Tri-bi-maximal mixing in a viable family symmetry unified model

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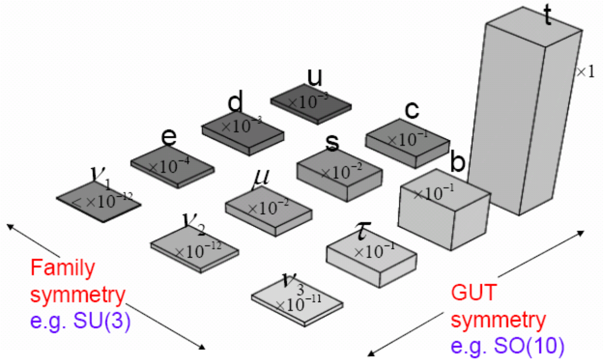
Outline

Summary of data: masses



Summary of data: quark mixing

Wolfenstein

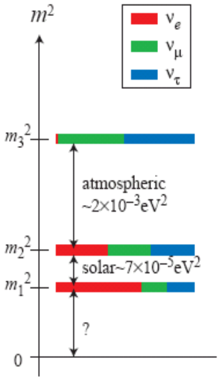
$$V_{CKM} \simeq \begin{pmatrix} 1 & \lambda & \lambda^3 \\ -\lambda & 1 & \lambda^2 \\ \lambda^3 & -\lambda^2 & 1 \end{pmatrix}$$

$\lambda \simeq 0.23$

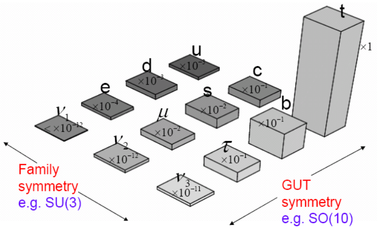
Summary of data: lepton mixing

HPS / Tri-bi-maximal (TBM)

$$V_{PMNS} = \begin{pmatrix} -\sqrt{\frac{2}{3}} & \sqrt{\frac{1}{3}} & 0 \\ \sqrt{\frac{1}{6}} & \sqrt{\frac{1}{3}} & \sqrt{\frac{1}{2}} \\ \sqrt{\frac{1}{6}} & \sqrt{\frac{1}{3}} & -\sqrt{\frac{1}{2}} \end{pmatrix}$$

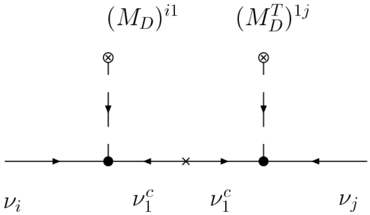


Seesaw mechanism



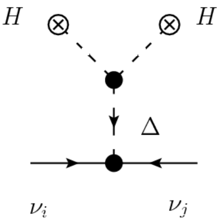
Type I: formula

$$m_\nu = (M_D)\,(M_{RR})^{-1}\,(M_D)^T$$

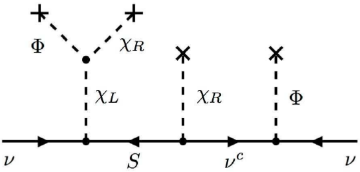


More seesaws

Type II



Linear seesaw:
Malinsky, Romão, Valle
(hep-ph/0506296)



Ingredients

Familons

- The fermions ψ_i, ψ^c_j are triplets
- The familons ϕ^i_A are (anti-)triplets
- Invariant mass terms e.g.: $\phi^i_A \psi_i \phi^j_B \psi^c_j H$

Desired familon vevs

$$\langle \phi_3 \rangle \propto (0, 0, 1)$$

$$\langle \phi_{23} \rangle \propto (0, 1, -1)$$

$$\langle \phi_{123} \rangle \propto (1, 1, 1)$$

Relatively easy to align with discrete non-Abelian symmetries (see Graham's talk)

Effective neutrino superpotential

Effective terms

$$P_\nu = \lambda_{@}(\phi^i_{23}\nu_i)(\phi^j_{23}\nu_j)HH$$

$$+\lambda_{\odot}(\phi^i_{123}\nu_i)(\phi^j_{123}\nu_j)HH$$

These give the ν TBM
(as Graham mentioned).
Enforced by effective Z_2 symmetry:

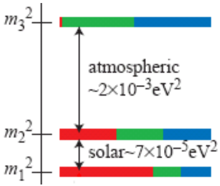
- $\phi_{23} \to -\phi_{23}$
- $\phi_{123} \to \phi_{123}$

Try to remember

Once again:

$\langle\phi_{23}\rangle \propto (0, 1, -1)$

$\langle\phi_{123}\rangle \propto (1, 1, 1)$



Getting the effective terms I

Dirac

dMV, Ross (hep-ph/0507176) ;
dMV, King, Ross (hep-ph/0607045) ;
dMV (0804.0015)

$$P_Y = (\phi^i_{23}\nu_i)(\phi^j_{123}\nu^c_j)H \rightarrow \circledcirc$$

$$+(\phi^i_{123}\nu_i)(\phi^j_{23}\nu^c_j)H \rightarrow \odot$$

$$+(\phi^i_3\nu_i)(\phi^j_3\nu^c_j)H \rightarrow 0$$

Also for all fermions, consistent with $SO(10)$!
(extra Georgi-Jarlskog factor - see Graham's talk)

Getting the effective terms II

Majorana

dMV, Ross (hep-ph/0507176) ;
dMV, King, Ross (hep-ph/0607045) ;
dMV (0804.0015)

$$P_M = (\phi^i_{123}\nu^c_i)(\phi^j_{123}\nu^c_j)(\ldots)_{@} \rightarrow @$$

$$+(\phi^i_{23}\nu^c_i)(\phi^j_{23}\nu^c_j)(\ldots)_{\odot} \rightarrow \odot$$

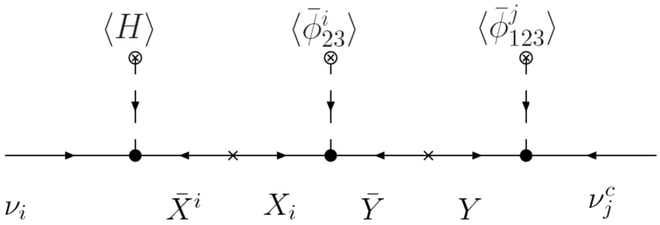
$$+(\phi^i_{3}\nu^c_i)(\phi^j_{3}\nu^c_j)(\ldots)_{3} \rightarrow 0$$

The (...) don't affect the structure but control the magnitude.
Have $(\ldots)_3 \gg (\ldots)_{@,\odot}$.

Drawing TBM 1

Step 1: Dirac

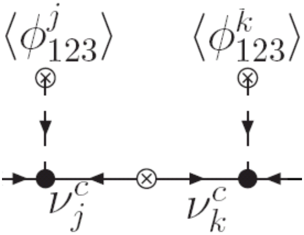
$$P_Y = (\phi^i_{23}\nu_i)(\phi^j_{123}\nu^c_j)H \to ©$$



Drawing TBM 2

Step 2: ... (Majorana)

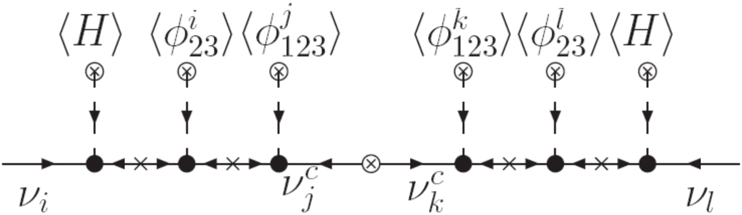
$$P_M = (\phi^j_{123}\nu^c_j)(\phi^k_{123}\nu^c_k)(\ldots) \to \copyright$$



Drawing TBM 3

Step 3: Profit! (desired effective neutrino)

$$P_Y = (\phi^k_{123}\nu^c_k)(\phi^l_{23}\nu_l)H \rightarrow \copyright$$



Added symmetry

Unwanted terms

$$P_T = (\phi_{23}^i \nu_i)(\phi_{23}^j \nu_j^c) H$$

It "seesaws" into $P_{\nu_{mix}}$, spoiling TBM:

$$\rightarrow P_{\nu_{mix}} = (\phi_{23}^i \nu_i)(\phi_{123}^j \nu_j) HH$$

- Added symmetry blocks terms like P_T
- The added symmetry contributes to produce effective Z_2

Very large Majorana $(...)_3$ decouples the ϕ_3 (SD)

Extended seesaw application

TBM with extra singlets

Bazzochi, dMV (0902.3250)

$$P_Y = (\phi_{23}^i \nu_i)(\phi_{23}^j \nu_j^c)(\ldots) \rightarrow @$$

$$+(\phi_{123}^i \nu_i)(\phi_{123}^j S_j)(\ldots) \rightarrow \odot$$

$$P_{M,S} = (\phi_{23}^i \nu_i^c)(\phi_{23}^j \nu_j^c)(\ldots) \rightarrow @$$

$$+(\bar{S}^j S_j)(\ldots) + (\bar{S}^j \nu_j)(\ldots) \rightarrow \odot$$

Summary

TBM through seesaw

- Tri-bi-maximal mixing through seesaw mechanisms is an interesting aspect of unified family symmetries.