Up sector Minimal Flavor Violation

Joshua Berger
SLAC National Accelerator Laboratory

Based on:
Y. Bai, J.B., J. Hewett, Y. Li: 1305.5537

August 16, 2013
Flavor Status Report

2

Friday, August 16, 13
Flavor Status Report

Bounds on $(f_i \bar{f}_j)(f_k \bar{f}_l)$

- $\Delta F = 2 \rightarrow 10^2 \text{ TeV} - 10^5 \text{ TeV}$
- $\Delta F = 1$ semi-leptonic $\rightarrow 10^2 \text{ TeV} - 10^5 \text{ TeV}$
- $\Delta F = 1$ hadronic? Much harder...
- Top sector? Just getting started...
- Possible NP CP violation in $D \rightarrow KK,\pi\pi$

Hewett, Weerts, et. al.: 1205.2671
D’Ambrosio, Giudice, Isidori, Strumia: hep-ph/0207036
Flavor Status Report

Bounds $\Lambda$ for $(f_i \bar{f}_j)(f_k \bar{f}_l)$

- $\Delta F = 2 \rightarrow 10^2 \text{ TeV} - 10^5 \text{ TeV}$
- $\Delta F = 1$ semi-leptonic $\rightarrow 10^2 \text{ TeV} - 10^5 \text{ TeV}$
- $\Delta F = 1$ hadronic? Much harder...
- Top sector? Just getting started...
- Possible NP CP violation in $D \rightarrow KK, \pi\pi$

Hewett, Weerts, et. al.: 1205.2671
D’Ambrosio, Giudice, Isidori, Strumia: hep-ph/0207036
Flavor Status Report

Bounds $\Lambda$ for $(f_i \bar{f}_j)(f_k \bar{f}_l)$

- $\Delta F = 2 \rightarrow 10^2 \text{TeV} - 10^5 \text{TeV}$
- $\Delta F = 1$ semi-leptonic $\rightarrow 10^2 \text{TeV} - 10^5 \text{TeV}$
- $\Delta F = 1$ hadronic? Much harder...
- Top sector? Just getting started...
- Possible NP CP violation in $D \rightarrow KK, \pi \pi$

Hewett, Weerts, et. al.: 1205.2671
D’Ambrosio, Giudice, Isidori, Strumia: hep-ph/0207036
Minimal Flavor Violation

- All flavor violation (incl. BSM) proportional to SM Yukawa matrices
- Treat Yukawas as “spurions” under flavor $SU(3)_Q \times SU(3)_U \times SU(3)_D \times SU(3)_L \times SU(3)_E$
- New fields also charged under flavor
- Constraints decrease to $\mathcal{O}(1 \text{ TeV})$

D'Ambrosio, Giudice, Isidori, Strumia: hep-ph/0207036
The Hardest Case?

- Focus on up-sector: Top and D physics
- Focus on hadronic operators
- Impose Minimal Flavor Violation
- Are there models? Can we see them?
The Punchline

• New model possible with extremely light (< 100 GeV) new states

• Gives novel signatures in top production and decay

• Could explain D-meson CP violation
Operators & Models
The $\Delta F = 1$ Operators

- Catalog all possible operators that give only $\Delta F = 1$

- Focus on two (out of four) operators that can have new CPV phases

\[ O_{V2} = 2V_{il}(\lambda_D^† V^† \lambda_U)_{kj}(\bar{u}_L^i u_R^j)_{R\alpha}(d_R^k d_L^l) \]

\[ O_{S2} = \frac{1}{2}(\lambda_U^† V)_{il}(\lambda_D^† V^†)_{kj}(\bar{u}_R^i u_L^j)_{R\alpha}(\bar{d}_R^k d_L^l) \]

- $\Lambda \sim 10$ GeV for D-meson CPV
The Model

• New gauge-neutral particle w/ flavor charge
• Can be as light as 10 GeV
• Couples only to quarks w/ FV suppressed by Yukawas + CKM
• Several flavor charges allowed
A Prototype Example

\[ \mathcal{L} \supset \kappa_{UL} \bar{u}_R^i (\lambda^*_U V)^{i\ell} \phi_{lk} (\lambda^*_D V^*)^{kj} u_L^j + \kappa_{UR} \bar{u}_L^i V^{i\ell} \phi_{lk} (\lambda^*_D V^* \lambda_U)^{kj} u_R^j + \kappa_D \bar{d}_R^k (\phi^*)_{kl} d_L^l + \text{h.c.} \]

- **Down-sector:** FV
- **Up-sector:** suppressed by Yukawas \( \lambda_U, \lambda_D \), CKM matrix \( V \)
- **Define** \( \bar{\kappa}_i = \kappa_i \lambda_t \lambda_b \)
Top Properties
The Dominant Effects

• Single top production ($u\bar{d} \rightarrow \bar{t}b$, $u\bar{g} \rightarrow t\varphi$)!
• Top pair production ($q\bar{q} \rightarrow t\bar{t}$)!
• Top decays ($t \rightarrow q\varphi$)!
Some details...

• Only $\kappa_{UR}$ contributes significantly

• $\kappa_{UL}$ always gets u/c Yukawa suppression or CKM angle suppression

• Dominant constraint: single top

• Non-standard top decay $\rightarrow$ smoking gun
Single Top Diagrams

\[ u \rightarrow t \]
\[ d \rightarrow b \]
\[ \phi_{31} \]

\[ g \rightarrow u \]
\[ \phi_{31} \]
Single Top Production

$|K_{UR}| = |K_D| = 0.2$

- Latest: $\Delta\sigma_{\text{TeV}} \lesssim 1\text{ pb}, \Delta\sigma_{\text{LHC}} \lesssim 10\text{ pb}$

CDF/PUB/TOP/PUBLIC/10793, CMS-PAS-TOP-12-011
Top Pair Production

\[ |K_{UR}| = 0.2 \text{ (solid), } |K_{UR}| = 0.3 \text{ (dashed)} \]

-\( \Delta \sigma (t\bar{t}) \text{ (pb)} \)

-\( m\phi \text{ (GeV)} \)

-\( \kappa = 0.2 \) (solid), \( \kappa = 0.3 \) (dashed)

- Latest: \( \Delta \sigma_{\text{TeV}} \leq 0.4 \text{ pb}, \Delta \sigma \leq 30 \text{ pb} \)

CDF/PUB/TOP/PUBLIC/10926, ATLAS-CONF-2012-149
Rare Top Decays

$|\kappa_{UR}| = 0.2$

$\text{Br}(t \rightarrow j + \phi)$ vs $m\phi$ (GeV)

- Latest: $\Delta \Gamma \approx 2$ GeV

D0: 1009:5686
Comments

• Room for $O(1)$ corrections to top
• Top cross-sections: naturally high priority
• Other properties need attention too!
Interlude: Rare Z Decay

- New Z decay: $Z \rightarrow q \bar{q} \phi$
- Strongest constraint from search for $Z \rightarrow 4 b \ @ \ LEP$
Charm Physics
2011 D Meson CPV

- Theory: Charm CPV in SM is small
- Experiment: LHCb (+others) measures

\[ \Delta A_{CP} = A_{CP}(D \to KK) - A_{CP}(D \to \pi\pi) = (-0.645 \pm 0.180) \% \]

HFAG

- 3.6\(\sigma\) "clear" evidence of new physics...
2013 D Meson CPV

- Theory: Some charm CPV may get OOM enhancement in SM
- Experiment: LHCb updates analysis

$$\Delta A_{CP} = (-0.329 \pm 0.121) \%$$

- Down to 2.7\(\sigma\) and smaller in magnitude
- For this talk: assume it’s real and it’s BSM
In Our Model

\[ C \rightarrow \phi_{22} \rightarrow \bar{S} \]

\[ u \rightarrow S \]
Calculating $\Delta A_{CP}$

$$A_{CP} \sim \frac{2\sqrt{2}}{3G_F} \lambda_c \lambda_s \left( \frac{1}{4} \sin \delta \Im C \right) \quad C_{L,R} = \frac{\kappa_{UL,R} \kappa_D^*}{2m_{\phi}^2}$$

- Phase of $\kappa_{UL,R} \kappa_D^*$ is physical
- $A_{CP}$ Proportional to strange Yukawa
- Naive factorization to get HME ratio
- For $m_\phi \lesssim 40$ GeV, sufficient contribution to $\Delta A_{CP}$ to explain measurement
\( m_\phi = 10 \text{ GeV} \)
Conclusions
UV Completion

- Model requires Higgs insertion to be SU(2) invariant $\rightarrow$ new physics at $\sim$ few 100 GeV
- SU(2) doublet scalar or SU(3) triplet fermion with appropriate flavor charge
- Needs further study
Recap

• Up sector is under-explored territory
• Rich new phenomena possible
• Many opportunities for LHC (top factory!), heavy flavor factories, GigaZ