Experiment νGeN at Kalinin NPP. Status and latest results.

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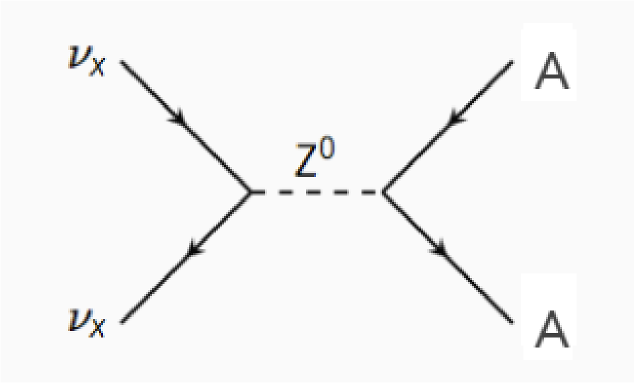
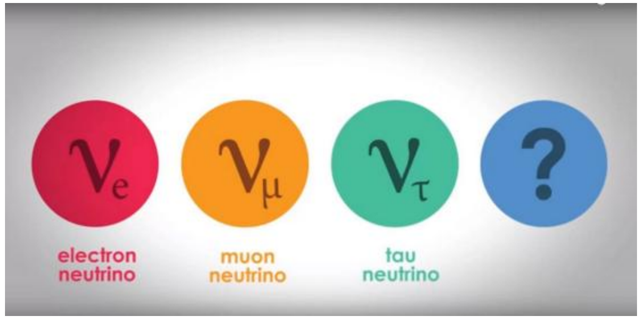
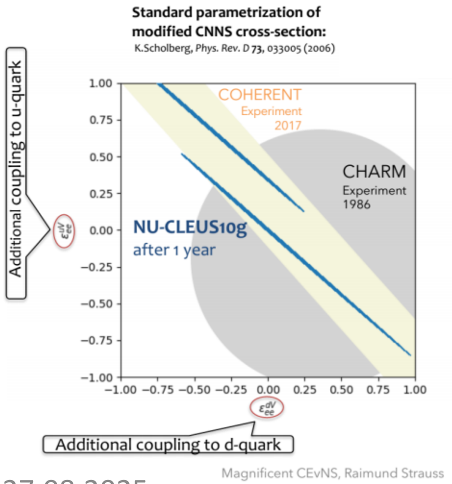
νGeN aims:

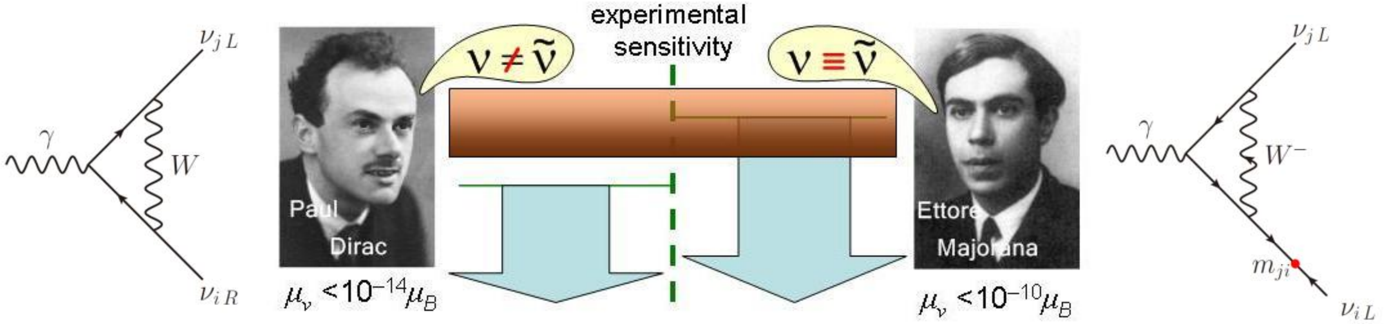
νGeN experiment is aimed to study neutrino scattering using antineutrinos from the reactor core of Kalinin Nuclear Power Plant (KNPP) at Udomlya, Russia. Main searches:

- **Coherent elastic neutrino-nucleus scattering (CEνNS).**
- Non-standard neutrino interactions.
- **Neutrino electromagnetic properties (μ_ν+millicharge).**
- Nuclear physics, sterile neutrino.
- Other rare and exotics processes.
- Applied usage: reactor monitoring.



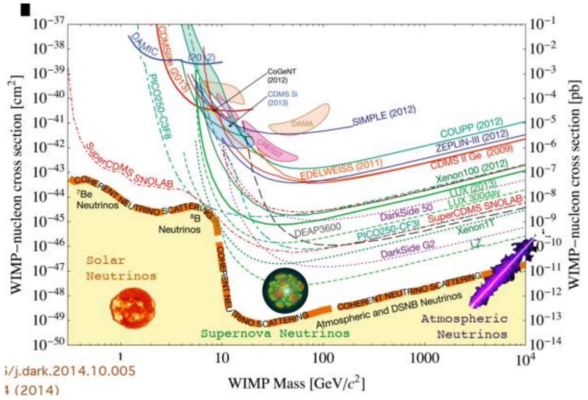




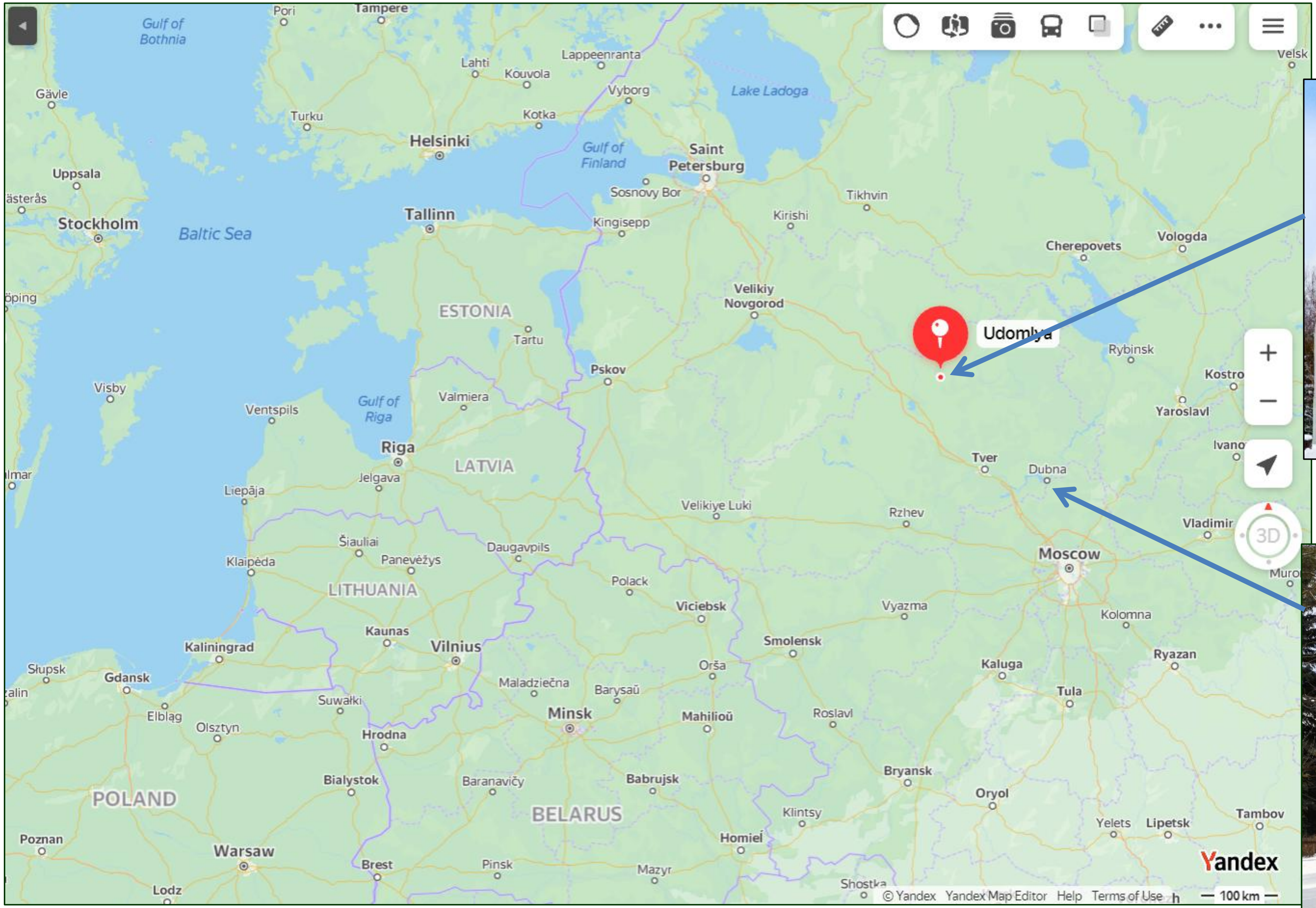


1: Magnetic moment diagram for Dirac neutrinos.

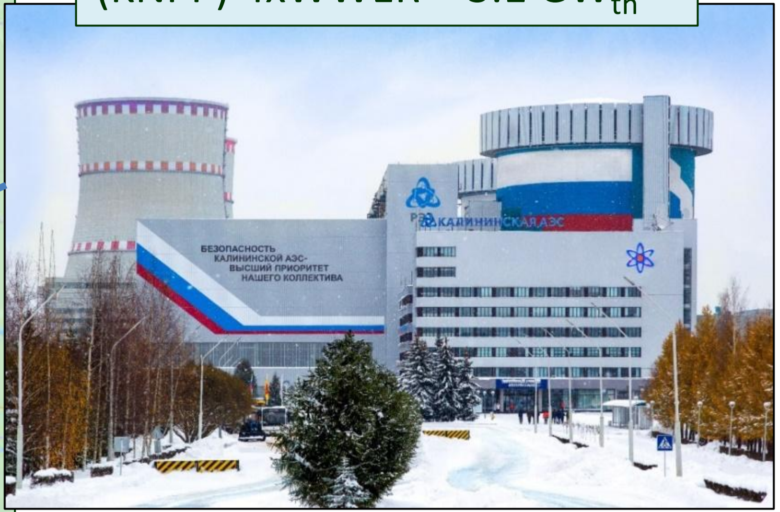
Figure 2: Magnetic moment diagram for Majorana neutrinos.



νGeN reactor site at Udomlya, Russia



Kalinin Nuclear Power Plant (KNPP) 4xWWER – 3.1 GW_{th}

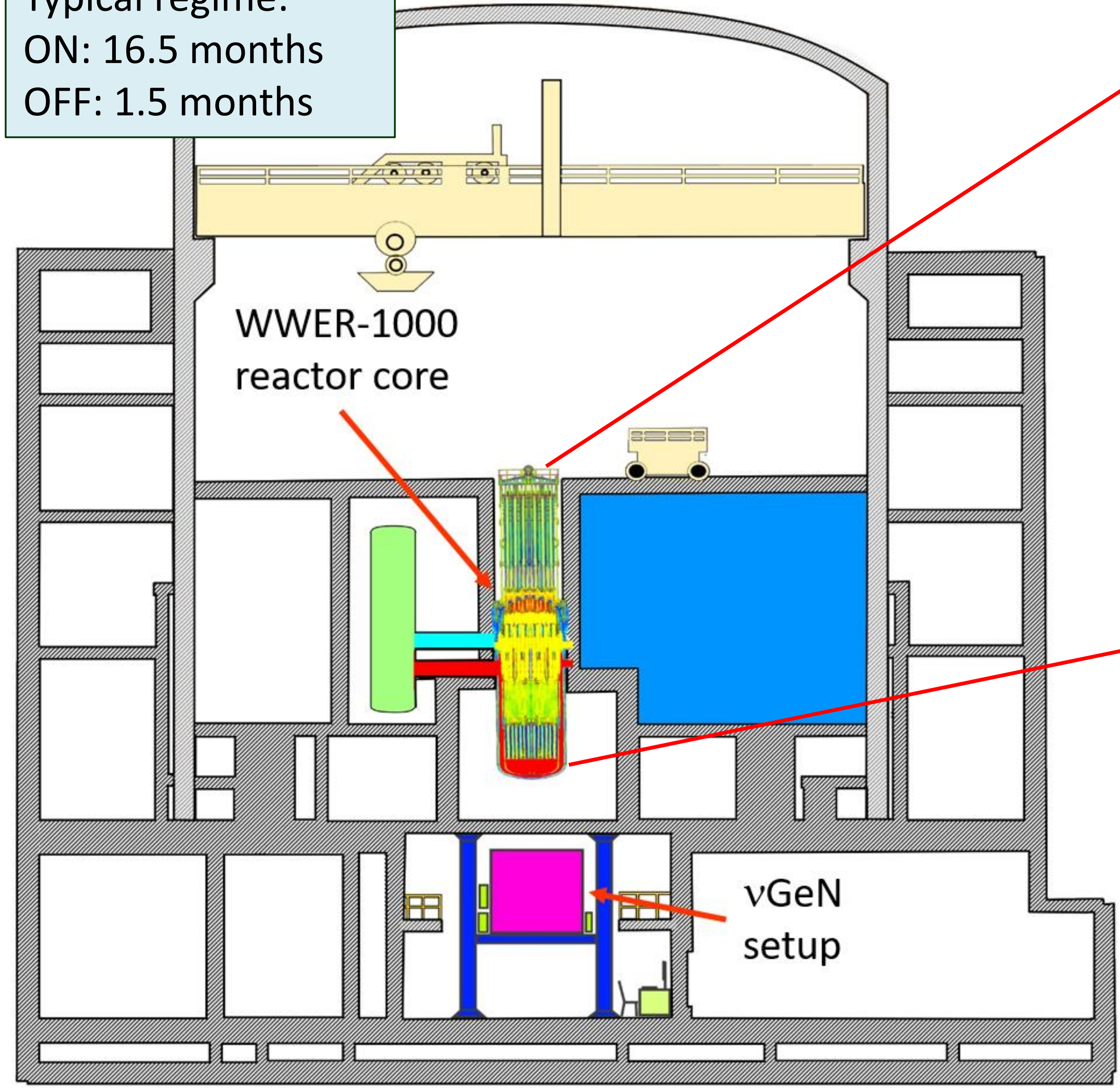


JINR, Dubna, 285 km from KNPP

Neutrino experiments at KNPP

Reactor unit #3 @ KNPP

Typical regime:
ON: 16.5 months
OFF: 1.5 months



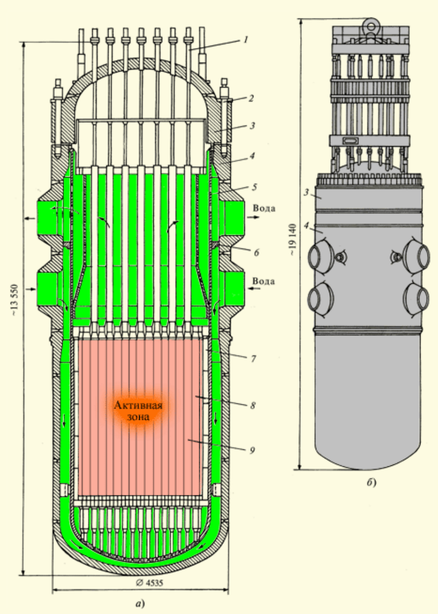
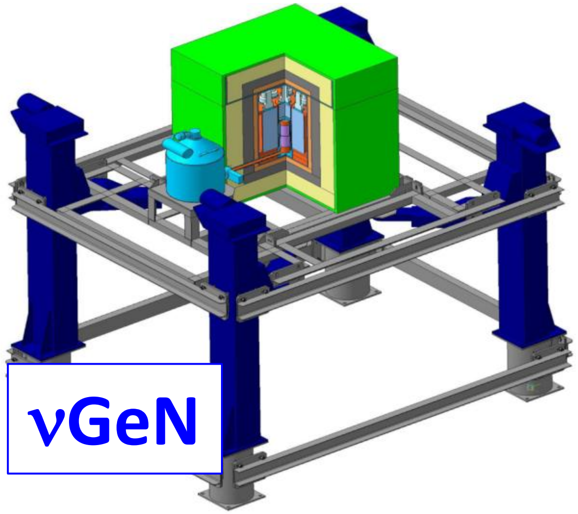


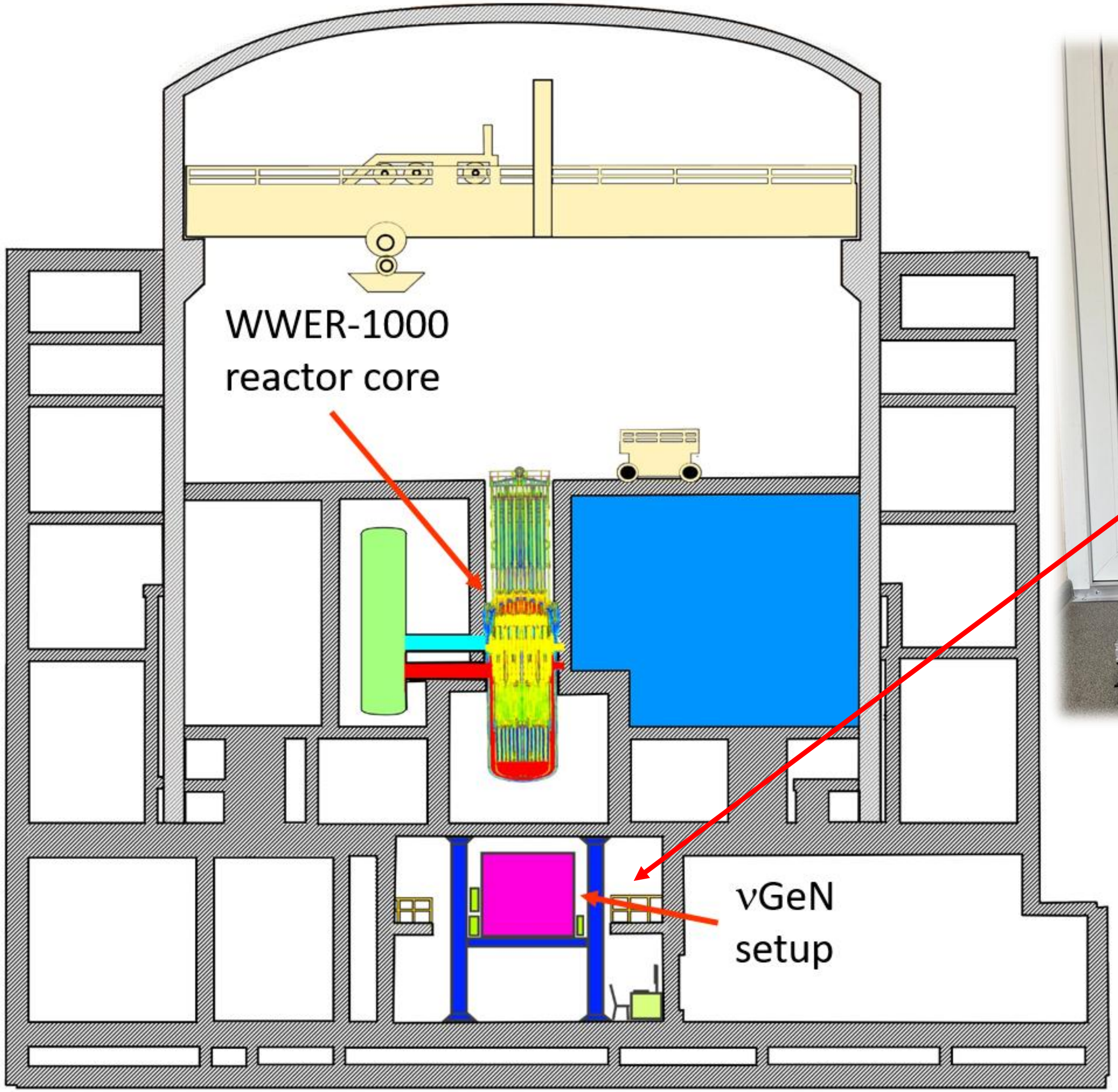
Рис. 5.4. Ядерный реактор ВВЭР-1000

Key sensitivity factors:
- High neutrino flux
- Low background
- Low threshold
- Discrimination of the noise
- Background knowledge
- Stability in time

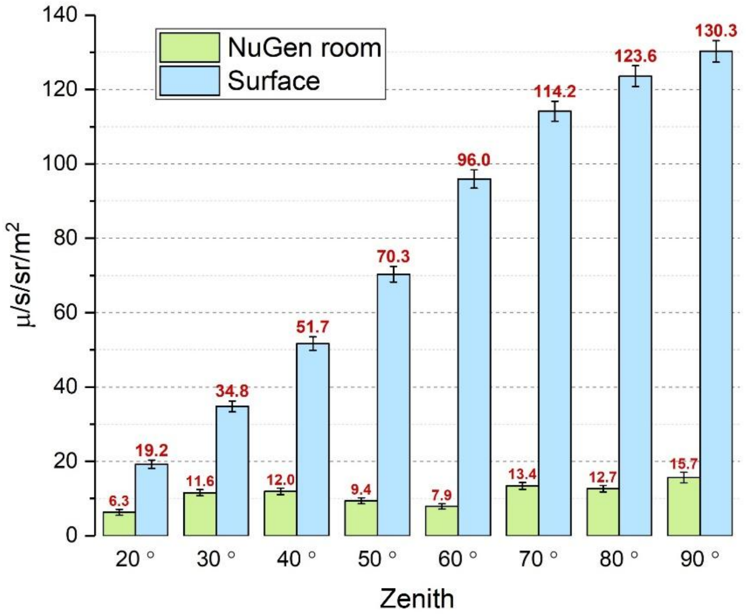


- Spectrometer **νGeN** under the reactor unit #3 (3.1 GW_{th})
- Distance from the detector to the center of the reactor core is 11 m, **$4.4 \cdot 10^{13}$ $\nu/(sec \cdot cm^2)$**
- Good support from KNPP

Reactor unit #3 @ KNPP



New measurements with automatic muon telescope confirms overburden ~ **50 m w.e.** Good suppression of the μ fast neutron background.

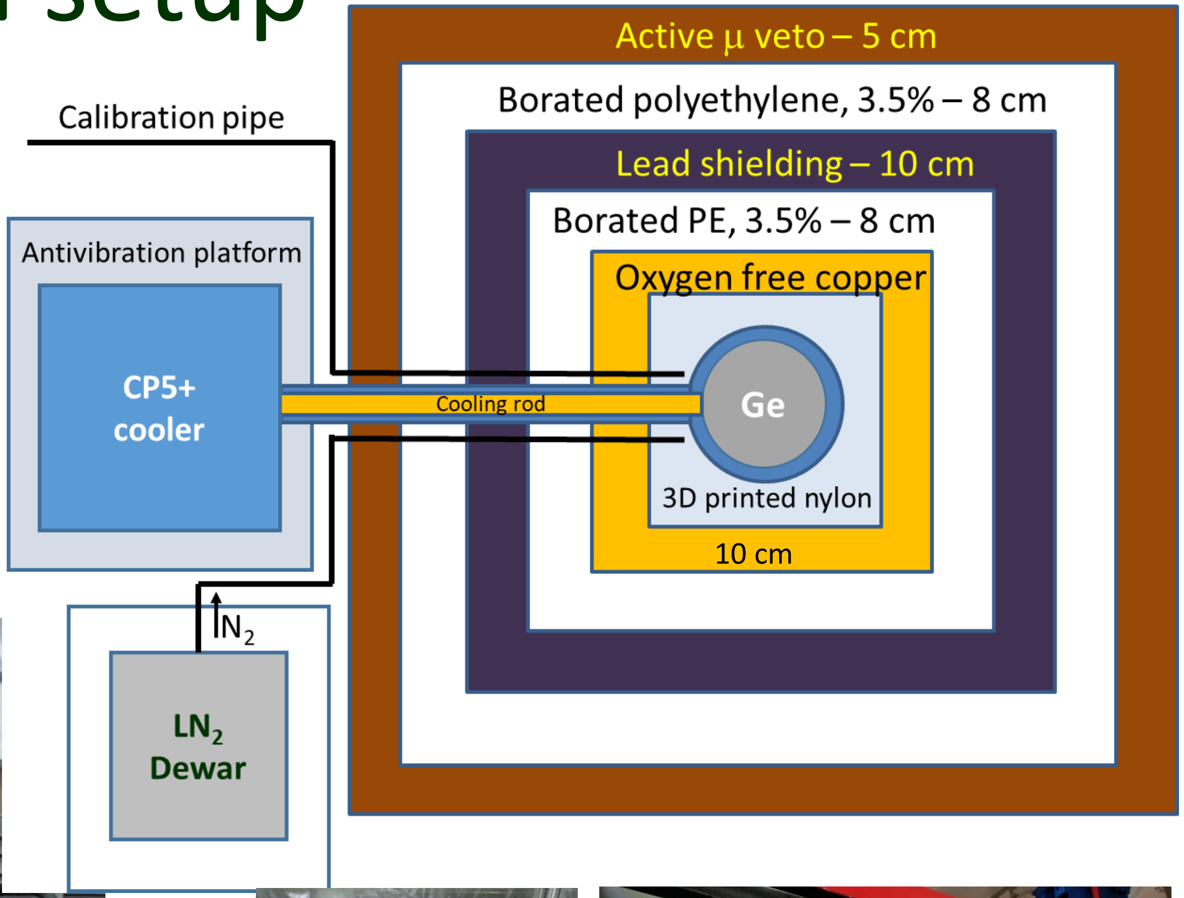


Comparison of the reactor sites

Experiment	Location	Neutrino flux $\nu/(cm^2\ s)$	Overburden [m w. e.]
νGeN	**KNPP, Russia**	**$\sim 4.4\times10^{13}$**	**~50**
CONUS+	Leibstadt, Switzerland	**1.45×10^{13}**	**7-8**
TEXONO	Kuo-Sheng NPP, Taiwan	**6×10^{12}**	**~30**
RED-100	KNPP, Russia	**1.4×10^{13}**	**>50**
CONNIE	Angra 2, Brazil	**7.8×10^{12}**	**0**
RICOCHET	ILL, France	**1.6×10^{12}**	**~15**
MINER	Texas A&M, USA	**2×10^{12}**	**~5**
NUCLEUS	Chooz, France	**1.7×10^{12}**	**~3**
NCC-1701	Dresden-II, USA	**4.8×10^{13}**	**-**
NEON	Hanbit 6, Korea	**7.1×10^{12}**	**~8**
SBS	Laguna Verde, Mexico	**3×10^{12}?**	**?**
RECODE	Sanmen NPP, China	**5.6×10^{13}**	**>15**

The νGeN setup

- To detect signals from neutrino scattering we use a low-threshold, low-background HPGe detector.
- Detector with a mass of 1.4 kg and e-cooling is used for the CEνNS detection at KNPP.
- The passive and active shielding protects detector from external radiation.
- A setup is installed on a lifting mechanism allows to change distance to the reactor's core from **11 to 12.5 m**.



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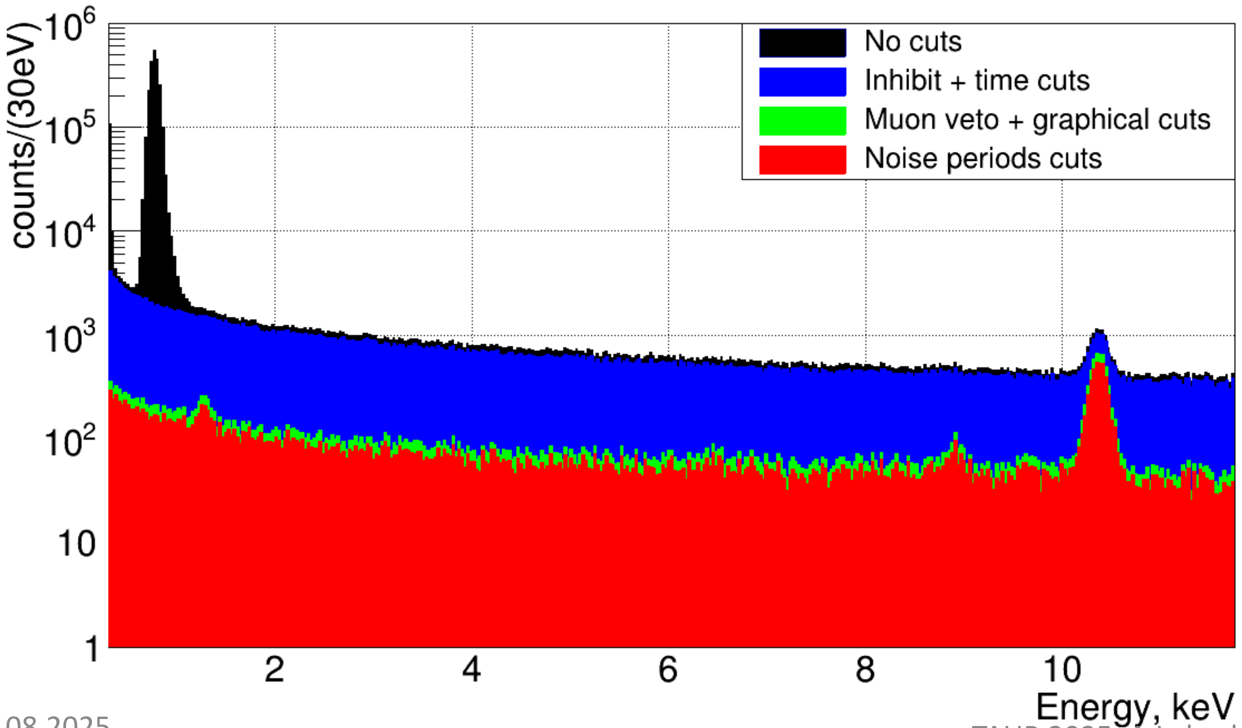
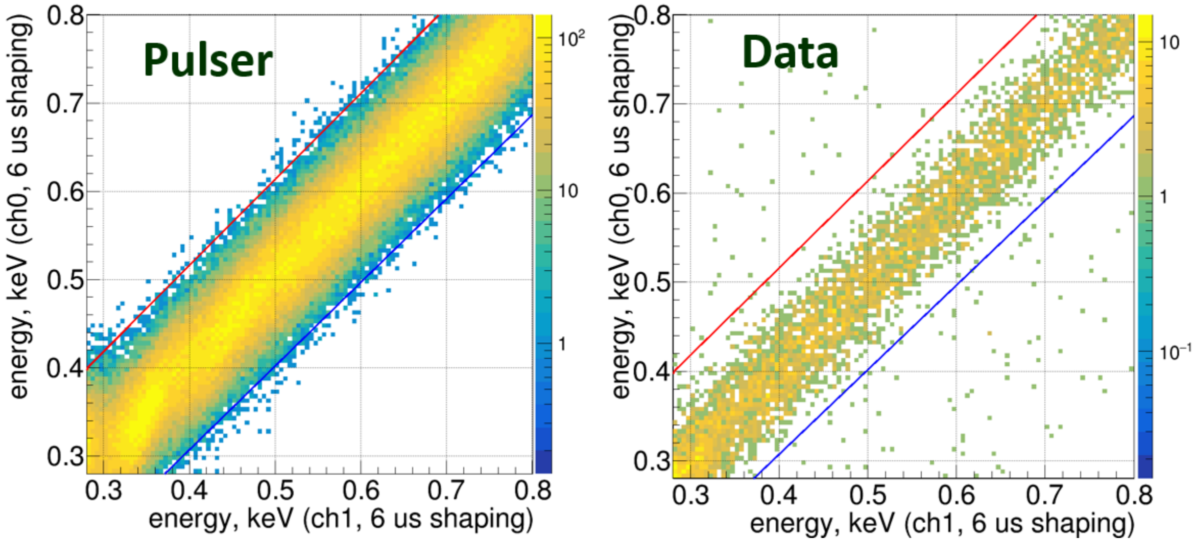
DAQ and cuts

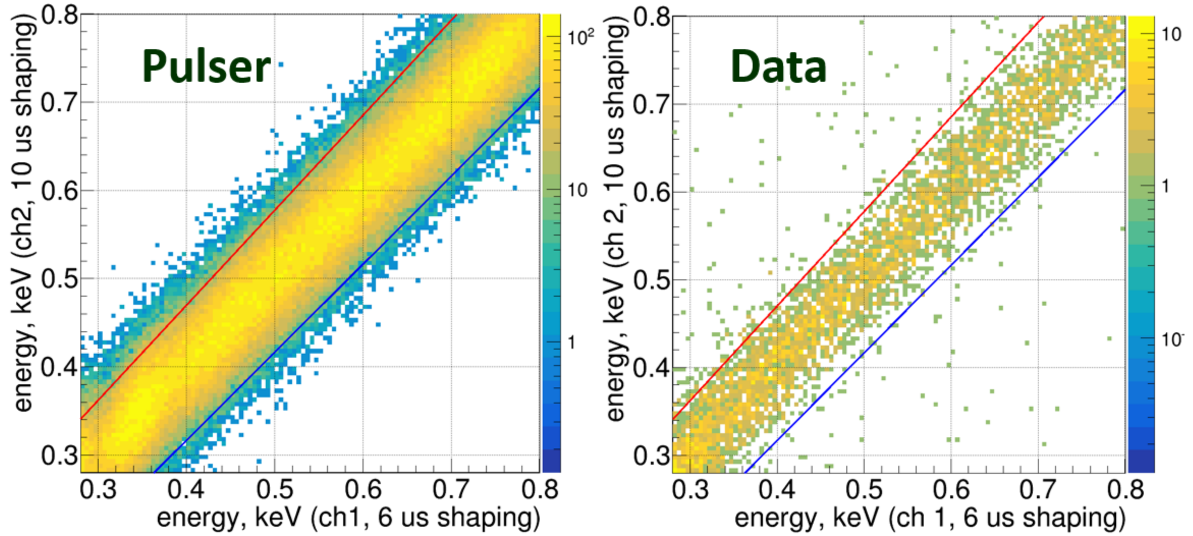
- Reset preamplifier
- DAQ organize with real-time ADC system.
- Shaping amplifiers / no WFs so far
- Noise suppression by comparison different signals
- For selections and veto:
  - «Inhibit» removing reset signal
  - Anticoincidence with muon veto



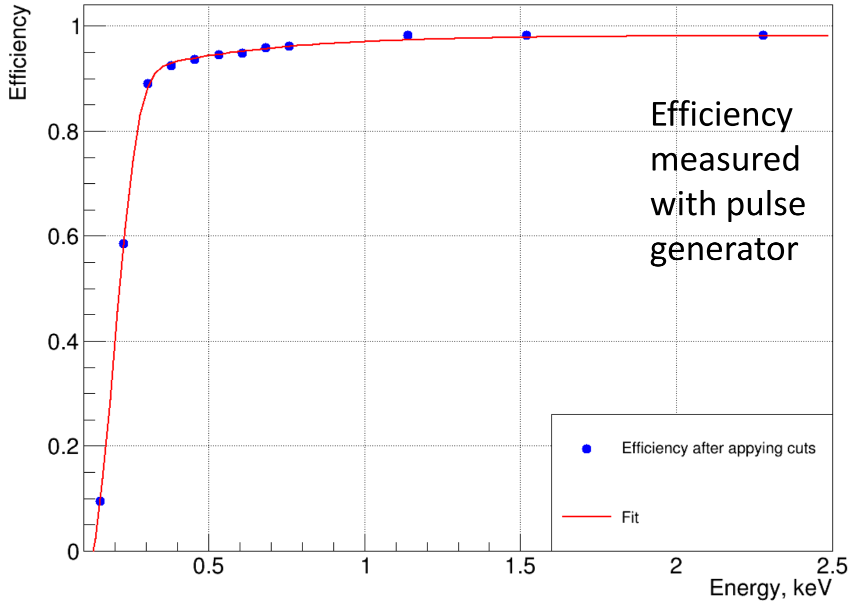
Comparison of two channels with the same τ_{sh}



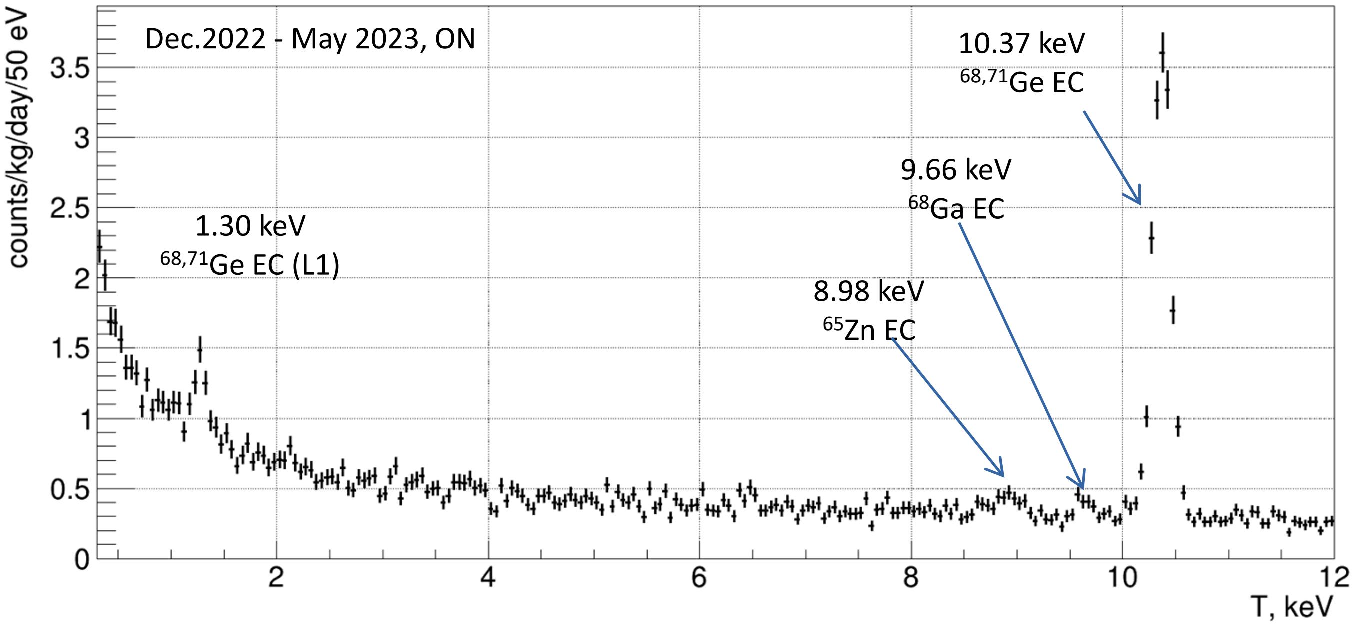
Comparison with the different τ_{sh}

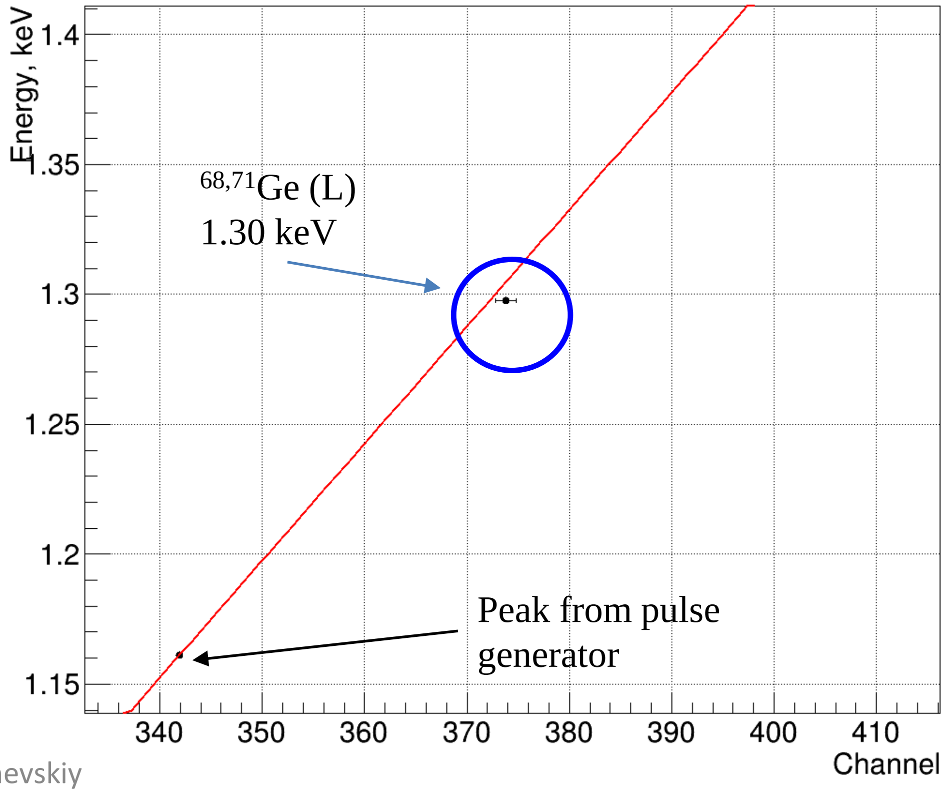


Calibration & efficiency



- Energy calibration at low energy is performed by means of 10.37 keV cosmogenic line and pulse generator.
- Calibration check with 1.3 keV line.
- Data taking shows very good stability of peak position during all measurement time.
- Energy resolution of 1.4 kg detector at KNPP is 101.6(5) eV (FWHM).



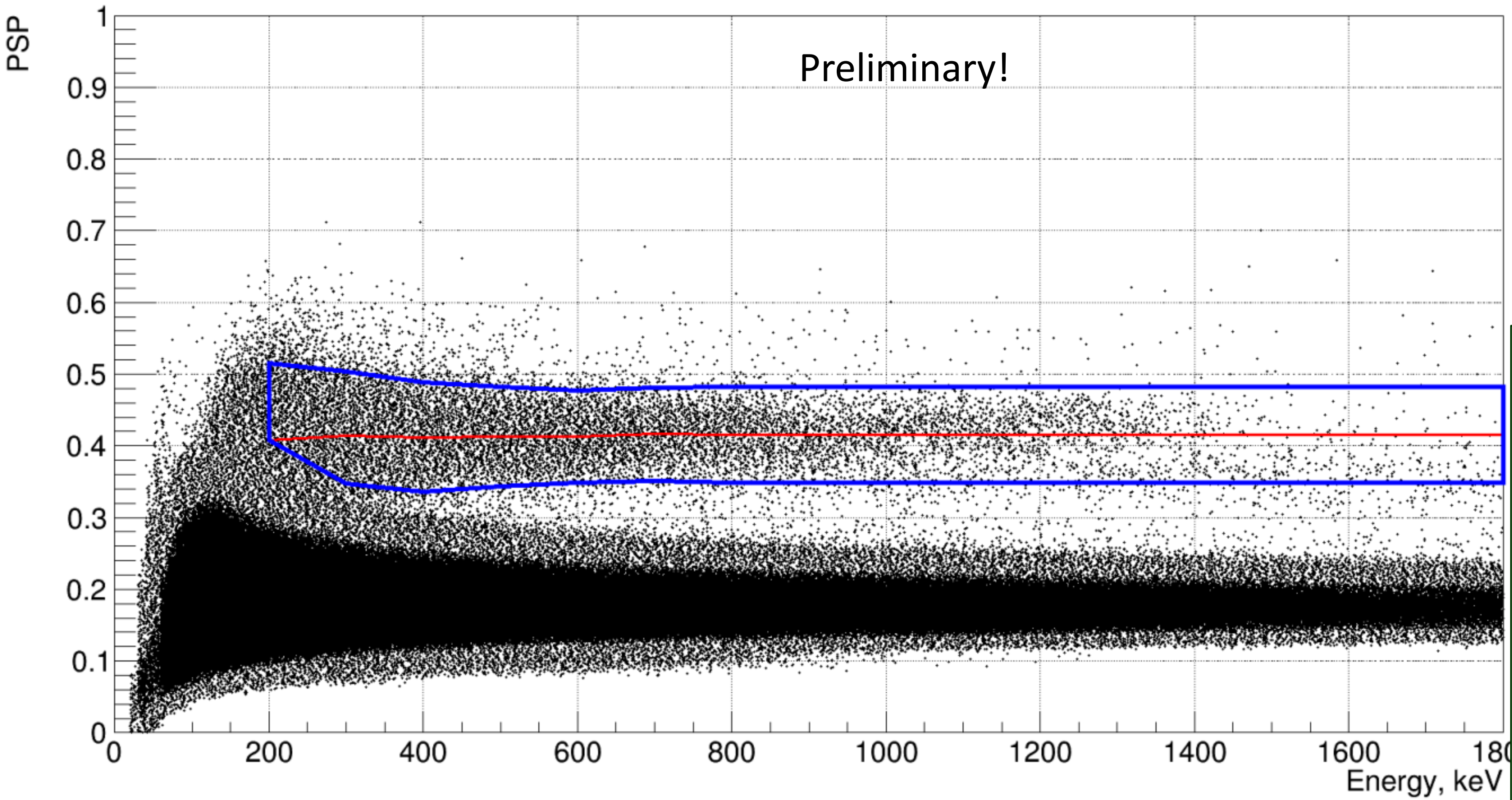


Control of experimental conditions

- The stable measurement conditions are very important, because instabilities can change amplification and noise level.
- ✓ Air temperature condition in the experimental hall is stabilized by three air-conditioners.
- ✓ Temperature and humidity are constantly monitored by two sensors.
- ✓ Gamma background outside shielding was checked with NaI detector.
- ✓ Neutron background outside shielding (fast and thermal) is measured by special low background He3 counter and NaI[L] detector and Bicron liquid scintillator.
- Cosmogenic activation products slowly decay in time and have to be taken into account during analysis.

Bicron neutron background

- Liquid scintillator based on BC-501A.
- Cylindrical volume h = 13cm, ∅ = 8 cm.
- Measurements at KNPP outside νGeN shielding, both ON and OFF.
- Measurements started from March 2024. Analysis ongoing.



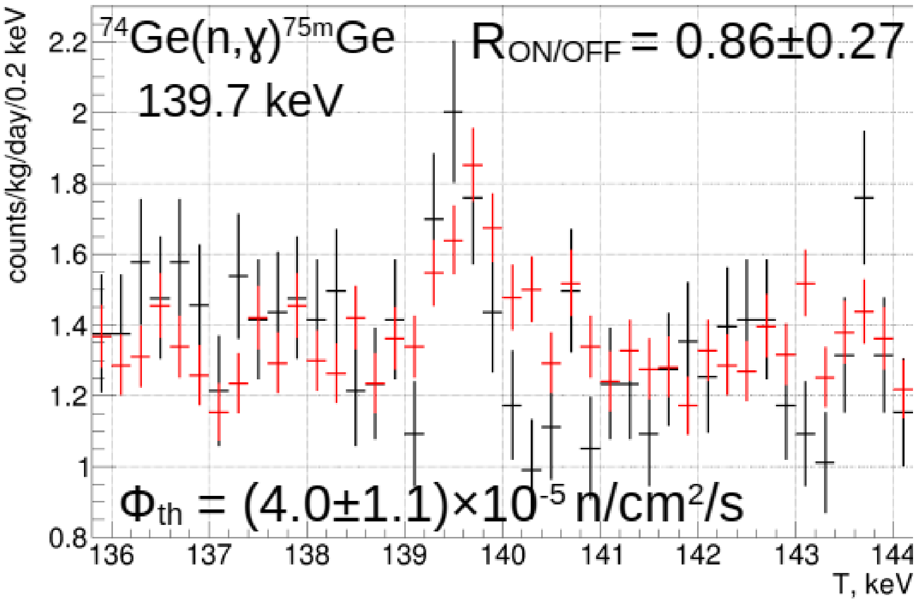
- Some correlation with ON/OFF
- Preliminary: E(n) > 1 MeV outside shielding:

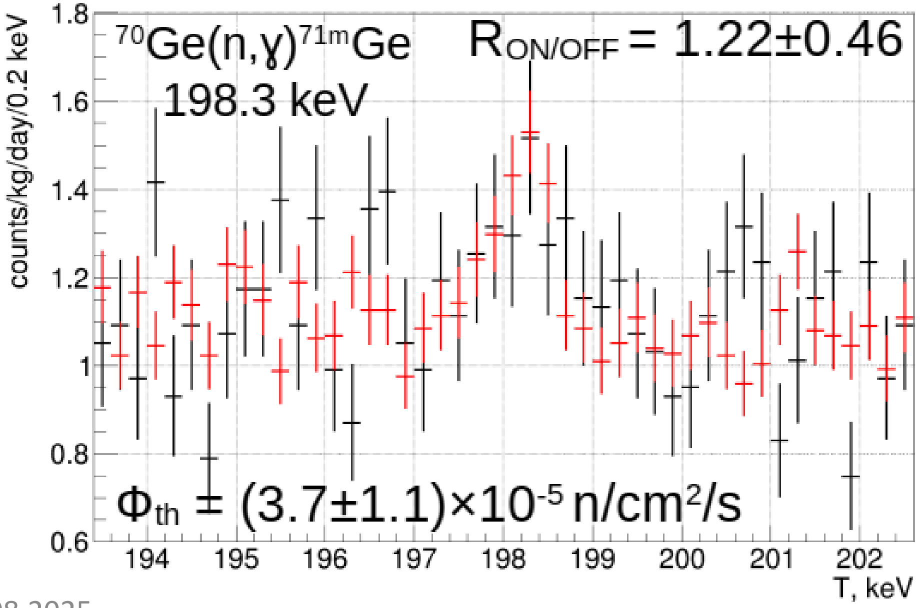
~ $5.6\ 10^{-5}$ neutron/($cm^2 \cdot s$)

- Preliminary MC predicts almost no contribution from neutrons to the νGeN background in the ROI

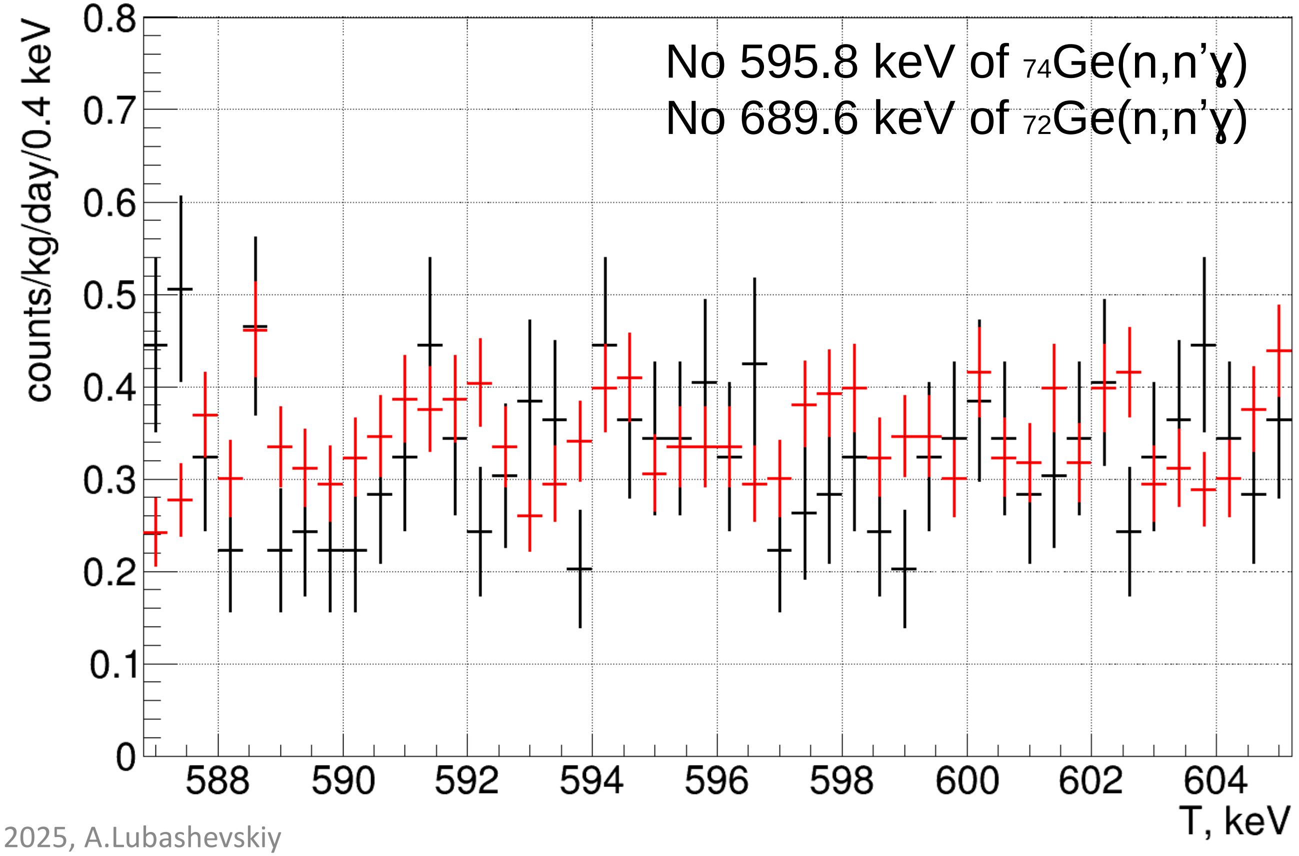
Neutron background

Thermal neutrons



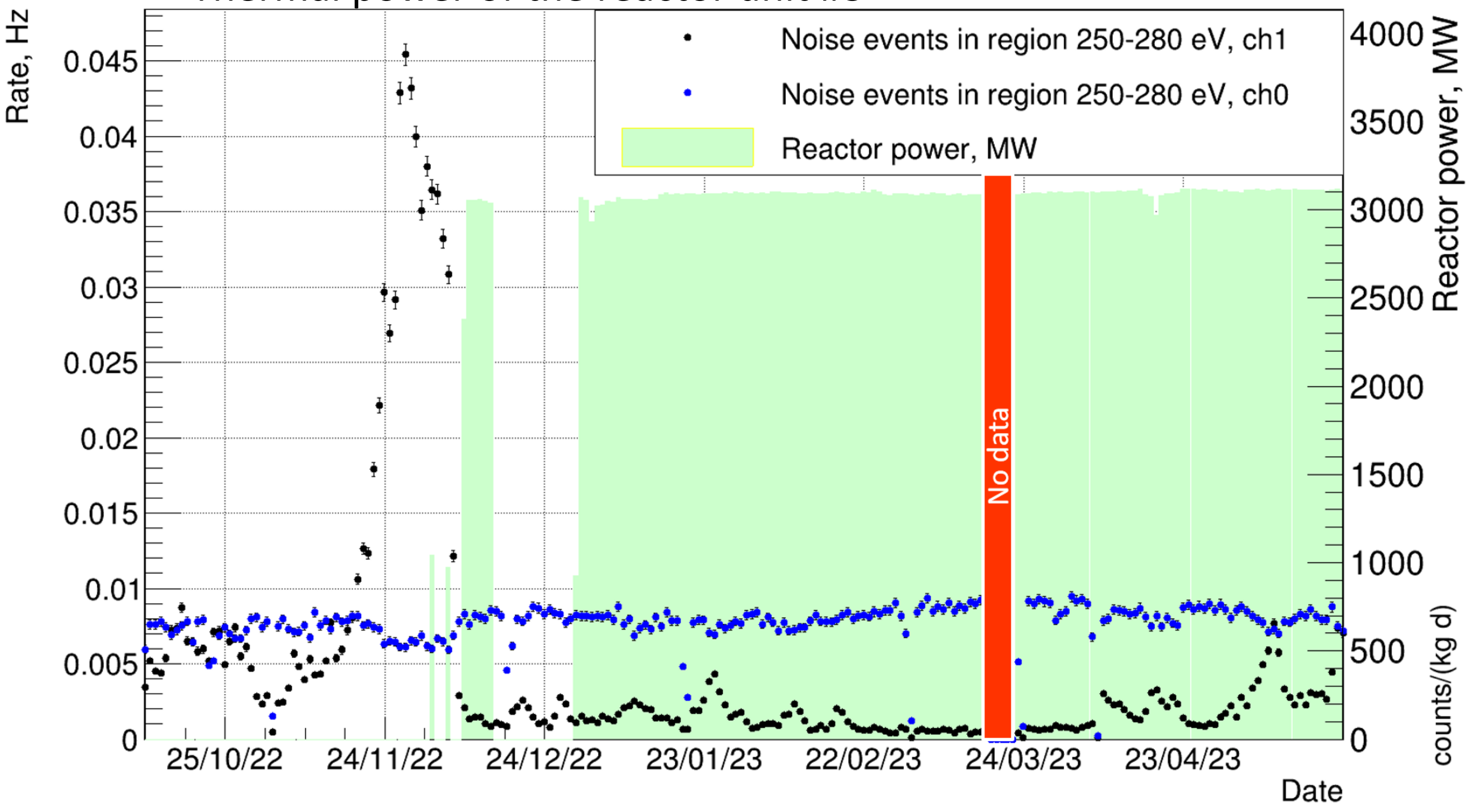


- Investigation of the “high” energy part of the νGeN spectrum give direct information about neutron flux in the HPGe detector.
- No difference in thermal flux in ON/OFF measurements.
- No evidence for fast neutrons scattering in the data.



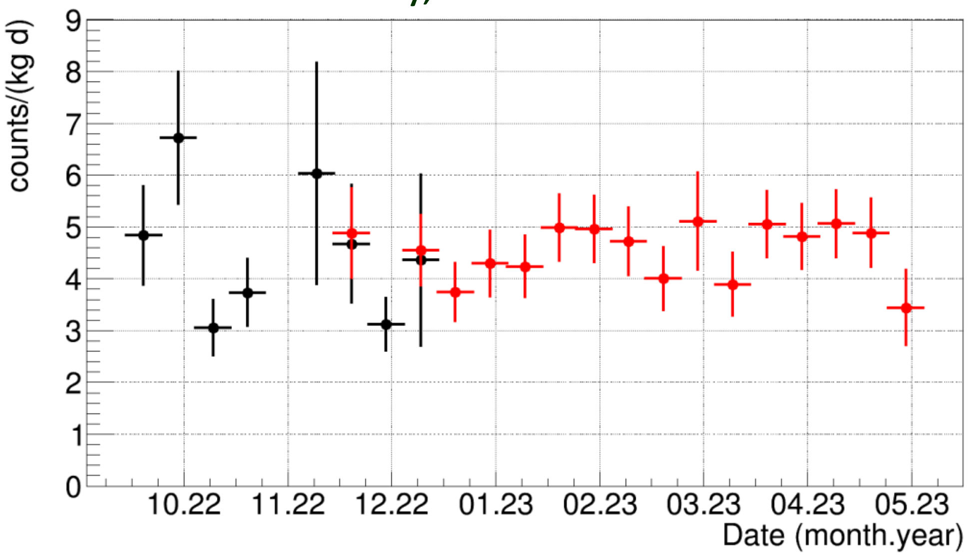
Data taking & stability

Thermal power of the reactor unit #3



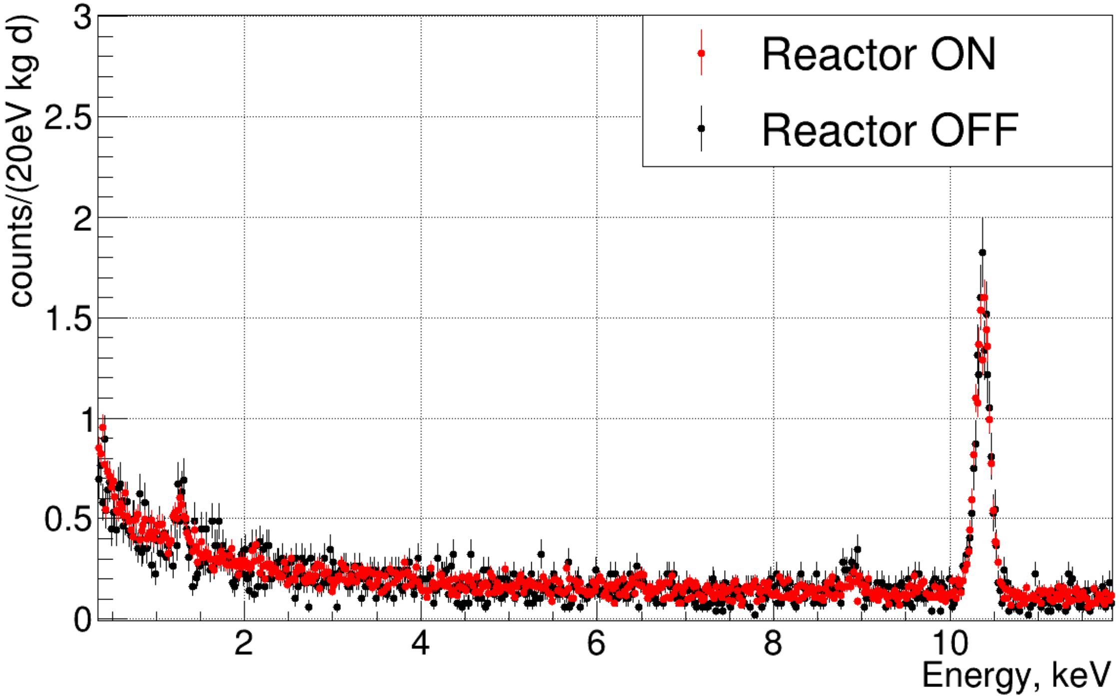
- Total exposition: more than **2200 kgd** taken.
- Some difference in noise and background conditions.
- Need to take into account this differences.

Stability, count rate 2-8 keV

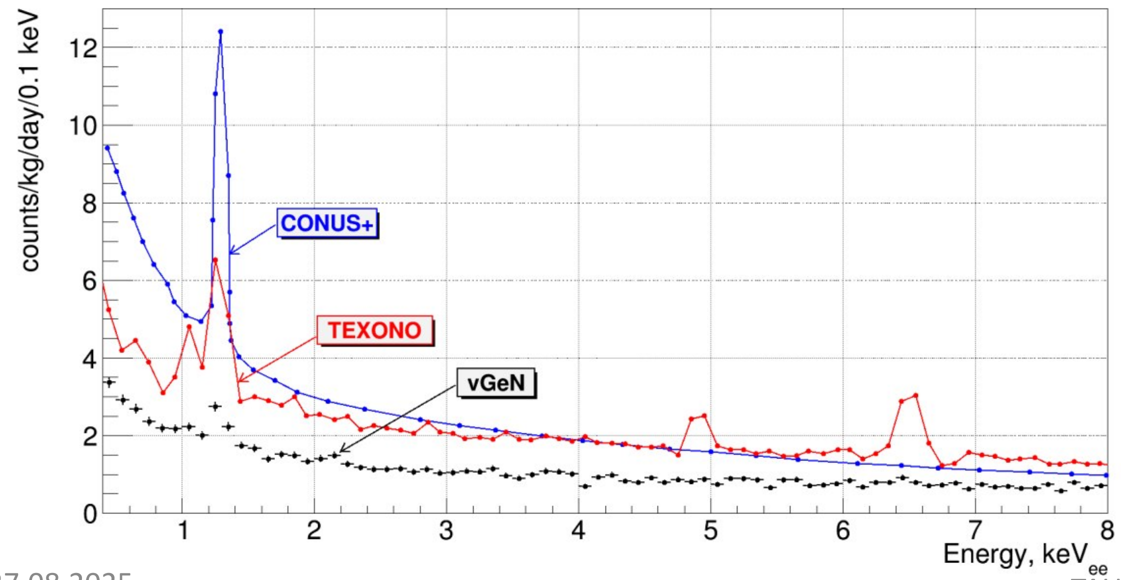


- Shown data: October 2022 — May 2023 at 11.1 m from the center of the reactor core.
- Background conditions were stable.
- Selected statistics: **OFF - 38 days**, **ON - 137 days.**

νGeN background



No significant difference in background level during reactor ON and OFF regimes is observed.



Comparison to other running Ge experiments

E, keV	Source	Rate, $(kg\times d)^{-1}$
1.30	^{71}Ge/^{68}Ge EC (L1)	~1.3$^{\times}$
8.98	^{66}Zn EC	~0.7$^{\times}$
9.66	^{68}Ga EC	~0.5$^{\times}$
10.4	^{71}Ge/^{68}Ge EC (K)	14.8$^{\times}$
46.5	^{210}Pb	1.1
66.7	^{72}Ge(n,γ)^{73m}Ge	6.1*
140	^{74}Ge(n,γ)^{75m}Ge	1.8
198	^{70}Ge(n,γ)^{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

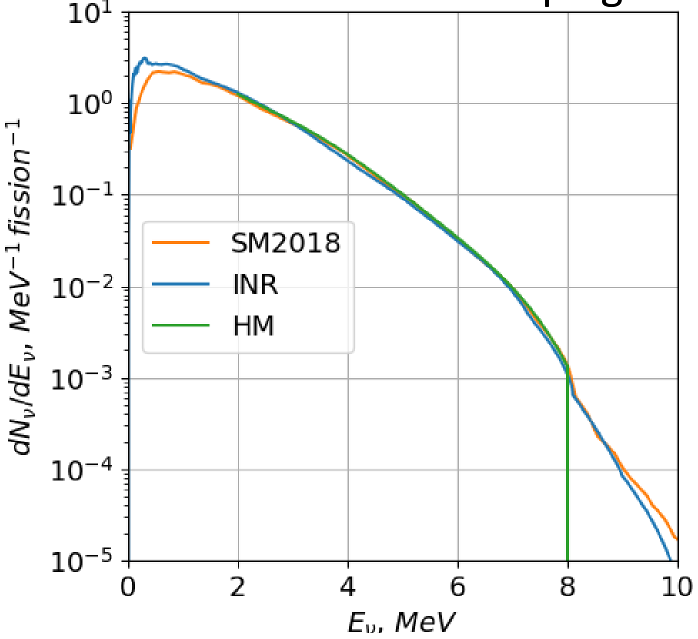
+ Pb, Bi X-rays

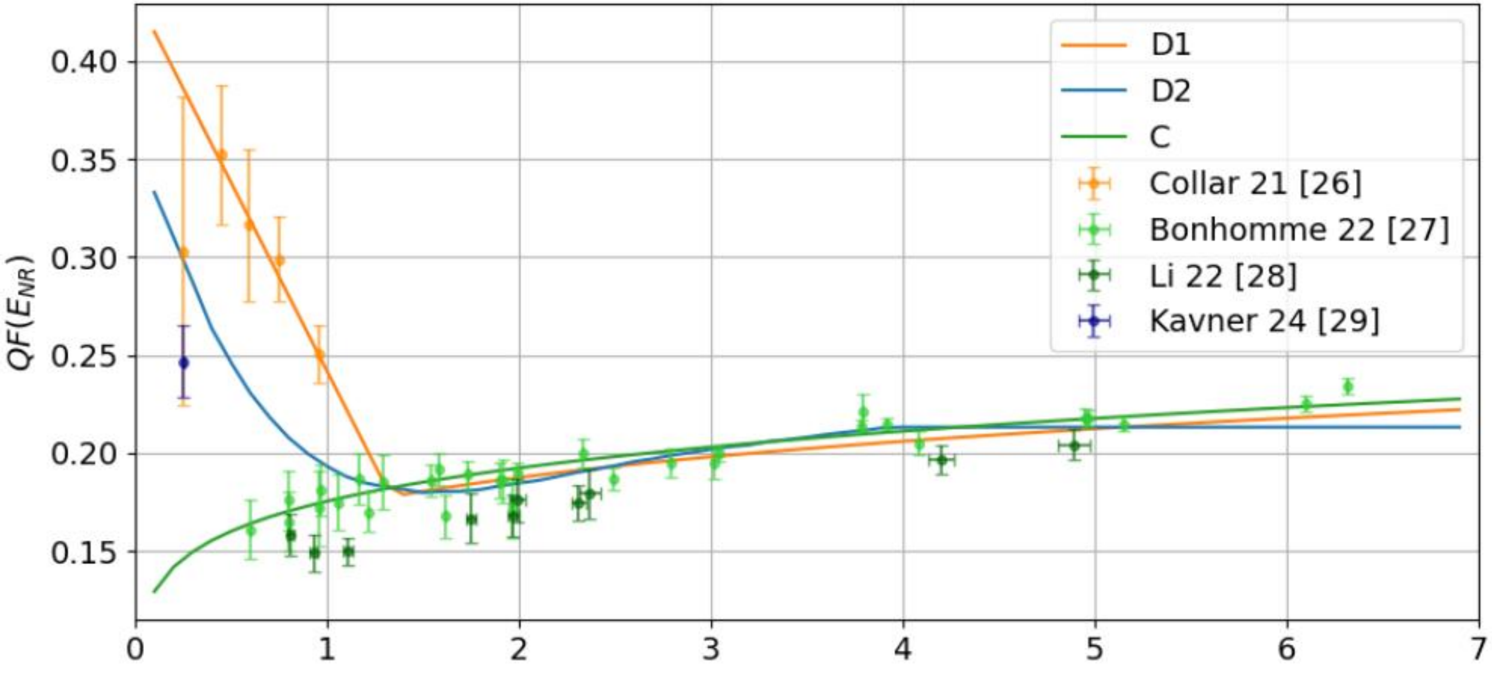
* - [53.4+13.3] keV, affected by τ_{sh}
$^{\times}$ - as of Dec. 2022- May 2023

CEνNS signal calculation

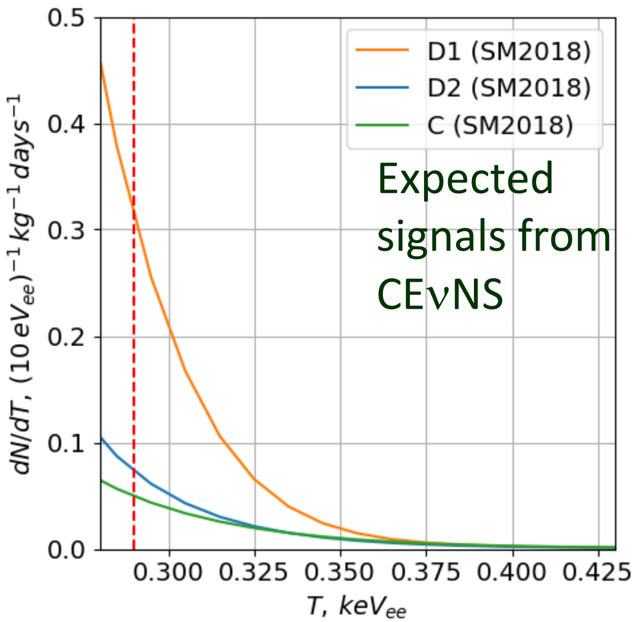
- Neutrino spectrum is calculated based on the SM2018 model up to 11 MeV taking into account fission fractions of isotopes and average thermal power of the reactor.
- The expected CEνNS spectrum was calculated for all germanium isotopes, taking into account detector's performance.
- Three cases for quenching (ionization part of the energy deposited) were considered for analysis.

For the standard campaign





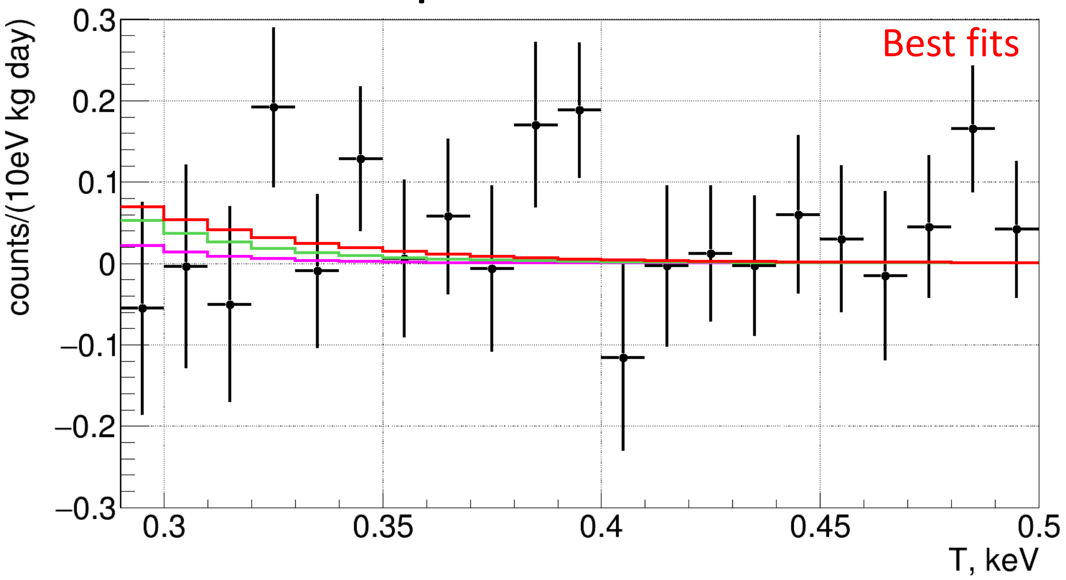
Energy, keV

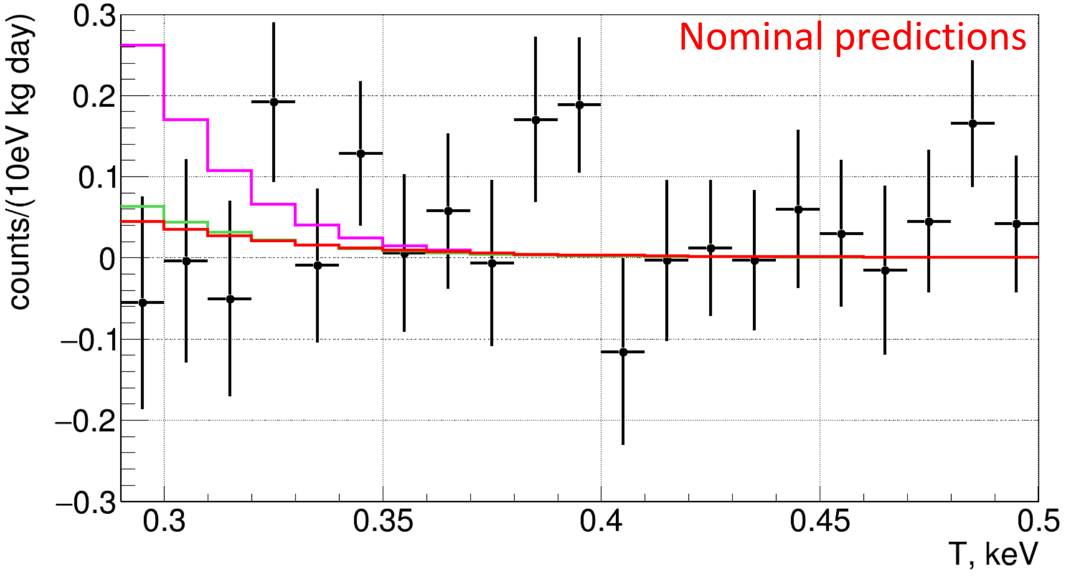


Expected signals from CEνNS

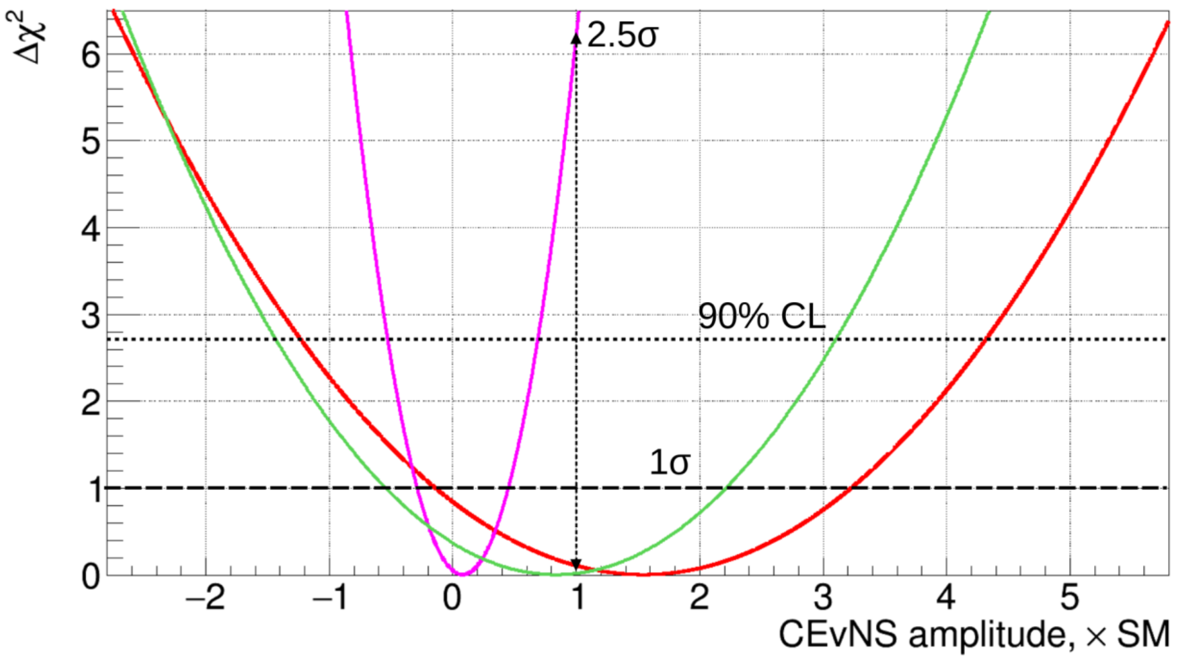
Fit and results

ON-OFF spectrum





- No assumptions about background and no fitting its components
- Only difference between ON-OFF spectra is used for analysis.

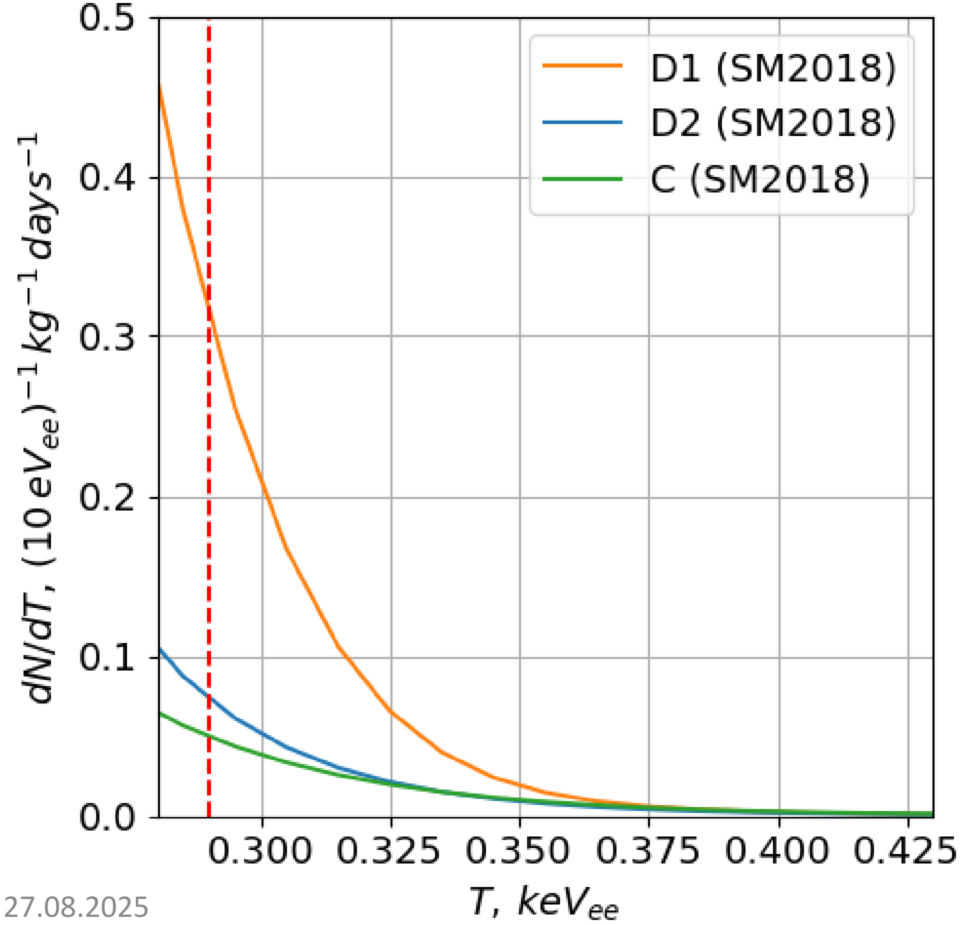


Chinese Physics C (2025),49, 5, 053004.

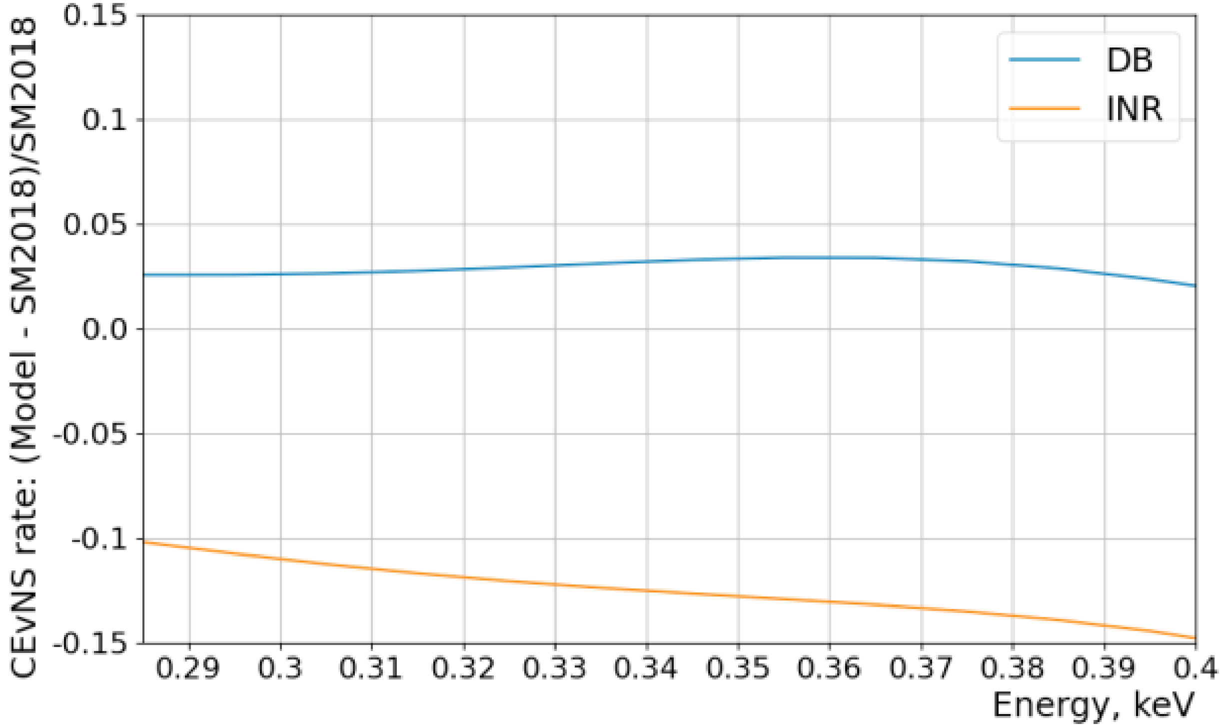
QF	$A_{best} \pm \sigma_A$, ×SM	χ^2_{best} (ndf=10)	S,×SM	L,×SM
C	1.5 ± 1.7	13.6	3.8	4.3
D1	0.1 ± 0.4	14.4	1.6	0.7
D2	0.8 ± 1.4	14.1	3.3	3.1

Systematic studies

Main systematic uncertainties:
- Quenching factor
- Precision of calibration at low energies
- Uncertainty of the neutrino spectrum

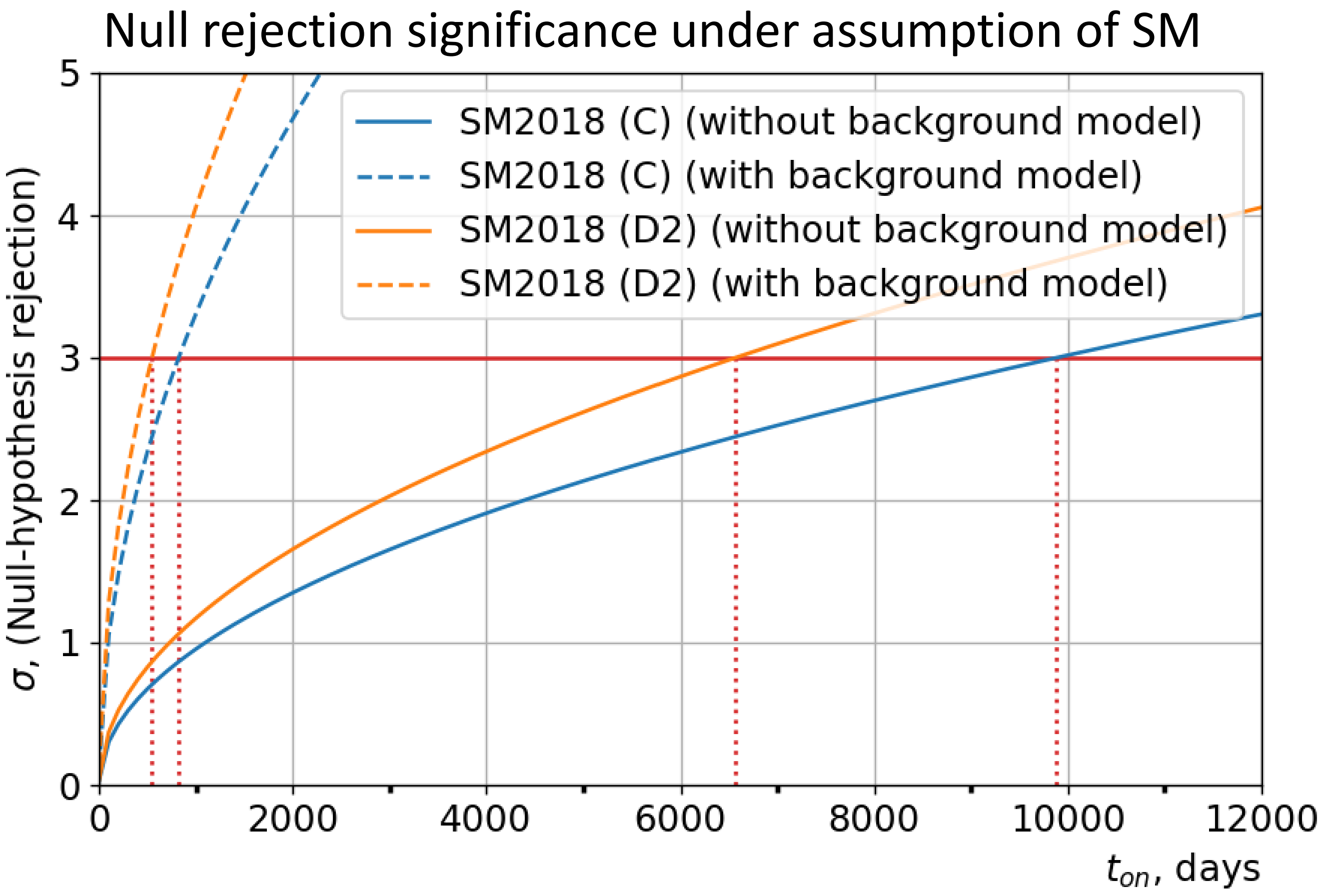


INR -Vlasenko A.P. et al. Physics of Atomic Nuclei. (2023). Vol. 86,6,1178-1188.



Energy scale	$A_{\text{best}} \pm \sigma_A$ $(C/D1/D2)$	Limit $(C/D1/D2)$
Default	1.5 ± 1.7 / 0.1 ± 0.4 / 0.8 ± 1.4	4.3 / 0.7 / 3.1
Global	1.8 ± 1.7 / 0.1 ± 0.4 / 1.0 ± 1.4	4.5 / 0.7 / 3.3
Modified	1.2 ± 2.4 / 0.0 ± 0.6 / 0.6 ± 2.1	5.1 / 1.1 / 4.1

Sensitivity exploration



Given the measured BG rate and currently achieved threshold we can extrapolate the sensitivity studies.
Two scenarios:

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

3σ at ~ 20/30 year OFF for a current energy threshold

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

3σ at ~ 1.5/3 years – (already have in hands)

Need to:
1. Deconvolve the BG → full BG model: studies and simulations ongoing
2. Improve energy threshold → noise reduction, improve energy resolution
3. Reduce background → modifications and upgrades of the setup

Upgrade and improvements

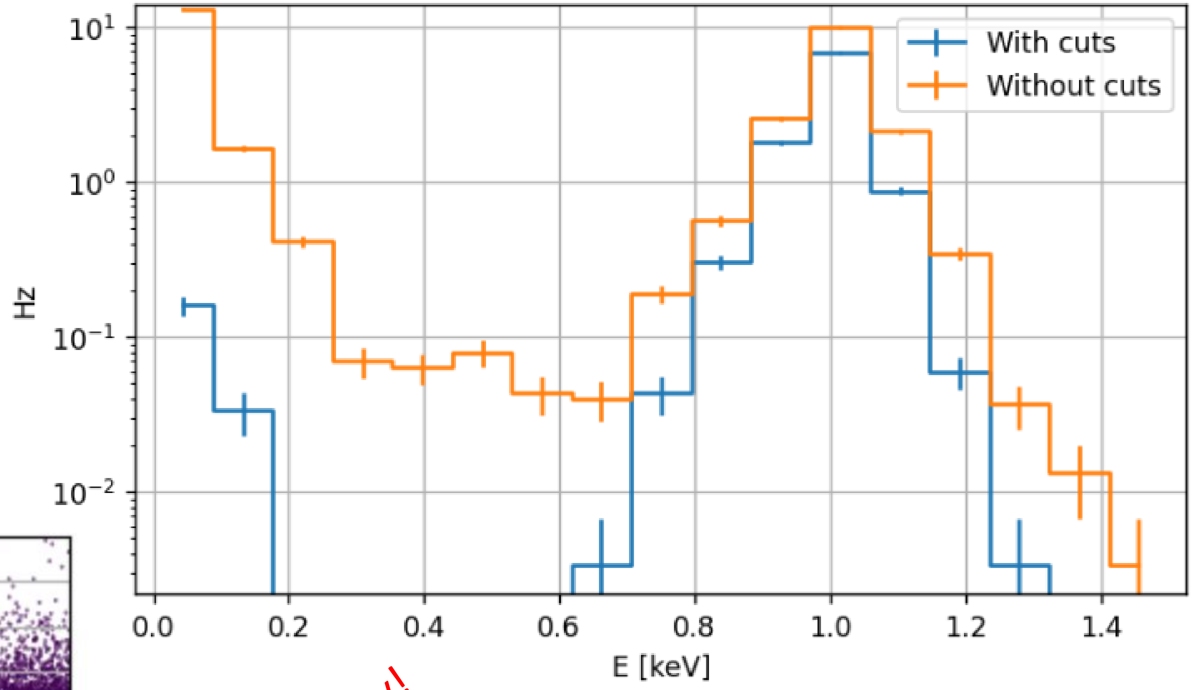
Plans to improve noise level and reduce background:

- «Compton veto around the detector» — set of NaI crystals to suppress multiple scattering events.
- Background level is currently testing at Baksan underground laboratory.
- Modifications of the cryocooler to reduce its power consumption and noise.

Upgrade and improvements

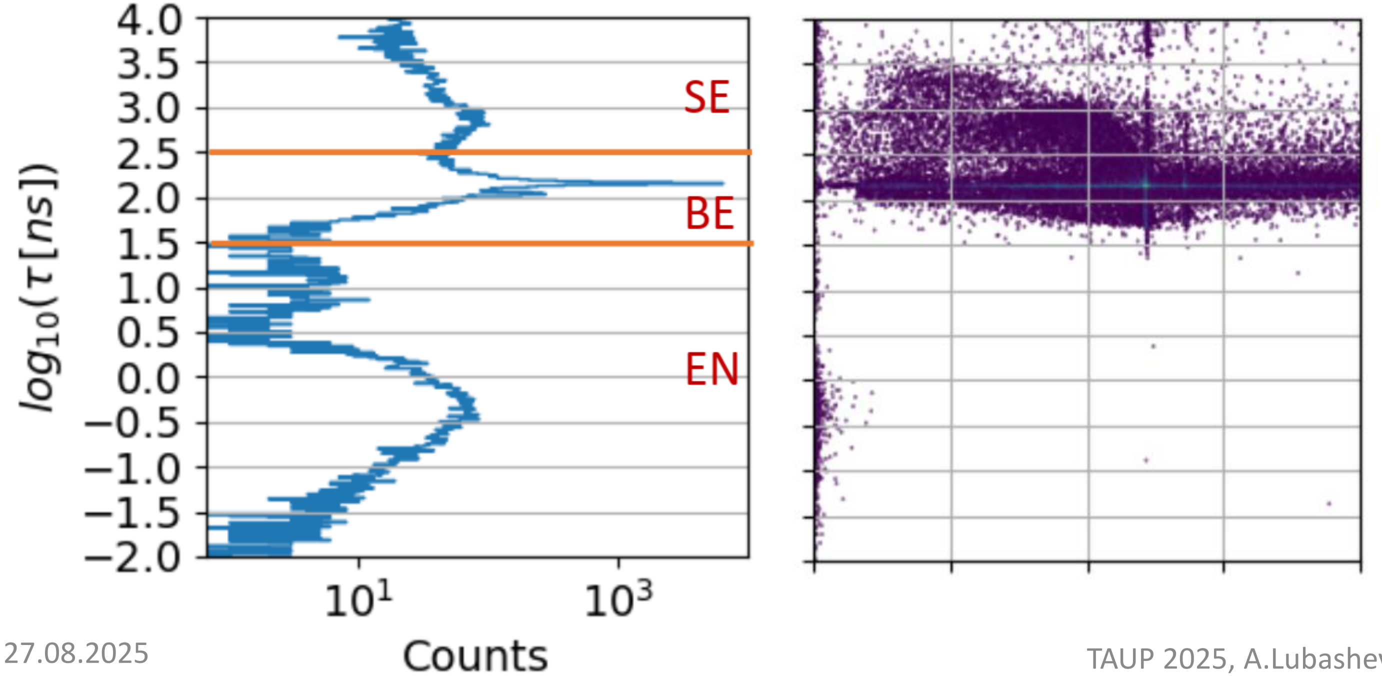
- New custom made DAQ with WF recording for a better discrimination of noise and surface events.
- Pulse shape analysis.
- New detector with lower threshold?

Test measurements with a pulse generator

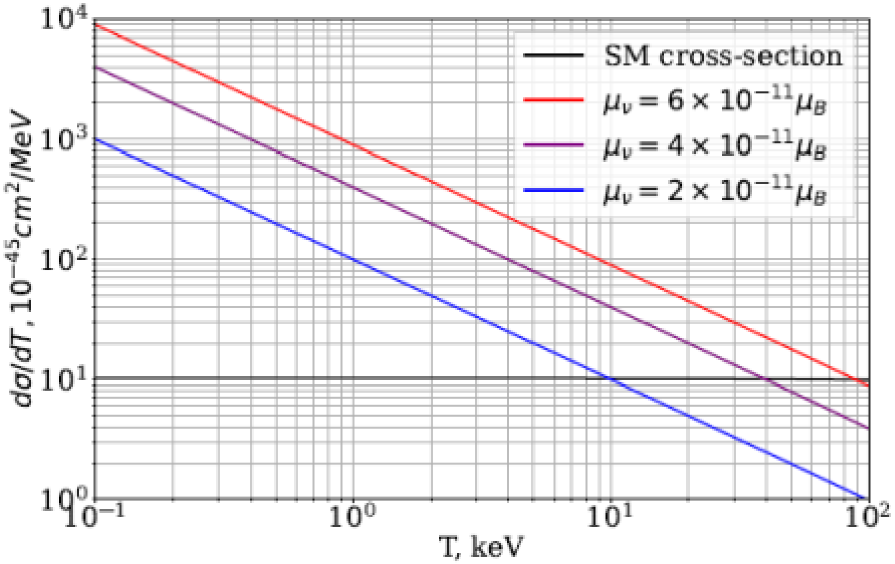


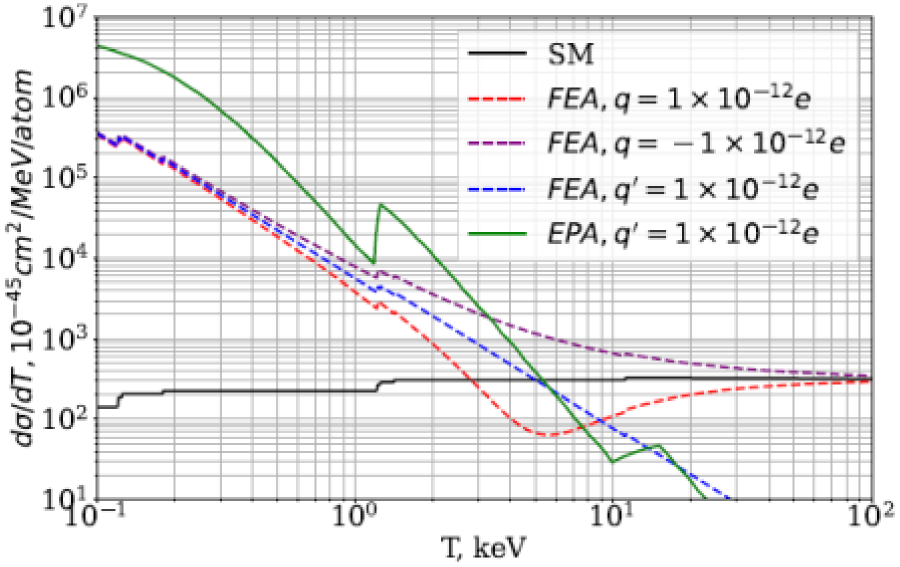
Very preliminary!

Tests with Co57



Other searches with νGeN





Magnetic moment

Limit, $10^{-11}\mu_B$	Experiment	Type	Comment
7.5	νGeN	reactor	ON-OFF
7.4	TEXONO	reactor	ON-OFF
5.2	CONUS	reactor	ON-OFF
2.9	GEMMA	reactor	ON-OFF
0.64	XENONnT	solar	ON only

Astrophys.: $\mu_\nu < 1.2\times10^{-12}\mu_B$ [F. Capozzi, 2022]

Millicharge

Limit, 10^{-12} e	Experiment	Type	Comment
2.7	GEMMA	reactor	FEA
1.2	TEXONO	reactor	EPA
2.4 (0.9)	νGeN	reactor	FEA (EPA)
0.6	CONUS+	reactor	EPA
0.224	LZ	solar	MCRRPA

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

(*preliminary results*)

Conclusion

- Measurements with the νGeN spectrometer at Kalinin Nuclear Power Plant are ongoing.
- The limit on the CEνNS rate for the Lindhard (k=0.162) QF is 4.3×SM (90% CL). Published at Chinese Physics C (2025),49, 5, 053004.
- Tension with Dresden-II (D1 QF) and νGeN result claim.
- The lab tests of the modifications to reduce background and improve the threshold are in the process.
- More than 2200 kgd of data has been accumulated so far. Data analysis and simulations for all available statistics are ongoing.
- New results with more statistics are expected soon.

νGeN collaboration

- Joint Institute for Nuclear Research, Dubna, Russia
- Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia

Thank you!

Спасибо!