STUDY OF NEUTRON PAIRING CORRELATIONS USING THE ^{138,136}Ba(p,t) REACTIONS

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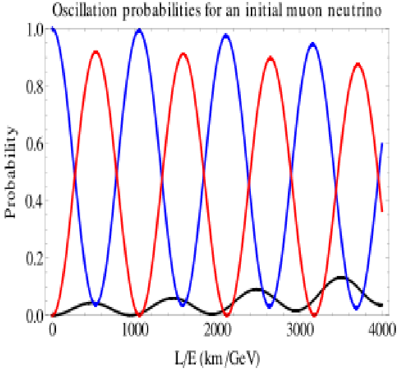
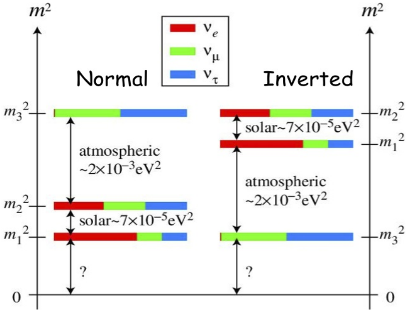
Outline

- Neutrino mass evidence
- Neutrino Double Beta Decay $\&$ Neutrinoless Double Beta Decay
- Nuclear Matrix Elements for Neutrinoless Double Beta Decay
- Pairing and BCS approximation
- Experiment
- 0^+ states in ^{136}Ba and ^{134}Ba
- Cross section angular distribution
- Conclusion

Neutrino mass evidence

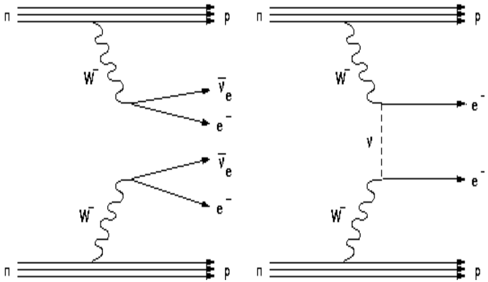




$$P_{a\to b} = sin^2(2\theta)sin^2(\frac{\Delta m^2 L}{4E})$$

Neutrino oscillation ⇒ all neutrinos cannot be massless, atleast two massive!

Neutrino Double Beta Decay & Neutrinoless Double Beta Decay

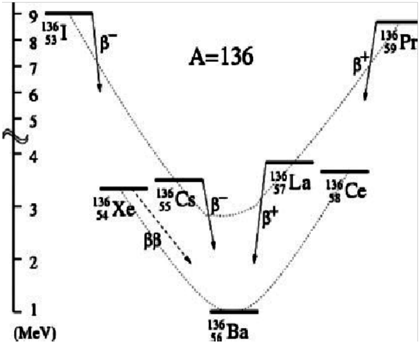


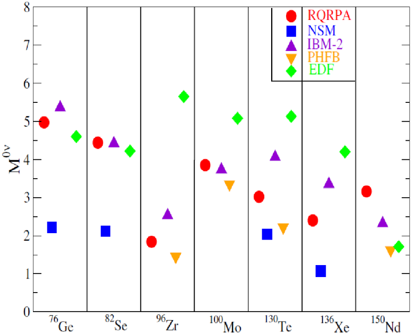
Observation of $0\nu\beta\beta$ decay $\Rightarrow$ Majorana fermion

Nuclear Matrix Elements for $0\nu\beta\beta$ decay

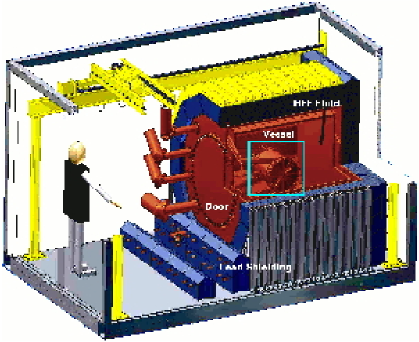
$$\left[T^{0\nu}_{1/2}\right]^{-1} = G^{0\nu}(Q,z)|M^{0\nu}|^2\left(\frac{\langle m_{\beta\beta}\rangle}{m_e}\right)^2$$

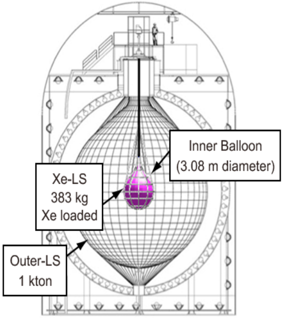
Where, $M^{0\nu}$ is the nuclear matrix element for the decay, $G^{0\nu}$(Q,z) is the phase-space factor, $m_{\beta\beta}$ is the effective Majorana neutrino mass and m_e is the electron mass.





Why is $^{136}\mathrm{Xe} \rightarrow^{136} \mathrm{Ba}\ 0\nu\beta\beta$ interesting?





- ^{136}Xe is relatively abundant, affordable and easy to purify.
- The liquid Xe allows for maximal background rejection via Barium ion-tagging.
- It has highly suppresed $2\nu 2\beta$ decay background, $M^{2\nu 2\beta}$ $\approx 0.02 MeV^{-1}$.

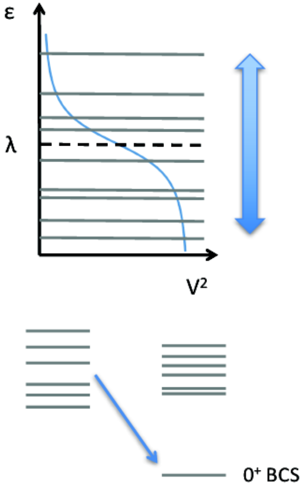
Why is $^{136}\mathrm{Xe} \rightarrow^{136} \mathrm{Ba}\ 0\nu\beta\beta$ interesting?

- Current ^{136}Xe $0\nu2\beta$ experiments show the 90% CL upper-bound on $< m_\nu >$ in the range $0.2 - 0.4$ eV depending on the choice of the nuclear matrix element (NME).
- ^{136}Xe is singly closed shell, so the matrix element calculations relatively easier.

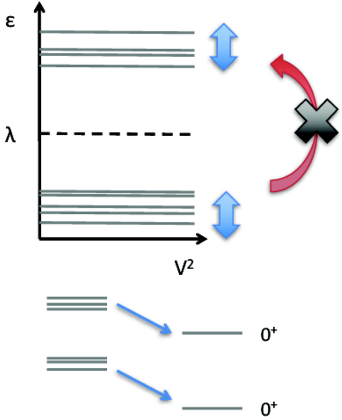
Pairing and BCS approximation

- In QRPA calculations, the initial and final states of the nuclei are described in terms of a BCS sea of neutron and proton pairs.
- Departures from the simplistic BCS approximation can occur due to gaps in the underlying single particle levels or due to deformations.
- Experimentally,this will be seen as fragmentation of the two nucleon transfer strength to excited 0^+ states in pair transfer reactions.

Breakdown in BCS Approximation

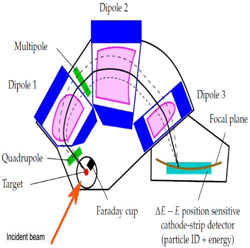


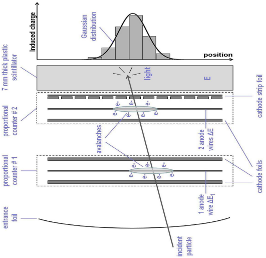
When the shell gap is larger than the pairing energy



Experimental procedure

- Reaction : ^{136}Ba(p,t)^{134}Ba, ^{138}Ba(p,t)^{136}Ba, with 22 MeV and 23 MeV protons respectively.
- Targets : 40 $\mu g/cm^2$ ^{136,138}Ba on 30 $\mu g/cm^2$ of ^{12}C backing
- Facility : High resolution Q3D Magnetic Spectrometer at Maier-Leibnitz Laboratorium (MLL), Garching (Germany)

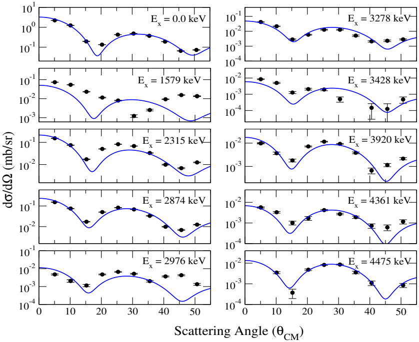


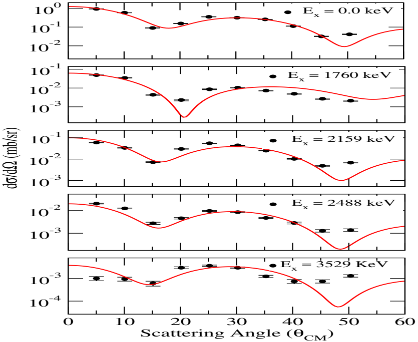


Identification of 0^+ states in ^{136}Ba and ^{134}Ba

- Natural parity states are preferably selected in (p,t) reactions, J = L, $\pi = (\text{-}1)^L$.
- L transfer obtained by comparing experimental cross-sections with Distorted-Wave Born approximation (DWBA) predictions.
- DWBA done using DWUCK4 code. DWUCK4 calculates cross-section amplitudes using the Optical Model Potential (OMP).
- R. L. Varner OMP for proton, and X. Li, C. Liang and C.Cai OMP for triton have been used for the present calculations.

Cross section angular distribution and strength calculations of 0^+ states





$$\left(\frac{d\sigma}{d\Omega}\right)_{rel} = \left(\frac{\left(\frac{d\sigma}{d\Omega}\right)^{lab}_{0^+_{ex}}}{\left(\frac{d\sigma}{d\Omega}\right)^{dwba}_{0^+_{ex}}}\right)\left(\frac{\left(\frac{d\sigma}{d\Omega}\right)^{lab}_{0^+_{gs}}}{\left(\frac{d\sigma}{d\Omega}\right)^{dwba}_{0^+_{gs}}}\right)^{-1}$$

Conclusion

- 6 new 0^+ states have been idenfied in ^{136}Ba above 2.5 MeV.
- Preliminary analysis show the $l = 0$ strength to the 0_2^+ and 0_3^+ states relative to the ground state is $\sim 10\%$ for each in ^{136}Ba.
- 1 new 0^+ state identified in ^{134}Ba.
- Complete angular distribution analysis currently in progress.

Collaborators

- University of Guelph, Canada : P.E. Garrett, A. Diaz-Varela, E. Rand, C. Burbadge, A. Radich, V. Bildstein
- TRIUMF, Canada : G.C. Ball
- LMU, Munich : R. Hertenberger, H.F. Wirth
- TUM, Munich : T. Faestermann
- UWC, Cape Town : B.M. Rebeiro, S. Triambak, R. Lindsay, J.N. Orce, M. Kamil, Z. Mabika
- iThemba Labs : P. Adsley