Constraining gluon momentum and spin distributions from jet observables

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November 2, 2020

Outline

- motivation
- challenges
- results

Exploring the structure of the nucleon

We (Jefferson Lab Angular Momentum Collaboration, i.e. JAM) aim to better understand

- the three-dimensional structure of the nucleon
- nonperturbative QCD ("soft" partonic physics)
- parton distribution functions (PDFs)

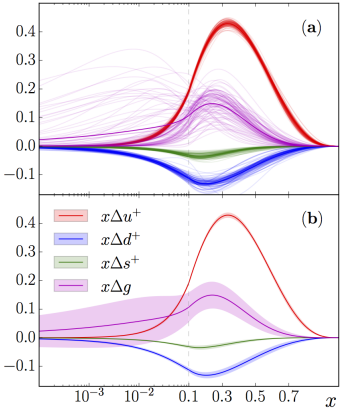
Proton spin decomposition

- Polarized jet data helps to understand proton spin decomposition ($Q^2 = m_c^2$)

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g, \quad \Delta\Sigma \approx 0.28$$

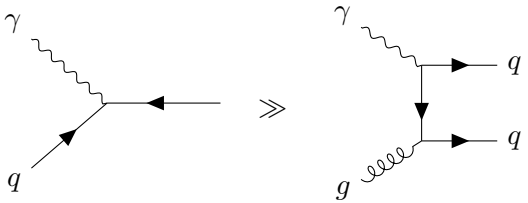
- Polarized DIS data is only sensitive to Δg via evolution and higher order effects.
- We need RHIC jet data that is sensitive to Δg.

[PRD **93**, 074005 (2016)]

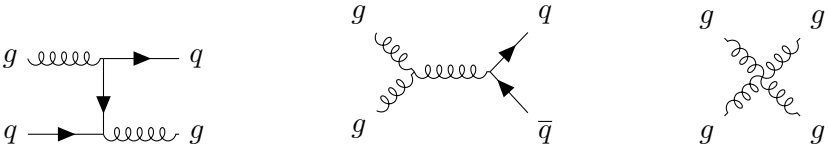


Sensitivity to gluon PDFs

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



On the other hand, in **jet production**, gluon diagrams appear at LO:



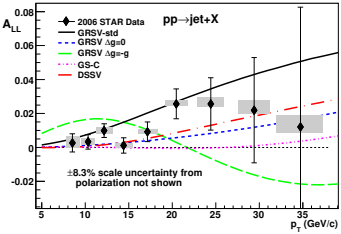
Polarized jet observables

- RHIC measures double longitudinal polarization asymmetry

[PRD **86**, 032006 (2012)]

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\Delta\sigma(\Delta g, \ldots)}{\overline{\sigma}(g, \ldots)}$$

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



- A_{LL} is sensitve to unpolarizd PDFs, **simultaneous** analysis is needed!

Bayesian posterior sampling

Here is how global analysis works, in a nutshell:

- parameterize PDFs at input scale Q_0

$$f_i(x, Q_0) = n_i x^{\alpha_i} (1-x)^{\beta_i} P(x)$$

where P is a polynomial or other function of x

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- parameterize PDFs at input scale Q_0
- evolve PDFs to experimental scale with DGLAP equations
- compute theoretical cross sections
- sample $\rho(\vec{p}|\text{data})$ to find the set that can best describe data

$$\rho(\vec{p}|\text{data}) \propto \mathcal{L}(\text{data}|\vec{p})\pi(\vec{p})$$

- $\pi(\vec{p})$ is prior belief on $\vec{p}$
- $\mathcal{L}(\text{data}|\vec{p})$ is likelihood of data given $\vec{p}$
- $\rho(\vec{p}|\text{data})$ is belief of $\vec{p}$ given data

Likelihood $\mathcal{L}$

The likelihood $\mathcal{L}(\text{data}|\vec{p})$ is

$$\mathcal{L}(\text{data}|\vec{p}) = e^{-\frac{1}{2}\chi^2(\text{data},\vec{p})} \tag{1}$$

and the basic definition of χ^2 is

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

where E is experimental value and T is predicted values, α is uncorrelated uncertainties and the sum is over data points.

Data resampling

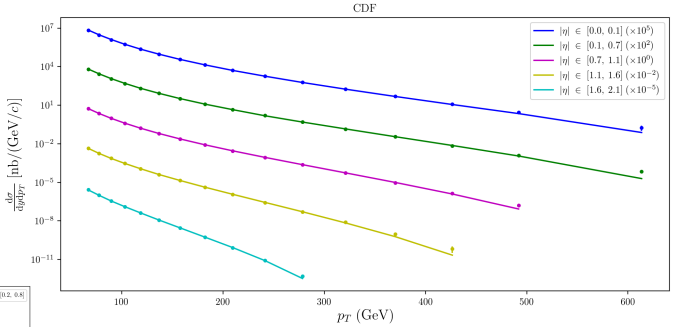
- We generate many resampled data sets $\widetilde{\sigma}_i$ with random numbers R_i and quadrature sum α_i of uncorrelated uncertainties

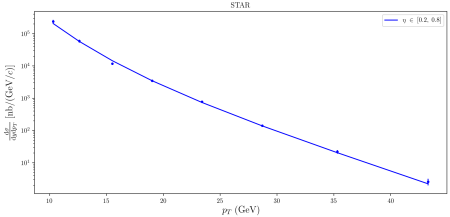
$$\widetilde{\sigma}_i = \sigma_i + R_i \alpha_i \tag{2}$$

- Monte Carlo sampling is used to avoid fits being trapped in local minima.
- Data are divided by experiment and included with multiple steps for fits to better converge.
- We currently include unpolarized data: DIS, Drell-Yan, jet production, and polarized data: inclusive DIS, jet production (total of **3822** data points).

Jet observables

first jet production in JAM

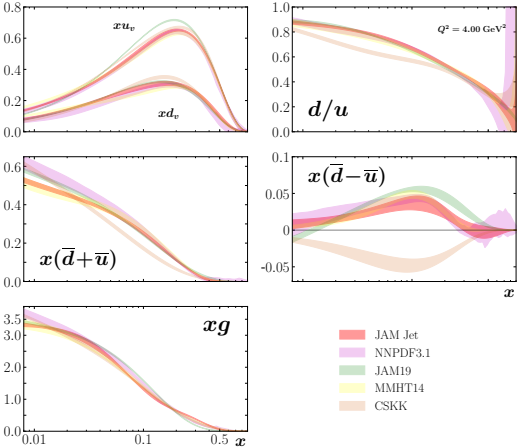




first inclusion of RHIC jet production ever

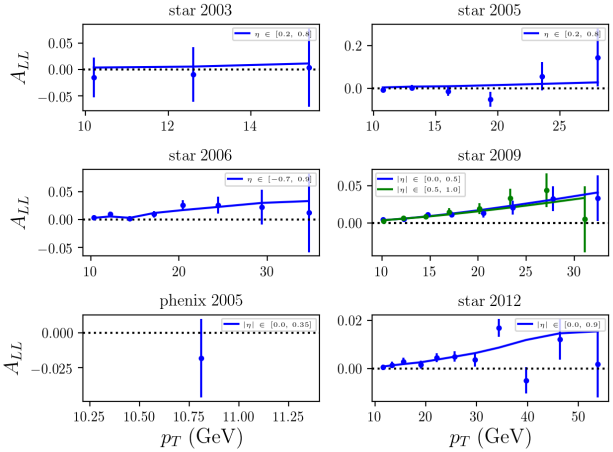
Preliminary unpolarized PDFs

- benchmark with other PDF groups
- χ^2 of 1.17 for 3126 data points



Polarized jet observables

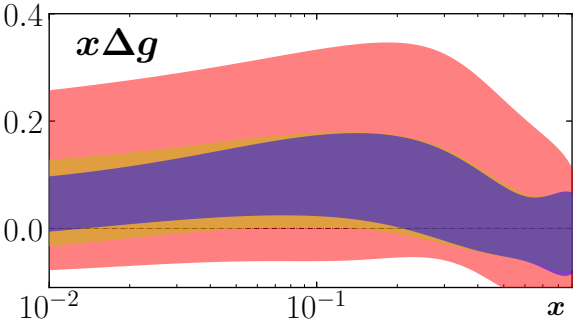
First polarized jet production included in JAM



Preliminary polarized PDFs

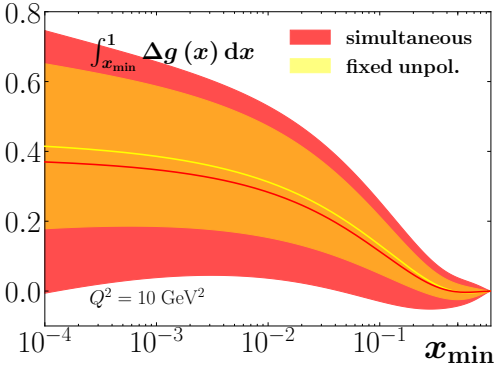
- polarized jet data can constrain Δg
- χ^2 of 1.14 for 3822 data points

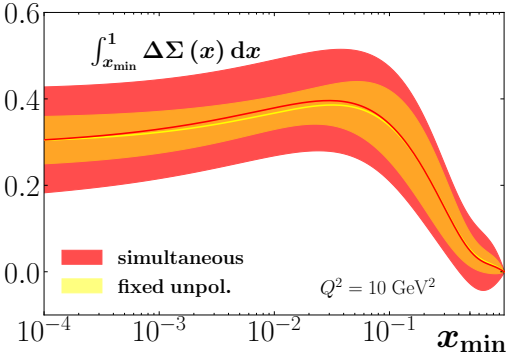
observables	distributions	$\int_{0.05}^{0.2} \Delta g \, \mathrm{d}x$
PDIS	PPDF	0.18 ± 0.26
+ PJET	PPDF	0.12 ± 0.11
+ unpol.	+ PDF	0.13 ± 0.09



Comparison with fixed unpolarized fits

Uncertainties of truncated moments from fixed unpolarized fits are largely **underestimated** (by as large as 60%)



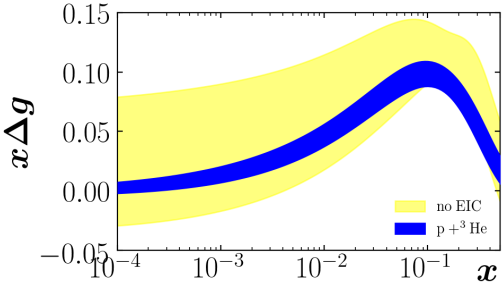


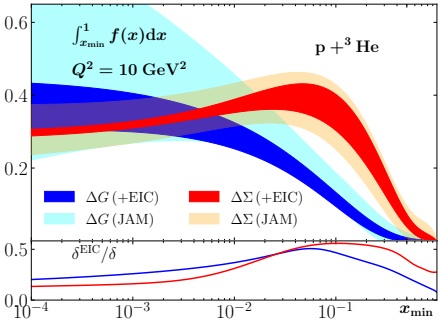
Summary

- We performed first global QCD analysis of unpolarized and polarized data from DIS and jets combined, simultaneously fitting spin-averaged and spin-dependent PDFs.
- Polarized jet data is needed to constrain Δg.
- Simultaneous analysis is necessary to avoid underestimation of uncertainties.

Outlook

- Future possibilities that EIC may offer (^{3}He: 10 fb^{-1}, $\sqrt{s} = 29, 66, 89$ GeV)





- We will also continue to analyze the difference between simultaneous fit and fixed unpolarized fit without polarized jet data.

Collaboration

The PDFs fitting project is in collaboration with Nobuo Sato, Wally Melnitchouk and Carlota Andrés in Jefferson Lab.