
HERAFitter Tutorial

introduction, installation and examples

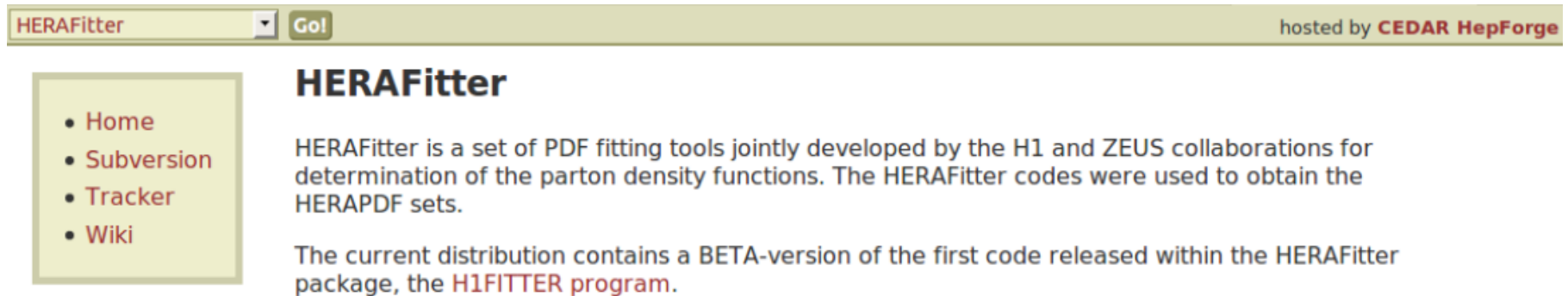
Ringailė Plačakytė



QCD@LHC
24.08.2012

Introduction

A fitting tool available for fast feedback to analysers and studies within the experimental working groups: **HERAFitter**



The screenshot shows the top navigation bar of the HERAFitter project page. On the left, there is a search box containing the text 'HERAFitter' and a 'Go!' button. On the right, it says 'hosted by CEDAR HepForge'. Below the navigation bar, there is a sidebar with a list of links: Home, Subversion, Tracker, and Wiki. The main content area features the title 'HERAFitter' in a large, bold font. Below the title, there is a paragraph of text: 'HERAFitter is a set of PDF fitting tools jointly developed by the H1 and ZEUS collaborations for determination of the parton density functions. The HERAFitter codes were used to obtain the HERAPDF sets.' Below this paragraph, there is another paragraph: 'The current distribution contains a BETA-version of the first code released within the HERAFitter package, the H1FITTER program.'

- a set of PDF fitting tools for determination of the parton distribution functions

- developers: H1 and ZEUS, ATLAS, CMS, theorists
- the first beta version released in September 2011
- **beta2** release in May 2012, July 2012

HERAFitter package available online at <http://projects.hepforge.org/herafitter/>

HERAFitter Project



HERAFitter

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More Actions:

HERAFitter



Welcome to HERAFitter Project

HERAFitter is a QCD Fit Package used to determine HERAPDFs and it is part of the HERAPDF project <https://www.desy.de/h1zeus>.

Downloads of HERAFitter software package

New HERAFitter release is available! The HERAFitter releases can be accessed [HERE](#) upon registration. Everyone is free to register.

Registration

To register, please log in (upper right corner) by creating an account (firstnamelastname, example: [JohnSmith](#)) and send your request and login name to herafitter-help@desy.de.

HERAFitter Meetings

- **User's Meetings:** monthly meetings to enhance communication between users and developers (open access)
- **Developer's Meeting:** technical weekly meetings to ensure communication among developers (restricted access)
- **Steering Group's Meeting** (restricted access)

Developers Info (restricted to developers)

[Internal Developments](#)

Organisation

- **Conveners:** Voica Radescu, Sasha Glazov, Amanda Cooper-Sarkar
- **Release coordinator:** Sasha Glazov
- **Contact Persons:** Klaus Rabbertz (CMS), Bogdan Malaescu (ATLAS), Olaf Behnke (ZEUS), Cristi Diaconu (H1)
- **Steering Group:** Voica Radescu, Sasha Glazov, Amanda Cooper-Sarkar, Klaus Rabbertz (CMS), Bogdan Malaescu (ATLAS), Olaf Behnke (ZEUS), Cristi Diaconu (H1, chair), Gavin Salam (theory)
- **Librarians:** authors/developers of individual modules
- **Getting help:** Send email to herafitter-help@desy.de

HERAFitter: HERAFitter (last edited 2012-08-13 15:25:22 by [VoicaRadescu](#))

License and References

- LICENSE: under GNU General Public License v3
- REFERENCES: Citation depending on the usage

If you use the HERAFITTER package in a scientific publication, please consider adding the following references. The main citations list contains the papers which should be cited for any use of the HERAFITTER program. In addition, some citations are required depending on the modules, data and theory tables used in the program.

=====

Main citations

=====

HERAFitter

1) "Combined Measurement and QCD Analysis of the Inclusive e^+p Scattering Cross Sections at HERA."
By H1 and ZEUS Collaboration (F.D. Aaron et al.). DESY-09-158, Oct 2009. 61pp.
Published in JHEP 1001:109,2010.
e-Print: arXiv:0911.0884 [hep-ex]

2) "A Precision Measurement of the Inclusive ep Scattering Cross Section at HERA."
By H1 Collaboration (F.D. Aaron et al.). DESY-09-005, 2009. 35pp.
Published in Eur.Phys.J.C64:561-587,2009.
e-Print: arXiv:0904.3513 [hep-ex]

QCDNUM (evolution code)

"Fast QCD Evolution and Convolution", M. Botje,
NIKHEF-10-002, May 2010. 74pp.
Published in Comput.Phys.Commun.182:490-532,2011.
e-Print: arXiv:1005.1481 [hep-ph]

=====

Citations depending on the usage

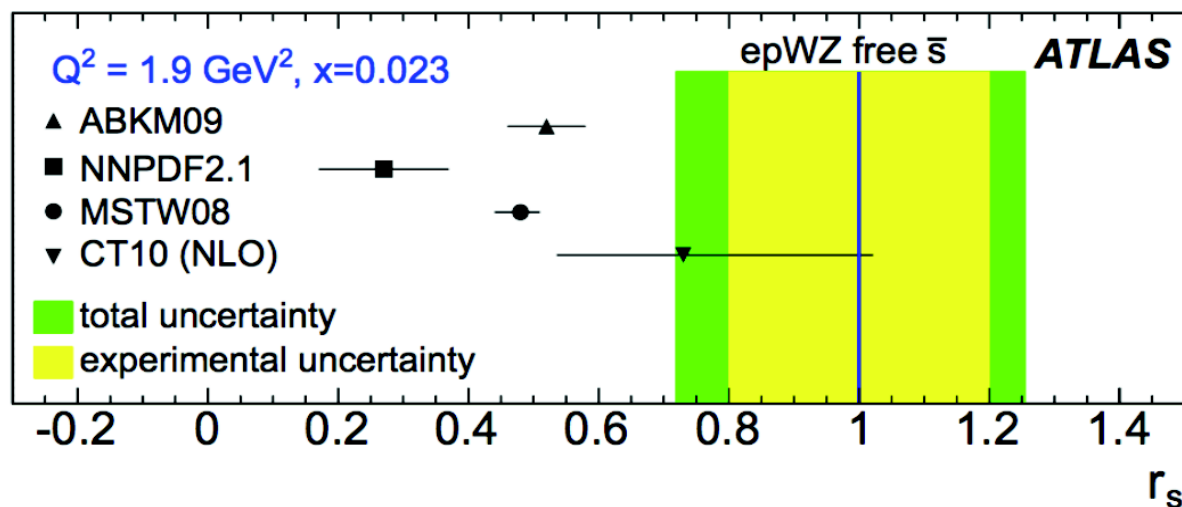
=====

Example of HERAFitter usage

New ATLAS result:

The differential W^\pm, Z cross section data of ATLAS (2010, 35/pb) were jointly analysed with $e^\pm p$ cross sections from HERA

<http://arxiv.org/pdf/1203.4051v1.pdf>



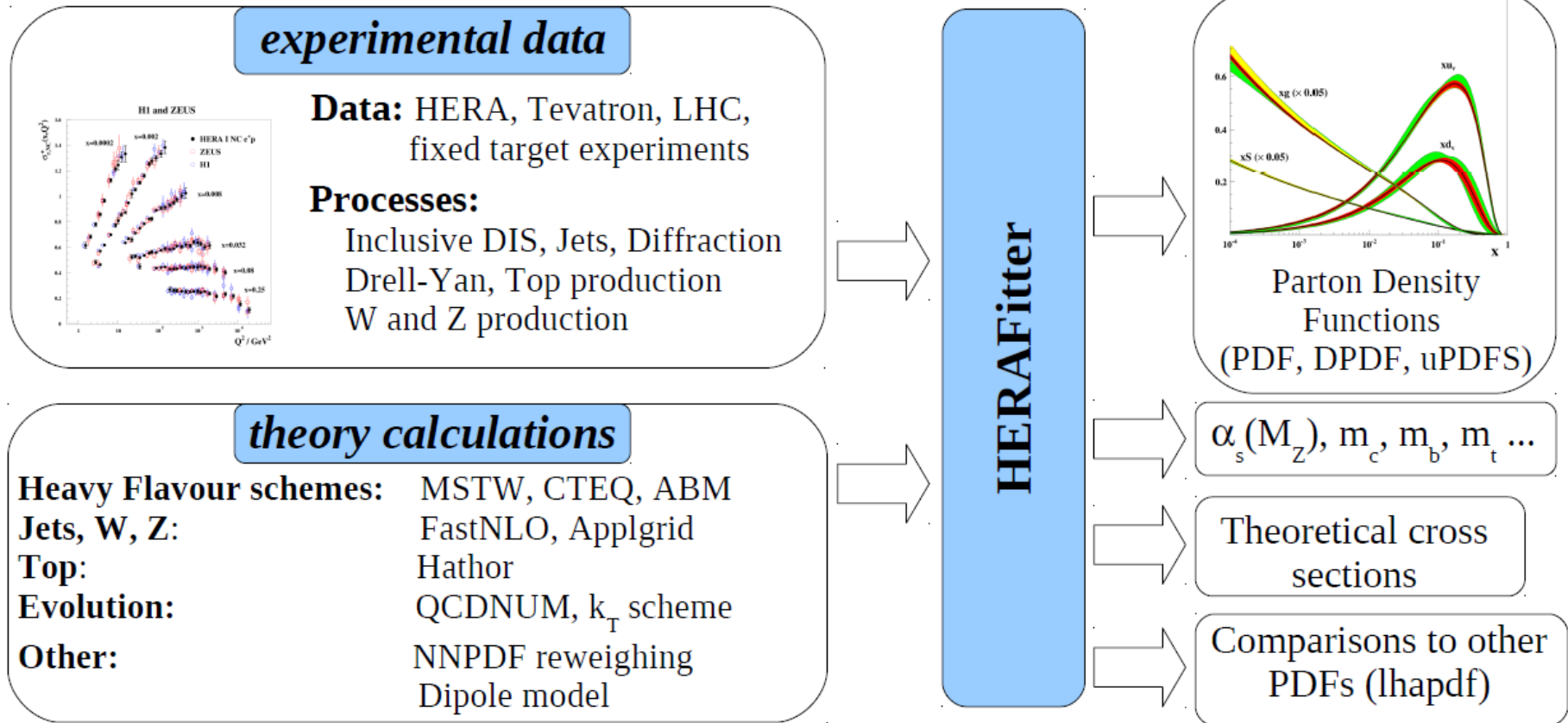
$$r_s = 1.00 \pm 0.20_{\text{exp}} \pm 0.07_{\text{mod}}^{+0.10} \pm 0.06_{-0.15}^{\text{par}} \pm 0.08_{-0.07}^{\alpha_S} \text{th.}$$

→ at LHC ratio of W/Z cross sections together with y_z shape provide a constraint on s-quark density

First LHC publication using HERAFitter

HERAFitter: Overview

Modular structure of HERAFitter:



HERAFitter: Physic Cases

- Determination of proton PDFs from HERA data
 - Inclusive NC and CC processes
 - including low Q^2 phenomenology (DIPOLE vs DGLAP models)
 - DIS charm data
 - Inclusive DIS jets * (PDF + alphas)
 - Diffractive PDF fits
- LHC data:
 - Inclusive differential W, Z cross sections
 - Drell Yan at low and higher masses
 - Jet production * (PDF + alphas)
 - ttbar cross sections
- Studies concerning different treatment of correlations
 - Hessian, MC, Offset
- Further developments:
 - Benchmarking of theories
 - Fits using kt evolution
 - averaging tool (combine measurements)
 - ratio of top/antitop cross sections
 - W+charm

HERAFitter description

The software code is a mixture of C++ and Fortran codes. The core interfaces are provided in the Fortran part of the code.

- standard Fortran method used to input information: namelist files

In the central steering file input data and fitting parameters defined

- contains several namelists, e.g. data cuts and data module

Output contains basic text information to

- control consistency of the input data/fit parameters (error logging),
- report quality of the fit: χ^2 , pulls, etc,
- report resulting PDFs: simple text and HERAGRID LHAPDF format.

HERAFitter: installation

Described in README

Pre-requirements

=====

- QCDNUM version at least qcdnum-17-00/04
<http://mbotje.web.cern.ch/mbotje/qcdnum/Site/QCDNUM17.html>

- CERNLIB
e.g. from CERN: [/afs/cern.ch/sw/lcg/external/cernlib/](http://afs.cern.ch/sw/lcg/external/cernlib/)

- Optional:
link to recent Root libraries (e.g. version 5.26)
APPLGRID, HATHOR, LHAPDF, NNPDFreweighting tool
(APPLGRID and NNPDF reweighting tool require Root to be installed)

- HERAFitter has been tested on various platforms:
SL4, SL5 (32 and 64 bit), Ubuntu 10.10, 11.10, MAC

HERAFitter: data

Data are provided as text files with a namelist header and the main body, as a table:

```
&Data
  Name = 'CC cross section HERA-I H1-ZEUS combined e-p.'
  NData = 34
  NColumn = 120 ! 3 bins, sigma and 116 errors
! Layout of the data table columns: 3 bins, cross-section and 116 errors
! The following types are predefined: Bin, Sigma, Error and Dummy (case sensitive!)
  ColumnType = 3*'Bin','Sigma',116*'Error'

! To treat error uncorrelately, then: first is uncor, then the sys_i(i=1,114) -> 115 sources
!   Bins      x-sec          Errors
  ColumnName = 'x','Q2','y','x-section','stat','uncor',110*'uncor',4*'ignore'

.....

! To take into account the correlations then set SystScales to 1. and uncomment below:
! ColumnName = 'x', 'Q2', 'y', 'Sigma',
!             'stat', 'uncor', 'h1', 'h2', 'h3', 'h4', 'h5', 'h6', 'h7', 'h8', 'h9', 'h10', .....
```

← *define data format*

← *error treatment*

HERAFitter: systematic uncertainties

Three types of systematic uncertainties are distinguished:

- statistical ('**stat**')
- uncorrelated (name contains '**uncor**' sub-string)
- correlated (**any other name**)

Systematic uncertainties are correlated among different data files if they have the same name;

After minimization, shifts and estimated reduction of uncertainty for the nuisance parameters corresponding to the systematic error sources are reported in **output/Results.txt** file:

Systematic shifts	(sigma)	(error)
1 h1	0.1348 +/-	0.4709
2 h2	-0.6975 +/-	0.8086
3 h3	0.0209 +/-	0.9939
4 h4	-1.0008 +/-	0.8446
5 h5	0.3473 +/-	0.9906
6 h6	0.5485 +/-	0.9268
7 h7	-2.1711 +/-	0.8740
.....		

HERAFitter: data

&Data

Name = 'CC cross section HERA-I H1-ZEUS combined e-p.'

NData = 34

NColumn = 120 ! 3 bins, sigma and 116 errors

← *define data format*

! Layout of the data table columns: 3 bins, cross-section and 116 errors

! The following types are predefined: Bin, Sigma, Error and Dummy (case sensitive!)

ColumnType = 3*'Bin','Sigma',116*'Error'

! To treat error uncorrelately, then: first is uncor, then the sys_i(i=1,114) -> 115 sources

! Bins x-sec Errors

ColumnName = 'x','Q2','y','x-section','stat','uncor',110*'uncor',4*'ignore'

← *error treatment*

NInfo = 4

DataInfo = 318., -1., 0., 0.

CInfo = 'sqrt(S)','e charge', 'reduced', 'e polarity'

← *additional information*

IndexDataset = 63

Reaction = 'CC e+-p'

← *reaction name*

! To take into account the correlations then set SystScales to 1. and uncomment below:

! ColumnName = 'x', 'Q2', 'y', 'Sigma',

! 'stat', 'uncor', 'h1', 'h2', 'h3', 'h4', 'h5', 'h6', 'h7', 'h8', 'h9', 'h10',

! To treat the uncertainties as absolute use "false"

← *abs or rel errors?*

Percent = 116>true

&END

Note: inclusion of new data tables for existing processes doesn't require code recompilation

HERAFitter: data relation to theory

Theory predictions for a given data file are controlled by the **Reaction** namelist variable

- at each iteration, a loop is run over the data files and the theory calculations are matched to the data inside **GetTheoryForDataset** subroutine

```
.....  
elseif (DATASETREACTION(IDataSet).eq.'NC e+-p charm') then  
    Call GetNCCharmXsection(IDataSet, HFSCHEME)  
elseif (DATASETREACTION(IDataSet).eq.'CC e+-p') then  
    Call GetCCXsection(IDataSet, HFSCHEME)  
elseif (DATASETREACTION(IDataSet).eq.'CC pp' .or.  
$    DATASETREACTION(IDataSet).eq.'CC ppbar' ) then  
    Call GetDYCCXsection(IDataSet)  
.....
```

To add a new theory module:

- add initialization call in **init_theory.f**, see subroutine **init_theory_datasets**
- add call to your theory module in **theory_dispatcher.f**, see **GetTheoryForDataset**

HERAFitter: data relation to theory

Theory predictions for a given data file are controlled by the **Reaction** namelist variable

- at each iteration, a loop is run over the data files and the theory calculations are matched to the data inside **GetTheoryForDataset** subroutine

```
Subroutine GetCCXsection(IDataSet, local_hfscheme)
call GetDisXsection(IDataSet, 'CCDIS', local_hfscheme)
```

C Get indexes for Q2, x and y bins:

```
idxQ2 = GetBinIndex(IDataSet,'Q2')
```

```
idxX = GetBinIndex(IDataSet,'x')
```

```
....
```

```
do i=1,NDATAPOINTS(IDataSet)
```

```
    idx = DATASETIDX(IDataSet,i)
```

```
    X(i) = AbstractBins(idxX,idx)
```

```
    Q2(i) = AbstractBins(idxQ2,idx)
```

```
enddo
```

```
call CalcReducedXsectionForXYQ2(X,Y,Q2,NDATAPOINTS(IDataSet),
$  charge,polarity,IDataSet,XSecType, local_hfscheme,XSec)
```

```
....
```

```
XSec = 0.5*(yplus*F2 + yminus*xF3 - y*y*FL)
```

← index of abstract bins determined by name

← get index of global data array

← build the cross section

→ see Mandy's talk

To add a new theory module:

-add initialization call in **init_theory.f**, see subroutine **init_theory_datasets**

-add call to your theory module in **theory_dispatcher.f**, see **GetTheoryForDataset**

HERAFitter: steering.txt

Central steering file to define input data and fitting parameters
steering.txt:

&InFiles

! Number of input files

NInputFiles = 4

! Input files:

InputFileNames(1) = 'datafiles/hera/H1ZEUS_NC_e-p_HERA1.0.dat'

InputFileNames(2) = 'datafiles/hera/H1ZEUS_NC_e+p_HERA1.0.dat'

InputFileNames(3) = 'datafiles/hera/H1ZEUS_CC_e-p_HERA1.0.dat'

InputFileNames(4) = 'datafiles/hera/H1ZEUS_CC_e+p_HERA1.0.dat'

&End

*

* (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

&End

← data files
(HERAPDF1.0)

← vary μ_R and μ_F scale
(currently works only for
jet data)

HERAFitter: steering.txt

&H1Fitter

ITheory = 0 ! =0 use collinear factorisation with QCDNUM

IOrder = 2 ! For itheory =0 (collinear factorisation) : LO fit (1) or NLO (2) or NNLO (3)

← *choose order*

Q02 = 1.9 ! Evolution starting scale

← *starting scale*

! --- Scheme for heavy flavors :

! --- HF_SCHEME = 'ZMVFNS' : ZM-VFNS (massless),

! --- HF_SCHEME = 'RT' : Thorne-Roberts VFNS (massive)

! --- HF_SCHEME = 'RT FAST' : Fast approximate TR VFNS scheme, usign k-factor

! --- HF_SCHEME = 'RT OPT' : Thorne-Roberts VFNS (massive)

! --- HF_SCHEME = 'RT OPT FAST' : Fast approximate TR VFNS scheme, usign k-factor

! --- HF_SCHEME = 'ACOT Full' : ACOT - F.Olness Version (massive), using k-factors

! --- HF_SCHEME = 'ACOT Chi' : ACOT - F.Olness Version (massive), using k-factors

! --- HF_SCHEME = 'ACOT ZM' : ACOT - F.Olness Version (massless), using k-factors

! --- HF_SCHEME = 'FF' : Fixed Flavour Number Scheme (qcdnum)

! --- HF_SCHEME = 'FF ABM' : Fixed Flavour Number Scheme (ABM)

HF_SCHEME = 'RT'

← *treatment for
heavy flavour
(more on next
slide)*

HERAFitter: steering.txt

HF_SCHEME = 'ZMVFNS'	: ZM-VFNS (massless)	
HF_SCHEME = 'RT'	: Thorne-Roberts VFNS (massive)	} <i>used by MSTW08</i>
HF_SCHEME = 'RT OPT'	: Thorne-Roberts VFNS (massive)	
HF_SCHEME = 'RT OPT FAST'	: Fast approximate TR VFNS scheme, using k-factor	
HF_SCHEME = 'RT FAST'	: Fast approximate TR VFNS scheme, using k-factor	
HF_SCHEME = 'ACOT Full'	: ACOT - F.Olness Version (massive), using k-factors	} <i>used by CTEQ/CT</i>
HF_SCHEME = 'ACOT Chi'	: ACOT - F.Olness Version (massive), using k-factors	
HF_SCHEME = 'ACOT ZM'	: ACOT - F.Olness Version (massless), using k-factors	
HF_SCHEME = 'FF'	: Fixed Flavour Number Scheme (qcdnum)	} <i>ABM (OPENQCDRAD, incl running mass)</i>
HF_SCHEME = 'FF ABM'	: Fixed Flavour Number Scheme (ABM)	

Note:

RT FAST : kfactors are ratio of SF(RT) to SF(QCDNUM), speed up factor ~ 15 ;

ACOT : kfactors are ratio of SF(NLO) to SF(LO)

FF scheme ($n_f=3$): requires smaller $\alpha_s(M_Z)$, proper scale choice and only NC DIS data can be fitted (NLO coefficients for CC, $W \rightarrow c$ available in latest OPENQCDRAD version)

HERAFitter: steering.txt

! PDF parameterisation style. Possible styles are currently available:
! '10p HERAPDF' -- HERAPDF-like with extra assumption $B_{uv} = B_{dv}$
! '13p HERAPDF' -- HERAPDF-like with B_{uv} and B_{dv} floated independently
! '10p H12000' -- H12000-like (D,U,Dbar,Ubar+g)
! 'CTEQ' -- CTEQ-like parameterisation
! 'CHEB' -- CHEBYSHEV parameterisation based on glu,sea, uval,dval evolved pdfs
! 'LHAPDFQ0' -- use lhpdf library to define pdfs at starting scale and evolve with local qcdnum parameters
! 'LHAPDF' -- use lhpdf library to define pdfs at all scales
! 'DDIS' -- use Diffractive DIS

PDFStyle = '10p HERAPDF'

← *choose parameterisation style*

HERAFitter: steering.txt

! PDF parameterisation style. Possible styles are currently available:
! '10p HERAPDF' -- HERAPDF-like with extra assumption $B_{uv} = B_{dv}$
! '13p HERAPDF' -- HERAPDF-like with B_{uv} and B_{dv} floated independently
! '10p H12000' -- H12000-like ($D, U, \bar{D}, \bar{U} + g$)
! 'CTEQ' -- CTEQ-like parameterisation
! 'CHEB' -- CHEBYSHEV parameterisation based on $glu, sea, u_{val}, d_{val}$ evolved pdfs
! 'LHAPDFQ0' -- use lhapdf library to define pdfs at starting scale and evolve with local $qcdnum$ parameters
! 'LHAPDF' -- use lhapdf library to define pdfs at all scales
! 'DDIS' -- use Diffractive DIS

PDFStyle = '10p HERAPDF'

← choose parameterisation style

10p HERAPDF:

$$\begin{aligned}xg(x) &= A_g x^{B_g} (1-x)^{C_g}, \\xu_v(x) &= A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} \left(1 + E_{u_v} x^2\right), \\xd_v(x) &= A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}, \\x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}}, \\x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}}.\end{aligned}$$

A: overall normalisation
B: small x behavior
C: $x \rightarrow 1$ shape

$xg, xu_v, xd_v, x\bar{U}, x\bar{D}$

where $x\bar{U} = x\bar{u}$ and $x\bar{D} = x\bar{d} + x\bar{s}$ at the starting scale ($x\bar{s} = f_s x\bar{D}$)

13p HERAPDF: $B_{uv} \neq B_{dv}$, $xg(x) = A_g x^{B_g} (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g}$

HERAFitter: steering.txt

! PDF parameterisation style. Possible styles are currently available:
! '10p HERAPDF' -- HERAPDF-like with extra assumption $B_{uv} = B_{dv}$
! '13p HERAPDF' -- HERAPDF-like with B_{uv} and B_{dv} floated independently
! '10p H12000' -- H12000-like (D,U,Dbar,Ubar+g)
! 'CTEQ' -- CTEQ-like parameterisation
! 'CHEB' -- CHEBYSHEV parameterisation based on glu,sea, uval,dval evolved pdfs
! 'LHAPDFQ0' -- use lhpdf library to define pdfs at starting scale and evolve with local qcdnum parameters
! 'LHAPDF' -- use lhpdf library to define pdfs at all scales
! 'DDIS' -- use Diffractive DIS

PDFStyle = '10p HERAPDF'

← *choose parameterisation style*

Note:

The χ^2 minimization in HERAFitter is based on MINUIT package which uses minuit steering cards included in `minuit.in.txt` file

HESSE reports improved error estimation and correlations among PDF parameters

HERAFitter: minuit.in.txt

```
set title
new 10p HERAPDF
parameters
 1 'Ag'          0.0000  0.
 2 'Bg'          0.213846 0.010000
 3 'Cg'          9.013846 0.500000
 4 'Dg'          0.0000  0.
 5 'Eg'          0.0000  0.
 7 'Aprig'       0.0000  0.
 8 'Bprig'       0.0000  0.
 9 'Cprig'       0.0000  0.
11 'Auv'         0.0000  0.
12 'Buv'         0.665589 0.010000
13 'Cuv'         4.652237 0.500000
14 'Duv'         0.0000  0.
15 'Euv'         9.693753 0.500000
....
23 'Cdv'         4.291377 0.500000
.....
33 'CUbar'       2.582025 0.100000
41 'ADbar'       0.162609 0.001000
42 'BDbar'      -0.165110 0.001000
43 'CDbar'       2.404802 0.100000
.....
```

other parametrisation styles
available in *input_steering/*

*PDF parameters
for HERAPDF1.0*

```
set eps 1.0e-11
```

```
*set print 3
call fcn 3
*migrad 200000
*hesse
```

1 iteration

run minimisation with error estimation (HESSE)

```
return
```

HERAFitter: steering.txt

```
! PDF parameterisation style. Possible styles are currently available:  
! '10p HERAPDF' -- HERAPDF-like with extra assumption  $B_{uv} = B_{dv}$   
! '13p HERAPDF' -- HERAPDF-like with  $B_{uv}$  and  $B_{dv}$  floated independently  
! '10p H12000' -- H12000-like (D,U,Dbar,Ubar+g)  
! 'CTEQ'      -- CTEQ-like parameterisation  
! 'CHEB'      -- CHEBYSHEV parameterisation based on glu,sea, uval,dval evolved pdfs  
! 'LHAPDFQ0'  -- use lhapdf library to define pdfs at starting scale and evolve with local qcdnum parameters  
! 'LHAPDF'    -- use lhapdf library to define pdfs at all scales  
! 'DDIS'     -- use Diffractive DIS
```

```
PDFStyle = '10p HERAPDF'
```

```
! -- Choice of the chi2 function  
! 'H12000' : Pascaud-like, systematic shifts to theory, no scaling of stat, uncor errors.  
! 'HERAPDF' : Pascaud-like + "mixed error scaling"  
! 'HERAPDF Sqrt' : Pascaud-like + "sqrt error scaling"  
! 'HERAPDF Linear' : Pascaud-like + "linear error scaling"
```

```
CHI2Style = 'HERAPDF'
```

```
! Debug flag  
LDEBUG = False
```

← choose
parametrisation
style (has to be
consistent with
minuit.in.txt)

← choose χ^2 style

HERAFitter: data model

Several χ^2 models are available, steerable by the `CHI2Style` parameter. For example, `CHI2Style = 'HERAPDF'` turns on default HERAPDF treatment:

$$\chi^2 = \sum_i \frac{(D_i - T_i^*)^2}{(\delta_i^{unc})^2}$$

↑
Uncorrelated error

$$T_i^* = T_i + \sum_j \xi_j \delta_i^{cor,j}$$

↑ ↑
Nuisance parameter Correlated error

$$\delta_i^{cor,j} = \beta_{ij} T_i$$

↑
Relative corr. error

Also covariance matrix approach available (**NOT IN BETA**) (defined in `CHI2Style` and correlations provided in data file):

Full covariance matrix approach (new)

$$\chi^2 = \sum_{i,j} (D_i - T_i) Cov_{i,j}^{-1} (D_j - T_j)$$

statistical uncorrelated correlated

↓ ↓ ↓

$$Cov = C^{stat} + C^{uncor} + C^{corr}$$

$$C_{i,j}^{stat} = Corr^{stat} \delta_i^{stat} \delta_j^{stat}$$

↑

Statistical correlations
between bins

$$C_{i,j}^{uncor} = \delta_{ij} \delta_i^{unc} \delta_j^{unc}$$

↑

Kronecker delta

$$C_{i,j}^{corr} = \sum_k \delta_i^{cor,k} \delta_j^{cor,k}$$

↑

Sum over all correlated
systematics

Advantage: statistical correlations can be taken into account

Disadvantage: All errors in one bin, no nuisance parameters

HERAFitter: steering.txt

```
* Add extra to minuit parameters. These MUST include alpha_S and fs
*
```

```
&ExtraMinimisationParameters
```

```
  name = 'alphas', 'fs', 'fcharm'
  value = 0.1176, 0.31, 0.
  step = 0.0 , 0.0 , 0. ! set to 0 to avoid minimisation
&End
```

← *extra parameters*

```
* Output steering cards
```

```
&Output
```

```
! -- Error bands on parton distributions
DoBands = True

! -- Q2 values at which the pdfs & errors are done (up to 20)
Q2VAL = 1.9, 4., 10., 100., 6464, 8317
.....
&End
```

← *uncertainty calculation (alternative is MC method)*

```
* Process dependent cuts
```

```
&Cuts
```

```
!----- CC ep -----

ProcessName(3) = 'CC e+-p'
Variable(3)    = 'Q2'
CutValueMin(3) = 3.5
CutValueMax(3) = 1000000.0

ProcessName(4) = 'CC e+-p'
Variable(4)    = 'x'
CutValueMin(4) = 0.000001
CutValueMax(4) = 1.0
```

← *apply cuts on data*

To run: bin/FitPDF < steering.txt

HERAFitter: output

contains basic text information to

- control consistency of the input data/fit parameters (error logging)
- report quality of the fit: χ^2 , pulls, etc.
- report resulting PDFs: simple text and HERAGRID in LHAPDF format

```
After minimisation  575.04  582  0.988
```

```
Dataset  1  106.61  145  NC cross section HERA-I H1-ZEUS combined e-p.
Dataset  2  419.26  379  NC cross section HERA-I H1-ZEUS combined e+p.
Dataset  3   19.82   34  CC cross section HERA-I H1-ZEUS combined e-p.
Dataset  4   29.35   34  CC cross section HERA-I H1-ZEUS combined e+p.
Correlated Chi2  0.0000000000000000
----- in store-pdfs -----
cpu_time  39.86  40.17  0.31
```

```
*****
***      Error Summary      ***
*****
```

```
Total number of logged errors:      710
Total number of errors not recorded:  0
```

HERAFitter: output

Fit parameters after minimisation are stored in `minuit.out.txt`

```
FCN= 575.0359 FROM MIGRAD STATUS=CONVERGED 615 CALLS 618 TOTAL
      EDM= 0.15E-05 STRATEGY=1 ERROR MATRIX ACCURATE
```

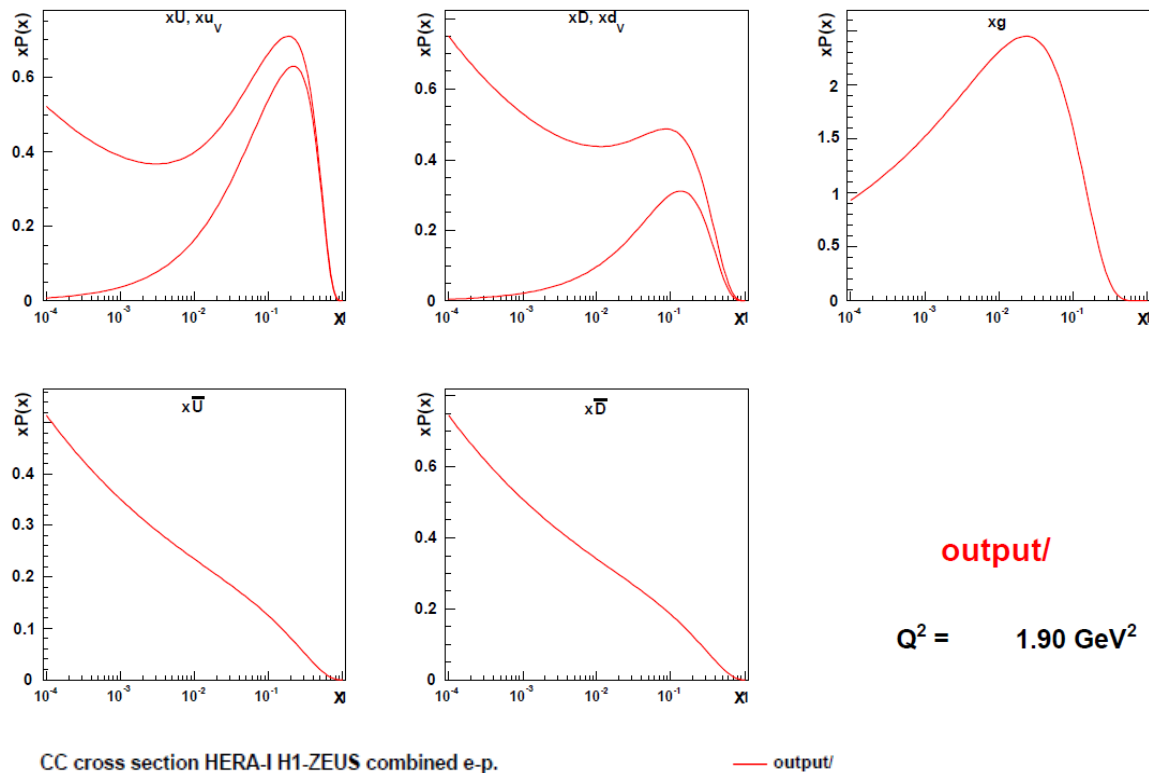
EXT	PARAMETER			STEP	FIRST
NO.	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	Ag	0.0000	constant		
2	Bg	0.21632	0.29456E-01	0.22902E-03	0.25760
3	Cg	9.0533	0.67835	0.36572E-02	-0.15650E-01
....					
12	Buv	0.66922	0.25666E-01	0.13553E-03	0.55788
13	Cuv	4.6363	0.16280	0.11213E-02	-0.62138E-01
15	Euv	9.5510	1.8416	0.98395E-02	0.72997E-02
23	Cdv	4.2411	0.40275	0.42453E-02	-0.17455E-01
33	CUbar	2.6620	0.42256	0.43560E-02	-0.20266E-01
....					
41	ADbar	0.16364	0.66138E-02	0.63512E-04	-0.67733
42	BDbar	-0.16460	0.54047E-02	0.43168E-04	1.6647
43	CDbar	2.4644	0.52313	0.28737E-02	-0.23417E-01

... and grid file in LHAPDF format
(use `tools/tolhapdf.cmd` to create PDF.LHgrid file)

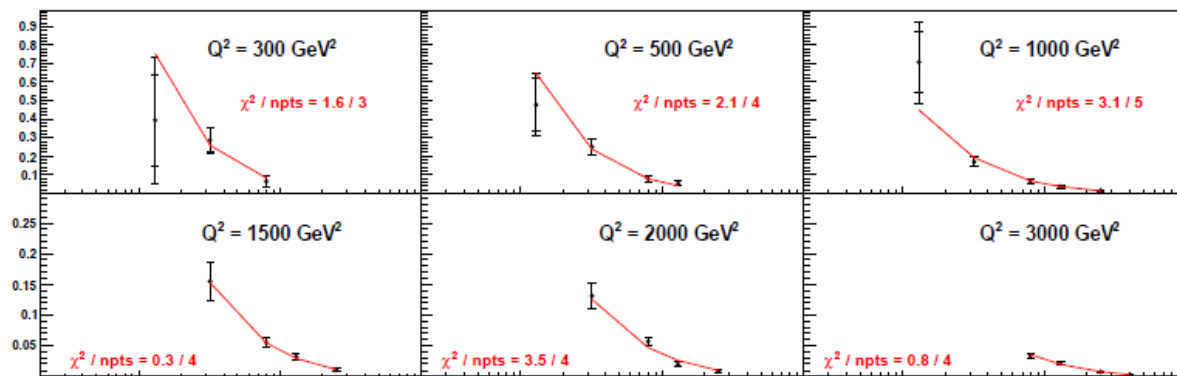
To plot: `bin/DrawResults` output

HERAFitter: output

- PDFs at specified scales



- Theory predictions for each data point
(also in `output/fittedresults.txt`)



HERAFitter: PDF uncertainties

HERAFitter package includes extension of the MINUIT package from J.Pumplin which allows to perform detailed error analysis of PDFs and report full errors in terms of eigenvectors
→ steerable by **DoBands** namelist parameter

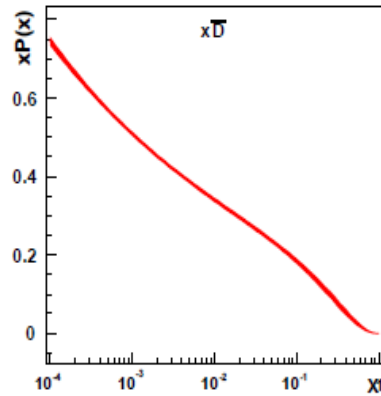
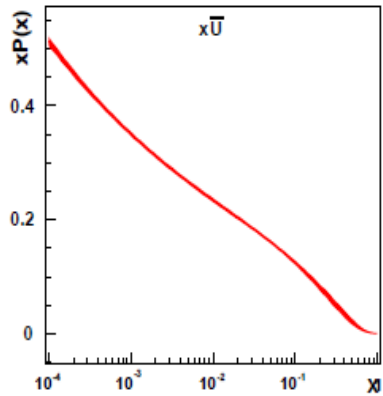
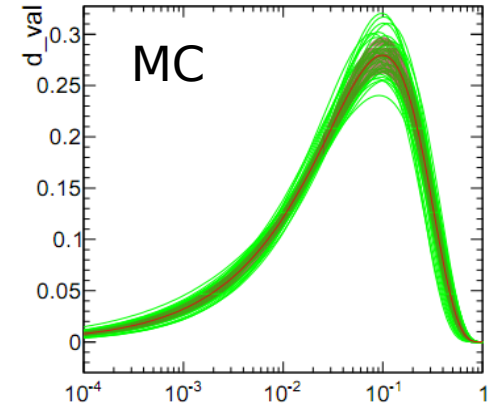
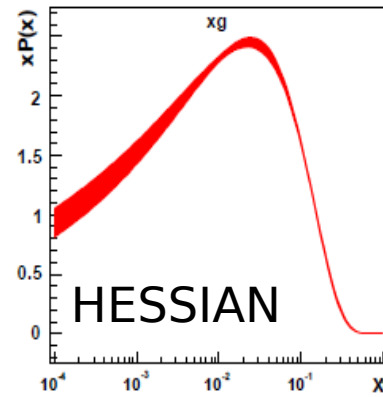
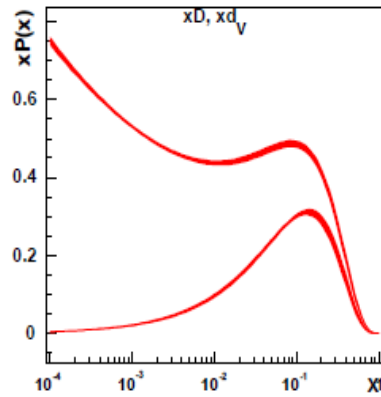
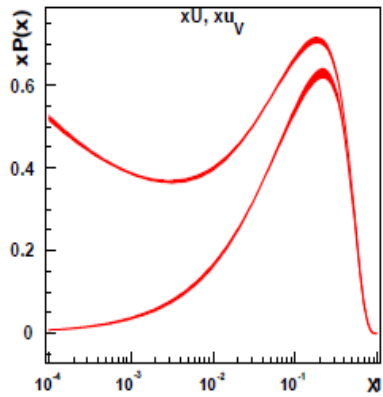
In addition, HERAFitter has code to perform error analysis using toy MC method

→ method uses uncertainties as reported in the data tables and can generate replica around the actual data values, to study error propagation, and around the predicted theoretical values, to study biases from the χ^2 definition.

→ see Voica's talk

HERAFitter: output

- Hessian vs MC error estimation



output/

$$Q^2 = 1.90 \text{ GeV}^2$$

HERAFitter: error handling

HERAFitter has a simple error logging facility, based on an H1 tool. The code allows for 4 levels of errors (I,W,S,F), with a steerable printout and sorted summary of the messages at the end of the run:

```
*****  
***   Error Summary   ***  
*****
```

```
Total number of logged errors:      709  
Total number of errors not recorded:  0
```

List of errors sorted by severity level:

```
*-----  
* Module | Error | Error |  
* Name | Type | Count | Error Description  
*-----
```

Informational messages:

```
*-----  
H1Fitter 12020501    1 I: steering.txt has been read successfully  
H1Fitter 12020502    1 I: data tables have been read successfully  
H1Fitter 12020503    1 I: theory modules initialised successfully  
H1Fitter 12020504    1 I: read minuit input params from file minuit.in.txt  
H1Fitter 12020515   705 I: FCN is called
```

```
*-----  
End of Error Summary
```

HERAFitter: adding additional data

Including e.g. Atlas Z rapidity data (2010) arXiv:1109.5141

&InFiles

! Number of input files

NInputFiles = 5

! Input files:

InputFileNames(1) = 'datafiles/hera/H1ZEUS_NC_e-p_HERA1.0.dat'

InputFileNames(2) = 'datafiles/hera/H1ZEUS_NC_e+p_HERA1.0.dat'

InputFileNames(3) = 'datafiles/hera/H1ZEUS_CC_e-p_HERA1.0.dat'

InputFileNames(4) = 'datafiles/hera/H1ZEUS_CC_e+p_HERA1.0.dat'

InputFileNames(5) = 'datafiles/lhc/atlas/WZ2010/Z0_applgrid_nnlo.dat'

&End

&DATA

Name = 'ATLAS Z rapidity, 2010 data'

Ndata = 8

NColumn = 36

ColumnType = 2*'Bin','Sigma',33*'Error'

ColumnName = 'eta1','eta2','Sigma', 'stat','uncor',
'a1','a2','a3','a4','a5','a6','a7','a8','a9','a10',.....

NInfo = 3

DataInfo = 7000., 20., 100000.

CInfo = 'sqrt(S)','pte cut','theoryunit'

IndexDataset = 91

Reaction = 'NC pp'

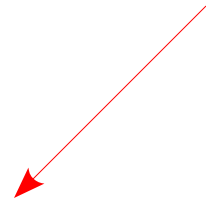
TheoryType = 'applgrid','kfactor'

NKfactor = 2

TheoryInfoFile = 'theoryfiles/atlas/WZ2010/Z0-applgrid.root', 'theoryfiles/atlas/WZ2010/KF-Z0-nnlo2nlo-ew.txt'

*includes applgrid with theory
(requires configuration with applgrid!)*

kfactors (NNLO)



HERAFitter: adding additional data

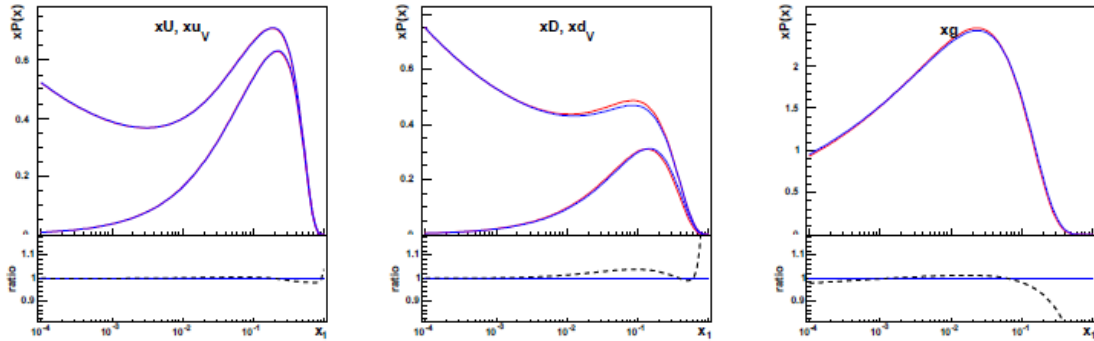
Including e.g. Atlas Z rapidity data (2010) arXiv:1109.5141

First iteration 582.98893971589655 590 0.98811684697609581
 After minimisation 581.85 590 0.986

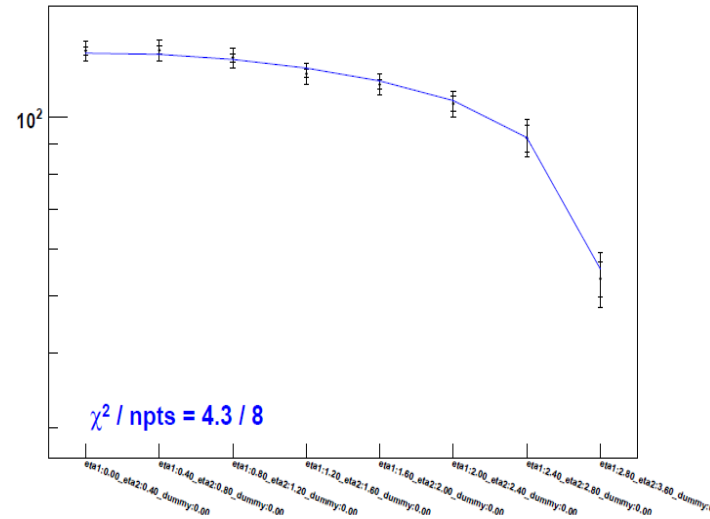
Partial chi2s

Dataset 1	105.98	145	NC cross section HERA-I H1-ZEUS combined e-p.
Dataset 2	420.70	379	NC cross section HERA-I H1-ZEUS combined e+p.
Dataset 3	20.16	34	CC cross section HERA-I H1-ZEUS combined e-p.
Dataset 4	29.14	34	CC cross section HERA-I H1-ZEUS combined e+p.
Dataset 5	4.28	8	ATLAS Z rapidity, 2010 data

Correlated Chi2 1.6052868754780432



ATLAS Z rapidity, 2010 data (*generic plotting tool*)



HERAFitter: running with external PDFs (LHAPDF)

→ useful for various cross checks and data to different PDF comparisons

1D) INSTALLATION with LHAPDF

- a) include lhpdf-config in your PATH variable
(e.g. export PATH=/your/path/to/lhapdf/bin)
- b) include libLHAPDF.so library in your LD_LIBRARY_PATH variable
(e.g. export LD_LIBRARY_PATH=/your/path/to/lhapdf/lib)
- c) enable the lhpdf in the configure: ./configure --enable-lhapdf

The lhpdf will be used if you change PDFStyle = 'LHAPDF' in the steering card.

Output using cteq66.LHgrid PDFs:

First iteration 1982.4085249690468 590 3.3600144491000794
After minimisation 1982.41 590 3.360

Partial chi2s

Dataset	1	137.91	145	NC cross section HERA-I H1-ZEUS combined e-p.
Dataset	2	1771.20	379	NC cross section HERA-I H1-ZEUS combined e+p.
Dataset	3	20.76	34	CC cross section HERA-I H1-ZEUS combined e-p.
Dataset	4	47.28	34	CC cross section HERA-I H1-ZEUS combined e+p.
Dataset	5	4.03	8	ATLAS Z rapidity, 2010 data

Correlated Chi2 1.2319808609806808

HERAFitter: NNPDF reweighting tool

NNPDF reweighting in HERAFitter:

- cross check to HERA fits
- check floating of data normalizations / errors
- compare results from the reweighting tool with real fit for a data set

Requires: ./configure --enable_nnpdfWeight

* (Optional) NNPDF steering cards

*

&nnpdf

FLAGNNPDF = True ! Should reweighting be done?

NNPDFSET = 'NNPDF21_100.LHgrid' ! LHAPDF grid file

NNPDFRWDATA = 'test' ! arbitrary name for new datasample to be put in

NNPDFREWEIGHTMETHOD = 1 ! either 1=chi2 or 2=data

DONNPDFONLY = True ! do / do not run usual HERA fit

NNPDFOUTREPLICAS = 10 ! how many output replica of the NNPDF should be kept?

&End

calculated theory predictions and χ^2 s provided to NNPDF code

- **C++ NNPDF reweighting code** determines which replicas to keep (based on HERA chi2 or NNPDF chi2 from data/theory)
- **Output new LHAPDF reweighted NNPDF set**

(more in NNPDF/README)

HERAFitter: HATHOR

Interface to HATHOR (Hadronic Top and Heavy quarks crOss Section calculatoR) in HERAFitter is available

1C) INSTALLATION with Hathor

=====

a) Download Hathor from <http://www-zeuthen.desy.de/~moch/hathor/>

and install it according to the instructions given there

(requires LHAPDF library -- create a symbolic link to lhpdf:

ln -s your_lhapdf_path lhpdf)

b) Define a variable HATHOR_ROOT such that \$HATHOR_ROOT points to the directory of your Hathor installation

c) Install the HERAFitter as described above but configuring it with the option "--enable-hathor" before building it

- *for each fit iteration PDFs and α_s are read via corresponding QCDNUM routines and fed into Hathor for calculating a new ttbar prediction*

- useful to study the impact of PDFs on ttbar cross sections,

- **goal**: include ttbar cross sections in PDF fit performing an m_t scan

HERAFitter: other modules

Diffractive PDF fit to DIS

Diffractive DIS data are fitted within the 'proton vertex factorisation' approach where the diffractive DIS is mediated by the exchange of hard Pomeron and a secondary Reggeon. The model was used in previous HERA fits:

1. ZEUS Collaboration, S. Chekanov, et al., Nucl. Phys. B 831 (2010) 1.
2. H1 Collaboration, A. Aktas, et al., Eur. Phys. J. C 48 (2006) 715.

- input files (minuit.in.txt.DIFFRACTION, steerig.txt.DIFFRACTION and ewparam.txt.DIFFRACTION) have be copied to minuit.in.txt, steering.txt and ewparam.txt, respectively before running the program.

(for more details see DiffDIS/README)

Fitting with DIPOLE models

DIPOLE (GBW, IIM) or DGLAP+DIPOLE models are available in HERAFitter,
- activation via steering (input_steering/steering.txt.DIPOLE)

Conclusions

HERAFitter:

- a ready open-source QCD platform to analyse new data in context of PDFs
- with active participation of many theory groups
- global benchmarking platform for PDFs and QCD

Upon request can be downloaded from:

<http://projects.hepforge.org/herafitter/>

HERAFitter mail-support: herafitter-help@desy.de

Weekly developers meetings: <https://znwiki3.ifh.de/HERAFitter/HERAFitterInternal/FitForumMeetings>

Monthly users' meetings: <https://znwiki3.ifh.de/HERAFitter/HERAFitterMeetings>

NEXT user's meeting: 17th September, 16:00 CET

Back-up slides

PDF Fit Groups

	MSTW08	CTEQ6.6/CT10	NNPDF2.1	HERAPDF1.0/1.5	ABKM09/ABM11	GJR08/JR09
PDF order:	LO NLO NNLO	NLO NNLO	LO NLO NNLO	NLO NNLO	NLO NNLO	NLO NNLO
HERA DIS	yes	yes	yes	yes	yes	yes
Fixed target DIS	yes	yes	yes	no	yes	yes
Fixed target DY	yes	yes	yes	no	yes	yes
Tevatron W,Z	yes	yes	yes	no	no	no
Tevatron jets	yes	yes	yes	no	no	yes
HF scheme	RT GMVF	SACOT	FONLL	RT	BMSN FFNS	FFNS
α_s (NLO)	0.120	0.118	0.119	0.1176	0.118	0.1135
α_s (NNLO)	0.1171	0.118	0.1174	0.1176	0.1135	0.1124

Data in PDF fits

DIS:

ep (HERA) data: quarks and gluon at small x (F_L), jets (moderate x), CC - flavour separation, heavy quark structure functions

fixed target data: higher x

neutrino DIS: flavour decomposition, $x > 0.01$

Drell-Yan:

quark-antiquark annihilation – high x sea quarks, deuterium target – \bar{u}/\bar{d} asymmetry

High Pt jets at colliders:

high x gluon

W/Z production:

different quark contributions

PDF determination in HERAPDF 1.0

DGLAP at NLO → QCD predictions

PDFs parametrised (at starting scale Q^2_0) using standard parametrisation form:

$$\begin{aligned}xg(x) &= A_g x^{B_g} (1-x)^{C_g}, \\xu_v(x) &= A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} \left(1 + E_{u_v} x^2\right), \\xd_v(x) &= A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}, \\x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}}, \\x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}}.\end{aligned}$$

A: overall normalisation

B: small x behavior

C: $x \rightarrow 1$ shape

The optimal number of parameters chosen by saturation of the χ^2

- central fit with:

10 free parameters for HERA I data

14 for HERA I and II data

$xg, xu_v, xd_v, x\bar{U}, x\bar{D}$

where $x\bar{U}=x\bar{u}$ and $x\bar{D}=x\bar{d}+x\bar{s}$ at the starting scale ($x\bar{s}=f_s x\bar{D}$ with $f_s=0.31$)

A_g, A_{u_v}, A_{d_v} are fixed by sum rules

extra constrains for small x behavior of d- and u-type quarks:

$B_{u_v}=B_{d_v}, B_{\bar{U}}=B_{\bar{D}}, A_{\bar{U}}=A_{\bar{D}}(1-f_s)$ for $\bar{u}=\bar{d}$ as $x \rightarrow 0$

Uncertainties:

experimental

small experimental uncertainties

model

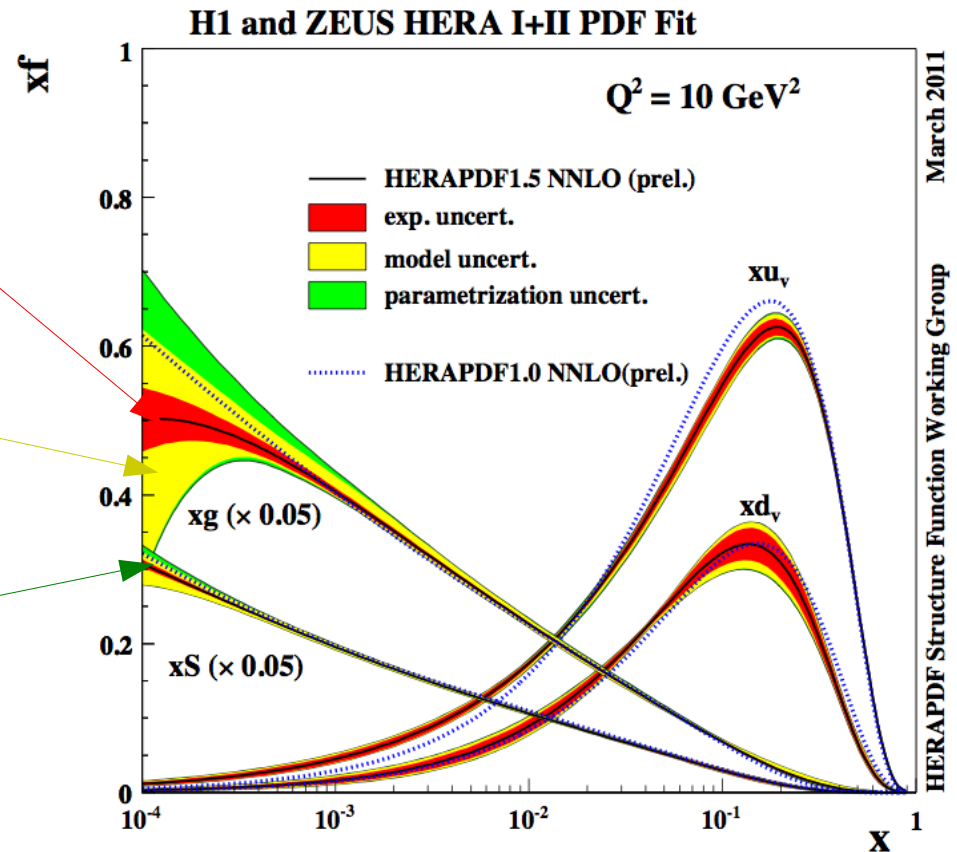
model uncertainties from: Q^2_{\min} , f_s , m_C , m_B

parametrisation

from different parametrisation assumptions

HERAPDF1.5f NNLO

(based on combined HERA I+II data)



HERAFitter: pp, ppbar data: DY code

DY integration code:

Simple LO cross section formulae: DY NC: $pp \rightarrow Z/\gamma \rightarrow e^+e^-$

$$\frac{d\sigma_\gamma^2}{dMdydcos\theta^*} = N_c C_{q\bar{q}}^2 \frac{8\alpha^2}{3M^3} \tau \times \sum_q e_q^2 f_q(x_1, M) f_{\bar{q}}(x_2, M) F_{q\bar{q}}(1 + \cos^2 \theta^*, \cos \theta^*)$$

DY CC: $pp \rightarrow W^\pm \rightarrow e^\pm \nu$

$$\frac{d\sigma_{W^\pm}^3}{dMdydcos\theta^*} = \frac{\pi\alpha^2}{48s_W^4} M\tau \frac{(1 - \cos\theta^*)^2}{(M^2 - M_W^2)^2 + \Gamma_W^2 M_W^2} \times \sum_{qq'} V_{qq'} f_q(x_1, M) f_{q'}(x_2, M)$$

where $\tau = \frac{M^2}{S_0}$, S_0 - beam energy.

$F_{q\bar{q}}(1 + \cos^2 \theta^*, \cos \theta^*)$ is a linear homogenous dependence on $1 + \cos^2 \theta^*$ and $\cos \theta^*$.

- Kfactors are determined from MCFM
- Cross checks of results:
 - between LO x kfactors and NLO using Applgrid
 - between LO x kfactors and DY code from J.Stirling (ZEUSFitter)

HERAFitter: New Developments

- Data file storage (published Tevatron, LHC data)
<https://znwiki3.ifh.de/HERAFitter/HERAFitter/downloads/datatables>
- New interfaces to DIS, DY, Applgrids and FASTNLO modules
- Developments in the top area: ttbar cross section using HATHOR
- Possibility to link to LHAPDF
- Addition of the NNPDF reweighting tool
- Diffractive fits (ZEUS)
- Additions to HERAFitter package: HERAaverager
→ used for combining the measurements
- Heavy flavour schemes:
 - ZM-VFNS (QCDNUM)
 - GM-VFNS RT from R. Thorne
 - ACOT VFNS (F.Olness)
 - FFNS (QCDNUM)
 - FFNS (ABM, running mass)
- Others developments for cross model benchmarking:
 - DIPOLE Models
 - Kt-evolution for unintegrated PDFs