



Rare penguin decays at LHCb

Beyond the 3SM generation at the LHC era

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NIKHEF

Introduction

Loop induced rare decays are sensitive to **New Physics**.

New Particles (such as 4th gen quarks) can modify the SM Wilson coefficients or introduce **new CPV** phases.

Physics interest	Measurement
- $B_s^0 \rightarrow \Phi \Phi$	Time dependent and direct CP Asymmetry
- $B_s^0 \rightarrow \Phi \gamma$, $B_d^0 \rightarrow K^{*0} \gamma$	V-A structure of the SM
- $B_d^0 \rightarrow K^{*0} \mu\mu$	Branching ratio and angular asymmetries
- $B_s \rightarrow \mu \mu$	

Physics interest

- $B_s^0 \rightarrow \Phi \Phi$
- $B_s^0 \rightarrow \Phi \gamma$, $B_d^0 \rightarrow K^{*0} \gamma$
- $B_d^0 \rightarrow K^{*0} \mu\mu$
- $B_s \rightarrow \mu \mu$

Measurement

- Time dependent and direct CP Asymmetry
- V-A structure of the SM
- Branching ratio and angular asymmetries

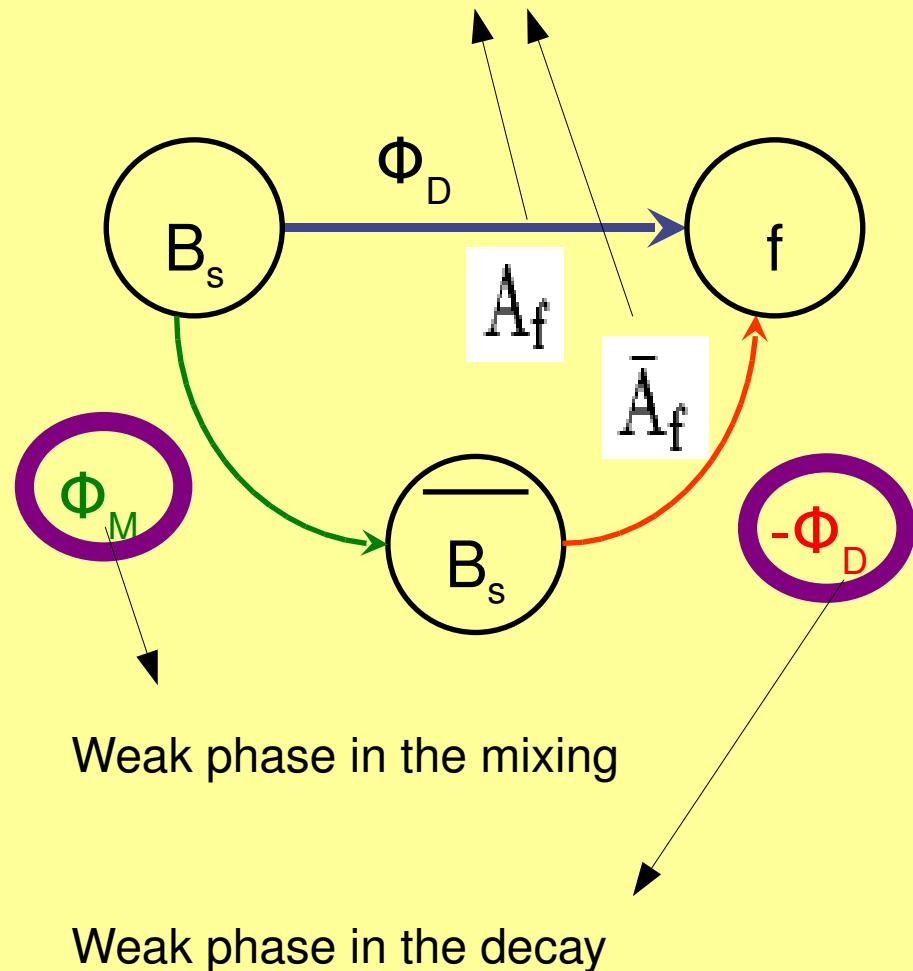
New CPV sources

V-A structure of the SM

Wilson Coefficients

CP Violation in B system

Decay amplitudes



The mixing between the B-CP eigenstates is described by:

$$|B_{H,L}\rangle = p|B^0\rangle \mp q|\bar{B}^0\rangle$$

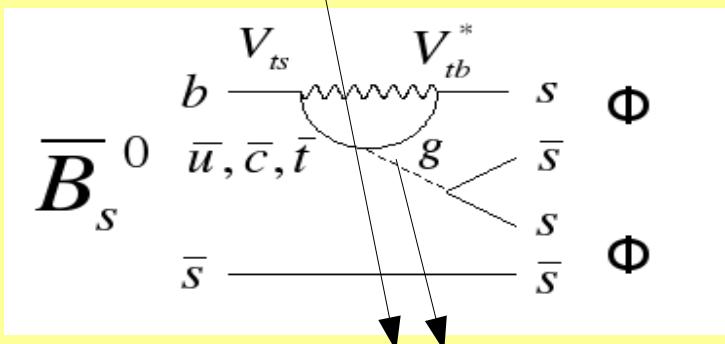
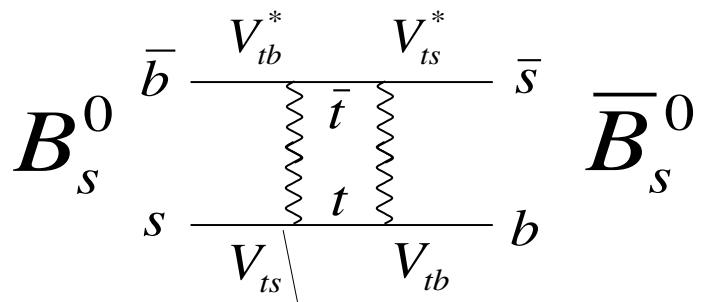
$$\lambda_f = \frac{q \bar{A}_f}{p A_f}$$

When the B_s decays in a CP-eigenstate (or a superposition of CP-eigenstates), CPV can arise in the interference between mixing and decay:

$$\left| \frac{q}{p} \right| = 1, \quad \left| \frac{\bar{A}_f}{A_f} \right| = 1, \quad \arg \lambda_f \neq 0$$

The CPV weak phase is given by:
 $\phi_s(B_s^0 \rightarrow f) \equiv \Phi_M(B_s^0) - \Phi_D(B_s^0 \rightarrow f)$

CPV in the $B_s \rightarrow \Phi\Phi$ decay



NP can enter in both the mixing and the decay contributing with new CPV phases (sensitive to the 4x4 CKM elements V_{ts} and V_{tb}).

Comparison between the $B_s \rightarrow J/\psi \Phi$ allows us to disentangle the two NP contributions.

For the $B_s \rightarrow \Phi\Phi$, the dependence on V_{ts} and V_{tb} in both the B_s mixing and the decay amplitude leads to a complete weak phase cancellation

$$\Phi_s^{\text{SM}}(B_s \rightarrow \Phi\Phi) \sim 0$$

$$\text{N.B.: } \Phi_s^{\text{SM}}(B_s \rightarrow J/\psi \Phi) = 2 \cdot \arg[V_{tb}^* V_{ts}] = -2 \cdot \beta_s$$

$B_s \rightarrow \Phi \Phi$ observed by CDF :

$$\text{BR}(B_s^0 \rightarrow \phi\phi) = (14^{+6}_{-5}(\text{stat.}) \pm 6(\text{syst.})) \times 10^{-6}$$

LHCb expectation for $B_s^0 \rightarrow \Phi(\rightarrow K^+K^-) \Phi(\rightarrow K^+K^-)$

$$N_{\text{sig}} = 3092 \pm 105 \text{ (in } 2\text{fb}^{-1}\text{)}$$

$$N_{\text{bg}} < 2.4 \cdot 10^3 \text{ (in } 2\text{fb}^{-1}\text{)}$$

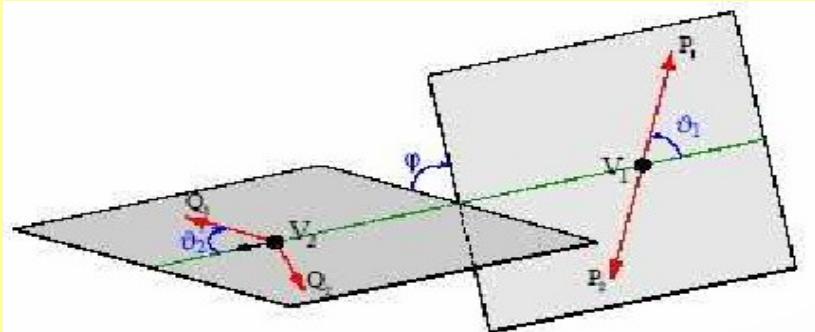
Time dependent CP Asymmetry in the $B_s \rightarrow \Phi\Phi$ decay

We can measure the weak CPV phase by measuring the time dependent CP asymmetry:

$$\mathcal{A}(t) \equiv \frac{\Gamma [\bar{B}_s^0(t) \rightarrow f] - \Gamma [B_s^0(t) \rightarrow f]}{\Gamma [\bar{B}_s^0(t) \rightarrow f] + \Gamma [B_s^0(t) \rightarrow f]} = \frac{\mathcal{A}^{\text{dir}} \cos(\Delta m_s t) + \mathcal{A}^{\text{mix}} \sin(\Delta m_s t)}{\cosh(\Delta \Gamma_s t/2) - \mathcal{A}^{\Delta \Gamma} \sinh(\Delta \Gamma_s t/2)}$$

Angular analysis needed to disentangle the different CP components :

$$\frac{d\Gamma(t)}{dcos\theta_1 dcos\theta_2 d\varphi} \propto \sum_{j=0}^6 K_j(t) f_j(\theta_1, \theta_2, \varphi)$$



SM prediction:

$$\mathcal{A}_l^{\text{dir,SM}} \cong 0,$$

$$\mathcal{A}_l^{\text{mix,SM}} = \eta_l \sin(\phi_s^{\text{SM}}) \cong 0,$$

$$\mathcal{A}_l^{\Delta \Gamma, \text{SM}} = \cos(\phi_s^{\text{SM}}) \cong 1.$$

LHCb sensitivity to the angle Φ_s ([LHCb-2007-047](#))

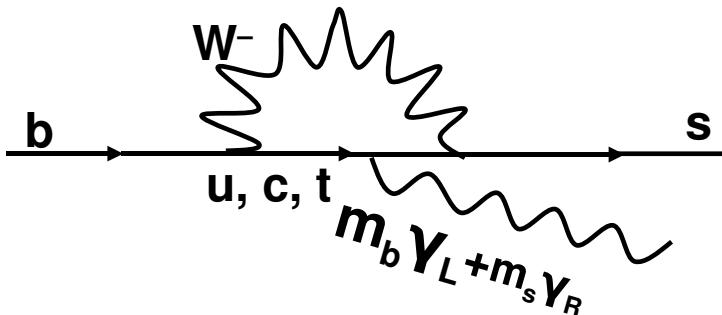
$\sigma(\Phi) = 0.12$ with 2fb^{-1} (1 year of LHCb)

$\sigma(\Phi) = 0.05$ with 10fb^{-1} (5 years of LHCb)

Radiative penguins $B \rightarrow V\gamma$

Photon polarization is sensitive to V-A structure

Photon polarization can be measured by time dependent CP asymmetry



Dominated by the C_7 Wilson coefficient.

Interesting channels:

$B_s \rightarrow \Phi\gamma$ and $B_d \rightarrow K^*\gamma$

SM prediction:

$$\text{Br}(B_s \rightarrow \Phi\gamma) = (39.4 \pm 10.7 \pm 5.4) \cdot 10^{-6}$$

$B_s \rightarrow \Phi\gamma$ observed by BELLE at the Y(5s)

([Phys. Rev. Lett. 100, 121801 \(2008\)](#)):

$$\text{Br}(B_s \rightarrow \Phi\gamma) = 57^{+18}_{-15} \text{ (stat)} \quad {}^{+12}_{-11} \text{ (syst)} \cdot 10^{-6}$$

$$\text{Br}(B_d \rightarrow K^*\gamma) = (4.01 \pm 0.20) \cdot 10^{-5}$$

observed by CLEO

([Phys. Rev. Lett. 84 5283](#)),

Babar ([Phys. Rev. D 70 112006](#))

and Belle ([Phys. Rev. D 69 112001](#))

$B_s \rightarrow \Phi\gamma$ at LHCb

Signal yield ($B_s \rightarrow \Phi(\rightarrow K^+K^-)\gamma$) : 7700 in 2fb^{-1} (1 year of LHCb)

Background events (in 2fb^{-1}) < 4700 (arXiv:0802.0876v1 LHCb-2007-030).

Time dependent CP asymmetry (for $|p/q|=1$) :

$$\mathcal{A}_{\text{CP}}(B_s \rightarrow \phi\gamma)[t] = \frac{S \sin(\Delta m_s t) - C \cos(\Delta m_s t)}{\cosh(\frac{\Delta \Gamma_s}{2}t) - H \sinh(\frac{\Delta \Gamma_s}{2}t)}$$

Free parameters: C, S and H

H and S sensitive to right-handed currents

C sensitive to new CPV phases (proportional to β_s)

To measure the parameters C and S the knowledge of the initial B-flavor is needed.

For the measurement of H (possible thanks to $\Delta \Gamma_s \neq 0$) no-flavor tagging is needed arXiv:0802.0876).

A similar analysis is also possible in the $B_s \rightarrow \Phi\mu\mu$ (under study)

Requires the measurement of $\Delta \Gamma_s$ elsewhere
(i.e. $B_s \rightarrow J/\psi \Phi$)

$B_s \rightarrow \Phi\gamma$ at LHCb

Right-handed currents contribution more detectable in H (proportional to cos of the total weak phase) rather than S (proportional to sine of the total weak phase).

Resolution for the S,C and H
parameters in 1 year of data taking at LHCb

$$\sigma_S = 0.11 \text{ (} 2 \text{ fb}^{-1} \text{)}$$

$$\sigma_C = 0.11 \text{ (} 2 \text{ fb}^{-1} \text{)}$$

$$\sigma_H = 0.16 \text{ (} 2 \text{ fb}^{-1} \text{)}$$

$B_d \rightarrow K^*\gamma$ at LHCb

The parameter S was already measured by the B-factories in the $B_d \rightarrow K^*\gamma$ decay

The average is $S_{K^*\gamma} = -0.19 \pm 0.23$ (arXiv:0704.3575v1).

Direct CP asymmetry in

$B_d \rightarrow K^{*0} (\rightarrow K^+ \pi^-) \gamma$ under study.

Annual yield: 68K events (2fb^{-1})

Bg events < 41K @ 90% CL (LHCb-2007-030)

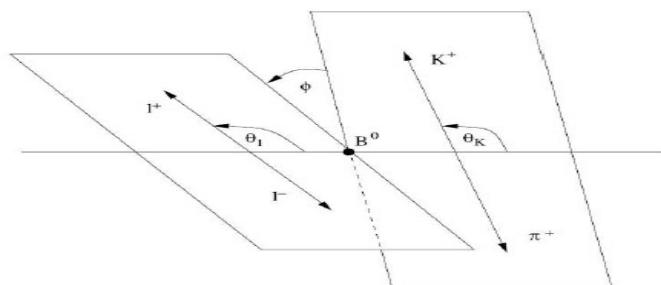
$$A_{CP} = \frac{N_{B^0 \rightarrow K^{*0}\gamma} - N_{\bar{B}^0 \rightarrow \bar{K}^{*0}\gamma}}{N_{B^0 \rightarrow K^{*0}\gamma} + N_{\bar{B}^0 \rightarrow \bar{K}^{*0}\gamma}}.$$

AFB in the $B_d \rightarrow K^{*0} \mu^+ \mu^-$

This decay is completely described by the differential decay rate:

$$\frac{d^4\Gamma_{\bar{B}_d}}{dq^2 d\theta_l d\theta_K d\phi} = \frac{9}{32\pi} I(q^2, \theta_l, \theta_K, \phi) \sin \theta_l \sin \theta_K$$

See LHCb-2007-057 for details



The AFB is the asymmetry between the forward going ($\cos \theta_l > 0$) and the backward going ($\cos \theta_l < 0$) μ^+ wrt the B flight direction in the $\mu\mu$ -rest frame.

The q^2 point (S_0) in which the $\text{AFB}(q^2)=0$ is very sensitive to NP and theoretically predicted (for the SM and several NP models).

The visible branching ratio is $\text{Br}(B \rightarrow K^{*0} (\rightarrow K^+ \pi^-) \mu^+ \mu^-) = 1.22_{-0.32}^{+0.38} \cdot 0.67 \cdot 10^{-6}$

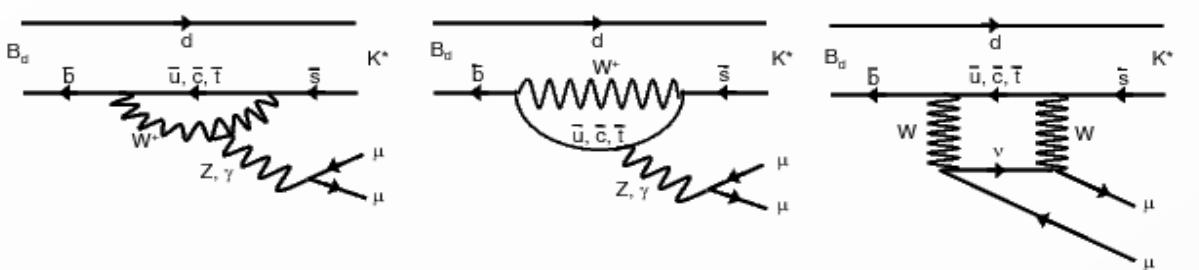
Signal yield: 7200 ± 180 events (2fb^{-1}),

Expected background events : 1770 events (2fb^{-1})

(Bg from non-resonant $B_d^0 \rightarrow K^+ \pi^- \mu\mu$ not considered). LHCb-2007-038

NP in the $B_d \rightarrow K^* \mu \mu$

SM diagrams for the $B_d \rightarrow K^* \mu \mu$ decay:



NP particles in the loops such as t' (4th generation) changes the AFB.

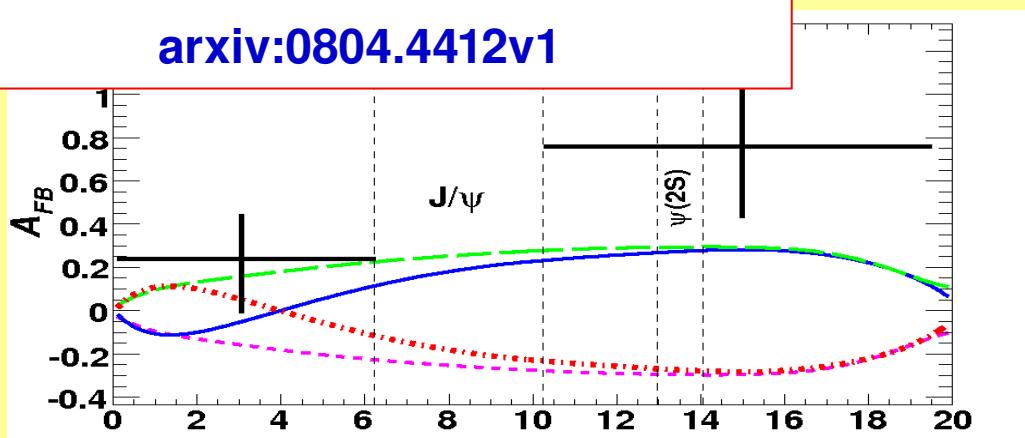
Number of events:

Belle ~ 230 events

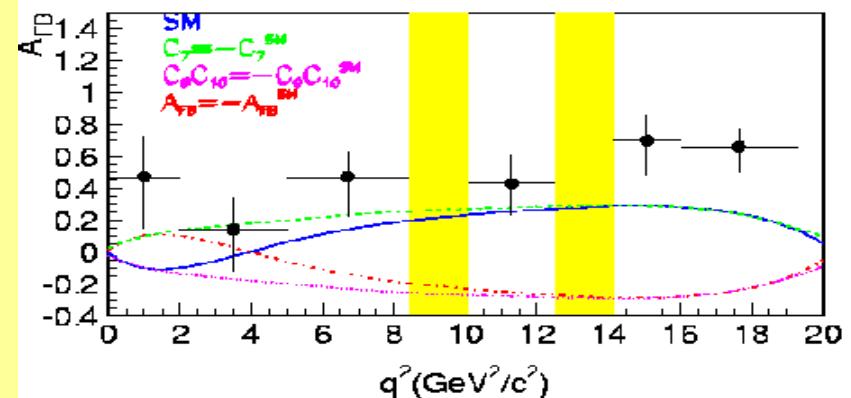
LHCb ~ 1800 events (end 2009)

Most recent BaBar measurement

[arxiv:0804.4412v1](https://arxiv.org/abs/0804.4412v1)



Belle Results from ICHEP 2008



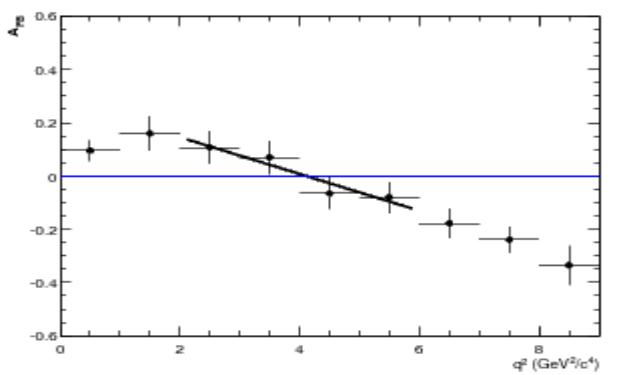
For Beyond the 3SM gen. see for instance Phys. Rev. D 77, 014016 (2008)

This process is dominated by the C_7 , C_9 and C_{10} Wilson coefficients.

$B_d \rightarrow K^* \mu \mu$: Extracting AFB and S_0

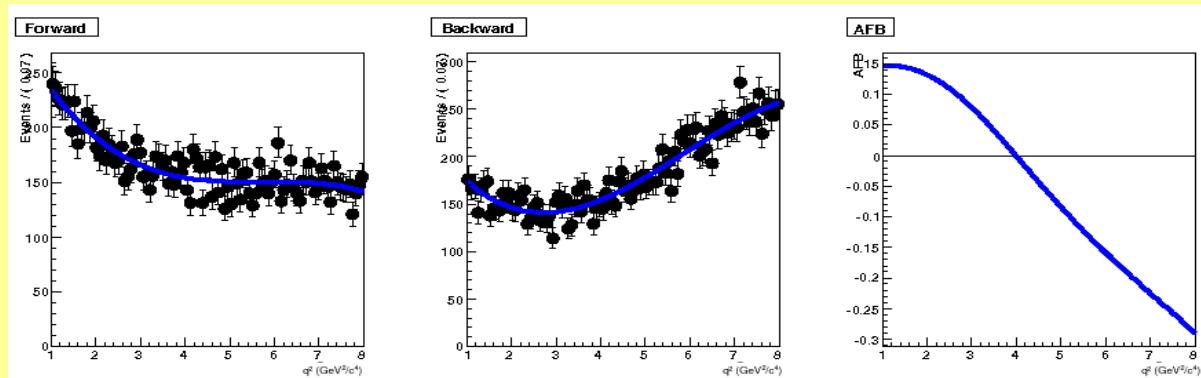
The simplest method to extract the AFB is a counting experiment, subtracting q^2 -histograms for forward and backward events.

AFB distribution for one 2fb^{-1} experiment (below the J/ψ resonance)



Straight line fit to extract S_0 ([LHCb-2007-039](#)):
 $\sigma(S_0)=0.46\text{GeV}^2$ in 2fb^{-1} .

We can do an unbinned likelihood fit of the q^2 distributions for forward and backward events

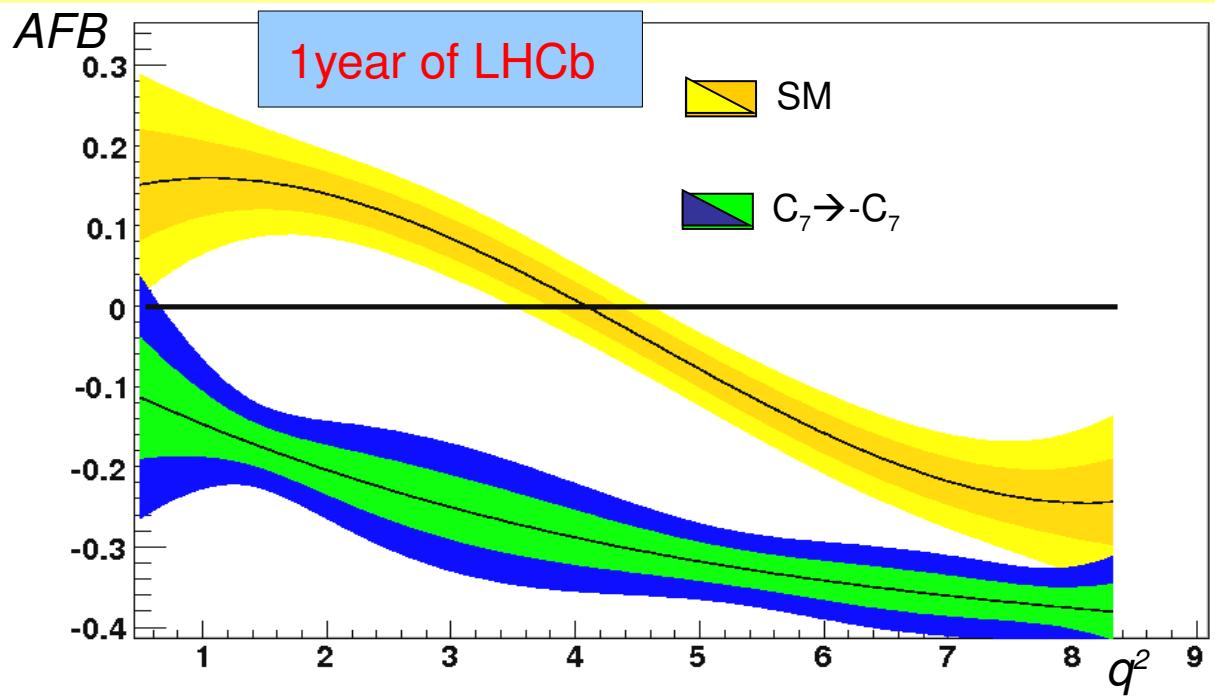


With this method we do not rely anymore on the straight-line-shape near S_0 .

$B_d \rightarrow K^* \mu \mu$: 2D unbinned projection fit

Another possibility is to extract the AFB fitting simultaneously the two distributions (see [LHCb-2007-057](#)):

$$\frac{d\Gamma}{dq^2 d\theta_l} = \frac{d\Gamma}{dq^2} \left(\frac{3}{4} F_L \sin^2 \theta_l + \frac{3}{8} (1 - F_L) (1 + \cos^2 \theta_l) + A_{FB} \cos \theta_l \right) \sin \theta_l$$
$$\frac{d\Gamma}{dq^2 d\theta_k} = \frac{3}{4} \frac{d\Gamma}{dq^2} \sin \theta_k (2 F_L \cos^2 \theta_k + (1 - F_L) \sin^2 \theta_k)$$



An improvement of
40% on $\sigma(S_0)$
expected wrt the
unbinned q^2 fit.

No bg and acceptance
considered!

$B_d \rightarrow K^* \mu \mu$: 4D unbinned likelihood fit

$$\frac{d^4\Gamma_{\bar{B}_d}}{dq^2 d\theta_l d\theta_K d\phi} = \frac{9}{32\pi} I(q^2, \theta_l, \theta_K, \phi) \sin \theta_l \sin \theta_K$$

$$I = I_1 + I_2 \cos 2\theta_l + I_3 \sin^2 \theta_l \cos 2\phi + I_4 \sin 2\theta_l \cos \phi + I_5 \sin \theta_l \cos \phi + I_6 \cos \theta_l \\ + I_7 \sin \theta_l \sin \phi + I_8 \sin 2\theta_l \sin \phi + I_9 \sin^2 \theta_l \sin 2\phi.$$

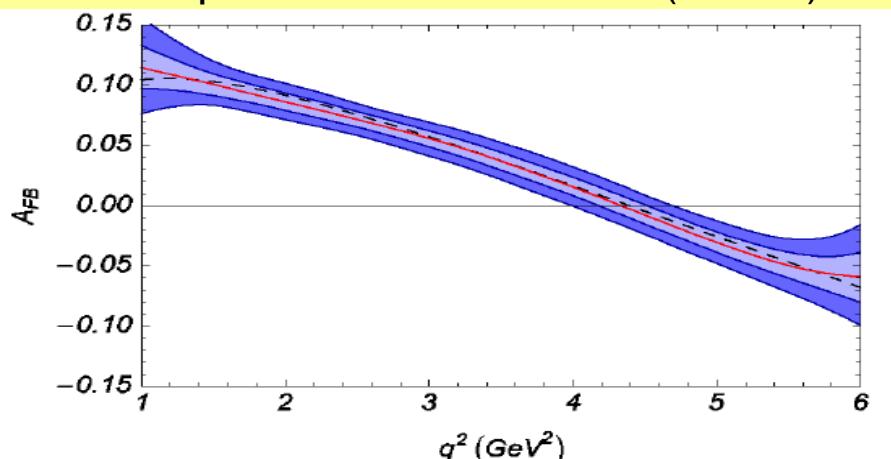
The I_i terms are functions of the amplitudes

$A_{||}^{L,R}$, $A_{\perp}^{L,R}$ and $A_0^{L,R}$ (6 complex numbers, which depend on q^2) .

We can probe more angular asymmetries which are a function of these amplitudes.

See [arXiv:0807.2589](https://arxiv.org/abs/0807.2589)

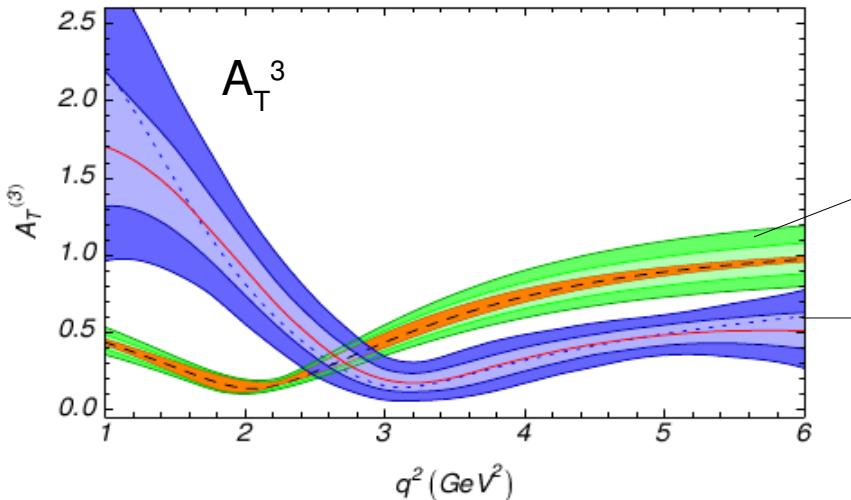
LHCb expectation for the AFB (10fb^{-1})



Improvement of the order of (20-30%) on $\sigma(S0)$ wrt the projection fit is expected.

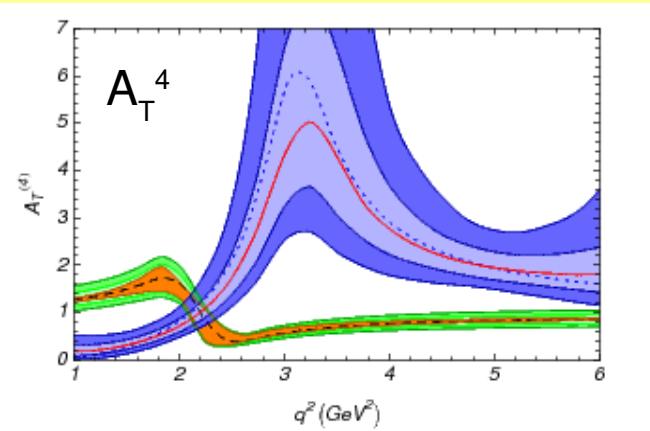
Systematics more difficult to control
(under study)
Form factors from
[M. Beneke et al. Eur. Phys. J. C41, 173 \(2005\)](https://doi.org/10.1088/0954-3899/41/1/173)

More asymmetries in $B_d \rightarrow K^* \mu\mu$



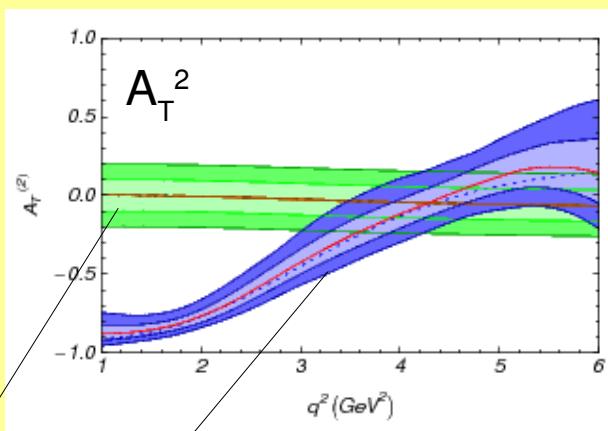
Theoretical prediction for the SM

LHCb expectation for SUSY-b (5 years)



Theoretical prediction for the SM

LHCb expectation for SUSY-b (5 years)



Similar for B_s analogy

$B_s \rightarrow \Phi \mu \mu$ under study (LHCb-2007-154).

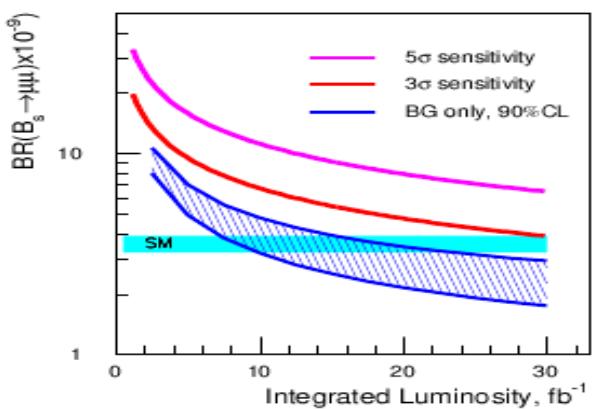
SUSY-b:
SUSY model with C_7'
non-SM contributions.
For details see:
[arXiv:0807.2589](https://arxiv.org/abs/0807.2589)

$B_s \rightarrow \mu \mu$: Branching Ratio

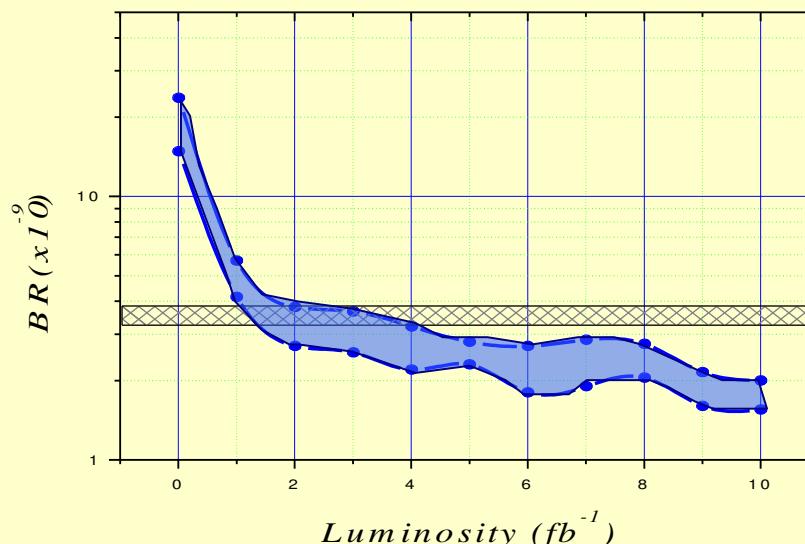
The branching ratio for the channel $B_s \rightarrow \mu \mu$ is sensitive to many NP theories.

For theories beyond 3SM generations the branching ratio depends on the t' mass and on the 4x4 CKM parameter $V_{t'b} V_{t's}^*$ (see [Eur.Phys.J. C27 \(2003\) 405-410](#)).

ATLAS/CMS ([arXiv:0801.1833v1](#))



3 σ observation (LHCb)



Assuming SM Branching ratio (LHCb):

$2 \text{ fb}^{-1} \Rightarrow 3\sigma \text{ evidence (1year)}$

$6 \text{ fb}^{-1} \Rightarrow 5\sigma \text{ observation (5years)}$

Assuming SM Branching ratio (ATLAS/CMS):

$30 \text{ fb}^{-1} \Rightarrow 3\sigma \text{ evidence (3years)}$

([LHCb-2008-018](#))

LHCb can exclude the BR above the SM with only 0.5 fb^{-1} of data (end of 2009)

The $B_s \rightarrow \mu \mu \gamma$ is under study within the LHCb collaboration.

Conclusions

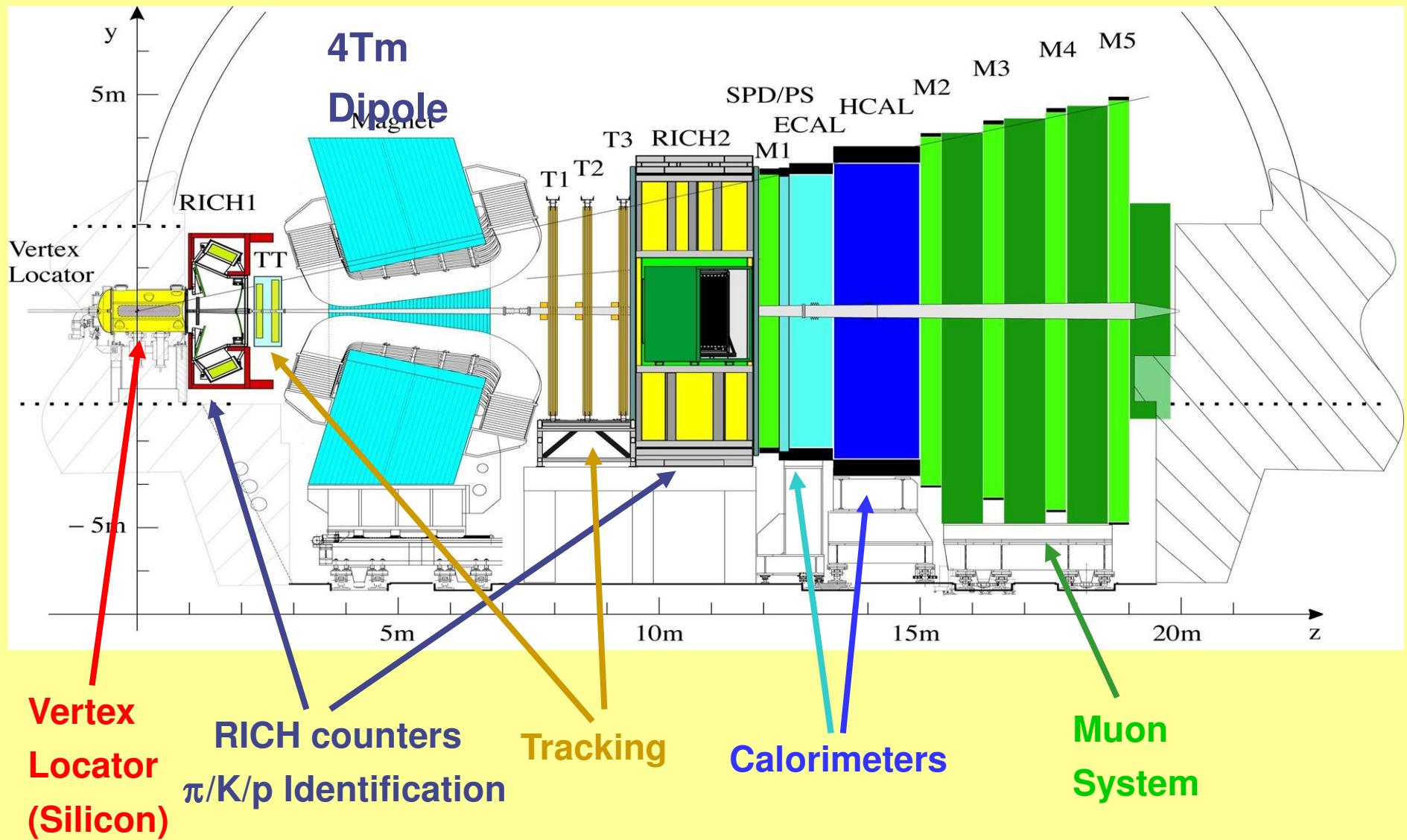
- Rare penguin decays are very sensitive to NP: test of CKM and the V-A structure of the SM.
- LHCb can strongly constrain or discover NP in the following channels:
 - $B_s^0 \rightarrow \Phi\Phi$: Weak CPV phase;
 - $B_{s/d} \rightarrow \Phi/K^*\gamma$: Time dependent (direct) CP asymmetry;
 - $B_d^0 \rightarrow K^{*0}\mu\mu$: AFB and more angular asymmetries;
 - $B_s \rightarrow \mu\mu$: Branching ratio.

We hope to find some non-SM penguins



Back-up SLIDES

The LHCb detector ($1.9 < \eta < 4.9$)



Fit model for $B_s \rightarrow \Phi \Phi$

$$\frac{d\Gamma(t)}{dcos\theta_1 dcos\theta_2 d\varphi} \propto \sum_{j=0}^6 K_j(t) f_j(\theta_1, \theta_2, \varphi).$$

$$f_1(\theta_1, \theta_2, \varphi) = 4\cos^2\theta_1\cos^2\theta_2,$$

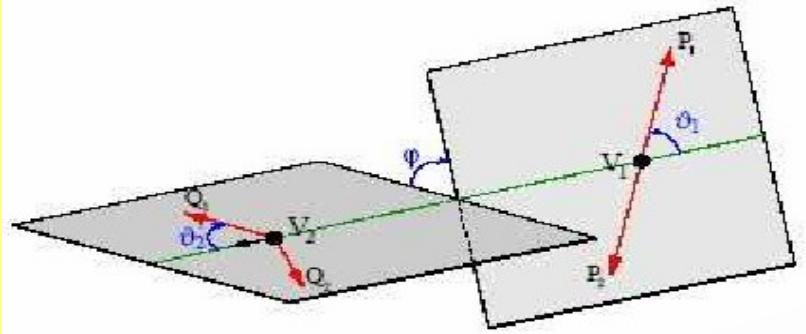
$$f_2(\theta_1, \theta_2, \varphi) = \sin^2\theta_1\sin^2\theta_2(1 + \cos 2\varphi),$$

$$f_3(\theta_1, \theta_2, \varphi) = \sin^2\theta_1\sin^2\theta_2(1 - \cos 2\varphi),$$

$$f_4(\theta_1, \theta_2, \varphi) = -2\sin^2\theta_1\sin^2\theta_2\sin 2\varphi,$$

$$f_5(\theta_1, \theta_2, \varphi) = \sqrt{2}\sin 2\theta_1\sin 2\theta_2\cos\varphi,$$

$$f_6(\theta_1, \theta_2, \varphi) = -\sqrt{2}\sin 2\theta_1\sin 2\theta_2\sin\varphi.$$



$$K_1(t) = \frac{1}{2}A_0^2 [(1 + \cos\phi_s)e^{-\Gamma_L t} + (1 - \cos\phi_s)e^{-\Gamma_H t} + 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s],$$

$$K_2(t) = \frac{1}{2}A_{||}^2 [(1 + \cos\phi_s)e^{-\Gamma_L t} + (1 - \cos\phi_s)e^{-\Gamma_H t} + 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s],$$

$$K_3(t) = \frac{1}{2}A_{\perp}^2 [(1 - \cos\phi_s)e^{-\Gamma_L t} + (1 + \cos\phi_s)e^{-\Gamma_H t} - 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s],$$

$$K_4(t) = |A_{||}| |A_{\perp}| [e^{-\Gamma_s t} \{ \sin\delta_1 \cos(\Delta m_s t) - \cos\delta_1 \sin(\Delta m_s t) \cos\phi_s \} \\ - \frac{1}{2} (e^{-\Gamma_H t} - e^{-\Gamma_L t}) \cos\delta_1 \sin\phi_s],$$

$$K_5(t) = \frac{1}{2} |A_0| |A_{||}| \cos(\delta_2 - \delta_1) \\ [(1 + \cos\phi_s)e^{-\Gamma_L t} + (1 - \cos\phi_s)e^{-\Gamma_H t} + 2e^{-\Gamma_s t}\sin(\Delta m_s t)\sin\phi_s],$$

$$K_6(t) = |A_0| |A_{\perp}| [e^{-\Gamma_s t} \{ \sin\delta_2 \cos(\Delta m_s t) - \cos\delta_2 \sin(\Delta m_s t) \cos\phi_s \} \\ - \frac{1}{2} (e^{-\Gamma_H t} - e^{-\Gamma_L t}) \cos\delta_2 \sin\phi_s] \quad \begin{aligned} \delta_1 &\equiv \arg(A_{\perp}/A_{||}) \\ \delta_2 &\equiv \arg(A_{\perp}/A_0) \end{aligned}$$

free parameters of the fit

ϕ_s , B/S, R_{\perp} , $R_{||}$, δ_1 , δ_2 , Γ_s and $\Delta\Gamma_s/\Gamma_s$

$$R_{\perp} \equiv |A_{\perp}|^2 / (|A_0|^2 + |A_{||}|^2 + |A_{\perp}|^2)$$

$$R_{||} \equiv |A_{||}|^2 / (|A_0|^2 + |A_{||}|^2 + |A_{\perp}|^2)$$

Fit model for $B_s \rightarrow \Phi \Phi$

The fit has 8 free parameters.

The total PDF has the form

$$p_{\text{tot}} = (1 - f_b)p_{\text{sig}} + f_b p_{\text{bg}}$$

where:

$$p_{\text{sig(bg)}} = \epsilon_{\text{sig(bg)}}^A(t) \times p_{\text{sig(bg)}}^{4D}(t, \cos\theta_1, \cos\theta_2, \varphi, I_{\text{cat}}) \times p_{\text{sig(bg)}}^{\text{mass}}(m_{B_s^0}),$$

Proper time acceptance

$$\epsilon_{\text{sig(bg)}}^A(t) \propto \frac{t^3}{b_{\text{sig(bg)}} + t^3}.$$

Mass distribution PDF:

Signal: gaussian distribution.

Background: flat distribution.

Angular and proper time dependent PDF:

Signal: Angular and proper time distribution (taken from theory) convoluted with the proper time resolution, also taking into account the tagging efficiency and the wrong tag probability.

Background: Constant distribution wrt to the angles ,times the function $e^{-\Gamma t}$ (for the

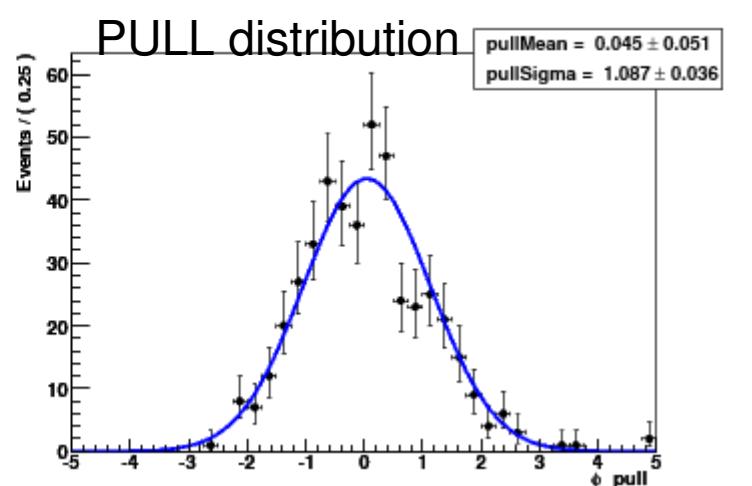
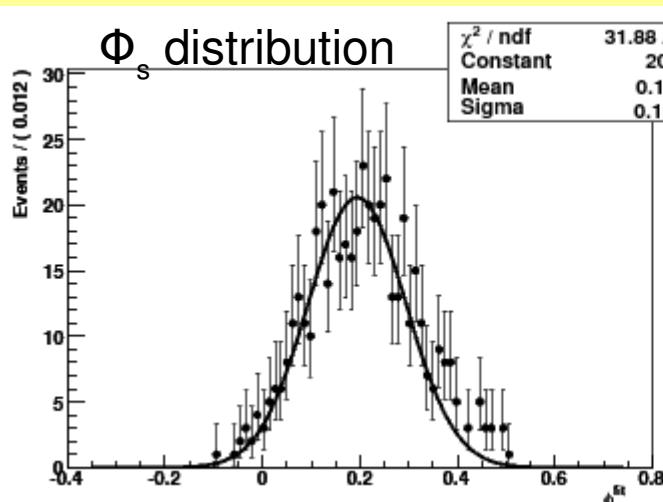
Result of 500 toy experiments with $\Phi^{\text{input}} = 0.20$.

$$\sigma(\Phi) = 0.11$$

$$\text{with } 2\text{fb}^{-1}.$$

$$\sigma(\Phi) = 0.05$$

$$\text{with } 10\text{fb}^{-1}.$$



Time dependent CP Asymm ($B_s \rightarrow \Phi\gamma$)

$$\mathcal{A}_{\text{CP}}(B_s \rightarrow \phi\gamma) \equiv \frac{\Gamma[\bar{B}_s \rightarrow \phi\gamma] - \Gamma[B_s \rightarrow \phi\gamma]}{\Gamma[\bar{B}_s \rightarrow \phi\gamma] + \Gamma[B_s \rightarrow \phi\gamma]}$$

Because $q/p \sim 1$ in the B_s system:

$$\mathcal{A}_{\text{CP}}(B_s \rightarrow \phi\gamma)[t] = \frac{S \sin(\Delta m_s t) - C \cos(\Delta m_s t)}{\cosh(\frac{\Delta\Gamma_s}{2}t) - H \sinh(\frac{\Delta\Gamma_s}{2}t)}$$

Theoretical prediction for $B_s \rightarrow \Phi\gamma$:

$$H_{\phi\gamma} = 0.047 \pm 0.025 + 0.015_{O(\alpha_s)} \quad S_{\phi\gamma} = 0 \pm 0.002$$

$$C_{\phi\gamma} = 0.005(5)$$

$$H[S] = \xi \frac{\pm 2 A_L A_R \cos(\delta_L - \delta_R) \cos[\sin](\phi_s - \phi_L - \phi_R)}{(A_L)^2 + (A_R)^2}$$

The parameters C, S and H can be written as a function of the left-handed (A_L) and right-handed (A_R) amplitudes as follow:

$$C = \frac{(|\mathcal{A}_L|^2 + |\mathcal{A}_R|^2) - (|\bar{\mathcal{A}}_R|^2 + |\bar{\mathcal{A}}_L|^2)}{|\mathcal{A}_L|^2 + |\bar{\mathcal{A}}_L|^2 + |\mathcal{A}_R|^2 + |\bar{\mathcal{A}}_R|^2}$$

$$S = \frac{2 \text{Im}[\frac{q}{p} (\bar{\mathcal{A}}_L \mathcal{A}_L^* + \bar{\mathcal{A}}_R \mathcal{A}_R^*)]}{|\mathcal{A}_L|^2 + |\bar{\mathcal{A}}_L|^2 + |\mathcal{A}_R|^2 + |\bar{\mathcal{A}}_R|^2}$$

$$H = \frac{2 \text{Re}[\frac{q}{p} (\bar{\mathcal{A}}_L \mathcal{A}_L^* + \bar{\mathcal{A}}_R \mathcal{A}_R^*)]}{|\mathcal{A}_L|^2 + |\bar{\mathcal{A}}_L|^2 + |\mathcal{A}_R|^2 + |\bar{\mathcal{A}}_R|^2}.$$

In the B_d , because $\Delta\Gamma$ is too small only S is measurable:

$$Bd \rightarrow K^*\gamma \quad S = 0.19 \pm 0.23 \text{ (HFAG)}$$

$$Bd \rightarrow \rho\gamma \quad S = 0.82 \pm 0.65 \pm 0.18 \text{ (BELLE)}$$

Time dependent CP Asymm ($B_s \rightarrow \Phi\gamma$)

Time dependent CP asymmetry:

$$\Gamma(B_q(\bar{B}_q) \rightarrow f^{CP} \gamma) \propto e^{-\Gamma_q t} \left(\cosh \frac{\Delta \Gamma_q t}{2} - \mathcal{A}^\Delta \sinh \frac{\Delta \Gamma_q t}{2} \pm \right. \\ \left. \pm \mathcal{C} \cos \Delta m_q t \mp \mathcal{S} \sin \Delta m_q t \right)$$

Within the SM:

$$S \approx \sin 2\psi \sin \varphi, A^\Delta \approx \sin 2\psi \cos \varphi, C \approx 0$$

Where:

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

$$\varphi = 2 \arg(V_{ts}^* V_{tb}) + \phi_R + \phi_L$$

$$\cos \varphi \sim 1$$

$$A^\Delta \approx \sin 2\psi$$

To extract the parameters A^Δ , C and S an unbinned likelihood fit was done:

$$\mathcal{L}_0 = \prod_{i=1}^{N_{B_s}} P_{-1}(m_i, t_i, \sigma_{ti}) \prod_{i=1}^{N_{\bar{B}_s}} P_1(m_i, t_i, \sigma_{ti}) \prod_{i=1}^{N_{untagged}} P_0(m_i, t_i, \sigma_{ti})$$

→ PDF for untagged events (k=0)

PDF for B_s tagged events (k=-1)

→ PDF for anti- B_s tagged events (k=1)

The variables m_i , t_i and σ_{ti} are the measured invariant mass, proper time and proper time error.

Fit model and results ($B_s \rightarrow \Phi\gamma$)

Defining:

$$I_+(\tau) = \cosh \frac{\Delta\Gamma\tau}{2} - \mathcal{A}^\Delta \sinh \frac{\Delta\Gamma\tau}{2}$$

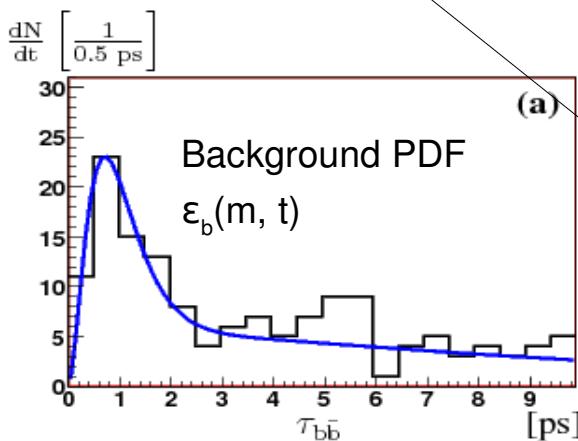
$$I_-(\tau) = \mathcal{C} \cos \Delta m_s \tau - \mathcal{S} \sin \Delta m_s \tau$$

The PDF for signal and background is :

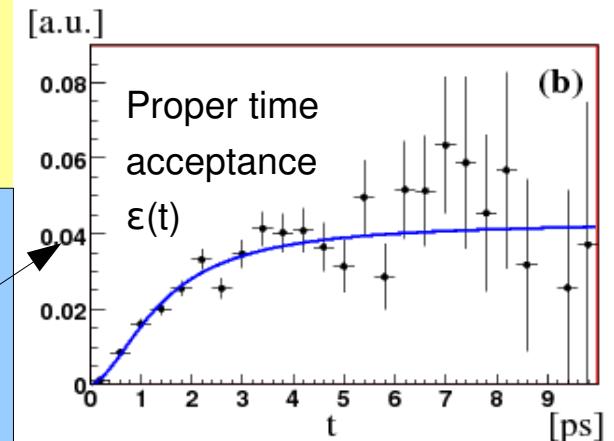
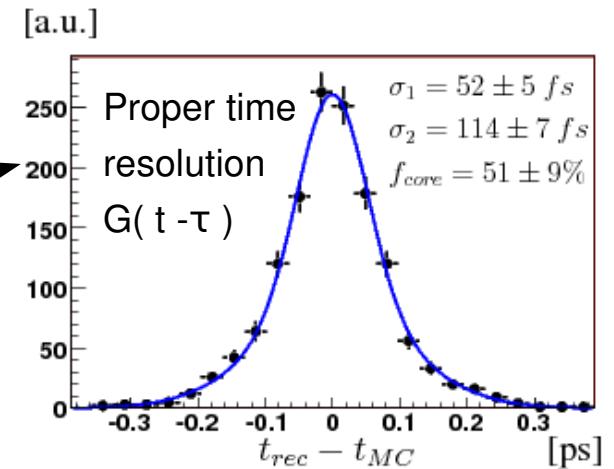
$$P_\kappa(t, m) = f_s \frac{\{e^{-\Gamma\tau}[I_+(\tau) + \kappa(1 - 2\omega)I_-(\tau)]\} \otimes G(t - \tau)\varepsilon(t)g_s(m)}{\int \{e^{-\Gamma\tau}[I_+(\tau) + \kappa(1 - 2\omega)I_-(\tau)]\} \otimes G(t' - \tau)\varepsilon(t')dt'} + (1 - f_s)\varepsilon_b(m, t)$$

Background PDF:

$$\varepsilon_b(m, t) \propto e^{-\mu m} \frac{(at)^c}{1 + (at)^c} \left((\alpha_0 + \alpha_1 \Delta m) e^{-\frac{t}{\tau_1}} + (\beta_0 + \beta_1 \Delta m) e^{-\frac{t}{\tau_2}} \right)$$



$k=-1, 0, 1$ (Tagging category)
 $g(m)$ =invariant mass norm. pdf
 $\varepsilon(t)$ = proper time acceptance
 w = wrong tag fraction
 $f_s = S/(S+B)$
 $G(t - \tau)$ = proper time resolution

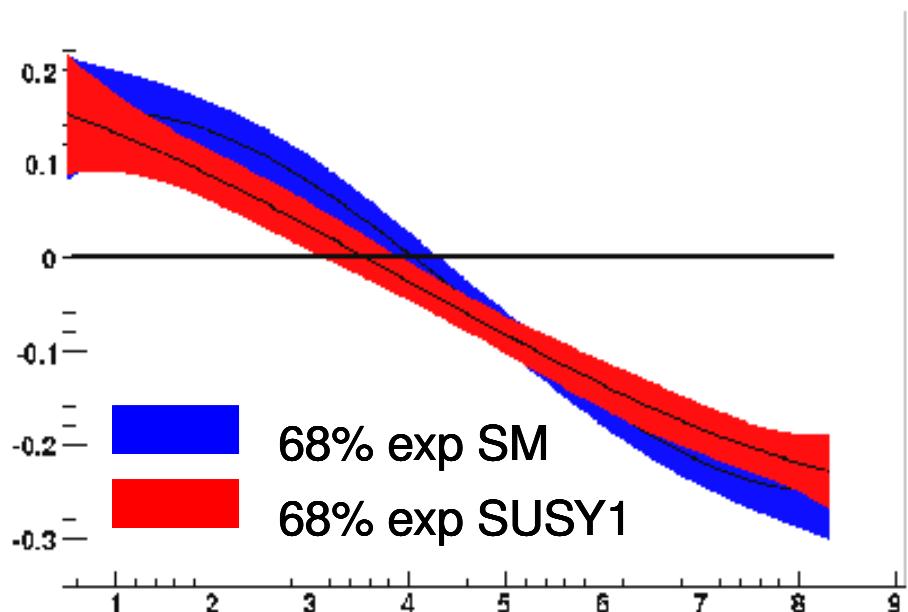
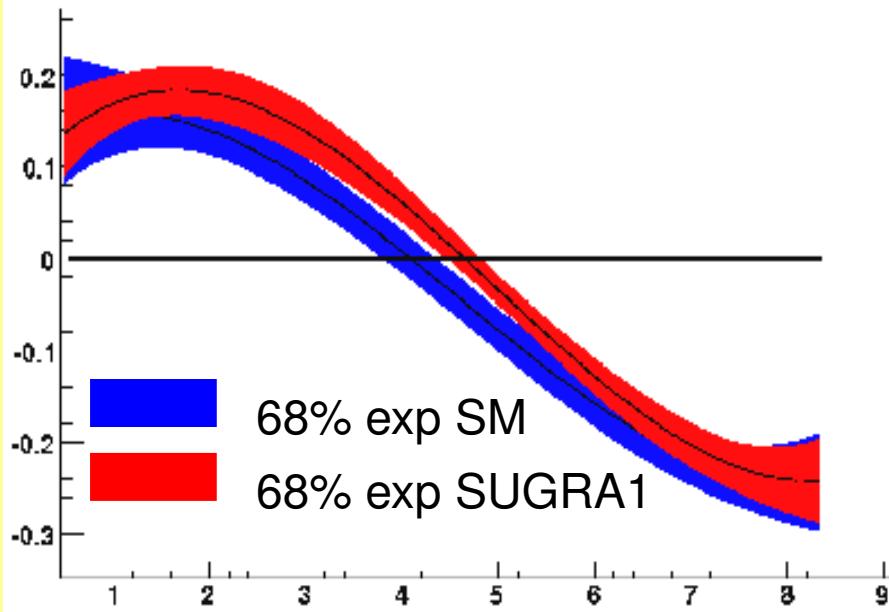


With a tagged analysis

Fit results:

$\sigma(\mathcal{A}^\Delta)$	$= 0.217 \pm 0.002$
$\sigma(\mathcal{S})$	$= 0.114 \pm 0.001$
$\sigma(\mathcal{C})$	$= 0.115 \pm 0.001$

Sensitivity to Wilson coefficients



Wilson coefficient modifiers: $C_n \rightarrow R_n C_n$

SUSY1 SUGRA1

R7: 0.83 1.2

R9: 0.92 1.03

R10: 1.61 1

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Using the 2D projection Fit
(with 2fb^{-1}).

Changing Wilson coefficients
inside the EvtGen package.
No background and acceptance
considered.

F_L and A_{FB} flipped C7

