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Semileptonic B-decays at LHCb, and the Prospects for Measuring V_{ub} and V_{cb}

Robert W. Lambert[*†]
CERN, Geneva, Switzerland
E-mail: Rob.Lambert@cern.ch

Now, at the end of the 2010 LHC run, the LHCb experiment has collected $\sim$38 pb^{-1} of pp-collisions at a centre-of-mass energy of 7 TeV. With such a data sample we aim to measure several features of semileptonic b-decays, moving towards a measurement of exclusive branching ratios of $B^0_{s/d} \to D^{(*)(*)}\mu\nu$ states and the q^2 dependence of the branching ratios necessary to constrain the B^0_s-system, determine V_{cb}, and later measure V_{ub}. I present a summary of the work so far on this topic in the first 0.8 pb^{-1} and also the prospects for the measurement of flavour-specific asymmetry, a_{fs} in 2011.

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*Speaker.
†On behalf of the LHCb collaboration.

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1. Introduction

The LHC B-hadron samples will rapidly overtake the samples collected to date by the B-factories and the Tevatron. Semileptonic B-decays are a very abundant class of B-decays, and are relatively easy to trigger. Competitive measurements of time-integrated and time-dependent quantities, and new results in the B_s^0-system, may be provided even by this initial run period (2010), where we have collected $\sim$38 pb^{-1} of integrated luminosity at a centre-of-mass energy of 7 TeV.

1.1 The LHCb detector

The LHCb detector is a forward-arm-spectometer described in detail elsewhere [1]. LHCb measures particles which appear within its angular acceptance of 10 mrad to 250 mrad vertically, and 10 mrad to 300 mrad horizontally [2]. This is less than 1 % of all solid angles, however, LHCb covers 34 % of the produced b-quarks since heavy-quark production peaks in the forward and backward directions at a TeV-scale hadron collider. The key components of LHCb which are significant for semileptonic studies, and differ considerably from previous experiments include: the LHCb vertex locator, or VELO; and the dedicated PID subsystems. The VELO is a silicon strip device approaching to within 8 mm of the beam line, that can provide excellent proper-time resolution of $\sim$ 50 fs for fully reconstructed final states. The dedicated PID subsystems, such as the two RICH detectors, Muon stations and Calorimeters, enable LHCb to efficiently separate final state particles, notably K/π mesons, enabling many formerly impossible exclusive studies.

LHCb has already reached an impressive 90 % efficiency on the collection of LHC data. At the time of this presentation we had collected around 15 pb^{-1}, although the results shown are from the first 0.8 pb^{-1}, and we now have $\sim$38 pb^{-1} in hand at the end of 2010.

1.2 Semileptonic studies at LHCb

We have already started reconstructing and analysing many different semileptonic B-decays, which can be examined separately at LHCb. In both cases the main backgrounds are from open

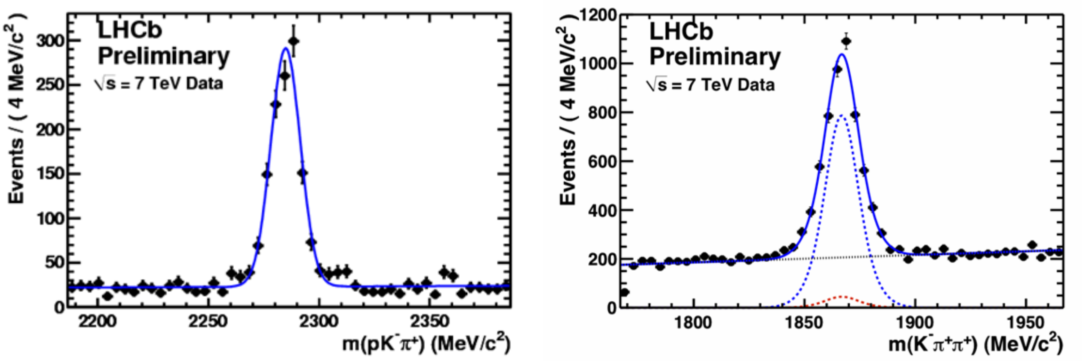

Figure 1: Two of the many examples of semileptonic decays reconstructed in LHCb, namely Λ_b (left), where we plot the mass distribution of the $(pK\pi)$ from the subsequent Λ_c-decay, and $b \to D^+ \mu \nu X$ (right), where the $K\pi\pi$ mass distribution is plotted. One may see that the combinatorial background is effectively suppressed. In black, the data; in solid blue, the total fit; in dashed blue, the detached-vertex-signal; in dashed red, the prompt peaking background; in dashed black, the combinatorial background.

charm or prompt charm production at the primary vertex (interaction point), and other light meson production. Since V_{cb} is much larger than V_{ub}, the charmed semileptonic decays were first to be seen. Here we pick two of the many examples of decays reconstructed in LHCb in Fig. 1, namely exclusive $\Lambda_b^+ \to \Lambda_c^+ \mu\nu$ and semi-inclusive $b \to D^+ \mu\nu X$.

Most of the measurements we want to make also require us to reconstruct the neutrino, e.g. to calculate the q^2 for measuring V_{ub} and distinguishing components of the different excited semileptonic decays, or to measure the proper time of the B-meson for time-dependent studies. Using the power of the VELO, we are able to overconstrain the decay. Since we know the direction between the interaction point and the decay vertex of the B, and the mass of the mother particle, we can calculate a momentum vector for the missing particle, assuming there is a single missing particle of zero rest mass [3]. In Fig. 2, on the left, is a simple cartoon of that calculation in a boosted frame, where you can see there are two ambiguous solutions to the neutrino momentum, since in essence we have a quadratic equation. To obtain the best resolution on the momentum, and hence the q^2, we can choose the lower of these two solutions, as demonstrated in the LHCb simulation (Monte Carlo or MC) on the right.

The LHCb collaboration has already started making measurements in the semileptonic sector, our second paper, the first b-physics paper, Ref. [4], is the determination of the $b\bar{b}$-cross-section from decays of the form $b \to D^0 \mu\nu X$. In that paper we demonstrate the use of the impact parameter (IP) distribution to effectively separate signal from background, because open charm and other combinatorics tend to be produced at the pp-interaction point (primary vertex), we can fit to the IP distribution of the reconstructed meson with respect to the primary vertex, to separate out the signal from the prompt background. Building upon the knowledge of these measurements, and our increasing knowledge of LHCb, we can look to make many other measurements of semileptonic decays, including V_{ub}.

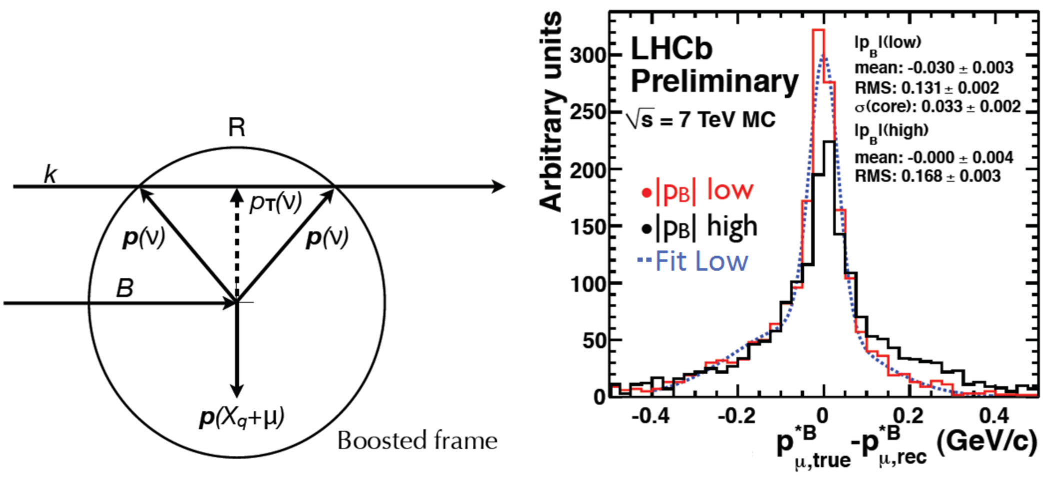

Figure 2: Neutrino reconstruction. Left, a simple cartoon of the calculation in a boosted frame where the reconstructed momentum is perpendicular to the flight direction. The circle, R, is the constraint from conservation of energy, and there are two ambiguous solutions. Right, the resulting resolution on the momentum from both solutions in the LHCb Simulation, (Monte Carlo or MC). The lower solution has a tighter and more significant core distribution, indicating that the lower solution minimises uncertainty on q^2.

1.3 Prospects for V_{ub} measurements

V_{ub} is an interesting parameter to measure for several reasons. V_{ub} constrains the length of the side of the unitarity triangle (UT) opposite the angle β, and so is an independent constraint of the corner of the UT. It is measured in tree-level $b \to u$ decays; however, even the most recent measurements do not provide a significant constraint on the UT fit [5]. V_{ub} is also very useful in separating out many different theoretical models and form factor descriptions. The BABAR collaboration, in a recent paper, presented also at this conference, measure V_{ub} in bins of q^2 [6], and use this to discriminate different form factor models. It is notable, that LHCb can probe V_{ub} both in the B_d^0 and in the B_s^0 system, where very little is currently known.

Decays involving V_{cb} form the main background to a measurement of V_{ub}, and so in the early data we must first understand decays involving V_{cb}, particularly B_s^0 decays. However, very little is currently known of either of the two inputs required to understand the B_s^0 system, namely the exclusive branching ratios and the hadronic form factors. The majority of the relevent form factors have yet to be calculated on the lattice, and there are only weak experimental constraints on the exclusive D_s and $D_s^{*(*)}$ branching ratios [7]. Particularly the branching ratios and form factors for the excited $D_s^{*(*)}$ decays are very important, as they are expected to contribute the majority of the total branching ratio [8].

2. Preliminary results on $b \to X_c l \nu$

A sample of $B_s^0 \to D_s \mu X$ decays is selected from the events passing the LHCb muon triggers, by searching for a charmed meson which forms a common vertex with the muon. Cuts were optimised for the signal over background ratio on MC data. We require excellent tracks, a well-isolated well-identified muon, well-identified hadrons and well-reconstructed vertices which point back to a pp-interaction vertex (primary vertex).

Specifically, the muon sample is cleaned by cutting on: the track quality, $\chi^2_{tr}/ndf < 5$; a minimum impact parameter (IP), $\chi^2_{IP} > 4$, to any primary vertex; a momentum, $p > 3\,\mathrm{GeV}c^{-1}$; and a transverse momentum $p_\mathrm{T} > 1.2\,\mathrm{GeV}c^{-1}$. Additionally the muons must have hits in all muon stations where none of the hits are shared with another muon track. The particle identification (PID) system must give a log likelihood difference (DLL) of greater than zero between muon and pion hypotheses $DLL(\mu - \pi) > 0$. The daughters of the charm hadron were selected as those with: track $\chi^2/ndf < 5$, $\chi^2_{PV} > 9$, $p > 2\,\mathrm{GeV}c^{-1}$, $p_\mathrm{T} > 300\,\mathrm{MeV}c^{-1}$. The p_T-cut was used to ensure good PID information, such that the kaons and pions could be separated by cutting on, $DLL(K - \pi) < 10$ for pions, $DLL(K - \pi) > 4$ for kaons.

From amongst all the charm hadrons found, a sample was selected with: a sum of the daughter $p_\mathrm{T} > 700\,\mathrm{MeV}c^{-1}$, a vertex quality $\chi^2_{vtx}/ndf < 6$, an IP< 7.4 mm to the vertex minimizing the IP, a flight distance separation of the charm meson with respect to that primary vertex of $\chi^2_{FD} > 100$, and an angle to that vertex with respect to the momentum vector of $cos\theta > 0.9$. The p_T cut on the D was selected to ensure good IP resolution, for the separation of B-signal from the prompt charm background as described in Ref. [4].

Charm hadrons were then combined with muons to make candidate B-mesons. We cut on $\chi^2_{vtx}/ndf < 6$ and $cos\theta > 0.999$. The charm meson was constrained to decay further downstream than the B and a signal mass window was applied that $3.1\,\mathrm{GeV}c^{-2} < m(D_s\mu) < 5.1\,\mathrm{GeV}c^{-2}$.

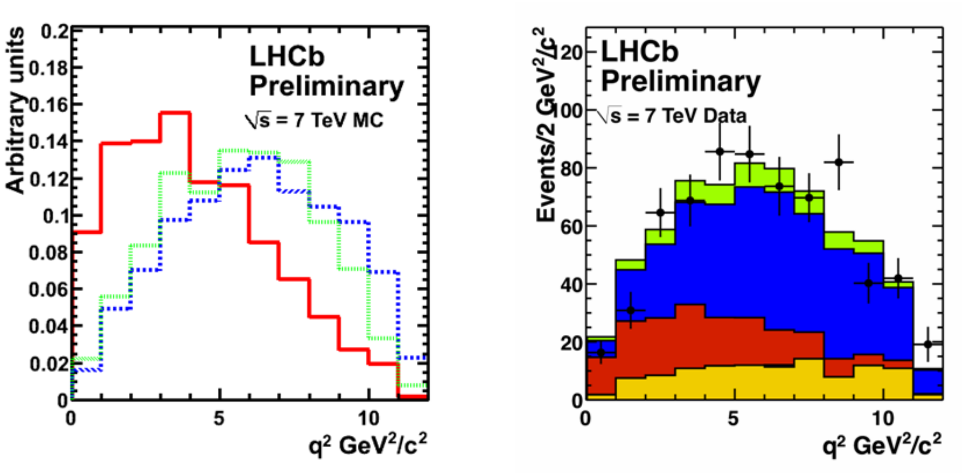

Figure 3: Signal yield in bins of q^2. On the left, from the LHCb MC, three normalized histograms show the relative shapes of: D_s, red solid; D_s^*, blue dashed; D_s^{**}, green dashed. On the right, the data are plotted in black, against the MC prediction (filled histogram) with proportions of the different contributions fixed from the MC. Red, blue and green are the same as on the left, contribution from prompt peaking background is in purple (not visible at this scale) and the contribution from combinatorial background is given in yellow from the data sidebands in the $(KK\pi)$ mass.

For each candidate a kinematic fit is used to reconstruct the missing neutrino, and the resultant yield is shown as a function of q^2 as the black points on the right in Fig. 3.

Since neither the form factors nor the branching ratios are well known, to make a comparison with our MC we choose a set of form factors based on our best knowledge, and fix the ratio of excited state decays to be the same as that in the B_d^0 system. The form factor shapes in q^2 are shown on the left in Fig. 3, and are scaled by the relative branching fractions into the coloured solid histograms on the right. With this small initial dataset, little can be concluded about the agreement or disagreement, but it is clear from this plot that with the full 2010 dataset a conclusive comparison against either the form factors or the branching ratios can be made. We are working towards a more complicated analysis for the extraction of both form factors and branching ratios.

3. Prospects for a_{fs}

The DØ collaboration recently produced an exciting and surprizing result in the measurement of flavour-specific asymmetry in the semileptonic decays of b-quarks [9]. They determine the total dimuon charge asymmetry, which is interpreted as the direct result of the flavour-specific asymmetries in the B_s^0 and B_d^0 system (a_{fs}^s and a_{fs}^d, respectively). They measure a quantity

$$A^b \approx (a_{fs}^s + a_{fs}^d)/2 = [-9.57 \pm 2.51(stat) \pm 1.46(syst)] \times 10^{-3}$$

which is 3.2 standard deviations from the standard model prediction [9].

In the environment of the LHC, such a measurement is made more challenging by the expected production asymmetry [10], however, using a novel time-dependent technique LHCb can make an accurate measurement of $\Delta A_{fs} = (a_{fs}^s - a_{fs}^d)/2$, with a statistical sensitivity (as predicted from the

MC) of 6 ± 10^{-4} in $1\,\text{fb}^{-1}$ [11]. This measurement is complementary to the DØ measurement, and almost orthogonal in the $(a^s_{fs} : a^d_{fs})$-plane. If the DØ central value holds, and the residual systematics are well controlled, this could provide a result 15 standard deviations from the Standard Model in the first $1\,\text{fb}^{-1}$, which is the expected 2011 dataset.

4. Conclusion

LHC and LHCb are performing excellently, and we have collected $\sim 38\,\text{pb}^{-1}$ of pp-collision data at $\sqrt{s} = 7\,\text{TeV}$ in this 2010 run period. With these data we will begin to understand the detector and constrain models of form factors and exclusive branching ratios of $B^0_s \to D^{(*)(*)}\mu\nu$ states, necessary for a measurement of V_{cb} and then V_{ub} by LHCb. In 2011 we expect to collect $1\,\text{fb}^{-1}$, which will allow us to make clean measurements within many topics including V_{ub} and $\Delta A_{fs} = (a^s_{fs} - a^d_{fs})/2$.

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