Radiative B decays at LHCb

Fatima Soomro, Imperial College London

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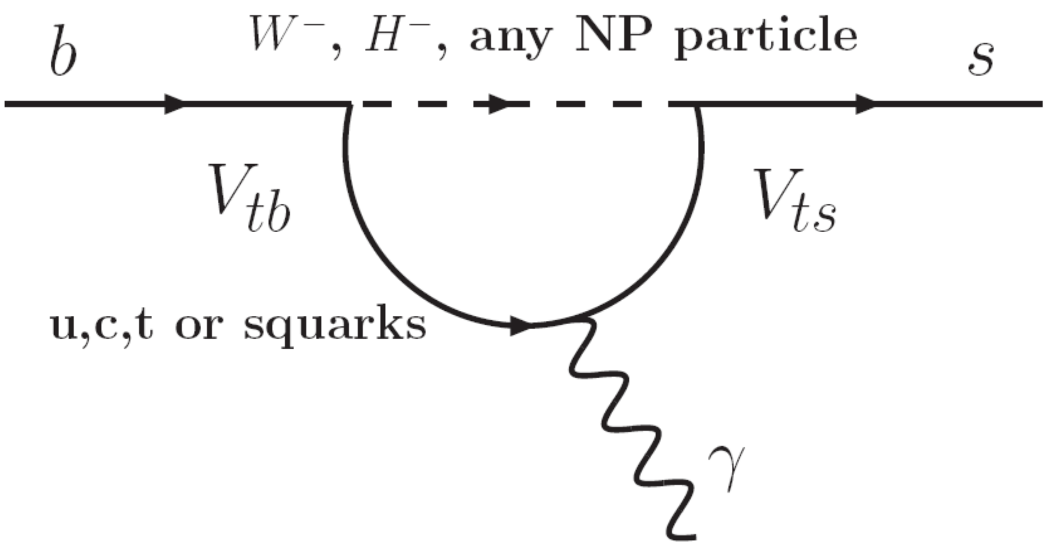
Contents

- ✓ The LHCb detector (introduced by previous speakers)
- Introduction to radiative B decays
- Photon polarization in radiative B decays
- Photon polarization measurement at LHCb
  - ➢ systematics
- Conclusion and outlook

Radiative decays of B mesons

- Radiative B decays are **$b \rightarrow s(d)\ \gamma$** transitions
- In the SM, allowed through a penguin loop
- Are sensitive to NP contribution
- Useful in constraining NP
  - ❑ Test mass scale of NP particles
  - ❑ Test the couplings of NP particles
  - ❑ Test if the couplings have a V-A structure



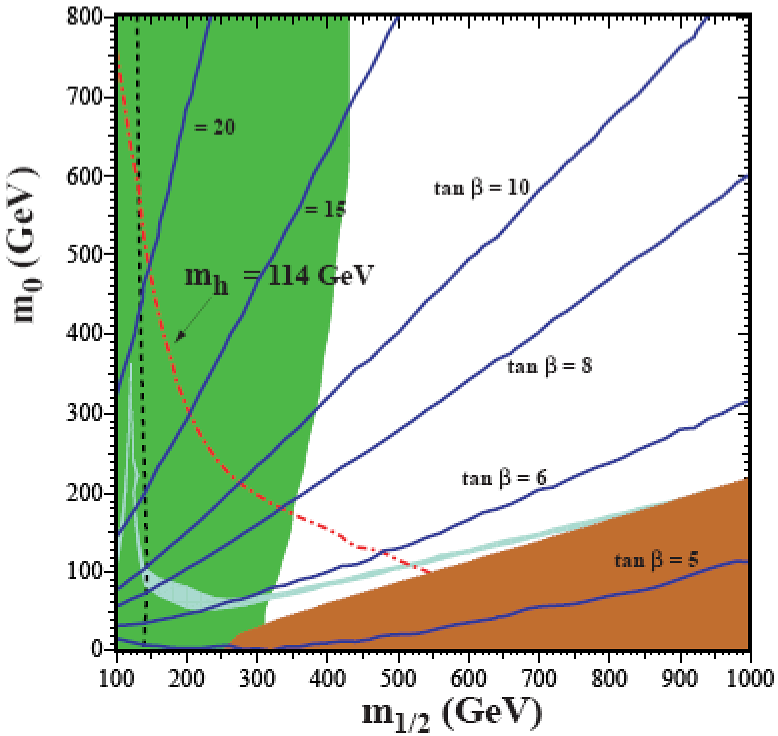
New Physics contribution

Branching ratio measurements

– $\mathcal{B}_{\text{inclusive, exp}}(B \to X_s\gamma) = 3.56 \pm 0.26 \times 10^{-4}$ [1] [3]
– $\mathcal{B}_{\text{inclusive, th}}(B \to X_s\gamma) = 3.15 \pm 0.23 \times 10^{-4}$ [2]

Good agreement puts limits on NP models

Exclusion areas in parameter space of a particular Supersymmetry model. Green: constrains from $b \to s\gamma$, brown: constrains from LSP, light blue: area favoured by WMAP [13]

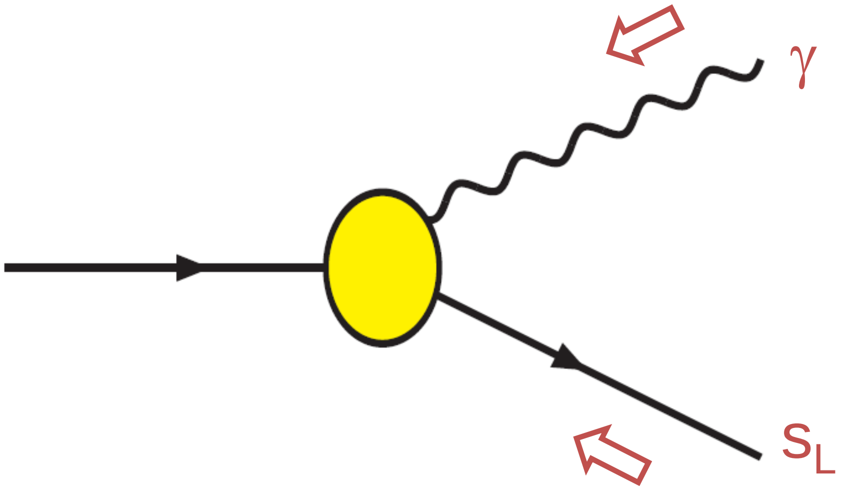


Photon polarization in $B \to f^{cp} \gamma$

Test the structure of NP operators if they contribute by measuring the photon polarization

In the SM, quarks that couple to the W are left handed

$\Rightarrow$ the photons are predominantly L handed in $\overline{B}^0$ decays



Photon polarization in B $\rightarrow f^{cp} \gamma$

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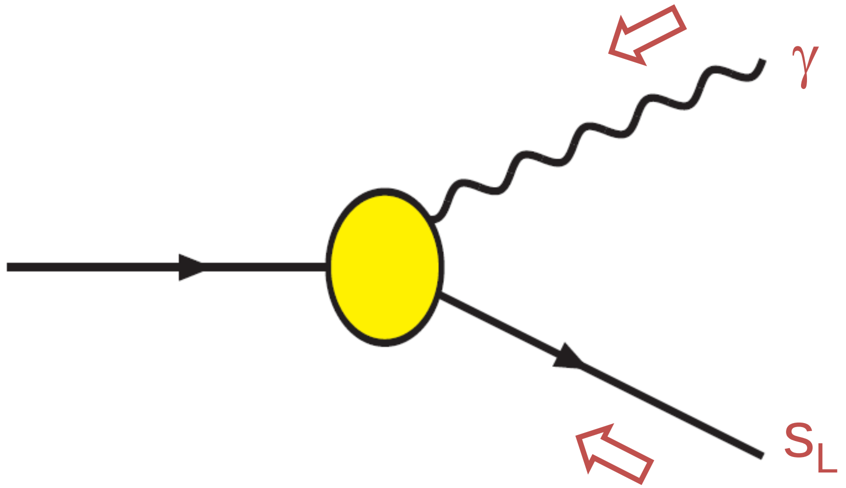

In the SM the ratio of “wrong” helicity photons is $\propto m_s/m_b$ and predicted to be ~0.4%

$\Rightarrow$ in some NP scenarios can be up to 10% [4]

(gluon emission can give upto a 1% effect as well [14])

Theoretical introduction: B $\rightarrow$ *f* ^{cp} γ

In a B $\rightarrow$ *f* ^{cp} γ decay, the time dependent decay width is parametrized as

$$\Gamma_{B^0_{(s)}\to f^{\mathcal{CP}}\gamma}(t) = |A|^2 e^{-\Gamma_{(s)}t}\left(\cosh\frac{\Delta\Gamma_{(s)}t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_{(s)}t}{2} + \mathcal{C}\cos\Delta m_{(s)}t - \mathcal{S}\sin\Delta m_{(s)}t\right)$$

$$\Gamma_{\bar{B}^0_{(s)}\to f^{\mathcal{CP}}\gamma}(t) = |A|^2 e^{-\Gamma_{(s)}t}\left(\cosh\frac{\Delta\Gamma_{(s)}t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_{(s)}t}{2} - \mathcal{C}\cos\Delta m_{(s)}t + \mathcal{S}\sin\Delta m_{(s)}t\right)$$

Where in the SM,

$$\mathcal{C}\approx 0, \quad \mathcal{S}\approx\sin 2\psi\sin\varphi_{(s)}\approx 0 \ (as\ \varphi_{(s)}\ is\ small),$$

$$and\ \mathcal{A}^{\Delta}\approx\sin 2\psi\cos\varphi_{(s)}$$

The parameter ψ contains information about the photon polarization:

$$\tan\psi \equiv \frac{\mathcal{A}\left(\bar{B}_{(s)}\to f^{\mathcal{CP}}\gamma_R\right)}{\mathcal{A}\left(\bar{B}_{(s)}\to f^{\mathcal{CP}}\gamma_L\right)}$$

Measurement of Photon polarization

One could use the fact that for small values of *S* and *C*, from the equations

$$\Gamma_{B^0_{(s)}\to f^{\mathcal{CP}}\gamma}(t) = |A|^2 e^{-\Gamma_{(s)}t}\left(\cosh\frac{\Delta\Gamma_{(s)}t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_{(s)}t}{2} + \mathcal{C}\cos\Delta m_{(s)}t - \mathcal{S}\sin\Delta m_{(s)}t\right)$$

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one gets

$$\Gamma_{B^0_s\to\Phi^{\mathcal{CP}}\gamma}(t) = |A|^2 e^{-\Gamma_s t}\left(\cosh\frac{\Delta\Gamma_s t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_s t}{2}\right)$$

$$\Gamma_{\bar{B}^0_s\to\Phi^{\mathcal{CP}}\gamma}(t) = \Gamma_{B^0_s\to\Phi^{\mathcal{CP}}\gamma}(t)$$

Measurement of Photon polarization

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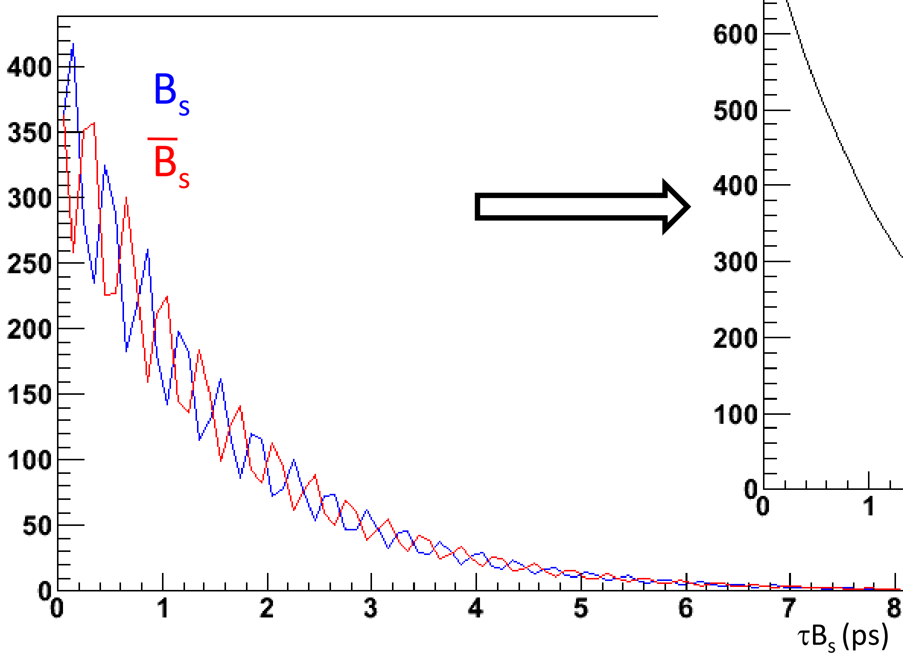
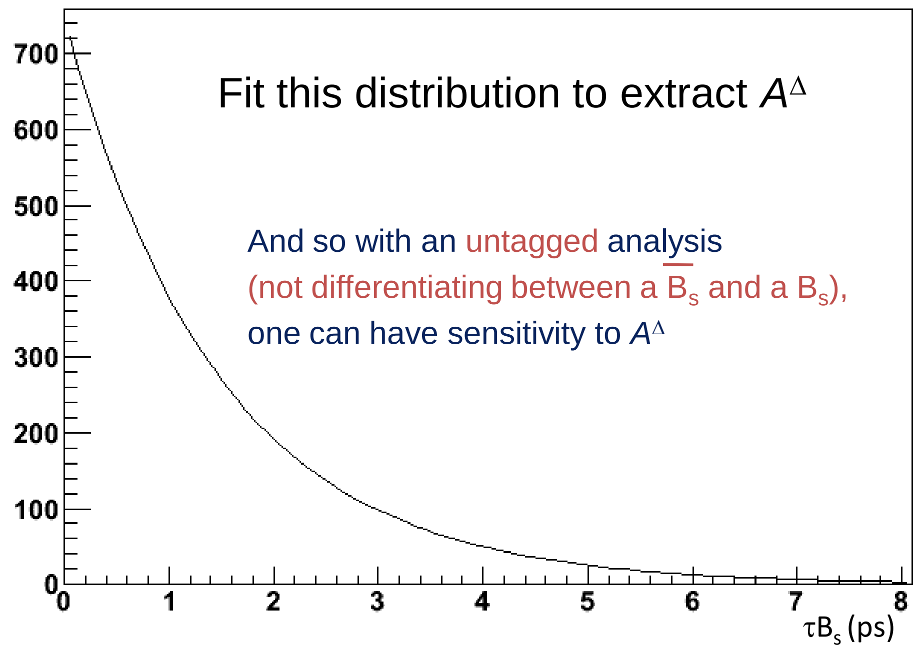
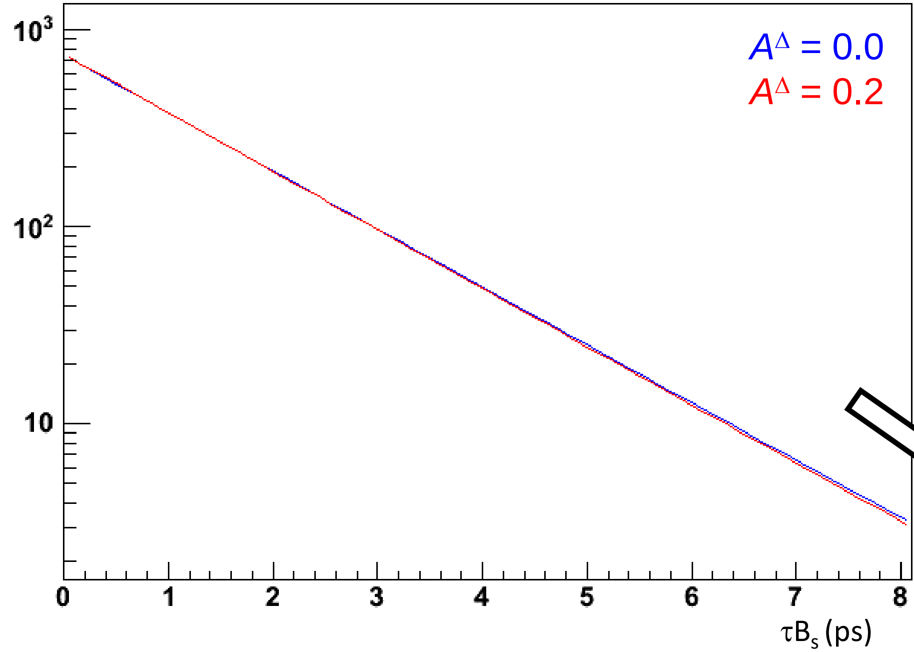
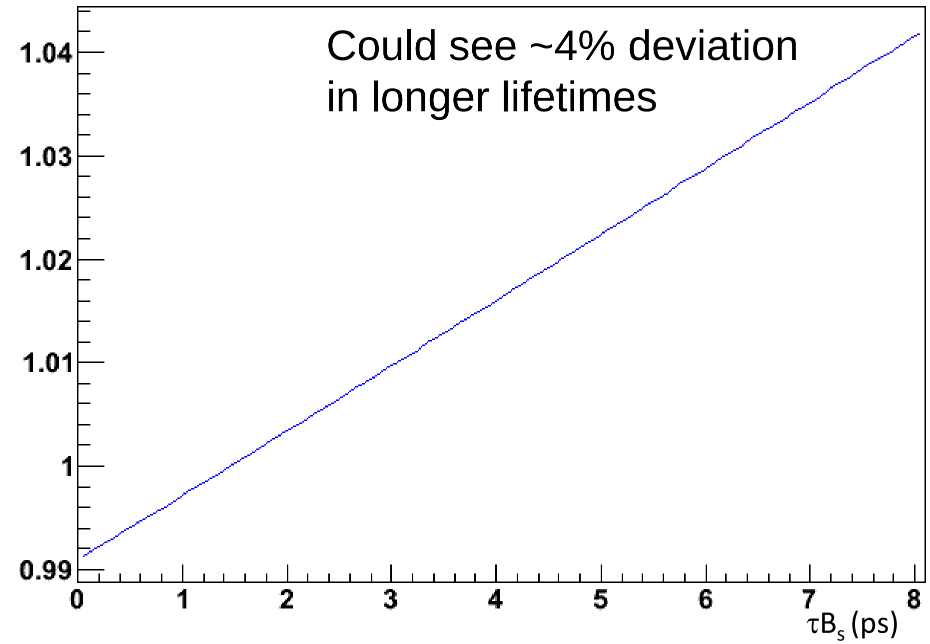




Perform fit for A^{Δ} (toy example)



Divide $A^{\Delta} = 0.0$ by $A^{\Delta} = 0.2$ distribution



γpolarization$_{B_s \to \phi\gamma}$ at LHCb

- Can be done with untagged B_s sample,

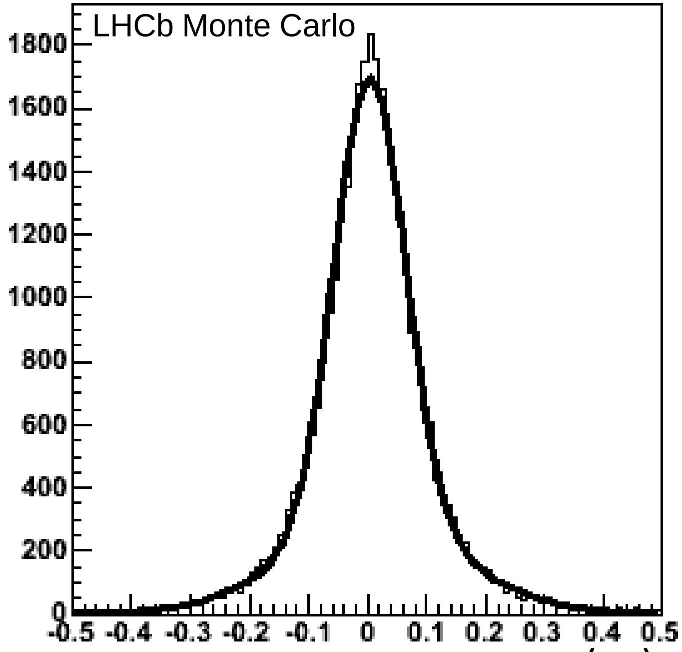
  $\sigma_{A^{\Delta}} = 0.22$ (nominal LHCb year, 11 k signal events expecetd)

- For a tagged analysis, $\sigma_S = 0.1$ (nominal LHCb year) (remember $S \approx \sin 2\psi \sin\varphi_s$)
  - measurements at Belle and BaBar with $B_d \to K^*(K_s\ \pi^0)\gamma$ $S = -0.19 \pm 0.23$[12]
  - Belle and Babar analyses based on a few hundred signal events

- Experimental requirements (it is a tough measurement):
  - Proper time resolution/bias to be precisely known
  - The lifetime acceptance function to be precisely known
  - Background distribution in lifetime to be known

The proper time resolution

- Proper time resolution is a measure of how well the B_s lifetime is reconstructed



<u>Fitted with a double gaussian</u>

μ_{core} = 3.9 $\pm$ 0.6 fs (notice the unit)

σ_{core} = 61 $\pm$ 1 fs (fraction$_{core}$ = 85%)

μ_{wide} = 10.6 $\pm$ 2 fs

σ_{wide} = 154 $\pm$ 3 fs

- A bias of 5 fs gives an uncertainty on A^{Δ} which is 1/3 of the statistical uncertainty for $2fb^{-1}$(nominal LHCb year)

Sources of proper time bias

The B_s proper time is given by

$$\tau = \frac{\vec{P} \, . \, \vec{d} \; m}{|P|^2}$$

Where $\vec{P}$ is the momentum of the B_s,

$\vec{d}$ is the distance between the primary and

the B_s decay vertex, and m is the B_s mass

Sources of proper time bias

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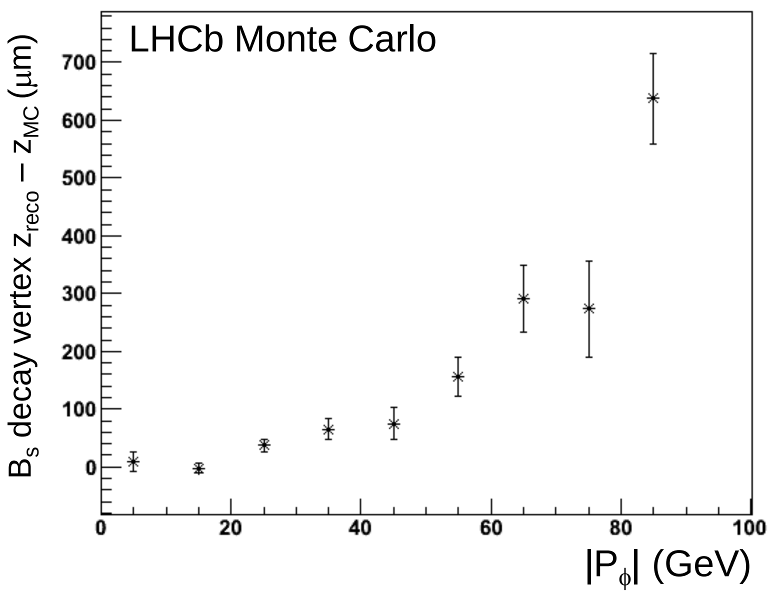


Is dominated by the vertex reconstruction

the ϕ vertex becomes increasingly difficult to reconstruct as the $\vec{P}_\phi$ increases

Control channel: $B_s \rightarrow J/\psi\ \phi$

Sources of proper time bias

The B_s proper time is given by

$$\tau = \frac{\vec{P} \cdot \vec{d}\, m}{|P|^2}$$

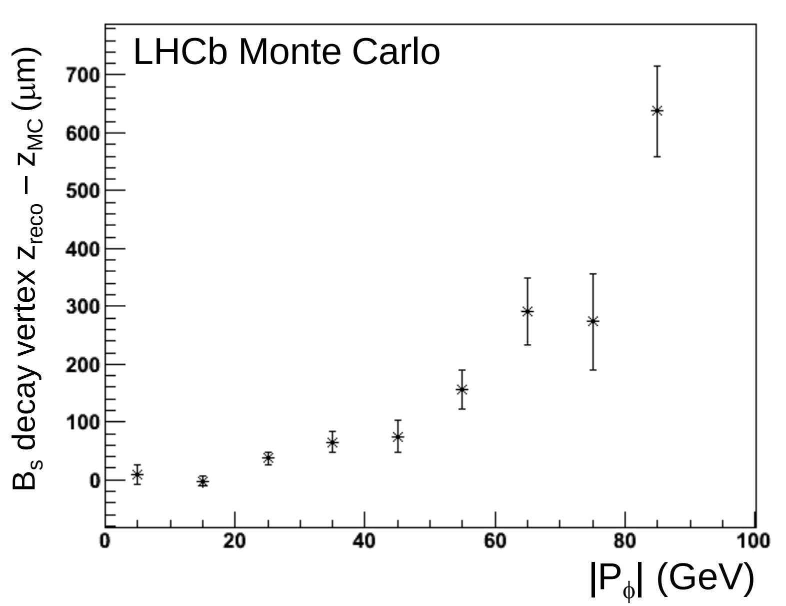
Where $\vec{P}$ is the momentum of the B_s, $\vec{d}$ is the distance between the primary and the B_s decay vertex, and m is the B_s mass

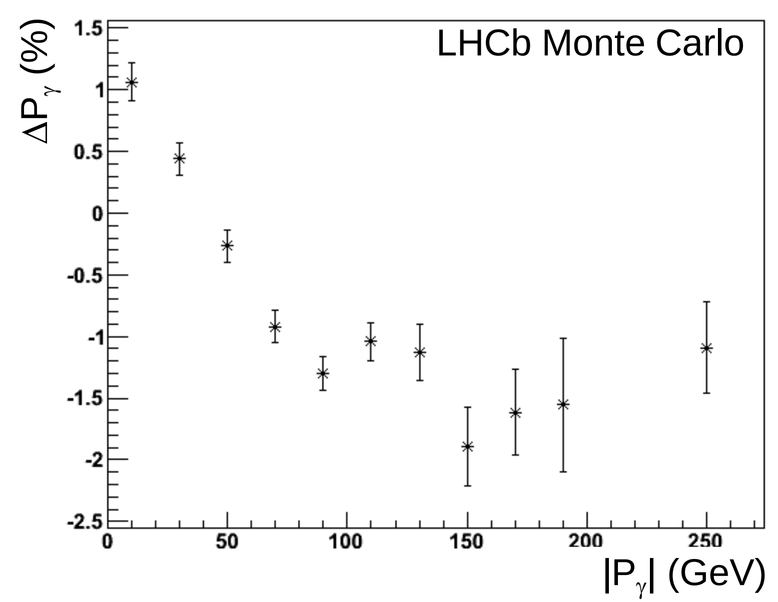
Is dominated by the vertex reconstruction the ϕ vertex becomes increasingly difficult to reconstruct as the $\vec{P}_\phi$ increases

Control channel: $B_s \to J/\psi\ \phi$

Are dominated by the photon momentum reconstruction (ECAL resolution)

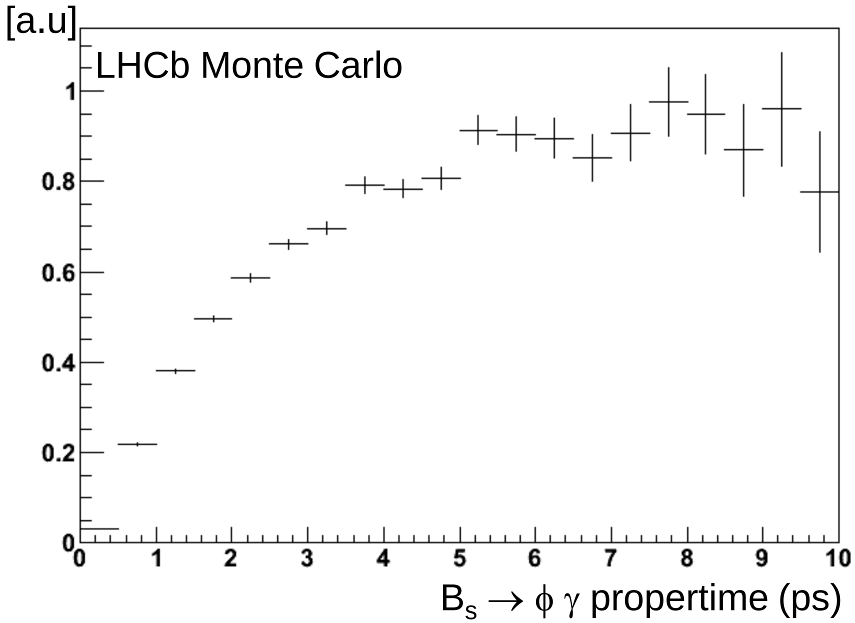
Control channel: $B_d \to K^*\gamma$





Proper time acceptance

- The efficiency to reconstruct and select events as a function of their proper time



- To keep it as simple as possible, avoid lifetime biasing cuts at the trigger and offline selection level
- Nevertheless, is non trivial
  - Calibrate using $B_s \to J/\psi\, \phi$

Calibration using $B_s \to J/\psi\phi$ and $B_d \to K^*\gamma$

1. For the proper time bias:
   - Look at the difference between the ϕ vertex and the J/ψ vertex in $B_s \to J/\psi\phi$
   - Establish a γ momentum correction from $B_d \to K^*\gamma$ (by constraining the B_d mass)

2. For the proper time acceptance:

   Again using $B_s \to J/\psi\phi$, compare the acceptance when cuts are applied to the J/ψ vertex and to the ϕ vertex

3. For the background model:

   Study mass sidebands

Conclusion and outlook

- Radiative decays of B hadrons are sensitive probes of NP
  - The roadmap measurement of A^{Δ} will require a lot of data and a very good control of systematics
- LHCb can make competitive measurements with early data
  - World's best measurement of the direct CP asymmetry in $B_d \rightarrow K^* \gamma$
  - Ratio of BR $B_d \rightarrow K^* \gamma$ / $B_s \rightarrow \phi\gamma$
- Radiative decays will be useful for calibration of the ECAL with early data

References and backup slides

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S parameter from $B_d \to K^*(K_s \pi^0)\gamma$

Experiment		$N(B\overline{B})$	$S_{CP}(b \to s\gamma)$	$C_{CP}(b \to s\gamma)$	Correlation
			$K^*(892)\gamma$		
BABAR	[340]	431M	$-0.08 \pm 0.31 \pm 0.05$	$-0.15 \pm 0.17 \pm 0.03$	0.05
Belle	[341]	535M	$-0.32\,^{+0.36}_{-0.33} \pm 0.05$	$0.20 \pm 0.24 \pm 0.05$	0.08
Average			-0.19 ± 0.23	-0.03 ± 0.14	0.06
Confidence level			0.43 (0.8σ)		
			$K^0_S\pi^0\gamma$ (including $K^*(892)\gamma$)		
BABAR	[342]	232M	-0.06 ± 0.37	-0.48 ± 0.22	0.05
Belle	[341]	535M	$-0.10 \pm 0.31 \pm 0.07$	$0.20 \pm 0.20 \pm 0.06$	0.08
Average			-0.09 ± 0.24	-0.12 ± 0.15	0.06
Confidence level			0.08 (1.8σ)		

[12] Heavy Flavor Averaging Group, arXiv:0808.1297v3 [hep-ex] (2009)

Branching Fraction and Photon Energy Spectrum for *b→sγ, The CLEO collaboration,* Phys. Rev. Lett. 87, 251807 (2001)

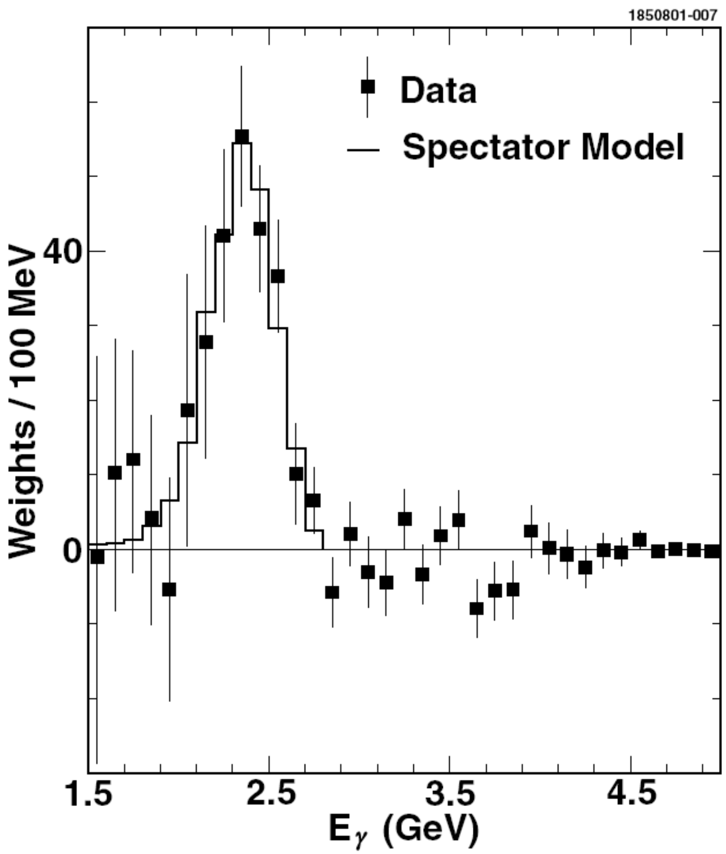
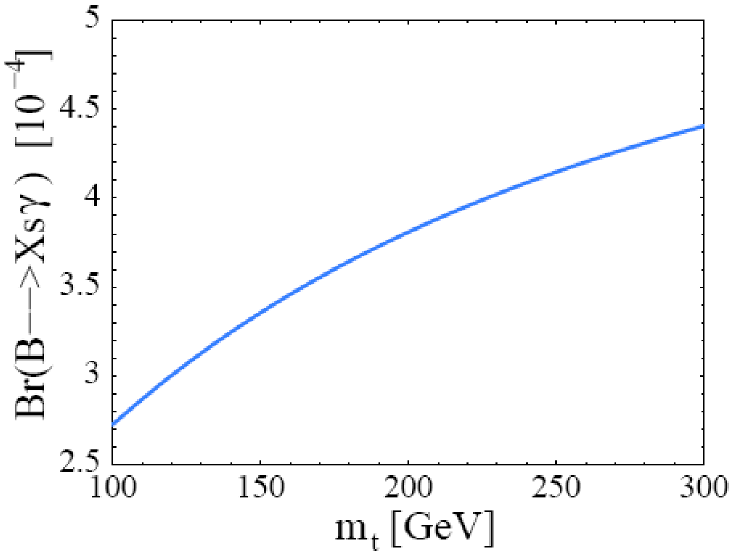
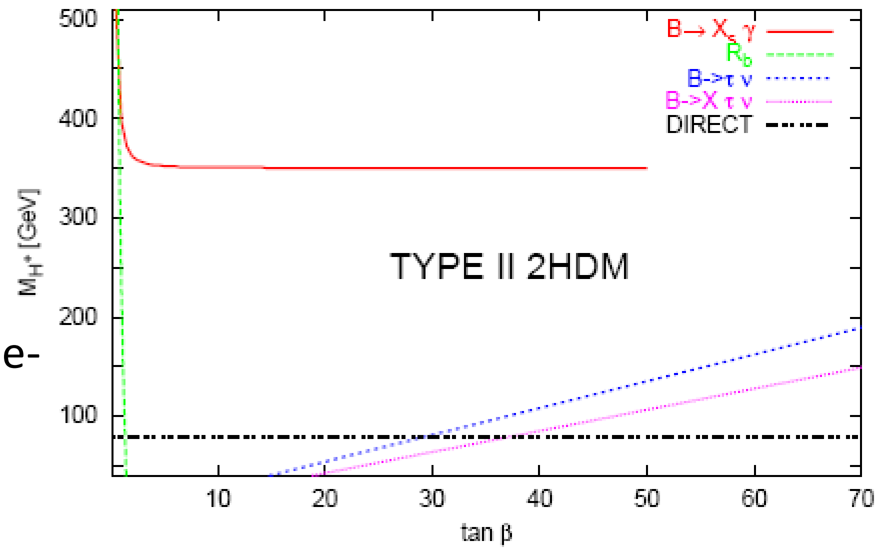


FIG. 2. Observed laboratory frame photon energy spectrum (weights per 100 MeV) for on minus scaled off minus B backgrounds, the putative $b \to s\gamma$ plus $b \to d\gamma$ signal. No corrections have been applied for resolution or efficiency. Also shown is the spectrum from Monte Carlo simulation of the Ali-Greub spectator model with parameters $\langle m_b \rangle = 4.690$ GeV, $P_F = 410$ MeV$/c$, a good fit to the data.

arXiv:hep-ph/0212360v1



Sensitivity of the B → Xsγ branching ratio to the top-quark mass



Bound on the charged-Higgs mass in the type-II 2HDM derived from the analysis of the inclusive B → Xsγ branching ratio (solid line)

P.Ball, R.Zwicky

- S_K*gamma S_K*gamma is the time dependent CP asymmetry of B -> K* gamma. In 97 it was noticed that the standard model (V-A interaction !) produces mainly left handed photons in \bar B -> \bar K* gamma_L(R), O(m_s/m_b). A non-vanishing time dependent CP-asymmetry demands both chiralities and is therefore very small \sim -2%. It was noticed that gluon emission from c and u-loops produce both chiralities and it was guestimated to give a contribution of -10% (hep-ph/0412019) plus a large uncertainty. We have performed a straightforward calculation and have shown that the contribution is 0.5% \pm 1% ! (hep-ph/0609037) and therefore S_K*gamma etc remain important (quasi) null tests of the standard model. The current HFAG value is S_K*gamma = -28 \pm 26 % ! All TDCP asymmetries for B-> V gamma are observables of primary interest for the SuperB-factory

  [http://www.ippp.dur.ac.uk/~zwicky/]

Probing NP with radiative B decays

1. Direct CP and isospin asymmetry in $B \to K^* \gamma$
   – Results from experiment [5] agree with theory [6], but large errors
   - ❑ $-0.033 < A_{cp} (B_d \to K^* \gamma) < 0.028$ (theory: <1%)
   - ❑ $0.017 < \Delta_{0-} < 0.116$ (theory: ~ 4%)

   – LHCb can make a competitive measurement of $A_{cp} (B_d \to K^* \gamma)$ with only 100 pb^{-1} [7]
2. The photon energy spectrum in inclusive $b \to s\gamma$ decays is a useful experimental test of
   – The parton model, mass of spectator quark and the motion of the b quark inside the hadron [3]
3. Inclusive $b \to s \gamma$ and $b \to d \gamma$ [8,9]
   – Provide measurements of V_{ts} and V_{td} and their ratio
   – Compare to the ones measured in B_s and B_d oscillations
4. Photon polarization

Measuring the photon polarization

1. $B_d \rightarrow K^*ee$
   - Angle b/w the $K\pi$ plane and ee plane
   - LHCb sensitivity to the the fraction of wrongly polarized photons is 0.1 for 2 fb^{-1} [11]

2. $\Lambda_b \rightarrow \Lambda\,(p\pi)\gamma$
   - A_{FB} of the proton flight direction wrt the Λ_b in Λ rest frame is proportional to the photon polarization

3. B to h_1 h_2 h_3 gamma (K resonances)
   - Only K(1400) has sensitivity, need to separate it from the other resonances

4. $Bs \rightarrow f^{cp}\gamma$