Enhanced $B_d^0 \to \mu^+\mu^-$ Decay: What if?

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Enhanced $B_d^0 \to \mu^+\mu^-$ Decay: What if?

If observed ≳ 4 x 10^{-10} (2011-2012 data!),
then the 126 GeV boson might not be the Higgs.

4G回馬槍?!

I. Intro: from Straub to Stone

Mild Motivation: sin2Φ_{Bd} ≡ sin2β/ϕ_1 tension

II. Constraints & Formulas

Δm_{B_d} and $B^+ \to \pi^+\mu^+\mu^-$

III. Pheno Results with t'-in-loop

IV. Discussion

b → d quadrangle; CKM hierarchy implication

V. Conclusion

WSH, Kohda, Xu, 1302.1471, to appear PRD

I. Intro: from Straub to Stone

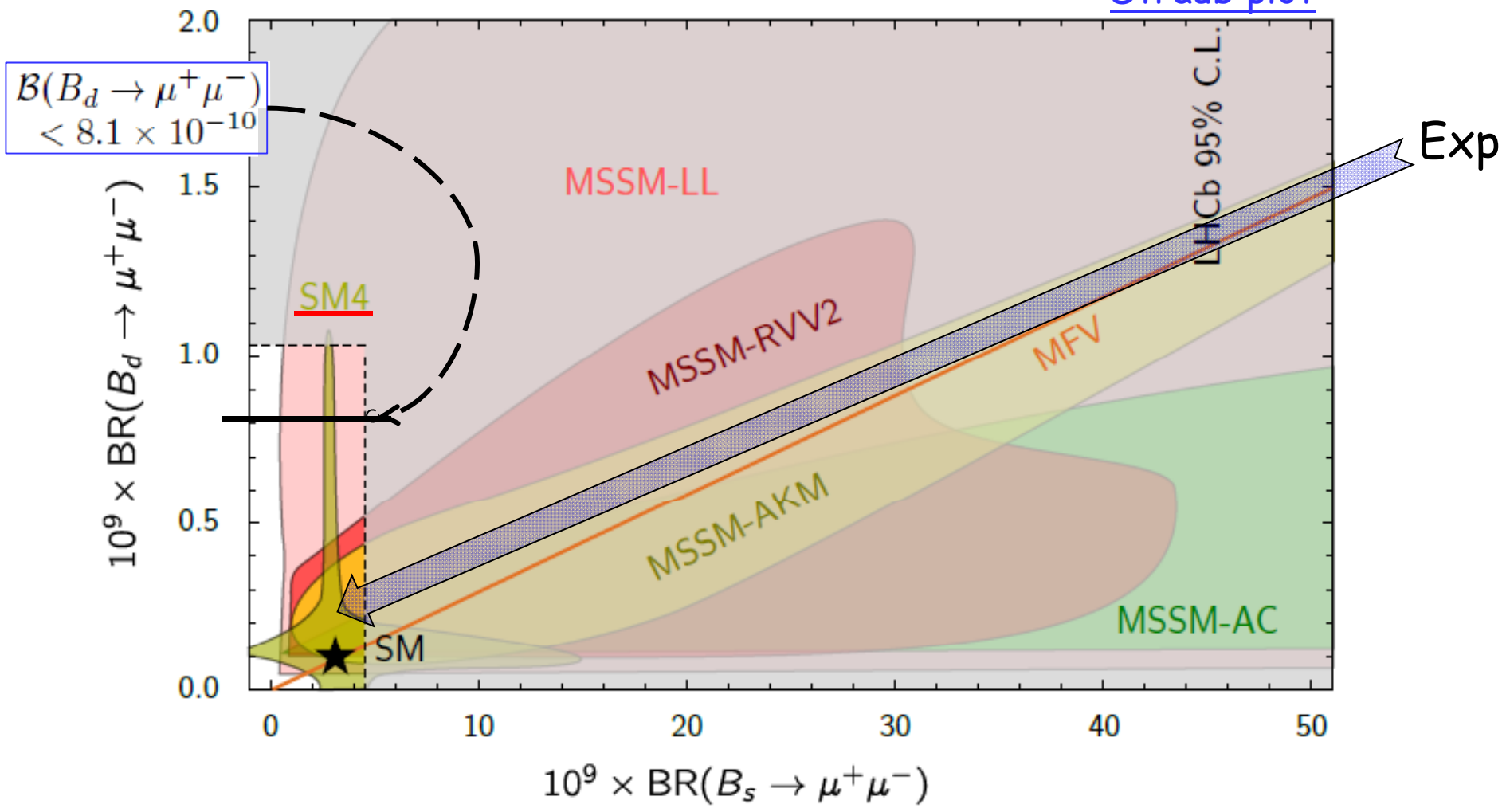
but, last chance for New Physics in flavor sector at LHC8

Mild Motivation: $\sin 2\Phi_{B_d} \equiv \sin 2\beta/\phi_1$ tension

Disappointment: No New Physics

the $\sin\phi_s$ destroyer-of-hope ...

"Straub plot"



David Straub (SNS & INFN, Pisa) Moriond EW Session, 2012

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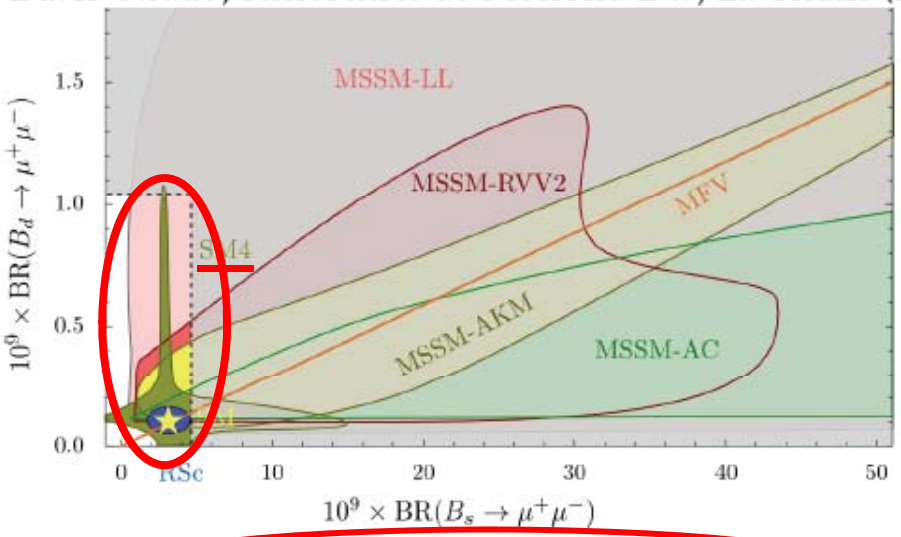
Sheldon Stone @ ICHEP2012

Implications II

David Straub, Rencontres de Moriond EW, La Thuile (2012)



The 125 GeV Higgs observations kills off 4th generation models as the production cross-section would be 9x larger & decays to $\gamma\gamma$ suppressed

ICHEP, Melbourne, July 9, 2012 39

R.I.P.

However, SM Higgs is flavor-blind

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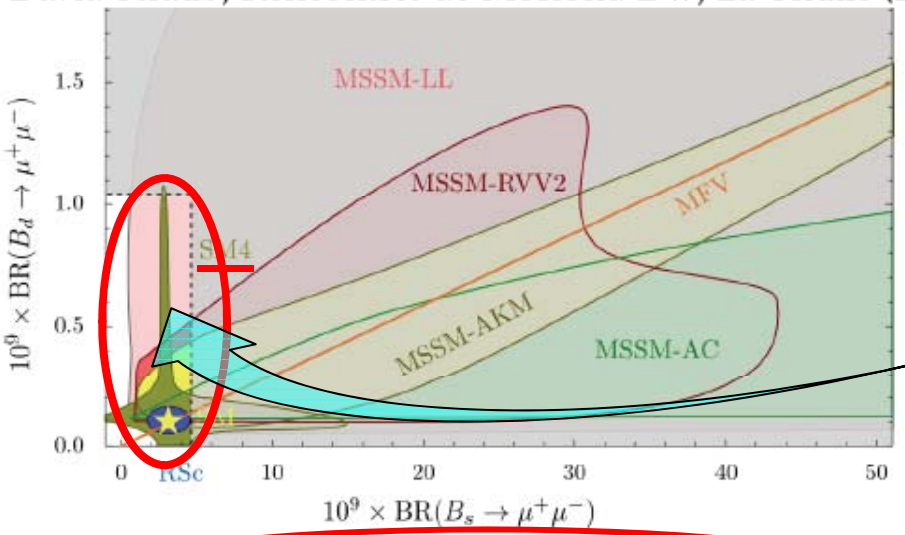

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Flavor people should keep CKM-extension in mind.

Higgs does not enter these loops;

and, 126 GeV boson could be "dilaton" still ...

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Keep on Searching w/ Gusto!

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last chance for New Physics in flavor sector at LHC8

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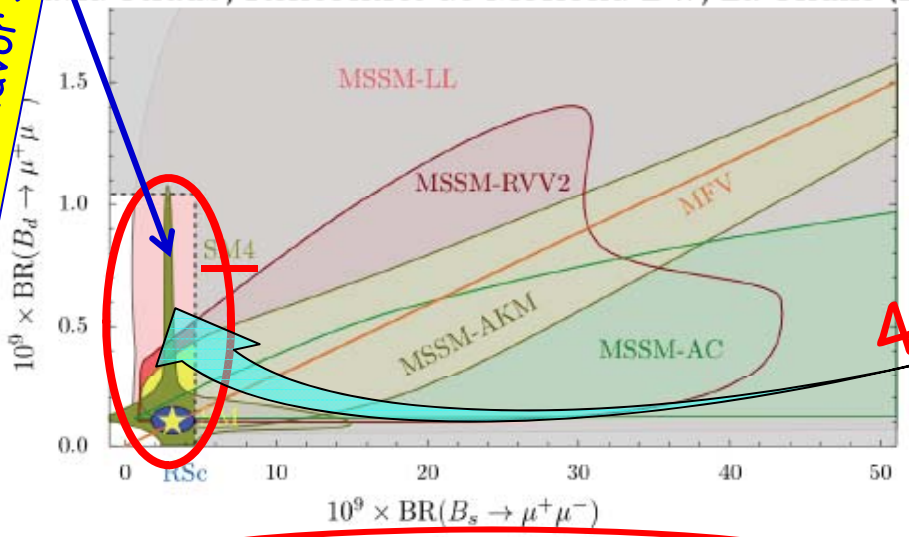

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N.B. For 4G dynamical EWSB that permits dilaton, see Mimura, WSH, Kohyama, 1206.6063

Mild Motivation: $\sin 2\Phi_{B_d} \equiv \sin 2\beta/\phi_1$ tension

Lunghi & Soni, '08; Buras & Guadagnoli, '08

- $\sin 2\beta/\phi_1 = 0.679 \pm 0.020$ — Direct Measurement

- $\sin 2\beta/\phi_1 = \begin{cases} 0.76 & \text{for } |V_{ub}|^{\text{ave}} \\ 0.63 & \text{for } |V_{ub}|^{\text{excl}} \end{cases}$ — Indirect from other meas.

arg

$$\lambda_t^{\rm SM} = -\lambda_u - \lambda_c \simeq -|V_{ud}||V_{ub}|e^{-i\phi_3} + |V_{cd}||V_{cb}|$$

taking $|V_{ud}| = 0.974,\ |V_{cd}| = 0.23$ and $|V_{cb}| = 0.041$

$$\phi_3 = (68^{+11}_{-10})^\circ$$

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parameterize t'-effect to alieviate tension

$$\lambda_t = \lambda_t^{\rm SM} - \lambda_{t'}$$

$V^*_{t'd}V_{t'b}$

$$\lambda_u + \lambda_c + \lambda_t + \lambda_{t'} = 0$$

$$\lambda_{t'} = r_{db}\, e^{i\phi_{db}}$$

Constrain

II. Constraints & Formulas

Δm_{B_d} and $\boxed{B^+ \to \pi^+ \mu^+ \mu^-}$

LHCb 2012: rarest B decay measured

N.B. $b \to d\gamma$ hard to separate from $b \to s\gamma$,
hard for LHCb, and insensitive to 4G.
$B \to \pi\pi$ much hadronic effect.

$$\Delta m_{B_d} \simeq \frac{G_F^2 M_W^2}{6\pi^2} m_{B_d} \hat{B}_{B_d} f_{B_d}^2 \eta_B |\Delta_{12}^d|,$$
$$\sin 2\Phi_{B_d} \simeq \sin(\arg \Delta_{12}^d),$$

sin2β/ϕ_1

$$\Delta_{12}^d \equiv (\lambda_t^{\rm SM})^2 S_0(x_t)$$
$$+ 2\lambda_t^{\rm SM}\lambda_{t'}\Delta S_0^{(1)} + \lambda_{t'}^2 \Delta S_0^{(2)}$$

Remaining hadronic uncertainty

t'-effect

$$\Delta S_0^{(1)} \equiv \tilde{S}_0(x_t, x_{t'}) - S_0(x_t),$$
$$\Delta S_0^{(2)} \equiv S_0(x_{t'}) - 2\tilde{S}_0(x_t, x_{t'}) + S_0(x_t),$$
$$x_i = m_i^2/M_W^2$$

$$\hat{\mathcal{B}}(B_d \to \mu^+\mu^-) \equiv \frac{\mathcal{B}(B_d \to \mu^+\mu^-)}{\Delta m_{B_d}} \Delta m_{B_d}^{\rm exp}$$
$$= C \frac{\tau_{B_d} \Delta m_{B_d}^{\rm exp}}{\hat{B}_{B_d}} \frac{\eta_Y^2}{\eta_B} \frac{\left|\lambda_t^{\rm SM} Y_0(x_t) + \lambda_{t'} \Delta Y_0\right|^2}{|\Delta_{12}^d|}$$

Ratio w/ Box

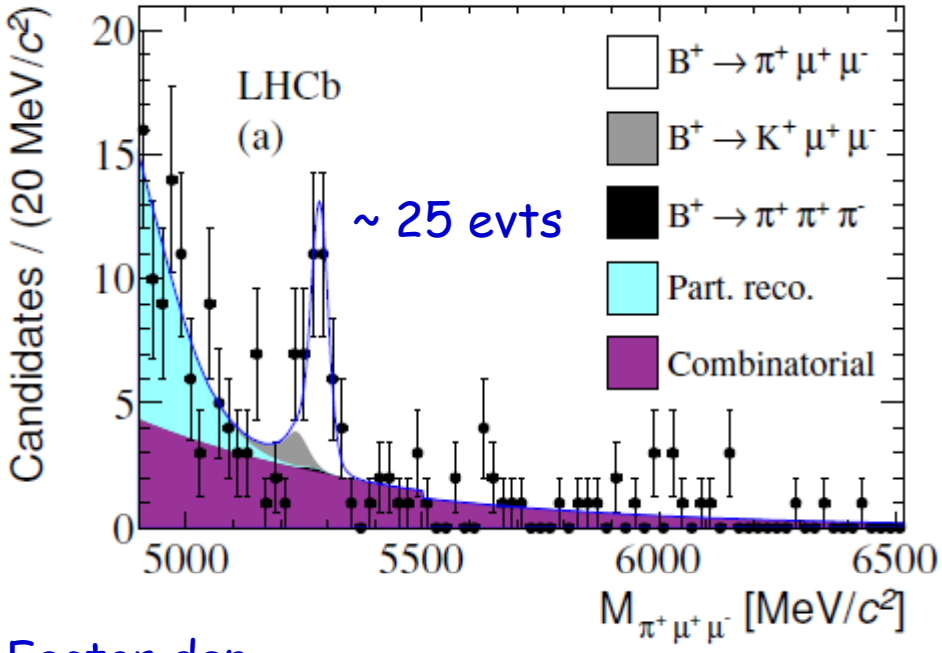
Buras '03

$$\Delta Y_0 = Y_0(x_{t'}) - Y_0(x_t)$$
$$C = 6\pi \left(\frac{\alpha}{4\pi \sin^2\theta_W}\right)^2 \frac{m_\mu^2}{M_W^2}$$

$$(2.3 \pm 0.6\ (\text{stat.}) \pm 0.1\ (\text{syst.})) \times 10^{-8}$$

LHCb, JHEP 2012

first observation of $B^+ \to \pi^+\mu^+\mu^-$ $b \to d\ell^+\ell^-$ transition



$1.0\,\text{fb}^{-1}$

To reduce Form Factor dep.

$$R_{\pi\mu\mu} \equiv \frac{\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)|_{4G}}{\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)|_{SM}}$$

integrated from $q^2 = (1,\ 6)\ \text{GeV}^2$

better numerical control

- W.C. @ NLO
- LO amplitude in QCDF

Beneke, Feldmann, Seidel, '01, '03

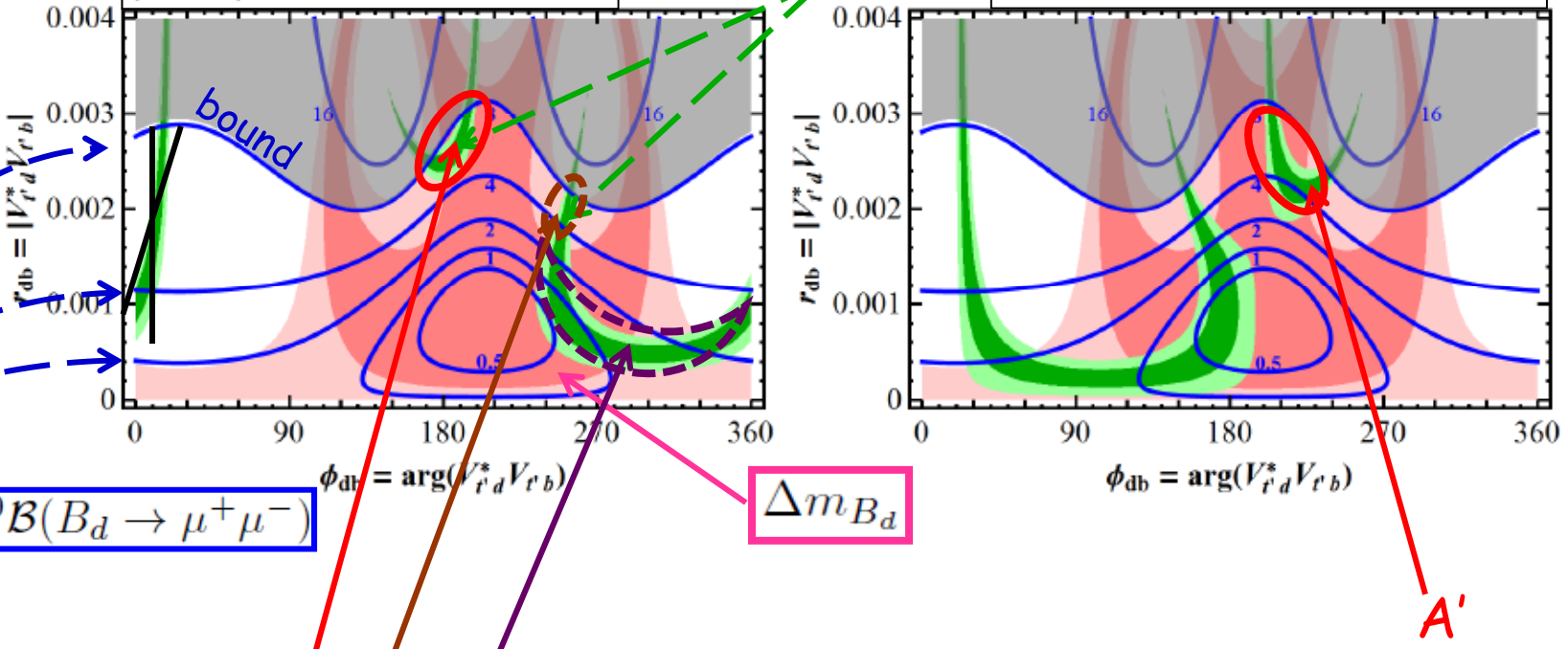
Will plot contours to 2x - 3x

otherwise LHCb could tell?

III. Pheno Results with t'-in-loop

$m_{t'} = 700$ GeV [LHC bound

~ incl. $|V_{ub}| = 4.15 \times 10^{-3}$ $\sin 2\Phi_{B_d}$ $|V_{ub}| \sim 3.23 \times 10^{-3}$ excl.



Regions A, B & C: A & B give $B_d \to \mu^+\mu^-$ > 4x SM
C gives broad cresent in phase

A point each from A & A' is taken for later illustration

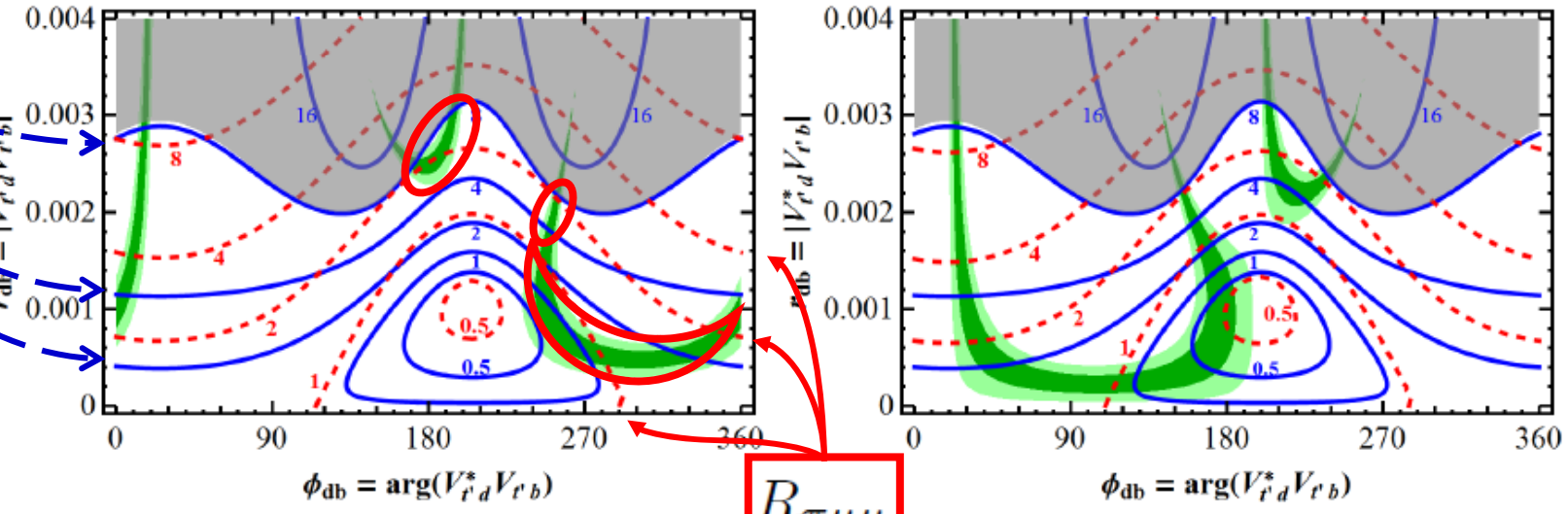
$m_{t'} = 700\ \mathrm{GeV}$ [LHC bound

~ incl. $|V_{ub}| = 4.15 \times 10^{-3}$ $|V_{ub}| \sim 3.23 \times 10^{-3}$ excl.

The 3 Regions survive $R_{\pi\mu\mu} \lesssim 2$ – 3 Constraint!

$$R_{\pi\mu\mu} \equiv \frac{\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)|_{\rm 4G}}{\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)|_{\rm SM}}$$

$10^{10}\mathcal{B}(B_d \to \mu^+\mu^-)$



$R_{\pi\mu\mu}$

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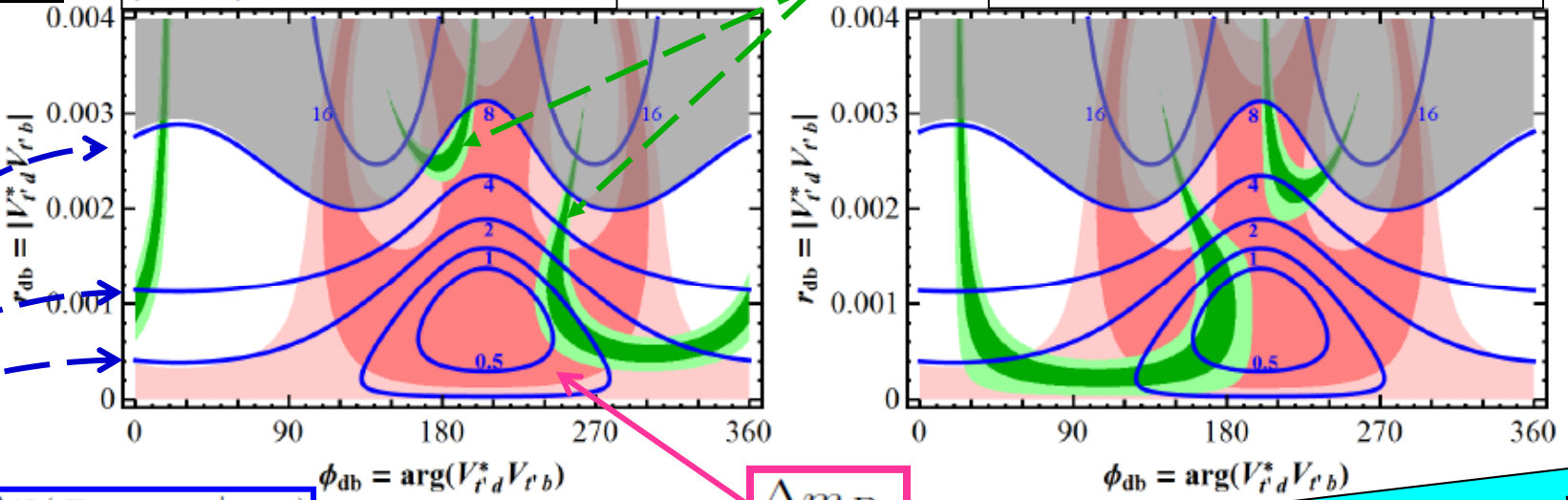
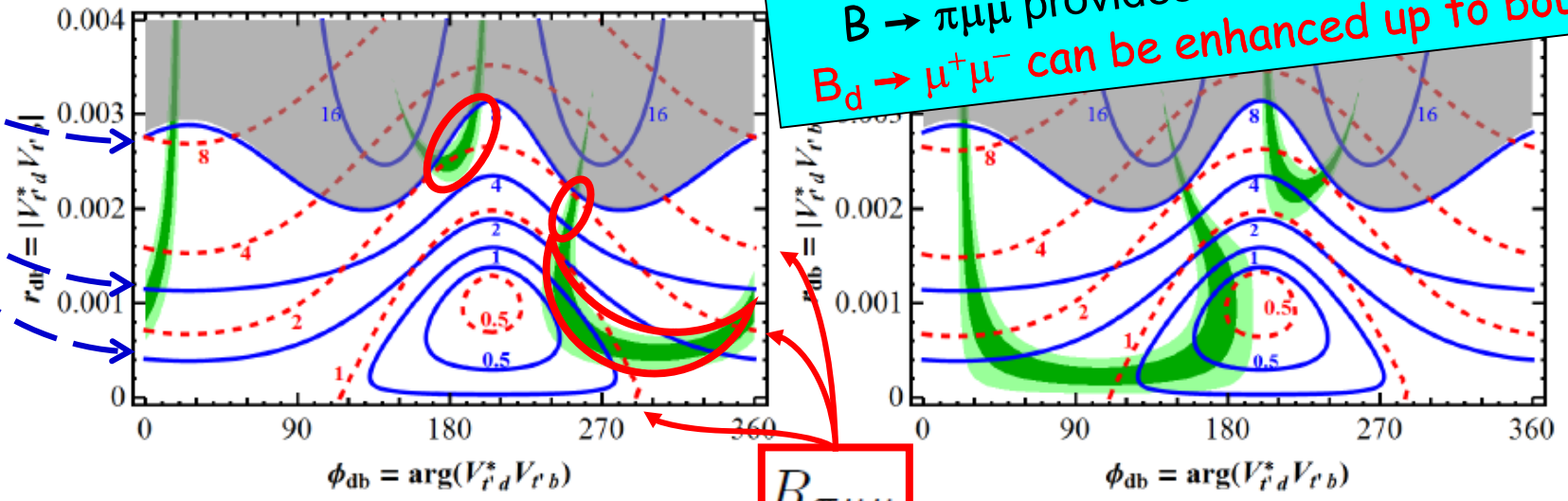


Δm_{B_d}

$10^{10}\mathcal{B}(B_d \to \mu^+\mu^-)$

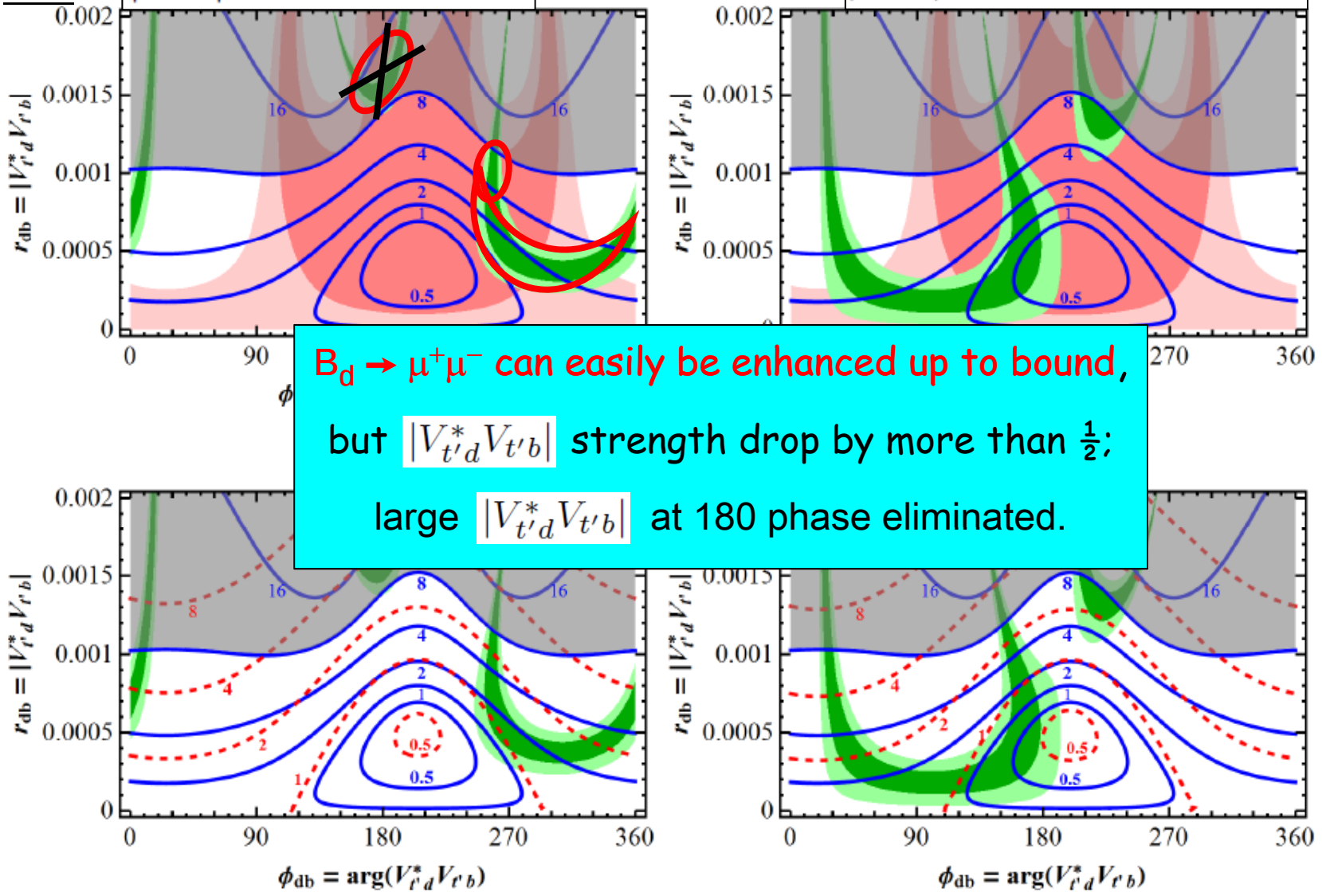


$R_{\pi\mu\mu}$

B → πμμ provides useful sanity check;
$B_d \to \mu^+\mu^-$ can be enhanced up to bound

$m_{t'} = 1000$ GeV [far beyond unitarity bound

~ incl. $|V_{ub}| = 4.15 \times 10^{-3}$ $|V_{ub}| \sim 3.23 \times 10^{-3}$ excl.



$B_d \to \mu^+\mu^-$ can easily be enhanced up to bound,

but $|V^*_{t'd}V_{t'b}|$ strength drop by more than $\frac{1}{2}$;

large $|V^*_{t'd}V_{t'b}|$ at 180 phase eliminated.

IV. Discussion

b → d quadrangle

CKM hierarchy implication

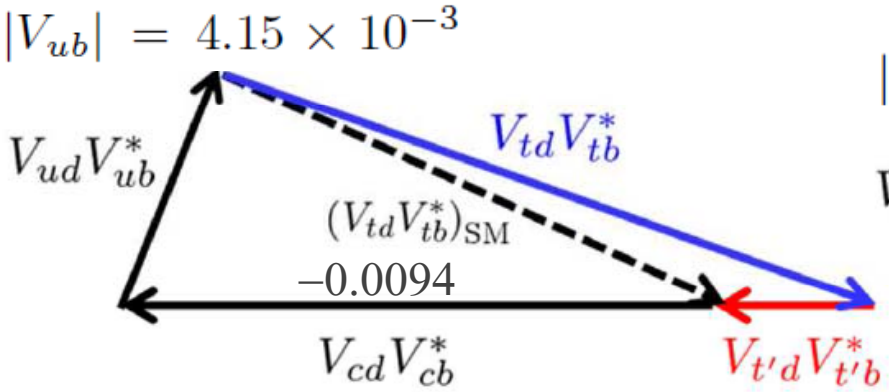
Discussion on CKM4

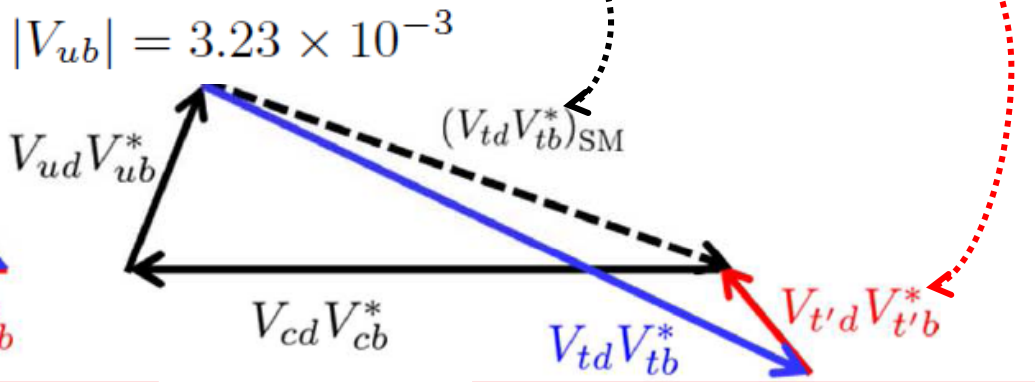
CPV4BAU?

- b → d quadrangle in our lap!

$$\lambda_u + \lambda_c + \lambda_t + \lambda_{t'} = 0$$

$$-\lambda_t^{\rm SM}$$





from: Region A $V_{t'd}^* V_{t'b} = 0.0025\, e^{i180^\circ}$

A' $V_{t'd}^* V_{t'b} = 0.0023\, e^{i230^\circ}$

- The above CKM4 values are quite large. [$V_{t'b} < 0.1$ necessary] WSH & Ma, PRD'11

  If we learn from $\sin\phi_s$ experience [CKM hierarchy seem upheld], then $B_d \to \mu^+\mu^-$ > 4x SM is possible, but not particularly likely.

  Heavier t' could still do it with more "naturally" small CKM4.

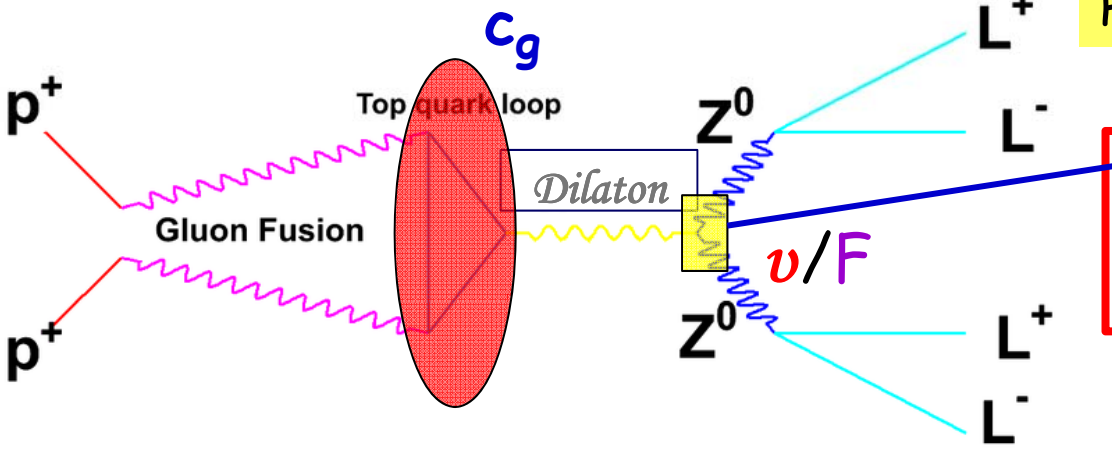
V. Conclusion

- 2013 Pivotal: If $B_d \to \mu^+\mu^- > 4x$ SM, We Will Discover It!
  Certainly in expt'l range, and w/ some $\sin 2\Phi_{Bd}$ motivation.
  Chance is finite, but not large, because of CKM hierarchy.

- If discovery with 2011-2012 data, then
  - Uplifting 4G (hopes again for CPV4BAU), but only in loop ...
  - Cast doubt on "the Higgs" — turning "it" into New Physics?
  - Theorist might scramble, but will need much fine-tuning ...

- If Discovery, Great !!
  More Likely: LHC (CMS+LHCb+...) pushes down towards SM ...
  Still Needs to Be Pursued with 13 TeV.

How does *Dilaton* rescue the situation ?



$H \to ZZ^* \to ee\mu\mu$

no convincing evidence
for VBF (Vector Boson Fusion)
or VH (Higgsstrahlung off V) so far

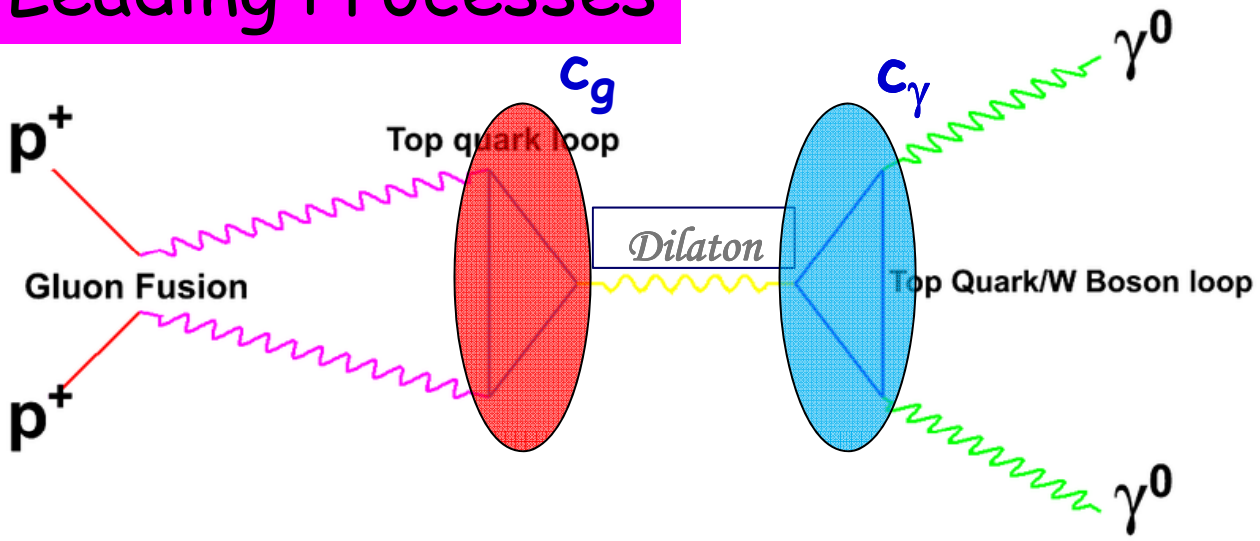
➜ *Dilaton* not ruled out!

Elander, Piai, 8/12

Treat 3 parameters

v/F, c_g, c_γ

Leading Processes



$H \to \gamma\gamma$