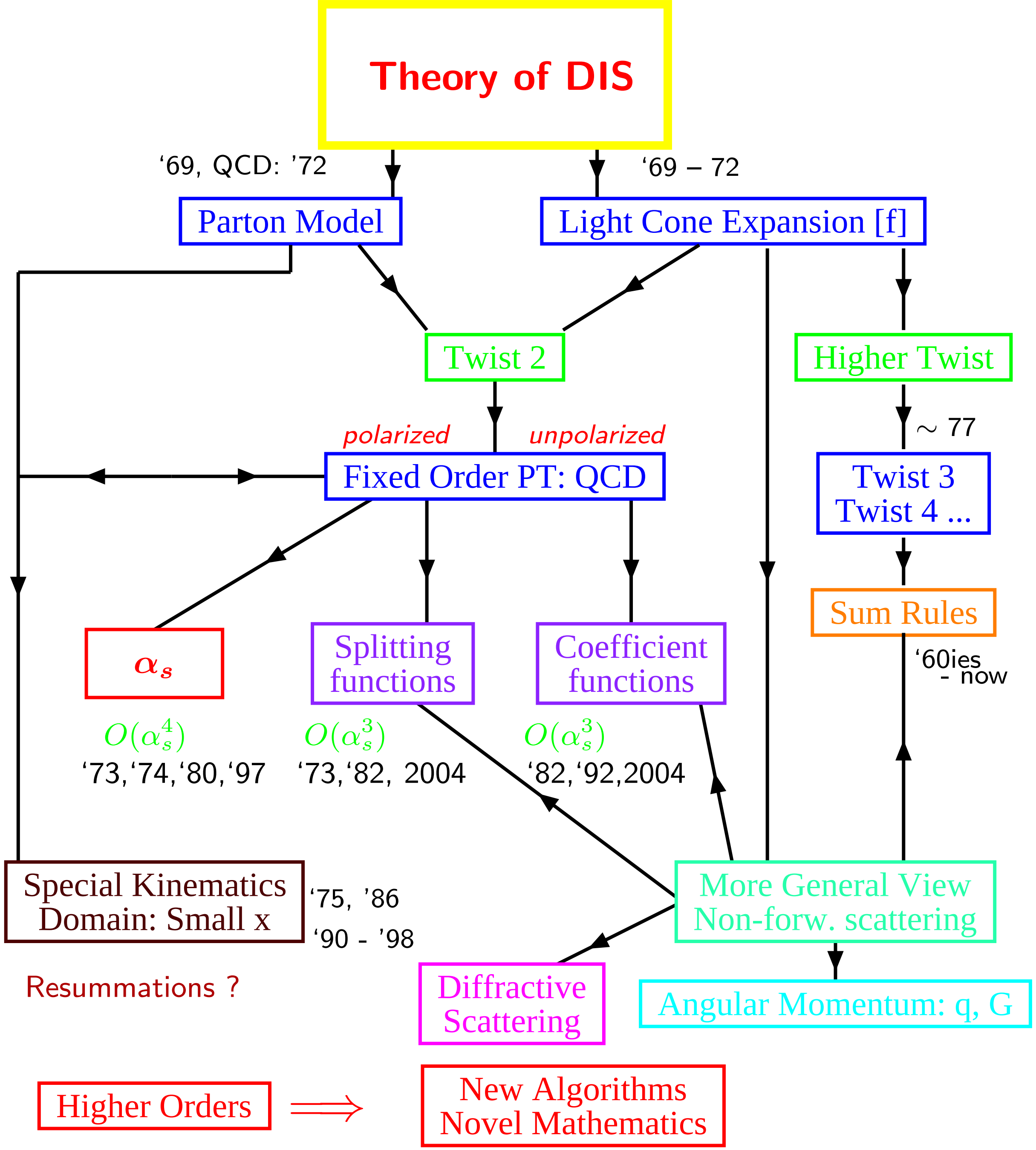
The Status of Polarized Parton Densities

Johannes Blümlein
DESY

- Remarks on Theory
- Polarized Parton Densities
- What we still would like to know: Future Avenues


Theory of DIS
'69, QCD: '72
'69 – 72
Parton Model
Light Cone Expansion [f]
Twist 2
Higher Twist
polarized
unpolarized
Fixed Order PT: QCD
∼ 77
Twist 3
Twist 4 ...
Sum Rules
'60ies - now
α_s
Splitting functions
Coefficient functions
$O(\alpha_s^4)$
'73,'74,'80,'97
$O(\alpha_s^3)$
'73,'82, 2004
$O(\alpha_s^3)$
'82,'92,2004
Special Kinematics Domain: Small x
'75, '86
'90 - '98
More General View Non-forw. scattering
Resummations ?
Diffractive Scattering
Angular Momentum: q, G
Higher Orders
New Algorithms Novel Mathematics

1

Highest order corrections of HO QCD

- Running α_s: $O(\alpha_s^4)$ Larin, van Ritbergen, Vermaseren 1997
- Pol. Bjorken Sum Rule: $O(\alpha_s^3)$ Larin, Vermaseren, 1991
- Pol. anomalous dimension: $O(\alpha_s^2)$ $\Delta P^{ij}_{S,NS}$ Mertig, van Neerven, 1995; Vogelsang 1995
  $O(\alpha_s^3)$ ΔP^{qq}_{NS} (due to Ward identity) Moch, Vermaseren, Vogt, 2004
- Pol. Wilson coefficients: $O(\alpha_s^2)$; $\Delta C^{q(G)}_{S,NS}$: van Neerven, Zijlstra 1994
- Pol. Heavy Flavor Wilson Coefficients: $O(\alpha_s^1)$, Watson 1982
- $Q^2 \gg m^2$ Pol. Heavy Flavor Wilson Coefficient : $O(\alpha_s^2)$ van Neerven, Smith et al. 1996, Blümlein and Klein, 2007
- Transversity: $O(\alpha_s^2)$, some moments anom. dim.: $O(\alpha_s^3)$, Hayashigaki, Kanazawa, Koike; Kumano, Miyama; Vogelsang; 1997; Gracey 2006
- Twist 3: low order results.

DIS: Microscopy of the Nucleon

- determination of all quark densities and the gluon distribution
- determination of all polarized parton densities

DIS: Fundamental Tests of QCD

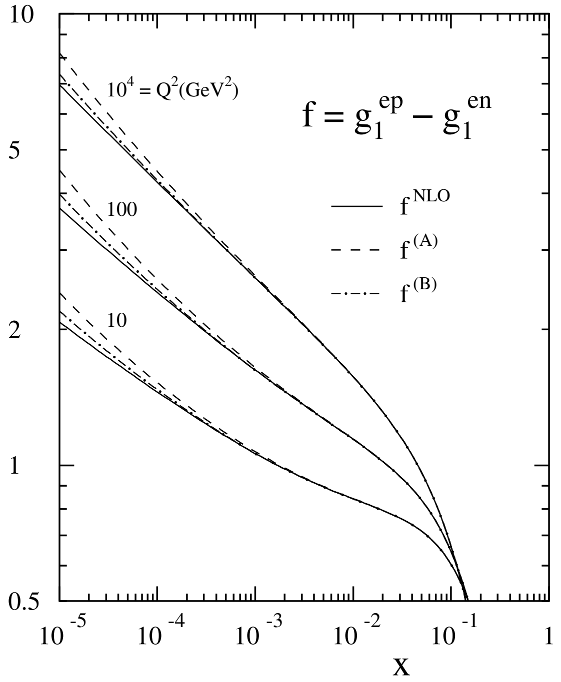
- precision measurement of Λ_{QCD} and $\alpha_s(M_Z^2)$
- Thorough verification of the prediction of the light cone expansion: to higher twist

Challenges for Theory:
perturbative and non-perturbative

- higher order precision calculations and data analysis
- Lattice gauge theory results for hadronic matrix elements

Small x Physics

The subleading terms cancel the small resummed corrections.
Furthermore: F-number conservation.
Resum using the Renormalization Group Equations.



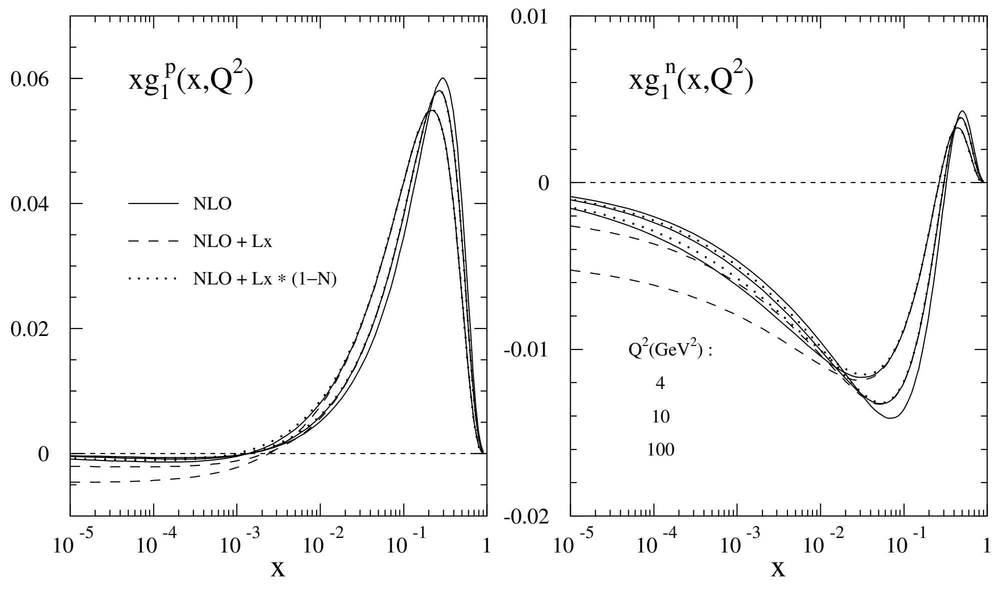


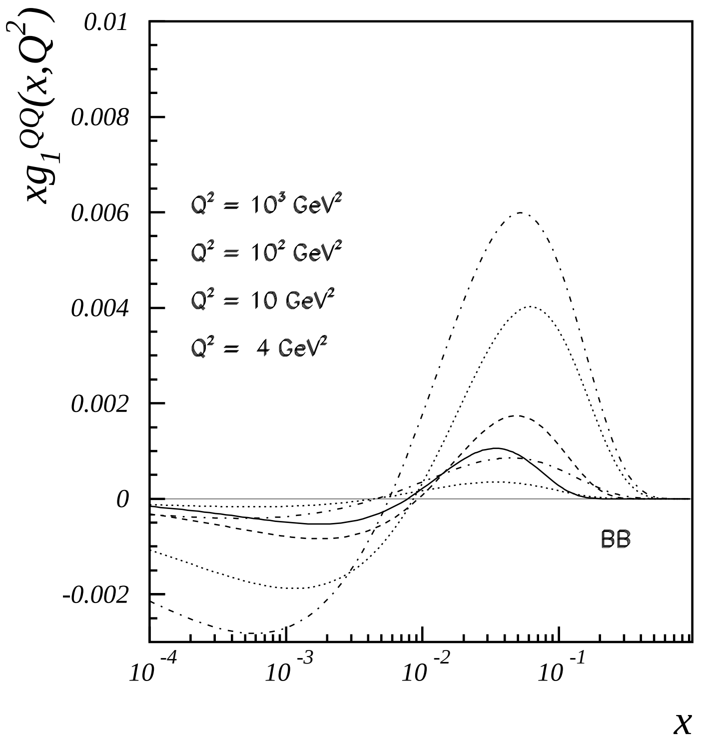
Fig. 2

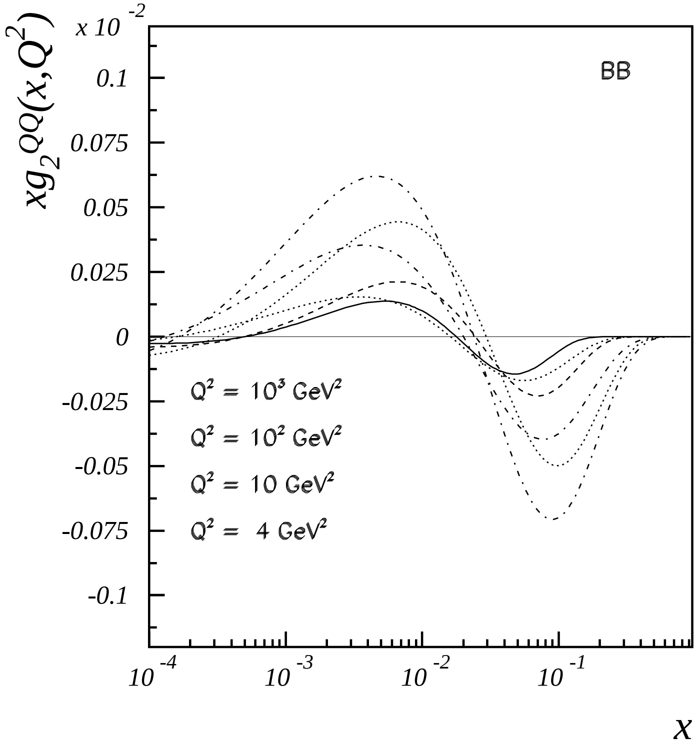
Blümlein and Vogt, 1995, 1996 There are no large small x effects.

The QCD Fits

- Consistent Data Analysis : - asymmetry denominator from data
- Consistent Data Analysis : - fit the numerator functions
- Not all parameters can be measured through the fit; careful study required.
- Low $Q^2 \geq 4$GeV^2 cut would be required. Only possible at EIC.
- Correlated fit of $\Lambda_{\rm QCD}$ mandatory: close relation to $\Delta G(x, Q^2)$
- Evolution of all errors throughout the Evolution Equations
- Include $c\bar{c}$-production.
- Tasks for Theory: NNLO corrections; higher twist contributions.

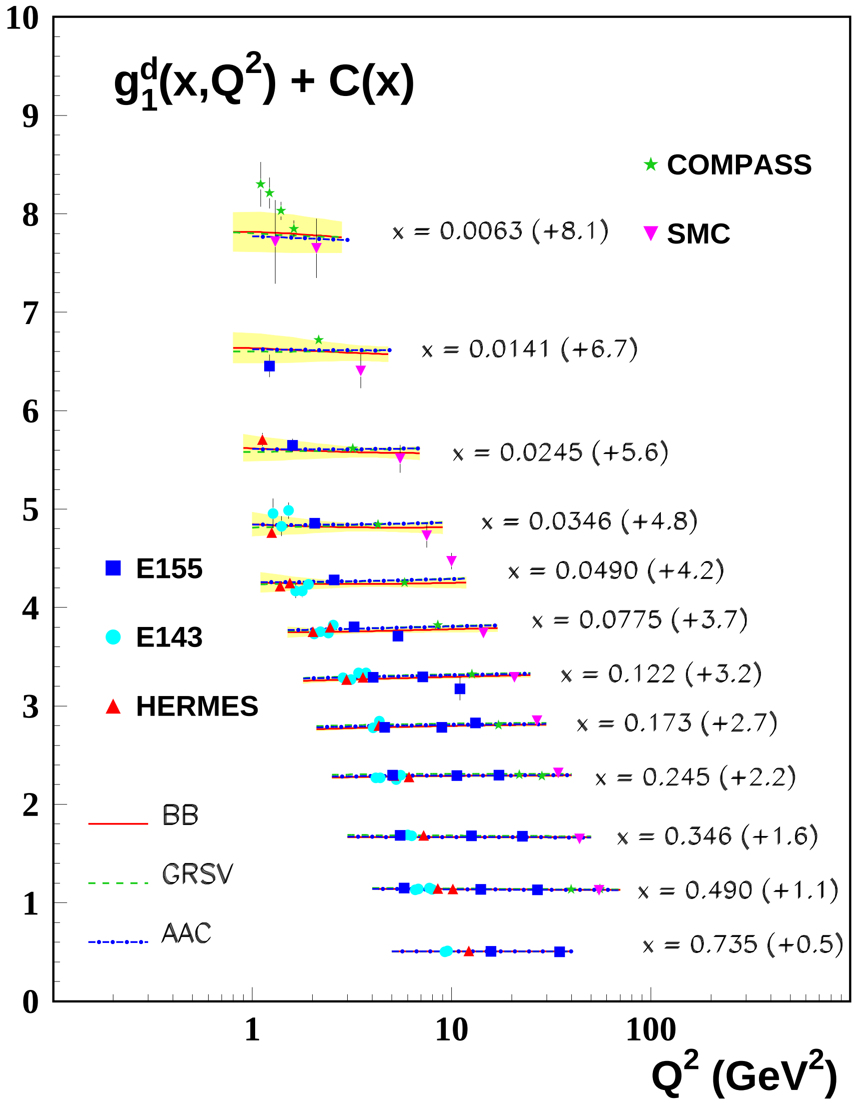
Charm Contributions





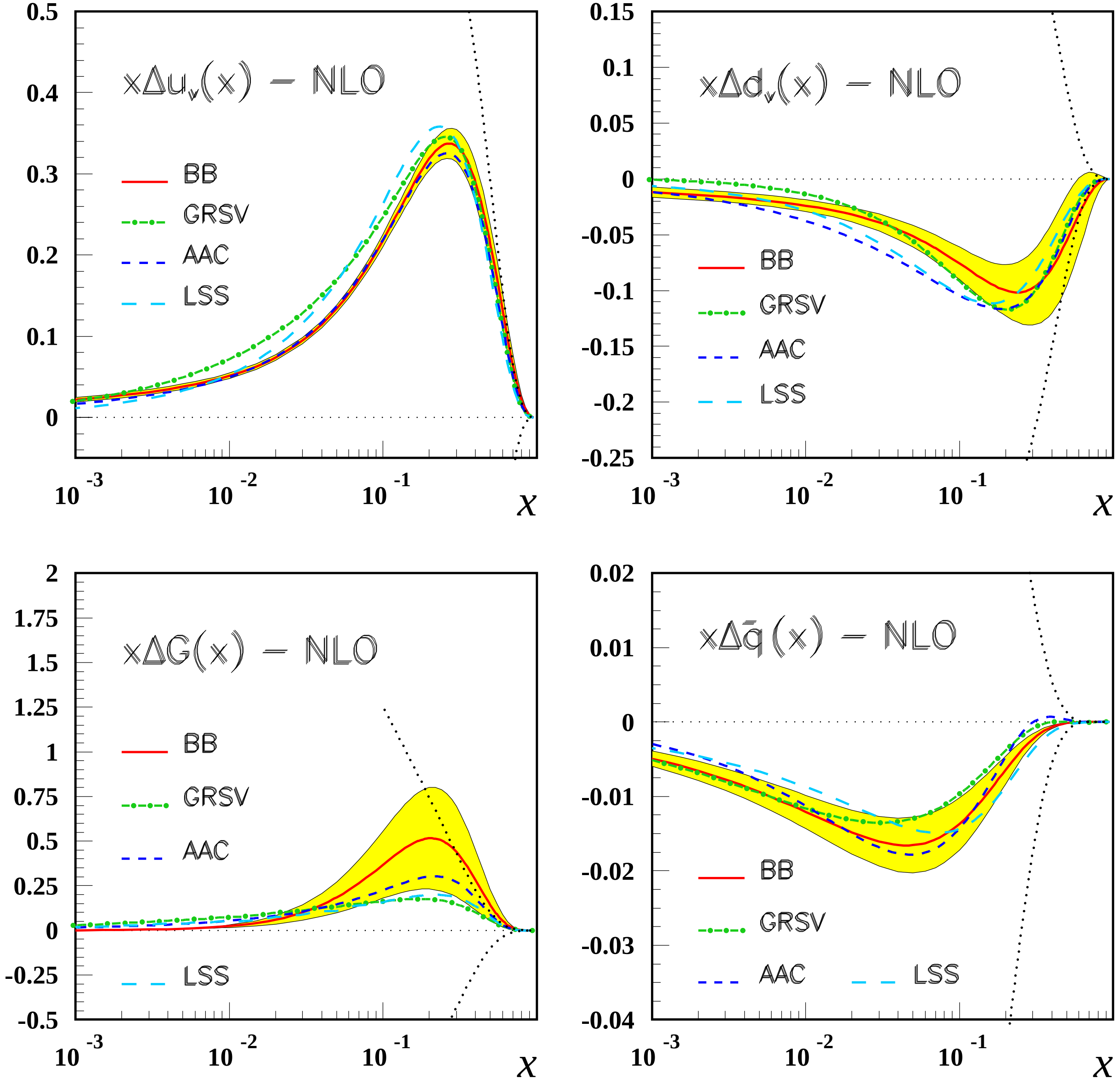
JB, Ravindran, van Neerven (2003): $g_{1,2}^{c\bar{c}}(x, Q^2)$

2. Polarized Parton Densities



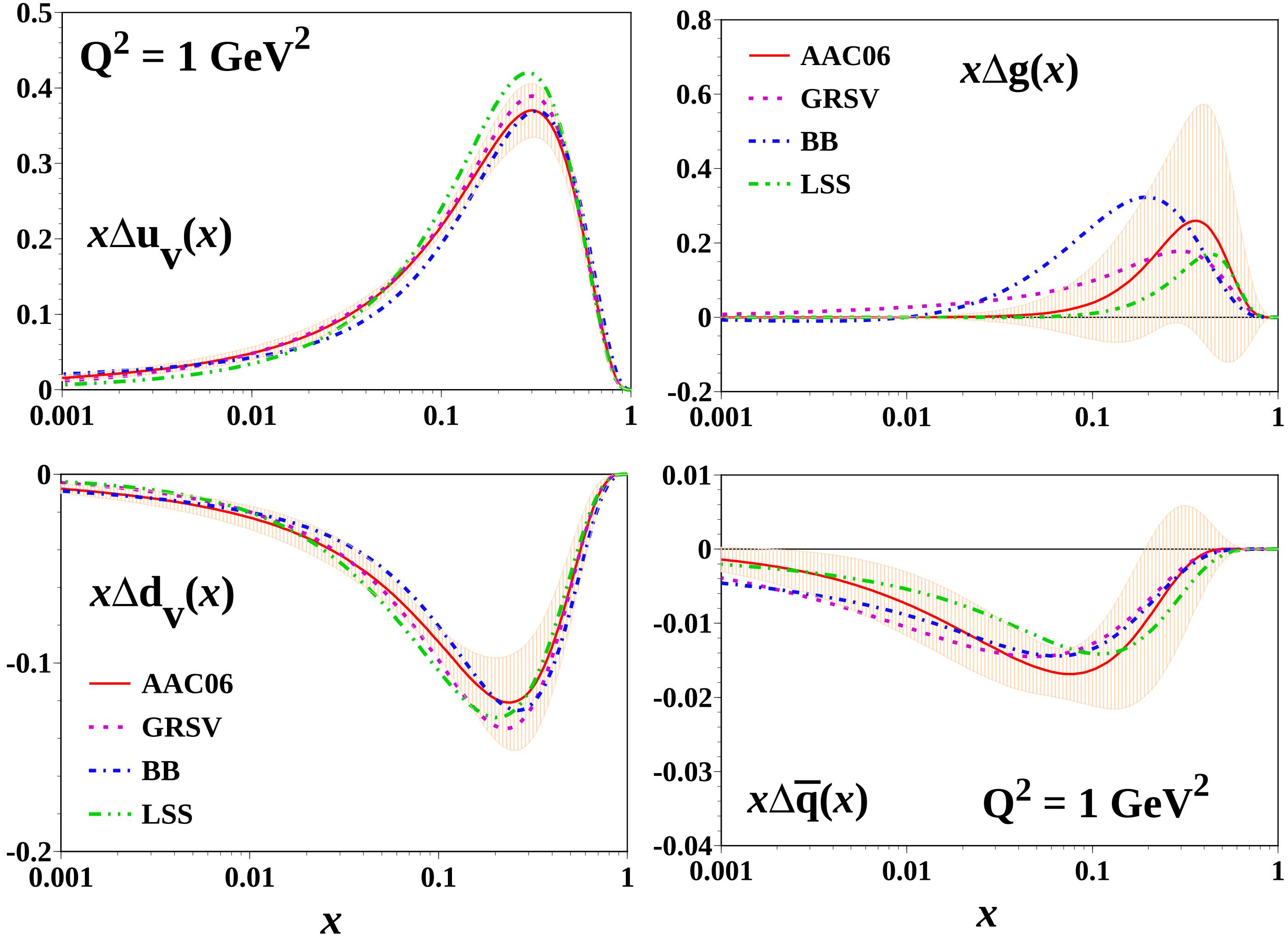
World Data: $g_d(x, Q^2)$

Polarized Parton Densities



J.B., H. Böttcher, 2002

Polarized Parton Densities



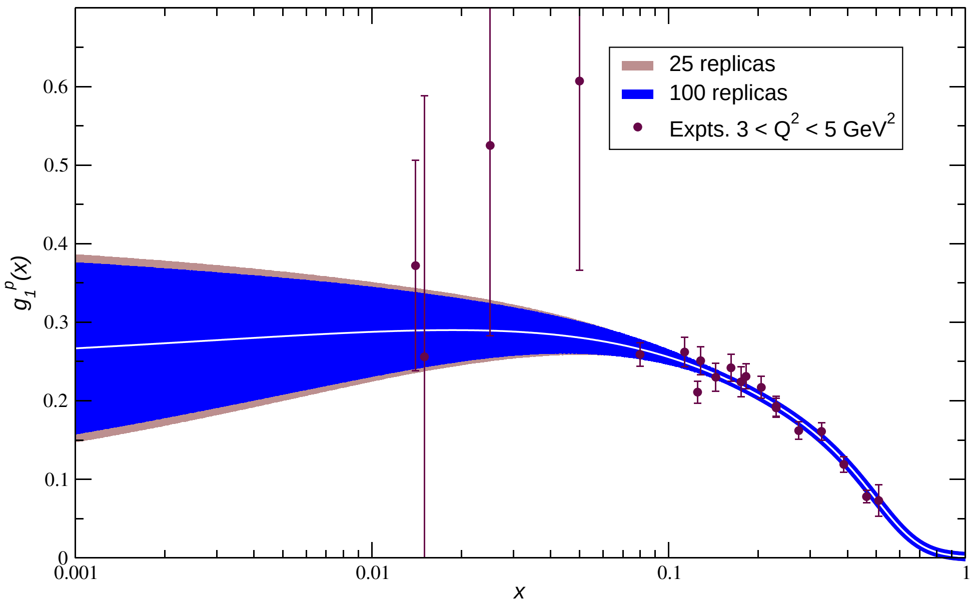
AAC 2006

Polarized Parton Densities

g_1 from Neural Networks

g_1^P from Neural Networks

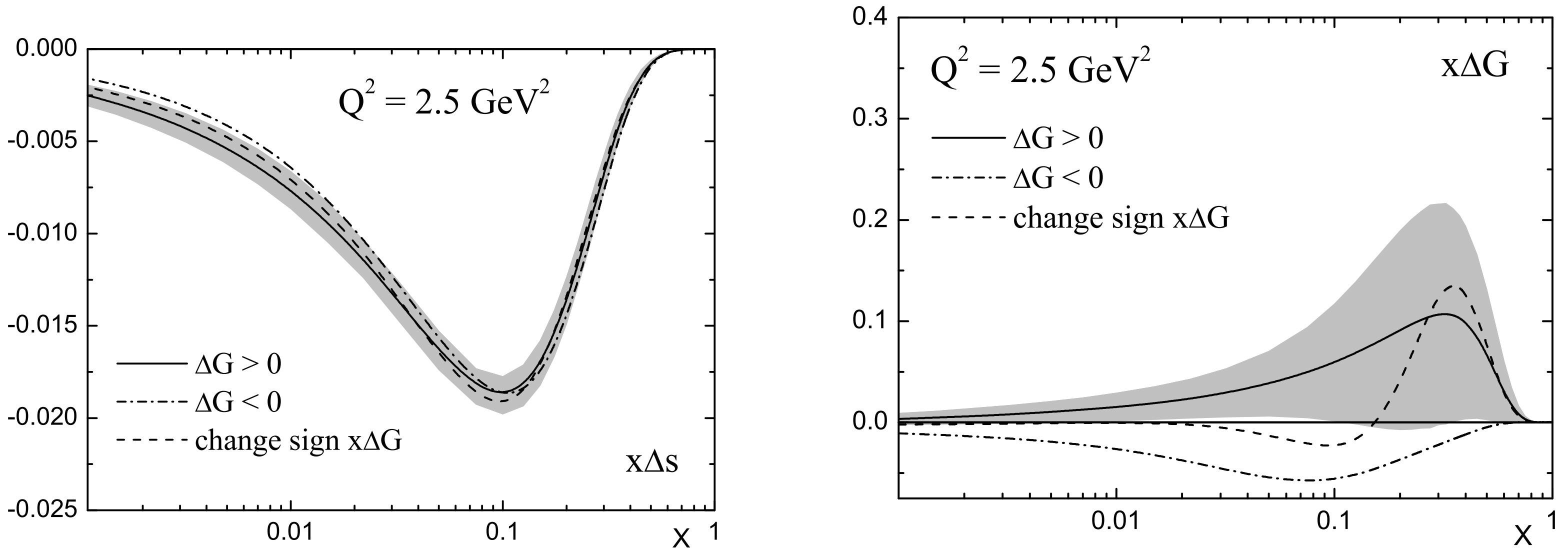
Preliminary Fit



A. Guffanti (UoE) SPIN 2006 14 / 16

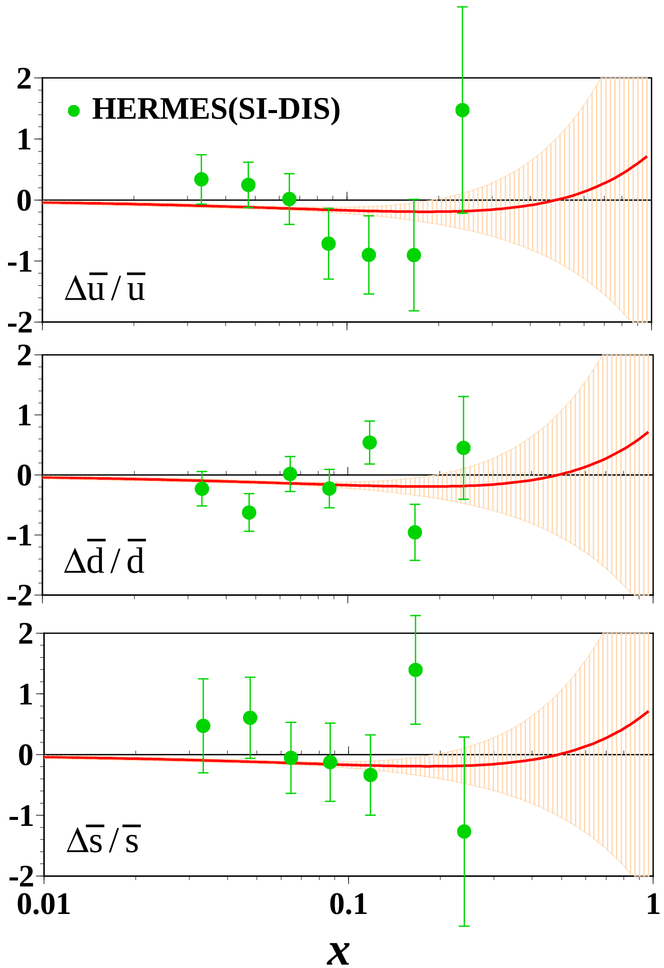
Neural Networks: L. Del Debbio & A. Guffanti

Polarized Parton Densities

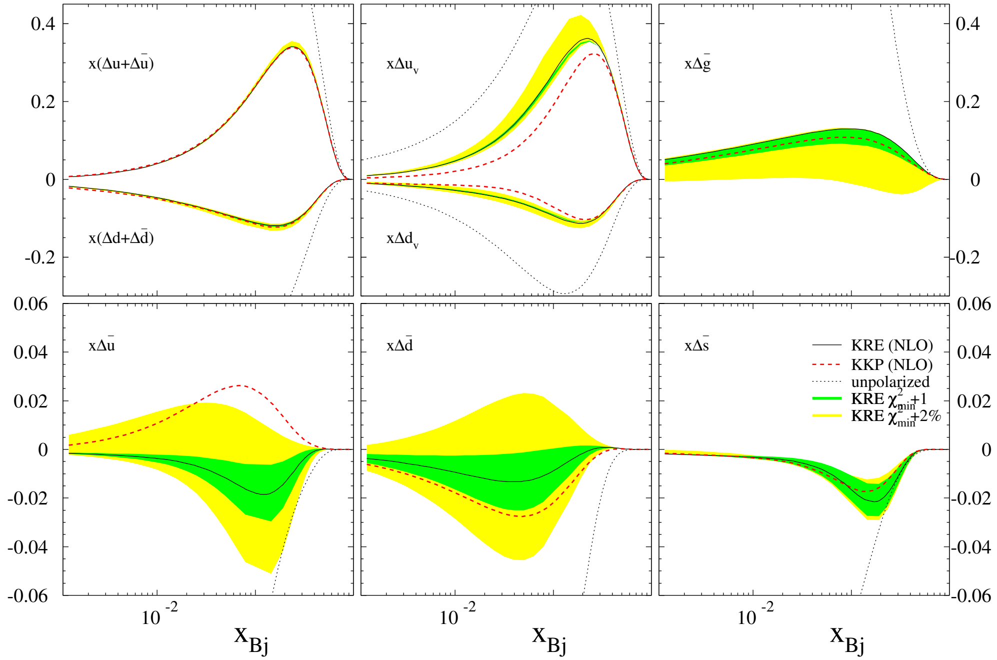


Leader, Sidorov, Stamenov (2006)

Polarized Parton Densities: Flavor Separation



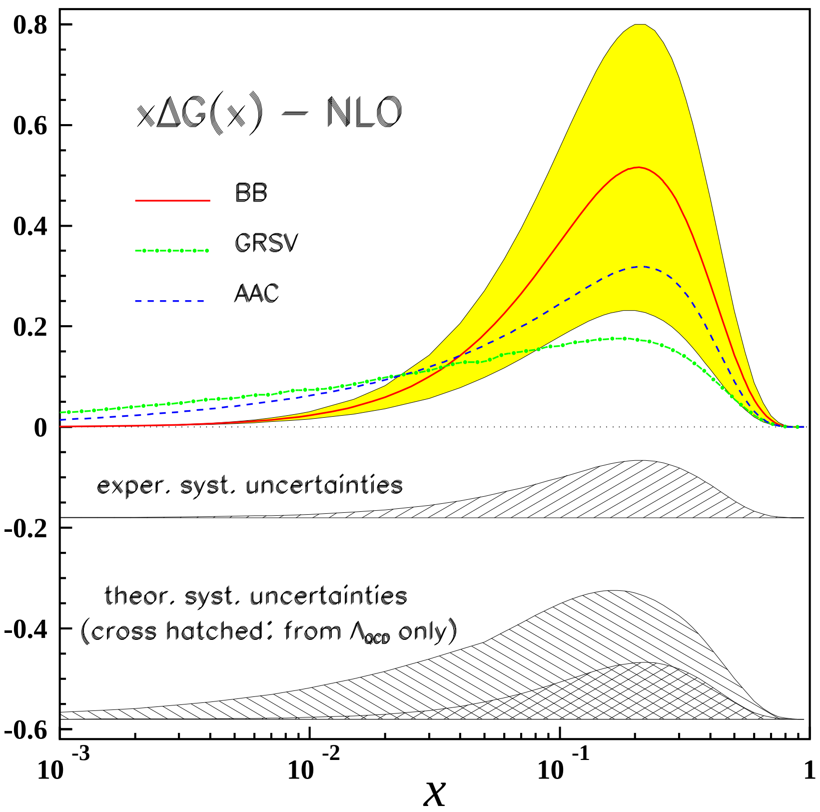
HERMES & AAC



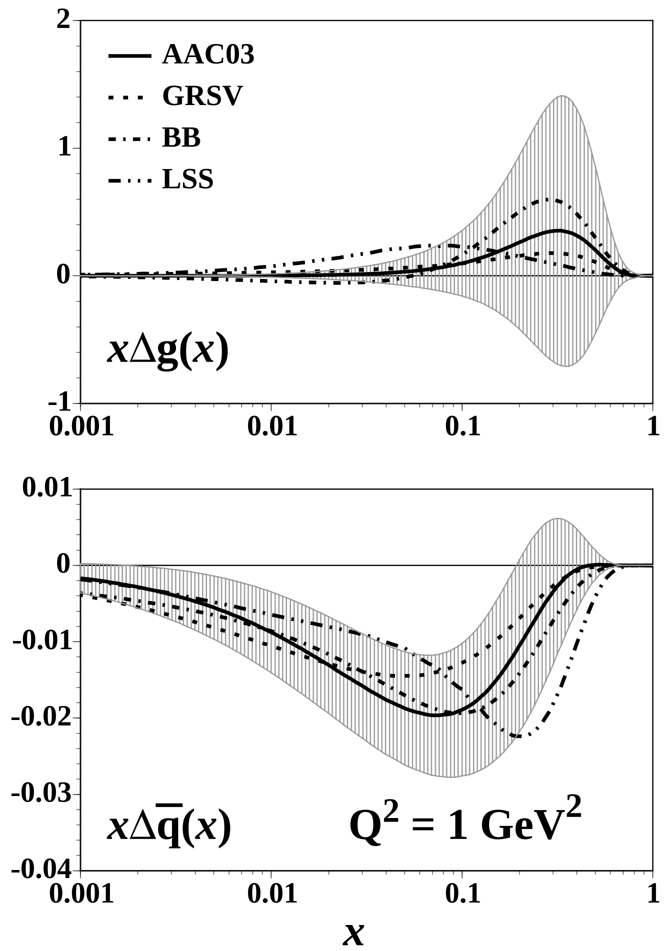
De Florian & Sassot, 2005

$\delta\Delta s$ too small ?

Polarized Gluon Density



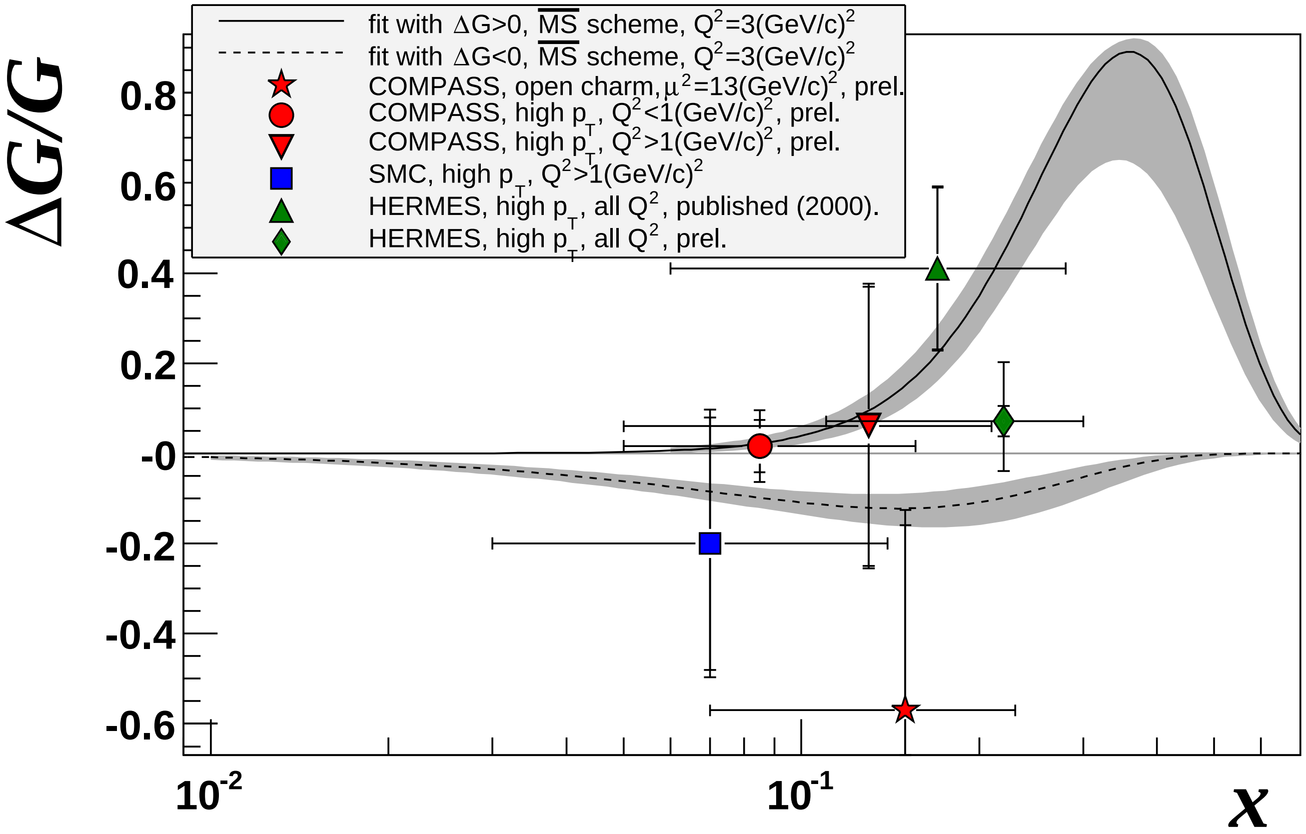
J.B., H. Böttcher, 2002



AAC

$\Longrightarrow$ Currently slight move towards lower values.

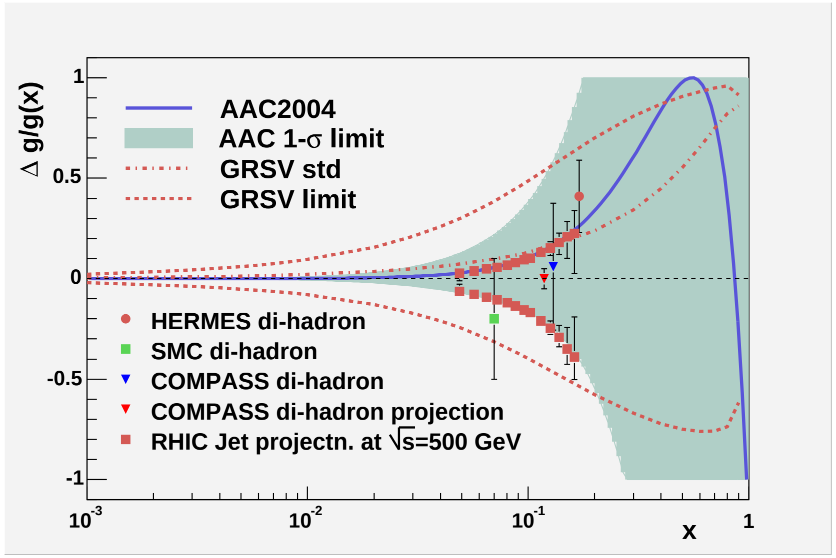
Polarized Gluon Density

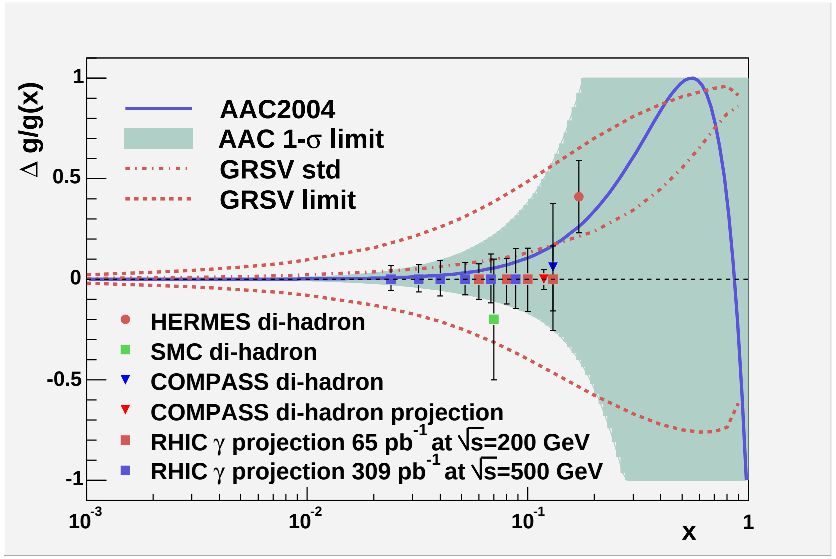


COMPASS 2006 compared to other measurements

$\Longrightarrow$ Rather low Q^2 (S. Koblitz)

Polarized Gluon Density





Research Plan for Spin Physics at RHIC

Moments of PDF's: PT + data

f	n	This Fit N^{3}LO	MRST04 NNLO	A02 NNLO
u_v	2	0.3006 ± 0.0031	0.285	0.304
	3	0.0877 ± 0.0012	0.082	0.087
	4	0.0335 ± 0.0006	0.032	0.033
d_v	2	0.1252 ± 0.0027	0.115	0.120
	3	0.0318 ± 0.0009	0.028	0.028
	4	0.0106 ± 0.0004	0.009	0.010
$u_v - d_v$	2	0.1754 ± 0.0041	0.171	0.184
	3	0.0559 ± 0.0015	0.055	0.059
	4	0.0229 ± 0.0007	0.022	0.024

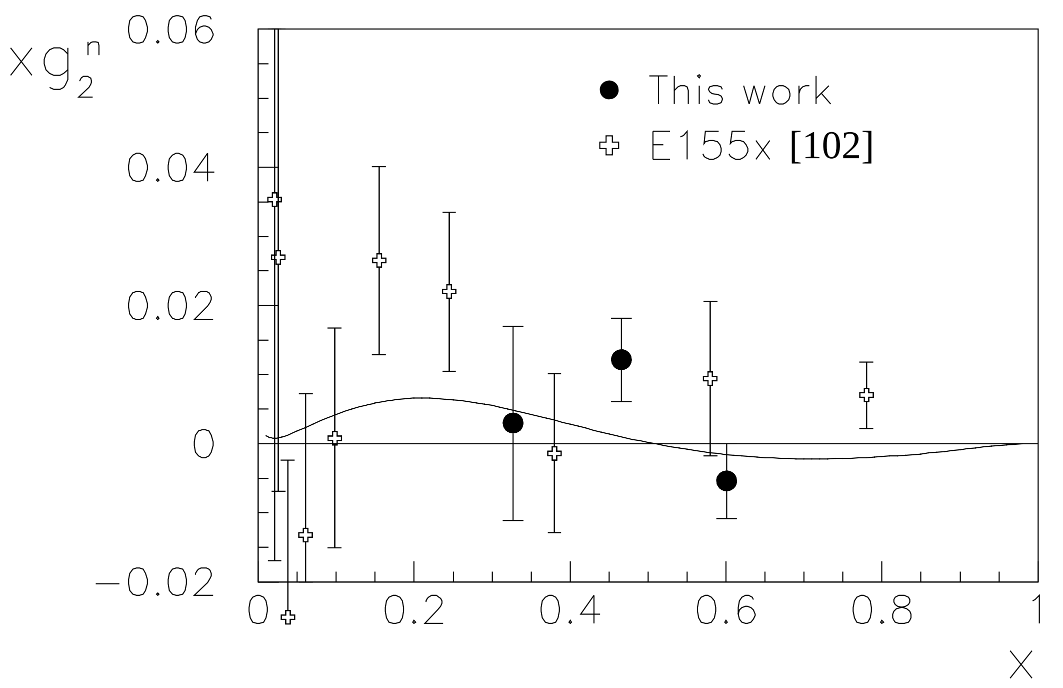
J.B., H. Böttcher, A. Guffanti, 2004

	Moment	BB, NLO
Δu_v	0	0.926
	1	0.163 ± 0.014
	2	0.055 ± 0.006
Δd_v	0	-0.341
	1	-0.047 ± 0.021
	2	-0.015 ± 0.009
$\Delta u_v - \Delta d_v$	0	1.267
	1	0.210 ± 0.025
	2	0.070 ± 0.011

J.B., H. Böttcher, 2002

Lattice Results : developing; different fermion-types studied. Low values of m_π crucial; values approach 270 MeV now.

$g_2(x, Q^2)$ - the Window to $\tau = 3$



JLAB Hall A (2004)

$\alpha_s(M_Z^2)$

NLO	$\alpha_s(M_Z^2)$	expt	theory	Ref.
CTEQ6	0.1165	± 0.0065		[1]
MRST03	0.1165	± 0.0020	± 0.0030	[2]
A02	0.1171	± 0.0015	± 0.0033	[3]
ZEUS	0.1166	± 0.0049		[4]
H1	0.1150	± 0.0017	± 0.0050	[5]
BCDMS	0.110	± 0.006		[6]
GRS	0.112			[10]
BBG	0.1148	± 0.0019		[9]
BB (pol)	0.113	± 0.004	$^{+0.009}_{-0.006}$	[7]

NLO

NNLO	$\alpha_s(M_Z^2)$	expt	theory	Ref.
MRST03	0.1153	± 0.0020	± 0.0030	[2]
A02	0.1143	± 0.0014	± 0.0009	[3]
SY01(ep)	0.1166	± 0.0013		[8]
SY01(νN)	0.1153	± 0.0063		[8]
GRS	0.111			[10]
A06	0.1128	± 0.0015		[11]
BBG	0.1134	$+0.0019/-0.0021$		[9]

$\mathbf{N^3LO}$	$\alpha_s(M_Z^2)$	expt	theory	Ref.
BBG	0.1141	$+0.0020/-0.0022$		[9]

NNLO and N^{3}LO

BBG: $N_f = 4$: non-singlet data-analysis at $O(\alpha_s^4)$: $\Lambda = 234 \pm 26$ MeV

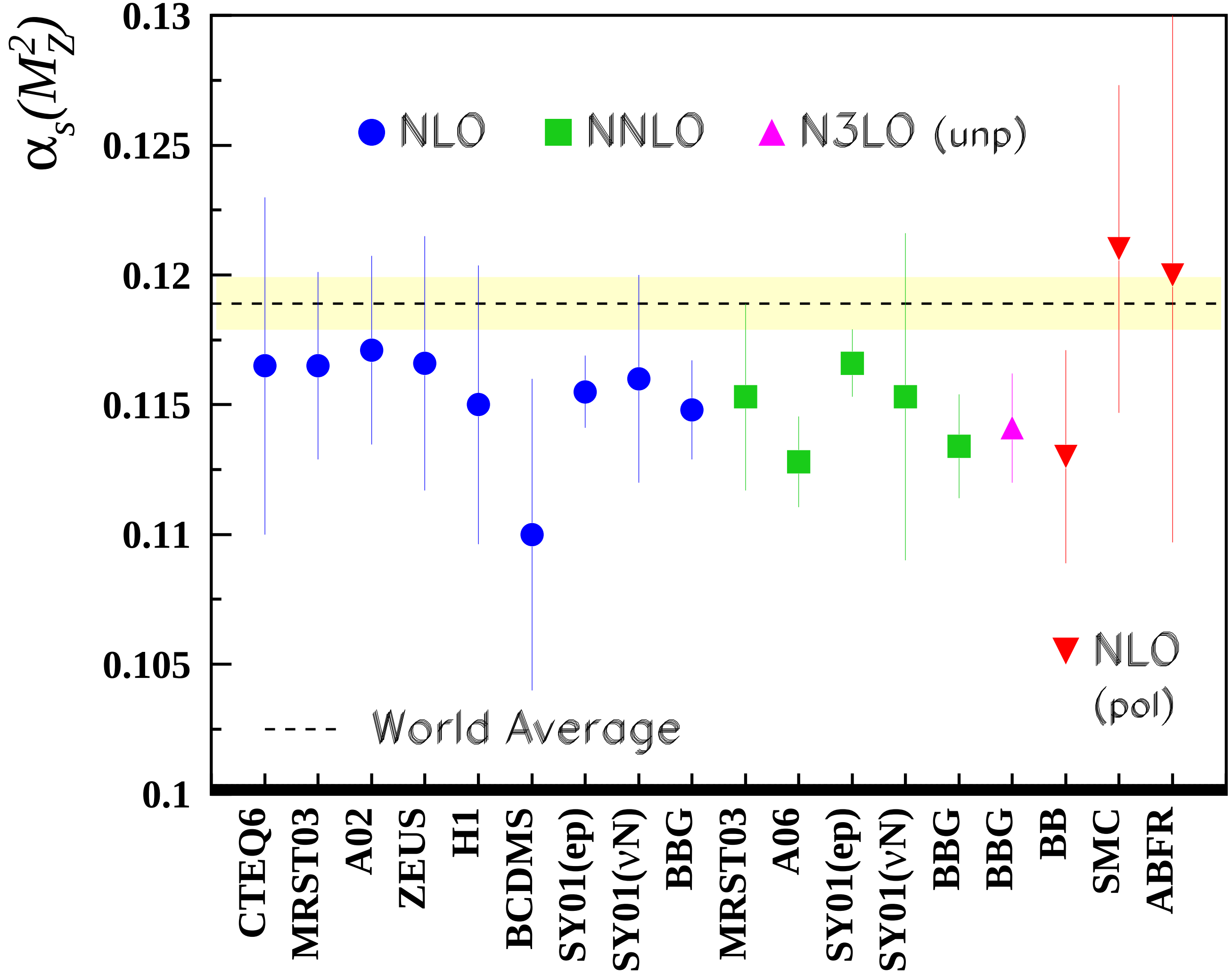
I. Savin: pol. $O(\alpha_s^2)$ this workshop.

Lattice results :

Alpha Collab: $N_f = 2$ Lattice; non-pert. renormalization $\Lambda = 245 \pm 16 \pm 16$ MeV

QCDSF Collab: $N_f = 2$ Lattice, pert. reno. $\Lambda = 261 \pm 17 \pm 26$ MeV

$\alpha_s(M_Z^2)$



J.B., H. Böttcher, A. Guffanti, 2006

3. Future Avenues : What would we like to know ?

HERMES & COMPASS :

- Finalize data analysis: get still better PDF's
- HERMES unpolarized: $F_2(x, Q^2)$ and $xs(x, Q^2)$.

RHIC :

- Improve constraints on polarized gluon and sea–quarks.

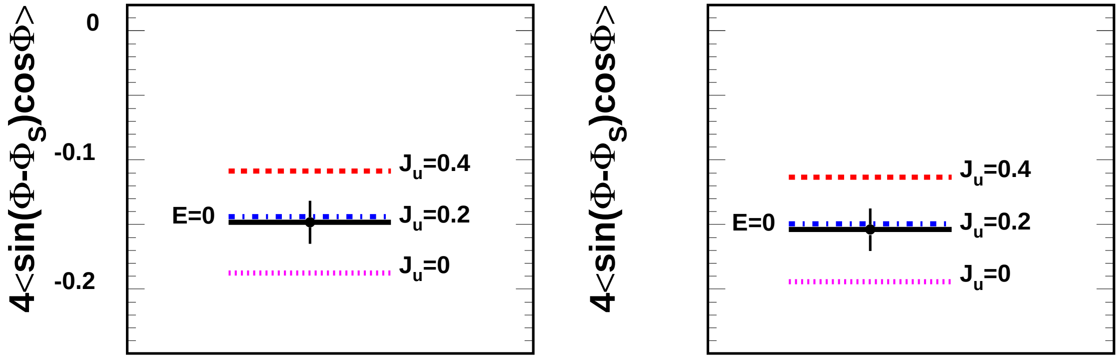
JLAB:

- High precision measurements in the large x domain at polarized targets.

L_q from DVCS

- HERA and JLAB : Improve DVCS data

Theory widely developed, cf. rev. Belitsky & Radyushkin, 2005



Expected DVCS asymmetry $A_{UT}^{\sin(\phi-\phi_S)\cos\phi}$ with $b_v = 1$, $b_s = \infty$, $J_u = 0.4(0.2, 0.0)$, $J_d = 0.0$ in the Regge (left panel) and factorized (right panel) ansatz, at the average kinematics of the full measurement. $E = 0$ denotes zero effective contribution from the GPD E. The projected statistical error for 8M DIS events is shown. The systematic error is expected to not exceed the statistical one.

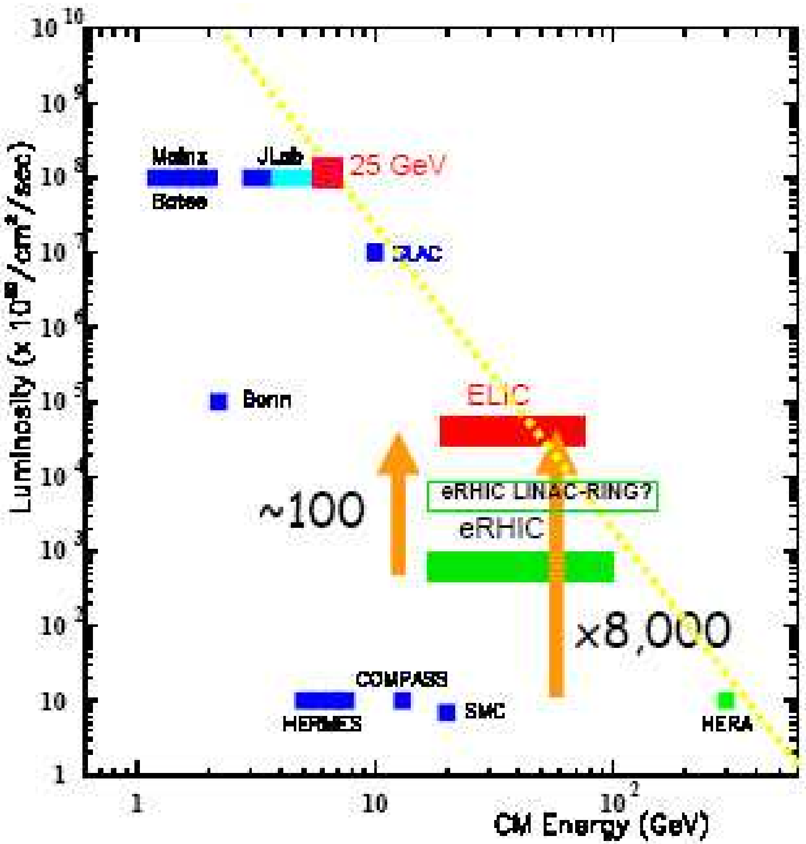
F. Ellinghaus et al. 2005

The measurement of L_q off data is model–dependent at the moment.
Lattice calculations at low pion masses are needed to complete the picture

New DIS Machines

Where to go ?

- High energies : small x, large Q^2 desirable.
- High luminosities : ELIC: $\sqrt{s}$ between CERN and HERA energies



R. Ent,2004
high precision physics
polarized and unpolarized

Would be an important extension of the present programmes in many respects.

Enhancing Precision Further...

- Determine the flavor structure of polarized nucleons
- Detailed Studies of twist–3 contributions and sum-rules.
- Measure the angular momentum of quarks and gluons
- Measure $\Lambda_{\rm QCD}$ of polarized data precisely
- Measure the scaling violations of $h_1(x, Q^2)$
- Study higher twist in a definite way - needs input from Lattice Gauge Theory

There is a strong need for the EIC, which should be started soon.