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

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

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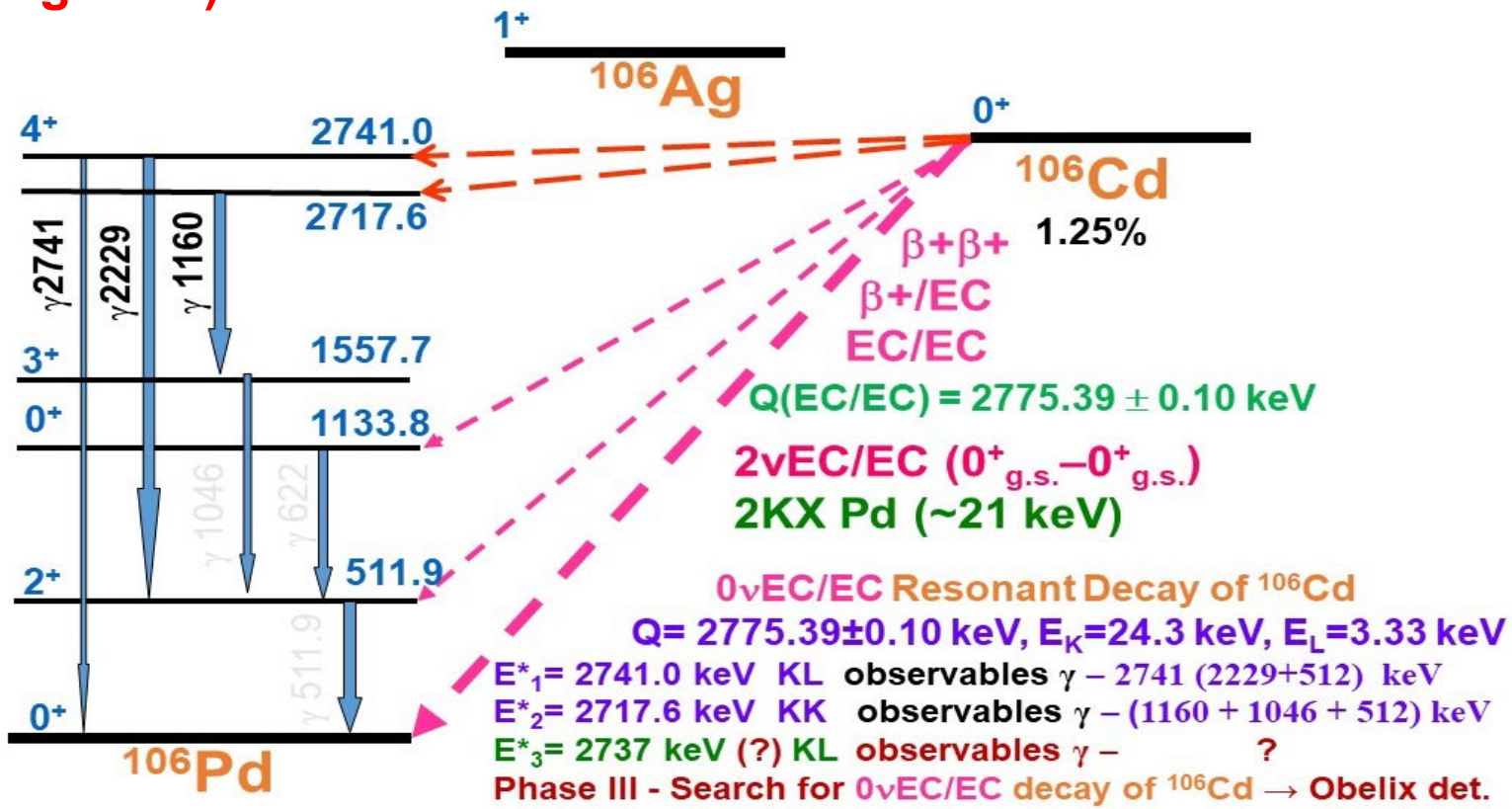
Phase III

~ 23.2 g of ^{106}Cd (99.57%)
(~ 1.3 x 10^{23} atoms of ^{106}Cd)
(Feb.2014 – Sep.2015, Apr.2016 – Aug.2021)
T ~47860 h

EC/EC $2e_b^- + {}^{106}Cd \rightarrow {}^{106}Pd + (2\nu_e) + (\gamma)$
Observables: 2KXPd (+ γ for e.s.)

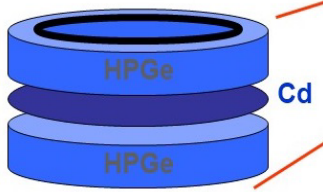
β+/EC $e_b^- + {}^{106}Cd \rightarrow {}^{106}Pd + e^+ + (2\nu_e) + (\gamma)$
Observables: KXPd + 2γ 511 (+ γ for e.s.)

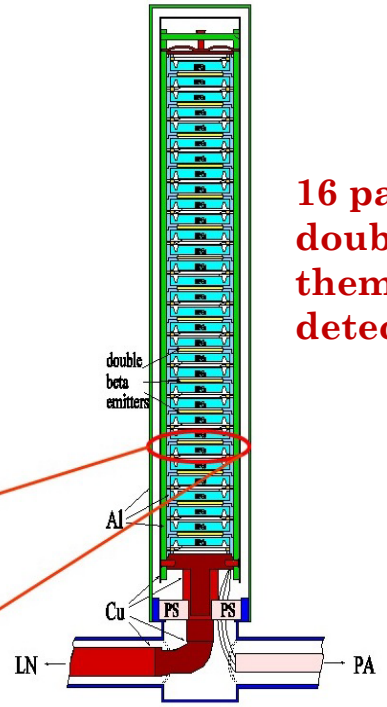
β+β+ $^{106}Cd \rightarrow {}^{106}Pd + e^+ + e^+ + (2\nu_e) + (\gamma)$
Observables: 4γ 511 (+ γ for e.s.)



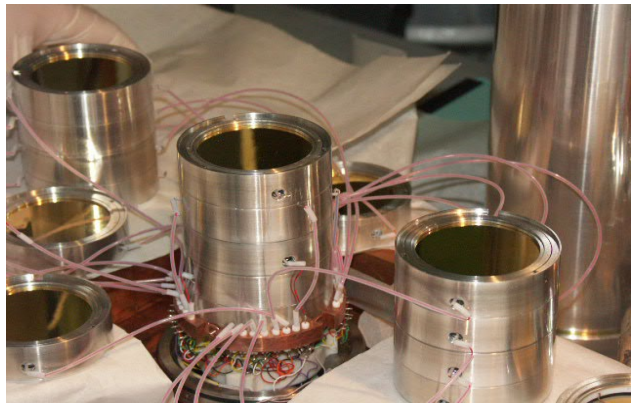
Telescope Germanium Vertical (TGV-2)

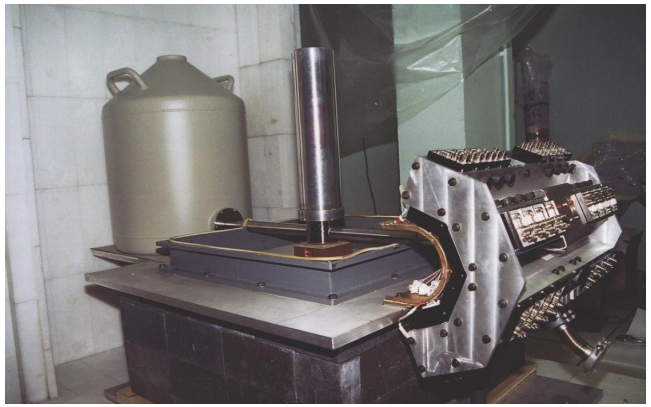
32 HPGe planar detectors ∅60 mm x 6 mm
with sensitive volume: 20.4 cm^2 x 6 mm
Total sensitive volume: ~400 cm^3
Total mass of detectors: ~3 kg
Total area of samples : 330 cm^2
Total mass of sample(s) : 10 ÷ 25 g
Total efficiency : 50 ÷ 70 %
E-resolution : 3 ÷ 4 keV @ ^{60}Co
LE-threshold : 5 ÷ 6 keV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



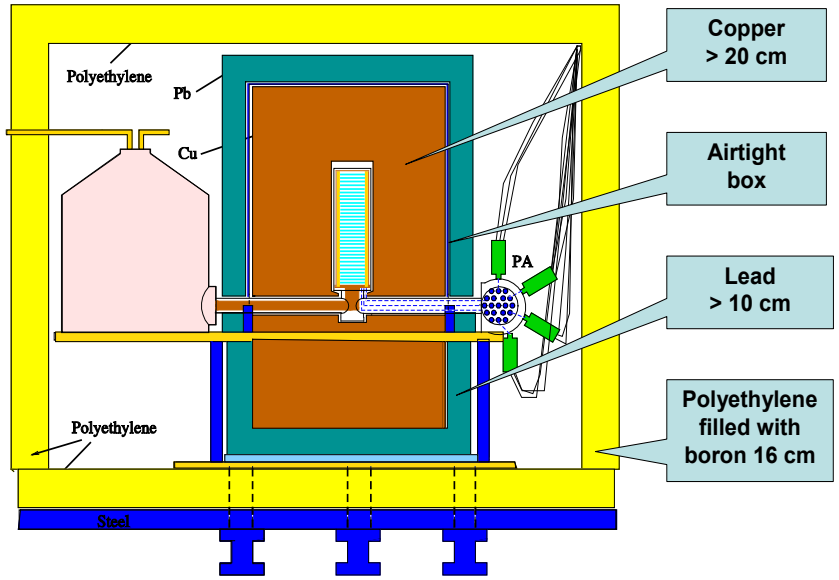


16 pairs of face-to-face detectors with double beta emitters placed between them.A distance from foils to detectors is ≤1.5 mm

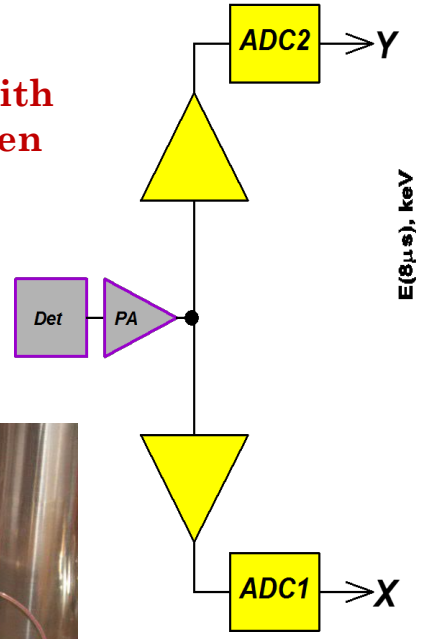


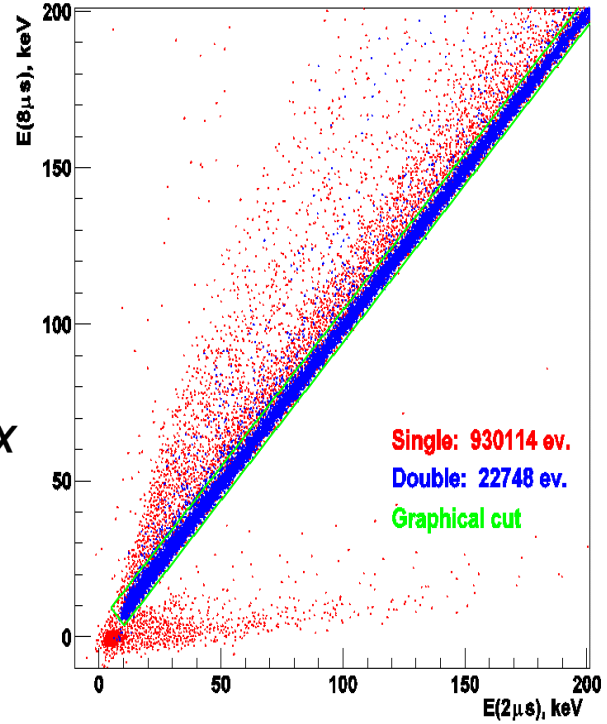


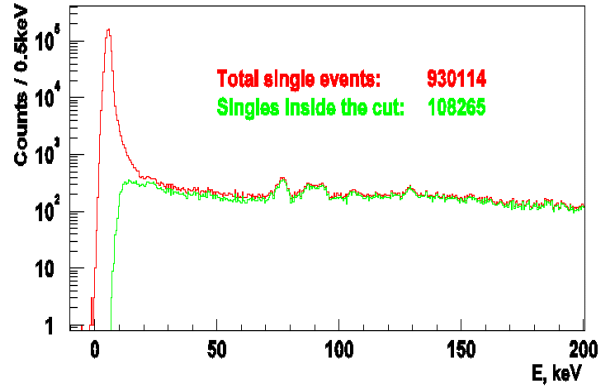
PASSIVE SHIELDING



Suppression of microphonic noise

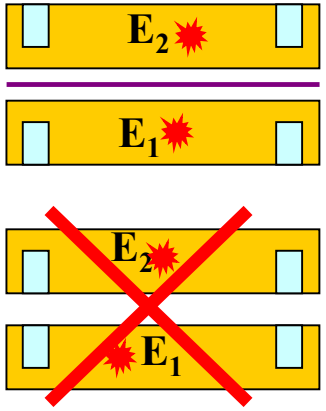






KK TGV signal patterns

KK-pair

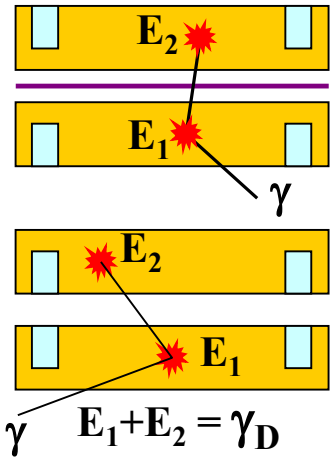


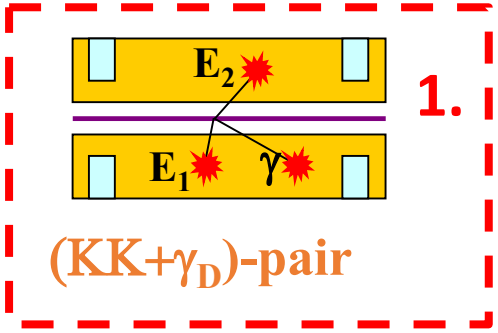
$E_1=E_2=K_{Pd}$

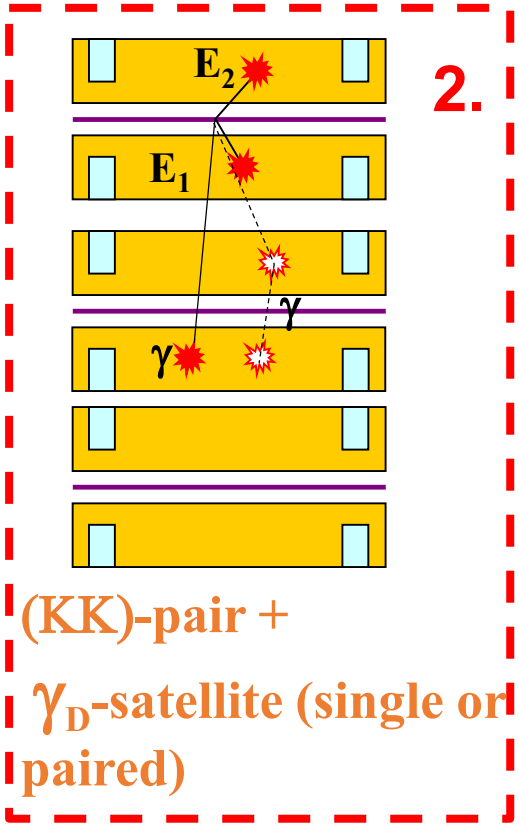
γ_D-single

$E_1=\gamma_D$

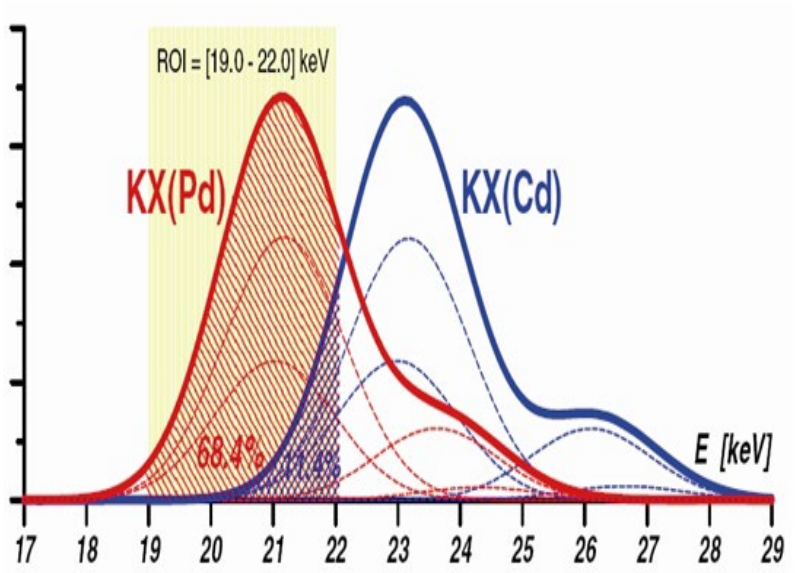
γ_D-paired





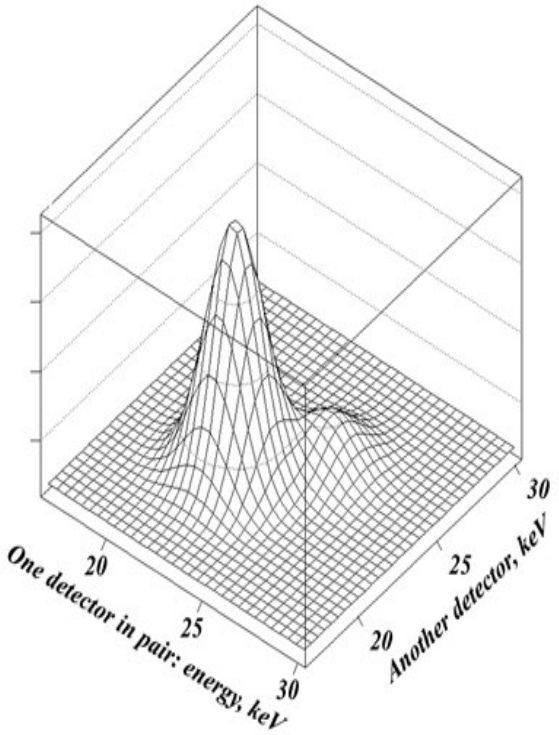


Two types of TGV-2 analysis to find possible KXPd-KXPd events*



1D method

A signal in the 19–22 keV energy window in one detector, while a signal from another face-to-face neighbor detector was collected in another. A final accumulated spectrum was fitted with a 1D-model which included the KXPd multiplet as signal, and the Cadmium KX-ray (KXCd) multiplet with linear underlay as background.

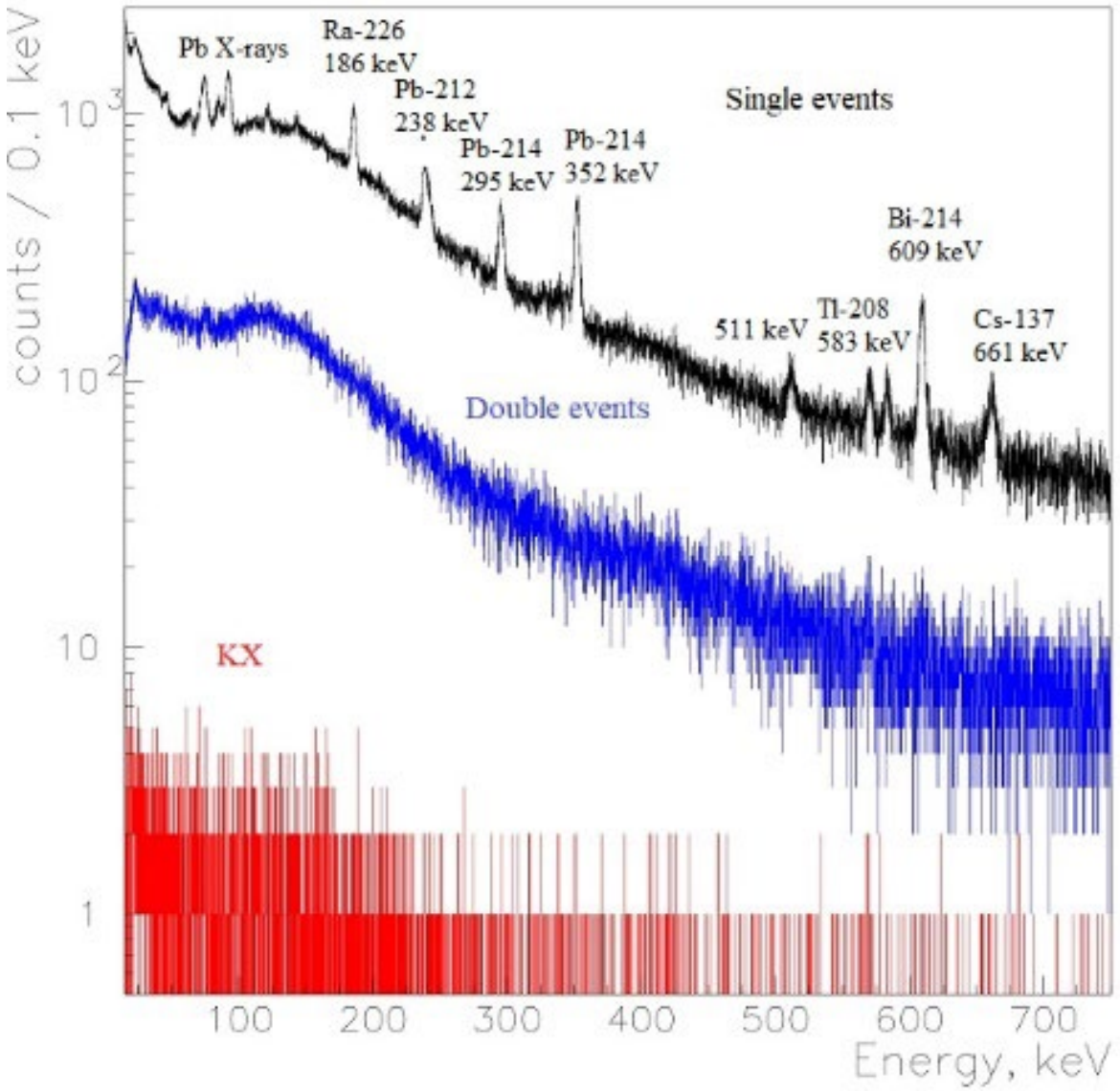


2D method

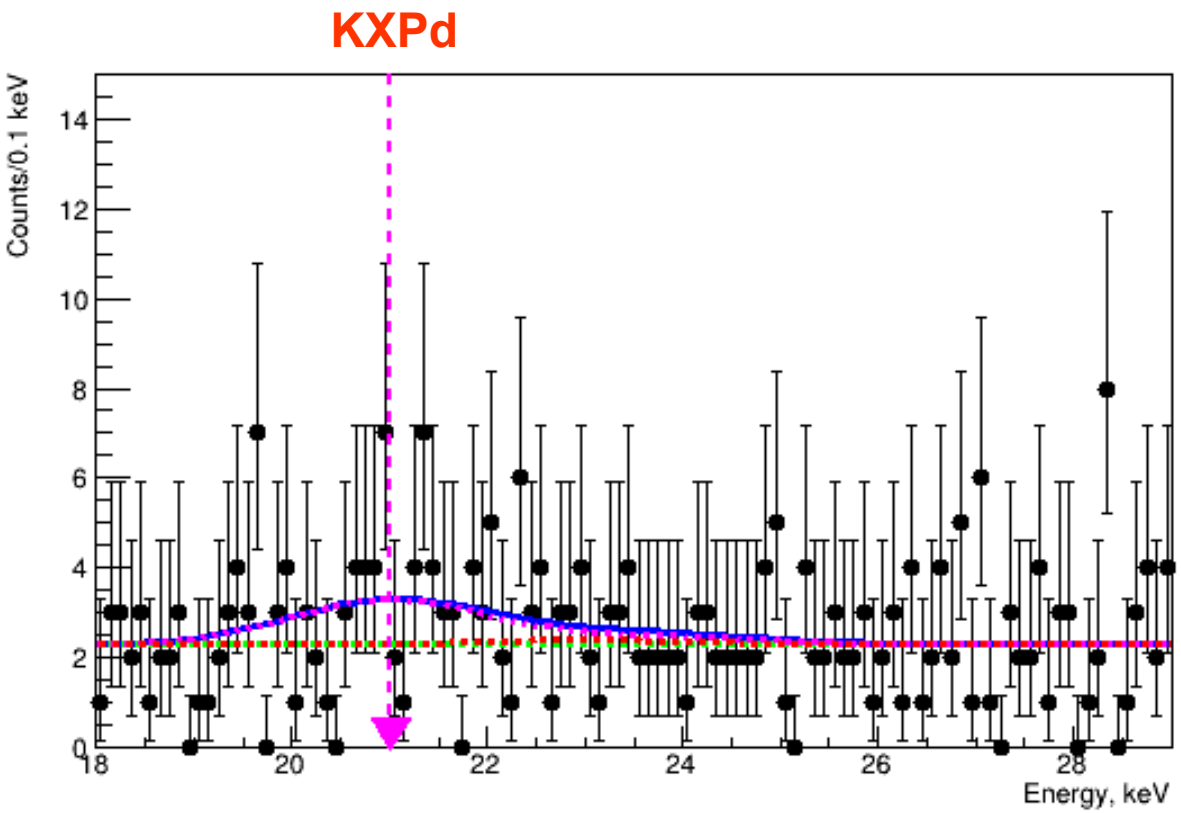
The double coincidence events from neighboring face-to-face detectors, both in the 16–30 keV energy range, were collected in a 2Dhistogram. The final 2D-spectrum was fitted by a 2D-model consisting of the 2D-Gaussian KXPd multiplet as signal, and the KXCd 2D-Gaussian multiplet together with the 2D-background slope as background

* *N.I. Rukhadze et al. / Nuclear Physics A 852 (2011) 197–206*

Suppression of TGV-2 background by using coincidence techniques.



One dimensional spectra of double coincidence events, obtained in measurement of enriched ^{106}Cd in phase III of experiment TGV-2 during 47860 h



TGV-2 Limits on double beta decay of ^{106}Cd (90%CL)

Decay mode	Final level of ^{106}Pd	$T_{1/2}$, y Phase II* (2012)	$T_{1/2}$, y Phase III (T=42500h)*	$T_{1/2}$, y Phase III (T=47860h)*
2ν*EC/EC*	0^+g.s.	4.2×10^{20}	7.2×10^{20}	1.2×10^{21}
	2^+,511.9 keV	1.2×10^{20}	8.9×10^{20}	1.2×10^{21}
	0^+_1,1134 keV	1.0×10^{20}	7.2×10^{20}	9.6×10^{20}
2νβ$^+$/*EC*	0^+g.s.	1.1×10^{20}	6.6×10^{20}	8.4×10^{20}
	2^+,511.9 keV	1.1×10^{20}	7.9×10^{20}	1.0×10^{21}
	0^+_1,1134 keV	1.6×10^{20}	9.0×10^{20}	1.2×10^{21}
2νβ$^+$β$^+$	0^+g.s.	1.4×10^{20}	3.9×10^{20}	4.9×10^{20}
	2^+,511.9 keV	1.7×10^{20}	4.7×10^{20}	6.0×10^{20}

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

*N.I.Rukhadze et al., *Journal of Physics: Conference Series* 375 (2012) 042020

*N.I.Rukhadze et al., *Journal of Physics: Conference Series 2156 (2022) 012134*

* N.I.Rukhadze on behalf of TGV collaboration, LXXII International conference Nucleus-2022, Moscow, 2022

We see some events of possible EC/EC decay of ^{106}Cd. To detect this effect with good confidence level we need to restore TGV spectrometer in working conditions, upgrade electronics and software, and continue measurement.
To realize this plans we need to have permission from LSM to come in Modane.

2. Search for double beta decay of ^{82}Se to excited states of ^{82}Kr with low-background highly sensitive HPGe detector Obelix (JINR-IEAP-LNGS-LSM-ITEP)

Double beta decay to excited states of daughter nuclei are accompanied by emission of γ-quanta in de-excitation of excited states. These 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).

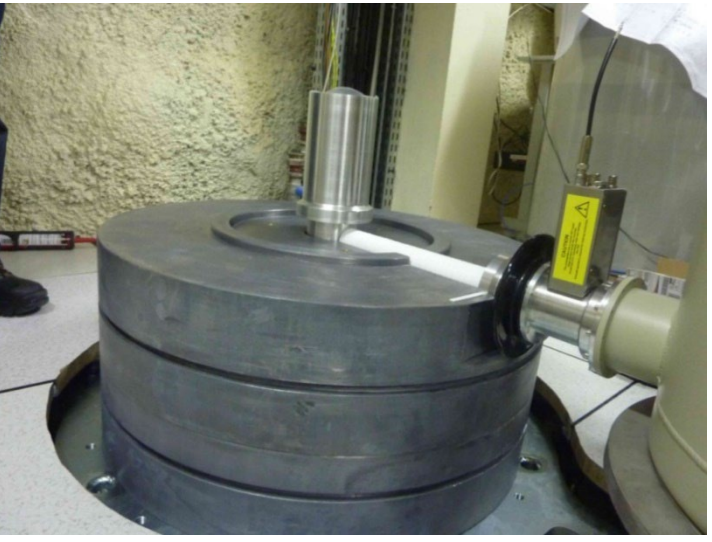
Investigations of ^{58}Ni-^{58}Fe,and ^{74}Se-^{74}Ge ββ processes were also performed using the Obelix spectrometer

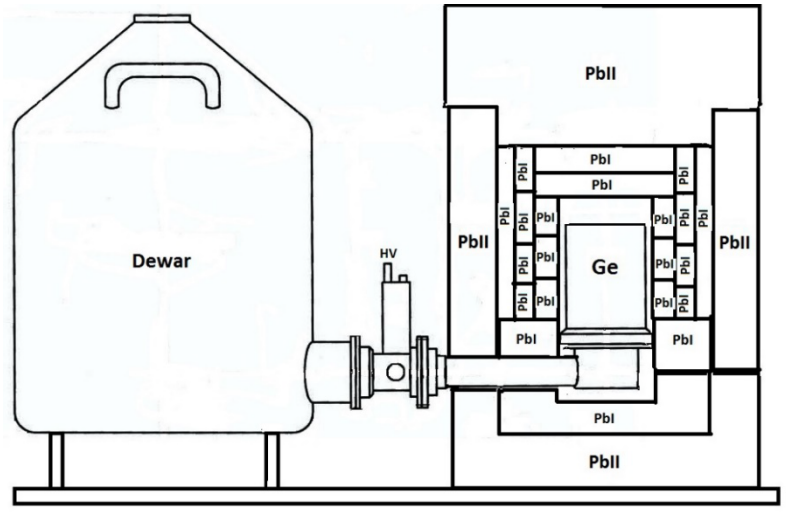
Detector Obelix*

P type coaxial HPGe detector Canberra in U-type ultra low background cryostat located at LSM, France (4800 m w.e.)

Sensitive volume	600 cm^3
Efficiency	~160%
Peak / Compton	83
Energy resolution	~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

*JINST 12 (2017) P02004.





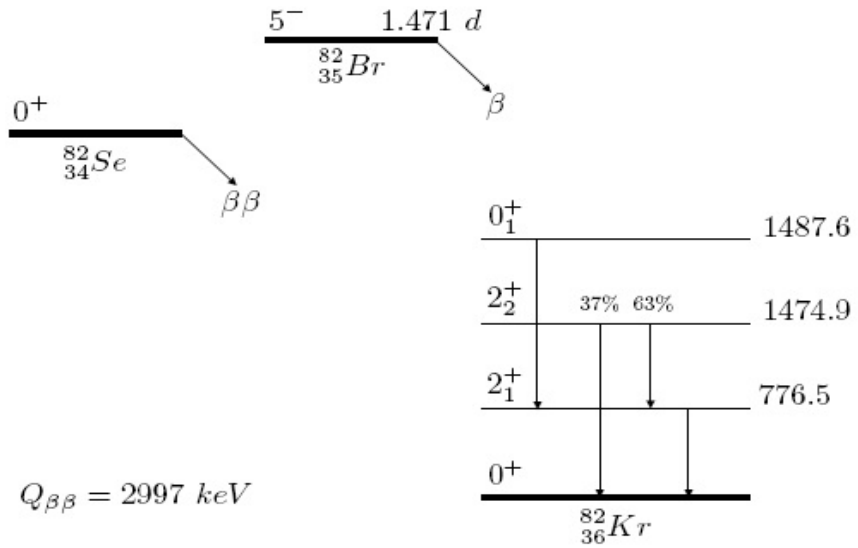
Passive Shielding
~12 cm arch. Pb
~20 cm low active Pb,
Radon free air

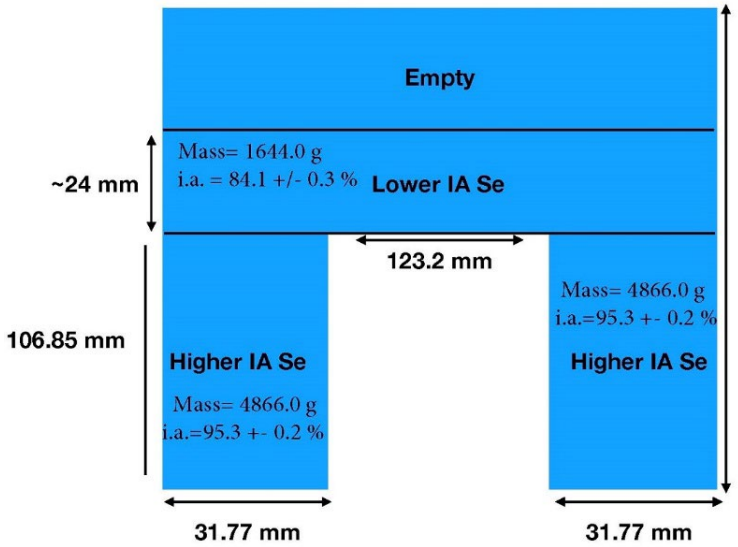
Measurement of ^{82}Se with the Obelix detector

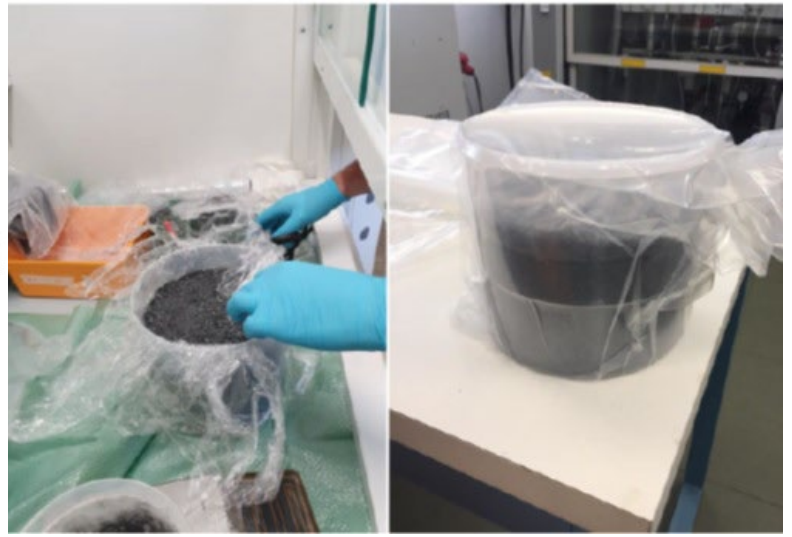
(JINR-IEAP-LNGS-LSM-ITEP)

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

^{82}Se decay scheme







ββ decay of ^{82}Se to the first 0+ excited state of ^{82}Kr will accompanied by 2 γ-lines, 711.1 keV and 776.5 keV.

Expected half-life can be (3.3-5.6)*10^{22} y.

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), $T_{1/2} > 4x10^{21}$years;

2) By NEMO-3 collaboration (R. Arnold, arXiv: 2001.06388 [physics .ins-det]), $T_{1/2} > 1.3\ x10^{21}$ years.

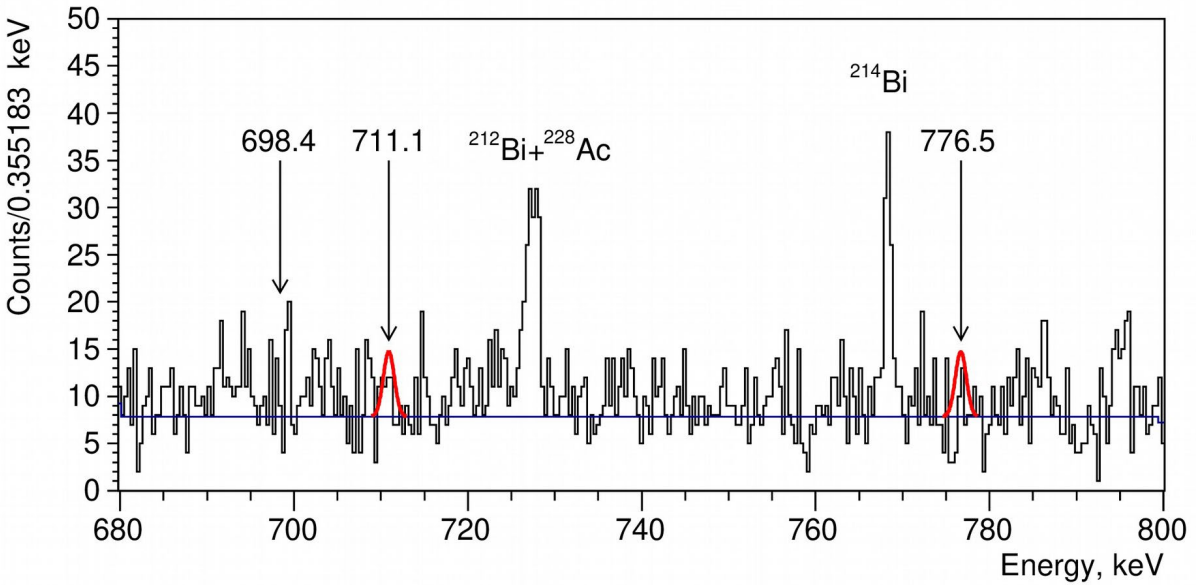
According to our estimation we can reach a level of sensitivity $T_{1/2}$~ 6 x 10^{22} y with the Obelix detector and ~6 kg of ^{82}Se sample and hope to detect DBD of ^{82}Se to excited states of ^{82}Kr for the first time.

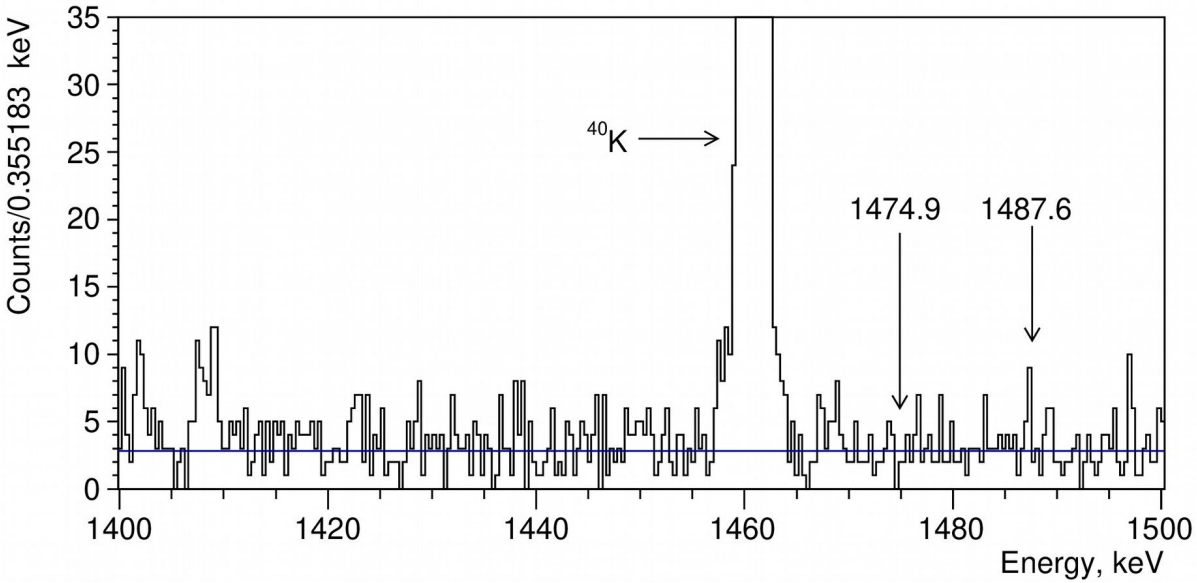
Before sending the ^{82}Se sample in LSM short test measurement of ^{82}Se was performed in LNGS during 62 days but previous limits on DBD of ^{82}Se to excited states of ^{82}Kr were not improved.

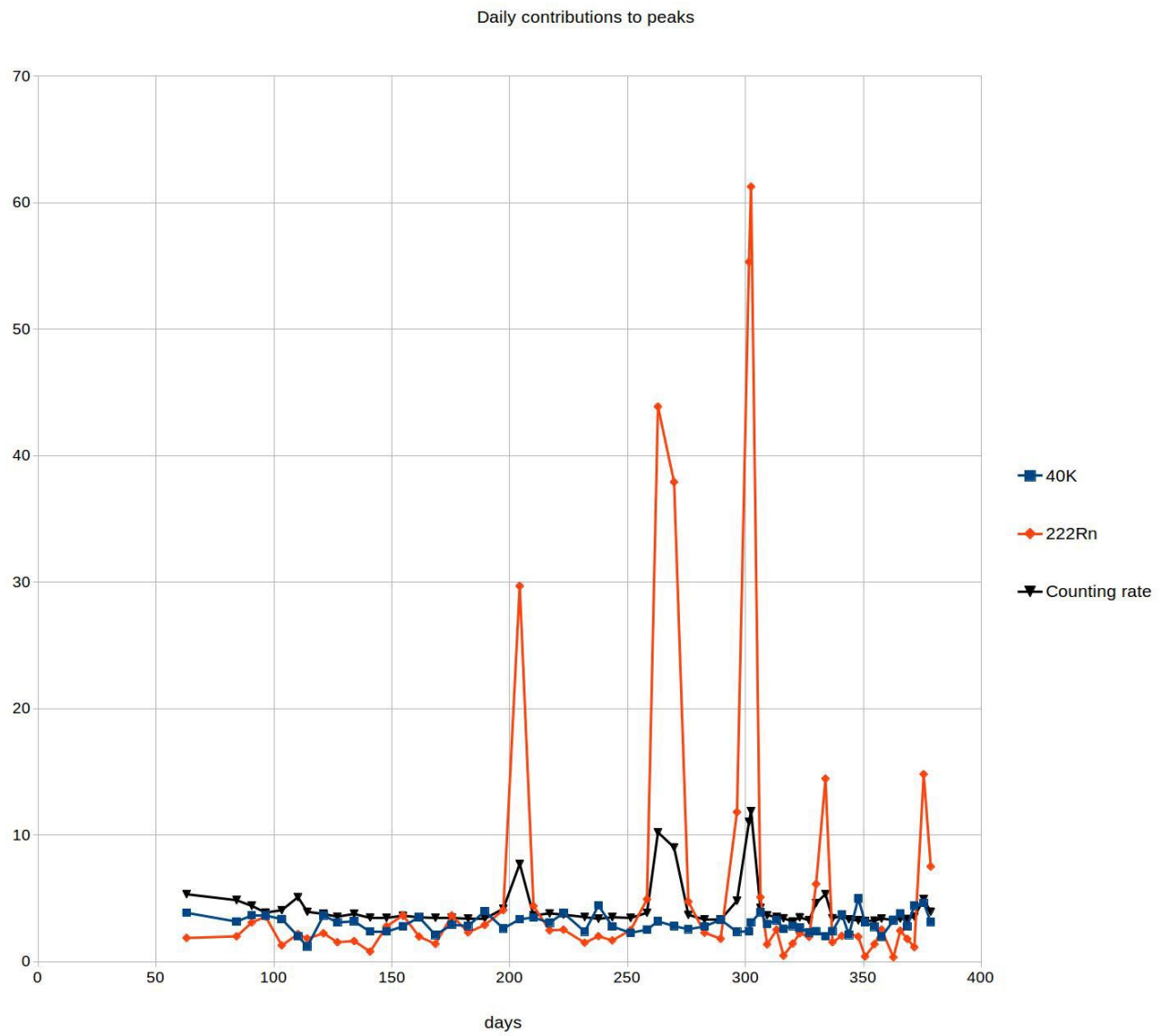
Our measurement of ^{82}Se was started with the Obelix detector 10.12.2021

Measurement of ^{82}Se sample with the Obelix detector

^{82}Se, T=8776 h







Spectrum in the region of interest with linear background.

Limits $T_{1/2}$ (90 CL), 10^{22} y, for ββ decays of ^{82}Se

Level of ^{82}Kr	Gammas ,keV with efficiencies	Obelix, Modane, T=8776h	MPI, Gran Sasso T=1488h	[1]
2^+_1 (776.5 keV)	776.5 (2.416%)	**5.89**	**1.19**	**1.3**
2^+_2 (1474.9 keV)	776.5 (1.341%) + 1474.9 (0.756%)	**4.53**	**1.02**	**1.0**
0^+_1 (1487.6 keV)	711.1 (2.129%)	2.39	0.95	
0^+_1 (1487.6 keV)	776.5 (2.076%)	5.06	1.10	
0^+_1 (1487.6 keV)	711.1 (2.129%) + 776.5 (2.076%)	**4.29**	**1.38**	**3.4**

[1] J. W. Beeman et al., Eur. Phys. J. 75 (2015) 591.

Sensitive volume of HPGe (MPI) = 400 cm^3, T_{meas}=1488h
Sensitive volume of HPGe (Obelix) = 600 cm^3, T_{meas}=8776 h

After 1 year of measurement with Obelix we improved existing experimental limits of ββ decay of ^{82}Se to exited states of ^{82}Kr and reached the level of ~4.2*10^{22} y for half-life of the process.
To detect this process or to reach the sensitivity $T_{1/2}\sim 6 \times 10^{22}$ y we need to continue the measurement for one year more.

In addition we are interested what is the situation with our second detector Idefix, as we have not information about it.