Measurements of the photon polarisation in $b \to s\gamma$ decays

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European Physical Society – HEP2015
Vienna, July 23rd 2015

Image credit: Vivek Sarma

Outline

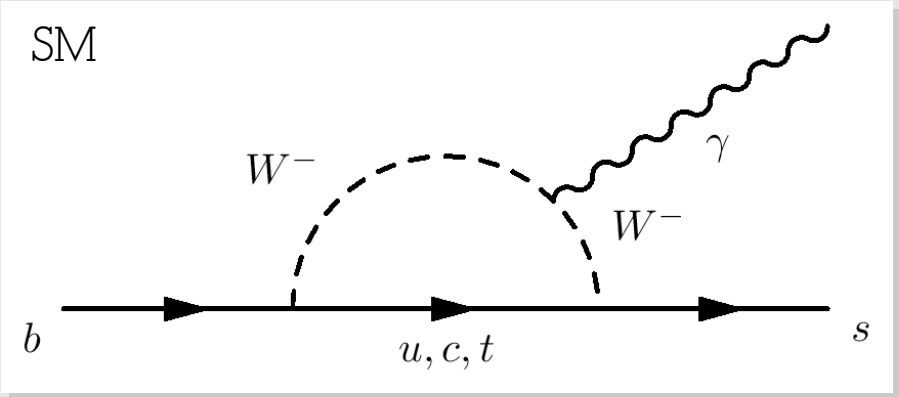
- Theoretical motivation
- Measuring photon polarization at LHCb
- Results
  - First observation of photon polarization in $B^+ \to K^+\pi^+\pi^-\gamma$
    [Phys. Rev. Lett. 112, 161801 (2014)]
  - Angular analysis of $B^0 \to K^{*0}e^+e^-$ in the low q^2 range
    [JHEP04(2015)064]
- Conclusions

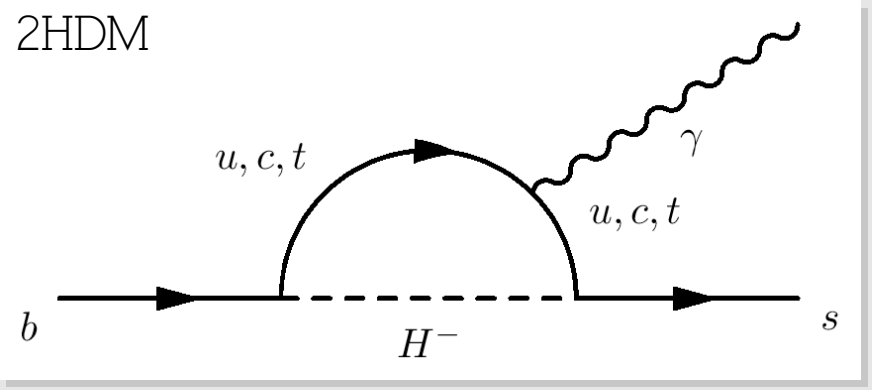
Theoretical Motivation

The $b \to s\gamma$ process is a FCNC, forbidden at tree level in the SM. It's described by the $O_{7\gamma}$ operator in OPE

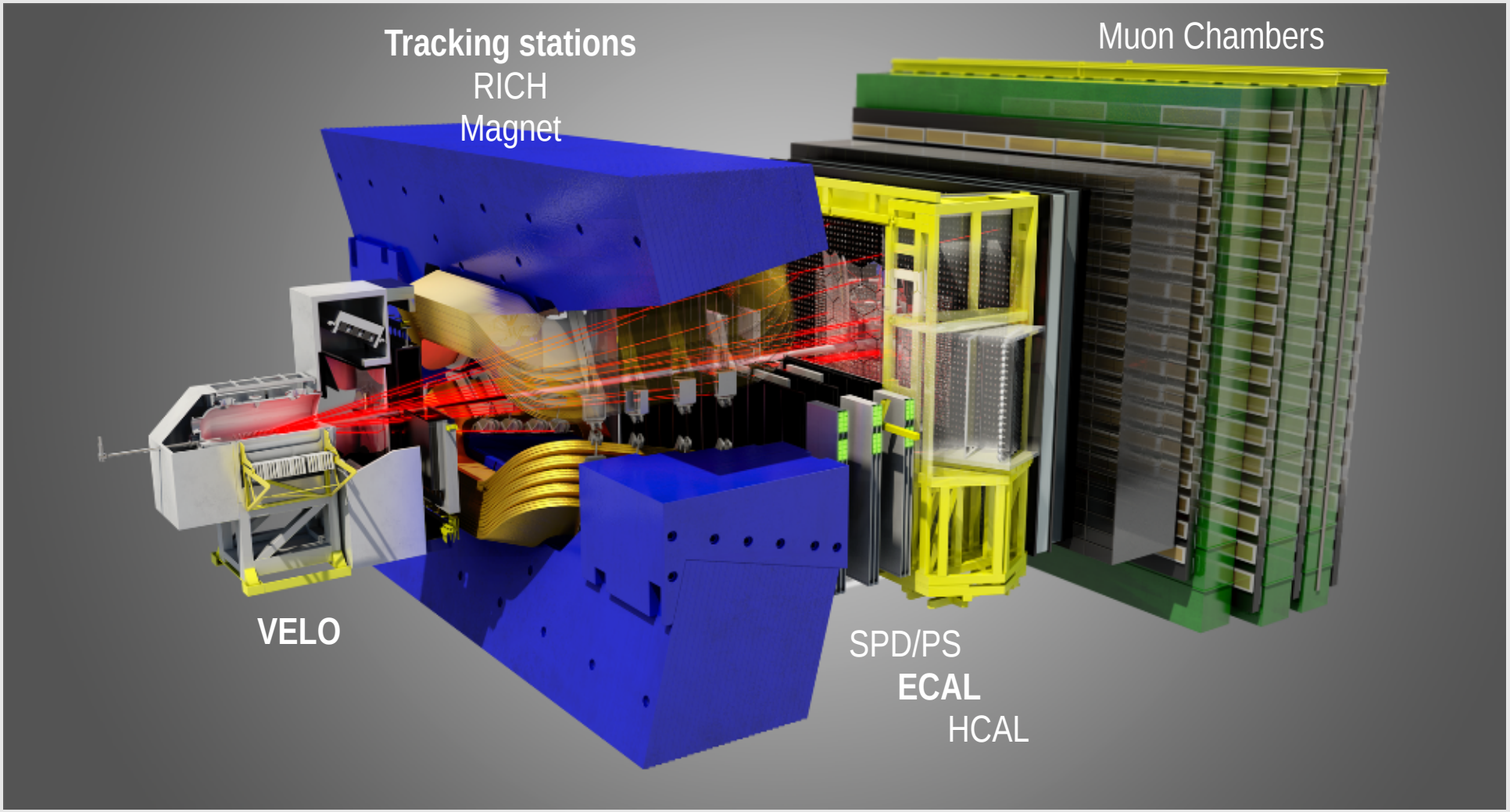
$$H_{eff} \propto \sum C_i \cdot O_i, \quad O_{7\gamma} = \frac{e}{16\pi^2}[m_b(\bar{s}_{L\alpha}\sigma^{\mu\nu} b_{R\alpha}) + m_s(\bar{s}_{R\alpha}\sigma^{\mu\nu} b_{L\alpha})]F_{\mu\nu}$$

The SM predicts a suppression of approximately the order m_s/m_b of right handed with respect to left handed photons, but some BSM models can enhance this contamination with participation of additional particles in the loop such as two Higgs Doublet models or SUSY

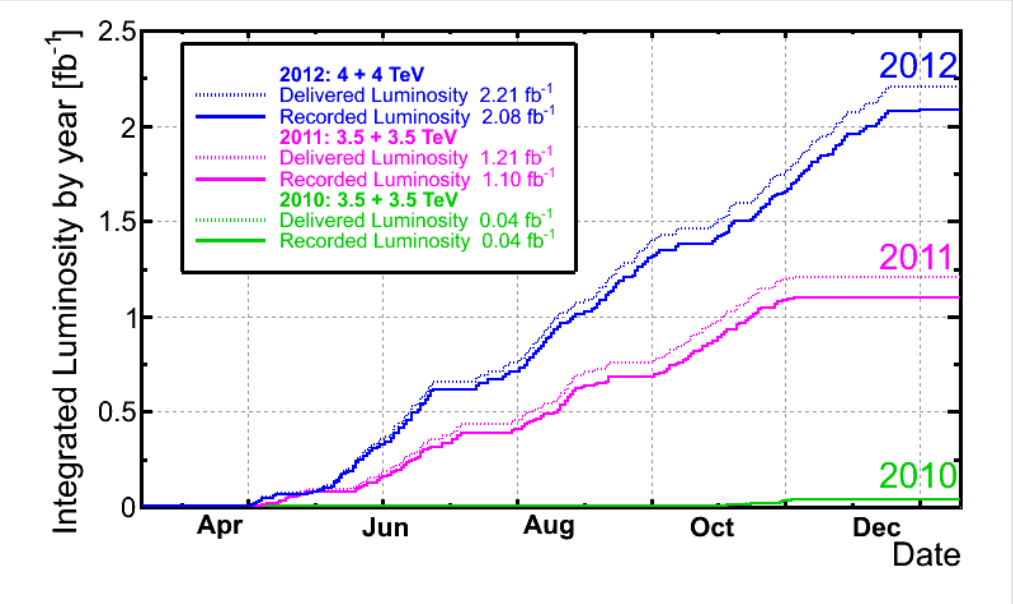


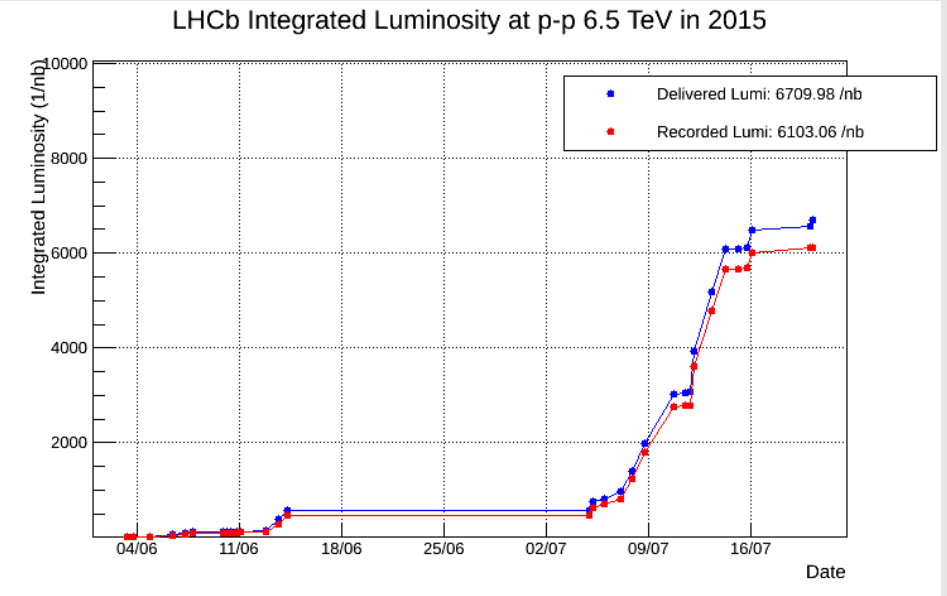


The LHCb detector (simplified)



The LHCb detector





- During Run I LHCb collected **1 fb^{-1}** @ 7 TeV and **2 fb^{-1}** @ 8 TeV
- Run II is underway, almost **7 pb^{-1}** collected @ 13 TeV since June

Measuring the photon polarization at LHCb

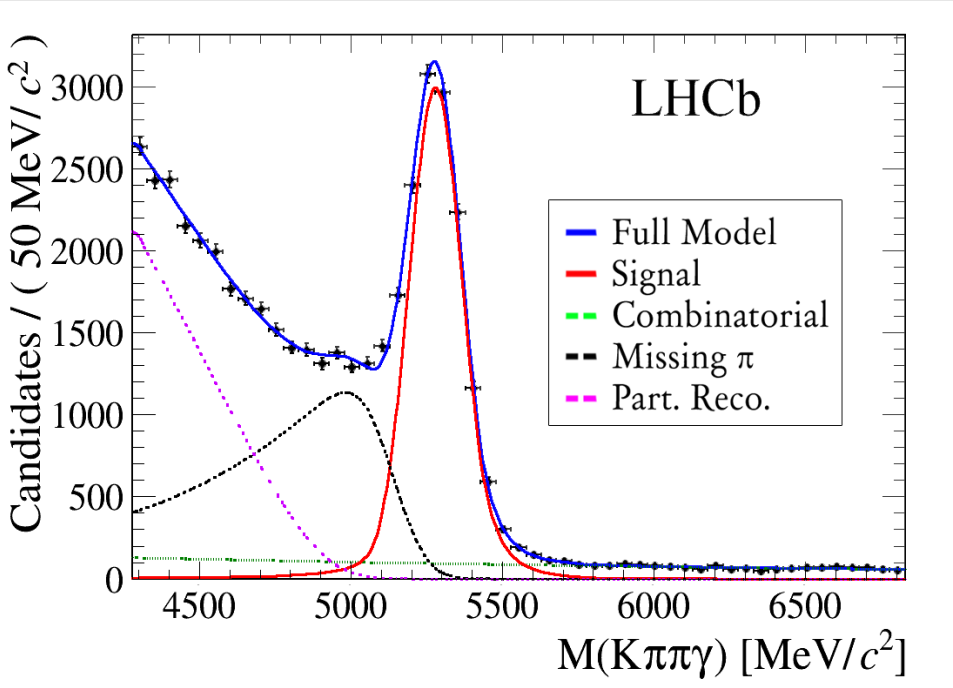
Since the photon polarization information is lost in the electromagnetic calorimeter, the polarization must be extracted from other observables, i.e. by studying the spatial distributions

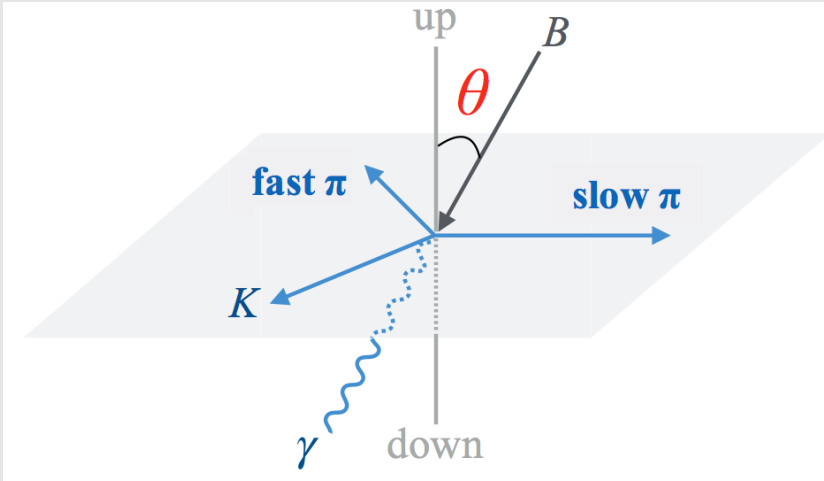
- Measuring the up-down asymmetries in the photon distributions in $B^+ \to K^+\pi^-\pi^+\gamma$
- For dilepton decays such as $B^0 \to K^{*0}e^+e^-$ one can measure angular amplitudes and these can be written in terms of Wilson coefficients, specifically for C_7 and C_7', related to left- and right-handed polarizations, respectively

Angular analysis of $B^+ \to K^+\pi^+\pi^-\gamma$

[Phys. Rev. Lett. 112, 161801 (2014)]

- First observation of photon polarization in $b \to s\gamma$ transitions
  - Measured a non zero up-down photon asymmetry ($\mathbf{A_{ud}}$) for a signal yield of **14k** events in **3fb^{-1}** (Run I data)





Angular analysis of $B^+ \to K^+\pi^+\pi^-\gamma$

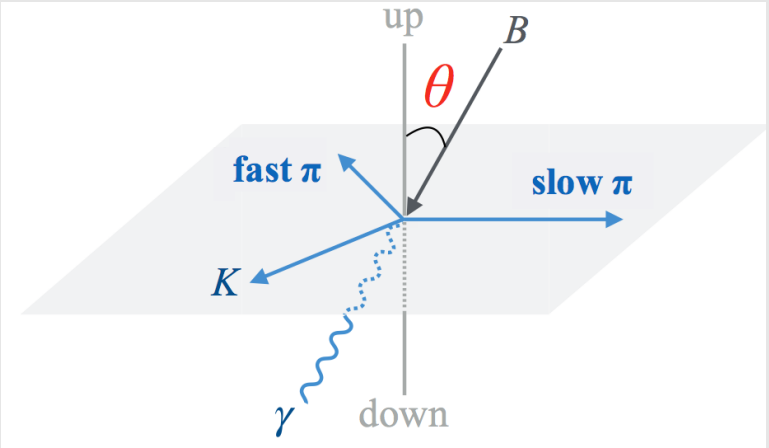
[Phys. Rev. Lett. 112, 161801 (2014)]

A_{ud} is proportional to the photon polarization (λ_γ), related to the wilson coefficients $C_7^{(\prime)}$

$$\lambda_\gamma = \frac{|C_7'|^2 - |C_7|^2}{|C_7'|^2 + |C_7|^2}$$

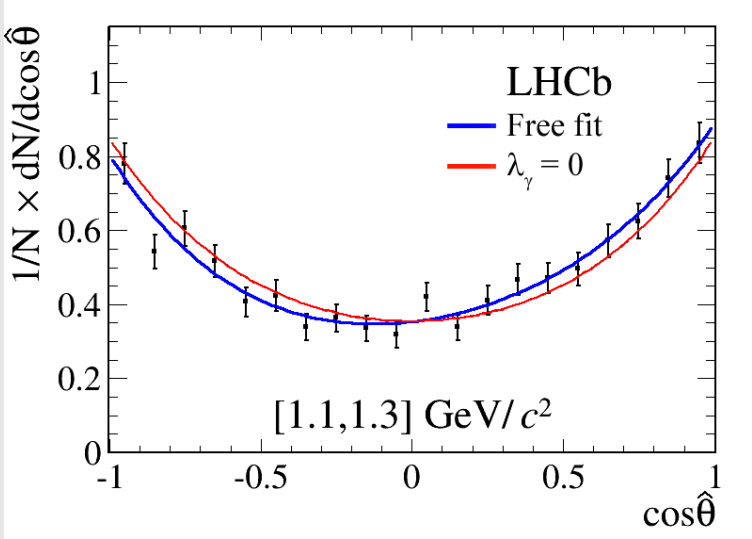
$$\frac{d\Gamma}{d\cos\theta} \propto \sum_{i=0,2,4} a_i \cos^i\theta + \lambda_\gamma \sum_{j=1,3} a_j \cos^j\theta,$$

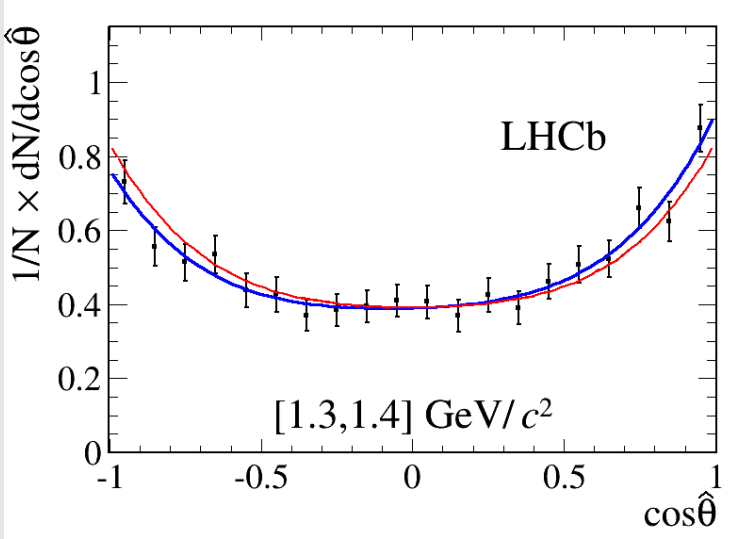
$$A_{ud} \equiv \frac{\int_0^1 d\cos\theta \frac{d\Gamma}{d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d\Gamma}{d\cos\theta}}{\int_{-1}^1 d\cos\theta \frac{d\Gamma}{d\cos\theta}}$$

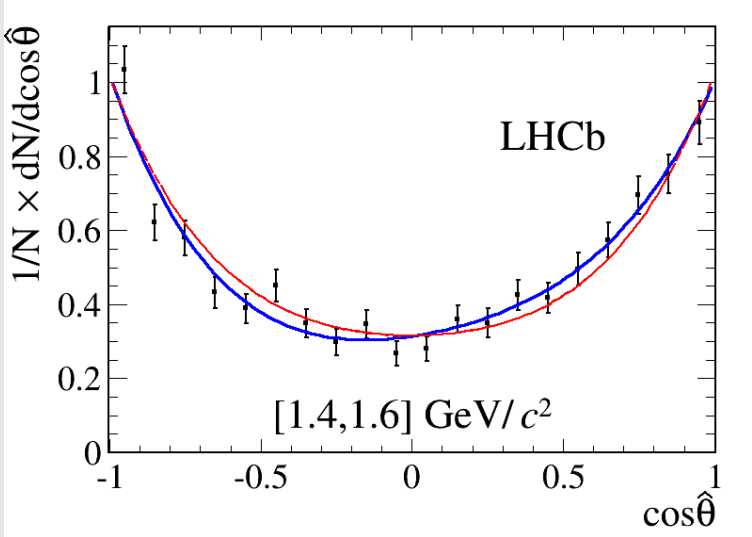


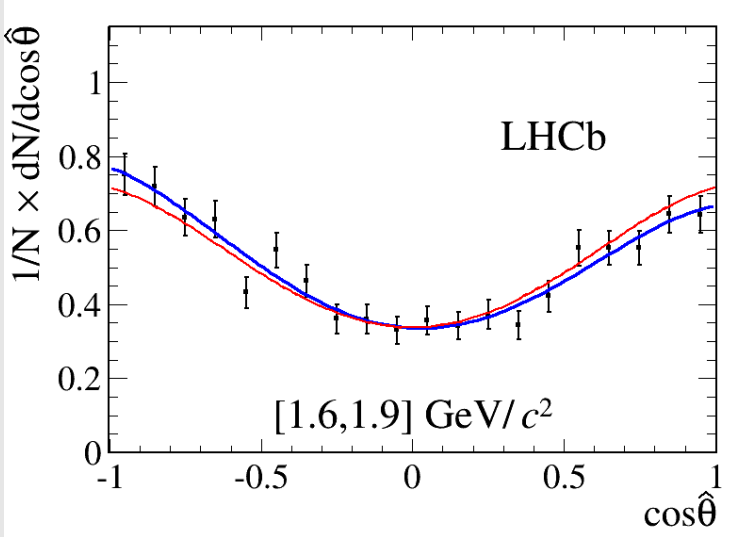
Angular analysis of $B^+ \to K^+\pi^+\pi^-\gamma$

[Phys. Rev. Lett. 112, 161801 (2014)]







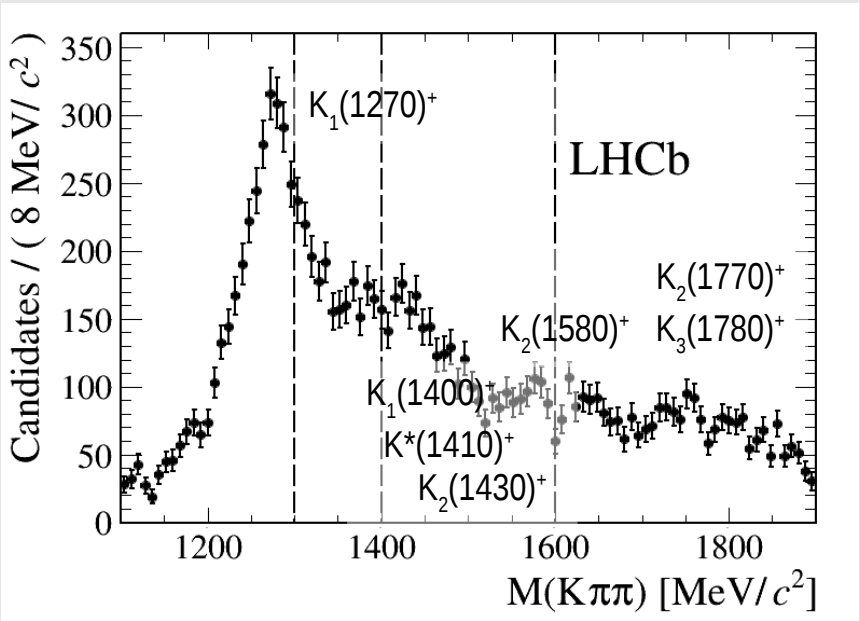


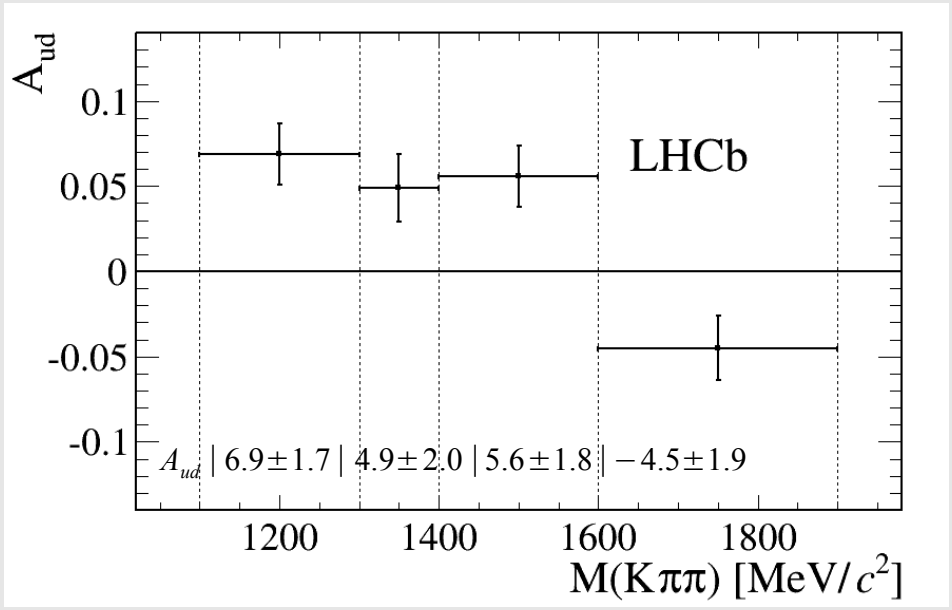
Angular analysis of $B^+ \to K^+\pi^+\pi^-\gamma$

[Phys. Rev. Lett. 112, 161801 (2014)]

The combined results show a 5.2σ deviation from the null hypothesis. We now know (experimentally) that there is a photon polarization, however, precise determination of λ_γ requires knowledge of the complicated resonant structures in the mass spectrum

- Combined full amplitude and angular analysis in progress





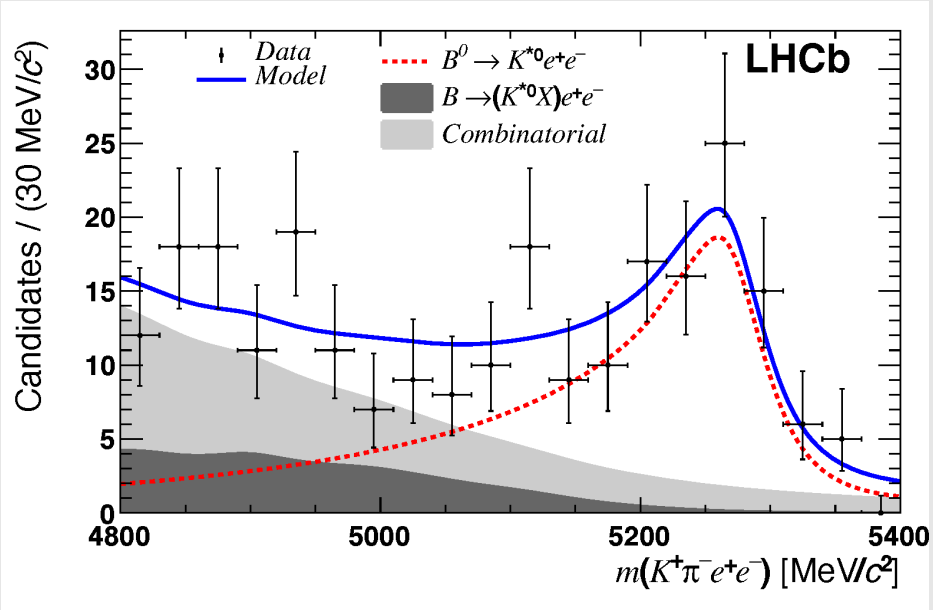
Angular analysis of $B^0 \to K^{*0} e^+ e^-$

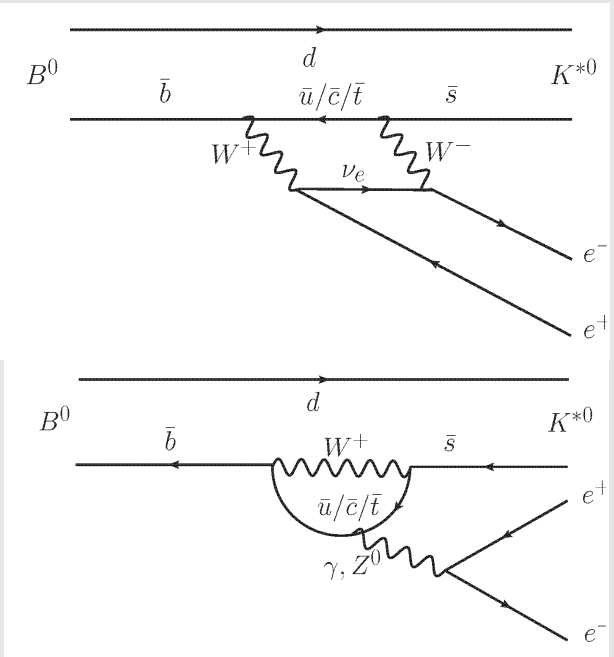
[JHEP04(2015)064]

In the very low q^2 range the photon contribution dominates, and electrons maximize sensitivity to the Wilson coefficients $C_7^{(')}$

Angular analysis performed on a yield of **120** signal candidates for **3fb^{-1}** in the q^2 range of **.002** to **1.120 GeV^2/c^4**

Bremsstrahlung has to be addressed, causes a long tail in the mass distribution



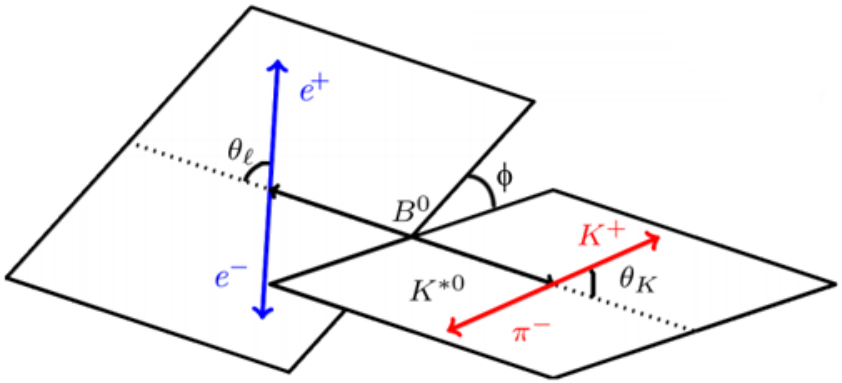


Angular analysis of $B^0 \to K^{*0} e^+ e^-$

[JHEP04(2015)064]

A simultaneous four dimensional fit to $m(k^+\pi^- e^+ e^-)$, $cos\theta_l$, $cos\theta_K$ and ϕ is performed to extract the angular observables F_L, $A_T^{(2)}$, A_T^{Re} and A_T^{Im}

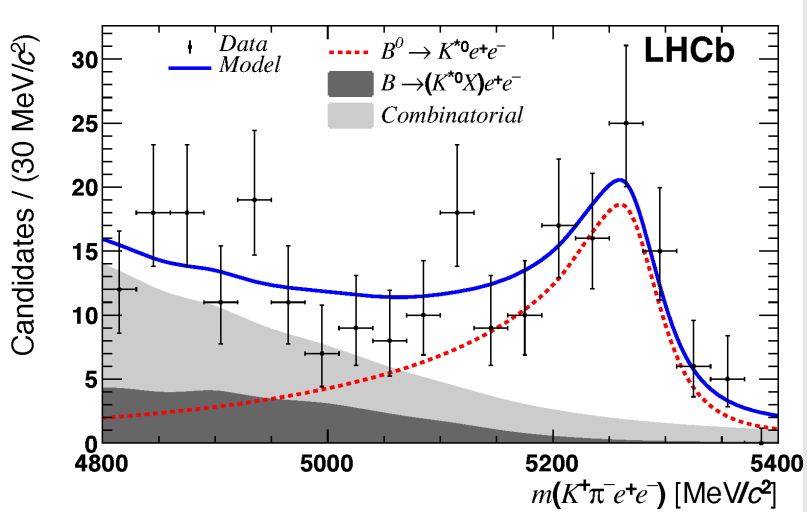
$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\tilde{\phi}} = \frac{9}{16\pi}\left[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \left(\frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K - F_\mathrm{L}\cos^2\theta_K\right)\cos(2\theta_\ell) + \frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\sin^2\theta_\ell\cos 2\tilde{\phi}\;\mathrm{A}_\mathrm{T}^{(2)} + (1-F_\mathrm{L})\sin^2\theta_K\cos\theta_\ell\;\mathrm{A}_\mathrm{T}^{\mathrm{Re}} + \frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\sin^2\theta_\ell\sin 2\tilde{\phi}\;\mathrm{A}_\mathrm{T}^{\mathrm{Im}}\right]$$

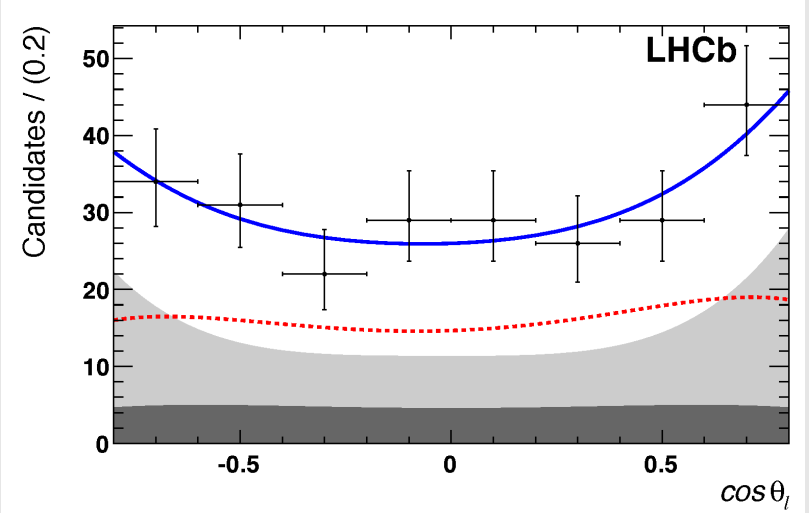


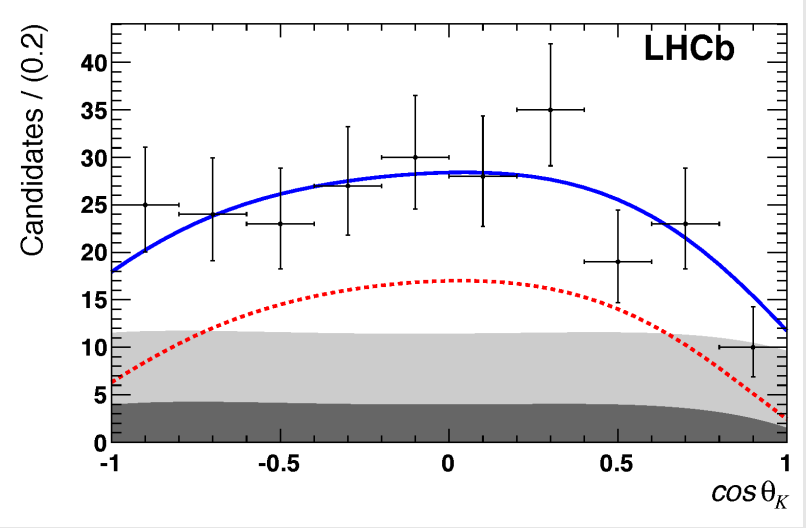
where $\tilde{\phi}=\phi+\pi$ for $\phi<0$

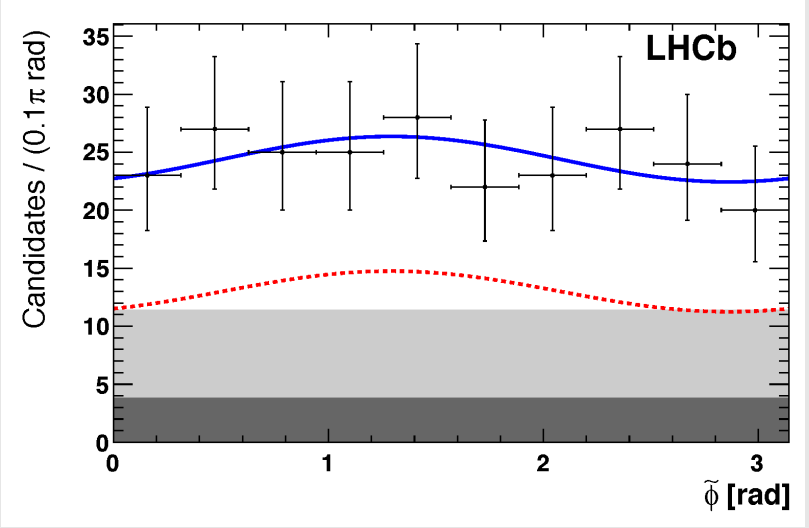
Angular analysis of $B^0 \to K^{*0} e^+ e^-$

[JHEP04(2015)064]









Angular analysis of $B^0 \to K^{*0} e^+ e^-$

[JHEP04(2015)064]

The results of the fit (with stat and syst. uncertainties, resp.)

$$F_L = 0.16 \pm 0.06 \pm 0.03, \quad A_T^{(2)} = -0.23 \pm 0.23 \pm 0.05,$$
$$A_T^{\mathrm{Im}} = +0.14 \pm 0.22 \pm 0.05, \quad A_T^{\mathrm{Re}} = +0.10 \pm 0.18 \pm 0.05,$$

compatible with SM predictions. These can be related to the electromagnetic Wilson coefficients $C_7^{(\prime)}$ in the $q^2 \to 0$ limit as

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

to further constrain these parameters

Conclusions

- First evidence of photon polarization in $b \to s\gamma$ decays in $B^+ \to K\pi^+\pi^-\gamma$
  - To be followed with a full amplitude and angular analysis for determining the actual value of λ_γ
- Results from $B^0 \to K^{*0}e^+e^-$ consistent with SM
  - At the end of Run II we should expect ~500 events, 4 times the yield of the reported analysis
    - Current uncertainty around 15%, could be reduced to 5-7% with RunII data

Thanks for your attention

Image credit: Vivek Sarma