B^0 and B_s^0 production asymmetries and Λ_b^0 production at LHCb

Maria Zangoli

On behalf of the LHCb Collaboration

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

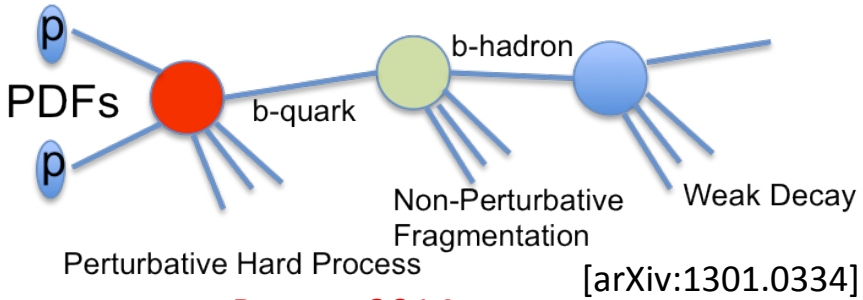
INFN
Istituto Nazionale
di Fisica Nucleare

Beauty 2014 – Edinburgh

14 July 2014

Introduction

- A precise understanding of the mechanisms of Heavy Flavour production can be viewed as one of the ultimate tests of QCD
- It allows us to probe our knowledge of the fundamental constituents of matter and their interactions
- Measurements in this field can provide useful tests of QCD, and give input for tuning models, and refining event generators
- Measurements at LHCb have a great potential to constraints models in regions of rapidity and transverse momentum complementary to other LHC detectors.
- Today
  - Measurement of Λ^0_b production in pp collisions [submitted to JHEP, arXiv:1405.6842]
  - Measurement of the B^0 - $\overline{B^0}$ and B^0_s - $\overline{B^0}_s$ production asymmetries in 7 TeV pp collision [LHCb-PAPER-2014-042, to be submitted for publication] **NEW**
  - Fundamental ingredients for CP violation and branching fraction measurements



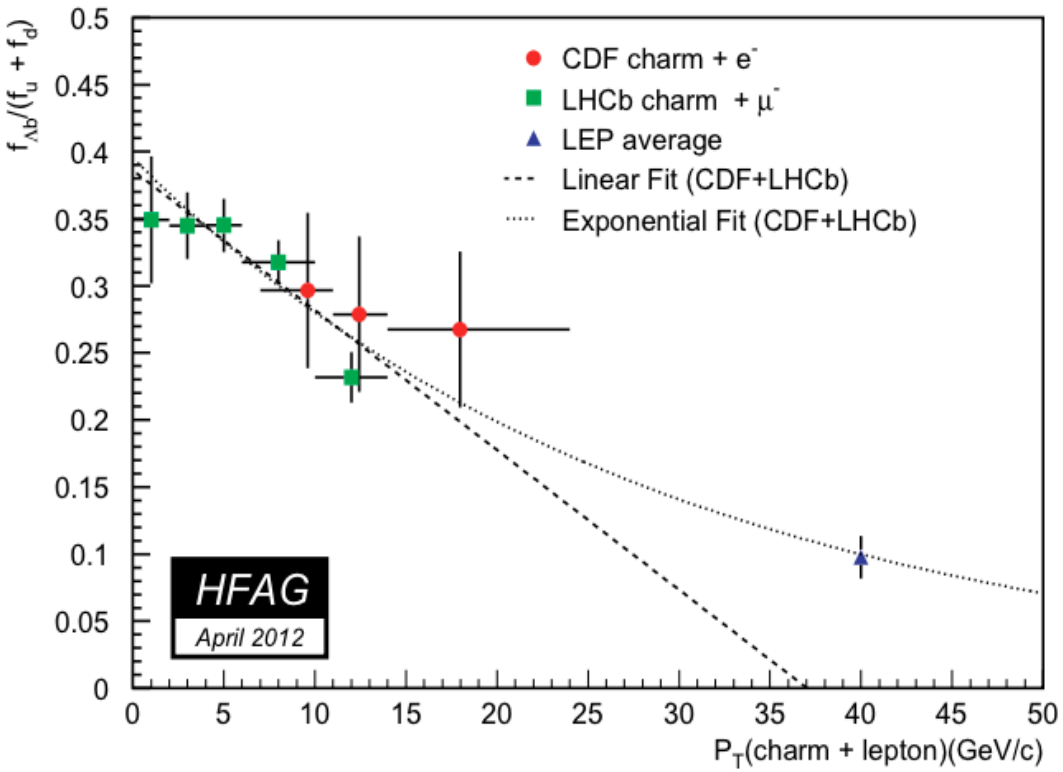
[arXiv:1301.0334]

Measurement of Λ^0_b production

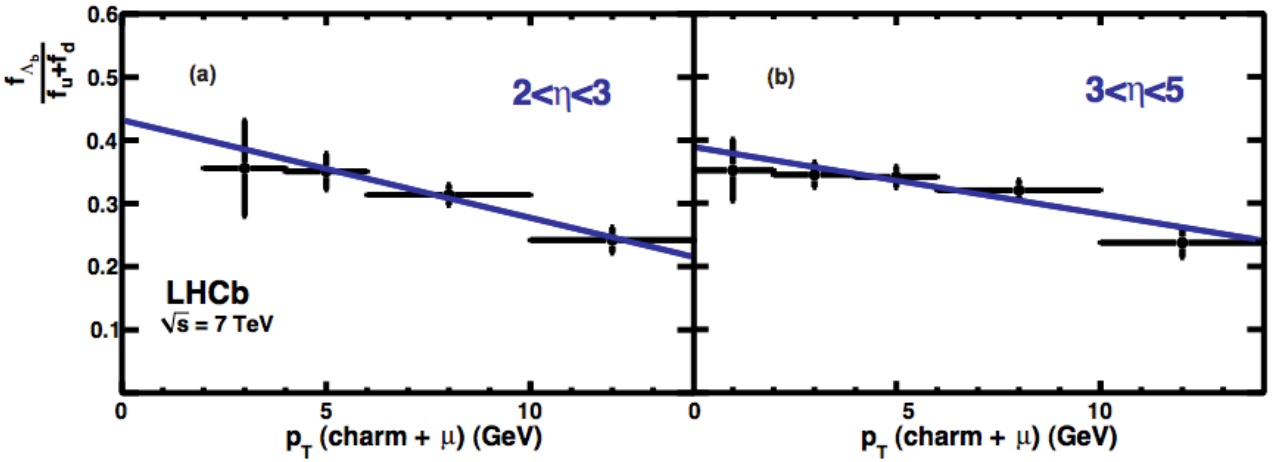
- The relative production rates of beauty hadrons are described by fragmentation fraction f_u, f_d, f_s, f_c and $f_{\Lambda^0_b}$ which describe the probability that a b quark fragments into a $B_{q= u,d,s,c}$ meson or a Λ^0_b baryon respectively
  - Depend on the kinematic proprieties of the b quark
- $f_{\Lambda^0_b}/ f_d$ is measured using $\Lambda^0_b \rightarrow \Lambda^+_c(pK^-\pi^+)\pi^-$ and $B^0 \rightarrow D^+(K^+\pi^-\pi^-)\pi^-$ (and their charge conjugates) decay rates
  - data set collected by LHCb in 2011, $\sqrt{s}$ = 7 TeV, corresponding to 1 fb^{-1} of integrated luminosity
- The analysis aims to clarify the extent and characteristics of the p_T dependences of $f_{\Lambda^0_b}/ f_d$ and study the η dependences in the fiducial region $1.5 < p_T < 40$ GeV/c and $2 < \eta < 5$

Previous knowledge

- Previous measurements of $f_{\Lambda_b^0}/f_d$ have been made in
  - e^+e^- collisions at LEP
    [HFAG, arXiv:1207.1158v2]
  - $p\bar{p}$ collisions at CDF
    [Phys. Rev. D 77, 072003 (2008), Phys. Rev. D 79, 032001 (2009]
  - pp collisions at LHCb
    [Phys. Rev. D85 032008 (2012)]



LHCb: semi-leptonic measurement [Phys. Rev. D85 032008 (2012)]



$\Lambda_b \rightarrow \Lambda_c^- \mu^+ \nu X$, $B^0 \rightarrow D^- \mu^+ \nu X$
2010 dataset $3 pb^{-1}$

Analysis strategy

- A precise measurement of the absolute value of $f_{\Lambda_b^0}/f_d$ is not feasible with these decays, since the $\Lambda^0_b \rightarrow \Lambda^+_c \pi^-$ branching fraction is poorly known
- However a precise measurement of the dependence of $f_{\Lambda_b^0}/f_d$ on the b-hadron kinematic properties is possible
- This is achieved by measuring the efficiency-corrected yield ratio in bins of p_T and η of the beauty hadron

$$\mathcal{R}(x) \equiv \frac{N_{\Lambda_b^0 \to \Lambda_c^+ \pi^-}(x)}{N_{\bar{B}^0 \to D^+ \pi^-}(x)} \times \frac{\varepsilon_{\bar{B}^0 \to D^+ \pi^-}(x)}{\varepsilon_{\Lambda_b^0 \to \Lambda_c^+ \pi^-}(x)}$$

Total reconstruction and selection efficiency

$X = p_T , \eta$

$$\frac{f_{\Lambda_b^0}}{f_d}(x) = \frac{\mathcal{B}(\bar{B}^0 \to D^+\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-)} \times \frac{\mathcal{B}(D^+ \to K^-\pi^+\pi^+)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} \times \mathcal{R}(x)$$

$$\equiv \mathcal{S} \times \mathcal{R}(x),$$

$\mathcal{S}$: scale factor

The absolute scale (S) of $f_{\Lambda_b^0}/f_d$ is fixed using the measurement of $f_{\Lambda_b^0}/f_d$ from semileptonic b-hadron decays [Phys. Rev. D85 032008 (2012)]

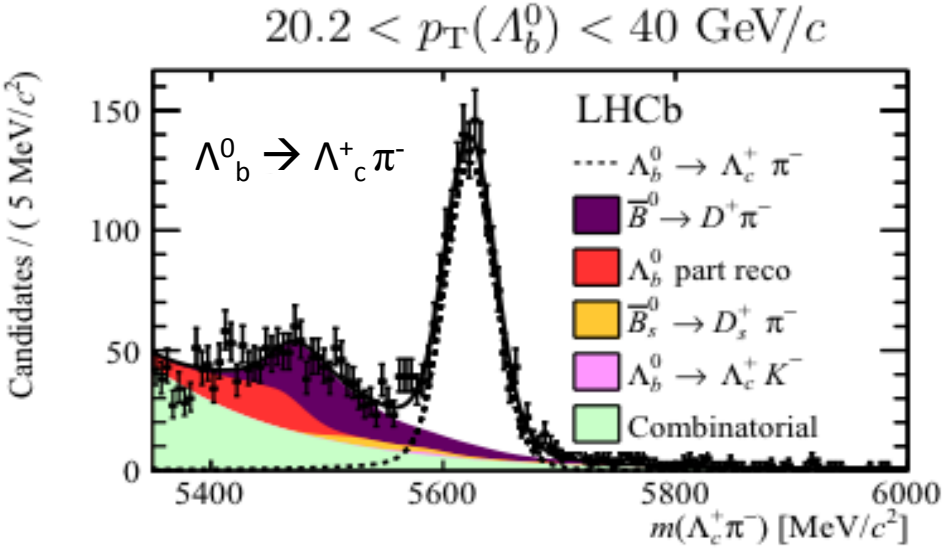
L=1 fb^{-1}

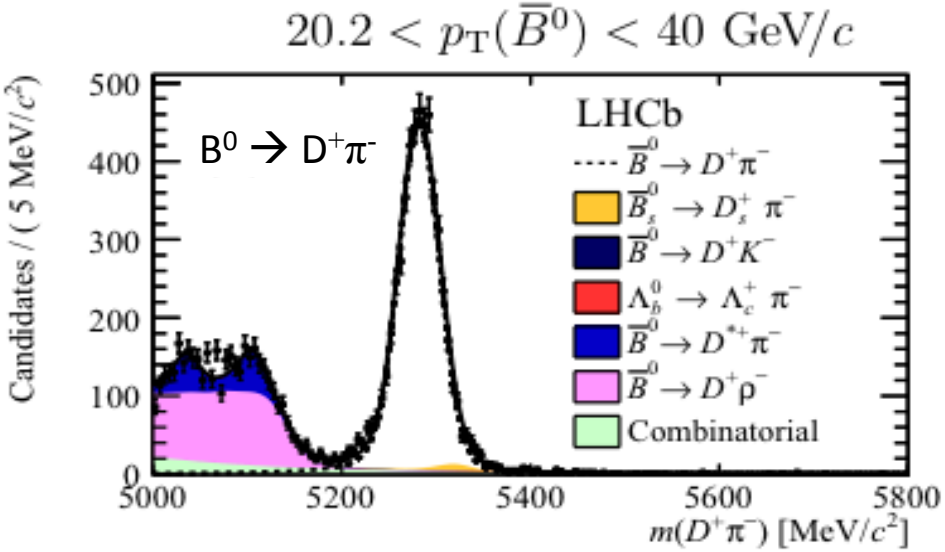
Event yields

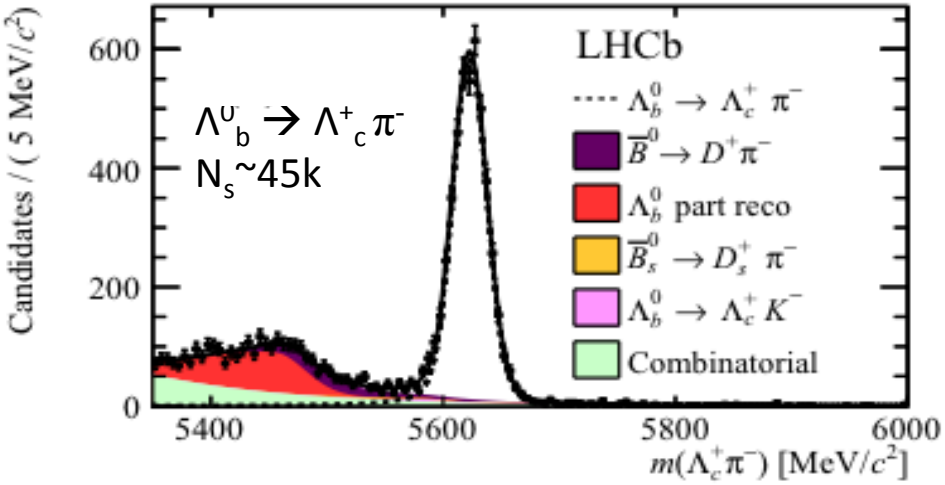
submitted to JHEP, LHCb-PAPER-2014-004

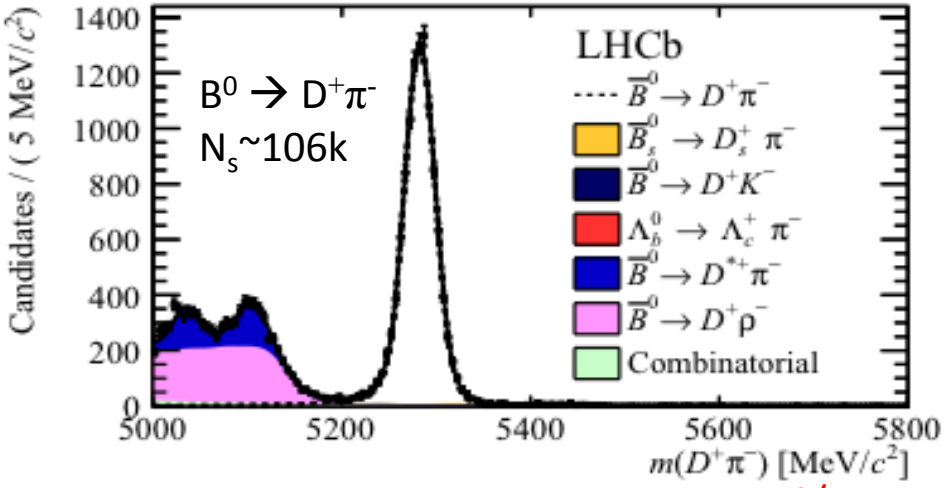
- The event sample is sub-divided in 20 bins in p_T and 10 bins in η
- The yields are determined by means of an unbinned maximum likelihood fit to the invariant mass in each bin of p_T and η

Example fits





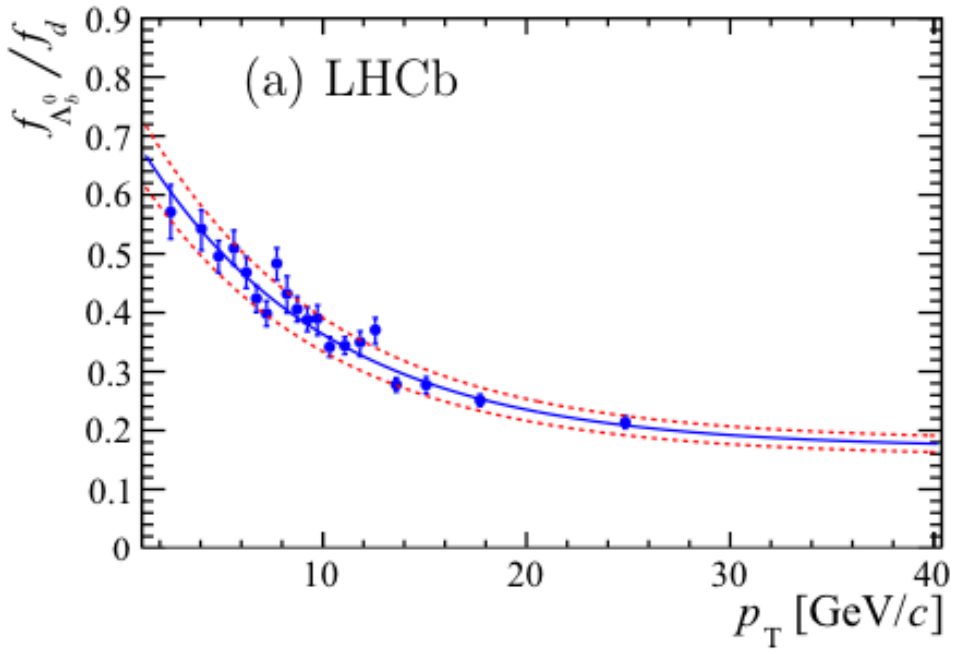


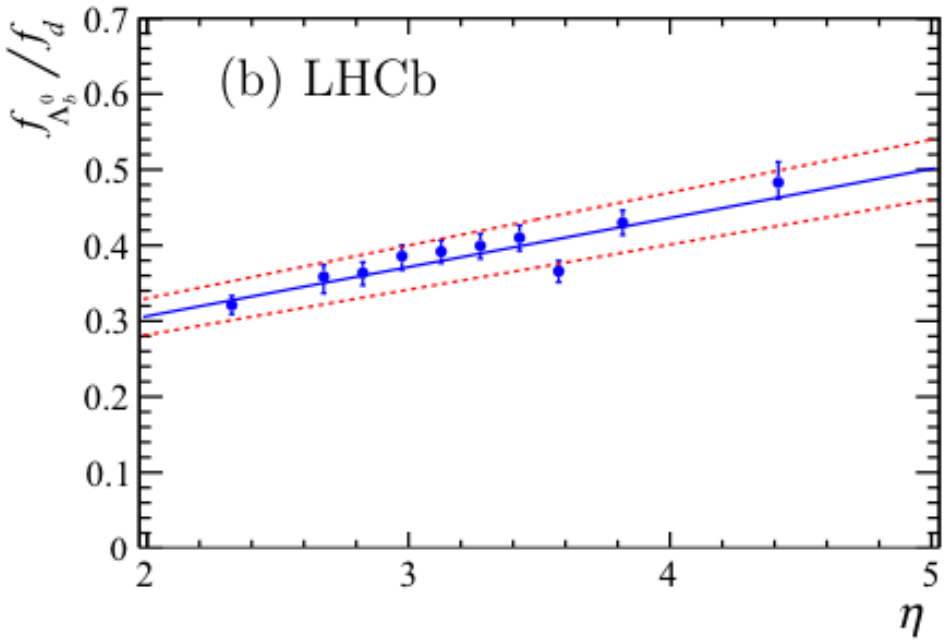


L=1 fb^{-1}

Final results

submitted to JHEP, LHCb-PAPER-2014-004





$$f_{\Lambda_b^0}/f_d(p_T) = a' + \exp(b' + c' \times p_T[\,\mathrm{GeV}/c])$$

$$f_{\Lambda_b^0}/f_d(\eta) = a' + b' \times (\eta - \overline{\eta})$$

Empirical description

$$\begin{aligned} a' &= +0.151 \pm 0.016\,^{+0.024}_{-0.025}, \\ b' &= -0.573 \pm 0.040\,^{+0.101}_{-0.097}, \\ c' &= -0.095 \pm 0.007 \pm 0.014\ [\mathrm{GeV}/c]^{-1} \end{aligned}$$

$$\begin{aligned} a' &= 0.387 \pm 0.013\,^{+0.028}_{-0.030} \\ b' &= 0.067 \pm 0.005\,^{+0.012}_{-0.009} \end{aligned}$$

- The error bars include the statistical and systematic uncertainties associated with the hadronic measurement. The dashed red lines indicate the uncertainty on the scale of $f_{\Lambda_b^0} / f_d$ from the semileptonic analysis.
- Systematic uncertainties are related to fitting model and determination of the efficiencies.

$\overline{B}^0_{(s)}$ - $B^0_{(s)}$ production asymmetries

- The production rates of b and $\bar{b}$ hadrons in pp collisions at LHC are not expected to be strictly identical
  - One can expect a slight excess in the production of B^+ and B^0 over B^- and $\overline{B}^0$, given rise to an asymmetry which must be compensated by an opposite asymmetry in the production of the other b-meson and baryon species
- The production asymmetry is one of the key ingredients to perform measurements of CP violation at LHC
- The production asymmetries for B^0 and B^0_s meson are defined as

$$A_{\mathrm{P}}\left(B^0_{(s)}\right) = \frac{\sigma\left(\overline{B}^0_{(s)}\right) - \sigma\left(B^0_{(s)}\right)}{\sigma\left(\overline{B}^0_{(s)}\right) + \sigma\left(B^0_{(s)}\right)}$$

σ is the production cross-section

- $A_p(B^0_{(s)})$ can be measured by means of an untagged time-dependent analysis of $B^0 \rightarrow J/\Psi(\mu^+\mu^-)K^{*0}(K^+\pi^-)$, $B^0 \rightarrow D^-(K^+\pi^-\pi^-)\,\pi^+$ and $B^0_s \rightarrow D^-_s(K^-K^+\pi^-)\,\pi^+$ decays (and their charge conjugates)

- The analysis is based on data collected by LHCb in 2011, corresponding to 1 fb^{-1} of integrated luminosity

The method

- Decay rate of a neutral $B^0_{(s)}$ - $\overline{B}^0_{(s)}$ decays to a flavour specific final state f or $\overline{f}$ is given by

A_{CP} Direct CP asymmetry

A_f Detection asymmetry

$$f(t,\psi) \propto (1-\psi A_{CP})(1-\psi A_f)\left\{e^{-\Gamma t}\left[\Lambda_+ \cosh\left(\frac{\Delta\Gamma t}{2}\right)+\psi\Lambda_- \cos(\Delta m t)\right]\right\}$$

$$\Lambda_\pm = (1-A_P)\left|\frac{q}{p}\right|^{1-\psi} \pm (1+A_P)\left|\frac{q}{p}\right|^{-1-\psi}$$

ψ → final state

$\psi = 1 \Rightarrow f$

$\psi = -1 \Rightarrow \overline{f}$

- for small values of A_{CP} and A_f, to first order the decay rate is

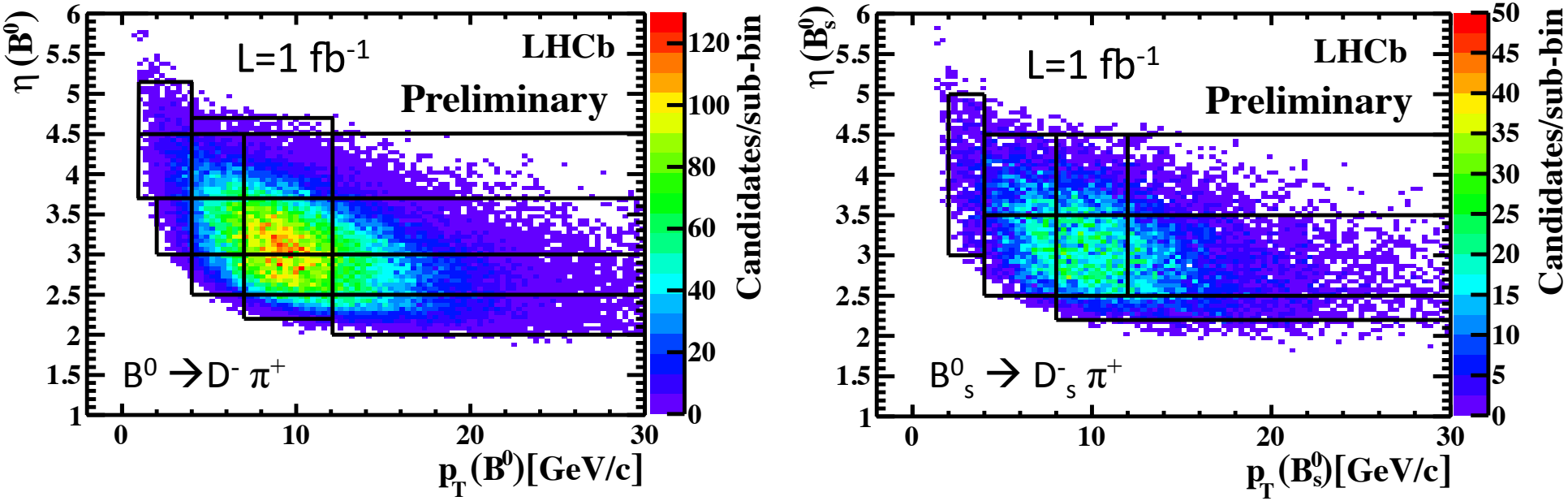
$$f(t,\psi) \propto \left[1-\psi\left(A_{CP}+A_f\right)\right]\cdot e^{-\Gamma\cdot t}\cdot\left[\Lambda_+ \cosh\left(\frac{\Delta\Gamma\cdot t}{2}\right)+\psi\Lambda_- \cos\left(\Delta m\cdot t\right)\right]$$

- it is sensitive to the sum of these two quantities. We fix A_{CP} to zero, whereas A_f is left as a free parameter.
- Any choice (up to few %) of A_{CP} → negligible variation on A_P

Determination of the production asymmetries

[LHCb-PAPER-2014-042, to be submitted for publication]

- The production asymmetries are determined by means of simultaneous fits to the invariant mass and decay time spectra.
- To test the fit model, we perform global fits to selected events for each of the three decay modes
- In order to account for the dependence of the values of the production asymmetries on the kinematics of the B^0 and B^0_s mesons, we split each data sample in bins of p_T and η, performing fits for each bin.



Background-subtracted distributions

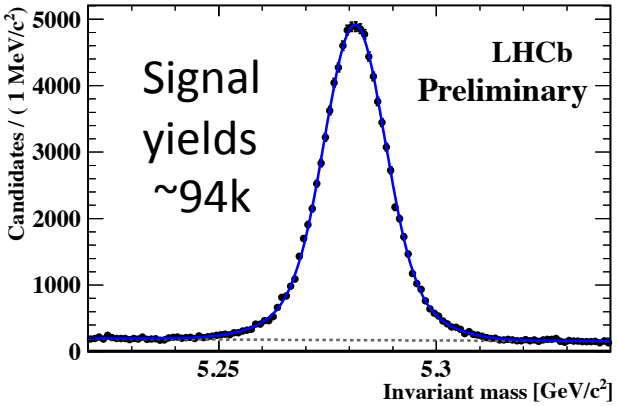
Fitting model

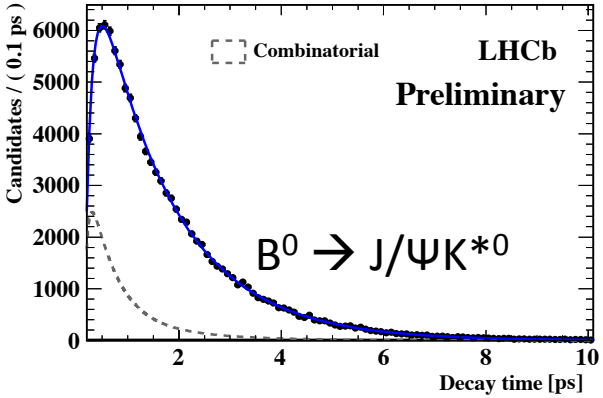
- For each signal and background component, the distributions of invariant mass and decay time of b-meson candidates are modelled
- We consider two categories of background:
  - the combinatorial background
  - the partially reconstructed background, present only for $B^0_{(s)} \rightarrow D^-_{(s)} \pi^+$ decays.
- Decay time resolution studied by reconstructing fake B candidates that are formed from a D^- and a π^+ track, both coming from the same PV
  - The decay time distribution of the fake B candidates yields an estimation of the decay time resolution of a real decay
  - We estimate an average decay time resolution of 49±8 fs
- The mass differences Δm_d and Δm_s, the mixing parameters $|q/p|_{B_0}$ and $|q/p|_{B^0_s}$, the average decay widths Γ_d and Γ_s, and the width differences $\Delta\Gamma_d$ and $\Delta\Gamma_s$ are fixed to the current experimental values

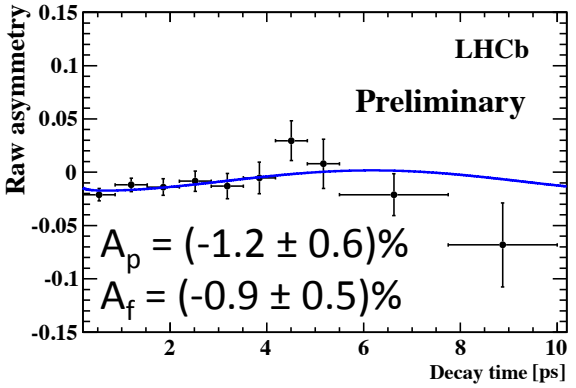
Global fits results

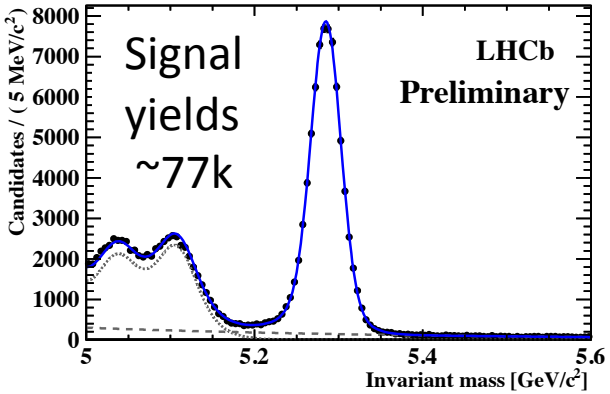
New

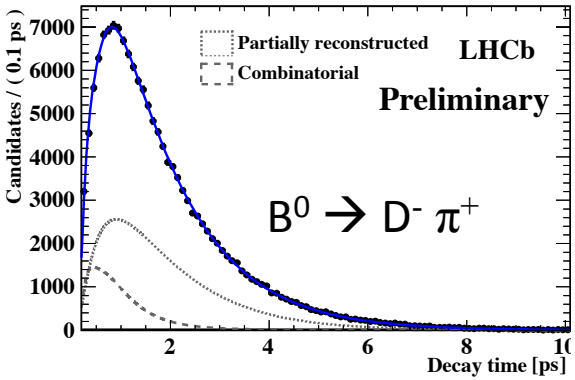
L=1 fb^{-1}

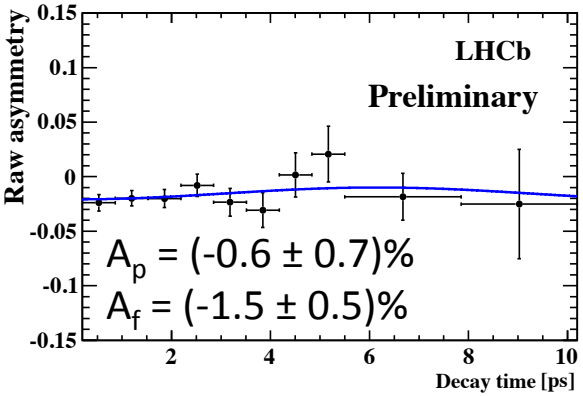




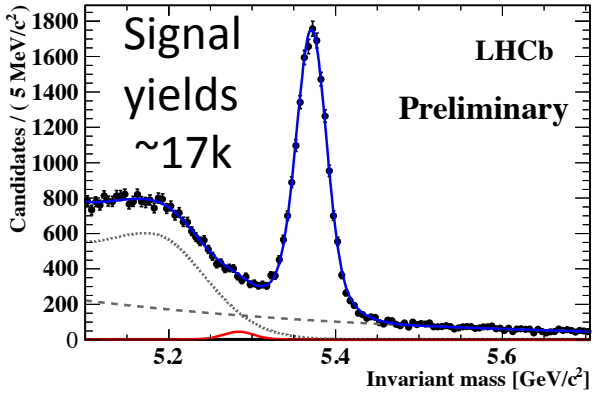


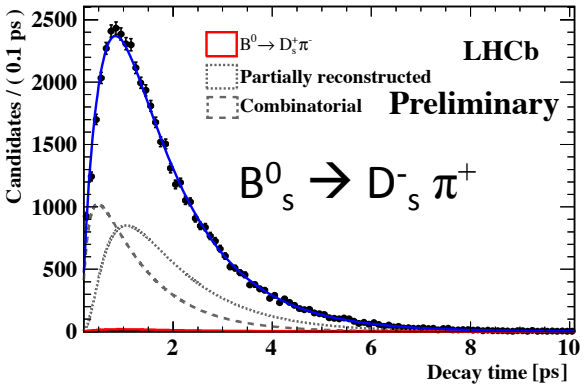


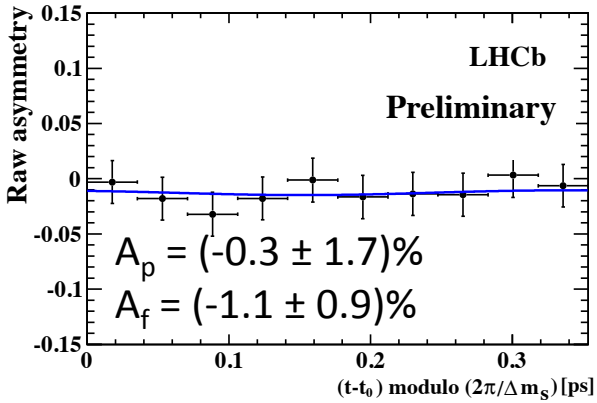




[LHCb-PAPER-2014-042, to be submitted for publication]





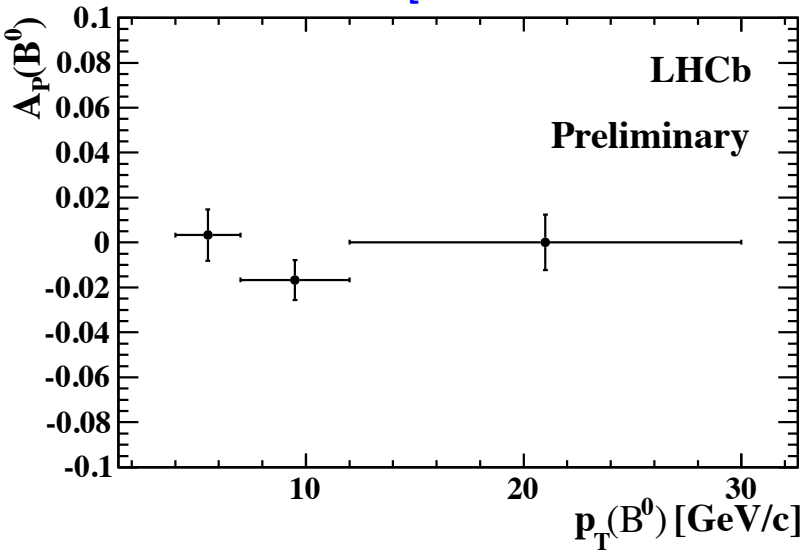


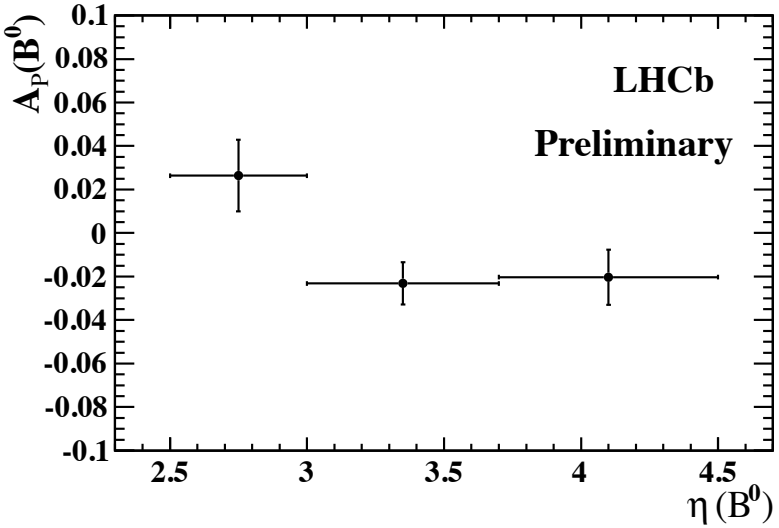
L=1 fb^{-1}

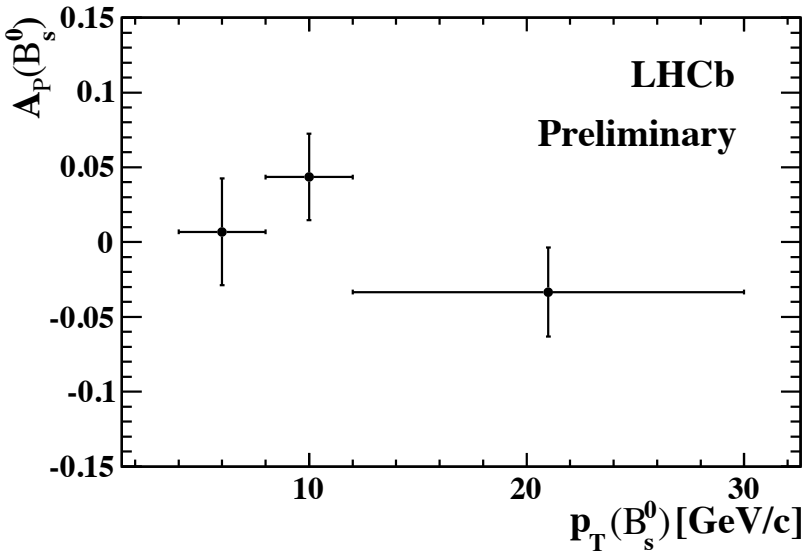
Production asymmetries vs p_T and η

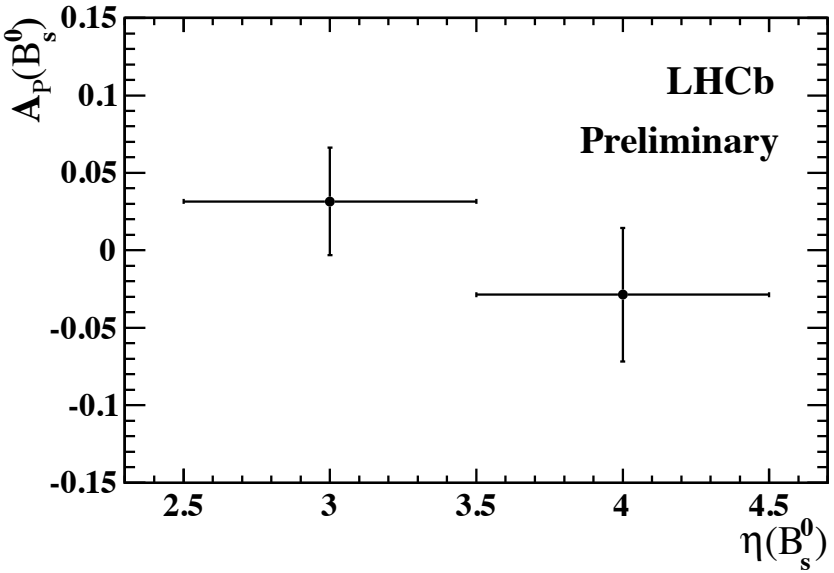
New

[LHCb-PAPER-2014-042, to be submitted for publication]









No evidence of dependences on the values of p_T and η has been observed

In the case of the B^0 meson, a slight excess towards positive A_P values is observed at small η

Systematic uncertainties

- We consider the following sources of systematic uncertainties
  - Invariant mass: inaccuracies in the shapes of any component, signals, combinatorial and partially reconstructed backgrounds
  - decay time: inaccuracies in the resolution and acceptance functions, uncertainties on the external inputs
- To estimate the contribution of each single source we repeat the fit for each single bin after having modified the baseline fit model.
  - The shifts from the relevant baseline values are accounted for as systematic uncertainties
- Main systematic for B^0: uncertainty of $|q/p|$ and invariant mass fitting model
  - within range 5-10% of statistical error
- Main systematic for B^0_s: uncertainty of $|q/p|$ and decay time resolution
  - within range 15-25% of statistical error

Averaged production asymmetries

- The integration over p_T and η of the bin-by-bin A_P value is performed within the range $4 < p_T < 30$ GeV/c and $2.5 < \eta < 4.5$.
- The integrated value of A_P is given by

$$A_{\mathrm{P}} = \frac{\sum_i \frac{N_i}{\varepsilon_i} A_{\mathrm{P},i}}{\sum_i \frac{N_i}{\varepsilon_i}}$$

- The signal yields in each bin can be expressed as

$$N_i = \mathcal{L} \cdot \sigma_{b\bar{b}} \cdot 2 \cdot f_{b(s)} \cdot \mathcal{B} \; f_i \cdot \varepsilon_i$$

total reconstruction efficiency in the i-th bin

fraction of B meson produced in i-th bin

and A_P becomes $A_{\mathrm{P}} = \sum_i \omega_i A_{\mathrm{P},i}$ where $\omega_i = f_i / \sum_i f_i$ and are determined from simulated events (independent from decay mode)

- These values are also extracted from data using $B^0 \rightarrow J/\psi K^{*0}$ → $\omega_i^{\mathrm{data}} = \frac{N_i}{\varepsilon_i^{\mathrm{rec}}} / \sum_i \frac{N_i}{\varepsilon_i^{\mathrm{rec}}}$ where ε_{rec} is measured from both simulated events and data control samples
- The values of ω_i and ω_i^{data} exhibit systematic difference at the level of 10%

Averaged production asymmetries

- The values of the production asymmetries integrated in the ranges $4 < p_T < 30$ GeV/c and $2.5 < \eta < 4.5$ have been determined to be

Preliminary

L=1 fb^{-1}

$$A_{\rm P}(B^0) = (-0.35 \pm 0.76\,({\rm stat}) \pm 0.28\,({\rm syst}))\%,$$
$$A_{\rm P}(B^0_s) = (\ \ 1.09 \pm 2.61\,({\rm stat}) \pm 0.61\,({\rm syst}))\%.$$

New

	$A_{\rm P}(B^0)$	$A_{\rm P}(B^0_s)$
Combined systematic uncertainties from bin studies	0.0004	0.0048
Statistical uncertainties on $\lvert q/p\rvert$	0.0013	0.0030
Difference between ω_i and $\omega_i^{\rm data}$	0.0024	0.0024
Total	0.0028	0.0061

[LHCb-PAPER-2014-042, to be submitted for publication]

Summary

- With 1 fb^{-1} of integrated luminosity LHCb has made
  - the first accurate measurements of the B^0 and B^0_s production asymmetries at $\sqrt{s}$=7 TeV
  - Confirmed with good precision the dependence of $f_{\Lambda_b^0}/ f_d$ as function of kinematics
- Expected soon updated measurements at $\sqrt{s}$=8 TeV with 2 fb^{-1}

Backup

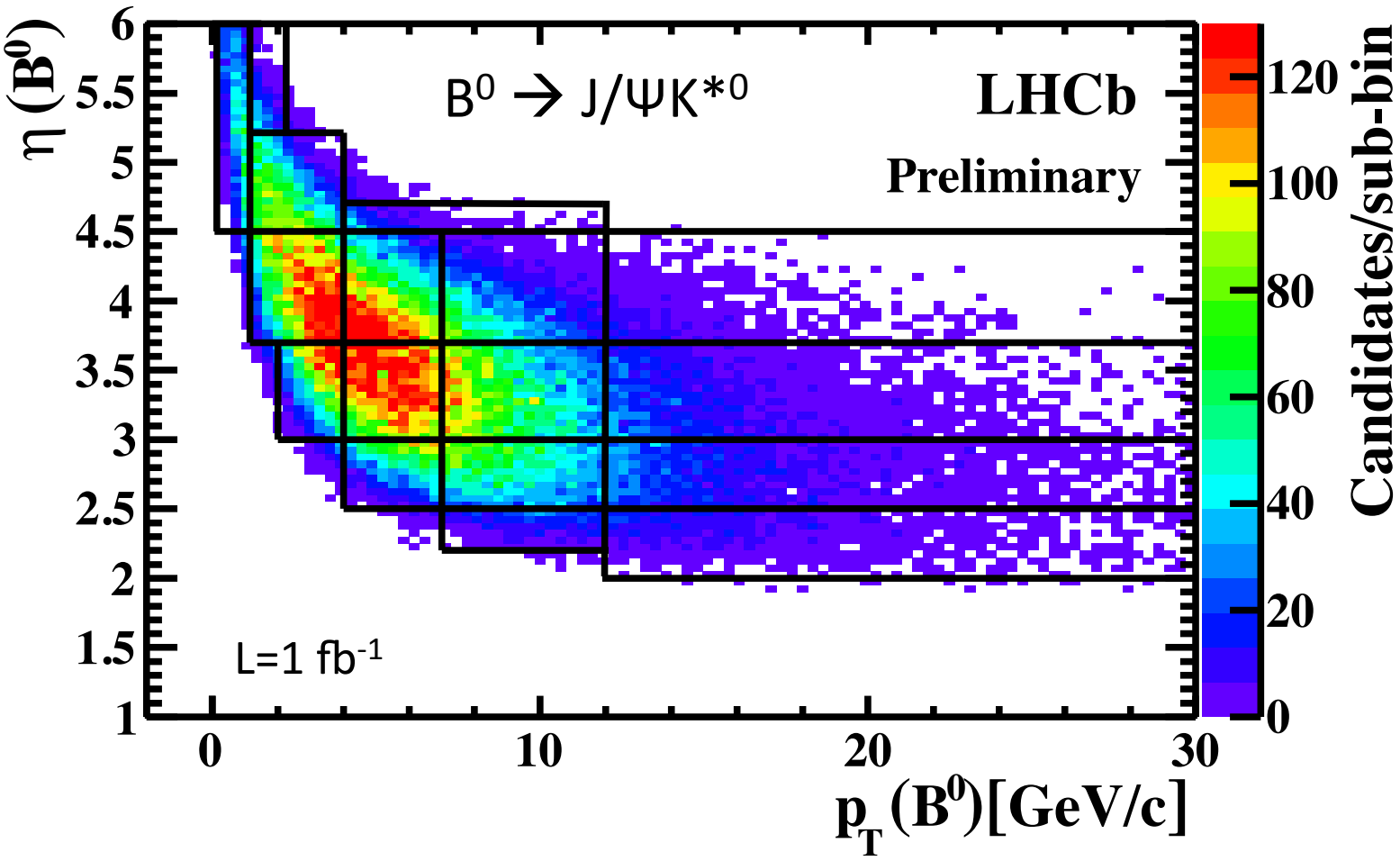
Parameter	Value	Reference
$\Delta m_d\,[\mathrm{ps}^{-1}]$	0.510 ± 0.004	[18]
$\Delta m_s\,[\mathrm{ps}^{-1}]$	17.768 ± 0.024	[19]
$\Gamma_d\,[\mathrm{ps}]$	0.6583 ± 0.0030	[18]
$\Gamma_s\,[\mathrm{ps}]$	0.6596 ± 0.0046	[18]
$\Delta\Gamma_d$	0	
$\Delta\Gamma_s\,[\mathrm{ps}^{-1}]$	0.081 ± 0.011	[18]
$\lvert q/p\rvert_{B^0}$	0.9997 ± 0.0013	[20]
$\lvert q/p\rvert_{B_s^0}$	1.0003 ± 0.0030	[21]

[18] Particle Data Group, J. Beringer *et al.*, *Review of particle physics*, Phys. Rev. **D86** (2012) 010001.

[19] LHCb collaboration, R. Aaij *et al.*, *Precision measurement of the B_s^0-$\bar{B}_s^0$ oscillation frequency with the decay $B_s^0 \to D_s^- \pi^+$*, New J. Phys. **15** (2013) 053021, arXiv:1304.4741.

[20] Heavy Flavor Averaging Group, Y. Amhis *et al.*, *Averages of b-hadron, c-hadron, and τ-lepton properties as of early 2012*, arXiv:1207.1158, update available online at http://www.slac.stanford.edu/xorg/hfag.

[21] LHCb collaboration, R. Aaij *et al.*, *Measurement of the flavour-specific CP-violating asymmetry a_{sl}^s in B_s^0 decays*, arXiv:1308.1048.


$B^0 \rightarrow J/\Psi K^{*0}$
LHCb
Preliminary
L=1 fb^{-1}
$\eta(B^0)$
$p_T(B^0)$[GeV/c]
Candidates/sub-bin
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0
10
20
30
120
100
80
60
40
20
0