Radiative B decays as probes of physics beyond the Standard Model (BSM)

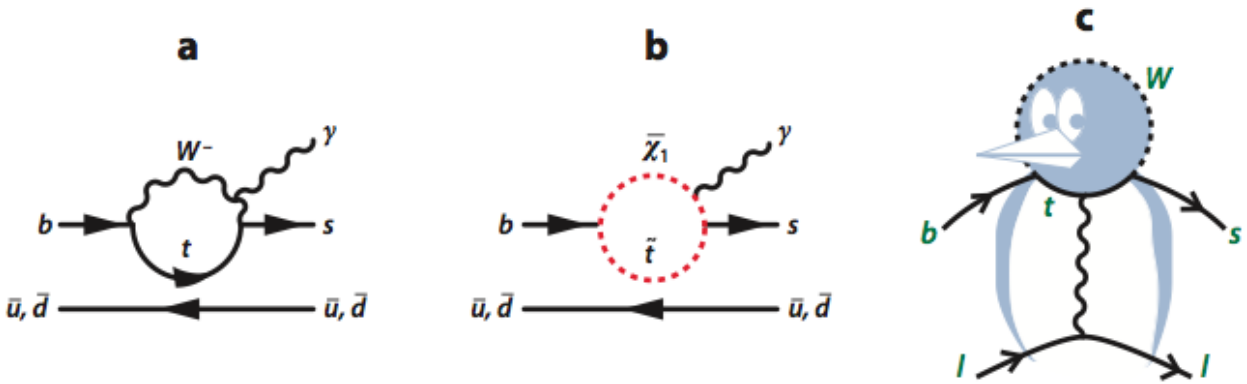
Zhirui XU (EPFL)
(On behalf of LHCb Collaboration)

Outline

- Physics BSM in radiative B decays
- The LHCb experiment
- Relative decay rate and CP asymmetry
- Photon polarisation in $b \to s\gamma$ transition
- Summary

Physics BSM in radiative B decays

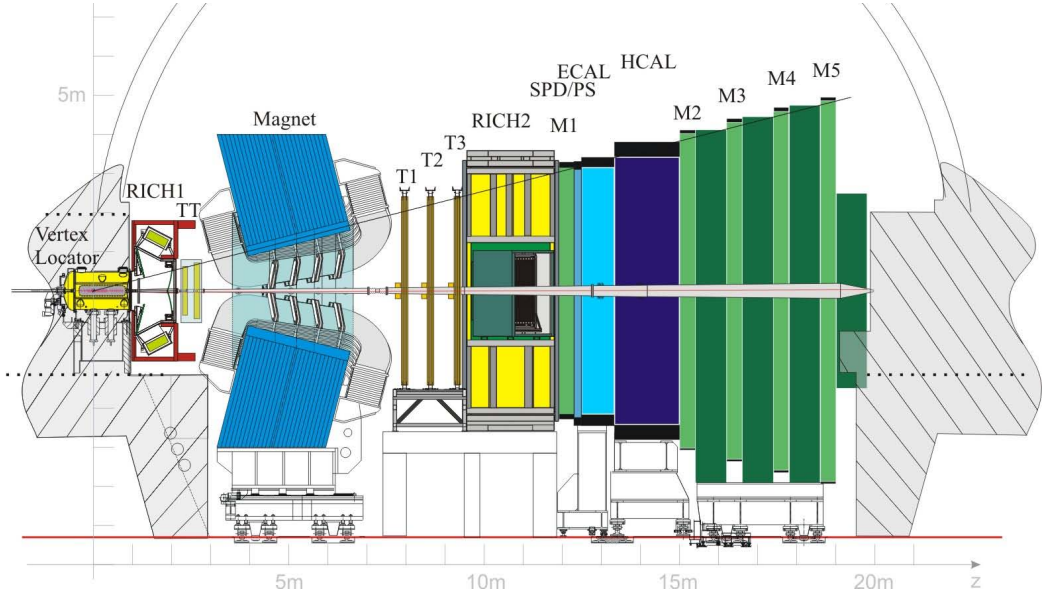
- In Standard Model (SM), flavor-changing neutral current (FCNC) amplitudes are suppressed because
  - loop effects involving the weak scale $[g^2/(4\pi)^2$ and $1/M_W^2]$.
  - smallness of the relevant CKM matrix elements.

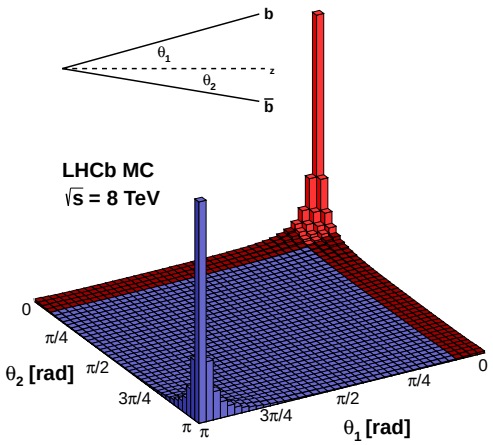


- The rates and various kinematic distributions as well as CP asymmetries and other properties, of rare decays can be predicted in the SM with low theoretical uncertainty, while the measured quantities may be affected by physics BSM.
- Comparisons between the predictions and the measurements therefore provide sensitive tests for BSM contributions.

The LHCb experiment

- The LHCb detector is a single arm spectrometer which covers the forward region at LHC.



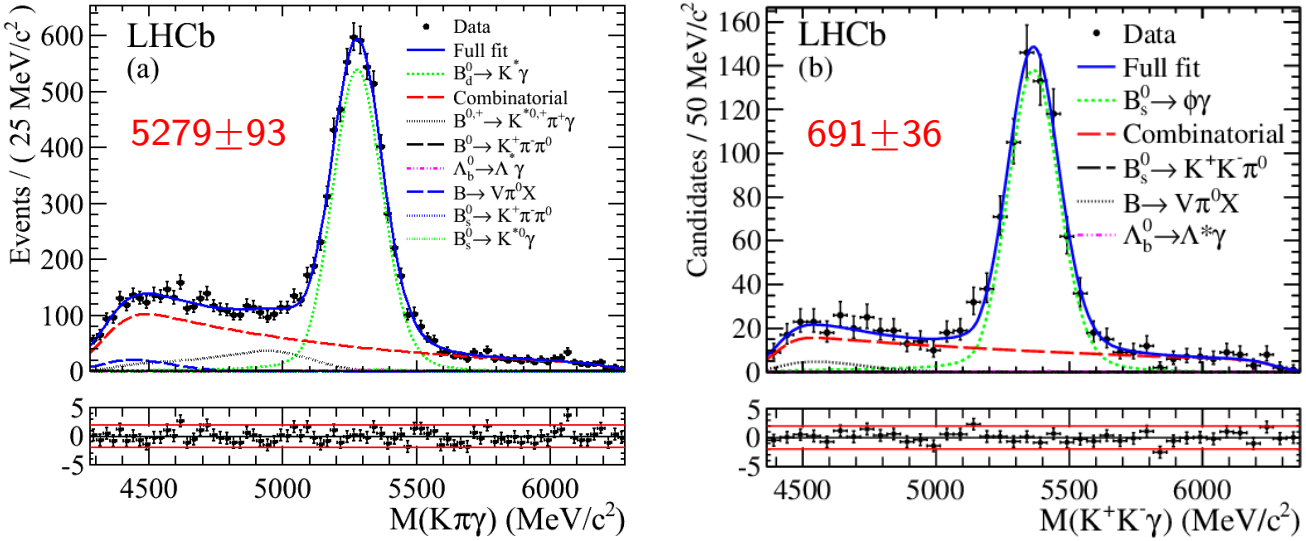


- Tracking:
  - $\Delta p/p \sim 0.4\%$ at 5GeV
  - $\sigma_{\mathrm{IP}} \sim 20\mu m$ for high-p_T tracks and $\sigma_\tau \sim 45fs$
- Particle identification:
  - π/K separation over 2-100GeV ($\epsilon_K \sim 90\%$ for $\sim 5\%$ $\pi \rightarrow K$ mid-id)
- Calorimeter system:
  - $\sigma_E/E \sim 10\%/\sqrt{E} \oplus 1\%$

Relative decay rate and CP asymmetry

- A measurement of $\mathcal{B}(B^0 \to K^{*0}\gamma)/\mathcal{B}(B_s^0 \to \phi\gamma)$ is performed on 1.0 fb^{-1} pp collision data collected in 2011 at 7 TeV.

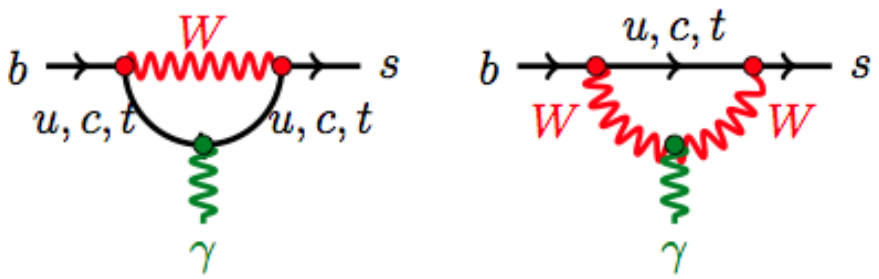
[Nuclear Physics B, 867, 1-18 (2013)]



- $\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.23 \pm 0.06(stat.) \pm 0.04(syst.) \pm 0.10(f_s/f_d)$ is consistent with the theoretical prediction 1.0 ± 0.2 [Eur. Phys. J. C 55:577 (2008)].
- Direct CP asymmetry $\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma) = (0.8 \pm 1.7(stat.) \pm 0.9(sys.))\%$ and the SM prediction is (-0.61±0.43)% [Phys. Rev. D72 (2005) 014013].

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

- Loop-driven B decays are very sensitive to the presence of new physics BSM.



- The SM photon in $b \to s\gamma$ is predominantly left-handed whilst the right-handed contribution can be significantly enlarged due to new physics [JHEP08(2012)090].
- Methods most sensitive to the photon polarisation provide complementary information:
  - 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-body 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 $B^0 \to K^*(892)^0 e^+e^-$
  - Direct measurement of the photon polarisation in baryons decays: $\Lambda_b \to \Lambda^{(*)}\gamma$, $\Xi_b \to \Xi^{(*)}\gamma$

Measurement of photon polarisation at LHCb

- The effective electroweak Hamiltonian relevant to $b \to s$ transitions in SM:

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha_e}{4\pi} \sum_i \mathcal{C}_i(\mu_s)\mathcal{O}_i(\mu_s)$$

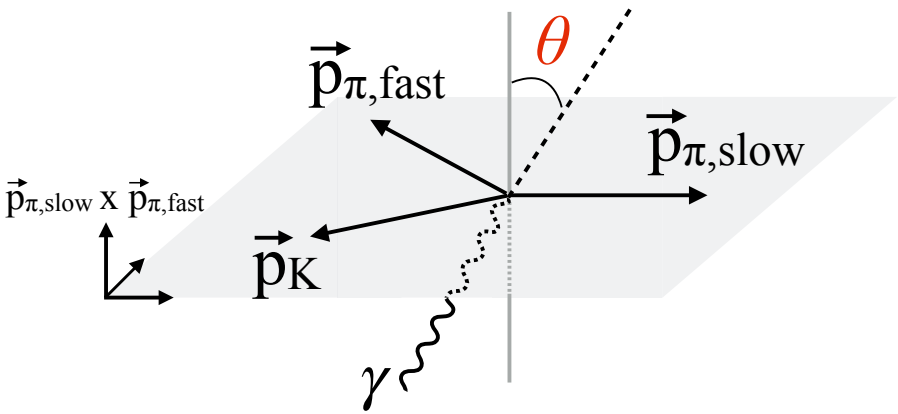
  - $\mathcal{O}_7^{(\prime)}$ is important for radiative b hadron decays:

$$\mathcal{O}_7 = \frac{m_b}{e}\bar{s}\sigma^{\mu\nu}\frac{1+\gamma_5}{2}bF_{\mu\nu}, \qquad \mathcal{O}_7' = \frac{m_b}{e}\bar{s}\sigma^{\mu\nu}\frac{(1-\gamma_5)}{2}bF_{\mu\nu}$$

  - Wilson coefficient $\mathcal{C}_7'$ is suppressed by $\mathcal{O}(m_s/m_b)$ due to the left-handedness of the charged-current interaction.
- Two analyses will be covered in this talk:
  - Photon polarisation study in $B^+ \to K^+_{\text{res}}(K\pi\pi)\gamma$ [PRL 112, 161801 (2014)]
  - Transverse asymmetry in $B^0 \to K^*(892)^0 e^+e^-$ [JHEP04(2015)064]

Photon polarisation in $B^+ \to K^+_{\text{res}}(K\pi\pi)\gamma$

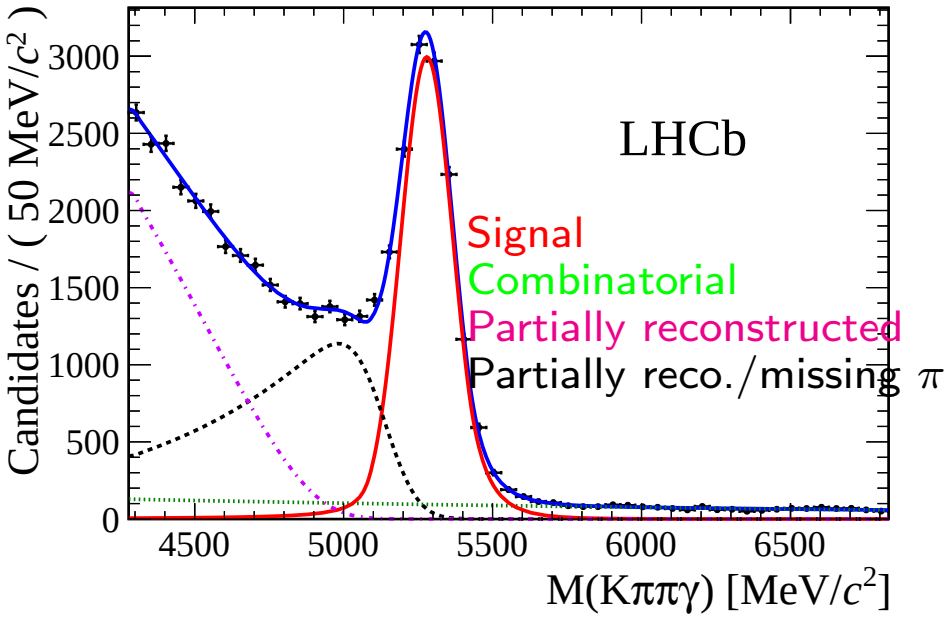
- Three-body decay of K_{res} needed to build a P-odd triple product, $\vec{p}_\gamma \cdot (\vec{p}_\pi \times \vec{p}_K)$, which changes sign for left- and right-handed photons.
- The photon polarisation parameter in $B \to K_{\text{res}}\gamma$ decay $\lambda_\gamma \equiv \frac{|C_{7R}|^2 - |C_{7L}|^2}{|C_{7R}|^2 + |C_{7L}|^2}$ is common to all K_{res}-states.
- The up-down asymmetry is proportional to the photon polarisation λ_γ



$$\mathcal{A}_{\text{up-down}} \equiv \frac{\int_0^1 d\cos\theta \frac{d\Gamma}{d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d\Gamma}{d\cos\theta}}{\int_{-1}^1 d\cos\theta \frac{d\Gamma}{d\cos\theta}} = \frac{3}{4}\lambda_\gamma \frac{\int ds ds_{13} ds_{23} Im[\vec{n} \cdot (\vec{\mathcal{J}} \times \vec{\mathcal{J}}^*)]}{\int ds ds_{13} ds_{23} |\vec{\mathcal{J}}|^2}$$

$B^{\pm} \to K^{\pm}\pi^{\mp}\pi^{\pm}\gamma$ at LHCb

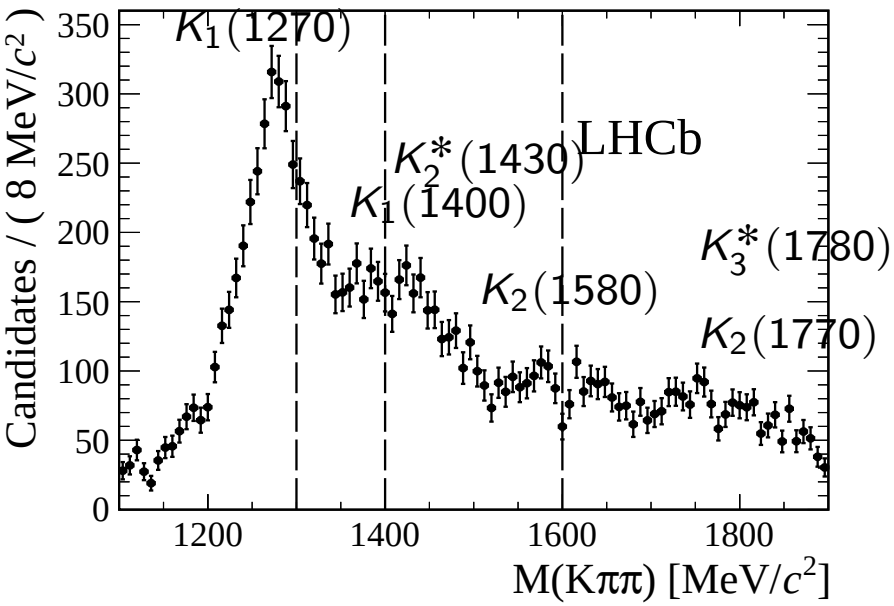
- Data collected in 2011 and 2012, corresponding to an integrated luminosity of 3 fb^{-1}
- A total signal yield of 13876$\pm$153 events from the fit of the mass distribution of the selected $B^{\pm} \to K^{\pm}\pi^{\mp}\pi^{\pm}\gamma$ candidates

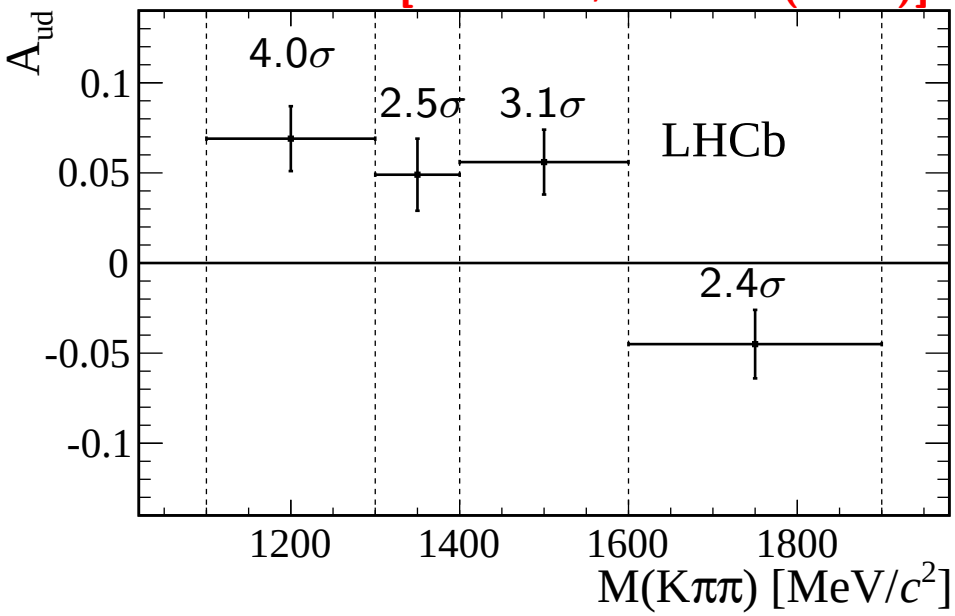


[PRL 112, 161801 (2014)]

Observation of photon polarisation

[PRL 112, 161801 (2014)]



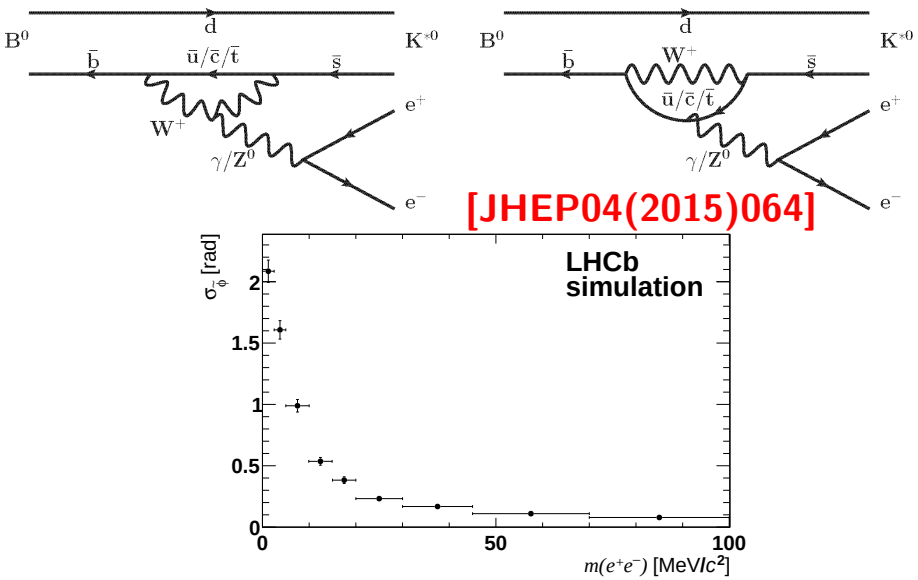


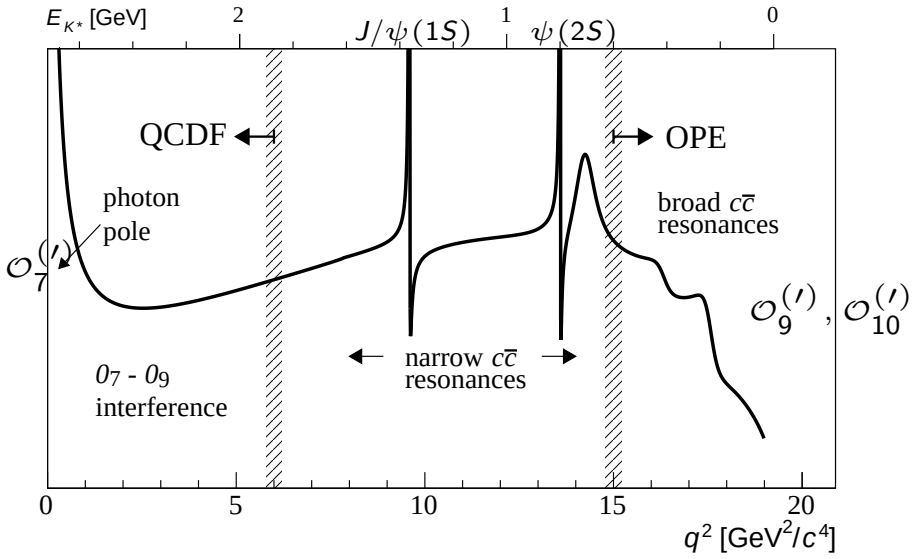
- A combined significance with respect to the non-polarisation scenario is extracted with $\mathcal{A}_{ud}$ different from zero at 5.2σ.
- **First observation of photon polarisation in $b \to s\gamma$ transition!**
- Detailed knowledge of the strong interactions of the K_{res} decay required to extract the photon polarisation.

Photon polarisation in $B^0 \to K^* e^+ e^-$

In the low q^2 region:

- some theoretical uncertainties from long distance contributions are greatly reduced,
- the contribution from a virtual photon coupling to the lepton pair dominates in the very low q^2 region.





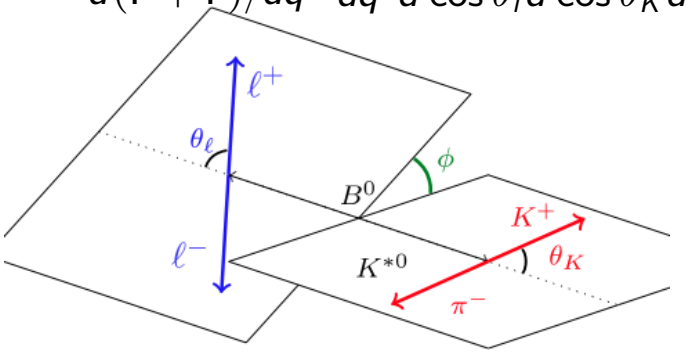
[Annu. Rev. Nucl. Part. Sci. 2015.65:113-143]

- The low q^2 limit is experimental driven:
  - angle between leptons which contains important information for photon polarisation measured with bad resolution due to multiple scattering,
  - $m(e^+e^-) > 20$ MeV/c^2 (q^2_{min}=0.0004 GeV^2/c^4) to veto $B^0 \to K^{*0}\gamma$ with γ conversion.

Angular analysis of $B^0 \to K^* e^+ e^-$ at low-q^2

The simplified angular expression for $B^0 \to K^* e^+ e^-$:

$$\frac{1}{d(\Gamma+\bar{\Gamma})/dq^2}\frac{d^4(\Gamma+\bar{\Gamma})}{dq^2 d\cos\theta_l d\cos\theta_K d\tilde{\phi}} = \frac{9}{16\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K$$
$$+ \Big(\frac{1}{4}(1-F_L)\sin^2\theta_K - F_L\cos^2\theta_K\Big)\cos 2\theta_l$$
$$+ \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_l\cos 2\tilde{\phi} + (1-F_L)A_T^{\mathrm{Re}}\sin^2\theta_K\cos\theta_l$$
$$+ \frac{1}{2}(1-F_L)A_T^{\mathrm{Im}}\sin^2\theta_K\sin^2\theta_l\sin 2\tilde{\phi}\Big]$$



fold $\phi \to \tilde{\phi} = \phi + \pi$ for $\phi < 0$

- Four observables:
  - $A_T^{(2)}$ and A_T^{Im} in low q^2 are linked to photon polarisation

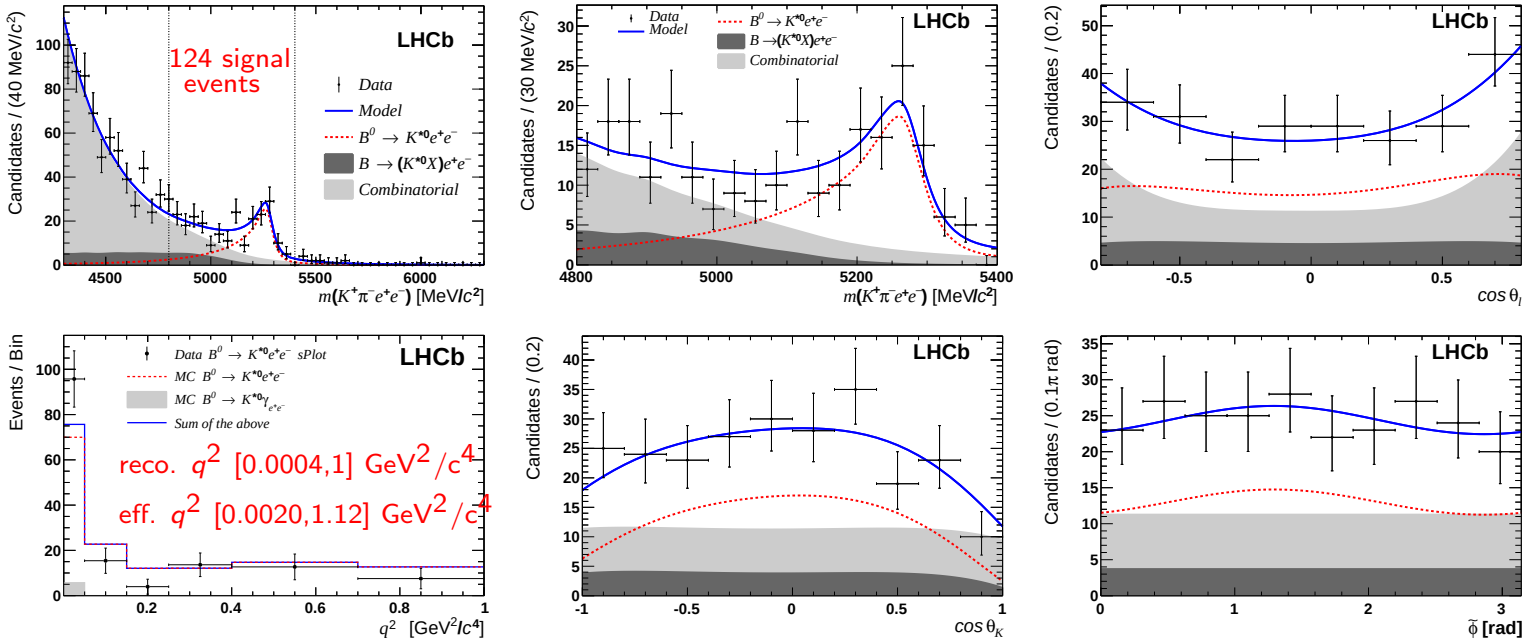
$$A_T^{(2)}(q^2 \to 0) = \frac{2\mathrm{Re}(C_7 C_7'^*)}{|C_7|^2 + |C_7'|^2} \qquad A_T^{\mathrm{Im}}(q^2 \to 0) = \frac{2\mathrm{Im}(C_7 C_7'^*)}{|C_7|^2 + |C_7'|^2}$$

  - F_L: longitudinal polarisation
  - $A_T^{\mathrm{Re}} = \frac{4}{3}A_{FB}/(1-F_L)$: related to forward-backward asymmetry

Angular analysis of $B^0 \to K^* e^+ e^-$ at low-q^2

- 4D fit to $m(K^+\pi^-e^+e^-)$ and the angles $\cos\theta_l$, $\cos\theta_K$ and $\tilde{\phi}$ to extract the four observables F_L, A_T^{Re}, $A_T^{(2)}$ and A_T^{Im}:

[JHEP04(2015)064]



- Angular observables firstly measured in an effective q^2 range from 0.0020 to 1.120 GeV^2/c^2 with 3 fb^{-1} data collected at LHCb ★:

F_L: **0.16±0.06±0.03 (0.10$^{+0.11}_{-0.05}$)**

$A_T^{(2)}$: **-0.23±0.23±0.05 (+0.03$^{+0.05}_{-0.04}$)**

A_T^{Re}: **+0.10±0.18±0.05 (-0.15$^{+0.04}_{-0.03}$)**

A_T^{Im}: **+0.14±0.22±0.05 ((-0.2$^{+1.2}_{-1.2}$)×10^{-4})**

★SM prediction in brackets: adapted from arXiv:1412.3183

Summary

- Radiative B decays are very good probes of new physics BSM.
- A measurement of $\mathcal{B}(B^0 \to K^{*0}\gamma)/\mathcal{B}(B_s^0 \to \phi\gamma)$ is performed on 1.0 fb^{-1} pp collision data collected in 2011 at 7 TeV and direct $A_{CP}(B^0 \to K^{*0}\gamma)$ is measured.
- The emitted photons are firstly observed to be polarised in the study of $B^\pm \to K^\pm\pi^\mp\pi^\pm\gamma$ decay with 3 fb^{-1} data sample but further amplitude analysis needed to isolate different resonances.
- Angular observables are firstly measured in an effective q^2 range [0.0020,1.120] GeV^2/c^4 in $B^0 \to K^* e^+ e^-$ and results are consistent with SM predictions.
- More results are coming soon!