Double-Parton-Scattering in Photon-Three-Jet Final States at the LHC

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Abstract
The possible detection of double-parton-scattering in final states with one photon and three jets at the LHC is discussed. We study suitable variables to discriminate double-parton-scattering from shower contributions. Predictions of two event generators with different multiple interaction models are compared.

1 Direct Observation of Multiple Parton Interactions

There are good reasons to expect that multiple parton-parton scatterings will occur in most pp collisions at the LHC. For one, including multiple interactions in event generators greatly improves the description of the *underlying event* at the Tevatron. But hadronic event generators have many ingredients, making it difficult to conclude unambiguously the observation of multiple scattering.

Instead, a direct observation of multiple interactions involving final states accessible to a perturbative treatment would rule out other interpretations of the underlying event data. Four high-p_T jets from two independent scatters in the same pp or $p\bar{p}$ collision (*double-parton-scattering, DPS*) is the most prominent process. A four-jet-signature with two pairs of jets where the members of each pair have equal and opposite transverse momentum has been searched for by the AFS experiment [1] at CERN ISR, by the UA2 experiment [2] at CERN SppS and most recently by the CDF experiment [3] at the Tevatron.

Despite the large jet cross sections, the above searches had to face significant backgrounds as there are three possible ways to group four jets into two pairs. On top, the jet energy measurement is best at large energies where the cross section for double-parton scattering is small. Lowering the jet E_T threshold complicates the identification of an E_T-balanced pair as the measured jet E_T's deviate from their true value.

In a new approach to detect DPS, the CDF experiment studied final states with one photon and three jets [4] looking for pairwise balanced photon-jet and dijet combinations. The data sample was selected with CDF's inclusive photon trigger, hence allowing to search for jets down to low energies. Measuring the photon's transverse energy more precise than the jet's transverse energy helps to identify an E_T-balanced pair.

2 Simulation of Double-Parton-Scattering

We present generator-level studies with version 8.108 of the PYTHIA [5] event generator program and with version 2.2.0 of the HERWIG++ [6] program. Both event generators model the underlying event including additional interactions, which are described in the context of perturbative QCD [7, 8].

Photon	$E_T(\gamma) \geq 20$ GeV
	$\|\eta(\gamma)\| \leq 2.5$
Jets	$E_T(\text{jet}) \geq 20$ GeV
	$E_T(\text{jet 2})/E_T(\text{jet 1}) < 0.8$
	$\|\eta(\text{jet})\| \leq 5$
	$\Delta R(\gamma,\text{jet}) \geq 0.2$
Missing normalized p_T	$\|\sum_i \vec{p}_{Ti}\|/\sum_i \|\vec{p}_{Ti}\| \leq 0.1$, $i \in \{\gamma, 1, 2, 3\}$

Table 1: Kinematic selection of photon-three-jet combinations.

We compare PYTHIA default, shower-only, multiple-interactions-only and HERWIG++ default. Prompt-photon events were simulated in 5 GeV-bins of $\hat{p}_T$ for PYTHIA, $E_T(\gamma)$ for HERWIG++, of 100000 events each starting at $\hat{p}_T = 10$ GeV/c and going up to 100 GeV/c. Additional jets come from multiple interactions or from parton showers. The respective samples were normalized to the total prompt photon production cross section. Note that this will give unphysical normalizations for the PYTHIA settings with one or several options switched off, but helps to identify phase space regions with enhanced contributions from multiple interactions.

3 Event Selection and Background Discrimination

A longitudinally invariant k_T-jet algorithm [9] with $R = 0.4$ was run after the hadronization step on all stable particles, except neutrinos. Kinematic selections on photon and jets are summarized in Table 1.

The polar acceptances of the CMS electromagnetic and hadronic calorimeter are reflected in pseudorapidity cuts of $|\eta(\gamma)| \leq 2.5$ and $|\eta(\text{jet})| \leq 5$, respectively. Photons and jets are required to have transverse energies above 20 GeV, corresponding to the reconstruction threshold [10]. Fig. 1 illustrates the three-jet thresholds for the various generator settings: The minimal jet transverse momentum is shown for the softest jet in the photon-three-jet-system. Jets from multiple interactions are softer in p_T than jets from initial state radiation: A balance has to be found between selecting a jet p_T threshold where jet reconstruction is of sufficient quality and a p_T threshold that still allows multiple interactions to contribute significantly to the final state. PYTHIA predicts more photon-three-jet combinations with one jet having a transverse momentum smaller than 25 GeV/c while at large transverse momenta, HERWIG++ and PYTHIA agree (Fig. 1 right).

In double-parton-scattering events, both scatterings are supposed to be uncorrelated in scale and direction. To test this assumption, AFS and CDF investigated azimuthal correlations between pairs (Fig. 2). Both chose to study the azimuthal difference between p_T-vectors representing each of the pairs. AFS constructed said p_T-vector from the vector difference between the two objects (upper), while CDF constructed the pair's p_T from the vector sum (lower). As the pair p_T must not be zero in order to compare its direction to the other pair's p_T, both methods fail for specific configurations: The AFS method fails for objects going in the same direction, while the CDF method fails for perfectly balanced objects. Both event generators predict similar shapes for the selected phase space, but PYTHIA's total cross section prediction is larger than HERWIG++'s, corresponding to a prediction of more photon-three-jet topologies in the detector

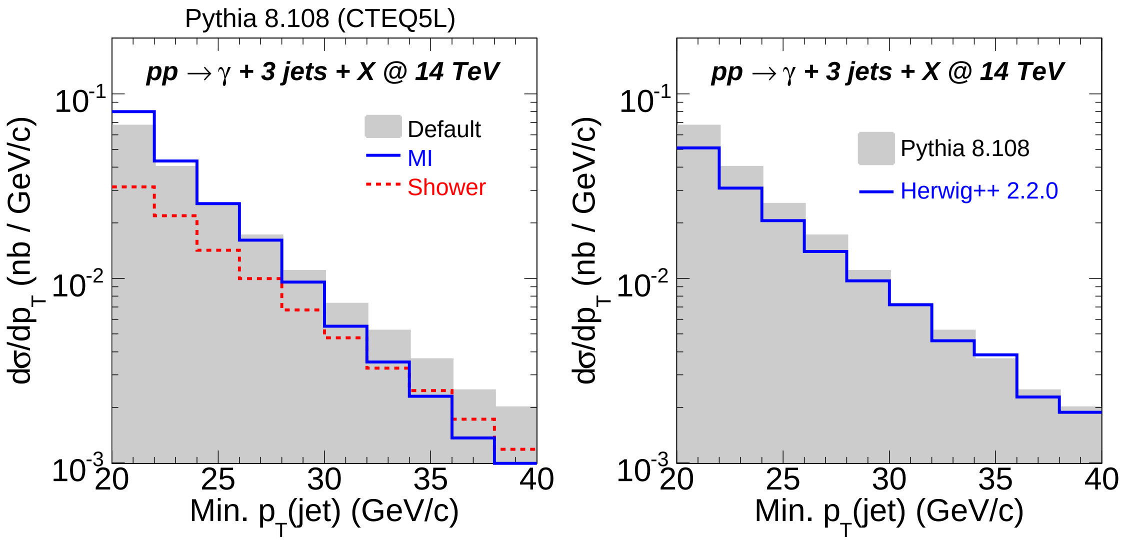

Fig. 1: Minimal jet p_T in photon-three-jet combinations. Comparison between three PYTHIA and default HERWIG prediction.

acceptance.

4 Conclusions

We studied predictions of two event generators for the production of prompt photons accompanied by three jets at the LHC. This final state is sensitive to detecting multiple interactions in double-parton-scattering events.

Detecting double-parton-scattering in photon-three-jet final states requires jet reconstruction in a region of phase space where multiple interactions contribute significantly to the photon-three-jet cross section, i. e. at small transverse energies. A promising approach might be the reconstruction of jets from tracks which have been demonstrated to give a reasonable response down to small transverse energies [11]. It will also be beneficial to reconsider double-parton-scattering processes in clean final states, such as double-Drell-Yan production of four muons.

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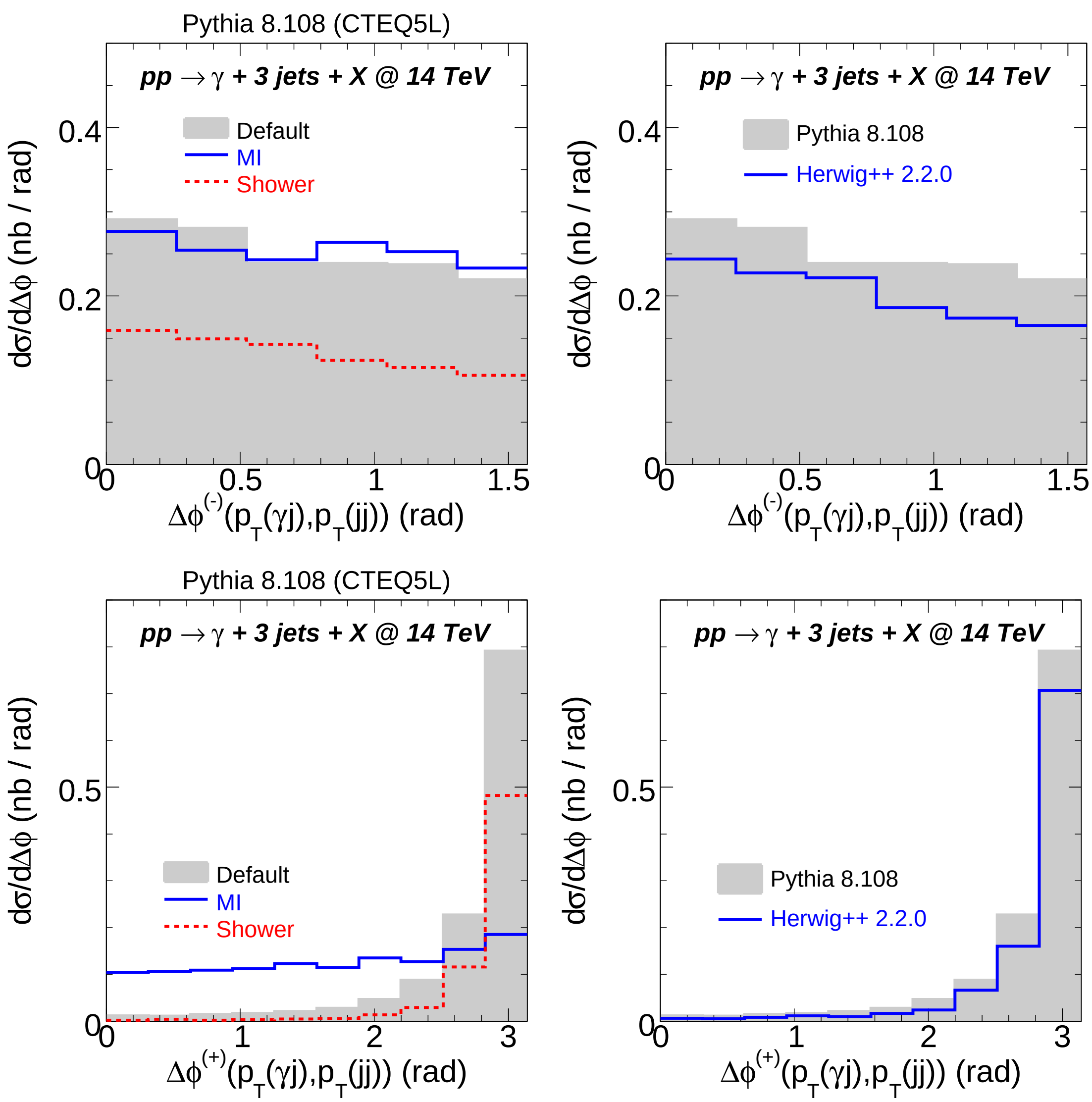

Fig. 2: Event shape variables for the photon-three-jet system.

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