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Central Exclusive Production at LHCb

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The installation of a new sub-detector has improved the ability of LHCb to measure central exclusive production in Run 2 at the LHC. A measurement of central exclusive J/ψ production is presented and improvements for the analysis of hadronic final states are discussed.

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1 Introduction

Central Exclusive Production (CEP) in hadron collisions occurs when colourless propagators are exchanged between the hadrons creating a central system, with the colliding hadrons remaining intact after the interaction. This leads to the unique experimental signature of a small number of particles in the central system with rapidity gaps extending to the projectiles. LHCb has performed measurements of the exclusive differential cross-sections as a function of rapidity of J/ψ , $\psi(2S)$ and Υ mesons [1, 2] in pp collisions at \sqrt{s} of 7 and 8 TeV. These vector mesons are created through photon-Pomeron fusion and the measurements probe the gluon PDF down to fractional parton momenta of 2×10^{-6} [3, 4], being potentially sensitive to saturation effects [5] or the existence of odderons [6], colourless three-gluon states. LHCb has also measured double charmonia production [7] in Pomeron-Pomeron fusion. This shows the complementarity of measurements through CEP and conventional QCD production [8], and demonstrates that CEP has potential to search for tetraquarks and exotic or hybrid mesons. In particular, double Pomeron exchange, being rich in gluons, is a good laboratory in which to search for glueball states.

In these proceedings, I discuss improvements made by LHCb in the collection and understanding of CEP events during Run 2, present a recent measurement of charmonia production in pp collisions at $\sqrt{s} = 13$ TeV, and outline the future potential of CEP measurements.

2 Central Exclusive Production at Run 2

Experience of CEP analyses in Run 1 at the LHC showed it was relatively easy to select events in the LHCb detector that had no other activity apart from the particles making up the central system. However, it was more difficult to determine whether these were truly exclusive, or whether the protons dissociated with the remnants travelling outside the acceptance of the LHCb detector. Discrimination was provided by considering the transverse momentum, p_T , of the central system. The distribution of events as a function of the Mandelstam variable, $t \approx p_T^2$ was assumed to follow a distribution $\exp(bt)$ where the slope b is greater for signal than for background: thus a fit to data can extract the relative proportion of exclusive events.

During Run 1, the LHCb detector was fully instrumented in the pseudorapidity region $2 < \eta < 5$, and could register the presence of charged tracks in the region $-3.5 < \eta < -1.5$. In order to extend the region where particle activity could be recorded, a new sub-detector, HeRSChL [9], consisting of five planes of scintillators was installed on both sides of LHCb in the LHC tunnel, during the LHC shutdown following Run 1. It adds a veto region of $5 < |\eta| < 10$ to the acceptance of LHCb for Run 2.

Each station of HeRScheL consists of four scintillators, 30 cm square, arranged symmetrically around the beam-pipe and read out by photomultiplier tubes. The digitised signals undergo a calibration procedure and the summed signal, Σ_H , is used as a discriminant. The response of HeRScheL to three classes of events is shown in Fig. 1. The first class is enriched in CEP events, which have been selected from dimuon candidates having $p_T^2 < 0.01 \text{ GeV}^2$ and masses greater than 1.5 GeV, but outside the charmonium or bottomonium regions. The second class consists of J/ψ candidates having $p_T^2 > 1 \text{ GeV}^2$ and are thus likely to be non-exclusive. The third class has events triggered by a low-multiplicity muon trigger but with 5 or more charged tracks. The activity observed in HeRScheL for exclusive events is lower than, and shows a clear distinction from, the activity in inclusive events. Therefore, requiring low activity in HeRScheL increases the fraction of exclusive events.

Events with low multiplicity were selected with a two-stage trigger. The first stage, L0, was a hardware trigger and required low multiplicity in the scintillating pad detector in conjunction with deposits in the muon chambers, electromagnetic or hadron calorimeters. The second stage was implemented in software. Improvements to the trigger in Run 2 included a lowering of the thresholds so that mesons produced with $p_T = 0 \text{ GeV}$ could be selected by the muon, electromagnetic and hadronic triggers if the mass of the meson was above 700, 300 and 400 MeV, respectively.

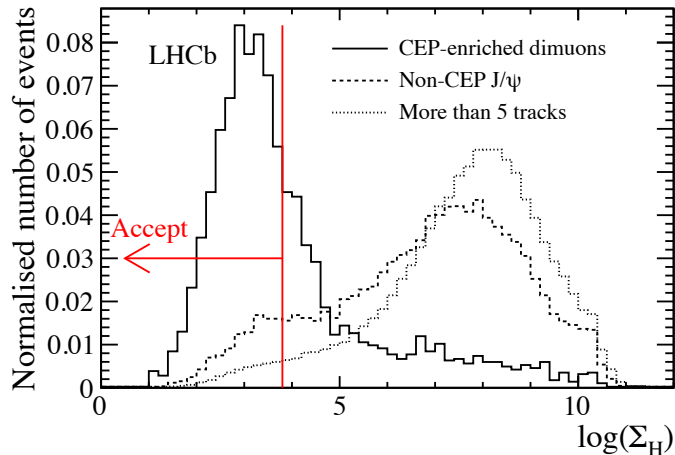


Figure 1: Summed energy in the HeRScheL detector for three classes of dimuon events: candidates for CEP from the QED continuum with $p_T^2 < 0.01 \text{ GeV}^2$; J/ψ non-exclusive candidates with $p_T^2 > 1 \text{ GeV}^2$; and low multiplicity events with five or more reconstructed tracks. The vertical line indicates the region used in the measurement of the J/ψ and $\psi(2S)$ cross-sections at $\sqrt{s} = 13 \text{ TeV}$.

3 Exclusive production of J/ψ and $\psi(2S)$ mesons

The selection of exclusive charmonia produced at $\sqrt{s} = 13$ TeV [10] and decaying to two muons was similar to the analysis published at 7 TeV [1], but with the addition of requiring little activity in the newly installed HeRSChel sub-detector, as indicated by the vertical line in Fig. 1. Precisely two muons were required in the event with no additional charged or neutral particles reconstructed. The invariant mass of the two muons is shown in Fig. 2 and candidates for J/ψ and $\psi(2S)$ were required to be within 65 MeV of their known masses. Contamination in the J/ψ sample due to feed-down from $\chi_c \rightarrow J\psi\gamma$ where the photon escapes detection was estimated by scaling, using simulation, the number of reconstructed χ_c events where the photon was observed. A fit to the p_T^2 distribution is sensitive to the relative amount of exclusive and non-exclusive events and is shown in Fig. 3 before and after the HeRSChel requirement. The new sub-detector roughly halves both the feed-down and proton-dissociation components, reducing the systematic uncertainties associated with knowledge of the backgrounds.

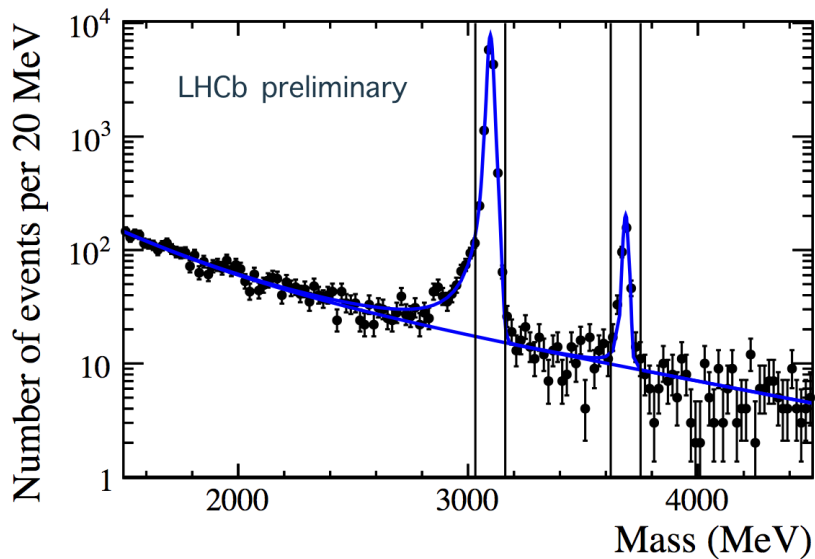


Figure 2: Invariant mass of exclusive dimuon candidates. The lines are fits to the data. The windows indicate the regions chosen for the J/ψ and $\psi(2S)$ analyses.

The efficiency for the selection was calculated using data. The efficiency for triggering, tracking and the muon selection used a tag-and-probe technique where one of the two muons was ‘tagged’ and the efficiency for the other was measured. The efficiency for the requirement on activity in HeRSChel was found from the QED-produced dimuon sample shown in Fig. 1. The purity was obtained from the fit shown in Fig. 3. The cross-section was obtained from the number of events produced

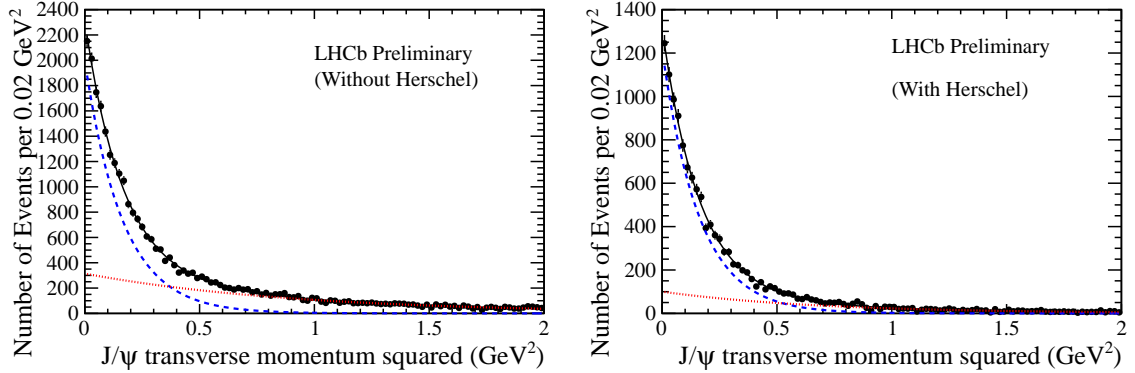


Figure 3: Transverse momentum squared of J/ψ candidates without (left) and with (right) the requirement that there be little activity in HeRSChEL. The solid line represents the total fit. The dashed line is the estimated exclusive component while the dotted line is the proton dissociation.

in the estimated integrated luminosity of $204 \pm 8 \text{ pb}^{-1}$. The differential cross-section as a function of rapidity for both J/ψ and $\psi(2S)$ are shown in Fig. 4 compared to approximate NLO theoretical calculations [11].

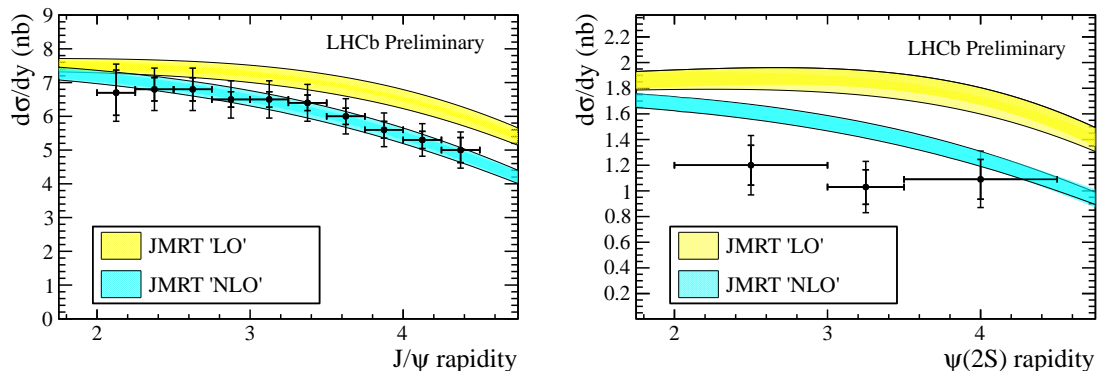


Figure 4: Differential cross-section for J/ψ (left) and $\psi(2S)$ (right) production at $\sqrt{s} = 13 \text{ TeV}$ compared to theoretical predictions.

4 Central exclusive production of pion pairs

The new triggers installed for Run 2 have allowed LHCb to collect a large sample of pion pairs with no other detector activity in proton-proton and proton-lead collisions. The dominant production mechanism is double pomeron exchange in the former while in the latter it is photoproduction with the pions produced from the decay of the ρ

meson. Photoproduction of the ρ on protons was measured at HERA up to photon-proton centre-of-mass energies of about 200 GeV [12]. However, LHCb can access values up to 1 TeV, corresponding to a parton fractional momentum, $x = 1 \times 10^{-6}$. At such small x values, saturation effects might contribute, and these would lead to a change in the cross-section rise measured at HERA.

A sample of exclusive dipions was selected by requiring precisely two charged tracks coming from the interaction region, consistent with the pion hypothesis (mainly coming from information in the RICH sub-detector), and with no other neutral or charged deposits in the LHCb detector. These events appear exclusive in LHCb but may not be truly exclusive if there exist other particles outside the LHCb acceptance. However, the HeRSChel sub-detector allows activity in a much wider pseudorapidity region to be vetoed. Using the response of the detector in QED-produced dimuon events, a threshold was defined that was compatible with no activity in HeRSChel. The invariant mass distribution for dipion events below and above this threshold is shown in Fig. 5. The rho resonance is clear in both distributions, but the activity outside the resonance region is strongly suppressed when no activity is present in HeRSChel. This suggests that the events without HeRSChel activity are enriched in central exclusive production.

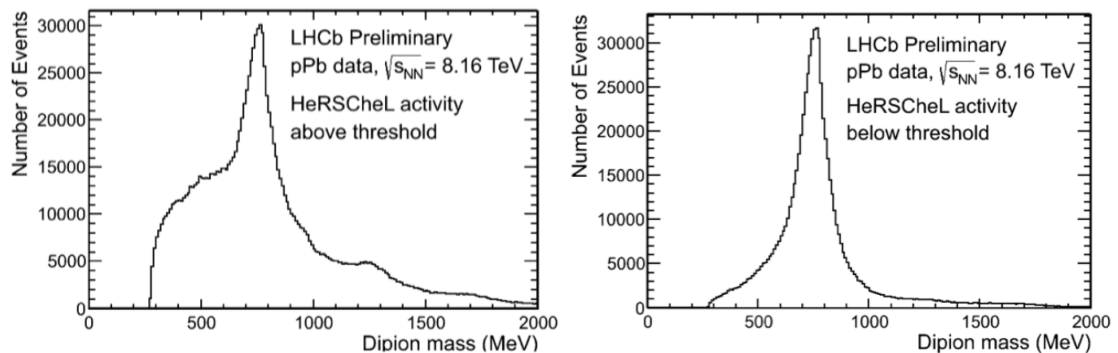


Figure 5: Candidates for exclusive dipion production in proton-lead collisions requiring activity in HeRSChel above (left) and below (right) a threshold.

5 Conclusions

The installation of the HeRSChel subdetector for Run 2 has increased the sensitivity of LHCb to central exclusive production. The cross-section for exclusive J/ψ production has been measured at $\sqrt{s} = 13$ TeV. Using HeRSChel together with improvements to the trigger, a large sample of central exclusive produced hadronic final states now awaits analysis. In addition to the potential to measure ρ production, pion, kaon and proton pairs can be measured in both proton-proton and proton-ion

collisions thus allowing an investigation of a wide variety of light meson and charm spectroscopy in both photoproduction and double pomeron exchange processes. Such spectroscopy is important in searches for glueballs and exotic hadrons as well as for new QCD phenomena such as odderons and saturation.

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