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Gluon helicity distributions

Yiyu Zhou, Nobuo Sato and Wally Melnitchouk

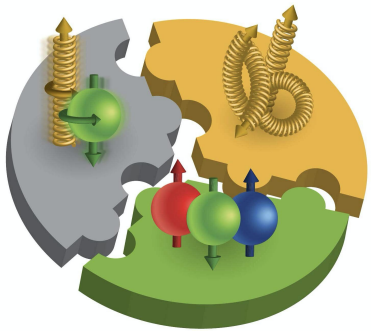
College of William & Mary
and Jefferson Lab

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: TMDs and GPDs



Global QCD analysis - Bayesian inference

Experiments = theory + errors

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

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

$$\mathrm{d}\sigma^{\mathrm{jets}} = \sum_{i,j} H_{ij}^{\mathrm{jets}} \otimes f_i \otimes f_j$$

Hadron Structure

posterior distribution

prior distribution

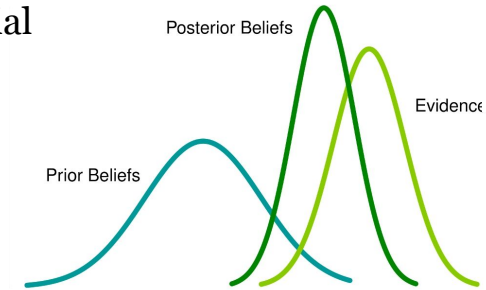
$$\rho\left(\boldsymbol{a}|\mathrm{data}\right) \sim \mathcal{L}\left(\boldsymbol{a}|\mathrm{data}\right)\pi\left(\boldsymbol{a}\right)$$

likelihood

polynomial

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

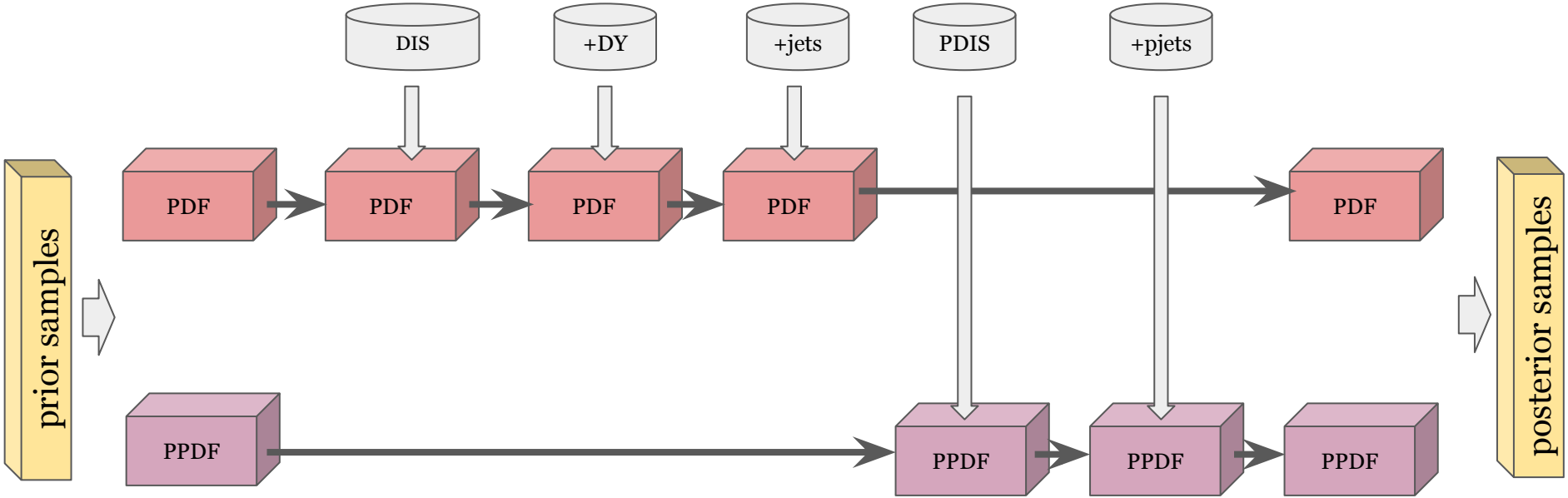
$$\boldsymbol{a} = \left(n_i, \alpha_i, \beta_i, \ldots\right)$$



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

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

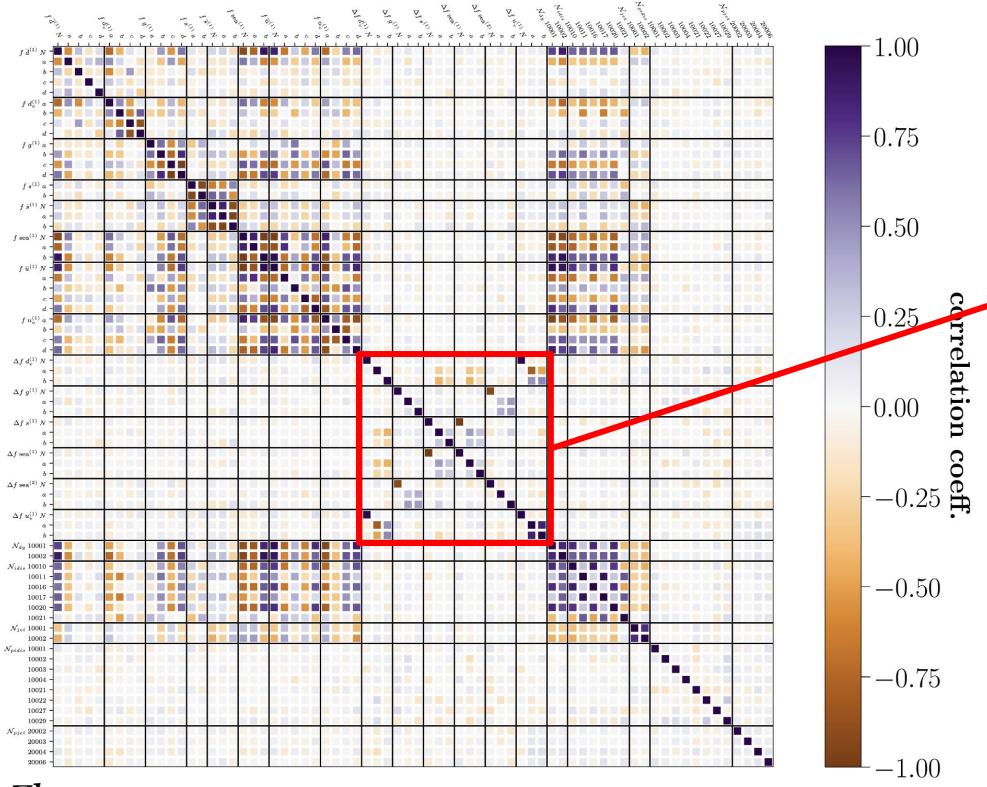
Multistep strategy



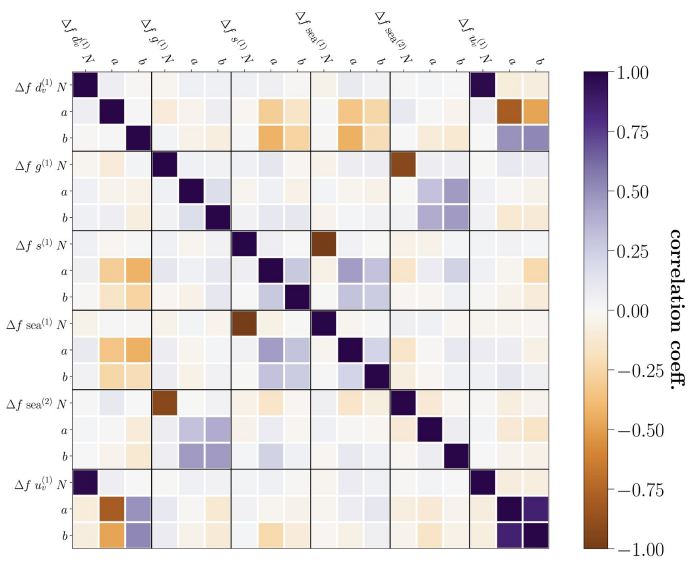
The challenge

- many data points
  - **3126** unpolarized data points
  - **428** polarized data points
- many parameters to fit
  - **30** parameters for unpolarized PDFs
  - **18** parameters for polarized PDFs
  - **24** normalization parameters
- thousands of χ^2 minimizations to sample a bayesian posterior distribution

Correlation of parameters



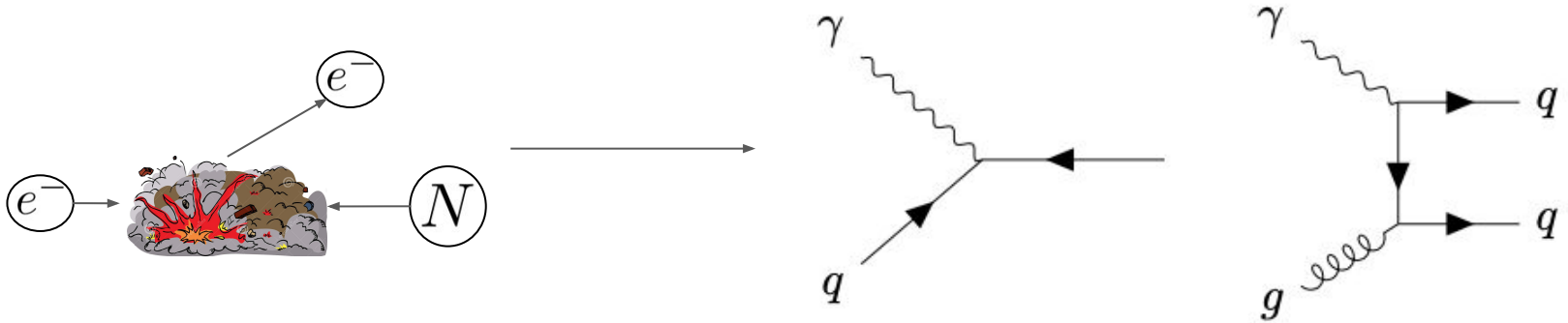
polarized PDFs



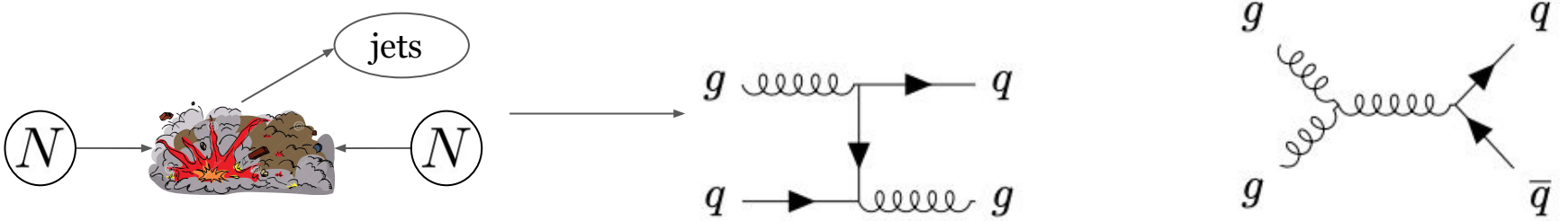
FAST NUMERICAL COMPUTATION NEEDED!

Jets as probes for gluons

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



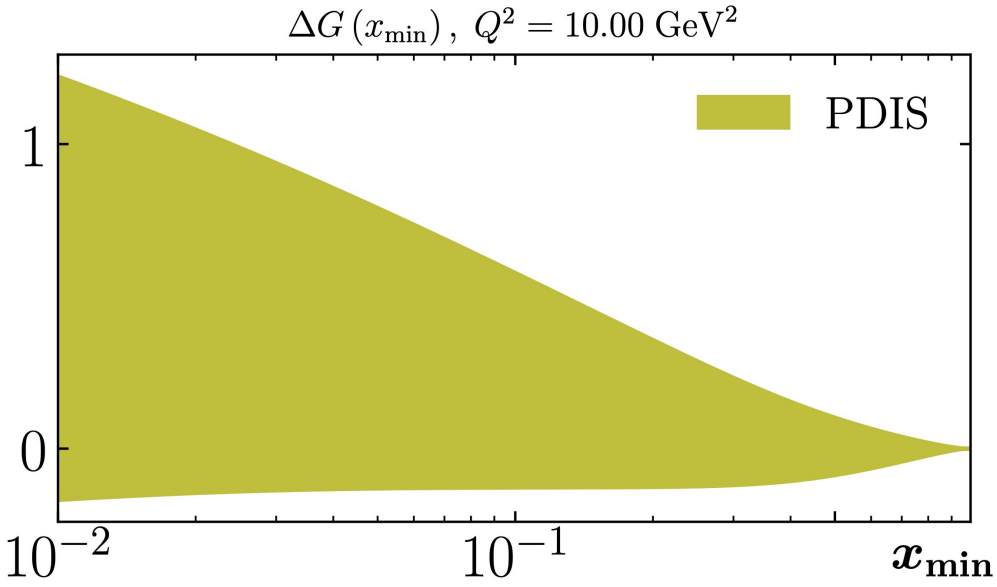
On the other hand, in jet production, gluon diagrams appear at its lowest order



Constraining gluon spin

- large uncertainty in truncated moment of polarized gluon

$$\Delta G\left(x_{\min}\right) = \int_{x_{\min}}^{1} \Delta g\left(x\right) \mathrm{d}x$$



JAM polarized DIS fit

Polarized jets

- RHIC measures double longitudinal spin asymmetry

$$A_{LL}^{\text{jets}} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\Delta\sigma\left(\Delta g, \ldots\right)}{\sigma\left(g, \ldots\right)}$$

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

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

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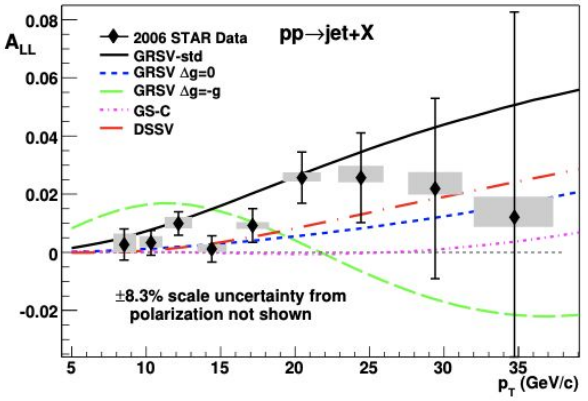
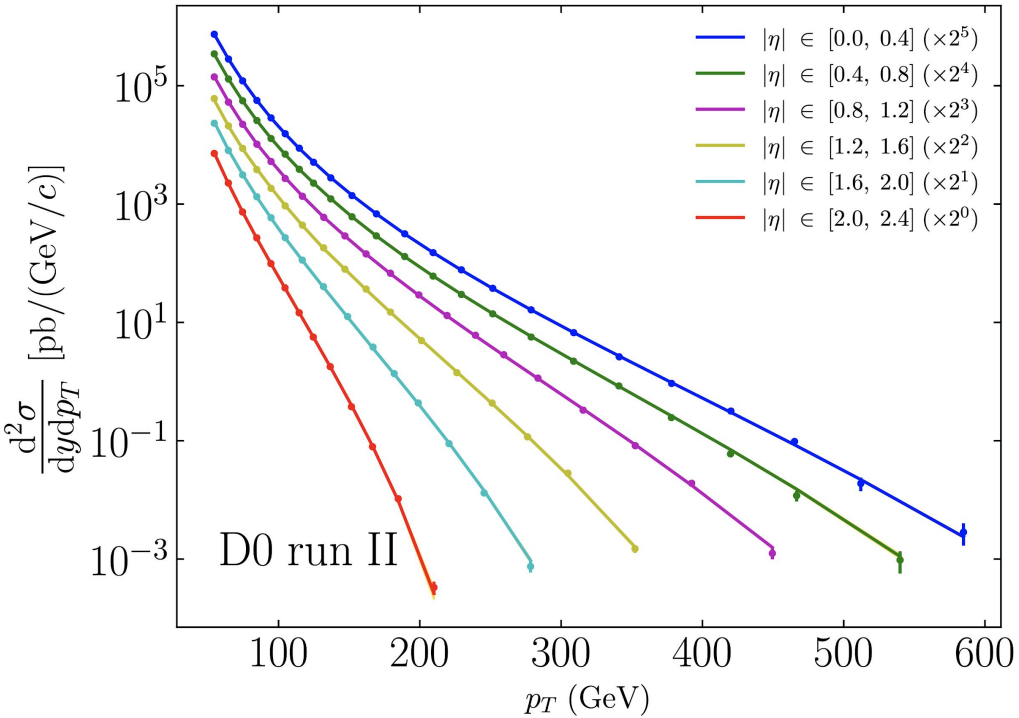
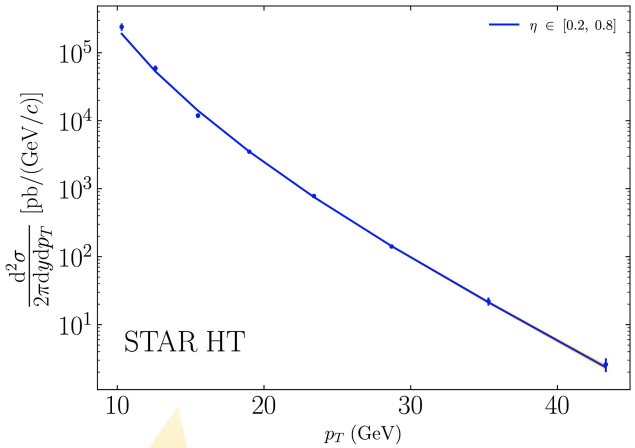


Unpolarized jets (including **RHIC** upolarized jets)



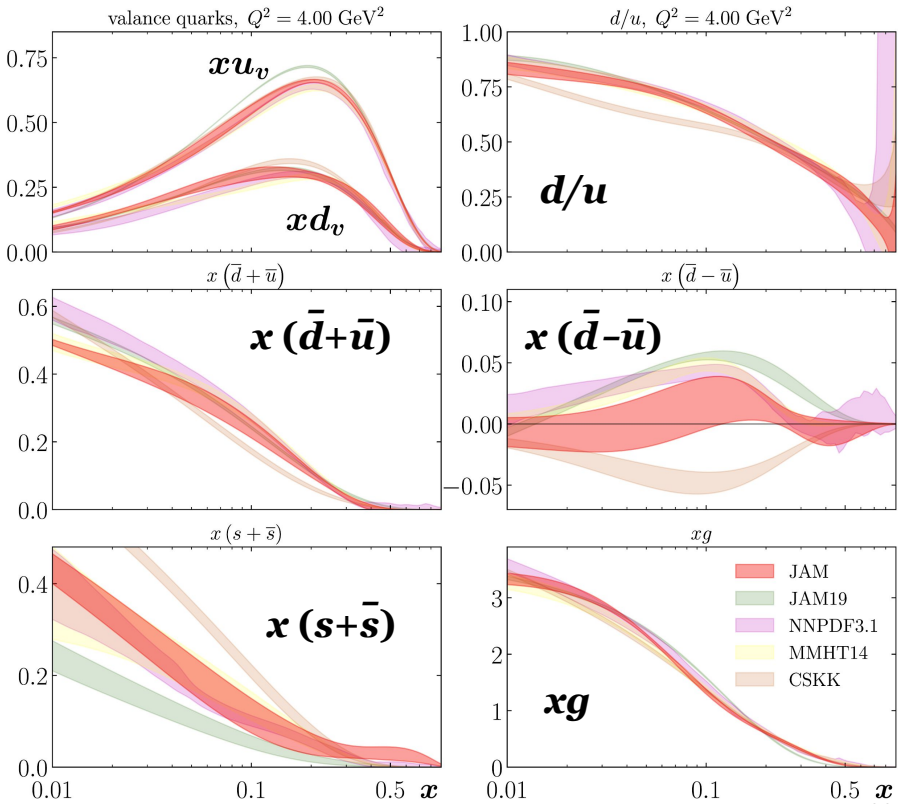


First inclusion of upolarized RHIC jets! ($\sqrt{S}$ = 200 GeV)

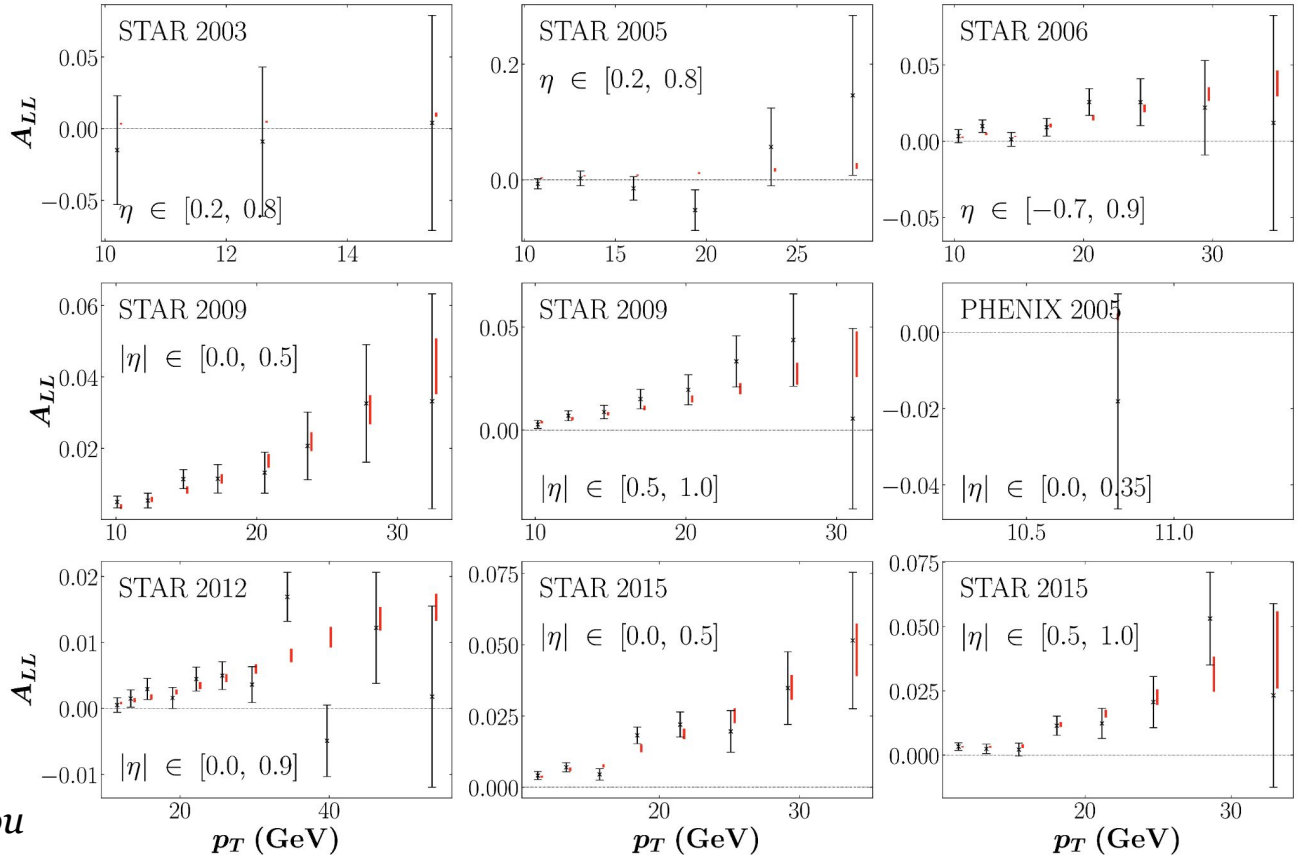
Unpolarized PDFs with jets

Unpolarized data are well fitted

- results generally in agreement with other groups
- DIS (fixed target and HERA), DY, jets (Tevatron + **RHIC**)



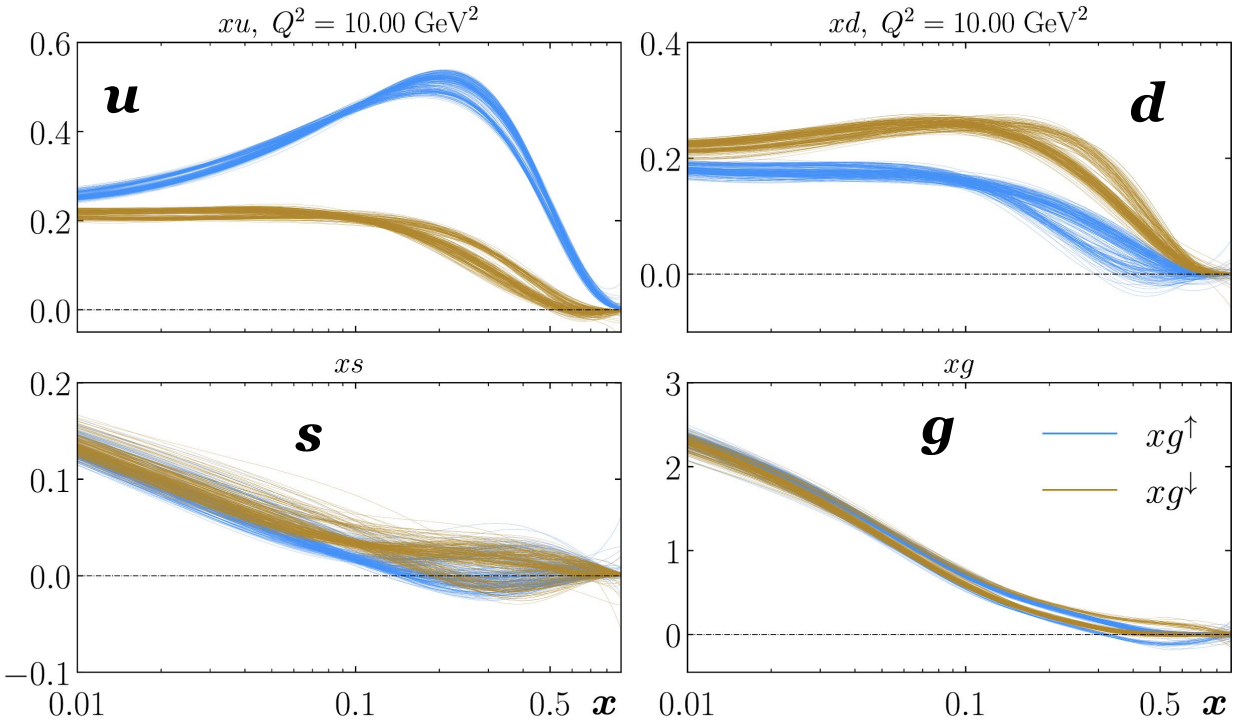
Jet asymmetry



$\chi^2 = 0.722$

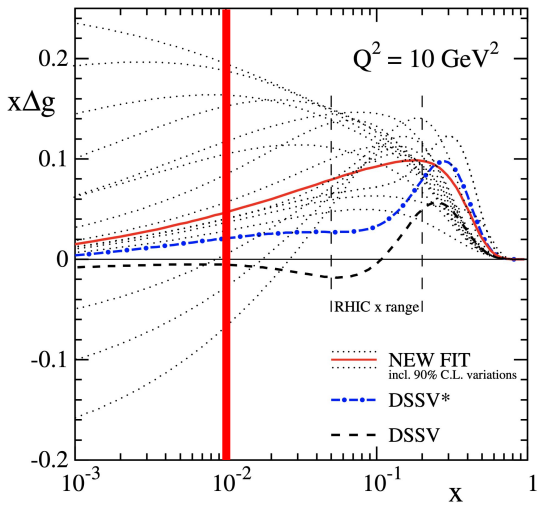
Helicity decomposition

- First simultaneous determination of individual helicity PDFs
- Consistent treatment of uncertainties!



Compare with DSSV

DSSV 14: positive helicity gluon



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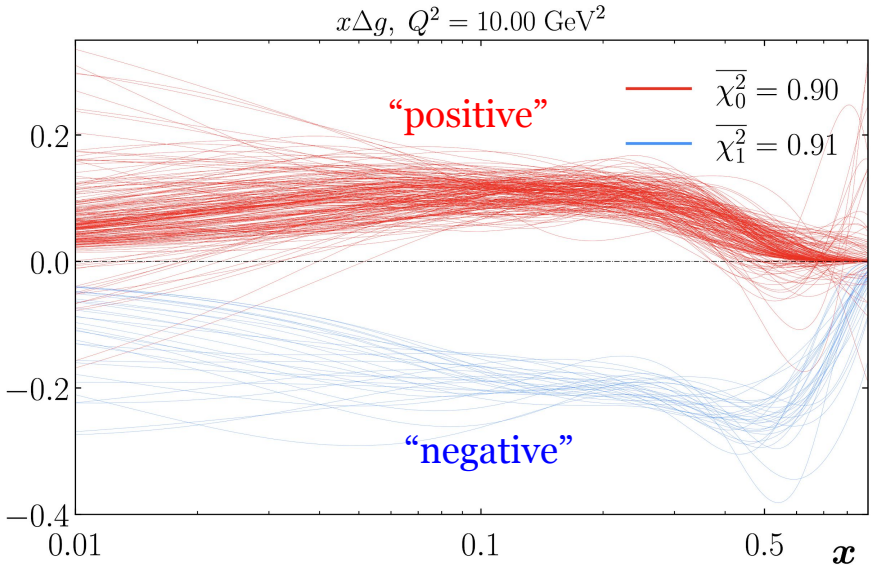
JAM: positive and negative helicity gluons



Theory assumptions

SU(2) only

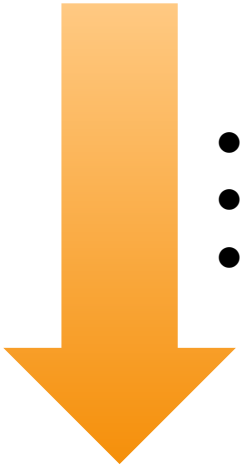
↓

SU(2) and SU(3)

↓

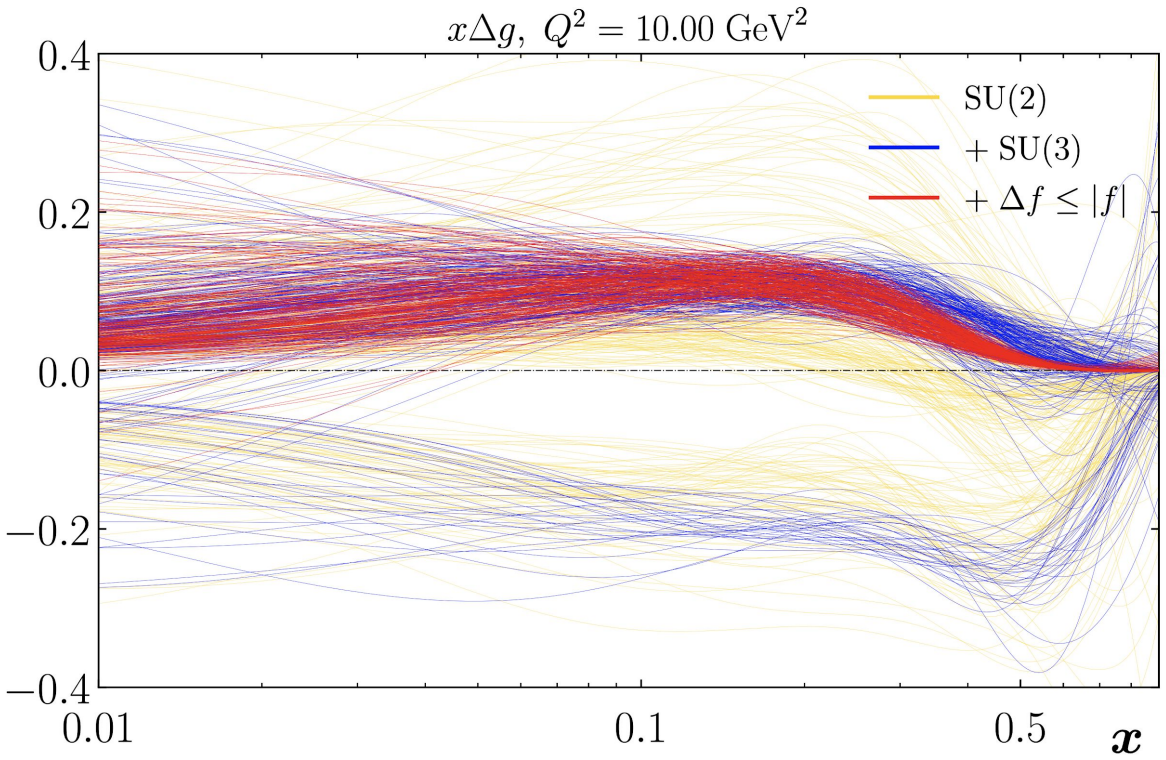
SU(2) and SU(3), and PDF positivity

→ $|\Delta f_i(x)| \leqslant |f_i(x)|$



- more constraint
- more bias
- less data driven

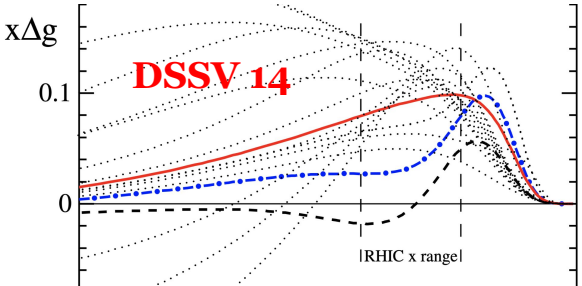
Theory assumptions



$$\int_{0.05}^{1} \Delta g\left(x, Q^2 = 10\ \mathrm{GeV}^2\right) \mathrm{d}x$$

- SU(2): 0.04 ± 0.33
  - positive: 0.2 ± 0.18
  - negative: -0.48 ± 0.13
- + SU(3): 0.13 ± 0.26
  - positive: 0.23 ± 0.04
  - negative: -0.56 ± 0.04
- + positivity: 0.21 ± 0.03

- DSSV 14: 0.2 ± 0.05



Conclusion

- Unpolarized jet data (Tevatron and RHIC) is well fitted.
- Polarized jet data can constrain gluon helicity.
- Gluon helicity PDFs depend largely on theory assumptions, SU(2/3) and positivity constraints.

Future

- Include SIDIS for a consistent extraction of Δs.
- AI may help improving the speed.
- Looking forward to EIC measurements.

Nobuo Sato

Wally Melnitchouk

Thank you!

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