Photon polarisation in $b \to s\gamma$ transition at LHCb

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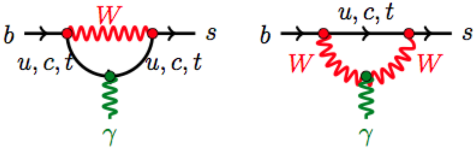
- Transitions driven by FCNC represent pure quantum effects within the SM



- Loop-driven B decays are more sensitive to the presence of New Physics beyond SM.
- The SM photon in $b \to s\gamma$ is predominantly left-handed

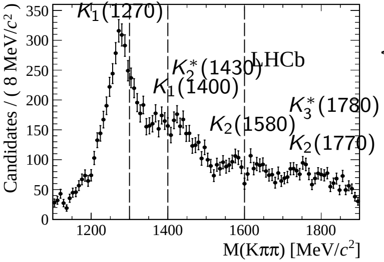
$$\bar{s}\Gamma_{\mu}^{b\to s\gamma} b = \frac{e}{(4\pi)^2}\frac{g^2}{2M_W^2} V_{ts}^{*} V_{tb} F_2 \bar{s} i \sigma_{\mu\nu} q^{\nu} \Big(m_b \frac{1+\gamma_5}{2} + \quad m_s \frac{1-\gamma_5}{2} \Big) b$$

$$b_R \to s_L \gamma_L \qquad\qquad b_L \to s_R \gamma_R$$

- The right-handed contribution can be significantly enlarged due to new physics.

Photon polarisation in radiative B decays

- Measuring the photon polarisation
  - The time-dependent CP-asymmetry in $B_{(s)} \to f^{CP}\gamma$: $B_s^0 \to \phi\gamma$, $B^0 \to K_S^0\pi^0\gamma$
  - Angular correlations among the three-boday decay products of the excited kaons in $B \to K_{res}(P_1P_2P_3)\gamma$: $B \to K_1(K\pi\pi)\gamma$, $B \to \phi K\gamma$
  - Transverse asymmetry in $B^0 \to K^*(892)^0 l^+ l^-$
  - Direct measurement of the photon polarisation in baryons decays: $\Lambda_b \to \Lambda^{(*)}\gamma$, $\Xi_b \to \Xi^{(*)}\gamma$
- Photon polarisation in $b \to s\gamma$ transition first observed in $B \to K\pi\pi\gamma$ [PRL 112, 161801 (2014)].



Time dependent CP asymmetry in $B_s^0 \to \phi\gamma$

The time-dependent decay rate for initial B_s^0 and $\overline{B}_s^0$ decaying into $\phi\gamma$:

$$\Gamma_{B_s^0\to\phi\gamma} \propto |A|^2 e^{-\Gamma_s t}(\cosh\frac{\Delta\Gamma_s t}{2} - A^{\Delta}\sinh\frac{\Delta\Gamma_s t}{2} + C\cos\Delta m_s t - S\sin\Delta m_s t)$$

$$\Gamma_{\overline{B}_s^0\to\phi\gamma} \propto |A|^2 e^{-\Gamma_s t}(\cosh\frac{\Delta\Gamma_s t}{2} - A^{\Delta}\sinh\frac{\Delta\Gamma_s t}{2} - C\cos\Delta m_s t + S\sin\Delta m_s t)$$

respectively, where

$$C = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} \approx 0 \text{ (SM)}$$

$$S \approx \sin 2\psi \sin\varphi_s \text{ (}\varphi_s \text{ is the } B_s \text{ mixing phase)}$$

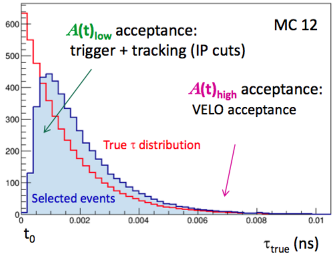
$$A^{\Delta} \approx \sin 2\psi \cos\varphi_s$$

ψ is given by the fraction of "wrongly"-polarized photons and defined as

$$\tan\psi = \left|\frac{A(\overline{B}_s^0 \to \phi\gamma_R)}{A(\overline{B}_s^0 \to \phi\gamma_L)}\right|$$

Lifetime measurement

- Physics: $\Gamma_{B_s^0 \to \phi\gamma} + \Gamma_{\overline{B}_s^0 \to \phi\gamma} \propto e^{-\Gamma_{B_s^0} t} (\cosh \frac{\Delta\Gamma_s t}{2} - A^{\Delta} \sinh \frac{\Delta\Gamma_s t}{2})$
- Acceptance: trigger, selection and reconstruction requirements



- Key in the photon polarization measurement;
- Need to be precisely determined or controlled.

- Resolution: dominated by the photon momentum, from Monte Carlo
- Background: the B mass distribution

The LHCb experiment

Tracking:

$\Delta p/p \sim 0.4\%$ at 5GeV

$\sigma_{\text{IP}} \sim 20\mu m$ for high-p_T tracks and $\sigma_\tau \sim 45fs$

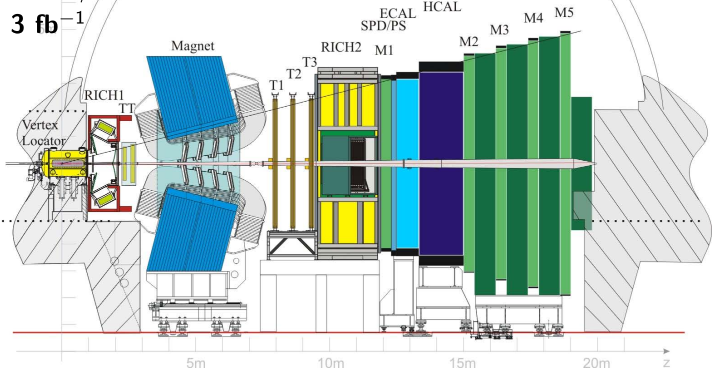
Particle identification:

π/K separation over 2-100GeV ($\epsilon_K \sim 90\%$ for $\sim 5\%$ $\pi \to K$ mid-id)

Calorimeter system:

$\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$

Run I: $\sim$ **3 fb^{-1}**



Acceptance

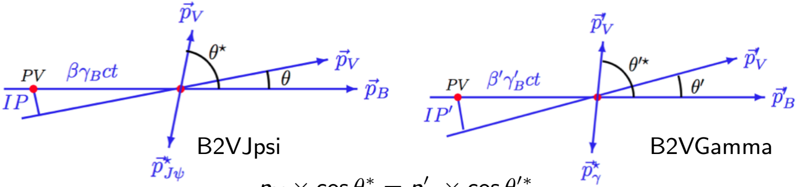
- The acceptance function $A(t)$ can be parametrized as:

$$A(t) = \underbrace{\frac{[a(t-t_0)]^n}{1+[a(t-t_0)]^n}}_{A(t)_{\text{low}}} \cdot \underbrace{e^{-\delta\Gamma t}}_{A(t)_{\text{high}}}$$

- Similar radiative decay: $B^0 \rightarrow K^{*0}\gamma$
  - Similar topology, same trigger for the photon, similar resolution, large statistics
  - Large background
  - Avoid selection cuts to introduce difference in acceptance
    - RL (Ratio Loose, 30000) and 4500 $B_s^0 \rightarrow \phi\gamma$
    - RT (Ratio Tight, 20000) and 3500 $B_s^0 \rightarrow \phi\gamma$
    - and DF (Direct Fit, 22000) and 3500 $B_s^0 \rightarrow \phi\gamma$

Acceptance

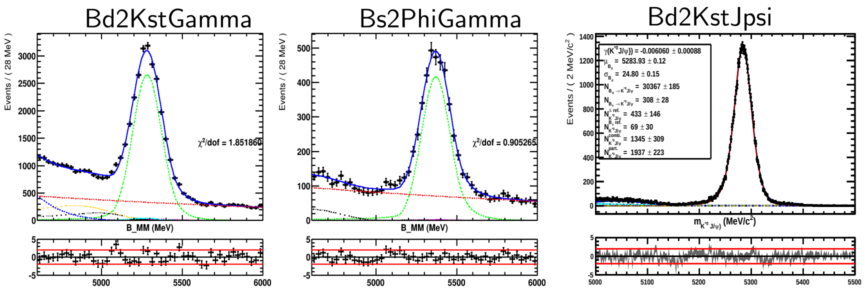
- Background free channel: $B^0 \to K^{*0} J/\psi$
  - Kinematic difference: mass difference between photon and J/ψ and the helicity difference between two channels.
  - $A(t)_{\text{high}}$: constrained from Monte Carlo in the final fit
  - $A(t)_{\text{low}}$: two geometrical variables related to vertex displacement — A 2D kinematical reweighting: helicity angle $\cos\theta_H$ and $p_V \cdot \cos\theta$ and then scale the related variables by a constant scaling factor



$$p_V \times \cos\theta^* = p'_V \times \cos\theta'^*$$

  - Events selected: DF, 30000 (3500 $B_s^0 \to \phi\gamma$)

Background



- $B^0 \to K^{*0}\gamma$ and $B_s^0 \to \phi\gamma$
  - Use sWeights from mass fits:
    the correlation between mass and proper time $\Rightarrow$ systematics
  - Direct background subtraction: crosscheck
- $B^0 \to K^* J/\psi$: background free in the signal region

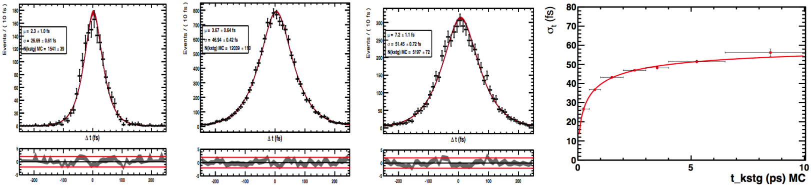
Lifetime resolution

- The proper time bias is reduced to about 5 fs and constant over the different calorimeter regions after applying the photon calibration.
- The Apollonios parametrization of the proper time resolution:

$$R(t) = e^{-b\sqrt{1+\frac{(t-\mu)^2}{\sigma^2}}}$$

- And the the evolution of the proper time resolution σ as a function of the reconstructed proper time is fitted with

$$\sigma(t) = \sigma_0 \times \frac{t^n}{1 + \alpha t^n}$$

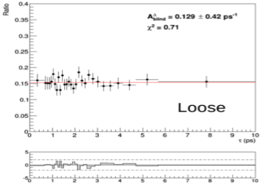


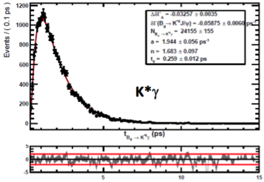
Lifetime fit procedure

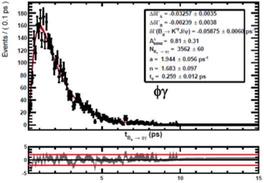
- Two approaches:
  - Ratio fit: $B_s^0 \to \phi\gamma / B^0 \to K^{*0}\gamma$

$$\frac{d\Gamma_{B_s^0 \to \phi\gamma}/dt}{d\Gamma_{B^0 \to K^{*0}\gamma}/dt} \propto \frac{R_{B_s^0(t,t')} \otimes N_{B_s^0} \cdot \epsilon_{B_s^0}(t') \cdot e^{-\Gamma_{B_s^0} t'} (\cosh \frac{\Delta\Gamma_s t'}{2} - A^\Delta \sinh \frac{\Delta\Gamma_s t'}{2})}{R_{B^0}(t,t') \otimes N_{B^0} \cdot \epsilon_{B^0}(t') \cdot e^{-\Gamma_{B^0} t'}}$$

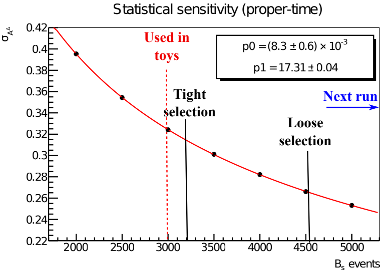
  - Direct fit: unbinned simultaneous ML fit to
    - $B_s^0 \to \phi\gamma$ and $B^0 \to K^{*0}\gamma$
    - $B_s^0 \to \phi\gamma$ and $B^0 \to K^{*0} J/\psi$
    - $B_s^0 \to \phi\gamma$ and $B^0 \to K^{*0}\gamma$ and $B^0 \to K^{*0} J/\psi$







Measurement of A^{Δ}: blind analysis

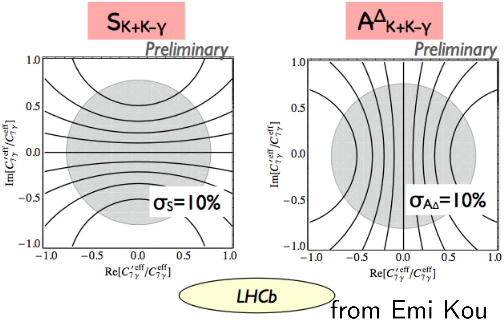


- The blinding method: add random number to result, i.e. A^{Δ} value
- Statistical uncertainty is worsened by using sPlot for background subtraction
- Systematics uncertainty is in progress: fit model, mass-time correlation, scaling and reweighting, calorimeter calibration, etc.

Roadmap for selected key measurements of LHCb

Next $B_s^0 \to \phi\gamma$ study

- Combining S and A^{Δ} of $B_s^0 \to \phi\gamma$ will lead to a very strong constraint on the C_7 and C_7' plane



from Emi Kou

- Instead of a combined sample, the measurement of S requires tagged sample.

The End