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Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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Exclusive dilepton and Upsilon production with CMS: a feasibility study

S. Ovyn, on behalf of the CMS Collaboration

Abstract

Exclusive production of dileptons with no significant additional activity in the CMS detector occurs with high cross section in gamma-mediated processes at the LHC. A feasibility study based on a full CMS simulation concludes that selecting events with a single pair of back-to-back $\mu^+\mu^-$ or e^+e^- provides a high-statistics calibration sample, e.g. for luminosity measurement and alignment of forward proton detectors. Photoproduction of Upsilon mesons, another copious source of exclusive dileptons, is also presented.

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Exclusive dilepton and Upsilon production with CMS: a feasibility study

S. Ovyn, on behalf of the CMS Collaboration

Université catholique de Louvain
Center for Particle Physics and Phenomenology (CP3)
B-1348, Louvain-la-Neuve, Belgium

Exclusive production of dileptons with no significant additional activity in the CMS detector occurs with high cross section in gamma-mediated processes at the LHC. A feasibility study based on a full CMS simulation concludes that selecting events with a single pair of back-to-back $\mu^+\mu^-$ or e^+e^- provides a high-statistics calibration sample, e.g. for luminosity measurement and alignment of forward proton detectors. Photo-production of Upsilon mesons, another copious source of exclusive dileptons, is also presented.

1 Introduction

The physics processes we are considering here result in events containing a single pair of back-to-back leptons and two protons scattered elastically and exiting CMS [1] with the beam protons. Two physics processes contribute to this signature: two-photon exchange $\gamma\gamma \rightarrow \ell^+\ell^-$ and Upsilon photoproduction $\gamma p \rightarrow \Upsilon p \rightarrow \ell^+\ell^-p$ (Figure 1). A common selection procedure is applied on both processes. A preliminary study [2] of the prospects for observing these processes with the CMS detector with 100 pb^{-1} of integrated luminosity has been performed. In the start-up phase of the LHC the number of extra interactions per beam crossing (pileup) is expected to be small. Pile-up backgrounds are therefore not considered in this study. Similar $\gamma\gamma$ and γp studies have been carried out in CMS for “ultraperipheral” Pb-Pb collisions at 5.5 TeV [3].

The elastic two-photon production of dilepton pairs is a pure QED process with a well known production cross section. During the phase of very low luminosity, such events can be used to measure the integrated luminosity collected by CMS [4, 5] and for studies of lepton reconstruction and identification. At higher lu-

minosity, they can serve as a control sample for studies beyond Standard Model [6] in $\gamma\gamma$ interactions and for calibration of forward tracking detectors [5, 7]. The Υ cross section and production dynamics, which is sensitive to the skewed gluon distribution [8, 9], have been measured with limited statistics at HERA [10, 11]. The high statistics expected at the LHC offers an opportunity to constrain more precisely models of QCD and diffraction. The very

Figure 1: Exclusive dileptons from elastic two-photon production (left) and Υ photoproduction (right).

good dimuon mass resolution of CMS leads to pronounced Υ peaks, suitable for use in the alignment of forward proton detectors.

2 Event Selection

The $\gamma\gamma \rightarrow \ell^+\ell^-$ signal samples for this analysis are generated with LPAIR [12]. The production cross section is expected to be large: 74.7 pb and 10.4 pb for the two muon ($p_T^\mu > 2.5$ GeV) and two electron ($p_T^e > 5.5$ GeV) final states, respectively. The largest source of irreducible background is dilepton production through inelastic photon-exchange events in which one or both of the protons dissociate. The Υ photoproduction has been generated using STARLIGHT [13, 14]. If the Υ is forced to decay into muon pairs, the predicted cross sections are 39, 13 and 10 pb for the 1S, 2S and 3S states. Pythia [15] is used to simulate all non exclusive backgrounds. The generated signal and background samples are processed through the full CMS detector simulation, trigger emulation, and reconstruction.

The total cross section falls off rapidly with the transverse energy of the leptons, therefore low trigger thresholds are needed in order to retain as many events as possible. The sample of dimuons must satisfy the trigger requirements $p_T > 3$ GeV. In order to maximize $\gamma\gamma \rightarrow e^+e^-$ trigger efficiency, a dedicated trigger has been developed which requires exactly two electrons with $E_T > 6$ GeV. Moreover, events are retained only if the E_T imbalance of the two electrons is smaller than 5 GeV and if they are essentially back-to-back in the transverse plane, i.e. their acoplanarity is equal to π within $\pm 20\%$.

Before the application of an additional selection, the most relevant backgrounds include non-exclusive dilepton production from Drell-Yan, Quarkonium decay and heavy-flavour jets. Dilepton events are selected using cuts based on the acoplanarity and transverse momentum balance of the leptons. In the $\mu^+\mu^-$ channel, we require $|\Delta\phi(\mu^+\mu^-)| > 2.9$ rad and $|\Delta p_T(\mu^+\mu^-)| < 2.0$ GeV. In the e^+e^- channel, we require $|\Delta\phi(e^+e^-)| > 2.7$ rad and $|\Delta E_T(e^+e^-)| < 5.0$ GeV. A common selection is applied for the dimuon and dielectron channels based on the lack of additional activity in the detector. The calorimeter exclusivity selection requires no “extra calorimeter towers”, defined as any tower with $E > 5$ GeV isolated from the nearest lepton in the event by a distance $\Delta R > 0.3$ in the $\eta - \phi$ plane. Because the CMS tracker and calorimeters do not cover the same pseudorapidity region ($|\eta| < 2.5$ for the tracker and $|\eta| < 5$ for the hadronic calorimeter), a complementary condition of exclusivity based on the number of charged tracks can be applied. We select events if no additional tracks with $p_T > 0.9$ GeV are found in the event.

The remaining background is dominated by the inelastic events, also generated using LPAIR. These events appear exclusive when all products of the proton remnant miss the CMS hadronic calorimetry coverage. In order to reduce this background, the very forward detectors ZDC [16, 17] and CASTOR [18] can be used. A study based on generator level particles estimates that approximately 2/3 of inelastic events could be suppressed using these forward detectors. This corresponds to a start-up scenario in which ZDC detectors are available on both sides of CMS, while CASTOR is available on one side only. These events are expected to have a cross section comparable in size to the one for the elastic events, which is however poorly known. This limits the utility of exclusive dilepton events for luminosity determination. The residual backgrounds from other non-exclusive processes will be estimated in data by performing a fit to the sideband of the extra calorimeter towers distribution. Application of this procedure to the Monte Carlo events gives an expectation of this contribution of the order of 6% of the muon signal.

2.1 Systematics

The systematic uncertainties, due to noisy and dead channels in the hadronic and electromagnetic calorimeters, have been studied. The muon topology is completely insensitive to dead towers, and the electron topology is only slightly affected. Noisy channels can strongly reduce the signal selection efficiency but hot channels can be masked. Finally, the poorly known cross section for inelastic photon-exchange introduces a theoretical uncertainty in the yield of selected events. An error of 19% is adopted, following the CDF estimation [19].

3 Results

Figure 2: Dimuon invariant mass after all cuts and for 100 pb^{-1} of integrated luminosity.

CMS to a precision of $\sim 4\%$ after 100 pb^{-1} . The possibility of reducing the pollution of the sample with inelastic events with cuts on $|\Delta p_T|$ and $|\Delta\phi|$ is under study in CMS. The number of Υ processes selected by the same cuts as used on to the $pp(\gamma\gamma \rightarrow \mu^+\mu^-)pp$ events is high. The contribution of the Υ photoproduction is extracted by using the invariant mass spectrum in the range $8 < m < 12 \text{ GeV}$. Assuming the STARLIGHT cross section, the first three 1S, 2S and 3S Υ states should be visible over the two photon continuum (see Figure 3).

4 Conclusion

After 100 pb^{-1} of integrated luminosity, a significant signal for exclusive dilepton production is expected. Backgrounds from non-exclusive processes can be reduced significantly. The muon sample may be used to obtain an absolute luminosity measurement with precision of order 4% or to align forward detectors. The Υ resonances will be visible, allowing measurements of their production cross sections and of the skewed gluon distribution in the proton.

The resulting dimuon invariant mass distribution is shown in Figure 2, scaled to an integrated luminosity of 100 pb^{-1} . The expected signal yields for the two-muon channel after applying all selection criteria are $N_{\text{elastic}}(\gamma\gamma \rightarrow \mu^+\mu^-) = 709 \pm 27$ and $N_{\text{inelastic}}(\gamma\gamma \rightarrow \mu^+\mu^-) = 223 \pm 15 \pm 42(\text{model})$. The statistical error is taken as $\sqrt{N}$, and the reduction due to CASTOR and ZDC is taken into account. The expected electron signals are much smaller due to the higher trigger thresholds and efficiency for low transverse energy electron reconstruction: $N_{\text{elastic}}(\gamma\gamma \rightarrow e^+e^-) = 67 \pm 8$ and $N_{\text{inelastic}}(\gamma\gamma \rightarrow e^+e^-) = 31 \pm 6 \pm 6(\text{model})$. Due to its higher trigger threshold, the electron topology is not sensitive to the Υ resonances. The number of elastic events in the di-muon sample would be sufficient to calibrate the integrated luminosity collected by

Figure 3: Dimuon mass distribution in the Υ region, from elastic and inelastic two-photon interactions as well as Υ photoproduction, as expected from a 100 pb^{-1} data set, with all cuts applied.

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