“Hands-on” session on Deep-Inelastic Scattering

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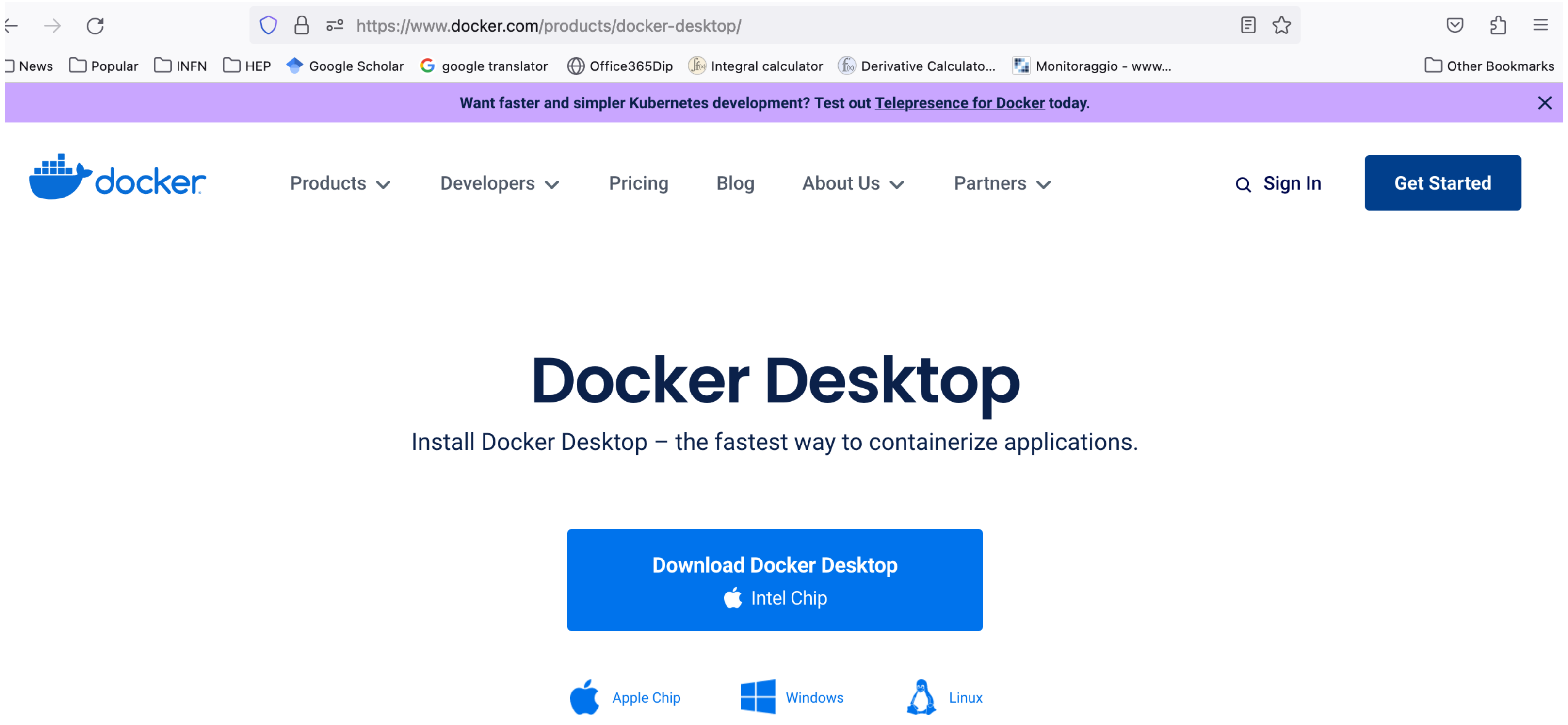
Outline (Lecture 3)

- Tutorial's setup
  - Docker, LHAPDF, Jupyterlab
- xFitter
  - Steering files and program execution
  - Interpretation of the results
- Hands-on session
  - Tutorial 1 ("HERA-only" DGLAP fit)
  - Tutorial 2 {"HERA+EIC-only" DGLAP fit)

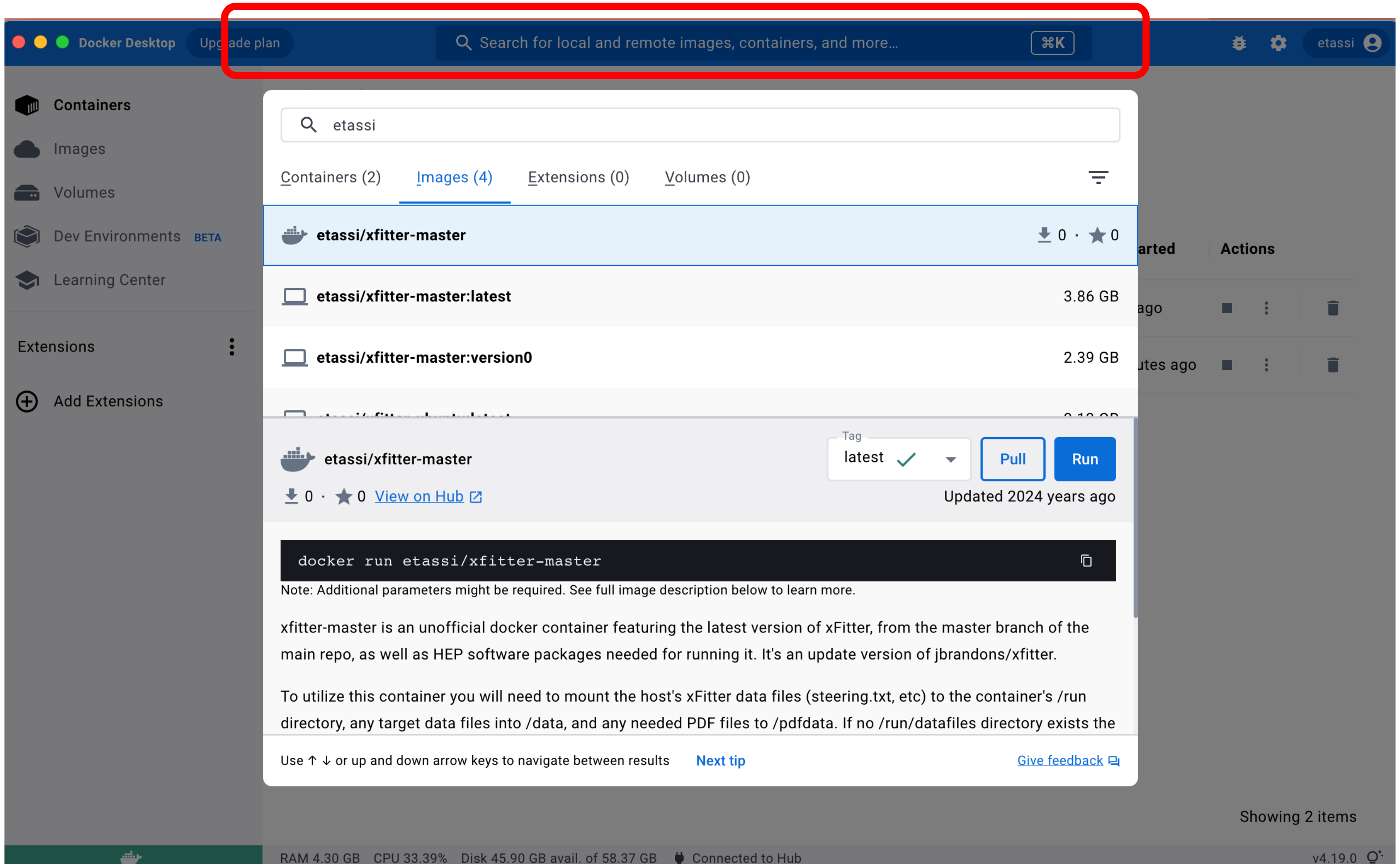
Docker Desktop

https://www.docker.com/products/docker-desktop/.   (available for macos, Windows and linux)



Docker Desktop

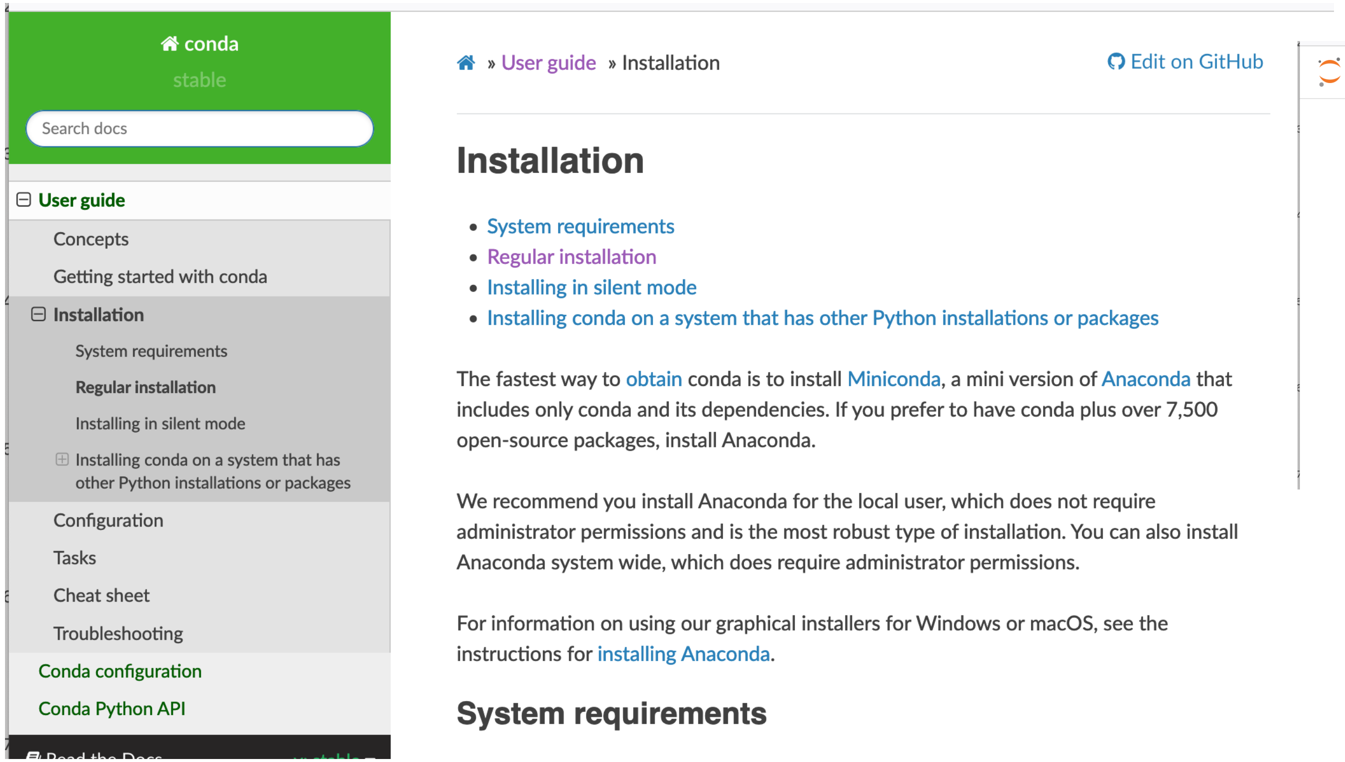
Once installed, run it and search for the following docker image: etassi/xfitter-master
Then “pull” the image



LHAPDF and Jupyter-lab

Both packages can be easily installed with conda:

https://docs.conda.io/projects/conda/en/stable/user-guide/install/index.html#regular-installation



conda
stable

Search docs

User guide
- Concepts
- Getting started with conda
- Installation
  - System requirements
  - Regular installation
  - Installing in silent mode
  - Installing conda on a system that has other Python installations or packages
- Configuration
- Tasks
- Cheat sheet
- Troubleshooting

Conda configuration
Conda Python API

» User guide » Installation — Edit on GitHub

Installation

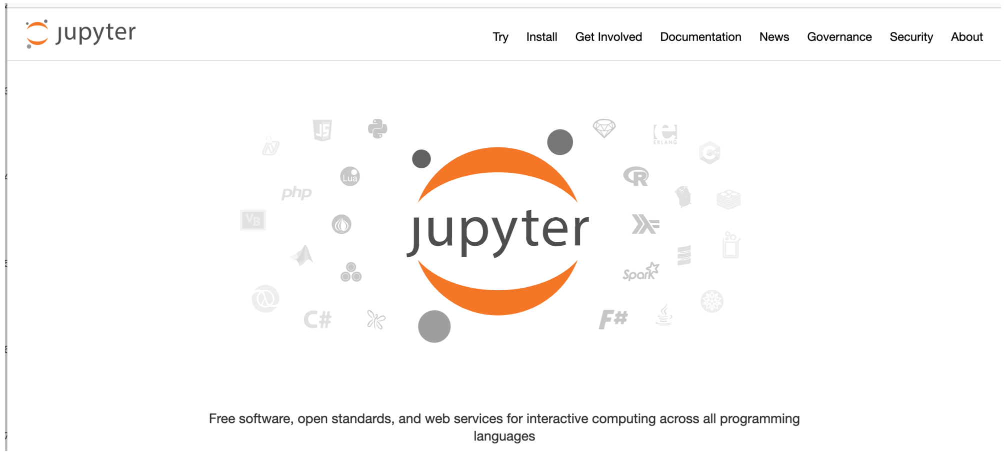
- System requirements
- Regular installation
- Installing in silent mode
- Installing conda on a system that has other Python installations or packages

The fastest way to obtain conda is to install Miniconda, a mini version of Anaconda that includes only conda and its dependencies. If you prefer to have conda plus over 7,500 open-source packages, install Anaconda.

We recommend you install Anaconda for the local user, which does not require administrator permissions and is the most robust type of installation. You can also install Anaconda system wide, which does require administrator permissions.

For information on using our graphical installers for Windows or macOS, see the instructions for installing Anaconda.

System requirements

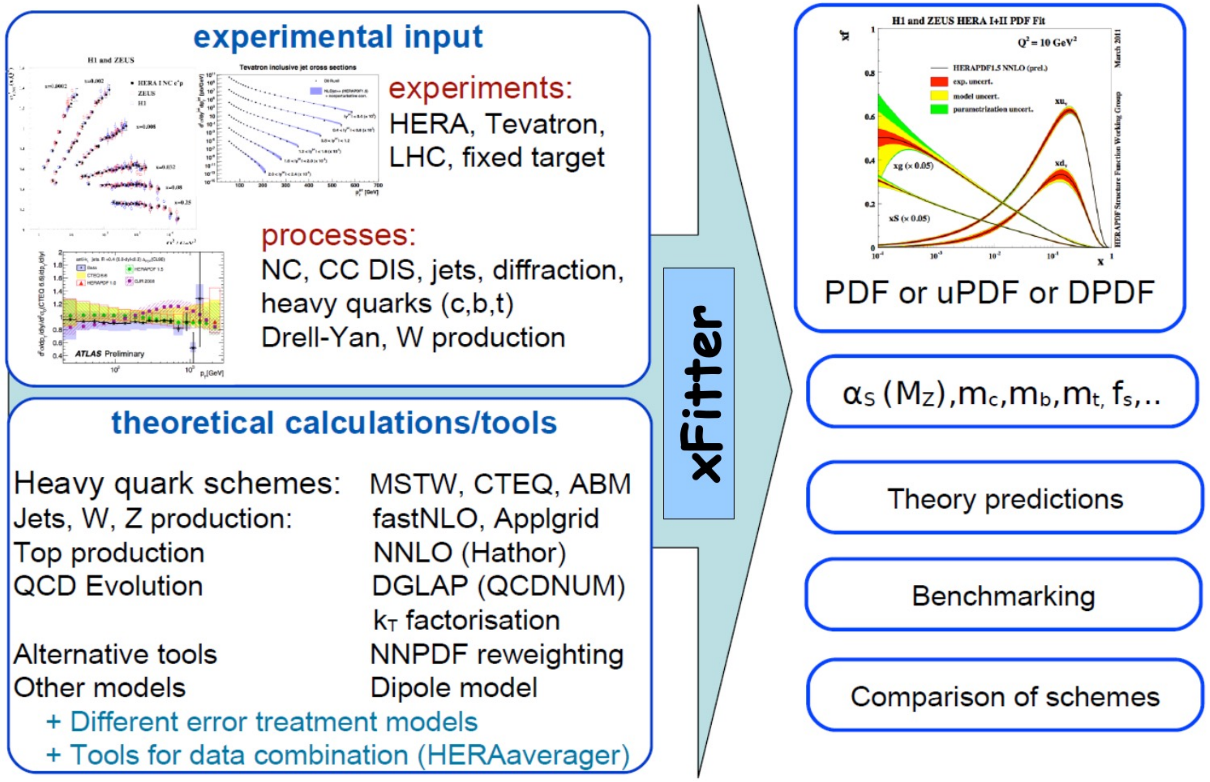


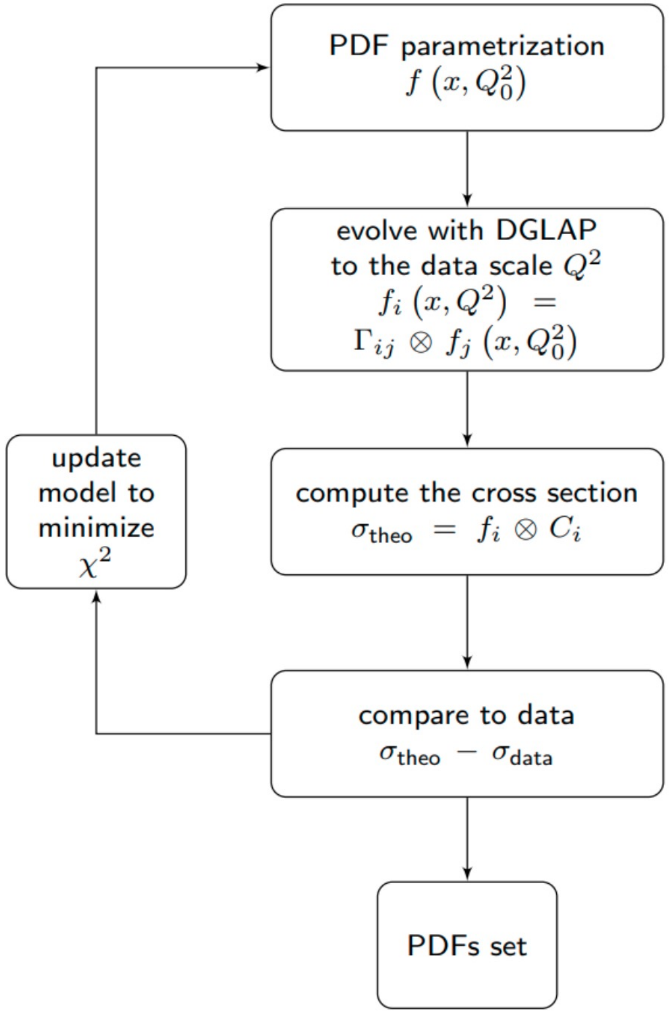
Intro on XFitter

Site: https://www.xfitter.org/xFitter/xFitter/

Gitlab: https://gitlab.cern.ch/fitters/xfitter (master branch)

Documentation (Wiki): https://gitlab.cern.ch/fitters/xfitter/-/wikis/home

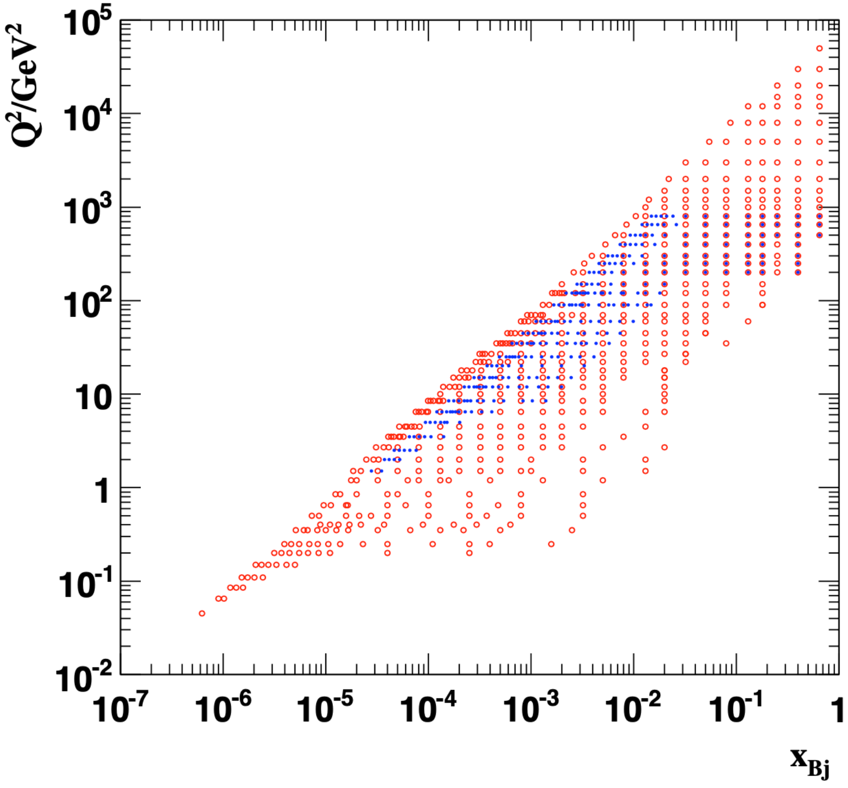




Tutorial 1

Hera-only DGLAP analysis (NNLO)

H1 and ZEUS



Data Set		x_{Bj} Grid from	x_{Bj} Grid to	Q^2[GeV^2] Grid from	Q^2[GeV^2] Grid to	$\mathcal{L}$ pb^{-1}	e^+/e^-	$\sqrt{s}$ GeV	x_{Bj},Q^2 from equations	Ref.
HERA I E_p = 820 GeV and E_p = 920 GeV data sets										
H1 svx-mb [2]	95-00	0.000005	0.02	0.2	12	2.1	e^+p	301, 319	13,17,18	[3]
H1 low Q^2 [2]	96-00	0.0002	0.1	12	150	22	e^+p	301, 319	13,17,18	[4]
H1 NC	94-97	0.0032	0.65	150	30000	35.6	e^+p	301	19	[5]
H1 CC	94-97	0.013	0.40	300	15000	35.6	e^+p	301	14	[5]
H1 NC	98-99	0.0032	0.65	150	30000	16.4	e^-p	319	19	[6]
H1 CC	98-99	0.013	0.40	300	15000	16.4	e^-p	319	14	[6]
H1 NC HY	98-99	0.0013	0.01	100	800	16.4	e^-p	319	13	[7]
H1 NC	99-00	0.0013	0.65	100	30000	65.2	e^+p	319	19	[7]
H1 CC	99-00	0.013	0.40	300	15000	65.2	e^+p	319	14	[7]
ZEUS BPC	95	0.000002	0.00006	0.11	0.65	1.65	e^+p	300	13	[11]
ZEUS BPT	97	0.0000006	0.001	0.045	0.65	3.9	e^+p	300	13, 19	[12]
ZEUS SVX	95	0.000012	0.0019	0.6	17	0.2	e^+p	300	13	[13]
ZEUS NC [2] high/low Q^2	96-97	0.00006	0.65	2.7	30000	30.0	e^+p	300	21	[14]
ZEUS CC	94-97	0.015	0.42	280	17000	47.7	e^+p	300	14	[15]
ZEUS NC	98-99	0.005	0.65	200	30000	15.9	e^-p	318	20	[16]
ZEUS CC	98-99	0.015	0.42	280	30000	16.4	e^-p	318	14	[17]
ZEUS NC	99-00	0.005	0.65	200	30000	63.2	e^+p	318	20	[18]
ZEUS CC	99-00	0.008	0.42	280	17000	60.9	e^+p	318	14	[19]
HERA II E_p = 920 GeV data sets										
H1 NC $^{1.5p}$	03-07	0.0008	0.65	60	30000	182	e^+p	319	13, 19	[8][1]
H1 CC $^{1.5p}$	03-07	0.008	0.40	300	15000	182	e^+p	319	14	[8][1]
H1 NC $^{1.5p}$	03-07	0.0008	0.65	60	50000	151.7	e^-p	319	13, 19	[8][1]
H1 CC $^{1.5p}$	03-07	0.008	0.40	300	30000	151.7	e^-p	319	14	[8][1]
H1 NC med Q^2 $^{*y.5}$	03-07	0.0000986	0.005	8.5	90	97.6	e^+p	319	13	[10]
H1 NC low Q^2 $^{*y.5}$	03-07	0.000029	0.00032	2.5	12	5.9	e^+p	319	13	[10]
ZEUS NC	06-07	0.005	0.65	200	30000	135.5	e^+p	318	13,14,20	[22]
ZEUS CC $^{1.5p}$	06-07	0.0078	0.42	280	30000	132	e^+p	318	14	[23]
ZEUS NC $^{1.5}$	05-06	0.005	0.65	200	30000	169.9	e^-p	318	20	[20]
ZEUS CC $^{1.5}$	04-06	0.015	0.65	280	30000	175	e^-p	318	14	[21]
ZEUS NC nominal ^{*y}	06-07	0.000092	0.008343	7	110	44.5	e^+p	318	13	[24]
ZEUS NC satellite ^{*y}	06-07	0.000071	0.008343	5	110	44.5	e^+p	318	13	[24]
HERA II E_p = 575 GeV data sets										
H1 NC high Q^2	07	0.00065	0.65	35	800	5.4	e^+p	252	13, 19	[9]
H1 NC low Q^2	07	0.0000279	0.0148	1.5	90	5.9	e^+p	252	13	[10]
ZEUS NC nominal	07	0.000147	0.013349	7	110	7.1	e^+p	251	13	[24]
ZEUS NC satellite	07	0.000125	0.013349	5	110	7.1	e^+p	251	13	[24]
HERA II E_p = 460 GeV data sets										
H1 NC high Q^2	07	0.00081	0.65	35	800	11.8	e^+p	225	13, 19	[9]
H1 NC low Q^2	07	0.0000348	0.0148	1.5	90	12.2	e^+p	225	13	[10]
ZEUS NC nominal	07	0.000184	0.016686	7	110	13.9	e^+p	225	13	[24]
ZEUS NC satellite	07	0.000143	0.016686	5	110	13.9	e^+p	225	13	[24]

QCD DGLAP analysis

Parameterisation at the starting scale:

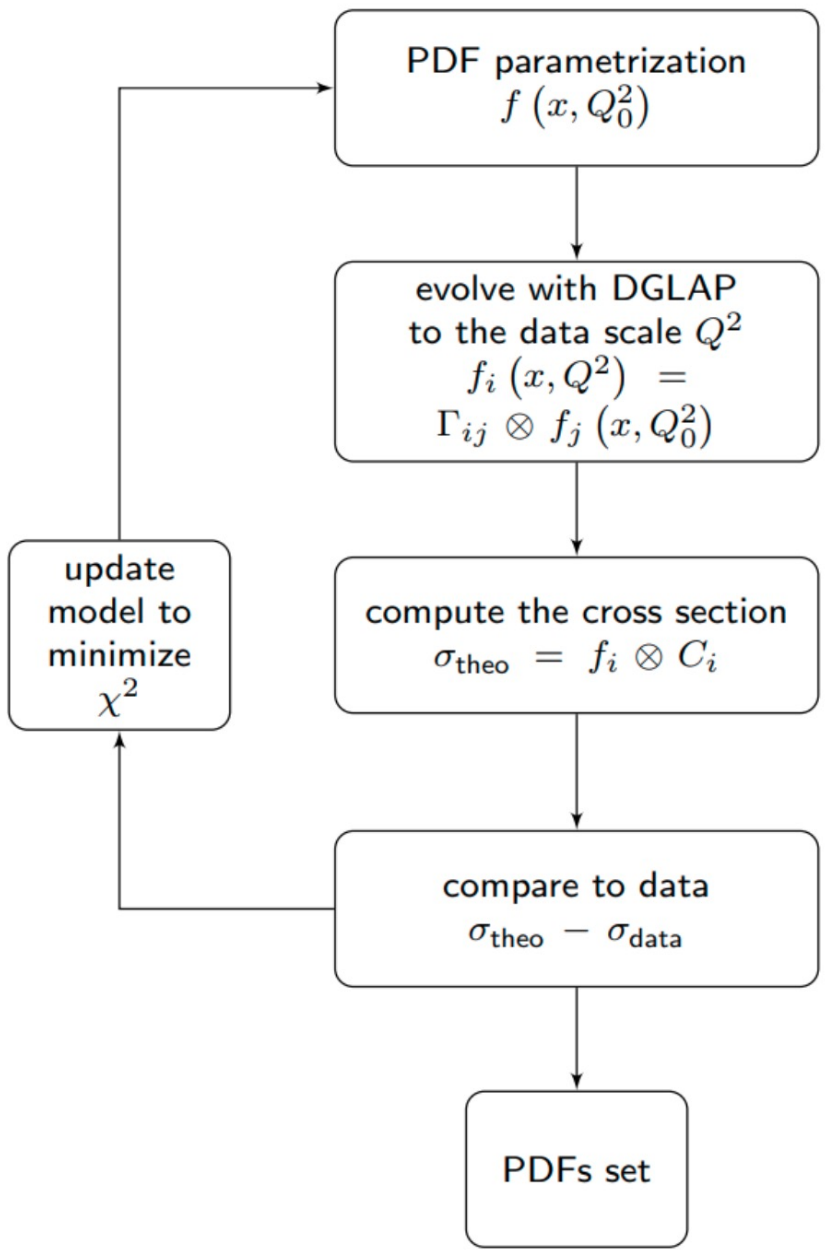
$$xf(x) = Ax^B(1-x)^C(1+Dx+Ex^2)$$

Parforme numerical evolution of PDFs and compute theoretical observables:

$$\sigma_{theo} = C_i \otimes f_i = C_i \otimes \Gamma_{i,j} \otimes f_i(Q_0^2)$$

Determine the PDFs parameters (and their uncertainties) at the starting scale via a chi2 minimization procedure:

$$\chi^2_{\text{exp}}(\boldsymbol{m}, \boldsymbol{s}) = \sum_i \frac{\left[m^i - \sum_j \gamma^i_j m^i s_j - \mu^i\right]^2}{\delta^2_{i,\text{stat}} \mu^i m^i + \delta^2_{i,\text{uncor}} (m^i)^2} + \sum_j s_j^2$$



HERAPDF2.0: Settings DGLAP analysis

- HERA combined data set

- Final analytical form (14 params) obtained via parameter scan:

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

- Heavy Flavours: Roberts-Thorne VFNS (RTOPT) and two FF Schemes
- Fits performed at LO, NLO and NNLO and for Q_{2min}=3.5 and 10 GeV^2
- Detailed study of PDFs uncertainties: experimental, model and parameterisation

Tutorial 1

Hera-only DGLAP analysis (NNLO) - HERAPDF2.0 settings

- Final analytical form (14 params) obtained via parameter scan:

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

The normalisation parameters, A_{u_v}, A_{d_v}, A_g, are constrained by the quark-number sum rules and the momentum sum rule. The B parameters $B_{\bar{U}}$ and $B_{\bar{D}}$ were set as equal, $B_{\bar{U}} = B_{\bar{D}}$, such that there is a single B parameter for the sea distributions. The strange-quark distribution is expressed as an x-independent fraction, f_s, of the d-type sea, $x\bar{s} = f_s x\bar{D}$ at μ^2_{f0}. The value $f_s = 0.4$ was chosen as a compromise between the determination of a suppressed strange sea from neutrino-induced di-muon production [36,85] and a recent determination of an unsuppressed strange sea, published by the ATLAS collaboration [86]. A further constraint was applied by setting $A_{\bar{U}} = A_{\bar{D}}(1 - f_s)$. This, together with the requirement $B_{\bar{U}} = B_{\bar{D}}$, ensures that $x\bar{u} \to x\bar{d}$ as $x \to 0$.

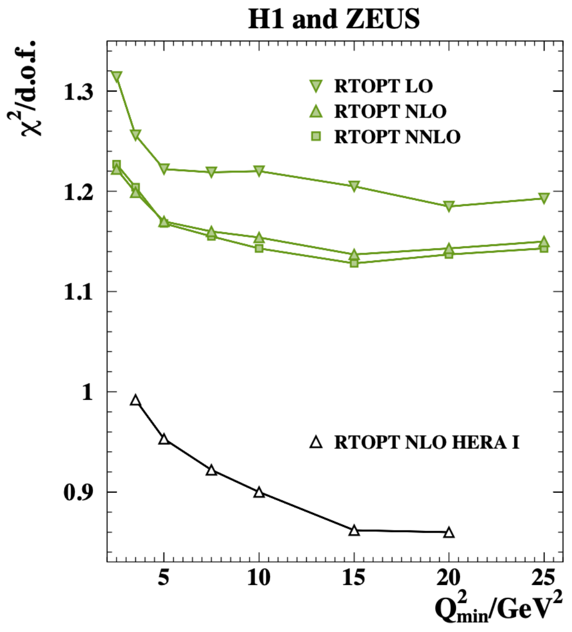
Tutorial 1

Hera-only DGLAP analysis (NNLO)

Additional fits:
- NLO vs NNLO
- Different parametrisations
- Kinematical cuts (on data)
- Starting scale Q_0^2 othe modell parameters
- Statistical interpretation of the results (Minuit)

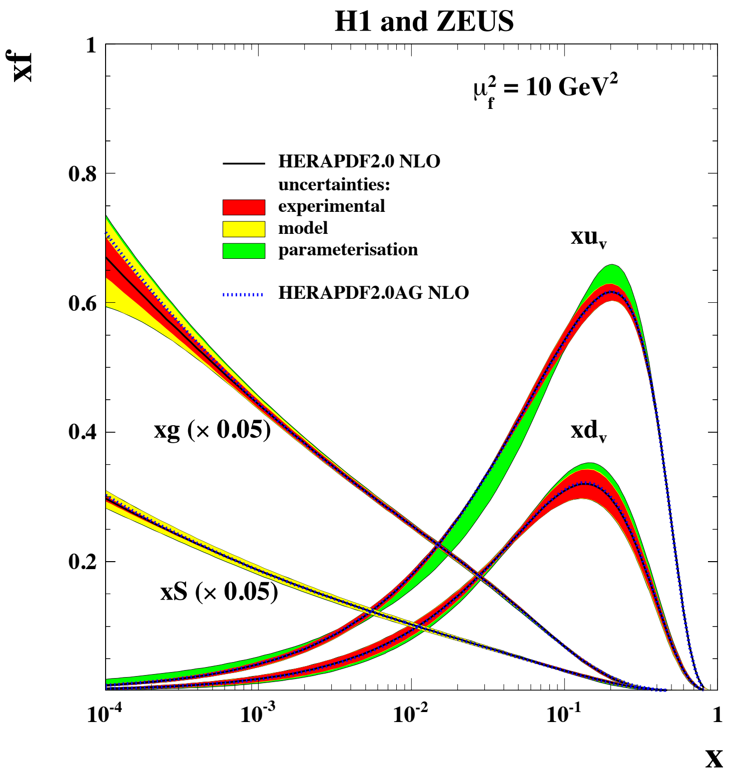
Variation	Standard Value	Lower Limit	Upper Limit
Q^2_{min} [GeV^2]	3.5	2.5	5.0
Q^2_{min} [GeV^2] HiQ2	10.0	7.5	12.5
M_c(NLO) [GeV]	1.47	1.41	1.53
M_c (NNLO) [GeV]	1.43	1.37	1.49
M_b [GeV]	4.5	4.25	4.75
f_s	0.4	0.3	0.5
$\alpha_s(M_Z^2)$	0.118	–	–
μ_{f_0} [GeV]	1.9	1.6	2.2

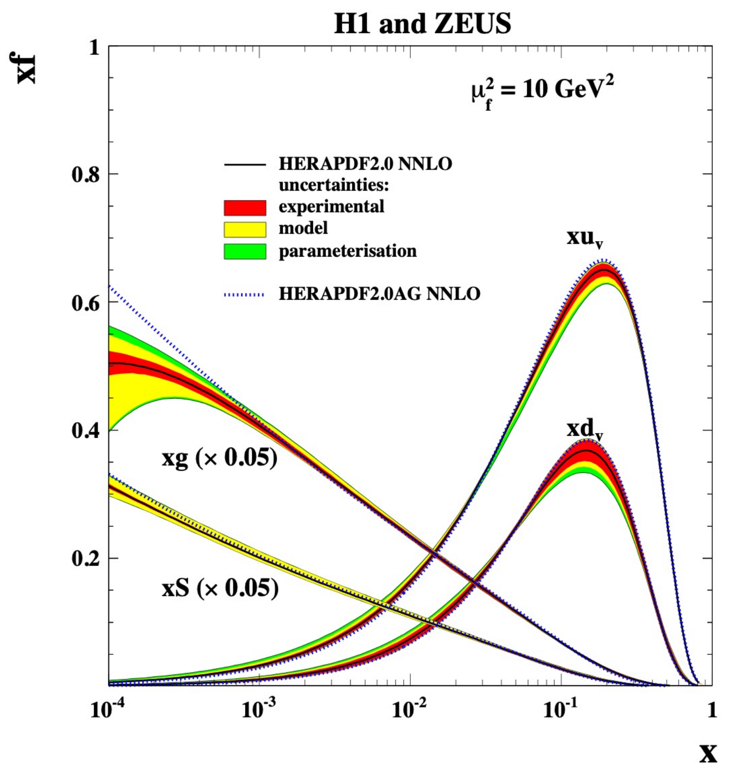
HERAPDF	Q^2_{min}[GeV^2]	χ^2	d.o.f.	χ^2/d.o.f
2.0 NLO	3.5	1357	1131	1.200
2.0HiQ2 NLO	10.0	1156	1002	1.154
2.0 NNLO	3.5	1363	1131	1.205
2.0HiQ2 NNLO	10.0	1146	1002	1.144
2.0 AG NLO	3.5	1359	1132	1.201
2.0HiQ2 AG NLO	10.0	1161	1003	1.158
2.0 AG NNLO	3.5	1385	1132	1.223
2.0HiQ2 AG NNLO	10.0	1175	1003	1.171
2.0 NLO FF3A	3.5	1351	1131	1.195
2.0 NLO FF3B	3.5	1315	1131	1.163
2.0Jets $\alpha_s(M_Z^2)$ fixed	3.5	1568	1340	1.170
2.0Jets $\alpha_s(M_Z^2)$ free	3.5	1568	1339	1.171



Tutorial 1

Fitted PDFs parameters at Q_0^2 (NLO, NNLO)





	A	B	C	D	E	A'	B'
xg	4.34	−0.015	9.11			1.048	−0.167
xu_v	4.07	0.714	4.84		13.4		
xd_v	3.15	0.806	4.08				
$x\bar{U}$	0.105	−0.172	8.06	11.9			
$x\bar{D}$	0.176	−0.172	4.88				

Table 5: Central values of the HERAPDF2.0 parameters at NLO.

	A	B	C	D	E	A'	B'
xg	2.27	−0.062	5.56			0.167	−0.383
xu_v	5.55	0.811	4.82		9.92		
xd_v	6.29	1.03	4.85				
$x\bar{U}$	0.161	−0.127	7.09	1.58			
$x\bar{D}$	0.269	−0.127	9.58				

Table 6: Central values of the HERAPDF2.0 parameters at NNLO.

Tutorial 2

Hera-only + simulated EIC data (YR) DGLAP analysis
- Comparison of the results with the HERAonly fit