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EIC impact on (un)polarized collinear PDFs

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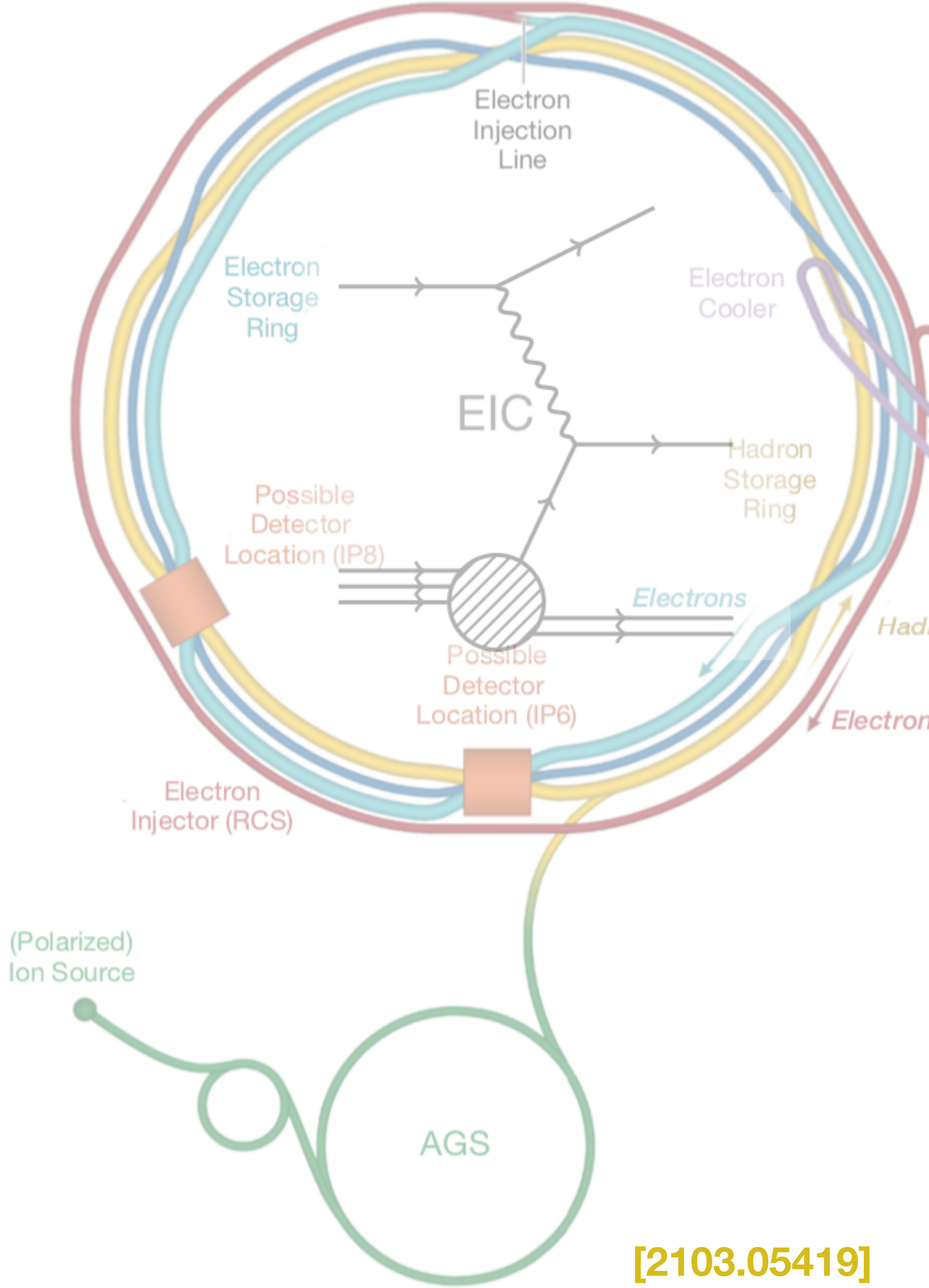
OUTLINE

- EIC impact on unpolarized PDFs

- on polarized PDFs
  - Double longitudinal asymmetry A_{LL}
  - Parity violating DIS asymmetry A_{UL}



[2103.05419]

EIC predictions: unpolarized PDFs

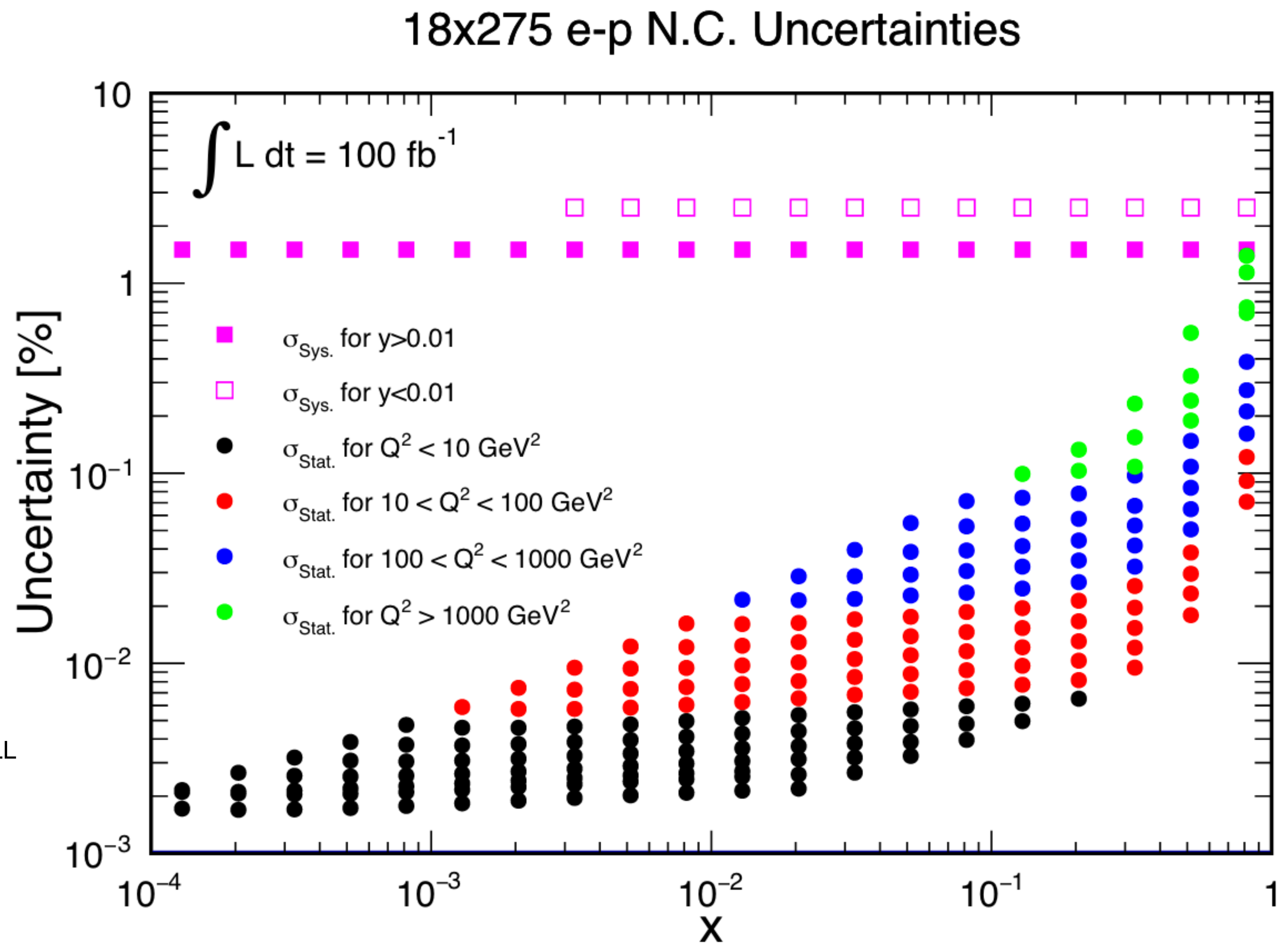
Current knowledge of unpolarized collinear PDFs has been driven by:

- inclusive neutral current (NC) and
- charged current DIS cross sections
- $p\bar{p}$ collisions at the Tevatron
- pp collisions at LHC

Range: *x* down to 10^{-5} and Q^2 up to 10^4 GeV^2.
Complementary in accessing the
small-x and large-*x* longitudinal hadron structure.

EIC: overlapping kinematic range between
HERA and the fixed-target experiments,
instantaneous luminosity 3 orders larger

Better constraint on existing measurements: A_{LL}
New observables available: A_{UL}



Simulated statistical and systematic uncertainties for eP NC DIS at $\sqrt{s} = 140.7$ GeV

PDFs at EIC: unpolarized reduced σ

To assess the impact of EIC data on the unpolarized PDF we study the reduced cross section for different configurations

Different scenarios

DIS Neutral Current

DIS Charged Current

$$\sigma_r = \frac{d\sigma^c}{dxdQ^2}\frac{xQ^4}{2\pi\alpha^2[1+(1-y)^2]} = F_2^c(x,Q^2) - \frac{y^2}{1+(1-y^2)}F_L^c(x,Q^2)$$

with electron and positron beam

For the neutral current

$$\left[F_2^\gamma, F_2^{\gamma Z}, F_2^Z\right] = x\sum_q \left[e_q^2, 2e_q g_V^q, g_V^{q2} + g_A^{q2}\right](q+\bar{q})$$

$$\left[F_3^\gamma, F_3^{\gamma Z}, F_3^Z\right] = \sum_q \left[0, 2e_q g_A^q, 2g_V^q g_A^q\right](q-\bar{q})$$

For the charged current

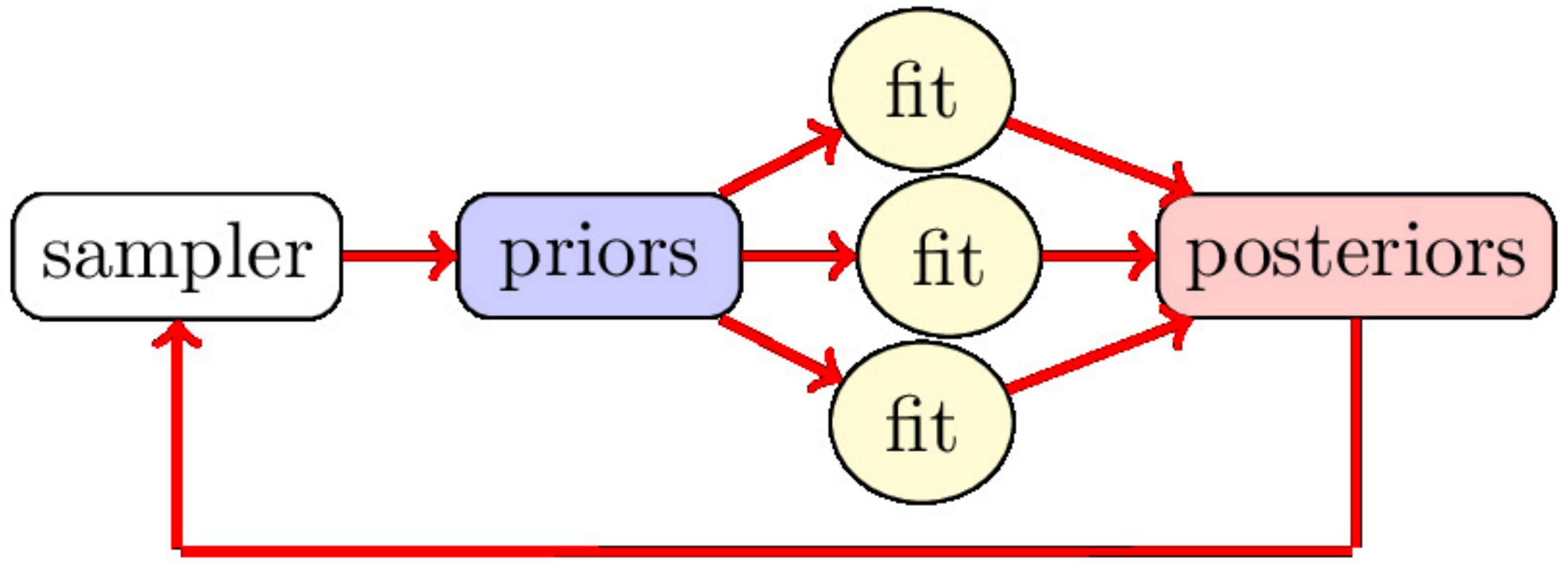
$$F_2^{W-} = 2x(u+\bar{d}+\bar{s}+c\ldots)$$

$$F_3^{W^-} = 2(u-\bar{d}-\bar{s}+c\ldots)$$

For W+ : $d \leftrightarrow u,\ s \leftrightarrow c$

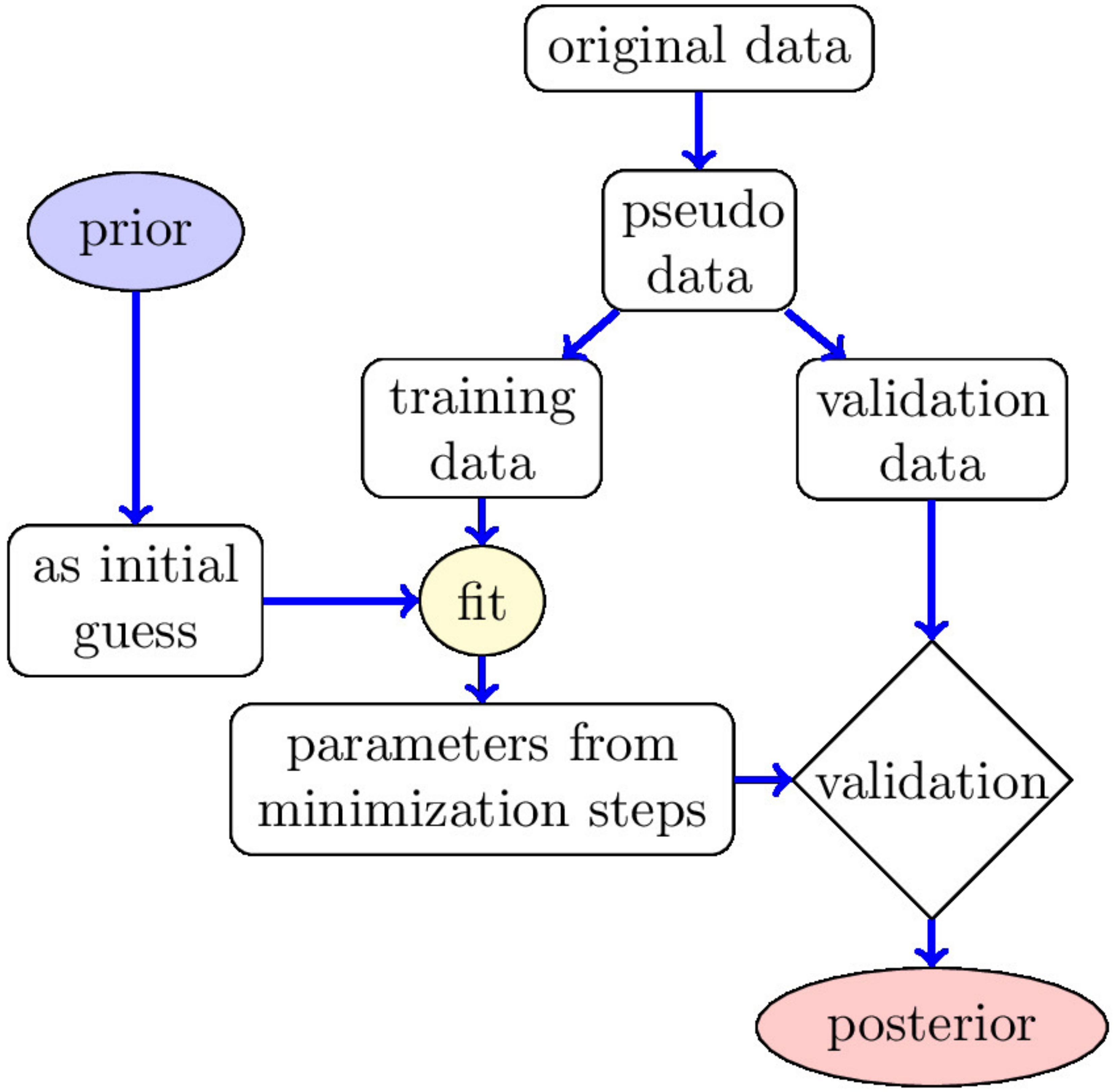
for neutron: $d \leftrightarrow u$

JAM Monte Carlo resampling methodology



PDF parametrization at input scale:

$$f(x) = Nx^{\alpha}(1-x)^{\beta}(1+\gamma\sqrt{(}x)+\eta x)$$



Determine set of parameters through Bayesian posterior resampling

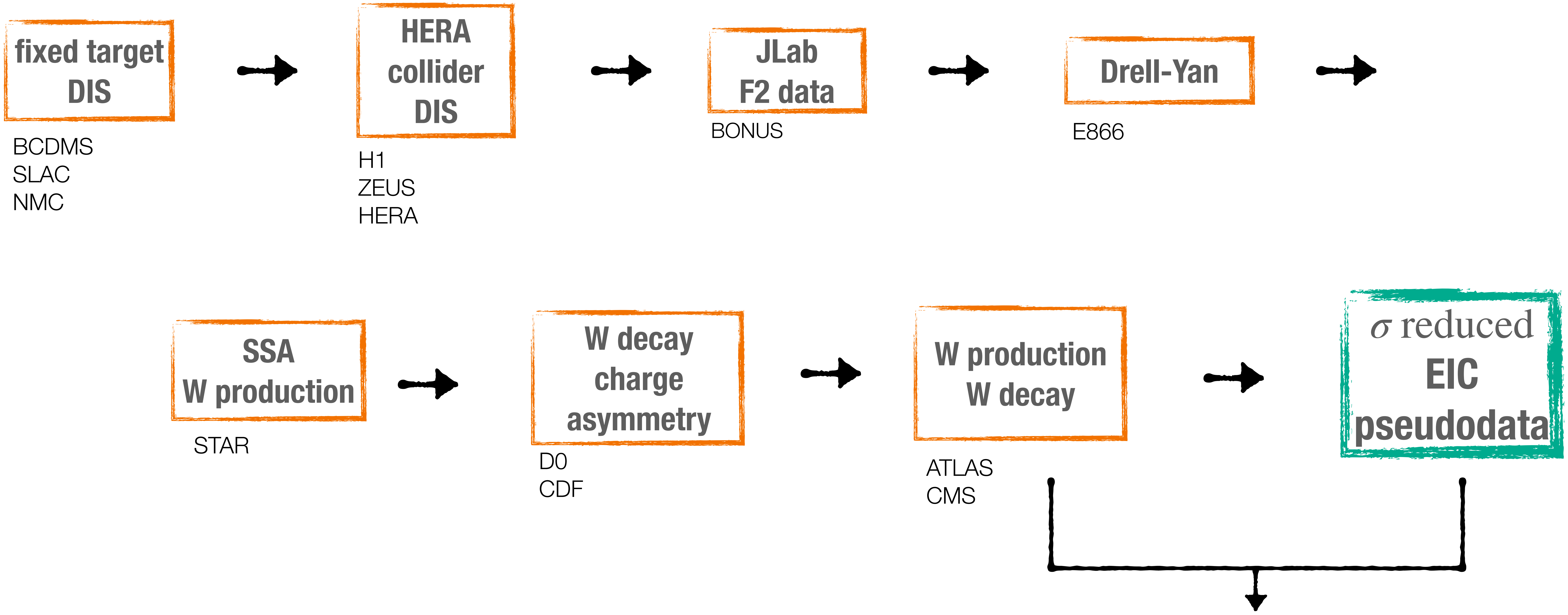
likelihood function $e^{-\frac{\chi^2}{2}}$

Multi-step procedure: repeated including additional datasets at each step

unpolarized EIC pseudodata

Multistep Monte Carlo procedure with Bayesian inference

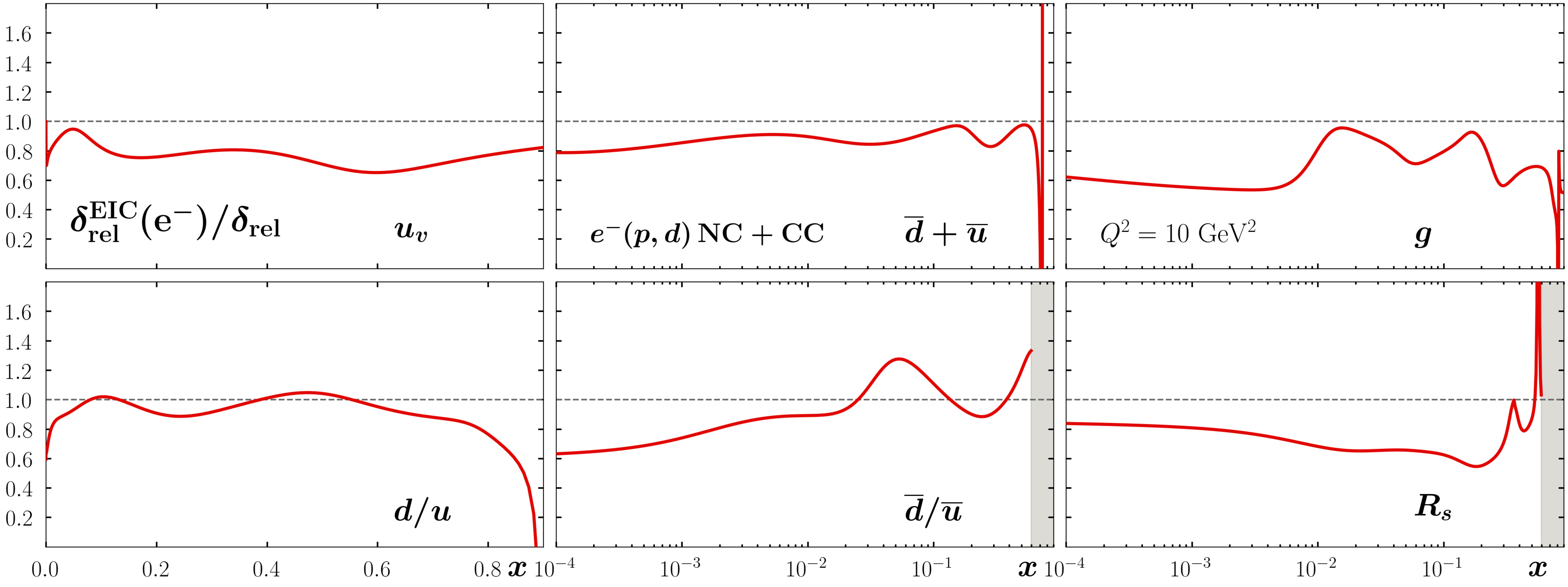
For spin-averaged PDFs



Compare the uncertainties of these two last steps

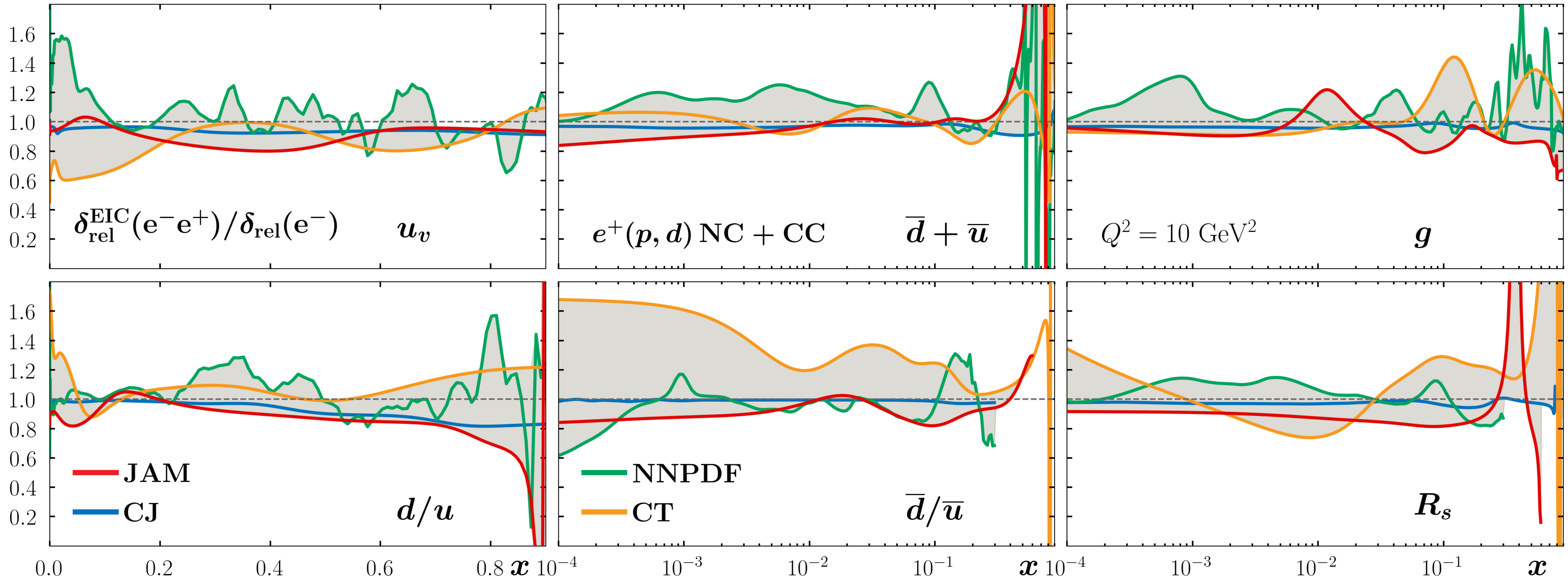
EIC impact: unpol. PDFs uncertainties

Comparison of relative uncertainties for unpolarized PDFs $xf(x)$ for multiple flavors, before and after the inclusion of EIC data for **electron beam**



EIC predictions: unpol. PDFs comparison

Comparison of relative uncertainties for unpolarized PDFs $xf(x)$ for multiple flavors, before and after the inclusion of EIC data for electron and positron beam <u>for different collaborations</u>



EIC predictions: impact on Δg uncertainties

A precise determination of the helicity gluon distribution function
***Δg** is one of the golden measurements of nucleon spin structure at the EIC*

EIC White Paper [1212.1701]

Proton Spin Puzzle: Open problem since EMC experiment

$$\frac{1}{2} = S_q + L_q + S_g + L_g$$

In particular for **gluons**

JAM

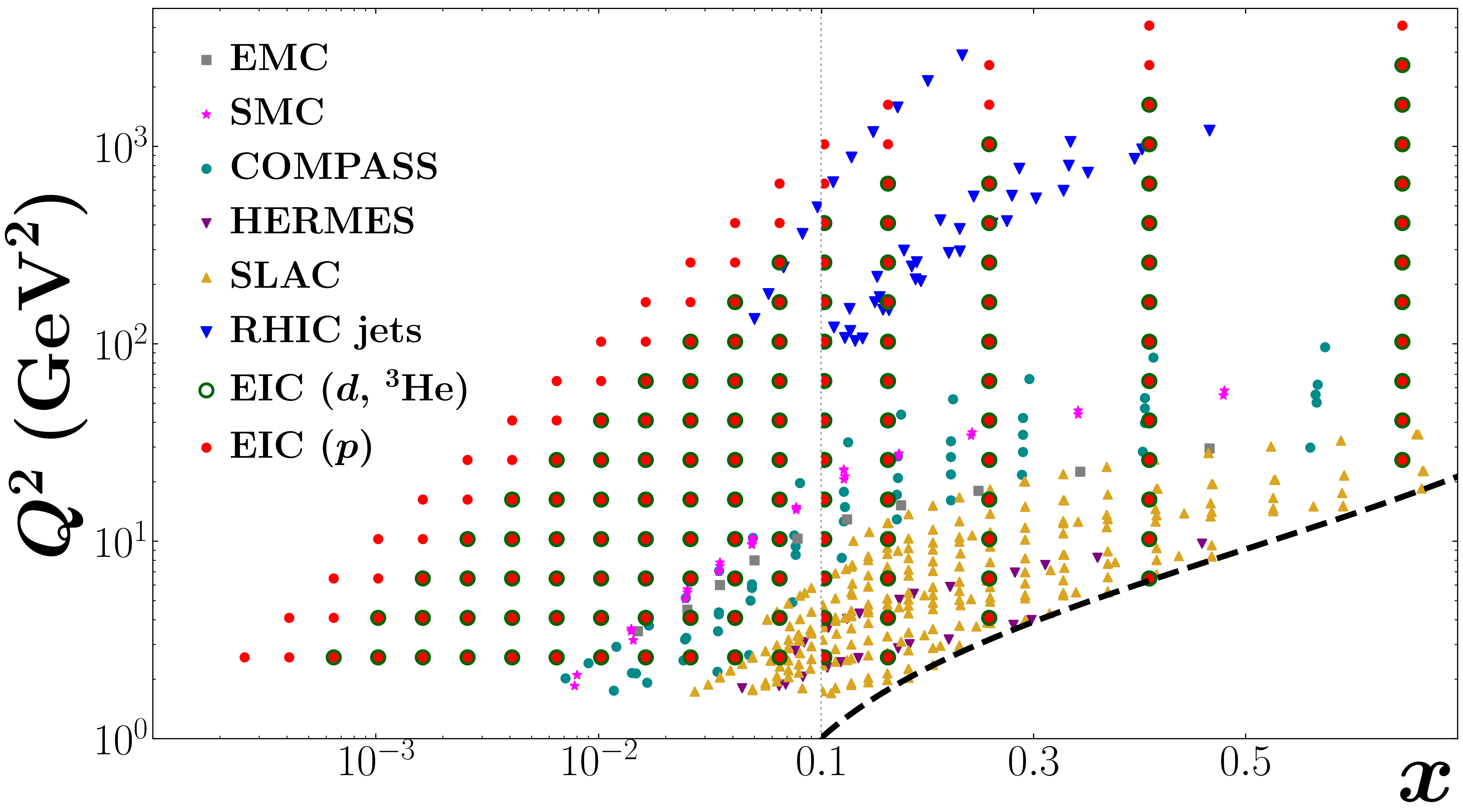
[2105.04434] -> PRD

$$S_g(Q^2) = \int_0^1 \Delta_g(x, Q^2) dx$$

$$\Delta f\left(x, Q^2\right) \equiv f^+\left(x, Q^2\right) - f^-\left(x, Q^2\right)$$

with f+ (f–) denoting the number density of partons with the same (opposite) helicity as the nucleons

Impact on polarized PDFs



DOUBLE LONGITUDINAL SPIN ASYMMETRY

$$A_{LL} = \frac{\sigma^{\uparrow\Uparrow} - \sigma^{\downarrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}}$$

longitudinally polarized e$^-$ off longit. polarized hadrons

PARITY VIOLATING ASYMMETRY

$$A_{\mathrm{UL}} = \frac{\sigma^{\Uparrow} - \sigma^{\Downarrow}}{\sigma^{\Uparrow} + \sigma^{\Downarrow}}$$

unpolarized leptons off
Longitudinally polarized hadrons

→ impact of future EIC data on quark and gluon helicity distributions in the proton

EIC impact on helicity PDFs

- EIC will cover a wider range of (x,Q^2)
- How much this will improve our determination of Δg ?

Pseudodata for double-spin asymmetry

$$A_{LL} = \frac{\sigma^{\uparrow\Uparrow} - \sigma^{\downarrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}} = D\left(A_1 + \eta A_2\right),$$

$$A_1 = \frac{(g_1 - \gamma^2 g_2)}{F_1}, \qquad A_2 = \gamma \frac{(g_1 + g_2)}{F_1}$$

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

$$g_1(x,Q^2) = \frac{1}{2}\sum_q e_q^2 \left(\left[\Delta C_{1q} \otimes \Delta q^+\right](x,Q^2) + \left[\Delta C_{1g} \otimes \Delta g\right](x,Q^2)\right)$$

Flavor separation p, d, ^{3}He

Parity violating asymmetry

$$A_{\mathrm{UL}} = \frac{\sigma^{\Uparrow} - \sigma^{\Downarrow}}{\sigma^{\Uparrow} + \sigma^{\Downarrow}}$$

scattering of unpolarized leptons
from longitudinally polarized hadrons

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

$$g_1^{\gamma Z}(x, Q^2) = \sum_q e_q g_V^q \Big(\big[\Delta C_{1q} \otimes \underline{\Delta q^+}\big](x, Q^2) + 2\big[\Delta C_{1g} \otimes \underline{\Delta g}\big](x, Q^2) \Big)$$

$$g_5^{\gamma Z}(x, Q^2) = \sum_q e_q g_A^q \big[\Delta C_{5q} \otimes \underline{\Delta q^-}\big](x, Q^2)$$

Independent linear combination of helicity PDFs together with g_1 allow cleaner flavor separation

Polarized pseudodata

Multistep Monte Carlo with Bayesian inference

For spin-averaged PDFs

fixed target DIS → **HERA collider DIS** → **Drell-Yan** → **Jet production** → **parameters of the spin-averaged PDFs are fixed**

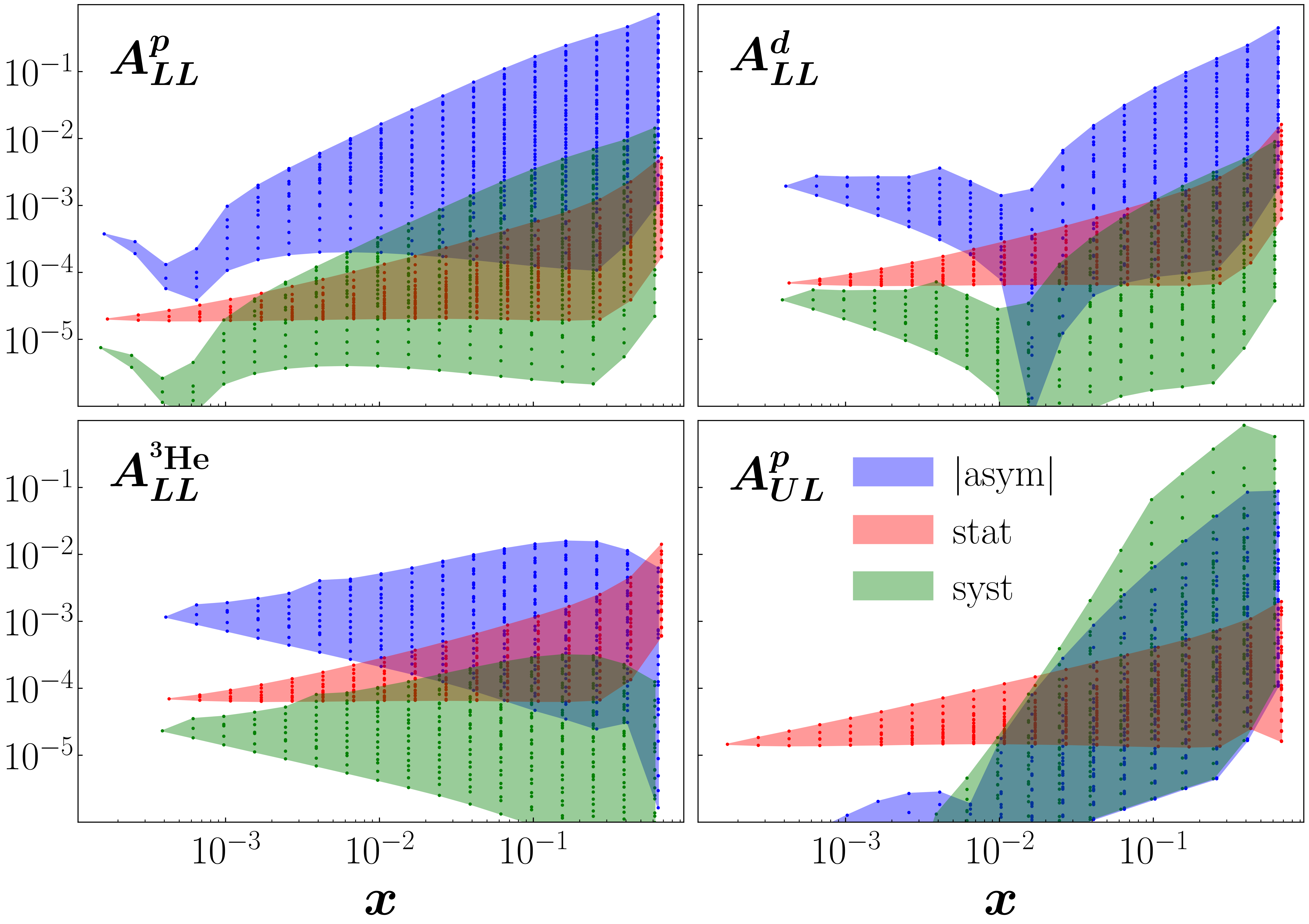
- fixed target DIS: BCDMS, SLAC, NMC
- HERA collider DIS: H1, ZEUS, HERA
- Drell-Yan: E866
- Jet production: D0, CDF, STAR

For spin-dependent PDFs

→ **polarized DIS** → **RHIC jet data Polarized pp** → **EIC pseudodata**

- polarized DIS: EMC, SMC, COMPASS, SLAC, HERMES
- RHIC jet data Polarized pp: STAR, PHENIX

Baseline PDFs for EIC pseudodata



6 scenarios

absolute statistical uncertainties for the asymmetries

$$\delta A \approx \frac{1}{\sqrt{\mathscr{L}\,\sigma_{\mathrm{unp}}}},$$

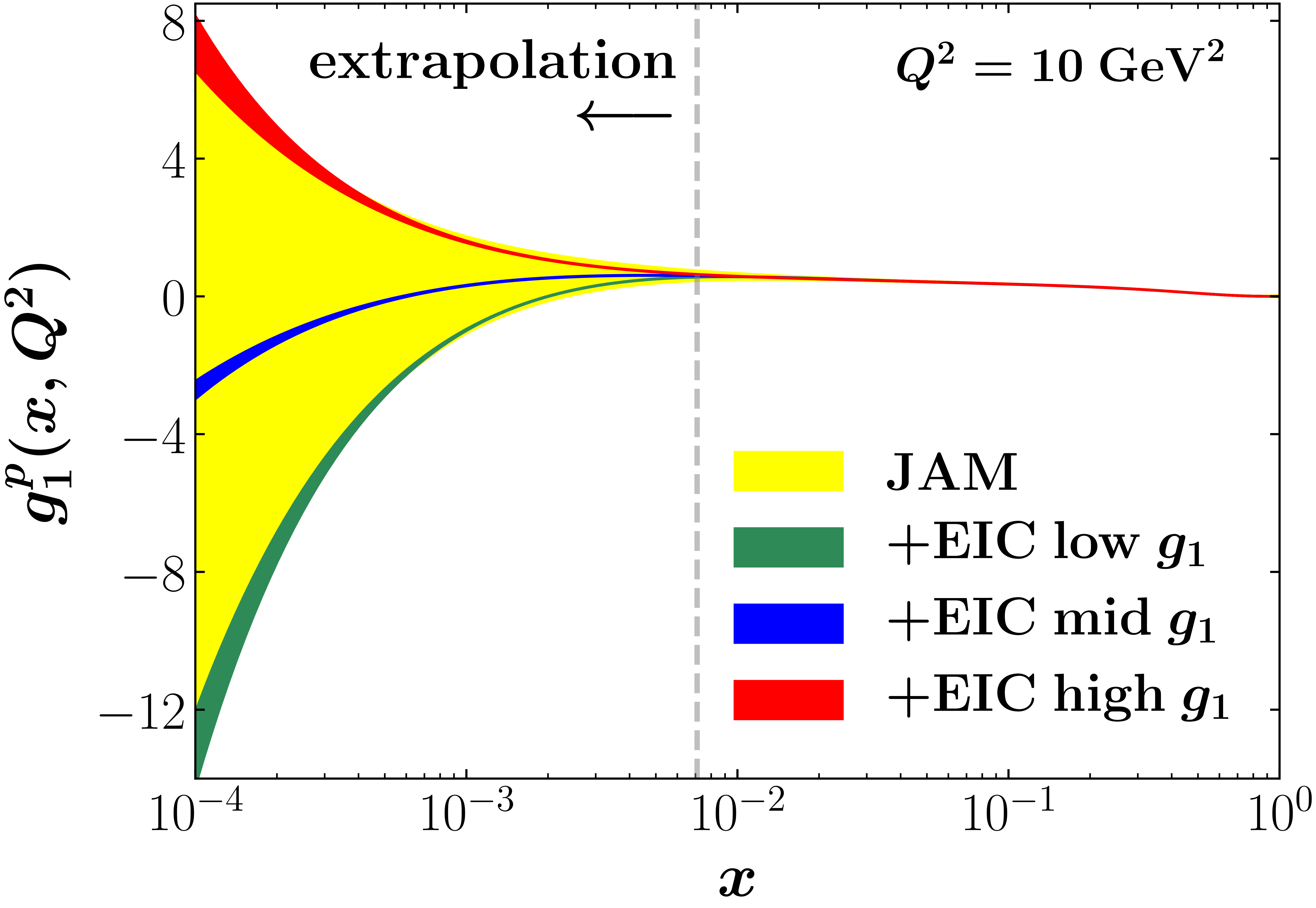
low $-1\,\sigma$ **mid** **high** $+1\,\sigma$

Imposing or not **SU(3) flavor symmetry**

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

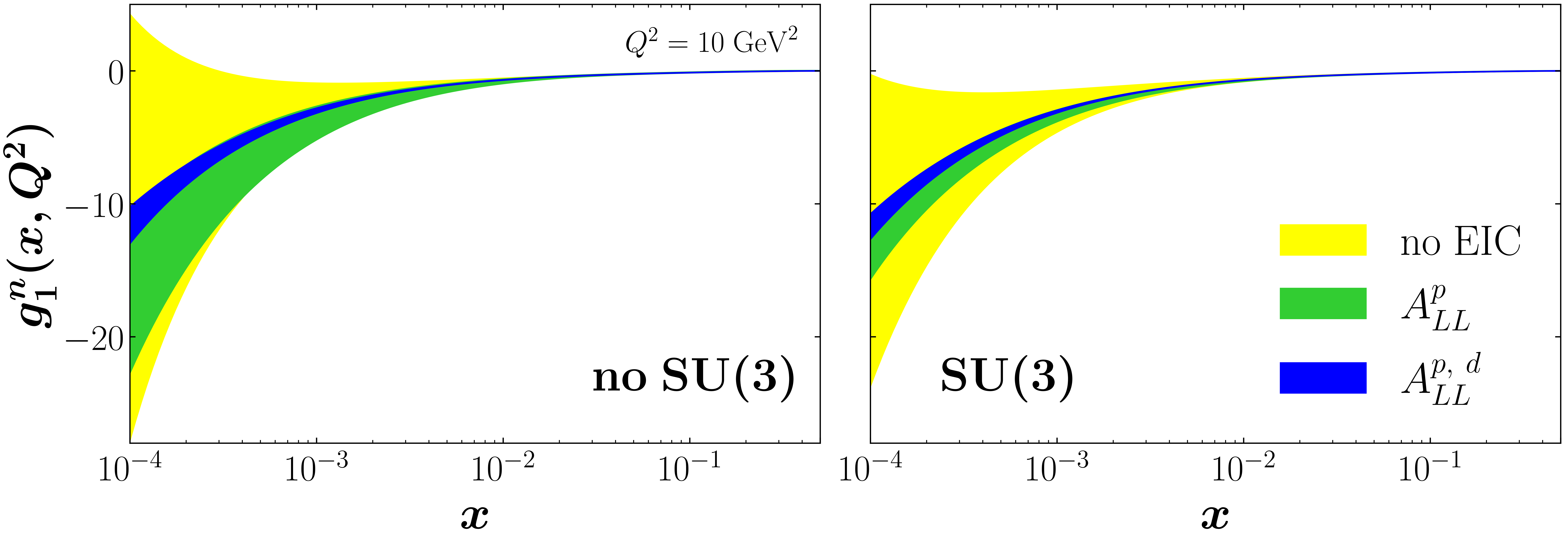
$$\int_0^1 dx\big[\Delta u^+(x,Q^2) + \Delta d^+(x,Q^2) - 2\Delta s^+(x,Q^2)\big] = a_8$$

EIC impact on g_1 uncertainties



Impact of projected e-p A_{LL} data on the proton g_1^p structure function

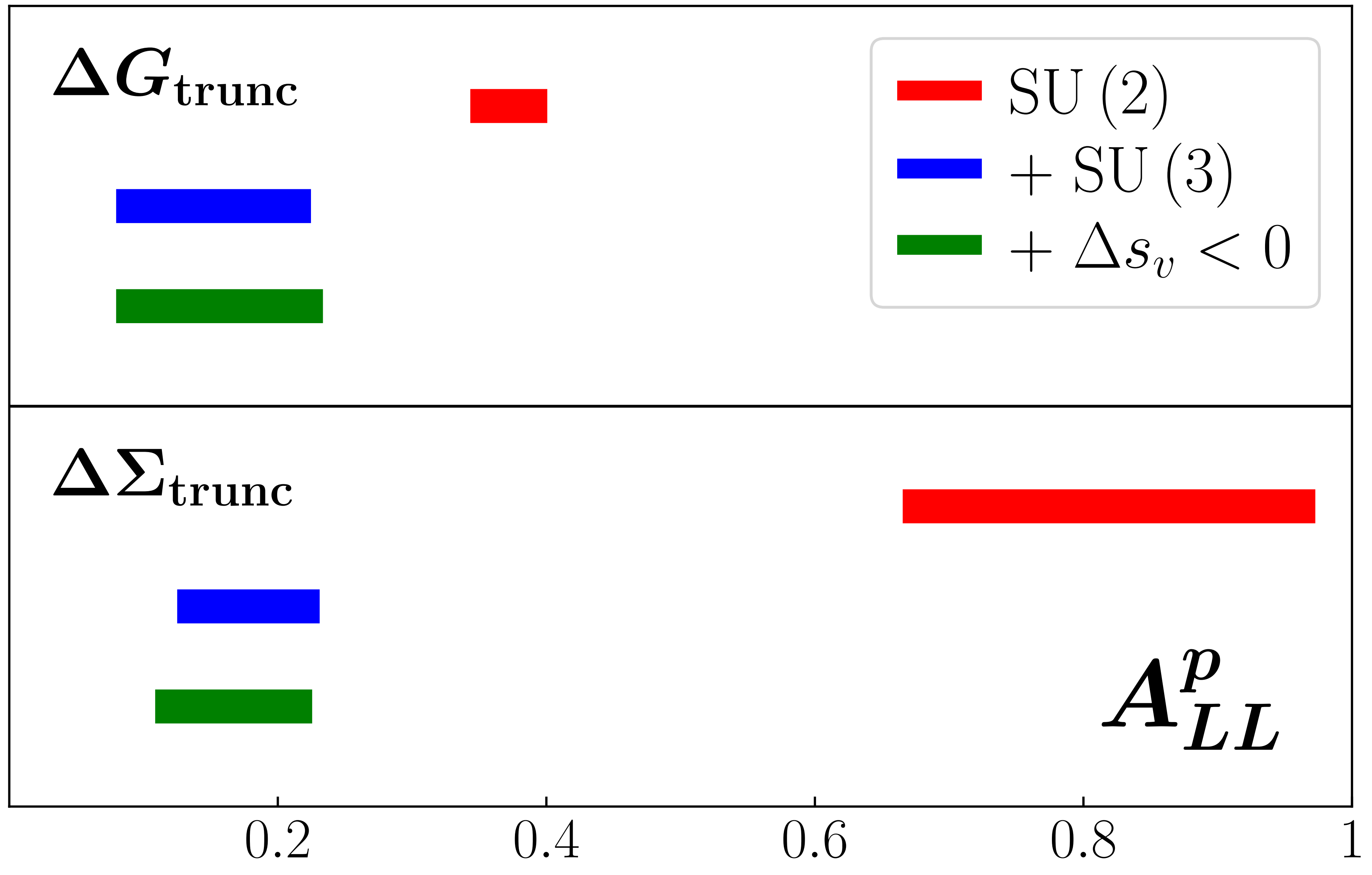
EIC impact on g_1 uncertainties



Impact of projected e-p A_{LL} data
on the neutron g_1^p structure function

EIC impact on truncated moments

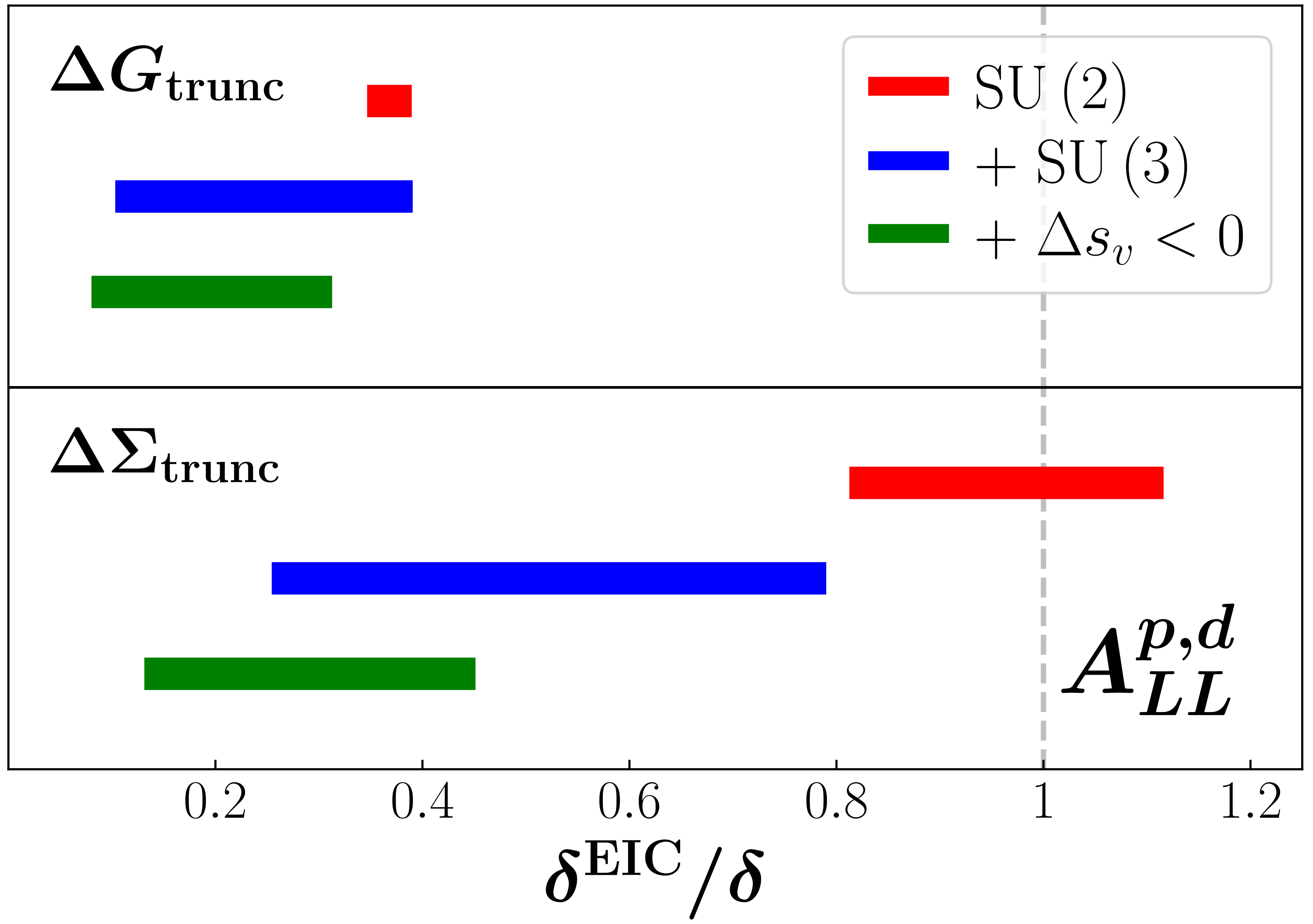
PROTON



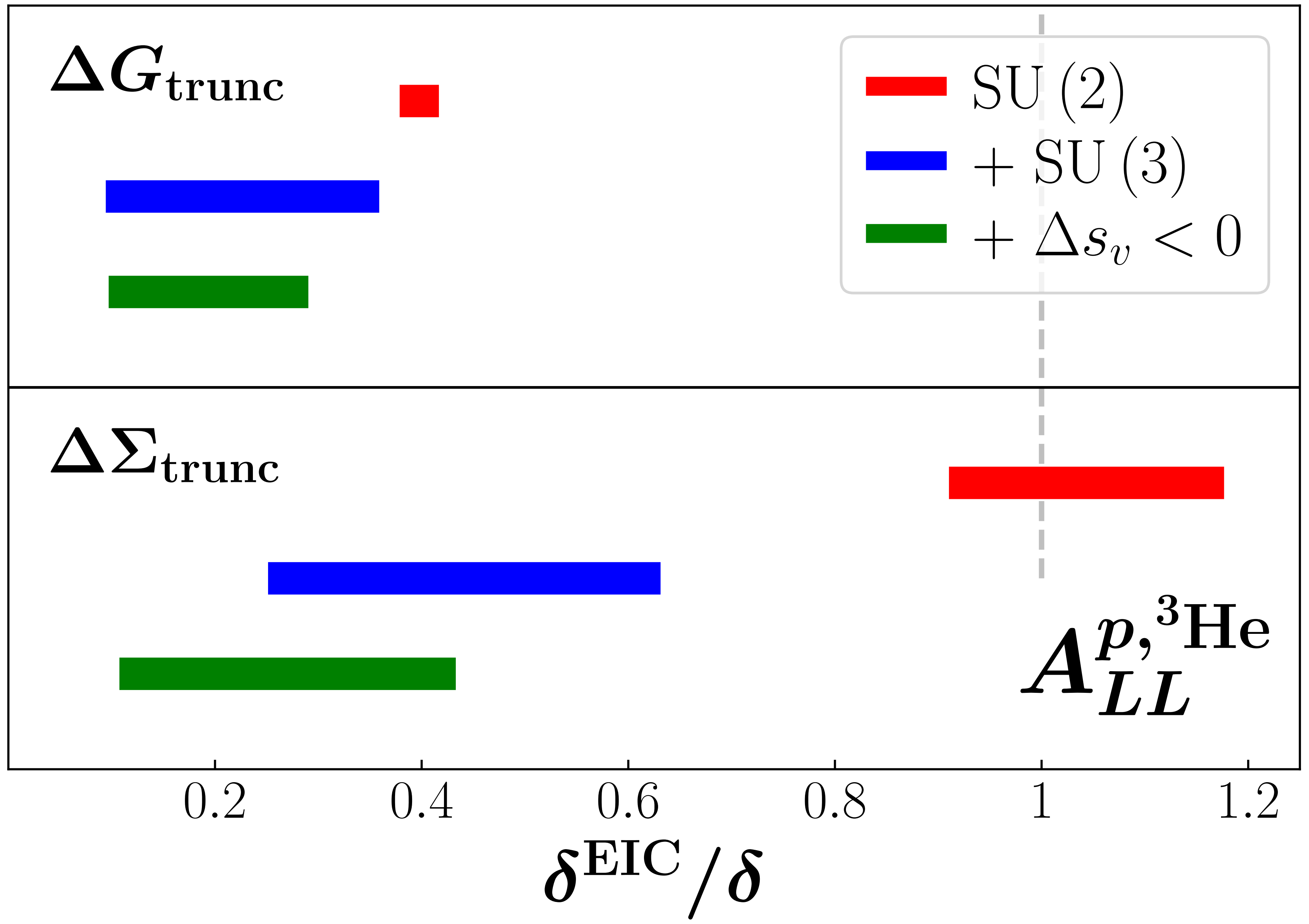
$$\Delta\Sigma_{\text{trunc}}\left(Q^2\right) = \sum_q \int_{10^{-4}}^{1} dx \left[\Delta q(x, Q^2) + \Delta\bar{q}(x, Q^2)\right]$$

$$\Delta G_{\text{trunc}}\left(Q^2\right) = \int_{10^{-4}}^{1} dx\, \Delta g(x, Q^2)$$

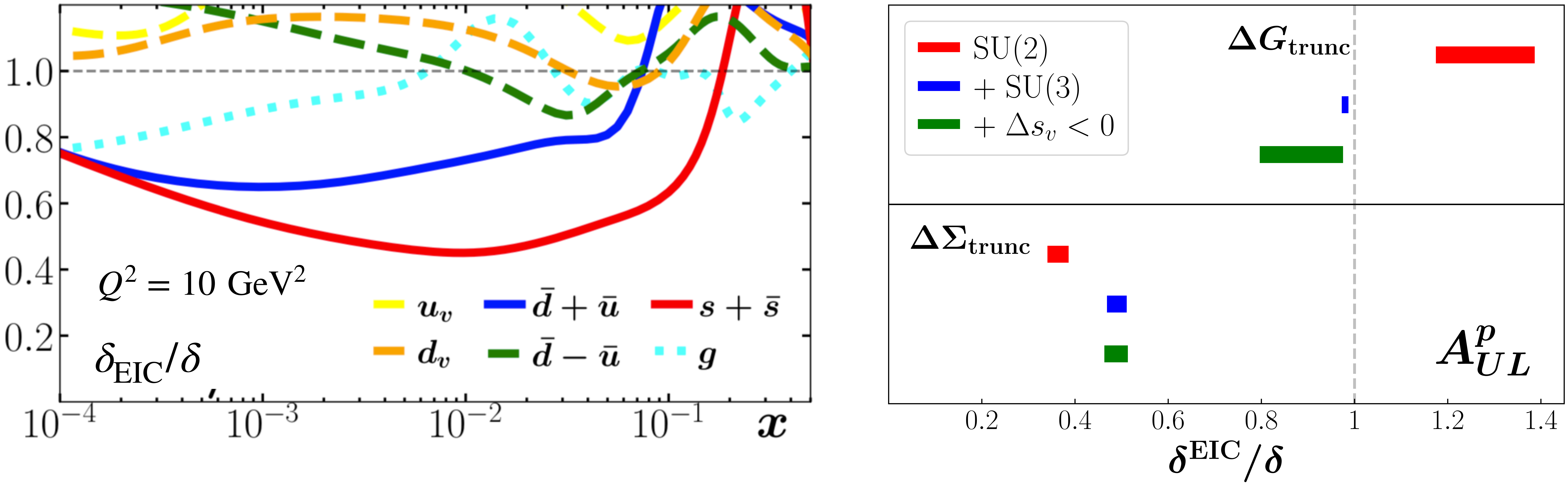
P + DEUTERON



HELIUM



PDFs constraints from A_{UL} pseudo data



Ratio of uncertainties on the PDFs as functions of x, including EIC data on the PVDIS asymmetry A_{PV} to those without EIC data

Conclusions

We performed a dedicated impact study of future EIC data on unpolarized cross section and polarization asymmetries, based on a global fit with a Monte Carlo approach

There is a significant impact in the unpolarized PDFs, mostly in the valence case

Study of polarized asymmetries can greatly improve the determination of helicity PDFs at low-x. ALL and APV acts in an almost complementary way on the quark singlet and gluon moment.

The EIC facility will provide unprecedented access to the flavor and spin structure of the nucleon in previously unexplored regions of kinematics at low x values