Investigation of neutrino properties with Ge detectors on KNPP

Kalininskaya Nuclear Power Plant (KNPP)

- Udomlya, ~ 280 km to the North from Moscow
- 4 reactor units
- 3 GW thermal power each
- Possibility to place experimental setup very close to reactor core

GEMMA

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Scientific motivation (GEMMA)

- Beyond the MSM:

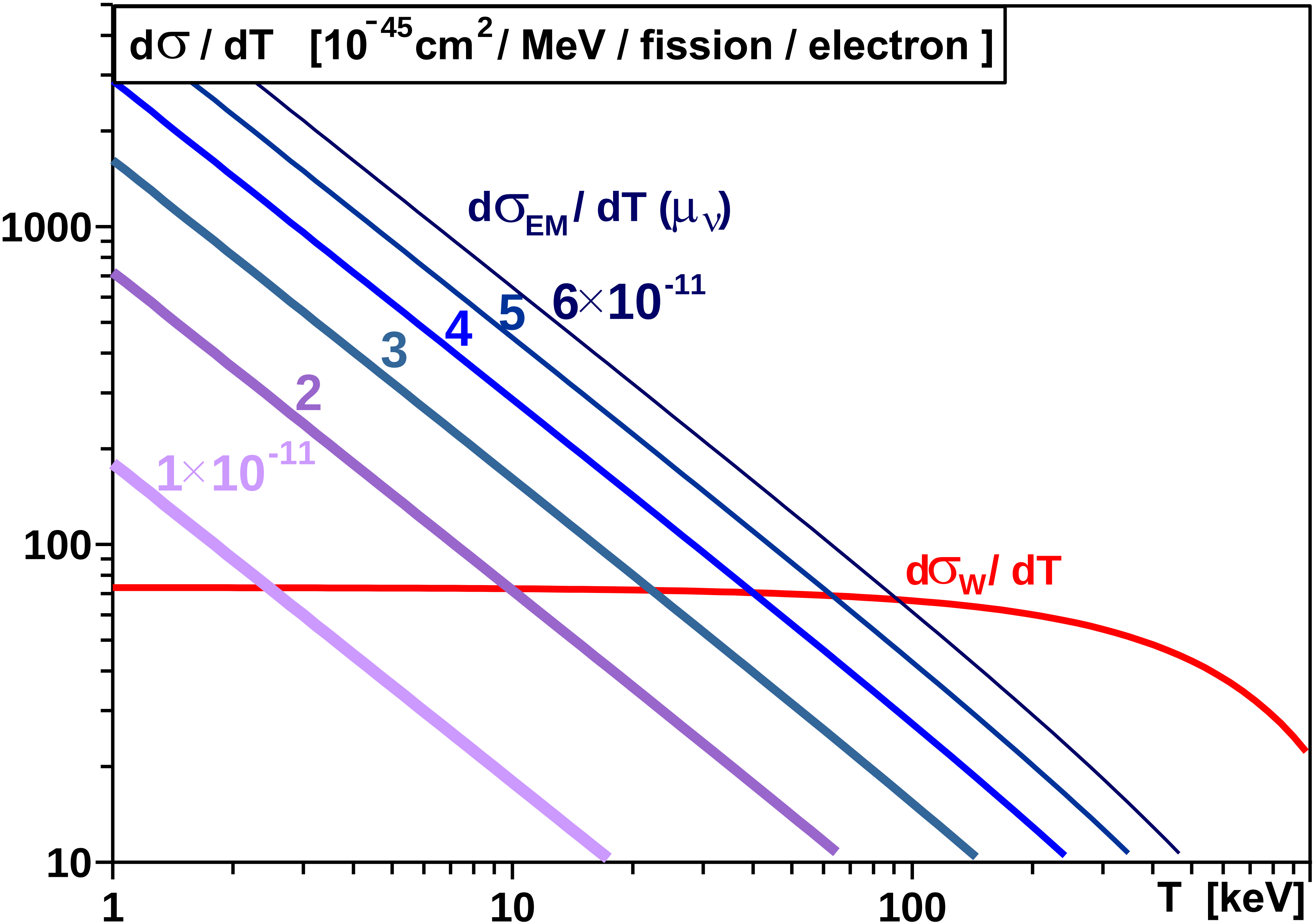
$$\mu_\nu \leq 10^{-14}\, \mu_B \times (m_\nu \,/\, 1\mathrm{eV})$$

$$\mu_\nu \sim 10^{-10} - 10^{-11}\, \mu_B$$

Scientific motivation (GEMMA)

in case $\mu_\nu \sim 10^{-11}$-$10^{-12}\ \mu_B$:

- Neutrino nature
- Λ parameter
- Astrophysical interest



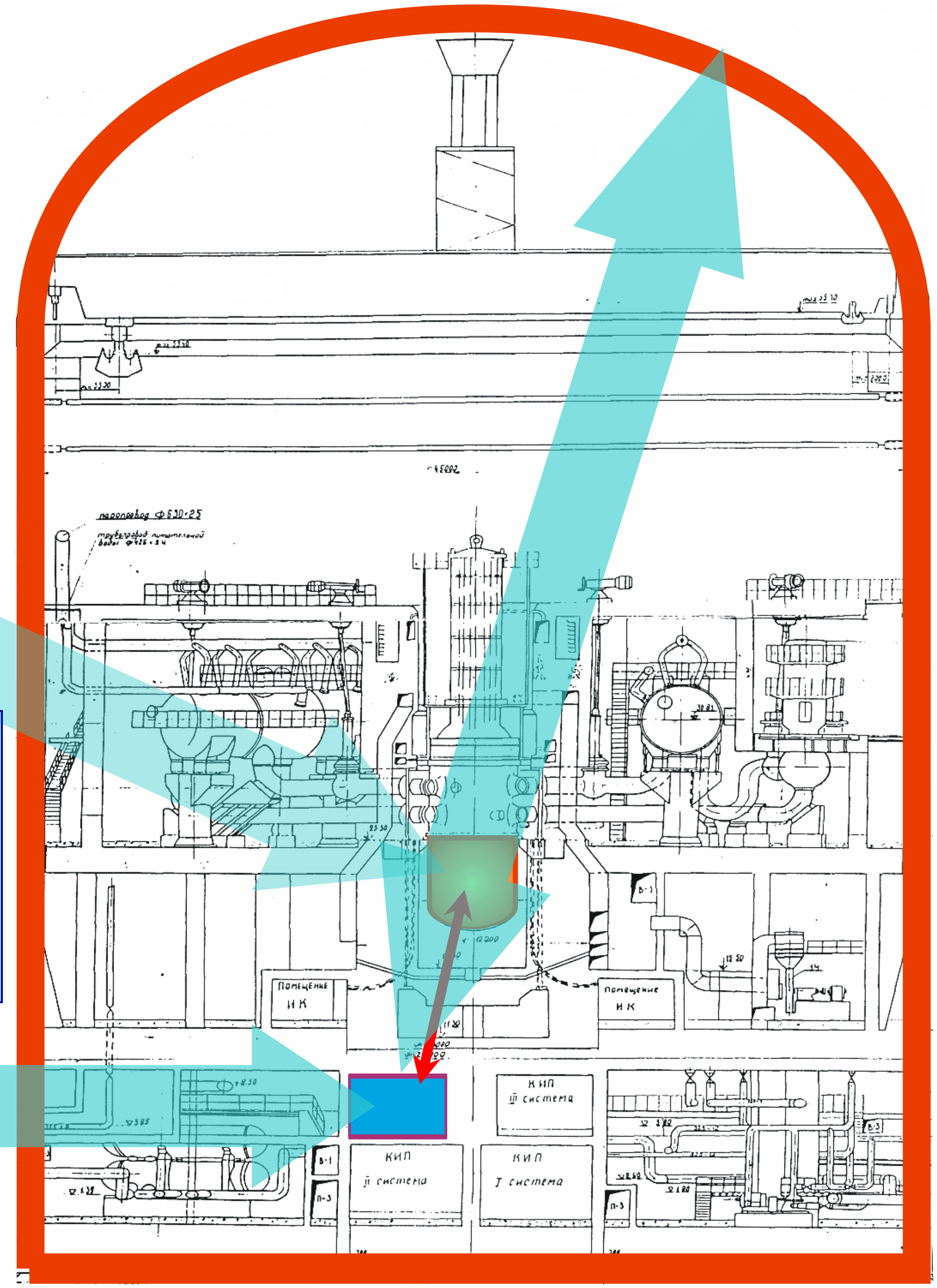
dσ / dT [10^{-45}cm^2/ MeV / fission / electron]
dσ$_{EM}$/ dT (μ$_ν$)
6×10^{-11}
5
4
3
2
1×10^{-11}
dσ$_W$/ dT
1000
100
10
1
10
100
T [keV]

Reactor unit #2 of the "Kalinin" Nuclear Power Plant (400 km North from Moscow)

Power: 3 GW
ON: **315** days/y
OFF: **50** days/y

Total mass above
(reactor, building, shielding, etc.):
~70 m of W.E.

Technological room
just under reactor
14 m only!
$2.7\times10^{13}\ \nu/cm^2/s$

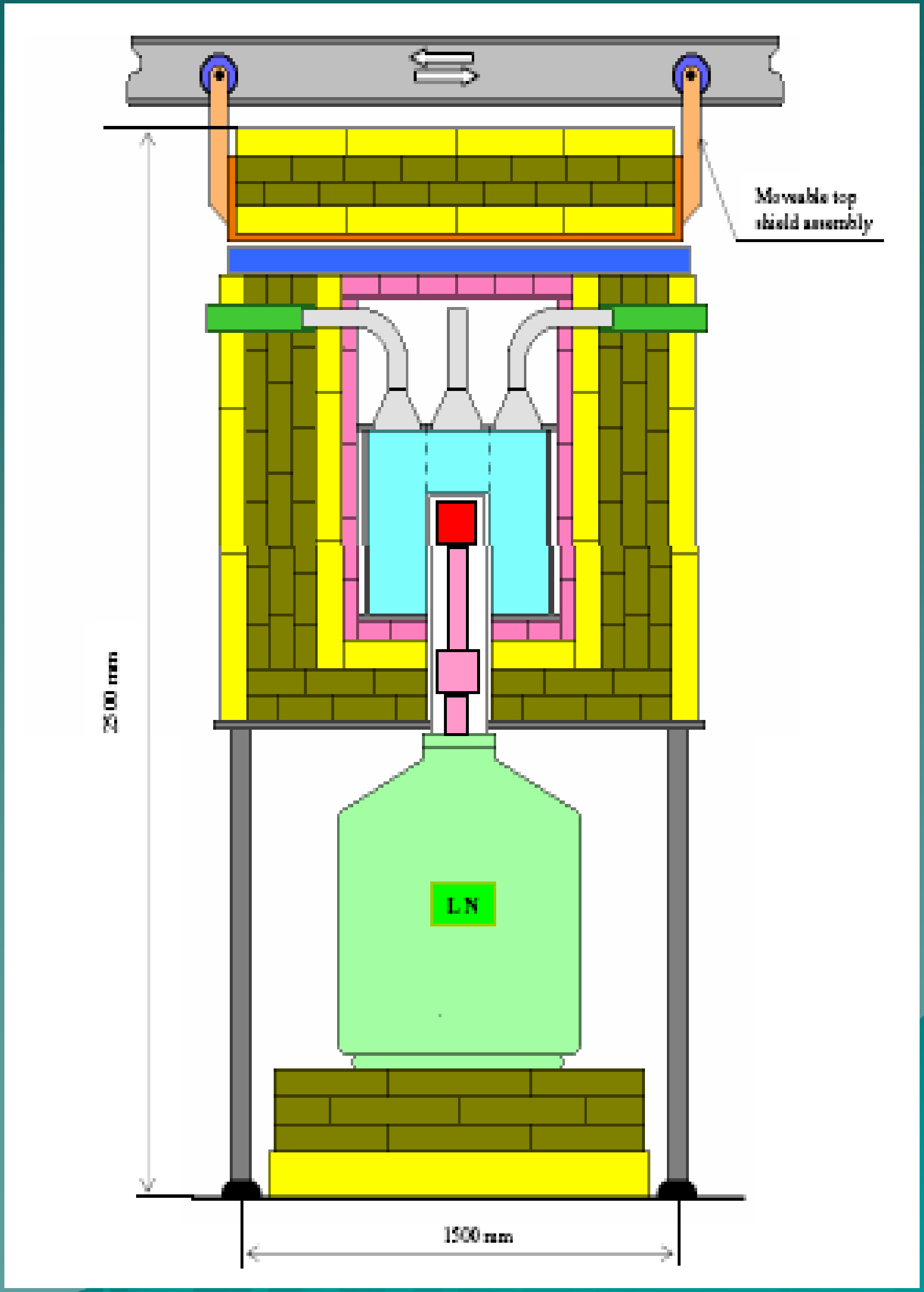


Experiment **GEMMA**

(**G**ermanium **E**xperiment for measurement of **M**agnetic **M**oment of **A**ntineutrino)

*[Phys. of At. Nucl.,**67**(2004)1948]*

- Spectrometer includes a HPGe detector of 1.5 kg installed within NaI active shielding.
- HPGe + NaI are surrounded with multi-layer passive shielding : electrolytic copper, borated polyethylene and lead.



Experimental sensitivity

$$\mu_\nu \propto \frac{1}{\sqrt{N_\nu}} \left(\frac{B}{mt} \right)^{\frac{1}{4}}$$

N_ν : number of signal events expected
B : background level in the ROI
m : target (=detector) mass
t : measurement time

$N_\nu \sim \varphi_\nu \, (\sim Power / r^2)$
$\sim (T_{max} - T_{min} / T_{max} * T_{min})^{1/2}$

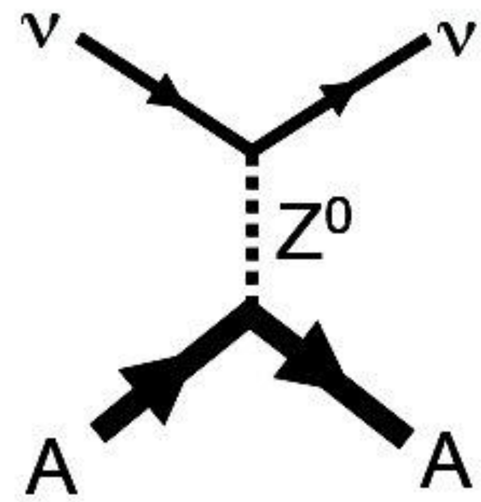
φ_ν ~ 2.7 ×10^{13} ν / cm^2 / s
t ~ 4 years
B ~ 2.5 keV^{-1} kg^{-1} day^{-1}
m ~ 1.5 kg
T_{th} ~ 2.8 keV

$$\mu_\nu \leq 2.9 \times 10^{-11} \mu_B$$

Scientific motivation (νGeN)

Coherent neutrino scattering

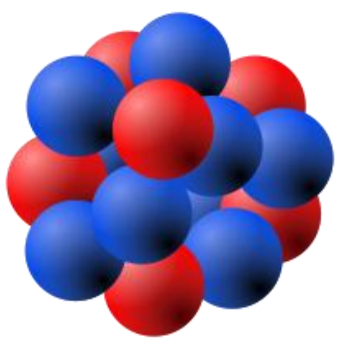
Coherent Neutral Current Neutrino-Nucleus Elastic Scattering



This mode of neutrino interaction with matter is well allowed in the Standard Model, the process was first described about 40 years ago by D.Z. Freedman

Cross section is enhanced by several orders of magnitude being proportional to the number of nuclear target neutrons squared

The target



$$\frac{d\sigma}{d(\cos\theta)} = \frac{G^2}{8\pi}[Z(4\sin^2\theta_W - 1) + N]^2 E^2 (1+\cos\theta)$$

Eν<50 MeV

It has yet remained undetected.
This is because the only signature of the process is a low nuclear recoil energy with max recoil energy $2E_\nu^2/M$

Scientific motivation (νGeN)

Why it's important to detect:

- We have never observed coherent neutrino scattering!

- Process of coherent neutrino scattering on nuclei was very important in the early Universe and is crucial for star evolution;

- Neutral current interaction is independent from known neutrino types. Therefore, observation of neutrino oscillations with a neutrino coherent scattering detector would be evidence for the existence of sterile neutrino(s);

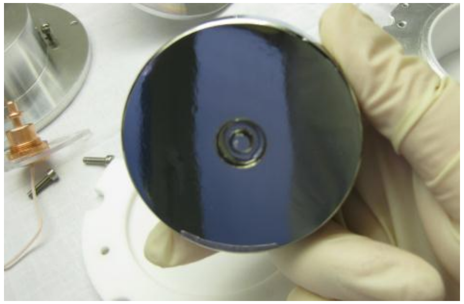
- Since the cross section is several orders higher with respect to usual neutrino interactions with matter a neutrino coherent scattering detector can be used for neutrino applied physics (like nuclear reactor monitoring).

νGeN : Experiment at KNPP for Detection of Coherent Neutrino – Ge Nucleus Elastic Scattering

Our aim is the first detection of coherent neutrino scattering !!!
The targets are Ge nuclei and detectors are point contact p-type HPGe.

How we want to achieve this aim

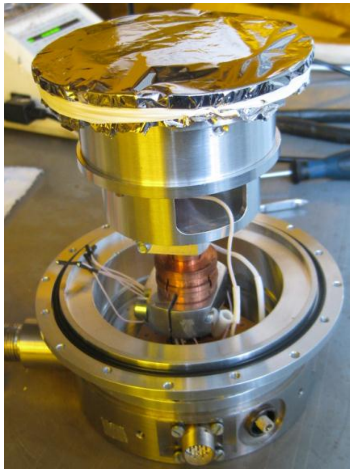
Detectors with low energy threshold



Point contact HPGe detectors produced at Dubna (~400 g. each detector).

The energy threshold from 300-350 eV

Low background cryostat and low noise electronics



This setup for 4 detectors is already produced and tested

Commissioning in ideal conditions

For correct interpretation of results many methodical studies (energy calibration for E~1 keV, fiducial volume, own background) are required.
We use one of the best low background infrastructure available – EDELWEISS-I shield in the LSM underground laboratory. The shield is already about 15 years underground, has radon-free air supply, etc)

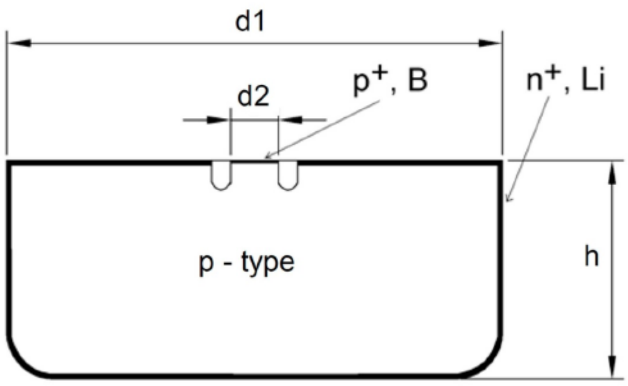
Measurements with highest available neutrino flux

Kalinin nuclear power plant. At 10 m from the reactor core the flux is 5.4 x 10^{13} $1/cm^2/sec$.

Improved low background shield of GEMMA experiment (world leader of neutrino magnetic moment measurement.) .
The available region for measurement is located just under the reactor, which provides about 70 m.w.e. shielding from cosmic rays.

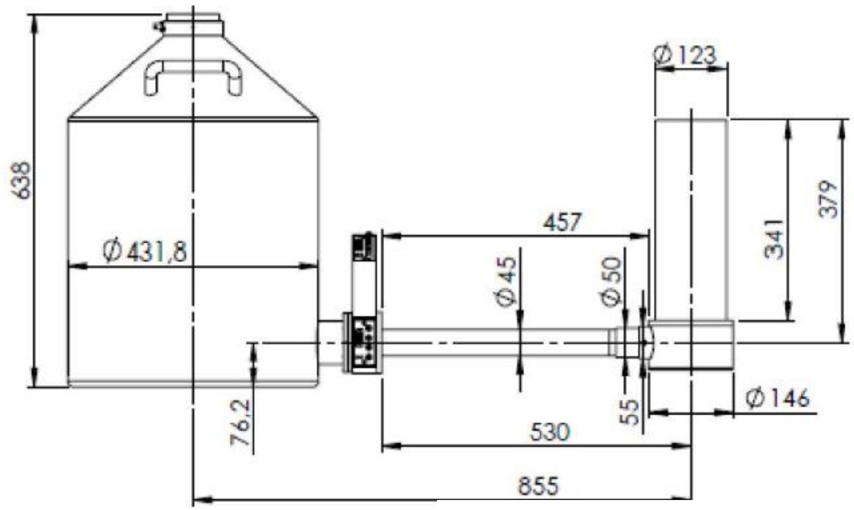
Detectors

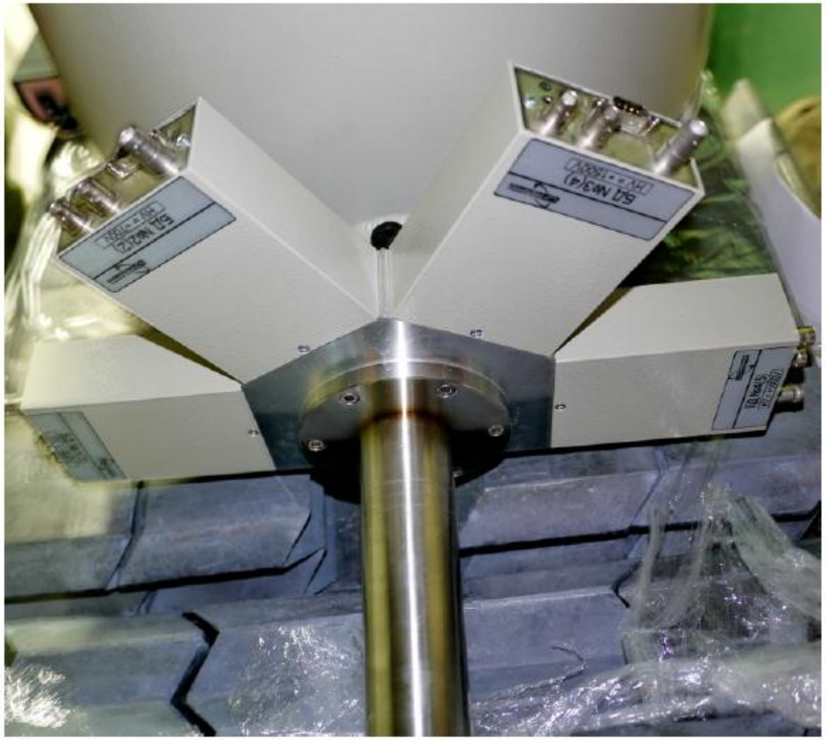
Low threshold high-purity Ge-detectors (HPGe) developed by JINR (Dubna, Russia) in collaboration with BSI (Baltic Scientific Instruments, Riga, Latvia)



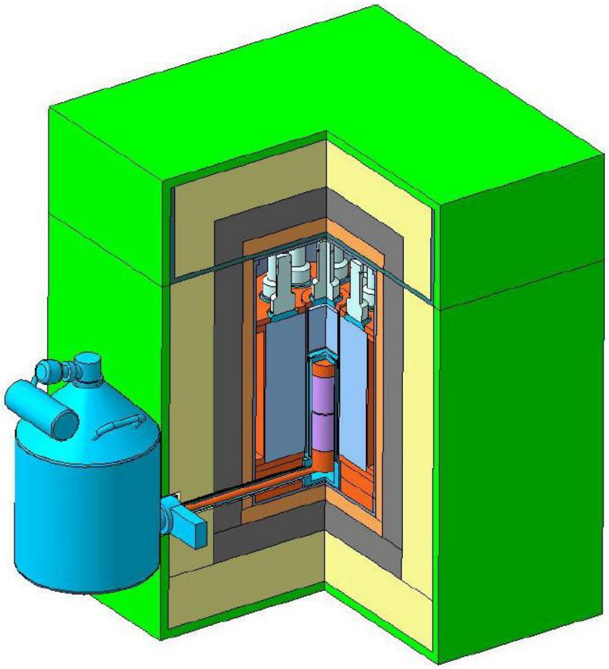
Size, mm \ Detector	N1	N2	N3	N4
d1	61.9	61.9	62.0	65.0
h	23.6	24.6	24.8	25.0
d2	5	5	5	5

Low background cryostat

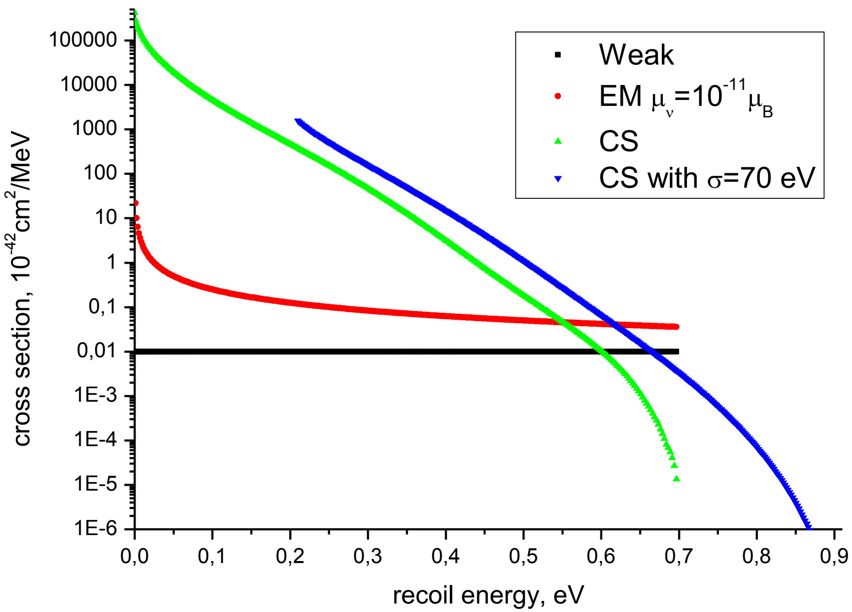


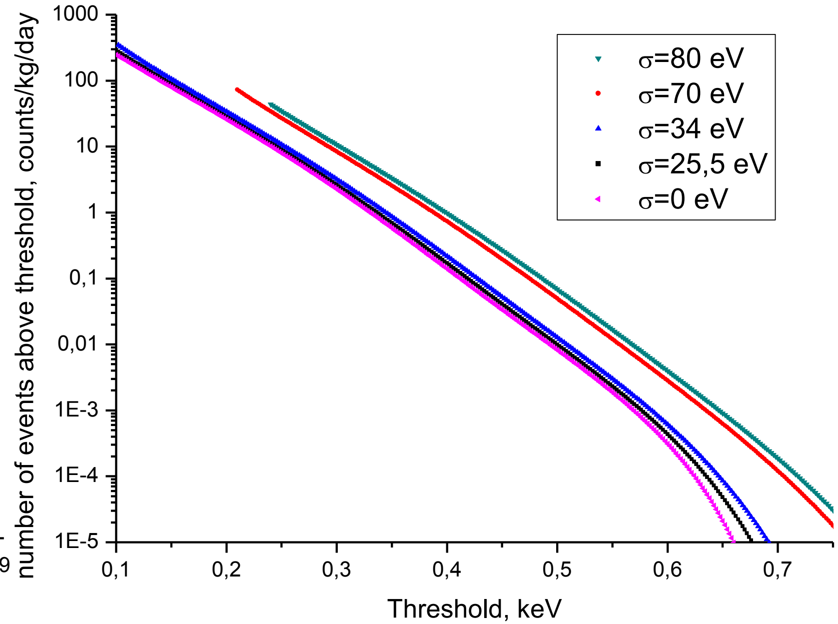


Shielding



Cross section and count rate



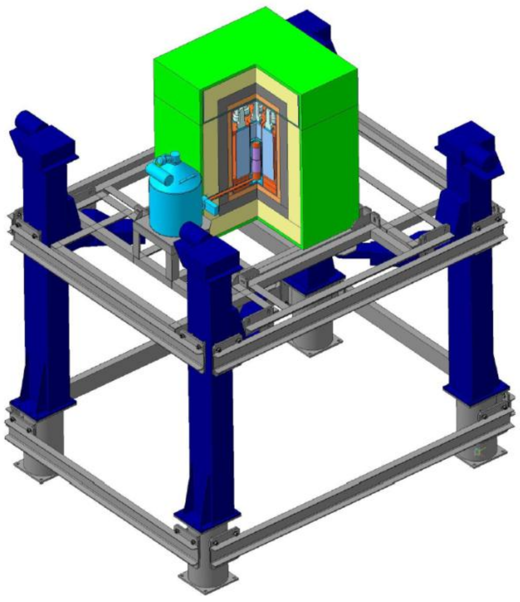


Summary / plans

- Low background cryostat with 4 low threshold detectors was created.
- Energy threshold from 350 eV without pulse Shape Discrimination method.

• Delivery of the setup to KNPP (July 2016). From results of GEMMA experiment we expect that background in the ROI will be <1 event/day;

• Calculations predict that with energy threshold 350 eV and with 1 kg of HPGe detectors located at the distance of 10 m from the reactor about 10 events of neutrino-nucleus coherent scattering will be detected per day;



• The result will be confirmed in two ways:
1) reactor ON/OFF measurements;
2) comparison of spectra at distances from 10 to 12 m from the reactor core (lifting device is already available)

Conclusion and outlook

• In neutrino physics which is a very active field of research the detection of low energy neutrinos (with energy below 50 MeV) via coherent scattering on nuclei remains a desired ambition;

• The present νGeN project uses low threshold high-purity Ge-detectors developed by JINR (Dubna) and BSI (Riga) for creation of setup designated for the first observation of neutrino coherent scattering on Ge;

• As a powerful neutrino source the experiment will use antineutrinos from one of the power-generating units of the Kalinin nuclear power plant;

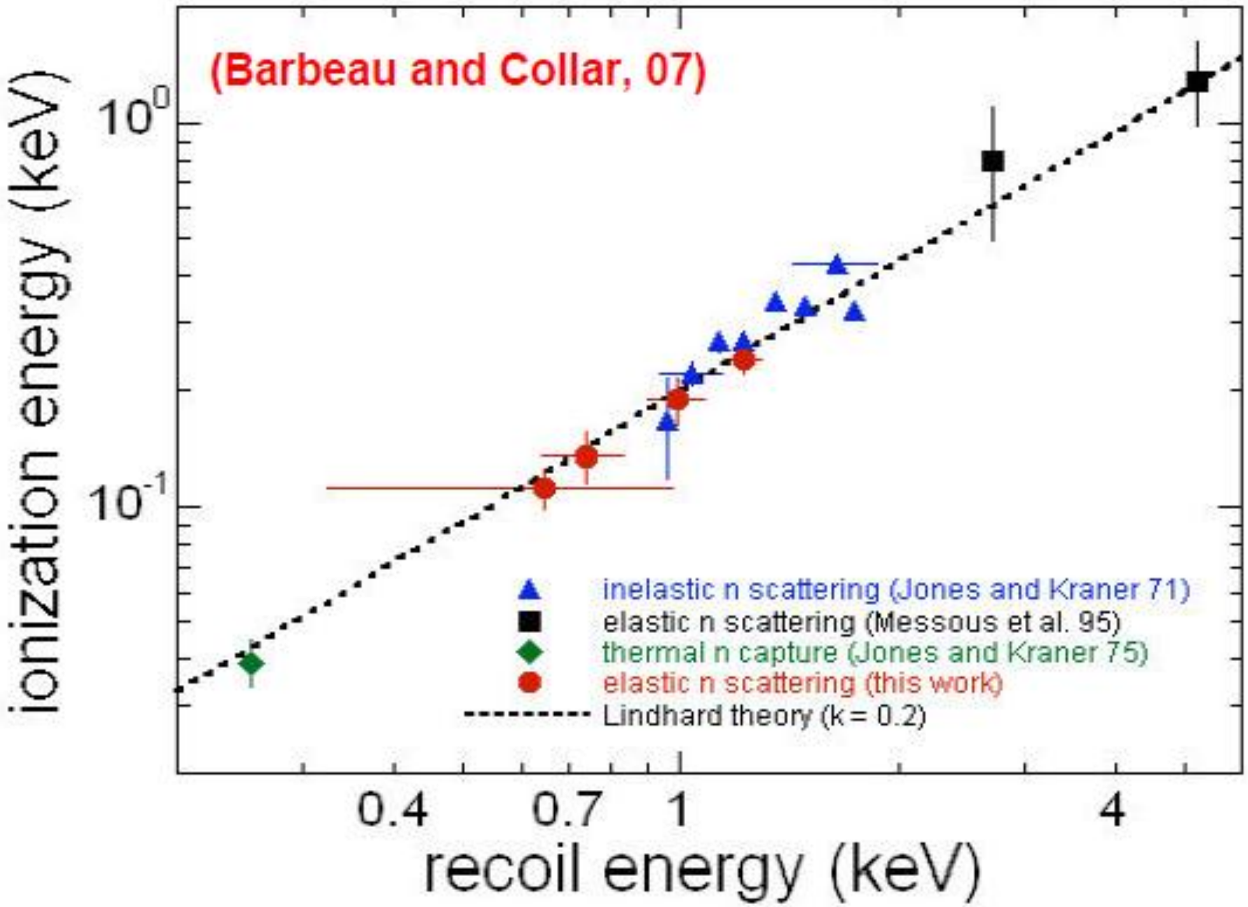
• Up to 10 events is expected to detect per day with background about 1 event.

• Sensitivity down to $\mu_\nu < (1\text{-}2)\times \mathbf{10^{-11}}\ \mu_B$ is expected to be achieved within 2 years of operating

• Thanks for financial support:

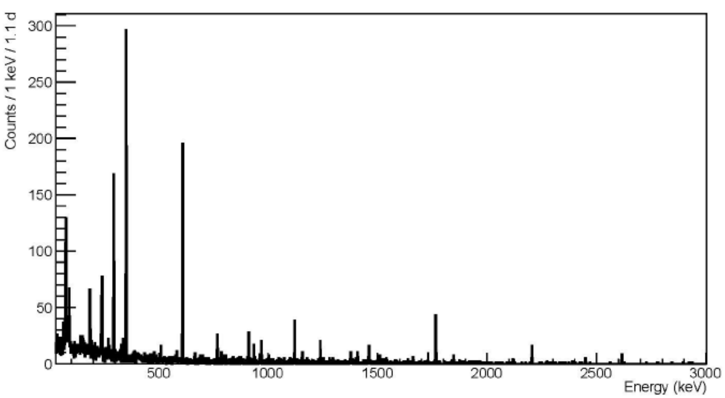
For R&D stage - RFBR,

Now – RSCF.

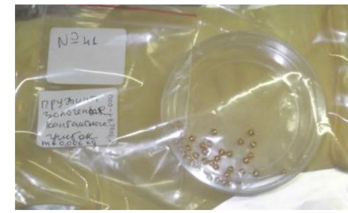

(Barbeau and Collar, 07)
ionization energy (keV)
10^0
10^-1
recoil energy (keV)
0.4
0.7
1
4
inelastic n scattering (Jones and Kraner 71)
elastic n scattering (Messous et al. 95)
thermal n capture (Jones and Kraner 75)
elastic n scattering (this work)
Lindhard theory (k = 0.2)

Material selection

Measurements of 50 samples of cryostat construction materials with low background HPGe detector OBELIX (LSM). December 2014 – April 2015.



OBELIX energy spectrum of FPM O-rings (71 grams) not accepted for use in the νGeN cryostat



Tests at LSM

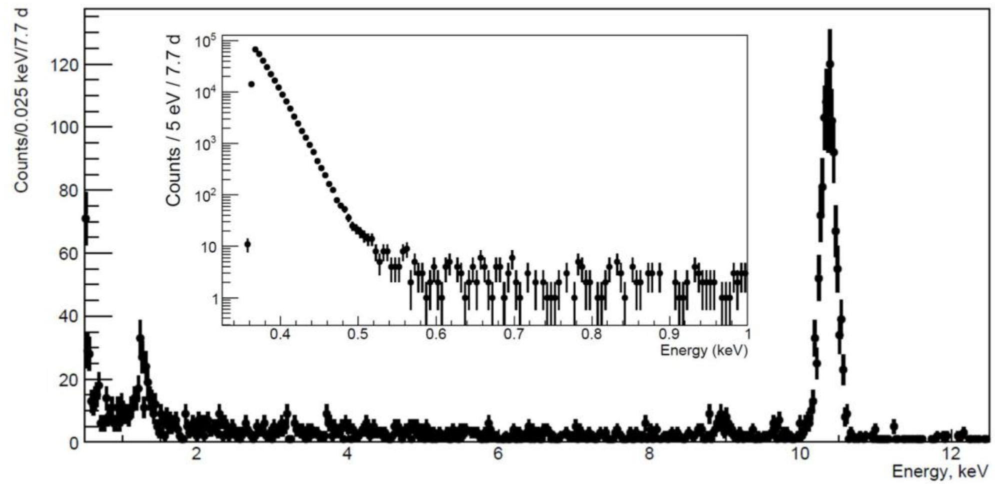
August-November 2015: test measurements in LSM underground laboratory

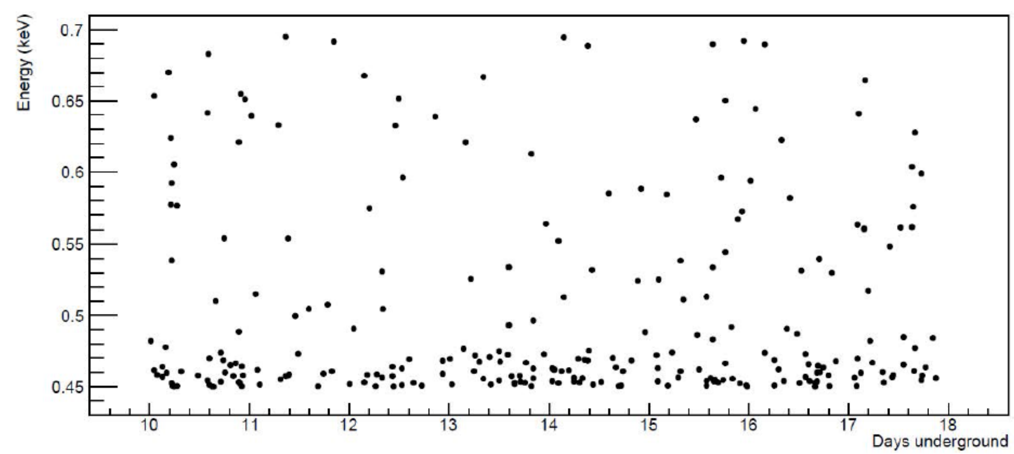
Some preliminary results:
FWHM 10.4 keV = 220 eV

Discriminator threshold ~350 eV (<1 Hz)

Background comparable with CoGeNT experiment

The main conclusion of the performed tests is that achieved energy thresholds and preliminary values of the experimental background are adequate in order to start further commissioning of the setup with proper acquisition chain and the veto systems at the KNPP experimental site.





Recoil energy $E_r = \dfrac{E_\nu^2(1-\cos\theta)}{MA}$, where M = nucleon mass[1]

Average recoil energy $\langle E_r \rangle = 716 \text{ eV} \dfrac{(E_\nu/\text{MeV})^2}{\boxed{A}}$

Lower A (and N) is better

If the maximum recoil energy is below threshold, we won't see any recoils at all. The optimized target isotope depends on detector performance.

With Germanium, ~3eV / electron, we drift 100's of electrons.

Challenge is to surpass electronic readout noise.

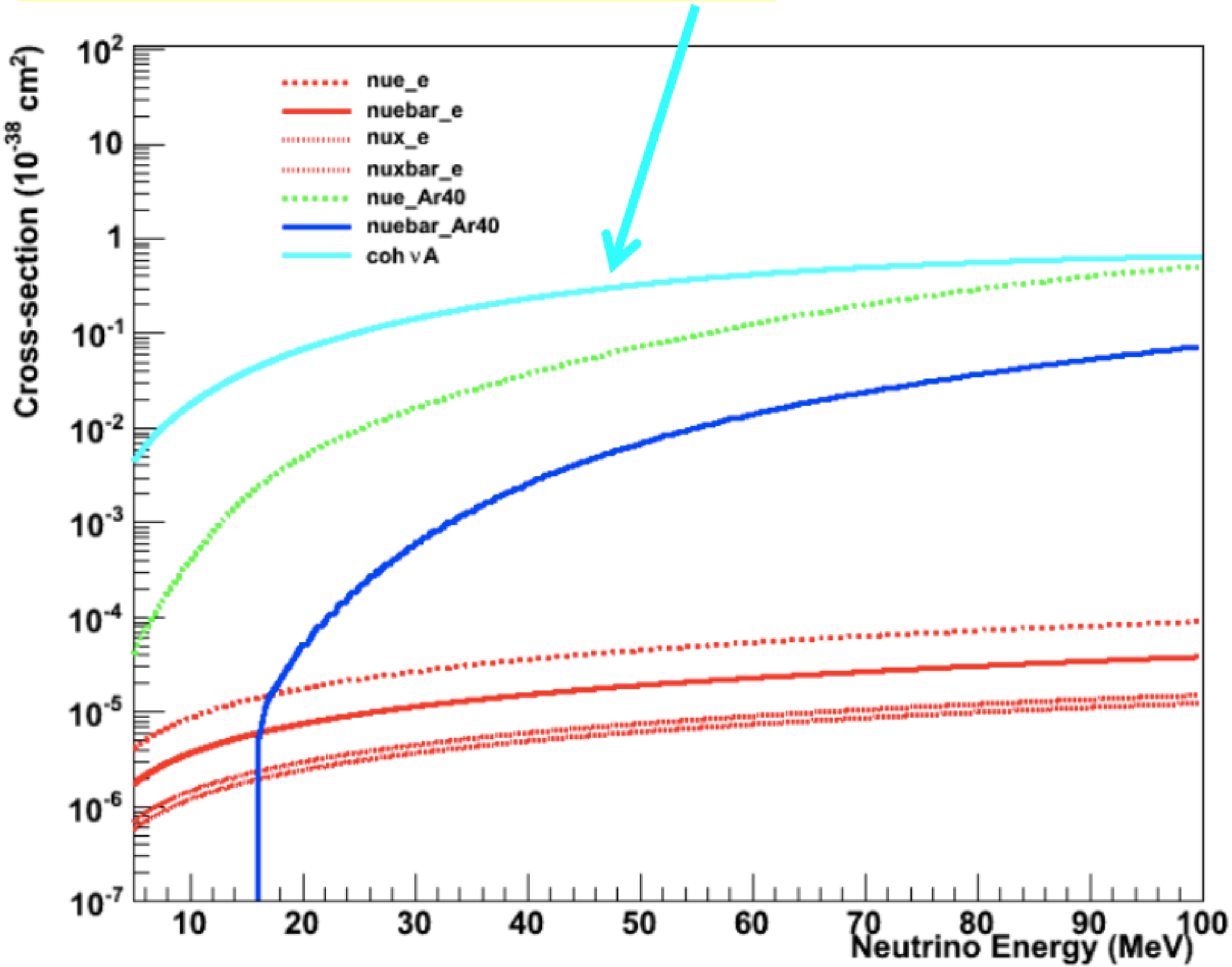
[1] Drukier & Stodolsky, *PRD* 30(11), 1984.

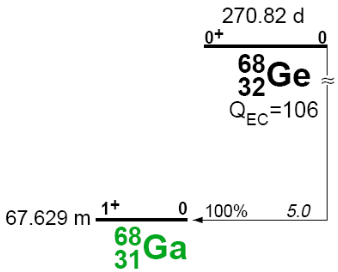
Ionization table

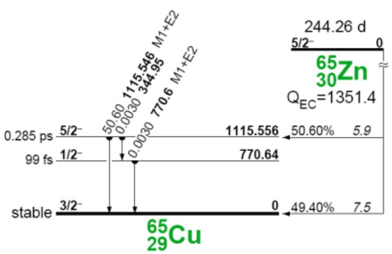
# of e^-	Ar (%)	Xe (%)
0	71.0	98.9
1	15.1	1.1
2	6.7	small
3	3.2	
4	1.7	
5	0.9	

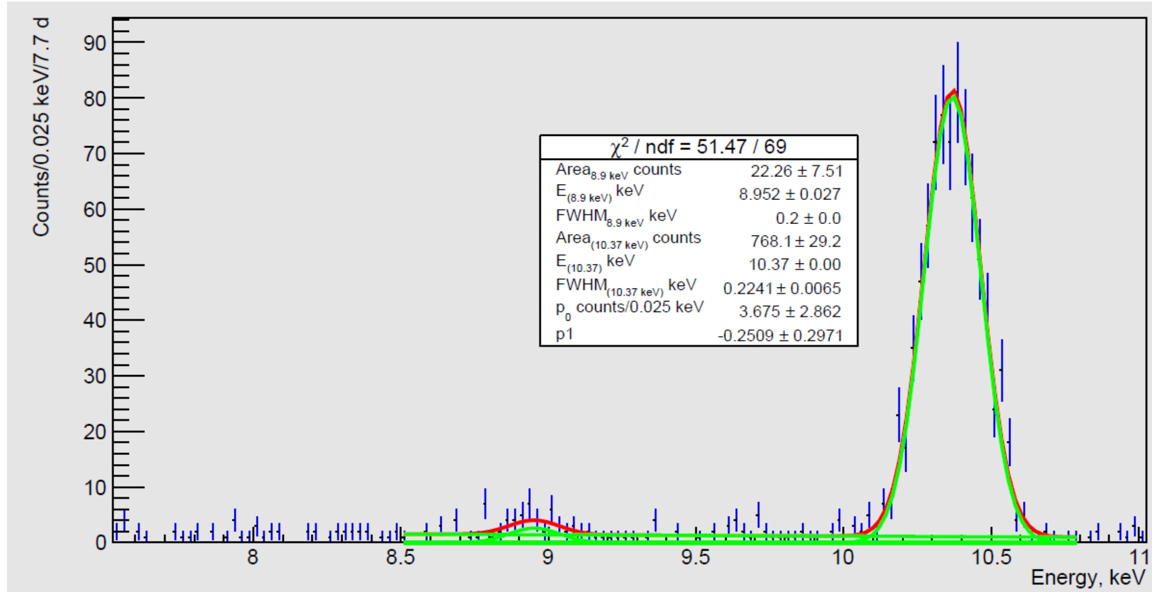
From David Reyna "Development of a Germanium Detector for Reactor Monitoring"

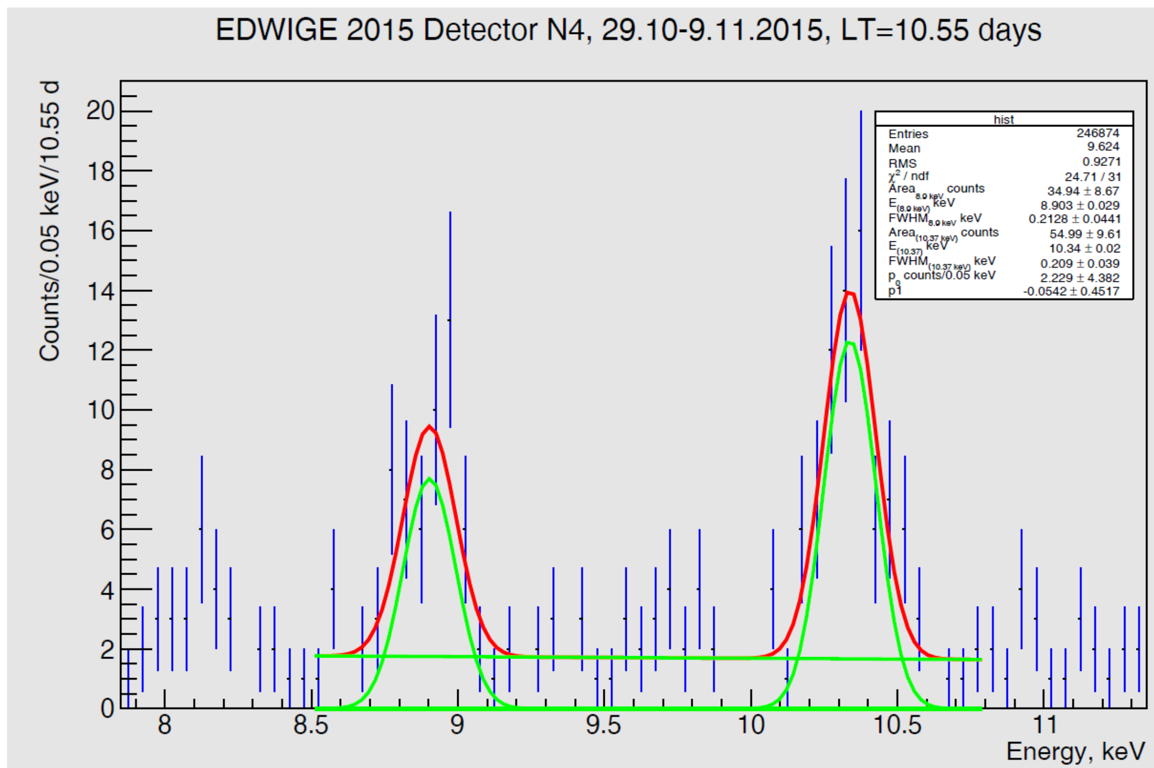
The cross-section is *large*

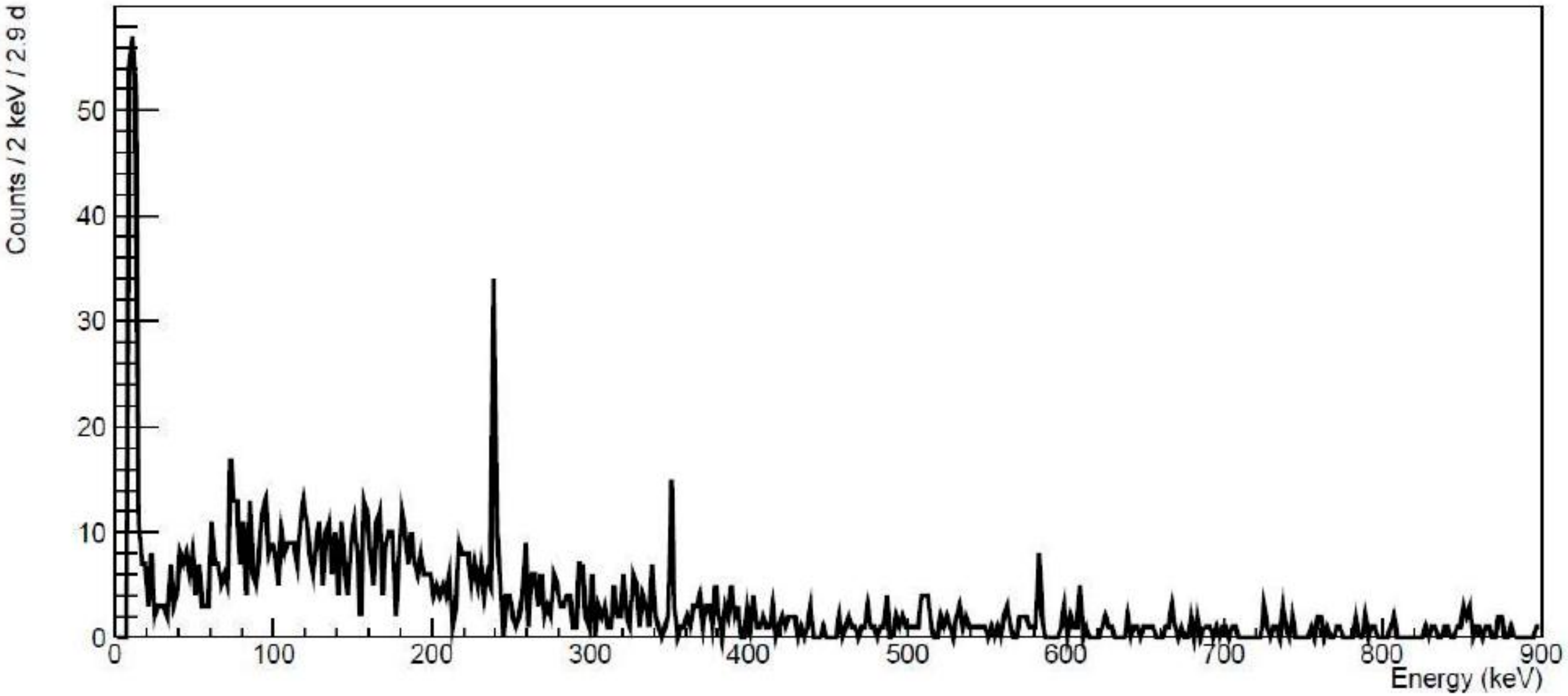



270.82 d
0+ 0
68 32 Ge
Q_EC=106
67.629 m 1+ 0 100% 5.0
68 31 Ga


244.26 d
5/2- 0
65 30 Zn
Q_EC=1351.4
1115.546 M1+E2
344.95
770.6 M1+E2
50.60
0.0030
0.0030
0.285 ps 5/2- 1115.556 50.60% 5.9
99 fs 1/2- 770.64
stable 3/2- 0 49.40% 7.5
65 29 Cu

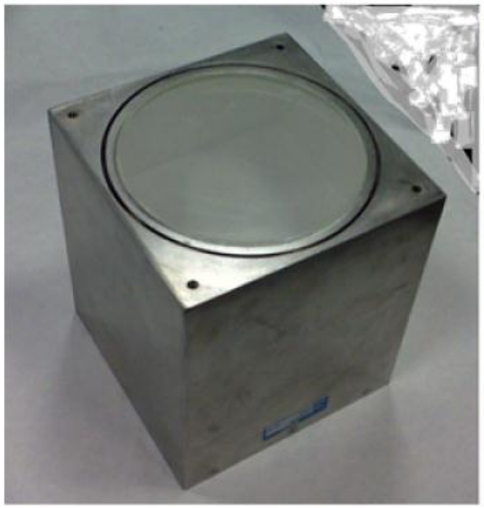

Counts/0.025 keV/7.7 d
χ² / ndf = 51.47 / 69
Area 8.9 keV counts 22.26 ± 7.51
E (8.9 keV) keV 8.952 ± 0.027
FWHM 8.9 keV keV 0.2 ± 0.0
Area (10.37 keV) counts 768.1 ± 29.2
E (10.37) keV 10.37 ± 0.00
FWHM (10.37 keV) keV 0.2241 ± 0.0065
p0 counts/0.025 keV 3.675 ± 2.862
p1 -0.2509 ± 0.2971
Energy, keV

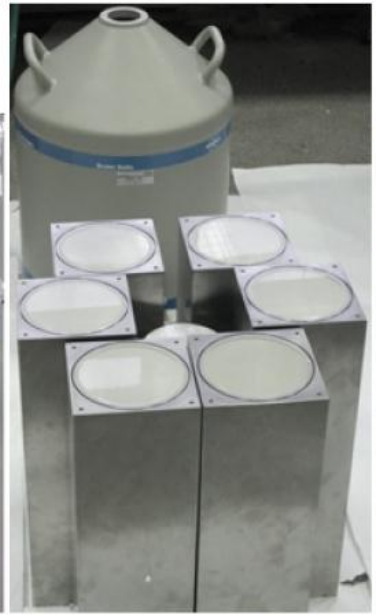

EDWIGE 2015 Detector N4, 29.10-9.11.2015, LT=10.55 days
Counts/0.05 keV/10.55 d
hist
Entries 246874
Mean 9.624
RMS 0.9271
χ² / ndf 24.71 / 31
Area 8.9 keV counts 34.94 ± 8.67
E (8.9 keV) keV 8.903 ± 0.029
FWHM 8.9 keV keV 0.2128 ± 0.0441
Area (10.37 keV) counts 54.99 ± 9.61
E (10.37) keV 10.34 ± 0.02
FWHM (10.37 keV) keV 0.209 ± 0.039
p0 counts/0.05 keV 2.229 ± 4.382
p1 -0.0542 ± 0.4517
Energy, keV



For the energy region from 100 to 600 keV the background index was found to be 0.66±0.03 cpd/kg/keV. For the region from 20 to 100 keV it is 1.11±0.07 cpd/kg/keV.

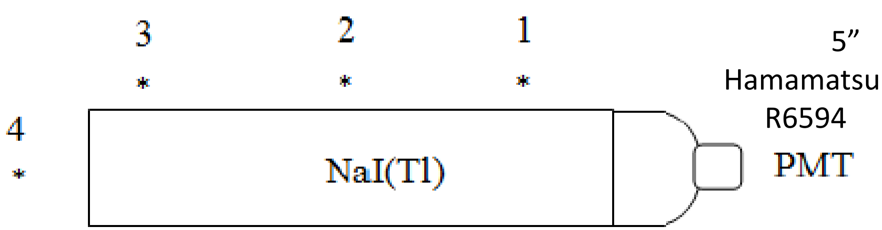
The work completed or in progress:



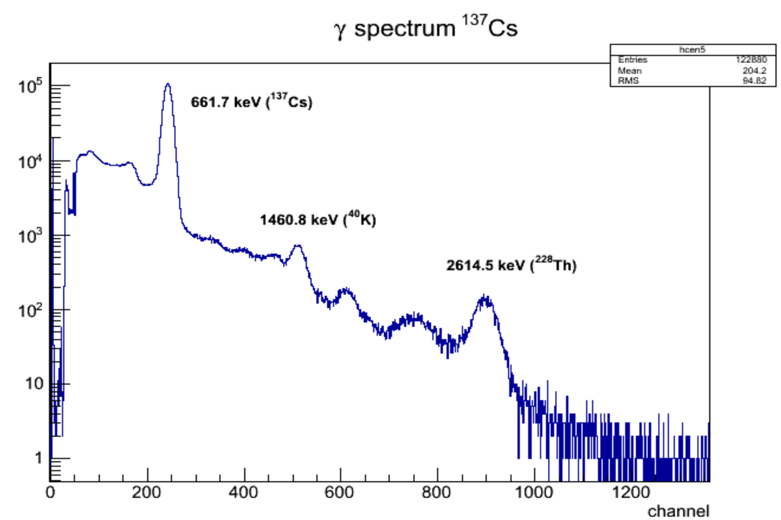


NaI anti compton veto
12 modules
1 155x155x175 mm
11 155x155x505 mm

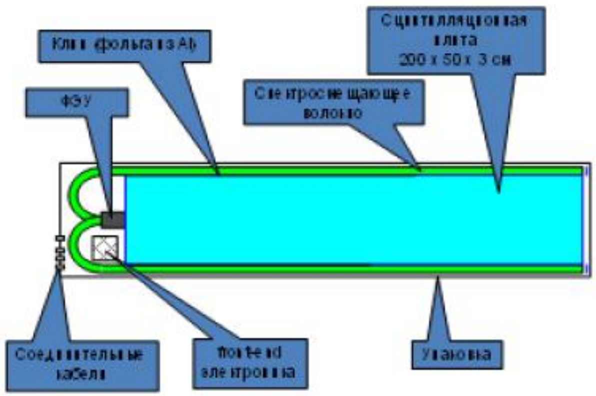
All tested with radioactive sources



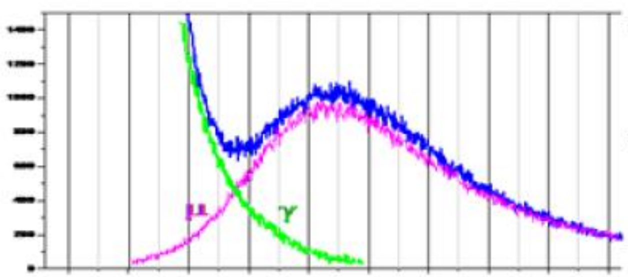
FWHM for 662 keV line: 8 to 9%

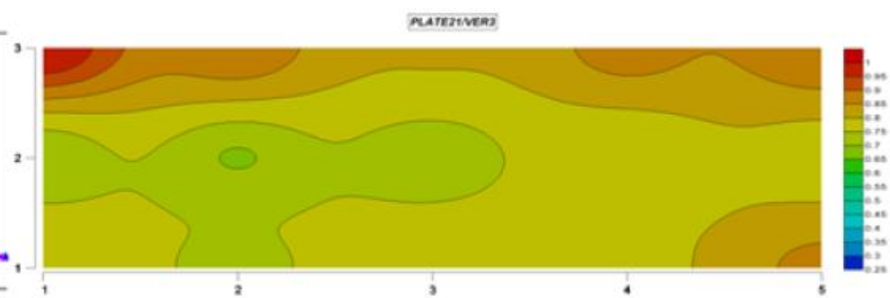


The work completed or in progress:




Scheme of one module for μ-veto system, modules available





Test spectra for one of the modules, right: non uniformity of the light yield

Why we decided to do

For long time our group at JINR developed and build low threshold X-ray HPGe detectors.
For these detectors with optical feedback achieved energy resolution (160-170 eV at 5.9 keV) and energy threshold (350 eV) satisfy needs of coherent neutrino search and low mass WIMP search.
Thus, for big detectors only detectors must be improved (capacitance decreased < 1 pF)