Experimental study of the time dependent decay rate in $B_s \rightarrow \phi\gamma$

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Outline

- Introduction
- Theoretical aspects
- Experimental issues
- Simulation studies
- Conclusions
- Discussion

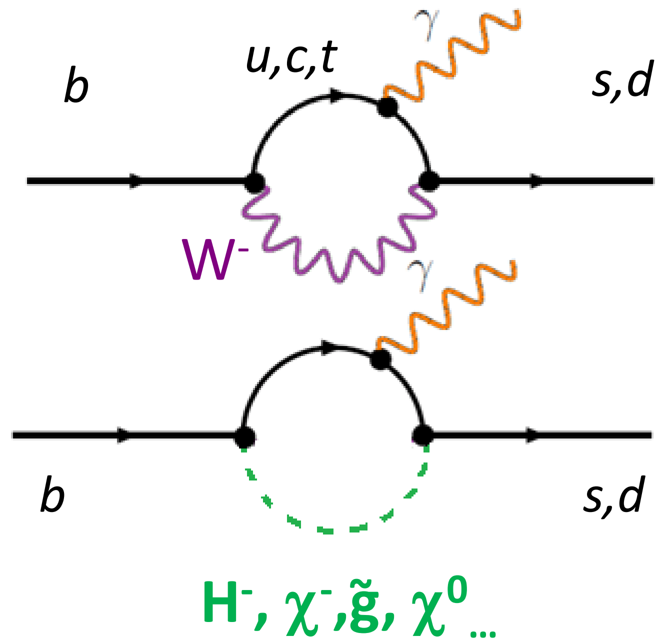
Introduction

- **We want to measure the photon polarization in $B_s \to \phi\gamma$ decays**

$\rightarrow$ Photons in ***b*** $\boldsymbol{\rightarrow s\gamma}$ are predicted to be left-handed in the SM (small corrections of order m_s/m_b)

$\rightarrow$ Sensitive to New Physics models, particularly **Left-Right Symmetric Models**

[D. Atwood, M. Gronau and A. Soni, PRL79(97)185]
[M. Gronau, D. Pirjol, PRD66(02)054008]
[F. Yu, E. Kou, C. Lü, JHEP12(2013)102]



Remind that LHCb has measured $\mathcal{B}(B \to K^*\gamma)/\mathcal{B}(B_s \to \phi\gamma)$ with $1fb^{-1}$ $= 1.23 \pm 0.06 \pm 0.04 \pm 0.10(f_s/f_d)$ **[Nuc. Phys. B 867 (2013) 1-18]**

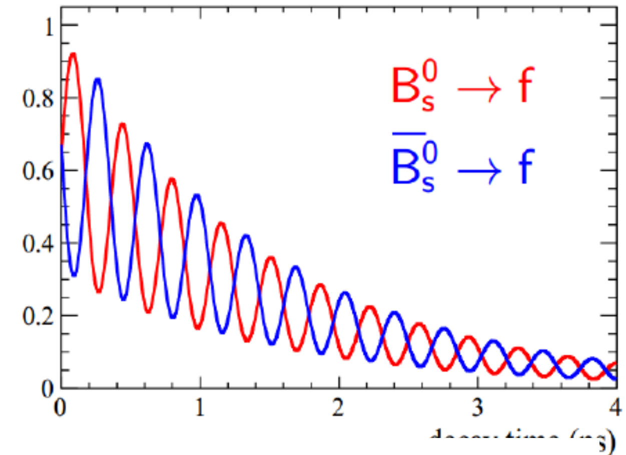
$\mathcal{B}(B_s \to \phi\gamma) = (3.5 \pm 0.4) \times 10^{-5}$

And has observed polarized photons in $B \to K\pi\pi\gamma$ decays!

[Phys. Rev. 112(2014)161801]

Theoretical aspects

→ The time-dependent decay rate for
$B_s \to \phi\gamma$ and $\bar{B}_s \to \phi\gamma$ decays is described by:



$$\Gamma_{\overset{(-)}{B}{}_s^0 \to \phi\gamma}(t) =$$

$$= |A|^2 e^{-\Gamma_s t} \left(\cosh\frac{\Delta\Gamma_s t}{2} - \mathcal{A}^{\Delta} \sinh\frac{\Delta\Gamma_s t}{2} \pm \mathcal{C}\cos\Delta m_s t \mp \mathcal{S}\sin\Delta m_s t\right)$$

~ 0 in the sm

$$\boxed{\mathcal{A}^{\Delta} \approx \sin 2\psi \cos\varphi_s}$$

$$\boxed{\mathcal{S} \approx \sin 2\psi \sin\varphi_s}$$ **~ 0 in the SM**

φ_s= weak mixing phase (<< in the SM)

Fraction of "wrongly" polarized photons: $\tan\psi \equiv \left|\frac{\mathcal{A}(\bar{B}_s \to \phi\gamma_R)}{\mathcal{A}(\bar{B}_s \to \phi\gamma_L)}\right|$

$\Delta\Gamma_s = \Gamma_L - \Gamma_H = (0.081 \pm 0.011)\ ps^{-1}$

$\Gamma_s = 1/\tau_{Bs} = (0.6596 \pm 0.0046)\ ps^{-1}$

Theoretical aspects

→ Untagged measurement of the time dependent $B_s \to \phi\gamma$ width:

$$\Gamma_{B_s^0}(t) = |A|^2 e^{-\Gamma_s t}\left(\cosh\frac{\Delta\Gamma_s t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_s t}{2}\right)$$

$$\approx |A|^2 e^{-\Gamma_{B_s\to\phi\gamma}t}$$ with

It can be seen as an "Effective lifetime" depending on the A^{Δ}

$$\Gamma_{B_s\to\phi\gamma} = \Gamma_s + \frac{\mathcal{A}^{\Delta}\Delta\Gamma}{2}$$

SM value: $A^{\Delta} = 0.047 \pm 0.025 \pm 0.015_{(\alpha_s)}$ [Muheim, Xie, Zwicky, PLB664(08)174]

Left-Right Symmetric models: A^{Δ} up to ~ 0.7 [Atwood, Gronau and Soni, PRL79(97)185]

→ Fraction of wrongly polarized photons ~ 40%

Theoretical aspects

→The time-dependent decay assymetry is then expressed:

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

$$= \frac{S \sin(\Delta m_s t) - C \cos(\Delta m_s t)}{\cosh(\frac{\Delta\Gamma_s}{2} t) - \mathcal{A}^{\Delta} \sinh(\frac{\Delta\Gamma_s}{2} t)}$$

→ **A_{CP}** expected to be **~zero** in the Standard Model

→ Enhanced in New Physics Models

→ Caveat: experimentally one needs to know the flavour of the B_s

Experimental issues

$\rightarrow$ Flavour tagging for B_s drastically reduces our data, even if we have (and will have more!) a lot of $B_s \rightarrow \phi\gamma$ decays

$\sigma(pp \rightarrow B_s + X) = 10.5 \pm 1.3\ \mu b$ [JHEP08(2013)11]

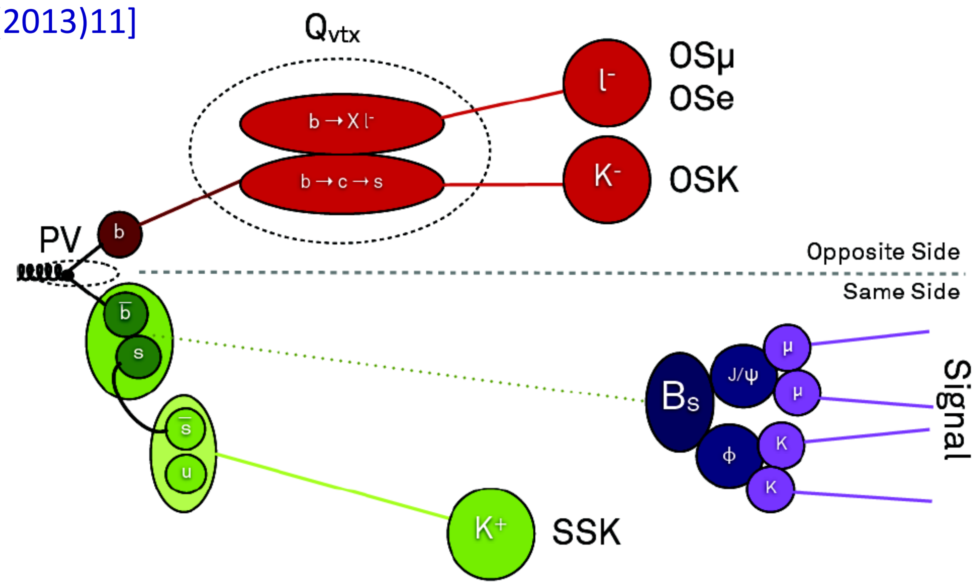
$\mathcal{B}(B_s \rightarrow \phi\gamma) = (3.5 \pm 0.4)\mathrm{x}10^{-5}$

$\varepsilon_{reconstruccion}\ (\phi + \gamma) \sim 1\%$

Tagging algorithms:

Same side (SS):
From fragmentation of the signal *b* (π for B, K for B_s)

Opposite side (OS):
From the opposite B:
- e, μ from semileptonic B decays,
- kaons from $b \rightarrow c \rightarrow s$,
- inclusive reconstruction of the opposite B vertex



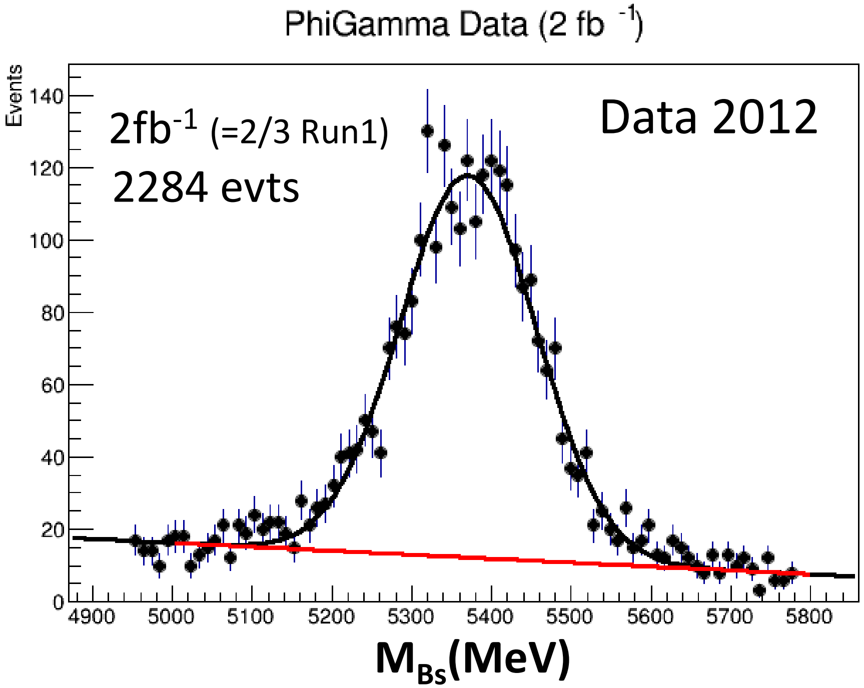
[Eur. Phys. J.C. 72 (2012) 2022, LHCb-CONF-2012-026]

Tagging efficicencies: ε ~5-16%, mistag probabilities ω ~ 30% $\rightarrow$ $\mathbf{N_{evts}\ x\ \varepsilon(1\text{-}2\omega)^2}$

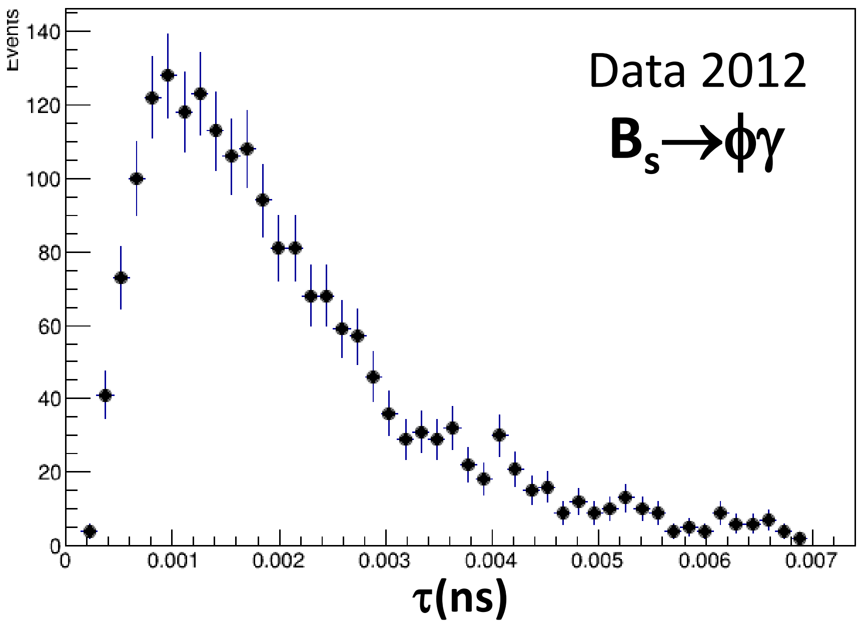
$\rightarrow$ Let's first to measure the untagged rate…

Experimental issues

$$\Gamma_{B_s^0}(t) \approx |A|^2 e^{-\Gamma_{B_s \to \phi\gamma} t}$$



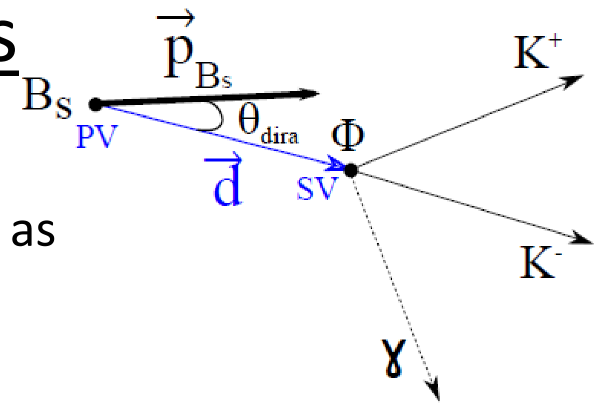
Untagged proper time distribution:



In practice we need to correct the measured B_s proper time distribution for acceptance and resolution effects:

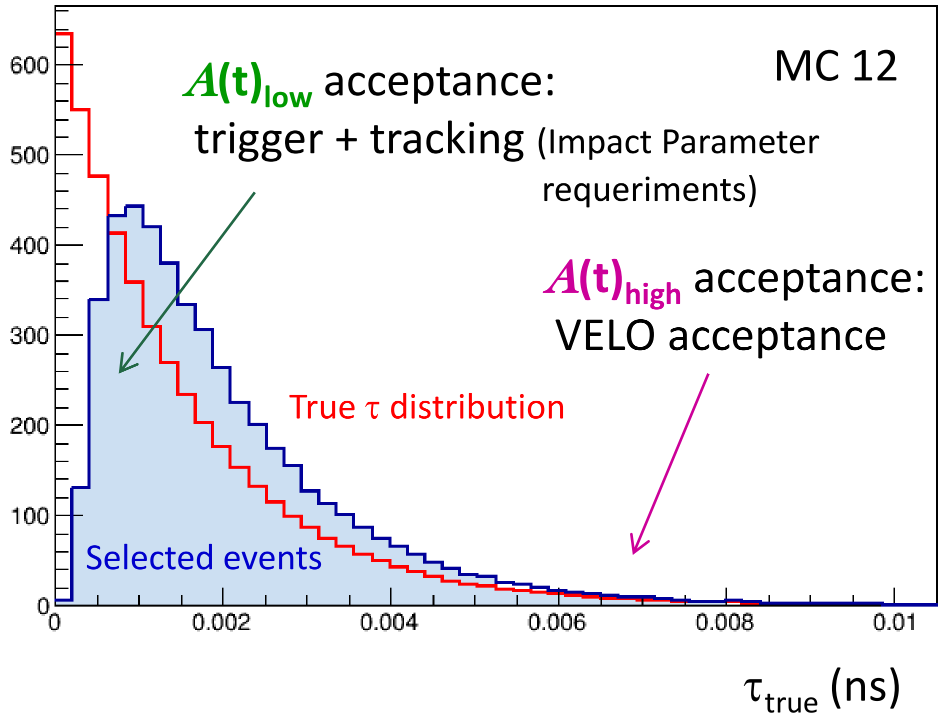
$$\Gamma_{Bs}(t_r) \text{ measured} = \mathcal{A}(t) \cdot \Gamma_{Bs}(t; A^{\Delta}) \otimes R(t,t_r)$$

Experimental issues



- At LHCb an unbiased selection is not possible. The ***acceptance function*** $\mathcal{A}(\mathbf{t})$ can be parametrized as

$$\mathcal{A}(t) = \frac{at^n}{1+at^n} \times (1+\beta t)$$



Key in the photon polarization measurement

→ Causes large uncertainties in the lifetime measurement

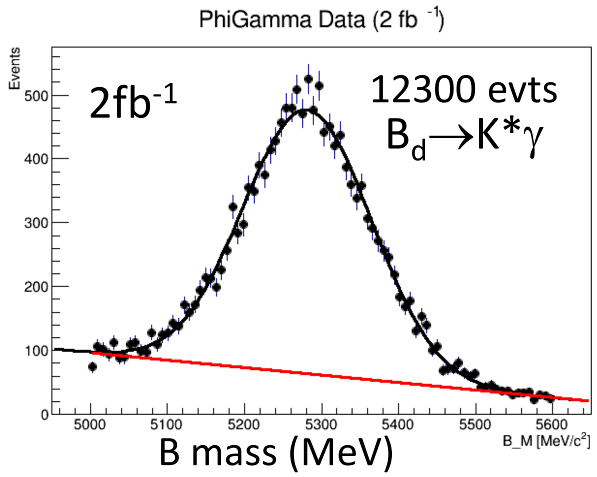
→ Needs to be precisely determined: a big effort is being done to extract it from data

Experimental issues

- Two different data control channels are being used to extract the acceptance:

Using the $B_d \to K^*\gamma$ as control channel:

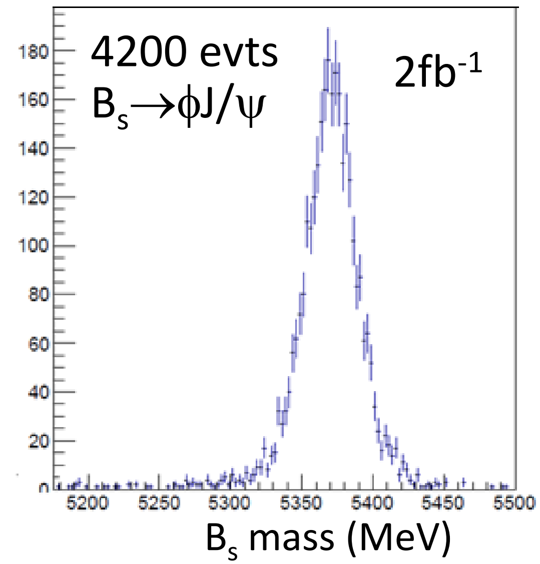
- Same topology (2 tracks + photon)
- Similar trigger (γ)
- Affected by tracking differences between the $K^* \to K\pi$ and $\phi \to KK$



- Large $B \to K^*\gamma$ to $B_s \to \phi\gamma$ ratio ~ 6
- Background contributions

Using the $B_s \to \phi J/\psi$ as control channel:

- Same tracking ($\phi \to KK$, unbias J/ψ)
- Different trigger (dimuon)



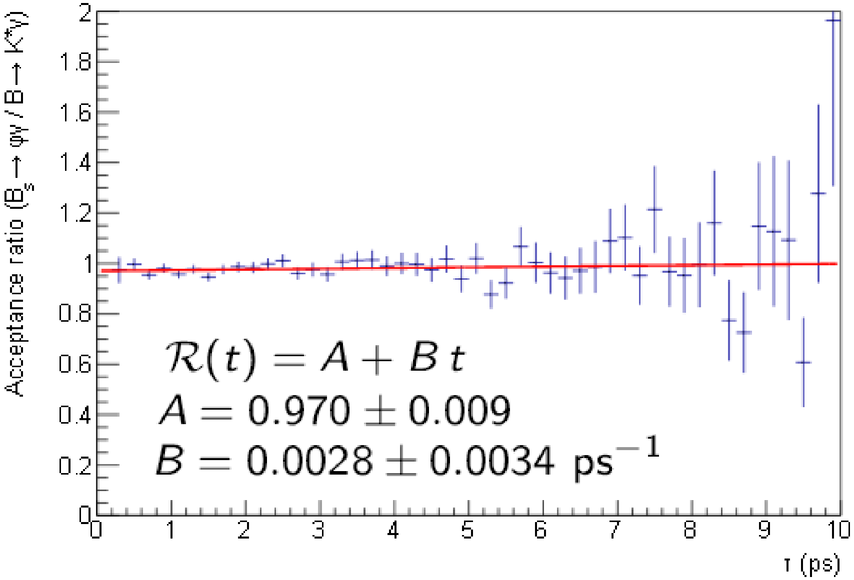
- $B_s \to J/\Psi\phi$ to $B_s \to \phi\gamma$ ratio ~ 2
- Very clean channel

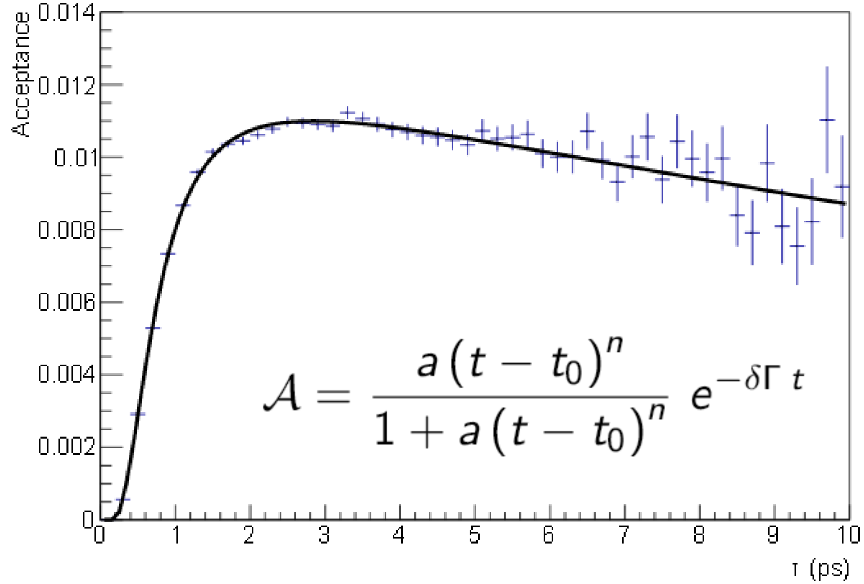
Sensitive to different (complementary) trigger, detector and systematics effects

Experimental issues

1) Using the $B_d \to K^*\gamma$ as control channel:

▶ Aiming for a selection that keeps the same proper time acceptance for the $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$ decay channels





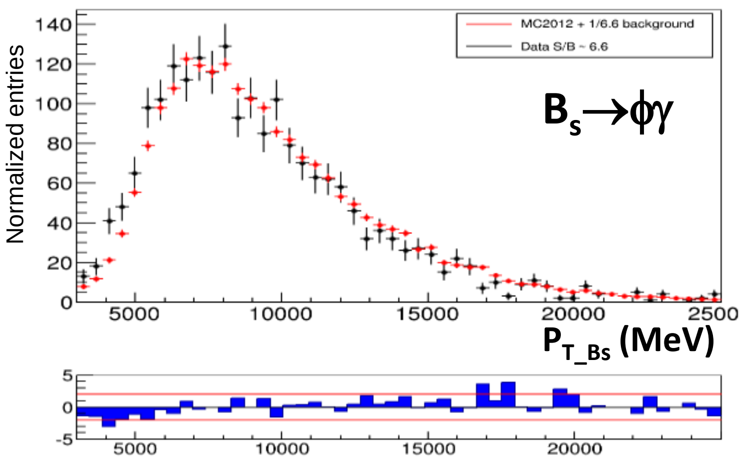
→ **Same acceptance for B_s and B_d within statistical MC uncertainties**

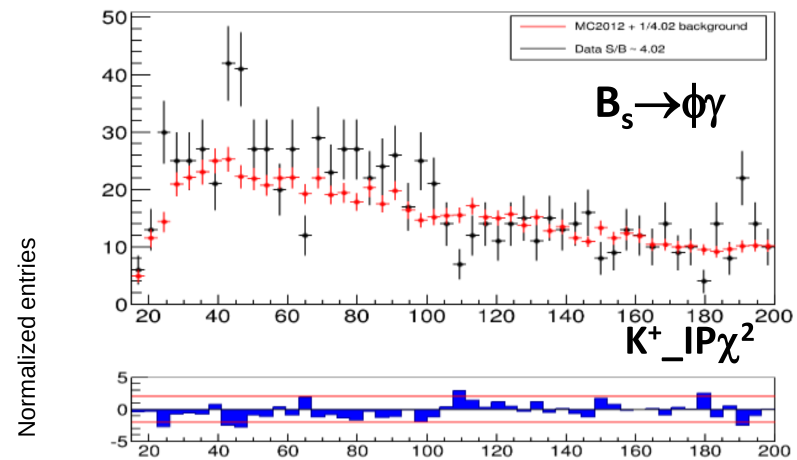
Signal events ($2fb^{-1}$) = 3200; S/B ~ 4

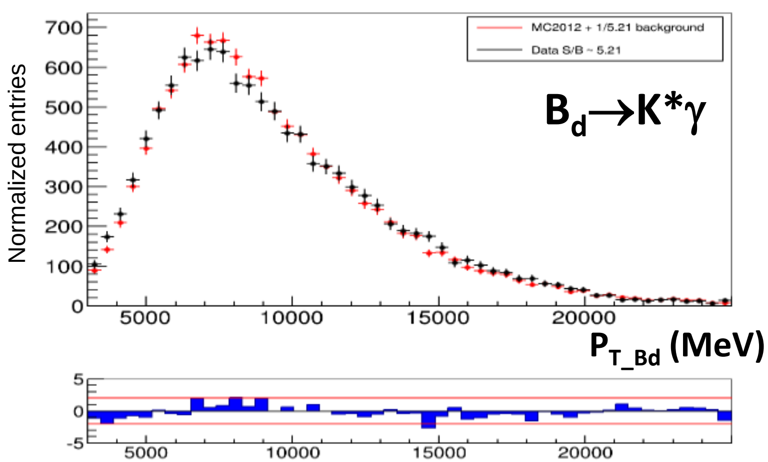
Tighter selection: Signal events ($2fb^{-1}$) = 2280; S/B ~ 7.4; still flat acceptance ratio

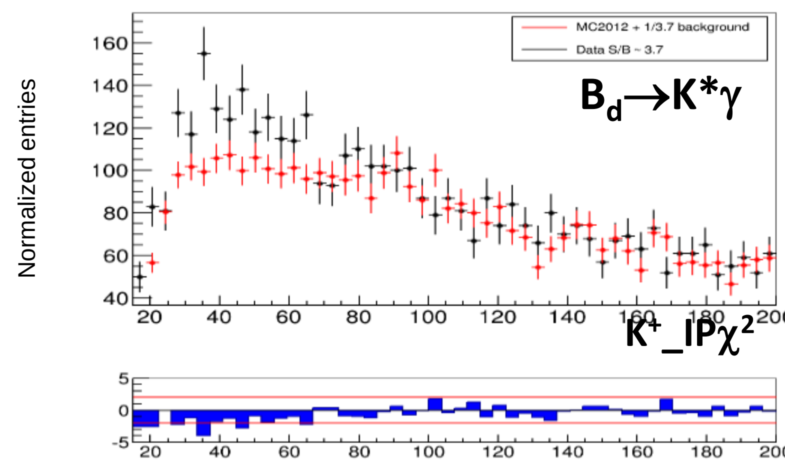
Experimental issues

▶ Comparing data and MC distributions to validate the selection:
In general the LHCb simulation reproduces quite well our data.
Some examples with the largest discrepancies, can be corrected:







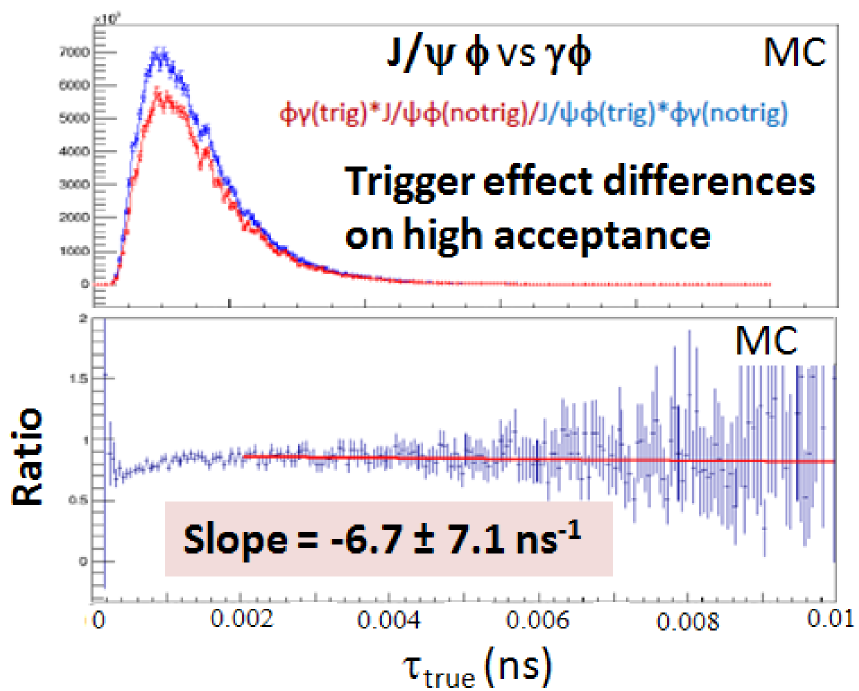


Experimental issues

2) Using the $B_s \to \phi J/\psi$ as control channel:

▶ Faking the photon with the J/ψ: use an "unbiased $B_s \to J/\psi\phi$ lifetime" (B_s vertices reconstructed only from the two kaon system) and apply the selection as if it was a radiative decay

Use the $B \to K^*J/\psi$ and $B \to K^*\gamma$ to assess the method



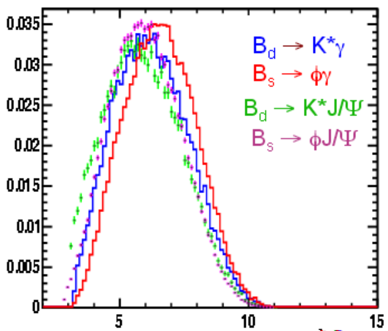
→ **Flat ratio of high acceptances within statistical uncertainties (MC)**

0 5 10

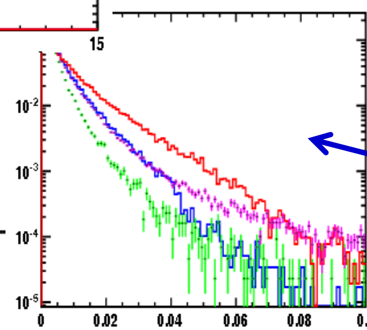
Experimental issues

▶ Some differences in geometry variables introduce differences at low decay time (related to vertex displacement)

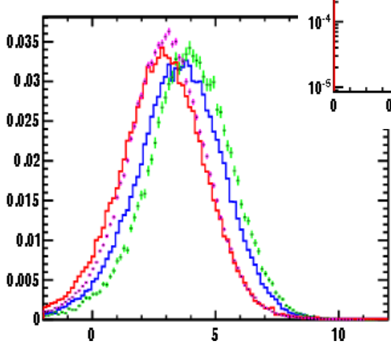
→ they can be corrected using a reweighting method



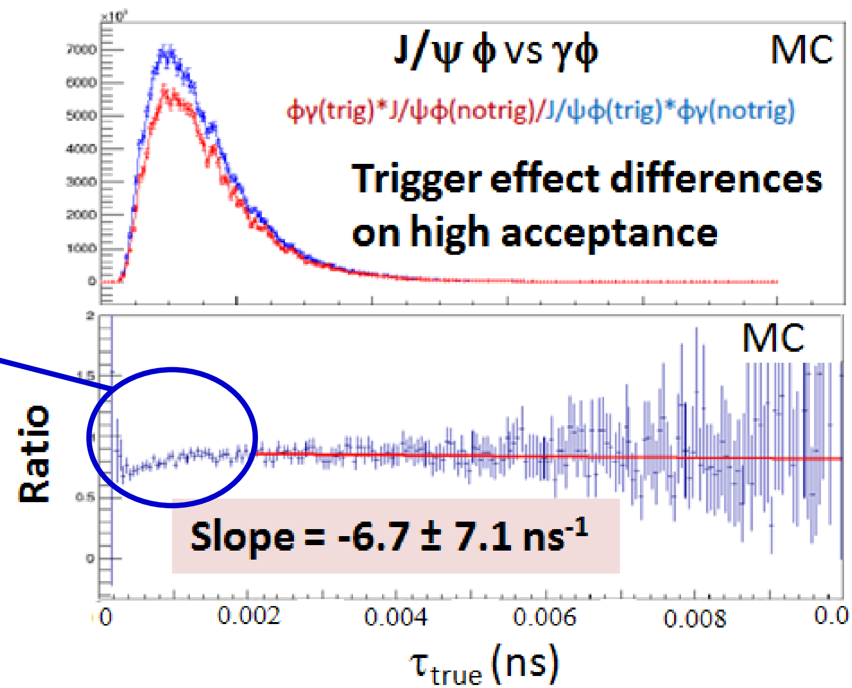
$h^{\pm}$_IPχ^2



DIRA angle (rad)



$\Delta\chi^2$



Experimental issues

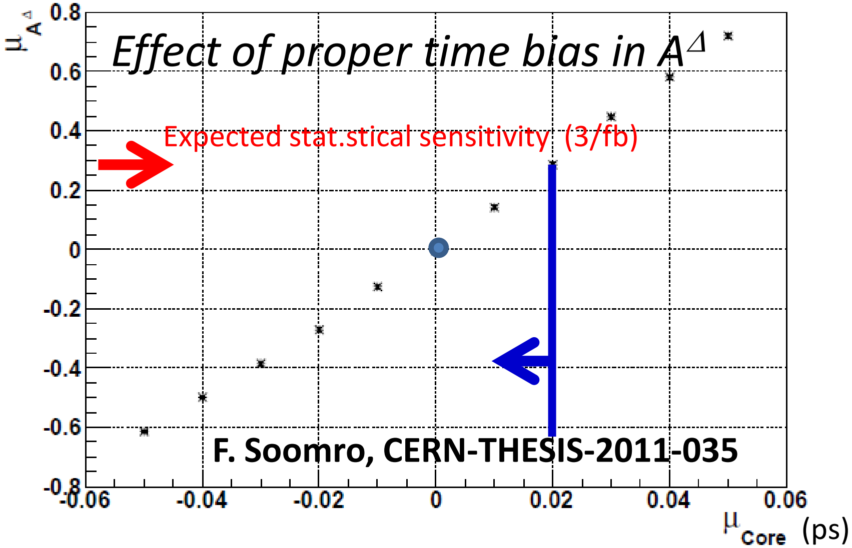
- The proper time resolution $\mathbf{R(t,t_r)}$ is crucial for an unbiased measurement of the photon polarization parameter $\mathbf{A^{\Delta}}$

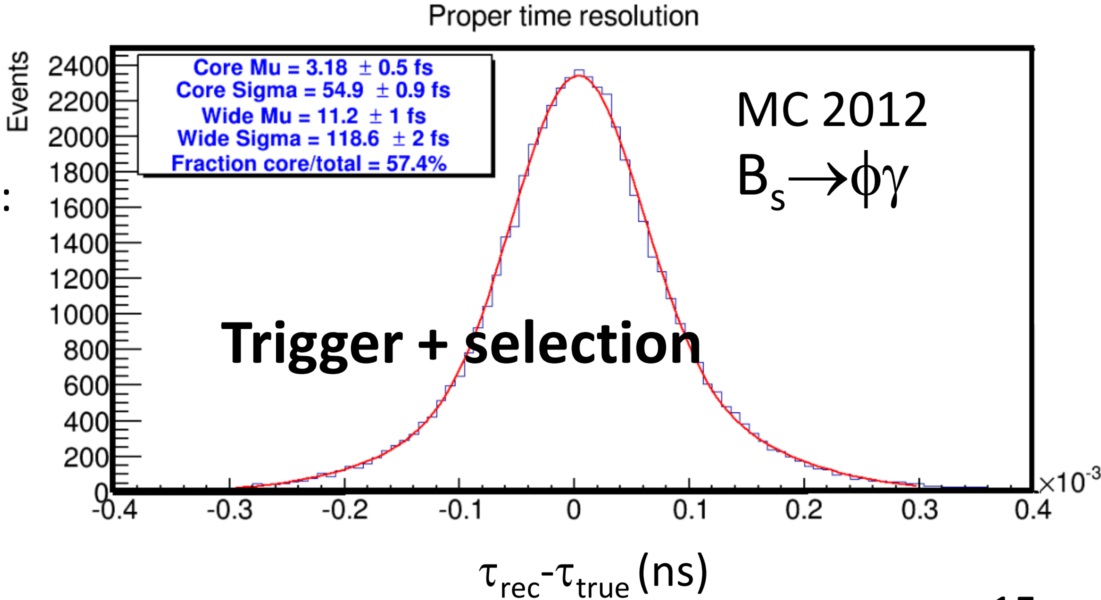
$$\mathbf{R(t,t_r)=Gauss_{core}(t,t_r)+Gauss_{wide}(t,t_r)}$$

- Bias in the resolution is dominated by photon related information

- Big effort has been done in the proper photon calibration (depending on the calorimeter region):

μ_{core}= **3.2 fs**
μ_{wide}= **11 fs**

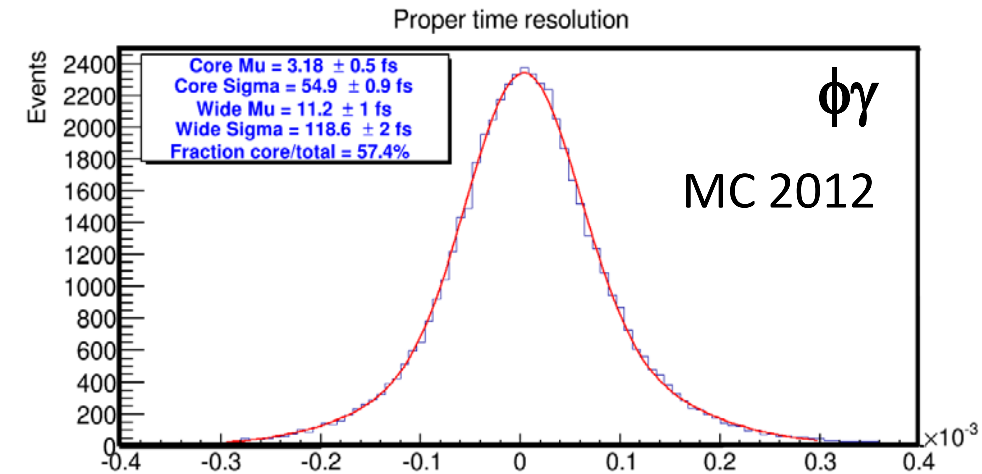


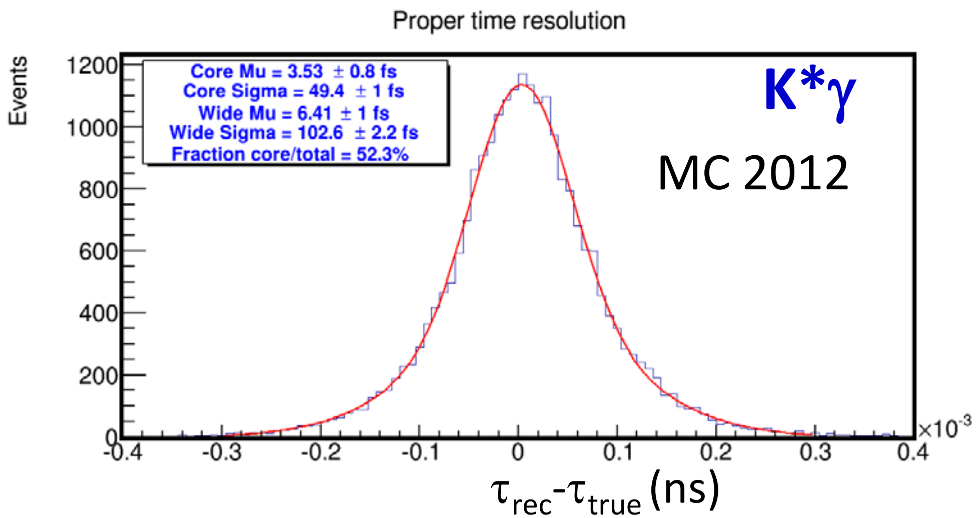


Experimental issues

- Similar resolution functions for the $B_s \to \phi\gamma$ and $B_d \to K^*\gamma$ decay channels:

2 Gaussian fit





Trigger + selection:

$B_s \to \phi\gamma$

σ_{core}= 55 ± 1 fs

μ_{core}= 3.2 ± 0.5 fs

σ_{wide}= 119 ± 2 fs

μ_{wide}= 11 ± 1 fs

Core fraction = 57%

$B_d \to K^*\gamma$

σ_{core}= 49 ± 1 fs

μ_{core}= 3.5 ± 0.8 fs

σ_{wide}= 103 ± 2 fs

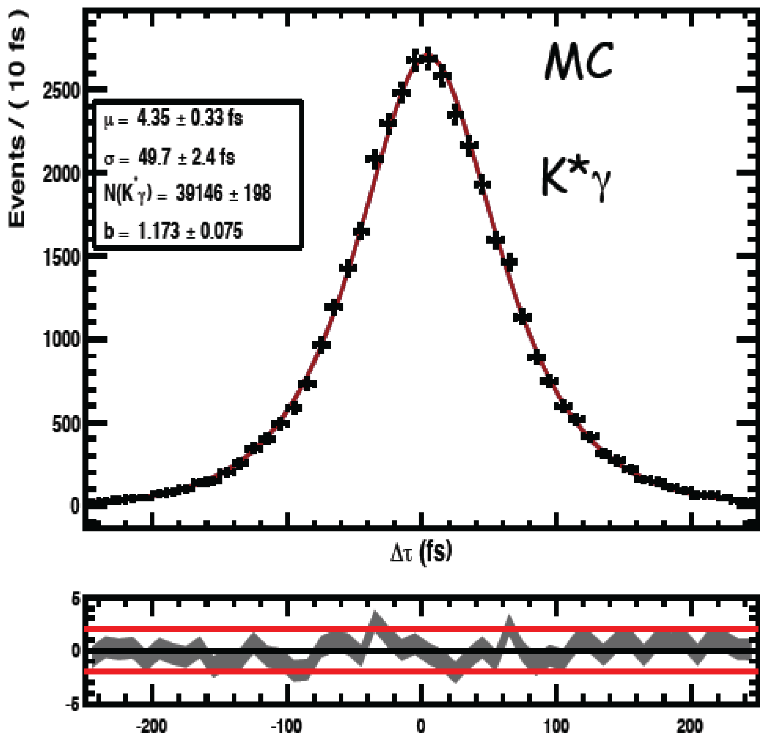
μ_{wide}= 6 ± 1 fs

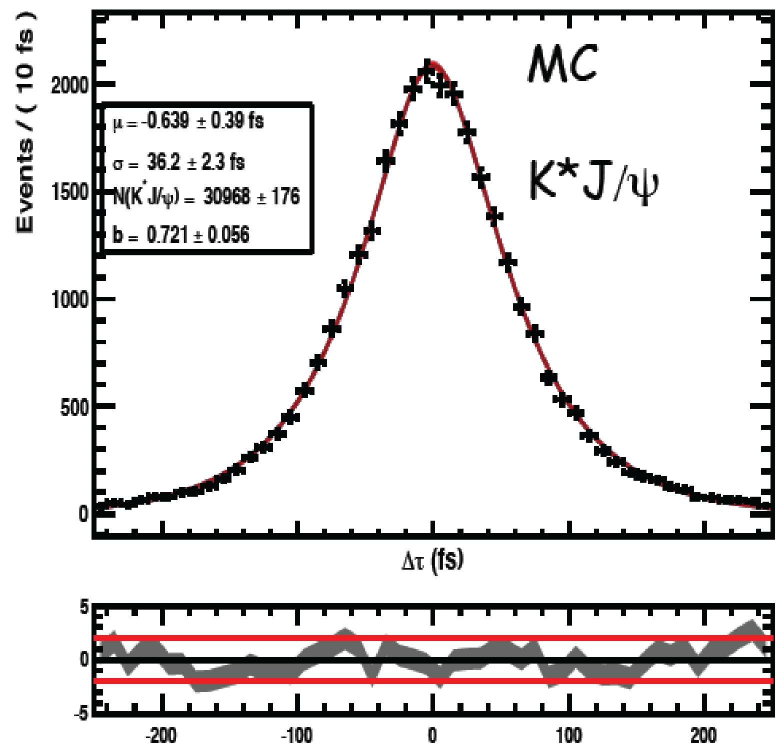
Core fraction= 52%

Experimental issues

- Resolution functions for the $B_d \to K^*\gamma$ and $B_d \to K^* J/\psi$:

$$\mathcal{R}(t) = e^{-b\sqrt{1+\frac{(t-\mu)^2}{\sigma^2}}}$$ (proper time dependent, corrected)



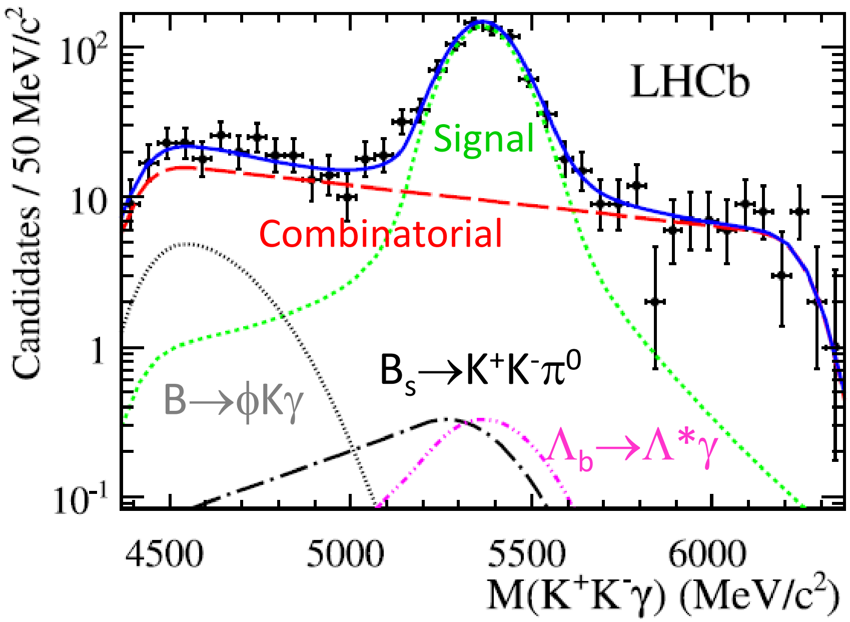


μ= 4.3 ± 0.3 fs
σ= 49± 2 fs
b= 1.17 ± 0.07

μ= -0.6 ± 0.4 fs
σ= 36± 2 fs
b= 0.72 ± 0.06

Experimental issues

- Background contributions: **[Nuc. Phys. B 867 (2013) 1-18]**



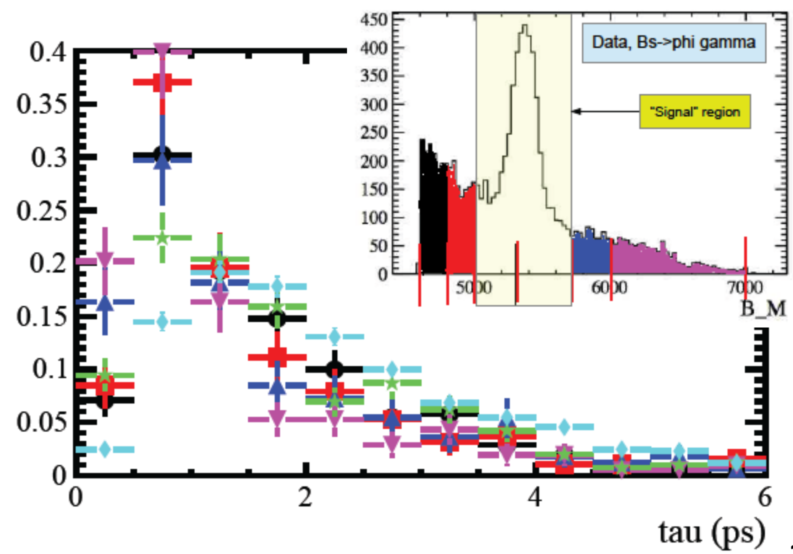
- Combinatorial background (mainly real $\phi + \gamma$)
- Contamination from merged π^0
- Baryonic radiative decays (b-baryons into $\Lambda^* + \gamma$).
- Partially reconstructed B decays ($B_s \to \phi X \gamma$, X non reconstructed)

Background model (toy simulations):

→ Combinatorial τ distributions as function of the mass region.

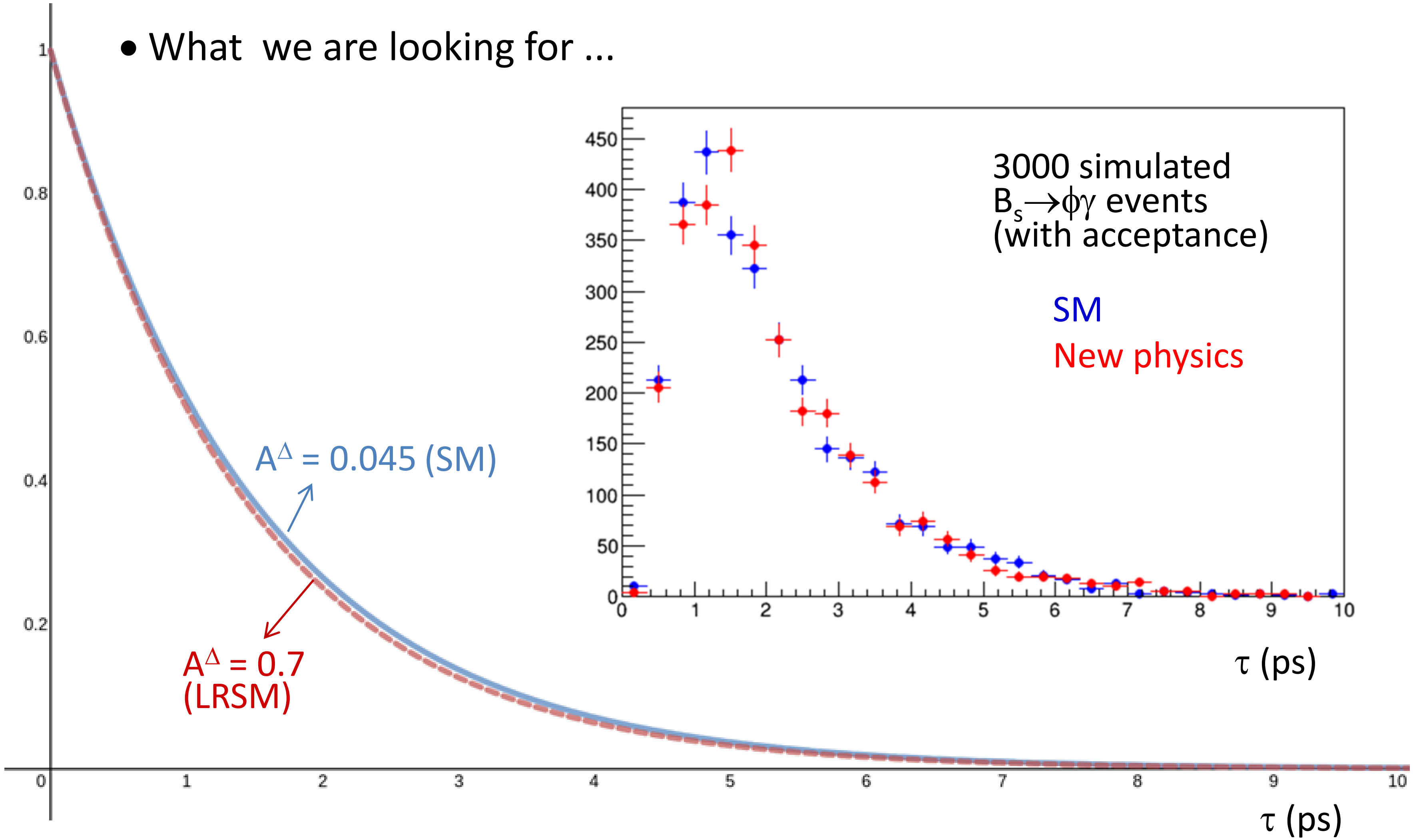
→ Contribution of physical backgrounds

The effect on A^{Δ} in progress → final selection



Simulation studies

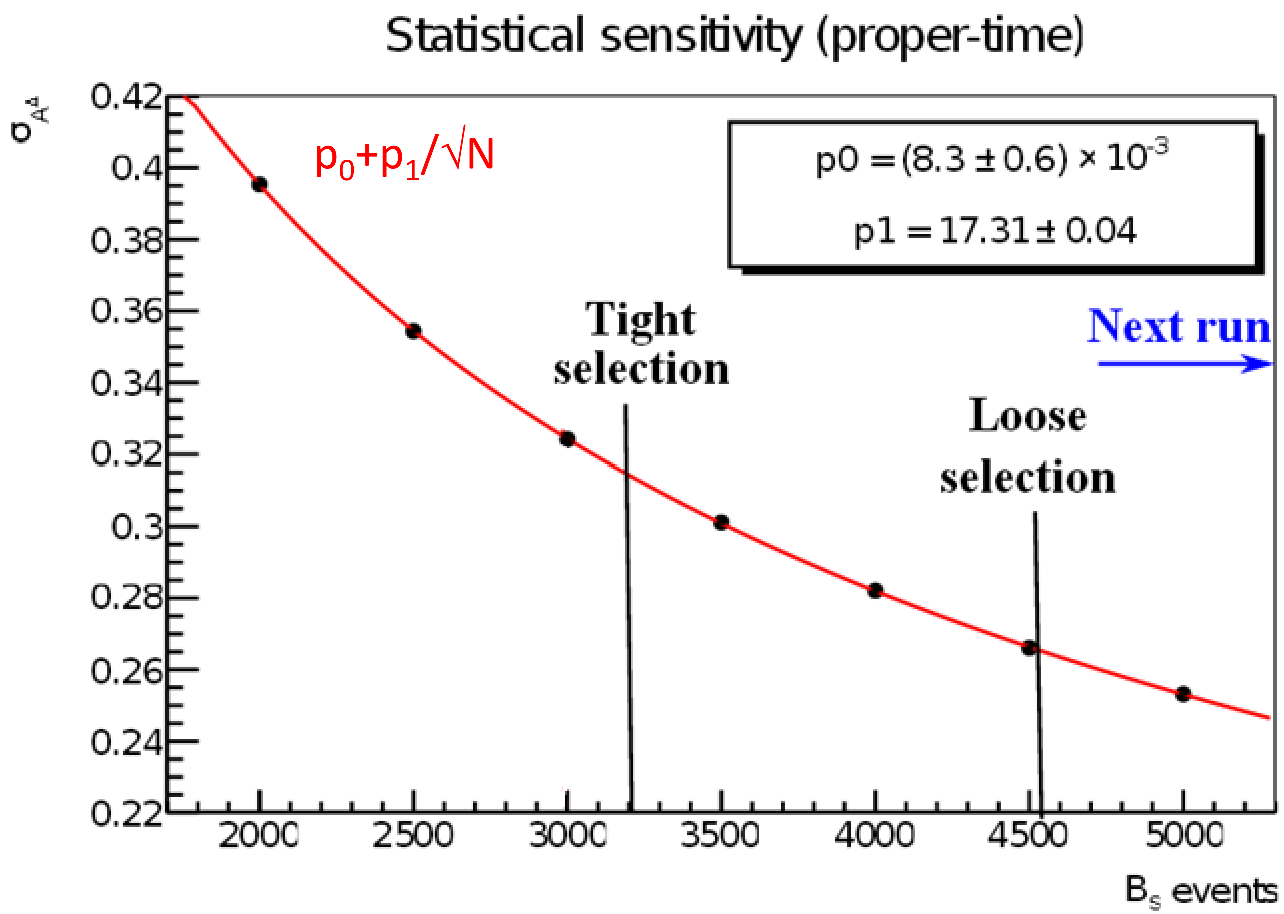
- What we are looking for ...



→ The small value of $\Delta\Gamma_s$ (~0.08) makes the measurement difficult…

Simulation studies

$\rightarrow$ But possible …



$\rightarrow$ **Statistical sensitivity on A^{Δ} ($3fb^{-1}$) ranging from 0.31 (3200 events) to 0.26 (4500) depending on the selection criteria** (compromise for background rejection)

Simulation studies

- Different fit strategies:

$$\Gamma_{B_s^0}(t) = |A|^2 e^{-\Gamma_s t} \left(\cosh \frac{\Delta\Gamma_s t}{2} - \mathcal{A}^{\Delta} \sinh \frac{\Delta\Gamma_s t}{2}\right)$$

- ▶ Binned L fit
- ▶ Unbinned ML fit
- ▶ Fit to the ratio of $B_s \to \phi\gamma / B_d \to K^*\gamma$: $\to$

$$\frac{d\Gamma_{B_s}/dt}{d\Gamma_{B_d}/dt} = \frac{N_{B_s}}{N_{B_d}} \frac{\hat{\varepsilon}_{B_s}(t)}{\hat{\varepsilon}_{B_d}(t)} \left(\frac{\Gamma_{B_s} + \frac{\mathcal{A}^{\Delta}\Delta\Gamma_s}{2}}{\Gamma_{B_d}} \right) \frac{e^{-\left(\Gamma_{B_s} + \frac{\mathcal{A}^{\Delta}\Delta\Gamma_s}{2}\right)t} \otimes \mathcal{R}_s(t,t')}{e^{-\Gamma_{B_d} t} \otimes \mathcal{R}_d(t,t')}$$

$\Delta\Gamma_d \ll$

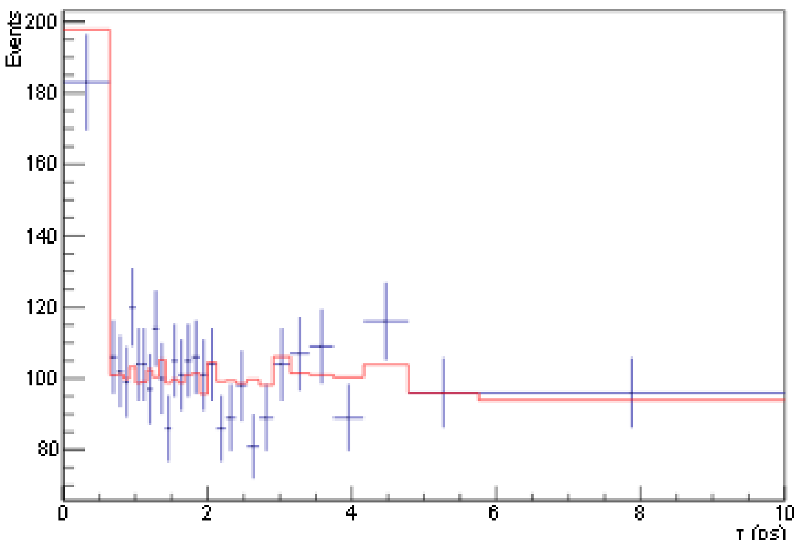
$\to$ At present several fitters have been implemented: running toys to validate the strategy and assess the uncertainties

Simulation studies

$\rightarrow$ Some examples of toy simulations (binned fit):

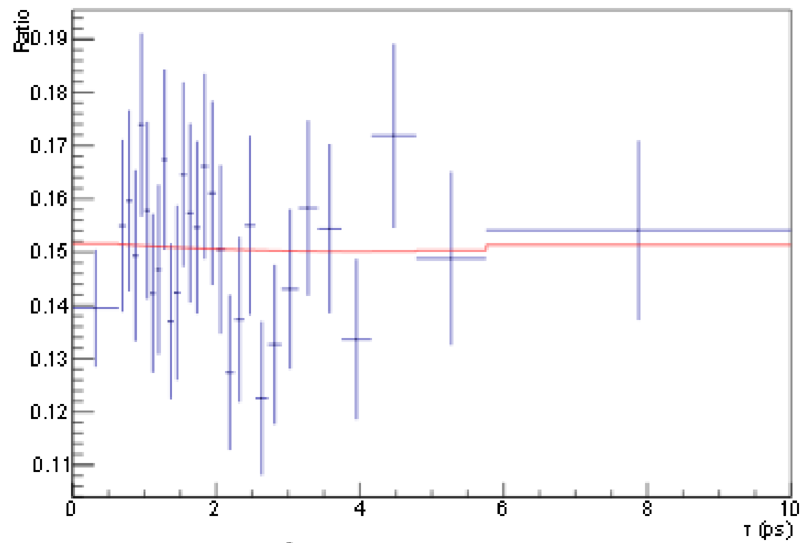
- Using adaptive binning to ensure a minimum of entries per bin (100-200)
- 3000 events for B_s, 20000 for B_d

Binned proper time fit



$$\mathcal{A}^{\Delta}_{\text{fit}} = 0.16 \pm 0.31$$

Fit to the ratio of $B_s \to \phi\gamma / B_d \to K^*\gamma$:



$$\mathcal{A}^{\Delta}_{\text{fit}} = 0.13 \pm 0.32$$

Simulation studies

- Error budget (preliminary studies) :

  - Statistical sensitivity to A^{Δ} (3000 events) **~ 0.3**
  - Statistical bias **~ 0.005**
  - Fit range and bias on A^{Δ} (finite τ) **< 0.01**
  - Effect of binning **< 0.01**
  - Effect of acceptance: **KEY one… in progress…**
  - Effect of resolution < **0.08**
  - Effect of external measurements: **~ 0.1**

    ($\Delta\Gamma_s$ =(0.081±0.011) ps^{-1} , Γ_s=(0.6596±0.0046) ps^{-1})
  - Effect of background: **(first evaluations $\rightarrow$ small)**

…

Conclusions

- The photon polarization measurement in $B_s \to \phi\gamma$ decays is possible at present with untagged events at LHCb (at least **3000 signal events**)
  - $\to$ measurement of the photon polarization parameter $\mathbf{A}^{\Delta}$
  - $\to$ expected statistical sensitivity $\sigma_{A^{\Delta}} \sim 0.3$
  - $\to$ evaluation of systematics in progress $\to$ **below statistical uncertainty**

    (use of $B \to K^*\gamma$ and $B_s \to J/\psi\phi$ events from data as control channels)

- We will have very soon more data… 3 fb^{-1} + 5 fb^{-1} (at 14 TeV, $\sigma_{pp \to bb}$ x 2):

  $\to$ untagged measurement: **~ 15K events** $\Rightarrow$ $\sigma_{A^{\Delta}} \sim 0.15$

- Sensivity studies with tagged events in progress: time dependent decay rate, A_{CP} (3 fb^{-1} (Run 1) ~ 150 events; Run1 + Run 2 ~ 500 evts)

Some naïve questions…

- Left and right amplitudes, A_L and $A_{R,}$ are related to the helicity amplitudes:

$A_L = 1/\sqrt{4}\ H_{++}$
$A_R = 1/\sqrt{4}\ H_{--}$

$$\tan\psi \equiv \left|\frac{\mathcal{A}\left(\bar{\mathrm{B}}_{\mathrm{s}} \to \phi\gamma_{\mathrm{R}}\right)}{\mathcal{A}\left(\bar{\mathrm{B}}_{\mathrm{s}} \to \phi\gamma_{\mathrm{L}}\right)}\right| \sim \frac{H_{--}}{H_{++}}$$

$$\mathcal{A}^{\Delta} \approx \sin 2\psi \cos\varphi_{\mathrm{s}}$$

- The ϕ is supposed to have the same polarization as the photon
  - have the kaons from the ϕ specific angular distributions depending on the model?
  - are we sensitive at LHCb?
  - are we sensitive in other channels ($\rho\pi$)?

- With the same argument, are we biasing our measurement if we have some angular/helicity cut?

- We assume that the weak phases ψ_L,ψ_R~ 0. What does it happen in other models?

Thanks!