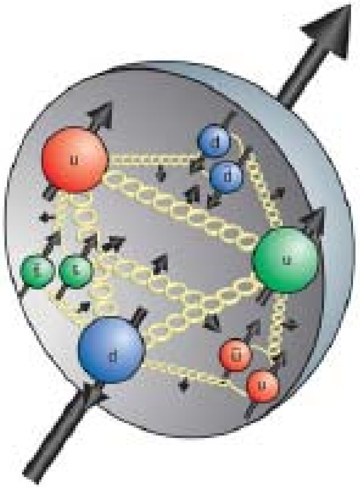
Polarized Parton Distributions and Structure Function

Ali Khorramian

- Physics Department of Semnan University, Semnan, Iran
- Institute for theoretical Physics and Mathematics (IPM), Tehran, Iran
- Stanford university, CA, USA

- Introduction
  - Why spin physics?
  - Experimental data in QCD spin physics
  - SIDIS data
- Unpolarized PDFs
  - Proton structure and DIS data
  - Structure Function F_2
  - NLO results for PDFs
- Polarized PDFs and structure function
  - Strange helicity puzzle
  - Spin structure of the proton
  - Asymmetry of nucleon sea
  - PPDFs and polarized structure function
- Results & Conclusions



- A fundamental challenge of high energy particle physics is to understand the spin structure of protons, neutrons, and nuclei in terms of their parton constituents.

- The increasing precision of experimental data on inclusive polarized deeply inelastic scattering (DIS) of leptons from nucleons allows us to perform QCD analyses of polarized structure functions to reveal the spin dependent partonic structure function of the nucleon.

- The PDF sets slightly differ in:
    I. The choice of datasets,
    II. The form of PDF parametrization,
    III. Several details of the QCD analysis,

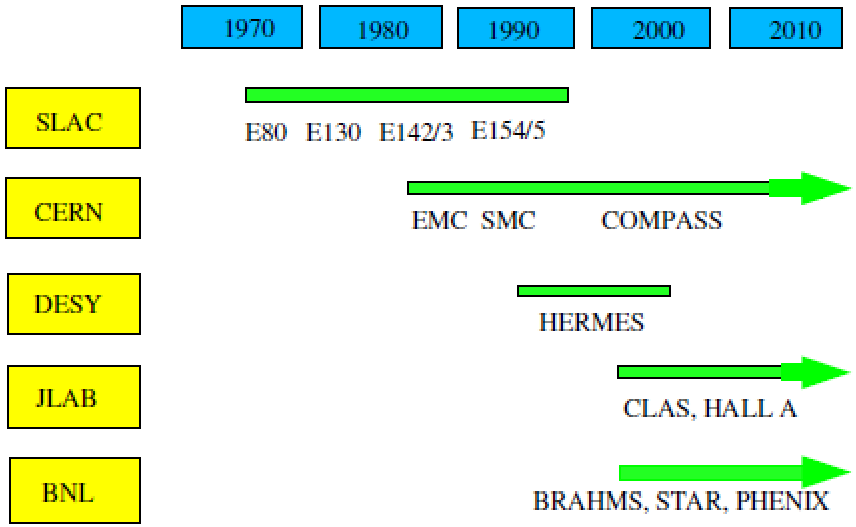
but they are all based on the standard Hessian methodology for PDF fitting and uncertainty determination, which has been widely used in the unpolarized and polarized case.

Remarkable experimental progress in QCD spin physics in the last years

Inclusive spin-dependent DIS
EMC, SMC, COMPASS
E142,E143,E154,E156
HERMES
Jlab-Hall A, B(CLAS)

Semi-inclusive DIS
SMC, COMPASS
HERMES

Polarized pp collisions
RHIC
PHENIX & STAR



More measurements in progress

Several upgrade and new experiments planned

Jefferson Lab
Thomas Jefferson National Accelerator Facility

STAR

Experiments

Experiment	Polarised beam	Polarised target	Energy (GeV)
SLAC	e	p, n, d	$\lesssim 50$
EMC	μ	p	100–200
SMC	μ	p, d	100, 190
HERMES	e	p, n, d	27.5
COMPASS	μ	p, d	160, 200
JLAB	e	p, n, d	$\lesssim 6$

DIS 2013

Part I:

Unpolarized PDFs

Part II:

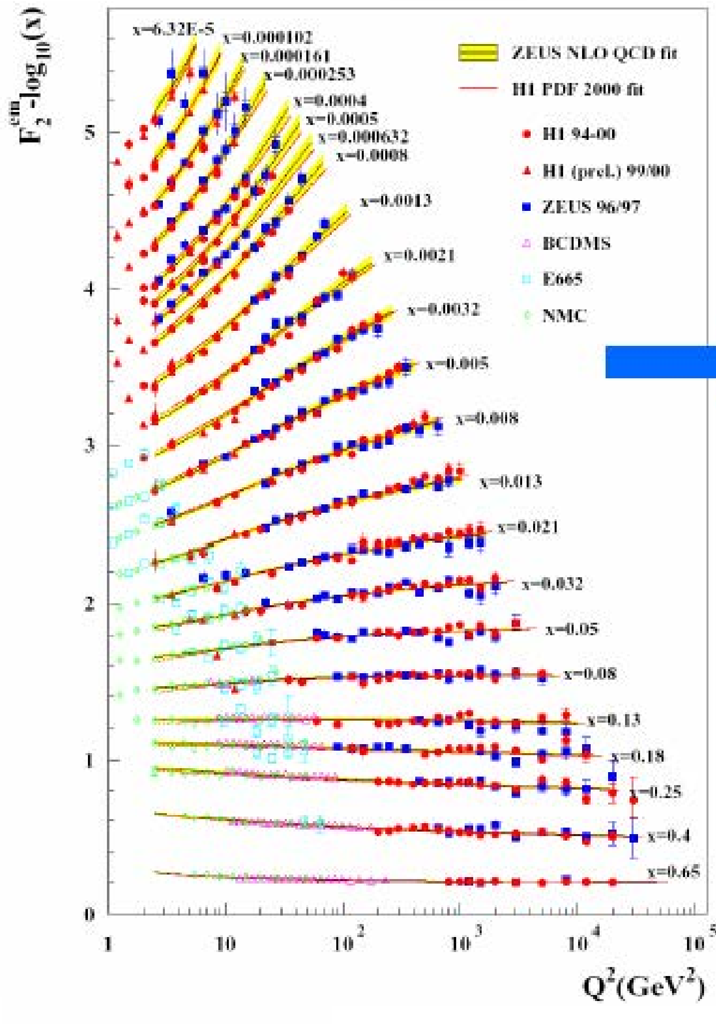
Spin physics & Polarized parton distribution functions

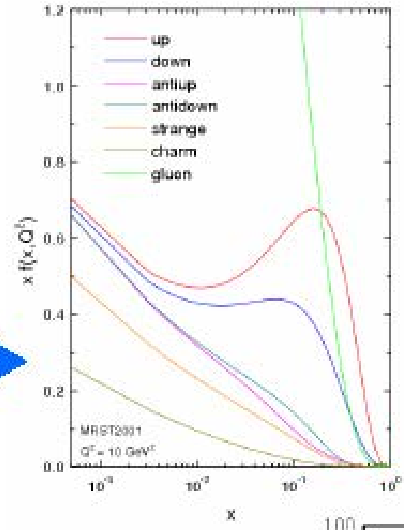
Part I:
Unpolarized PDFs

Part II:

Spin physics & Polarized parton distribution functions

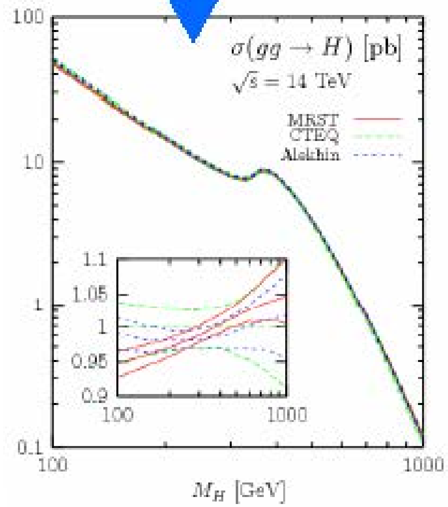
Structure of the Proton : PDFs from HERA

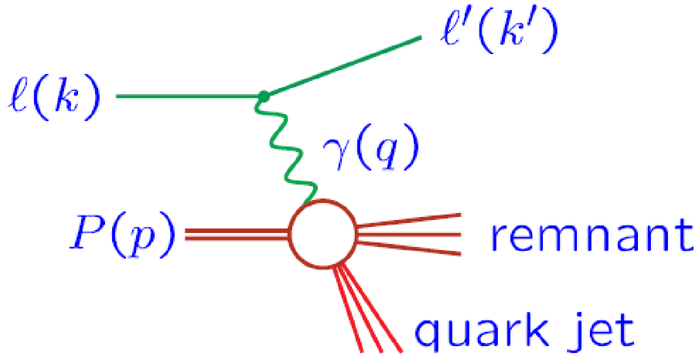




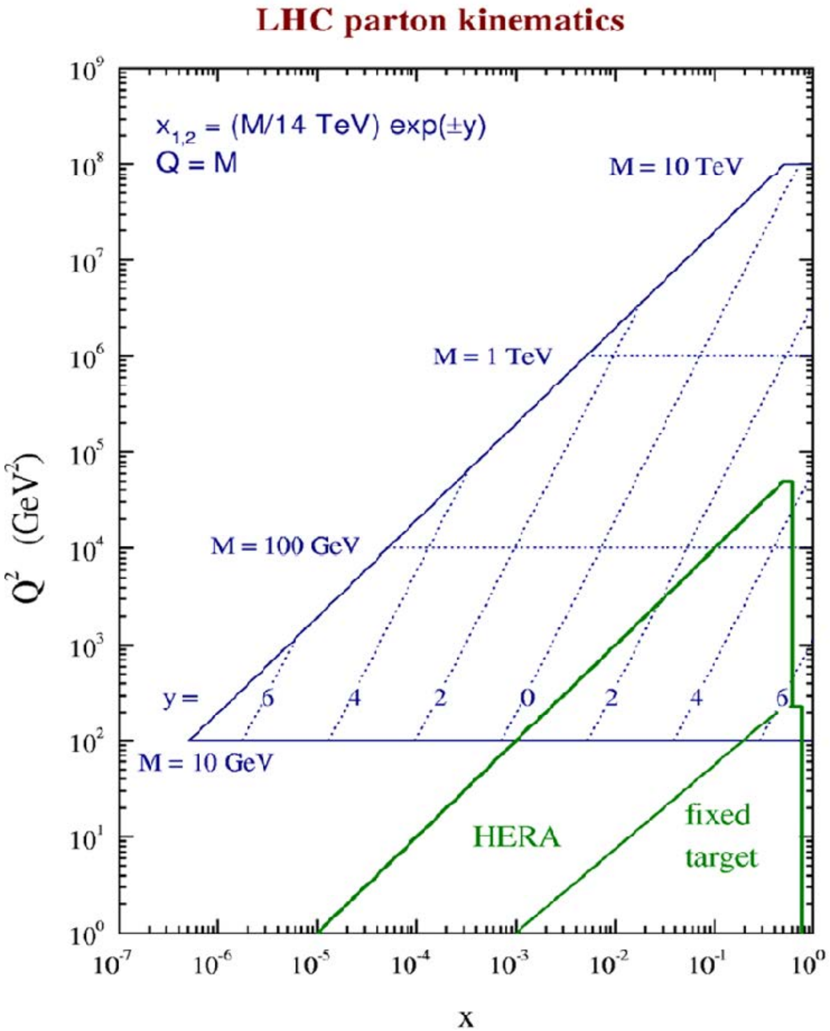
to

LHC



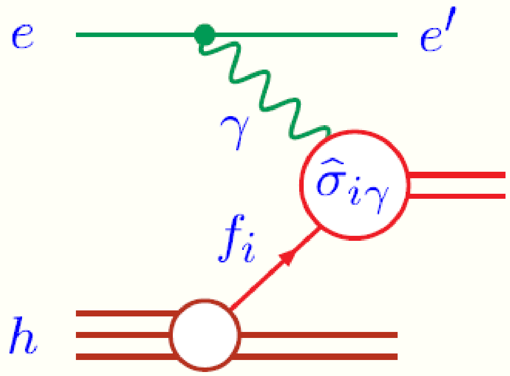


s	$=$	$(k+p)^2$	ℓP centre of mass energy squared
Q^2	$=$	$-q^2$	Negative 4-momentum transfer squared
x	$=$	$Q^2/(2p\cdot q)$	Parton momentum fraction in Breit frame
y	$=$	$(p\cdot q)/(p\cdot k)$	E_γ/E_ℓ in proton rest frame (inelasticity)
W^2	$=$	$(p+q)^2$	γP centre of mass energy squared



- PDFs cannot be calculated from theory and are obtained from fits to data
- DIS data are important: the structureless e, μ or ν directly probes the hadron:

$$\sigma_{eh} = \sum_i f_i \otimes \hat{\sigma}_{i\gamma}$$



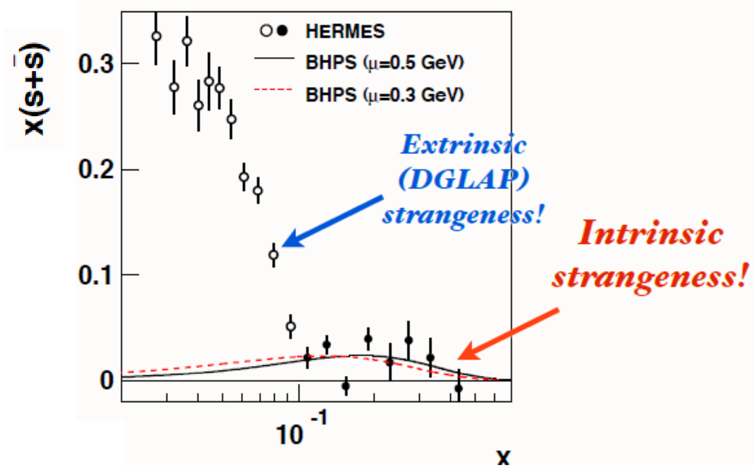
- Our Parametrization for PDFs

$$xu_v(x, Q_0^2) = A_u x^{\alpha_u} (1-x)^{\beta_u} (1 + \gamma_u x^{\delta_u} + \eta_u x),$$
$$xd_v(x, Q_0^2) = A_d x^{\alpha_d} (1-x)^{\beta_d} (1 + \gamma_d x^{\delta_d} + \eta_d x),$$
$$x\Delta(x, Q_0^2) = A_\Delta x^{\alpha_\Delta} (1-x)^{\beta_S+\beta_\Delta} (1 + \gamma_\Delta x^{\delta_\Delta} + \eta_\Delta x),$$
$$xS(x, Q_0^2) = A_S x^{\alpha_S} (1-x)^{\beta_S} (1 + \gamma_S x^{\delta_S} + \eta_S x),$$
$$xg(x, Q_0^2) = A_g x^{\alpha_g} (1-x)^{\beta_g} (1 + \gamma_g x^{\delta_g} + \eta_g x).$$

- With

$$xS = 2x(\bar{u} + \bar{d} + \bar{s}), x\Delta = x(\bar{d} - \bar{u})$$

$$\begin{cases} 2\bar{u}(x, Q_0^2) = 0.4S(x, Q_0^2) - \Delta(x, Q_0^2), \\ 2\bar{d}(x, Q_0^2) = 0.4S(x, Q_0^2) + \Delta(x, Q_0^2), \\ 2\bar{s}(x, Q_0^2) = 0.2S(x, Q_0^2), \end{cases}$$



H. Khanpour , A.K. , J.Phys. G40 (2013) 045002

Strange Quark PDF Uncertainty:

A. Kusina, T. Stavreva, S. Berge, F.I. Olness, I. Schienbein, K. Kovarik, T. Jezo, J.Y. Yu, K. Park, arXiv:1302.1889 [hep-ph]

- Proton structure function and NLO QCD analysis

$$F_2(x,Q^2) = F^+_{2,\mathrm{NS}}(x,Q^2) + F_{2,S}(x,Q^2) + F_2^{(c,b)}(x,Q^2,m^2_{c,b}),$$

here:

$$\frac{1}{x}F^+_{2,\mathrm{NS}}(x,Q^2) = [C^{(0)}_{2,q} + a_s C^{(1)}_{2,\mathrm{NS}}] \otimes \left[\frac{1}{18}q_8^+ + \frac{1}{6}q_3^+\right](x,Q^2),$$

$$\frac{1}{x}F_{2,S}(x,Q^2) = \frac{2}{9}\{[C^{(0)}_{2,q} + a_s C^{(1)}_{2,q}] \otimes \Sigma + a_s C^{(1)}_{2,g} \otimes g\}(x,Q^2),$$

$$F_2^h(x,Q^2) = \sum_i C^{\mathrm{FFNS},n_f}_{2,i}(Q^2/m_h^2) \otimes f_i^{n_f}(Q^2),$$

Martin, Stirling , Thorne and Watt, Eur. Phys. J. C 63 189 (arXiv:0901.0002 p-ph])

Neerven and Vogt, Nucl. Phys. B 588 345 (arXiv:hep-ph/0006154)
Neerven and Vogt, Nucl. Phys. B 568 263 (arXiv:hep-ph/9907472)
Vermaseren , Vogt and Moch, Nucl. Phys. B 724 3 (arXiv:hep-ph/0504242)

T. Stavreva, F.I. Olness, I. Schienbein, T. Jezo, A. Kusina, K. Kovarik, J.Y. Yu, arXiv:1206.2582 [hep-ph]

Data sets fitted in NLO QCD analysis

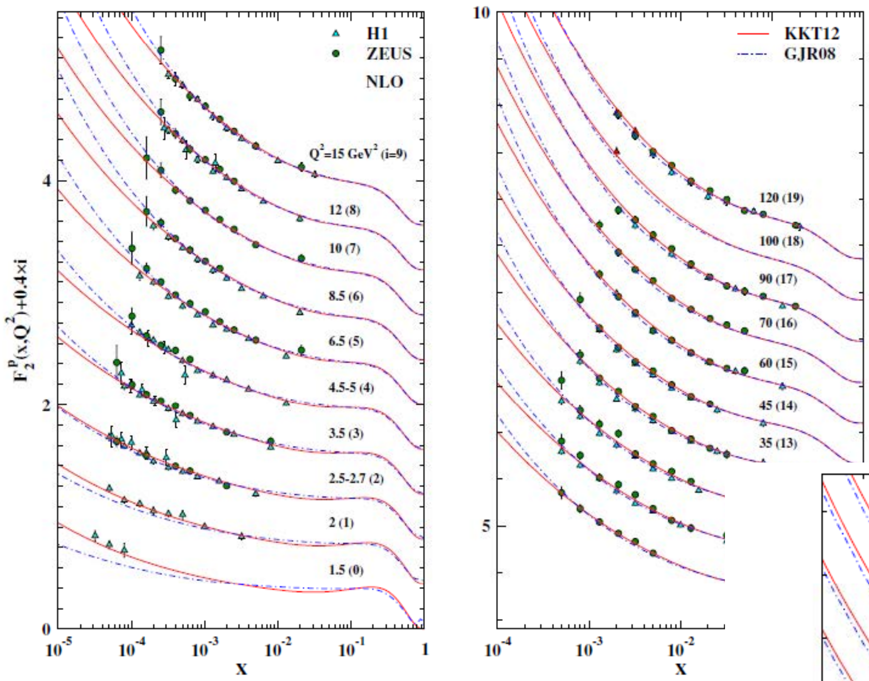
Table 1. Data sets fitted in our NLO QCD analysis. The fitted normalizations $\mathcal{N}_n$ of the data sets included in the global QCD fit, together with the total normalization uncertainty, $\Delta\mathcal{N}_n$, for each data set n are also shown in the table. The details of corrections to data and the kinematic cuts applied are contained in the text.

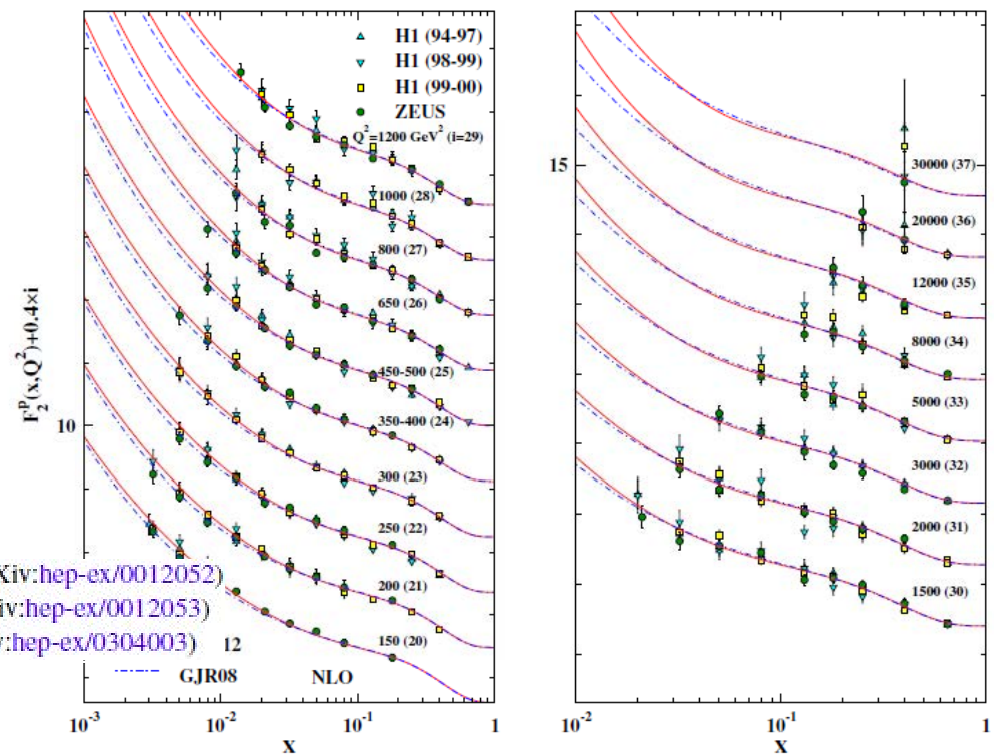
Experiment	x-range	Q^2-range (GeV^2)	No. of data points	$\Delta\mathcal{N}_n$	$\mathcal{N}_n$
H1 high Q^2 94–97 e^+p NC	0.003 – 0.65	150.0 – 30 000.0	130 [66]	1.5%	0.9991
H1 high Q^2 98–99 e^-p NC	0.0032 – 0.65	150.0 – 30 000.0	126 [67]	1.8%	0.9999
H1 Q^2 96–97 e^+p NC	5.0E-5 – 0.2	2.0 – 150.0	144 [68]	1.7%	1.0078
H1 high Q^2 99–00 e^+p NC	0.002 – 0.65	100.0 – 30 000.0	147 [69]	1.5%	0.9999
H1 Q^2 99–00 e^+p NC	5.0E-6 – 0.02	2.0 – 12.0	85 [70]	0.5%	0.9994
H1 Q^2 00 e^+p NC	2.0E-4 – 0.1	12.0 – 150.0	99 [71]	0.5%	0.9987
ZEUS SVX 95 e^+p NC	5.4E-5 – 0.0019	2.50 – 17.0	30 [72]	1.5%	1
ZEUS 96–97 e^+p NC	6.32E-5 – 0.65	2.70 – 30 000.0	242 [73]	2%	0.9995
ZEUS 06–07 e^+p NC	5.0 E-4 – 0.007	20.0 – 130.0	162 [74]	2.7%	1.0012
ZEUS 98–99 e^-p NC	0.050 – 0.65	200.0 – 30 000.0	92 [75]	1.8%	0.9996
ZEUS 99–00 e^+p NC	0.050 – 0.65	200.0 – 30 000.0	90 [76]	2.5%	0.9968
H1 03–07 $e^{\pm}p$ NC	2.9E-5 – 0.01	2.0 – 120.0	134 [77]	4 %	0.9997
NMC μp F_2	0.0045 – 0.5	2.50 – 65.0	126 [78]	2 %	1.0023
NMC μd F_2	0.0045 – 0.5	2.50 – 65.0	126 [78]	2 %	1.0023
NMC $\mu n/\mu p$	0.008 – 0.675	2.23 – 99.03	156 [84]	0.15%	1
BCDMS μp F_2	0.07 – 0.75	7.5 – 230.0	167 [79]	3%	0.9900
BCDMS μd F_2	0.07 – 0.75	8.75 – 230.0	155 [83]	3%	0.9900
E665 μp F_2	0.0037 – 0.38726	2.046 – 64.269	53 [80]	1.85%	1.0012
E665 μd F_2	0.0037 – 0.38726	2.046 – 64.269	53 [80]	1.85%	1.0012
SLAC ep F_2	0.007 – 0.65	2.01 – 22.21	53 [81]	2%	1.0128
HERMES ep F_2	0.006 – 0.66	2.0 – 12.0	39 [82]	7.55%	1.0167
HERMES ed F_2	0.006 – 0.66	2.0 – 12.0	39 [82]	7.55%	1.0167
H1 ep F_2^c	1.3E-4 – 0.02	6.50 – 60.0	25 [85]	7.5%	1
H1 ep F_2^c	0.005 – 0.032	200.0 – 650.0	4 [86]	1.5%	1
H1 ep F_2^c	2.0E-4 – 0.05	5.0 – 2000.0	29 [87]	1.5%	1
H1 ep F_2^c	1.97E-4 – 0.05	12.0 – 60.0	6 [88]	1.5%	1
H1 ep F_2^c	1.3E-4 – 0.00316	3.50 – 60.0	10 [89]	1.5%	1
H1 ep F_2^c	8.0E-4 – 0.008	12.0 – 45.0	9 [90]	1.5%	1
ZEUS ep F_2^c	1.3E-4 – 0.00676	4.20 – 111.8	5 [91]	1.8%	1
ZEUS ep F_2^c	1.3E-4– 0.02	4.0 – 130.0	18 [92]	1.65%	1
ZEUS ep F_2^c	3.0E-5 – 0.03	2.0 – 500.0	31 [93]	2.2%	1
ZEUS ep F_2^c	8.0E-5 – 0.03	30.0 – 1000.0	8 [96]	1.5%	1
H1 ep F_2^b	0.005 – 0.032	200.0 – 650.0	4 [86]	1.5%	1
H1 ep F_2^b	2.0E-4 – 0.05	5.0 – 2000.0	12 [87]	1.5%	1
H1 ep F_2^b	1.97E-4 – 0.05	12.0 – 60.0	6 [88]	1.5%	1
ZEUS ep F_2^b	2.0E-4 – 0.013	12.0 – 600.0	9 [94]	2 %	1
ZEUS ep F_2^b	1.3E-4 – 0.013	3.0 – 450.0	11 [95]	2 %	1
ZEUS ep F_2^b	8.0E-5 – 0.03	30.0 – 1000.0	8 [96]	1.5%	1
H1 ep F_2^c/F_2^p	8.0E-4 – 0.008	12.0 – 45.0	9 [90]	1.5%	1
FNAL E866/NuSea	0.026 – 0.315	54 (Fixed)	30 [97, 98]	0.6%	1
H1/ZEUS F_L	4.27E-5 – 0.0049	2.0 – 110.0	127 [68, 74, 77, 99]	–	1
CHORUS νN xF_3	0.02 – 0.65	2.052 – 81.55	50 [100]	2.1%	1.0023
NuTeV νN xF_3	0.015 – 0.75	3.162 – 125.89	64 [101]	2.1%	1.0023
DØ I $p\bar{p}$ incl. jets			90 [107]	6 %	1.0021
CDF II $p\bar{p}$ incl. jets			76 [108]	5.8%	1.0023
DØ II $p\bar{p}$ incl. jets			110 [109]	6.1%	1.0221
ZEUS 96–97 e^+p incl. jets			30 [105]	2 %	0.9988
ZEUS 98–00 $e^{\pm}p$ incl. jets			30 [106]	2.5%	0.9980
CDF II $p\bar{p}$ incl. jets			20 [110]	6 %	0.9972
All data sets			3279		

Input PDF parameter

Table 3. Minimum values of χ^2 together with the input PDF parameters at $Q_0^2 = 2\,\mathrm{GeV}^2$ determined from the two different global analysis (Fit A for KKT12 and Fit B for KKT12C).

Parameter	Fit A—(KKT12)	Fit B—(KKT12C)
A_u	0.3346	0.3753
α_u	0.3271 ± 0.0039	0.3126 ± 0.0041
β_u	3.5858 ± 0.0123	3.6536 ± 0.0103
δ_u	0.4573	0.5036
γ_u	5.4618	3.2716
η_u	20.1864	21.2864
A_d	0.3730	0.6124
α_d	0.3668 ± 0.0105	0.4226 ± 0.0092
β_d	4.8277 ± 0.1001	5.1529 ± 0.0654
δ_d	0.6306	0.9553
γ_d	4.6633	-3.7475
η_d	7.5520	14.1380
A_Δ	10.0048 ± 0.8417	15.8096 ± 0.3160
α_Δ	1.7030 ± 0.0290	1.4430 ± 0.0336
β_Δ	9.8938 ± 0.3506	10.4343 ± 0.4278
δ_Δ	0.6625	0.4972
γ_Δ	-7.3512	-7.5151
η_Δ	23.7067	20.4901
A_S	0.3494 ± 0.0019	0.3506 ± 0.0023
α_S	-0.1740 ± 0.0012	-0.1775 ± 0.0012
β_S	8.2970 ± 0.0953	8.9898 ± 0.0990
δ_S	0.5129	0.8764
γ_S	0.2434	0.4549
η_S	9.8585	12.4246
A_g	6.2512	7.1383
α_g	0.1179 ± 0.0101	0.1348 ± 0.0051
β_g	8.4027 ± 0.1663	10.0188 ± 0.1494
γ_g	0.2600	1.3264
η_g	-1.4998	-0.9499
χ^2/dof	3590.589/3266 = 1.098	2622.118/2472 = 1.060





Adloff C *et al* (H1 Collaboration) 2001 *Eur. Phys. J.* C 19 269 (arXiv:hep-ex/0012052)
Adloff C *et al* (H1 Collaboration) 2001 *Eur. Phys. J.* C 21 33 (arXiv:hep-ex/0012053)
Adloff C *et al* (H1 Collaboration) 2003 *Eur. Phys. J.* C 30 1 (arXiv:hep-ex/0304003)

Structure Function F_2 , Low & Large -x

HERA, BCDMS,SLAC, NMC

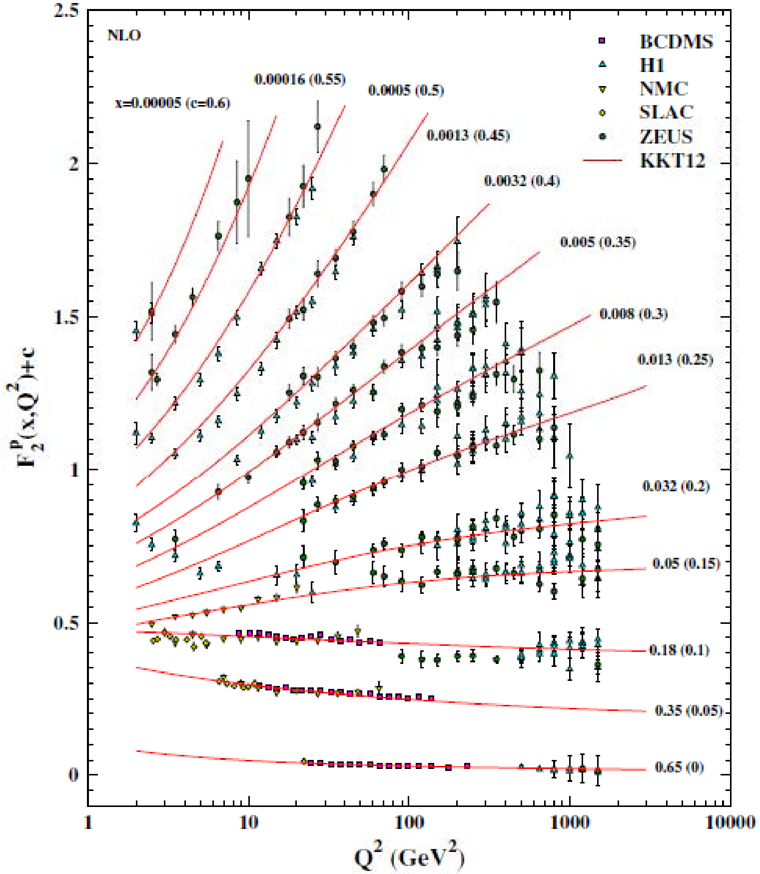
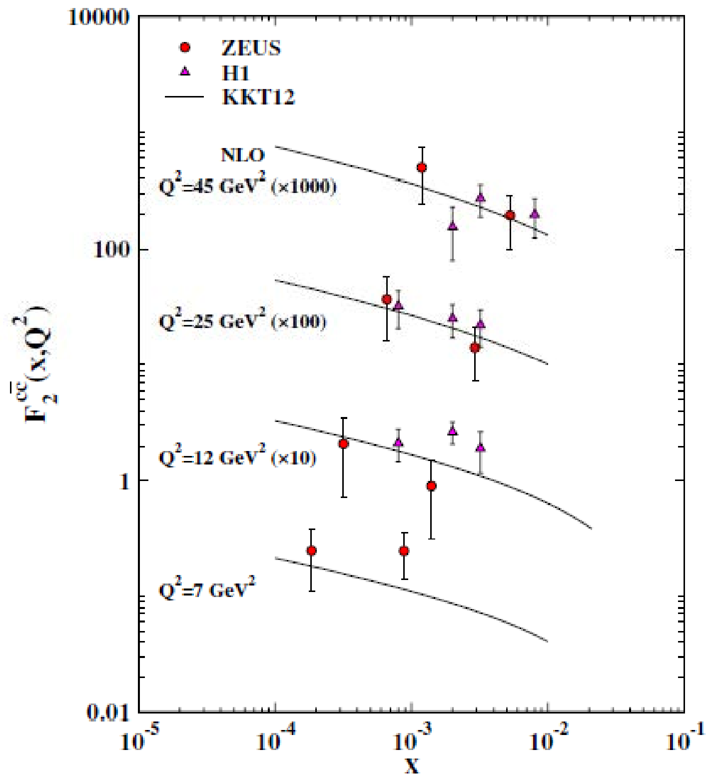
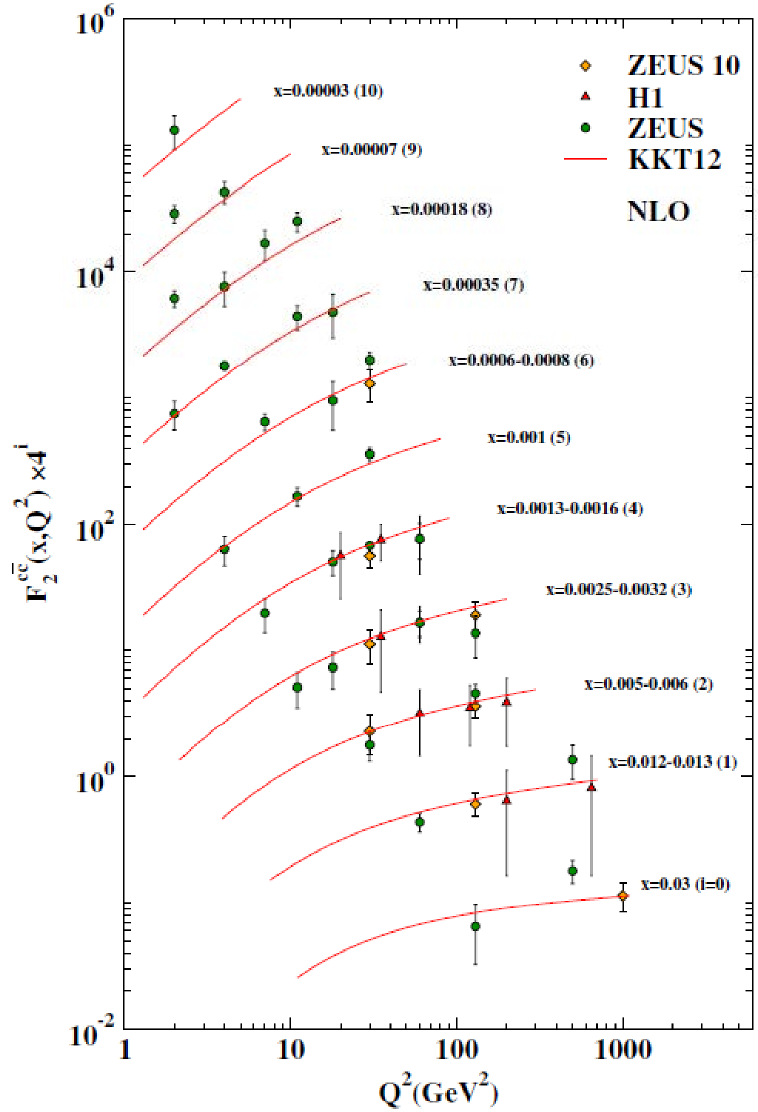


Figure 5. Comparison of our standard NLO ($\overline{\text{MS}}$) results for $F_2^p(x, Q^2)$ with HERA data [66–69, 72, 73] and fixed target data of NMC [78], BCDMS [79] and SLAC [81]. To facilitate the graphical presentation we have plotted $F_2^p(x, Q^2) + c$, with c indicated in parentheses in the figure.





Aktas A *et al* (H1 Collaboration) 2005 *Eur. Phys. J.* C **40** 349 (arXiv:hep-ex/0411046)
Aaron F D *et al* (H1 Collaboration) 2010 *Eur. Phys. J.* C **65** 89 (arXiv:0907.2643 [hep-ex])
Aktas A *et al* (H1 Collaboration) 2006 *Eur. Phys. J.* C **45** 23 (arXiv:hep-ex/0507081)
Adloff C *et al* (H1 Collaboration) 2002 *Phys. Lett.* B **528** 199 (arXiv:hep-ex/0108039)
Adloff C *et al* (H1 Collaboration) 1996 *Z. Phys.* C **72** 593 (arXiv:hep-ex/9607012)
Chekanov S *et al* (ZEUS Collaboration) 2007 *J. High Energy Phys.* JHEP07(2007)074 [hep-ex])
Breitweg J *et al* (ZEUS Collaboration) 2000 *Eur. Phys. J.* C **12** 35 (arXiv:hep-ex/9908012)
Chekanov S *et al* (ZEUS Collaboration) 2004 *Phys. Rev.* D **69** 012004 (arXiv:hep-ex/03080

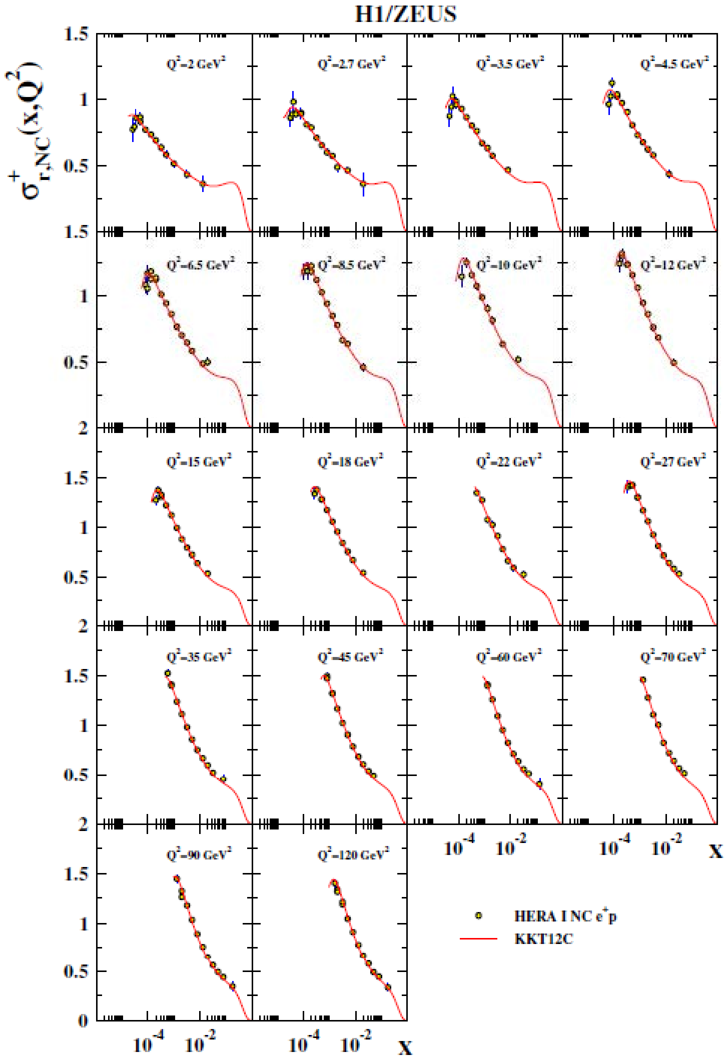


Figure 6. Our results of KKT12C fit for reduced cross section, $\sigma^{+}_{r,\mathrm{NC}}(x, Q^2)$, in comparison with HERA combined NC $e^{+}p$ reduced cross section [14] as a function of x for different values of Q^2 bins for 2 GeV$^2 \leqslant Q^2 \leqslant$ 120 GeV^2. The error bars indicate the total experimental uncertainty.

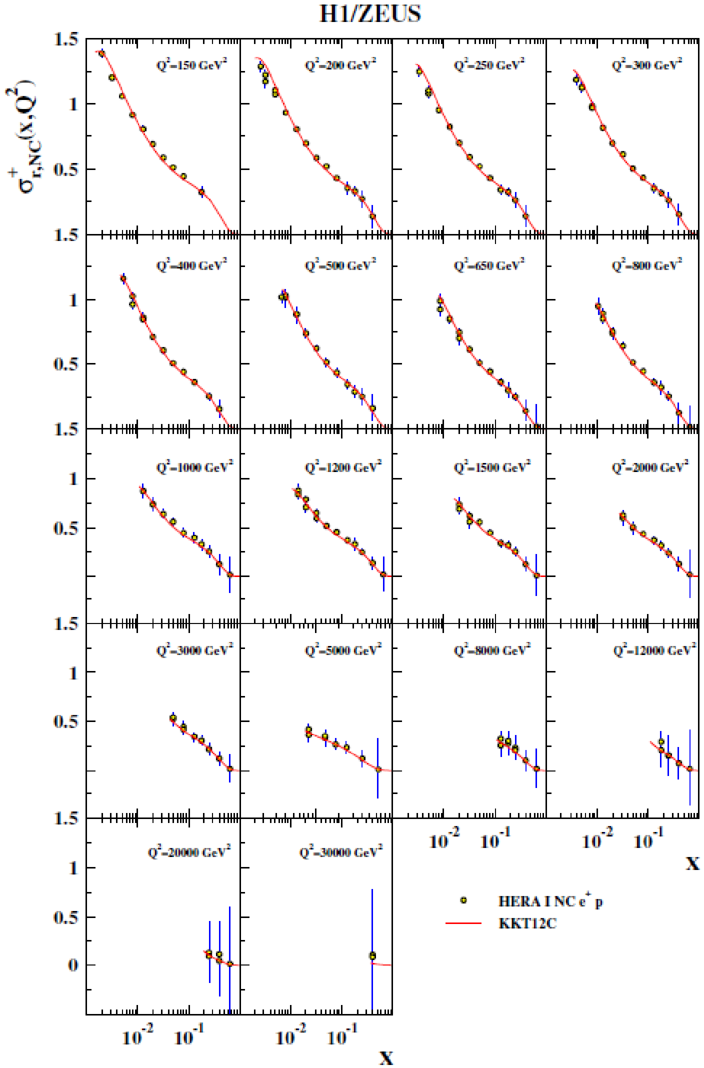


Figure 7. Our results of KKT12C fit for reduced cross section, $\sigma^{+}_{r,\mathrm{NC}}(x, Q^2)$, in comparison with HERA combined NC $e^{+}p$ reduced cross section [14] as a function of x for different values of Q^2 bins for 150 GeV$^2 \leqslant Q^2 \leqslant$ 30 000 GeV^2. The error bars indicate the total experimental uncertainty.

Nagy Z 2002 *Phys. Rev. Lett.* 88 122003 (arXiv:hep-ph/0110315)
Nagy Z 2003 *Phys. Rev.* D 68 094002 (arXiv:hep-ph/0307268)

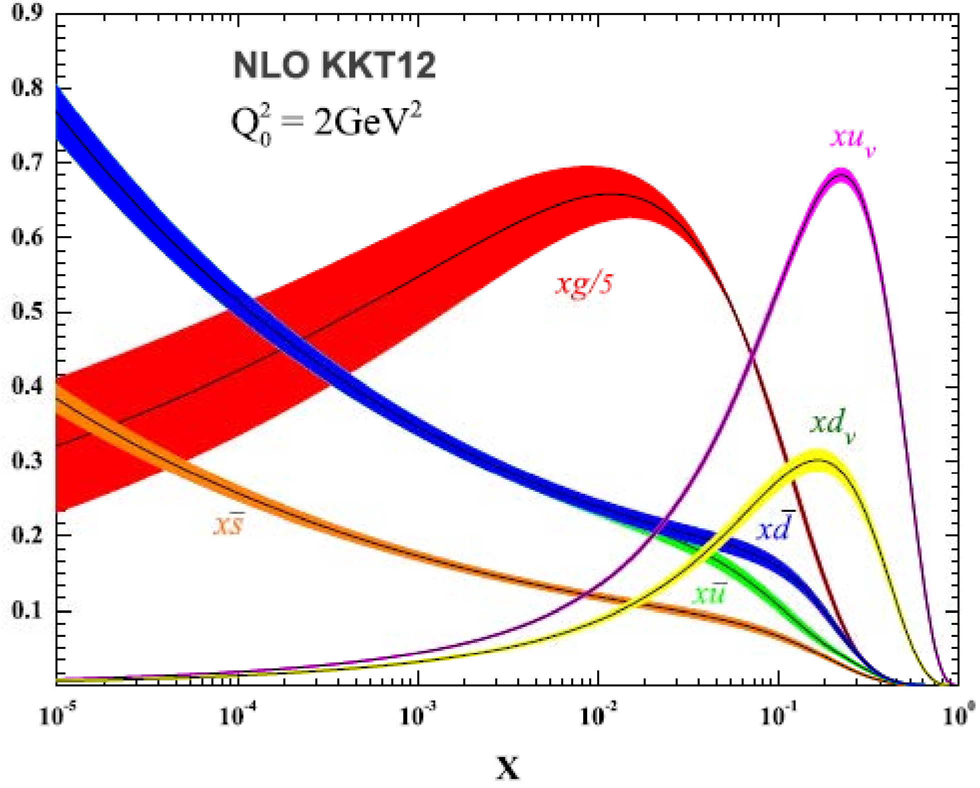


Figure 10. The KKT12 parton distributions at input scale $Q_0^2 = 2$ GeV^2 as a function of x in the NLO approximation.

H. Khanpour , A.K. , J.Phys. G40 (2013) 045002

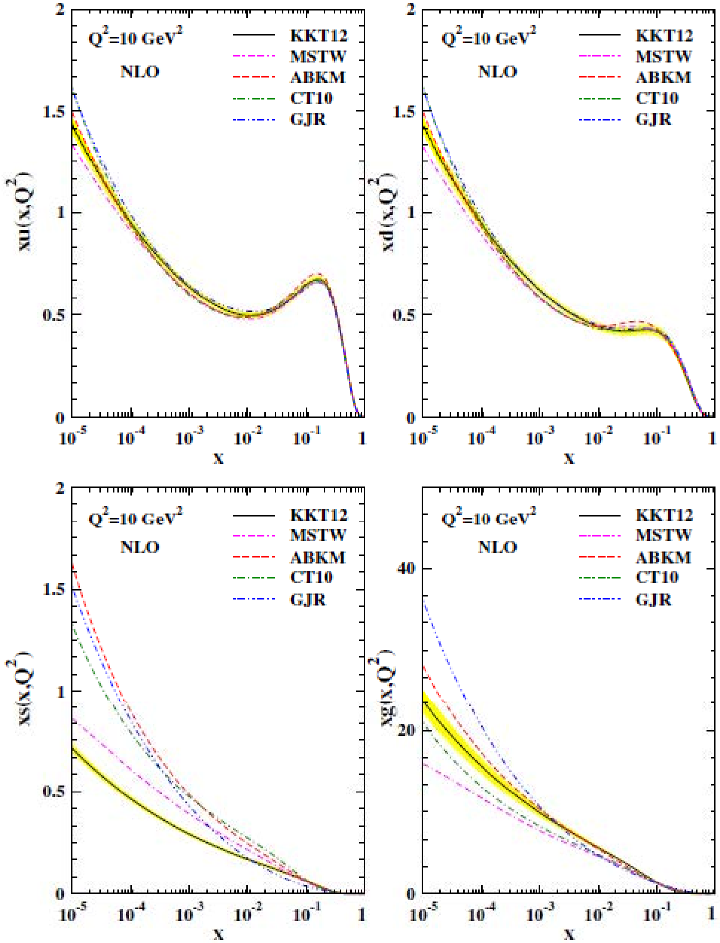


Figure 12. The u-, d-, s-quark and gluon distributions xg at $Q^2 = 10$ GeV^2 as a function of x in the NLO approximation in comparison with the results obtained by CT10 [3], MSTW08 [6], ABKM10 [10] and GJR08 [11].

Part I:

Unpolarized PDFs

Part II:

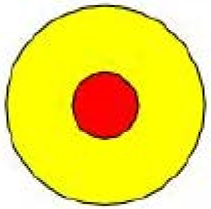
Spin physics & Polarized parton distribution functions

Make some generic assumptions about the functional form with a few parameters and fit them to data.

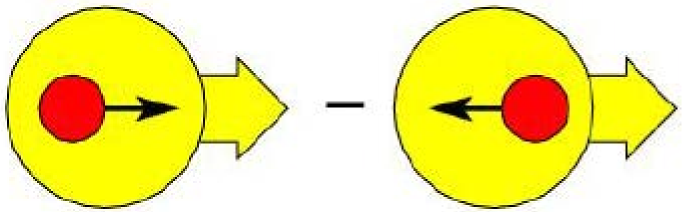
Many efforts in the past have been made :

Gluck, Reya, Stratmann, Vogelsang (2001)
Blumlein and Bottcher (2003)
A.K. et al. JHEP (2004)
Leader, Sidorov, Stamenov (2006)
Hirai, Kumano, Saito (2006)
…
A.K. et al. PRD (2009)
A.K. et al. PRD (2011)
…
One of the recent QCD NLO analysis by NNPDF Collaboration (hep-ph/ 1303.7236) is available based on NNPDFS methodology.

A Set of polarized parton distributions
Pavel M. Nadolsky, **Z.Phys. C63 (1994) 601-609.**

$q(x) =$ 

Quark momentum DF;
well known (unpolarised DIS $\rightarrow F_{1,2}(x)$).

$\Delta q(x) =$ 

Difference in DF of quarks with spin parallel or antiparallel to the nucleon's spin;
known (polarised DIS $\rightarrow g_1(x)$).

- When the proton (or neutron) is polarized, the quarks and gluons are polarized as well.
- Polarized PDF can be extracted from the experimental data through global fits.

- What is the role of gluons and sea quarks
- What is the role of orbital angular momentum

Strange helicity puzzle

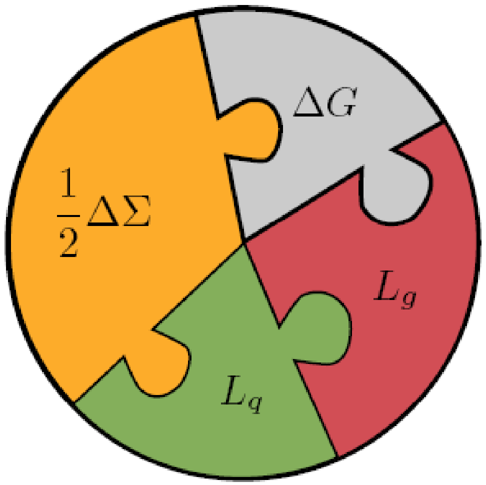
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta G + L_g$$

Well known !

In 1988 EMC measured
$\Delta\Sigma$ = 0.12 ± 0.17 (Phys.Lett.B206,364)

A recent result, including COMPASS, gives:
$\Delta\Sigma$ = 0.30 ± 0.01(stat.) ± 0.02(evol.) Phys.Lett.B647,8

Not known !



Not completely known

Exploratory and discovery stage.
Some experiments and data might give hints.

COMPASS, HERMES, CLAS, STAR, PHENIX, EIC.

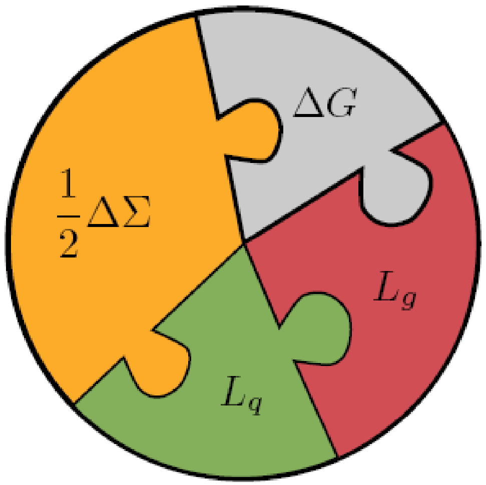
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta G + L_g$$

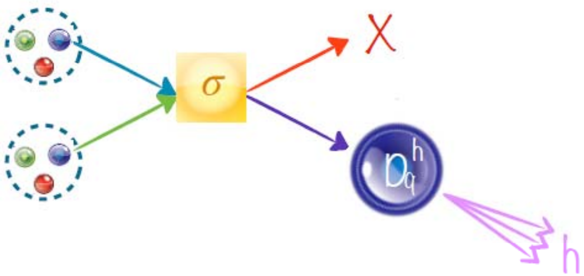
Spin contribution

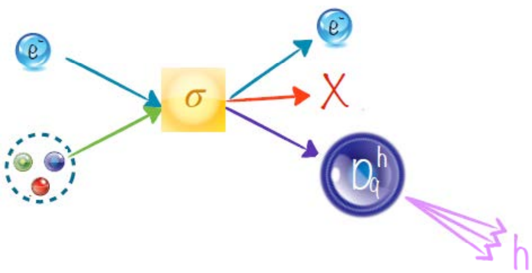
Spin sum rule :

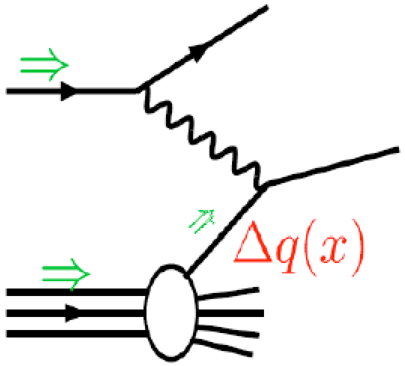
$$S_z = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^g + L_z^q$$

where $\Delta\Sigma = \Delta u + \Delta d + \Delta s$

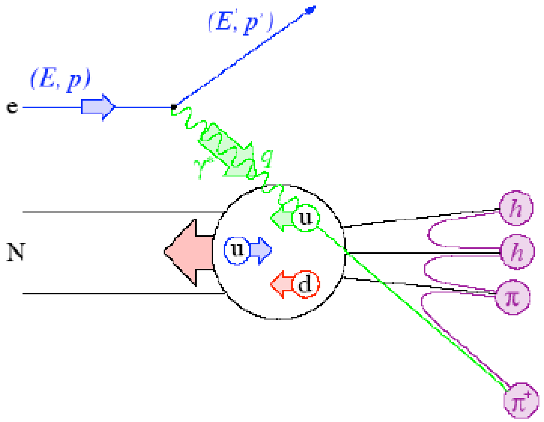




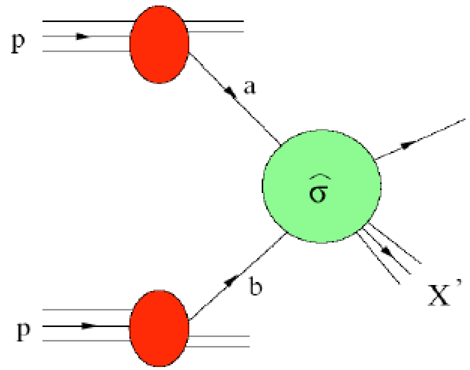




DIS



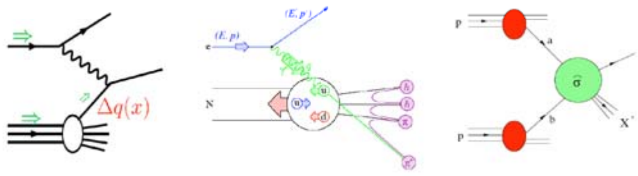
SIDIS



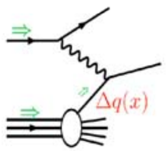
RHIC

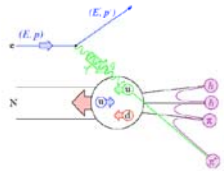
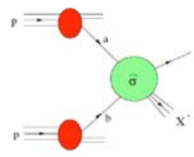
SIDIS: essential for flavor separation

- Each reaction provides insights into different aspects and x-ranges
- All processes tied together: universality of pdfs & Q2 - evolution
- Need to use NLO for quantitative analysis



	DIS	SIDIS	RHIC	Last Update	
NNPDF Ball, Forte, Guffanti, …	✓	✗	✗	1303.7236	
DSSV Florian, Sassot, Stratmann , Vogelsang	✓	✓	✓	0904.3821	
LSS Leader, Sidorov, Stmenov	✓	✓	✗	1010.0574	
KATAO Khorramin, Atashbar, Taheri, Arbabifar, Olness	✓	✗	✗	1011.4873	Jacobi Polynomials
BB Blumlein, Bottcher	✓	✗	✗	1010.3113	
KT Khorramin, Atashbar	✓	✗	✗	0705.2647	
GRSV Gluck, Reya, Stratmann , Vogelsang	✓	✗	✗	9508347	



	DIS	SIDIS	RHIC	Last Update	
NNPDF Ball, Forte, Guffanti, …	✓	✗	✗	1303.7236	
DSSV Florian, Sassot, Stratmann , Vogelsang	✓	✓	✓	0904.3821	
LSS Leader, Sidorov, Stmenov	✓	✓	✗	1010.0574	
KATAO Khorramin, Atashbar, Taheri, Arbabifar, Olness	✓	✓	✗	1011.4873	Moment space
BB Blumlein, Bottcher	✓	✗	✗	1010.3113	
KT Khorramin, Atashbar	✓	✗	✗	0705.2647	
GRSV Gluck, Reya, Stratmann , Vogelsang	✓	✗	✗	9508347	

Polarized Parton Distributions

Unbroken and Broken scenario

We will parameterize the polarized PDFs at initial scale $Q_0^2 = 1\ \mathrm{GeV}^2$ using the following form:

$$
\begin{aligned}
x\,\delta u_v &= \mathcal{N}_{u_v}\eta_{u_v}x^{a_{u_v}}(1-x)^{b_{u_v}}(1+d_{u_v}x)\ ,\\
x\,\delta d_v &= \mathcal{N}_{d_v}\eta_{d_v}x^{a_{d_v}}(1-x)^{b_{d_v}}(1+d_{d_v}x)\ ,\\
x\,(\delta\bar{d}-\delta\bar{u}) &= \mathcal{N}_{\bar{d}-\bar{u}}\eta_{\bar{d}-\bar{u}}x^{a_{\bar{d}-\bar{u}}}(1-x)^{b_{\bar{d}-\bar{u}}}(1+c_{\bar{d}-\bar{u}}\sqrt{x})\ ,\\
x\,(\delta\bar{d}+\delta\bar{u}) &= \mathcal{N}_{\bar{d}+\bar{u}}\eta_{\bar{d}+\bar{u}}x^{a_{\bar{d}+\bar{u}}}(1-x)^{b_{\bar{d}+\bar{u}}}(1+c_{\bar{d}+\bar{u}}\sqrt{x})\ ,\\
x\,\delta s = x\,\delta\bar{s} &= \mathcal{N}_s\eta_s x^{a_s}(1-x)^{b_s}(1+d_s x)\ ,\\
x\,\delta g &= \mathcal{N}_g\eta_g x^{a_g}(1-x)^{b_g}(1+d_g x),
\end{aligned}
$$

where the polarized PDFs are determined by unknown parameters.

The normalization constants

$$\frac{1}{\mathcal{N}_q} = \left(1 + d_q \frac{a_q}{a_q + b_q + 1}\right) B\left(a_q, b_q + 1\right) + c_q B\left(a_i + \frac{1}{2}, b_q + 1\right) \ ,$$

are chosen such that

$$\eta_q = \int_0^1 dx \delta q(x, Q_0^2)$$

are the first moments of polarized PDFs.

The parameters : η_{u_v} , η_{d_v} denote the first moments of the u_v *and* d_v polarized valence quark distributions; these quantities can be related to *F and D* which evaluated in neutron and hyperon β decays

$$a_3 = \int_0^1 dx\, \delta q_3 = \eta_{u_v} - \eta_{d_v} = F + D \,,$$
$$a_8 = \int_0^1 dx\, \delta q_8 = \eta_{u_v} + \eta_{d_v} = 3F - D \,,$$

under the assumption of flavor symmetries

$$\delta\bar{u} = \delta\bar{d} = \delta\bar{s} = \delta s$$

here a_3 *and* a_8 designate non-singlet combinations of the first moments of the polarized parton distributions corresponding to

$$q_3 = (\delta u + \delta\overline{u}) - (\delta d + \delta\overline{d}) \,,$$
$$q_8 = (\delta u + \delta\overline{u}) + (\delta d + \delta\overline{d}) - 2(\delta s + \delta\overline{s}) \,,$$

rewrite the equations

$$a_3 = \Delta\Sigma_u - \Delta\Sigma_d = \eta_{u_v} - \eta_{d_v} = F + D \ ,$$
$$a_8 = \Delta\Sigma_u + \Delta\Sigma_d - 2\Delta\Sigma_s = \eta_{u_v} + \eta_{d_v} = 3F - D \ .$$

Use F,D value constraint on 1st moments:

$$F = 0.464 \pm 0.008 \text{ and } D = 0.806 \pm 0.008$$

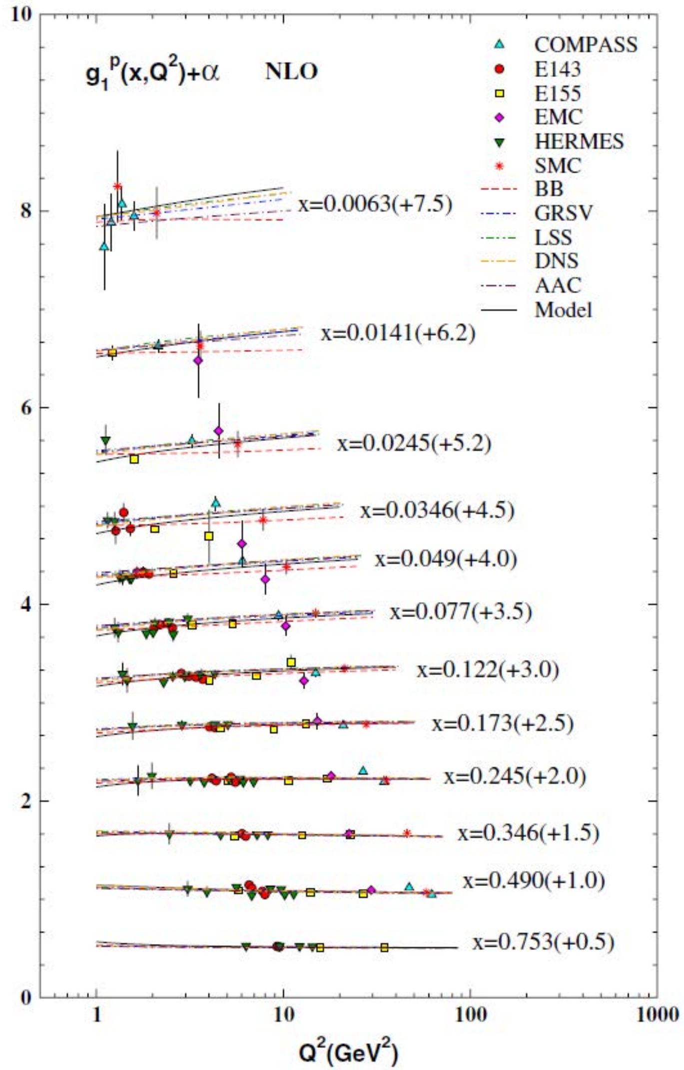
so with these measured values we find

$$\eta_{u_v} = +0.928 \pm 0.014 \ ,$$
$$\eta_{d_v} = -0.342 \pm 0.018 \ .$$

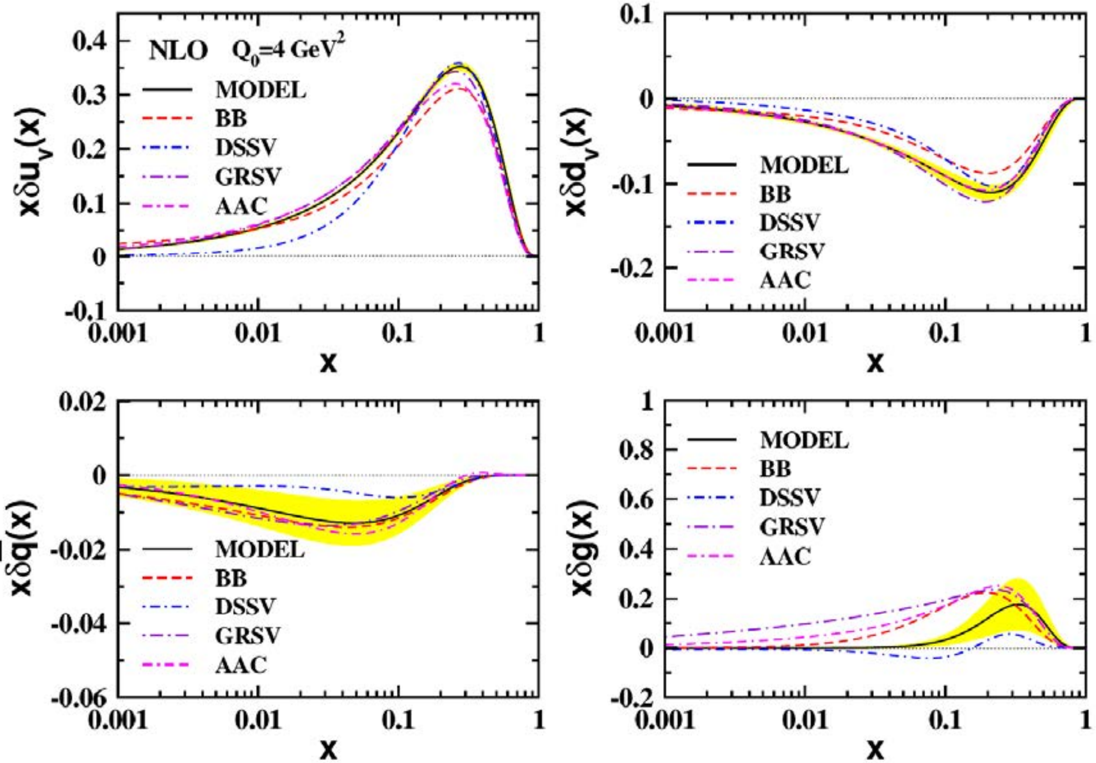
$$\delta\bar{u} = \delta\bar{d} = \delta\bar{s} = \delta s$$

$$\begin{aligned} x\delta u_v &= A_{u_v}\eta_{u_v}x^{a_{uv}}(1-x)^{b_{uv}}(1+c_{u_v}x) \\ x\delta d_v &= A_{d_v}\eta_{d_v}x^{a_{dv}}(1-x)^{b_{dv}}(1+c_{d_v}x) \\ x\delta\bar{q} &= A_s\eta_s x^{a_s}(1-x)^{b_s} \\ x\delta g &= A_g\eta_g x^{a_g}(1-x)^{b_g} \end{aligned}$$

	η_{u_v}	0.928 (*fixed*)		$\eta_{\bar{q}}$	-0.054 ± 0.029
δu_v	a_{u_v}	0.535 ± 0.022	$\delta\bar{q}$	$a_{\bar{q}}$	0.474 ± 0.121
	b_{u_v}	3.222 ± 0.085		$b_{\bar{q}}$	9.310 (*fixed*)
	c_{u_v}	8.180 (*fixed*)		$c_{\bar{q}}$	0
	η_{d_v}	−0.342 (*fixed*)		η_g	0.224 ± 0.118
δd_v	a_{d_v}	0.530 ± 0.067	δg	a_g	2.833 ± 0.528
	b_{d_v}	3.878 ± 0.451		b_g	5.747 (*fixed*)
	c_{d_v}	4.789 (*fixed*)		c_g	0
$\alpha_s(Q_0^2) = 0.381 \pm 0.017$					
$\chi^2/dof = 273.6/370 = 0.74$					



A. Khorramian, et al., Physical Review D **83** (2011) 054017.



Polarized parton distributions at $Q_0{}^2$ = 4 GeV^2 as function of x in NLO approximation. The solid curve is our model and other curves are other models respectively.

A. Khorramian et al. Physical Review D 83 (2011) 054017.
D. de Florian, R. Sassot, M. Stratmann and W. Vogelsang, Phys. Rev. Lett. 101, (2008) 072001.
J. Blumlein and H. Bottcher, Nucl. Phys. B 841 (2010) 205.
M. Gl¨uck, E. Reya, M. Stratmann and W. Vogelsang, Phys. Rev. D 63(2001) 094005.
M. Hirai and S. Kumano [Asymmetry Analysis Collaboration], Nucl. Phys. B 813, (2009) 106 .

Broken symmetry scenario

- Polarized structure function in x space:

$$g_1(x,Q^2) = \frac{1}{2}\sum_{q=u,d,s} e_q^2 \int_x^1 \frac{dz}{z}\left\{\left[1+\frac{\alpha_s}{2\pi}\Delta C_q\left(z,\frac{Q^2}{\mu_f^2}\right)\right]\times\left[\delta q\left(\frac{x}{z},\mu_f^2\right)+\delta\bar{q}\left(\frac{x}{z},\mu_f^2\right)\right]\right.$$
$$\left. + \frac{\alpha_s}{2\pi}2\Delta C_g\left(z,\frac{Q^2}{\mu_f^2}\right)\delta g\left(\frac{x}{z},\mu_f^2\right)\right\} ,$$

$\Delta C_{q,g}$	wilson coefficient functions
e_q	denotes the charge of the quark flavor
$\delta q, \delta\bar{q}, \delta g$	polarized quark, anti-quark, and gluon distributions

B. Lampe and E. Reya, Phys. Rept. **332** (2000) 1 [arXiv:hep-ph/9810270].

$$\Delta\Sigma_u - \Delta\Sigma_d = (F + D)\left[1 + \varepsilon_{SU(2)}\right] \ ,$$
$$\Delta\Sigma_u + \Delta\Sigma_d - 2\Delta\Sigma_s = (3F - D)\left[1 + \varepsilon_{SU(3)}\right] \ .$$

$\varepsilon_{SU(2,3)}$ parameterize the deviation from SU(2) and SU(3) symmetries and are included in the QCD procedure.

D. de Florian, R. Sassot, M. Stratmann and W. Vogelsang, Phys. Rev. D 80, (2009) 034030,.

For numerical calculations we need the scale evolution of the PPDFs from input scale Q0 to each of the scales related to the data points.

This evolution is done by a well-known set of DGLAP equations, that can be easily solved analytically after a transformation from x space to Mellin N-moment space.

The Mellin transform of a generic function f depending on momentum fraction x is defined as

$$F(N) \equiv \int_0^1 x^{N-1} f(x)\, dx \ .$$

In the current analysis, the DGLAP evolution equations are solved in Mellin space. The Mellin transform of the parton distributions q are defined similar to above equation

$$\delta q(N, Q_0^2) = \int_0^1 x^{N-1}\, \delta q(x, Q_0^2)\, dx = \mathcal{N}_q \eta_q \left(1 + d_q \frac{N - 1 + a_q}{N + a_q + b_q}\right) \times B\left(N - 1 + a_q, b_q + 1\right) + c_q B\left(N + a_q - \frac{1}{2}, b_q + 1\right) \ ,$$

$q = \{u_v, d_v, \bar{d} - \bar{u}, \bar{d} + \bar{u}, s, g\}$ B denotes the Euler beta function.

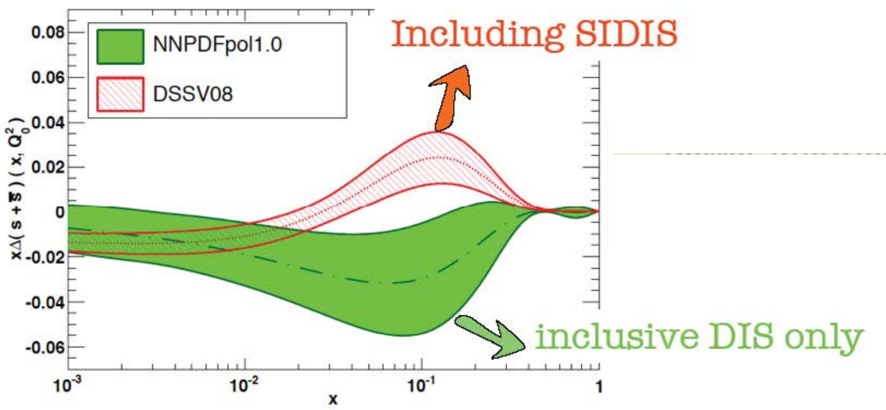
In our QCD analysis we do fit procedure on $A_1 = g_1/F_1$ DIS data, using the experimental data for the unpolarized structure function

$$A_1 = \frac{g_1(x,Q^2)}{F_1(x,Q^2)} ,$$

For SIDIS asymmetry the approximate equation

$$A_{1N}^h(x,z,Q^2) = \frac{g_{1N}^h(x,z,Q^2)_{NLO}}{F_{1N}^h(x,z,Q^2)_{NLO}},$$

Better knowledge of Fragmentation Functions is needed for SIDIS



Nucleon spin structure: observables in $\vec{\mu}\vec{\mathrm{N}}$ scattering

- Inclusive asymmetry

$$A_1 = D\,\frac{g_1(x,Q^2)}{F_1(x,Q^2)} = D\,\frac{\sum_q e_q^2 \Delta q(x,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

$$\Delta q = q^+ - q^-, \quad q = q^+ + q^-,$$

$$g_1^d = g_1^N (1 - \frac{3}{2}\omega_D) = \frac{g_1^p + g_1^n}{2}(1 - \frac{3}{2}\omega_D);$$

$$\omega_D = 0.05 \pm 0.01$$

- semi–inclusive asymmetry,

$$A_1^h(x,z,Q^2) \approx \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)} \qquad z = \frac{E_h}{\nu} \qquad D_q^h \neq D_{\bar{q}}^h$$

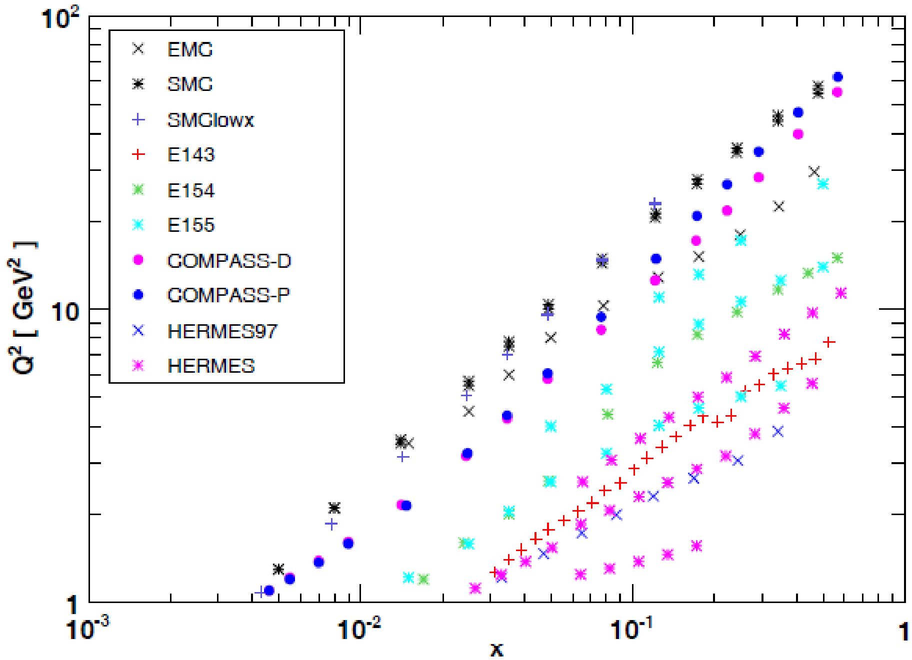
structure functions g_1 and F_1 have the following forms:

$$2g_1^h(x,z,Q^2) = \sum_{q,\bar{q}}^{n_f} e_q^2 \Big\{ \Delta q(x,Q^2) D_q^h(z,Q^2) + \frac{\alpha_s(Q^2)}{2\pi} \Big[\Delta q \otimes \Delta C_{qq}^{(1)} \otimes D_q^h + \Delta q \otimes \Delta C_{gq}^{(1)} \otimes D_g^h + \Delta g \otimes \Delta C_{qg}^{(1)} \otimes D_q^h \Big] (x,z,Q^2) \Big\},$$

- fragmentation functions (FFs) for quarks, antiquarks and gluons $D^h_{q,\bar{q}}$, D^h_g
- NLO partonic coefficient Functions $\Delta C^{(1)}_{ij}(x,z)$ $\quad C^{(1)}_{ij}(x,z)$

$$2F_1^h(x,z,Q^2) = \sum_{q,\bar{q}}^{n_f} e_q^2 \Big\{ q(x,Q^2) D_q^h(z,Q^2) + \frac{\alpha_s(Q^2)}{2\pi} \Big[q \otimes C_{qq}^{(1)} \otimes D_q^h + q \otimes C_{gq}^{(1)} \otimes D_g^h + g \otimes C_{qg}^{(1)} \otimes D_q^h \Big] (x,z,Q^2) \Big\}.$$

Now by having PPDFs and Wilson coefficients, we are able to make polarized asymmetry function



Experimental data in the x and Q plane.

We have excluded from our analysis all data points with Q^2 ≤ 1 GeV^2, since below such energy scale perturbative QCD cannot be considered reliable.

Experiment	Process	N_{data}
EMC[53]	DIS(p)	10
SMC[54]	DIS(p)	12
SMC[54]	DIS(d)	12
COMPASS[55]	DIS(p)	15
COMPASS[56]	DIS(d)	15
SLAC/E142[57]	DIS(n)	8
SLAC/E143[58]	DIS(p)	28
SLAC/E143[58]	DIS(d)	28
SLAC/E154[59]	DIS(n)	11
SLAC/E155[60]	DIS(p)	24
SLAC/E155[61]	DIS(d)	24
HERMES[62]	DIS(p)	9
HERMES[62]	DIS(d)	9
JLab-Hall A[63]	DIS(n)	3
CLAS[64]	DIS(p)	151
CLAS[64]	DIS(d)	482
SMC[65]	SIDIS(p,h^+)	12
SMC[65]	SIDIS(p,h^-)	12
SMC[65]	SIDIS(d,h^+)	12
SMC[65]	SIDIS(d,h^-)	12
HERMES[62]	SIDIS(p,h^+)	9
HERMES[62]	SIDIS(p,h^-)	9
HERMES[62]	SIDIS(d,h^+)	9
HERMES[62]	SIDIS(d,h^-)	9
HERMES[62]	SIDIS(p,π^+)	9
HERMES[62]	SIDIS(p,π^-)	9
HERMES[62]	SIDIS(d,π^+)	9
HERMES[62]	SIDIS(d,π^-)	9
HERMES[62]	SIDIS(d,K^+)	9
HERMES[62]	SIDIS(d,K^-)	9
COMPASS[66]	SIDIS(d,h^+)	12
COMPASS[66]	SIDIS(d,h^-)	12
COMPASS[67]	SIDIS(d,π^+)	10
COMPASS[67]	SIDIS(d,π^-)	10
COMPASS[67]	SIDIS(d,K^+)	10
COMPASS[67]	SIDIS(d,K^-)	10
COMPASS10[52]	SIDIS(p,π^+)	12
COMPASS10[52]	SIDIS(p,π^-)	12
COMPASS10[52]	SIDIS(p,K^+)	12
COMPASS10[52]	SIDIS(p,K^-)	12
TOTAL:		1091

$$\chi^2_{\text{global}} = \sum_n w_n \chi^2_n \,,$$

$$\chi^2_n = \left(\frac{1-\mathcal{N}_n}{\Delta\mathcal{N}_n}\right)^2 + \sum_i \left(\frac{\mathcal{N}_n\, A_{1,i}^{exp} - A_{1,i}^{theor}}{\mathcal{N}_n\, \Delta A_{1,i}^{exp}}\right)^2 .$$

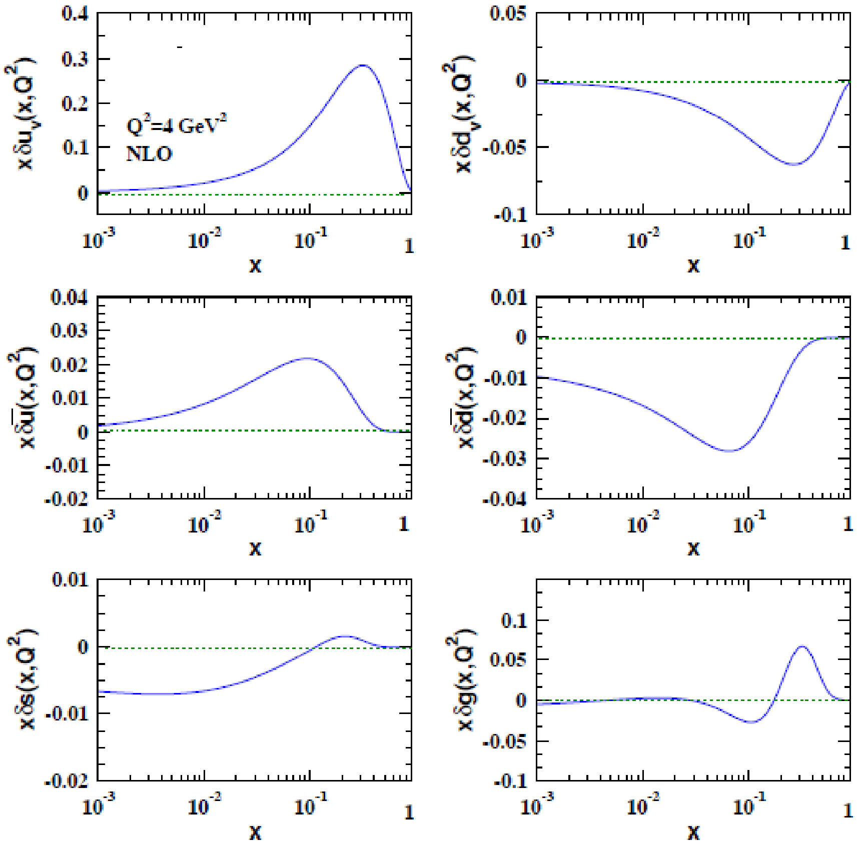
Here, $g_{1,i}^{exp}$, $\Delta g_{1,i}^{exp}$, and $g_{1,i}^{theor}$ are the experimental measured value, the experimental uncertainty and theoretical value for the i^{th} data point, respectively. $\Delta\mathcal{N}_n$ corresponds to the experimental normalization uncertainty and $\mathcal{N}_n$ is an overall normalization factor relevant to the data of experiment n. We allow for a relative normalization shift $\mathcal{N}_n$ between various data sets within uncertainties $\Delta\mathcal{N}_n$ reported by the experiments.

Table 2. Final parameter values and their statistical errors at the input scale $Q_0^2 = 1.0$ GeV^2.

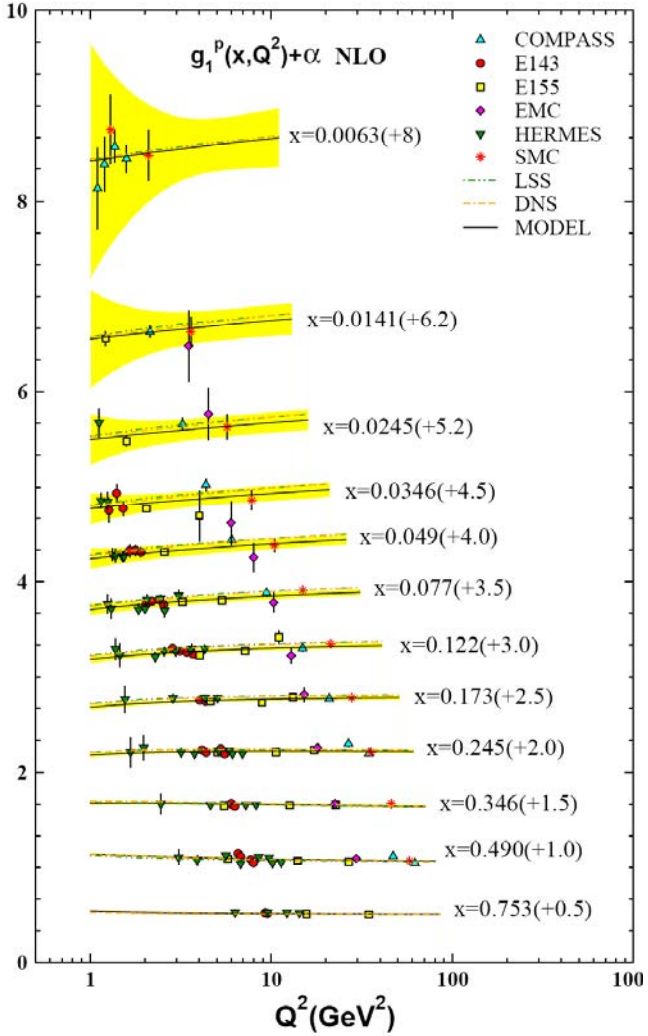
δu_v	η	0.62	$\delta\bar{d}$	η	-0.18
	a	0.79		a	0.11
	b	2.66		b	10.0
	c	0.52		c	0.0
	d	16.50		d	50.15
δd_v	η	-0.15	δs	η	-0.08
	a	0.11		a	0.11
	b	2.23		b	10.0
	c	0.01		c	0.0
	d	497.74		d	-11.09
$\delta\bar{u}$	η	0.07	δg	η	-0.08
	a	0.79		a	3.32
	b	10.0		b	10.0
	c	0.0		c	0.0
	d	8.10		d	-3.60
			$\chi^2/NDF = 1260.329/1073$		

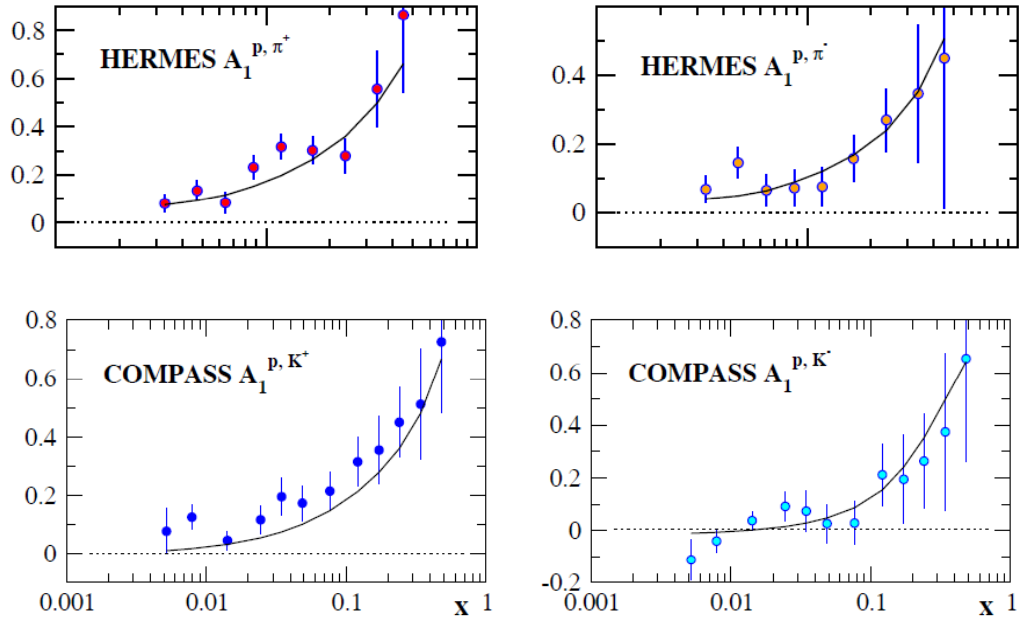
$\varepsilon_{SU(2)} = -0.019$ $\varepsilon_{SU(3)} = -0.012$

PRELIMINARY



PRELIMINARY





PRELIMINARY

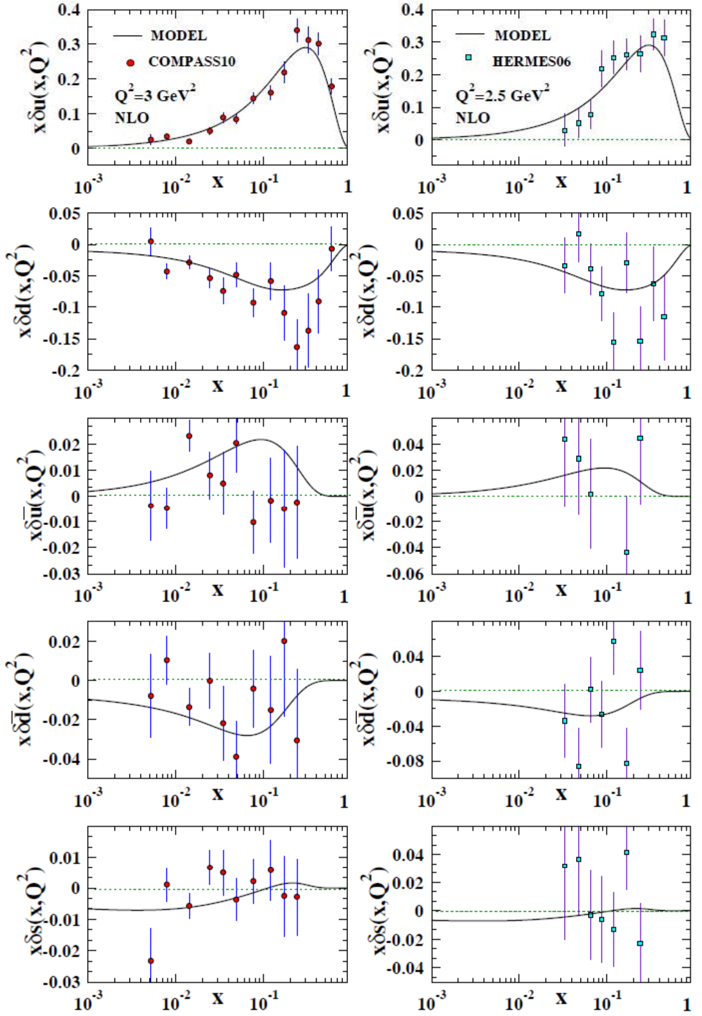
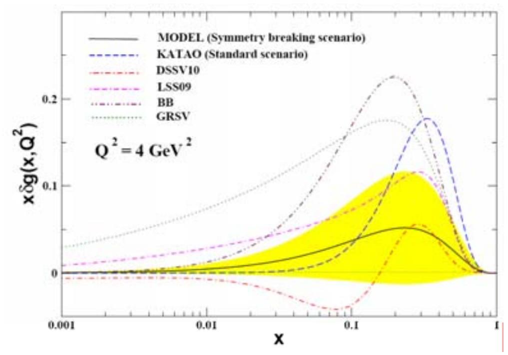
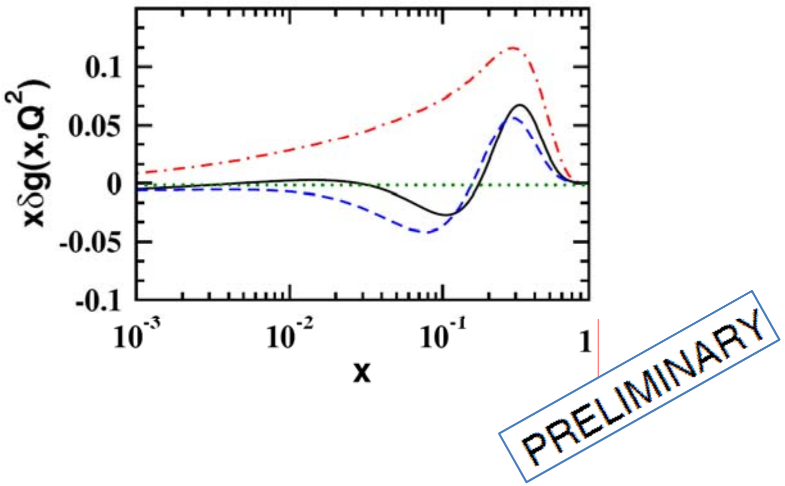
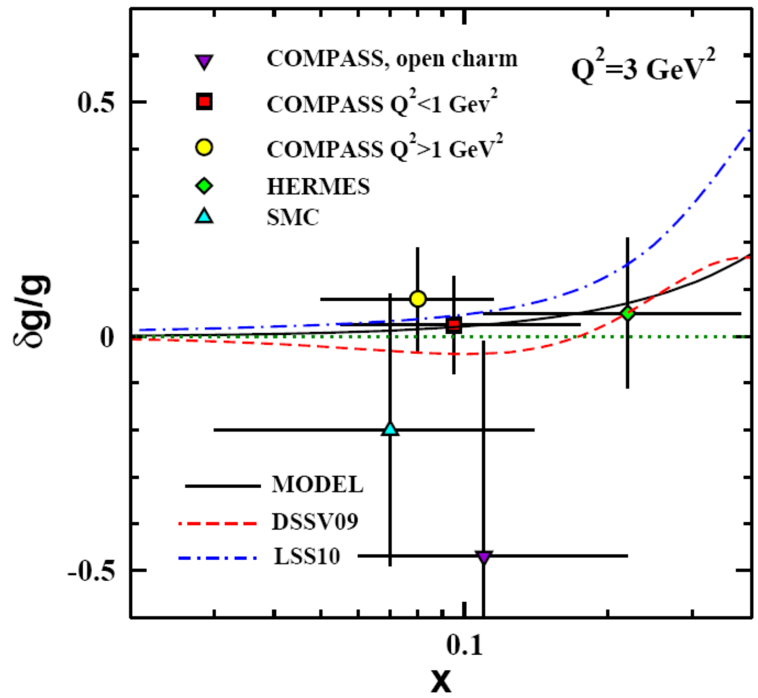


Fig. 3. The quark helicity distributions evaluated at $Q^2 = 2.5,\ 3\ \mathrm{GeV}^2$ comparing to the COMPASS10[52] and HERMES06[51] data.(primary results)


MODEL (Symmetry breaking scenario)
KATAO (Standard scenario)
DSSV10
LSS09
BB
GRSV
Q^2 = 4 GeV^2
xδg(x,Q^2)
x


xδg(x,Q^2)
0.1
0.05
0
-0.05
-0.1
10^-3
10^-2
10^-1
1
x
PRELIMINARY


COMPASS, open charm
COMPASS Q^2<1 Gev^2
COMPASS Q^2>1 GeV^2
HERMES
SMC
Q^2=3 GeV^2
MODEL
DSSV09
LSS10
δg/g
0.5
0
-0.5
0.1
x

• We have presented a NLO QCD analysis of the polarized lepton-DIS and SIDIS data on nucleon.

• During the analysis we consider SU(2) and SU(3) symmetry breaking scenario i.e. $\bar{u} \neq \bar{d} \neq \bar{s}$, since the available experimental data are not enough to distinguish s from $\bar{s}$, we take them equal $s = \bar{s}$.

• The role of the semi-inclusive data in determining the polarized sea quarks is discussed and we have found also that the polarized gluon density is still depend on the kind of the experimental data.

• Having extracted the polarized PDFs, we compute nucleon structure function g1 and sum rules. We also calculate the error of PPDFs and Polarized structure functions by Gaussian error propagation.

• In general, we find good agreement with the experimental data, and our results and with other theoretical models, DSSV09 and LSS10.

Thank you for your attention!