The Z′ contribution in the B_s meson mixing and the recent LHCb result

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Parallel talk, pheno 2012, 7 May 2012

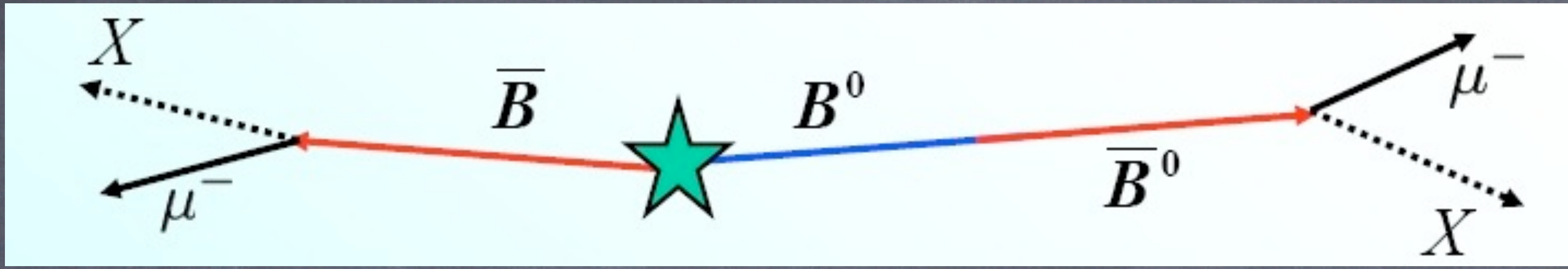
Work in progress with R. Dermisek, H.D. Kim, S.G. Kim

Phys. Rev. D83, 036003 (2010) with Jihn E. Kim and M.S. Seo

Outline

- Like-sign dimuon charge asymmetry at the D0
- Experimental constraints including LHCb $1fb^{-1}$ result
  - Mass difference ΔM_s
  - Decay width difference $\Delta\Gamma_s$
  - Phase in the indirect CP asymmetry $\phi_s^{J/\psi\,\phi}$
  - Model dependent bounds : $b \to s\upsilon\upsilon$, $B \to J/\psi K_s$
- The upper limit of the coupling in the Z′ model
- Conclusions

Like-sign dimuon charge asymmetry at D0



Asymmetry in the number N^{++} and N^{--}

N^{++} : # of events $\mu^+\mu^+$
N^{--} : # of events $\mu^-\mu^-$

from the semi-leptonic decays of $B_{d,s}$ meson

$$A^b_{s\ell} = \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

$A_{s\ell} \neq 0$: $\not{CP}$ in the mixing

First observation 2010 at $6.1 fb^{-1}$ D0

$$A^b_{s\ell} = -(9.52 \pm 2.51 \pm 1.46) \times 10^{-3}$$

3.2σ deviation from the SM value

$$(A^b_{s\ell})^{\rm SM} = (-2.8^{+0.5}_{-0.6}) \times 10^{-4}$$

Second observation 2011 at $9.0 fb^{-1}$ D0

$$A^b_{s\ell} = -(7.87 \pm 1.72({\rm stat.}) \pm 0.93({\rm syst.})) \times 10^{-3}$$

3.9σ deviation (error reduced)

Need additional CP violation source in $B_{d,s}$ mixing

Obtain $A^b_{s\ell}$ from B_d mixing + B_s mixing

$$a^d_{s\ell} \equiv \frac{\Gamma(\overline{B}_d \to \mu^+ X) - \Gamma(B_d \to \mu^- X)}{\Gamma(\overline{B}_d \to \mu^+ X) + \Gamma(B_d \to \mu^- X)}$$

$$a^s_{s\ell} \equiv \frac{\Gamma(\overline{B}_s \to \mu^+ X) - \Gamma(B_s \to \mu^- X)}{\Gamma(\overline{B}_s \to \mu^+ X) + \Gamma(B_s \to \mu^- X)}$$

At 1.96 TeV

2010 result

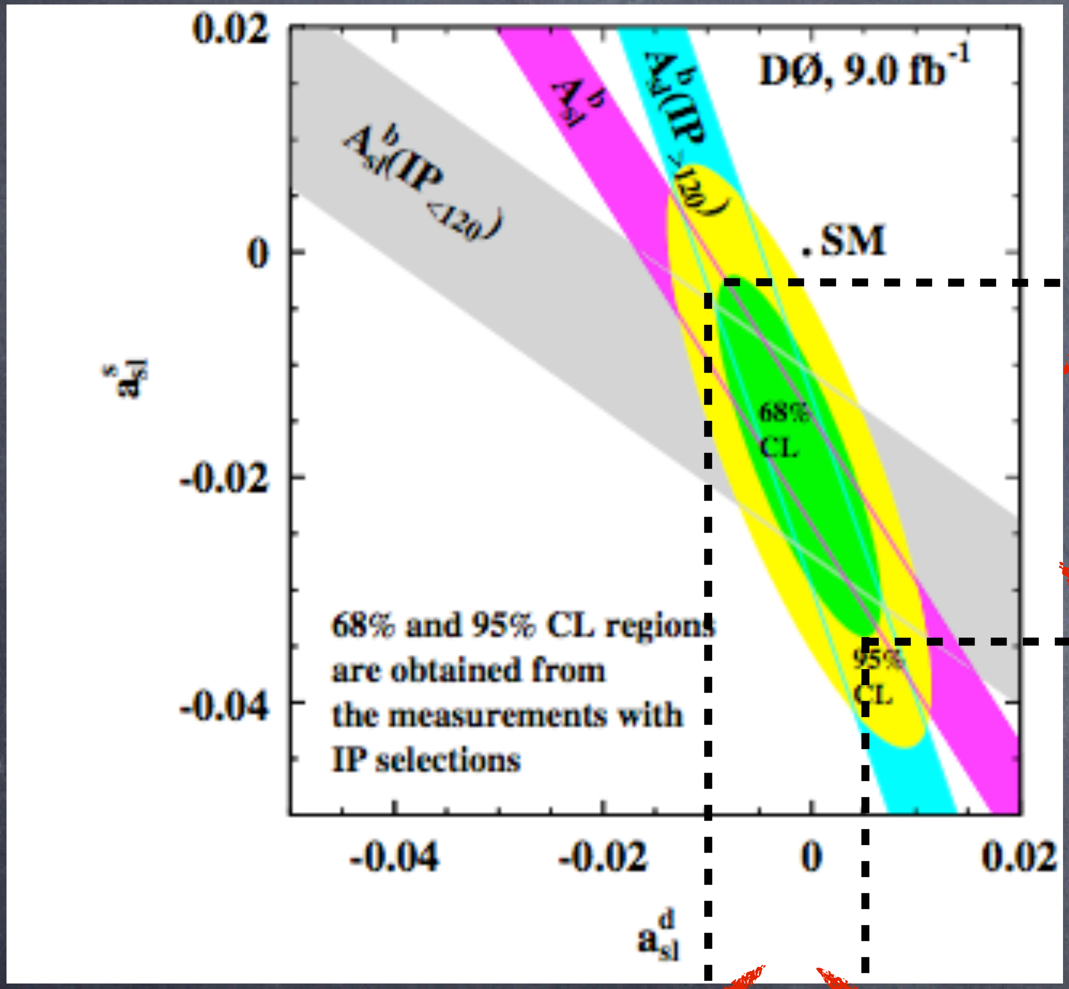
$$A^b_{s\ell} = (0.506 \pm 0.043) a^d_{s\ell} + (0.494 \pm 0.043) a^s_{s\ell}$$

2011 result

$$A^b_{s\ell} = (0.594 \pm 0.043) a^d_{s\ell} + (0.406 \pm 0.043) a^s_{s\ell}$$

2011 result of 3.9σ

IP > 120μm : reduce background (less data)



separately reading the asymm.

$$a^s_{s\ell} = -(18.1 \pm 10.6) \times 10^{-3}$$

1.7σ

$$(a^s_{s\ell})^{\rm SM} = (1.9 \pm 0.3) \times 10^{-5}$$

$$a^d_{s\ell} = -(1.2 \pm 5.2) \times 10^{-3}$$ < 1σ → **2-3σ**

$$(a^d_{s\ell})^{\rm SM} = -(4.1 \pm 0.6) \times 10^{-4}$$

$B_{s,d} - \overline{B}_{s,d}$ mixing

$$i\frac{\mathrm{d}}{\mathrm{d}t}\begin{pmatrix}|B^0\rangle\\|\overline{B}^0\rangle\end{pmatrix} = \left(M - i\frac{\Gamma}{2}\right)\begin{pmatrix}|B^0\rangle\\|\overline{B}^0\rangle\end{pmatrix}$$

M and Γ : 2×2 hermitian mass and decay matrices

Mixing via off-shell (dispersive) intermediate states and on-shell (absorptive) intermediate states

$$\Delta M_q = 2|M_{12}^q| \qquad \Delta\Gamma_q = 2|\Gamma_{12}^q|\cos\phi_q$$

$$\phi_q = \mathrm{Arg.}\left(-\frac{M_{12}^q}{\Gamma_{12}^q}\right)$$

$$\phi_d^{\mathrm{SM}} = (-7.5 \pm 2.4) \times 10^{-2}$$

$$\phi_s^{\mathrm{SM}} = (3.8 \pm 1.1) \times 10^{-3}$$

$$a^q_{s\ell} = \mathrm{Im}\frac{\Gamma^q_{12}}{M^q_{12}} = \frac{|\Gamma^q_{12}|}{|M^q_{12}|}\sin\phi_q = \frac{\Delta\Gamma_q}{\Delta M_q}\tan\phi_q$$

(LHCb 0.34 fb^{-1})

$$\Delta M_s = 17.725 \pm 0.041(\mathrm{stat.}) \pm 0.026(\mathrm{syst.})\ \mathrm{ps}^{-1}$$

$$(\Delta M_s)^{\mathrm{SM}} = (17.3 \pm 2.6)\ \mathrm{ps}^{-1}$$

If $\Gamma^s_{12} = \Gamma^{s,\,\mathrm{SM}}_{12}$ only even with $\sin\phi_s = -1$

Impossible to obtain the central value of $a^s_{s\ell}$

NP contribution to Γ^s_{12} & No large to Γ_{B_s}

For convenience, let's define

$$\frac{\Gamma^{q\,\mathrm{NP}}_{12}}{\Gamma^{q\,\mathrm{SM}}_{12}} \equiv \tilde{h}_q e^{i2\tilde{\sigma}_q}\ ,\quad \frac{M^{q\,\mathrm{NP}}_{12}}{M^{q\,\mathrm{SM}}_{12}} \equiv h_q e^{i2\sigma_q}$$

STRATEGY

New Physics

- Sizable contribution to Γ_{12}^s

  ① Light new particles which B_s can decay into
  (one of which < m_{B_s})

  or

  ② New interactions to the light SM particles
  (without new $\mathbb{Z}_2$ parity)

  Otherwise, the new contribution : loop suppressed

- Very small contribution to Γ_{B_s}

  ① Constrained by the new particle mass bound

  ② Constrained by the Br. ($B_s \rightarrow$ particles) → $\tau^+\tau^-$

$$\mathrm{Br.}(\bar{B}_s \to \tau^+\tau^-) < 5\%$$
$$\mathrm{Br.}(\bar{B} \to X_s\tau^+\tau^-) < 5\%$$

Not so severe constraints

$\mathcal{O}(1)\tilde{h}_s$

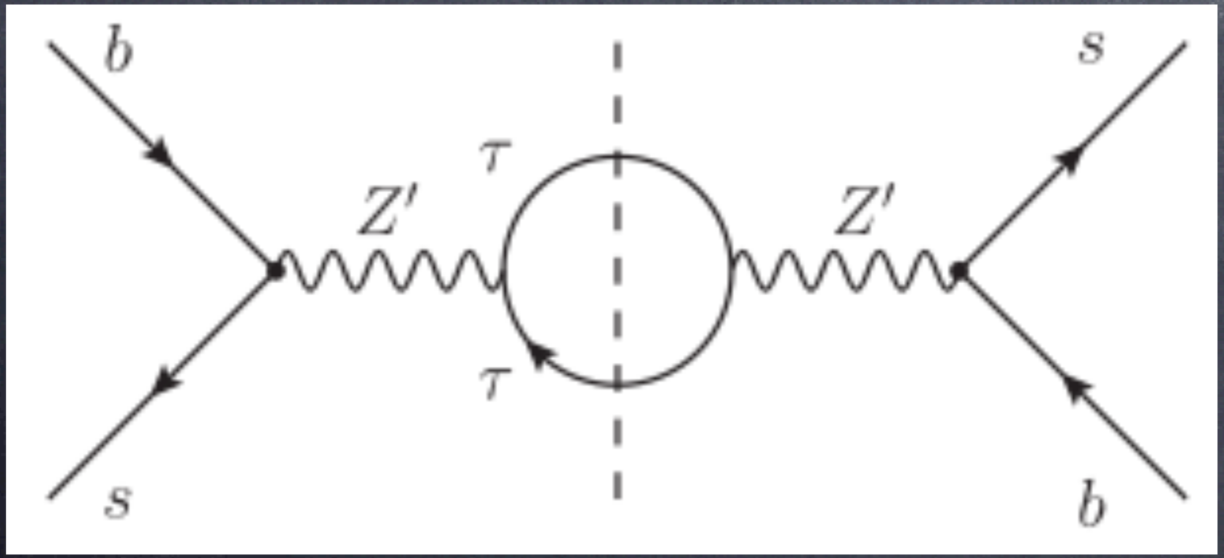
If $(\bar{b}s)(\bar{\tau}\tau)_{V,A}$ is the only nonzero NP interaction

⇒ safe from b → s γ

Bauer & Dunn, Phys. Lett. B696, 362 (2011)

Bobeth & Haisch, arXiv:1109.1826

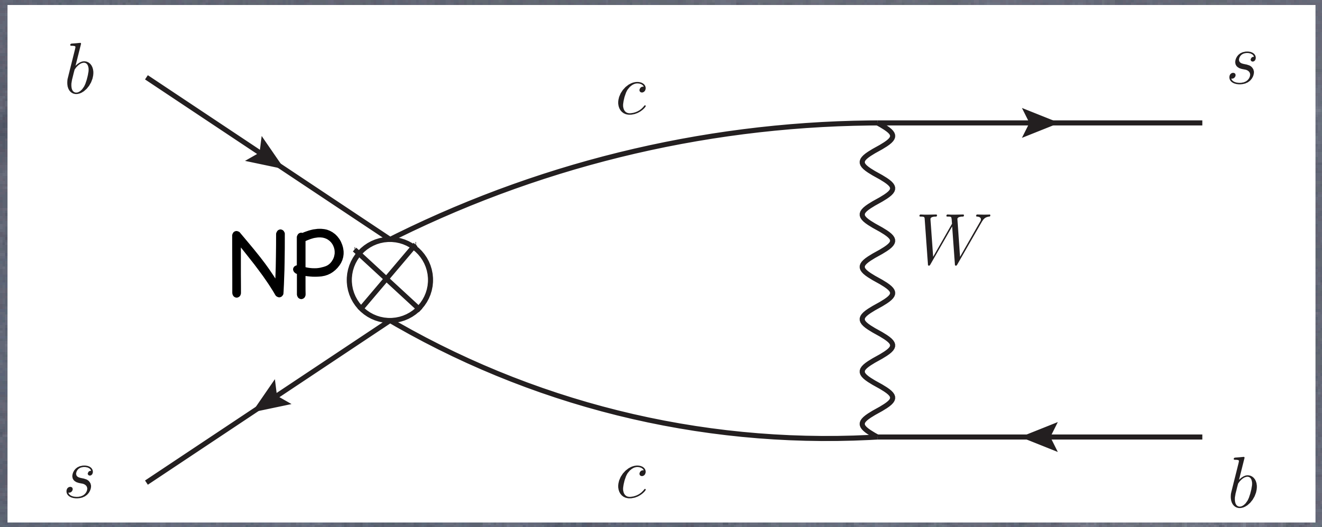
My work with Jihn E. Kim and M.-S. Seo, Phys. Rev. D83, 036003 (2010)



Alok, Baek, London, JHEP 07, 111 (2011)

another way out

Interference of NP with the SM through charm



because $\Gamma_{12}^{s} \propto$ NP coupling linearly

small to avoid ex. constraints

My work in progress with R. Dermisek, H.D. Kim, S.G. Kim

Alok, Baek, London, JHEP 07, 111 (2011)

The analysis in this work

- Analyze the various recent experimental results (e.g., LHCb $1fb^{-1}$) which can constrain the NP models explaining the dimuon charge asymmetry

- See what extent the NP parameter can be constrained by them : *Z' modeL*
  - Scenario with Z′ to tau pair
  - Scenario with Z′ to charm quark pair

When the sizable NP in the B_s mixing

Experimental constraints

- Mass difference ΔM_s
- Decay width difference $\Delta\Gamma_s$
- $2\beta_s$
- Model dependent experimental constraints
  $b \to s\upsilon\upsilon$, $B \to J/\psi K_s$

Z' model to analyze the possible parameter region

Z' : 6 real free parameters

g_{sb}^{L} : $Z'\bar{s}_L b_L$ $\quad g_{sb}^{R}$: $Z'\bar{s}_R b_R$ $\quad g_{\tau\tau}^{L}$: $Z'\bar{\tau}_L \tau_L$ $\quad g_{\tau\tau}^{R}$: $Z'\bar{\tau}_R \tau_R$

complex off-diagonal $\qquad$ or charm

$$g_{sb}^{L(R)} \equiv |g_{sb}^{L(R)}| e^{i\theta_{L(R)}}$$

- Every experimental result : $(g_{\psi\chi}^{L,R}/g_1)(M_Z/M_{Z'})$

  $g_1 = g/\cos\theta_W$ $\quad$ g : SU(2)

- To see the magnitude of coupling, we can fix $M_{Z'}$
  For simplicity, analyze the case when $M_{Z'} \approx M_Z$

A_{FB}^{b} $\quad$ Phys. Rev. D84, 035006 (2011) by Dermisek, Kim, Raval

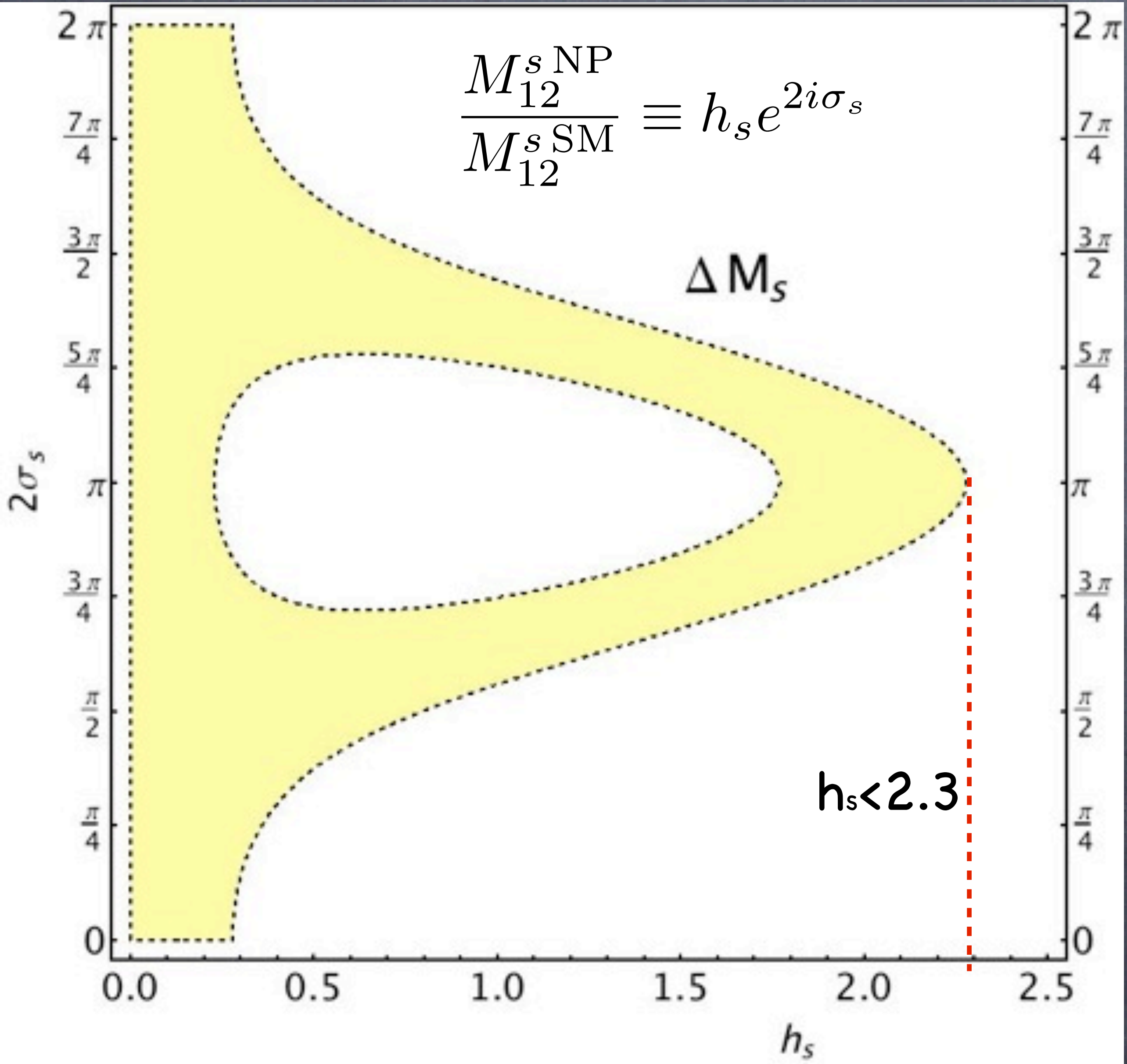
Mass difference ΔM_s

LHCb 0.34 fb^{-1}

$$\Delta M_s = 17.725 \pm 0.041(\text{stat.}) \pm 0.026(\text{syst.})\ \text{ps}^{-1}$$

No significant deviation

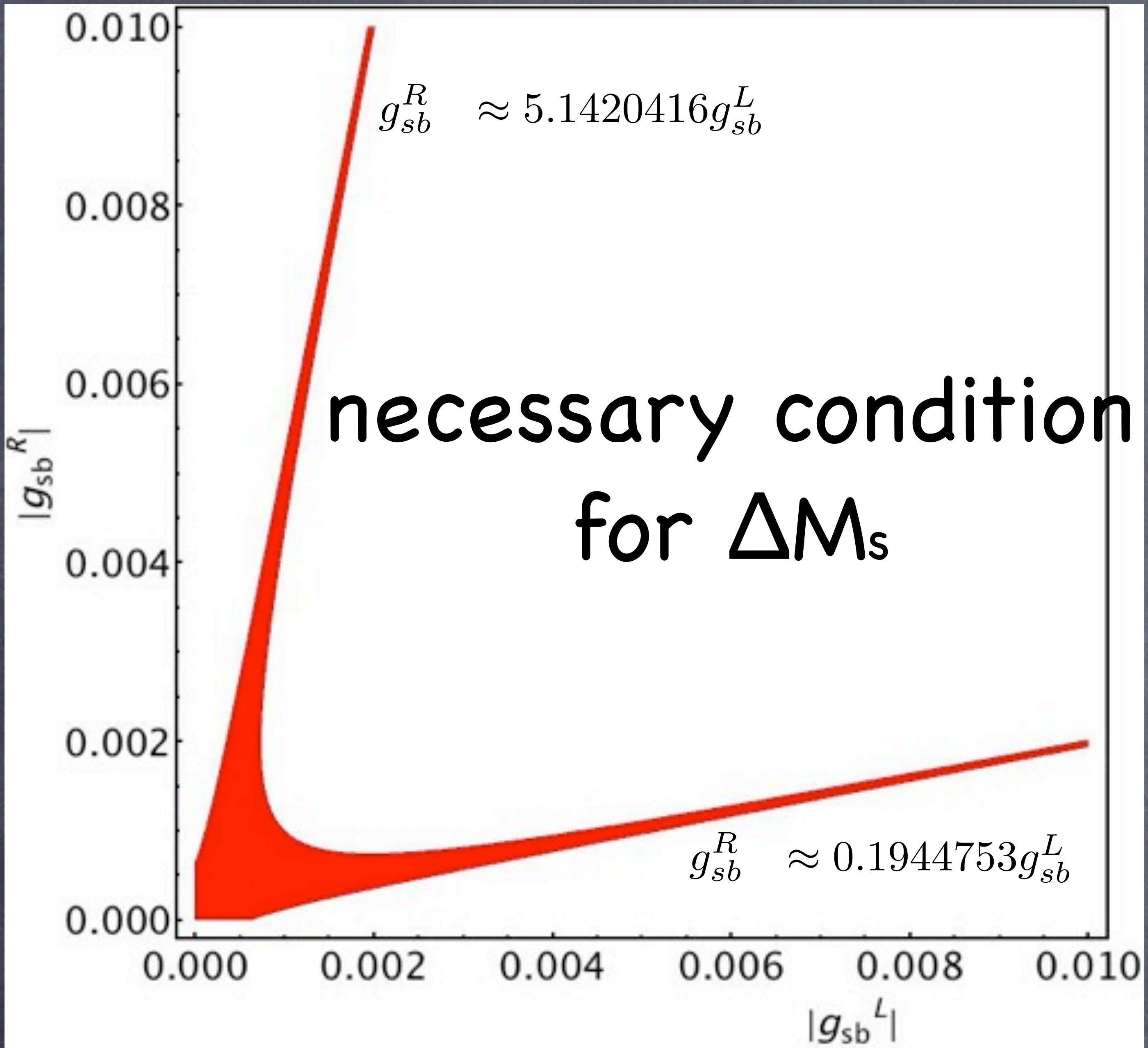
$$(\Delta M_s)^{\text{SM}} = (17.3 \pm 2.6)\ \text{ps}^{-1}$$



In terms of general parameters

NP contribution is highly constrained!

In terms of Z′ model parameters



Tree level FCNC

- Natural $|g_{sb}| < 10^{-3}$
- If $|g_{sb}| > 10^{-3}$

On the asymptotic lines

↓

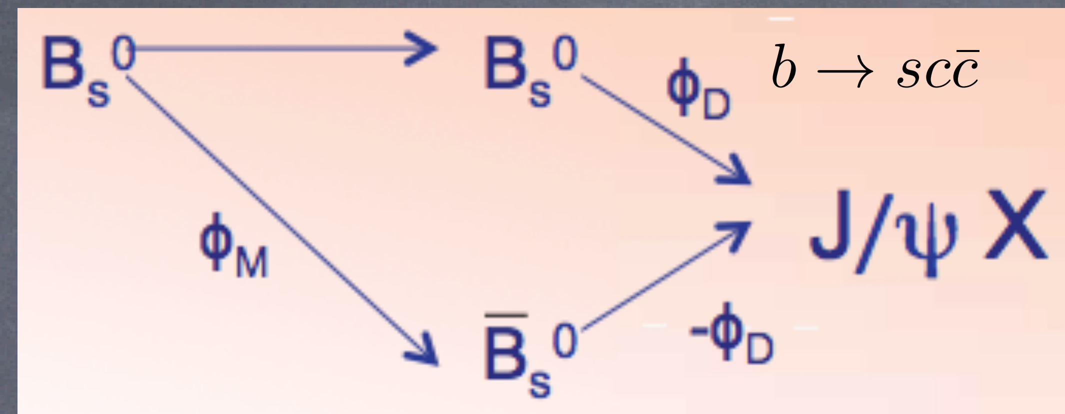
Fine tuning

If one of $g_{sb} = 0$ → Remaining $|g_{sb}| < 10^{-3}$

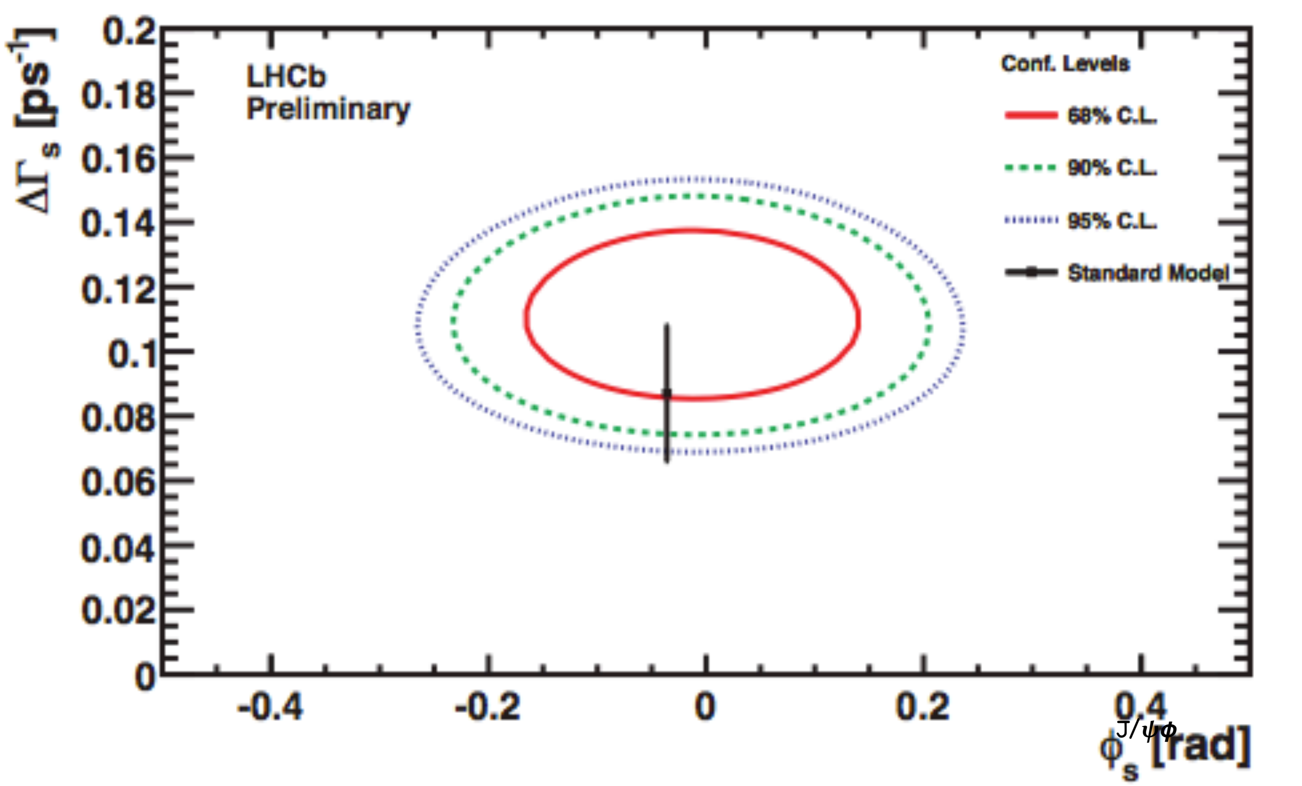
The diagonal couplings should be larger > 1

We need both of g_{sb}^L & g_{sb}^R

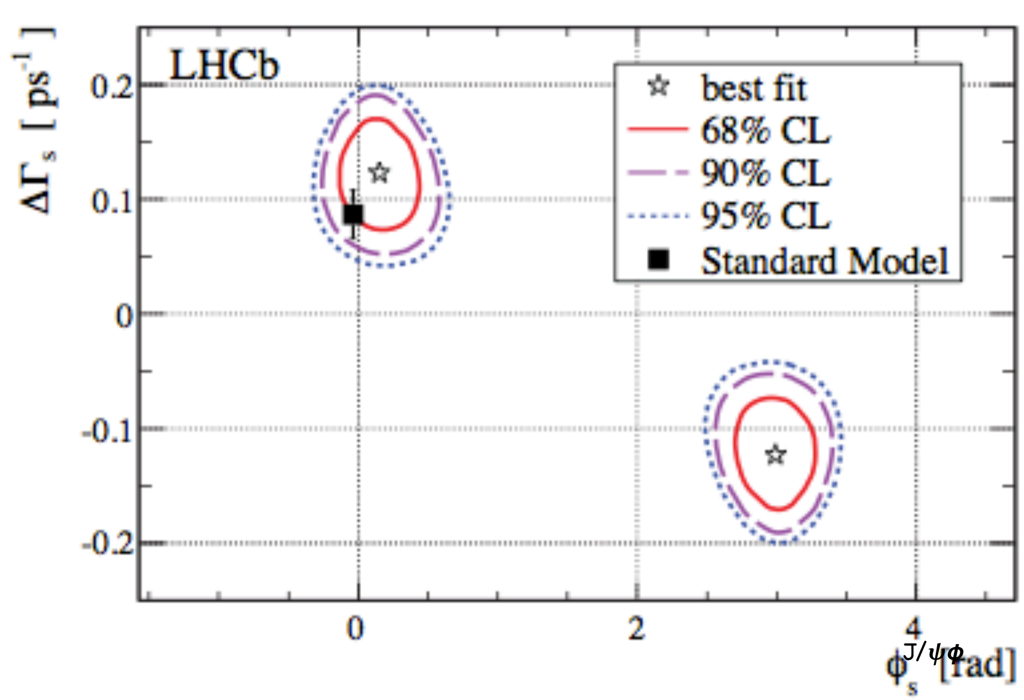
$\Delta\Gamma_s$ & $\phi_s^{J/\psi\,\phi}$ from $B_s \to J/\psi\phi$



This new preliminary result 1.0 fb^{-1}



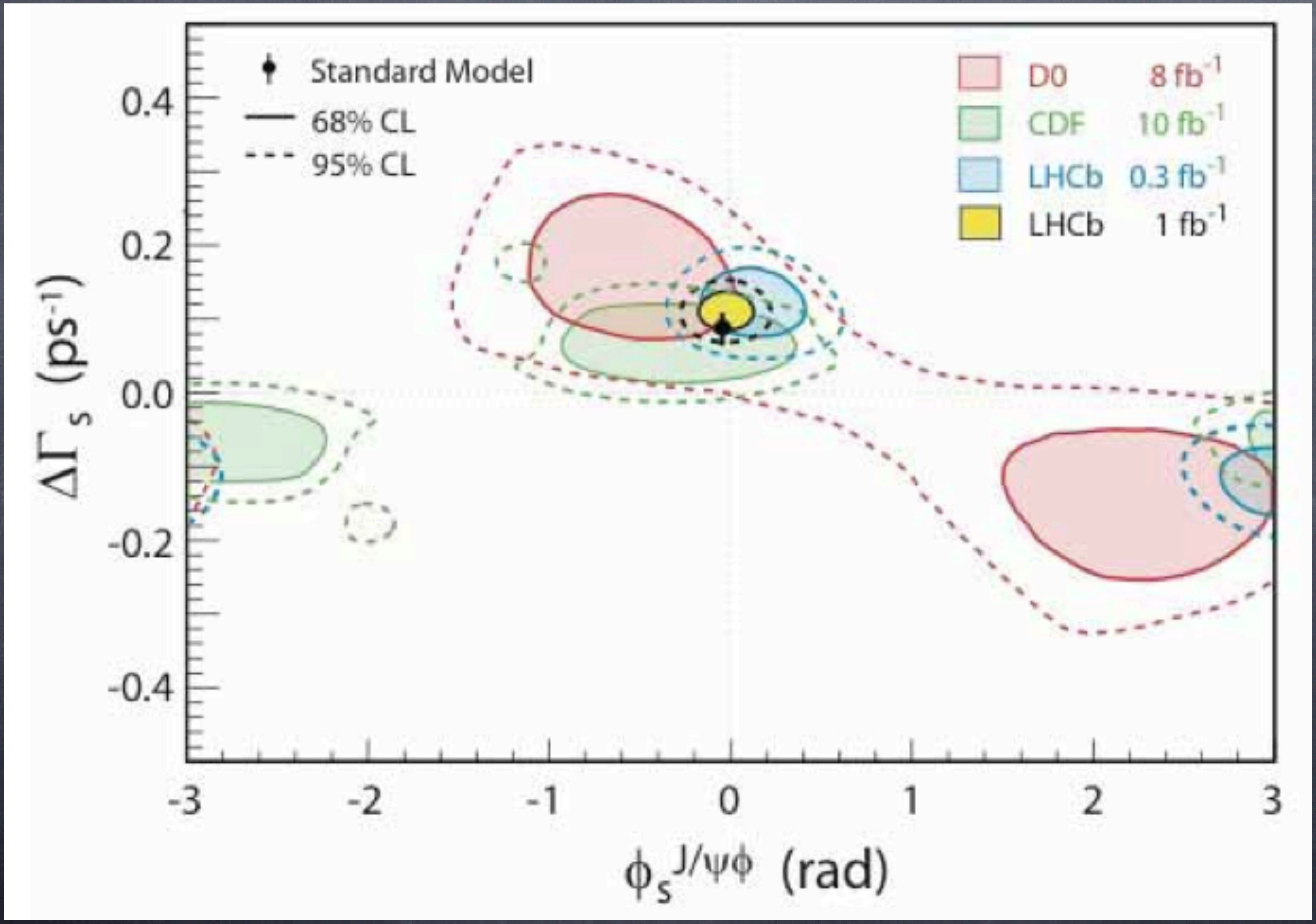
Previous published result 0.37 fb^{-1}
arXiv:1112.3183



Γ_s = 0.6580 ± 0.0054(stat.) ± 0.0066(syst.) ps^{-1}
$\Delta\Gamma_s$ = 0.116 ± 0.018(stat.) ± 0.006(syst.) ps^{-1}
$\phi_s^{J/\psi\phi}$ = -0.001 ± 0.101(stat.) ± 0.027(syst.) rad.

Γ_s = 0.657 ± 0.009(stat.) ± 0.008(syst.) ps^{-1}
$\Delta\Gamma_s$ = 0.123 ± 0.029(stat.) ± 0.011(syst.) ps^{-1}
$\phi_s^{J/\psi\phi}$ = 0.151 ± 0.18(stat.) ± 0.06(syst.) rad.

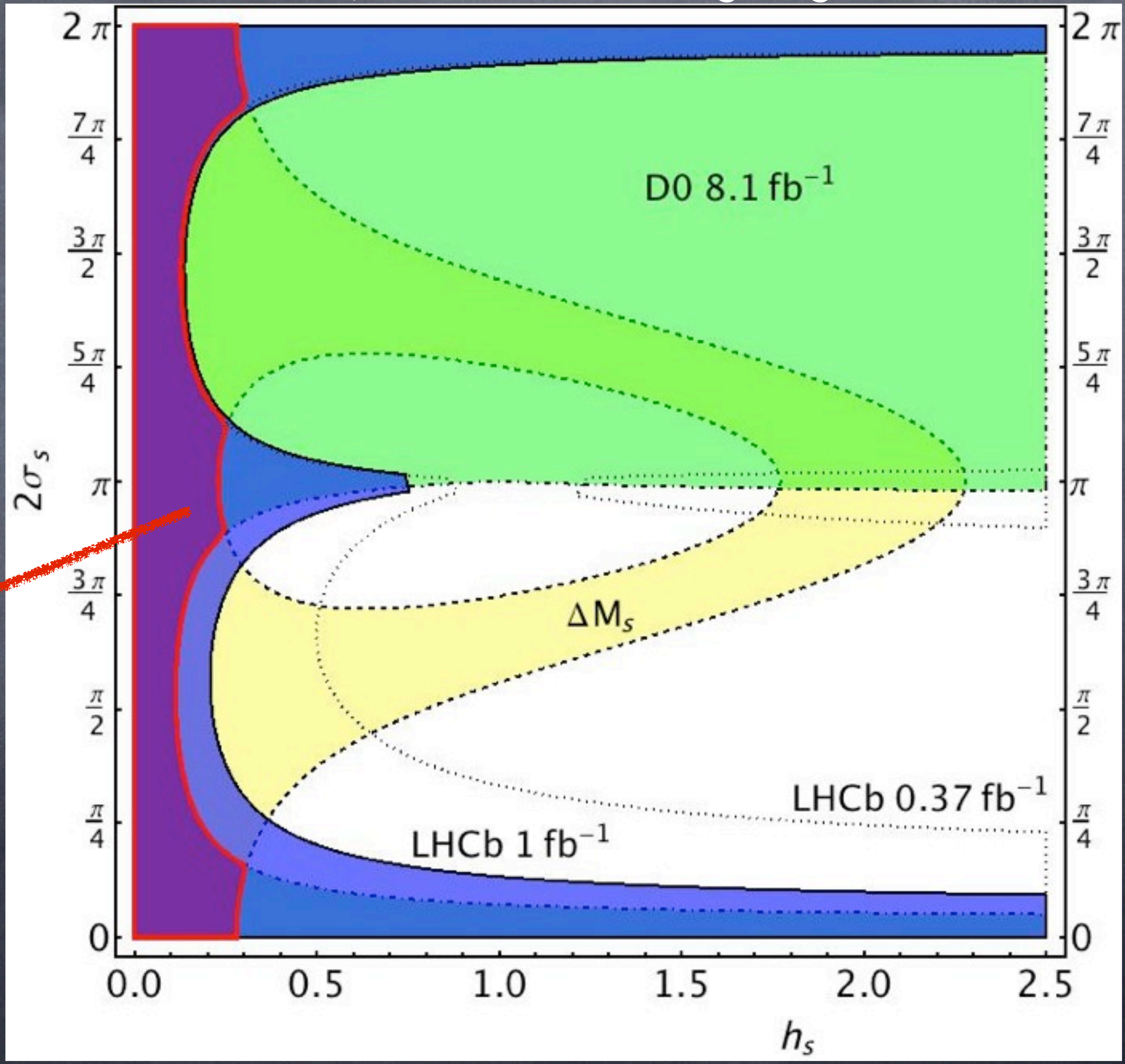
Approach to the SM prediction



Without new phase contribution in $B_s \to J/\psi\phi$

(The new contribution is only from the mixing, e.g., $Z'\tau^+\tau^-$)

$\phi_s^{J/\psi\,\phi}$



$h_s < 0.3$

$$\frac{M_{12}^{s\,\mathrm{NP}}}{M_{12}^{s\,\mathrm{SM}}} \equiv h_s e^{2i\sigma_s}$$

With new phase contribution in $B_s \to J/\psi\phi$

(e.g., Z′cc)

⇒ additional contribution in $\phi_s^{J/\psi\,\phi}$

In the scenario with Z′cc

Z′cc is (almost) axial vector-like

or the coupling is very small

$$|g_{sb}^{R} g_{cc}^{L,R} \sin\theta_R| \quad < \mathcal{O}(10^{-5})$$
$$|g_{sb}^{L} g_{cc}^{L,R} \sin\theta_L| \quad < 2\times 10^{-4}$$

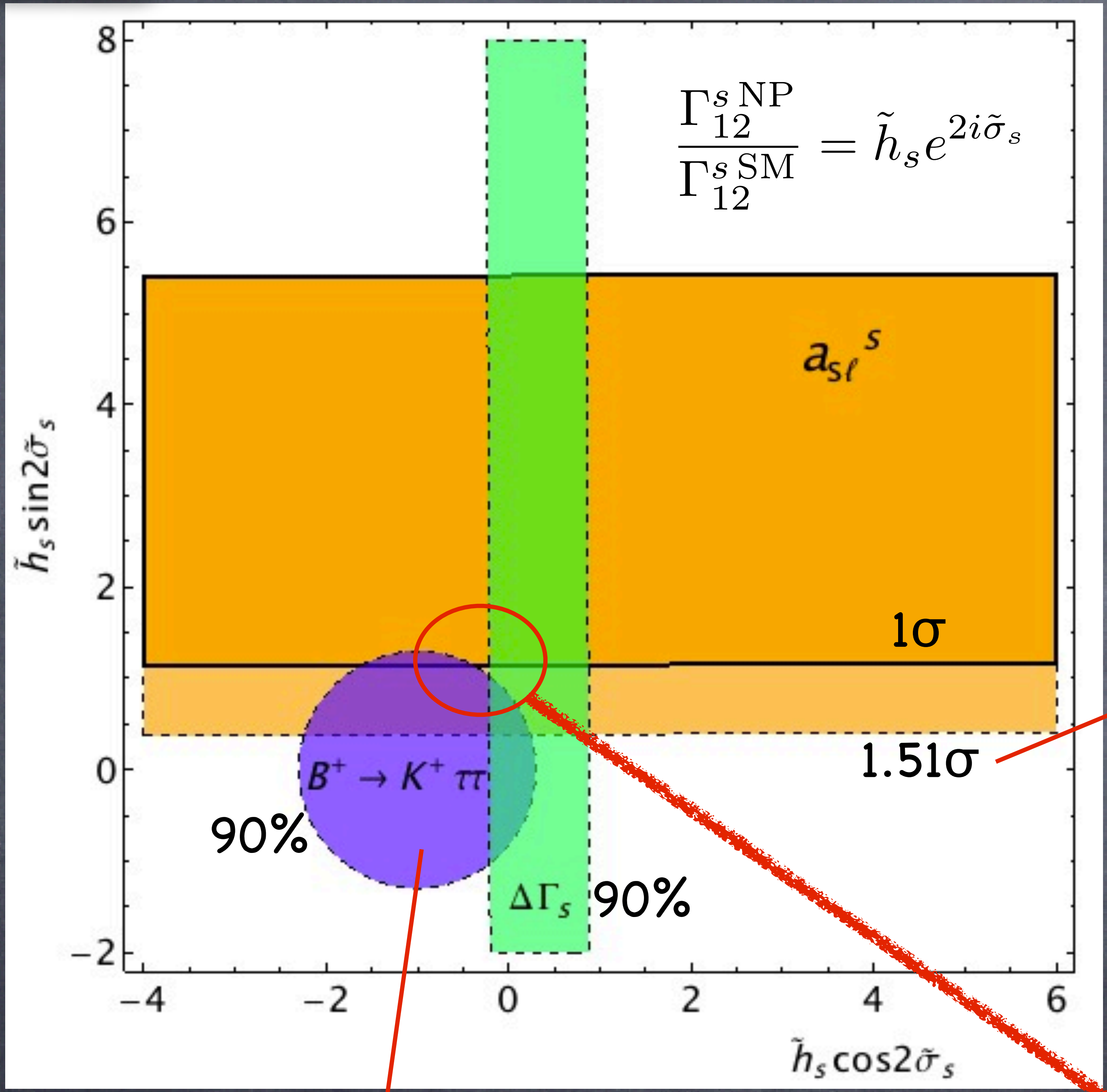
When the contribution from the mixing is small

: $h_s \ll 1$

$\Delta \Gamma_s$

when $h_s \ll 1$

No constraint from ΔM_s



less enhancement : about 100 times the SM

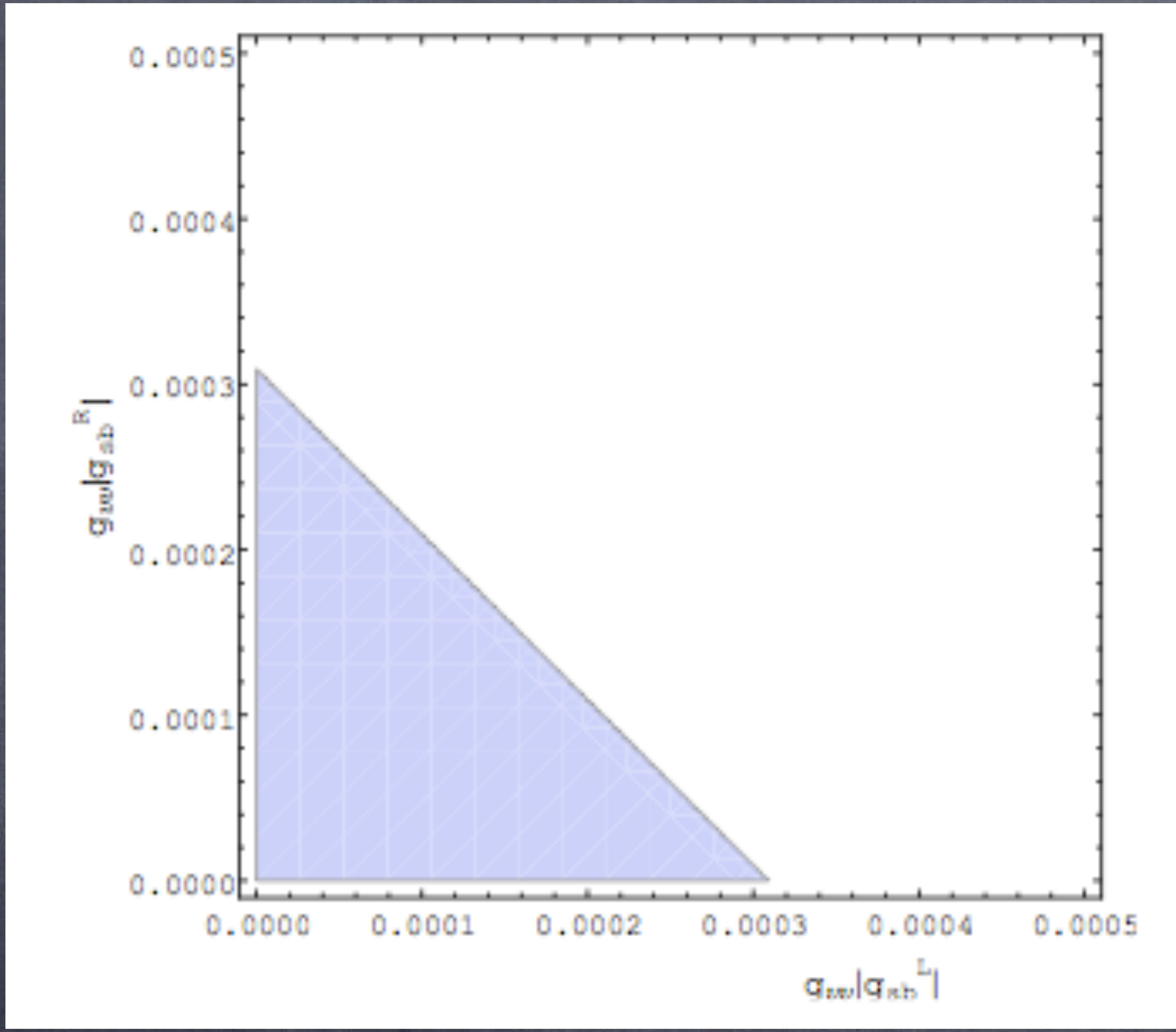
(1σ : about 395 times central : 953 times)

1109.1826, Bobeth & Haisch

marginally consistent

Model dependent experimental constraints

① NP with τ_L is constrained by b → $s\upsilon\upsilon$



$$\theta_L = \theta_R = \pi/4$$

$$\theta_{L,R} = \text{Arg.}(g_{sb}^{L,R})$$

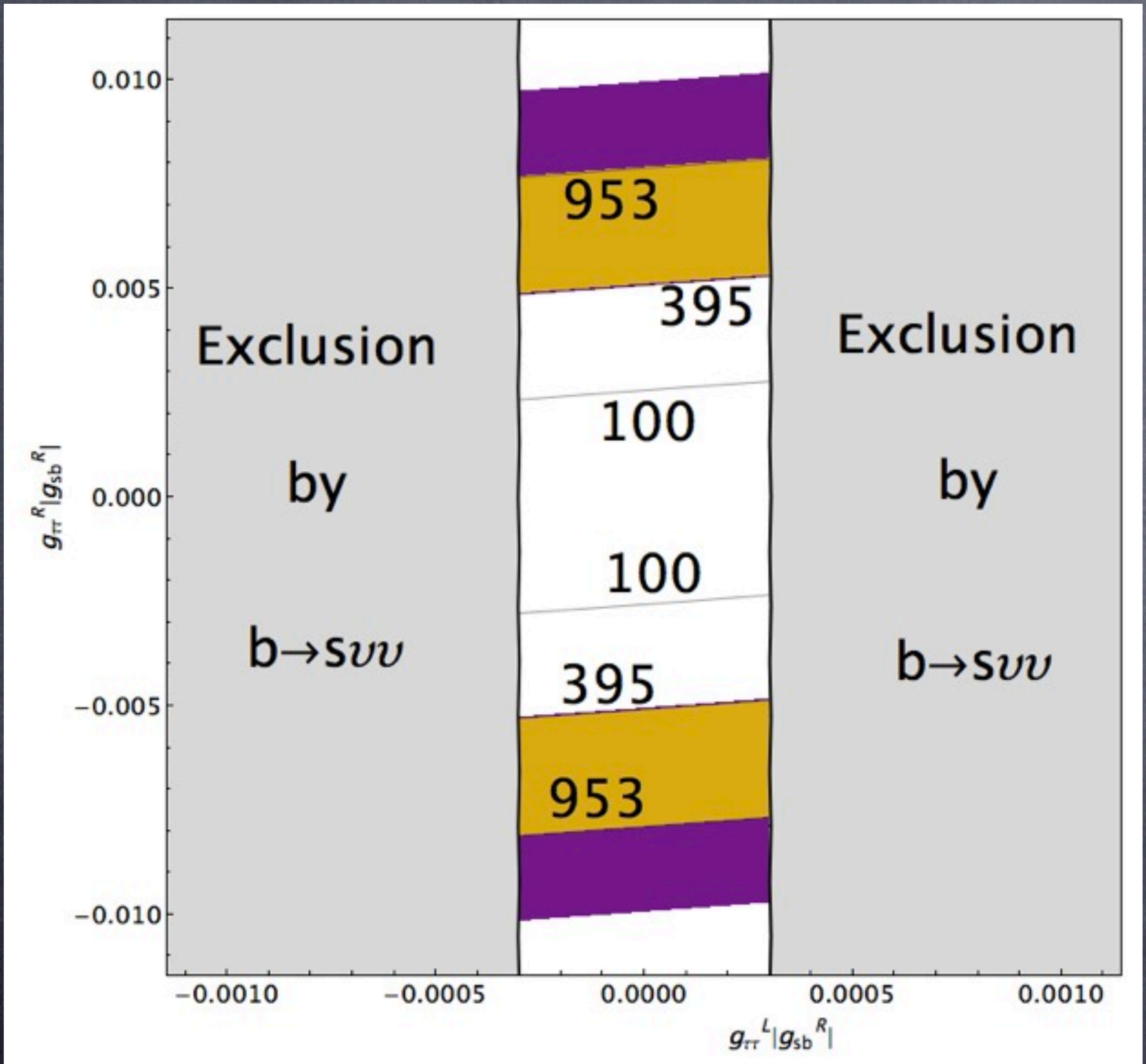
$$|g^L_{\tau\tau} g_{sb}| < 10^{-3}$$

$$\text{Br.}(B \to K^* \nu\bar{\nu}) < 8 \times 10^{-5}$$

$$\text{Br.}(B \to K \nu\bar{\nu}) < 1.3 \times 10^{-5}$$

$$\text{Br.}(B \to X_s \nu\bar{\nu}) < 6.4 \times 10^{-4}$$

For the scenario with $Z'\tau^+\tau^-$



Numbers :

$$-a^s_{s\ell}/(a^s_{s\ell})^{\rm SM}$$

1σ : about 395times the SM

central : 953 times the SM

On the asymptotic line

$$|g^R_{sb}| \approx 5.1420416\ |g^L_{sb}|$$

$$\theta_L = \theta_R = \pi/4$$

$$g^L_{\tau\tau} < 0.1 g^R_{\tau\tau}$$

Model dependent experimental constraints

② NP with c is constrained by B → $J/\psi K_s$

⇒ sin2β

$$\sin 2\beta^{\rm meas} = 0.668 \pm 0.028$$

$$\sin(2\beta)^{\rm fit} = 0.731 \pm 0.038$$

In the scenario with Z'cc

$$|(g^L_{cc} + g^R_{cc})(g^L_{sb} + g^R_{sb}) \sin\varphi| < 2.0 \times 10^{-4}$$

Another approach in sin2β

$$|V_{ub}|_{\rm excl} = (31.2 \pm 2.6) \times 10^{-4}$$
$$|V_{ub}|_{\rm incl} = (43.4 \pm 1.6^{+1.5}_{-2.2}) \times 10^{-4}$$

large difference

Remove from the input

instead, use

$\epsilon_K, \Delta M_s/\Delta M_d,$

$\gamma, {\rm Br}(B \to \tau\nu)$

$$\sin(2\beta)^{\rm fit} = 0.867 \pm 0.048$$

more than 3σ

Lunghi & Soni, 1104.2117, 1010.6069

Z′cc

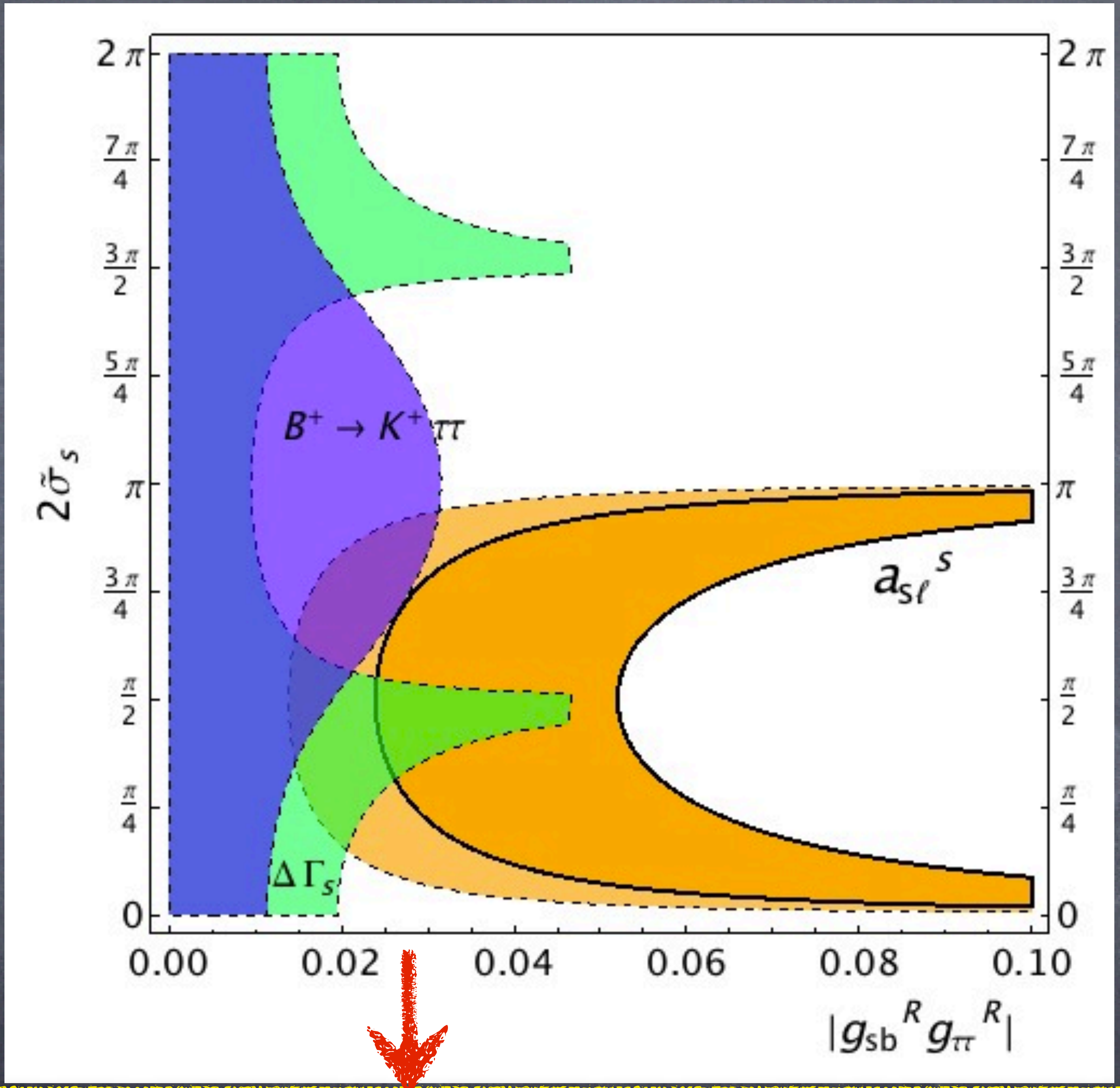
$$1.8 \times 10^{-4} < |(g^L_{cc} + g^R_{cc})(g^L_{sb} + g^R_{sb}) \sin\varphi| < 6.0 \times 10^{-4}$$

Z' scenario with τ couplings

① $h_s \ll 1$

ΔM_s & $\phi_s^{J/\psi\,\phi}$

② $g^L_{\tau\tau} < 0.1 g^R_{\tau\tau}$

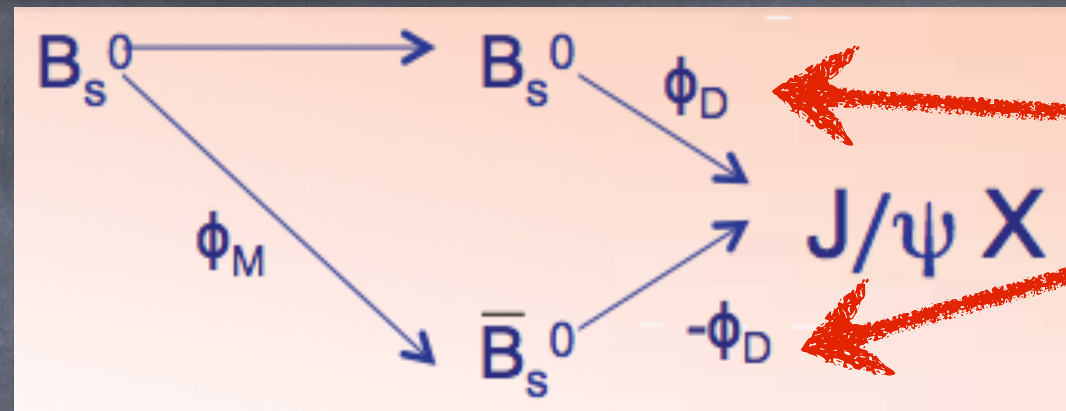


Consistent region : at least $|g^R_{sb} g^R_{\tau\tau}| \sim \mathcal{O}(10^{-2})$

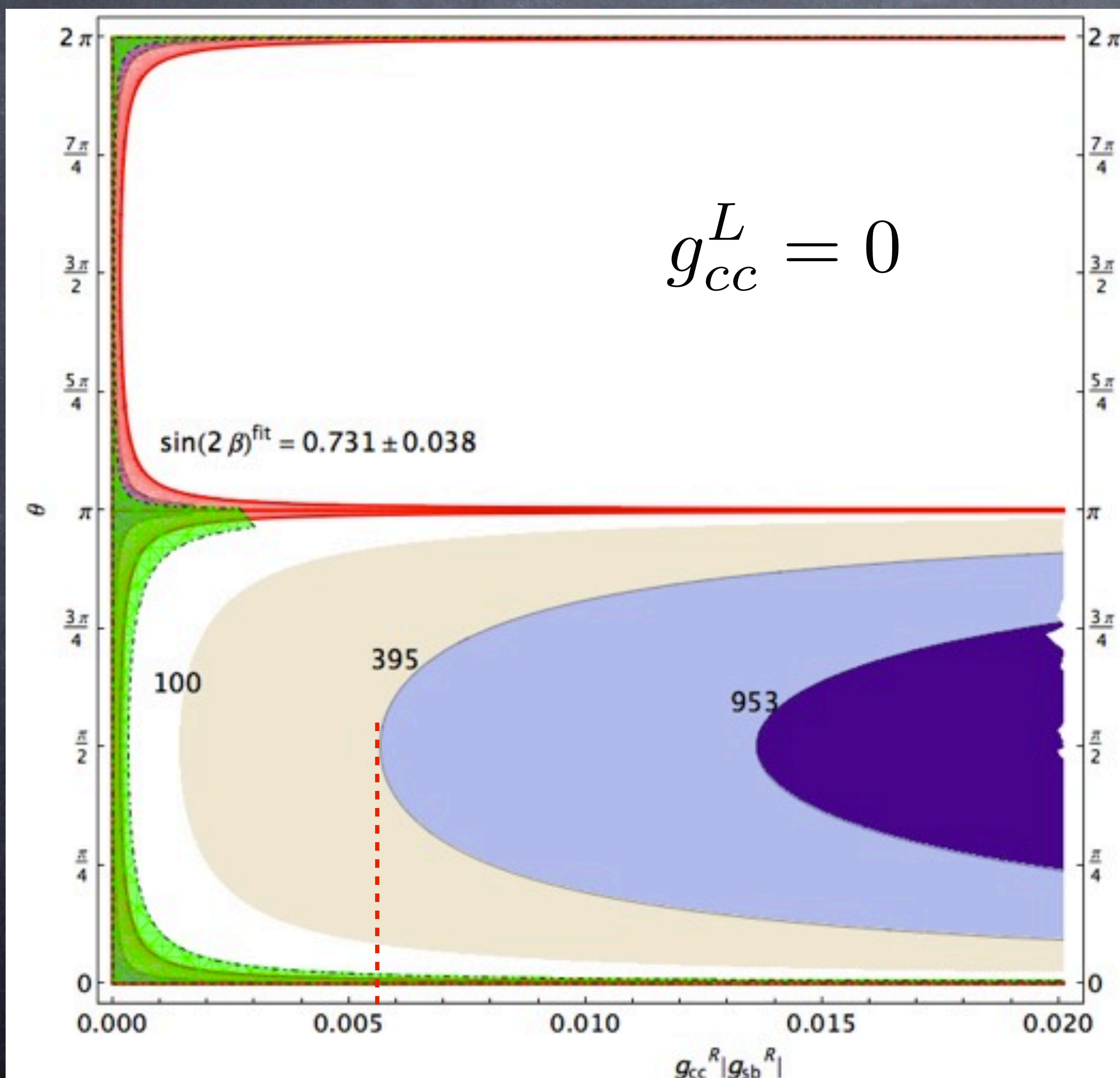
$|g^R_{\tau\tau}| < 1$ → $|g^R_{sb}| \gg 10^{-3}$ → Fine-tuning from ΔM_s

Z′ scenario with *c-quark* couplings

$\phi_s^{J/\psi\phi}$



b → scc

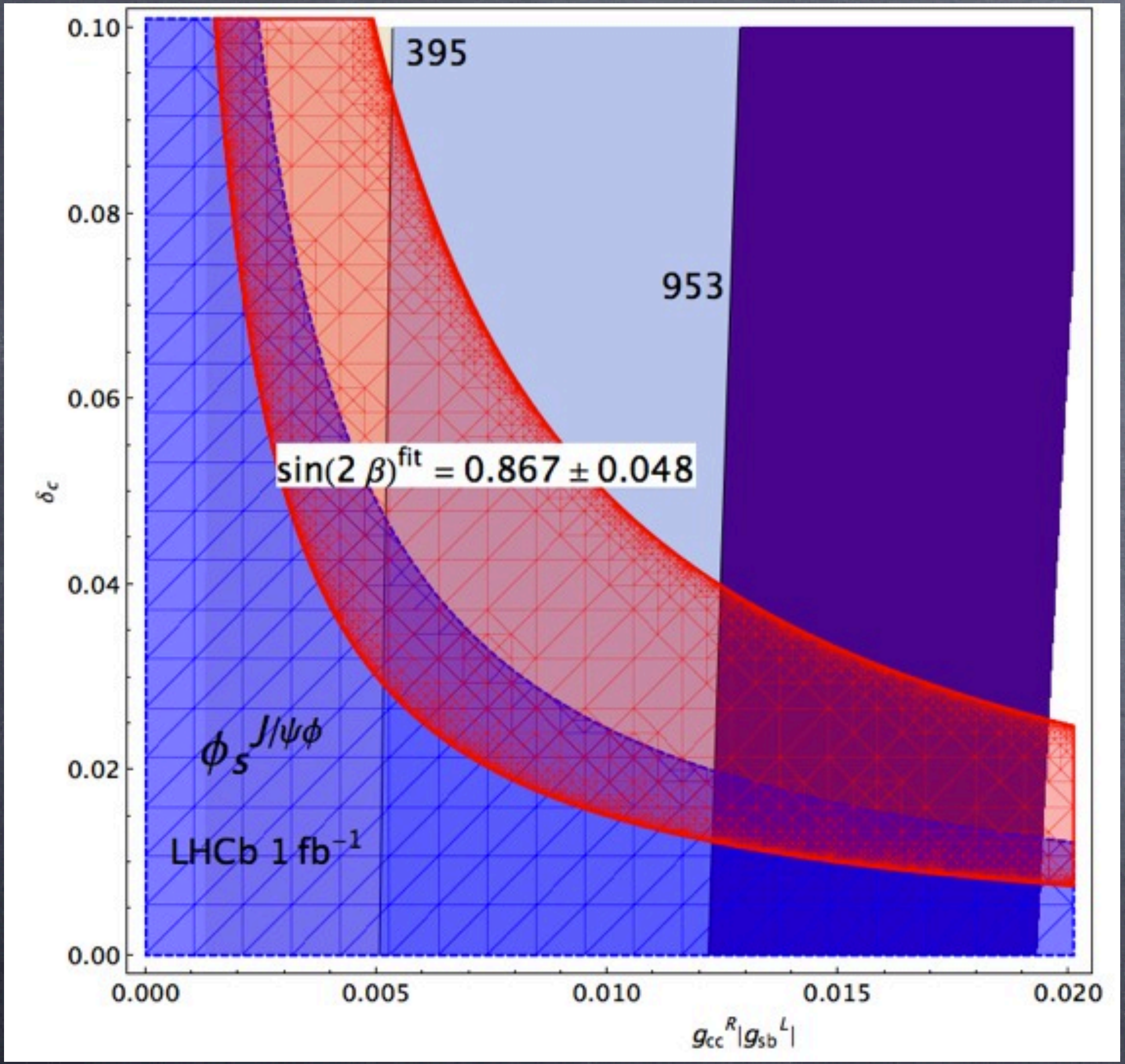


Favors (almost)
axial vector-like
Z′cc interaction

Numbers : $-a^s_{s\ell}/(a^s_{s\ell})^{\rm SM}$

1σ : about 395times the SM
central : 953 times the SM

What extent Z'cc is axial-vector like



Discrepancy from the axial vector interaction

$$\delta_c \equiv (g^L_{cc} + g^R_{cc})/g^R_{cc}$$

The case

$$|g^L_{sb}| \approx 5.1420416\ |g^R_{sb}|$$

Fine tuning from ΔM_s is loosen

Consistent region : at least $|g_{cc}g_{sb}| \sim \mathcal{O}(10^{-3})$ $\delta_c < 5 \times 10^{-2}$

Z′ scenario with *c-quark* couplings

Consistent $|g_{cc} g_{sb}| \sim \mathcal{O}(10^{-3})$

- Less Fine-tuning from ΔM_s compared to the τ case

- To satisfy the recent LHCb result of 1fb^{-1},
  Z′cc interaction is almost axial vector-like
  → sizable g^L_{cc} → sizable g^L_{ss}

Cannot easily avoid the constraints (fine tuning + α)

$$B_d^0 - \bar{B}_d^0 \ , \ K^0 - \bar{K}^0 \ , \ D^0 - \bar{D}^0 \ , \pi \text{ production } , \cdots$$

$$g^L_{bd} \ , g^L_{ds} \ , g^L_{uc} \ , g^L_{uu} \ , g^L_{dd} \ , \cdots$$

Conclusions

- The like-sign dimuon charge asymmetry
 : observed at the D0 since 2010 and now has about 3.9σ deviation

- The sizable CP violating effect in $B_{d,s}$ mixing (Γ_{12} is large but $\Gamma_{B_{d,s}}$ must be small)

- Recent experimental constraints are analyzed.
 (LHCb result heads to the SM prediction)
 ΔM_s , $\Delta\Gamma_s$, $\phi_s^{J/\psi\phi}$, $b \to s\upsilon\upsilon$, $B \to J/\psi K_S$

- Obtain the limit of the Z′ parameters from the experimental bounds.

Conclusions

- New off-diagonal interaction Z′bs provides the enough contribution with $Z'\tau\tau$ coupling or Z′cc coupling.
- However, not free from the fine tuning from various experiments.
- ΔM_s & $\phi_s^{J/\psi\,\phi}$
- For Z′cc : almost axial vector-like
  (model construction very hard)
- NP in the B_d mixing ??
  : need only about 10 times the SM
  although the experimental bounds strong

Thank you!!


Pheno 2012 Symposium
LHC lights the way to new physics
University of Pittsburgh
PITTsburgh Particle physics, Astrophysics
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May 7-9, 2012

Back-up slides from now on

2010

$$A_{sl}^b = \frac{f_d Z_d a_{sl}^d + f_s Z_s a_{sl}^s}{f_d Z_d + f_s Z_s}, \quad \text{(A9)}$$

where

$$Z_q \equiv \frac{1}{1-y_q^2} - \frac{1}{1+x_q^2}, \quad \text{(A10)}$$

$$y_q \equiv \frac{\Delta\Gamma_q}{2\Gamma_q}, \quad \text{(A11)}$$

$$x_q \equiv \frac{\Delta M_q}{\Gamma_q}, \quad \text{(A12)}$$

with $q = d, s$. The quantities f_d and f_s are the production fractions for $\bar{b} \to B_d^0$ and $\bar{b} \to B_s^0$, respectively. These fractions have been measured for $p\bar{p}$ collisions at the Tevatron [2]:

$$f_d = 0.323 \pm 0.037, \qquad f_s = 0.118 \pm 0.015. \quad \text{(A13)}$$

All other parameters in (A9) are also taken from Ref. [2]:

$$x_d = 0.774 \pm 0.008, \qquad y_d = 0,$$
$$x_s = 26.2 \pm 0.5, \qquad y_s = 0.046 \pm 0.027. \quad \text{(A14)}$$

Substituting these values in Eq. (A9), we obtain

$$A_{sl}^b = (0.506 \pm 0.043)a_{sl}^d + (0.494 \pm 0.043)a_{sl}^s. \quad \text{(A15)}$$

Using the values of a_{sl}^d, a_{sl}^s from Ref. [1],

$$a_{sl}^d(\text{SM}) = (-4.8^{+1.0}_{-1.2}) \times 10^{-4}$$
$$a_{sl}^s(\text{SM}) = (2.1 \pm 0.6) \times 10^{-5}, \quad \text{(A16)}$$

the predicted value of A_{sl}^b in the standard model is

$$A_{sl}^b(\text{SM}) = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}. \quad \text{(A17)}$$

The current experimental values of the two semileptonic asymmetries are $a_{sl}^d = -0.0047 \pm 0.0046$ [24] and $a_{sl}^s = -0.0017 \pm 0.0091$ [25].

2011

$$A_{sl}^b = C_d a_{sl}^d + C_s a_{sl}^s, \quad \text{(2)}$$

$$\text{with } a_{sl}^q = \frac{\Delta\Gamma_q}{\Delta M_q} \tan\phi_q, \quad \text{(3)}$$

where ϕ_q is a *CP*-violating phase, and ΔM_q and $\Delta\Gamma_q$ are the mass and width differences between the eigenstates of the propagation matrices of the neutral B_q^0 mesons. The coefficients C_d and C_s depend on the mean mixing probabilities and the production fractions of B^0 and B_s^0 mesons. We use the production fractions measured at LEP as averaged by the Heavy Flavor Averaging Group (HFAG) [3] and obtain

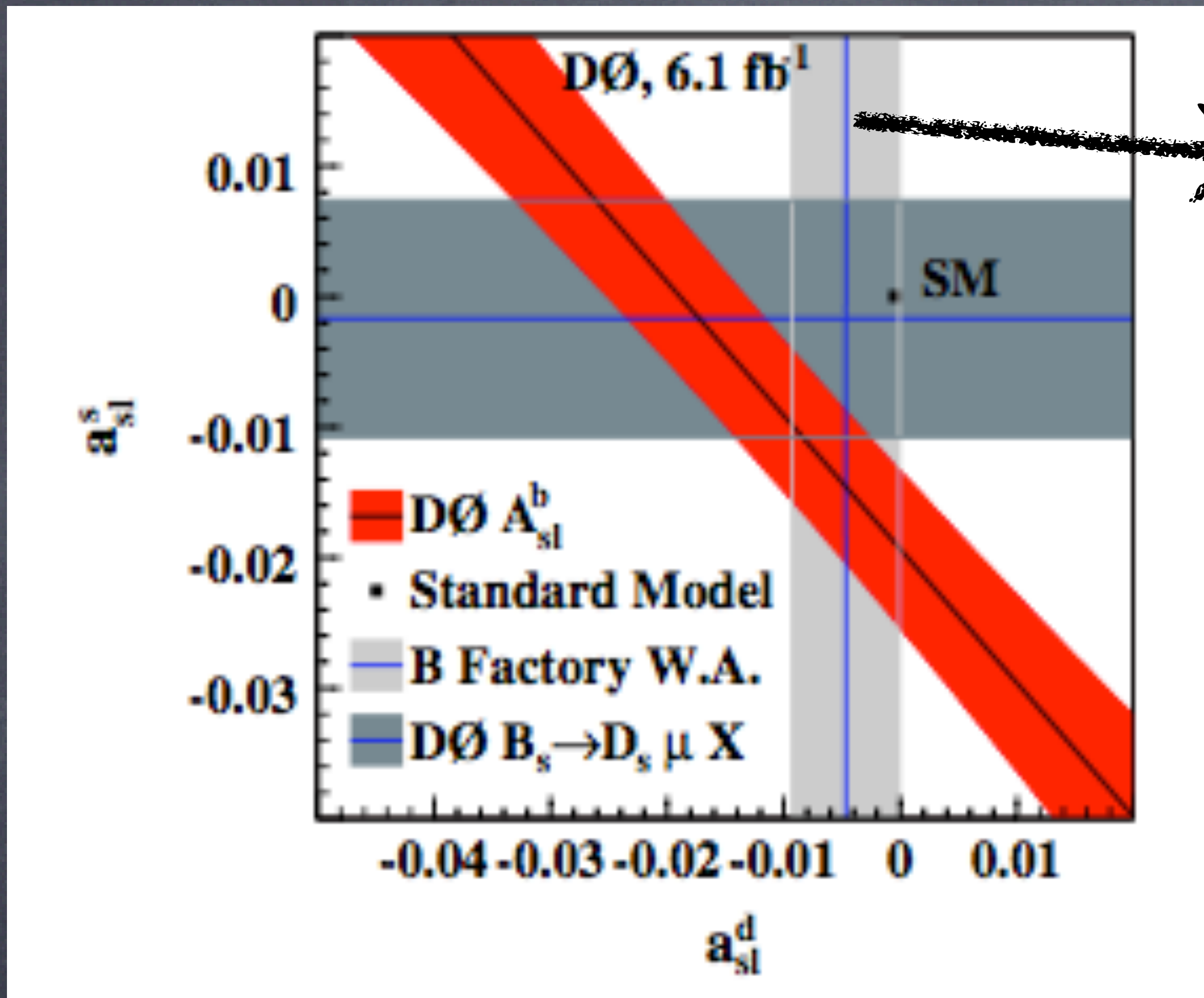
$$C_d = 0.594 \pm 0.022, \qquad C_s = 0.406 \pm 0.022. \quad \text{(4)}$$

The mean mixing probability measured by the CDF Collaboration recently [4] is consistent with the LEP value, which supports this choice of parameters. Using the standard model (SM) prediction for a_{sl}^d and a_{sl}^s [5], we find

$$A_{sl}^b(\text{SM}) = (-0.028^{+0.005}_{-0.006})\%, \quad \text{(5)}$$

$f_d = 0.397$ and $f_s = 0.112$

2010 result of 3.2σ



From the B factories

$$a^d_{s\ell} = -(4.7 \pm 4.6) \times 10^{-3}$$

↓

$$a^s_{s\ell}$$

From the D0 result

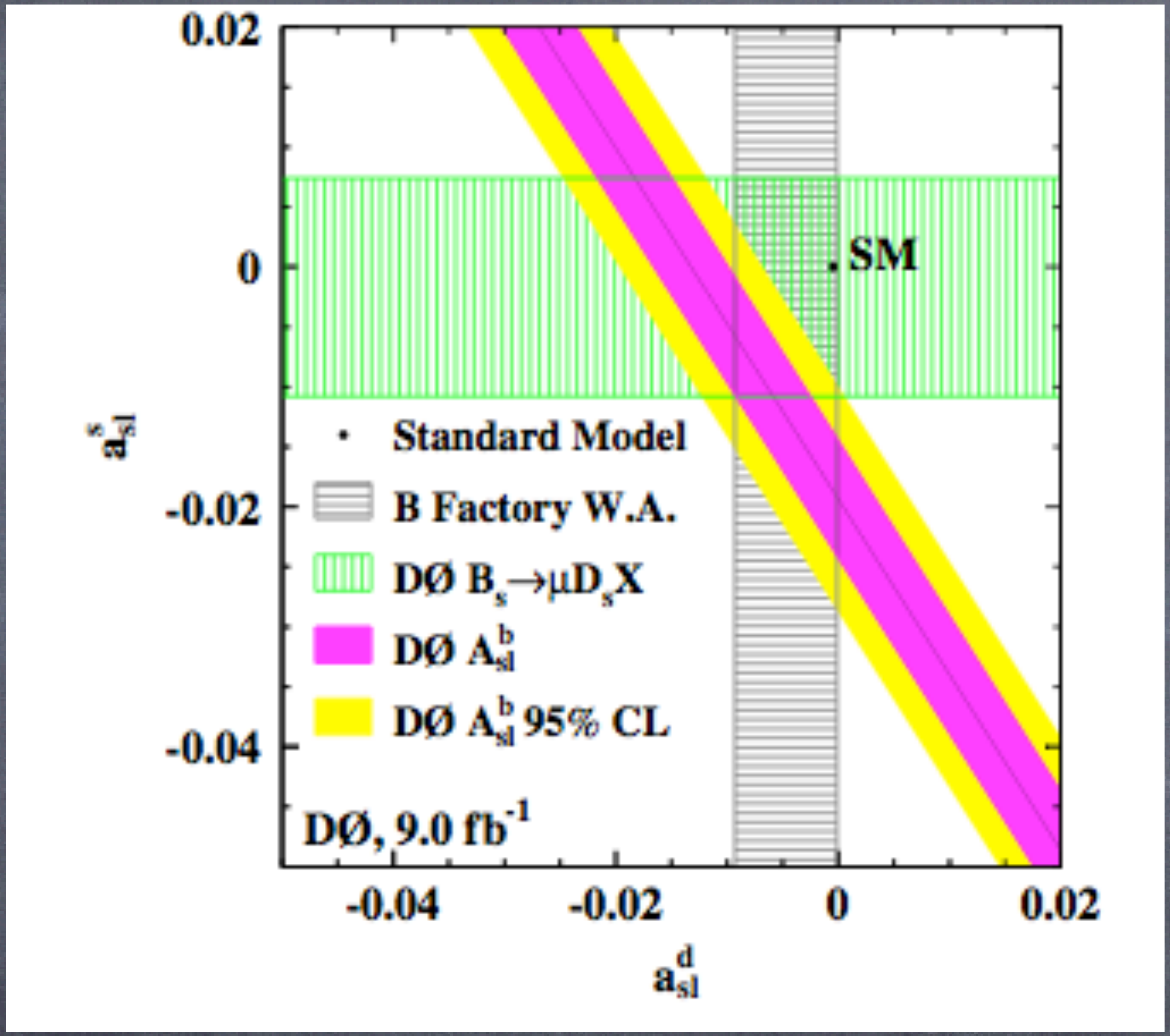
+

CDF result of 1.6 fb^{-1}

$$(a^s_{s\ell})_{\rm ave} = -(12.7 \pm 5.0) \times 10^{-3}$$

2.5σ from $(a^s_{s\ell})^{\rm SM} = (1.9 \pm 0.3) \times 10^{-5}$

2011 result of 3.9σ



The deviation increased and the most interesting change in the 2011 data is..........

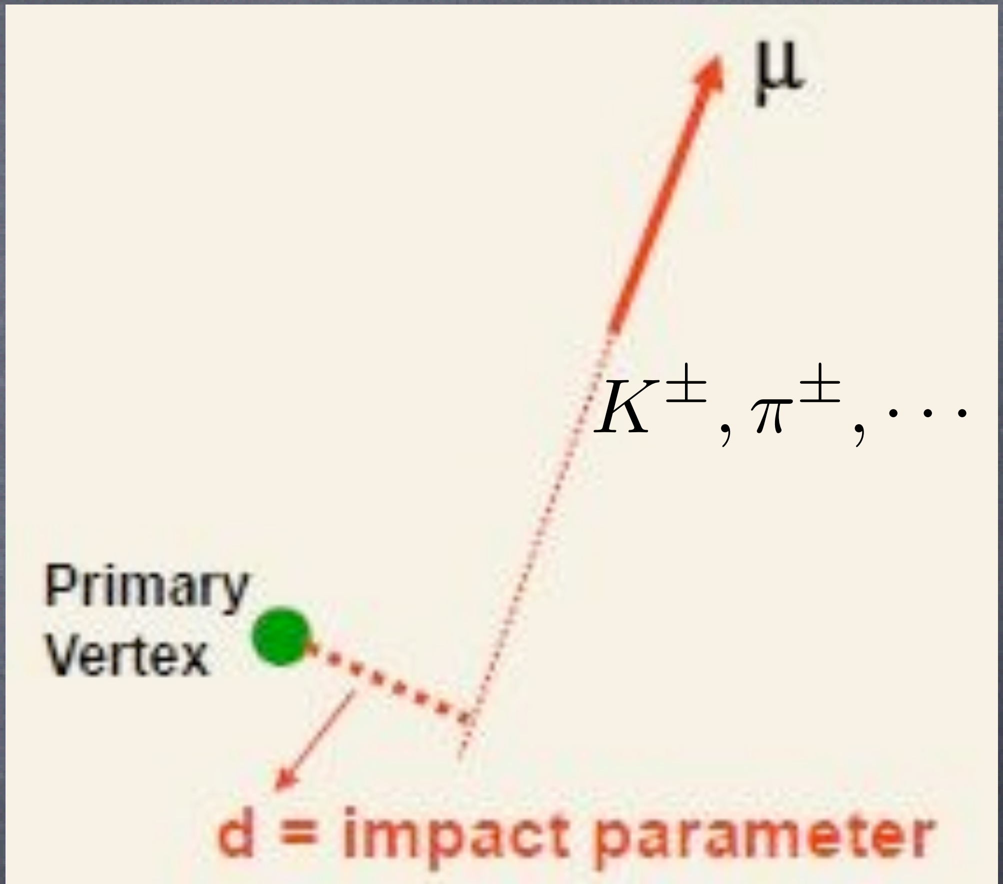
2011 result of 3.9σ

Background reduction muon impact parameter cut

Charged Hadron produced at the primary vertex

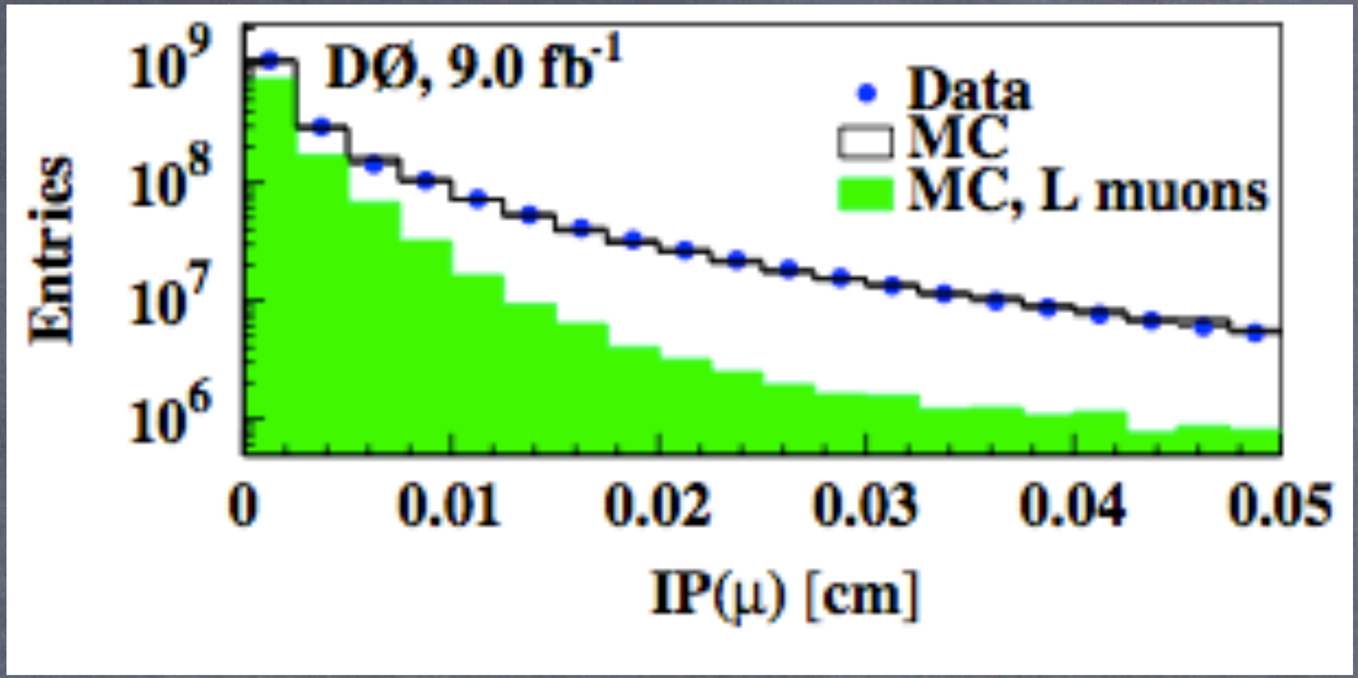
($K^+ \to \mu^+$ & $K^- \to \mu^-$, ...)

Difference in the interaction with the detector material



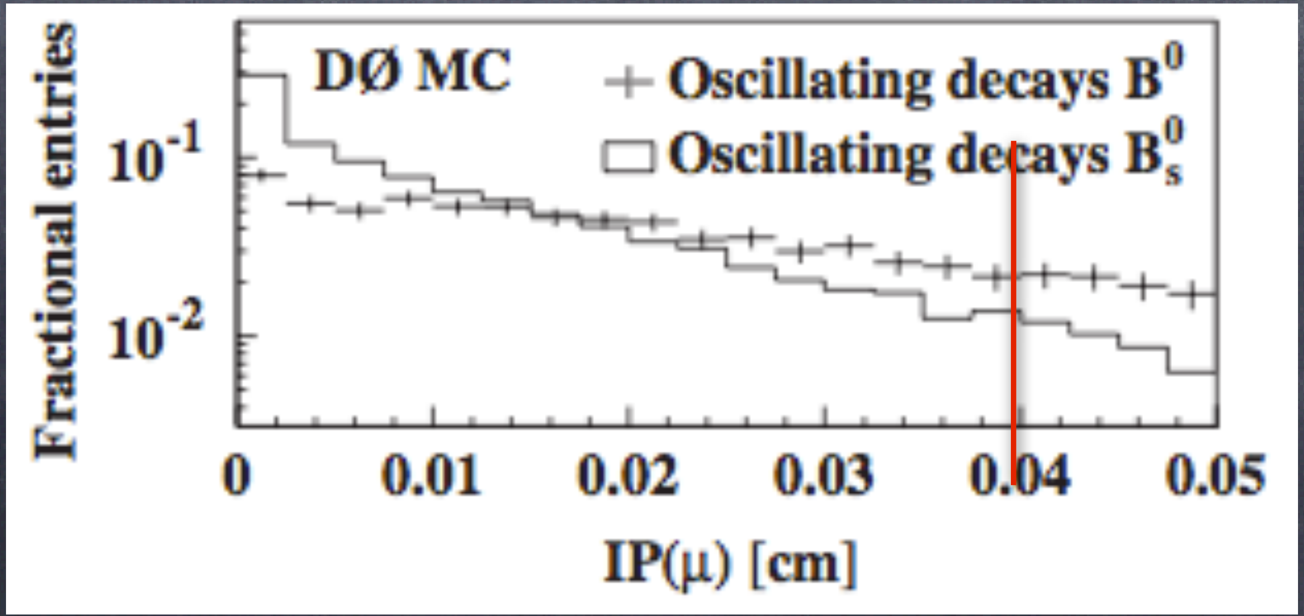
Long-lived charged mother particles can mimic the track of muons → small IP

Compare with the computational result



Muon IP difference in B_d^0, B_s^0

$\Delta M_s \gg \Delta M_d$ Bs mixing time << Bd mixing time



Without new contribution to Γ_{12}^s outside 1σ

Usual MSSM : M_{12} only

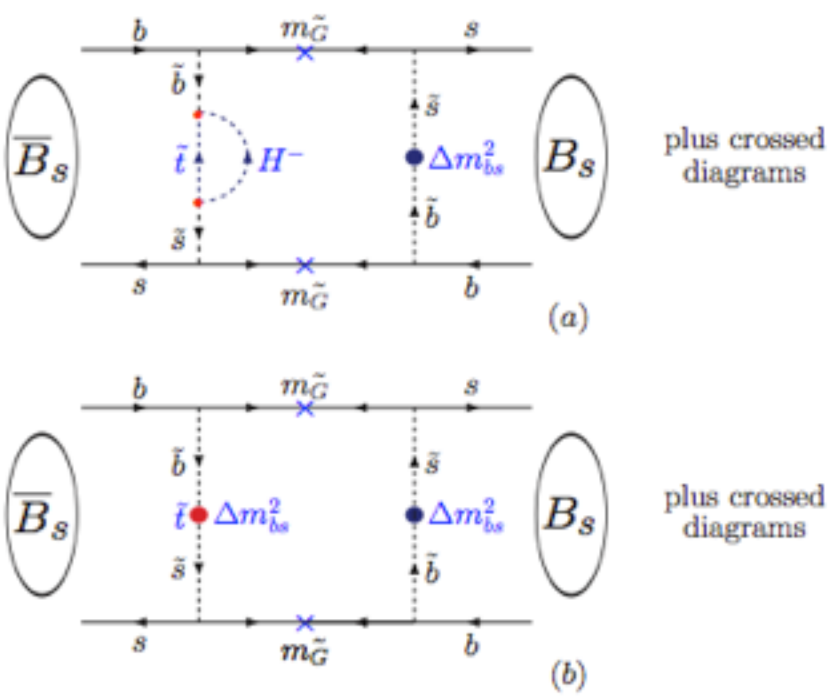
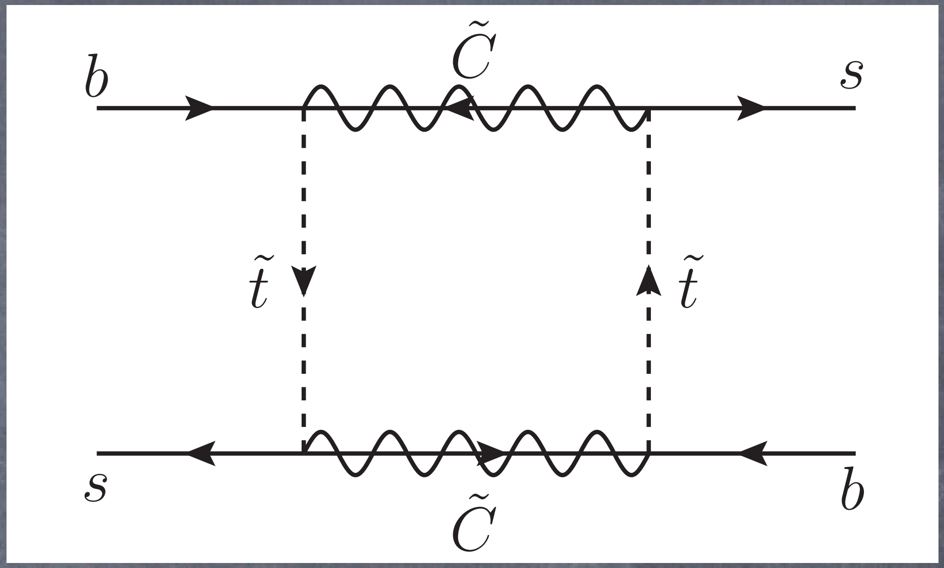


FIG. 4. The $B_s - \overline{B}_s$ mixing through the gluino mass: (a) A detail of one mass mixing and (b) all mass mixings without details. The diagram with the charged gauginos which is a mere supersymmetrization of the SM FCNC is also possible, but with smaller gauge couplings. (a) is drawn again in (b). The red bullet in (b) contains a CP phase whose origin is shown in (a). The A terms are colored red, and the box diagram of (a) has an unremovable CP phase.

or



Low $\tan\beta$

Chargino and stop mass

CP violation source : CKM

or DP Suppressed by exp.

Buras et al. hep-ph/0207241 PLB

$$
\begin{aligned}
\Delta M_s &= 17.77 \pm 0.10(\text{stat.}) \pm 0.07(\text{sys.})\ \text{ps}^{-1} \\
&= (11.7 \pm 0.07 \pm 0.05) \times 10^{-12}\ \text{GeV}
\end{aligned}
$$

→ CDF measurement 1.6 fb^{-1}

LHCb

LHCb-CONF-2011-050
November 28, 2011

Measurement of Δm_s in the decay $B_s^0 \to D_s^-(K^+K^-\pi^-)\pi^+$ using opposite-side and same-side flavour tagging algorithms

The LHCb Collaboration

Abstract

The B_s^0-$\overline{B}_s^0$ oscillation frequency Δm_s is measured on a data sample of 340 pb^{-1} from the LHCb physics run in 2011. A total of 9189 B_s^0 signal candidates are reconstructed in the $B_s^0 \to D_s^-\pi^+$ decay, with an average decay time resolution of 45 fs. We established an oscillation signal using for the first time in LHCb the same-side kaon tagging and measured its effective tagging efficiency of $\epsilon_{\text{eff,SSKT}} = 1.3 \pm 0.4$ %. The most precise value of the oscillation frequency is found to be $\Delta m_s = 17.725 \pm 0.041$ (stat) ± 0.026 (syst) ps^{-1} using a combination of opposite-side and same-side flavour tagging algorithms.

LHCb-CONF-2011-050
28/11/2011

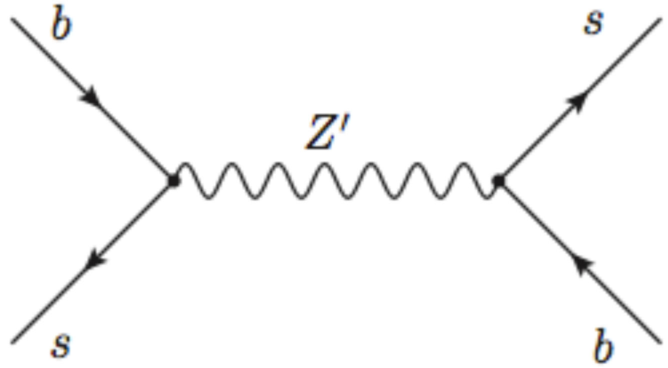


FIG. 9. The tree level $B_s - \overline{B}_s$ mixing via the new Z' gauge boson.

Tree level mixing : M_{12}

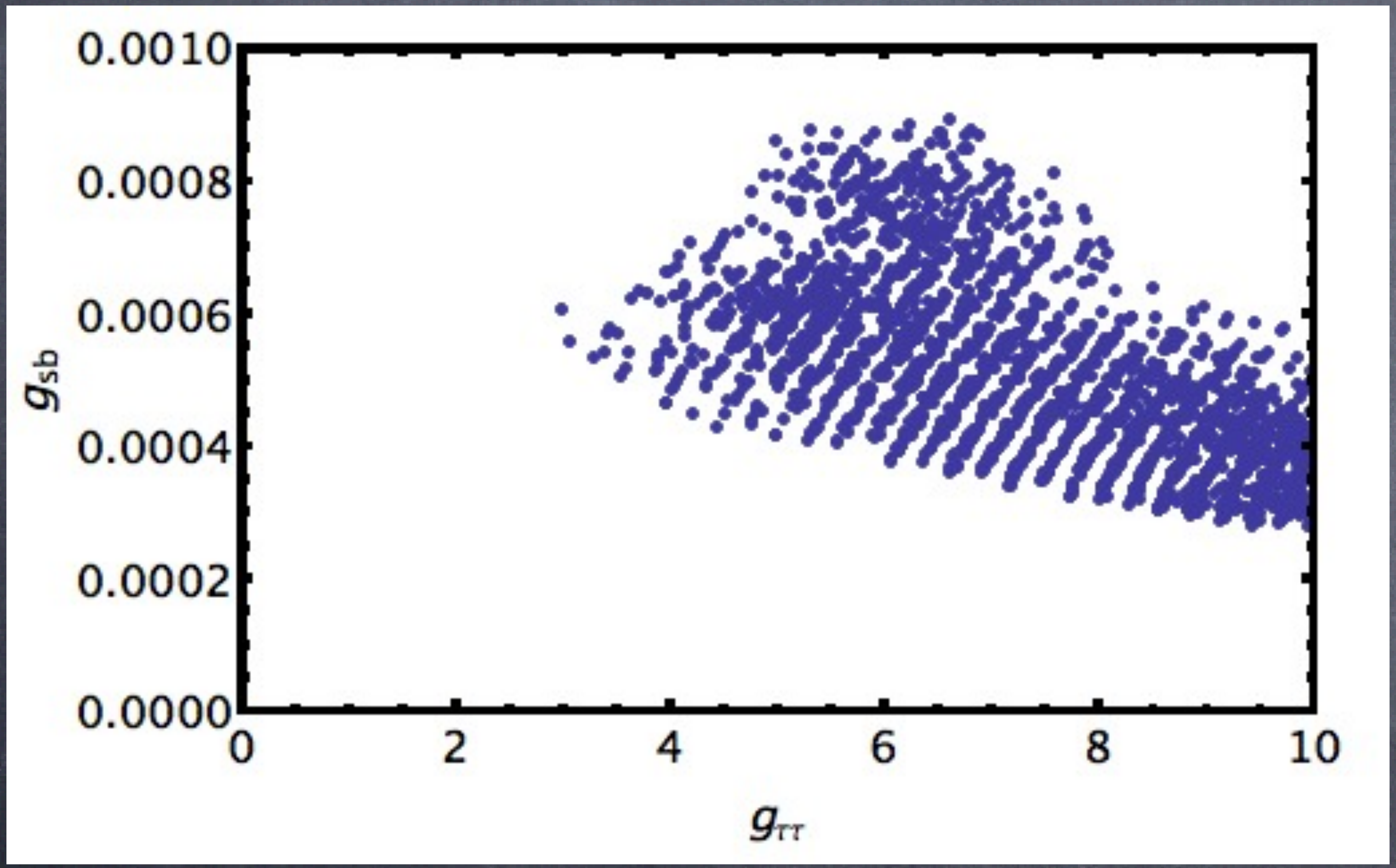
$$h_s = \frac{3.858\times 10^5}{g_1^2} \times \text{Abs.}\left[(g_{sb}^L)^2 + (g_{sb}^R)^2 - 6\,\eta^{-3/23} g_{sb}^L g_{sb}^R \left(\frac{1}{4} + \frac{1}{6}\left(\frac{m_{B_s}}{m_b+m_s}\right)^2\right) + 4\left(\eta^{-3/23} - \eta^{-30/23}\right) g_{sb}^L g_{sb}^R \left(\frac{1}{24} + \frac{1}{4}\left(\frac{m_{B_s}}{m_b+m_s}\right)^2\right)\right]$$

$$\eta = \alpha_s(M_{Z'})/\alpha_s(m_b)$$

If one of $g_{sb} = 0$

The diagonal couplings should be large

$$\Gamma_{12} : (g_{sb}^{L,R} g_{\tau\tau}^{L,R}) \; , (g_{sb}^{L,R} g_{cc}^{L,R})$$



Too large coupling

We need both of g_{sb}^{L} & g_{sb}^{R}

LHCb 1fb^{-1}

$\phi_s^{J/\psi\,\phi}$

$$\phi_s^{J/\psi\,\phi} \quad = \quad -0.001 \pm 0.101(\text{stat.}) \pm 0.027(\text{syst.})$$

$\updownarrow$ 0.3σ

$$(\phi_s^{J/\psi\,\phi})_{\text{SM}} = -2\beta_s^{\text{SM}} = -0.036 \pm 0.002$$

Provides very strong constraint in the NP

LHCb 1fb^{-1}

$\Delta\Gamma_s$

Sign fixed : positive

$$\Delta\Gamma_s \quad = \quad 0.116 \pm 0.018(\text{stat.}) \pm 0.006(\text{syst.})\ \text{ps}^{-1}$$

↕ **1.2σ**

$$(\Delta\Gamma_s)^{\text{SM}} = (0.087 \pm 0.021)$$

$$\frac{\Delta\Gamma_s}{(\Delta\Gamma_s)^{\rm SM}} = \frac{1}{\sqrt{1+h_s^2+2h_s\cos 2\sigma_s}}$$

near to 1

determines $\Delta\Gamma_s$

$$\times \Big[(1+h_s\cos 2\sigma_s)(1+\tilde{h}_s\cos 2\tilde{\sigma}_s) + h_s\tilde{h}_s\sin 2\sigma_s\sin 2\tilde{\sigma}_s$$

$$- \tan\phi_s^{\rm SM}\left(h_s\sin 2\sigma_s(1+\tilde{h}_s\cos 2\tilde{\sigma}_s) - \tilde{h}_s\sin 2\tilde{\sigma}_s(1+h_s\cos 2\sigma_s)\right)\Big]$$

0.0038

$$-a_{s\ell}^q/(a_{s\ell}^q)^{\rm SM} = \frac{1}{1+h_q^2+2h_q\cos 2\sigma_q}$$

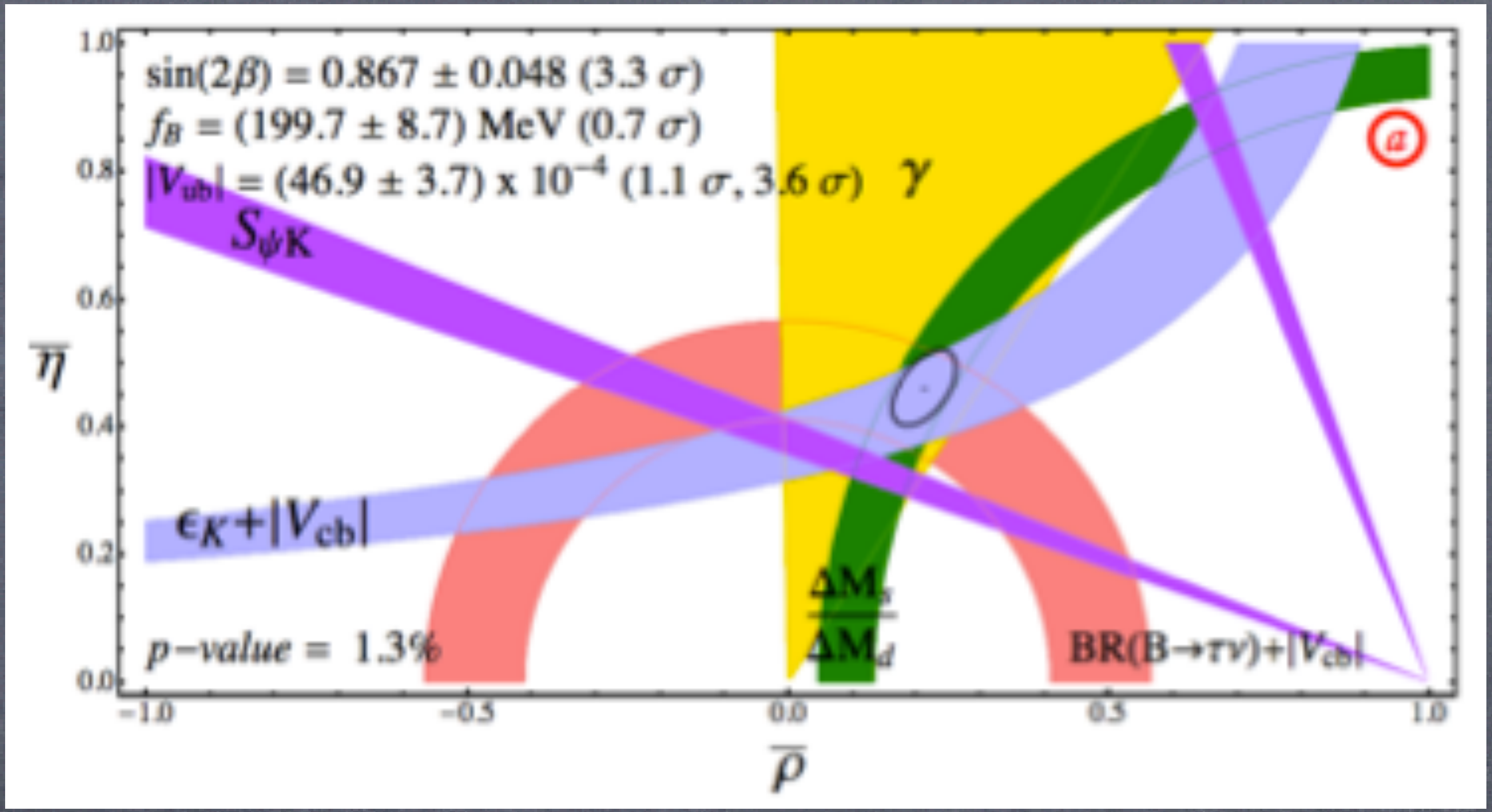
near to 1

determines the asymm

263

$$\times \Big[\left\{\tilde{h}_q\sin 2\tilde{\sigma}_q(1+h_q\cos 2\sigma_q) - h_q\sin 2\sigma_q(1+\tilde{h}_q\cos 2\tilde{\sigma}_q)\right\}\cot\phi_q^{\rm SM}$$

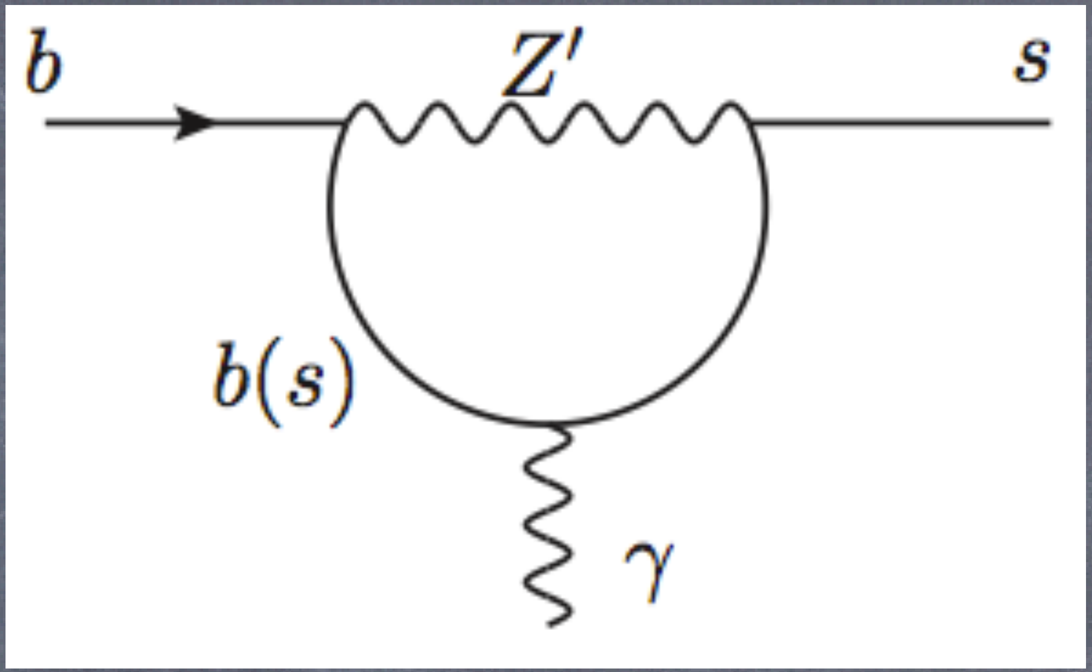
$$- \left\{(1+\tilde{h}_q\cos 2\tilde{\sigma}_q)(1+h_q\cos 2\sigma_q) + h_q\tilde{h}_q\sin 2\sigma_q\sin 2\tilde{\sigma}_q\right\}\Big]$$



sin(2β) = 0.867 ± 0.048 (3.3 σ)
f_B = (199.7 ± 8.7) MeV (0.7 σ)
$|V_{ub}|$ = (46.9 ± 3.7) x 10^{-4} (1.1 σ, 3.6 σ)
γ
$S_{\psi K}$
$\epsilon_K + |V_{cb}|$
$\frac{\Delta M_s}{\Delta M_d}$
p−value = 1.3%
BR(B→τν)+$|V_{cb}|$
a
$\bar{\eta}$
$\bar{\rho}$

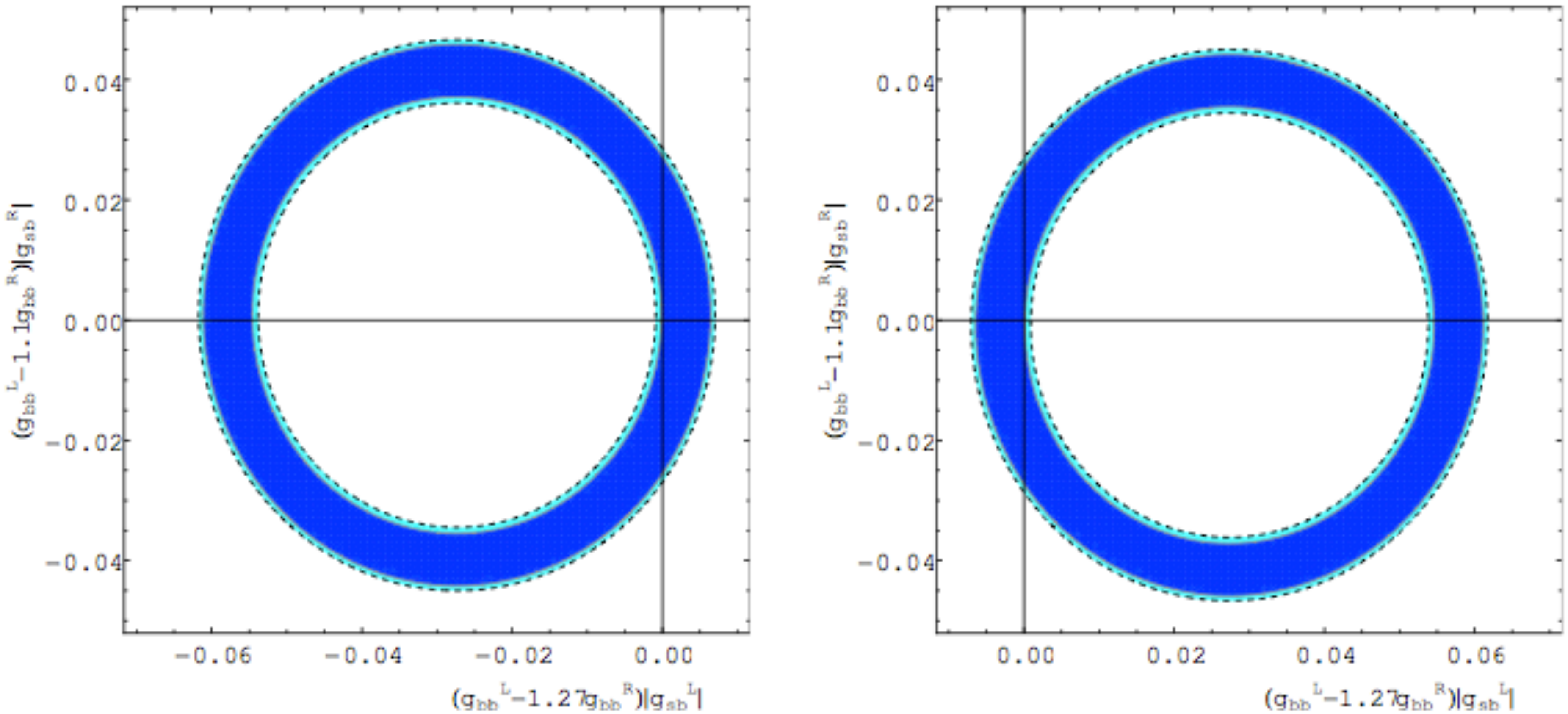
Model dependent experimental constraints

② $g_{bb} \neq 0$ or $g_{ss} \neq 0$ is constrained by $b \to s\gamma$



$$\mathrm{Br.}(B \to X_s \gamma)_{\mathrm{exp}} = (3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$$
$$\mathrm{Br.}(B \to X_s \gamma)_{\mathrm{SM}} = (3.15 \pm 0.23) \times 10^{-4}$$

Natural value $|g_{bb} g_{sb}| < \mathcal{O}(10^{-2})$



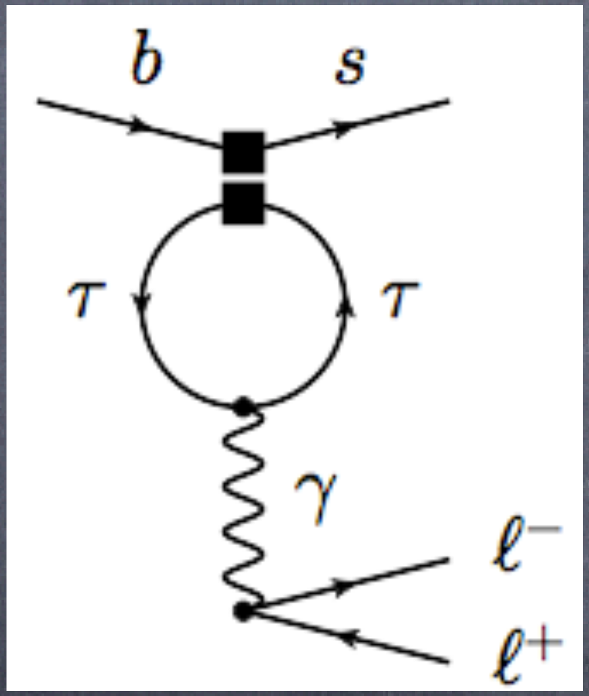
(a) $\theta_L = \theta_R = \pi/4$

(b) $\theta_L = \theta_R = 3\pi/4$

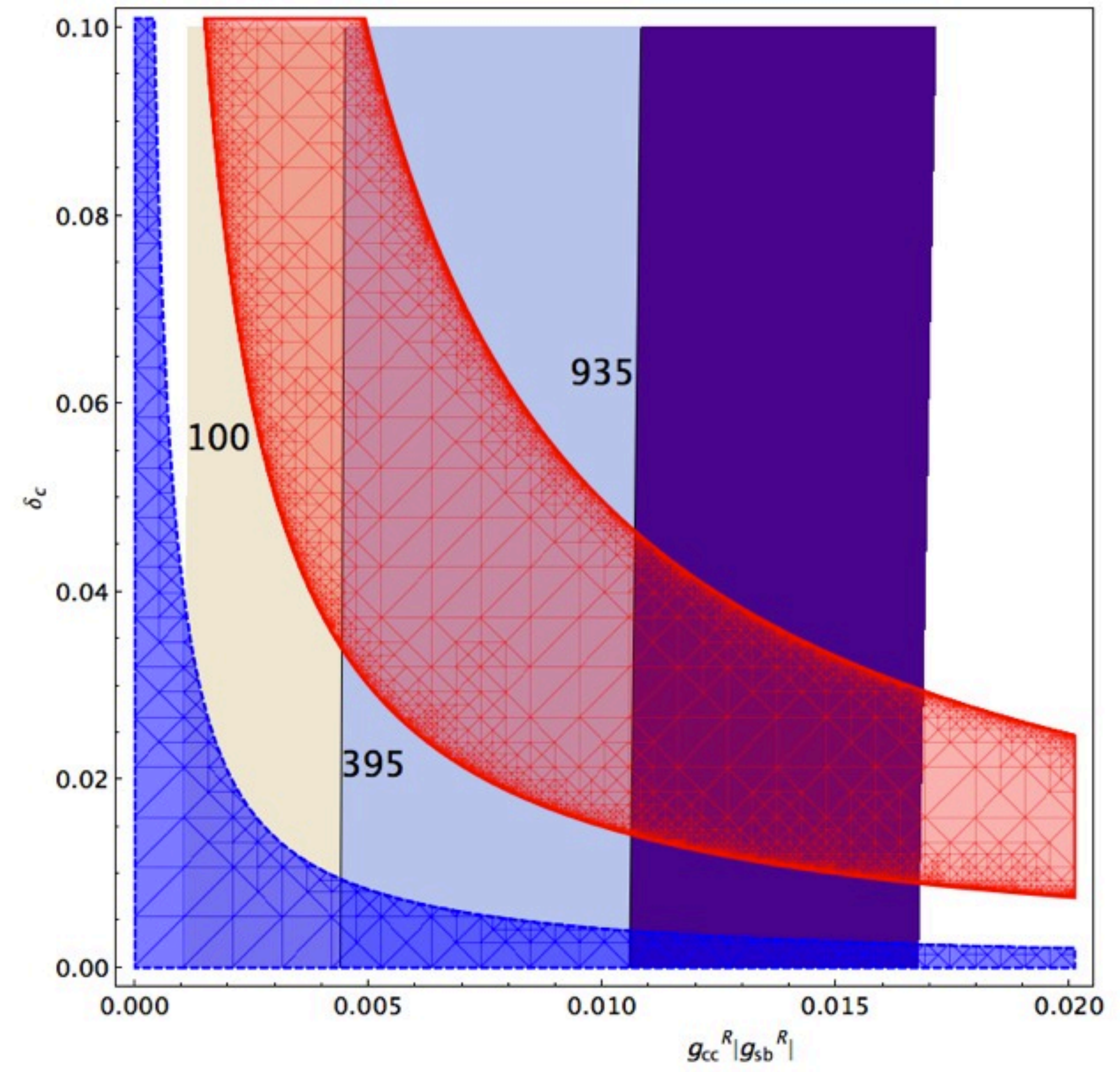
FIG. 3. The limit of the couplings from the experimental bounds of 90% C.L (Blue) and 95% C.L. (Cyan, Dashed boundary line) of $B \to X_s\gamma$ for fine-tuned cases (a) $\theta_L = \theta_R = \pi/4$ and (b) $\theta_L = \theta_R = 3\pi/4$.

② τ V,A is constrained by $b \to s\ell\ell$

Bobeth & Haisch, arXiv:1109.1826



$$\left| \frac{\Gamma_{12}^s}{(\Gamma_{12}^s)^{\rm SM}} \right| < 1.3$$



$$g_{sb}^L \approx 0.1944753 g_{sb}^R$$

$$\delta_c < 10^{-2}$$

Fine tuning is worse

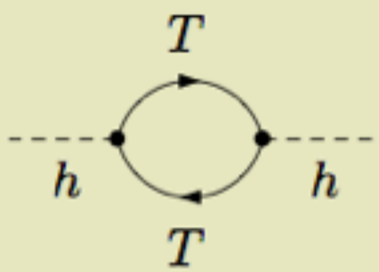
Off-diagonal couplings : $< \mathcal{O}(10^{-4})$

For D mesons : Giudice, Isidori, Paradici, 1201.6204

Neubert, Moriond 2012

$$\mathcal{L}_{\rm EFT} = \Lambda_{\rm UV}^2 \Phi^\dagger\Phi - \lambda(\Phi^\dagger\Phi)^2 + \mathcal{L}_{\rm SM}^{\rm gauge} + \mathcal{L}_{\rm SM}^{\rm Yukawa} + \frac{\mathcal{L}^{(5)}}{\Lambda_{\rm UV}} + \frac{\mathcal{L}^{(6)}}{\Lambda_{\rm UV}^2} + \dots$$

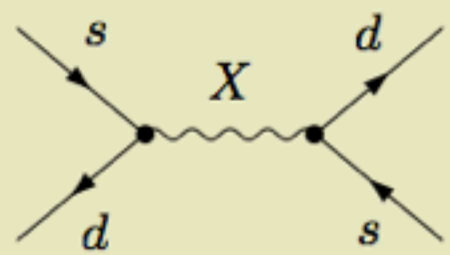
electroweak symmetry breaking ⇓ Higgs mass



$$\sim \frac{g_T^2}{16\pi^2}\Lambda_{\rm UV}^2$$

no fine-tuning ⇓

⇓



$$\sim \frac{g_X^2}{\Lambda_{\rm UV}^2}$$

bounds on flavor mixing ⇓ assuming *generic* flavor structure

$\Lambda_{\rm Higgs} \lesssim 1$ TeV $\Lambda_{\rm flavor} \gtrsim 10^3$ TeV

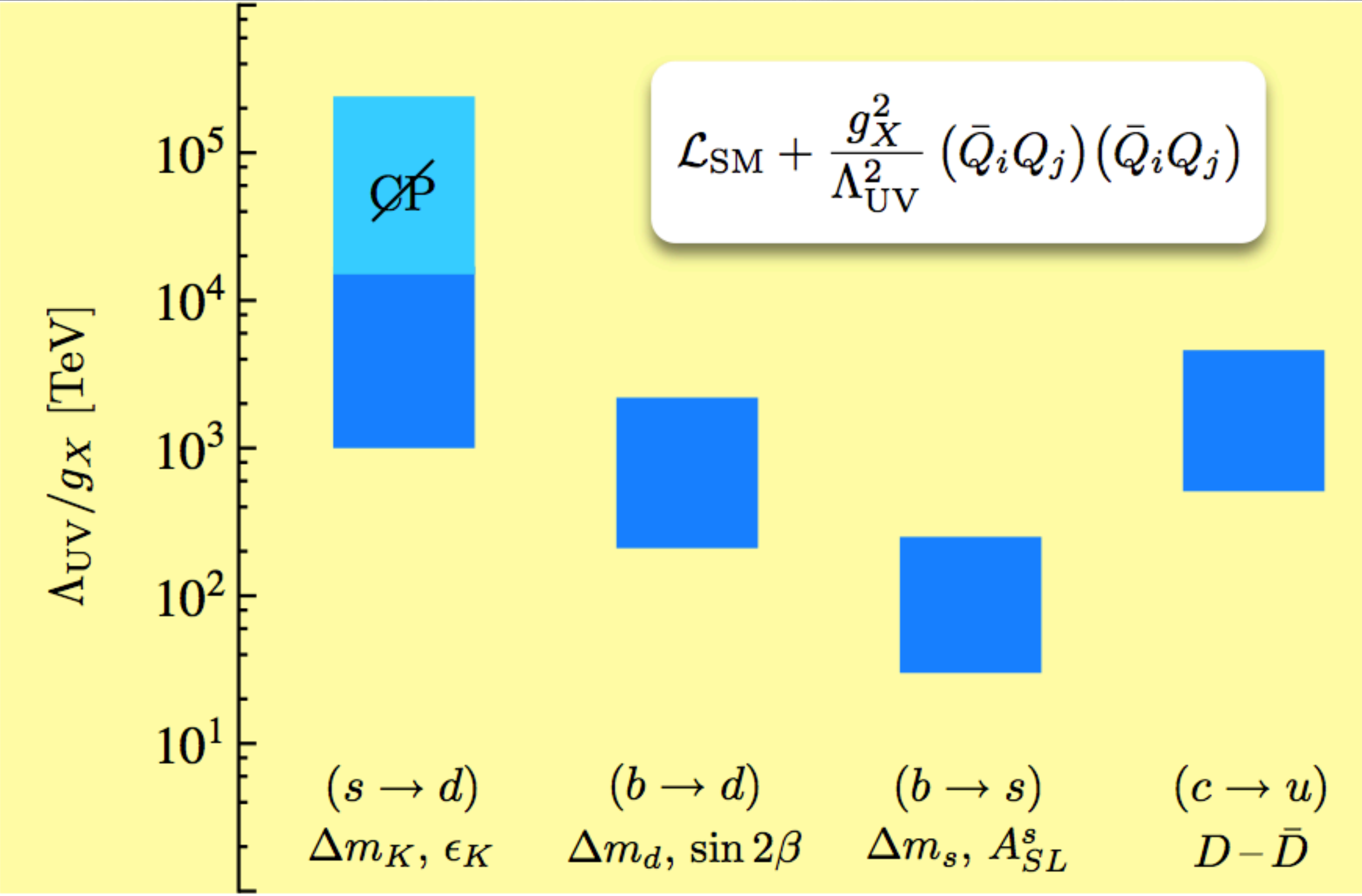
Possible solutions to flavor problem explaining $\Lambda_{\rm Higgs} << \Lambda_{\rm flavor}$:

(i) $\Lambda_{\rm UV} >> 1$ TeV: **Higgs fine tuned**, new particles too heavy for LHC

(ii) $\Lambda_{\rm UV} \approx 1$ TeV: quark flavor-mixing protected by a **flavor symmetry**

Our Z′ scenario

$g_{\tau\tau}$: $\Lambda_{\rm UV}$ 10 TeV g_{cc} : $\Lambda_{\rm UV}$ 100 TeV



Generic bounds without flavor symmetry

Z′ scenario with τ couplings

Consistent $|g_{sb} g^R_{\tau\tau}| \sim \mathcal{O}(10^{-2})$

- Fine-tuning from ΔM_s
  (Without fine-tuning, $|g^R_{\tau\tau}| > 1$)

- $|g^L_{\tau\tau}| \ll |g^R_{\tau\tau}|$ from $b \to s\upsilon\upsilon$

- $h_s \ll 1$ to satisfy ΔM_s & $\phi_s^{J/\psi\,\phi}$ constraint