Comenius University Bratislava

50 years from foundation of Department of Nuclear Physics

Double beta decay: NEMO3 and SuperNEMO experiments

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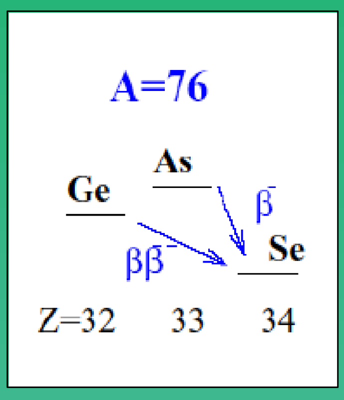
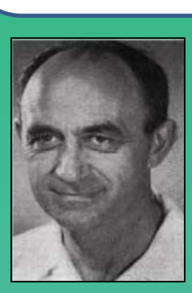
Faculty of Mathematics, Physics and Informatics

Double beta decay

Double beta decay can occur when the single beta decay to the neighbor nuclei is energetically forbidden due to pairing force.




E. Fermi

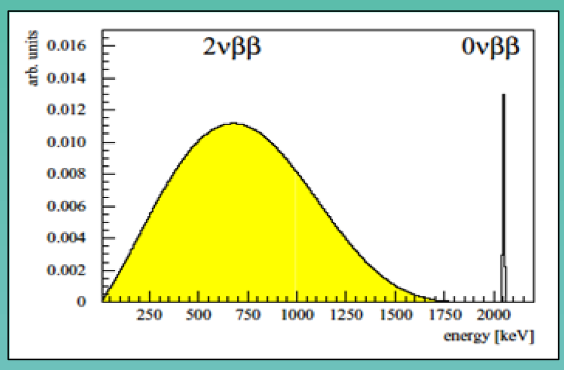

M. G. Mayer


W.H. Furry

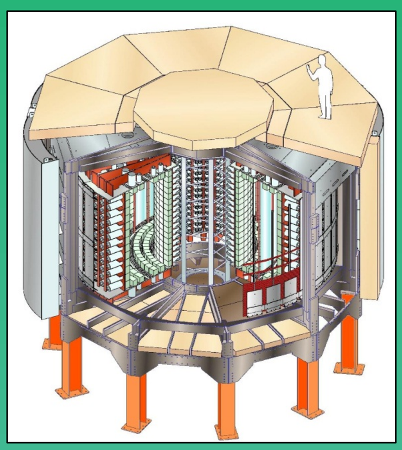

E. Majorana

- **1934:** *Enrico Fermi*, β decay theory
- **1935:** *M. G. Mayer* calculated 2νßß decay
- **1939:** *W. Furry* proposed 0νßß decay assuming ν's to be Majorana particles

The difference between the two modes is in the differential decay rate versus the sum of kinetic energies of the two emitted electrons.



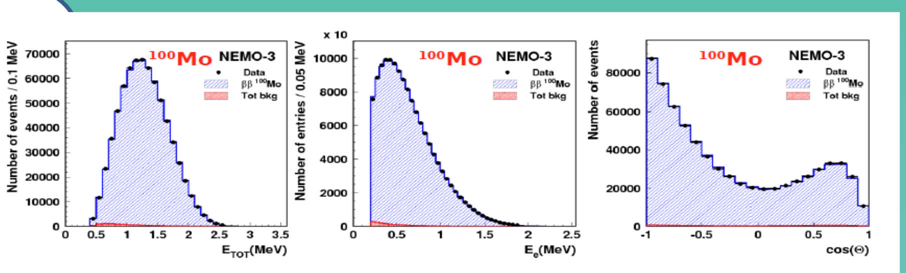
NEMO3 experiment at Frejus underground laboratory



Experimental investigation of the double β decay

- **Source:** 10 kg of ββ isotopes (^{100}Mo, ^{82}Se, ^{116}Cd, ^{96}Zr, ^{150}Nd, ^{48}Ca, ^{130}Te)
- **Tracking detector:** drift wire chamber operating in Geiger mode (6180 cells)
- **Calorimeter:** 1940 plastic scintillators coupled to low PMTs
- **Magnetic field:** 25 Gauss
- **Gamma shield:** Pure iron (18 cm)
- **Neutron shield:** 30 cm water (ext. wall), 40 cm wood (top & bottom)
- **Particle identification:** e^-, e^+, α, γ

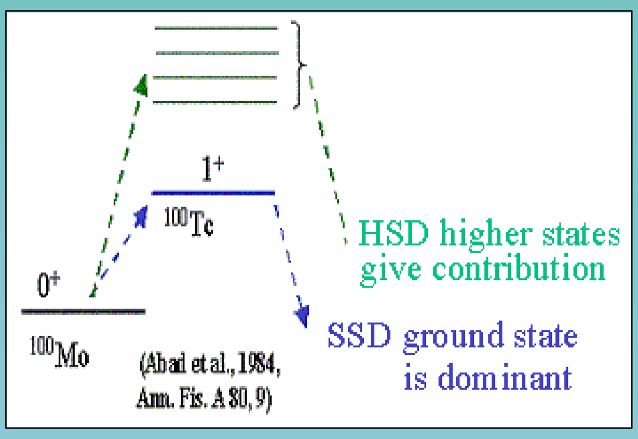
- 7×10^5 events for ^{100}Mo foils
- S/B = 76
- ε(2νßß) = 0.043
- $T_{1/2}$(2νßß) = (7.16±0.01)10^{16} y



Phys. Rev. Lett. **95** (2005) 483

Single State Dominance hypothesis and two-neutrino double beta decay

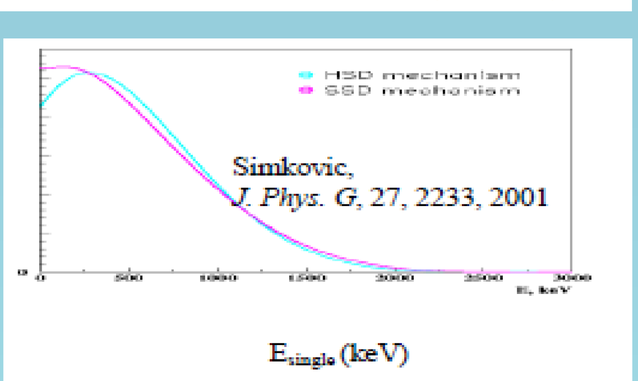
The transition through the 1^+ ground state of intermediate nucleus gives the dominant contribution to the nuclear matrix element of the double β decay.



$$M^K_{GT} = \sum_m \left(\frac{M^i_m(1^+)M^f_m(1^+)}{E_m - E_i + e_{10} + \nu_{10}} + \frac{M^i_m(1^+)M^f_m(1^+)}{E_m - E_i + e_{20} + \nu_{20}} \right)$$

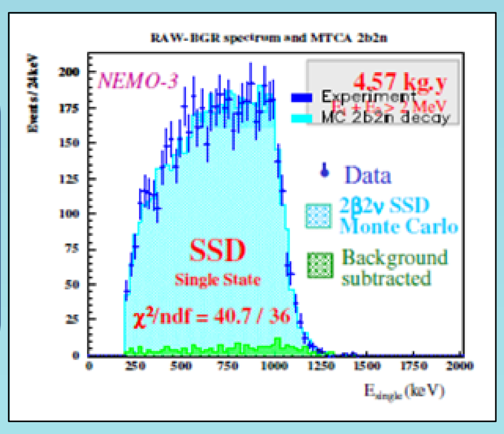
$$\text{SSD} \Rightarrow \frac{M^i_1(1^+)M^f_1(1^+)}{E_1 - E_i + e_{10} + \nu_{10}} + \frac{M^i_1(1^+)M^f_1(1^+)}{E_1 - E_i + e_{20} + \nu_{20}}$$

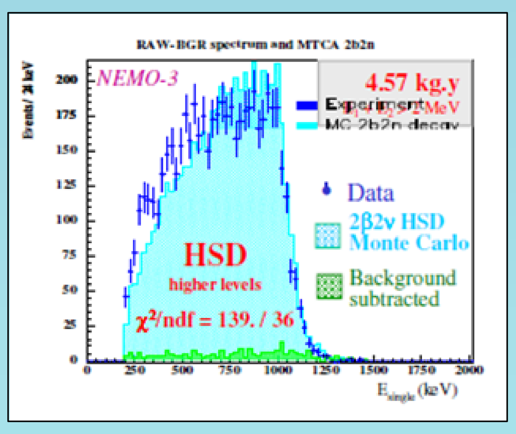
The difference between SSD and HSD hypotheses is in the single electron energy distribution.



Šimkovic, Domin, Semenov, *J. Phys. G* **27**, 2233 (2001)

Single electron energy spectrum from NEMO3 data confirms SSD for ^{100}Mo.





Bosonic neutrinos in two-neutrino double beta decay

Mixing of fermionic and bosonic neutrinos

$$|\nu> = \hat{a}^\dagger|0> \equiv \cos\delta\ \hat{f}^\dagger|0> + \sin\delta\ \hat{b}^\dagger|0> = \cos\delta\ |f> + \sin\delta\ |b>$$

Commutation relations

$$\hat{f}\hat{b} = e^{i\phi}\hat{b}\hat{f} \qquad \hat{f}^\dagger\hat{b}^\dagger = e^{i\phi}\hat{b}^\dagger\hat{f}^\dagger$$
$$\hat{f}\hat{b}^\dagger = e^{-i\phi}\hat{b}^\dagger\hat{f} \qquad \hat{f}^\dagger\hat{b} = e^{-i\phi}\hat{b}\hat{f}^\dagger$$

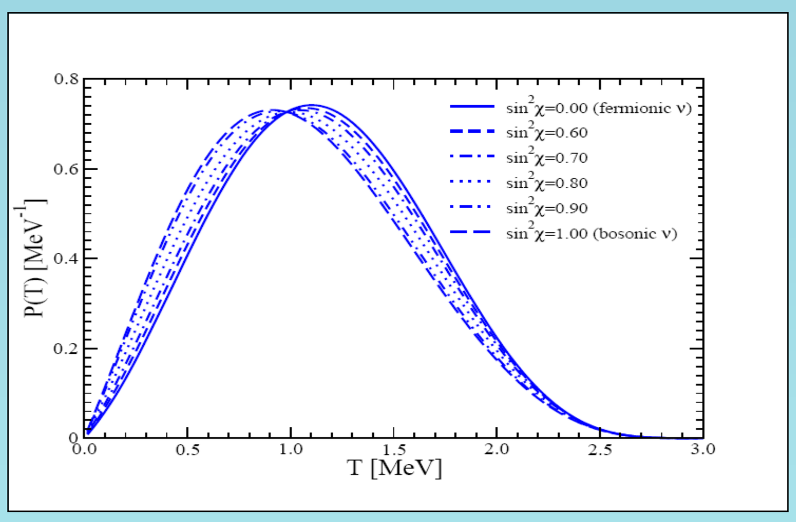
Amplitude of the 2νßß decay

$$A^{2\nu} = [\cos\delta^4 + \cos\delta^2\sin\delta^2(1-\cos\phi)]A^f + [\cos\delta^4 + \cos\delta^2\sin\delta^2(1+\cos\phi)]A^b = \cos\chi^2 A^f + \sin\chi^2 A^b$$

The decay rate is a sum of the decay rates for pure fermionic and pure bosonic neutrinos

$$W^{2\nu} = \cos\chi^4\ W^f + \sin\chi^4\ W^b = (1-b^2)\ W^f + b^2\ W^b$$

^{100}Mo → ^{100}Ru (SSD)



- NEMO3 data yield $\sin^2\chi < 0.6$
- Pure bosonic ν is excluded

Barabash, Dolgov, Dvornicky, Šimkovic, Smirnov, *Nucl. Phys. B* **783**, 90 (2007)

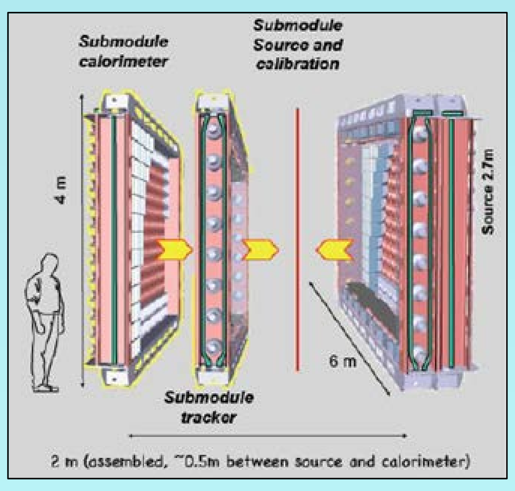
SuperNEMO experiment

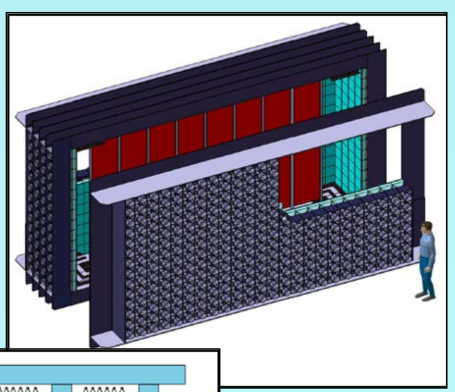
$$\frac{1}{T^{0\nu}_{1/2}} = \left|\frac{m_{\beta\beta}}{m_e}\right|^2 G^{01}(E_0,Z)\ \left|M^{0\nu}\right|^2$$

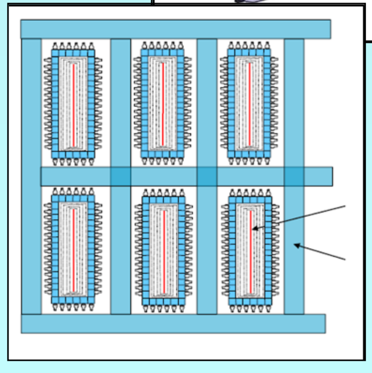
- Planar and modular design
- ~140 kg of enriched isotopes (20 modules x 7 kg)

Single module:

- **Source:** ~7 kg of ^{72}Se (^{150}Nd, ^{48}Ca)
- **Tracking:** drift chamber in Geiger mode (2000 cells)
- **Calorimeter:** scintillators + PMTs (~550)





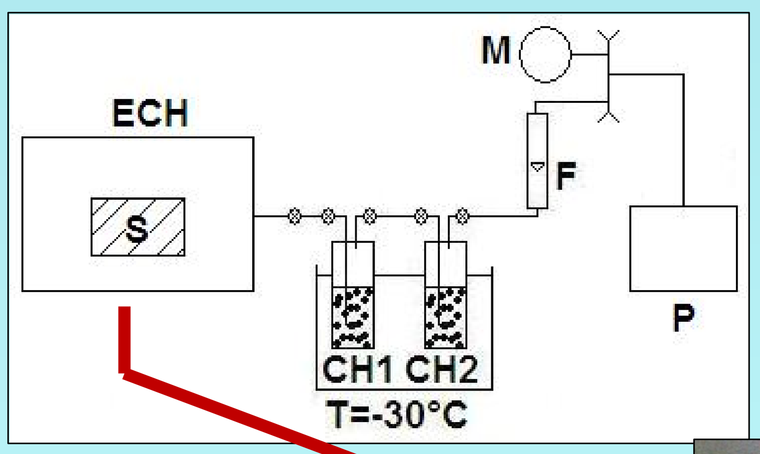


Schedule highlights:

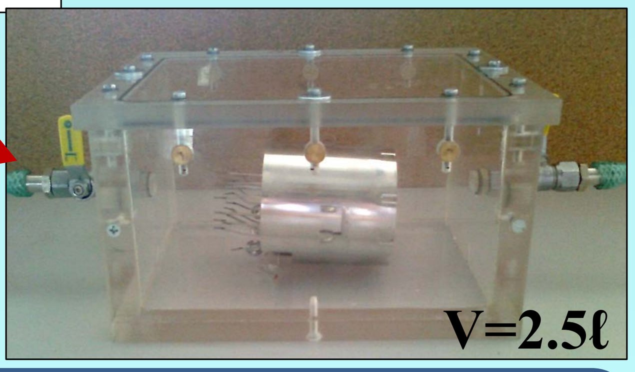
- **2011-2012:** Demonstrator construction, placed in the NEMO3's current location at **Modane Underground Laboratory**
- 2013: Demonstrator physics run startup
- 2014: Full SuperNEMO detector construction startup placed in a new cavity
- 2015: Klapdor-Kleingrothaus claim to be verified
- **2019: sensitivity $m_{\beta\beta}$ ~ 0.05 eV**

Development of methods for radon emanation measurements

Radon transfer scheme



ECH – emanation chamber
S – sample
CH1 and **CH2** – charcoal columns
F – flow rate meter
M – manometer
P – pump



Results of photomultiplier measurements

Whole photomultiplier → E = (3.8 ± 0.8) $\cdot10^{-8}$ Bq·s^{-1}
Dynodes → E = (3.03 ± 0.5) $\cdot10^{-8}$ Bq·s^{-1}
Glass casing → E = (1.04 ± 0.8) $\cdot10^{-8}$ Bq·s^{-1}

SuperNEMO (~100 people)