Search for the coherent elastic neutrino-nucleus scattering and other rare processes in νGeN experiment at Kalinin nuclear power plant

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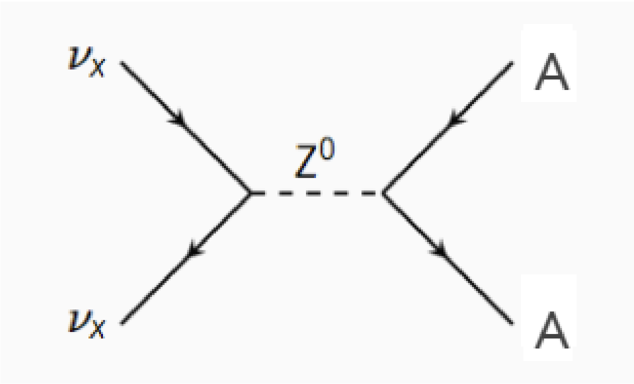
νGeN collaboration

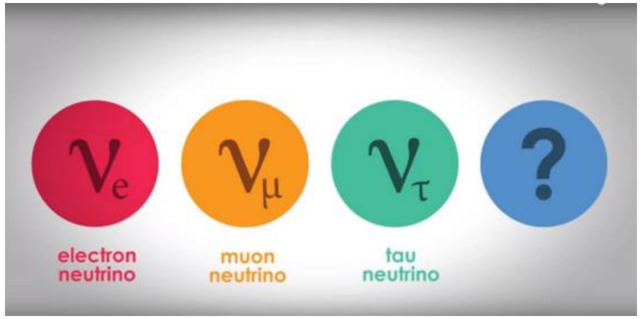
- Joint Institute for Nuclear Research, Dubna, Russia
- Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia
- Institute of Experimental and Applied Physics, Czech Technical University in Prague

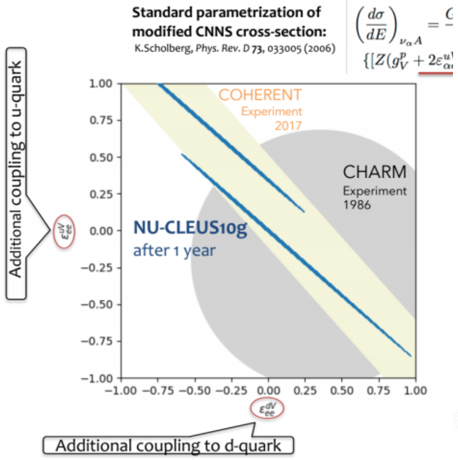
νGeN aims:

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:

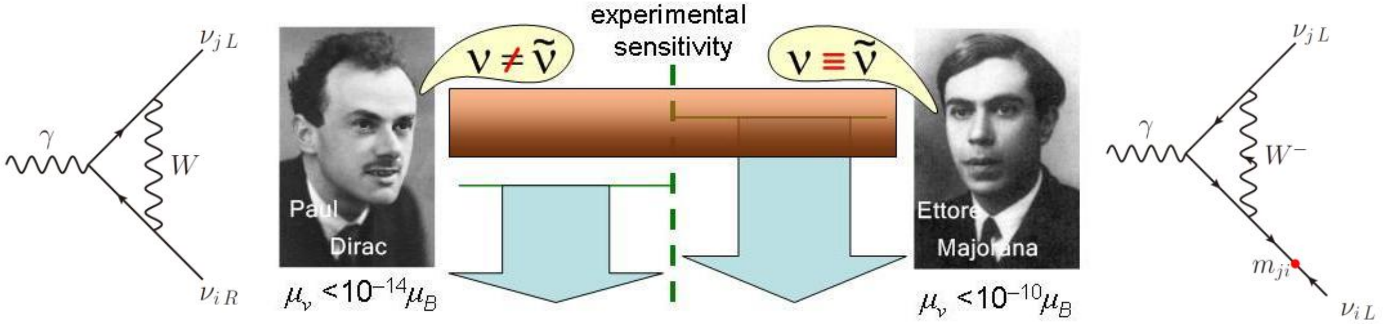
- Coherent elastic neutrino-nucleus scattering (CEνNS).
- Non-standard neutrino interactions.
- Magnetic moment of neutrino.
- Nuclear physics, sterile neutrino.
- Other rare and exotics processes.
- Applied usage: reactor monitoring.





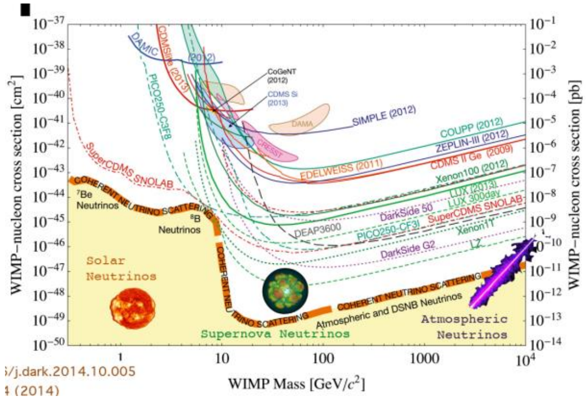


Magnificent CEvNS, Raimund Strauss



1: Magnetic moment diagram for Dirac neutrinos.

Figure 2: Magnetic moment diagram for Majorana neutrinos.

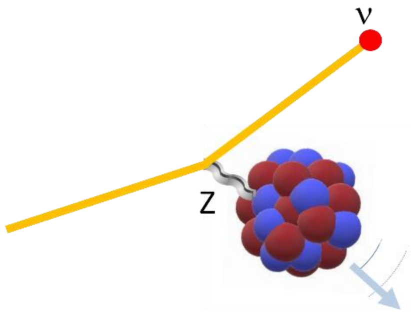


Detection of CEνNS

Energy of nuclear recoil from CEvNS is very low:

$$E_A = \frac{2E^2(1-cos\theta)}{2MA}$$

A.Drukier and L.Stodolsky, Phys.Rev.D 30, 2295 (1984)



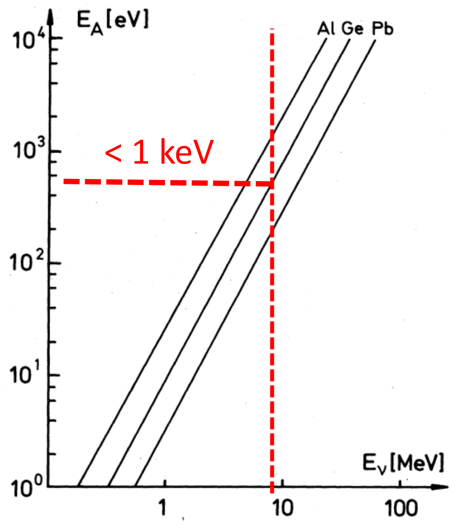
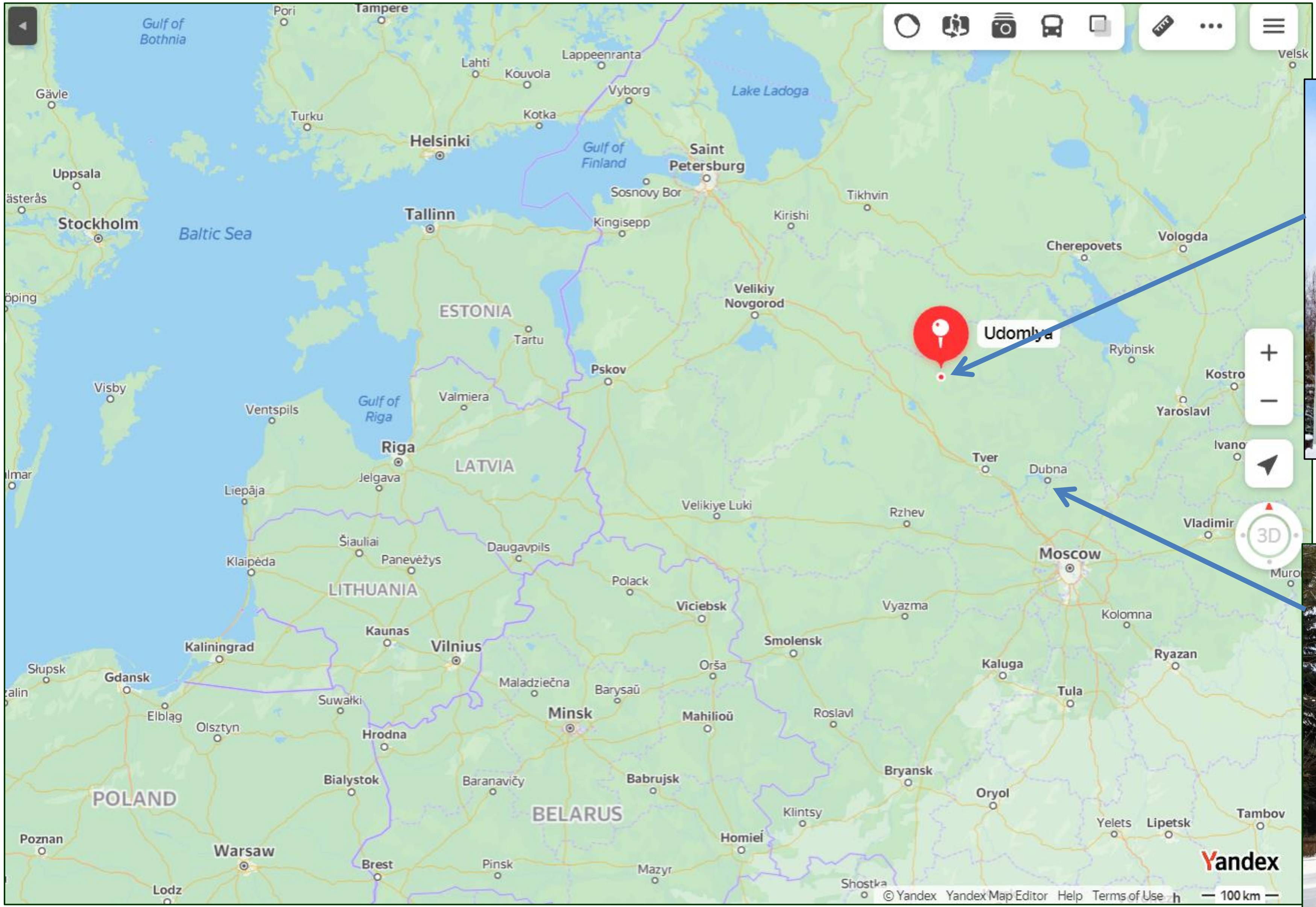


FIG. 2. Average recoil energy for various nuclei as a function of neutrino energy.

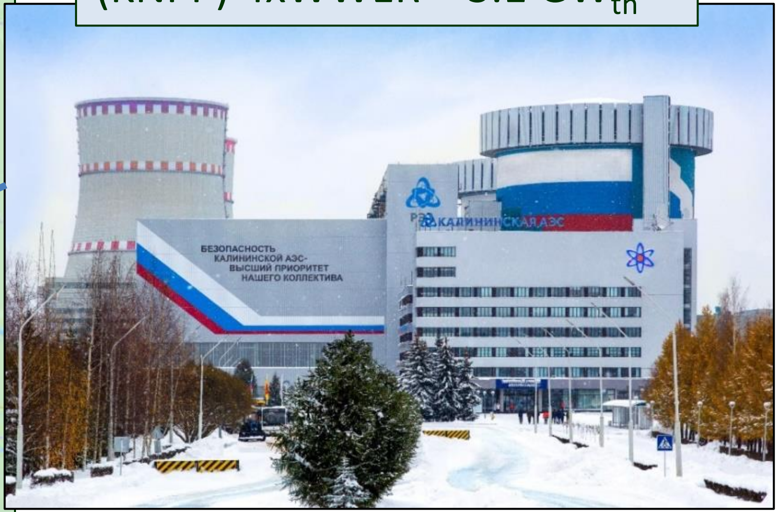
The detection of this process is very challenging, also taking into account that often only part of the energy can be detected due to quenching.

- Powerful neutrino source in full coherency regime < 30 MeV.
- Low threshold and low background detector.
- Effective separation of signals from background.
- Big target mass and good efficiency.
- Stable performance and knowledge of systematical errors.

νGeN reactor site at Udomlya, Russia



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



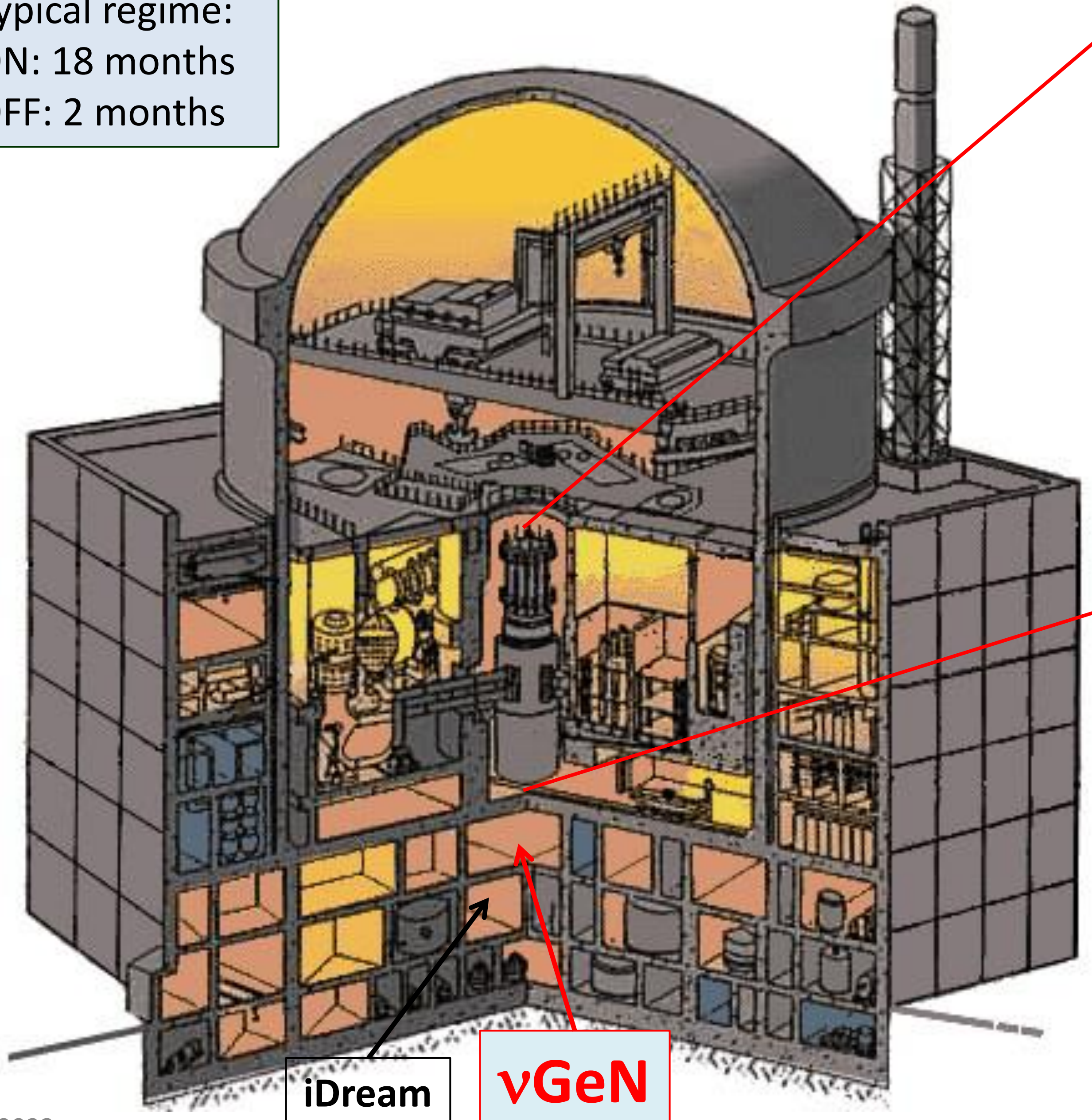
JINR, Dubna, 285 km from KNPP

Comparison of the reactor sites

Experiment	Location	Neutrino flux $\nu/(cm^2\ s)$	Overburden [m w. e.]
νGeN	**KNPP, Russia**	**$\sim(3.6\text{-}4.4)\times10^{13}$**	**~50**
CONUS	Brokdorf, Germany	**2.4×10^{13}**	**10-45**
TEXONO	Kuo-Sheng NPP, Taiwan	**6.4×10^{12}**	**~30**
RED-100	KNPP, Russia	**1.7×10^{13}**	**>50**
CONNIE	Angra 2, Brazil	**7.8×10^{12}**	**0**
RICOCHET	ILL, France	**2×10^{12}**	**~15**
MINER	Texas A&M, USA	**2×10^{12}**	**~5**
NUCLEUS	Chooz, France	**2×10^{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}?**	**?**

Reactor unit #3 @ KNPP

Typical regime:
ON: 18 months
OFF: 2 months



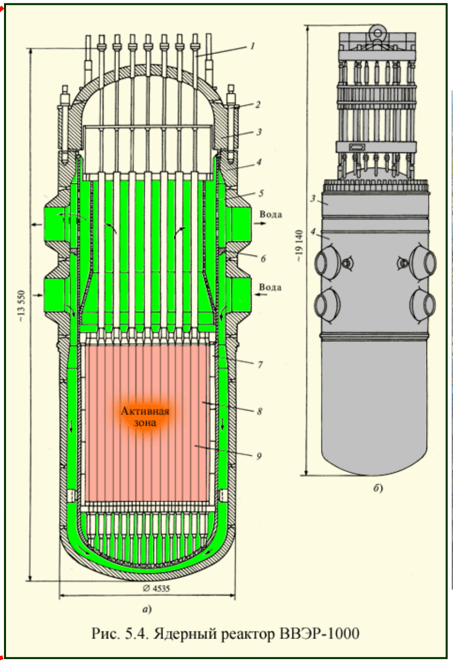
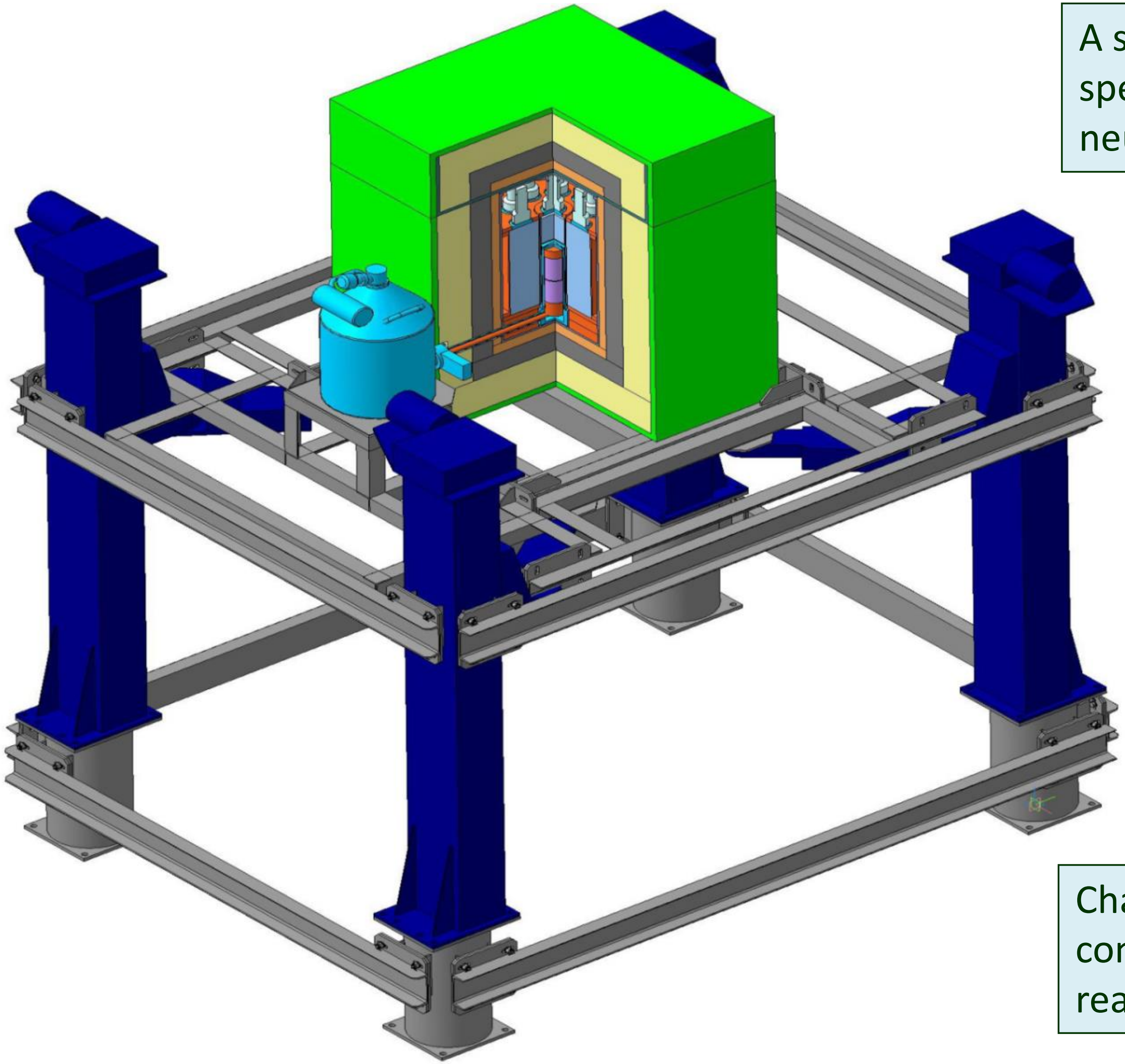


Рис. 5.4. Ядерный реактор ВВЭР-1000

KNPP #3

- Spectrometer **νGeN** is located under the reactor unit #3 (3.1 GW_{th} – thermal power)
- Distance to the center of the reactor core is about 11 m, this gives **> $4{\cdot}10^{13}$ ν/(sec·cm^2)**
- Overburden ~ **50 m w.e.** – good shielding against cosmic radiation due to reactor's surrounding
- Good support from KNPP administration

νGeN @ KNPP – lifting mechanism



A special lifting mechanism has been installed to move the spectrometer towards the reactor core to change the neutrino flux through the detector.

11.09 m – top position (current)

12.14 m – first position

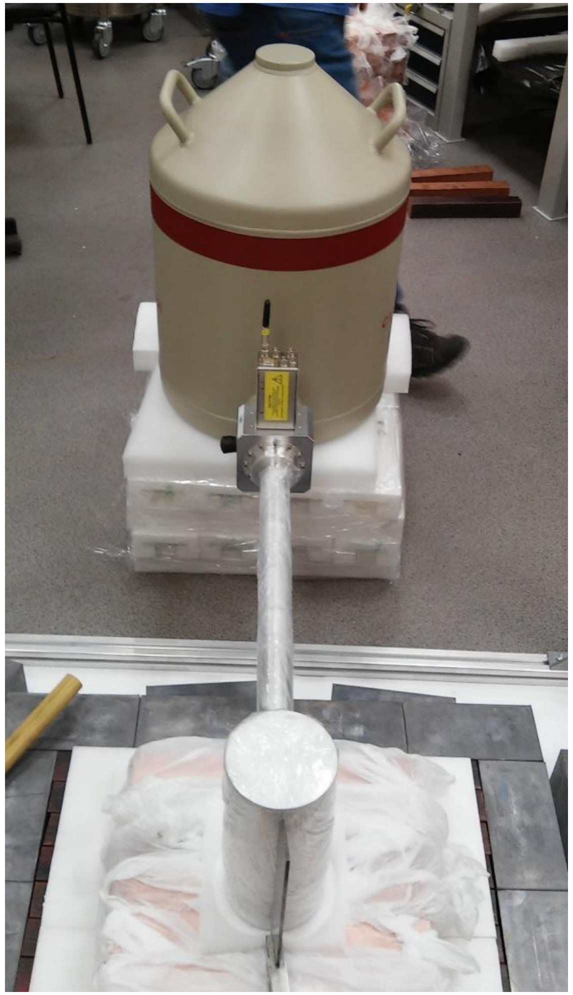
~12.5 m – lower position

Distances to the center of reactor core:

Changes of the ν flux help to suppress systematic errors connected with changes of the background while the reactor ON/OFF

HPGe detector for νGeN

To detect signals from neutrino scattering we use a specially produced by CANBERRA (Mirion, Lingosheim) low-threshold, low-background HPGe detectors. The detectors are chilled by electric and nitrogen types of cooling. At the moment, only one detector with a mass of 1.4 kg and e-cooling is used for the detection at KNPP.



Current scheme of νGeN shielding

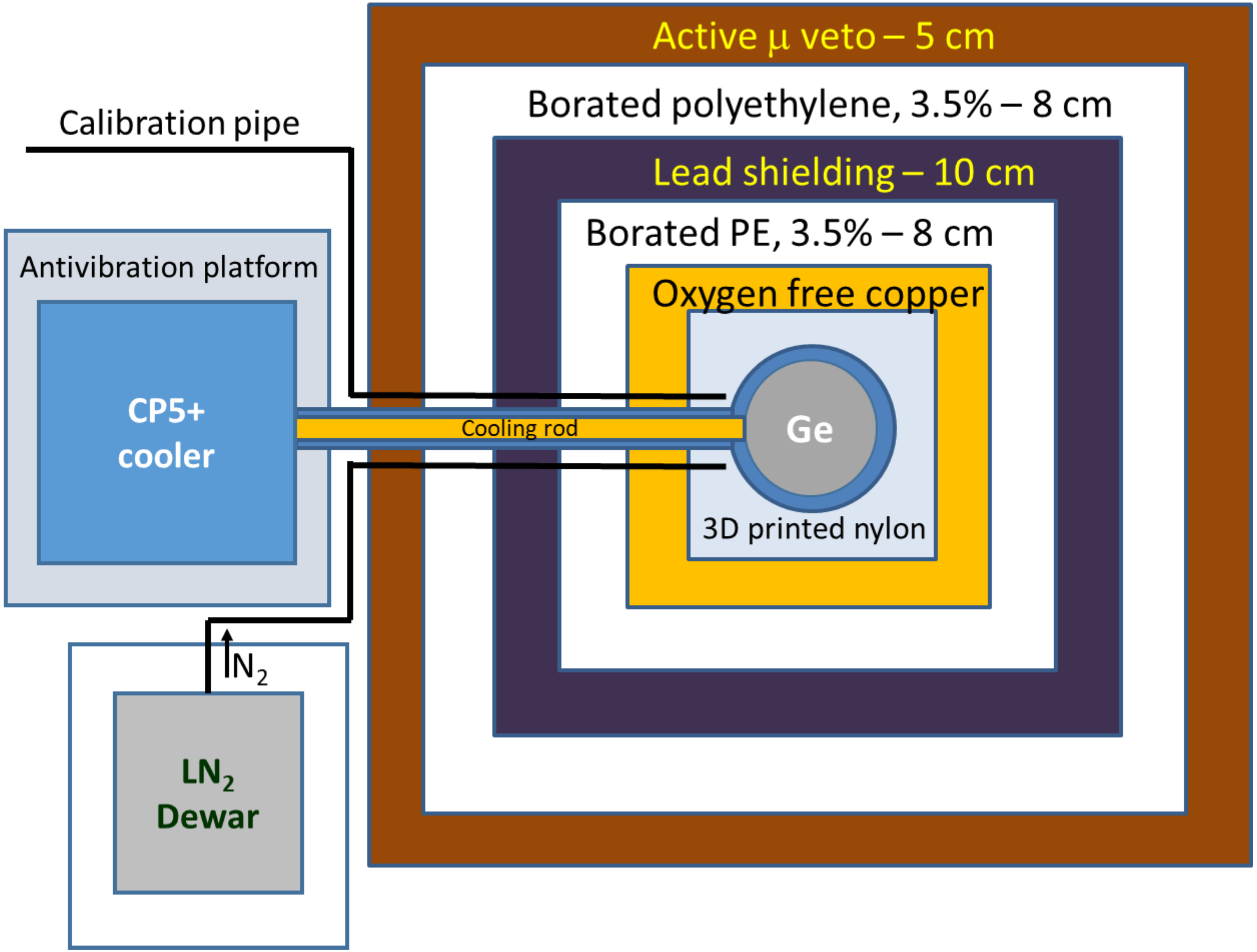


Photo from installation at KNPP in 11.2019

Control of experimental conditions

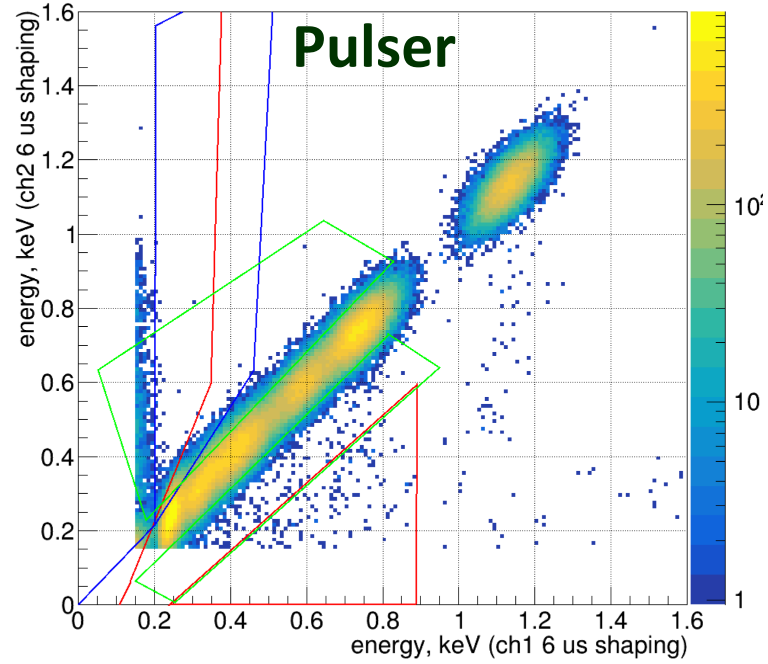
- The stable measurement conditions are very important, because instabilities can change amplification and noise level.
- Cosmogenic activation products slowly decay in time and have to be taken into account during analysis.

✓ Air temperature condition in the experimental hall is stabilized by three air-conditioners.

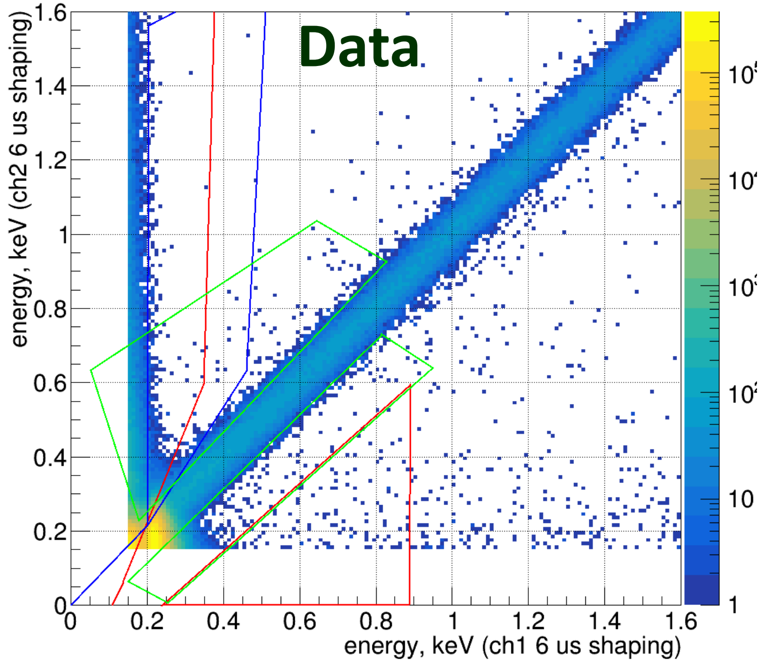
✓ Temperature and humidity are constantly monitored by two sensors.

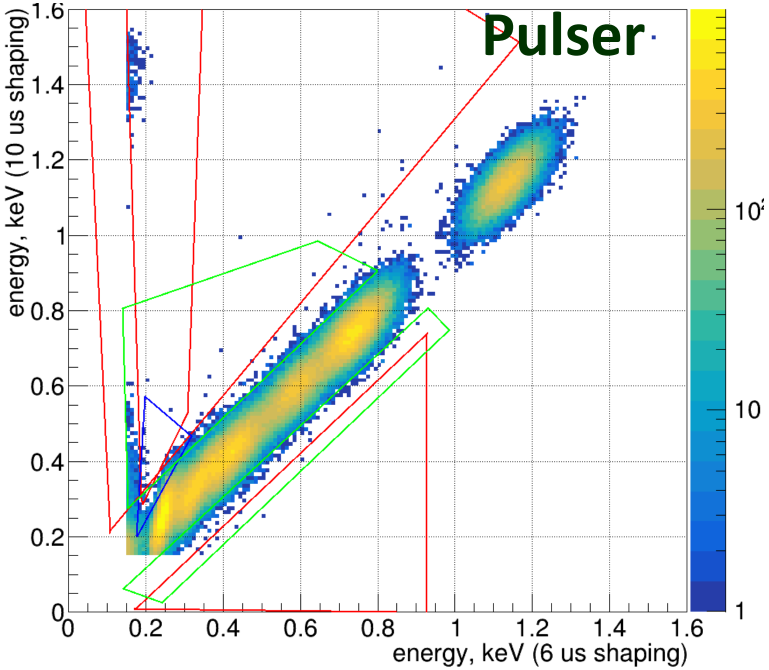
✓ Neutron background outside shielding (fast and thermal) is measured by special low background He3 counter and NAIL detector.

Noise cuts

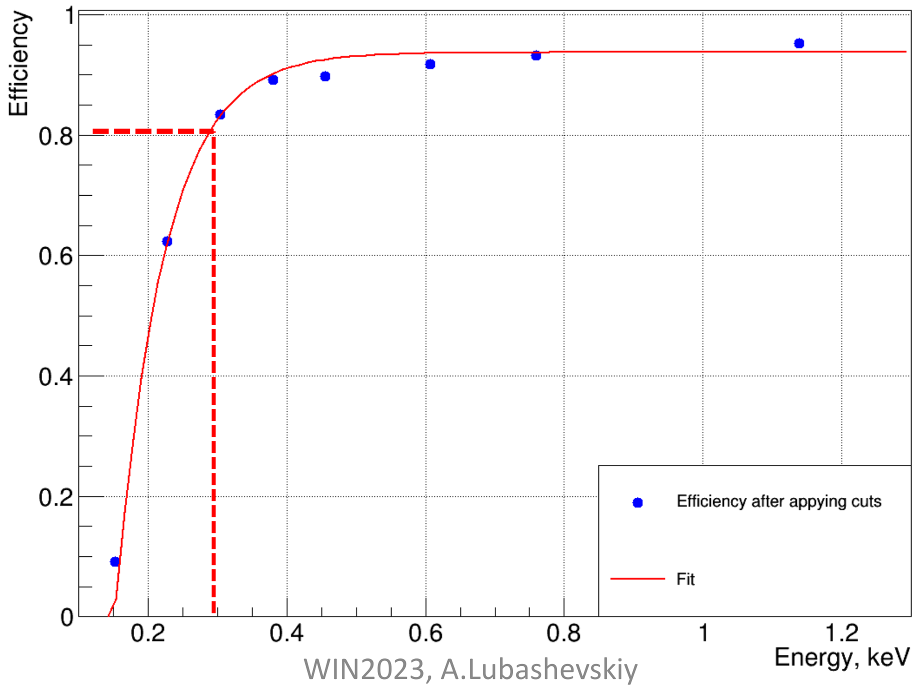


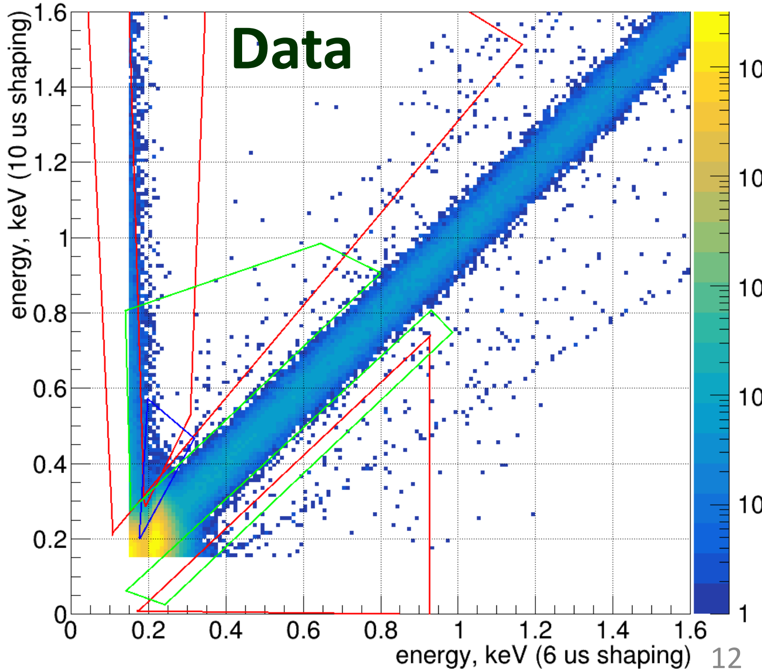
- Different shaping times of preamplifiers are used to suppress the noise with the help of graphical cuts.
- Time cuts allow to suppress signals generated by reset of the preamplifier and other artificial signals.
- Even at 200 eV efficiency is > 40% after applying cuts



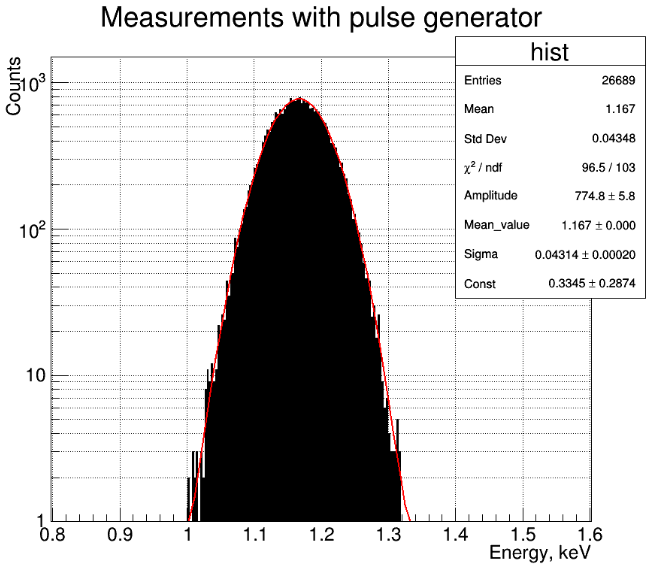


Efficiency measured with pulse generator

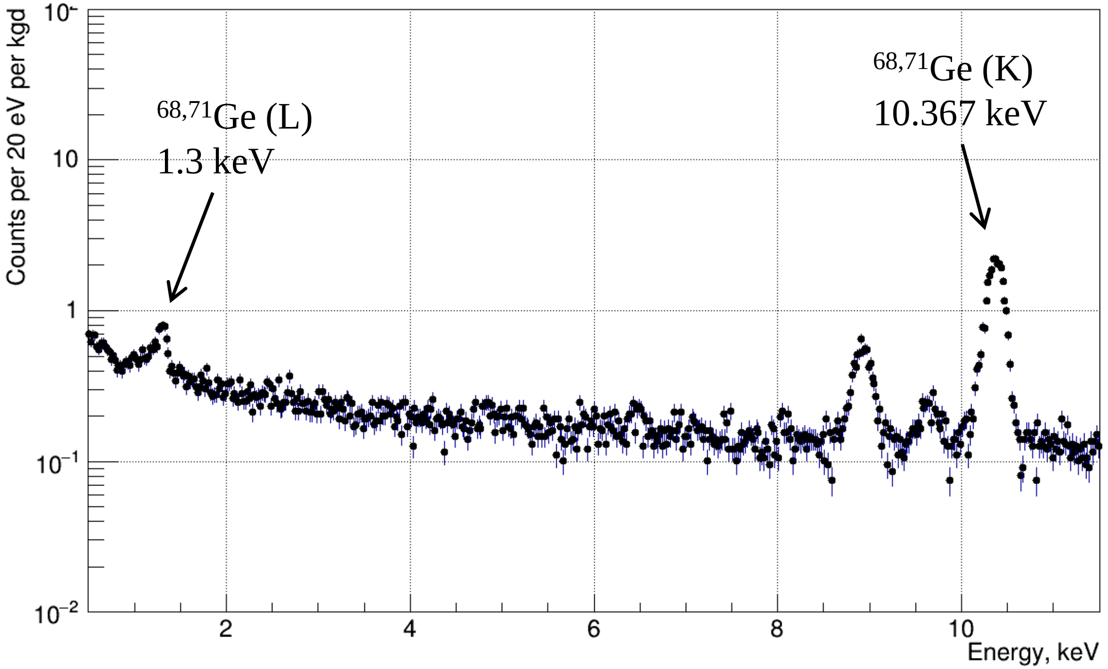


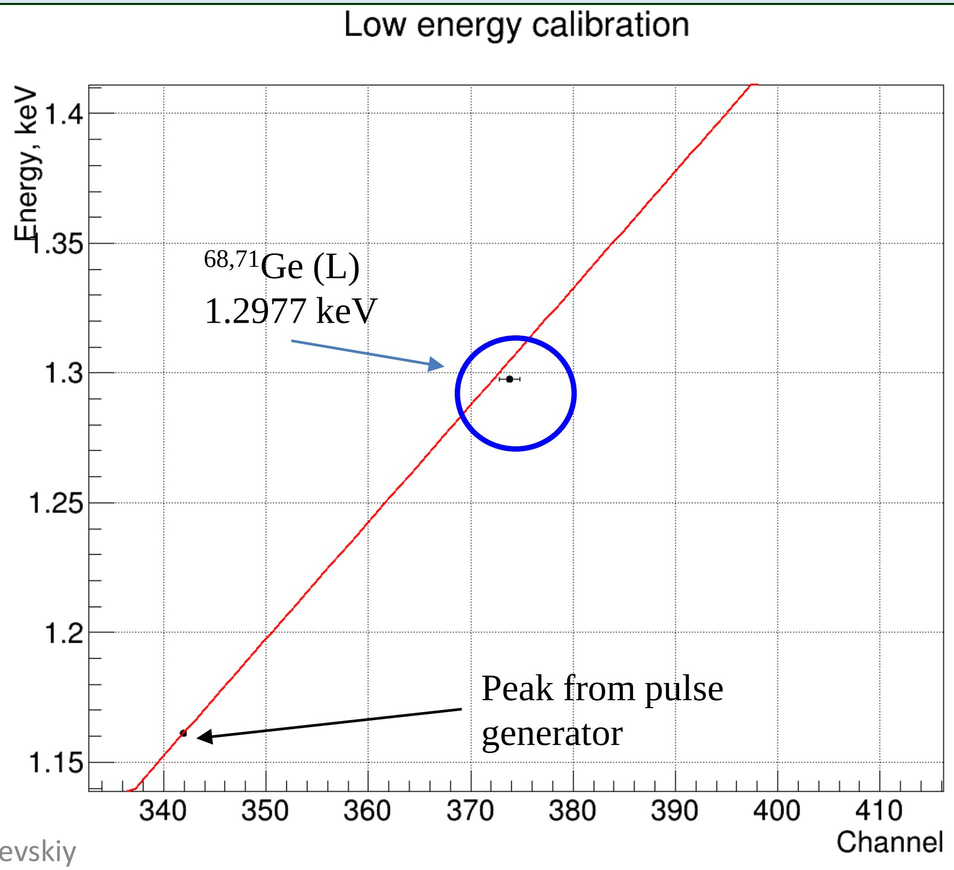


Calibration at low energies



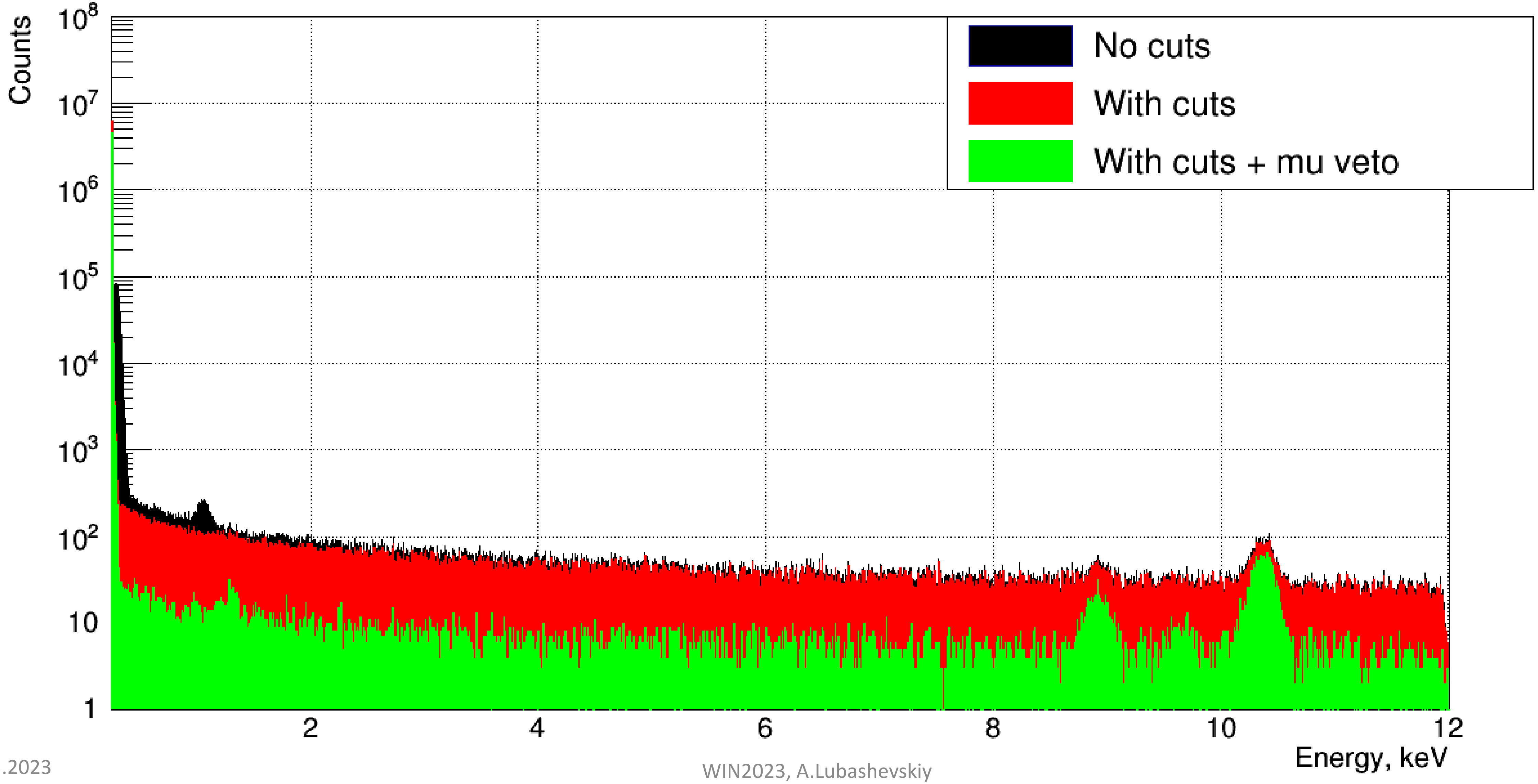
- Energy calibration at low energy is performed by means of 10.37 keV cosmogenic line and pulse generator.
- Calibration check with 1.3 keV line
- Data taking shows very good stability of peak position during all measurement time.
- Energy resolution of 1.4 kg detector at KNPP is 101.6(5) eV (FWHM).



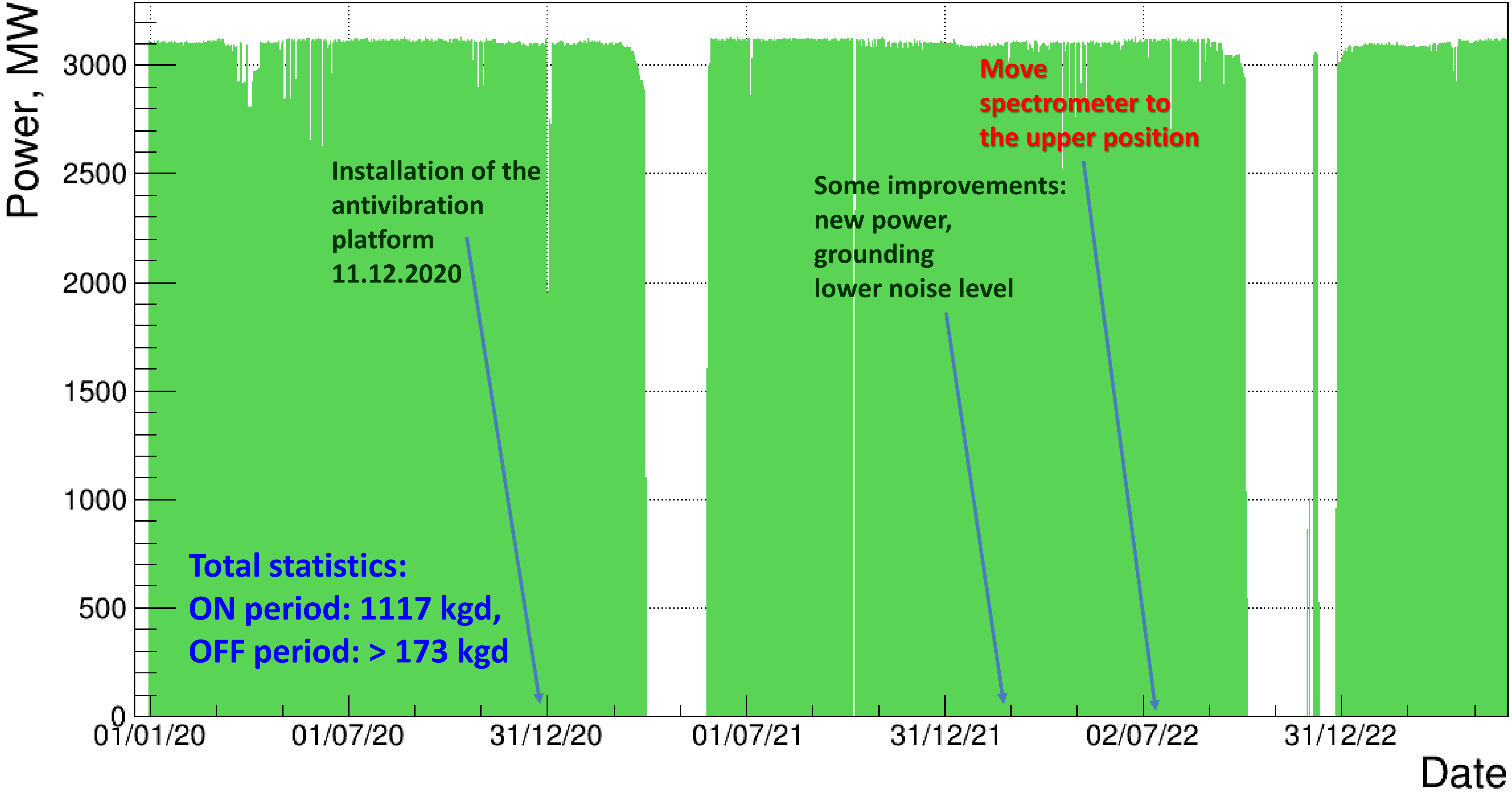


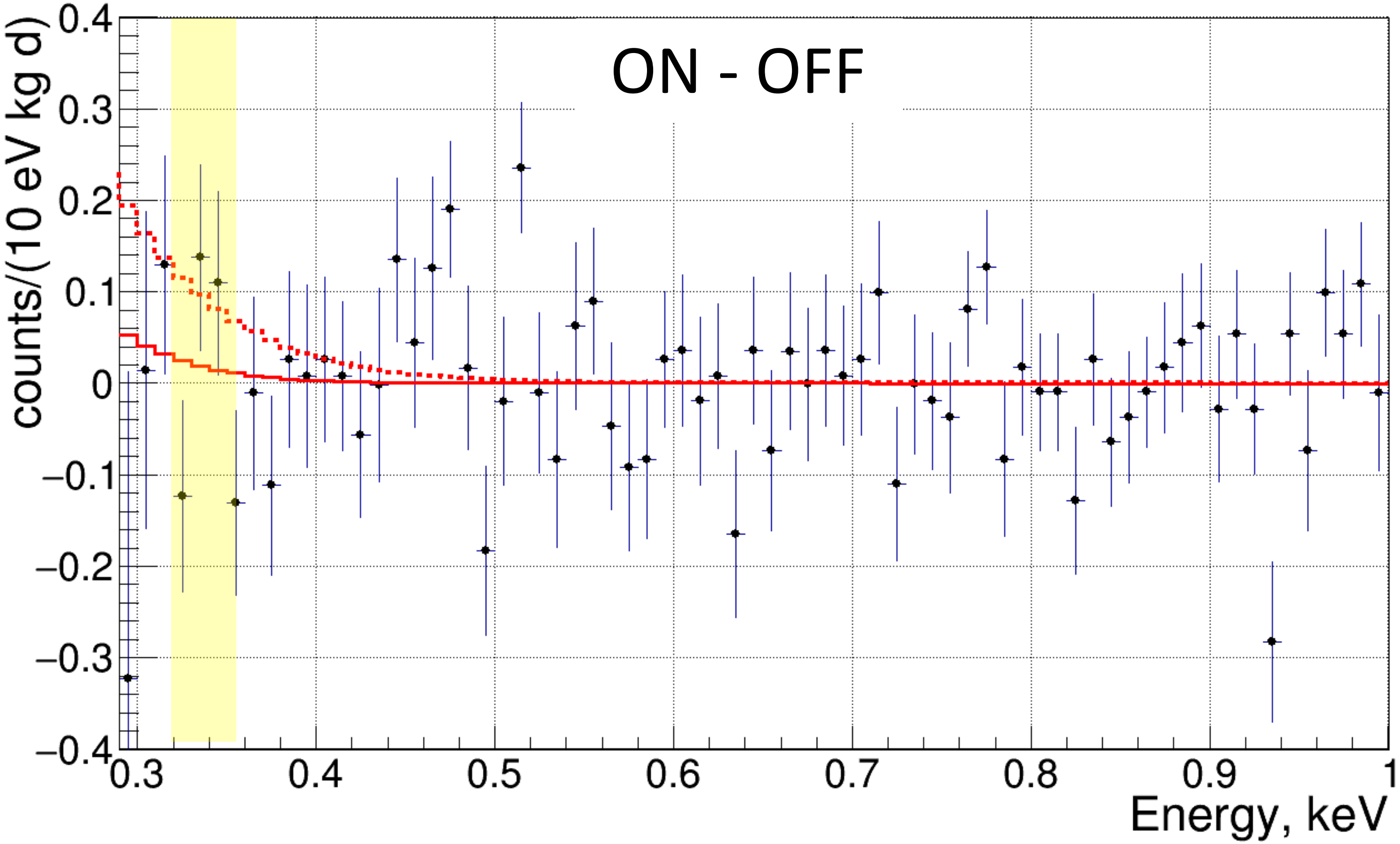
Muon veto & time cuts

- Coincidences with muon veto allow to suppress background connected with muons
- Efficiency of all cuts together with muon veto determined by 10.37 keV line is **85.3(19)%**



Thermal power of reactor unit #3

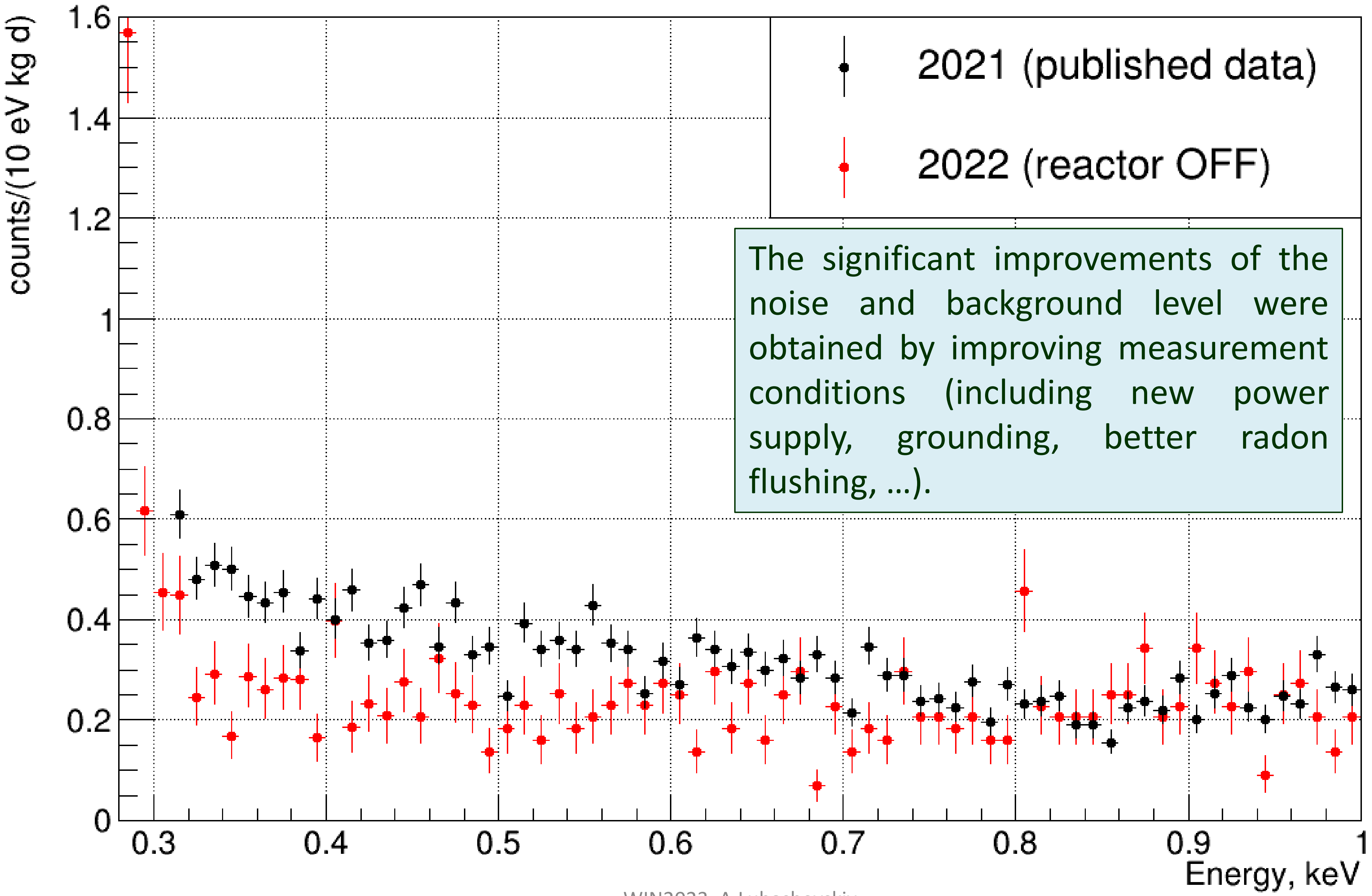




2022 ANALYSIS

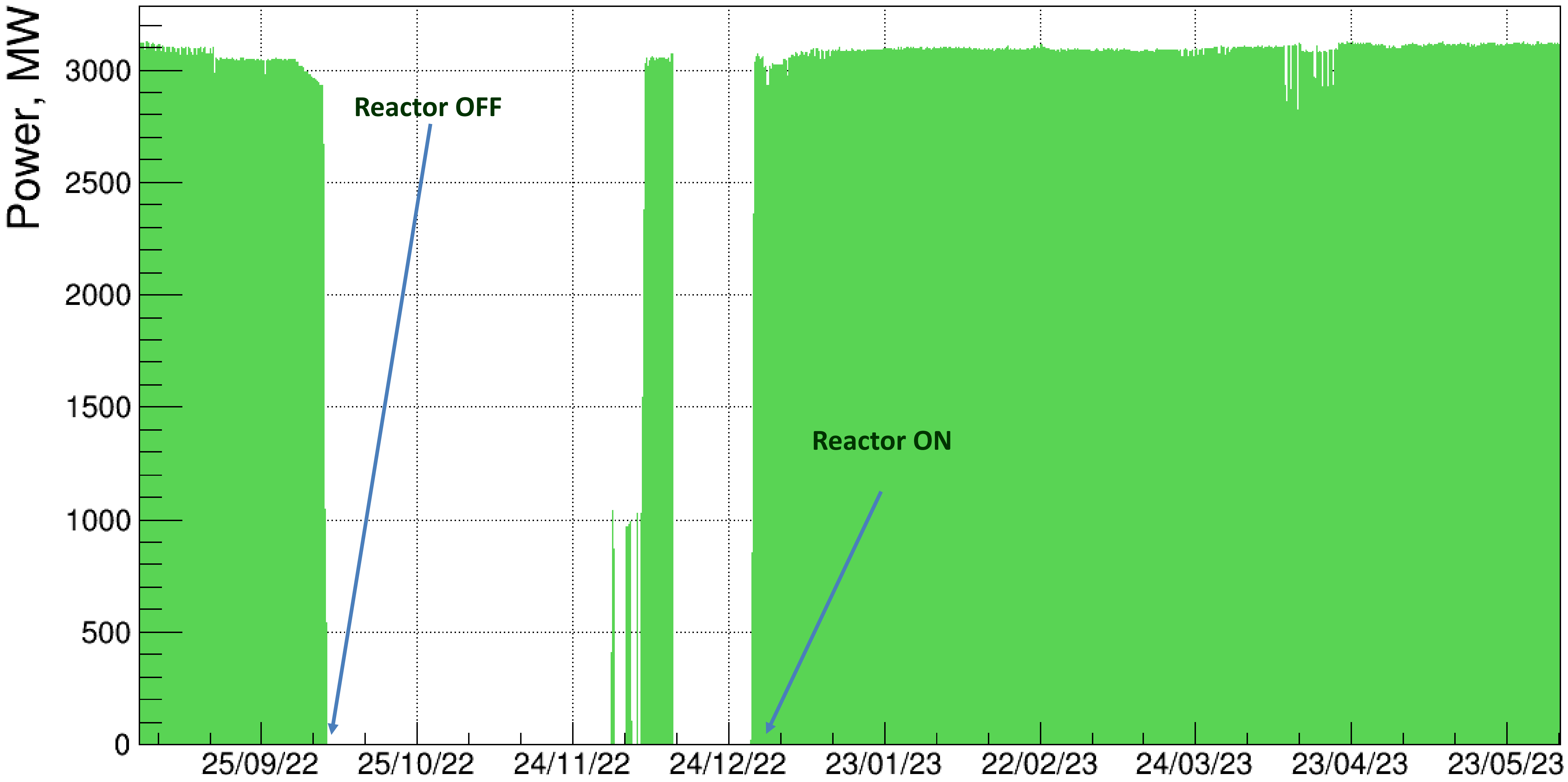
Analysis of the first data showed no significant difference in background level during reactor ON and OFF regimes. No excess at low energy connected with the CEνNS has been observed. The upper limit on the quenching parameter **k < 0.26** with 90% CL has been obtained (dashed line). Red solid line for k = 0.179.

	Counts in region [320..360] eV	Measurement time, days	Counts per kgd (stat. error only)
Reactor ON	**251**	**94.5**	**2.32 ± 0.15**
Reactor OFF	**126**	**47.1**	**2.34 ± 0.21**
ON-OFF			**-0.017 ± 0.255**
CEνNS, k = 0.26	**55**		**0.46**



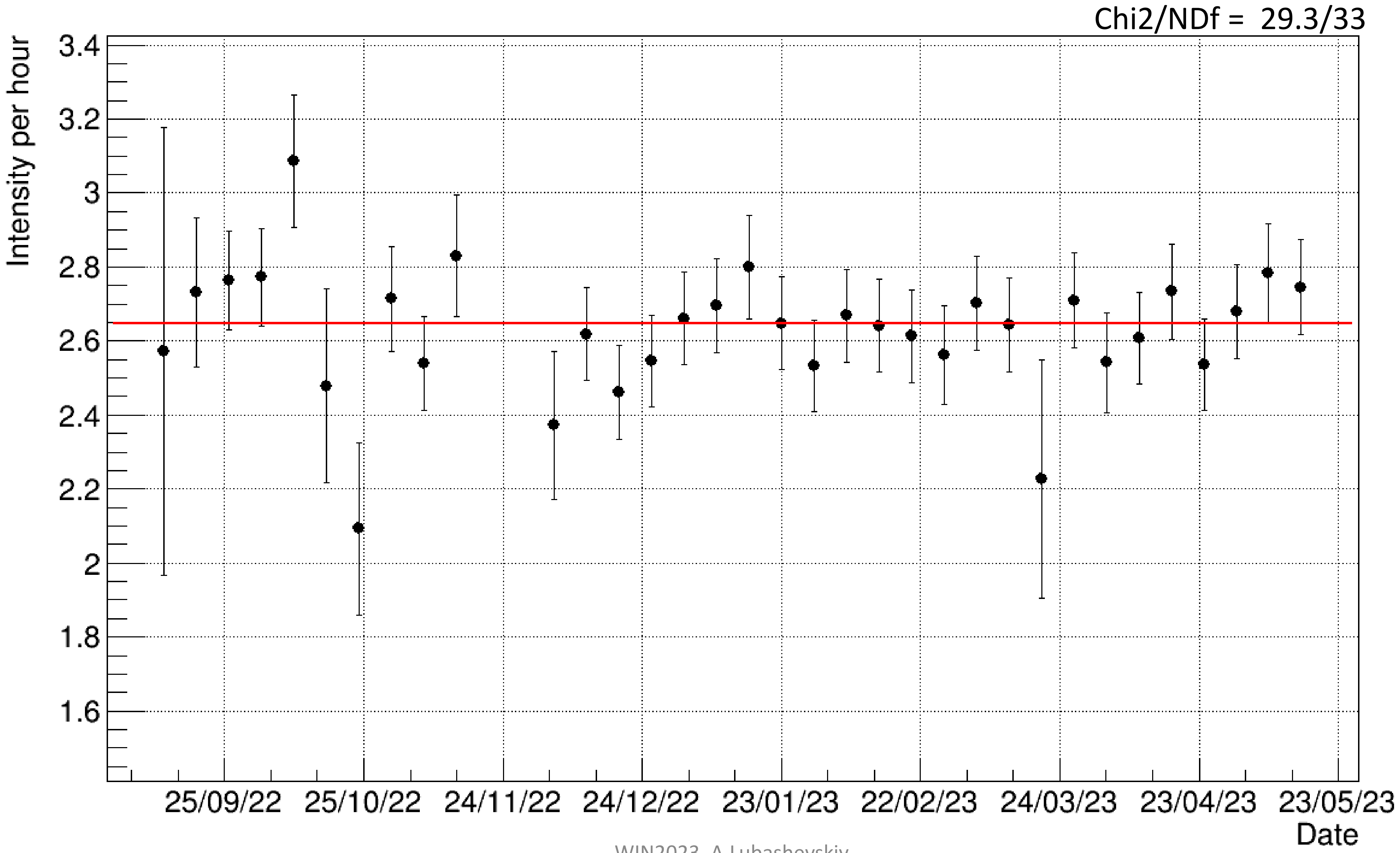
The significant improvements of the noise and background level were obtained by improving measurement conditions (including new power supply, grounding, better radon flushing, …).

Thermal power of reactor unit #3, upper position

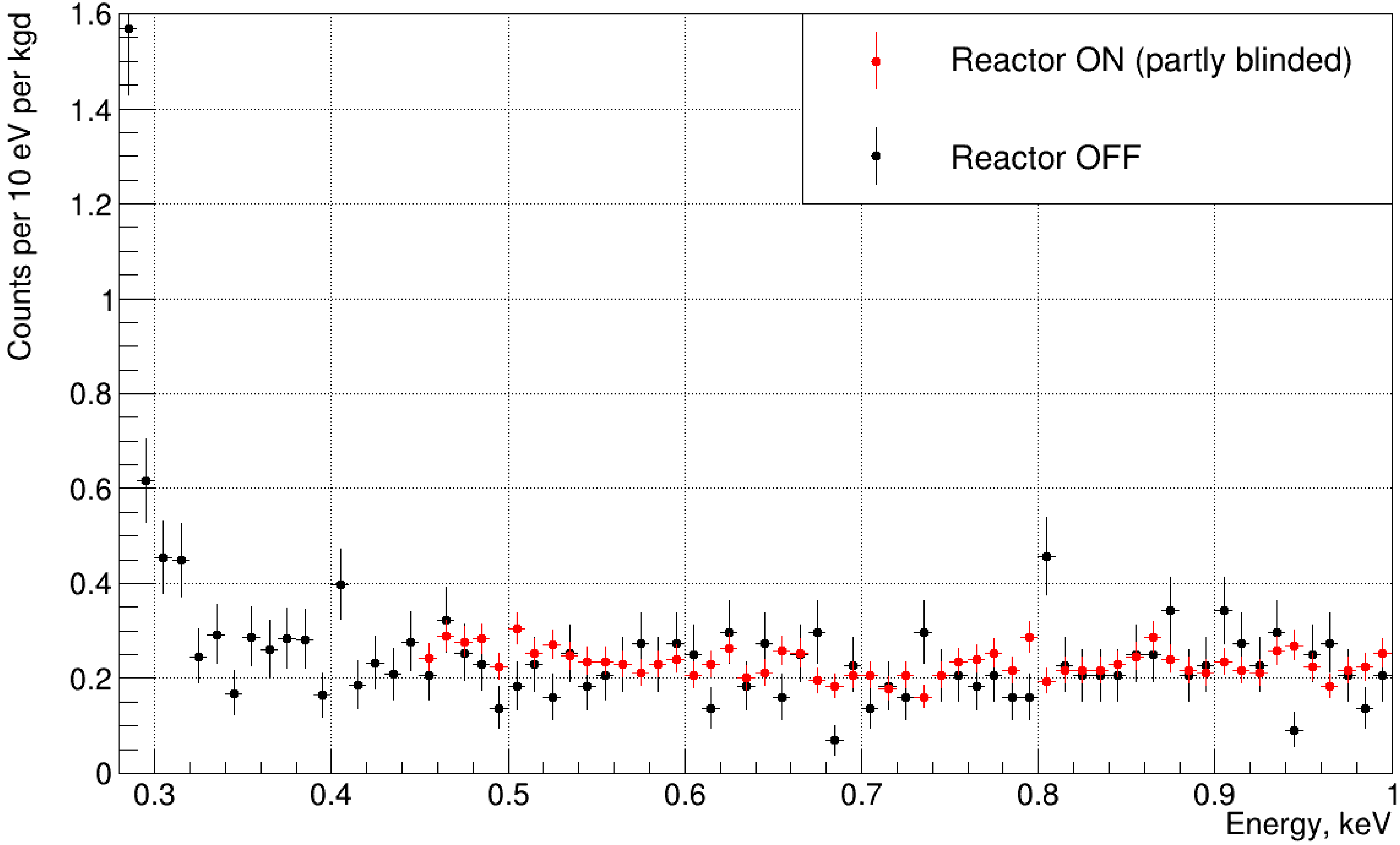


At the moment in the upper position we accumulated ON: 217 kgd and OFF: 55 kgd (after all cuts).

Stability, count rate 2-8 keV

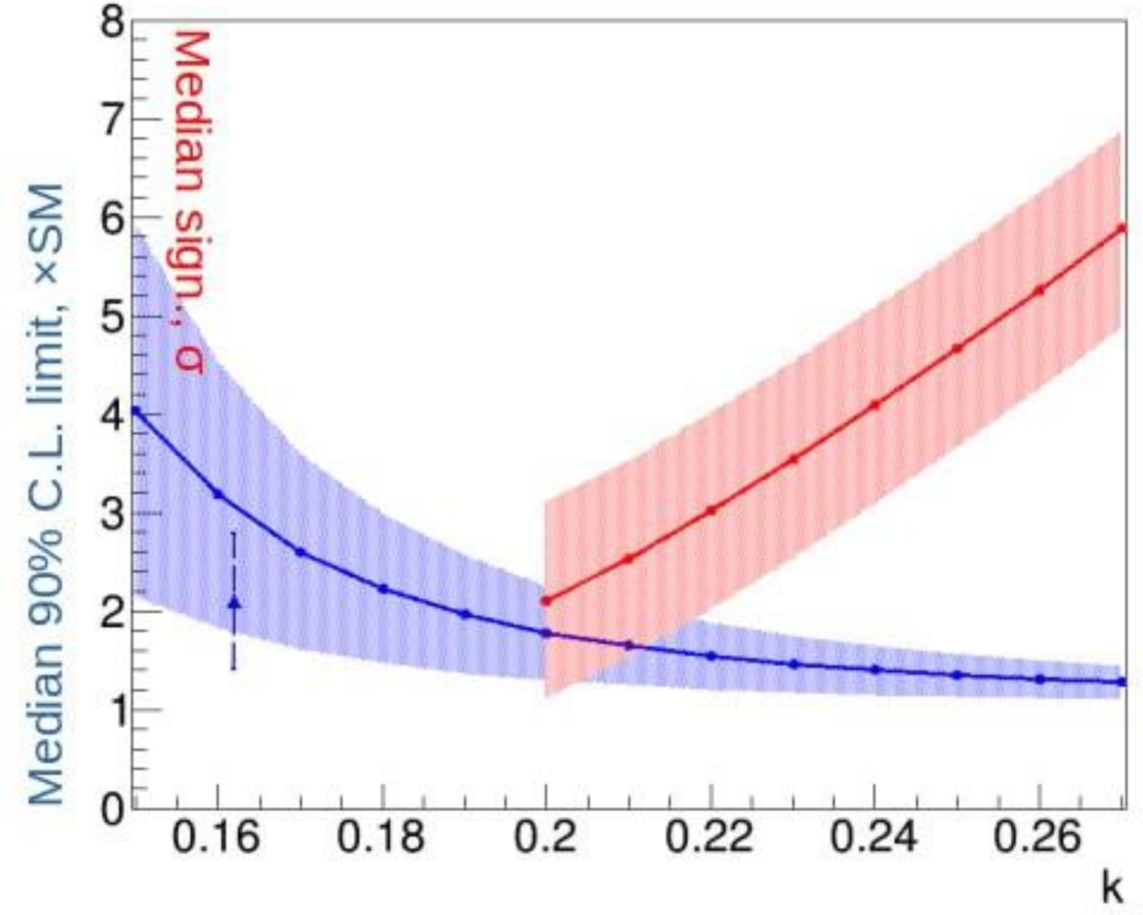


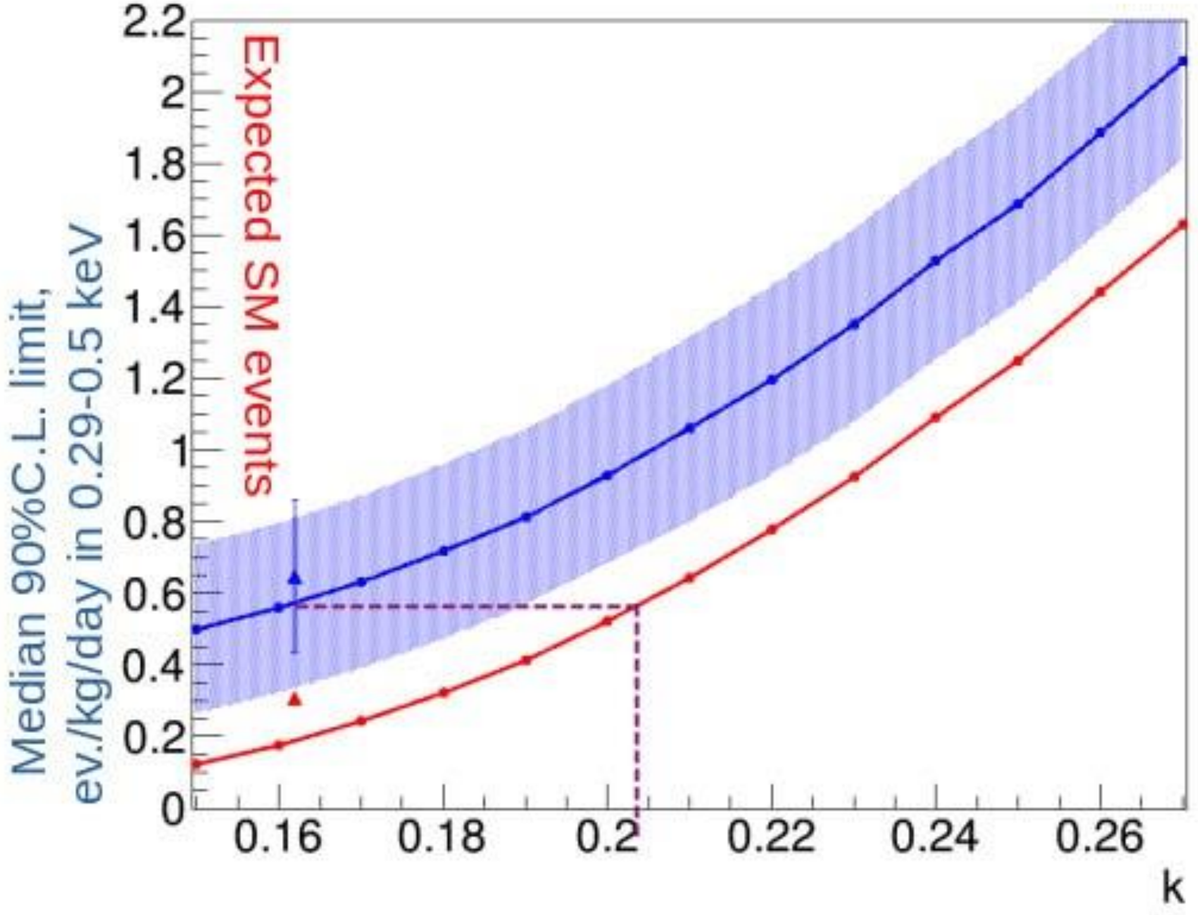
New data 2023, upper position



Sensitivity studies

Taking into account OFF spectrum (55 kgd) and Azimov data sets (generated spectra contains CEνNS signals + OFF, taken statistic equivalent to current real one – 217 kgd), we created a predictions for sensitivity for CEνNS.





Conclusion

- Measurements with the νGeN spectrometer at Kalinin Nuclear Power Plant are ongoing.
- Good performance and stability were observed during measurements. No significant difference between regimes with reactor ON and OFF due to CEvNS has been observed so far.
- Lifting mechanism is in operation, and since 09/2022 we perform data taking at reduced distance to the reactor core (11.04 m from the center of reactor core).
- More than 1200 kgd of data has been accumulated so far.
- The optimization of data taking is performed as well. New results in the upper position with more statistics are expected soon.

Thank you!
谢谢

РЭА
КАЛИНИНСКАЯ АЭС
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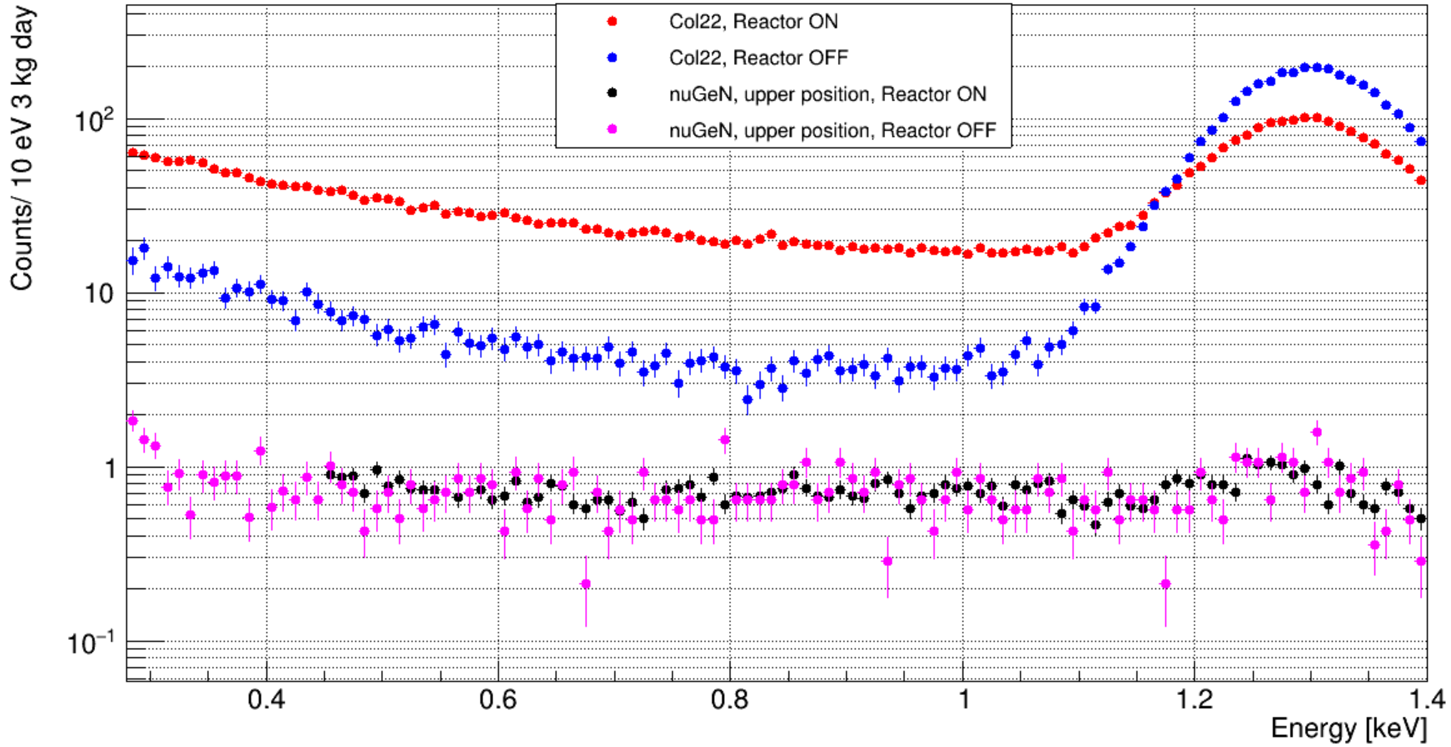
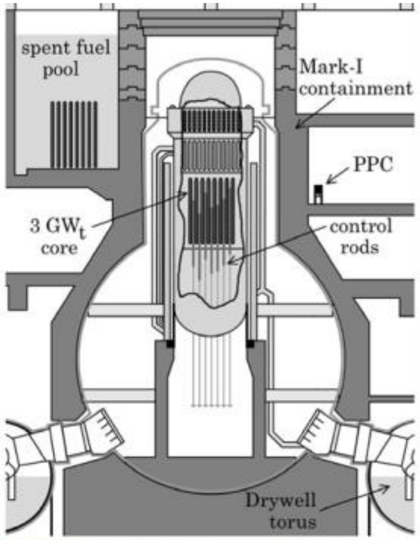
ВЫСШИЙ ПРИОРИТЕТ
НАШЕГО КОЛЛЕКТИВА

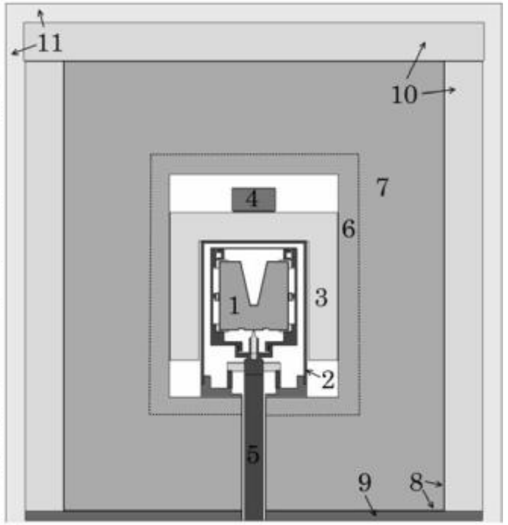
Backup slides

J. Colaresi, J. I. Collar,* T. W. Hossbach , C. M. Lewis , and K. M. Yocum, «Measurement of Coherent Elastic Neutrino-Nucleus Scattering from Reactor Antineutrinos», PHYSICAL REVIEW LETTERS 129, 211802 (2022)

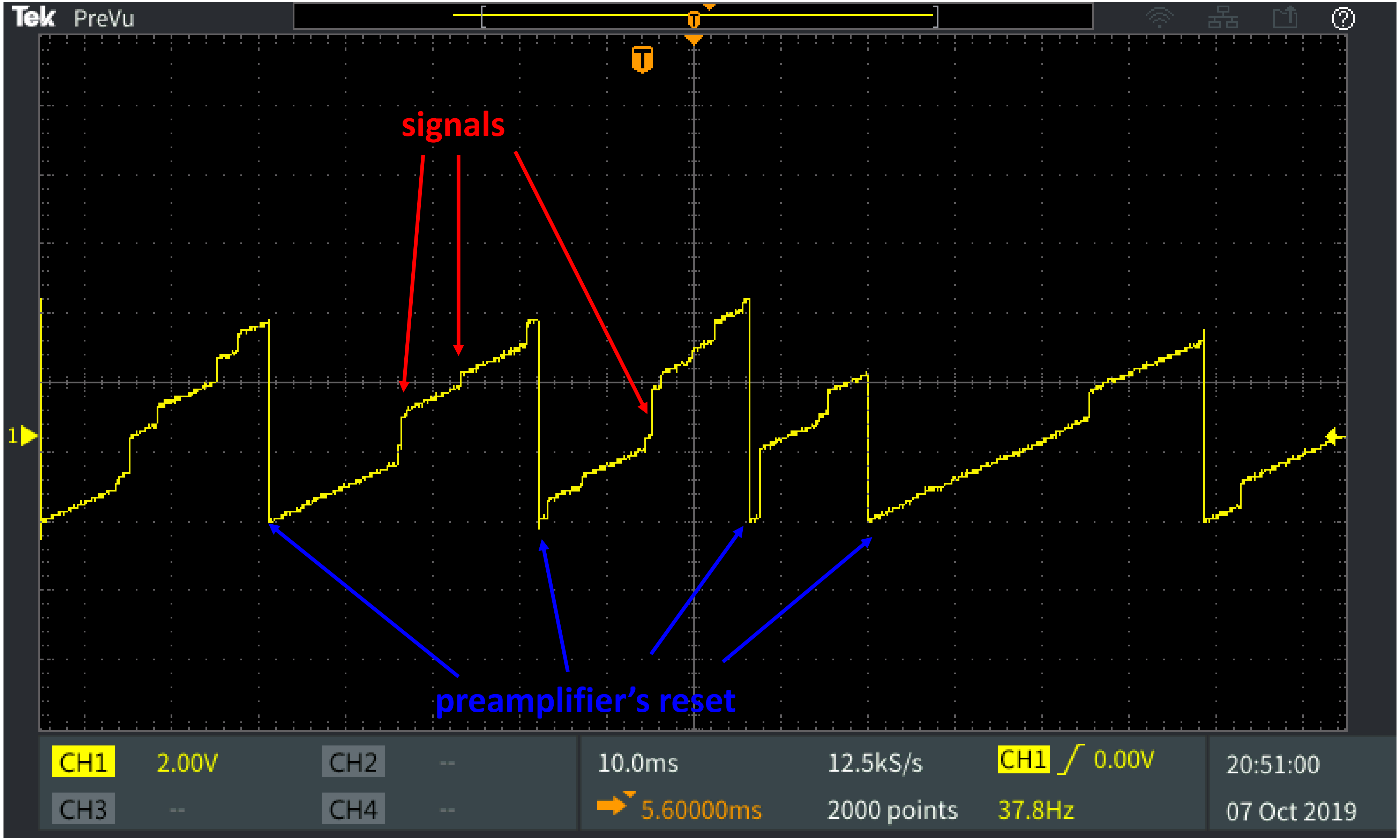
- Claimed about strong preference ($p<1.2\cdot10^{-3}$) for the presence of CEvNS.
- Similar to nuGeN antineutrino flux from reactor ($4.8\ 10^{13}$ ν/cm2/sec)
- Sideway location gives almost no overburden (cosmogenic background).
- Almost no shielding against fast neutrons.
- Different shielding during reactor ON and OFF
- Big difference in background levels during reactor ON and OFF
- Moderate energy resolution > 160 eV (FWHM) (in nuGeN – 101.6(5) eV)





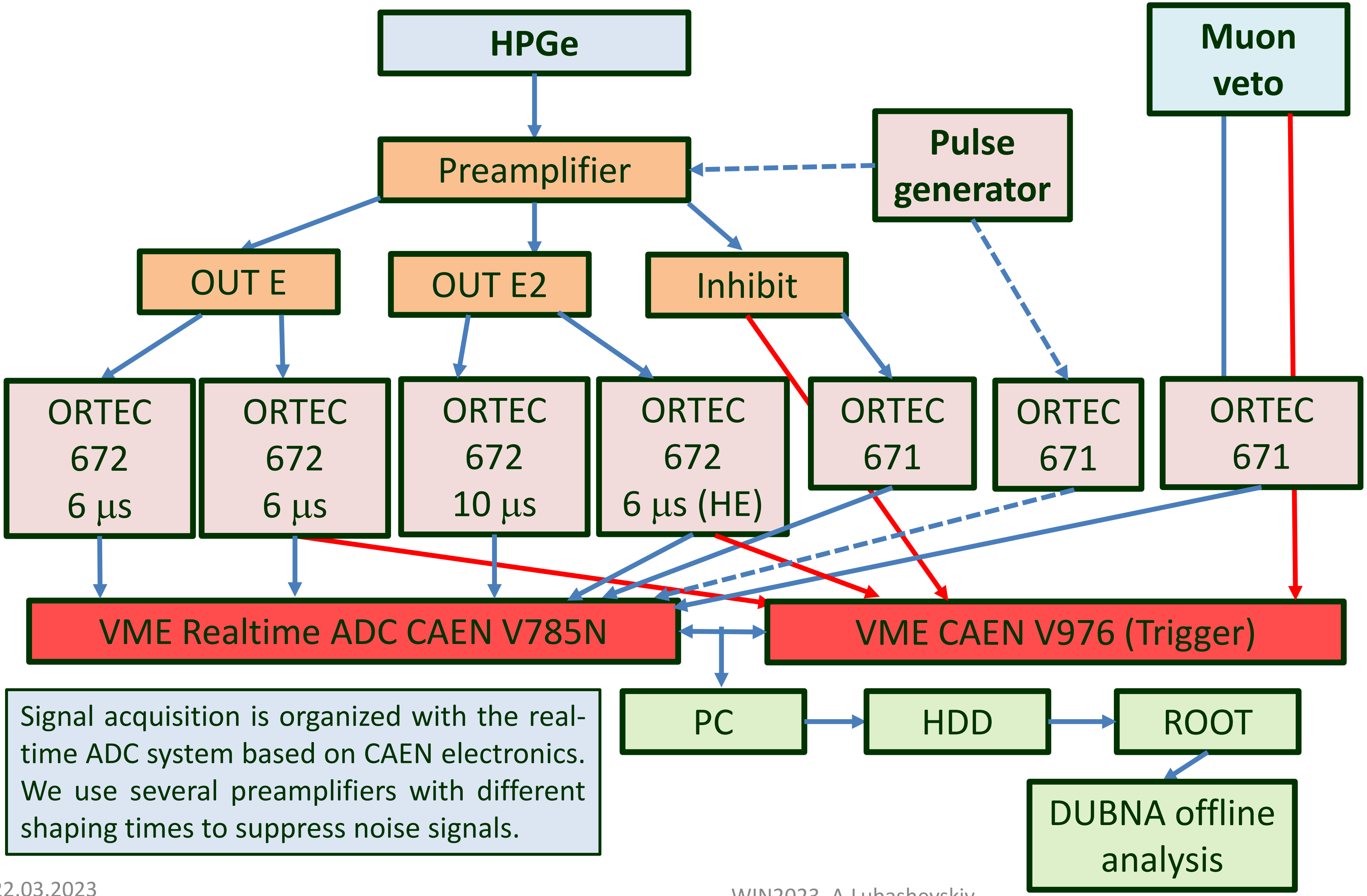


Signals from detector

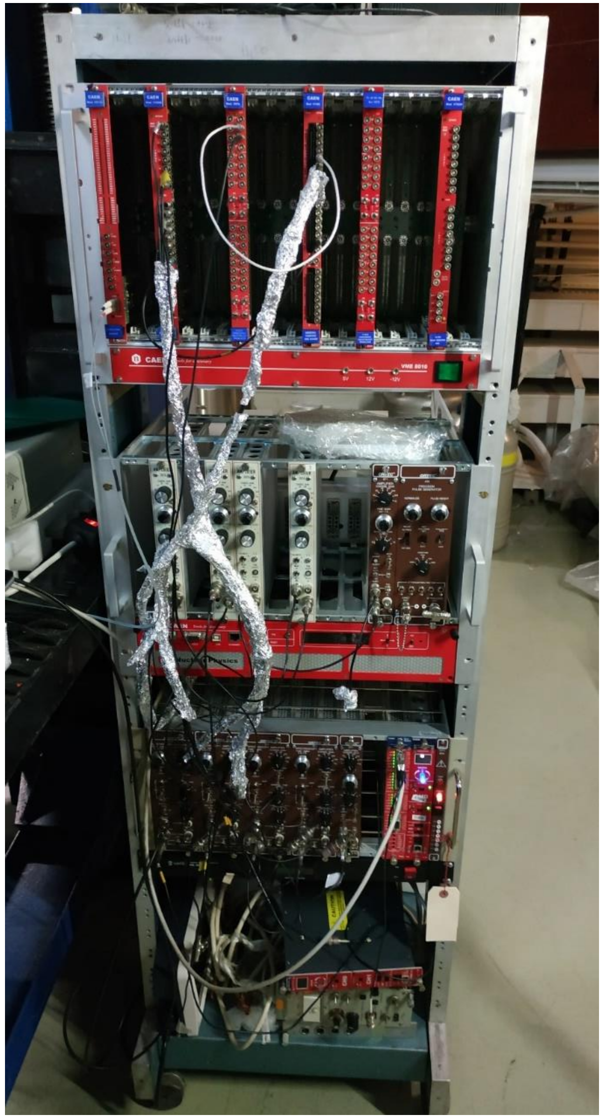


- Detectors are equipped with reset preamplifier.
- There is a special inhibit signal that indicates the time when the reset happens.
- The signals are shaped with amplifiers and processed with a real-time ADC.

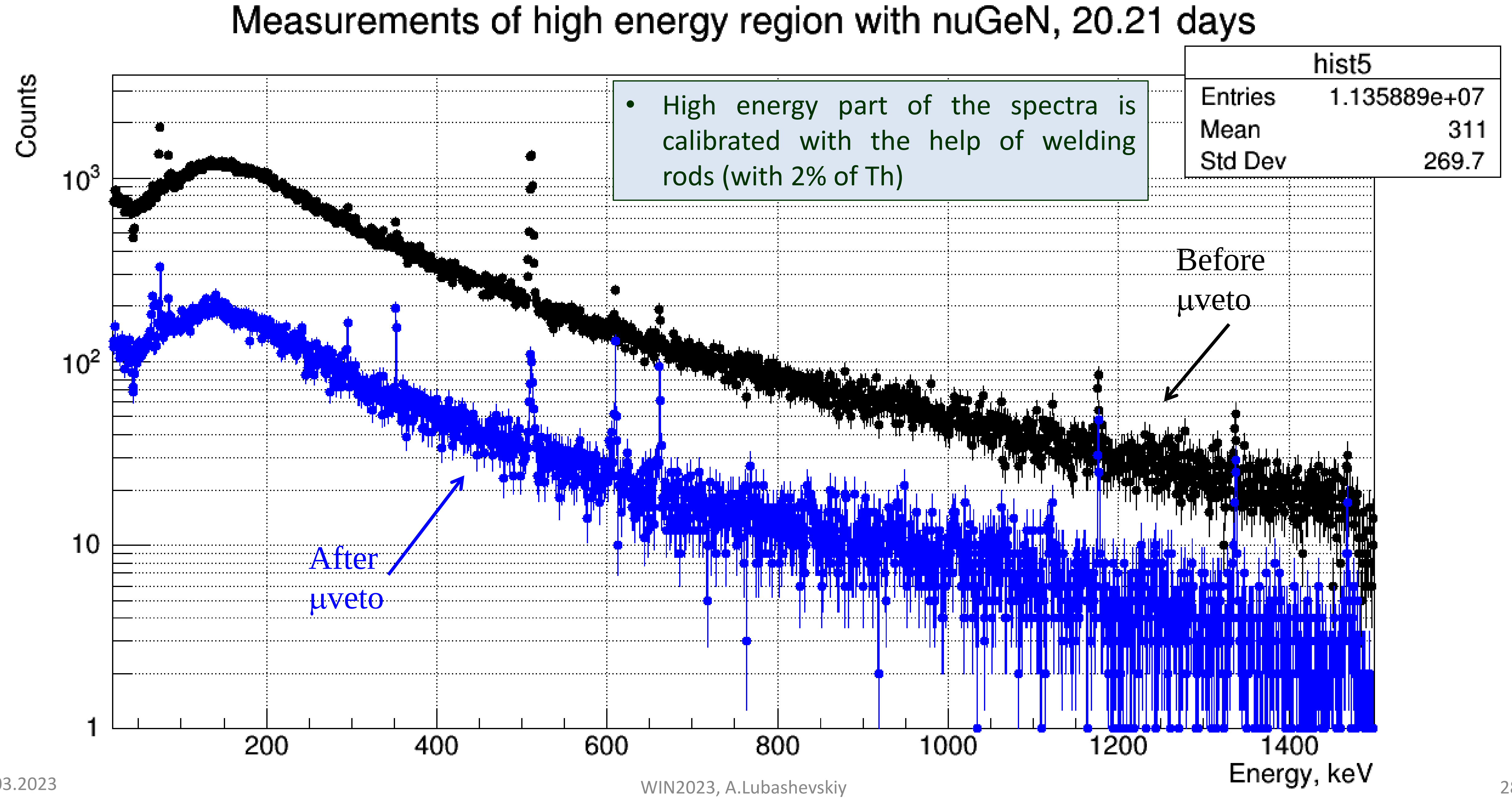
Simplified scheme of measurements



Signal acquisition is organized with the real-time ADC system based on CAEN electronics. We use several preamplifiers with different shaping times to suppress noise signals.



High energy part of the spectrum



- High energy part of the spectra is calibrated with the help of welding rods (with 2% of Th)