Gluon helicity distributions

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Proton spin puzzle

- What is the decomposition of the proton spin?

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

- current extraction of \( \Delta \Sigma \) is around 0.3
- spin: parton distribution functions (PDFs)
- orbital angular momentum extracted from GPDs
QCD global analysis - Bayesian inference

Experiments = theory + errors

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

\[ f_i(x) = a_0 x^{a_1} (1 - x)^{a_2} P(x) \]
\[ \mathbf{a} = (a_0, a_1, a_2, \ldots) \]

\[ \rho(\mathbf{a}|\text{data}) \sim \mathcal{L}(\mathbf{a}|\text{data}) \pi(\mathbf{a}) \]

\[ \mathcal{L}(\mathbf{a}, \text{data}) = \exp \left[ -\frac{1}{2} \chi^2(\mathbf{a}, \text{data}) \right] \]

\[ \chi^2 = \sum_i \frac{1}{\alpha_i^2} (E_i - T_i)^2 \]
Jets as probes of hadron structure

In inclusive DIS, sensitivity to gluon PDF only appears at NLO

On the other hand, in jet production, gluon diagrams appear at lowest order
Polarized jets

- RHIC measures double longitudinal polarization asymmetry

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

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

- \( A_{LL}^{\text{jets}} \) is sensitive to unpolarized PDFs → perform **simultaneous** analysis to check
Unpolarized jets

Good agreement between theory and Tevatron data

First inclusion of unpolarized RHIC jets!
Unpolarized PDFs - $\chi^2 = 1.18$

An overall good agreement is found.

Differences are caused by choices of datasets.
Polarized jets

First inclusion of jets from polarized $pp$ collisions in JAM!
Theory assumptions

NNPDF pol 1.1

$\Delta g(x, Q^2 = 10 \text{ GeV}^2)$

- SU(3) flavor symmetry
- positivity constraints

DSSV14

$Q^2 = 10 \text{ GeV}^2$

[PRL 113, 012001 (2014)]
Theory assumptions

SU(2) only

SU(2) and SU(3)

SU(2) and SU(3), and PDF positivity

- more constraint
- more bias
- less data driven

\[ |\Delta f_i(x)| \leq |f_i(x)| \]
Helicity quark PDFs - $\chi^2 \approx 0.94$

- SU(3) flavor symmetry reduces significantly the uncertainties on $\Delta u$, $\Delta d$ and $\Delta s$
- Positivity constraints again greatly reduce the uncertainty on $\Delta s$

$\Delta q^+ = \Delta q + \Delta \bar{q}$, $q = u, d, s$
Helicity gluon PDF

- $\Delta g$ is observed to have two distinct solutions
- SU(3) flavor symmetry reduces slightly the uncertainty on $\Delta g$
- positivity constraints eliminate the “negative” solution from $\Delta g$
Both $\Delta g$ solutions can describe the data equally well!
Gluon truncated moment $\Delta G$

\[
\int_{0.05}^{1} \Delta g \left( x, Q^2 = 10 \text{ GeV}^2 \right) \, dx
\]

- SU(2): $-0.02 \pm 0.39$
  - positive: $0.21 \pm 0.15$
  - negative: $-0.57 \pm 0.12$
- + SU(3): $0.12 \pm 0.32$
  - positive: $0.26 \pm 0.03$
  - negative: $-0.60 \pm 0.03$
- + positivity: $0.24 \pm 0.03$
- DSSV 14: $0.2 \pm 0.05$

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

- First simultaneous extraction of both helicity basis PDFs.
- Can we distinguish the two helicity basis PDFs?
ROC/AUC

- indistinguishable

- somewhat distinguishable

- clearly distinguishable

ROC: receiver operating characteristic curve

AUC: area under curve of ROC
AUC for helicity basis PDFs

Helicity basis PDFs for...

- up and down are only mildly affected by theory inputs
- strange are more distinguishable with SU(3), but less affected by positivity
- gluon are only clearly distinguishable from each other when positivity constrains are imposed

\[ Q^2 = 10 \text{ GeV}^2 \]
Conclusion

- Jet data in unpolarized and polarized $pp$ or $p\bar{p}$ collisions (Tevatron and RHIC) are well fitted.

- Gluon helicity distributions have two solutions.

- Helicity strange and gluon distributions are strongly biased by theory inputs.
Thank you!

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