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# EIC impact on collinear PDFs


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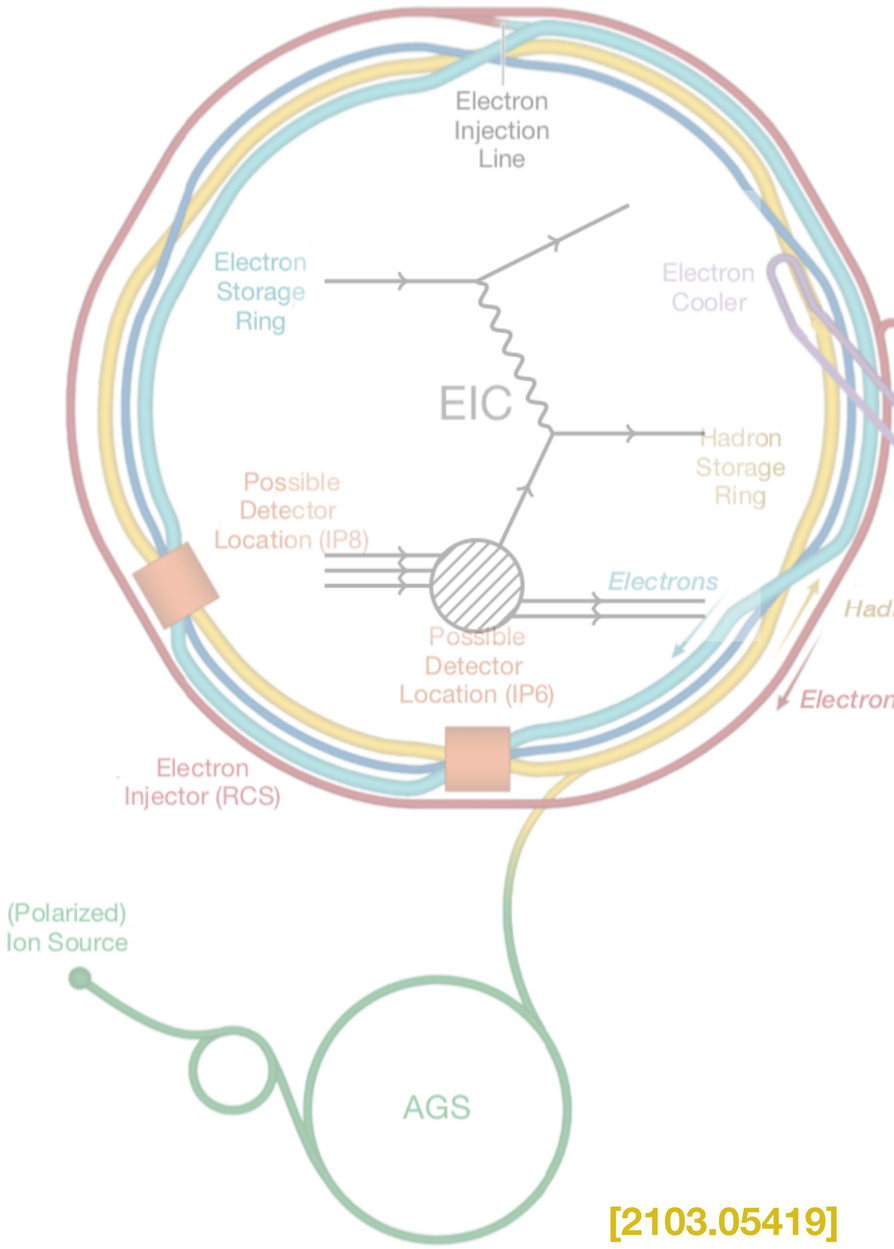
# OUTLINE

- EIC impact on unpolarized PDFs
- on polarized PDFs
  - Double longitudinal asymmetry $A_{LL}$
  - Parity violating DIS asymmetry $A_{PV}$




[2103.05419]

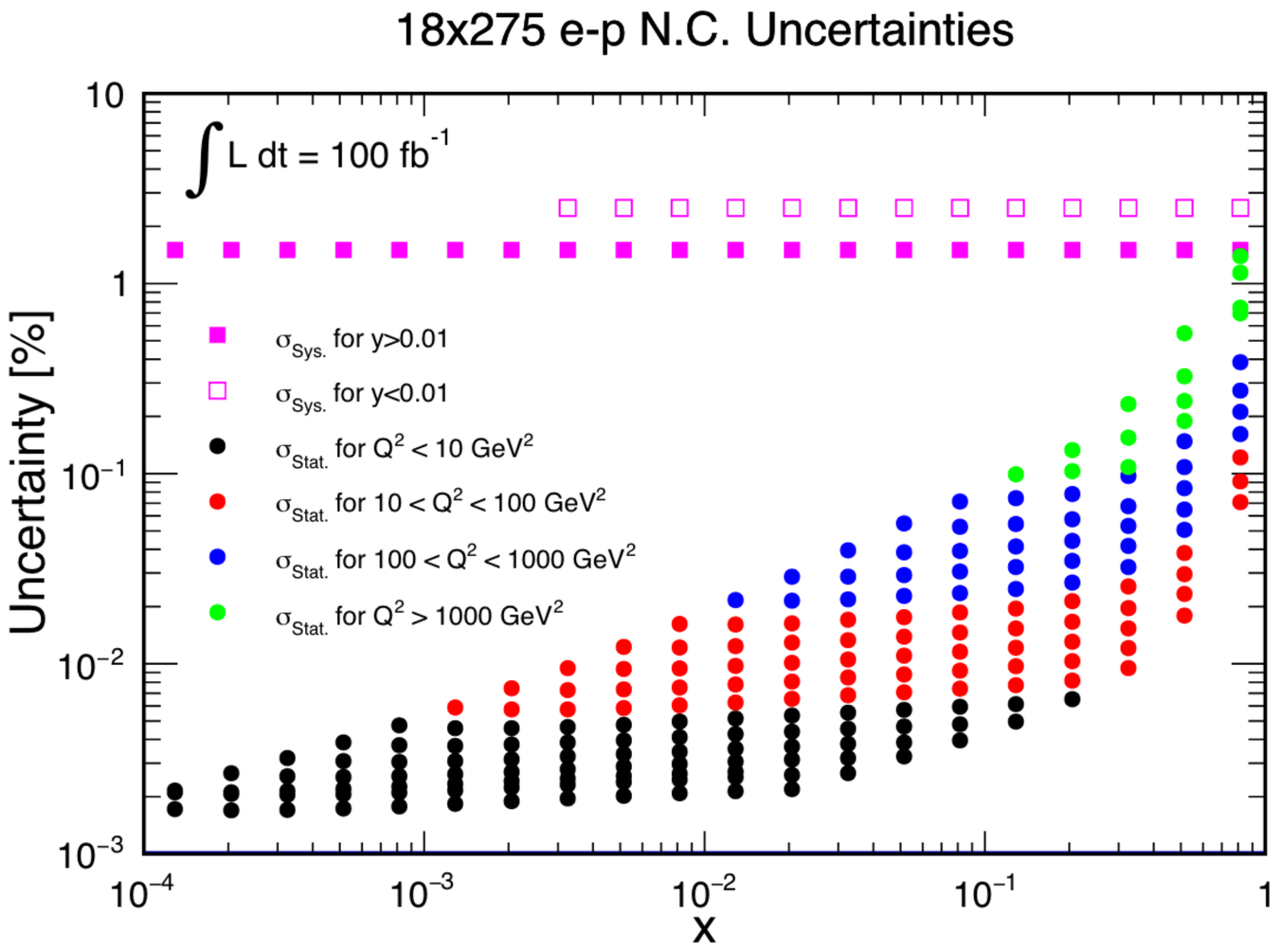
# EIC predictions: unpolarized PDFs

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




Simulated statistical and systematic uncertainties for $eP$ NC DIS at $\sqrt{s} = 1$

# 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

with electron and positron beam

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

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

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

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

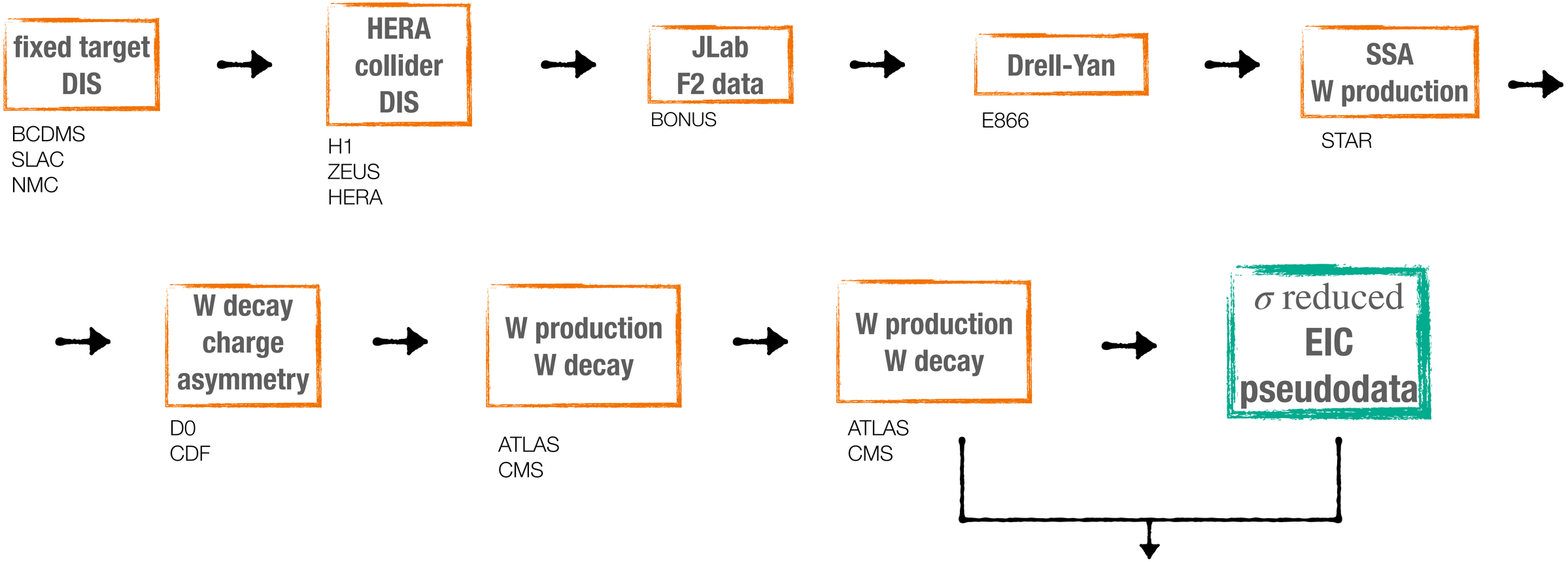
For W+ : $d \leftrightarrow u,\ s \leftrightarrow c$

for neutron: $d \leftrightarrow u$

# unpolarized EIC pseudodata

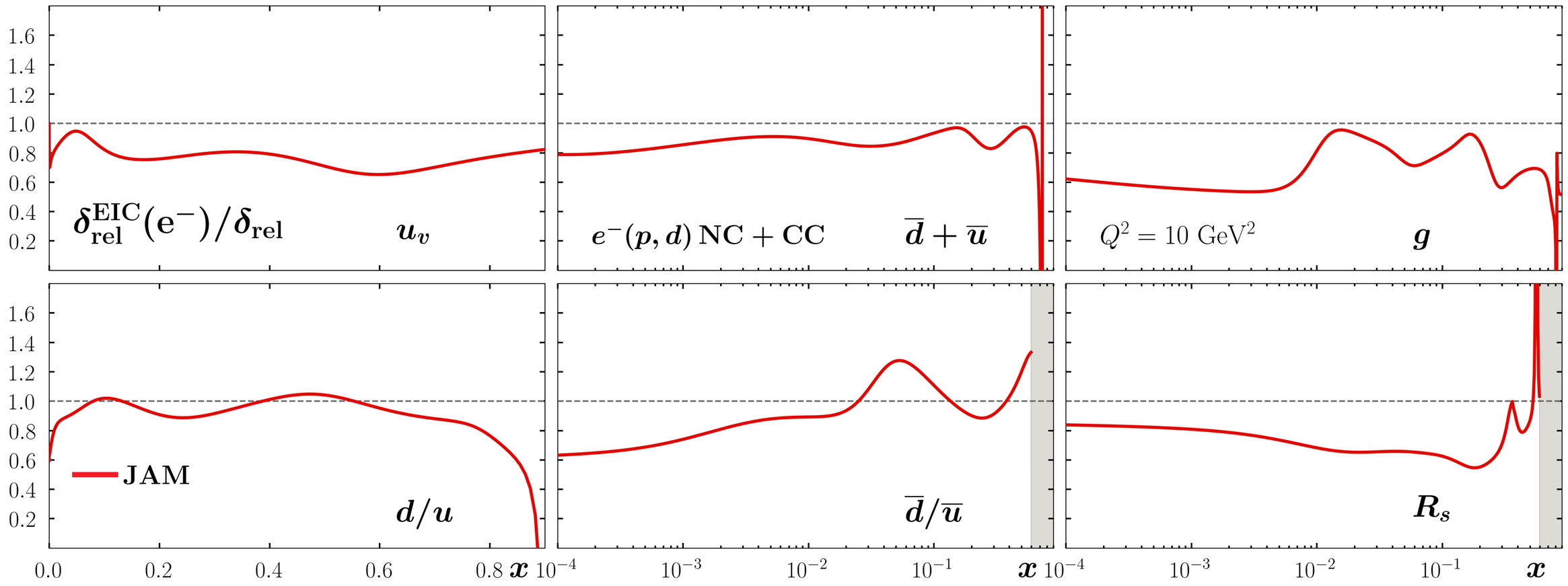
Multistep Monte Carlo procedure with Bayesian inference

For spin-averaged PDFs



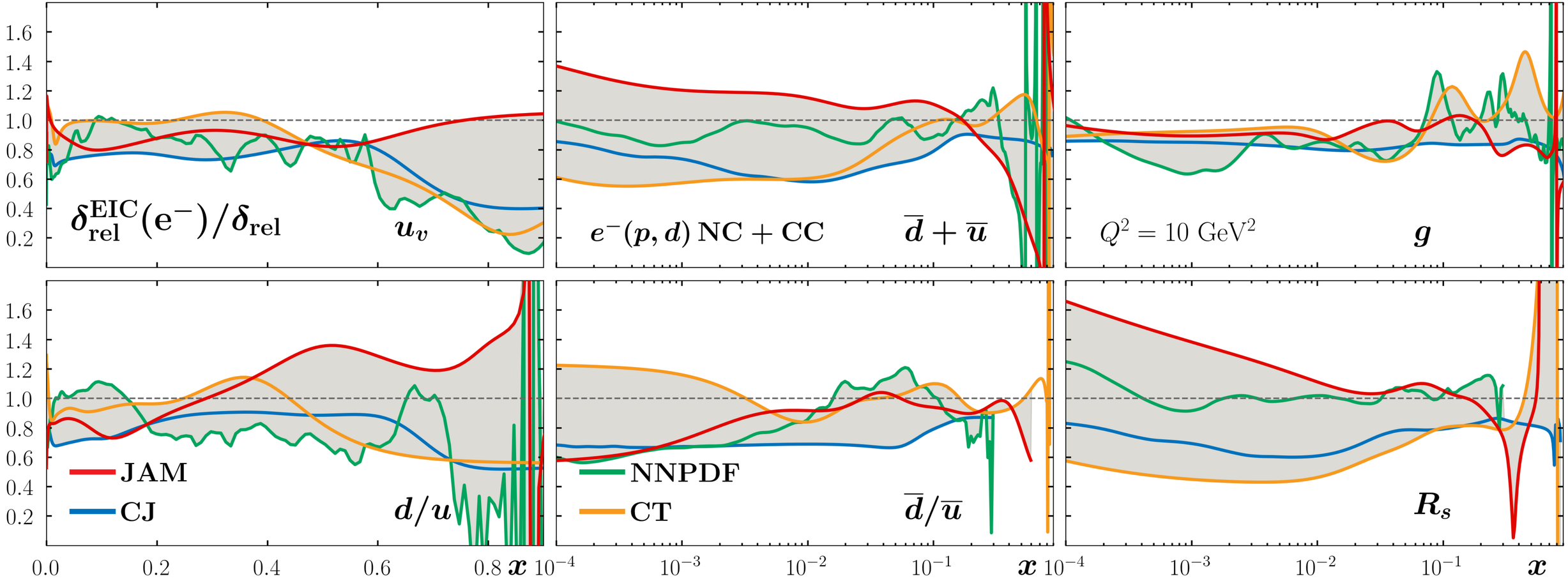

Compare the uncertainties of these two last steps

# EIC impact: unpol. PDFs uncertainties



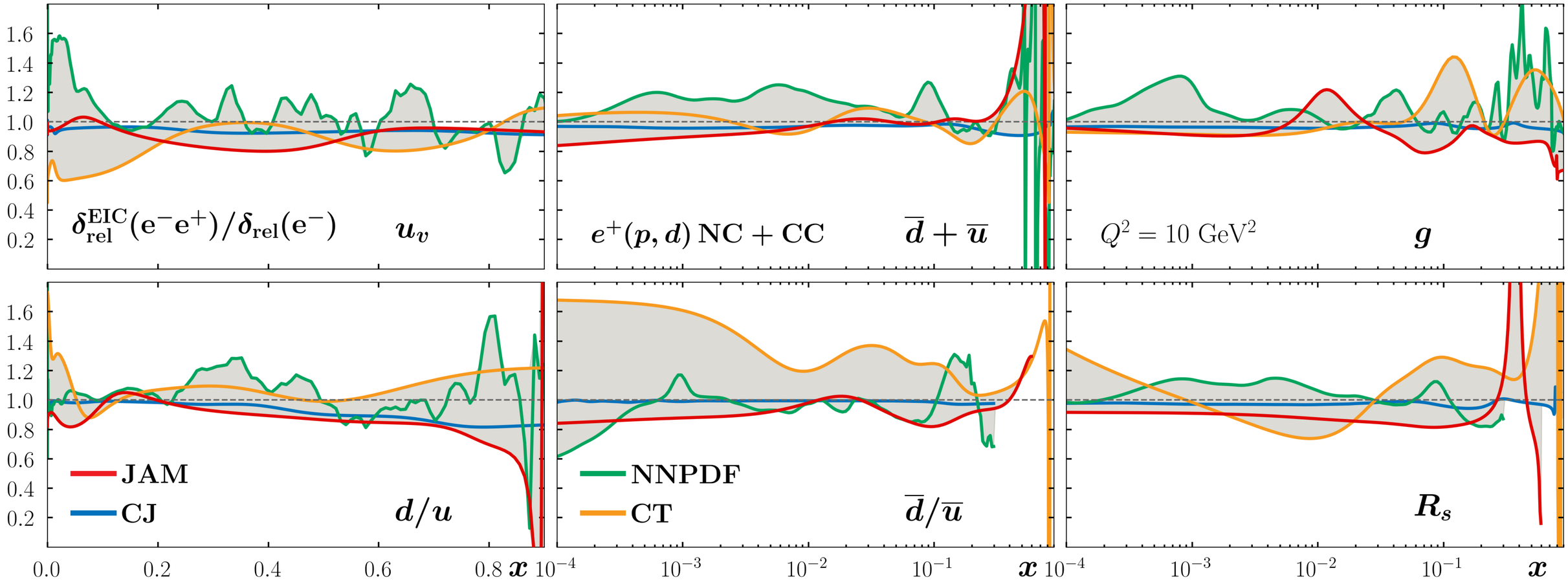

Comparison of relative uncertainties for unpolarized PDFs $xf(x)$ for multiple flavors, before and after the inclusion of EIC data for electron beam

# 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 beam for different collaborations

# 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

# 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**

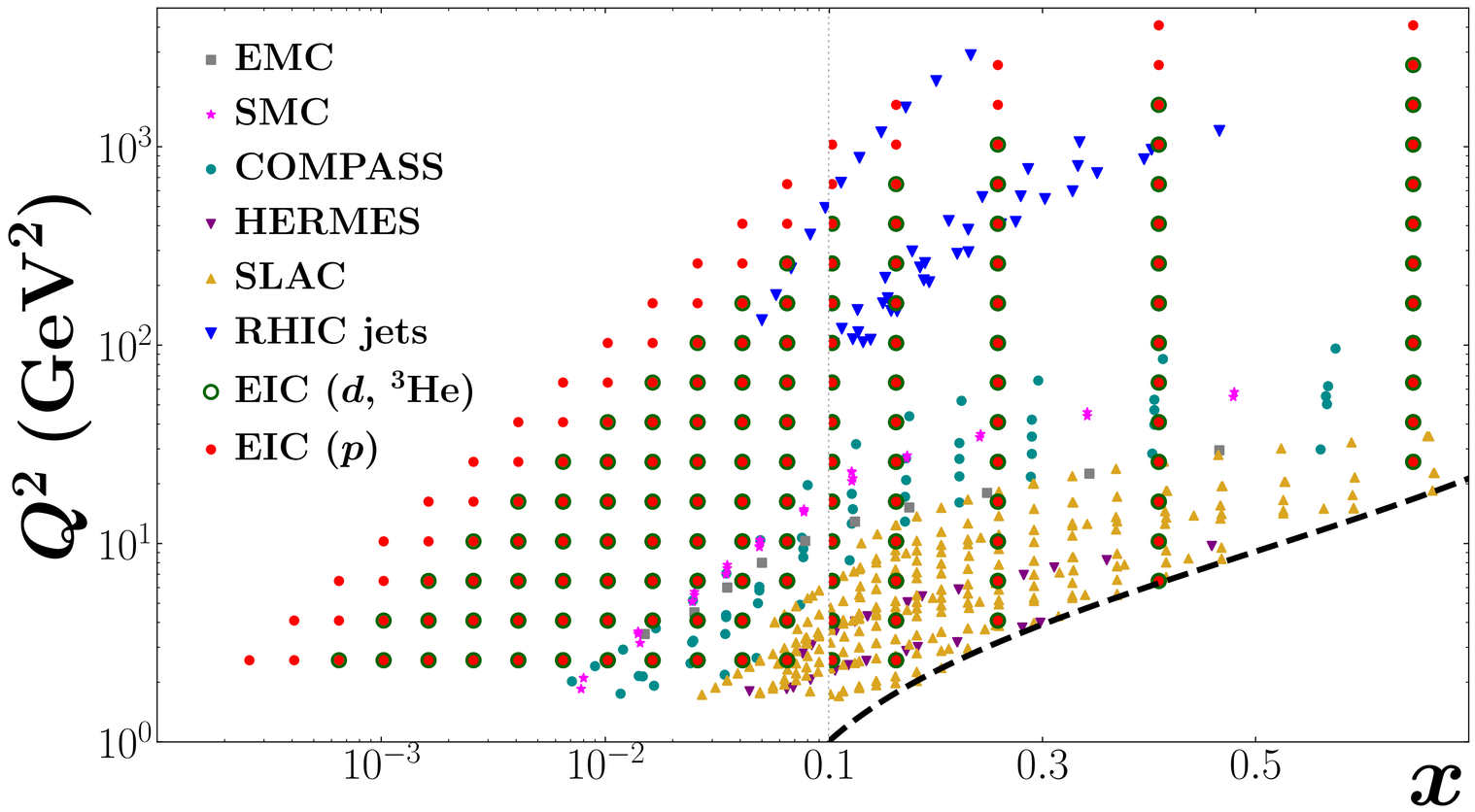
$$S_g(Q^2) = \int_0^1 \Delta_g(x, Q^2) dx$$

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

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

$$g_1^h(x, Q^2, z) = \frac{1}{2} \sum_q e_q^2 \left[\Delta q(x, Q^2) D_q^h(z, Q^2) + \Delta \bar{q}(x, Q^2) D_{\bar{q}}^h(z, Q^2)\right]$$

# 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

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

unpolarized leptons off longit. 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

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

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

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

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

Flavor separation $\mathrm{p, d, {}^3He}$

# Parity violating asymmetry

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

scattering of unpolarized leptons
from longitudinally polarized hadrons

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

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

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

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**

BCDMS
SLAC
NMC

H1
ZEUS
HERA

E866

D0
CDF
STAR

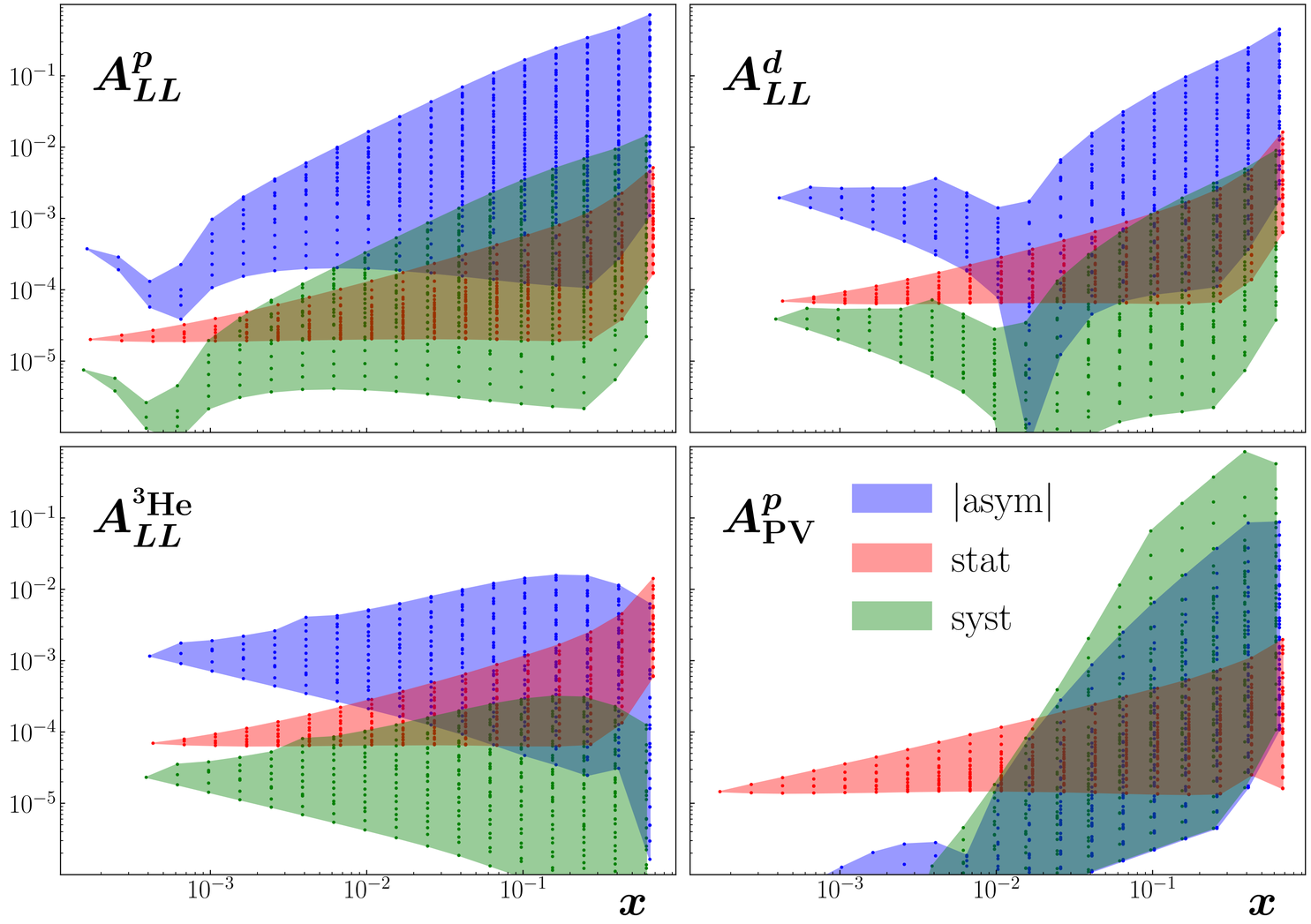
For spin-dependent PDFs

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

EMC, SMC
COMPASS
SLAC
HERMES

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** **mid** **high**

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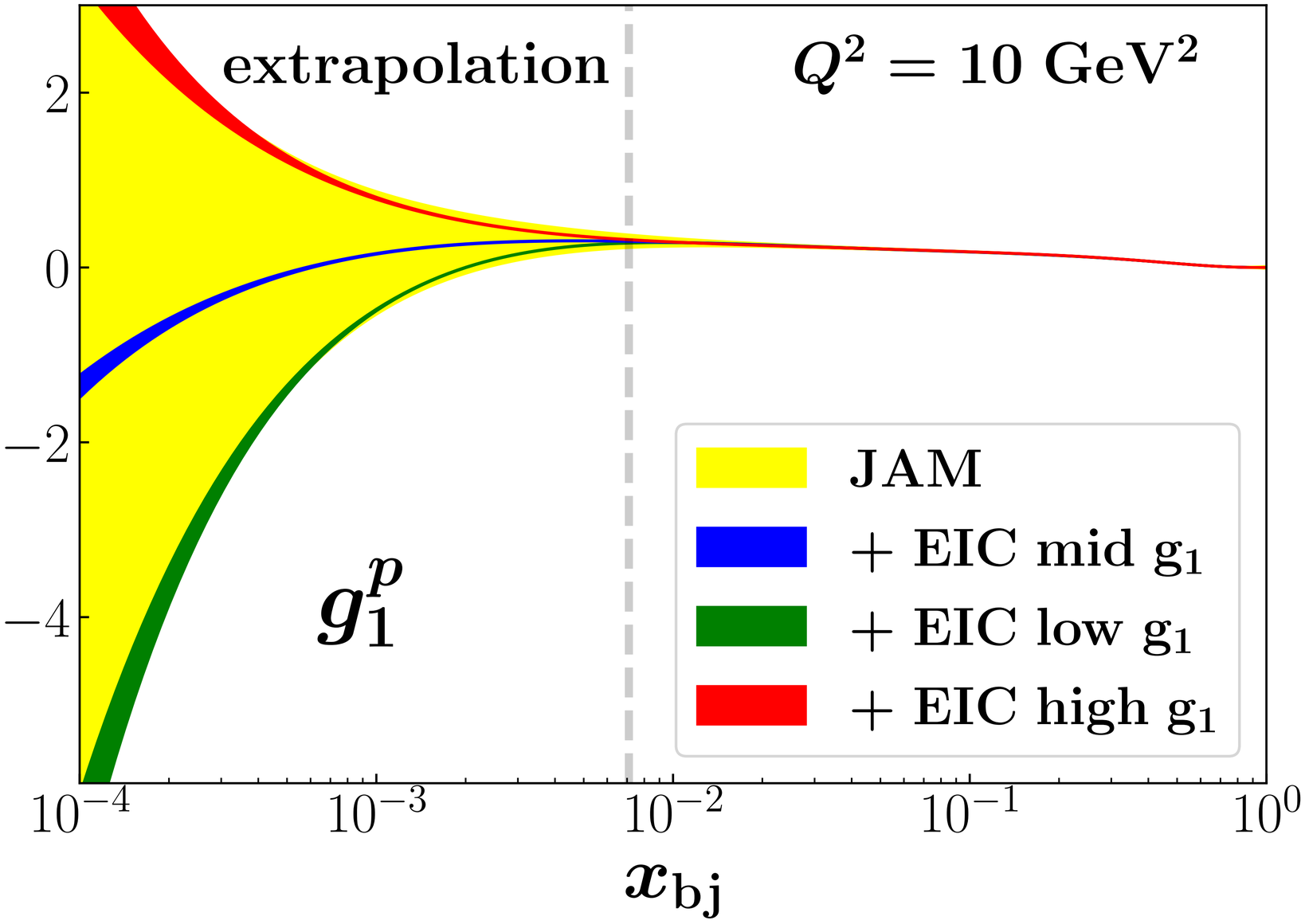
Imposing or not **SU(3) flavor symmetry**

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

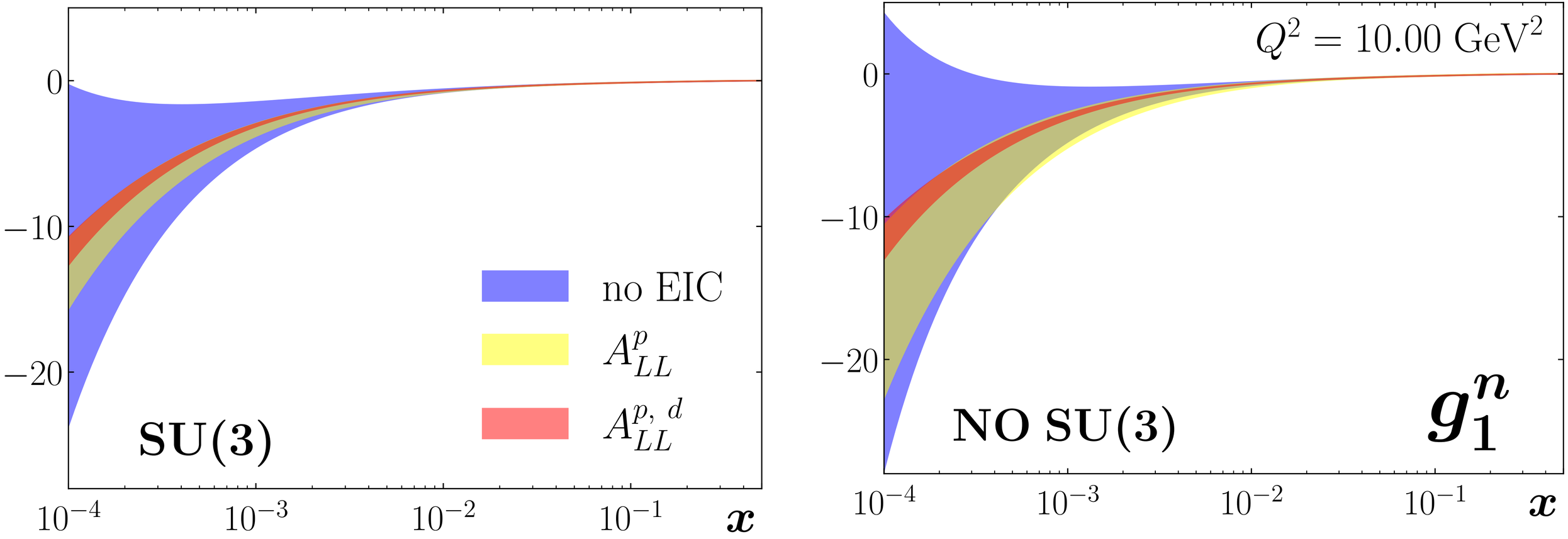
$$\int_0^1 dx\left[\Delta u^+(x,Q^2) + \Delta d^+(x,Q^2) - 2\Delta s^+(x,Q^2)\right] = a_8$$

# EIC impact on $g_1$ uncertainties



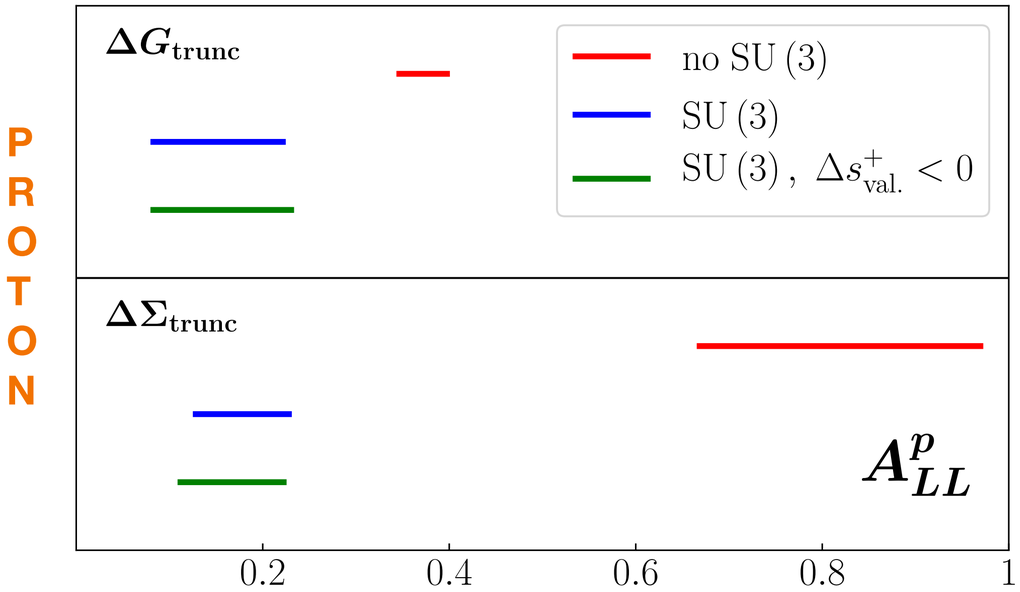

Impact of projected e-p $A_{LL}$ data on the proton $g_1^p$ structure function

# EIC impact on $g_1$ uncertainties



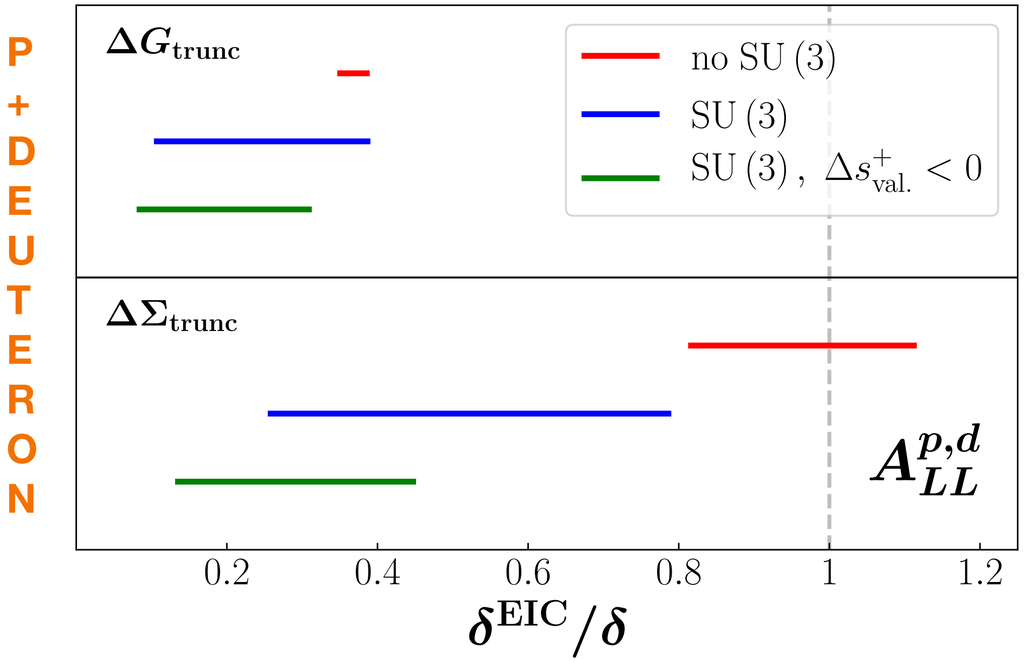

Impact of projected e-p $A_{LL}$ data
on the neutron $g_1^p$ structure function

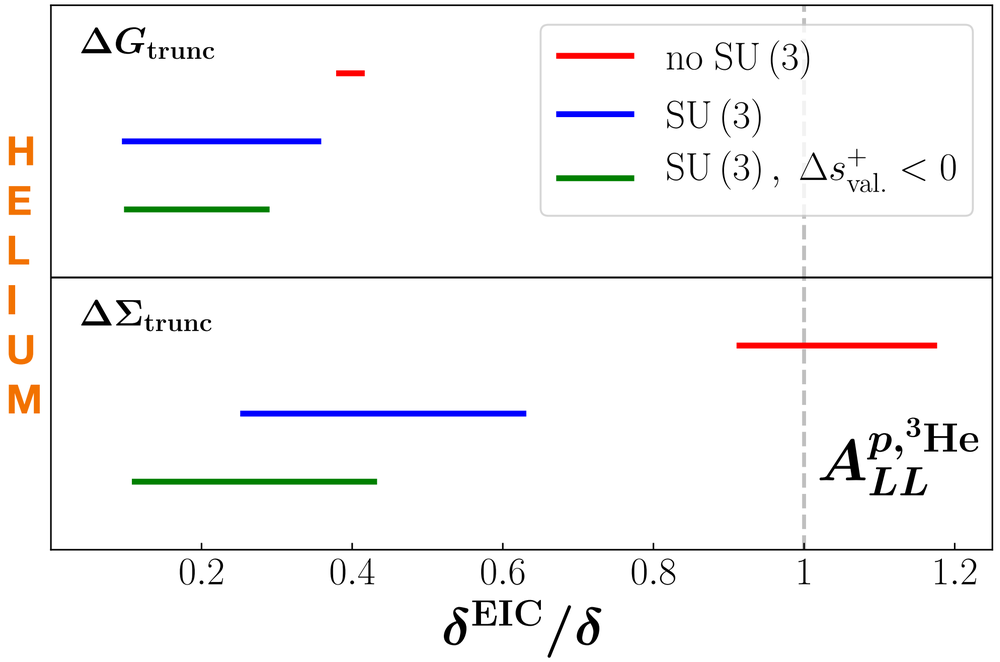
# EIC impact on truncated moments



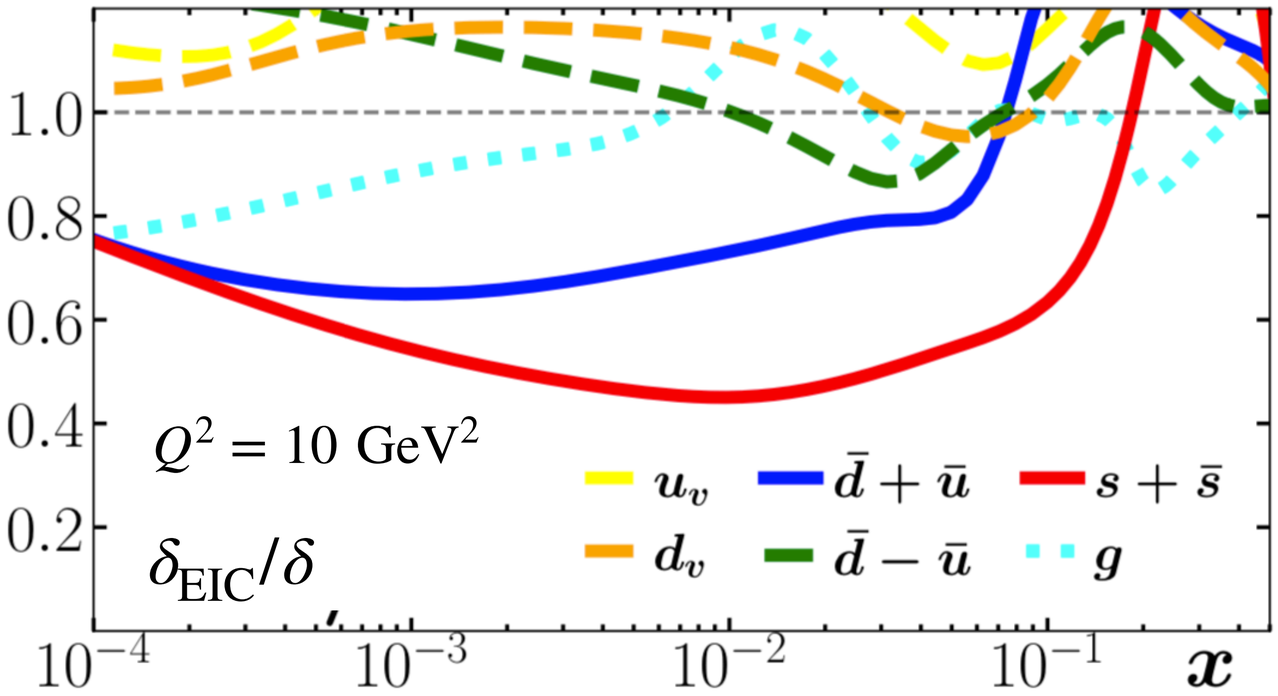

$$\Delta\Sigma_{\rm trunc}\left(Q^2\right) = \sum_q \int_{10^{-4}}^{1} dx \left[\Delta q(x,Q^2) + \Delta\bar{q}(x,Q^2)\right]$$

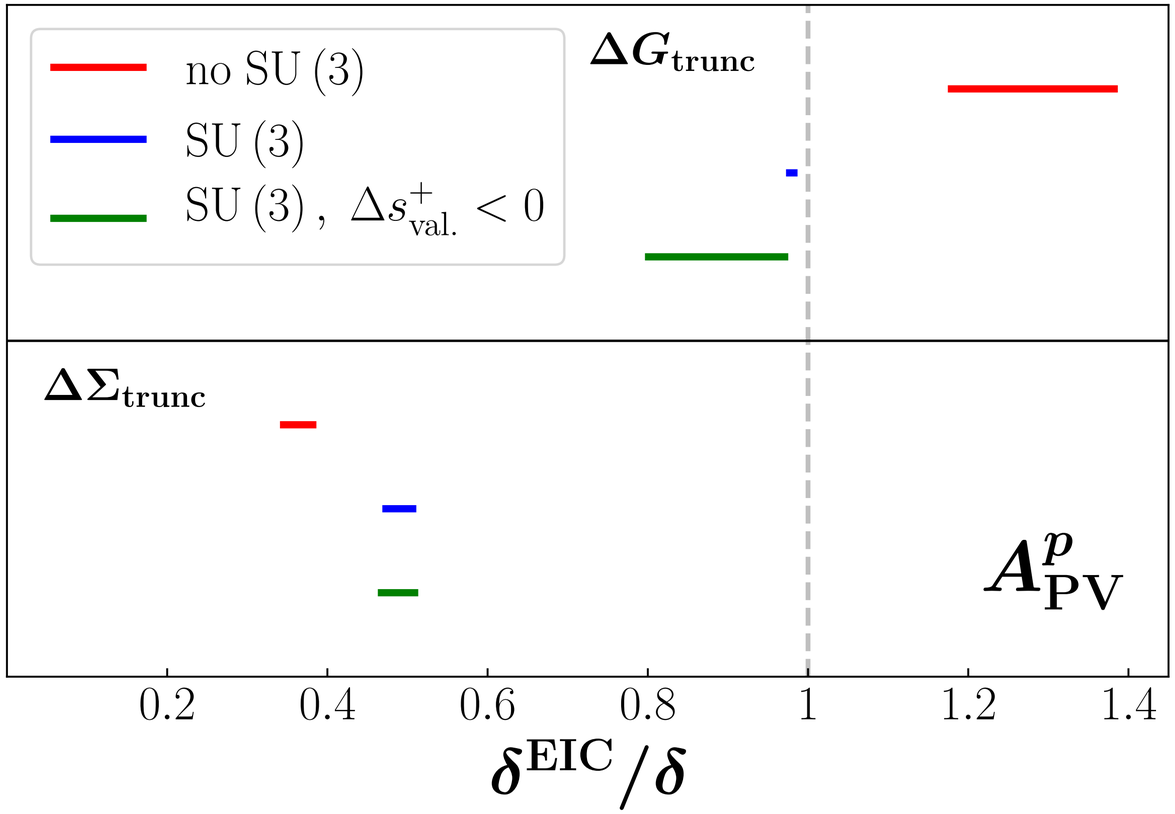
$$\Delta G_{\rm trunc}\left(Q^2\right) = \int_{10^{-4}}^{1} dx\, \Delta g(x,Q^2)$$



# PDFs constraints from $A_{PV}$ 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

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

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

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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