About a possibility to study double beta decay with the help of nuclear emulsion

Svetlana Zemskova

January 27, 2009
Neutrino physics at accelerators

Outline

- $0\nu\beta\beta$
- Current and future $0\nu\beta\beta$ experiments
- Using of emulsion in $0\nu\beta\beta$ searching

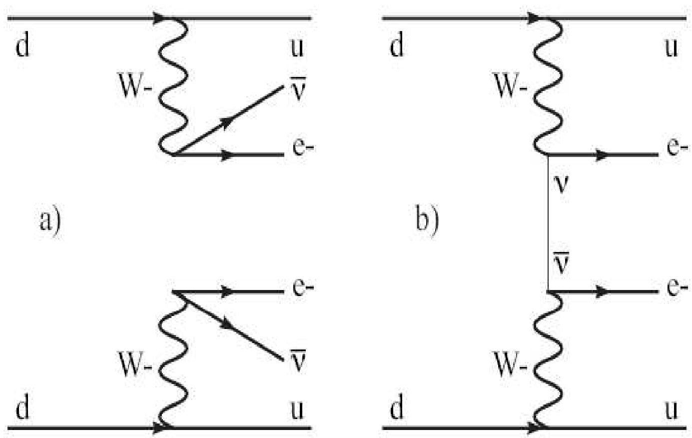
$0\nu\beta\beta$

The current interest in $0\nu\beta\beta$ is that the existence of this process is closely related to the following fundamental aspects of particle physics:

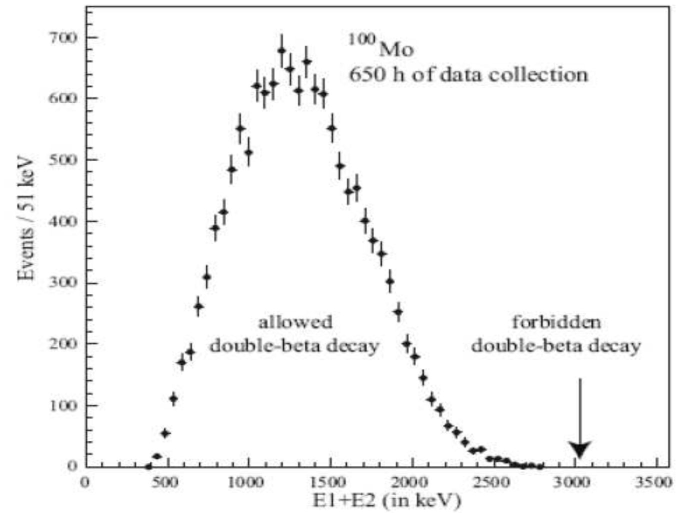
- lepton number nonconservation
- the presence of a neutrino mass and its origin
- the existence of right-handed currents in electroweak interactions
- the existence of Majoron
- the structure of the Higgs sector
- supersimmetry
- the existence of leptoquarks
- the existence of heavy sterile ν
- the existence of composite ν

All of these issues are beyond the standart model of electroweak interaction. Of couse, interest in this process is caused primarily by the problem of a neutrino mass. If $0\nu\beta\beta$ is discovered, this will be mean that the rest mass of at least one neutrino flavor is nonzero and is of Majorana origin.

$0\nu\beta\beta$



a-allowed $2\nu\beta\beta$, b-forbidden $0\nu\beta\beta$



Observed $\beta\beta$ for ^{100}Mo by NEMO-3 experiment

In $\beta\beta$ experiments the $2e^-$ of both processes are detected. For the 1-st case, the e^- energy distribution is quite broad due to the missing ν energy while for the forbidden process the energy is well defined mainly dispersed by the detector energy resolution. (These energy is about 2.8-4.3 MeV, depends on the decaying nucleus.)

Current and future $0\nu\beta\beta$ experiments

2 approaches have been adopted by these experiments:

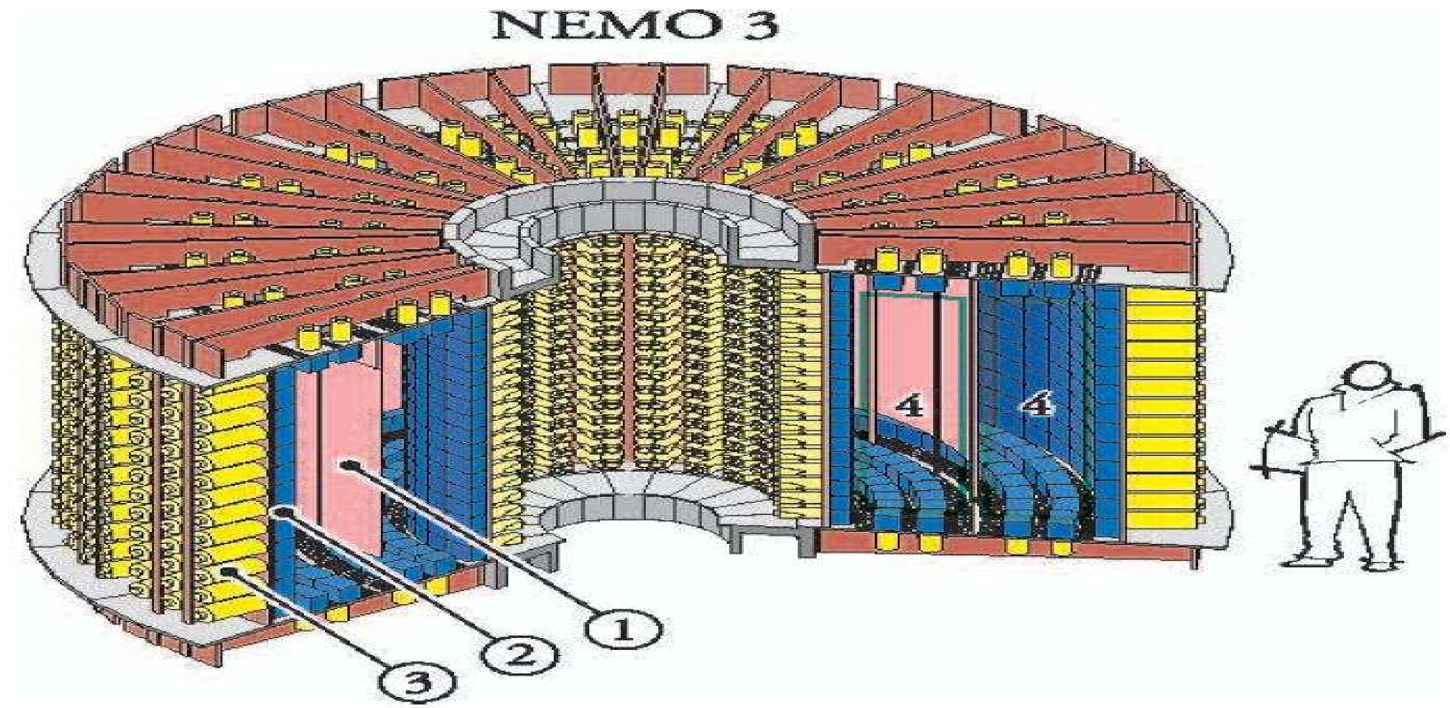
- just measuring with high precision the energy - is affected by many other processes deposing energy in the detector (γ ...) - IGEX, CUORICINO

- measuring the energy and also detecting the 2 e^- - less energy resolution but better background rejection - NEMO-3, Super-NEMO

NEMO-3: expected sensitivity up to m_ν ~3 eV, uses 7 kg isotopes with a target foil surface of 20 m^2 and thickness of about 60 μm, energy resolution $\Delta E/E \sim 15\%$

Super-NEMO proposed: expected sensitivity up to m_ν ~50 meV, uses 70 kg isotopes, energy resolution $\Delta E/E \sim 7\%$

Current and future $0\nu\beta\beta$ experiments



The NEMO-3 detector without shielding:

1 - sourse foil

2 - plastic scintillator

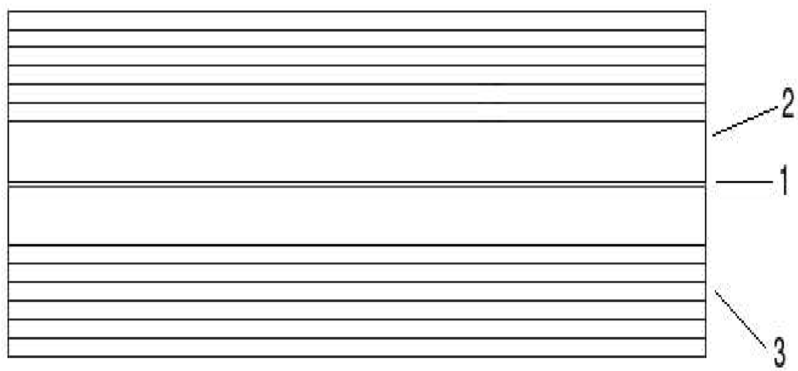
3 - low radioactivity PMT

4 - tracking chamber

Using of emulsion in $0\nu\beta\beta$ searching

Attempt of studying of possibility of $\beta\beta$ experiment was in 1990:

A.S. Barabash, O.K. Egorov, A.A. Klimenko, E.D. Kolganova, E.A. Pozharova, T.Yu. Skorodko, V.A. Smirnitsky, A.A. Smolnikov "The search for 2β-decay of ^{96}Zr and ^{94}Zr with photographic emulsion", Preprint ITEP 90-131/



It is possible to register not only the existence of $0\nu\beta\beta$, but all characteristics of the process:

- full energy $E_{2\beta}$
- energy of each e^-
- angle between them

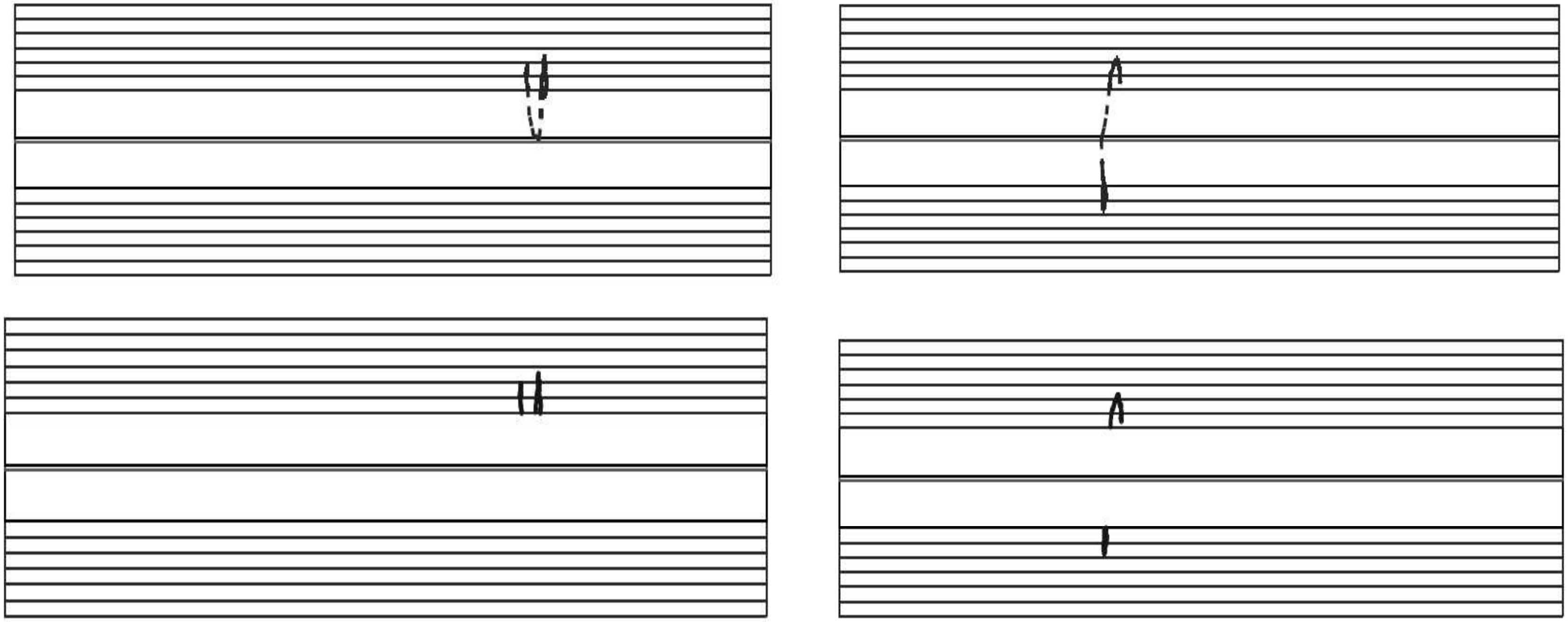
1 - sourse layer
2 - mylar layers
3 - emulsion layers

^{96}Zr - $T_{1/2} > 1 * 10^{17}$ year - best result for that time $2\nu2\beta$ (now measured in NEMO-3 $T_{1/2} = (2.3 \pm 0.5) * 10^{19}$)

^{94}Zr - $T_{1/2} > 0.6 * 10^{16}$ year - first result for that time $2\nu2\beta$

Conclusion: increase of sensitivity with the emulsion method will be possible only using automatic scanning

Using of emulsion in $0\nu\beta\beta$ searching



These pictures were made with the help of

- generator DECAY0 (O.A.Ponkratenko, V.I.Tretyak, Yu.G.Zdesenko, "Event Generator DECAY4 for Simulating Double-Beta Processes and Decays of Radioactive Nuclei", Phys. At. Nucl. 63 (2000) 1282 (nucl-ex/0104018))
- VMCViewer(A. Chukanov, D. Naumov, E. Naumova, A. Sheshukov, S. Zemskova, "Fedra Virtual Monte Carlo. Applications", OPERA Internal Note 94)

Using of emulsion in $0\nu\beta\beta$ searching

- NEMO-3 isotope surface is 20 m^2
- Super-NEMO isotope surface is 10*20 m^2
- To cover the same isotope surface with emulsions (both sides to detect the 2 e^-) an emulsion surface 2*200 = 400 m^2 is needed

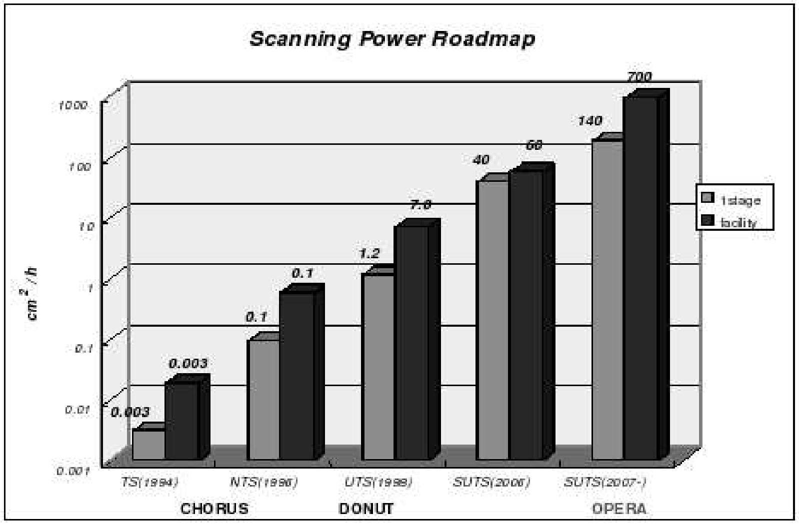
Just for a comparison, one OPERA emulsion has about 0.012 m^2 and 1 brick 0.68 m^2. Thus, 400 m^2 $\sim$ 600 OPERA bricks (OPERA has more than 150 000 bricks).

Keep all these envelops for some time (e.g. 12 months) in the experiment and after this period start scanning them one after the other. They could be replaced by new envelops during 5 years in order to accumulate something equivalent to what Super-NEMO could do: $\sim$ 5*400 year*m^2.

Emulsion detector is compact - V=400 m^2*5 mm = 2 m^3 (only emulsion+sourse without covers)

Using of emulsion in $0\nu\beta\beta$ searching

- How much time is needed to make a full scan of 2000 m^2 (is a full scan in all volume really needed?)?
- If the Japanese S-UTS scanning system is used with a speed of 50 sm^2/hour (be careful with thickness), for one scanning table: 25 m^2/year (200 working days/year). By using 16 tables and extracting 100 m^2/3 months (1 year exposure at the beginning and putting back new emulsions with the same isotopes), this finally will take less than 5 years (as Super-NEMO).
- Probably the emulsion thickness needed to detect these 2 e^- will need more scanning time and the speed would be significantly less than 50 sm^2/h. On the other hand, scanning speed increases with time



Using of emulsion in $0\nu\beta\beta$ searching

Pending questions:

Energy resolution

- NEMO: 15% for 3 MeV electrons
- Super-NEMO: lower than 7% (goal 4%)
- Emulsion experiment: ??? (monoenergetic 1 MeV e^- from ^{207}Bi could be used to have a good estimate of this resolution)

Reconstruction efficiency

- NEMO: 15%
- Super-NEMO: 40%
- Emulsion experiment: ???

Afforded background ???

Possibility to take thinner isotope sheets (60 μm for NEMO-3) and have better energy resolution (but also more scanning for the same isotope mass)