Joint Institute for Nuclear Research, Dubna

Lebedev Physical Institute of RAS, Moscow

A. Konovalov (LPI RAS) on behalf of the νGeN collaboration

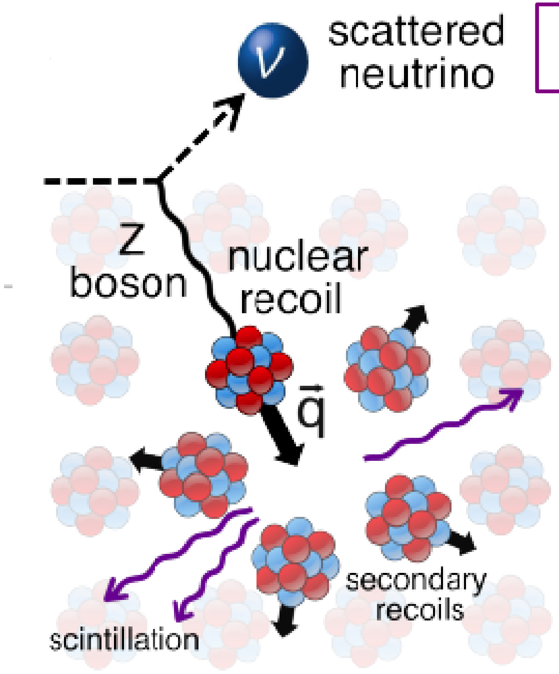
Status and perspectives of the νGeN neutrino experiment at Kalinin NPP

This work is supported by the Russian Science Foundation (project no. 24-72-10089)

NUCLEUS-2025, Saint Petersburg

July 3 2025

CEvNS — coherent elastic neutrino-nucleus scattering



«Coherent effect of a weak neutral current», D. Freedman, PRD v.9, iss.5 (1974)

«Isotopic and chiral structure of neutral current», V.Kopeliovich, L. Frankfurt, ZhETF. Pis. Red., v.19 n.4 (1974)

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{4\pi}\Big([1-4\sin^2\theta_W]Z - N\Big)^2\Big[1-\frac{T}{T_{max}}\Big]F_{nucl}^2(q^2)$$

$$T_{max} = 2E_\nu^2/(M+2E_\nu)$$

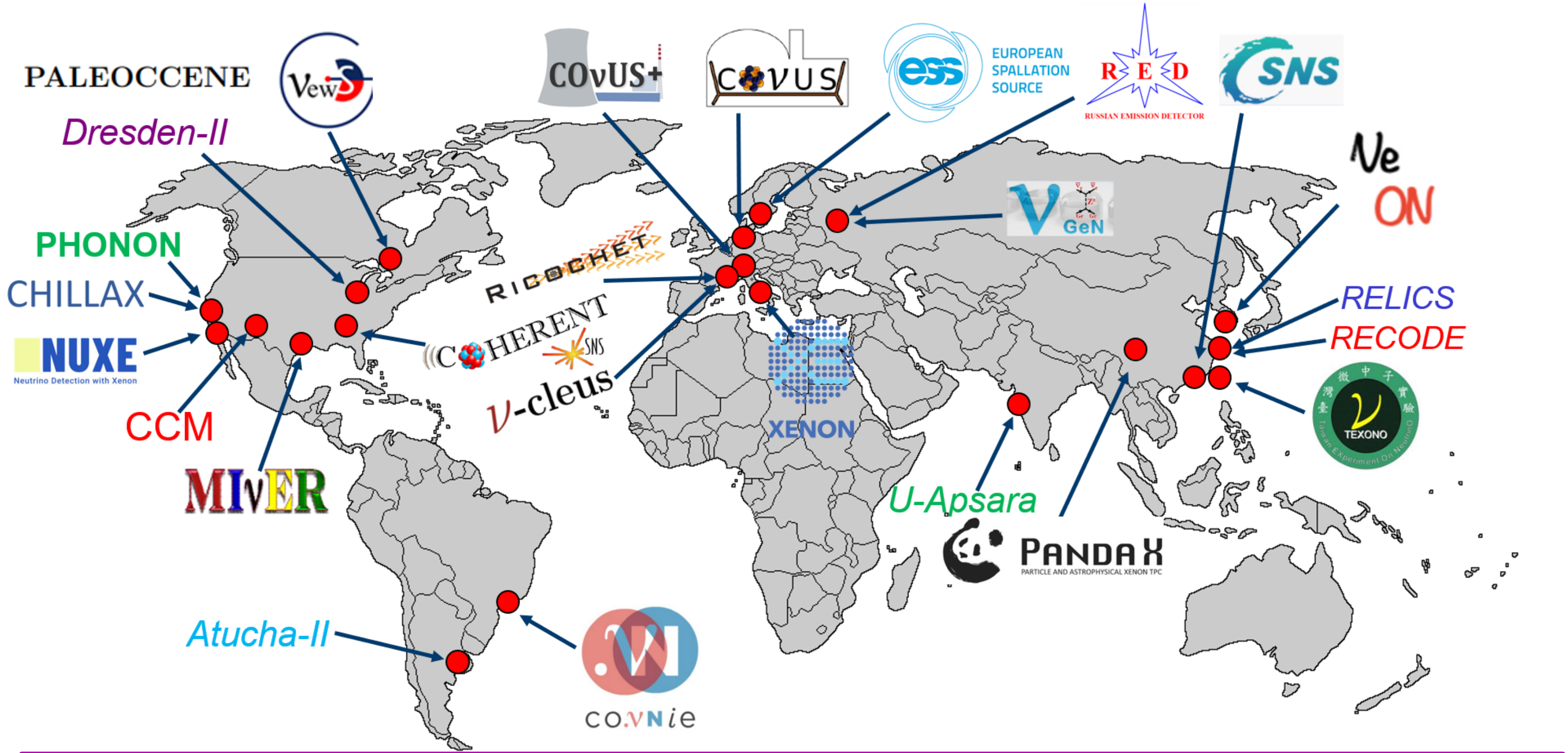
Nucleus	T_{max}, keV (E_ν =5 MeV)	T_{max}, keV (E_ν =30 MeV)
^{12}C	4.44	159.0
^{23}Na	2.32	83.2
^{40}Ar	1.33	47.9
^{74}Ge	0.72	25.9
^{133}Cs	0.40	14.4

Motivation: NC ν-q NSI | Nuclear FF | Reactor monitoring

Results at πDAR: COHERENT (CsI, Ar, Ge)   Hints of solar: PandaX-4T, XENONnT (Xe)

Controversy at reactors: tension between claims of Dresden-II and CONUS+ (Ge)

Worldwide effort



Two experiments in Russia at KNPP (νGeN, RED-100) + international collaboration (COHERENT, RICOCHET)

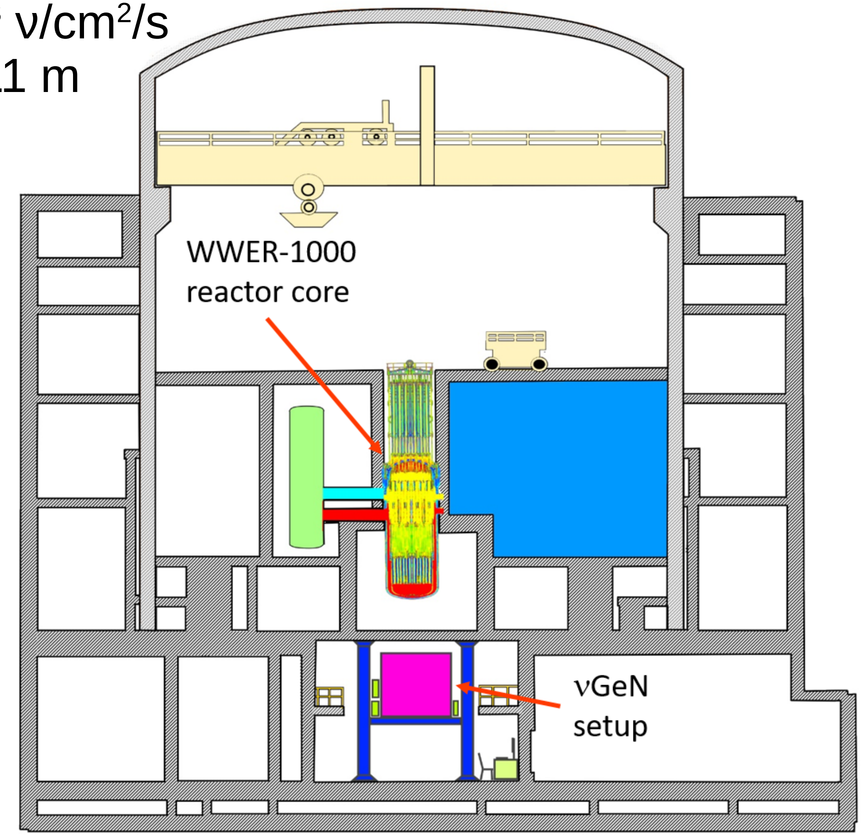
Neutrino experiments at Kalinin NPP

Four neutrino experiments at the same nuclear power plant!

4 WWER-1000 reactors, 3.1 GW_{th} each

Typically 18 months ON, 45 days OFF

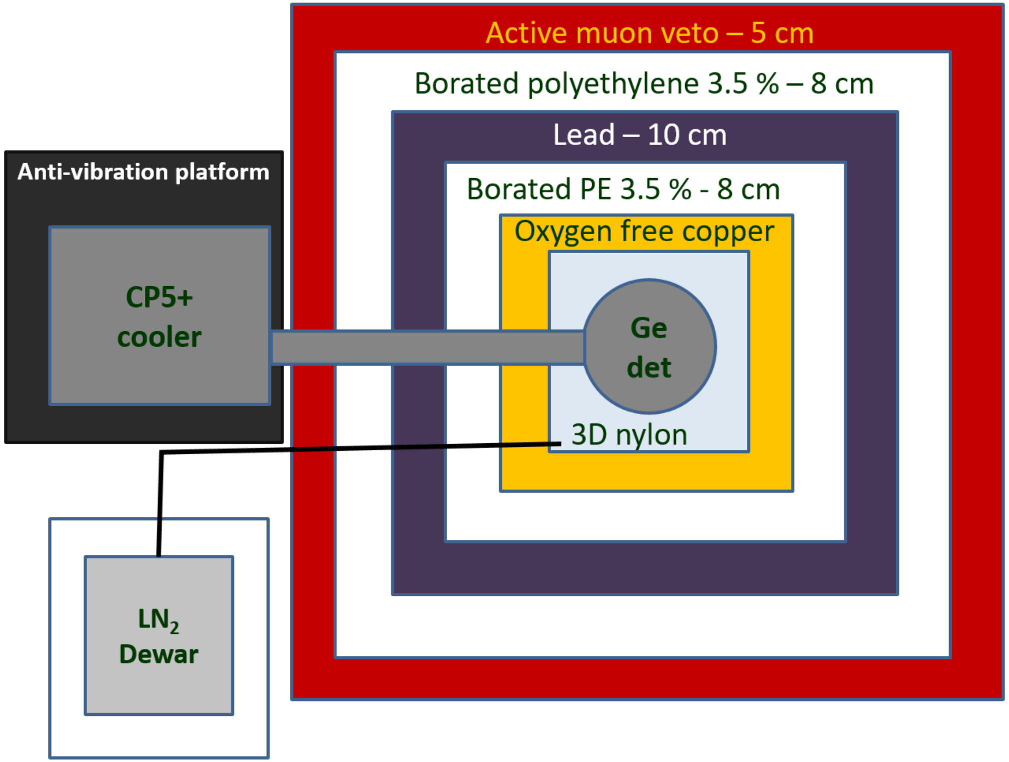
$4.4 \cdot 10^{13}$ ν/cm²/s at 11 m

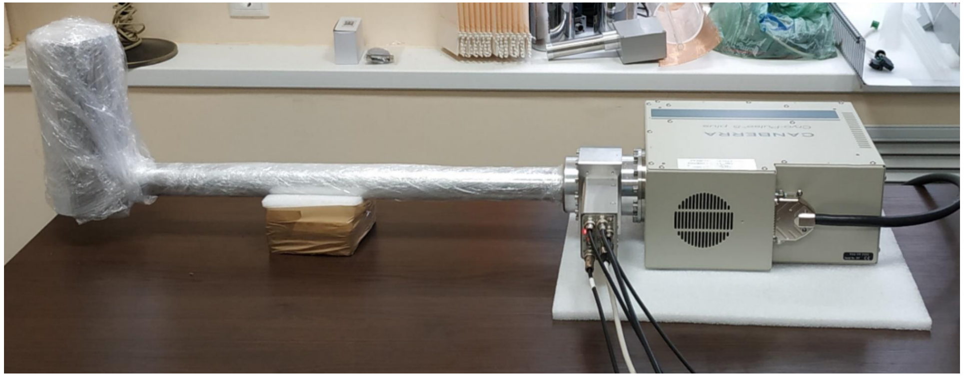


Overburden of 50 m.w.e.

The νGeN setup

The multi-layered shielding protects
the Ge detector





CANBERRA (Mirion, Lingosheim) detector

- HPGe PPC, 1.4 kg active mass
- pulser FWHM of 102 eV at KNPP
- reset preamplifier
- low T by a cryocooler

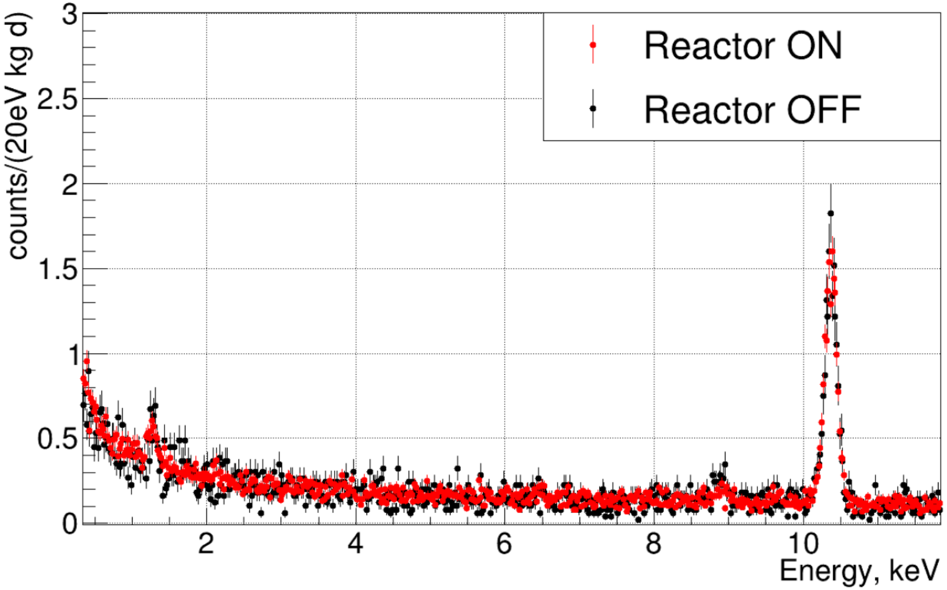
Data taking via spectroscopic shaping amplifiers – comparison of different preamplifier outputs and different shaping times provides noise discrimination capability

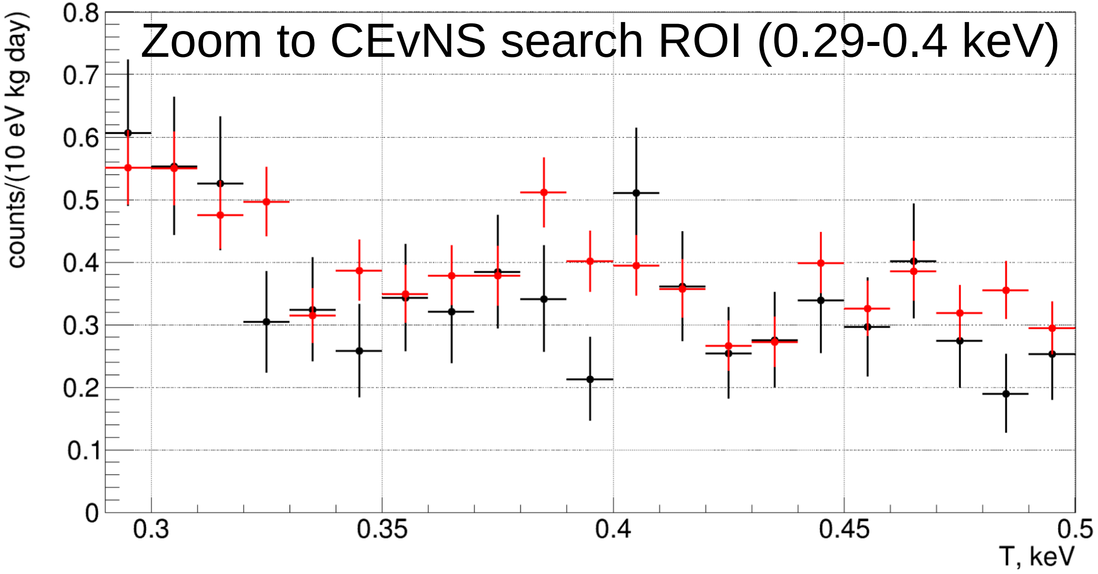
Total exposition: more than 2000 kg×d up to 2025, but different noise and BG conditions

Dataset

Collected October 2022 — May 2023 at 11.1 m from the reactor core

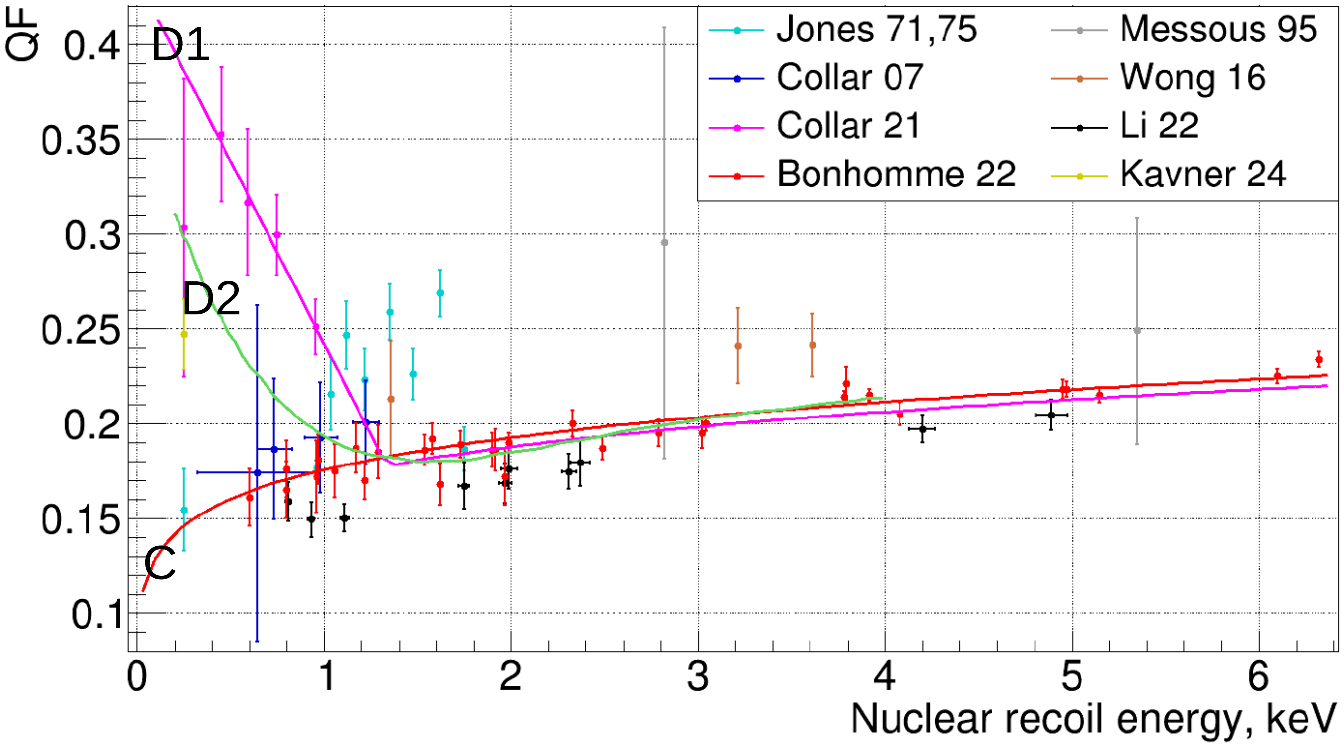
OFF (black): 38 days, ON (red): 137 days





No apparent differences depending on the reactor status - ON/OFF

Approach to the quenching problem



Dresden-II

Phys. Rev. D 103, 122003 (2021)

CONUS

Eur. Phys. J. C (2022) 82:815

TUNL, L.Li, PhD thesis (2022)

https://hdl.handle.net/10161/25153

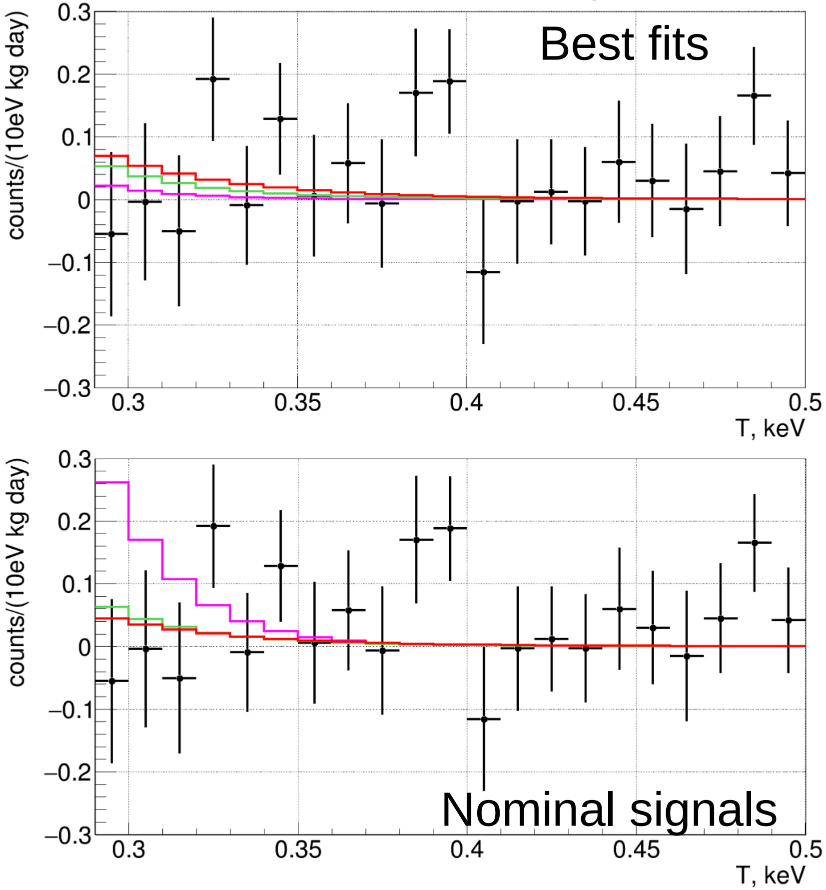
Kavner & Jovanovic

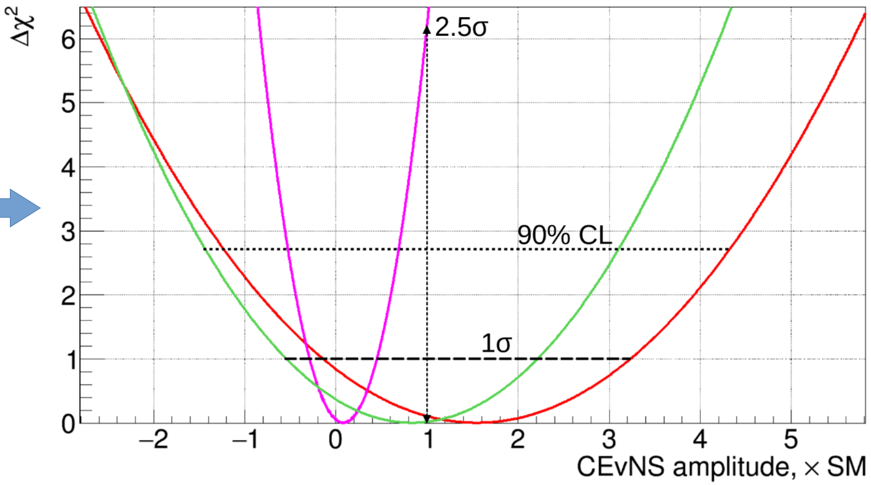
Phys.Rev.D 110, 083043 (2024)

Three scenarios: CONUS (C), Dresden FeF-based (D1) and photo-neutron based (D2)

Fit and results

QF-color correspondence: C – red, D1 – magenta, D2 - green





Sensitivity and upper limits (90% CL)

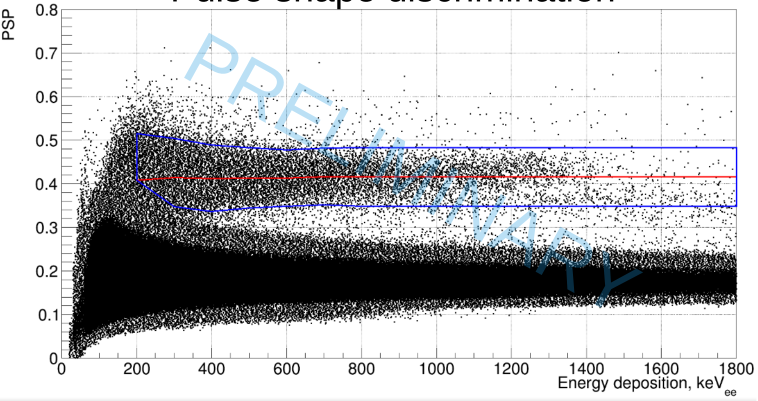
QF	$A_{best} \pm \sigma_A$, ×SM	χ^2_{best} (ndf=10)	S,×SM	L,×SM
C	1.5 ± 1.7	13.6	3.8	4.3
D1	0.1 ± 0.4	14.4	1.6	0.7
D2	0.8 ± 1.4	14.1	3.3	3.1

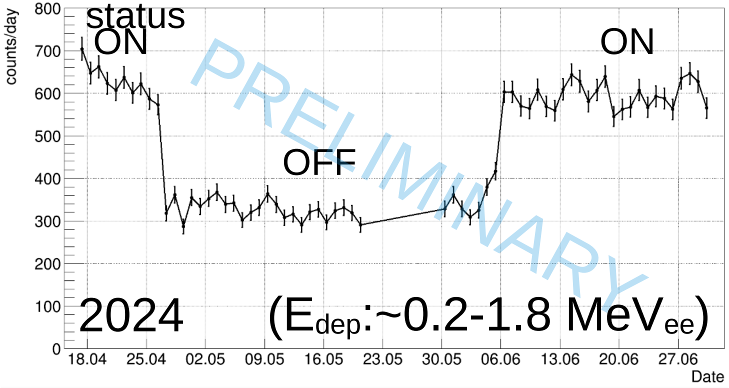
Upper limit (90% CL) at 4.3 times above SM (C QF)

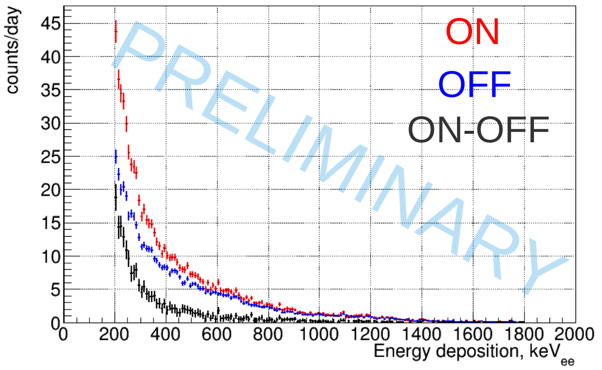
Tension with D1-scenario

Backgrounds: neutrons, gammas, ^{222}Rn

Neutrons in BC501A LS outside the shielding:

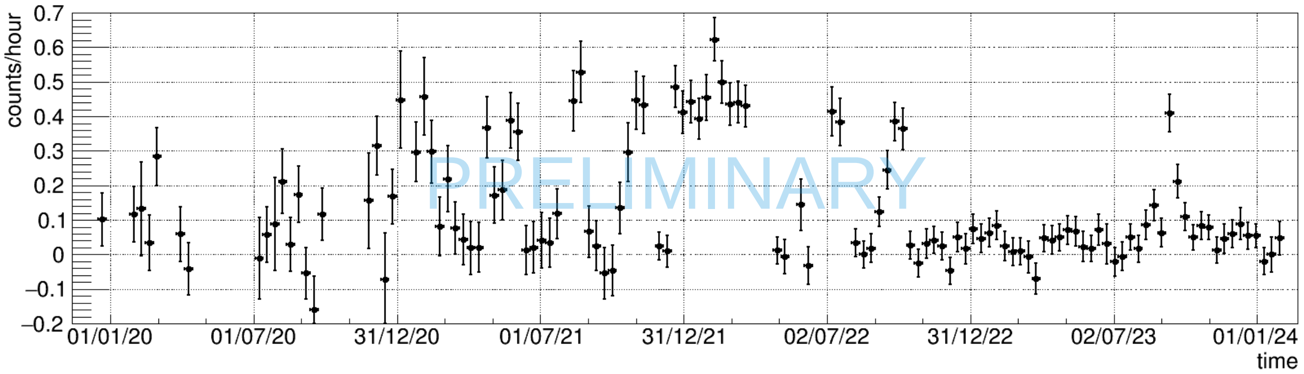






First simulations and estimates: residual neutron contribution of about 10^{-2} of BG count rate in HPGe ROI

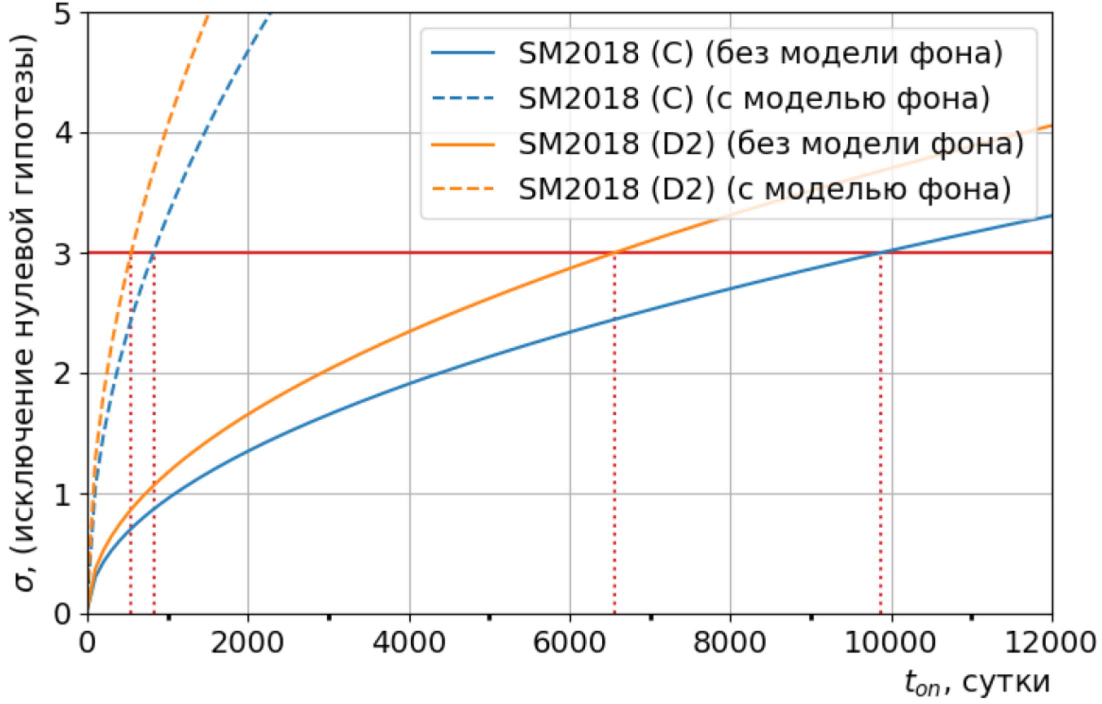
Radon (by ^{214}Bi 609 keV line):



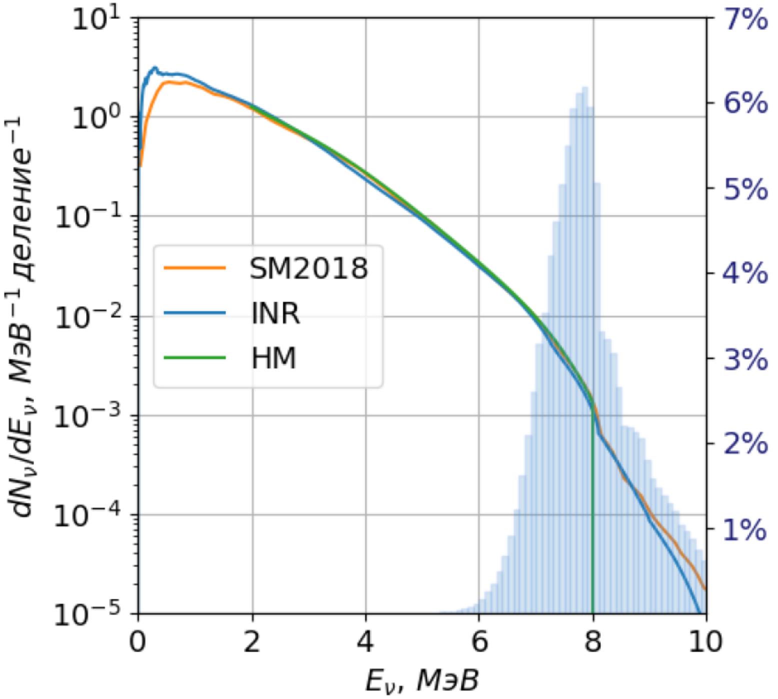
Analysis and simulations ongoing to include all the stat. (2000 kg×d) in CEvNS and EM properties search

Sensitivity extrapolation

Typical reactor cycle: 16.5 months ON + 1.5 months OFF



Which part of reactor ν spectrum matters?



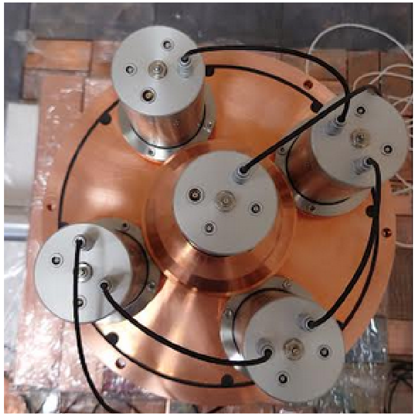
O(10%) dependence on E_ν model (SM2018, Daya Bay, INR)

Paths forward:

1. Analysis: BG deconvolution (optimistic) / BG fit + non-stable components (realistic)
2. Setup modifications and upgrades: improve threshold / reduce BG

Upgrades and modifications

1. “Compton veto”: ~30 kg NaI to reject gamma rays by coincidence with HPGe



More than 2x BG supression in the lab with shielding and µ veto. Now - tests at Baksan

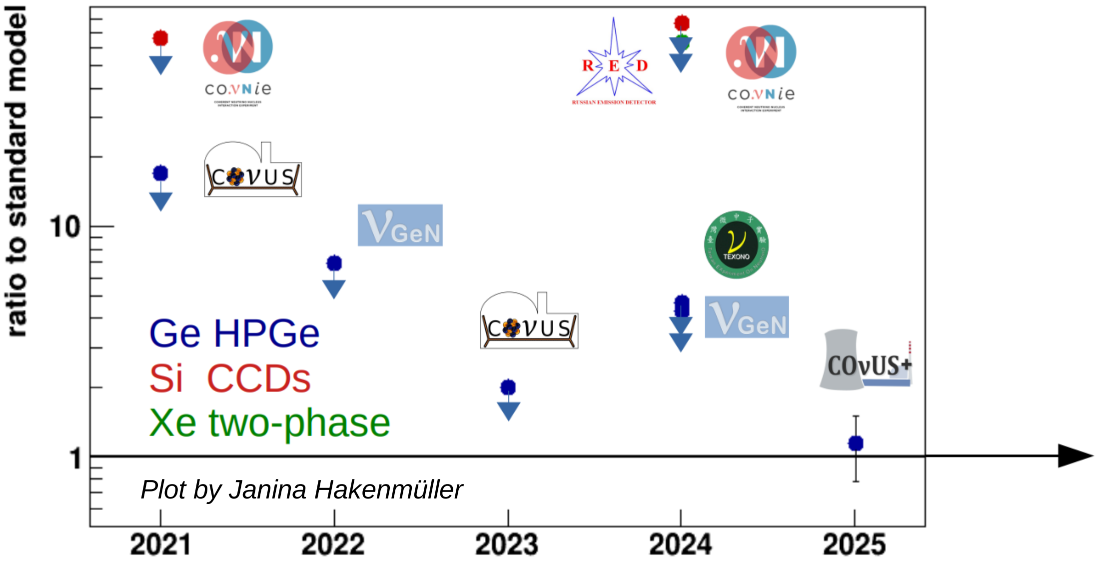
2. DAQ modification: recording HPGe waveforms → Surface events rejection → Noise rejection at the threshold

See poster by Maxim Dovbnenko (JINR), July 5, 18:00
“A system for collecting and recording data from CAEN electronics in the νGen experiment”

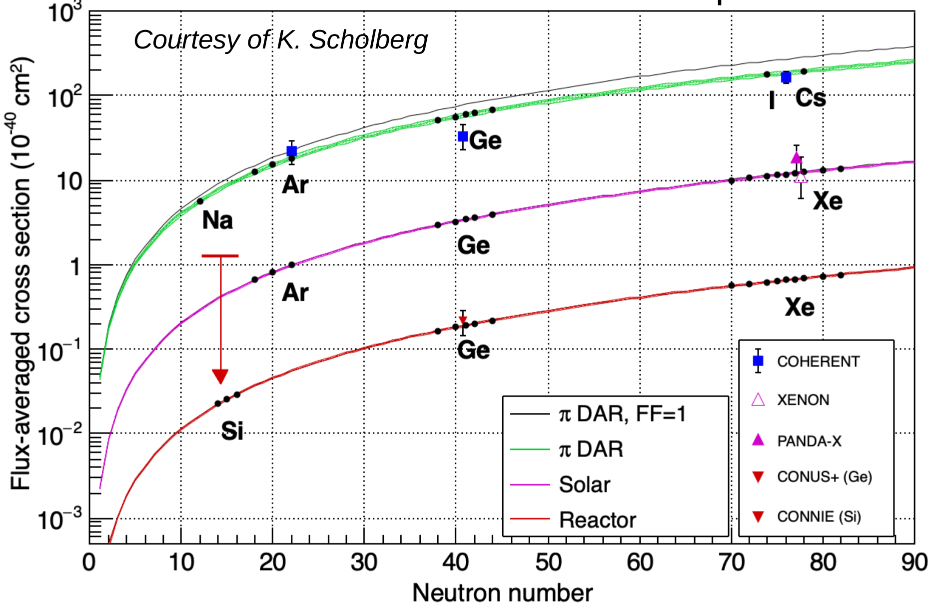
3. Modifications of the cryocooler: reduce power consumption → suppress vibrations → reduce noise

Global context

Reactor CEvNS timeline



CEvNS cross section landscape

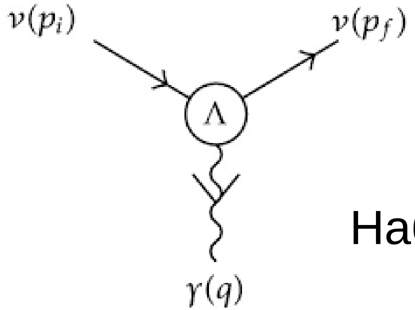


Ge CEvNS tension:

1. Dresden-II (2022): observation claim for D1/D2 QF
2. COHERENT (2024/2025): 2σ below SM prediction
3. CONUS+ (2025): observation claim for C QF

Can be tested by
νGeN, TEXONO, RICOCHET

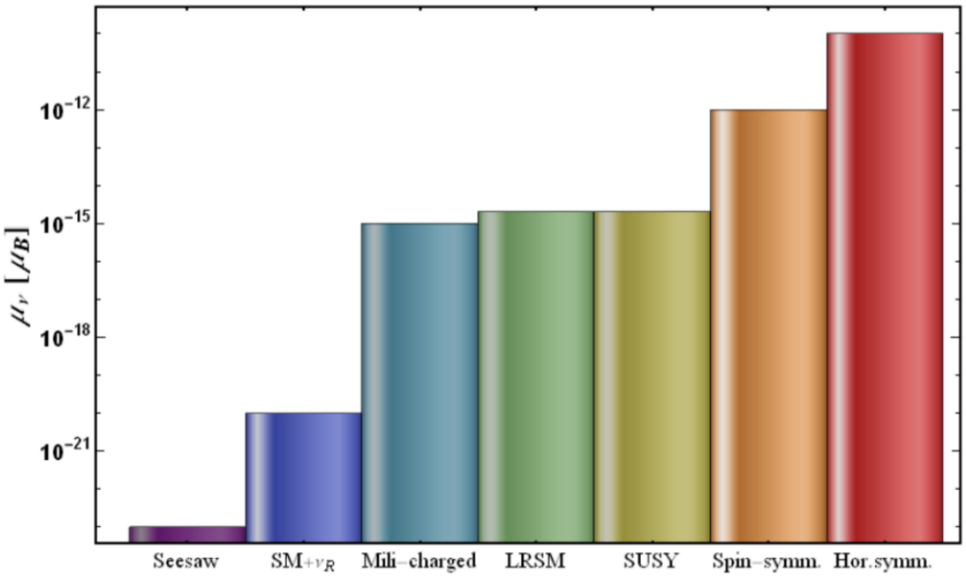
Electromagnetic neutrino properties



$$\Lambda_\mu(q) = F_Q(q^2)\gamma_\mu - F_M(q^2) i\sigma_{\mu\nu}q_\nu + F_E(q^2)\sigma_{\mu\nu}q_\nu\gamma_5 + F_A(q^2)(q^2\gamma_\mu - q_\mu q_\nu \gamma_\nu)\gamma_5$$

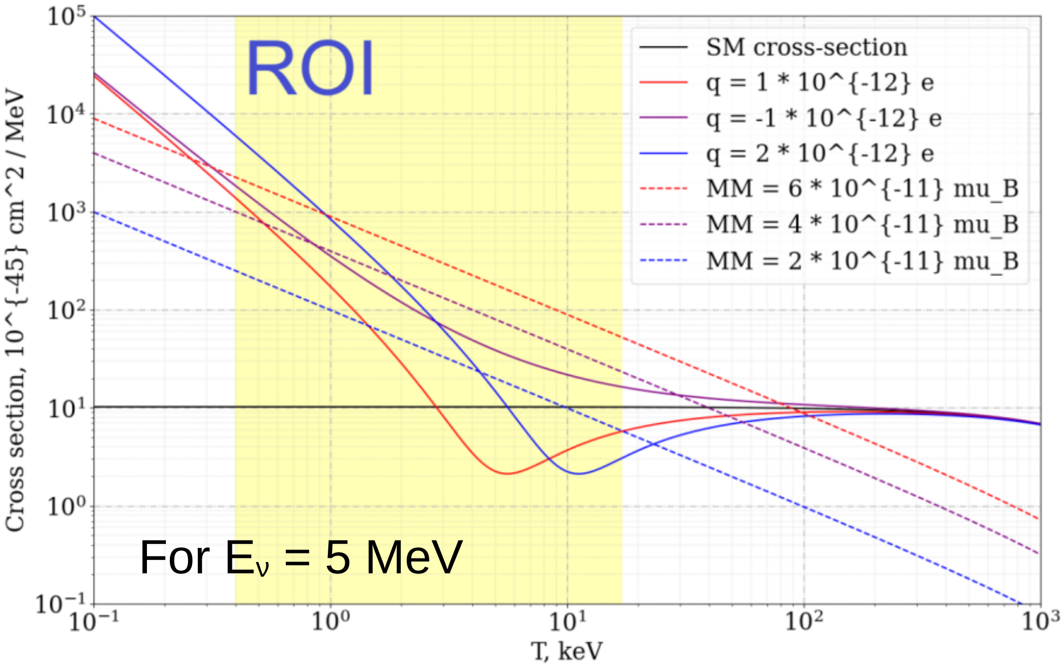
Наблюдаемые комбинации: магнитный момент, заряд и зарядовый радиус

Examples of models inducing large μ



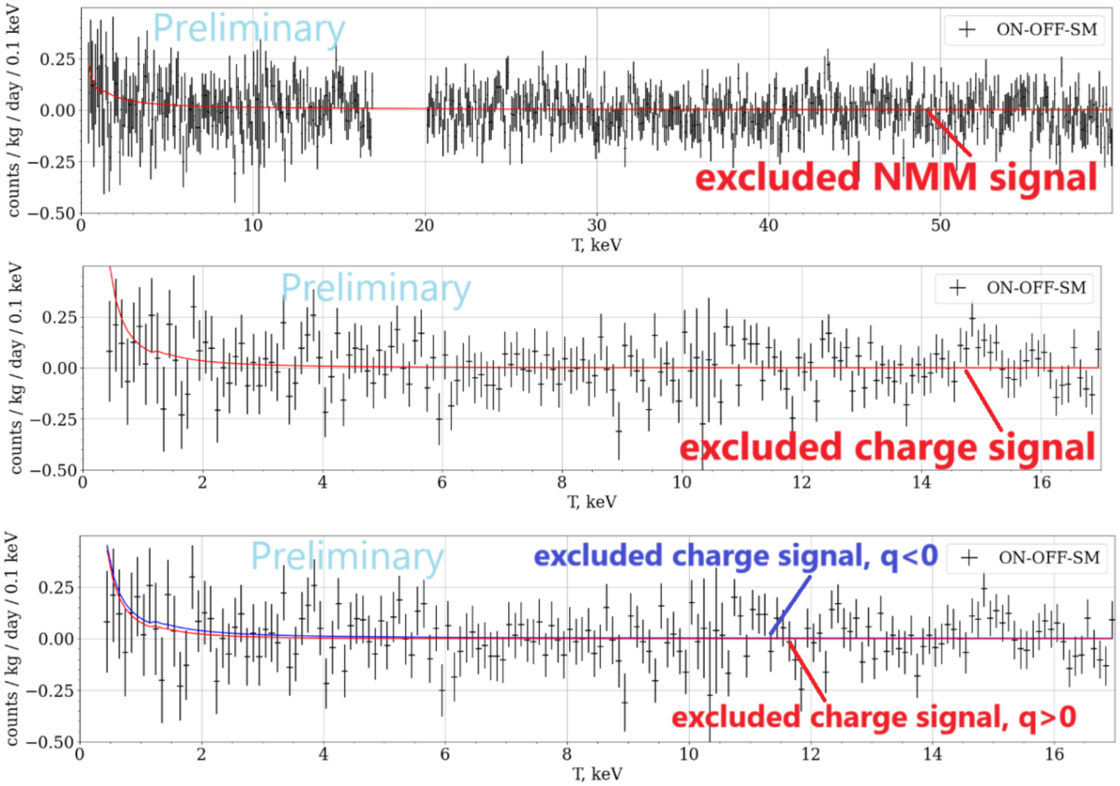
[SJ, PoS(DISCRETE2020-2021)037]

Modifies ν-electron (and nucleus) cross sections



Limits on neutrino EM properties

Extended analysis range and loose cuts to increase sensitivity (ON - 140 days, OFF – 69 days)



More in Georgy Ignatov's talk at NPS RAS Rubakov Conference 2025 (19.02.2025)

Magnetic moment

Предел, $10^{-11}\mu_B$	C.L.	Эксперимент
28	90%	D-II & COHERENT [P. Coloma et al., 2022]
7.5	90%	CONUS [H. Bonet et al., 2022]
7.4	90%	TEXONO [H.T. Wong et al., 2007]
2.9	90%	GEMMA [A.G. Beda et al., 2013]
0.64	90%	XENONnT [E. Aprile et al., 2022]

Astrophys: $\mu_\nu < 1.2 \times 10^{-12}$ (95%C.L.) [F. Capozzi, 2022].

νGeN limit (90% CL): $\mu_\nu < 7.5 \times 10^{-11} \mu_B$

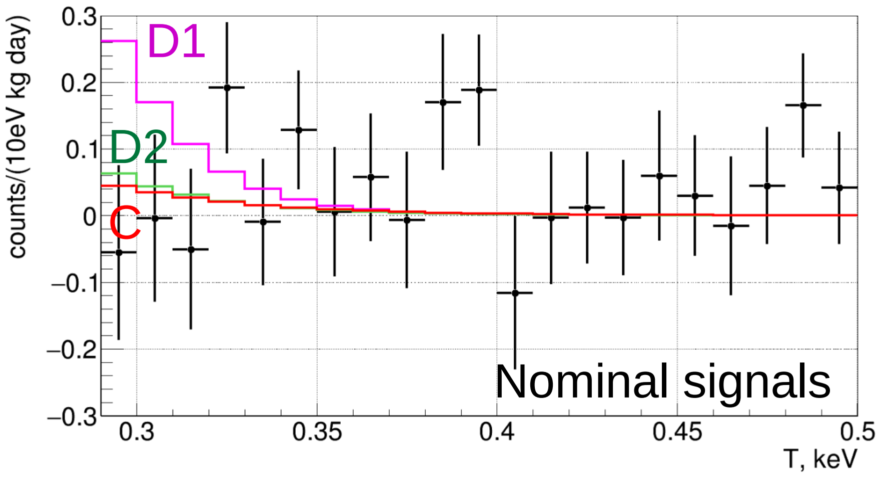
Charge

Предел, $10^{-12}e$	C.L.	Эксперимент
0.224	90%	LZ [J. Aalbers et al., 2023]
~ 9	90%	Dresden-II [M. Corona et al., 2022]
~ 3.3	90%	CONUS [H. Bonet et al., 2022]
2.7	90%	GEMMA [V.B. Brudanin et al., 2016]
2.1	90%	TEXONO [J.W. Chen et al., 2014]
2.4 (0.9)	90%	νGeN

Matter neutrality: $q_\nu^{lim} \sim 10^{-35}$ [C. Caprini, 2003]

Best ν millicharge limits evaluated in a scattering experiment at a short baseline without a BG model!

Summary



Limit on the CEvNS rate at 4.3×SM

Tension with D-II QF and CEvNS claim

V. Belov et al. Chinese Phys. C 49 053004 (2025)

Limits on ν EM properties

$\mu_\nu < 7.5 \times 10^{-11}\ \mu_B$

$q_\nu < 2.4\ (0.9^*) \times 10^{-12}\ e_0$

PRELIMINARY

* depending on FEA/EPA approach to cross section calc.

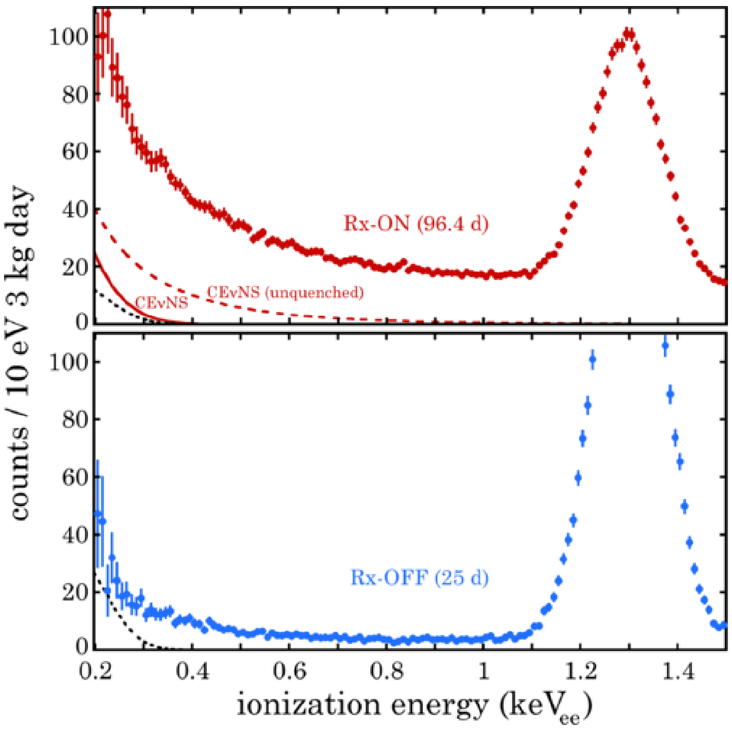
Ongoing data analysis and simulations to use all available statistics (more than 2000 kg×d total) + setup upgrade soon!

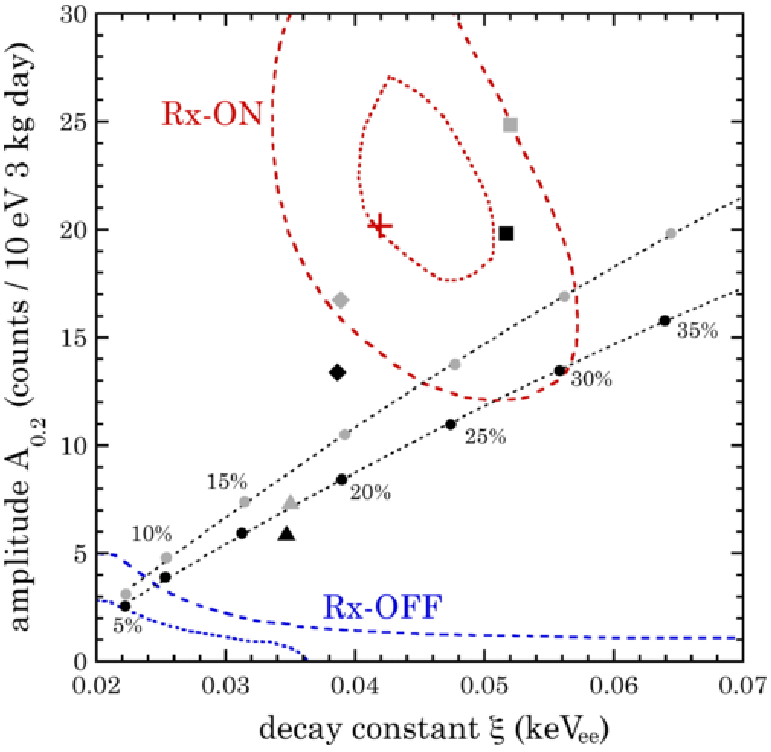
Latest collaboration meeting in JINR

Thank you for your attention!

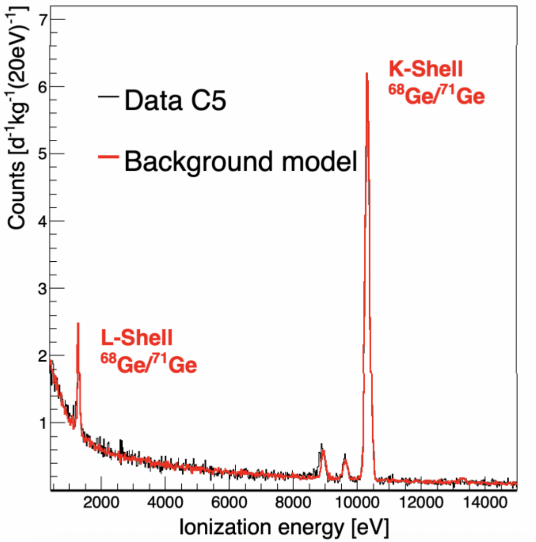
Backup 1: Dresden-II (Phys. Rev. Lett. 129, 211802)

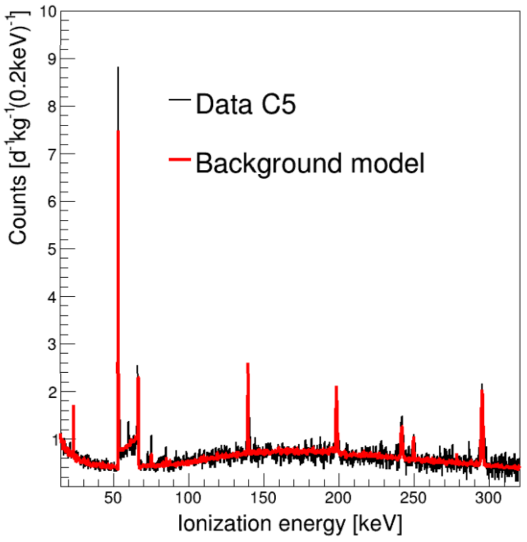
The 96.4 day exposure of a 3 kg ultralow noise germanium detector to the high flux of antineutrinos from a power nuclear reactor is described. A very strong preference ($p < 1.2 \times 10^{-3}$) for the presence of a coherent elastic neutrino-nucleus scattering (CEνNS) component in the data is found, when compared to a background-only model. No such effect is visible in 25 days of operation during reactor outages. The best-fit CEνNS signal is in good agreement with expectations based on a recent characterization of germanium response to sub-keV nuclear recoils. Deviations of order 60% from the standard model CEνNS prediction can be excluded using present data. Standing uncertainties in models of germanium quenching factor, neutrino energy spectrum, and background are examined.





Backup 2: CONUS+ (arXiv:2501.05206)





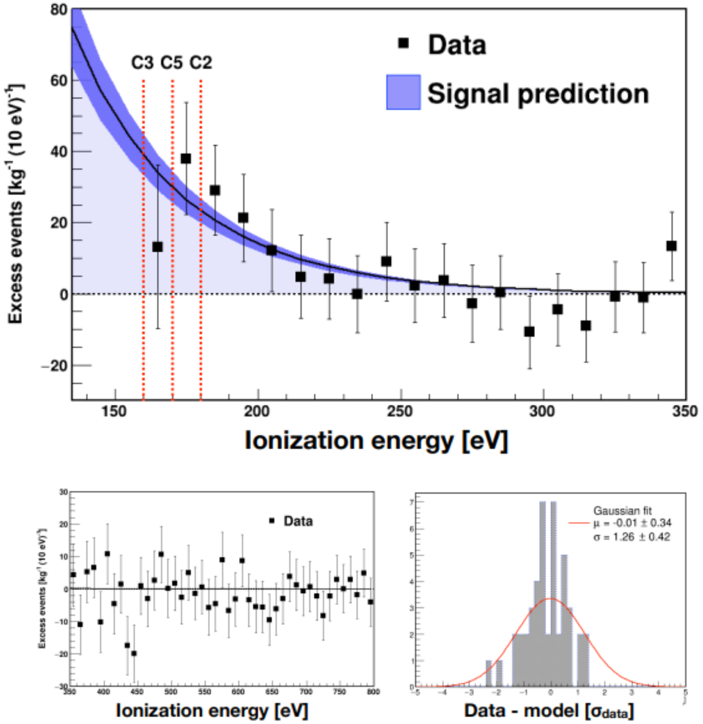


Fig. 3: The plot on top shows the difference between data in the full reactor on time and the background model scaled to the total detector mass. At low energies the rise from the neutrino signal can be seen. The line shows the predicted signal shape including uncertainties for comparison. The vertical lines indicate the energy thresholds of the three detectors used in the analysis. In the first bin only C3 contributes, in the second C3+C5 and above 180 eV all three detectors. On the bottom left, there is an extension of the top plot showing the good agreement between data and background model above the signal region from 350 – 800 eV. The histogram on the bottom right shows the corresponding spread of the data points around the model.

Abstract

Neutrinos are elementary particles that interact only very weakly with matter. Neutrino experiments are therefore usually big, with masses on the multi-ton scale. The thresholdless interaction of coherent elastic scattering of neutrinos on atomic nuclei leads to drastically enhanced interaction rates, that allows for much smaller detectors. The study of this process gives insights into physics beyond the Standard Model of particle physics. The CONUS+ experiment was designed to first detect elastic neutrino-nucleus scattering in the fully coherent regime with low-energy neutrinos produced in nuclear reactors. For this purpose, semiconductor detectors based on high-purity germanium crystals with extremely low energy threshold of 160−180 eV were developed. Here we show the first observation of a neutrino signal with a statistical significance of 3.7 sigma from the CONUS+ experiment, operated at the nuclear power plant in Leibstadt, Switzerland. In 119 days of reactor operation (395±106) neutrinos were measured compared to a predicted number from calculations assuming standard model physics of (347±59) events. The good agreement between data and prediction constrains