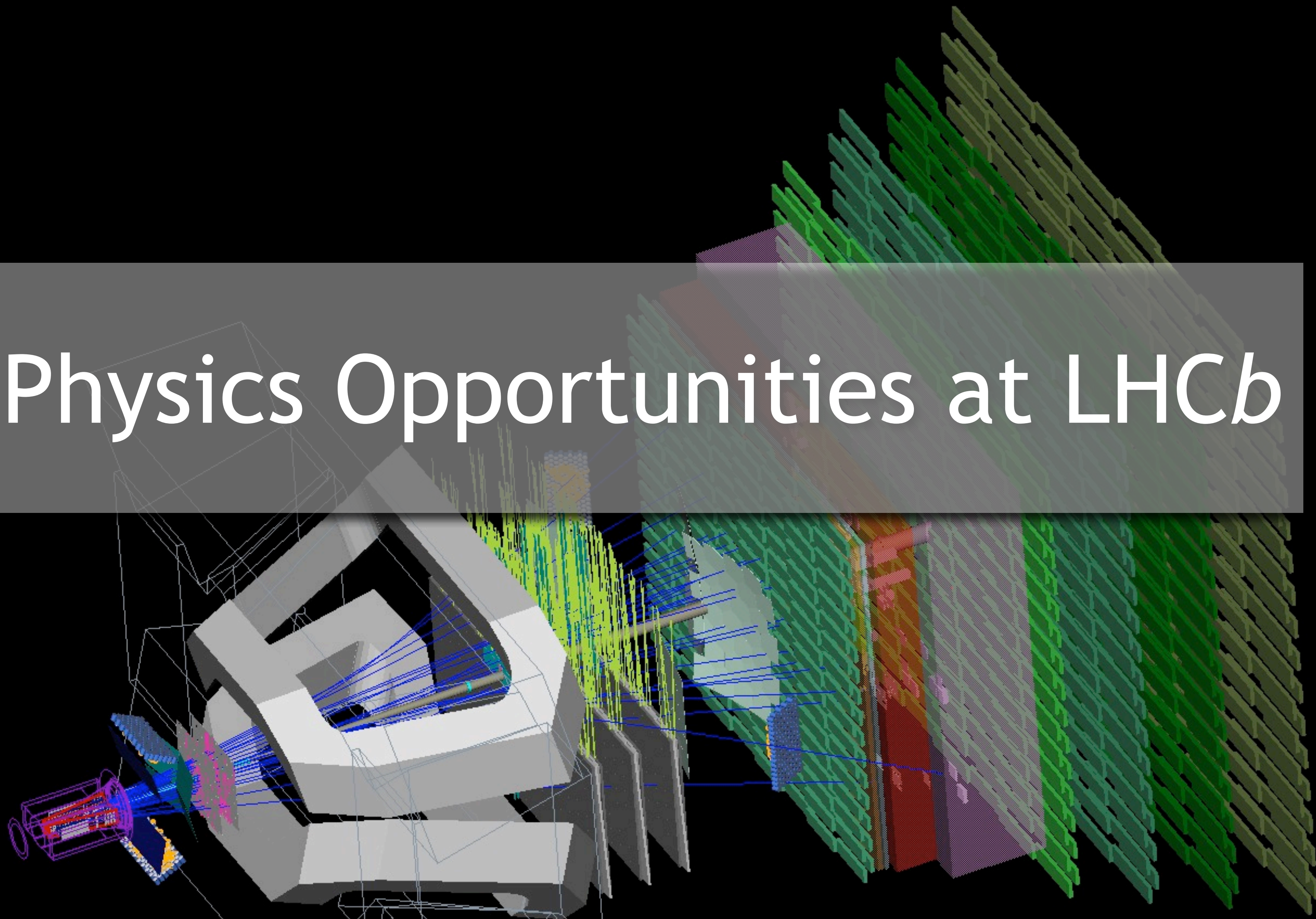


Physics Opportunities at LHC*b*

Matthias Neubert

Institut für Physik (THEP)

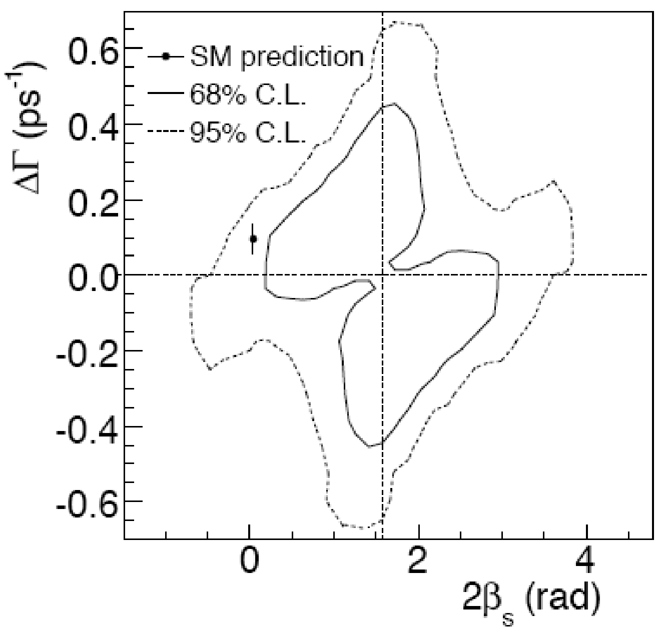
Johannes Gutenberg-Universität Mainz

LHC*b* Capabilities on Resolving Flavor Puzzles in B Physics

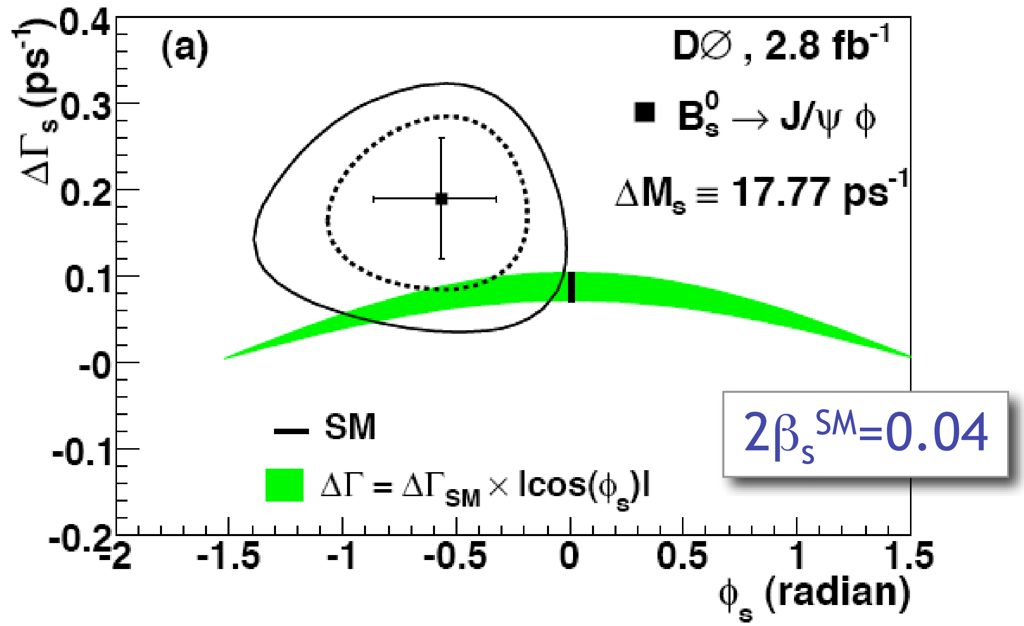
- New Physics CP phase in B_s mixing
- $\sin 2\beta$ from tree vs. penguins
- CP violation in $B \to \pi K$ decays
- ε_K vs. $\sin 2\beta$

New physics in B_s mixing ?

- Main information from flavor-tagged analysis of mixing-induced CP violation in $B_s \to J/\psi\ \phi$ decay
- Combined probability regions for $\phi_s = 2\beta_s$ and $\Delta\Gamma_s$



CDF (Dec. 2007)



D0 (Feb. 2008)

New physics in B_s mixing ?

- Combined analysis (UT*fit* collab., March 2008):

$$\Delta m_s \oplus A_{SL}{}^{s} \oplus A_{SL}{}^{\mu\mu} \oplus \tau(B_s) \oplus \{\phi_s, \Delta\Gamma_s\}$$

(CDF) (D0) (CDF, D0) (ALEPH, DELPHI, OPAL, CDF, D0) (CDF, D0)

$\oplus$

some bayesian magic …

New physics in B_s mixing ?

FIRST EVIDENCE OF NEW PHYSICS IN $b \leftrightarrow s$ TRANSITIONS

(**UT***fit* Collaboration)

M. Bona,[1] M. Ciuchini,[2] E. Franco,[3] V. Lubicz,[2,4] G. Martinelli,[3,5] F. Parodi,[6] M. Pierini,[1]
P. Roudeau,[7] C. Schiavi,[6] L. Silvestrini,[3] V. Sordini,[7] A. Stocchi,[7] and V. Vagnoni[8]

[1]*CERN, CH-1211 Geneva 23, Switzerland*
[2]*INFN, Sezione di Roma Tre, I-00146 Roma, Italy*
[3]*INFN, Sezione di Roma, I-00185 Roma, Italy*
[4]*Dipartimento di Fisica, Università di Roma Tre, I-00146 Roma, Italy*
[5]*Dipartimento di Fisica, Università di Roma "La Sapienza", I-00185 Roma, Italy*
[6] *Dipartimento di Fisica, Università di Genova and INFN, I-16146 Genova, Italy*
[7]*Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS et Université de Paris-Sud, BP 34, F-91898 Orsay Cedex, France*
[8]*INFN, Sezione di Bologna, I-40126 Bologna, Italy*

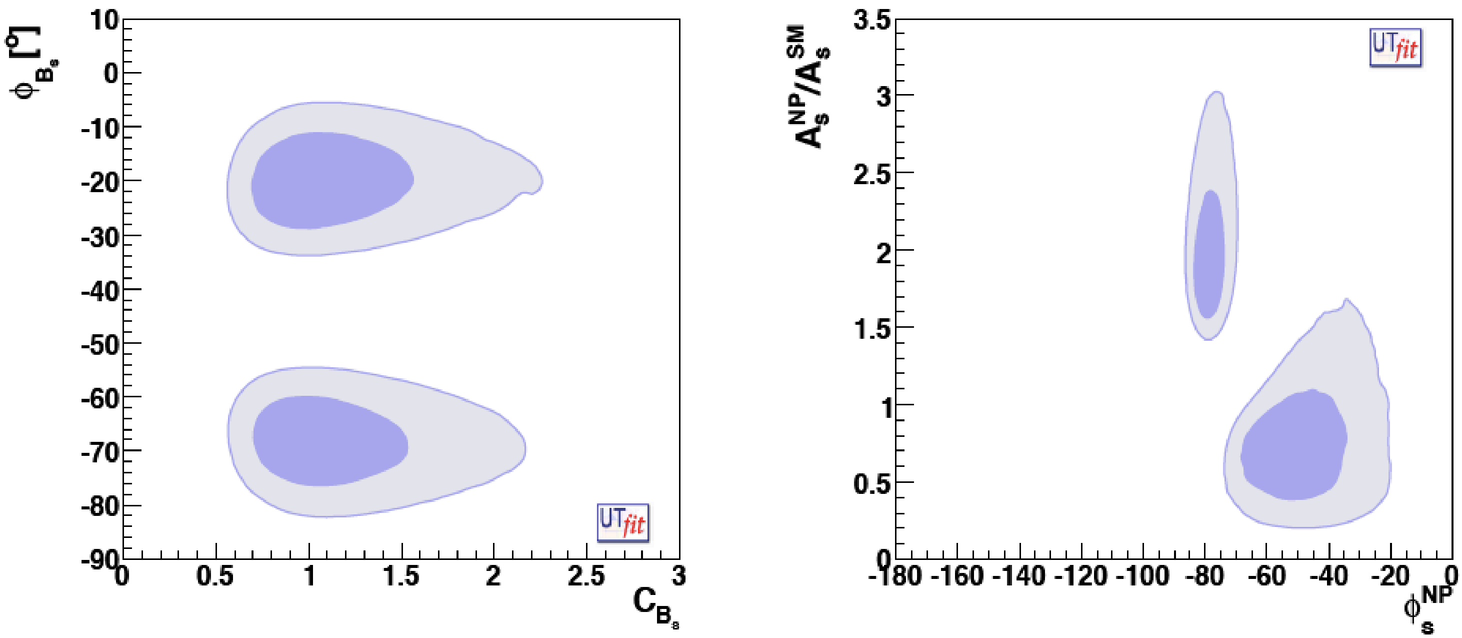
We combine all the available experimental information on B_s mixing, including the very recent tagged analyses of $B_s \to J/\Psi\phi$ by the CDF and DØ collaborations. We find that the phase of the B_s mixing amplitude deviates more than 3σ from the Standard Model prediction. While no single measurement has a 3σ significance yet, all the constraints show a remarkable agreement with the combined result. This is a first evidence of physics beyond the Standard Model. This result disfavours New Physics models with Minimal Flavour Violation with the same significance.

3.7σ evidence for a non-standard CP phase!

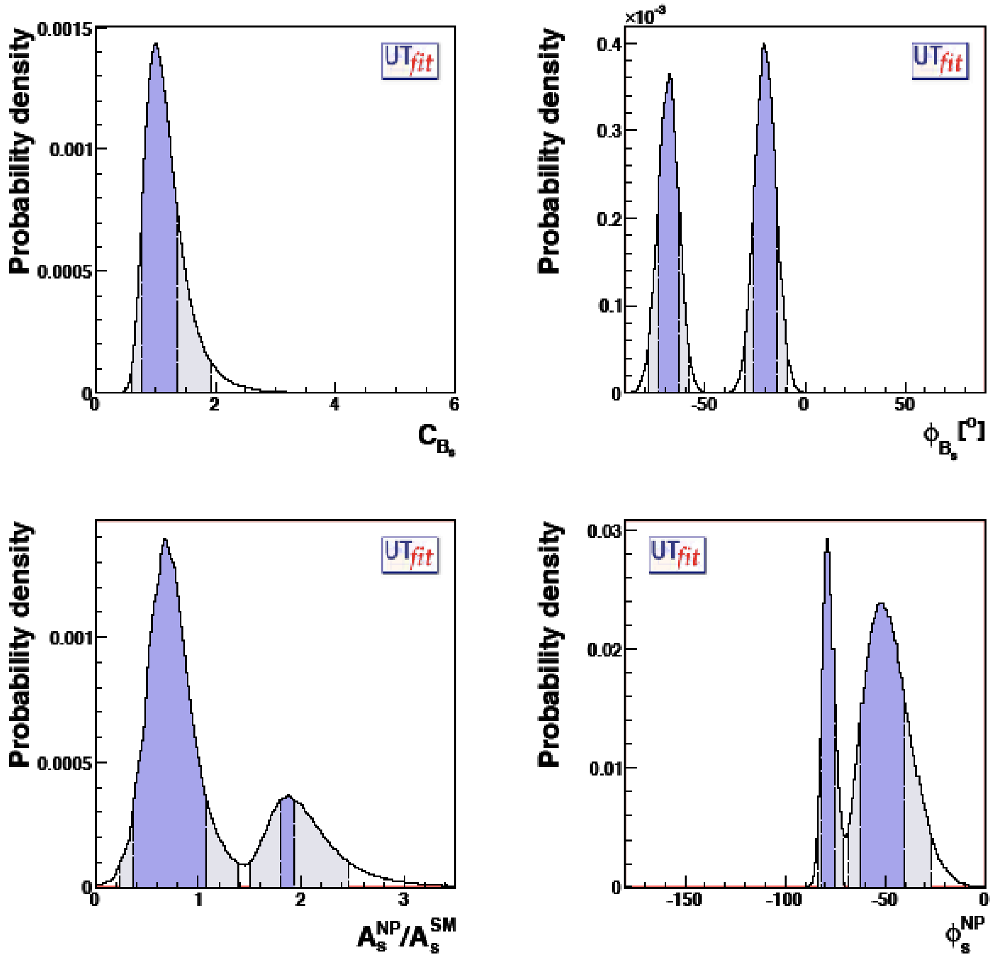
New physics in B_s mixing ?

- Model-independent parameterization:

$$C_{B_s}\, e^{2i\phi_{B_s}} = \frac{A_s^{\rm SM} e^{-2i\beta_s} + A_s^{\rm NP} e^{2i(\phi_s^{\rm NP}-\beta_s)}}{A_s^{\rm SM} e^{-2i\beta_s}}$$



New physics in B_s mixing ?



- Parameterization:

$$C_{B_s}\, e^{2i\phi_{B_s}} = \frac{A_s^{\rm SM} e^{-2i\beta_s} + A_s^{\rm NP} e^{2i(\phi_s^{\rm NP}-\beta_s)}}{A_s^{\rm SM} e^{-2i\beta_s}}$$

- If confirmed with more data, this would be clear evidence for new physics!

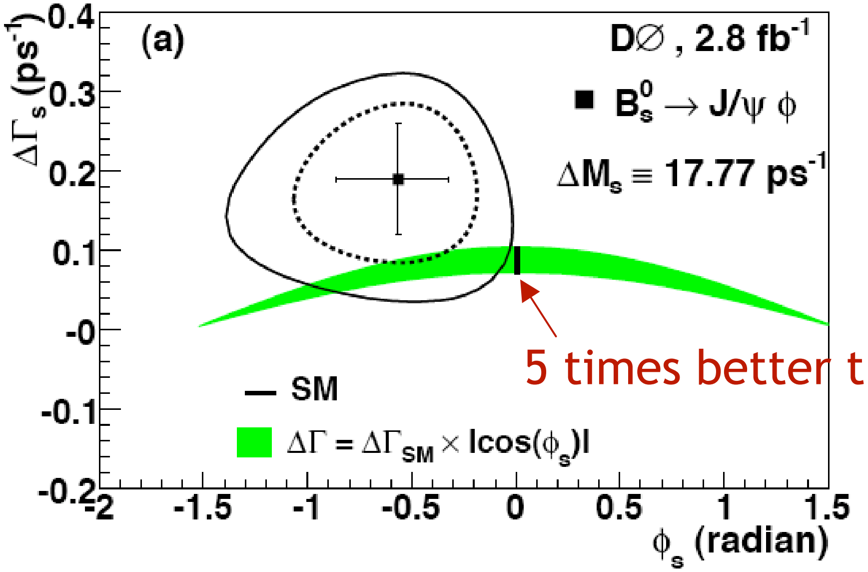
see also:
Lenz, Nierste (2006)

New physics in B_s mixing ?

- Capabilities of LHC*b*:

Luminosity	0.5 fb^{-1} (~2009)	2 fb^{-1} (~2010)	10 fb^{-1} (~2013)
$\sigma(2\beta_s)$	0.046	0.021	0.009

- Precision:

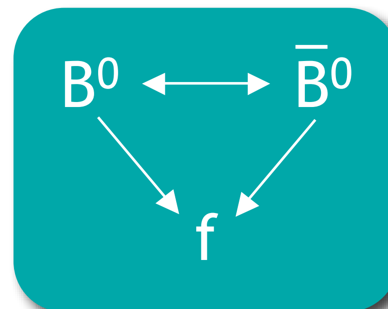


5 times better than this bar!

$2\beta_s^{SM}=0.04$

New physics in rare B decays (I) ?

- CP violation in interference of mixing and decays in neutral B decays into CP eigenstates
- Time-dependent CP asymmetry provides direct access to angles of the unitarity triangle:

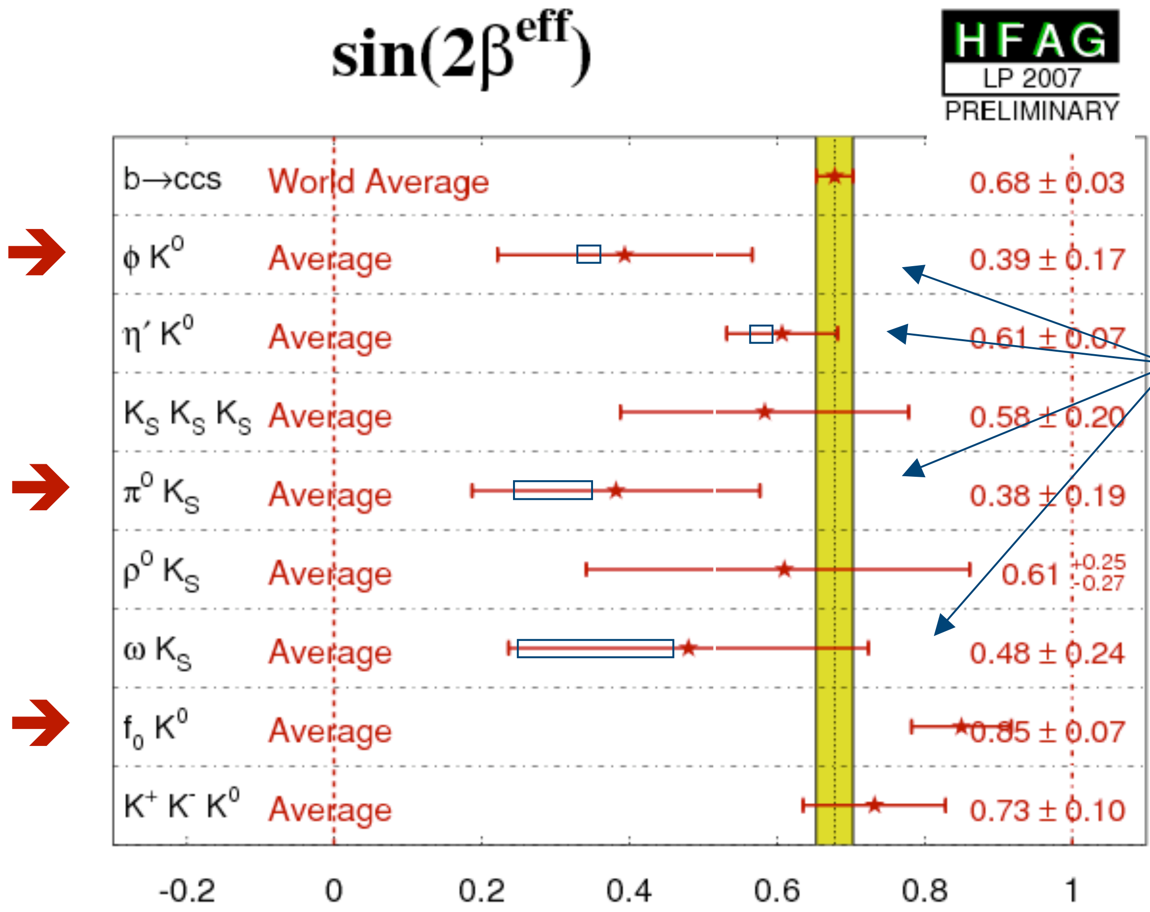


$$A_{\mathrm{CP}}(t) = \frac{\Gamma(\bar{B}^0(t) \to f) - \Gamma(B^0(t) \to f)}{\Gamma(\bar{B}^0(t) \to f) + \Gamma(B^0(t) \to f)} = \boxed{\sin 2(\beta - \varphi_A)}\, \sin(\Delta m t)$$

- Consider modes with $\varphi_A = 0$ and compare results for $\sin 2\beta$ from tree- and loop-dominated processes

Grossman, Worah (1996)

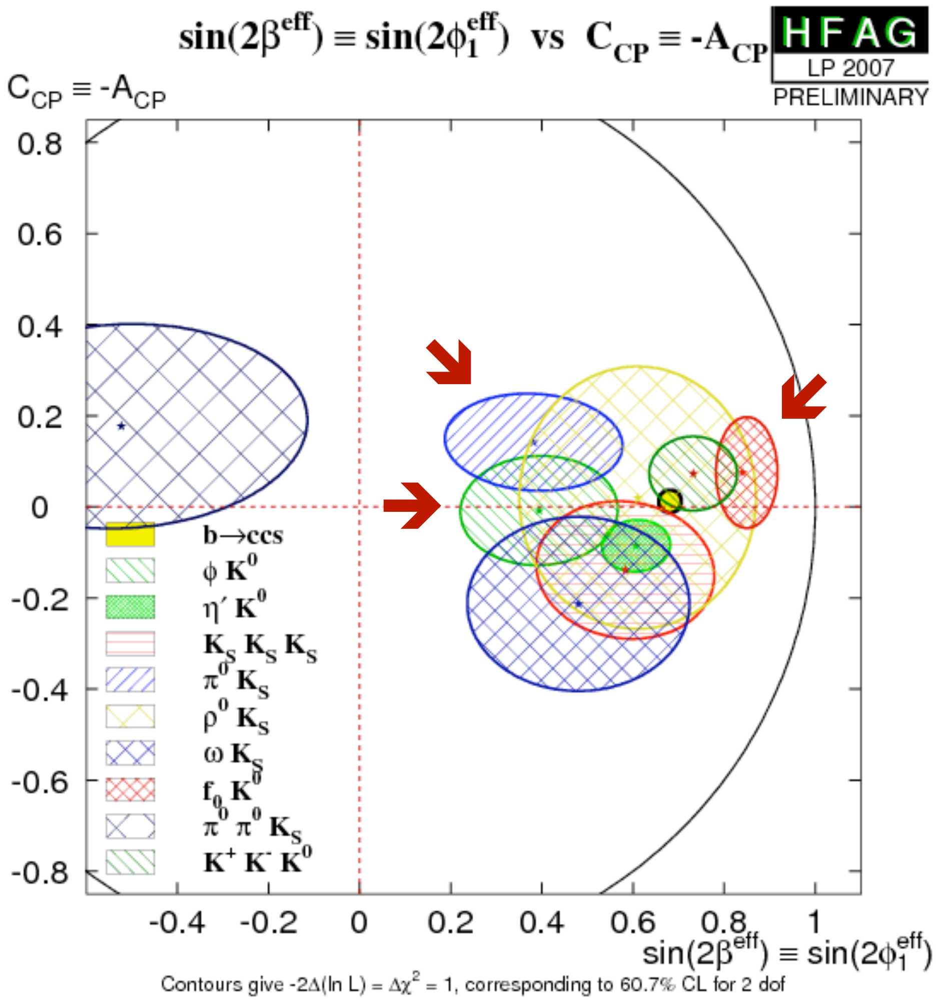
$(\sin 2\beta)_{\rm tree}$ vs. $(\sin 2\beta)_{\rm penguin}$



theor. corrections increase deviations

Beneke, MN (2003)

$(\sin 2\beta)_{tree}$ vs. $(\sin 2\beta)_{penguin}$



- Present accuracy:

  $\sigma(\sin 2\beta_{\phi K_s}) = 0.17$

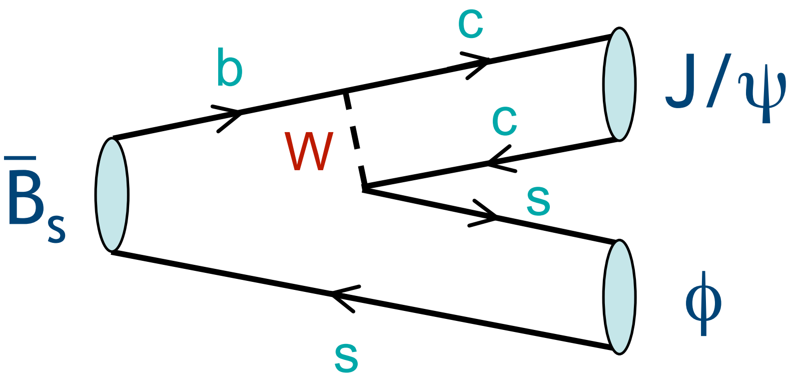
- LHC*b* capability with 10 fb^{-1}:

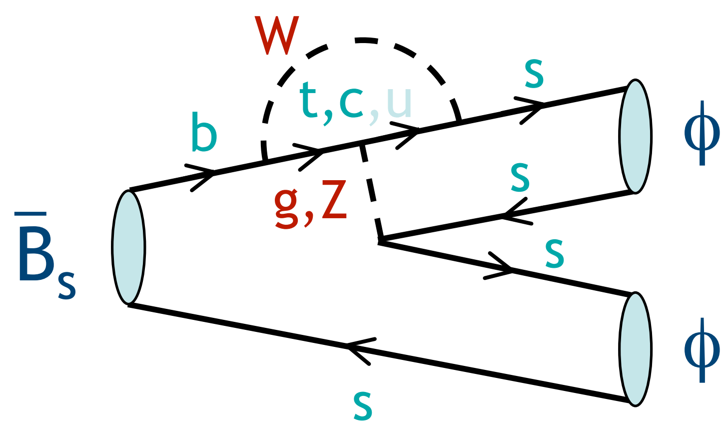
  $\sigma(\sin 2\beta_{\phi K_s}) = 0.10$

$\Rightarrow$ Super-B factory!

$(\sin 2\beta_s)_{tree}$ vs. $(\sin 2\beta_s)_{penguin}$

- But LHC*b* can do analogous test using B_s decays
- Compare $\sin 2\beta_s$ values extracted from $B_s \to J/\psi\ \phi$ vs. $B_s \to \phi\phi$





Luminosity	2 fb^{-1} (~2010)	10 fb^{-1} (~2013)
$\sigma(2\beta_s^{\phi\phi})$	0.11	0.04

$2\beta_s^{\phi\phi,SM}=0$

New physics in rare B decays (II) ?

- Belle and Babar observe large difference in direct CP asymmetries between $B^{\pm} \to K^{\pm}\pi^{0}$ and $B^{0} \to K^{\pm}\pi^{-+}$ decays (Belle paper in *Nature*, March 2008):
  "this large deviation in direct CP violation between charged and neutral B meson decays could be an indication of new sources of CP violation"
- World-average experimental data:

$$A_{CP}(B^{-} \to K^{-}\pi^{0}) = +\ 0.050 \pm 0.025$$

$$A_{CP}(B^{0} \to K^{-}\pi^{+}) = -\ 0.097 \pm 0.012$$

LHC*b* capability: $\sigma(A_{CP}(B^{0} \to K^{-}\pi^{+})) = 0.0014$ with 10 fb^{-1}

A "πK puzzle" ?

- Amplitude interference:

$$\sqrt{2}\,A(B^-\to K^-\pi^0) = P - (T + C)\,e^{-i\gamma} + P_{EW}$$

$$A(B^0\to K^-\pi^+) = P - T\,e^{-i\gamma}$$

- QCD predictions (model independent):

$$P_{EW} = f_{real}(m_t/m_W)\,(T + C)$$

U-spin symmetry and Fierz relations

Fleischer (1996); MN, Rosner (1998)

$$\arg(C/T) = O[\alpha_s(m_b),\, \Lambda_{QCD}/m_b]$$

QCD factorization, SCET

Beneke, Buchalla, MN, Sachrajda (1999-2001)

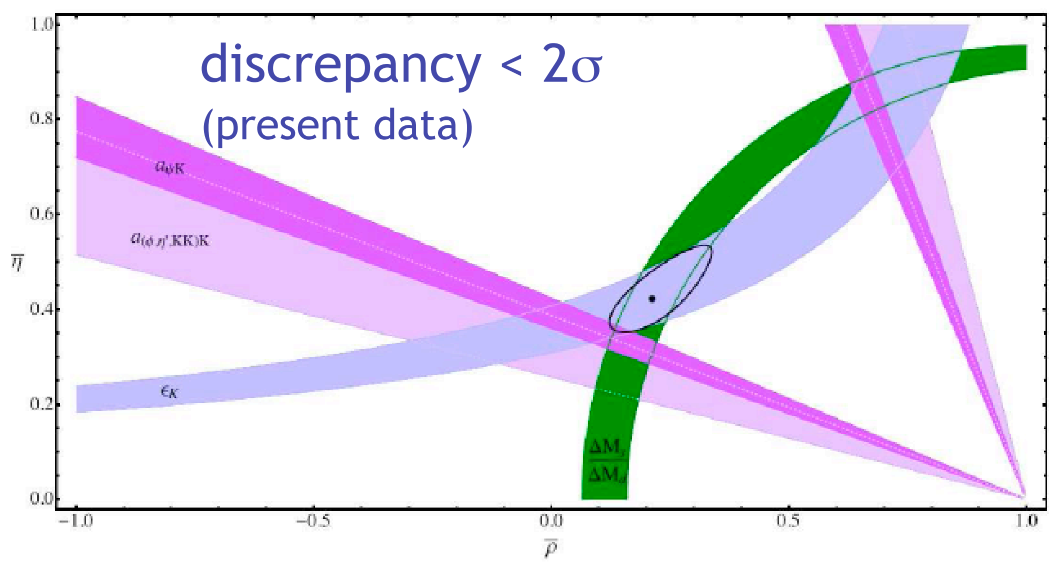
Bauer, Rothstein, Stewart (2005)

CP asymmetries predicted to have same sign !
(and similar magnitude)

→ test of theoretical assumptions requires Super-B factory

A crack in the unitarity triangle ?

- Using improved determinations of lattice matrix elements, find slight stress between CP violation measurements in K (ε_K) and B_d mixing ($\sin 2\beta$)
- Result independent of $|V_{ub}|$



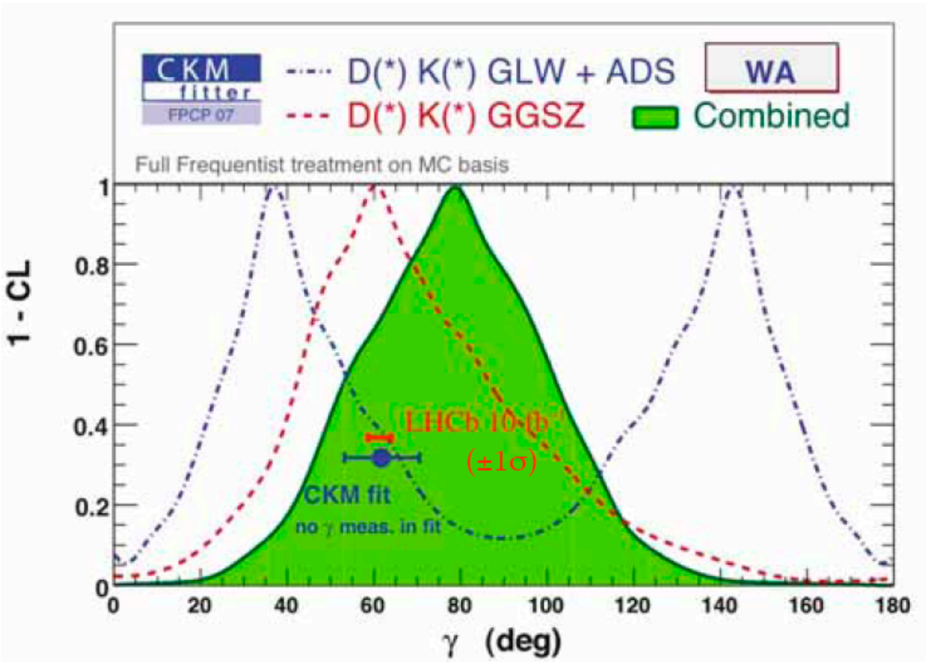
Lunghi, Soni (2008)

see also: Buras, Guadagnoli (2008)

A crack in the unitarity triangle ?

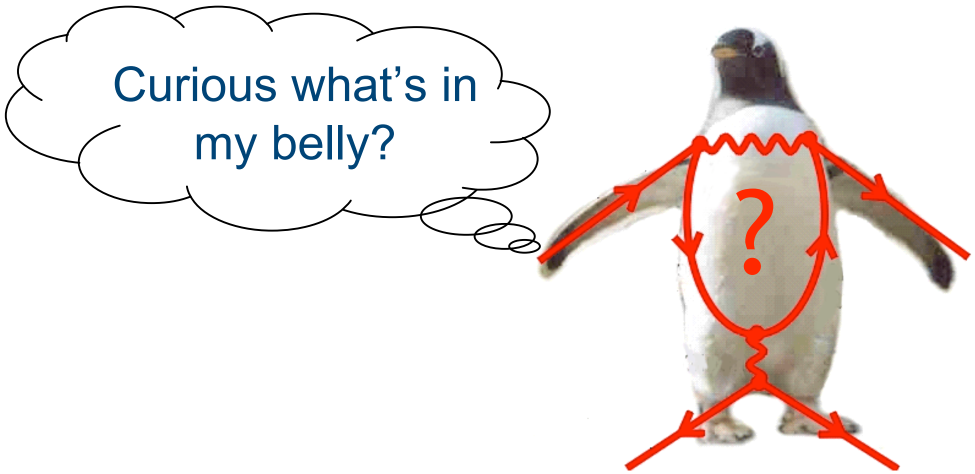
- Possible explanation in terms of new CP-violating effects in K and/or B_d mixing
- Precise measurement of γ could add important information
- LHC*b* capability: (with 10 fb^{-1})

$\boxed{\sigma(\gamma)\sim(2\text{-}3)^o}$



If any of these effects are real …

- Hints at O(1) new physics effects in mixing amplitudes and rare decay amplitude
- Requires large, O(1) new CP-violating phases



Check at ATLAS/CMS!

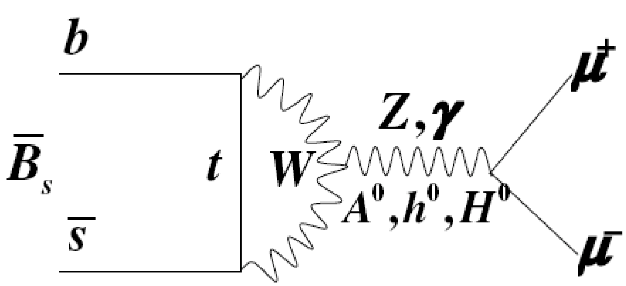
Not a Minimal Flavor Violation scenario !

Other Opportunities at LHC*b*

- $B_s \to \mu^+\mu^-$ decay (probing large $\tan\beta$)
- Radiative decays $B_d \to K^*\mu^+\mu^-$ and $B_s \to \phi\gamma$
- D mixing
- Exotic searches

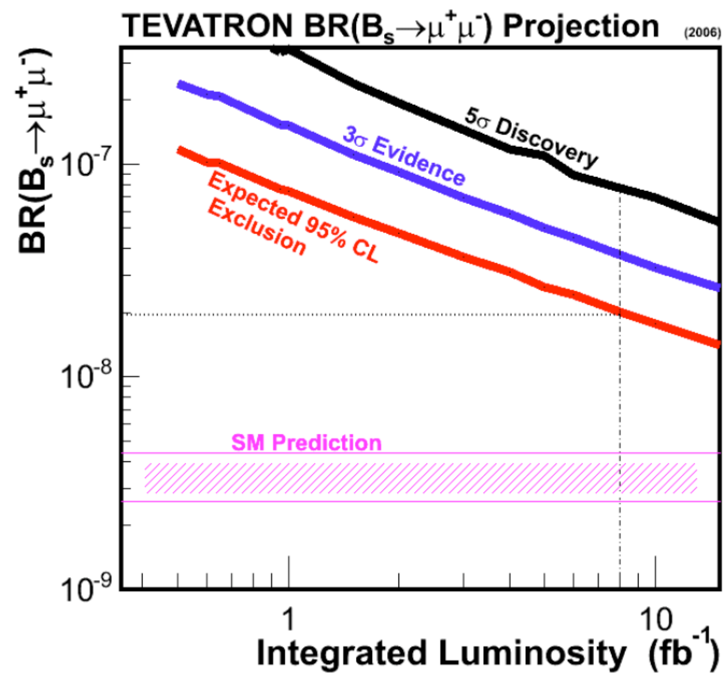
Rare decay $B_s \to \mu^+\mu^-$

- Sensitive probe of scalar boson exchange (vector boson exchange helicity suppressed)



- Huge enhancement of rate possible in models with large $\tan\beta$

- Tevatron sensitivity:

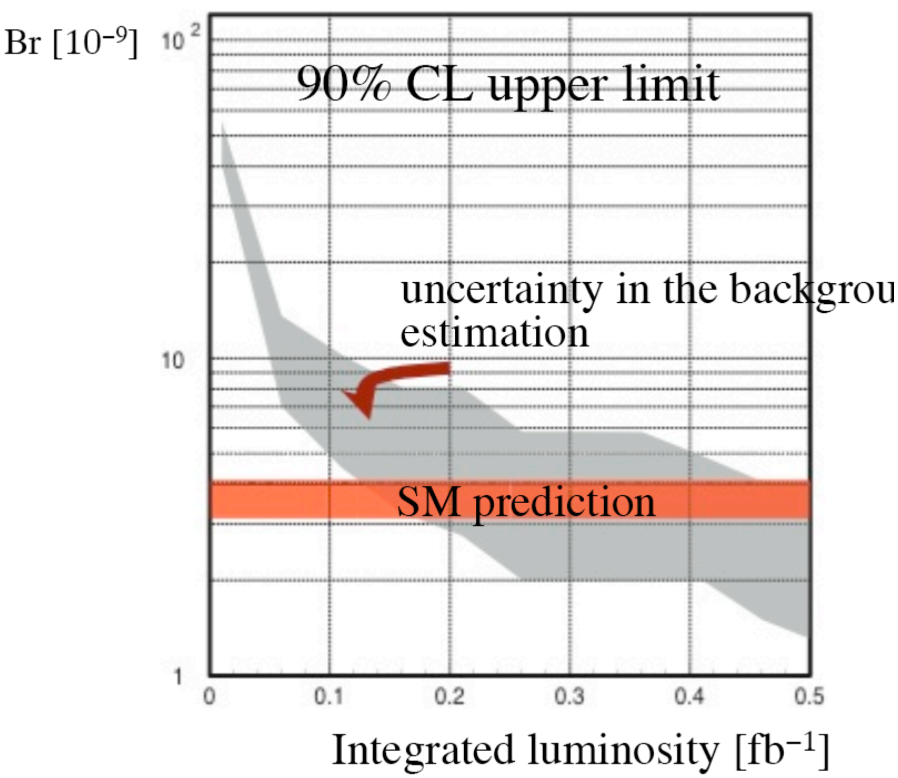


- Best present bound (CDF):

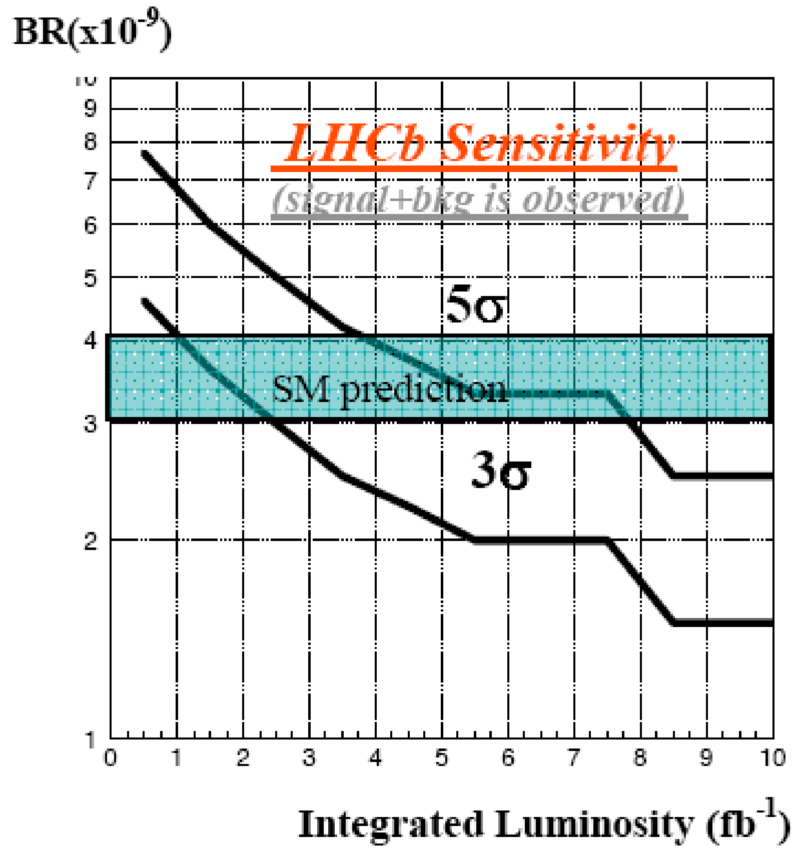
$Br(B_s \to \mu^+\mu^-) < 5.8 \cdot 10^{-8}$ @ 95% CL

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

- Projections for LHC*b*:



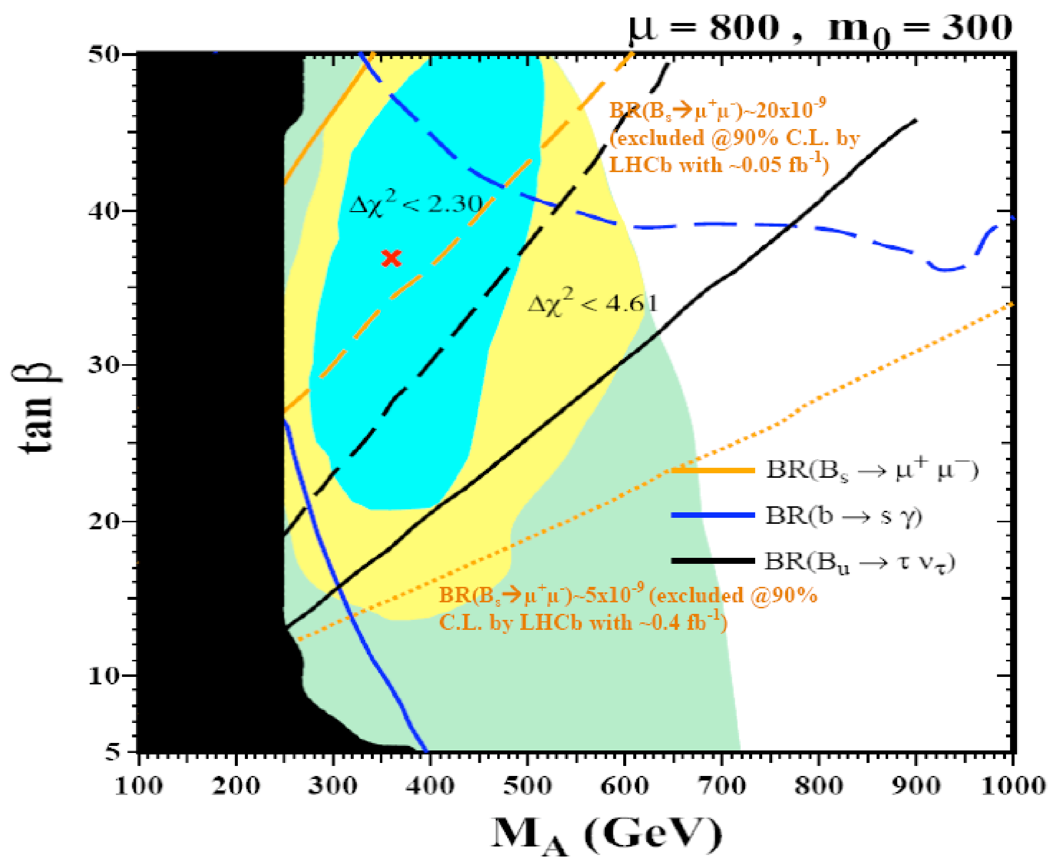
early phase (~2009)



later phase (~2010-2013)

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

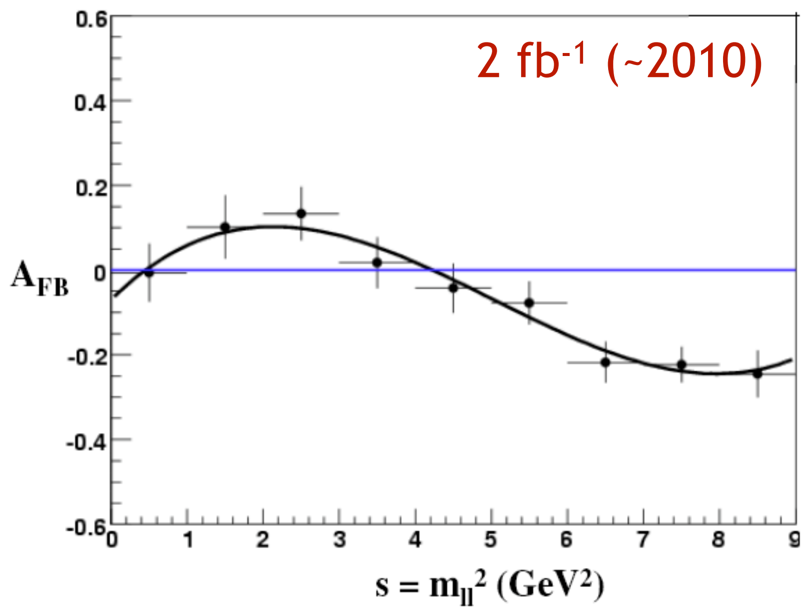
- Important impact on CMSSM parameter space

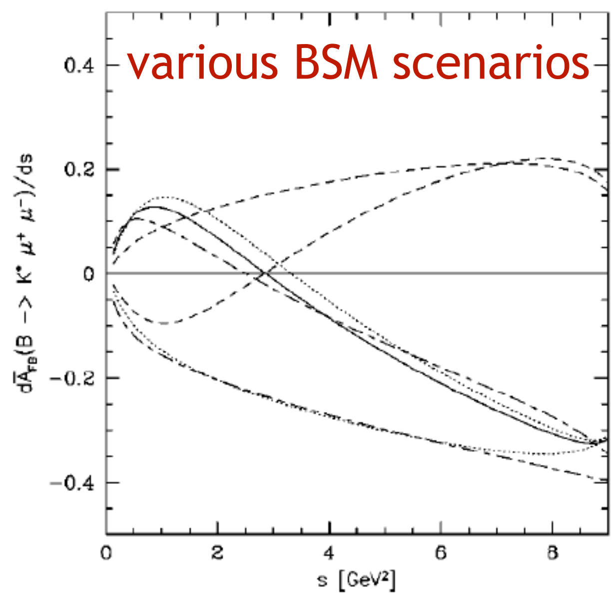


Ellis et al. (2009)

Radiative decay $B_d \rightarrow K^* \mu^+ \mu^-$

- Zero of forward-backward asymmetry sensitive to Wilson coefficients in effective Hamiltonian





- With 10 fb^{-1}, precision on zero $\sigma(s_0)=0.27\ \text{GeV}^2$

Radiative decay $B_s \to \phi\gamma$

- LHC*b* will collect 11k (68k) events of $B_s \to \phi\gamma$ ($B_d \to K^*\gamma$) per 2 fb^{-1}
  - 1% sensitivity to CP asymmetry
  - < 0.2 sensitivity to suppressed γ polarization fraction
- With 10 fb^{-1}, time-dependent CP asymmetry (sensitive to photon polarization) can be measured to $\sigma(S_{\phi\gamma})$=0.05

D mixing

- LHC*b* performance with 10 fb^{-1} (~2013):

$$\sigma(x'^2) = 0.06\cdot10^{-3} \qquad \sigma(y') = 0.7\cdot10^{-3}$$

at present: ±0.20 $\qquad {}^{+2.8}_{-3.7}$

- Performance on CP violation under study
  - preliminary result: >8·10^{6} flavor-tagged $D\to K^+K^-$ decays with 10 fb^{-1} (Belle has 10^{5} decays with 540 fb^{-1})

Searches for exotics

- Possibility of Higgs discovery via highly displaced vertices from decays of new neutral particles, e.g.:
  - MSSM with an additional scalar Chang, Fox, Weiner (2005)
  - hidden-valley models Strassler, Zurek (2006)
  - SUSY with R-parity violation and light neutralino (in this case, also reach for superpartner searches up to 1 TeV squark masses) Kaplan, Rehermann (2007)
- LHC*b* particularly well suited for such studies

Summary

- LHC*b* experiment offers significant reach to physics beyond SM
- Capability to definitively settle question of new CP phases in B_s mixing, and shed light on possible new physics effects in rare B_s and B_d decays
- Broad range of other important measurements in B_s, B_d, and D physics, including precise determination of unitarity triangle parameters
- Possibly, significant reach in Higgs/SUSY searches via displaced vertices