xFitter project - a framework for QCD studies

Agnieszka Łuszczak
DESY, Hamburg, Germany

on behalf of the xFitter Developers' Team

supported by the Polish Ministry under program Mobility Plus

QCD - Old Challenges and New Opportunities

WE-Heraeus Physics School, 24-30.09.2017, Bad Honnef

Outline

- Description of the xFitter project: methods, schemes and data used for PDF determination.
- Selected results from xFitter (HERA, ATLAS, CMS).
- The main results for the photon PDF: F.Giuli and xFitter Developers' Team.
- Dipole models in xFitter - signs of saturation of gluon density:
  - based on: "Dipole model analysis of highest precision HERA data, including very low Q^2's", Phys.Rev.D 95, 2017.

Motivation

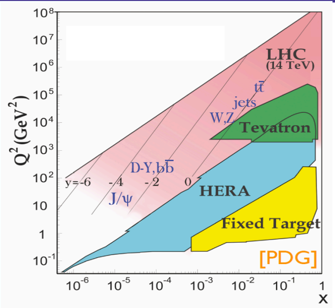
- The recent discovery of the Higgs boson and the extensive searches for signals of new physics in LHC pp collisions demand high-precision calculations to test the validity of the Standard Model (SM) and factorisation in (QCD).
- The factorisation theorem for a hadronic cross section read:

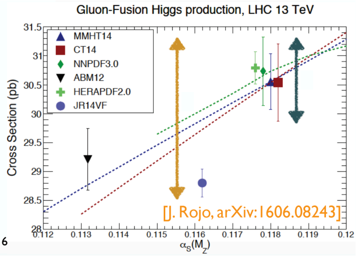
$$d\sigma_{had} = W_{ij} \otimes f_i \otimes f_j d\Phi$$

- partonic cross section:
  - Process dependent
  - High-energy dominated
  - Computable in perturbation theory
- parton distribution functions:
  - Universal (for a given hadronic species)
  - Low-energy dominated
  - Perturbation theory inapplicable

- The rapid flow of new data from the LHC has motivated the development of a tool to combine them together in a fast, efficient, open-source framework :
  xFitter framework
- How do we determine parton distribution functions (PDFs)?
- Presently, the most accurate and reliable way is through **fits to data**.

- Data sets:
  - as large and varied as possible
  - spanning a wide kinematic range
- Estimate of the uncertainties:
  - include full experimental uncertainties
  - ensure a faithful representation
- Choice of the parametrisation:
  - avoid parametrisation biases
- Theoretical inputs:
  - higher order corrections
  - Heavy-quarks mass effect
  - ...
- Different choices may lead to different results.

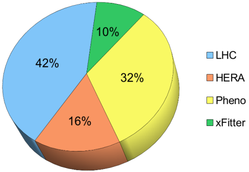




The xFitter Project

- The xFitter project (former HERAFitter) is an unique open-source QCD fit framework.
- GitLab (CERN) is now the main repository of the project:
  https://gitlab.cern.ch/fitters/xfitter
  (open access to download for everyone - read only)

- This code allows users to:
  - extract PDFs from a large variety of experimental data
  - assess the impact of new data on PDFs
  - check the consistency of experimental data
  - test different theoretical assumptions



- Around 30 active developers between experimentalists and theorists.
- LHC experiments provide the main developments and usage of the xFitter platform.

xFitter Developers Meeting

- External xFitter's meeting in Oxford:
  - 33 participants
  - 2.5 days workshop with number of talks and many discussions

- More than 40 publications obtained using xFitter from the beginning of the project:https://www.xfitter.org/xFitter/xFitter/results

List of analyses by xFitter

The link to the list of analyses using former HERAFitter can be accessed here

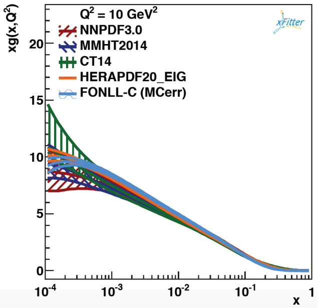
6	07.2017	xFitter Developers	arXiv:1707.05343	Impact of the heavy quark matching scales in PDF fits
5	01.2017	F. Giuli, xFitter Developers' team and M. Lisovyi	Eur.Phys.J. C77 (2017) no.6 400, arXiv:1701.08553	The photon PDF from high-mass Drell Yan data at the LHC
4	03.2016	xFitter and APFEL teams and A. Geiser	JHEP 1608 (2016) 050, arXiv:1605.01946	A determination of mc(mc) from HERA data using a matched heavy flavor scheme

List of analyses using xFitter

Number	Date	Group	Reference	Title
2016				
45	07.2017	Leszek Motyka et. al.	arXiv:1707.05992	Evidence of quasi-partonic higher-twist effects in deep inelastic scattering at HERA at moderate Q2Q2
44	08.2017	A. Vafaee, A.N. Khorramian	Nucl.Phys. B921 (2017) 472	The role of different schemes in the QCD analysis and determination of the strong coupling
43	05.2017	CMS	arXiv:1705.02628	Measurement of the triple-differential dijet cross section in proton-proton collisions at sqrt(s) = 8 TeV and constraints on parton distribution functions
42	03.2017	CMS	arXiv:1703.01630, submitted to EPJC (TOP-14-013)	Measurement of double differential cross sections for top quark pair production in pp collisions at 8 TeV and impact on PDFs
41	02.2017	A. Aleedaneshvara, M. Goharipour, S. Rostami	Chin Phys C 41, 2 (2017) 023101	Uncertainty of parton distribution functions due to physical observables in a global analysis
40	01.2017	Y.G. Gbedo, M. Mangin-Brinet	arXiv:1701.07678	Markov Chain Monte Carlo technics applied to PDF determination: proof of concept
39	01.2017	ABMP	arXiv:1701.05838	Parton Distribution Functions, αs and Heavy-Quark Masses for LHC Run II
38	12.2016	ATLAS	arXiv:1612.03636	Measurements of top-quark pair to Z-boson cross-section ratios at s = 13; 8; 7 TeV with the ATLAS detector
37	12.2016	ATLAS	arXiv:1612.03016	Precision measurement and interpretation of inclusive W and Z production with the ATLAS detector
36	12.2016	A. Aleedaneshvara, M. Goharipour, S. Rostami	EPJA (2016) 52: 352	The impact of intrinsic charm on the parton distribution functions
35	11.2016	CMS	CMS PAS SMP-16-011	Measurement of triple-differential dijet cross sections at 8 TeV with the CMS detector and constraints on PDFs
34	11.2016	A. Luszczak and H. Kowalski	arXiv:1611.10100, PRD 95 (2017)014030	Dipole model analysis of highest precision HERA data, including very low Q2's

PDFs Fits in xFitter

- Parametrise PDFs at the initial scale:
  - several functional forms available ("standard", Chebyshev, etc.)
  - define parameters to be fitted
- Evolve PDFs to the scales of the fitted data points:
  - DGLAP evolution up to NNLO in QCD and NLO QED (QCDNUM, APFEL, MELA)
  - non-DGLAP evolutions (dipole, CCFM)
- Compute predictions for DIS and hadron colliders:
  - several heavy quarks treatments are avaliable in DIS (ZM-VFNS, ACOT, FONLL, RT, FFNS)
  - predictions for hadron-collider data through fast interfaces (APPLgrid, FastNLO)
- Comparison data-predictions via χ^2 :
  - multiple definitions available
  - consistent treatment of the systematic uncertainties
- Minimise the χ^2 w.r.t. the fitted parameters:
  - using MINUIT
- Useful drawing tools.



xFitter release 2.0.0

- https://www.xfitter.org/xFitter/xFitter/DownloadPage

Sample data files:
LHC: ATLAS, CMS, LHCb
Tevatron: CDF, D0
HERA: H1, ZEUS, Combined
Fixed Target: ...
User Supplied: ...

xFitter

xFitter/xFitterTalks » xFitter/../xFitterDevel.. » xFitter/../Meeting2017-.. » xFitter » xFitter/DownloadPage

Wiki
WikiPolicy
RecentChanges
FindPage
HelpContents
xFitter/DownloadPage

Page
Immutable Page
Info
Subscribe
Add Link
Attachments
More Actions:

xFitter / DownloadPage

Releases of the xFitter QCD analysis package

- Versioning convention: **i.j.k** with
  - **i** - stable release
  - **j** - beta release
  - **k** - bug fixes.
- The release notes can be found in this attachment: xFitter_release_notes.pdf .
- Installation script for xFitter together with QCDNUM, APFEL, APPLGRID, LHAPDF install-xfitter
- The script to download coupled data and theory files xfitter-getdata.sh.
- Data and theory files are also stored in hepforge and can be accessed from there ("List of Data Files").

Date	Version	Files	Remarks
03/2017	**2.0.0 FrozenFrog**	xfitter-2.0.0.tgz	stable release with decoupled data and theory files
07/2016	**1.2.2**	xfitter-1.2.2.tgz	release with decoupled data and theory files
05/2016	**1.2.1**	xfitter-1.2.1.tgz	release with decoupled data and theory files
02/2016	**1.2.0**	xfitter-1.2.0.tgz	release with decoupled data and theory files

- By default, only final combined HERA I+II data are distributed.
- getter-xfitter.sh script to download data with corresponding theory files.
- In directory 'datasets' located all available files.

xFitter on Hepforge: data access

- http://xfitter.hepforge.org/

- Possibility to download data files (including theory).
- Updated automatically with new data added to svn.
- Your feedback is welcome! (via email: xfitter-help@desy.de)

- http://xfitter.hepforge.org/data.html

This page contains the list of publicly available experimental data sets (with corresponding theory grids if available) in the xFitter package.
To download data set please click on the arXiv link (and open/save tar.gz file).

No	Collider	Experiment	Reaction	arXiv	Readme
1	fixedTarget	bcdms	inclusiveDis	cern-ep-89-06	README
2	hera	h1	beautyProduction	0907.2643	
3	hera	h1	inclusiveDis	1012.4355	
4	hera	h1	jets	0706.3722	README
5	hera	h1	jets	0707.4057	README
6	hera	h1	jets	0904.3870	README
7	hera	h1	jets	0911.5678	README
8	hera	h1	jets	1406.4709	README
9	hera	h1zeusCombined	charmProduction	1211.1182	
10	hera	h1zeusCombined	inclusiveDis	0911.0884	
11	hera	h1zeusCombined	inclusiveDis	1506.06042	
12	hera	zeus	beautyProduction	1405.6915	
13	hera	zeus	diffractiveDis	0812.2003	
14	hera	zeus	jets	0208037	
15	hera	zeus	jets	0608048	
16	hera	zeus	jets	1010.6167	
17	lhc	atlas	drellYan	1305.4192	
18	lhc	atlas	drellYan	1404.1212	
19	lhc	atlas	jets	1112.6297	

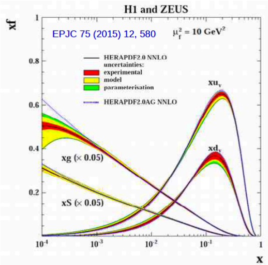
xFitter examples (CTEQ School)

- www.xfitter.org/xfitter/tutorials

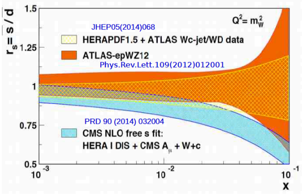
- A list of educational examples are provided in the package - prepared for the CTEQ summer school 2016:
- Exercise 1: PDF fit:
  - learn the basic settings of a QCD analysis, based on HERA data only
- Exercise 2: Simultaneous PDF fit and as:
  - learn the basic of an as extraction using H1 jet data
- Exercise 3: LHAPDF analysis:
  - how to estimate impact of a new data without fitting
  - profiling and reweighting techniques
- Exercise 4: Plotting LHAPDF files:
  - direct visualisation of PDFs from LHAPDF6 using simple python scripts

Results obtained with xFitter: Examples (1)

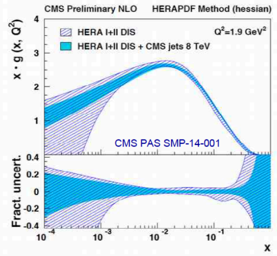
- DIS inclusive processes



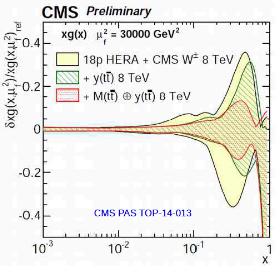
- Drell-Yan processes (strange quark density determination)



- Jet production

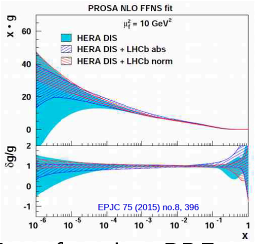


- Top-quark production

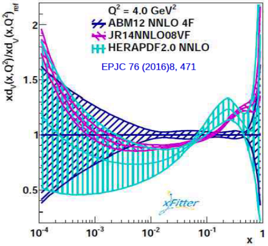


Results obtained with xFitter: Examples (2)

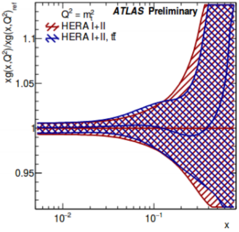
- Heavy quark production



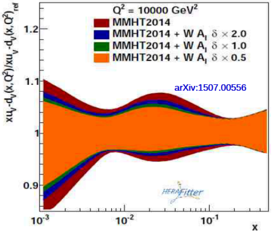
- Evolution of modern PDFs (benchmarking)



- The ratio of the fitted gluon PDF with and without $t\bar{t}$ data included

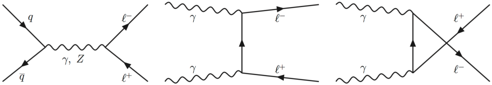


- PDF4LHC report (benchmarking)



Latest xFitter Developers' paper on PDF photon

- Interpretation of the LHC data requires theoretical calculations that include not only QCD corrections, but also the EW effects for the TeV region:
  - pure weak corrections
  - QED corrections → photon PDF   published in EPJC 77 (2017) 400
- **Drell-Yan data** at LHC provide direct handle on the **photon PDF**:



ATLAS high mass Drell Yan at 8 TeV: JHEP 1608 (2016) 009

- Presented as $d\sigma/dm_{ll}, d^2\sigma/dm_{ll}d\triangle|\eta_{ll}|$ and $d^2\sigma/dm_{ll}d|y_{ll}|$

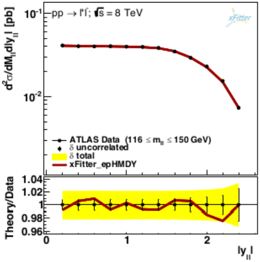
  (expected to provide most sensitivity to PDFs.)

- PDF evolution and DIS cross sections via APFEL program:
  - Accurate up to NNLO in QCD + NLO in QED
  - Includes relevant mixed QCD + QED correction (NOVELTY)
  - FONLL general-mass scheme
- LHC hmDY cross sections calculated via Madgraph5.aMC@NLO .
- NNLO QCD + NLO QED corrections to DY obtained using FEWZ3.1.

Results I

- Good description of the dataset (remarkably, for DY data $\chi^2/N_{data} = 48/48$).

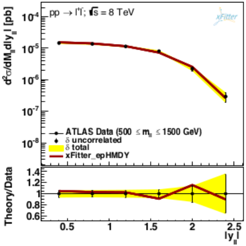
Dataset	χ^2/N_{dat}
HERA I+II	1236/1056
high-mass DY 116 GeV $\leq m_{ll} \leq$ 150 GeV	9/12
high-mass DY 150 GeV $\leq m_{ll} \leq$ 200 GeV	15/12
high-mass DY 200 GeV $\leq m_{ll} \leq$ 300 GeV	14/12
high-mass DY 300 GeV $\leq m_{ll} \leq$ 500 GeV	5/6
high-mass DY 500 GeV $\leq m_{ll} \leq$ 1500 GeV	4/6
Correlated (high-mass DY) χ^2	1.17
Log penalty (high-mass DY) χ^2	-0.12
Total (high-mass DY) χ^2/N_{dat}	$\boxed{48/48}$
Combined HERA I+II and high-mass DY χ^2/N_{dof}	1284/1083

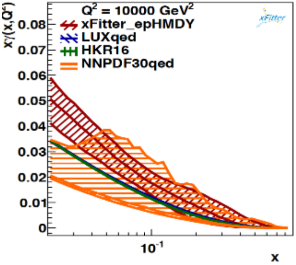


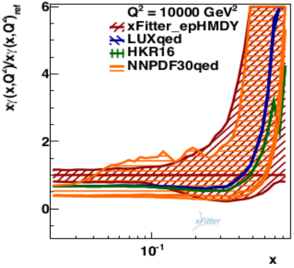
- Comparision beetwen the results of the fit ATLAS data for the ($|m_{ll}|$,$|y_{ll}|$ double-differential Drell-Yan cross sections. as function of $|y_{ll}|$

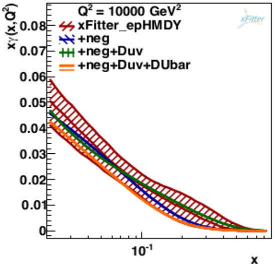
$$\begin{aligned}
xu_v(x) &= A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + E_{u_v} x^2), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}} (1-x)^{C_{\bar{U}}}, \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}} (1-x)^{C_{\bar{D}}}, \\
xg(x) &= A_g x^{B_g} (1-x)^{C_g}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

PDF parameterisation

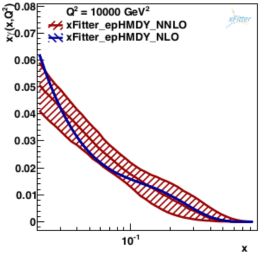








- Agreement within uncertainties for all determinations for $x \geqslant 0.1$ (1σ level).
- For $x \geqslant 0.1$ LUXqed and HKR16 are softer than xFitter.epHMDY (agreement at (2σ level).
- Smaller uncertainty as compared to NNPDF3.0qed ($\sim 30\%$ below $x = 1$) the only other direct determination.
- Direct determination not competitive with theoretical calculations, but fully consistent with them.
- Robustness of the fit and his perturbative stability studied (NLO vs NNLO).

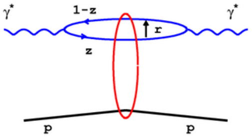


Dipole model of DIS in xFitter framework

- Motivation: Investigation of the gluon density with so-called BGK dipole model, as an alternative to the PDF approach. BGK dipole model, uses a very similar evolution scheme as PDFs, i.e. DGLAP evolution in the kt factorization scheme (in contrast to the collinear factorization for PDFs).
- The precise knowledge of the gluon density is mandatory to fully exploit the LHC physics potential - because gluon density determines the Higgs production rate.
- We analyse, within a dipole model, the final, inclusive HERA DIS cross section data in the low x region, using fully correlated errors.
- We show, that these highest precision data are very well described within the dipole model framework starting from very low Q^2 values of 0.3 GeV^2 to the highest values of $Q^2 = 250$ GeV^2.
- We discuss the saturation question and the properties of the gluon density obtained in this way.
- The analysis was done using xFitter framework.

Dipole model of DIS

- Dipole picture of DIS at small x in the proton rest frame:



r - dipole size

z - longitudinal momentum fraction of the quark/antiquark

- Factorization: dipole formation + dipole interaction

$$\sigma^{\gamma p} = \frac{4\pi^2 \alpha_{em}}{Q^2} F_2 = \sum_f \int d^2 r \int_0^1 dz \, |\Psi^\gamma(r, z, Q^2, m_f)|^2 \;\; \hat{\sigma}(r, x)$$

- Dipole-proton interaction:

$$\hat{\sigma}(r, x) = \sigma_0 \left(1 - \exp\{-\hat{r}^2\}\right) \qquad\qquad \hat{r} = r/R_s(x)$$

- GBW (Golec-Biernat-Wüsthoff) parametrization with heavy quarks: $f = u, d, s, c$

$$\hat{\sigma}(r,x) = \sigma_0 \left(1 - \exp(-r^2/R_s^2)\right), \qquad R_s^2 = 4 \cdot (x/x_0)^{\lambda} \ \mathrm{GeV}^2$$

- The dipole scattering amplitude in such a case reads:

$$\hat{N}(\mathbf{r},\mathbf{b},x) = \theta(b_0 - b)\left(1 - \exp(-r^2/R_s^2)\right)$$

where

$$\hat{\sigma}(r,x) = 2\int d^2b\, \hat{N}(\mathbf{r},\mathbf{b},x)$$

- Parameters b_0, x_0 and λ from fits of $\hat{N}$ to F_2 data:

$$\lambda = 0.288 \qquad x_0 = 4 \cdot 10^{-5} \qquad 2\pi b_0^2 = \sigma_0 = 29\ \mathrm{m}b$$

- BGK (Bartels-Golec-Kowalski) parametrization:

$$\hat{\sigma}(r,x) = \sigma_0 \left\{1 - \exp\left[-\pi^2 r^2 \alpha_s(\mu^2) xg(x,\mu^2)/(3\sigma_0)\right]\right\}$$

- $\mu^2 = C/r^2 + \mu_0^2$ is the scale of the gluon density
- μ_0^2 is a starting scale of the QCD evolution: $\mu_0^2 = Q_0^2$
- gluon density is evolved according to the LO or NLO DGLAP eq.
- soft gluon:

$$xg(x,\mu_0^2) = A_g\, x^{\lambda_g}\, (1-x)^{C_g}$$

- soft + hard gluon:

$$xg(x,\mu_0^2) = A_g\, x^{\lambda_g}\, (1-x)^{C_g} (1 + D_g x + E_g x^2)$$

- The total cross section for a small $q\bar{q}$ dipole to pass through a dilute gluon cloud is proportional to the dipole area, the strong coupling constant, and the number of gluons in the cloud.

$$\sigma_{q\bar{q}} = \frac{\pi^2}{N_c} r^2 \alpha_s(\mu^2) xg(x, \mu^2)$$

- where $xg(x, \mu^2)$ is gluon density at some scale μ^2. Now imagine that the density of gluons in the target is not small. Divide the target into thin slices of thickness dz. The probability that a dipole does not suffer an inelastic interaction passing through one slice of the proton is:

$$P = 1 - \frac{\pi^2}{N_c} r^2 \alpha_s(\mu^2) xg(x, \mu^2) \rho(z) dz$$

- Here $\rho(z)$ denotes density of the gluons within a proton and is normalized to 1,

$$\int dz \; \rho(z) = 1$$

- Exponentiating this result, the probability that the dipole suffers no inelastic interactions passing through the entire proton is $|S|^2$:

$$\int |S|^2 = \exp\left(-\frac{\pi^2}{N_c} r^2 \alpha_s(\mu^2) xg(x, \mu^2) \right)$$

- Dipole model BGK fit with fixed valence quarks

TABLE I. BGK fit with fixed valence quarks for σ_r for H1ZEUS-NC data in the range $Q^2 \geq 3.5$ or 8.5 GeV^2 and $x \leq 0.01$. NLO fit. *Soft gluon.* $m_{uds} = 0.14$, $m_c = 1.3$ GeV. $Q_0^2 = 1.9$ GeV^2.

Q^2_{min} [GeV^2]	$\sigma_0[mb]$	A_g	λ_g	C_g	N_{df}	χ^2	χ^2/N_{df}
3.5	87.0 ± 8.9	2.32 ± 0.009	-0.056 ± 0.11	8.21 ± 0.80	534	551.1	1.03
8.5	72.4 ± 7.4	2.77 ± 0.009	-0.042 ± 0.123	6.54 ± 0.632	448	452.5	1.01

- Dipole model BGK fit with fitted valence quarks

TABLE II. BGK fit with fitted valence quarks for σ_r for H1ZEUS-NC data in the range $Q^2 \geq 3.5$ GeV^2 and $x \leq 0.01$. NLO fit. *Soft gluon.* $m_{uds} = 0.14, m_c = 1.3$ GeV. $Q_0^2 = 1.9$ GeV^2.

Q^2_{min} [GeV^2]	$\sigma_0[mb]$	A_g	λ_g	C_g	N_{df}	χ^2	χ^2/N_{df}
3.5	89.99 ± 9.2	2.44 ± 0.145	-0.079 ± 0.099	7.24 ± 0.61	530	540.35	1.02

Results of the Fits

- Dipole model BGK fit without valence quarks

TABLE VI. BGK fit without valence quarks for σ_r for H1ZEUS-NC data in the range $Q^2 \geq 3.5$ GeV^2 and $x \leq 0.01$. NLO fit. *Soft gluon.* $m_{uds} = 0.14, m_c = 1.3$ GeV. $Q_0^2 = 1.9$ GeV^2.

$Q^2_{\min}$ [GeV^2]	$\sigma_0[mb]$	A_g	λ_g	C_g	N_{df}	χ^2	χ^2/N_{df}
3.5	105.20 ± 12.234	2.4788 ± 0.093	-0.066 ± 30.004	6.9093 ± 0.510	534	554.68	1.04

- Parameters of valence quarks from HERAPDF fit

TABLE VIII. Parameters of valence quarks obtained in HERAPDF NLO fits for $Q^2 > 3.5$ GeV^2.

No	Auv	Buv	Cuv	Euv	Adv	Bdv	Cdv
1	4.073 ± 0.123	0.713 ± 0.016	4.841 ± 0.214	13.405 ± 0.921	3.151 ± 10.121	0.806 ± 0.056	4.079 ± 0.301

Results of the Fits

- HERAPDF fit with fitted valence quarks for $x < 1$

TABLE VII. HERAPDF NLO fits to the same data set as for the dipole model but in the full x range. $Q_0^2 = 1.9$ GeV^2.

No	Q^2_{min} [GeV^2]	Heavy flavors scheme	Np	χ^2	χ^2/Np
1	3.5	Roberts-Thorne	1131	1356.70	1.20
2	8.5	Roberts-Thorne	456	470.88	1.15

- HERAPDF fit with fitted valence quarks for $x < 0.01$

TABLE IX. HERAPDF NLO fits with fixed valence quarks to the same data set as for the dipole model, but with $x < 0.01$ range. $Q_0^2 = 1.9$ GeV^2. No. 1, *soft gluon*; No. 2, *soft+hard gluon*.

No	Q^2_{min} [GeV^2]	Heavy flavors scheme	Np	χ^2	χ^2/Np
1	3.5	FONLL-B	534	539.3	1.01
2	3.5	FONLL-B	532	537.3	1.01

Results of the Fits

- HERAPDF fit with fitted valence quarks for $x < 0.01$, soft gluon

No	Q^2	HF Scheme	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	RT	534	572.69	1.07

Table 1: HERAPDF NLO fits with fixed valence quarks to the same data set as for the dipole model, but with $x < 0.01$ range. $Q_0^2 = 1.9$ GeV^2.

- HERAPDF fit with fitted valence quarks for $x < 0.01$, soft+hard gluon

No	Q^2	HF Scheme	Np	χ^2	χ^2/Np
1	$Q^2 \geq 3.5$	RT	532	564.80	1.06

Table 2: HERAPDF NLO fits with fixed valence quarks to the same data set as for the dipole model, but with $x < 0.01$ range. $Q_0^2 = 1.9$ GeV^2.

- $m_{u,d,s} = 140\ MeV,\ m_c = 1.3\ GeV$
- $\hat{\sigma}(r,x) = \sigma_0 \left\{1 - \exp\left[-\pi^2 r^2 \alpha_s(\mu^2) x g(x,\mu^2)/(3\sigma_0)\right]\right\}$ with saturation

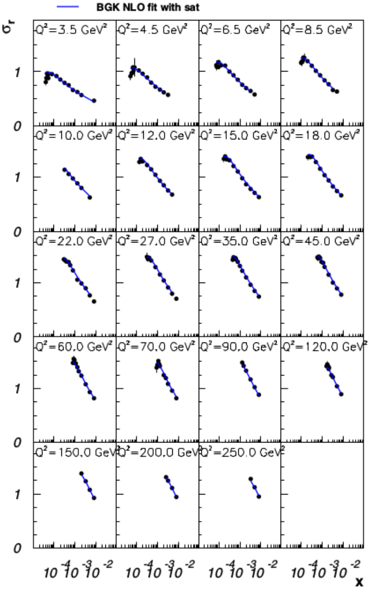
TABLE IV. BGK fit with valence quarks for σ_r for H1ZEUS-NC data in the range $Q^2 \geq 3.5$ or 8.5 GeV^2 and $x \leq 0.01$. NLO fit. *Soft +hard gluon*. $m_{uds} = 0.14, m_c = 1.3$ GeV. $Q_0^2 = 1.9$ GeV^2.

$Q^2_{\rm min}$ [GeV^2]	$\sigma_0[mb]$	A_g	λ_g	C_g	D_g	E_g	N_{df}	χ^2	χ^2/N_{df}
3.5	77.6 ± 18.6	2.62 ± 0.16	-0.064 ± 0.0087	37.1 ± 5.06	3.06 ± 6.51	1406.4 ± 552.7	532	534.2	1.00
8.5	63.5 ± 18.5	2.11 ± 0.10	-0.054 ± 0.0065	21.3 ± 4.062	1.10 ± 5.76	867.2 ± 423.7	448	439.0	0.98

- $\hat{\sigma}(r,x) = \sigma_0\ \left[\pi^2 r^2 \alpha_s(\mu^2) x g(x,\mu^2)/(3\sigma_0)\right]$ without saturation

TABLE X. BGK fit with valence quarks for σ_r for H1ZEUS-NC data in the range $Q^2 \geq 3.5$ GeV^2 and $x \leq 0.01$. NLO fit. *Soft+hard gluon*. $m_{uds} = 0.14, m_c = 1.3$ GeV, nonsaturation ansatz. $Q_0^2 = 1.9$ or 1.1 GeV^2.

$Q^2_{\rm min}$ [GeV^2]	Q_0^2 [GeV^2]	A_g	λ_g	C_g	D_g	E_g	Ndf	χ^2	χ^2/Np
3.5	1.9	2.33 ± 0.10	-0.094 ± 0.006	14.8 ± 11.5	9.80 ± 14.7	-99.5 ± 74.830	533	556.17	1.04
3.5	1.1	3.80 ± 0.22	0.10 ± 0.01	32.5 ± 1.6	-25.2 ± 3.49	1868 ± 252	533	539.2	1.01


BGK NLO fit with sat
σ_r
Q²=3.5 GeV²
Q²=4.5 GeV²
Q²=6.5 GeV²
Q²=8.5 GeV²
Q²=10.0 GeV²
Q²=12.0 GeV²
Q²=15.0 GeV²
Q²=18.0 GeV²
Q²=22.0 GeV²
Q²=27.0 GeV²
Q²=35.0 GeV²
Q²=45.0 GeV²
Q²=60.0 GeV²
Q²=70.0 GeV²
Q²=90.0 GeV²
Q²=120.0 GeV²
Q²=150.0 GeV²
Q²=200.0 GeV²
Q²=250.0 GeV²
x

Results of the Fits

- BGK dipole model fit for $Q^2 \geq 0.35\ GeV^2$, saturation ansatz

TABLE XI. BGK fit with valence quarks for σ_r for H1ZEUS-NC data in the range $Q^2 \geq 0.35$ GeV^2 and $x \leq 0.01$. NLO fit. *Soft+hard gluon*. $m_{uds} = 0.14$, $m_c = 1.3$ GeV, saturation ansatz. $Q_0^2 = 1.9$ or 1.1 GeV^2.

Q_0^2 [GeV^2]	σ_0 [mb]	A_g	λ_g	C_g	D_g	E_g	N_{df}	χ^2	χ^2/N_{df}
1.9	38.2 ± 4.1	2.80 ± 0.14	-0.063 ± 0.006	46.3 ± 4.58	12.1 ± 6.00	1970.4 ± 566.0	653	790.4	1.21
1.1	196.1 ± 105	6.24 ± 0.53	0.098 ± 0.012	52.3 ± 6.5	-22.0 ± 10.64	2145.0 ± 835.7	653	894.1	1.37

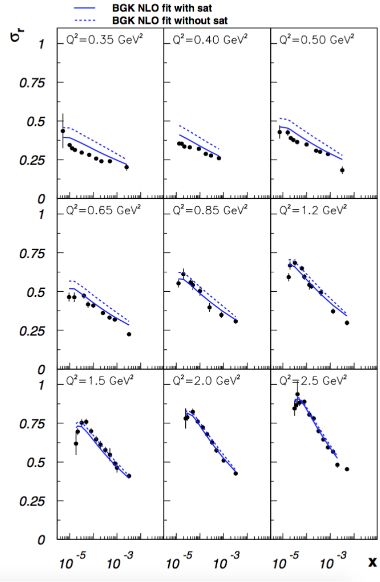
- BGK dipole model fit for $Q^2 \geq 0.35\ GeV^2$, non saturation ansatz

TABLE XII. BGK fit with valence quarks for σ_r for H1ZEUS-NC data in the range $Q^2 \geq 0.35$ GeV^2 and $x \leq 0.01$. NLO fit. *Soft +hard gluon*. $m_{uds} = 0.14$, $m_c = 1.3$ GeV, non-saturation ansatz. $Q_0^2 = 1.9$ or 1.1 GeV^2.

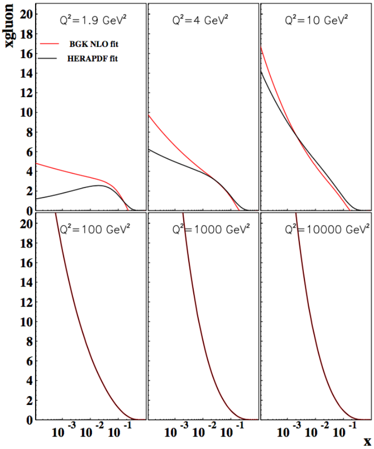
Q_0^2 [GeV^2]	A_g	λ_g	C_g	D_g	E_g	N_{df}	χ^2	χ^2/N_{df}
1.9	3.05 ± 0.092	-0.022 ± 0.004	40.3 ± 1.067	-32.3 ± 3.02	3158.3 ± 219.3	654	1024.3	1.56
1.1	5.62 ± 0.13	0.158 ± 0.001	43.320 ± 0.15	-55.011 ± 8.62	3791.6 ± 187.7	654	999.98	1.53

Comparision with HERA I+II data

- The χ^2/N_{df} in the region: $0.3 < Q^2 < 250$ GeV^2 is sizably higher than in the fits in the region $3.5 < Q^2 < 250$ GeV^2.
- $\chi^2/N_{df} = 1.21$, with the saturation ansatz and $\chi^2/N_{df} = 1.52$ without the saturation ansatz.
- The fit in the whole Q^2 region, $0.3 < Q^2 < 250$ GeV^2 is only slightly better than in the extrapolated case.
- The systematic overshoot of the fits over data remains.

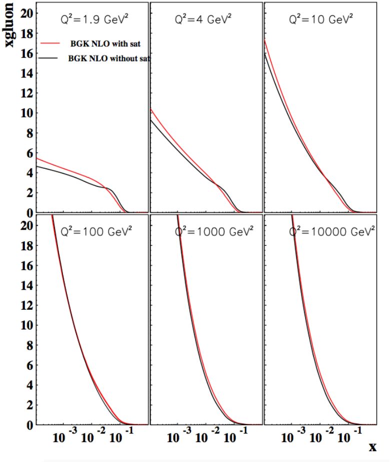


Gluon density



- The differences are disappearing at larger Q^2.

Gluon density



- The differences are disappearing at larger Q^2.

Summary I

- BGK dipole fits (with saturation) describe the final, high precision HERA data with $x < 0.01$, very well: $\chi^2/Np \to 1$.
- Little sensitivity to valence quarks contribution observed.
- Gluon density from the BGK model is higher than the PDFs gluon at low Q^2.
- The extrapolation to the very low Q^2 region shows a sizable overshoot. This indicates that at very low Q^2 saturation effects of the eikonal aproximation are too small.
- In the lower $Q^2 < 3.5$ GeV^2 range the saturated ansatz of the gluon density seems to be prefered.

Summary II

- **xFitter** (former **HERAFitter**) is a unique **open-source** package oriented to fits of PDFs that provides a framework for the **interpretation** and the **analysis** of the experimental data.
- xFitter is presently widely used for many analyses of the **LHC data** to quantify the **constraints on PDFs**.
- **xFitter-2.0.0** is latest (recommended) release.
- Over 40 public results obtained using xFitter.
- The photon PDF from high-mass Drell-Yan data at the LHC is determined.
- I have presented one of the many recent results obtained with xFitter:
    - Dipole model analysis of highest precision HERA data, including very low Q^2's

We welcome new ideas and developers :)

special thanks to: S. Glazov (DESY), F. Giuli (Oxford Univ.), S. Zenaiev (DESY)