✓ **Stable run conditions for all detectors**

# Run 2 - Background model



# Run 2 - Background model




- Detailed geometry
  (detector array, shield design)
- Simulated physics:
  - **Cosmogenic activation**
    (of Ge crystals and surrounding materials)
  - **Muon**- and **neutron**-induced events
  - Environmental and intrinsic **radon**
  - Residual **γ contamination**
- Detector response:
  - **Trigger efficiency**
  - **Quenching** (Lindhard model)
  - **Fano statistics**
  - **Charge collection efficiency**
  - **Energy resolution**

# Run 2 – CEνNS analysis

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

**Binned Poisson likelihood fit**

- Simultaneously on reactor ON and OFF data
- First background fit above 400 $eV_{ee}$ → get background normalizations

- Gaussian pull terms
  - Trigger efficiency
  - Energy calibration
  - Active mass
  - Normalizations of the 7 bg. components



# Run 2 – CEνNS analysis

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

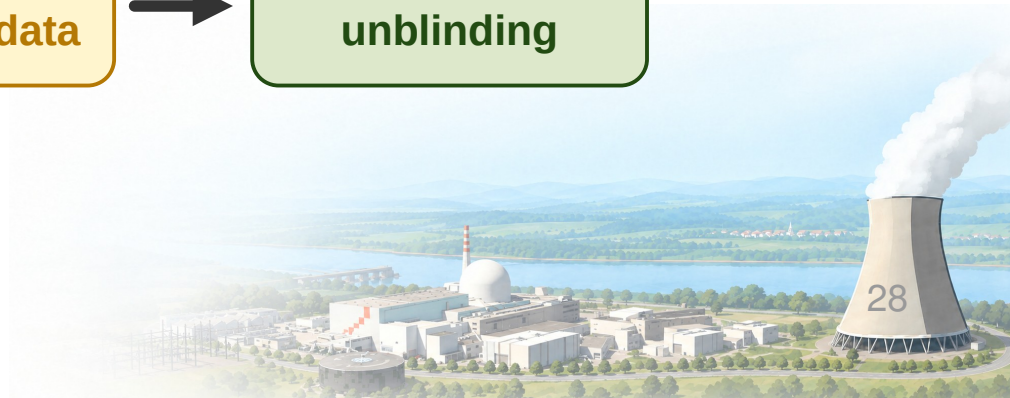
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**Likelihood A**

Test likelihood improvements on **Run 1 data** → Test on Run 2 like **Asimov data** → Detector-wise **unblinding**



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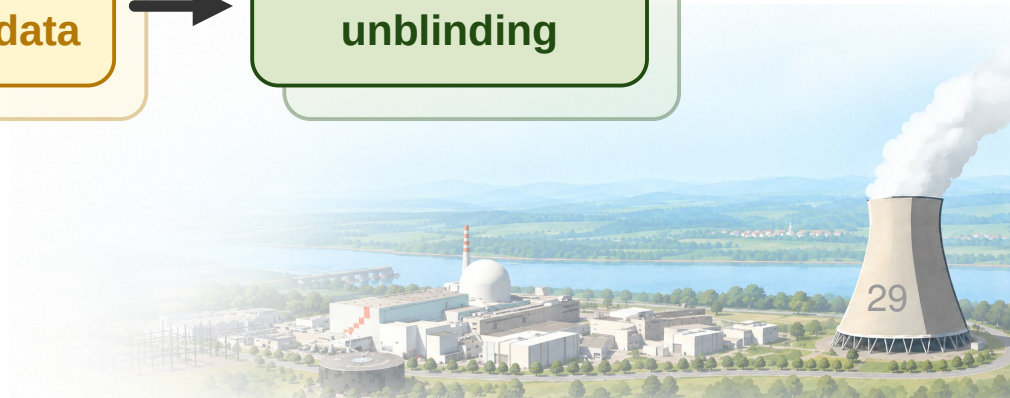
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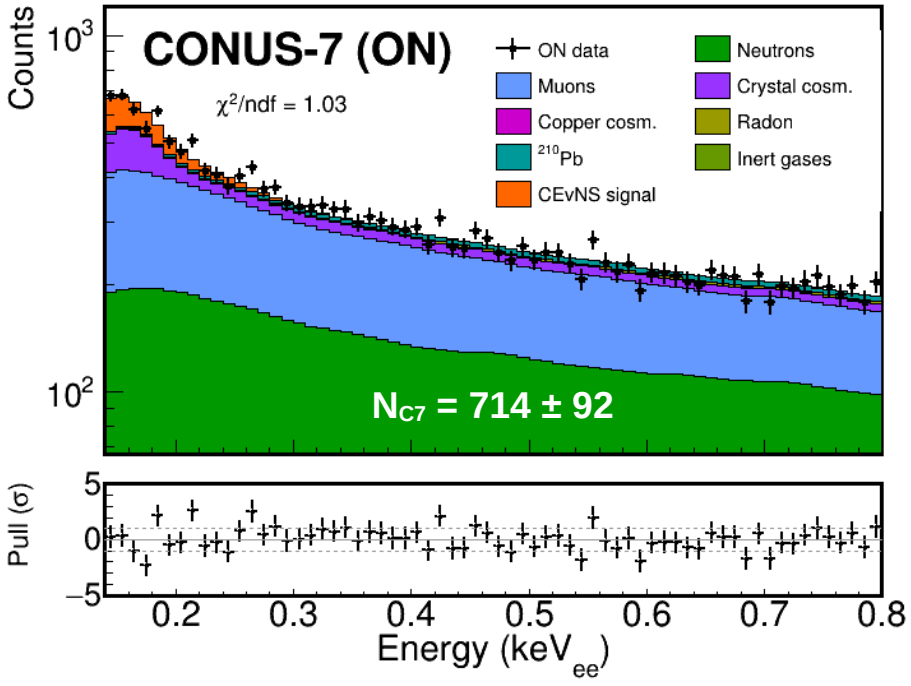
**Likelihood A**

Test likelihood improvements on **Run 1 data** → Test on Run 2 like **Asimov data** → Detector-wise **unblinding**

**Likelihood B**

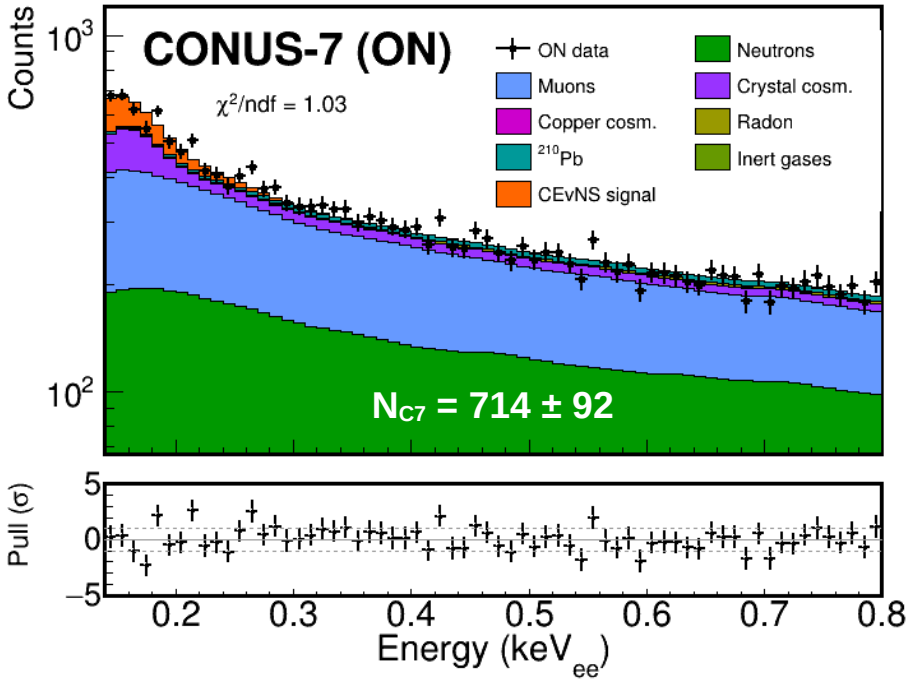


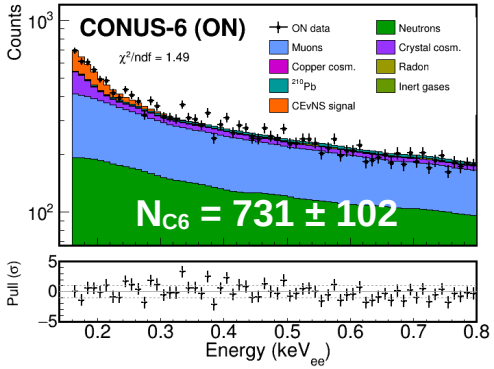
# Run 2 – CEνNS result

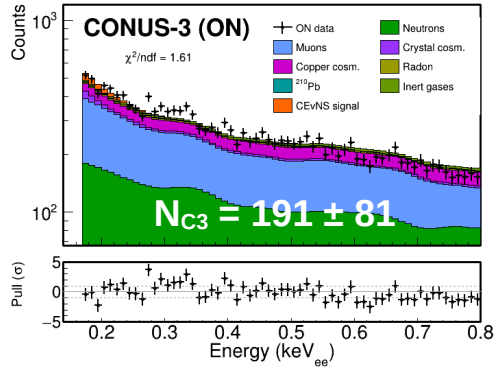





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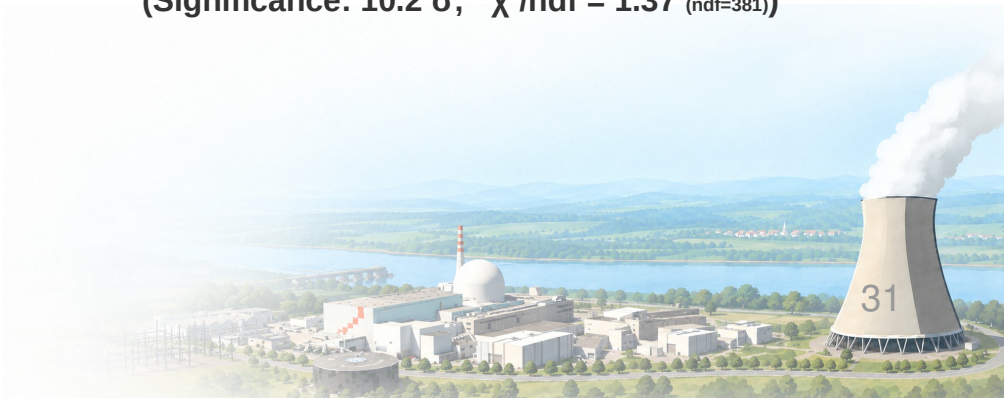



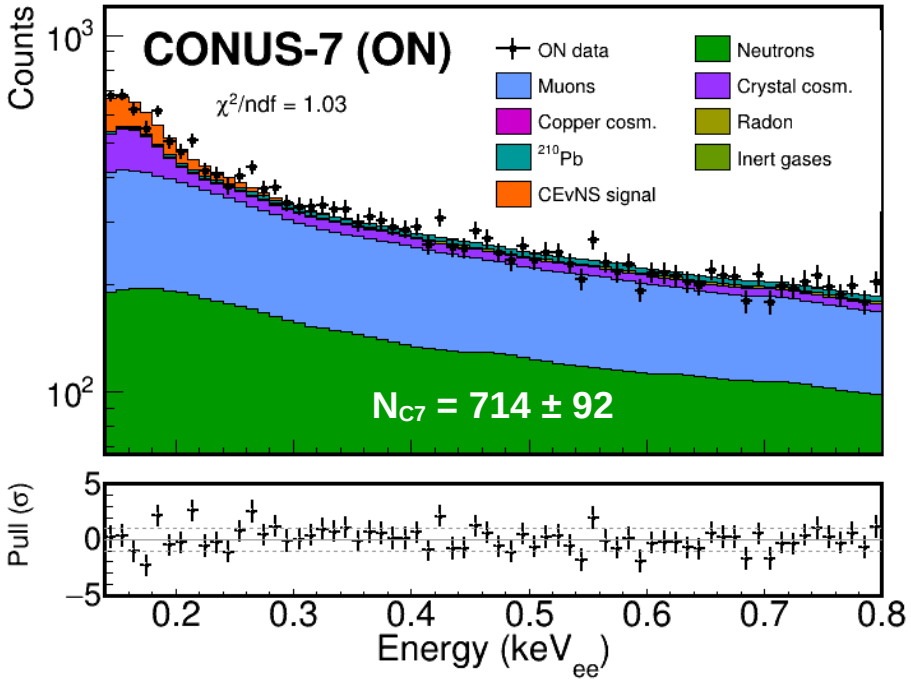

**Combined fit:**

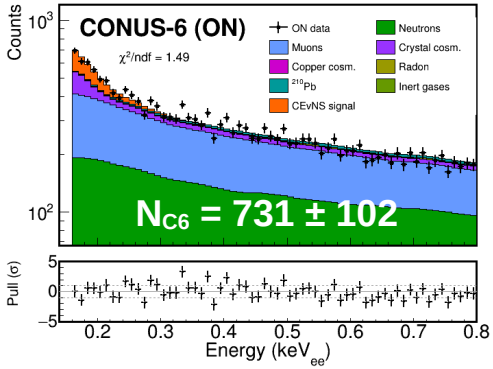
**$N_{CEvNS}$ = 1555 ± 116 (stat) ± 98 (syst)**

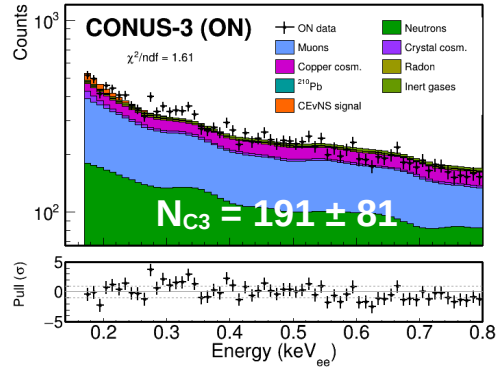
**(Significance: 10.2 σ; $\chi^2$/ndf = 1.37 (ndf=381))**



# Run 2 – CEνNS result




## Combined fit:

$N_{CEvNS}$ = 1555 ± 116 (stat) ± 98 (syst)

(Significance: 10.2 σ; $\chi^2$/ndf = 1.37 (ndf=381))

## Standard Model:

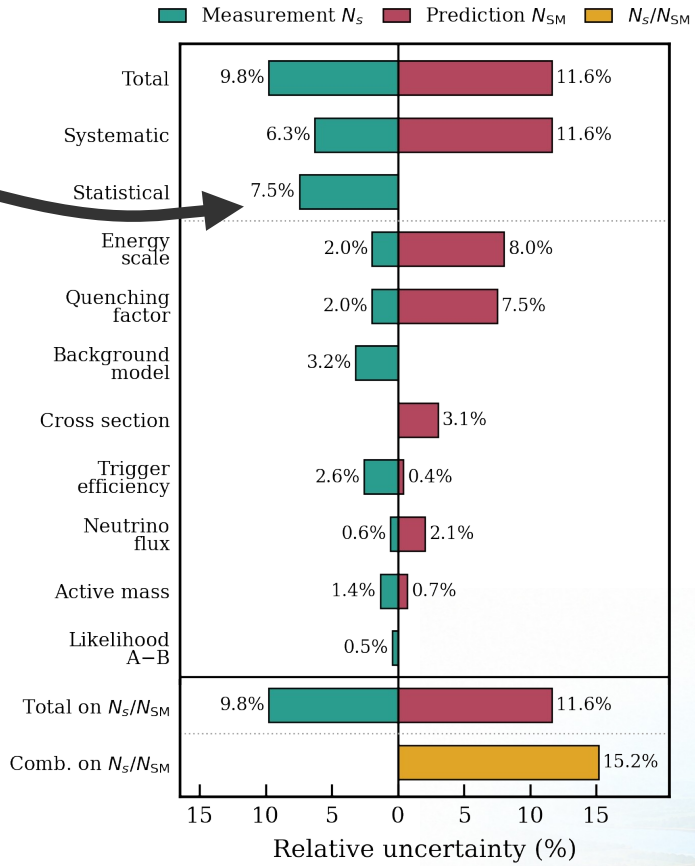
$N_{SM}$ = 1701 ± 198

$N_{CEvNS}$ /$N_{SM}$ = 0.91 ± 0.14

# Run2 – Meas. uncertainties

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

**Statistics dominated** measurement



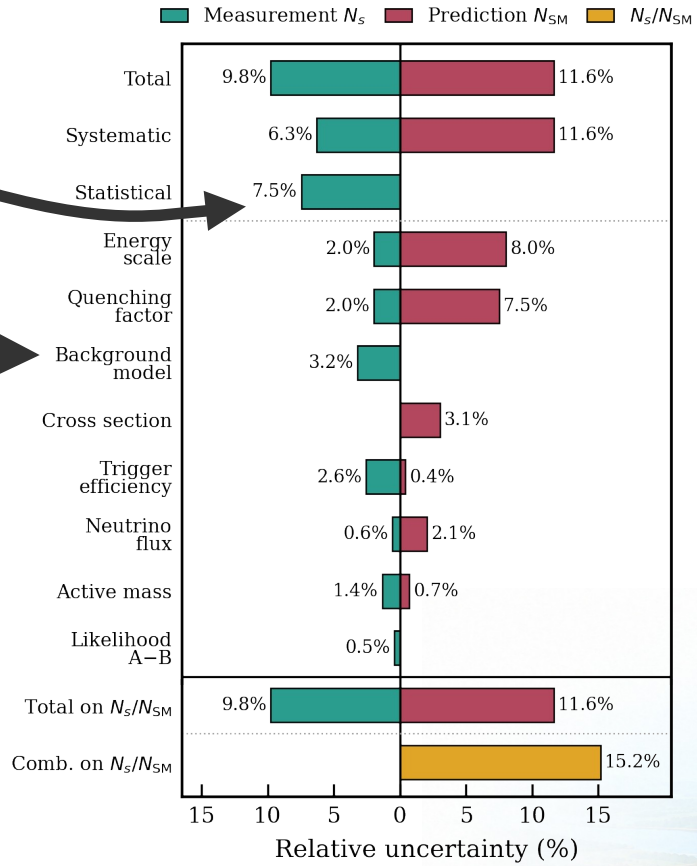
# Run2 – Meas. uncertainties

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

**Statistics dominated** measurement

Imperfect description of the background shape

(Inflated uncertainties yield consistent result of 9.3 σ)



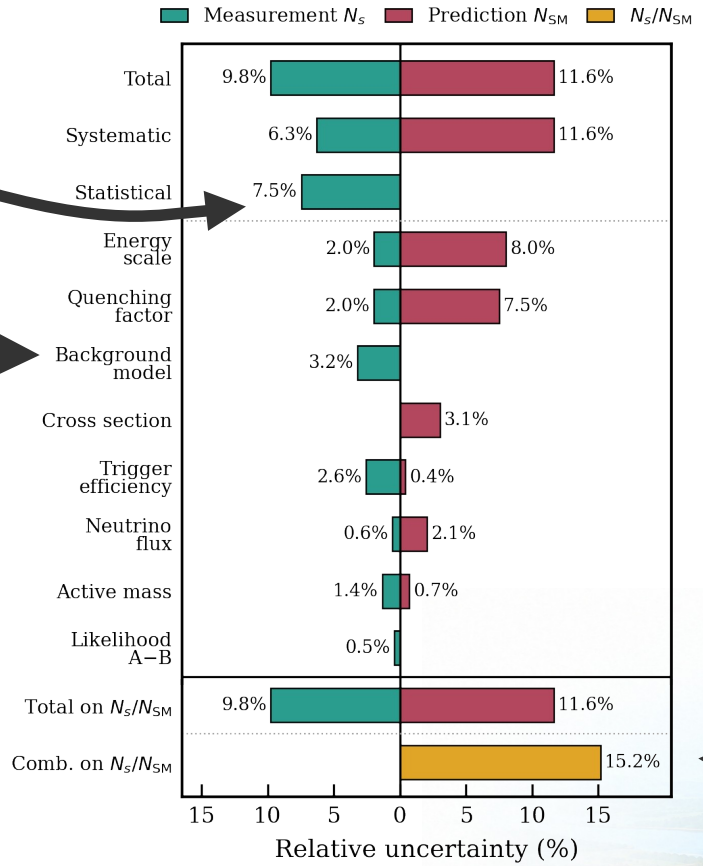
# Run2 – Meas. uncertainties

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

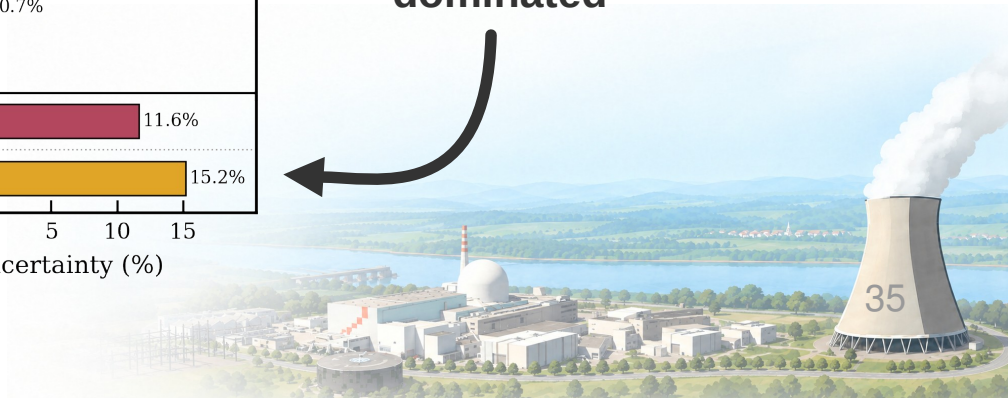
**Statistics dominated** measurement

Imperfect description of the background shape

(Inflated uncertainties yield consistent result of 9.3 σ)




Comparison with Standard Model is **Systematics dominated**



# Summary

- Power plant enables **fully coherent CEvNS** measurement
- First detection with CONUS+ Run 1 data (2025)



# Summary

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

- Power plant enables **fully coherent CEνNS** measurement
- First detection with CONUS+ Run 1 data (2025)



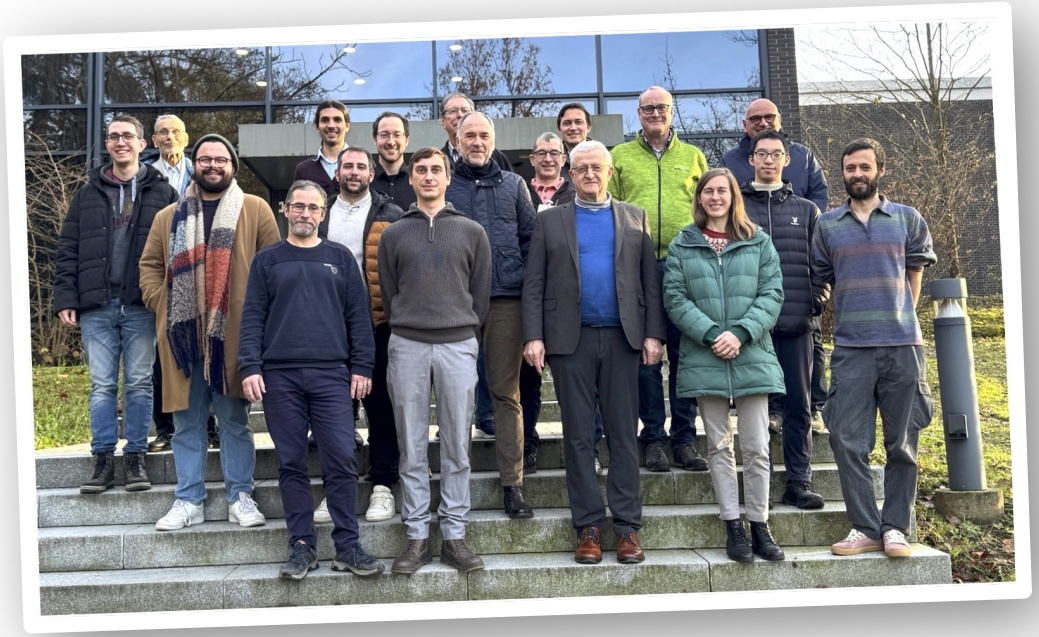

- **Fourfold exposure** in Run 2
- Measurement stability confirmed over 1.5 years
- **Excellent detector performance** and understanding of the energy spectrum down to 140 $eV_{ee}$
- Detection of **1555 ± 152** CEνNS events with **10.2σ**

**Two new publications online**

- Short-Form Publication: arXiv:2610.37318
- Detailed analysis report: arXiv:2610.37345



MAX-PLANCK-INSTITUT FÜR KERNPHYSIK



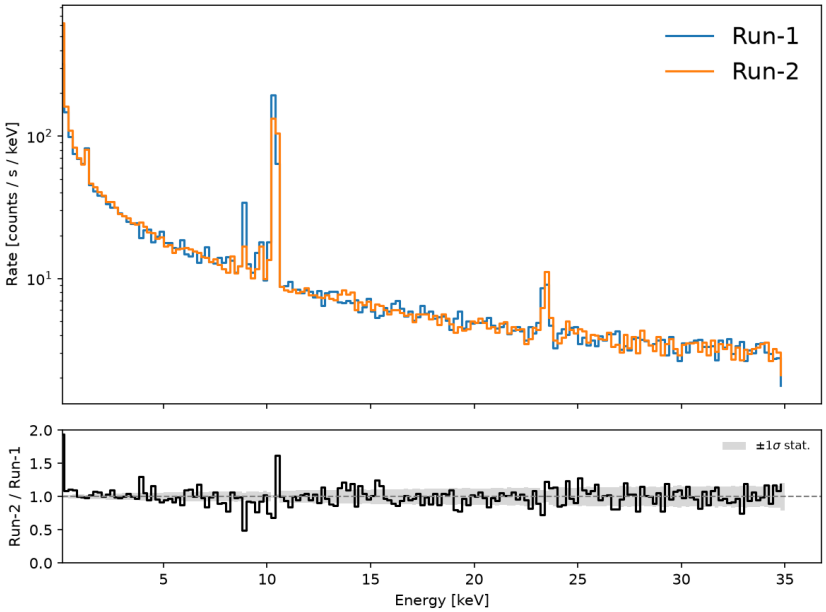
# Thank you for your attention!

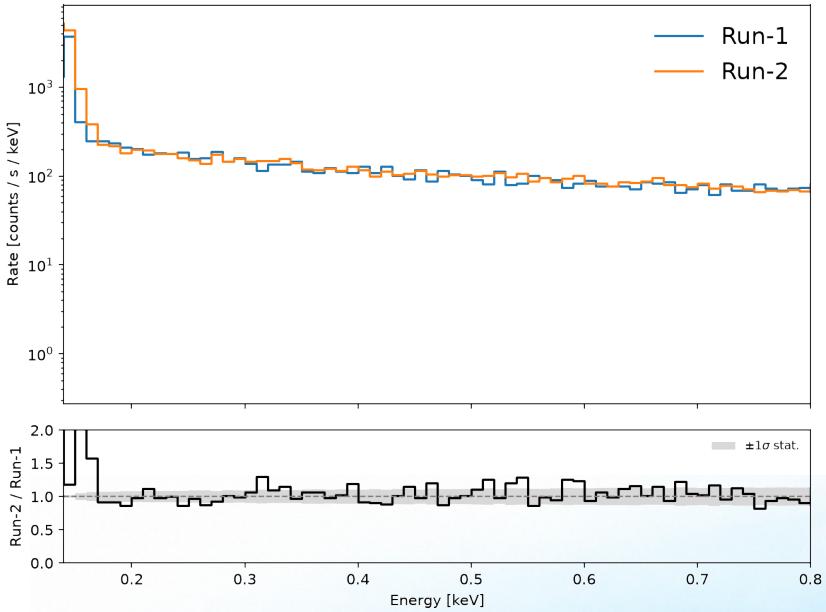


# Backup

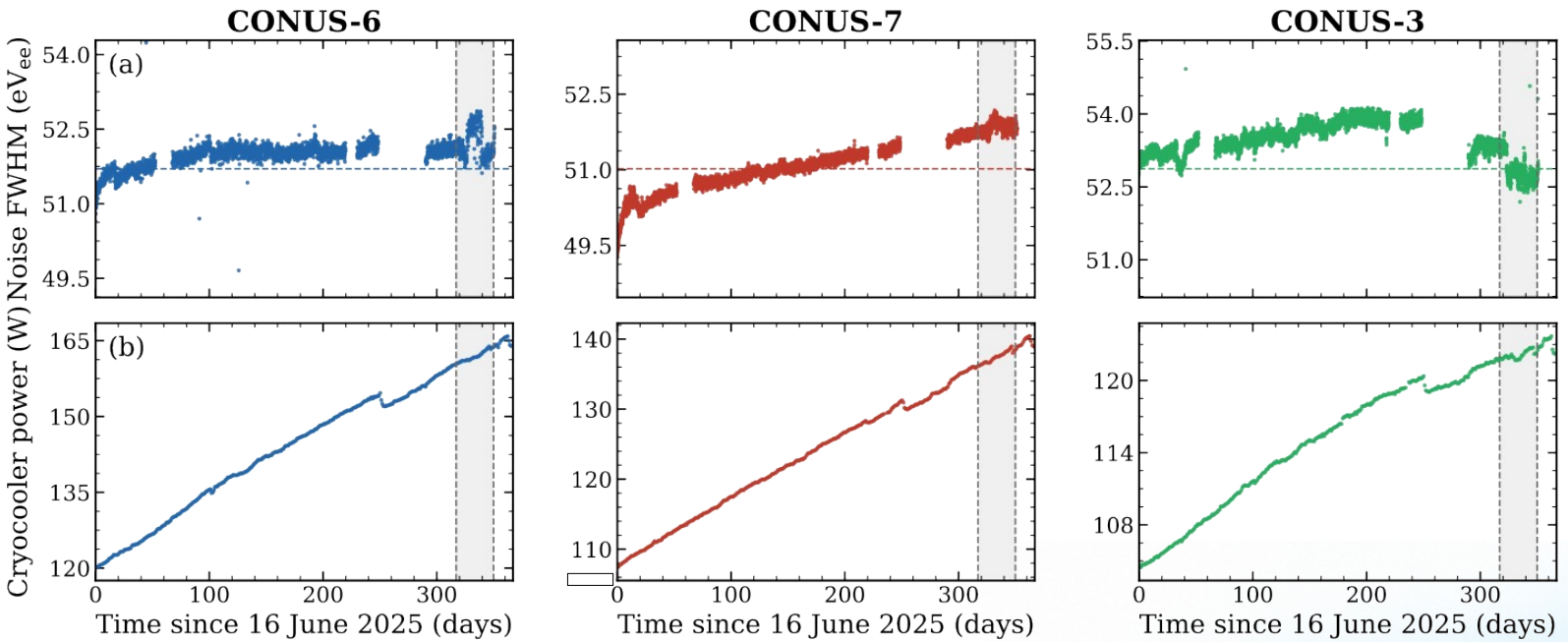


# C3 Run 1 vs Run 2

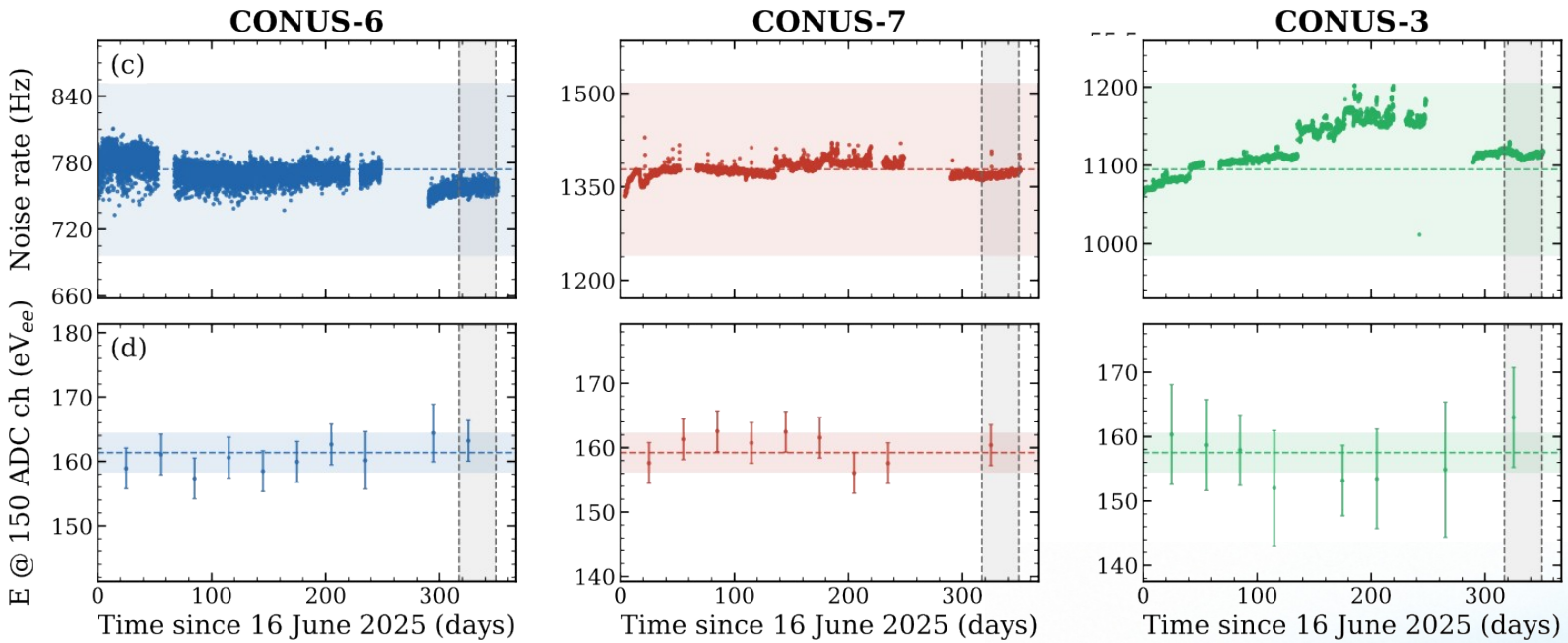


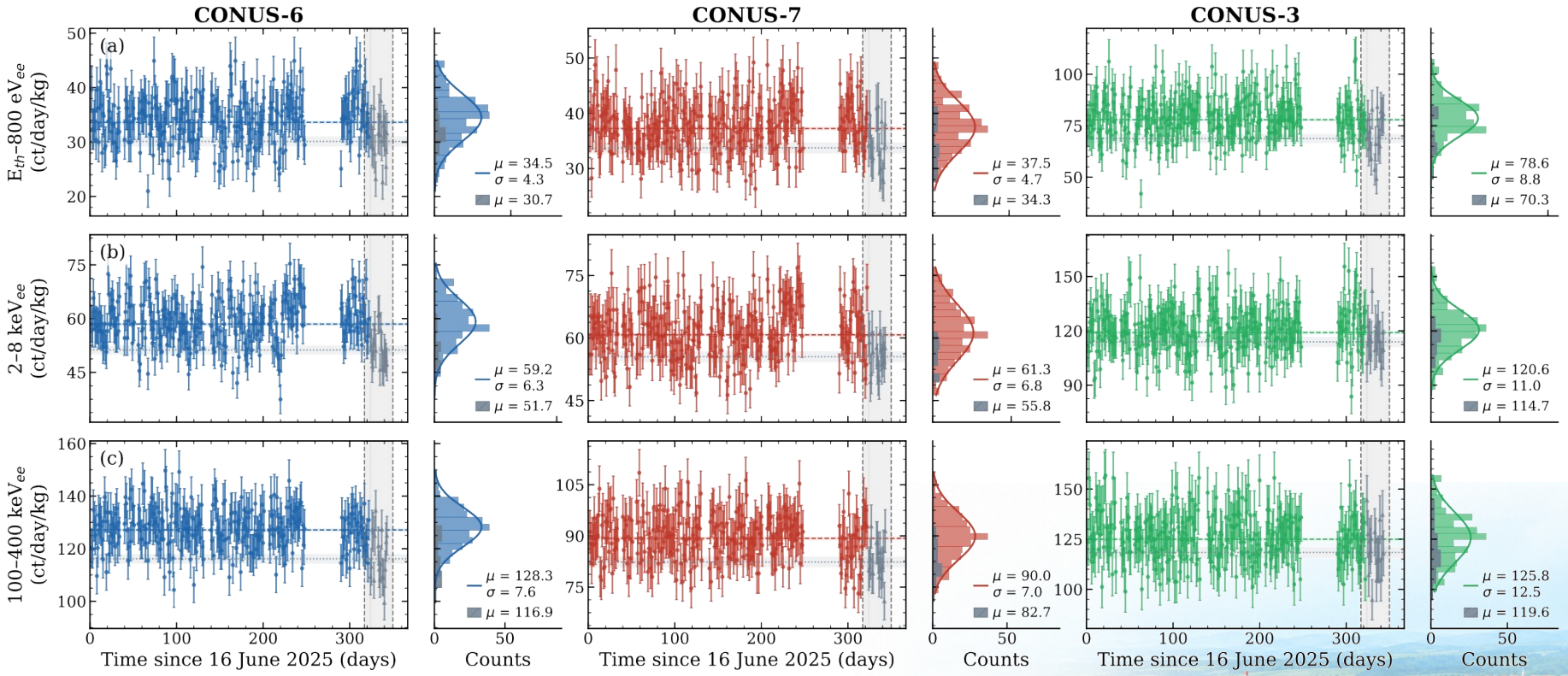
# Run 2 - Stability



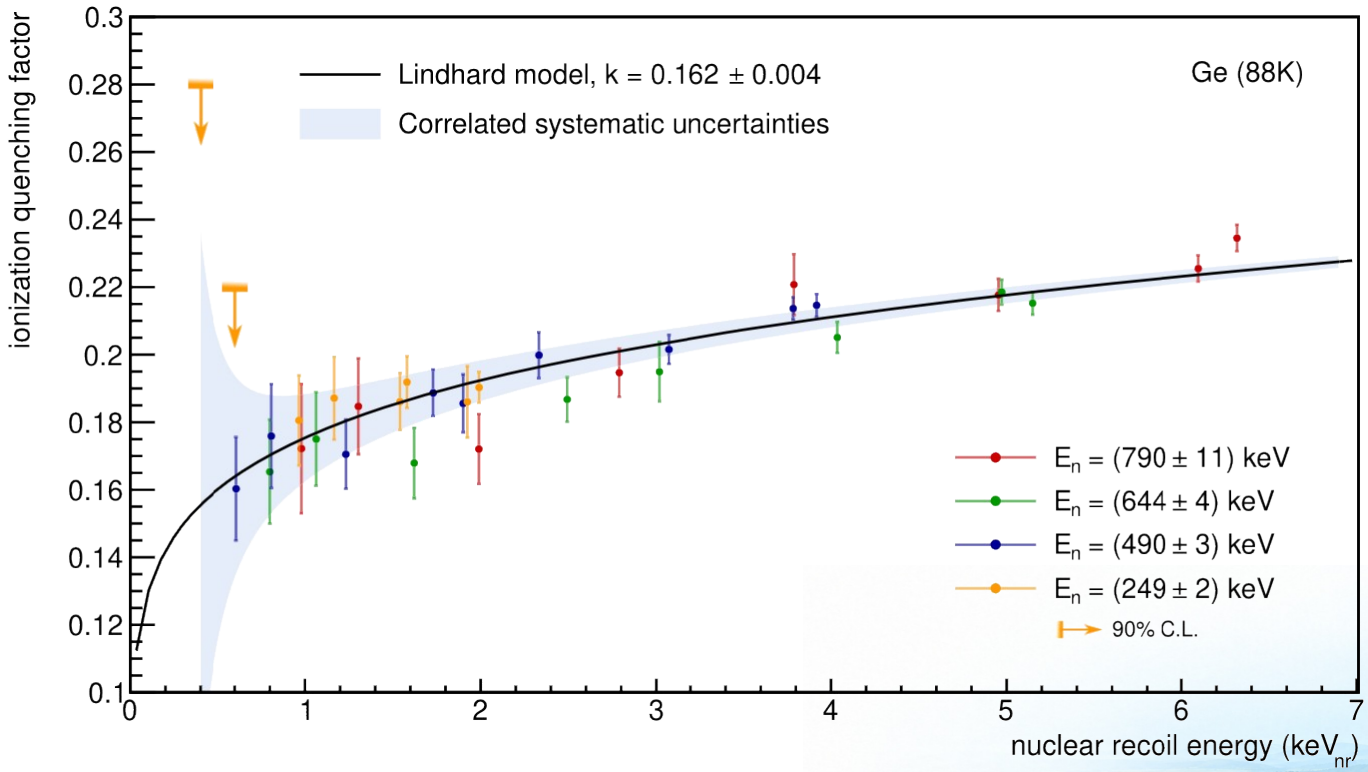
# Run 2 - Stability



# Run 2 - Stability



# Quenching measurement




https://link.springer.com/article/10.1140/epjc/s10052-022-10768-1

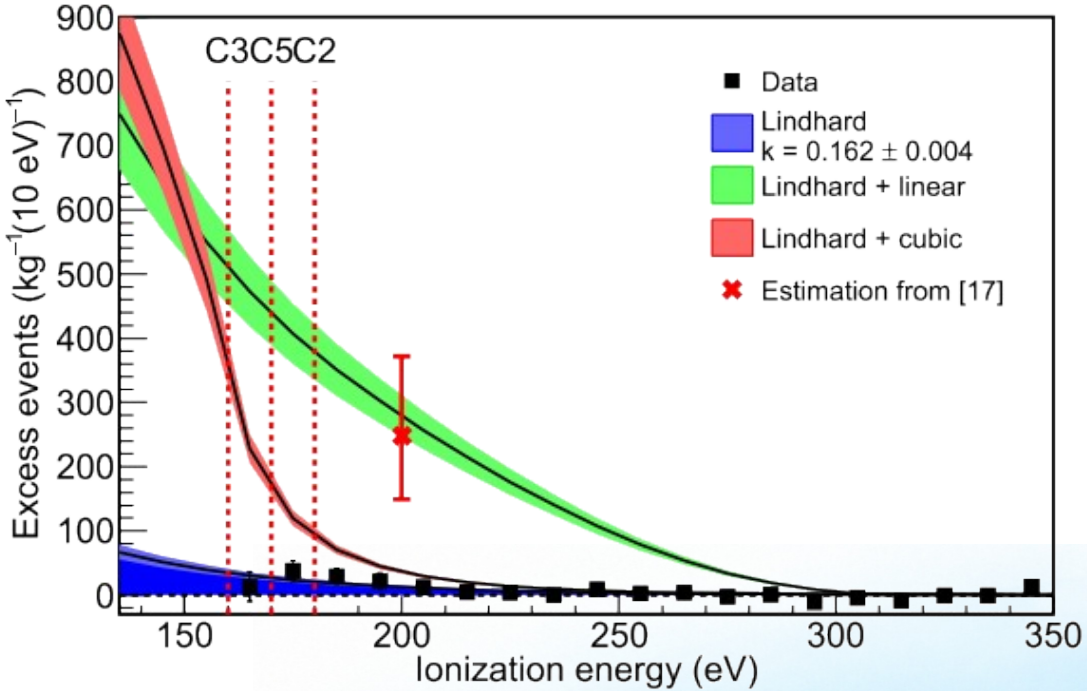
# Run 1 quenching investigation

**Models from:**

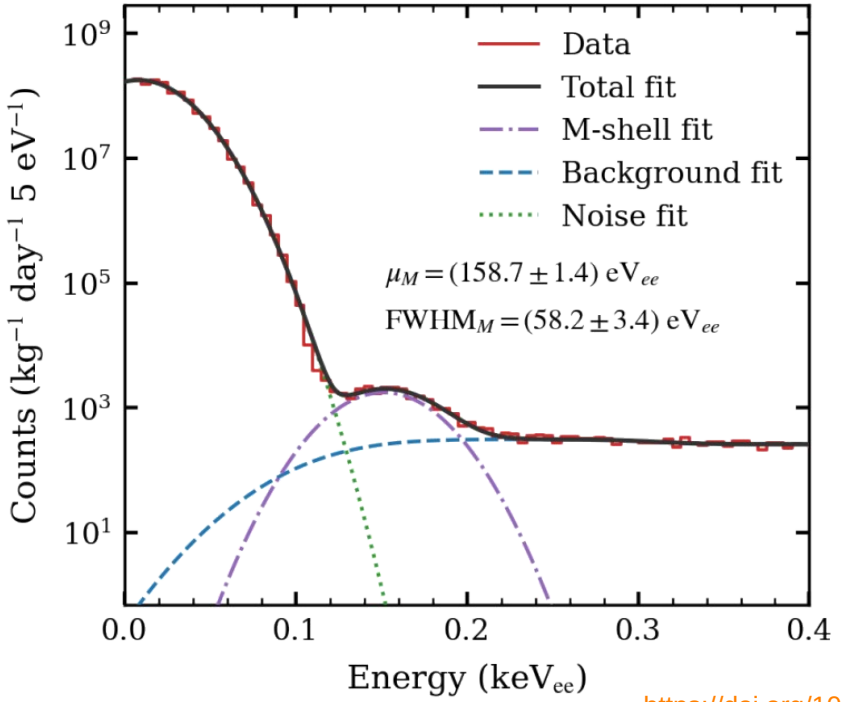
Colaresi, J., Collar, J. I., Hossbach, T. W., Lewis, C. M. & Yocum, K. M. Measurement of coherent elastic neutrino-nucleus scattering from reactor antineutrinos. Phys. Rev. Lett. 129, 211802 (2022).

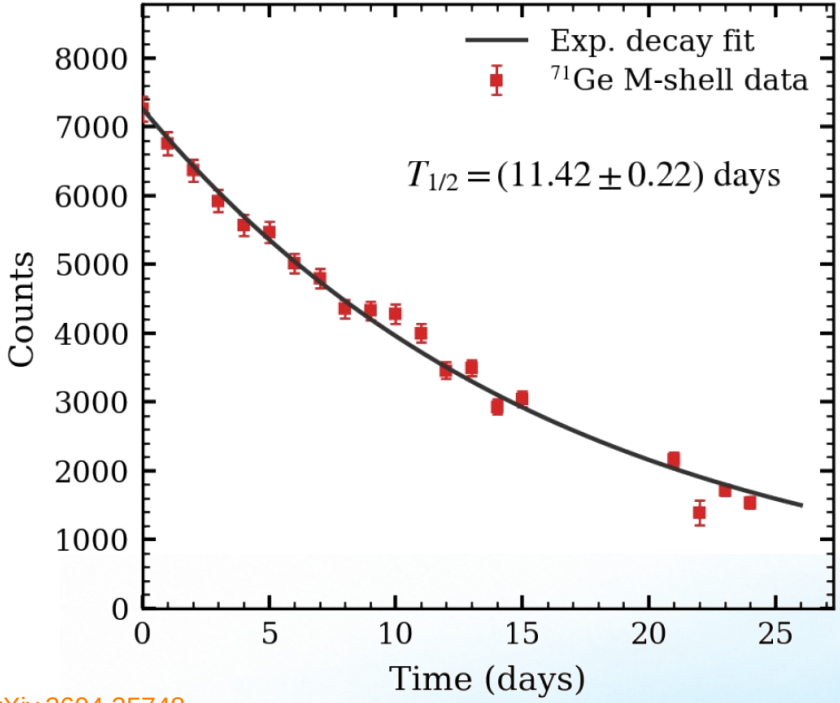
**Data point from:**

Collar, J. I., Kavner, A. R. L. & Lewis, C. M. Germanium response to sub-keV nuclear recoils: a multipronged experimental characterization. Phys. Rev. D 103, 122003 (2021).



# Sub-kev energy calibration



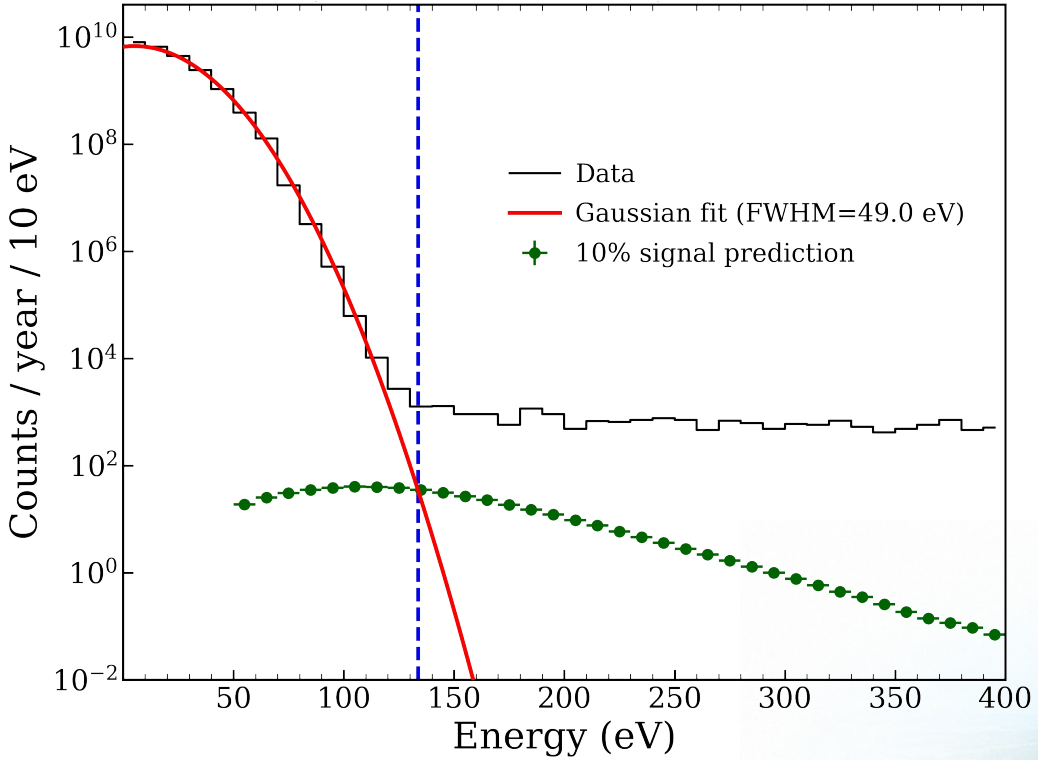

https://doi.org/10.48550/arXiv.2604.25748

Achieved thanks to:

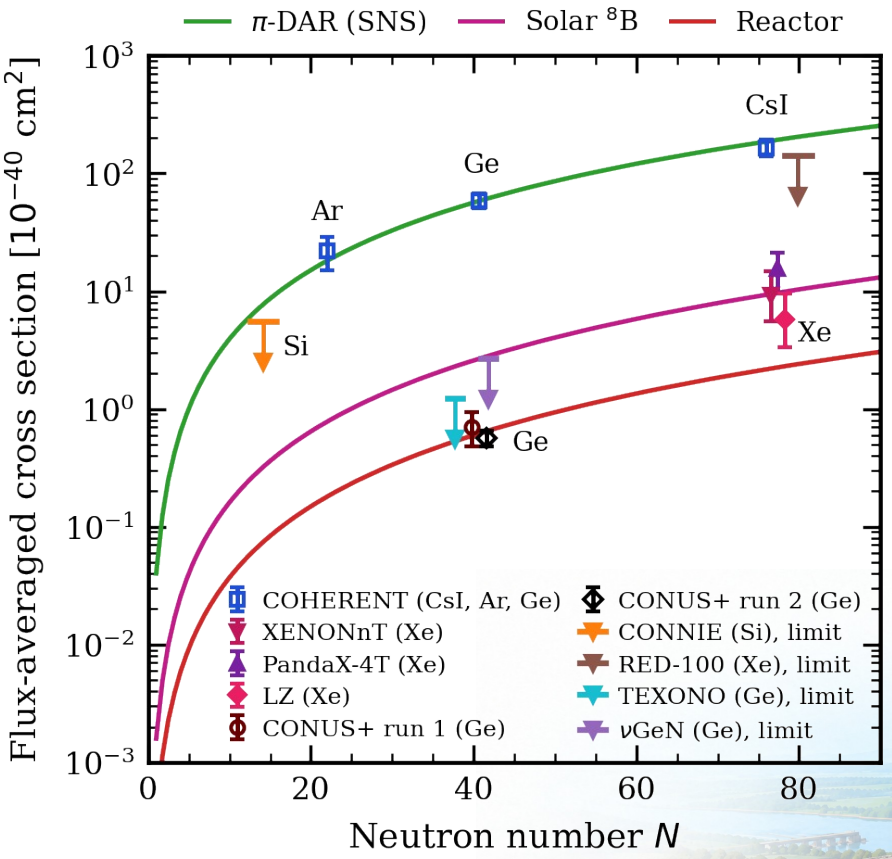
- Precise linear energy calibration
- **Reduction of non-linearity** + correction for the remaining
- Very accurate model of the **trigger efficiency** and its interplay with the detector resolution
- Noise investigations to correctly distinguish the noise spectrum from physical events

**Validation of energy reconstruction down to the energy threshold!**

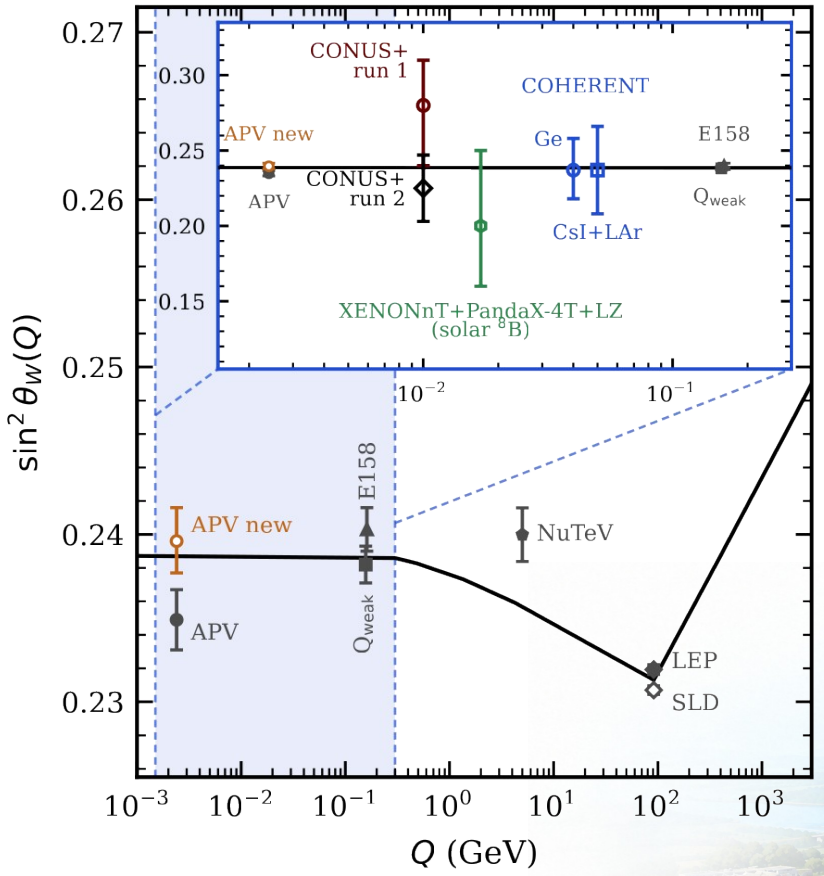
# Threshold definition



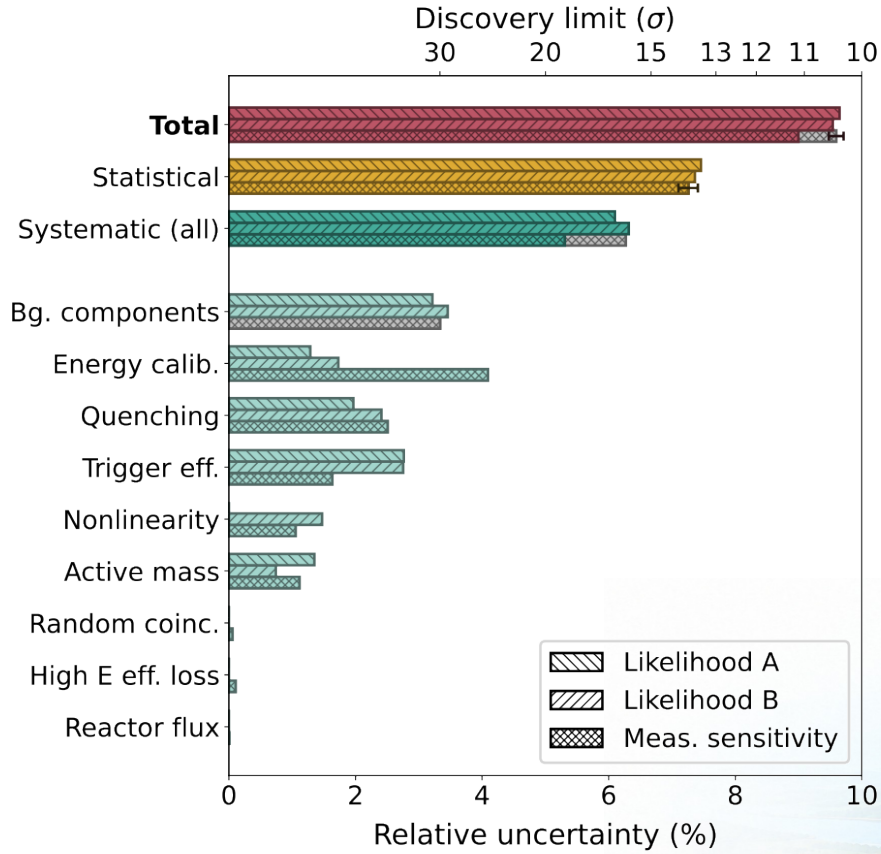
# Comparison to other experiments



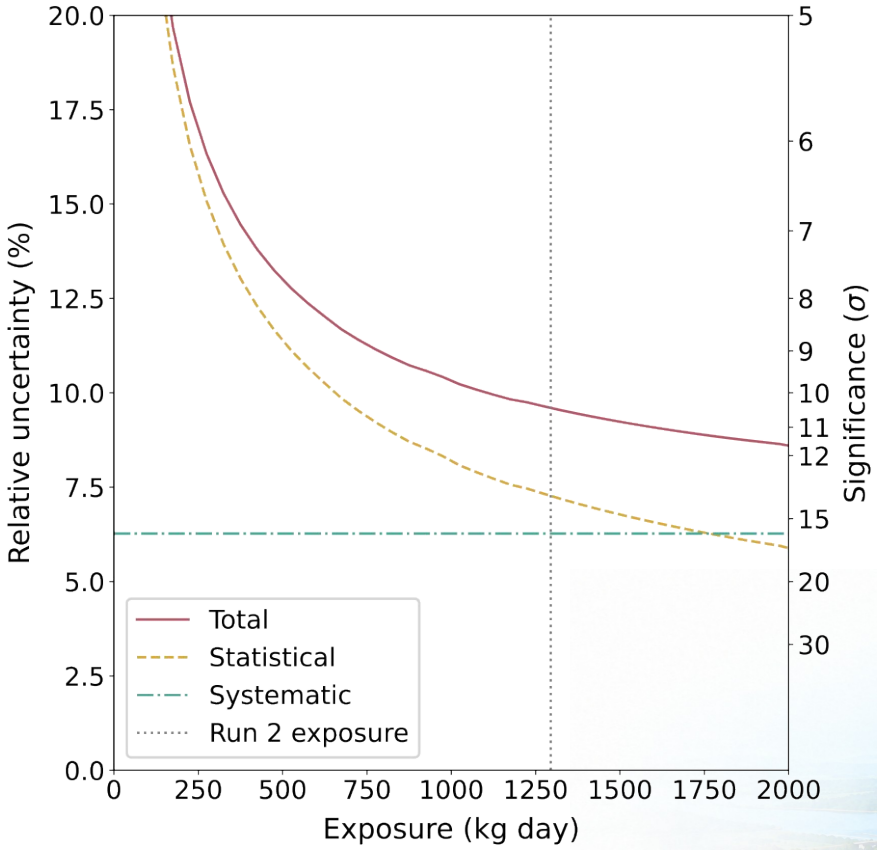
# Weinberg angle



# Run2 – Meas. uncertainties



# Run2 – Meas. uncertainties



# Crosschecks

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TABLE VI. Summary of the consistency checks performed on the final CE$\nu$NS result. For each test, the number of signal counts $N_s$ (or the signal rate $R_s$ for the reactor-on minus reactor-off fit) is compared to the final combined fit or to the SM expectation $N_{\mathrm{SM}}$ for the corresponding configuration. All uncertainties include statistical and systematic contributions.

| Test description | Result | Assessment |
|---|---|---|
| Reactor-on only fit | $N_s = 1562 \pm 156$ | Agrees with final fit result |
| Reactor-off fit with free signal | $N_s = 22 \pm 29$ | Consistent with zero |
| Thresholds + 10 $\mathrm{eV}_{ee}$ | $N_s = 1248 \pm 141$ | Consistent with SM prediction ($N_{\mathrm{SM}} = 1369 \pm 163$) |
| Thresholds + 20 $\mathrm{eV}_{ee}$ | $N_s = 1039 \pm 139$ | Consistent with SM prediction ($N_{\mathrm{SM}} = 1092 \pm 131$) |
| Fit range to 2 $\mathrm{keV}_{ee}$ | $N_s = 1617 \pm 140$ | Agrees with final fit result |
| Fit range to 8 $\mathrm{keV}_{ee}$ | $N_s = 1636 \pm 139$ | Agrees with final fit result |
| Uncertainties scaled for goodness of fit | $N_s = 1555 \pm 167$ | Agrees with final fit result, significance $9.3\,\sigma$ |
| Reactor-on minus reactor-off fit | $R_s = (5.75 \pm 1.83)\ \mathrm{d}^{-1}$ | Corresponds to $N_s = 1817 \pm 578$ and agrees with final fit result |

