Joint Institute for Nuclear Research, Dubna

Lebedev Physical Institute of
the Russian Academy of Sciences, Moscow

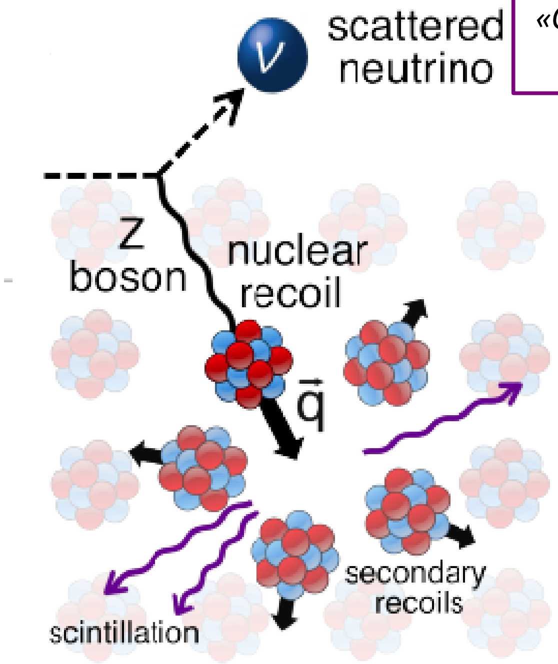
The νGeN neutrino experiment at the Kalinin NPP

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

BCVSPIN-2024, Kathmandu

December 13 2024

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)

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

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

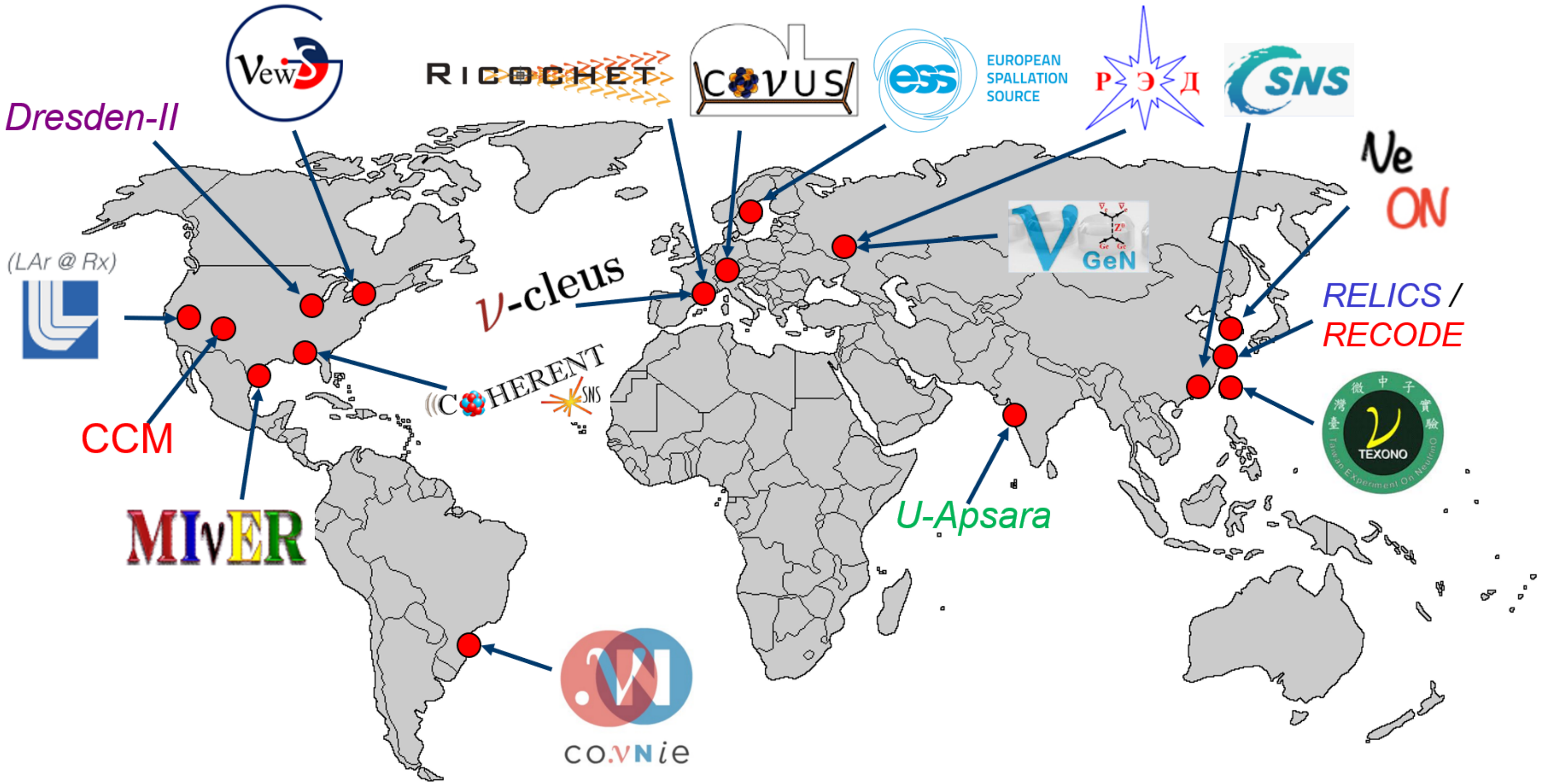
Nucleus	T_{max}, keV (E_ν =5 MeV)	T_{max}, keV (E_ν =30 MeV)
^{12}C	4.44	159.0
^{23}Na	2.32	83.2
^{40}Ar	1.33	47.9
^{74}Ge	0.72	25.9
^{133}Cs	0.40	14.4

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 Dresden-II claim and the CONUS limit (Ge)

Worldwide effort



BCVSPIN projects: RELICS/RECODE at Sanmen (China), Si/Ge ptoject at U-Apsara (India)

2405.05554, PRD 110 (2024) 7

PoS TAUP2023 (2024) 296

2304.00912, PRD 108 (2023) 11

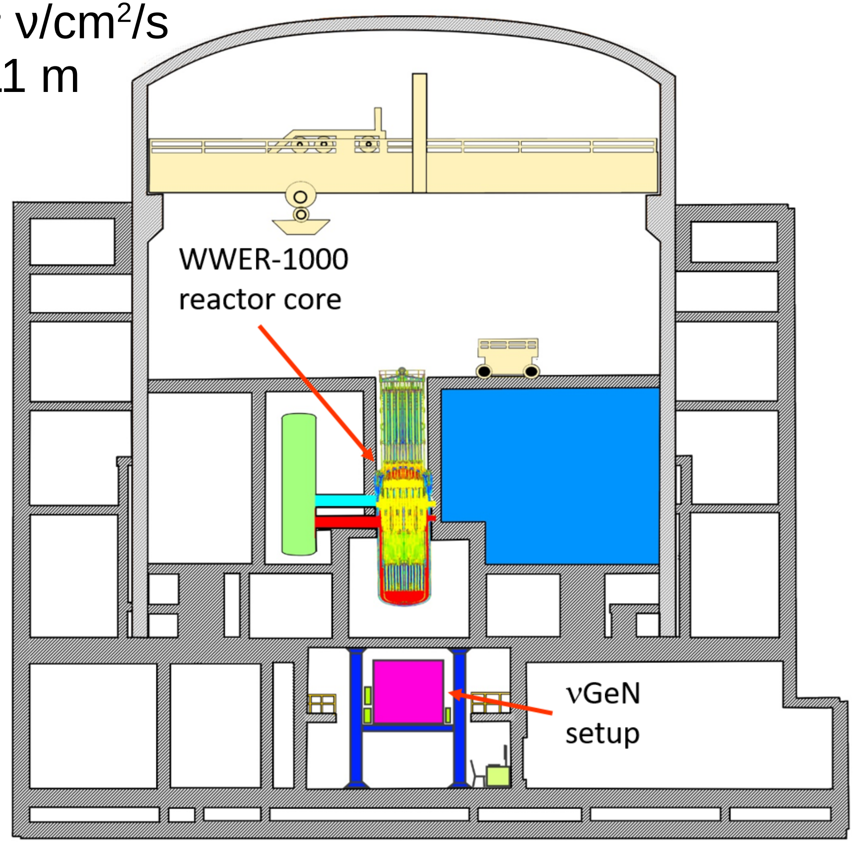
Neutrino experiments at Kalinin NPP

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

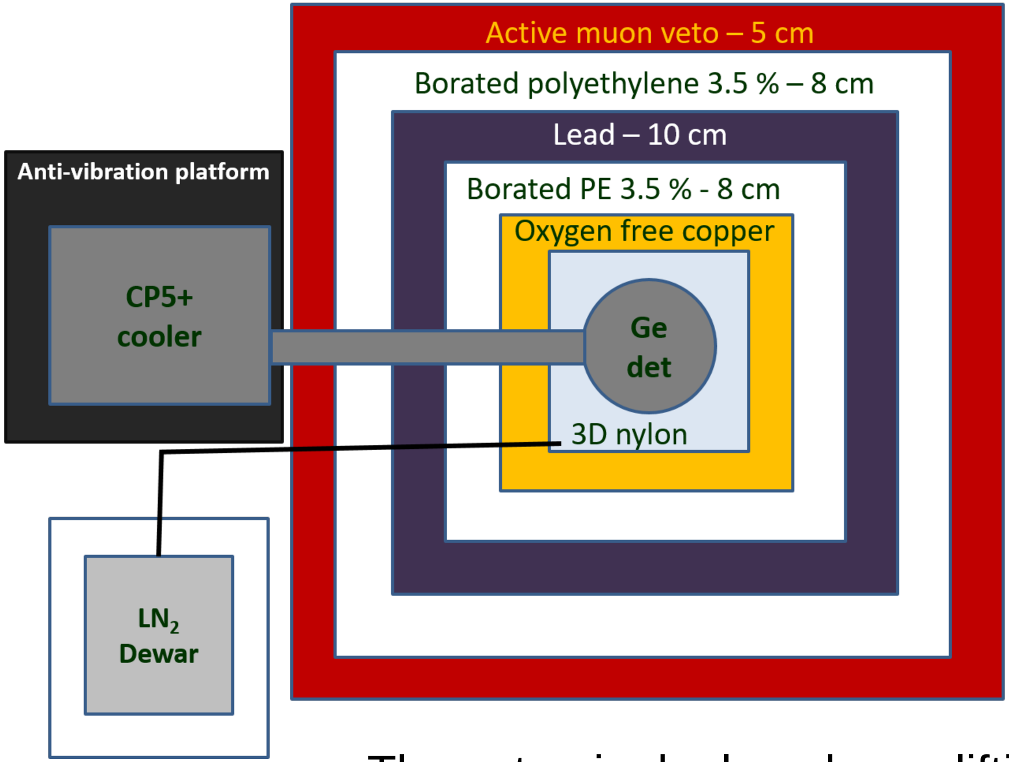
$4.4 \cdot 10^{13}$ ν/cm²/s at 11 m

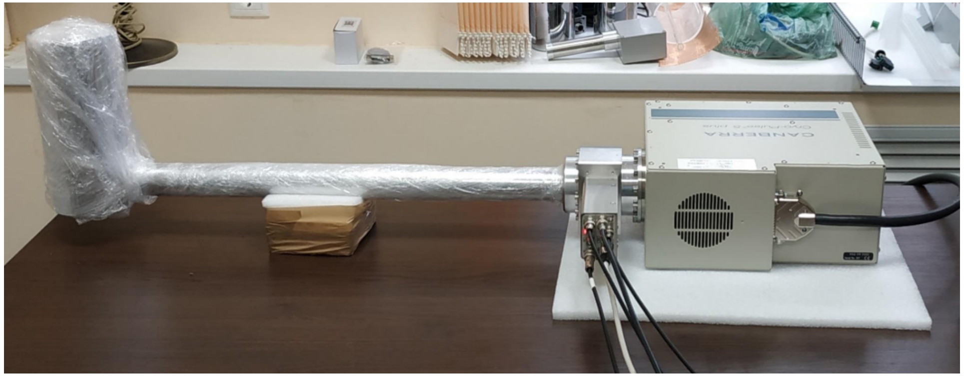


50 m.w.e. of materials above

The νGeN setup

The multi-layered shielding protects
the Ge detector



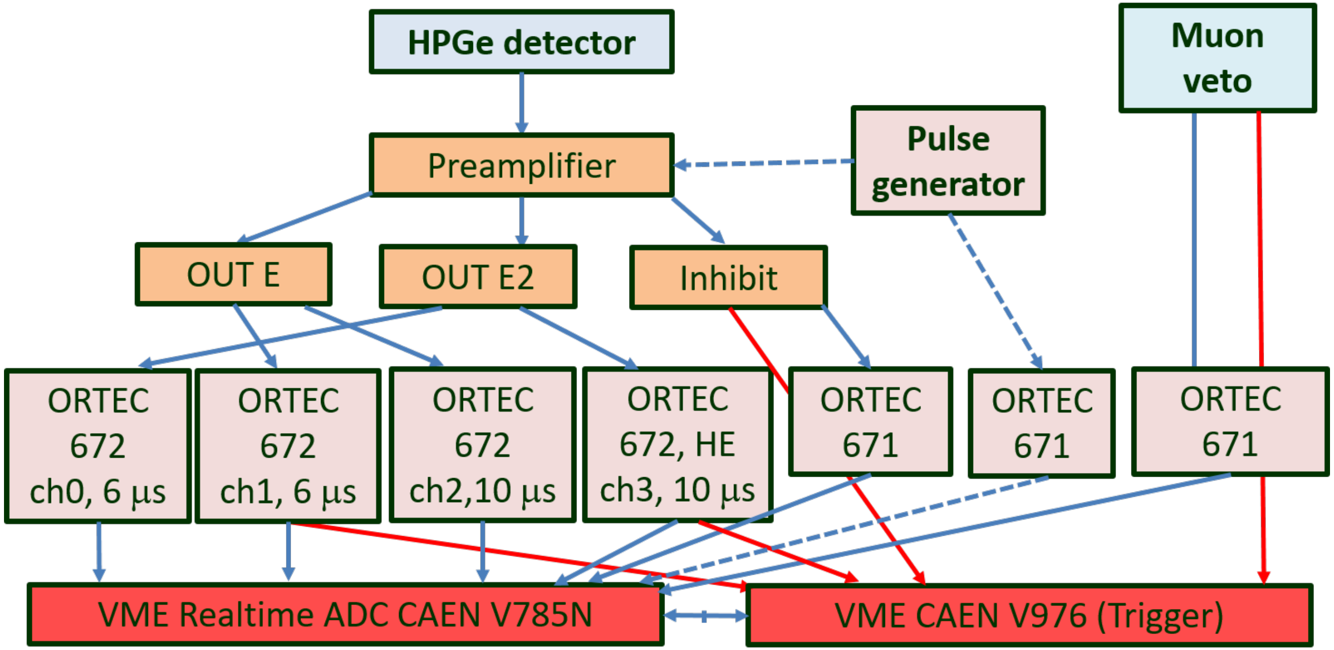


CANBERRA (Mirion, Lingosheim) detector

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

The setup is deployed on a lifting mechanism (L = 12.5 -> 11.0 m),
the shielding is on an anti-vibration platform

Electronics & DAQ



- Reset preamplifier
- Shaping amplifiers / no WFs
- Noise supression:
  - OUT E to E2, same τ_{sh}
  - 6 μs to 10 μs for OUT E
- For selections and veto:
  - «inhibit» reset signal
  - muon veto

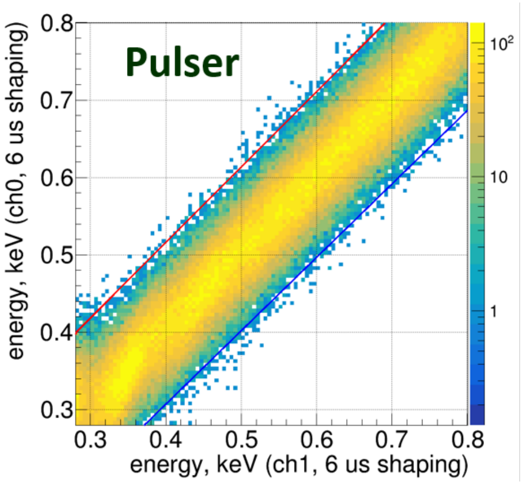
Dynamic range:

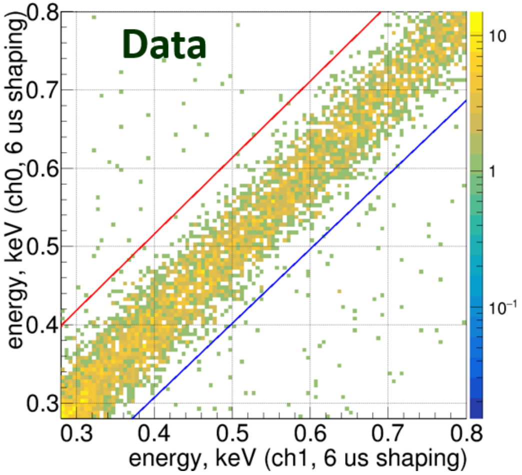
1. «Low energy»: ~0.2 to 17 keV
2. «High energy»: 17 keV to ~1 MeV

Total exposition: more than 1500 kg×d up to 2024, but different noise and BG conditions

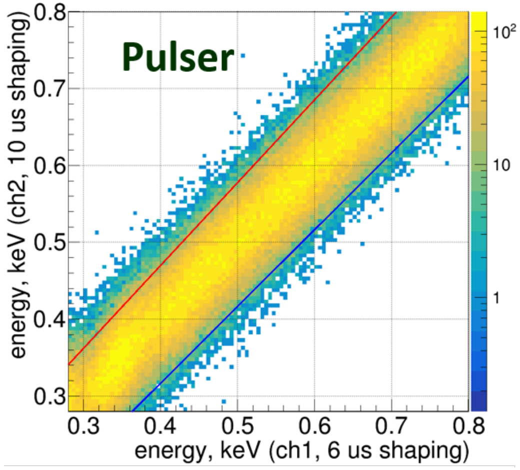
Selections

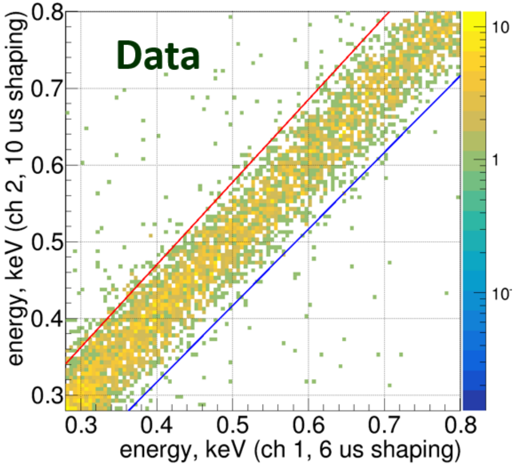
Correlation of two channels with the same τ_{sh}





Comparison of channels with different τ_{sh}

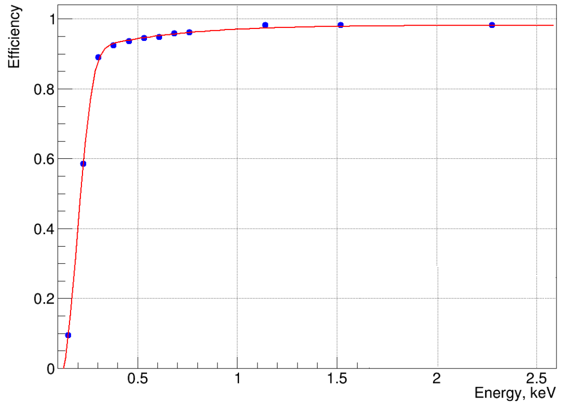




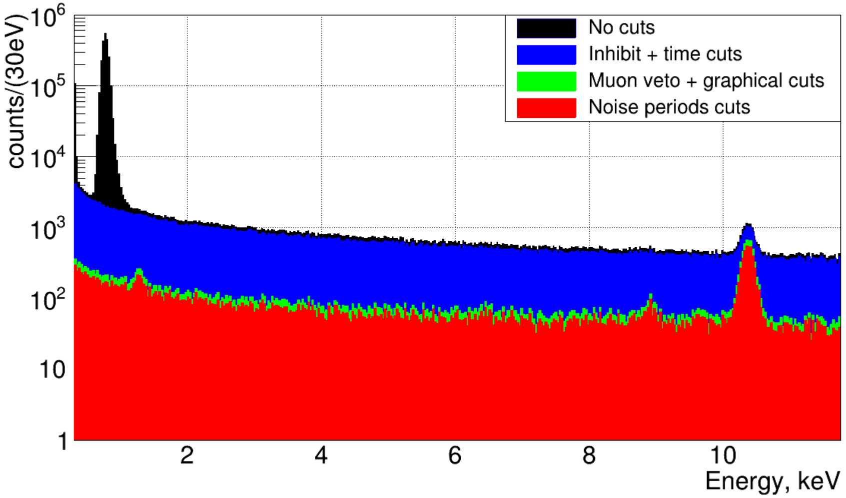
Efficiency of a trigger + graphical cuts:

~45% for 0.2 keV
~90% for 0.3 keV

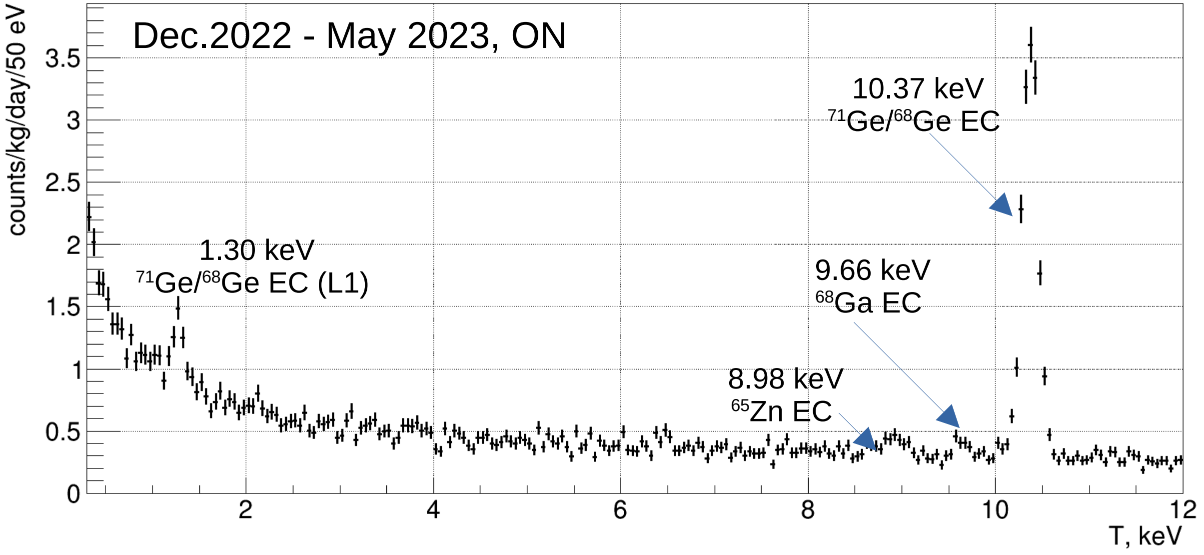
Inhibit and μ veto
Introduce ~10%
dead time total



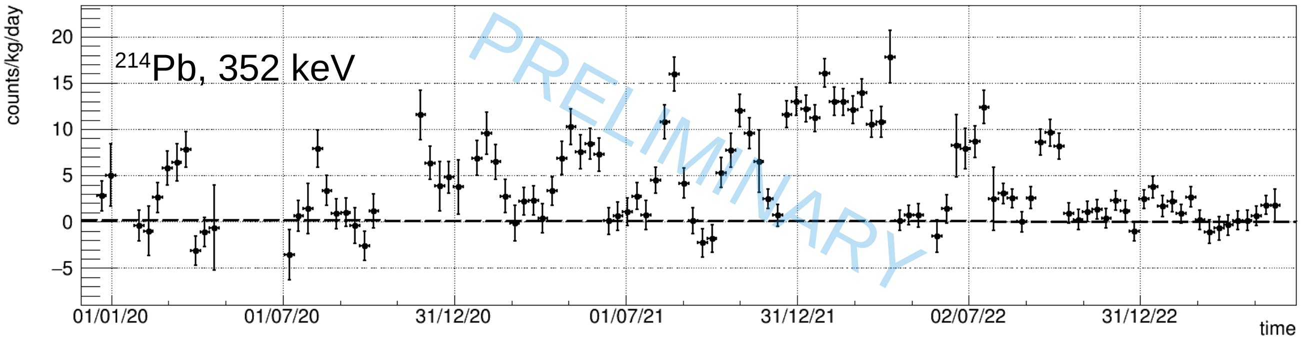
BG reduction by the selections



BG and its stability



Fluctuations of Rn affect the whole range, including CEvNS ROI



+ slow general decrease of the BG substrate count rate

E, keV	Source	Rate, $(kg\times d)^{-1}$
1.30	^{71}Ge/^{68}Ge EC (L1)	~1.3$^{×}$
8.98	^{66}Zn EC	~0.7$^{×}$
9.66	^{68}Ga EC	~0.5$^{×}$
10.4	^{71}Ge/^{68}Ge EC (K)	14.8$^{×}$
46.5	^{210}Pb	1.1
66.7	^{72}Ge(n,ɣ)^{73m}Ge	6.1*
140	^{74}Ge(n,ɣ)^{75m}Ge	1.8
198	^{70}Ge(n,ɣ)^{71m}Ge	1.7
242	^{214}Pb (^{222}Rn)	0−3.2
295	^{214}Pb (^{222}Rn)	0−7.8
352	^{214}Pb (^{222}Rn)	0-13.2
511	annihilation	11.6
609	^{214}Bi (^{222}Rn)	0−9.5
662	^{137}Cs	5.9
1173	^{60}Co	3.5

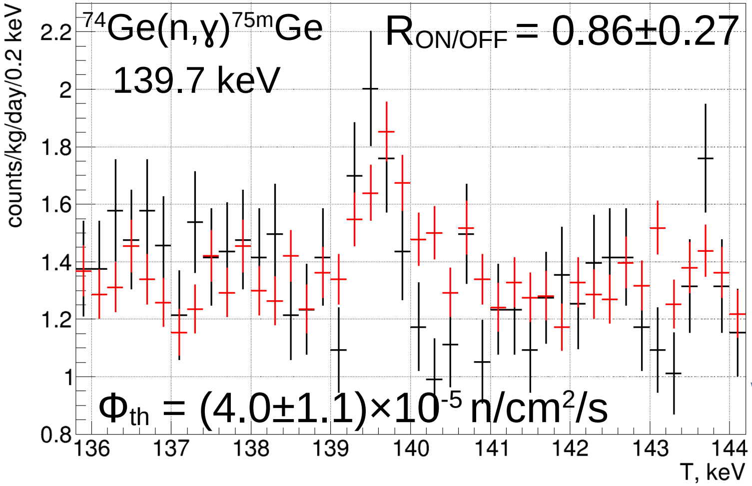
PRELIMINARY

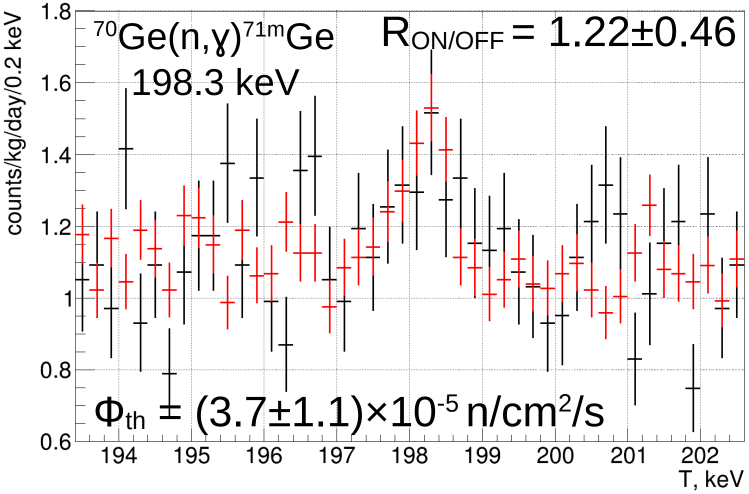
+ Pb, Bi X-rays

* - [53.4+13.3] keV, affected by τ_{sh}
× - as of Dec. 2022- May 2023

Neutron background characterization

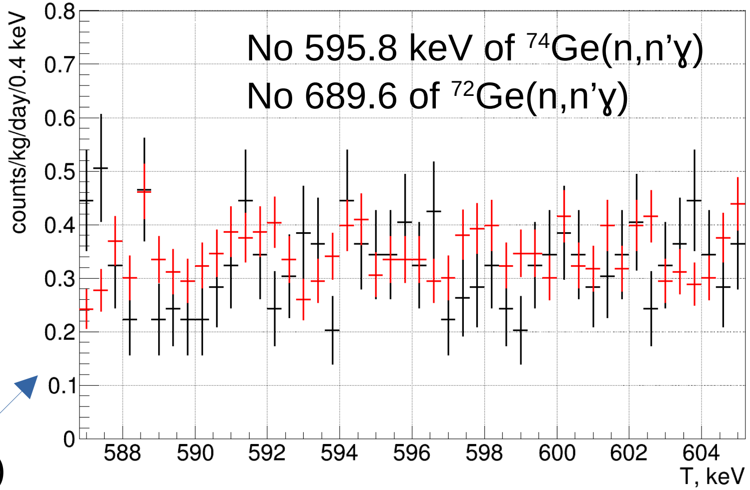
Thermal neutrons





Plots for
OFF: 38 d (black)
ON: 137 d (red)

Absense of peaks from inelastics



Ongoing simulations and a measurement for verification: ^{252}Cf in the lab with a similar HPGe

Fast neutron flux measurements

Measurements with the Bicron LS cell (PSD) in March-July 2024 at KNPP, both ON and OFF. Ongoing analysis.

Approach to the quenching problem

Ongoing discussion

Dresden-II

Phys. Rev. D 103, 122003 (2021)

TUNL, L. Li, PhD thesis (2022)

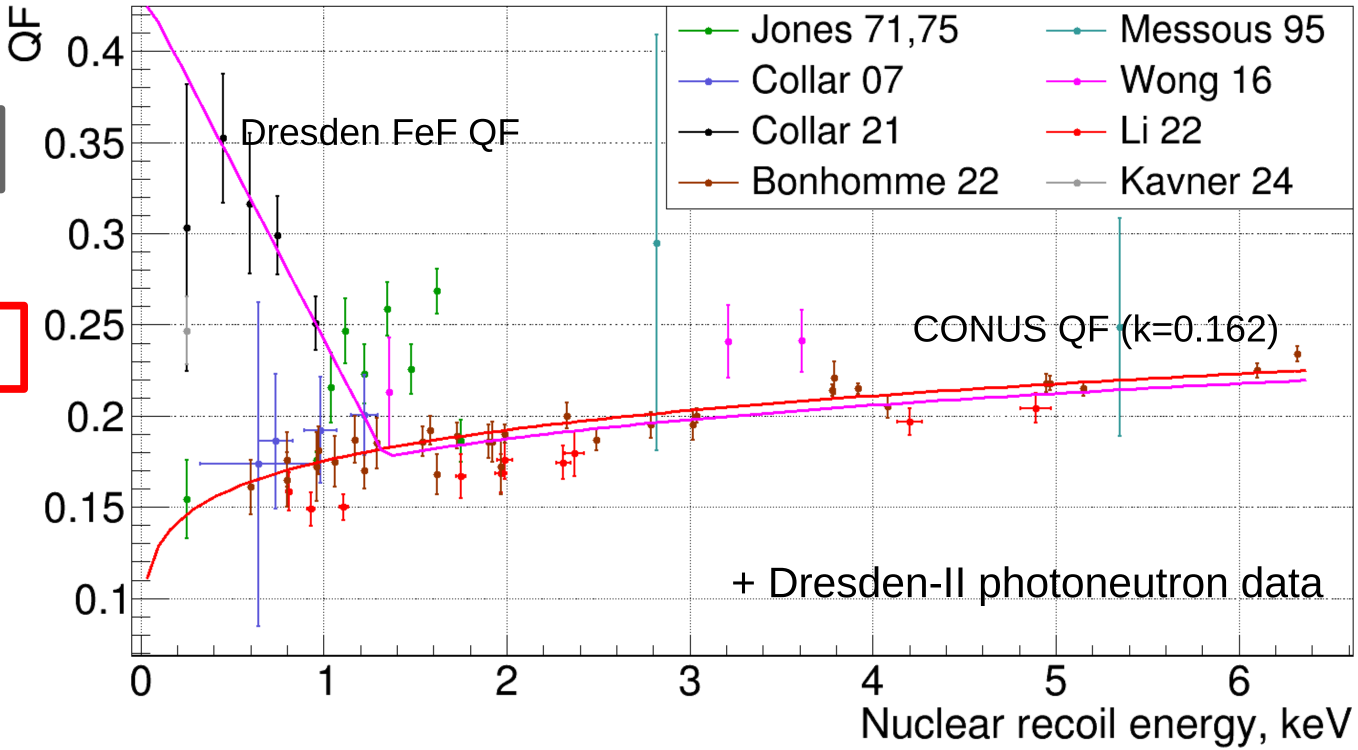
https://hdl.handle.net/10161/25153

CONUS

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

Kavner & Jovanovich

Phys.Rev.D 110, 083043 (2024)



We consider two cases: CONUS QF (Lindhard k=0.162), Dresden QF (FeF, mod. k=0.157)

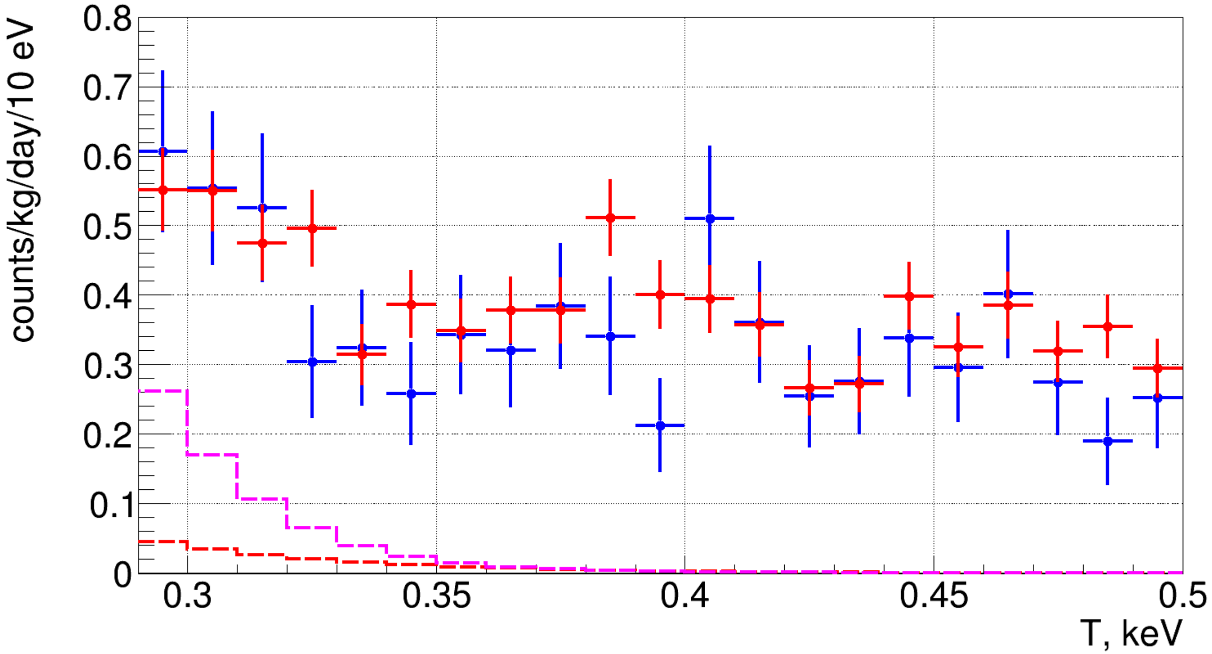
Dataset

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

Analysis ROI: 0.29-0.4 keV

0.29 keV — stability considerations
0.40 keV — provides <1% loss of the sensitivity

QF	Prediction, ev./kg/day	Sensitivity, ×SM	68% expectation for a 90% C.L. limit, ×SM
CONUS	0.184	3.7	2.0-5.4
Dresden	0.705	1.6	1.2-2.0



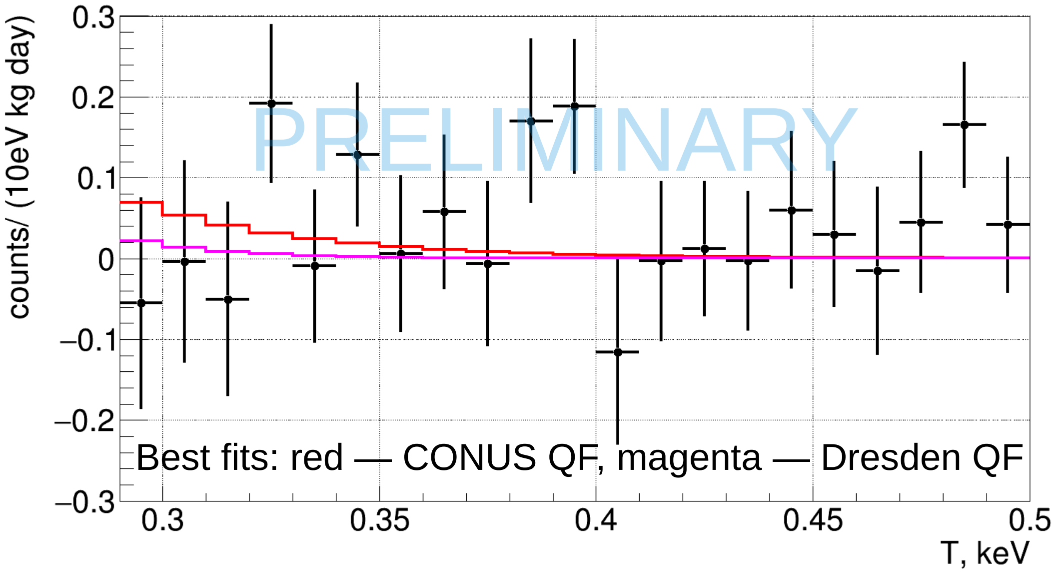
OFF (blue): 38 days
ON (red): 137 days

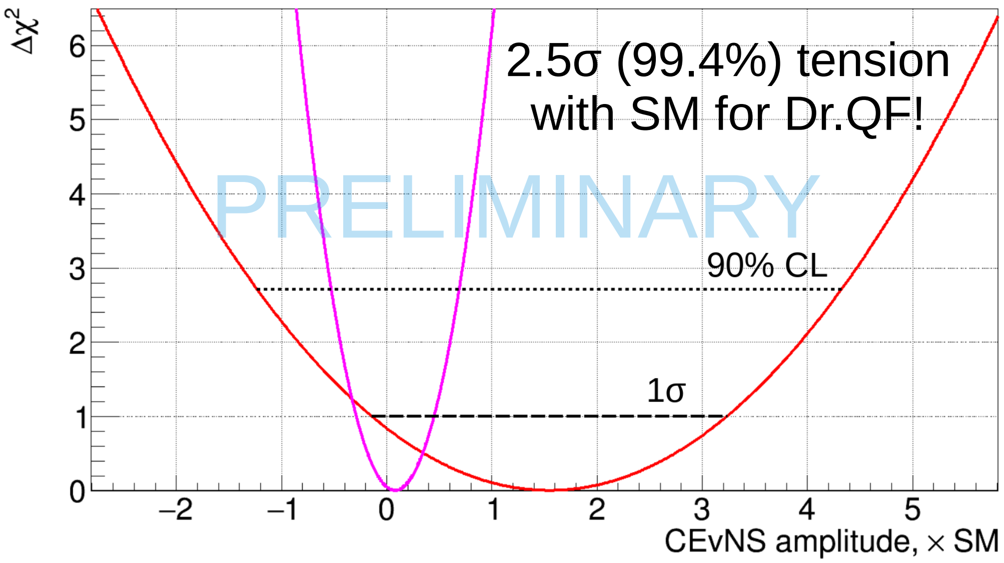
Prediction (SM2018 spectra):

CONUS QF — red line
Dresden QF — magenta line

Fit and results

Best fits and $\Delta\chi^2$ profiles: CONUS QF(red line), Dresden QF (magenta line)

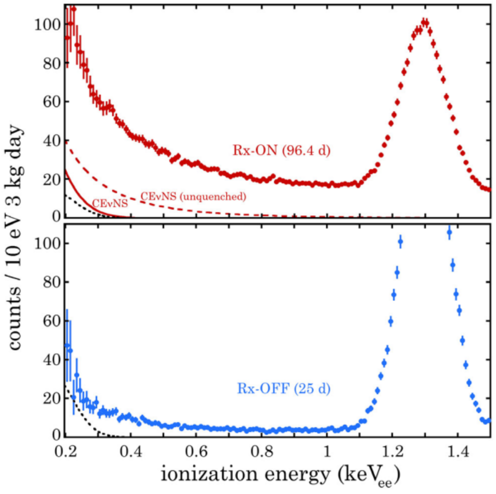


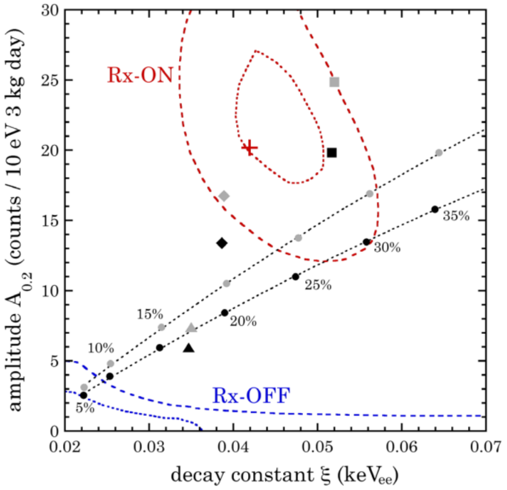


QF	Prediction, ev./kg/day	Sensitivity, ×SM	68% expectation for a 90% C.L. limit, ×SM	Best fit, ×SM	90% C.L. limit
CONUS	0.184	3.7	2.0-5.4	1.6 ± 1.7	4.3
Dresden	0.705	1.6	1.2-2.0	0.1 ± 0.4	0.7

Comparison to other experiments

Dresden-II,PRL 129, 211802 (2022)

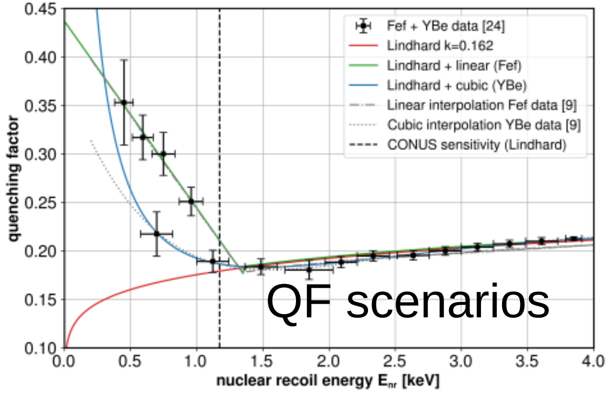


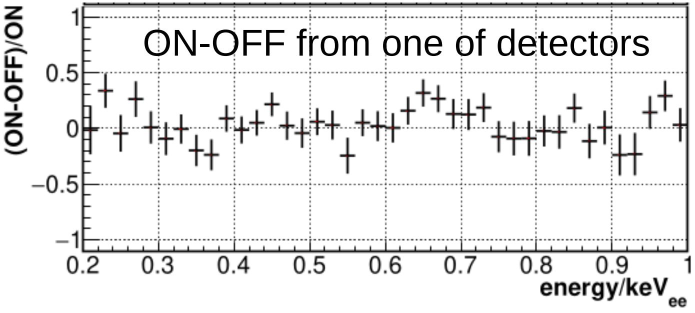


«A very strong preference ($p < 1.2\times10^{-3}$) for the presence of CEvNS»

vGeN results are in tension with Dresden-II claim under assumption of Fef QF as data from CONUS are

CONUS, arXiv:2401.07684 (2024)



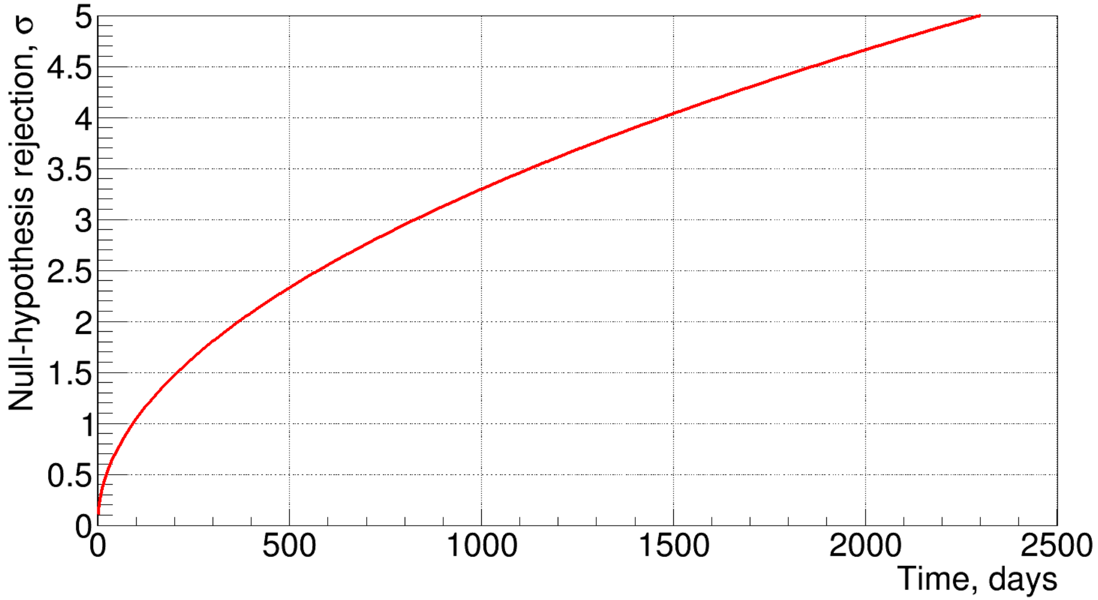


quenching description	prediction	Run-5 limit (90% C.L.)
Lindhard (k=0.162 [22])	91^{+11}_{-9}	143
linear low E excess [24]	645^{+59}_{-90}	99
cubic low E excess [24]	115^{+13}_{-11}	122

Sensitivity extrapolation

Given the measured BG rate and currently achieved threshold we can extrapolate the sensitivity studies

Null rejection significance under assumption of SM (CONUS QF)



Two scenarios:

1. Direct ON - OFF: time = OFF, ON = 11×OFF

   3σ at ~800 days OFF depending on QF

   unrealsitic for a current E_{th}

2. ON - BG model (no syst.): time = ON

   3σ at ~2 years, 5σ at ~6 years

Need to:

1. Deconvolve the BG -> full BG model: studies and simulations ongoing
2. Improve threshold / reduce BG -> modifications and upgrades

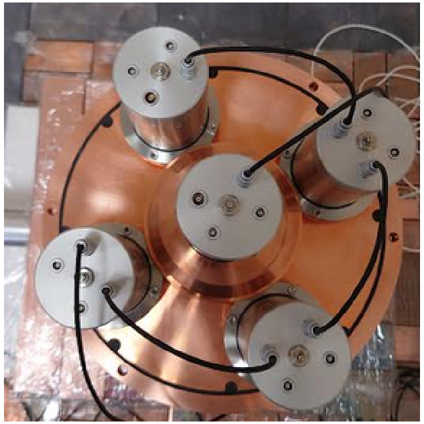
Upgrades and modifications

Noise & BG reduction tests in the JINR lab:

1. «Compton veto» — set of NaI crystalls to supress multiple scattering events

2. Modifications of the cryocooler to reduce its power consumption

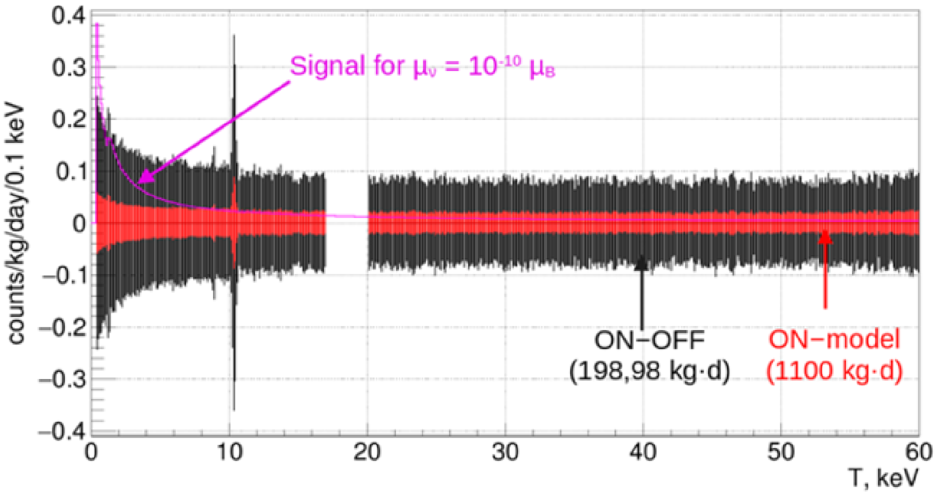
3. DAQ tests for a better discrimination of noise and surface events

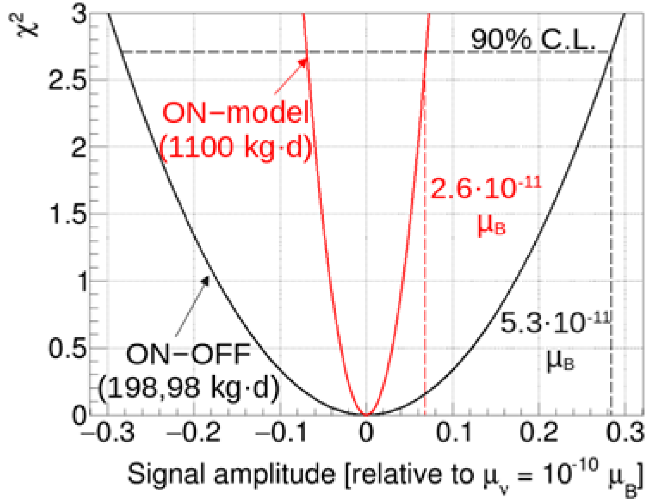


Sensitivity to neutrino EM properties

The best NMM limit at reactors is set by GEMMA in 2013 — $\mu_\nu < 2.9\cdot10^{-11}\ \mu_B$ (90% C.L.)

Experiment	Mass, kg	ν flux, $cm^{-2}s^{-1}$	E_{th}, keV_{ee}	Reference
GEMMA	1.5	$2.7\cdot10^{13}$	2.8	Adv.High Energy Phys. 2012
νGeN	1.4	$4.4\cdot10^{13}$	0.2-0.3	Phys.Rev.D 106 (2022)
COνUS	3.7	$2.3\cdot10^{13}$	0.2-0.3	Eur.Phys.J.C 82 (2022)
Dresden-II	2.9	$4.8\cdot10^{13}$	0.2-0.3	JHEP 05 037 and JHEP 09 164 (2022)

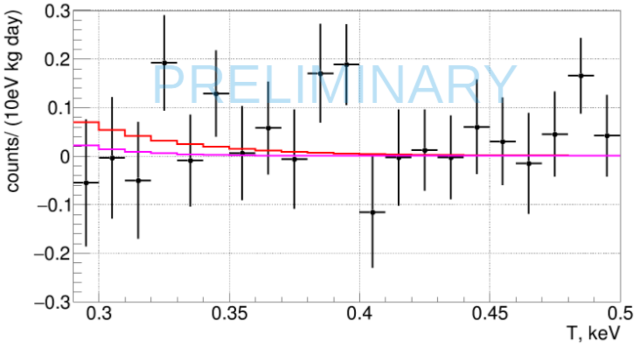


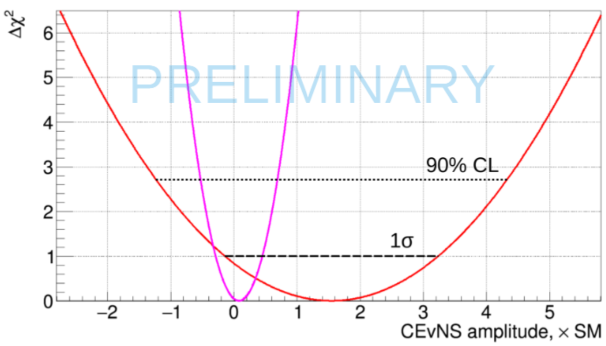


νGeN is capable of stricter NMM limits for the exposition same to GEMMA

Summary

- The limit on the CEvNS rate for the Lindhard (k=0.162) QF is 4.3×SM (90% CL)





- For Dresden (Fef) QF SM is excluded at 2.5σ (99.4%), tension (as in CONUS) with the Dresden-II CEvNS claim

- We continue the data analysis and simulations to use all available statistics (more than 1500 kg×d total)

- We perform lab tests of the modifications to reduce BG and improve the threshold

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Thank you for your attention!