

Shiva King UCL 27th June 2005

Introduction

- o Main aims of the NEMO 3 experiment
 - Search for $0\nu\beta\beta$ decay for several different isotopes
 - Is the neutrino a Dirac or Majorana particle?
 - Absolute mass scale of the neutrino <m₂>
 - Lepton number violation
- Also possible to study $2\nu\beta\beta$ decay for different transitions of different isotopes

NEMO 3 Detector

SOURCE DISTRIBUTION in NEMO 3







- Tracking-calorimeter technique
- Cylindrical design, divided into 20 equal sectors
- o Four main parts
 - Tracking chamber
 - Calorimeter
 - Source foils
 - Shielding

NEMO 3 Backgrounds

- Internal backgrounds:
 - ²¹⁴Bi and ²⁰⁸TI (uranium and thorium decay chains) from the source foils
- External backgrounds:
 - From components of the detector
 - Radon and thoron present inside the tracking chamber
 - Thermal neutrons and photons, and cosmic rays
 - Magnet, iron shield, water shield...
- New anti-radon shield for the suppression of radon, installed and shows a factor of 6-8 improvement.

- The measurement of $2\nu\beta\beta$ (0⁺₁) nuclear matrix element (NME) is a good test of the nuclear model used to calculate the $0\nu\beta\beta$ NME.
- The model used in this case is the quasi particle random phase approximation...or QRPA for short.
- The NME depend on the particle strength parameter g_{pp} which is different for ground state transitions and excited state transitions.
- So the study of $2\nu\beta\beta$ (0⁺₁) allows us to probe different parts of the QRPA.



• Rare nuclear process, which occurs spontaneously between two nuclei with the same mass number

$$(A,Z) \to (A,Z+2) + e_1^- + e_2^- + \bar{\nu}_{e_1} + \bar{\nu}_{e_1} \qquad (A,Z) \to (A,Z+2) + e_1^- + e_2^-$$





o General equations for half-life for $\beta\beta$ decay

$$(T_{1/2}^{2\nu})^{-1} = G^{2\nu} \mid M_{2\nu} \mid^2$$

 $(T_{1/2}^{2\nu}(0^+, 2^+)) = G^{2\nu}(0^+, 2^+) \mid M_{2\nu}(0^+, 2^+) \mid^2$

 $(T_{1/2}^{0\nu})^{-1} = G^{0\nu} \mid M_{0\nu} \mid^2 \langle m_{\nu} \rangle^2$

$$N = N_0 e^{-\lambda t} \qquad \qquad T_{1/2}^{2\nu} = \frac{W N_A}{N_{dec}} ln2t$$

2νββ Excited states Analysis of ¹⁰⁰Mo, Comparison Study

- **o** Two different versions of NEMO software:
 - Version 6.2 (v6.2)
 - Version 7.0 (v7.0)
 - Released April this year
 - Differences in tracking (local track fit)
- o Study of reconstructed raw data file
 - x, y, and z vertices of the reconstructed track
 - The number of scintillators hit
 - The number of assigned tracks to a scintillator
 - The number of tracks
 - The energy deposit in each scintillator
 - Number of geiger cell hits

2νββ Excited states Analysis of ¹⁰⁰Mo, Comparison Study



2νββ Excited states Analysis of ¹⁰⁰Mo, Comparison Study



27/06/05

2νββ Excited states Analysis of ¹⁰⁰Mo, Comparison Study

- Analysis can be carried out in two different ways:
 - Estimate the background using MC simulations of all known backgrounds
 - Simulate background in the non-Mo sectors of the detector
 - This is the main estimator of the background for the detector
- Background estimation:
 - $2\nu\beta\beta$ decay of ¹⁰⁰Mo (g.s to g.s)
 - Internal and external background from ²¹⁴Bi and ²⁰⁸TI
 - Radon inside the helium gas in the geiger wire chamber

| Half-life ($\times 10^{20}$ yrs) | events | bg events | S/B |
|---|--------|-----------|-----|
| $4.23^{+0.95}_{-0.65}$ (stat) ± 1.0 (syst) | 55 | 10.7 | 4.1 |
| $4.7^{\pm 1.0}_{-0.7}(\text{stat})\pm 0.5(\text{syst})$ | 74 | 8.2 | 2.9 |

• • • • 2 $\nu\beta\beta$ Excited states Analysis of ¹⁰⁰Mo, Comparison Study

• Three different analyses:

- Analysis 1: J. Thomas and V. Vasiliev with v6.2
- Analysis 2: V. Kovalenko (cuts) with v6.2
- Analysis 3: S. King (analysis 1 cuts) with v7.0

| Half-life ($\times 10^{20}$ yrs) | events | bg events | S/B | Eff. | Analysis |
|-----------------------------------|--------|-----------|------|--------|------------|
| 7.29 + 1.74 - 1.18 | 176 | 118.27 | 0.41 | 0.0016 | Analysis 1 |
| 6.12 + 2.34 - 1.33 | 75 | 49.29 | 0.52 | 0.0006 | Analysis 2 |

| Half-life ($\times 10^{20}$ yrs) | events | bg events | S/B | Eff. | Ref. |
|-----------------------------------|--------|-----------|------|--------|------------|
| 4.85 + 0.97 - 0.69 | 49 | 8.71 | 4.63 | 0.0007 | Analysis 1 |
| 7.26 + 3.51 - 1.83 | 50 | 30.99 | 0.61 | 0.0005 | Analysis 2 |

2νββ Excited states Analysis of ¹⁰⁰Mo, Comparison Study: Selection Criteria

- **o** Topology of the 0^+_1 state:
 - 2 e-
 - 2 γ (590 Kev and 540 Kev)



2νββ Excited states Analysis of ¹⁰⁰Mo, Comparison Study: Selection Criteria

- o Two tracks associated with different scintillator hits
- Energy deposited > 200 Kev
- Both particles must have a -ve charge
- Two tracks must have a common vertex in the source foils
- Internal hypothesis: probability the two e- leave source foil at a common point, go through geiger wire chamber and detected by different scintillators > 1%
- External hypothesis: probability a 'crossing' particle enters tracking volume by one scintillator, crosses through the source foil and detected by one scintillator <0.1%

2νββ Excited states Analysis of ¹⁰⁰Mo, Comparison Study: Selection Criteria

o Also should take into account photons, and α -particles (in the background)

| | Analysis 1 | Analysis 2 |
|----------------------------|------------|--------------------|
| probeut $\gamma\gamma$ min | 0.01 | 0.04 |
| probeut $\gamma\gamma$ max | 0.01 | 0.001 |
| E_{γ} min | 0.22 Mev | $0.125 { m Mev}$ |
| $E_{\gamma} \max$ | 0.55 Mev | 2.0 Mev |
| $E_e \min$ | 0.22 Mev | 0.2 Mev |
| $E_e \max$ | 1.5 Mev | 2.0 Mev |
| $E_{\gamma\gamma}$ min | 0.6 | 0.5 Mev |
| $E_{\gamma\gamma} \max$ | 1.2 | 1.5 Mev |
| $E_e e \min$ | 0.2 Mev | 0.4 Mev |
| $E_e e \max$ | 1.4 Mev | 1.5 Mev |
| xy vertex | ; 4.0 cm | $1.5 \mathrm{~cm}$ |
| z vertex | ; 4.0 cm | 4.0 cm |

2νββ Excited states Analysis of ¹⁰⁰Mo, Comparison Study: Selection Criteria

Analysis 1: before energy cuts



$2\nu\beta\beta$ Excited states Analysis of ¹⁰⁰Mo, Comparison Study: Selection Criteria

Analysis 2: before energy cuts



2νββ Excited states Analysis of ¹⁰⁰Mo, Comparison Study: Selection Criteria

Analysis 3: before energy cuts



$2\nu\beta\beta$ Excited states Analysis of ¹⁰⁰Mo, Comparison Study: Selection Criteria

Analysis 1: after energy cuts



$2\nu\beta\beta$ Excited states Analysis of ¹⁰⁰Mo, Comparison Study: Selection Criteria

Analysis 2: after energy cuts



2νββ Excited states Analysis of ¹⁰⁰Mo, Comparison Study: Selection Criteria

Analysis 3: after energy cuts



Half Life and Nuclear Matrix Element Results

$$T_{1/2}^{2\nu} = \eta \frac{WN_A}{N_{dec}} ln2t$$

After all cuts

$$T_{1/2} = 4.63 + - 0.8 \times 10^{20} \text{ yr}$$

 $M^{2v}(0_{1}^{+}) = 0.114$

Conclusions

- The reconstructed raw data file study was not conclusive.
- The energy cuts of the non-Mo MC are not well understood, more work is needed in understanding the background. Are all backgrounds considered?
- The differences in definitions of γ -clusters should also be considered

• • • Further Work

- Carry on with the comparison study, looking at backgrounds and γ -clustering.
- More analysis:
 - Excited states analysis with radon free data
 - $0\nu\beta\beta$ decay analysis with new radon free data
 - $2\nu\beta\beta$ decay analysis of ⁸²Se and ¹³⁰Te
- o SuperNEMO
 - MC
 - General detector development









| Isotope | Q value (Mev) |
|-------------------|---------------|
| ¹⁰⁰ Mo | 3.03 |
| ^{82}Se | 3.00 |
| ¹¹⁶ Cd | 2.81 |
| ¹³⁰ Te | 2.53 |
| ^{96}Zr | 3.35 |
| ¹⁵⁰ Nd | 3.37 |
| ⁴⁸ Ca | 4.27 |