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Determination of charm mass and fragmentation as input parameters to the Next-to-Leading Order calculation using the data of H1 experiment

DESY Summer Student report

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Abstract

The theoretical predictions of the next-to-leading order (NLO) calculation HVQDIS of charm production in deep inelastic scattering are fitted to the H1 measurements of the visible production cross section of D* mesons. The parameters of the fit are the charm mass and the parameter of the phenomenological fragmentation model. The data are collected with the H1 experiment at HERA corresponding to the integrated luminosity of 344 pb^{-1}. The deep inelastic scattering is defined by the event kinematics $5<Q^2<1000$ GeV^2, $0.02<y<0.7$. The visible range of D* production, defined by $p_t(D^*)>1.5$ GeV and $|\eta(D^*)|<1.5$ was explored. The visible total cross section and the differential cross sections $d\sigma/dp_t(D^*)$, $d\sigma/d\eta(D^*)$ and $d\sigma/dQ^2$ have been used in the fit. The values of the charm mass of 1.52 GeV and of the fragmentation parameter α (Kartvelishvili) of 2.72 corresponding to the minimum of the χ^2-test are obtained.

1 Introduction

The precision measurement of the gluon density at HERA is of the major importance for the main physics focus at the LHC. One of the methods to constrain the gluon density is the investigation of heavy quark production. At HERA energies charm and beauty quarks have to be considered as heavy. They originate mostly from the photon-gluon fusion, in leading order depicted in Fig. 1.

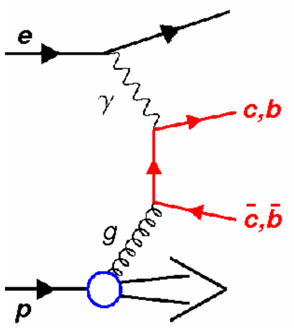

Fig. 1 The Leading Order graph of the boson-gluon fusion process

The big advantage of this production mechanism is the gluon being always involved. Similar to the inclusive case, the contribution of charm (beauty) to the proton structure function, F^c_2 (F^b_2) [1] can be extracted from the measured charm (beauty) cross sections. The double-differential charm (beauty) cross sections and F^c_2 (F^b_2) can be used to constrain the gluon density in the proton.

From the point of view of the theory, heavy flavour production is a multi-parameter problem. There are several parameters and unknown functions of the theoretical models for heavy flavour production like the transformation of the heavy quark into hadrons (fragmentation) and the heavy quark mass. Those parameters are not precisely known and therefore introduce large theoretical uncertainties. However it is possible to use precise measurements to pin down the model parameters. The choice of the renormalisation and factorisation scales introduces however an additional theoretical uncertainty, which is irreducible if no higher order calculations are provided. In this paper the measurements of charm production in deep inelastic scattering (DIS) at the H1 experiment is used to derive the charm mass and the fragmentation parameter for the Next-to-Leading order (NLO) calculation HVQDIS.

Both charm mass and the hardness of the fragmentation function influence not only the total cross section of charm production but also the slopes of the visible differential distributions. This feature is used to apply a fit to the measured kinematical distributions in the visible range with the modelled cross sections where variety of the charm mass and the fragmentation parameter was used.

This paper is organized as follows: the experimental data are described first with the following description of the used NLO pertrubative QCD calculation and charm hardronization. Finally, the results of the model fit to the measured kinematical distributions are discussed.

2 Measurements of charm production at H1

To tag charm events mesons containing a charm quark are used, e.g. D*- mesons which subsequently decay into a D^0-meson and a pion, which are reconstructed in the H1 detector. The cross sections of D*-meson production are analysed as functions of the kinematics of the scattered electron and of the D*-meson.

The statistics collected by H1 in 2004-2007 (HERA-II running period), which corresponds to the integrated luminosity of 344 pb^{-1}, is used. The kinematics of the DIS events is determined by $5 < Q^2 < 1000$ GeV^2, $0.02 < y < 0.7$. The visible range for the D* meson production is given by the transverse momentum of the D* meson $p_t(D^*) > 1.5$ GeV and its pseudorapidity $|\eta(D^*)| < 1.5$. The D* mesons are reconstructed from the tracks in the detector using the "golden" decay channel: $D^* \rightarrow D^0 + \pi \rightarrow K + \pi + \pi$ mesons are selected with the invariant mass difference method using the distribution $\Delta M_{D^{*\pm}} = M(K\pi\pi_S) - M(K\pi)$ [2]. The details of the measurement are presented in [3]. For the moment this measurement is the most statistically precise HERA measurement of the D* cross section.

The statistical merit can be used to decrease the systematic and theoretical uncertainties. The main emphasis of this work is put on the reduction of the systematic uncertainties of the model. The data are used to constrain model parameters like the mass of the charm quark and the fragmentation function.

3 Models of charm production and fragmentation

The description of production of heavy quarks in electron proton collisions is based on pertrubative QCD. The dominant contribution is the photon gluon fusion process, in the next-to-leading order are also several calculation schemes available [4, 5, 6, 7, 8]. The momentum densities of the valence quarks and the gluon in the proton can be described with the DGLAP or CCFM evolution equations. [9]

The theoretical calculations is performed using the HVQDIS program [10] uses the Next-to-Leading Order (NLO) calculation of the boson-gluon fusion matrix element, treating the charm quark as massive particle. This calculation is done in the fixed flavour number scheme, i.e. it is assumed that the proton has 3 (4) active flavours and charm (beauty) are produced dynamically. The evolution of the parton densities is performed according to the DGLAP equations. HVQDIS allows the calculation of exclusive quantities by providing the four-momenta of the outgoing partons.

The hadronization of the outgoing partons can be described with different fragmentation functions. Fragmentation functions are not directly measurable quantities because the momentum of the heavy quark is not directly experimental accessible. The momenta of the hadrons after the heavy quark hadronization are measurable, but only within a restricted phase space.

The Kartvelishvili fragmentation function [11] depending on a single free parameter α is used in this analysis to model of the charm fragmentation into a charmed hadron:

$$D_Q^H(z) \propto z^{\alpha}(1-z) \ ,$$

where z denotes the fractional energy of the fragmented quark carried by a hadron. Parameter α determines the “hardness" of the fragmentation function and is specific to the flavour of the quark. Similar to the quark mass it is a phenomenological constant which can not be derived from the first principles and has to be determined experimentally.
The charm fragmentation function has been recently measured in the H1 experiment in different ranges of the phase space [1]. The results of this measurement were used as an input to the model calculations.

4 Results

In the HVQDIS model the charm mass was varied from 1.20 GeV to 1.75 GeV in steps of Δm_c=0.05 GeV. Taking into account the results of the [1], two values of the fragmentation parameter were used depending on the center-of mass energy of the hard process, $\hat{s}$. Close to the charm production threshold, $\hat{s} < 70$ GeV^2, α=6.0, otherwise α=3.3 is used. Only the soft part of the fragmentation is varied in this analysis, corresponding to 2.1 <α< 4.0 in steps of $\Delta\alpha$=0.1.

The fit has been made with the χ^2 test, which is a statistical hypothesis test which shows the deviation of the theory from the data, with following χ^2 definition:

$$\chi^2 = \sum_i \frac{(y_{\exp} - y_{i,th})^2}{\sigma^2{}_{i,\exp}}$$

where

- y_{exp} is a measurement,
- $y_{i,th}$ is a theoretical prediction i,
- $\sigma_{i,exp}$ is the total uncertainty of the measurement

Small χ^2 value means small deviation between the theory and data. Using $y_{i,th}$ with different input parameters m_c and α minimal χ^2 can be found, which would be the optimal parameters for the theory.

The χ^2-distributions for normalized differential cross sections $\frac{d\sigma}{dp_T(D^*)}, \frac{d\delta}{d\eta(D^*)}, \frac{d\sigma}{dQ^2(D^*)}$ can be seen in figures 2, 3 and 4. The distribution for the total cross section σ_{Total} is shown in figure 5.
In figure 2 the χ^2 –dependence on charm mass and fragmentation parameter for $d\sigma/dp_t$ and $d\sigma/dp_t$ is shown. The distribution $d\sigma/d\eta$ is almost independent of α and slightly depends on m_c, as shown in Fig. 3. Figures 4 and 5 show that $d\sigma/dQ^2$ and σ_{total} strongly depend on m_c and slightly on α.
To obtain the minimum the different distribution were combined into. Since the χ^2 is a dimensionless function (differential cross sections are normalized to the total cross section), the χ^2 values of each distribution could be added. The final distribution is represented in Fig. 6, from which the pronounced minimum is obtained. A fit with a 2-dimentional parabola has been used to calculate the minimum, which corresponds to **m_c=1.53 GeV and α=2.72.**

The uncertainty of the parameters was not calculated since the parabola appeared too wide in the α direction (see figure 7). To avoid this problem more distributions can be taken into account and the broader variation of the α parameter can be done.

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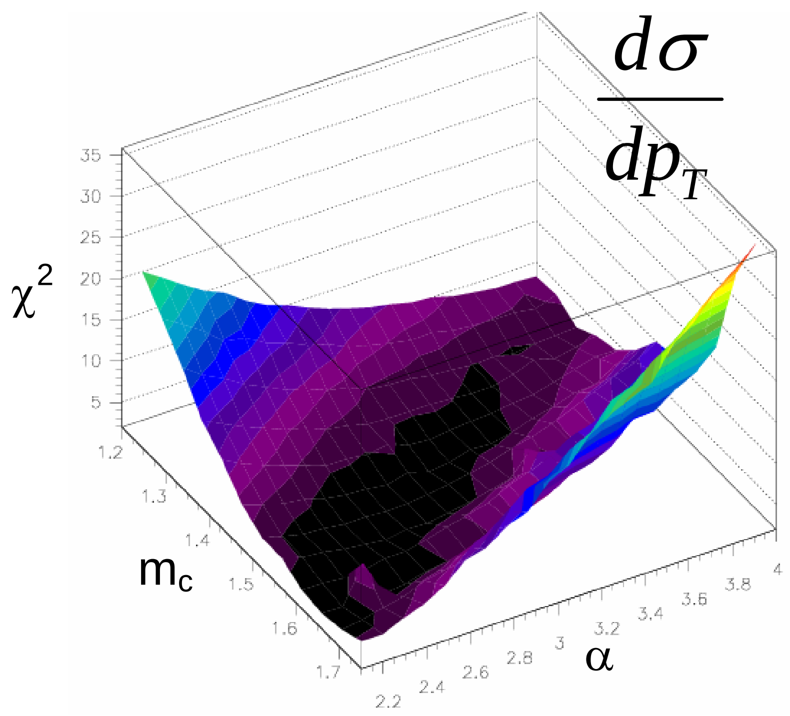

Figure 2: $\chi 2$ distribution of differential cross section $d\sigma/dp_t$ in dependence of charm mass m_c and fragmentation parameter α

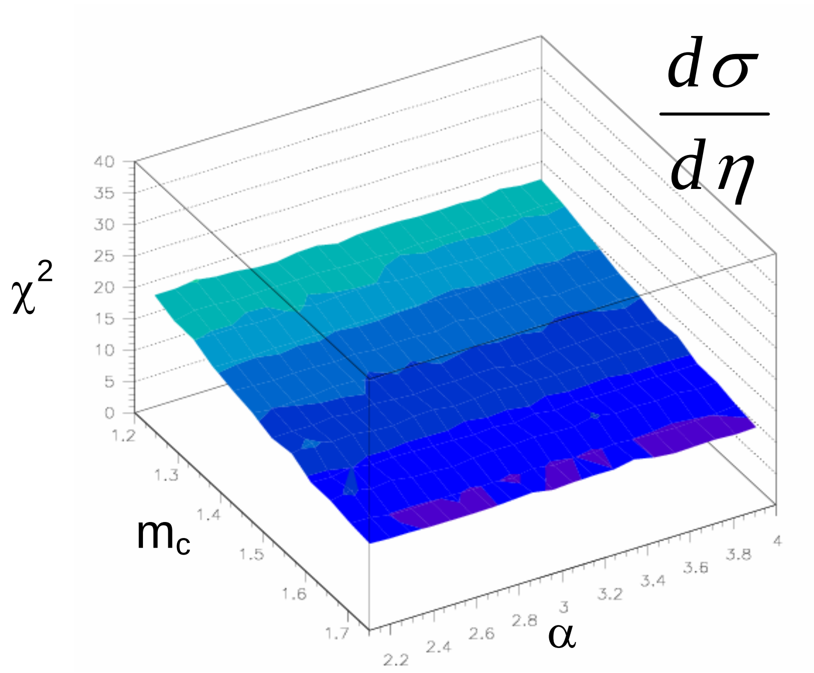

Figure 3: χ2 distribution of differential cross section dσ/dη in dependence of charm mass m_c and fragmentation parameter α

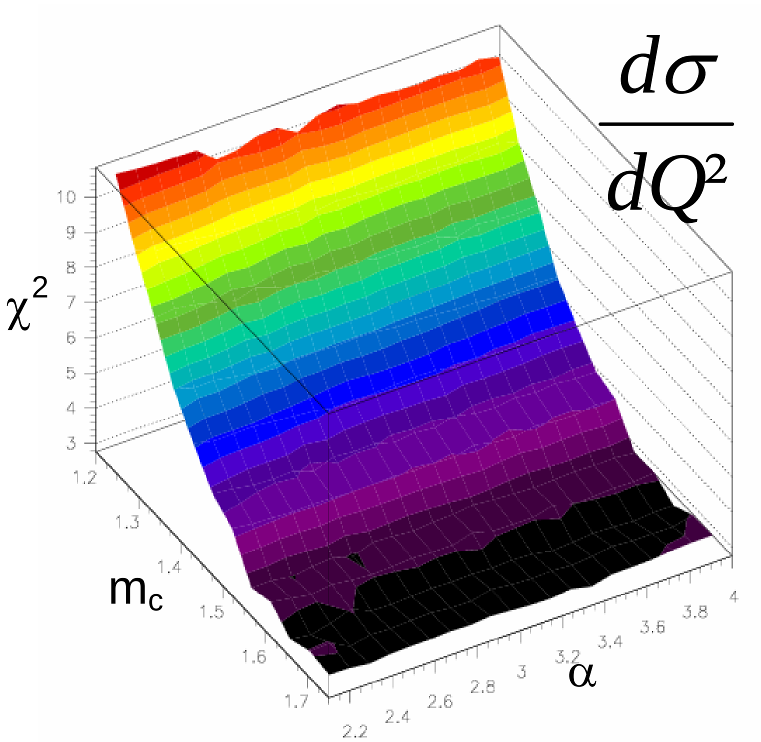

Figure 4: χ2 distribution of differential cross section $d\sigma/dQ^2$ in dependence of charm mass m_c and fragmentation parameter α

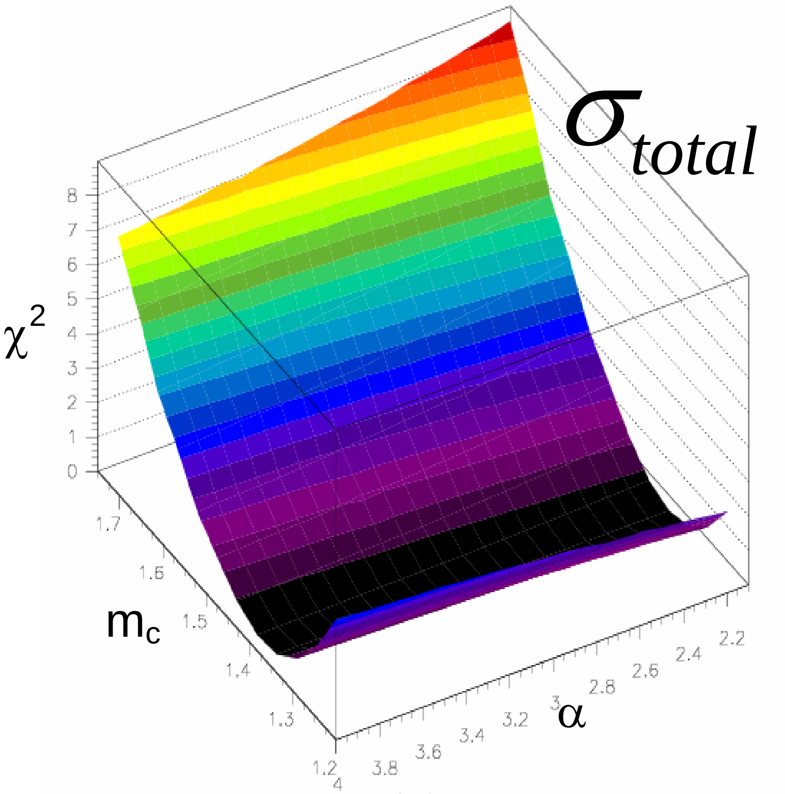

Figure 5: $\chi 2$ distribution of total cross section σ in dependence of charm mass m_c and fragmentation parameter α

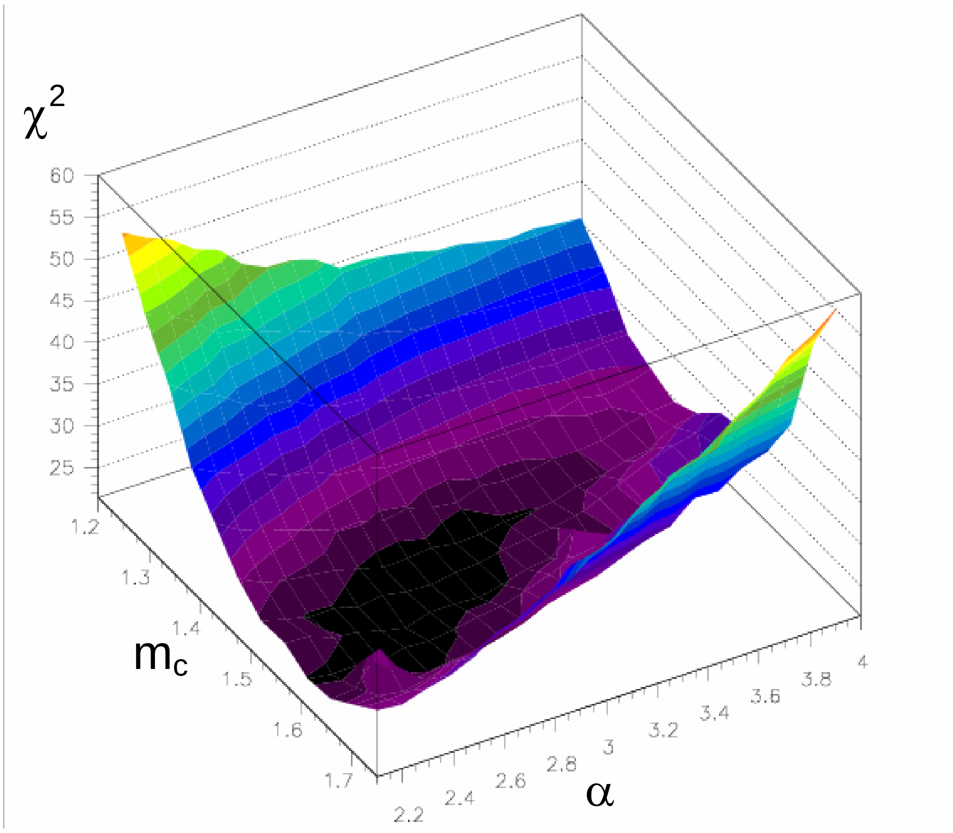

Figure 6: $\chi 2$ distribution of sum of the differential cross sections (Figures 2-4) and total cross section (Figure 5) in dependence of charm mass m_c and fragmentation parameter α

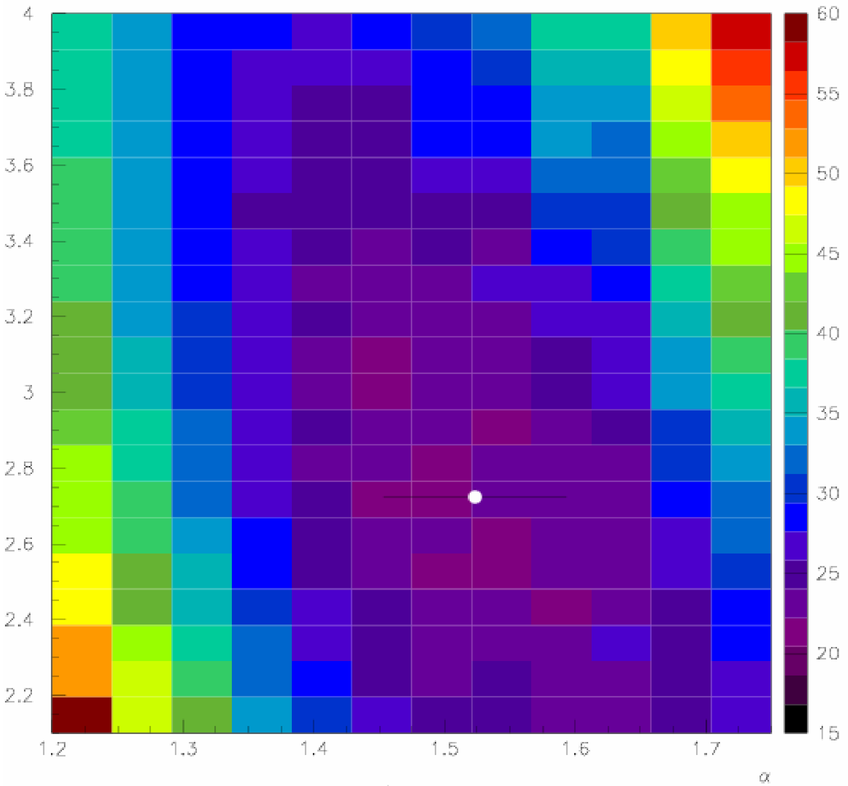

Figure 7: Two-dimensional parabolic fit on χ2 distribution of sum (Figure 6) with the minimum at m_c=1.52360 GeV and α=2.72373.