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LHCb Production: Onia, Cross Section, Correlations

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LHCb is ready to exploit first data from the LHC. In this article the potential of the experiment to make measurements of quarkonia production is presented, focusing on the study of J/ψ production.

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1. Introduction

LHCb is a dedicated b physics experiment at the LHC[1, 2]. As most $b\bar{b}$-quark pairs are expected to be produced in the forward and backward direction in high energy proton-proton collisions, LHCb is built as a forward spectrometer covering the polar angle of 15-300 mrad. This corresponds to a pseudorapidity coverage for B-mesons of $1.9 < \eta < 4.9$, which complements the central η-coverage of ATLAS and CMS of about $-2.5 < \eta < 2.5$. The installation of the LHCb detector has been finished in spring 2008 and later tuned and commissioned with cosmic and beam-induced events[3]. The detector is ready for collecting events from the first physics run of the LHC.

The primary goal of the LHCb experiment is to explore possible New Physics beyond the Standard Model through the studies of rare decays of charm and beauty-flavoured hadrons and precision measurements of CP-violating observables. At its very first running phase, a large minimum bias data sample ($\sim 10^8$ events) will be collected to complete the commissioning of the sub-detectors and of the trigger. Some physics studies, such as the production rates of K_s^0, Λ and D-mesons, are also expected to be performed based on the minimum bias data sample[4]. Once the event rate reaches the nominal LHCb logging rate, 2 kHz, carefully designed trigger conditions will be applied to collect events for physics studies. A lifetime-unbiased muon trigger, simply requiring at least one muon track with $p_T > 1\,\mathrm{GeV}/c$ at the Level-0 trigger (L0) will allow us to collect a large, clean sample of those events which have di-muon in their final states, such as $J/\psi \to \mu\mu$ or $\Upsilon \to \mu\mu$. The muon-triggered sample to be collected during the first year of physics running will already allow LHCb to realize a number of very interesting b-physics measurements.

In this article, the performance of charmonia and bottomonia-related measurements at LHCb will be presented. The article is organized as follows: after this introduction, measurements of prompt J/ψ production and the $b\bar{b}$ cross-section are discussed in Section 2. Other charmonia and bottomonia-related studies are mentioned in Section 3. The last section contains a brief conclusion.

2. J/ψ production

The large discrepancy observed between QCD calculations and experimental measurements has triggered a long standing puzzle in understanding the mechanism of quarkonia production in hadron-hadron collisions[5]. Measurements on the production of J/ψ and other quarkonia states at the LHC may shed new light on this difficult problem.

The study of J/ψ production at LHCb has been performed using fully-simulated Monte Carlo events. $J/\psi \to \mu\mu$ candidates are reconstructed by combining pairs of oppositely charged tracks originating from a common vertex. The requirements on the quality of track and vertex fit are used to reduce the dominant background due to decays in flight of pions and kaons. In addition, both tracks are required to be identified as muons, and one of the tracks is requires to have $p_T > 1.5\,\mathrm{GeV}/c$. Figure 1 shows the J/ψ signal seen in a sample of 19.3 million Monte Carlo minimum bias events, generated at a centre-of-mass energy of 14 TeV, and at a luminosity of $2 \times 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ to simulate multiple interactions. A fit with a Crystal-Ball function[6] representing the signal and a linear function representing the background gives a mass resolution of $\sim 11\ \mathrm{MeV}/c^2$ and a S/B of ~ 4. Extrapolating the results to $\sqrt{s} = 8\,\mathrm{TeV}$, which may be the initial

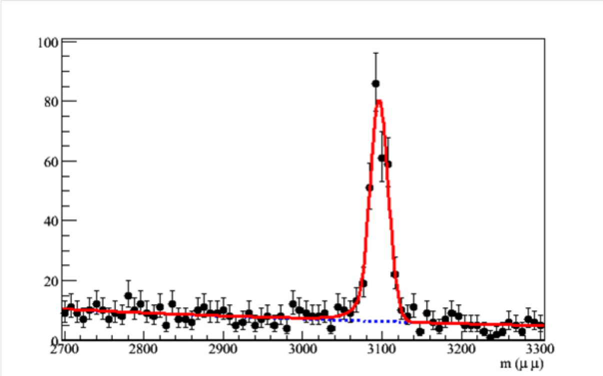

Figure 1: Invariant mass distribution for selected J/ψ candidate events.

LHC centre-of-mass energy, 3.2×10^6 signal events are expected with an integrated luminosity of 5pb^{-1}.

The lifetime information of b hadrons is used to separate prompt J/ψ from those from b decays. For this purpose, a quasi proper time variable, t, is defined as

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

Here d_z is the distance along the z-axis between the J/ψ decay vertex and the primary vertex from which it originates. $p_z^{J/\psi}$ and $m^{J/\psi}$ are respectively the momentum in the z direction and the invariant mass of the reconstructed J/ψ. The t distribution for selected J/ψ candidates is shown in Figure 2. The number of J/ψ events produced promptly, n^{prompt}, and those from b hadron decays, n^{b}, can

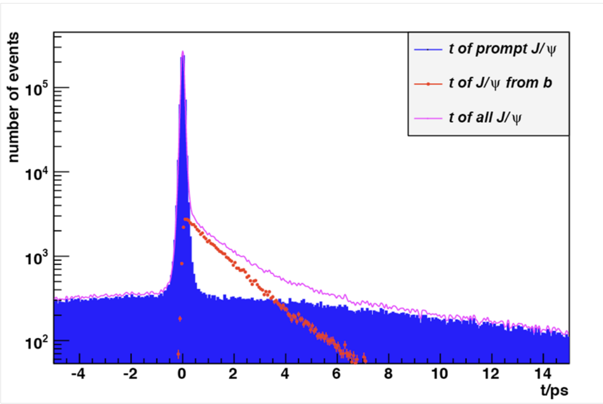

Figure 2: t distribution for selected J/ψ candidate events.

be extracted by performing a fit to the distribution. The fit function consists of four different components:

- The prompt component due to J/ψ produced at the primary vertex is modeled by a Gaussian distribution peaked at zero. The width of the distribution reflects the detector resolution on t.
- The component due to J/ψ produced in b decays can be described by an exponential function convoluted with the Gaussian distribution given above.

- Contributions from the combinatorial background can be estimated from the J/ψ mass side-bands.

- The long tail presented in the distribution, which is due to the association of the J/ψ to the wrong primary vertex, will be extracted from data by mixing a J/ψ candidate from one event with the primary vertex from a different event.

Studies show that the event numbers, $n^{\rm prompt}$ and $n^{\rm b}$ extracted from the fit can well reproduce the input values given in the Monte Carlo sample.

The goal of the analysis is to measure the prompt cross-section in bins of η and $p_{\rm T}$. Monte Carlo will be used to correct for the detector acceptance and efficiencies for the trigger and offline selections. Detailed studies have shown that the polarisation of the prompt J/ψ contributes a non-negligible effect on the selection efficiency. This means that in addition to the binning of η and $p_{\rm T}$, the decay angle θ^* has to be binned as well to take into account such an effect, where θ^* is defined as the angle between the direction of the J/ψ momentum and the direction of the μ^+ momentum measured in the rest frame of the J/ψ. Hence in the analysis, the number of prompt J/ψ, the number of J/ψ from b decays, and the polarisation are simultaneously measured at each η and $p_{\rm T}$ bin. The procedure has been validated by Monte Carlo studies. The large statistics to be collected by the LHCb detector will enable such a measurement. As an example, with an integrated luminosity of 5pb^{-1} at $\sqrt{s} = 8\,$TeV, 380,000 events are expected in the phase space of $2 < \eta < 3$ and $2 < p_{\rm T} < 4\,{\rm GeV}/c$, and about 40,000 events in $2 < \eta < 3$ and $p_{\rm T} > 10\,{\rm GeV}/c$. The statistical errors on prompt J/ψ cross-sections are expected to be well below 10% for the majority of η and $p_{\rm T}$ bins.

Several methods are proposed in LHCb to measure the integrated luminosity, one of the ingredients needed for cross-section measurements. For example, a 10% measurement is feasible by monitoring the beam-gas interactions inside the vertex detector[7]. Other systematic uncertainties induced by acceptance calculations, and by the fit procedure and the resolution modeling, are under study. For the determination of the b cross-section there is an additional 9% error from the measured branching ratio of b $\rightarrow$ J/ψX.

3. Other studies

It has been known from the measurements at the Tevatron that about 30% of prompt J/ψ's are from the decays of $\chi_{c1,2} \rightarrow$ J/$\psi\gamma$[8]. The effects of these decays on the prompt J/ψ cross-section and polarisation must be taken into account when comparing the theoretical predictions with the experimental measurements. The ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ is also an observable which can be used to test different theoretical models[9]. A χ_c candidate may be reconstructed by combining a photon with $p_{\rm T} > 0.5\,{\rm GeV}/c$ with a J/ψ candidate discussed in Section 2. The J/ψ candidate is further required to be within $\pm 40\,{\rm MeV}/c^2$ of the nominal J/ψ mass. The distribution of $\Delta M = m_{\mu\mu\gamma} - m_{\mu\mu}$ for selected candidates is shown in Figure 3. The $\chi_{c1,2}$ signal is extracted by a fit to the ΔM distribution with two Gaussians which model the signal and a function modeling the background given by

$$P(\Delta M) = (\Delta M)^{c_0} \cdot \exp\left(-c_1 \cdot \Delta M - c_2 \cdot \Delta M^2\right),$$

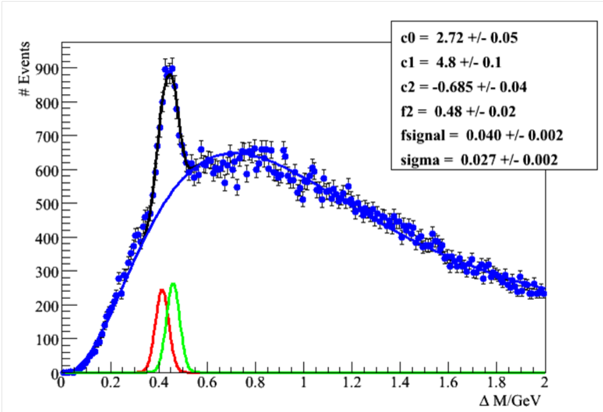

Figure 3: ΔM distribution for selected χ_c candidate events. The result of the fit (see text) is superimposed.

where c_0, c_1, c_2 are free parameters. The χ_c mass resolution is $27\,\mathrm{MeV}/c^2$, compared to the difference between the $\chi_{c1,2}$ masses of $55\,\mathrm{MeV}/c^2$, hence the discrimination between $\chi_{c1,2}$ at LHCb is possible. More studies aimed to get the best possible performance are underway.

The program discussed in Section 2 could be also applied to the measurement of the $\psi(2S)$ production cross-section and its polarisation. In addition, the ratio $\sigma(\psi(2S))/\sigma(\mathrm{J}/\psi)$ provides a clean measurement as most systematic uncertainties cancel in the ratio.

Due to the lack of a b-decay component, it is in principle easier to repeat the measurements in the charmonia sector with the Υ resonances, once enough statistics are accumulated. As an example, the invariant mass distribution of $\Upsilon \to \mu\mu$ candidates is shown in Figure 4. A very clean signal with a mass resolution of $\sim 37\,\mathrm{MeV}/c^2$ is seen.

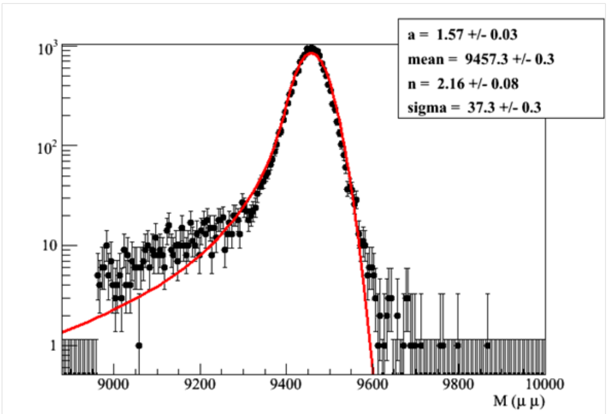

Figure 4: Invariant mass distribution for selected Υ candidate events.

Still under study are the possibilities to make measurements of the exotic X, Y and Z states. In particular, the quantum numbers of X(3872) may be determined from the studies of $\mathrm{B} \to \mathrm{X}(3872)\mathrm{K}$ by taking advantage of the LHCb RICH detectors.

4. Conclusions

The LHCb detector has been fully installed and commissioned and is ready to exploit first data from the LHC in 2009/2010. The first 5pb^{-1} of data collected with the muon trigger will allow us to extract both the prompt J/ψ and $b \to J/\psi$ cross-sections. Other quarkonia-related measurements will also be performed.

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References

[1] The LHCb Collaboration, LHCC-2003-030 (2003).

[2] The LHCb Colaboration, Journal of Instrumentation, 2008 JINST 3 S08005.

[3] M. John, these proceedings.

[4] R.-A. Muresan, these proceedings.

[5] For a recent review, see J. P. Lansberg, Int. J. Mod. Phys. A 21, 3857 (2006).

[6] J. E. Gaiser, Ph.D. Thesis, SLAC-R-225 (1982).

[7] M. Ferro-Luzzi, CERN-PH-EP-2005-023, (2005).

[8] T. Affolder et al. (The CDF Collaboration), Phys. Rev. Lett. 86, 3963 (2001).

[9] N. Brambilla et al. (The Quakonium Working Group), CERN-2005-005 (2005).