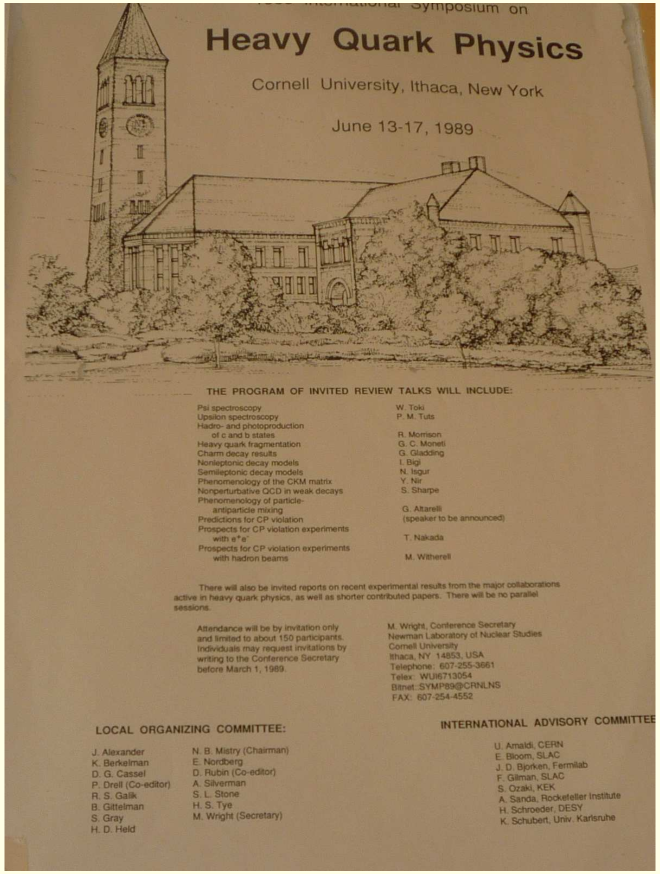
Flavorful Hadron Colliders

Lepp Particle Theory Seminar, Cornell University
7 September 2011

Yossi Nir (*Weizmann Institute of Science*)

Visiting Cornell



Symposium on

Heavy Quark Physics

Cornell University, Ithaca, New York

June 13-17, 1989

THE PROGRAM OF INVITED REVIEW TALKS WILL INCLUDE:

Psi spectroscopy	W. Toki
Upsilon spectroscopy	P. M. Tuts
Hadro- and photoproduction of c and b states	R. Morrison
Heavy quark fragmentation	G. C. Moneti
Charm decay results	G. Gladding
Nonleptonic decay models	I. Bigi
Semileptonic decay models	N. Isgur
Phenomenology of the CKM matrix	Y. Nir
Nonperturbative QCD in weak decays	S. Sharpe
Phenomenology of particle-antiparticle mixing	G. Altarelli
Predictions for CP violation	(speaker to be announced)
Prospects for CP violation experiments with e^+e^-	T. Nakada
Prospects for CP violation experiments with hadron beams	M. Witherell

There will also be invited reports on recent experimental results from the major collaborations active in heavy quark physics, as well as shorter contributed papers. There will be no parallel sessions.

Attendance will be by invitation only and limited to about 150 participants. Individuals may request invitations by writing to the Conference Secretary before March 1, 1989.

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- My first ever conference talk
- CDF report: Top quark excluded in the mass range 30 to 60 GeV

Thanks to my flavor and top collaborators:

Kfir Blum, Cédric Delaunay, Jonathan Feng, Sky French, Iftah Galon, Oram Gedalia, Eilam Gross, Daniel Grossman, Yuval Grossman, Gudrun Hiller, Yonit Hochberg, Gino Isidori, David Kirkby, Seung Lee, Christopher Lester, Zoltan Ligeti, Gilad Perez, David Sanford, Yael Shadmi, Yotam Soreq, Jesse Thaler, Ofer Vitells, Tomer Volansky, Felix Yu, Jure Zupan

Why is flavor physics interesting?

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

Plan of Talk

1. Flavor and $A_{\rm FB}^{t\bar{t}}$
2. ATLAS/CMS and flavor
3. (Flavor and $a_{\rm SL}^{b}$)

$$\boxed{A_{\mathrm{FB}}^{t\bar{t}}}$$

Blum, Hochberg, Nir, 1107.4350

Evidence for New Physics

- $A_{\mathrm{FB}}^{t\bar{t}} = \frac{\sigma(\cos\theta_{tp}>0)-\sigma(\cos\theta_{tp}<0)}{\sigma(\cos\theta_{tp}>0)+\sigma(\cos\theta_{tp}<0)}$
- The Standard Model:

  $A_{\mathrm{FB}}^{t\bar{t}}(M_{t\bar{t}} > 450\ \mathrm{GeV}) = 0.11^{+0.02}_{-0.01}$

  [Ahrens et al., 1106.6051]

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- CDF:

  $$\boxed{A_{\mathrm{FB}}^{t\bar{t}}(M_{t\bar{t}} > 450\ \mathrm{GeV}) = 0.47 \pm 0.10 \pm 0.05}$$

  [CDF, PRD 83, 112003 (2011)]

Hints for New Physics

$A_{\mathrm{FB}}^{t\bar{t}}$	SM	Exp
inclusive	0.07 ± 0.01	0.20 ± 0.05
$M_{t\bar{t}} > 450$ GeV	0.11 ± 0.02	0.47 ± 0.11
$M_{t\bar{t}} < 450$ GeV	0.05 ± 0.01	-0.11 ± 0.15
$\lvert\Delta y\rvert > 1.0$	0.15 ± 0.02	0.61 ± 0.26
$\lvert\Delta y\rvert < 1.0$	0.05 ± 0.01	0.03 ± 0.11

What New Physics?

- Order one modification to SM tree-level strong-interaction
- Enhanced $A_{\mathrm{FB}}^{t\bar{t}} \Leftrightarrow$ No substantial changes in $\sigma_{\mathrm{total}}^{t\bar{t}}$

$$\Downarrow$$

- Interference effect with tree-level electroweak-scale NP
- New vector-boson or new scalar that mediates $u\bar{u} \to t\bar{t}$
- If scalar – it must have an off-diagonal (up-top) coupling

Scalar-mediated $u\bar{u} \to t\bar{t}$

- The possible $SU(3) \times SU(2) \times U(1)$ representations:
  - $(3, 1)_{-4/3}$
  - $(\bar{6}, 1)_{-4/3}$
  - $(3, 1)_{-1/3}$
  - $(\bar{6}, 1)_{-1/3}$
  - $(3, 3)_{-1/3}$
  - $(\bar{6}, 3)_{-1/3}$
  - $(8, 2)_{-1/2}$
  - $(1, 2)_{-1/2}$
- Only three relevant parameters: m_Φ, $\lambda_{\Phi ut}$, (Γ_Φ)
- Sign of leading interference terms, and possibility of forward kinematical features, dictated purely by color representation

Scalar-mediated $u\bar{u} \to t\bar{t}$

- $\sigma_h \equiv \sigma^{t\bar{t}}(700\ \text{GeV} < M_{t\bar{t}} < 800\ \text{GeV})$
  $N_h \equiv |\sigma_h^{\rm NP}|/\sigma_h^{\rm SM}$
  $N_h < 1$

- $\sigma_i \equiv \sigma^{t\bar{t}}_{\rm inclusive}$
  $N_i \equiv \sigma_i^{\rm NP}/\sigma_i^{\rm SM}$
  $-0.1 < N_i < +0.3$

When enhancing the forward-backward asymmetry to
$A_h \equiv A_{\rm FB}^{t\bar{t}}(M_{t\bar{t}} > 450\ \text{GeV}) > 0.20$:

- All colored representations (triplet, sextet, octet) in severe tension with the measured differential $t\bar{t}$ producton cross section: $N_h > 1$ and/or $N_i > 0.3$ or < -0.1

$\Phi(1,2)_{-1/2}$-mediated $u\bar{u} \to t\bar{t}$

Only $\Phi(1,2)_{-1/2}$ can enhance A_h while being consistent with $\sigma_{h,i}$

- $m_\phi \lesssim 130$ GeV
- $|\lambda_{\phi\bar{u}t}| \gtrsim 0.6$

- $\sigma(gu \to t\phi)$ large
  Consistency with single top (tbX) production?
  Work in progress

$\Phi(1,2)_{-1/2}$ and flavor

$$\begin{aligned}\mathcal{L}_{\Phi,u} &= 2\Phi Q_{Li}^{\dagger} X_{ij} u_{Rj} + \text{h.c.} \\ &= 2\phi^{0} u_{Li}^{\dagger} X_{ij} u_{Rj} + 2\phi^{-} d_{Li}^{\dagger} (V^{\dagger} X)_{ij} u_{Rj} + \text{h.c.}\end{aligned}$$

- $\lambda_{\phi \bar{u} t} = X_{13}$ or X_{31} must be $\mathcal{O}(1)$
- Cannot avoid ϕ-mediated FCNC simultaneously in the up and the down sectors
- "Minimum flavor damage":
  A single X_{ij} entry in the up mass basis ("*up alignment*")
  or a single $(V^{\dagger} X)_{ij}$ in the down mass basis ("*down alignment*")

$X_{13} = \mathcal{O}(1)$, up-alignment

- $\mathcal{L}_{\Phi,u} = 2\phi^0 u_{Li}^\dagger X_{ij} u_{Rj} + 2\phi^- d_{Li}^\dagger (V^\dagger X)_{ij} u_{Rj} + \mathrm{h.c.}$
- Align in the up mass basis ($\phi^0 \bar{u}_L t_R$):

$$X = \lambda \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \; ; \quad V^\dagger X = \lambda \begin{pmatrix} 0 & 0 & V_{ud}^* \\ 0 & 0 & V_{us}^* \\ 0 & 0 & V_{ub}^* \end{pmatrix}$$

- $t + \phi^-$ contribution to $K^0 - \overline{K}^0$ mixing enhanced by $\left|\frac{V_{ud}V_{us}}{V_{td}V_{ts}}\right|^2 \sim 10^5$ compared to the SM $t + W^-$ contribution

$$\Delta m_K \implies |\lambda|^4 \mathcal{F}\left(\frac{m_t^2}{m_\phi^2}\right) < 4 \times 10^{-4} \left(\frac{m_\phi}{250\ \mathrm{GeV}}\right)^2$$

- $\boxed{\text{Excluded as an explanation of } A_{\mathrm{FB}}^{t\bar{t}}}$

$X_{13} = \mathcal{O}(1)$, down-alignment

- $\mathcal{L}_{\Phi,u} = -2\phi^0 u^\dagger_{Li} X_{ij} u_{Rj} + 2\phi^- d^\dagger_{Li} (V^\dagger X)_{ij} u_{Rj} + \mathrm{h.c.}$
- Align in the down mass basis ($\phi^- \bar{b}_L t_R$):

$$X = \lambda \begin{pmatrix} 0 & 0 & V_{ud} \\ 0 & 0 & V_{cd} \\ 0 & 0 & V_{td} \end{pmatrix} \; ; \quad V^\dagger X = \lambda \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

- ϕ^0-mediated contribution to $D^0 - \overline{D}^0$ mixing enhanced by $\left| \frac{V_{ud} V_{cd}}{V_{ub} V_{cb}} \right|^2 \sim 10^6$ compared to the SM W-mediated contribution

$$\Delta m_D \implies |\lambda|^4 \mathcal{F}\left(\frac{m_t^2}{m_\phi^2}\right) < 2.7 \times 10^{-4} \left(\frac{m_\phi}{250\ \mathrm{GeV}}\right)^2$$

- $\boxed{\text{Excluded as an explanation of } A_{\mathrm{FB}}^{t\bar{t}}}$

$X_{31} = \mathcal{O}(1)$, up-alignment

- $\mathcal{L}_{\Phi,u} = 2\phi^0 u_{Li}^\dagger X_{ij} u_{Rj} + 2\phi^- d_{Li}^\dagger (V^\dagger X)_{ij} u_{Rj} + \mathrm{h.c.}$
- Align in the up mass basis ($\phi^0 \bar{t}_L u_R$):

$$X = \lambda \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} ; \quad V^\dagger X = \lambda \begin{pmatrix} V_{td}^* & 0 & 0 \\ V_{ts}^* & 0 & 0 \\ V_{tb}^* & 0 & 0 \end{pmatrix}$$

- ϕ^--mediated contribution to $b \to u\bar{u}s$ enhanced by $\left|\frac{V_{tb}V_{ts}}{V_{ub}V_{us}}\right|^2 \sim 2500$ compared to the SM W-mediated contribution

$$\mathrm{BR}(\overline{B}^0 \to \pi^+ K^-) \implies |\lambda|^2 < 0.06 \left(\frac{m_\phi}{250\ \mathrm{GeV}}\right)^2$$

- $\boxed{\text{Excluded as an explanation of } A_{\mathrm{FB}}^{t\bar{t}}}$

$X_{31} = \mathcal{O}(1)$, down-alignment

- $\mathcal{L}_{\Phi,u} = 2\phi^0 u^\dagger_{Li} X_{ij} u_{Rj} + 2\phi^- d^\dagger_{Li} (V^\dagger X)_{ij} u_{Rj} + \text{h.c.}$
- Align in the down mass basis ($\phi^- \bar b_L u_R$):

$$X = \lambda \begin{pmatrix} V_{ub} & 0 & 0 \\ V_{cb} & 0 & 0 \\ V_{tb} & 0 & 0 \end{pmatrix} ; \quad V^\dagger X = \lambda \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$$

- No ϕ-mediated contributions to $\Delta m_{K,B,B_s}$ and to B-decays

  Suppressed contributions to Δm_D

- The only viable explanation of $A_{\rm FB}^{t\bar t}$

$\Phi(1,2)_{-1/2}$-mediated $d\bar{d} \to t\bar{t}$?

- $\mathcal{L}_{\Phi,d} = 2\widetilde{\Phi} Q^{\dagger}_{Li} \widetilde{X}_{ij} d_{Rj} + \text{h.c.}$
- $\widetilde{\lambda}_{\phi dt} = \widetilde{X}_{31}$ must be $\mathcal{O}(1)$ to play a role

$\widetilde{X}_{31} = \mathcal{O}(1)$, up-alignment

- $\mathcal{L}_{\Phi,d} = 2\phi^+ u^\dagger_{Li}\widetilde{X}_{ij}d_{Rj} - 2\phi^{0*}d^\dagger_{Li}(V^\dagger\widetilde{X})_{ij}d_{Rj} + \text{h.c.}$
  $\mathcal{L}_{\Phi,u} = 2\phi^0 u^\dagger_{Li}X_{ij}u_{Rj} + 2\phi^- d^\dagger_{Li}(V^\dagger X)_{ij}u_{Rj} + \text{h.c.}$
- Align in the up mass basis ($\phi^+\bar{t}_L d_R$):

$$\widetilde{X} = \widetilde{\lambda}\begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}\ ; \quad V^\dagger\widetilde{X} = \widetilde{\lambda}\begin{pmatrix} V^*_{td} & 0 & 0 \\ V^*_{ts} & 0 & 0 \\ V^*_{tb} & 0 & 0 \end{pmatrix}$$

- ϕ^0-mediated contribution to $b \to d\bar{d}s$ enhanced by $\left|\frac{V_{tb}V_{ts}}{V_{ub}V_{us}}\right|^2 \sim 2500$ compared to the SM W-mediated contribution

  $\text{BR}(B^- \to \pi^-\overline{K}^0) \implies |\widetilde{\lambda}|^2 < 0.07\left(\frac{m_\phi}{250\ \text{GeV}}\right)^2$

- Cannot play a significant role in $A_{\rm FB}^{t\bar{t}}$

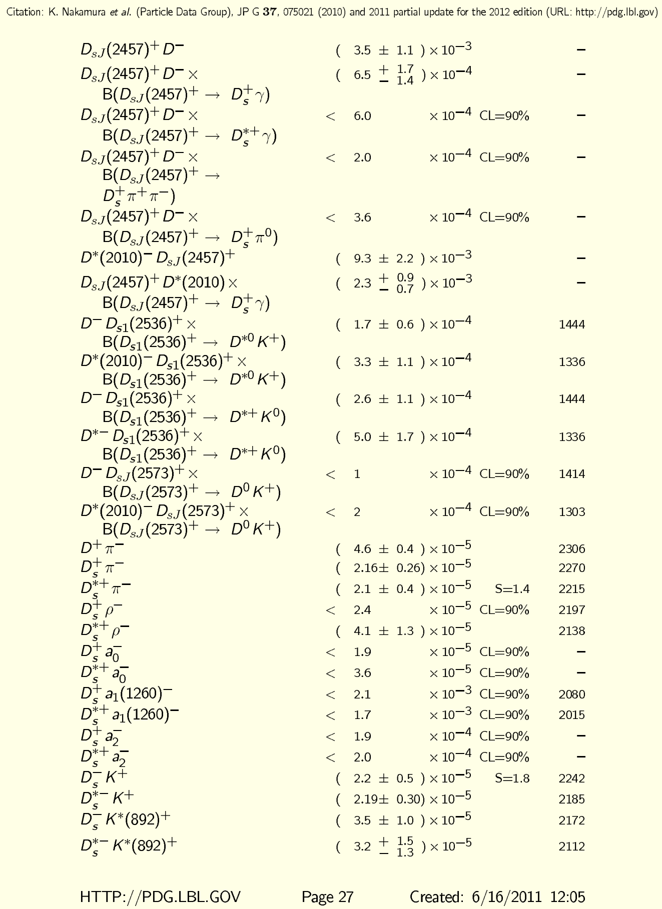
$\widetilde{X}_{31} = \mathcal{O}(1)$, down-alignment

- $\mathcal{L}_{\Phi,d} = 2\phi^+ u^\dagger_{Li} \widetilde{X}_{ij} d_{Rj} - 2\phi^{0*} d^\dagger_{Li} (V^\dagger \widetilde{X})_{ij} d_{Rj} + \text{h.c.}$
- Align in the down mass basis ($\phi^0 \bar{b}_L d_R$):

$$X = \lambda \begin{pmatrix} V_{ub} & 0 & 0 \\ V_{cb} & 0 & 0 \\ V_{tb} & 0 & 0 \end{pmatrix} ; \quad V^\dagger \widetilde{X} = \widetilde{\lambda} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$$

- When X_{31} and $\widetilde{X}_{31}$ are both of $\mathcal{O}(1)$:
  ϕ^0-mediated contribution to $b \to u\bar{c}d$ enhanced by $\left|\frac{V_{cb}}{V_{ub}V_{cd}}\right|^2 \sim 2500$ compared to the SM W-mediated contribution, but $\text{BR}(B^+ \to D^{*+}\pi^0) < 10\text{BR}(B^+ \to D^{*+}\pi^0)^{\rm SM}$
- $\boxed{\widetilde{X}_{31} \text{ cannot play a role in } A_{\rm FB}^{t\bar{t}}}$

Read the small letters



Citation: K. Nakamura *et al.* (Particle Data Group), JP G **37**, 075021 (2010) and 2011 partial update for the 2012 edition (URL: http://pdg.lbl.gov)

$D_{sJ}(2457)^+ D^-$	$(3.5 \pm 1.1) \times 10^{-3}$		–
$D_{sJ}(2457)^+ D^- \times$ $B(D_{sJ}(2457)^+ \rightarrow D_s^+ \gamma)$	$(6.5 {}^{+1.7}_{-1.4}) \times 10^{-4}$		–
$D_{sJ}(2457)^+ D^- \times$ $B(D_{sJ}(2457)^+ \rightarrow D_s^{*+} \gamma)$	$< 6.0 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+ D^- \times$ $B(D_{sJ}(2457)^+ \rightarrow$ $D_s^+ \pi^+ \pi^-)$	$< 2.0 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+ D^- \times$ $B(D_{sJ}(2457)^+ \rightarrow D_s^+ \pi^0)$	$< 3.6 \times 10^{-4}$	CL=90%	–
$D^*(2010)^- D_{sJ}(2457)^+$	$(9.3 \pm 2.2) \times 10^{-3}$		–
$D_{sJ}(2457)^+ D^*(2010) \times$ $B(D_{sJ}(2457)^+ \rightarrow D_s^+ \gamma)$	$(2.3 {}^{+0.9}_{-0.7}) \times 10^{-3}$		–
$D^- D_{s1}(2536)^+ \times$ $B(D_{s1}(2536)^+ \rightarrow D^{*0} K^+)$	$(1.7 \pm 0.6) \times 10^{-4}$		1444
$D^*(2010)^- D_{s1}(2536)^+ \times$ $B(D_{s1}(2536)^+ \rightarrow D^{*0} K^+)$	$(3.3 \pm 1.1) \times 10^{-4}$		1336
$D^- D_{s1}(2536)^+ \times$ $B(D_{s1}(2536)^+ \rightarrow D^{*+} K^0)$	$(2.6 \pm 1.1) \times 10^{-4}$		1444
$D^{*-} D_{s1}(2536)^+ \times$ $B(D_{s1}(2536)^+ \rightarrow D^{*+} K^0)$	$(5.0 \pm 1.7) \times 10^{-4}$		1336
$D^- D_{sJ}(2573)^+ \times$ $B(D_{sJ}(2573)^+ \rightarrow D^0 K^+)$	$< 1 \times 10^{-4}$	CL=90%	1414
$D^*(2010)^- D_{sJ}(2573)^+ \times$ $B(D_{sJ}(2573)^+ \rightarrow D^0 K^+)$	$< 2 \times 10^{-4}$	CL=90%	1303
$D^+ \pi^-$	$(4.6 \pm 0.4) \times 10^{-5}$		2306
$D_s^+ \pi^-$	$(2.16 \pm 0.26) \times 10^{-5}$		2270
$D_s^{*+} \pi^-$	$(2.1 \pm 0.4) \times 10^{-5}$	S=1.4	2215
$D_s^+ \rho^-$	$< 2.4 \times 10^{-5}$	CL=90%	2197
$D_s^{*+} \rho^-$	$(4.1 \pm 1.3) \times 10^{-5}$		2138
$D_s^+ a_0^-$	$< 1.9 \times 10^{-5}$	CL=90%	–
$D_s^{*+} a_0^-$	$< 3.6 \times 10^{-5}$	CL=90%	–
$D_s^+ a_1(1260)^-$	$< 2.1 \times 10^{-3}$	CL=90%	2080
$D_s^{*+} a_1(1260)^-$	$< 1.7 \times 10^{-3}$	CL=90%	2015
$D_s^+ a_2^-$	$< 1.9 \times 10^{-4}$	CL=90%	–
$D_s^{*+} a_2^-$	$< 2.0 \times 10^{-4}$	CL=90%	–
$D_s^- K^+$	$(2.2 \pm 0.5) \times 10^{-5}$	S=1.8	2242
$D_s^{*-} K^+$	$(2.19 \pm 0.30) \times 10^{-5}$		2185
$D_s^- K^*(892)^+$	$(3.5 \pm 1.0) \times 10^{-5}$		2172
$D_s^{*-} K^*(892)^+$	$(3.2 {}^{+1.5}_{-1.3}) \times 10^{-5}$		2112

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- $B^0 \to D^+\pi^- = \bar{b} \to c\bar{u}d$ transition
- Not a measurement!
- Belle measure $\mathrm{BR}(B^0 \to D_s^+\pi^-)$...
- ... and then use theory:
  $\mathrm{BR}_{D^0} = \mathrm{BR}_{D_s} (f_D/f_{D_s})^2 \tan^2\theta_C$.

[Belle, PRD 82, 051103 (2010)]

Summary

- 8 possible scalar reps relevant to $A_{\mathrm{FB}}^{t\bar{t}}$; Only $\Phi(1,2)_{-1/2}$ can enhance $A_h > 0.2$ and remain consistent with $\sigma^{t\bar{t}}$
- $m_\phi \lesssim 130$ GeV, $\quad |\lambda_{\phi u t}| \gtrsim 0.6$
- Two types of couplings of Φ can contribute to $u\bar{u} \to t\bar{t}$: $X_{13} q_{L1}^\dagger \Phi t_R$ and $X_{31} q_{L3}^\dagger \Phi u_R$:
  1. $X_{13} = \mathcal{O}(1)$ excluded by $K^0 - \overline{K}^0$ and/or $D^0 - \overline{D}^0$ mixing
  2. Generic $X_{31} = \mathcal{O}(1)$ excluded by BR$(B \to \pi K)$
  3. $X_{31} = \mathcal{O}(1)$ viable only if carefully aligned so that ϕ^- couples only to b_L (but not to s_L and d_L)
- The flavor constraints might be circumvented if the contributions to flavor changing processes cancel against contributions from additional scalar doublets – MFV?
  Grinstein, Kagan, Zupan, Trott, 1108.4027

Flavor at ATLAS/CMS

Feng, Lester, Nir, Shadmi *et al.*, PRD77(2008)076002; PRD80(2009)114004; JHEP01(2010)047

Experimentalists: Flavor at ATLAS/CMS???

- ATLAS/CMS are not optimized for flavor

Experimentalists: Flavor at ATLAS/CMS???

- ATLAS/CMS are not optimized for flavor

But...

- They can identify $e, \mu, (\tau)$
- They can tell 3rd generation quarks (b, t) from light quarks

Theorists: Flavor at ATLAS/CMS???

- The scale of flavor dynamics is unknown
- Very likely, it is well above the LHC direct reach

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- The scale of flavor dynamics is unknown
- Very likely, it is well above the LHC direct reach

But...

- If new particles that couple to the SM fermions are discovered –
  $\Longrightarrow$ New flavor parameters can be measured
  - Spectrum (degeneracies?)
  - Flavor decomposition (alignment?)
- In combination with flavor factories, we may...
  - Understand how the NP flavor puzzle is (not) solved
    $\Longrightarrow$ Probe NP at $\Lambda_{\rm NP} \gg TeV$
  - Get hints about the solution to the SM flavor puzzle

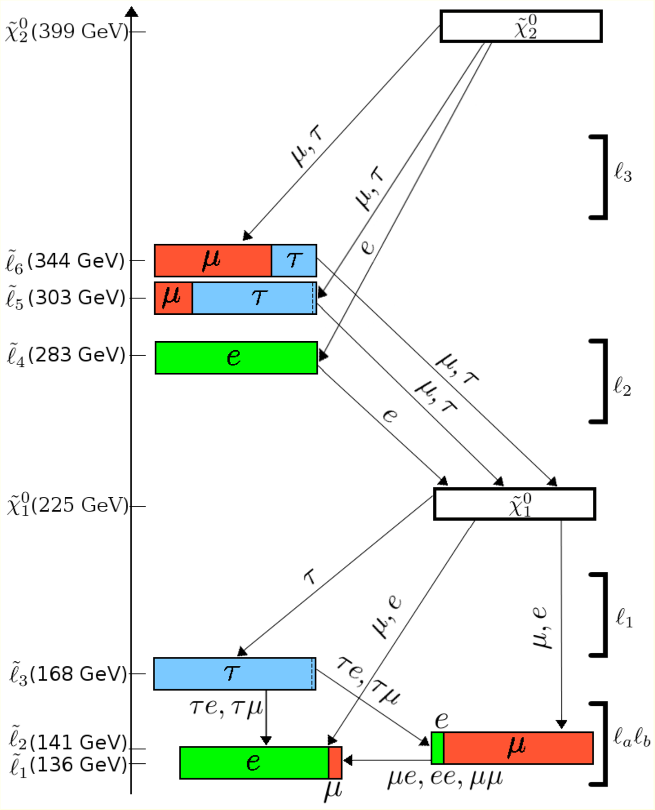
Gauge+Gravity Mediation

- Example: High (but not too high) scale gauge mediation
  - Gravity mediation sub-dominant but non-negligible
  - $r = \frac{\text{gravity}-\text{med}}{\text{gauge}-\text{med}} \sim \left(\frac{\pi m_M}{\alpha m_P}\right)^2 \frac{1}{n_M}$
  - $\widetilde{M}^2_{\tilde{E}_{L,R}}(m_M) = \tilde{m}^2_{\tilde{E}_{L,R}}(\mathbf{1} + rX_{\tilde{E}_{L,R}})$
  - $\boxed{\text{Degeneracy depends on } r}$

Assume: The flavor structure of X determined by FN:

- $X_{\tilde{E}_L} \sim \begin{pmatrix} 1 & U_{e2} & U_{e3} \\ \cdot & 1 & U_{\mu 3} \\ \cdot & \cdot & 1 \end{pmatrix}; \quad X_{\tilde{E}_R} \sim \begin{pmatrix} 1 & \frac{m_e/m_\mu}{U_{e2}} & \frac{m_e/m_\tau}{U_{e3}} \\ \cdot & 1 & \frac{m_\mu/m_\tau}{U_{\mu 3}} \\ \cdot & \cdot & 1 \end{pmatrix}$
- $\boxed{\text{Mixing depends only on } X \text{ which is related to the SM flavor}}$

SUSY flavor parameters from $\tilde{\ell}_1, e, \mu$



	True	Measured
$\tilde{\ell}_1$	135.83 GeV	135.9 ± 0.1 GeV
χ_1^0	224.83 GeV	225.10 ± 0.04 GeV
$\Delta m(\tilde{\ell}_{1,2})$	4.95 GeV	5.06 ± 0.06 GeV
$\tilde{\ell}_4$	282.86 GeV	283.1 ± 0.2 GeV
$\tilde{\ell}_5$	303.41 GeV	306 ± 1 GeV
$\tilde{\ell}_6$	343.53 GeV	341 ± 1 GeV
$\lvert K_{e2}/K_{\mu 2}\rvert^2$	0.069	0.054 ± 0.008

[Feng, Lester, Nir, Shadmi *et al.*, PRD77(2008)076002; PRD80(2009)114004; JHEP01(2010)047]

Lessons from $\tilde{\ell}_1, e, \mu$

- Determine Δm_{21} and $\sin\theta_{12}$:
  It is consistent with $\mu \to e\gamma$?
  How the SUSY flavor problem is solved
- Determine Δm_{21}, Δm_{54}, $\ldots$:
  What is messenger scale of gauge mediation (M_m)?
  Probe physics at $M_m \sim 10^{15}$ GeV
- Determine $|K_{e2}/K_{\mu 2}|$:
  Is the FN mechanism at work?
  How the SM flavor puzzle is solved

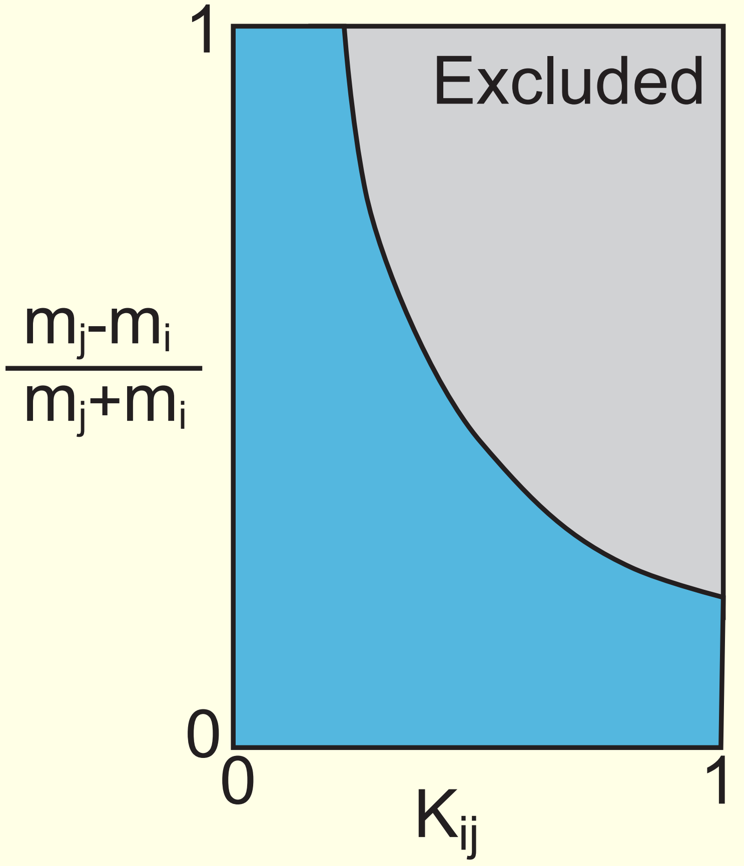
The role of flavor factories (FF)

ATLAS/CMS and flavor factories give complementary information

- In the absence of NP at ATLAS/CMS:
  flavor factories will be crucial to find Λ_{NP}
- Consistency between ATLAS/CMS and FF:
  necessary to understand the NP flavor puzzle
- NP in $c \to u$? $s \to d$? $b \to d$? $b \to s$? $t \to c$? $t \to u$?
  $\mu \to e$? $\tau \to \mu$? $\tau \to e$?
  - MFV?
  - Structure related to SM?
  - Structure unrelated to SM?
  - Anarchy?

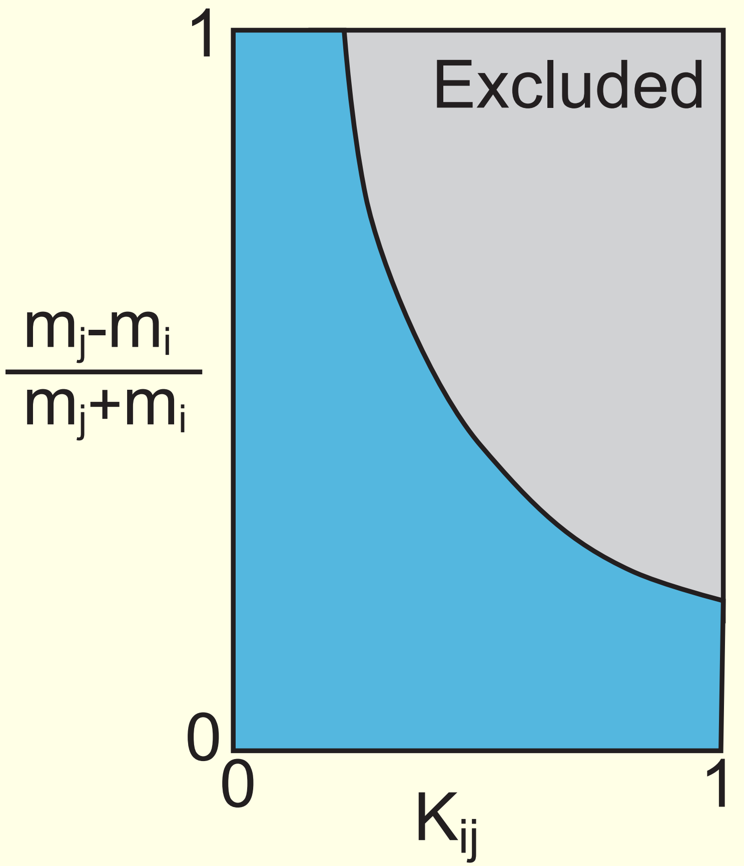
[Hiller, Hochberg, Nir, JHEP0903(09)115; JHEP1003(10)079]]

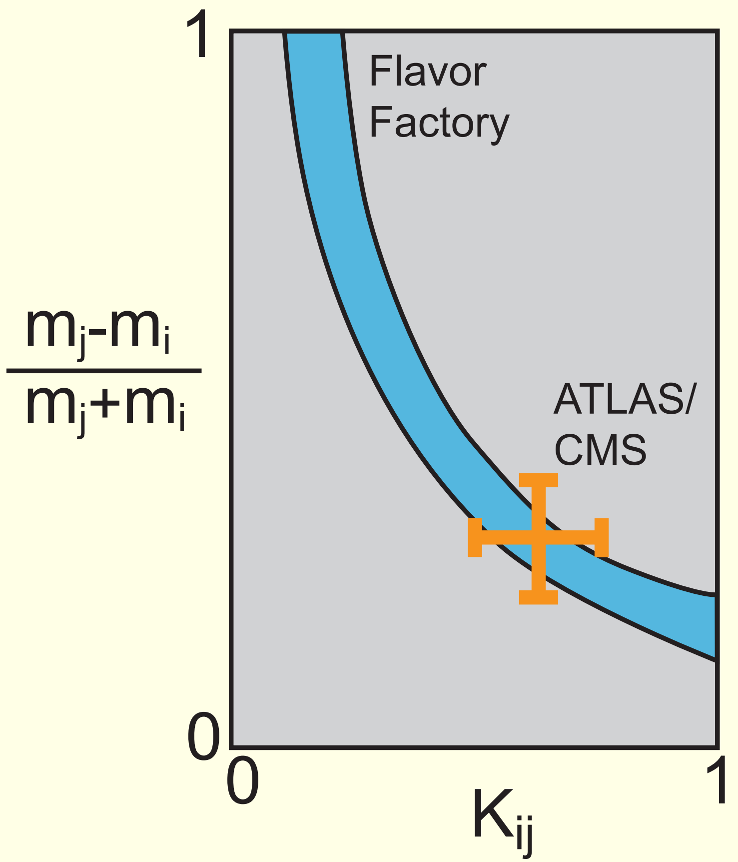
Summary



Flavor Factories

Summary





Flavor Factories

FF+ATLAS/CMS

[Grossman, Ligeti, Nir, PTP122(09)125 [0904.4262]]

Conclusions

- If ATLAS/CMS discover new particles that couple to the SM quarks and/or leptons, they can measure new flavor parameters
- We will probably understand how the NP flavor puzzle is solved
- Surprisingly, we may even make progress on the SM flavor puzzle

- If either or both of $A_{\rm FB}^{t\bar t}$ and $A_{\rm SL}^{b}$ are true $\Longrightarrow$ new bosons with elctroweak-scale masses and order one couplings to quarks
- A surprising flavor structure is implied:
  MFV with the new bosons in a non-singlet flavor rep?
  Something completely different?

$$\boxed{A^b_{\rm SL}}$$

Blum, Hochberg, Nir, JHEP 09 (2010) 035

Evidence for New Physics

- $A^b_{\rm SL} = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$
- The Standard Model:

  $A^b_{\rm SL} = -(2.8 \pm 0.5) \times 10^{-4}$

  [Lenz and Niesrte, JHEP 0706, 072 (2007)]

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- D0:

  $$\boxed{A^b_{\rm SL} = -(7.9 \pm 1.7 \pm 0.9) \times 10^{-3}}$$

  [D0, 1106.6308; PRD82,032001 (2010)]

Hints for New Physics?

	SM	Exp	
$A^b_{\rm SL}$	-0.00028 ± 0.00005	-0.008 ± 0.002	D0
$A^d_{\rm SL}$	-0.0006 ± 0.0002	-0.005 ± 0.005	HFAG
$\phi_s(B_s \to J/\psi\phi)$	-0.036 ± 0.002	$+0.13 \pm 0.18 \pm 0.07$	LHCb
$\phi_s(B_s \to J/\psi f^0)$	-0.036 ± 0.002	$-0.44 \pm 0.44 \pm 0.02$	LHCb

Four-quark operators

$$\mathcal{H}_{\rm eff}^{\Delta B=\Delta S=2} = \frac{1}{\Lambda^2}\left(\sum_{i=1}^{5} z_i Q_i + \sum_{i=1}^{3} \tilde{z}_i \widetilde{Q}_i\right)$$

$$\begin{aligned}
Q_1^{sb} &= \bar{b}_L^\alpha \gamma_\mu s_L^\alpha \bar{b}_L^\beta \gamma_\mu s_L^\beta, \quad \widetilde{Q}_1^{sb} = \bar{b}_R^\alpha \gamma_\mu s_R^\alpha \bar{b}_R^\beta \gamma_\mu s_R^\beta, \\
Q_2^{sb} &= \bar{b}_R^\alpha s_L^\alpha \bar{b}_R^\beta s_L^\beta, \quad \widetilde{Q}_2^{sb} = \bar{b}_L^\alpha s_R^\alpha \bar{b}_L^\beta s_R^\beta, \\
Q_3^{sb} &= \bar{b}_R^\alpha s_L^\beta \bar{b}_R^\beta s_L^\alpha, \quad \widetilde{Q}_3^{sb} = \bar{b}_L^\alpha s_R^\beta \bar{b}_L^\beta s_R^\alpha, \\
Q_4^{sb} &= \bar{b}_R^\alpha s_L^\alpha \bar{b}_L^\beta s_R^\beta, \quad Q_5^{sb} = \bar{b}_R^\alpha s_L^\beta \bar{b}_L^\beta s_R^\alpha
\end{aligned}$$

$$\boxed{A_{\rm SL}^b \implies \Lambda \lesssim 700~\text{TeV}}$$

MFV

- $\tilde{z}_i$ highly suppressed;

$$\begin{aligned}\frac{z_1}{y_t^4(V_{ts}V_{tb}^*)^2} &= r_1^+ - r_1^- y_b^2,\\ \frac{z_{2,3}}{y_t^4(V_{ts}V_{tb}^*)^2} &= r_{2,3}(v^2/\Lambda^2)y_b^2,\\ \frac{z_{4,5}}{y_t^4(V_{ts}V_{tb}^*)^2} &= r_{4,5}^+ y_b y_s - r_{4,5}^- y_b^3 y_s\end{aligned}$$

- $r^+_{1,4,5}$ - real

- $\boxed{A^b_{\rm SL} \implies \Lambda_{\rm MFV} \lesssim 500\ \text{GeV}\ \tan\beta}$

MFV + small tan β

- If $y_b \ll 1$: Only $Q_{2,3}$ can give large CPV in $B_s - \overline{B}_s$ mixing
- $\boxed{A^b_{\rm SL} \implies \Lambda_{Q_2} \lesssim 250\ {\rm GeV}\ \sqrt{\tan\beta}}$
- Further predictions:
  $S_{\psi K} \approx S^{\rm SM}_{\psi K} - 0.15 \approx 0.65 \pm 0.05$
  $S_{\psi\phi} \approx S^{\rm SM}_{\psi\phi} + 0.25 \approx 0.25 \pm 0.06$
- Most likely, tree-level exchange of a scalar

CP violation as a probe of New Physics

The size of new MFV effects on CP violating observables:

	$y_b \sim 1$			$y_b \ll 1$		
i	$S_{\psi\phi}$	$S_{\psi K}$	ϵ_K	$S_{\psi\phi}$	$S_{\psi K}$	ϵ_K
1	small	small	large	small	small	large
2,3	large	large	small	large	large	small
4,5	large	small	large	small	small	large

- A-priori, seven different patterns
- Four would exclude MFV: SLL, SLS, LSS, LLL
- Within MFV:
  LLS $\Longrightarrow$ $Q_{2,3}$, LSL $\Longrightarrow$ $Q_{4,5}$+large $\tan\beta$, SSL $\Longrightarrow$ $Q_{1,4,5}$