Transverse Momentum Dependence of parton density for vector boson scattering

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Abstract

Using Pythia we wrote a separate code for generating the parton shower and the hard process to analyze the Transverse Momentum Dependence of the momentum fraction when parton showers generate parton emission. Our interest concerns only the kinematics involved in the transverse momentum dependence. In this project were performed simulations using different quark parton density functions. Finally were compared results obtained for gluons.

Contents

1 Introduction

In the parton model, partons are defined with respect to a physical scale [6]. The number of partons in a hadron actually goes up with momentum transfer. At low energies (i.e. large length scales), a baryon contains three valence partons (quarks) and a meson contains two valence partons (a quark and an antiquark parton). At higher energies, however, observations show sea partons (nonvalence partons) in addition to valence partons.
A parton distribution function (*pdf*) within so called collinear factorization [3] is defined as the probability density for finding a particle with a certain longitudinal momentum fraction x at resolution scale Q^2. Because of the inherent non-perturbative nature of partons which can not be observed as free particles, parton densities can not be fully obtained by perturbative QCD. Within QCD one can, however study the variation of the parton density with the resolution scale provided by an external probe. Such a scale is for instance provided by a virtual photon with virtuality Q^2 or by a jet pT. Due to the limitations in present lattice QCD calculations, the known parton distribution functions are instead obtained by fitting observables to experimental data.
Experimentally determined parton distribution functions are available from various groups worldwide. The major unpolarized data sets are:

1. ABM by S. Alekhin, J. Bluemlein, S. Moch
2. CTEQ, from the CTEQ Collaboration
3. GRV/GJR, from M. Glck, P. Jimenez-Delgado, E. Reya, and A. Vogt
4. HERAPDFs, by H1 and ZEUS collaborations
5. MRST/MSTW, from A. D. Martin, R. G. Roberts, W. J. Stirling, R. S. Thorne and G. Watt
6. NNPDF, from the NNPDF Collaboration

In the figure 1 an incoming quark carries a fraction x_2 of the initial hadrons momentum and moves to a lower momentum fraction by emitting a gluon. This emission can go on successively. The gluon in question is generated with a certain z momentum, leaving a reminder in the quark of x.

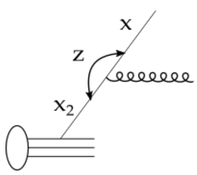

Figure 1: The fraction of the longitudinal momentum x conserved by a parton after it has emitted a quarks with a certain z momentum

Table 1: PDF used in the simulations

Hard Process	Parton Shower
Simple *pdf*	Pythia Default
Real *pdf* + QCD evolution	Pythia Default
Real *pdf* + QCD evolution	

$$\textit{simple pdf} \longrightarrow g(x) = \frac{3(1-x)^5}{x} \tag{1}$$

$$\textit{cteq } 61 \longrightarrow \textit{pp data}$$

2 Techniques

2.1 Events generated with MC using Pythia

In our project we use Pythia program [1]. Pythia is a standard tool for the generation of events in high-energy collisions, comprising a coherent set of physics models for the evolution from a few-body hard process to a complex multiparticle final state. It contains a library of hard processes, models for initial- and final-state parton showers, matching and merging methods between hard processes and parton showers, multiparton interactions, beam remnants, string fragmentation and particle decays. It also has a set of utilities and several interfaces to external programs.
Pythia 8.2 is the second main release after the complete rewrite from FORTRAN to C++, and now has reached such a maturity that it offers a complete replacement for most applications, notably for LHC physics studies. Many new features should allow an improved description of data.

2.2 Why we had to write a separate code?

We had to write a separate code for generating the parton shower and the hard process because we want to:

1. fix x_1 (figure 2) of one of the incoming partons so we can make a kinematic reconstruction of the other one. This is because we want to extract the parton density after parton shower simulation.

2. have events distributed according to the *pdf*, NOT to the cross section. If we would have used just a normal process, like Z production, we would have to correct for the cross section and would have to reconstruct the other variable x_1.

3. easily switch from quarks to gluons, which of course is unphysical, but since we want the TMD parton density, we do not have to worry about the physics of the hard process, only about the kinematics.

2.3 Rivet event analysis

Rivet is a C++ class library, which provides the infrastructure and calculational tools for particle-level analyses for high energy collider experiments, enabling physicists to validate event generator models and tunings with minimal effort and maximum portability [2].

We reconstruct the four-momentum of the second parton using the proton's and boson's momentum 5:

$$p_{g_2} = p_B - x_1 \cdot p_p \tag{2}$$

- p_{g_2} = gluon's/quark's momentum
- p_B = boson's momentum
- x_1 = momentum fraction
- p_p = proton's momentum

Then we extract the momentum fraction:

$$x_2 = \frac{(E + p_z)_g}{(E + p_z)_p} \tag{3}$$

- x_2 = momentum fraction
- $(E + p_z)_g$ = gluon/quark energy and momentum in z direction
- $(E + p_z)_p$ = proton's energy and momentum in z direction

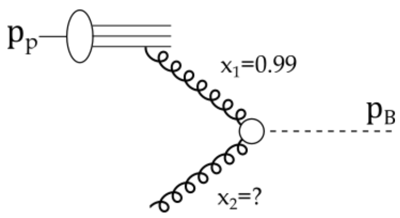

Figure 2: computing the momentum fraction

Then we use the equation 2 and 3 in Rivet to fill our histograms with the results.

3 Results

3.1 Simple x Distribution

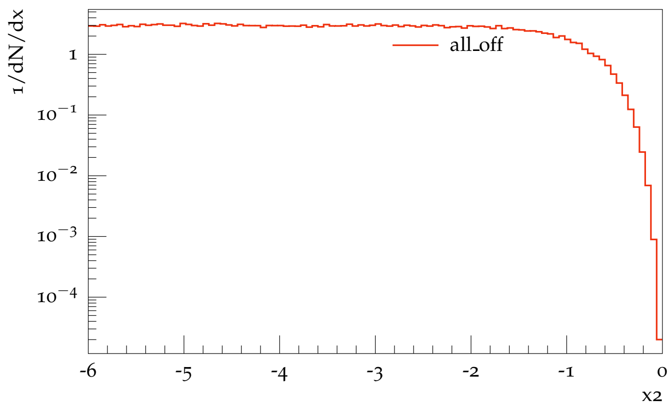

Figure 3: Momentum fraction distribution using simple pdf

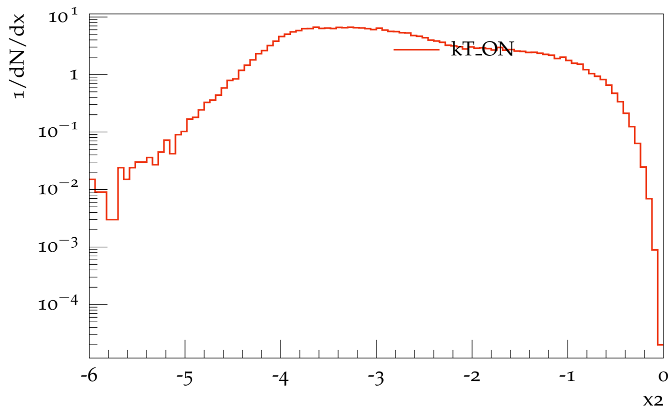

Figure 4: Momentum fraction distribution using simple *pdf* with primordialKT activated

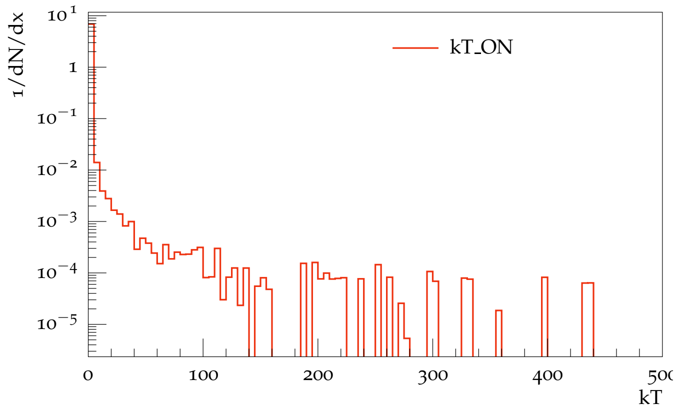

Figure 5: Transverse momentum spectra sing simple *pdf* with primordialKT activated

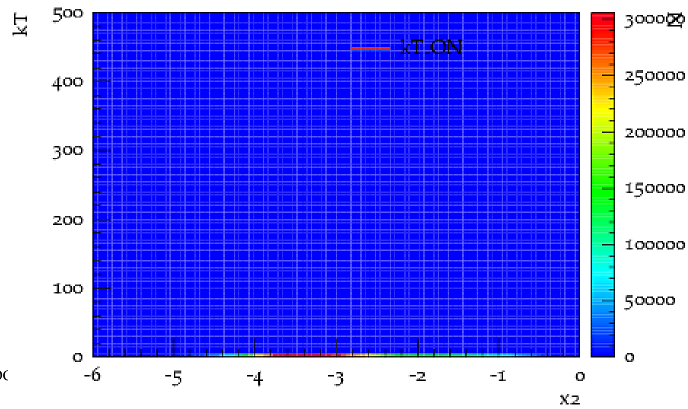

Figure 6: Correlation between the transverse momentum and momentum fraction

In the above figures we can see for small x is more likely to find parton radiation, therefore the quark density is very high. The figure 3 follows the same behavior that the equation 1 for *simple pdf* since all processes are off. The figure 4 has a different behavior due to the kinematics of the process.

3.2 Parton Shower Effect

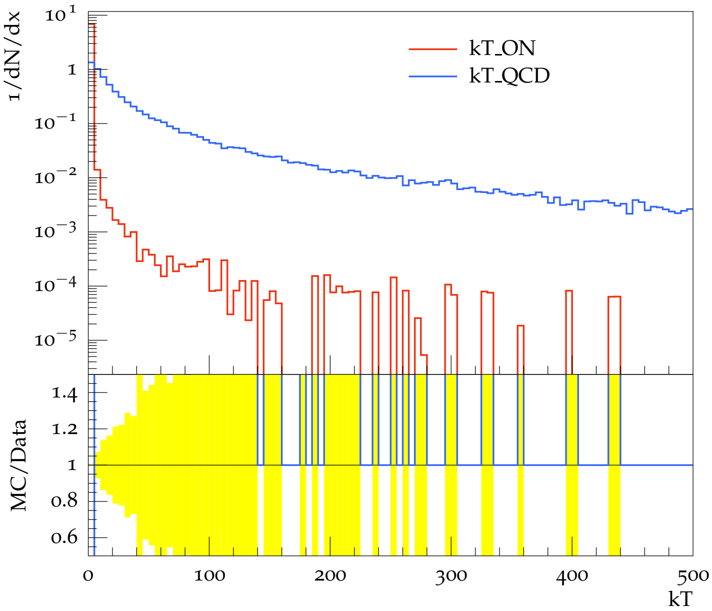

Figure 7: Comparison between single kT and kT plus shower

The figure 7 shows the differences obtained by shower switch on. This difference is given by the multiple parton emissions that contribute to an increase of the *pdf* for large values of kT.

3.3 Real Hard Process

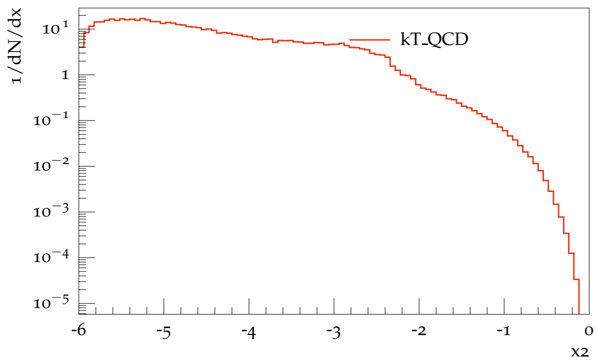

Figure 8: x_2 distribution in Real Hard Process

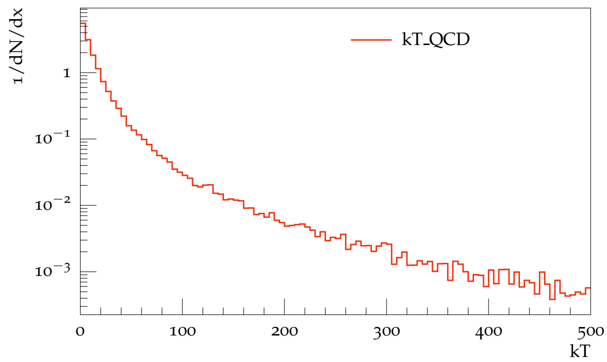

Figure 9: kT distribution in Real Hard Process

3.4 Real Hard Process + Parton Shower

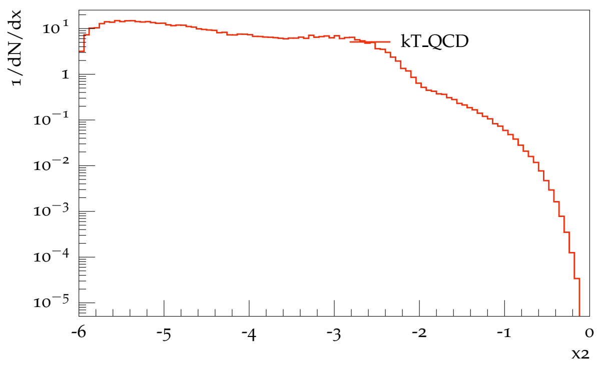

Figure 10: x_2 distribution in Real Hard Process plus parton shower

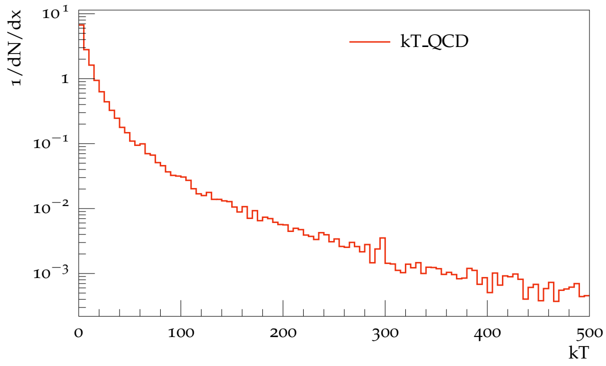

Figure 11: kT distribution in Real Hard Process plus parton shower

3.5 Comparison

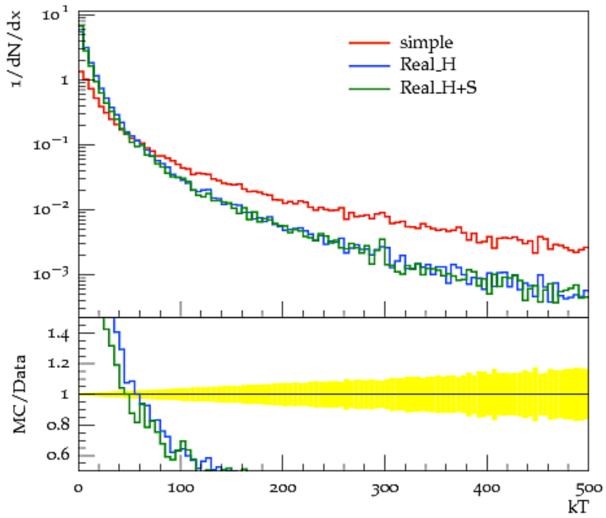

Figure 12: kT distribution with comparison for multiple *pdf*

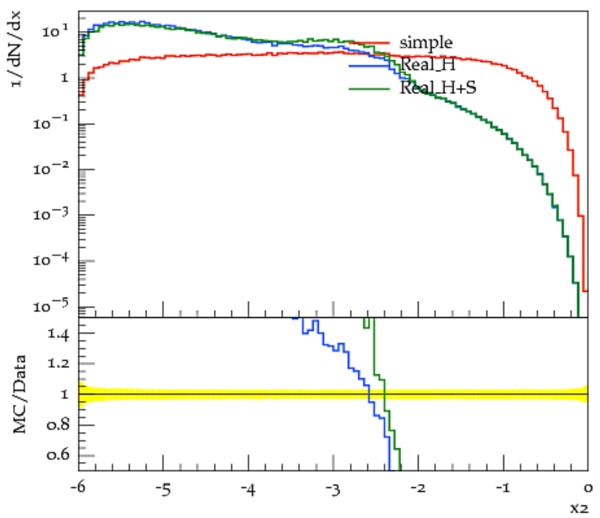

Figure 13: x_2 distribution with comparison for multiple *pdf*

In Figure 12 and 13 we can see differences between the simple *pdf* and the real one when parton shower are activated. The differences between the simple and the real were to be expected since the simple *pdf* is just a simplified theoretical case. Another result is that we do not get significant difference when the realistic *pdf* is activated in the hard process and in the shower.

3.6 Comparison Quarks vs Gluons

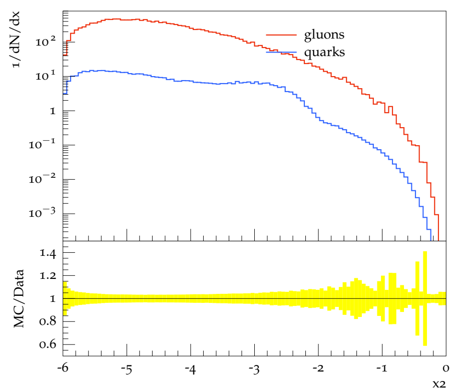

Figure 14: x_2 distribution with comparison quarks vs gluons

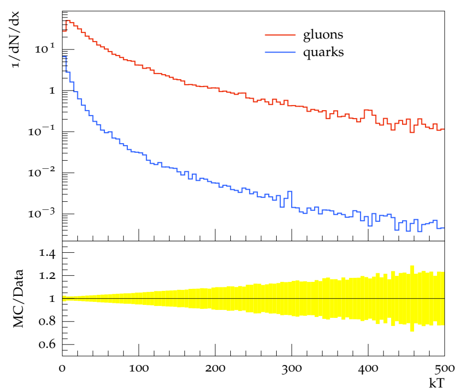

Figure 15: kT distribution with comparison quarks vs gluons

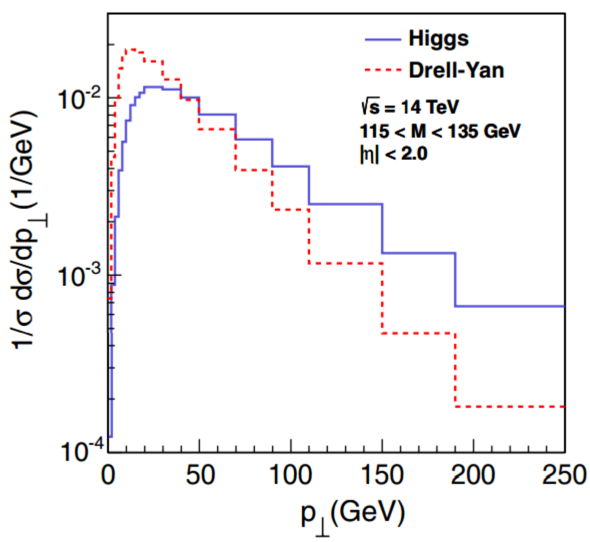

Figure 16: kT for Higgs bosons and for Drell-Yan pairs.

In figure 14 and 15, where compare the TMD for quark and gluon, we may notice a marked difference in the gluon and quark distribution . Although these curves have different normalization we can notice a big difference. The gluon curve is flatter that of the quarks thus obtaining high values of *pdf* with the increase of transverse momentum . One of the reason is that it is more likely to find gluon radiation ($P_{gg} >> P_{qq}$), therefore gluon density is very high.
The production of the Higgs boson proceeds via gluons fusion and the Drell-Yan process come from quark and antiquark. If we compare our results with the transverse momentum spectra of Higgs (matched to the simulation using gluons) and Drell-Yall (matched

to the simulation using quarks) [4], we observe that have pT different for Higgs is higher than that for Drell-Yall production. This effect come from the different kT distribution of quark and gluon (Figure 15)

4 Conclusions

During the investigations we came to some conclusions about the behavior of kT and x_2 distribution, and their comparisons to quarks and gluons. These are:

- There is a clear difference in the transverse momentum when the parton showers are activated.
- The distributions have a tail at large k_T when parton shower is switched on.
- We observe a difference in k_T for quarks and gluons.
- With our study we can easily explain the difference in k_T spectra of Z and H production.

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