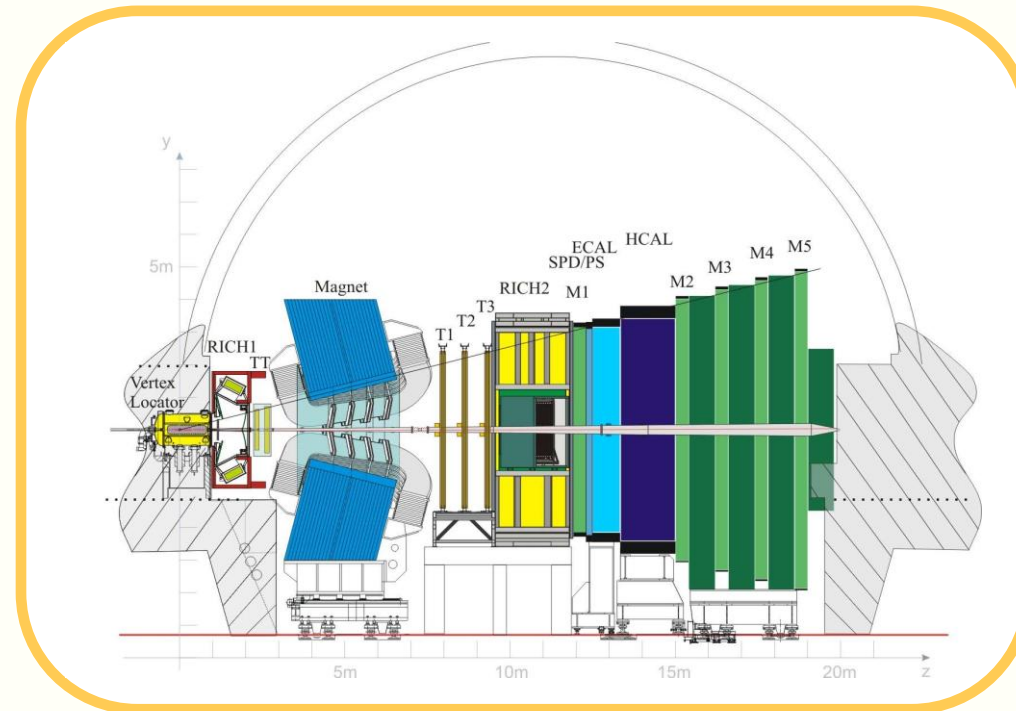




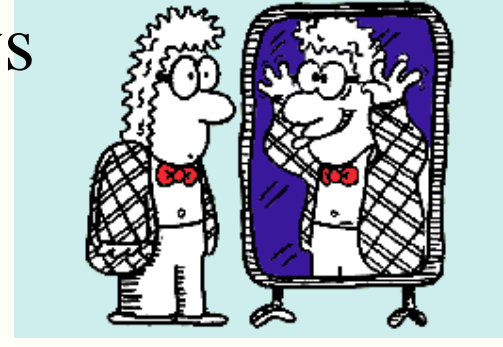
Probing photon polarization in $B_s \rightarrow \phi \gamma$ decay at LHCb

Presented by Lesya Shchutka, ITEP, Moscow and MIPT
On behalf of the LHCb collaboration

The LHC beauty experiment



Is dedicated for precise measurements of CP violation and rare decays of B mesons.

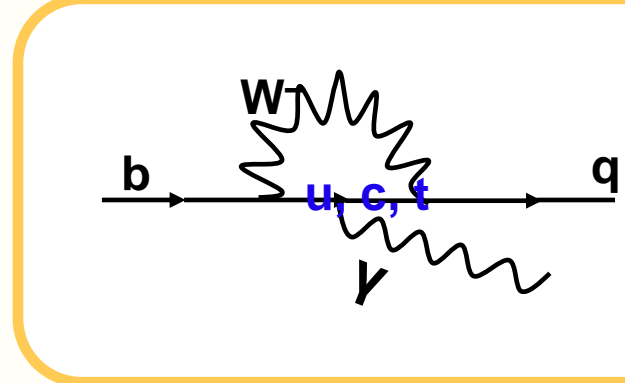


- ➔ **Forward geometry**: at high energies both the b and \bar{b} hadrons are produced at the same forward (backward) cone.
- ➔ Operating luminosity $\mathcal{L} = 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$: 80% of bunch-crossings produce 1 pp-collision.
- ➔ VERTeX LOCator allows precise **resolution of B** production ($\sigma_z = 8.3 \mu\text{m}$, $\sigma_{xy} = 0.4 \mu\text{m}$) and decay **vertices**.
- ➔ 2 Ring Imaging Cherenkov detectors provide **hadron identification** in a wide momentum range (1-100 GeV/c)

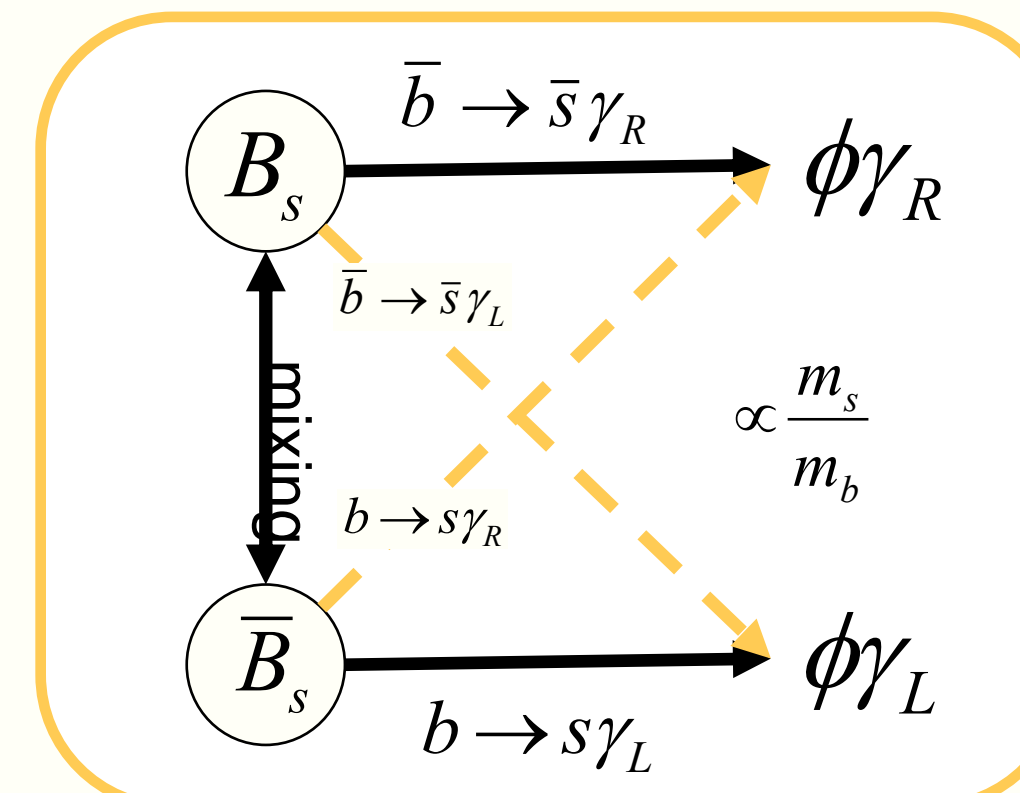
1

$b \rightarrow s \gamma$ process

In the SM photon is almost 100% polarized
⇒ final state is **flavor specific**.
Interference can happen only with a **helicity flip**.



Measuring CP-violating effects we therefore indirectly probe photon polarization.



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New horizon at LHCb

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

B-factories



B^0 -system:

$$\Delta\Gamma \approx 0 \Rightarrow$$

\mathcal{A}^Δ not measurable

$$\mathcal{S} \approx \sin 2\psi \times \sin 2\beta$$

$$\mathcal{C} \approx 0 - \text{direct CPV}$$

Current precision $\sigma_{\sin 2\psi} \approx 0.4$

$\sin 2\psi$ -fraction of wrong-polarized photons
 $\approx 2m_s/m_b$ in the SM

LHCb



B_s -system:

$$\Delta\Gamma/\Gamma \approx 0.1 \Rightarrow \mathcal{A}^\Delta !$$

$$\mathcal{A}^\Delta \approx \sin 2\psi \times \cos 2\phi_s \approx \sin 2\psi$$

$$\mathcal{S} \approx \sin 2\psi \times \sin 2\phi_s \ll 1$$

$$\mathcal{C} \approx 0$$

$$\tan \psi = \frac{\mathcal{A}(B \rightarrow f^{CP} \gamma_R)}{\mathcal{A}(B \rightarrow f^{CP} \gamma_L)}$$

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Measured decay rate

Tagged events:

$$R(t) = \varepsilon_{\text{tag}} \left(\int [(1 - \omega) \Gamma_{B_s \rightarrow \phi \gamma}(\tau) + \omega \Gamma_{\bar{B}_s \rightarrow \phi \gamma}(\tau)] \varepsilon(\tau) G(\tau - t) d\tau + \frac{1}{2} B(t) \right) =$$

$$= \varepsilon_{\text{tag}} \int |A|^2 e^{-\Gamma t} \left(\cosh \frac{\Delta\Gamma t}{2} - \mathcal{A}^\Delta \sinh \frac{\Delta\Gamma t}{2} + \mathcal{C} \cos \Delta m_s t - \mathcal{S} \sin \Delta m_s t \right) \varepsilon(\tau) G(\tau - t) d\tau + \frac{1}{2} B(t)$$

Untagged events:

$$R_{\text{untagged}}(t) = (1 - \varepsilon_{\text{tag}}) \left(\int [\Gamma_{B_s \rightarrow \phi \gamma}(\tau) + \Gamma_{\bar{B}_s \rightarrow \phi \gamma}(\tau)] \varepsilon(\tau) G(\tau - t) d\tau + B(t) \right) =$$

$$= (1 - \varepsilon_{\text{tag}}) \int |A|^2 e^{-\Gamma t} \left(\cosh \frac{\Delta\Gamma t}{2} + \mathcal{A}^\Delta \sinh \frac{\Delta\Gamma t}{2} \right) \varepsilon(\tau) G(\tau - t) d\tau + B(t)$$

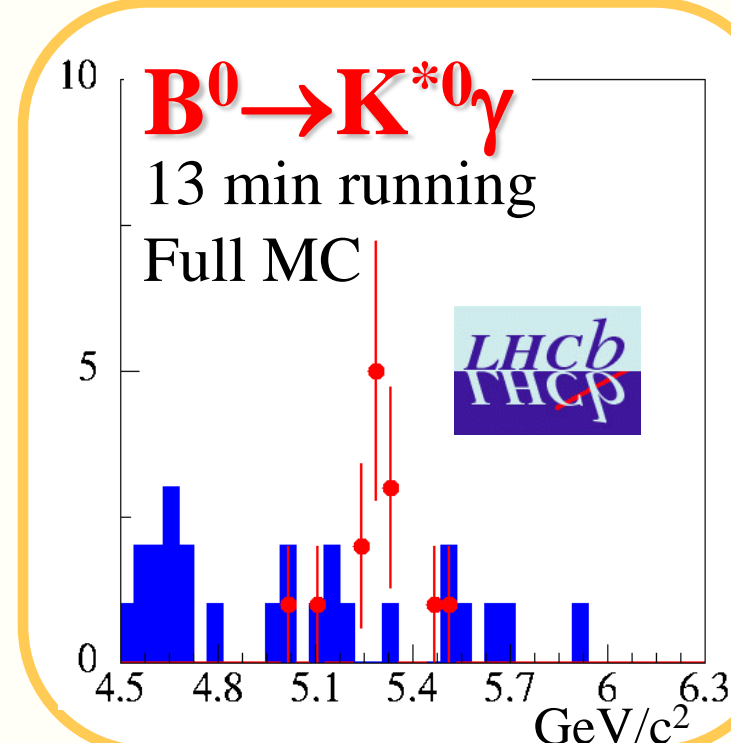
Effective statistics for:

C and S is $\varepsilon_{\text{tag}}(1 - 2\omega)N = 0.24N$

\mathcal{A}^Δ is N

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Event selection and yield



At LHCb we will select per 2fb^{-1} :

$B^0 \rightarrow K^{*0} \gamma$: 68k, $B/S = 0.60 \pm 0.16$

$B_s \rightarrow \phi \gamma$: 11k, $B/S < 0.55$ @ 90CL

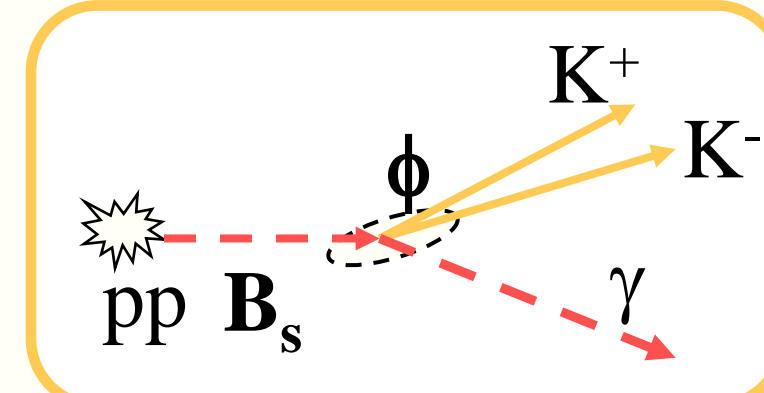
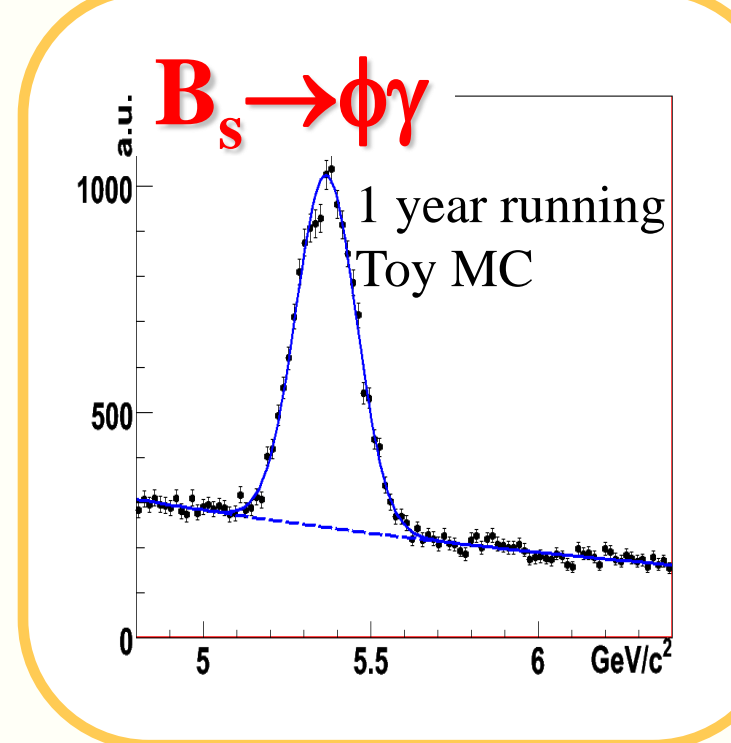
Resolutions for $B_s \rightarrow \phi \gamma$:

mass: $90 \text{ MeV}/c^2$

proper time (average): 78 fs

Similar selections:

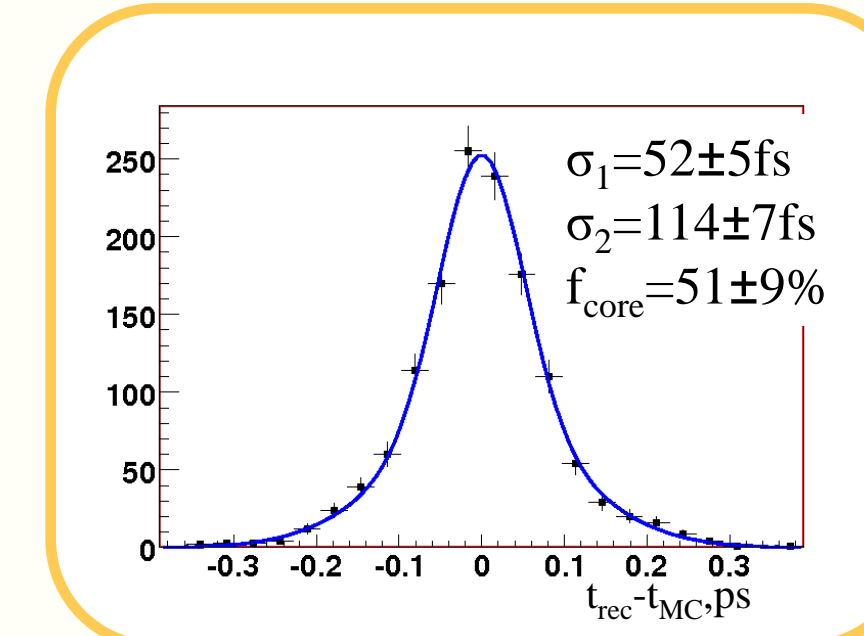
2 charged tracks not pointing to pp-vertex + energetic photon



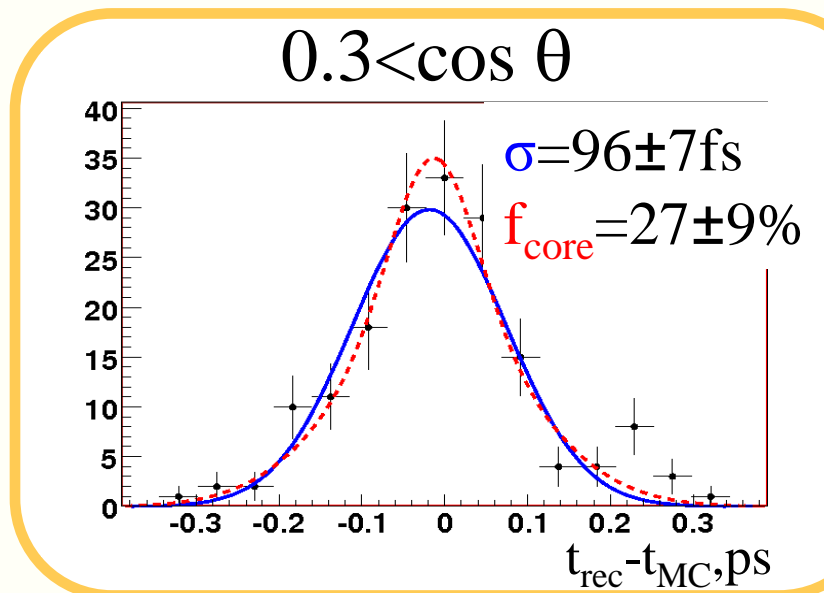
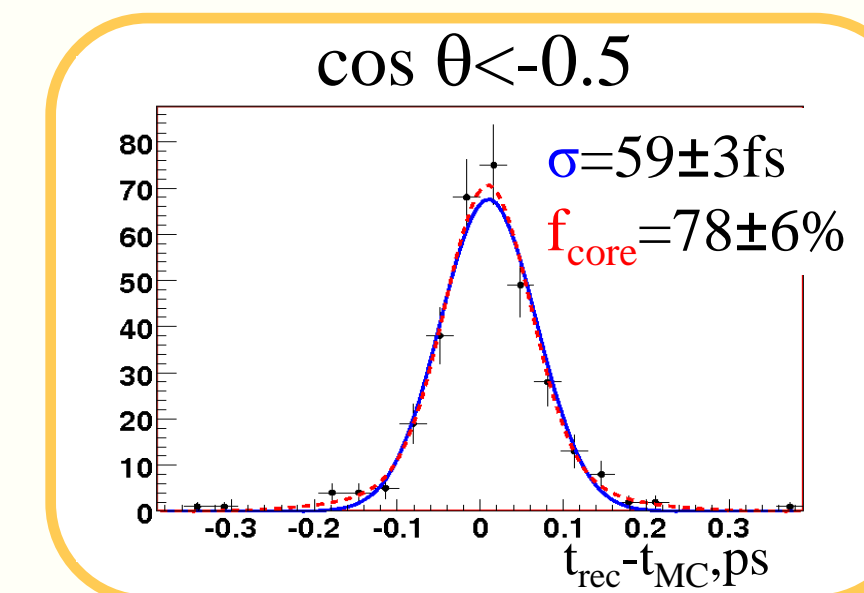
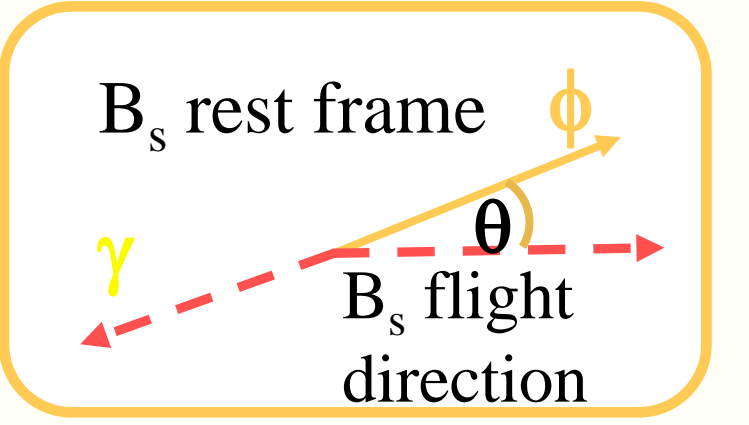
B-candidate points to pp-vertex and its momentum direction coincides with the production-decay vertices direction

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Signal proper time resolution



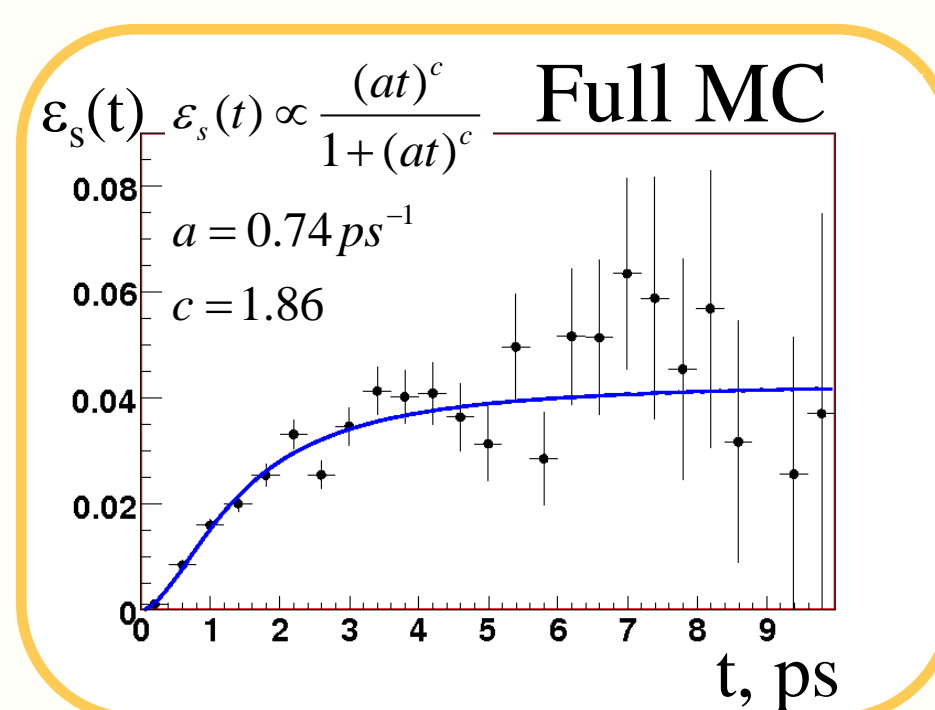
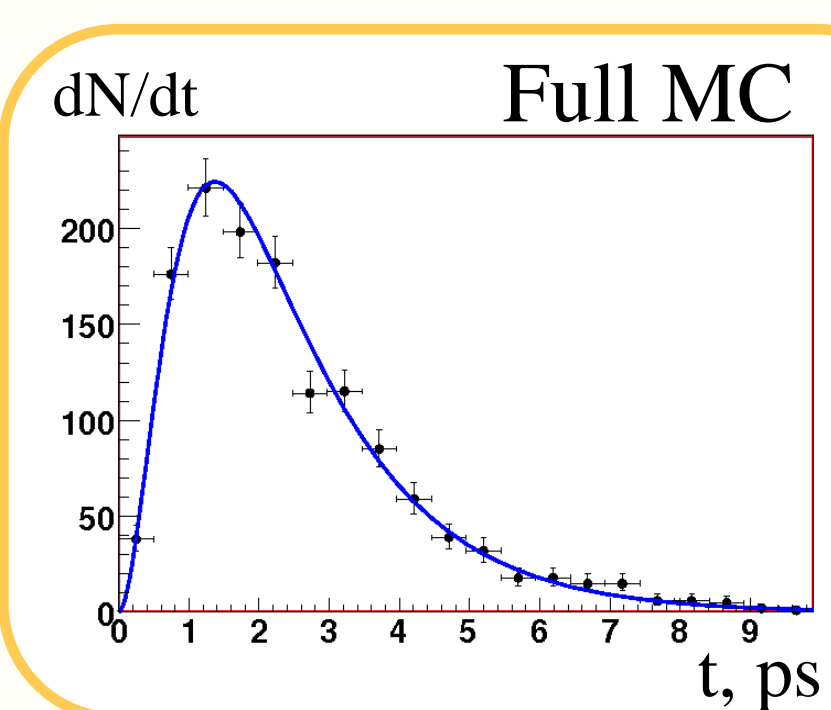
depends on decay angle θ :



To describe the effect measured proper time errors used for per-event resolution.

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Signal proper time acceptance



Efficiency of selection as a function of proper time.

Have to be "known" precisely:

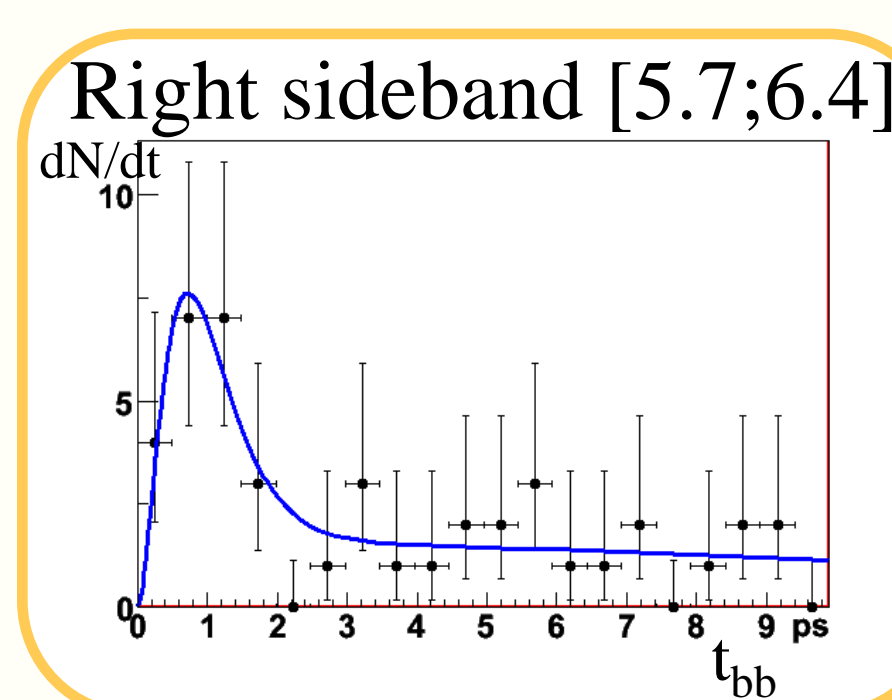
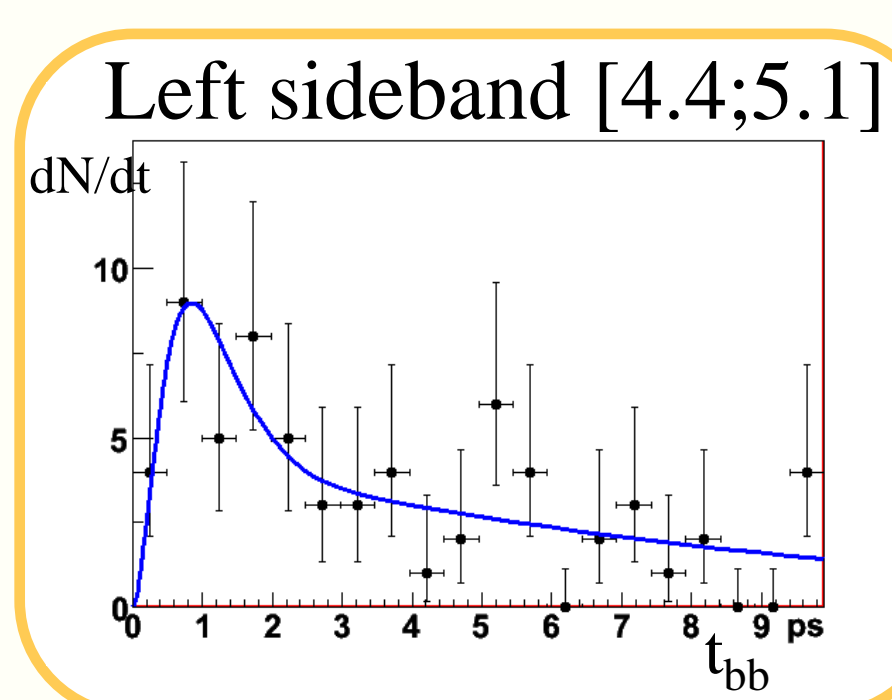
5% bias in "a" ⇒ bias in $\sin 2\psi \sim 0.2$

Can be extracted from data using control channels:

$B^0 \rightarrow K^{*0} \gamma$ or $B_s \rightarrow J/\psi \phi$

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Background treatment



Background shape estimated from the full MC with the relaxed selection.

Time shape changes with mass ⇒ careful with the transition between the sidebands:

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

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Toy Monte Carlo studies

$O(10^4)$ experiments with RooFit.

Unbinned maximum likelihood fit:

mass, proper time and its error distributions.

➔ Proper time resolution from per-event proper time errors.

➔ Signal acceptance function will be extracted from the control channels.

➔ $\Delta\Gamma/\Gamma = 0.12$ for the main study, will be known from other LHCb measurements.

➔ $\Delta m_s = 17.77 \text{ ps}^{-1}$

➔ Background mass-time shape is found from the sidebands.

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Likelihood function

Performed simultaneous fit of tagged and untagged events. For each tagging category κ (B_s^- : -1, \bar{B}_s^- : +1, untagged: 0):

$$P_\kappa(t, m) = f_s \int \{ e^{-\Gamma \tau} [I_+(\tau) + \kappa(1 - 2\omega)I_-(\tau)] \} \otimes G(t - \tau) \varepsilon(t) g_s(m) + (1 - f_s) \varepsilon_b(m, t)$$

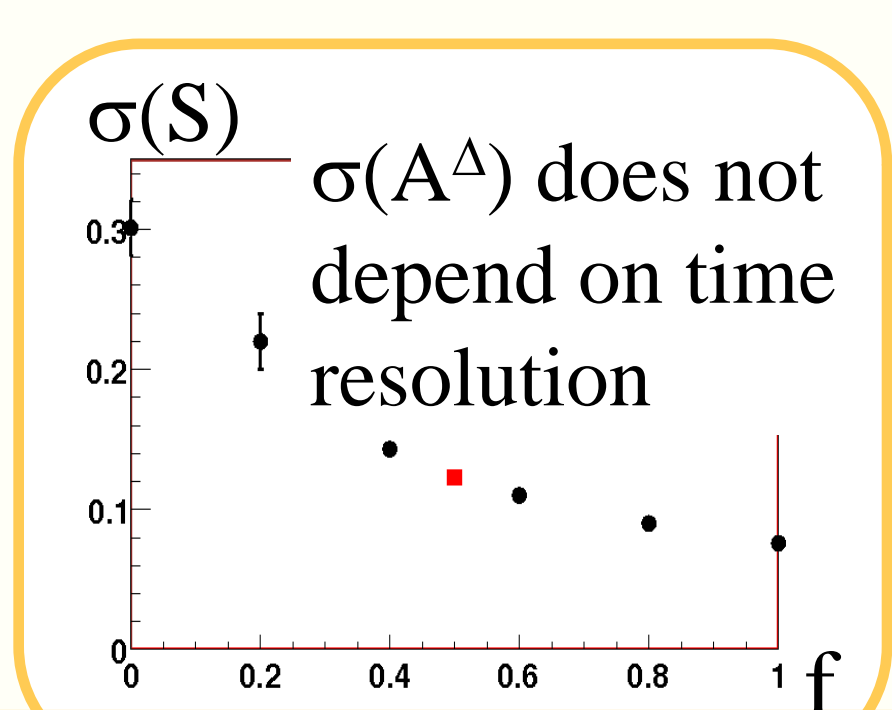
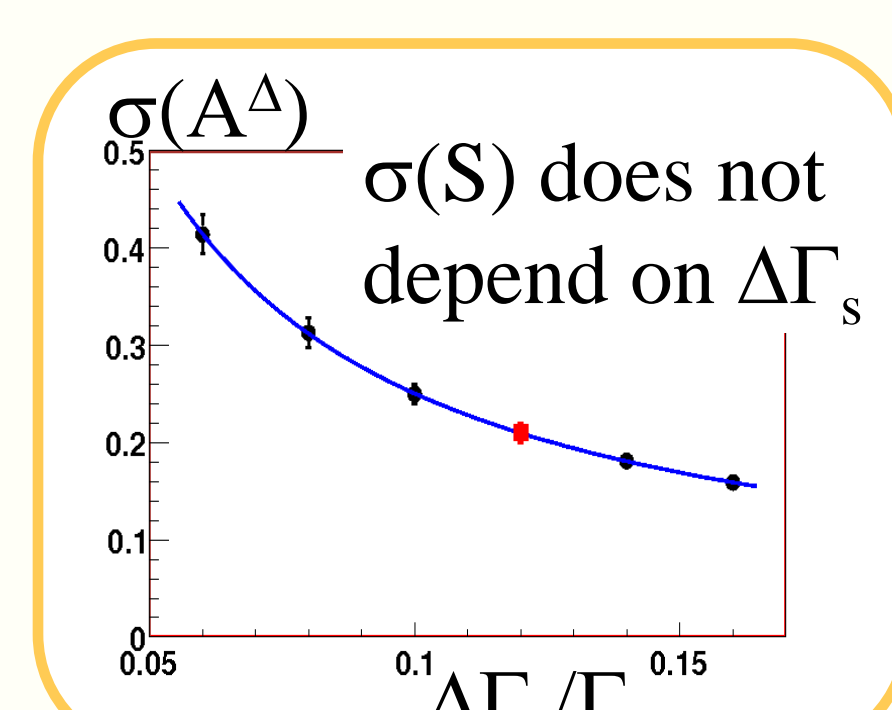
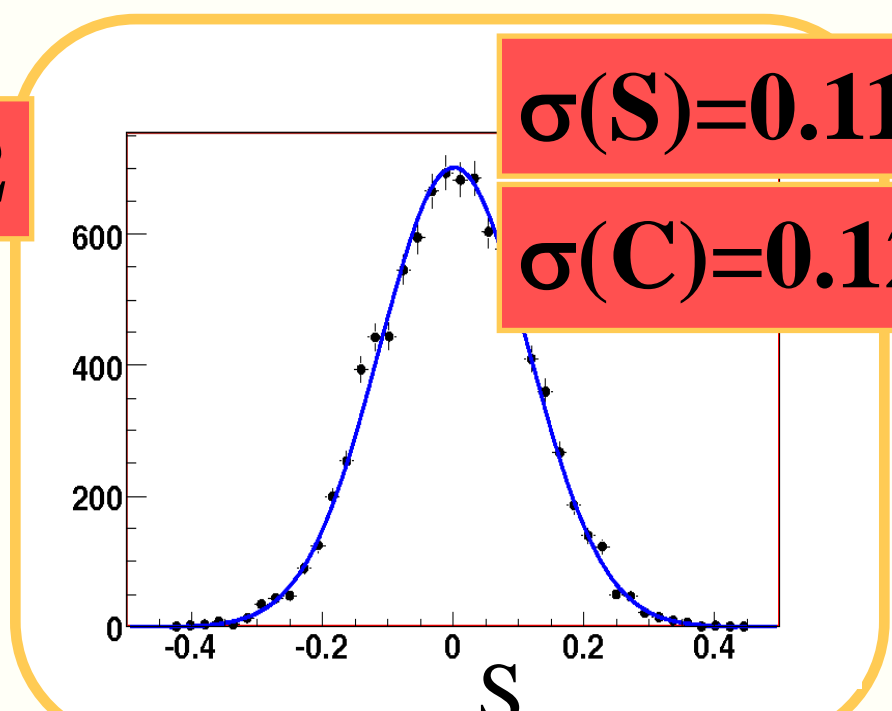
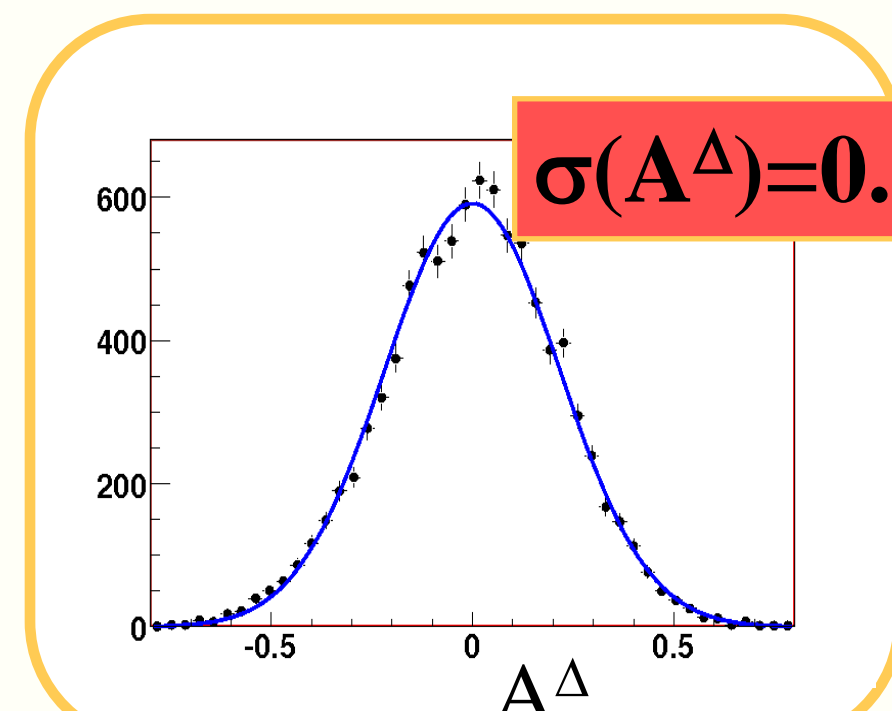
$$I_+(\tau) = \cosh \frac{\Delta\Gamma \tau}{2} - \mathcal{A}^\Delta \sinh \frac{\Delta\Gamma \tau}{2},$$

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

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

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Sensitivity to parameters \mathcal{A}^Δ , S, C



$$G(t - \tau) = f \times G_1(\sigma = 52 \text{ fs}) + (1 - f) \times G_2(\sigma = 114 \text{ fs})$$

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Summary and follow-ups

➔ The expected sensitivity to the measurement of photon polarization after 1 year is $\sigma(\mathcal{A}^\Delta) = 0.22$, $\sigma(S) = 0.11$, $\sigma(C) = 0.12$.

➔ The proper time acceptance should be determined from data: $B^0 \rightarrow K^{*0} \gamma$ or $B_s \rightarrow J/\psi \phi$. This issue is under study now.

➔ The precision of \mathcal{A}^Δ measurement won't suffer in case we have worse proper time resolution than found from full MC.

➔ Dependence on the background composition is quite moderate but on its amount is more pronounced. The background shape can be precisely determined from the sidebands.

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