The Flavor of Higgs

The Search for Fundamental Physics:
Higgs Bosons and Supersymmetry

$\boxed{\text{Dine + Haber} = 120}$

UCSC, 6 January 2013

Yossi Nir (*Weizmann Institute of Science*)

- My papers with Howie :
  - 1990: *Multiscalar models with a high-energy scale*
  - 1992: *The decay* $h^0 \to A^0 A^0$ *in the MSSM*
  - 1993: *The decay* $Z \to A^0 A^0 \nu \bar{\nu}$ *and* $e^+ e^- \to A^0 A^0 Z$ *in 2HDM*
  - 1995: *QCD corrections to* H^+*-mediated* $b \to c\tau\nu$ *decay*
- My papers with Michael :
  - 1996: *New tools for low energy DSB*
  - 1997: *Variations on minimal GMSB*
  - 1998: *Enhanced symmetries and the GS of string theory*
  - 2001: *CP violation and the scale of supersymmetry breaking*
  - 2002: *Product groups, discrete symmetries, and GU*
  - 2003: *Time variations in the scale of GU*

Plan of Talk

1. The standard flavor
2. The flavor of Higgs
3. The flavor of top
4. The flavor of neutrinos

The Standard Flavor

PHYSICAL REVIEW D, VOLUME 63, 116005

CP violation and the scale of supersymmetry breaking

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(Received 22 January 2001; published 27 April 2001)

Supersymmetric models with a high supersymmetry breaking scale give, in general, large contributions to ε_K and/or to various electric dipole moments, even when contributions to CP conserving, flavor changing processes are sufficiently suppressed. Some examples are models of dilaton dominance, alignment, non-Abelian flavor symmetries, heavy first two generation sfermions, anomaly mediation and gaugino mediation. There is then strong motivation for "approximate CP," that is, a situation where all CP violating phases are small. In contrast, in supersymmetric models with a low breaking scale it is quite plausible that the CKM matrix is the only source of flavor and CP violation. Gauge mediation provides a concrete example. Approximate CP is then unacceptable. Upcoming measurements of the CP asymmetry in $B\to\psi K_S$ might exclude or support the idea of approximate CP and consequently probe the scale of supersymmetry breaking.

Why is flavor physics interesting?

- Flavor physics is sensitive to new physics at $\Lambda_{\rm NP} \gg E_{\rm experiment}$
  FCNC suppressed within the SM by $\alpha_W^n, |V_{ij}|, m_f$
- The Standard Model flavor puzzle:
  Why are the flavor parameters small and hierarchical?
  (Why) are the neutrino flavor parameters different?
- The New Physics flavor puzzle:
  If there is NP at the TeV scale, why are FCNC so small?
  The solution $\Longrightarrow$ Clues for the subtle structure of the NP

The SM flavor puzzle

$$Y_t \sim 1, \quad Y_c \sim 10^{-2}, \quad Y_u \sim 10^{-5}$$
$$Y_b \sim 10^{-2}, \quad Y_s \sim 10^{-3}, \quad Y_d \sim 10^{-4}$$
$$Y_\tau \sim 10^{-2}, \quad Y_\mu \sim 10^{-3}, \quad Y_e \sim 10^{-6}$$
$$|V_{us}| \sim 0.2, \quad |V_{cb}| \sim 0.04, \quad |V_{ub}| \sim 0.004, \quad \delta_{\rm KM} \sim 1$$

- For comparison: $g_s \sim 1, \quad g \sim 0.6, \quad g' \sim 0.3, \quad \lambda \sim 1$
- SM flavor parameters have structure: smallness + hierarchy
- Why? = The SM flavor puzzle
  - Approximate symmetry? [Froggatt-Nielsen]
  - Strong dynamics? [Nelson-Strassler]
  - Location in extra dimension? [Arkani-Hamed-Schmaltz]
  - ?

The NP flavor puzzle

- $\frac{z_{ij}}{(1 \text{ TeV})^2}\ \bar{q}_i q_j \bar{q}_i q_j$

	$z_{ij} \lesssim$		$\mathcal{I}m(z_{ij}) \lesssim$
$\frac{\Delta m_K}{m_K} = 7.0 \times 10^{-15}$	9×10^{-7}	$\epsilon_K = 2.3 \times 10^{-3}$	4×10^{-9}
$\frac{\Delta m_D}{m_D} = 8.7 \times 10^{-15}$	6×10^{-7}	$A_\Gamma \leq 0.004$	1×10^{-7}
$\frac{\Delta m_B}{m_B} = 6.3 \times 10^{-14}$	5×10^{-6}	$S_{\psi K_S} = 0.67 \pm 0.02$	1×10^{-6}
$\frac{\Delta m_{B_s}}{m_{B_s}} = 2.1 \times 10^{-12}$	2×10^{-4}	$S_{\psi\phi} \leq 0.2$	1×10^{-4}

- The flavor structure of NP@TeV must be highly non-generic: Degeneracies/Alignment
- How? Why? = The NP flavor puzzle

A brief history of CPV

- $1964 - 2000$
  - $|\varepsilon| = (2.228 \pm 0.011) \times 10^{-3}$; $\mathcal{R}e(\varepsilon'/\varepsilon) = (1.65 \pm 0.26) \times 10^{-3}$

A brief history of CPV

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  - $|\varepsilon| = (2.228 \pm 0.011) \times 10^{-3}$; $\mathcal{R}e(\varepsilon'/\varepsilon) = (1.65 \pm 0.26) \times 10^{-3}$
- $2000-2012,\ 5\sigma$
  - $S_{\psi K_S} = +0.68 \pm 0.02$
  - $S_{\phi K_S} = +0.74 \pm 0.12$, $S_{\eta' K_S} = +0.59 \pm 0.07$, $S_{f K_S} = +0.69 \pm 0.11$
  - $S_{K^+K^-K_S} = +0.68 \pm 0.10$
  - $S_{\pi^+\pi^-} = -0.65 \pm 0.07$, $C_{\pi^+\pi^-} = -0.36 \pm 0.06$
  - $S_{\psi\pi^0} = -0.93 \pm 0.15$, $S_{D^+D^-} = -0.98 \pm 0.17$, $S_{D^{*+}D^{*-}} = -0.77 \pm 0.10$
  - $\mathcal{A}_{K^\mp\pi^\pm} = -0.087 \pm 0.008$
  - $\mathcal{A}_{D_+K^\pm} = +0.19 \pm 0.03$

Summary I: The Standard Flavor

- The KM phase is different from zero (SM violates CP)
- The KM mechanism is the dominant source of the CP violation observed in meson decays
- Complete alternatives to the KM mechanism are excluded (Superweak, Approximate CP)

- No evidence for corrections to CKM
- NP contributions to the observed FCNC are at most comparable to the CKM contributions ($s \leftrightarrow d, b \leftrightarrow d, b \leftrightarrow s, c \leftrightarrow u$)
- TeV-scale NP must have degeneracy/alignment

The Flavor of Higgs

Liron Barak, Shikma Bressler, Avital Dery, Aielet Efrati, Yonit Hochberg, YN, in progress

MULTI-SCALAR MODELS WITH A HIGH-ENERGY SCALE*

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Received 6 November 1989

Present

Observable	Experiment
$R_{\gamma\gamma}$	1.6 ± 0.3
R_{ZZ^*}	1.0 ± 0.4

- Indication that $Y_t = \mathcal{O}(1)$
- The beginning of Higgs flavor physics

Future

Observable	SM
$R_{\tau^+\tau^-}$	1
$X_{\mu\mu} = \frac{\mathrm{BR}(h\to\mu^+\mu^-)}{\mathrm{BR}(h\to\tau^+\tau^-)}$	$(m_\mu/m_\tau)^2$
$X_{\mu\tau} = \frac{\mathrm{BR}(h\to\mu^\pm\tau^\mp)}{\mathrm{BR}(h\to\tau^+\tau^-)}$	0

- What can we learn from $R_{\tau\tau},\ X_{\mu\mu},\ X_{\tau\mu}$?
- Interplay of flavor with electroweak symmetry breaking

MHDM with NFC

- Only one Higgs doublet couples to the charged lepton sector ϕ_ℓ
- $\phi_h = V_{h\ell}\phi_\ell + \cdots$

MHDM with NFC

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- $\phi_h = V_{h\ell}\phi_\ell + \cdots$

$$\Downarrow$$

- $Y_\tau = \frac{V_{h\ell}v}{\langle\phi_l\rangle}\ \frac{\sqrt{2}m_\tau}{v}$

  2HDM type II: $Y_\tau = -\frac{\sin\alpha}{\cos\beta}\ \frac{\sqrt{2}m_\tau}{v}$
- $\frac{Y_\mu}{Y_\tau} = \frac{m_\mu}{m_\tau}$
- $Y_{\mu\tau} = Y_{\tau\mu} = 0$

1HDM with MFV

- $\lambda_{ij}\bar{L}_i\phi E_j + \frac{\lambda'_{ij}}{\Lambda^2}(\phi^\dagger\phi)\bar{L}_i\phi E_j + \cdots$
- MFV: $\lambda' = a\lambda + b\lambda\lambda^\dagger\lambda + \cdots$

1HDM with MFV

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- MFV: $\lambda' = a\lambda + b\lambda\lambda^\dagger\lambda + \cdots$

$$\Downarrow$$

- $Y_\tau = \left(1 + \frac{av^2}{\Lambda^2}\right)\ \frac{\sqrt{2}m_\tau}{v}$
- $\frac{Y_\mu}{Y_\tau} = \left[1 - \frac{2b(m_\tau^2 - m_\mu^2)}{\Lambda^2}\right]\ \frac{m_\mu}{m_\tau}$
- $Y_{\mu\tau} = Y_{\tau\mu} = 0$

1HDM with FN

- $\lambda_{ij}\bar{L}_i\phi E_j + \frac{\lambda'_{ij}}{\Lambda^2}(\phi^\dagger\phi)\bar{L}_i\phi E_j + \cdots$
- FN: $\lambda'_{ij} = \mathcal{O}(1) \times \lambda_{ij}$

1HDM with FN

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- FN: $\lambda'_{ij} = \mathcal{O}(1) \times \lambda_{ij}$

$$\Downarrow$$

- $Y_\tau = \left[1 + \mathcal{O}\left(\frac{v^2}{\Lambda^2}\right)\right] \ \frac{\sqrt{2}m_\tau}{v}$
- $\frac{Y_\mu}{Y_\tau} = \left[1 + \mathcal{O}\left(\frac{v^2}{\Lambda^2}\right)\right] \ \frac{m_\mu}{m_\tau}$
- $Y_{\mu\tau} = \mathcal{O}\left(\frac{|U_{23}|vm_\tau}{\Lambda^2}\right), \quad Y_{\tau\mu} = \mathcal{O}\left(\frac{vm_\tau}{|U_{23}|\Lambda^2}\right)$

Summary II: The flavorful h

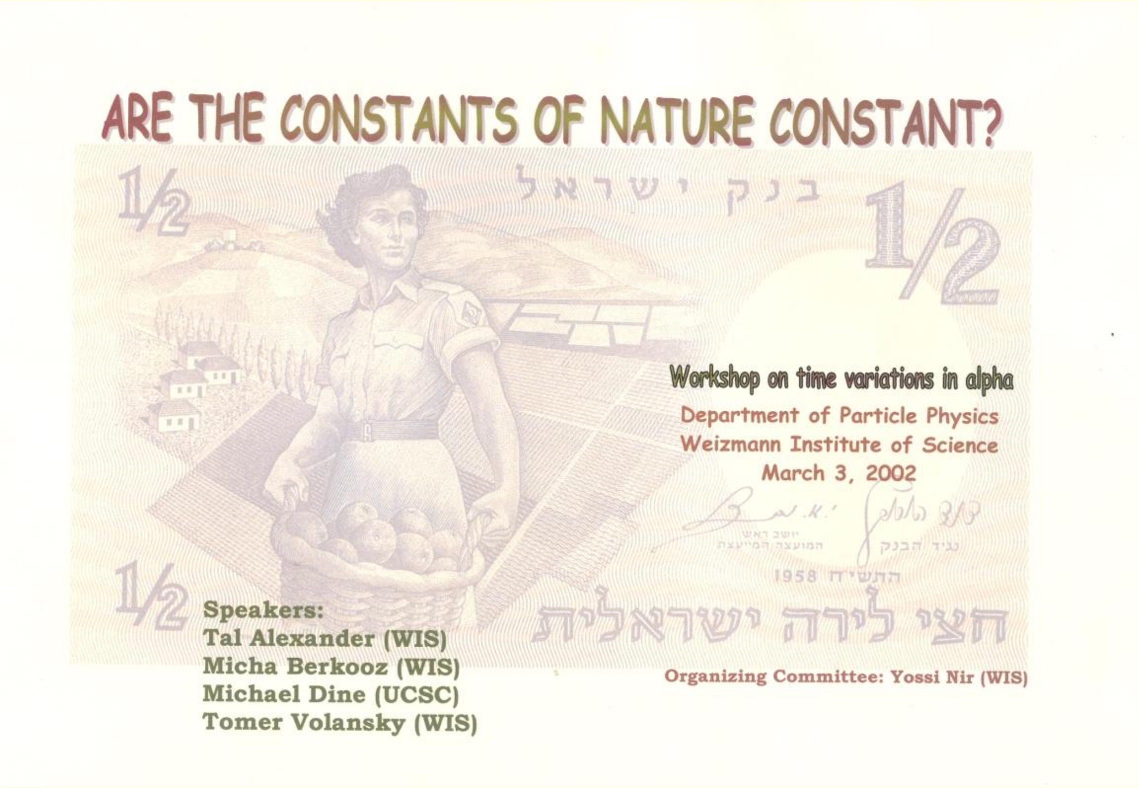
Model	$R_{\tau^+\tau^-}$	$X_{\mu^+\mu^-}/(m_\mu^2/m_\tau^2)$	$X_{\tau\mu}$
SM	1	1	0
NFC	$(V_{h\ell}v/v_\ell)^2$	1	0
MSSM	$(\sin\alpha/\cos\beta)^2$	1	0
MFV	$1+2av^2/\Lambda^2$	$1-4bm_\tau^2/\Lambda^2$	0
FN	$1+\mathcal{O}(v^2/\Lambda^2)$	$1+\mathcal{O}(v^2/\Lambda^2)$	$\mathcal{O}(\lvert U_{23}\rvert m_\tau v/\Lambda^2)$

The Flavor of Top

Blum, Hochberg, Nir, JHEP1110, 124 [1107.4350]

Hochberg, Nir, PRL108, 261601 [1112.5268]

Hiller, Hochberg, Nir, PRD85, 116008 [1204.1046]



Experiments: A^t_{FB}

Observable	Experiment	SM
A^t_{FB}	0.18 ± 0.04	~ 0.08
A^ℓ_{FB}	0.15 ± 0.04	~ 0.02
$A^t_{\mathrm{FB}}(m_{t\bar{t}} > 450)$	0.28 ± 0.06	$0.10 - 0.15$

Scalar mediation

- CDF: $A^t_{\mathrm{FB}}(m_{t\bar{t}} > 450\ \mathrm{GeV}) = 0.47 \pm 0.11$
- SM: $A^t_{\mathrm{FB}}(m_{t\bar{t}} > 450\ \mathrm{GeV}) = 0.09 \pm 0.01$
- Suggestive of a new boson-mediated tree-level $u\bar{u} \to t\bar{t}$
- Scalars: t-channel exchange of one of $(1,2), (8,2), (\bar{6},1), (\bar{6},3), (3,1), (3,3)$
- All colored rep's in tension with other t-related measurements
- Focus on $\Phi(1,2)_{-1/2}$ with $m \sim 130$ GeV and $\lambda_{\phi ut} \sim 1$

Flavor constraints – $\lambda \overline{Q_{L1}} t_R \phi$

Consider $m_\phi \sim 130$ GeV, $\lambda \sim 1$

- $\lambda(\overline{u_L} t_R \phi^0 + V^*_{ui} \overline{d_{Li}} t_R \phi^-)$:
  $K^0 - \overline{K^0}$ mixing with intermediate top $\propto (V_{ud} V^*_{us})^2$
  Excluded by $\Delta m_K^\phi \sim 10^3 \Delta m_K^{\rm exp}$
- $\lambda(\overline{d_L} t_R \phi^- + V_{id} \overline{u_{Li}} t_R \phi^0)$:
  $D^0 - \overline{D^0}$ mixing with intermediate top $\propto (V_{cd} V^*_{ud})^2$
  Excluded by $\Delta m_D^\phi \sim 10^3 \Delta m_D^{\rm exp}$

Flavor constraints – $\lambda \overline{Q_{L3}} u_R \phi$

Consider $m_\phi \sim 130$ GeV, $\lambda \sim 1$:

- $\lambda(\overline{t_L} u_R \phi^0 + V_{ti}^* \overline{d_{Li}} u_R \phi^-)$:
  $b \to u\bar{u}s$ at tree level $\propto (V_{tb}^* V_{ts})$
  Excluded by $\mathrm{BR}(\overline{B^0} \to \pi^+ K^-)^\phi \sim 200 \times \mathrm{BR}(\overline{B^0} \to \pi^+ K^-)^{\mathrm{exp}}$
- $\boxed{\lambda(\overline{b_L} u_R \phi^- + V_{ib} \overline{u_{Li}} u_R \phi^0)}$
  The only (flavor-) viable possibility

$A^t_{FB} \Rightarrow \Delta A^D_{CP}$

- $\Delta A_{\rm CP} \equiv A_{\rm CP}(K^+K^-) - A_{\rm CP}(\pi^+\pi^-)$
- $A_{\rm CP}(f) = \frac{\Gamma(D^0 \to f) - \Gamma(\overline{D^0} \to f)}{\Gamma(D^0 \to f) + \Gamma(\overline{D^0} \to f)}$

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- $A_{\rm CP}(f) = \frac{\Gamma(D^0\to f)-\Gamma(\overline{D^0}\to f)}{\Gamma(D^0\to f)+\Gamma(\overline{D^0}\to f)}$
- Consider $\lambda(\overline{b_L}u_R\phi^- + V_{ib}\overline{u_{Li}}u_R\phi^0)$
- t-channel tree-level exchange of ϕ^0 generates $\frac{4|\lambda|^2 V_{ub}V^*_{cb}}{m^2_\phi}(\overline{u_R}c_L)(\overline{u_L}u_R)$
- Predicts $\Delta A^\phi_{\rm CP} = 2\sqrt{2}(G_0/G_F)I_{\rm CKM}I_{\rm QCD} \sim (0.02 - 0.07)I_{\rm QCD}$
  - $G_0 \equiv \frac{4|\lambda|^2}{m^2_\phi} = (10 - 30) \times \frac{G_F}{\sqrt{2}}$
  - $I_{\rm CKM} \equiv 2\mathcal{I}m\left(\frac{V_{ub}V^*_{cb}}{V_{us}V^*_{cs}}\right) \sim 0.001$
- Guess $I_{\rm QCD} \sim f_D/m_D \Longrightarrow |\Delta A^\phi_{\rm CP}| \sim 0.005$

Experiments: ΔA_{CP}

Observable	Experiment	SM
ΔA_{CP}	-0.0066 ± 0.0015	$0.0002 X_{\text{QCD}}$
$A_{\pi^+\pi^-}$	$+0.0020 \pm 0.0022$	
$A_{K^+K^-}$	-0.0023 ± 0.0017	

Scalar mediated A^t_{FB}

- A scalar $\phi(1,2)_{1/2}$
- Yukawa couplings $\lambda\overline{Q_{L3}}u_R\phi = \lambda(\overline{b_L}u_R\phi^- + V_{ib}\overline{u_{Li}}u_R\phi^0)$
- $G_0 \equiv \frac{4|\lambda|^2}{m_\phi^2} = (10-30)\times\frac{G_F}{\sqrt{2}}$
- Explains two puzzles:
  - Gives $A^t_{FB}(m_{t\bar{t}} > 450\text{ GeV}) \gtrsim 0.2$
  - Gives $|\Delta A_{CP}| \sim 0.005$
- Testable (and, sadly, might soon be (is?) excluded):
  - Large contribution to atomic parity violation (4σ)
  - Enhancement of 1b/2b
  - Possible enhancement of $h \to \gamma\gamma$

Summary III: The flavorful t

- A wonderful example of collider $\leftrightarrow$ flavor interplay
- The model is radically different from MFV,
  yet not excluded by flavor
- Are we too much "committed" to MFV?

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- A wonderful example of collider $\leftrightarrow$ flavor interplay
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- $A^t_{\rm FB}$: scalar-mediated mechanisms involve flavor non-universal couplings in the up sector
- ΔA_{CP}: involves flavor non-universal couplings in the up sector
- The two observables, if BSM, might be related
- Our model provides a specific example;
  Are there any others?

The Flavor of Neutrinos

Shahar Amitai, 1211.6252; 1212.5165

$$\Gamma(Z \to AA\nu\bar{\nu}) = \frac{g^6 m_Z}{3 \cdot 2^{17} \pi^5 \cos^6 \theta_W} \left[\frac{\pi^2}{2} - \frac{349}{72} \right] . \qquad (10)$$

It is unfortunate that the factor in brackets is rather small (roughly 0.09), thereby reducing the partial width by more than an order of magnitude over a naive initial estimate. The branching ratio is most easily displayed by normalizing our result to $\Gamma(Z \to \nu\bar{\nu}) = g^2 m_Z / (96\pi \cos^2 \theta_W)$. We find

$$\frac{\Gamma(Z \to A^0 A^0 \nu\bar{\nu})}{\Gamma(Z \to \nu\bar{\nu})} = \frac{\alpha^2 (\frac{\pi^2}{2} - \frac{349}{72})}{256\pi^2 \sin^4 \theta_W \cos^4 \theta_W} , \qquad (11)$$

ν-flavor parameters for anarchists

- $\Delta m^2_{21} = (7.5 \pm 0.2) \times 10^{-5}\ \mathrm{eV}^2, \quad |\Delta m^2_{32}| = (2.5 \pm 0.1) \times 10^{-3}\ \mathrm{eV}^2$
- $|U_{e2}| = 0.55 \pm 0.01, \quad |U_{\mu 3}| = 0.64 \pm 0.02, \quad \boxed{|U_{e3}| = 0.15 \pm 0.01}$

Gonzalez-Garcia et al., 1209.3023

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Gonzalez-Garcia et al., 1209.3023

- $|U_{\mu 3}| >$ any $|V_{ij}|$;
- $|U_{e2}| >$ any $|V_{ij}|$
- $|U_{e3}| \not\ll |U_{e2} U_{\mu 3}|$
- $m_2/m_3 \gtrsim 1/6 >$ any m_i/m_j for charged fermions
- So far, neither smallness nor hierarchy
- Anarchy?

ν-flavor parameters for tribimaximalists

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Gonzalez-Garcia et al., 1209.3023

- $\sqrt{1/3}$ = trimaximal mixing: $|U_{e2}| = \sqrt{1/3} - 0.03$;
- $\sqrt{1/2}$ = bimaximal mixing: $|U_{\mu 3}| = \sqrt{1/2} - 0.06$;
- 0 = bimaximal mixing: $\boxed{|U_{e3}| = 0 + 0.15}$

- Tribimaximal mixing?
- Non-Abelian flavor symmetry? A_4?

Structure is in the eye of the beholder

$$|U|_{3\sigma} = \begin{pmatrix} 0.79-0.85 & 0.51-0.59 & 0.13-0.18 \\ 0.20-0.54 & 0.42-0.73 & 0.58-0.81 \\ 0.21-0.55 & 0.41-0.73 & 0.57-0.80 \end{pmatrix}$$

- Tribimaximal-ists:

$$|U|_{\mathrm{TBM}} = \begin{pmatrix} 0.82 & 0.58 & 0 \\ 0.41 & 0.58 & 0.71 \\ 0.41 & 0.58 & 0.71 \end{pmatrix}$$

- Anarch-ists:

$$|U|_{\mathrm{anarchy}} = \begin{pmatrix} \mathcal{O}(0.6) & \mathcal{O}(0.6) & \mathcal{O}(0.6) \\ \mathcal{O}(0.6) & \mathcal{O}(0.6) & \mathcal{O}(0.6) \\ \mathcal{O}(0.6) & \mathcal{O}(0.6) & \mathcal{O}(0.6) \end{pmatrix}$$

What are the small parameters?

$$
\begin{aligned}
m_e/m_\mu &= 0.0048 \\
r_{23} \equiv |\Delta m^2_{21}/\Delta m^2_{31}| &= 0.030 \\
m_\mu/m_\tau &= 0.059 \\
s_{13} \equiv |U_{e3}| &= 0.15
\end{aligned}
$$

- Normal hierarchy (NH): $\sqrt{r_{23}} = 0.18 \sim s_{13}$
- Inverted hierarchy (IH): $r_{23} = 0.03 \sim s^2_{13}$
- Quasi-degeneracy (QD): $\Delta m^2_{21}/m^2 \ll r_{23}$

s_{13} and, for NH, m_2/m_3 can be accidentally somewhat small

Lessons for model building

- Abelian symmetries that explain $s_{13} \ll 1$ give either $r_{23} = \mathcal{O}(1)$ or $r_{23} = \mathcal{O}(s_{13})$
  $\Longrightarrow$ Fine tuning at the level of s_{13}

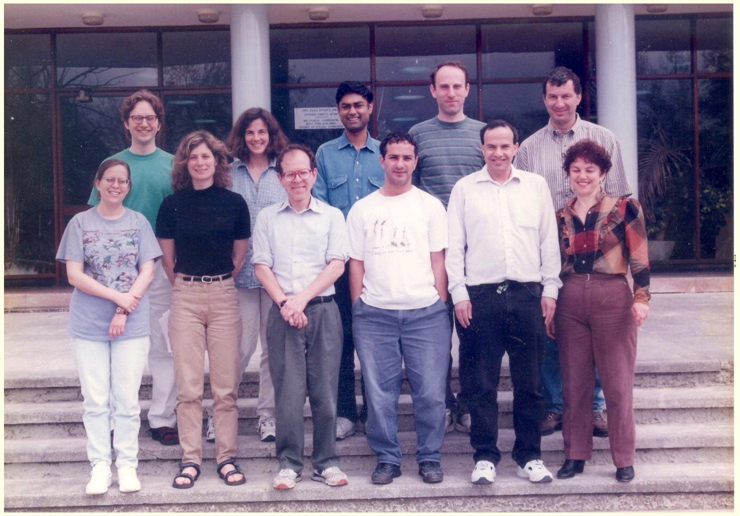
- The Altarelli-Feruglio A_4 models that give TBM give $r_{23} = \mathcal{O}(1)$
  $\Longrightarrow$ Fine tuning at the level of s_{13}^2

Summary IV: The flavorful ν

- $|U_{e3}| \sim 0.15$ strengthens the case for neutrino mass anarchy
- $|U_{e3}| \sim 0.15$ weakens the case for tribimaximal mixing
- If interpreted as small parameters, $s_{13} \sim m_2/m_3$ is very challenging for model builders
- If interpreted as order one parameters, $s_{13}, m_2/m_3 = \mathcal{O}(1)$: a hint of $H(L_1) = H(L_2) = H(L_3)$

Thank you, Howie and Michael

January 28, 1990



April 15, 1997

$\boxed{\text{Backup Transparencies}}$

$\Delta A^D_{CP} \Rightarrow \epsilon'/\epsilon$

Consider $\lambda(\overline{b_L} u_R \phi^- + V_{ib} \overline{u_{Li}} u_R \phi^0)$

- The same Yukawa couplings of ϕ^0 that contribute to ΔA_{CP} contribute unavoidably to ϵ'/ϵ
- A box diagram involving ϕ^0 and W generates $\frac{\sqrt{2}|\lambda|^2 G_F}{\pi^2} \frac{\ln(m_\phi^2/m_W^2)}{1-(m_\phi^2/m_W^2)} (V^*_{ud} V_{cs} V_{ub} V^*_{cb})(\overline{u_R} s_L)(\overline{d_L} u_R)$
- Predicts $\frac{\mathcal{R}e(\epsilon'/\epsilon)_\phi}{\mathcal{R}e(\epsilon'/\epsilon)_{\rm EWP}} = +10 \pm 3$
- Requires $\frac{\mathcal{I}m A_0}{\mathcal{R}e A_0} = -(4-7) \times 10^{-4}$: a factor of 3 above and same sign as the value extracted within the SM
- Given the large hadronic uncertainties, such an enhancement cannot be used to exclude the model

Electroweak Precision Tests

Consider $\lambda(\overline{b_L} u_R \phi^- + V_{ib}\overline{u_{Li}} u_R \phi^0)$:

- S parameter: no meaningful constraint
- T parameter: $\frac{m_+ - m_0}{m_{\mathrm{average}}} \lesssim 0.45 \, \frac{250 \text{ GeV}}{m_{\mathrm{average}}}$
- R_b: no meaningful constraint
- Q_W: disfavors the model at 4σ [Gersham, Kim, Tulin, Zurek, 1203.1320];

Additional Top Physics

Consider $\lambda(\overline{b_L} u_R \phi^- + V_{ib} \overline{u_{Li}} u_R \phi^0)$:

- Same sign tops: $\sigma(uu \to tt) \propto \lambda_{t_L u_R} \lambda_{t_R u_L} \ll 1$
- Top decay: $\Gamma(t \to u\phi^0)$ large but within bounds
- Single top: $\sigma(ug \to t\phi)$ large, modifies 1b/2b [Huang, Urbano, 1212.1399]