Comments to the draft v.05-July 27, 2020

*Impact of jet production on the NNLO determination of HERAPDF2.0 parton distributions*

Dieter Haidt, August 24, 2020

The present analysis of the H1 and ZEUS data from HERA based on the inclusive processes as well as jet production within NNLO of pQCD is a major achievement and constitutes an essential part of HERA’s legacy. Some of the authors remember the very first steps performed by MARK at SLAC and Gargamelle at CERN, half a century ago, and appreciate the huge effort to arrive at the mature results of HERA. The huge progress on the experimental side is complemented by the equally huge progress on the theory side allowing now for a comparison at NNLO level.

The emphasis of the present analysis is to study the impact of data on jet production when added to the previous analyses of the inclusive data alone. Apart from increasing the statistics the unique value of jet production comes from the direct dependence of the gluon (lines 217-231). I suggest therefore devote the first chapter to discussing the improvement in the pdf parameters and their correlations determining the phenomenological parton distribution functions. The crux of all analyses is the limited knowledge of the gluon distribution function obtained from the triangular phasespace in (x,Q2). The jetdata provide a genuine new insight. Within the same framework : compare the parameter fit using the inclusive data alone with the new fit in this paper of inclusive data + jetdata. Illustrate it with two figures and make it quantitative with tables of the bestvalues and their correlations in both cases. Comments on the improved gluon distribution are welcome.

Thanks to Katarzyna I had a chance to study the correlation table of the combined data. I had anticipated strong correlations the gluon and the seaquark parameters and also between alpha\_s and the gluon parameters, but to my surprise there are only rather moderate correlations with all pdf parameters. Perhaps the comparison with the correlation table using the inclusive data alone will elucidate my prejudice.

Line 139 : The momentum sumrule is an integral in x from 0 to 1. Given the conditions of our analysis the application of the momentum sumrule is useless and only introduces a bias. The reason is that an integration is required over the full range in x for all Q2. The behavior of the pdf at low x is unknown. Due to the triangular shape of the phase space the constraint for increasing Q2 is getting more and more uncertain, since there are no measurements for low x, while the parametric x -dependence merely reflects the evolved information from the low Q2-region. Therefore, drop the momentum sumrule.

The heavy flavor contribution is included through pQCD evolution from massless quarks. A remark would be in order, why we did not use our own direct measurements. Is it because of missing NNLO predictions ?

It is of particular interest to illustrate the impact of the systematic sources on the value of alpha\_s. A figure showing the variation of alpha\_s with the scale parameters would be revealing, since the uncertainty of the bestfit is dominated by the scale uncertainties. The parametric dependence should be done for fixed pdf, otherwise the effect may be compensated partially by adjusting the (many) pdf parameters. The point will be whether the value of alpha\_s is significantly shifted when varying the scale parameters. If it turns out that the central value of alpha\_s is little dependent on the scale uncertainties, then we have a strong argument that our determination in the spacelike region differs from the one in the timelike region, which is also affected by scale uncertainties.

The determination of the parton distribution functions and alpha\_s are linked. The key to the understanding of our paper is largely related to the chisquare function and the way it is exploited. I suggest to devote a detailed presentation, technicalities may be deferred to an Appendice.

1. How is the chi2-function defined ?

chi2(p) = Term with matrix(yi,f,C) + Term with constraints

yi = measurements

xi = kinematic variables

f = prediction depending upon kinematics and free parameters

C = correlation matrix containing the uncertainties

p = alpha\_s + pdf-parameters + systematic parameters

1. How are the systematic uncertainties implemented ? and in particular the splitting ?
2. Is the fit performed simultaneously for all free parameters ? Or in terms of fixed values for alpha\_s ? Is the “so-called” chisquare scan a sequence of ch2-fits with fixed values of alpha\_s including all other parameters as free, also the scale parameters ?
3. The chi2/dof is quoted as 1.2. Does this indicate an underestimation of some uncertainties, perhaps the scale uncertainties ? If so, would it be possible to repeat the fit with enlarged uncertainties to see the effect on the bestvalue of alpha\_s ?
4. Is the meaning of chi2 the same everywhere in the text ?
5. Is the gluon distribution function dominating value and size of alpha\_s among the pdfs ? How big are the shifts in alpha\_s caused by the systematics in the pdfs and the scales ? Shifts are linear effects. It may be justified to average over some of them.
6. The determination of alpha\_s is dominated by the systematic theory error of +-0.0024 compared to the experimental error +-0.001. One may ask whether the treatment of the systematics has an important effect on the central fit value of alpha\_s (see point f)

Line 284 : why is the scale uncertainty almost equal to this analysis (and not bigger) ?

Figure 2a : I don’t understand. Are all parameters except for alpha\_s free ? also the scales ? Note my remarks above. It seems to me vital to understand the interplay between alpha\_s and the systematics, before any conclusion can be reached about the central value of alpha\_s.

Figures 3-7 : Why is the green band for medium x broad for uv and not for dv ? The figures for different alpha\_s do not mean very much, since the pdfs are part of the fit.

Figure 8 : I don’t understand. What remains constant and what is part of the fit ? What do you conclude ?

Line 344 : are we quoting the fit values and correlations for the two values of alpha\_s assumed.

Line 347 : A careful discussion should be given qualifying “compatible”. Note my remarks above.

I suggest a much extended conclusion. I have - for my own sake - tried to highlight what we have achieved., since the present paper is perhaps the last word and therefore a legacy of HERA inviting some remarks on the overall increase in knowledge as well as some critical remarks on further improvements left to future studies. We may comment on the performance of the collider HERA, the experimental achievements of H1 and ZEUS with detailed publications and a final comparison with QCD (for the first time) at NNLO. The confrontation of experiment and theory provides a consistent picture.

The basic question is to what extent we have tested QCD. Our concern is perturbative QCD, which reduces the question to stating in which (x,Q2)-region pQCD is valid. This implies to worry about two frontiers (a) the transition in Q2 from the nonperturbative to perturbative regime and (b) the transition from moderate x-values to very low x-values. The first question is addressed by considering various starting scales in Q2, thus getting safe against higher twists. The other question, though important, may remain disregarded, since it concerns only the small tip in the phase space region at low Q2 and low x. Given the assumption that in the selected phase space region pQCD be valid the data are used to determine the parton distribution function, which are the necessary input to predict the observables. Since pQCD is applied at order NNLO (which is an achievement in itself), there is an intrinsic purely theoretical uncertainty coming from the truncation of the perturbative series. We address this uncertainty by varying the scales involved. Our conclusion about the impact of these systematic uncertainties will be decisive in judging the difference of our determination in the spacelike regime of alpha\_s and the existing one in the timelike regime. In any case here is a task for future work in theory.

The determination of the parton distributions is of value in itself and represents an important achievement, although there are still several weak aspects : the a priori assumption of the shapes, specific assumptions regarding the flavours , in particular the unknown s sbar-quark contribution and the role of the gluon. It should be emphasized that all in all the present knowledge is remarkable.

The experimental information is shared between the determination of the parton distribution functions and the confrontation with pQCD. Is is possible to make an educated guess what fraction of the experimental information is actually available for testing pQCD ? The observation that the correlations between the pdf parameters and alpha\_s are weak, is perhaps a strong argument in favour of real test of pQCD.

Our analysis demonstrates a consistent picture and complements the efforts in the timelike region.