

b production measurements with ATLAS

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Abstract

The Large Hadron Collider at CERN will produce b hadrons with unprecedentedly high statistics, and with a higher energy reach than any previous machine. The ATLAS detector will offer excellent acceptance and performance for b physics studies and will make high statistics measurements of b quark production to probe QCD. ATLAS can contribute to an understanding of the large discrepancy seen between the QCD prediction and Tevatron cross-section measurements. Measurements will be made of the absolute and differential production cross-sections. Measurements of $b\bar{b}$ correlations will be made to test the NLO contributions to the cross-section and to place limits on non perturbative effects.

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1 Introduction

The Large Hadron Collider at CERN will collide protons at a centre-of-mass energy of 14 TeV and will evolve in two phases, with collisions initially occurring at a luminosity of $10^{33} \text{cm}^{-2} \text{s}^{-1}$, and later at $10^{34} \text{cm}^{-2} \text{s}^{-1}$. The physics program during the initial ‘low luminosity’ running will be dominated by b-hadron physics, and the ‘high luminosity’ running providing an emphasis on search physics. First collisions are scheduled to occur in 2005. The LHC will produce a huge number of $b\bar{b}$ pairs, one in every hundred events being a $b\bar{b}$, and offering a better signal-to-noise ratio than lower energy hadron machines.

Full simulation studies have been made of the ATLAS performance for b production studies. These have emphasised the importance of the muon system for identification and reconstruction of prompt muons from semi-leptonic b hadron decays and of J/ψ meson decays to dimuons. The possibilities for measurements of the b production cross-section will be presented. Potential measurements of the angular correlations in $b\bar{b}$ production have been studied in some detail, and recent work on the development of novel techniques in this area are discussed.

2 b production measurements

Measurements of b production offer an important probe of perturbative QCD. The comparison of measurements with theoretical predictions allows a testing of the completeness and precision of QCD. A full next-to-leading order (NLO) calculation [1] suggests that the NLO terms ($O(\alpha^3)$) are of the same size as the Born ($O(\alpha^2)$) terms. It is not feasible to calculate higher order (i.e. NNLO) terms, but these may also be large. Techniques exist to estimate such terms, an example of which is the use of resummation [2], which enables an estimation of the size of large log terms to all orders. It nevertheless remains the case that the theoretical error on the cross-section is dominated by the uncertainty on the size of the higher order terms.

An additional source of discrepancy between perturbative QCD and measurement is the contribution of non-perturbative effects [3]. The effect of a non-perturbative fragmentation function can significantly affect the shape and size of the measured cross-section, as can non-perturbative effects such as intrinsic parton k_T . Direct photon production data has suggested a value as high as $\langle k_T \rangle \sim 4$ GeV [4], but this value is considered unphysically high. The effect of both fragmentation and intrinsic parton k_T is shown in Figure 1, which shows the prediction of the FMNR program for the absolute cross-section at LHC as a function of transverse momentum, p_T .

Measurements of the b production cross-section at the Tevatron ($\sqrt{s}=1.8$ TeV), indicate a significant discrepancy relative to the perturbative QCD prediction, the data being a factor ~ 2.4 higher [3]. However the general shape of the cross-section appears to be well represented by theory. A primary task of b production measurements at the LHC will be to attempt to understand the source of this discrepancy.

b production must also be understood to make other measurements at the LHC: to control systematic uncertainties on CP violation channels through production asymmetries, and to understand $b\bar{b}b\bar{b}$ production as a background to Higgs decays.

3 The ATLAS detector

ATLAS is a general purpose detector [5] that offers excellent performance for the triggering and reconstruction of b hadron decays [6]. The kinematic reach offered by the ATLAS detector is both large and substantially orthogonal to that seen in the LHCb experiment, [3].

The 40 MHz bunch crossing rate provides a challenging triggering environment. For b hadron physics a 6 GeV single muon Level-1 trigger is used, [7]. At higher trigger levels dedicated triggers

exist for general b quark decays, and specific B-hadron channels [8]. The ATLAS Inner Detector [9] provides precise tracking of charged particles through the use of three layers of pixel detectors (including a layer for b physics 5 cm from the beam pipe), a SemiConductor Tracker using 4 layers of silicon detectors each providing a 3D space-point, and a Transition Radiation Tracker that provides, on average, 36 straw tubes associated to each track. At the typical p_T of tracks in b jets p_T resolution is $\sim 2\%$, and transverse impact parameter resolution 15-60 μm . The ATLAS muon spectrometer [10] offers extremely high precision measurements of muon momenta across a large acceptance ($|\eta| < 2.7$). Monitored Drift Tubes provide at least 20 points per muon with a resolution of $\sim 80\mu\text{m}$, providing a resolution on the sagitta measurement of $\sim 30\mu\text{m}$. When combined with Inner Detector measurements the muon system offers a resolution on muon p_T of $\sim 2\%$ up to 100 GeV p_T .

Full simulation studies have been made of the response of the ATLAS detector to muons [11]. Muons have been reconstructed in the muon system, and combined with tracks reconstructed in the Inner Detector. The efficiency for muon reconstruction is seen to plateau close to 100% at 6 GeV, with a limited efficiency for softer muons. Substantial rejection of $K/\pi \rightarrow \mu$ decays has been demonstrated in simulation.

J/ψ mesons have been reconstructed through their decay to dimuons. The J/ψ mass resolution is ~ 41 MeV [12]. No significant non-Gaussian tails are seen in the mass plot. Mis-matches of identified muons to the wrong Inner Detector track occur for only $\sim 1\%$ of tracks, even in a dense jet environment. This remains true even when the sample is restricted to b quarks of $p_T > 50$ GeV, where the jet is highly collimated.

4 Measurement possibilities at ATLAS

Both exclusive B-hadron decays and inclusive b-hadron decays are collected at ATLAS. The exclusive channels provide a very clean sample of B decays and will include $B_d \rightarrow J/\psi K^0$, $J/\psi K^*$ and $B^+ \rightarrow J/\psi K^+$, $B_s^0 \rightarrow J/\psi \phi$, that will also be used for CP-violation studies. Statistics can be extended using inclusive $b \rightarrow J/\psi$.

b-jets can also be tagged inclusively using impact parameter information. Full simulation studies show that high rejection factors of light quark and gluon jet backgrounds can be achieved whilst maintaining good efficiency for b-jets. Such a technique also allows access to the highest b-jet p_T ranges up to 400 GeV p_T .

The yield of b quark events at ATLAS is shown in Figure 2, after three years low luminosity ($10^{33} \text{cm}^{-2} \text{s}^{-1}$, corresponding to 30fb^{-1}) running, for both inclusive and exclusive channels. Yields are in excess of 10^8 events at low p_T , and there is significant yield for p_T as high as 350 GeV.

4.1 Cross-section measurements

The most important measurements that can be made involving the products of a single b quark fragmentation and decay are those of absolute and differential cross-section. Such measurements can be made by ATLAS, CMS and LHCb with substantial overlap in the phase space permitting cross-checks between experiments.

The measurement of the differential cross-section at LHC can be considered a test of re-summation techniques, particularly at high- p_T . ATLAS will collect b quarks up to and beyond $p_T = 300$ GeV, and will be able to make measurements at higher p_T than any currently available.

4.2 $b\bar{b}$ correlations

One of the most interesting questions to be investigated at the LHC is a test of the NLO and higher contributions to the b cross-section. The shape of angular correlations in $b\bar{b}$ production are highly sensitive to the higher order terms, the azimuthal separation of the $b\bar{b}$, $\Delta\phi_{b\bar{b}}$, for example, being dominated by the NLO terms in the region $\Delta\phi_{b\bar{b}} < \pi/2$ [3].

Traditionally $b\bar{b}$ correlations have been measured in dimuon events, assuming that both muons are the products of semi-leptonic b -hadron decays. However this technique yields a sample very high in background, particularly from K/π decays and cascade decays, and analyses are forced to make cuts that reduce acceptance in the low $\Delta\phi_{b\bar{b}}$ region, precisely where there is most interest. ATLAS has developed a technique to measure $\Delta\phi_{b\bar{b}}$ using events containing a J/ψ , and measuring the $J/\psi - \mu$ angle, $\Delta\phi_{J/\psi-\mu}$ [12]. This technique, made possible by the very high statistics at the LHC, greatly reduces the background. It is hoped that such a technique will remove the need for depopulating cuts at low $\Delta\phi_{b\bar{b}}$.

Several samples of Monte Carlo B decays have been investigated regarding the $\Delta\phi_{J/\psi-\mu}$ measurement, using full simulation of the ATLAS detector. Figure 3 shows the generated and reconstructed $\Delta\phi_{J/\psi-\mu}$ distributions in $B_s^0 \rightarrow J/\psi + \phi$ events.

The high number of K^\pm decays to μ present in such events creates substantial background, and so provides a challenging environment. The lower plot in Figure 3 shows the result after the application of K/π decay rejection. It can be seen that the shape of the distribution at the generated level is well reproduced. Figure 4 shows the efficiency of the $J/\psi - \mu$ reconstruction in such events, as a function of $\Delta\phi_{J/\psi-\mu}$. The expected drop along the axis of the event, where particle densities are high is slight relative to the mean efficiency. These studies will continue with the addition of combinatorial backgrounds.

It is hoped that such measurements will enable definitive conclusions to be drawn about the precision of the QCD prediction of the NLO terms of the cross-section. For the very high- p_T region ($p_T > 300$ GeV) the $\Delta\phi_{\mu\mu}$ technique will be used since both statistics and backgrounds are low.

4.3 Other measurements

Additional b production measurements that will be made at ATLAS include studies of quarkonium, multiple $b\bar{b}$ pair production, the polarization of b -hadrons (such as the Λ_b^0) and charge production asymmetries needed for CP violation measurements.

5 Conclusions

The ATLAS detector is well engineered for studies of b production, and together with the huge rate of b -quark production that will be seen at LHC, offers great potential for the making of novel measurements. A new technique has been developed in ATLAS for measuring $b\bar{b}$ correlations, and initial studies suggest this will yield results which will shed new light on our understanding of the QCD cross-section for $b\bar{b}$ production.

References

- [1] P. Nason, S. Dawson and R.K. Ellis, Nucl. Phys. **B303**, 607 (1988)
S. Frixione, M.L.Mangano, P. Nason and G. Ridolfi, Nucl. Phys. **B412**, 225 (1994)
- [2] M. Cacciari, M. Greco and P.Nason, JHEP05(1998) 007, hep-ph/9808467.

- [3] P. Nason *et al.*, procs. ‘*Workshop on Standard Model Physics (and more) at the LHC*’, CERN, Geneva, 25th-26th May 1999, hep-ph/0003142.
- [4] L. Apansevich *et al.*, Phys. Rev. **D59** 0(1999)74007, hep-ph/9808467.
- [5] ATLAS Technical Proposal, CERN/LHCC/94-43, December 1994.
- [6] D. Rousseau, ‘ATLAS B-Physics overview’, *Talk given at Beauty 2000, Kibbutz, Ma’agan, Israel. Sept. 2000.* Procs. ed. P. Schlein.
- [7] ATLAS Level-1 Trigger Technical Design Report, CERN/LHCC/98-14, June 1998.
- [8] ATLAS DAQ, Higher Level Triggers and DCS Technical Proposal, CERN/LHCC/2000-17, March 2000.
J. Baines, ‘The ATLAS B-Physics trigger’, *Talk given at Beauty 2000, Kibbutz, Ma’agan, Israel. Sept. 2000.* Procs. ed. P. Schlein.
- [9] ATLAS Inner Detector Technical Design Report, CERN/LHCC/97-16-17, April 1997.
S. Gadomski, ‘ATLAS Inner Detector performance’, *Talk given at Beauty 2000, Kibbutz, Ma’agan, Israel. Sept. 2000.* Procs. ed. P. Schlein.
- [10] ATLAS Muon Spectrometer Technical Design Report, CERN/LHCC/97-22, May 1997.
- [11] ATLAS Detector and Physics Performance Technical Design Report, CERN/LHCC/99-14, May 1999.
- [12] S. Robins, ‘*Measuring $b\bar{b}$ correlations in ATLAS*’, ATL-PHYS-2000-026.

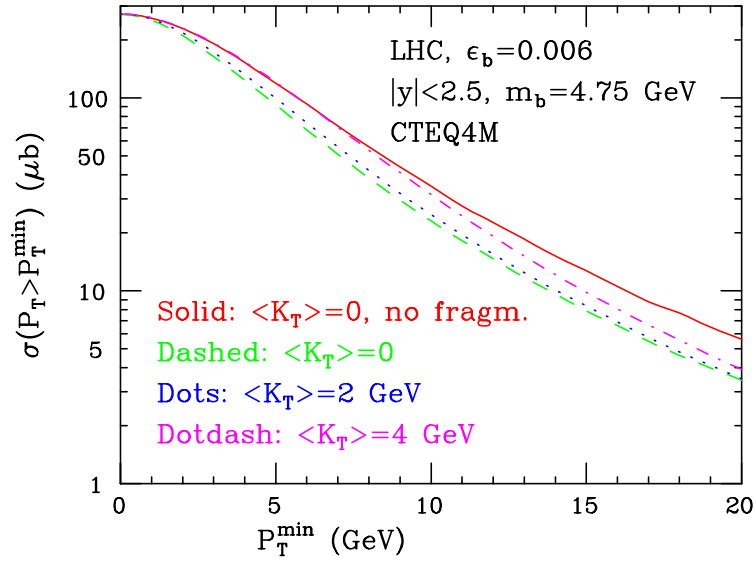


Figure 1: The predicted b cross-section at LHC, as a function of p_T , from the FMNR program. The cross-section with and without fragmentation, and with and without intrinsic parton $\langle k_T \rangle$ is shown.

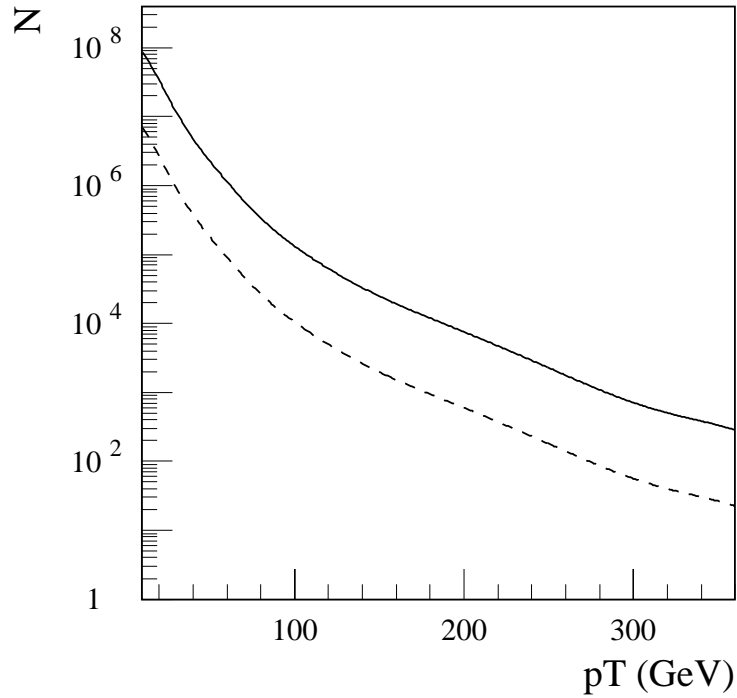


Figure 2: The yield of b-hadron events in ATLAS after three years of running at $10^{33} \text{cm}^{-2} \text{s}^{-1}$, for inclusively reconstructed (solid line) and exclusively reconstructed (dashed line) events.

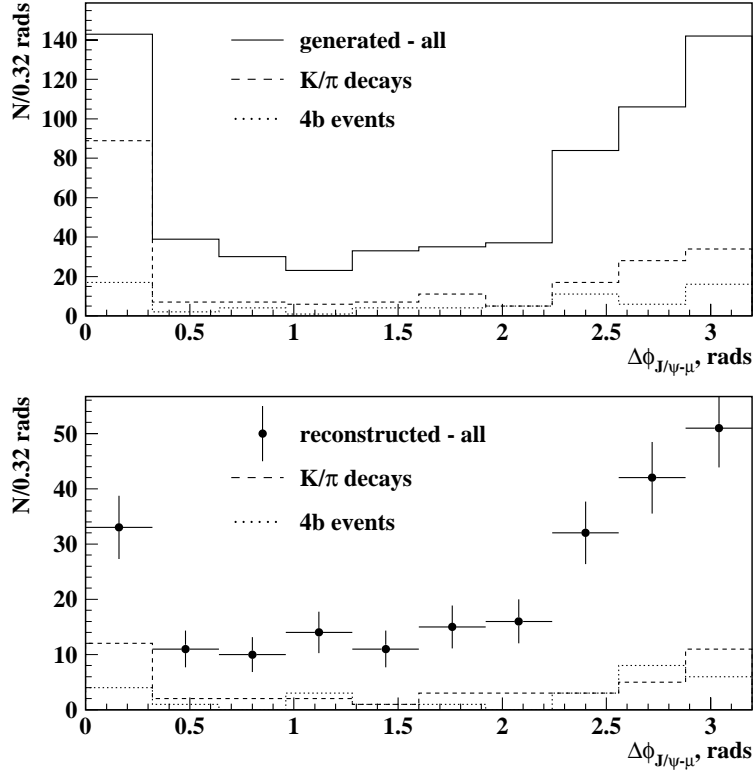


Figure 3: Measurements of $b\bar{b}$ correlations using the angle $\Delta\phi_{J/\psi-\mu}$ in $B_s^0 \rightarrow J/\psi + \phi$ events. The upper plot shows the generated distribution, and the lower the reconstructed distribution.

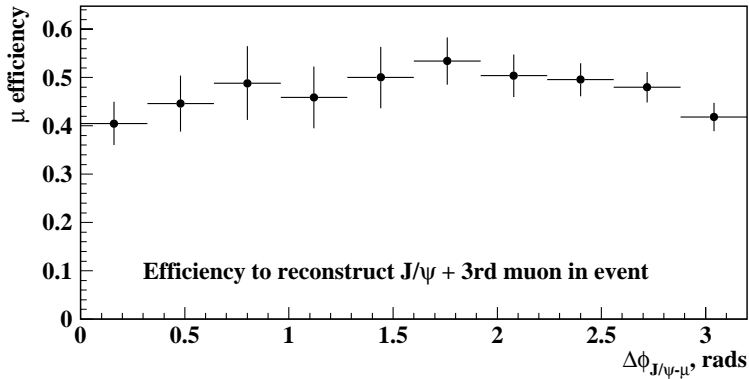


Figure 4: The efficiency for the reconstruction of events for the measurement of $\Delta\phi_{J/\psi-\mu}$, shown as a function of $\Delta\phi_{J/\psi-\mu}$. The loss of efficiency in the region of high particle density ($\Delta\phi_{J/\psi-\mu} = 0$ and π) is small relative to the mean efficiency.