Gluon helicity distribution

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Outline

1. Introduction
2. Unpolarized PDFs
3. Polarized PDFs
4. Helicity
Proton spin puzzle

What is the decomposition of the proton spin [Nucl. Phys. B 337, 509-546 (1990)]?

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

- current extraction of $\Delta \Sigma$ is around 0.3
- spin can be extracted from parton distribution functions (PDFs)
- orbital angular momentum can be extracted from GPDs
Parton distribution functions

- Probability to find a quark $i$ or a gluon $g$ in a hadron $h$ carrying a fraction $x$ of the hadron’s momentum.

- Spin-averaged (unpolarized): $f = f^\uparrow + f^\downarrow$

- Spin-dependent (polarized): $\Delta f = f^\uparrow - f^\downarrow$
Global QCD analysis of high-energy scattering reactions

- Factorization theorems
- Bayesian inference
- Monte Carlo sampling
- Multi-step strategy
- Mellin transformation
**Introduction**

Unpolarized  Polarized  Helicity

**Global QCD analysis - Bayesian inference**

\[ d\sigma^{\text{DIS}} = \sum_i H_i^{\text{DIS}} \otimes f_i \]
\[ d\sigma^{\text{DY}} = \sum_{i,j} H_i^{\text{DY}} \otimes f_i \otimes f_j \]
\[ d\sigma^{\text{jet}} = \sum_{i,j} H_i^{\text{jet}} \otimes f_i \otimes f_j \]

hadron structure

\[ \rho(\vec{p}|\text{data}) \sim L(\vec{p}|\text{data})\pi(\vec{p}) \]

likelihood

polynomial

\[ f_i(x) = n_i x^{\alpha_i} (1 - x)^{\beta_i} P(x) \]
\[ \vec{p} = (n_i, \alpha_i, \beta_i, \ldots) \]

posterior beliefs

\[ L(\vec{p}|\text{data}) = \exp\left(-\frac{1}{2}\chi^2(\vec{p}|\text{data})\right) \]

evidence

\[ \chi^2 = \frac{1}{N} \sum_{i=1}^{N} \frac{(E_i - T_i)^2}{\alpha_i^2} \]

**Gluon helicity distribution**
RHIC measures double longitudinal spin asymmetry

\[ A_{LL}^{jets} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\Delta \sigma(\Delta g, \ldots)}{\sigma(g, \ldots)} \]

- \( \sigma^{\pm} \) are differential cross sections when proton beams have equal & opposite helicity
- denominator is spin-averaged cross section

We also include unpolarized DIS, Drell-Yan, and polarized inclusive DIS (total of 3576 points).
Fits to jet in unpolarized collisions

Good agreement between theory and Tevatron data

First inclusion of unpolarized RHIC jets!

PRD 105, 074022 (2022)
An overall good agreement is found.
Previous extractions of $\Delta f$

PRL 113, 012001 (2014)

Introduction

Unpolarized

Polarized

Helicity

Theory assumptions

1. SU(2) flavor symmetry only
2. SU(2) and SU(3)
3. SU(2) and SU(3), and PDF positivity

more constraints
more biases
less data driven
Extracted polarized PDFs

\[ \Delta q^+ = \Delta q + \Delta \bar{q}, \quad q = u, d, s \]
Fits to jet $A_{LL}$

Good agreement with data for $\Delta g > 0$ and $\Delta g < 0$

Large cancellation between $gg$ and $qg$ channels for $\Delta g < 0$

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First moments - $\Delta G = \int_{0.05}^{1} \Delta g \, dx$

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

- **SU(2):**
  - $\Delta g > 0$: $0.20 \pm 0.13$
  - $\Delta g < 0$: $-0.56 \pm 0.12$

- **SU(3):**
  - $\Delta g > 0$: $0.27 \pm 0.03$
  - $\Delta g < 0$: $-0.61 \pm 0.04$

- **SU(3) + pos:** $0.25 \pm 0.03$

- **DSSV14:** $0.2 \pm 0.05$

PRL 113, 012001 (2014)

PRD 105, 074022 (2022)


Helicity basis PDFs

- $u^\uparrow / \downarrow$ and $d^\uparrow / \downarrow$ are well separated.
- $s^\uparrow / \downarrow$ can be hardly distinguished.
- First simultaneous extraction of $f^\uparrow$ and $f^\downarrow$.
- $g^\uparrow / \downarrow$ for $\Delta g > 0$ (blue and green) and $\Delta g < 0$ (orange and red).

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ROC and AUC

- indistinguishable
- somewhat distinguishable
- clearly distinguishable

ROC: receiver operating characteristic curve
AUC: area under curve of ROC

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AUC for helicity PDFs

- 0.5: can barely discriminate $f^{↑}$ and $f^{↓}$
- 1.0: can clearly discriminate $f^{↑}$ and $f^{↓}$
Currently working on...

- polarized SIDIS with large $q_T$: linear dependence on $\Delta g$ at LO
- di-jets: also sensitive $\Delta g$ at LO
- $\pi^\pm$ and $K^\pm$ production in $pp$ collisions
In collaboration with Nobuo Sato and Wally Melnitchouk in Jefferson Lab.

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