Future High Precision Measurements on g_1^p and g_1^n at EIC

Win Lin
Stony Brook University

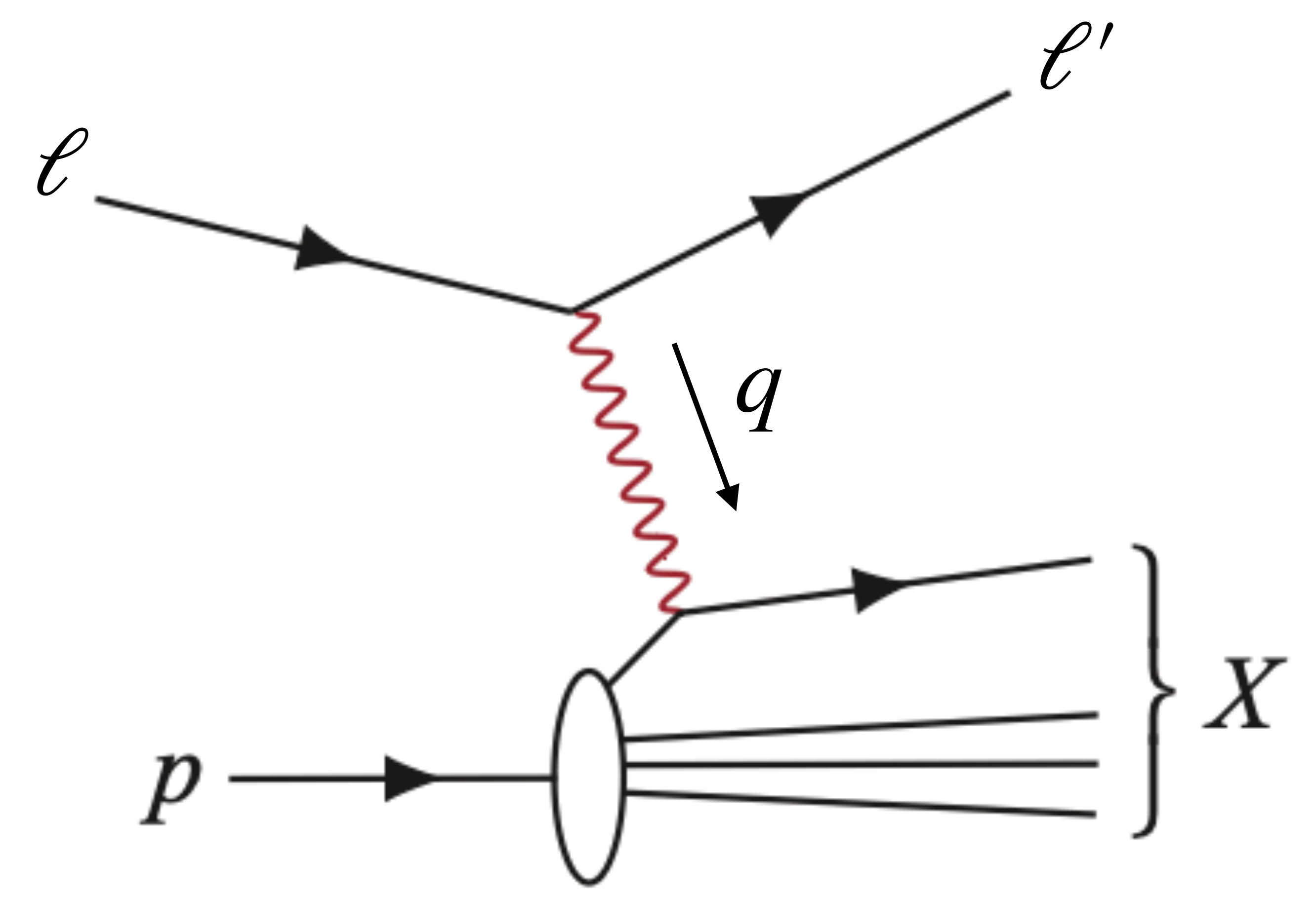
DIS 2026
05/06/2026

Stony Brook University

Center for Frontiers in Nuclear Science

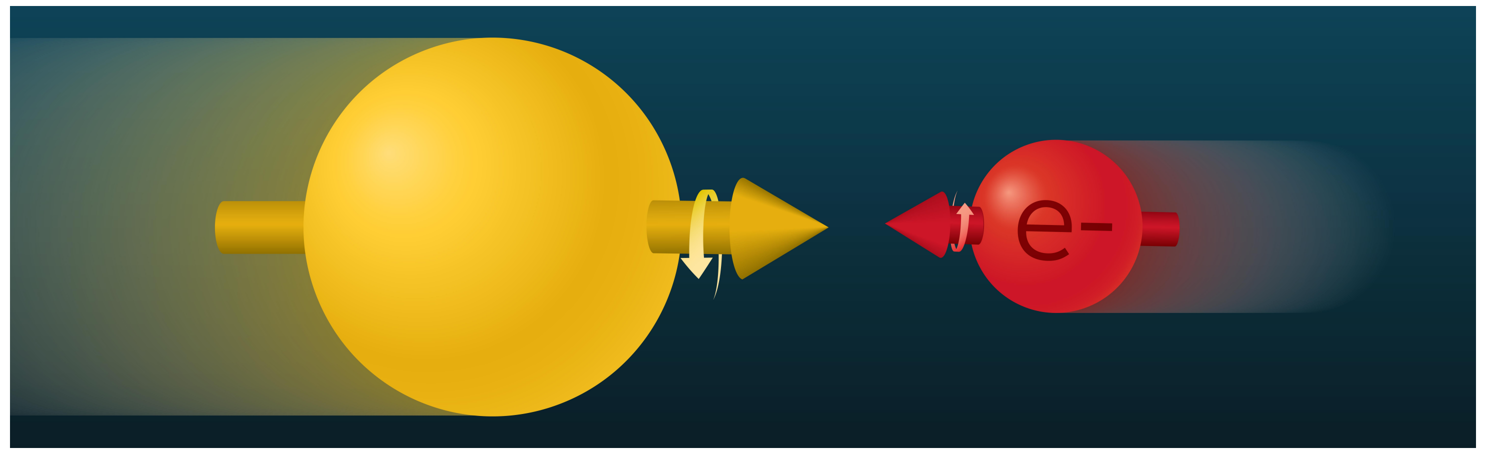
ePIC

The spin structure function



NC Inclusive DIS: $e + p \to e' + X$

https://arxiv.org/abs/2103.05419



Polarized DIS:

$$\frac{d^3\sigma(\beta)}{dQ^2dxd\phi} = \frac{d^3\sigma_0}{dQ^2dxd\phi} - \frac{d^3\Delta\sigma(\beta)}{dQ^2dxd\phi}$$

$$\frac{d^2\sigma}{dQ^2dx} = \frac{4\pi\alpha^2}{Q^4}\frac{1}{x}\left[xy^2F_1(x,Q^2) + \left(1 - y - \frac{Mxy}{2E}F_2(x,Q^2)\right)\right]$$

$$\frac{d^3\Delta\sigma(\beta)}{dQ^2dxd\phi} = \frac{4\alpha^2}{Q^2}y\left\{\cos\beta\left[\left(1 - \frac{y}{2} - \frac{\gamma^2y^2}{4}\right)g_1(x,Q^2) - \frac{\gamma^2y}{4}g_2(x,Q^2)\right]\right.$$
$$\left. -\cos\phi\sin\beta\frac{\sqrt{Q^2}}{\nu}\left(1 - y - \frac{\gamma^2y^2}{4}\right)^{\frac{1}{2}}\left[\frac{y}{2}g_1(x,Q^2) + g_2(x,Q^2)\right]\right\}$$

The spin structure function

D. De Florian et al. https://doi.org/10.1103/PhysRevLett.113.012001

$\Delta G \sim 0.2?$

$L^q = ?$

$L^g = ?$

$\Delta\Sigma \sim 0.25?$

Spin composition (Jaffe-Manohar sum):

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L^q + L^g$$

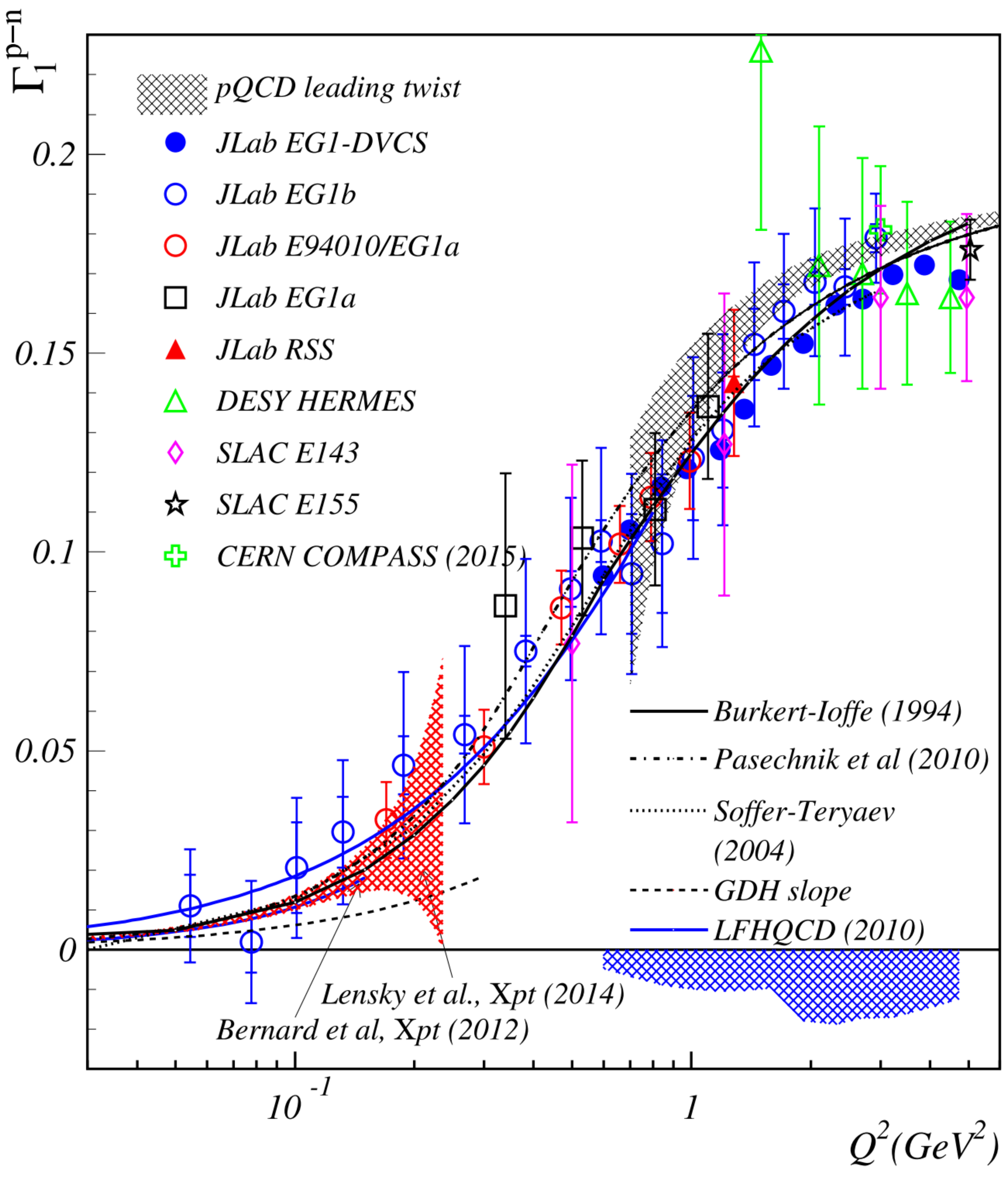
Perturbative QCD:

$$g_1(x,t) = \frac{1}{2}\sum_{k=1}^{n_f}\frac{e_k^2}{n_f}\int_x^1 \frac{dy}{y}\left[C_q^S\left(\frac{x}{y},\alpha_s(t)\right)\boxed{\Delta\Sigma(y,t)} + 2n_f C_g\left(\frac{x}{y},\alpha_s(t)\right)\boxed{\Delta G(y,t)} + C_q^{\mathrm{NS}}\left(\frac{x}{y},\alpha_s(t)\right)\Delta q_{\mathrm{NS}}(y,t)\right]$$

Follow DGLAP evolution

g_1 constrains the contributions through Q^2 dependence

The spin structure function



A. Deur et al. DOI 10.1088/1361-6633/ab0b8f

- Bjorken integral:

$$\Gamma_1^{p-n}(\alpha_s) = \Gamma_1^{p-n}(Q^2) = \int_0^{1^-} (g_1^p(Q^2) - g_1^n(Q^2))\, dx$$

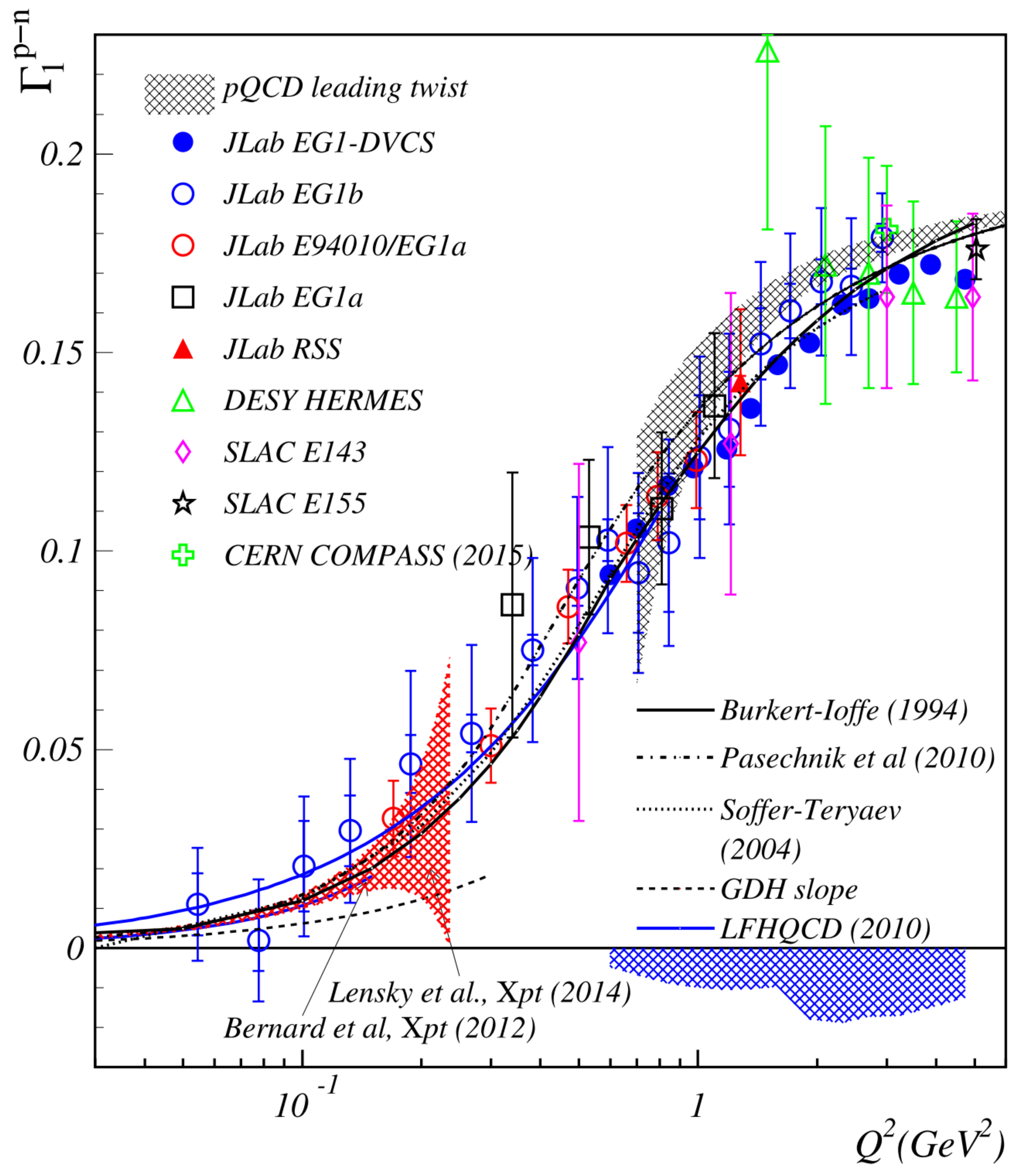
- For $Q^2 \to \infty$:

$$\Gamma_1^{p-n} = \frac{g_A}{6}$$

- At finite Q^2:

$$\Gamma_1^{p-n}(\alpha_s) = \sum_{n>0} \frac{\mu_{2n}^{p-n}(\alpha_s)}{Q^{2n-2}} = \frac{g_A}{6}\left[1 - \frac{\alpha_S(Q^2)}{\pi} - 3.58\left(\frac{\alpha_S(Q^2)}{\pi}\right)^2 - 20.21\left(\frac{\alpha_S(Q^2)}{\pi}\right)^3 - 175.7\left(\frac{\alpha_S(Q^2)}{\pi}\right)^4 - \mathcal{O}((\alpha_S)^5)\right]$$

The spin structure function



A. Deur et al. DOI 10.1088/1361-6633/ab0b8f

- Bjorken integral:

$$\Gamma_1^{p-n}(\alpha_s) = \Gamma_1^{p-n}(Q^2) = \int_0^{1^-} (g_1^p(Q^2) - g_1^n(Q^2))\, dx$$

- For $Q^2 \to \infty$:

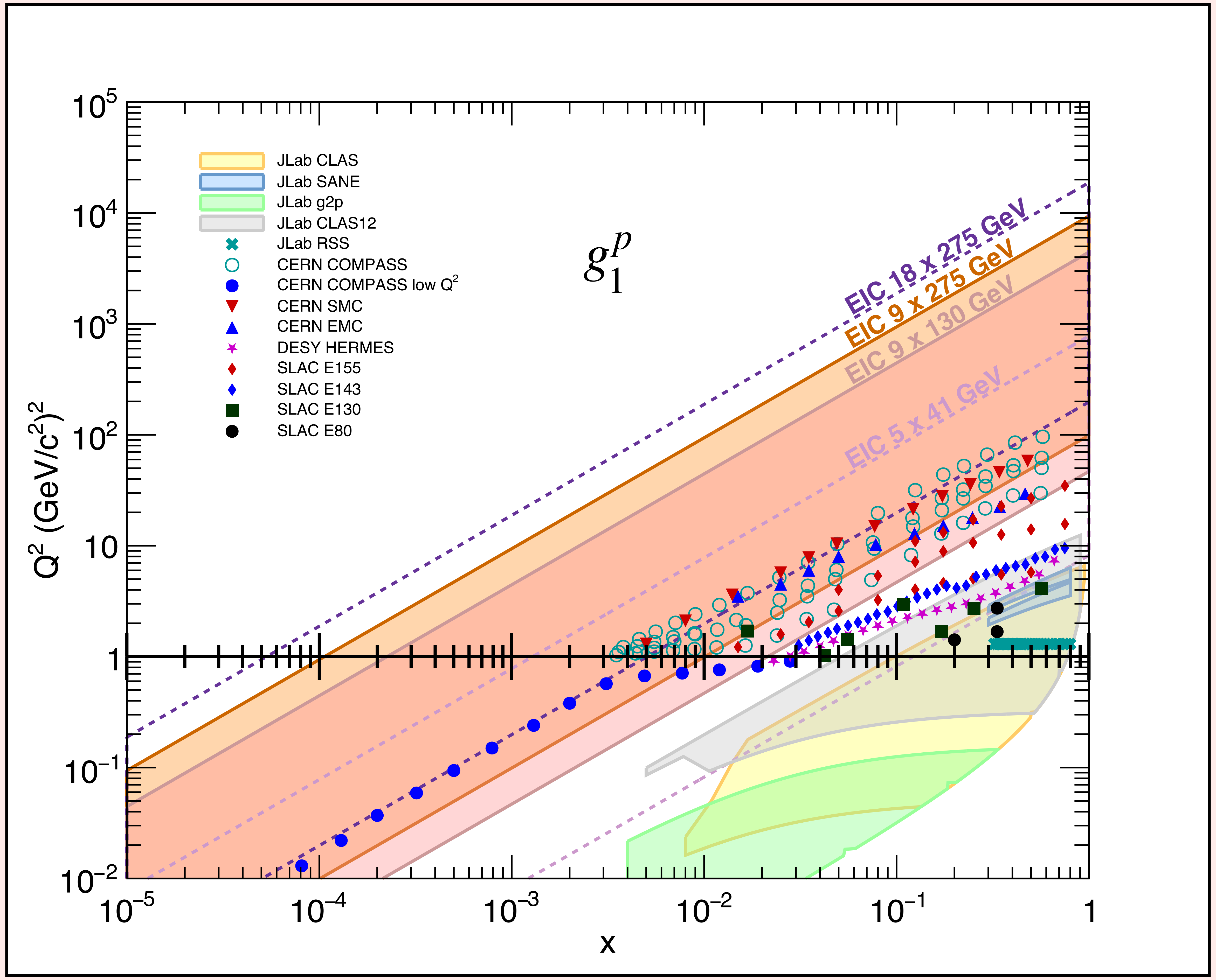
$$\Gamma_1^{p-n} = \frac{g_A}{6}$$

- At finite Q^2:

$$\Gamma_1^{p-n}(\alpha_s) = \sum_{n>0} \frac{\mu_{2n}^{p-n}(\alpha_s)}{Q^{2n-2}} = \frac{g_A}{6}\left[1 - \frac{\alpha_S(Q^2)}{\pi} - 3.58\left(\frac{\alpha_S(Q^2)}{\pi}\right)^2 -20.21\left(\frac{\alpha_S(Q^2)}{\pi}\right)^3 - 175.7\left(\frac{\alpha_S(Q^2)}{\pi}\right)^4 - \mathcal{O}((\alpha_S)^5)\right]$$

Need wide range data in x and Q^2 !

World data on g_1



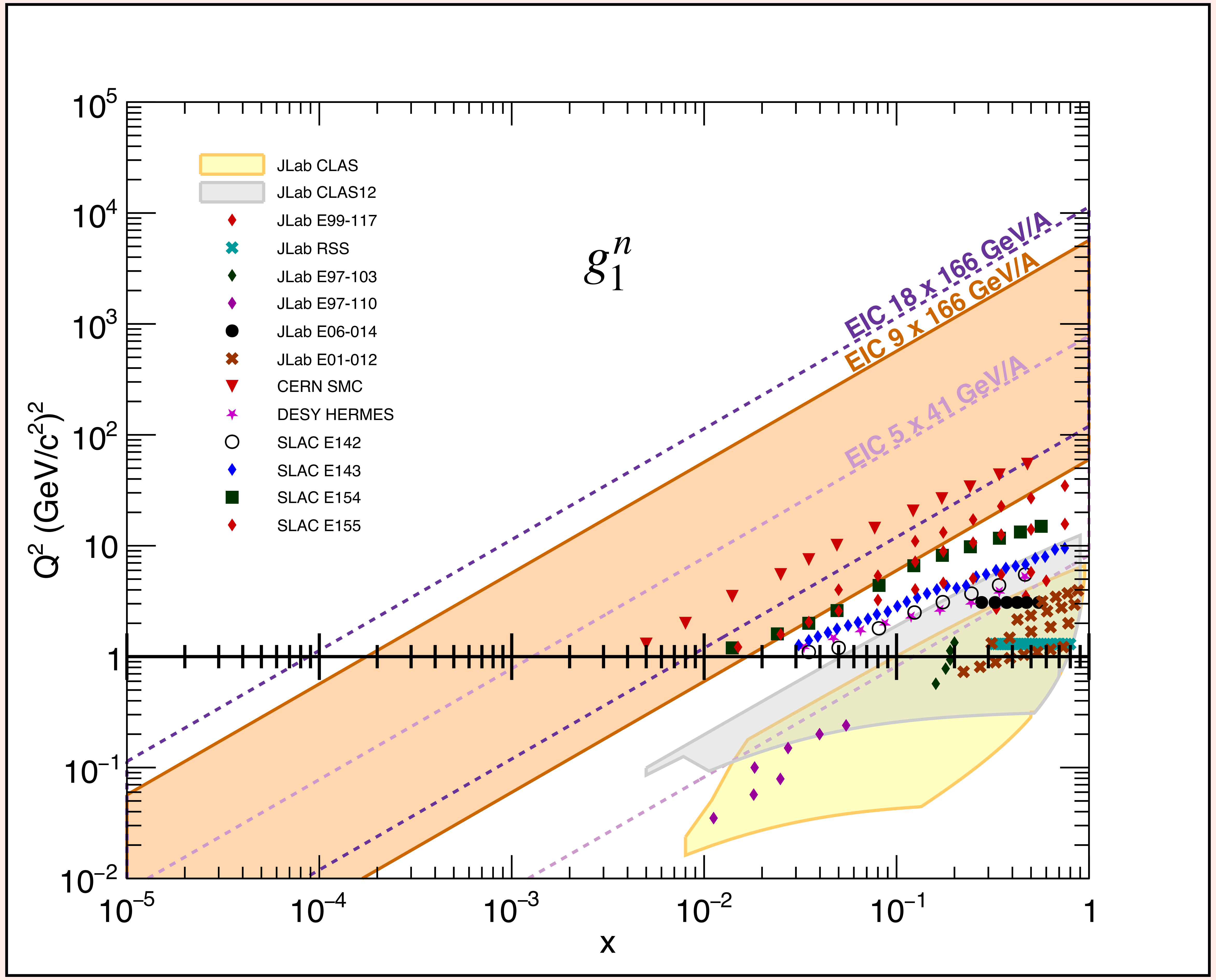
SLAC: Late 1970s -
First measurements with doubly-polarized DIS

CERN: Late 1980s -
EMC: muon beam, spin crises
Continued as SMC, COMPASS

DESY: 1995 - 2007
HERMES

Jefferson Lab: Late 1990s -
CLAS, SANE, RSS, g2p, CLAS12
Higher x, low Q2, resonance region

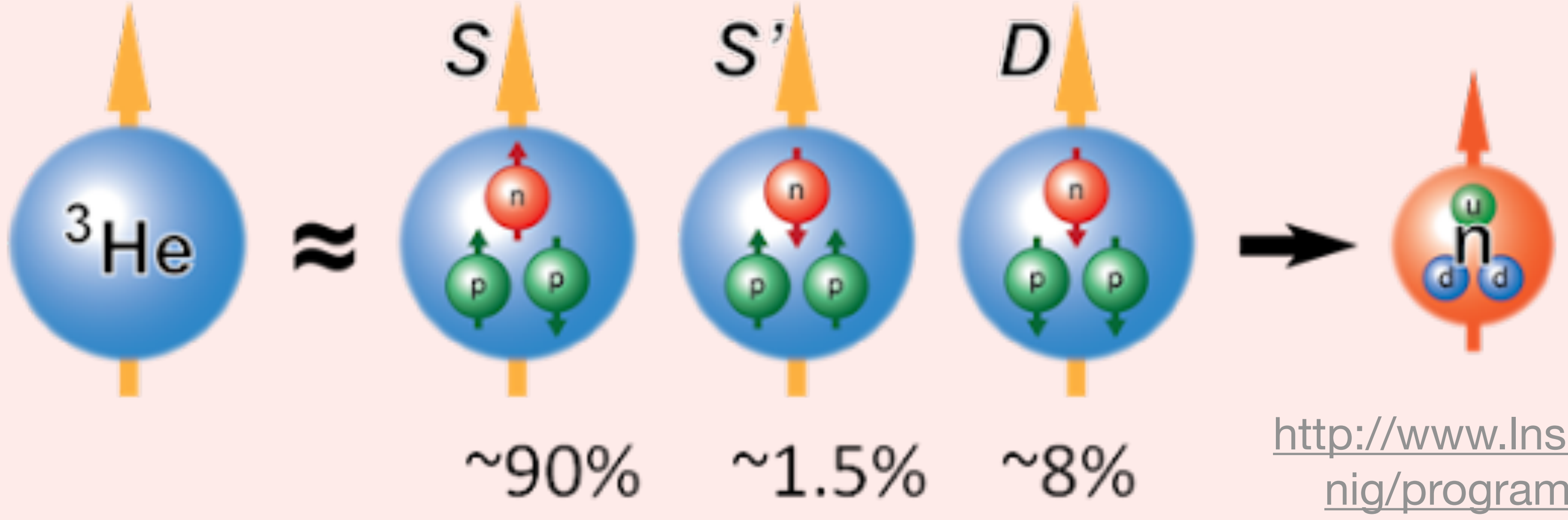
World data on g_1



- Neutron data is usually extracted from eHe3 or eD scattering

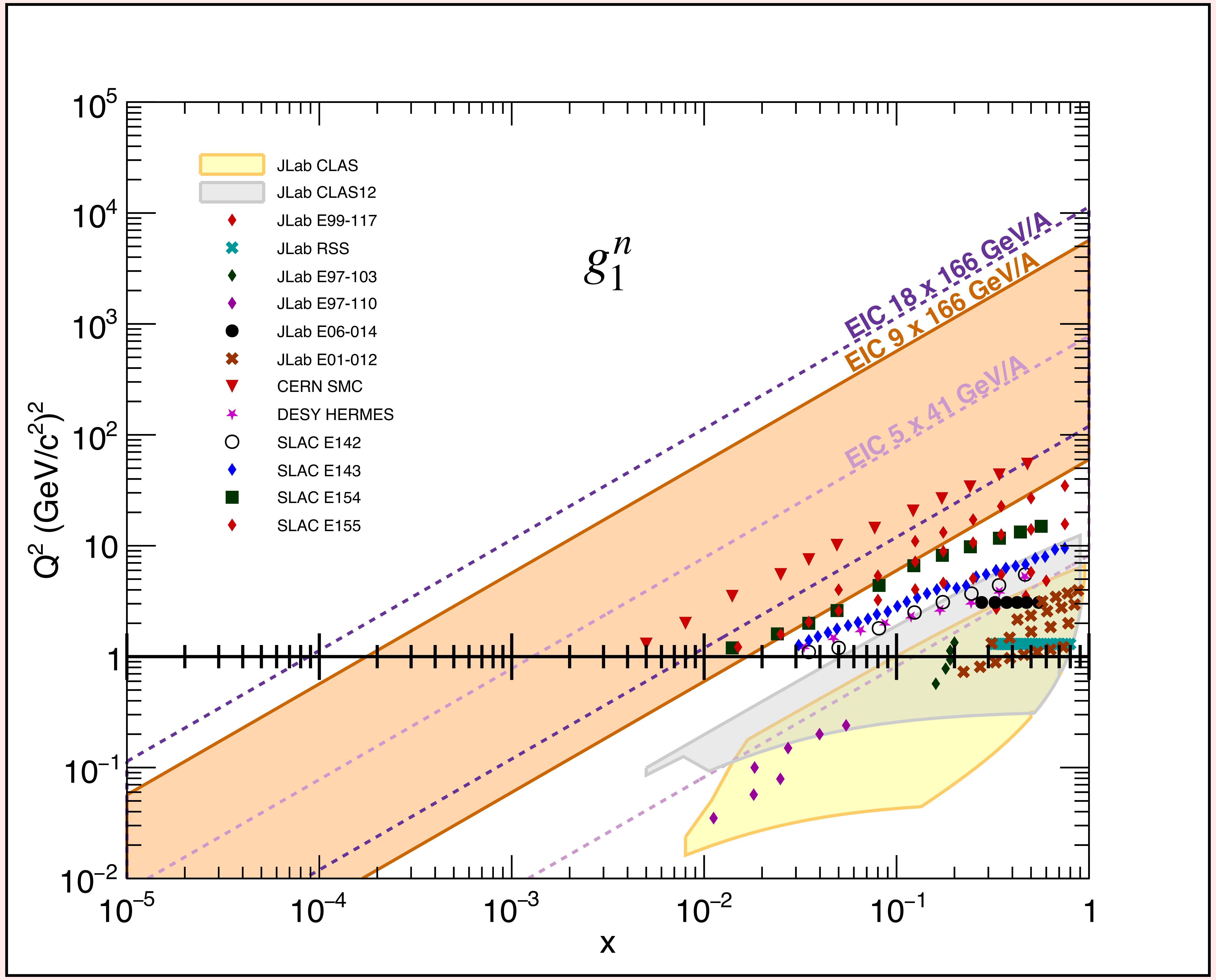
$$A_1^{^3\mathrm{He}} = P_n \frac{F_2^n}{F_2^{^3\mathrm{He}}} A_1^n + 2P_p \frac{F_2^p}{F_2^{^3\mathrm{He}}} A_1^p$$

$$P_n = 0.86 \pm 0.02 \qquad P_p = -0.028 \pm 0.004$$

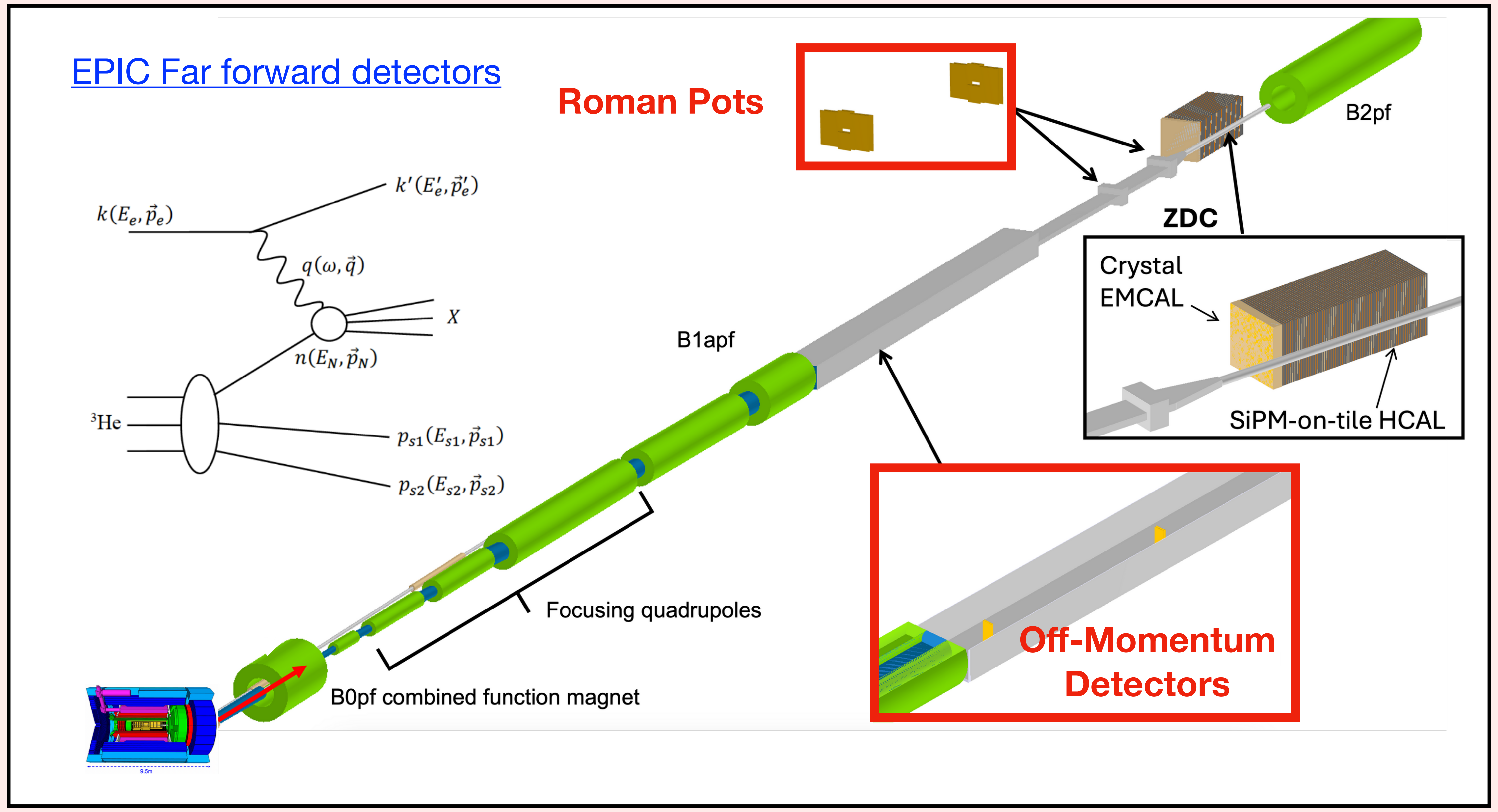


http://www.lns.mit.edu/nig/programs.html

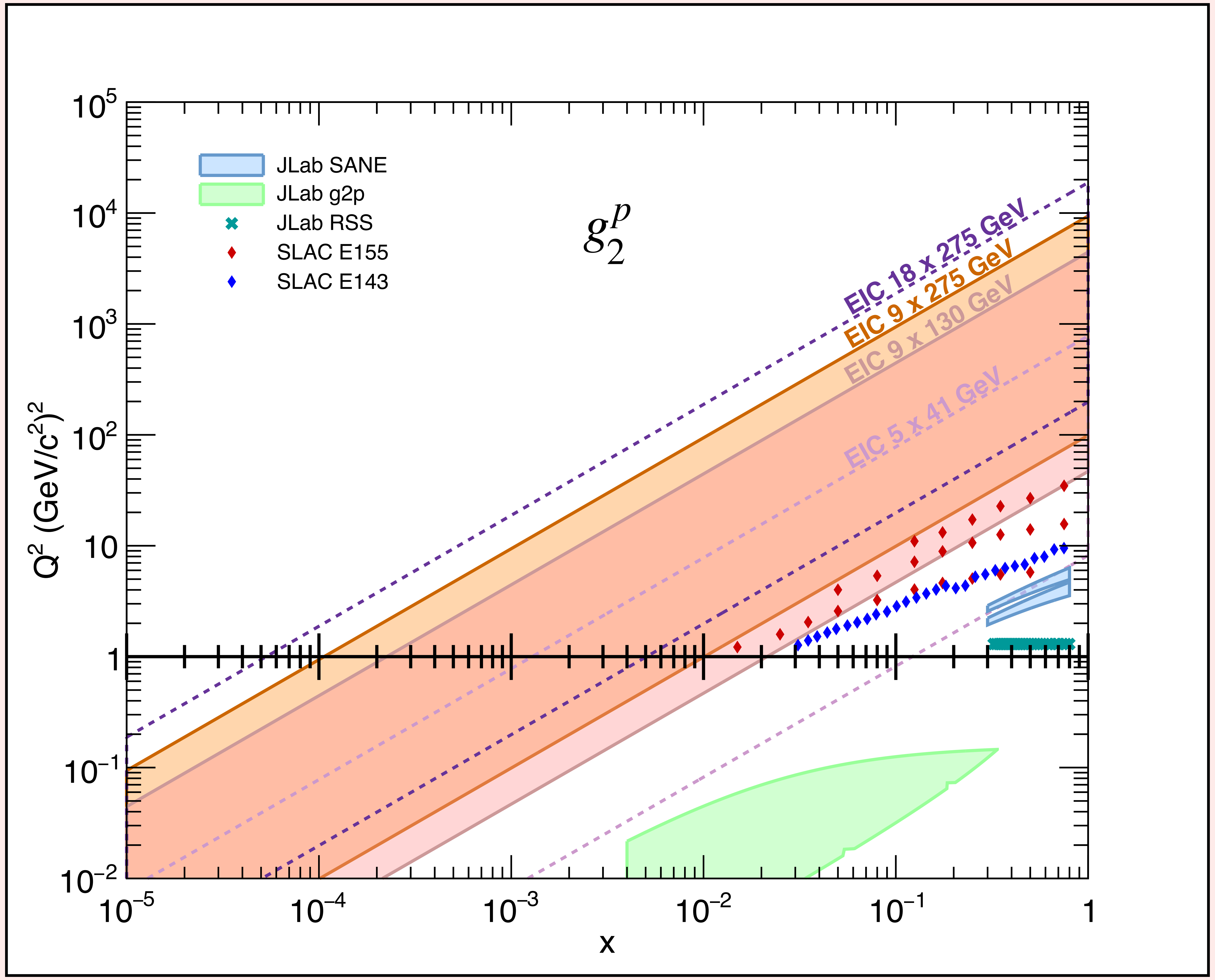
World data on g_1

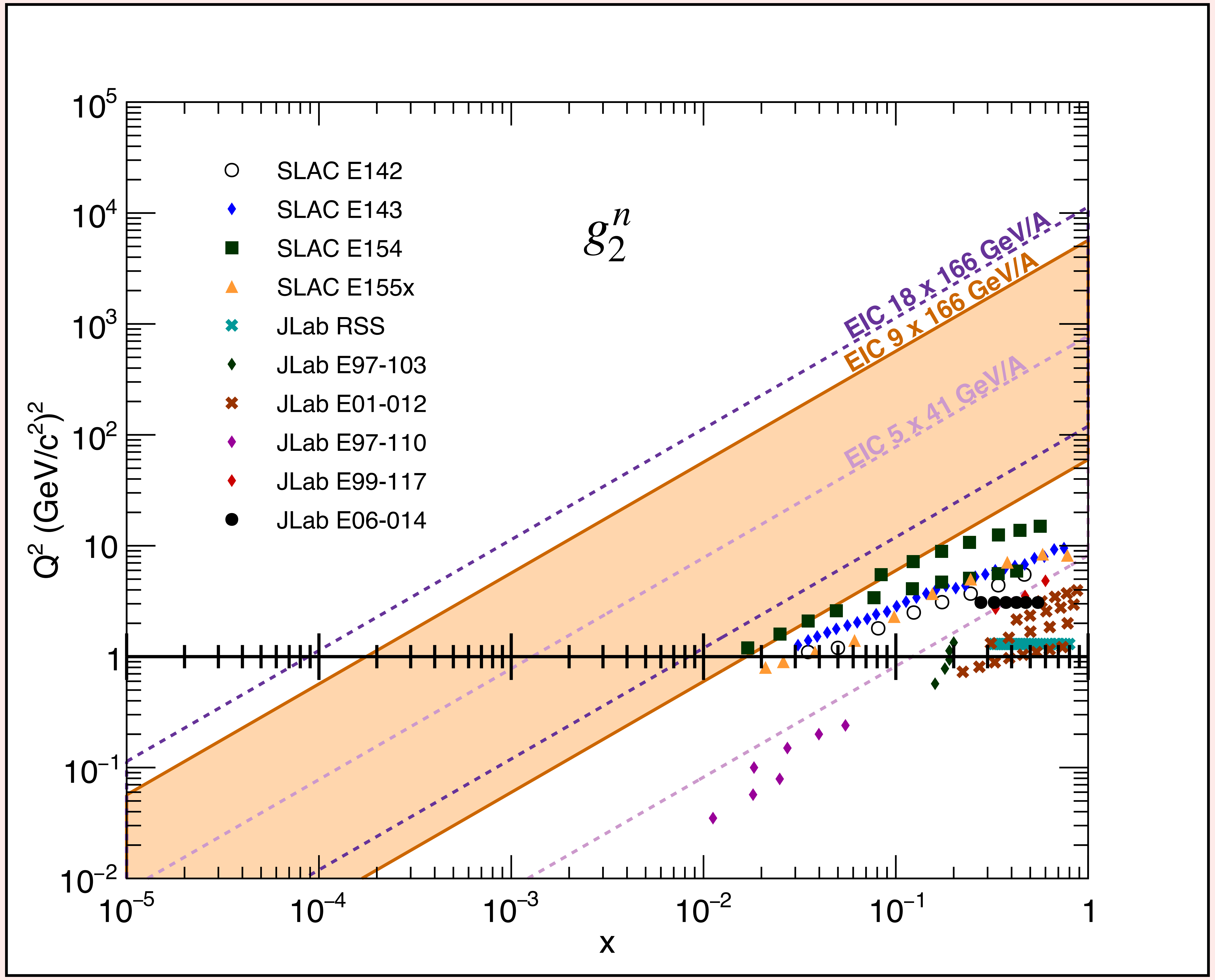


- In additional to the fully inclusive approach, ePIC can also perform tagged DIS to measure neutron spin structure:



World data on g_2





EIC will greatly expand the number of g2 datapoints, which are currently very limited

Measuring g_1 and g_2

Extraction from cross-section difference:

$$g1 = \frac{2ME\nu Q^2}{8\alpha^2 E'(E+E')}\left[\Delta\sigma_{\parallel} + \tan\frac{\theta}{2}\Delta\sigma_{\perp}\right]$$

$$g2 = \frac{M\nu^2 Q^2}{8\alpha^2 E'(E+E')}\left[\frac{E+E'\cos\theta}{E'\sin\theta}\Delta\sigma_{\perp} - \Delta\sigma_{\parallel}\right]$$

$$\Delta\sigma_{\parallel} = \frac{d^2\sigma_{\downarrow\Uparrow}}{dE'd\Omega} - \frac{d^2\sigma_{\uparrow\Uparrow}}{dE'd\Omega}$$

$$\Delta\sigma_{\perp} = \frac{d^2\sigma_{\downarrow\Rightarrow}}{dE'd\Omega} - \frac{d^2\sigma_{\uparrow\Rightarrow}}{dE'd\Omega}$$

- No unpolarized contributions
- Absolution cross sections may lead to large systematic uncertainties

Measuring g_1 and g_2

Extraction from cross-section difference:

$$g1 = \frac{2ME\nu Q^2}{8\alpha^2 E'(E+E')}\left[\Delta\sigma_{\parallel} + \tan\frac{\theta}{2}\Delta\sigma_{\perp}\right]$$

$$g2 = \frac{M\nu^2 Q^2}{8\alpha^2 E'(E+E')}\left[\frac{E+E'\cos\theta}{E'\sin\theta}\Delta\sigma_{\perp} - \Delta\sigma_{\parallel}\right]$$

$$\Delta\sigma_{\parallel} = \frac{d^2\sigma_{\downarrow\Uparrow}}{dE'd\Omega} - \frac{d^2\sigma_{\uparrow\Uparrow}}{dE'd\Omega}$$

$$\Delta\sigma_{\perp} = \frac{d^2\sigma_{\downarrow\Rightarrow}}{dE'd\Omega} - \frac{d^2\sigma_{\uparrow\Rightarrow}}{dE'd\Omega}$$

- No unpolarized contributions
- Absolution cross sections may lead to large systematic uncertainties

Extraction from double spin asymmetry:

$$g_1 = \frac{F_2}{2x(1+R)}(A_1 + \gamma A_2)$$

$$g_2 = \frac{F_2}{2x(1+R)}\left(\frac{A_2}{\gamma} - \gamma A_1\right)$$

$$A_1(x,Q^2) \equiv \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{A_{\parallel}}{D(1+\eta\xi)} - \frac{\eta A_{\perp}}{d(1+\eta\xi)}$$

$$A_2(x,Q^2) \equiv \frac{2\sigma_{LT}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{\xi A_{\parallel}}{D(1+\eta\xi)} + \frac{A_{\perp}}{d(1+\eta\xi)}$$

- Systematics uncertainties are largely canceled out
- Need F_1 and F_2

Double Spin Asymmetry

$$A_1(x, Q^2) \equiv \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{A_\parallel}{D(1+\eta\xi)} - \frac{\eta A_\perp}{d(1+\eta\xi)}$$

$$A_\parallel = \frac{\sigma_{\downarrow\Uparrow} - \sigma_{\uparrow\Uparrow}}{\sigma_{\downarrow\Uparrow} + \sigma_{\uparrow\Uparrow}}$$

p & e spins anti-aligned ($\sigma_{\downarrow\Uparrow}$)

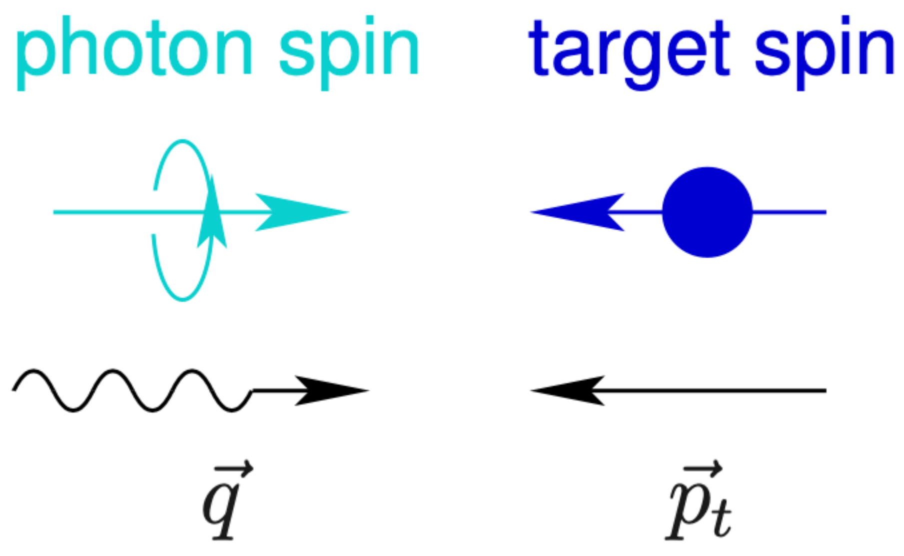
p & e spins aligned ($\sigma_{\uparrow\Uparrow}$)

$$A_\perp = \frac{\sigma_{\downarrow\Rightarrow} - \sigma_{\uparrow\Rightarrow}}{\sigma_{\downarrow\Rightarrow} + \sigma_{\uparrow\Rightarrow}}$$

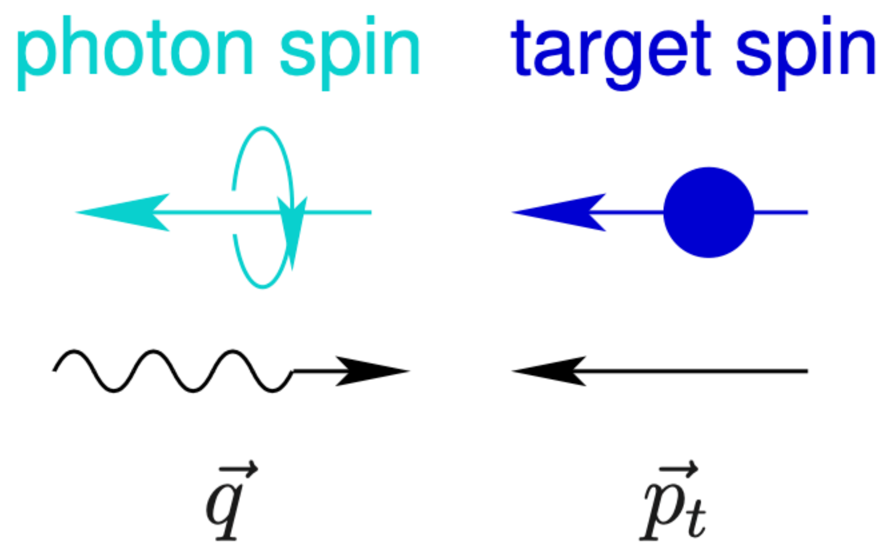
p & e spins perpendicular ($\sigma_{\uparrow\Rightarrow}$)

$$D = \frac{y(2-y)(2+\gamma^2 y)}{2(1+\gamma^2)y^2 + (4(1-y)-\gamma^2y^2)(1+R)} \qquad d = \frac{D\sqrt{4(1-y)-\gamma^2y^2}}{2-y}$$

$$R \equiv \frac{\sigma_L}{\sigma_T} = \frac{F_L}{F_2 - F_L} \qquad \gamma^2 = \frac{4M^2x^2}{Q^2} \qquad \eta = \frac{4(1-y)-\gamma^2y^2}{(2-y)(2+\gamma^2 y)} \qquad \xi = \frac{\gamma(2-y)}{2+\gamma^2 y}$$



$\sigma_{1/2}$: p & γ^* spins anti-aligned



$\sigma_{3/2}$: p & γ^* spins aligned

https://phys-zheng.uvacreate.virginia.edu/wp-content/uploads/2025/06/A1n_6GeV_thesis.pdf

EIC early science

*eA luminosity is per nucleon

Species	Beam energy (GeV)	Integrated luminosity	Electron-beam polarization	Hadron-beam polarization
e+Ag	9×115	$1.0\ \text{fb}^{-1}$	NO	N/A
e+D	9×130	$1.5\ \text{fb}^{-1}$	LONG	NO
$e+p$	9×130	$1.0\ \text{fb}^{-1}$	LONG	TRANS and/or LONG
$e+p$	9×275	$2.5\ \text{fb}^{-1}$	LONG	TRANS and/or LONG
e+Au	9×100	$1.0\ \text{fb}^{-1}$	LONG	N/A
$e+{}^3$He	9×166	$1.5\ \text{fb}^{-1}$	LONG	TRANS and/or LONG

In full running compactly and future upgrade:

Electron: 5 - 18 GeV

Proton: 41 - 275 GeV

higher luminosities

Exact energies, species and luminosities will depend on ongoing accelerator R&D, physics motivation, and commissioning etc.

EIC early science

*eA luminosity is per nucleon

Species	Beam energy (GeV)	Integrated luminosity	Electron-beam polarization	Hadron-beam polarization
e+Ag	9×115	1.0 fb^{-1}	NO	N/A
e+D	9×130	1.5 fb^{-1}	LONG	NO
$e+p$	9×130	1.0 fb^{-1}	LONG	TRANS and/or LONG
$e+p$	9×275	2.5 fb^{-1}	LONG	TRANS and/or LONG
e+Au	9×100	1.0 fb^{-1}	LONG	N/A
$e+{}^3$He	9×166	1.5 fb^{-1}	LONG	TRANS and/or LONG

In full running compactly and future upgrade:

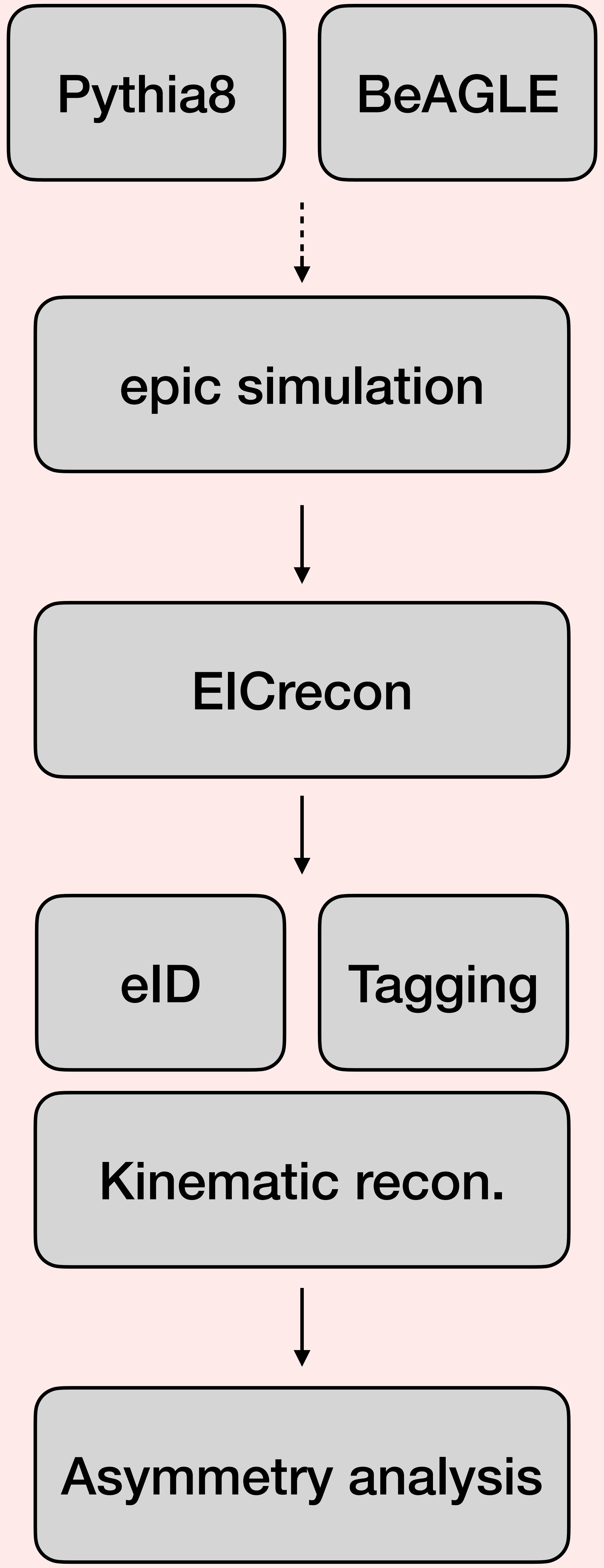
Electron: 5 - 18 GeV

Proton: 41 - 275 GeV

higher luminosities

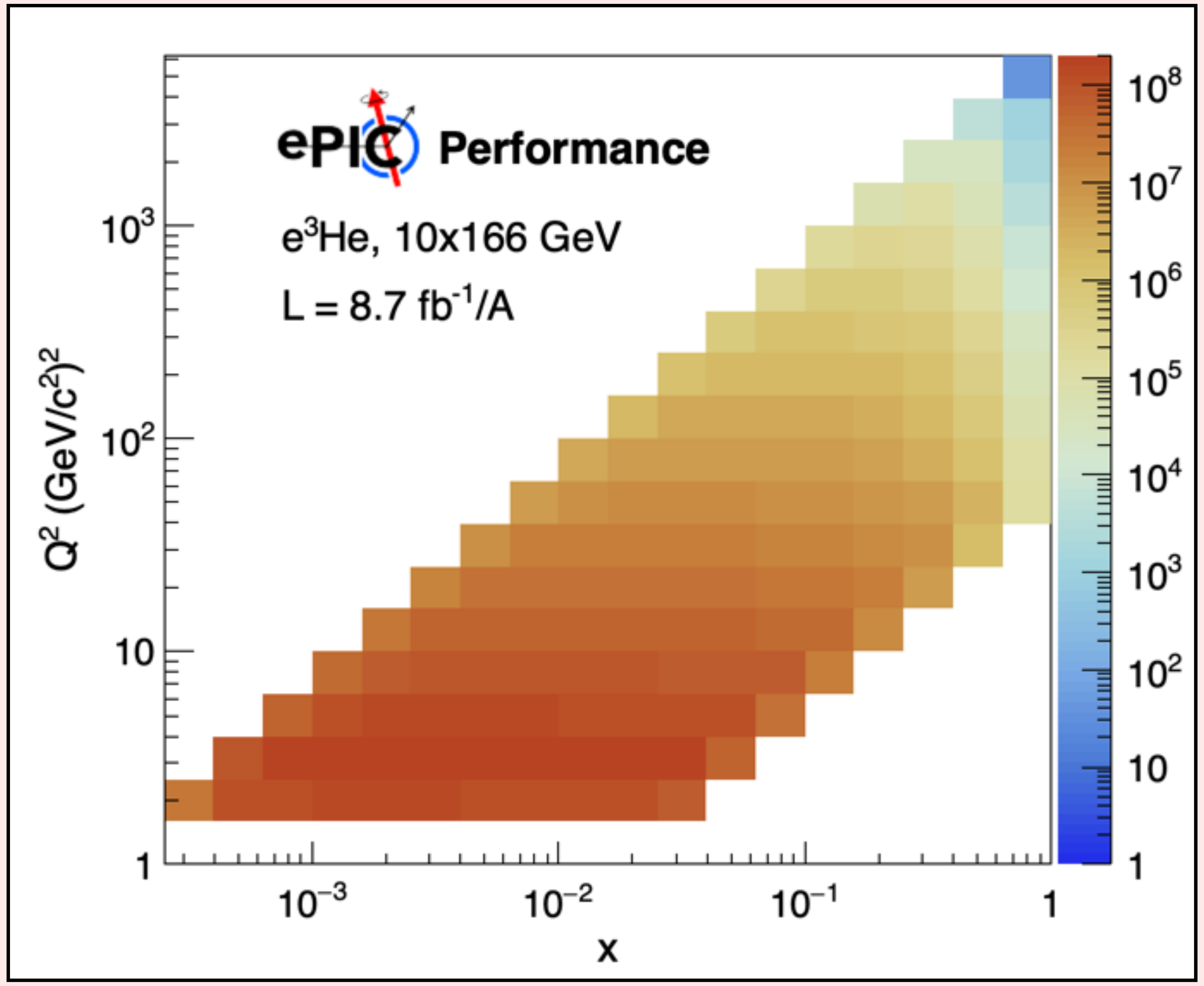
ePIC will measure A_1, A_2, g_1, g_2 for the proton and neutron with large phase space coverage and reach very low x!

Projection study for g_1 at ePIC



- Simulation with full detector setup, beam crossing angle and smearing included
- Primitive realistic analysis with latest software development

- Generated non-polarized events; no QED radiative effect
- Use generated event to estimate statistical uncertainty: $\delta A_{\|,\perp} = \dfrac{1}{\sqrt{N P_e P_N}}$



Generated events scaled to planned luminosity

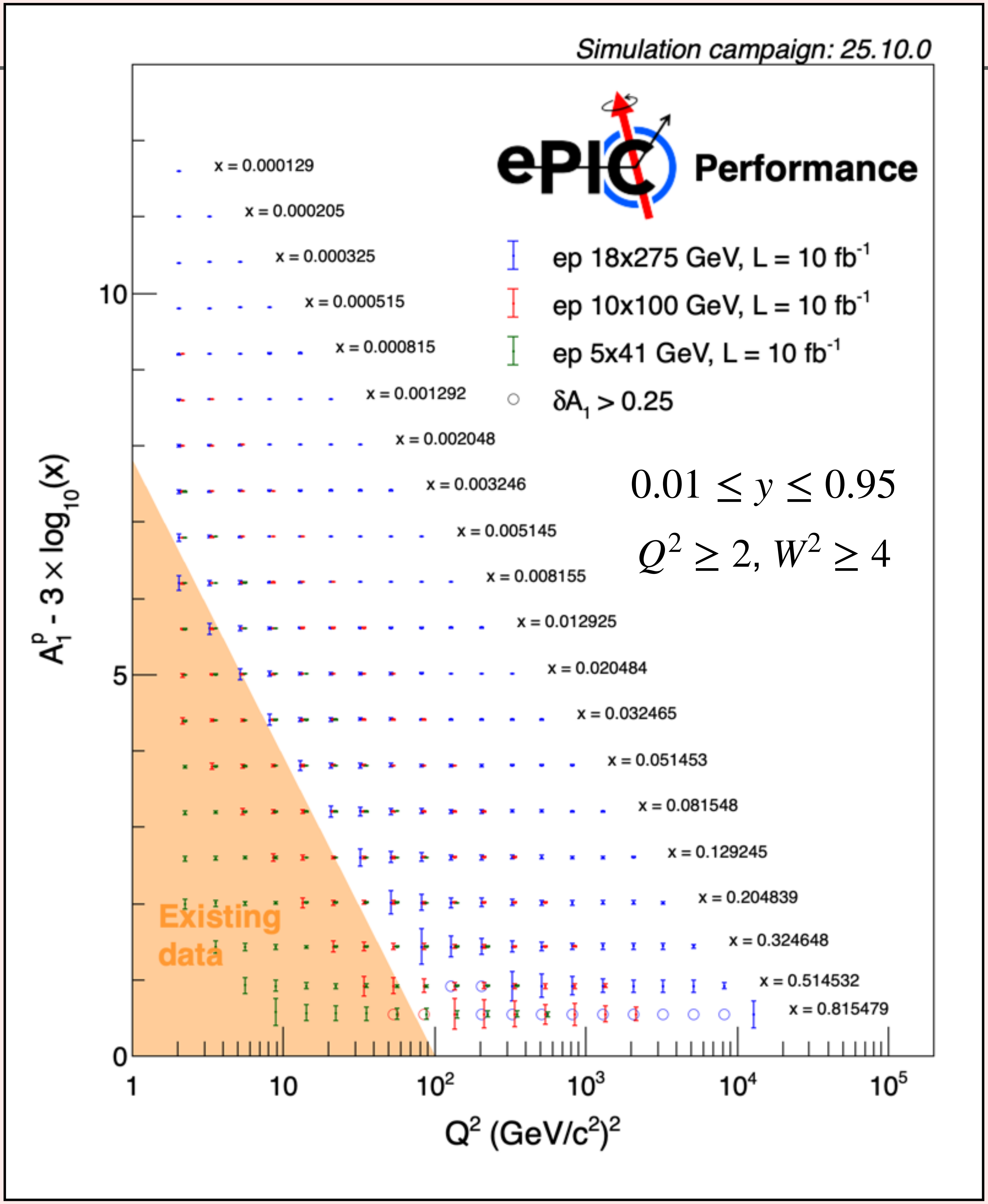
More on BeAGLE:
Thu. 11:55AM WG1 Arjun K., Win L.

Projected A_1^p at EIC

- Projection with statistical uncertainty
- Data split evenly between $A_{||}$ and $A_{\perp}$
- $P_e = P_p = 70\,\%$
- $$\delta A_{||,\perp} = \frac{1}{\sqrt{N P_e P_N}}$$
- $$A_1(x, Q^2) \equiv \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{A_{||}}{D(1+\eta\xi)} - \frac{\eta A_{\perp}}{d(1+\eta\xi)}$$
- Parameterization for A_1:

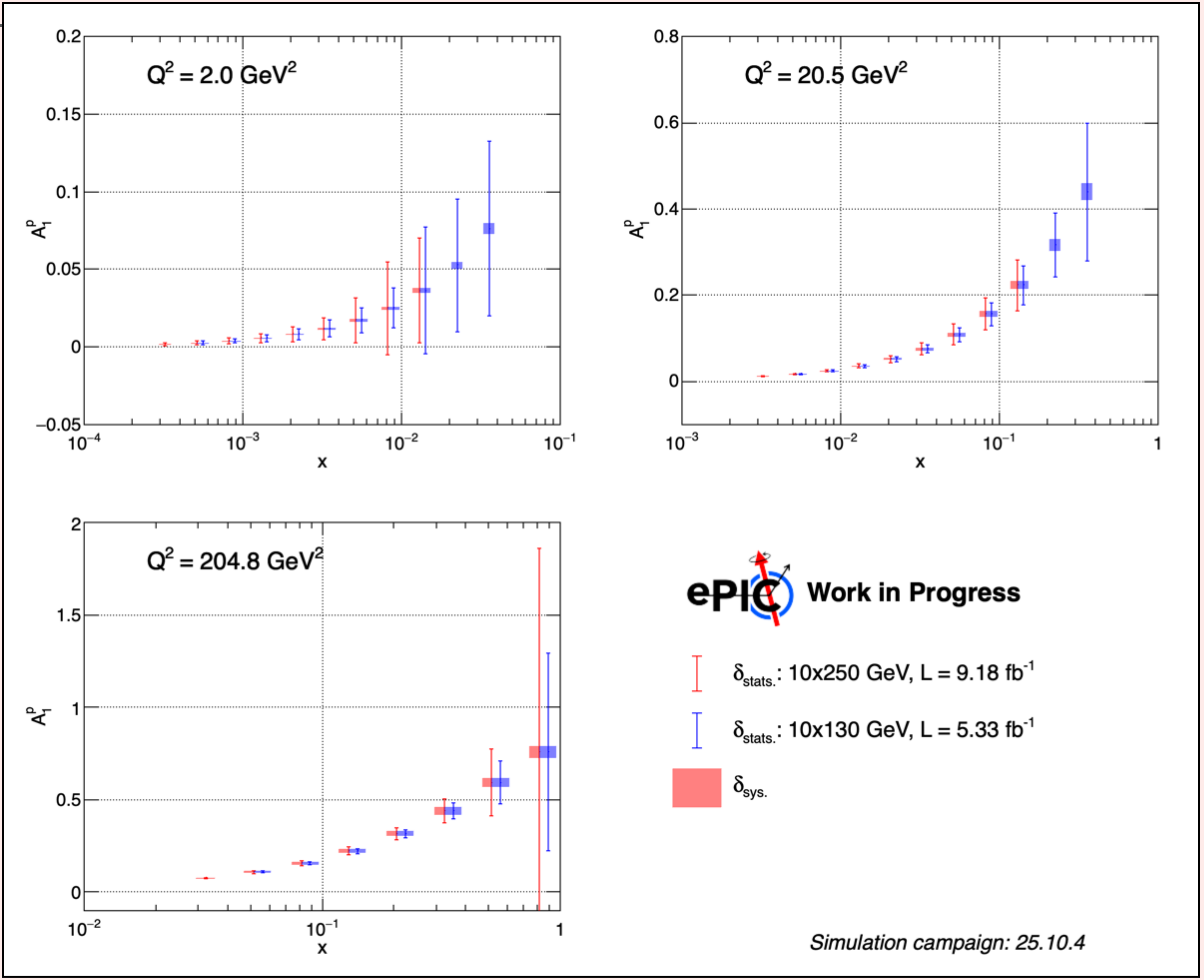
  X. Zheng et al. DOI: 10.1103/PhysRevC.70.065207
- Parameterization for R:

  K. Abe et al. DOI: 10.1016/S0370-2693(99)00244-0



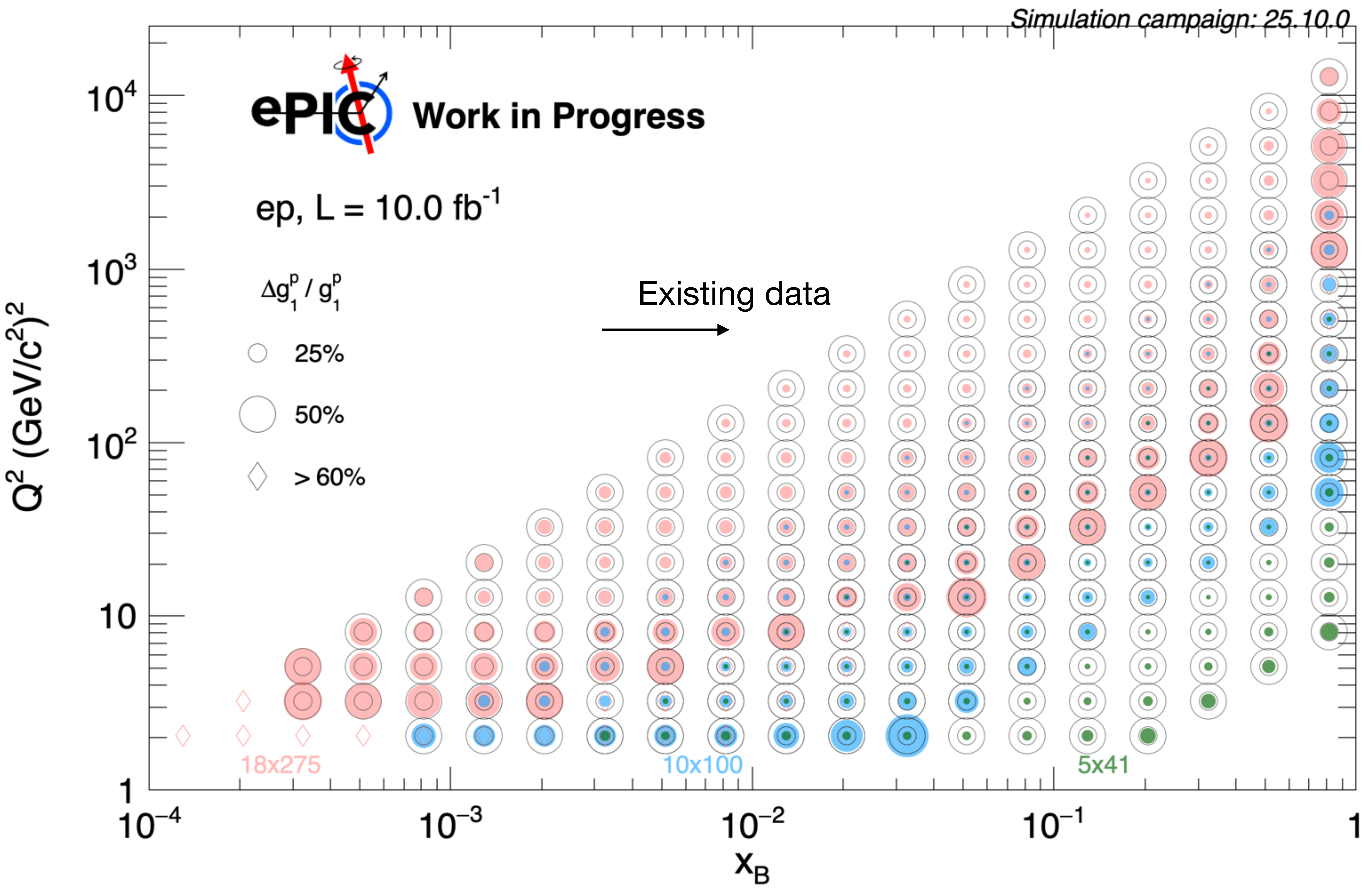
Systematic uncertainty

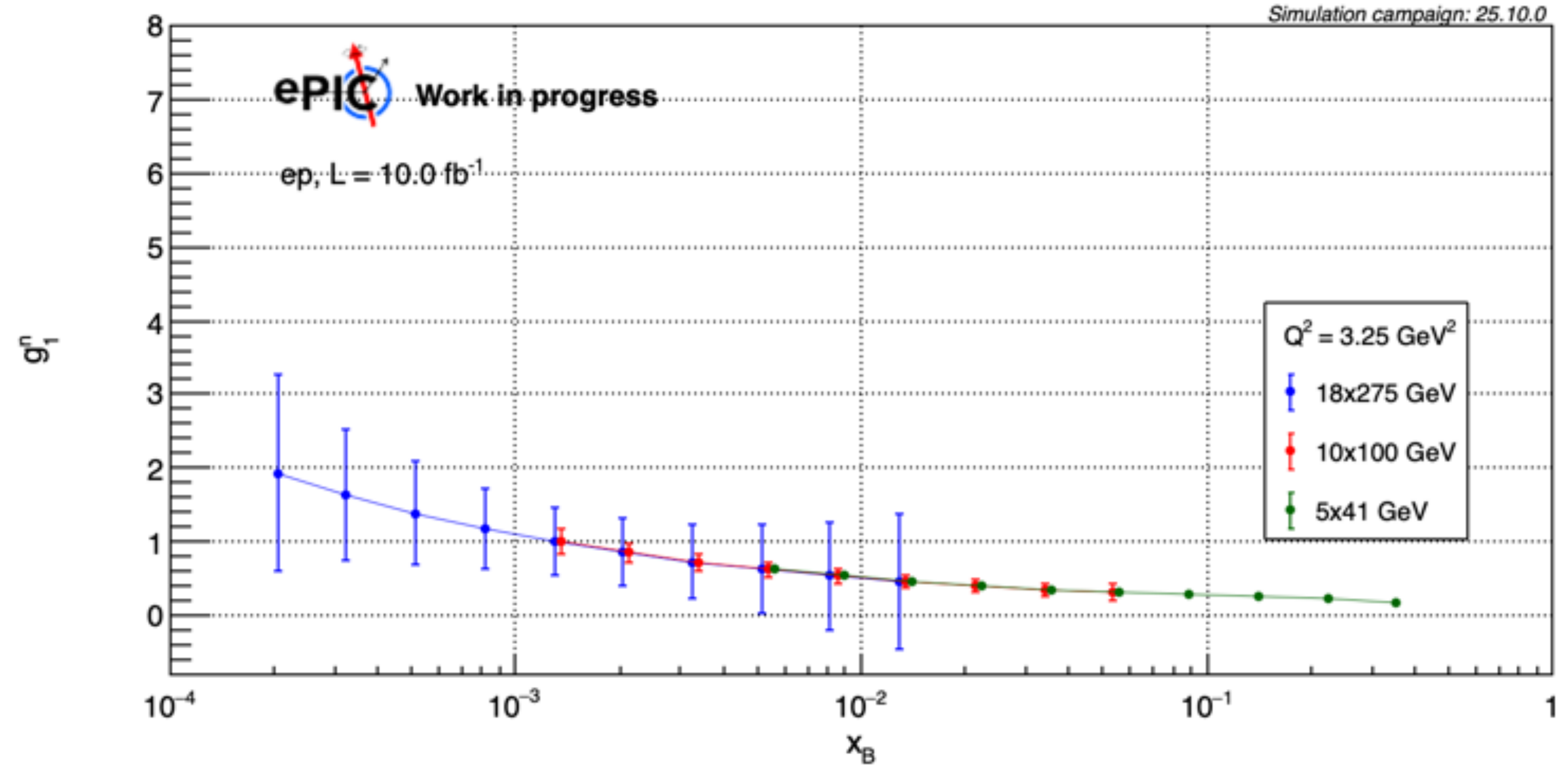
- estimation for ATHENA for $A_{\|}$
  - 1.5% point-by-point uncorrelated
  - 3% pion contamination
  - 2.9% normalization
    - 1.5% δP_e, 1.5% δP_N
    - 1-2% detector effects
- Estimated using $A_1 \approx \frac{A_{\|}}{D}$
- Systematics to be studied in more details

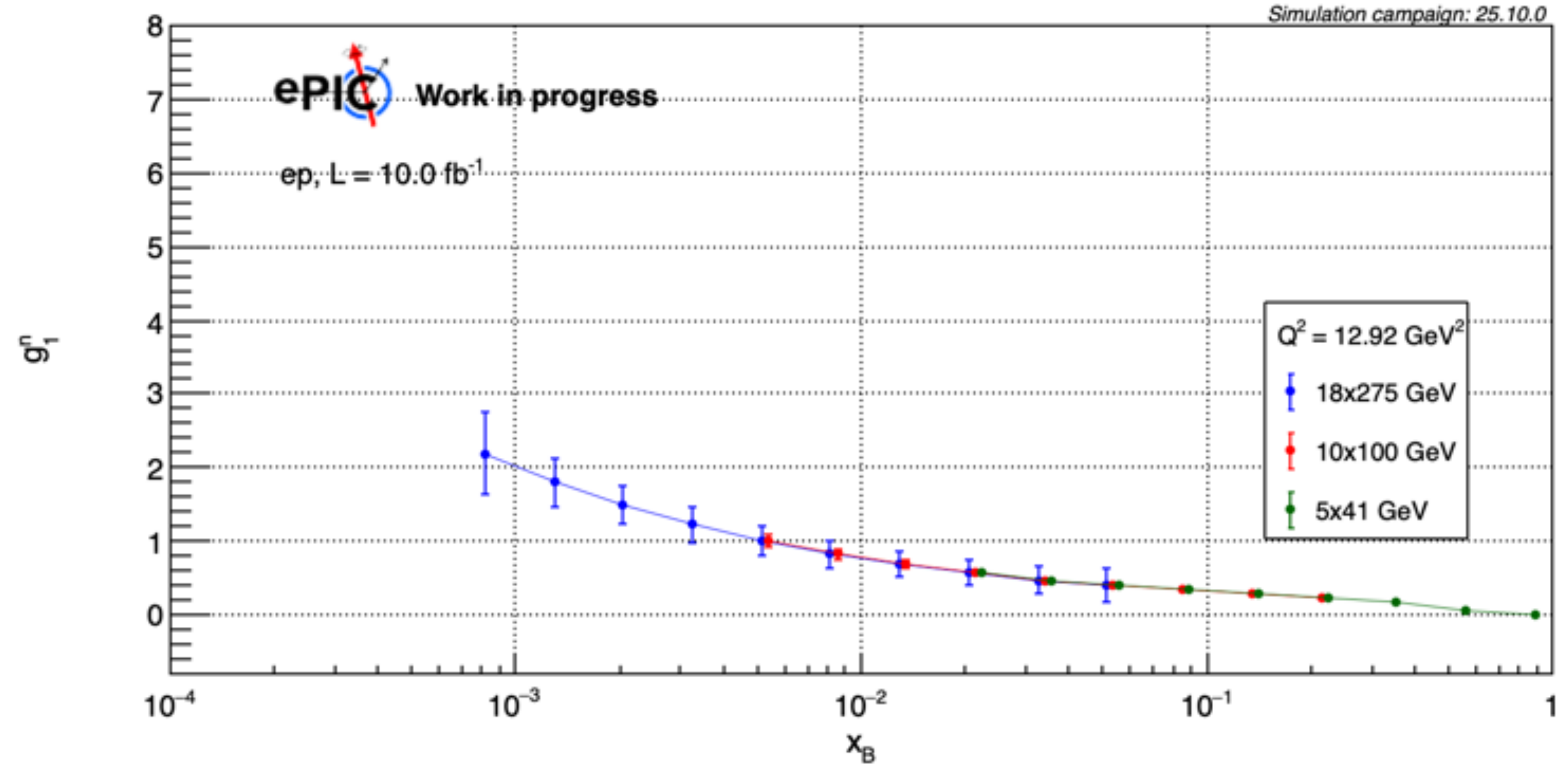


Projected g_1^p at EIC

- $A_1 \approx g_1/F_1$ with F_1 calculated from JAM22
- Statistical uncertainties only

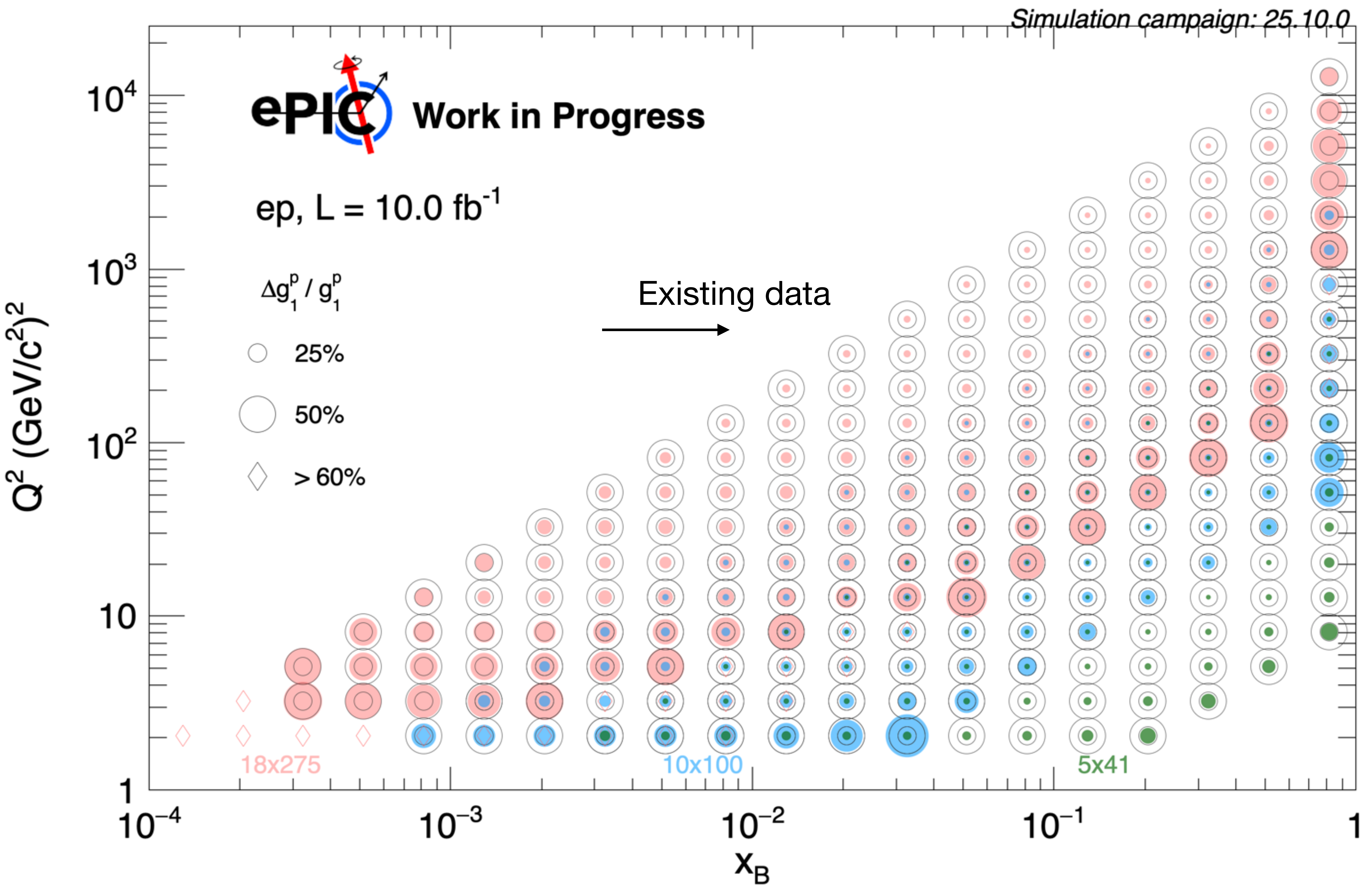


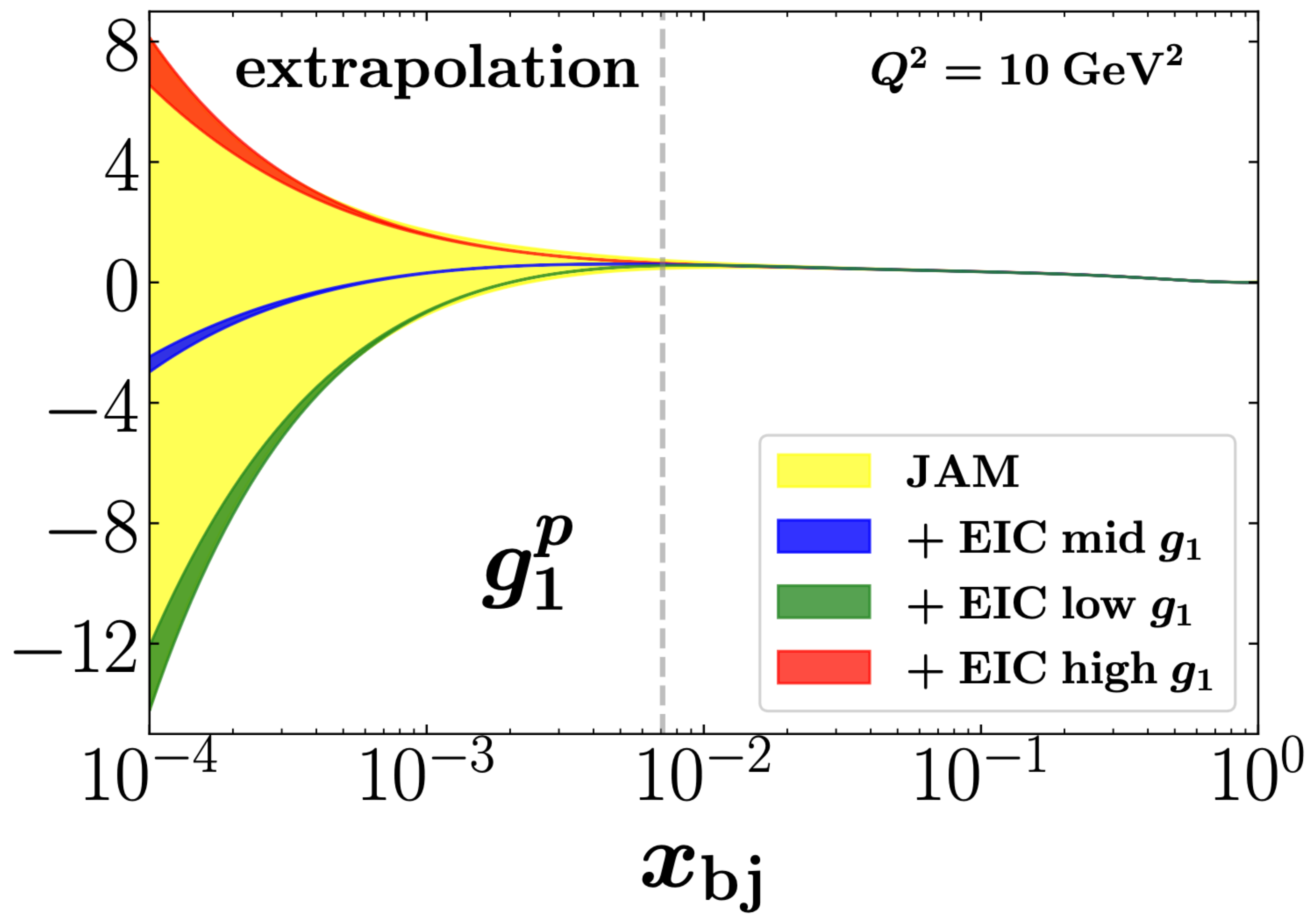




Projected g_1^p at EIC

- $A_1 \approx g_1/F_1$ with F_1 calculated from JAM22
- Statistical uncertainties only





R. Abdul Khalek et al. DOI: 0.1016/j.nuclphysa.2022.122447

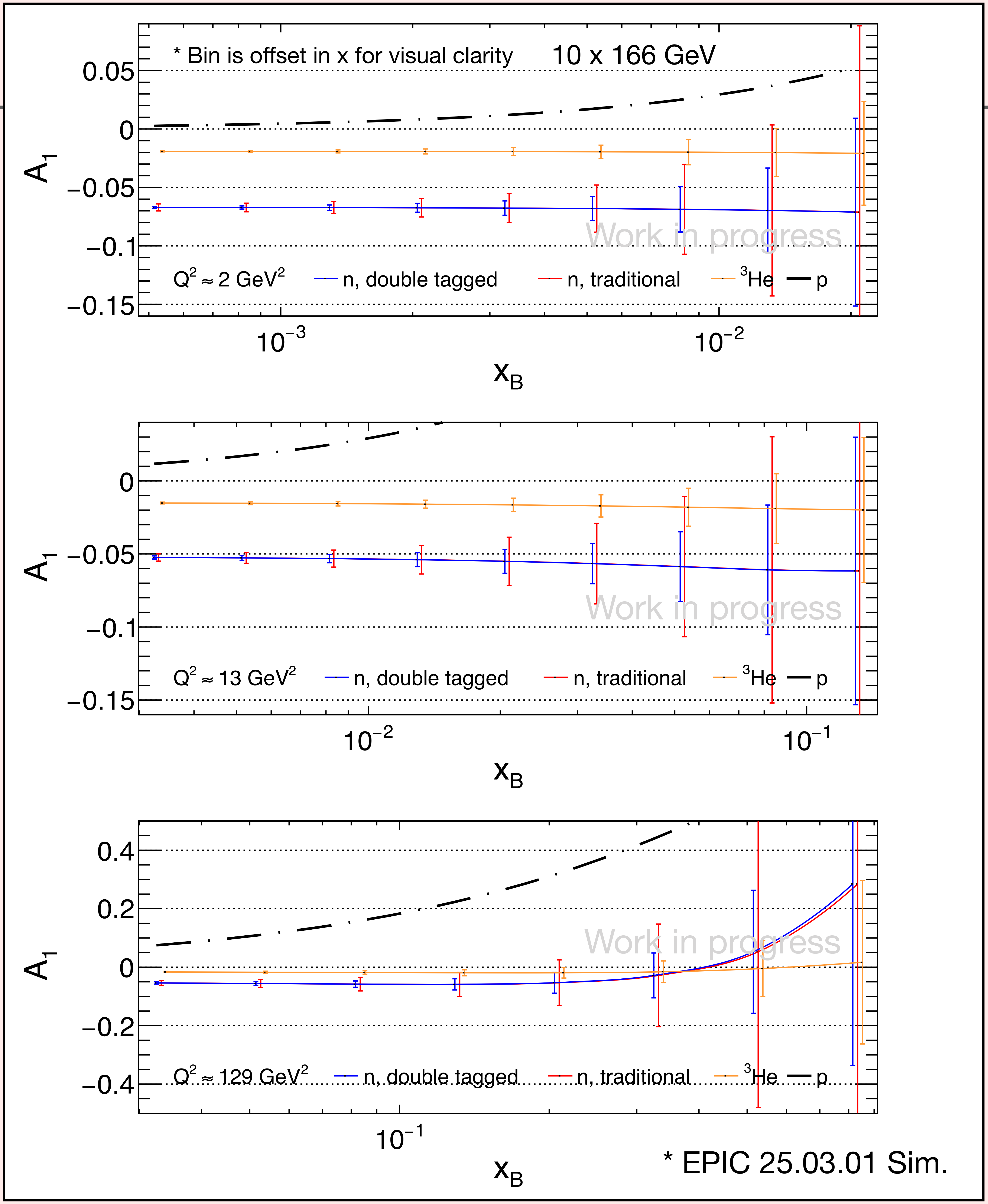
Projected A_1^n at EIC

- $A_1^{^3\mathrm{He}} = P_n \frac{F_2^n}{F_2^{^3\mathrm{He}}} A_1^n + 2P_p \frac{F_2^p}{F_2^{^3\mathrm{He}}} A_1^p$
- $\delta A_{\parallel,\perp}^{^3\mathrm{He}} = \frac{1}{\sqrt{N P_e P_N}}$

- F_2 obtained from JAM22
- Parameterization for A_1:

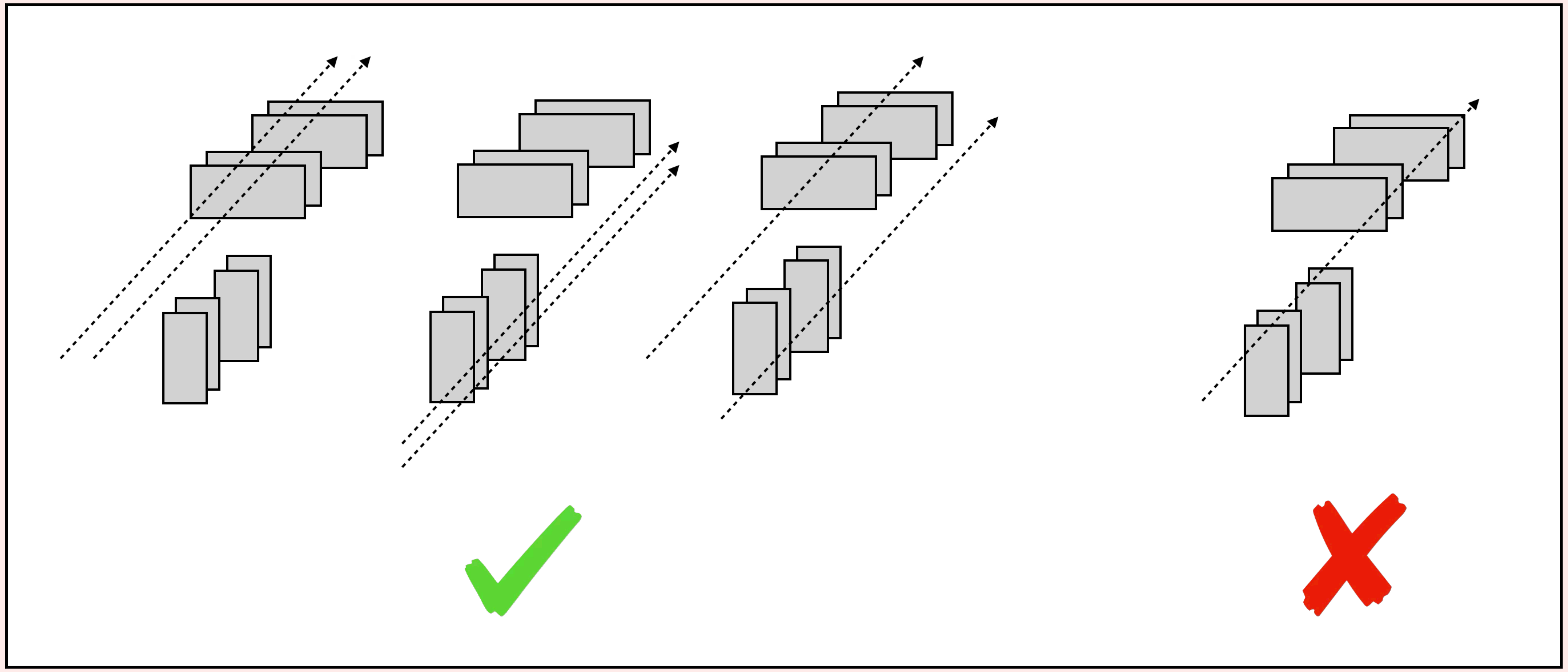
  X. Zheng et al. DOI: 10.1103/PhysRevC.70.065207
- Parameterization for R:

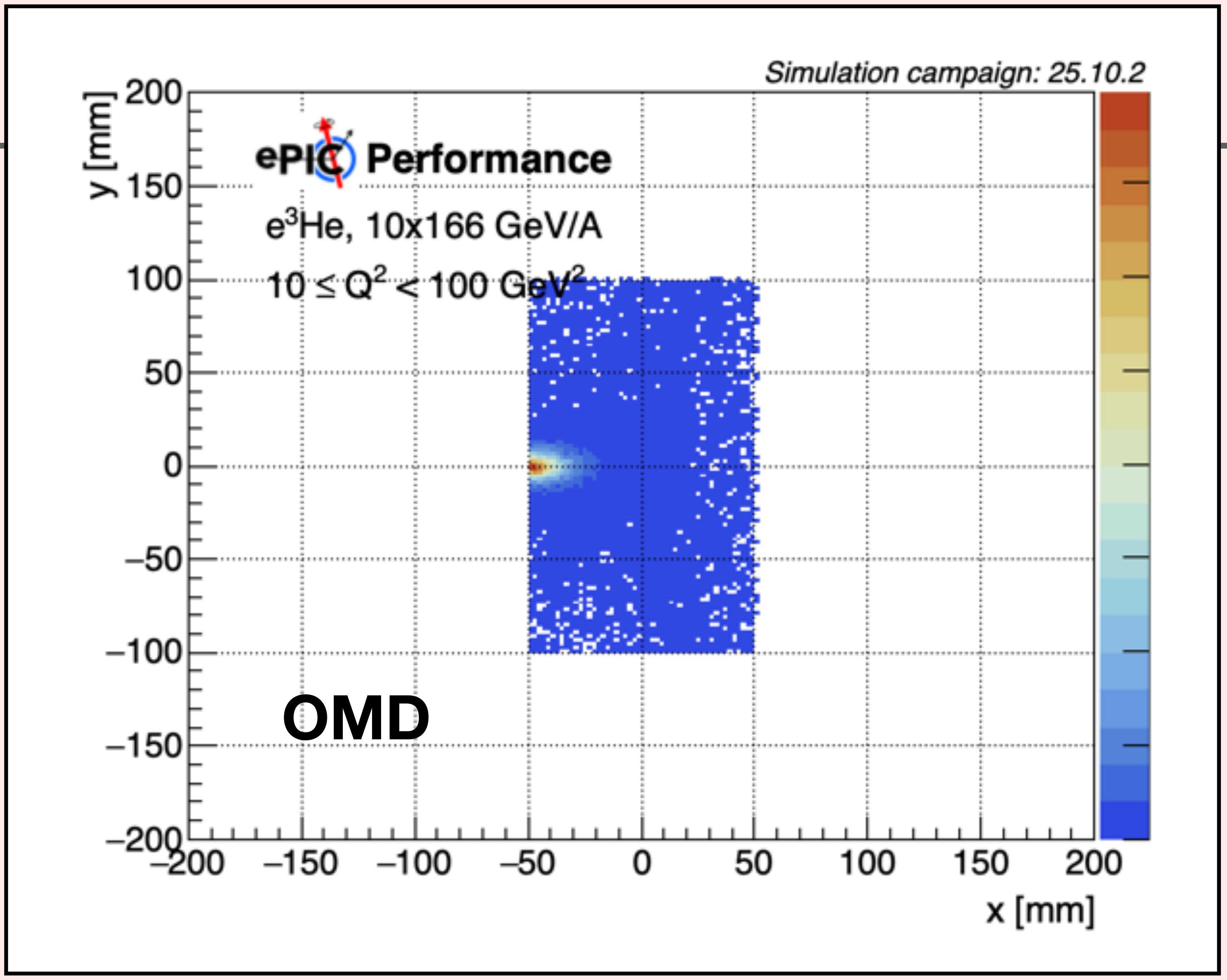
  K. Abe et al. DOI: 10.1016/S0370-2693(99)00244-0

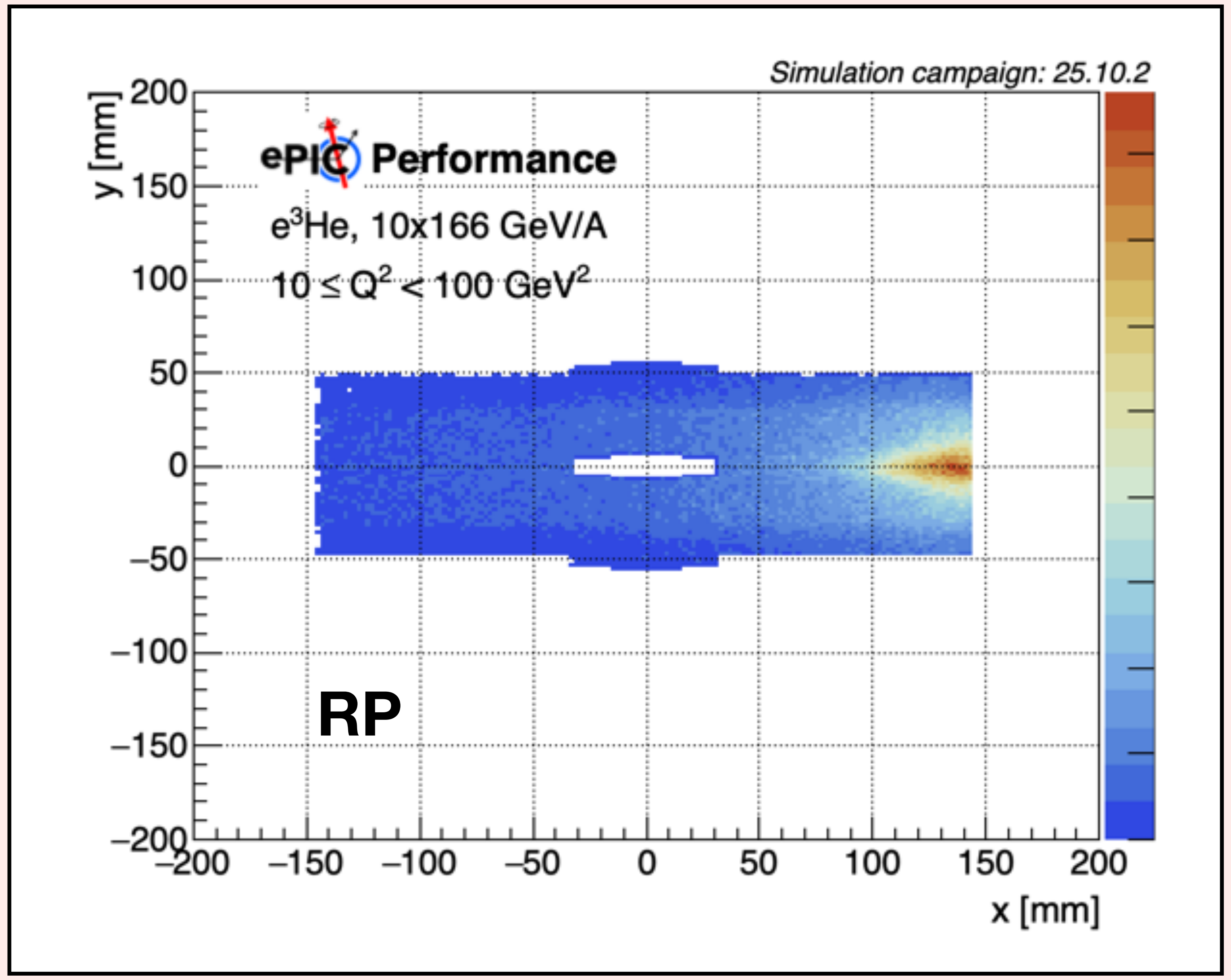


e^3He double spectator tagging

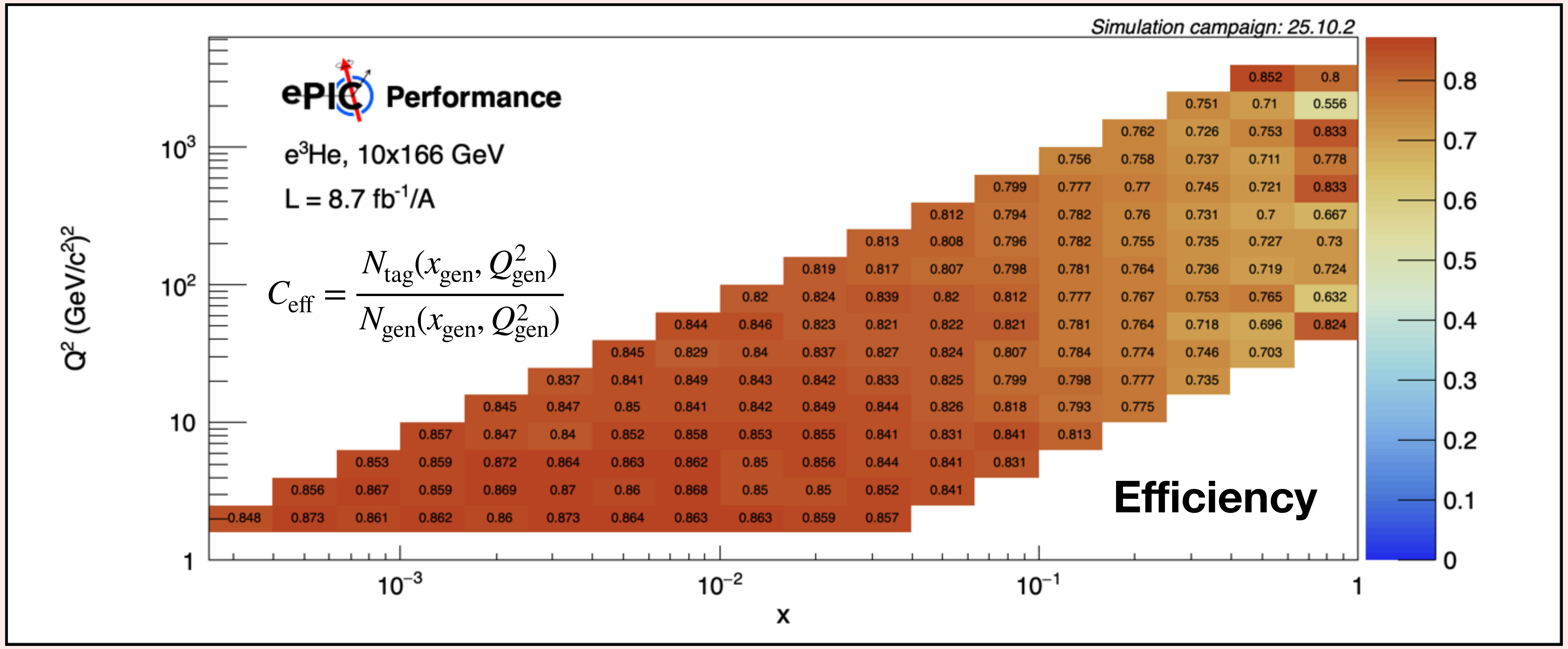
- Hit-based tagging algorithm
- Number of proton tracks = min number of hits per plane per detector
- If number of proton tracks > 2, then tag as double spectators
- Tracking-based algorithm is under development

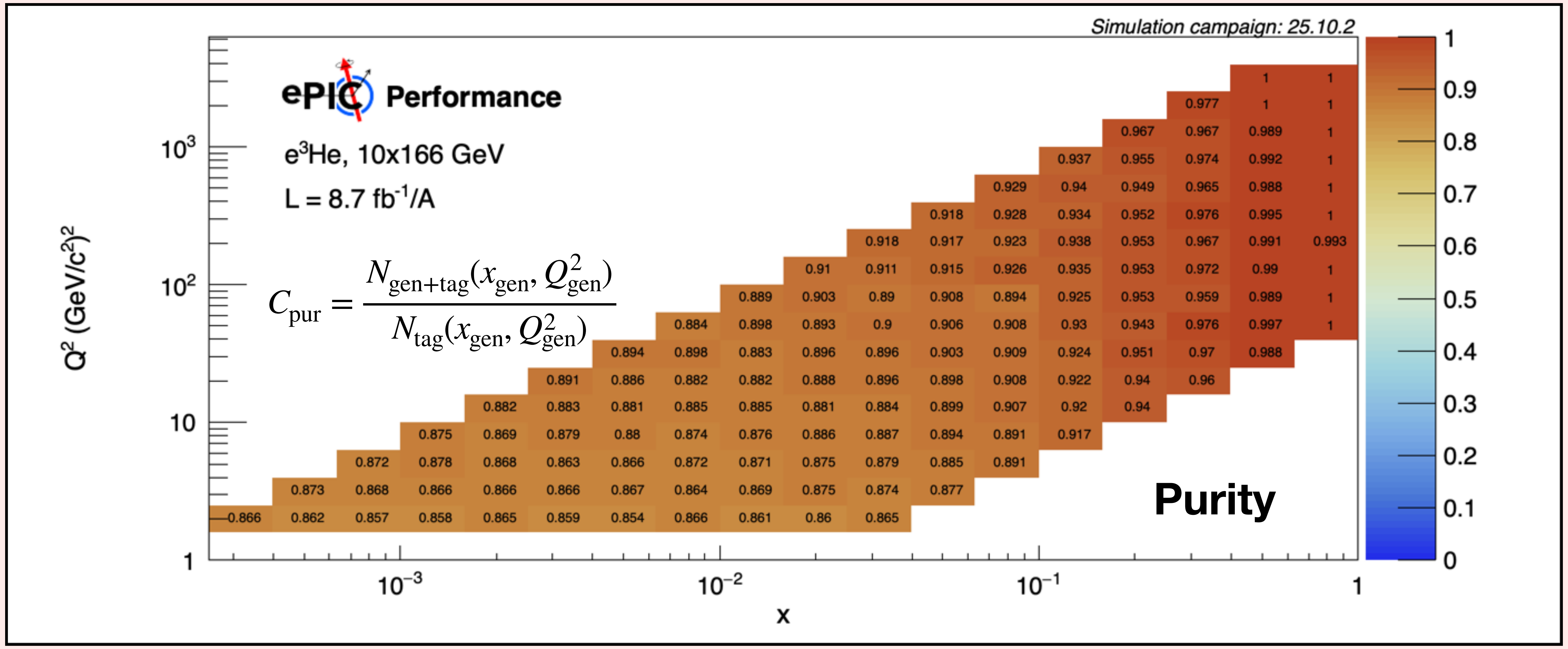






e^3He double spectator tagging



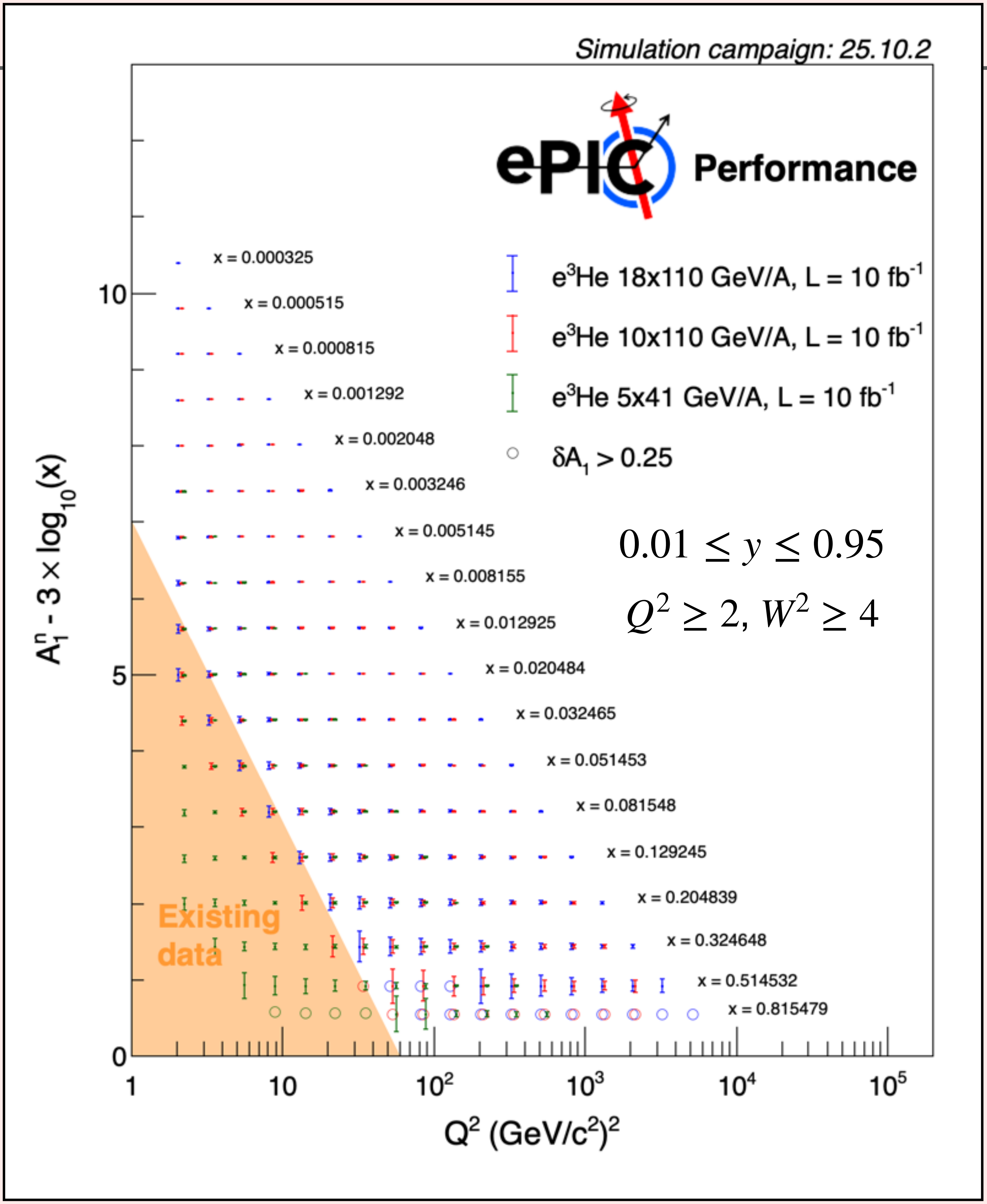


Projected A_1^n at EIC

- Projection with statistical uncertainty
- Data split evenly between $A_\parallel$ and $A_\perp$
- $P_e = P_p = 70\,\%$
- $$\delta A_{\parallel,\perp} = \frac{1}{\sqrt{N P_e P_N}}$$
- $$A_1(x, Q^2) \equiv \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{A_\parallel}{D(1+\eta\xi)} - \frac{\eta A_\perp}{d(1+\eta\xi)}$$
- Parameterization for A_1:

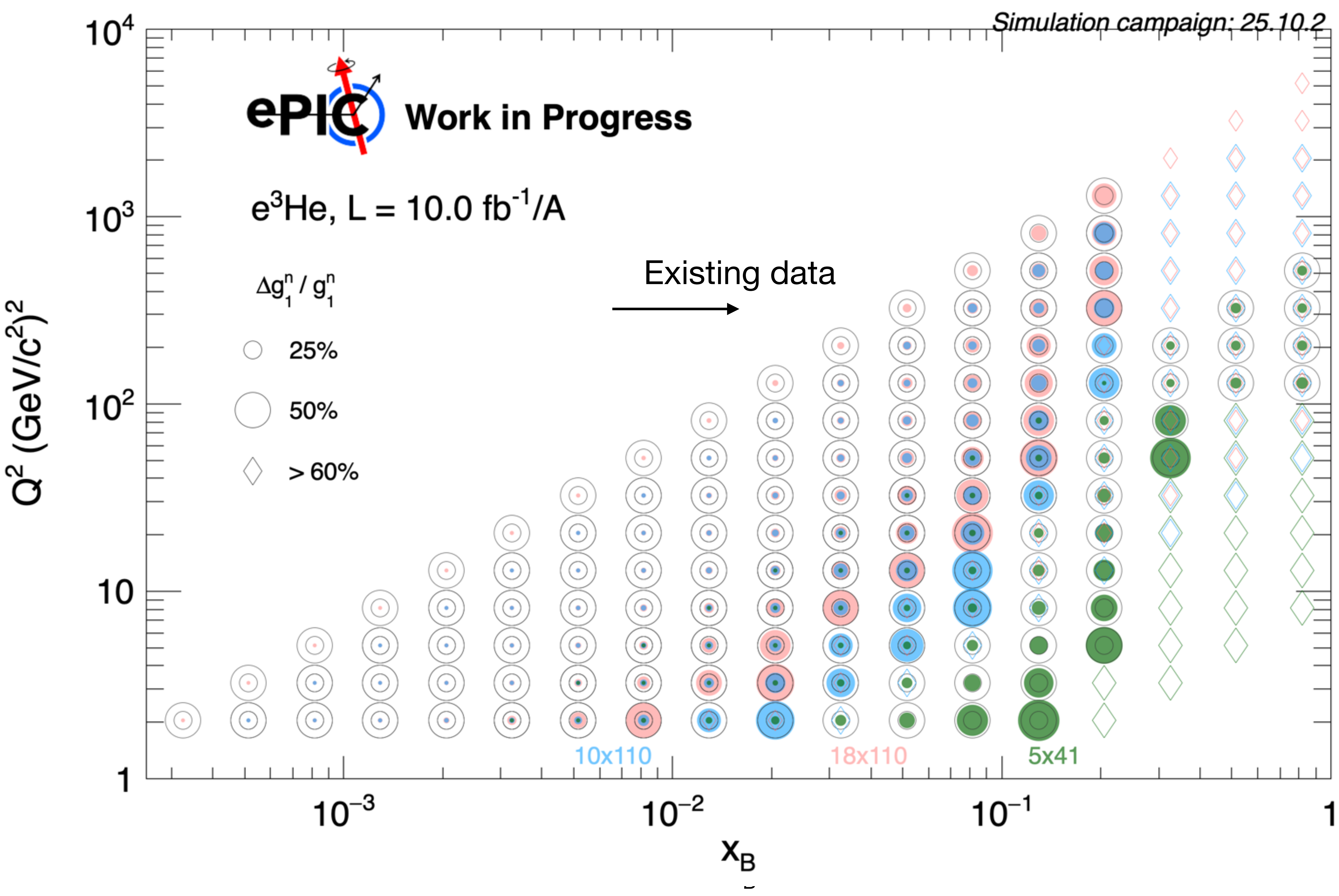
  X. Zheng et al. DOI: 10.1103/PhysRevC.70.065207
- Parameterization for R:

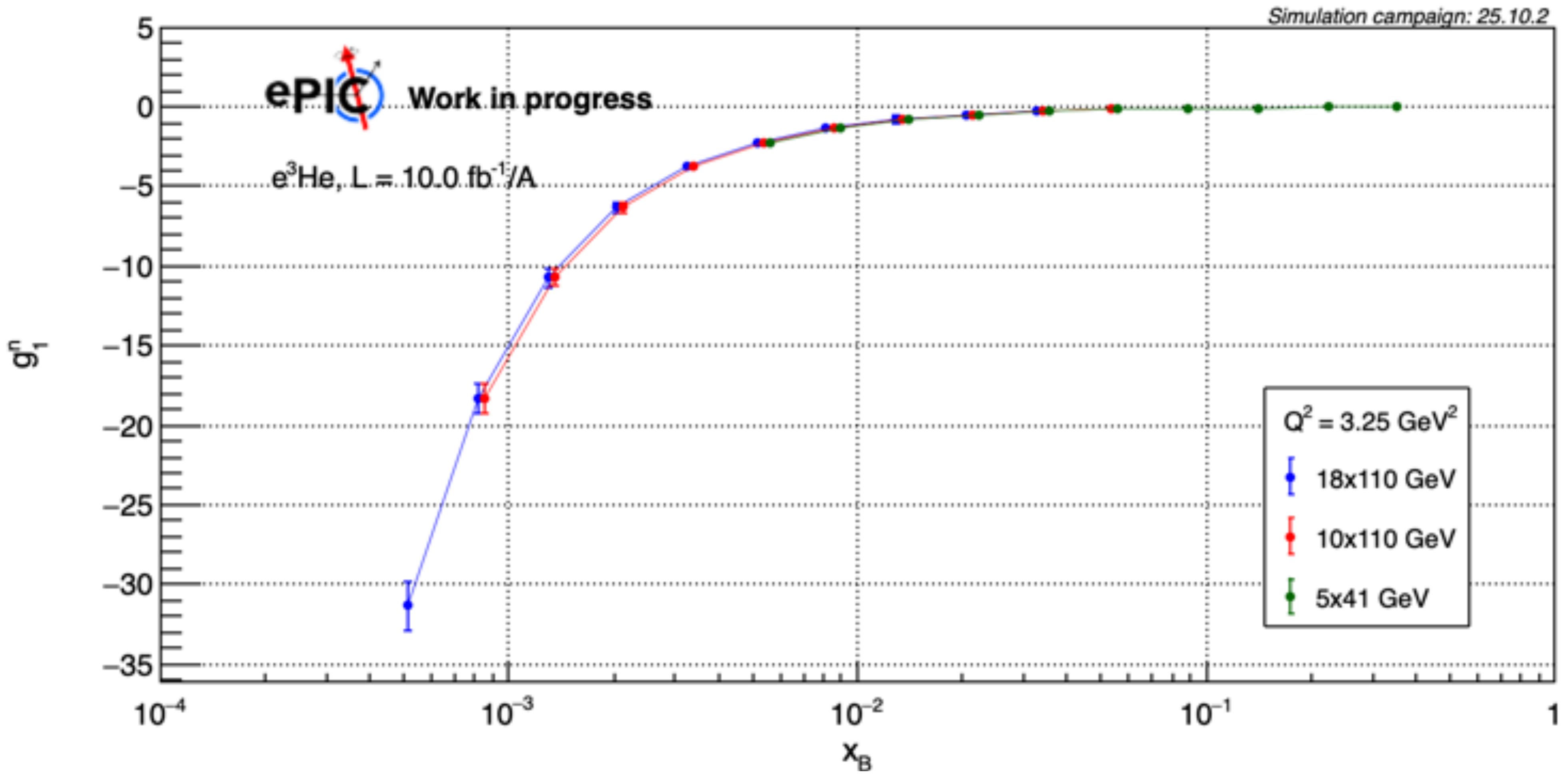
  K. Abe et al. DOI: 10.1016/S0370-2693(99)00244-0

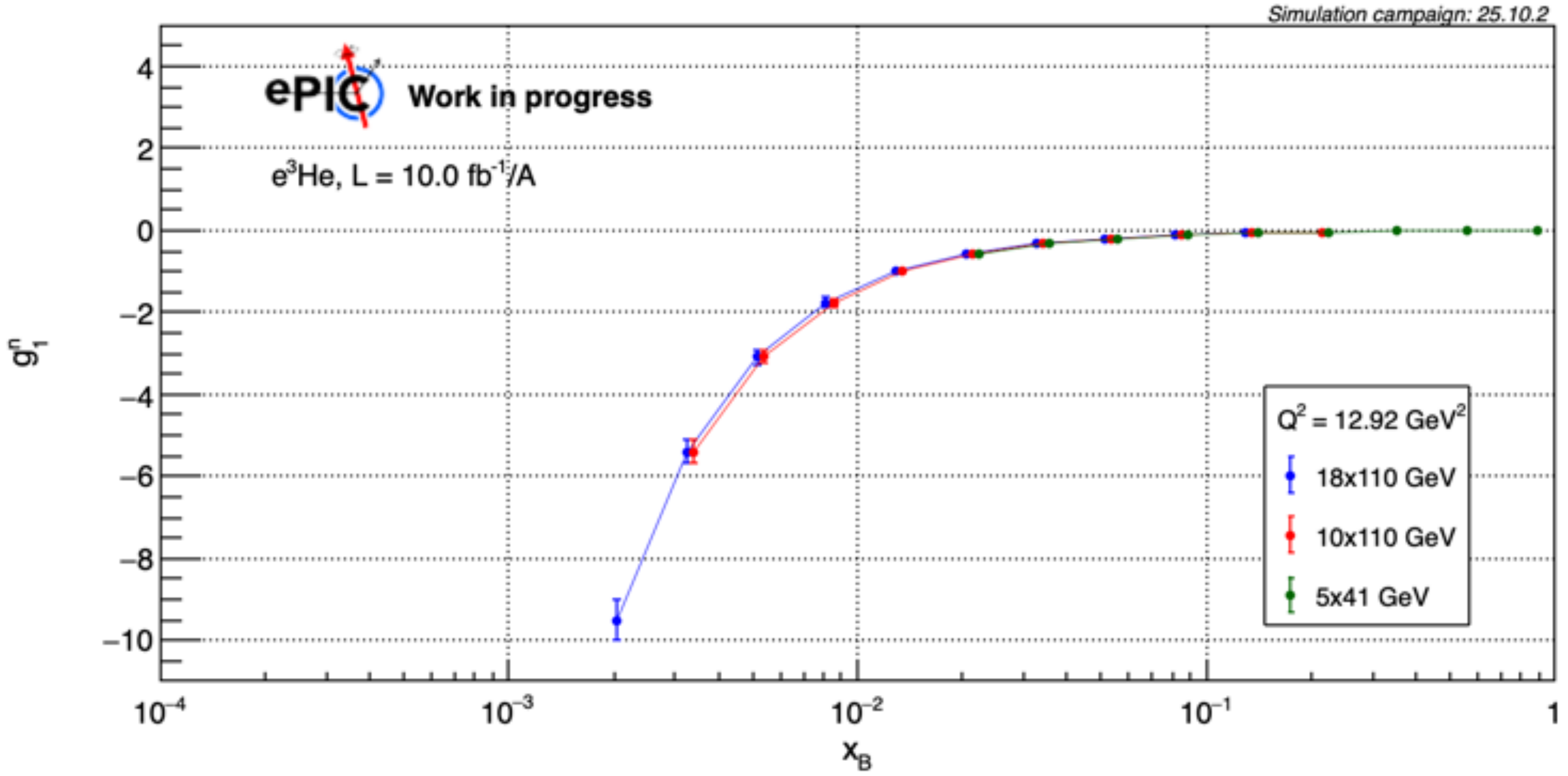


Projected g_1^n at EIC

- $A_1 \approx g_1/F_1$ with F_1 calculated from JAM22
- Statistical uncertainties only



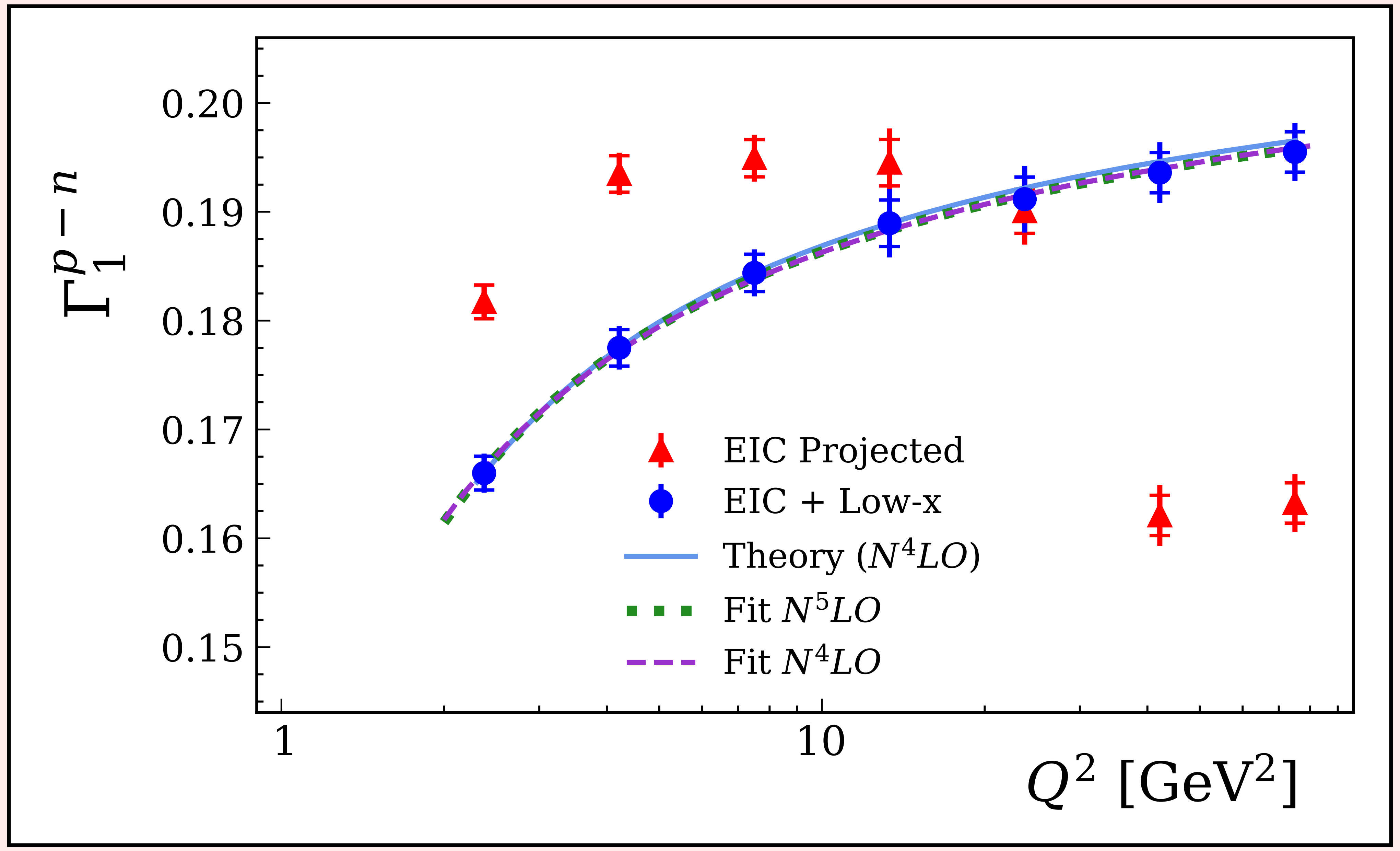


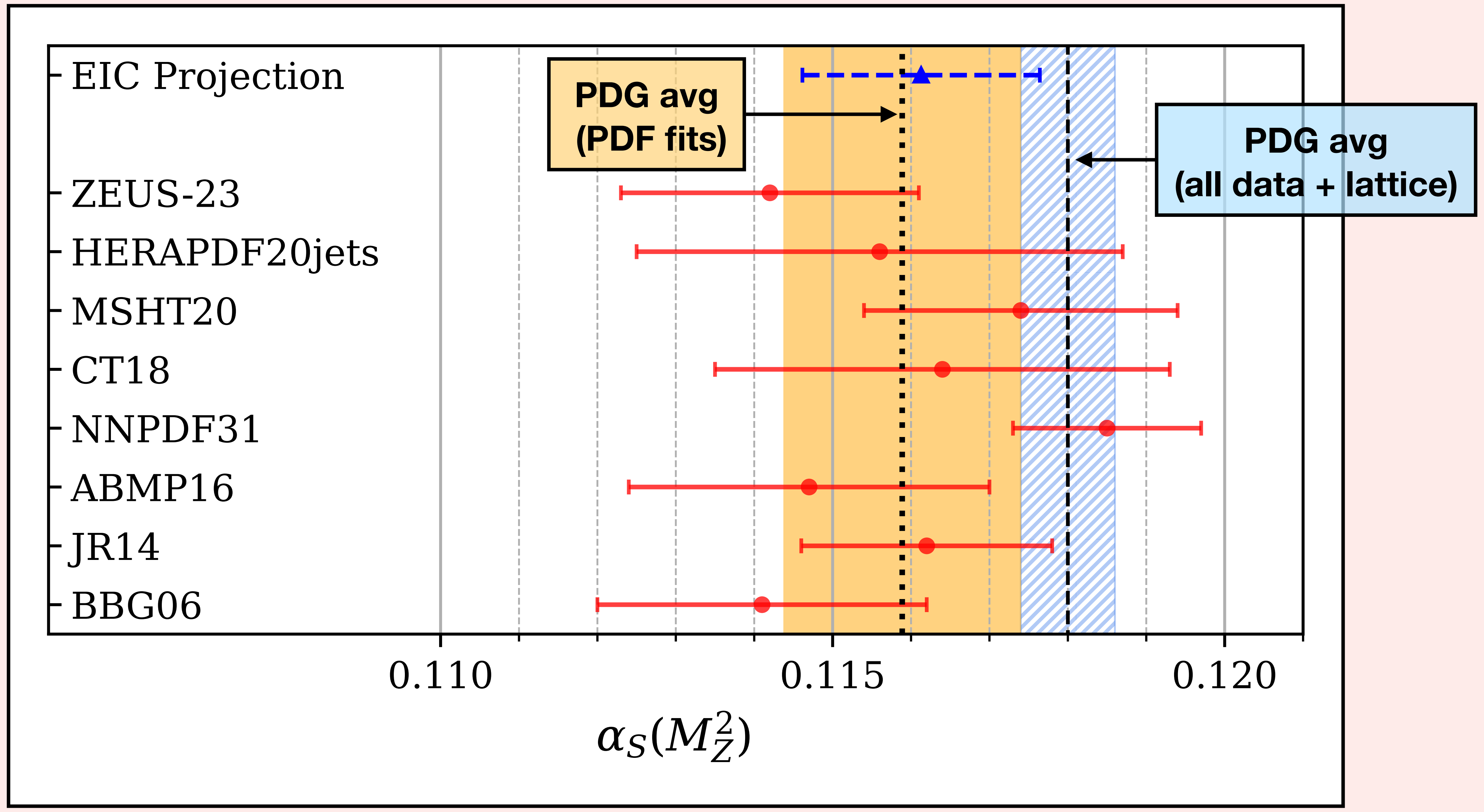


α_s and Bjorken Sum

$$\Gamma_1^{\mathrm{p-n}}(\alpha_s) = \Gamma_1^{\mathrm{p-n}}(Q^2) = \int_0^{1^-} (g_1^p(Q^2) - g_1^n(Q^2))\, dx = \sum_{n>0} \frac{\mu_{2n}^{p-n}(\alpha_s)}{Q^{2n-2}}$$

$$= \frac{g_A}{6}\left[1 - \frac{\alpha_S(Q^2)}{\pi} - 3.58\left(\frac{\alpha_S(Q^2)}{\pi}\right)^2 - 20.21\left(\frac{\alpha_S(Q^2)}{\pi}\right)^3 - 175.7\left(\frac{\alpha_S(Q^2)}{\pi}\right)^4 - \mathcal{O}((\alpha_S)^5)\right] \quad \text{at finite } Q^2$$





Assume $\mathscr{L} = 10\ \mathrm{fb}^{-1}$ for each setting:

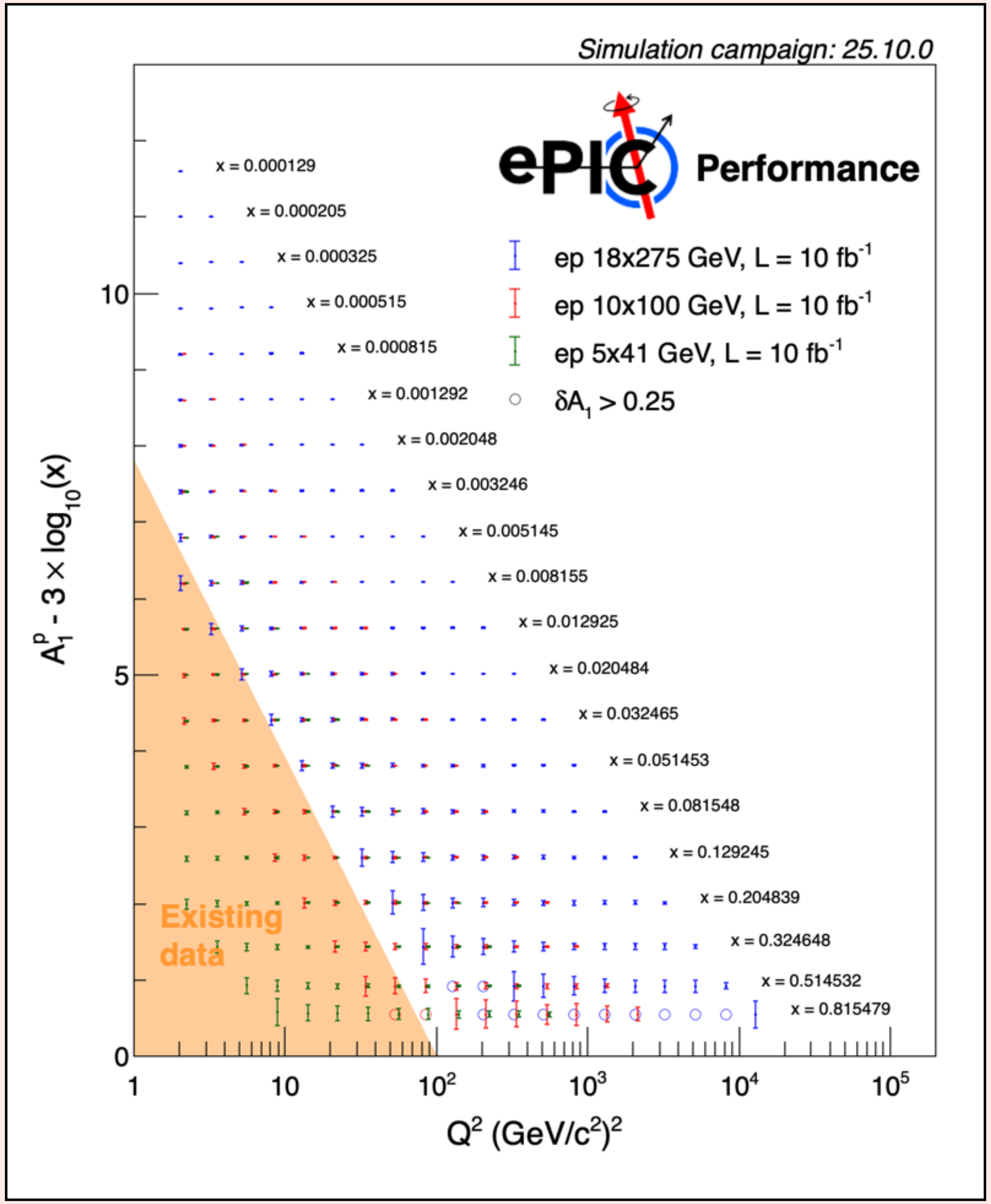
5x41, 10x100, 18x275 ep DIS

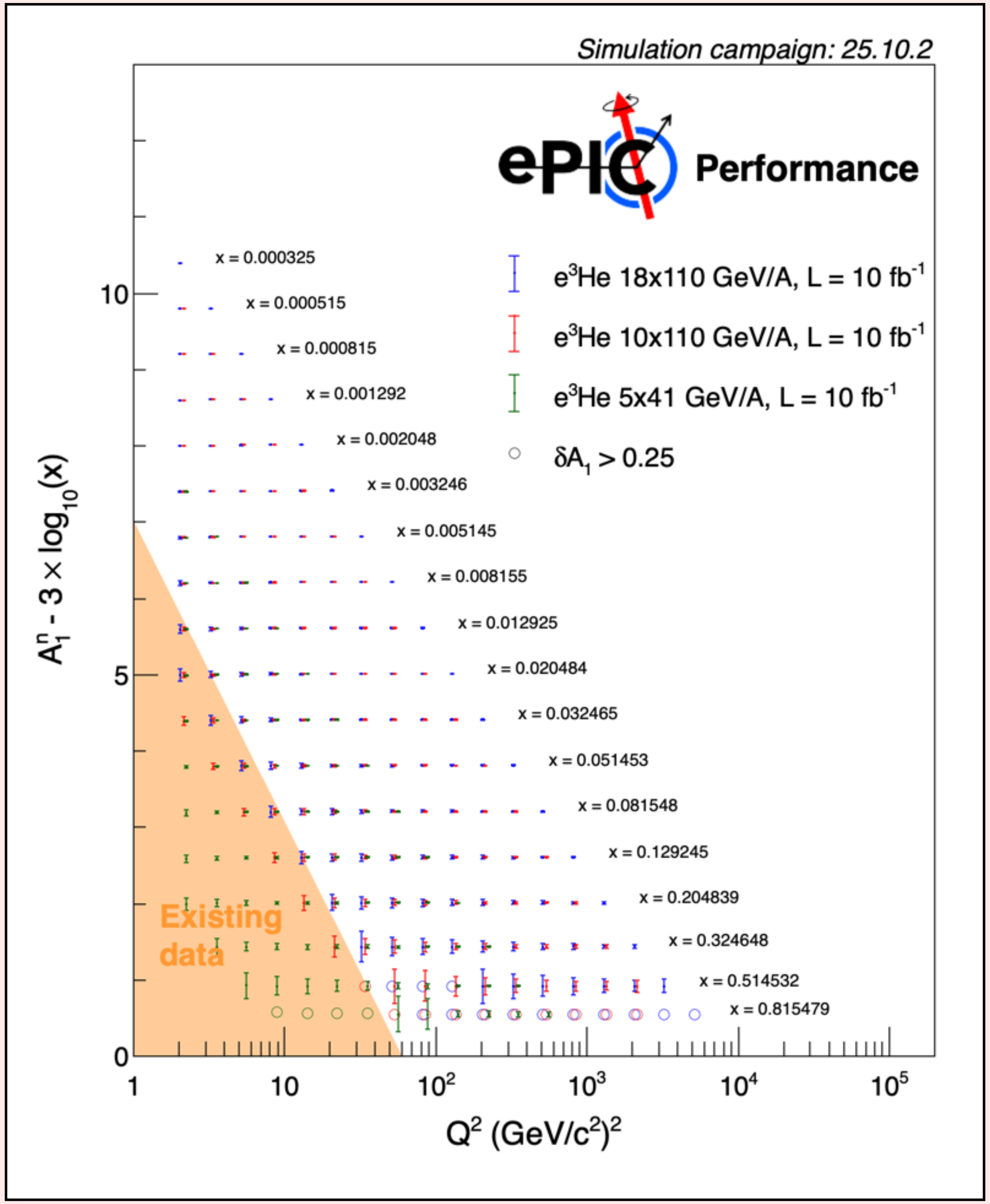
5x41, 10x100, 18x166 en DIS

T. Kutz et al. https://doi.org/10.1103/PhysRevD.110.074004

$$\Delta\alpha_s(M_Z)/\alpha_s(M_Z) = 1.3\ \%$$

Summary





Thank you :)

More on ePIC inclusive physics: Thu. 12PM WG1 Stephen M.