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UNDERLYING EVENTS AND DIFFRACTION STUDIES AT THE LHC

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Abstract

The potential of the LHC experiments to study the underlying events and diffractive processes in proton-proton collisions at $\sqrt{s}$ =14 TeV is described. The underlying event is studied by examining charged particles in the region transverse to jets and in the central region of Drell-Yan muon-pair production. The diffractive program includes studies of QCD, low-x structure of the proton, and central exclusive production of SM and MSSM Higgs. The measurement of the scattered protons at appropriate locations along the beam-line is especially useful at high instantaneous luminosities.

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1 The Underlying Event

The Underlying Event (UE) in a hard scattering process is everything accompanying an event but the hard scattering component of the collision.

The UE measurement plan at the LHC benefices of the solid experience of the CDF studies[1, 2]. One can use the topological structure of the hard scattering process in order to define regions of the η-ϕ space that are sensitive to the UE components of the interaction. By comparing different processes such as high transverse momentum jets, "back-to-back" dijet production, or Drell-Yan, one can partially isolate the various components contributing to the UE.

Charged jets are constructed from the charged particles using an iterative cone algorithm. The direction of the leading charged particle jet (chgjet1) is used to isolate regions of η-ϕ space that are sensitive to the UE, defining $\Delta\phi = \phi - \phi_{\text{chgjet1}}$, i.e. the relative azimuthal angle between a charged particle and the direction of chgjet1. In particular the Transverse region, defined by $\pi/3 < |\phi - \phi_{\text{chgjet1}}| < 2\pi/3$, is expected to be particularly sensitive to the UE.

Figure 1 shows different LHC predictions for the average density of charged particles, $dN_{chg}/d\eta d\phi$, in the Transverse region for $|\eta| < 1$ with $P_T > 0.5$ GeV/c and $P_T > 0.9$ GeV/c versus the transverse momentum of the leading charged particle jet. The charged particle density is constructed by dividing the average number of charged particles per event by the area in η-ϕ space. The QCD models considered here are different settings, called tunes, of relevant parameters in HERWIG 6.5[3] and PYTHIA 6.2[4]. One of the PYTHIA tunes is due to ATLAS[5], while the other one (PY Tune DW) has been prepared by R. Field along the lines of the PYTHIA Tune A[6, 7]. All these models use the CTEQ5L parton distribution functions[8].

The multiple parton interactions[9] make the PYTHIA tunes rise rapidly and then reach an approximately flat "plateau" region. At very high $P_T(\text{chgjet1})$ they begin to rise again due to initial and final state radiation which increases as the Q^2 scale of the hard scattering increases. The purely phenomenological description available in HERWIG provides a very useful reference of a model not implementing multiple interactions: it has considerably fewer particles in the Transverse region and predicts a steady rise resulting from initial and final state radiation.

These different predictions on the amount of UE activity at the LHC, based on extrapolations from the lower energy data, differ greatly. Figure 1 also indicates that the ratio between the predictions obtained for $P_T > 0.5$ GeV/c and $P_T > 0.9$ GeV/c is sensitive to the differences between the models. This fact may help to reduce the systematic uncertainties affecting charged track reconstruction.

In order to combine the measurements performed at different leading charged jet scales, on top of the MB trigger, CMS uses two additional triggers based on the P_T of the leading high level trigger jet: $P_T > 60$ GeV/c and $P_T > 120$ GeV/c, which will be referred to as JET60 and JET120. Jets are reconstructed with an iterative cone algorithm of radius 0.5 in the pseudorapidity-azimuth space. Tracks arising from the piled-up interactions are suppressed requiring the extrapolated coordinate along the beam axis to be inside 1 mm with respect to the primary vertex associated to the leading charged jet.

The charged PT_{sum} density is the average *scalar* P_T sum of charged particles per event divided by the area in η-ϕ space ($dPT_{sum}/d\eta d\phi$).

In the CMS UE feasibility study[10] the shapes of uncorrected reconstruction level distributions for both $dN_{chg}/d\eta d\phi$ and $dPT_{sum}/d\eta d\phi$ in the Transverse region agree with the corresponding generator level ones. The difference in absolute scale (about -20%) turns out to be compatible with charged track inefficiencies and fake rates. Figure 2 reports the ratio between the $dPT_{sum}/d\eta d\phi$ distributions in the Transverse region obtained for $P_T > 0.9$ GeV/c and $P_T > 0.5$. The CMS study confirms that these ratios are not only sensitive to the difference between the models but also nicely free from the systematic effects enumerated above. Using these ratios, there's no longer need of applying corrections when comparing between the reconstruction level and the corresponding generator level observables.

Drell-Yan muon pair production also provides an excellent way to study the UE[10, 11]. Here one studies the outgoing charged particles as a function of the muon-pair invariant mass. After removing the muon-pair everything else is UE. Single muon and muon-pair triggers ensure very high efficiencies for this process at the LHC.

2 Diffraction

The CMS collaboration is pursuing a program on forward and diffractive physics, also in conjunction with near-beam detectors such as those at ± 220 m from the interaction point (IP) that are part of the TOTEM experiment[12]. The goal is to carry out this program as part of the routine CMS data taking with nominal LHC optics and up to the highest luminosities. In addition, TOTEM suggests short runs at low luminosity, where a special optics would substantially increase the TOTEM near-beam detector acceptance.

The forward and diffractive physics program as part of routine data taking would span the full lifetime of the LHC, and the accessible physics is a function of the instantaneous and integrated luminosity[13]. In the absence of pile-up, i.e. up to about 10^{32} cm^{-2}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 large rapidity gaps (LRG) in the event.

The SD and DPE cross sections should amount to approximately 15% and 1% of the total proton-proton cross section, their precise measurement at the LHC energies will be essential for the interpretation of the LHC data with superimposed pile-up at higher luminosity.

The study of SD and DPE events including high-E_T jets, heavy quarks or vector bosons allows the diffractive parton distribution functions to be accessed and the LRG suppression at the LHC to be evaluated, the latter effect being deeply connected to the amount of multiple partonic interactions[15], hence to the UE and MB physics. For example one can assume the multiple interactions component of the UE to be suppressed in DPE jet production with surviving LRG.

The accessible rich program at high luminosity will benefit from additional near-beam detectors at ± 420 m from the IP, as suggested by the FP420 R&D collaboration[14]. These detectors will extend the coverage in the fractional momentum loss, ξ, of the proton to $0.002 < \xi < 0.02$, as compared to $0.02 < \xi < 0.2$ for detectors at ± 220 m. Additional fast timing detectors would provide good veto performance against fake diffractive events which result from the coincidence of a non-diffractive hard scatter with protons from pile-up events.

First level (L1) trigger efficiencies for several diffractive topologies have been studied by CMS in collaboration with TOTEM for trigger conditions that combine central and near-beam detector requirements[16, 17].

Figure 3 shows the selection efficiency for $pp \to pWX$, with the W boson decaying to jets[19] as a function of the L1 jet E_T threshold value, normalized to the number of events where for the diffractively scattered proton has energy loss in the range $0.001 < \xi < 0.2$. Three different trigger conditions are considered: trigger on central detector quantities alone (i), trigger on central detector quantities in conjunction (ii) with the single-arm 220 m condition, and (iii) with the single-arm 420 m condition. Also shown is the number of events expected to pass the L1 selection per pb^{-1} of LHC running.

With an integrated luminosity of tens of fb^{-1}, the central exclusive production process becomes a tool to search and characterize any new particle that couples to gluons. A signal-to-background ratio of order $0.1 - 1$ can be achieved for Standard Model Higgs production and more than one order of magnitude larger for certain MSSM scenarios[20].

Triggering on diffractive events poses a special challenge at the LHC. In order to retain, for example, a Higgs boson of 120 GeV mass from central exclusive production, di-jet thresholds as low as 40 GeV per jet would be required, which would result in an inacceptable large L1 output rate of $\mathcal{O}(50)$ kHz. By using the dijet trigger condition in conjunction with a single-arm 220 m condition, the output rate for luminosities of up to 2×10^{33} can be kept at $\mathcal{O}(1)$ kHz, while about 10% of the signal would be retained[17].

3 Conclusions

Predictions on the amount of activity in UE at the LHC based on extrapolations from the lower energy data differ greatly. CMS demonstrates the feasibility of the reference UE measurements at the LHC for jet and Drell-Yan topologies, enhancing the capability to distinguish between the models through the usage of ratios between homogeneous UE observables obtained with different thresholds for the P_T of the charged tracks.

The rich diffractive program at the LHC is luminosity oriented. It includes the measurement of SD and DPE cross sections with and without hard scale, the search for Light SM and MSSM Higgs, etc.

The main challenge for selecting diffractive events at the LHC are triggering and the rejection of fake diffractive events where the protons are from coincidences with pile-up events. Measuring to what extent hard diffractive factorization is broken at the LHC provides an interesting interplay with the MB and UE physics in the context of models with multiple parton interactions.

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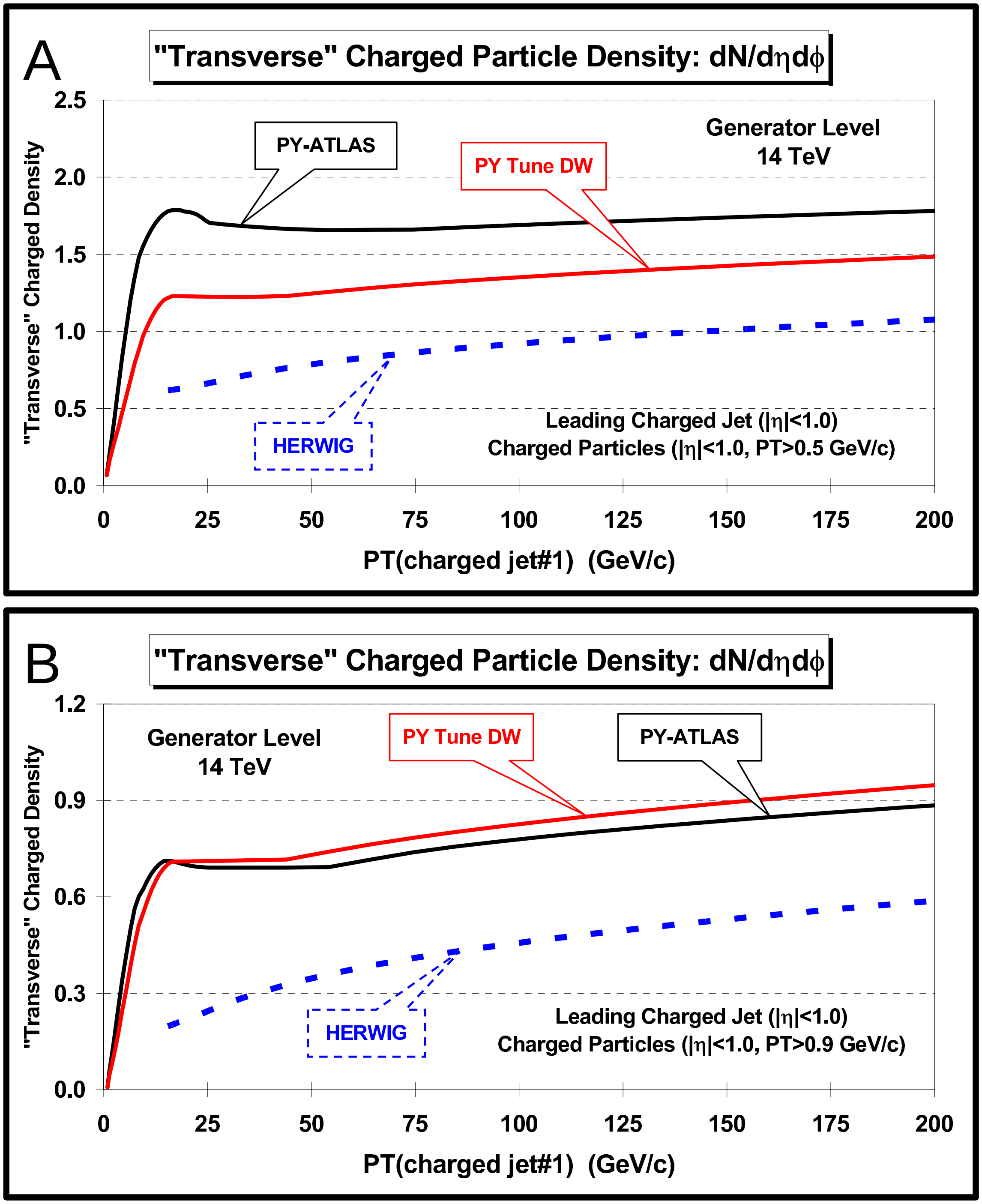

Figure 1: QCD Monte Carlo models predictions for charged particle jet production at the LHC. Average density of charged particles, $dN_{chg}/d\eta d\phi$, with $|\eta| < 1$ in the Transverse region versus the transverse momentum of the leading charged particle jet for $P_T > 0.5$ GeV/c (*A*) and $P_T > 0.9$ GeV/c (*B*).

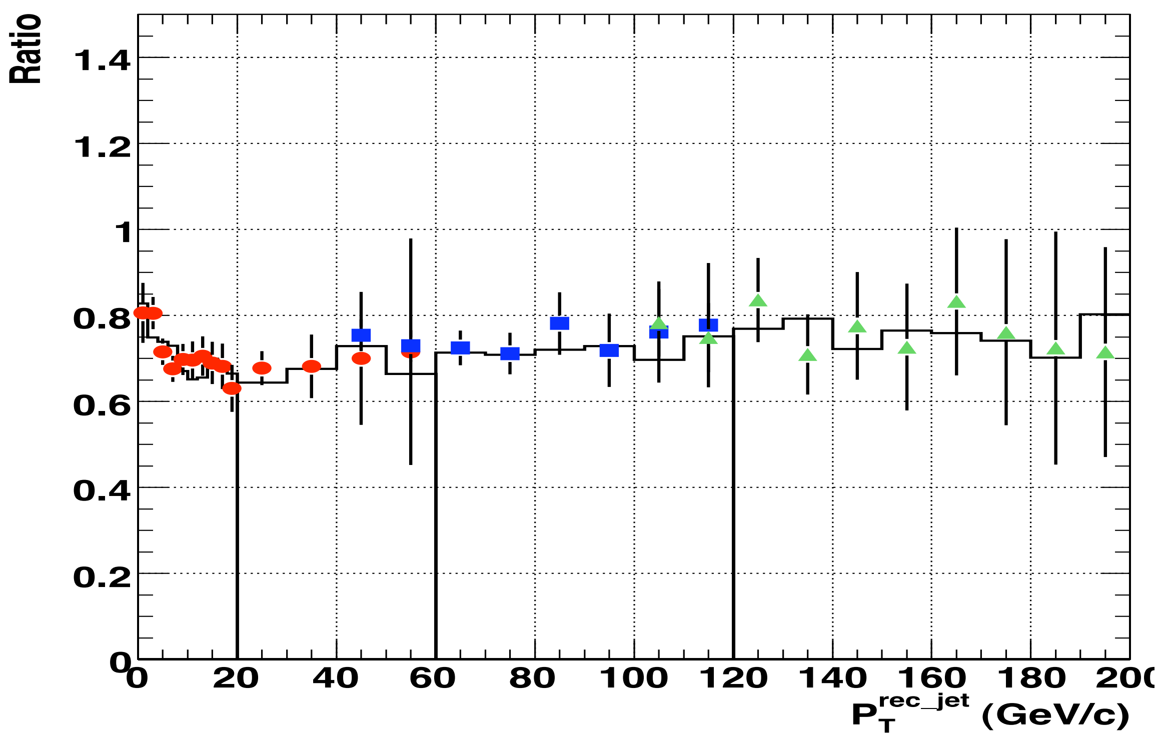

Figure 2: Charged jet production at CMS. Ratio between PT_{sum} density with $P_T > 0.9$ GeV/c and $P_T > 0.5$ GeV/c. (*circles*) = Minimum Bias; (*squares*) = JET60; (*triangles*) = JET120. The solid lines show the generator level distributions; the points with error bars correspond to the raw (uncorrected) reconstruction level distributions.

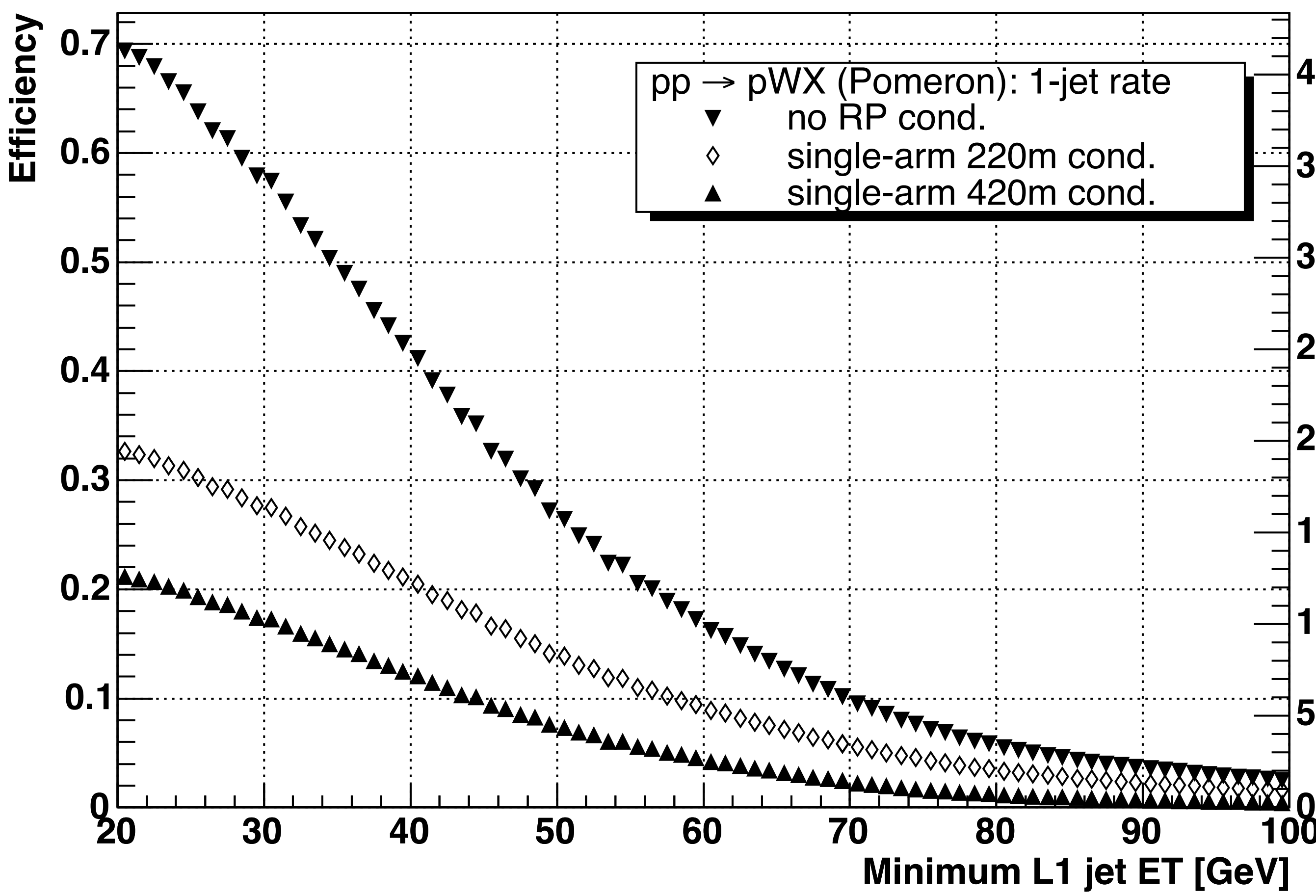

Figure 3: L1 selection efficiency as function of the E_T threshold value for $pp \to pWX$ when at least one L1 jet ($|\eta| < 5$) above threshold is required.