# Neutrino Masses or New Interactions

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## Message

- Present and future experiments on the beta spectrum near the end point are sensitive to

    1. neutrino masses,

    2. neutrino mixings,
    **and**

    3. **new, non $V - A$, interactions.**

- Such non $V - A$ interactions are expected in almost every extension of the standard model.

- When new experiments are done
**One must take the opportunity to search beyond the standard model, and not just look for standard model parameters**

## Message ...ctd.

- These new interactions, at a strength allowed by other experiments, can distort the $\beta$ spectrum, leading to false mass values when the analysis ignores this possibility.

- The anaylsis of the next generation of experiments should be done to extract, the neutrino mass, the neutrino mixing, and the strength of the new interactions, or put limits on appropriate combinations of all of them.

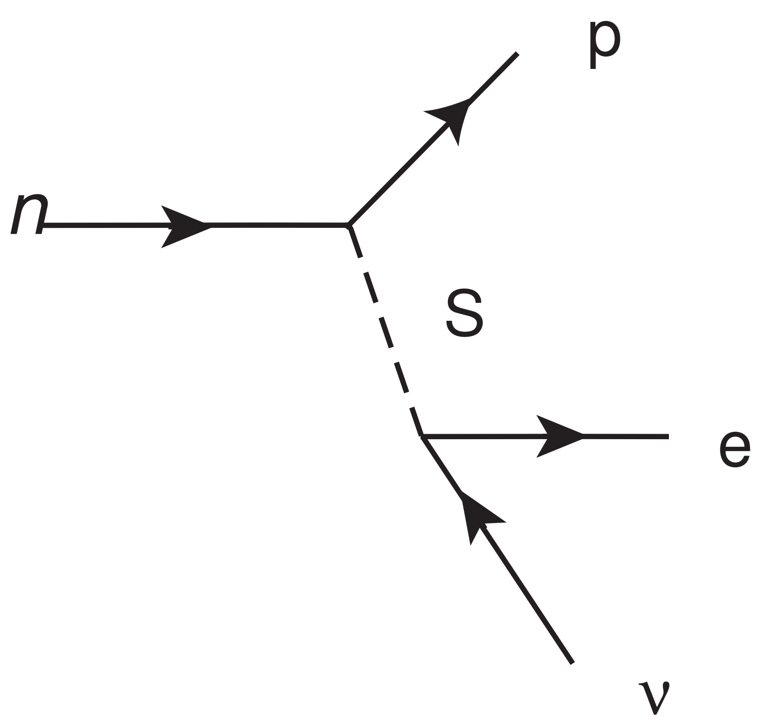
- **Remember to allow for surprises when analyzing data.**

## Non- $V - A$ interactions?

- **Why non- $V - A$ interactions?**

Most scenarios for "Physics beyond the standard model" include some non- $V - A$ interactions, *eg*

Exchange of a charge-changing scalar, arising, for example, in supersymmetric models



## Non- $V-A$ interactions? . . . ctd

- **How strong are non- $V-A$ interactions?**

Many models suggest very weak interactions, but the coupling strength and masses involved are not always well determined. Many conjectures about non-standard model physics in the TeV region, which could produce new interactions at the level of 1% of the weak interactions

Existing experiments limit $\rho_X$, the strength of the interaction $X$ relative to the $L-L$ interaction of the SM, assuming no neutrino mixing, and zero neutrino mass, to

$$\begin{aligned} |\rho_R| &\leq .07 \\ \left|\rho_{S_R}\right| &\leq .1 \\ \left|\rho_{S_L}\right| &\leq .01 \end{aligned}$$

## The Beta Spectrum with Non-Standard Interactions

**Remember:** Fermi's original spectrum (pure $V$) was not the shape near the end point that we are now familiar with.

Studies of the beta spectrum near the end point were originally proposed as a way of determining the interaction.

▷ Koeford-Hansen — 1948, Enz — 1957, Trieman and Wyld — 1957

**• To determine the neutrino mass from the spectrum near the end point one needs to know the interaction**

$V - A$ so dominates our thinking that this once obvious fact has been erased from our collective memory. It is now time to put it back.

## New Interactions

$$H_I = \sum_{\alpha,\beta=S_L,S_R,R,L,T} G^{\alpha\beta} \sum_f \left( J^\dagger_{h\alpha} . J_{f\beta} + h.c. \right)$$

- $f = e,\ \mu,\ \tau$, labels the weak eigenstate
- for Tritium $J_{e\lambda} = \bar{\psi}_e \Gamma_\lambda \psi_{\nu_e}$ is the electron current
- $J_{h\alpha}$ is the hadronic current.
- The $\Gamma_\lambda$ are

$$\begin{aligned} \Gamma_{S_L} &= (1 - \gamma_5) \\ \Gamma_{S_R} &= (1 + \gamma_5) \\ \Gamma_R &= \gamma^\mu (1 + \gamma_5) \\ \Gamma_L &= \gamma^\mu (1 - \gamma_5) \\ \Gamma_T &= [\gamma^\mu, \gamma^\nu]/2\ . \end{aligned}$$

- In the SM, only $\beta = L$ and $\alpha = L, R$ occur.

$$\begin{aligned} G^{RL} + G^{LL} &= V_{ud} \frac{\pi \alpha_W}{\sqrt{2} M_W^2}\ , \\ (G^{RL} - G^{LL}) &= \frac{G_A}{G_V} (G^{RL} + G^{LL}). \end{aligned}$$

## Mass, $V - A$ and non-SM Eigenstates

• The super-K and SNO results tell us to include neutrino mixing. With an orthogonal MNS matrix(Maki, Nakagawa, Sakata (1962)). Neglecting $CP$ violation, the states which couple to the leptons via the $L$ current are $\nu_\ell = \sum_i \Lambda_{\ell i} \nu_i$. The notation is that $\ell \in \{e, \mu, \tau\}$ runs over the lepton species, and $i \in \{1, 2, 3\}$ runs over the mass eigenstates.

• States which couple to non-SM currents *eg* $\tilde{\nu}_{e,SL}$ in $\bar{e}\, \tilde{\nu}_{e,SL_L}$ are a new mixture, $\tilde{\nu}_{e,SL} = \sum_i \tilde{\Lambda}^{SL}_{\ell i}\, \nu_i$

• The ratio of the strength of the "new interaction" now includes the ratio of mixing matrix elements: $\hat{\rho}_X = \rho_X \left(\tilde{\Lambda}^X_{e1}\right) / \left(\Lambda_{e1}\right)$

Note that the sign of $\hat{\rho}_X$ is not fixed in the way the sign of $\rho_X$ is fixed.

## An Example

The SM with an additional $S_R$ interaction with relative strength $\widehat{\rho}_{S_R}$ gives a beta spectrum proportional to

$$\left\{\left(1+\frac{3G_A^2}{G_V^2}\right)E_\nu E_\beta + 2\widehat{\rho}_{S_R}\left(-m_\nu E_\beta\right) + \widehat{\rho}_{S_R}^2\left(E_\nu E_\beta\right)\right\}$$
$$\propto \ (1+\varepsilon)\,E_\nu E_\beta\left\{1+\frac{\phi}{E_\nu}\right\},$$

The parameters $\varepsilon, \phi$ are given by

$$\begin{aligned}\varepsilon &= \frac{G_V^2}{G_V^2+3G_A^2}\,\widehat{\rho}_{S_R}^2\\ \phi &= -m_\nu\,\frac{G_V^2}{G_V^2+3G_A^2}\,\frac{2\widehat{\rho}_{S_R}}{1+\widehat{\rho}_{S_R}^2}\end{aligned}$$

To see the distortion of the spectrum we need to be near the endpoint, where $E_\nu \sim m_\nu$

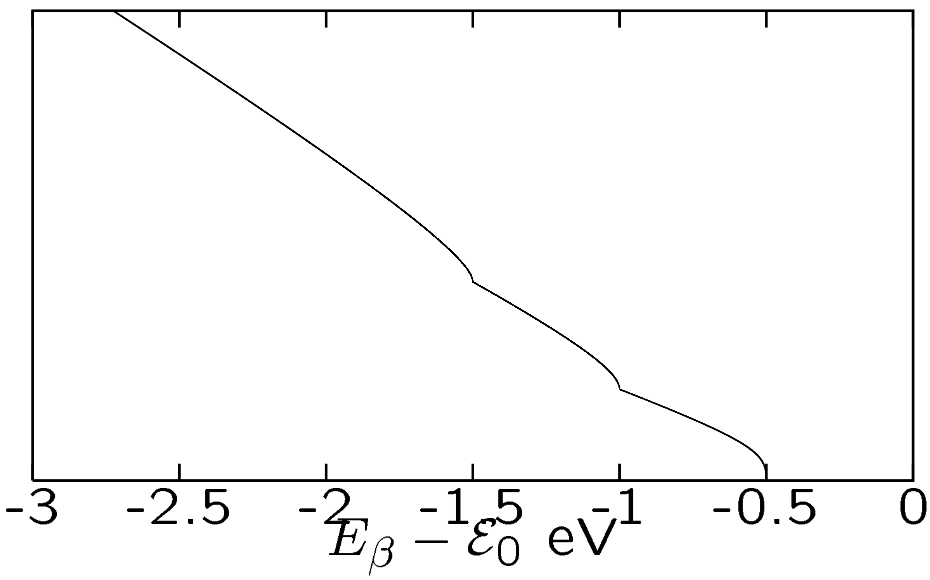
# An approximate spectrum

• The final spectrum involves summation over the atomic/molecular final states, $i$, with end-points $\mathcal{E}_0^i$, and a differential spectrum $\frac{dN_i}{dE_\beta}$, and each of these involves a sum over possible non $V-A$ interactions $X$, and over mass eigenstates $k$.

• With near endpoint approximations

$$\frac{dN_i}{dE_\beta} \cong A\sum_k (1+\varepsilon_k)\,|\Lambda_{ek}|^2\,(\mathcal{E}_0^i - E_\beta)^2 \left[1+\frac{\phi_k}{(\mathcal{E}_0^i - E_\beta)}\right] \sqrt{1-\frac{m_k^2}{(\mathcal{E}_0^i - E_\beta)^2}}\,\Theta(\mathcal{E}_0^i - E_\beta - m_k)$$

## Distortion of the spectrum




As has long been known (McKellar, 1980; Schrock, 1980) mixing produces distortions of the spectrum near the end point.

The last 5 eV of a Kurieplot for a fictitious mixing scheme. The three mass eignestates of $m_1 = 0.5$, $m_2 = 1.0$ and $m_3 = 1.5$ eV are maximally mixed.

- $\varepsilon_k$ and $\phi_k$ are summed over contributions from the possible interactions, each with their own mixing. The interaction strengths $\widehat{\rho}_R$, $\widehat{\rho}_{S_L}$ and $\widehat{\rho}_{S_R}$ enter differently in these new parameters.

— See our paper PRD, **62**, 093013 (2000) for details.

- Near the endpoint, $R$, $S_L$ and $S_R$ interactions give identical spectral shape and cannot be distinguished by measurements in that region, although the spectral measurements undertaken to look for the neutrino mass are a sensitive way to find out if at least one of these non-standard interactions is present.

- If one finds that $\varepsilon_k$ and/or $\phi_k$ are non-zero, and thus that new interactions are present, then one can attempt to design experiments to determine the nature of the interaction.

## A model of the data analysis

• Modern experiments are integral measurements which accept all $\beta$s with energy above some cutoff energy $E_\beta(C)$.

• With a collection of results for a number of values of the cut off energy, in the Mainz experiment a weighted average of these values, for values of $E_\beta^{(C)} > E_\ell$, a lowest cut off energy, is taken and fitted.

• A crude model of this process is to take the integral of the integral spectrum $N_i(E_\beta^{(C)})$ from $E_\ell$ to infinity. Do this to gain insight.

$$G_i(E_\ell) \;=\; \int_{E_\ell}^{\infty} N_i(E_\beta^{(C)})dE_\beta^{(C)}$$

## Approximation to the model

Use the approximation that $E_{\ell,i} \gg m_k$ to get a feeling for the behaviour of the equation:

$$G_i(E_\ell) \approx \sum_k \frac{A'_k}{12} E^4_{\ell,i} \left[ 1 - 3\frac{m_k^2}{E^2_{\ell,i}} + 2\frac{\phi_k}{E_{\ell,i}} \right]$$

• In the analysis of the data we expect the neutrino mass $m_k$ and the mixing-interaction parameter $\phi_k$ to be strongly correlated.

• To a first approximation the contribution of the $k$th mass eigenstate to the doubly integrated spectrum near the end point is a function only of the variable $1.5m_k^2 - \phi_k E_{\ell,I}$.

• **Note the mixing of information about masses and new interactions**

• A mass of 0.3eV and an analysis extending to 40eV below the endpoint allows a sensitivity to $\tilde{\rho}$ of 1%

# Sensitivity to Mixing

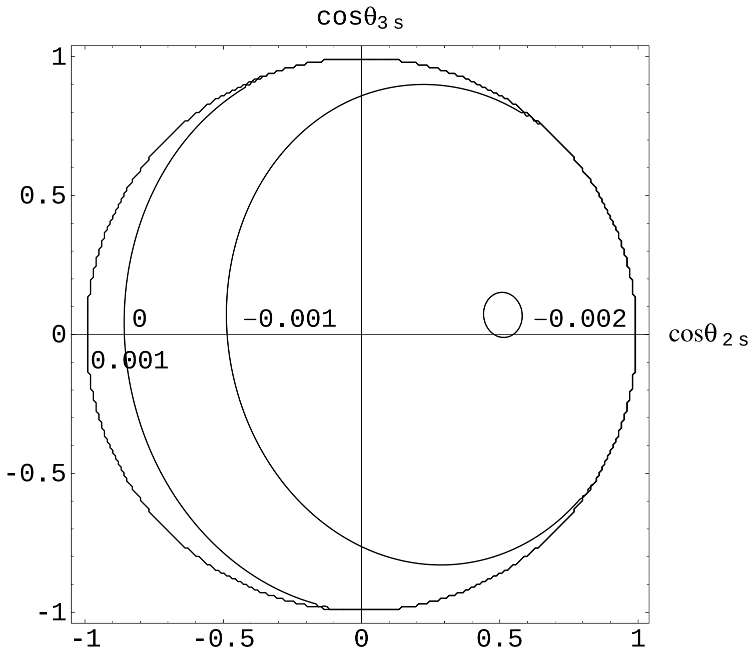
• Generalize to the case where all mass eigenstates participate in the decay.

• The KATRIN experiment mass sensitivity of 0.3 eV, is about a 0.02% shift in $G_0(E_l)$ at an energy of $E_{\nu_l i} \approx 40$ eV.

• To investigate the magnitude of this influence the absolute value of the relative difference between the spectra with and without $S_R$ and $R$ interactions ($G_0^X$ and $G_0'$ respectively) are shown as contours on the plane $(\cos\theta_{2X},\ \cos\theta_{3X})$.

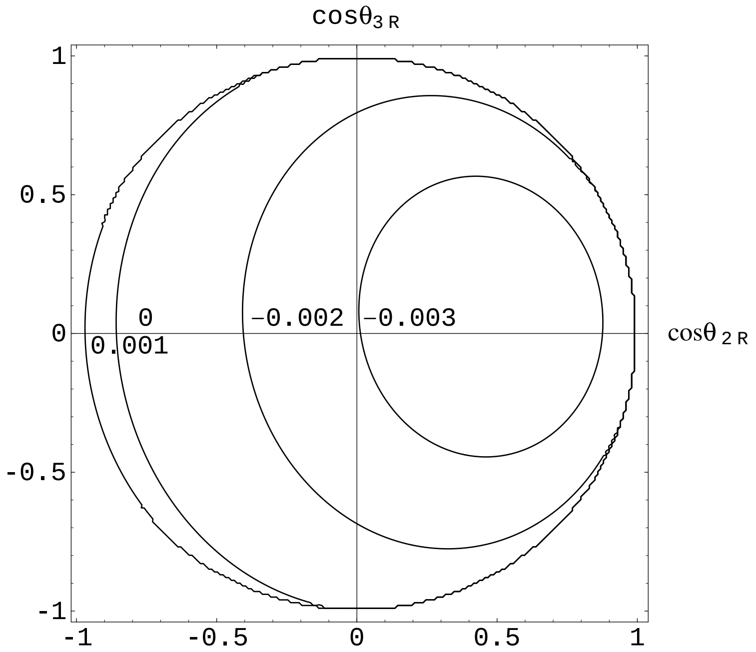
• The Large Mixing Angle solution to the solar neutrino problem defines the mass differences and the $L$ mixing angles.

## The $S_R$ Case




**Constant value contours of $\triangle G$ for the right-chiral scalar interaction as compared to the spectrum produced assuming no additional interactions and the Large Mixing Angle solution of the solar neutrino data. In this plot the third mass eigenstate has a mass of $m_3 = 1$ eV. The numbers immediately to the right of each contour give the value of $\triangle G$.**

## The $R$ Case




**Constant value contours of $\Delta G$ for the right-handed vector interaction as compared to the spectrum produced assuming no additional interactions and the Large Mixing Angle solution of the solar neutrino data. In this plot the third mass eigenstate has a mass of $m_3 = 1$ eV. The numbers immediately to the right of each contour give the value of $\Delta G$**

## Lessons

- There is a range of parameters which cannot be distinguished from the "no new interactions, no mixing" case

- Interactions other than the dominant $V-A$ interaction may play a role in precision measurements of the Tritium beta decay spectrum.

- If these are not correctly accounted for, fits to the neutrino mass will be misleading, and a door to new physics may be closed.

- Note that the charged current interactions of the right handed "sterile" neutrino introduced here suggest that "sterile" neutrinos will have interactions with matter after all, albeit of a smaller strength than the normal charged current weak interactions.

Analyses which assume that the "sterile" neutrinos do not interact may be missing vital clues.

# CONCLUSION

- Remember to be alert to surprises.

- Take the opportunity to search beyond the standard model, and not just look for standard model parameters