



 Semnan
University



School of
Particles and
Accelerators

The effect of $SU(2)$ and $SU(3)$ symmetry breaking on PPDF QCD analysis

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Spring IPM conference 1392

OUTLINE

1 - Introduction

2 - DIS and SIDIS processes

3 - QCD analysis of symmetry broken scenario

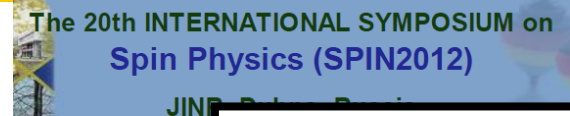
4 - Results and conclusions

Why spin physics?...Motivation

- Spin is a fundamental property of particles, so:
- Test of a theory is not complete without a full test of spin-dependent decays and scattering.
- The theoretical and experimental status on the spin structure of the nucleon has been discussed in great detail in several recent reviews and confs.
- By extraction of new experimental data from the HERMES and COMPASS collaborations of the spin structure function g_1 , we had enough motivation to study and utilize the spin structure and quark helicity distributions



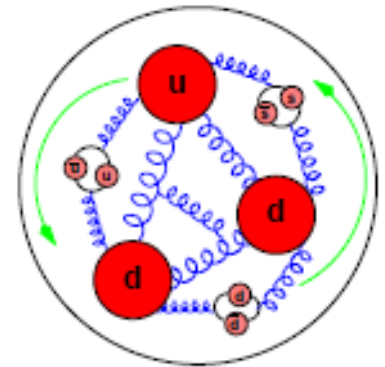
COMPASS collaboration, Phys. Lett. B 693, 227, (2010).
HERMES Collaboration, Phys. Rev. D 71, 012003, (2006).



Spin Crisis

the spin structure of the nucleon:

$$\langle S_z^N \rangle = \frac{1}{2} = \frac{1}{2} \Delta\Sigma + L_q + \Delta G + L_g$$



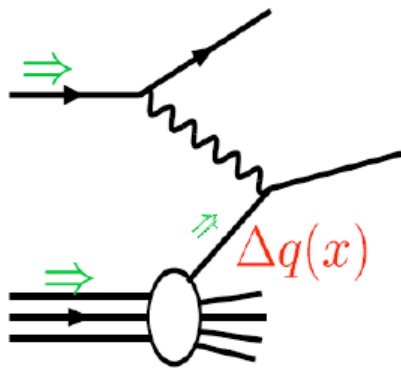
$\Delta\Sigma$ is found to be **small** in inclusive DIS experiments

- ~1980: SLAC: connection of nucleon spin with quarks
- 1988: EMC: "spin crisis" $\Delta\Sigma = 0.12 \pm 0.17 \approx 0?$
- 1988–2000: SLAC, CERN, DESY: $\Delta\Sigma \approx 0.2 \dots 0.4 > 0$

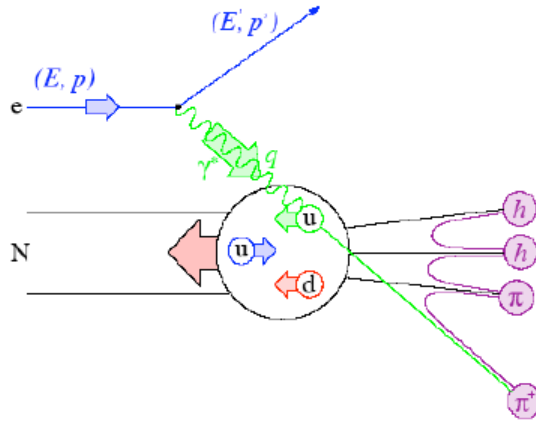
possible contributions to $\langle S_z \rangle$ still **unknown**

- strange sea polarization Δs ?
- gluon polarization ΔG ?
- orbital angular momentum $L_{q,g}$?

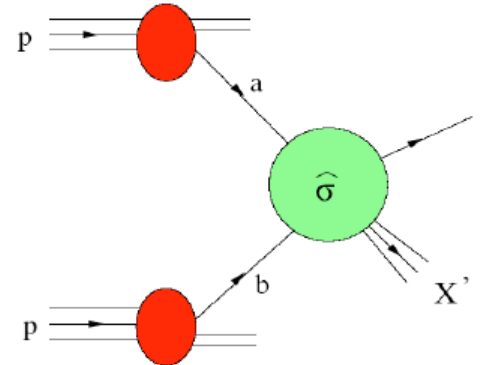
information on nucleon spin structure available from



DIS



SIDIS



RHIC

- each reaction provides insights into *different* aspects and x-ranges
- all processes tied together: universality of pdfs & Q^2 - evolution
- need to use NLO for quantitative analysis

task: extract reliable pdfs not just compare some curves to data

Remarkable experimental progress in QCD spin physics in the last 20 years

- Inclusive spin-dependent DIS

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

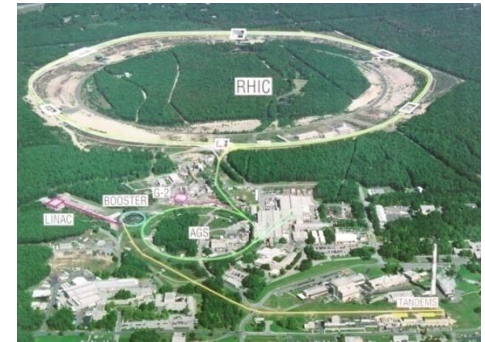


- Semi-inclusive DIS

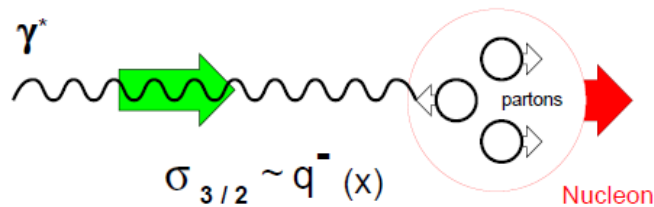
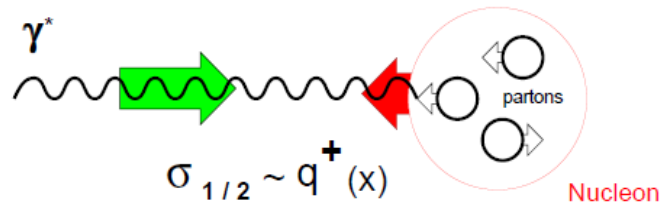
- SMC, COMPASS
- HERMES

- Polarized pp collisions

- RHIC
 - PHENIX & STAR



Quark Parton Model



QPM:

$$q(x) = q^+(x) + q^-(x)$$

$$F_1(x) = \frac{1}{2} \sum_f e_f^2 q_f(x)$$

$$F_2 = 2xF_1$$

$$\Delta q(x) = q^+(x) - q^-(x)$$

$$g_1(x) = \frac{1}{2} \sum_f e_f^2 \Delta q_f(x)$$

$$g_2 = 0$$

simple physical interpretation of g_1 in terms of quark helicity distributions $\Delta q_f(x)$

- Virtual photon can only couple to quarks of opposite helicity
- Select $q^-(x)$ or $q^+(x)$ by changing the orientation of target nucleon spin or helicity of incident lepton beam

As in the unpolarized case the main goal is:

- to test **QCD**
- to extract from the DIS data the **polarized** PDFs

$$\begin{aligned}\Delta q(x, Q^2) &= q_+(x, Q^2) - q_-(x, Q^2) \\ \Delta \bar{q}(x, Q^2) &= \bar{q}_+(x, Q^2) - \bar{q}_-(x, Q^2) \\ \Delta G(x, Q^2) &= G_+(x, Q^2) - G_-(x, Q^2)\end{aligned}$$

where "+" and "-" denote the helicity of the parton, along or opposite to the helicity of the parent nucleon, respectively.

A. N. Khorramian, H. Khanpour and S. A. Tehrani, Phys. Rev. D **81**, 014013 (2010).

A. Khorramian, S. Atashbar Tehrani, S. Taheri Monfared, F. Arbabifar, and F. I. Olness, Phys. Rev. D **83**, 054017 (2011).

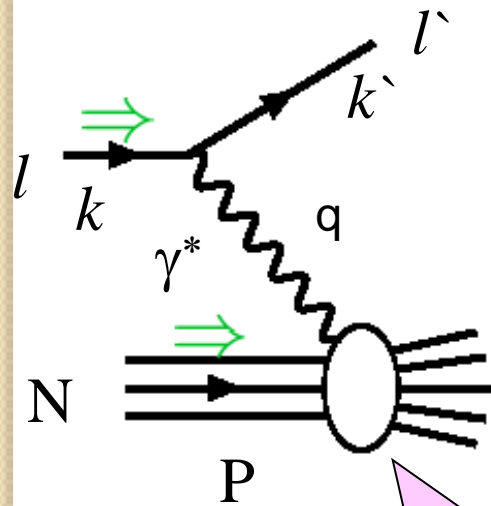
When we integrate out the momentum fraction x the first moments of the unpolarized parton distributions measure the number of valence quarks in the proton:

$$\begin{aligned}\int_0^1 dx (u - \bar{u})(x) &= 2 \\ \int_0^1 dx (d - \bar{d})(x) &= 1 \\ \int_0^1 dx (s - \bar{s})(x) &= 0\end{aligned}$$

The first moment of PPDFs is interpreted as the fraction of the proton's spin which is carried by quarks (and anti-quarks) of flavour q

$$\Delta q = \int_0^1 dx \Delta q(x)$$

Inclusive DIS



$$x = Q^2/(2pq)$$

DIS regime $\Rightarrow Q^2 \gg M^2$

pQCD

$F_i(x, Q^2)$ $g_i(x, Q^2)$

unpolarized SF

polarized SF

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

Structure function in NLO approximation

Polarized SF from QCD analysis

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

Unpolarized SF from NMC

- Polarized structure function in x space:

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

- Complicated calculations!

Structure function in NLO approximation (Mellin space)

The twist-2 contributions to the structure function $g_1(N, Q^2)$ can be represented in terms of the polarized parton densities and the coefficient functions ΔC_i^N in the Mellin -N space by

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

Running coupling constant

$$\frac{1}{a_s(\mu_r^2)} = \frac{1}{a_s(\mu_0^2)} + \beta_0 \ln \left(\frac{\mu_r^2}{\mu_0^2} \right) - b_1 \ln \left\{ \frac{a_s(\mu_r^2) [1 + b_1 a_s(\mu_0^2)]}{a_s(\mu_0^2) [1 + b_1 a_s(\mu_r^2)]} \right\}$$

Neutron and Deuteron polarized structure function

Because of isospin symmetry the polarized structure functions for proton and neutron are related by exchange of up and down quarks and anti quarks.

$$g_1^n(x, Q^2) = g_1^p(x, Q^2) - \frac{1}{6}[\delta u_v(x, Q^2) - \delta d_v(x, Q^2)]$$

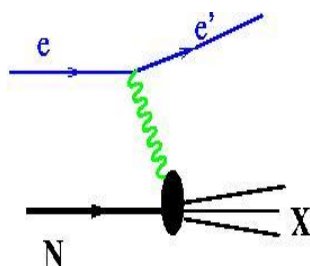
The polarized deuteron spin structure function can be obtained via this relation:

$$g_1^d(x, Q^2) = \frac{1}{2}[g_1^p(x, Q^2) + g_1^n(x, Q^2)](1 - \frac{3}{2}w_D)$$

$w_D(\simeq 0.058)$

A. Khorramian, S. Atashbar Tehrani, S. Taheri Monfared, F. Arbabifar, and F. I. Olness, Phys. Rev. D **83**, 054017 (2011).

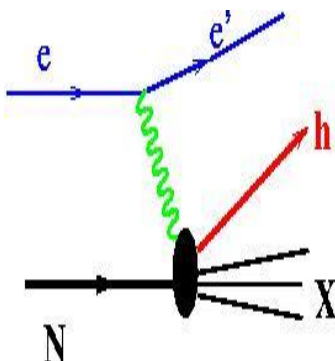
Semi-Inclusive DIS (SIDIS)



DIS: Major source of QCD tests and PDF studies

- Probes only the sum of quarks and anti-quarks
- Requires assumptions on sea

$$\sum e_q^2 (q + \bar{q})$$



SIDIS: “Tagging” to distinguish different quark flavors.

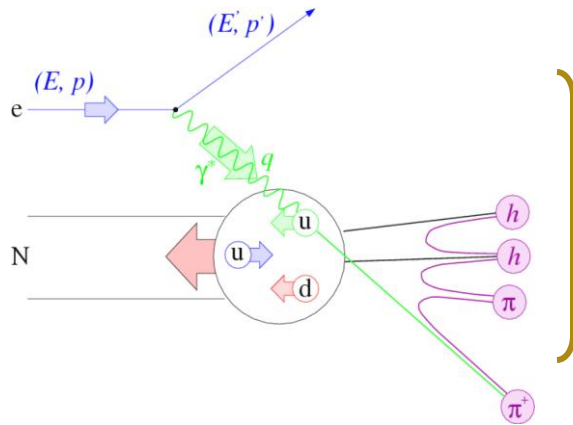
- Provide access to quark distributions with fragmentation acting as a weight factor:

$$\sum_{f=q,\bar{q}} e_f^2 f(x, Q^2) D_f^H(z, Q^2)$$

Main focus of SIDIS studies:

- No assumptions on sea quarks
- parton distributions at large x

Semi-Inclusive DIS asymmetry



Use correlation between detected hadron and struck quark -> 'Flavor separation'

D_q^h is a measure of the probability that a quark of flavor q will fragment into a hadron of type h

$$A_1^h(x, Q^2) \sim \frac{\sum_q e_q^2 \Delta q(x, Q^2) \int dz D_q^h(z, Q^2)}{\sum_q e_q^2 q(x, Q^2) \int dz D_q^h(z, Q^2)}$$

SIDIS asymmetry in NLO

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

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

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

PDFs \otimes Coefficient functions \otimes FFs

Wilson coefficients in z-n space

$$C_{qq}^1 = C_F \left\{ -8\delta(1-x)\delta(1-z) + \delta(1-x) \left[\tilde{P}_{qq}(z) \ln \frac{Q^2}{M_F^2} + L_1(z) + L_2(z) \right. \right. \\ \left. \left. + (1-z) \right] + \delta(1-z) \left[\tilde{P}_{qq}(x) \ln \frac{Q^2}{M^2} + L_1(x) - L_2(x) + (1-x) \right] + \right. \\ \left. + 2 \frac{1}{(1-x)_+} \frac{1}{(1-z)_+} - \frac{1+z}{(1-x)_+} - \frac{1+x}{(1-z)_+} + 2(1+xz) \right\},$$



Transfer to n space by Mellin transformation just on x

$$M_n(\delta C_{qq}) = C_F \left\{ \delta(1-z) \left[-8 + \frac{3}{2} \ln \frac{Q^2}{M_F^2} + \ln \frac{Q^2}{M^2} \left(\frac{3}{2} - 2\gamma - \frac{1}{n} - \frac{1}{1+n} - 2\Psi(n) \right) \right. \right. \\ \left. \left. + \frac{1}{6} \left(6\gamma^2 + 3 \left(\frac{1}{n^2} + \frac{1}{(1+n)^2} \right) + 6\gamma \left(\frac{1}{n} + \frac{1}{1+n} \right) + \pi^2 + 12\gamma\Psi(n) + 3\Psi^2(n) \right. \right. \right. \\ \left. \left. \left. + 3\Psi^2(n+2) - 6 \frac{d\Psi(n)}{dn} \right) + \zeta(2, n) + \zeta(2, 2+n) + \frac{1}{n(n+1)} \right] \right. \\ \left. - \frac{2}{(1-z)_+} [\gamma + \Psi(n)] + (1+z) [\gamma + \Psi(n)] \right. \\ \left. - \frac{1}{(1-z)_+} \left(\frac{1}{n} + \frac{1}{1+n} \right) + 2 \left(\frac{1}{n} + \frac{z}{1+n} \right) \right. \\ \left. \left. + \tilde{P}_{qq}(z) \ln \frac{Q^2}{M_F^2} + L_1(z) + L_2(z) + (1-z) \frac{n^2 - 3n - 2}{n(n+1)} \right\},$$

Broken symmetry scenario

Here one assumes:

$$\delta\bar{u}(x, Q^2) \neq \delta\bar{d}(x, Q^2) \neq \delta\bar{s}(x, Q^2)$$

i.e. a broken flavor symmetry as motivated by the situation in the corresponding unpolarized sector. Analyses of polarized PDFs routinely use constraints that can be derived from baryonic semi-leptonic β -decays under the assumption of SU(2) and SU(3) flavor symmetries. These relate combinations of the first moments of the PDFs to the constants F and D parameterizing the β -decay rates.

$$\begin{aligned}\Delta\Sigma_u - \Delta\Sigma_d &= (F + D) \\ \Delta\Sigma_u + \Delta\Sigma_d - 2\Delta\Sigma_s &= (3F - D)\end{aligned}$$

We make use of these constraints in our present analysis; however, rather than imposing the exact SU(2) and SU(3) flavor symmetry relations, we allow for deviations in our fit within the uncertainty ranges of the F, D values like DSSV09, since the best result was taken in this case. Specifically, we set

$$\begin{aligned}\Delta\Sigma_u - \Delta\Sigma_d &= (F + D) [1 + \varepsilon_{\text{SU}(2)}], \\ \Delta\Sigma_u + \Delta\Sigma_d - 2\Delta\Sigma_s &= (3F - D) [1 + \varepsilon_{\text{SU}(3)}],\end{aligned}$$

$\varepsilon_{su(2,3)}$ parameterize the departures from exact SU(2) and SU(3) symmetries, and where we use the latest values $F + D = 1.269$ and $3F - D = 0.586$.

data selection

initial step: verify that the theoretical framework is adequate !

In the **symmetry breaking scenario** global analysis we use all DIS and SIDIS sources of data:

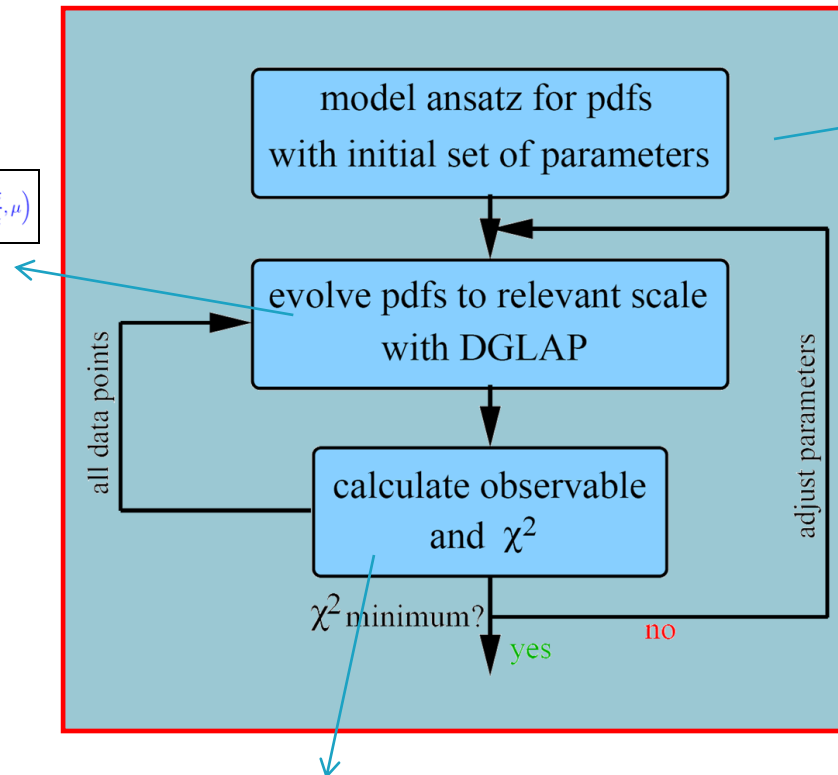
"classic" inclusive DIS data
routinely used in PDF fits
! $\Delta q + \Delta q$

semi-inclusive DIS data
so far only used in DNS, LSS fit
! flavor separation

first RHIC pp data (used only by DSSV)
! Δg

fit procedure

$$\mu \frac{d}{d\mu} \left(\frac{\Delta q(x, \mu)}{\Delta g(x, \mu)} \right) = \int_x^1 \frac{dz}{z} \begin{pmatrix} \Delta \mathcal{P}_{qq} & \Delta \mathcal{P}_{qg} \\ \Delta \mathcal{P}_{gq} & \Delta \mathcal{P}_{gg} \end{pmatrix}_{(z, \alpha_s(\mu))} \cdot \left(\frac{\Delta q}{\Delta g} \right) \left(\frac{x}{z}, \mu \right)$$



$$x\delta q(x, Q_0^2) = \mathcal{N}_q \eta_q x^{a_q} (1-x)^{b_q} (1+c_q x),$$

change $O(20)$ parameters $\{a_j\}$ about 5000 times

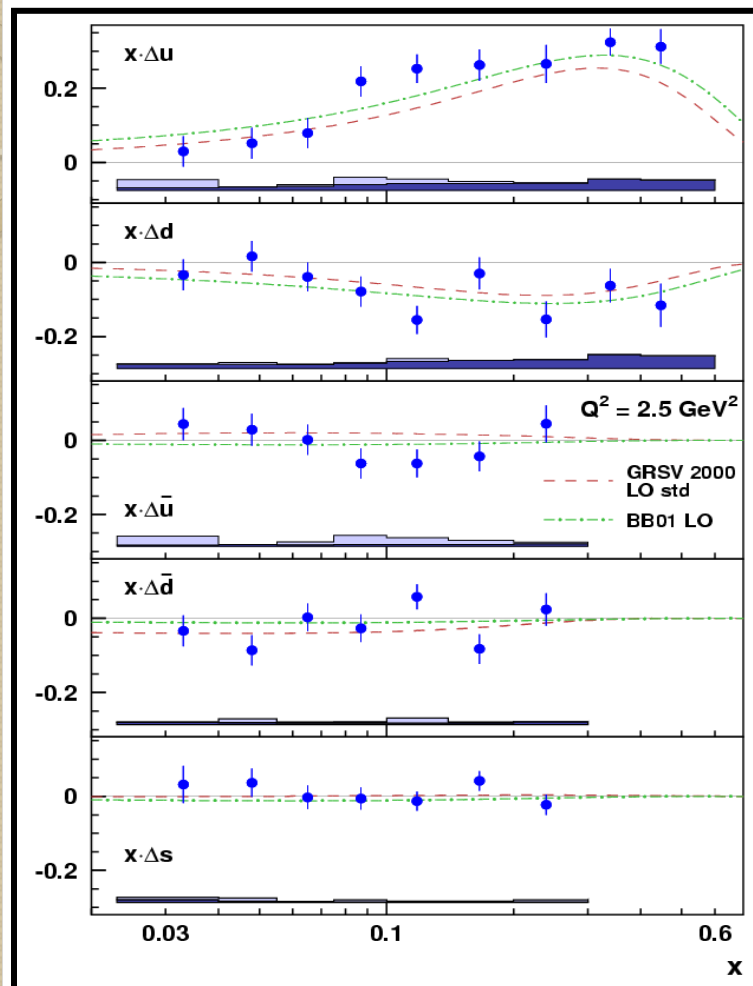
another 5000+ calls for studies of uncertainties

bottleneck !

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

computing time for a global analysis at NLO becomes excessive

The published HERMES 5-flavor Δq extraction



~ First complete separation
of pol.PDFs without assumption
on sea polarization

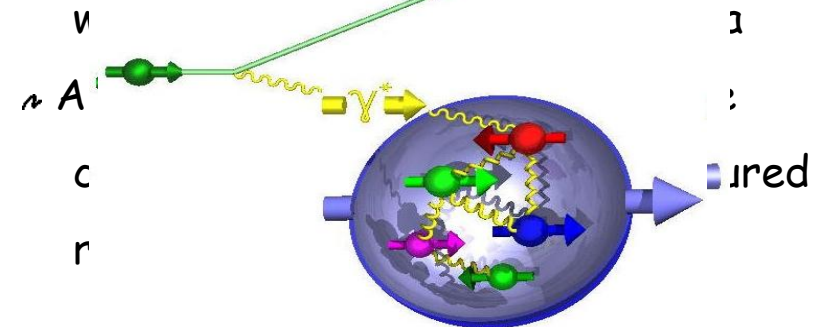
~ $\Delta u(x) > 0$

polarized parallel to the proton
spin orientation

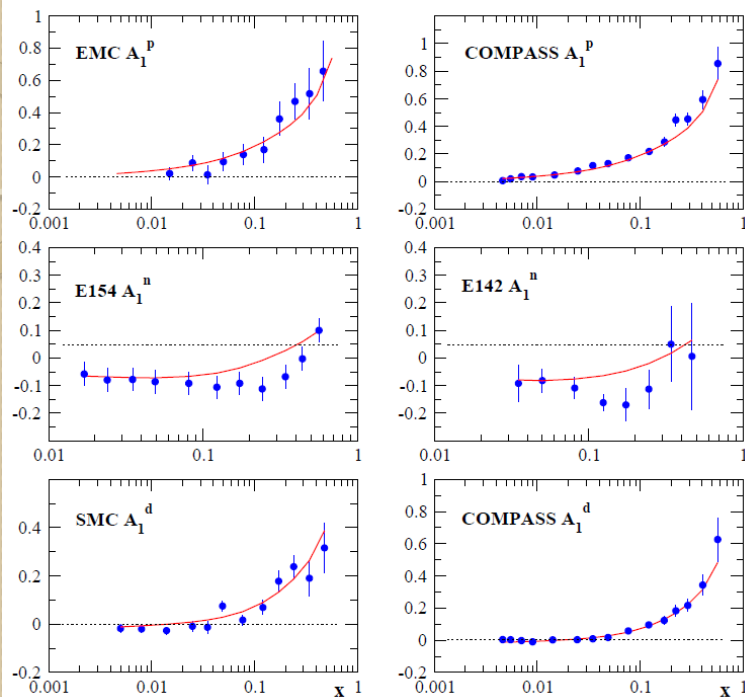
~ $\Delta d(x) < 0$

polarized anti-parallel to the proton

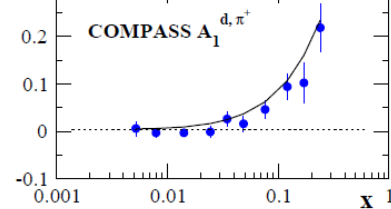
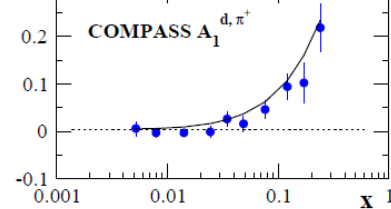
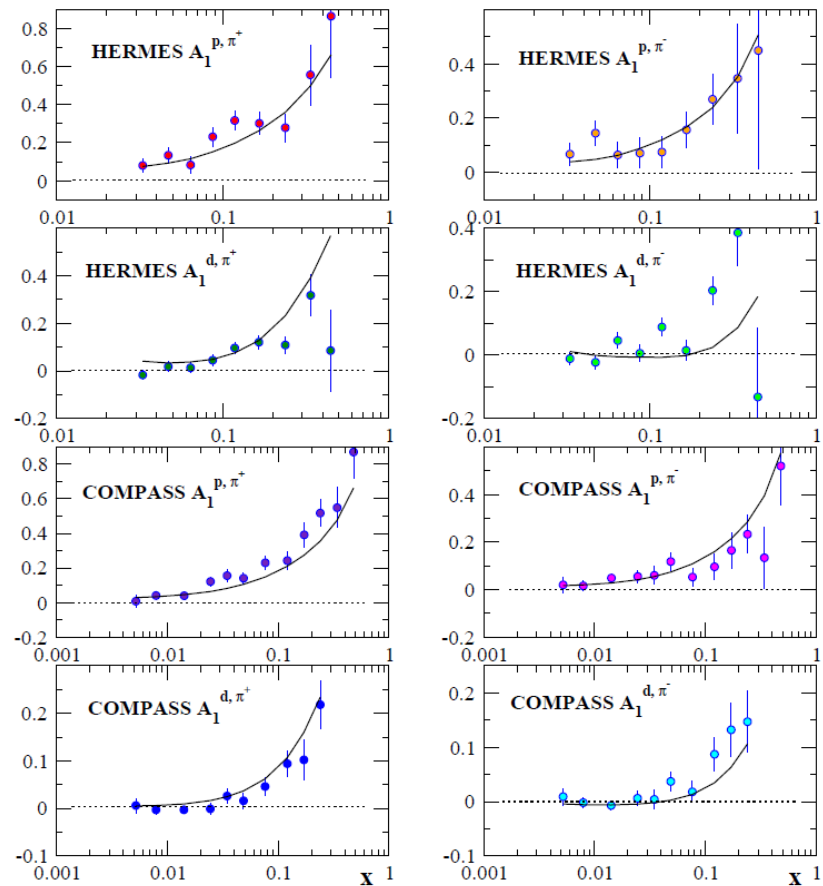
~ Δ

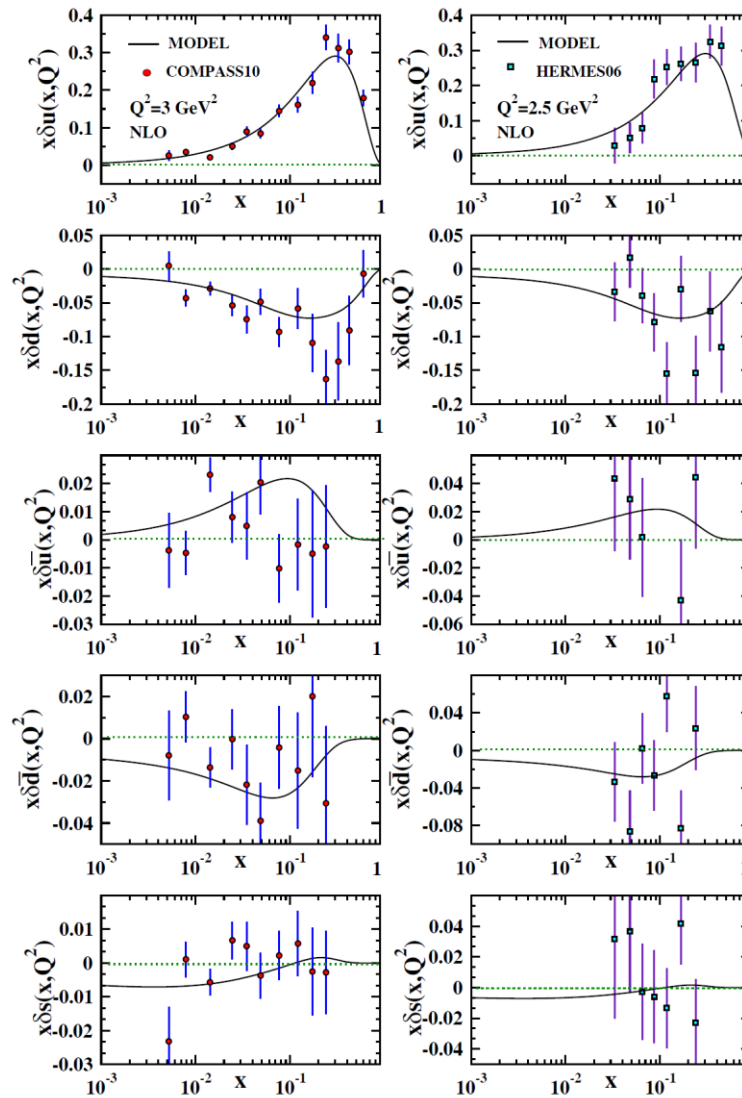


QCD fit results of asymmetry



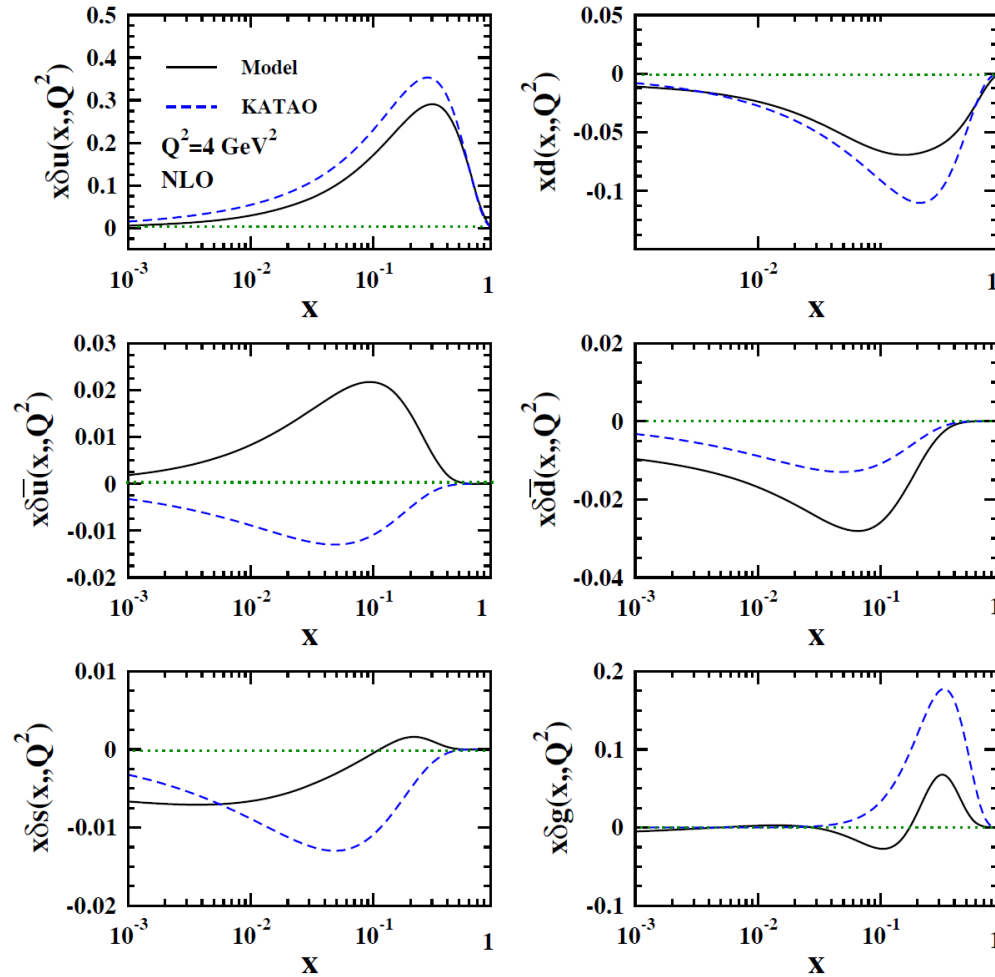
δu_v	η	0.62	$\delta \bar{d}$	η	-0.18
	a	0.79		a	0.11
	b	2.66		b	10.0
	c	0.52		c	0.0
	d	16.50		d	50.15
δd_v	η	-0.15	δs	η	-0.08
	a	0.11		a	0.11
	b	2.23		b	10.0
	c	0.01		c	0.0
	d	497.74		d	-11.09
$\delta \bar{u}$	η	0.07	δg	η	-0.08
	a	0.79		a	3.32
	b	10.0		b	10.0
	c	0.0		c	0.0
	d	8.10		d	-3.60
$\alpha_s(Q_0^2) = 0.5952$			$\chi^2/NDF = 1260.329/1073 = 1.17$		





The quark helicity distributions evaluated at $Q^2=2.5, 3 \text{ GeV}^2$ comparing to the COMPASS10 and HERMES06 data.

Comparison of AKT (symmetry breaking scenario) and KATAO (symmetry scenario)



The quark densities in the NLO approximation as a function of x comparing with symmetry scenario.

A. Khorramian, S. Atashbar Tehrani, S. Taheri Monfared, F. Arbabifar, and F. I. Olness, Phys. Rev. D **83**, 054017 (2011).

conclusion

- 1 - We have performed the standard next-to-leading order QCD analysis of DIS and SIDIS data to extract polarized distributions
- 2 - Our results for polarized asymmetries are in good agreements with available experimental data on proton, neutron and deuteron.
- 3 - The comparison of our polarized distribution results in both symmetry and symmetry breaking scenario with the experimental data gives a very good agreement, specially for strange sea quarks in the symmetry breaking scenario.



Thanks for your attention