Investigation of double beta decay of ^{58}Ni with the Obelix spectrometer

N.I.Rukhadze (JINR, Dubna)
on behalf of Obelix collaboration

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

Medex'17, Prague, May 31, 2017

SEARCH FOR DOUBLE BETA DECAY

- At present **$2\nu2\beta^-$** decay was detected in **11** nuclei:

^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te, ^{136}Xe, ^{150}Nd, ^{238}U

and **2νEC/EC** in **^{130}Ba** was detected in geochemical experiment

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.

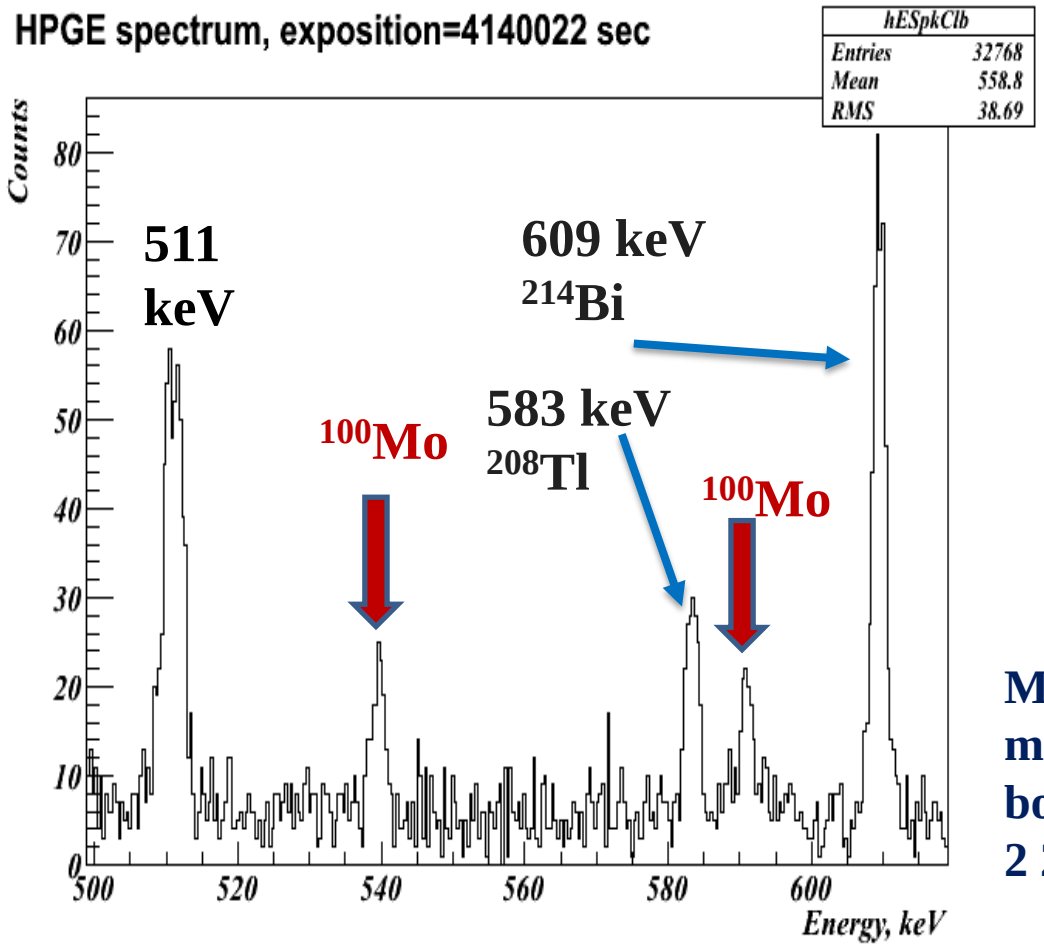
$2\nu2\beta^-$ decay to excited states was detected in

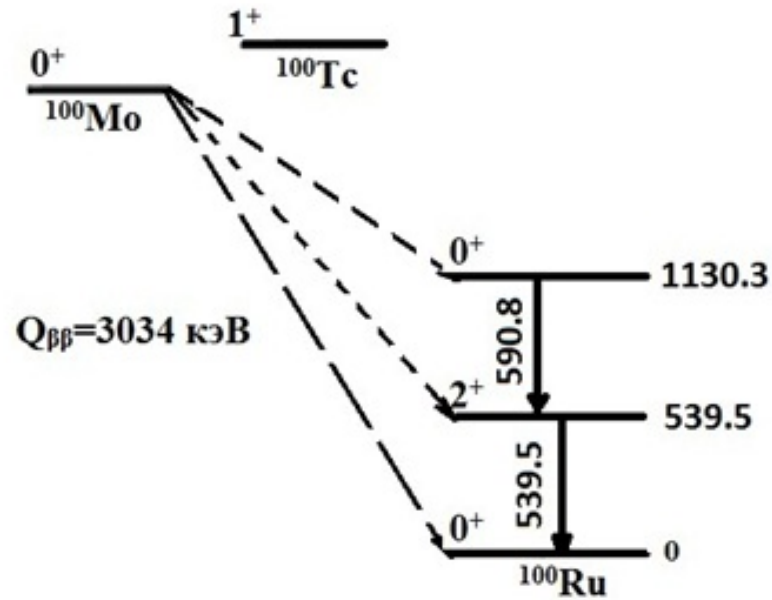
^{100}Mo - ^{100}Ru (0^+_1, 1130.3 keV) and **^{150}Nd - ^{150}Sm (0^+_1, 740.4 keV)**.

^{100}Mo - ^{100}Ru (0^+_1, 1130.3 keV) decay was detected in several experiments, including measurements performed at LSM, Modane with the Obelix HPGe spectrometer

(**R. Arnold et al. Nucl. Phys. A 925 (2014) 25**)

Investigation of 2νββ decay of ^{100}Mo-^{100}Ru to excited states





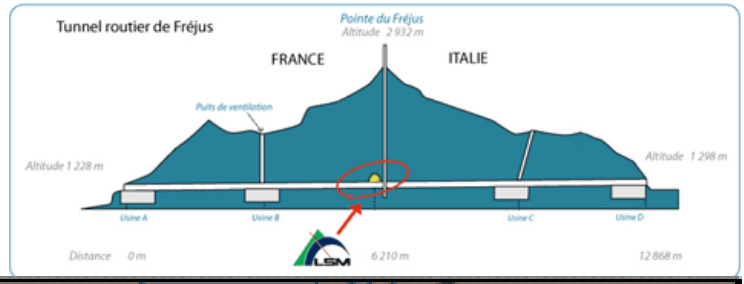
Metallic foil of enriched ^{100}Mo with a total mass of 2 505 g was measured in Marinelli bobbin with the OBELIX spectrometer for 2 288 hours.

^{100}Mo → 0$^+$, 1130 keV ^{100}Ru* observable γ590.8+γ539.5 keV
^{100}Mo → 2$^+$, 540 keV ^{100}Ru observable γ539.5 keV

$$T_{1/2}\,(0^+_1,\ 1130.3\ \text{keV}) = [7.5 \pm 0.6(\text{stat.}) \pm 0.6(\text{sys.})] \times 10^{20}\ \text{yr}\ (90\ \%\ \text{CL})$$

*R. Arnold et al., Nuclear Physics A*925 (2014) 25

Laboratoire Souterrain de Modane



Fréjus Tunnel at the French-Italian border

Depth - 1800 m of rock (4800 mwe)

Muons flux - 4 muons / m^2 x day^{-1} ($2x10^6$ reduction factor)

Neutrons flux - 3000 fast neutrons (>1MeV) per m^2 and per day (1000 reduction factor)

Detector Obelix*

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

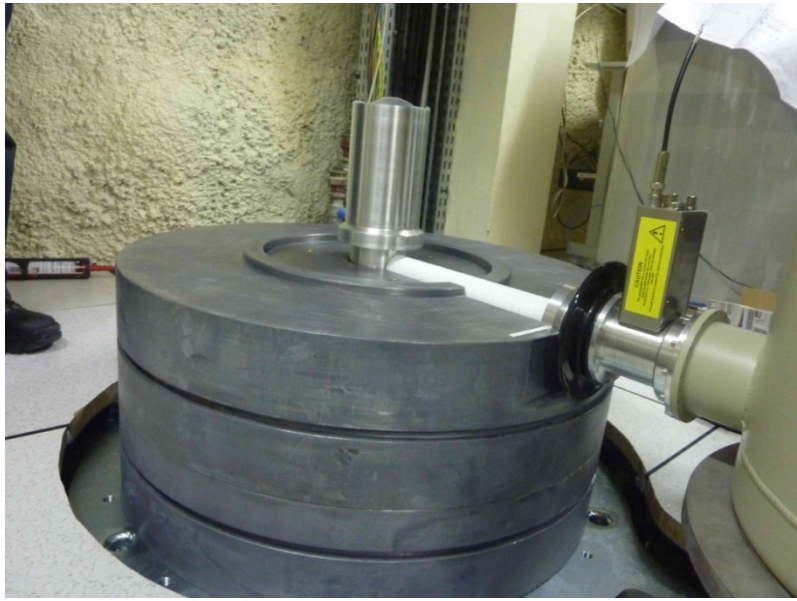
JINR Dubna, Russia,
IEAP, CTU Prague, Czech Republic,
LSM Modane, France

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

~12 cm arch. Pb

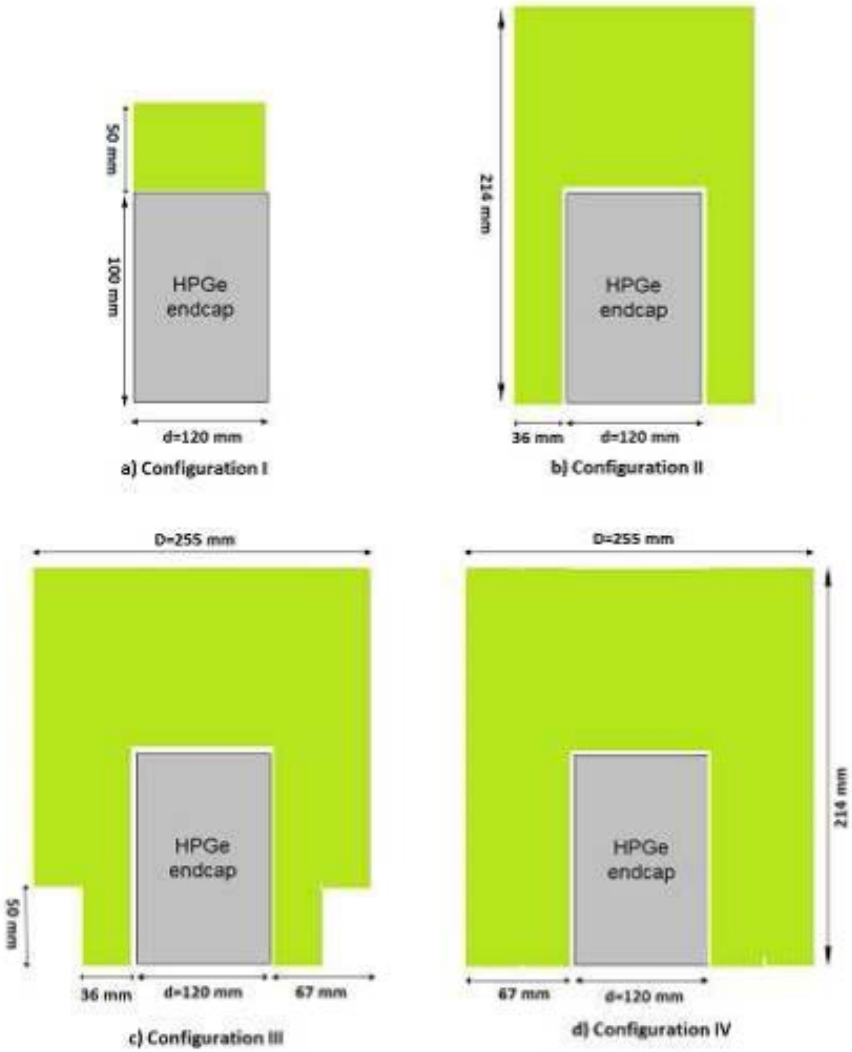
~20 cm low active Pb

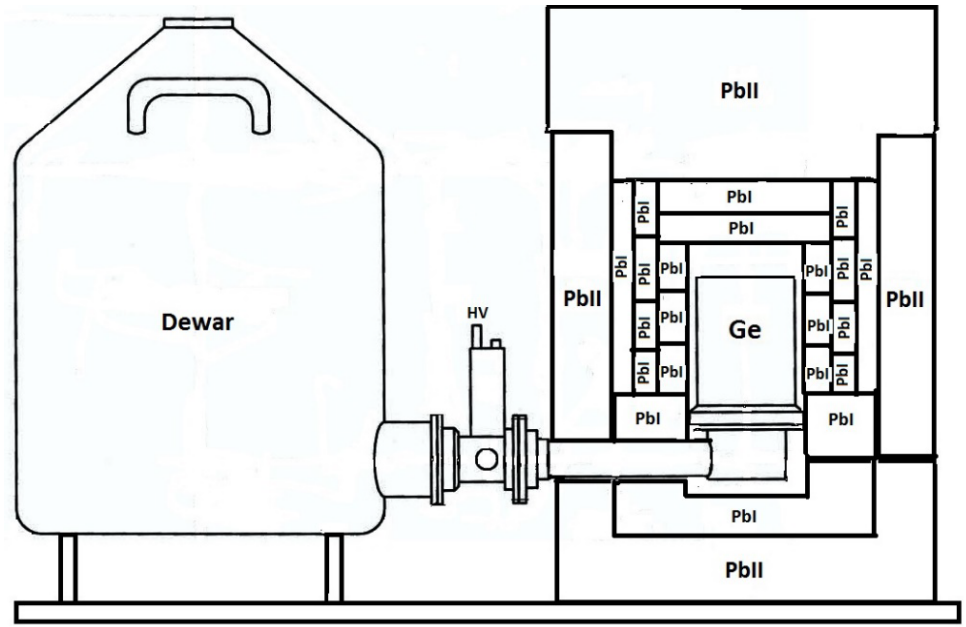
Radon free air



*JINST 12 (2017) P02004.

Configurations of the Obelix passive shielding

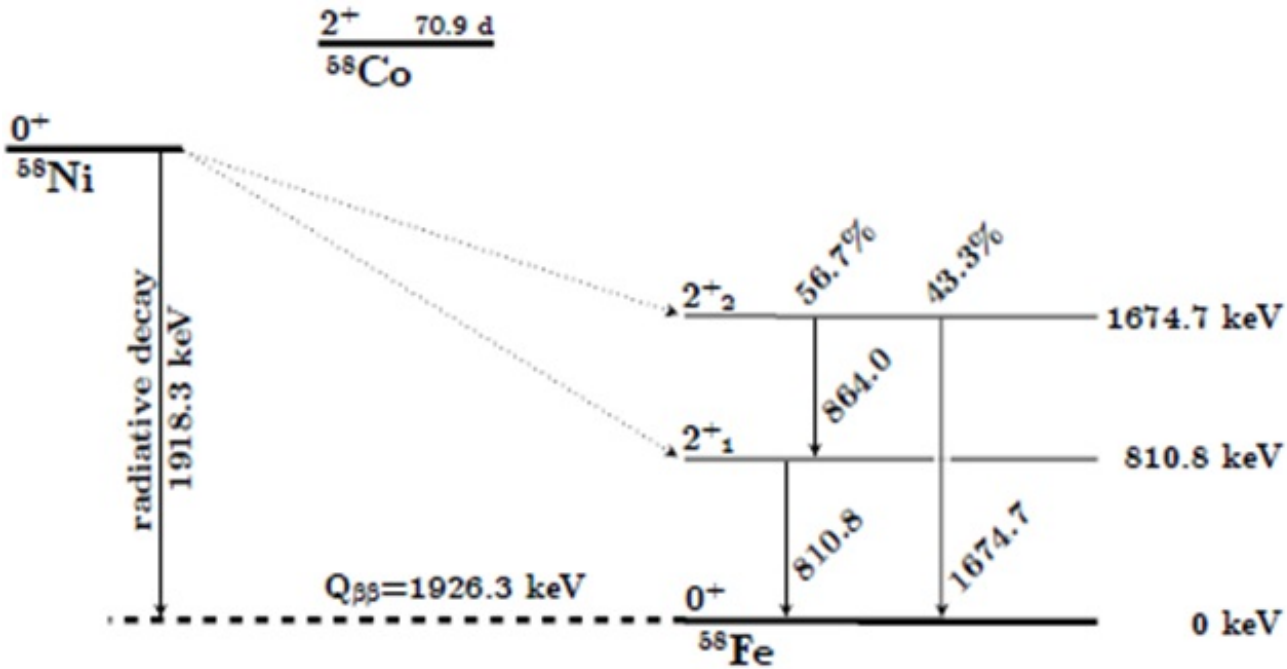




PbI ~ 12 cm of archeological lead
(activity of < 60 mBq/kg)
(~7 cm can be removed)

PbII ~ 20 cm of low-active lead
(activity of 5 - 20 Bq/kg)

Double beta decay of ^{58}Ni



Decay scheme of ^{58}Ni-^{58}Fe (B. Lehnert et al., J. Phys. G: Nucl. Part. Phys. 43 (2016) 065201)

$$2\nu\mathrm{ECEC}: \ {}^{58}\mathrm{Ni} + 2e^- \rightarrow {}^{58}\mathrm{Fe}(2_1^+) + 2\nu_e + 2\gamma_{\mathrm{shell}} + \gamma_{(810.8\ \mathrm{keV})}$$

$$2\nu\mathrm{ECEC}: \ {}^{58}\mathrm{Ni} + 2e^- \rightarrow {}^{58}\mathrm{Fe}(2_2^+) + 2\nu_e + 2\gamma_{\mathrm{shell}} + \gamma_{(1674.8\ \mathrm{keV})}$$

$$\rightarrow {}^{58}\mathrm{Fe}(2_2^+) + 2\nu_e + 2\gamma_{\mathrm{shell}} + \gamma_{(810.8\ \mathrm{keV})} + \gamma_{(864.0\ \mathrm{keV})}$$

$$2\nu\mathrm{EC}\beta^+: \ {}^{58}\mathrm{Ni} + e^- \rightarrow {}^{58}\mathrm{Fe}(\mathrm{g.s.}) + 2\nu_e + e^+ + \gamma_{\mathrm{shell}} + 2\gamma_{(511\ \mathrm{keV})}$$

$$0\nu\mathrm{ECEC}: \ {}^{58}\mathrm{Ni} + 2e^- \rightarrow {}^{58}\mathrm{Fe}(\mathrm{g.s.}) + \gamma_K + \gamma_L + \gamma_{(1918.3\ \mathrm{keV})}$$

Measurement of ^{58}Ni

Run 1 - 2014

15.10.2914-11.11.2014
T_1=2348724 s=652.4 h

14.11.2014- 08.12.2014
T_2=1758647 s=488.5 h

T= 1141 h**= 47.5 d**

Run 2 - 2015

28.08.2015 – 17.09.2015
T= 1639946 s = 456 h **= 19 d**.

Run 3 - 2017

07.04.2017 - ….. (in progress)
T= 3760800s = 1044.7 h = **43.5 d**.

Sample of natural nickel with a mass of ~21.7 kg, containing ~68% of ^{58}Ni

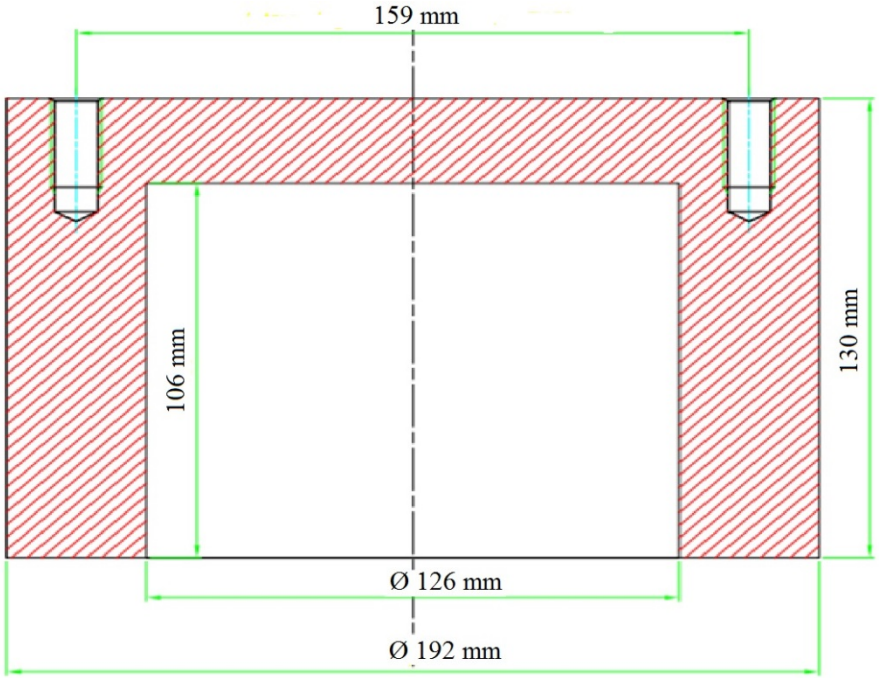
Theoretical prediction:

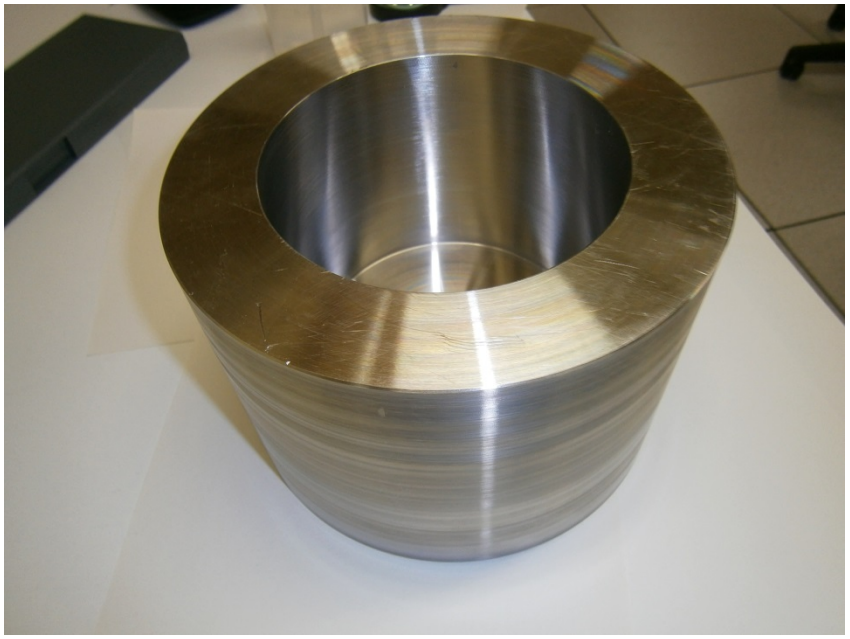
$T_{1/2}(2\nu\beta^+EC,\ 0^+\rightarrow0^+) = 8.6\times10^{25}$ y
$T_{1/2}(2\nu EC/EC,\ 0^+\rightarrow0^+) = 6.1\times10^{24}$ y
$T_{1/2}(0\nu EC/EC$ radiative$) = 2\times10^{35} - 3\times10^{36}$ y

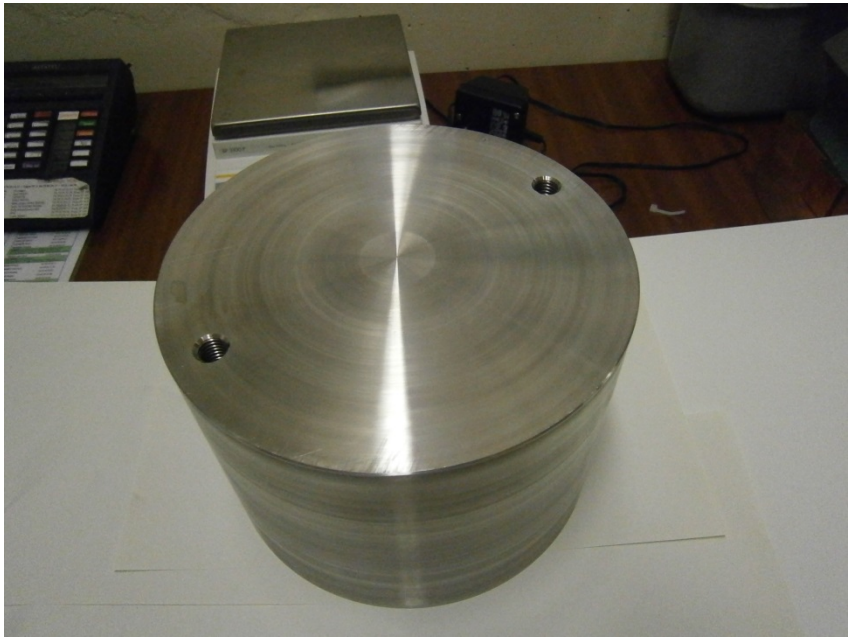
Existing experimental limits:

$T_{1/2}(2\nu\beta^+EC, 0^+\rightarrow0^+) > 7.0\times10^{20}$ y (68%CL)
$T_{1/2}(2\nu\beta^+EC, 0^+\rightarrow2_1^+) > 4.0\times10^{20}$ y (68%CL)
$T_{1/2}(2\nu EC/EC, 0^+\rightarrow2_1^+) > 4.0\times10^{19}$ y (90%CL)
$T_{1/2}(2\nu EC/EC, 0^+\rightarrow2_2^+) > 4.0\times10^{19}$ y (90%CL)
$T_{1/2}(0\nu EC/EC$ radiative$) > 2.1\times10^{21}$ y (90%CL)

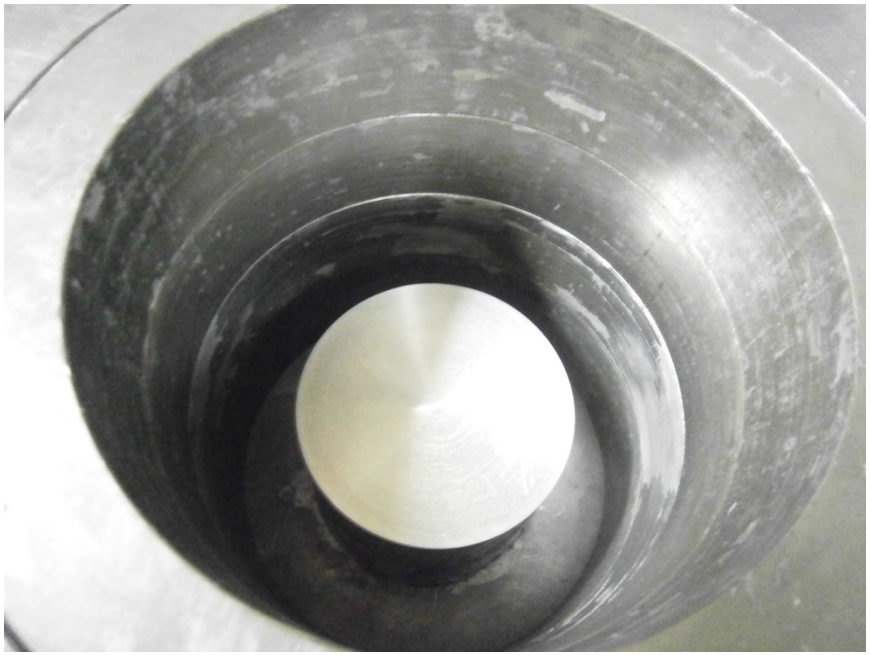
Measurement of ^{58}Ni

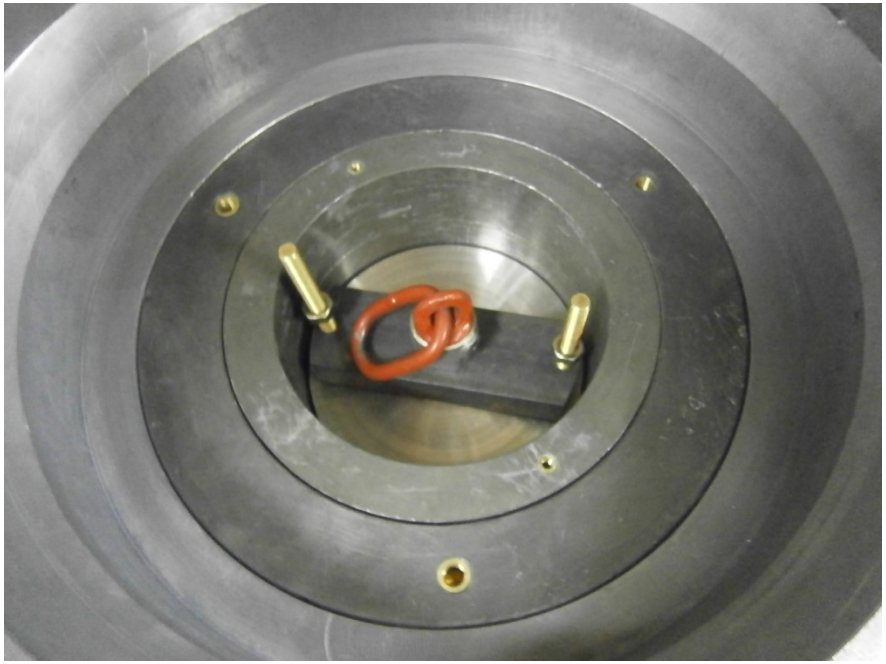


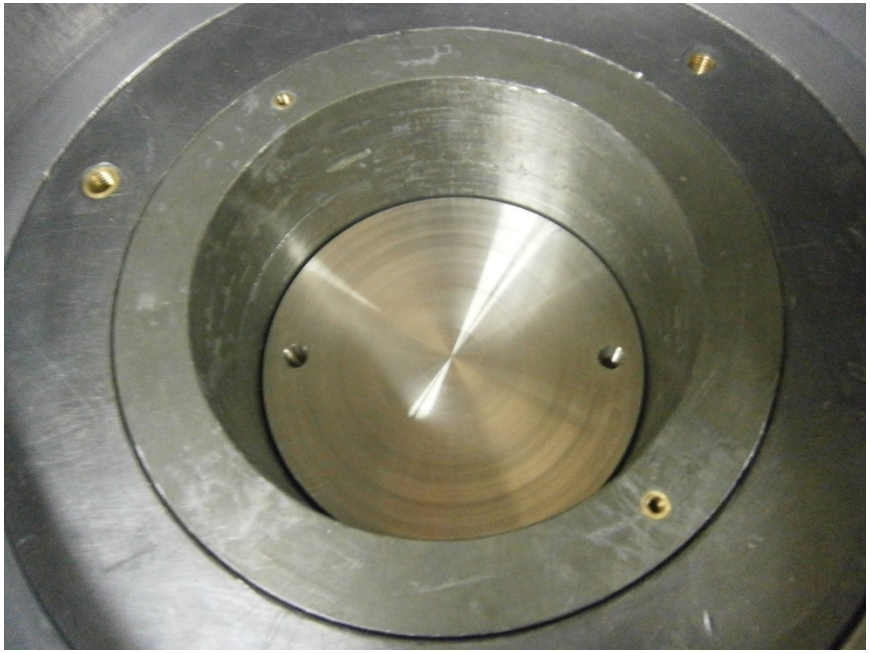




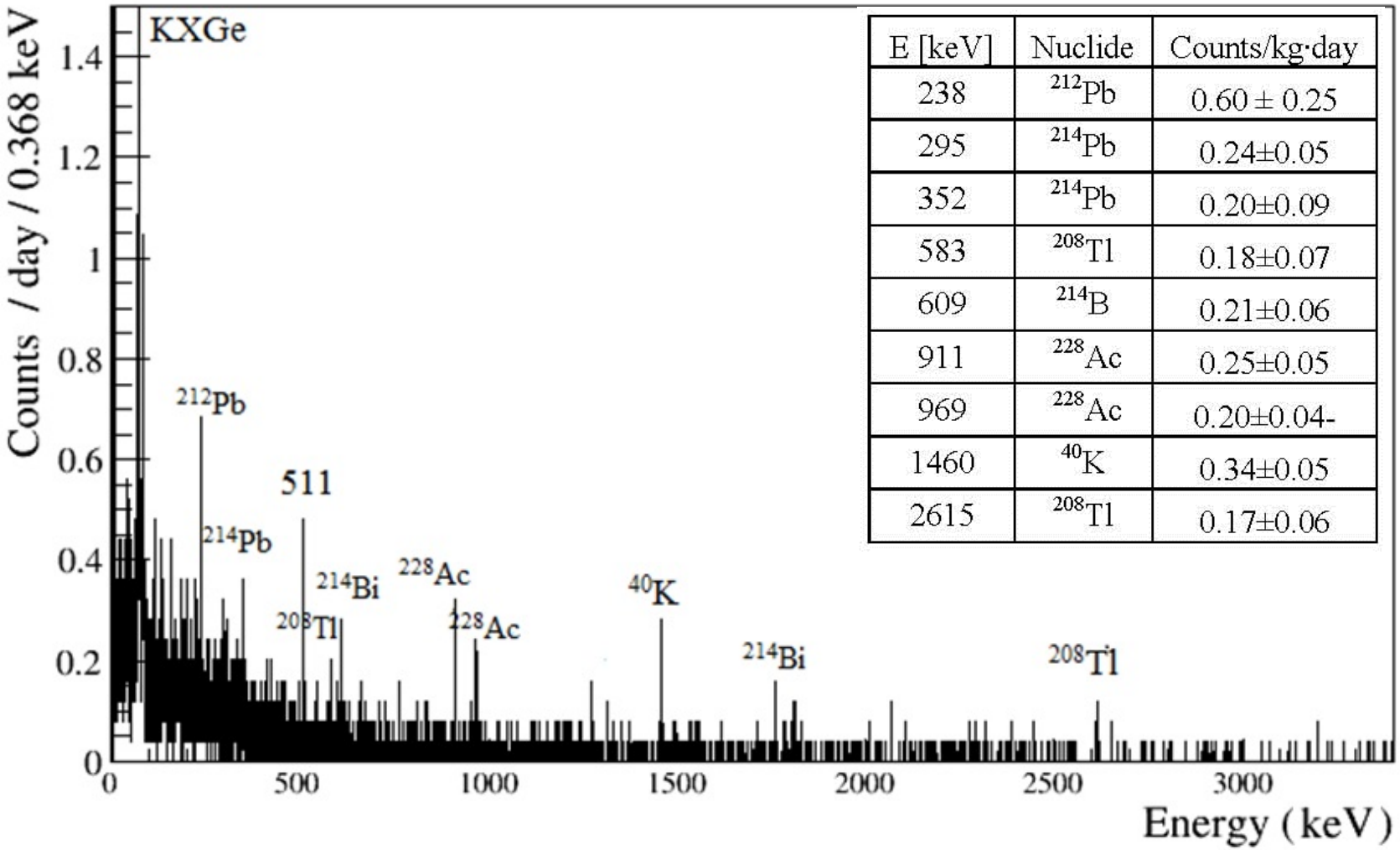
Measurement of ^{58}Ni







Background of the Obelix spectrometer



E [keV]	Nuclide	Counts/kg·day
238	^{212}Pb	0.60 ± 0.25
295	^{214}Pb	0.24±0.05
352	^{214}Pb	0.20±0.09
583	^{208}Tl	0.18±0.07
609	^{214}B	0.21±0.06
911	^{228}Ac	0.25±0.05
969	^{228}Ac	0.20±0.04-
1460	^{40}K	0.34±0.05
2615	^{208}Tl	0.17±0.06

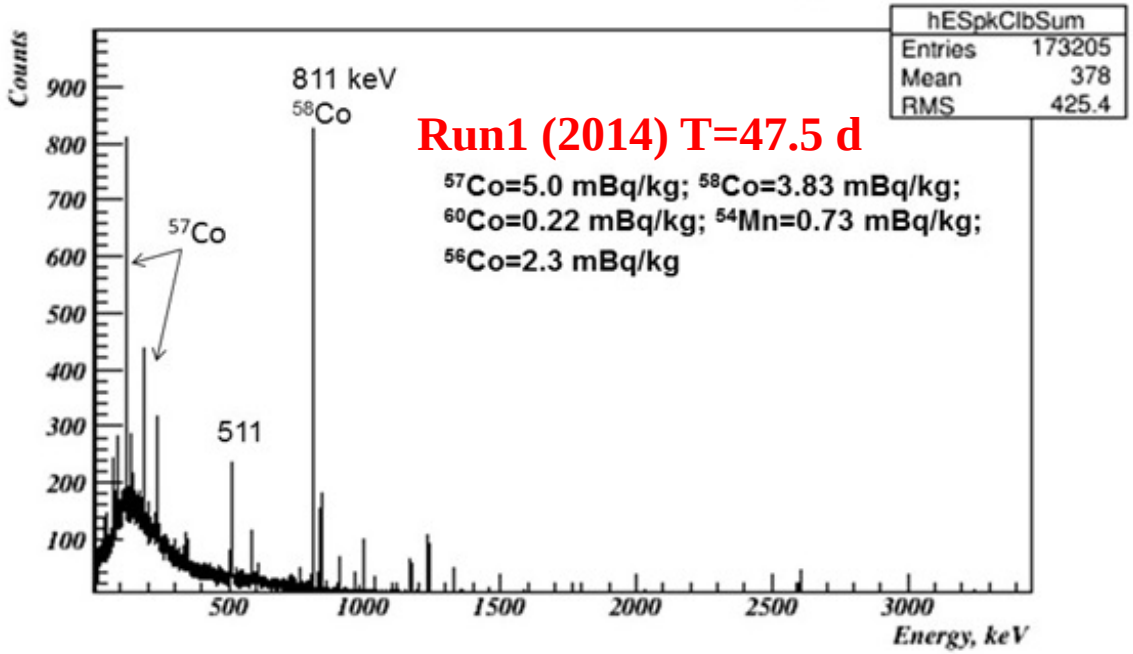
Integral count rate [30-3000 keV]:

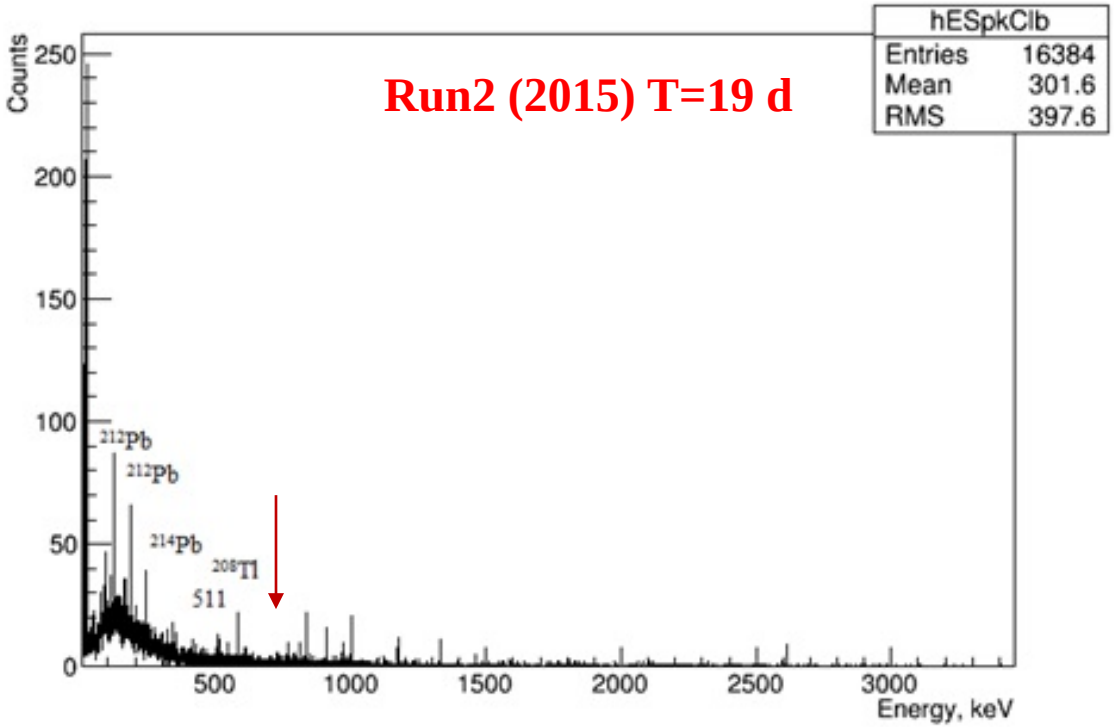
2011 – **173 counts/kg · d**

2014 – **73 counts/kg · d**

2017 - **95 counts/ kg·d** (after the detector was repaired by Canberra)

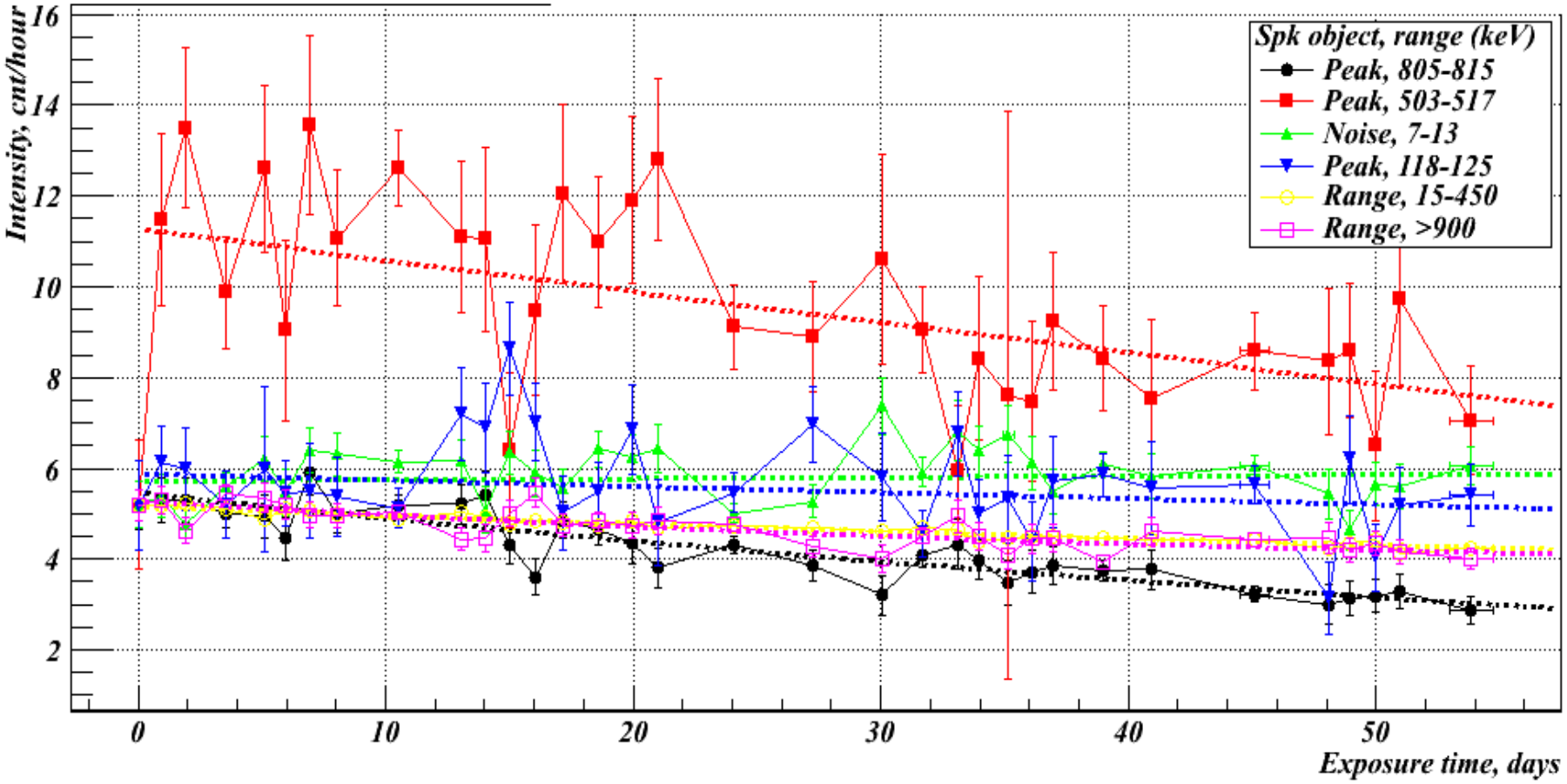
Measurement of ^{58}Ni





Sample: natural Ni **(~68% of ^{58}Ni)**
Total mass: ~**21.7 kg**
The investigations of double beta decay (β^+EC, EC/EC)
Regions of interest: 511 keV , 811 keV, 864 keV, 1675 keV, 1918 keV

Time dependence of radiation intensity in 2014

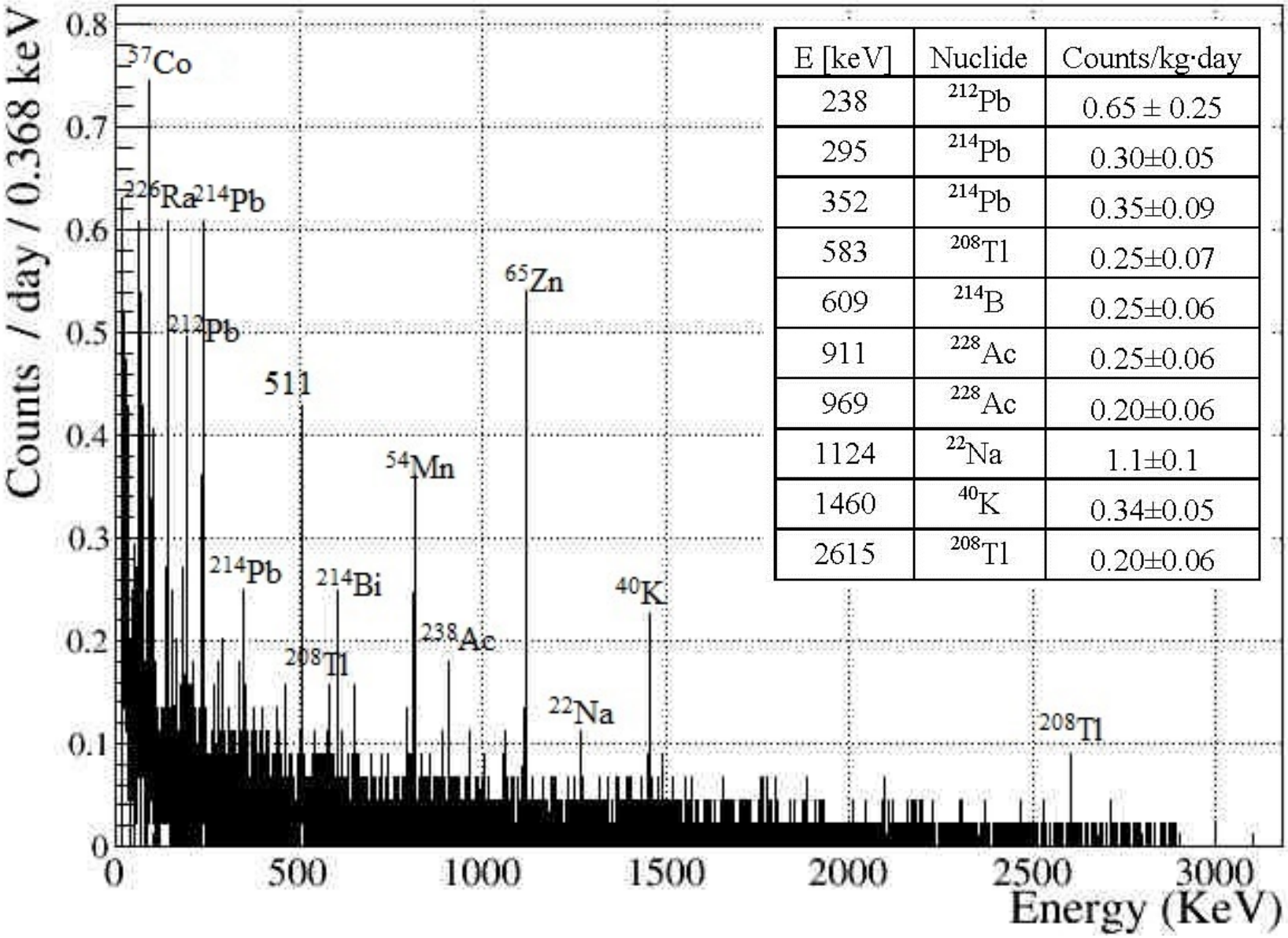


Activity of ^{58}Co in nickel sample at the start of measurements in 15/10/2014 was

$A(^{58}Co) = 5.4 \pm 0.5$ mBq/kg

Background measurement with Obelix in 2017

T=44d



E [keV]	Nuclide	Counts/kg·day
238	^{212}Pb	0.65 ± 0.25
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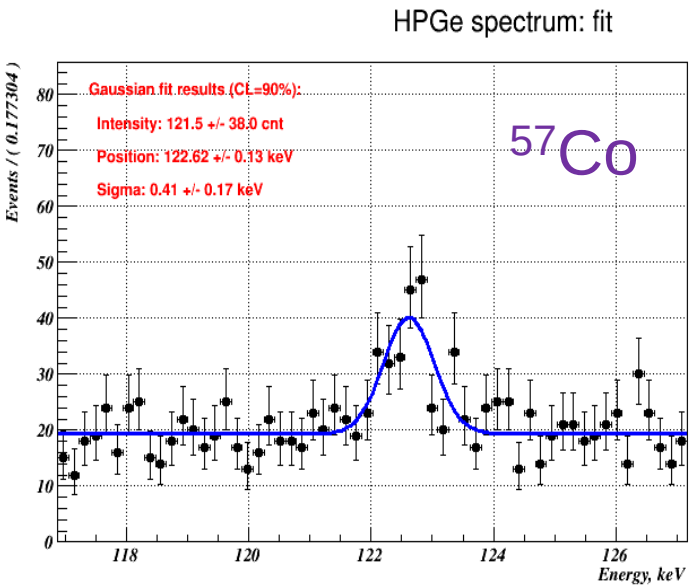
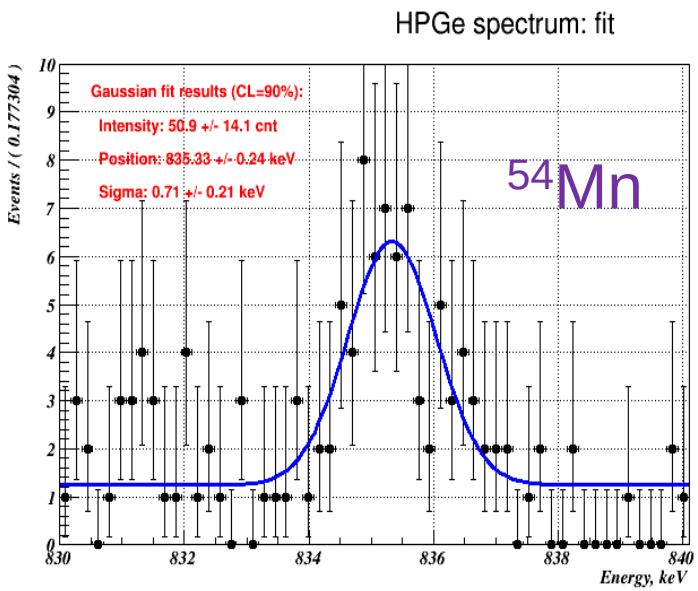
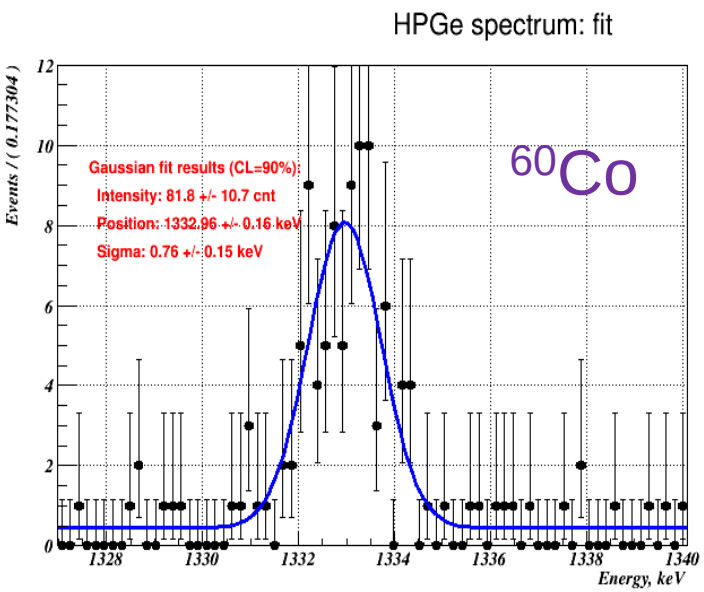
352	^{214}Pb	0.35±0.09
583	^{208}Tl	0.25±0.07
609	^{214}B	0.25±0.06
911	^{228}Ac	0.25±0.06
969	^{228}Ac	0.20±0.06
1124	^{22}Na	1.1±0.1
1460	^{40}K	0.34±0.05
2615	^{208}Tl	0.20±0.06

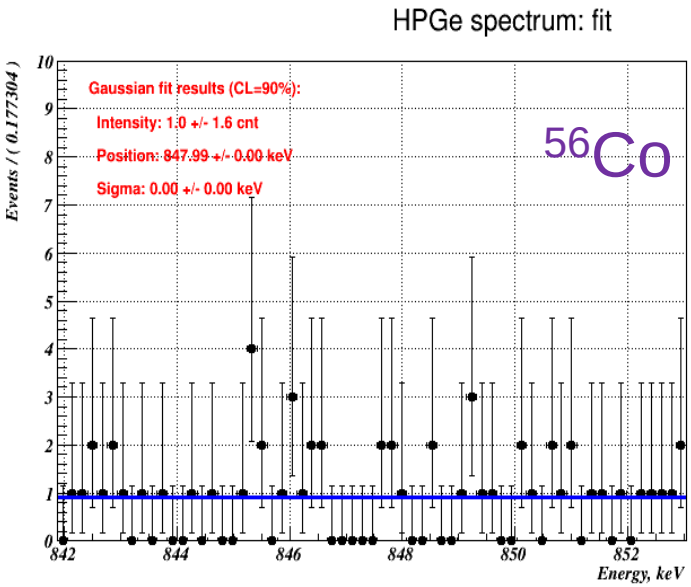
Counting rate [30 – 2900 keV] 95 counts/day•kg

Cosmogenic isotopes in 2017

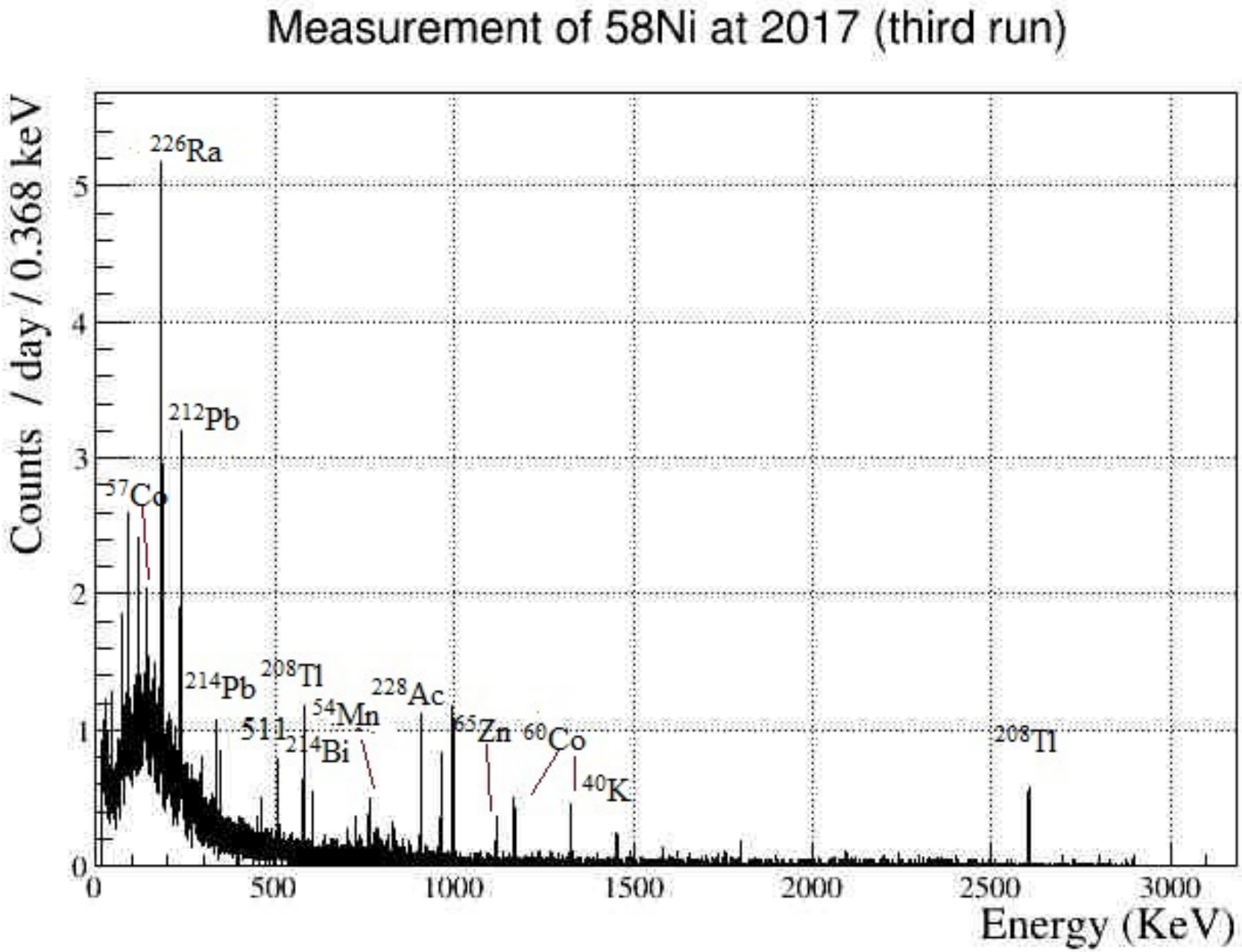


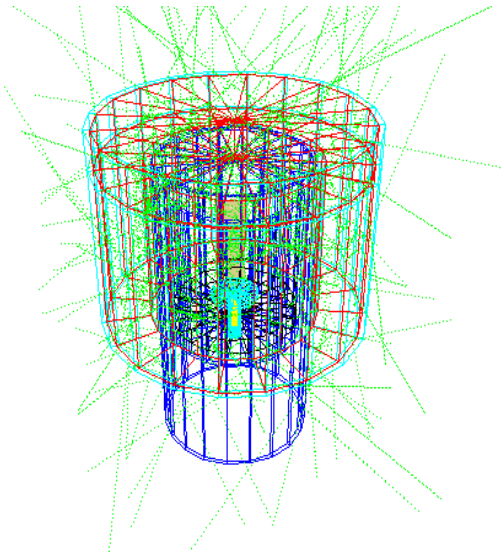






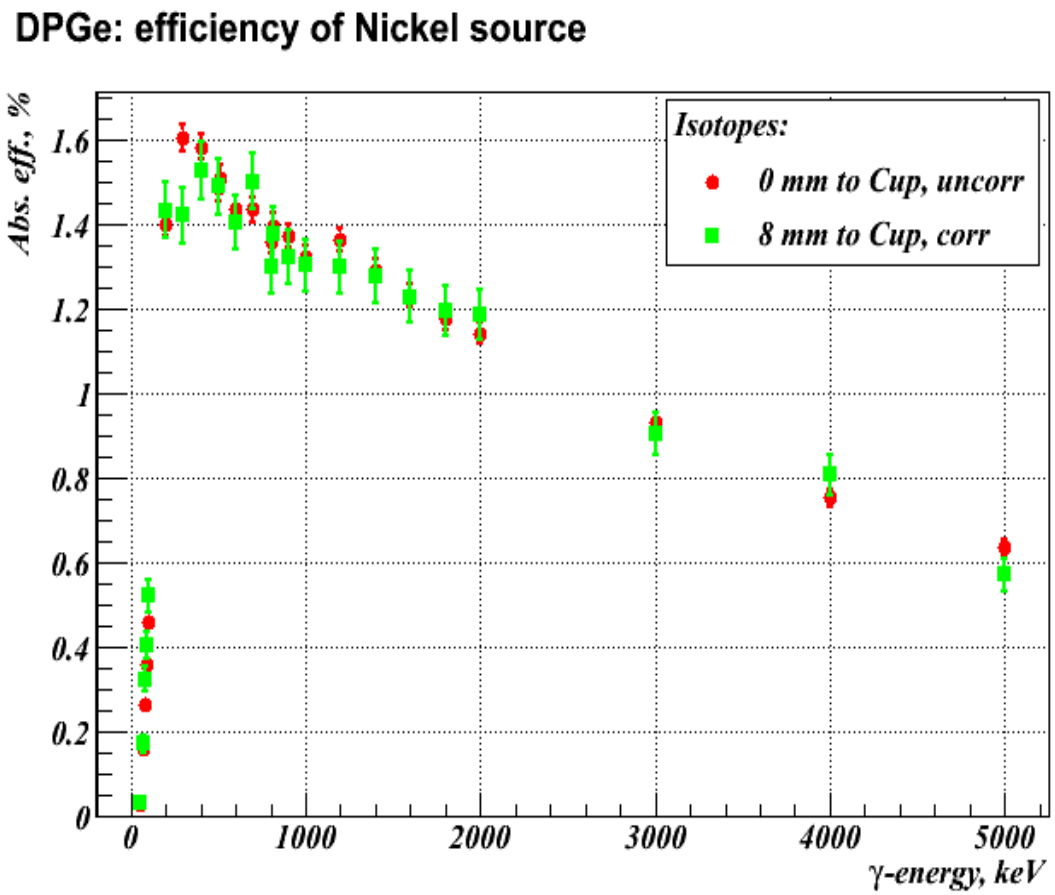
T=43.5d (3760800s)



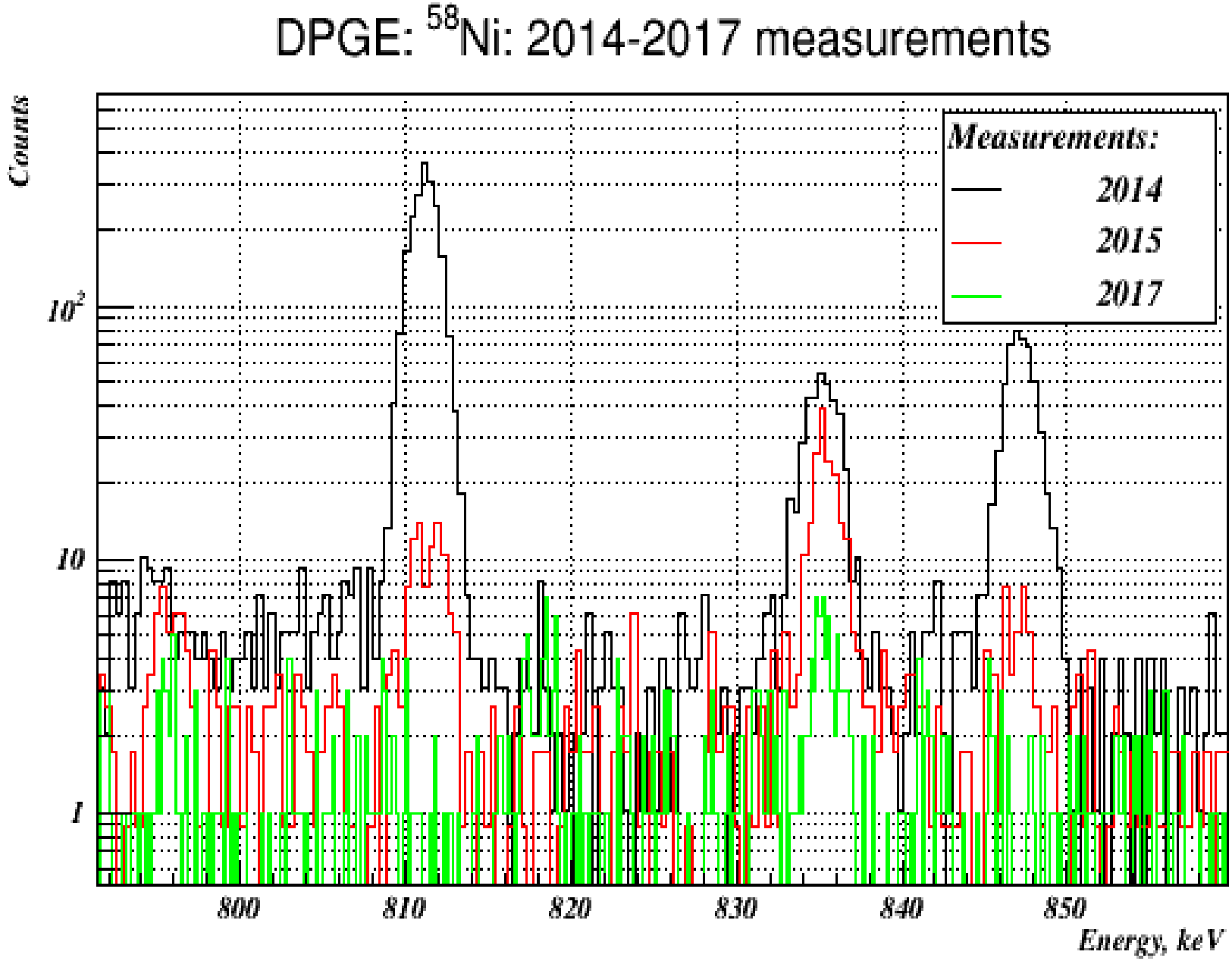


Calculated efficiency

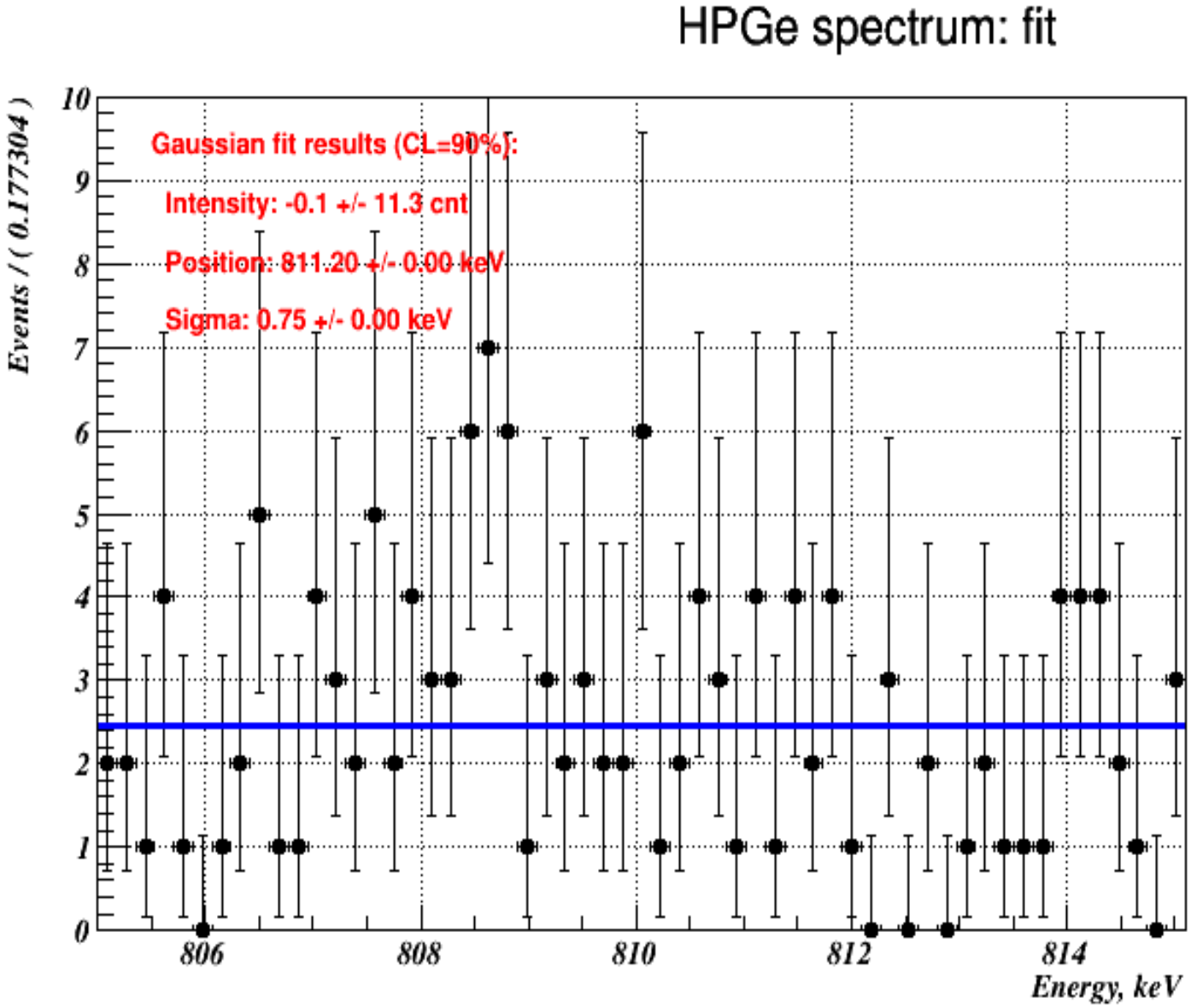
Simulation was performed using ROOT-VMC-GEANT4 DPGE package in the energy region of 0.05- 5 MeV.



811 keV ROI

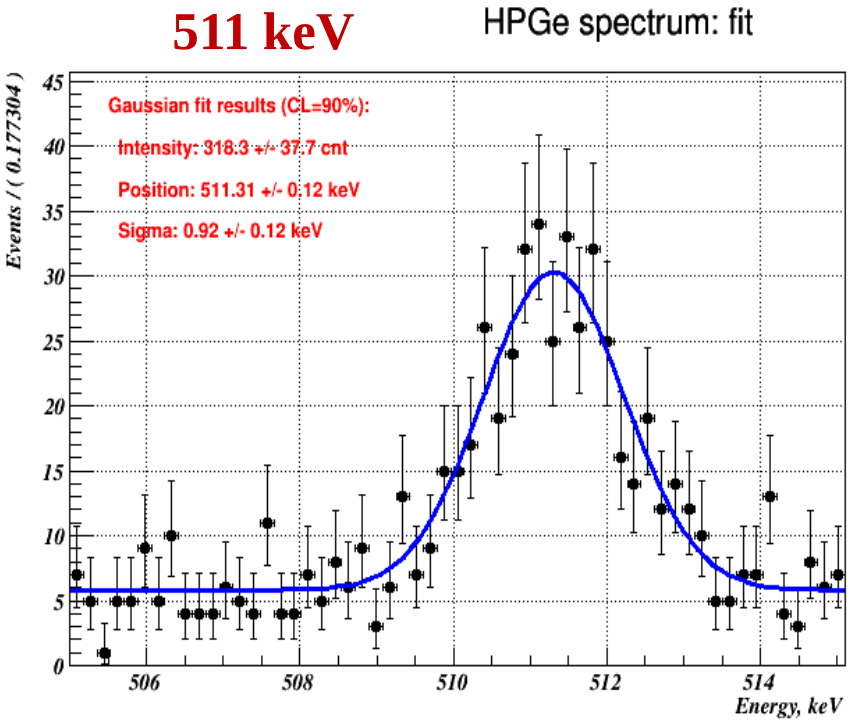

DPGE: 58Ni: 2014-2017 measurements
Counts
10²
10
1
800
810
820
830
840
850
Energy, keV
Measurements:
2014
2015
2017

811 keV

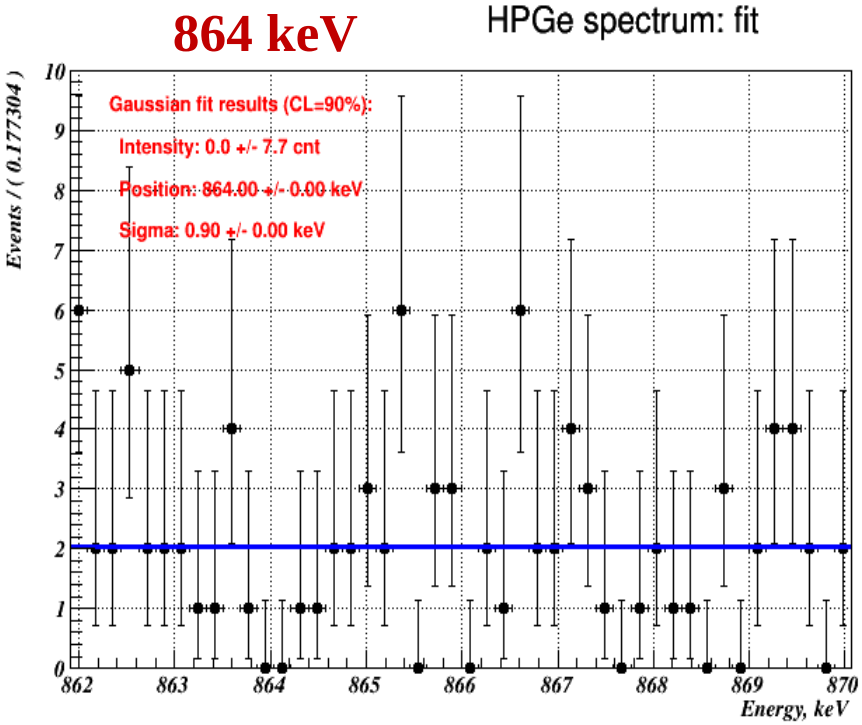


N_{EXCL}=11 events

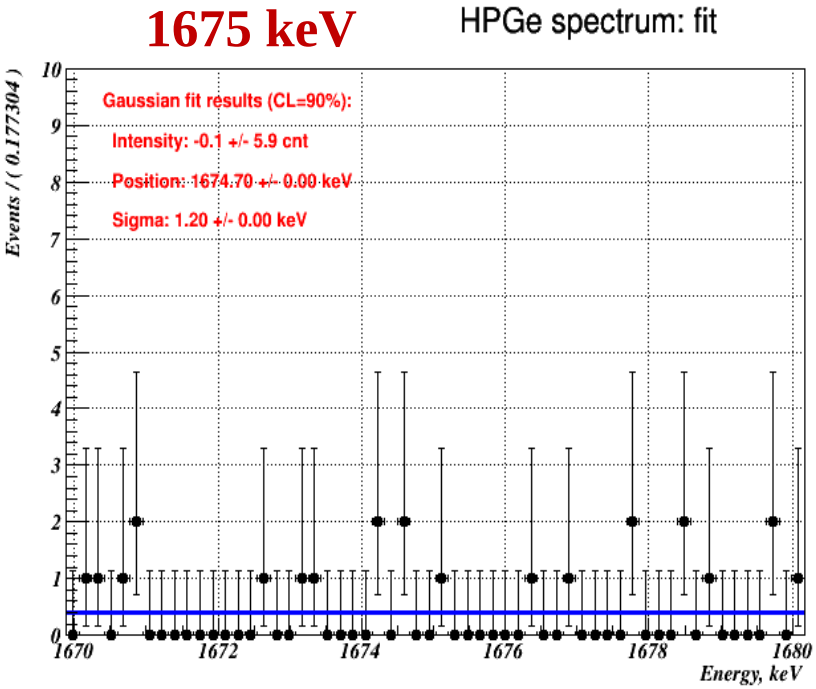
511 keV



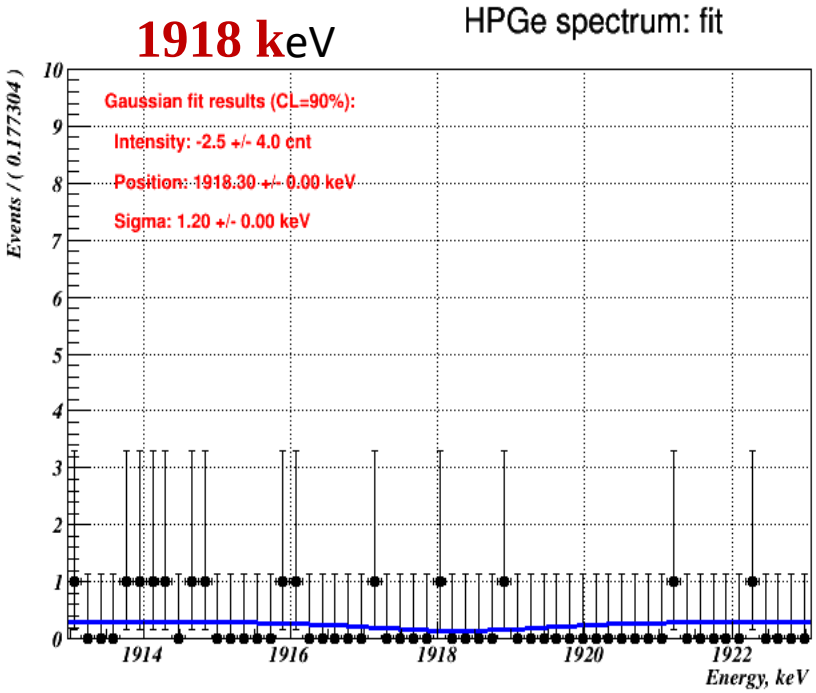
864 keV



1675 keV



1918 keV



Preliminary results for double beta decay of ^{58}Ni

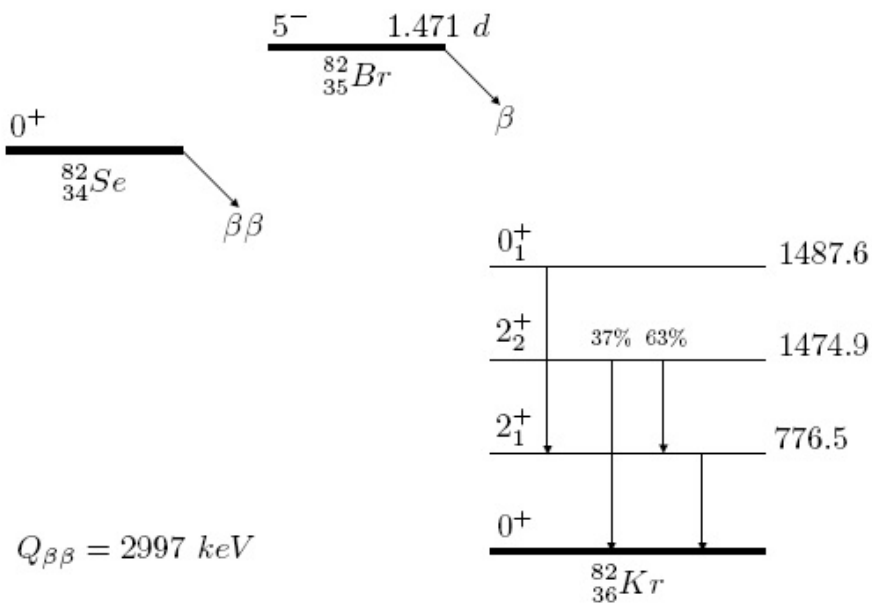
Decay mode	Final state or Decay transition	$T_{1/2}$, (90% CL)	Previous limits, $T_{1/2}$
β^+EC	g.s.	9.7×10^{21} y	7.0×10^{20} y (68%CL)*
β^+EC	811 keV	1.2×10^{22} y	4.0×10^{20} y (68%CL)*
EC/EC	811 keV	1.6×10^{22} y	4.0×10^{19} y (90%CL)**
EC/EC	1675 keV	8.3×10^{21} y	4.0×10^{19} y (90%CL)**
0νEC/EC resonant	Radiative 1918 keV	5.1×10^{22} y	2.1×10^{21} y (90%CL)***

*S.I. Vasil'ev et al., JETP Lett. 57 (1993) 631.
**E. Bellotti et al., Lett. Nuovo Cim. 33 (1982) 273.
***B. Lehnert et al., J. Phys. G: Nucl. Part. Phys. 43 (2016) 065201

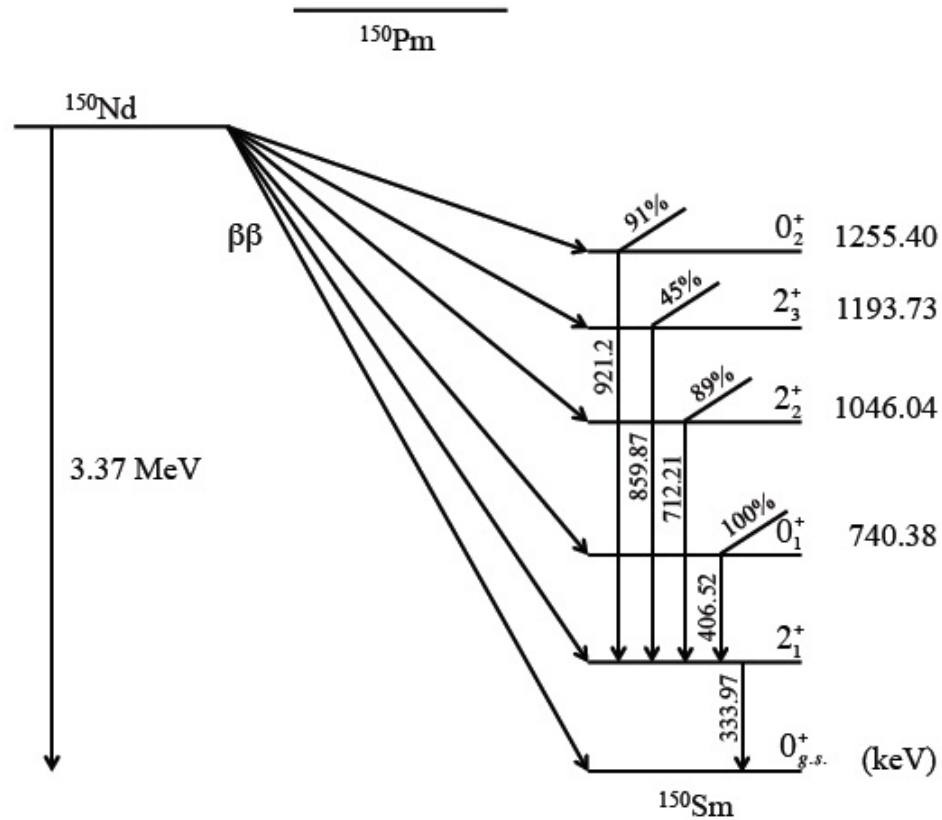
Future plans of measurements with Obelix

1. Continue our measurement of ^{58}Ni to improve our experimental limits on various double beta decay modes of 58Ni which are now the best.
2. Perform the investigation of double beta decay of ^{82}Se and ^{150}Nd to excited states

^{82}Se decay scheme



^{150}Nd decay scheme



Thank you for your attention

Additional slides

Preliminary results

Energy	Efficiency	Nexcl	$T_{1/2}$, (90% CL)	Previous limits
Kb+ (811 keV)				
811 keV	1.0%	11.0	1.2×10^{22} y	4.0×10^{20} y (68%CL)*
Kb+ (g.s.)				
511 keV	2.9%	38.0	0.97×10^{22} y	7.0×10^{20} y (68%CL)*
KK (811 keV)				
811 keV	1.4%	11.0	1.6×10^{22} y	4.0×10^{19} y (90%CL)**
0νKK-resonant (1918 keV)				
1918 keV	1.2%	3.0	5.1×10^{22} y	2.1×10^{21} y (90%CL)***
KK (1675 keV)				
811 keV	1.0%	14.1	0.90×10^{22} y	
1675 keV	1.3%	13.9	1.2×10^{22} y	4.0×10^{19} y (90%CL)**

*S.I. Vasil'ev et al., JETP Lett. 57 (1993) 631.
**E. Bellotti et al., Lett. Nuovo Cim. 33 (1982) 273.
***B. Lehnert et al., J. Phys. G: Nucl. Part. Phys. 43 (2016) 065201

Calculation of the limit

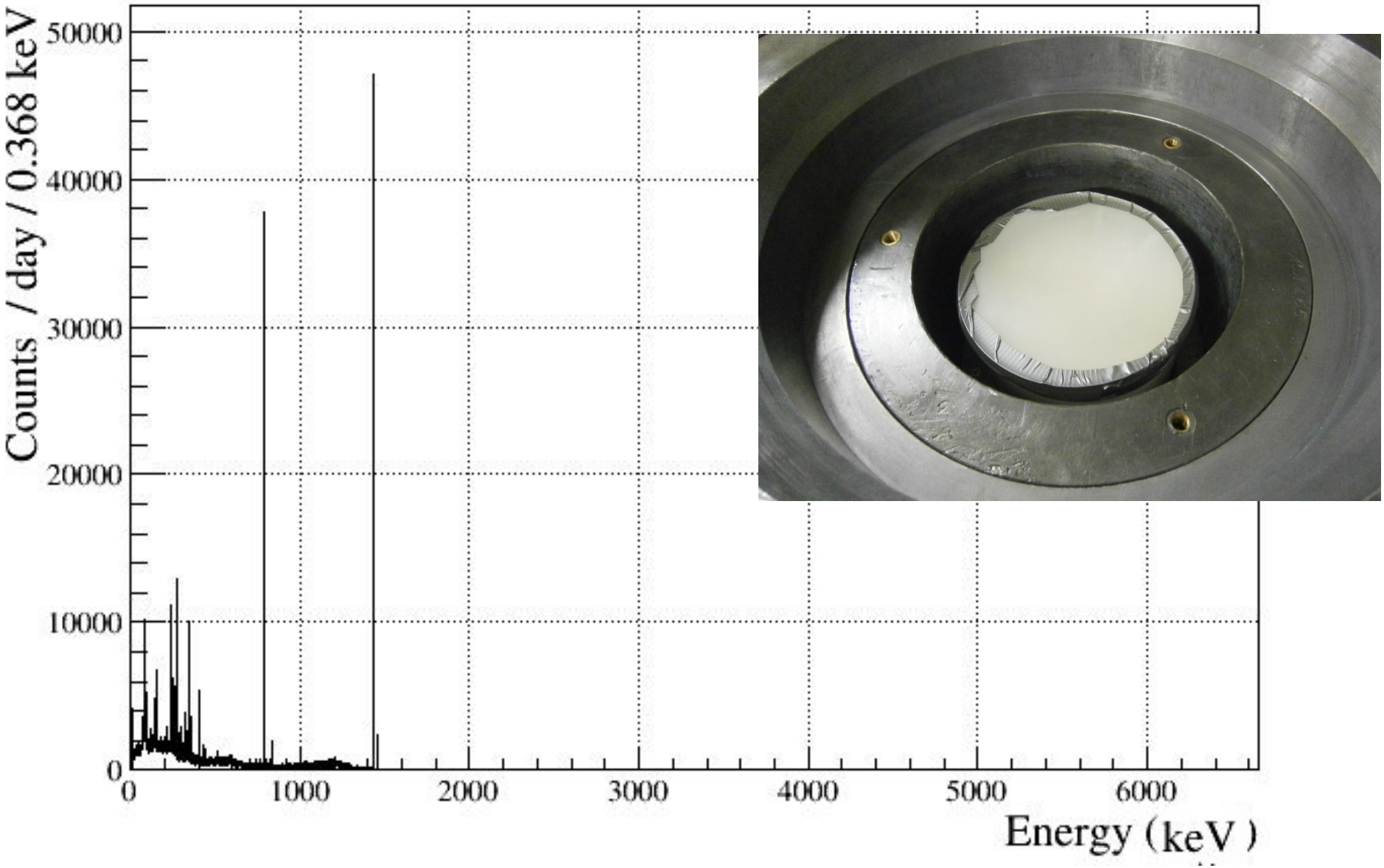
$$T_{1/2}^{LIM} > \ln(2) \times \varepsilon \times M_{TOT} \times O(^{58}Ni) \times T_{EXP} \times N_A/A/N_{EXCL}$$

Использованные в расчетах параметры	
Параметр	**Величина**
NA/10^20	**6022.142**
M_{TOT}, г	**21754**
O(^{58}Ni)	**68.27%**
A	**58**

K.Zuber

http://wwwarchive.ph.ed.ac.uk/sussp61/lectures/05_Zuber_NeutrinolessDoubleBetaDecay/StAndrews_2006_lect2_orig.ppt

Measurement of La powder at Marinelli backer



Efficiency of the Obelix for different geometries of measurements