Jefferson Lab Angular Momentum Collaboration

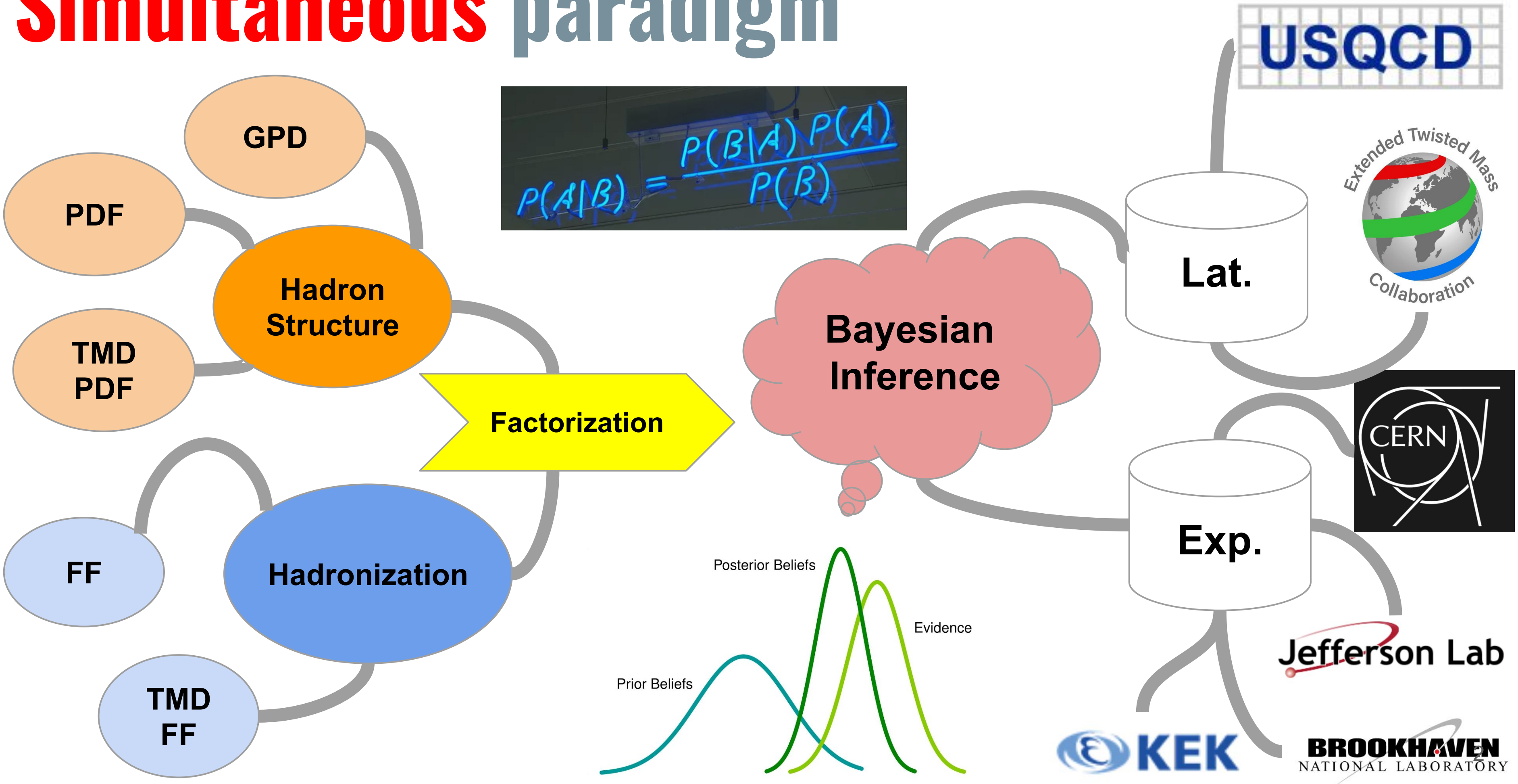
Recent results on Proton Structure from JAM

Nobuo Sato

2021 RHIC/AGS Annual Users meeting
Virtual, Jun 8-11 2021

Jefferson Lab

Simultaneous paradigm



Newsstand 20-21

Revisiting quark and gluon polarization in the proton at the EIC

Y. Zhou (William-Mary Coll.), C. Cocuzza (Temple U.), F. Delcarro (Jefferson Lab), W. Melnitchouk (Jefferson Lab), A. Metz (Temple U.) et al. (May 10, 2021)

e-Print: 2105.04434 [hep-ph]

Isovector EMC effect from global QCD analysis with MARATHON data

C. Cocuzza (Temple U.), C.E. Keppel (Jefferson Lab), H. Liu (Massachusetts U., Amherst), W. Melnitchouk (Jefferson Lab), A. Metz (Temple U.) et al. (Apr 14, 2021)

e-Print: 2104.06946 [hep-ph]

Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report #

R. Abdul Khalek (Vrije U., Amsterdam and Nikhef, Amsterdam), A. Accardi (Hampton U. and Jefferson Lab), J. Adam (Brookhaven), D. Adamiak (Ohio State U.), W. Akers (Jefferson Lab) et al. (Mar 8, 2021)

e-Print: 2103.05419 [physics.ins-det]

Towards the 3-dimensional parton structure of the pion: integrating transverse momentum data into global QCD analysis #4

N.Y. Cao (Harvard U.), P.C. Barry (North Carolina State U. and Jefferson Lab), N. Sato (Jefferson Lab), W. Melnitchouk (Jefferson Lab) (Mar 2, 2021)

e-Print: 2103.02159 [hep-ph]

Electron-Ion Collider impact study on the tensor charge of the nucleon #7

Leonard Gamberg (Penn State U., Berks-Lehigh Valley), Zhong-Bo Kang (UCLA), Daniel Pitonyak (Lebanon Valley Coll.), Alexei Prokudin (Jefferson Lab), Nobuo Sato (Jefferson Lab) et al. (Jan 15, 2021)

Published in: *Phys.Lett.B* 816 (2021) 136255 • e-Print: 2101.06200 [hep-ph]

First analysis of world polarized DIS data with small-x helicity evolution #6

Daniel Adamiak (Ohio State U., Columbus (main)), Yuri V. Kovchegov (Ohio State U., Columbus (main)), W. Melnitchouk (Jefferson Lab), Daniel Pitonyak (Lebanon Valley Coll.), Nobuo Sato (Jefferson Lab) et al. (Feb 11, 2021)

e-Print: 2102.06159 [hep-ph]

Simultaneous Monte Carlo analysis of parton densities and fragmentation functions #8

Eric Moffat (Old Dominion U.), Wally Melnitchouk (Jefferson Lab), Ted Rogers (Jefferson Lab and Old Dominion U.), Nobuo Sato (Jefferson Lab) (Jan 12, 2021)

e-Print: 2101.04664 [hep-ph]

Confronting lattice parton distributions with global QCD analysis #10

J. Bringewatt (Maryland U., College Park), N. Sato (Jefferson Lab), W. Melnitchouk (Jefferson Lab), Jian-Wei Qiu (Jefferson Lab), F. Steffens (Bonn U.) et al. (Oct 1, 2020)

Published in: *Phys.Rev.D* 103 (2021) 1, 016003 • e-Print: 2010.00548 [hep-ph]

Origin of single transverse-spin asymmetries in high-energy collisions

Jefferson Lab Angular Momentum Collaboration • Justin Cammarota (Coll. William and Mary and Lebanon Valley Coll.) et al. (Feb 19, 2020)

Published in: *Phys.Rev.D* 102 (2020) 5, 054002 • e-Print: 2002.08384 [hep-ph]


Simultaneous Monte Carlo analysis of parton densities and fragmentation functions

#8

Eric Moffat (Old Dominion U.), Wally Melnitchouk (Jefferson Lab), Ted Rogers (Jefferson Lab and Old Dominion U.), Nobuo Sato (Jefferson Lab) (Jan 12, 2021)

e-Print: 2101.04664 [hep-ph]

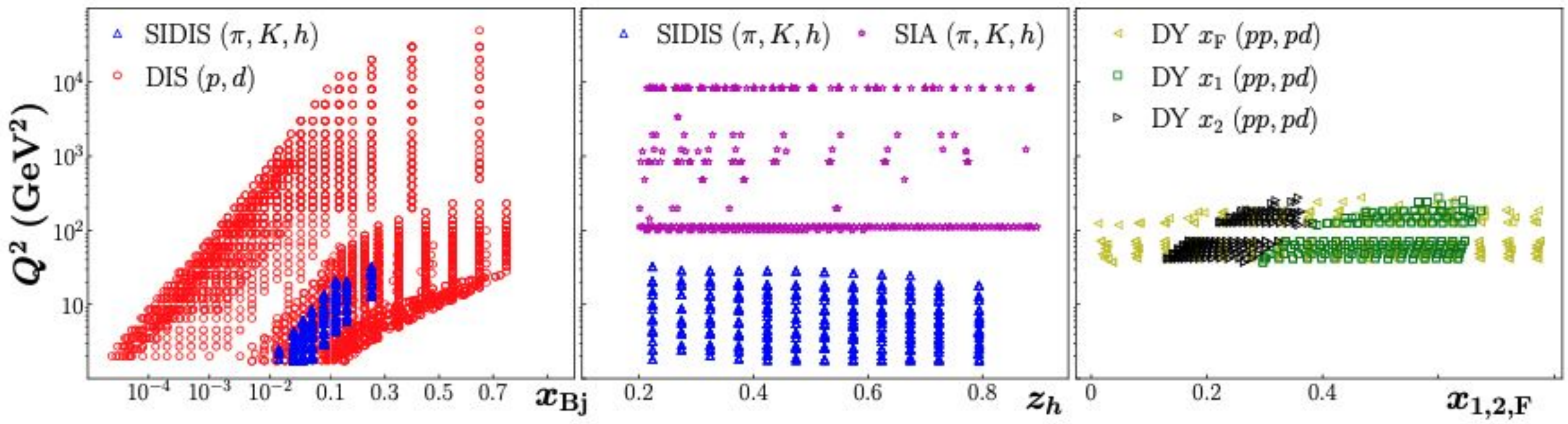
$$\frac{d\sigma_{\text{DIS}}}{dQ^2 dx_{\text{Bj}}} = \sum_{i \in \text{flavors}} \mathcal{H}_i^{\text{DIS}} \otimes f_i \,,$$

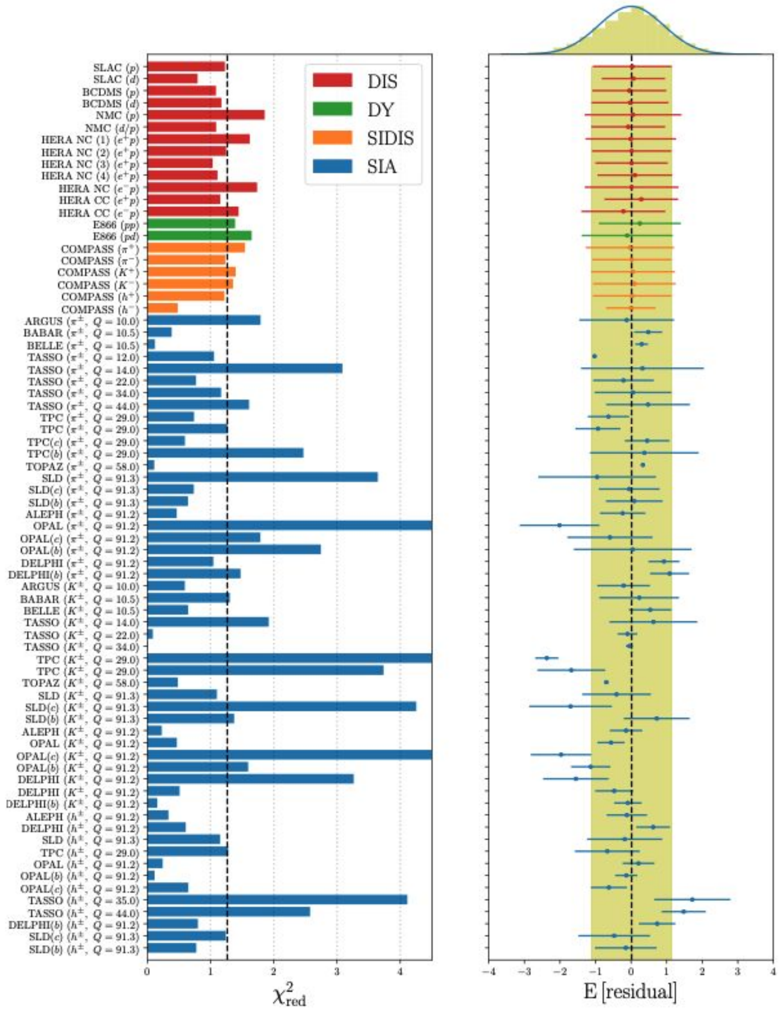
$$\frac{d\sigma_{\text{SIDIS}}}{dQ^2 dx_{\text{Bj}} dz_h} = \sum_{ij \in \text{flavors}} \mathcal{H}_{ij}^{\text{SIDIS}} \otimes f_i \otimes D_j^h \,,$$

$$\frac{d\sigma_{\text{DY}}}{dQ^2 dx_{\text{F}}} = \sum_{ij \in \text{flavors}} \mathcal{H}_{ij}^{\text{DY}} \otimes f_i \otimes f_j \,,$$

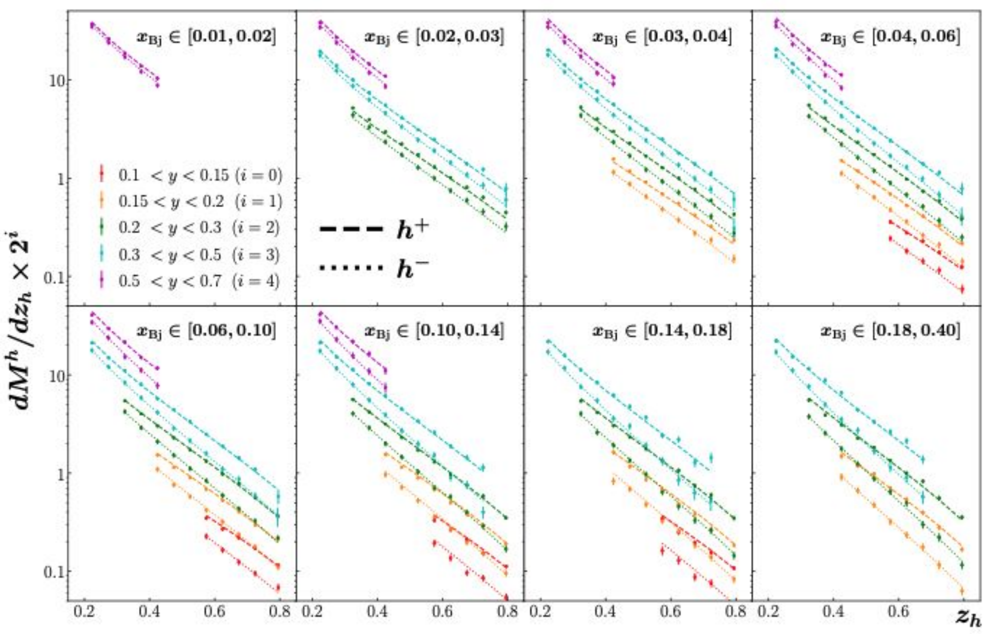
$$\frac{d\sigma_{\text{SIA}}}{dQ^2 dz_h} = \sum_{j \in \text{flavors}} \mathcal{H}_j^{\text{SIA}} \otimes D_j^h \,,$$

- Inclusion of unidentified charge hadron COMPASS data (pT integrate)
- Important for upol TMD analysis
- More flexible parametrization relative to previous analysis

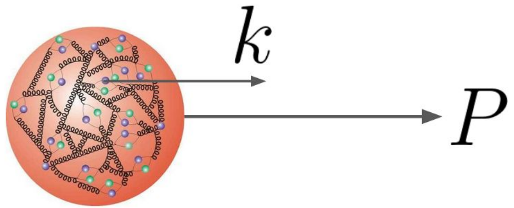




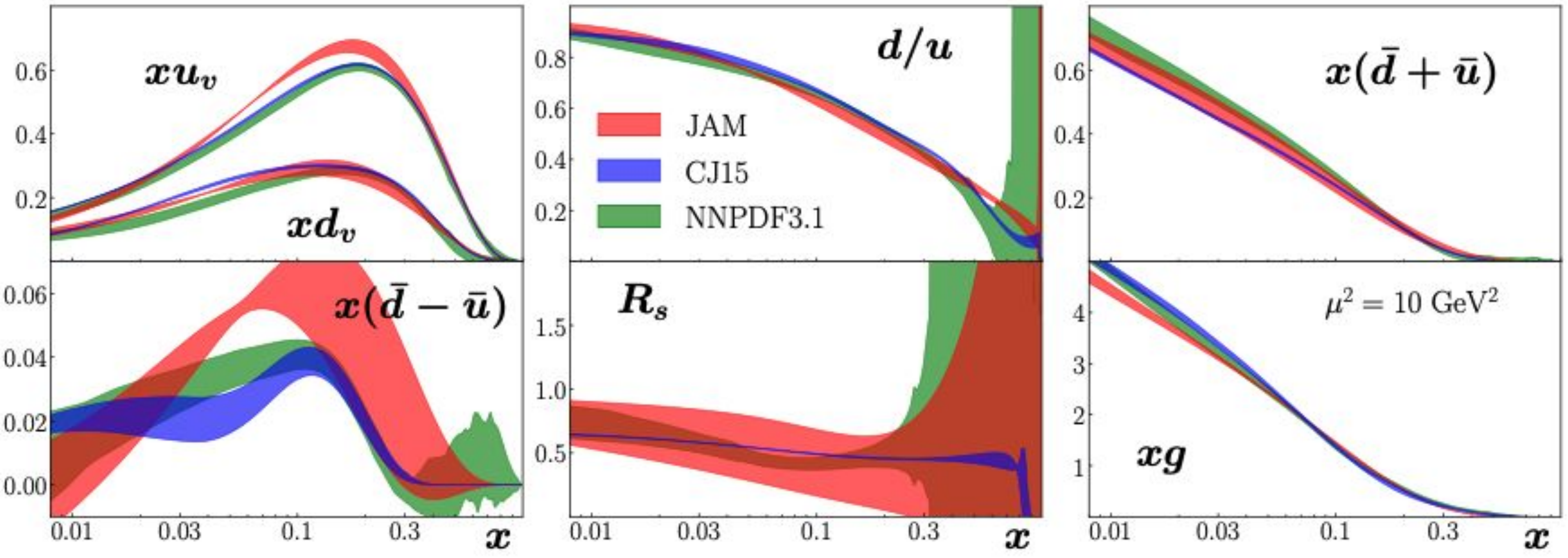
SIDIS multiplicities



Unpol. PDFs

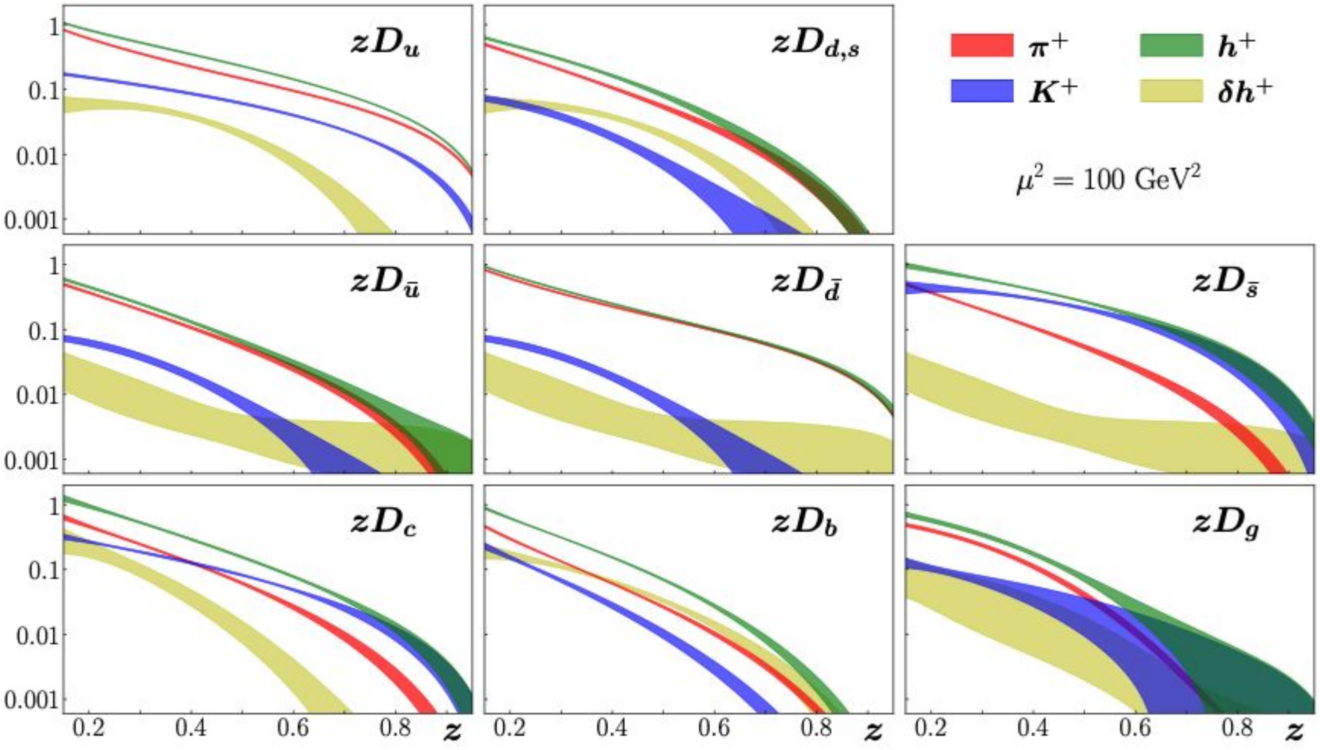


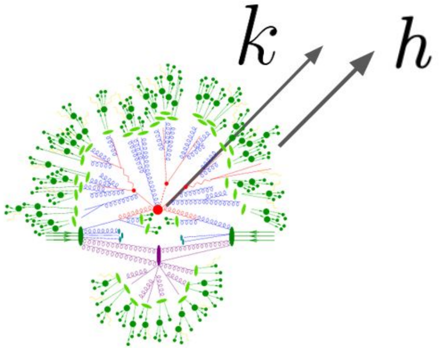
k
P



xu_v
xd_v
d/u
JAM
CJ15
NNPDF3.1
$x(\bar{d}+\bar{u})$
$x(\bar{d}-\bar{u})$
R_s
$\mu^2 = 10$ GeV^2
xg
0.01
0.03
0.1
0.3
x

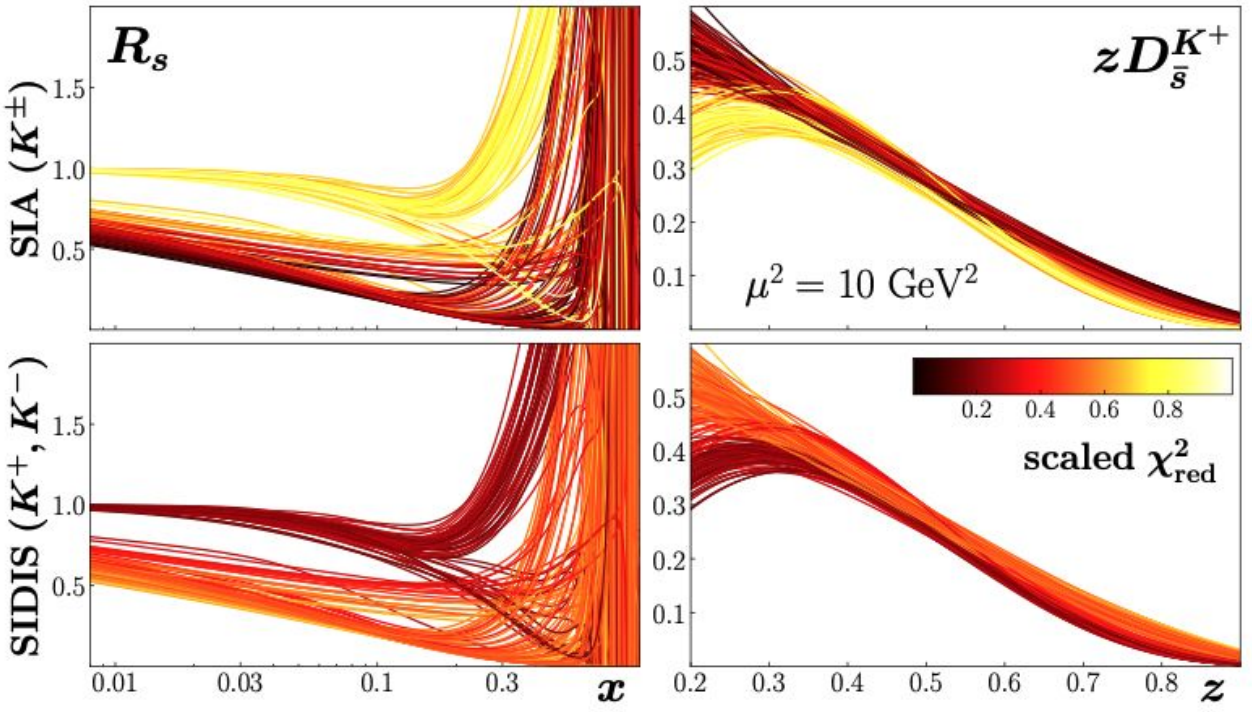
Fragmentation Functions





All hadron flavors of FFs fitted simultaneously

A less strange nucleon



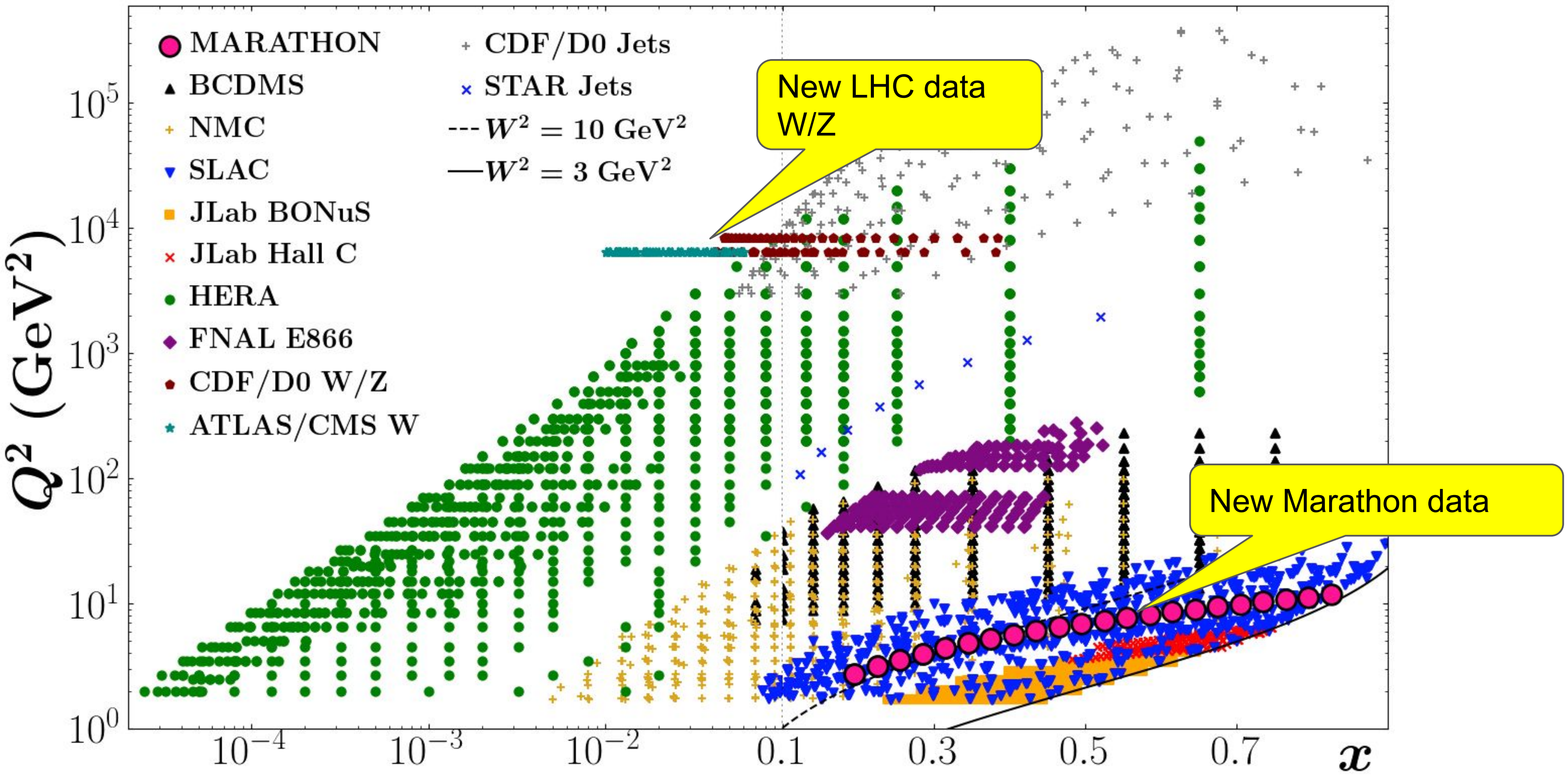
$$R_s = \frac{s + \bar{s}}{\bar{u} + \bar{d}}$$

The simultaneous fit of PDFs and FFs provides new insights on nucleon strangeness


Isovector EMC effect from global QCD analysis with MARATHON data

C. Cocuzza (Temple U.), C.E. Keppel (Jefferson Lab), H. Liu (Massachusetts U., Amherst), W. Melnitchouk (Jefferson Lab), A. Metz (Temple U.) et al. (Apr 14, 2021)

e-Print: 2104.06946 [hep-ph]



MARATHON
BCDMS
NMC
SLAC
JLab BONuS
JLab Hall C
HERA
FNAL E866
CDF/D0 W/Z
ATLAS/CMS W
CDF/D0 Jets
STAR Jets
$W^2 = 10$ GeV^2
$W^2 = 3$ GeV^2
New LHC data W/Z
New Marathon data
Q^2 (GeV^2)
x

Theory details for DIS

NLO

HT parametrization

Nucleon structure functions

$$F_2^N(x,Q^2) = \Big(\sum_q e_q^2 [C_q \otimes q_N^+] + [C_g \otimes g_N]\Big)(x,Q^2) \times \left(1 + \frac{C_N^{\mathrm{HT}}(x)}{Q^2}\right)$$

PDFs for light nuclei

$$q_A(x,Q^2) = \sum_N q_{N/A}(x,Q^2) = [q_{N/A}^{(\mathrm{on})} + q_{N/A}^{(\mathrm{off})}](x,Q^2)$$

Nuclear smearing

$$q_{N/A}^{(\mathrm{on})}(x,Q^2) = [f_{N/A}^{(\mathrm{on})} \otimes q_N]$$

Offshell quark parametrization

$$q_{N/A}^{(\mathrm{off})}(x,Q^2) = [f_{N/A}^{(\mathrm{off})} \otimes \delta q_{N/A}]$$

12 -> 2 Offshell functions

Charge symmetry

$$\delta u_{p/D} = \delta d_{n/D}, \quad \delta d_{p/D} = \delta u_{n/D},$$
$$\delta u_{p/^3\mathrm{He}} = \delta d_{n/^3\mathrm{H}}, \quad \delta d_{p/^3\mathrm{He}} = \delta u_{n/^3\mathrm{H}},$$
$$\delta u_{p/^3\mathrm{H}} = \delta d_{n/^3\mathrm{He}}, \quad \delta d_{p/^3\mathrm{H}} = \delta u_{n/^3\mathrm{He}},$$

Isospin symmetry

$$\delta u_{p/D} = \delta u_{p/^3\mathrm{H}} \equiv \delta u,$$
$$\delta d_{p/D} = \delta d_{p/^3\mathrm{H}} \equiv \delta d,$$

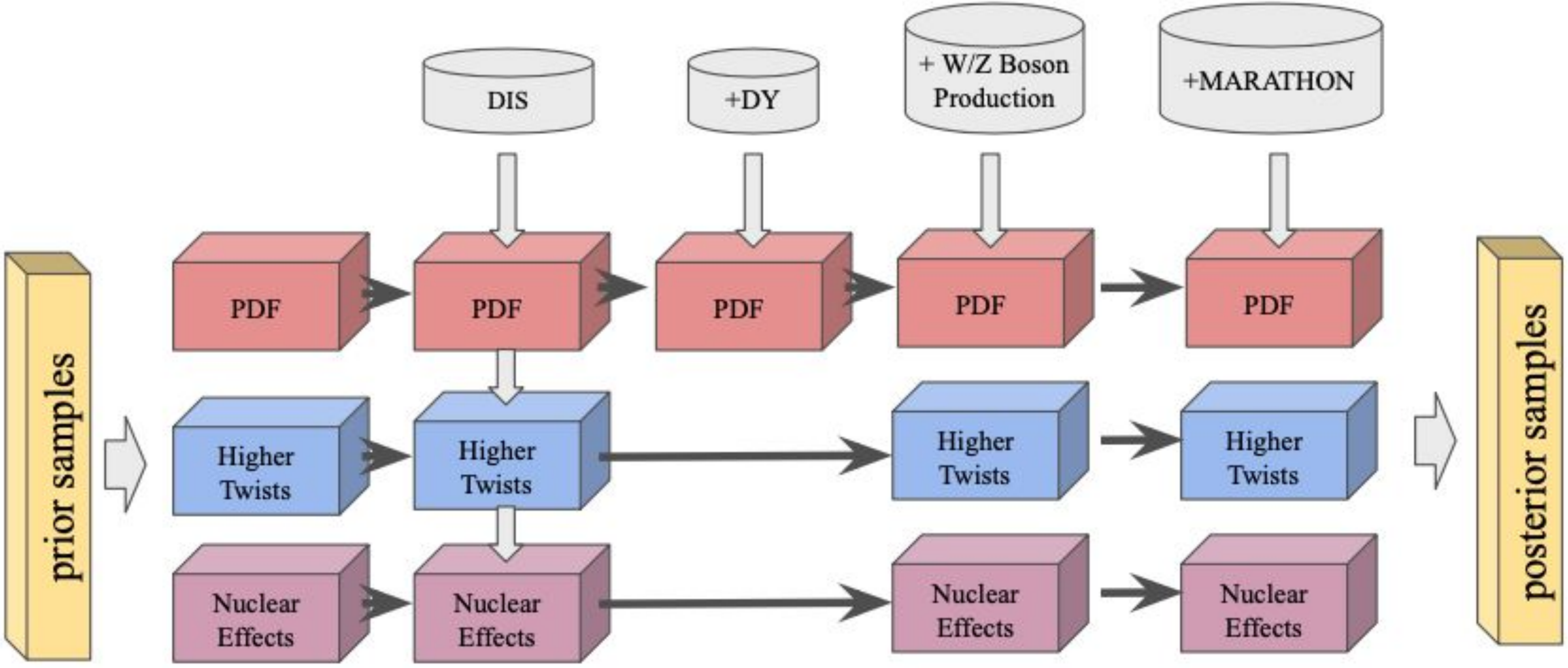
Valence number sum rule

$$\int_0^1 \mathrm{d}x\ \delta u(x) = \int_0^1 \mathrm{d}x\ \delta d(x) = 0.$$

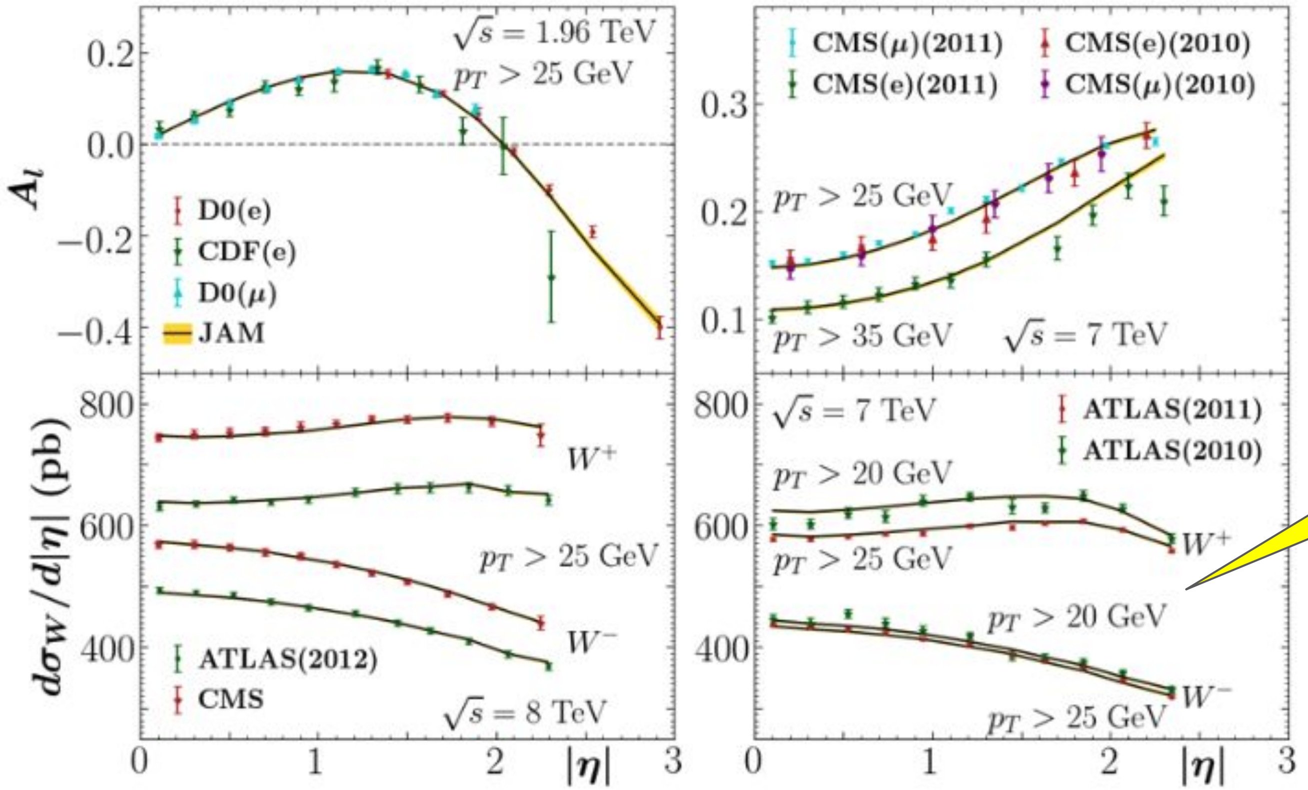
No isovector components in 3He from proton offshell effects

$$\delta u_{p/^3\mathrm{He}} \approx \delta d_{p/^3\mathrm{He}} = \frac{1}{2}\left(\delta u + 2\,\delta d\right).$$

Multi-step strategy

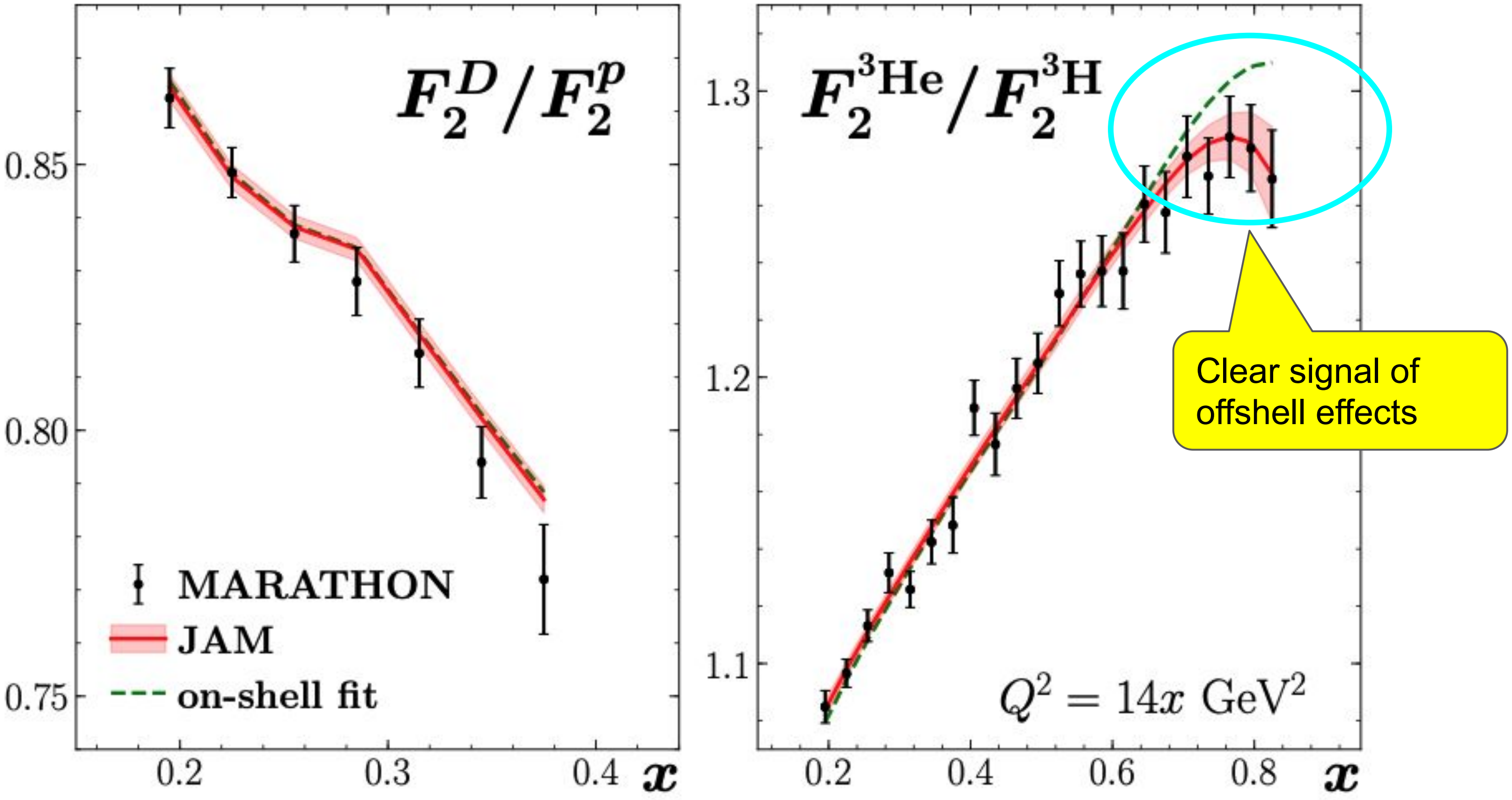


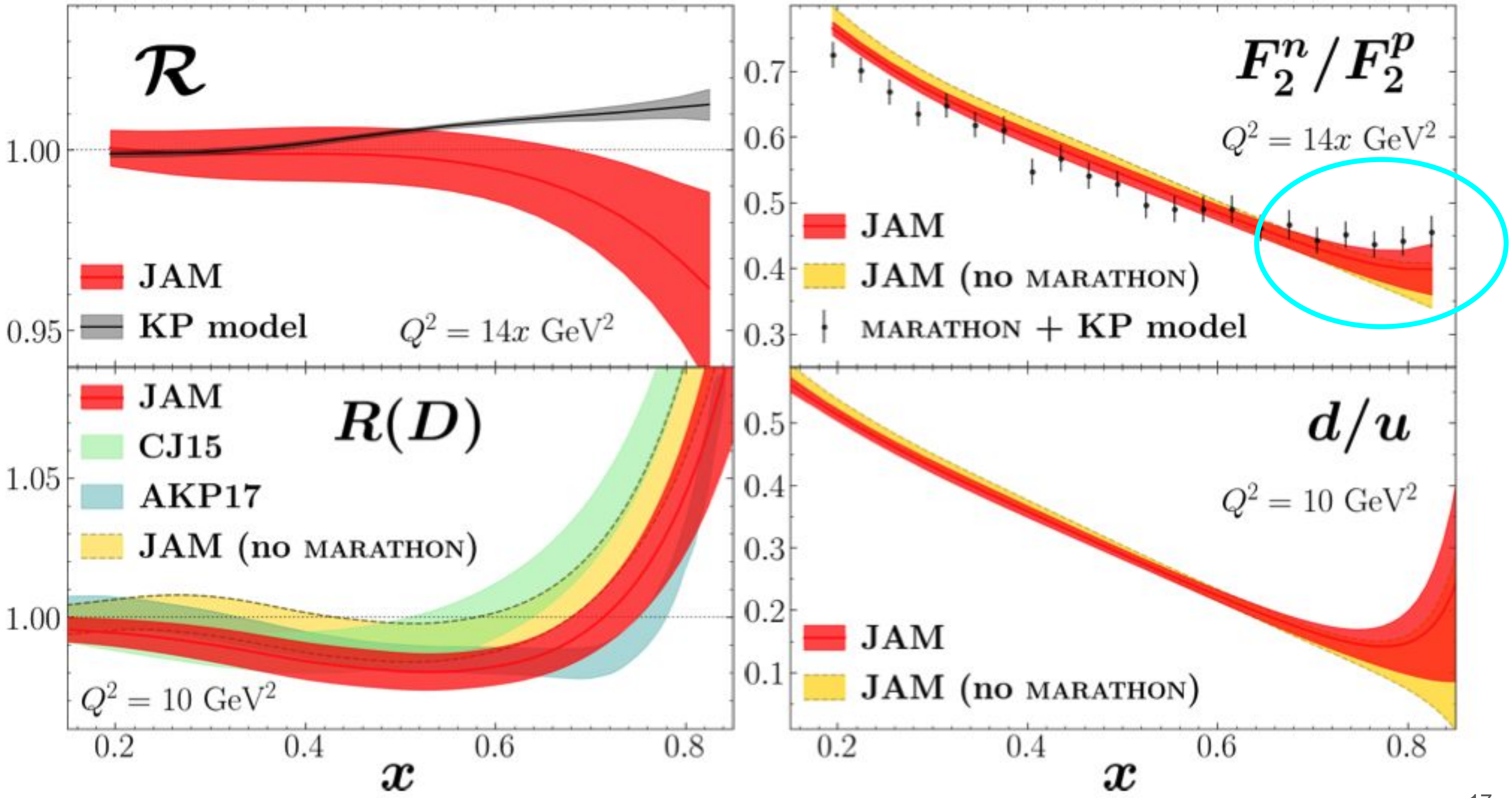
LHC W data



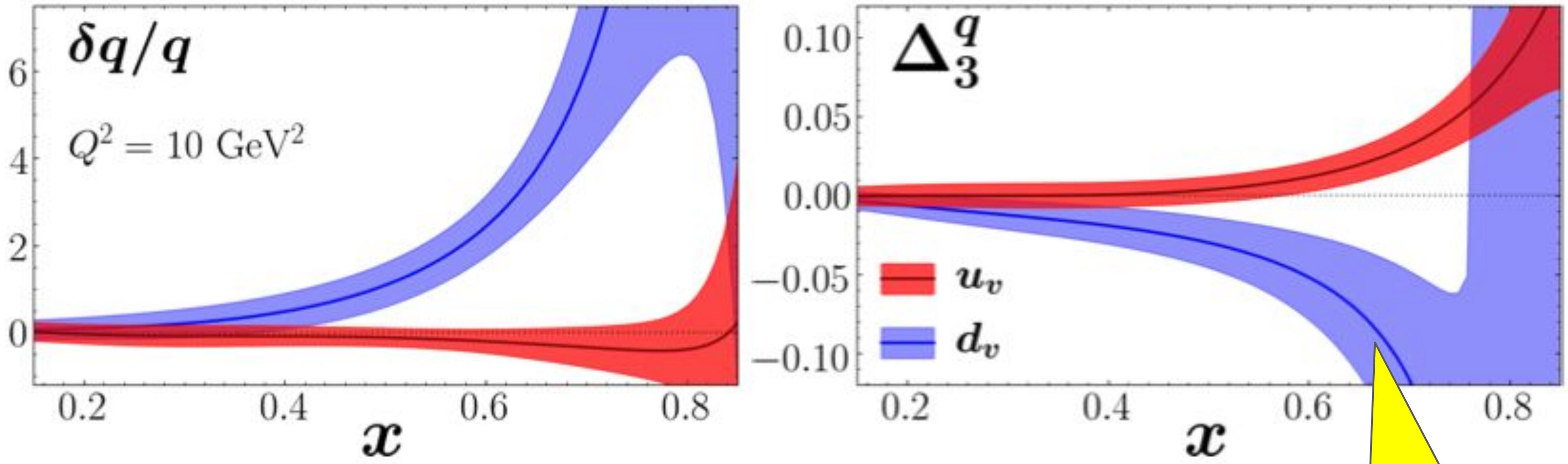
Excent agreement between theory and data

Marathon data





$\mathcal{R}$
JAM
KP model
$Q^2 = 14x$ GeV^2
1.00
0.95
F_2^n / F_2^p
$Q^2 = 14x$ GeV^2
JAM
JAM (no MARATHON)
MARATHON + KP model
0.7
0.6
0.5
0.4
0.3
JAM
CJ15
AKP17
JAM (no MARATHON)
$R(D)$
$Q^2 = 10$ GeV^2
1.05
1.00
d/u
$Q^2 = 10$ GeV^2
JAM
JAM (no MARATHON)
0.5
0.4
0.3
0.2
0.1
0.2
0.4
0.6
0.8
x

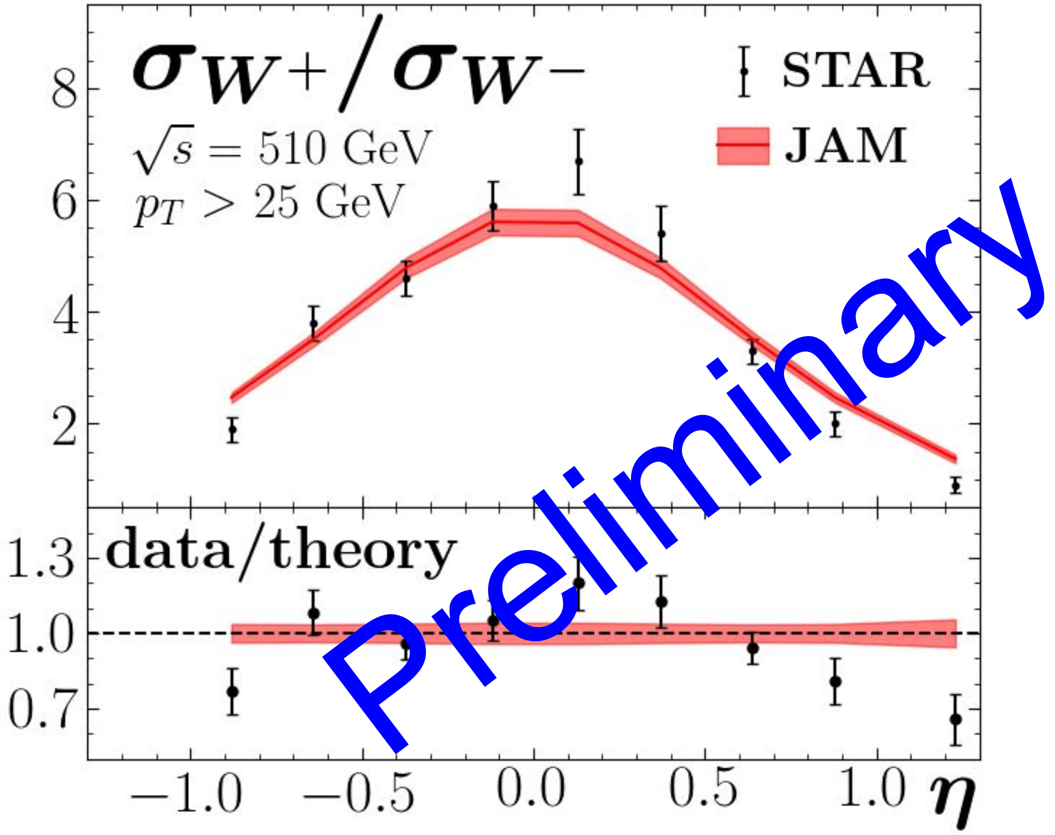


Strength of isovector effects

Clear signature of isovector effects

$$\Delta_3^q \equiv \frac{q_{p/^3\mathrm{H}} - q_{p/^3\mathrm{He}}}{q_{p/^3\mathrm{H}} + q_{p/^3\mathrm{He}}}$$

Inclusion of RHIC W data



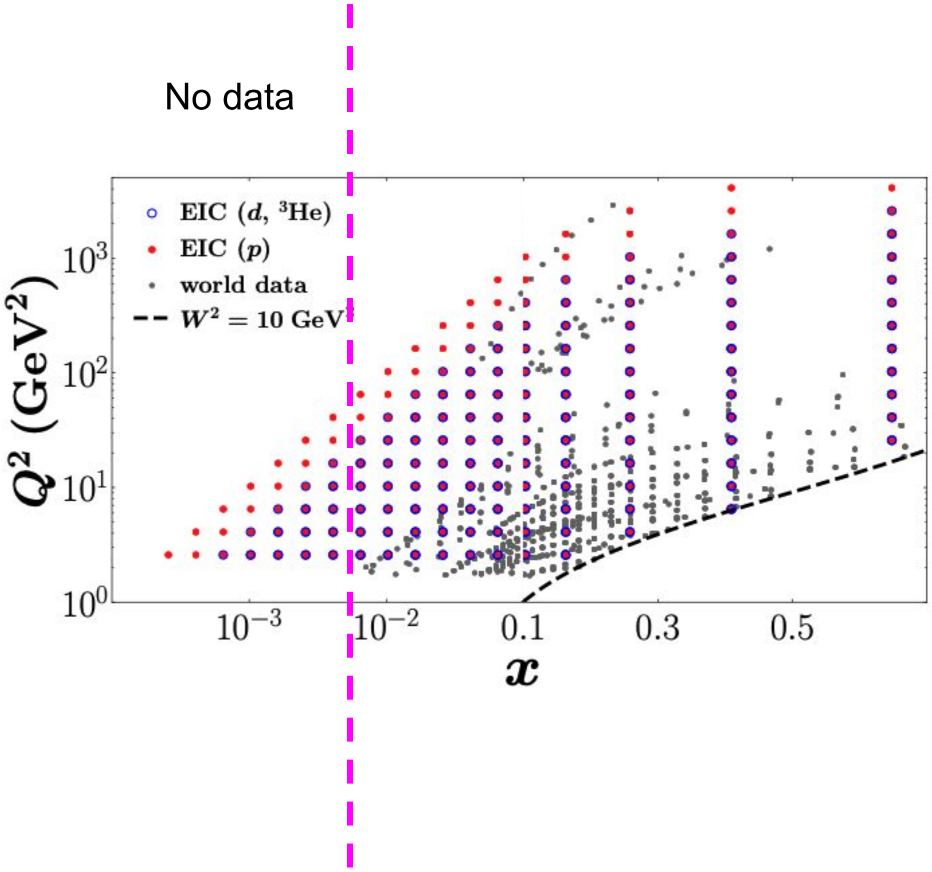
Excellent agreement with data

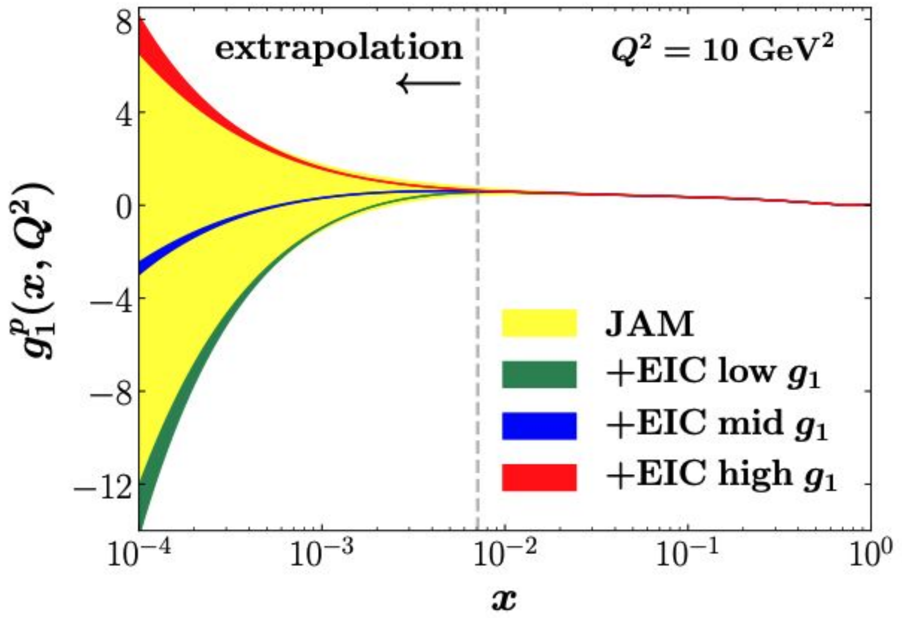
Revisiting quark and gluon polarization in the proton at the EIC

Y. Zhou (William-Mary Coll.), C. Cocuzza (Temple U.), F. Delcarro (Jefferson Lab), W. Melnitchouk (Jefferson Lab), A. Metz (Temple U.) et al. (May 10, 2021)

e-Print: 2105.04434 [hep-ph]

Q1: role of small x extrapolation





Q2: role of theory assumptions

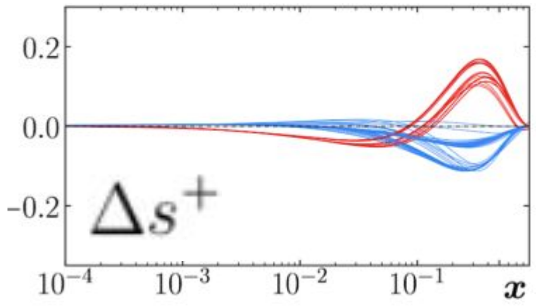
$$\int_0^1 dx\left[\Delta u^+(x,Q^2) - \Delta d^+(x,Q^2)\right] = g_A,$$

$$\int_0^1 dx\left[\Delta u^+(x,Q^2) + \Delta d^+(x,Q^2) - 2\Delta s^+(x,Q^2)\right] = a_8,$$

$$g_A = 1.269(3), \qquad [\mathrm{SU}(2)]$$

$$a_8 = 0.586(31), \qquad [\mathrm{SU}(3)]$$

The strange PDF is largely unconstrained. SU(3) favors negative strange



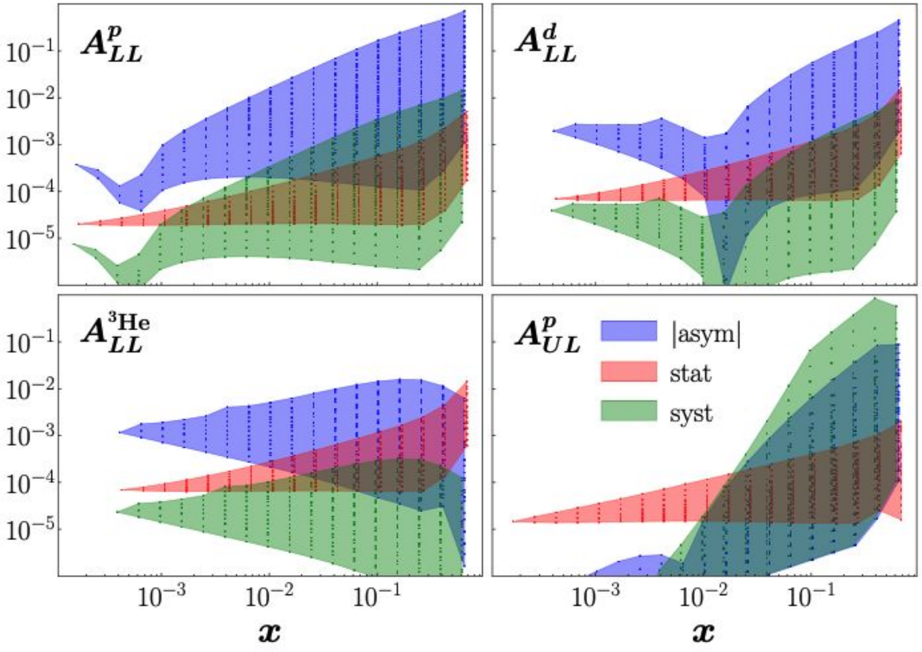
Inclusive observables

$$A_{LL} = \frac{y(2-y)}{y^2 + 2(1-y)(1+R)} \frac{g_1}{F_1}.$$

$$A_{UL} = \frac{G_F x Q^2}{2\sqrt{2}\pi\alpha} \left(\frac{g_A^e Y^- g_1^{\gamma Z} + g_V^e Y^+ g_5^{\gamma Z}}{x y^2 F_1 + (1-y) F_2} \right)$$

Parity violating DIS

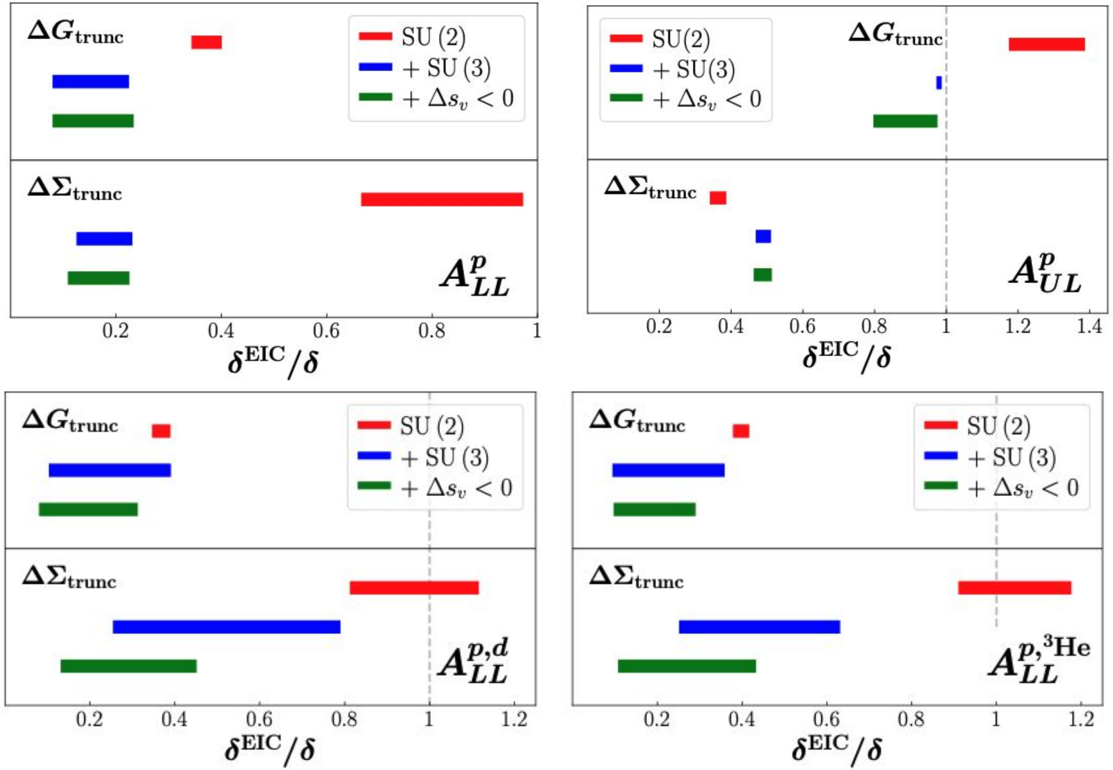
$$g_1^{\gamma Z,p}(x, Q^2) \approx \frac{1}{9} \Delta\Sigma(x, Q^2),$$



EIC impact

$$\Delta G_{\rm trunc}(Q^2) \equiv \int_{x_{\rm min}}^{1} dx\, \Delta g(x, Q^2),$$

$$\Delta \Sigma_{\rm trunc}(Q^2) \equiv \int_{x_{\rm min}}^{1} dx \sum_q \Delta q^+(x, Q^2), \qquad x_{\rm min} = 10^{-4}.$$

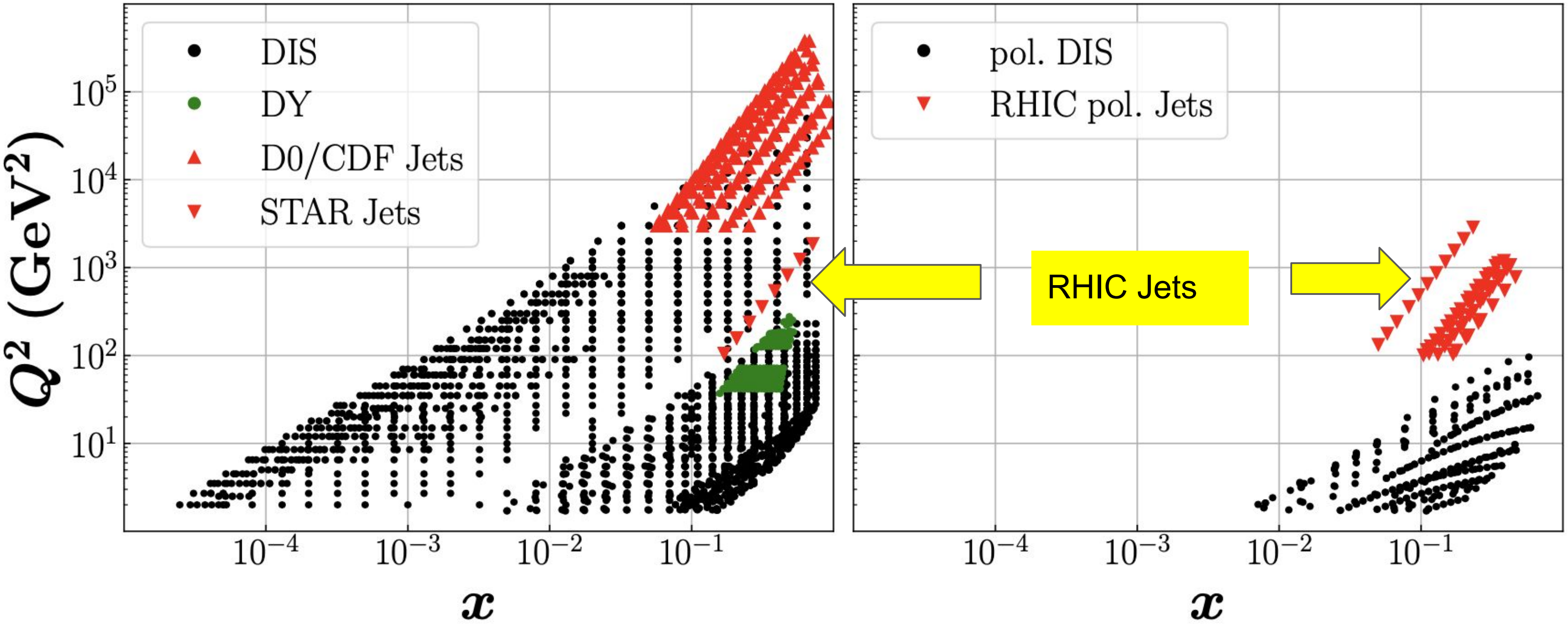


- Impact of ALL on delta G is stable against extrapolation and assumptions
- PVDIS is needed in order to constraint further delta sigma at small x

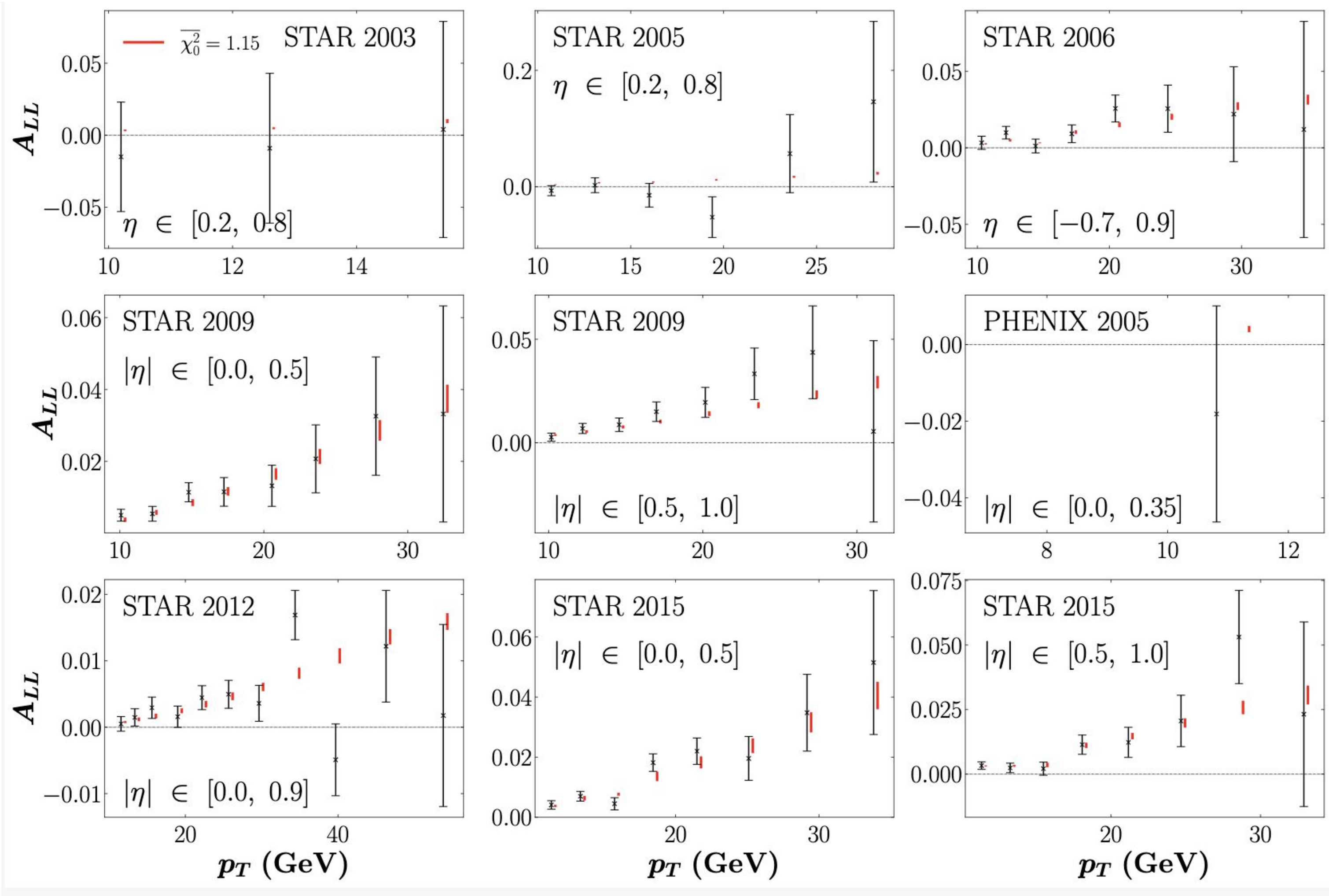
First simultaneous extraction of unpolarized and polarized glue distributions from jet and other observables

Y. Zhou,[1,2] N. Sato,[2] and W. Melnitchouk[2]

In preparation

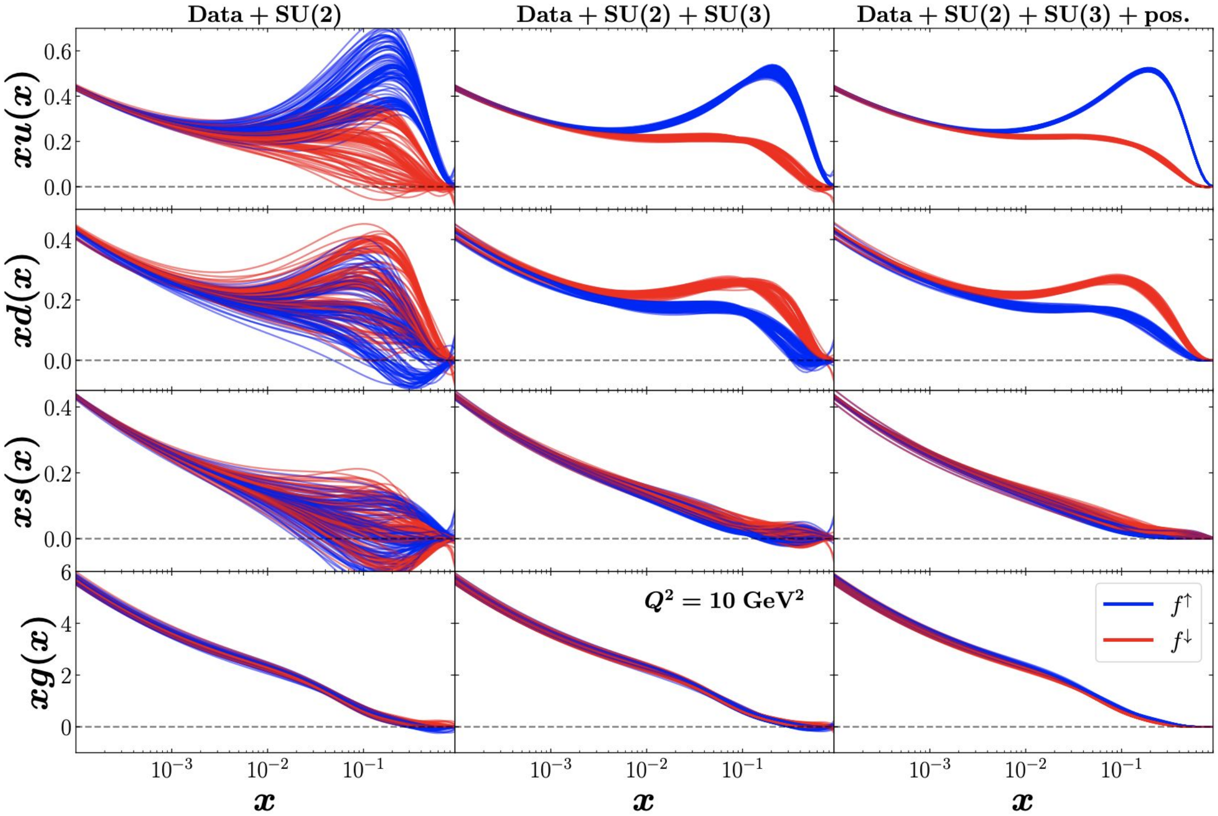


DIS
DY
D0/CDF Jets
STAR Jets
pol. DIS
RHIC pol. Jets
RHIC Jets
Q^2 (GeV^2)
10^1
10^2
10^3
10^4
10^5
10^{-4}
10^{-3}
10^{-2}
10^{-1}
x

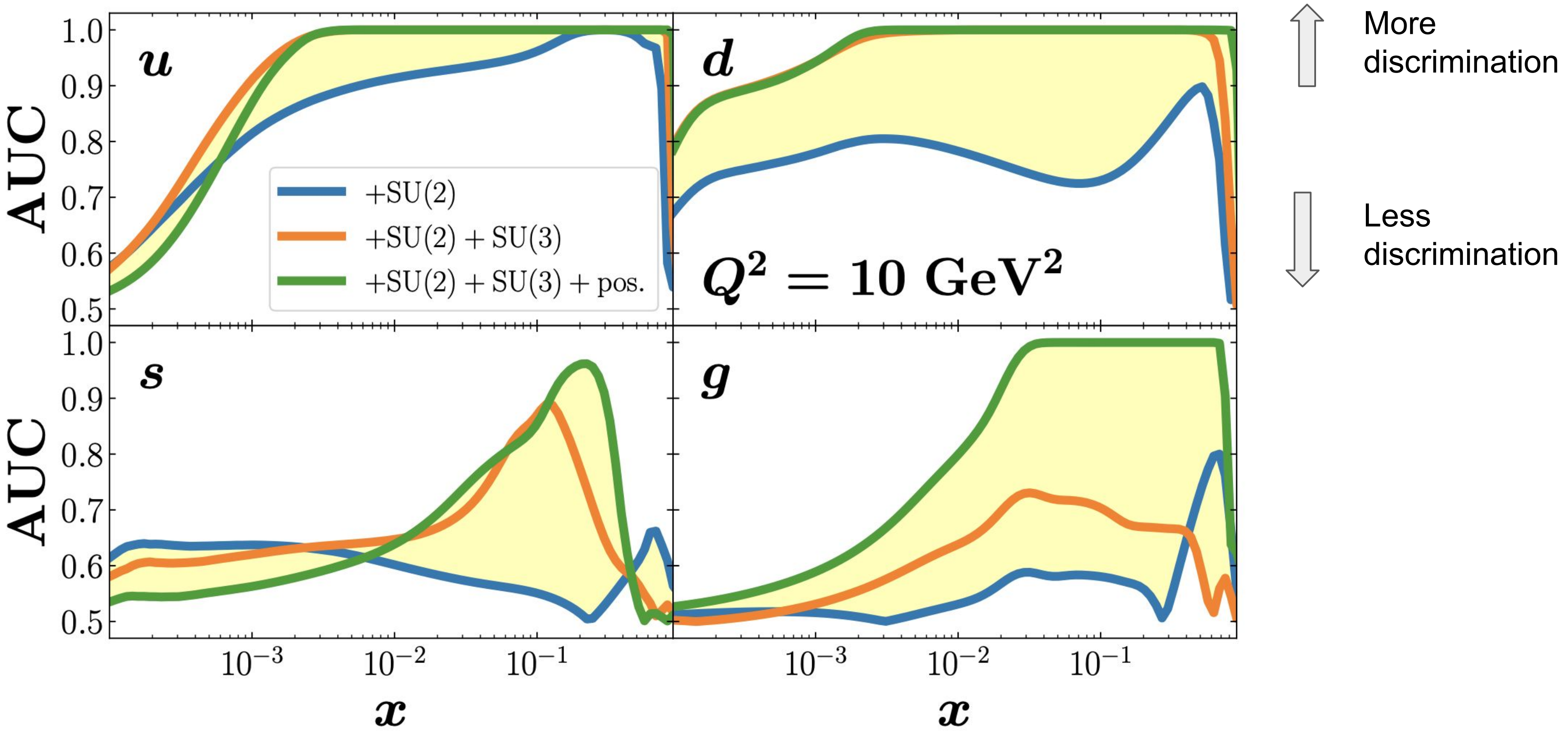


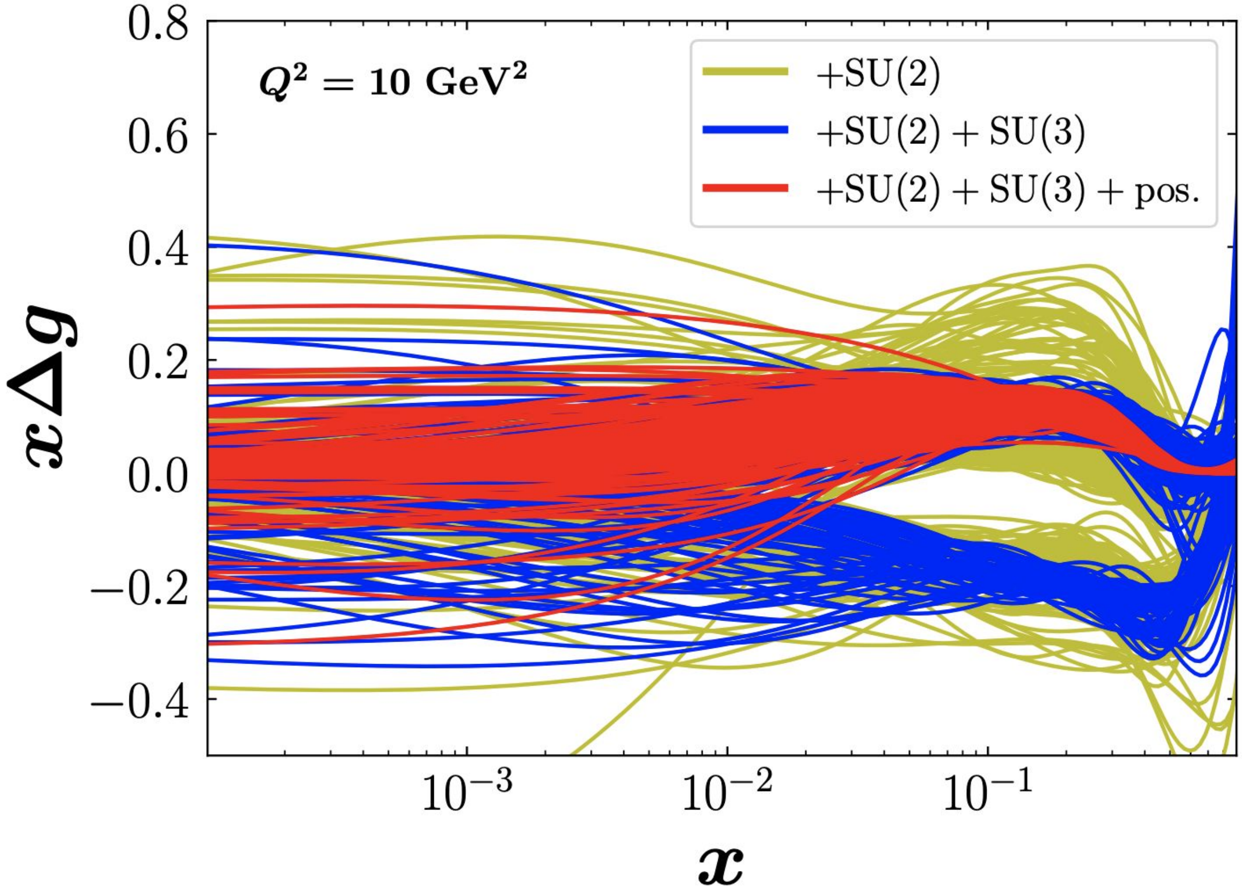
Good description of Jet data overall

First simultaneous extraction of helicity pdfs

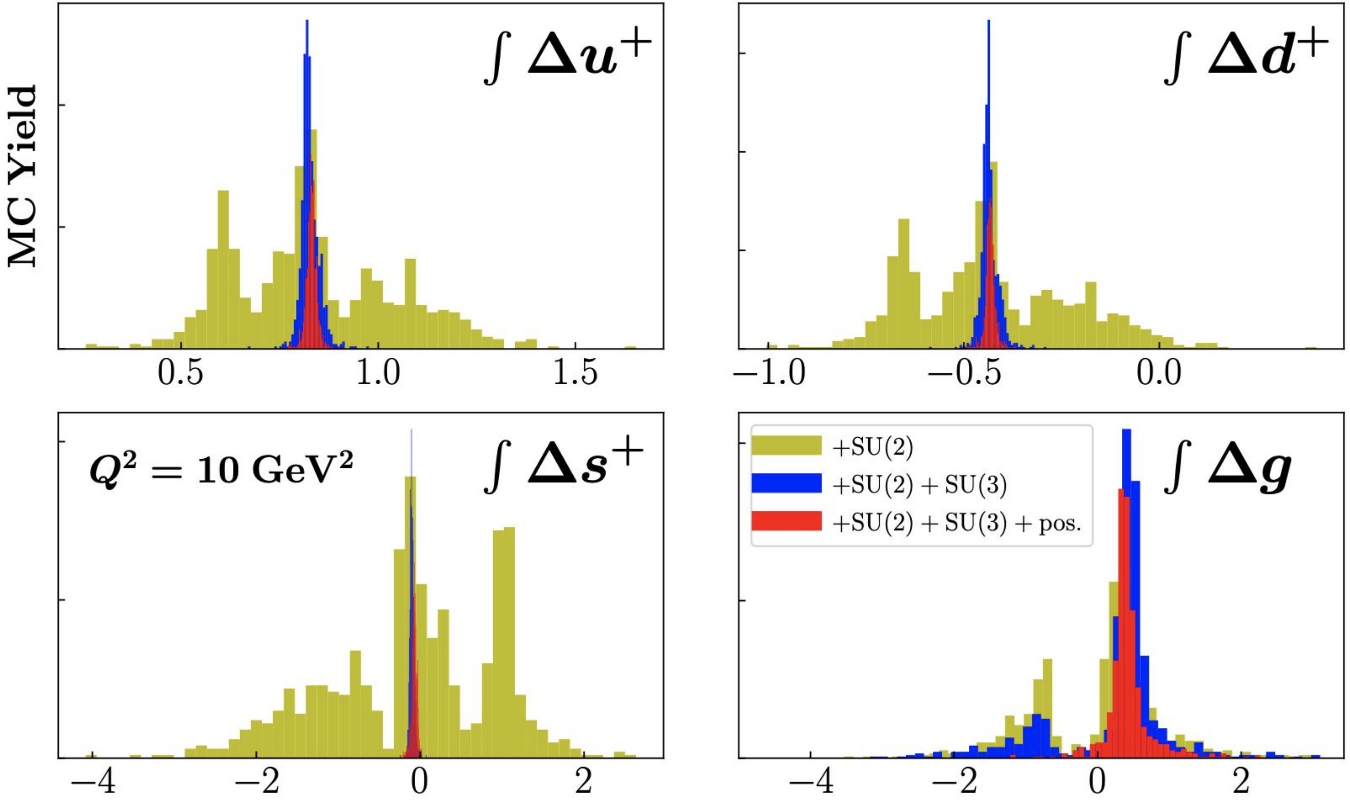


AUC discrimination test for helicity PDFs





Gluon polarization mostly driven by SU3+pos.



PDF are mostly driven from SU(3) constraints.

Summary & outlook

- New analysis of PDFs & FFs -> confirms nucleon strange suppression
- Inclusion of Marathon data -> isovector effects
- Combined pol. upol Jet -> the role of SU(3) and positivity
- Impact of future EIC

JAM collaboration

Staff / Faculty

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