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Measurement of charge asymmetry in heavy quark production

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Abstract

The forward-central charge asymmetry in $b\bar{b}$ and $c\bar{c}$ production at LHCb is measured in pp collisions at a centre-of-mass eneregy of 13 TeV.

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1 Introduction

Precision measurements of heavy quark production at the LHC form an important part of understanding the landscape of flavour physics.

The forward-central asymmetry is defined as,

$$A^{b\bar{b}} \equiv \frac{N(\Delta\eta > 0) - N(\Delta\eta < 0)}{N(\Delta\eta > 0) + N(\Delta\eta < 0)}, \tag{1}$$

and was previoulsy measured using 2011 data [1]. This analysis attempts to provide an improved measurement of the asymmetry.

In recent years, results from LHCb in b-physics have shown tensions with the Standard Model (SM). Many models that attempt to explain these anomalies invoke new gauge bosons which would cause an alteration in the value of the asymmetry. By making a precise measurement of the asymmetry, these models may be further constrained. Furthermore, the values of the couplings Zbb and Zcc can be determined by taking a ratio of the measured asymmetries for beauty and charm production. The results for these couplings will be competitive with the previous measurements made at LEP.

2 Analysis strategy

This analysis will be based on the full Run 1 and Run 2 dataset. To make a measurement of the charge asymmetry in quark production both the quark and antiquark must be detected, and the charge of at least one must be determined. The steps to measure the asymmetry for $b\bar{b}$ production are as follows:

- Data events that passed the *HltQEEJetsDiJetSVSV* HLT2 line, which requires two high transverse momentum jets containting a secondary vertex, are selected.

- Jets are reconstructed offline and the Secondary Vertex (SV) tagging algorithm is used to identify jets that originated from a b quark. Fiducial cuts are also applied and dijet candidates are selected.

- Charge tagging (qTAG) is performed by requiring that the highest p_{T} displaced track in at least one of the jets is a muon. The charge of the muon is then used to tag the jet as b or $\bar{b}$.

- The events are categorised based on whether the b or $\bar{b}$ has a greater pseudorapidity. They are then binned in the dijet mass (m_{bb}) such that the asymmetry in each of these bins can be calculated.

- To correct the measured distributions for detector effects, unfolding procedures are applied. The response matrices, which describe the detector effects, are obtained from simulation.

The initial selection of jets is taken from the cross section analysis ANA-note, not sure how to reference this.

The current binning scheme for dijet mass includes seven bins:

$$[40, 75);\ [75, 85);\ [85, 95);\ [95, 105);\ [105, 150);\ [150, 200);\ [200, 300)$$

3 Data and simulated samples

3.1 Data samples

The analysis is performed using the full Run-II dataset collected by LHCb at 13 TeV, corresponding to a total integrated luminosity of $5.9\,\mathrm{fb}^{-1}$.

Will be lots to say here on different stripping lines etc. I'm sure - could take from cross section analysis but thought I'd wait until we actually have the full data sample.

3.2 Simulation samples

For the analysis, simulation samples of $b\bar{b}$, $c\bar{c}$ and $q\bar{q}$ dijets (where q stands for a light parton u, d, s or g) were required for a few purposes:

- to model the distributions of SV-tagging related observables for the different flavours. These are used in the fit for measuring sample purity,
- to produce response matrices that can be used to unfold detector effects from the measured distributions,
- to estimate the performance of the qTAG procedure.

For each dijet type a simulation sample was produced with and without the condition that a muon be present in the final LHCb acceptance. This allowed for the efficiency of qTAG to be calculated, whilst also ensuring there was a significant number of events with muons present to analyse the performance further. The six event types were produced in three bins of m_{bb} to ensure there was a significant amount of events across the full range of the measurement.

4 Reconstruction and selection

4.1 Jet Reconstruction

Jets are reconstructed using the algorithm available in the *JetAccessories* package, which applies the particle flow selection and performs the clustering with the anti-k_T algorithm [2], using a jet radius parameter of $R = 0.5$.

4.2 Fiducial cuts

Two jets are required to have a pseudorapidity in the range $2.2 < \eta < 4.2$, a transverse momentum greater than 20 GeV and an angular difference between the two jets in the azimuthal plane of greater than 2.6 radians. These requirements are chosen to ensure that the jets are well defined, within the LHCb acceptance and likely to be $b\bar{b}$ events. The requirements are summarised in Table 1. In Table 1 and the Sections following, the jet with the highest transverse momentum will be referred to as the leading jet and variables relating to it will have a subscript 0, the other jet in the pair will be the sub-leading jet and variables carry the subscript 1.

Table 1: Summary of the fiducial cuts applied to the jets.

$p_{T0} > 20\,\mathrm{GeV}$
$p_{T1} > 20\,\mathrm{GeV}$
$2.2 < \eta_0 < 4.2$
$2.2 < \eta_1 < 4.2$
$\lvert\Delta\phi\rvert > 2.6$

4.3 Jet tagging

The standard LHCb jet tagging algorithm [3] for identification of beauty and charm quark jets has been used. This tagging reconstructs secondary vertices (SV) using tracks inside and outside the jet and will be referred to as SV-tagging in this note. If an SV is found inside the cone of the jet then it is SV-tagged.

Two boosted decision trees (BDTs) are then used on the SV-tagged jets to determine the flavour of the quark that originated it [4–6]. One BDT distinguishes between light and heavy jets ($\mathrm{BDT}_{bc|udsg}$) and the second distinguishes between b- and c-jets ($\mathrm{BDT}_{b|c}$). The variables used as input for the BDTs are those related to the SVs that provide the highest discrimination power between the flavours. They are as follows:

- the SV mass,
- the SV corrected mass,
- the transverse flight distance of the two-body particle closest to the PV and built with tracks that belong to the SV,
- the fraction of the jet p_{T} carried by the SV,
- the number of tracks that form the SV,
- the number of tracks that form the SV with $\Delta R < 0.5$ from the jet axis,
- the total charge of tracks in the SV,
- the SV flight distance χ^2,
- the sum of χ^2_{IP} for all the tracks in the SV.

Need to check the versions of the BDTs that are used etc. as I think these have changed from the cross-section analysis.

5 Charge tagging (qTAG)

Jets are tagged for flavour as discussed in Sec. 4.3, but for the asymmetry measurement we also need to tag the charge of these jets. The aim of this analysis is to measure the asymmetry up to very high values of m_{bb}, however current LHCb methods for charge tagging are optimised for lower energies. It is also important that the charge tagging procedure is unlikely to generate any fake asymmetries or mistag jets in a way that is difficult to understand and account for.

For this reason we use a simple and robust method similar to that which was used in the previous measurement at LHCb [1], which we shall refer to as qTAG. The basis of this is to use only the muons produced in $b \rightarrow \mu X$ decays. A notable source of mistagging comes from $b \rightarrow c \rightarrow \mu X$ type decays where now the muon and original b-quark differ in sign.

qTAG is applied to jets whose highest p_{T} displaced ($\chi^2_{\mathrm{IP}} > 16$) track passes muon selection criteria ($\mathrm{DLL}_{\mu\pi} > 0.5$ and `isMuon` = `true`). Only one jet needs to be qTAG in the event as the charge of the other b-quark can then be inferred.

A notable source of mistagging comes from $b \rightarrow c \rightarrow \mu X$ type decays as now the muon and original b-quark would differ in sign. These are suppressed by the qTAG procedure as the muons from this source will have a significantly lower p_{T} than those that come from the b-quark and are hence less likely to be the highest p_{T} displaced track in the jet. They must, however, still be accounted for and attempts made to minimise their inclusion in the qTAG sample.

To measure the performance of qTAG we use the figure of merit εD^2, where ε is the fraction of total events that are tagged, and $D = 1 - 2\omega$ is the dilution factor, with ω the incorrect tag rate. The dilution factor also relates the measured value of the asymmetry with the true value $A^{b\bar{b}}_{\mathrm{mea.}} \equiv DA^{b\bar{b}}_{\mathrm{true}}$. The performance of qTAG should thus be optimised to maximise εD^2.

5.1 Theoretical qTAG performance

To calculate the theoretically expected performance of qTAG the branching fractions of $b \rightarrow \mu X$ and $b \rightarrow c \rightarrow \mu X$ type relevant decays must be used, these are listed in Table 2. As the branching fractions are given in hadronic form the fraction of b-quarks found in each hadron must also be accounted for, these are listed in Table 3.

5.2 Tests of performance

Details of performance tests on simulation / data.

Table 2: Relevant branching fractions for calculating qTAG performance [7]

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Decay	Branching Fraction (%)
$B^+ \to \mu^+ X$	10.99
$B^0 \to \mu^+ X$	10.33
$B_s^0 \to \mu^+ X$	10.2
$\overline{\Lambda}_b^0 \to \mu^+ X$	10.4
$B^+ \to D^- X$	9.9
$B^+ \to \overline{D}^0 X$	79
$B^+ \to D_s^- X$	1.1
$B^+ \to \overline{\Lambda}_c^- X$	2.8
$B^0 \to D^- X$	36.9
$B^0 \to \overline{D}^0 X$	47.4
$B^0 \to D_s^- X$	<2.6
$B^0 \to \overline{\Lambda}_c^- X$	5
$D^- \to \mu^- X$	17.6
$\overline{D}^0 \to \mu^- X$	6.8
$D_s^- \to \mu^- X$	5.4
$\overline{\Lambda}_c^- \to \mu^- X$	3.5

Table 3: b quark hadronic fractions [8]

	Hadron	Fraction
f_u	B^-	0.362
f_d	$\overline{B}^0$	0.362
f_s	$\overline{B}_s^0$	0.187
f_b	Λ_b^0	0.088

6 Unfolding

6.1 Detector resolution

6.2 Mis-qTAG

6.3 Detector acceptance

7 Fitting procedure

References

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