From $A_{\rm FB}^{\rm top}$ to $\Delta A_{\rm CP}^{\rm charm}$ – and Back

Workshop on Flavor Physics

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Plan of Talk

1. $A^t_{\rm FB}$
2. $\Delta A^D_{\rm CP}$
3. Is the model viable?

$$\boxed{A^t_{\rm FB}}$$

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

Experiments

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

Scalar mediation

- CDF: $A^t_{\rm FB}(m_{t\bar t} > 450 \text{ GeV}) = 0.47 \pm 0.11$
- SM: $A^t_{\rm FB}(m_{t\bar t} > 450 \text{ GeV}) = 0.09 \pm 0.01$
- 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 $\Delta m^\phi_K \sim 10^3 \Delta m^{\mathrm{exp}}_K$
- $\lambda(\overline{d_L}t_R\phi^- + V_{id}\overline{u_{Li}}t_R\phi^0)$:
  $D^0 - \overline{D^0}$ mixing with intermediate top $\propto (V_{cd}V^*_{ud})^2$
  Excluded by $\Delta m^\phi_D \sim 10^3 \Delta m^{\mathrm{exp}}_D$

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

$$\boxed{\Delta A_{\rm CP}}$$

Hochberg, Nir, PRL, in press [1112.5268]

Experiments

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

$A_{FB}^t \Rightarrow \Delta A_{CP}^D$

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 $\frac{4|\lambda|^2 V_{ub} V_{cb}^*}{m_\phi^2} (\overline{u_R} c_L)(\overline{u_L} u_R)$
- Predicts $\Delta A_{\rm CP}^\phi = 2\sqrt{2}(G_0/G_F) I_{\rm CKM} I_{\rm QCD} \sim (0.02 - 0.07) I_{\rm QCD}$
  - $G_0 \equiv \frac{4|\lambda|^2}{m_\phi^2} = (10 - 30) \times \frac{G_F}{\sqrt{2}}$
  - $I_{\rm CKM} \equiv 2\mathcal{I}m\left(\frac{V_{ub}V_{cb}^*}{V_{us}V_{cs}^*}\right) \sim 0.001$
- Guess $I_{\rm QCD} \sim f_D/m_D \Longrightarrow |\Delta A_{\rm CP}^\phi| \sim 0.005$

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

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$$\Delta A_{CP} = \begin{cases} -(8.2 \pm 2.4) \times 10^{-3} & [\text{LHCb, 1112.0938}] \\ -(6.2 \pm 2.3) \times 10^{-3} & [\text{CDF, note 10784}] \end{cases}$$

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

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

Is the model viable?

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: $\frac{m_+ - m_0}{m_{\rm average}} \lesssim 0.45\ \frac{250\ {\rm GeV}}{m_{\rm average}}$
- R_b: no meaningful constraint
- Q_W: disfavors the model at 4σ [Gersham, Kim, Tulin, Zurek, 1203.1320]; Work in progress

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
  Possibly excluded, work in progress

Summary

- 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 excluded):
  - Large contribution to atomic parity violation
  - Enhancement of 1b/2b

Philosophical comments

- The model is radically different from MFV, yet not excluded by flavor
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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?