Gluon helicity distribution

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Outline

Proton spin puzzle

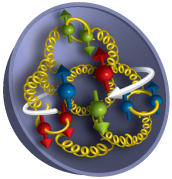
What is the decomposition of the proton spin [Nucl. Phys. B **337**, 509-546 (1990)]?

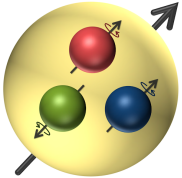
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta G + L_g$$

- 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

Global QCD analysis of high-energy scattering reactions

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

Global QCD analysis - Bayesian inference

$$d\sigma^{\mathrm{DIS}} = \sum_i H_i^{\mathrm{DIS}} \otimes f_i$$

$$d\sigma^{\mathrm{DY}} = \sum_{i,j} H_i^{\mathrm{DY}} \otimes f_i \otimes f_j$$

$$d\sigma^{\mathrm{jet}} = \sum_{i,j} H_i^{\mathrm{jet}} \otimes f_i \otimes f_j$$

hadron structure

posterior belief

prior belief

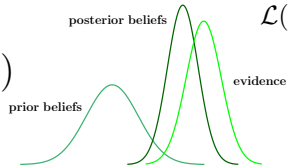
$$\rho(\vec{p}|\mathrm{data}) \sim \mathcal{L}(\vec{p}|\mathrm{data})\pi(\vec{p})$$

likelihood

polynomial

$$f_i(x) = n_i x^{\alpha_i}(1-x)^{\beta_i} P(x)$$

$$\vec{p} = (n_i, \alpha_i, \beta_i, \ldots)$$



$$\mathcal{L}(\vec{p}|\mathrm{data}) = \exp\left(-\frac{1}{2}\chi^2(\vec{p}|\mathrm{data})\right)$$

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

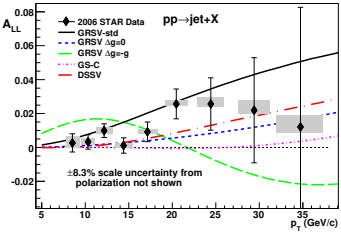
Data included

- RHIC measures double longitudinal spin 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

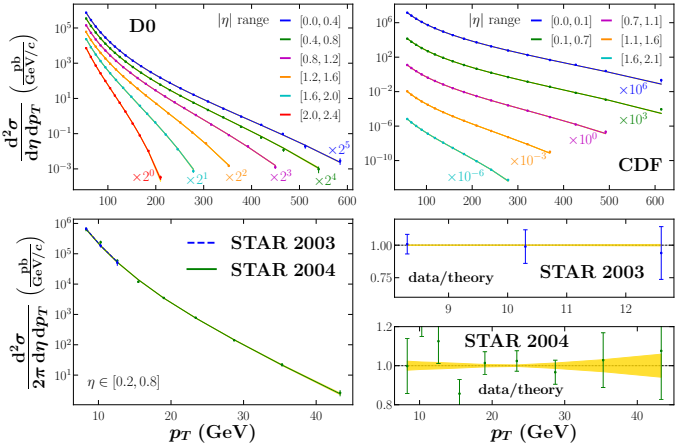
- We also include unpolarized DIS, Drell-Yan, and polarized inclusive DIS (total of **3576** points).



PRD **86**, 032006 (2012)

Fits to jet in unpolarized collisions

Good agreement between theory and Tevatron data

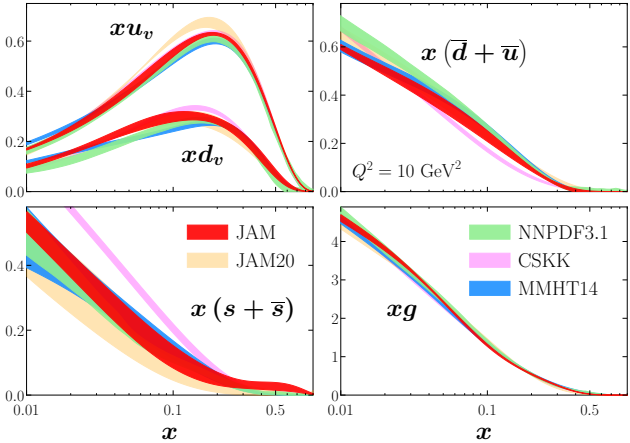


First inclusion of unpolarized RHIC jets!

PRD **105**, 074022 (2022)

Unpolarized PDFs

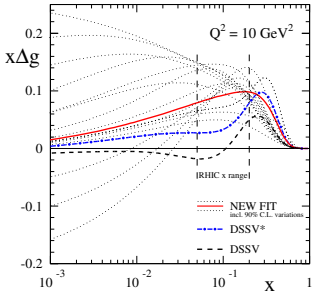
Differences are caused by choices of datasets.



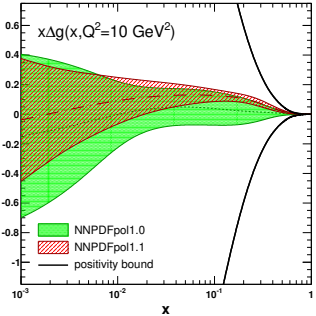
An overall good agreement is found.

PRD **105**, 074022 (2022)

Previous extractions of Δf



PRL **113**, 012001 (2014)



Nucl.Phys.B **887** (2014) 276

Extracted with SU(3) flavor symmetry and positivity constraints

Theory assumptions

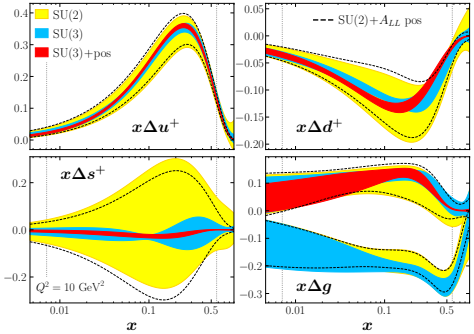
1. **SU(2)** flavor symmetry only
2. **SU(2)** and **SU(3)**
3. **SU(2)** and **SU(3)**, and **PDF positivity**

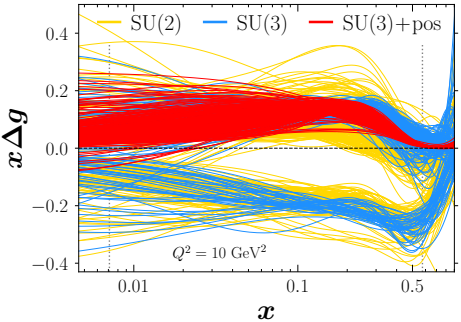
more constraints

more biases

less data driven

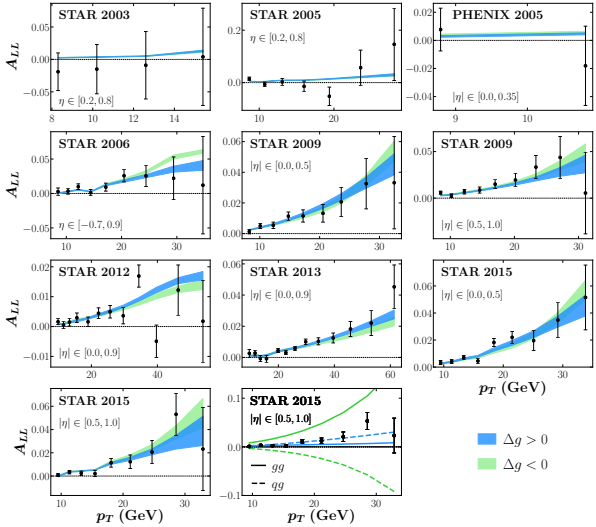
Extracted polarized PDFs





$$\Delta q^+ = \Delta q + \Delta\overline{q},\ q = u, d, s$$

Fits to jet A_{LL}

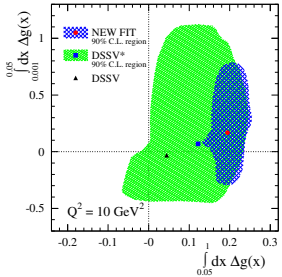


Good agreement with data for $\Delta g > 0$ and $\Delta g < 0$

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

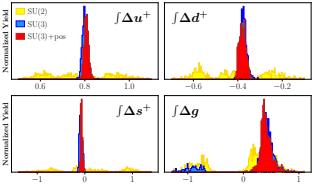
First moments - $\Delta G = \int_{0.05}^{1} \Delta g \, \mathrm{d}x$

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



PRL **113**, 012001 (2014)

- **SU(2)**:
  - $\Delta g > 0$: 0.20 ± 0.13
  - $\Delta g < 0$: -0.56 ± 0.12
- **SU(3)**:
  - $\Delta g > 0$: 0.27 ± 0.03
  - $\Delta g < 0$: -0.61 ± 0.04
- **SU(3) + pos**: 0.25 ± 0.03
- **DSSV14**: 0.2 ± 0.05

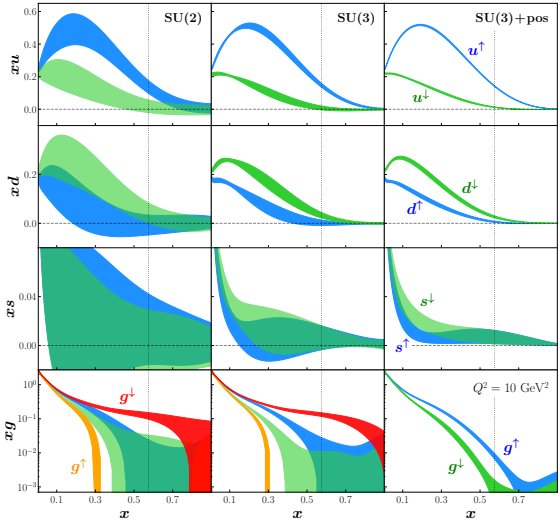


PRD **105**, 074022 (2022)

Helicity basis PDFs

$u^{\uparrow/\downarrow}$ and $d^{\uparrow/\downarrow}$ are well separated

$s^{\uparrow/\downarrow}$ can be hardly distinguished

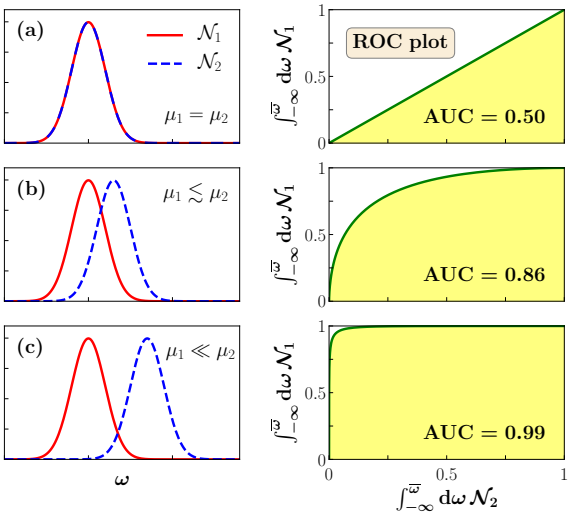


First simultaneous extraction of $f^\uparrow$ and $f^\downarrow$!

$g^{\uparrow/\downarrow}$ for $\Delta g > 0$ (blue and green) and $\Delta g < 0$ (orange and red)

ROC and AUC

- indistinguishable
- somewhat distinguishable
- clearly distinguishable

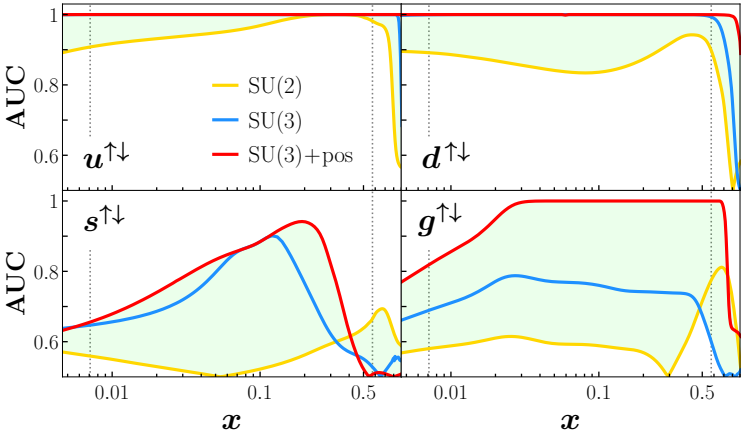


ROC: *receiver operating characteristic curve*

AUC: *area under curve of ROC*

AUC for helicity PDFs

- 0.5: can barely discriminate $f^{\uparrow}$ and $f^{\downarrow}$
- 1.0: can clearly discriminate $f^{\uparrow}$ and $f^{\downarrow}$



Currently working on...

- polarized SIDIS with large q_T: linear dependence on Δg at LO
- di-jets: also sensivite Δg at LO
- $\pi^{\pm}$ and $K^{\pm}$ production in pp collisions

Collaboration

In collaboration with Nobuo Sato and Wally Melnitchouk in Jefferson Lab.

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