Studies of parton shower and TMD distributions in e-p collisions.

Tymoteusz Stróżniak

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1 Introduction.

1.1 Parton model.

Parton model has been formulated by Richard Feynman in 1969. In this model we can study high energy collision between hardons and photons or leptons. Parton model discribes particles like protons or neutrons as a more complex objects. According to this model we can interpret deep inelastic scattering as scattering process of lepton on quasi free praticles, called parton.

1.2 Deep inelastic scattering.

Deep inelastic scattering of electrons on protons

$$ep \to eW \tag{1}$$

has been central to exploration of proton structure and quark-gluon dynamic as described by perturbative Quantum Chromo Dynamics (pQCD).

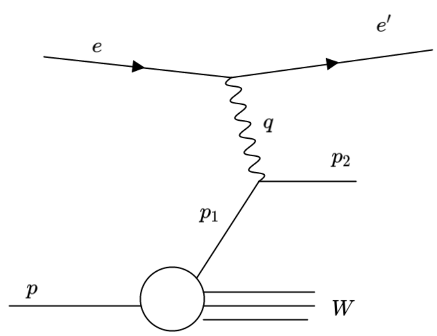

Figure 1: Deep inelastic scattering.

Intresting fact is that in scattering procces W, which is hadronic mass, is always bigger than mass of the incoming proton. When the four momentum of the virtual photon (Q^2) is much bigger than proton mass we can name it deep inelastic scattering.

1.3 Monte Carlo simulation.

Monte Carlo generators, which are based on QCD models, simulate deep inelastic scatternig interaction and give full information about all particles as four momenta forming a final state. It provides us with theoretical predictions for experimental measurement, which is especially important in this area of phase space where calculations don't exist or can't be used. This programs can also estimate hadronic corrections.

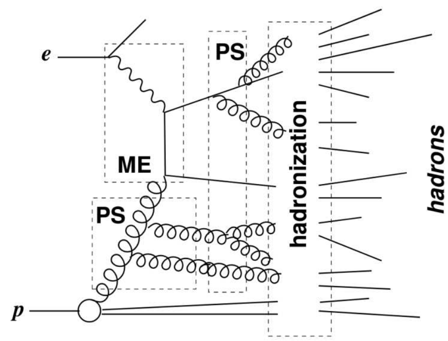

Figure 2: Schematic representation of MC generator in e-p collision. ME - matrix element PS - parton shower (multiparton radiation)

In generation of e-p collision events we can feature three steps, which are shown in fig 2:

- Precise calculations QCD matrix element in leading order for hard process.
- Simulation of parton cascade from initial state.
- Modeling of final state: simulation parton cascade from final state and nonperturbative hadronization.

1.4 Rapgap and pythia 8 event generators.

In my project I worked on two MC event generators (pytha 8 and rapgap). The most important difference between this two generators is that rapgap generator was specialy developed to discribe e-p collision in DIS but pythia is a general purpose generator which has no dedicated development for DIS. Because parton shower have become a standart component in the description of high energy collision we tested two different approaches in pythia 8: default shower and new, dipole recoil.

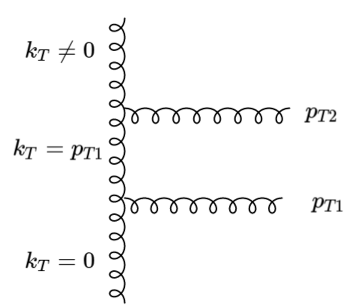

Figure 3: Default shower approach.

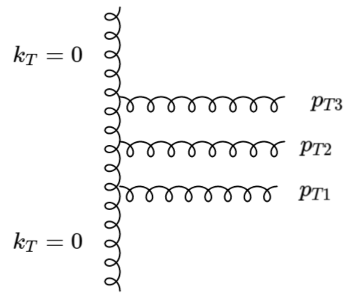

Figure 4: Dipole recoile approach

The difference between this to approaches we can illustrate in figure 3 and figure 4. Incoming parton in both approaches is the same but the important difference is that outgoing parton in default shower has k_T not equal 0 as in dipole recoil. Another essential point, there is one incoming parton and it splits into two partons in default shower but in dipole recoil approach which is actually scattering process, we have two partons coming in and it produce three outgoing partons.

1.5 F_2 structure function.

DGLAP evolution equations let us calculate parton distribution dependent of Q^2 and also Q^2 evolution of structure function F_2. If we know input parton distribution in x for initial scale Q^2 we can make a prediction of F_2 function at larger value of Q^2. Comparing prediction of pQCD with a result of measurement structure function of proton F_2 in deep inelastic scattering of lepton on nucleons was one of the first and most important test of quantum chromodynamics. Structure function F_2 can be expressed as a density of quarks and anti-quarks. In general, F_2 function is given by this formula:

$$F_2(x, Q^2) = x \sum_i e_i^2 [q_i(x, Q^2) + \overline{q}_i(x, Q^2)] \qquad (2)$$

2 Project

In my project we simulated higher order corrections with parton shower, which is multiparton radiation, which can be also used to define a transverse momentum dependent parton density.

2.1 F_2 distribution function with old measurement of inclusive DIS

At the beging we make a prediction for F_2 structure function for old measurement, that is H1 from 1996[1], with two different MC event generators: rapgap and pythia 8. To observe impact of parton shower on F_2 distribution we generate prediction with different kind parton shower (initial parton shower, final parton shower) and also without parton shower. All predictions were generated in wide range of Q^2 (from $1.7GeV^2$ to $70000GeV^2$).

2.1.1 Result for pythia 8

In figure 5, there is a exemplary histogram of F_2 distribution made with pythia generator for $Q^2 = 15GeV^2$ with default shower. The interesting thing it that we can observe significant effects for F_2 distribution generated with initial parton shower which motivated us to go further into this topic.

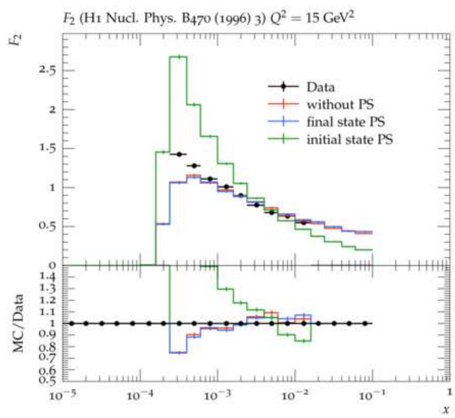

Figure 5: Predicion of F_2 function structure generated with default shower approach compared to data[1].

In figure 6, there is again a exemplary histogram of F_2 distribution made with pythia 8 event generator for $Q^2 = 15GeV^2$ but with dipole recoil approach. There is clearly visible that prediction with dipole recoil approach discribe data better than prediction with a default shower.

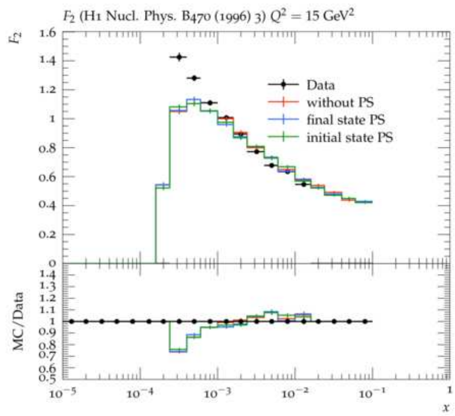

Figure 6: Predicion of F_2 function structure generated with dipole recoil approach compared to data[1].

2.1.2 Result for rapgap

To observe impact of parton shower in other MC event generators we made a prediction of F_2 dstribution also with rapgap generator for old measurement. In figure 6, there is histogram made with rapgap for $Q^2 = 15GeV^2$ with all kind of parton shower. As expected rapgap generator give us much better agreement with data than pythia 8.

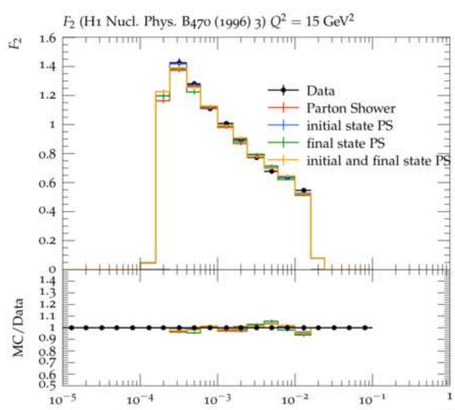

Figure 7: Predicion of F_2 function structure compare to data[1].

2.2 F_2 distribution function with new measurement inclusive DIS

The next step of my project was prepering analysis routine for new data, that is H1 + ZEUS, including HERA 1 and HERA 2 [2]. Format of HEP data wasn't usable in Rivet (analysis tool) so we had to export data from txt file to special file, required in Rivet. To better see result we needed to split a data in smaller ranges. Doing this by hand would be to much time-consuming so we made a simple c++ program which can automatically spilt data, calculate x errors and export from txt format to yoda format at once.

2.2.1 Result for pythia 8

In fiugre 8, there is prediction of F_2 distribution for new measurement generated with initial parton shower and without parton shower. This distribution was made with pythia event generator for $Q^2 = 15GeV^2$ with default shower approach. As expected, the prediction obtained with inital parton shower does not discribe data well.

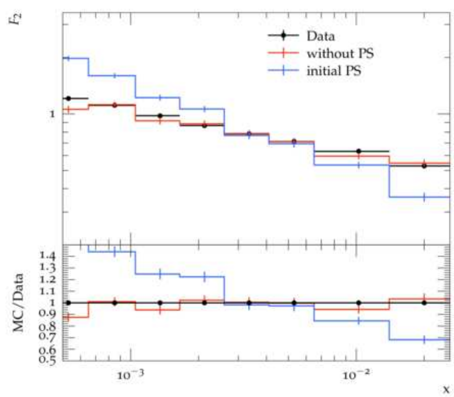

Figure 8: Predicion of F_2 function structure generated with default shower comapared to data[2].

Prediction of F_2 distribution for new measurement with dipole recoile approch discribe data even better that for old data which confirmed that dipole recoil approach is more suitable for parton shower.

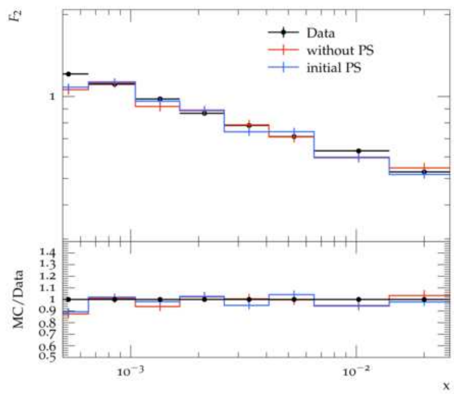

Figure 9: Predicion of F_2 function structure generated with dipole recoil approach comapared to data[2].

2.2.2 Result for rapgap

We also generate predicton of F_2 structure function for new measurement with rapgap event generator and again we get nice prediction compare with most of data points. Exemplary result for $Q^2 = 15GeV^2$ it shown at figure 10. In this case predicion looks a little bit worse compare to prediction made with pythia 8 with dipole recoile approach.

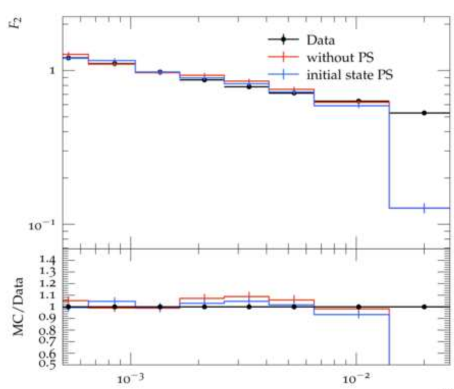

Figure 10: Predicion of F_2 function structure compare to data[2].

2.3 Prediction for k_T

To better understand why parton shower have a large impact on F_2 distribution we decide to compare a predicion of two different k_T, the transverse momentum of propagator parton. First k_T is intrinsic k_T and the second is a k_T generate with initial parton shower. Figure 11 illustrates the difference between k_{T1} and k_{T2}

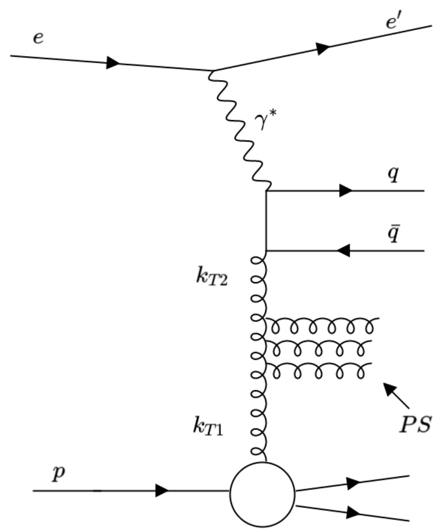

Figure 11: Difference of k_{T1} and k_{T2}

2.3.1 Result of prediction for k_T.

As expected we can't observe significant difference between k_T prediction generate with intial parton shower and without parton shower for intrinsic k_T, shown in figure 12.

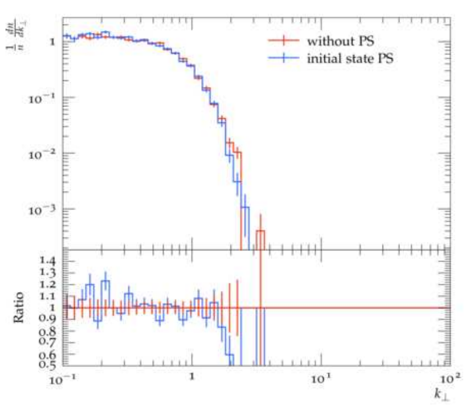

Figure 12: Prediction of k_{T1}.

However there is large difference in k_{T2} distribution. In figure 13, there is clearly visible the difference between k_T generated with initial parton shower and without parton shower. This difference makes us to apply special treatment in predicion of F_2 distribution generated with parton shower.

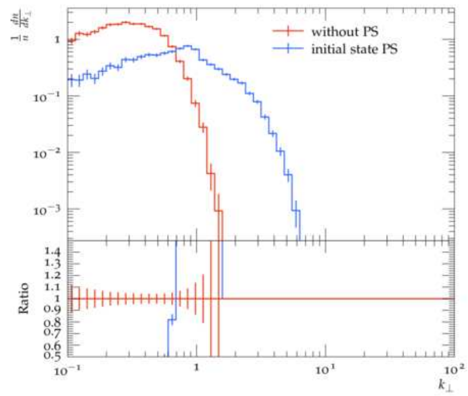

Figure 13: Prediction of k_{T2}.

3 Summary

Parton shower effect is really important in predicion for F_2 stucture function. In my project we have shown explicitly how significant parton shower effect in inclusive deep inelastic scatternig is. We also prove that there is special treatment needed to apply parton shower in deep inelastic scatternig. We have shown the difference between dipole recoil and default shower in pythia 8 as well.

References

[1] S. Aid et al. *A Measurement and QCD analysis of the proton structure function f2 (x, q**2) at HERA* H1 Nucl. Phys. B470(1996)3

[2] Abramowicz, H. et al *Combination of measurements of inclusive deep inelastic ep scattering cross section and QCD analysis of HERA data*, Eur. Phys. J.,C75(12),580