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Prospects in quarkonium studies at LHCb

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Summary. — Quarkonium production mechanism is not yet completely understood. CDF data have demonstrated that both Colour Singlet and Octet Model fail to explain the production of quarkonium prompt component. LHCb has the possibility to explore a pseudo-rapidity range complementary to the other LHC and Tevatron experiments. In this paper the quarkonium program at LHCb will be presented, together with the prospects and the possible measurements.

PACS 14.40.Pq – Heavy quarkonia.

1. – Introduction

The mechanism of quarkonium production has been the subject of many interesting studies in the recent years. CDF Run II data have demonstrated that Colour Singlet Model (CSM) [1] underestimates the J/ψ production cross section of prompt component (produced directly in the collisions or coming from the decays of heavier states) by an order of magnitude [2], while Colour Octet Model (COM) [3], derived from the NRQCD, seems to correctly reproduce the cross section as a function of transverse momentum. However COM is not able to predict the J/ψ and $\psi(2S)$ polarization [4]. In this theme LHCb [5] has the possibility to explore a unique range of pseudo-rapidity with $2 < \eta < 5$, which is complementary to the other LHC and Tevatron experiments. Moreover the large amount of J/ψ created from the very first collisions gives the possibility of verifying the calibration of the apparatus. In addition to the prompt component, charmonium has also a delayed one, coming from the decay of b hadrons, so the study of this second component leads to a better understanding of B physics. Other heavier quarkonium states will be efficiently detected by LHCb and their study is briefly discussed in sect. **2**˙3.

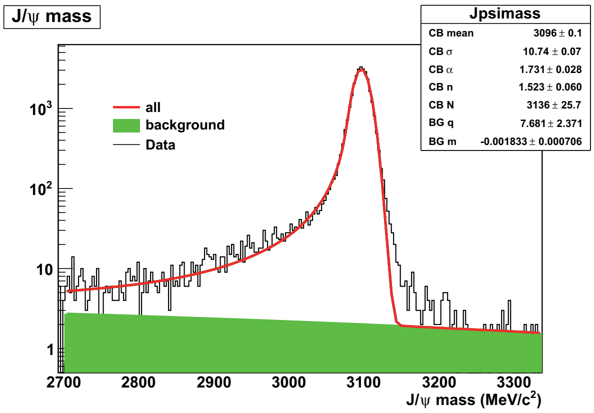

Fig. 1. – J/ψ mass distribution: the signal is fitted by a Crystal Ball function while the background is fitted by a straight line.

2. – Charmonium production at LHCb

2˙1. *J/ψ production at LHCb.* – The J/ψ production cross section expected at LHCb for $p_T < 7\,\text{GeV}$ and $3 < \eta(J/\psi) < 5$ is

$$\sigma_{prompt} \times \mathcal{B}(J/\psi \to \mu\mu) = (2597 \pm 12 \pm 24)\,\text{nb}, \tag{1a}$$

$$\sigma_{from\,b} \times \mathcal{B}(J/\psi \to \mu\mu) = (161 \pm 4 \pm 2)\,\text{nb}, \tag{1b}$$

where $\mathcal{B}(J/\psi \to \mu\mu)$ is the branching ratio of J/ψ decay in two muons, while σ_{prompt} and $\sigma_{from\,b}$ are the production cross sections, respectively, for the prompt and delayed components. At LHCb we expect about $0.65 \cdot 10^6$ in $1\,\text{pb}^{-1}$ at $\sqrt{s} = 7\,\text{TeV}$. Thanks to the large abundance of J/ψ already from the first collisions, it is possible to measure cross section and polarization in bins of transverse momentum and pseudorapidity. For the results discussed here the $J/\psi \to \mu^+\mu^-$ decay has been reconstructed from a Monte Carlo sample: the selections consists of cuts on muon tracks and primary vertex quality and on muon transverse momentum, higher than 1 GeV. In fig. 1 the J/ψ mass distribution is shown, fitted by a Crystal Ball function and a straight line. The mass resolution computed by the fit is $11\,\text{MeV}/c^2$. The pseudo proper time t_z can be used to disentangle the prompt and the delayed J/ψ components. The variable t_z is defined as

$$t_z = \frac{(z_{J/\psi} - z_{PV})m_{J/\psi}}{p_z}\,, \tag{2a}$$

where $z_{J/\psi}$ and z_{PV} are respectively the position of J/ψ decay vertex and primary vertex along the beam line, p_z is the J/ψ momentum along the beam direction and $m_{J/\psi}$ is the J/ψ mass. From the t_z distribution (fig. 2) it is possible to distinguish the prompt component (filled in green), Gaussian shaped and centred on 0 ps, and the delayed one (solid red line), with exponential shape. The tail, in yellow, corresponds to events where the decay vertex was associated to the wrong primary vertex. The decay time estimated by the fit is $\tau_b = (1.495 \pm 0.008)$ ps, in rough agreement with the decay time of a b-hadrons admixture [6].

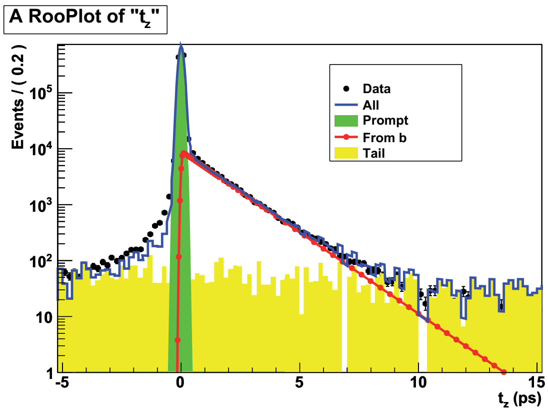

Fig. 2. – (Colour on-line) Distribution of t_z. Prompt and delayed components are, respectively, in green and red. In yellow is the tail (see text).

2˙2. *$\psi(2S)$ production at LHCb.* – The expected number of recorded $\psi(2S)$ at LHCb is about 3% of the collected J/ψ. This corresponds to $1.6 \cdot 10^4$ $\psi(2S)$ in $1\,\text{pb}^{-1}$ at 7 TeV. The decay $\psi(2S) \to \mu^+\mu^-$ is reconstructed on a Monte Carlo sample, applying the same selection applied to the J/ψ. In fig. 3 the $\psi(2S)$ mass distribution is shown: from the fit (same function as for the J/ψ) a mass resolution of about $13\,\text{MeV}/c^2$ is estimated.

2˙3. *Heavier state detection.* – Heavier quarkonium states will be detected at LHCb as well as for J/ψ and $\psi(2S)$ the production cross section and the polarization can be measured. Among charmonium states χ_c can be reconstructed from $\chi_c \to \gamma + J/\psi$: the expected statistic is about 30% of J/ψ and the estimated mass resolution is about $27\,\text{MeV}/c^2$. The three bottomonium states $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ can be reconstructed from the decay $\Upsilon \to \mu^+\mu^-$ with estimated mass resolution $37\,\text{MeV}/c^2$. The number of Υ expected are a fraction of about 10^{-3} of the J/ψ sample. Finally another extremely interesting study concerns the new exotic states, recently discovered at B-factories, in

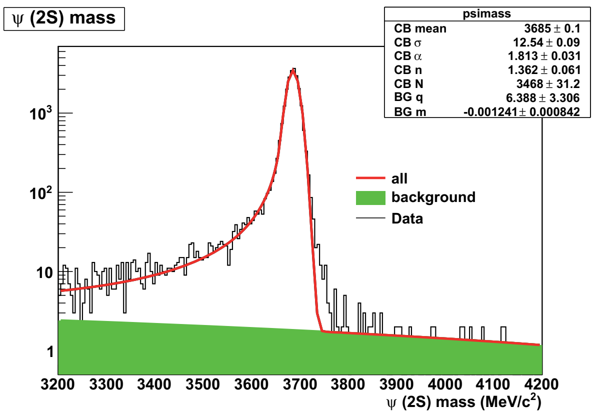

Fig. 3. – $\psi(2S)$ mass distribution, fitted by a Crystal Ball function and a straight line.

particular $X(3872)$ and $Z(4430)^{\pm}$. About 1800 decays $B^{\pm} \to X(3872)\, K^{\pm}$ and 6200 decays $B^0 \to Z(4430)^{+} (\to \psi(2S)\, \pi^{+})\, K^{-}$ are expected to be collected in $2\,\mathrm{fb}^{-1}$ of data at $\sqrt{s} = 14\,\mathrm{TeV}$. The nature of these states is still unknown but with this statistics it should be possible to disentangle $X(3872)$ J^{PC} quantum number 1^{++} from 2^{-+}.

3. – Conclusions

Quarkonium physics is still an extremely interesting sector, both for its implications in B physics and for the knowledge of prompt component production mechanism. Among the possible measurements which will be done at LHCb, there are production cross section and polarization of various charmonium states like J/ψ and $\psi(2S)$, heavier states as χ_c or bottomonium states like the Υ resonances. Besides the interest in quarkonium production sector LHCb will be able to detect some of the newest exotic states $X(3872)$ and $Z(4430)^{\pm}$, which can be revealed as decay products of B mesons. The expected statistics will give the possibility to measure some of their quantum numbers, which are still unknown.

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