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Gluon helicity distributions

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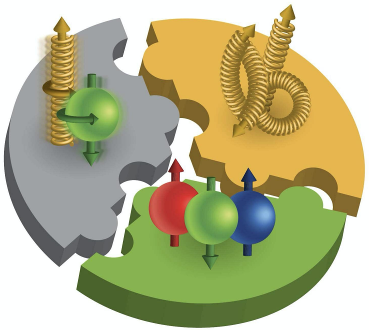
Proton spin puzzle

- What is the decomposition of the proton spin?

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

  - 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

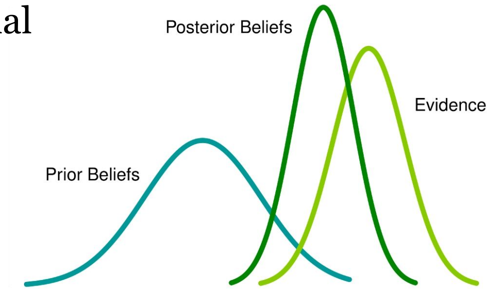
$$\rho\left(\boldsymbol{a}|\mathrm{data}\right) \sim \mathcal{L}\left(\boldsymbol{a}|\mathrm{data}\right) \pi\left(\boldsymbol{a}\right)$$

likelihood

polynomial

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

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

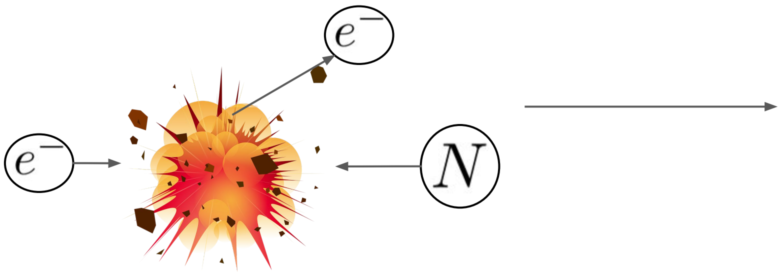


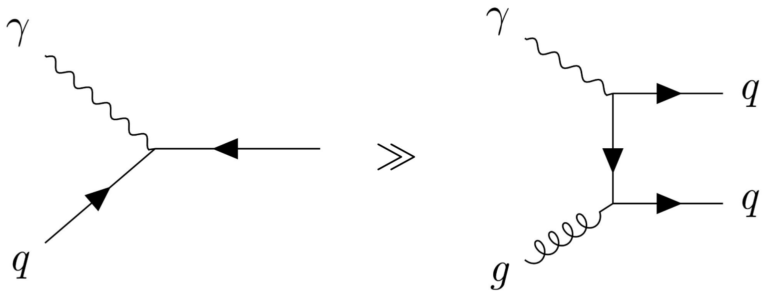
$$\mathcal{L}(\boldsymbol{a}, \mathrm{data}) = \exp\left[-\frac{1}{2}\chi^2(\boldsymbol{a}, \mathrm{data})\right]$$

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

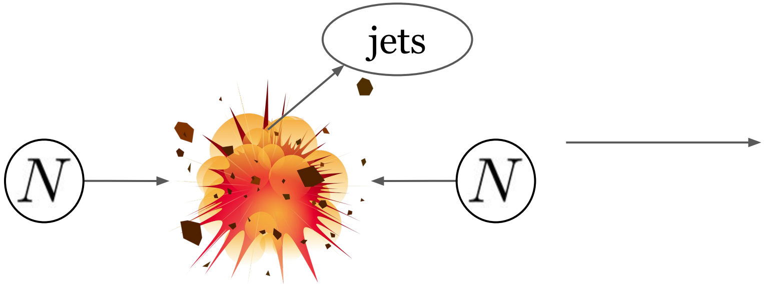
Jets as probes of hadron structure

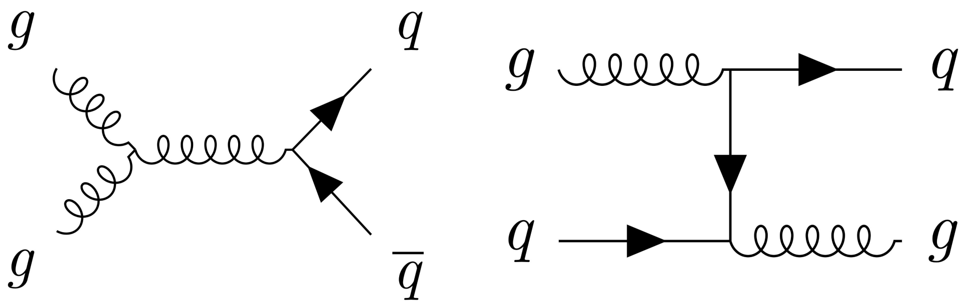
In inclusive DIS, sensitivity to gluon PDF only appears at NLO





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





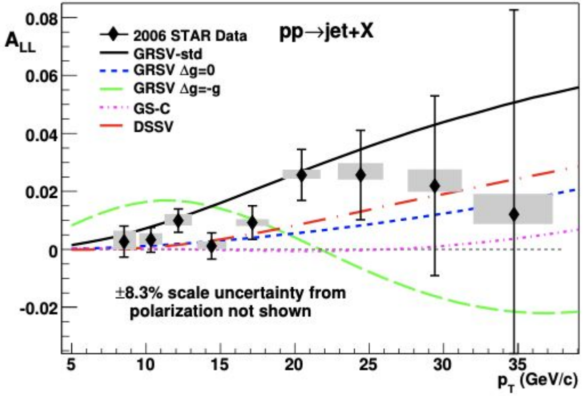
Polarized jets

- RHIC measures double longitudinal polarization asymmetry

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

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

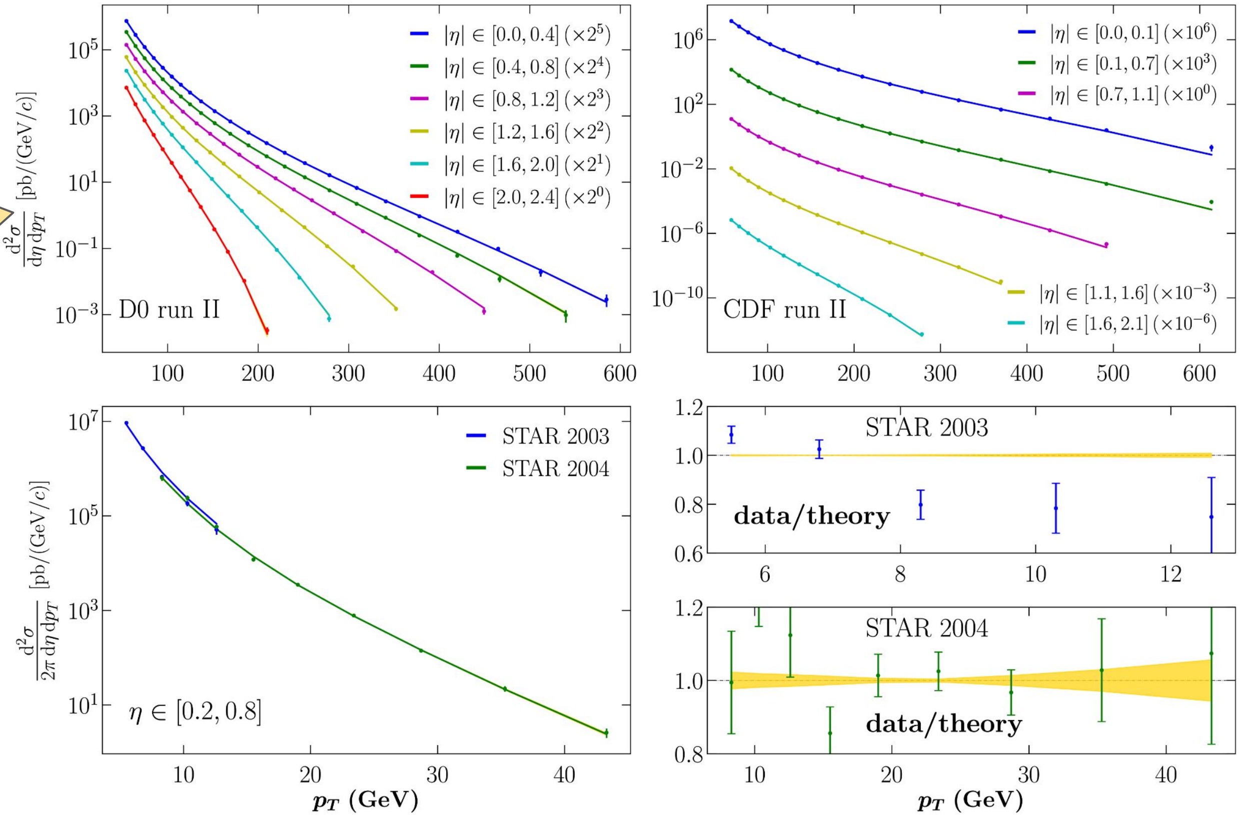
  - $\sigma^{+\pm}$ are differential cross sections when proton beams have equal & opposite helicity
  - denominator is spin-averaged cross section



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

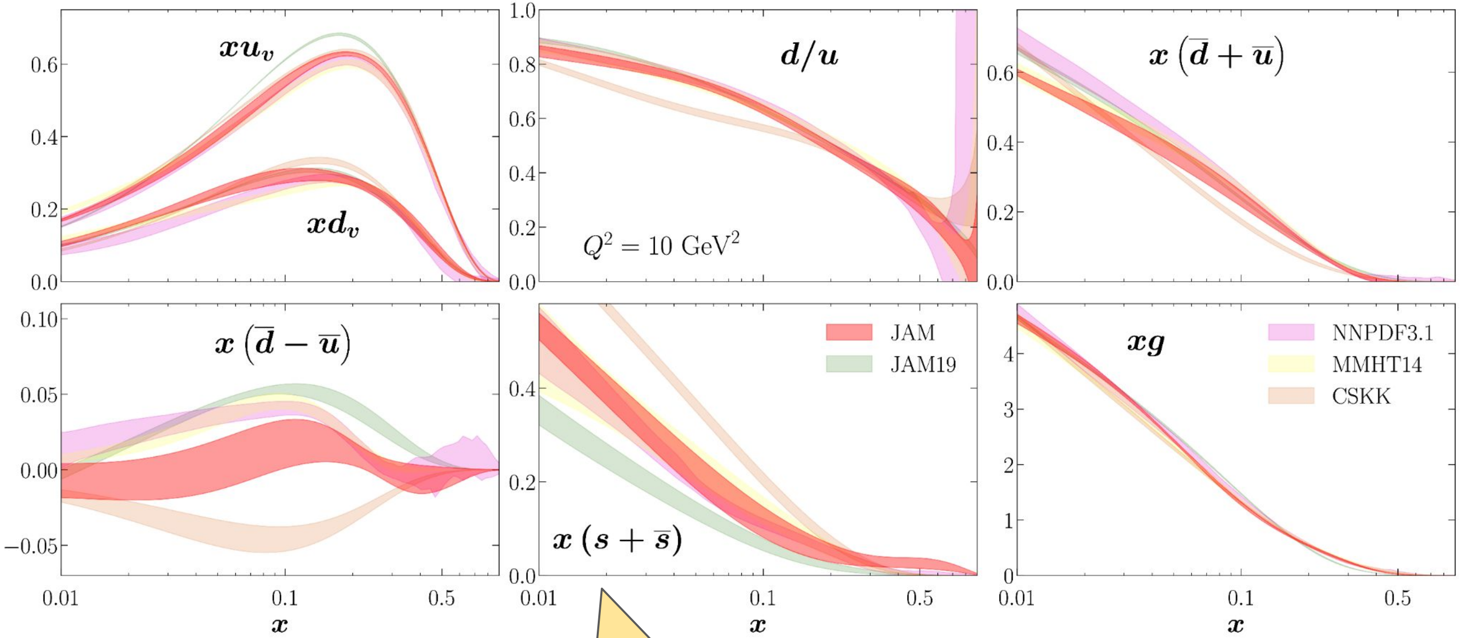
Unpolarized jets

Good agreement between theory and Tevatron data



First inclusion of unpolarized RHIC jets!

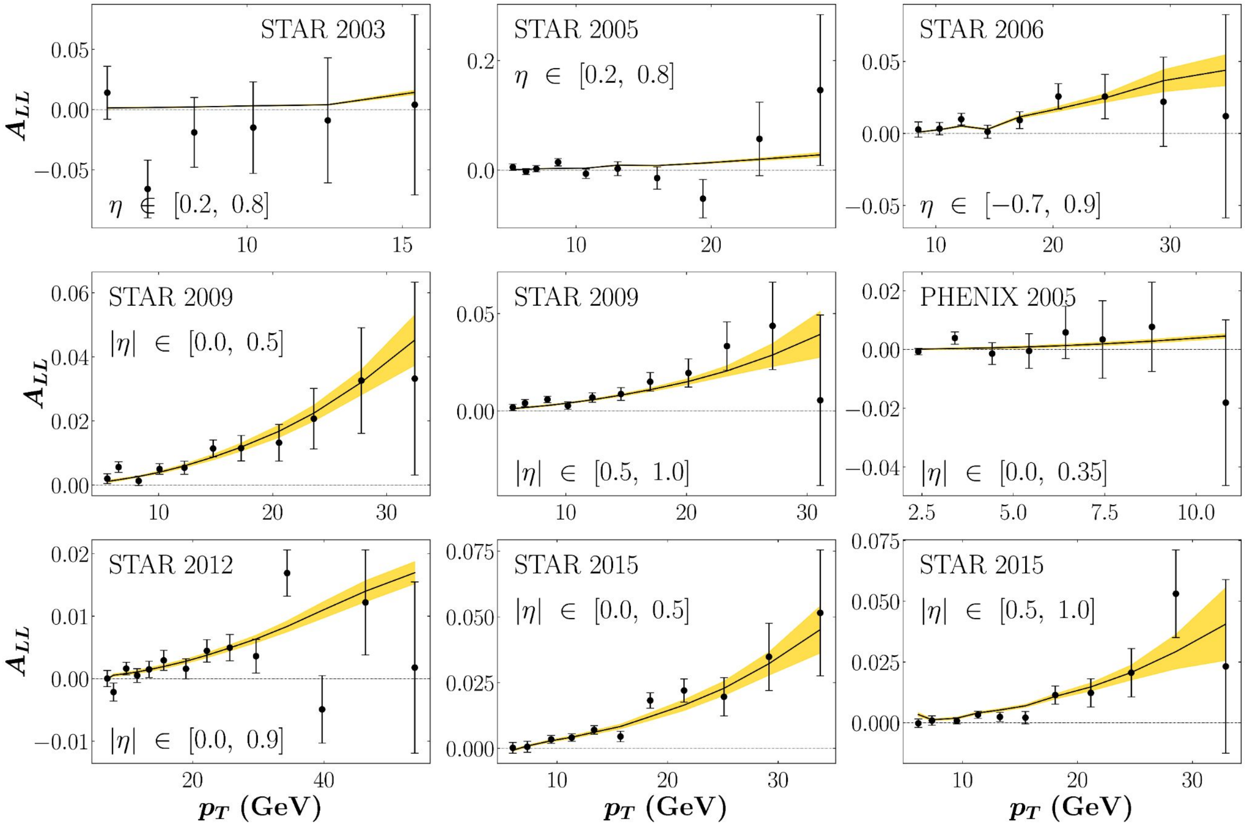
Unpolarized PDFs - $\chi^2 = 1.18$



An overall good agreement is found.

Differences are caused by choices of datasets.

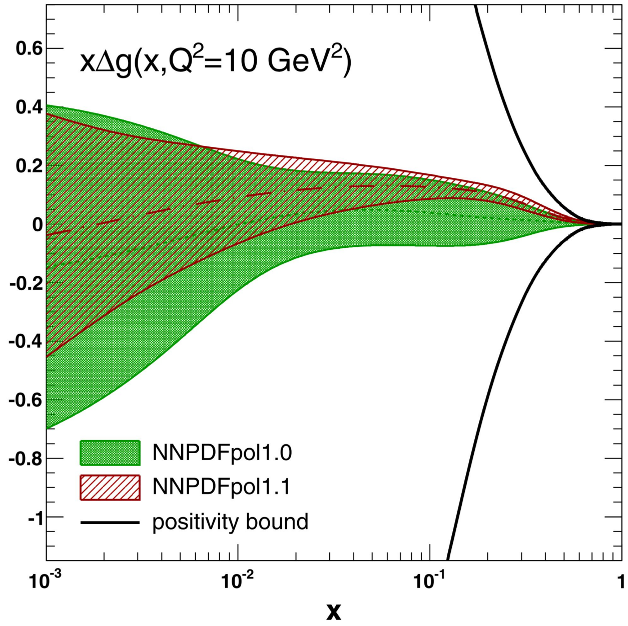
Polarized jets



First inclusion of jets from polarized *pp* collisions in JAM!

Theory assumptions

NNPDF pol 1.1



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

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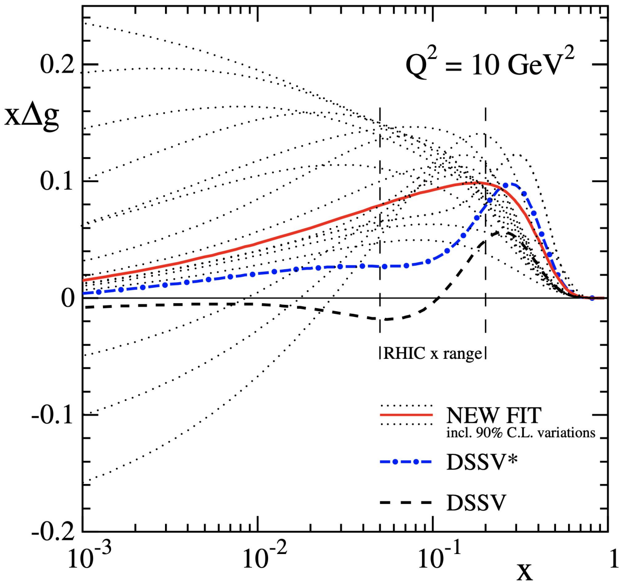


[PRL **113**, 012001 (2014)]

- SU(3) flavor symmetry
- positivity constraints

Theory assumptions

SU(2) only

↓

SU(2) and SU(3)

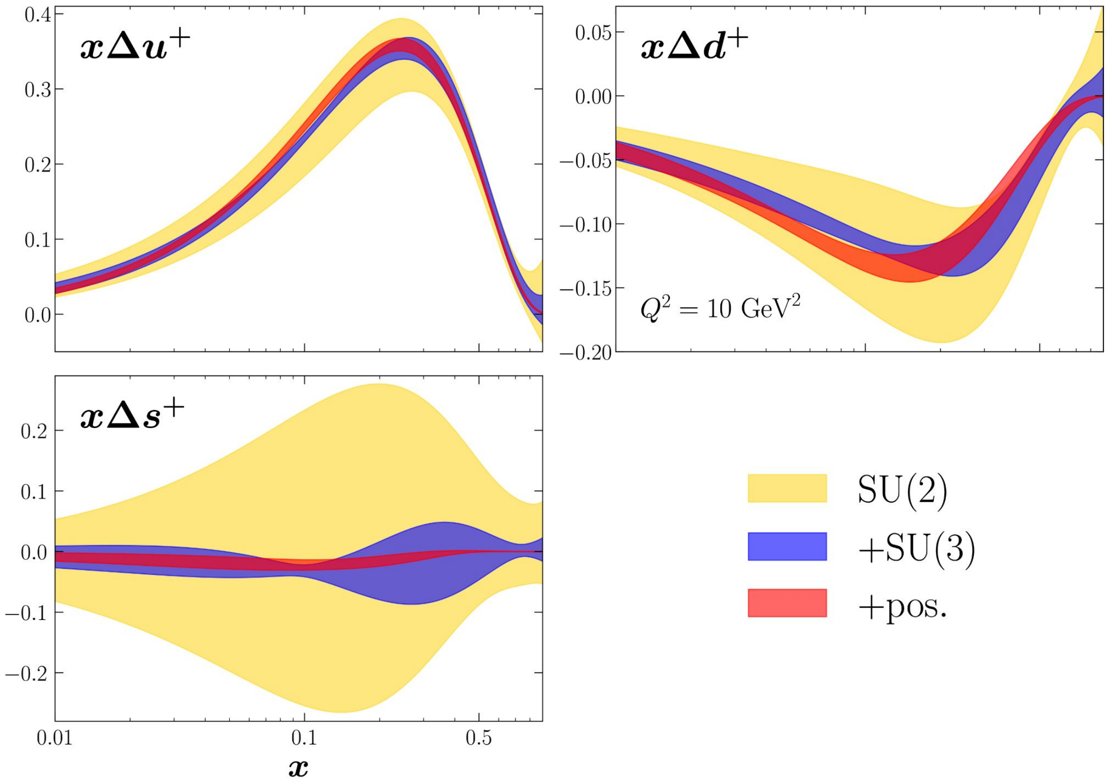
↓

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

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

- more constraint
- more bias
- less data driven

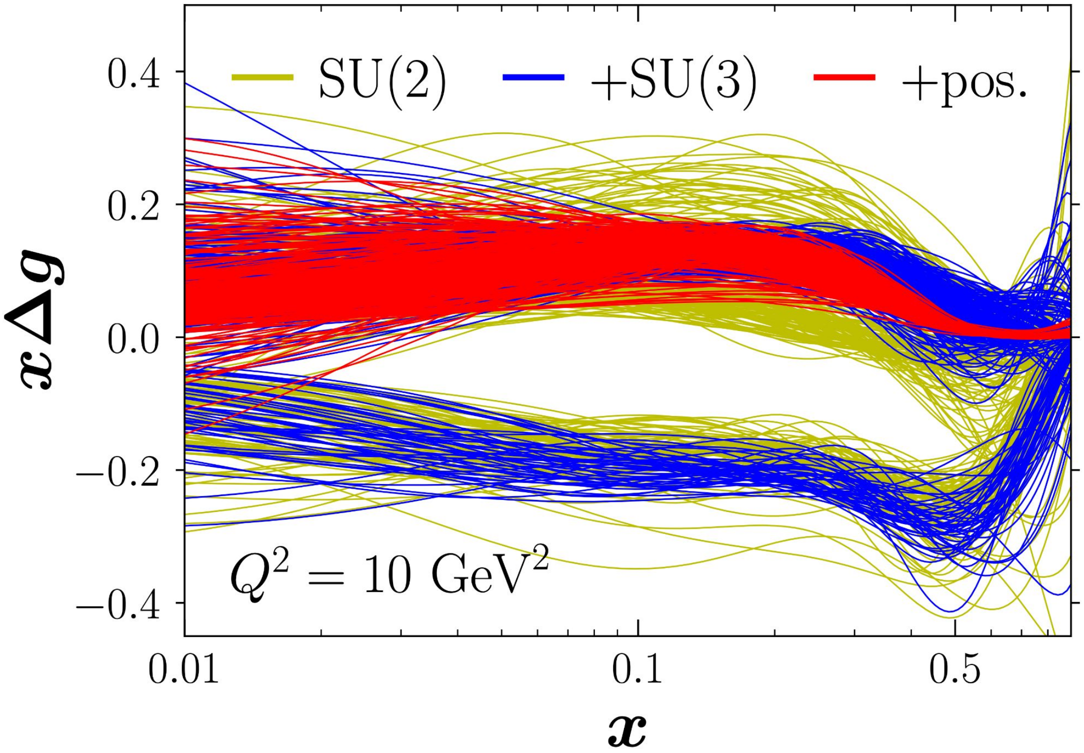
Helicity quark PDFs - $\chi^2 \approx 0.94$



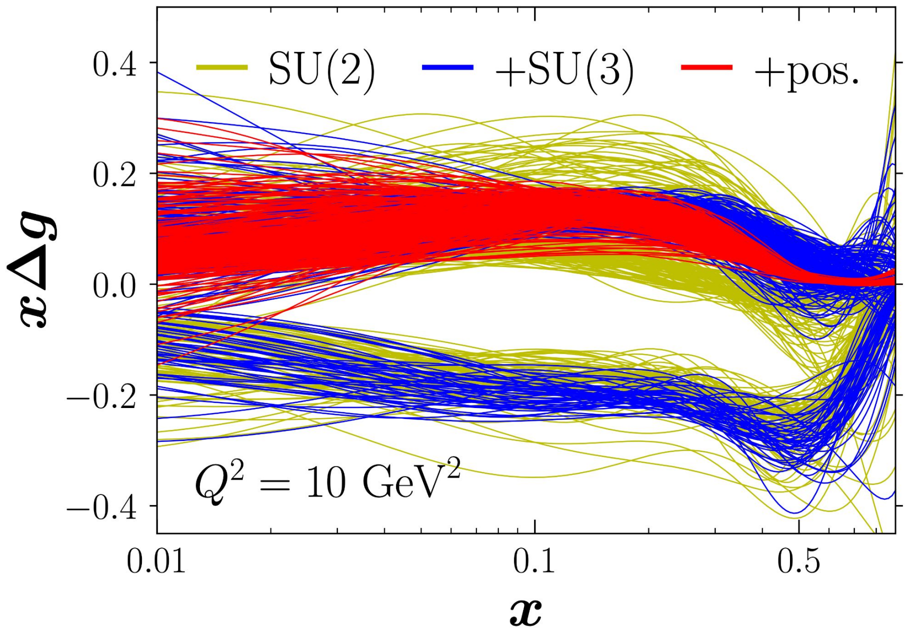
- SU(3) flavor symmetry reduces significantly the uncertainties on Δu, Δd and Δs
- positivity constraints again greatly reduce the uncertainty on Δs

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

Helicity gluon PDF



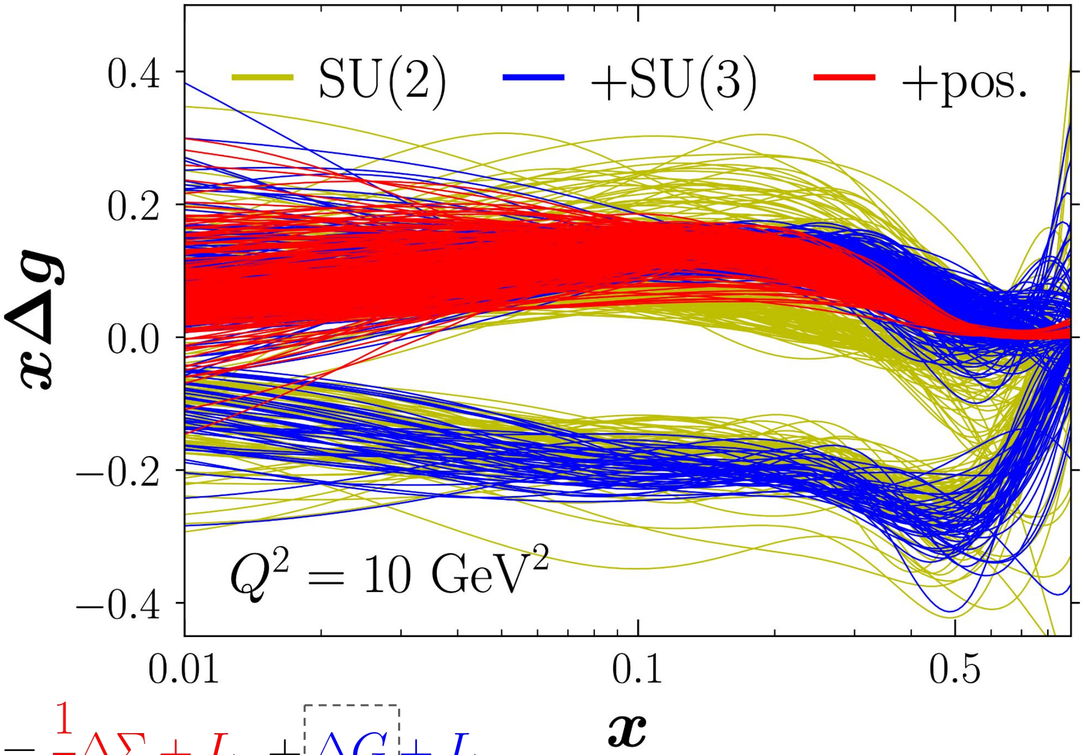
- Δg is observed to have two distinct solutions
- SU(3) flavor symmetry reduces slightly the uncertainty on Δg
- positivity constraints eliminate the “negative” solution from Δg



Both Δg solutions can describe the data equally well!

experiment	reference	observable	reaction	N_{dat}	χ^2/N_{dat}		
					A	B	C
EMC	[40]	A_1	μp	10	0.28	0.28	0.28
SMC	[41]	A_1	μp	11	0.33	0.30	0.36
SMC	[42]	A_1	μp	7	1.41	1.41	1.33
SMC	[41]	A_1	μd	11	1.63	1.62	1.68
SMC	[42]	A_1	μd	7	0.63	0.63	0.64
COMPASS	[43]	A_1	μp	11	1.01	1.07	1.25
COMPASS	[45]	A_1	μp	35	0.91	0.93	0.90
COMPASS	[44]	A_1	μd	11	0.43	0.46	0.60
SLAC (E80, E130)	[46]	$A_\parallel$	$e^- p$	10	0.76	0.78	0.79
SLAC (E143)	[48]	$A_\parallel$	$e^- p$	39	0.81	0.80	0.82
SLAC (E155)	[50]	$A_\parallel$	$e^- p$	59	1.28	1.28	1.37
SLAC (E143)	[48]	$A_\parallel$	$e^- d$	39	1.08	1.08	1.17
SLAC (E155)	[51]	$A_\parallel$	$e^- d$	59	0.99	0.98	0.96
SLAC (E142)	[47]	A_1	$e^- h$	4	0.91	0.92	0.40
SLAC (E154)	[49]	$A_\parallel$	$e^- h$	15	0.38	0.37	0.66
HERMES	[52]	A_1	$e^+ n$	5	0.13	0.13	0.10
HERMES	[53]	$A_\parallel$	$e^+ p$	16	0.59	0.57	0.59
HERMES	[53]	$A_\parallel$	$e^+ d$	16	1.03	1.02	1.10
STAR (2003)	[22]	A_{LL}	pp	6	1.52	1.52	1.51
STAR (2005)	[23]	A_{LL}	pp	10	1.12	1.12	1.12
STAR (2006)	[23]	A_{LL}	pp	9	0.34	0.35	0.36
STAR (2009)	[24]	A_{LL}	pp	22	0.83	0.82	0.93
STAR (2012)	[25]	A_{LL}	pp	14	1.59	1.55	1.53
STAR (2015)	[26]	A_{LL}	pp	22	1.07	1.10	1.08
PHENIX (2005)	[27]	A_{LL}	pp	8	0.60	0.60	0.61
total				**456**	**0.94**	**0.94**	**0.98**

Gluon truncated moment ΔG

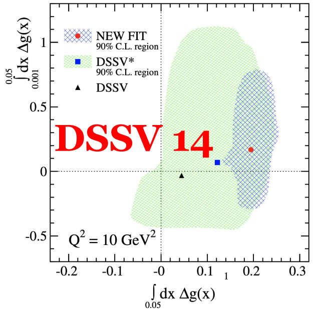


$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \boxed{\Delta G} + L_g$$

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

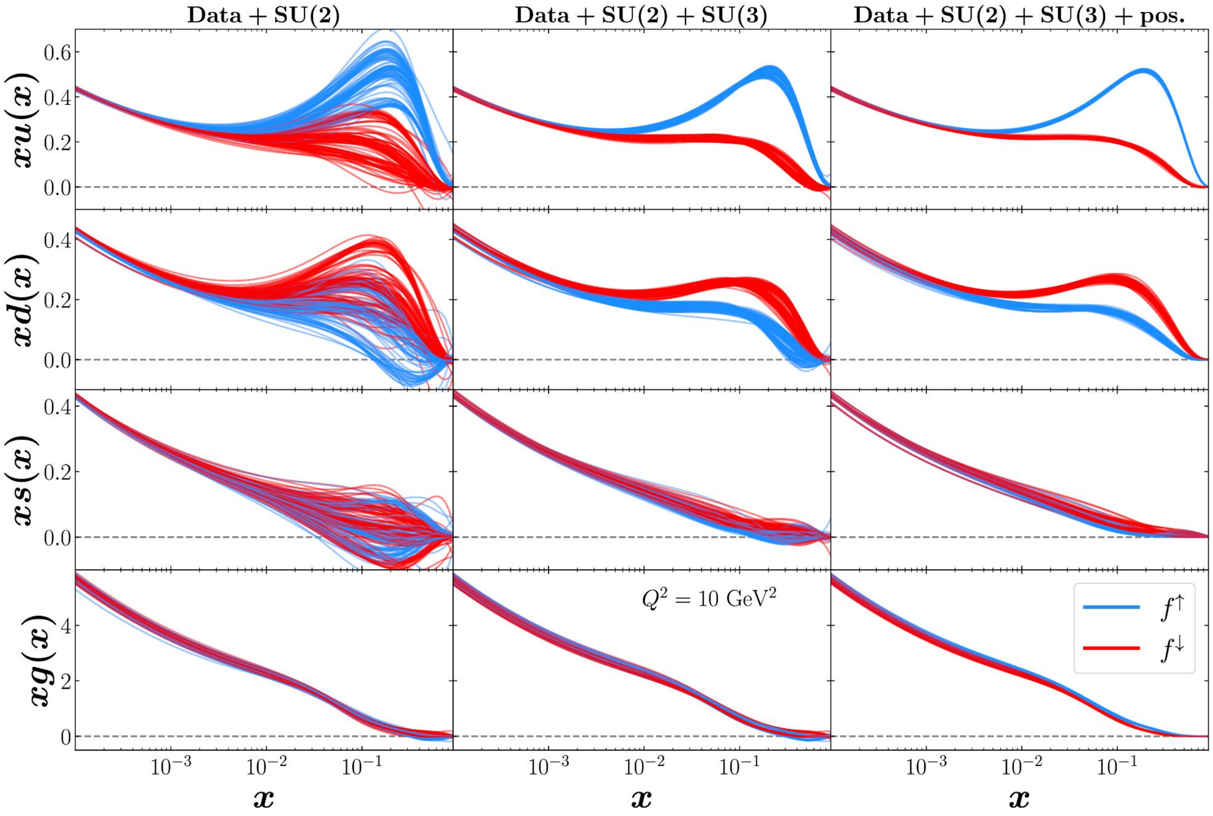
- SU(2): -0.02 ± 0.39
  - positive: 0.21 ± 0.15
  - negative: -0.57 ± 0.12
- + SU(3): 0.12 ± 0.32
  - positive: 0.26 ± 0.03
  - negative: -0.60 ± 0.03
- + positivity: 0.24 ± 0.03

- DSSV 14: 0.2 ± 0.05



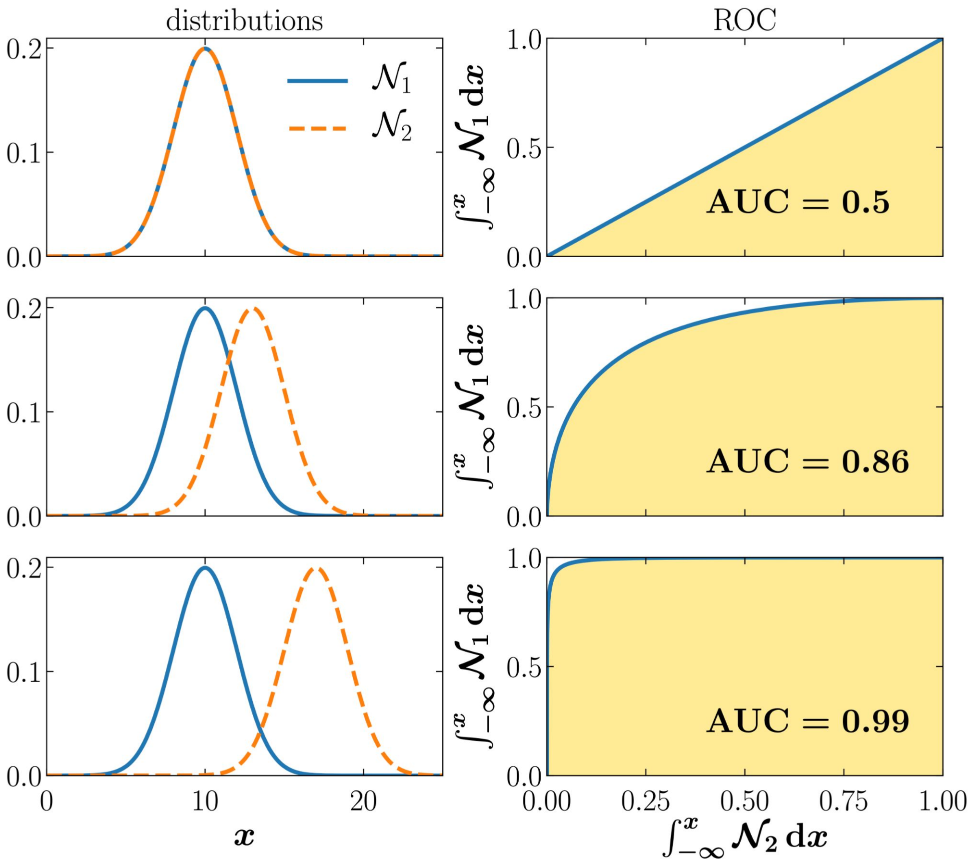
Simultaneous extraction

- First simultaneous extraction of both helicity basis PDFs.
- Can we distinguish the two helicity basis PDFs?



ROC/AUC

- indistinguishable
- somewhat distinguishable
- clearly distinguishable



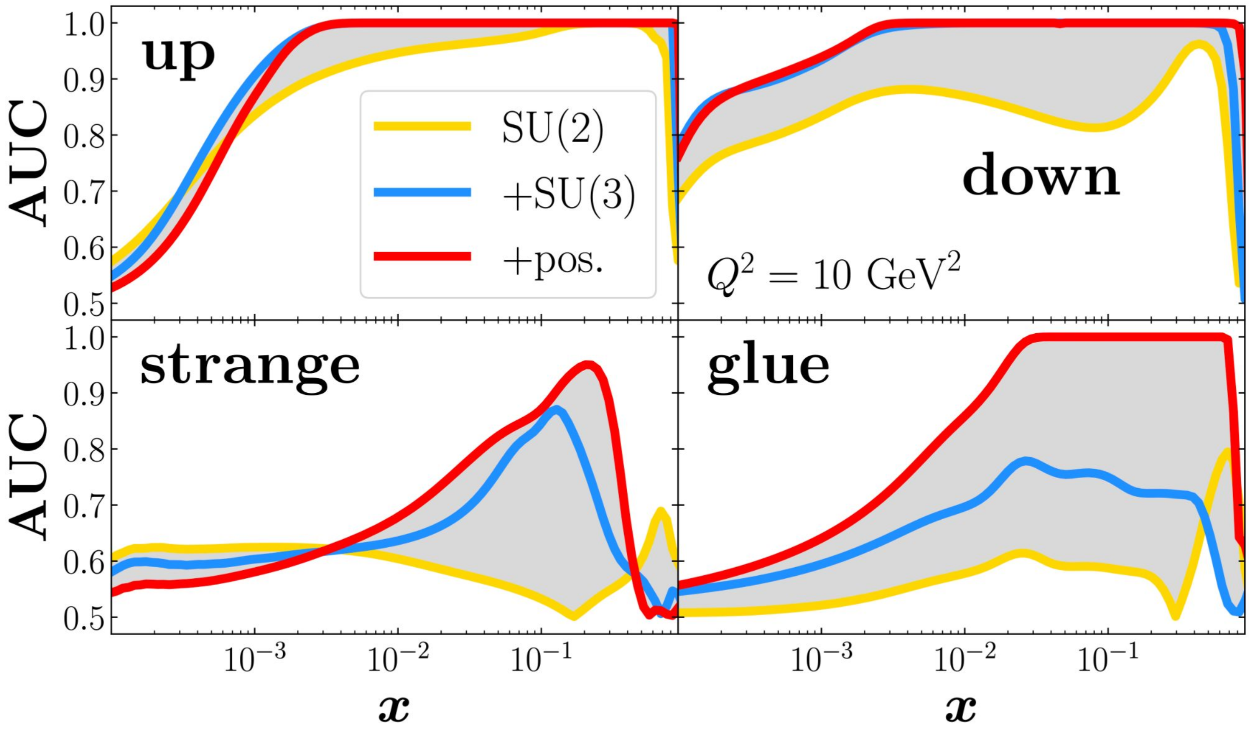
ROC: *receiver operating characteristic curve*

AUC: *area under curve of ROC*

AUC for helicity basis PDFs

Helicity basis PDFs for…

- up and down are only mildly affected by theory inputs
- strange are more distinguishable with SU(3), but less affected by positivity
- gluon are only clearly distinguishable from each other when positivity constrains are imposed



Conclusion

- Jet data in unpolarized and polarized pp or $p\bar{p}$ collisions (Tevatron and RHIC) are well fitted.

- Gluon helicity distributions have two solutions.

- 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