Investigation of neutrino properties with the low-background germanium spectrometer νGeN

A.Lubashevskiy for the νGeN collaboration

(continuation of GEMMA project)

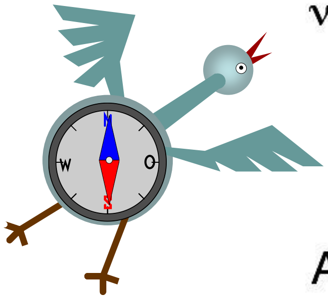
JINR

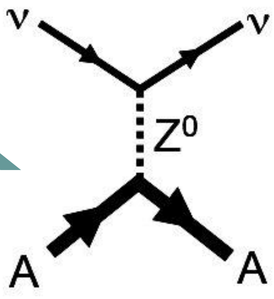
Aims

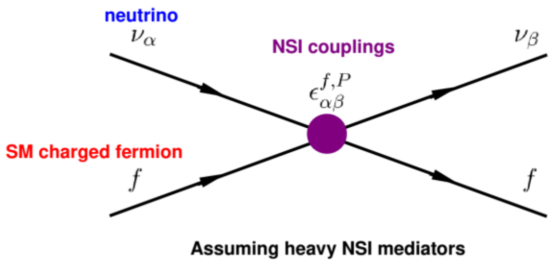
The **νGeN** experiment is a continuation of GEMMA projects, where the best current limit on the neutrino magnetic moment was set. The main aim of the νGeN project is the investigation of the neutrino properties with help of low threshold HPGe detectors located at the close vicinity of nuclear power reactor.

Main aims for νGeN:

- Search for **neutrino magnetic moment (NMM)**
- Search for **coherent elastic neutrino-nucleus scattering (CEvNS)**
- Search for non-standard neutrino interactions (NSI)
- Investigation of the nuclear structure (form-factors, Weinberg angle at low energy)
- Other processes (axions, sterile neutrinos, non-elastic scattering,…)
- Applied usage, reactor monitoring

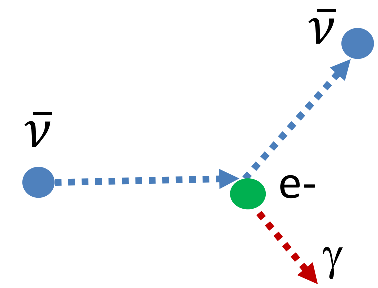




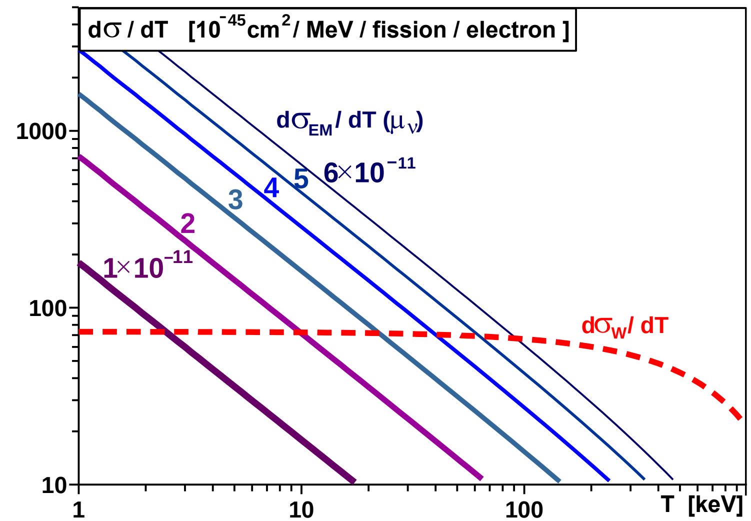


Neutrino magnetic moment

A magnetic moment is a fundamental parameter of the neutrino and its investigation may lead to results beyond the standard concepts of elementary particle physics and astrophysics (SM). In minimally extended SM the value of NMM is very low **($\mu_\nu < 10^{-19}\mu_B$)**, and can not be checked in modern experiments. However, many extensions of SM predicts much higher values: **$10^{-(10\div12)}$ μ_B.** The observation of NMM above **10^{-14} μ_B** would be a New Physics beyond the SM and indicate Majorana nature of neutrino.
The predecessor of νGeN - GEMMA-I experiment set the current best laboratory limit of **$\mu_\nu < 2.9\cdot10^{-11}$ μ_B**.



Additional EM component



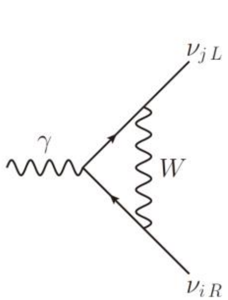
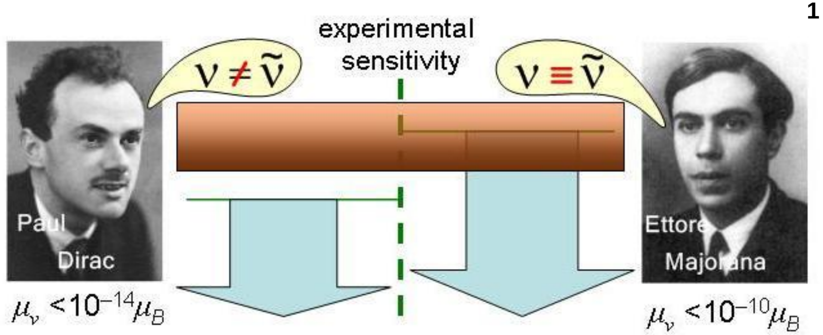


Figure 1: Magnetic moment diagram for Dirac neutrinos.



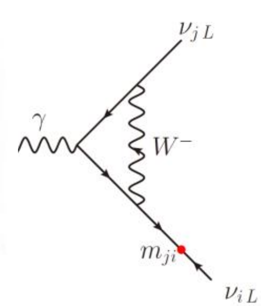
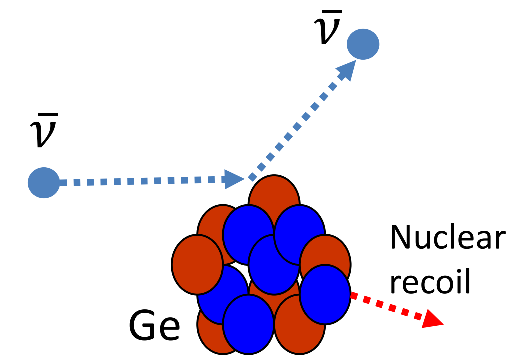


Figure 2: Magnetic moment diagram for Majorana neutrinos.

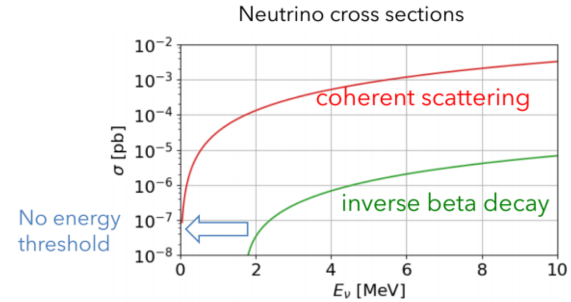
CEvNS

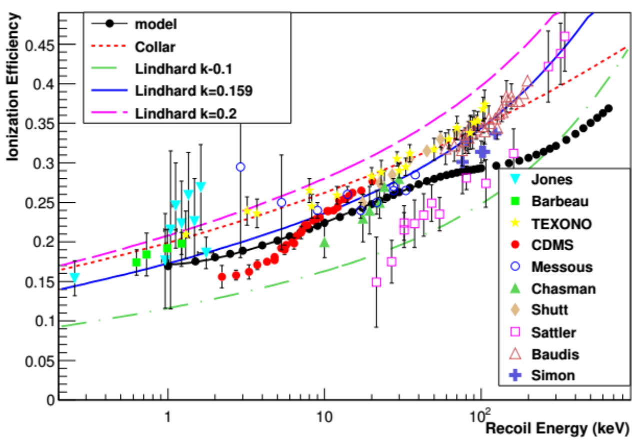


Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) is a process predicted by the Standard Model, but has not been observed yet for the reactor neutrino. The detection of this process would be an important test of the Standard Model. Such observations can also help for the search of non-standard neutrino interactions, sterile neutrinos and other investigations.

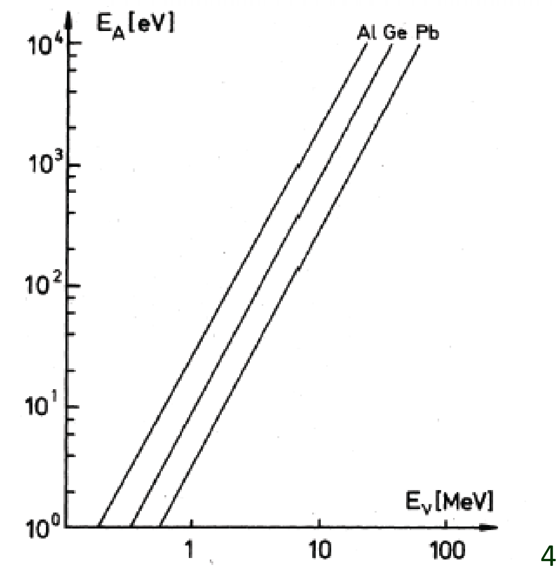
$$\sigma_{tot} \approx \frac{G_F{}^2}{4\pi^2} \cdot N^2 \cdot E_\nu{}^2$$

- E_ν < 50 MeV (full coherency ~ 30 MeV)
- Cross-section is being proportional to the number of nuclear target neutrons squared.
- Several orders of magnitude higher than “usual” cross-section of neutrino.
- Energy of recoils is very low (usually less than few keV).
- Moreover often only part of its energy can be detected (for Ge detector ~ 20%)



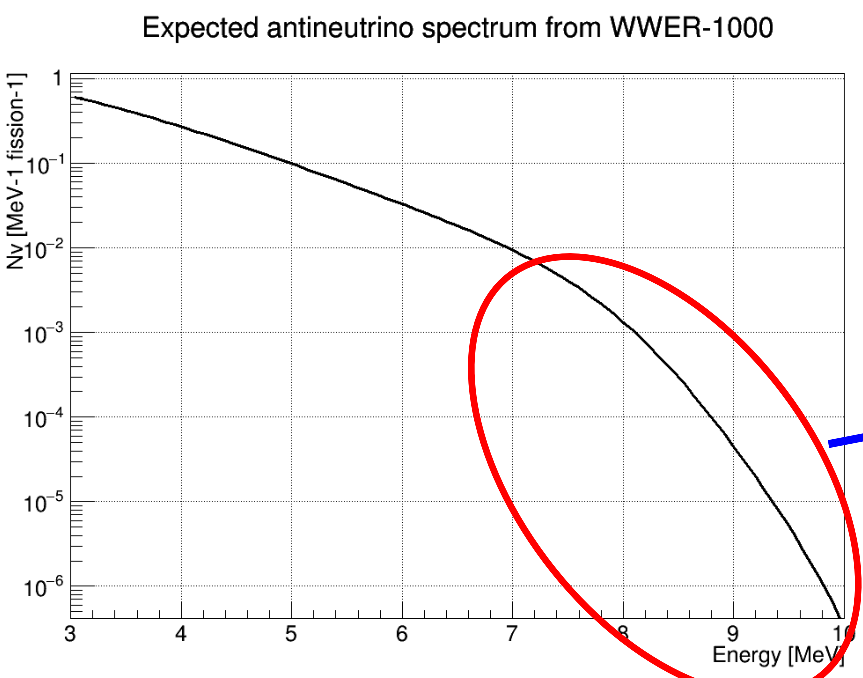


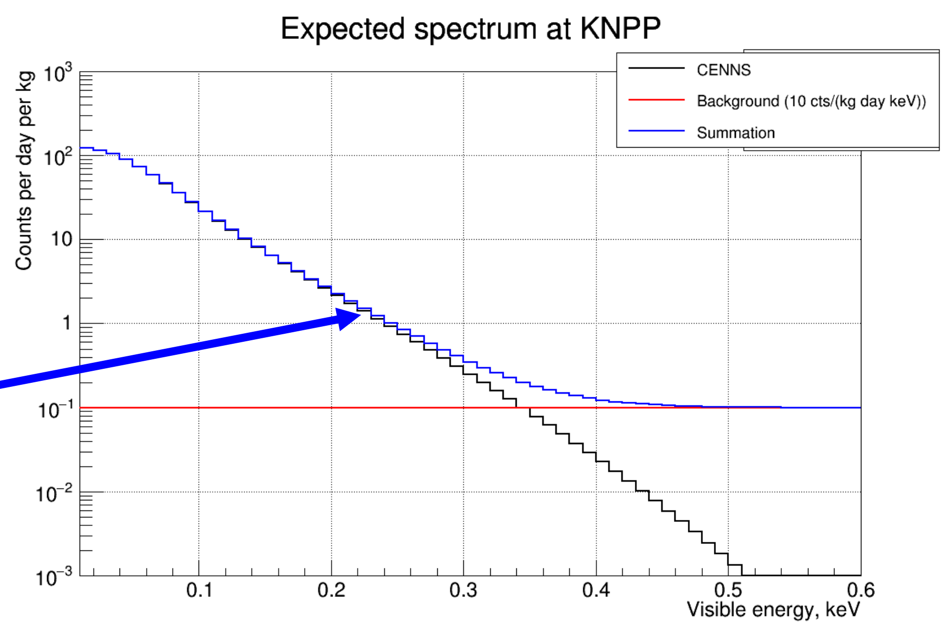
Recently COHERENT experiment claims to detect CEvNS, however with a rather high energy ν from accelerator, close to its coherency limit. We are going to check this result.



Neutrino detection

- Expected signals from neutrino scattering produce a continuous spectrum at low energy region. It is difficult to distinguish them from background or noise spectra.
- Regions for the search of the neutrino scattering:
  - For CEvNS < 600 eV
  - 600 eV < NMM ≲ 30 keV
- To detect neutrino scattering one needs:
  - Powerful source of the neutrino in a region of full coherency
  - Low threshold detectors with big mass and high efficiency
  - Low background and possibility to discriminate expected signal from noise and background.

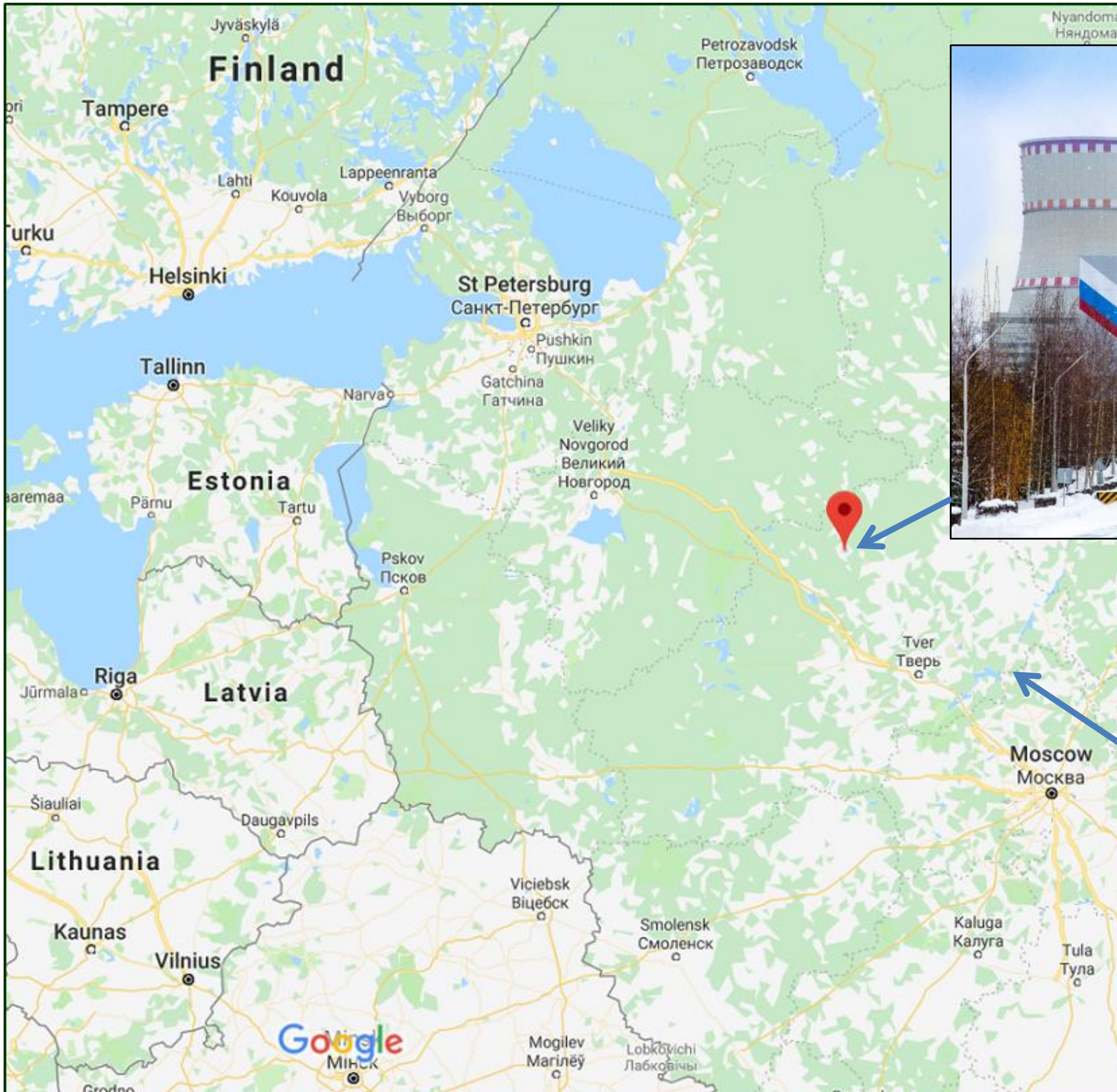




Comparison of the reactor sites

Experiment	Location	Neutrino flux [cm^2 s]	Overburden [m w. e.]
vGeN	KNPP, Russia	5×10^{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	6.8×10^{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

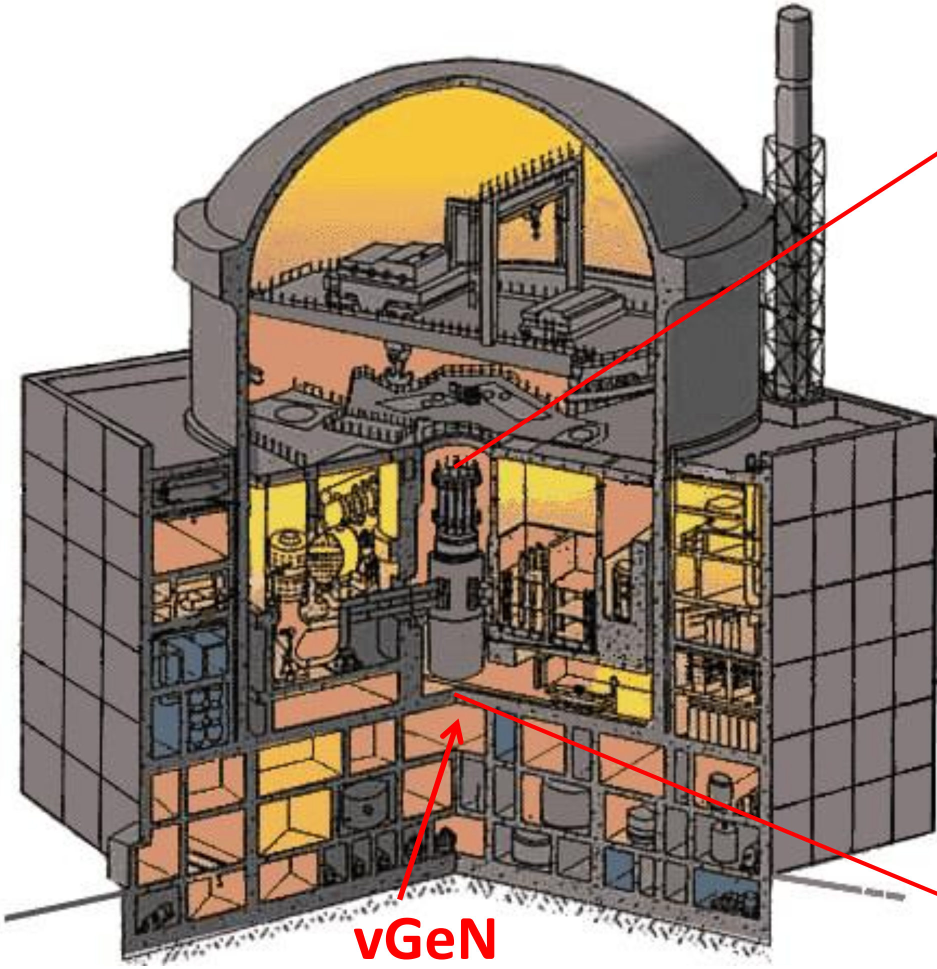
JINR reactor's site at Udomlya



Kalinin Nuclear Power Plant (KNPP) 4x WWER - 1000

JINR, Dubna, 285 km from KNPP

Neutrino source



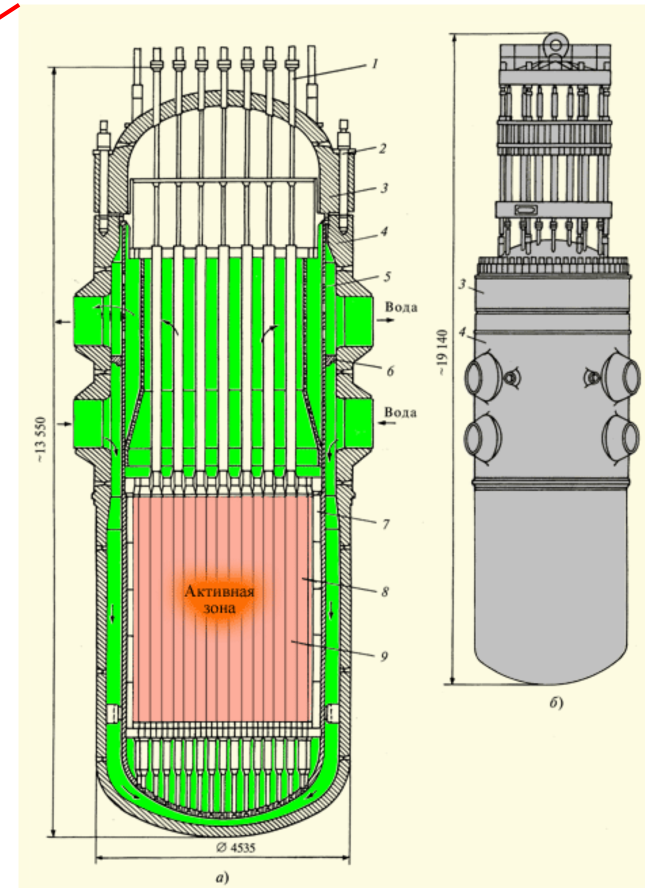
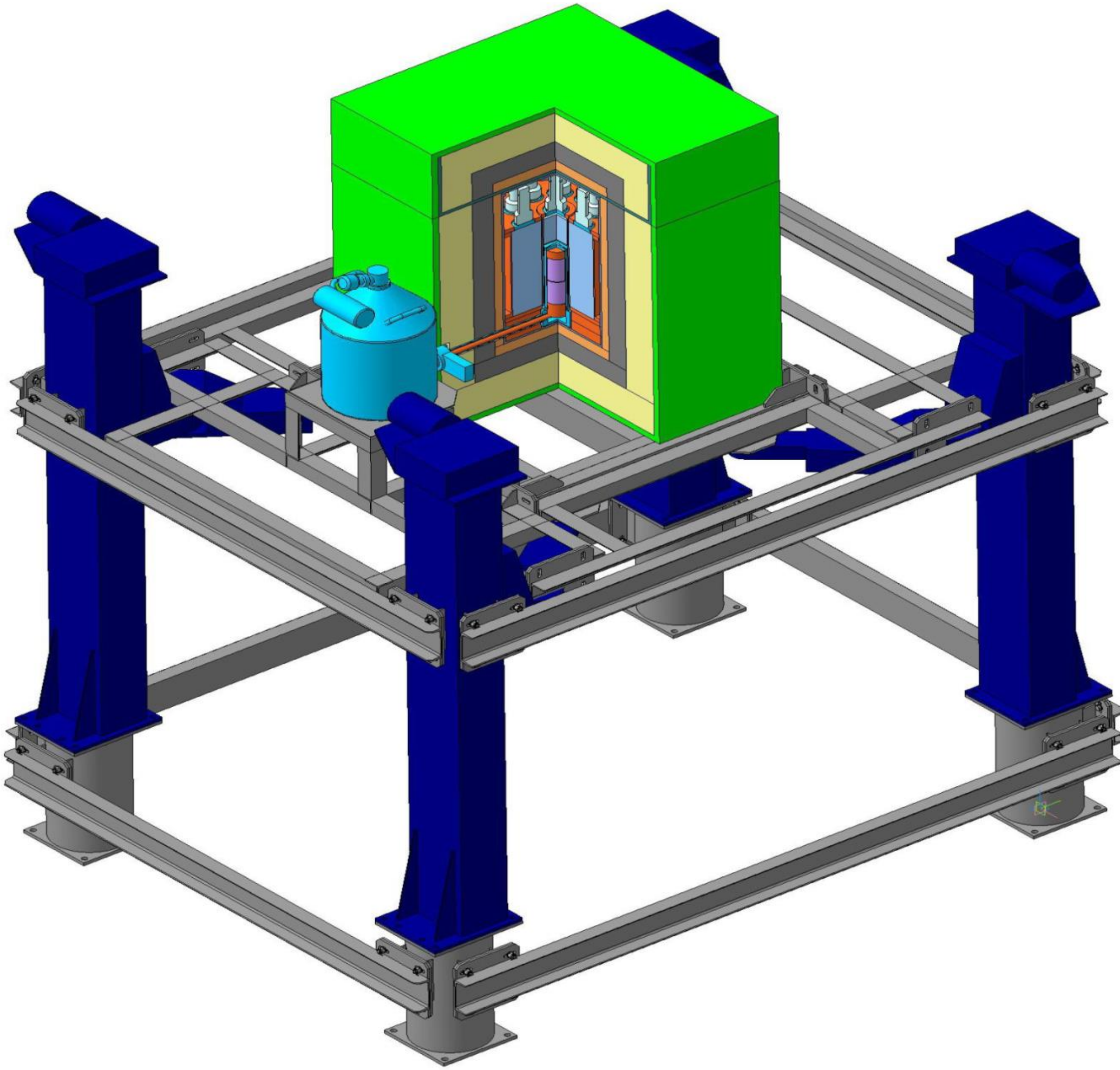


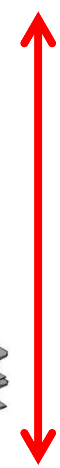
Рис. 5.4. Ядерный реактор ВВЭР-1000

vGeN spectrometer is been constructing at the close vicinity of the reactor core. It is located at **~ 10 m** from powerful 3.1 GW reactor's core under an enormous antineutrino flux of more than **$>5\cdot10^{13}$ $\nu/(s\cdot cm^2)$.** Experimental setup is located under the reactor **~ 50 m w.e.** (good shielding against cosmic radiation).

Lifting mechanism



We produced a special lifting mechanism to move the spectrometer towards the reactor core to change the neutrino flux through the detector. Such device also helps to distinguish neutrino signals from the background.



10.869 м – higher position

Distances to the reactor core:

11.935 м – lower position

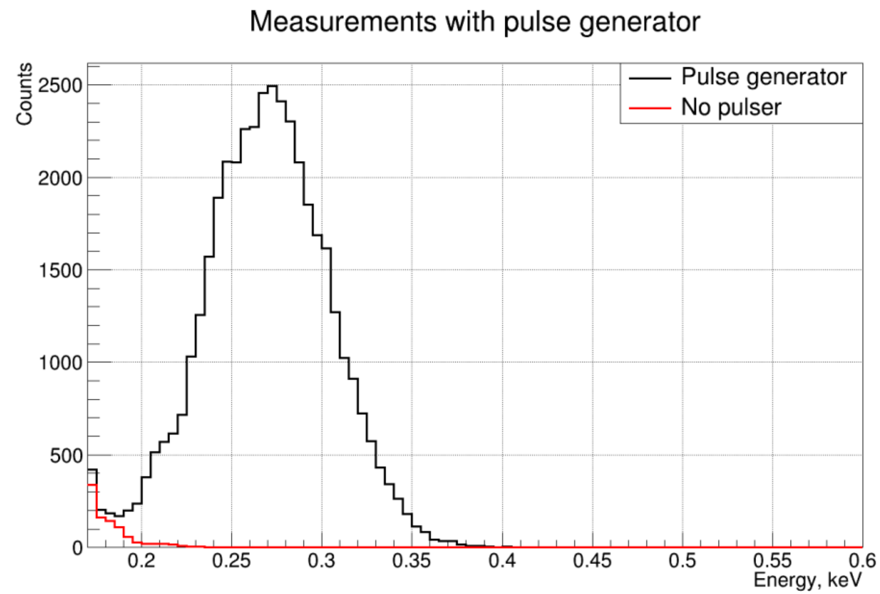
Changes of the ν flux helps to suppress systematics errors connected with changes of background while reactor ON/OFF

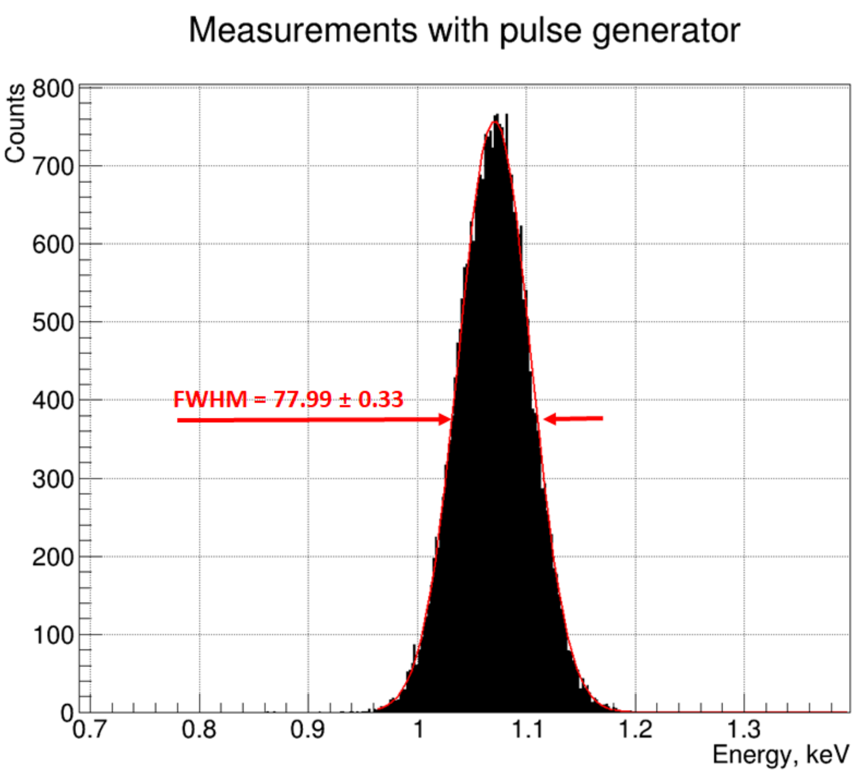
HPGe detector for vGEN

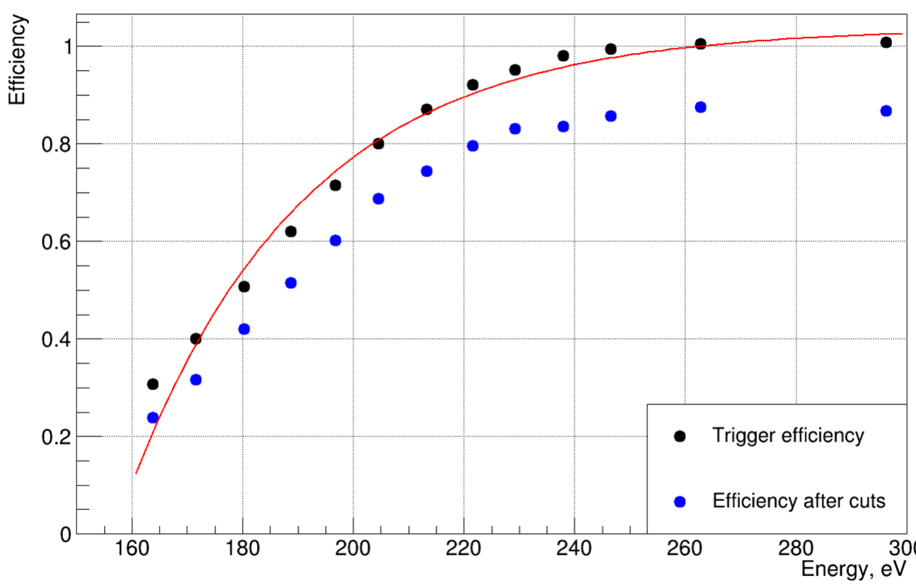
To detect signal from neutrino scattering we use specially produced by CANBERRA (Mirion, Lingosheim) low-threshold, low-background HPGe detectors. We use detectors both with electric and nitrogen cooling.

Tests at JINR

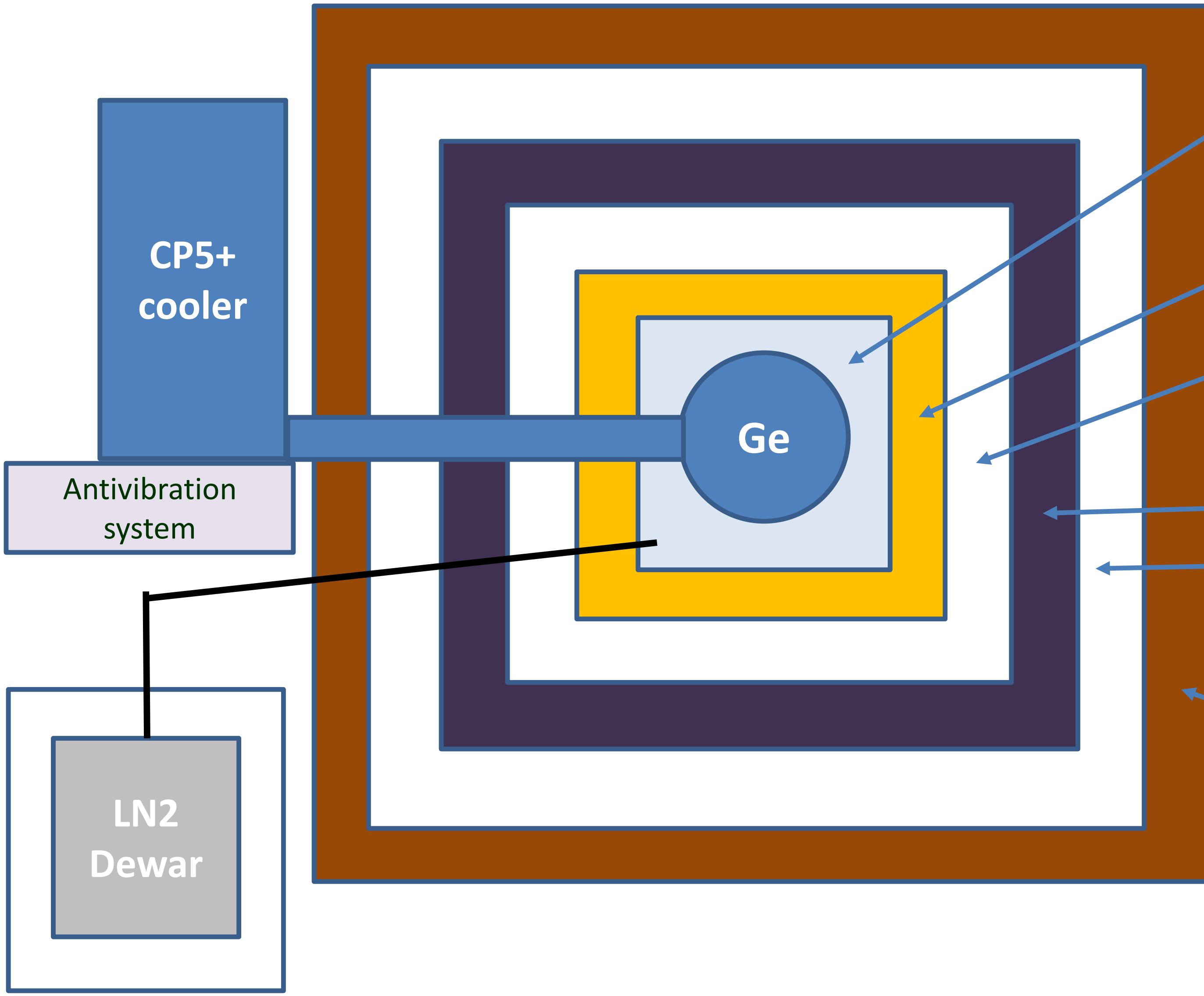
Test measurements at JINR showed a good energy resolution of a first detector – **77.99(33) eV** (FWHM), stable performance. A possibility to acquire signals **below 250 eV** (with trigger efficiency of about 70%) was demonstrated.





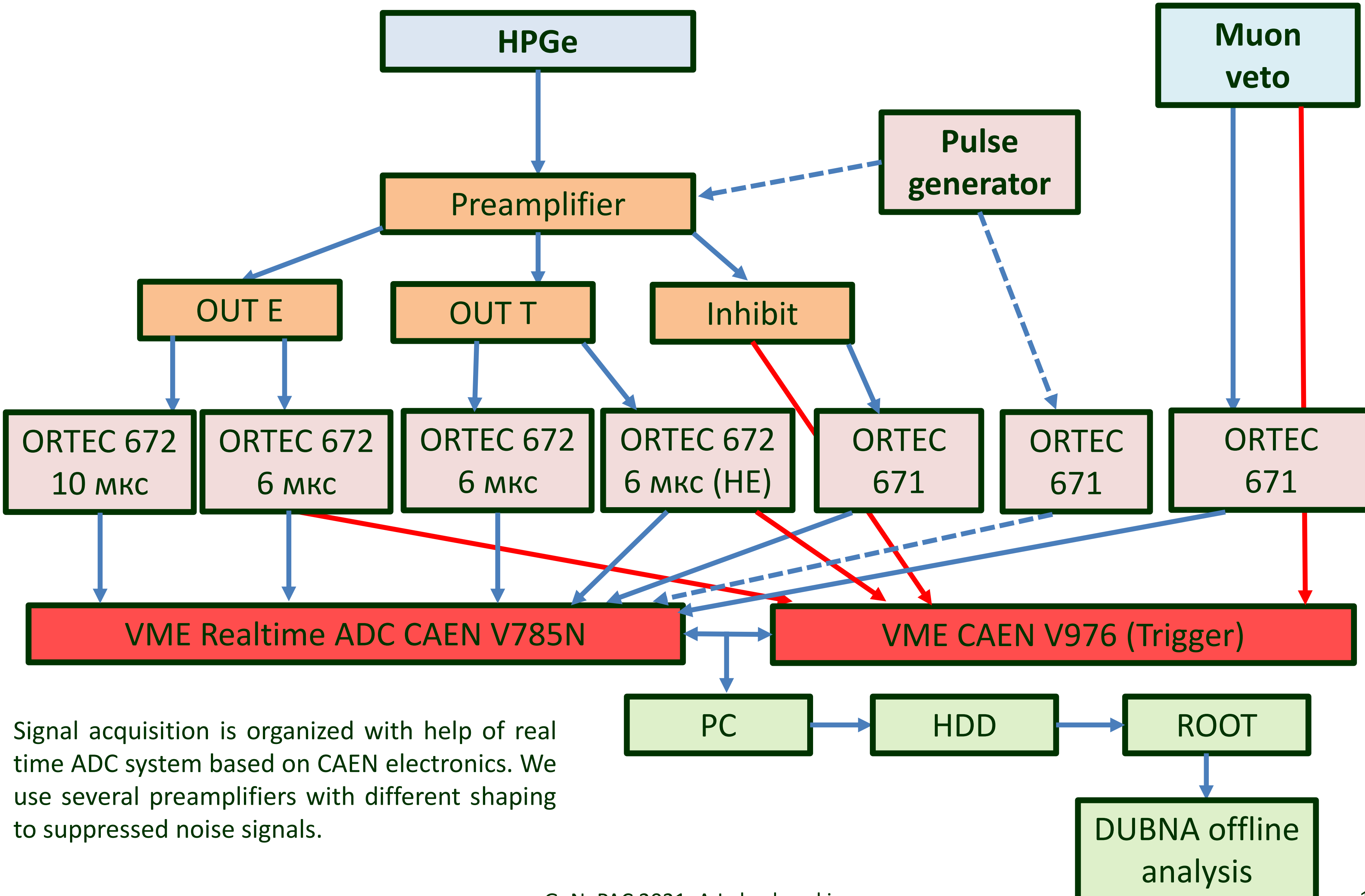


Current scheme of shielding



- 3D printed nylon for radon displacement
- Oxygen free copper – 10 cm
- Borated polyethylene 3.5 % – 8 cm
- Lead – 10 cм
- Borated polyethylene 3.5% – 8 cm
- Active muon veto – 5 cm

Simplified scheme of measurements



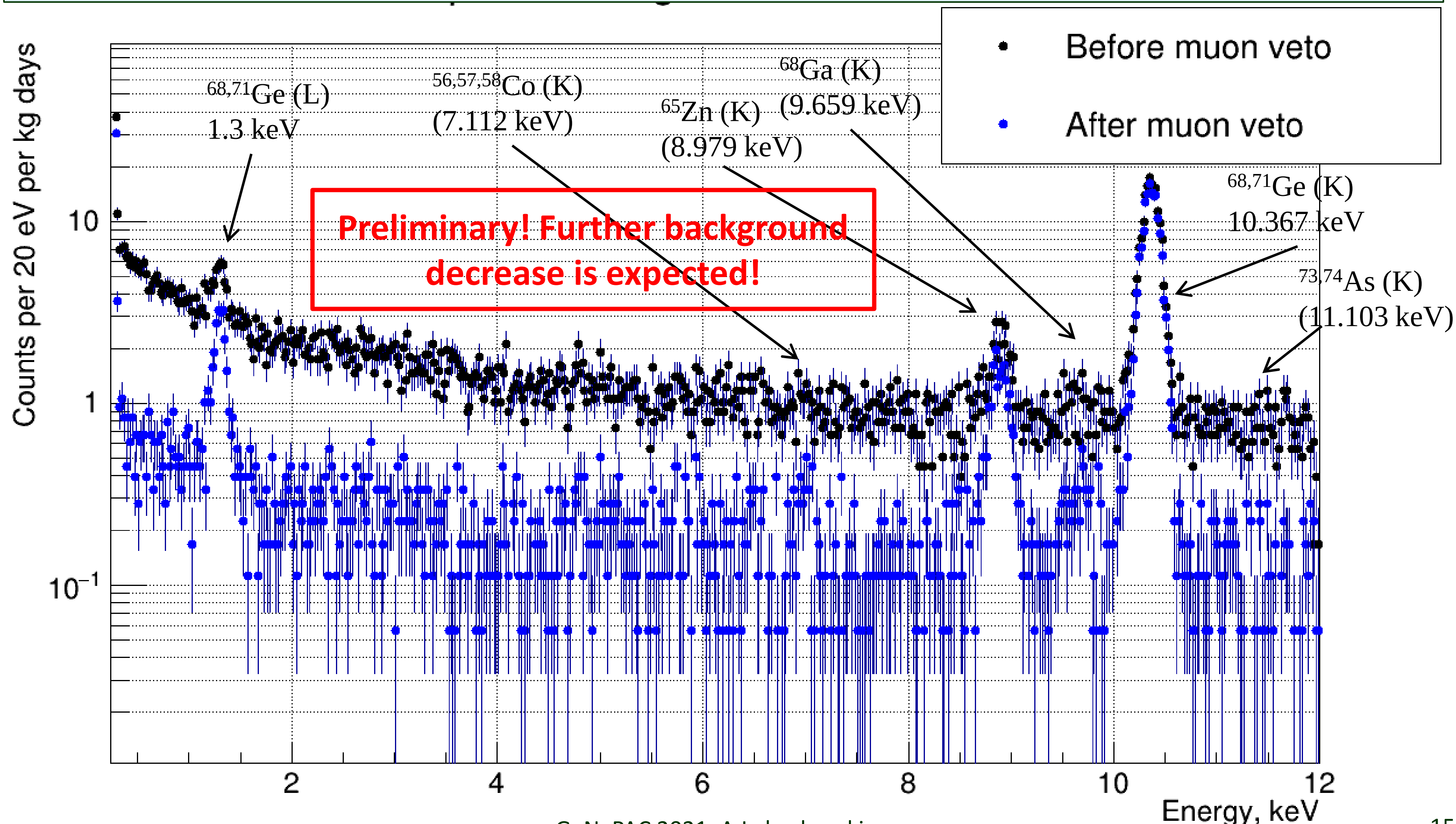
Signal acquisition is organized with help of real time ADC system based on CAEN electronics. We use several preamplifiers with different shaping to suppressed noise signals.

Installation at KNPP

- First detector has been successfully installed at KNPP.
- Active and passive shielding according to above scheme has been organized.
- Test measurements have been started.

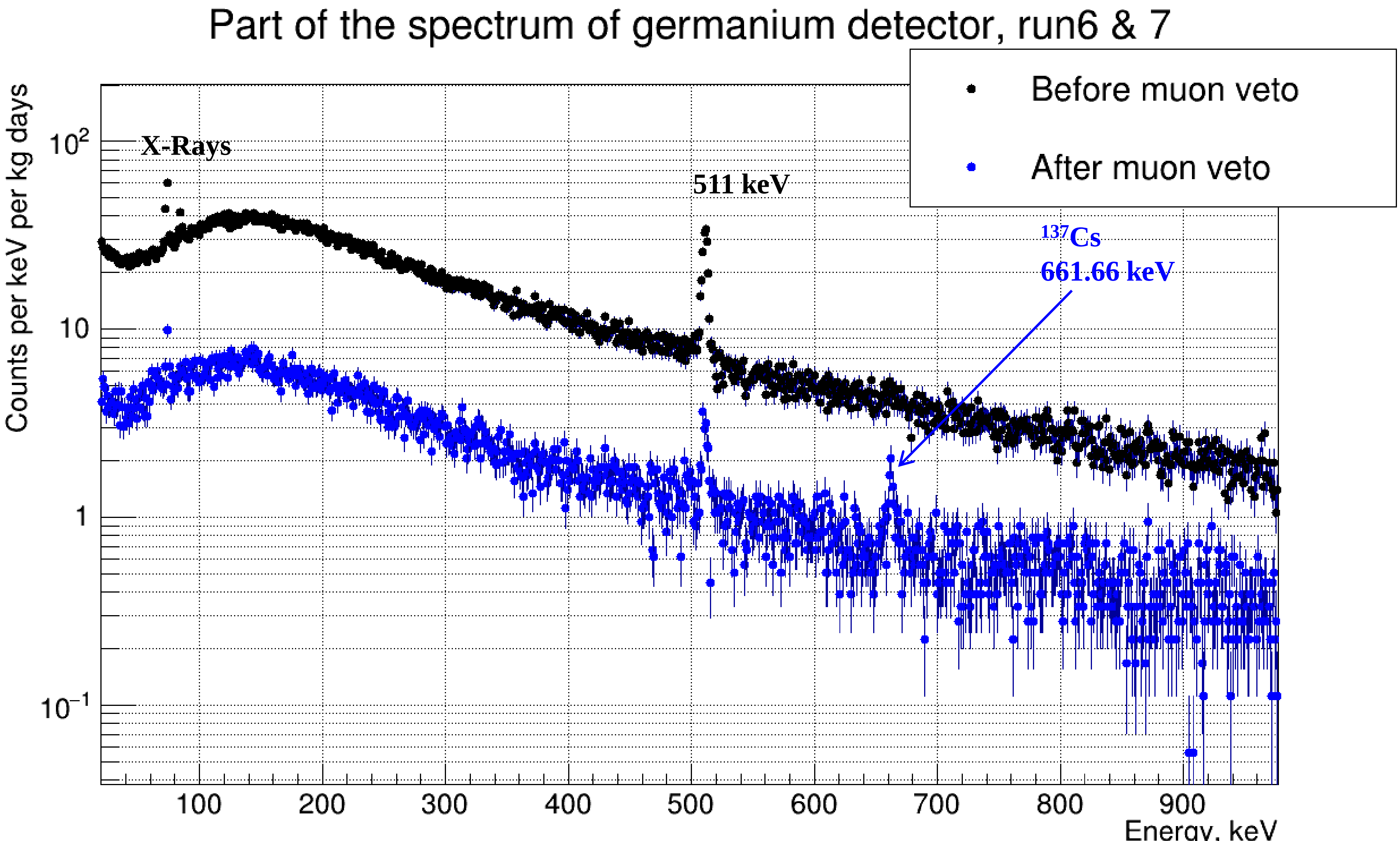
Energy spectrum

All visible lines at the low energies are from cosmogenic activation. These isotopes decay in time. Background level is much better than in some dark matter germanium experiments. Resolution at **10.37 keV** – **187(3) eV (FWHM)**, на **1.3 keV** – **124(9) eV (FWHM).**



High energy region

High energy part of the spectra taken by 11.9 days of measurements.



SWOT

- Very good experimental conditions at the reactor site – the highest antineutrino flux available (of more than 5×10^{13} $\nu/(cm^2\times s)$).
- Most dangerous cosmic background is strongly suppressed by the reactor surrounding (overburden of 50 m w.e.).
- In comparison to other projects, we can use a lifting mechanism to change the neutrino flux, reducing systematical errors.
- Our group at DLNP JINR holds huge expertise connected with different low background projects. The core group of the project is relatively young people, with good experience in neutrino physics and low-background projects.
- Our group has proved the capability to achieve the best experimental results in the world, setting up the best limit on the NMM.
- Many scientists put their efforts into this field and the level of competition is very high. So, it is possible, that somebody else can obtain better experimental results than we would do.
- The results obtained in this project may open up the possibility for another fundamental or applied investigation of neutrino properties. For example, searches for the fundamental non-standard neutrino interactions or applied research, like reactor monitoring.
- Personnel and administration of KNPP supports our activities, however, we cannot completely exclude potential difficulties at KNPP due to changes in regulation, rules, etc.

Personnel

The collaboration consists of scientists from **JINR** and **ITEP**. The list of the involved people is shown below:

JINR (Dubna):

V.V.Belov, V.B.Brudanin, V.A.Evsenkin, S.A.Evseev, D.V.Filosofov, M.V.Fomina, L.Grubchin, U.B.Gurov, A.Kh.Inoyatov, S.L.Katulina, S.V.Kazarcev, S.P.Kiyanov, A.S.Kuznecov, A.V.Lubashevskiy, D.V.Medvedev, D.V.Ponomarev, D.S.Pushkov, A.V.Salamatin, K.V.Shakhov, Z.Kh.Khukhvatov, V.G.Sandukovsky, M.V.Shirchenko, E.A.Shevchik, S.V.Rozov, I.E.Rozova, V.P.Volnikn, I.V.Zhitnikov, E.A.Yakushev

ITEP (Moscow):

A. G. Beda, A. S. Starostin

Estimation of human resources of JINR group:
Total FTE (Engineers): 3.5,
Total FTE (Scientific staff): 3.2,
Total FTE: 6.7

Estimated expenditures for the Project

#	Designation for outlays	Total cost	1 year	2 year	3 year
1.	Networking	**6.0k US$**	**2.0**	**2.0**	**2.0**
2.	DLNP workshop	**600 norm-hours**	**200**	**200**	**200**
3.	Materials	**45.0k US$**	**35.0**	**10.0**	**0.0**
4.	Equipment	**350.0k US$**	**130.0**	**20.0**	**200.0**
5.	Expenses for R&D on a contract base	**6.0k US$**	**2.0**	**2.0**	**2.0**
6.	Travel expenses, including	**60.0k US$**	**20.0**	**20.0**	**20.0**
	a) to non-rouble zone countries		**5.0**	**5.0**	**5.0**
	б) to cities of rouble zone countries		**15.0**	**15.0**	**15.0**
	Total	**467 k$**	**189 k$**	**54 k$**	**224 k$**

Conclusion

- Measurements with νGeN spectrometer with a first detector at KNPP has been started.
- Results of first measurements shows that achieved background level allows to search for CEvNS at KNPP.
- More optimization and new detectors are ongoing.
- Measurements in a regime with turned off reactor is expected from March 2021
- New results and observation of CEvNS are expected soon.
- Planned sensitivity to NMM ~ $(5\text{-}9)\cdot 10^{-12}\ \mu_B$ after several years of measurements.

Supplementary materials

Schedule and resources

			List of parts and devices; Resources; Financial sources	Cost of parts (K US$), resources needs	Allocation of resources and money 1st year	2nd year	3rd year
Main parts and equipment			1. Cryogenic and vacuum equipment for the detectors. New advance detector.	270	70		200
			2. Materials and equipment for calibration and shielding.	45	35	10	
			3. Electronics NIM	40	30	10	
			4. Electronics VME	40	30	10	
			Total	395	165	30	200
Resources	Norm-hours		DLNP workshop	600	200	200	200
Financial sources	JINR budget		Budget spending	395	165	30	200
	Off-budget sources		Grants; Other sources (these funds are not currently guaranteed)	45	20	15	10

Involved personnel

Name	Category	Responsibilities	FTE
V.V.Belov	Junior researcher	Muon veto, MC, data taking	0.2
V.B.Brudanin	Major researcher	Administrative work, project management	0.1
V.A.Evsenkin	Engineer	Constructions, detector building	0.5
S.A.Evseev	Engineer	Constructions, detector building	0.4
D.V.Filosofov	Head of sector	Calibration sources	0.1
M.V.Fomina	Junior researcher	Muon veto, MC	0.1
L.Grubchin	Leading researcher	Detector development	0.1
U.B.Gurov	Senior engineer	Detector development	0.2
A.Kh.Inoyatov	Head of sector	Spectroscopy measurements	0.1
S.L.Katulina	Senior engineer	Administrative work, materials preparations	0.1
S.V.Kazarcev	Junior researcher	Electronics, data taking	0.1
S.P.Kiyanov	Senior engineer	Data taking at KNPP	0.3
A.S.Kuznecov	Engineer	Data taking, MC	0.1
A.V.Lubashevskiy	Head of sector	Data analysis, MC, commissioning and administrative work	0.5
D.V.Medvedev	Researcher	Data analysis, MC	0.7
D.V.Ponomarev	Engineer	Constructions, detectors building, testing. Experiment running.	0.7
D.S.Pushkov	Senior enginieer	3D modeling and design of experimental setup	0.2
A.V.Salamatin	Senior reseacher	Electronics	0.1
K.V.Shakhov	Engineer	3D printing, construction	0.1
Z.Kh.Khukhvatov	Junior researcher	MC	0.2
V.G.Sandukovsky	Head of sector	Detector configuration, constructions	0.5
E.A.Shevchik	Senior engineer	Mu-veto, constructions	0.1
M.V.Shirchenko	Senior researcher	Data taking, analysis	0.1
S.V.Rozov	Engineer	Detector building, testing, calibration, running.	0.3
I.E.Rozova	Engineer	Data analysis, constructions	0.5
V.P.Volnikn	Engineer	Computer support	0.1
I.V.Zhitnikov	Junior researcher	Experiment running, data analysis	0.1
E.A.Yakushev	Head of department	Building, commissioning, running, data analysis	0.2
Total FTE (Engineers): 3.5, Total FTE (Scientific staff): 3.2, Total FTE: 6.7			

SWOT

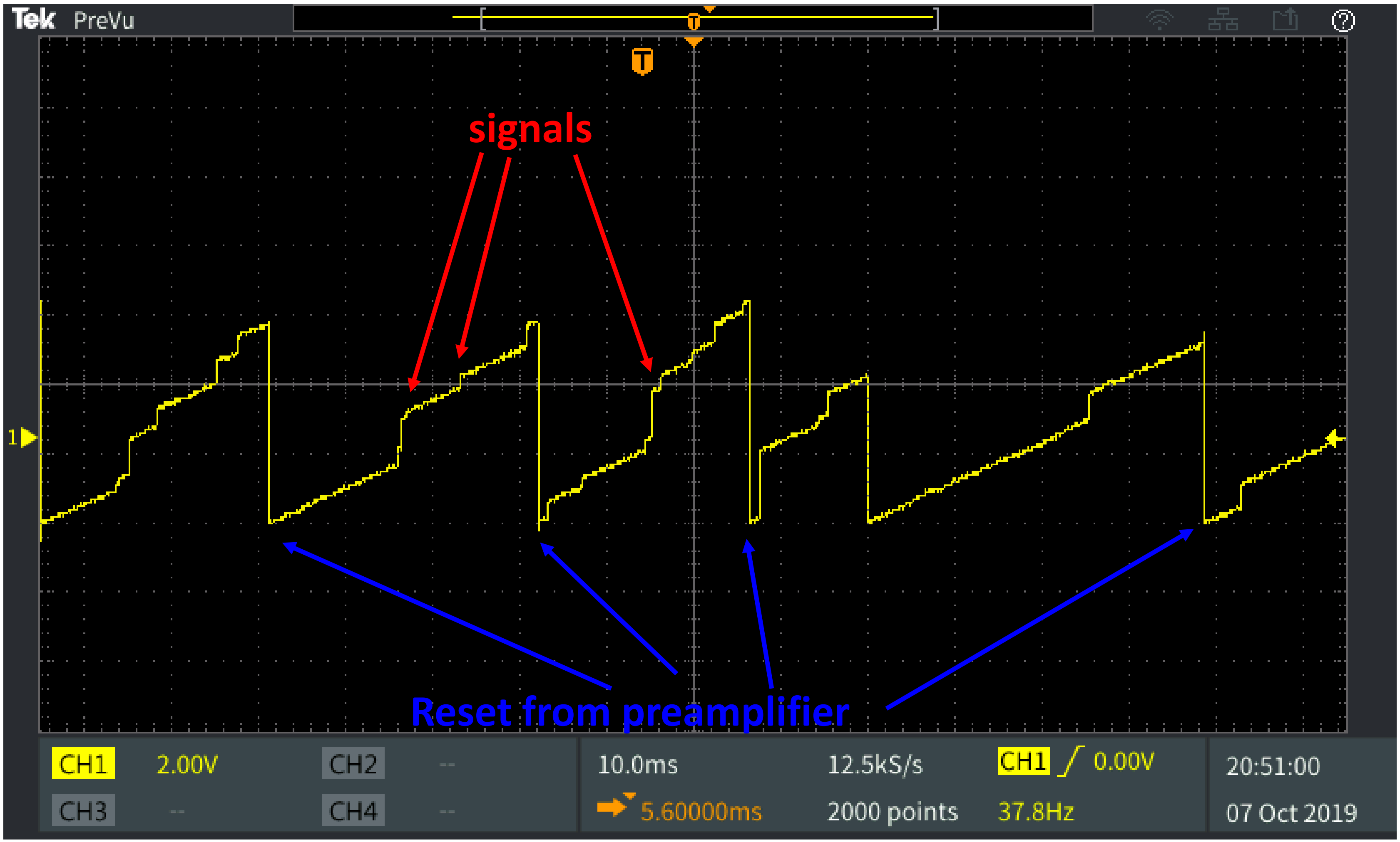
Strengths, Weaknesses, Opportunities, Threat (SWOT) analysis of νGeN project is discussed below.
The investigation of the properties of the neutrino attracts interests of many experimental groups around the Earth. Many scientists put their efforts in this field and the level of competition is very high. Due to this factor, it is possible that somebody can obtain better experimental result than we would do. This is one of the main threats of our project. But nevertheless, this gives a good opportunity to do interesting investigation on the first edge of the neutrino physics. The results obtained in this project may open up the possibility for another fundamental or applied investigations of neutrino properties. For example, searches for the fundamental non-standard neutrino interactions or applied research, like reactor monitoring.
Our group has proved capability to achieve the best experimental results in the world, setting up a best limit on the MMN. The big strengths of our project is the possibility to perform investigations with the enormous antineutrino flux of more than $5 \cdot 10^{13}$ $\nu/(cm^2 \cdot s)$. Moreover, the most dangerous cosmic background in the experimental room is strongly suppressed by the reactor building and various materials inside it. This is very suitable conditions to build an experiment for testing of fundamental properties of neutrino. In comparison to other projects we have possibility to use lifting mechanism that allows us to change the neutrino flux from the reactor by moving the spectrometer away from the core, reducing systematical errors. This is important due to the fact that sought signals typically have a signature similar to background or noise components. Personnel and administration of KNPP greatly supports our activities, however we cannot completely exclude potential difficulties at KNPP due to changes of regulation, rules etc. Therefore, this is a possible weakness of the project.
Our group at DLNP JINR holds huge expertises connected with different low background projects. Our division participates in many big international experiments for dark matter and neutrinoless double beta decay searches. Such interconnection gives us a big advantage of having the modest expertise and access to the recent developments in low background technique. From previous experiment, we have some low-background materials available and they can be used for the construction of a new experiment.
In addition, one of the most important strength of our project is people. The core group of the project is relatively young people, however already with a good experience in the neutrino physics and low-background projects. Many people have experience working for international collaborations. The investigations are leaded by big experts in the field. Therefore, there is good balance between youth and experience in this project.

Installation at KNPP

Nitrogen flushing is used to suppressed radon background.

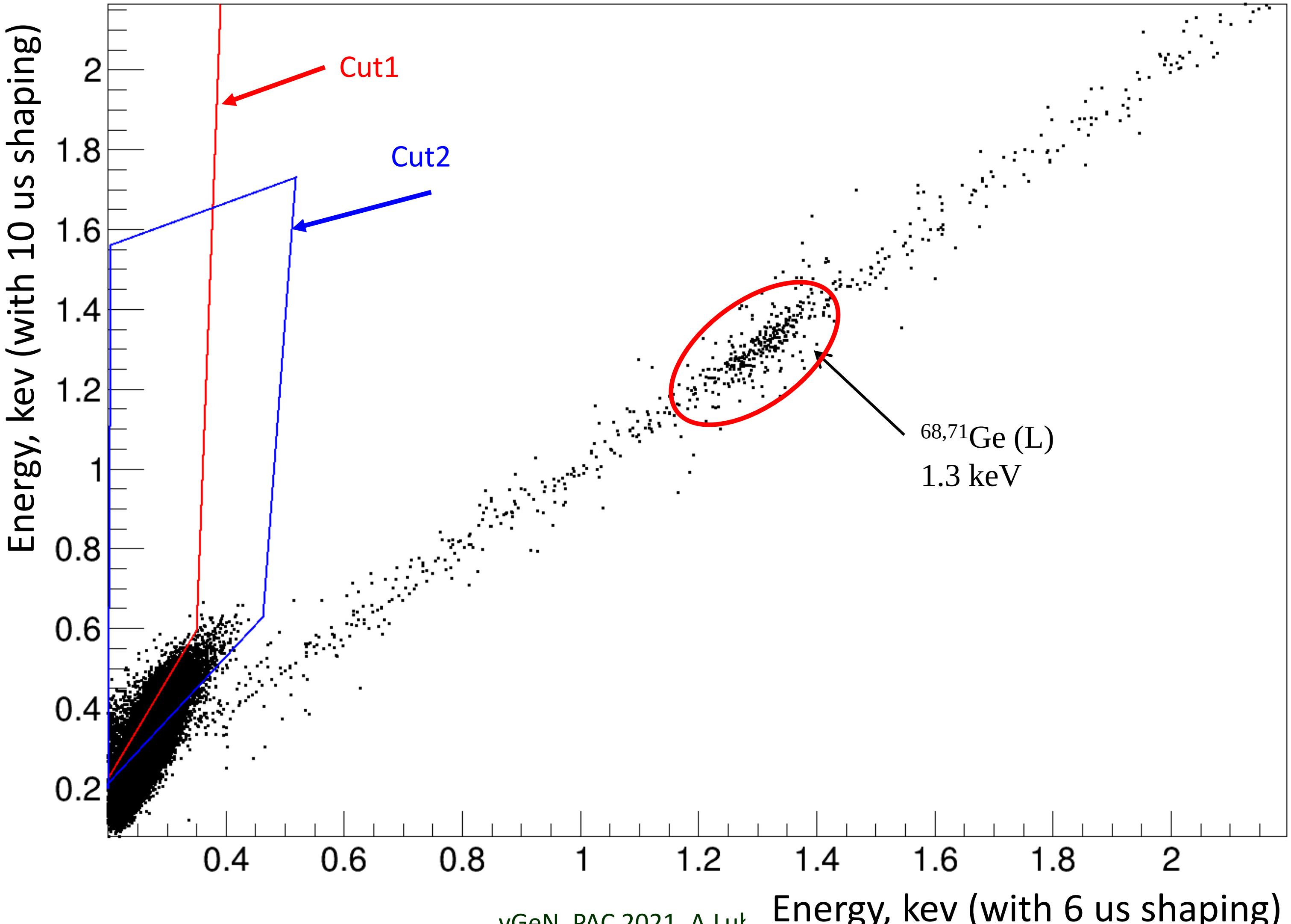
Signals from detector

Detector are equipped with reset preamplifier. Typical rate of the reset is ~ 5-30 Hz. There is a special inhibit signal indicates then time when the reset happens.



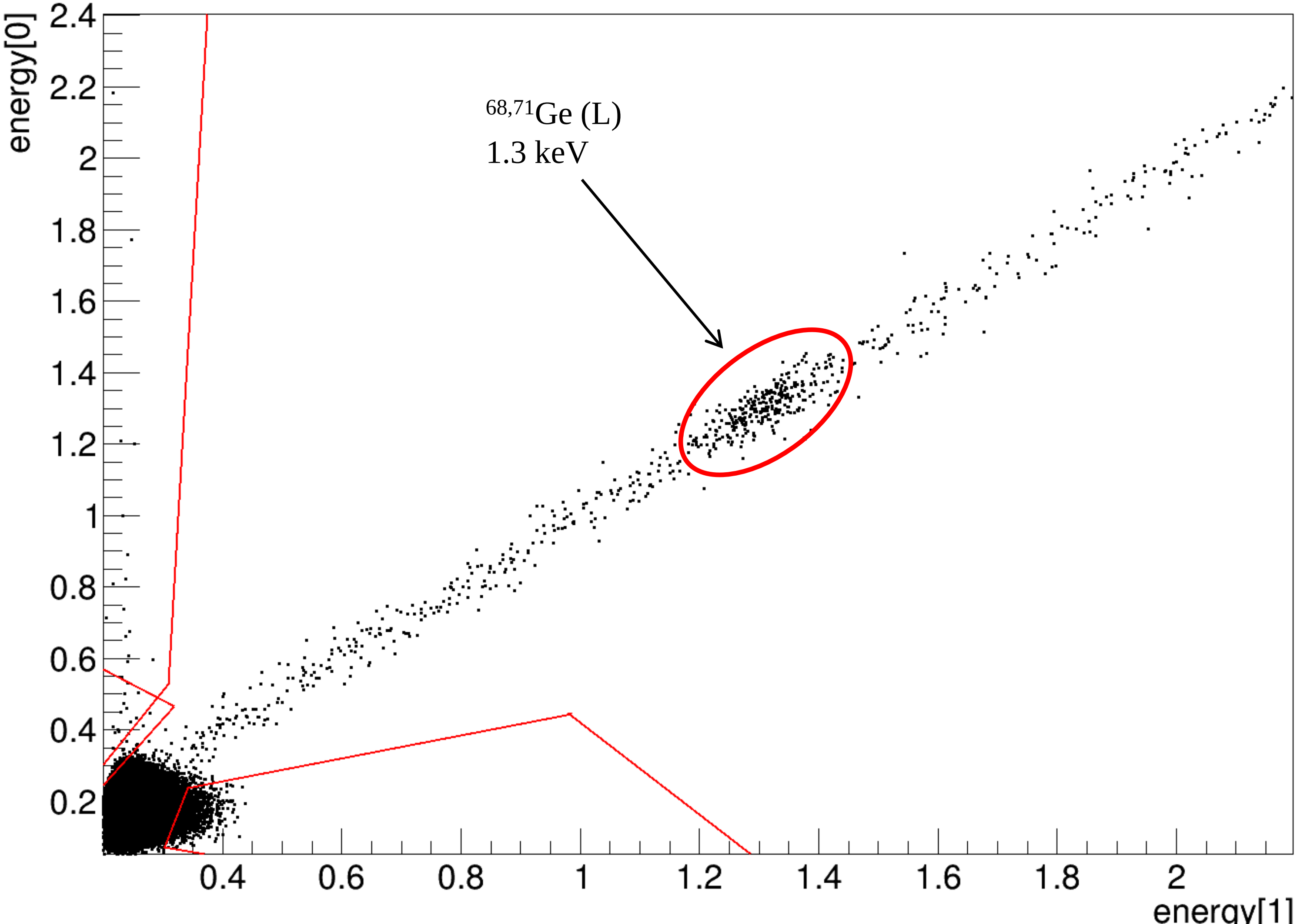
Noise suppression

Signal shapes with help of several preamplifiers (ORTEC 672). Different shaping times is use to suppress the noise.

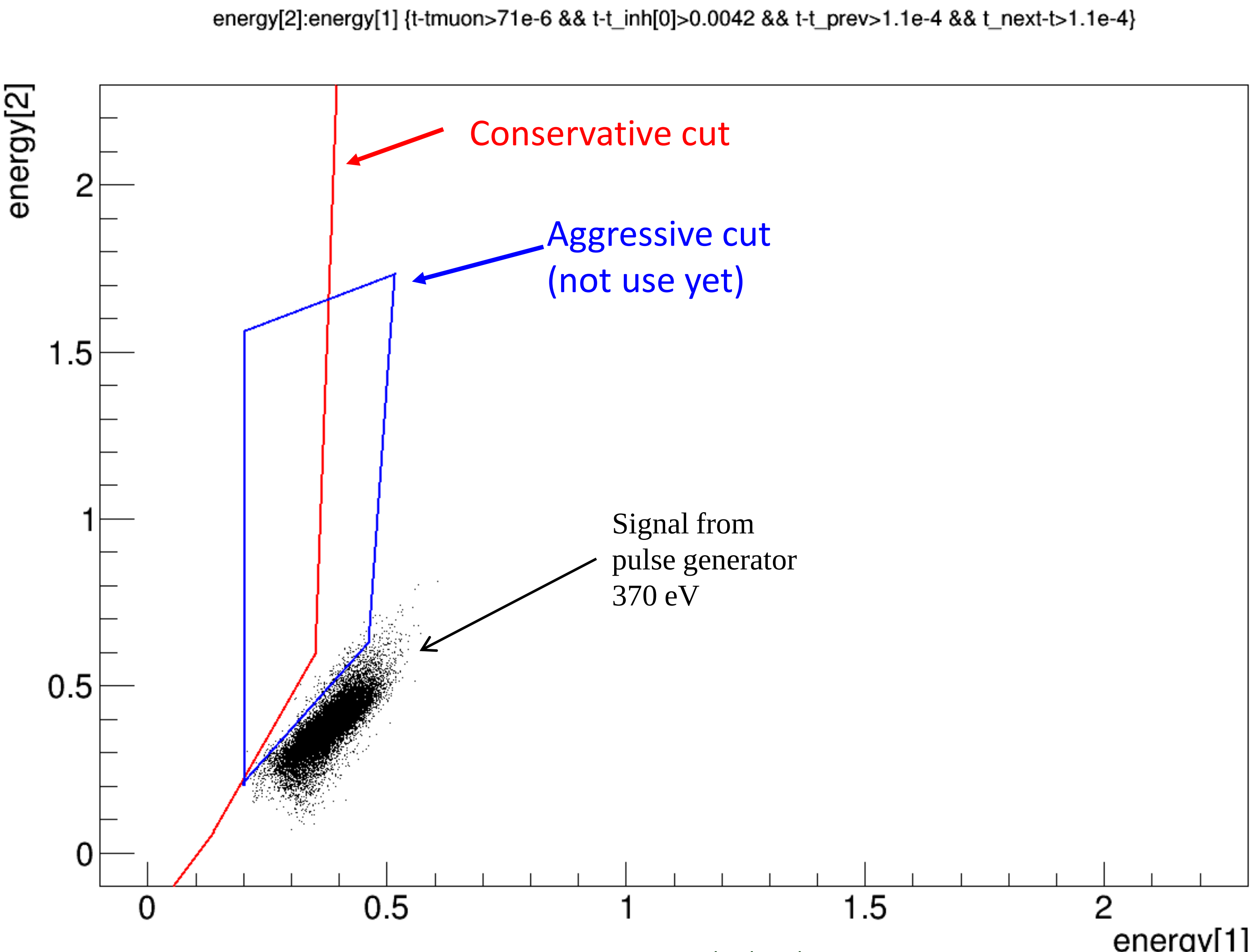


Noise suppression

For further suppression of the noise signals we perform comparison of the parallel signals from preamplifier.



Measurements with pulse generator



Measurements with pulse generator