JINR activities in LSM

Evgeny Yakushev on behalf of JINR teams

НАУКА
СБЛИЖАЕТ
НАРОДЫ

SCIENCE
BRINGING
NATIONS
TOGETHER

Previous “Joint Underground Laboratory in Europe” (“JOULE”) agreement that has been signed between JINR and LSM on 24 October 2005 and in frame of which we worked till end of 2020 is now replaced with new Agreement signed in 2021. Thanks to Jules GASCON!!!

JINR activities in LSM are linked with major experiments conducted in the laboratory. In particular with:

– **SuperNEMO** dedicated to further development of $0\nu2\beta$ decay search on an unprecedented level of sensitivity;
– **EDELWEISS** scientific program dedicated to direct search for non-baryonic Dark Matter;
– **Obelix / Idefix** double-beta decay to excited states;
– **TGV** dedicated to search for double beta decay processes ($\beta^+\beta^+$, β^+EC, EC/EC) of ^{106}Cd;
– **SHIN** dedicated to search for the presence of super heavy elements in nature.

We also have some other common equipment with LSM and with Czech and Slovak colleagues (two HPGe spectrometers, alpha spectrometer, radon detectors, neutron detectors).

Thanks to the fact that JINR is international organization additional funding is available from its Members. For LSM such funding was used for anti-radon factory production, for Obelix detector purchase, for development and running of the TGV setup, etc. For example, in 2021 60 k$ was provided by JINR (from JINR Slovakia fund) for SuperNEMO demonstrator shield.


SPECIFIC AGREEMENT OF COOPERATION BETWEEN CNRS – JINR

IN THE FIELD OF “Search for rare phenomena in ultra-low radioactivity environments”

For CNRS/IN2P3

Date 28/7/2021

Reynald Pain
Director of IN2P3

For JINR

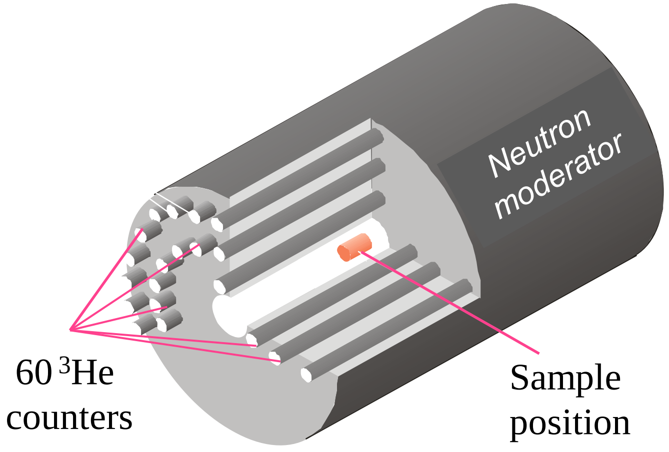
Date 25.06.2021

Grigory Trubnikov
Director of JINR

SHIN: the experiment conducted in the LSM have world leading sensitivity on the presence of super heavy elements in nature

Goal:

Search for superheavy elements in nature.



Method:

Registration of neutron flashes from the spontaneous fission of superheavy elements (n≥3 signs the spontaneous fission of a very heavy element).

Current status:

Xe (enriched) sample measurements.
The experiment started on 25 October 2019.
Current duration: **812 days** and 405 days without any interruptions (up to 14 January 2022).

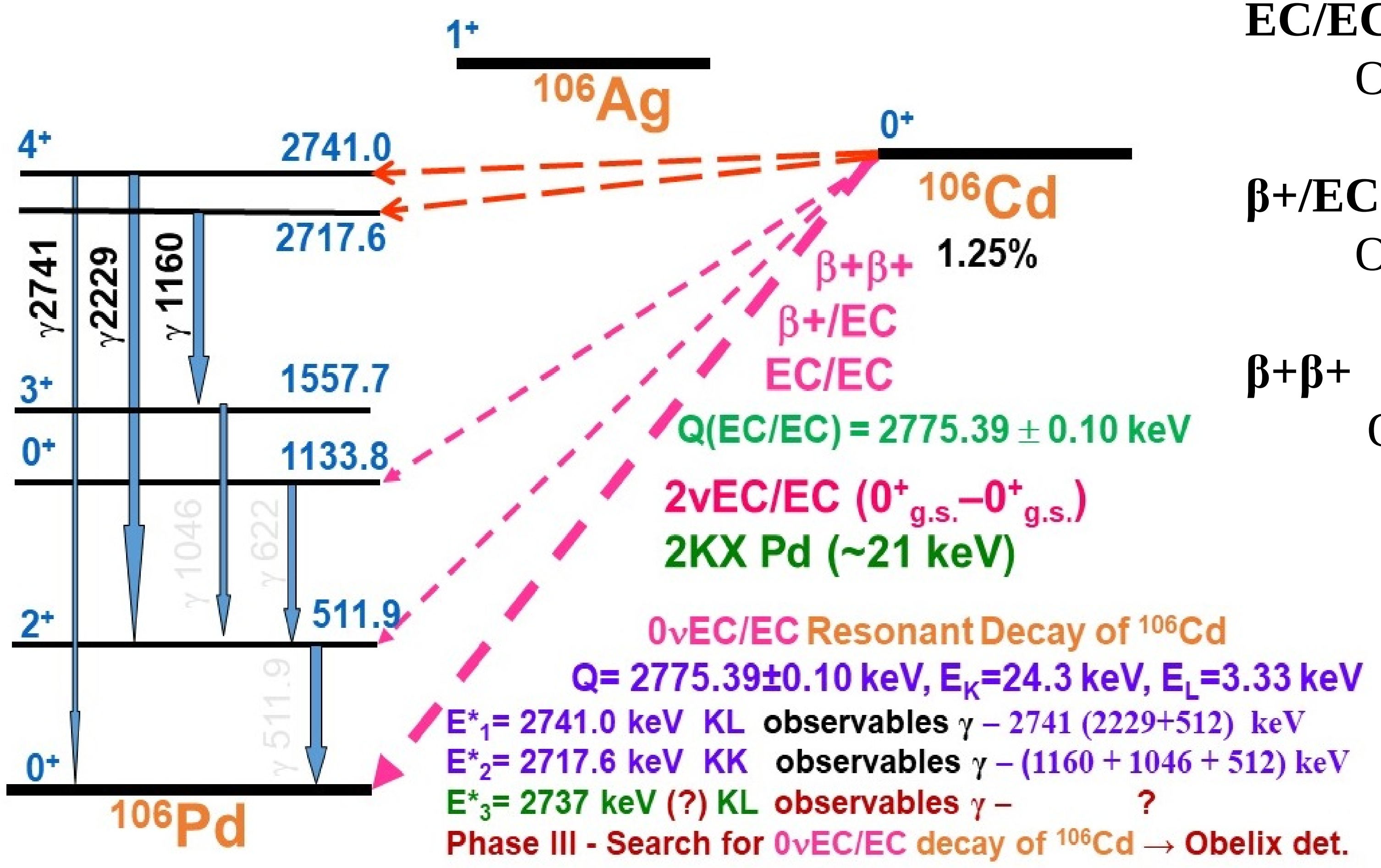
Plans (blocked by COVID-19):

– background measurements;
– new sample installation;
– electronics upgrade.

Yu. Oganesyan and the SHIN setup

TGV-2 – search for double beta decay of ^{106}Cd

JINR Dubna, Russia, IEAP, CTU Prague, Czech Republic, CU Bratislava, Slovakia, LSM Modane, France



EC/EC $2e_b^- + {}^{106}Cd \rightarrow {}^{106}Pd + (2\nu_e) + (\gamma)$

Observables: 2KXPd (+ γ for e.s.)

β+/EC $e_b^- + {}^{106}Cd \rightarrow {}^{106}Pd + e^+ + (2\nu_e) + (\gamma)$

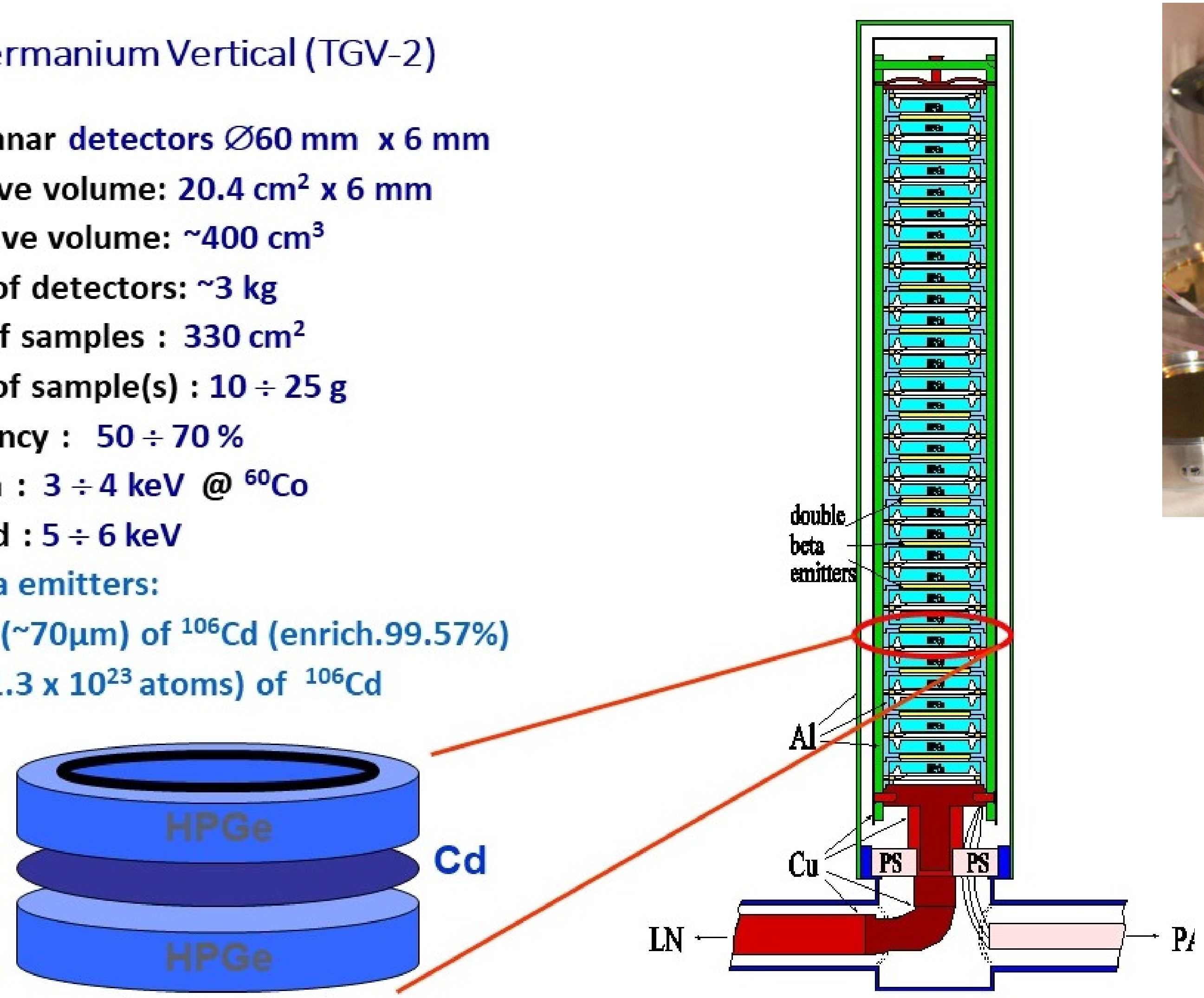
Observables: KXPd + 2γ 511 (+ γ for e.s.)

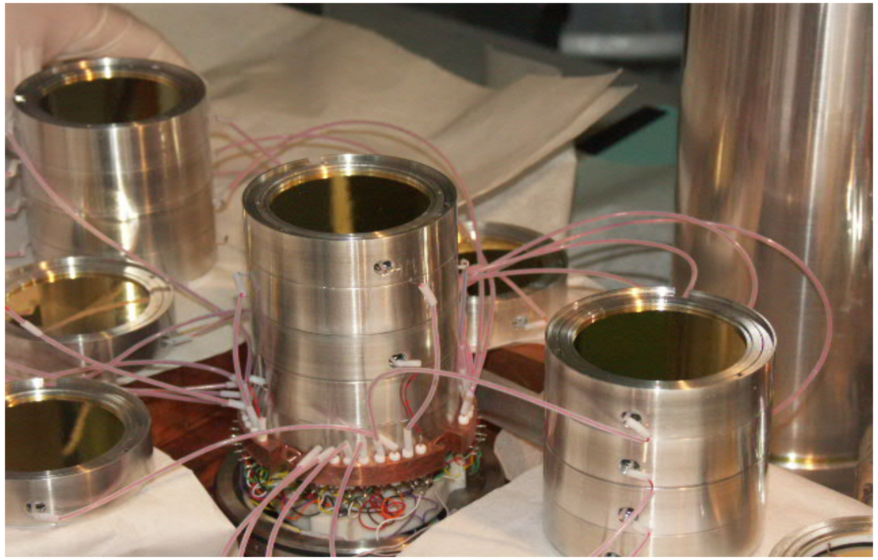
β+β+ ${}^{106}Cd \rightarrow {}^{106}Pd + e^+ + e^+ + (2\nu_e) + (\gamma)$

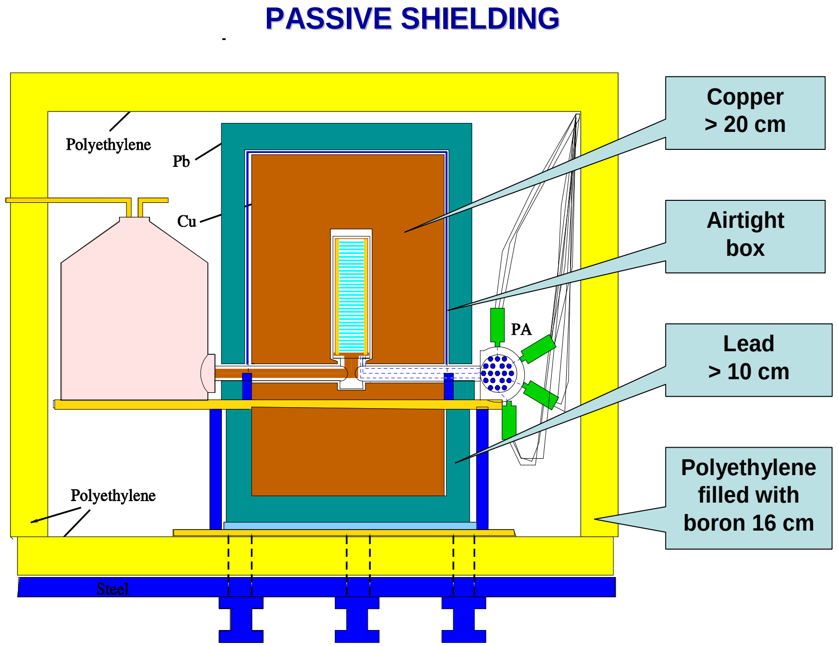
Observables: 4γ 511 (+ γ for e.s.)

Telescope Germanium Vertical (TGV-2)

32 HPGe planar detectors ∅60 mm x 6 mm
with sensitive volume: 20.4 cm^2 x 6 mm
Total sensitive volume: ~400 cm^3
Total mass of detectors: ~3 kg
Total area of samples : 330 cm^2
Total mass of sample(s) : 10 ÷ 25 g
Total efficiency : 50 ÷ 70 %
E-resolution : 3 ÷ 4 keV @ ^{60}Co
LE-threshold : 5 ÷ 6 keV
Double beta emitters:
16 samples (~70μm) of ^{106}Cd (enrich.99.57%)
~23.2 g (~ 1.3 x 10^{23} atoms) of ^{106}Cd





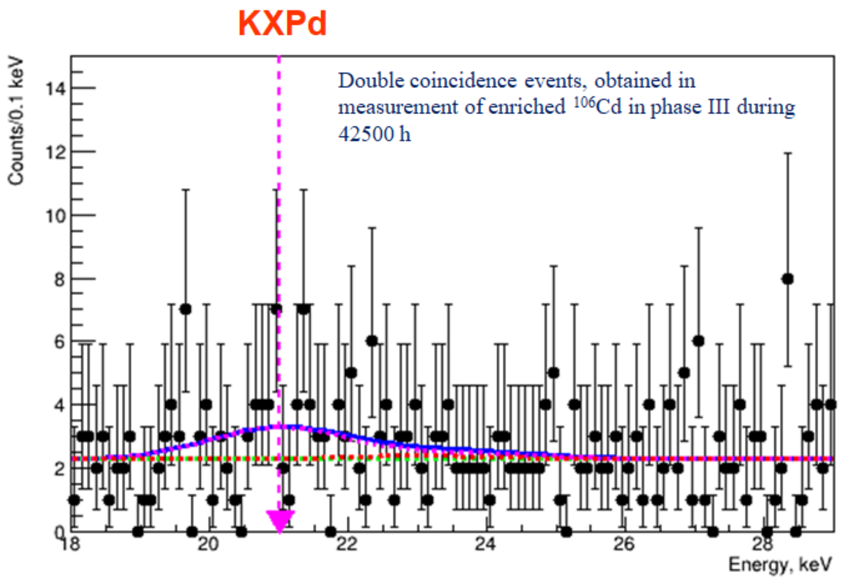


(Feb.2014 – …..) in progress, T >1770 days

Preliminary limits on double beta decay of ^{106}Cd

Decay mode	Final level of ^{106}Pd	$T_{1/2}$, y (90%CL) Phase II*	$T_{1/2}$, y (90%CL) Phase III*
2νEC/EC	0^+g.s.	4.2×10^{20}	7.2×10^{20}
	2^+, 511.9 keV	1.2×10^{20}	8.9×10^{20}
	0^+_1, 1134 keV	1.0×10^{20}	7.2×10^{20}
0νEC/EC	2717.6 keV	1.6×10^{20}	1.4×10^{20} (Obelix)
0νEC/EC	4^+, 2741 keV	1.8×10^{20}	0.9×10^{20} (Obelix)
2νβ^+/EC	0^+g.s.	1.1×10^{20}	6.6×10^{20}
	2^+, 511.9 keV	1.1×10^{20}	7.9×10^{20}
	0^+_1, 1134 keV	1.6×10^{20}	9.0×10^{20}
2ν$\beta^+\beta^+$	0^+g.s.	1.4×10^{20}	3.9×10^{20}
	2^+, 511.9 keV	1.7×10^{20}	4.7×10^{20}

**N.I.Rukhadze et al., Journal of Physics: Conference Series 375 (2012) 042020*
**N.I.Rukhadze on behalf of TGV collaboration, TAUP 2021, Valencia, Spain, 26.08-03.09.2021*



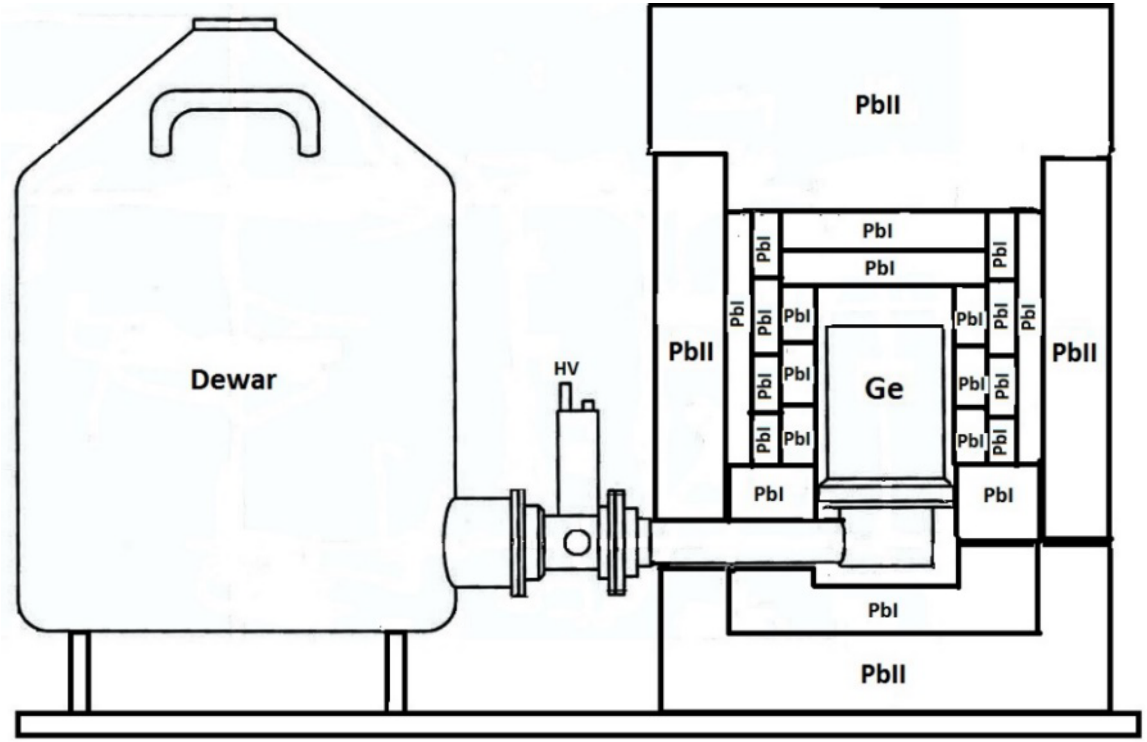
Expected Pd peak: 30.5±25.2 events

$T_{1/2}$theor. (2ν*EC/EC*) ~ $10^{20} - 10^{22}$

Plans: to move forward and finally see the peak(s?) we have to make a significant upgrade of the setup. Two main parts of the upgrade: 1) cold FETs on short cables to improve the energy resolution by several times, 2) new modern acquisition for further noise suppression.

Obelix

“Obelix” is HPGe spectrometer with a sensitive volume of 600 cm^3 that was jointly developed by JINR (Dubna), IEAP (Prague) and LSM. The main goals of the “Obelix” are investigations of rare nuclear processes accompanied by emission of γ–quanta, such as 0νEC/EC resonant decay of ^{106}Cd, two-neutrino double beta decay to the excited states of daughter nuclei (^{100}Mo, ^{150}Nd), measurements of radioactive contaminations of various samples.



P type coaxial HPGe detector produced by Canberra in U-type ultra low background cryostat
Energy resolution (FWHM) ~1.2 keV at 122 keV (^{57}Co),
~2 keV at 1332 keV (^{60}Co)
Distance from cap 4 mm
Entrance window Al, 1.6 mm
Integral background in LSM for energies above 30 keV: ~200 cpd (i.e. <0.03 per keV per kg day)

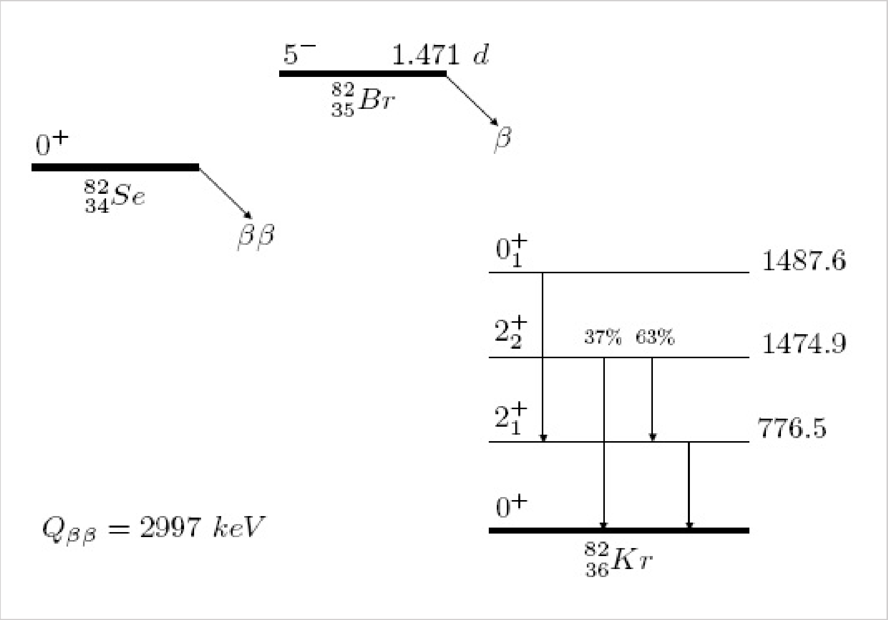
Search for double beta decay of ^{82}Se to excited states of ^{82}Kr

Double beta decay to excited states of daughter nuclei are accompanied by emission of γ-quanta in de-excitation of excited states.
γ-quanta may be detected by low background HPGe detectors with high efficiency and good energy resolution.

$2\nu2\beta^-$ decay to excited states was detected in
^{100}Mo - ^{100}Ru (0^+_1, 1130.3 keV) the most accurate result was obtained with the Obelix HPGe spectrometer (R. Arnold et al. Nucl. Phys. A 925 (2014) 25) and ^{150}Nd - ^{150}Sm (0^+_1, 740.4 keV).

Recently there were two attempts to measure DBD of ^{82}Se to excited states of ^{82}Kr but positive signal was not detected:

1) by CUPID-0 collaboration (O. Azzolini et al., Eur.Phys.J. C78 (2018) no.11, 888), $T_{1/2} > 4\text{x}10^{21}$ years;
2) By NEMO-3 collaboration (R. Arnold, arXiv: 2001.06388 [physics .ins-det]), $T_{1/2} > 1.3\ \text{x}10^{21}$ years.



Search for double beta decay of ^{82}Se to excited states of ^{82}Kr

According to our estimation we can reach a level of sensitivity $T_{1/2}$~ 6 x 10^{22} y with the Obelix detector and ~6 kg of ^{82}Se sample and hope to detect DBD of ^{82}Se to excited states of ^{82}Kr for the first time.

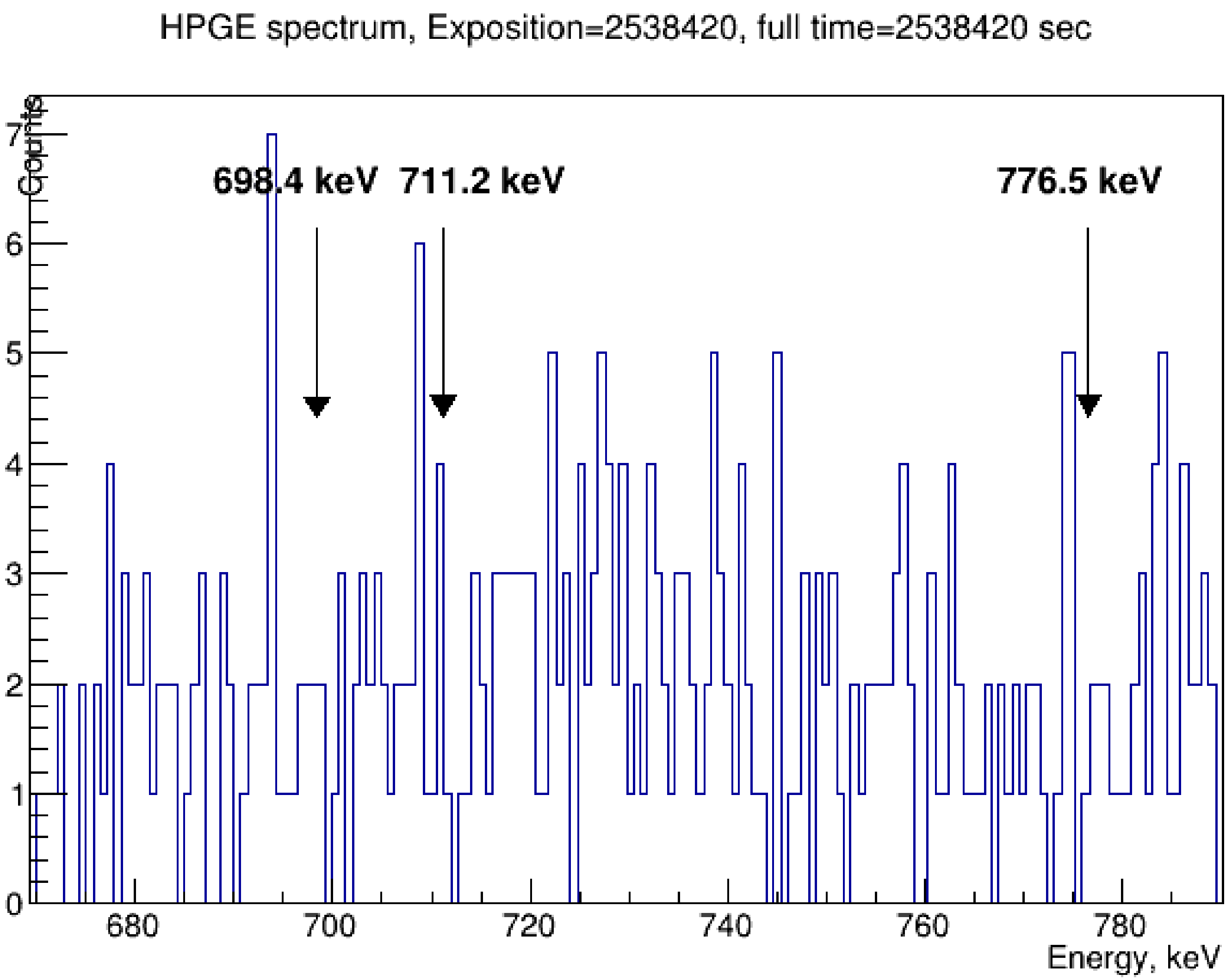
The required Se-82 amount was available from our colleagues and was located in the LNGS.

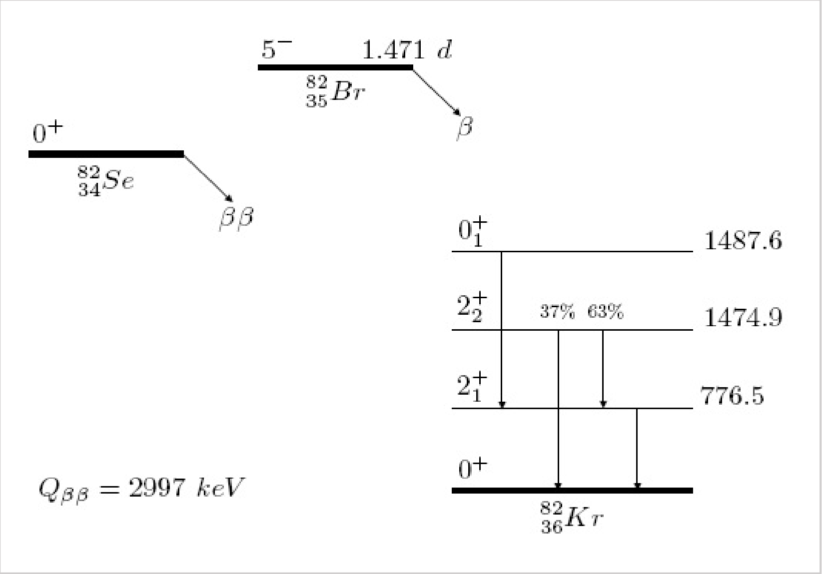
Before sending the ^{82}Se sample to LSM a short test measurement of ^{82}Se was performed in LNGS during 62 days with one of the best (by its background level) LNGS HPGe detector (GeMPI4). No unwelcome contaminations as well signs of DBD of ^{82}Se to excited states were detected.

Obelix measurements of ^{82}Se were started on December 10th, 2021.

Sample of enriched ^{82}Se (enrichment ~95%) with a mass of 6019.9 g of ^{82}Se was prepared in Marinelli of Obelix detector in LNGS in July 2020.

Search for double beta decay of ^{82}Se to excited states of ^{82}Kr





ROI spectrum after first month of the Obelix measurement

Zr-96 project

Long, long time ago, in post NEMO-3 time question about possibility to get enriched Zr-96 as the source of double beta decay was initiated by Serge Jullian, Oleg Kochetov, Fabrice Puquemal, Yuri Shitov and Dmitrii Filosofov.

ISOTOPE (part of the Rosatom) http://www.isotop.ru/en/ in know as supplier of enriched materials produced by centrifugation and we established good contacts with themes.

At that time technology of Zr enrichment by centrifugation was not available (room temperature Zr containing gas phase was the main problem). The ISOTOPE decided to develop the technology by themselves (so it remained their property).

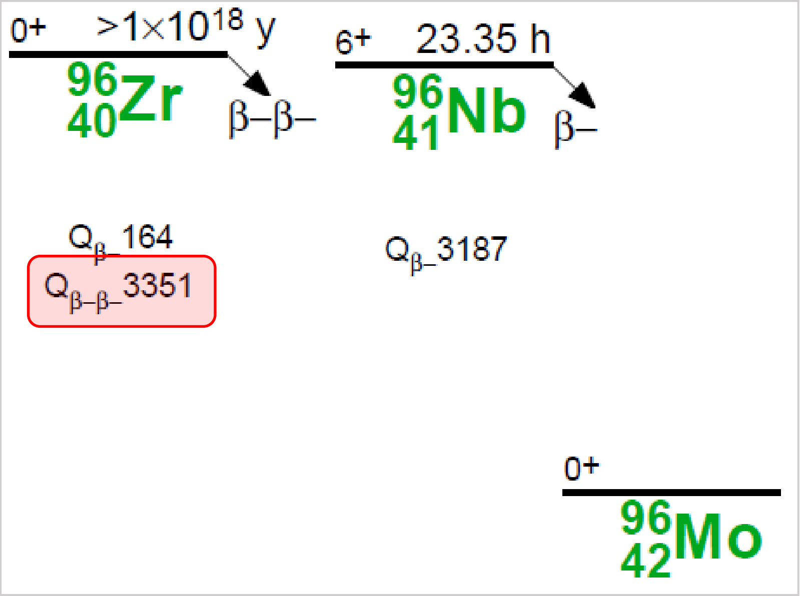
In 2021 we got an excellent news: the technology is now available and macro quantities of enriched Zr-96 can be produced.

~200-250 grams will be produced by ISOTOPE for JINR in 2022

Zr-96 enrichment is >85%

The price is ~220 euro $gram^{-1}$

Two samples will be provided: ZrO_2 and ZrB_2, both in form of powder (how it recovered from the gas). We asked to provide the samples of equal weights (i.e. ~ 120 g /each). Radioactive purity of the samples will be the main question.

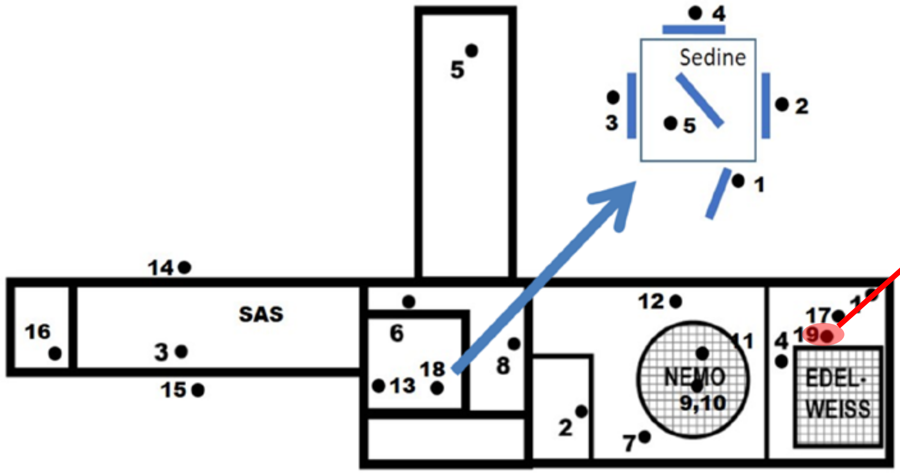


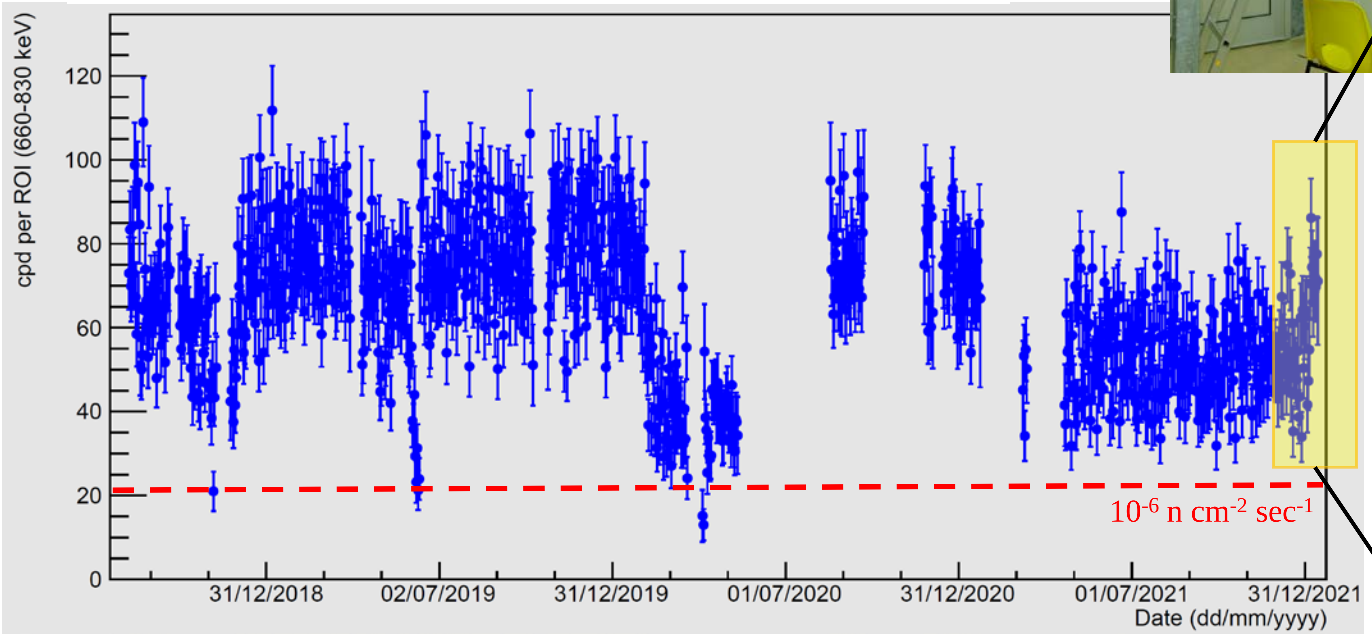
As samples are small, no need for huge detectors to be used for screening. We asked Maryvonne for cooperation in the measurements with help of Gentian spectrometer. Exact time schedule is not known for the moment.

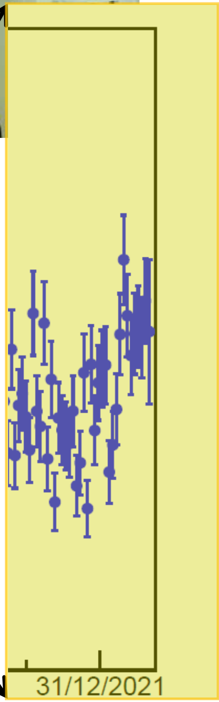
Can obtain a result for DBD to excited states.

Future of Zr-96: bolometers?

Neutron field monitoring / low background He-3







Point	Year, comments	Thermal neutron flux, 10^{-6} n/cm^2/sec
1	2008	3.64 ± 0.07
	2012	3.72 ± 0.11
	2011	3.54 ± 0.03
2	2008	4.7 ± 0.5
	2012	5.1 ± 0.4
3	2008	6.3 ± 0.6
	2010	6.7 ± 0.4
	2012	7.1 ± 0.6
4	2008	2.1 ± 0.2
	2012	2.9 ± 0.2
5	2008	4.5 ± 0.5
	2012	5.3 ± 0.4
6	2008	2.1 ± 0.2
	2012	2.9 ± 0.2
7	2008	2.1 ± 0.2
	2012	2.9 ± 0.2
8	2008	2.1 ± 0.2
	2012	2.9 ± 0.2
9	2012	4.4 ± 0.3
10	2012	4.1 ± 0.3
11	2013	3.6 ± 0.3
12	2013	9.9 ± 0.4
	2013+PE	9.6 ± 0.1
13	2014	8.5 ± 0.1
14	2010	7.7 ± 0.5
15	2010	8.2 ± 0.2
16	2011	6.2 ± 0.4
17	2017 (top of the EDW-I)	2.3 ± 0.1
	2017 (near the concrete wall)	3.1 ± 0.1
18	2016, Sedine 1	1.91 ± 0.10
	2016, Sedine 2	1.50 ± 0.08
	2016, Sedine 3	2.14 ± 0.09
	2016, Sedine 4	2.32 ± 0.08
	2016, Sedine 5	1.29 ± 0.06
19	2018	3.05 ± 0.05
	2019	3.39 ± 0.02
20	2019, same place as point 2 with significantly different surrounding	3.0 ± 0.2
NEMO	2011, Inside of the NEMO-3 central tower	<0.06 (90% CL)
EDEL-WEISS	2008-2010 EDW-II inside shields	0.0073 ± 0.0018
	2015, EDW-III inside shields	<0.007 (90% CL)
	2016, EDW-III inside shields	<0.01 (90% CL)

Plans: re-measure the flux in different locations in the lab, as configuration of the lab and the shields of some experiments are significantly changed.

Neutron field monitoring / other ideas

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NaI(Tl+Li) scintillator as multirange energies neutron detector

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ABSTRACT: Novel NaIL detector (5 × 6 inch) was investigated for its neutron detection in wide energy range. It has been found that the detector together with its known ability to detect the γ-radiation it also allows to distinguish neutron signals in three quasi-independent ways. It is sensitive to neutron fluxes on a level down to 10^{-3} cm^{-2} s^{-1}. In this work intrinsic α-background and neutron detection sensitivity for the NaIL detector were obtained. Experimental data was compared with results of Geant4 Monte Carlo (MC).

KEYWORDS: Neutron detectors (cold, thermal, fast neutrons); Scintillators, scintillation and light emission processes (solid, gas and liquid scintillators)

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New NAIL detectors: (NaI(Tl+Li)): simultaneous detection of ionizing radiation together with neutrons in a wide energy range thanks to presence of Li-6 in the scintillator.

- Thermal neutron capture on Li-6: $^{6}Li+n_{th}\rightarrow{}^{4}He+{}^{3}H+4.79$ MeV, σ=940 b
- Thermal neutron capture on iodine with detection of delayed γγ–coincidences (137 keV isomeric state): $^{127}I+n_{th}\rightarrow{}^{128}I^{*}+6.8$ MeV, σ_{th}=6.2 b (was already teasted in LSM); That reaction is also has reasonable high cross section for epithermal neutrons. From 50 eV to 10 keV its integral is 153.9 b. Thus in the bulk which could be unreachable by thermal neutrons, thanks to Li-6, the reaction is become suitable for epithermal and fast neutron studies (see MC below).
- Inelastic scattering of fast neutrons on I-127 with excitation of 57.6 keV level can be detected

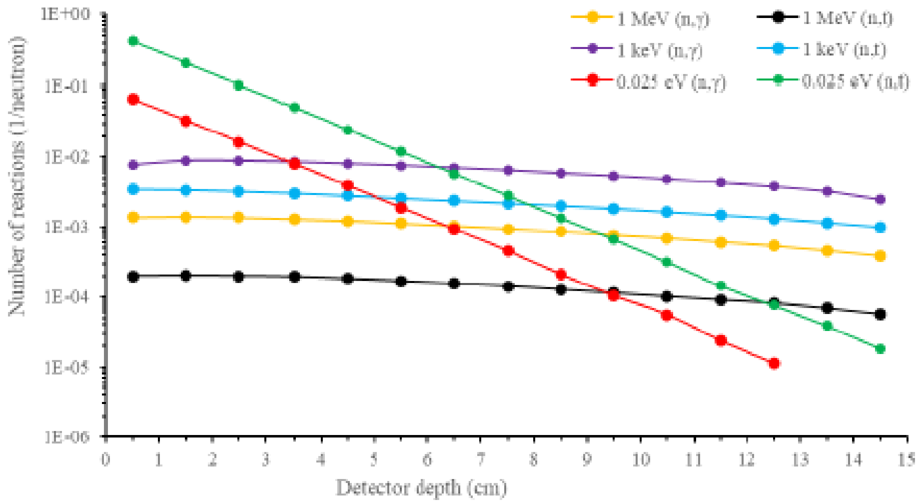
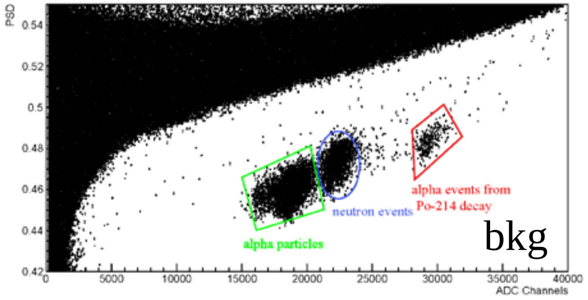
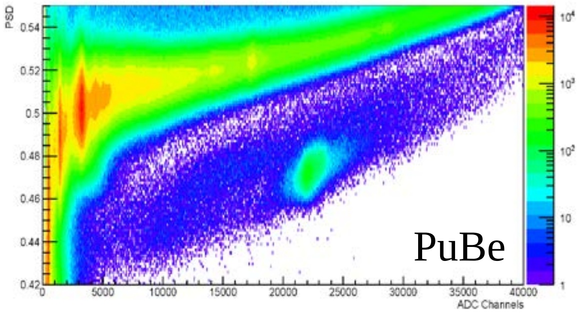


Figure 8. Number of interactions per one entering neutron as a function of depth for the NaIL detector with 2% of enriched lithium per mol (Monte Carlo).





The method works very well in Dubna, will be interesting to test for lower flux

Other developments in Dubna

In the end of 2021 to improve our facilities we purchased ICP-MS (Thermo Scientific iCAP RQ) that suppose to be commissioned in 2022. It will improve home based facilities for low radioactive research.

As we have radiochemistry group with huge experience in preparation (concentration) of the samples we hope that with new facility we will help experiments with our participation to improve the knowledge about composition and radioactivity of the materials.

Other facilities available in JINR: clean rooms, HPGe detectors of different sizes, home organic scintillator production, home Si detector production, 3D printing (include low radioactive nylon), shielding materials (Pb, Cu, W, polyethylene), production of purified materials (radiochemistry), etc.

Cooperation with CTU Prague, Czech Republic and CU Bratislava, Slovakia for further development of neutron detection and radon emanation techniques.

Special Thanks

Situation with the COVID developed very fast and Dubna group (as probably many others) was not prepared;

We have equipment and facilities (apartment) in Modane;

We are really THANKS to LSM staff for all help that they provided with the apartment, equipment, and other issues!

We hope be able to visit LSM in 2022 to see all of you in person.