PROCEEDINGS OF SCIENCE

Mini review of Central Exclusive Production at LHC

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The LHC experiments provide an unprecedented coverage in pseudo-rapidity. This advantage and high LHC luminosity allow for broad studies of central exclusive production (CEP) processes such as exclusive production of Υ, di-leptons, di-photons and di-jets. Finally, with the proposed near beam detectors (FP420 and FP220) the exclusive Higgs and SUSY states will be also accesible. The discussion is focused on the CMS programme, as both CMS and ATLAS have similar kinematical coverage and may perform similar studies.

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The forward programme at the LHC covers a wide range of physics subjects one of which is the central exclusive production (CEP). The CEP is a process of the type: $pp \rightarrow p+X+p$ with X being a well defined system e.g. di-lepton or di-jet. The "+" sign denotes the absence of additional activity between the outgoing protons and X. The final state consists of the scattered protons, that survive the interaction intact, and of the system X or its decay products. In the CEP three distinct processes may be involved, namely photon-photon, photon-pomeron and pomeron-pomeron interactions. The scattered protons may be reconstructed in dedicated forward close to the beam detectors - proposed FP420 (having an acceptance for scattered protons for $0.002 < \xi < 0.02$) and existing proton taggers - part of TOTEM, in case of interactions in CMS, (with an acceptance for $0.02 < \xi < 0.2$).

To enable CEP studies the detector should have a large coverage in η[1], together with low electronic noises. These conditions are essential to ensure an efficient selection of the events, where no other states are produced but the central system X. A good coverage in the forward region is especially important to reject the background events in which a central state is produced but one or both protons dissociate. For the first months of LHC operation the ideal conditions for CEP studies - no pileup - will be present. Later, with high pileup, the studies will be much more difficult, but still possible if the detector and the reconstruction procedure is well understood and controlled. The FP420 equipped with the fast timing detectors will give an important contribution to the selection of the exclusive events with the pileup present.

The central part of CMS, which spans to $|\eta| < 3$, is optimized for processes with large polar angles and high values of p_T. It consists of a tracker, hadronic and electromagnetic calorimeters and muon chambers. In the forward region CMS is complemented by several subdetectors. The CMS Hadronic Forward (HF) calorimeters cover range of $3 < |\eta| < 5.2$. They are located 11.2 meters from the interaction point on both sides of the detector and consist of iron absorbers and embedded radiation hard quartz fibers, which provide a fast collection of Cherenkov light. The calorimeters are segmented in both η and ϕ. The CMS CASTOR calorimeter is located 14 meters from the interaction point only at one side of the detector (with plans to add a second, symmetric, calorimeter at the opposite side in future) and covers range of $-5.2 > \eta > -6.6$. It is a sampling calorimeter with tungsten absorber plates and fused silica plates as an active medium. It is composed of two parts - an electromagnetic one, 22 radiation length deep, and a hadronic one. The total depth is 10.3 interaction lengths. CASTOR is segmented only in ϕ. The CMS Zero Degree Calorimeters (ZDC) are installed at the end of straight beam line section, 140 meters from the interaction point, at both sides of the detector. They are able to detect neutrals, and cover $|\eta| > 8.1$. The coverage of the ATLAS detector is similar, except for $6 > |\eta| > 5$, where instead of a calorimeter, pointing Cherenkov counters (LUCID) are located. They will be used for luminosity monitoring and as a part of a rapidity gap trigger. The CMS and ATLAS detectors are described in details in [1].

The near beam detectors - FP420 [2] which are proposed for both, CMS and ATLAS, will be equipped with proton taggers build in 3-D Silicon technology (edgeless highly radiation hard) and with fast timing Cherenkov detectors (with resolution of 10 ps). The space limitation and the high timinig resolution required do not allow for roman pots technique. Instead the FP420 will be installed in a dedicated movable part of the pipe. The detectors will be located 420 meters from the

[1]Pseudo-rapidity $\eta = -ln\left[tan\left(\frac{\theta}{2}\right)\right]$, where θ is the angle between the particle momentum and the beam axis.

interaction point in the cold area of the LHC. The complementary FP220 detectors, proposed to be located $\sim$220 meters from the interaction point, will be working in a warm LHC region. The much closer position of FP220 will allow them to be included in a trigger, selecting CEP events with a main aim for exclusive H.

In the CEP of Υ ($\gamma p \rightarrow \Upsilon p \rightarrow l^+ l^- p$) a photon emitted by one of the protons fluctuates into a qq pair which then interacts *via* a pomeron with the other proton (Fig. 1a). The cross section for the process is sensitive to the generalized parton distribution functions (GPDs) of the proton. It was measured previously at HERA [3]. A similar measurement at the LHC will extend the coverage in the γp center-of-mass energy by approximately a factor of 2-3 and improve the precision for the GPDs. The four-momentum transfer t at the proton vertex for this process will be also studied as the t variable is highly correlated with the measured transverse momentum of Υ.

Exclusive di-lepton production ($\gamma\gamma \rightarrow l^+ l^-$) is a nearly pure QED process (Fig. 1b). Therefore its cross section is precisely known. In the early LHC running the process will be used for the calibration of the absolute luminosity, then can be used for the alignment of the forward proton detectors and as a control sample for the studies of the beyond Standard Model physics in $\gamma\gamma$ high energy interactions.

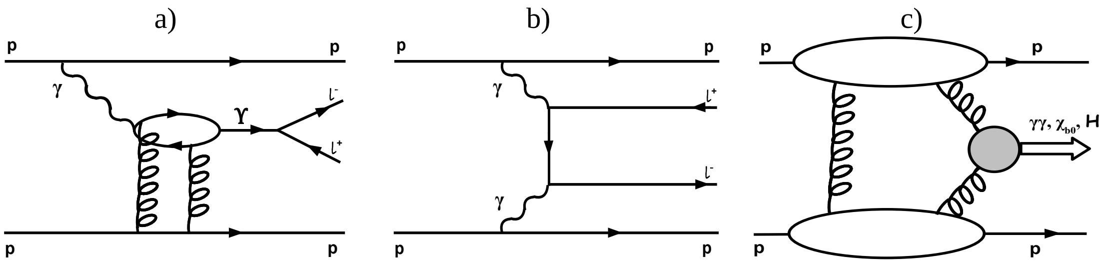

Figure 1: Central exclusive production of: a) Υ, b) di-lepton, c) di-photon, χ_{b0}, H.

Both, Υ and di-leptons, have similar experimental signatures, two opposite sign leptons, back-to-back in the azimuthal angle ϕ and balanced in transverse momentum. The main background is the two photon di-lepton production where one (or both) protons dissociate and all products of the fragmentation escape detection. For the analysis presented here the exclusive and disociative $\gamma\gamma \rightarrow l^+ l^-$ events were generated with LPAIR, while the CEP of Υ was simulated with STARLIGHT [4]. The studies were done in both channels, di-electron and di-muon. For the di-muon channel the emulation of a standard CMS trigger was used with the requirement of two muon candidates with $p_T > 3$ GeV, while for the di-electrons a new trigger was proposed with two electron candidates of $E_T > 6$ GeV and high acoplanarity. With the offline cuts a sample was selected with di-leptons balanced in p_T ($|\Delta p_T(\mu^+\mu^-)| < 2$ GeV or $|\Delta E_T(e^+e^-)| < 5$ GeV) and back-to-back ($|\Delta\phi(\mu^+\mu^-)| > 2.9$ rad or $|\Delta\phi(e^+e^-)| > 2.75$ rad). Then an exclusivity requirement was imposed with a demand that no more than 5 extra calorimeter towers having $E > 5$ GeV were reconstructed and there were no additional tracks in the region covered by the tracker. Moreover a veto was applied on the activity in the ZDC and CASTOR calorimeters. The veto removed 2/3 of the dissociative background. The other backgrounds (Drell-Yan production, quarkonium decays, heavy flavours semi-leptonic decays), studied with Pythia generator, were effectively rejected with the exclusivity requirements.

With the selection described, 7 TeV per each LHC beam and 100 pb^{-1} of the integrated luminosity, the expected exclusive $\gamma\gamma \to \mu^+\mu^-$ yield is 709 $\pm$ 27 on top of the 223 $\pm$ 15 $\pm$ 42(model) dissociative background. For the $\gamma\gamma \to e^+e^-$, due to higher trigger treshold, the expected sample is much smaller: 67 $\pm$ 8 on top of the 31 $\pm$ 6 $\pm$ 6(model) background. The statistical error is taken as $\sqrt{N}$ and 19% model dependent uncertainty on the inelastic cross-section is assumed (see [5]). With the collected number of $\mu^+\mu^-$ the integrated luminosity can be calibrated up to 4% [6].

The reconstruction of the exclusive Υ in CMS is only possible in the $\mu^+\mu^-$ channel, as the high trigger treshold for the exclusive e^+e^- pairs rejects these comming from the decays of centrally produced Υ. The extraction of Υ is done by fitting the di-muon invariant mass distribution in a range of 8-12 GeV with single Gaussians (one for each of the 1S, 2S and 3S resonances) and a second order polynomial for the background. With the integrated luminosity of 100 pb^{-1} clear three Υ states are visible (Fig. 2). The mean γp center-of-mass energy for the selected sample is 537 GeV.

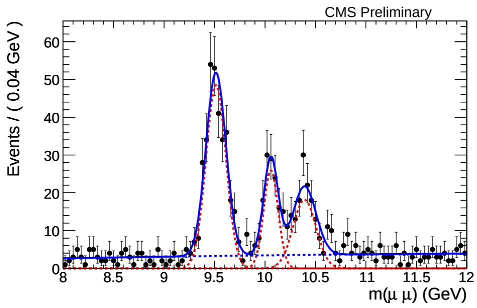

Figure 2: Di-muon invariant mass in the Υ mass region. For details see text.

The CEP of di-photons provides information on several ingredients needed for the exclusive Higgs search (Fig. 1c), that is on the unintegrated gluon distribution $g(x_1, x_2)$, the Sudakhov form factor (i.e. the probability of no gluon radiation) and on the rapidity gap survival probability S^2 (i.e. the probability of no other parton-parton interactions). The predicted cross section [7] for CEP of di-photons, where both photons have $p_T > 5$ GeV and $|\eta| < 2$, is 600 fb, with a factor of 3 uncertainty. Assuming 100 pb^{-1} of the integrated luminosity without pileup, not taking into account exact CMS acceptance (only the $|\eta| < 2$ cut) and efficiency, the expected number of di-photon events is 10-50. The measured cross section for exclusive di-photons will give an estimation what CEP H cross section to expect. When the exclusive H is found, the ratio $\#H/\#(\gamma\gamma)$ (corrected for kinematic dependencies) will determine the ggH coupling in a unique way. A complementary process which tests exclusive H production is CEP of χ_{b0}: $pp \to p\chi_{b0}p \to p\Upsilon\gamma p \to p\mu^+\mu^-\gamma p$. In this case however the selection of events will be much more challenging, as γ from χ_{b0} decay has $p_T < 0.5$ GeV, which makes it very difficult to reconstruct at CMS.

Another CEP process that will be studied is the production of the exclusive di-jets: $pp \to pjjp$. It will provide information on the QCD aspects of the vacuum quantum number exchange, and may be used, together with the exclusive di-lepton and χ_{b0}, as a "standard candle" against which the theoretical models predicting the exclusive H production can be calibrated. The search for the exclusive di-jets will be done by comparing collected data with the generated di-jet mass fraction distribution, $R_{jj} = M_{jj}/M_X$. The M_{jj} is a di-jet invariant mass, while M_X is an invariant mass of a total central hadronic system. The exclusive events should appear as an excess of data

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over simulation at high R_{jj} ($\sim$1). The exclusive di-jet production has been observed at CDF at Tevatron [8]. The expected cross section for the process in the LHC is higher, of the order of a few picobarns. Therefore with a dedicated trigger, the collected event sample will be large. Moreover the observation of the production of three exclusive jets, and the comparison to the CEP of the di-jets, will be an additional tool to constrain the Sudakhov factor.

The other two CEP processes that will be accessible at the LHC are the WW pairs production ($\gamma\gamma \rightarrow W^+W^- \rightarrow l^+l^-\nu\bar{\nu}$) and the slepton pairs production ($\gamma\gamma \rightarrow \tilde{l}^+\tilde{l}^- \rightarrow \tilde{\chi}_1^0 l^+ \tilde{\chi}_1^0 l^-$). The CEP of WW is a QED process for which the cross section can be precisely calculated. If an enhancement in the production is measured it will be an indication of an anomalous quartic coupling, giving an insight into physics beyond the Standard Model. The selection of the WW pairs will be done in their leptonic decay modes asking for two lepton candidates (e or μ) of high p_T and requiring low additional activity in the detector. The search for CEP of SUSY pairs requires high integrated luminosities ($\sim$100 fb^{-1}). It will be done *via* the reconstruction of the missing mass. Therefore, as in the final state there are two neutral particles ($\tilde{\chi}_1^0$), the measurement of both scattered protons is crucial. For this the FP420 (FP220) detectors have to be installed.

The study of the CEP of Higgs has several assets. The outgoing protons remain intact and scatter through small angles. Therefore to a good approximation a produced central state has known quantum numbers: $J^{PC} = 0^{++}$. This selection rule permits a clean determination of the quantum numbers of any new resonance observed in CEP. The energy loss of the protons is directly related to the invariant mass of the produced system. This allows to determine the mass irrespective of the decay mode and achieve an excellent mass resolution of the order of 2 GeV. Finally, a signal-to-background ratio of the order 1 (for SM Higgs) or even significantly higher (for certain MSSM Higgs scenarios) is expected. For instance CEP of Higgs will be the only way to exploit the $H \rightarrow b\bar{b}$ channel, which is not available for other Higgs analyses due to overhelming background. For some beyond SM scenarios the CEP of Higgs may be its discovery channel [2].

The CEP defines a long and extensive programme at LHC. It will provide important physics results during the early data taking (10–100 pb^{-1} data collected) - Υ, di-lepton and di-jet studies; during the 1-3 year of the LHC - di-photon, WW studies; and during the high luminosity period - Higgs, SUSY and exotic states searches. Both CMS and ATLAS are ready for the first (low luminosity, low pileup) phase. For the high luminosity new forward detectors are proposed.

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