Minimal $\beta\beta0\nu$ Rates From Approximate Flavor Symmetries

A survey of broken $U(1)_f$ model space and induced m_{ee}

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PHENO 2008, Madison

Outline

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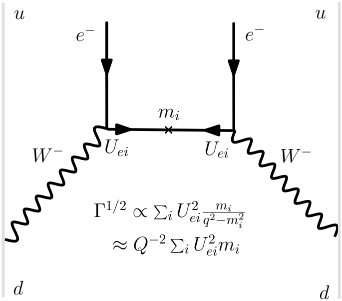
Neutrinoless Double Beta Decay

The standard, high sensitivity probe of LNV and Majorana neutrino masses



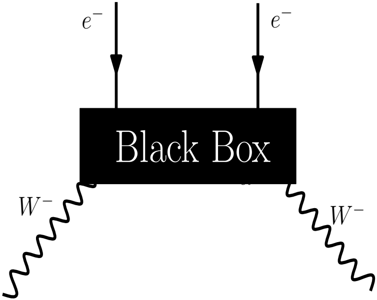
- A $\Delta L = 2$ process that proceeds via
  - Majorana neutrino exchange – $\beta\beta0\nu$ is only realistic probe of LNV
  - Some (as yet) unknown high scale process
- Experiments typically set upper limits on $m_{ee}^{eff} \neq m_{ee}$

Standard picture: small $m_{ee}^{eff} = m_{ee}$ can arise in the normal hierarchy via cancellations among mixing angles and phases.

With new physics, other nontrivial cancellations are possible, but induce a feedback mechanism!

Majorana Neutrinos and Lepton Number Violation

The Black Box and extended Black Box theorems



- Black Box Theorem Schechter & Valle, 1982
    - LNV operators yield Majorana neutrino mass
    - Majorana neutrino mass yields effective LNV operators
- $m_{ee}^{eff} = \sum_i (\mathcal{O}_i + m_{ee}^{\mathcal{O}_i})$
  Exact cancelations are possible but require fine tuning

Extended Black Box Theorem: Assuming 3 ν mixing & arbitrary LNV, $m_{ee} = 0$ is *not* consistent with oscillation data!

Hirsch, Kovalenko & Schmidt 2006

Majorana Neutrinos and Lepton Number Violation

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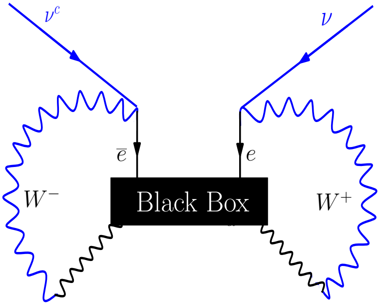

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Abelian Flavor Symmetries

Exact $m_{ee} = 0$ is stabilized by an appropriate flavor symmetry...

Assume 3 *light* Majorana neutrino states charged under global $U(1)_f$ as n_e, n_μ and n_τ

$$\mathcal{L} \supset M\frac{1}{2}\left(\overline{\nu_e^c}, \overline{\nu_\mu^c}, \overline{\nu_\tau^c}\right)\begin{pmatrix} a_{ee}\delta_{2n_e,0} & a_{e\mu}\delta_{n_e+n_\mu,0} & a_{e\tau}\delta_{n_e+n_\tau,0} \\ a_{e\mu}\delta_{n_e+\nu_\mu,0} & a_{\mu\mu}\delta_{2n_\mu,0} & a_{\mu\tau}\delta_{n_\mu+n_\tau,0} \\ a_{e\tau}\delta_{n_e+n_\tau,0} & a_{\mu\tau}\delta_{n_\mu+n_\tau,0} & a_{\tau\tau}\delta_{2n_\tau,0} \end{pmatrix}\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}$$

Charged ν_e forbids a $\overline{\nu_e^c}\nu_e$ mass term & implies vanishing $\Gamma_{\beta\beta0\nu}$

What about extensions to non-abelian symmetries?

- Correlated quantum numbers defined by representations
- Reduced number of $a_{\alpha\beta}$ constants to tweak

Therefore $U(1)$ provides the most freedom for minimizing m_{ee}

Texture Classes and Predictions

Class	Charge	Matrix	Predictions
1	$(n_e, 0, 0)$	$\begin{pmatrix} 0 & 0 & 0 \\ 0 & a_{\mu\mu} & a_{\mu\tau} \\ 0 & a_{\mu\tau} & a_{\tau\tau} \end{pmatrix}$	$s_{12}=0,\ s_{13}=0$ (Normal Hierarchy) $s_{12}=0,\ s_{23}=0$ (Inverted Hierarchy) Can tune $\Delta^2 m$'s to fit data
2	$(n_e, n_\mu, -n_\mu)$	$\begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & a_{\mu\tau} \\ 0 & a_{\mu\tau} & 0 \end{pmatrix}$	$\Delta^2 m_{sol}=0,\ \Delta^2 m_{atm}=a_{\mu\tau}^2$ $s_{13}=1/\sqrt{2},\ t_{23}=0,\ t_{12}=0$ Inverted hierarchy
3	$(n_e, 0, n_\tau)$	$\begin{pmatrix} 0 & 0 & 0 \\ 0 & a_{\mu\mu} & 0 \\ 0 & 0 & 0 \end{pmatrix}$	$\Delta^2 m_{sol}=0,\ \Delta^2 m_{atm}=a_{\mu\mu}^2$ $s_{13}=\sin\theta,\ t_{23}=\cos\theta,\ t_{12}=0$ Normal hierarchy,
4	$(n_e, n_\mu, 0)$	$\begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & a_{\tau\tau} \end{pmatrix}$	$\Delta^2 m_{sol}=0,\ \Delta^2 m_{atm}=a_{\tau\tau}^2$ $s_{13}=0,\ t_{23}=0,\ t_{12}=\tan\theta$ Normal hierarchy
5	$(n_e, n_e, -n_e)$	$\begin{pmatrix} 0 & 0 & a_{e\tau} \\ 0 & 0 & a_{\mu\tau} \\ a_{e\tau} & a_{\mu\tau} & 0 \end{pmatrix}$	$\Delta^2 m_{sol}=0,\ \Delta^2 m_{atm}=a_{e\tau}^2+a_{\mu\tau}^2$ $s_{13}=1/\sqrt{2},\ t_{23}=0,\ t_{12}=a_{\mu\tau}/a_{e\tau}$ Inverted hierarchy
6	$(n_e, -n_e, n_e)$	$\begin{pmatrix} 0 & a_{e\mu} & 0 \\ a_{e\mu} & 0 & a_{\mu\tau} \\ 0 & a_{\mu\tau} & 0 \end{pmatrix}$	$\Delta^2 m_{sol}=0,\ \Delta^2 m_{atm}=a_{\mu\tau}^2+a_{e\mu}^2$ $s_{13}^2=\frac{a_{\mu\tau}^2}{2(a_{e\mu}^2+a_{\mu\tau}^2)},\ t_{23}^2=a_{\mu\tau}^2/2a_{e\mu}^2,\ t_{12}^2=\frac{a_{e\mu}^2+a_{\mu\tau}^2}{a_{e\mu}{}^2}$ Inverted hierarchy, $s_{13}=t_{23}/t_{12}$
7	$(n_e, 0, -n_e)$	$\begin{pmatrix} 0 & 0 & a_{e\tau} \\ 0 & a_{\mu\mu} & 0 \\ a_{e\tau} & 0 & 0 \end{pmatrix}$	$\Delta^2 m_{sol}=0,\ \lvert\Delta^2 m_{atm}\rvert=\lvert a_{\tau\tau}^2-a_{e\mu}^2\rvert$ $\lvert\theta_{13}\rvert=\pi/4,\ \theta_{23}=0,\ \theta_{12}=0$
8	$(n_e, -n_e, 0)$	$\begin{pmatrix} 0 & a_{e\mu} & 0 \\ a_{e\mu} & 0 & 0 \\ 0 & 0 & a_{\tau\tau} \end{pmatrix}$	$\Delta^2 m_{sol}=0, \lvert\Delta^2 m_{atm}\rvert=\lvert a_{\tau\tau}^2-a_{e\mu}^2\rvert$ $\theta_{13}=0,\ \theta_{23}=0,\ \lvert\theta_{12}\rvert=\pi/4$
9	$(n_e, -n_e, -n_e)$	$\begin{pmatrix} 0 & a_{e\mu} & a_{e\tau} \\ a_{e\mu} & 0 & 0 \\ a_{e\tau} & 0 & 0 \end{pmatrix}$	$\Delta^2 m_{sol}=0,\ \Delta^2 m_{atm}=a_{e\tau}^2+a_{e\mu}^2$ $s_{13}^2=\frac{a_{e\tau}^2}{2(a_{e\mu}^2+a_{e\tau}^2)},\ t_{23}^2=\frac{a_{e\tau}^2}{2a_{e\mu}^2},\ t_{12}^2=\frac{a_{e\mu}^2}{2(a_{e\mu}^2+a_{e\tau}^2)}$ Inverted hierarchy, $s_{13}=t_{23}t_{12}$
10	$(n_e, -n_e, n_\tau)$	$\begin{pmatrix} 0 & a_{e\mu} & 0 \\ a_{e\mu} & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$	$\Delta^2 m_{sol}=0,\ \Delta^2 m_{atm}=a_{e\mu}^2$ $s_{13}=0,\ t_{23}=0,\ t_{12}=1$ Inverted hierarchy
11	$(n_e, n_\mu, -n_e)$	$\begin{pmatrix} 0 & 0 & a_{e\tau} \\ 0 & 0 & 0 \\ a_{e\tau} & 0 & 0 \end{pmatrix}$	$\Delta^2 m_{sol}=0,\ \Delta^2 m_{atm}=a_{e\tau}^2$ $s_{13}=1/\sqrt{2},\ t_{23}=0,\ t_{12}=0$ Inverted hierarchy

11 discrete texture classes... None accommodate mixing data!

Majorana ν + Oscillations $\Longrightarrow \Gamma_{\beta\beta0\nu} \neq 0$

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Symmetry Breaking

The general idea

Expect that small m_{ee} values are induced by associated small breakings of $U(1)_f$ symmetry

Introduce new spurious scalar s with charge n_s

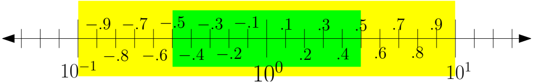
1. Write all relevant Lagrangian terms to given order
2. Give s *small* VEV ϵ (breaks symmetry!)
3. Fit ϵ, M & $a_{\alpha\beta}$ parameters to oscillation data
4. Search for smallest allowed m_{ee}
5. Extract other predictions
6. Do this for *all* nontrivial breaking patterns to given order

This results in only 230 textures divided into 11 classes!

Symmetry Breaking

Some more details

$$m_{\alpha\beta} = M \times a_{\alpha\beta} \times \epsilon^{\left|\frac{n_\alpha + n_\beta}{n_s}\right|} \times \delta_{\mathrm{mod}(n_\alpha+n_\beta, n_s),0}$$



- $a_{\alpha\beta}$ provides parameter tuning
  - Sets *naturalness criterion*
  - Set $a_{ee} = 1$ (rescaling freedom)
  - Others fluctuate near 1
  - Parameterize range by C
  - $C = 0.5$: order of magnitude!

$$10^{-C} \leq |a_{\alpha\beta}| \leq 10^{C}$$

- M provides mass scale
  - $M \leq 1$ eV
- ϵ yields texture structure
  - $\epsilon < 2/3$
  - smallest $\epsilon \nleftrightarrow$ smallest m_{ee}

Fitting the mixing data requires a complex interplay between M, ϵ and $a_{\alpha\beta}$!

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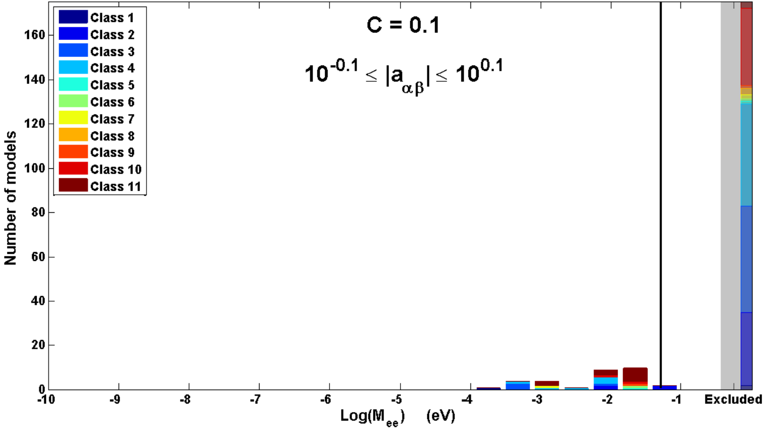
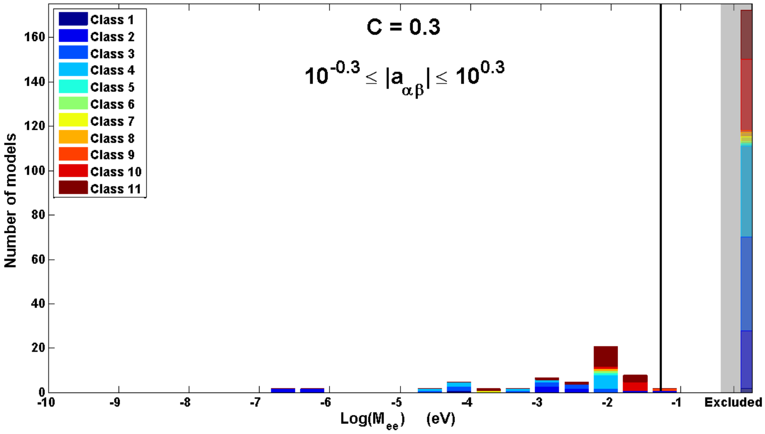
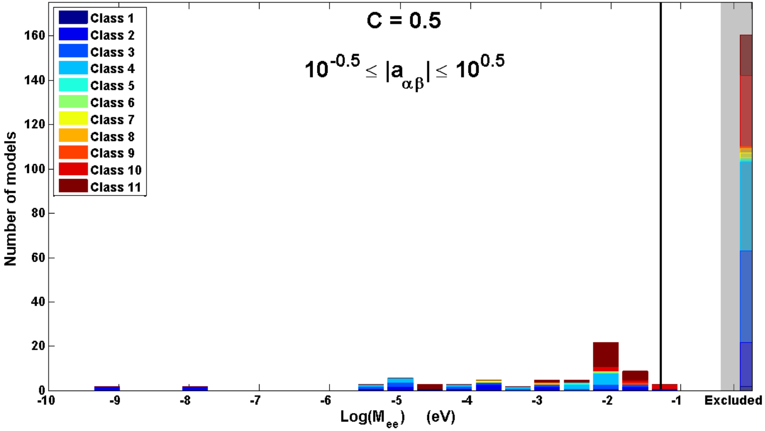
m_{ee} Distribution: $C = 0.1$



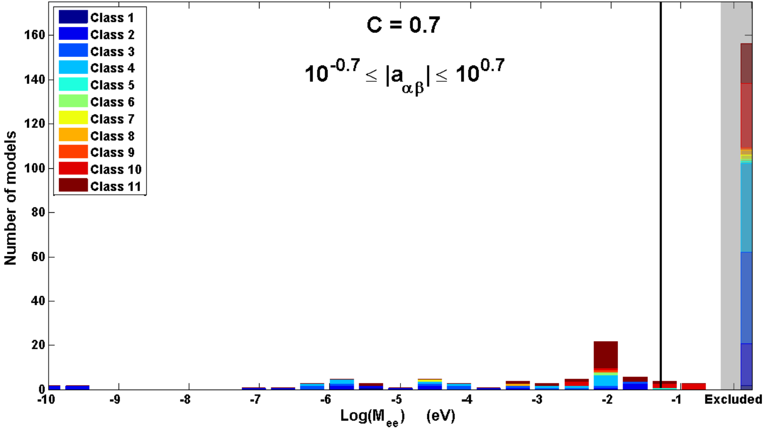
m_{ee} Distribution: $C = 0.3$



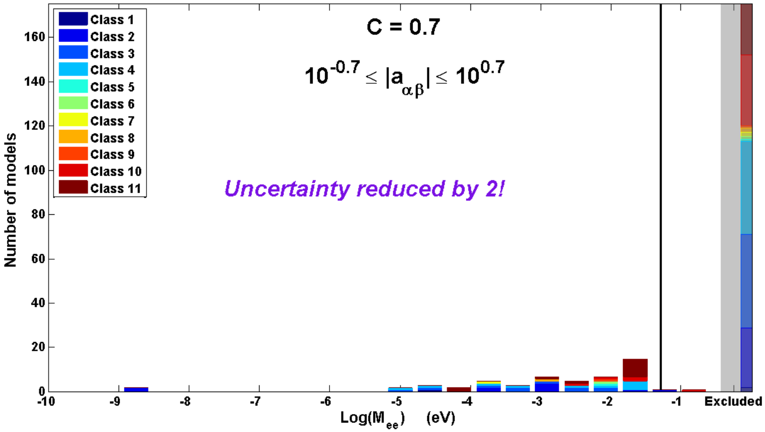
m_{ee} Distribution: $C = 0.5$



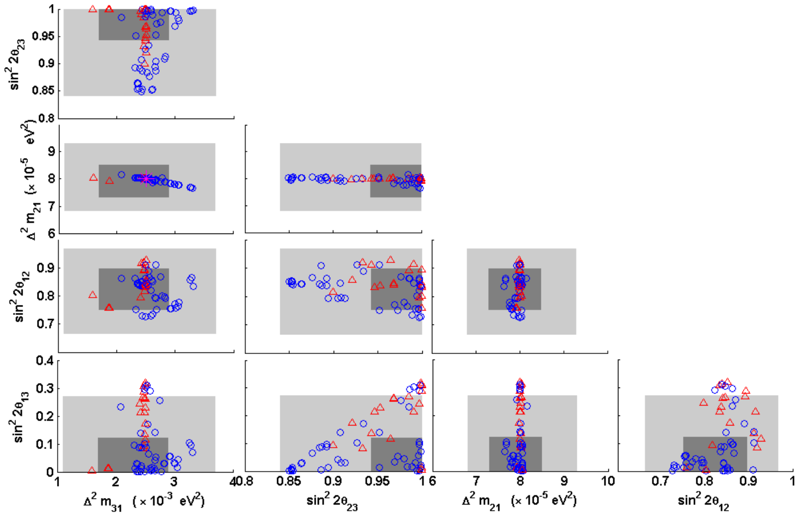
m_{ee} Distribution: $C = 0.7$



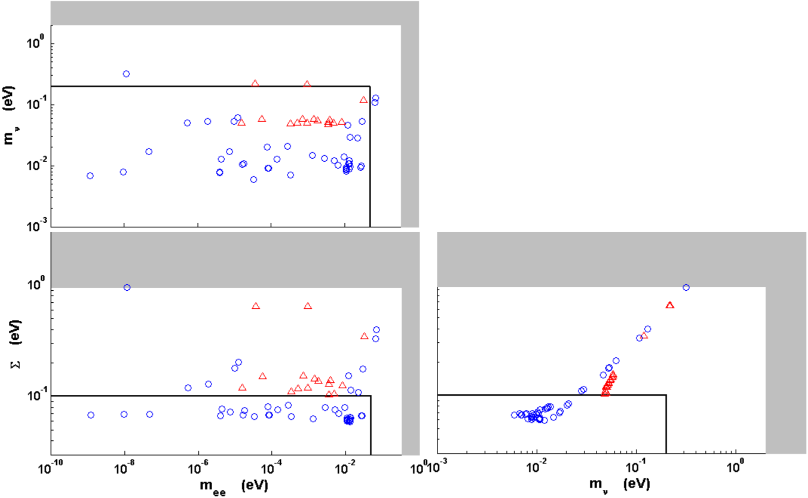
m_{ee} Distribution: $C = 0.7$ (Reduced Uncertainty)



$C = 0.5$ Oscillation Parameter Scatter Plots



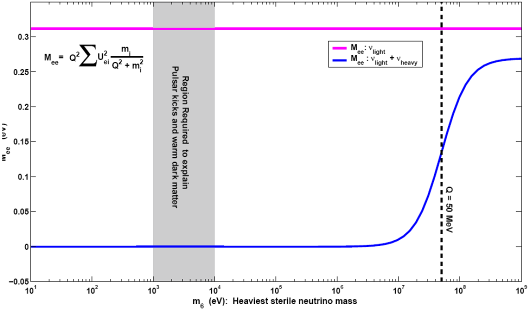
$C = 0.5$ Kinematic Scatter Plots



$\beta\beta0\nu$ With Light Sterile Neutrinos

Example for $3+2+1$ See Saw case:

Many reasonable (and mostly testable) assumptions are employed in this analysis... Bounds may be evaded!



- New *light* degrees of freedom
  - SeeSaw Mechanism

$$M^{flavor} = \begin{pmatrix} 0 & vy \\ vy^T & M_R \end{pmatrix}$$

  - True for all $m_{\alpha\beta}$!
- Naturalness issues
- “Black Box” contributions

The observation **or** non-observation of $\beta\beta0\nu$ reveals much about potential new physics !

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Summary

While exact $\Gamma_{\beta\beta0\nu} = 0$ *cannot* be protected by flavor symmetries small m_{ee} values may be obtained from small breakings.

I scan the model space of broken $U(1)_f$ in search of small m_{ee}

- m_{ee} as small as 10^{-9} eV are still allowed
- Future measurements will increase these limits
  - Neutrino mass hierarchy
  - Oscillation parameters
  - m_ν and Σ
- May be evaded by new light states or unnatural couplings

Combining information from $\beta\beta0\nu$, oscillation searches and other probes can reveal much about the nature of new physics.

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