Status of the νGeN experiment

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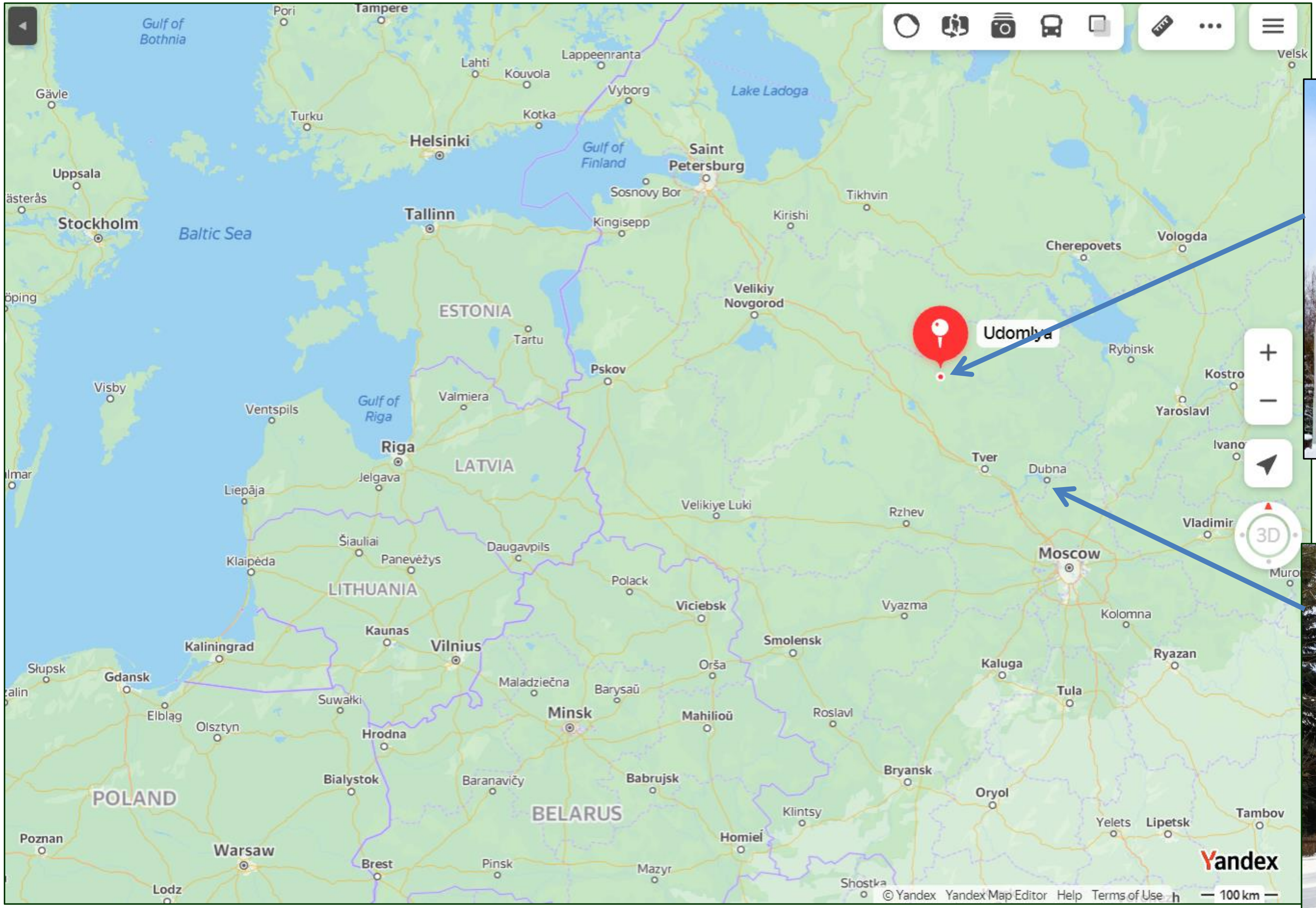
JINR

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 reactor site at Udomlya, Russia



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

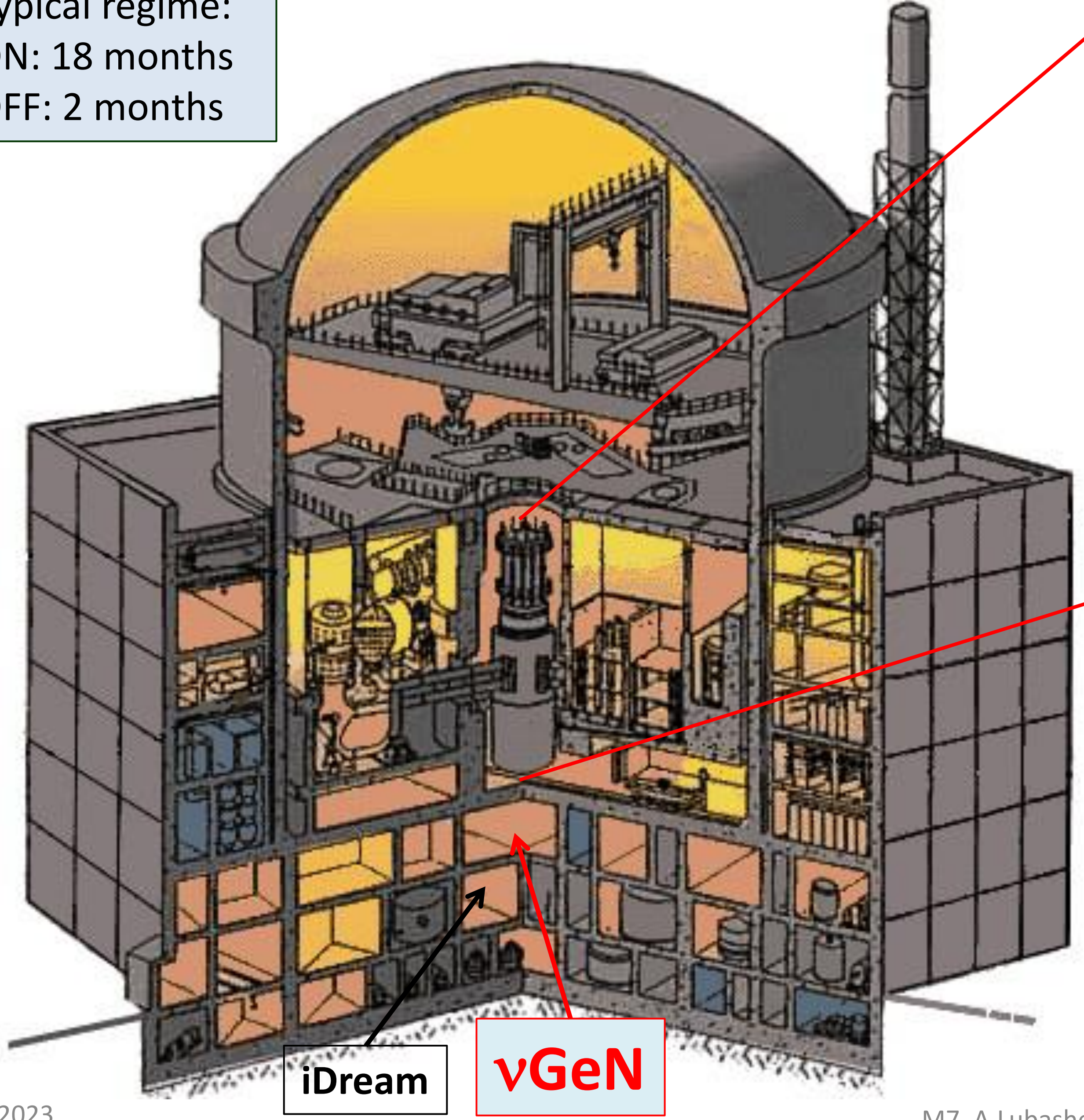
JINR, Dubna, 285 km from KNPP

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



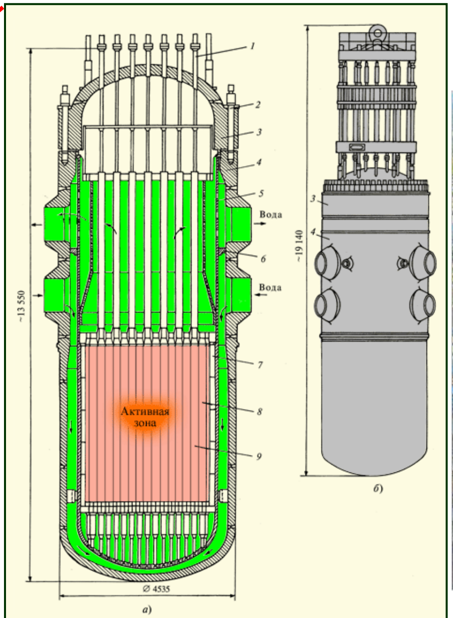
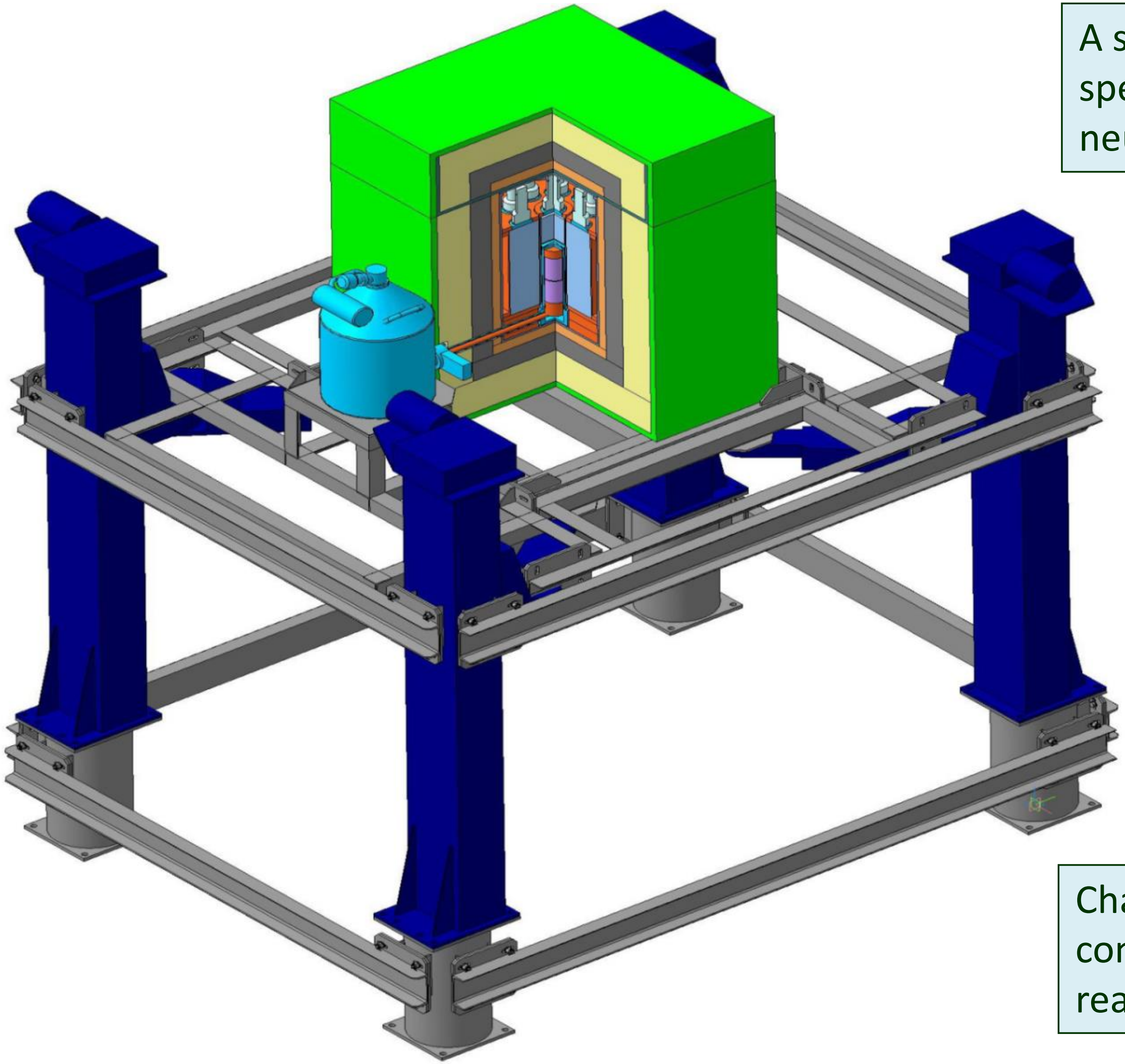


Рис. 5.4. Ядерный реактор ВВЭР-1000

- 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·cm²)**
- 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

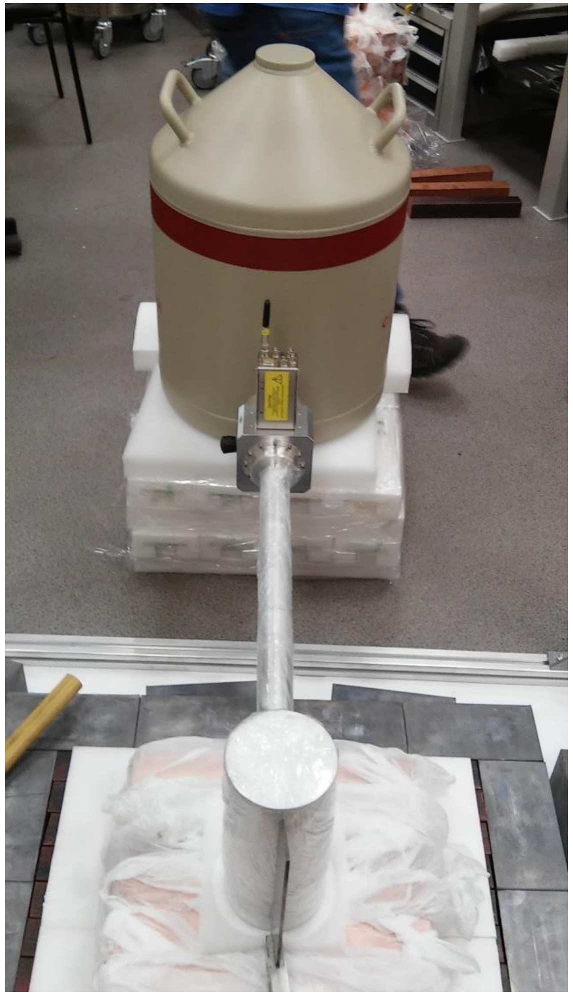
~12.5 m – lower position

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

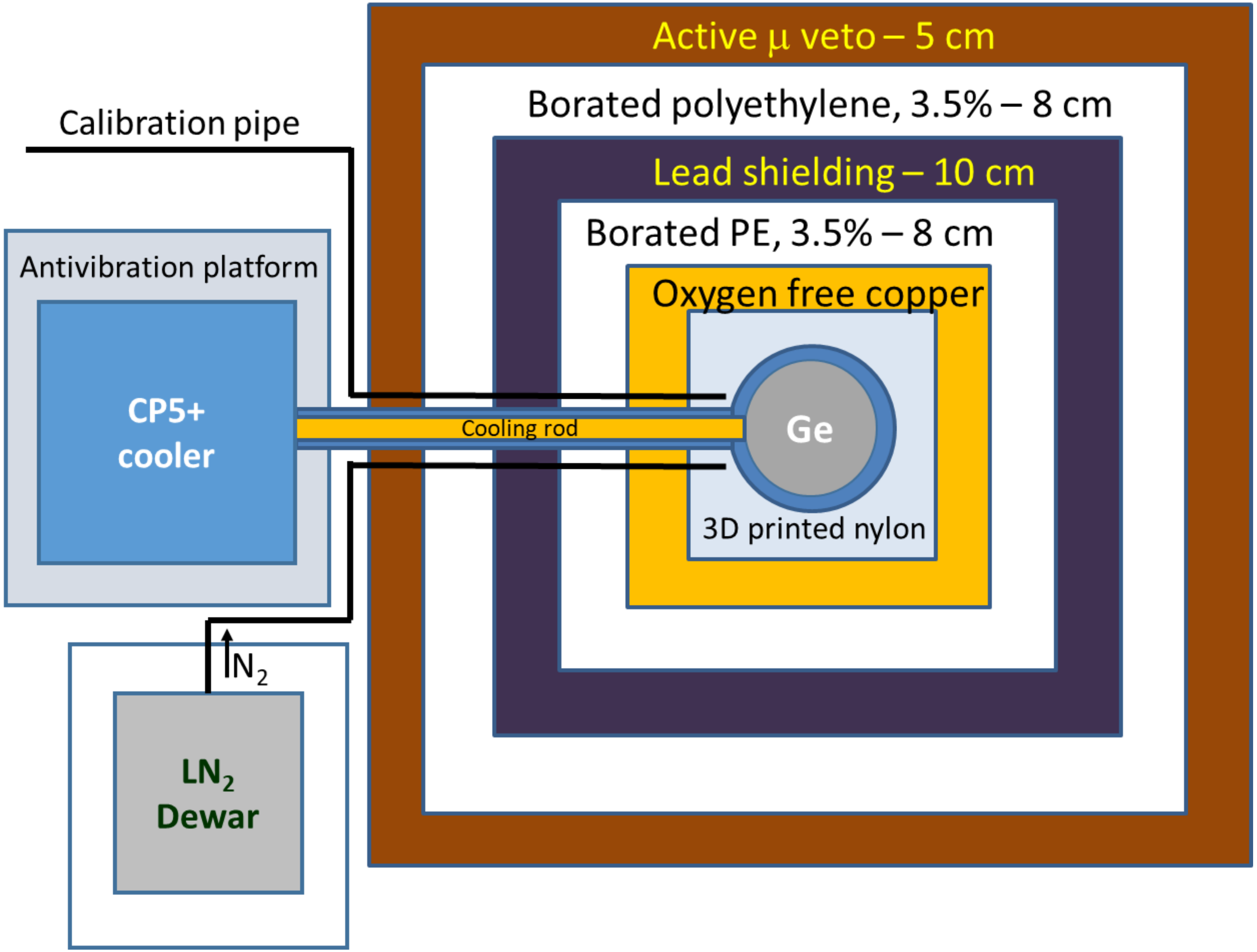
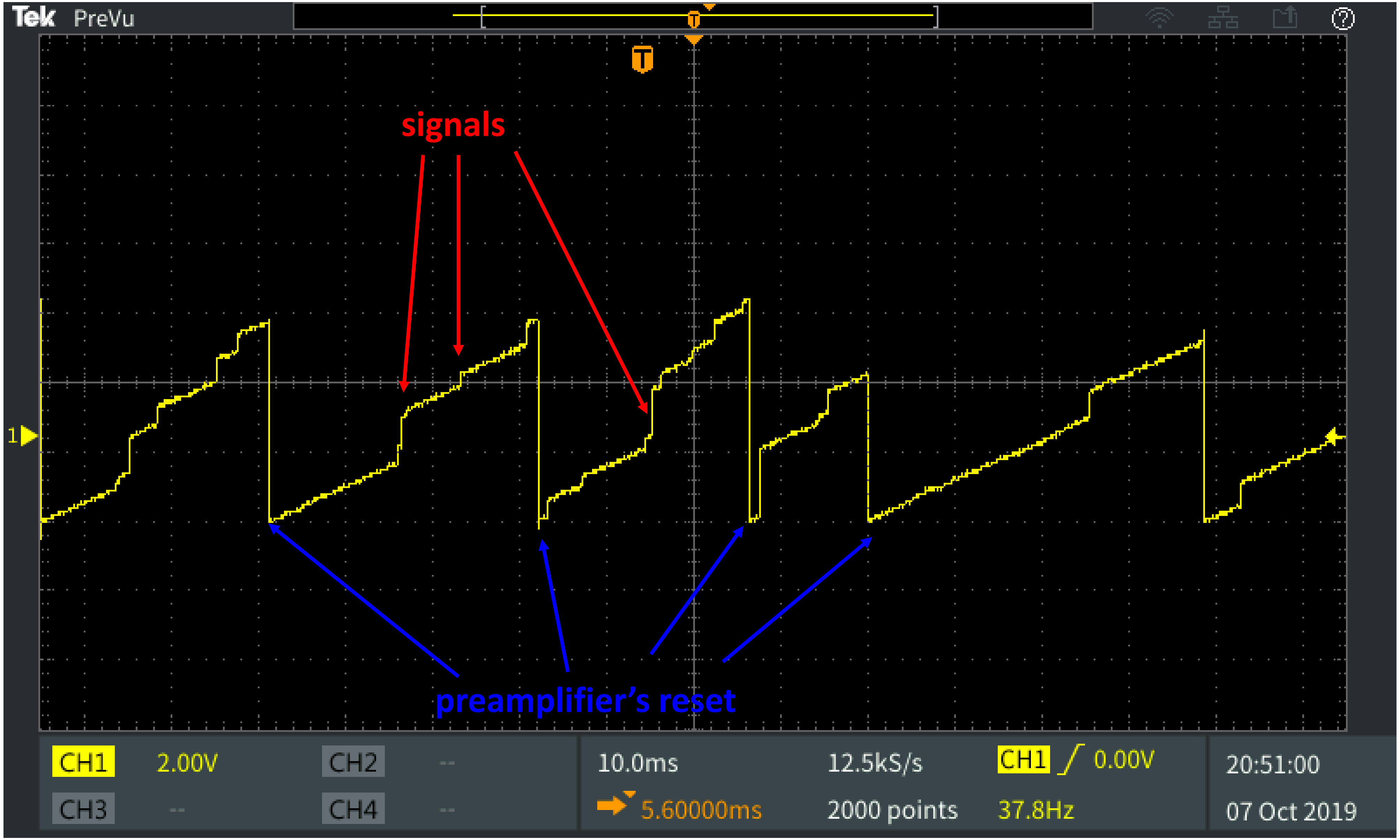


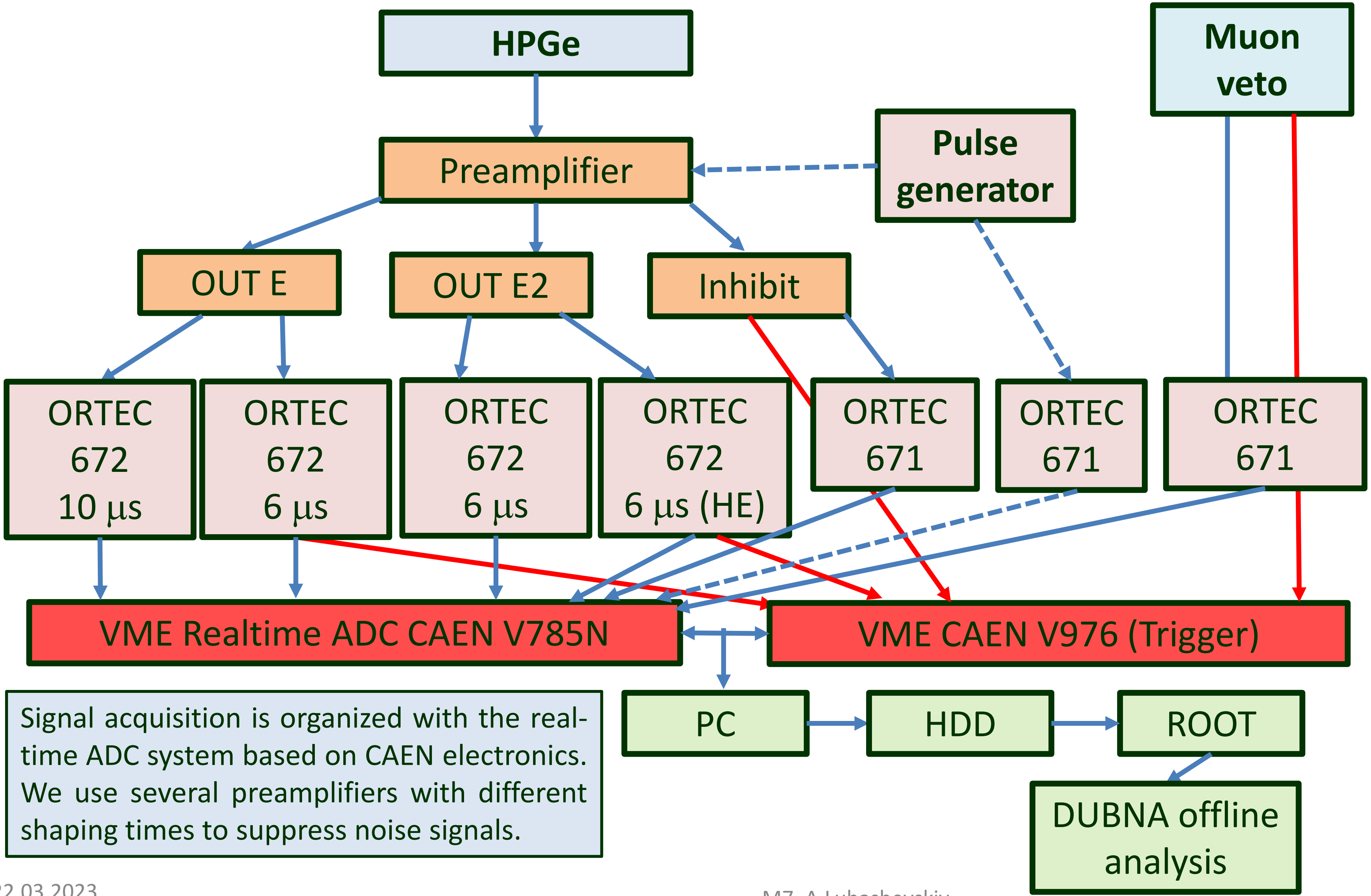
Photo from installation at KNPP in 11.2019

Signals from detector

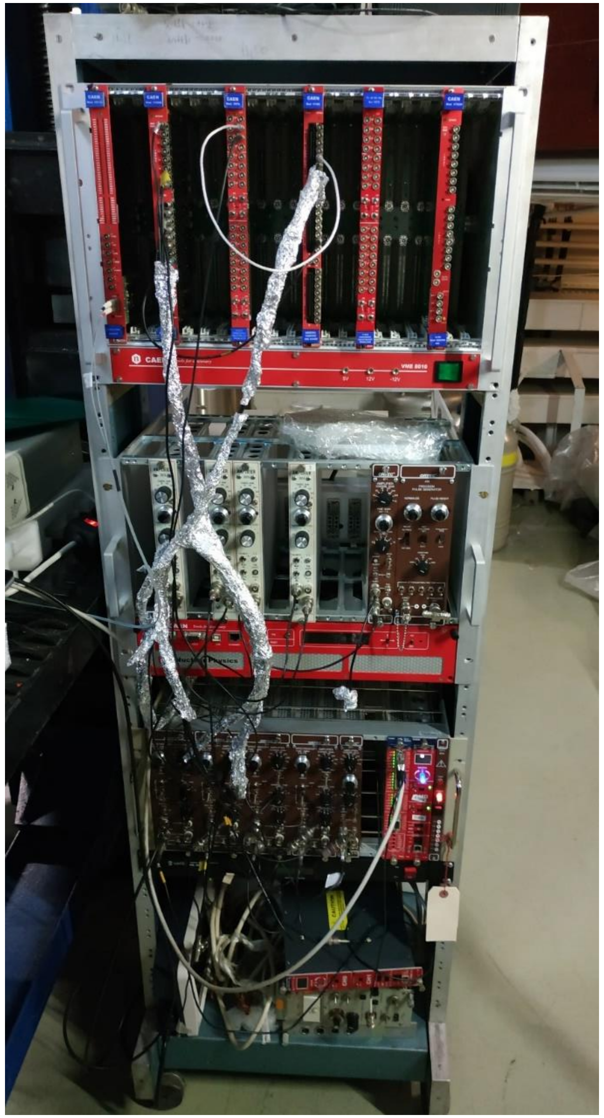


- Detectors are equipped with reset preamplifier.
- There is a special inhibit signal that indicates the time when the reset happens.
- The signals are shaped with amplifiers and processed with a real-time ADC.

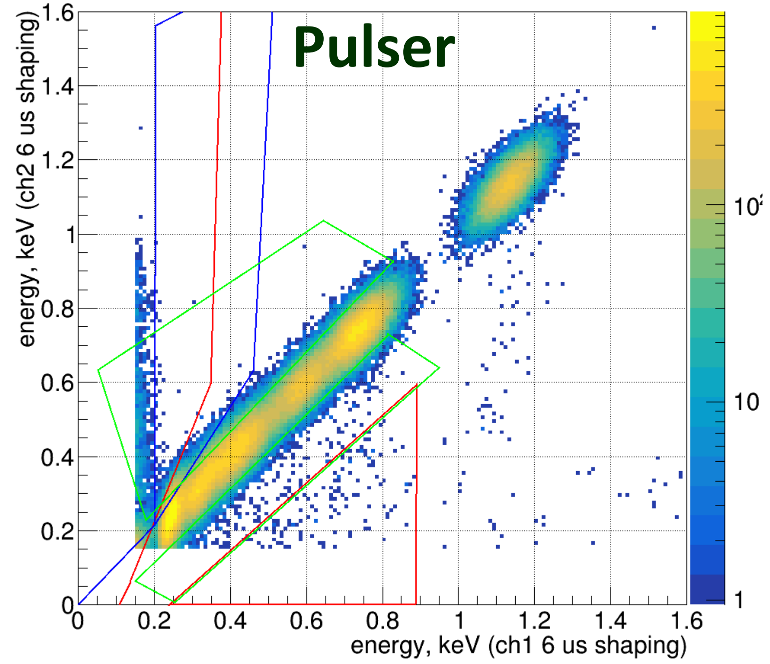
Simplified scheme of measurements



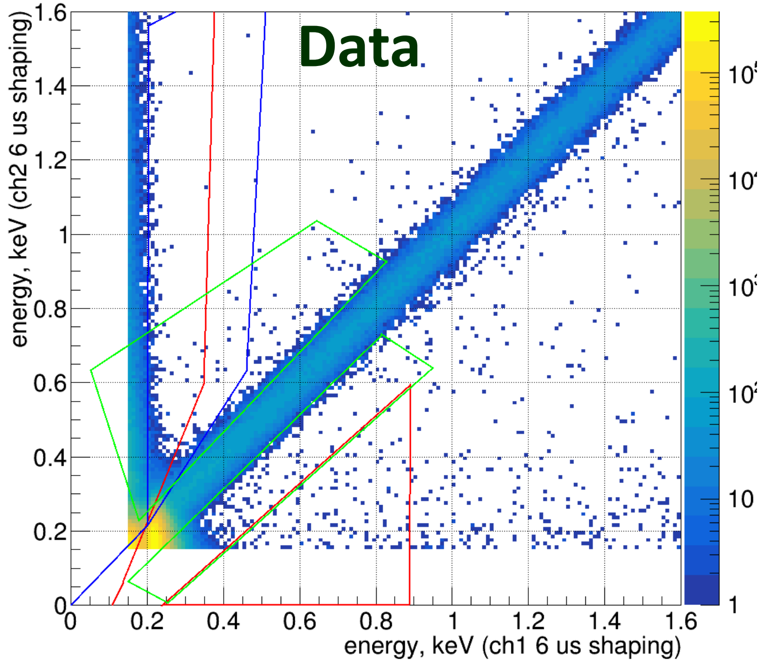
Signal acquisition is organized with the real-time ADC system based on CAEN electronics. We use several preamplifiers with different shaping times to suppress noise signals.

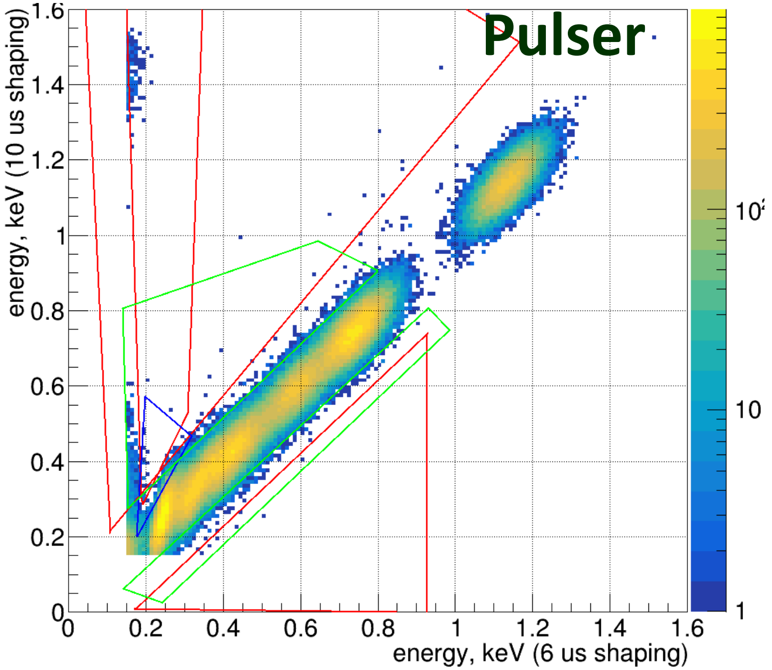


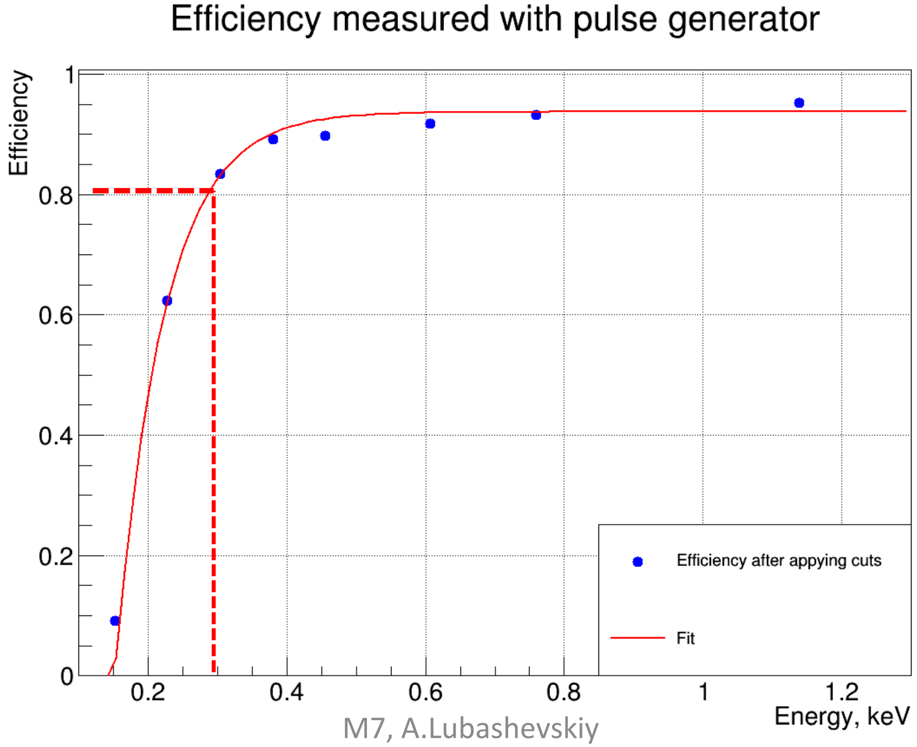
Noise cuts

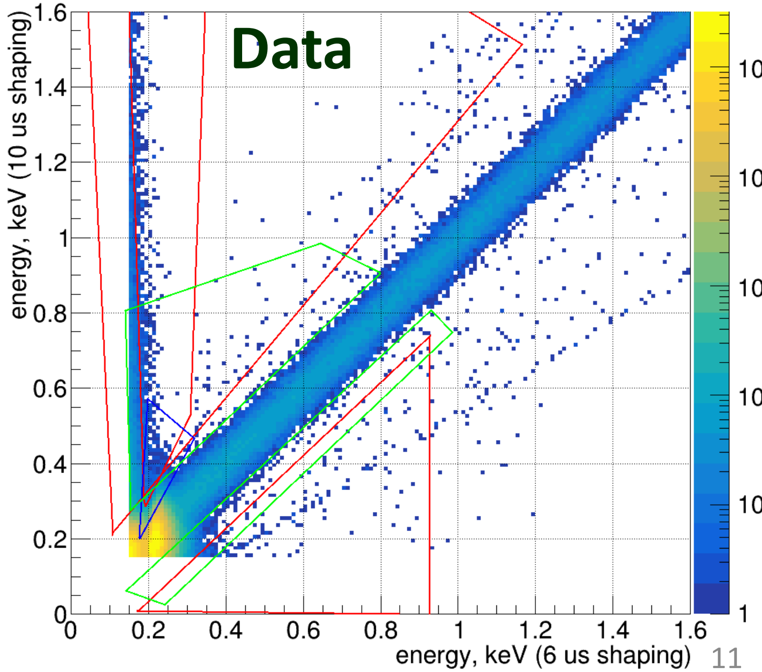


- Different shaping times of preamplifiers are used to suppress the noise with the help of graphical cuts.
- Time cuts allow to suppress signals generated by reset of the preamplifier and other artificial signals.
- Even at 200 eV efficiency is > 40% after applying cuts



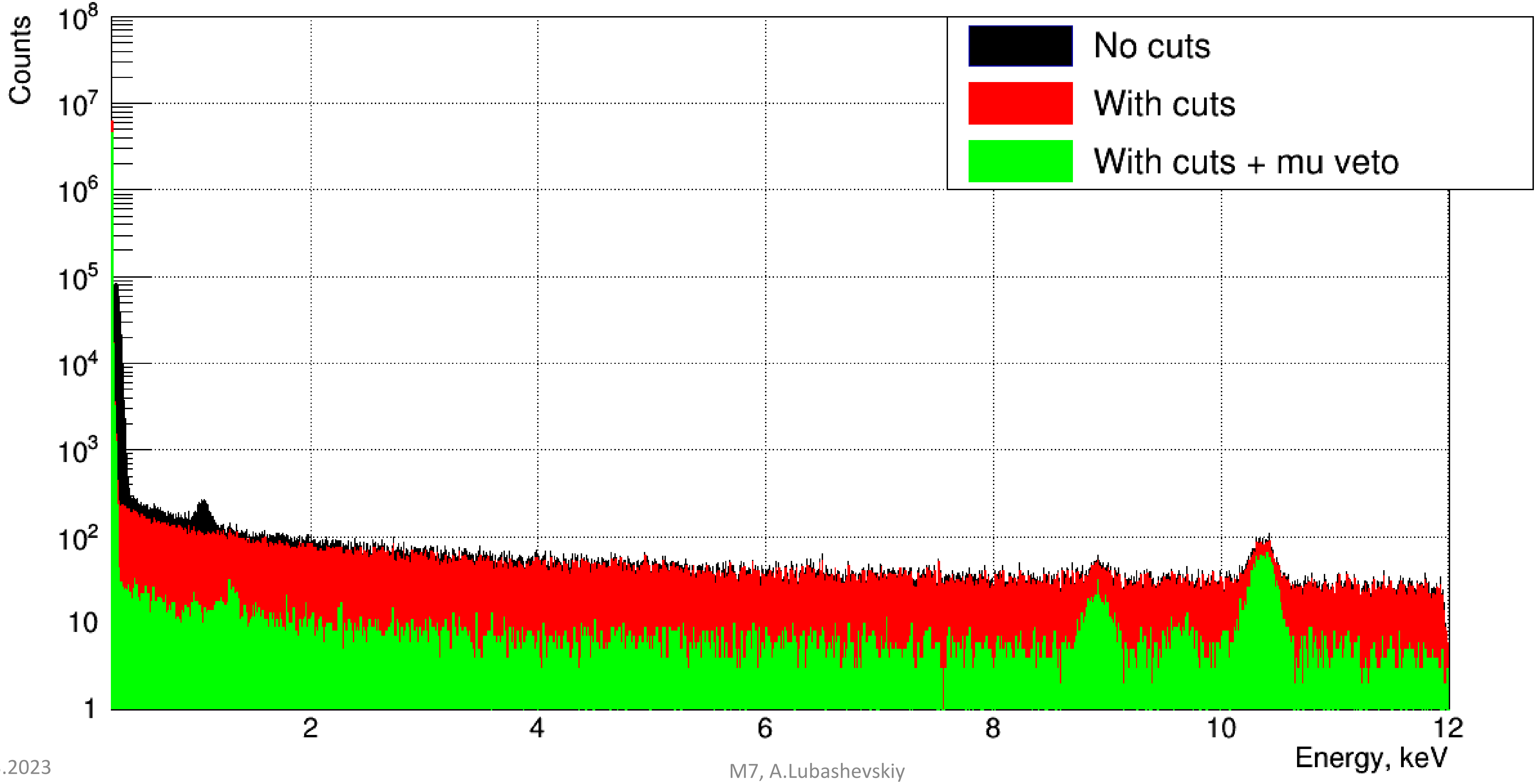




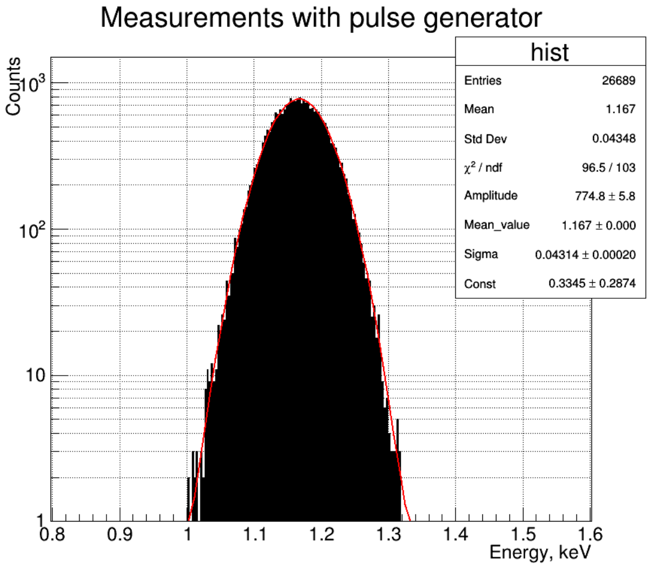


Muon veto & time cuts

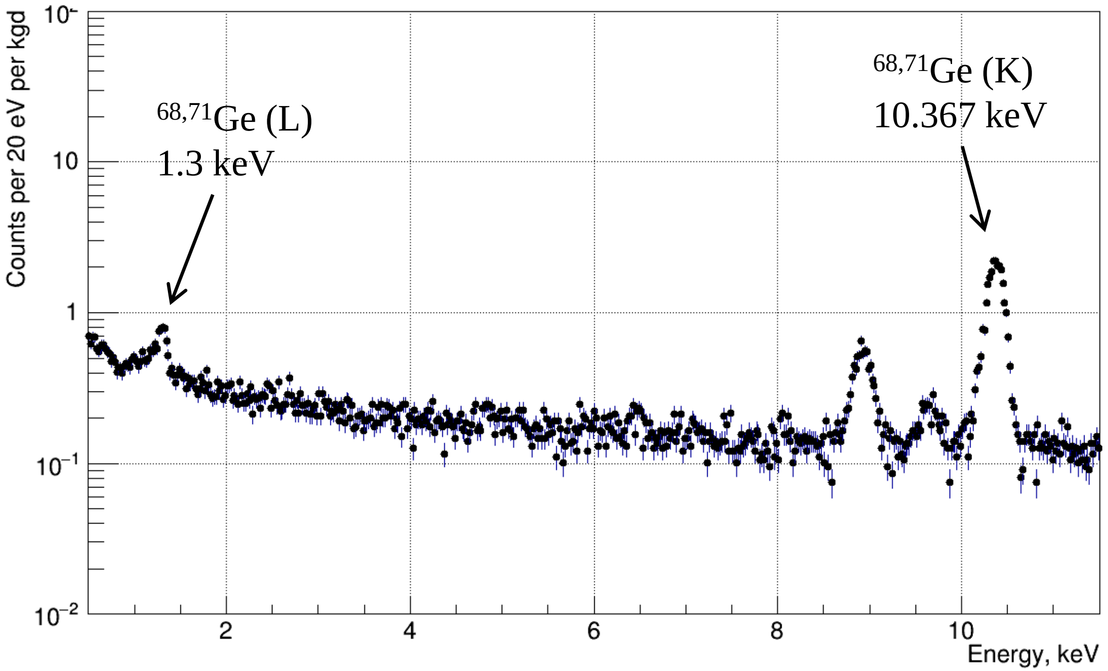
- Coincidences with muon veto allow to suppress background connected with muons
- Efficiency of all cuts together with muon veto determined by 10.37 keV line is **82.2(22)%**

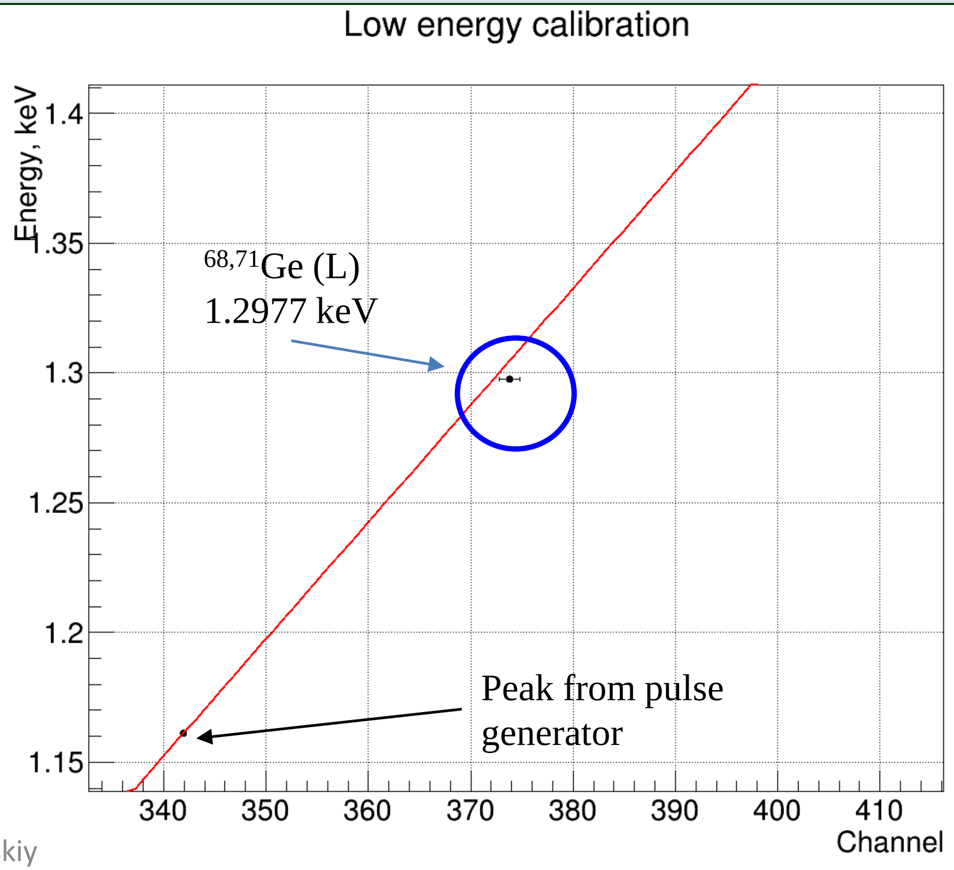


Calibration at low energies

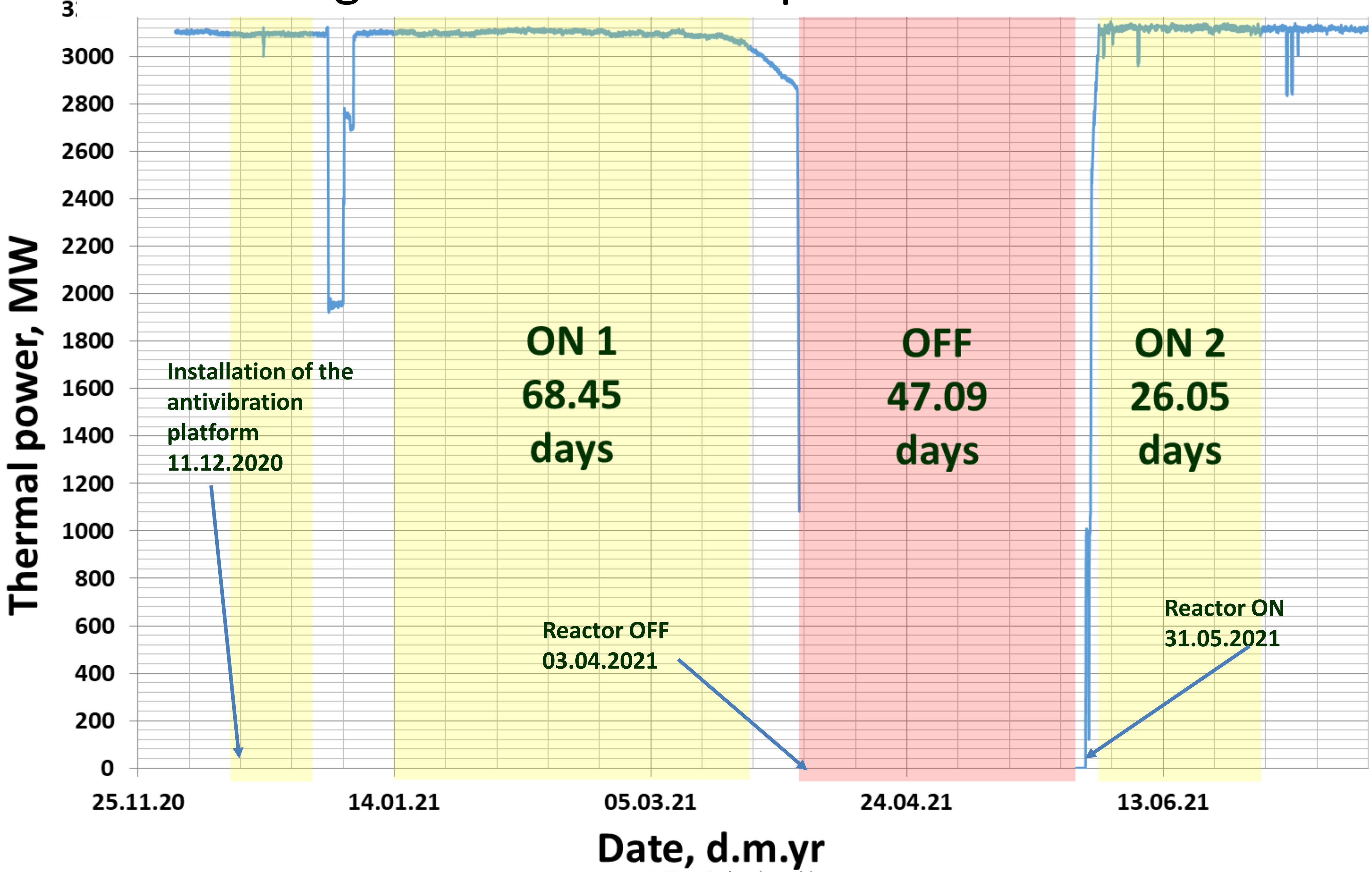


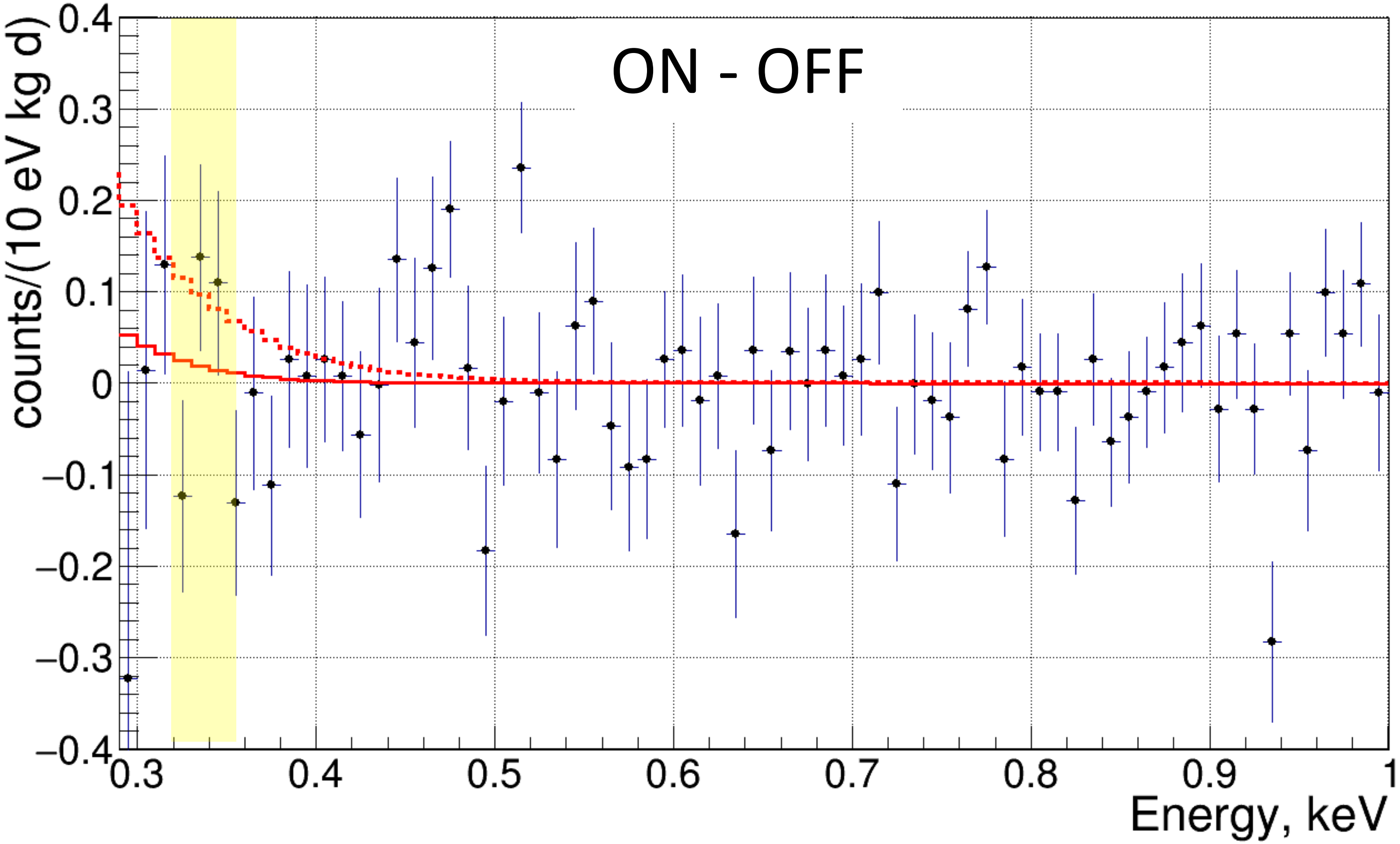
- Energy calibration at low energy is performed by means of 10.37 keV cosmogenic line and pulse generator.
- Calibration check with 1.3 keV line
- Data taking shows very good stability of peak position during all measurement time.
- Energy resolution of 1.4 kg detector at KNPP is 101.6(5) eV (FWHM).





Time changes of the thermal power of reactor unit #3



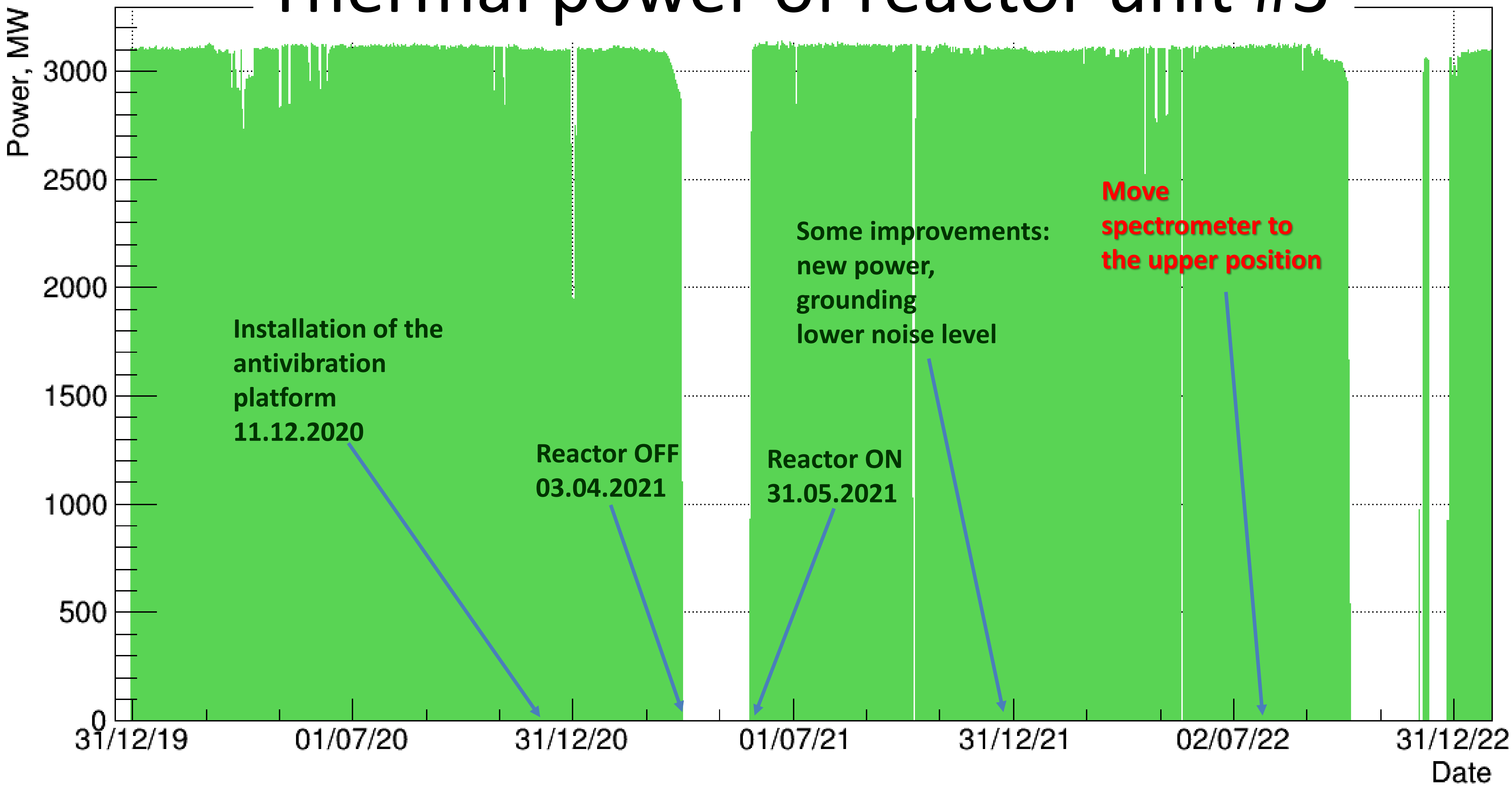


2022 ANALYSIS

Analysis of the first data shows 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.

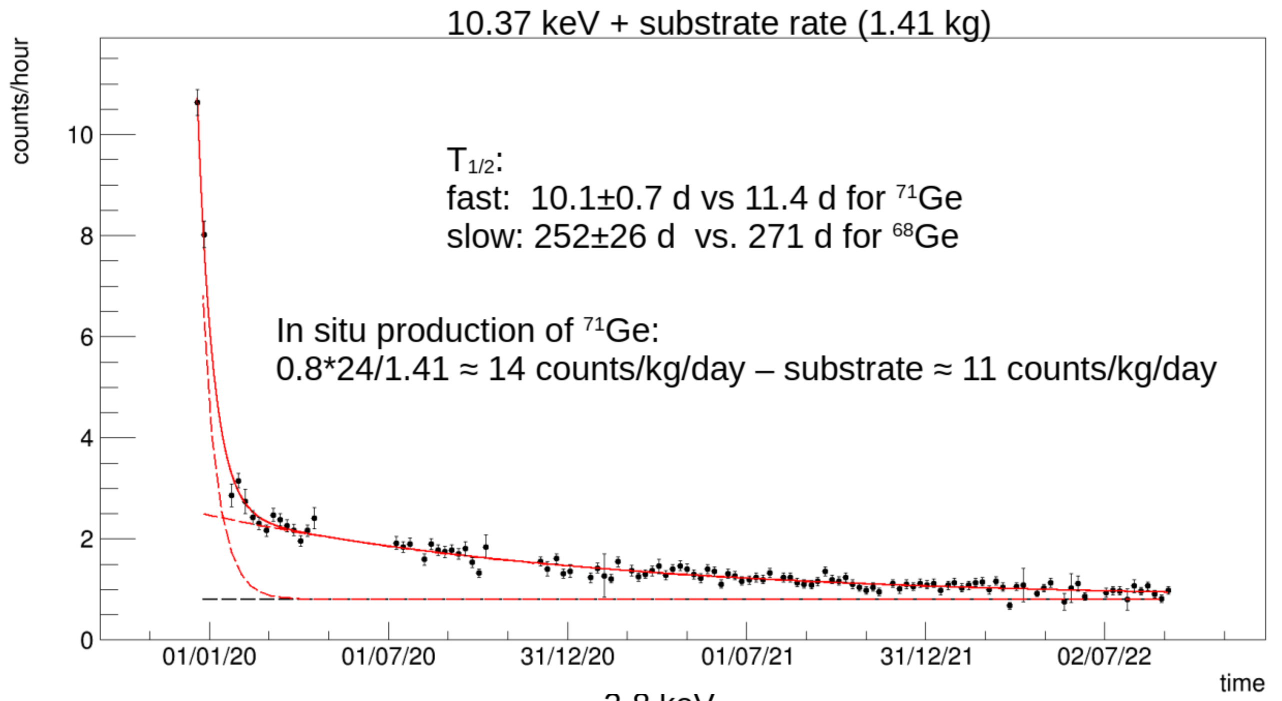
	Counts in region [320..360] eV	Measurement time, days	Counts per kgd (stat. error only)
Reactor ON	**251**	**94.5**	**2.32 ± 0.15**
Reactor OFF	**126**	**47.1**	**2.34 ± 0.21**
ON-OFF			**-0.017 ± 0.255**
CEνNS, k = 0.26	**55**		**0.46**

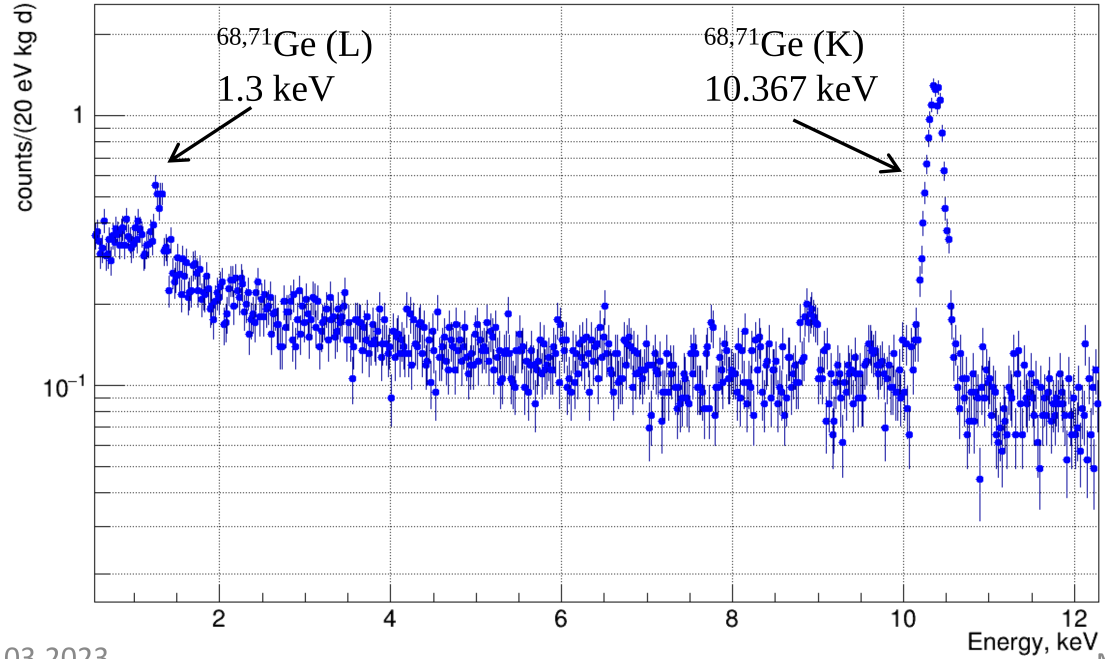
Thermal power of reactor unit #3

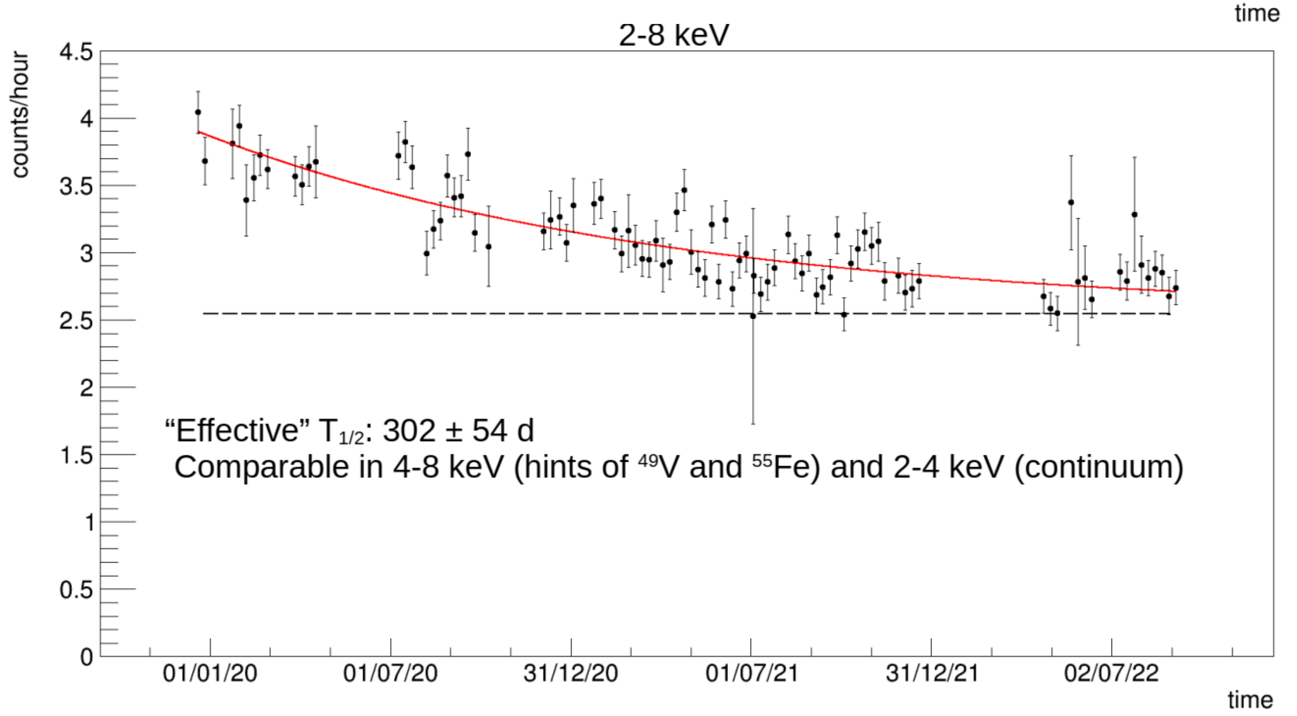


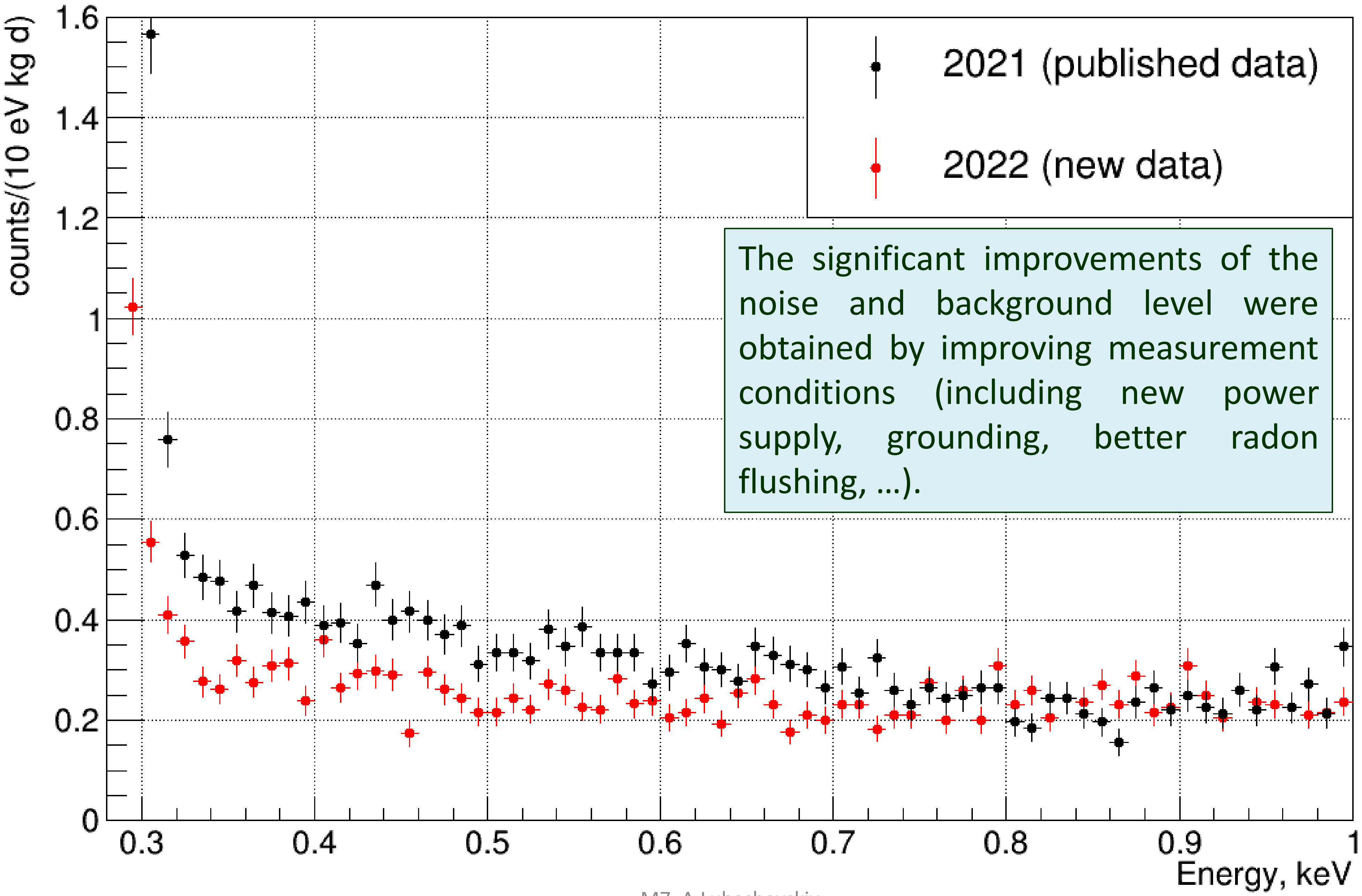
Total amount of data since start of measurements: ON period ~ 1100 kgd, off period > 170 kgd

- Stability is an important factor for the correct data interpretation.
- The air conditioners provide a stable temperature at experimental hall. Temperature is constantly monitored by two sensors.
- Changes of the backgrounds or noise level have to be taken into account.
- Cosmogenic activation products slowly decay in time and have to be taken into account.

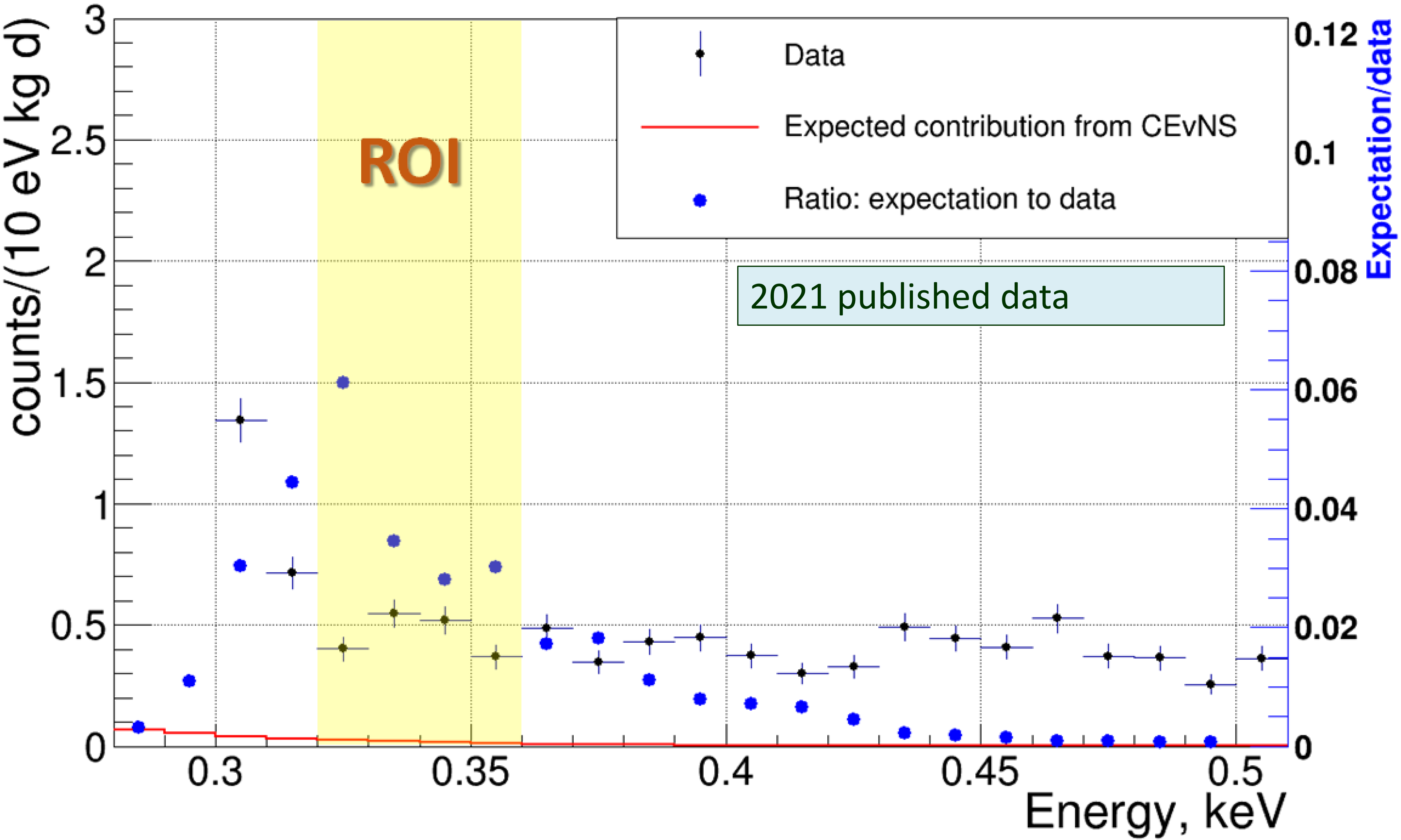




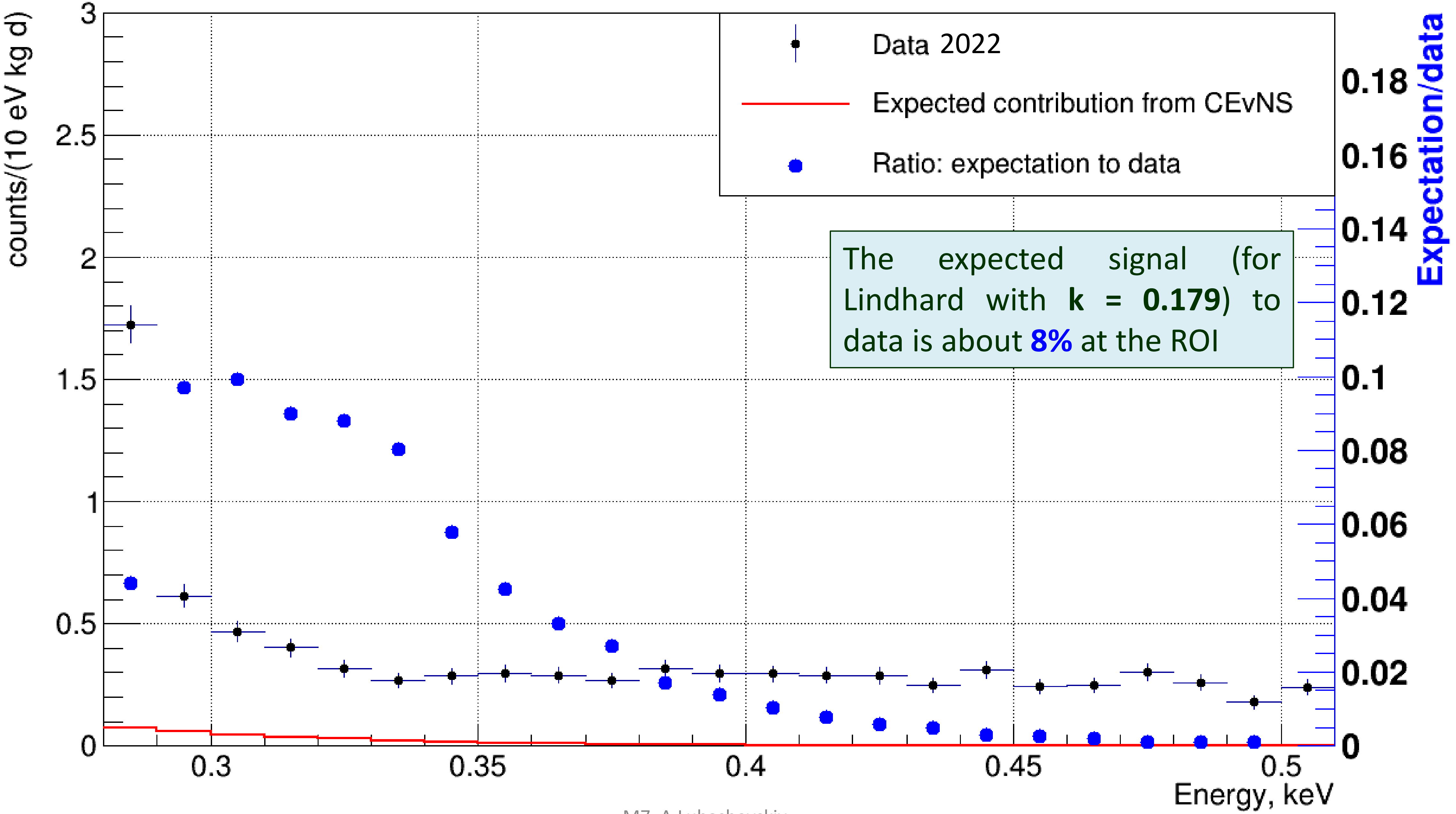




The significant improvements of the noise and background level were obtained by improving measurement conditions (including new power supply, grounding, better radon flushing, …).



counts/(10 eV kg d)
3
2.5
2
1.5
1
0.5
0
0.3
0.35
0.4
0.45
0.5
Energy, keV
0.12
0.1
0.08
0.06
0.04
0.02
0
Expectation/data
ROI
Data
Expected contribution from CEvNS
Ratio: expectation to data
2021 published data



counts/(10 eV kg d)
Expectation/data
Energy, keV
Data 2022
Expected contribution from CEvNS
Ratio: expectation to data
The expected signal (for Lindhard with **k = 0.179**) to data is about **8%** at the ROI

Conclusion

- Measurements with the νGeN spectrometer at Kalinin Nuclear Power Plant are ongoing.
- First results have showed that achieved background level allows to search for CEνNS at KNPP. No significant difference between regimes with reactor ON and OFF 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 with more statistics are expected soon.

Thank you!


КАЛИНИНСКАЯ АЭС
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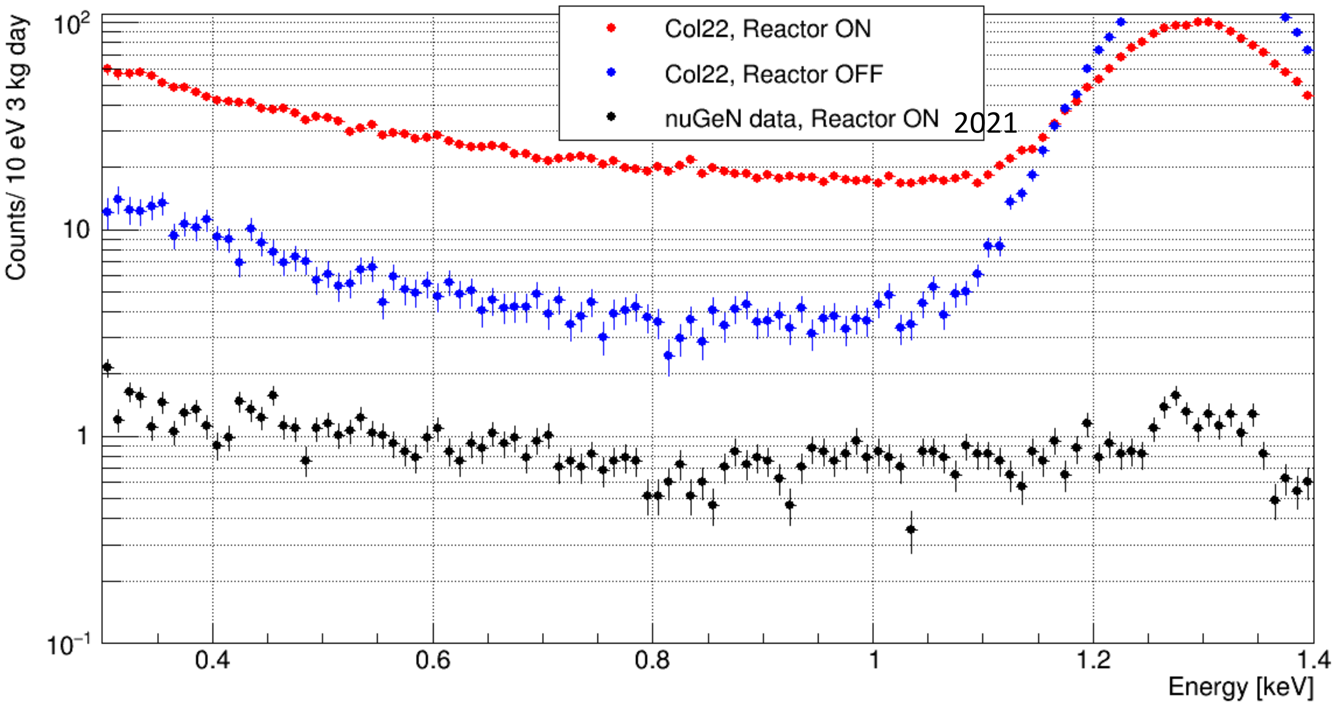
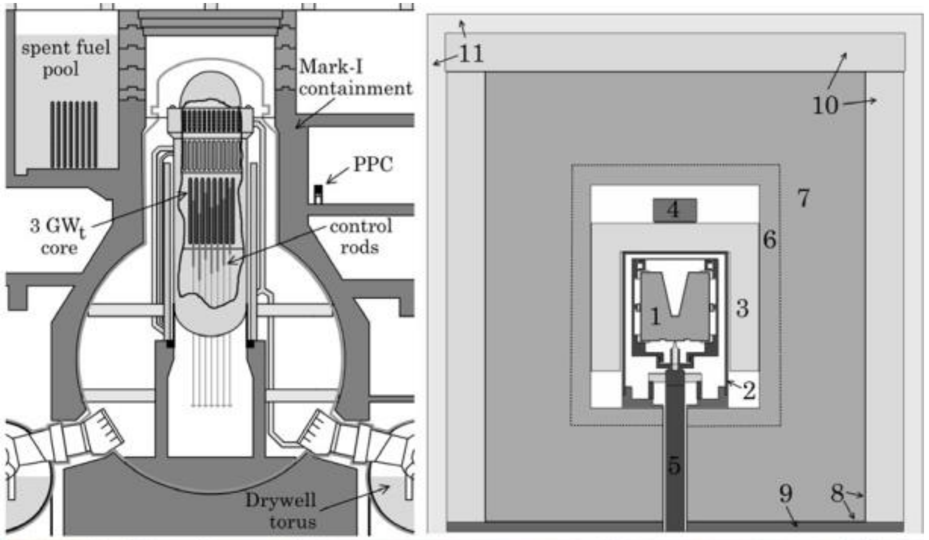
ВЫСШИЙ ПРИОРИТЕТ
НАШЕГО КОЛЛЕКТИВА

Backup slides

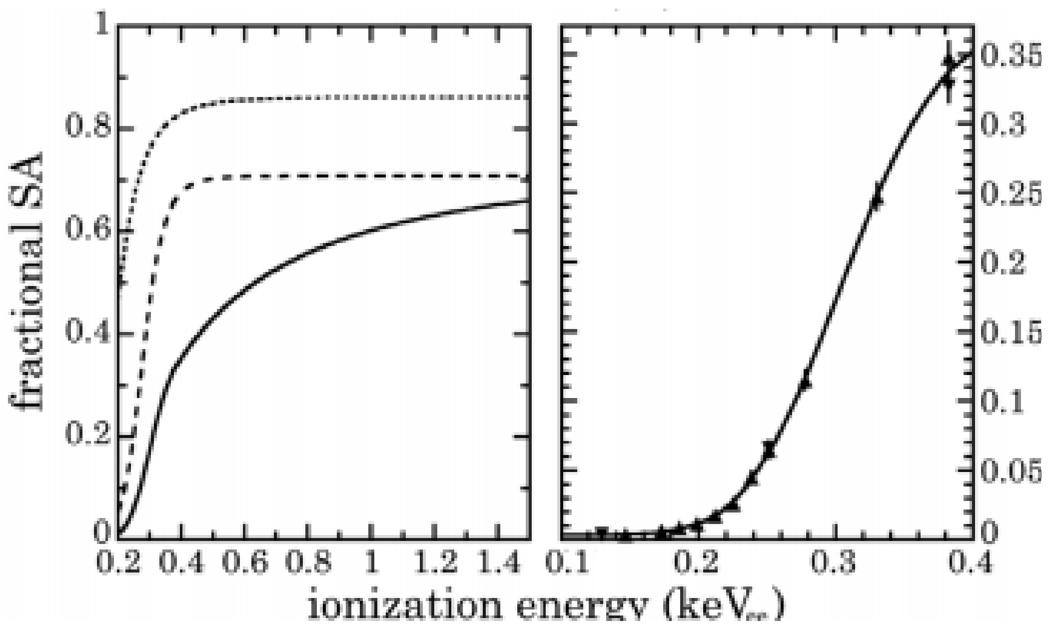
J. Colaresi, J. I. Collar,* T. W. Hossbach , C. M. Lewis , and K. M. Yocum, «Measurement of Coherent Elastic Neutrino-Nucleus Scattering from Reactor Antineutrinos», PHYSICAL REVIEW LETTERS 129, 211802 (2022)

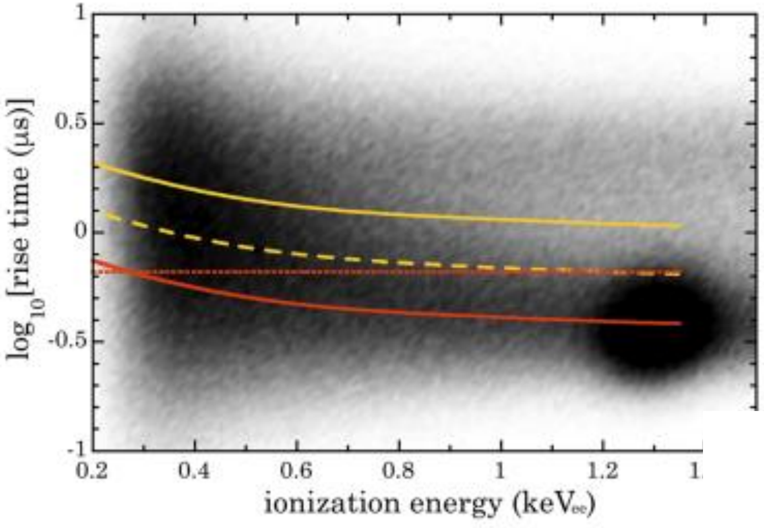
- Claimed about strong preference ($p<1.2\cdot10^{-3}$) for the presence of CEvNS.
- Similar to nuGeN antineutrino flux from reactor (4.8 10^{13} v/cm2/sec)
- Sideway location gives almost no overburden (cosmogenic background).
- Almost no shielding against fast neutrons.
- Different shielding during 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)





Collar data taking





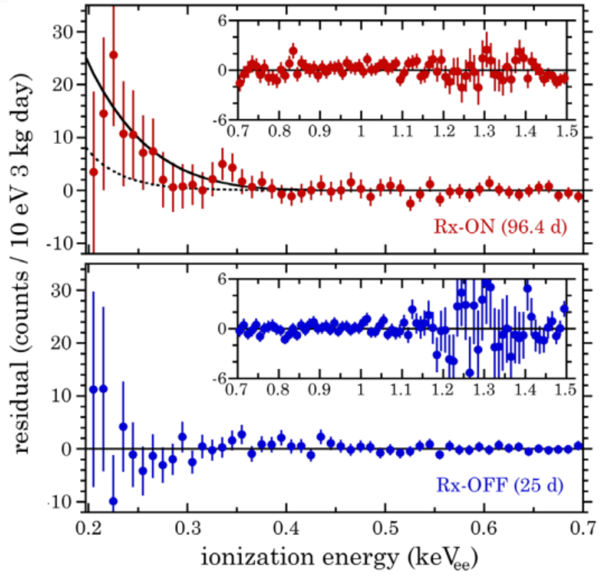
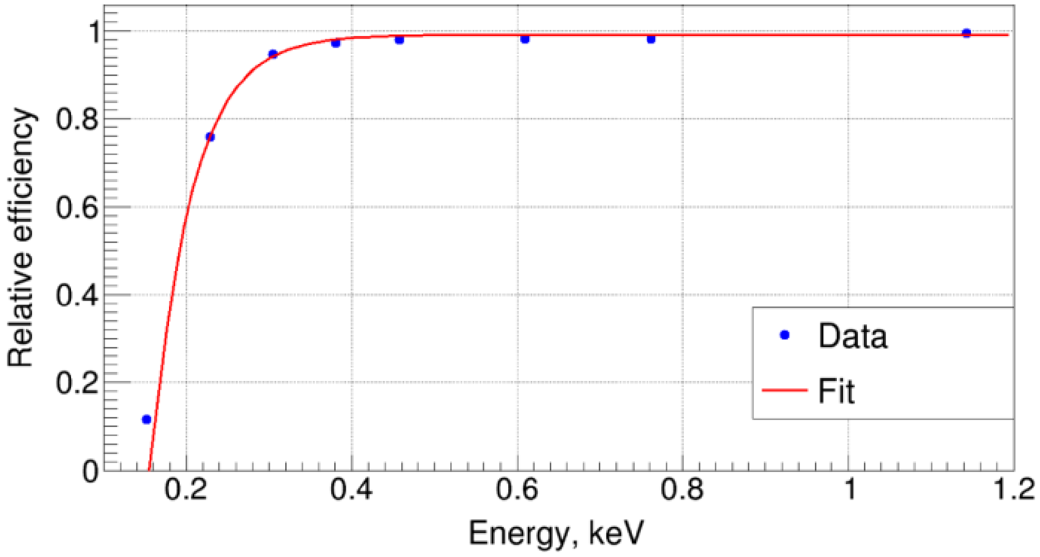


FIG. 5. Residual difference between the spectra of Fig. 1 and the best-fit background components (epithermal neutron, M-, L_1-, and L_2-shell EC) in the alternative hypothesis H_1 when using an exponential approximation for the CEνNS signal (see text). A solid (dotted) line shows the calculated CEνNS signal prediction for MHVE-Fef (MHVE-Lindhard) in the SM. The insets expand the residual above 0.7 keV$_{ee}$.



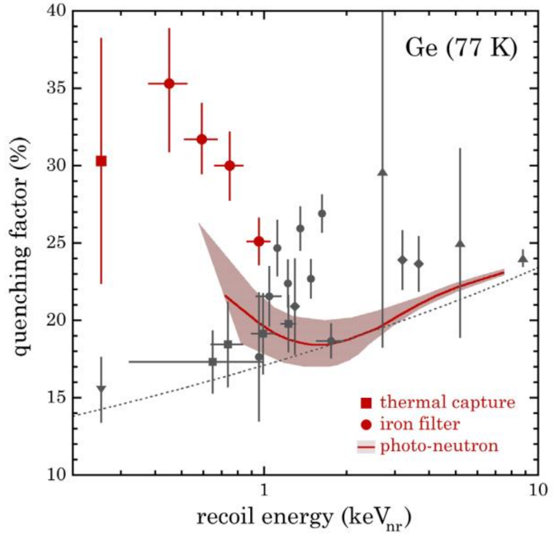
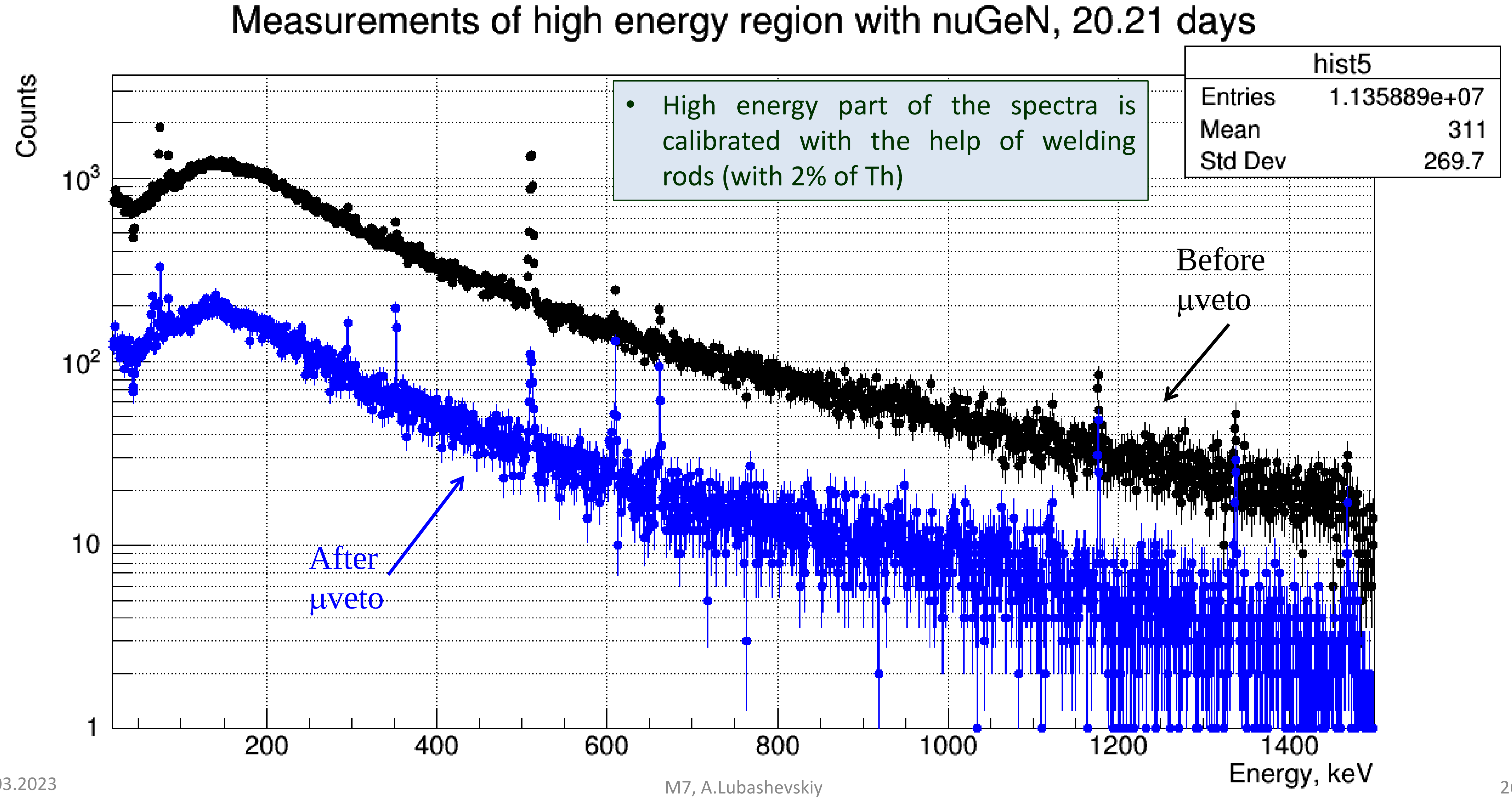
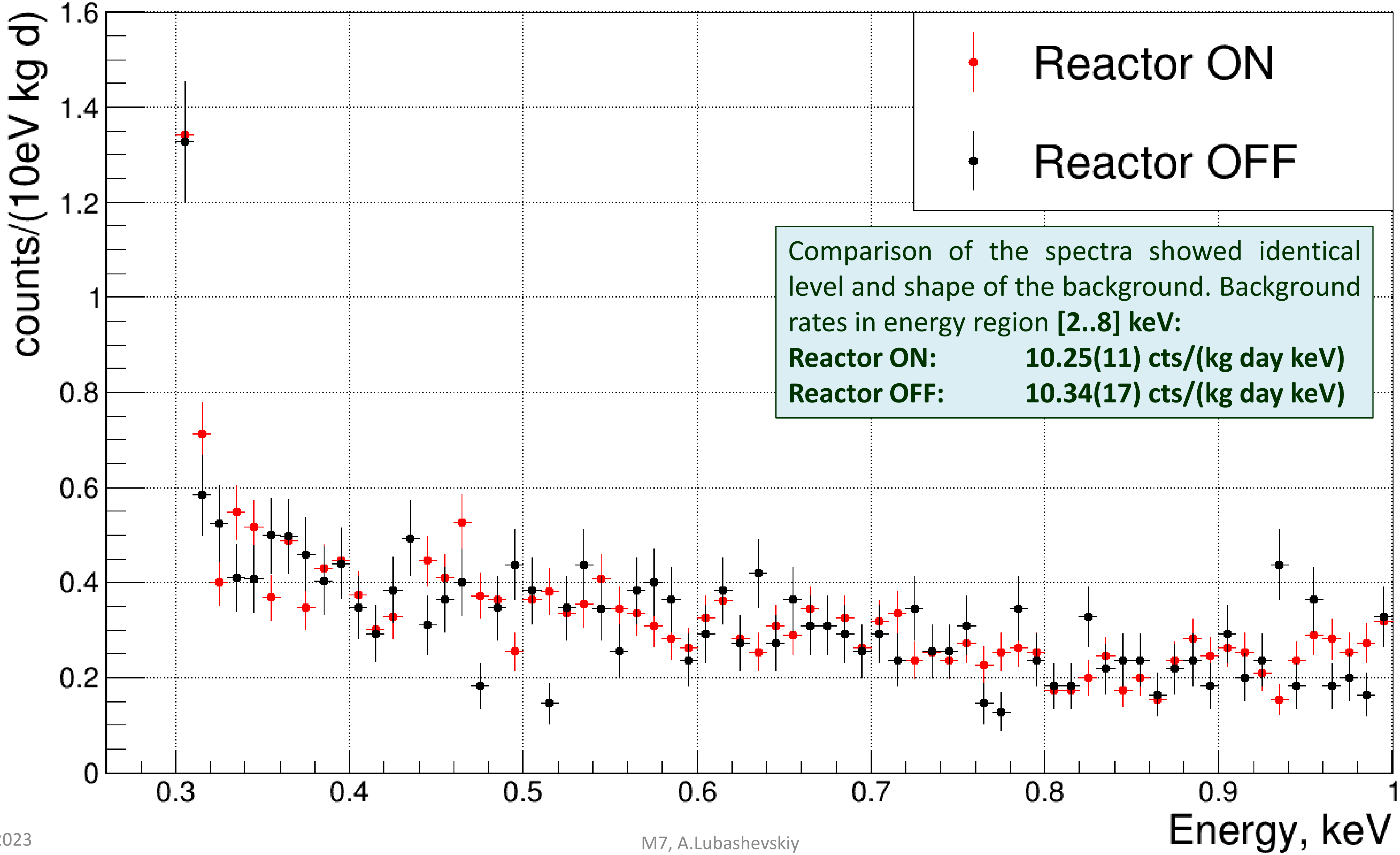


FIG. 9. Present QF results, labeled by calibration technique. A red band shows the 95% C.L. region for the model-independent fit of Fig. 2. A dotted line is the Lindhard model with a default germanium value of $k = 0.157$ [22]. Previous measurements are shown in gray: circles [57], squares [9,25], diamonds [65], triangles [66], and inverted triangle [51].

High energy part of the spectrum



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



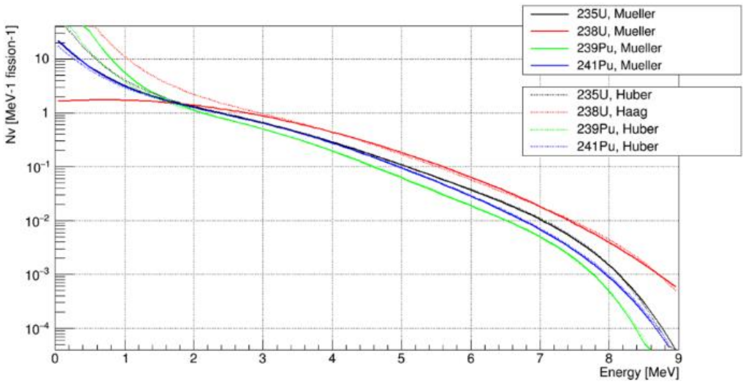
Comparison of the spectra showed identical level and shape of the background. Background rates in energy region **[2..8] keV:**

Reactor ON: **10.25(11) cts/(kg day keV)**

Reactor OFF: **10.34(17) cts/(kg day keV)**

The expected spectrum in Ge

Энергетические спектры нейтрино от различных изотопов



- Neutrino spectrum from reactor < 10 MeV
- Calculated from conversion of electron spectra (Huber2011 и Haag2014).
- Isotopes ratio of reactor WWER-1000 taken from [Kopeikin2012]
- Scattering calculated for each Ge isotopes.
- Quenching is calculated by Lindhard model with k = 0.1789 [Scholz2016]
- Convolution with detector's resolution

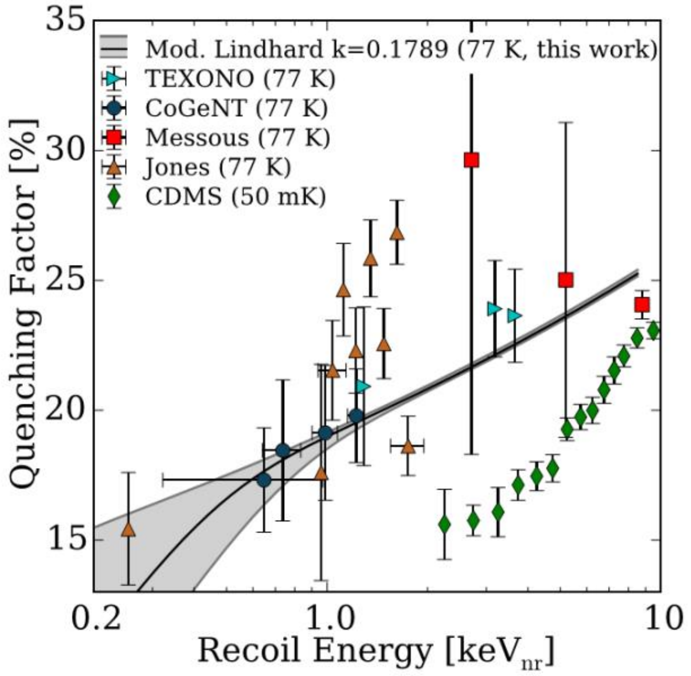
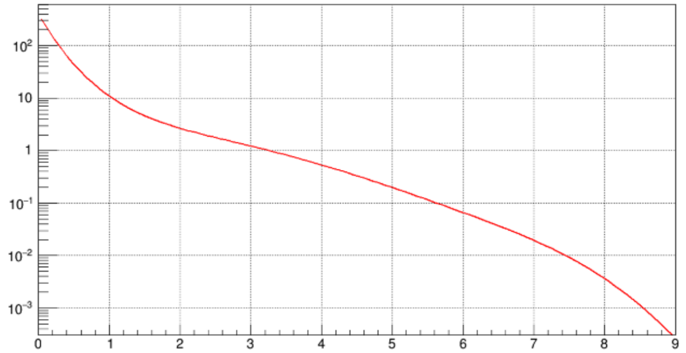


Таблица 1. Относительные вклады $\alpha_i(t)$ делящихся изотопов ^{235}U, ^{239}Pu, ^{238}U, ^{241}Pu в число делений стандартной кампании реактора ВВЭР-1000 ($\Sigma\alpha_i = 1$, $i = 5, 9, 8, 1$)

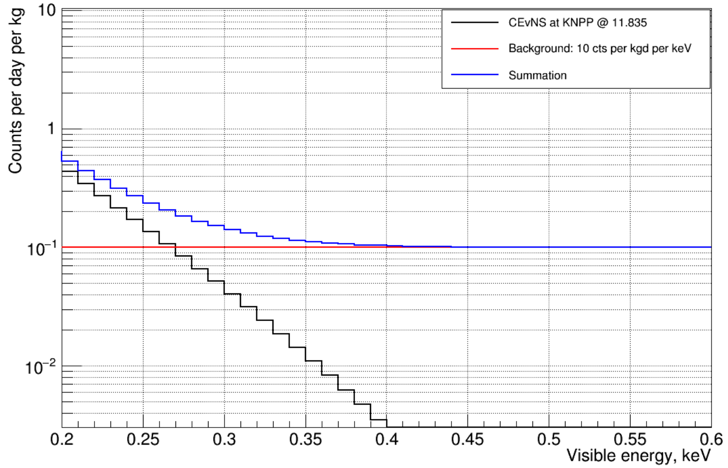
	α_5	α_9	α_8	α_1
Начало кампании	0.65	0.24	0.07	0.04
Середина кампании	0.56	0.31	0.07	0.06
Конец кампании	0.48	0.37	0.07	0.08



Суммарный спектр нейтрино от ВВР-1000 в середине топливной компании

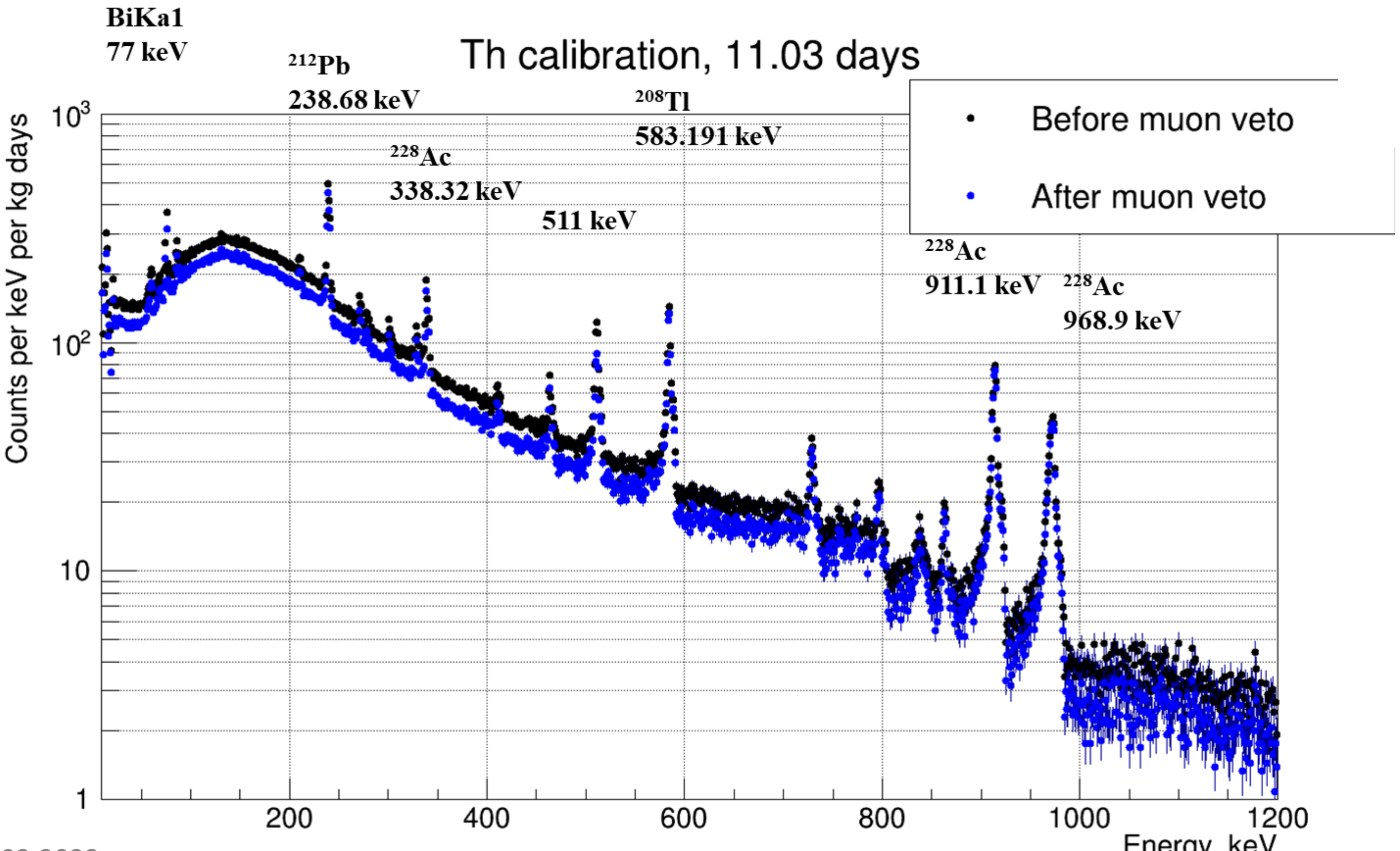
Isotope, A	% atoms	M atom (M_{nucl}+M_{elec}*32 - binding energies), GeV/c²	% mass, our calculations	N / N², neutrons
70	21.23(4)	65.1504	20.45	38 / 1444
72	27.66(3)	67.0113	27.40	40 / 1600
73	7.73(1)	67.9441	7.77	41 / 1681
74	35.94(2)	68.8735	36.60	42 / 1764
76	7.44(2)	70.7367	7.78	44 /1936
∑	100		100	

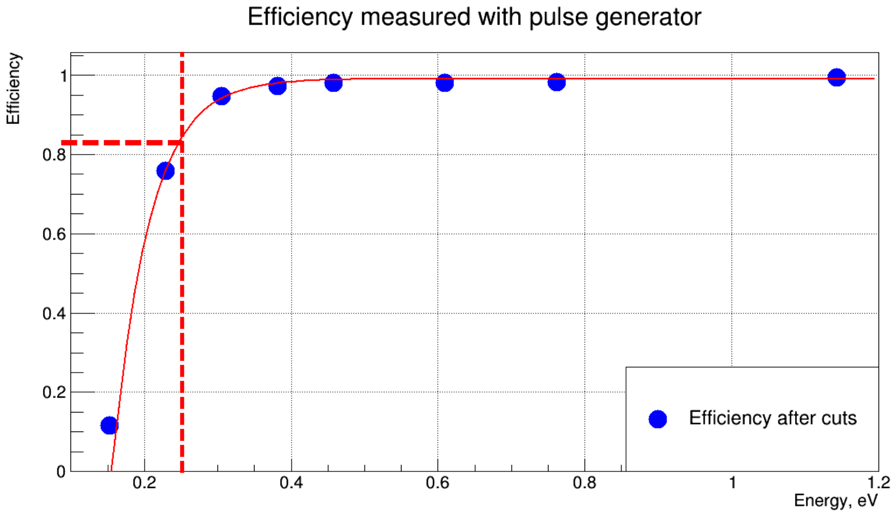
Expected spectrum at KNPP

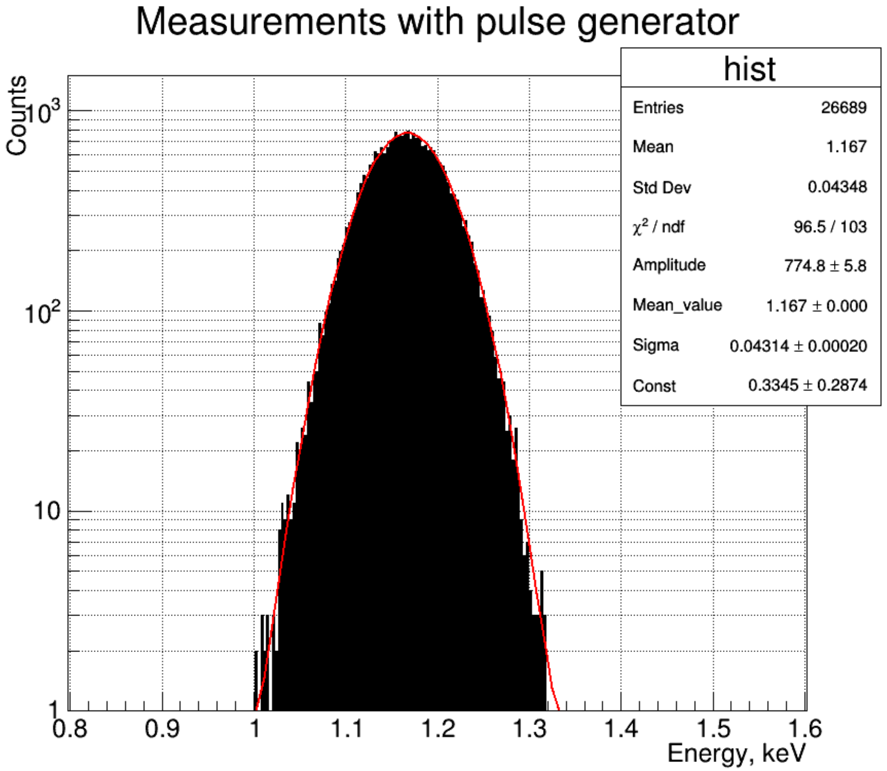


Measurements at KNPP

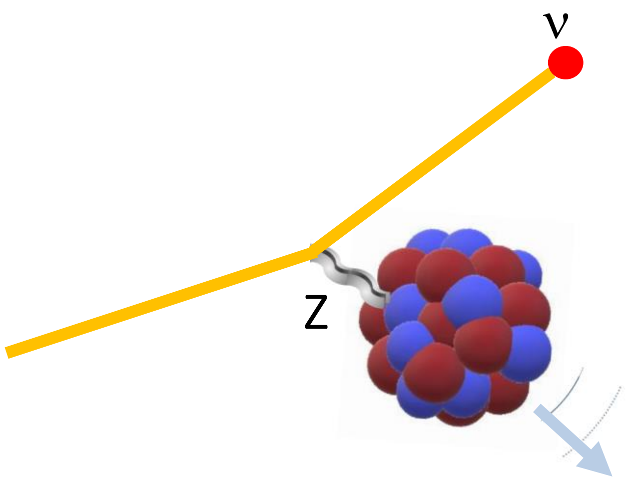
- High energy part of the spectra is calibrated with the help of welding rods (with 2% of Th)
- Energy resolution of 1.4 kg detector at KNPP is **101.6(5) eV** (FWHM).
- Trigger efficiency of signals above 250 eV is > 80%.







CEvNS



Coherent elastic neutrino-nucleus scattering is the process allowed in a Standard Model. Neutrino interacts coherently with nucleus as a single particle. This process was predicted in 1974 by Freedman [D. Freedman, Phys.Rev. D 9 1389 (1974)]. CEvNS cross-section:

$$\frac{d\sigma_{CE\nu NS}}{dT} = \frac{G_F^2 M}{2\pi}\left[2 - \frac{2T}{E_\nu} + \left(\frac{T}{E_\nu}\right)^2 - \frac{MT}{{E_\nu}^2}\right]\frac{Q_W^2}{4}F^2(Q^2)$$

$E_\nu - energy\ of\ neutrino,\ G_F\ - Fermi\ constant, M$
$- mass\ of\ nuclues,\ F - nuclear\ form\ factor(\sim 1\ for\ CE\nu NS),$
$Q_W = N - (1 - 4sin^2\theta_W)Z \approx N - 0.045\,Z$
$sin^2\theta_W \sim 0.239\ (at\ low\ energy) - Weinberg's\ angle,\ N, Z$
$- number\ of\ neutrons\ and\ nuclear\ charge$

- Proportional to number of neutrons squared: N^2
- Several orders of magnitude higher that usual neutrino cross-section.
- CEvNS is a domination process of neutrino scattering at low energies (E_ν < 50 MeV)
- **Full coherency < 30 MeV**