Studies on the inclusive jet cross-section in pp collisions at $\sqrt{s} = 7$ TeV.

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Abstract

An investigation of the pure-NLO output from POWHEG compared to PYTHIA Monte Carlo event generator by studying the inclusive jet cross-section in pp collisions at $\sqrt{s} = 7$ TeV is presented. The main goal was to study the differences between the modified and true NLO and PYTHIA in a wide range of p_T. Using a program developed by us the output of POWHEG (just to NLO) was transformed into YODA format, allowing us to do studies in the RIVET framework. With this work we probe the matching problem of Parton Showers with Matrix Elements, specifically the POWHEG approach.

Contents

1 Introduction

High-energy hadron-hadron collisions are described within the framework of quantum chromodynamics (QCD), which is currently the best description of the fundamental strong force. When two hadrons collide at high energy, the process of evolution to the multi particle final state can be factorized in three components: A first moment comes when we have the partons inside the hadron and we can describe them with a probability function of finding a certain parton with a fraction of the momentum of the incoming hadron, this is called the Parton Distribution Function(PDF); the second moment occurs when the interaction between quasi-free partons takes place (hard scattering); and the final moment when the outgoing partons manifest themselves, through quark and gluon soft radiation and hadronization processes, as localized streams of particles, identified as jets. In the figure 1 we can see a pictorial representation of a hadron-hadron collision.

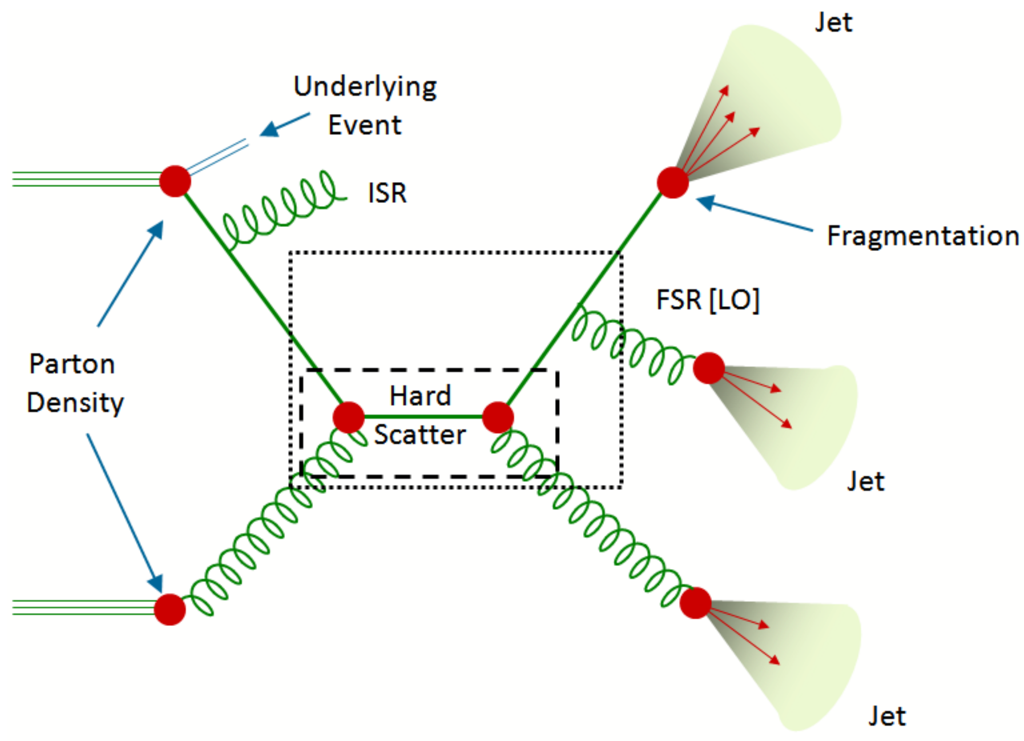

Figure 1: *Representation of a hadron-hadron collision.*

The probability of creating a certain set of jets is described by the jet production cross section, which is an average of elementary perturbative QCD quark, antiquark, and gluon processes, weighted by the PDFs. In the last years the main tools describing high energy collisions have been fixed order matrix calculations at Leading Order (LO), together with Shower Monte Carlo (SMC) programs which are essential in order to be able to obtain these large number of particles in the final state. But SMC generators fail to describe well separated high p_T multi-jets final state, nevertheless we can make

an improvement of this programs if we add next-to-leading order (NLO) corrections to the hard scattering.
In this project the main idea is to study the influence of considering the NLO precision in the calculations of the inclusive jet cross-section in pp collisions at $\sqrt{s} = 7$ TeV. In order to achieve this we are going to compare the inclusive jet cross-section for a pure-NLO calculation using POWHEG BOX and the results from a SMC generator, in this case PYTHIA.

2 Theory

2.1 Merging NLO with Parton Shower

Matching the NLO calculations with the SMC generators would improve the results largely, however, a problem appears when merging the NLO with parton shower models: the overcounting problem. In order to explain this problem an interesting example of the Z decay into a $q\bar{q}$ pair is shown in the figure 2.

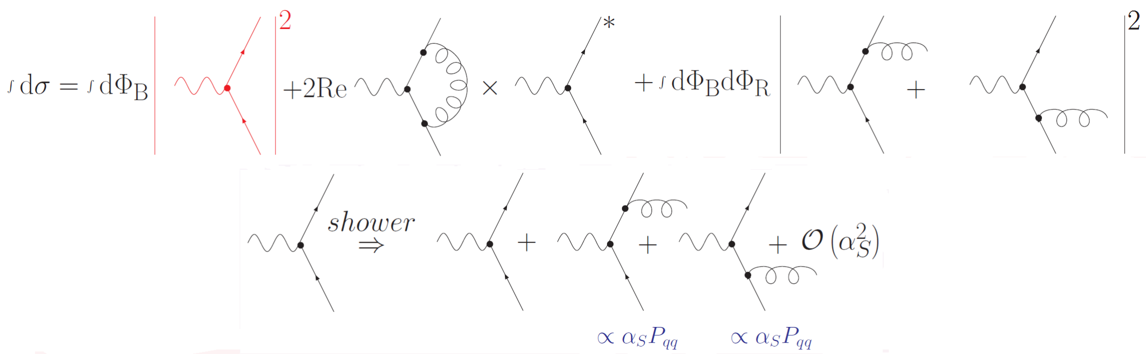

Figure 2: *Feynman diagrams to the NLO of the process $Z \longrightarrow q\bar{q}$ and for a showering at LO.*

In the figure above we can see the representation of the cross section expressed by Feynman diagrams to NLO and also a first shower emission done to the leading logarithmic (LL) order. It is very easy to notice that if we include the showering we are reproducing twice the last two diagrams of the NLO, which give us an overestimation of the total cross section.
In order to solve this problem there exist a first proposal, the MC@NLO; the main idea of the MC@NLO method is to subtract the PS approximation for the first emission from the NLO and add it back to the LO + unresolved contributions. It is possible to stand out about MC@NLO that its spectra coincide in shape with the pure parton shower in the soft-collinear region and coincide both in shape and in normalization with the pure NLO for hard emission. The bad thing about MC@NLO is that sometime appear negative weights, which means non-physical processes, and this could require more time in the process of calculation for obtaining a good statistic; also is dependent on the PS program that has been interfaced. Another proposal was POWHEG (Positive Weight

Hardest Emission Generator), the basic idea is to generate the hardest radiation first by modifying the NLO cross section and then feed the event to any shower generator. POWHEG is independent upon the SMC generator and has not negative weights, so we need smaller statistics to get equally smooth plots than in MC@NLO.

2.2 Observable

In our case the observable to measure is the inclusive cross section. The double-differential inclusive jet cross section is defined as:

$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{L}\frac{N_j}{\Delta p_T \Delta y'} \tag{1}$$

where L is the integrated luminosity, N_j is the number of jets in a bin of a width Δp_T in transverse momentum and $\Delta y'$ in rapidity.

3 Techniques

3.1 Main Tools

In our work as Monte Carlo event generator, we used PYTHIA 8 to generate the high energy collisions. This is based on a combination of analytical results and various QCD-based models, and provide us a good tool for generating the PS with the possibility of controlling many parameters associated to this process.
We also used POWHEG BOX, as the name tell us, is a computer framework for implementing NLO calculations in SMC programs according to the POWHEG method for up to three partons.
Finally RIVET was used for extract the necessary information from PYTHIA using a standard routine corresponding to the inclusive jets analysis, and for plotting the RIVET output together with the POWHEG output, allowing us to compare both with the experimental data.

3.2 My Analysis

In particular my analysis was to run PYTHIA with a proton-proton collision at $\sqrt{s} = 7$ TeV; here HardQCD, PS and MPI were switch on. The analysis was done in RIVET with help of a RIVET-routine corresponding to the Inclusive Jets Cross Section at $\sqrt{s} = 7$ TeV ($CMS\_2011\_S9086218$). The measurement was made for jet transverse momenta in the range 18-1100 GeV and for absolute values of rapidity less than 2.5. The data sample corresponds to an integrated luminosity of 34 pb^{-1}. Furthermore, POWHEG was run until the second step, which means true NLO, because we wanted to analyse the pure-NLO and the modified NLO from POWHEG. POWHEG was run for a pp collision at $\sqrt{s} = 7$ TeV as well, and from it the inclusive jets cross section was extracted.

3.3 Matching RIVET and NLO (POWHEG) output

One of the main tasks in our work was matching RIVET and POWHEG output because the POWHEG output can not be directly plotted in the RIVET framework, due to the different input format of the latest. So the first task was to extract the binning information from RIVET output(.yoda) and then insert it into POWHEG, allowing us to plot both results in the same framework; for achieving that we did a code. After running POWHEG we obtained a file (.top) with the histogram information, so we designed another program to get this information and put it in a file, with the desired structure, which RIVET could read. A representation of the conversion process is shown in the figure 3.

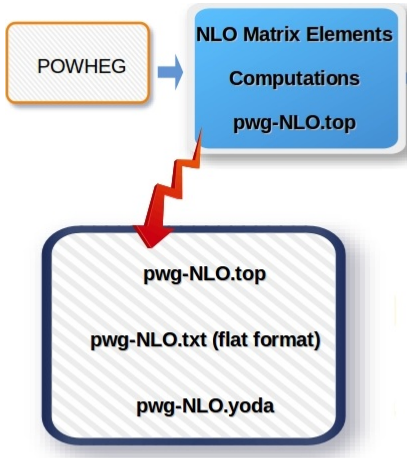

Figure 3: *Schematic representation of the change in the structure of output files.*

4 Results

4.1 Comparison between NLO and PYTHIA

In the figure 4 we can see the results obtained for the inclusive jet cross section in five intervals of rapidity. It is easy to notice that in the five intervals pure-NLO behaves better than PYTHIA, even in the last interval where pure-NLO do not match very well with data. In general the pure-NLO matches better with data than PYTHIA in almost all the p_T region (18-1100 GeV), but in particular, at very high p_T values the behaviour of pure-NLO and PYTHIA is similar. This agreement could be explained if we take into account that for very high p_T values there is little phase-space for a third hard emission, so the two-jet final state contribution from POWHEG will be predominant, hence behaving similar to PYTHIA. For the middle-high p_T region the phase-space for a third hard emission is enhanced, and this is better described by the Born $2 \rightarrow 3$ of POWHEG.

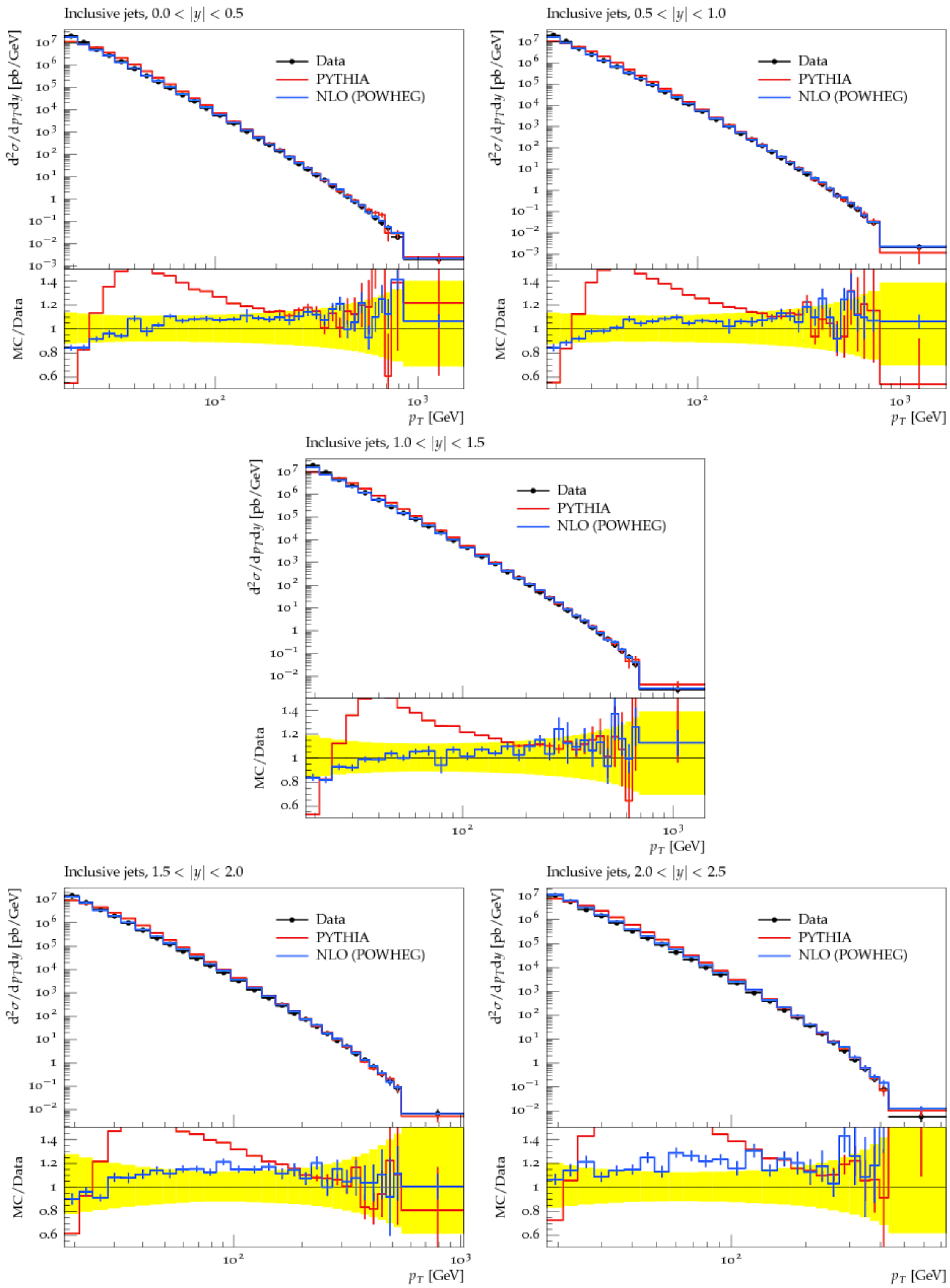

Figure 4: *Inclusive jets cross section as a function of* p_T *for five different rapidity intervals.*

5 Conclusions

Summarizing, the study of inclusive jet cross-section in pp collisions at $\sqrt{s} = 7$ TeV has been carried out. PYTHIA was compared to with pure-NLO and we can say that up to three partons in the final state at NLO accuracy pure-NLO agrees better with data than standard $2 \rightarrow 2$ accuracy from PYTHIA in the 18-1100 GeV p_T region. In particular for very high values of p_T pure-NLO and PYTHIA behave similar, nevertheless in the middle-high p_T region PYTHIA tends to fail while pure-NLO matches well.

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