Gluon helicity distributions

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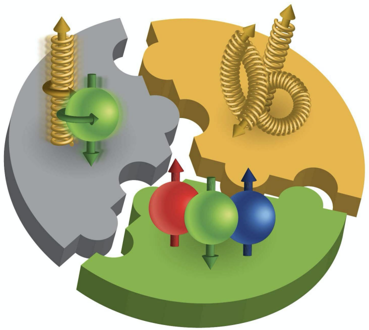
Proton spin puzzle

- 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

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

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

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

Hadron Structure

posterior belief

prior belief

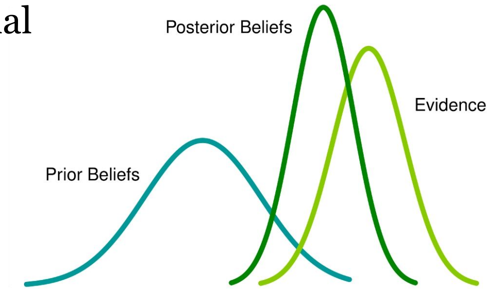
$$\rho\left(\boldsymbol{a}|\mathrm{data}\right) \sim \mathcal{L}\left(\boldsymbol{a}|\mathrm{data}\right)\pi\left(\boldsymbol{a}\right)$$

likelihood

polynomial

$$f_i\left(x\right) = a_0 x^{a_1}\left(1-x\right)^{a_2} P\left(x\right)$$

$$\boldsymbol{a} = \left(a_0, a_1, a_2, \ldots\right)$$

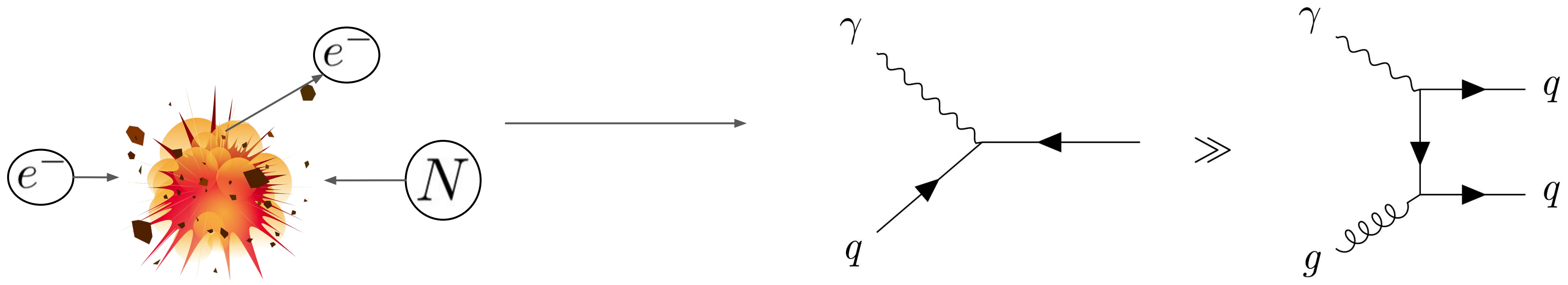


$$\mathcal{L}(\boldsymbol{a}, \mathrm{data}) = \exp\left[-\frac{1}{2}\chi^2(\boldsymbol{a}, \mathrm{data})\right]$$

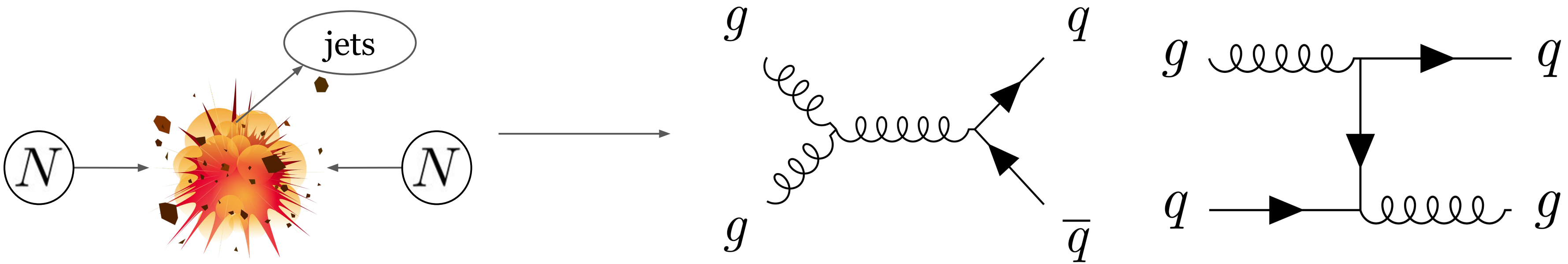
$$\chi^2 = \sum_i \frac{1}{\alpha_i^2}(E_i - T_i)^2$$

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



Jets in polarized collisions

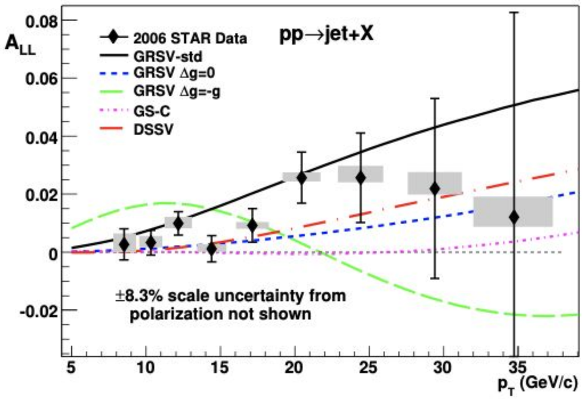
- RHIC measures double longitudinal spin asymmetry

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

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

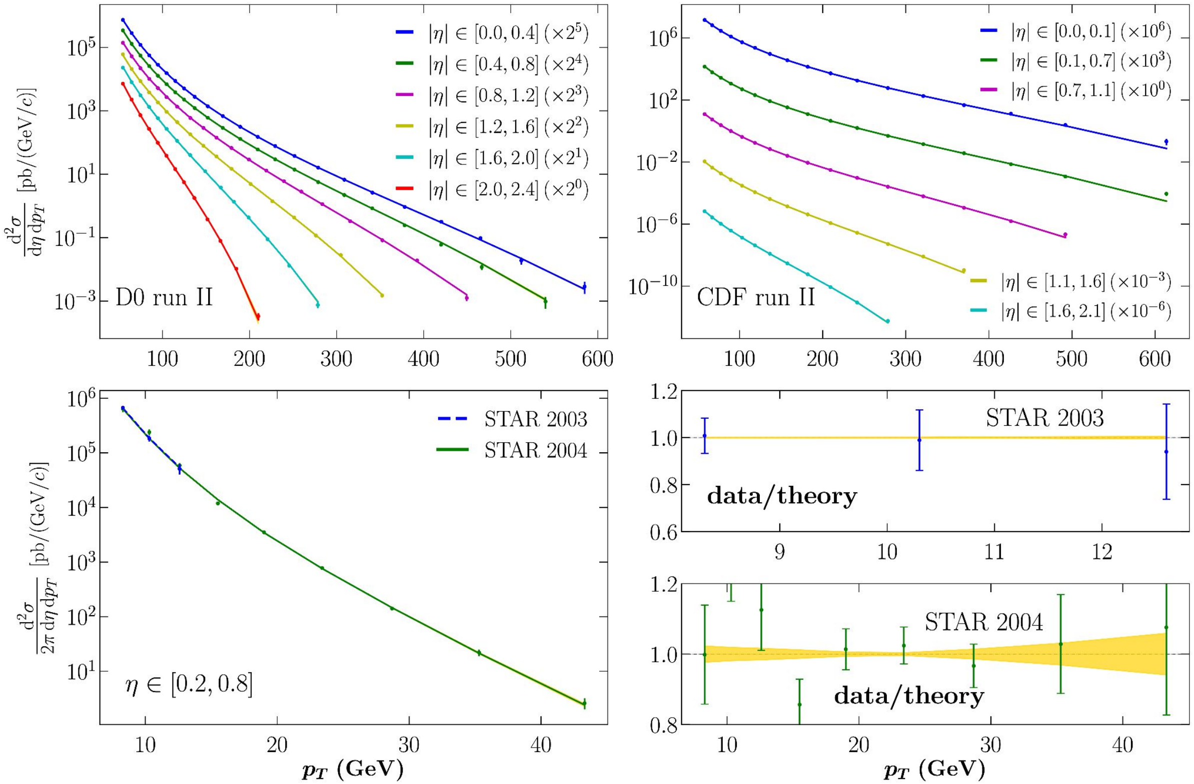
- A_{LL}^{jets} is sensitive to unpolarizd PDFs $\rightarrow$ perform **simultaneous** analysis to check

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



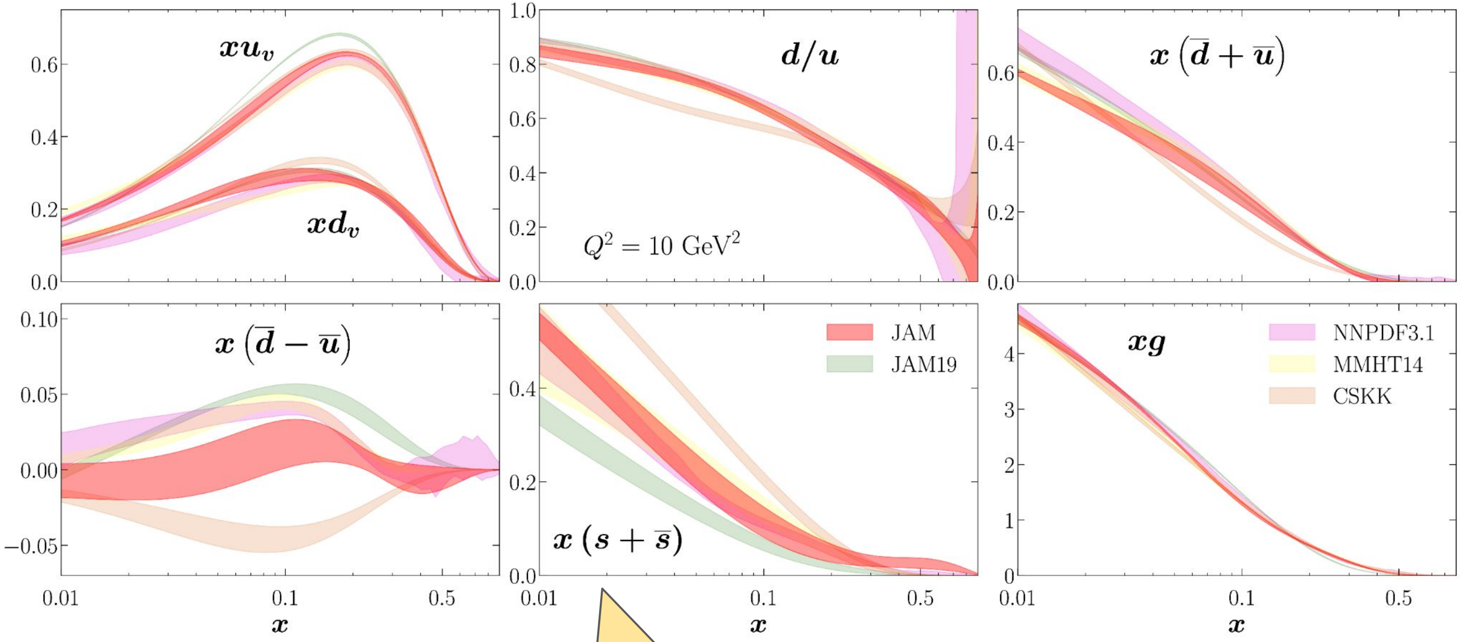
Jets in unpolarized collisions

Good agreement between theory and Tevatron data



First inclusion of unpolarized RHIC jets!

Unpolarized PDFs



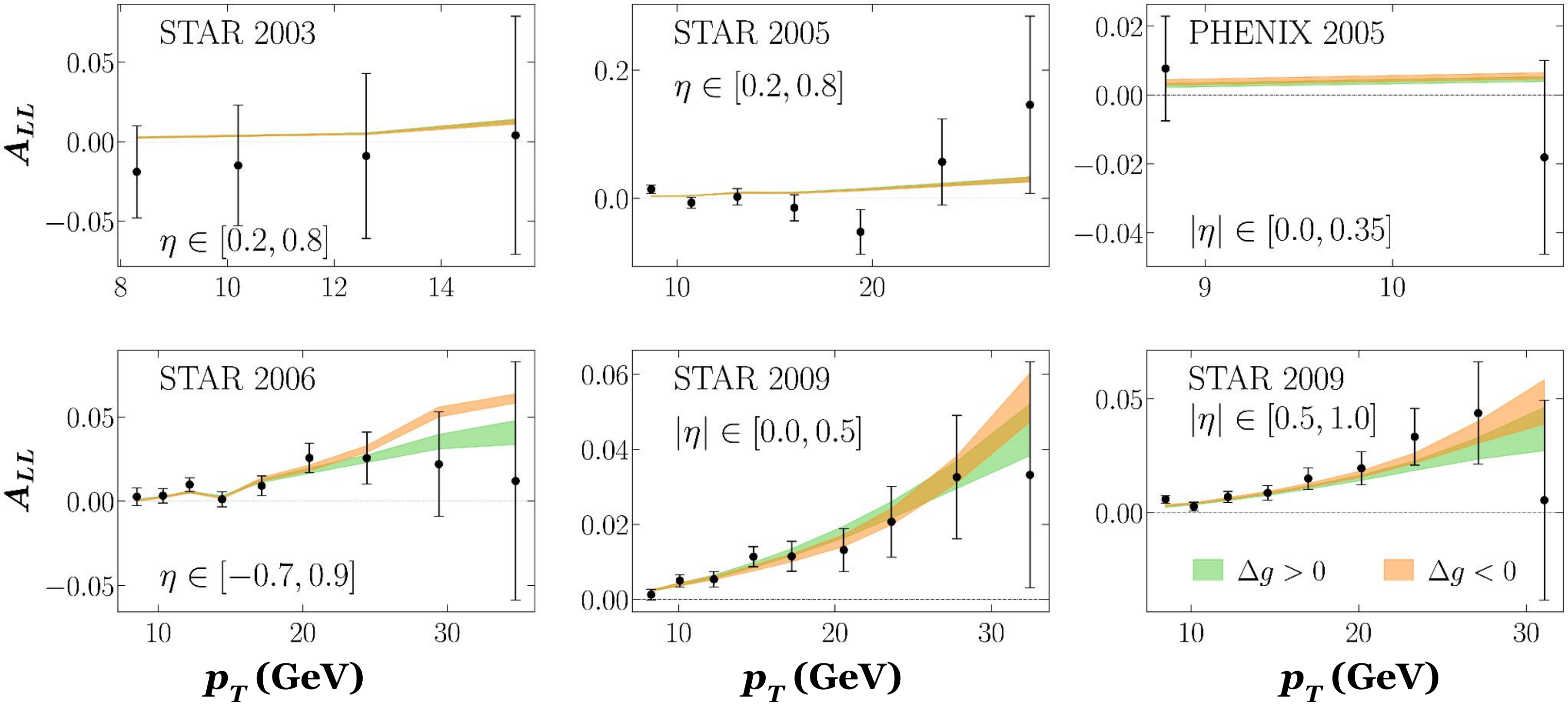
An overall good agreement is found.

Differences are caused by choices of datasets.

Gluon helicity - jet A_{LL}

$$A_{LL}^{\text{jets}} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

PRELIMINARY

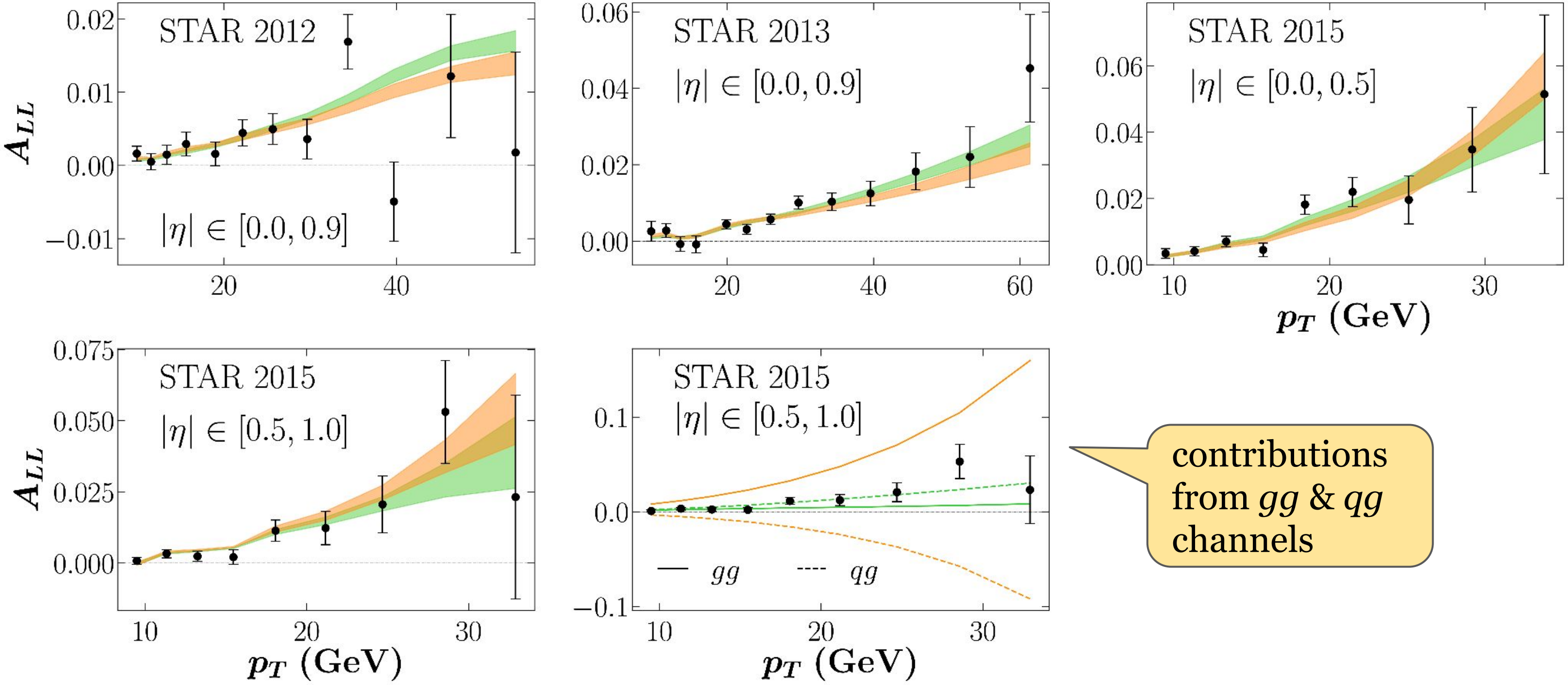


positive
negative

Gluon helicity - jet A_{LL}

$$A_{LL}^{\text{jets}} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

PRELIMINARY

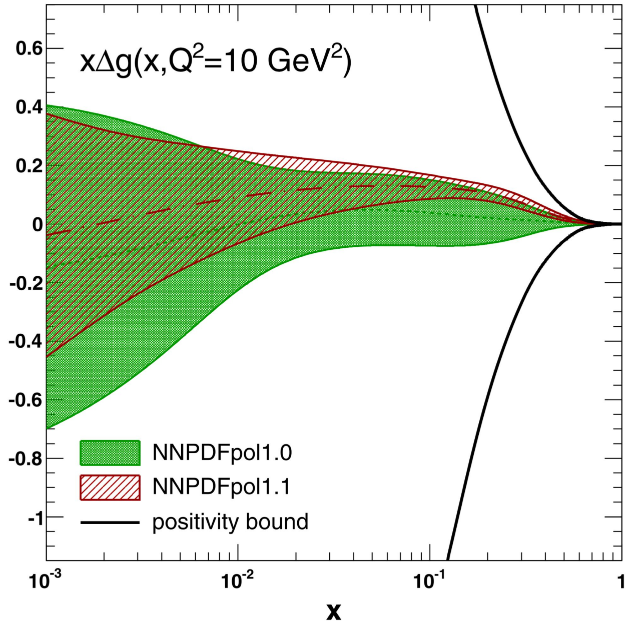


positive
negative

contributions from gg & qg channels

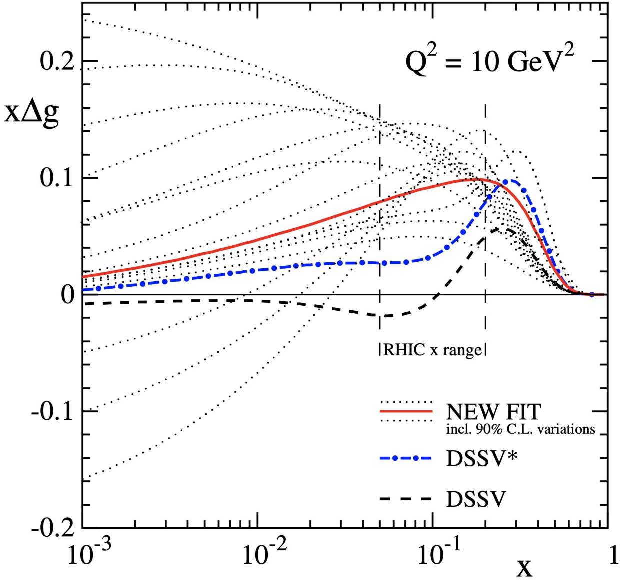
Polarized PDFs - **theory assumptions**

NNPDF pol 1.1



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

DSSV14



[PRL **113**, 012001 (2014)]

- SU(3) flavor symmetry
- positivity constraints

Theory assumptions

SU(2)* only

↓

SU(2)* and SU(3)*

↓

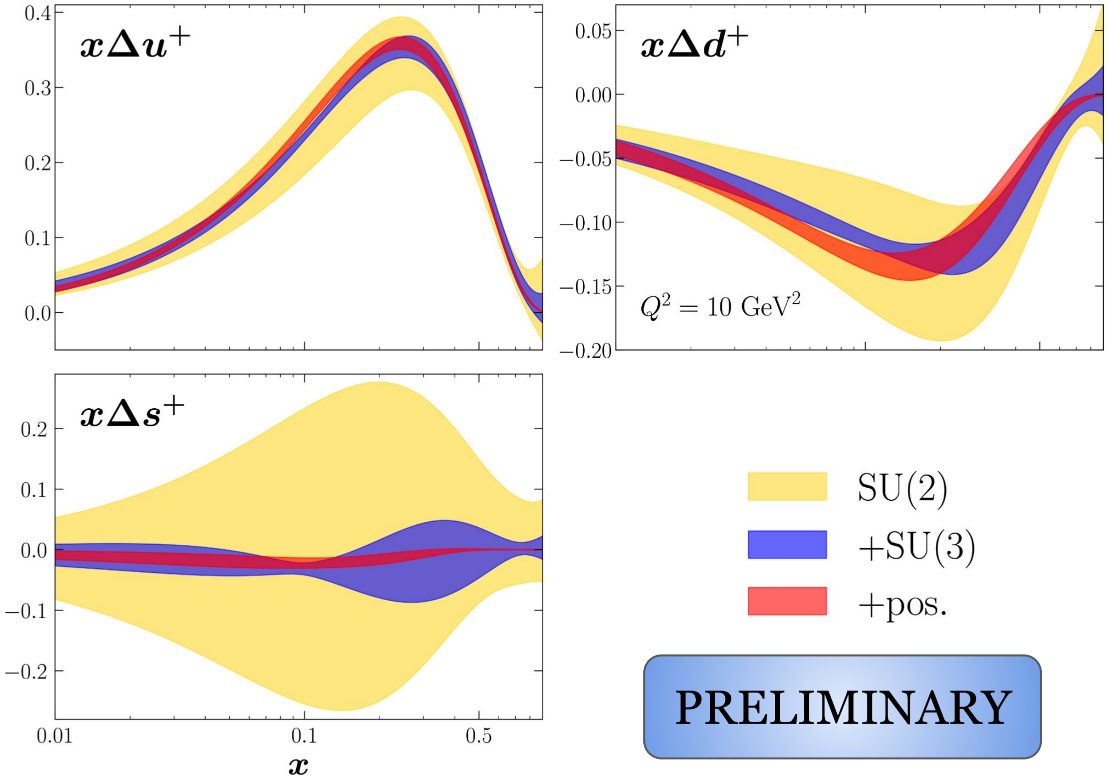
SU(2) and SU(3), and PDF positivity

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

- more constraint
- more bias
- less data driven

*flavor symmetry

Helicity quark PDFs

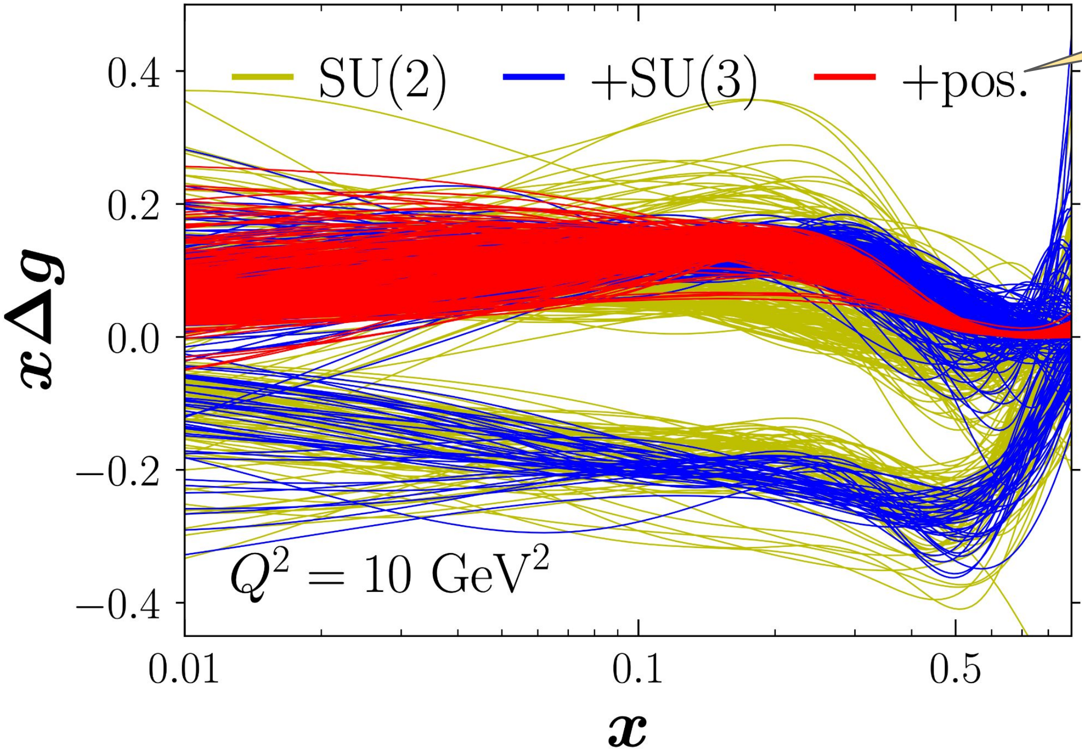


- SU(3) flavor symmetry reduces significantly the uncertainties on Δu, Δd and Δs
- positivity constraints again greatly reduce the uncertainty on Δs

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

Gluon helicity

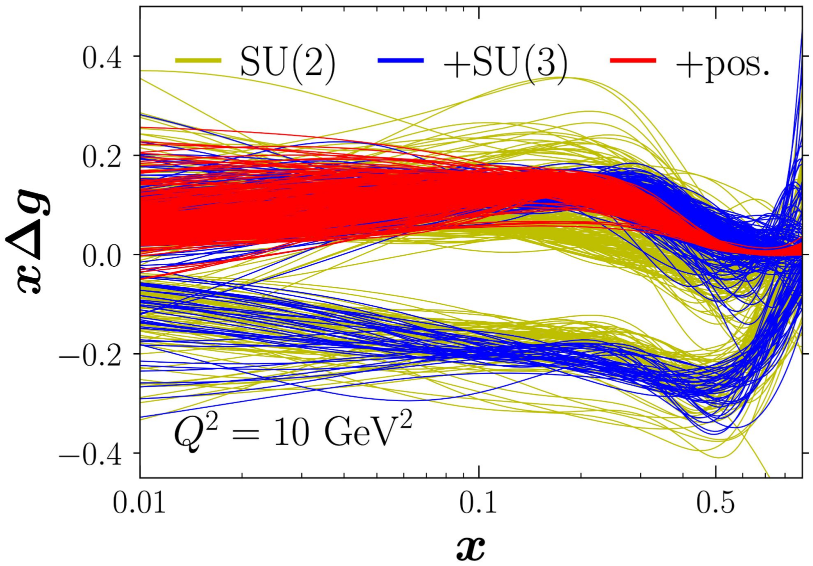
PRELIMINARY



DSSV and NNPDF do this

- Δg is observed to have two distinct solutions
- SU(3) flavor symmetry reduces the uncertainty slightly
- positivity constraints eliminate the "negative" solution from Δg

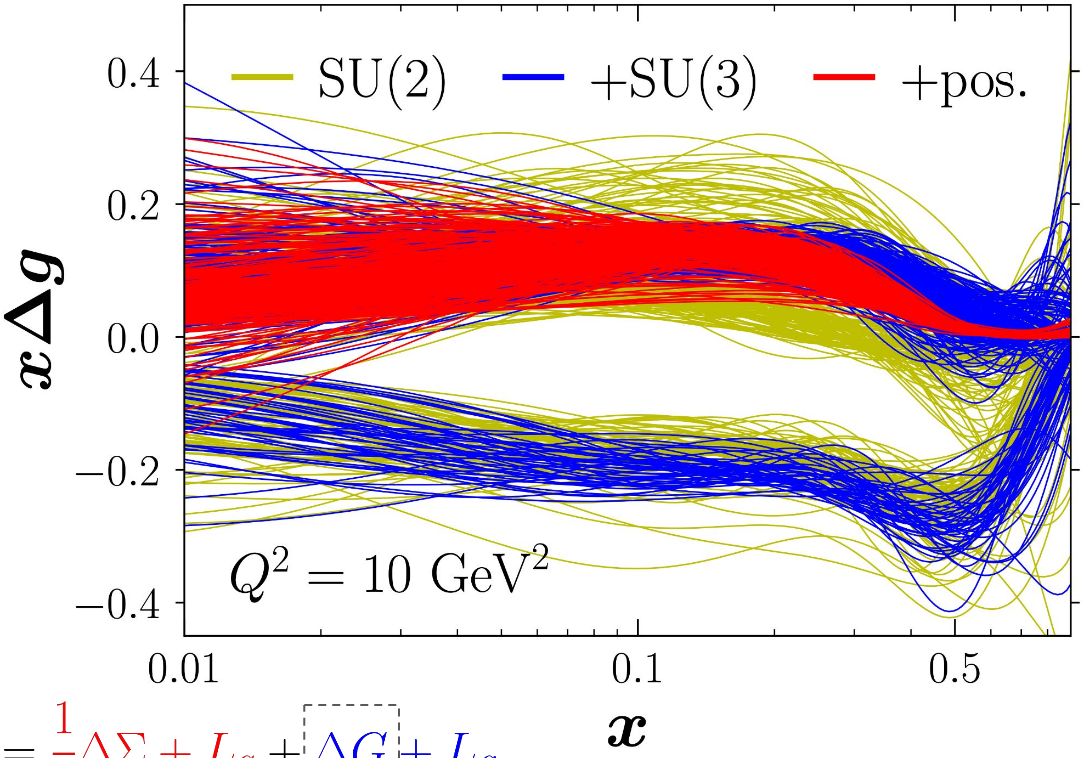
Gluon helicity - χ^2



col.	year	positive	negative
STAR	2003	0.22	0.22
STAR	2005	1.51	1.45
STAR	2006	0.31	0.43
STAR	2009	0.56	0.47
STAR	2012	1.60	1.41
STAR	2013	0.70	0.93
STAR	2015	0.75	0.92
PHENIX	2005	0.38	0.39

Both Δg solutions can describe the data equally well!

Gluon truncated moment ΔG

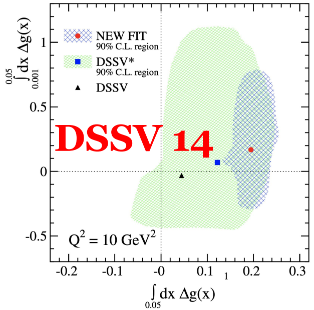


$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta G + L_g$$

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

- SU(2): -0.02 ± 0.39
  - positive: 0.21 ± 0.15
  - negative: -0.57 ± 0.12
- + SU(3): 0.12 ± 0.32
  - positive: 0.26 ± 0.03
  - negative: -0.60 ± 0.03
- + positivity: 0.24 ± 0.03

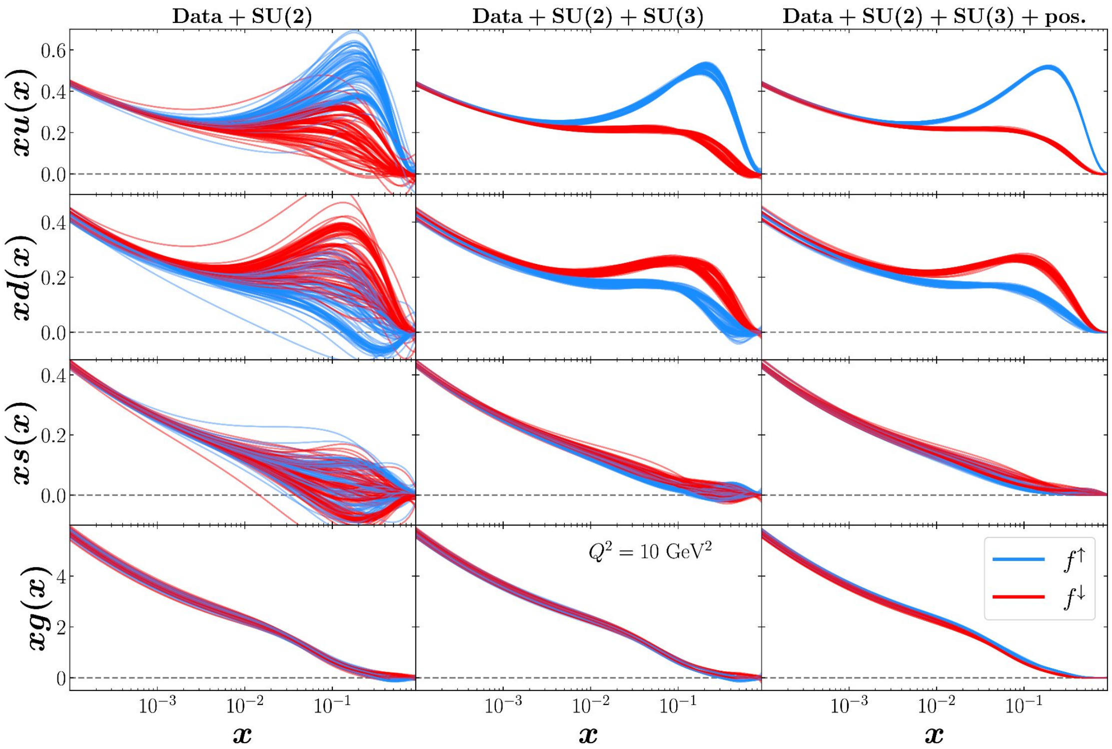
- DSSV 14: 0.2 ± 0.05



Simultaneous extraction of $f^{\uparrow}$ and $f^{\downarrow}$

PRELIMINARY

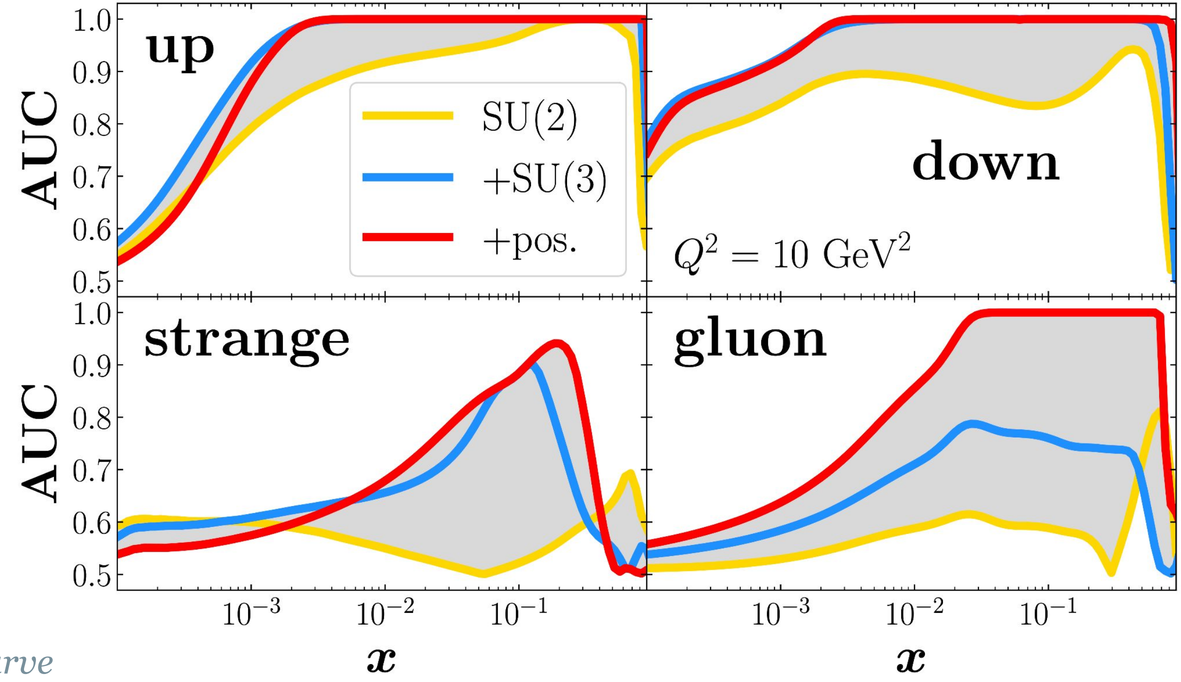
$$f^{\uparrow/\downarrow} = (f \pm \Delta f)/2$$



[Y. Zhou *et al.* (2021)]

Simultaneous extraction of $f^{\uparrow}$ and $f^{\downarrow}$

PRELIMINARY



0.5: can **barely** discriminate $f^{\downarrow}$ and $f^{\downarrow}$

1.0: can **clearly** discriminate $f^{\downarrow}$ and $f^{\downarrow}$

AUC: *area under curve of ROC*

ROC: *receiver operating characteristic curve*

[Y. Zhou *et al.* (2021)]

Conclusion

- Jet data in unpolarized and polarized collisions are well fitted.
- Jet A_{LL} can be described equally well with $\Delta g \gtrsim 0$ and $\Delta g \lesssim 0$.
- Helicity strange and gluon distributions are strongly biased by theory inputs.

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Thank you!

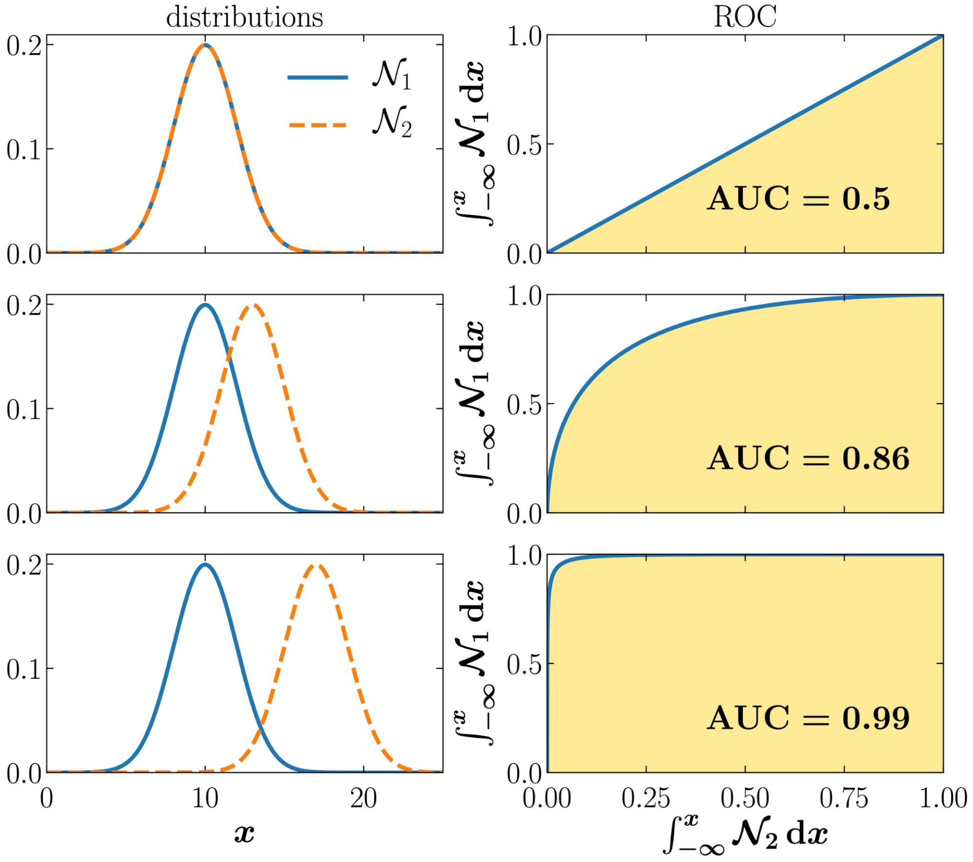
Thank Christopher Cocuzza, Patrick Barry and Carlota Andres for helpful discussions

Outlook

- Include SIDIS, W production data in polarized collisions
    - complete flavor separation of spin-dependent PDFs
- Polarized SIDIS with large transverse momentum of produced hadron
    - polarized gluon distributions
    - sensitivity at leading order
- Extend JAM to 3D
    - TMDs extraction from SIDIS and other data

ROC/AUC

- indistinguishable
- somewhat distinguishable
- clearly distinguishable



ROC: *receiver operating characteristic curve*

AUC: *area under curve of ROC*