SSD MECHANISM: EXPERIMENTAL LOOK ON THE PROBLEM

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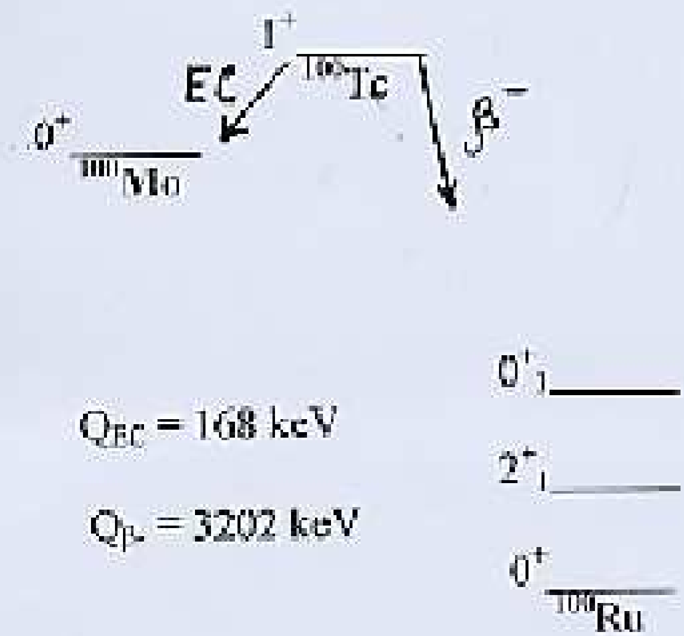
PLAN

1. Intoduction
2. NEMO-3 result
3. Future measurements
4. Conclusion

1. Introduction

1.1

J. Abad, A.Morales, R.Nunez-Lagos and A.F.Pasheco "An estimation of the rates of (two-neutrino) double beta decay and related processes"
JOURNAL DE PHYSIQUE, Colloque C3, supplement n.3, 45 (1984) C3.



Nuclide	$(\log ft)_1$	$(\log ft)_2$	$T_{1/2}$, y
^{100}Mo	4.5*)	4.7	$1.05\cdot10^{19}$
^{110}Pd	4.1	4.7	$1.53\cdot10^{20}$
^{116}Cd	4.0*)	4.7	$5.16\cdot10^{18}$
^{128}Te	5.1	6.1	$1.4\cdot10^{25}$
^{106}Cd	4.9	4.4	$6.5\cdot10^{22}$
^{130}Ba	5.1	5.4	$8.3\cdot10^{23}$
^{136}Ce	4.6	5.5	$3.7\cdot10^{23}$

*) Estimated value.

1.2. Electron –capture decay of ^{100}Tc and ^{116}In.

These decays were measured by A.Garcia et al:

^{100}Tc: **^{100}Mo(p,n)^{100}Tc;** 97.4% enriched sample;
17,4 keV X-rays were measured by Ge-detector;

branch is $(1.8 \pm 0.9)\cdot 10^{-3}$%
$(\log ft) = 4.45^{+0.18}_{-0.30}$
(A.Garcia et al., Phys. Rev. C 47 (1993) 2910).

^{116}In: **^{115}In(d,p)^{116}In**; natural (95.7%) and enriched (99.99%)samples;
– 23 keV X-rays were measured by Ge-detector.

branch is $(2.27 \pm 0.63)\cdot 10^{-2}$%
$(\log ft) = 4.39^{+0.10}_{-0.15}$
(M.Bhattacharya, A.Garcia et al., Phys. Rev. C 58 (1998) 2910).

SO, WE HAVE ONLY ONE DIRECT MEASUREMENT FOR ^{100}Tc AND ONLY ONE DIRECT MEASUREMENT FOR ^{116}In

[In fact there are data from H. Akimine at al., "GT strength studied by (3He,t) reactions and nuclear matrix elements for double beta decays", Phys. Lett. B 394 (1997) 23.]

1.3. **F.Simkovic, P.Domin and S.V.Semenov** "The single **state dominance** hypothesis and the two-neutrino double beta decay of ^{100}**Mo**", J. Phys. G 27 (2001) 2233; nucl-th/0006084.

Transition	$(\log ft)_1$	$(\log ft)_2$	$T_{1/2}$, y; approximated	$T_{1/2}$, y; SSD	$T_{1/2}$, y; experiment
0^+-$0^+_{g.s.}$	$4.45^{*)}$	4.6	$8.97\cdot10^{18}$ **(8.97±4.5)**	$7.15\cdot10^{18}$ **(7.15±3.6)**	$(8\pm0.7)\cdot10^{18}$ average'01 $(7.7\pm0.5)\cdot10^{18}$ NEMO'04
0^+-0^+_1	$4.45^{*)}$	5.0	$5.44\cdot10^{20}$ **(5.44±2.7)**	$4.45\cdot10^{20}$ **(4.45±2.2)**	$(6.8\pm1.2)\cdot10^{20}$ average'01 NEMO -?
0+ - 2^+_1	$4.45^{*)}$	6.5	$4.66\cdot10^{22}$ **(4.66±2.3)**	$1.73\cdot10^{23}$ **(1.73±0.9)**	$> 1.6\cdot10^{21}$

*) From A.Garcia et al., Phys. Rev. C47 (1993) 2910.
In fact $(\log ft) = 4.45^{+0.18}_{-0.30}$

It was shown that single electron differential decay rate is not the same for **SSD** and **HSD** mechanism.

1. **M.Ericson, T.Ericson and P.Vogel,** "High energy Gamov-Teller **strength** in double beta decay", Phys.Lett. B328 (1994) 259.
2. **O.Civitarese and J.Suhonen,** "**Is** the single-**state** dominance realized in 2β-decay transision?", Phys.Rev. C58 (1998) 1535.
3. **O.Civitarese and J.Suhonen,** "Systematic study of the single-state dominance in 2νββ decay transition", Nucl.Phys. A653 (1999) 321.
4. **O.Civitarese, J.Suhonen and H.Ejiri,** "Perturbative analysis of the 2νββ decay of ^{100}Mo and ^{116}Cd", Eur.Phys.J. A16 (2003) 353.

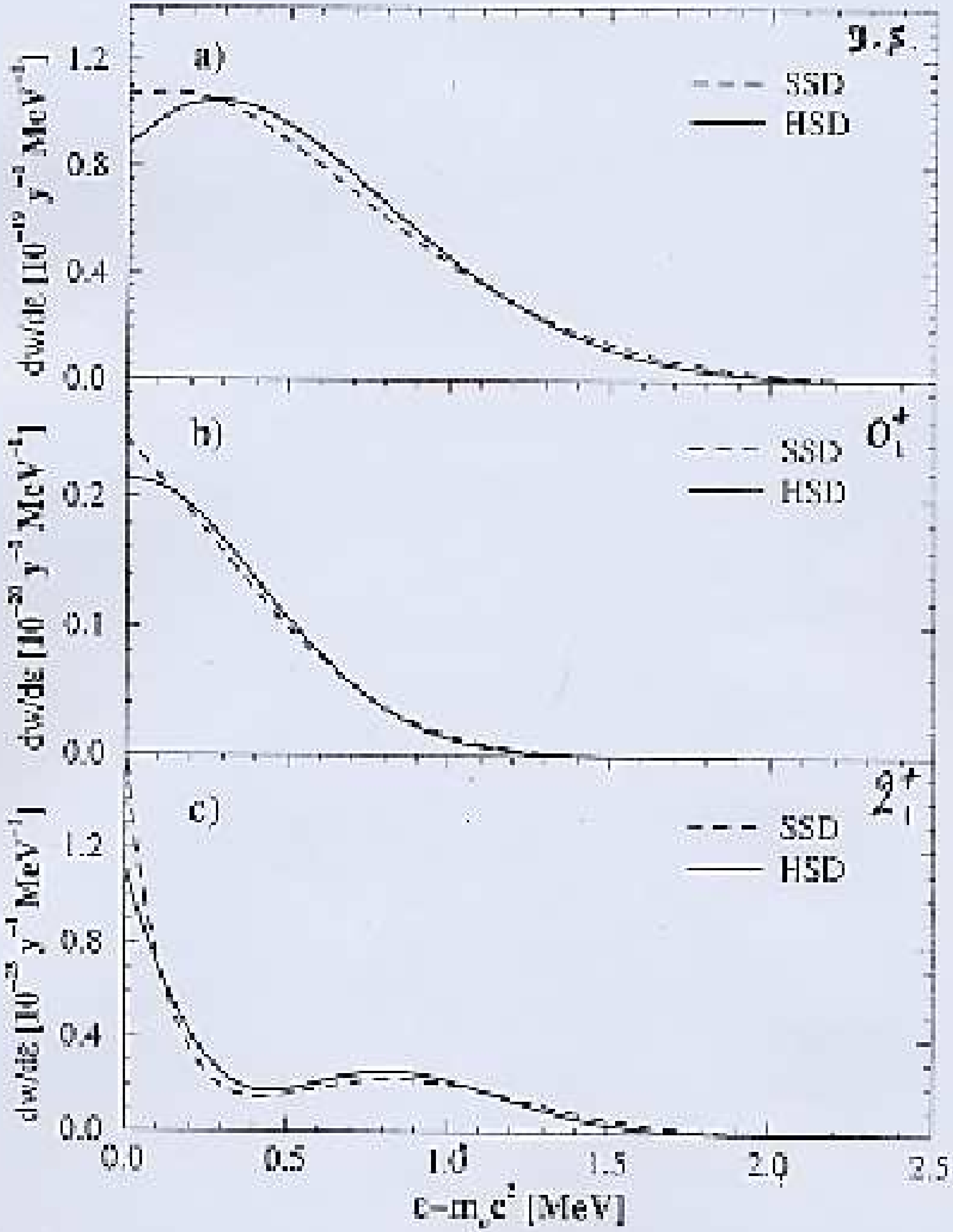


FIG. 1. Single electron differential decay rate $dw/d\epsilon$ for the $2\nu\beta\beta$-decay of ^{100}Mo to the 0^+ ground (a), the first 0_1^+ excited (b) and the first 2^+ excited (c) states in ^{100}Ru. ϵ and m_e represent the energy and mass of the electron, respectively. The calculations have been performed within the single state dominance hypothesis [SSD-exact calculation] and by assuming the dominance of higher lying states (HSD).

1.4. P.Domin, S.Kovalenko, F.Simkovic and S.V.Semenov "Neutrino accompanied $\beta^{\pm}\beta^{\pm}$, β^{+}/EC and EC/EC processes within single state dominance hypothesis" Nucl. Phys.A 753 (2005) 337.

Transition	(log ft)$_1$	(log ft)$_2$	$T_{1/2}$, y; SSD	$T_{1/2}$, y; experiment
^{100}Mo $0^+-0^+_{g.s.}$	4.45$^{*)}$	4.6	$6.8\cdot10^{18}$ (6.8±3.4)	$(8\pm0.7)\cdot10^{18}$ average'01 $(7.7\pm0.5)\cdot10^{18}$ NEMO'04
^{100}Mo $0^+-0^+_1$	4.45$^{*)}$	5.0	$4.2\cdot10^{20}$ (4.2±2.1)	$(6.8\pm1.2)\cdot10^{20}$ average'01
^{100}Mo $0^+-2^+_1$	4.45$^{*)}$	6.5	$1.7\cdot10^{23}$	$>1.6\cdot10^{21}$

Transition	(log ft)$_1$	(log ft)$_2$	$T_{1/2}$, y; SSD	$T_{1/2}$, y; experiment
^{116}Cd $0^+-0^+_{g.s.}$	4.39$^{*)}$	4.662	$1.1\cdot10^{19}$ (1.1±0.3)	$(2.8\pm0.3)\cdot10^{19}$ NEMO'04 $2.9^{+0.4}_{-0.3}\cdot10^{19}$ Solotvino
^{116}Cd $0^+-0^+_1$	4.39$^{*)}$	5.88	$1.8\cdot10^{21}$	$>2.1\cdot10^{21}$
^{116}Cd $0^+-2^+_1$	4.39$^{*)}$	5.85	$6.8\cdot10^{24}$	$>2.4\cdot10^{21}$

ECEC(2ν) to the ground state.

Transition	(log ft)$_1$	(log ft)$_2$	$T_{1/2}$, y; SSD	$T_{1/2}$, y; experiment
^{106}Cd $0^+-0^+_{g.s.}$	$>4.1^{*)}$	4.92	$>4.4\cdot10^{21}$	$>5.8\cdot10^{17}$ TGV -?
^{130}Ba $0^+-0^+_{g.s.}$	5.36	5.073	$5.0\cdot10^{22}$	$>4\cdot10^{21}$ $(2.2\pm0.5)\cdot10^{21}$ geochem. exp.
^{112}Sn $0^+-0^+_{g.s.}$	4.12	4.7	$1.7\cdot10^{22}$	-

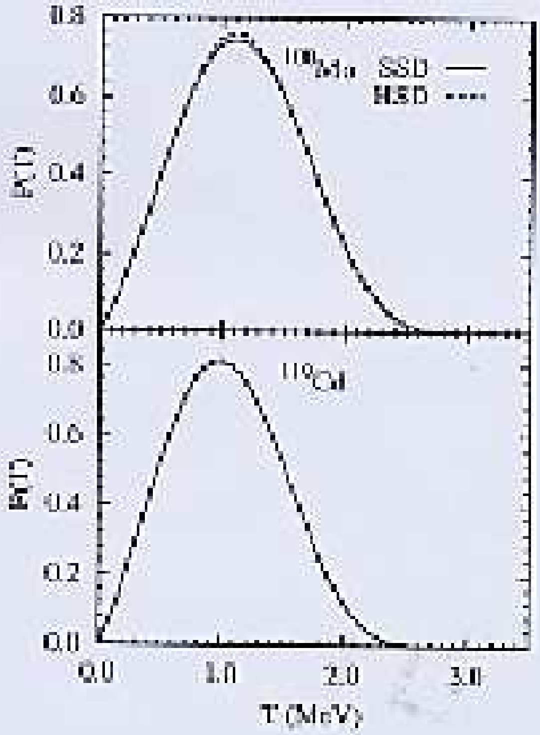


Fig. 2. The differential decay rates normalized to the total decay rate $P(T) = (1/\Gamma)\, d\Gamma/dT$ vs. the sum of the kinetic energy of outgoing electrons $T = m_e(\epsilon_1 + \epsilon_2 - 2)$ for $2\nu\beta\beta$-decay of ^{100}Mo and ^{116}Cd to the ground state of final nucleus. The conventions are the same as in Fig. 1.

order-of-magnitude estimates they may help in evaluation of the prospects of experimental searches for mentioned processes.

The SSD results presented in Tables 5–8 show that there is a chance to observe $2\nu ee$-decay for ^{106}Cd, ^{112}Sn and ^{130}Ba at the level of $10^{21}-10^{22}$ years. On the other hand for $2\nu e\beta^+$- and $2\nu\beta^+\beta^+$-decays the SSD predicts, in general, significantly larger half-lives looking quite pessimistic from the view point of the experimental observation of these processes in the near future. We also found that with the exception of the $2\nu\beta^-\beta^-$-decay of ^{100}Mo to 0^+_1 excited state the SSD half-lives of all the studied transitions to excited states 0^+ and 2^+ states are above 10^{22} years.

We proposed the study of the differential decay rates as a new perspective possibility for the experimental verification of the SSD hypothesis. One theoretically important point with respect to these characteristics consists in the fact that the differential rates normalized to the corresponding full decay rates do not depend on the values of the associated nuclear matrix elements. We have shown that the best candidates for this study are double beta decay chains with low-lying 1^+ ground states of intermediate nucleus. In this case the shape of the single electron/positron distribution and the summed electron spectrum calculated within the SSD are very sensitive to the lepton energies present in the energy denominators. On the other hand, if the main contribution to the double beta decay matrix elements comes, contrary to the SSD hypothesis, from the transition through the higher lying states of intermediate nucleus (HSD hypothesis) the dependence on lepton energies in the en-

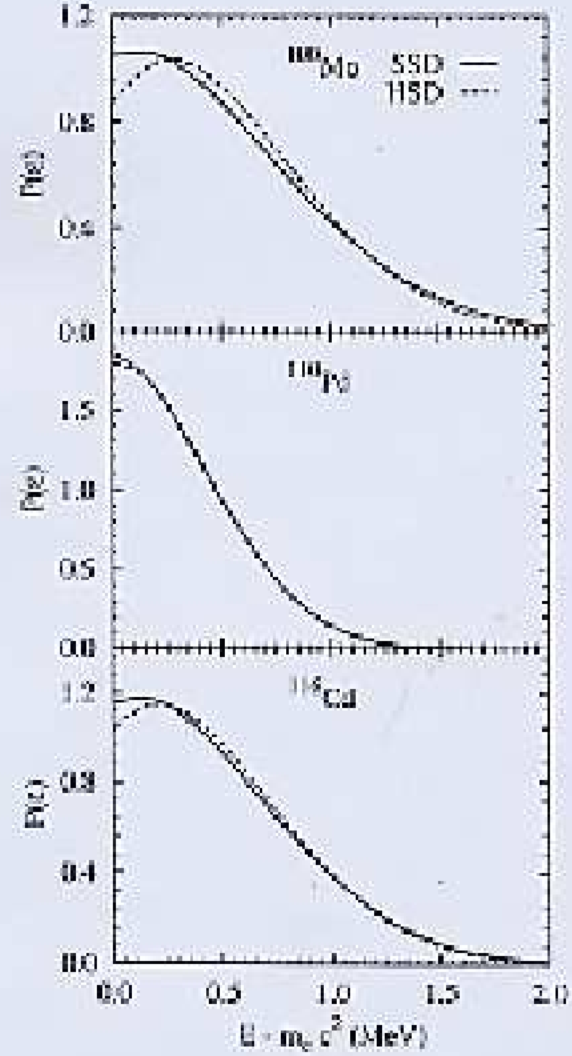
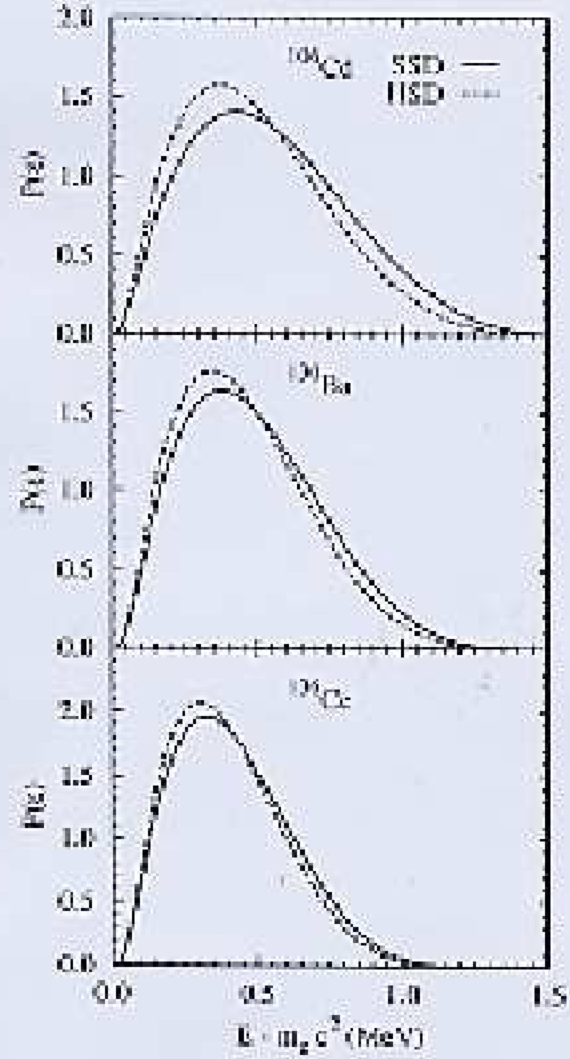


Fig. 4. The single electron differential decay rate normalized to the total decay rate $P(\varepsilon) = (1/\Gamma) d\Gamma/d\varepsilon$ vs. the electron energy ε for $2\nu\beta^-\beta^-$-decay to the 0^+ ground state. The results are presented for the cases of $^{100}Mo \to {}^{100}Ru$, $^{110}Pd \to {}^{110}Cd$, and $^{116}Cd \to {}^{116}Sn$. The calculations have been performed within the single-state dominance hypothesis (SSD) and with the assumption of dominance of higher lying states (HSD).

We demonstrated that the existing experimental data on the half-lives of the $2\nu\beta^-\beta^-$-decay of ^{100}Mo (to 0^+ ground [27] and 0_1^+ excited [5] states) and of ^{116}Cd (to 0^+ ground state [28]) show a clear tendency to favor the SSD hypothesis. However, we are not yet in the position to make definite conclusion on the validity of the SSD hypothesis. This is, partially, because of quite large uncertainties (about 50%) in the SSD predictions stemmed from insufficient precision of the existing experimental measurements of the $\log ft_{EC}$ values for electron capture. Thus, a more accurate experimental information on the associated β- and $\beta\beta$-transitions is needed.

The SSD approach allowed us to make the predictions for those neutrino (antineutrino) accompanied $\beta\beta$ decays to ground and excited final states, which have not yet been experimentally observed. Despite the fact that these predictions should be taken as



$T_{1/2} > 2.7 \cdot 10^{22}$ y.

$T_{1/2} = 1.3 \cdot 10^{24}$ y.

$T_{1/2}$

Fig. 3. The single positron differential decay rate normalized to the total decay rate $P(\epsilon) = (1/w)dw/d\epsilon$ vs. the positron kinetic energy ϵ for the ground state to ground state $2\nu EC\beta^+$-decay transitions $^{106}Cd \to {}^{106}Pd$, $^{130}Ba \to {}^{130}Xe$, and $^{136}Ce \to {}^{136}Ba$. The electron capture from the K shell is assumed. The conventions are the same as in Fig. 1.

ergy denominators is negligible resulting in the distributions which can be experimentally distinguished from the SSD case.

In the present paper we have shown that the precision measurements of the differential characteristics of the two-neutrino modes of the $\beta^-\beta^-$-decay of ^{100}Mo and ^{116}Cd and EC/β^+-decay of ^{106}Cd, ^{130}Ba and ^{136}Ce are able to confirm or rule out the SSD hypothesis. Recently the NEMO 3-Collaboration has started the data analysis aimed to distinguish between the SSD and HSD predictions for the $2\nu\beta^-\beta^-$-decay of ^{100}Mo and the first results are already presented [27]. At present, more than 100000 $2\nu\beta\beta$-decay events for ^{100}Mo have been registered. The statistics will be significantly improved within the next few years. It is supposed that from the observed normalized differential characteristics one will be able to judge clearly about the validity or invalidity of the SSD hypothesis [31]. Let us note also that the $2\nu\beta\beta$-decay half-life of ^{100}Mo measured by the NEMO 3 experiment

2. NEMO-3 results

^{100}Mo.

NEMO'04 result:

1) g.s.-g.s. transition; ~ **140000** events; **S/B ≈ 50**.
"Preliminary analysis of the experimental single electron energy spectrum favors the SSD hypothesis" (R.Arnold et al., JETP Lett. 80 (2004) 377.)
We continue to improve our knowledge of the detector (calibrations, MC simulations,…), and will produce new result with new portion of data. Sum energy spectrum, single electron energy spectrum and angular distribution will be investigated.
2) We see the transition to the 0^+ excited state too. The result for half-life will be published soon.

^{116}Cd.

Now we have ~ **3000** events (**S/B ≈7**). We will collect ~ **10000** events and then will try to investigate the spectrum (2β, single electron and angular distribution). I hope that it will be possible to make a clear conclusion about **SSD** too.

We estimate present accuracy for half-life values (g.s.-g.s. transition) as ~ 7%. Using special calibrations we can reach ~ 2-3%.
For $0^+_{g.s.}$-0^+_1 transition in ^{100}Mo accuracy for half-life can be ~ 5-10%.

NEMO Collaboration

CENBG, IN2P3-CNRS et Université de Bordeaux, France

CFR, CNRS Gif sur Yvette, France

LAL, IN2P3-CNRS et Université Paris-Sud, France

LPC, IN2P3-CNRS et Université de Caen, France

IReS, IN2P3-CNRS et Université de Strasbourg, France

FNSPE, Prague University, Czech Republic

Jyvaskyla University, Finland

ITEP, Moscou, Russia

JINR, Dubna, Russia

INEEL, Idaho Falls, USA

Mount Holyoke College, USA

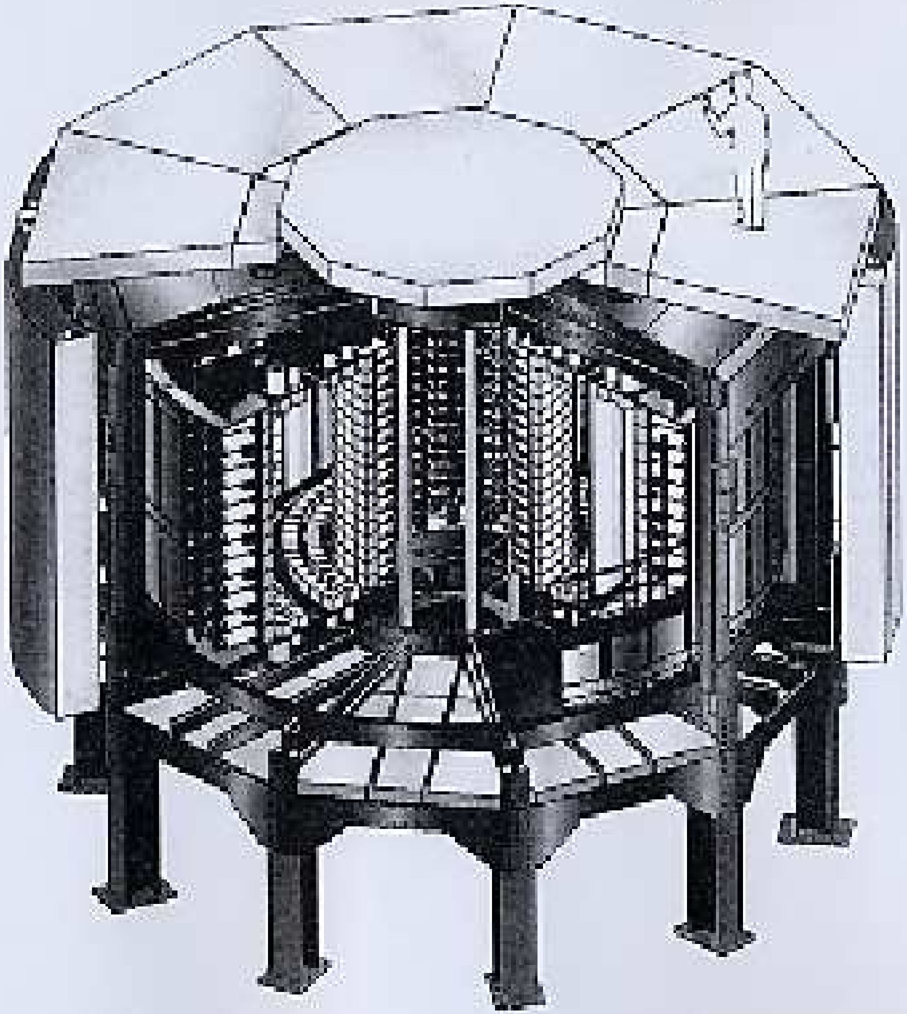
Saga University, Japan

UCL, London, UK

Europe, Japan,Russia, USA

The NEMO3 detector

Fréjus Underground Laboratory : 4800 m.w.e.



<u>Source</u>: 10 kg of ββ isotopes
cylindrical, S = 20 m^2, e ~ 60 mg/cm^2

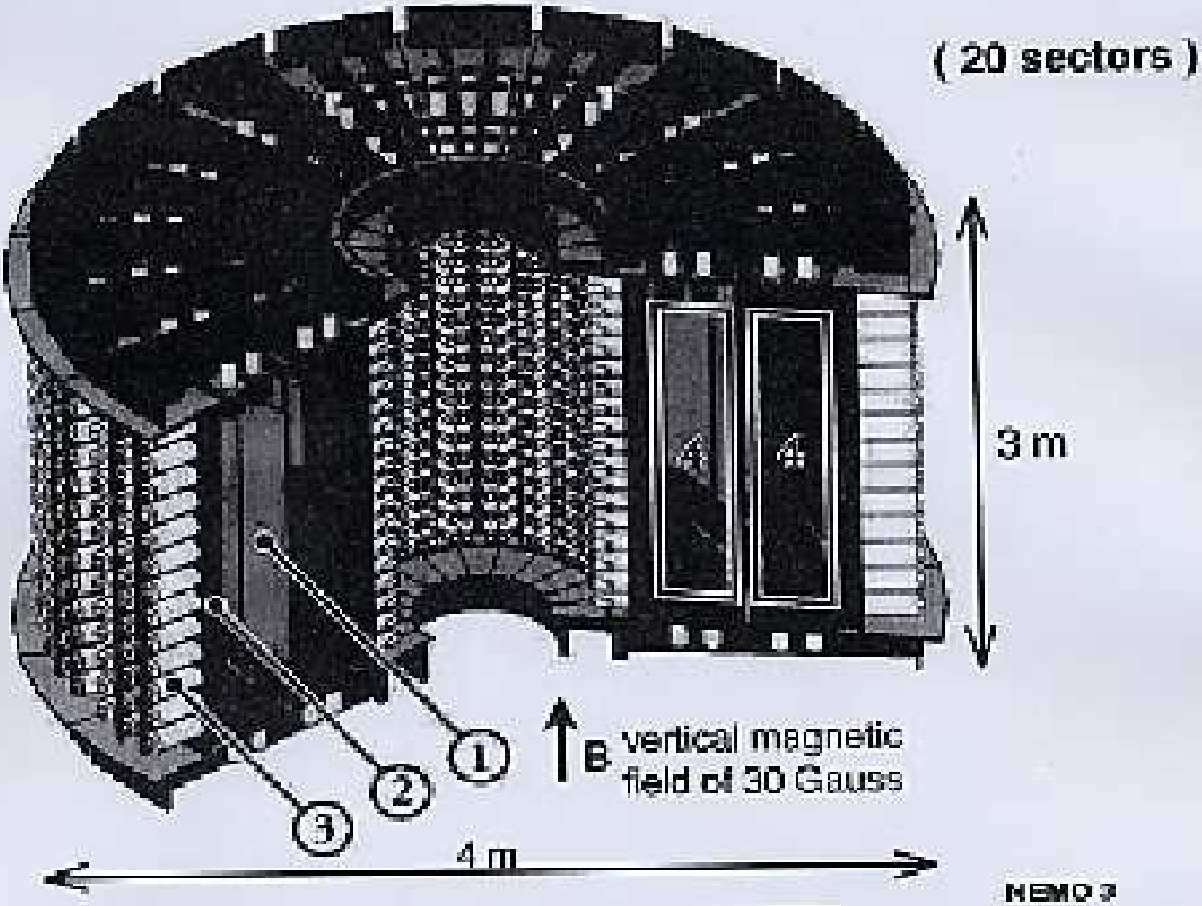
<u>Tracking detector</u>:
drift wire chamber operating
in Geiger mode (6180 cells)
Gas: He + 4% ethyl alcohol + 1% Ar + 0.1% H_2O

<u>Calorimeter</u>:
1940 plastic scintillators
coupled to low radioactivity PMTs

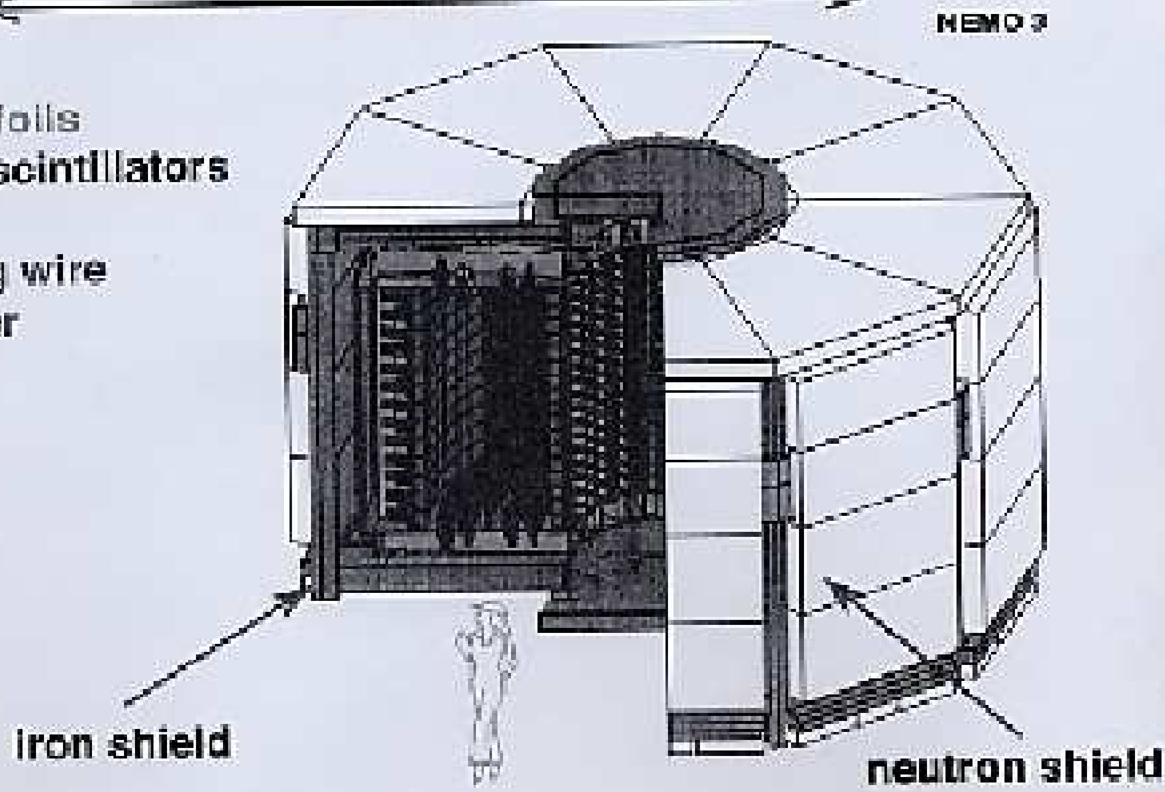
Magnetic field: 25 Gauss
Gamma shield: Pure Iron (e = 18 cm)
Neutron shield: 30 cm water (ext. wall)
40 cm wood (top and bottom)
(since march 2004: water + boron)

→ **Able to identify e^-, e^+, γ and α**

NEMO3 detector description (1/2)



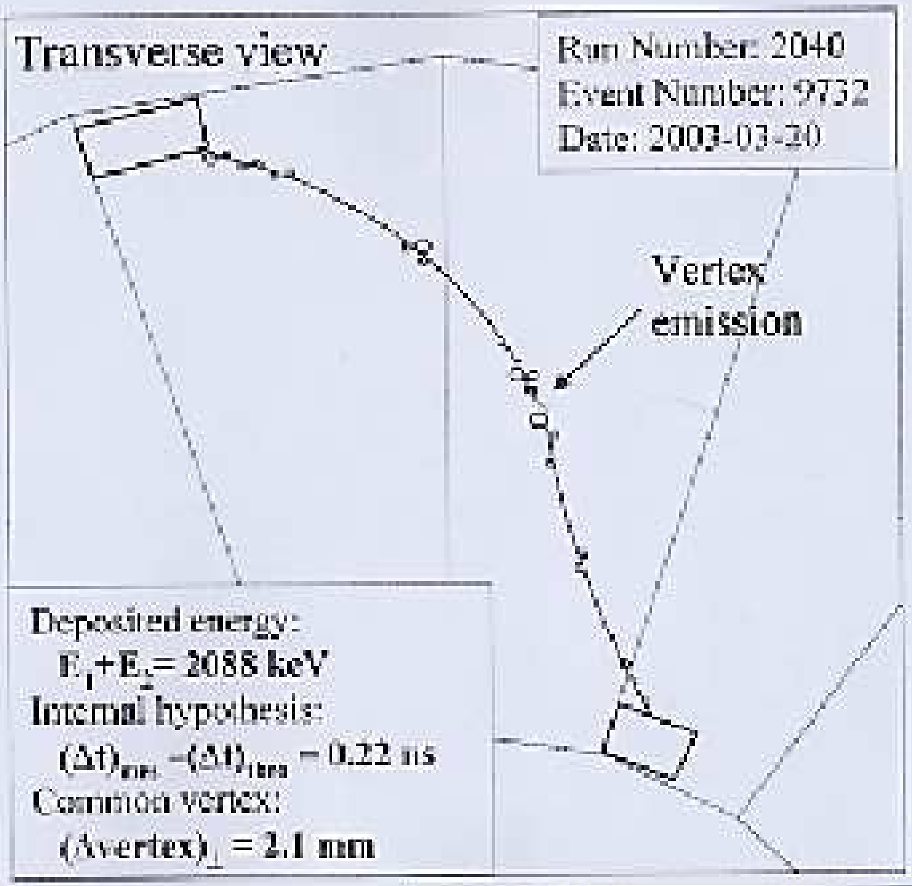
1 : source foils
2 : plastic scintillators
3 : PMTs
4 : tracking wire chamber

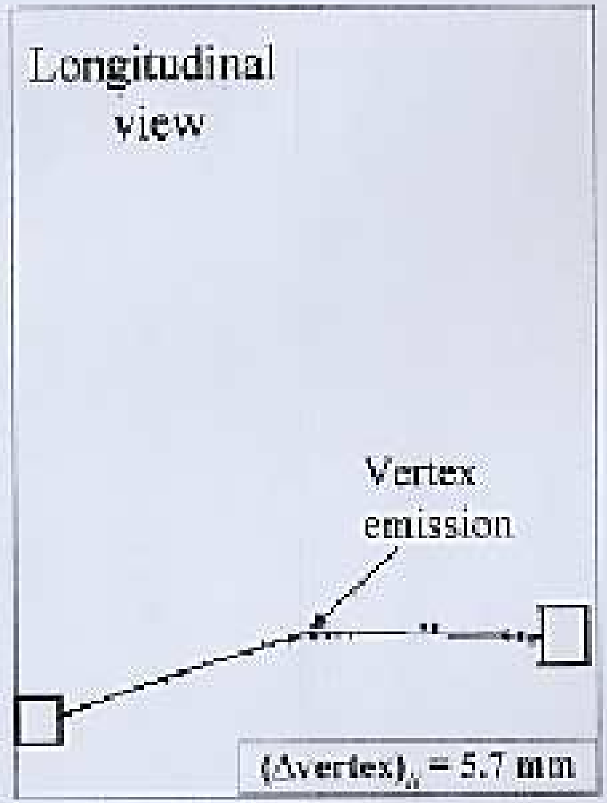


Frejus Underground Laboratory (4800 m.w.e.)

ββ events selection in NEMO-3

Typical ββ2ν event observed from ^{100}Mo



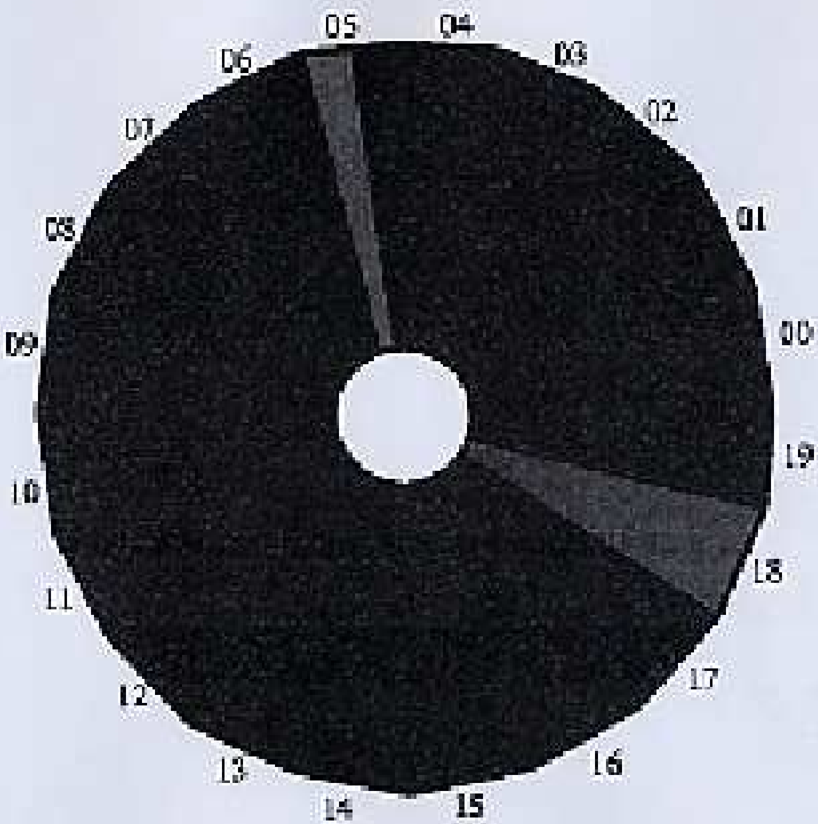


Trigger: 1 PMT > 150 keV
3 Geiger hits (2 neighbour layers + 1)

Trigger rate = 7 Hz

ββ events: 1 event every 1.5 minutes

ββ decay isotopes in NEMO-3 detector



^{100}Mo 6.914 kg
$Q_{\beta\beta}$ = 3034 keV

^{82}Se 0.932 kg
$Q_{\beta\beta}$ = 2995 keV

ββ0ν search

ββ2ν measurement

^{116}Cd 405 g
$Q_{\beta\beta}$ = 2805 keV

^{96}Zr 9.4 g
$Q_{\beta\beta}$ = 3350 keV

^{150}Nd 37.0 g
$Q_{\beta\beta}$ = 3367 keV

^{48}Ca 7.0 g
$Q_{\beta\beta}$ = 4272 keV

^{130}Te 454 g
$Q_{\beta\beta}$ = 2529 keV

^{nat}Te 491 g

Cu 621 g

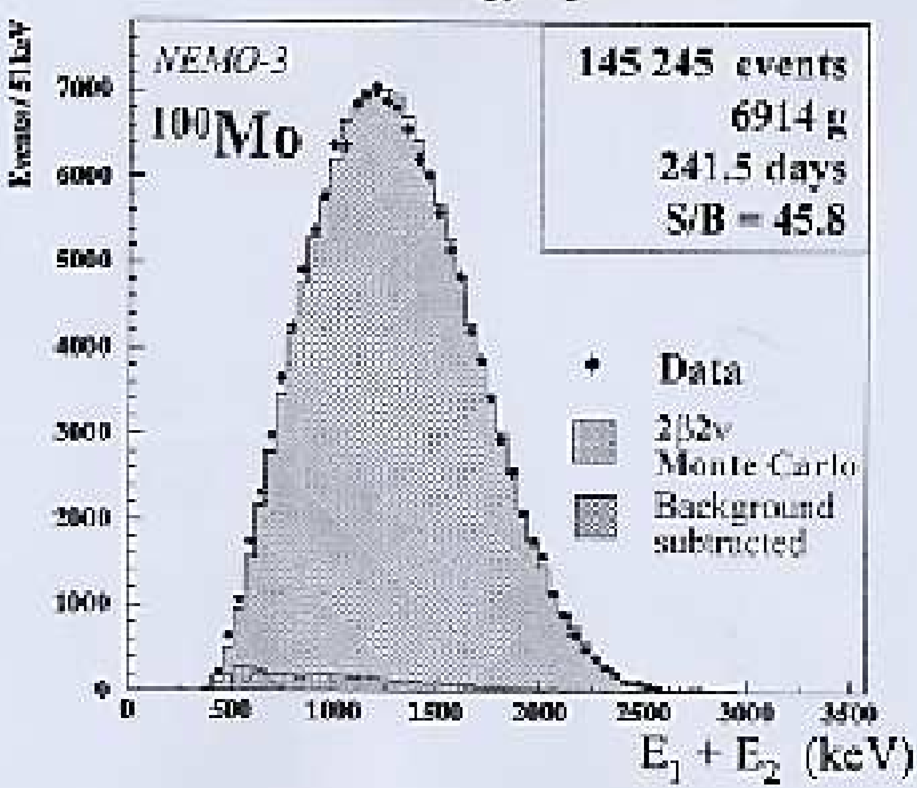
External bkg measurement

(All the enriched isotopes produced in Russia)

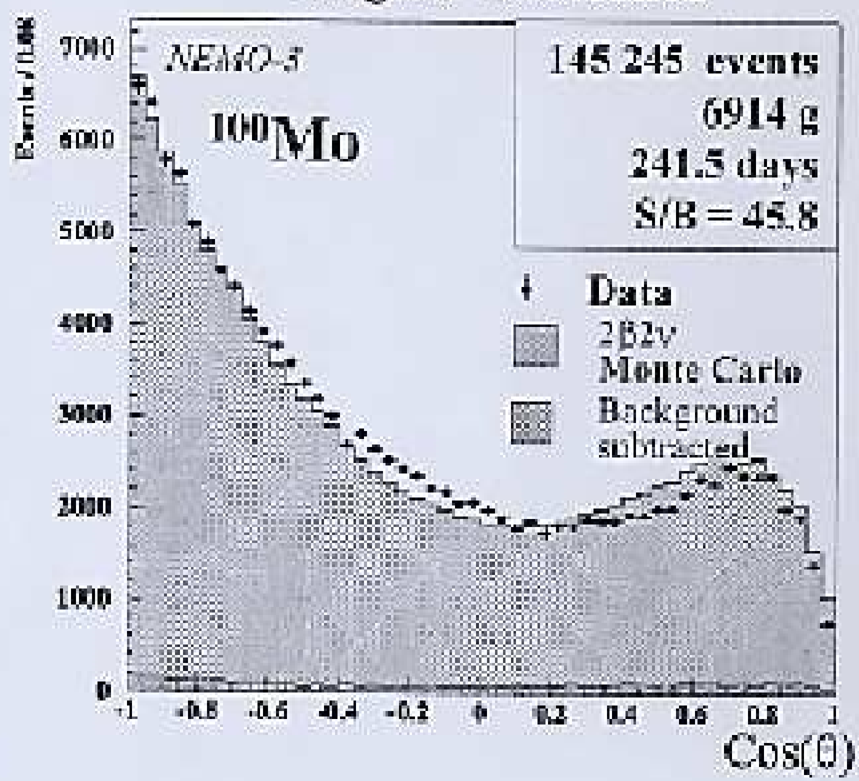
^{100}Mo $2\beta2\nu$ preliminary results

(Data 14 Feb. 2003 – 22 Mar. 2004)

Sum Energy Spectrum



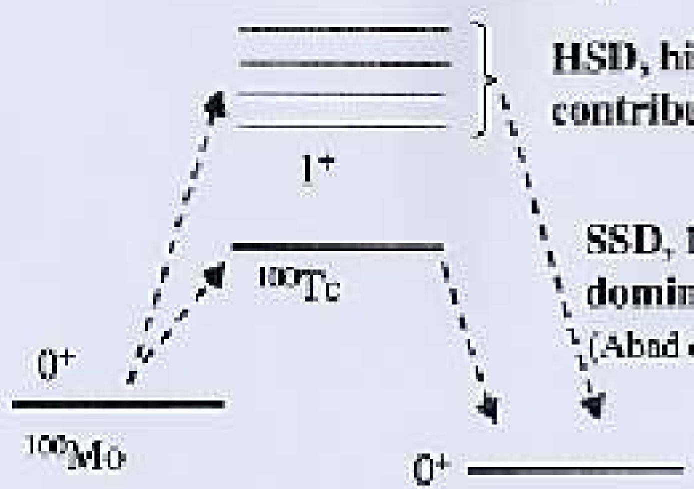
Angular Distribution



4.57 kg.y

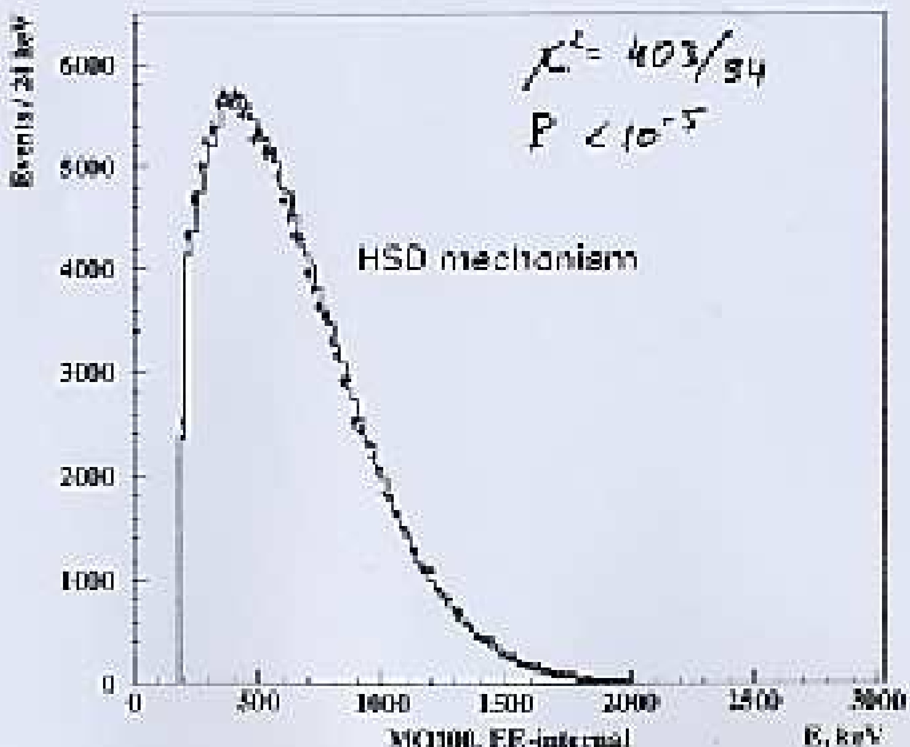
$T_{1/2} = 7.72 \pm 0.02$ (stat) ± 0.54 (syst) $\times 10^{18}$ y

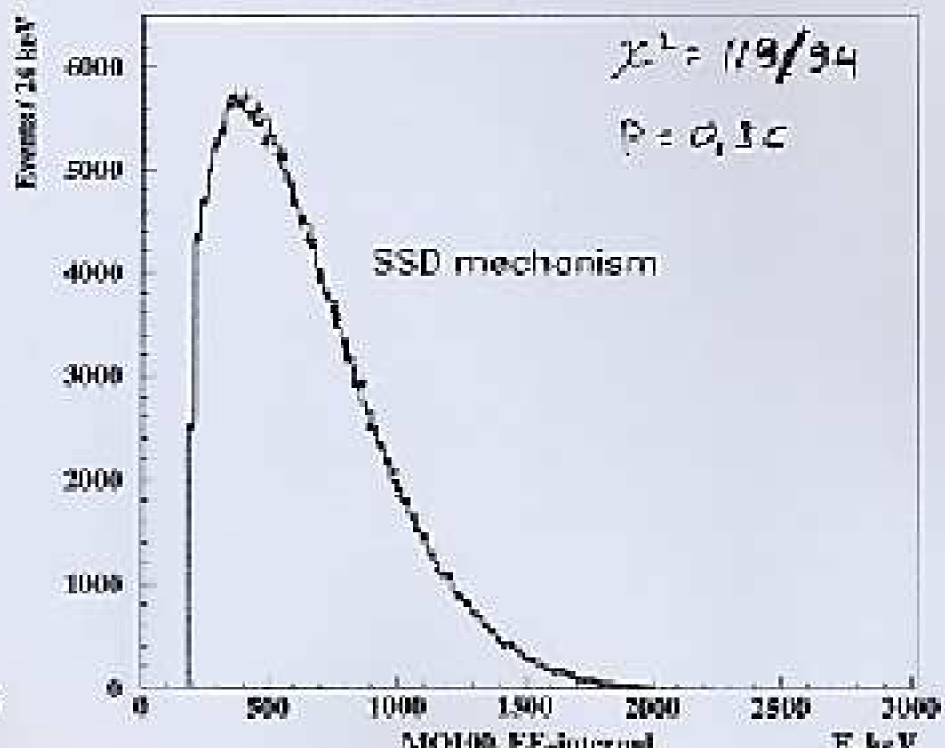
^{100}Mo 2β2ν Single Energy Distribution



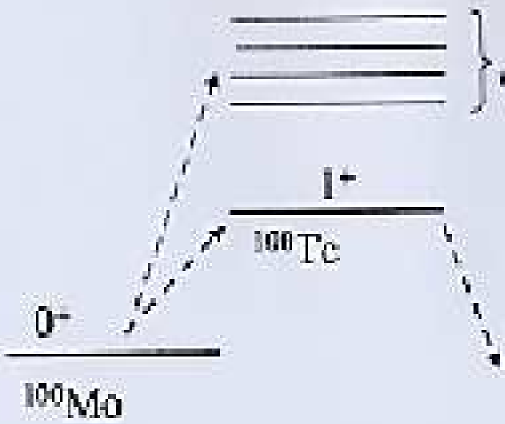
Calculations for ^{100}Mo:
(Simkovic, *J. Phys. G*, 27, 2233, 2001)

Effect in one electron spectrum





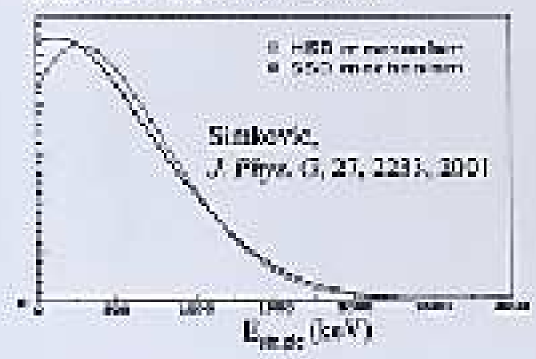
^{100}Mo 2β2ν Single Energy Distribution

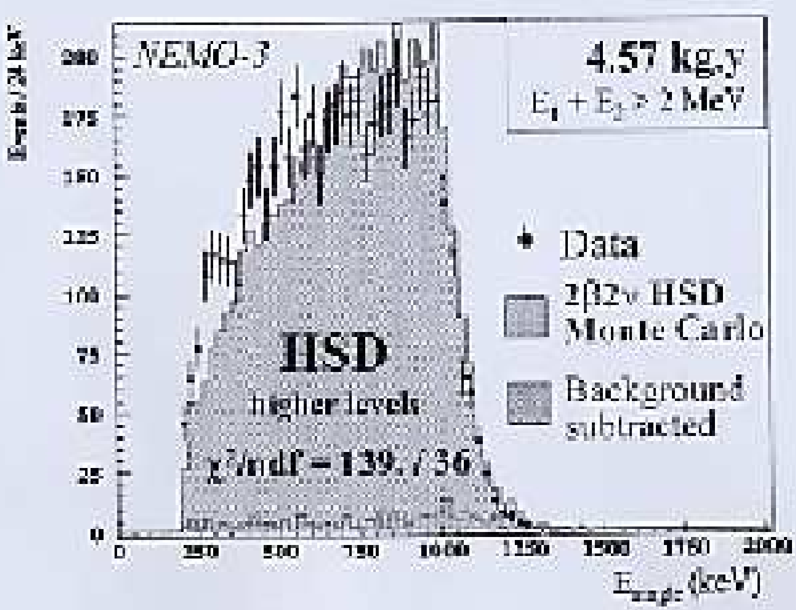


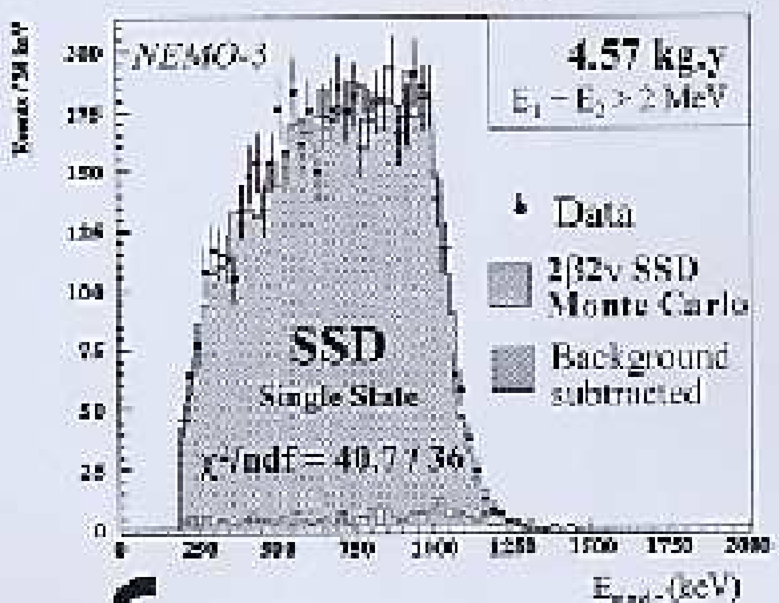
HSD, higher levels contribute to the decay

SSD, 1+ level dominates in the decay (Abad et al., 1984, *Ann. Fis.* A 80, 9)

Single electron spectrum different between SSD and HSD







HSD: $T_{1/2} = 8.61 \pm 0.02\ (stat) \pm 0.60\ (syst) \times 10^{18}$ y

SSD: $T_{1/2} = 7.72 \pm 0.02\ (stat) \pm 0.54\ (syst) \times 10^{18}$ y

^{100}Mo 2β2ν single energy distribution in favour of Single State Dominant (SSD) decay

3. Future measurements

3.1. Electron capture in ^{100}Tc and ^{116}In

WE NEED NEW MEASUREMENTS

Accuracy can be improved up to ~ 10% in the nearest future.

In the case of ^{100}Tc main problem was connected with background from other Mo isotopes in enriched ^{100}Mo sample. Enrichment of used sample was 97.4%. If one will use 99.31% ^{100}Mo sample the background will be decreased in ~ 10 times.

%	^{100}Mo	^{98}Mo	^{97}Mo	^{96}Mo	^{95}Mo	^{94}Mo	^{92}Mo
A.Garcia	97.42	0.96	0.28	0.34	0.29	0.18	0.53
ITEP	99.31	0.49	0.05	0.05	0.04	0.02	0.04

3.2. New NEMO-3 results.

In 3 years:

1) **^{100}Mo - g.s.-g.s.** transition, N ~ $5\cdot10^{3}$ events, pure effect, low systematics.
2) **^{100}Mo – g.s.-0^{+}_{1}** transition, N ~ 200 events , low background.
3) **^{116}Cd – g.s.-g.s.** transition, N ~ 10^{4} events, low background.

4. CONCLUSION

1. Theory predict SSD mechanism for ^{100}Mo and ^{116}Cd.

2. Present NEMO-3 data for ^{100}Mo prefer the SSD mechanism.

3. This result will be checked using new (more clear and reliable) NEMO-3 data for ^{100}Mo and ^{116}Cd. Reachable accuracy for decay rate is ~ 2-3%.

4. EC decay rate in ^{100}Tc and ^{116}In can be measured with accuracy ~ 10%.