Determination of Unintegrated Parton Density Functions in J/ψ Production at HERA

Plamen Petrov

School of Physics and Astronomy, University of Birmingham, UK

Summer Student Programme at DESY 2007

Supervisor: Hannes Jung

Abstract

The process of inelastic electro and photoproduction of J/ψ mesons at HERA is used to study the uPDFs. Monte Carlo simulations are compared with data from the H1 detector. Two Hztool[6] routines are written on Fortran 77 for that purpose. The production of J/ψ mesons is simulated with CASCADE. A fitting procedure is applied in order to determine the normalization constant N and the power of x - B_g in the uPDF starting function. The research is based on data and theory from two papers - 02-059[1] and 07-071[2]

The normalization constant is estimated to be 0.161 and $B_g = 0.0378$ for photoproduction and N = 0.136, B = 0.0616 for electroproduction.

1 Introduction

The production of J/ψ mesons has been studied intensively at HERA. The high energy allows the contributing mechanisms to be studied in a wide kinematic range. Depending on the size of Q^2 and W we have photo and electroproduction. Here Q^2 is the negative squared four-momenta of the exchanged photon and W is the centre of mass energy of the photon proton system. The

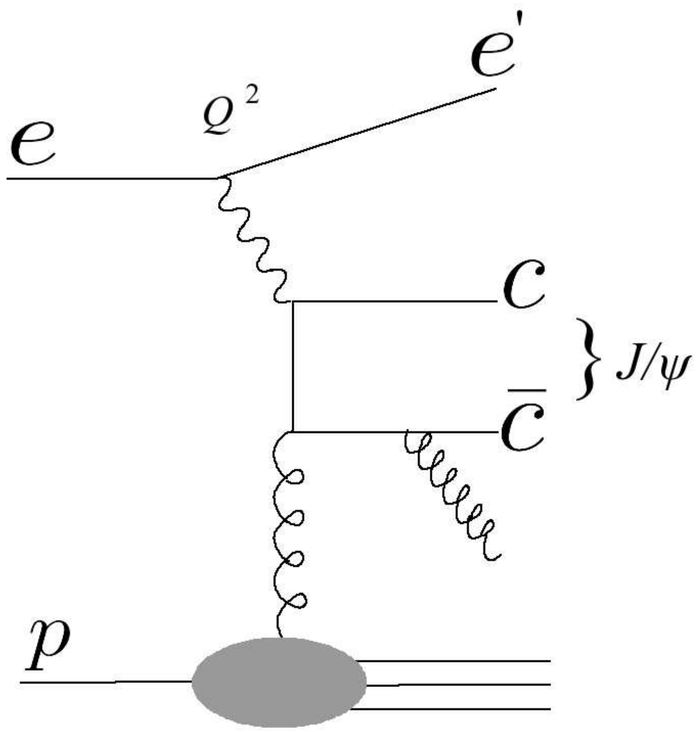

Figure 1: *Feynman diagram for charm - anticharm pair production.*

inelastic process being studied is dominated by a photon-gluon fusion. A photon emitted from the incoming lepton interacts with a gluon from the proton to produce a $c\bar{c}$ pair which forms the J/ψ. The following kinematic variables are used to describe J/ψ production: the square of the ep centre of mass energy s = $(k + p)^2$, the negative squared four-momentum transfer Q^2 = $-q^2$, the photon proton centre of mass energy W = $(p^2 + q^2)^2$. Here k, p and q are the four-momenta of the incident lepton, proton and exchange boson respectively. The fraction of the photon energy transfered to J/ψ meson in the rest frame of the proton is given by

$$z = \frac{p_\psi \cdot p}{q \cdot p}, \tag{1}$$

and the fraction of the energy transfered from the lepton to the hadronic final state is:

$$y = \frac{q.p}{k.p} \tag{2}$$

In the case when Q^2 is very small we have a photorpoduction. In this case we consider only interactions of quasi-real photons (Q^2<1 GeV^2).
Different models have been suggested to describe these events like the Colour Singlet Model (CSM) for example. CSM is implemented into the MC generator CASCADE in leading order. CASCADE contains an implementation of the k_t factorization approach using the CCFM evolution. CCFM provides a description of the evolution of the cross-section of the interaction. The direct heavy quark production processes γg > c$\bar{c}$ and b$\bar{b}$ are implemented using off-shell matrix elements convoluted with k_t-unintegrated parton distributions in the proton. Fitting the uPDFs would improve the simulation of heavy quark-antiquark pairs.

2 Comparison of Data and Simulation

Two different Hztool routines were written to implement the theory and the H1 data for the photo and electroproduction of J/ψs. The routine for the electroproduction is based on 07-071[2]. There are specific cuts which have to govern the event selection: 3.6<Q^2<100 GeV^2, 50<W<225 GeV, 0.3<z<0.9, $p_t{}^2$>1 GeV^2. Differential cross sections are measured as functions of the above parameters.
The routine for the photoproduction (HZ02059) simulates production of J/ψ mesons using parameters which have been tuned to the HERA measurements described in paper 02-059[1] The main cuts are on Q^2<1 GeV^2, $p_t{}^2$>1 GeV^2. To facilitate specific analyses the measurements have been taken into three different datasets which differ in the kinematic requirements for z, W:

I: 60<W<240 GeV, 0.3<z<0.9,
II: 120<W<260 GeV, 0.05<z<0.45,
III: 120<W<260 GeV, 0.3<z<0.9

Histograms of the single and double differential cross sections as a function of z,W,$p_t{}^2$ and Q^2 are produced for both H1 and MC data. The cross sections for the J/ψ photoproduction have been normalised by the photon flux as:

$$d\sigma_{ep} = \sigma_{\gamma p} f_{\gamma/e}(y) dy \tag{3}$$

$$f_{\gamma/e} = \frac{\alpha}{2\pi}\left(2m_e^2 y\left(\frac{1}{Q^2_{min}} - \frac{1}{Q^2_{max}}\right) + \frac{1+(1-y)^2}{y}\log\frac{Q^2_{max}}{Q^2_{min}}\right) \tag{4}$$

3 Fitting uPDFs

The uPDF is a convolution of starting distribution $A_0(x_0)$ and a perturbative evolution:

$$xA_0(x) \propto Nx^{B_g} \tag{5}$$

In CASCADE the uPDF is evolved with CCFM. A fitting is applied to optimize the parameters N and B in the starting function in order to minimize the difference between theory and data - χ^2.

$$\chi^2 = \sum i \frac{(T-D)^2}{(\sigma^2 stat + \sigma^2 uncor)}, \tag{6}$$

where T and D are the theoretical data from the MC simulations and the H1 data.
A fitting routine is used to scan for a minimum in the χ^2 distribution with respect to a chosen parameter from the starting function. A χ^2 minimums are observed for both N and B_g. The scan is not as precise as the fitting but it gives an idea of the values of the parameters. A real fitting of the uPDF parameters leads to a better description of the data by MCs and better detector simulation.

4 Results

The data from the H1 detector is compared to MC simulations done using CASCADE together with the Hztool routines HZ02059 and HZ07071 A very good agreement between H1 and MC is observed. The kinematic parameters Q^2 and ${p_t}^2$ are represented almost perfectly by the simulation.
The simulation data improves significantly after fitting the starting function. Best results could be observed for z where the deviation from experimental data was notable. The two starting functions for the electro and photoproduction have been estimated and have almost equal parameters.

$$N_{photo} = 0.136 \; N_{elec} = 0.161$$
$$B_{photo} = 0.0616 \; B_{elec} = 0.0378$$

A similar study of uPDF has been done using D* production at HERA [5]. The normalization constant have been estimated to be 0.465. This value is bigger than the one for J/ψs which brings up some questions. The two normalization constants should be similar since in both studies has been used the same MC generator (CASCADE) and the same fitting routines.

5 Acknowledgments

I am grateful to the DESY directorate for the hospitality. I would like to thank the H1 group fot the assistance. I would like to thank Dr.Hannes Jung for helping me with the theory of the MC simulations and for the continous support, and to Axel Cholewa, Thomas Chapman and Federico von Samson who have also contributed to my work.

References

[1] Inelastic Photoproduction of J/ψ Mesons at HERA, DESY-02-059

[2] Inelastic Electroproduction of Charmonium at HERA, EPS2007,19-25/07/2007, Manchester

[3] Transverse Momentum of Gluons in ep-Scattering at HERA, A. Cholewa, 11/2005, DESY

[4] Light-cone Variables, Rapidity and All That, John C. Collins, hep-ph/9705393, 22/05/1997, Penn State University

[5] Investigation of Gluon Density Parameters of Charged D* Meson Production, Thomas Chapman, DESY 09/2007

[6] J. M. Butterworth, S. Butterworth, B. M. Waugh, W. J. Stirling and M. R. Whalley, [arXiv:hep-ph/0412139]. http://www.cedar.ac.uk, *hztool version 4.2*

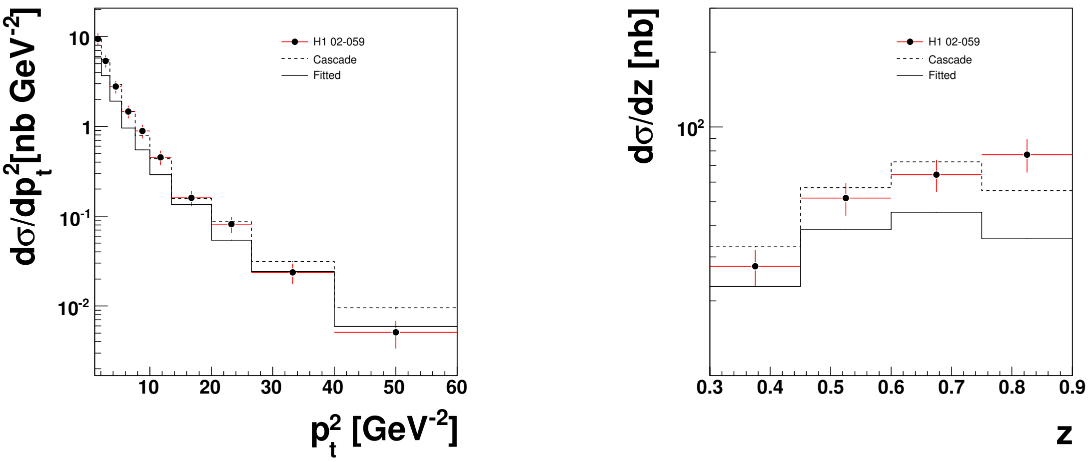

Figure 2: *Differential cross sections for J/ψ photoproduction as a function of z and p_t^2 in the region 60< W<240 GeV, 0.3<z<0.9 and $p_t{}^2$>1*

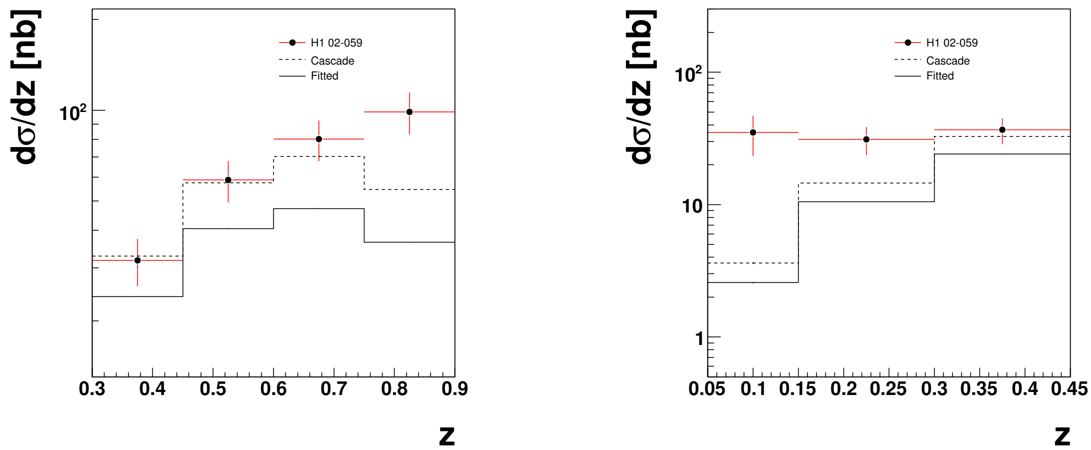

Figure 3: *Differential cross sections for J/ψ photoproduction as a function of z and p_t^2 in the region 120< W<260 GeV and $p_t{}^2$>1* The left plot presents data in the 0.3<z<0.9 range and the right one 0.05<z<0.45

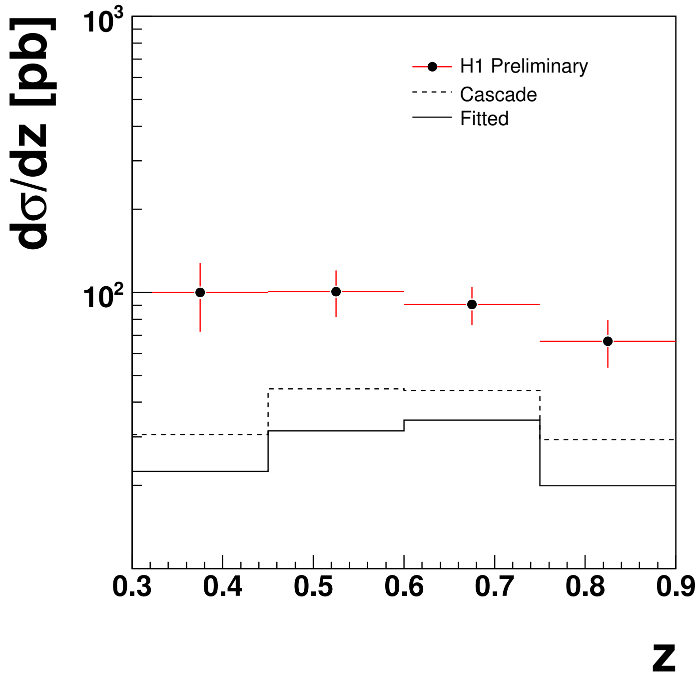

Figure 4: *Differential cross section of J/ψ electroproduction as a function of z in the region* $1 < p_t < 2$ *GeV*

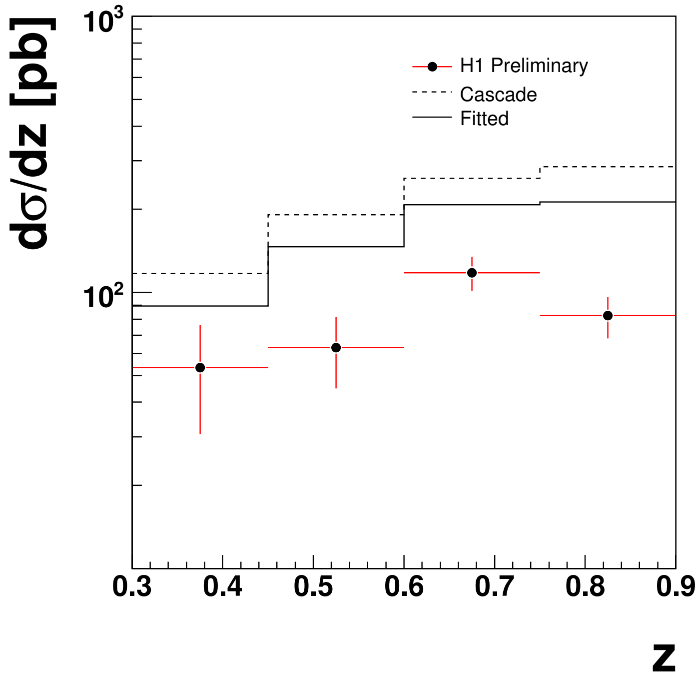

Figure 5: *Differential cross section of* J/ψ *electroproduction as a function of* z *in the region* $2 < p_t < 3.5\ GeV$

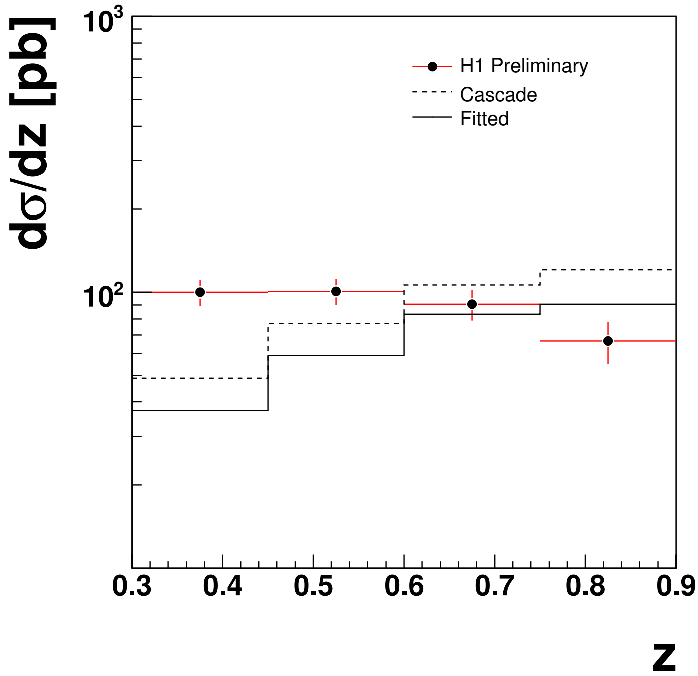

Figure 6: *Differential cross section of* J/ψ *electroproduction as a function of* z *in the region* $3.5 < p_t < 10\ GeV$

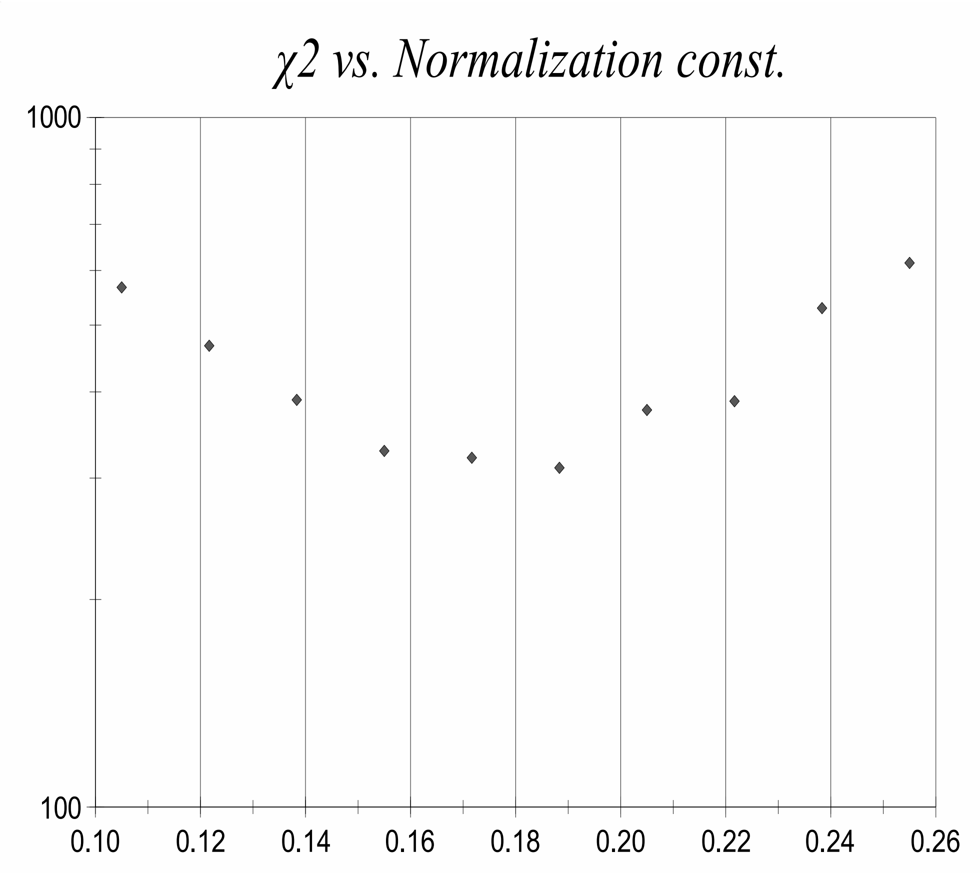

Figure 7: *The χ^2 minimum for the normalization constant*

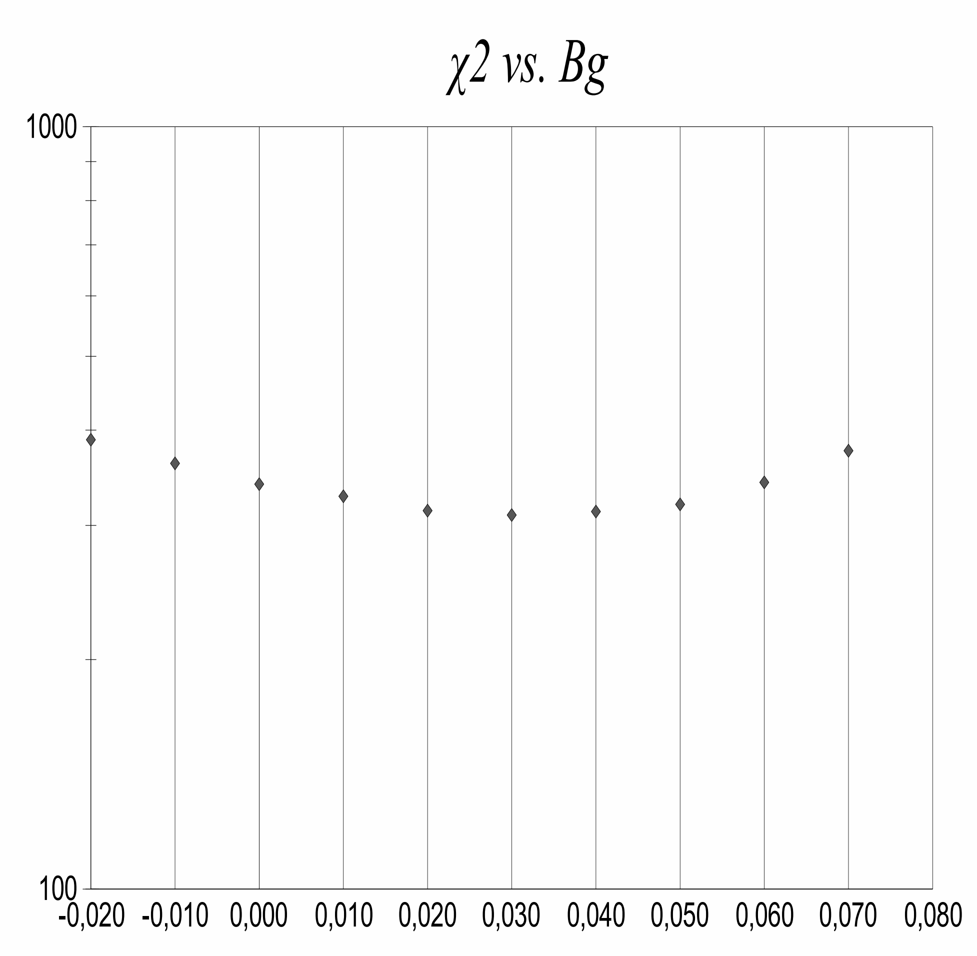

Figure 8: *The χ^2 minimum for B_g*