Double Beta Decay of ^{150}Nd in the NEMO 3 Experiment

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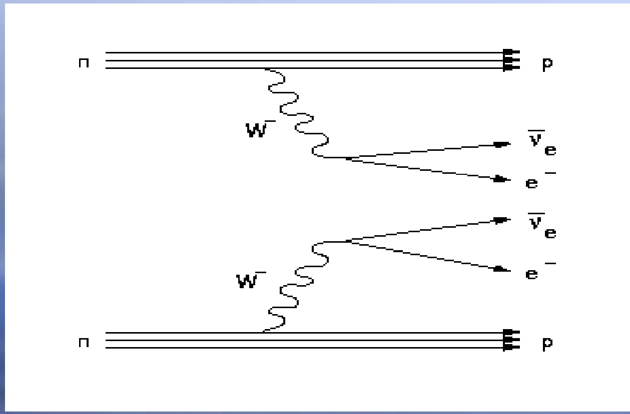
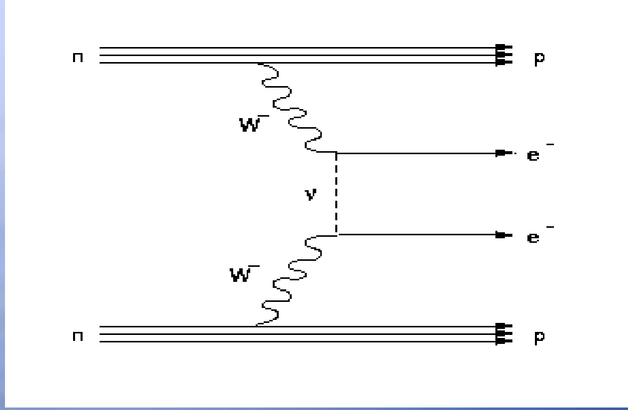
IOP HEPP meeting, Lancaster

31st March 2008

Double beta decay physics

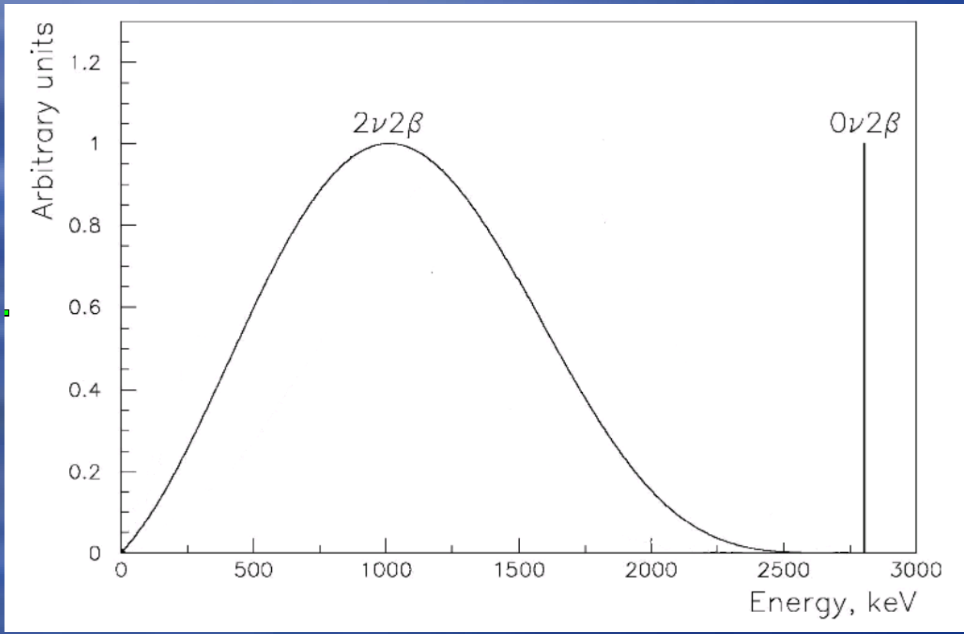


$$(T^{2\nu}_{1/2})^{-1} = G^{2\nu}|M^{2\nu}|^2$$



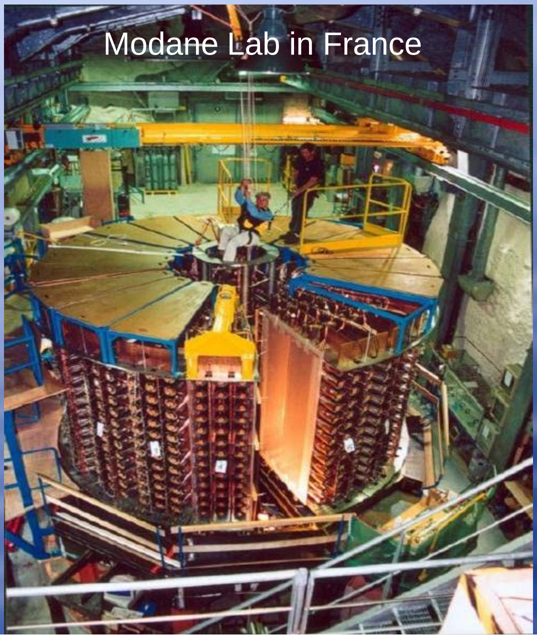
$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}|M^{0\nu}|^2|\langle m_\nu\rangle|^2$$

- Nuclear matrix element can be tested by measuring half-life of 2νββ.
- 2νββ forms irreducible background to 0νββ.
- Observation of 0νββ would prove neutrinos are Majorana particles.
- Half-life would give effective neutrino mass.



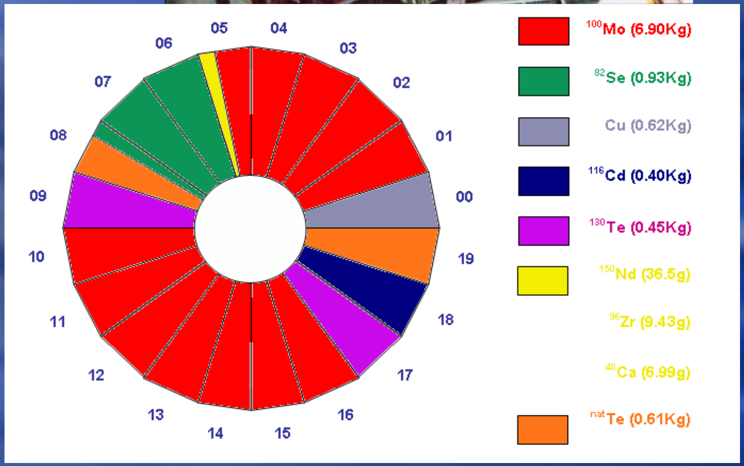
Overview of the NEMO 3 detector

- Tracker plus calorimeter technique.
- Good particle identification: electron (e), photon (γ) and alpha (α).
- Cylindrical design, divided into 20 equal sectors.
- 10 kg of $\beta\beta$ ▪ isotopes.
- Consists of four main parts: tracking chamber, calorimeter, source foils and shielding.



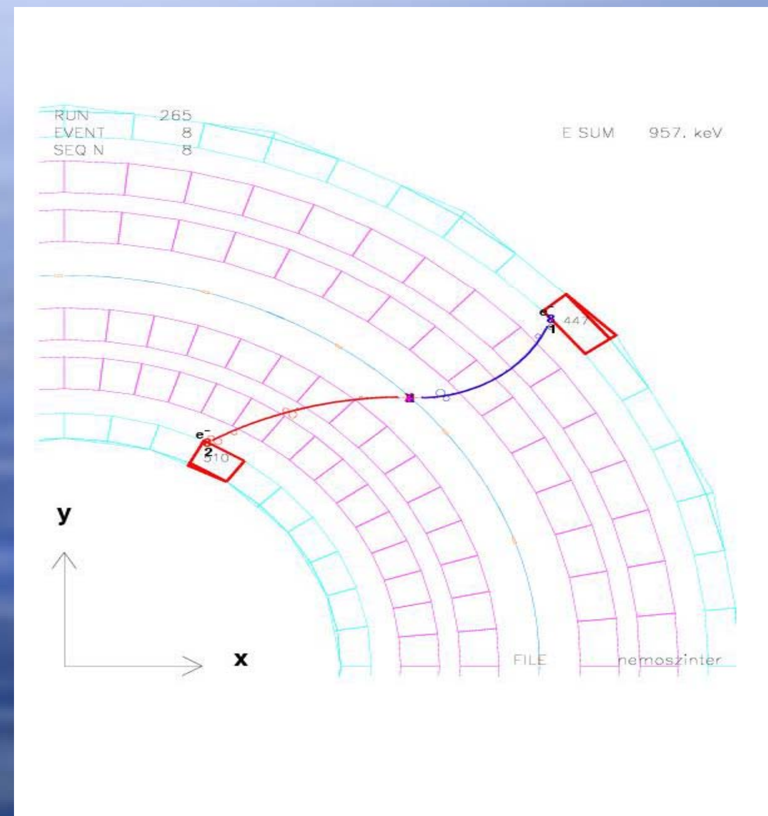
^{150}Nd in NEMO3:

- ^{150}Nd has a high nuclear transition energy ($Q_{\beta\beta}$=3.367 MeV).
- Lower natural radioactivity background and large phase space factor (strong candidate for SuperNEMO).
- 37 g mass in NEMO 3 (compare to possible 100 kg in SuperNEMO).



Selection criteria for 2e events

- Two tracks with negative charge associated with isolated scintillator hits.
- Energy deposit in each scintillator E > 0.2 MeV.
- Two tracks must have a common vertex in the ^{150}Nd source foil.
- Track length > 30cm.
- The tracks must go through one of the first two layers of tracking chamber.
- TOF cut in order to reject events coming from outside of foil.



Background to double beta decay

- Two types of backgrounds: internal and external.
- Internal from contaminants inside the foil.
- External from radon and calorimeter PMTs.

Activity from data

Data taking time

$$N_{bgr} = \Sigma_i A_i \epsilon_i t$$

Selection Efficiency (MC simulation)

- Activity of the contaminants in ^{150}Nd measured by looking at two control channels:

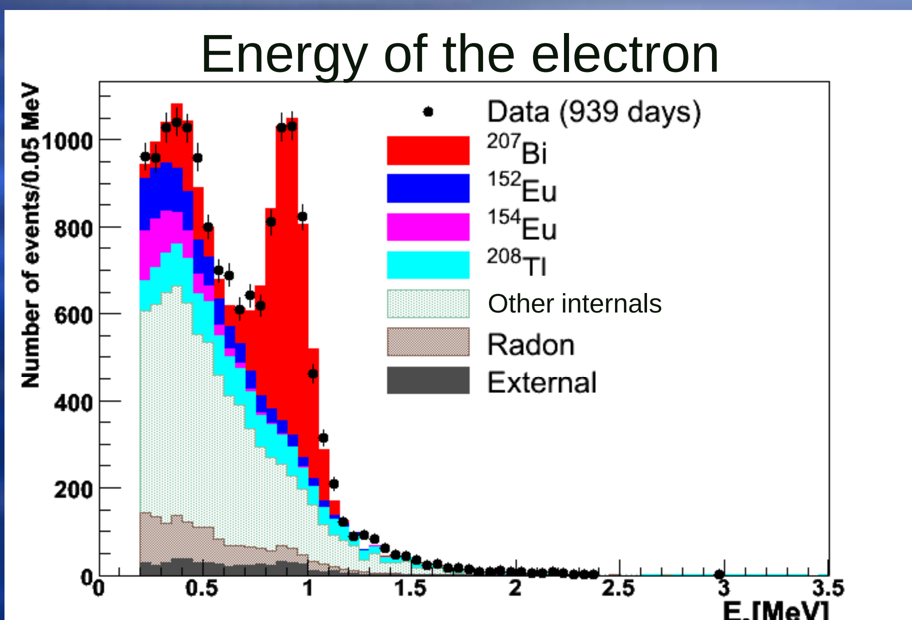
  - electron-photon (eγ)

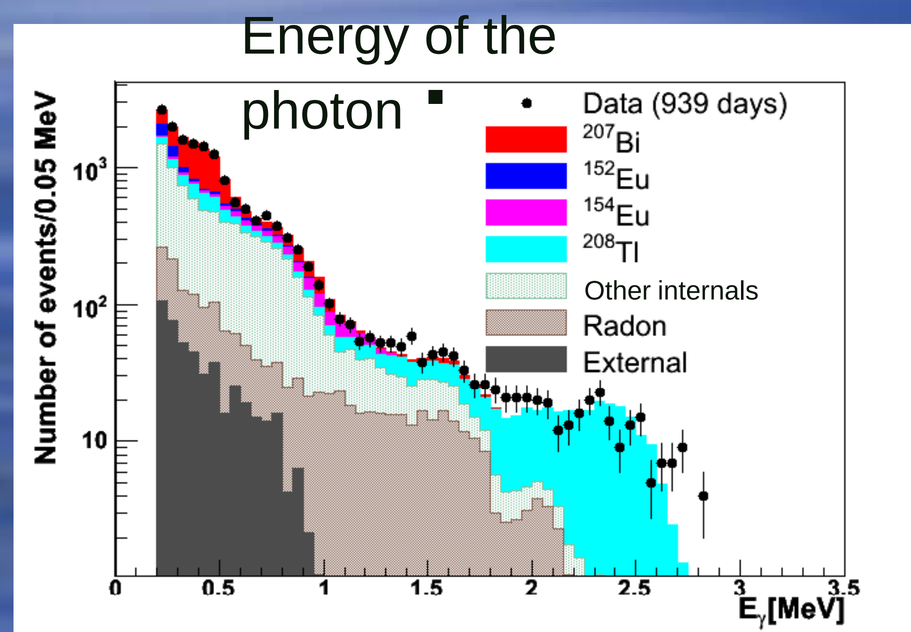
  - single electron (1e).

eγ control channel

- ^{207}Bi decays to an electron and a photon via conversion process.
- ^{152}Eu and ^{208}Tl decay to an electron and a photon via a beta decay and de-excitation of their daughter isotope.

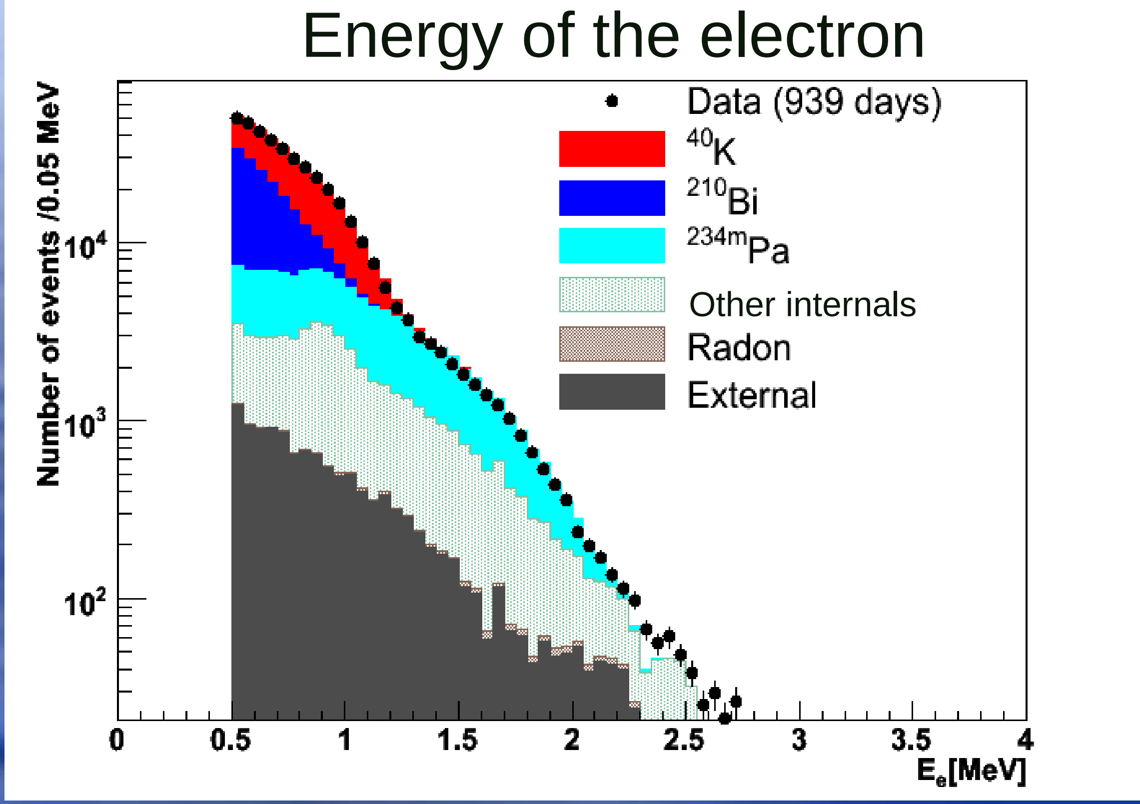
- Background MC fits data well in eγ control channel.





Single electron control channel

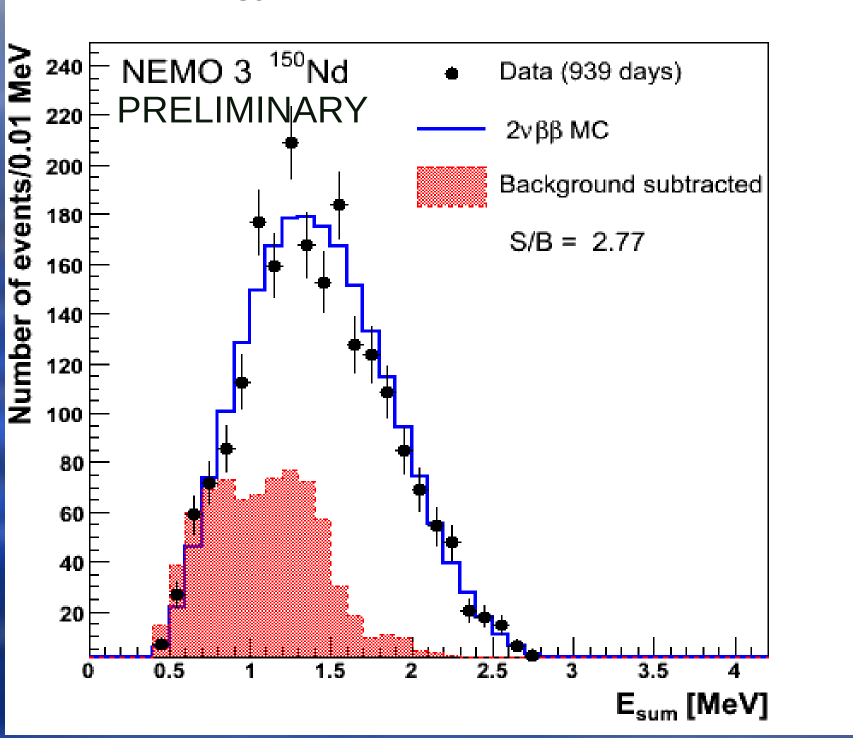
- ^{40}K, ^{234m}Pa and ^{210}Bi decay to an electron via beta decay.
- Background MC fits data well in single electron channel.



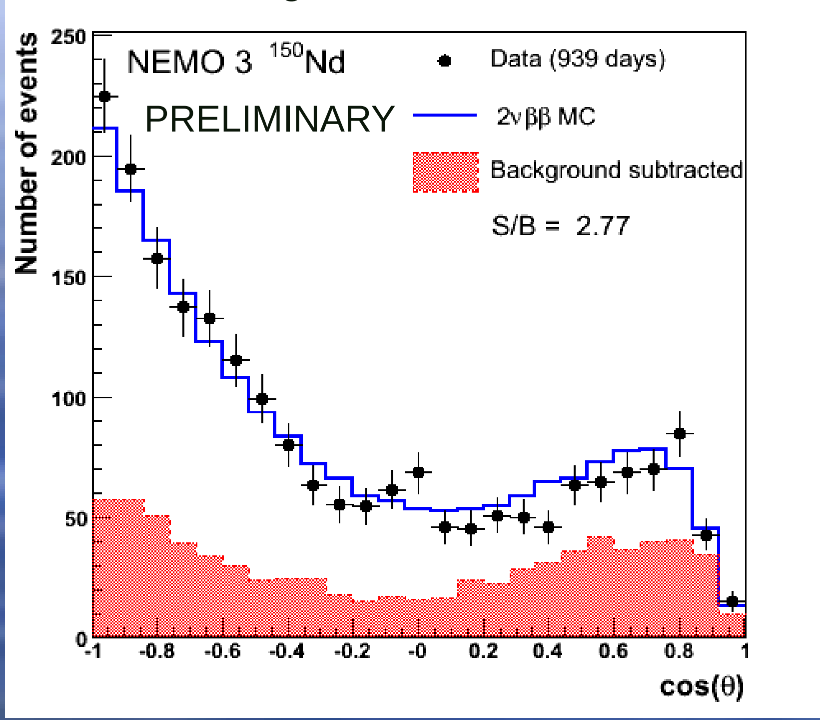
$2\nu\beta\beta$ results for ^{150}Nd

- 939 days of data collection (Feb 2003-Dec 2006), 2828 events passed the selection criteria.

Energy sum of the electrons



Angular distribution



Half-life of $2\nu\beta\beta$:

$$T_{1/2}\ (2\nu\beta\beta) = (9.20\ ^{+0.25}_{-0.22}\ (stat) \pm 0.73\ (syst)) \times 10^{18}\ y$$

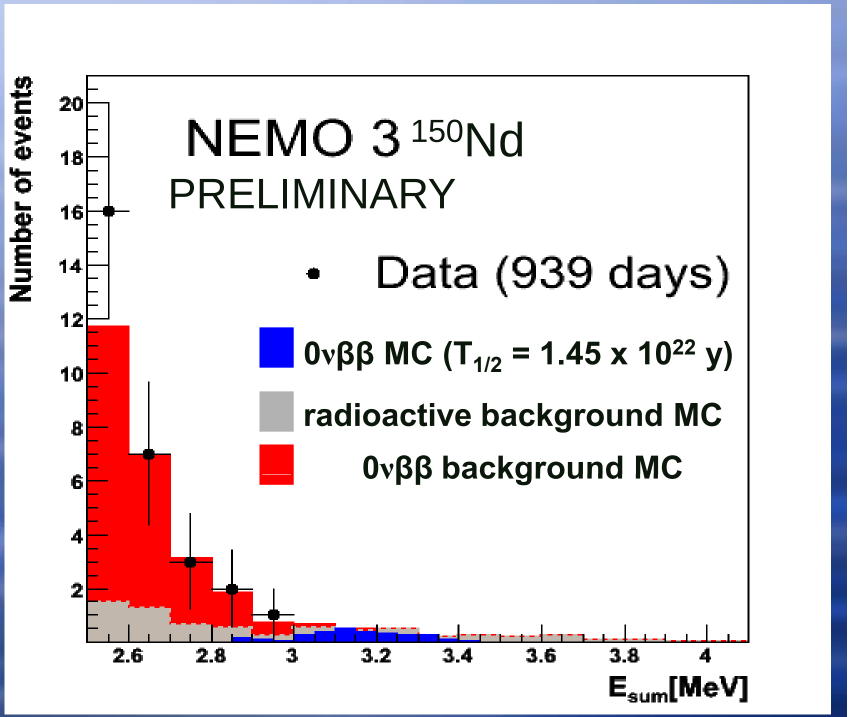
0νββ results for ^{150}Nd

- To set limit on 0νββ, the LEP CLs method was used.
- Energy above 2.5 MeV.
- Signal detection efficiency: 19%.

$T_{1/2}$ (0νββ) > 1.45 x 10^{22} y   90 % CL

⟨$m_ν$⟩ < 3.7 – 5.1 eV

using NME from V.A. Rodin et al., Nucl. Phys. A 766 (2006) 107



Above 2.5 MeV
28.6 ± 2.7 events expected from background
29 events observed

- Improved limit by almost a factor 10.

Previous result: $T_{½}$ > 1.7 x 10^{21} y   90 % CL

A.A. Klimenko et al., Nucl. Instr. Meth. B 17 (1986) 445

Summary

- The NEMO 3 detector is still collecting data.
- The half-life of the $2\nu\beta\beta$ decay of ^{150}Nd was obtained:

$$T_{1/2}(2\nu\beta\beta) = (9.20\ ^{+0.25}_{-0.22}\ (stat) \pm 0.73\ (syst)) \times 10^{18}\ y.$$

- The limit on the half-life of the $0\nu\beta\beta$ has been improved by almost a factor 10:

$$T_{1/2}(0\nu\beta\beta) > 1.45 \times 10^{22}\ y \quad 90\%\ CL \qquad \langle m_\nu \rangle < 3.7 - 5.1\ eV.$$

- World's best limit of $0\nu\beta\beta$ half-life for ^{150}Nd has been obtained.

Backup

Background name	Efficiency	Activity,mBq	Number of events
Ac228	0.00046	1.7+0.1-0.6	63.55
Bi212	0.00029	1.7+0.1-0.6	40.21
Tl208	0.0011	0.62+0.04-0.23	56.55
Eu152	9.44267e-05	4.13+2.24-0.62	31.42
Bi207	0.00015	0.98 +0.125 -0.05	120.12
Bi214	0.00098	0.187±0.043	14.87
Pb214	0.000418296	0.187±0.043	2.36
K40	0.75103e-05	16.0±0.5	100.667
Pa234m	0.00075199	2.65±0.02	161.757
Total			591.5+24.1-34.3
Radon			26.3±1
Total Bi210			23.27±1
Externat Background			9.6±1
Background from ^{100}Mo , ^{96}Zr, ^{90}Y (^{48}Ca)			118.67±9
Total background			769.3+25.7-35.5

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Settling Limits on different neutrinoless modes using LEP CL method (D0 statistical tools[1])

Systematic considered for the limit setting:

	Signal	$2\nu\beta\beta$	other backgrounds
Eff	5%	5%	5%
Act	x	x	+3.3%, -4.7%
Stat	x	+2.5%,-2.29%	x

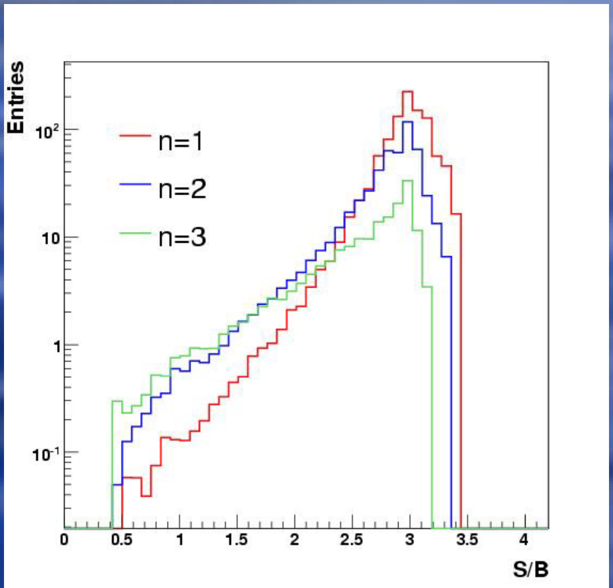
1- Systematic and limit calculations,
Wade Fisher FERMILAB-TM-2386-E, Dec 2006. 6pp

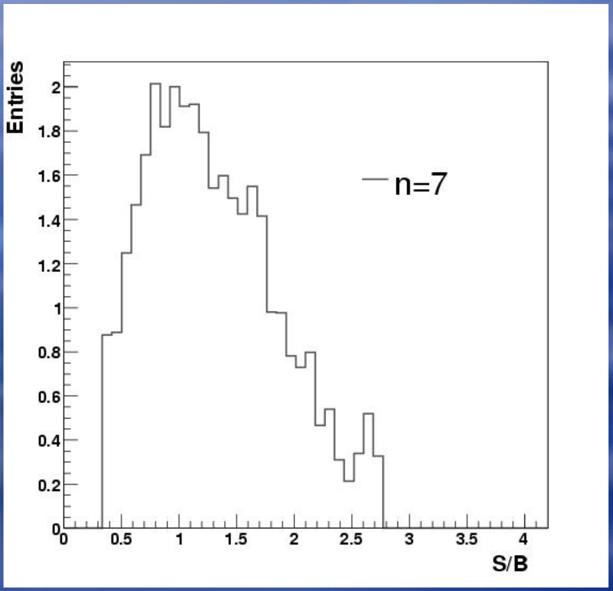
Limit for Neutrinoless double beta decay

Mode	Energy (MeV)	Efficiency %	N<	Half-life >
$0\nu\beta\beta$	> 2.5	19	3.33	$1.45\ x10^{22}$y
$0\nu\beta\beta rc$	>2.5	11	3.29	$1.27x10^{22}$ y

Different Majoron modes

To set a more accurate limit, the limit is set in a energy region with maximum S/B.





At 90% CL:

Mode	Energy (MeV)	Efficiency %	N<	Half-life >
M1	2.0-3.5	8.25	13.99	1.55×10^{21} y
M2	1.5-3.5	7.95	36.19	5.79×10^{20} y
M3	1.5-3.5	5.68	57.54	2.61×10^{20} y
M7	0.5-2.1	3.8	266.72	3.80×10^{19} y

In comparison with Helene method

Helene Equation (without considering the uncertainties)

M1 [2.0-3.19 MeV]	>8.06 X 10^{20} year
M2 [1.5-3.19 MeV]	>5.35 X 10^{20} year
M3 [1.5-3.19 MeV]	>3.08 X10^{20} year
M7 [0.5-2.1 MeV]	>8.70 X 10^{19} year