

Neutrino-less Double Beta Decay

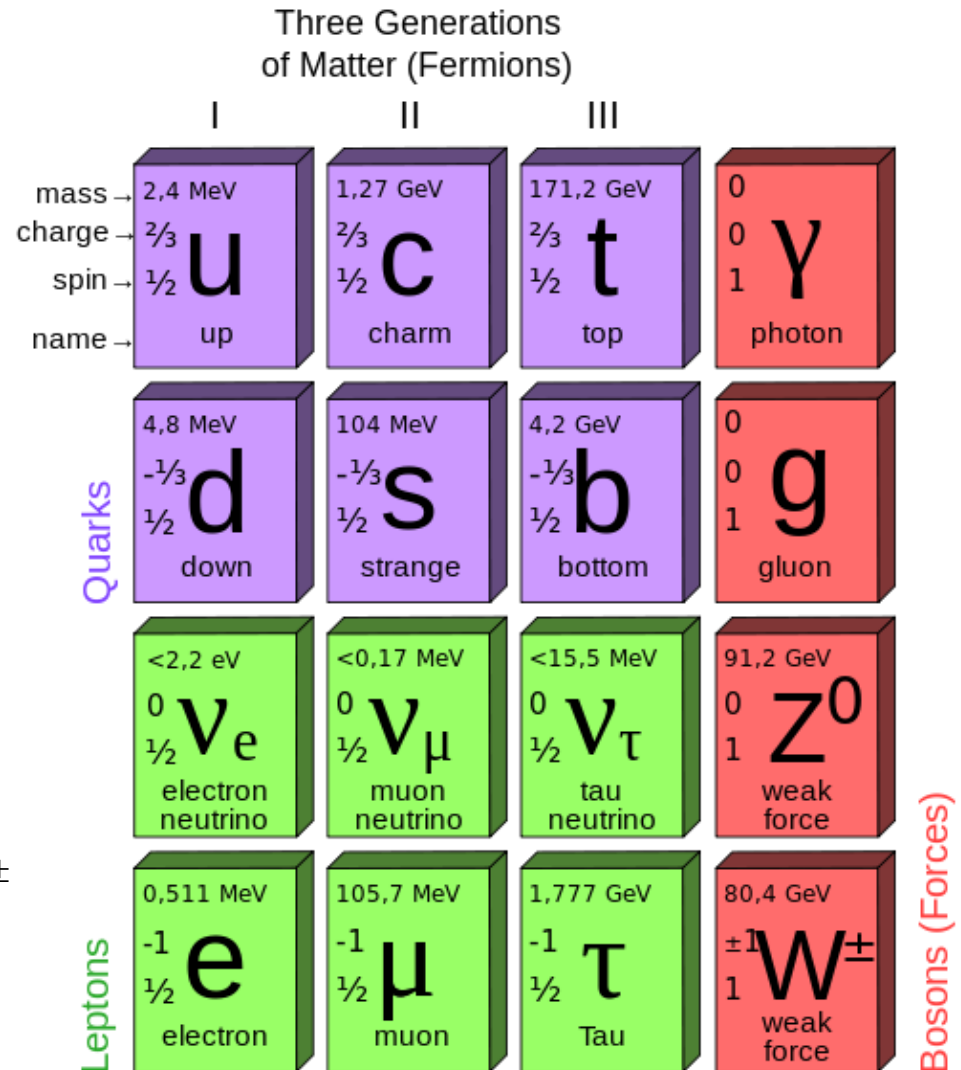
Nicholas I Chott
PHYS 730
Fall 2011

Outline

- ▶ The Standard Model
- ▶ What is Beta-Decay?
- ▶ Beta decay leads to ν discovery
- ▶ Early History of the Double Beta Decay
- ▶ Why is $0\nu\beta\beta$ Important?
- ▶ $\beta\beta$ -Decay
- ▶ $2\nu\beta\beta$ vs. $0\nu\beta\beta$
- ▶ Conclusion

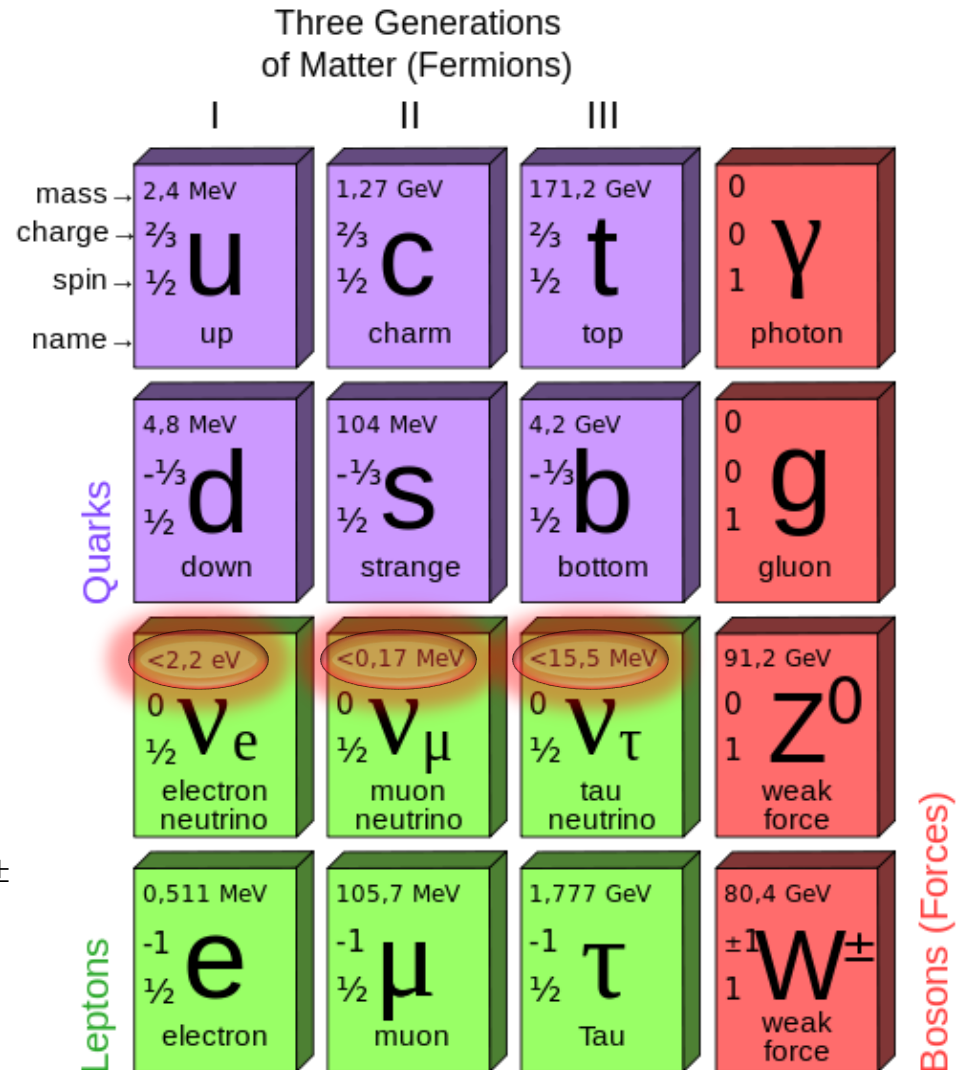
The Standard Model

- ▶ 16 known particles
- ▶ 12 spin $\frac{1}{2}$ fermions
- ▶ Quarks & Leptons = Normal Matter
- ▶ 4 spin 1 bosons
- ▶ Gauge Bosons = Interaction particles
- ▶ 3 generations: 2 quarks/2 leptons
- ▶ SM predicted 7/16 before discovery:
Charm, top, bottom, ν_τ , gluon, Z^0 & W^\pm
- ▶ Theory is good but still has problems



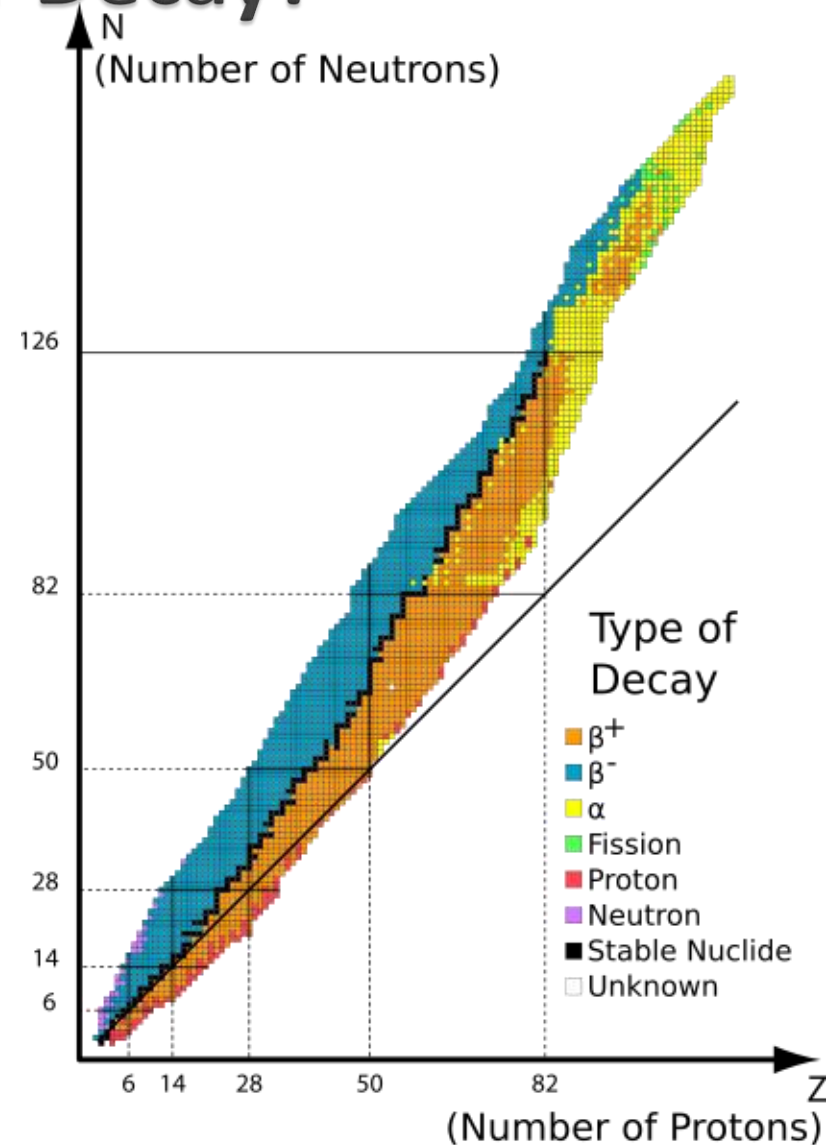
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What is Beta-Decay?

- ▶ Most common form of radioactive decay
- ▶ Observed for isotopes of almost every element excluding heavy nuclei



What is Beta-Decay?

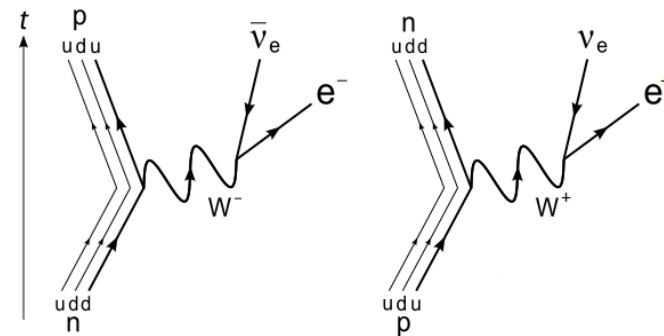
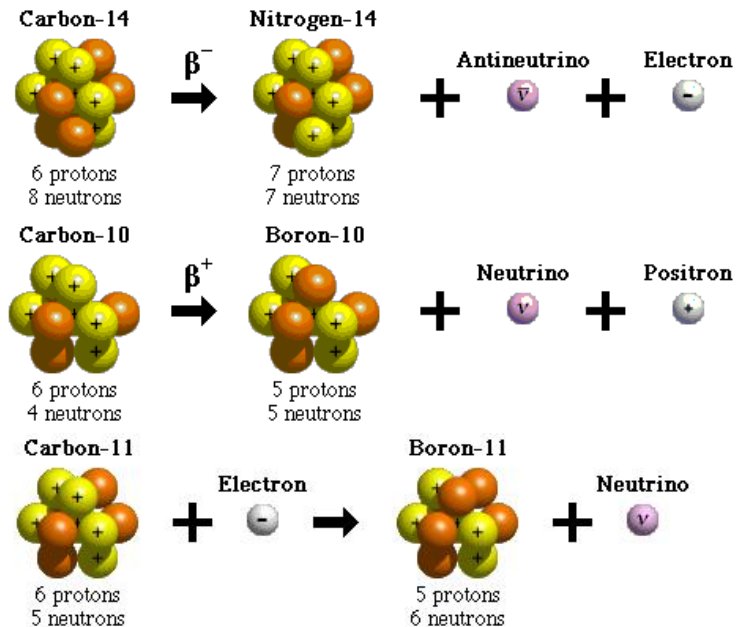
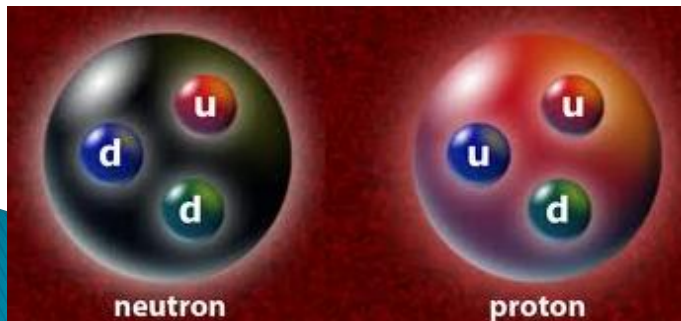
► Nucleon level:

$$n \rightarrow p + e^{-} + \bar{\nu}_e$$

$$p + \text{energy} \rightarrow n + e^{+} + \nu_e$$

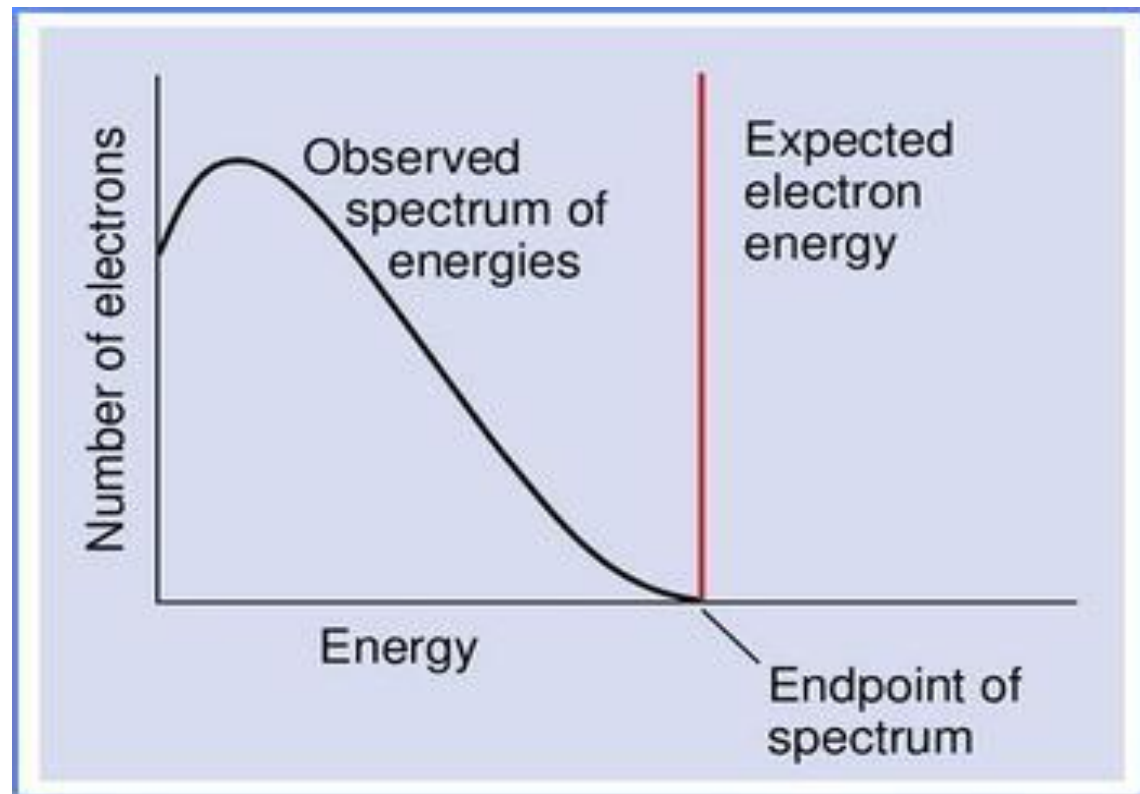
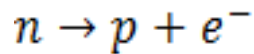
$$p + e^{-} + \text{energy} \rightarrow n + \nu_e$$

► Quark level:



β -Decay leads to neutrino discovery

- ▶ Continuous energy spectrum of β -particles
- ▶ Exp. spin did not match theory
- ▶ 2-body decay: violates conservation of energy and momentum



β -Decay leads to neutrino discovery

- ▶ 1930: Pauli suggests 3-body decay
- ▶ Neutral, spin $\frac{1}{2}$ with little to no mass

“I have done a terrible thing.
I have postulated a particle that
cannot be detected.” -W. Pauli



- ▶ 1956: Reines and Cowan confirm electron (anti-)neutrino existence



Early History of the Double Beta Decay

- ▶ 1935 – M. Goppert-Mayer published paper on “Double Beta-Disintegration”
- ▶ 1937 – E. Majorana suggests neutrino was indistinguishable from anti-neutrino
- ▶ 1937 – Racah suggests using DBD to test Majorana’s theory ($0\nu\beta\beta$)



Maria Goeppert Mayer



Ettore Majorana



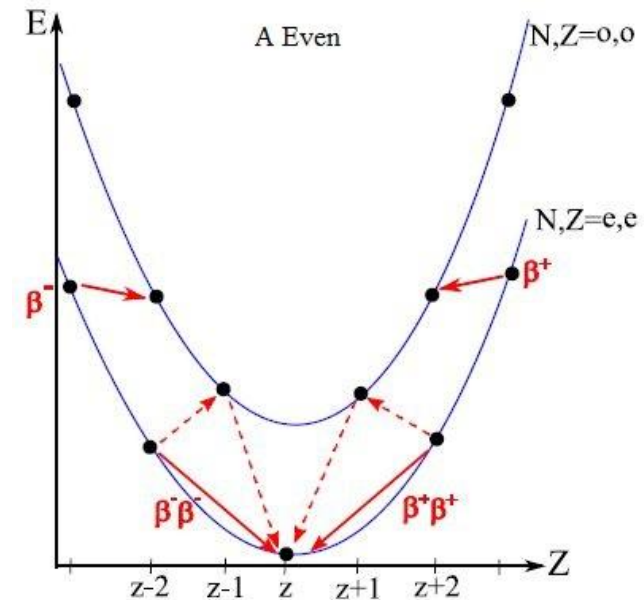
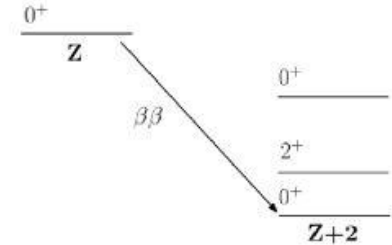
Giulio Racah

$\beta\beta$ -Decay

- ▶ Rare decay among isobaric nuclei ($\tau_{1/2} \sim 10^{18} - 10^{22}$ years)
- ▶ Simultaneously emits 2 β particles via intermediate state

(Short lived unobservable quantum state that mediates forbidden transitions)

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- ▶ Situation occurs naturally b/c of “pairing” interaction of nuclei with even A
- ▶ Semi-empirical mass formula: $m = Zm_p + Nm_n - \frac{E_B}{c^2}$

$$E_B = a_V A - a_S A^{2/3} - a_C \frac{Z(Z-1)}{A^{1/3}} - a_A \frac{(A-2Z)^2}{A} + \delta(A, Z)$$

Volume

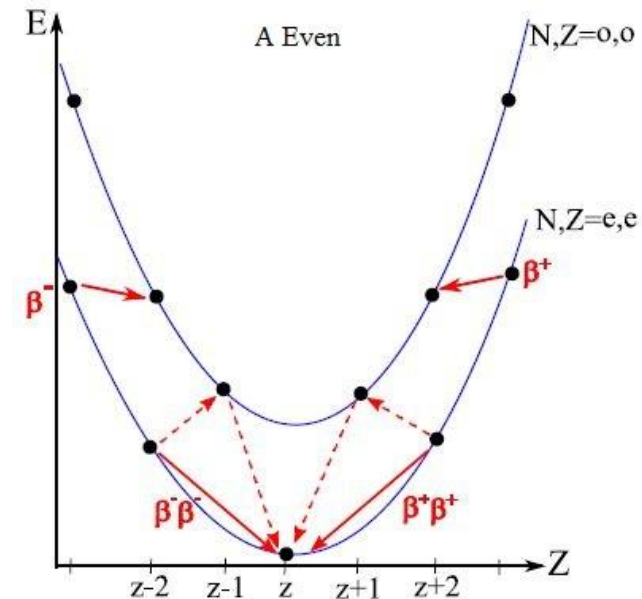
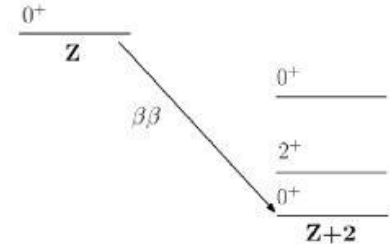
Surface

Coulomb

Asymmetry

Pairing

$$\delta(A, Z) = \begin{cases} +\delta_0 & Z, N \text{ even (A even)} \\ 0 & A \text{ odd} \\ -\delta_0 & Z, N \text{ odd (A even)} \end{cases}$$



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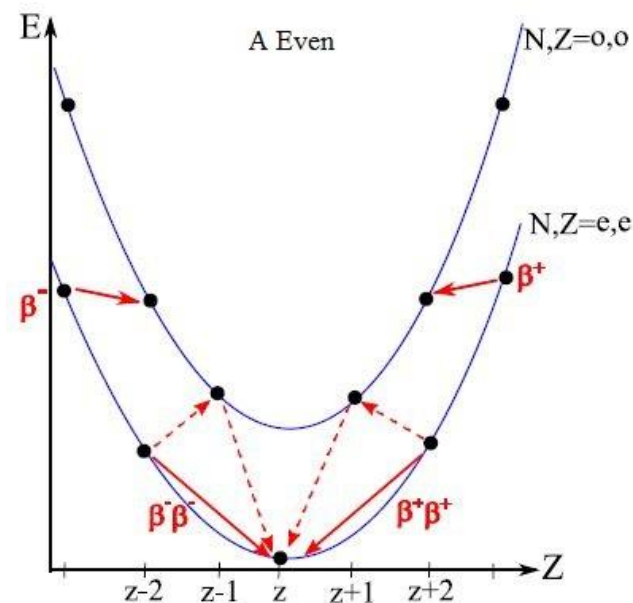
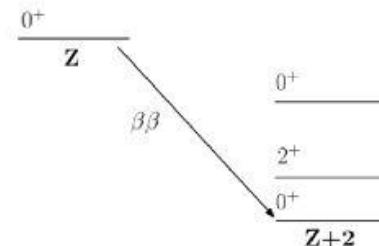
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- ▶ Over 60 isotopes capable of DBD, 12 observed:

$^{48}\text{Ca}, ^{76}\text{Ge}, ^{82}\text{Se}, ^{96}\text{Zr}, ^{100}\text{Mo}, ^{116}\text{Cd},$
 $^{128}\text{Te}, ^{130}\text{Te}, ^{130}\text{Ba}, ^{136}\text{Xe}, ^{150}\text{Nd}, ^{238}\text{U}$

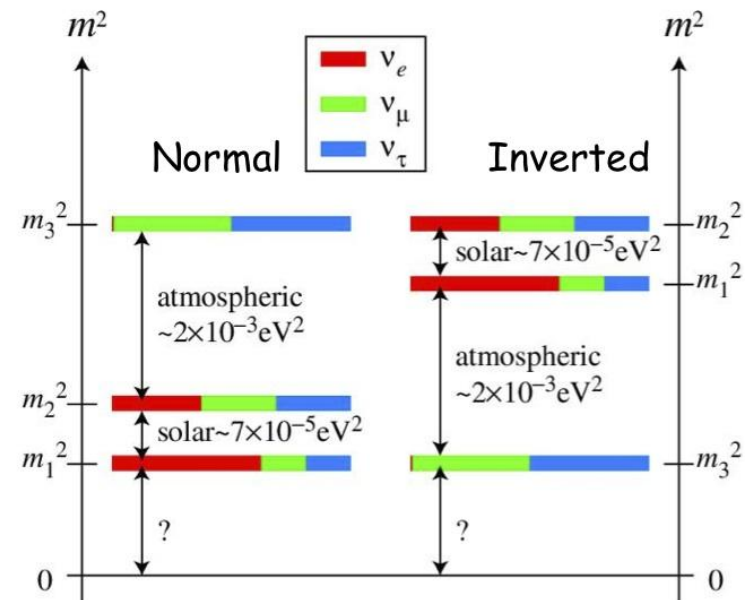
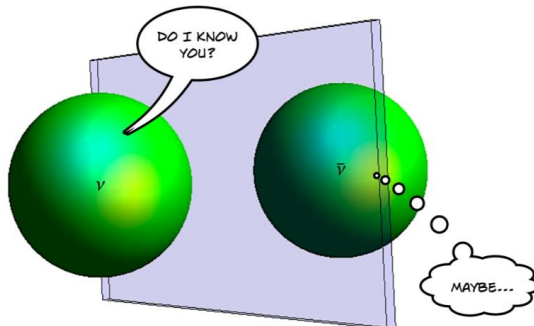


Why is $0\nu\beta\beta$ Important?

- ▶ From atmospheric, solar, and accelerator data, neutrinos oscillate; therefore, they must have mass: $|\nu_\alpha\rangle = \sum_i U_{\alpha i} |\nu_i\rangle$
- ▶ This data yields mass differences and imply 3-mass eigenstates
- ▶ Only bounds on the lightest mass eigenstate; at least 0.04 eV

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- ▶ Two important pieces of information missing about the neutrino
- ▶ Are they Majorana or Dirac particles? What is the absolute mass scale?



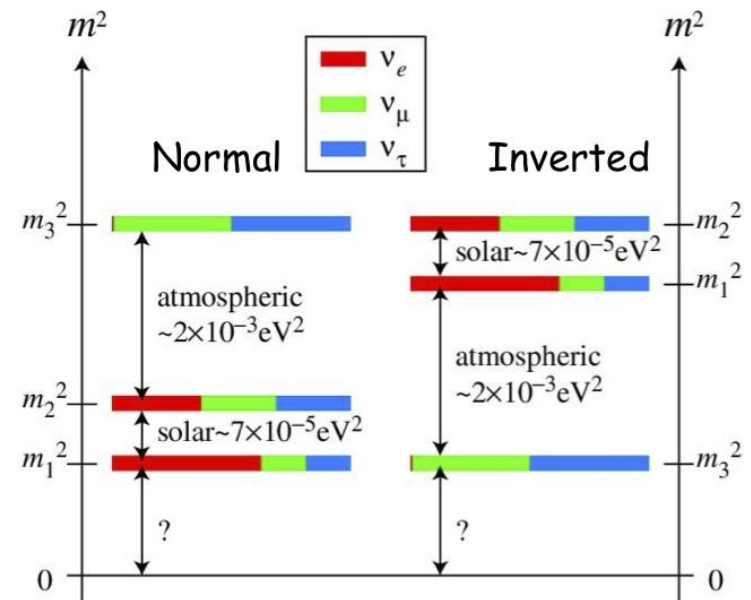
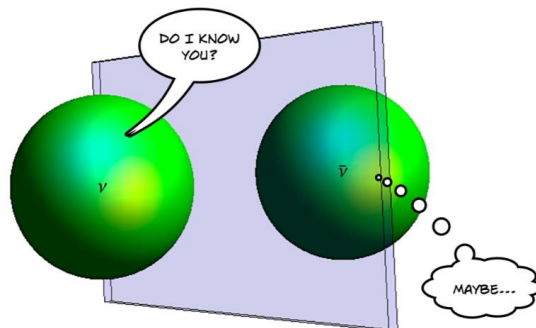
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- ▶ $0\nu\beta\beta$ can be used as a tool to answer these fundamental questions
- ▶ Immediate implication of discovery:

Neutrino is a Majorana particle

Total Lepton number is not conserved

Neutrino mass can be determined



2νββ vs. 0νββ

2νββ

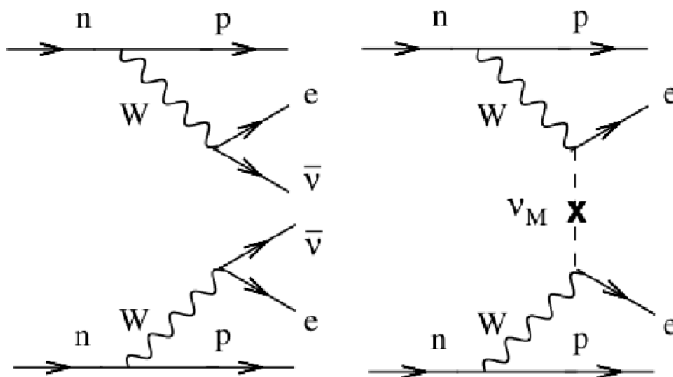
- ▶ Allowed by SM and observed exp.
- ▶ Imposes no requirements on neutrino properties
- ▶ Several decay modes possible:

$$(A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\bar{\nu}_e \quad (\beta\beta^-)$$

$$(A, Z) \rightarrow (A, Z - 2) + 2e^+ + 2\nu_e \quad (\beta\beta^+)$$

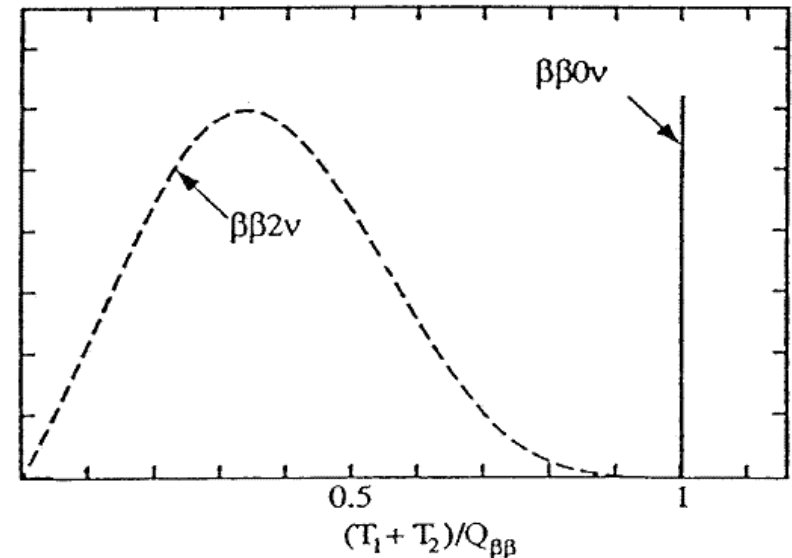
$$(A, Z) + 2e^- \rightarrow (A, Z - 2) + 2\nu_e \quad (ECEC)$$

$$(A, Z) + e^- \rightarrow (A, Z - 2) + e^+ + 2\nu_e \quad (EC\beta^+)$$



0νββ

- ▶ Not allowed by SM ($\Delta L = 2$)
- ▶ Hypothetical/can only happen if:
Mass $\neq 0$, since helicity has to flip
(ν : LH Helicity; $\bar{\nu}$: RH Helicity)
Neutrino is its own anti-particle: $\bar{\nu} = \nu$
- ▶ Decay mode: $(A, Z) \rightarrow (A, Z + 2) + 2e^-$



Conclusion

- ▶ Neutrino properties are important to fundamental questions in physics
- ▶ DBD used as a tool to look for currently unknown properties
- ▶ Majorana or Dirac particle
- ▶ Determine neutrino mass
- ▶ This information needed to further adapt understanding of the SM
- ▶ Many experimental challenges

- ▶ Thank you!
- ▶ Questions?