DIFFRACTION AND FORWARD PHYSICS AT CMS

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A survey is given of the diffractive and forward physics that can be accessed by CMS alone and in combination with the TOTEM experiment as well as with detectors at ±420 m from the interaction point, presently under discussion. Results on the feasibility of a forward detectors trigger stream are also summarised.

1. Introduction

In diffractive events at the LHC the incoming proton(s) emerge from the interaction intact or excited into a low mass state, with only a small energy loss. Topologically such processes are characterized by a gap in the rapidity distribution of the final-state hadrons, due to the lack of color of the exchanged object, the so called Pomeron, now understood in terms of partons from the proton.

The CMS detector is described in details elsewhere[1]. The central detector has an acceptance in pseudorapidity, η, of roughly $|\eta| < 2.5$ for tracking information and $|\eta| < 5$ for calorimeter information. The coverage in the forward direction will be extended by two calorimeters on both sides of the interaction region, CASTOR ($5.1 < |\eta| < 6.5$) and a Zero Degree Calorimeter (ZDC). The TOTEM experiment [2] will have two identical arms, one at each side of the CMS interaction point (IP), each of which comprising two forward tracker telescopes, T1 and T2, as well as silicon detectors housed in Roman Pot (RP) stations along the LHC beam line, placed at a distance of ±147 m and ±220 m from the CMS IP. The combined pseudorapidity coverage of the CMS and TOTEM experiments will be unprecedented at a hadron collider. Further detectors to be integrated in CMS at a distance of ±420 m from the CMS IP in the cryogenic region of the LHC ring are currently being studied by the FP420 project [3].

Studies are ongoing on the diffractive and forward physics that CMS can do alone and in conjunction with TOTEM and FP420. A wealth of results is already available, including a survey of the accessible processes and trigger rate and signal efficiency studies for the CMS Level-1 (L1) and High Level Trigger (HLT) [4].

One key element in a diffractive physics program at the LHC is the trigger, notably at high luminosity, when the amount of pile-up collisions overlaid to the interesting hard event becomes high. This is particularly difficult since pile-up events are themselves largely diffractive.

2. A survey of the accessible diffractive/forward processes

The accessible physics is a function of the integrated luminosity. In the following we assume standard LHC optics with $\beta^* = 0.5$ m, unless stated otherwise. The scenario of higher β^* optics, mostly interesting for TOTEM, is discussed in [5].

At modest instantaneous luminosities, up to $10^{32}\text{cm}^{-2}\text{s}^{-1}$, inclusive single diffractive (SD) events, $pp \to pX$, as well as inclusive double-Pomeron exchange (DPE) events, $pp \to pXp$, can be studied by requiring the presence of one or two rapidity gaps in the event. The inclusive SD and DPE cross sections amount to approximately 15% and 1% of the total proton-proton cross section, respectively. Since diffractive events constitute a major fraction of the pile-up events, their measurement is mandatory to be able to properly simulate and understand high-luminosity data, where, at instantaneous luminosities of $10^{34}\text{cm}^{-2}\text{s}^{-1}$, approximately 35 pile-up events are superimposed, on average, to any event. The selection of diffractive events by requiring a rapidity gap is only possible at luminosities below $10^{33}\text{cm}^{-2}\text{s}^{-1}$, where event pile-up is small.

The study of SD and DPE events in which the diffractively excited state includes high-E_T jets, heavy quarks or vector bosons opens up the possibility of accessing diffractive Parton Distribution Functions (DPDFs) and Generalised Parton Distribution functions (GPDs). The comparison of the DPE and SD rates for these processes may also give information on the hard diffractive factorization breaking at LHC.

As the delivered luminosity reaches tens of fb^{-1}, the central exclusive production process (DPE) discussed extensively in [6] and references therein becomes a tool to study the properties of a light Higgs boson or even discover it.

3. CMS forward detectors trigger stream

The investigation of the feasibility of a special forward detectors trigger stream, with a L1 output target rate of $O(1)$ kHz, as well as of the potential of the already foreseen CMS L1 trigger streams for retaining events with diffractive processes is discussed in [4] and references therein. The main results are summarized in the following.

The proposed forward detectors trigger stream combines the information of the central CMS detector with that from TOTEM T1 and T2 tracker telescopes as well as from the TOTEM RPs, which will be available to the CMS L1 trigger. [a] Also considered are the RP detectors at a distance of 420 m. They are too far from the IP and cannot be included in the L1 trigger without an increase in the L1 latency of 3.2 μs.

An exemplary process is central exclusive production of a light Higgs boson. Triggering such a DPE produced Higgs, $pp \to pHp$, with mass close to the current exclusion limit, is particularly challenging: the dominant decay of a SM Higgs boson of mass $\sim$120 GeV is into two b-quarks and generates 2 jets with at most 60 GeV transverse momentum, p_T, each. The L1 trigger tables of CMS are optimized for events with high p_T; lowering the threshold, the rate from standard QCD processes for events with at least 2 central jets exceeds by far the target output rate of $O(1)$ kHz. Therefore using L1 jet trigger alone is not an option and additional conditions need to be employed to keep the overall rate at acceptable levels. For SM Higgs masses above 120 GeV, the $H \to WW$ branching ratio becomes sizable: in this case the final state contains high-p_T leptons and triggering is not a problem.

The efficacy of several L1 conditions was investigated by means of a sample of QCD background events generated with the PYTHIA Monte Carlo overlaid with a sample of pile-up events, including elastic and single diffractive events, also generated with PYTHIA. A reduction of the QCD rate to levels compatible with a L1 output target rate of $O(1)$ kHz by including RP detectors at a distance of 220 m from the CMS IP was found to be feasible for luminosities up to $2 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, as long as a cut on ξ, the fractional momentum loss, can be administered in the L1 trigger. Higher luminosities would necessitate inclusion of the RP detectors at 420 m distance in the L1 trigger.

[a] The results obtained do not depend on the specific hardware implementation of the TOTEM T1, T2 and RP detectors; they hold for any tracker system with the T1, T2 η coverage in conjunction with RPs at 220 m from the IP.

The effect of the L1 trigger selection on the H(120 GeV, DPE) $\rightarrow$ b$\bar{\text{b}}$ and H(140 GeV, DPE) $\rightarrow WW$ channels was studied with signal samples generated with the Monte Carlo programs EDDE [7] (version 1.1) and EX-HUME [8] (version 1.0). As far as the b$\bar{\text{b}}$ channel is concerned the single-arm 220 m (420 m) condition resulted in an efficiency of order 12% (15%), the double-arm 420 m condition in one of 8% and the asymmetric 220 m + 420 m condition in one of 6%. This also means that, even without the possibility of including FP420 detectors in the L1 trigger, 6% of the signal events can be triggered with the single-arm 220 m condition, but will have a track also in the 420 m RPs which can be used in the HLT.

Of further interest is the question how many signal events are being retained by the already foreseen trigger streams, notably the muon trigger. About 20% of the $H \rightarrow b\bar{b}$ events have a muon in the final state. Requiring at least one (two) L1 muon(s) yields an efficiency of 6% (2%). Demanding at least 1 muon and 1 jet is a condition not yet foreseen in the CMS trigger tables. For a muon p_T threshold of 3 GeV, the rate at a luminosity of 10^{33} cm^{-2} s^{-1} is slightly less than 3 kHz, and about half of the decays with muons in the final state (i.e. 9 %) are retained. About 23% of the $H \rightarrow WW$ events have at least one muon in the final state. Approximately 70% of these (i.e. 16%) are retained by requiring at least one muon with a p_T threshold of 14 GeV. An extra $\approx$ 10% (i.e. 2%) would be retained by implementing a muon/jet slot with thresholds of 3 GeV on the muon p_T and 40 GeV on the jet E_T.

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