Investigation of double beta decay of ^{100}Mo to excited final states of ^{100}Ru

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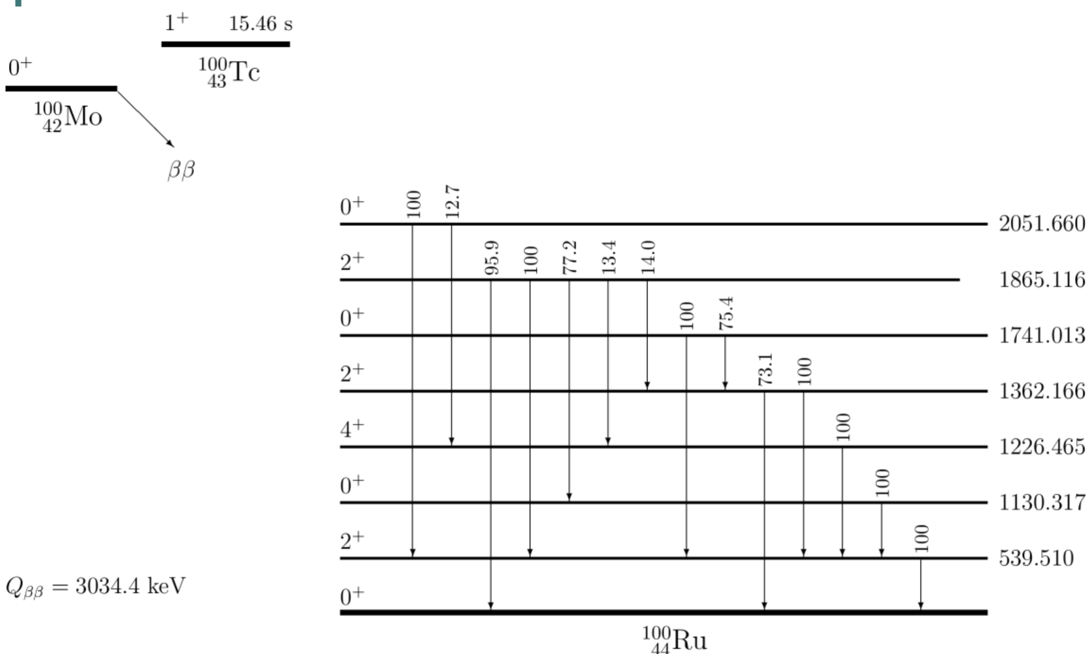
DECAY SCHEME OF ^{100}Mo



Energy of 2β transitions to 0^+_1 and 2^+_1 states:

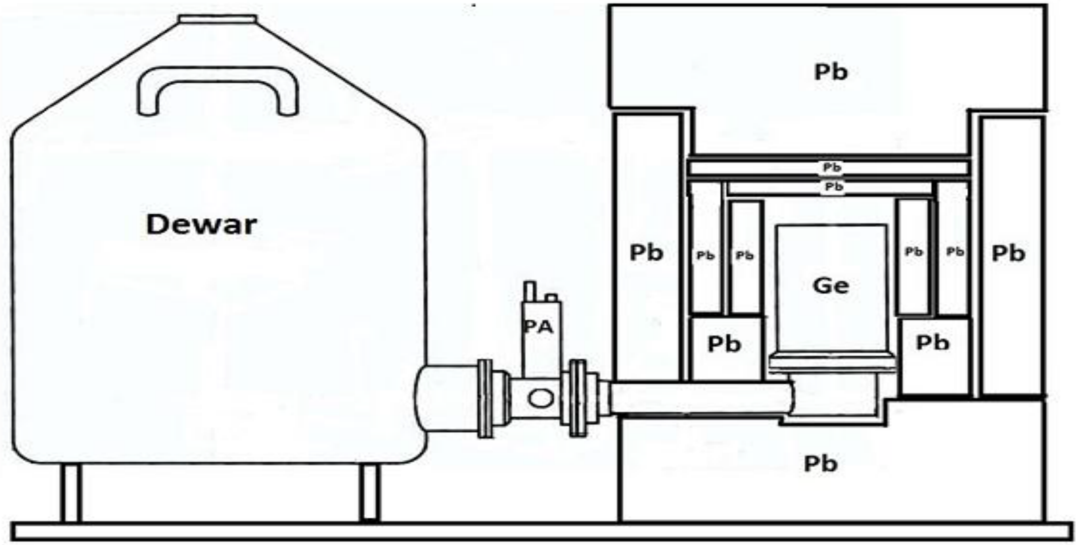
$E_{2\beta}(0^+ - 0^+_1) = 1904$ keV

$E_{2\beta}(0^+ - 2^+_1) = 2495$ keV

Main motivations:

1. Nuclear spectroscopy (to know decay schemes of nuclei)
2. Nuclear matrix elements
3. Examination of some new ideas ("bosonic" neutrino,…)
4. Neutrino mass investigations (very good signature)

Detector OBELIX



-**Location:** Modane Underground Laboratory, 4800 m w.e.;

-**volume** **of HPGe detector:** 600 cm^3;

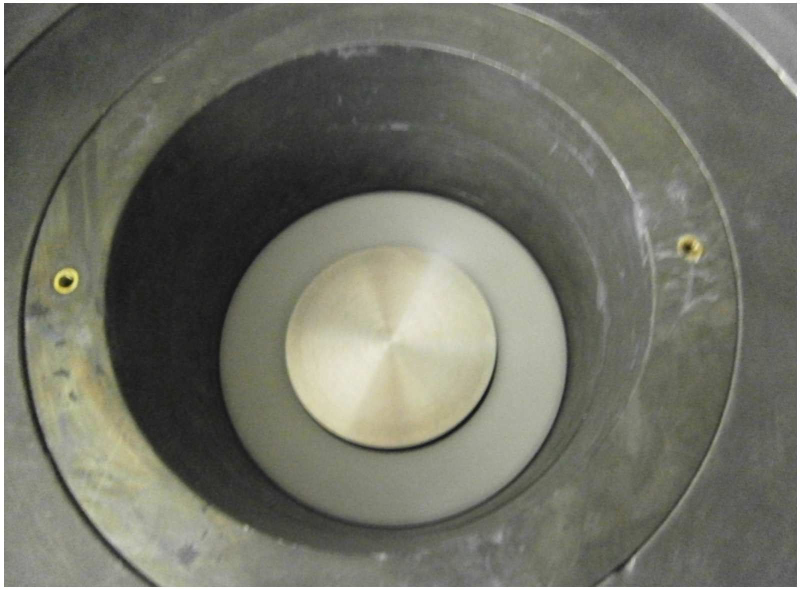
-**energy resolution:** **2 keV** (at 1332 keV of ^{60}Co).

Passive shield:
- 12 cm of roman lead;
- 20 cm of low-radioactivity lead

Passive shield is flushed with radon-free air **(~ 15 mBq/m^3 of ^{222}Rn)**

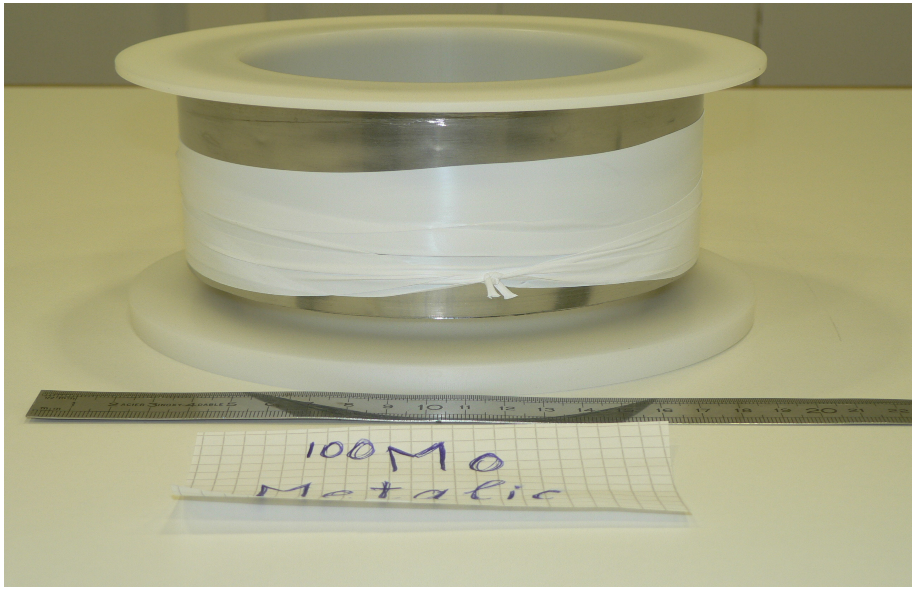
^{100}Mo source (metallic foils)

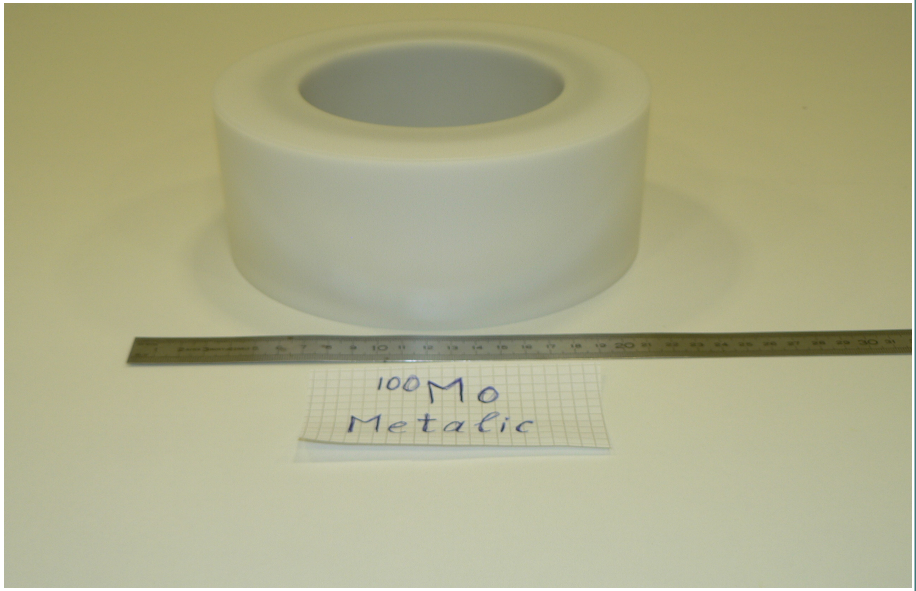
- ^{100}Mo foil was packed into bobbin, specially made for the 600 cm^3 detector
- Mass of foils is **2588 g**
- Mass of Mo is **2583 g** (99.8%)
- Average enrichment is **97.5%**
- Mass of ^{100}Mo is **2518 g (1.52·10^{25} nuclei)**
- Measurement time is **2288 h**



The foil was used in measurements with NEMO-3 detector

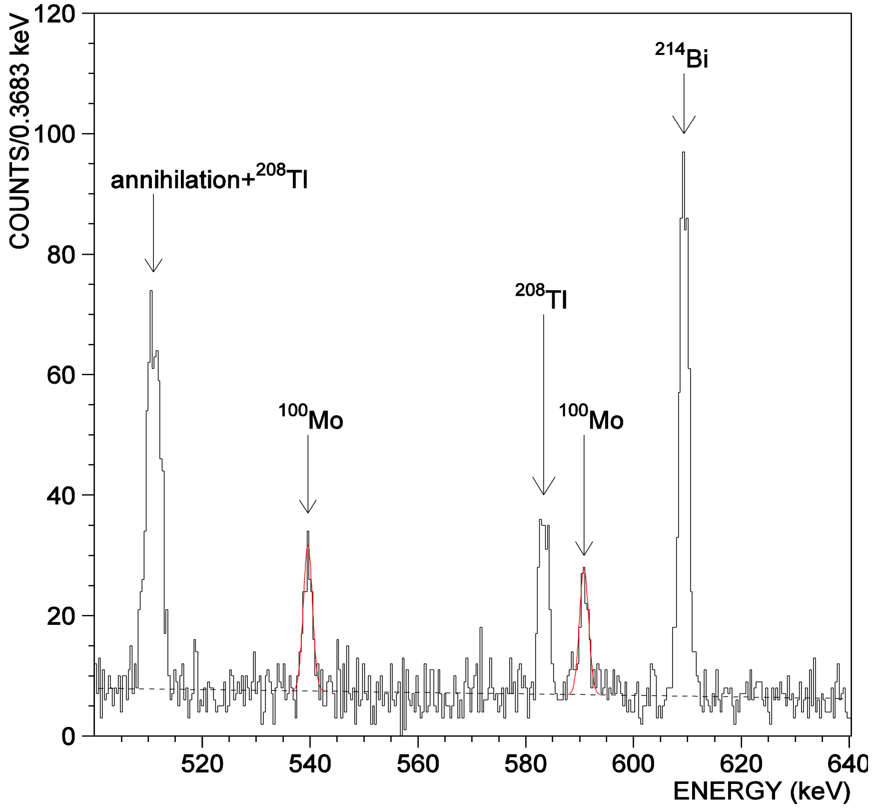
Mo-100 source





Bobbin is made of derlin

Experimental spectrum



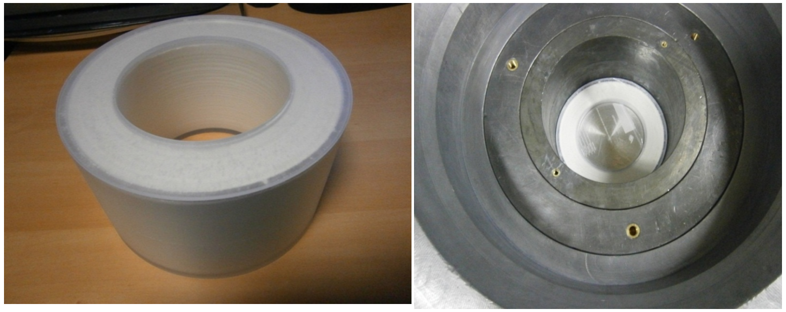
Measurement time is 2288 h

$E_{\gamma 1}$ = 539.5 keV

$E_{\gamma 2}$ = 590.8 keV

Calibrations

- **<u>^{238}U</u>**: compact source (∅47 mm, h=3mm) with activity **28.36(9) Bq** was placed 1) on the endcap and 2) 33 mm above endcap
- **<u>^{152}Eu</u>:** point-like source with activity **2323(46) Bq** was placed 310 mm above the endcap (more than 10 different energy γ-lines were used for calibration)
- **<u>^{138}La</u> (788 and 1435 keV)**: mix of flour (934 g) and La_2O_3 (238 g) in the box around the detector (approximately the same geometry as for **^{100}Mo measurement**). $T_{1/2}$ = 1.02(1)·10^{11} yr, ^{138}La – 0.0888(7)%.
  Activity is **168.26(2.13) Bq**.



La source

- **MC simulations were adjusted to results of calibration measurements**

Conservative estimation of the error in the efficiency is ± 7%

Results for transition to 0^+_1 excited state

- **539.5 keV**
  N= 129 ± 14 ε=3.29%
  $T_{1/2}=7.0^{+0.9}_{-0.7} \cdot 10^{20}$ yr

- **590.8 keV**
  N= 110 ± 13 ε=3.22%
  $T_{1/2}=8.0^{+1.1}_{-0.8} \cdot 10^{20}$ yr

- **539.5 keV + 590.8 keV**
  N=239 ± 19 ε=6.51%
  $T_{1/2}(2\nu) = [7.5 \pm 0.6(\text{stat}) \pm 0.6(\text{syst})] \cdot 10^{20}$ yr
  (preliminary result)
  $M^{2\nu}(0^+ - 0^+_1) = 0.092 \pm 0.006$

Experiment is sensitive to both 2ν and 0ν decay.

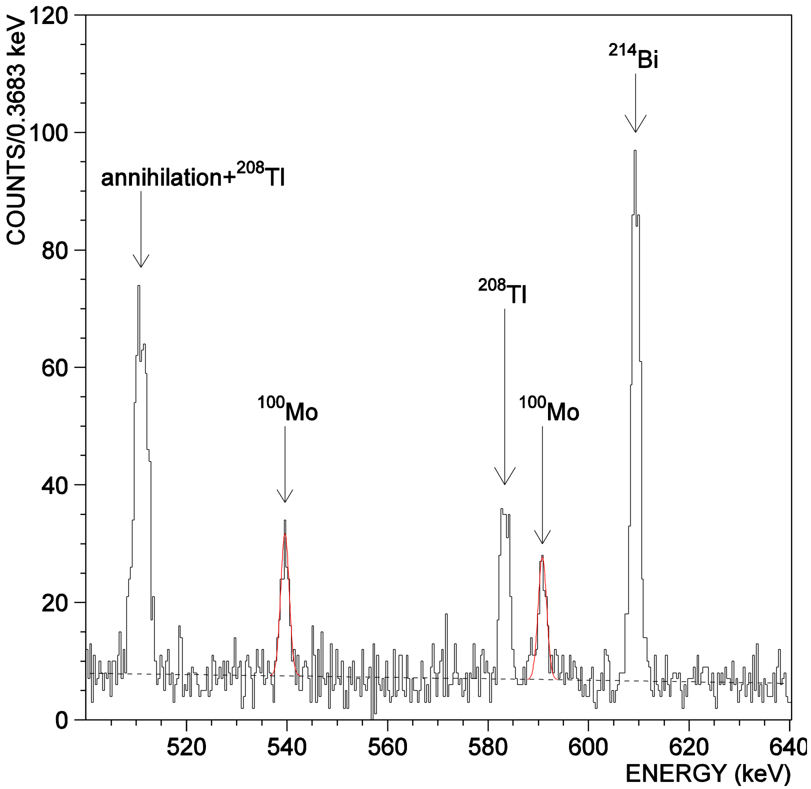
But, in fact, we see 2ν transition because there is limit from NEMO-3 : $T_{1/2}(0\nu) > 8.9 \cdot 10^{22}$ yr

Systematic error: efficiency – 7%, number of events – 4%, position of the source -2%.

Comparison with previous results

1. $6.1^{+1.8}_{-1.1}$ x 10^{20} yr, 1995, ITEP-USC-PNL
2. ($9.3^{+2.8}_{-1.7}$ ± 1.4) x 10^{20} yr, 1999, ITEP-Bordeaux
3. ($5.9^{+1.7}_{-1.1}$ ± 0.6) x 10^{20} yr, 2001, ITEP-TUNL (2xHPGe)
4. ($5.7^{+1.3}_{-0.9}$ ± 0.8) x 10^{20} yr, 2007, NEMO-3 (tracking det.)
5. ($5.5^{+1.2}_{-0.8}$ ± 0.3) x 10^{20} yr, 2009, ITEP-TUNL (2xHPGe)
6. ($6.9^{+1.0}_{-0.8}$ ± 0.7) x 10^{20} yr, 2010, KINR-DAMA
7. [7.5 ± 0.6(stat) ± 0.6(syst)] x 10^{20} yr (our result; lowest statistical error!)

Comparison with the first result



Present result

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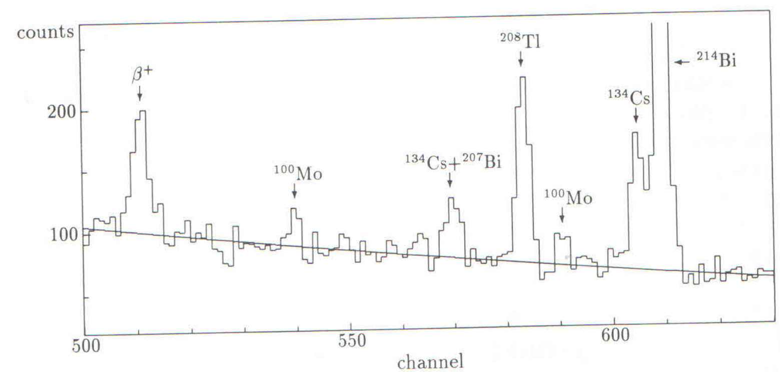

Fig. 2. Energy spectrum in the region of interest.

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V_{HPGe} = 114 cm^3, m = 956 g,
T_{mes} = 9970 h, S/B = 1:6

V_{HPGe} = 600 m^3, m = 2518 g, t_{mes} = 2288 h, S/B = 3:1

Comparison of NMEs for transitions to 0^+ ground and 0^+_1 excited states

$$M^{2\nu}(0^+ - 0^+_1) = 0.092 \pm 0.006$$

(Obtained using $T_{1/2} = (7.5 \pm 0.9) \cdot 10^{20}$ yr)

$$M^{2\nu}(0^+ - 0^+_{g.s.}) = 0.1273^{+0.0038}_{-0.0034}$$

(Obtained using $T_{1/2} = (7.1 \pm 0.4) \cdot 10^{18}$ yr)

(g_A = 1.27 and **G** from J. Kotila and F. Iachello, PRC (2012) 034316.)

One can conclude that $M^{2\nu}(0^+ - 0^+_{g.s.})$ is ~ 25% greater than $M^{2\nu}(0^+ - 0^+_1)$
The "effect" is more than 4σ

Result for transition to 2^+_1 excited state

- Conservative approach:

539.5 keV line – 590.8 keV line ⇒ **17 ± 19 events** (ε =4.02 %)

⇓

$T_{1/2}(0\nu+2\nu) > 2.5\cdot10^{21}$ yr (90% CL)

(preliminary result)

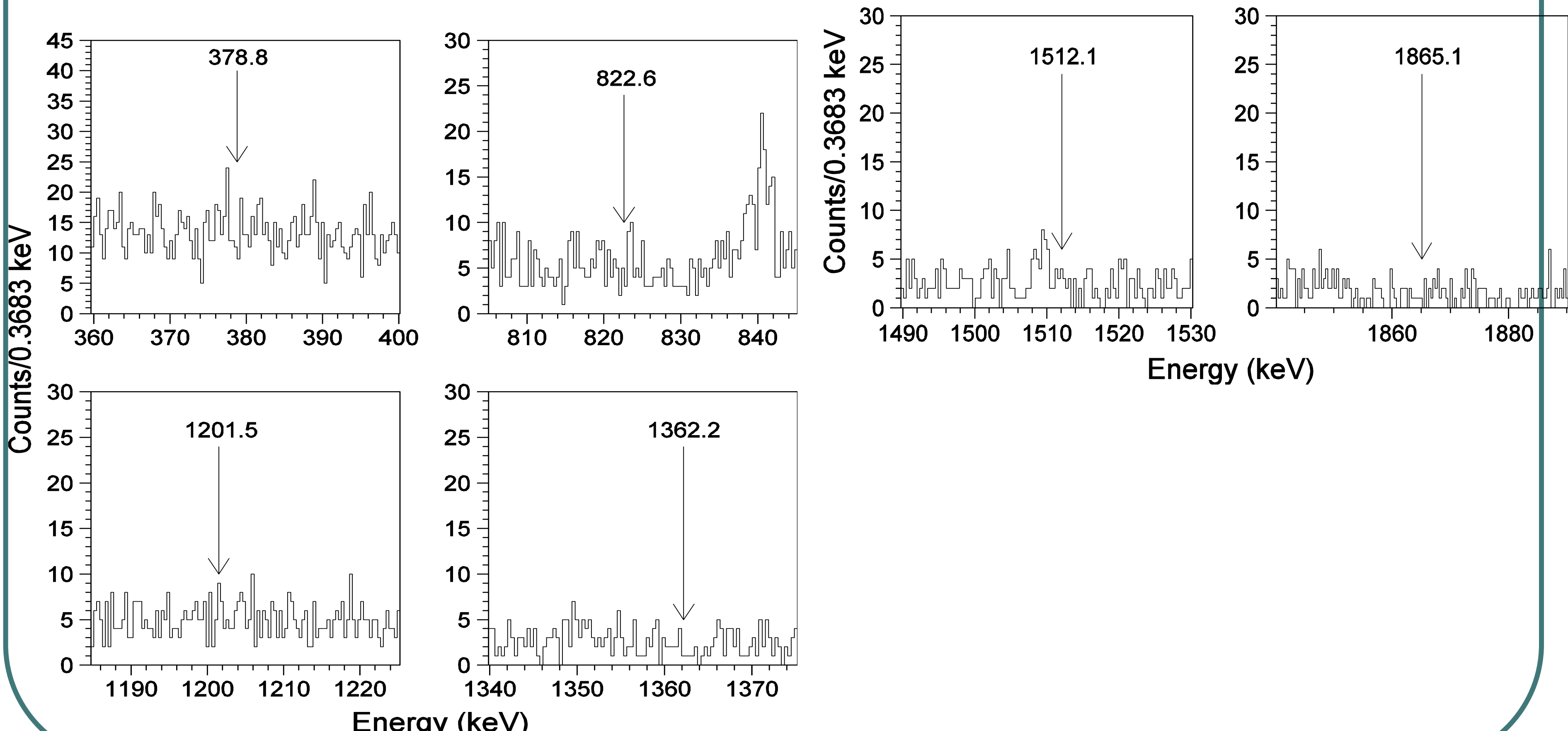
Previous limits:

> $1.6\cdot10^{21}$ yr ($0\nu+2\nu$)), 1995, ITEP-USC
> $1.1\cdot10^{21}$ yr (2ν), 2007, NEMO-3

SSD predicts for 2ν mode ~ $(1\text{-}3)\cdot10^{23}$ yr

"Bosonic" neutrino scheme predicts enhancement for this transition (up to ~ **100 times**)

Spectra for transitions to 2^+_2, 2^+_3, 0^+_2 and 0^+_3 excited states



Limits for transitions to 2^+_2, 2^+_3, 0^+_2 and 0^+_3 excited states

Excited state	Our limit, yr (0ν+2ν)	Previous limit, yr (ITEP-TUNL; NPA 821 (2009) 251)
2^+_2 (1362.17)	$> 1.1 \cdot 10^{22}$	$> 4.4 \cdot 10^{21}$
0^+_2 (1741.01)	$> 4.0 \cdot 10^{21}$	$> 4.8. \cdot 10^{21}$
2^+_3 (1865.1)	$> 4.9 \cdot 10^{21}$	$> 4.3 \cdot 10^{21}$
0^+_3 (2051.66)	$> 4.3 \cdot 10^{21}$	$> 4.0 \cdot 10^{21}$

All obtained results are still preliminary

CONCLUSION

- **Half-life of ^{100}Mo** for **2β(2ν)** transition to **0^+_1** excited states is measured with high accuracy:

  $$T_{1/2} = [7.5 \pm 0.6(stat) \pm 0.6\,(syst)]\cdot 10^{20}\ yr$$

  $$M^{2\nu}(0^+ - 0^+_1) = 0.092 \pm 0.006$$

- For other **(0ν+2ν)** transitions limits on the level **$(0.25\text{-}1.1)\cdot 10^{22}$ yr** are obtained