First observation of reactor anti-neutrinos via coherent scattering with CONUS+

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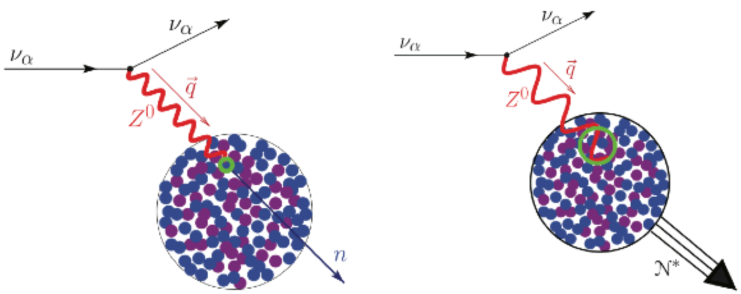
Neutrino Telescopes, Padova, Oct 1st 2025

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

Coherent elastic neutrino nucleus scattering

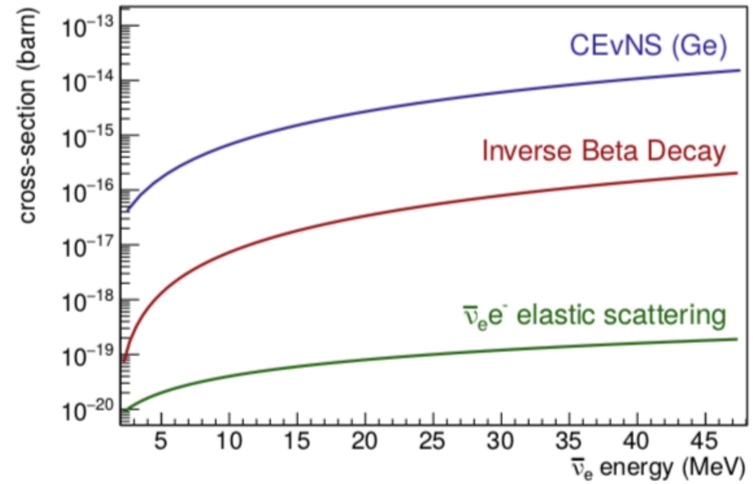
M. Cadeddu et al 2023 EPL 143



Inelastic incoherent $\lambda_{Z^0} \ll 2R$

Elastic incoherent $\lambda_{Z^0} \lesssim 2R$

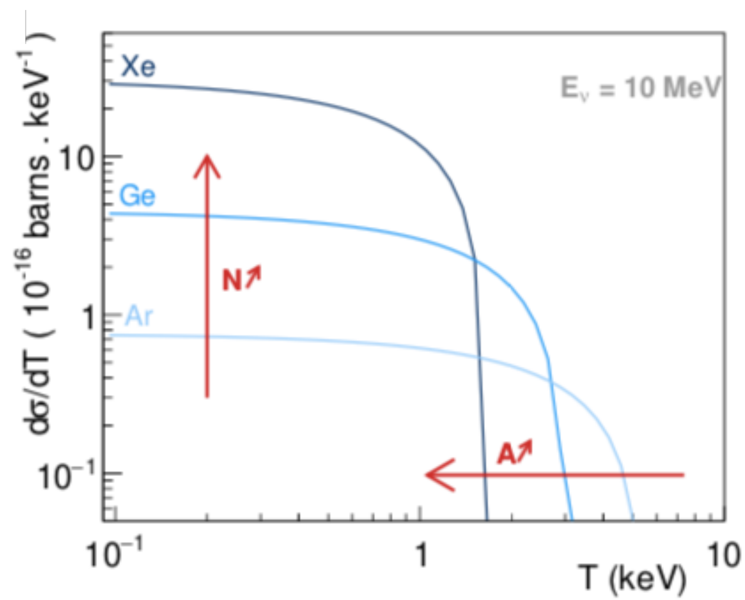
Elastic coherent (CEνNS) $\lambda_{Z^0} \gtrsim 2R$



CEvNS advantages:

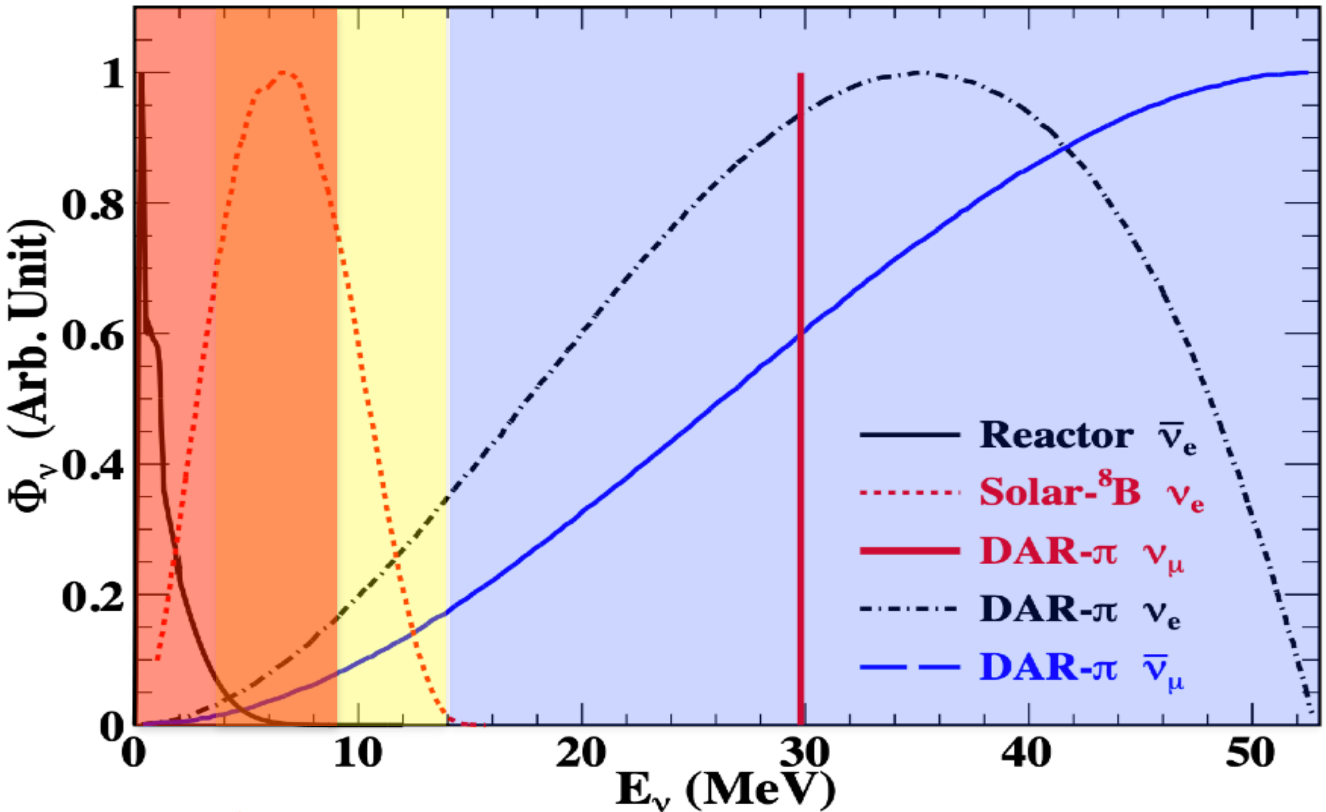
- **NC interaction ==> all flavors**
- **No reaction threshold**
- **"Small" neutrino detectors**

$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi}\underbrace{\left[N-(1-4\sin^2\theta_w)Z\right]^2}_{\sim N^2}\underbrace{F^2(q^2)}_{\to 1}\, M\left(1-\frac{MT}{2E_\nu^2}\right)$$



Challenge: tiny recoil E

Neutrino sources for CEvNS studies

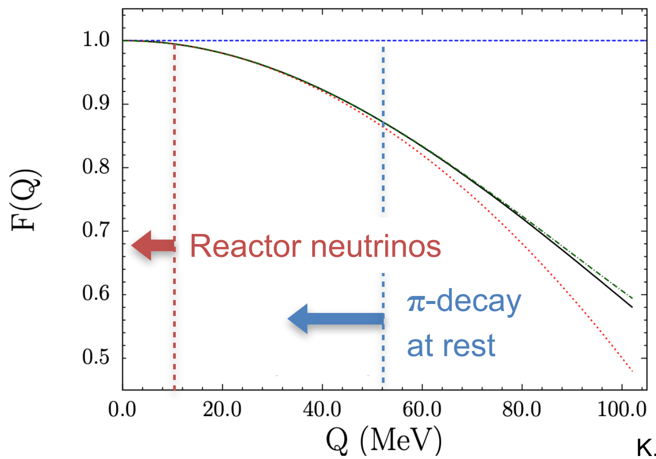


TEXONO, arXiv2502.20007

Reactor	Pion decay-at-rest
• Pure electron antineutrino flux	• Different neutrino flavors
• E < 10 MeV ==> form factor ~1	• E > 10 MeV ==> form factor <1

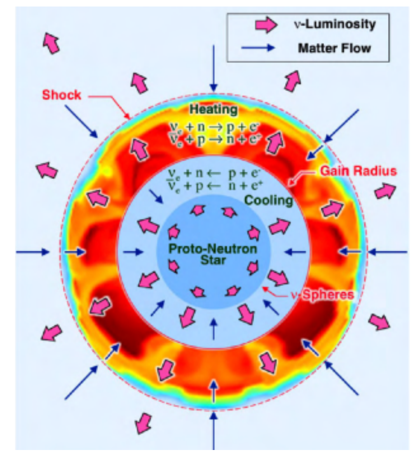
Implications

Nuclear physics



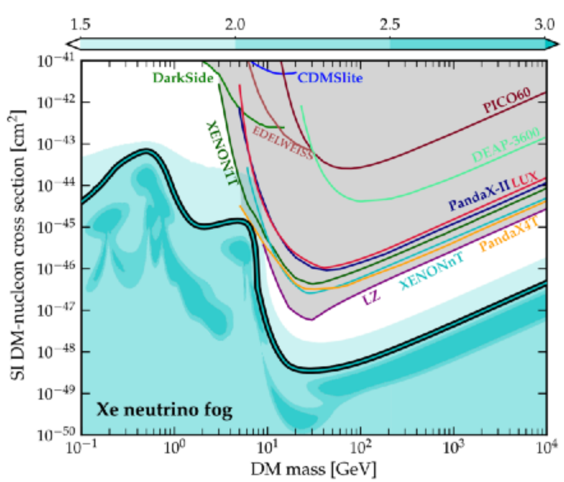
K. Patton et al., PRC 86, 024612 (2012)

Astrophysics



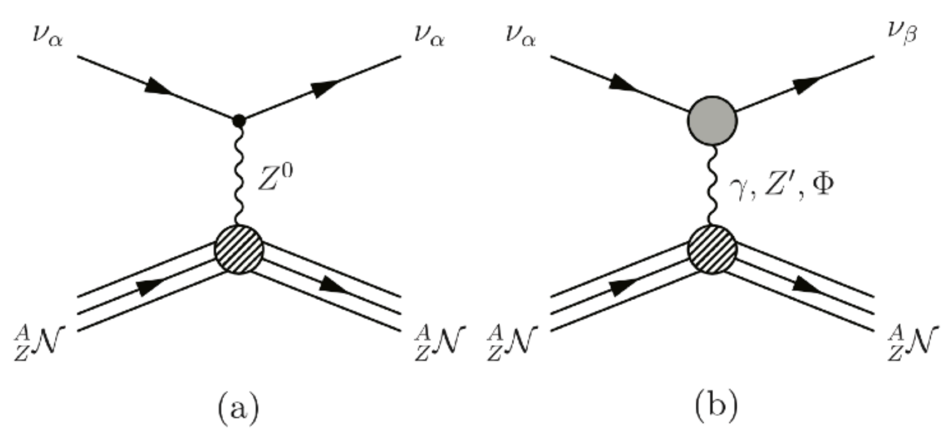
https://science.osti.gov/-/media/ascr/ascac/pdf/meetings/mar03/Mezzacappa.pdf

Dark matter ("neutrino floor")



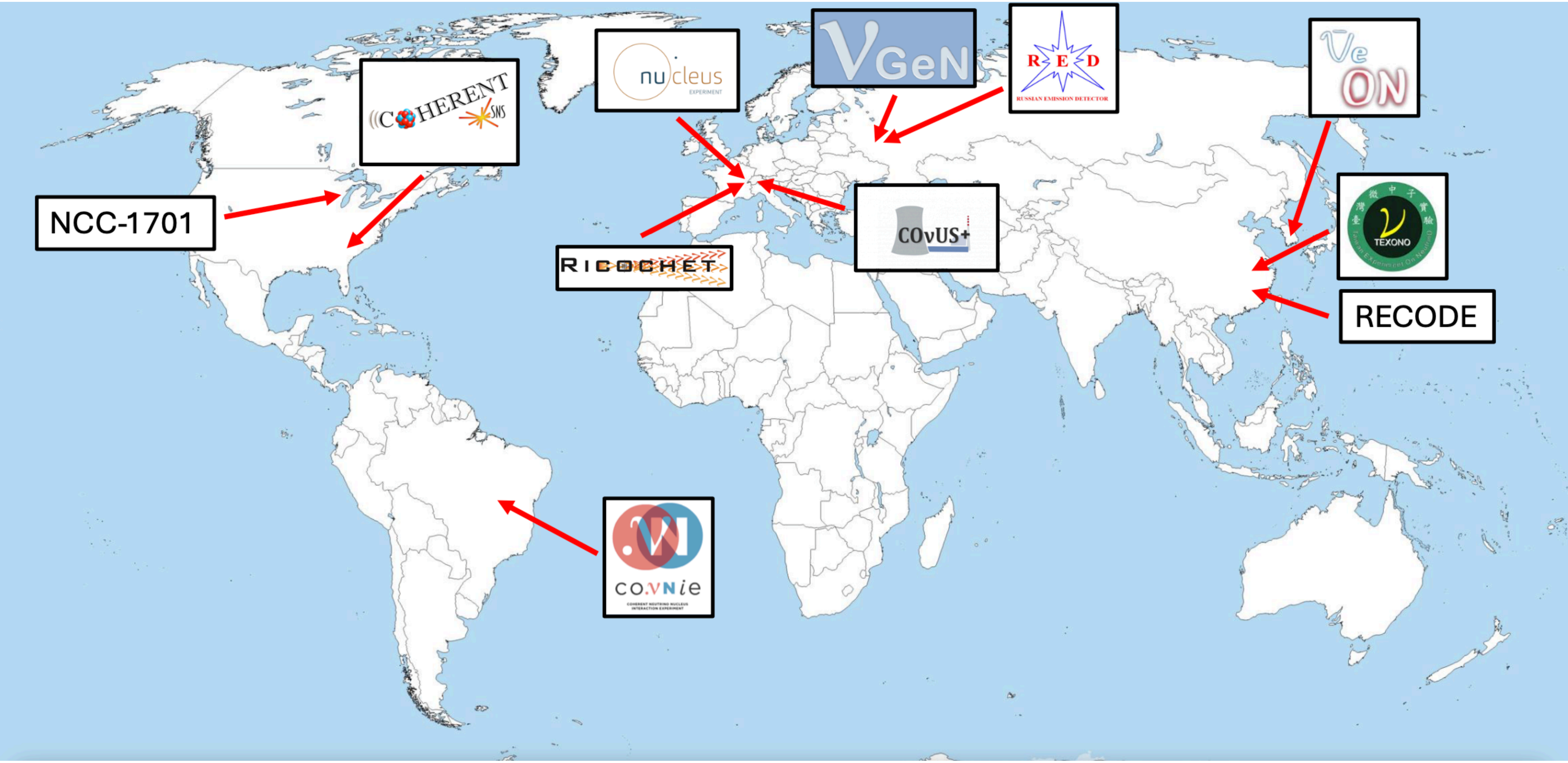
J.Tang et al., PRD 108, 062004 (2023)

BSM physics



M. Cadeddu et al., EPL 143 (2023)

CEvNS worldwide



First observation: COHERENT in 2017 (CsI at SNS)

CONUS Collaboration

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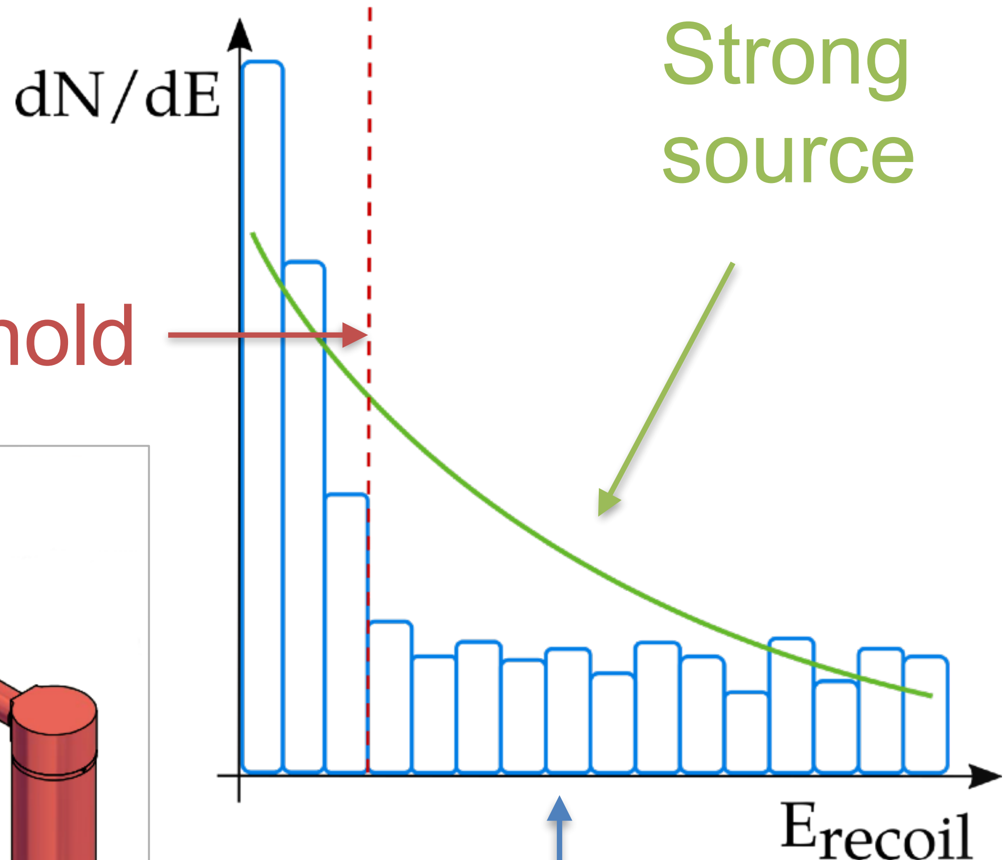
Kernkraftwerk Leibstadt AG (KKL), Switzerland

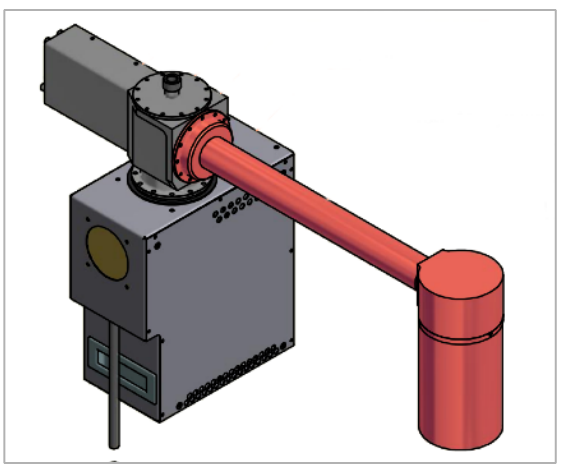
Concept

Nuclear power plant (Leibstadt, CH, KKL)

Strong source

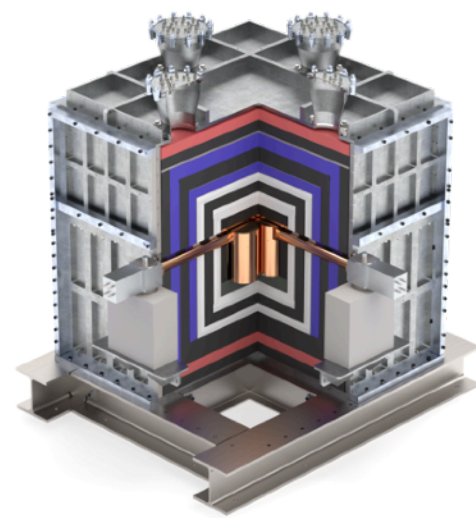
Low threshold





Ge spectrometers

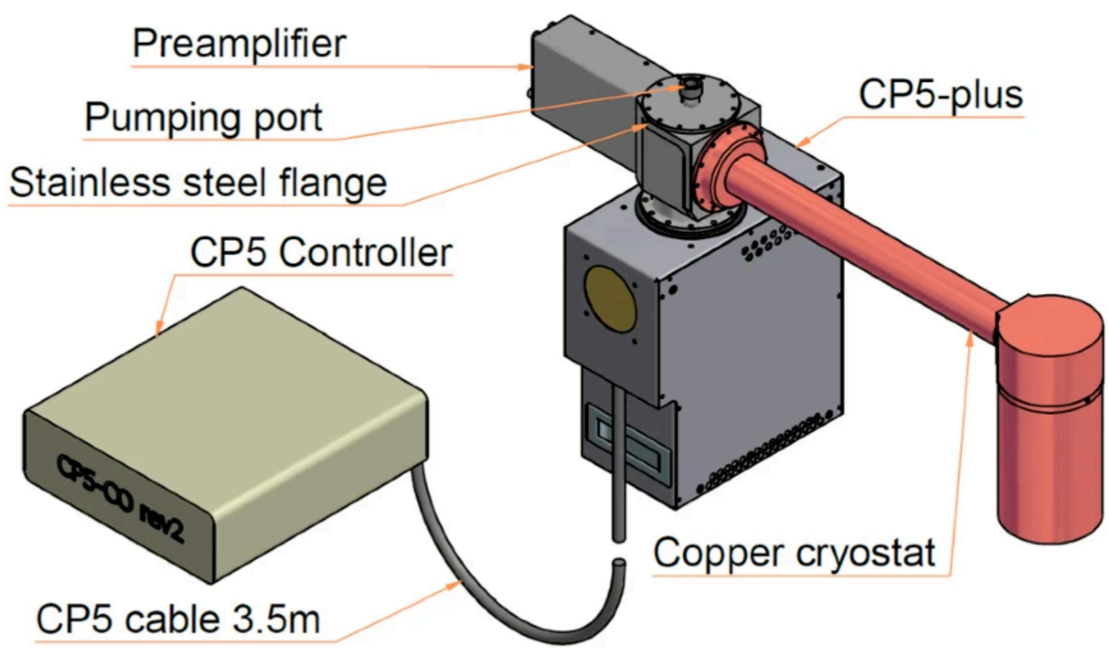
Low background

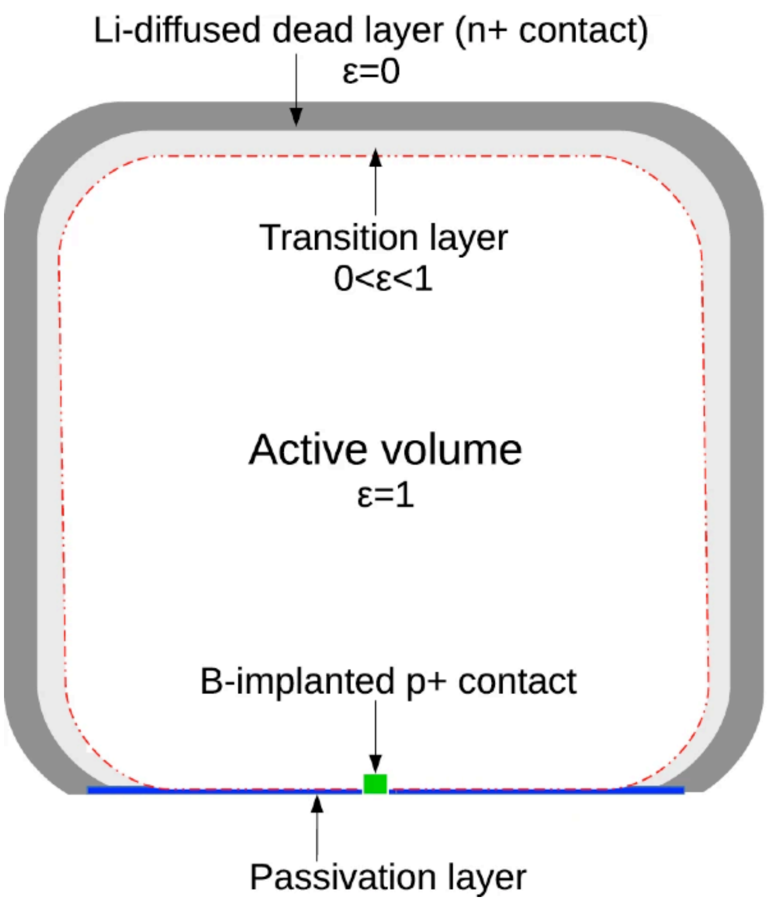


Shield

The CONUS Ge detectors

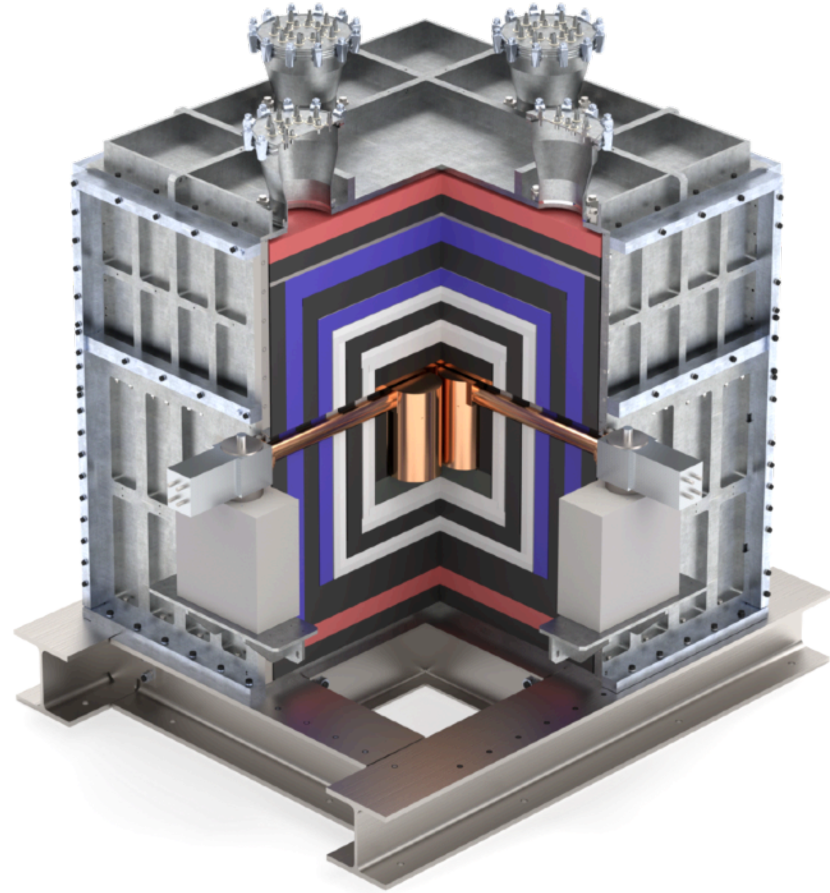
- High-purity PPC Ge detectors (4x)
- Each 1 kg mass
- Electrical cryo-cooling
- Low threshold, high E resolution



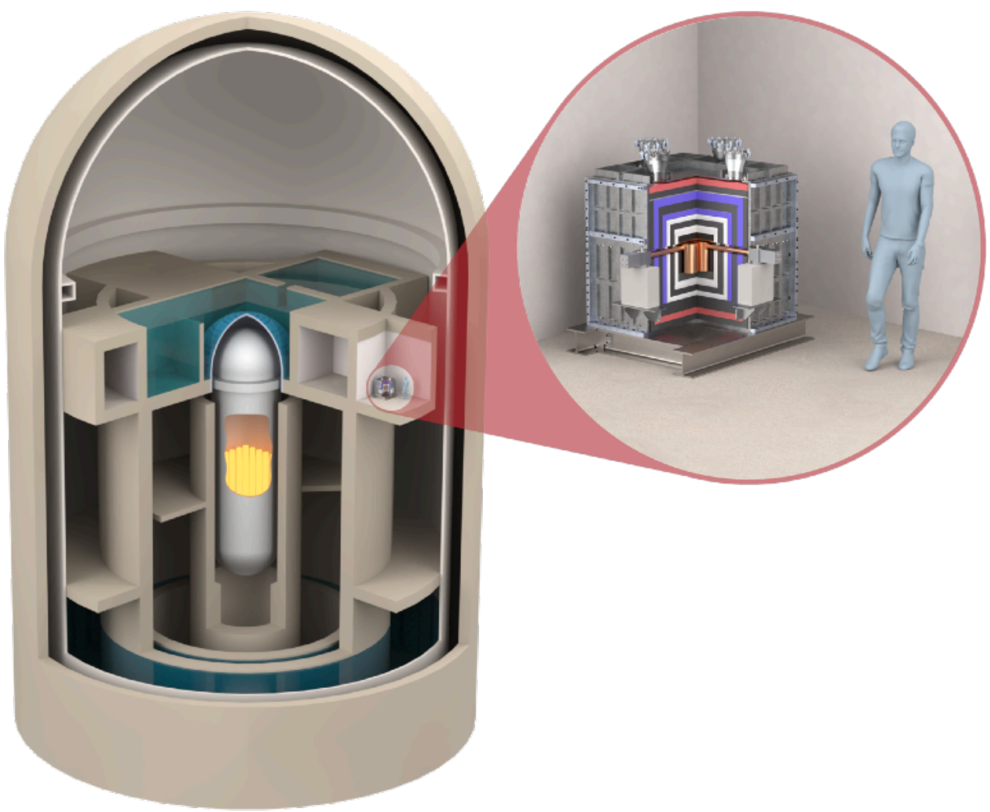


The CONUS+ shield

- ~ 10 tons, 1.65 m^3
- Low radioactivity Pb
- Borated PE
- Active muon veto
- Flushing with air bottles (Rn removal)
- Steel structure (earthquake-resistant)
- ~ 4 orders of magnitude background reduction



Experimental site



- Moved from Brokdorf to Leibstadt, Switzerland
- 3.6 GW thermal power
- Distance 20.7 m
- Flux: ~$1.5 \cdot 10^{13}$ /(s·cm^2)
- Overburden: 7.4 m w.e.
- About 4 weeks of reactor OFF/year
- Direct data transfer and online monitoring

Challenging environment: Restricted materials, access, safety rules, ON vs OFF stability,…

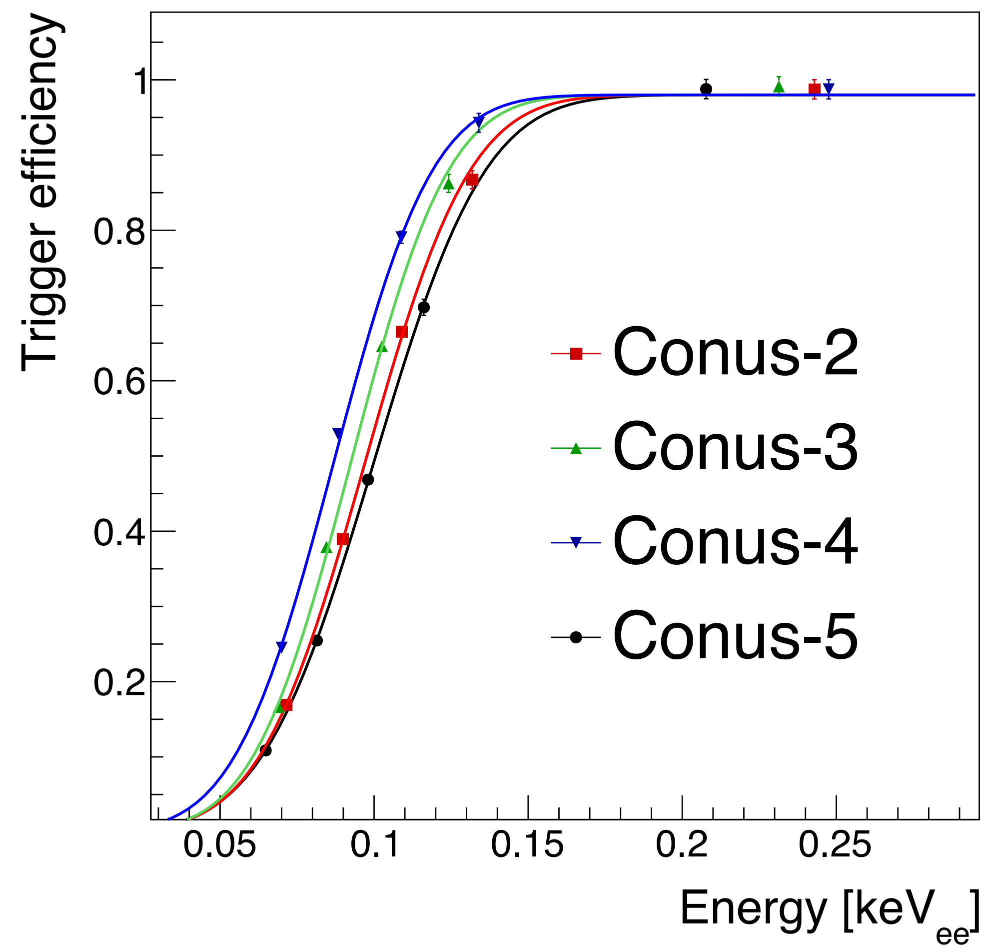
HPGe detector upgrade

Pulser resolution (FWHM)

Detector	Before	After
C2	77 eV_{ee}	48 eV_{ee}
C3	64 eV_{ee}	47 eV_{ee}
C4	68 eV_{ee}	47 eV_{ee}
C5	85 eV_{ee}	47 eV_{ee}

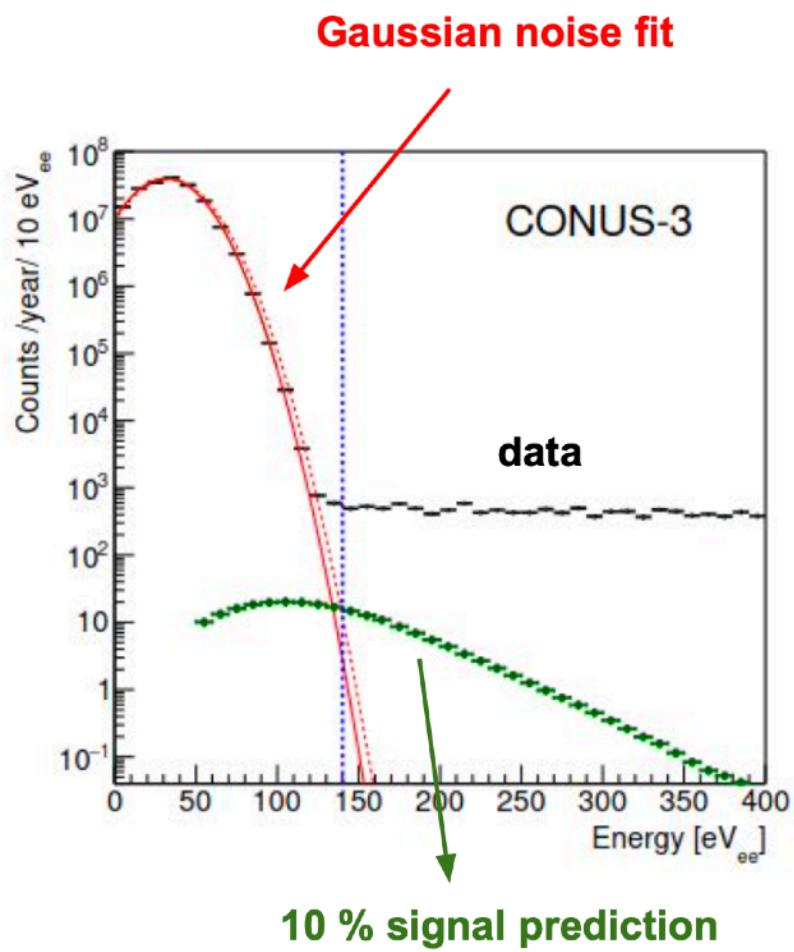
CONUS, EPJC 84 (2024) 1265

Trigger efficiency



50%: ~300eV_{ee} to ~100 eV_{ee}

Region of interest definition



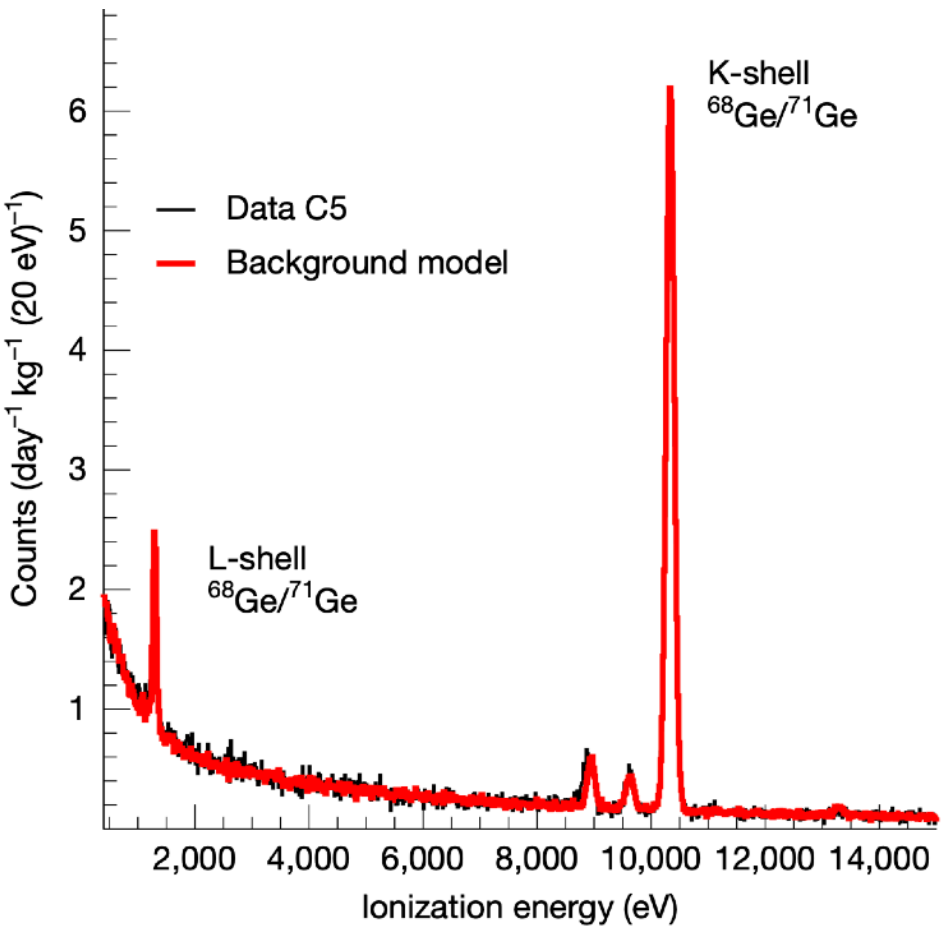
CONUS, EPJC 84 (2024) 1265

Detector	Threshold
C2	180 eV$_{ee}$
C3	160 eV$_{ee}$
C4	-
C5	170 eV$_{ee}$

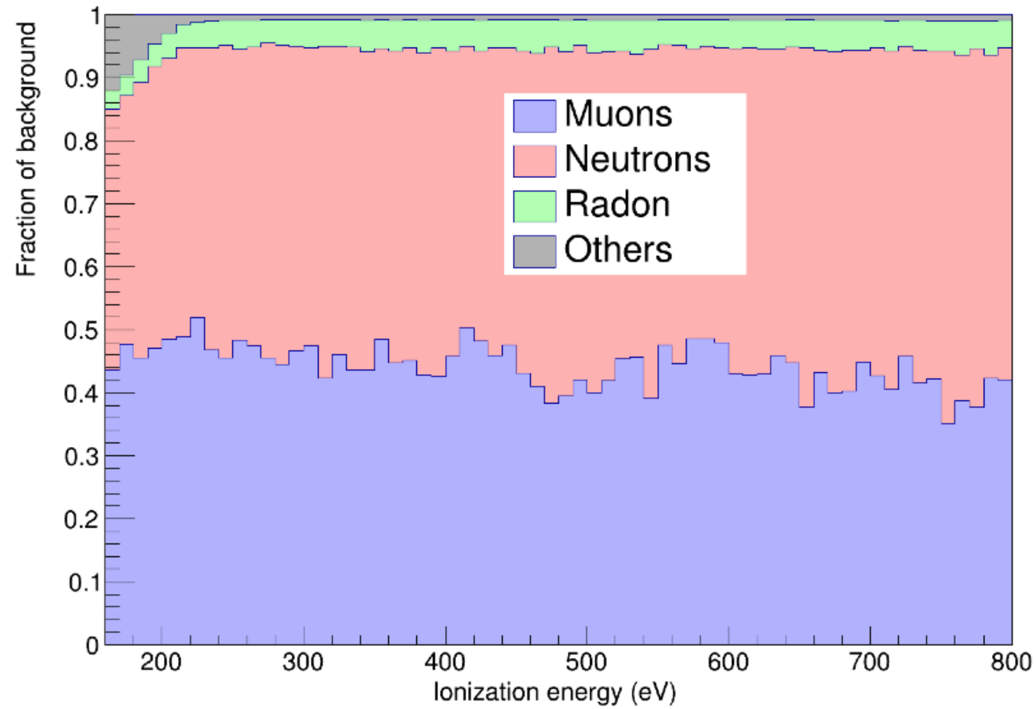
Energy threshold improved from 210 eV to ~160 eV!

Background model

CONUS, Nature 643 (2025) 1229



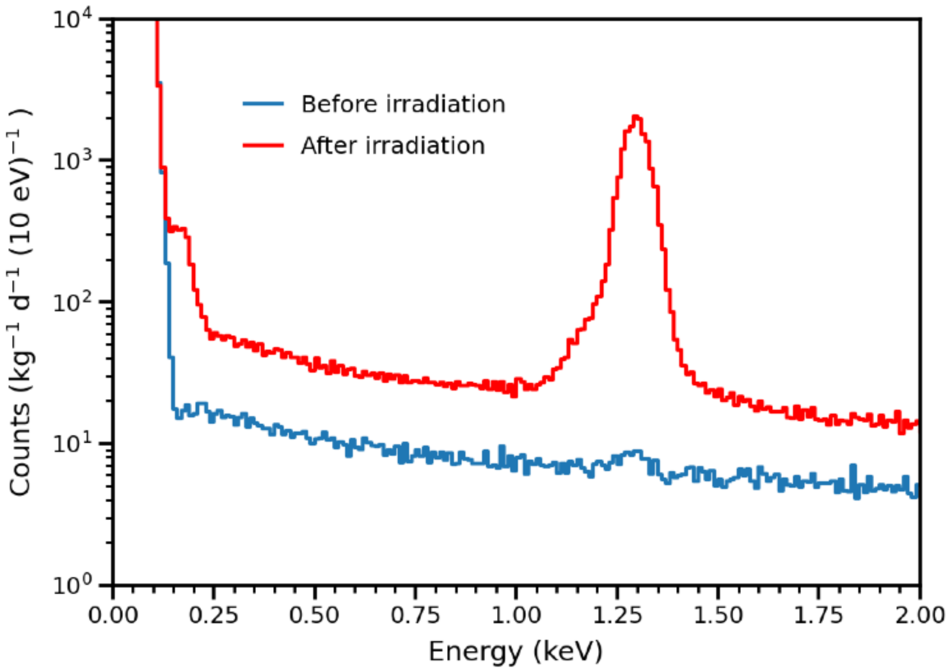
E calibration using K/L shell lines

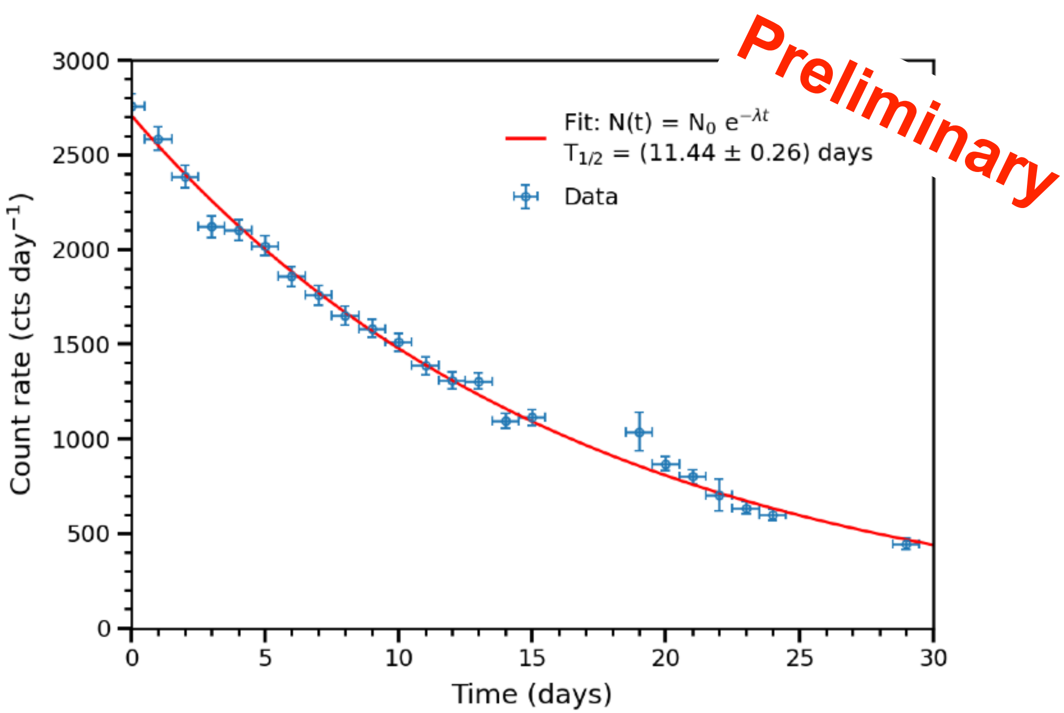


Most relevant background components reactor uncorrelated (mainly cosmic)

M-shell line

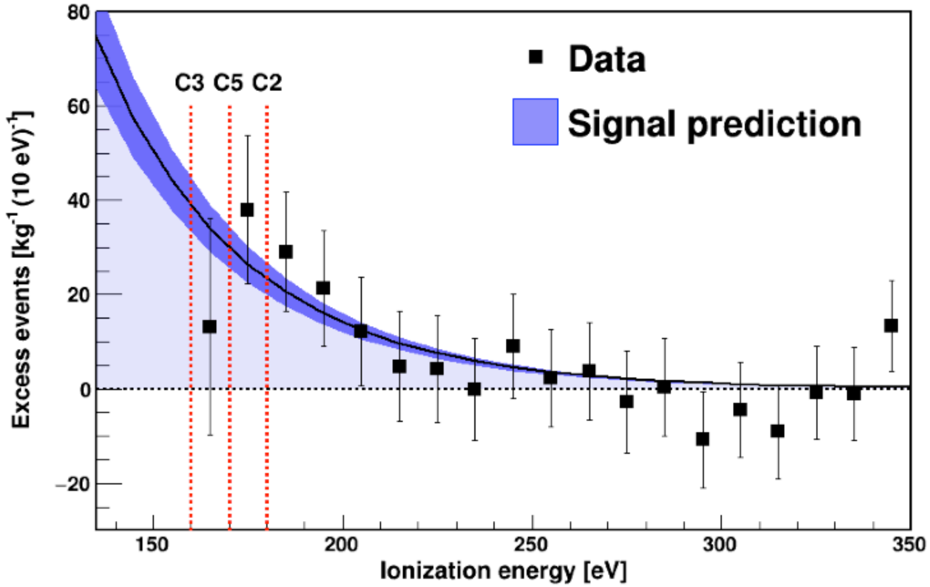
- Production of ^{71}Ge (EC) with n source (also possible on-site)
- Peak position: 162±4 eV (lit.158.1±0.5 eV, CDMS 162±2 eV)
- Decay time 11.4±0.3 d, resolution (FWHM): 65±4 eV (as expected)
- Ratios: L/K 0.1334±0.0003 (lit. 0.1331), M/K 0.021 (lit. 0.027)

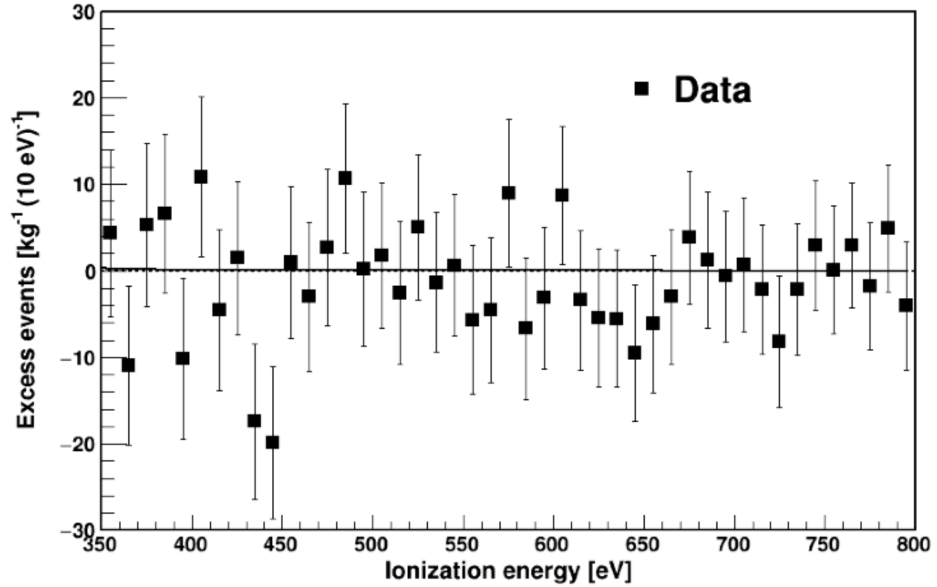




Results

CONUS, Nature 643 (2025) 1229



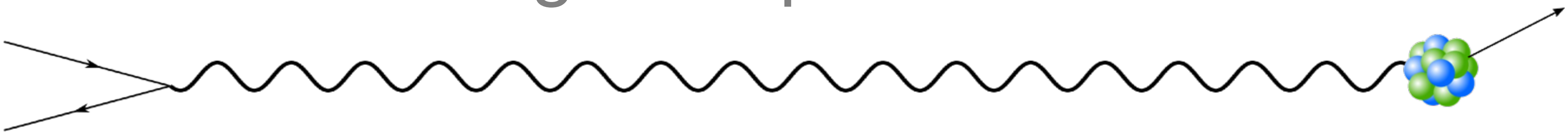


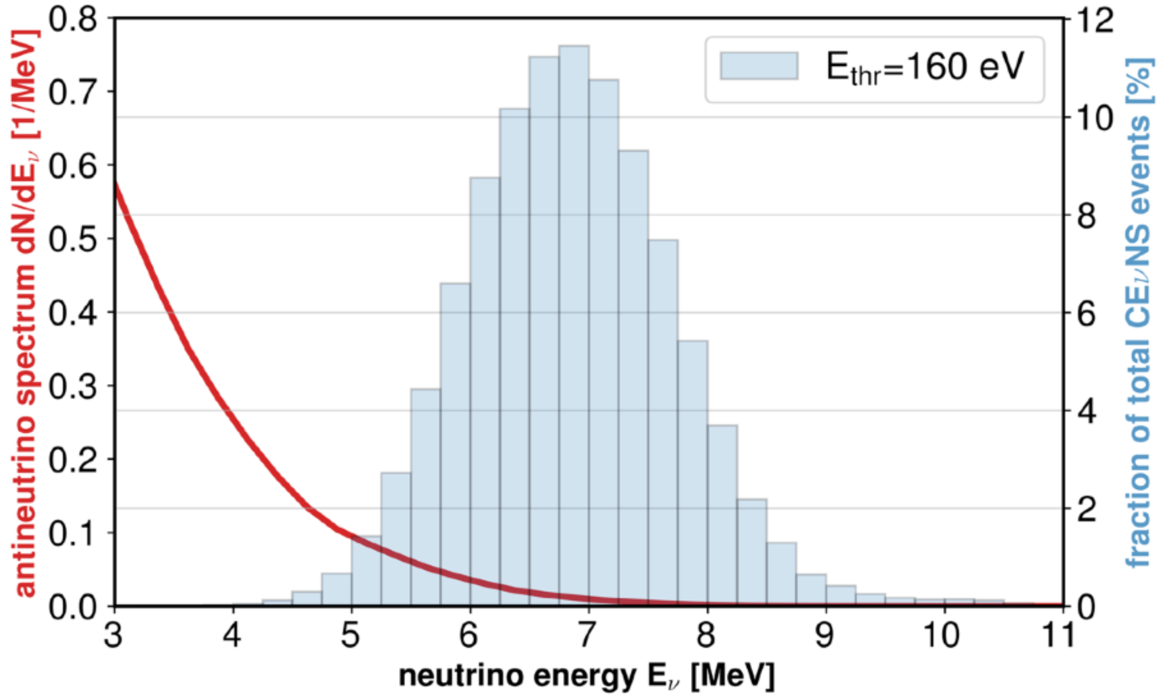
Exposure: 327 (kg d) reactor ON and 60 (kg d) reactor OFF

Signal events from combined fit: 395±106

Data/prediction: 1.14±0.36

Signal expectation



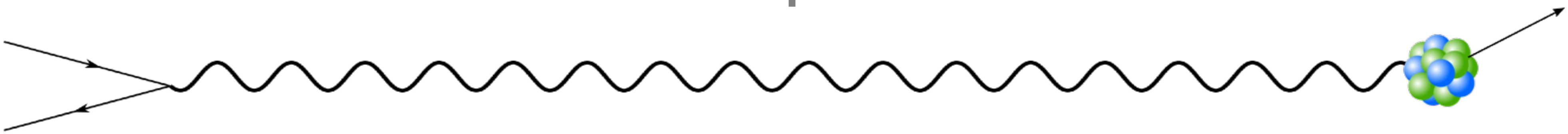


Detector	Threshold	Live time	Predicted events
C2	180 eV	117 d	96 ± 16
C3	160 eV	110 d	135 ± 23
C5	170 eV	119 d	116 ± 20

Prediction uncertainties

Energy	14.1 %
Quenching	7.3%
Reactor flux	4.6%
Cross-section	3.2%
Active mass	1.1%
Trigger efficiency	0.7%

Global picture



Experiment	Source	Target	Signal	Data/SM
COHERENT	Accelerator	Cs	306±20	0.90±0.14
COHERENT	Accelerator	Ar	140±40	1.22±0.49
COHERENT	Accelerator	Ge	21±7	0.59±0.26
XENONnT	Sun (^{8}B)	Xe	11±4	0.90±0.66
PandaX-4T	Sun (^{8}B)	Xe	3.5±1.3	1.25±0.69
CONUS+	Reactor	Ge	395±106	1.14±0.36

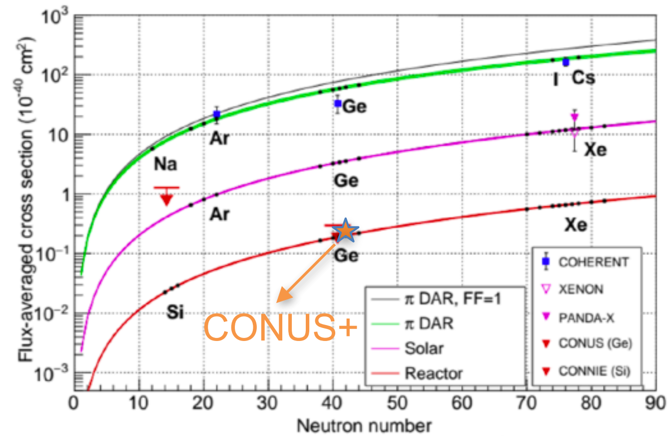
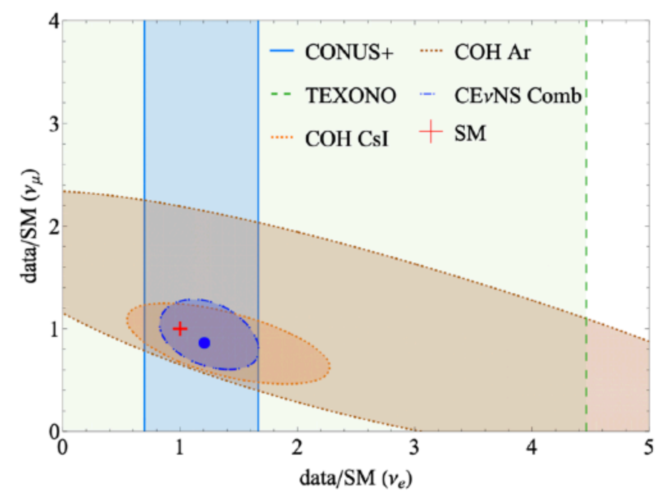


Figure courtesy of K. Scholberg

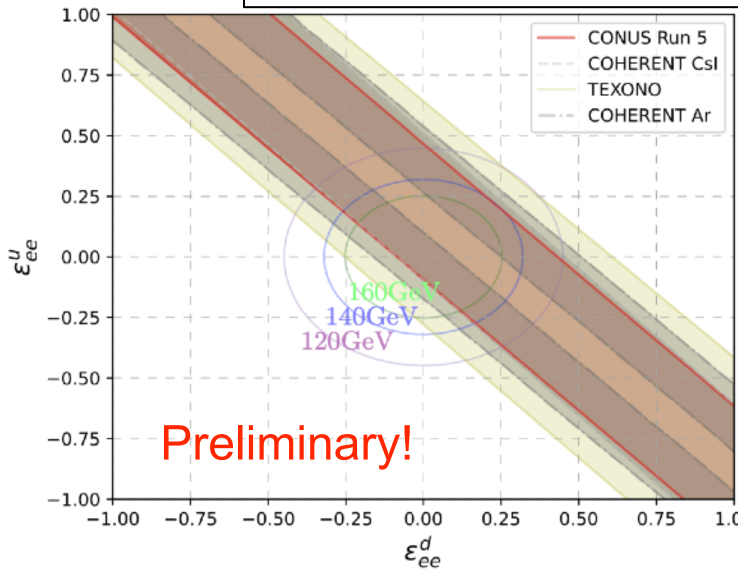


M.Atzori Corona et al., *PRD* 112 (2025) 1, 015007

CONUS+: lowest neutrino energy, highest rate for single element

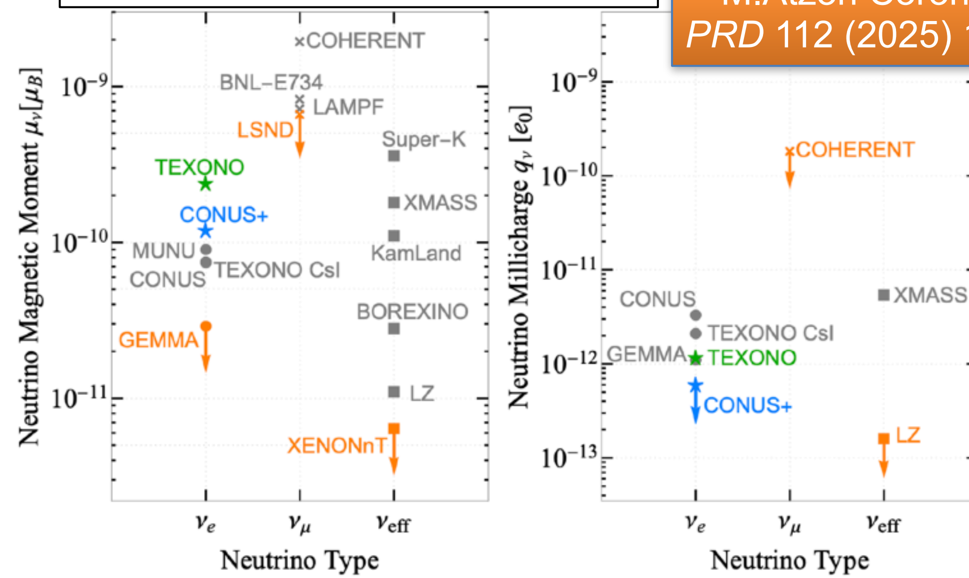
BSM studies

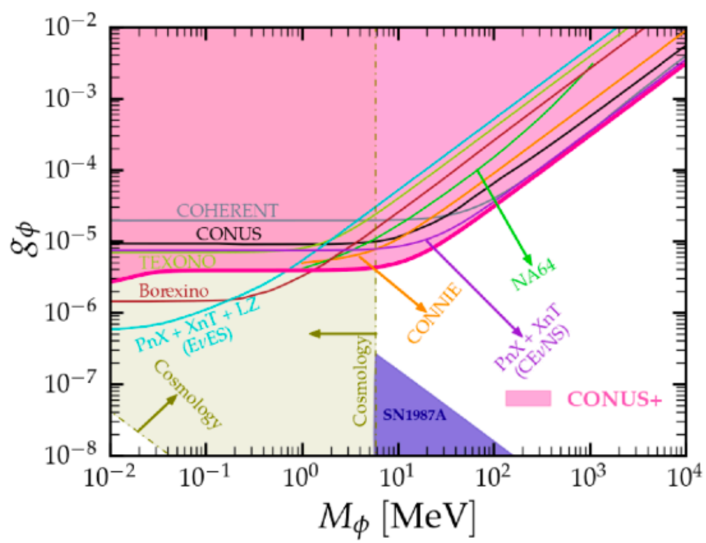
Non-standard interactions

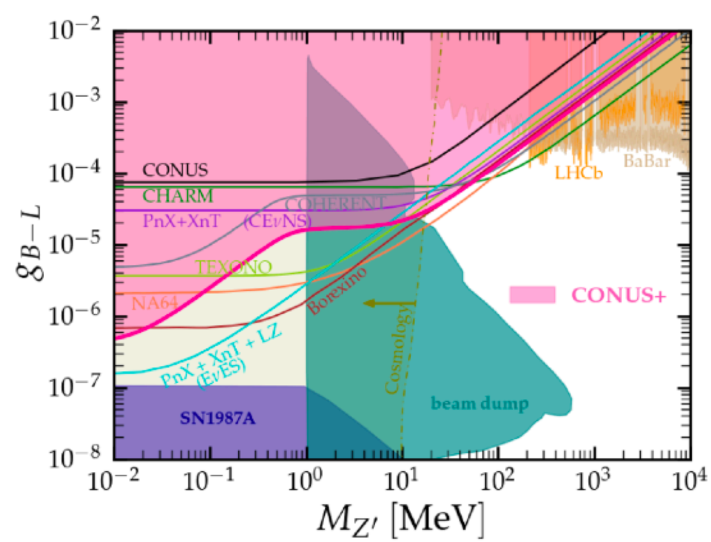


Electromagnetic properties

M.Atzori Corona et al., *PRD* 112 (2025) 1, 015007



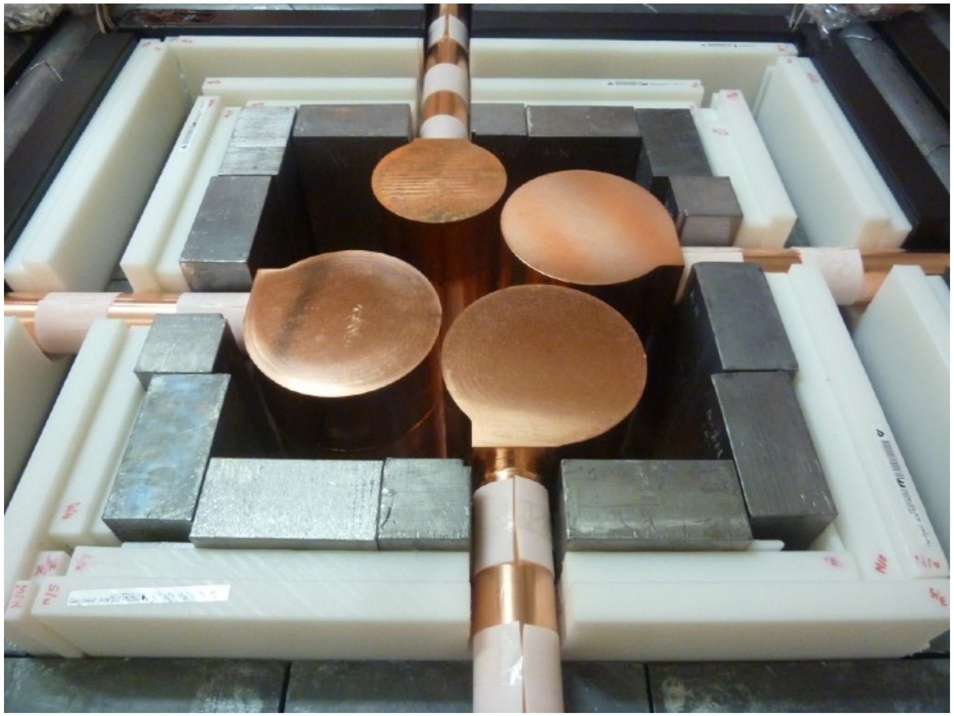




Light mediators

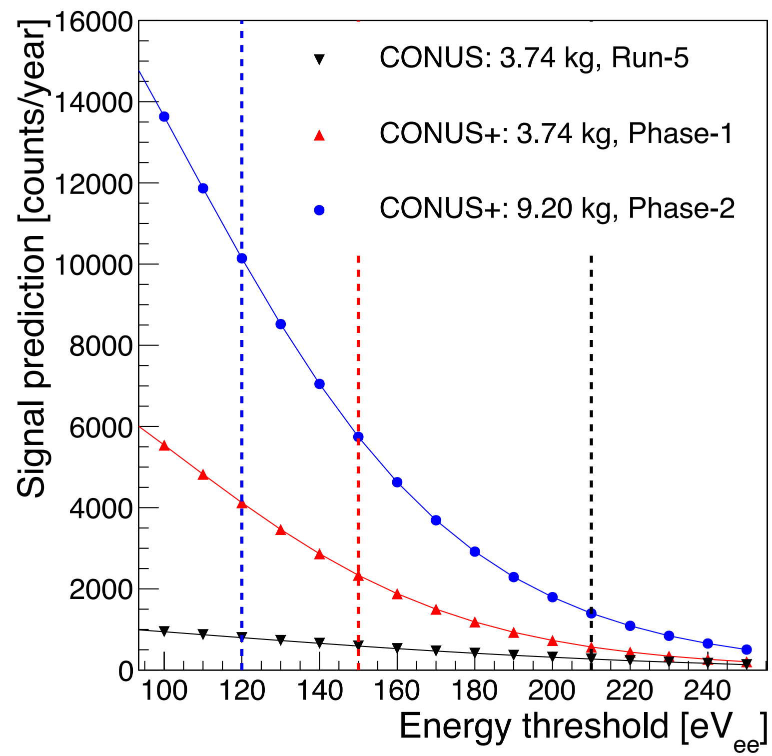
A.Chattaraj et al., arXiv 2501.12441 (2025)

Outlook



- 3 detectors replaced by larger mass crystals (2.4 kg)
- Run-2 started early 2025
- Include pulse shape discrimination

- Improve precision
- Technology scalable
- 100 kg ⇒ >100000 $\overline{\nu}$/year



Summary

- High cross-section of CEvNS ==> compact neutrino detectors
- CONUS+: HPGe detectors at 20.7 m from reactor core
- Mainly cosmic background events: reactor power uncorrelated!
- First CEvNS detection at nuclear reactor (3.7 sigma)
- Result consistent with theoretical models and predictions
- Run-2 with increased mass has started