Angular analysis of $\Lambda_b \to \Lambda\mu^+\mu^-$

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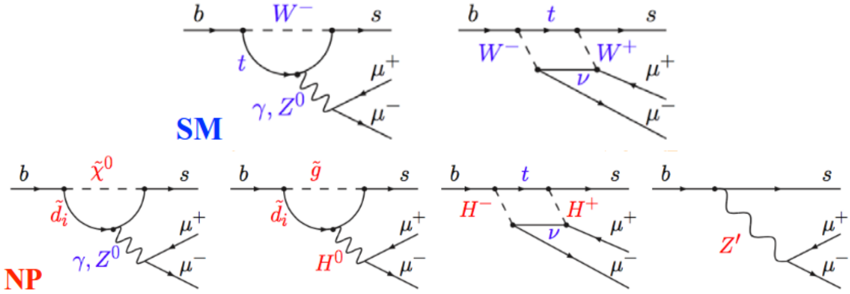
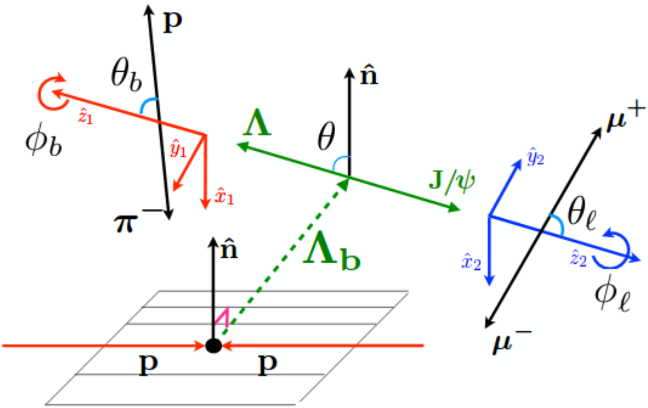
Introduction

- $\Lambda_b \to \Lambda\mu^+\mu^-$ is a flavor changing neutral current (**FCNC**) decay and so very sensitive to new physics effects (NP).
- NP can alter branching fractions and **angular observables**.
- Aim to measure angular observables of $\Lambda_b \to \Lambda\mu^+\mu^-$ which are sensitive to NP.



Angular distribution of $\Lambda_b \to \Lambda\mu^+\mu^-$

[Adapted from arXiv:1802.04867v1]



Differential decay rate [JHEP11(2017)138]

$$
\begin{aligned}
\frac{32\pi^2}{3}\frac{d^6\Gamma}{dq^2 d\cos\theta d\cos\theta_l d\cos\theta_b d\phi_l d\phi_b} = & \left(J_1 \sin^2\theta_l + J_2 \cos^2\theta_l + J_3 \cos\theta_l\right) + \\
& \left(J_4 \sin^2\theta_l + J_5 \cos^2\theta_l + J_6 \cos\theta_l\right)\cos\theta_b + \\
& (J_7 \sin\theta_l \cos\theta_l + J_8 \sin\theta_l)\sin\theta_b \cos(\phi_b + \phi_l) + \\
& (J_9 \sin\theta_l \cos\theta_l + J_{10} \sin\theta_l)\sin\theta_b \sin(\phi_b + \phi_l) + \\
\cos\theta \{ & \left(J_{11} \sin^2\theta_l + J_{12} \cos^2\theta_l + J_{13} \cos\theta_l\right) + \\
& \left(J_{14} \sin^2\theta_l + J_{15} \cos^2\theta_l + J_{16} \cos\theta_l\right)\cos\theta_b + \\
& (J_{17} \sin\theta_l \cos\theta_l + J_{18} \sin\theta_l)\sin\theta_b \cos(\phi_b + \phi_l) + \\
& (J_{19} \sin\theta_l \cos\theta_l + J_{20} \sin\theta_l)\sin\theta_b \sin(\phi_b + \phi_l) \} + \\
\sin\theta \{ & (J_{21} \cos\theta_l \sin\theta_l + J_{22} \sin\theta_l)\sin\phi_l + \\
& (J_{23} \cos\theta_l \sin\theta_l + J_{24} \sin\theta_l)\cos\phi_l + \\
& (J_{25} \cos\theta_l \sin\theta_l + J_{26} \sin\theta_l)\sin\phi_l \cos\theta_b + \\
& (J_{27} \cos\theta_l \sin\theta_l + J_{28} \sin\theta_l)\cos\phi_l \cos\theta_b + \\
& \left(J_{29} \cos^2\theta_l + J_{30} \sin^2\theta_l\right)\sin\theta_b \sin\phi_b + \\
& \left(J_{31} \cos^2\theta_l + J_{32} \sin^2\theta_l\right)\sin\theta_b \cos\phi_b + \\
& \left(J_{33} \sin^2\theta_l\right)\sin\theta_b \cos(2\phi_l + \phi_b) + \\
& \left(J_{34} \sin^2\theta_l\right)\sin\theta_b \sin(2\phi_l + \phi_b) \} \ .
\end{aligned}
$$

- **Differential decay rate is written in terms of five angles and dimuon invariant mass squared (q^2)**
- J_i **depend on** q^2

Angular observables of $\Lambda_b \to \Lambda\mu^+\mu^-$

- Observables J_{11} - J_{34} depend on **production polarisation** of Λ_b.
- Define new set of observables as, $M_i = J_i/(2J_1 + J_2)$.
- In total we measure 34 angular observables (**M_1 to M_{34}**).
- Related to three angular asymmetries.

$$M_i = \frac{1}{N}\int \frac{\mathrm{d}^6\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta\mathrm{d}\cos\theta_l\mathrm{d}\cos\theta_b\mathrm{d}\phi_l\mathrm{d}\phi_b}\times f_i(\cos\theta, \cos\theta_l, \cos\theta_b, \phi_l, \phi_b)\ \mathrm{d}\cos\theta\mathrm{d}\cos\theta_l\mathrm{d}\cos\theta_b\mathrm{d}\phi_l\mathrm{d}\phi_b\ .$$

$$N = \int \frac{\mathrm{d}^6\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta\mathrm{d}\cos\theta_l\mathrm{d}\cos\theta_b\mathrm{d}\phi_l\mathrm{d}\phi_b}\ \mathrm{d}\cos\theta\mathrm{d}\cos\theta_l\mathrm{d}\cos\theta_b\mathrm{d}\phi_l\mathrm{d}\phi_b\ .$$

Forward-backward (FB) asymmetries

$$A_{FB}^{l} = \frac{3}{2}M_3 \qquad A_{FB}^{h} = M_4 + \frac{1}{2}M_5 \qquad A_{FB}^{lh} = \frac{3}{4}M_6$$

Extracting the angular observables

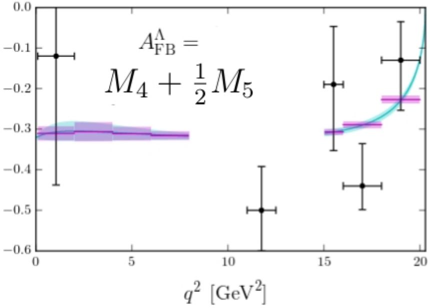
- Angular observables are extracted using **moments analysis** (small data set size).
- Angular observables are integrated over $q^2 \in [15 - 20]\ \mathrm{GeV}^2/c^4$. This bin is where we have enough data to perform angular analysis.

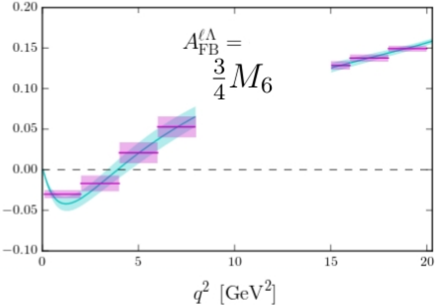
Moments can be extracted as:

$$M_i = \sum_e^{N_{\mathrm{ev}}} (w_e/\varepsilon_e) f_i(\cos\theta_l^{(e)}, \cos\theta_b^{(e)}, \phi_l^{(e)}, \phi_b^{(e)}, \cos\theta^{(e)}) \Big/ \sum_e^{N_{\mathrm{ev}}} (w_e/\varepsilon_e)\ .$$

- f_i are the **weighting functions** that project out M_i.
- w_e are the **sWeights**, used for background subtraction.
- ε_e are the **efficiency weights**.
- Estimate errors using **Bootstrapping**.
- Moments and errors are **not** sensitive to normalisation.

Predictions





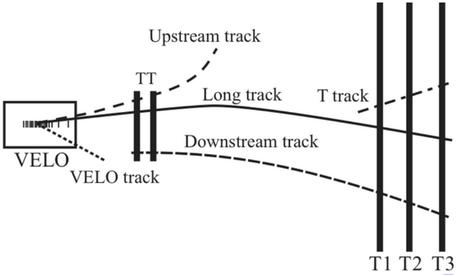
- Data points are experimental data from LHCb [**JHEP06(2015)115**].
- Previous LHCb measurement performed **1D Likelihood** fits on the **angular projections** of $\cos\theta_l$ and $\cos\theta_b$, using Run1 data.
- Predictions for angular observables, without binning (cyan curves) and with binning (magenta curves) [**Phys. Rev. D 93, 074501**].

Data analysis

Analysis is performed using data collected by **LHCb** detector during **LHC Run1** (3fb^{-1} at 7-8 TeV) and **Run2** (2fb^{-1} at 13 TeV).

$\Lambda(\to p\pi^-)$ is a long lived particle.
Events considered in two track categories.

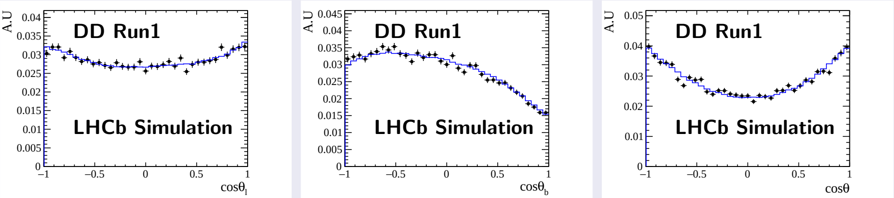
- With hits in VELO (**long events - LL**).
- With no hits in VELO (**downstream events - DD**).
- LL and DD events have different **resolution** and **efficiency**.



Data analysis

- Candidates chosen using loose preselection followed by MVA.
- Working point of MVA is chosen by maximising $S/\sqrt{(S+B)}$.
- **Efficiency** is parametrised in **five angles and q^2**, using Legendre polynomials (LP).
- The control mode used in the analysis is the $\boldsymbol{\Lambda_b \to J/\psi\Lambda}$. The latter is used to understand the signal mass model of the $\Lambda_b \to \Lambda\mu^+\mu^-$ and perform validation studies related to the angular efficiency.

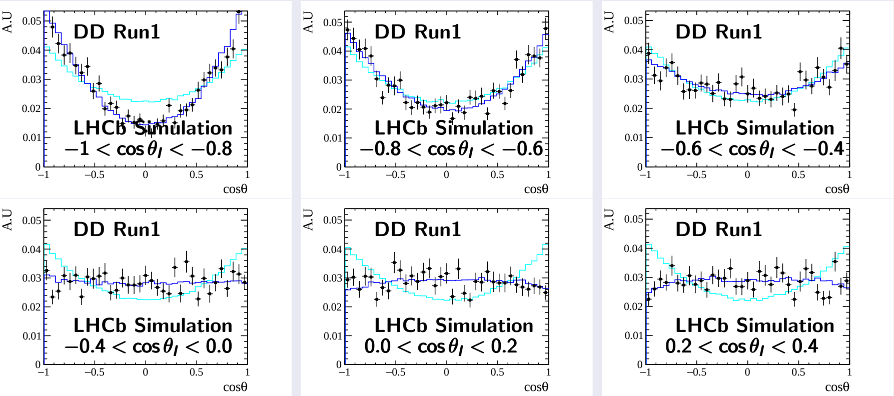
Data points represent MC and blue line is the total angular projection.



Data analysis

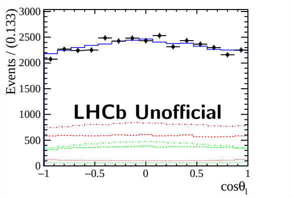
- Correlations between angles and q^2 in efficiency parametrisation are properly described.

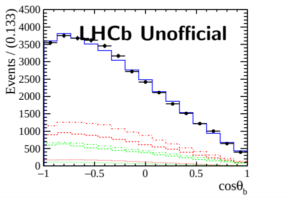
Example of 1D angular efficiency projections of $\cos\theta$ in bins of $\cos\theta_l$. Data points represent MC, blue and cyan lines represent angular efficiency with and without taking into account correlations.

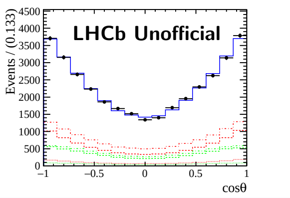


Cross-check with $\Lambda_b \to J/\psi\Lambda$

Data points are the combined data for Run1 and Run2, corrected for background (sWeighted). Blue line is the total 1D angular projection, while red, green and dotted, dotted&dashed, dashed lines represent the contribution for DD, LL for 2011 + 2012, 2015 and 2016 contribution.





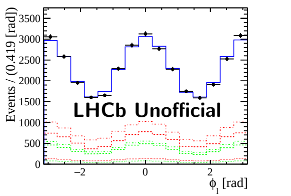


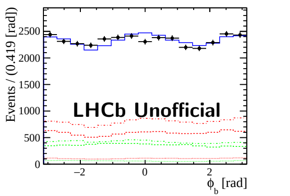
Previously measured

Phys. Lett. B724 (2013) 27 (LHCb)

Phys. Rev. D 89, 092009 (ATLAS)

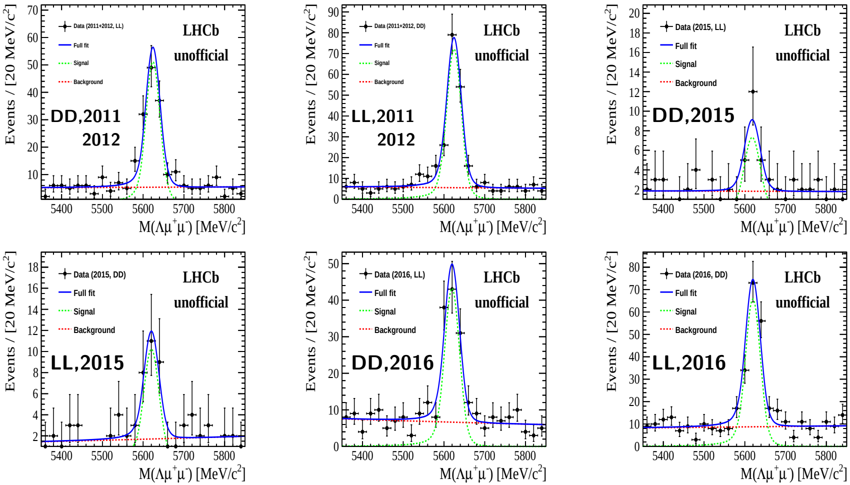
arXiv:1802.04867v1 (CMS)





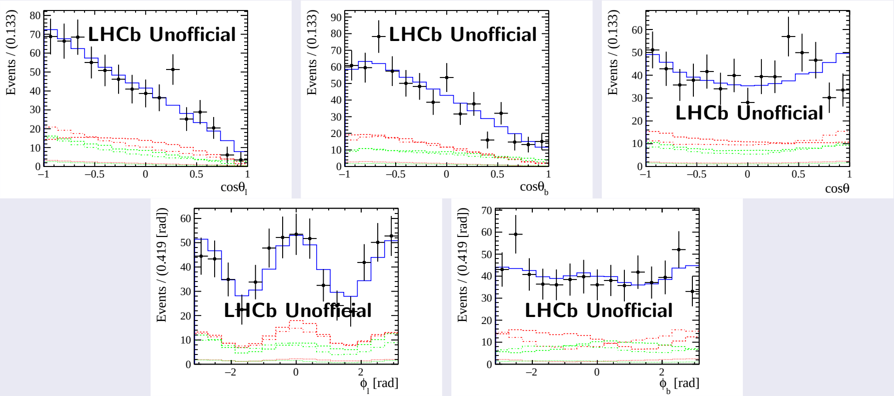
Total Signal yield of $\Lambda_b \to \Lambda\mu^+\mu^-$

Total signal yield for the decay of $\boldsymbol{\Lambda_b \to \Lambda\mu^+\mu^-}$ is found to be $\mathbf{610 \pm 29}$



Results

Data points are the combined data for Run1 and Run2, corrected for background (sWeighted). Blue line is the total 1D angular projection, while red, green and dotted, dotted&dashed, dashed lines represent the contribution for DD, LL for 2011 + 2012, 2015 and 2016 contribution.



Conclusion

Asymmetry parameters for the **combined** Run1 and Run2 datasets, with blinded central values are presented, $A^{l}_{FB} = x.x \pm 0.045(stat)$, $A^{h}_{FB} = x.x \pm 0.049(stat)$, $A^{lh}_{FB} = x.x \pm 0.041(stat)$. In this analysis we measure the full set of angular observables of $\Lambda_b \to \Lambda\mu^+\mu^-$ and we improve precision of angular observables extracted relative to previous LHCb measurement [JHEP06(2015)115].

Combined systematic uncertainties are expected to be on the order of 0.20% of the statistical uncertainty of the moments (M_i).

Analysis will be finished very soon.