The Gluon Spin Contribution to the Proton Spin

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Outline
Motivation
Tools
Measurement
Constraint on Gluon Spin Contribution
Future
The nucleon is a composite particle, made up of quarks and gluons

Properties of the proton arise from properties of the constituents

- Charge: \[ +1 = \frac{2}{3} + \frac{2}{3} + \frac{1}{3} \]
The Nucleon Structure

- The nucleon is a composite particle, made up of quarks and gluons
- Properties of the proton arise from properties of the constituents
  - Charge:  $+1 = \frac{2}{3} + \frac{2}{3} + \frac{1}{3}$

\[+1 = e_u \int_0^1 dx [u(x) - \bar{u}(x)] + e_d \int_0^1 dx [d(x) - \bar{d}(x)] + e_s \int_0^1 dx [s(x) - \bar{s}(x)] + \ldots\]
Structure of the Nucleon

- Properties of the proton arise from properties of the constituents
  - Momentum: \( 1 = \frac{1}{3} + \frac{1}{3} + \frac{1}{3} \)
Structure of the Nucleon

• Properties of the proton arise from properties of the constituents
  – Momentum: \[ 1 \neq \sum_q \int_0^1 x dq [q(x) + \bar{q}(x)] \]
• Properties of the proton arise from properties of the constituents
  – Momentum: \[ 1 = \sum_q \int_0^1 x dq(x) + \bar{q}(x) + \int_0^1 x dg(x) \]
Structure of the Nucleon

- Properties of the proton arise from properties of the constituents
  - Momentum:
    \[ 1 = \sum_{q} \int_{0}^{1} x \, dx \left[ q(x) + \bar{q}(x) \right] + \int_{0}^{1} x \, dx \, g(x) \]

- Knowledge of the gluon PDF comes primarily from scaling violation in DIS measurements, accessible due to large range of \( x \) and \( Q^2 \)
• Properties of the proton arise from properties of the constituents
  – Spin:

\[ S_p = \frac{1}{2} = \frac{1}{2} + \frac{1}{2} - \frac{1}{2} \]
Structure of the Nucleon

- Properties of the proton arise from properties of the constituents
  - Spin:
    \[ S_p = \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L_q + L_g \]
    \[ \Delta \Sigma = \sum \int_0^1 dx [q^+(x) - q^-(x)] \sim 0.3 \]
    \[ \Delta G = \int_0^1 dx [g^+(x) - g^-(x)] \]
    \[ L_q = \text{quark OAM} \]
    \[ L_g = \text{gluon OAM} \]

Where is the proton spin?
Helicity Structure of the Nucleon

\[ S_p = \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L_{z,q} + L_{z,g} \]

- Can use DIS to understand the quark spin contribution, \( \Delta \Sigma \)
- For the gluon spin contribution, \( \Delta G \), current fixed target data do not cover a wide enough \( x \) and \( Q^2 \) range to determine the gluon contribution
• $\int L dt = 25 \text{ pb}^{-1}$ at $\sqrt{s}=200$ GeV and $P_{\text{max}}=60\%$
• $\int L dt = 50 \text{ pb}^{-1}$ at $\sqrt{s}=500$ GeV and $P_{\text{max}}=50\%$
  – Expect another 200 pb$^{-1}$ next year at 500 GeV
• Change proton helicity every 106 ns
**PHENIX Detector**

- **Electromagnetic Calorimeter:**
  - 6 sectors PbSc with 64 layers of Pb and scintillator
  - 2 sectors PbGl, used in WA98
  - $\Delta \eta \times \Delta \phi \approx 0.01 \times 0.01$

- **Charged Particle Veto**
  - Pad chambers directly in front of EMCal

**Luminosity Determination**

- **Beam Beam Counters**
  - $3.1<|\eta|<3.9$ from IP along z axis, detect charged particles

- **Zero Degree Calorimeters**
  - 18m from IP, detect neutrons
Measuring $A_{LL}$

$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{1}{P_bP_y} \frac{N^{++} - RN^{+-}}{N^{++} + RN^{+-}}$

+ - = Opposite helicity =
++ = Same helicity =

- Helicity Dependent Particle Yields (N)
  - $\pi^0$, $\pi^+$, $\pi^-$, $\gamma$, $\eta$, etc

- Beam Polarization (P)

- Relative Luminosity ($R=L_{++}/L_{+-}$)
Calculating $A_{LL}$

1. Calculate $A_{LL}(\pi^0+BG)$ and $A_{LL}(BG)$ separately.
2. Get background ratio ($w_{BG}$) from fit of all data.
3. Subtract $A_{LL}(BG)$ from $A_{LL}(\pi^0+BG)$:

$$A_{LL}(\pi^0+BG) = w_{\pi^0} \cdot A_{LL}(\pi^0) + w_{BG} \cdot A_{LL}(BG)$$

Two photon invariant mass

- **Red**: Signal+BG region
- **Blue**: BG region

**$\pi^0$+BG region**:
- $\pm 25$ MeV around $\pi^0$ peak

**BG region**:
- two 50 MeV regions around peak
Neutral Pion $A_{LL}$

- Why $\pi^0$?
  - Abundant in pp
  - 99% decay to $\gamma\gamma$
  - Finely segmented EMCal
  - high $p_T$ photon trigger
  $\rightarrow$ large statistics

- 2005:
  - PRD 76, 051106

- 2006:
  - PRL 103, 012003
Constraining $\Delta G$

- Global analysis of helicity PDFs (similar to MSTW, CTEQ but with polarized data)
- DSSV fit world date including p+p for first time.
  - PRL 101:072001, 2008
  - PRD 80:034030, 2009
- RHIC data offer significant constraint at $0.05 < x < 0.2$.
- Large uncertainty remains below RHIC x range.
Joining Forces

• As was presented yesterday, many complications in determining PDF uncertainties
• Initial fit treated all uncertainties as uncorrelated
• Experimentalists joining Theorists to work towards thorough uncertainty determination
  – Proper handling of experimental uncertainties
  – Determination of theoretical uncertainties
  – Inclusion of additional data.
Future $\Delta G$ Constraints

- New data from PHENIX and STAR indicate nonzero $\Delta G$
- Higher luminosity at $\sqrt{s}=500$ GeV will extend reach towards lower $x$
- To get more complete measurement of $\Delta G$, need a polarized EIC
Polarized Electron Ion Collider

- Add electron ring to RHIC $\rightarrow$ eRHIC
- Significantly extend $x$ and $Q^2$ coverage

![Diagram of eRHIC and current polarized DIS data](image-url)
Polarized Electron Ion Collider

• Add electron ring to RHIC → eRHIC
• Significantly extend $x$ and $Q^2$ coverage
• Extract $\Delta G$ through evolution of $g_1^p$ for $x > 10^{-4}$.
Conclusions

- Quark spin contribution to proton spin ~30%
- Gluon spin contribution poorly known from fixed target polarized DIS
- PHENIX $\pi^0 A_{LL}$ measurements constrain $\Delta G$
- $\Delta G$ appears small
  - Need more accurate estimate of uncertainty
  - Joint Exp.-Theo. effort underway
  - New data indicate positive $\Delta G$
- Future polarized electron ring at RHIC (eRHIC) will be able to determine $\Delta G$ over wide range in $x$

THANK YOU
BACKUPS
Accessing $\Delta G$ through $A_{LL}$

Is this valid?

\[
A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\sum_{a,b,c=q,\bar{q},g} \Delta f_a \otimes \Delta f_b \otimes \Delta \hat{\sigma} \otimes D_{\pi/c}}{\sum_{a,b,c=q,\bar{q},g} f_a \otimes f_b \otimes \Delta \hat{\sigma} \otimes D_{\pi/c}}
\]

- If $\Delta f = \Delta q$, then we have this from pDIS
- So $r c A_{LL} \approx a_{gg} \Delta g^2 + b_{gq} \Delta g \Delta q + c_{qq} \Delta q^2$

From ep (&pp) (HERA mostly)

pQCD NLO

From e+e- (& SIDIS,pp)

Erice--ISSP 2012 23
Validity of pQCD Framework

π⁰ @ 200 GeV

Direct γ @ 200 GeV

arXiv:0704.3599 [hep-ex]

pQCD Works!