Charmonia and Bottom production measurements with J/ψ at LHCb

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LHCb, a dedicated b physics experiment will commence data taking at the end of 2009. In this paper the potential of the experiment to make measurements of charmonia and bottom production using J/$\psi \to \mu^+\mu^-$ is discussed.

1 Introduction

LHCb is a dedicated b physics experiment at the LHC [2]. Since at the LHC at the production of b pairs is peaked in the forward region the LHCb detector is a single arm spectrometer covering the a polar angle of 15 - 300 mrad. This corresponds to a range in pseudorapidity, η, of 2 - 5. The experiment is installed and will start data taking at the end of 2009.

Once there are colliding beams the first aim of the experiment is to collect a sample of 10^8 minimum bias events. This sample will be used for alignment and detector calibration. The second goal will be to collect a large J/$\psi \to \mu^+\mu^-$ sample with a muon trigger. This will allow to make studies of J/ψ production with a unique coverage in η and transverse momentum with respect to the beam direction (p_t).

Measurements of J/$\psi \to \mu^+\mu^-$ production in hadron-hadron collisions have been performed at the Tevatron by CDF [3, 4]. The observed p_t spectrum and cross-section can be reproduced in Non-Relativistic QCD (NRQCD) if Colour Octet terms are taken into account [5]. However, NRQCD also predicts an increasing transverse polarization of the J/ψ as the p_t increases. This is not observed in the Tevatron data. An alternative model, Colour Evapouration, gives a reasonable description of the p_t spectrum but predicts zero quarkonium polarization. Further measurements with J/ψ and other quarkonia states are needed to discriminate between the models and clarify the situation.

2 J/ψ selection

The selection studies have been performed using the LHCb Monte Carlo simulation based on Pythia and Geant4. The Colour Octet Mechanism in Pythia has been tuned to reproduce the cross-section and p_t spectrum observed at the Tevatron [6]. A full event reconstruction is applied to the simulated events.

J/ψ candidates are formed by combining pairs of oppositely charged tracks originating from a common vertex. Cuts are made on the quality of the vertex and track fit. The latter cut reduces by 30% the dominant background which is due to decays in flight of pions and kaons. To ensure that the selection is well aligned with the L0 muon trigger, which requires a muon with a p_t above 1 GeV, one of the tracks is required to have $p_t > 1.5$ GeV. Both tracks are required to be identified as muons. One of them is required to be well identified by cutting hard on likelihood of the muon hypothesis relative to the pion [7]. With an

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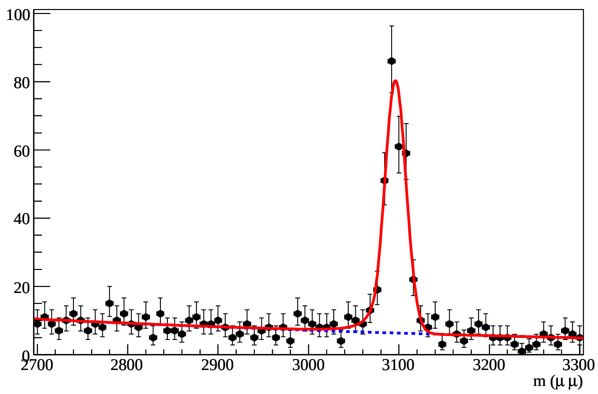

Figure 1: Invariant mass distribution for selected J/ψ candidates in a sample of 19.3 million minimum bias events. A fit with a Crystal-Ball function representing the signal and an exponential function for the background component is superimposed.

integrated luminosity of 5 pb^{-1}, 3.2×10^6 events are expected with a S/B of 4. Figure 1 shows the J/ψ signal seen in a sample of 19.3 million minimum bias events at a luminosity of 2×10^{32} cm^{-2}s^{-1}. The mass resolution is around 11 MeV.

To separate prompt J/ψ's from those from b decays the variable:

$$t = \frac{dz}{p_z^{J/\psi}} \times m^{J/\psi}$$

is used. Studies at the generator level indicate that this gives a simple approximation of

the proper time of the b quark in the forward direction. This distribution for selected J/ψ candidates is shown in Figure 2. It can be described by four components:

- A prompt component due to J/ψ produced in the primary vertex. This is modeled by a Gaussian distribution.
- A combinatorial component due to particles from the primary vertex The form of this distribution will be extracted from the J/ψ mass sidebands.
- An exponential component due to J/ψ's produced in b decays.
- A long tail component due to the association of the J/ψ to the wrong primary vertex. The form of this distribution will be extracted from data by mixing a J/ψ candidate from one event with the primary vertex from a different event.

The need to separate prompt J/ψ's from those from b decays means that the measurement of the prompt J/ψ cross-section will also lead to a determination of the b cross-section.

3 Cross-section measurement

The measurement of the prompt cross-section will be performed in bins of η and p_t. Monte Carlo will be used to correct for the detector acceptance and efficiencies for the trigger and

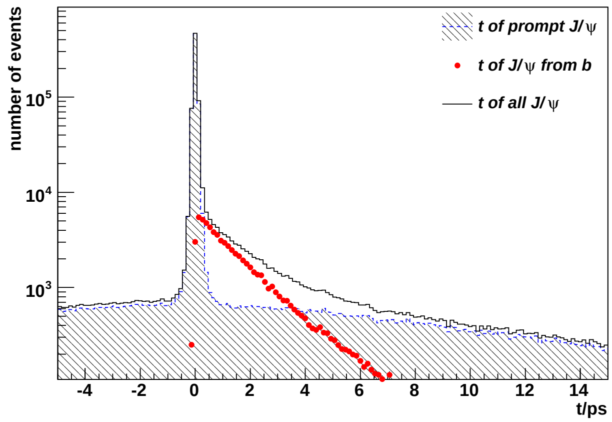

Figure 2: t distribution for selected J/ψ candidates.

offline selections. Fig 3 shows the distribution of η versus p_t for selected J/ψ candidates. The majority of the events have $p_t \sim 3$ GeV and are located within the LHCb acceptance ($2 < \eta < 5$). With an integrated luminosity of 5 pb^{-1} 380,000 events are expected in the phase space $2 < \eta < 3$ and $2 < p_t < 4$ GeV. However, the statistics at higher p_t is also significant. For example 40,000 events are expected with $2 < \eta < 3$ and $p_t > 10$ GeV.

The large statistics that will be collected mean the measurement will be dominated by systematic uncertainties. In the acceptance calculation, as well as ensuring that the simulation models the detector geometry correctly the polarization of prompt J/ψ's must be correctly taken into account. Simulation studies have shown that the acceptance of the detector leads to a fake transverse polarization. For example if a sample of fully transversely polarized J/ψ's are generated and the cross-section measurement made ignoring the polarization, the cross-section will be underestimated by 13 %. This means that as well as binning it η and p_t it will be necessary to bin in terms of the polarization angle θ where in the helicity frame θ is defined as the angle between the μ^+ and the direction of the J/ψ in the laboratory boosted into the centre of mass of the J/ψ. Hence, the measurement of the cross-section naturally leads to a measurement of the polarization.

In addition to the systematics discussed above there will an uncertainties from the knowledge of the integrated luminosity, the fit procedure and the resolution model. For the determination of the b cross-section there will be an additional 9% uncertainty due to the knowledge of the b→ J/ψ X branching ratio.

4 $\chi_{c1,c2}$ production

From measurements at the Tevatron it is known that ~ 30 % of prompt J/ψ's originate from feed down from decays of $\chi_{c1,c2}$ [8] and hence have a different polarization. To fully understand the polarization measurement the fraction of these decays must be taken into account. In addition, the ratio:

$$R(\chi_c) = \frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})}$$

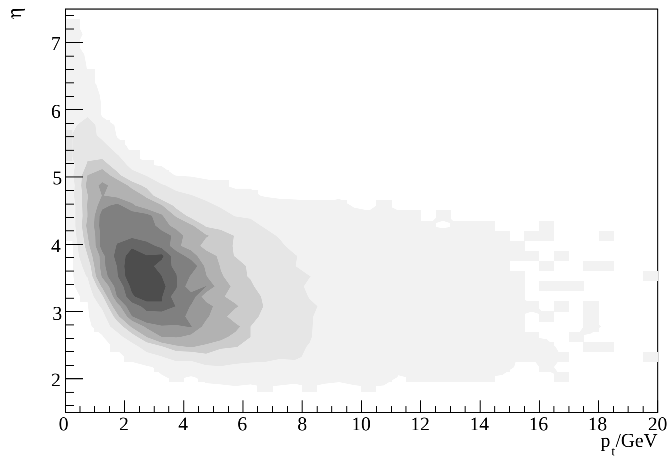

Figure 3: η versus p_t/GeV for J/ψ candidates.

provides another observable to distinguish between different production models [5]. The Colour Evaporation Model predicts that this ratio should be close to the expectation from spin-counting of $\frac{5}{3}$ whereas NRQCD predicts that this ratio should be close to one. The event generator used in the LHCb simulation gives that around ~ 20 % of the J/ψ's originate from radiative χ_{c1} decays and ~ 20 % from radiative χ_{c2} decays.

To create χ_c candidates a photon candidate with $p_t > 500$ MeV is combined with a J/ψ candidate selected with the cuts discussed in Section 2 together with the additional requirement that the candidate be within $\pm$ 40 MeV of the nominal J/ψ mass. Figure 4 shows the distribution of $\Delta M = m_{\mu\mu\gamma} - m_{\mu\mu}$ for selected candidates. A clear signal above the combinatorial background is seen. To extract the $\chi_{c1,c2}$ signal a combination of two Gaussians modeling the signal together with a background component given by

$$P(\Delta M) = \Delta M^{c0} \cdot exp(-c1 \cdot \Delta M - c2 \cdot \Delta M^2).$$

where c_0, c_1, c_2 are free parameters, is fitted to the ΔM distribution. The χ_c mass resolution is 27 MeV and is dominated by the measurement of the energy of the photon. This is to be compared to the known difference in the χ_{c2} and χ_{c1} masses of 55 MeV. Hence, discrimination between χ_{c2} and χ_{c1} decays and a measurement of R(χ_c) is possible.

5 Other Studies

In addition, to the program discussed above other measurements related to charmonia and bottomnia production are under investigation. Measurement of the cross-section for $\psi(2S)$ production together with its polarization are being investigated. The ratio $\sigma(\psi(2S))/\sigma(\mathrm{J}/\psi)$ provides a clean measurement as most systematics cancel in the ratio. The measurements made in the charmonia sector will also be repeated with the Υ resonances.

The possibility to make measurements of the exotic X,Y and Z charmonia states observed in recent years (see [9] for a recent review) is also under study. In particular it is planned

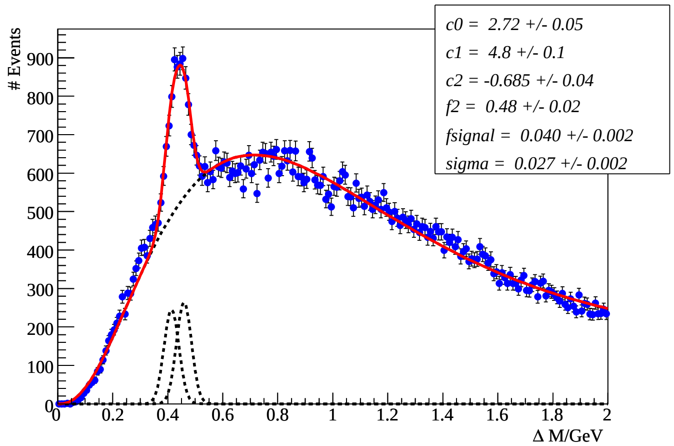

Figure 4: ΔM distribution for selected χ_c candidates. The result of a fit with the χ_c signal modeled by two Gaussians together with the background component discussed in the text is superimposed.

to measure the quantum numbers of the X(3872) to differenciate between the 1^{++} and 2^{-+} assignments. In addition, a search for the Z^+(4430) that is observed by Belle but as yet not confirmed by Babar will be made.

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