Dimuon CP Asymmetry in B decays

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Z.Ligeti, M.P., G.Perez, J.Zupan, PRL 105 (2010) 131601

Rencontres de Moriond
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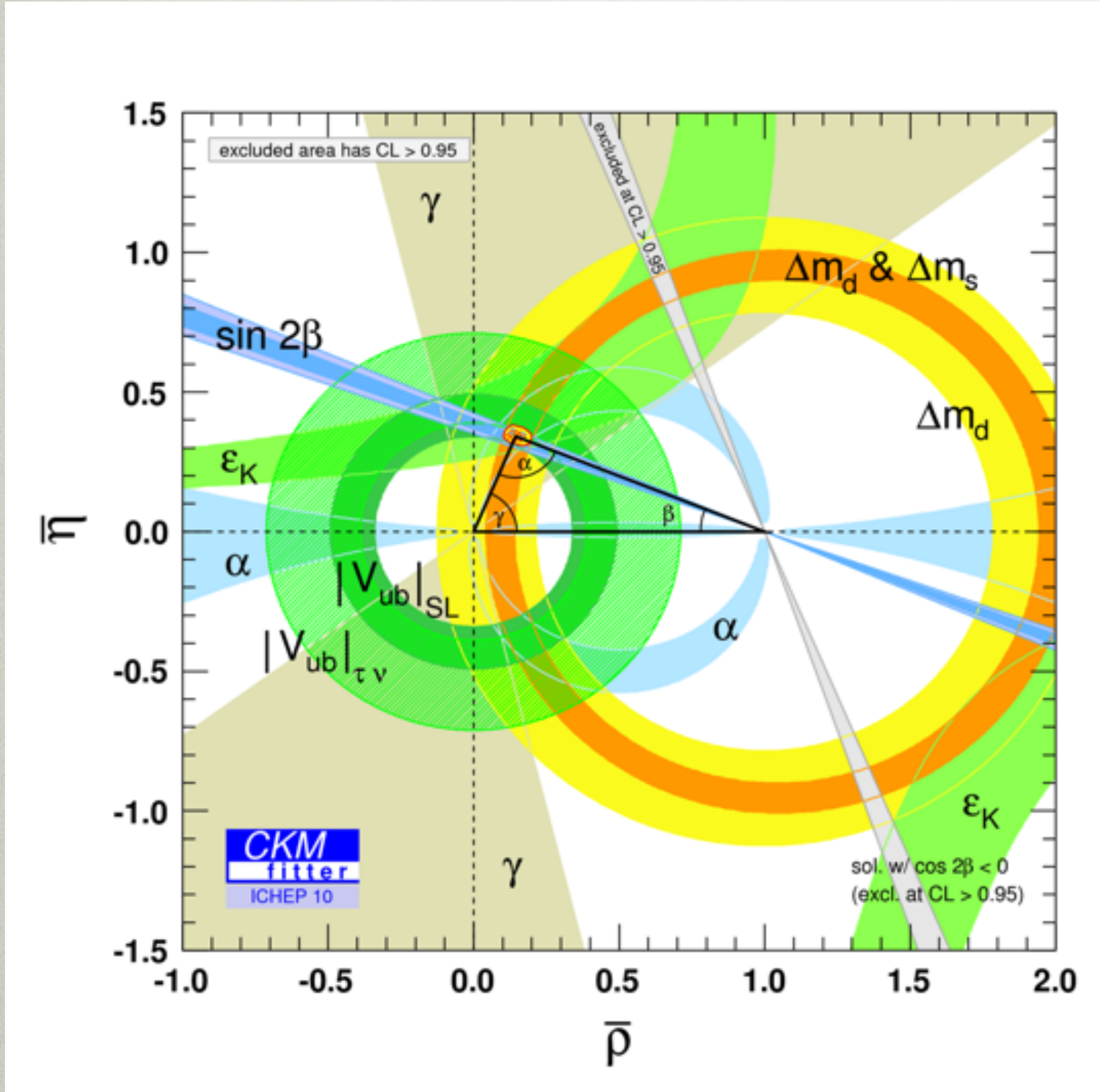
Outline

- Brief introduction to CP viol′ in neutral $B_{(s)}$ meson systems
  - D∅ di-muon charge asymmetry
  - CP viol′ in $B_s \to J/\psi\phi$
- Implications for Physics Beyond the SM
- Conclusions

(See also U. Nierste talk this morning)

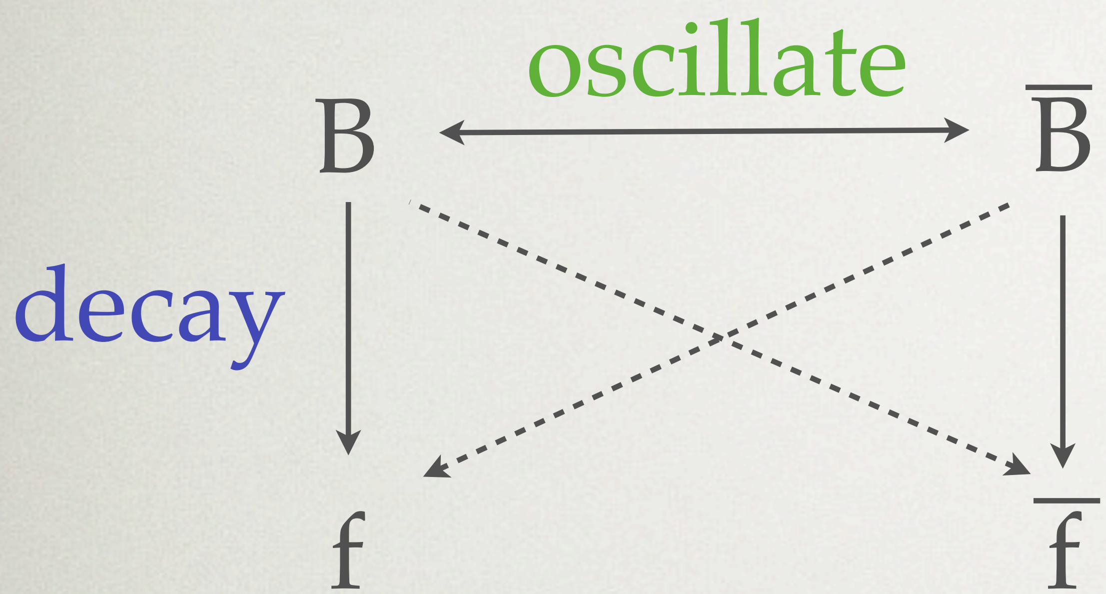
Experim. Status: the SM

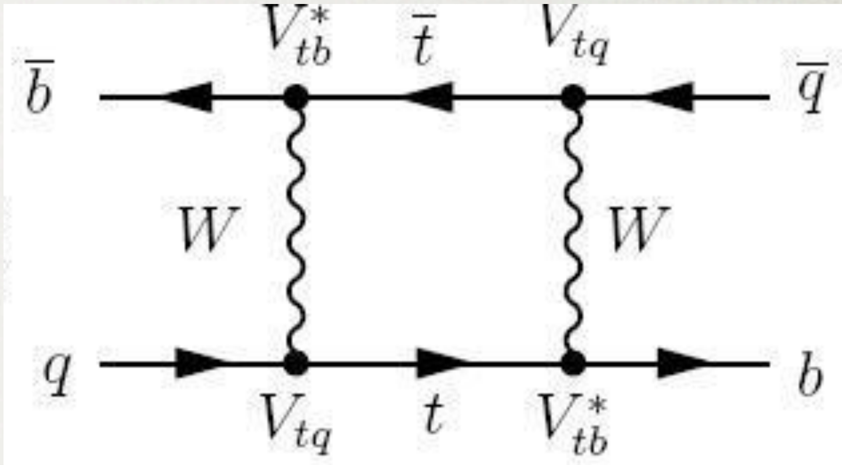


- SM agrees with data
- CKM unitarity well tested → triangle closes!
- Non-degenerate triangle → CP violation!
- Now look for deviations as sign of New Physics

FCNCs @ 1-loop → small in the SM → good places to look for NP

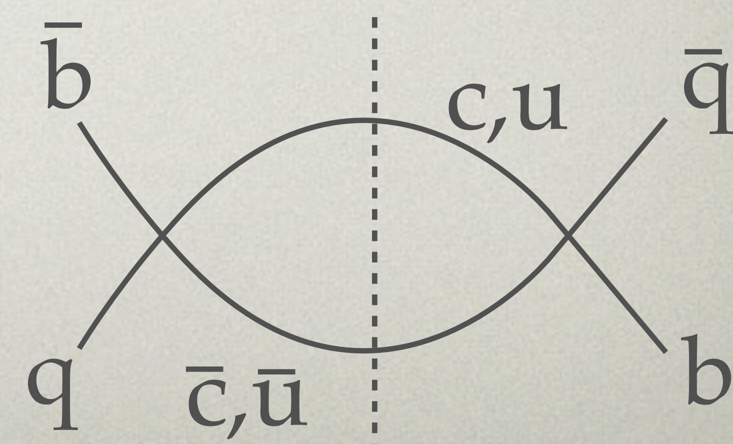
CP violation in $B_{(s)}$-$\bar{B}_{(s)}$ system





- Oscillations ($\Delta m \neq 0$): dispersive part (short distance)

- Width difference: absorptive part (long distance)



CP violation in $B_{(s)}$-$\bar{B}_{(s)}$ system

$$\begin{tikzcd} B \arrow[rr, leftrightarrow, "\text{oscillate}"] \arrow[d, "\text{decay}"'] & & \bar{B} \arrow[d] \\ f & & \bar{f} \end{tikzcd}$$

$$\mathcal{A}_{flav.spec.} \equiv \frac{\Gamma(B \to f) - \Gamma(\bar{B} \to \bar{f})}{\Gamma(B \to f) + \Gamma(\bar{B} \to \bar{f})}$$

- $B \to \mu\, \nu\, X$, $e\, \nu\, X$ (tree level $W^{\pm}$ exchange, no CP viol')

$$\mathcal{A}_{SL} \equiv \mathcal{A}_{flav.spec.}$$

CP violation in $B_{(s)}$-$\overline{B}_{(s)}$ system

$$\begin{tikzcd}
B \arrow[rr, leftrightarrow, "\text{oscillate}"] \arrow[d, "\text{decay}"'] & & \overline{B} \arrow[dll] \\
f=\overline{f} & &
\end{tikzcd}$$

Probes CP viol' in the interference between mixing and decay:

$$\mathcal{A}_{f_{CP}}(t) = \frac{d\Gamma/dt\left[\bar{B} \to f_{CP}\right] - d\Gamma/dt\left[B \to f_{CP}\right]}{d\Gamma/dt\left[\bar{B} \to f_{CP}\right] + d\Gamma/dt\left[B \to f_{CP}\right]}$$

$$\mathcal{A}_f(t) = S_f \sin(\Delta m t) - C_f \cos(\Delta m t)$$

For B_d use: $J/\psi K_S$

$S_{J/\psi K_S} = \sin(2\beta)$

For B_s use: $J/\psi\phi$

$S_{J/\psi\phi} = \sin(2\beta_s) = -\sin(\phi_s)$

Meson Mixing

- 5 parameters:

$$M^q_{H,L} \quad \Gamma^q_{H,L} \quad \phi_q = \arg(-M^q_{12}/\Gamma^q_{12})$$

- 6 observables:

$$\frac{M_H + M_L}{2} \quad \frac{\Gamma_H + \Gamma_L}{2} \quad \Delta M \quad \Delta\Gamma \quad \mathcal{A}_{SL} \quad \sin(2\beta_q)$$

- 1 relation among them:

$$\mathcal{A}^s_{SL} = -\frac{|\Delta\Gamma_s|}{\Delta M_s}\frac{S_{J/\psi\phi}}{\sqrt{1 - S^2_{J/\psi\phi}}}$$

and similarly for B_d

absence of direct CP viol' only assumption, valid even with NP

Recent Measurements: A_{SL}

DØ measures charge asymmetry in muons:

$$\frac{N_\mu^{++} - N_\mu^{--}}{N_\mu^{++} + N_\mu^{--}}$$

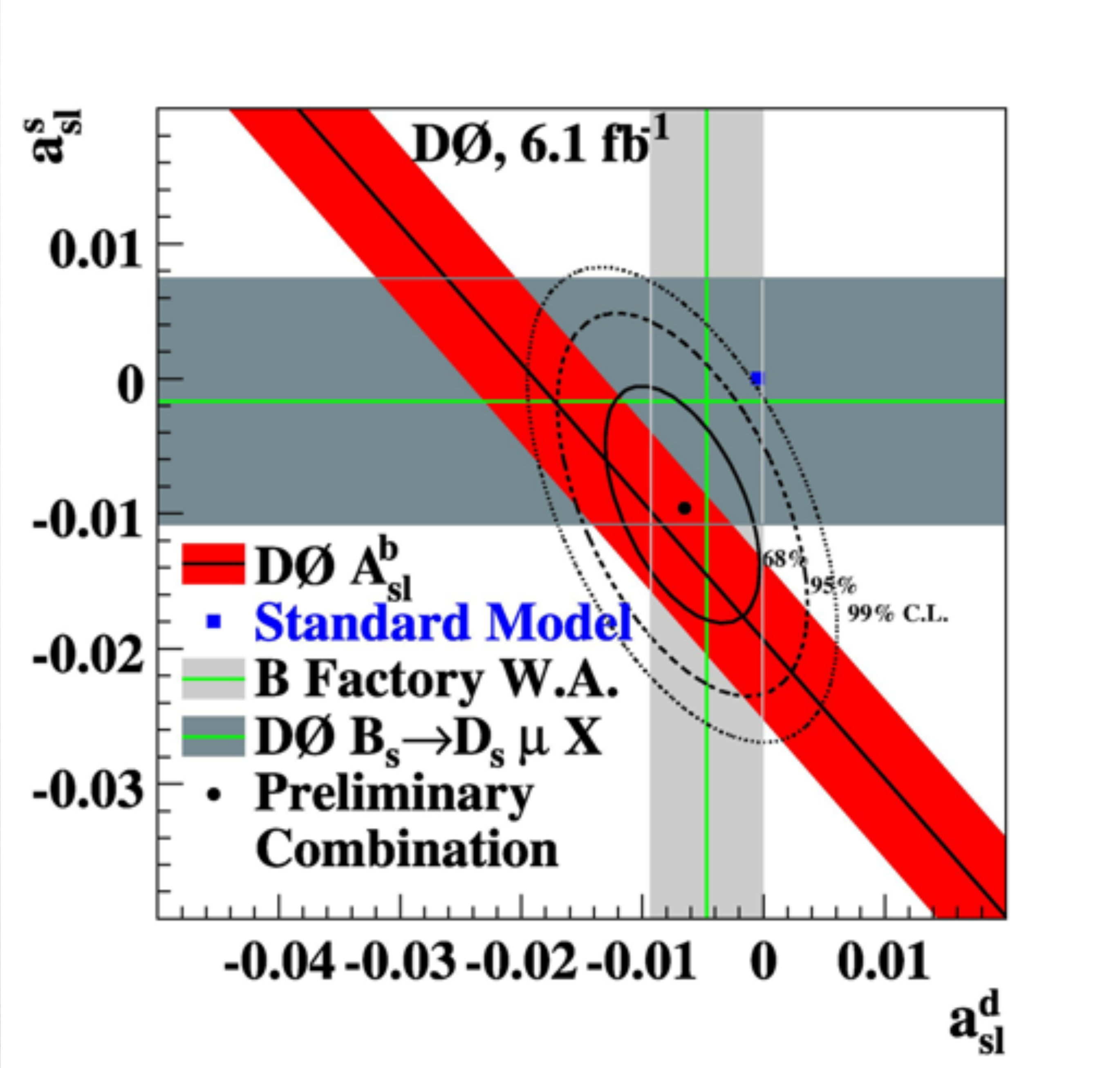
Backgrounds due to in-flight meson decays, matter effects, etc. are removed

Remainder interpreted as coming from $B_{d,s}$ decays:

$$A^b_{SL} \sim 0.5 A^d_{SL} + 0.5 A^s_{SL}$$

no b identification

(could be due to something else)



3.1σ discrepancy

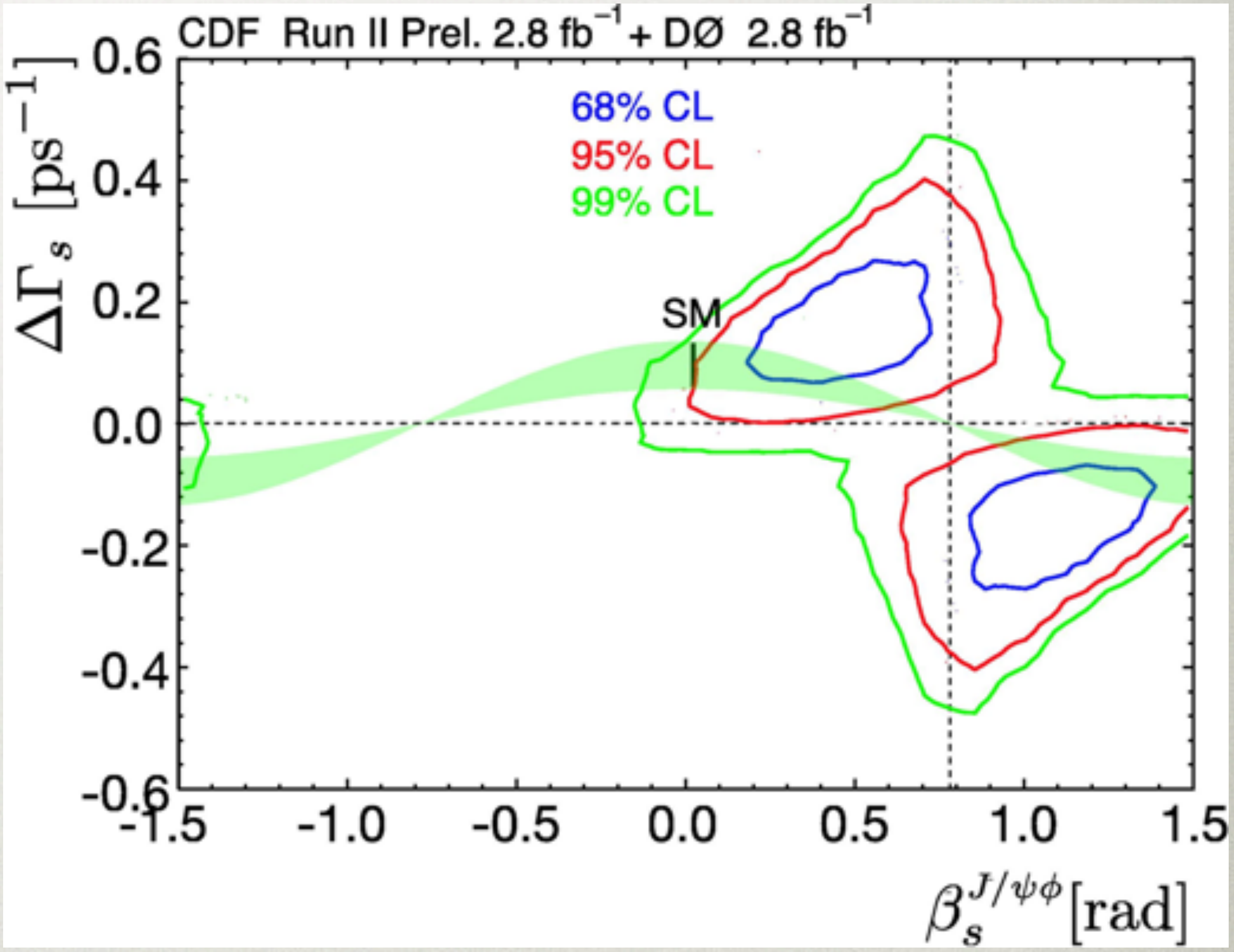
(w/ A_{SL}^s and A_{SL}^d meas')

Recent Measurements: β_s vs. $\Delta\Gamma_s$

- CDF and DØ measured time dep' CP asym in $B_s \rightarrow J/\psi\phi$

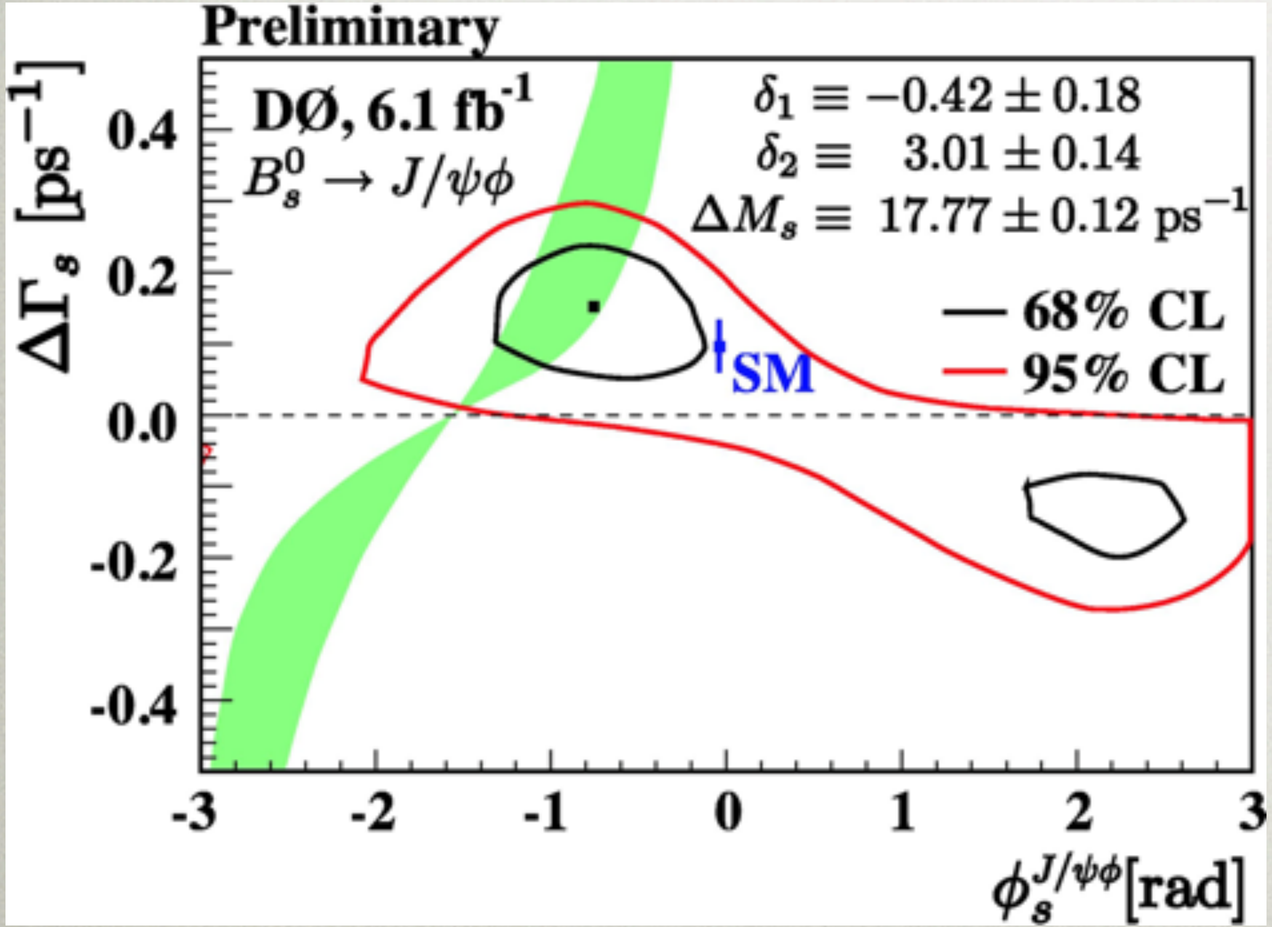
- SM pred': $\beta_s \sim 10^{-2}$
- pre-summer 2010 combination:

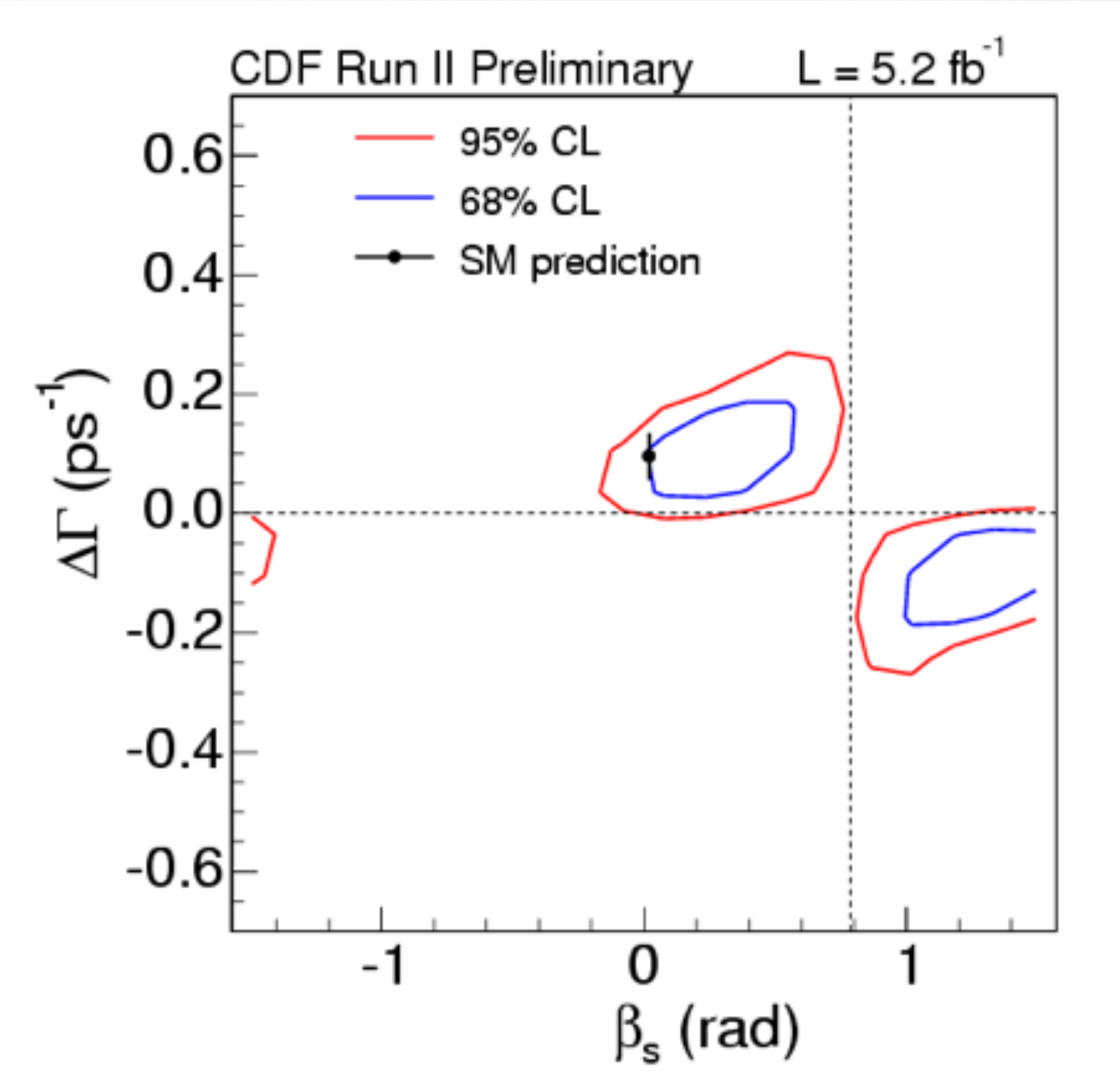
  2.1σ discrepancy with the SM



Recent Measurements: β_s vs. $\Delta\Gamma_s$

- Both CDF and DØ updated their results in the summer
- Discrepancy with SM is decreased (more on CDF side)
- CDF+DØ combination not available yet (we use D0 2.8fb^{-1} + CDF 5.2fb^{-1} ϕ_s 1D likelihood)





What can it be?

- Both A_{SL}^b and $S_{\psi\phi}$ may be statistical fluctuations…
- A_{SL}^b may be something totally different (new) not related to B physics…
- A_{SL}^b and $S_{\psi\phi}$ may be due to NP in B physics

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Compatibility?

Consistency Check

- From A_{SL}^{b}, A_{SL}^{d}, ΔM_s one gets:

$$|\Delta\Gamma_s| \sim \left[(0.28 \pm 0.15)\mathrm{ps}^{-1}\right] \sqrt{1 - S_{\psi\phi}^2}/S_{\psi\phi}$$

- To be compared with the best fit point of $(|\Delta\Gamma_s|, S_{\psi\phi}) \sim (0.15\mathrm{ps}^{-1}, 0.5)$

- Also consistent if using new CDF+D0 data

Non trivial test for NP! → assume the discrepancies are due to NP and study consequences

New Physics?? (A Model Indep. Analysis)

Modify only the mixing amplitude:

$$\frac{M_{12}^{q}}{M_{12}^{\mathrm{SM},q}} = 1 + \frac{M_{12}^{\mathrm{NP},q}}{M_{12}^{\mathrm{SM},q}} = 1 + h_q\,\mathrm{e}^{\mathrm{i}2\sigma_q}$$

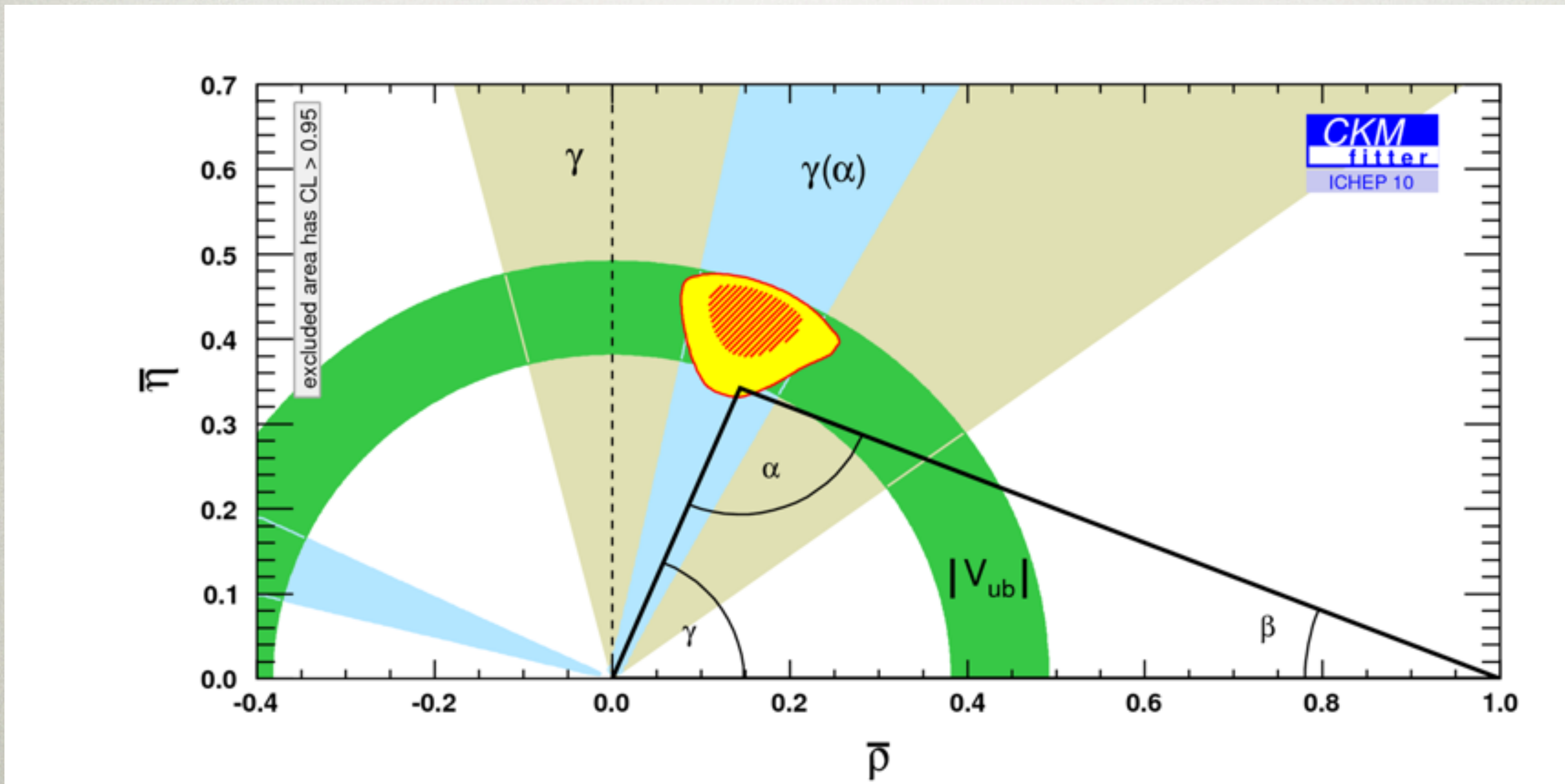
In the fit: other 4 real params on top of ϱ, η from the Unit. Triangle

$$\begin{aligned}
\Delta m_q &= \Delta m_q^{\mathrm{SM}}\left|1 + h_q e^{2i\sigma_q}\right|,\\
\Delta\Gamma_s &= \Delta\Gamma_s^{\mathrm{SM}}\,\cos\left[\,\arg\left(1 + h_s e^{2i\sigma_s}\right)\right],\\
A_{\mathrm{SL}}^{q} &= \mathrm{Im}\left\{\Gamma_{12}^{q}/\left[M_{12}^{q,\mathrm{SM}}(1 + h_q e^{2i\sigma_q})\right]\right\},\\
S_{\psi K} &= \sin\left[2\beta + \arg\left(1 + h_d e^{2i\sigma_d}\right)\right],\\
S_{\psi\phi} &= \sin\left[2\beta_s - \arg\left(1 + h_s e^{2i\sigma_s}\right)\right].
\end{aligned}$$

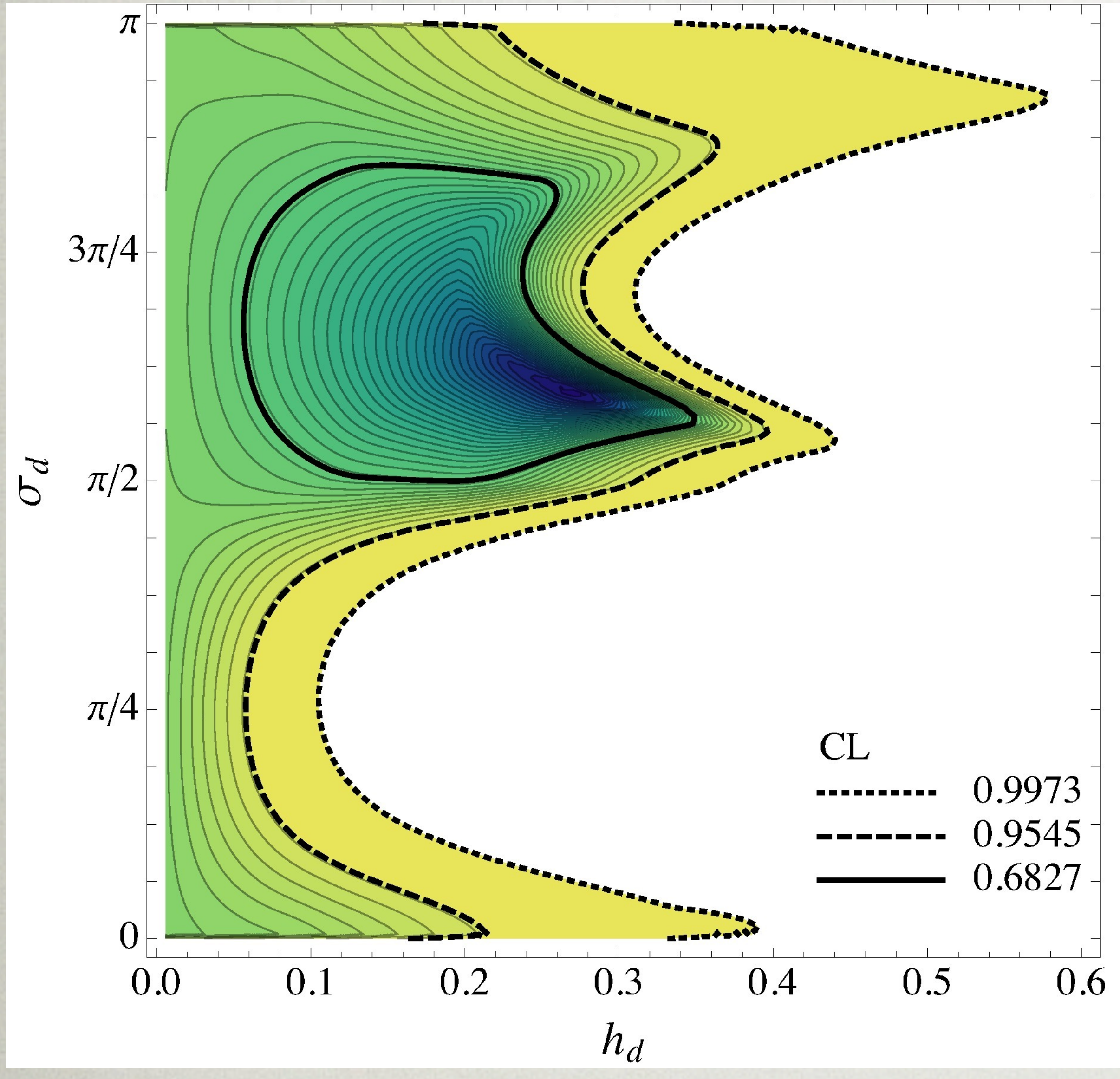
(CKMFitter package used)

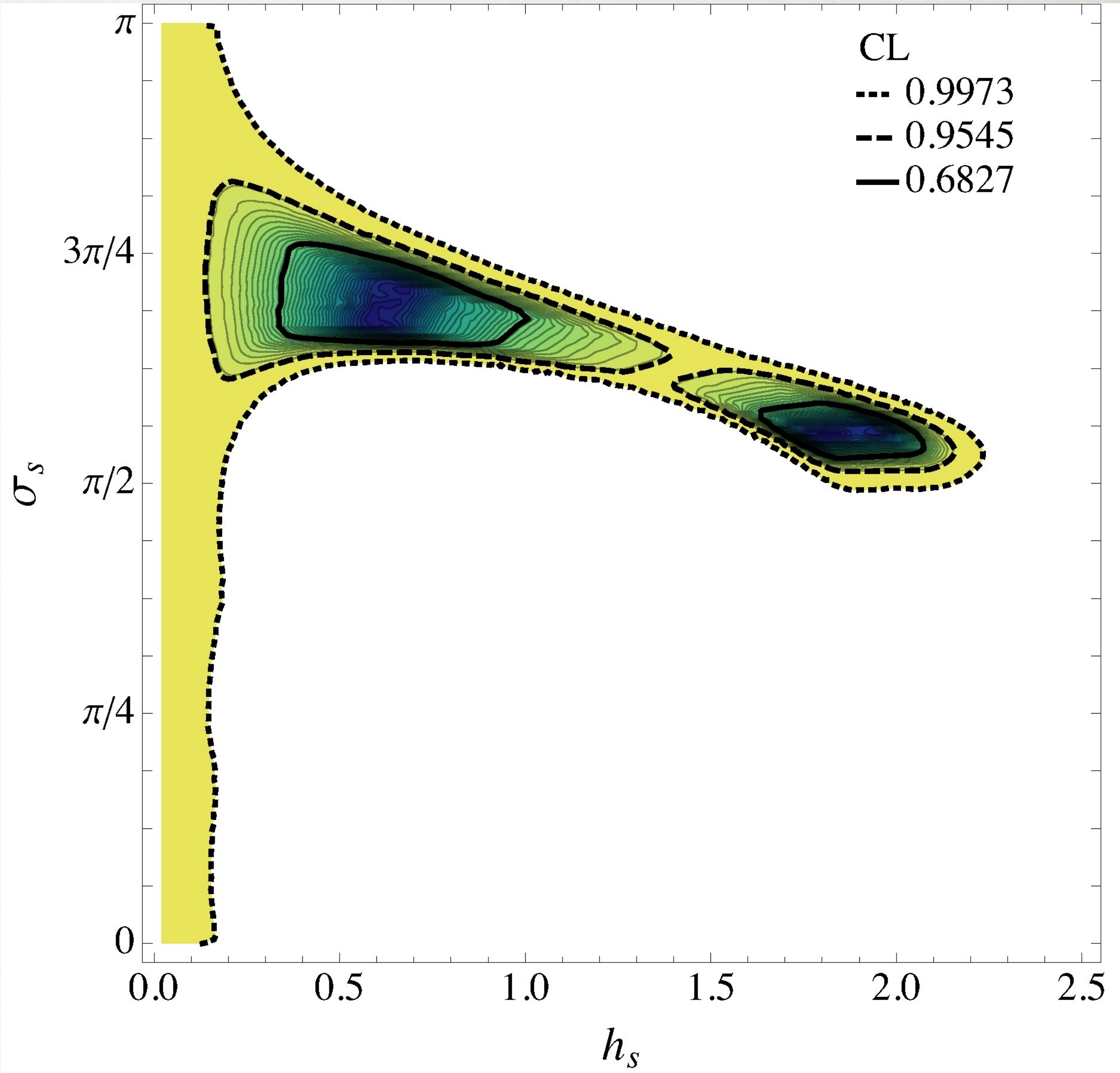
New Physics?? (A Model Indep. Analysis)

Loops are contaminated from NP → use tree level observables to determine ϱ, η:



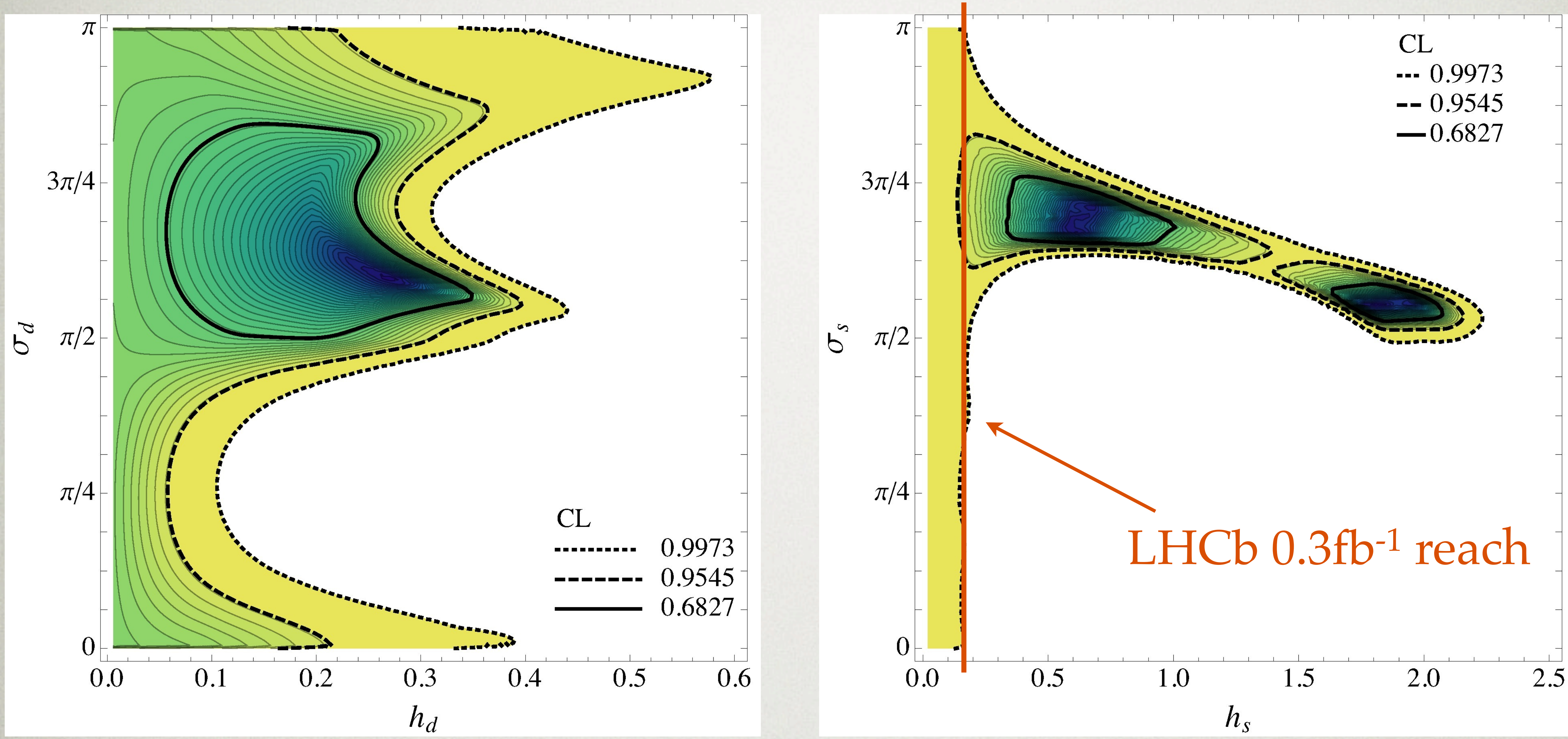
NEW PHYSICS?? (A MODEL INDEP. ANALYSIS)





- Favored regions are for $h_d \sim 0.25$ $\sigma_d \sim 110^o$ and $h_s \sim 0.5$ $\sigma_s \sim 120^o$ or $h_s \sim 1.8$ $\sigma_s \sim 100^o$
- σ_s and σ_d are very close → same origin?
- $h_s=0$ is disfavored at 2.6σ, $h_d=0$ at $<2\sigma$

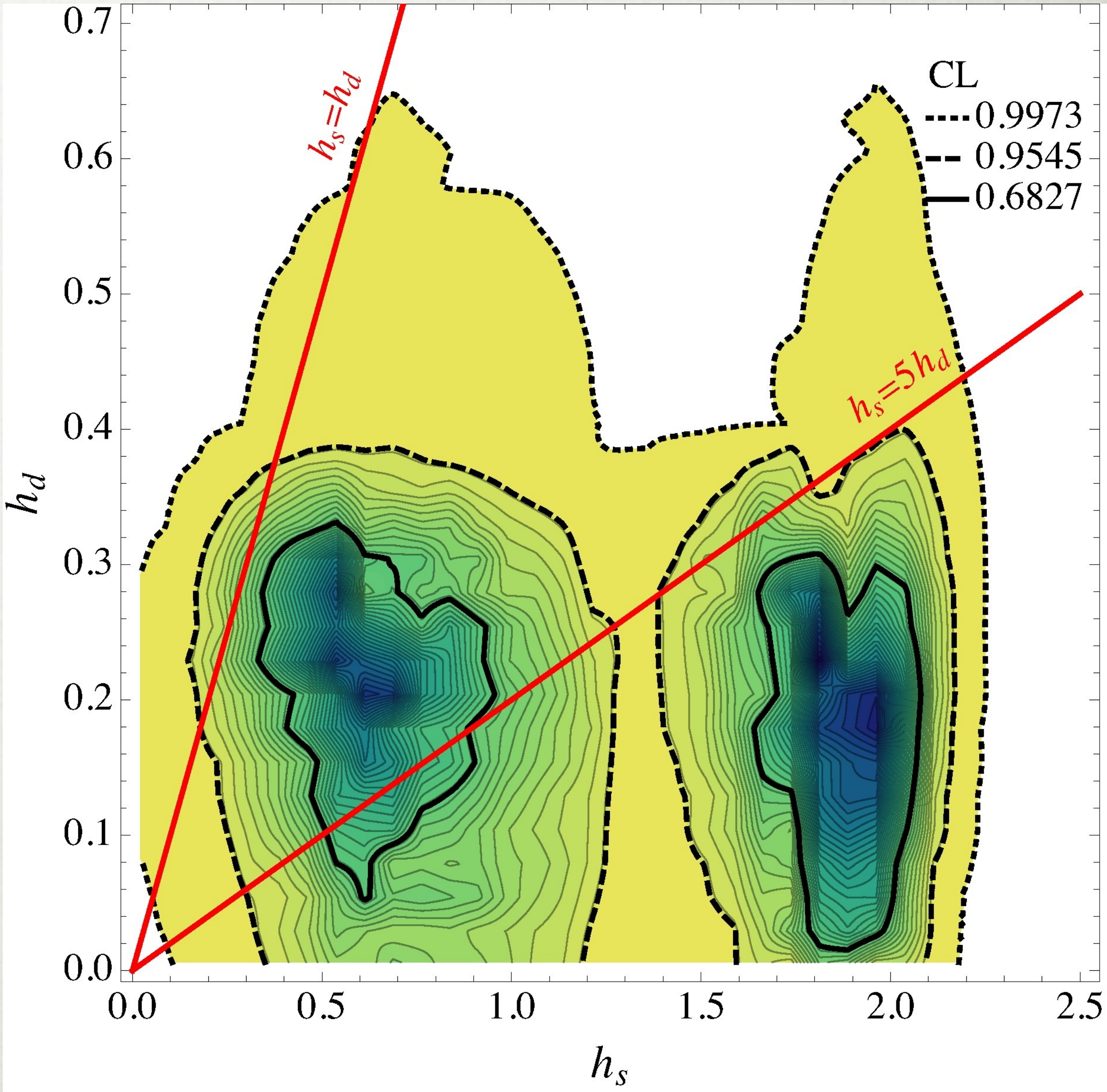
New Physics?? (A Model Indep. Analysis)



- Favored regions are for h_d~0.25 σ_d~110° and h_s~0.5 σ_s~120° or h_s~1.8 σ_s~100°
- σ_s and σ_d are very close → same origin?
- h_s=0 is disfavored at 2.6σ, h_d=0 at <2σ

New Physics?? (A Model Indep. Analysis)

- h_s and h_d not strongly correlated
- $h_s = h_d = 0$ (SM) disfavored at 3.3σ
- $h_s = h_d$ is not ruled out but data prefer $h_s \gtrsim h_d$



New Physics Models?

- $h_{s,d}$, $\sigma_{s,d}$ is a general parameterization. Which types of NP models can account for this?
- Are new sources of flavor viol' needed?
- Are new sources of CP viol' needed?
- How to get $h_s \gtrsim h_d$?

The smallest perturbation of the SM picture:

Minimal Flavor Violation (MFV)

- New particles & new interactions? Yes
- New Flavor viol' sources at ***low energy***? No

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i c_i(y_u, y_d) \frac{\mathcal{O}_i}{\Lambda^2}$$

Flavor & CP Viol' in (G)MFV

- What about new CP phases? → Can be flavor-blind phases (e.g. in SUSY the phases coming from gaugino masses, etc.)

E.g.: $$c(y_u^\dagger y_u, y_d^\dagger y_d)\frac{(\bar{b}_L\gamma^\mu s_L)(\bar{b}_L\gamma^\mu s_L)}{\Lambda^2}$$

$$\begin{aligned}c(y_u^\dagger y_u, y_d^\dagger y_d) &= a_1(y_u^\dagger y_u)^2_{32}\\ &+ a_2(y_u^\dagger y_u)_{32}(y_u^\dagger y_u y_d^\dagger y_d)_{32} + a_3(y_u^\dagger y_u)_{32}(y_d^\dagger y_d y_u^\dagger y_u)_{32}\\ &+ \ldots\end{aligned}$$

Some of the a_i can be complex → new sources of CPV

Λ ~ few hundreds GeV ÷ few TeV to account for the data (depends on y_b)

Flavor & CP Viol' in MFV

- What about $h_s \gg h_d$?
- $m_s \gg m_d \rightarrow$ down yukawa coupling can do it! (that's the only way in MFV...)
- Requires one Y_d insertion:
- "scalar" operator involving $b_L s_R$, $b_L d_R$ (similar to an Higgs exchange):

E.g. : $[\bar{Q}_3(A_d^m A_u^n Y_d)_{3i} d_i]\,[\bar{d}_3(Y_d^\dagger A_d^{l,\dagger} A_u^{p,\dagger})_{3i} Q_i]$

$$A_{u,d} \equiv Y_{u,d} Y_{u,d}^\dagger$$

$h_d/h_s \propto m_d/m_s \sim O(5\%) \rightarrow$ testable prediction

New Physics Models?

CAVEAT: flavor blind phases → potential problems with EDMs

Electric Dipole Moments are generated by different operators, but in specific models the size of the contrib' to EDMs and to CPV in B_s mixing is correlated

(model building gymnastics required, various working examples in the literature)

Flavor & CP Viol' beyond SM

- What about non-MFV models?
  - New sources of flavor viol′ and new flavor-dependent CP phases
  - Can account easily for the data BUT if new sources generate $h_s \neq h_d$ then constraints from Kaon and D-meson mixing may be non-trivial

(Model building needed...)

Problem with $\Delta\Gamma_s$?

- The SM prediction for $\Delta\Gamma_s$ is in some tension with the DØ (slightly more than 1σ…)
- The data prefers a $\Delta\Gamma_s$ larger by a factor ~2-2.5

  (shallow profile, new CDF+DØ data should lower the "tension" to a factor of 1.x)
- Could be a fluctuation in the data
- Could be a problem with the SM prediction
- It's very hard to account a shift in $\Delta\Gamma_s$ with new physics but possible (e.g. need a new light state)

(Bai, Nelson 2010)

CONCLUSIONS

- The dimuon CP asymmetry may be due to BSM physics finally showing up in the flavor sector.
- Very easy to account for the data ($\rightarrow$ quite generic)
- Data does not exclude MFV (at least its general definition)
- More exp' input needed $\rightarrow$ available later this year!

On the LHC feedback

"...most important of all, Switzerland is now the home of the Largest Superconducting Supercollider which was moved from Texas to Switzerland after the '94 budget, but we still have smaller ones in the United States. The first significant discovery came [...] last year. They may offer a key on how life began after the Big Bang. [...] The smallest subatomic particle, the muon, it turns out, that based on their findings, which will be confirmed or contradicted when the Swiss machine is up and going, […] [It] turns out that there's slightly more positive than negative muons in all of our atoms which will justify the faith of all the believers of the world, make you more optimistic and gives us an explanation for how we might have all come to this moment from the primordial slack."

William J. Clinton, World Economic Forum, Davos, 2011