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QCD Interpretation of Inclusive Deep-Inelastic Scattering and Jet Production Data at HERA

H1 Collaboration

Abstract

The gluon density in the proton is extracted using the information from scaling violations of the inclusive cross sections and from the direct contribution to the dijet cross section. The dijet data provides additional information in the region of high x ($0.01 < x < 0.1$) where a significant fraction of the gluon momentum is found. The fit uses massless next-to-leading order QCD predictions folded in Mellin space with parameterized parton densities evolved from a starting scale to the corresponding scale. The gluon density from scaling violations only and from the combined fit are compared and demonstrate the consistency and influence of the data sets.

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1 Introduction

Deep-inelastic ep scattering can be described by the scattering of a parton inside the proton with the beam electron. Parton density functions describe the non-perturbative part, while for the hard parton photon scattering a perturbative expansion in the strong coupling strength α_s is performed.

The graph in zeroth order in α_s arises from a quark or anti-quark of the proton scattering off the photon radiated by the electron. This diagram may lead to a one jet event and contributes to the lowest order of the inclusive cross section.

The simplest QCD process that directly depends on the gluon density in the proton is given by the Boson-Gluon-Fusion graph. The matrix element is of order one in α_s. In addition, the gluon contributes to the observed scaling violations and, therefore, to the dependence of the total cross section or, equivalently, the structure functions on the scale. This allows the gluon density to be extract indirectly. Equivalent diagrams appear in calculations of the next-to-leading order inclusive cross section for deep-inelastic scattering and in the lowest order dijet cross section.

The extractions of the gluon density in the proton performed by the H1 collaboration currently either use the indirect scaling violation or the direct dijet information. In this fit, the gluon density is extracted using both informations simultaneously.

2 Data sets

The inclusive cross section σ has been measured by the H1 collaboration in the kinematic region 20 GeV$^2 \leq Q^2 \leq 5000$ GeV^2 for the data taking period of 1995 till 1997[1, 2]. For these data sets together with additional fixed target data, extractions of the gluon density from scaling violations have been performed in the cited papers.

The hadronic final state of the events in the same data set is studied with the help of the the longitudinal boost-invariant k_t algorithm[3]. The double differential dijet cross section $\frac{d^2\sigma_2}{dQ^2dx}$ for photon virtualities between 200 GeV$^2 \leq Q^2 \leq 5000$ GeV^2 is determined[4].

3 Fit method

The fit is performed by using the MINUIT package[5] where the quality parameter χ^2 is defined by comparing the theoretical calculation with the corresponding measured value taking into account the statistical and systematic errors.

While the evolution of the parton densities is defined by the perturbative expansion, the densities have to be parameterized at a starting scale of $Q_0^2 = 4$ GeV^2. The parameterizations used for the gluon, the up valence quark and the combined sea quark densities are of the form

$$xf(x, Q_0^2) = A_f x^{\alpha_f}(1-x)^{\beta_f}. \tag{1}$$

Leaving additional freedom by introducing a polynom of the form $(1+\gamma_f x+\epsilon_f\sqrt{x})$ or $(1+\gamma_f x^{\epsilon_f})$ does neither change the gluon distribution more than allowed by the error band nor improves the quality of the fit significantly.

The down valence quark density is assumed to be correlated to the up valence quark density by $d(x,Q_0^2) = R(1-x)^2u(x,Q_0^2)$, where R is a constant given by the valence counting rules. Studies on the dependence of the fit on this assumption showed that, while the quarks densities vary drastically, the gluon density does not change significantly and, thus, is independent of this input.

The sea is taken to have the same up and down contribution. The strange contribution is suppressed by a factor of two while the heavy quark contributions are negligible at the input scale. Repeating the fit with a flavor symmetric light sea does not change the results.

The insensitivity of the gluon density of the exact composition of the quark densities of the individual flavors is understood by the fact that for both data sets the quark distributions to a good approximation appear in a sum over all flavors weighted by the quark charge squared.

The parton densities are evolved using Mellin space evolution. Both, Mellin space and x space evolutions, are expansions of the evolution equations up to next-to-leading order in α_s but differ in the treatment of the higher order contributions. Therefore, the comparison of fits using Mellin and x space evolutions can give an estimate on the size of higher order contributions.

The theoretical calculations in this fit have been performed in next-to-leading order. For the dijet data, the DISENT[7] program is used in order to take into account the definition of the jet algorithms and the cuts. For all calculations, the renormalization and the factorization scales are set to Q^2 and the dependence on the scales are estimated by varying the values independently between $\frac{1}{4}Q^2$ to $4Q^2$.

The value of the theory prediction also strongly depends on the value of the strong coupling strength. Since this value has been measured very accurately in various processes and is much better known than the gluon density, the current world average of $\alpha_s(M_Z^2) = 0.119$ enters the fit. The influence of the uncertainty on the strong coupling is taken into account by repeating the fit with values of 0.116 and 0.122 which is displayed by superimposing the resulting error bands.

4 Gluon density

The dependence in performing the evolution in Mellin space and in x space is evaluated by performing fits using the inclusive data set only with both fit programs. In figure 1 both fits are shown for data starting at $Q^2_{\text{min}} = 3.5\ \text{GeV}^2$. The curves agree well in a large region of the momentum fraction x. For low virtualities, mass effects become important. Therefore, a fit including massive partons is shown as a separate error band.

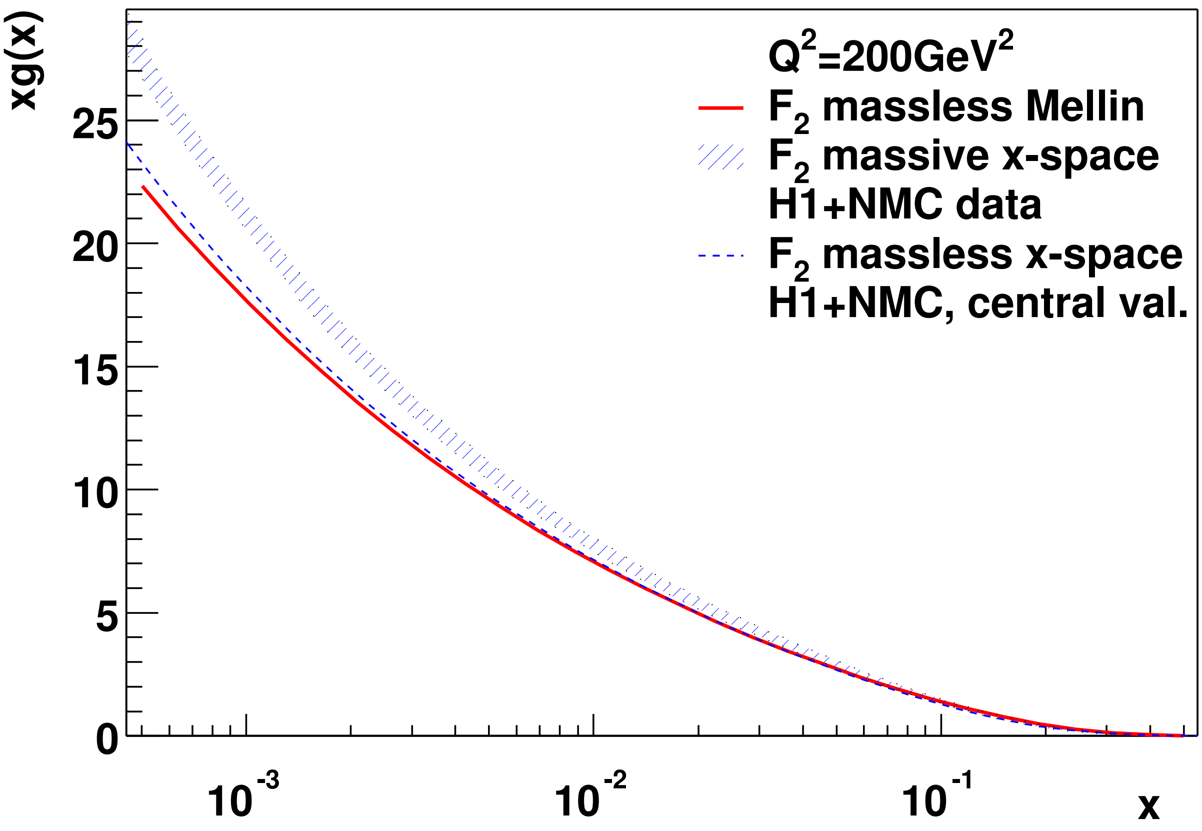

Figure 1: Result of the fits to the inclusive data. Dijet data are not included. The full line shows a fit using evolution in Mellin space and the dashed line a fit with evolution in x space. For comparison the x space fit with massive partons is plotted including error band as hashed area.

While the inclusive data dominate the low x region, the dijet data contribute at high x ($0.01 \leq x \leq 0.1$) where data from other processes are sparse. The combined fit is shown in figure 2 in the medium x region. The thick line surrounds the error band of the combined fit. Two fits using single data sets allow for a comparison of the influence of the individual data sets. The gluon extracted from dijet data (dashed line) alone is consistent but has considerably larger uncertainties. The thin line gives the error band of a fit of the inclusive data only. The size of the uncertainty of this fit is only slightly larger than the one of the combined fit. This demonstrates that with the current HERA data the scaling violations provide valuable information on the gluon density which are confirmed by the dijet data. The dijet data also improve the fit stability.

In figure 3, the measured dijet cross section is shown together with the NLO theory prediction by DISENT using the parton densities extracted in the fit. A good agreement is found.

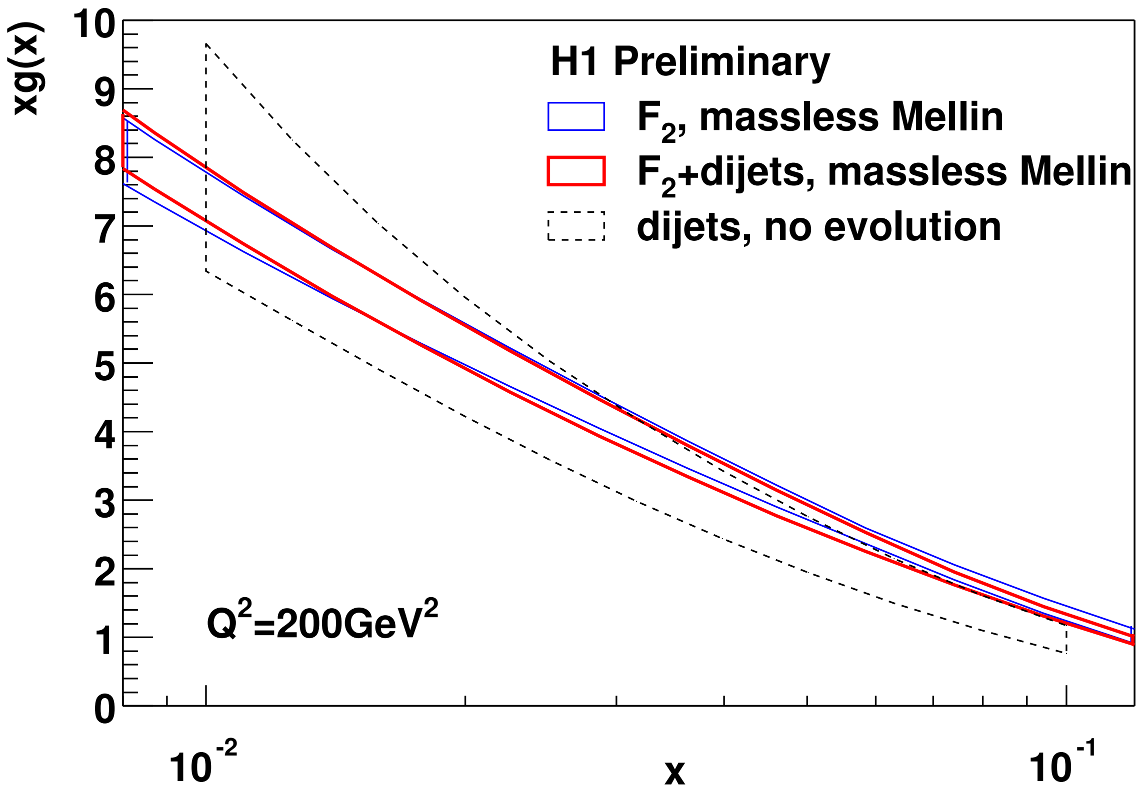

Figure 2: Result of fit at $Q^2 = 200$ GeV^2. The gluon density is plotted together with corresponding error band (thick, full line). For comparison the gluon densities of a fit using the dijet data (dashed line) or the inclusive data only (thin, full line) is shown.

5 Conclusions

The gluon density in the proton is extracted in this article. For the first time, the fit uses both, the size of the scaling violations of the inclusive cross section and the direct information from the dijet cross section. Both data sets, taken from measurements of the H1 experiment only, are well described. The inclusion of the dijet cross section results improves the fit stability compared to an extraction using the inclusive cross section only.

The result is compatible with the latest fits[2] despite of the different evolution codes indicating that the uncertainties in the treatment of the higher orders in the evolution codes is smaller than the uncertainty on the gluon density.

References

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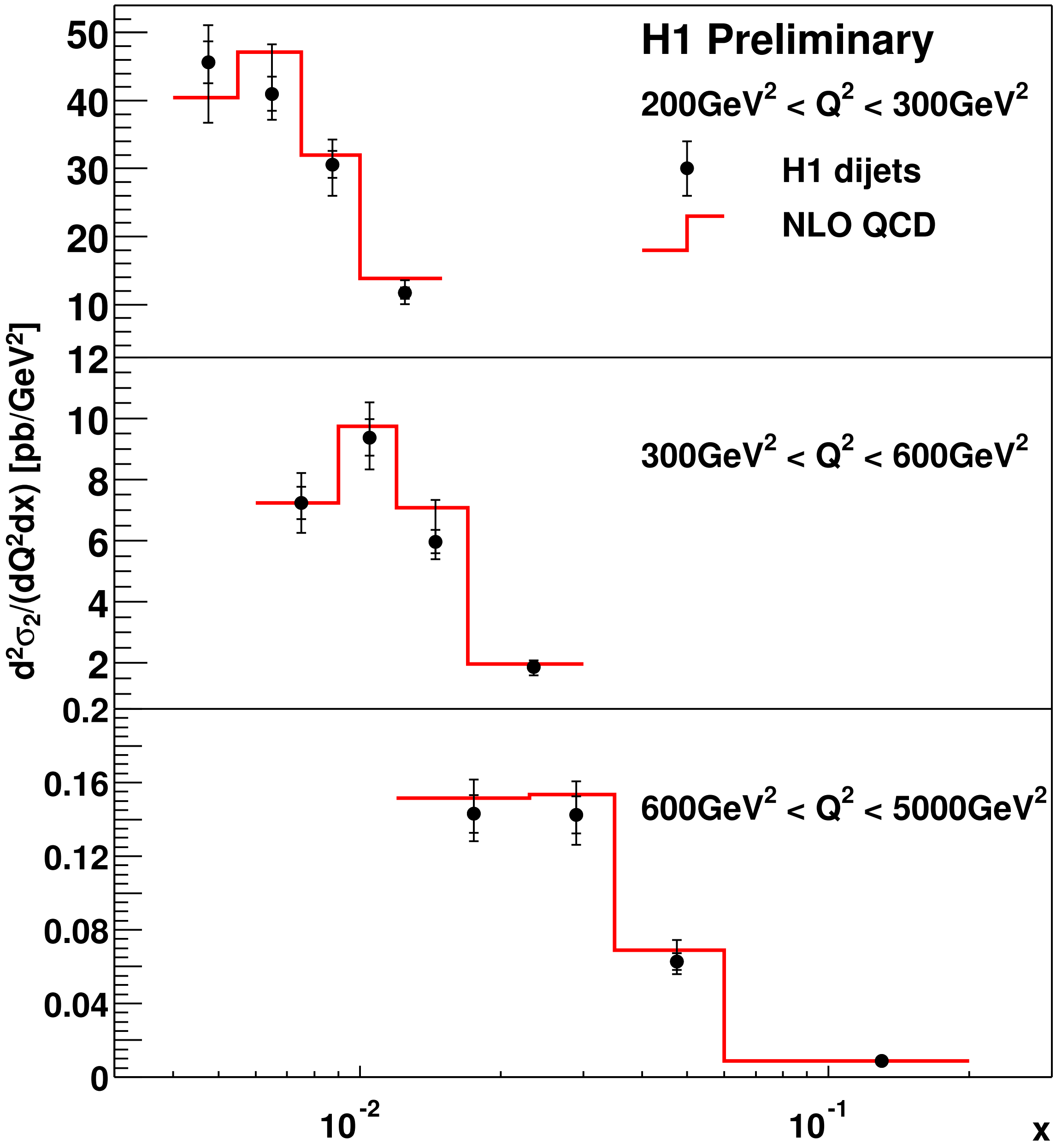

Figure 3: Dijet cross section data and NLO theory prediction using the parton densities as extracted in the fit.

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