The Status of Polarized Parton Densities

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DESY

Remarks on Theory

Polarized Parton Densities

What we still would like to know: Future Avenues
Theory of DIS

Parton Model

Light Cone Expansion [f]

Twist 2

Higher Twist

Fixed Order PT: QCD

\( \alpha_s \)

\( O(\alpha_s^4) \)

\('73,'74,'80,'97\)

\( O(\alpha_s^3) \)

\('73,'82, 2004\)

\( O(\alpha_s^3) \)

\('82,'92,2004\)

Splitting functions

Coefficient functions

Special Kinematics Domain: Small x

\('75, '86\)

\('90 - '98\)

Resummations ?

Diffractive Scattering

Angular Momentum: \( q, G \)

More General View

Non-forw. scattering

Higher Orders \( \implies \)

New Algorithms

Novel Mathematics

\( O(4s) \)

\( O(3s) \)

\( O(3s) \)

\('73,'74,'80,'97\)

\('69 - '72\)

\('69, QCD: '72\)
Running $\alpha_s$: $O(\alpha_s^4)$ Larin, van Ritbergen, Vermaseren 1997

Pol. Bjorken Sum Rule: $O(\alpha_s^3)$ Larin, Vermaseren, 1991

Pol. anomalous dimension: $O(\alpha_s^2) \Delta P_{S,NS}^{ij}$ Mertig, van Neerven, 1995; Vogelsang 1995

$O(\alpha_s^3) \Delta P_{NS}^{qq}$ (due to Ward identity) Moch, Vermaseren, Vogt, 2004

Pol. Wilson coefficients: $O(\alpha_s^2); \Delta C_{S,NS}^{q(G)}$: 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 $\Lambda_{QCD}$ 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
The subleading terms cancel the small resummed corrections.
Furthermore: F-number conservation.
Resum using the Renormalization Group Equations.

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 $Q^2 \geq 4\text{GeV}^2$ cut would be required. Only possible at EIC.
- Correlated fit of $\Lambda_{\text{QCD}}$ 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: $g_d(x, Q^2)$

J. Blümlein
Status of Polarized PDF's ...
DIS07, Munich, April 2007
– p.8
Polarized Parton Densities

$\times \Delta u_\nu (x) - NLO$

$\times \Delta d_\nu (x) - NLO$

$\times \Delta g (x) - NLO$

$\times \Delta \bar{q} (x) - NLO$

J.B., H. Böttcher, 2002
Status of Polarized PDF's ...

DIS07, Munich, April 2007
Polarized Parton Densities

$Q^2 = 1 \text{ GeV}^2$

$x\Delta u_V(x)$

$x\Delta d_V(x)$

$x\Delta g(x)$

$x\Delta \overline{q}(x)$

$Q^2 = 1 \text{ GeV}^2$

AAC 2006
Polarized Parton Densities

$g_1^P$ from Neural Networks

Preliminary Fit

$g_1^P$ from Neural Networks

Neural Networks: L. Del Debbio & A. Guffanti

Neural Networks: L. Del Debbio & A. Guffanti
Polarized Parton Densities

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$Q^2 = 2.5$ GeV$^2$

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Leader, Sidorov, Stamenov (2006)
**Polarized Parton Densities: Flavor Separation**

**De Florian & Sassot, 2005**

$\delta \Delta s$ too small?
Currently slight move towards lower values.
COMPASS 2006 compared to other measurements

$\Rightarrow$ Rather low $Q^2$  
(S. Koblitz)
Polarized Gluon Density

Research Plan for Spin Physics at RHIC
Moments of PDF’s: PT + data

|   |   | This Fit N^3 LO | MRST04 NNLO | A02 NNLO | Moment | BB, NLO |
|---|---|-----------------|-------------|----------|--------|---------|
|   |   |                  |             |          |        |         |
| $u_v$ | 2 | 0.3006 ± 0.0031 | 0.285       | 0.304    | 0      | 0.926   |
|      | 3 | 0.0877 ± 0.0012 | 0.082       | 0.087    | 1      | 0.163 ± 0.014 |
|      | 4 | 0.0335 ± 0.0006 | 0.032       | 0.033    | 2      | 0.055 ± 0.006 |
| $d_v$ | 2 | 0.1252 ± 0.0027 | 0.115       | 0.120    | 0      | −0.341  |
|      | 3 | 0.0318 ± 0.0009 | 0.028       | 0.028    | 1      | −0.047 ± 0.021 |
|      | 4 | 0.0106 ± 0.0004 | 0.009       | 0.010    | 2      | −0.015 ± 0.009 |
| $u_v - d_v$ | 2 | 0.1754 ± 0.0041 | 0.171       | 0.184    | 0      | 1.267   |
|      | 3 | 0.0559 ± 0.0015 | 0.055       | 0.059    | 1      | 0.210 ± 0.025 |
|      | 4 | 0.0229 ± 0.0007 | 0.022       | 0.024    | 2      | 0.070 ± 0.011 |

J.B., H. Böttcher, A. Guffanti, 2004

J.B., H. Böttcher, 2002

Lattice Results: developing; different fermion-types studied. Low values of $m_\pi$ 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            | $\pm 0.0065$  |              | [1]  |
| MRST03    | 0.1165            | $\pm 0.0020$  | $\pm 0.0030$ | [2]  |
| A02       | 0.1171            | $\pm 0.0015$  | $\pm 0.0033$ | [3]  |
| ZEUS      | 0.1166            | $\pm 0.0049$  |              | [4]  |
| H1        | 0.1150            | $\pm 0.0017$  | $\pm 0.0050$ | [5]  |
| BCDMS     | 0.110             | $\pm 0.006$   |              | [6]  |
| GRS       | 0.112             |               |              | [10] |
| BBG       | 0.1148            | $\pm 0.0019$  |              | [9]  |
| BB (pol)  | 0.113             | $\pm 0.004$   | $^{+0.009}_{-0.006}$ | [7]  |

### NNLO and N$^3$LO

| NNLO      | $\alpha_s(M_Z^2)$ | expt          | theory       | Ref. |
|-----------|-------------------|---------------|--------------|------|
| MRST03    | 0.1153            | $\pm 0.0020$  | $\pm 0.0030$ | [2]  |
| A02       | 0.1143            | $\pm 0.0014$  | $\pm 0.0009$ | [3]  |
| SY01(ep)  | 0.1166            | $\pm 0.0013$  |              | [8]  |
| SY01($\nu$N) | 0.1153         | $\pm 0.0063$  |              | [8]  |
| GRS       | 0.111             |               |              | [10] |
| A06       | 0.1128            | $\pm 0.0015$  |              | [11] |
| BBG       | 0.1134            | $^{+0.0019/-0.0021}$ |              | [9]  |
| BBG       | 0.1141            | $^{+0.0020/-0.0022}$ |          | [9]  |

### N$^3$LO

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

**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
\[ \alpha_s(M_Z^2) \]

The figure shows the status of polarized PDFs as of April 2007, with data from various experiments and theoretical calculations. The different symbols represent NLO, NNLO, and N3LO unpolarized and polarized results. The world average is indicated by a dashed line.

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 $x s(x, Q^2)$.

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

\[ 4 \langle \sin(\phi - \phi_S) \cos \phi \rangle \]

Expected DVCS asymmetry \( A_{UT}^{\sin(\phi - \phi_S) \cos \phi} \) with \( b_v = 1, b_u = \infty, J_u = 0.4(0.2, 0.0), J_d = 0.0 \) 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 $\Lambda_{QCD}$ 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.