Heavy Flavours III

FAPPS 2011 at Les Houches

Emi KOU (LAL/IN2P3)

19/10/2011

Plan

- 1st lecture: Introduction to flavour physics
  - ★ Weak interaction processes (charges, neutral processes, GIM mechanism)
  - ★ Discovery of CP violation in the K system
  - ★ Measuring oscillation in the B system
- 2nd lecture: Describing oscillations within SM
  - ★ Kobayashi-Maskawa mechanism for CP violation
  - ★ Testing the unitarity of the CKM matrix

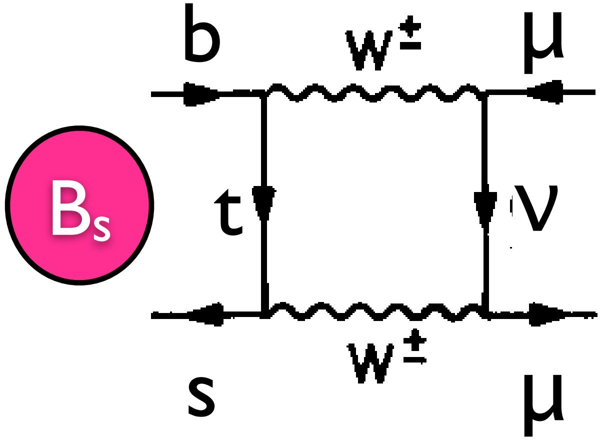
Plan

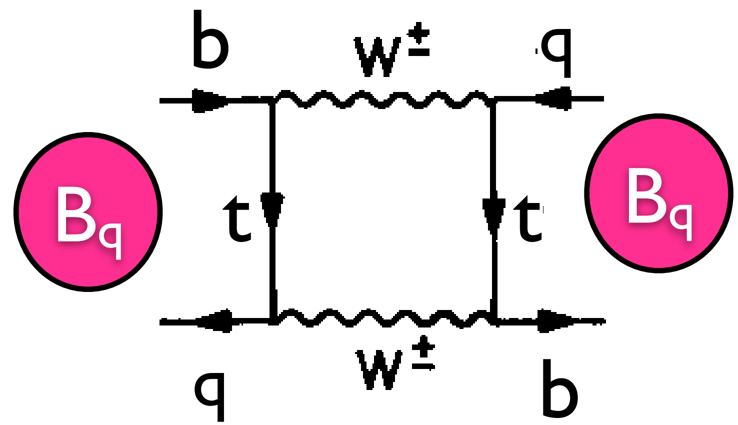
- 3rd lecture: Searching new physics with flavour physics
  - ★ Some examples (estimating top quark mass, charged Higgs mass in 2HDM, neutral Higgs mass in SUSY)
  - ★ SUSY CP/flavour Problem
  - ★ Hot topics in flavour physics

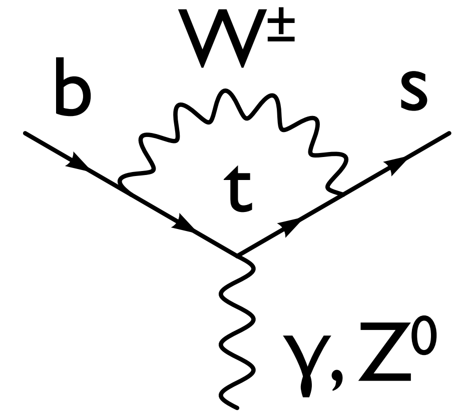
Further reading: "CP Violation" Bigi and Sanda (Cambridge Press)

New particle searches in flavour physics

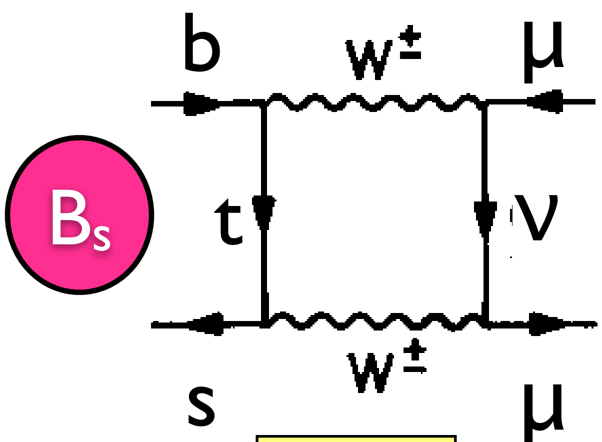
Searching new particle with loop process



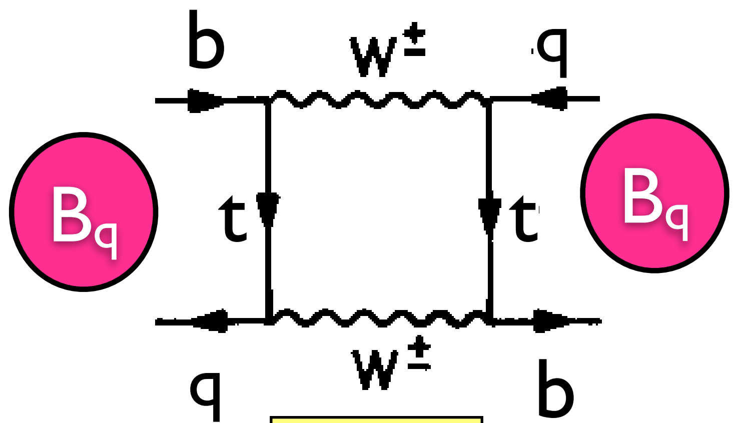




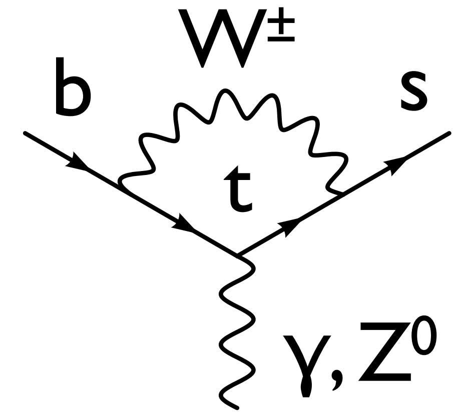
Searching new particle with loop process



$B_0(x)$



$C_0(x)$

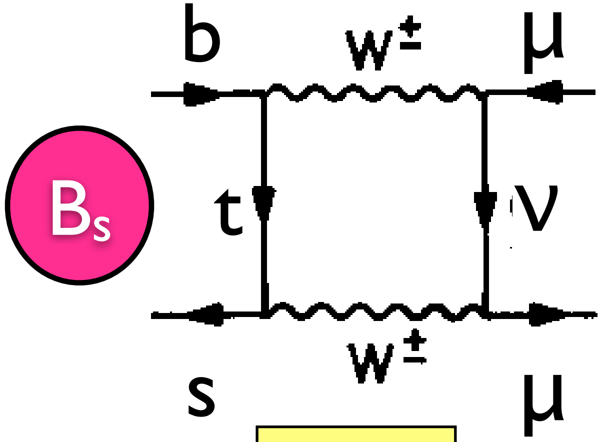


$D'_0(x)$, $S_0(x)$

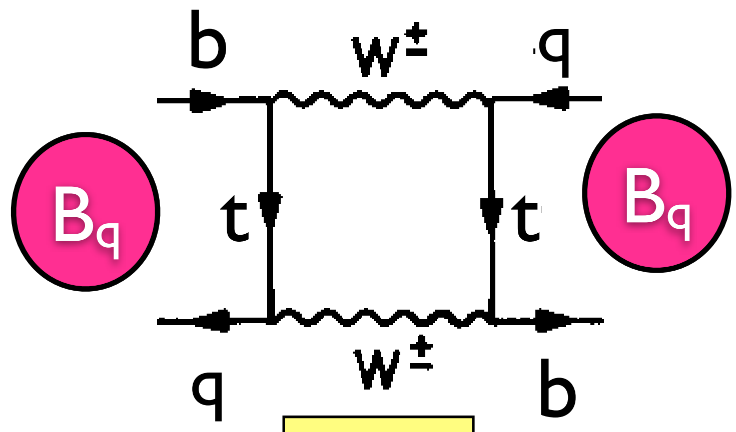
loop function
$x=m_t^2/m_W^2$

Indeed, the top quark mass was predicted to be around >100 GeV after the first measurement of ΔM_d (1987 by ARGUS Experiment)

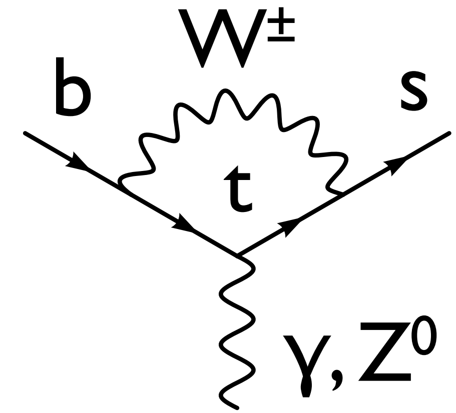
Searching new particle with loop process



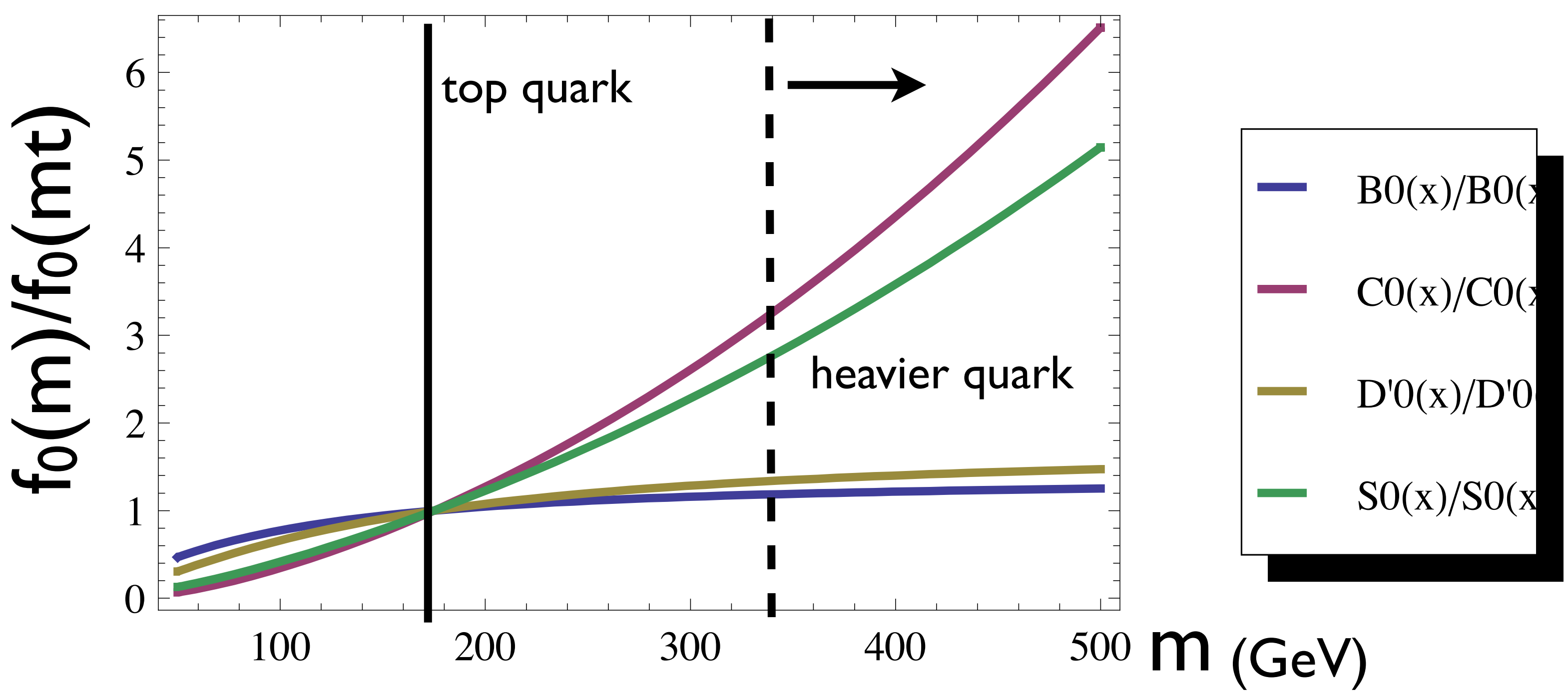
$B_0(x)$



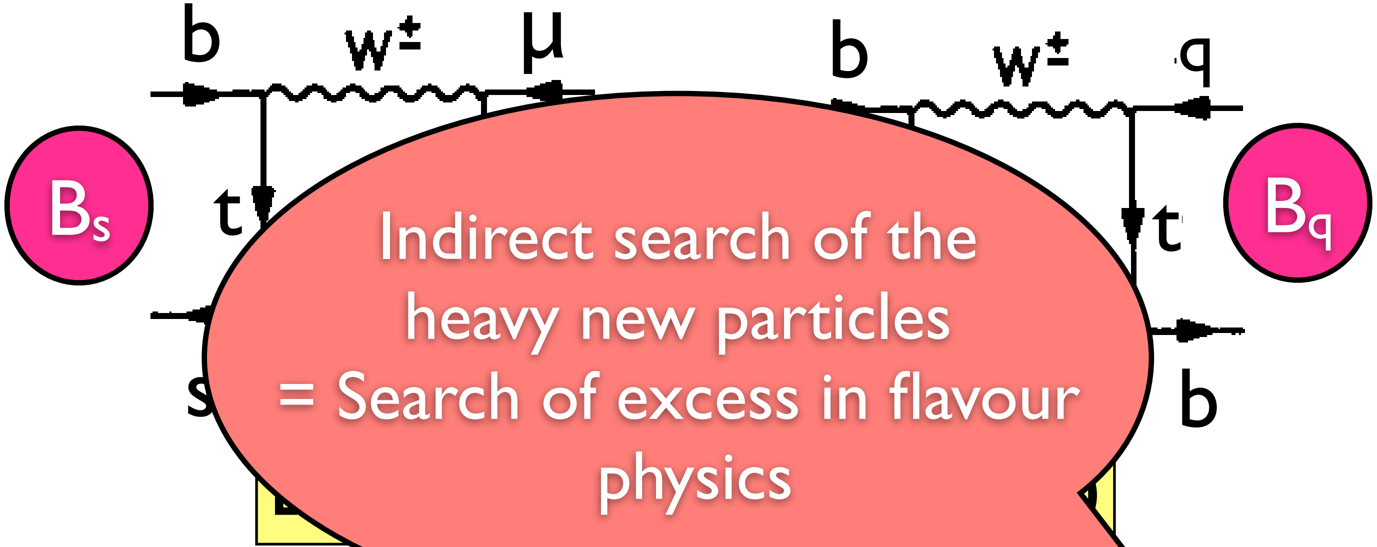
$S_0(x)$



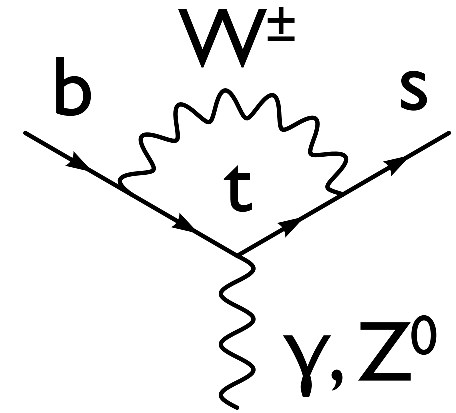
$C_0(x), D'_0(x)$



Searching new particle with loop process



Indirect search of the heavy new particles
= Search of excess in flavour physics



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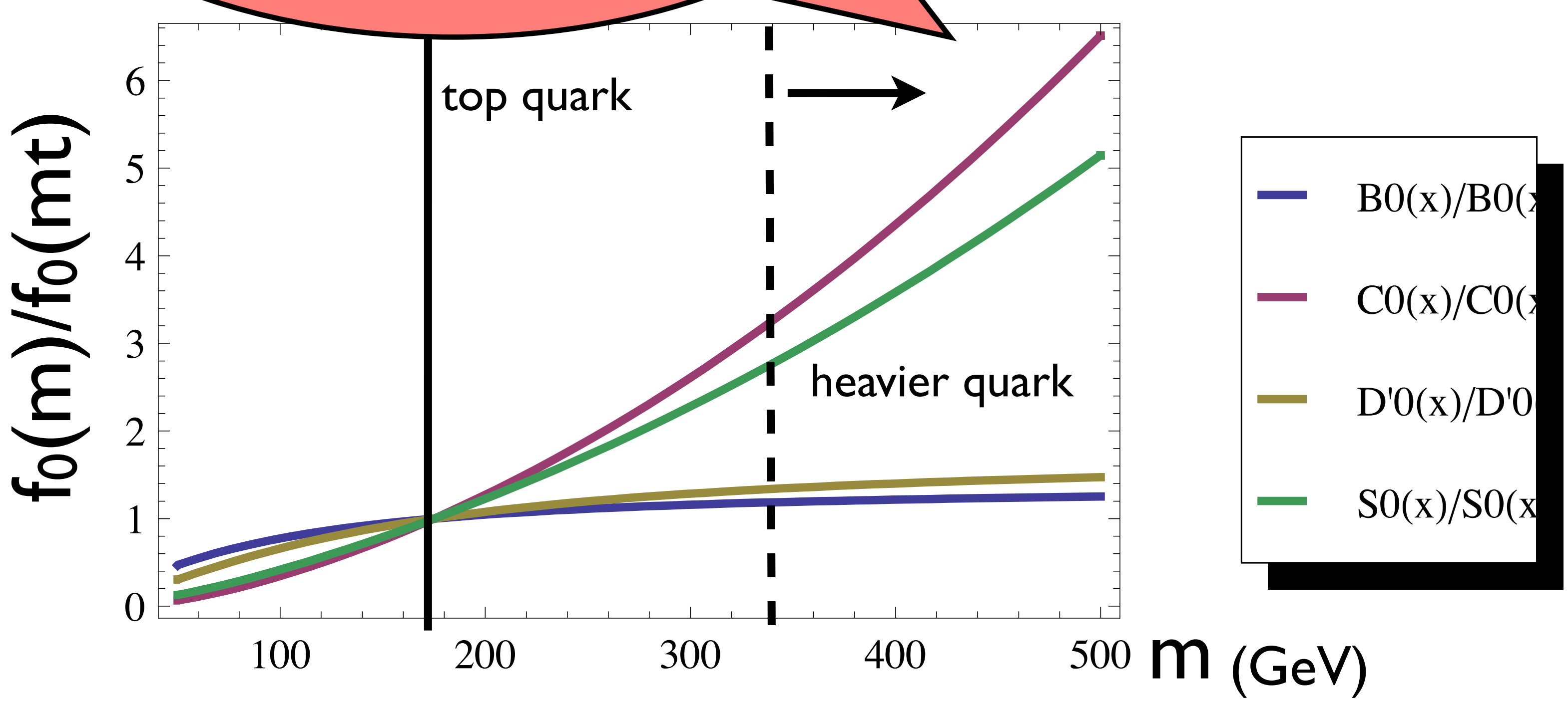
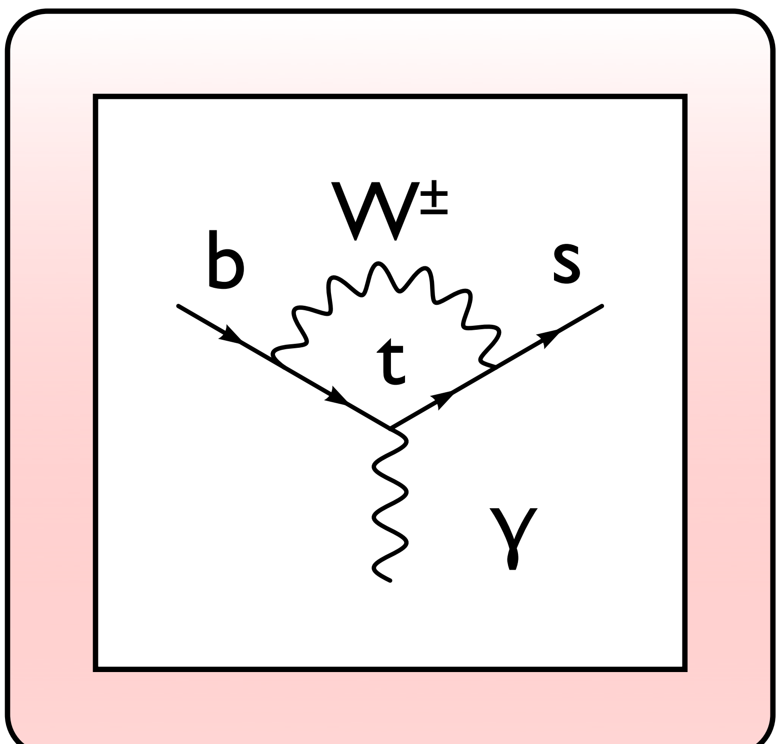
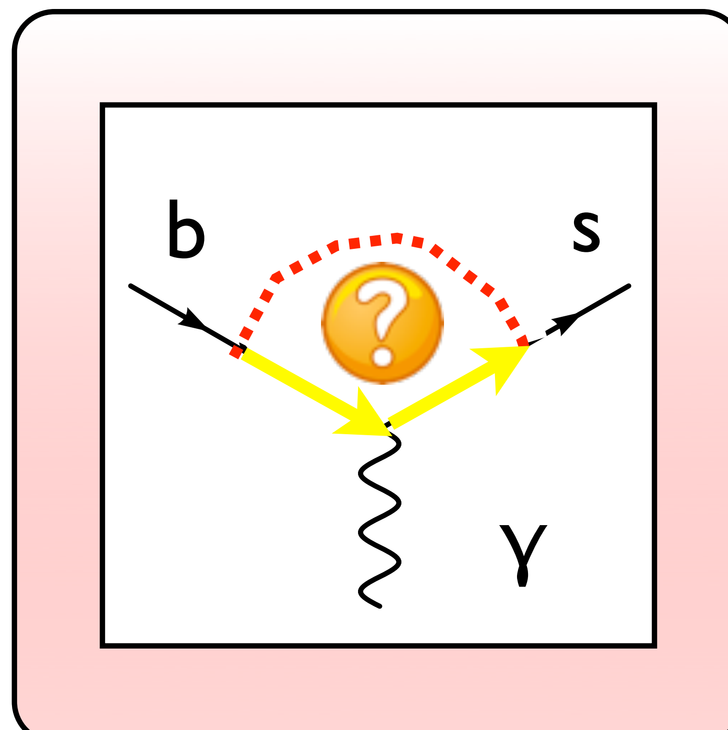
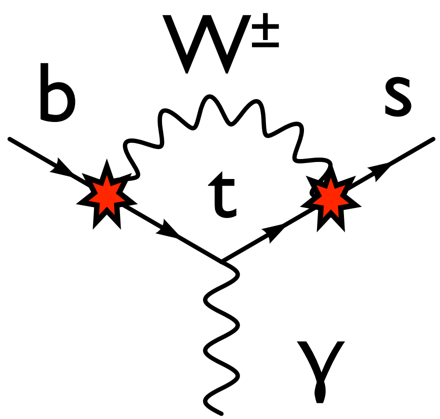


New physics contributions to the b ➔ s γ process





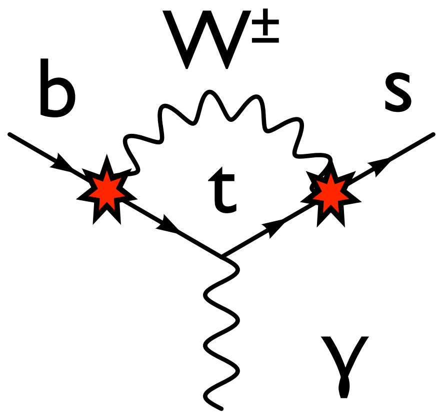
SM computation of the b → s γ process



$$\mathcal{L}_{CC} = \frac{g}{\sqrt{2}}(J_\mu^+ W^{-\mu} + J_\mu^- W^{+\mu})$$

$$J_\mu^+ = V_{\text{CKM}}\overline{U}_L \gamma_\mu D_L = \sum_{i,j} V_{ij}\overline{u}_i\gamma_\mu(1-\gamma_5)d_j \,/4$$

SM computation of the b → s γ process



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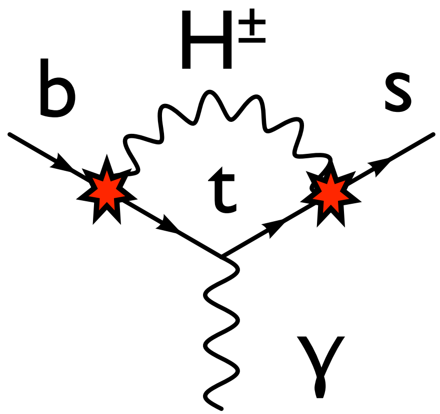
loop function
$x=m_t^2/m_W^2$

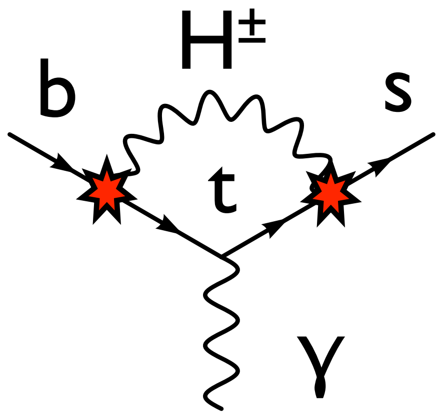
$$\boxed{\bar{b}A_\mu s = -iV_{tb}V_{ts}^*\frac{G_F e}{8\pi^2\sqrt{2}}D_0'(x_t)\,\bar{s}\left[i\sigma_{\mu\nu}q^\nu[m_b(1+\gamma_5)]\right]b}$$

$$D_0'(x_t) = -\frac{(8x_t^3+5x_t^2-7x_t)}{12(1-x_t)^3} + \frac{x_t^2(2-3x_t)}{2(1-x_t)^4}\ln x_t$$

New physics model I: Two Higgs doublet model



New physics model I: Two Higgs doublet model



$$\mathcal{L} = \frac{g}{2\sqrt{2}M_W} H^{\pm} \left[V_{ij} m_{u_i} A_u \bar{u}_i (1-\gamma_5) d_j + V_{ij} m_{d_j} A_d \bar{u}_i (1+\gamma_5) d_j \right] +$$

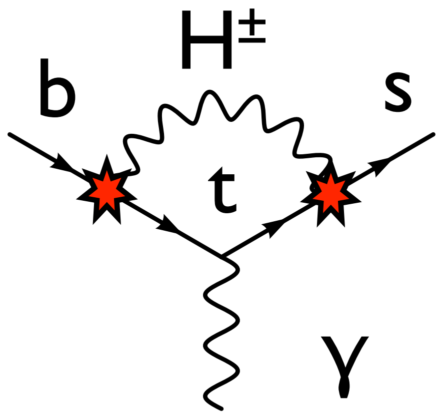
$\Phi_1=(\Phi_0,\Phi^+)_1 \rightarrow v_1$; $\Phi_2=(\Phi_0,\Phi^+)_2 \rightarrow v_2$

$\tan\beta = v_2/v_1$, $v_1^2 + v_1^2 = v^2$

Type I: $A_u=\cot\beta, A_d=-\cot\beta$

Type II: $A_u=\cot\beta, A_d=\tan\beta$

New physics model I: Two Higgs doublet model



$$\mathcal{L} = \frac{g}{2\sqrt{2}M_W} H^{\pm}\left[V_{ij} m_{u_i} A_u \bar{u}_i (1-\gamma_5) d_j + V_{ij} m_{d_j} A_d \bar{u}_i (1+\gamma_5) d_j\right]$$

$\Phi_1=(\Phi_0,\Phi^+)_1 \rightarrow v_1$; $\Phi_2=(\Phi_0,\Phi^+)_2 \rightarrow v_2$

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Type I: $A_u=\cot\beta, A_d=-\cot\beta$

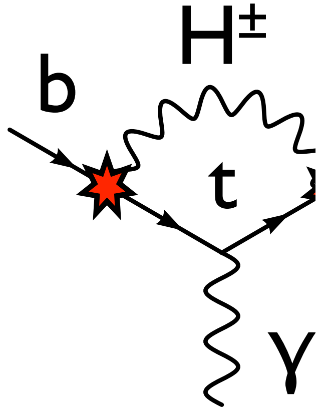
Type II: $A_u=\cot\beta, A_d=\tan\beta$

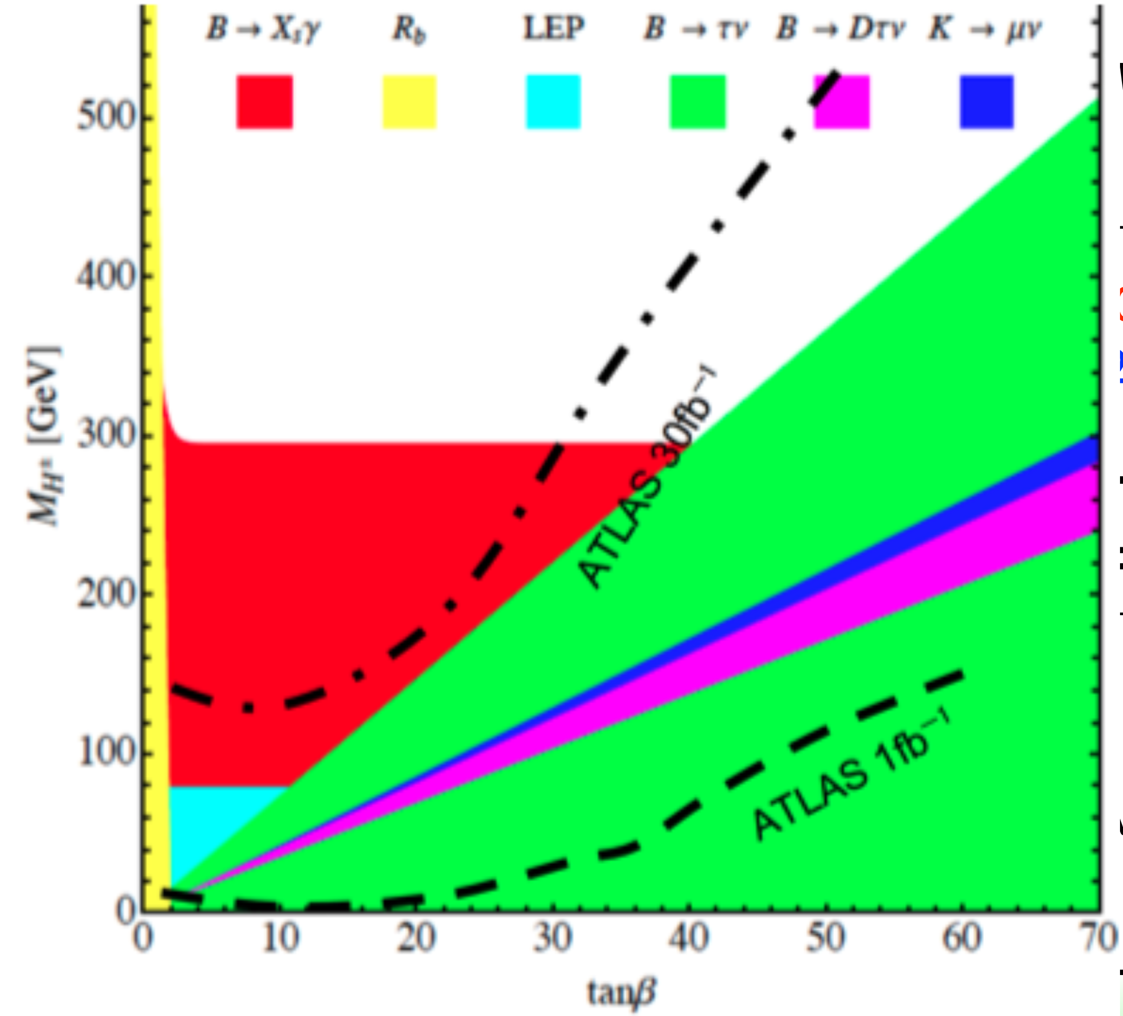
Now the loop function looks like...

$$c_{7,8}(M_W) = G_{7,8}(m_t^2/M_W^2) + \frac{1}{3\tan^2\beta} G_{7,8}(m_t^2/m_{H^\pm}^2) + \lambda F_{7,8}(m_t^2/m_{H^\pm}^2)$$

The measurement of b → s γ can give prediction orconstraint on the Higgs mass and tanβ

New physics model I: Two Higgs doublet model





$V_{ij} m_{d_j} A_d \bar{u}_i (1+\gamma_5) d_j \big]$ +

,Φ⁺)₂ → v₂

=v²

-cotβ

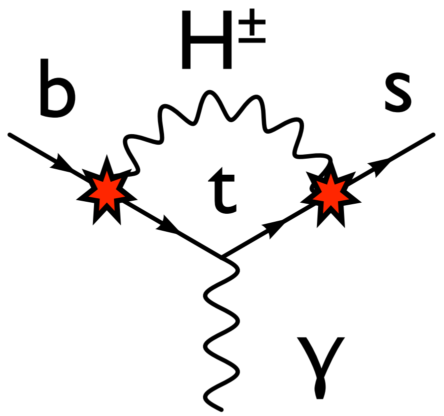
=tanβ

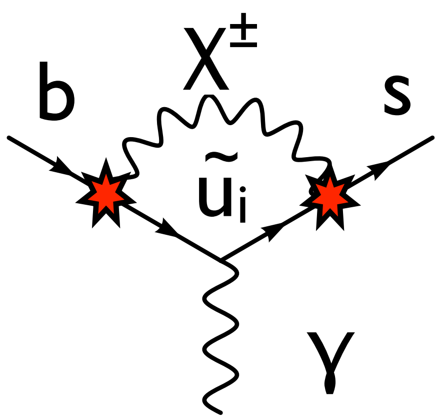
Now the loop fu

$c_{7,8}(M_W) = ($ … $F_{7,8}(m_t^2/m_{H^\pm}^2)$

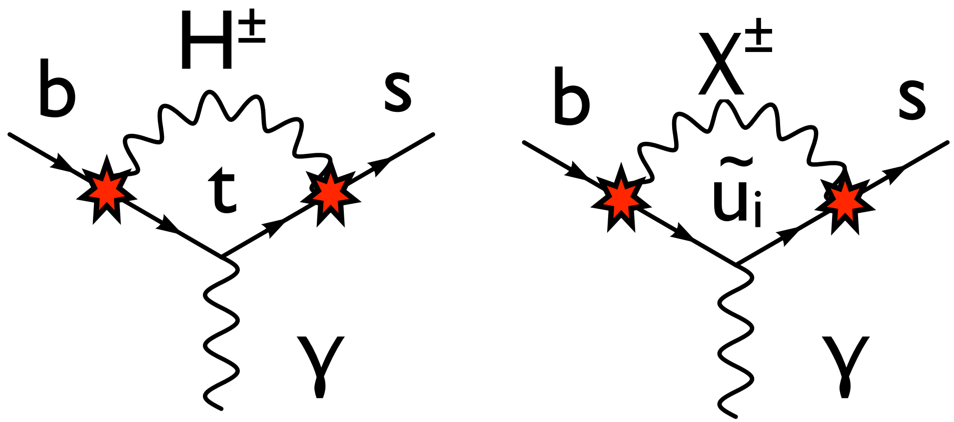
The measurement of b → s γ can give prediction orconstraint on the Higgs mass and tanβ

New physics model II: Supersymmetry (minimum...)





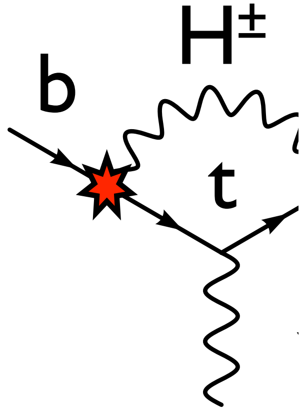
New physics model II: Supersymmetry (minimum...)



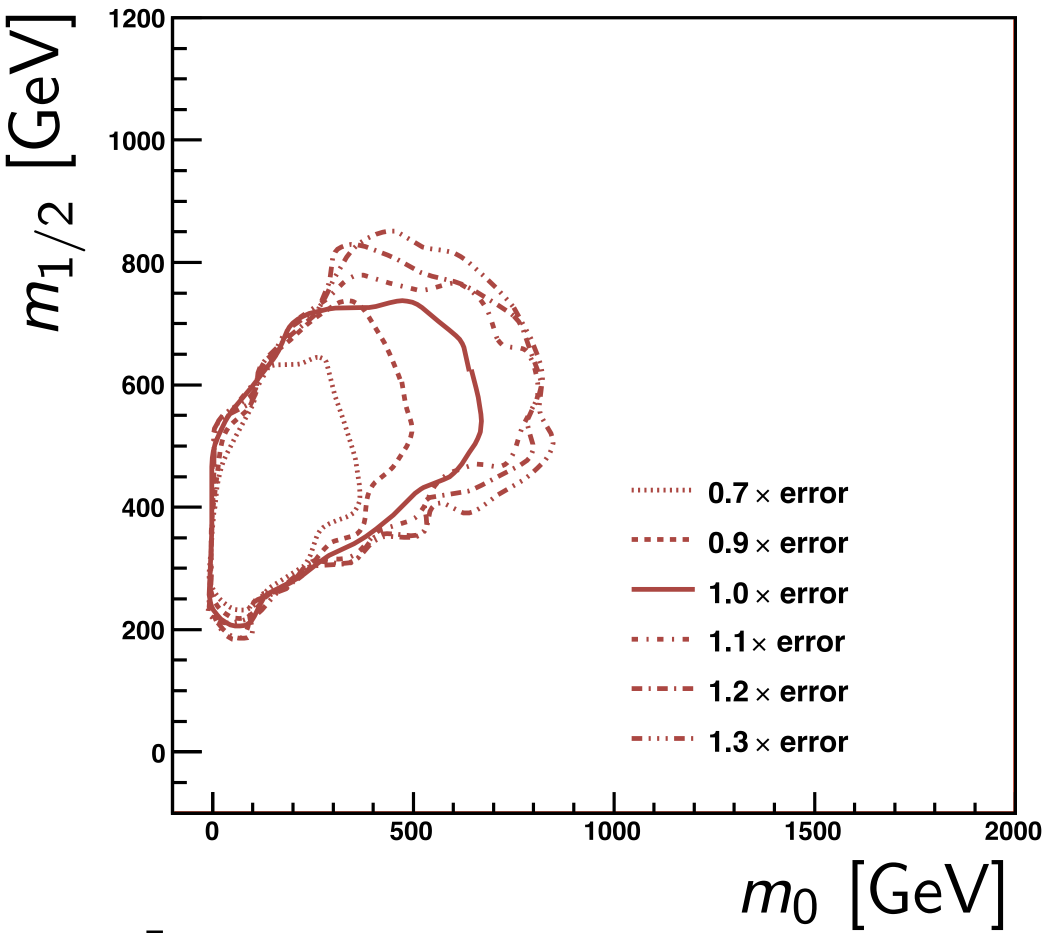
The loop function for chargino diagram looks like...

$$
\begin{aligned}
c_{7,8}^{\tilde{\chi}^\pm}(M_W) \;\simeq\; & \sum_{j=1}^{2}\left\{\frac{M_W^2}{\tilde{m}_{\chi_j^\pm}^2}|V_{j1}|^2 G_{7,8}\left(\frac{\tilde{m}^2}{\tilde{m}_{\chi_j^\pm}^2}\right) - \frac{M_W U_{j2} V_{j1}}{\tilde{m}_{\chi_j^\pm}\sqrt{2}\cos\beta} H_{7,8}\left(\frac{\tilde{m}^2}{\tilde{m}_{\chi_j^\pm}^2}\right)\right. \\
& + \sum_{k=1}^{2}\left[-\frac{M_W^2}{\tilde{m}_{\chi_j^\pm}^2}\left|V_{j1}T_{k1} - \frac{m_t V_{j2} T_{k2}}{M_W\sqrt{2}\sin\beta}\right|^2 G_{7,8}\left(\frac{\tilde{m}_{t_k}^2}{\tilde{m}_{\chi_j^\pm}^2}\right)\right. \\
& \left.\left. + \frac{M_W U_{j2} T_{k1}}{\tilde{m}_{\chi_j^\pm}\sqrt{2}\cos\beta}\left(V_{j1}T_{k1} - \frac{m_t V_{j2} T_{k2}}{M_W\sqrt{2}\sin\beta}\right) H_{7,8}\left(\frac{\tilde{m}^2}{\tilde{m}_{\chi_j^\pm}^2}\right)\right]\right\}
\end{aligned}
$$

New physics model II: Supersymmetry (minimum...)



The loop functio



$$c_{7,8}^{\tilde{\chi}^\pm}(M_W) \simeq \quad H_{7,8}\left(\frac{\tilde{m}^2}{\tilde{m}^2_{\chi_j^\pm}}\right)$$

$$\frac{\tilde{m}^2_{t_k}}{\tilde{m}^2_{\chi_j^\pm}}\Bigg)$$

$$+\frac{M_W U_{j2} T_{k1}}{\tilde{m}_{\chi_j^\pm}\sqrt{2}\cos\beta}\left(V_{j1}T_{k1} - \frac{m_t V_{j2} T_{k2}}{M_W\sqrt{2}\sin\beta}\right) H_{7,8}\left(\frac{\tilde{m}^2}{\tilde{m}^2_{\chi_j^\pm}}\right)\Bigg]\Bigg\}$$

SUSY CP/flavour problem

SUSY CP/flavour problem

SM

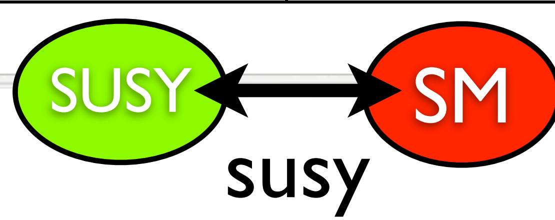
- There is only one source of CP violation.
- FCNC is suppressed naturally by the GIM mechanism.

SUSY

- There is many (too many) sources of CP violation.
- FCNC can occur since there is, a priori, no GIM mechanism.

SUSY CP/flavour problem

Names		spin 0	spin 1/2	$SU(3)_C,\ SU(2)_L,\ U(1)_Y$
squarks, quarks	Q	$(\widetilde{u}_L \quad \widetilde{d}_L)$	$(u_L \quad d_L)$	$(\,\mathbf{3},\ \mathbf{2}\,,\ \frac{1}{6})$
($\times$3 families)	$\overline{u}$	$\widetilde{u}^*_R$	$u^\dagger_R$	$(\,\overline{\mathbf{3}},\ \mathbf{1},\ -\frac{2}{3})$
	$\overline{d}$	$\widetilde{d}^*_R$	$d^\dagger_R$	$(\,\overline{\mathbf{3}},\ \mathbf{1},\ \frac{1}{3})$
sleptons, leptons	L	$(\widetilde{\nu} \ \ \widetilde{e}_L)$	$(\nu \quad e_L)$	$(\,\mathbf{1},\ \mathbf{2}\,,\ -\frac{1}{2})$
($\times$3 families)	$\overline{e}$	$\widetilde{e}^*_R$	$e^\dagger_R$	$(\,\mathbf{1},\ \mathbf{1},\ 1)$
Higgs, higgsinos	H_u	$(H^+_u \quad H^0_u)$	$(\widetilde{H}^+_u \quad \widetilde{H}^0_u)$	$(\,\mathbf{1},\ \mathbf{2}\,,\ +\frac{1}{2})$
	H_d	$(H^0_d \quad H^-_d)$	$(\widetilde{H}^0_d \quad \widetilde{H}^-_d)$	$(\,\mathbf{1},\ \mathbf{2}\,,\ -\frac{1}{2})$



MSSM

SUSY CP/flavour problem

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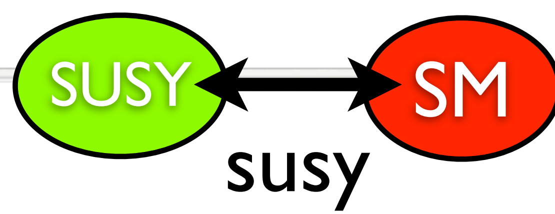
squarks, quarks	Q	$(\widetilde{u}_L\ \ \widetilde{d}_L)$	$(u_L\ \ d_L)$	$(\ \mathbf{3},\ \mathbf{2}\ ,\ \frac{1}{6})$
($\times$3 famili				$-\frac{2}{3})$
				$\frac{1}{3})$
sleptons, lep				$-\frac{1}{2})$
($\times$3 families)	e	e_R	e_R	$(\ \mathbf{1},\ \mathbf{1},\ 1)$
Higgs, higgsinos	H_u	$(H_u^+\ \ H_u^0)$	$(\widetilde{H}_u^+\ \ \widetilde{H}_u^0)$	$(\ \mathbf{1},\ \mathbf{2}\ ,\ +\frac{1}{2})$
	H_d	$(H_d^0\ \ H_d^-)$	$(\widetilde{H}_d^0\ \ \widetilde{H}_d^-)$	$(\ \mathbf{1},\ \mathbf{2}\ ,\ -\frac{1}{2})$

If Supersymmetry is unbroken*, the SM particles and their SUSY partners would have the same mass!



MSSM

**The same is true if SUSY is broken spontaneously* $Tr[M^2_{\text{real scalar}}] = 2Tr[M^2_{\text{chiral fermions}}]$

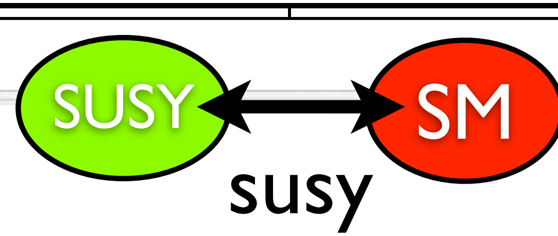
SUSY CP/flavour problem

Names		spin 0	spin 1/2	$SU(3)_C,\ SU(2)_L,\ U(1)_Y$
squarks, quarks (×3 famili	Q	$(\widetilde{u}_L\ \ \widetilde{d}_L)$	$(u_L\ \ d_L)$	$(\ \mathbf{3},\ \mathbf{2}\ ,\ \frac{1}{6})$
				$-\frac{2}{3})$
				$\frac{1}{3})$
sleptons, lep				$-\frac{1}{}$
(×3 families)	e			
Higgs, higgsinos	H_u			
	H_d			

If Supersymmetry is unbroken*, the SM particles and their SUSY partners wo

$m_e = m_{selectron}$???

We would have seen it then!



MSSM

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SUSY CP/flavour problem

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$(\times 3$ famili				$-\frac{2}{3})$
				$\frac{1}{3})$
sleptons, lep				$-\frac{1}{\ })$
$(\times 3$ families$)$	e			
Higgs, higgsinos	H_u			
	H_d			

If Supersymmetry is unbroken*, the SM particles and their SUSY partners wo

$m_e = m_{selectron}$???

SUSY

We must break SUSY!!!

**The same is true if SUSY is broken spontaneously* $Tr[M^2_{\text{real scalar}}] = 2Tr[M^2_{\text{chiral fermions}}]$

Origin of the SUSY CP/ flavour problem

We must start with most general Soft SUSY breaking term

$$
\begin{aligned}
\mathcal{L}_{\mathrm{soft}}^{\mathrm{MSSM}} = &-\frac{1}{2}(M_3\tilde{g}\tilde{g} + M_2\tilde{W}\tilde{W} + M_1\tilde{B}\tilde{B}) + c.c. \\
&-(\tilde{\bar{u}}\mathbf{a_u}\tilde{Q}H_u - \tilde{\bar{d}}\mathbf{a_d}\tilde{Q}H_d - \tilde{\bar{d}}\mathbf{a_d}\tilde{L}H_d) + c.c. \\
&-m_{H_u}^2 H_u^* H_u - m_{H_d}^2 H_d^* H_d - (bH_uH_d + c.c) \\
&-\tilde{Q}^\dagger \mathbf{m_Q^2}\tilde{Q} - \tilde{L}^\dagger \mathbf{m_L^2}\tilde{L} - \tilde{\bar{u}}\mathbf{m_{\bar{u}}^2}\tilde{\bar{u}}^\dagger - \tilde{\bar{d}}\mathbf{m_{\bar{d}}^2}\tilde{\bar{d}}^\dagger - \tilde{\bar{e}}\mathbf{m_{\bar{e}}^2}\tilde{\bar{e}}^\dagger
\end{aligned}
$$

The SUSY breaking term introduces 105 new masses, mixings and phases.

Origin of the SUSY CP/ flavour problem

Squark mass matrix

$$V = \tilde{u}_L^\dagger \mathbf{M^2_{LL}} \tilde{u}_L + \tilde{u}_R^\dagger \mathbf{M^2_{RR}} \tilde{u}_R + \tilde{u}_L^\dagger \mathbf{M^2_{LR}} \tilde{u}_R + \tilde{u}_R^\dagger \mathbf{M^2_{RL}} \tilde{u}_L$$

$$\begin{aligned}
\mathbf{M^2_{LL}} &= \left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right)\frac{g'^2+g^2}{4}(v_d^2 - v_u^2)\mathbf{1} + v_u^2 \mathbf{y_u^{*2}} + \mathbf{m_Q^2} \\
\mathbf{M^2_{RR}} &= \frac{2}{3}\sin^2\theta_W \frac{g'^2+g^2}{4}(v_d^2 - v_u^2)\mathbf{1} + v_u^2 \mathbf{y_u^{*2}} + \mathbf{m_{\bar{u}}^2} \\
\mathbf{M^2_{LR}} &= -\mu \cot\beta v_u \mathbf{y_u^*} + v_u \mathbf{a_u^*} \\
\mathbf{M^2_{RL}} &= -\mu^* \cot\beta v_u \mathbf{y_u^*} + v_u \mathbf{a_u^*}
\end{aligned}$$

Terms from spontaneous symmetry breaking

Terms from soft SUSY breaking

By the way, what is the ... that mixing

Slide from the first day...

Diagonalization

$$(\bar{d}, \bar{s}, \bar{b}) \begin{pmatrix} .. & .. & .. \\ .. & (Y_d)^2 & .. \\ .. & .. & .. \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \Rightarrow (\bar{\tilde{d}}, \bar{\tilde{s}}, \bar{\tilde{b}}) \begin{pmatrix} m_d^2 & 0 & 0 \\ 0 & m_s^2 & 0 \\ 0 & 0 & m_b^2 \end{pmatrix} \begin{pmatrix} \tilde{d} \\ \tilde{s} \\ \tilde{b} \end{pmatrix}$$

Unitary transformation to diagonalize the Yukawa matrix

$$U_d (Y_d)^2 U_d^\dagger = (M_d^2)_{diag}$$

Transformation from interaction eigen-basis to mass eigen-basis

$$U_d \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \begin{pmatrix} \tilde{d} \\ \tilde{s} \\ \tilde{b} \end{pmatrix}$$

Origin of the SUSY CP/flavour problem

Rotating squark field with the same matrix which diagonalizes quark field

$$U_d \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{\text{weak}} = \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{\text{mass}} \quad \Longrightarrow \quad U_d \begin{pmatrix} \tilde{d} \\ \tilde{s} \\ \tilde{b} \end{pmatrix}_{\text{weak}} = \begin{pmatrix} \tilde{d} \\ \tilde{s} \\ \tilde{b} \end{pmatrix}_{\text{mass}}$$

$$V = \tilde{u}_L^\dagger \mathbf{M^2_{LL}} \tilde{u}_L + \tilde{u}_R^\dagger \mathbf{M^2_{RR}} \tilde{u}_R + \tilde{u}_L^\dagger \mathbf{M^2_{LR}} \tilde{u}_R + \tilde{u}_R^\dagger \mathbf{M^2_{RL}} \tilde{u}_L$$

$$\begin{aligned}
\mathbf{M^2_{LL}} &= \left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right)\frac{g'^2+g^2}{4}(v_d^2 - v_u^2)\mathbf{1} + v_u^2 \mathbf{y_u^{*2}} + \mathbf{m_Q^2} \\
\mathbf{M^2_{RR}} &= \frac{2}{3}\sin^2\theta_W \frac{g'^2+g^2}{4}(v_d^2 - v_u^2)\mathbf{1} + v_u^2 \mathbf{y_u^{*2}} + \mathbf{m^2_{\bar{u}}} \\
\mathbf{M^2_{LR}} &= -\mu \cot\beta v_u \mathbf{y_u^*} + v_u \mathbf{a_u^*} \\
\mathbf{M^2_{RL}} &= -\mu^* \cot\beta v_u \mathbf{y_u^*} + v_u \mathbf{a_u^*}
\end{aligned}$$

The red terms remains non-diagonal.

Origin of the SUSY CP/flavour problem

Rotating squark field with the same matrix which diagonalizes quark field

$$U_d \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{\text{weak}} = \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{\text{mass}} \quad \Rightarrow \quad U_d \begin{pmatrix} \tilde{d} \\ \tilde{s} \\ \tilde{b} \end{pmatrix}_{\text{weak}} = \begin{pmatrix} \tilde{d} \\ \tilde{s} \\ \tilde{b} \end{pmatrix}_{\text{mass}}$$

$$V = \tilde{u}_L^\dagger \mathbf{M^2_{LL}} \tilde{u}_L + \tilde{u}_R^\dagger \mathbf{M^2_{RR}} \tilde{u}_R + \tilde{u}_L^\dagger \mathbf{M^2_{LR}} \tilde{u}_R + \tilde{u}_R^\dagger \mathbf{M^2_{RL}} \tilde{u}_L$$

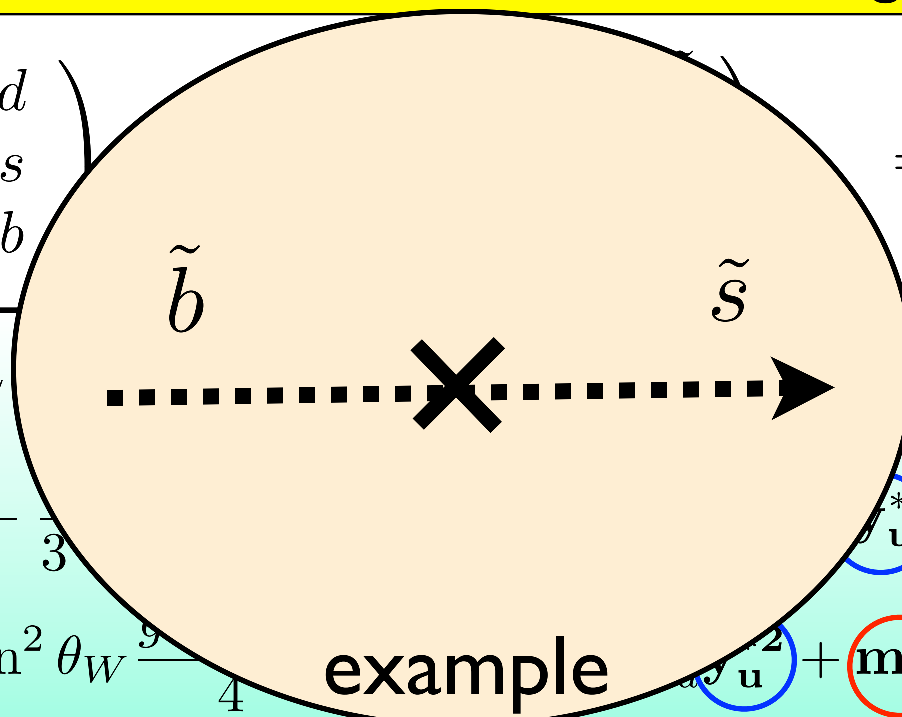
$$\begin{aligned}
\mathbf{M^2_{LL}} &= \left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right)\frac{g'^2+g^2}{4}(v_d^2 - v_u^2)\mathbf{1} + v_u^2 \mathbf{y_u^{*2}} + \mathbf{m_Q^2} \\
\mathbf{M^2_{RR}} &= \frac{2}{3}\sin^2\theta_W \frac{g'^2+g^2}{4}(v_d^2 - v_u^2)\mathbf{1} + v_u^2 \mathbf{y_u^{*2}} + \mathbf{m_u^2} \\
\mathbf{M^2_{LR}} &= -\mu \cot\beta v_u \mathbf{y_u^*} + v_u \mathbf{a_u^*} \\
\mathbf{M^2_{RL}} &= -\mu^* \cot\beta v_u \mathbf{y_u^*} + v_u \mathbf{a_u^*}
\end{aligned}$$

Squark is not on the mass eigen-basis ⟺ **Flavour mixture in the propagator**

Origin of the SUSY CP/flavour problem

Rotating squark field with the same matrix which diagonalizes quark field

$$U_d \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{\text{weak}} = \begin{pmatrix} d \\ s \\ b \end{pmatrix} \quad \ldots \quad = \begin{pmatrix} \tilde{d} \\ \tilde{s} \\ \tilde{b} \end{pmatrix}_{\text{mass}}$$



$$V = \tilde{u}_L^\dagger \mathbf{M^2_{LL}} \tilde{u}_L \ldots \mathbf{M^2_{RL}} \tilde{u}_L$$

$$\mathbf{M^2_{LL}} = (\frac{1}{2} - \frac{\ldots}{3} \ldots \mathbf{y_u^{*2}} + \mathbf{m_Q^2}$$

$$\mathbf{M^2_{RR}} = \frac{2}{3}\sin^2\theta_W \frac{\ldots}{4} \ldots \mathbf{y_u^{*2}} + \mathbf{m_u^2}$$

$$\mathbf{M^2_{LR}} = -\mu \cot\beta v_u \mathbf{y_u^*} + v_u \mathbf{a_u^*}$$

$$\mathbf{M^2_{RL}} = -\mu^* \cot\beta v_u \mathbf{y_u^*} + v_u \mathbf{a_u^*}$$

Squark is not on the mass eigen-basis ⟺ **Flavour mixture in the propagator**

Avoiding SUSY CP/flavour problem I

$$V = \tilde{u}_L^\dagger \mathbf{M^2_{LL}} \tilde{u}_L + \tilde{u}_R^\dagger \mathbf{M^2_{RR}} \tilde{u}_R + \tilde{u}_L^\dagger \mathbf{M^2_{LR}} \tilde{u}_R + \tilde{u}_R^\dagger \mathbf{M^2_{RL}} \tilde{u}_L$$

$$\begin{aligned}
\mathbf{M^2_{LL}} &= \left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right)\frac{g'^2+g^2}{4}(v_d^2 - v_u^2)\mathbf{1} + v_u^2 \mathbf{y_u^{*2}} + \mathbf{m^2_Q} \\
\mathbf{M^2_{RR}} &= \frac{2}{3}\sin^2\theta_W \frac{g'^2+g^2}{4}(v_d^2 - v_u^2)\mathbf{1} + v_u^2 \mathbf{y_u^{*2}} + \mathbf{m^2_{\bar{u}}} \\
\mathbf{M^2_{LR}} &= -\mu \cot\beta v_u \mathbf{y_u^*} + v_u \mathbf{a_u^*} \\
\mathbf{M^2_{RL}} &= -\mu^* \cot\beta v_u \mathbf{y_u^*} + v_u \mathbf{a_u^*}
\end{aligned}$$

Assumption

Fix the SUSY breaking parameters so that the red terms can be diagonalized together with the blue terms

$$\mathbf{m^2_Q} = m_Q^2\mathbf{1}, \mathbf{m^2_L} = m_L^2\mathbf{1}, \mathbf{m^2_{\bar{u}}} = m_{\bar{u}}^2\mathbf{1}, \mathbf{m^2_{\bar{d}}} = m_{\bar{d}}^2\mathbf{1}, \mathbf{m^2_{\bar{e}}} = m_{\bar{e}}^2\mathbf{1}$$

$$\mathbf{a_u} = A_{u0}\mathbf{y_u}, \quad \mathbf{a_d} = A_{u0}\mathbf{y_d}, \quad \mathbf{a_e} = A_{u0}\mathbf{y_e}$$

$$\arg(M_{1\sim 3}), \arg(A_{u0}), \arg(A_{d0}), \arg(A_{e0}) = 0, \text{or } \pi$$

e.g. mSUGRA

Constraining the Soft SUSY parameters from flavour physics

Squark mass matrix

$$V = \tilde{u}_L^\dagger \mathbf{M^2_{LL}} \tilde{u}_L + \tilde{u}_R^\dagger \mathbf{M^2_{RR}} \tilde{u}_R + \tilde{u}_L^\dagger \mathbf{M^2_{LR}} \tilde{u}_R + \tilde{u}_R^\dagger \mathbf{M^2_{RL}} \tilde{u}_L$$

$$\begin{aligned}
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\mathbf{M^2_{RL}} &= -\mu^* \cot\beta v_u \mathbf{y_u^*} + v_u \mathbf{a_u^*}
\end{aligned}$$

Instead of (artificially) choosing the parameters, why don't we constrain from the flavour phenomena, first?!

Constraining the Soft SUSY parameters from flavour physics

$$\mathbf{m}^{\mathbf{2}\,\mathrm{SCKM}}_{\mathbf{AB}} = \begin{pmatrix} (m^2_{AB})_{11} & (\Delta_{AB})_{12} & (\Delta_{AB})_{13} \\ (\Delta_{AB})_{21} & (m^2_{AB})_{22} & (\Delta_{AB})_{23} \\ (\Delta_{AB})_{31} & (\Delta_{AB})_{32} & (m^2_{AB})_{33} \end{pmatrix}$$

$$\frac{(\Delta_{AB})_{ij}}{m_{\mathrm{squark}}} \equiv (\delta_{AB})_{ij}$$

Mass Insertion Parameter

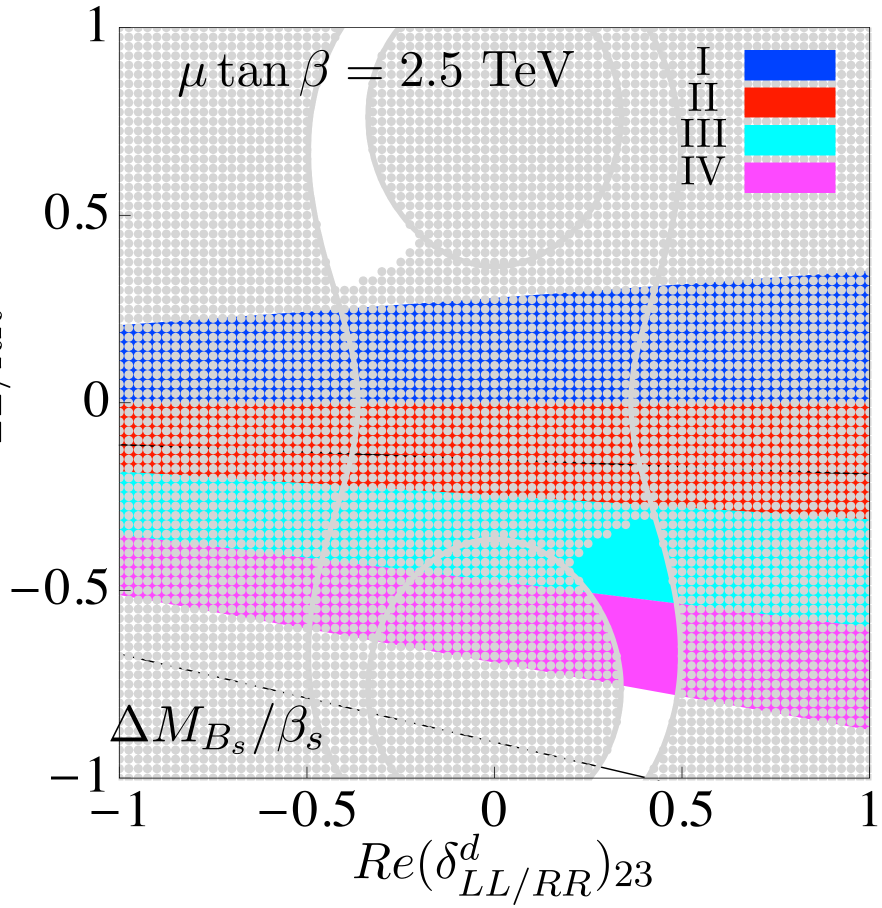
$$(\delta_{AB})_{12} \longrightarrow \Delta m_K, \quad \epsilon, \quad \epsilon'/\epsilon$$

$$(\delta_{AB})_{13} \longrightarrow \Delta m_{B_d}, \quad A_{CP}(B \to J/\psi K_S),$$

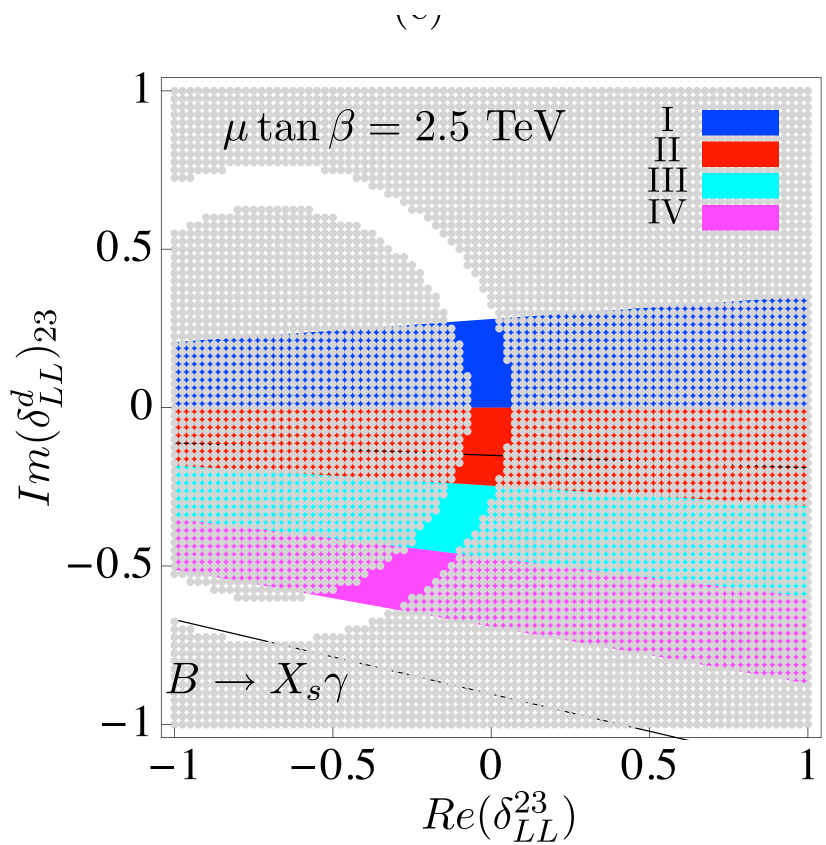
$$(\delta_{AB})_{23} \longrightarrow \Delta m_{B_s}, \quad b \to s\gamma, \quad A_{CP}(B \to \phi K_S)$$

many future measurements

$(\delta_{AB})_{23}$ determination



Bs-$\overline{\text{B}}$s oscillation



b →s γ

New particle searches in flavour physics ~hot topics~

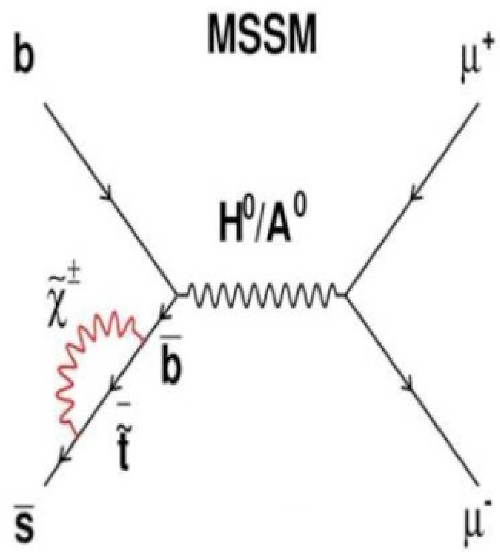
$$B_s \to \mu^+\mu^-$$

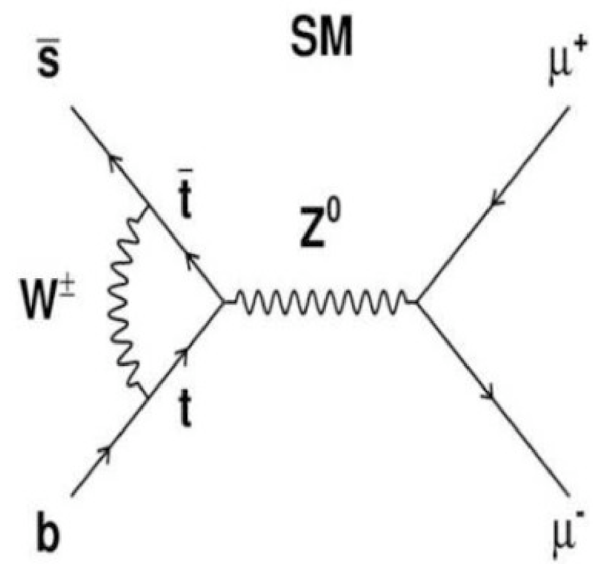
$$A_{SL}^b$$

$$S_{B_s \to J/\psi\phi} (= \sin 2\beta_s)$$

SUSY particle contributions to $B_s \to \mu^+\mu^-$

SUSY particle contributions to $B_s \to \mu^+\mu^-$





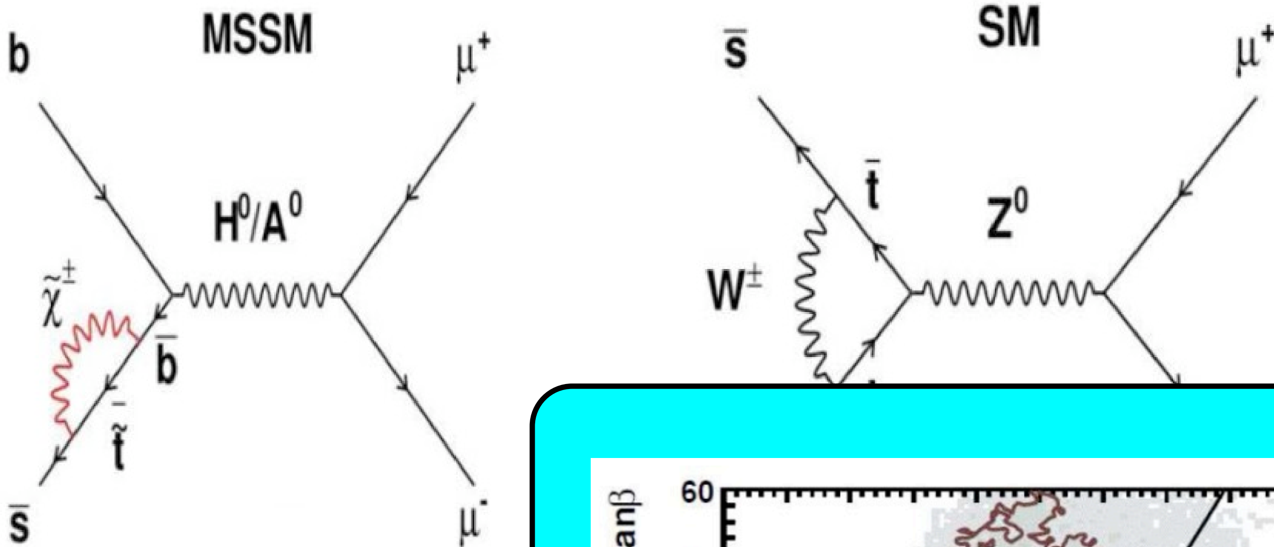
$$\boxed{Br(B_s \to \mu^+\mu^-)_{\rm MSSM} = \frac{m_b^2 m_\mu^2 \tan^6\beta}{M_{A_0}^4}}$$

$$\boxed{Br(B_s \to \mu^+\mu^-)_{\rm SM} = (3.2 \pm 0.2) \times 10^{-9}}$$

It could be large if tanβ is large

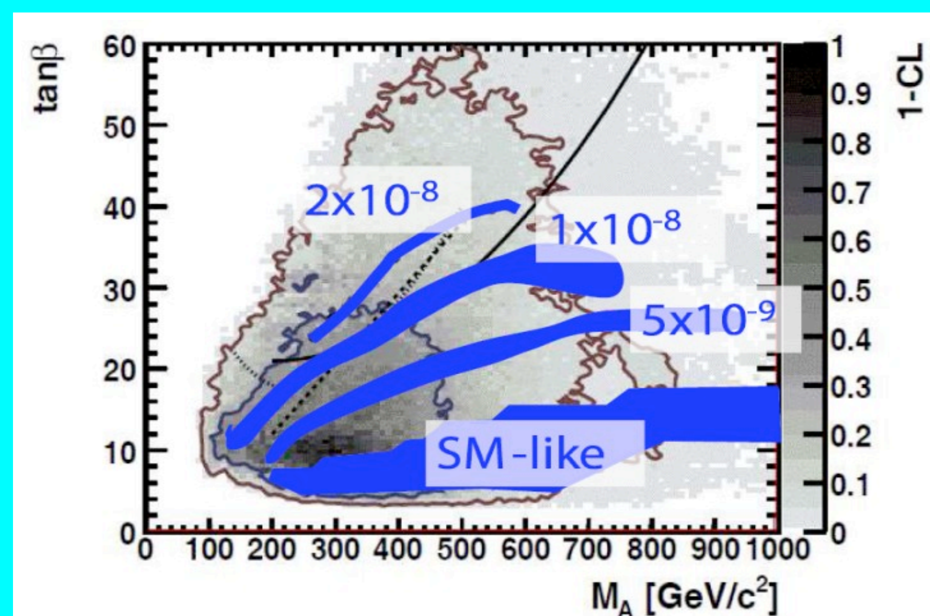
extremely small!!

SUSY particle contributions to $B_s \to \mu^+\mu^-$



$$Br(B_s \to \mu^+\mu^-)_{\mathrm{MSS}}$$
$$= \frac{m_b^2 m_\mu^2 \tan^6\beta}{M_{A_0}^4}$$

It could be large if tanβ is large



SUSY particle contributions to $B_s \to \mu^+\mu^-$

Excitement in the summer 2011!!!

Early summer, CDF (7fb^{-1}) announced...

$$Br(B_s \to \mu^+\mu^-) = (1.8^{+1.1}_{-0.9}) \times 10^{-8}$$

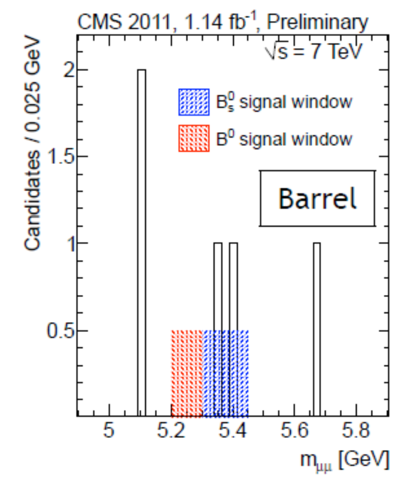
arXive:1107.2304

CMS 1.14fb^{-1} (EPS2011)

No significant excess seen

	Barrel	Endcap
$N^{\rm exp}_{\rm signal}$	0.80 ± 0.16	0.36 ± 0.07
$N^{\rm exp}_{\rm bg}$	0.60 ± 0.35	0.80 ± 0.40
$N^{\rm exp}_{\rm peak}$	0.07 ± 0.02	0.04 ± 0.01
$N_{\rm obs}$	2	1

this is B→hh

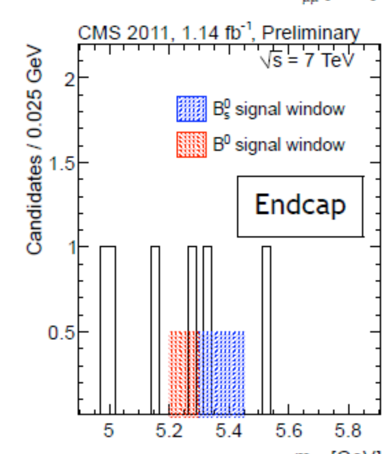


Calculate upper limits using frequentist CLs approach and taking $f_s/f_u = 0.282 \pm 0.037$ [PDG]

Expected limit at 95% C.L. (including presence of SM signal) — 1.8×10^{-8}

Observed limit at 95% (90%) C.L. — $\boxed{1.9\ (1.6) \times 10^{-8}}$

p-value of bckgd only hypothesis — 11%



SUSY particle contributions to $B_s \to \mu^+\mu^-$

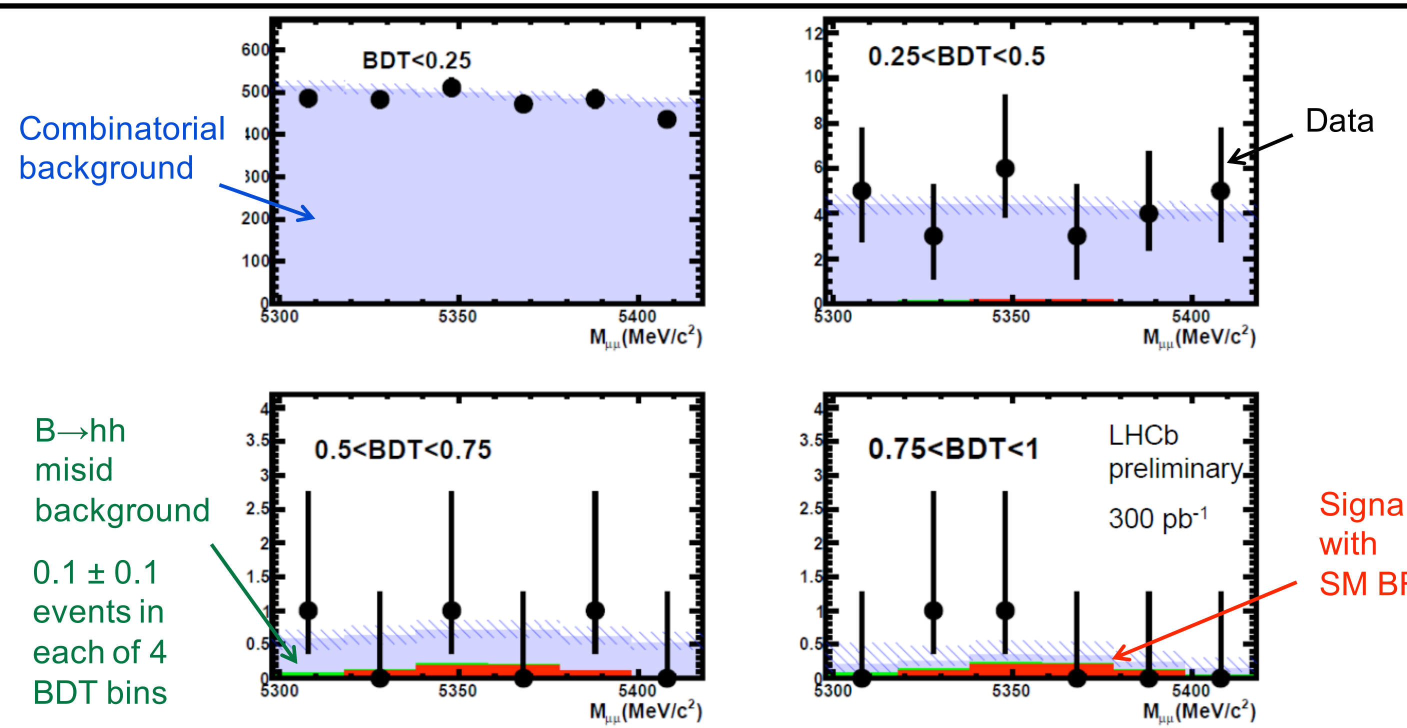
Excitement in the summer 2011!!!

Early summer, CDF (7fb^{-1}) announced...

$$Br(B_s \to \mu^+\mu^-) = (1.8^{+1.1}_{-0.9}) \times 10^{-8}$$

arXive:1107.2304

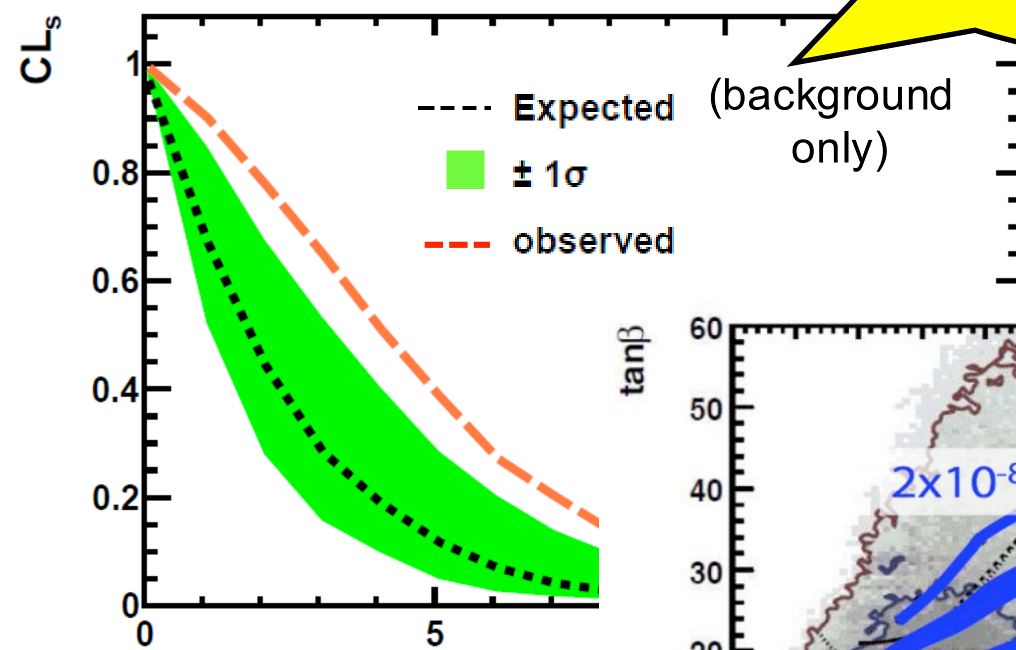
LHCb
300pb^{-1}
(EPS2011)

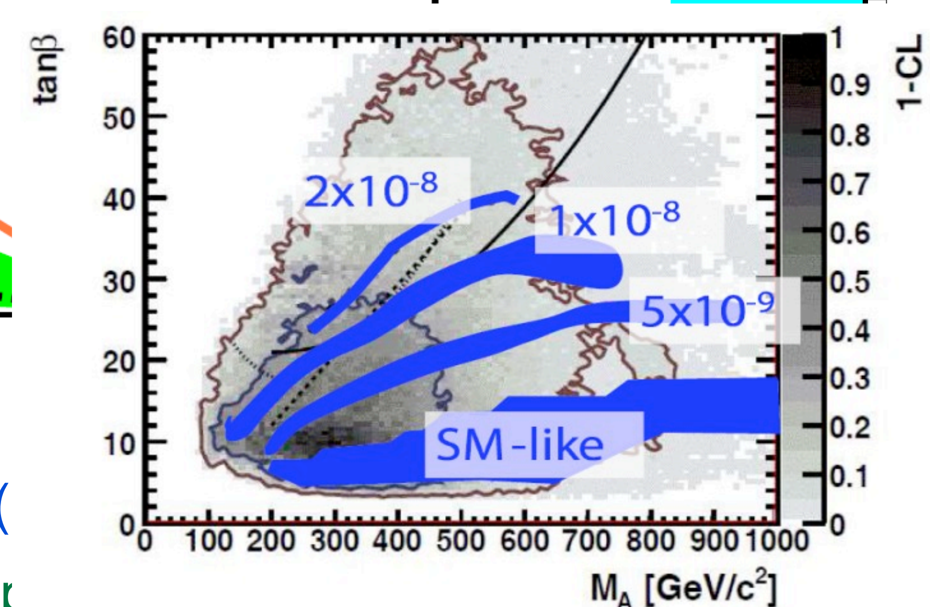


	BDT<0.25	0.25<BDT<0.5	0.5<BDT<0.75	0.75<BDT
Exp.combinatorial	2968 ± 69	25 ± 2.5	2.99 ± 0.89	0.66 ± 0.40
Exp. SM signal	1.26 ± 0.13	0.61 ± 0.06	0.67 ± 0.07	0.72 ± 0.07
Observed	2872	26	3	2

SUSY particle contributions to $B_s \to \mu^+ \mu^-$

So far we don't see it.
But then...





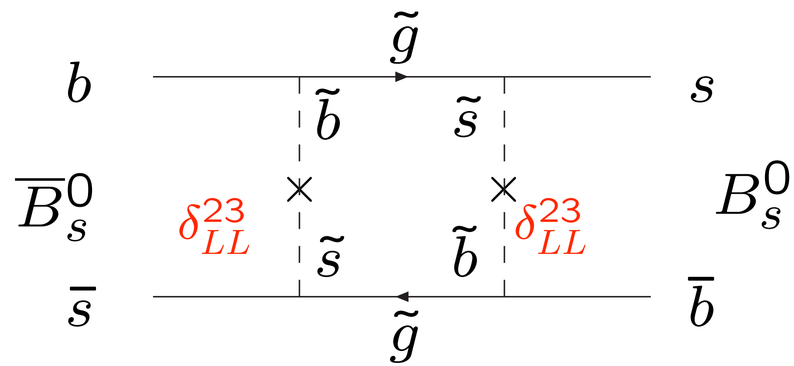
Observed limit at 95% (

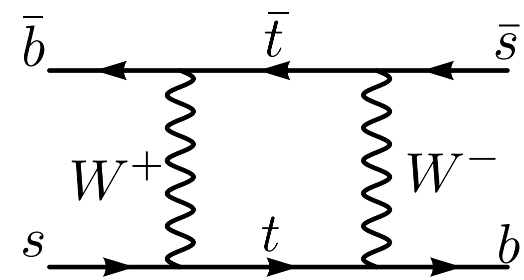
This is 3.4 times the exp

A BR of 1.8 x 10^{-8} has a CLs value of ~0.3%

New particle contributions to Bs oscillation

New particle contributions to Bs oscillation





$$S_{J/\psi\phi} = Im\left[\underbrace{\frac{q}{p}}_{oscill.}\underbrace{\frac{A(\overline{B_s}\to J/\psi\phi)}{A(B_s\to J/\psi\phi)}}_{decay}\right]$$

$$\simeq Im\left[\underbrace{\frac{\delta^{23}_{LL}}{\delta^{23*}_{LL}}}_{oscill.}\underbrace{\frac{V_{cb}V^*_{cs}}{V^*_{cb}V_{cs}}}_{decay}\right]$$

$$= \sin 2\beta_s$$

β_s can be large in BSM

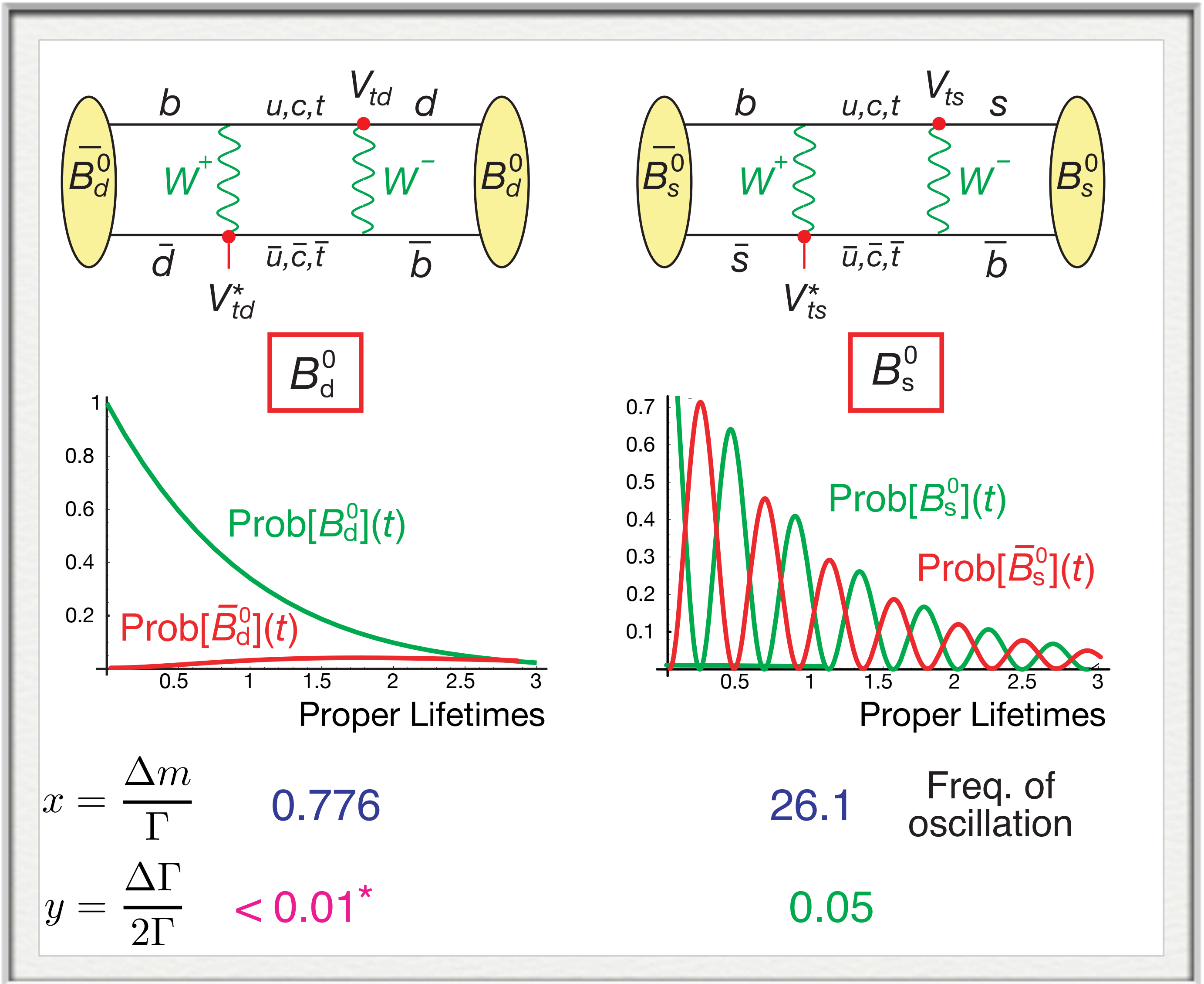
$$S_{J/\psi\phi} = Im\left[\underbrace{\frac{q}{p}}_{oscill.}\underbrace{\frac{A(\overline{B_s}\to J/\psi\phi)}{A(B_s\to J/\psi\phi)}}_{decay}\right]$$

$$= Im\left[\underbrace{\frac{V_{tb}V^*_{ts}}{V^*_{tb}V_{ts}}}_{oscill.}\underbrace{\frac{V_{cb}V^*_{cs}}{V^*_{cb}V_{cs}}}_{decay}\right]$$

$$= \sin 2\beta_s$$

$\beta_s \simeq 1°$ in SM

Bs oscillation measurement at LHC/Tevatron I: $B_s \to J/\psi\Phi$

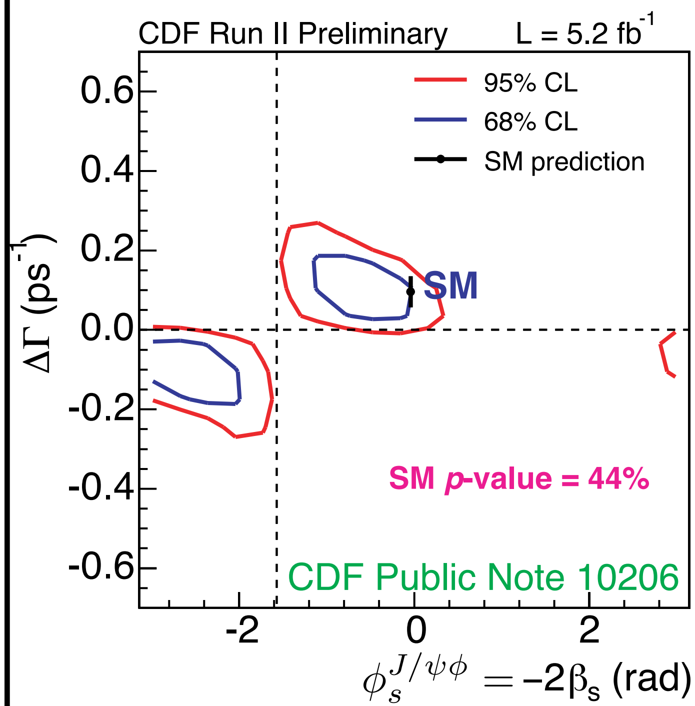


Difference between the Bd/Bs system

- ✓ Bs oscillation is much faster (we need more Lorentz boost=LHC/Tevatron!)
- ✓ Non-negligible width difference modify the master formula

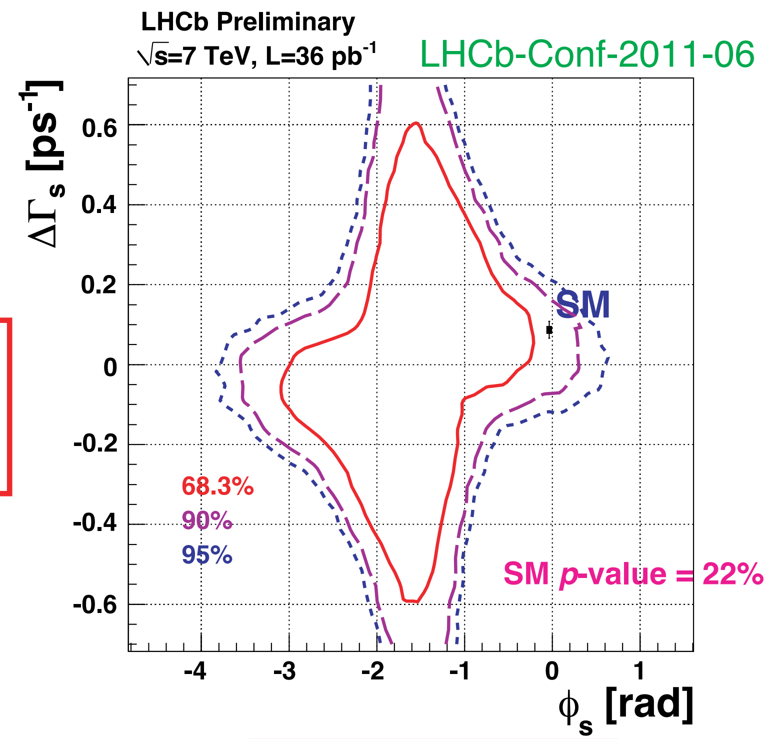
Bs oscillation measurement at LHC/Tevatron I: $B_s \to J/\psi\Phi$

- Constraints in $(\Delta\Gamma_s, \phi_s)$ plane



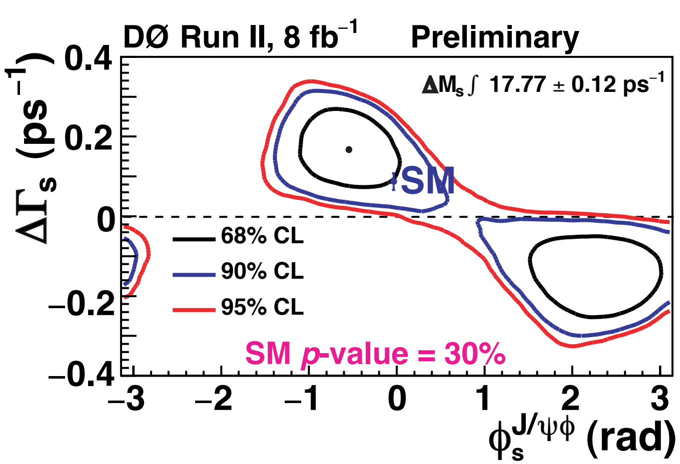
Plots all scaled to have identical axis unit sizes

$$\phi_s \in [-3.10, -2.16] \cup [-1.04, -0.04]$$
68% CL



$$\phi_s \in [-2.7, -0.5]$$
68% CL

Tevatron: with less data, was previously at ≳2σ deviation from SM



$$\phi_s = -0.55^{+0.38}_{-0.36}$$

L
d
st

Lenz, Nierste, arXiv:110

$$\Delta\Gamma_s^{\rm SM} = 0.087 \pm 0.021\ {\rm ps}$$

LHCb result with 300 pb^{-1} haven't been published: STAY TUNED!!!

Bs oscillation measurement at LHC/Tevatron II: dimuon charge asymmetry

Direct semileptonic decay

Neutral *B* meson oscillation and then semileptonic decay

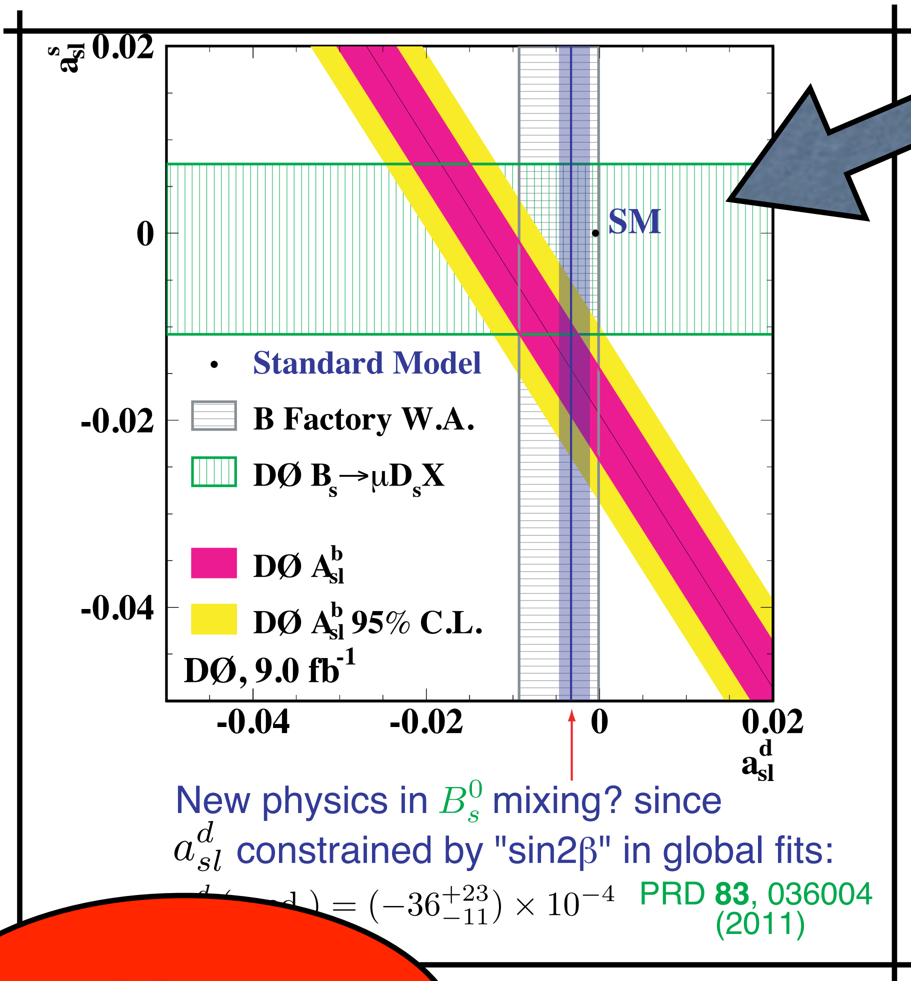
- Measure *CP* violation in mixing via

$$\boxed{A^b_{sl} = \frac{N_b(\mu^+\mu^+) - N_b(\mu^-\mu^-)}{N_b(\mu^+\mu^+) + N_b(\mu^-\mu^-)}}$$

- DØ: Evidence for anomalous dimuon charge asymmetry, (6 fb^{-1},PRL **105**, 081801 (2010))
  3.2σ deviation from $A^b_{sl}(SM) = (-0.023^{+0.005}_{-0.006})\%$

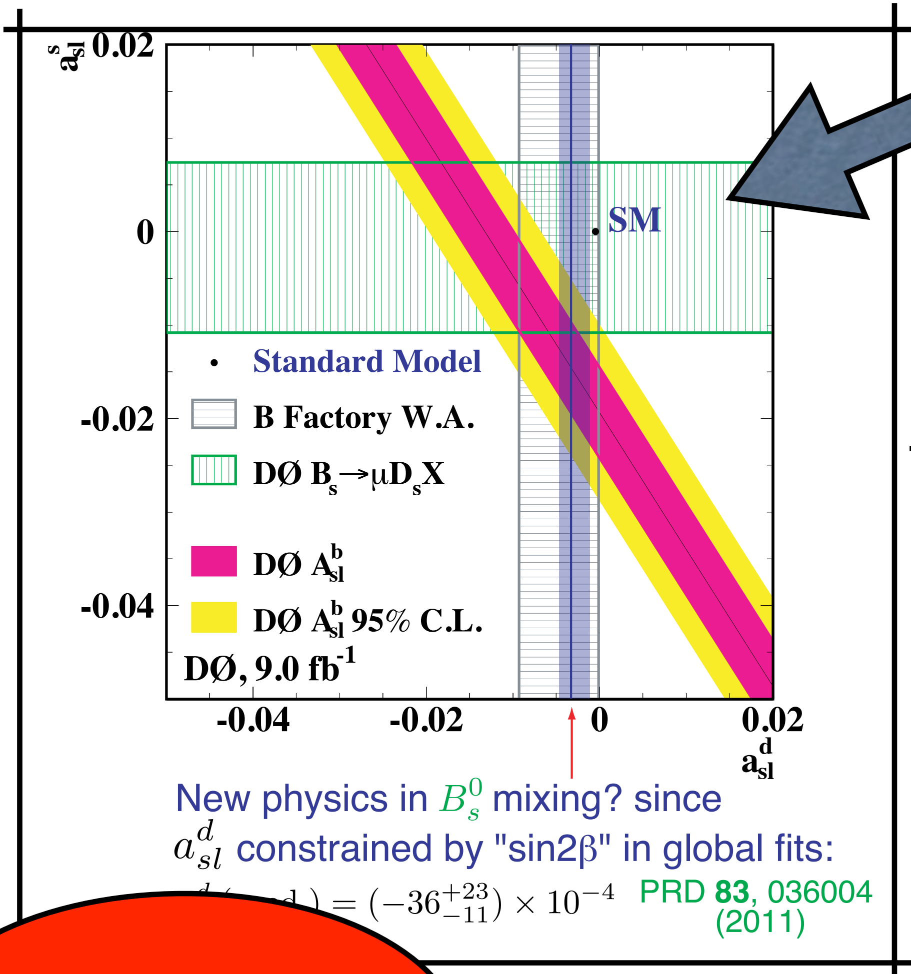
Bs oscillation measurement at LHC/Tevatron II:

dimuon charge asymmetry



New physics?!?!?!

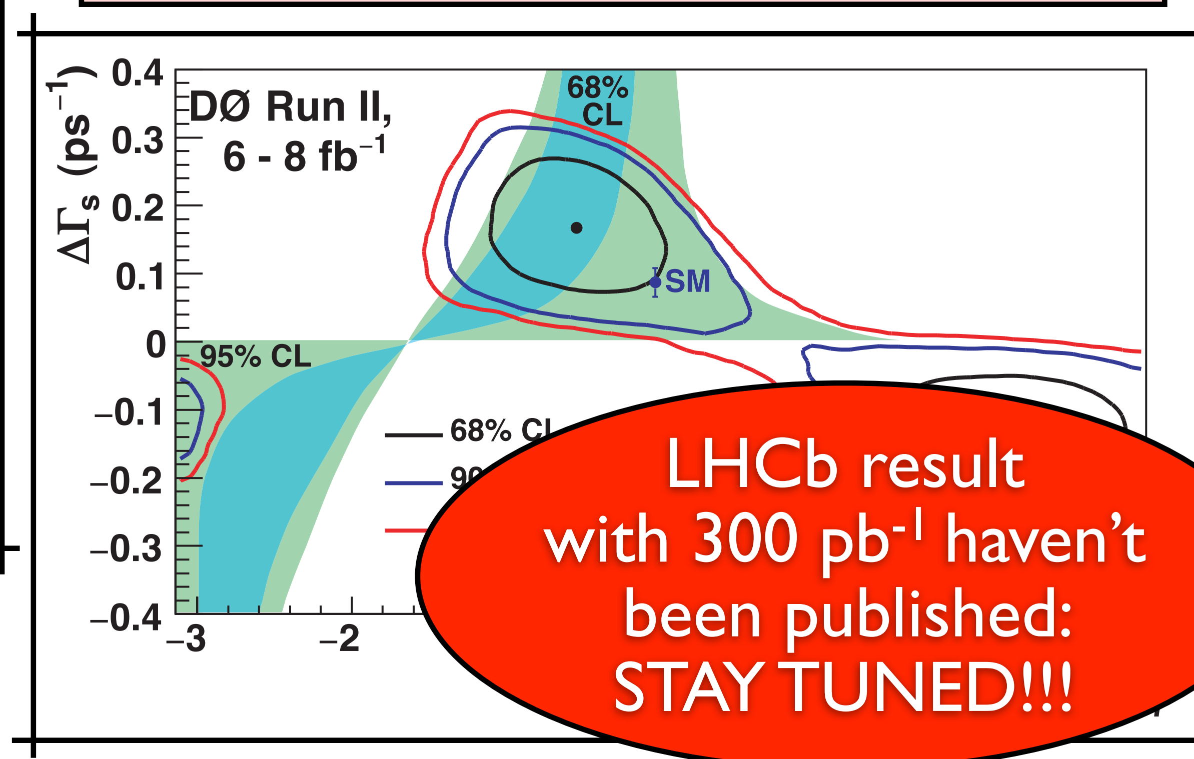
Bs oscillation measurement at LHC/Tevatron II:
dimuon charge asymmetry



New physics?!?!?!

One can compare to the B_s oscillation measurement from $B_s \to J/\psi\Phi$

$$a^s_{sl} = \frac{|\Gamma^{12}_s|}{|M^{12}_s|}\sin\phi_s = \frac{\Delta\Gamma_s}{\Delta M_s}\tan\phi_s'$$



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