Central exclusive $J/\psi$ and $\chi_c$ production at LHCb

Scott Stevenson, on behalf of the LHCb collaboration

Department of Physics, University of Oxford, Oxford, United Kingdom

Central exclusive $J/\psi$ and $\chi_c$ meson production has been measured in decays to dimuons with the LHCb detector, in data corresponding to 36 pb$^{-1}$ of integrated luminosity from $\sqrt{s} = 7$ TeV proton-proton collisions. Cross-section measurements for $J/\psi$, $\psi(2S)$ and $\chi_{c0,1,2}$ production are presented, and the $J/\psi$ photoproduction cross-section is measured as a function of the photon-proton centre-of-mass energy and compared to measurements made at HERA.

1 Introduction

Central exclusive production in proton-proton collisions is a process in which the initial state protons scatter elastically via colour singlet exchange. The protons remain intact and escape undetected down the beampipe. Additional particles are produced in the central region, accompanied by rapidity gaps. This provides a clean experimental environment for measurements of the quantum numbers of the produced state, and those processes involving pomeron exchange provide a testing ground for the predictions of QCD. Dimuon production via charmonium resonances has a high predicted cross-section and a clear experimental signature and can be used to test the theoretical predictions \[7\]. These proceedings present measurements of the cross-section times branching fractions for exclusive $J/\psi$ and $\chi_c$ mesons to produce two muons in the pseudorapidity range $2 < \eta < 5$ at a proton-proton centre-of-mass energy of $\sqrt{s} = 7$ TeV. The measurements are compared to results from HERA and a number of theoretical models.

2 The LHCb detector

The LHCb detector \[3\] is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$. The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector surrounding the interaction region, a large-area silicon-strip detector located upstream of a dipole magnet, and three stations of silicon-strip detectors and straw drift tubes placed downstream. The vertex detector allows reconstruction of backward tracks in the range $-4 < \eta < -1.5$. Different types of charged hadrons are distinguished by information from two ring-imaging Cherenkov detectors.

Photon, electron and hadron candidates are identified by a calorimeter system consisting of scintillating pad (SPD) and preshower detectors, an electromagnetic calorimeter and a hadronic calorimeter. The scintillating pad detector provides a measure of charged particle multiplicity. Muons are identified by a system composed of alternating layers of iron and multiwire proportional chambers.

The trigger consists of a hardware stage, based on information from the calorimeter and muon systems, followed by a software stage, which applies a full event reconstruction.
The unique forward acceptance of the LHCb detector, in addition to the low pileup encountered and its sensitivity to low momentum particles, make it well suited to central exclusive production studies.

3 Event selection

J/ψ and χc mesons are reconstructed from their decays to dimuons [1, 9]. The analyses are based on data corresponding to an integrated luminosity of 36 pb$^{-1}$ collected at $\sqrt{s} = 7$ TeV in 2010. The hardware trigger requires a single muon with transverse momentum $p_{\perp} > 400$ MeV/$c$, or a dimuon, each track with $p_{\perp} > 80$ MeV/$c$, and less than 20 hits in the SPD. The software trigger requires a dimuon mass greater than 2.9 GeV/$c^2$, or greater than 1 GeV/$c^2$ with $p_{\perp} < 900$ MeV/$c$ and a distance of closest approach of the tracks less than 150 µm. In the offline selection the tracks are required to lie within $2.0 < \eta < 4.5$ and the dimuon mass to be within 65 MeV/$c^2$ of the J/ψ or ψ(2S) masses [4]. It is required there be no photons or other tracks (including backwards tracks) in the detector, but for a single photon with $E_{\perp} > 200$ MeV in the χc selection.

4 Exclusive purity determination

Three backgrounds are considered: non-resonant production via diphoton fusion, exclusive ψ(2S) and χc feed-down to the J/ψ sample, and inelastic production with additional gluon radiation or proton dissociation.

The non-resonant contribution is estimated by fitting the dimuon invariant mass distribution, shown in Figure 1. The resonances are modelled with a crystal ball function and the continuum with an exponential. The non-resonant contribution is estimated as $(0.8 \pm 0.1)\%$ and $(16 \pm 3)\%$ of events within 65 MeV/$c^2$ of the J/ψ mass and ψ(2S) mass, respectively.

Exclusive χc production can feed down to the J/ψ sample via $\chi_c \rightarrow J/\psi \gamma$ where the photon is undetected. Events in data containing a J/ψ and photon are identified as feed-down candidates and their contribution estimated by scaling the χc yield in data by the ratio of fake exclusive J/ψ to exclusive χc in simulation. The contribution is estimated as $(9.0 \pm 0.8)\%$.

Exclusive ψ(2S) production can feed-down to the J/ψ sample via decays of the type $\psi(2S) \rightarrow J/\psi X$ where additional particles X are undetected. The contribution is estimated from a...
simulated $\psi(2S)$ sample normalised to the $\psi(2S) \rightarrow \mu\mu$ yield in data, and determined to be $(1.8 \pm 0.3)$%.

The inelastic contribution is extracted from a fit to the dimuon $p_{\perp}$ spectrum. A Novosibirsk function fitted to events with three to eight tracks is extrapolated to events with exactly two tracks for the background shape. The signal shape is taken from simulation. The contribution for events with a dimuon $p_{\perp} < 900$ MeV/c is estimated as $(30 \pm 4 \pm 6)$% for $J/\psi$ and $\psi(2S)$, and $(61 \pm 13)$% for $\chi_c$.

The dominant systematic uncertainties are on the signal and background shapes in the dimuon $p_{\perp}$ fit, the muon identification efficiency, and the trigger efficiency.

5 Results

The number of exclusive candidates passing the selection are 1492 $J/\psi$, 40 $\psi(2S)$, and 194 $\chi_c$, and the overall exclusive purity for $p_{\perp} < 900$ MeV/c is estimated as $(62 \pm 4 \pm 5)$% for the $J/\psi$, $(59 \pm 4 \pm 5)$% for the $\psi(2S)$, and $(39 \pm 13)$% for the $\chi_c$.

The cross-section times branching fractions for central exclusive $J/\psi$, $\psi(2S)$ and $\chi_c$ decaying to two muons with pseudorapidities between 2.0 and 4.5 are measured as

$$
\sigma_{J/\psi \rightarrow \mu\mu} \left( 2.0 < \eta_{\mu\mu} < 4.5 \right) = 307 \pm 21 \pm 36 \text{ pb},
$$
$$
\sigma_{\psi(2S) \rightarrow \mu\mu} \left( 2.0 < \eta_{\mu\mu} < 4.5 \right) = 7.8 \pm 1.3 \pm 1.0 \text{ pb},
$$
$$
\sigma_{\chi_{c0} \rightarrow J/\psi \gamma \rightarrow \mu\mu\gamma} \left( 2.0 < \eta_{\mu\mu,\gamma} < 4.5 \right) = 9.3 \pm 2.2 \pm 3.5 \pm 1.8 \text{ pb},
$$
$$
\sigma_{\chi_{c1} \rightarrow J/\psi \gamma \rightarrow \mu\mu\gamma} \left( 2.0 < \eta_{\mu\mu,\gamma} < 4.5 \right) = 16.4 \pm 5.3 \pm 5.8 \pm 3.2 \text{ pb},
$$
$$
\sigma_{\chi_{c2} \rightarrow J/\psi \gamma \rightarrow \mu\mu\gamma} \left( 2.0 < \eta_{\mu\mu,\gamma} < 4.5 \right) = 28.0 \pm 5.4 \pm 9.7 \pm 5.4 \text{ pb},
$$

where the first uncertainty is statistical and the second systematic. The measured $J/\psi$ cross-section is consistent with theoretical predictions from Gonçalves and Machado, Motyka and Watt, SuperCHIC and STARlight [6, 10, 7, 8].

For comparison with HERA results, the differential $J/\psi$ photoproduction cross-section is measured in ten bins of $J/\psi$ rapidity and reweighted by the photon flux. There are two solutions in each rapidity bin, due to the ambiguity over which proton emitted the photon. The two solutions are plotted in Figure 2. With the limited precision of the measurement, the LHCb results are consistent with HERA and confirm a similar power law behaviour for the photoproduction cross-section [2, 3].

6 Conclusion

The cross-sections for central exclusive $J/\psi$ and $\chi_c$ production have been measured in decays to dimuons with the LHCb detector, and the measurements found to be consistent with a number of theoretical predictions. Additionally, the exclusive $J/\psi$ photoproduction cross-section has been measured as a function of the photon-proton centre-of-mass energy. A power law fit shows consistency with HERA results.
Figure 2: The $J/\psi$ photoproduction cross-section as a function of the photon-proton centre-of-mass energy. The red and blue points are HERA data, and the black points LHCb data. The dashed and solid lines are power law fits to the HERA and LHCb data respectively.

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