xFitter Tutorial

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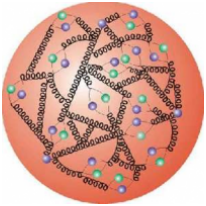
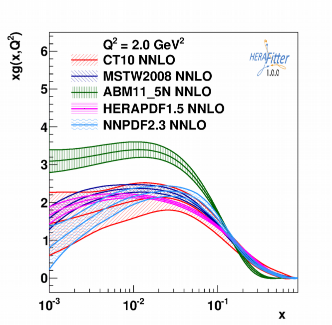
xFitter tutorial

- Introduction: PDFs and the xFitter framework (formerly HERAFitter)
- An example of xFitter usage:

  QCD analysis of W and Z boson production at the Tevatron
- Exercises





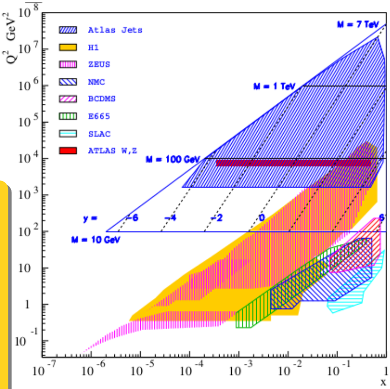
PDFs in the LHC era

Factorisation theorem:

PDFs $\otimes$ **Partonic cross sections**

$$\sigma_{pp\to X} = \Sigma_{i,j} \int dx_1\, dx_2\, f_i^p(x_1,\mu)\, f_j^p(x_2,\mu) \times \sigma_{i,j}$$

- Cross section are calculated by convoluting short distance partonic reactions with Parton Distribution Functions (PDFs)
- Discovery of new exciting physics relies on precise knowledge of proton structure.
- PDFs are among the dominant uncertainties for the W mass measurement and gg → H production



xFitter provides a framework for

- Investigation of various methodologies in PDF fits
- Assess the impact of new data on PDF
- Help the experiments to improve the sensitivity of new measurements to PDF

Schematic of PDF fits

Input data

Theory predictions

Partonic cross sections ⊗ **PDF evolved at all scales**

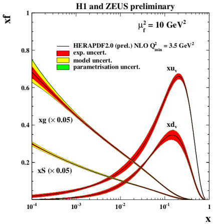
χ^2 test

Minimisation (Fit) of the PDF parameters at the starting scale

DGLAP evolution

PDF parametrisation at the starting scale ~ 1 GeV with ~ 20 free parameters

Result:
$f(x,Q^2)$
at all scales



Schematic of PDF fits

Open-source xFitter implementation of QCD analysis

arXiv:1410.4412

http://xfitter.org

xFitter 1.2.2

Correlated uncertainties

Input data

Cov Matrix, nuisance parameters

χ^2 test

Theory predictions

Partonic cross sections $\otimes$ **PDF evolved at all scales**

APPLGRID, FastNLO

QCDNUM

DGLAP evolution

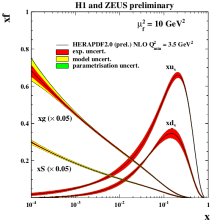
MINUIT

Minimisation (Fit) of the PDF parameters at the starting scale

PDF parametrisation at the starting scale ~ 1 GeV with ~ 20 free parameters

Various flexible parametrization forms

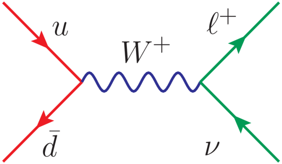
Result:
$f(x,Q^2)$
at all scales

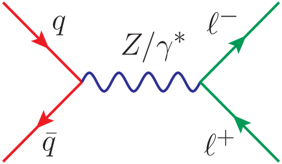


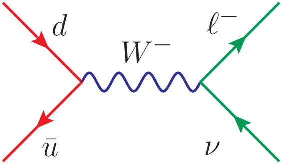
QCD analysis of W and Z Tevatron data

arXiv:1503.05221

- This analysis provides an extensive example of usage of xFitter, and is a good reference for a typical phenomenological study that can be performed with xFitter
- Various PDF fitting techniques were used: MINUIT minimisation, Hessian profiling, Bayesian reweigthing
- The paper provides detailed descriptions of the settings of a QCD analysis and of the χ^2 definition
- Various PDF parametrisation forms are explored
- All the plots in the paper are produced with xFitter



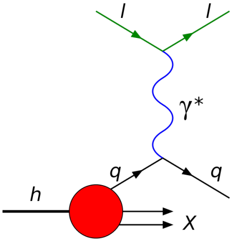


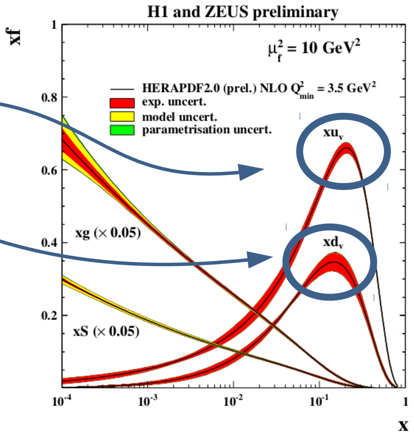


Motivation

- Precise determination of the quark valence PDFs is essential for precision measurements at the LHC, like the W mass and the weak mixing angle, and also for searches of new physics

- DIS collider data provide better constraints on u-quark valence, and less constraints on d-quark valence





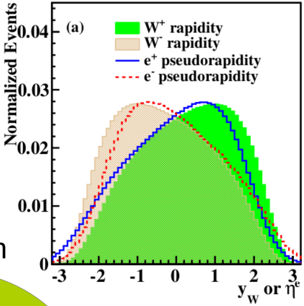
H1prelim-14-042,ZEUS-prel-14-007

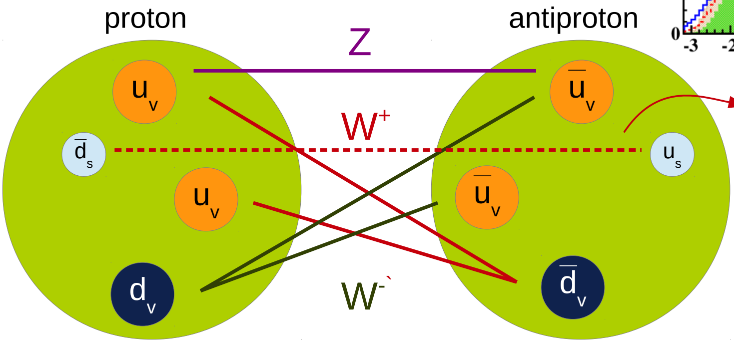
  - The reason is the stronger coupling of photons to u-quark than d-quark

Motivation

- In proton-antiproton collisions, DY processes of W and Z production are valence-quark dominated
- They can be used to improve quark valence PDFs, and especially the d-quark type, which is less constrained by DIS collider data

Most sensitive observable is the W charge asymmetry

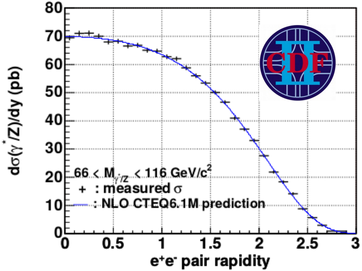




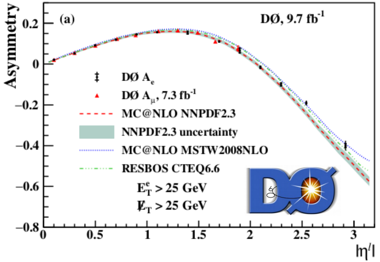
Small contribution from sea-initiated production

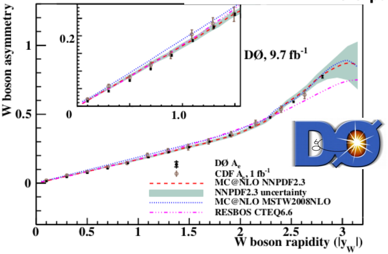
Tevatron W and Z data sets

- 3 types of observables
  - Z dσ/dy (CDF and D0)
  - Lepton charge asymmetry in W → l,ν (D0)
  - W charge asymmetry (CDF and D0)



Fast theory predictions calculated with MCFM+APPLGRID





- Revised correlation model: uncertainties of data-driven corrections are treated as bin-to-bin uncorrelated (lepton ID, trigger, and charge efficiencies)
- Reasonable assumption: these corrections are influenced by stat noise

PDF fit of Tevatron W and Z production

QCD fit at NLO of HERA I and Tevatron W, Z data

The PDF parametrisation at the starting scale $Q^2 = 1.7\ \mathrm{GeV}^2$ is optimised through a χ^2 scan

Start from a simple 3-parameters functional form → Add exp, linear and quadratic terms → Stop when $\Delta\chi^2 \leq 1$

$$f(x) = \underbrace{Ax^B(1-x)^C}_{} \times \underbrace{e^{Fx}(1+Dx+Ex^2)}_{}$$

The optimal parametrisation has 15 parameters

Data set	Experiment	χ^2/points
DIS	H1 - ZEUS	516/550
Z dσ/dy	D0	23/28
Z dσ/dy	CDF	32/28
W μ-asymmetry	D0	12/10
W asymmetry	CDF	14/13
W asymmetry	D0	8/14
Total χ^2/dof		606/628

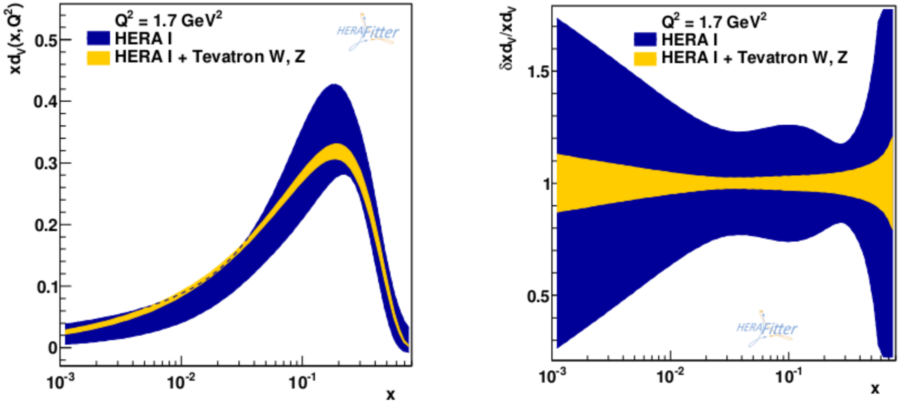
Needed additional freedom in the valence PDFs to fit the W data, exp terms preferred

→ Good overall and partial χ^2 of the QCD fit

Impact on d-quark valence PDF

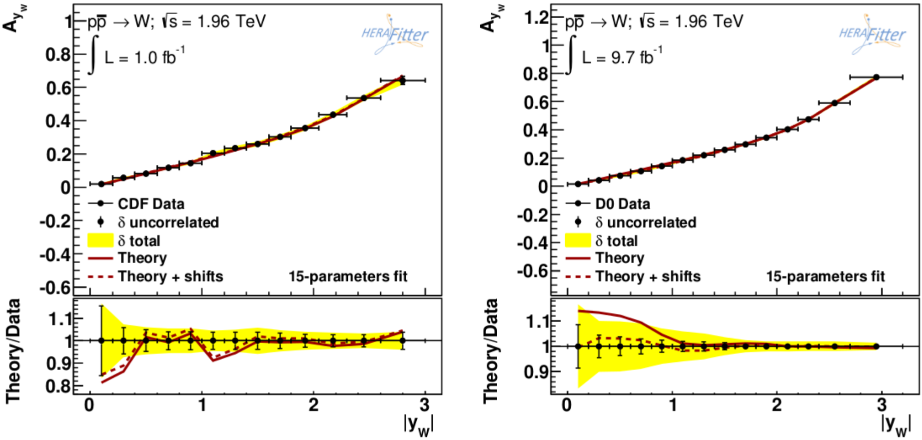
- The impact of the Tevatron W, Z data is assessed by comparing PDFs extracted from a fit to only HERA I data
- Observed large impact on d-quark valence PDF, mainly driven by the measurements of W charge asymmetry

Example of plots that can easily be produced with xFitter



W charge asymmetry, D0 and CDF

Example of plots that can
easily be produced with xFitter

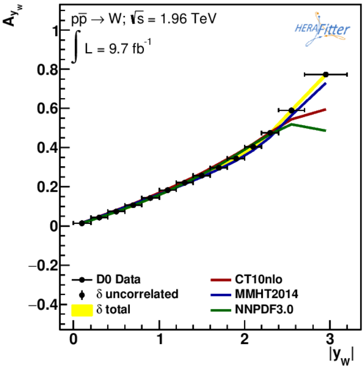


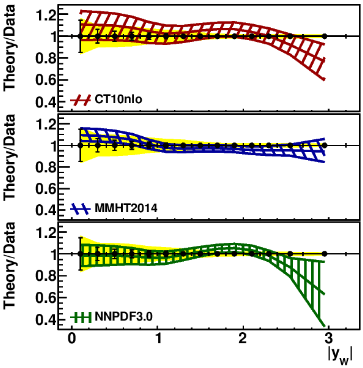
- The results of the PDF fit are illustrated with data/theory comparison plots

Compatibility with global PDF sets

xFitter is used to assess the compatibility between the data and various PDF set

PDF	χ^2/dof
CT10nlo	39/37
MMHT2014nlo	7/14
NNPDF3.0nlo	36/37





Good agreement between W asymmetry data and NLO predictions with global PDF sets

Profiling global PDF sets

Assess the impact of the Tevatron data on the global PDF fits with a hessian profiling technique

Add the hessian PDF uncertainties as nuisance parameters β in the χ^2

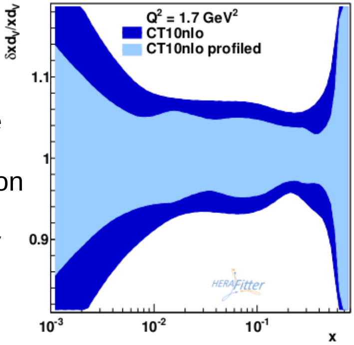
Minimise the χ^2 and profile the PDF shifts β to the data

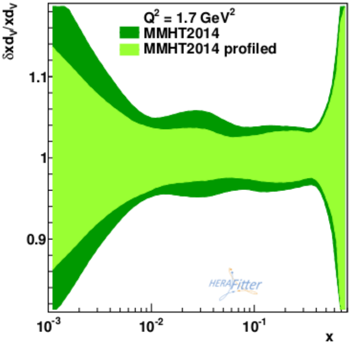
$$\chi^2(\boldsymbol{\beta}_{\mathrm{exp}}) \rightarrow \chi^2(\boldsymbol{\beta}_{\mathrm{exp}}, \boldsymbol{\beta}_{\mathrm{th}})$$

xFitter is used to asses the impact of new data on already existing PDF sets

Propagate the shifts and the reduction of the uncertainties to the PDFs

Also in this case observed a significant reduction of the d-valence PDF uncertainty





List of exercises

1. PDF fit to HERA I+II data
2. PDF fit and α_s extraction from HERA jets data
3. LHAPDF analysis: PDF profiling
4. Plotting of LHAPDF6 files
5. Equivalence of χ^2 definitions

xFitter tutorial loading...

Open a shell and do:

```
student@mcnet:~$ cd tutorial/xfitter
student@mcnet:~/tutorial/xfitter$ svn up
```

Overview

- Each of the five exercise is in a separate directory:

```
exercise1/
exercise2/
exercise3/
exercise4/
exercise5/
```

- You can find the xFitter manual, the README file, and this tutorial in doc/

```
doc/manual.pdf
doc/README
doc/tutorial.pdf
```

General structure of the exercises

As a general rule, each exercise has:

- A `README` file, which contains all the commands to perform the exercise
- A `input/` directory, with all the necessary input settings for running xFitter
- During the exercise, we will create a `run/` directory, where we will run xFitter
- The results will be saved in the `output/` directory, for further manipulation

xFitter programs

On a shell type `xfitter` and press the `Tab` character twice

- `xfitter`: The main xFitter program, to perform PDF fits
- `xfitter-draw`: Graphical visualisation of the results
- `xfitter-process`: Post-fit or pre-fit manipulation of LHAPDF files
- `xfitter-config`: Provide compiler options to link xFitter as an external library

Input configuration files for xFitter

In general, each time we want to run xFitter, we need to care about three configuration files:

- steering.txt
  - Running mode: PDF fit or LHAPDF analysis
  - List of data sets
  - PDF parametrisation
  - QCD Order, heavy flavour scheme
  - χ^2 settings
- ewparam.txt
  - EW and SM parameters (mainly used for the DIS cross section)
- minuit.in.txt
  - Settings and commands for minuit
  - Fix and free parameters of the PDF parametrisation

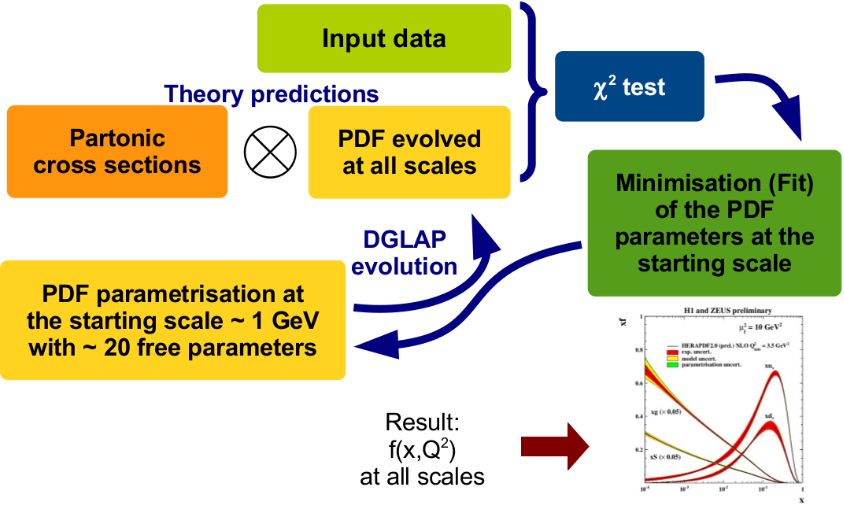
Exercise 1
PDF fit

```
cd exercise1
```

Exercise 1

- *purpose:* Learn the basic settings of a QCD analysis
- *data set:* HERA I+II inclusive DIS data
- *QCD order:* NNLO

Schematic of a PDF fit



Exercise 1 - Settings

The HERA I+II data sets are set in
`input/steering.txt`

```
&InFiles
  ! Number of intput files
    NInputFiles = 7

  ! Input files:

    InputFileNames(1) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_NCep_920.dat'
    InputFileNames(2) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_NCep_820.dat'
    InputFileNames(3) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_NCep_575.dat'
    InputFileNames(4) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_NCep_460.dat'
    InputFileNames(5) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_NCem.dat'
    InputFileNames(6) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_CCep.dat'
    InputFileNames(7) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_CCem.dat'
&End
```

Exercise 1 - Settings

We will use the option `RunningMode = 'Fit'` in `input/steering.txt`

```
&xFitter
  RunningMode = 'Fit'
               ! 'Fit'             -- standard MINUIT-minimization of PDF and other parameters
               ! 'LHAPDF Analysis' -- Evalutate input LHAPDF set uncertaitnies, chi2, profiling or reweig
               !                      Requires &LHAPDF namelist to specify the set name. If PDFSTYLE is n
               !                      set to LHAPDFQ0, LHAPDF or LHAPDFNATIVE, sets it to LHAPDF
               ! 'PDF Rotate'      -- performs PDF re-diagonalization. Requires theo.in files to operate
 ...

&End
```

Exercise 1 - Settings

The order in perturbative QCD is set in `input/steering.txt`

```
&xFitter
  ...
  Order   = 'NNLO'       ! 'LO', 'NLO' or 'NNLO', used for DGLAP evolution.
  ...
&End
```

Exercise 1 - Settings

The starting scale `Q02` of the PDF parametrisation is set in `input/steering.txt`

```
&xFitter
  ...
  Q02      = 1.9 ! Evolution starting scale
  ...
&End
```

Exercise 1 - Settings

The Heavy flavour scheme is set in
`input/steering.txt`

```
&xFitter
  ...
 ! --- Scheme for heavy flavors
 ! ---  HF_SCHEME = 'ZMVFNS'            : ZM-VFNS (massless) from QCDNUM,
 ! ---  HF_SCHEME = 'ZMVFNS MELA'       : ZM-VFNS (massless) from MELA (N-space),
 ! ---  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 = 'FF ABM RUNM'       : Fixed Flavour Number Scheme (ABM) using run mass def
 ! ---  HF_SCHEME = 'FONLL-A'           : FONLL-A mass scheme provided by APFEL with pole masses (available
 ! ---  HF_SCHEME = 'FONLL-A RUNM OFF'  : FONLL-A mass scheme provided by APFEL with MSbar masses running (
 ! ---  HF_SCHEME = 'FONLL-A RUNM ON'   : FONLL-A mass scheme provided by APFEL with MSbar masses running (
 ! ---  HF_SCHEME = 'FONLL-B'           : FONLL-B mass scheme provided by APFEL with pole masses (available
 ! ---  HF_SCHEME = 'FONLL-B RUNM OFF'  : FONLL-B mass scheme provided by APFEL with MSbar masses running (
 ! ---  HF_SCHEME = 'FONLL-B RUNM ON'   : FONLL-B mass scheme provided by APFEL with MSbar masses running (
 ! ---  HF_SCHEME = 'FONLL-C'           : FONLL-C mass scheme provided by APFEL with pole masses (available
 ! ---  HF_SCHEME = 'FONLL-C RUNM OFF'  : FONLL-C mass scheme provided by APFEL with MSbar masses running (
 ! ---  HF_SCHEME = 'FONLL-C RUNM ON'   : FONLL-C mass scheme provided by APFEL with MSbar masses running (
                                        ! (Any of the FONLL schemes at LO is equivalent to the ZM-VFNS)

  HF_SCHEME = 'RT OPT'
 ...
&End
```

Exercise 1 - Settings

The PDF parametrisation is set in
`input/steering.txt`

```
&xFitter
 ...
 ! PDF parameterisation style. Possible styles are currently available:
 !  'HERAPDF' -- HERAPDF-like with uval, dval, Ubar, Dbar, glu evolved pdfs
 !  'CTEQ'       -- CTEQ-like parameterisation
 !  'CTEQHERA'   -- Hybrid: valence like CTEQ, rest like HERAPDF
 !  '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 para
 !  'LHAPDF'     -- use lhapdf library to define pdfs at all scales
 !  'LHAPDFNATIVE'-- use lhapdf library to access pdfs and alphas
 !  'DDIS'       -- use Diffractive DIS
 !  'BiLog'      -- bi-lognormal parametrisation

  PDFStyle = 'HERAPDF'
 ...
&End
```

Exercise 1 - Settings

Convention for the HERAPDF-like PDF parametrisation

$$Ax^B(1-x)^C(1+Dx+Ex^2) - A'x^{B'}(1-x)^{C'}$$

Exercise 1 - Settings

The starting values of the parameters are set in `input/minuit.in.txt`

```
set title
new  14p HERAPDF
parameters
    2   'Bg'   -0.061953    0.027133
    3   'Cg'    5.562367    0.318464
    7   'Aprig'    0.166118    0.028009
    8   'Bprig'   -0.383100    0.009784
    9   'Cprig'   25.000000    0.000000
   12   'Buv'    0.810476    0.016017
   13   'Cuv'    4.823512    0.063844
   15   'Euv'    9.921366    0.835891
   22   'Bdv'    1.029995    0.061123
   23   'Cdv'    4.846279    0.295439
   33   'CUbar'    7.059694    0.809144
   34   'DUbar'    1.548098    1.096540
   41   'ADbar'    0.268798    0.008020
   42   'BDbar'   -0.127297    0.003628
   43   'CDbar'    9.586246    1.448861

call fcn 3
*migrad 200000
*hesse
set print 3

return
```

The first number is the starting value, if the second number is set to 0, the parameter is fixed

Exercise 1 - Settings

To do a real MINUIT minimisation fit (about 1000-10000 iterations):

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

To run only 3 iterations:

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

Exercise 1 - Run

Setup a run directory

```
mkdir run
ln -s ~/xfitter/xfitter-1.2.2/datafiles run/datafiles
cp input/* run
```

Run xFitter

```
cd run
xfitter
```

Exercise 1 - Visualize the results

cd .. (or cd ~/tutorial/xfitter/exercise1)

```
xfitter-draw output
evince output/plots.pdf
```

To see the full list of plotting options do:

```
xfitter-draw --help
```

Exercise 2

Simultaneous PDF fit and α_s extraction from HERA jets data

```
cd exercise2
```

Exercise 2

- *purpose:* Learn the basics of an α_s extraction
- *data set:* H1 jets data
- *QCD order:* NLO

Exercise 2 - Settings

We add the H1 jets data to the list of data sets in `input/steering.txt`

```
&InFiles
  ! Number of intput files
    NInputFiles = 12

  ! Input files:

    InputFileNames(1) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_NCep_920.dat'
    InputFileNames(2) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_NCep_820.dat'
    InputFileNames(3) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_NCep_575.dat'
    InputFileNames(4) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_NCep_460.dat'
    InputFileNames(5) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_NCem.dat'
    InputFileNames(6) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_CCep.dat'
    InputFileNames(7) = 'datafiles/hera/h1zeusCombined/inclusiveDis/1506.06042/HERA1+2_CCem.dat'

  ! H1 Jets:
    InputFileNames(8) = 'datafiles/hera/h1/jets/0706.3722/H1_InclJets_HighQ2_99-00.dat',
    InputFileNames(9) = 'datafiles/hera/h1/jets/0911.5678/H1_InclJets_LowQ2_99-00.dat',

    InputFileNames(10) = 'datafiles/hera/h1/jets/1406.4709/H1_NormTrijets_HighQ2_03-07.dat'
    InputFileNames(11) = 'datafiles/hera/h1/jets/1406.4709/H1_NormInclJets_HighQ2_03-07.dat'
    InputFileNames(12) = 'datafiles/hera/h1/jets/1406.4709/H1_NormDijets_HighQ2_03-07.dat'
&End
```

Exercise 2 - Settings

For the H1 jets data we need to add also the files containing the uncertainty correlation matrices in
`input/steering.txt`

```
&InCorr
  ! Number of correlation (statistical, systematical or full) files
    NCorrFiles = 6

  ! Correlation files:
  CorrFileNames(1) = 'datafiles/hera/h1/jets/1406.4709/H1_NormDijets_HighQ2_03-07___H1_NormDijets_HighQ2_(
  CorrFileNames(2) = 'datafiles/hera/h1/jets/1406.4709/H1_NormDijets_HighQ2_03-07___H1_NormTrijets_HighQ2_
  CorrFileNames(3) = 'datafiles/hera/h1/jets/1406.4709/H1_NormInclJets_HighQ2_03-07___H1_NormDijets_HighQ2
  CorrFileNames(4) = 'datafiles/hera/h1/jets/1406.4709/H1_NormInclJets_HighQ2_03-07___H1_NormInclJets_High
  CorrFileNames(5) = 'datafiles/hera/h1/jets/1406.4709/H1_NormInclJets_HighQ2_03-07___H1_NormTrijets_High(
  CorrFileNames(6) = 'datafiles/hera/h1/jets/1406.4709/H1_NormTrijets_HighQ2_03-07___H1_NormTrijets_HighQ2
&End
```

Exercise 2 - Settings

The highest order in perturbative QCD for which the jets data are available is NLO, and is set in
`input/steering.txt`

```
&xFitter
  ...
  Order   = 'NLO'       ! 'LO', 'NLO' or 'NNLO', used for DGLAP evolution.
  ...
&End
```

Exercise 2 - Settings

We have to free the $\alpha_s(m_Z)$ parameter
`input/steering.txt`

```
&ExtraMinimisationParameters
   name  = 'alphas',   'fs',   'fcharm'
   value =  0.118 ,   0.4,      0.
   step  =  0.001    ,   0.0 ,      0.      ! set to 0 to avoid minimisation
&End
```

Exercise 2 - Settings

To do a real MINUIT minimisation fit (about 1000-10000 iterations):

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

To run only 3 iterations:

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

Exercise 2 - Run

\# Setup a run directory

```
mkdir run
cp input/* run
ln -s ~/xfitter/xfitter-1.2.2/datafiles run/datafiles
```

\# Run `xfitter`

```
cd run
xfitter
```

Exercise 2 - Visualize the results

cd .. (or cd ~/tutorial/xfitter/exercise2)

```
xfitter-draw output
evince output/plots.pdf
```

Exercise 3
LHAPDF analysis

```
cd exercise3
```

Exercise 3

- *purpose:* Learn how to include a new data set into an existing PDF set, without redoing a PDF fit
- *data set:* Tevatron W-boson charge asymmetry
- *QCD order:* NLO

Exercise 3 - LHAPDF

Download PDF sets from LHAPDF

```
cd ~/tutorial/xfitter/pdfsets
```

LHAPDF is a convenient library for the generic interpolation of PDFs as functions of x and q^2. PDFs are saved as tables of PDF values at fixed points in x and q^2, and fast interpolation functions allow to access the PDFs at any other value.

Exercise 3 - LHAPDF

```
cd ~/tutorial/xfitter/pdfsets
lhapdf --pdfdir=./ install CT14nlo
export LHAPATH=`pwd`/:$LHAPATH
```

The inclusion of new data into an existing PDF set can be done with a Hessian profiling technique
We define a χ^2 with theory uncertainties (β_{th} are the PDF uncertainties)

$$\chi^2(\boldsymbol{\beta}_{\mathbf{exp}}, \boldsymbol{\beta}_{\mathbf{th}}) = \boldsymbol{\chi}^{\mathbf{2}}_{\mathbf{exp}} + \boldsymbol{\chi}^{\mathbf{2}}_{\mathbf{th}} =$$

$$\sum_{i=1}^{N_{\mathrm{data}}} \frac{\left(\sigma_i^{\mathrm{exp}} + \sum_j \Gamma_{ij}^{\mathrm{exp}} \beta_{j,\mathrm{exp}} - \sigma_i^{\mathrm{th}} - \sum_k \Gamma_{ik}^{\mathrm{th}} \beta_{k,\mathrm{th}}\right)^2}{\Delta_i^2}$$

$$+ \sum_j \beta_{j,\mathrm{exp}}^2 + \sum_k \beta_{k,\mathrm{th}}^2$$

- Find the $\beta_{k,\mathrm{th}}$ which minimised the χ^2 on the new data
- The fit is done by solving a system of linear equations
- Reinterpret the $\beta_{k,\mathrm{th}}^2$ shifts as optimisation of the PDFs

Exercise 3 - Settings

The Tevatron W asymmetry data sets and correlation files are set in
`input/steering.txt`

```
&InFiles
  ! Number of intput files
    NInputFiles = 2

! Tevatron W asymmetry:
    InputFileNames(1) = 'datafiles/tevatron/cdf/wzProduction/0901.2169/CDF_W_asymmetry.dat'
    InputFileNames(2) = 'datafiles/tevatron/d0/wzProduction/1312.2895/D0_W_asymmetry.dat'
&End

&InCorr
  ! Number of correlation (statistical, systematical or full) files
    NCorrFiles = 1

  ! Correlation files:
    CorrFileNames(1) = 'datafiles/tevatron/d0/wzProduction/1312.2895/D0_W_asymmetry.corr'
&End
```

Exercise 3 - Settings

We will use the option `RunningMode = 'LHAPDF Analysis'` in `input/steering.txt`

```
&xFitter
  RunningMode = 'LHAPDF Analysis''
              ! 'Fit'              -- standard MINUIT-minimization of PDF and other parameters
              ! 'LHAPDF Analysis' -- Evalutate input LHAPDF set uncertaitnies, chi2, profiling or reweig
              !                      Requires &LHAPDF namelist to specify the set name. If PDFSTYLE is n
              !                      set to LHAPDFQ0, LHAPDF or LHAPDFNATIVE, sets it to LHAPDF
              ! 'PDF Rotate'      -- performs PDF re-diagonalization. Requires theo.in files to operate
 ...

&End
```

Exercise 3 - Settings

PDFs are taken from LHAPDF, so there is no need to specify a parametrisation in `input/steering.txt`

```
&xFitter
  PDFStyle = 'LHAPDFNATIVE'
...
  AsymErrorsIterations = 20
...
&End
```

We have also enable the treatment of asymmetric PDF uncertainties with an iterative procedure

Exercise 3 - Run

\# Setup a run directory

```
mkdir run
cp input/* run
ln -s ~/xfitter/xfitter-1.2.2/datafiles run/datafiles
```

\# Run `xFitter`

```
cd run
xfitter
```

Exercise 3 - Visualize the results

cd .. (or cd ~/tutorial/xfitter/exercise3)

```
cp -r run/output .
xfitter-draw output:CT14nlo \
             profile:output:CT14nlo-profiled \
             --asym --bands --therr
evince plots/plots.pdf
```

Exercise 3 - Produce a new PDF set

\# Produce a new PDF in lhapdf6 format:

```
xfitter-process profile \
          output/pdf_shifts.dat output/pdf_rotate.dat \
          ../pdfsets/CT14nlo/ CT14nlo-TEVW
```

\# Save the new PDF set into our lhapdf6 collection:

```
cp -r CT14nlo-TEVW/ ../pdfsets/
```

Exercise 3 - Produce a new PDF set

The new PDF set you have produced is ready to be used in the next Monte Carlo tutorials!

To use it:

```
export LHAPATH=~/tutorial/xfitter/pdfsets/:$LHAPATH
```

Exercise 4
Plotting LHAPDF files

```
cd exercise4
```

Exercise 4

- *purpose:* Direct visualisation of PDFs from LHAPDF6
- *language:* Python

Exercise 4

Take an output PDF from a previous exercise:

```
cp -r ../exercise1/output .
```

Start the jupyter notebook:

```
jupyter notebook
```

In the browser, select new $\rightarrow$ Python2
Cut and paste from testPlot.py into the browser
Execute commands with Alt+Enter

Exercise 5
Equivalence of χ^2 representations

```
cd exercise5
```

Exercise 5

- *purpose:* Test the equivalence of the nuisance parameters and covariance matrix χ^2 formulas
- *data set:* Tevatron W asymmetries

Exercise 5

Nuisance parameters representation of the χ^2

$$\chi^2(\boldsymbol{\beta}) = \sum_{i=1}^{N_{\rm data}} \frac{\left(\sigma_i^{\rm exp} + \sum_j \Gamma_{ij}^{\rm exp}\beta_j - \sigma_i^{\rm th}\right)^2}{\Delta_i^2} + \sum_j \beta_j^2$$

Covariance matrix representation of the χ^2

$$\chi^2(C) = \sum_{ij}^{N_{\rm data}} (\sigma_i^{\rm exp} - \sigma_i^{\rm th})\, C_{{\rm tot}\ ij}^{-1}\, (\sigma_j^{\rm exp} - \sigma_j^{\rm th})\,.$$

The two representations are matematically equivalent. In xFitter we can switch from one to the other.

Exercise 5

To convert a covariance matrix into nuisance parameters representation:

```
&CovarToNuisance
   ! Global switch for using nuisance param representation for covariance mat.

   ! ----> change this setting
   LConvertCovToNui = .true.

   ! Tolerance -- zero means exact transformation
  Tolerance = 0.0

   ! The following lines allow to adjust error scaling properties (default: :M)
  DataName     = 'D0 W asymmetry 2013'
  DataSystType = ':A'
&End
```

Exercise 5

To convert a nuisance parameters (correlated systematic uncertainties) into covariance matrix representation:

```
&xFitter
  ...
  CHI2SettingsName = 'StatScale', 'UncorSysScale', 'CorSysScale', 'UncorChi2Type', 'CorChi2Type'
  ! ----> change this setting
  !Chi2Settings     = 'Poisson'  , 'Linear',        'Linear'     , 'Diagonal'     , 'Hessian'
  Chi2Settings     = 'Poisson'  , 'Linear',        'Linear'     , 'Diagonal'     , 'Matrix'
  ...
&End
```

Exercise 5

The first dataset has a covariance matrix provided, we test the conversion to nuisance parameter representation

```
diff input1-cov input1-nui
```

Run the χ^2 test in xFitter:

```
ln -s ~/xfitter/xfitter-1.2.2/datafiles/ input1-cov/datafiles
ln -s ~/xfitter/xfitter-1.2.2/datafiles/ input1-nui/datafiles
cd input1-cov && xfitter && cd ..
cd input1-nui && xfitter && cd ..
```

Compare results:

```
xfitter-draw input1-cov/output:covariance input1-nui/output:nuisance --outdir plots1
```

Exercise 5

The second dataset has nuisance parameters provided in the form of systematic uncertainties, we test the conversion to covariance matrix representation

```
diff input2-nui input2-cov
```

Run the χ^2 test in xFitter:

```
ln -s ~/xfitter/xfitter-1.2.2/datafiles/ input2-nui/datafiles
ln -s ~/xfitter/xfitter-1.2.2/datafiles/ input2-cov/datafiles
cd input2-nui && xfitter && cd ..
cd input2-cov && xfitter && cd ..
```

Compare results:

```
xfitter-draw input2-nui/output:nuisance input2-cov/output:covariance
```

Summary

- xFitter is a framework for QCD analyses. It allows to perform PDF fits, sensitivity studies to PDFs, extraction of fundamental SM parameters, inclusion of new data on already existing PDF, and a variety of other phenomenological studies involving QCD and EW physics
- The program has many settings to address very different problems, nevertheless big efforts are made to keep the user interface accessible for simple and basic usage
- In this tutorial we have learned how to
  - Perform a PDF fit
  - Extract the value of the strong-coupling constant $\alpha_s(m_Z)$
  - Include new data sets into existing PDF sets by mean of Hessian profiling
  - Perform basic manipulation and plotting of PDF sets
  - Test the equivalence of the χ^2 representations

Conclusions

- xFitter is a powerful tool to answer questions in QCD and PDF matters
- Which kind of questions?
  - How much can we improve our knowledge of PDFs by adding new data to the PDF fits?
  - What are the implications of using predictions based on different QCD theoretical model?
  - Which is the most effective strategy to reduce PDF uncertainties for searches for new physics, and for the determination of the fundamental parameters of the SM at hadron colliders?

Thanks for your attention