Exclusive dimuon measurements with LHCb

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1 Introduction

Exclusive particle production in proton-proton collisions is an elastic process in which the protons remain intact, $p+p \to p+X+p$, and the additional particles are created through photon and/or gluon propagators. In the case of purely photon propagators, this is an electromagnetic process which can be theoretically calculated with high accuracy. When gluons are involved, these processes constitute an important testing ground for QCD, since the object that couples to the proton must be colourless. In this paper, we summarise preliminary cross-section measurements of exclusive production processes involving dimuon final states, with the 2010 data collected by the LHCb detector. More in depth details are provided in [1]. The processes we considered are the resonant Central Exclusive Production (CEP) of J/Ψ and $\Psi(2S)$ and the non-resonant diphoton production, resulting in a dimuon continuum. The addition of a photon in the final state further allows the cross-section for exclusive χ_c to be measured and the contributions coming from χ_{c0}, χ_{c1}, and χ_{c2} to be estimated.

2 Prerequisites

The LHCb detector is a single arm forward spectrometer [2]. It has two key features which makes it efficient for the study of CEP: (1) LHCb is fully instrumented in the forward region, between pseudorapidities, η, of 1.9 and 4.9 and (2) LHCb is able to trigger on low momentum μ, down to $P > 3$ GeV/c and transverse momentum $P_T > 0.4$ GeV/c. For this analysis we made particular use of the following sub-detectors. The tracking system consists of the vertex locator (VELO), 42 silicon strip detectors placed along the beamline, a Silicon Tracker and an Outer Tracker of straw tubes. The VELO surrounds the interaction region allowing for partial reconstruction of Backward tracks ($-4.0 < \eta < -1.5$) and Forward tracks down to $\eta = 1.0$. The calorimeter system includes a scintillating pad detector (SPD), providing the multiplicity in charged tracks at the first trigger level. The muon detectors consist of five stations located within 20 interaction lengths of absorbers.

Dedicated Monte Carlo generators have been used to produce exclusive signal events which are then passed through the full LHCb detector simulation. The diphoton produced dimuons have been generated using LPAIR [3]. Two generators have been used to make samples of exclusive J/Ψ and $\Psi(2S)$: StarLight [4] and SuperChic[5]. The production of χ_c by double pomeron fusion has been performed with SuperChic. In addition diffractive events were generated using POMWIG [6] and DPEMC [7].

3 Selection of exclusive events

The final state protons are only marginally deflected in CEP. They remain in the beam-pipe and so are undetected in LHCb. Consequently, the experimental signature is a dimuon only final state with possibly a single photon from a χ_c. However, because LHCb is not hermetic, there is sizable backgrounds from non-elastic processes where the companion inelastic products are outside of the detector acceptance. Much of the work involved in this analysis concerned the evaluation of this inelastic background, which was taken from the data insomuch as is possible. The experimental study was restricted to clear single elastic processes, requiring only one interaction per bunch-crossing. The corresponding effective integrated luminosity was of $\sim$3 pb^{-1}, instead of 36 pb^{-1} for the full 2010 LHCb data set.

CEP involves colourless propagators which can be signed by the lack of QCD correlated particle production. Experimentally it results in a pseudorapidity gap. By requiring that the dimuon triggered events have no Backward tracks in the VELO one indeed sees the emergence of a clear peak of events with only 2 forward tracks. Those are candidates for CEP.

The resonant J/Ψ and $\Psi(2S)$ are selected by requiring a dimuon invariant mass within 65 MeV/c^2 of the PDG value [8]. The J/Ψ suffers from feed down from $\Psi(2S) \to J/\Psi\pi^+\pi^-$ and $\chi_c \to J/\Psi\gamma$ with companion products of the J/Ψ outside of the detector acceptance. These feed downs were estimated from simulation and normalised to the observed number of $\Psi(2S)$ and χ_c in the data. Since inelastic events tend to have an average P_T higher than elastic ones, the respective fractions of elastic and inelastic exclusive J/Ψ were estimated from a fit of the P_T spectrum. The shape of the signal was taken from simulation and the shape of the background from the data sidebands, considering events with more than 2 forward tracks. It was cross-checked that the latter background shape little depends on the number of additional forward tracks in the event. For the $\Psi(2S)$ we assumed the same contamination in inelastic events than for the J/Ψ. In addition, in both cases the selection of elastic events was purified by requiring a dimuon $P_T < 0.9$ GeV/c, resulting in a $\sim$70% purity.

χ_c candidates were selected from exclusive J/Ψ with a single additional γ. Feed down from $\Psi(2S)$ decaying to $\chi_c\gamma$, $J/\Psi\eta$ and $J/\Psi\pi^0\pi^0$ was estimated from simulation, normalised to the number of $\Psi(2S)$ in the data. The fraction of inelastic events is larger than previously with. The purity is of $\sim$40%, estimated from a fit of the P_T spectrum of the J/Ψ as for the CEP J/Ψ. Finally the three χ_c resonances are disentangled by a fit of the invariant mass spectrum with shapes taken according to the simulation.

Dimuons from exclusive diphoton are selected in the continuum by vetoing on the dimuon invariant mass of resonances. Furthermore, in order to nullify the background from miss-identified pions and kaons decaying in flight, a dimuon invariant mass greater than 2.5 GeV/c^2 was required. The fraction of inelastic events was determined from the P_T spectrum as for the J/Ψ. In this case a theoretical prediction for the background is provided by LPAIR and POMWIG. Good agreement was found with the background shape estimated from the data, which provides an overall cross-check of the background extraction procedure from the data. Further requiring $P_T < 100$ MeV/c we have an almost 100% pure selection.

4 Cross-section determination

The cross-section σ, was calculated from the number, N, of selected events having corrected for the total efficiency, ϵ, and purity, p, and dividing by the effective luminosity, L, via $\sigma = (pN)/(\epsilon L)$. The preliminary results are compiled in Table 1 together with their detailed error budget. The total efficiency varies from 71% for Ψ's down to 25% for diphotons. It was taken from the simulation with systematics based on Monte-Carlo to data comparisons. It includes triggering, track reconstruction, muons and photon identification as well as selection efficiencies. Note that the acceptance is not included in the efficiency, hence the numbers we quote are cross-section times the branching ratio into the final state of interest, with all final state particles between pseudorapidities of 2 and 4.5. The effective luminosity determination in this analysis currently has a large uncertainty. The uncertainty on the luminosity for this analysis was estimated as 10% with and additional uncertainty of 10% on the calculation of the number of interactions per crossing, μ, resulting in a total uncertainty of 20%.

5 Conclusion

LHCb has observed the first clear signals for exclusive J/Ψ, $\Psi(2S)$ and χ_c mesons in p-p collisions. The preliminary measured cross-section are consistent with previous results [9, 10, 11] and theoretical estimates considering uncertainties. In addition, we were able to separate the individual χ_c components and found out that the χ_{c0}, χ_{c1} and χ_{c2} resonances appear to be produced roughly equally.

In the future it is foreseen to measure the diphoton cross section down to a dimuon invariant mass of 1 GeV/c^2. This channel is actually a candidate for high precision luminosity measurements at the LHC, due to both the accurate theoretical prediction and clean experimental measurement.

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	Efficiency	# Events	Purity	L_{eff} (pb^{-1})	$\sigma(\eta \in [2; 4.5]) \times BR$ (pb)
J/Ψ	0.71 ± 0.07	1468 ± 38	0.71 ± 0.03	3.1 ± 0.6	$474 \pm 12 \pm 51 \pm 92$
$\Psi(2S)$	0.71 ± 0.07	40 ± 6	0.67 ± 0.03	3.1 ± 0.6	$12.2 \pm 1.8 \pm 1.3 \pm 2.4$
χ_{c0}	0.34 ± 0.06	25 ± 6	0.39 ± 0.13	3.1 ± 0.6	$9.3 \pm 2.2 \pm 3.5 \pm 1.8$
χ_{c1}	0.43 ± 0.05	56 ± 18	0.39 ± 0.13	3.1 ± 0.6	$16.4 \pm 5.3 \pm 5.8 \pm 3.2$
χ_{c2}	0.44 ± 0.04	99 ± 29	0.39 ± 0.13	3.1 ± 0.6	$28.0 \pm 5.4 \pm 9.7 \pm 5.4$
di-γ	0.25 ± 0.03	40 ± 6	0.97 ± 0.01	2.3 ± 0.5	$67 \pm 10 \pm 7 \pm 15$

Table 1: Summary of numbers in preliminary cross-section calculation. The sources of uncertainty quoted for $\sigma \times BR$ are statistical, systematic and luminosity.