Charming New Physics

Yonit Hochberg

[1] Kfir Blum, YH and Yosef Nir JHEP 1110 (2011) 124 [1107.4350]
[2] YH and Yosef Nir [1112.5268], accepted to PRL
[3] Gudrun Hiller, YH and Yosef Nir [1204.1046], accepted to PRD

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Outline

- The measurement: Charm ΔA_{CP}
- Scalar-mediated ΔA_{CP}
  - Scalar-mediated A_{FB}
  - Interplay with flavor ⟹ ΔA_{CP}
- Supersymmetric ΔA_{CP}
  - Flavor models

Charm ΔA_{CP}

Evidence of direct CPV in D decays: $\Delta A_{CP} \equiv A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$

- **LHCb:** $\Delta A_{CP} = -(8.2 \pm 2.4) \times 10^{-3}$

  CDF: $\Delta A_{CP} = -(6.2 \pm 2.3) \times 10^{-3}$

  World average: $\Delta A_{CP} = -(6.6 \pm 1.5) \times 10^{-3}$

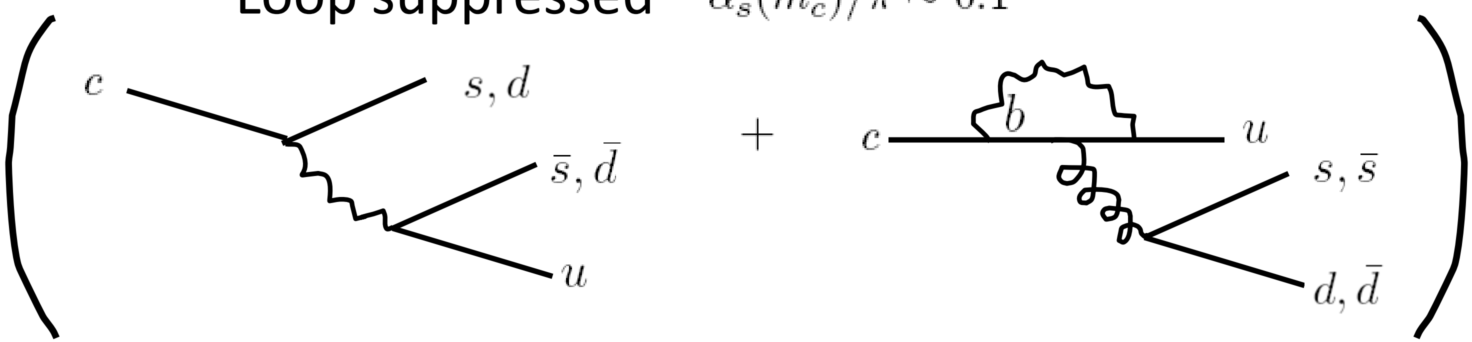
4.3σ from zero

- **SM prediction:**

$$\Delta A_{CP} \propto \ I_{\mathrm{CKM}} \equiv 2\mathcal{I}m\left(\frac{V_{ub}V_{cb}^*}{V_{us}V_{cs}^*}\right) \approx 1.2 \times 10^{-3}$$

New physics?

Loop suppressed $\alpha_s(m_c)/\pi \sim 0.1$



Scalar-mediated ΔA_{CP}

Blum, YH and Nir, JHEP 10 (2011) 124
YH and Nir [1112.5268], accepted to PRL

Top A_{FB}

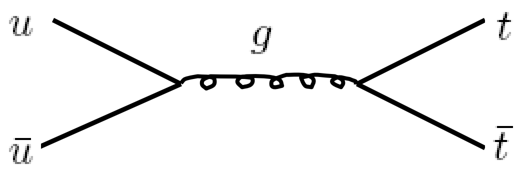
- Evidence for a large forward-backward $t\bar{t}$ production asymmetry:

CDF: $A^t_{FB}(M_{t\bar{t}} > 450 \text{ GeV}) = +0.30 \pm 0.07$

SM: $A^t_{FB}(M_{t\bar{t}} > 450 \text{ GeV}) = +0.09 \pm 0.01$

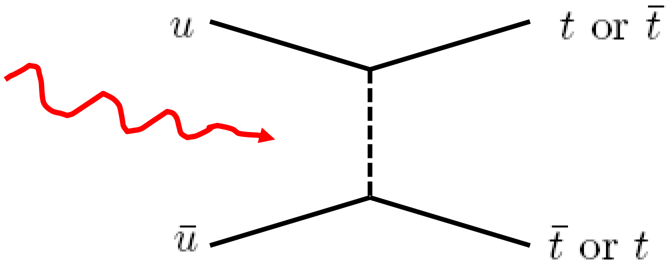
New physics?

- Suggestive of a new boson-mediated tree level $u\bar{u} \to t\bar{t}$ interfering with the SM gluon-mediated amplitude



Scalar-mediated A_{FB}

- Focus on intermediate scalar:



- Reps that can interfere with SM in $t\bar{t}$ production @ the Tevatron:

$$(\bar{6},1)_{-\frac{4}{3}},\ (\bar{6},1)_{-\frac{1}{3}},\ (\bar{6},3)_{-\frac{1}{3}},\ (3,1)_{-\frac{4}{3}},\ (3,1)_{-\frac{1}{3}},\ (3,3)_{-\frac{1}{3}},\ (8,2)_{-\frac{1}{2}},\ (1,2)_{-\frac{1}{2}}$$

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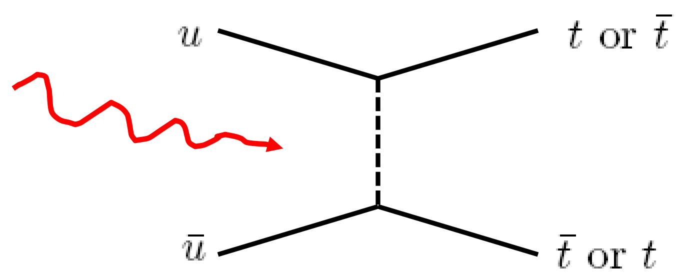

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- All colored reps in tension with other top-related measurements
- Focus on $\Phi(1,2)_{-1/2}$ with $m \sim 100\ \mathrm{GeV}$ and $\lambda_{ut\Phi} = \mathcal{O}(1)$

Flavor constraints

<u>Consider $\Phi(1,2)_{-1/2}$ with $m \sim 100\ \mathrm{GeV}$ and $\lambda_{ut\Phi} = \mathcal{O}(1)$:</u>

1) $\mathcal{L}_\Phi = 2\lambda\left(\phi^0 u_L^\dagger t_R + \phi^- V_{ui}^* d_{Li}^\dagger t_R + \mathrm{h.c.}\right)$ $\Longrightarrow$ $\Delta m_K^\Phi \gtrsim 10^3 \Delta m_K^{\mathrm{exp}}$ ✗

2) $\mathcal{L}_\Phi = 2\lambda\left(\phi^- d_L^\dagger t_R + \phi^0 V_{id} u_{Li}^\dagger t_R + \mathrm{h.c.}\right)$ $\Longrightarrow$ $\Delta m_D^\Phi \gtrsim 10^3 \Delta m_D^{\mathrm{exp}}$ ✗

3) $\mathcal{L}_\Phi = 2\lambda\left(\phi^0 t_L^\dagger u_R + \phi^- V_{ti}^* d_{Li}^\dagger u_R + \mathrm{h.c.}\right)$

$\Longrightarrow$ $\mathrm{BR}(\overline{B}^0 \to \pi^+ K-) \sim 200\ \mathrm{BR}(\overline{B}^0 \to \pi^+ K-)^{\mathrm{exp}}$ ✗

4) Focus on $\mathcal{L}_\Phi = 2\lambda\left(\phi^- b_L^\dagger u_R + \phi^0 V_{ib} u_{Li}^\dagger u_R + \mathrm{h.c.}\right)$ ✓

Collider (top) measurements

→ Single scalar representation

→ Flavor physics

→ Single Lagrangian configuration:

$$\mathcal{L}_\Phi = -V(\Phi) + 2\lambda\left[\phi^0 (U_L)_i^\dagger V_{ib} u_R + 2\phi^- b_L^\dagger u_R + \text{h.c.}\right]$$

(The $\bar{t}_L u_R$ coupling accounts for A_{FB})

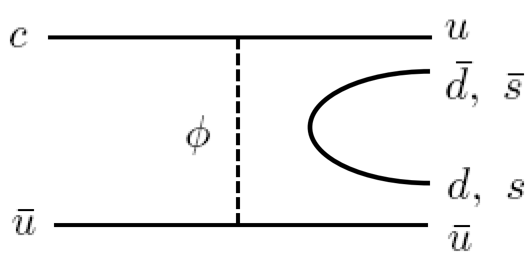
Flavor predictions

The Lagrangian: $\mathcal{L}_\Phi = -V(\Phi) + 2\lambda \left[\phi^0 (U_L)^\dagger_i V_{ib} u_R + 2\phi^- b^\dagger_L u_R + \text{h.c.} \right]$

- Has couplings $\lambda V_{cb} \phi^0 \bar{c}_L u_R + \lambda V_{ub} \phi^0 \bar{u}_L u_R$ that generate

$$\Longrightarrow \quad \frac{4|\lambda|^2}{m^2_{\phi^0}} V_{ub} V^*_{cb} (\bar{u}_R c_L)(\bar{u}_L u_R)$$

- This operator contributes via annihilation diagram to both $D^0 \to K^+ K^-$, $D^0 \to \pi^+ \pi^-$:



$(c\bar{u} \to u\bar{u})$

Scalar-mediated ΔA_{CP}

Predicts $\Delta A_{CP} = 2\sqrt{2}\,(G_0/G_F)\, I_{\rm CKM}\, I_{\rm QCD} \sim (2-7)\times 10^{-2} I_{\rm QCD}$

- factor 2 from the U-spin limit
- $G_0 \equiv 4|\lambda|^2/m^2_{\phi^0}$ and A_{FB} dictates $G_0/(G_F/\sqrt{2}) \sim 10-30$
- $I_{\rm CKM} \equiv 2\mathcal{I}m\left(\frac{V_{ub}V^*_{cb}}{V_{us}V^*_{cs}}\right) \sim 0.001$
- $I_{\rm QCD}$ = hadronic aspects of the decay

All EW parameters known

Scalar-mediated ΔA_{CP}

$$\Delta A_{CP} \sim 0.01$$

prediction of the model

Additional tests

- Large cross section for $ug \to t\phi^0$
- Leading decay modes $\phi^0 \to c\bar{u},\ \phi^0 \to u\bar{b}W$
- Contribution to 1b/2b in top production modes
- ϵ'/ϵ [Isidori, Kamenik, Ligeti, Perez, PLB 711 (2012), 46
- Top decay $t \to u\phi$
- Atomic parity violation [Gersham, Kim, Tulin, Zurek 1203.1320]
- Charge asymmetries
- Lepton threshold asymmetry [Falkowski, Perez, Schmaltz 1110.3796]
- Sum rules in charm data [Grossman, Kagan, Zupan 1204.3557]
- …

Supersymmetric ΔA_{CP}

Giudice, Isidori and Paradisi [1201.6204]
Hiller, YH and Nir [1204.1046], accepted to PRD

Supersymmetric ΔA_{CP}

Explaining $|\Delta A_{CP}| \sim 0.006$ via supersymmetry:

- Possible via large chromomagnetic operator

  Kagan, Grossman, Nir, PRD 75 (2007) 036008 $Q_{8g} = -\frac{g_s}{8\pi^2} m_c \bar{u} \sigma_{\mu\nu} (1+\gamma_5) T^a G_a^{\mu\nu} c$

- Large left-right mass insertion $\mathcal{I}m\left[(\delta_{LR})^u_{12}\right] \sim 0.001$

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- Typically in non-MFV supersymmetry: $(\delta^u_{LR})_{12} \sim \frac{\tilde{a}}{\tilde{m}} \frac{m_c |V_{us}|}{\tilde{m}}$
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(

Explaining $m_h \sim 125 \text{ GeV}$ with supersymmetry:

- Large $\tilde{a}/\tilde{m}$ favored

)

Supersymmetric ΔA_{CP}

Flavor models:

Parametric relations between different mass insertions

→ between different constraints

- ϵ'/ϵ : $\dfrac{(\delta^u_{LR})_{12}}{(\delta^d_{LR})_{12}} \sim \dfrac{m_c}{m_s}$
- EDMs: $\dfrac{\mathcal{I}m(\delta^u_{LR})_{12}}{\mathcal{I}m(\delta^q_{LR})_{11}} \sim \dfrac{m_c|V_{us}|}{m_q}, \quad (q=u,d)$

} O(1) factors, Hadronic uncertainties

$$\mathcal{I}m(\delta_{LR})^u_{12} \lesssim 10^{-4}$$

$\Delta A^{\rm SUSY}_{CP}$ of order a permil

Summary

Charm ΔA_{CP} -- NP?

- Scalar-mediated ΔA_{CP}
  - Top A_{FB} + flavor = ΔA_{CP} of order a percent
  - Signatures/tests
- Supersymmetric ΔA_{CP}
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  - ΔA_{CP} of order 10^{-3}

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SM or NP?
Examine NP candidates and their further deviations from the SM

Thanks!