Probing TeV-Scale Physics with Heavy Flavors

Ulrich Uwer

Heidelberg University

Hamburg, November 2009

Disclaimer: Subject of this talk is B-Physics at LHC (b).

Flavor in the Standard Model

$$\mathcal{L}_{SM} = \mathcal{L}_{gauge}(A_a, \psi_i) + \underline{\mathcal{L}_{Higgs}(\phi, A_a, \psi_i)}$$

$$\mathcal{L}_Y = \underbrace{\overline{Q}_L Y_D d_R \phi + \overline{Q}_L Y_U u_R \phi_C}_{} + \overline{L}_L Y_E e_R \phi + h.c.$$

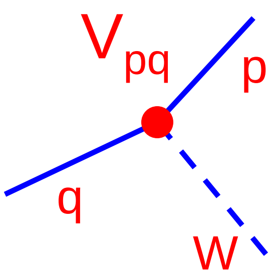
$\Downarrow$ EWSB

Quarks

$$\overline{Q}_L M_D d_R + \overline{Q}_L M_U u_R \quad M_{U,D} = Y_{U,D} \frac{\upsilon}{\sqrt{2}}$$

Diagonalization of mass matrices:

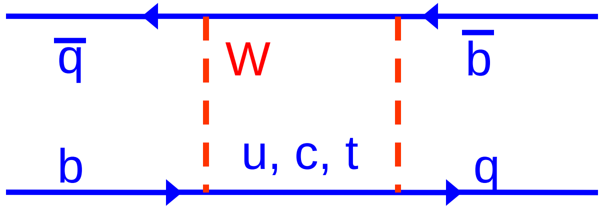
6 Dirac masses, quark mixing in CC described by V_{CKM}



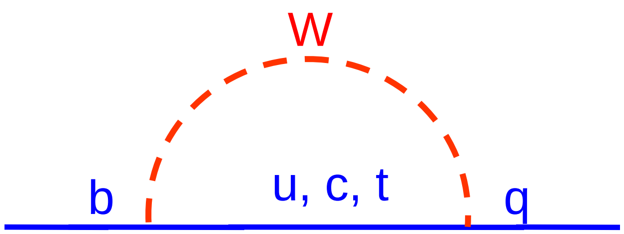
- In SM Yukawa interaction only source of Flavor Violation
- Masses and the mixing angles cannot be understood within SM

FCNC Processes in the SM

$\Delta F = 2$



$\Delta F = 1$



$$\mathcal{A}_{SM}(B_q^0 \leftrightarrow \bar{B}_q^0) \sim (V_{tb}V_{tq}^*)^2 \cdot \frac{g^2}{16\pi^2}\frac{m_t^2}{m_W^2}$$

$$\mathcal{A}_{SM}(b \rightarrow q) = V_{tb}V_{tq}^* \cdot \frac{g^2}{16\pi^2}\frac{m_t^2}{m_W^2}$$

FCNC in SM suppressed:

- Only in loop diagrams
- CKM couplings small
- GIM suppression (in B decays inactive)

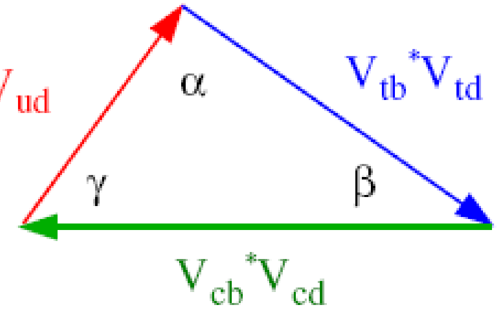
} Result of SM particle content and hierarchical Yukawa couplings

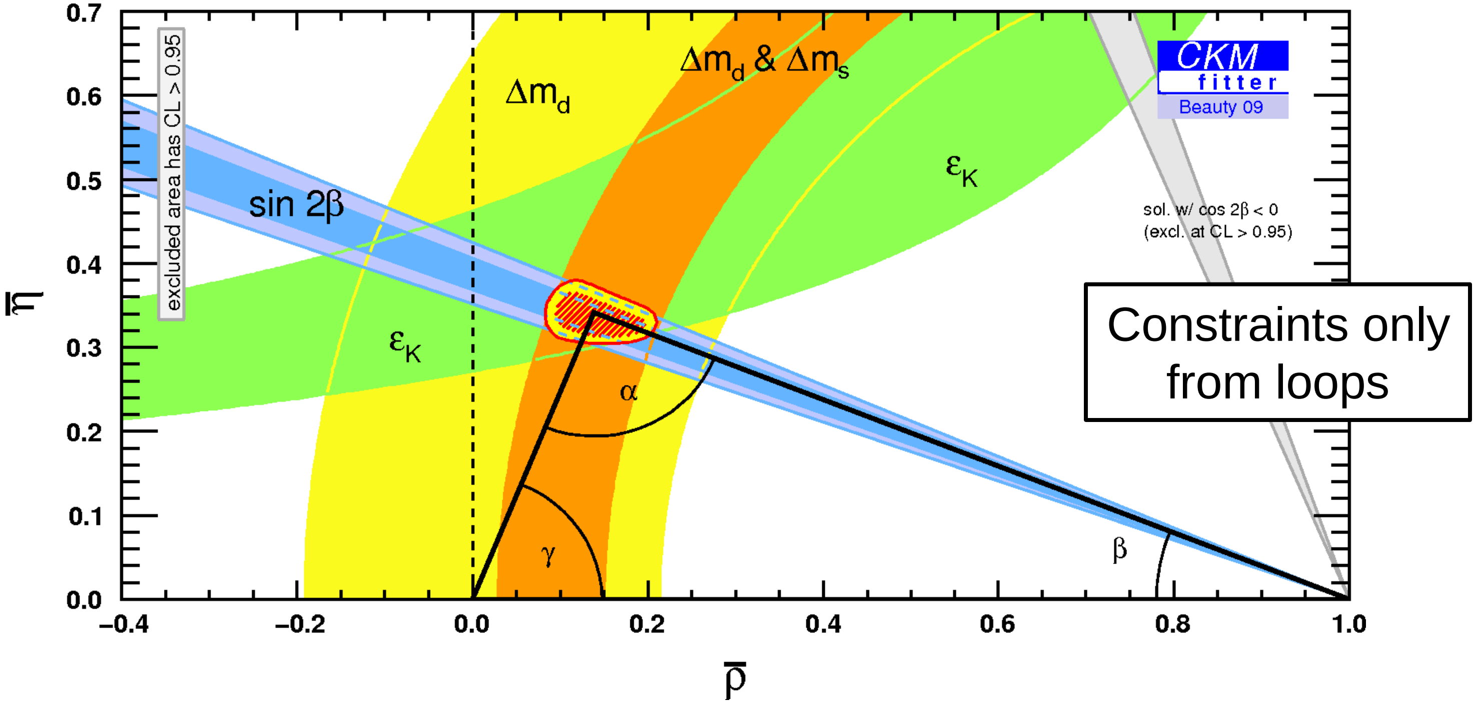
$\rightarrow$ Suppression of FCNC processes not necessary present in generic extensions of SM.

CKM paradigm works well

$$V_{CKM}V_{CKM}^{+} = I$$

$$V_{ub}^{*}V_{ud} + V_{cb}^{*}V_{cd} + V_{tb}^{*}V_{td} = 0$$





Within uncertainties, Flavor Changing data well described by SM.
New Physics effects only appear corrections to leading SM terms.

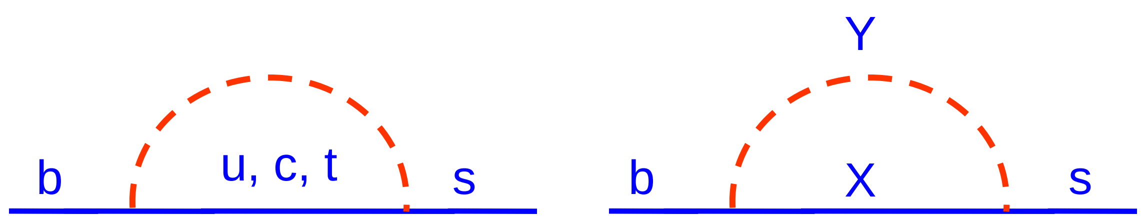
Flavor Violation beyond the SM

New Physics*) at $\Lambda = O(\Lambda_{EW})$ in low-energy effective theory

*) electroweak

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{d>4} \sum_{n=1}^{N_d} \frac{c_n^{(d)}}{\Lambda^{d-4}} O_n^{(d)}$$

Effect on flavor changing amplitudes:



$$\mathcal{A}_{BSM}(b \to q + X) = \mathcal{A}_0 \left(\frac{c_{SM}}{m_W^2} + \frac{c_{NP}}{\Lambda^2} \right)$$

"CKM" factors
Loop-factors

In most general case NP with generic flavor structure!

Flavor Problem

No indication of large $O(1)$ New Physics contribution to FCNC processes.

$\Rightarrow$ Puts severe constraints on New Physics.

Example: $\Delta F=2$ mixing measurements

$$\mathcal{A}(B_d \leftrightarrow \bar{B}_d) \sim \frac{(V_{tb}^{*}V_{td})^2}{16\,\pi^2\, m_W^2} + c_{NP}\,\frac{1}{\Lambda^2}$$

G. Isidori (2009)

c_{NP}:

- ~ 1 $\xrightarrow{\text{tree + generic flavor}}$ $\Lambda > 2\times10^4$ TeV [K]
- $\sim 1/(16\,\pi^2)$ $\xrightarrow{\text{loop + generic flavor}}$ $\Lambda > 2\times10^3$ TeV [K]
- $\sim (V_{tb}^{*}V_{td})^2$ $\xrightarrow{\text{tree + MFV}}$ $\Lambda > 5$ TeV [K&B]
- $\sim (V_{tb}^{*}V_{td})^2 / (16\,\pi 2)$ $\xrightarrow{\text{loop+ MFV}}$ $\Lambda > 0.5$ TeV [K&B]

Not too far from EW scale

Minimal Flavor Violation

Flavor Physics

New Physics at TeV-scale must have*) non-generic flavor structure.

*) modulo some conspiracy

Minimal flavor violation:

Standard Model Yukawa couplings are the only non-trivial flavor-breaking terms also beyond the Standard Model.

Minimal flavor violation realized “by construction” in MSSM SUSY models (CMSSM, NUHM) often used as reference point.

MFV should not be taken as granted!

Flavor Structure of New Physics

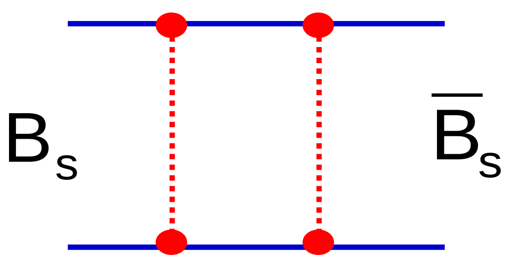
Limit discussion to B decays important at LHC

Test MFV Hypothesis - Flavor breaking terms beside SM Yukawas ?

Study flavor structure of new particles if found by ATLAS/CMS.

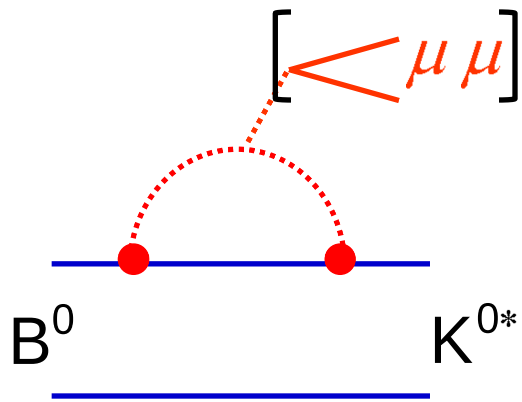
Expect sizeable deviation even in MVF models

B_s mixing phase ϕ_s



A_{CP} ($B_s \to J/\psi\ \phi$)

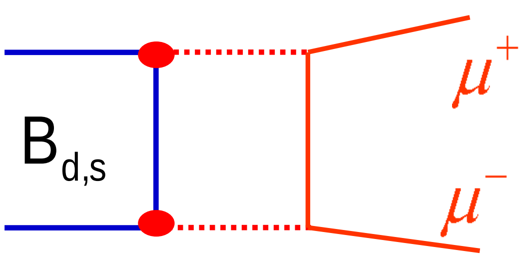
$b \to s\ \gamma$ penguins



$B_d \to K^*\gamma$

$B_d \to K^*\ \mu\mu$

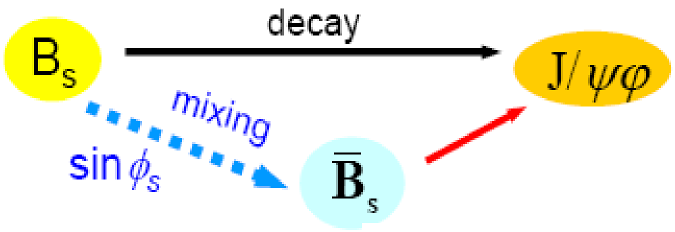
Very rare FCNC proc.



$B_{d,s} \to \mu\mu$

B_s Mixing Phase ϕ_s

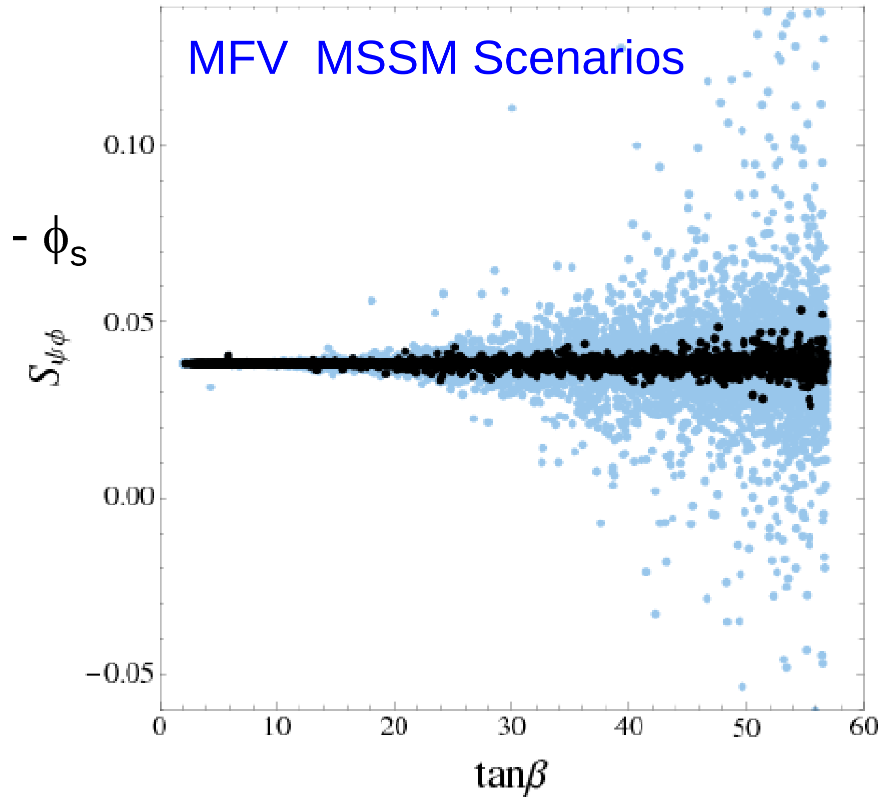
ϕ_s from $A_{CP}(B_s \to J/\psi\phi)$



$$\phi_s^{SM} = -2\beta_s \approx -0.04$$

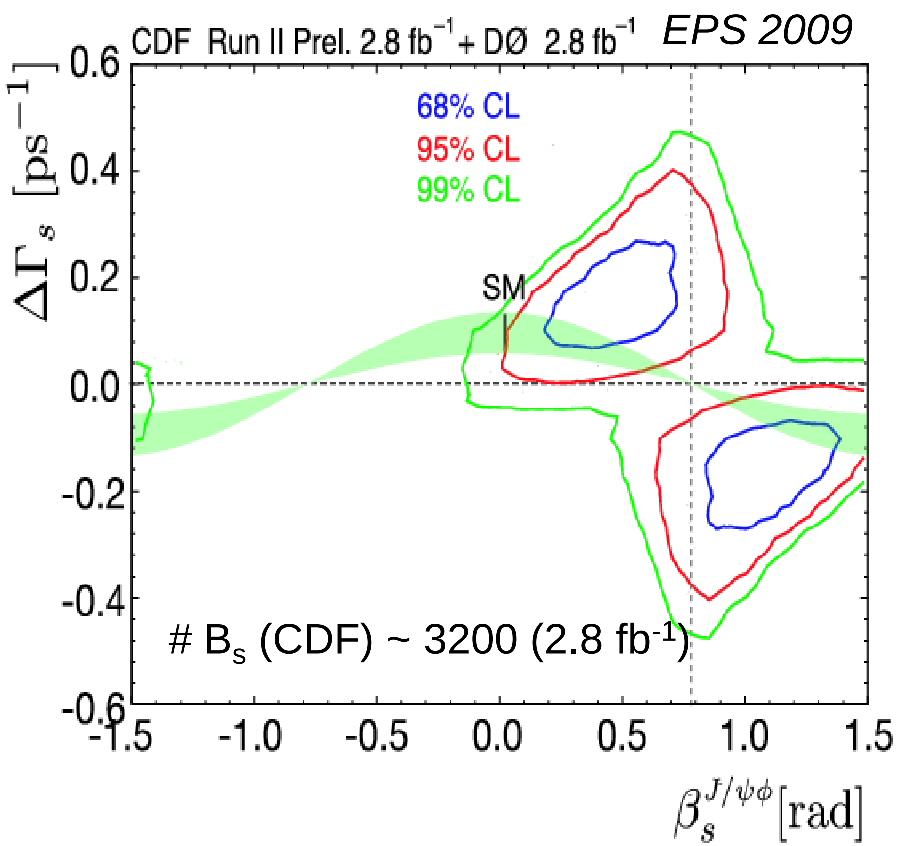
$$A_{CP}(t) = \frac{\Gamma(\overline{B_S^0}(t) \to f) - \Gamma(B_S^0(t) \to f)}{\Gamma(\overline{B_S^0}(t) \to f) + \Gamma(B_S^0(t) \to f)}$$

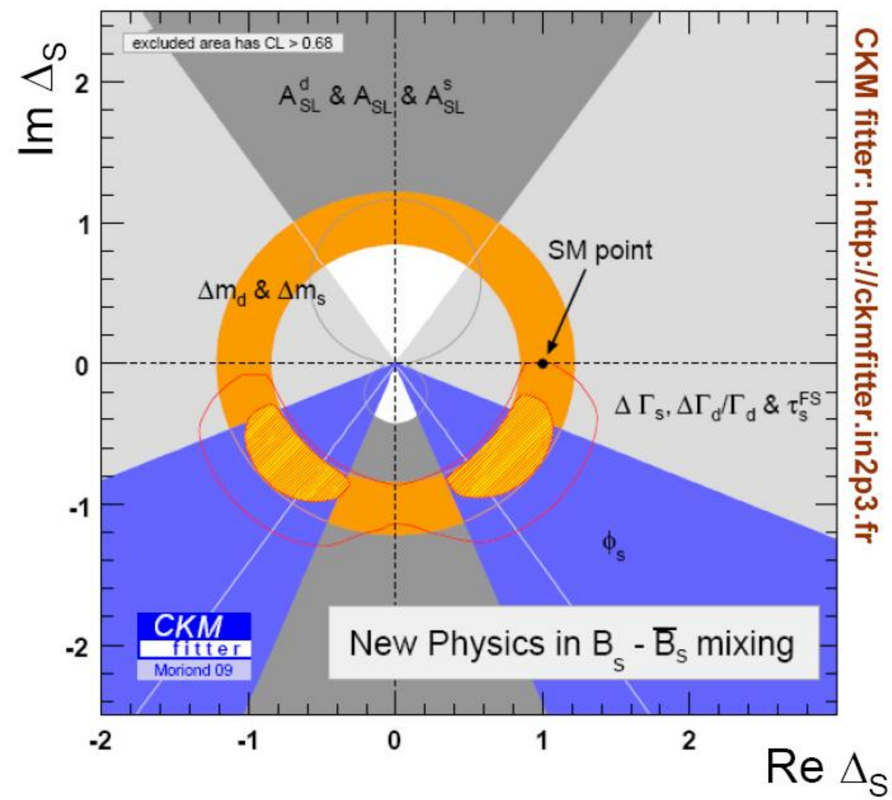
Buras et al. (2009)

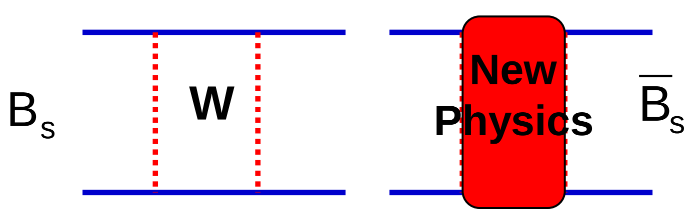


Large (non-zero) CP asymmetry in $B_s \to J/\psi\phi$ rules out SM and MFV MSSM

Experimental Status







$$\mathcal{A}_{SM+NP} = \mathcal{A}_{SM} \times (\mathrm{Re}(\Delta_q) + i\,\mathrm{Im}(\Delta_q))$$

A.Lenz, U.Nierste

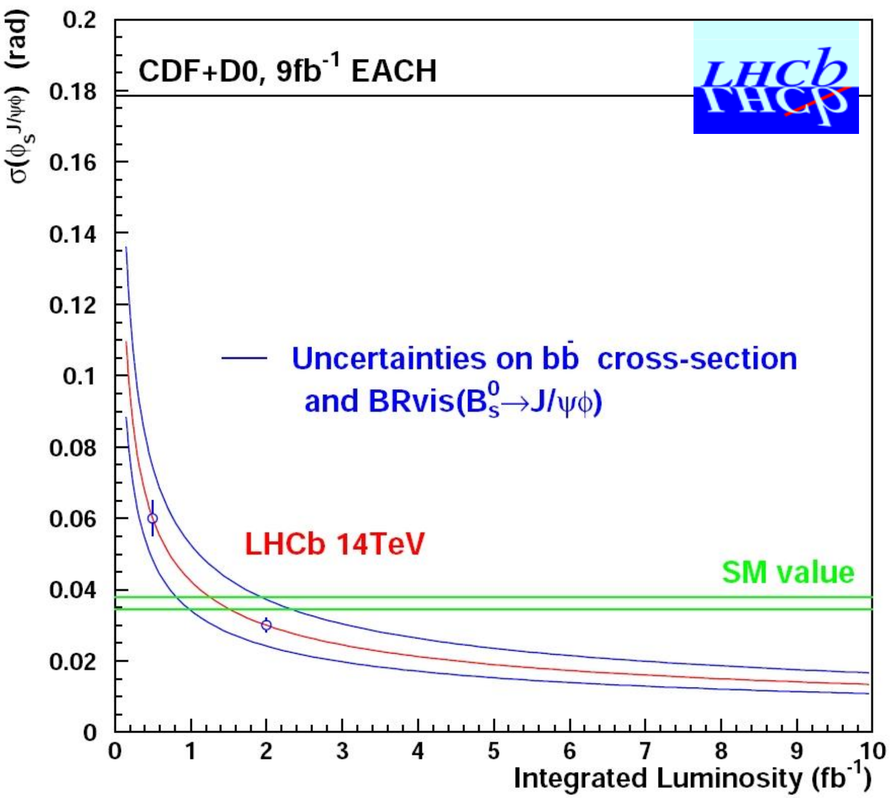
There is room for NP in B_s mixing.

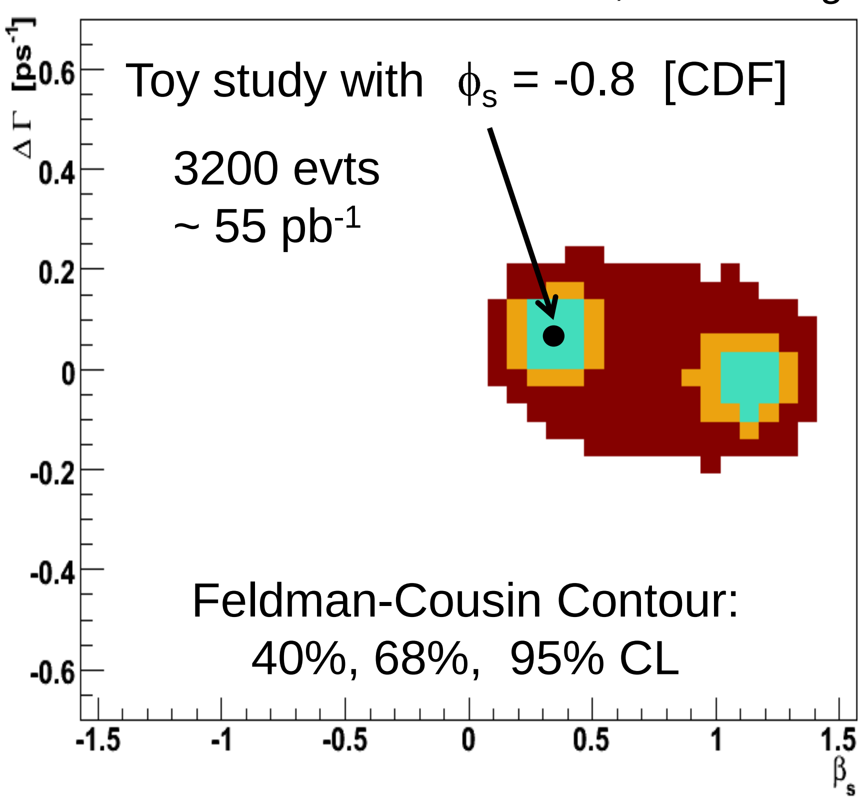
LHCb Prospects for ϕ_s

#Evts (2fb^{-1})	B/S	ε_{tag}(%)
117k	2.0	6.2

$$\phi_s^{SM} = -2\beta_s \approx -0.04$$

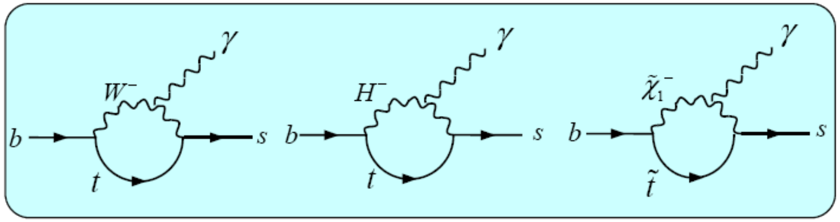
A. Bien, Heidelberg





$B \to X_s \gamma$

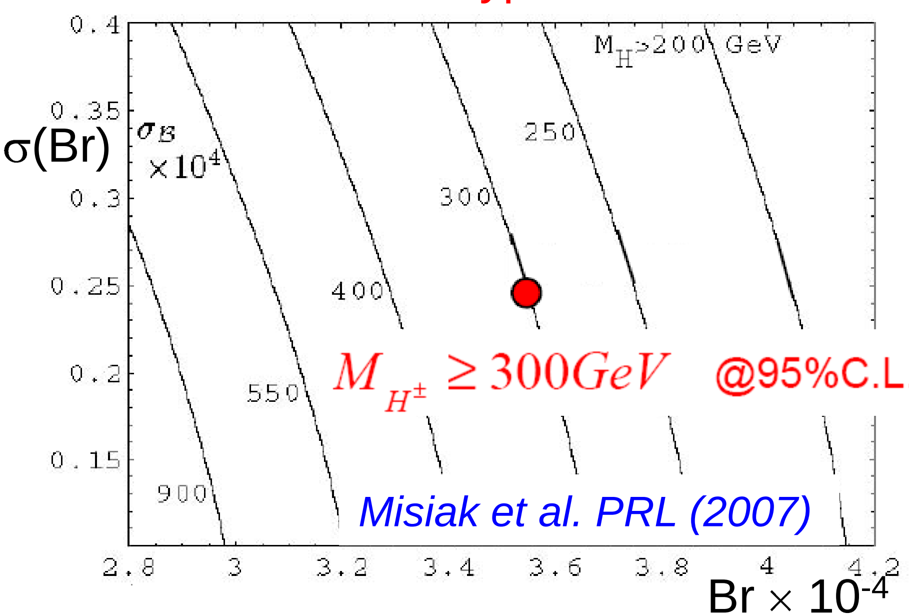
Challenge for any NP model



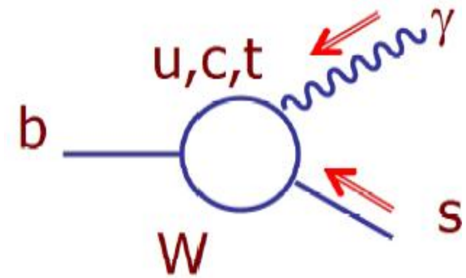
$$Br(B \to X_s \gamma) = (3.57 \pm 0.24) \times 10^{-4}$$

$$Br_{SM}(B \to X_s \gamma) = (3.15 \pm 0.23) \times 10^{-4}$$

Constraints on Type II 2HDM



Probe photon polarization:



$B_s \to \phi\gamma$ events: LHCb: 12k (2fb^{-1})

From time dependent decay rates:

$$\tan\psi \equiv \left| \frac{A(\bar{B} \to f^{CP}\gamma_R)}{A(\bar{B} \to f^{CP}\gamma_L)} \right|$$

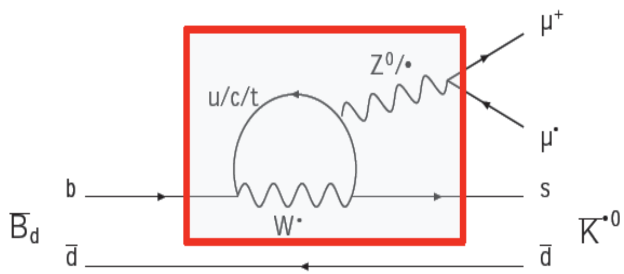
LHCb: $\sigma(\psi) \approx 0.11$

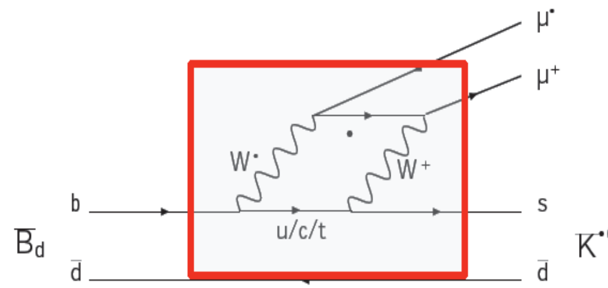
= amount of wrong pol. photons

➡ Test models w/ RH currents

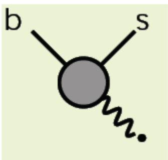
$B^0 \rightarrow K^*\mu\mu$

Standard Model

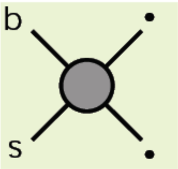




Effective Theory



O_7



O_9 O_{10}

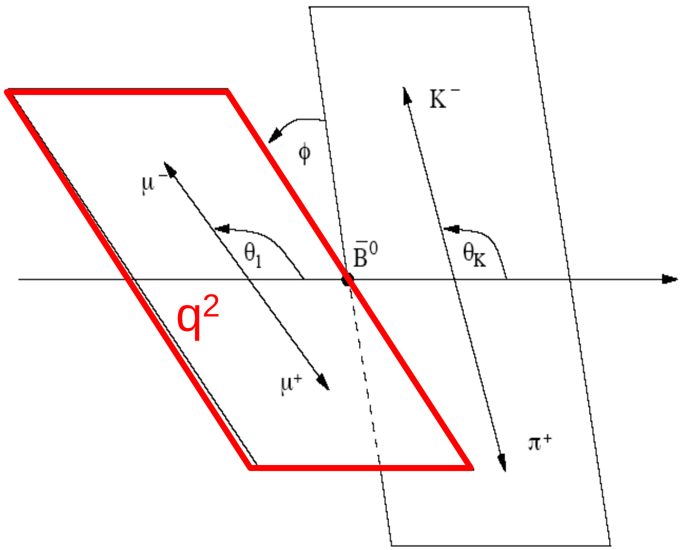
Operator Product Expansion

$$\mathcal{H}_{\text{eff}} = -4\frac{G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum C_i(\mu)O_i(\mu)$$

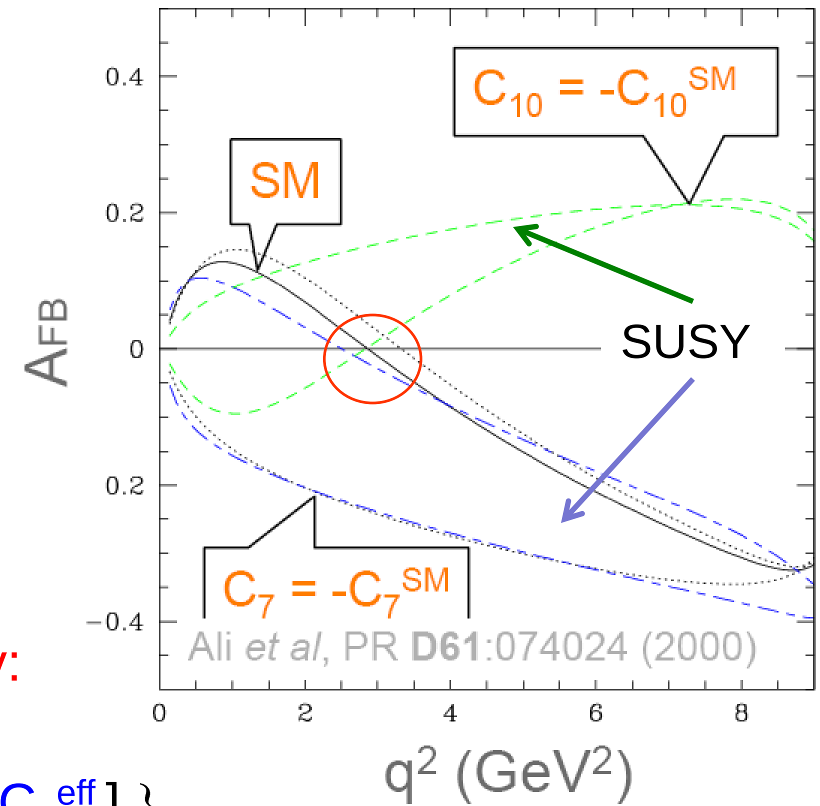
Corresponding Wilson coefficients C_i describe short-range physics.

New Physics in Wilson coefficients $C_i = C_i^{SM} + C_i^{NP}$ or new operators.

Sensitivity of Angular Observables



Observables: θ_l, θ_K, ϕ, $m^2_{\mu\mu}$



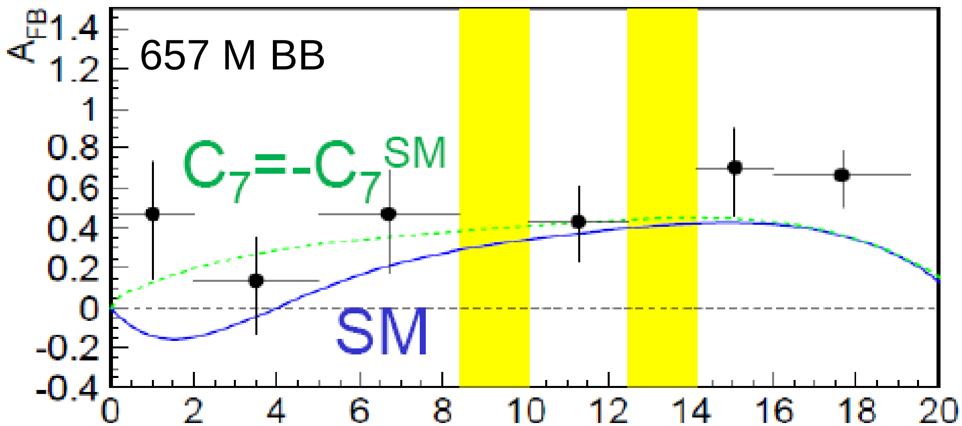
→ $\mu\mu$ forward-backward asymmetry:

$$A_{FB}(q^2) \sim -\,\mathrm{Re}\,\{\, C_{10}^{*}\,[\, C_7^{eff} + \beta(q^2)\, C_9^{eff} \,]\,\}$$

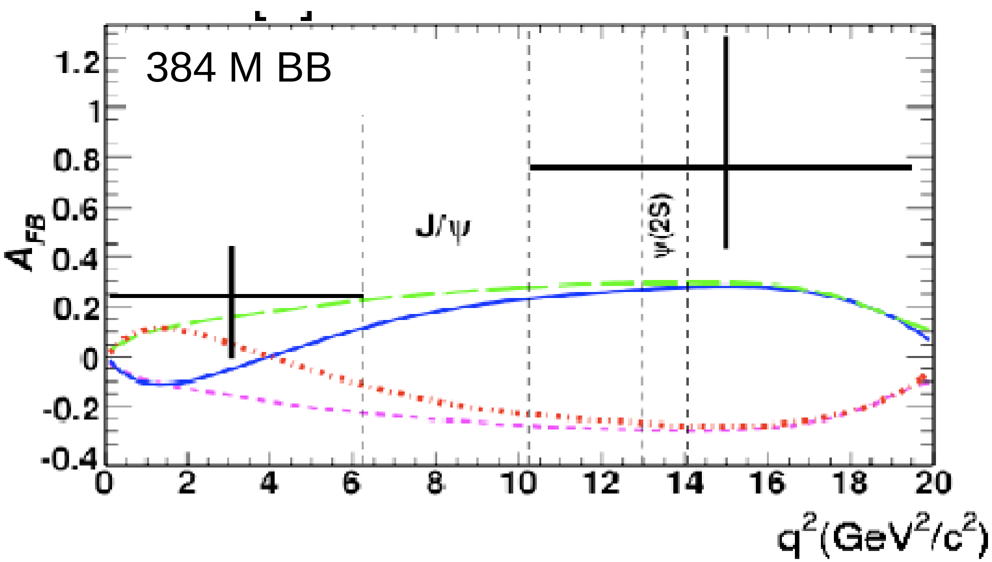
Angular observables offer a powerful test bench for any New Physics model

$B^0 \rightarrow K^*\mu\mu$ - Experimental Status

BELLE arXiv:0904.07770



BABAR PR D79:031102



<u>$B^0 \rightarrow K^*\mu\mu$ events:</u>

- Belle: ~250 evts
- Babar: ~100 evts
- CDF: ~100 evts (4.4 fb^{-1})

~450 evts

Poor agreement with SM.
LHCb data will clarify.

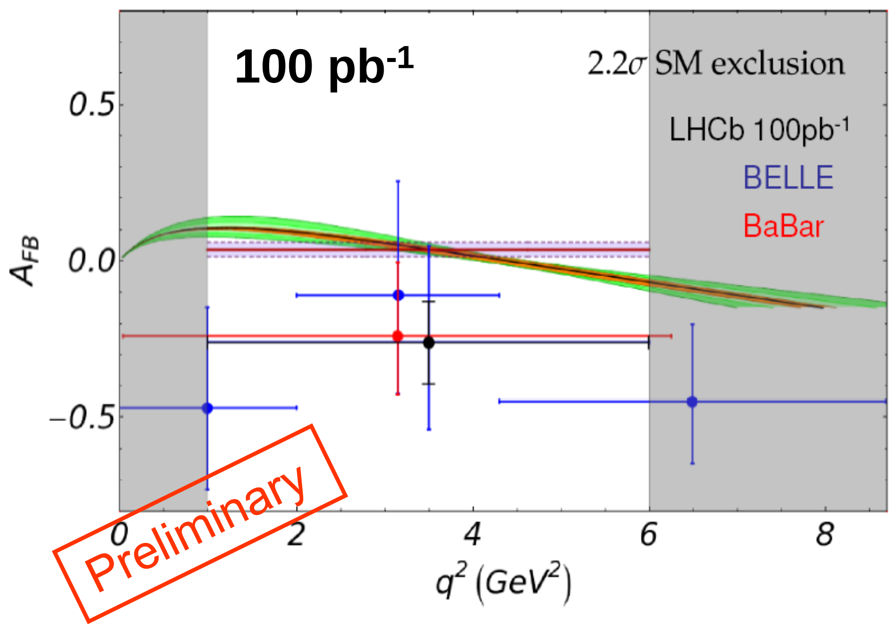
<u>LHCb expectation for 2 fb^{-1}</u>
~7000 events w/ B/S~0.25

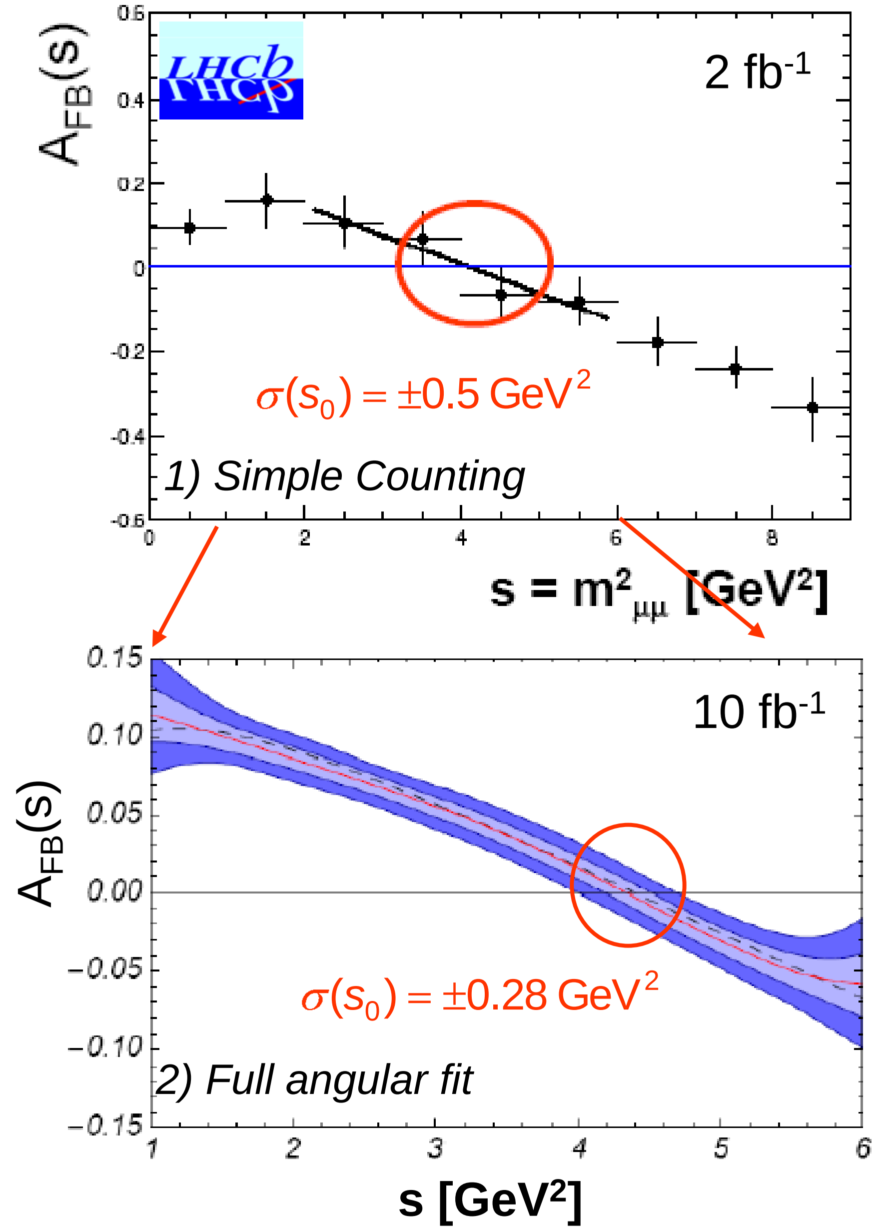
➡ 700 events for 200 pb^{-1}

$B^0 \rightarrow K^*\mu\mu$ - Prospects

Example:

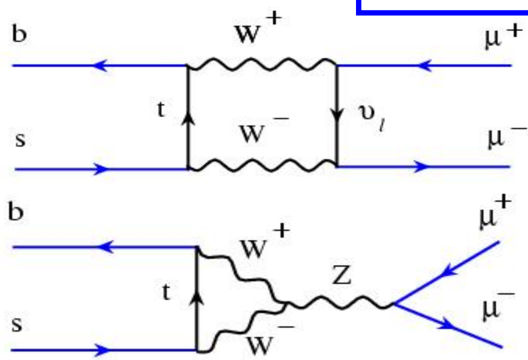
LHCb sensitivity for early data
(assume BELLE values for A_{FB})





Very Rare Decays - $B_{d,s} \rightarrow \mu\mu$

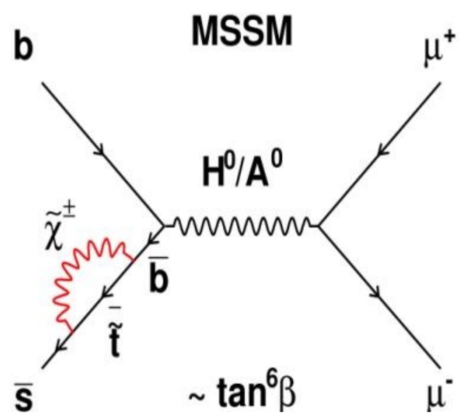
$$B_{d,s} \rightarrow \mu^+ \mu^-$$



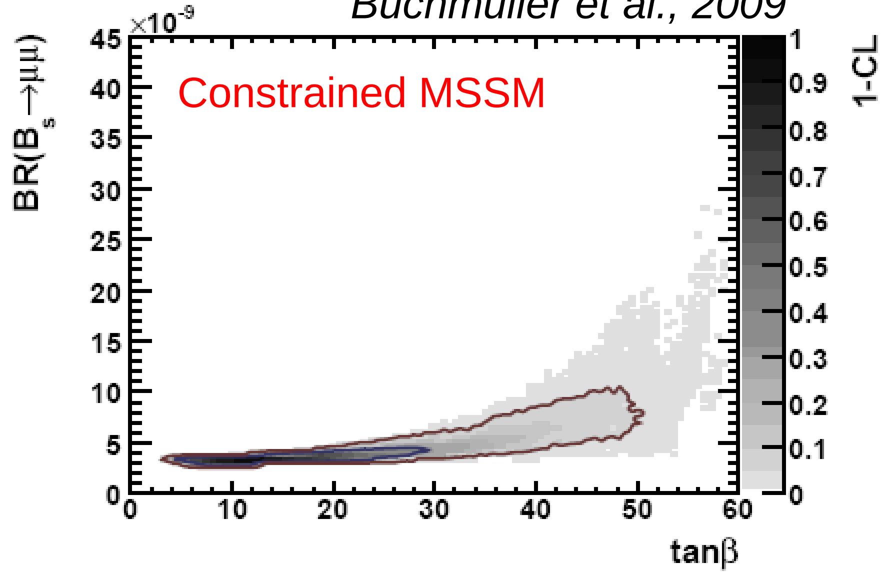
SM: $BR(B_s \rightarrow \mu^+\mu^-) = (3.2\ \ 0.2) \times 10^{-9}$

$BR(B_d \rightarrow \mu^+\mu^-) = (1.0\ \ 0.1) \times 10^{-10}$

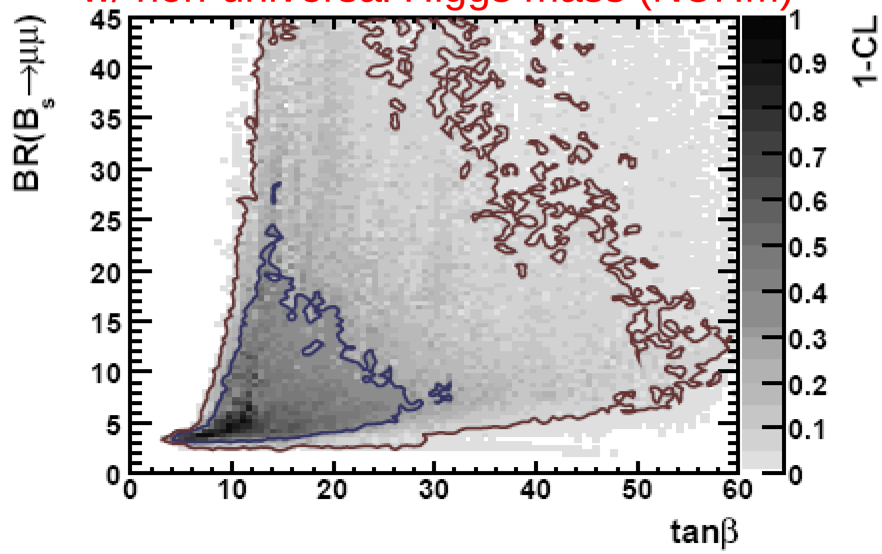
Large SUSY contributions possible



Buchmüller et al., 2009



w/ non-universal Higgs mass (NUHM)



LHCb Prospects for $B_s \rightarrow \mu\mu$

<u>Experimental status:</u> *CDF 2009*

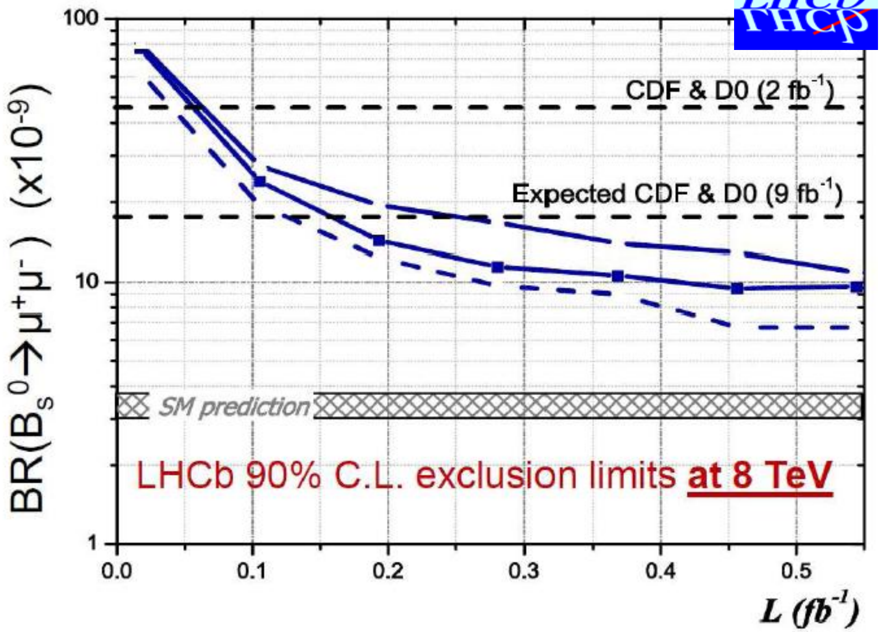
$BR(B_s \rightarrow \mu^+ \mu^-) < 4.3\times10^{-8}$ 95% CL

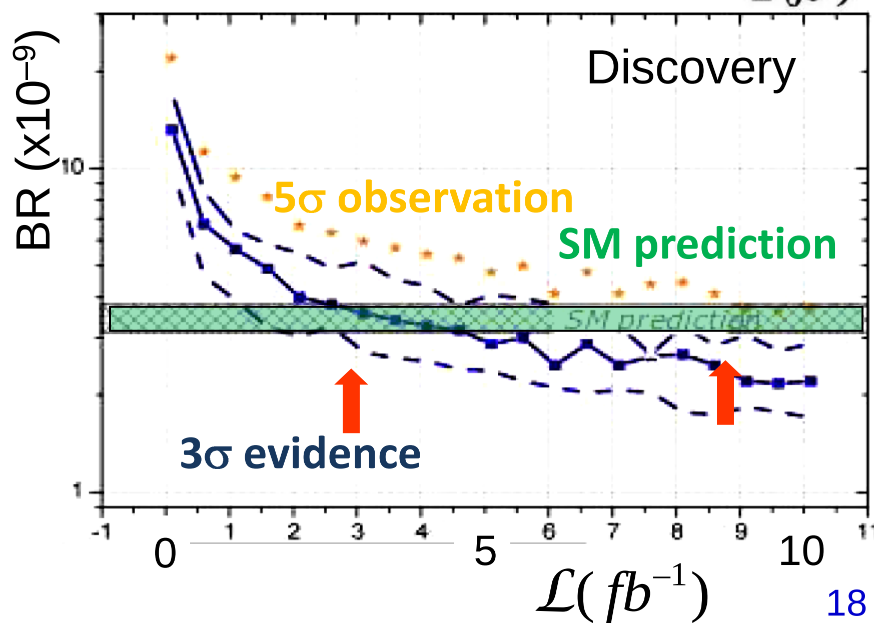
$BR(B_d \rightarrow \mu^+ \mu^-) < 7.6\times10^{-9}$ 95% CL

For ~150 pb^{-1} LHCb expects to reach the final Tevatron sensitivity.

$$R_{\mu\mu} = \frac{\mathcal{B}(B_s \rightarrow \mu\mu)}{\mathcal{B}(B_d \rightarrow \mu\mu)} \sim \left.\frac{|V_{ts}|^2}{|V_{td}|^2}\right|_{\substack{SM\\MFV}}$$

Ratio is sensitive test for MFV





Conclusion & Outlook

- We have learned a lot about and from heavy flavor physics: TeV-scale physics must have a sophisticated flavor structure not to be excluded by existing data.
- High-precision flavor physics provides the tools to further explore the flavor structure of New Physics at the Tera-scale: Flavor structure of new particles found by direct searches.
- LHCb has the possibility to perform several unique measurements: For some key observables early results (2010 data?) are possible.
- Experimental flavor program will be complemented by the Kaon physics program and by a Super-B factory.

Backup

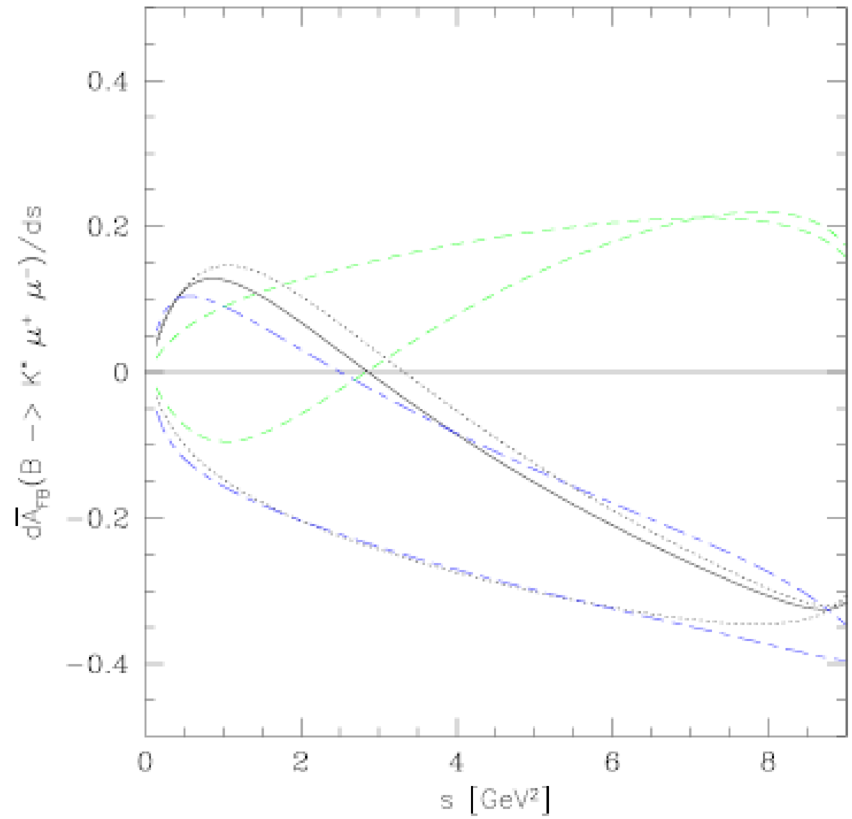


Figure 8: *The normalized forward-backward asymmetry in $B \to K^*\mu^+\mu^-$ decay as a function of s, using the form factors from the LCSR approach. All resonant $c\bar{c}$ states are parametrized as in Ref. [29]. The solid line denotes the SM prediction. The dotted (long-short dashed) lines correspond to the SUGRA (the MIA-SUSY) model, using the parameters given in Eq. (6.4) (Eq. (6.10)) with the upper and lower curves representing the $C_7^{\rm eff} < 0$ and $C_7^{\rm eff} > 0$ case, respectively. The dashed curves indicating a positive asymmetry for large s correspond to the MIA-SUSY models using the parameters given in Eq. (6.11), i.e. the "best depression scenario" with $C_{10} > 0$.*