B-physics and Linear Collider signatures of light Stop and Sbottom

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Introduction

In supersymmetry (SUSY) ...

scalar-quark sector can have non-trivial flavor structure

what if its not aligned with quark sector?

If new phases are big, 1st and 2nd generation squarks must be heavy

....in order to escape neutron EDM constraints

“Effective-SUSY” with only 3rd generation (right-handed) scalars light

We consider a scenario with sizable $(\mathcal{M}^2_{RL,RR,LL})_{32,23}$

...motivated by $U(2)$ flavor symmetry

[see: S.G & C.-P.Yuan, hep-ph/0410181, Phys.Rev.D71:035012, 2005]

Here, focus on the effective theory

What are the implications to rare B decays?

What are the collider signatures (ILC, LHC)?

SUSY flavor structure

Without worrying about what generates this flavor structure...

...consider an effective SUSY breaking $\mathcal{L}$ (in superCKM basis)

$$\mathcal{L} \supset -(\,\tilde{d}_L^* \quad \tilde{s}_L^* \quad \tilde{b}_L^*\,)\,\mathcal{M}^2_{LL}\begin{pmatrix}\tilde{d}_L\\ \tilde{s}_L\\ \tilde{b}_L\end{pmatrix} - (\,\tilde{d}_R^* \quad \tilde{s}_R^* \quad \tilde{b}_R^*\,)\,\mathcal{M}^2_{RR}\begin{pmatrix}\tilde{d}_R\\ \tilde{s}_R\\ \tilde{b}_R\end{pmatrix} + \\ + (\,\tilde{d}_R^* \quad \tilde{s}_R^* \quad \tilde{b}_R^*\,)\,\mathcal{M}^2_{RL}\begin{pmatrix}\tilde{d}_L\\ \tilde{s}_L\\ \tilde{b}_L\end{pmatrix} + h.c.$$

$$\mathcal{M}^2_{RR} = \begin{pmatrix} m_1^2 & i\epsilon' m_5^2 & 0 \\ -i\epsilon' m_5^2 & m_1^2 + \epsilon^2 m_2^2 & \epsilon m_4^{2*} \\ 0 & \epsilon m_4^2 & m_3^2 \end{pmatrix} \qquad \mathcal{M}^2_{RL} = v_d \begin{pmatrix} O & -A_1\epsilon' & O \\ A_1\epsilon' & A_2\epsilon & A_4\epsilon \\ O & A_4'\epsilon & A_3 \end{pmatrix}$$

SUSY br scale $\equiv m_0^2$ $\qquad$ A-term scale $\equiv A$

Parameters

Define $\delta^{RL,RR,LL}_{32,23} \equiv \frac{(\mathcal{M}^2_{RL,RR,LL})_{32,23}}{m_0^2}$

Natural sizes: $\delta^{RL}_{32,23} = 6.82 \times 10^{-4}\, d^{RL}_{32,23}$ $\delta^{RR}_{32} = 0.02\, d^{RR}_{32}$

SUSY spectrum: (“effective” SUSY)

m_0	1000	$\tan\beta$	5
$m_{\tilde{b}_R,\tilde{t}_R}$	100	μ	$200\, e^{i\,2.2}$
$m_{\tilde{d}_R,\tilde{s}_R}$	1000	M_2	250
$m_{\tilde{q}_L}$	1000	$M_{\tilde{g}}$	300
A	1000	$m_{H^\pm}$	250
d^{LR}_{32}	$2\, e^{i\,3.2}$	d^{RR}_{32}	$1.75\, e^{i\,1.6}$

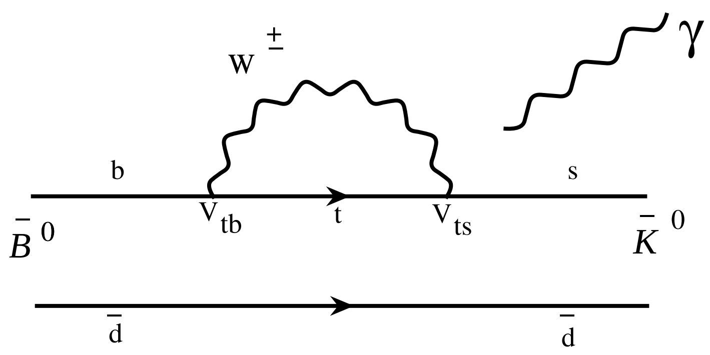
All masses are in GeV

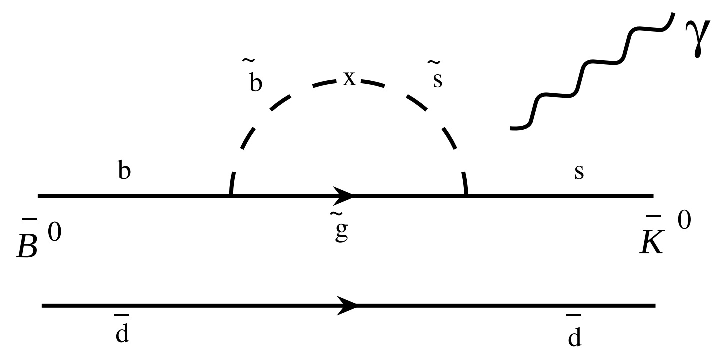
Neutron EDM suppressed in effective SUSY in spite of new $\mathcal{O}(1)$ phases

Flavor Changing Neutral Currents (FCNC)

- Minimal flavor violation (MFV)
  - A-terms aligned w/ SM Yukawas. So FCNC $\propto V_{CKM}$
  - SM, $H^{\pm}$, $\tilde{\chi}^{\pm}$
- Non-minimal flavor violation (NMFV)
  - General A-terms. So FCNC $\propto$ new phases
  - Gluino ($\tilde{g}$)

Example: $\Delta B = 1$ $B_d \to X_s \gamma$



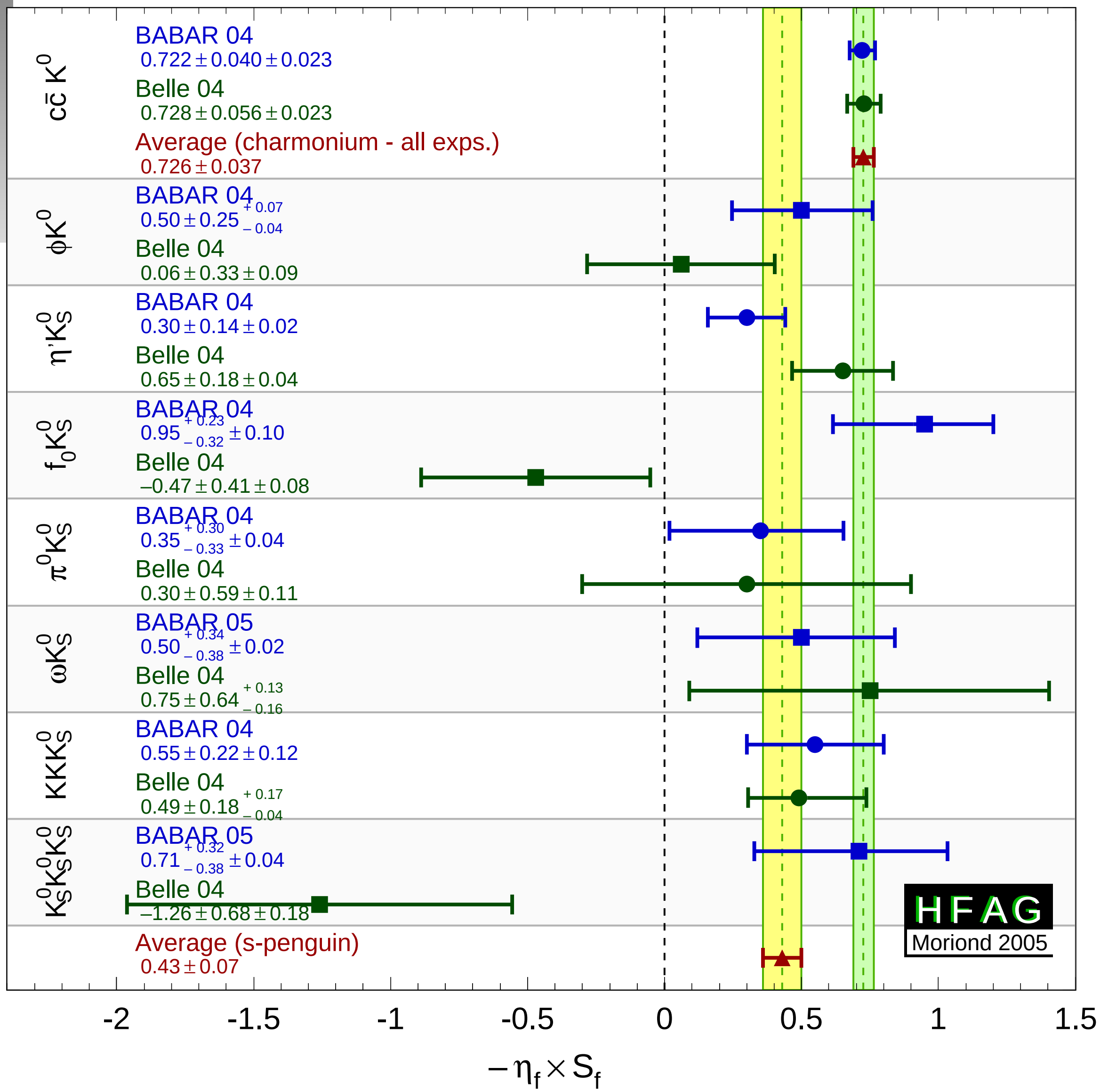


B-meson (and K) FCNC

FCNC Effects in:

- $\Delta S = 2$:
  - $K^0 - \bar{K}^0$ mixing (ϵ_K)
- $\Delta B = 2$:
  - $B_d \bar{B}_d$ mixing (Δm_{B_d}), $B_d \to \psi K_s$ ($\sin 2\beta$)
  - $B_s \bar{B}_s$ mixing (Δm_{B_s})
- $\Delta B = 1$ (B.R. and C.P. Violation):
  - $B_d \to X_s \gamma$, $B_d \to X_s\, g$
  - $B_d \to X_s \ell^+ \ell^-$
  - $B_d \to \phi K_s$

Recent $\sin 2\beta$ ***data***



$\Delta B = 2$: $B_s\bar{B}_s$ mixing

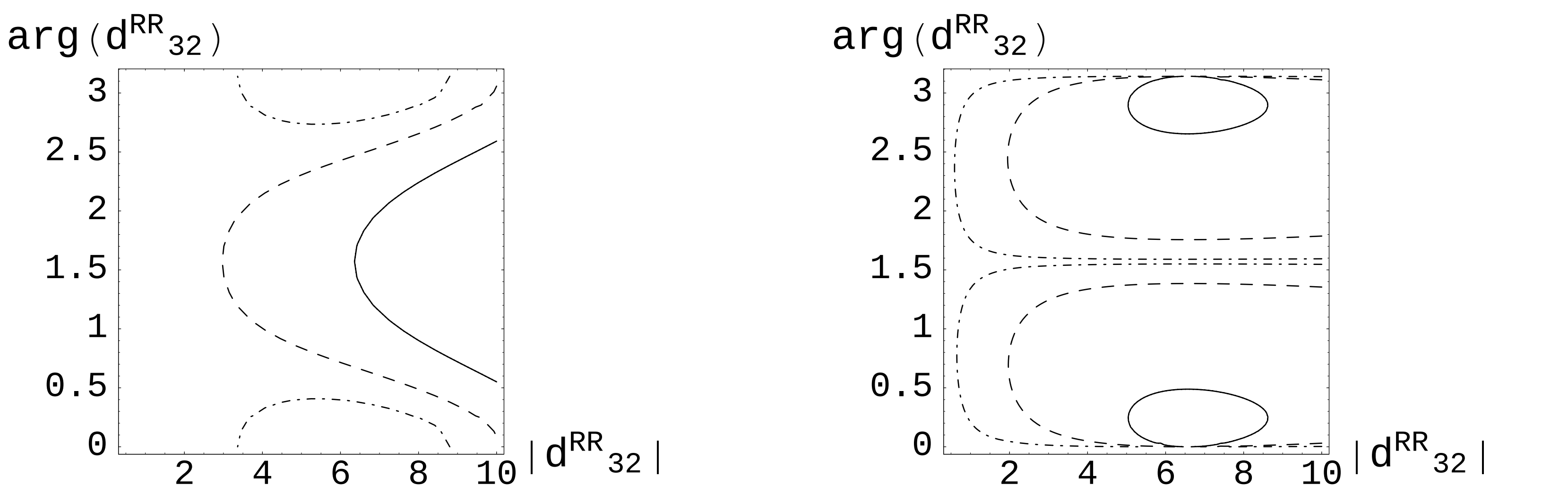
Limit: $\Delta m_{B_s} > 14.4\, ps^{-1}$ @ 95% C.L. [PDG2004]
SM prediction: $14 \text{ ps}^{-1} < \Delta m_{B_s} < 20 \text{ ps}^{-1}$

Dilepton asymmetry: $A_{ll}^{B_q} \equiv \frac{N(B_q B_q) - N(\bar{B}_q \bar{B}_q)}{N(B_q B_q) + N(\bar{B}_q \bar{B}_q)}$

SM prediction: $A_{ll}^{B_s} \approx 10^{-4}$

(15, 25, 40) ps^{-1} contours of Δm_{B_s}

(10^{-4}, 10^{-3} and 10^{-2}) contours of $|A_{ll}^{B_s}|$



$\Delta B = 1$: $B_d \to X_s\gamma$, $B_d \to X_s\, g$

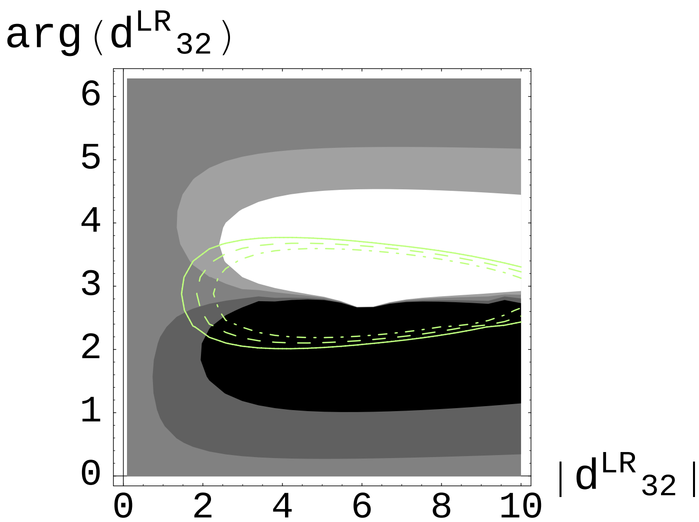
$B.R.(B_d \to X_s\gamma) = (3.52^{+0.3}_{-0.28}) \times 10^{-4}$ [HFAG-ICHEP04]

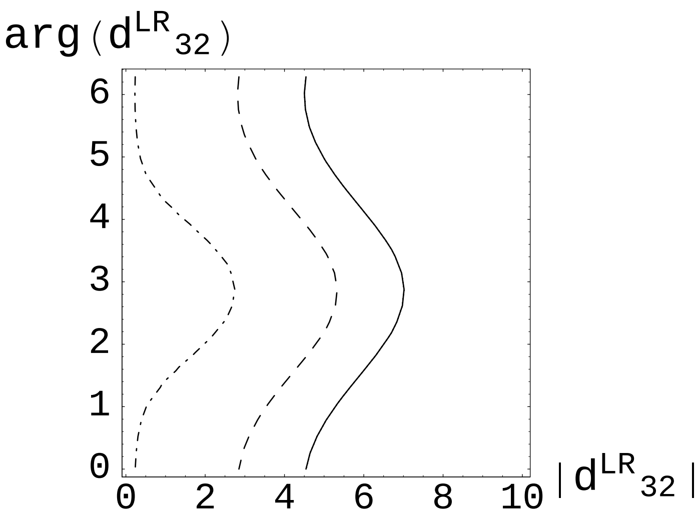
$A_{CP}^{B_d \to X_s\gamma}(\delta) = \frac{\Gamma(\bar{B}_d \to X_s\gamma) - \Gamma(B_d \to X_{\bar{s}}\gamma)}{\Gamma(\bar{B}_d \to X_s\gamma) + \Gamma(B_d \to X_{\bar{s}}\gamma)}$ $\quad -0.07 < A_{CP}^{B_d \to X_s\gamma} < 0.07$ @ 95% C.L.

with $E_\gamma > (1-\delta)E_\gamma^{max}$

$\tilde{g}$ contrib strongly constrains δ_{32}^{RL}

(-7, -3, 3, 7) % cont of $A_{CP}^{B_d \to X_s\gamma}$ $\quad$ $(1,\ 7.5,\ 15$ %) cont of B.R.($B_d \to X_s\, g$)



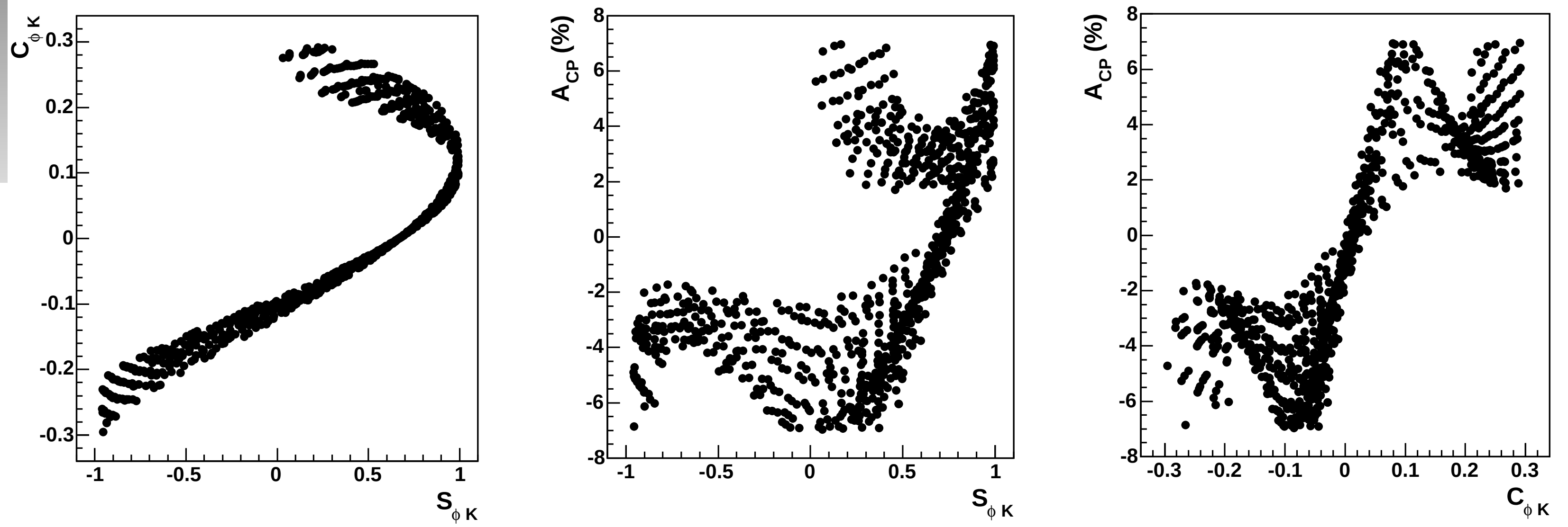


$\Delta B = 1$: $B_d \to \phi K_s$

$$A_{CP}^{B_d \to \phi K_s} \equiv \frac{\Gamma\left(\bar{B}_d(t) \to \phi K_s\right) - \Gamma\left(B_d(t) \to \phi K_s\right)}{\Gamma\left(\bar{B}_d(t) \to \phi K_s\right) + \Gamma\left(B_d(t) \to \phi K_s\right)}$$
$$= -C_{\phi K} \cos\left(\Delta m_{B_d} t\right) + S_{\phi K} \sin\left(\Delta m_{B_d} t\right)$$

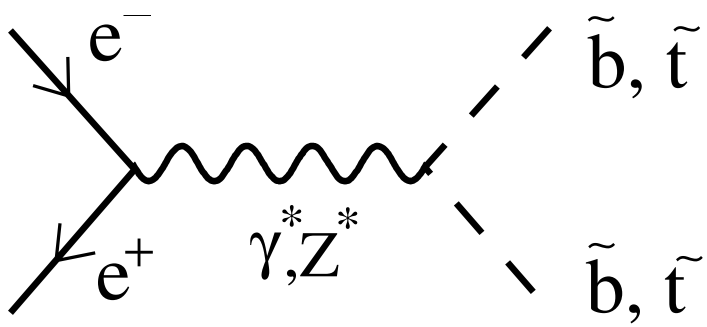
	Experiment [HFAG-ICHEP04]	SM prediction
$B.R.(B_d \to \phi K_s)$	$8.3^{+1.2}_{-1.0} \times 10^{-6}$	$\sim 5 \times 10^{-6}$
$S_{\phi K}$	0.34 ± 0.2	0.725 ± 0.037
$C_{\phi K}$	-0.04 ± 0.17	0

$B_d \to \phi K_s$ **and** $B_d \to X_s\gamma$ **scan**



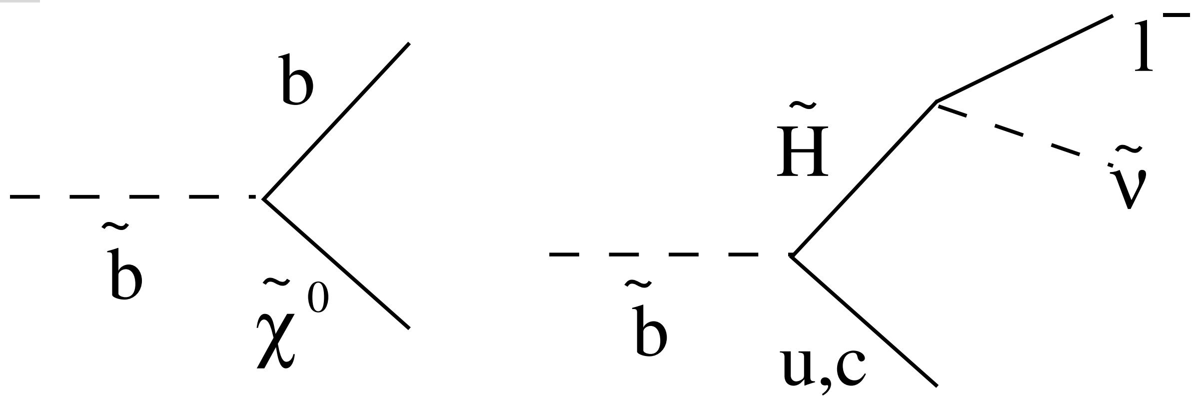
Linear collider signatures

$\tilde{b}$, $\tilde{t}$ production



[See recent paper: Carena et al, hep-ph/0508152]

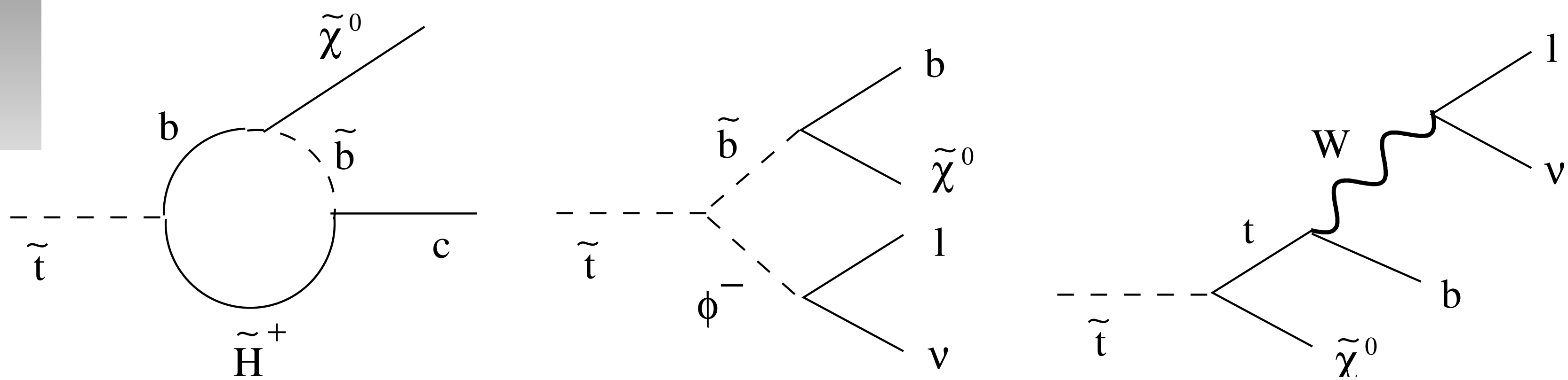
$\tilde{b}_R$ ***decay***



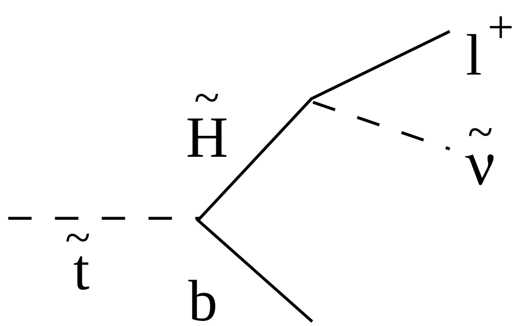
If $\tilde{\chi}^0$ LSP

If $\tilde{\nu}$ is LSP

$\tilde{t}_R$ ***decay***



If $\tilde{\chi}^0$ LSP



If $\tilde{\nu}$ is LSP

Conclusions

Considered Effective-SUSY with sizable $(\mathcal{M}^2_{RL,RR,LL})_{32,23}$

Is consistent with B-meson (and K) FCNC data

...can explain $B_d \to \phi K_s$ “anomaly”

Await more data (improved accuracy) in:

$B_s \bar{B}_s$ mixing, $A_{CP}^{B_d \to X_s \gamma}$, $B_d \to \phi K_s$

Outlined ILC signatures - details to be worked out

LHC signatures - future work

BACKUP SLIDES

U(2) Flavor Symmetry

[Barbieri, Dvali, Hall]

$$\boxed{\begin{matrix} u \\ d \end{matrix}} \leftrightarrow \boxed{\begin{matrix} c \\ s \end{matrix}} \quad \begin{matrix} t \\ b \end{matrix}$$

$a, b = (1, 2)$

U(2) index

$$\mathcal{L} = m_3\, \bar{\psi}_3 \psi_3 + \frac{\lambda_1}{M}\, \phi^a \phi^b \psi_a \psi_b + \frac{\lambda_2}{M}\, \phi^{ab} \psi_a \psi_b + \frac{\lambda_3}{M}\, S^{ab} \psi_a \psi_b$$

ϕ^a, $\phi^{[ab]}$, $S^{\{ab\}}$: $U(2)$ tensor “flavon” fields

U(2) symmetric mass:

$$M^u = m_t \begin{pmatrix} 0 & & \\ & 0 & \\ & & 1 \end{pmatrix} \qquad M^d = m_b \begin{pmatrix} 0 & & \\ & 0 & \\ & & 1 \end{pmatrix}$$

U(2) breaking (gives 1^{st} & 2^{nd} gen mass):

$$\frac{<\phi^2>}{M} = \frac{<S^{22}>}{M} \equiv \epsilon \approx 0.02 \qquad \frac{<\phi^{12}>}{M} \equiv \epsilon' \approx 0.004$$

$$M^u = m_t \begin{pmatrix} 0 & -\epsilon' & 0 \\ \epsilon' & \epsilon & \epsilon \\ 0 & \epsilon & 1 \end{pmatrix} \qquad M^d = m_b \begin{pmatrix} 0 & -\epsilon' & 0 \\ \epsilon' & \epsilon & \epsilon \\ 0 & \epsilon & 1 \end{pmatrix}$$

(in the Gauge Basis: $W^{\pm}$ diagonal)

Gauge basis $\rightarrow$ Mass Basis implies CKM matrix

SUSY U(2)

SUSY and U(2) dictate structure of the theory

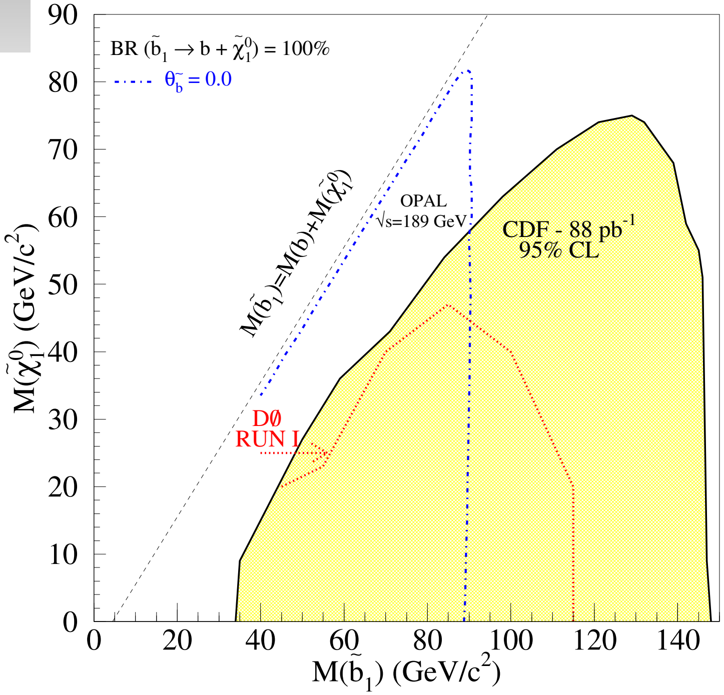
SUSY preserving Superpotential:

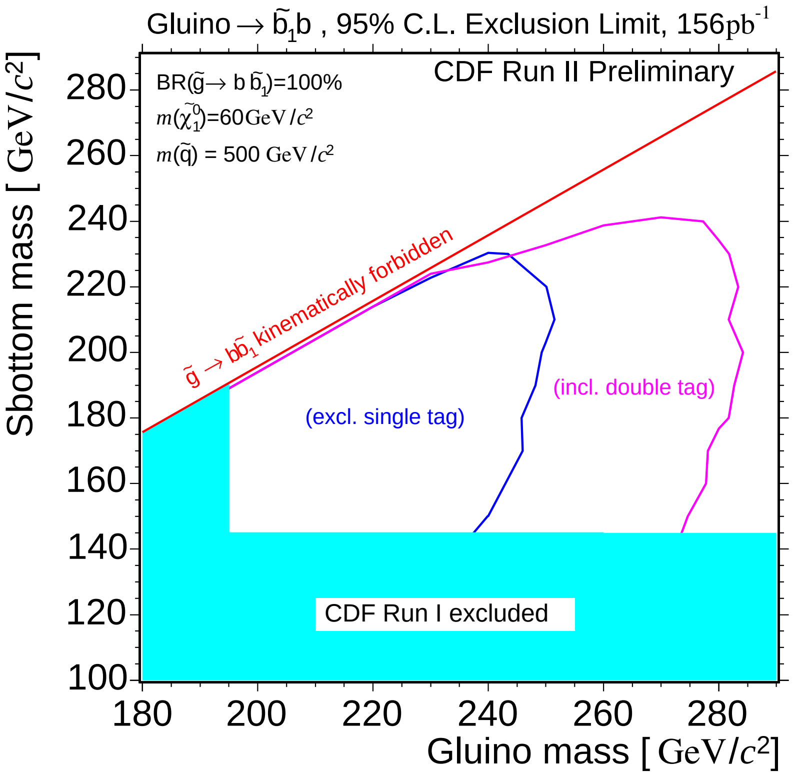
$$\mathcal{W} = \psi H \psi + \frac{\phi^a}{M} \psi H \psi_a + \frac{\phi^{ab}}{M} \psi_a H \psi_b + \frac{\phi^a \phi^b}{M^2} \psi_a H \psi_b + \frac{S^{ab}}{M} \psi_a H \psi_b + \mu H_u H_d$$

$$\left[\psi_i H \psi_j \equiv Q_i U_j^c H_u + U_i^c Q_j H_u - Q_i D_j^c H_d - D_i^c Q_j H_d\right]$$

Tevatron bounds

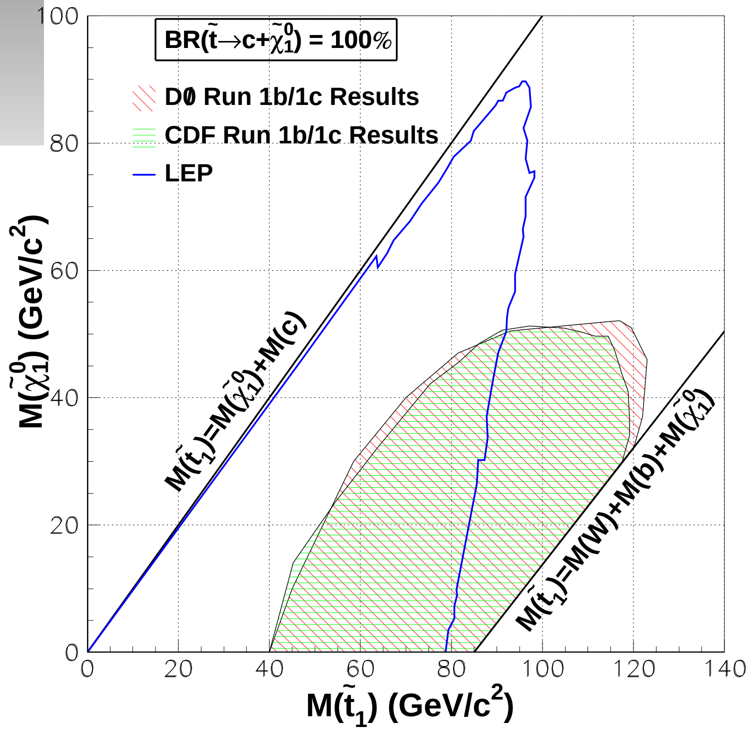
Source: [D. Bortoletto, C. Rott]
[hep-ex/9910049, 0410007]





Tevatron bounds

[hep-ex/0404028]



Operator product expansion (OPE)

Example: $\Delta B = 1$ effective Hamiltonian

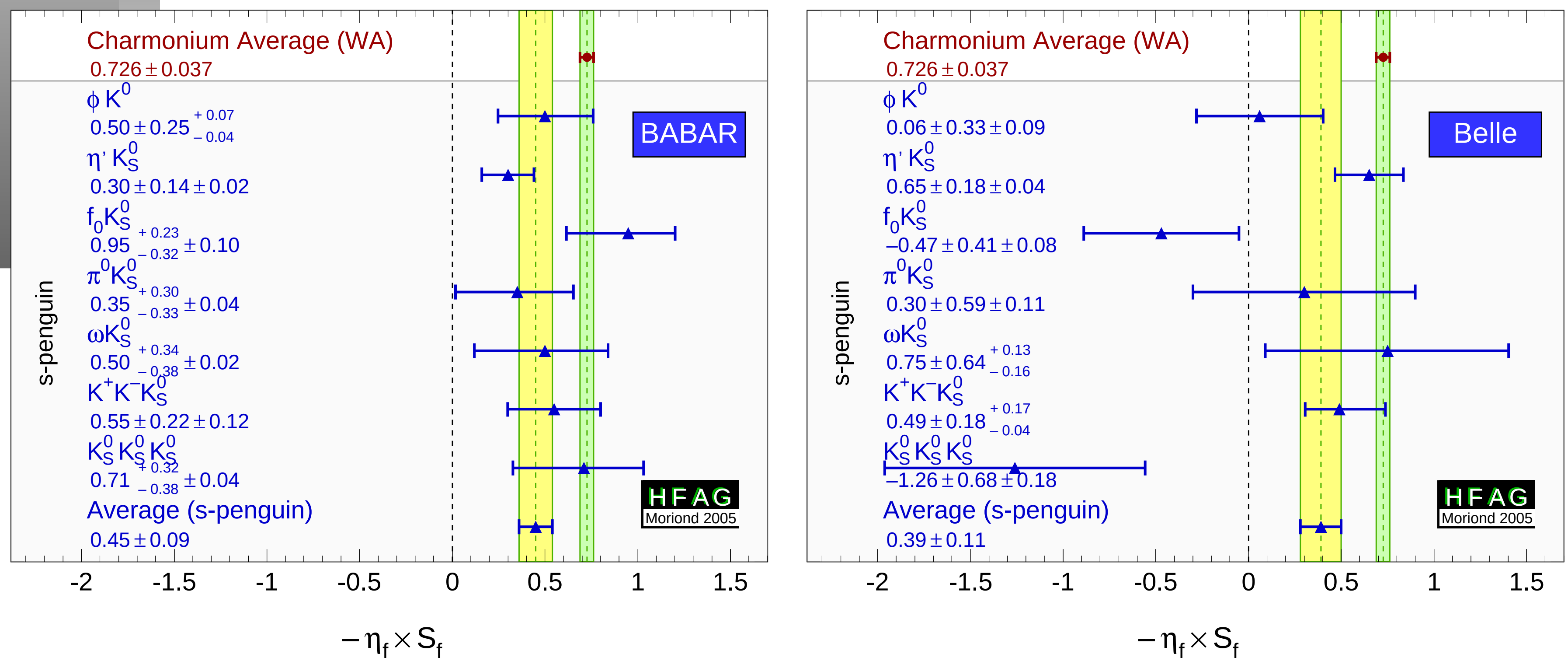
$$\begin{aligned}
\mathcal{H}^{eff}_{\Delta B=1} &= -\frac{G_F}{\sqrt{2}} V_{ts} V^*_{tb} \left(\sum_{i=1\ldots 6,9,10} C_i(\mu) O_i(\mu) + C_{7\gamma}(\mu) O_{7\gamma}(\mu) + C_{8g}(\mu) O_{8g}(\mu) \right) \\
O_2 &= (\bar{s}c)_{V-A} (\bar{c}b)_{V-A} \\
O_{7\gamma} &= \frac{e m_b}{8\pi^2}\, \bar{s}_L \sigma^{\mu\nu} b_R F_{\mu\nu} \\
O_{8g} &= \frac{g_s m_b}{8\pi^2}\, \bar{s}_L \sigma^{\mu\nu} T^a b_R G^a_{\mu\nu}
\end{aligned}$$

Renormalization group evolution from high scale to m_b

New physics contribution to Wilson coefficients:

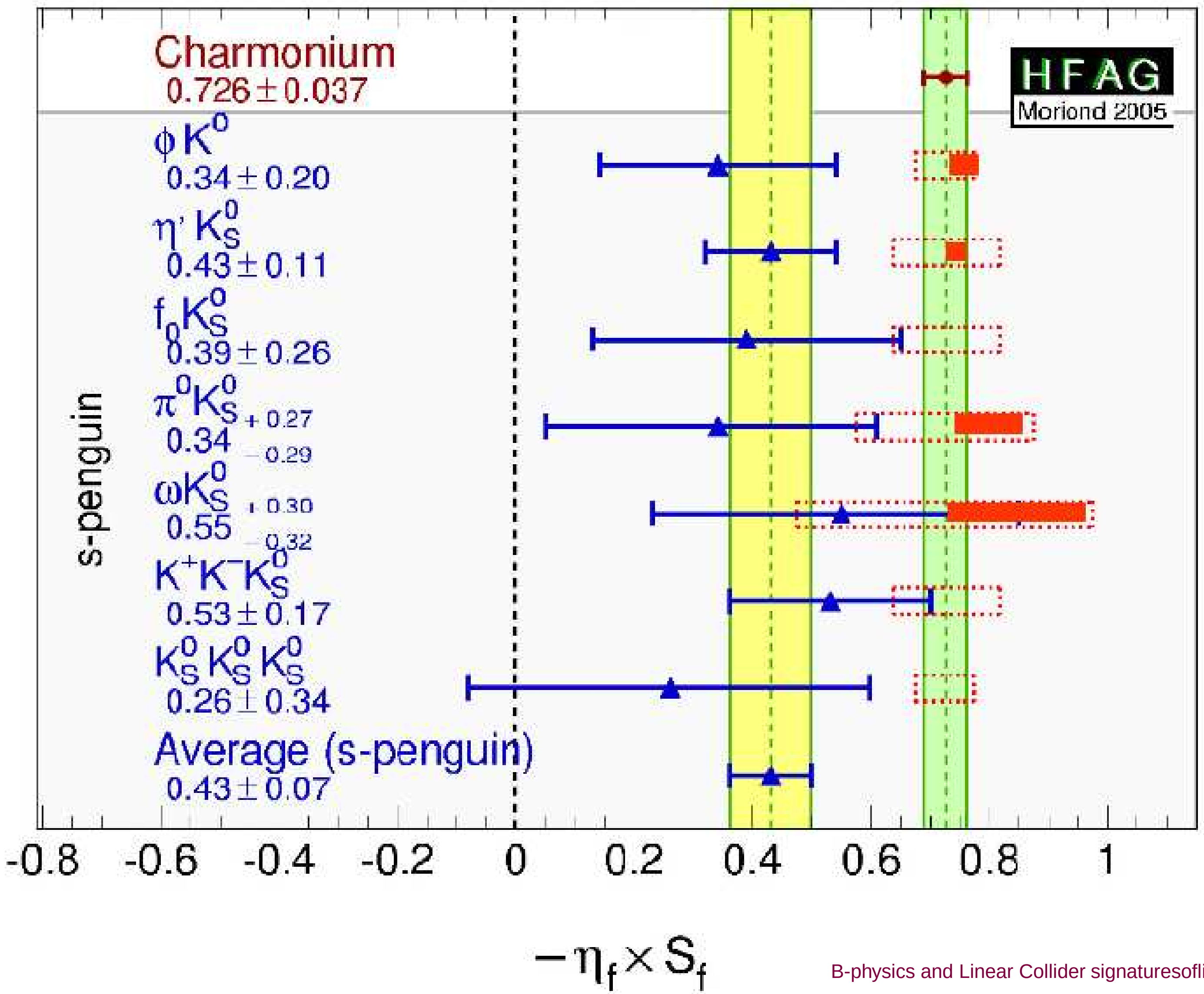
$$\begin{aligned}
C_2 &= C_2^{SM} \\
C_{7\gamma} &= C_{7\gamma}^{SM} + 0.67 C_{7\gamma}^{new}(M_W) + 0.09 C_{8g}^{new}(M_W) \\
C_{8g} &= C_{8g}^{SM} + 0.70 C_{8g}^{new}(M_W)
\end{aligned}$$

Recent $\sin 2\beta$ *data*



Additional corrections?

Beneke, Neubert - 2005



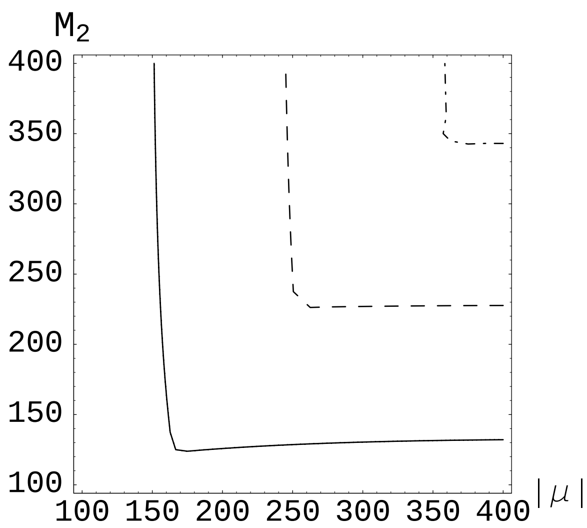
$\Delta S = 2$: *Kaon mixing*

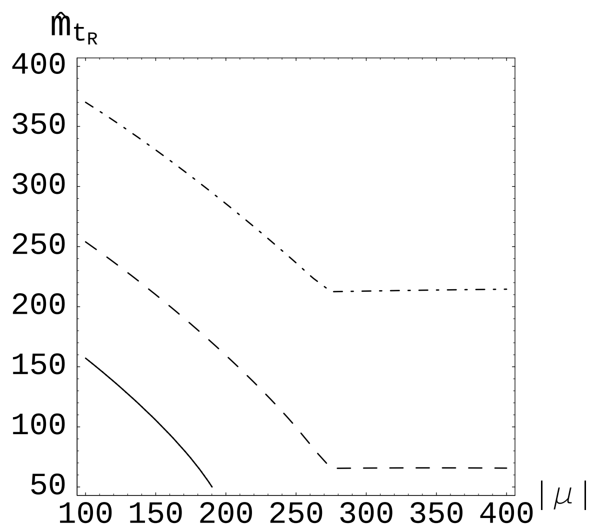
CP violation due to mixing: $|\epsilon_K| = (2.284 \pm 0.014) \times 10^{-3}$ [PDG2004]

- Constrains MFV contributions (SM, $H^\pm$, $\tilde{\chi}^\pm$)
- NMFV gluino contributions not constrained

About 25 % uncertainty in calculating hadronic matrix element (in Bag factor B_K)

(1.05, 1.1, 1.2) contours of $\frac{\epsilon_K^{MFV}}{\epsilon_K^{SM}}$:





ϵ'_K/ϵ_K has large hadronic uncertainties

$\Delta B = 2$: $B_d \bar{B}_d$ mixing

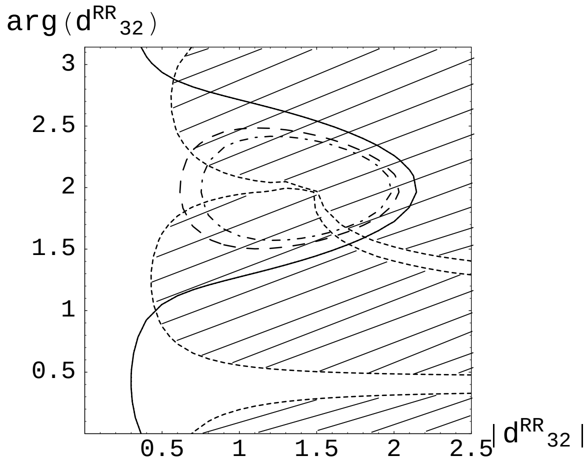
$\Delta m_d = 0.502 \pm 0.007\ \mathrm{ps}^{-1}$
$a_{\psi K_s} = 0.725 \pm 0.037$ ($\sin 2\beta$ in SM) [PDG2004, HFAG-ICHEP04]

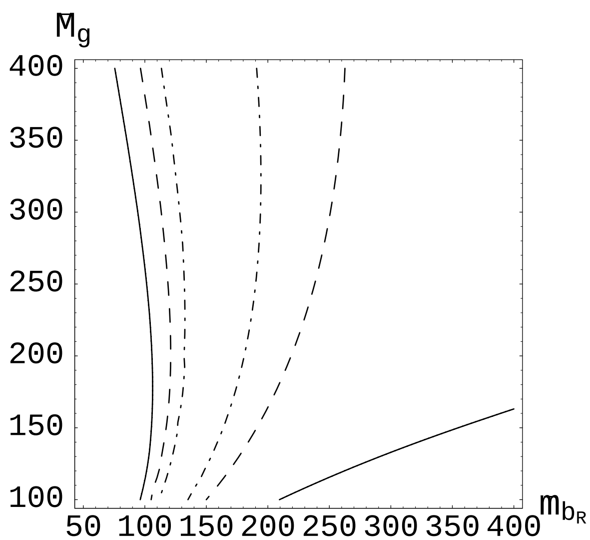
MFV constraints similar to Kaon case

For large $\tilde{d}_R \tilde{s}_R$ (squark) mixing, NMFV ($\tilde{g}$) contrib strongly constrains δ_{32}^{RR}

About 15% uncertainty in decay constant f_B

(0.9, 1.0, 1.25) contours of $\frac{\Delta m_d}{\Delta m_d^{SM}}$





Hatched area excluded by $a_{\psi K_s}$

$\Delta B = 2$: $B_s\bar{B}_s$ *mixing*

Limit: $\Delta m_{B_s} > 14.4\, ps^{-1}$ @ 95% C.L. [PDG2004]

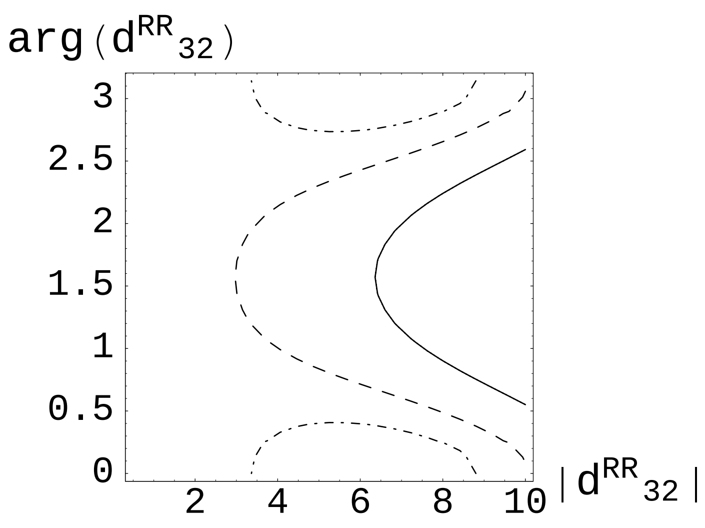
SM prediction: $14\ \mathrm{ps}^{-1} < \Delta m_{B_s} < 20\ \mathrm{ps}^{-1}$

Dilepton asymmetry: $A_{ll}^{B_q} \equiv \frac{N(B_qB_q)-N(\bar{B}_q\bar{B}_q)}{N(B_qB_q)+N(\bar{B}_q\bar{B}_q)}$ SM prediction: $A_{ll}^{B_s} \approx 10^{-4}$

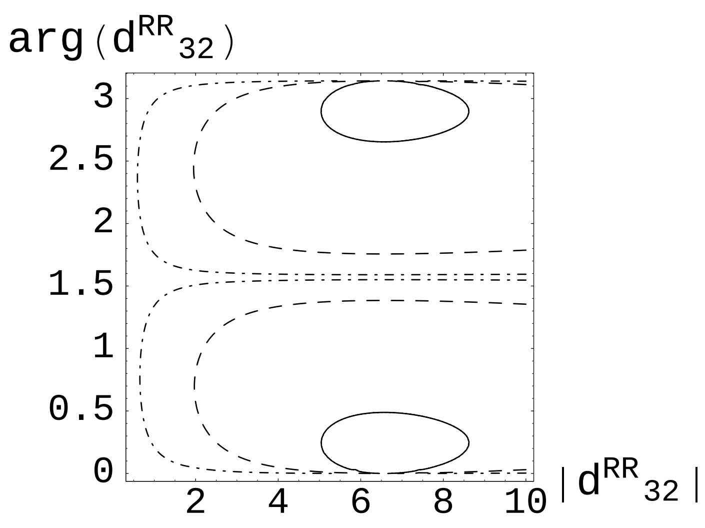
For large $\tilde{d}_R\tilde{s}_R$ mixing (with $B_d\bar{B}_d$ mixing constraints): $\Delta m_{B_s} \approx 22\, ps^{-1}$

For small $\tilde{d}_R\tilde{s}_R$ mixing (no $B_d\bar{B}_d$ mixing constraints):

(15, 25, 40) ps^{-1} contours of Δm_{B_s}



(10^{-4}, 10^{-3} and 10^{-2}) contours of $|A_{ll}^{B_s}|$

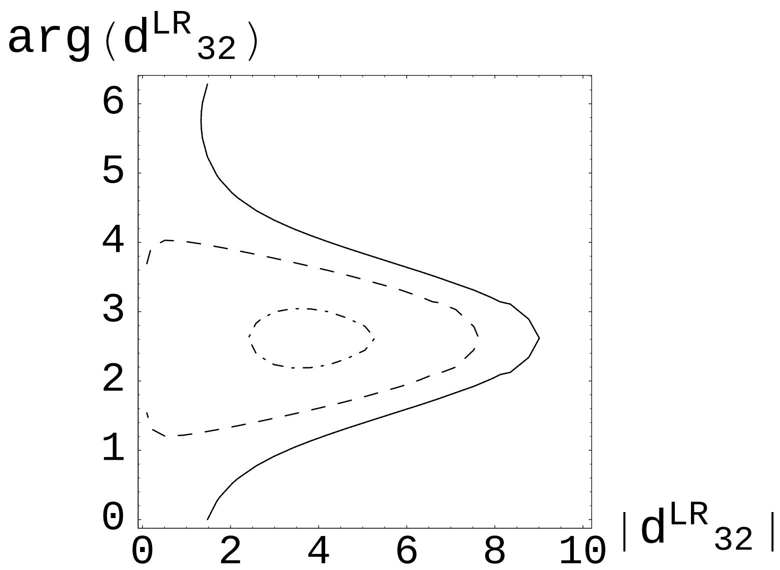


$\Delta B = 1$: $B_d \to X_s \ell^+ \ell^-$

	Experiment [HFAG-ICHEP04]	SM prediction
$B.R.(B_d \to X_s \ell^+ \ell^-)$	$4.46^{+0.98}_{-0.96} \times 10^{-6}$	5.3×10^{-6}

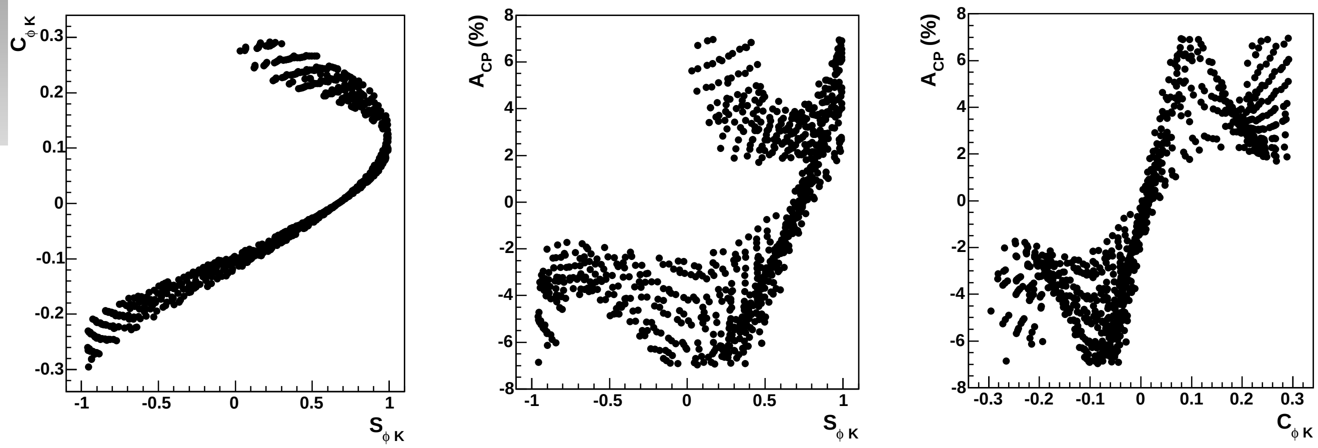
$(p_{\ell^+} + p_{\ell^-})^2 > (0.2\ \mathrm{GeV})^2$

(5.25, 6.25, 7.25)$\times 10^{-6}$ contours of $B_d \to X_s \ell^+ \ell^-$



$B_d \to \phi K_s$ **and** $B_d \to X_s\gamma$ **scan**

For small $\tilde{d}_R \tilde{s}_R$ mixing (no new phase in $B_d \bar{B}_d$ mixing):



For large $\tilde{d}_R \tilde{s}_R$ mixing (with new phase in $B_d \bar{B}_d$ mixing):