A possibility of large CP violation in B system (and possible connection to D system)

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HD Kim, SG Kim and S Shin, arXiv:1205.6481
(in preparation)

CERN BSM TH Institute
2012, June 21

Tevatron : Anomaly Generator

multi-muon
top AFB
Wjj
like-sign dimuon

LHC : Anomaly Cleaner
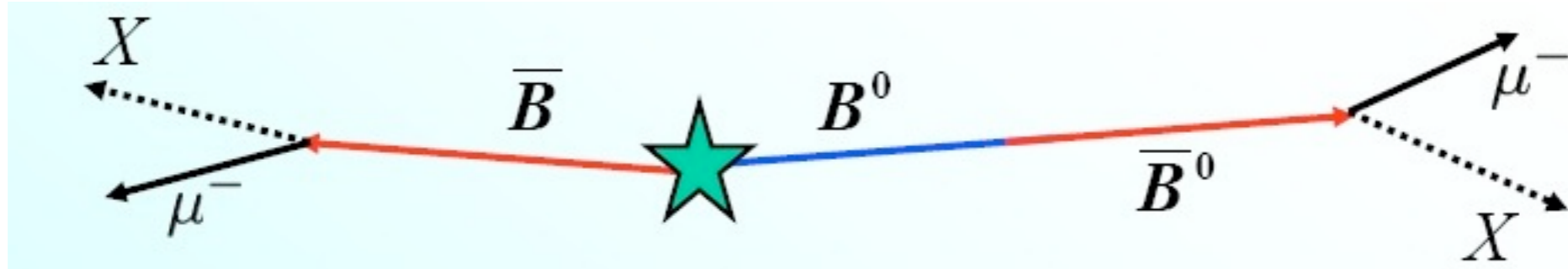
Tevatron : Anomaly Generator

multi-muon
top AFB
Wjj
~~like-sign dimuon~~   LHCb : S_psiphi

LHC : Anomaly Cleaner

Like-sign dimuon charge asymmetry at D0

$$A_{sl}^b = \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

$A_{sl}^b \neq 0 \quad \longrightarrow \quad$ CP violation in mixing
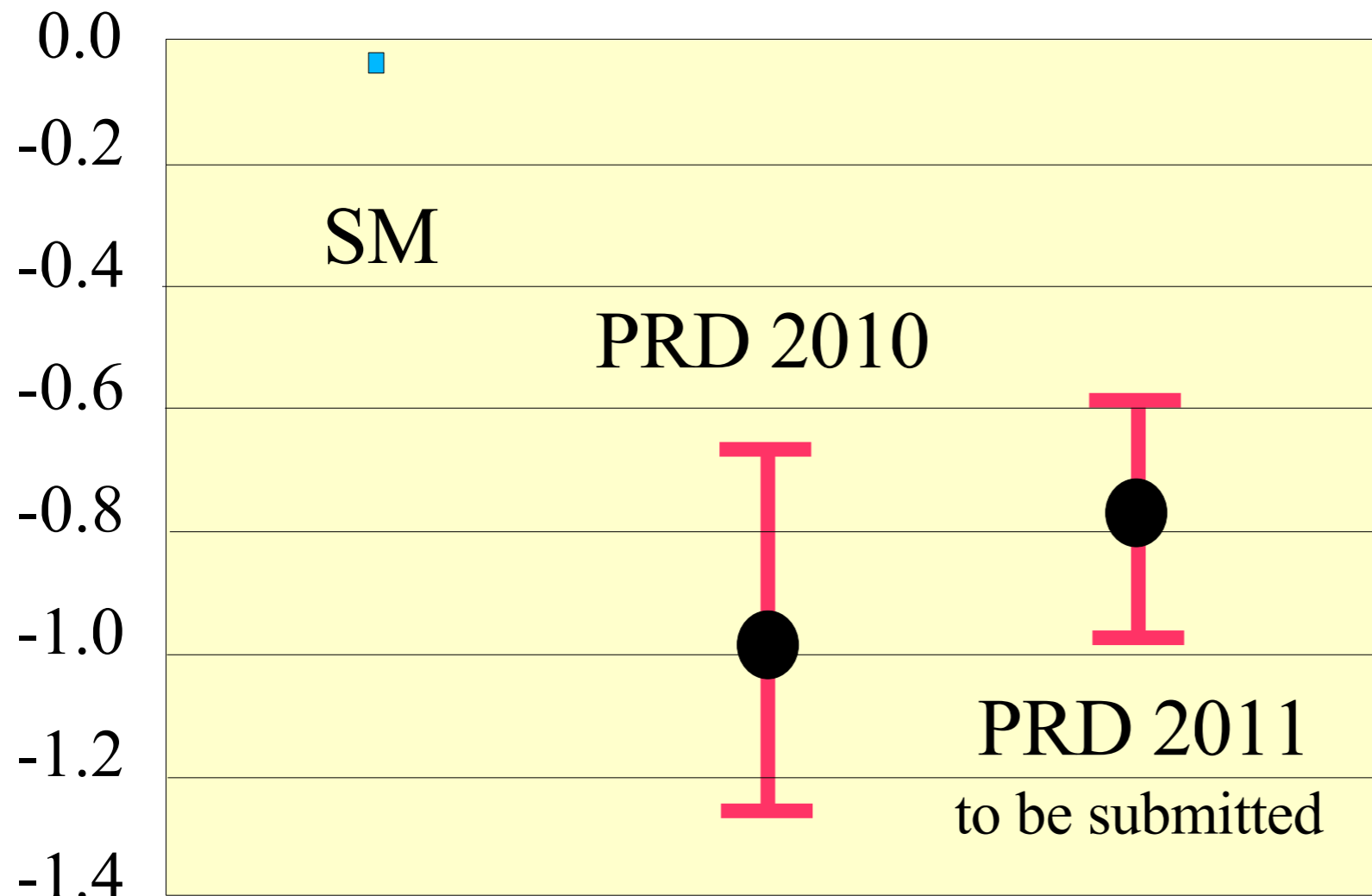
Like-sign dimuon charge asymmetry at D0   9.0 fb^-1 in 2011

$$A_{\mathrm{res}} = (-0.246 \pm 0.052 \ (\mathrm{stat}) \pm 0.021 \ (\mathrm{syst}))\%$$

$$A_{sl}^{b} = -(7.87 \pm 1.72 \pm 0.93) \times 10^{-3}$$

$$A_{sl}^{b} \ (\text{in per cent}) \qquad A_{sl}^{b}{}^{\mathrm{SM}} = (-2.8^{+0.5}_{-0.6}) \times 10^{-4}$$

SM

PRD 2010

PRD 2011
to be submitted

3.9σ deviation from the SM prediction

Bruce Hoeneisen, DPF talk, 2011

from Bd or Bs?

$$A_{sl}^b = (0.59 \pm 0.02)a_{sl}^d + (0.41 \pm 0.02)a_{sl}^s$$

flavor specific asymmetry

$$a_{sl}^s = \frac{\Gamma(\bar{B}_s \to \mu^+ X) - \Gamma(B_s \to \mu^- X)}{\Gamma(\bar{B}_s \to \mu^+ X) + \Gamma(B_s \to \mu^- X)}$$

Same for Bd

Impact parameter analysis : Bd or Bs?
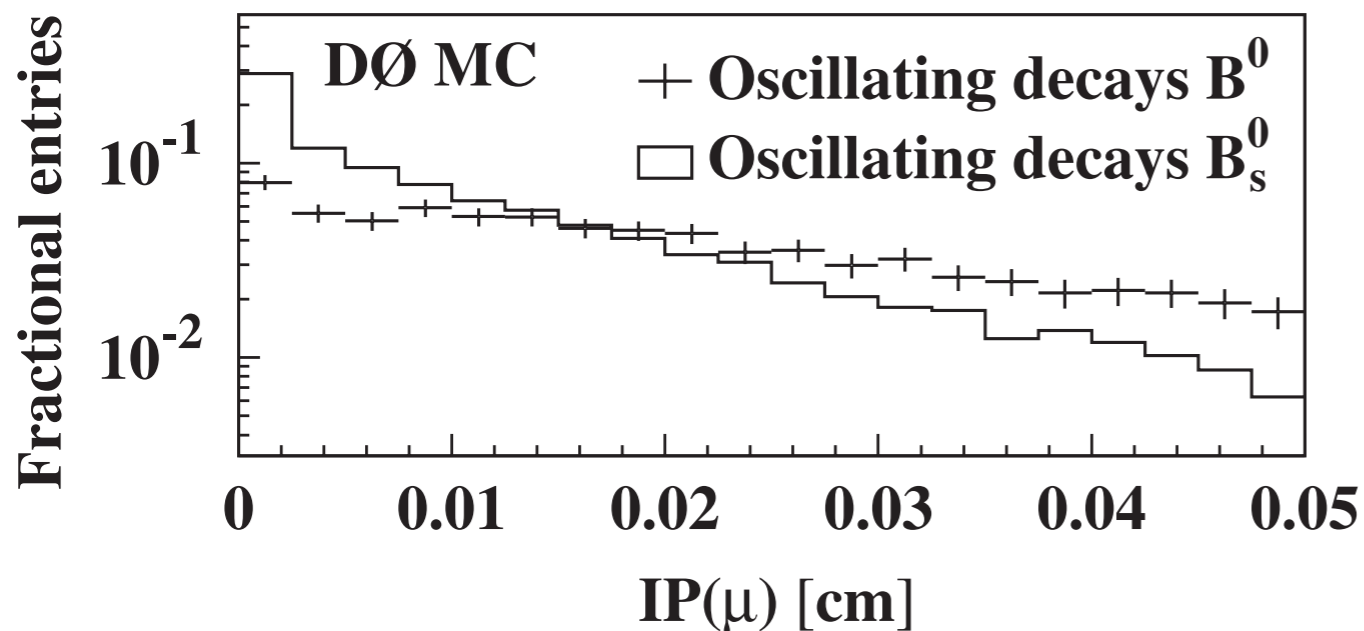
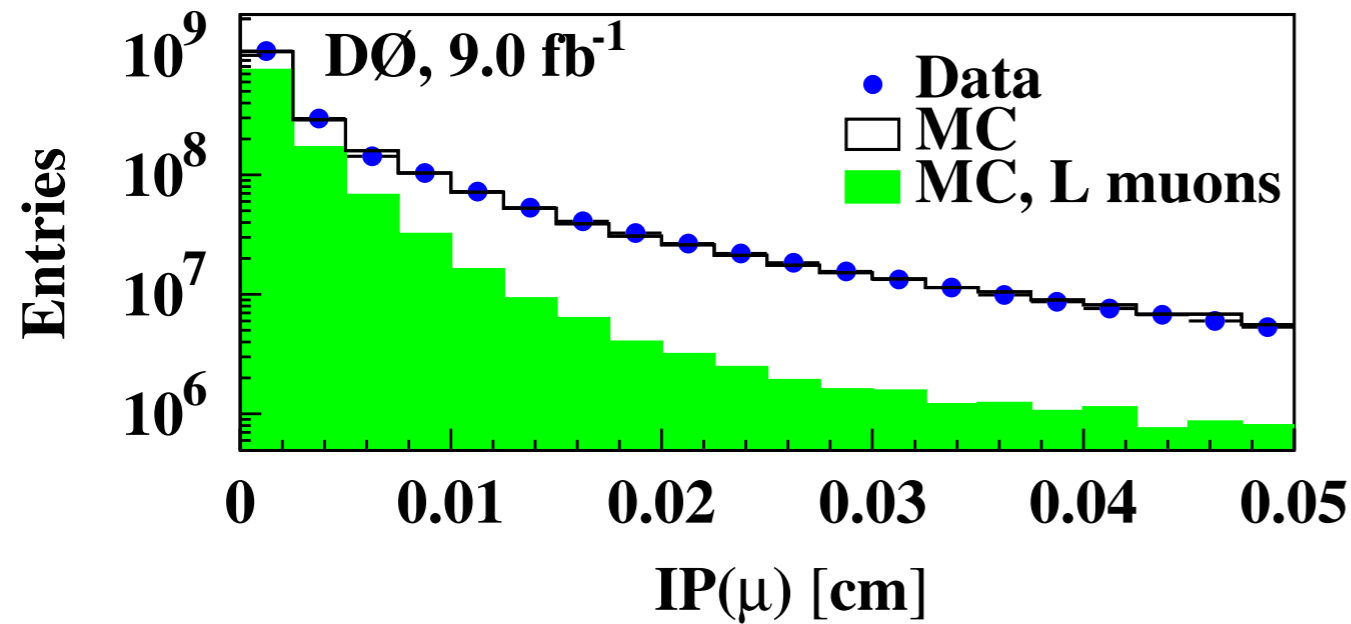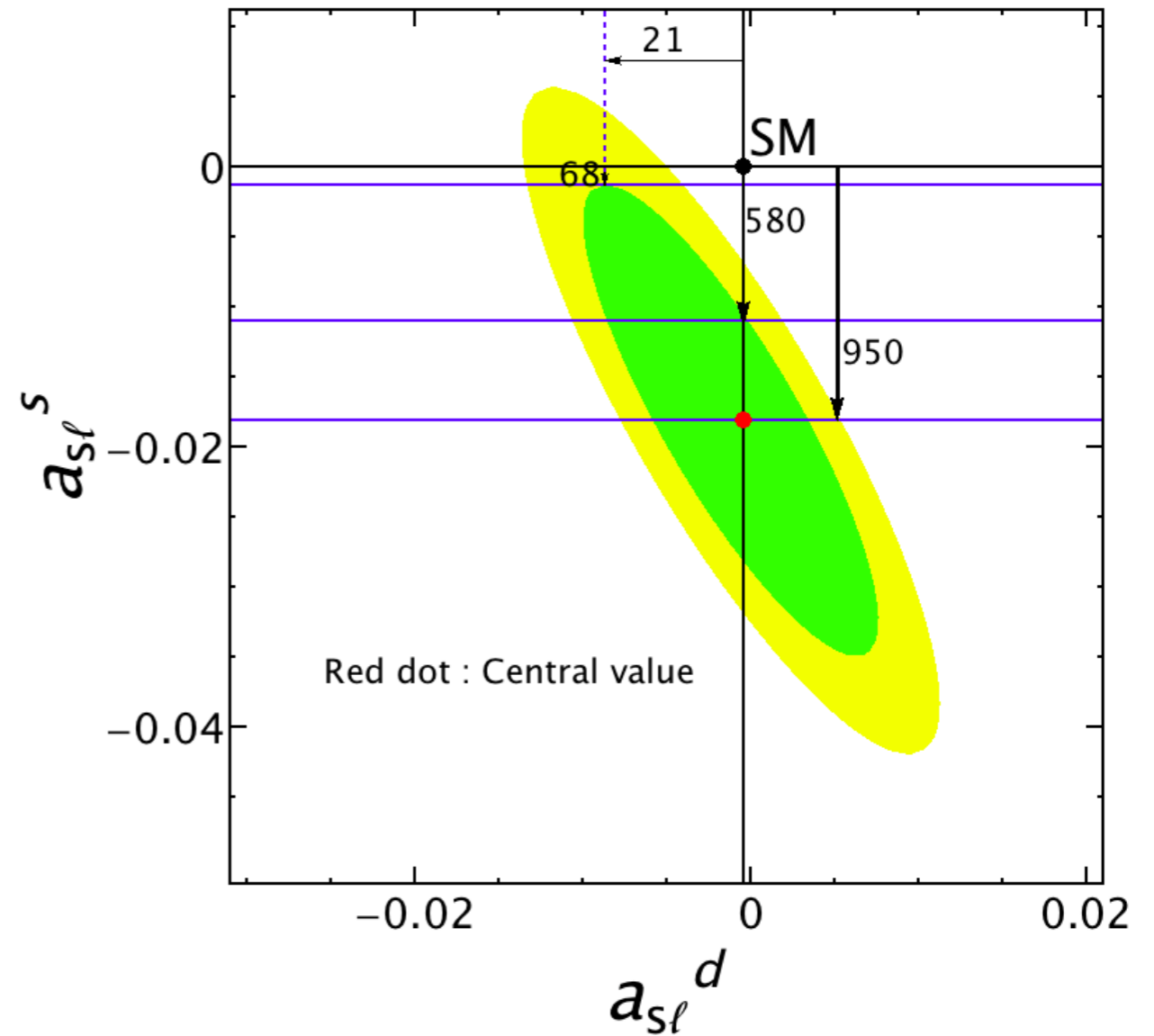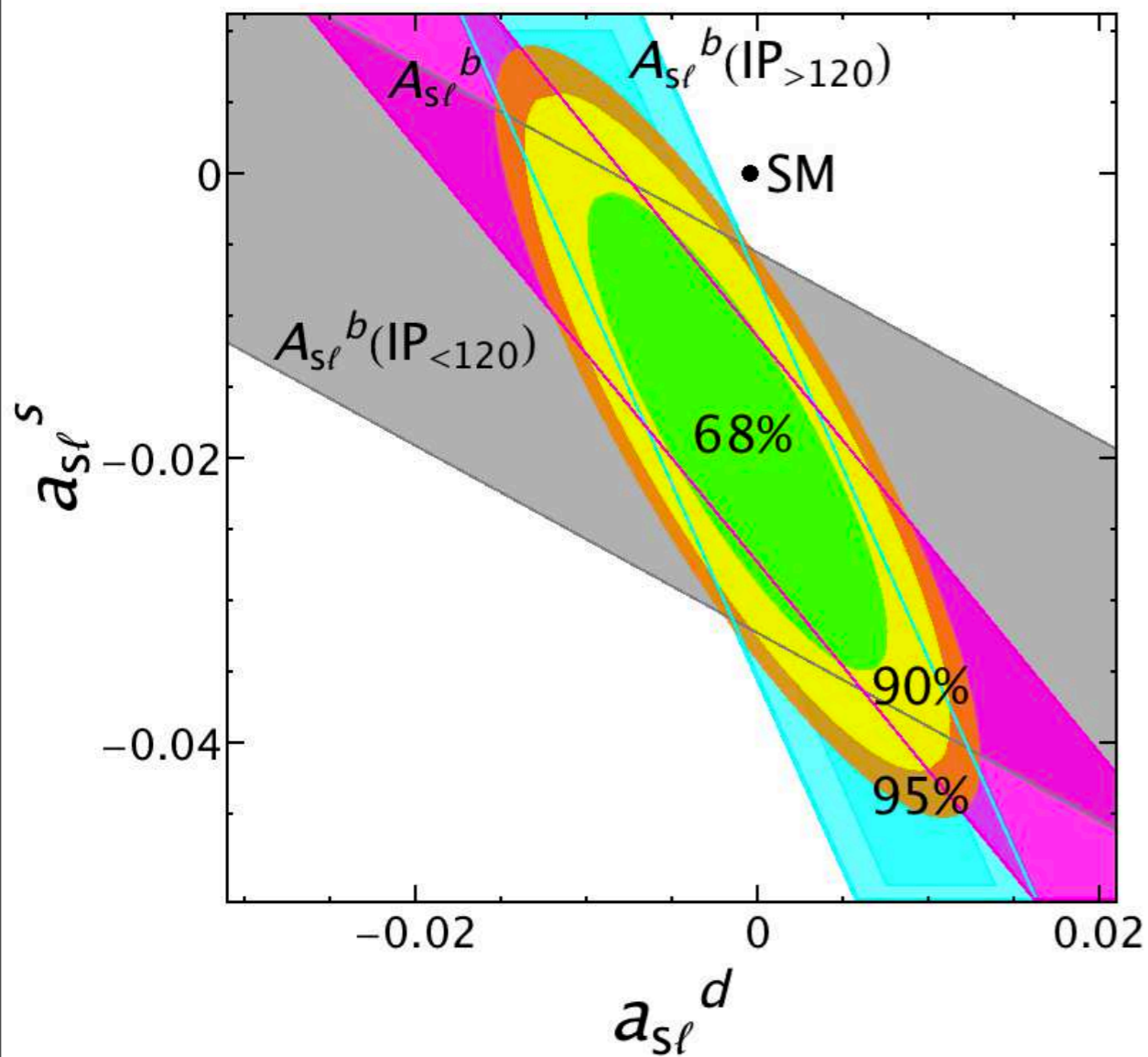PHYSICAL REVIEW D **84,** 052007 (2011)

TABLE XXIII. Values of A^b_{sl} with their statistical and systematic uncertainties obtained for different IP selections.

Selection	Sample	Central value $\times 10^2$	Uncertainty $\times 10^2$ statistical	systematic
All events	1μ	-1.042	1.304	2.313
	2μ	-0.808	0.202	0.222
	comb.	-0.787	0.172	0.093
IP $< 50\ \mu$m	1μ	-3.244	4.101	7.466
	2μ	-2.837	0.776	1.221
	comb.	-2.779	0.674	0.694
IP $> 50\ \mu$m	1μ	-0.171	0.343	0.311
	2μ	-0.593	0.257	0.074
	comb.	-0.533	0.239	0.100
IP $< 80\ \mu$m	1μ	-1.293	3.282	5.841
	2μ	-1.481	0.541	0.810
	comb.	-1.521	0.458	0.501
IP $> 80\ \mu$m	1μ	-0.388	0.280	0.179
	2μ	-0.529	0.285	0.048
	comb.	-0.472	0.226	0.091
IP $< 120\ \mu$m	1μ	-1.654	2.774	4.962
	2μ	-1.175	0.439	0.590
	comb.	-1.138	0.366	0.323
IP $> 120\ \mu$m	1μ	-0.422	0.240	0.121
	2μ	-0.818	0.342	0.067
	comb.	-0.579	0.210	0.094

Asymmetry is from Bs or prompt background

necessary enhancement factor for charge asymmetry

$$(a_{s\ell}^d/(a_{s\ell}^d)^{\mathrm{SM}},\ a_{s\ell}^s/(a_{s\ell}^s)^{\mathrm{SM}}) = (21, -68),\ (1, -580),\ (1, -950)$$

Impact parameter analysis : Bd or Bs?

$$a_{sl}^{s} = (-1.8 \pm 1.1) \times 10^{-2}$$

$$1.6\sigma \text{ deviation from}$$

$$a_{sl}^{s}{}^{\text{SM}} = (1.9 \pm 0.3) \times 10^{-5}$$

$$a_{s\ell}^{d} = -(1.2 \pm 5.2) \times 10^{-3}$$

$$a_{s\ell}^{d\text{SM}} = -(4.1 \pm 0.6) \times 10^{-4}$$

B meson mixing

$$i\frac{d}{dt}\left(\begin{array}{c}|B^0\rangle \\ |\bar{B}^0\rangle\end{array}\right) = \left(M - i\frac{\Gamma}{2}\right)\left(\begin{array}{c}|B^0\rangle \\ |\bar{B}^0\rangle\end{array}\right)$$

$$M - i\frac{\Gamma}{2} = \left(\begin{array}{cc} M_{11} - i\frac{\Gamma_{11}}{2} & M_{12} - i\frac{\Gamma_{12}}{2} \\ M_{21} - i\frac{\Gamma_{21}}{2} & M_{22} - i\frac{\Gamma_{22}}{2} \end{array}\right)$$

$$\Delta M_q = 2|M_{12}^q|$$

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

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

$$\propto \boxed{\phi_M - \phi_\Gamma}$$

$$\boxed{a_{sl}^q = \operatorname{Im}\frac{\Gamma_{12}^q}{M_{12}^q} = \frac{|\Gamma_{12}^q|}{|M_{12}^q|}\sin\phi_q = \frac{\Delta\Gamma_q}{\Delta M_q}\tan\phi_q}$$

$$a_{\text{sl}} = \left| \frac{\Delta\Gamma}{\Delta M} \right| \tan\phi$$

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

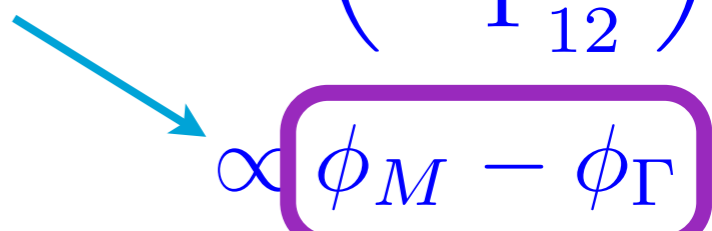$$\propto \boxed{\phi_M - \phi_\Gamma}$$

Bd

$$\left| \frac{\Delta\Gamma}{\Delta M} \right|^{\text{SM}} \sim 4 \times 10^{-3}$$

$$\phi_d^{\text{SM}} \sim -0.1$$

$$a_{sl}^{d\text{SM}} \sim -4 \times 10^{-4}$$

20 times ~ 1%

Bs

$$\left| \frac{\Delta\Gamma}{\Delta M} \right| \sim 0.07$$

$$\phi_s^{\text{SM}} \sim 4 \times 10^{-3}$$

$$a_{sl}^{s\text{SM}} \sim 2 \times 10^{-5}$$

1,000 times ~ 1%

Rule of the game for large CPV : Bs

$\text{Im } \Gamma_{12}$ is not constrained at all

If $\text{Im } \Gamma_{12}$ can be large
and ΔM is not affected,
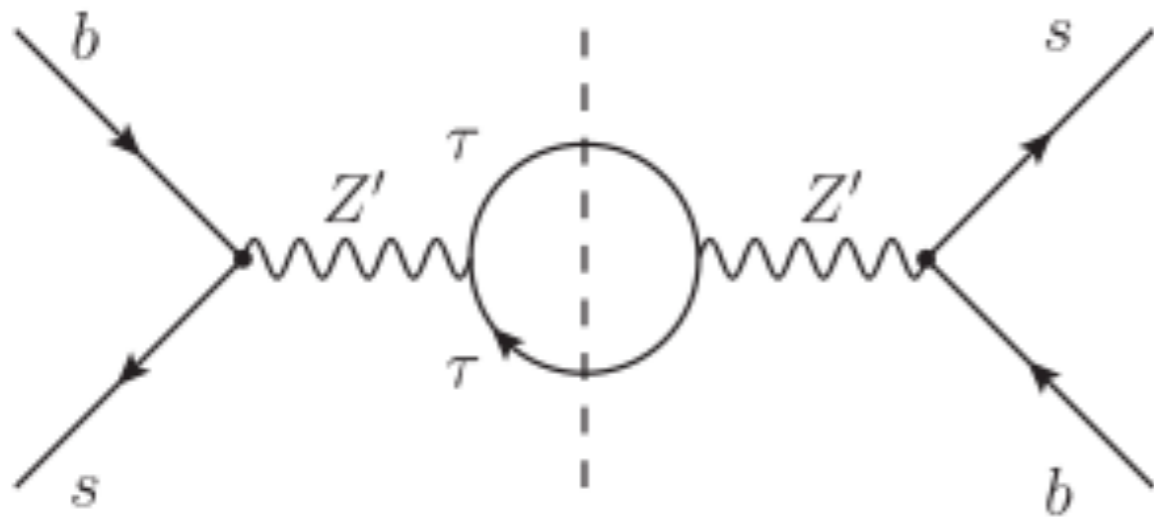CP asymmetry can be highly enhanced.

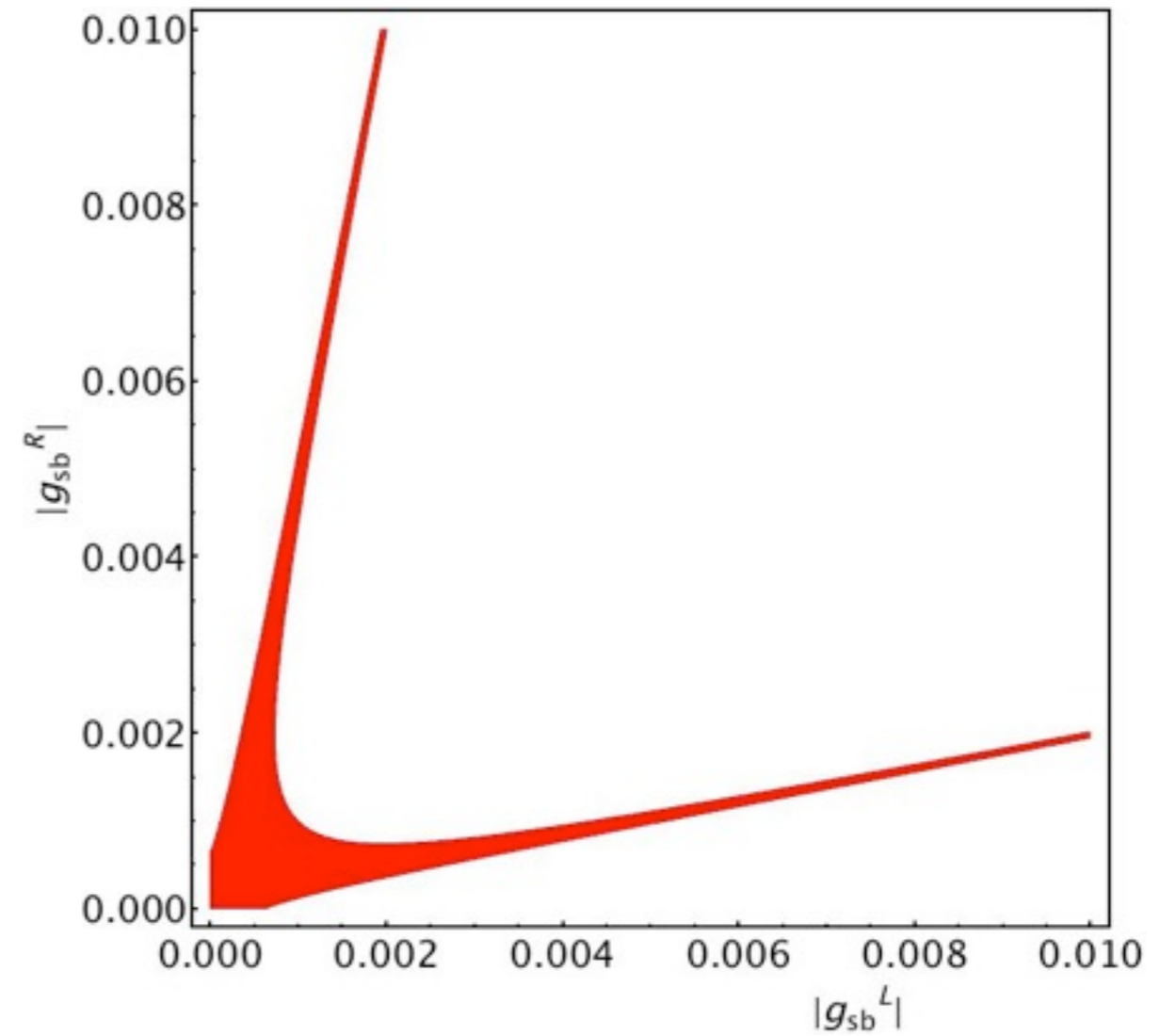Γ_{12}
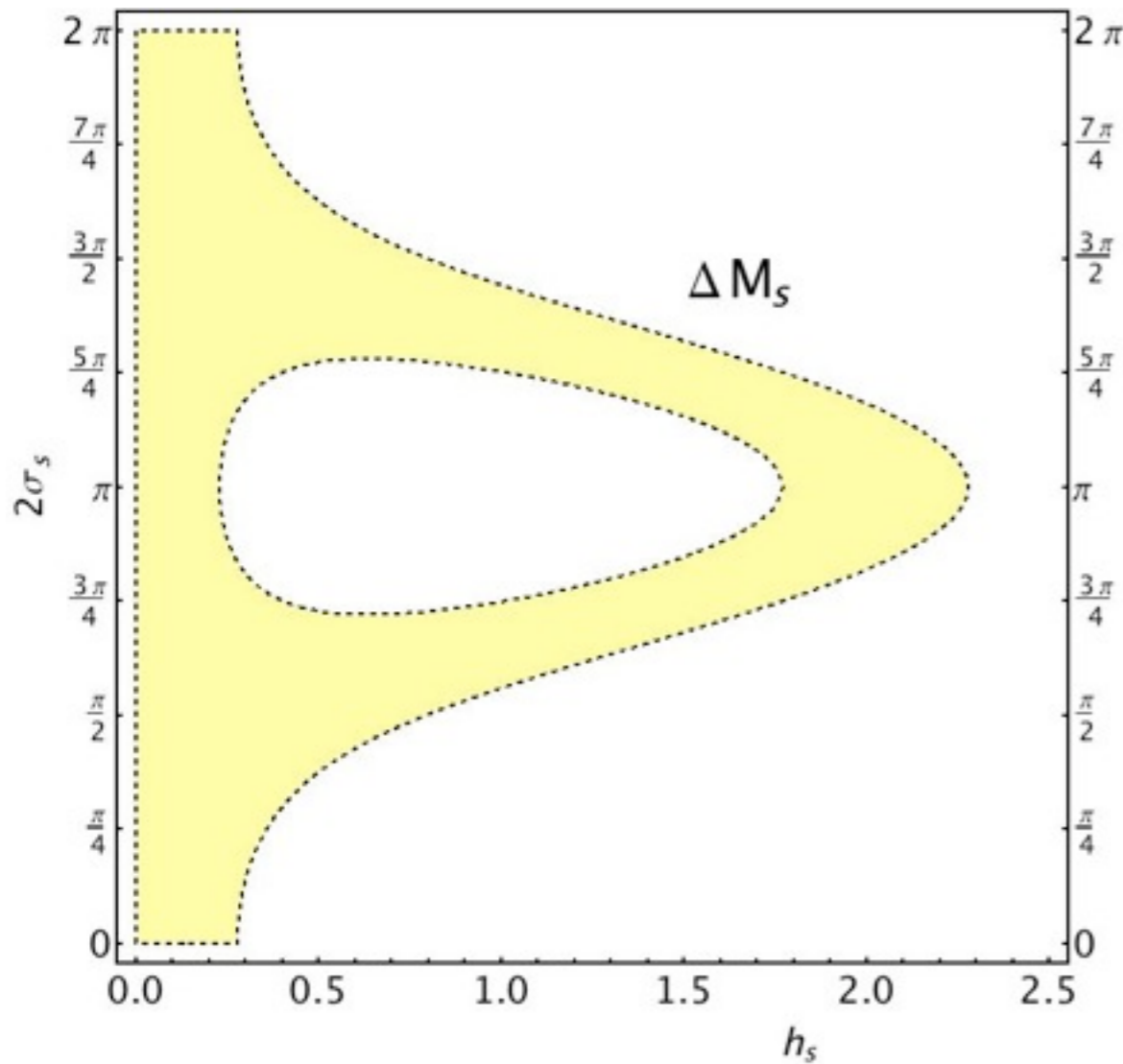
Alok, Baek, London (2011)
Bobeth, Haisch (2011)

Bs decay to taus/charms are less constrained
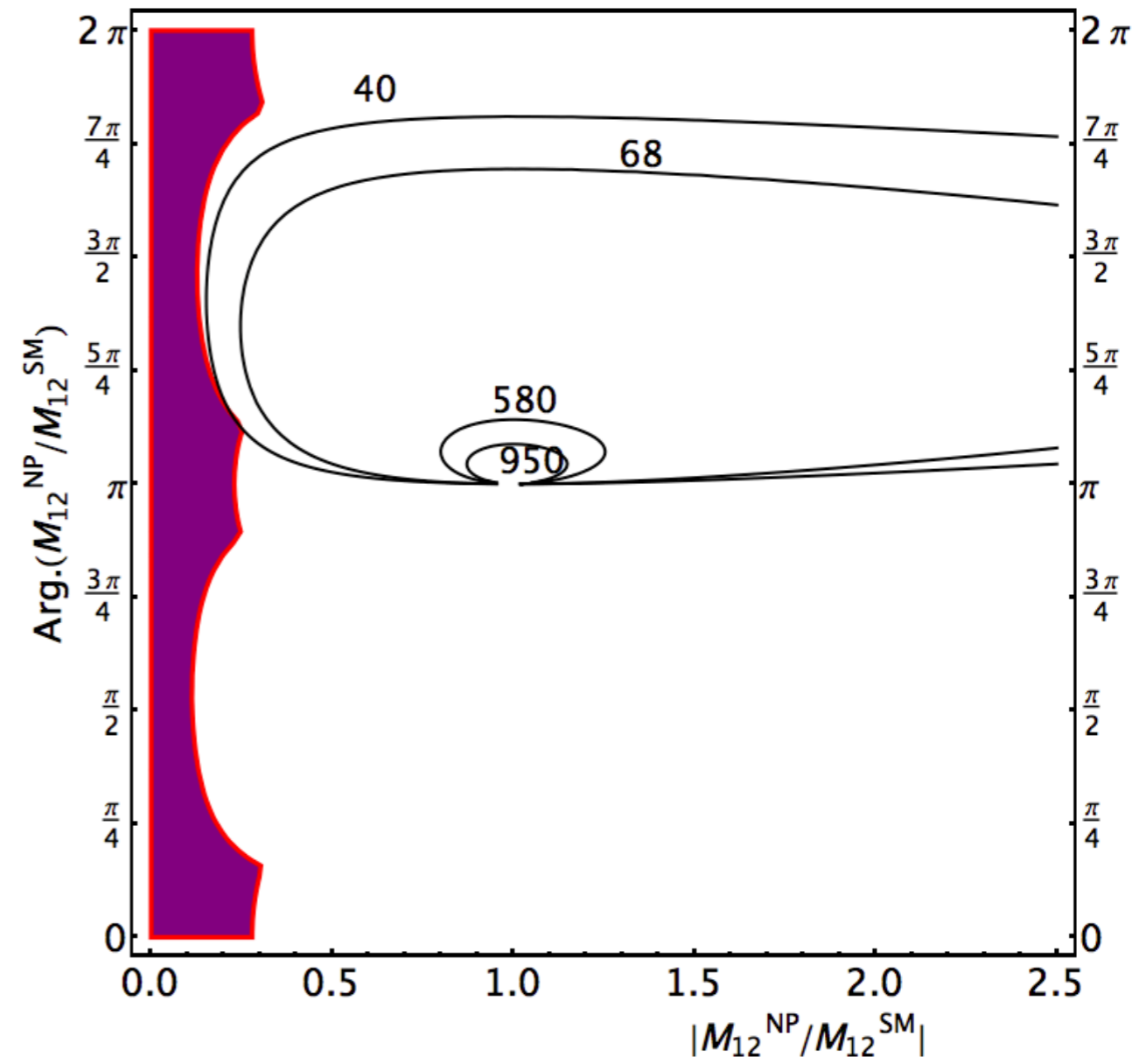(upper bound on Br ~ 3%)

O(1) contribution from new physics is allowed

Delta M is precisely measured
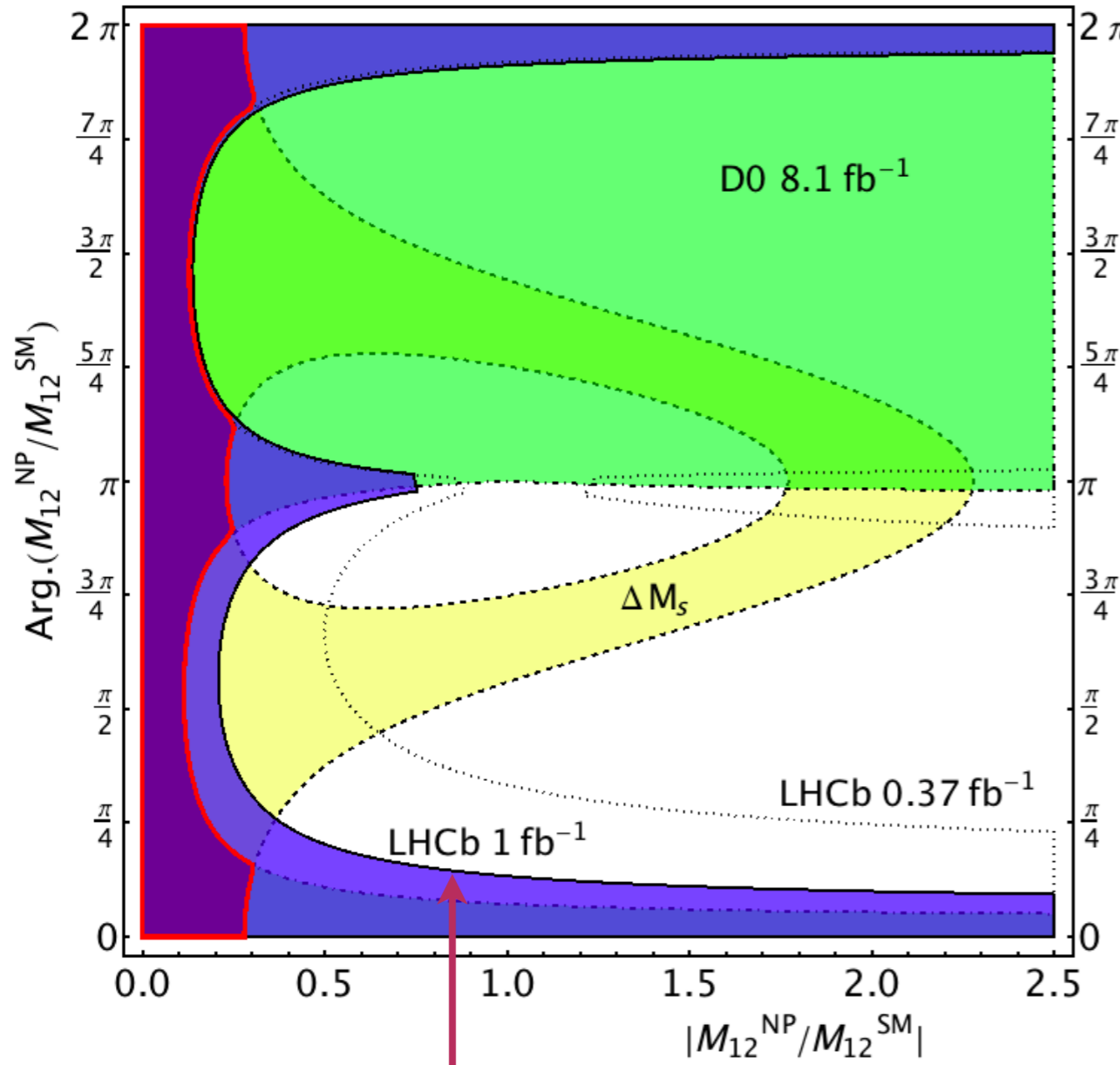
Mass difference : Delta Ms

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

$$M_{Z'} = M_Z$$

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

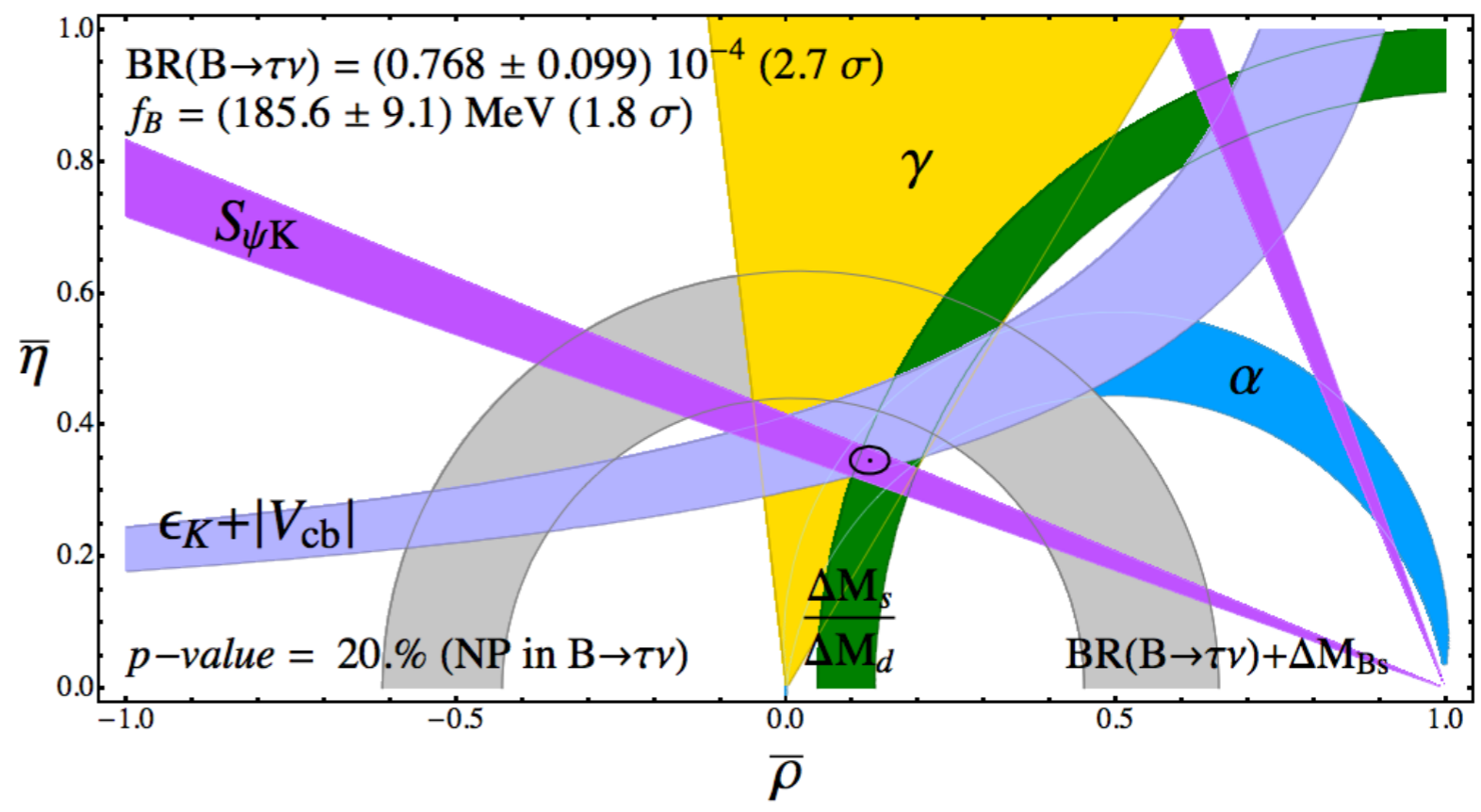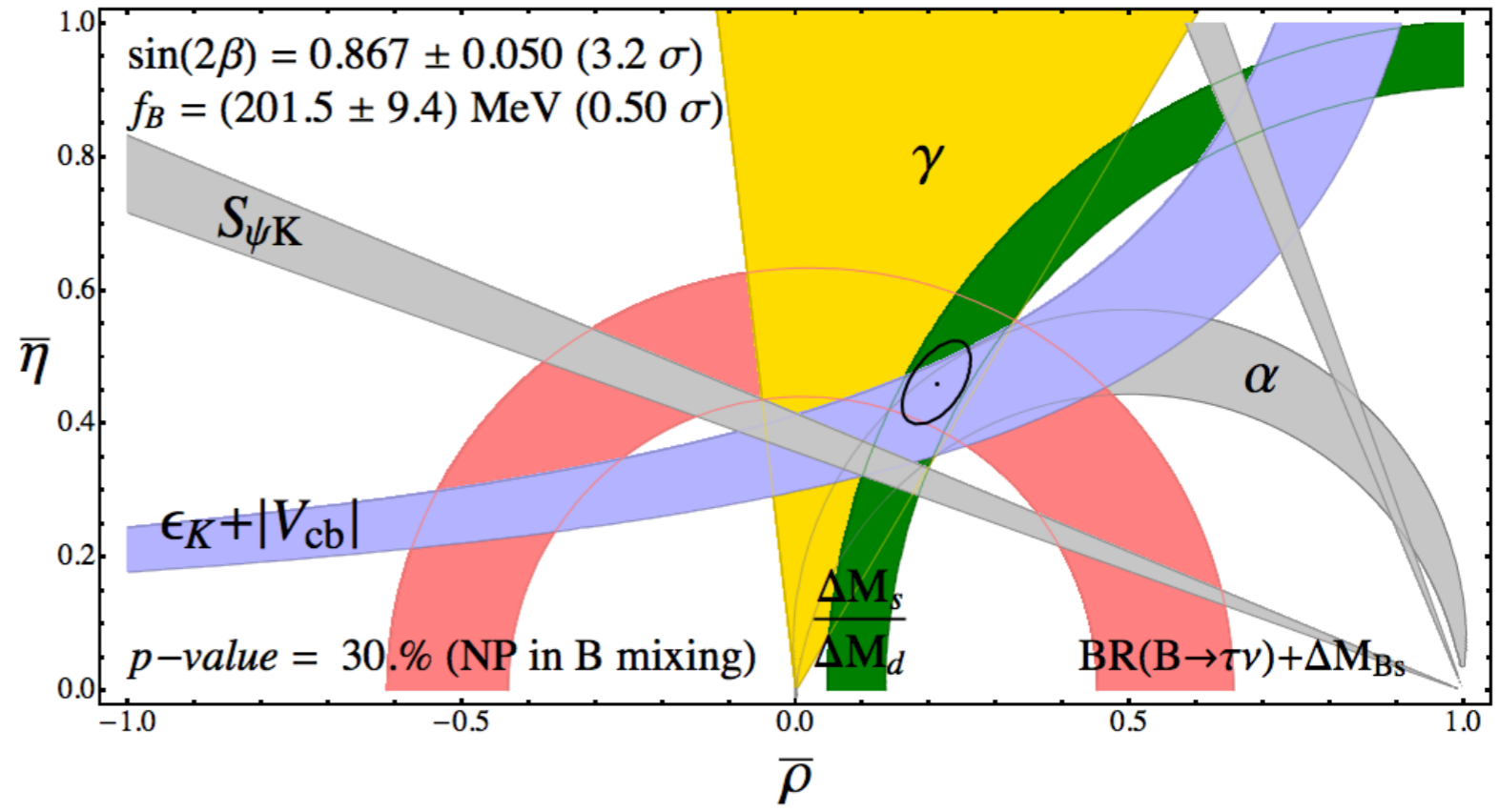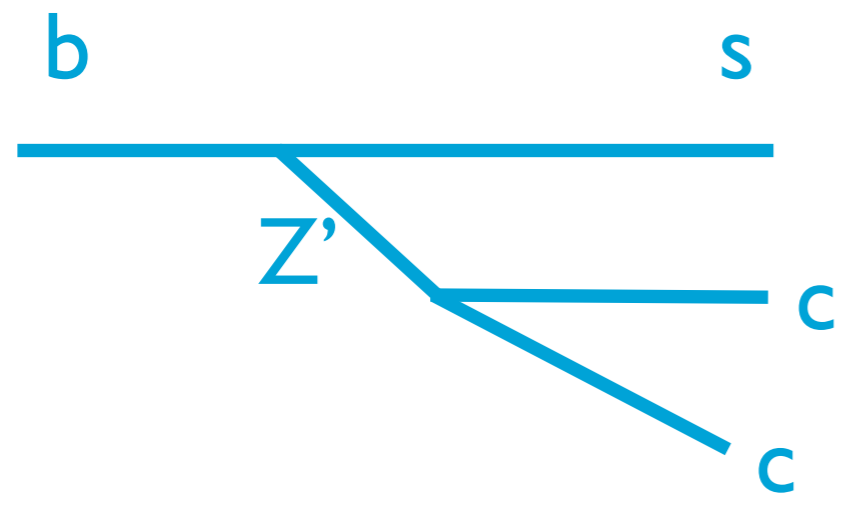$$\phi_s^{J/\psi\phi} = -0.001 \pm 0.101(\text{stat.}) \pm 0.027(\text{syst.}) \text{ rad} \quad,$$
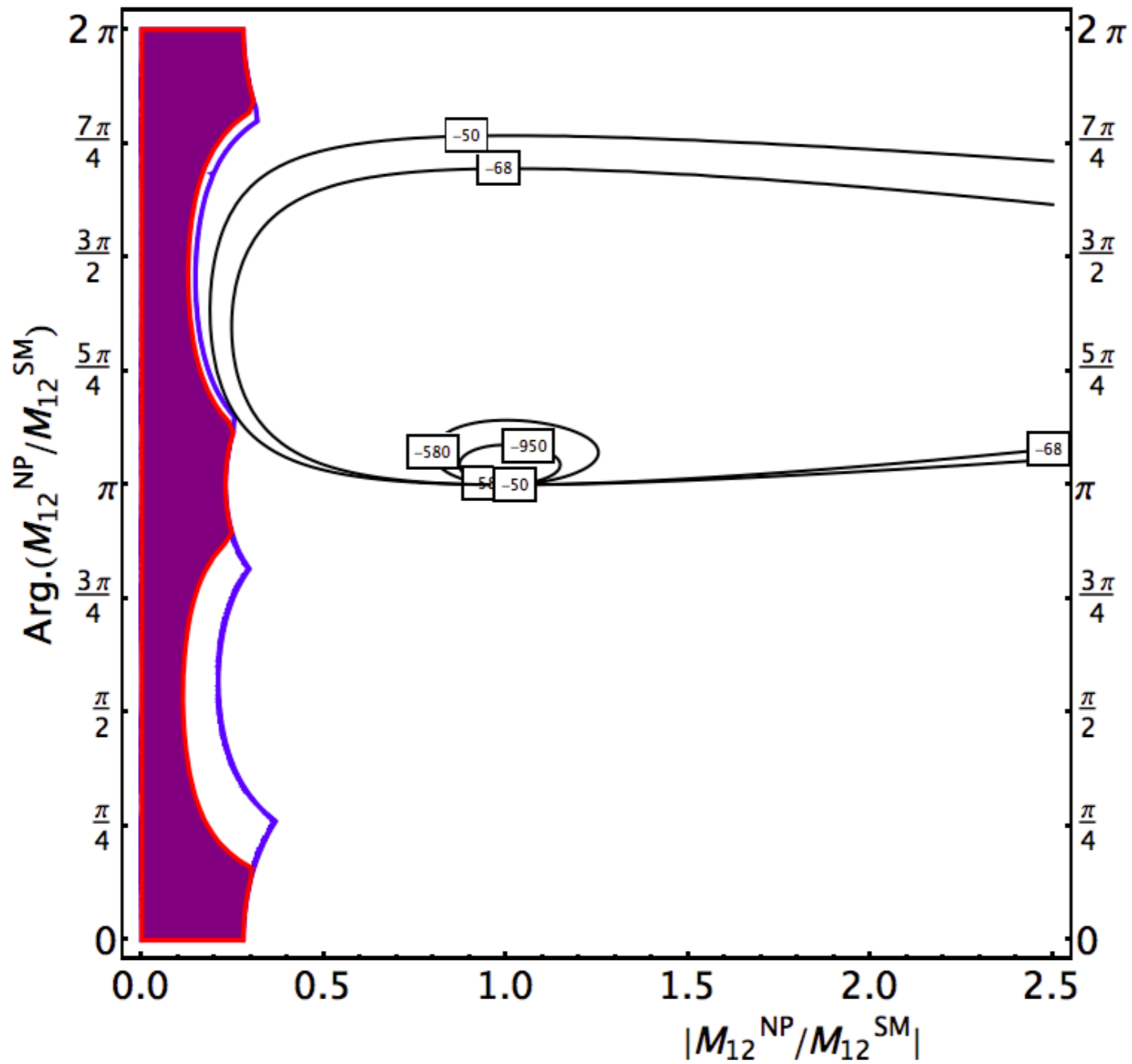
Demise of CKM & its aftermath[a]

Enrico Lunghi[†] and Amarjiit Soni[††b]

$$\sin 2\beta \propto \epsilon_K$$

The golden mode can be contaminated

b   s

Z'

c

c

$\sin(2\beta) = 0.867 \pm 0.050\ (3.2\ \sigma)$
$f_B = (201.5 \pm 9.4)\ \text{MeV}\ (0.50\ \sigma)$

γ

$S_{\psi K}$

α

$\epsilon_K + |V_{cb}|$

$\frac{\Delta M_s}{\Delta M_d}$

$p-value = 30.\%$ (NP in B mixing)

$BR(B\to\tau\nu)+\Delta M_{Bs}$

$\overline{\eta}$

$\overline{\rho}$

$BR(B\to\tau\nu) = (0.768 \pm 0.099)\ 10^{-4}\ (2.7\ \sigma)$
$f_B = (185.6 \pm 9.1)\ \text{MeV}\ (1.8\ \sigma)$

γ

$S_{\psi K}$

α

$\epsilon_K + |V_{cb}|$

$\frac{\Delta M_s}{\Delta M_d}$

$p-value = 20.\%$ (NP in B→τν)

$BR(B\to\tau\nu)+\Delta M_{Bs}$

$\overline{\eta}$

$\overline{\rho}$

Thursday, June 21, 12

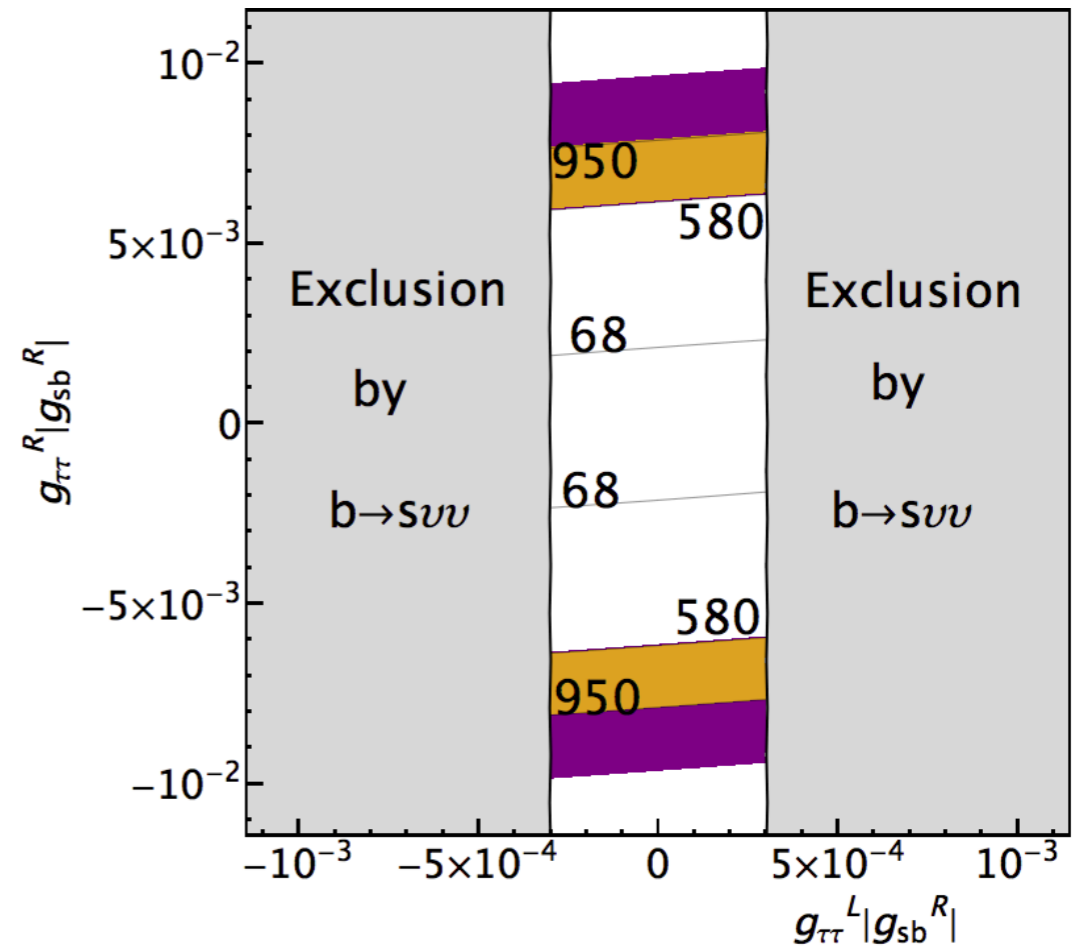$$\sin \phi_s^{J/\psi \phi} = -\sin 2\beta_s^{\mathrm{SM}} + \sin \phi_M^s + 2|r_\lambda| \cos \phi_M^s \sin \varphi_\lambda$$
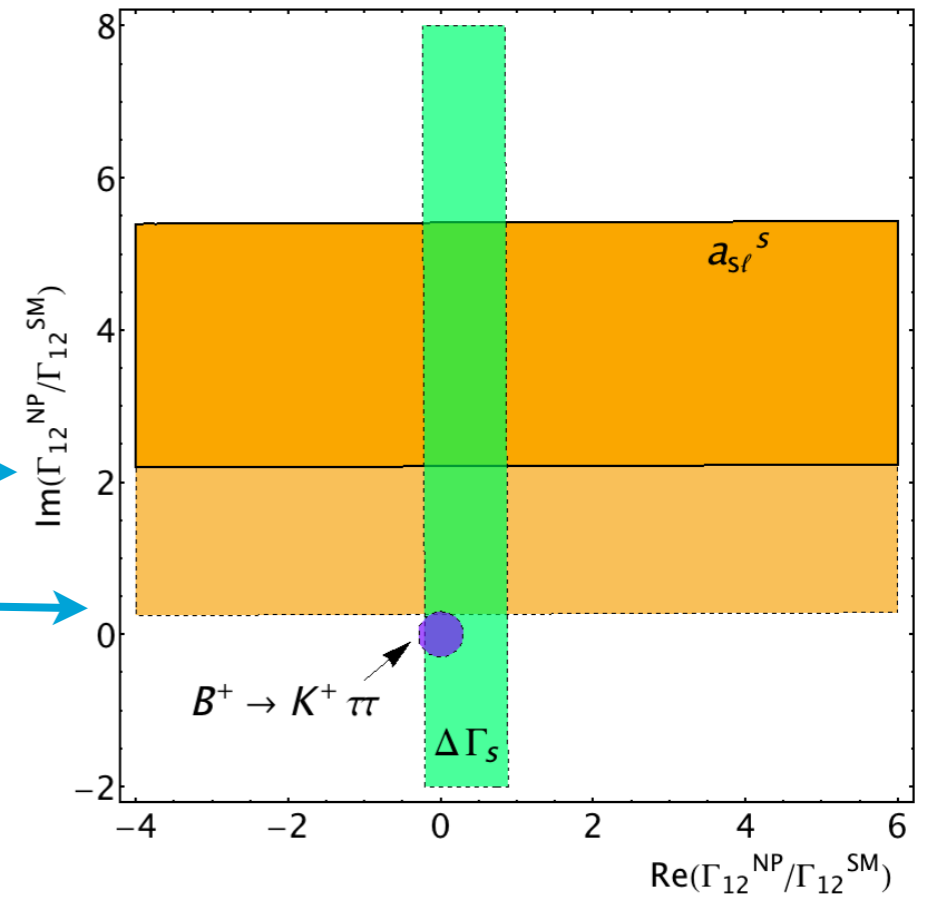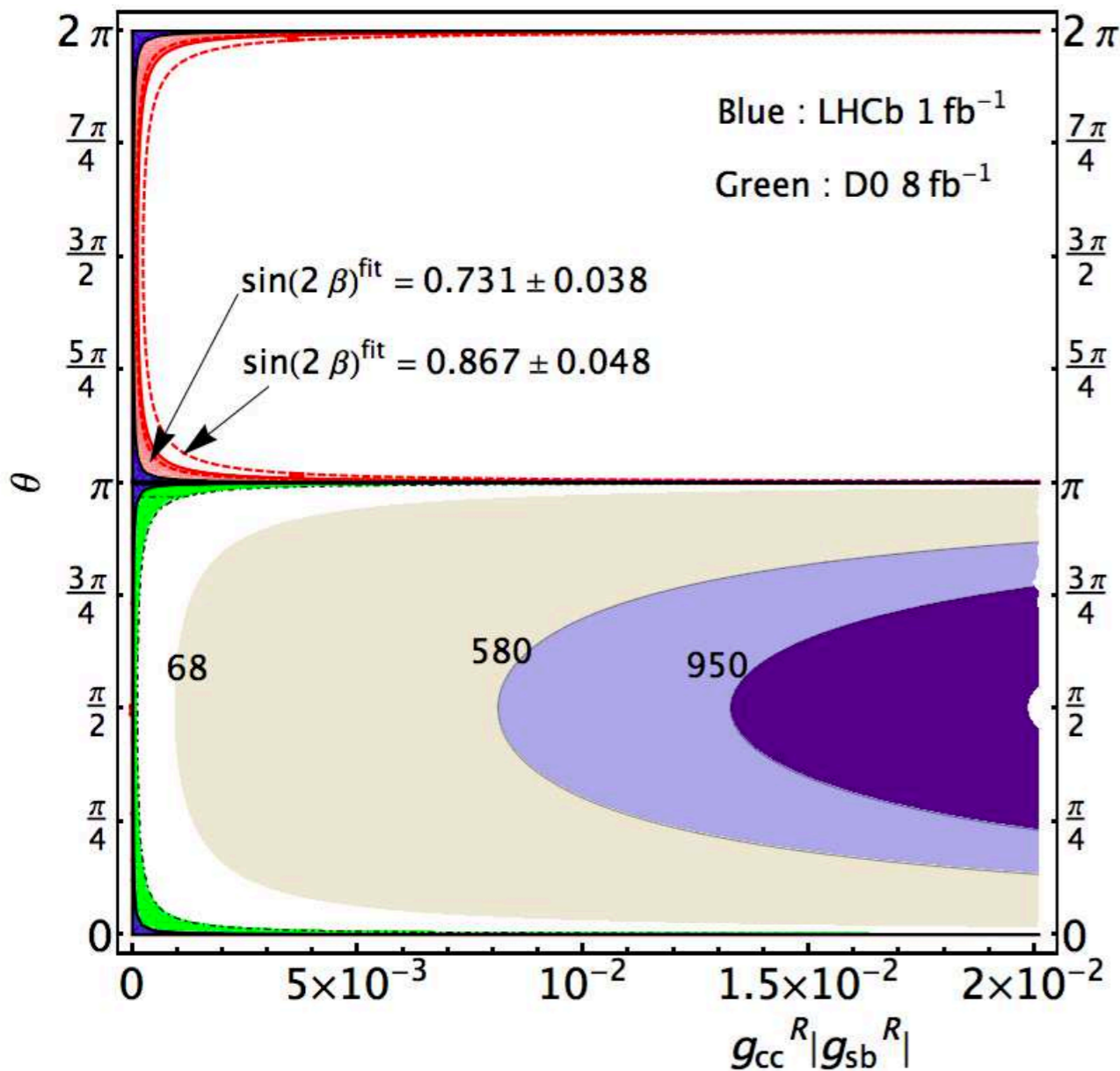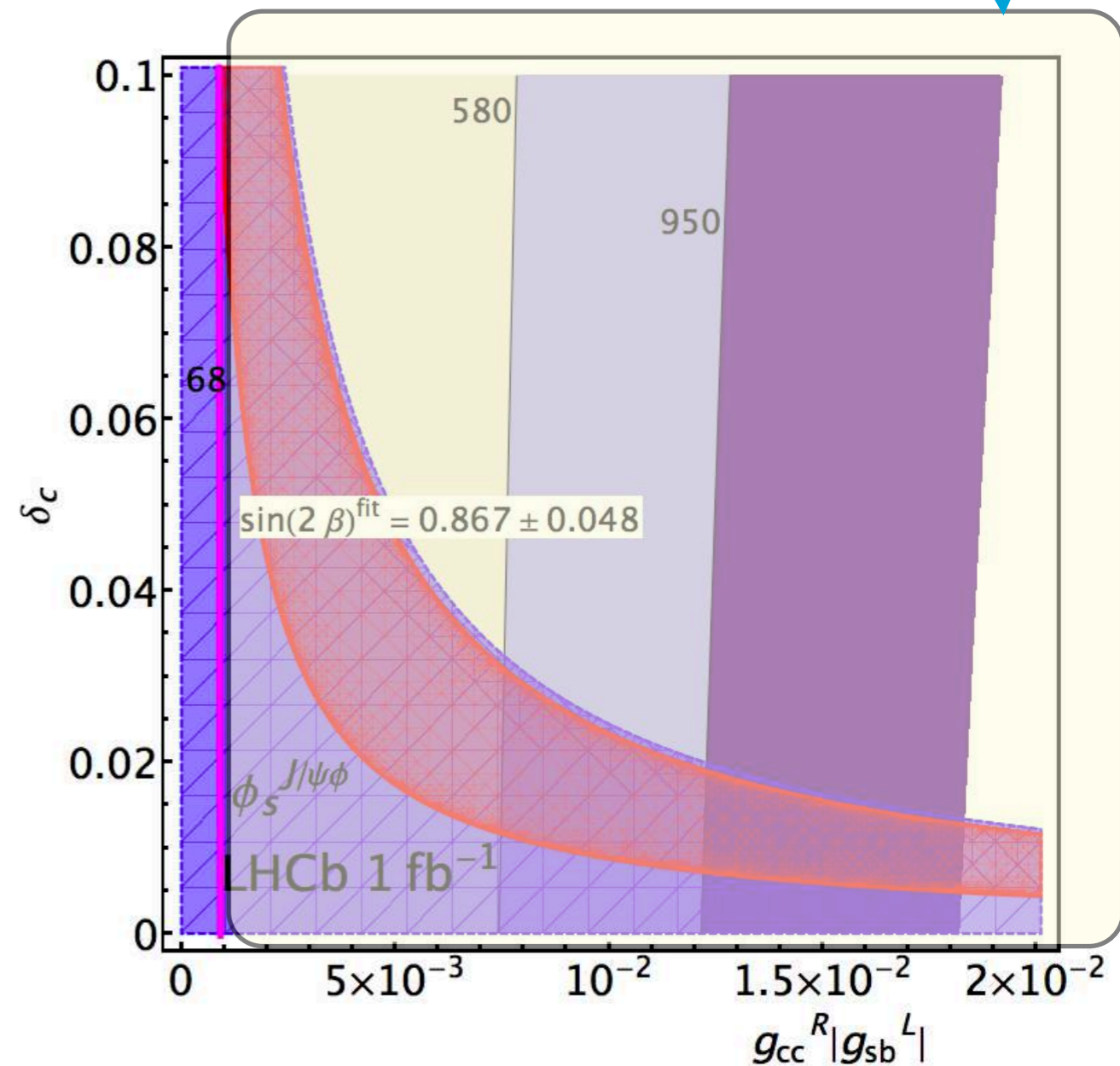
When Z' couples to taus

When Z' couples to charms

not allowed by CKM rotation

left(right)-handed coupling to charm

axial vector coupling to charm

Summary

When Z' couples to tau,
AsI can be 68 times enhanced from Bs.

When Z' couples to charm axially,
AsI can be 68 times enhanced from Bs.

AsI from Bd should be 21 times enhanced
in either case to be within 90% CL region.

Large CP violation in charm (direct)

$$\Delta A_{CP} = A_K -$$

ΔA_{CP}(LHCb) = [-0.82 ± 0.

$\Delta A_{CP}^{dir} = (-0.67 \pm 0.16)\%$

$A_{CP}^{ind} = (-0.02 \pm 0.22)\%$

Is there a chance that like-sign dimuon comes from D mesons?

Yes if CP asymmetry is order one. (large indirect CPV)

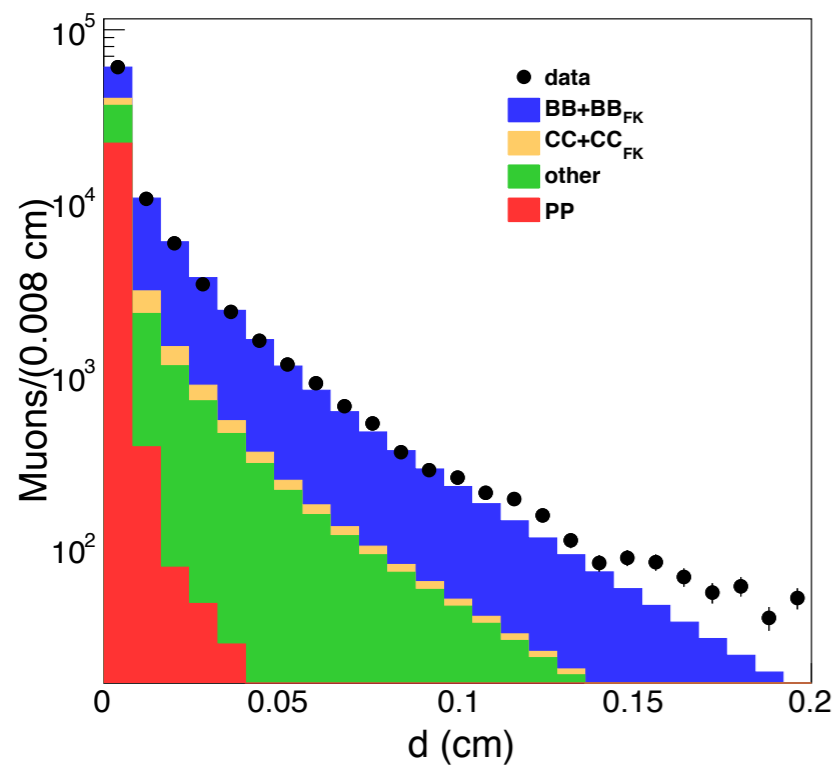$$\frac{q}{p} = \pm\sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}$$
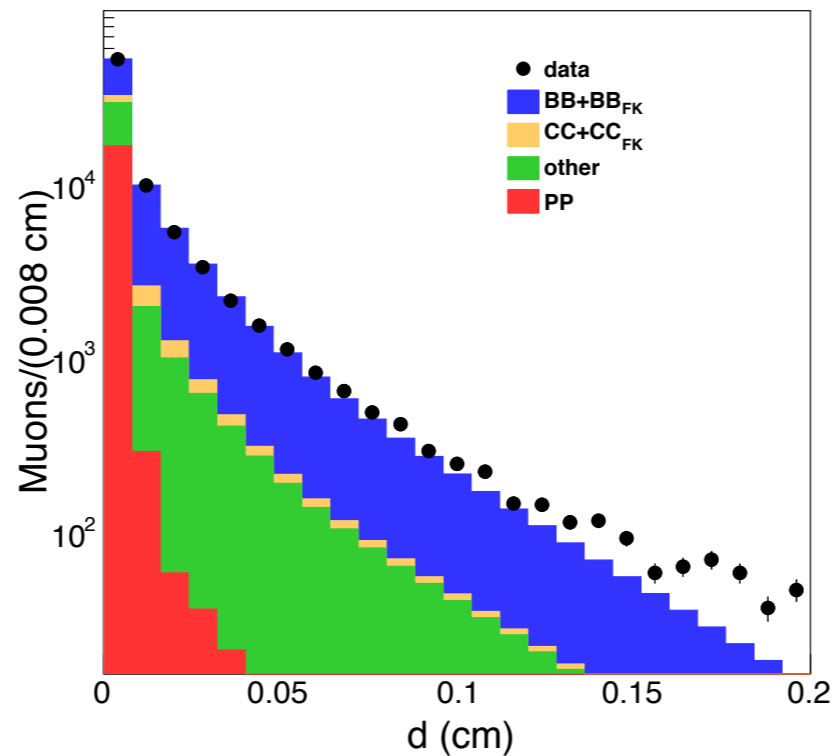
$|q/p| = 0.86^{+0.18}_{-0.15}$

0.6 < |q/p| < 1.3

No CP violation
P-value = 8.04×10⁻⁵

ΔA_{CP} CDF
ΔA_{CP} BABAR
ΔA_{CP} Belle
ΔA_{CP} LHCb
A_Γ BABAR
A_Γ Belle
A_Γ LHCb

2-dim 68.27% CL
2-dim 95.45% CL
2-dim 99.73% CL
1-dim 68.27% CL

ΔA_{CP}^{dir} [%]

A_{CP}^{ind} [%

2-dim 68.
2-dim 95.
2-dim 99.
1-dim 68.

$$\left|\frac{q}{p}\right| \in \{0.6, 1.28\}, \ \phi \in \{-27.5^o, 8.4^o\} \implies$$ can be order one

$$a_{s\ell}(D^0) \equiv \frac{\Gamma(D^0(t) \to \ell^- X) - \Gamma(\bar{D}^0(t) \to \ell^+ X)}{\Gamma(D^0(t) \to \ell^- X) + \Gamma(\bar{D}^0(t) \to \ell^+ X)} = \boxed{\frac{1 - |p/q|^4}{1 + |p/q|^4}}$$

0.1mm

0.2 ~ 0.8
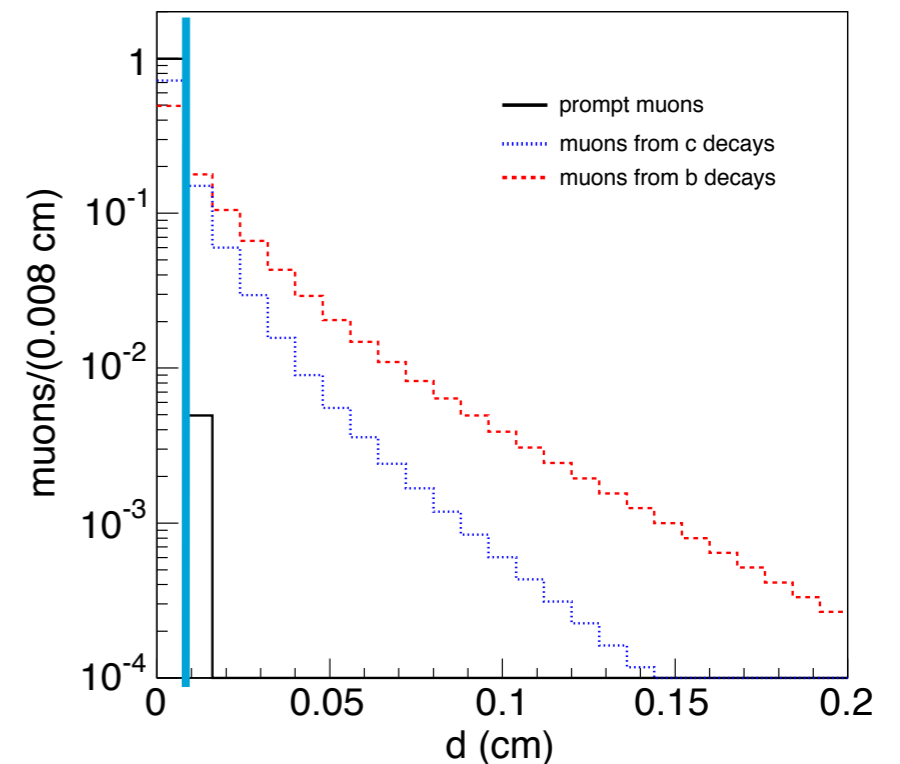

$\mu^+ \mu^+$

$\mu^- \mu^-$

0710.1895 (Tevatron)

$$r_D \equiv \frac{\Gamma(D^0 \to l^- X)}{\Gamma(D^0 \to l^+ X)} = \frac{x_D^2 + y_D^2}{2} \le 0.6 \times 10^{-3}$$

CP asymmetry $\left|\dfrac{q}{p}\right| - 1$

K $\qquad 10^{-3}$

Bd $\qquad 10^{-4}$

Bs $\qquad 10^{-5}$

D0 $\qquad \mathcal{O}(1)$

$\mu^+\mu^-$

BB : 1

CC : 0.8

$\mu^+\mu^+$

$\mu^-\mu^-$

BB : 0.15

BB : 0.15

CC : 0.8*a*rD

CC : 0.8*b*rD

a-b=0.6

charm A_SL = 0.8*(a-b)*rD/0.3 ~ rD = 0.1%

not entirely negligible compared to 0.25%
also impact parameter cut will enhance A_SL

impact parameter cut analysis can be explained