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# Central exclusive production at LHCb

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**Abstract.** LHCb has made several measurements of CEP in $pp$ collisions at $\sqrt{s}$ of 7 and 8 TeV. A new sub-detector consisting of five planes of scintillators was installed in 2015 and extends the pseudorapidity region in which particles can be detected. With the aid of this, measurements of $J/\psi$ and $\psi(2S)$ meson production have been made in $pp$ collisions at $\sqrt{s}$ = 13 TeV, leading to an improved experimental precision. A measurement of $J/\psi$ production in lead-lead collisions at $\sqrt{s_{NN}}$ = 5 TeV is also presented.

## 1 Introduction

Central Exclusive Production (CEP) is a diffractive process involving the exchange of colourless objects, where the colliding hadrons remain intact. It is an excellent laboratory in which to study the physics of the vacuum, investigate QCD, measure proton and nuclear PDFs, and search for exotic phenomena such as saturation, odderon production and glueballs.

Experimentally, the CEP process results in a handful of particles with low transverse momenta ($p_T$) that are typically less than 1 GeV. LHCb is an excellent detector for the investigation of CEP, as it is fully instrumented between pseudorapidities ($\eta$) of 2 and 5, operates in low pile-up conditions and has special low-multiplicity and low $p_T$ triggers, being able to trigger on electrons, photons, muons and hadrons above 400 MeV and on short-lived mesons that are reconstructed from their decay products in real-time. The detection of the exclusivity of CEP relies on an effective veto of additional activity. This is aided by the low number of visible interactions per beam-crossing at LHCb, which is typically 1.1 in proton-proton collisions, and much smaller in proton-lead and lead-lead collisions. LHCb has published several measurements of single or pairs of $J/\psi$, $\psi(2S)$ and $\Upsilon$ mesons in $pp$ collisions at centre of mass energies, $\sqrt{s}$, of 7 and 8 TeV [1–3].

In 2015, a new sub-detector, HeRSCheL [4], consisting of five planes of scintillators was installed on both sides of LHCb in the LHC tunnel in order to veto backgrounds where the proton dissociates. Three planes are upstream of the interaction point at 114, 19.7 and 7.5 m and two are downstream at 20 and 114 m: this extends the veto region to $5 < |\eta| < 10$. HeRSCheL's response to three classes of events is shown in Fig. 1: events enriched in CEP show lower activity in HeRSCheL than non-CEP candidates. In this report I concentrate on the physics improvements that HeRSCheL brings and present new measurements of $J/\psi$ and $\psi(2S)$ CEP in $pp$ collisions at $\sqrt{s}$ = 13 TeV [5] and a preliminary measurement of $J/\psi$ CEP in lead-lead collisions at a centre of mass energy per nucleon, $\sqrt{s_{NN}}$, of 5 TeV [6].

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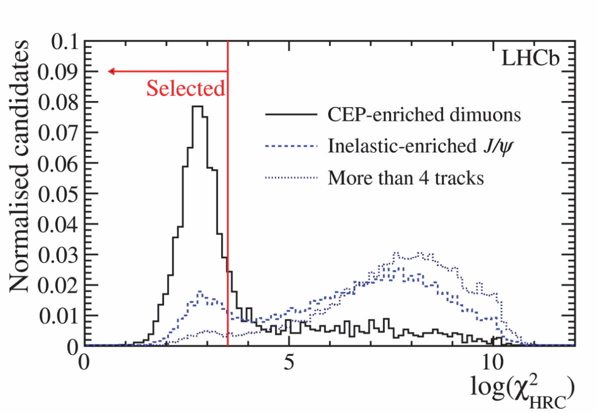


**Figure 1.** Distributions of the discriminating variable $\chi^2_{HRC}$ that is related to activity in HeRSCheL for three classes of events. CEP-enriched dimuons are selected from events with two identified muons whose vector sum has $p_T^2 < 0.01$ GeV$^2$, which are estimated to have a purity of 97% for electromagnetic dimuon CEP. Inelastic-enriched $J/\psi$ have two muons consistent with the $J/\psi$ mass but with $p_T^2 > 1$ GeV$^2$.

## 2 CEP $J/\psi$ and $\psi(2S)$ in $pp$ collisions at $\sqrt{s}$ =13 TeV

A data set corresponding to an integrated luminosity of $204 \pm 8$ pb$^{-1}$ collected by LHCb with the HeRSCheL detector active is analysed. Candidates for $J/\psi$ and $\psi(2S)$ mesons in CEP are selected by requiring two reconstructed muons with an invariant mass consistent with the known meson mass and $p_T^2 < 0.8$ GeV$^2$. Events with additional charged or neutral activity are vetoed. The HeRSChel activity is characterised by a variable $\chi^2_{HRC}$, which is shown in Fig. 1 for different classes of events. For this analysis, it is required that the activity is below the indicated threshold. All selection efficiencies are found from data using calibration samples.

Three background sources are considered: firstly, non-resonant dimuon production, which is measured by extrapolating the invariant mass distribution under the resonant peaks; secondly, feed-down from other charmonia, which is estimated by inverting the veto on neutral activity and reconstructing $\chi_{cJ}(1P)$ candidates; thirdly, inelastic events where the proton dissociates, which is found by inverting the HeRSCheL requirement and analysing the $p_T^2$ spectrum. Backgrounds are roughly halved compared to the analysis performed at 7 TeV without HeRSCheL. In addition, remaining backgrounds are estimated more precisely, leading to a significant reduction in the systematic uncertainties, the largest of which (1.7%) is due to the precision with which the HeRSCheL veto efficiency is determined.

The differential cross-sections measured are shown in Fig. 2 and compared to theoretical predictions [**?** ]. Agreement is found with the NLO predictions. The products of the cross-section times branching fractions for the decays to dimuons, where both muons are in the pseudorapidity range $2.0 < \eta < 4.5$, are measured to be

$$\sigma_{J/\psi\to\mu^+\mu^-} = 435 \pm 18 \pm 11 \pm 17 \text{ pb}$$
$$\sigma_{\psi(2S)\to\mu^+\mu^-} = 11.1 \pm 1.1 \pm 0.3 \pm 0.4 \text{ pb},$$

where the first uncertainties are statistical, the second are systematic, and the third are due to the luminosity determination. As a consequence of the addition of HeRSCheL to the $J/\psi$ analysis, the systematic uncertainty is reduced from 5.6% at $\sqrt{s}$ = 7 TeV to 2.7% at $\sqrt{s}$ = 13 TeV.

## 3 CEP $J/\psi$ in PbPb collisions at $\sqrt{s_{NN}}$ =5 TeV

CEP of $J/\psi$ mesons has also been measured in ultraperipheral PbPb collisions by LHCb in a data sample corresponding to an integrated luminosity of $10.1 \pm 1.3$ $\mu$b$^{-1}$. Candidates are

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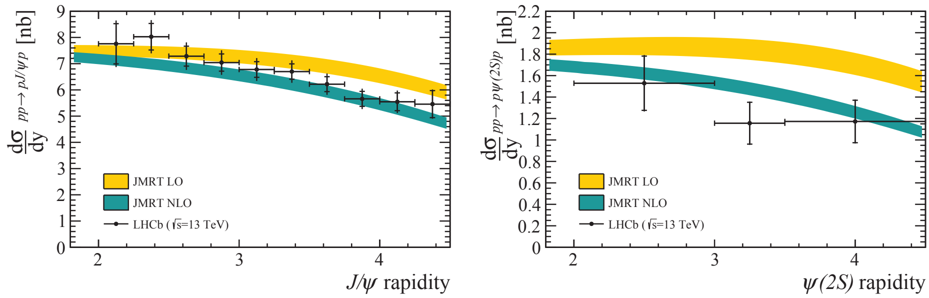


**Figure 2.** Differential cross-sections as a function of meson rapidity for $J/\psi$ (left) and $\psi(2S)$ (right) CEP, compared to JMRT predictions [7, 8].

selected in a similar way to the analysis in $pp$ collisions, requiring two muons with an invariant mass consistent with that of the $J/\psi$ meson and no other activity. The distribution for $p_T^2$ is shown in Fig. 3 compared to the expectations of the STARlight generator [9]. Events where the photon propagator interacts coherently with the nucleus have lower $p_T^2$ than those that interact incoherently. If little activity is required in the HeRSCheL detector, it can be seen that the incoherent peak is suppressed, as these events are less ultra-peripheral and thus more likely to cause nuclear breakup resulting in increased activity in HeRSCheL. The measured differential cross-section is shown in Fig. 4 compared to various theoretical models for the nucleus that include saturation effects [10–13]. With a higher event yield, a better discrimination between models will be possible.

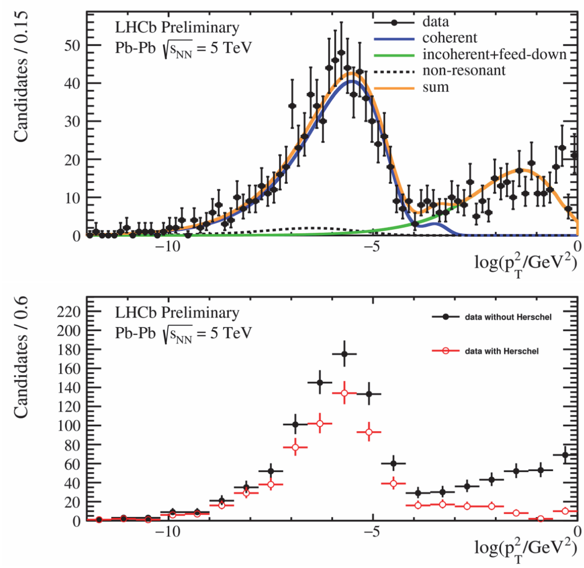


**Figure 3.** Upper plot: Distribution of $p_T^2$ for CEP $J/\psi$ candidates compared to predictions from the STARlight generator. Lower plot: Data shown without and with the requirement that there be little activity in HeRSCheL.

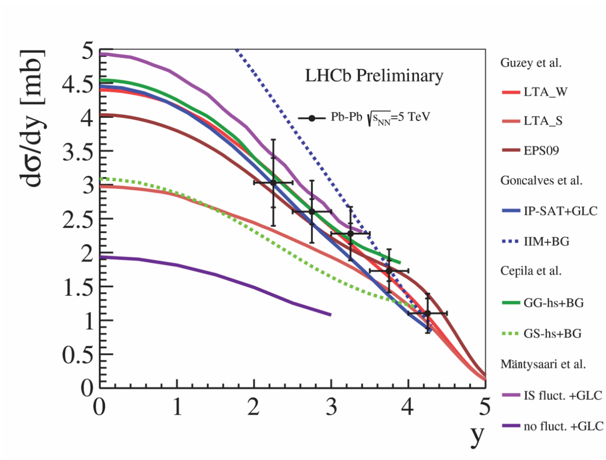


**Figure 4.** Differential cross-section as a function of $J/\psi$ rapidity compared to various theoretical models.

## 4 Conclusions

Several CEP $pp$ measurements at 7, 8 and now 13 TeV have been performed by LHCb using muons. The new HeRSCheL detector extends the detection of rapidity gaps and reduces the experimental uncertainty. Preliminary measurements have been shown for CEP in lead-lead collisions. Work is ongoing for measurements in proton-lead collisions and in hadronic modes.

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