QCD & free α_s fits for dijets with ZEUS & H1 combined datasets.

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Summer 2013

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ABSTRACT

In this investigation, α_s values are extracted from dijet cross-sections by QCD & free α_s fits and free α_s only fits. Uncertainties are calculated and their dependence on various factors is examined. It is concluded that using a combined dataset confers a reduction in experimental uncertainties. Still the precision of such measurements remain largely restricted by the dominance of theoretical uncertainties.

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Contents

Introduction

In this brief investigation, the aim was to perform QCD and free α_s fits on inclusive and dijet datasets from ZEUS & H1. The main motivation was to perform these fits with separate and combined datasets, compare results for various datasets and check the performance of the fits and the respective results on α_s.
For this purpose, the latest version of Herafitter 0.3.1 (6) was used together with LHAPDF. For the purposes of visualising results the newest trunk version of Herafitter was used in conjunction with the DrawResults package.

The datasets used in this investigation were:

- H1ZEUS CC e+p HERA1.5 (See ref. (9) & (10))
- H1ZEUS CC e-p HERA1.5 (See ref. (9) & (10))
- H1ZEUS NC e+p HERA1.5 (See ref. (9) & (10))
- H1ZEUS NC e-p HERA1.5 (See ref. (9) & (10))
- ZEUS dijet 98-07, published (8)
- H1 dijet in ZEUS binning and phase space, unpublished
- Combined ZEUS & H1, (mentioned above) unpublished

This report is structured as such: first the methods used to run QCD & free α_s fits for various datasets are introduced, then the sensitivity of dijet data to α_s is being illustrated, demonstrating that dijet datasets are a good match for performing such fits. Results on QCD & free α_s fits and free α_s fits follow for separate and combined datasets, escorted by a series of sections on how different kind of uncertainty were calculated. The dependence of theoretical uncertainties on scales and PDF choices is investigated and an addendum on how data was visualised, along with a small development on Herafitter's trunk version follow. The report concludes with presenting all results and comparing them with previous investigations and current literature and discussing their significance.

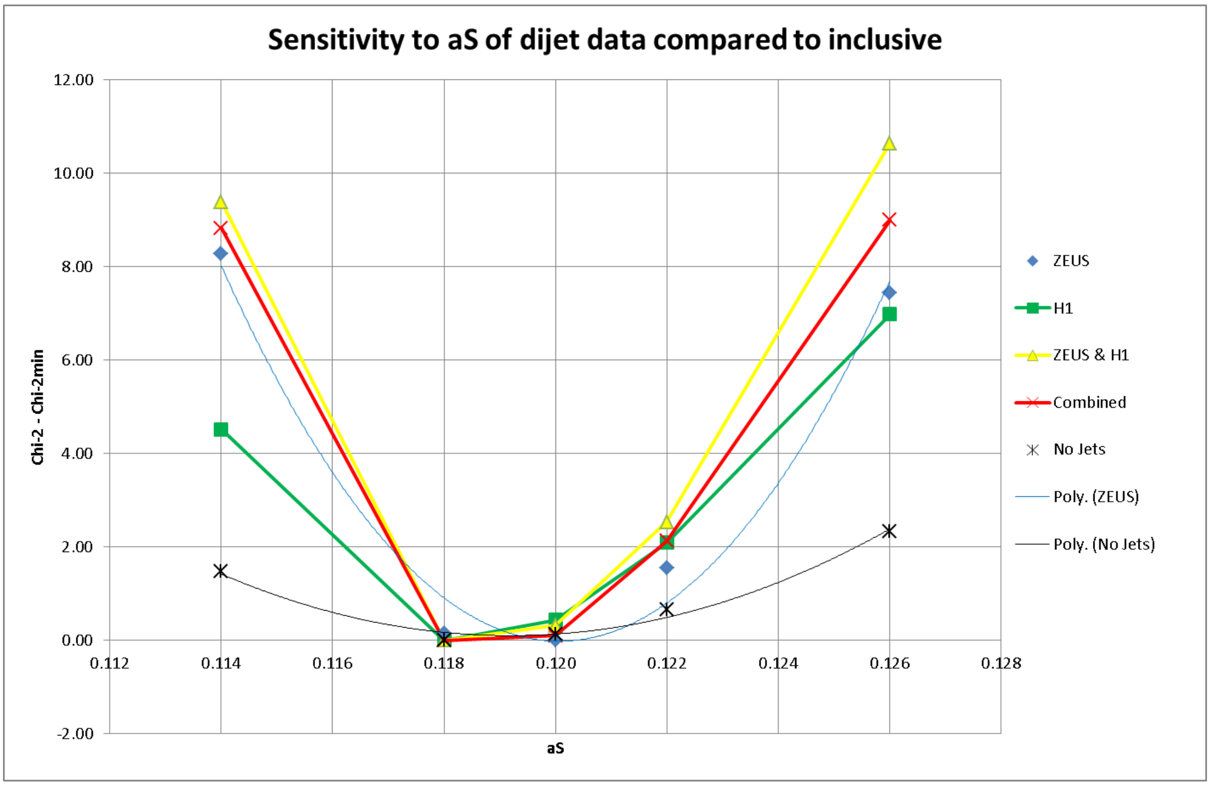
Method

Initially Herafitter 0.3.1 was set up along with the necessary components and dependencies (QCDNUM & LHAPDF). A few test fits were performed and some previously published results in the literature replicated to ensure that everything was functioning appropriately and that the different functionalities of the program were well understood and could be efficiently operated. QCD and free α_s fits were performed for the 4 inclusive datasets using different χ^2 definitions (HERAPDF , H12011, H12000)(11)(12), to ensure that such fits were independent.

CTEQ6.6	**μF=(Q²+pT²)/2**	**μR=(Q²+pT²)/2**	
χ^2	**H12011**	**H12000**	**HERAPDF**
αS	0.1180	0.1183	0.1196
exp. Uncertainty	0.0030	0.0030	0.0031

From the above table it can be seen that results only vary slightly, well within the experimental uncertainty margins, yielding a high consistency between them.
In replicating literature results, it was found that 10 free parameter fits were too restrictive and often failed to converge in QCD & free α_s fits. For this purpose 14 free parameter fits (14p) were chosen. In 13 free parameter fits, the parameters A_g,Au_v, Ad_v are constrained by the sum rules. It is assumed that $B_{\bar{U}} = B_{\bar{D}}$, $C_g^{'} = 25, A_{\bar{U}} = A_{\bar{D}}(1 - f_s)$ where f_s is the strangeness factor. Additional constraints enforced are: $A_g^{'} = B_g^{'} = 0, B_{d_v} = B_{u_v}$. 14 free parameters fits were performed using the

13 free parameters (13p) *minuit* file and freeing up D_{u_v} one of the *u*-valence quark parameters.
Note that free α_s only fits, need a special treatment and a specific *minuit* file needs to be run in conjunction with LHAPDF. In all *minuit* files the *migrad* and *hesse* options were used.
The first test performed on the datasets was a QCD fit with fixed α_s at different values to examine the sensitivity of dijet data to α_s. For this purpose 5 separate fits were performed: a) inclusive, b) inclusive & ZEUS dijet dataset, c) inclusive & H1 dijet in ZEUS binning dataset, d) inclusive & ZEUS & H1 datasets, e) inclusive & combined datasets, all set in the μF=μR=(Q2+pT2)/2 scale.



From the above plot, it can be seen that the inclusive fit is relaxed in par with α_s, whereas dijet fits are much more restrictive and sensitive to α_s variations. This is a good indication that dijet data confer an advantage in determining α_s through free α_s fits. Additionally, it is evident that using both ZEUS & H1 datasets, either separately or combined offer a significant advantage over using only one of them, even though there isn't much of a difference between the separate (ZEUS & H1) and combined fits.
The next natural step since QCD fits for dijets show sensitivity to α_s, would be to free α_s and observe how fits are being influenced. For this purpose 4 fits were performed, the inclusive only fit was abandoned as it was not sensitive enough to α_s. The fits were as above a) inclusive & ZEUS, b) inclusive & H1, c) inclusive & ZEUS & H1, d) inclusive & combined.

QCD & aS	Chi-2	Chi2/DOF	Data Points	aS	exp. error
ZEUS	751.96	1.104	681	0.1191	0.0018
H1	759.20	1.115	681	0.1184	0.0020
ZEUS & H1	777.85	1.106	703	0.1187	0.0015
Combined	750.59	1.102	681	0.1189	0.0016

From the table above it can be seen that α_s values for different datasets are compatible, as is the χ^2. Experimental uncertainties coming only from data uncertainties are lower when 2 datasets are being used, be it in the separate (ZEUS & H1) or in the combined case.
Similarly for α_s only fits, the results follow. In these fits the dijet datasets are being fitted on their own and not along the 4 inclusive datasets. The following fits were performed: a) ZEUS dijet, b) H1

dijet, c) ZEUS & H1 dijet, d) combined dijet. CT10 PDF was used for the purpose of these fits. The scales used for theory calculations were chosen to be: $\mu^2_R = \mu^2_F = (Q^2+P_T^2)/2$.

aS ONLY					
CT10 $\mu^2R=\mu^2F=(Q^2+PT^2)/2$	**Chi-2**	**Chi-2/DOF**	**Data Points**	**aS**	**exp.**
ZEUS	17.93	0.854	21	0.1189	0.0031
H1	24.63	1.173	21	0.1197	0.0027
ZEUS & H1	42.60	0.991	42	0.1194	0.0020
Combined	10.60	0.517	21	0.1191	0.0017

Once again, α_s values are compatible amongst the different datasets and so is χ^2. Uncertainties are once again lower when using ZEUS & H1 dijet datasets, be it in the separate or combined case. Next a section on how different uncertainty values are being calculated for each fit and dataset follows.

<u>Theory Uncertainties</u>

Theory uncertainties have been calculated by varying the renormalisation (μ^2R) and factorisation (μ^2F) scales, rerunning the fit and adding in quadrature the deviations from the nominal α_s value. The scales were varied by a factor of 2 and 0.5 separately for each respective scale. This yielded four additional variants to the nominal value fit for each dataset (ZEUS, H1, ZEUS & H1, combination). Additionally, different scales were used, as well as different PDFs to check dependence of theory uncertainties on these factors. Tables of values can be found in appendix 1. These options were accessible in the *steering* file and the files containing the data for each dataset. More specifically factoring the scale was done through the *steering* file and different scales were set inside the respective dataset file.

<u>Steering File</u>

```
* (Optional) Modify renormalisation/factorisation scales,
dataset
* dependently. The numbering follows sequential numbering
of input files
*
&Scales
   DataSetMuR  = 4*1.0    ! Set muR scale to 1 for all 4
datasets
   DataSetMuF  = 4*1.0    ! Set muF scale to 1 for all 4
datasets
   DataSetIOrder = 4*2    ! Set Order for APPLGRID (needed
for NNLO fits)
&End
```

<u>Data File</u>

```
 NInfo   = 4
   DataInfo = 319.,      1.,            3.,    3.   ! to be updated
   CInfo    = 'sqrt(S)', 'PublicationUnits','MurDef', 'MufDef'
```

From scale variations and different PDF style fits it was determined that theory uncertainties don't have such dependence. The PDF choice of CT10 yielded slightly higher values of α_s compared to MSTW2008. From the tables in Appendix 1 it is clear that varying the renormalisation scale μR leads to the largest changes in fitted α_s. The theory uncertainties are much larger than experimental ones.

						Theory	
QCD & aS	Chi-2	Chi2/DOF	Data Points	aS	exp. error	+	-
ZEUS	751.96	1.104	681	0.1191	0.0018	-	-
H1	759.20	1.115	681	0.1184	0.0020	-	-
ZEUS & H1	777.85	1.106	703	0.1187	0.0015	-	-
Combined	750.59	1.102	681	0.1189	0.0016	0.0030	0.0043

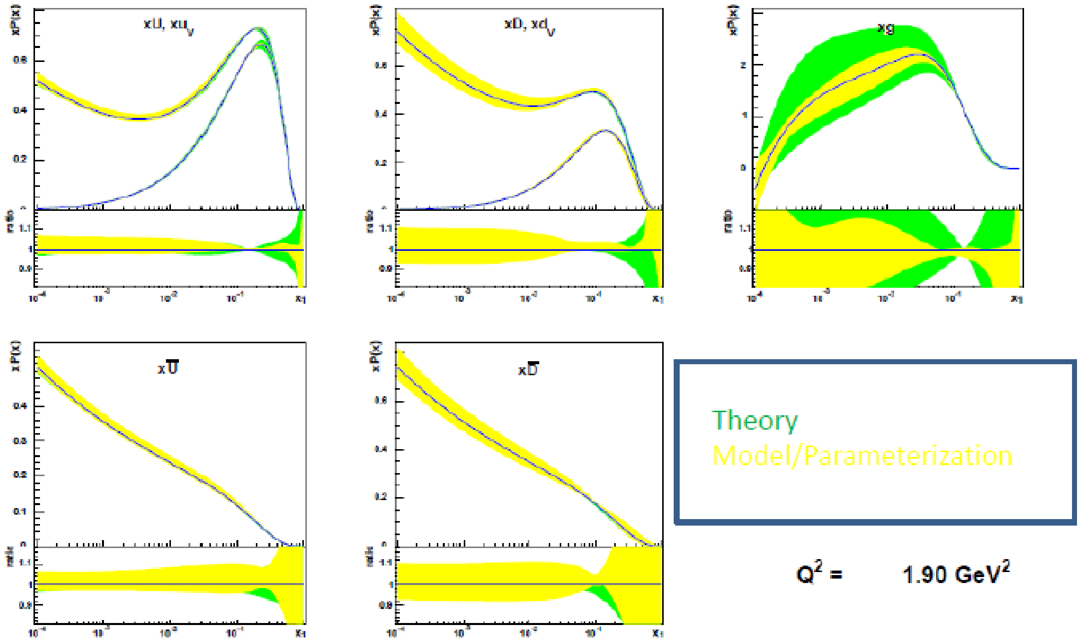
aS ONLY						Theory	
CT10 $\mu^2R=\mu^2F=(Q^2+PT^2)/2$	Chi-2	Chi-2/DOF	Data Points	aS	exp.	+	-
ZEUS	17.93	0.854	21	0.1189	0.0031	0.0071	0.0083
H1	24.63	1.173	21	0.1197	0.0027	0.0052	0.0050
ZEUS & H1	42.60	0.991	42	0.1194	0.0020	0.0059	0.0065
Combined	10.60	0.517	21	0.1191	0.0017	0.0045	0.0043

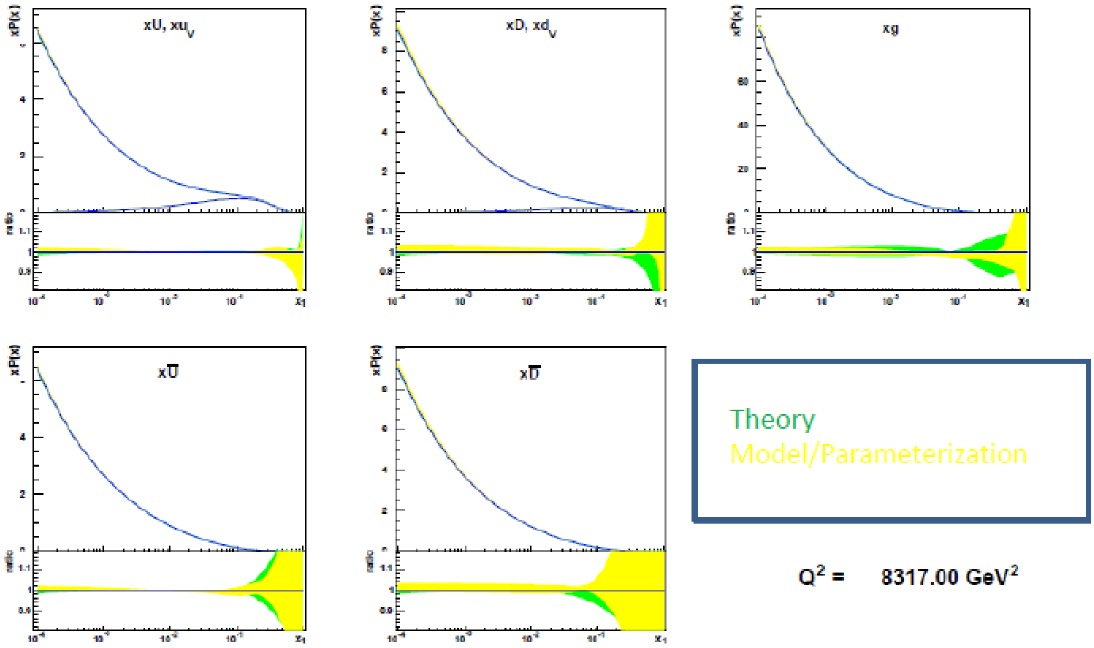
Model/ Parameterisation Uncertainties

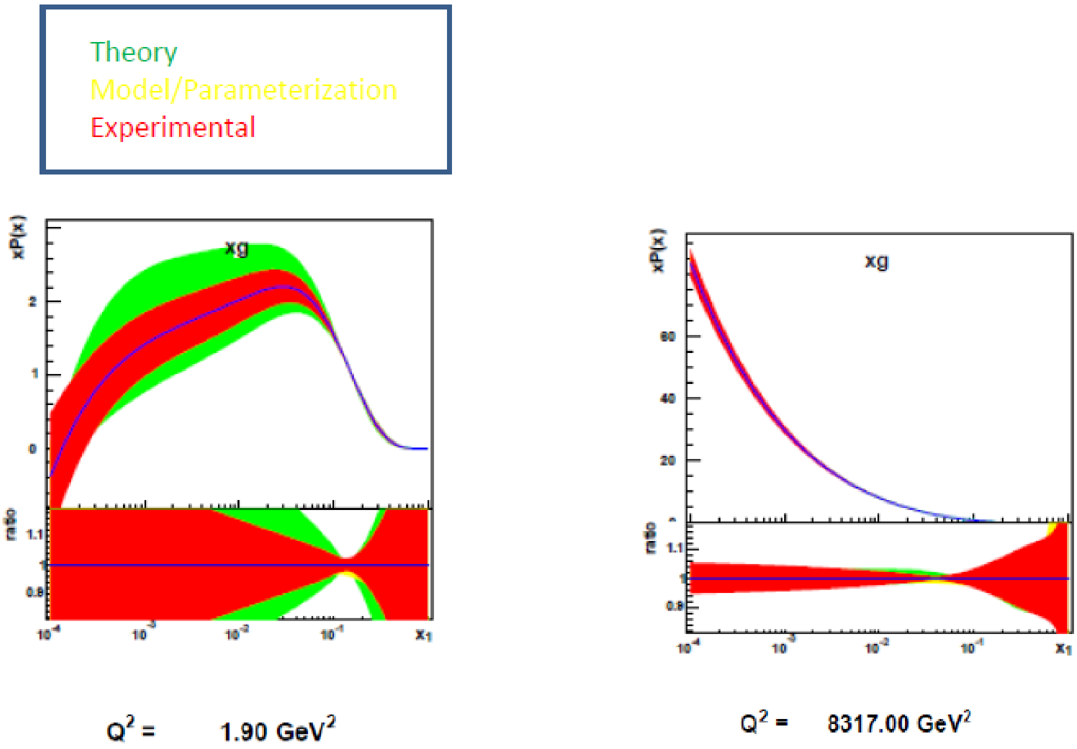
Concerning model and parameterisation uncertainties, these were determined using the model assumption variations as those performed for HERAPDF1.5. Uncertainties are calculated by adding in quadrature the deviations from the nominal value of α_s yielded by a QCD & α_s free fit for the inclusive dataset and the corresponding dijet dataset(s). The table below demonstrates the model parameter variations:

Model parameter	Nominal Value	Lower Limit	Upper Limit
Strange fraction f_s	0.31	0.23	0.38
Charm mass m_c [GeV]	1.4	1.35	1.65
Beauty mass m_b *[GeV]*	4.75	4.3	5.0
Minimum Q^2 [GeV^2]	3.5	2.5	5.0

Model/Parameterization uncertainties compared to theory uncertainties for QCD & free α_s fits with combined datasets:


xU, xu_V
xD, xd_V
xg
xŪ
xD̄
Theory
Model/Parameterization
Q² = 1.90 GeV²


xU, xu_V
xD, xd_V
xg
xŪ
xD̄
Theory
Model/Parameterization
Q² = 8317.00 GeV²



From these plots it can be seen that the theory uncertainty has the largest contribution. Model/parameterization uncertainties are comparable to experimental uncertainties as seen for QCD & free α_s fits.

Hadronization Uncertainty

To determine hadronization uncertainties, QCD & free α_s fits and free α_s only fits were performed whilst varying the hadronization corrections by ±1.5%. Note that this is not a valid method for calculating hadronization uncertainties, which should be done using Monte Carlo simulations, but is rather a quick and nifty way to get an estimate of the order of magnitude and hence contribution from this source of uncertainty. The estimation of ±1.5% as hardroization correlated uncertainty comes from the ZEUS published paper and private communication with the H1 group.

Results

						Model/Param		Theory		Hadronisation	
QCD & aS	Chi-2	Chi2/DOF	Data Points	aS	exp. error	+	-	+	-	+	-
ZEUS	751.96	1.104	681	0.1191	0.0018	0.0016	0.0004	-	-	0.0006	0.0012
H1	759.20	1.115	681	0.1184	0.0020	0.0019	0.0007	-	-	0.0009	0.0016
ZEUS & H1	777.85	1.106	703	0.1187	0.0015	0.0012	0.0003	-	-	0.0002	0.0018
Combined	750.59	1.102	681	0.1189	0.0016	0.0016	0.0006	0.0030	0.0043	0.0004	0.0011

aS ONLY						Theory		Hadronisation	
CT10 3-3 Scale	Chi-2	Chi-2/DOF	Data Points	aS	exp.	+	-	+	-
ZEUS	17.93	0.854	21	0.1189	0.0031	0.0071	0.0083	0.0010	0.0025
H1	24.63	1.173	21	0.1197	0.0027	0.0052	0.0050	0.0012	0.0010
ZEUS & H1	42.60	0.991	42	0.1194	0.0020	0.0059	0.0065	0.0011	0.0017
Combined	10.60	0.517	21	0.1191	0.0017	0.0045	0.0043	0.0011	0.0015

Here follows a comparison of HERAPDF1.6 (top value) with the results previously shown. HERAPDF1.6 refers to a QCD & free α_s fit with 4 inclusive jet datasets. All results from this investigation relate to dijet data only.

$$a_s(M_Z) = 0.1202 \pm 0.0013(\exp) \pm 0.0007(param) \pm 0.0012(hadronisation)^{+0.0045}_{-0.0036}(scale)$$
$$a_s(freeZEUS\ \&\ H1) = 0.1194 \pm 0.0020(\exp)^{+0.0059}_{-0.0065}(scale)^{+0.0011}_{-0.0017}(hadronisation)$$
$$a_s(freeCOMBINED) = 0.1191 \pm 0.0017(\exp)^{+0.0045}_{-0.0043}(scale)^{+0.0011}_{-0.0015}(hadronisation)$$
$$a_s(QCD\ \&\ aScombined) = 0.1189 \pm 0.0016(\exp)^{+0.0016}_{-0.0006}(param)^{+0.0030}_{-0.0043}(scale)^{+0.0004}_{-0.0011}(hadronisation)$$

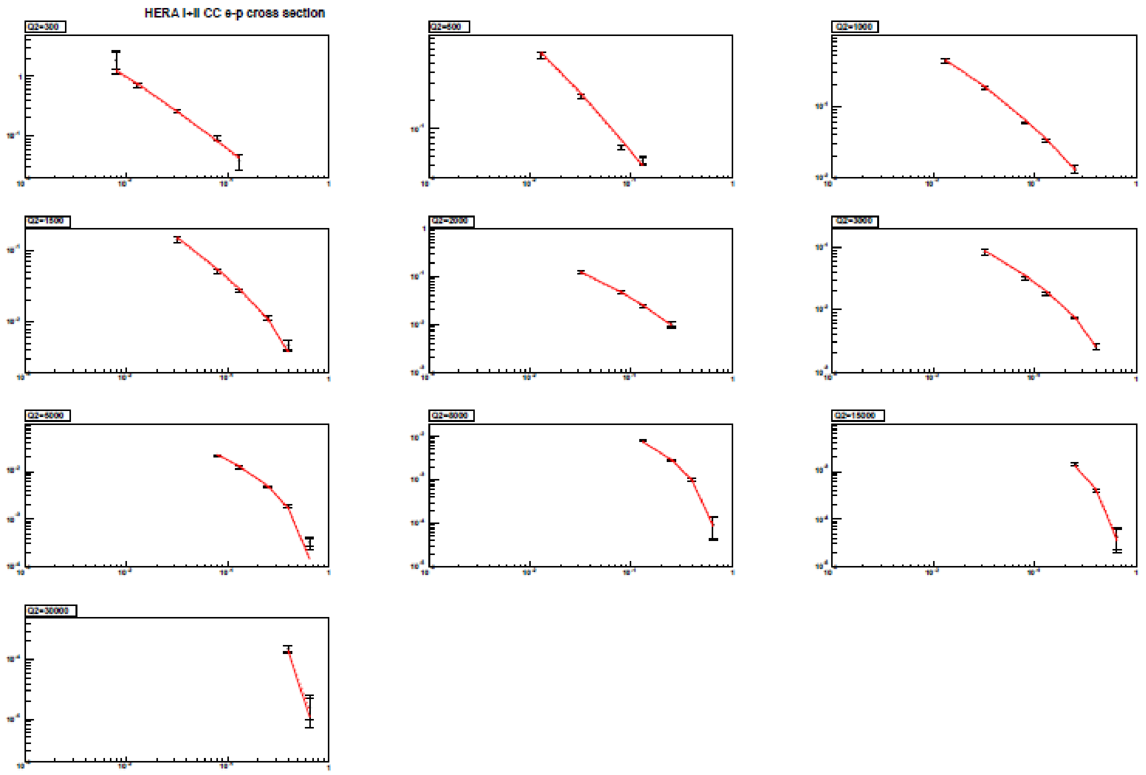
Discussion

Theory uncertainties have the largest contribution amongst all sources of uncertainty. Experimental uncertainties are slightly larger in the results of this investigation. Still theory uncertainties are compatible amongst different fits, and the same applies to hadronization uncertainties.

Development

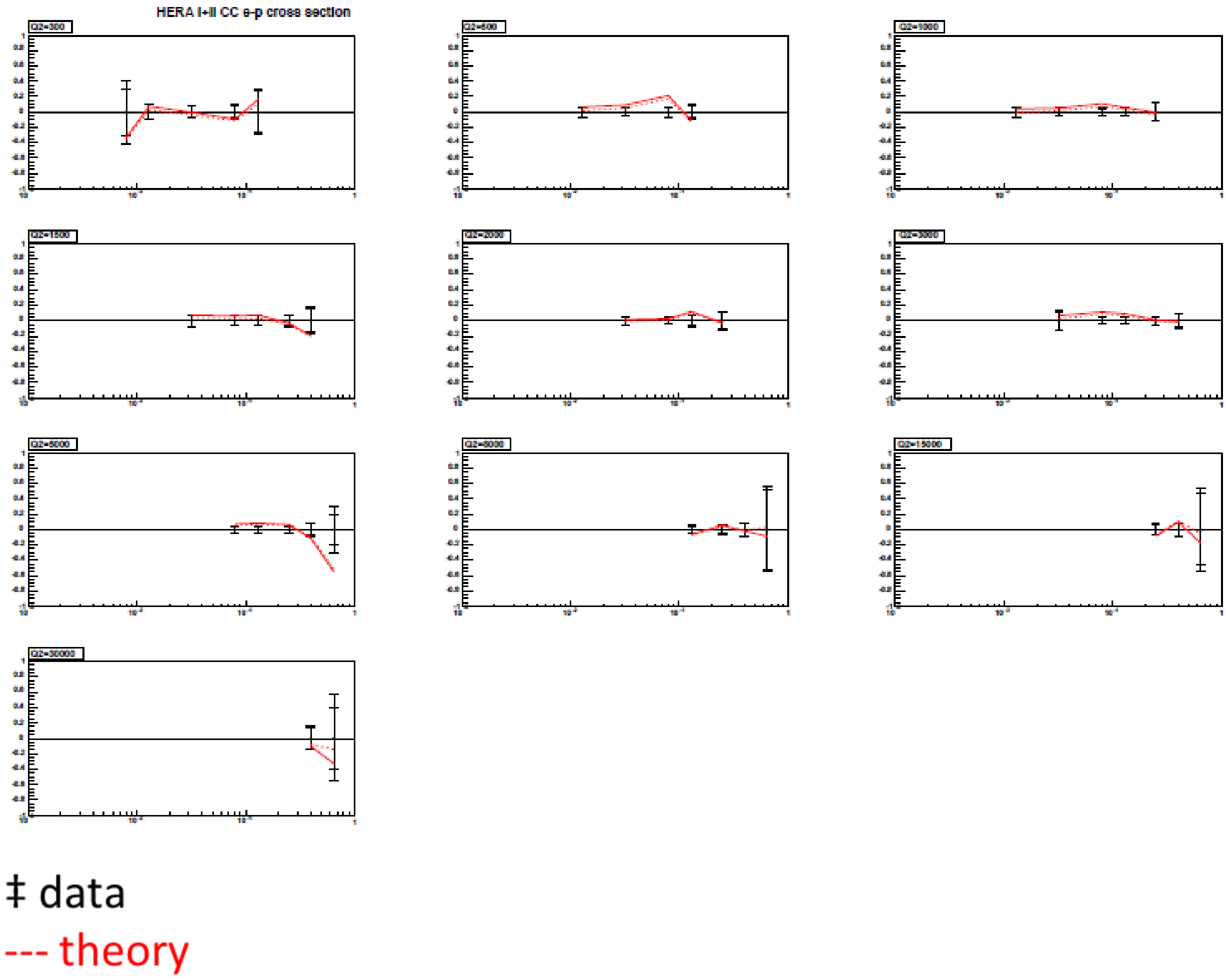
For this part of the investigation, a small development in the trunk version of Herafitter was carried out. The three dijet dataset files (ZEUS, H1, combined) were modified to produce plots of cross sections in bins of Q^2 and P_T of jet, including uncertainties, when using the DrawResults functionality, which is part of the DrawResults package. An example follows demonstrating a binned plot of dijet cross sections and a second example displaying ratios of measured cross sections to theory predictions.

Cross Sections



‡ data
--- theory

Ratio of data & theory



Summary

This investigation focused on the performance of QCD & free α_s fits and free α_s fits only using dijet datasets. Results for α_s values have been presented and compared to published values. Various kinds of uncertainties have been calculated or estimated for these fits and α_s values. Theory uncertainties were found to have the largest contribution. Model/parametrization uncertainties were of the same order of magnitude as experimental uncertainties. Hadronization uncertainties were only estimated roughly but yielded a sensible result, of the same order of magnitude as those in the literature (HERAPDF1.6). All uncertainties were found to be of the same order of magnitude and comparable to those found in the literature for similar fits. A development of the trunk version of Herafitter was completed which allowed visualisation of cross sections in bins of Q^2 and P_T of jet, including uncertainties, for inclusive and dijet datasets in DrawResults functionality.

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Appendix 1

Dependence on scale and different PDFs.

aS ONLY			Theory				
CT10 $\mu^2R=\mu^2F=(Q^2+PT^2)/2$	**aS**	**exp.**	**+**	**-**	**Chi-2**	**Chi-2/DOF**	**Data Points**
ZEUS	0.1189	0.0031	0.0071	0.0083	17.93	0.854	21
H1	0.1197	0.0027	0.0052	0.0050	24.63	1.173	21
ZEUS & H1	0.1194	0.0020	0.0059	0.0065	42.60	0.991	42
Combined	0.1191	0.0017	0.0045	0.0043	10.60	0.517	21

aS ONLY			Theory				
CT10 μ2R= (Q^2+PT^2), μ2F=Q^2	**aS**	**exp.**	**+**	**-**	**Chi-2**	**Chi-2/DOF**	**Data Points**
ZEUS	0.1222	0.0034	0.0072	0.0074	14.49	0.690	21
H1	0.1220	0.0029	0.0057	0.0046	28.70	1.366	21
ZEUS & H1	0.1221	0.0022	0.0062	0.0057	43.18	1.004	42
Combined	0.1211	0.0018	0.0051	0.0041	15.38	0.732	21

aS ONLY			Theory				
MSTW2008 $\mu^2R=\mu^2F=(Q^2+PT^2)/2$	**aS**	**exp.**	**+**	**-**	**Chi-2**	**Chi-2/DOF**	**Data Points**
ZEUS	0.1174	0.0031	0.0070	0.0080	17.58	0.837	21
H1	0.1191	0.0027	0.0051	0.0049	26.57	1.265	21
ZEUS & H1	0.1184	0.0020	0.0058	0.0064	44.32	1.031	42
Combined	0.1183	0.0017	0.0045	0.0042	11.99	0.571	21

aS ONLY			Theory				
MSTW2008 μ2R= (Q^2+PT^2), μ2F=Q^2	**aS**	**exp.**	**+**	**-**	**Chi-2**	**Chi-2/DOF**	**Data Points**
ZEUS	0.1206	0.0033	0.0070	0.0071	13.99	0.666	21
H1	0.1214	0.0029	0.0056	0.0046	30.31	1.443	21
ZEUS & H1	0.1211	0.0022	0.0061	0.0057	44.33	1.031	42
Combined	0.1203	0.0018	0.0050	0.0041	15.92	0.758	21