Recent results from LHCb

or: where to search for New Physics in flavor

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On behalf of the LHCb Collaboration

Berkeley Workshop on SUSY
October 19-21, 2011
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   limits on the rare decay $B_s \rightarrow \mu^-\mu^+$
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   the study of the decay $B \rightarrow K^* \mu^-\mu^+$
The LHCb detector

Single arm forward spectrometer optimized for b and c physics

covers $1.9 < \eta < 4.9$
The LHCb detector

The main important features:

Tracking
Good mass and impact parameter resolutions
Good vertex resolution for time dependent analysis

Excellent particle identification
π/K/p separation over 2-100 GeV
Powerful muon identification

Can trigger on hadronic final states

Operates at levelled Luminosity
The LHCb detector operation

Luminosity Leveling

Fill 2156: Instantaneous Luminosity

- Maintain luminosity close to the optimal (luminosity efficiency of ~98%)
- Control luminosity in order to have a stable detector
- Adjust automatically luminosity, moving the beams relative to each other
The LHCb detector operation

1 fb$^{-1}$ on tape on 13/10/2011

Delivered Lumi: 974.0
Recorded Lumi: 877.5
The LHCb trigger

With 1092 bunches, $3 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$:
Visible crossing: 8.5 MHz
L0 output rate: 650 kHz
HLT output rate: 3.6 kHz
HLT Farm CPU busy at 80%

Mass peaks seen online in the control room, at the output of the trigger.
• Physics objective:

probing New Physics Beyond the Standard Model (BSM) through virtual effects in loops mediated processes

Through many aspects (not an exhaustive list!!!) :

1. Mass measurements
2. Lifetime measurements
3. Production and Spectroscopy \((B_c, Y's, \chi_{c2}, \chi_{c1}, \ldots)\)
4. \(B_s\) decays
   - rare and less rare, Cabibbo favored and Cabibbo suppressed,
   - determination of \(f_s/f_d\), \(B_s^0 \rightarrow K^{*0} K^0\), \(B_s^0 \rightarrow D^0 K^*0\), \(B^0 \rightarrow Dh(hh), \ldots\)
5. CP violation time dependent measurements
   - \(\Delta m_s, \Delta m_d\), angular analysis of \(B^0 \rightarrow J/\psi K^*, B^0 \rightarrow J/\psi \phi, B^0 \rightarrow J/\psi K^{0}_s, \ldots\)
6. Integrated CP violation measurements

… and much more
Can in principle access higher scales and therefore see effects earlier:

- Third quark family inferred by Kobayashi and Maskawa (1973) to explain small CP violation measured in kaon mixing (1964), but only directly observed in 1977 (b) and 1995 (t)
- c and t quarks were first “seen” via their effects produced in FCNC processes in K and B physics respectively
- Neutral currents (ν+N→ν+N) discovered in 1973, but real Z discovered in 1983

Can in principle also access the phases of the new couplings:
NP at TeV scale needs to have a “flavour structure” to provide the suppression mechanism for FCNC processes → once NP is discovered, it is important to measure this structure, including new phases

Complementary to the “direct” approach:
If NP found in direct searches at LHC, B (as well as D, K) physics measurements will help understanding its nature and flavour structure
All measurements related with electroweak quark transitions are coherent with the Cabibbo-Kobayashi-Maskawa picture of the Standard Model.

Overconstrained tests of the CKM matrix to the level of precision warranted by theoretical uncertainties (will theory be able to calculate hadronic parameters with 1% precision in few years?)

The CKM phase is consistent with being the source for all CP-violating phenomena observed in the laboratory.

There must, however, be additional sources of CP violation.

The SM fails to explain the cosmic matter-antimatter asymmetry.

Need New Physics (NP) beyond the SM.
Current status of CKM parameters

Accuracy of angles is limited by experiment:

Accuracy of sides is limited by theoretical uncertainty (extraction of $V_{ub}$, lattice calculation of $\xi$,...)

$\bar{\rho} = 0.144^{+0.027}_{-0.018}$

$\bar{\eta} = 0.343 \pm 0.014$

**Examples**

1. $\phi_s^{SM} = -2\beta_s \equiv -2 \arg \left( -\frac{V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*} \right)$ phase of $B_s$ mixing
   - CKM fit prediction is very precise – $0.036 \pm 0.002$ rad

2. Measurement of rare decay $Br(B_{s,d} \to \mu\mu)$
   - Expect large contributions from NP models

3. Angular distributions and other observables (ex: in $B_d \to K^*\mu\mu$)
   - Sensitive to non-SM operators in interactions

4. $\gamma \approx -\arg(V_{ub})$
   - Comparison of tree processes with measurements from loop processes can reveal NP

**But also:** $B_s \to \phi\gamma$, $B^0 \to K^*\gamma$, $B_s \to \phi\phi$, ... $D^0$ mixing or decays, lepton flavor violation in charged leptons FCNC ($\tau \to \mu + \gamma$ and $\mu \to e + \gamma$), deviation from $\mu$-$e$ universality in $R_{K,\pi,B}$ ($R_K = \Gamma(K \to e\nu)/\Gamma(K \to \mu\nu)$, $R_B = (B \to K^*ee)/(B \to K^*\mu\mu)$)
the measurement of \( \Phi_s \) from \( B_s \rightarrow J/\psi \phi (f_0) \) decays
New physics in $B_s$ mixing

- Measure CP violation through interference of decays with and without mixing: $\phi_s = \phi_M - 2\phi_D$

- In SM it is predicted to be small [A. Lenz, arXiv: 1102.4274]

$$\phi_s \overset{\text{SM}}{=} -2\beta_s \equiv -2 \arg \left( -\frac{V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*} \right) = -0.036 \pm 0.002 \text{ rad}$$

- New physics can affect mixing adding large terms to $\phi_s$: SUSY, Little Higgs, extra dimension, 4$^\text{th}$ generation, extra $Z'$, ...

$$\Phi_s = \Phi_s^{\text{SM}} + \Phi_s^{\text{NP}}$$
Examples New Physics effects

Little Higgs Model with T-Parity

Warped Extra Dimension Model
[M. Blanke et al., JHEP 0903:001, 2009]

SUSY "AC" Model

MFV SUSY Model

[W. Altmannshofer et al., arXiv:0909.1333]
Very clean final states thanks to:
- powerful muon trigger
- excellent kaon/pion identification
- require $t(B_s)>0.3$ ps to remove dominant background from prompt $J/\psi$

$LHCb$-CONF-2011-049

measuring $\Phi_s$ from $B_s \to J/\psi \phi$ in $LHCb$

$LHCb$-CONF-2011-051

$L=337$ pb$^{-1}$

8276 $\pm$ 96 $J/\Psi\Phi$ signals events

1428 $\pm$ 47 $J/\Psi f_0$ signals events

$B_s \to J/\psi \phi$

$B_s \to J/\psi f_0$
measuring $\Phi_s$ in $B_s \to J/\psi \phi$ : the ingredients

Transition Pseudoscalar $\to$ Vector Vector $\to$ 3 polarization amplitudes

Need to separate CP-odd and CP-even final states

Description in trasversity basis:
l=1 : $A_T$ (CP-odd)
l=0,2 : $A_0, A_1$ (CP-even)

The phase $\phi_s$ is extracted with an unbinned max L fit to $m, t,$ initial $B_s$ flavor, and the 4 body decay angles. The physics parameters include $\Delta \Gamma_s, \Gamma_s, \Delta m_s, \phi_s,$ the complex amplitudes.

$$S(\vec{\lambda}, t, \vec{\Omega}) = \varepsilon(t, \vec{\Omega}) \times \left( \frac{1+qD}{2} s(\vec{\lambda}, t, \vec{\Omega}) + \frac{1-qD}{2} \bar{s}(\vec{\lambda}, t, \vec{\Omega}) \right) \otimes R_t$$

Basic ingredients: acceptance, flavour tagging, proper time resolution
measuring $\Phi_s$ from $B_s \rightarrow J/\psi \phi$

\[
|A_0|^2(t) = |A_0|^2 e^{-\Gamma_s t} \left[ \cosh \left( \frac{\Delta \Gamma}{2} t \right) - \cos \phi_s \sinh \left( \frac{\Delta \Gamma}{2} t \right) + \sin \phi_s \sin (\Delta m t) \right],
\]
\[
|A_\parallel(t)|^2 = |A_\parallel|^2 e^{-\Gamma_s t} \left[ \cosh \left( \frac{\Delta \Gamma}{2} t \right) - \cos \phi_s \sinh \left( \frac{\Delta \Gamma}{2} t \right) + \sin \phi_s \sin (\Delta m t) \right],
\]
\[
|A_\perp(t)|^2 = |A_\perp|^2 e^{-\Gamma_s t} \left[ \cosh \left( \frac{\Delta \Gamma}{2} t \right) + \cos \phi_s \sinh \left( \frac{\Delta \Gamma}{2} t \right) - \sin \phi_s \sin (\Delta m t) \right],
\]
\[
\Im(A_\parallel(t) A_\perp(t)) = |A_\parallel||A_\perp| e^{-\Gamma_s t} \left[ - \cos(\delta_\perp - \delta_\parallel) \sin \phi_s \sinh \left( \frac{\Delta \Gamma}{2} t \right) - \cos(\delta_\perp - \delta_\parallel) \cos \phi_s \sin (\Delta m t) + \sin(\delta_\perp - \delta_\parallel) \cos (\Delta m t) \right],
\]
\[
\Re(A_0(t) A_\parallel(t)) = |A_0||A_\parallel| e^{-\Gamma_s t} \cos(\delta_\parallel - \delta_0) \left[ \cosh \left( \frac{\Delta \Gamma}{2} t \right) - \cos \phi_s \sinh \left( \frac{\Delta \Gamma}{2} t \right) + \sin \phi_s \sin (\Delta m t) \right],
\]
\[
\Im(A_0(t) A_\perp(t)) = |A_0||A_\perp| e^{-\Gamma_s t} \left[ - \cos(\delta_\parallel - \delta_0) \sin \phi_s \sinh \left( \frac{\Delta \Gamma}{2} t \right) - \cos(\delta_\parallel - \delta_0) \cos \phi_s \sin (\Delta m t) + \sin(\delta_\parallel - \delta_0) \cos (\Delta m t) \right],
\]
\[
|A_s(t)|^2 = |A_s|^2 e^{-\Gamma_s t} \left[ \cosh \left( \frac{\Delta \Gamma}{2} t \right) + \cos \phi_s \sinh \left( \frac{\Delta \Gamma}{2} t \right) - \sin \phi_s \sin (\Delta m t) \right],
\]
\[
\Re(A_s^*(t) A_\parallel(t)) = |A_s^*||A_\parallel| e^{-\Gamma_s t} \left[ - \sin(\delta_\parallel - \delta_s) \sin \phi_s \sinh \left( \frac{\Delta \Gamma}{2} t \right) - \sin(\delta_\parallel - \delta_s) \cos \phi_s \sin (\Delta m t) + \cos(\delta_\parallel - \delta_s) \cos (\Delta m t) \right],
\]
\[
\Im(A_s^*(t) A_\perp(t)) = |A_s^*||A_\perp| e^{-\Gamma_s t} \left[ \sin(\delta_\perp - \delta_s) \sin \phi_s \sinh \left( \frac{\Delta \Gamma}{2} t \right) + \cos \phi_s \sin (\Delta m t) \right],
\]
\[
\Re(A_s^*(t) A_0(t)) = |A_s^*||A_0| e^{-\Gamma_s t} \left[ - \sin(\delta_0 - \delta_s) \sin \phi_s \sinh \left( \frac{\Delta \Gamma}{2} t \right) - \sin(\delta_0 - \delta_s) \cos \phi_s \sin (\Delta m t) + \cos(\delta_0 - \delta_s) \cos (\Delta m t) \right].
\]
Proper time resolution

- Time resolution model obtained from prompt J/ψ events
- Effective proper time resolution 50 fs
- 2% systematic error

Acceptance

- Detector covers 10<θ<400 mrad
- Determined from MC simulation
- Deviation from uniform within 5%
Use opposite side (for now) 4 taggers: high pt $\mu$’s, e’s, K’s and vertex charge

Wrong tagging probability calibrated with $B^+ \rightarrow J/\psi K^+$

$\epsilon_{\text{tag}} = (27 \pm 0.4)\%$
Average dilution factor $D = (27.7 \pm 0.28)\%$
Effective tagging power $\epsilon_{\text{tag}} D^2 = (2.08 \pm 0.41)\%$
measuring $\Phi_s$ from $B_s \rightarrow J/\psi \phi$ : fit projections

Time and angular distributions in data

Projections are very well described
Two ambiguous solutions $\phi_s \leftrightarrow \pi\phi_s; \Delta\Gamma_s \leftrightarrow -\Delta\Gamma_s$

World’s most precise measurement of $\phi_s$

$\phi_s = 0.13 \pm 0.18 \text{ (stat)} \pm 0.07 \text{ (sys)} \text{ rad}$ consistent with SM prediction $\phi_{s}^{\text{SM}} = -0.036 \pm 0.002 \text{ rad}$

4σ evidence for $\Delta\Gamma_s \neq 0$

$\Delta\Gamma_s = 0.123 \pm 0.029 \text{ (stat)} \pm 0.008 \text{ (sys)} \text{ ps}^{-1}$
measuring $\Phi_s$ adding $B_s \to J/\psi f_0$

$B_s \to J/\psi f_0$

CP odd final state: no angular analysis required

Using $\Delta \Gamma_s$ and $\Gamma_s$ from $B_s \to J/\psi \phi$

$\phi_s = -0.44 \pm 0.44 \pm 0.02$ rad

(+ ambiguous solution)

Simultaneous fit of $B_s \to J/\psi \phi$ and $B_s \to J/\psi f_0$ data

$\phi_s = 0.03 \pm 0.16$ (stat) $\pm 0.07$ (sys) rad

(+ ambiguous solution)

Caveat for the combination [R. Fleischer et al., arXiv:1109.1112]]

– Hadronic nature of $f_0$ not clear

– Different hadronic effects in $B_s \to J/\psi f_0$ and $B_s \to J/\psi \phi$
measuring $\Phi_s$: next steps

Already significant improvement on existing data $\rightarrow$ but still more improvement to come

More luminosity being added (more statistics)

Improve tagging with same side kaons

Solve the ambiguity by looking at relative S-wave phase vs $M(KK)$ in $J/\psi\Phi$

….for end of 2011:
Decrease the error from $\sim 0.2$ to $\sim 0.1$


This is just flipping and scaling the PDFs taken from talks to give impression
Search for the rare decay $B_s \rightarrow \mu^+\mu^-$
**SM expectation:**

\[
\text{BR}(B_s \rightarrow \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9} \\
\text{BR}(B_d \rightarrow \mu^+\mu^-) = (1.0 \pm 0.5) \times 10^{-10}
\]

(FCNC suppression and helicity suppressed)


**In Supersymmetry:**

Large contributions in some SUSY models

\[
\text{BR}(B_{d,s} \rightarrow \mu^+\mu^-) \text{ very sensitive if high values of } \tan \beta
\]

\[
\text{Br}_{\text{MSSM}}(B_q \rightarrow \ell^+\ell^-) \propto \frac{M_b^2 M_\ell^2 \tan^6 \beta}{M_A^4}
\]

Measurement or limit will become strong constraint on

NP on \((\tan \beta, M_A)\) plane  [O. Buchmuller et al., arXiv0907.5568]
CDF recently (July 2011) reported a hint of signal with 7 fb$^{-1}$

- p-value background only: 0.3%
- p-value background + SM BR: 1.9%
- p-value background + 5.6×SM BR: 50%

\[ B(B_s \rightarrow \mu^+\mu^-) = 1.8^{+1.0}_{-0.9} \times 10^{-8} \]
LHCb analysis of the decay $B_s \rightarrow \mu^+\mu^-$

2010 LHCb analysis published in [PLB 699 (2011) 330]

Update with $\approx 300 \text{ pb}^{-1}$ LHCb-CONF-2011-037

Discriminating signal from background using 2 variables

- Invariant mass of $\mu^+\mu^-$ and
- A Boosted Decision Tree (BDT) combining 9 kinematical and topological variables

BDT calibrated on $B \rightarrow h^+h^-$ for the signal and sidebands for the background

Mass resolution obtained $J/\psi \rightarrow \mu\mu$ and $Y(1S)\rightarrow \mu\mu$ (and $B^0 \rightarrow K\pi$, $B_s \rightarrow KK$)

To obtain relative BR, use normalization channels:

- $B^+ \rightarrow J/\psi K^+$, $B_s \rightarrow J/\psi \phi$ and $B_d \rightarrow K\pi$

and use LHCb results $f_s/f_d = 0.267^{+0.021}_{-0.020}$ [LHCb arXiv: 1106.4435]
Look at 4 regions in BDT and 6 in $\mu\mu$ invariant mass
LHCb analysis of the decay $B_s \rightarrow \mu^+\mu^-$

4 bins in BDT output
120 MeV B mass search window divided into 6 bins

<table>
<thead>
<tr>
<th></th>
<th>BDT&lt;0.25</th>
<th>0.25&lt;BDT&lt;0.5</th>
<th>0.5&lt;BDT&lt;0.75</th>
<th>0.75&lt;BDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp. combinatorial</td>
<td>2968 ± 69</td>
<td>25 ± 2.5</td>
<td>2.99 ± 0.89</td>
<td>0.66 ± 0.40</td>
</tr>
<tr>
<td>Exp. SM signal</td>
<td>1.26 ± 0.13</td>
<td>0.61 ± 0.06</td>
<td>0.67 ± 0.07</td>
<td>0.72 ± 0.07</td>
</tr>
<tr>
<td>Observed</td>
<td>2872</td>
<td>26</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Signal with SM Br
LHCb limit on $\text{Br} (B_s \rightarrow \mu^+\mu^-)$

Determine limits using CLs method

Observed limit: $\text{BR}(B_s \rightarrow \mu^+\mu^-) < 1.6 (1.3) \times 10^{-8}$ @ 95% (90%) C.L.

Combined with 2010 data: $\text{BR}(B_s \rightarrow \mu^+\mu^-) < 1.5 (1.2) \times 10^{-8}$ @ 95% (90%) C.L.

Near future prospects (winter 2012 conferences):
3σ evidence for SM (but could be even better!!!)
LHCb + CMS combined limit on $\text{Br} (B_s \rightarrow \mu^+\mu^-)$

cf. CMS result using 1.14 fb$^{-1}$

<table>
<thead>
<tr>
<th>Expected limit</th>
<th>Observed limit</th>
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<tbody>
<tr>
<td>$&lt; 1.8 \times 10^{-8}$ @ 95% C.L.</td>
<td>$&lt; 1.9 \times 10^{-8}$ @ 95% C.L.</td>
</tr>
</tbody>
</table>

LHCb and CMS have performed a combined limit

Combined LHCb+CMS: $\text{BR}(B_s \rightarrow \mu^+\mu^-) < 1.08 (0.9) \times 10^{-8}$ @ 95% (90%) C.L.
Example of possible implication on SUSY models

From arXiv:1108.3018 (A.G Akeroyd et al.)

Figure 15: Constraints from $\text{BR}(B_s \rightarrow \mu^+\mu^-)$ and the double ratio $R$ in the CNMSSM parameter plane $(m_{1/2}, m_0)$ for $A_0 = 1000 \text{ GeV}$, $A_K = -60 \text{ GeV}$, $\tan \beta = 50$ and $\lambda = 0.1$. 

Allowed region
LHCb: the decay $B_s \rightarrow \mu^+\mu^-$

$m_{\mu\mu} = 5.357$ GeV
BDT = 0.90
Decay length = 11.5 mm
Tracks shown for $p_T > 0.5$ GeV
Search for rare decay $B \rightarrow K^* \mu^+ \mu^-$
Search for $B^0 \to K^{*0} \mu^+ \mu^-$ decay

$b\to s$ transitions: FCNC process very sensitive to NP in loops

SM processes contributing to decay:

$$BR(B^0 \to ll\ell) = 4.5 \times 10^{-6}$$
$$BR(B^0 \to llK) = 0.5 \times 10^{-6}$$
$$BR(B^0 \to llK^*) = 3.3 \pm 1.0 \times 10^{-6}$$

Analysis of angular distributions allow to extract information about New Physics (SUSY, graviton exchange, extra dimension)
Forward-backward asymmetry $A_{FB}(s)$ in the $\mu\mu$ rest-frame is sensitive probe of New Physics:

- Predicted zero of $A_{FB}(s)$ depends on Wilson coefficients $C_7^{\text{eff}}/C_9^{\text{eff}}$

$$A_{FB}(s) = \frac{\int_0^1 \frac{d^2\Gamma}{dsd\cos\theta}d\cos\theta - \int_{-1}^0 \frac{d^2\Gamma}{dsd\cos\theta}d\cos\theta}{\int_0^1 \frac{d^2\Gamma}{dsd\cos\theta}d\cos\theta + \int_{-1}^0 \frac{d^2\Gamma}{dsd\cos\theta}d\cos\theta}$$

Transverse Asymmetry:
(asymmetry in the spin amplitude of the $K^*$

$$A_T^{(2)}(s) = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}.$$}

$K^*$ polarisation can be measured

$q^2$ Invariant mass squared of the dimuon system $q^2 = m_{\mu^+\mu^-}^2$.

$\theta_\ell$ Angle between the direction of the $\mu^-$ in the $\mu^+\mu^-$ rest frame and the direction of the $\mu^+\mu^-$ in the $\bar{B}_d$ rest frame.

$\theta_K$ Angle between the kaon in the $\bar{K}^{*0}$ rest frame and the $\bar{K}^{*0}$ in the $\bar{B}_d$ rest frame.

$\phi$ Angle between planes defined by $\mu^-\mu^+$ and the $K\pi$ in the $\bar{B}_d$ frame.
$A_{FB}$ in $B^0 \rightarrow K^{*0}\mu^+\mu^-$ decay

Present results from B-factories and CDF have poor precision.
LHCb analysis of $B^0 \rightarrow K^{*0}\mu^+\mu^-$ decay

Select events using a Boosted Decision Tree

Veto $J/\psi$ and $\psi(2S)$ regions

$323 \pm 21$ signals in $309 \text{ pb}^{-1}$
LHCb analysis of \( B^0 \rightarrow K^{*0} \mu^+ \mu^- \) decay

Measure in 6 bins of \( q^2 \):

- Differential BR \( d\Gamma/dq^2 \) relative to BR \( (B^0 \rightarrow J/\psi K^*) \)
- \( A_{FB} \)
- Longitudinal polarization \( F_L \)

Perform simultaneous fit of \( \theta_1 \) and \( \theta_K \)

\[
\frac{1}{\Gamma} \frac{d^2\Gamma}{d\cos \theta_K dq^2} = \frac{3}{2} F_L \cos^2 \theta_K + \frac{3}{4} (1 - F_L)(1 - \cos^2 \theta_K)
\]

\[
\frac{1}{\Gamma} \frac{d^2\Gamma}{d\cos \theta_\ell dq^2} = \frac{3}{4} F_L (1 - \cos^2 \theta_\ell) + \frac{3}{8} (1 - F_L)(1 + \cos^2 \theta_\ell) + A_{FB} \cos \theta_\ell
\]

Fit procedure validated on \( B^0 \rightarrow J/\psi K^* \) data and MonteCarlo
LHCb results of $B^0 \rightarrow K^{*0}\mu^+\mu^-$ decay

Small systematic uncertainty

Data in agreement with SM and with previous experiments (BaBar, Belle, CDF)

Future: measure other observables ($A_T^{(2)}, K^* \text{pol}$)
LHCb results for $A_{FB}$: comparison

Results ($A_{FB}$ and $F_L$) are consistent with measurements from previous experiments.

LHCb-CONF-2011-038

LHCb results as a constraint on $C_7^{(\ell)}$

From [arXiv:1104.334]

$A_I(K^{*0}\gamma)$, $S_{K^{*0}\gamma}$, $\mathcal{B}(b \to s\gamma)$

$A_{FB}$ probes $C_{10}(C_9 + \beta(q^2)C_7)$

$A_{FB}$ does not strongly constrain $C_7^{(\ell)}$. Large effects in $A_T^{2\ell}$ can still be possible with SM-like $A_{FB}$. 
Summary

Flavor Physics can give information on some major open problems of physics today

The effects of New Physics in loops can be seen in rare decay branching fractions (B, $\tau$) and kinematic distributions, and in $CP$-violating asymmetries in channels with small ($10^{-5}$- $10^{-6}$)

Branching Fractions

New source of CP violation must exist: find out where it is will disclose New Physics

LHCb will (and already does) contribute crucially to this field now and for the years to come
Summary

other future projects will greatly contribute in improving the knowledge in the flavor sector:

- in the near future LHCb will improve with higher precision, better understanding of the detector, the study of a wide variety of processes where loops can contain New Physics

- Super $B$-Factories can, in the next decade, provide high precision measurements ($\rightarrow$ leptonic decays, searches for lepton flavor violation) complementary to those of hadronic experiments ($\rightarrow B_s$, and $B_d/B_s$ very rare decays at LHC)

- Rare $K$ decay experiments ($K \rightarrow \pi \nu \nu$, $K \rightarrow \pi^{+} \pi^{-}$ $Br \sim 10^{-10}$, $10^{-11}$)

Better theoretical understanding and predictions will be fundamental for the achievement of this program
# Effects on flavor physics

Buras, arXiv:0910.1032v1

<table>
<thead>
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<th>AC</th>
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<th>AKM</th>
<th>δLL</th>
<th>FBMSSM</th>
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<td>★★★</td>
<td>★</td>
<td>★</td>
<td>★</td>
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<td>$\varepsilon_K$</td>
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<td>$A_{\text{CP}}(B \to X_s \gamma)$</td>
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<td>★</td>
<td>★</td>
<td>★★★</td>
<td>★</td>
<td>★</td>
<td>?</td>
</tr>
<tr>
<td>$A_{7,8}(B \to K^* \mu^+ \mu^-)$</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★★★</td>
<td>★</td>
<td>★★★</td>
<td>?</td>
</tr>
<tr>
<td>$A_{9}(B \to K^* \mu^+ \mu^-)$</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>?</td>
</tr>
<tr>
<td>$B \to K^{(*)} \nu \bar{\nu}$</td>
<td>★</td>
<td>★</td>
<td>★</td>
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<tr>
<td>$B_s \to \mu^+ \mu^-$</td>
<td>★★★</td>
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<tr>
<td>$K^+ \to \pi^+ \nu \bar{\nu}$</td>
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<tr>
<td>$K_L \to \pi^0 \nu \bar{\nu}$</td>
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<tr>
<td>$\mu \to e \gamma$</td>
<td>★★★</td>
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<tr>
<td>$d_n$</td>
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<tr>
<td>$(g-2)_\mu$</td>
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<td>★★★</td>
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</tr>
</tbody>
</table>

**Table 2:** “DNA” of flavour physics effects [55] for the most interesting observables in a selection of SUSY and non-SUSY models. ★★★ signals large effects, ★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.