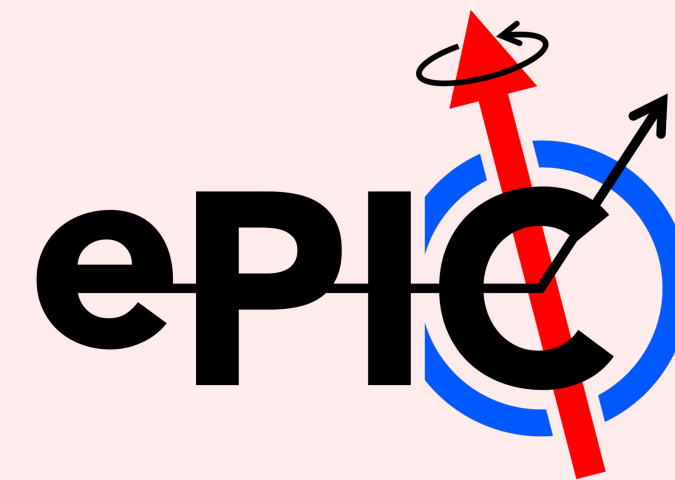
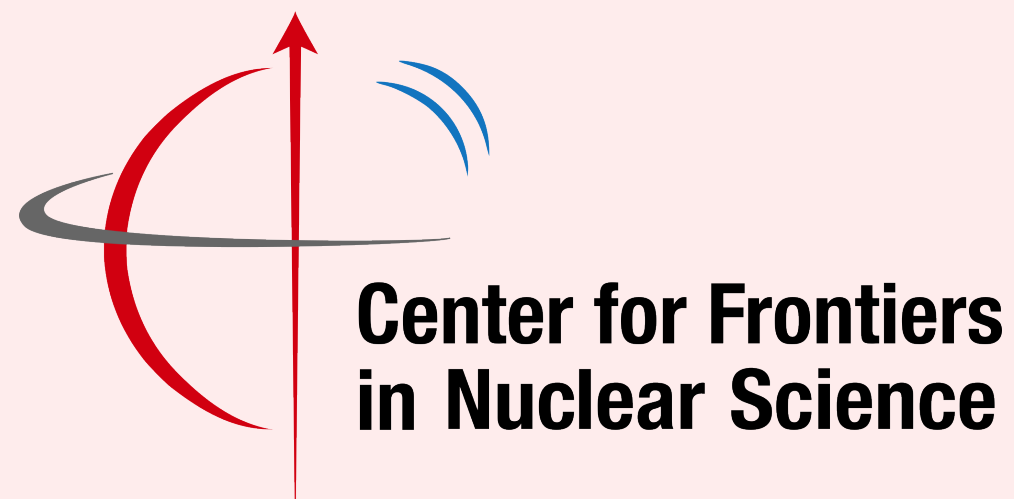


Inclusive measurement opportunities during early running at ePIC

Win Lin · Stony Brook University

On behalf of the ePIC inclusive PWG

MENU, 10/22/2026

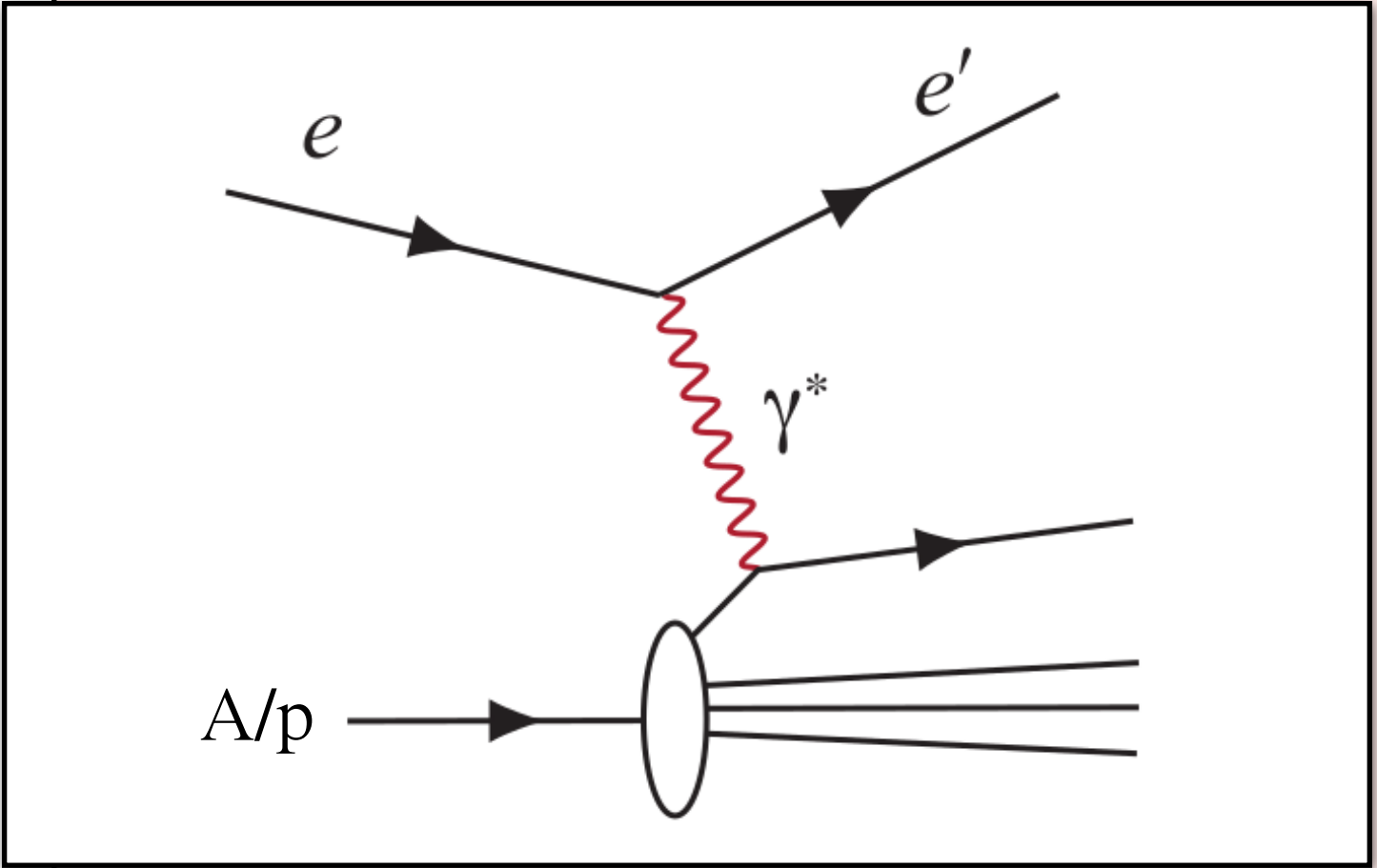


Early running achievable physics goals

NAS Science Pillars and ePIC early science Measurements

Examples inside each cell indicate how ePIC early physics measurements connect to the three NAS pillars

ePIC early science measurement type	Origin of nucleon mass	Origin of nucleon spin	Emergent properties of dense gluon matter
Inclusive DIS	Supporting F_2 and F_L structure functions - Proton PDFs and α_S	Strong $A_1^{p,n}$ and $g_1^{p,n}$ - Gluon helicity PDFs	Important - Nuclear F_2 ratios - Nuclear PDF constraints
Semi-inclusive DIS	Supporting - Unpolarized TMD PDFs - Nuclear fragmentation functions	Strong - Sivers A_{UT} - Collins asymmetries - Quark helicity PDFs	Strong - Di-hadron correlations - Nuclear hadronization / fragmentation
Exclusive / Diffractive / Tagged	Strong - DVCS / GPD imaging - Quarkonium production - Meson form factors / structure functions	Important - Spectator-tagged $A_1(n)$ - GPD constraints on OAM	Strong Coherent/incoherent VM in eA
Jets & Heavy Flavor	Important - Open charm production Λ_c/D^0 ratio	Supporting Δg from charm/jets - Hadron-in-jet Collins FF	Important - Charged-jet R_{eA} D^0-in-jet R_{eA}



- Inclusive DIS gives controlled access to quark and gluon structure
- ePIC will provide important nucleon structure and spin data starting from the beginning of EIC running

- ▶ In the first 5 to 6 years of planned running, multiple beam species, energies and polarization configurations will already become available
- ▶ Luminosities will be lower compared to EIC full operation, but still significant (H1 and ZEUS collected $\sim 1 \text{ fb}^{-1}$ between them over their entire lifetime)

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

*eA luminosity is per nucleon

In full running capacity and future upgrade:

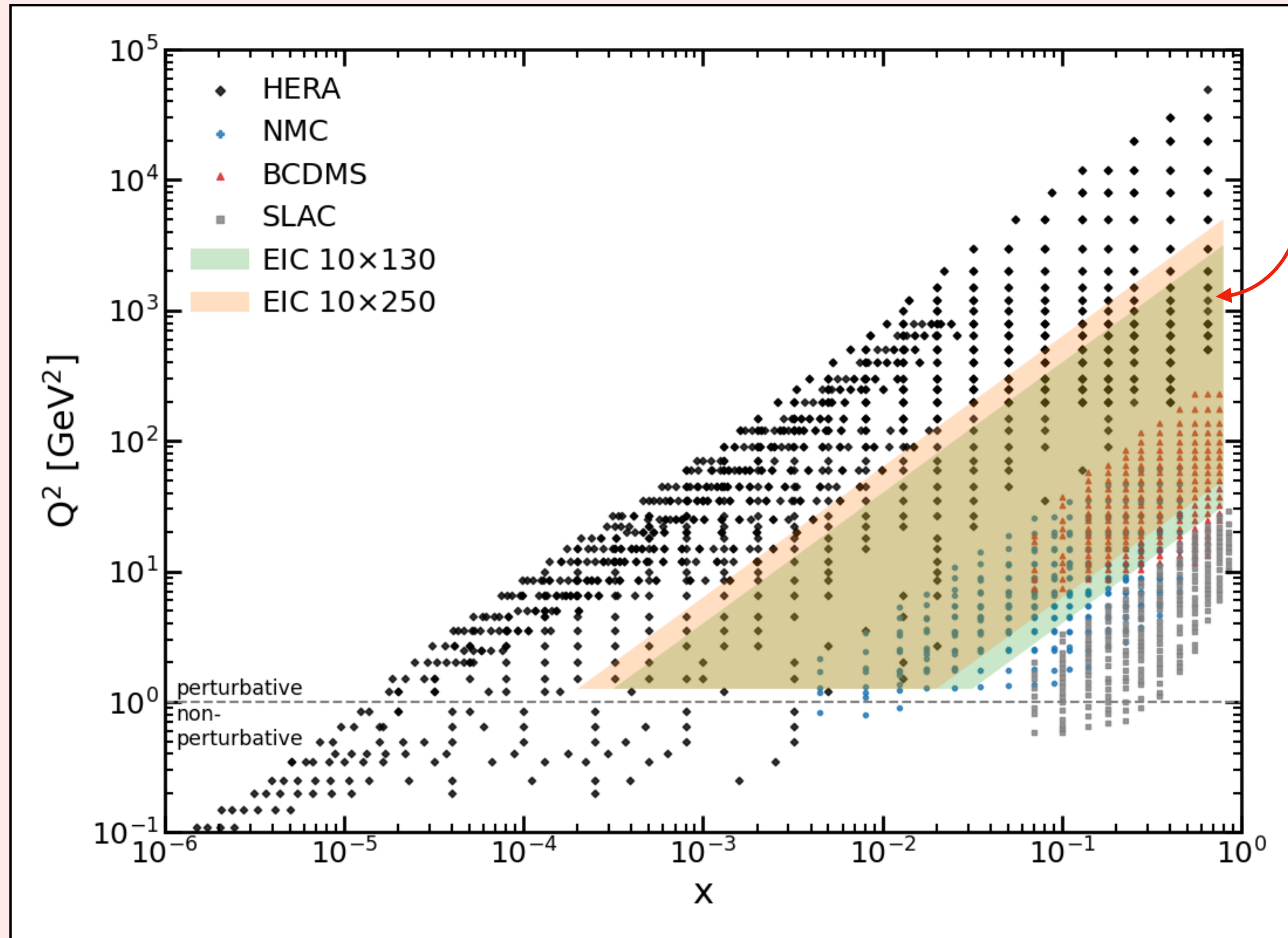
Electron: 5 - 18 GeV

Proton: 41 - 275 GeV

higher luminosities

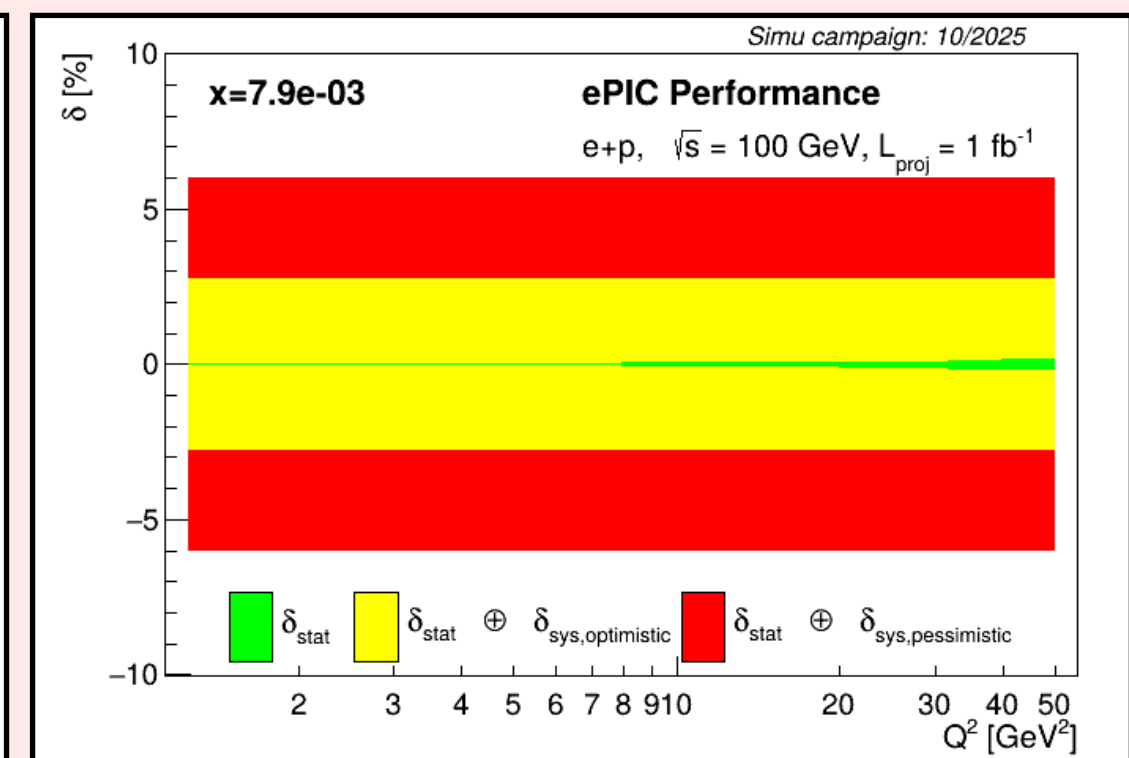
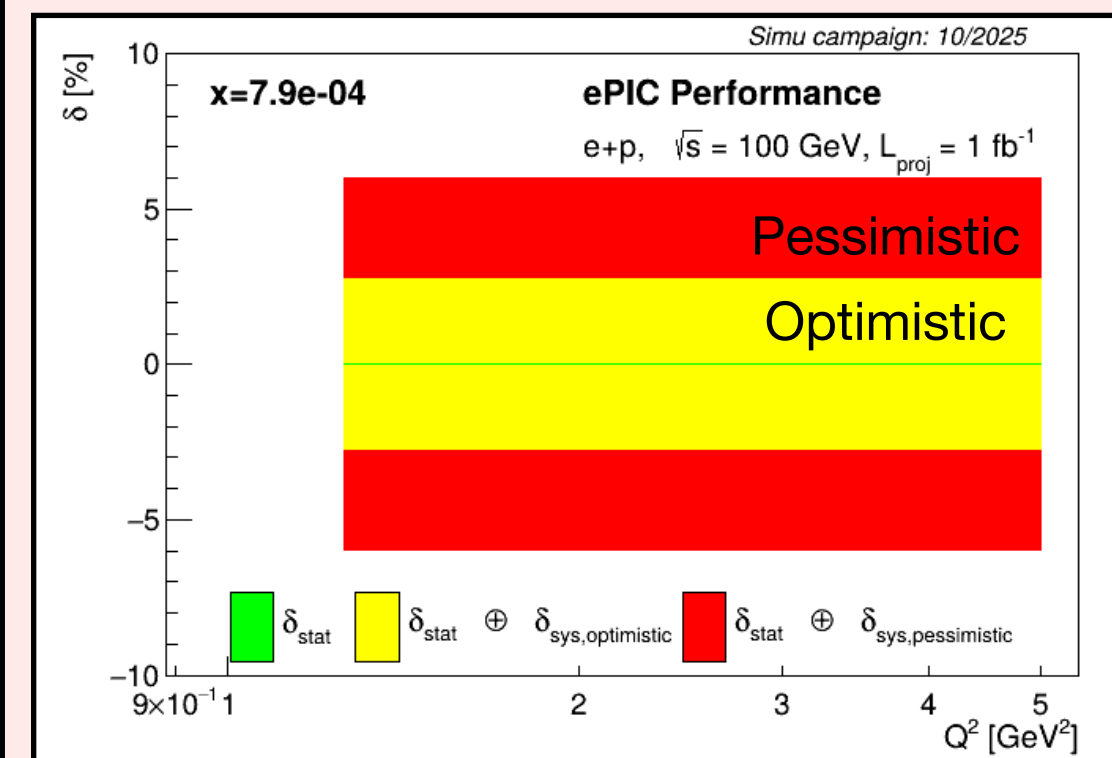
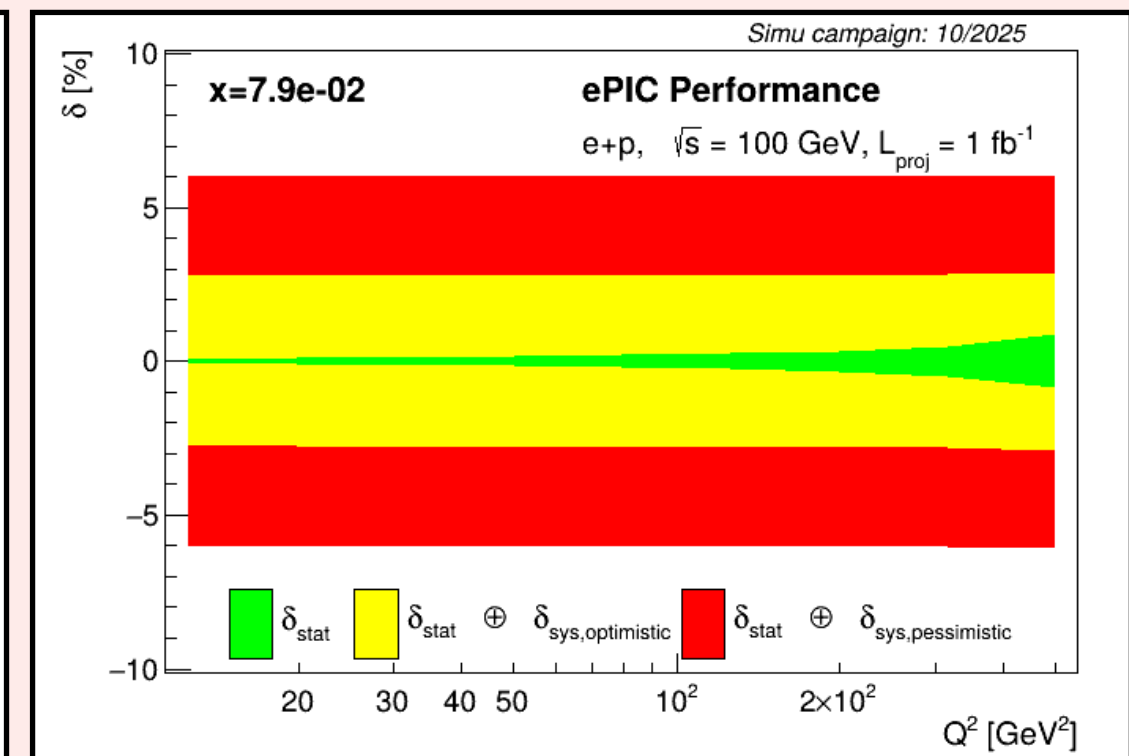
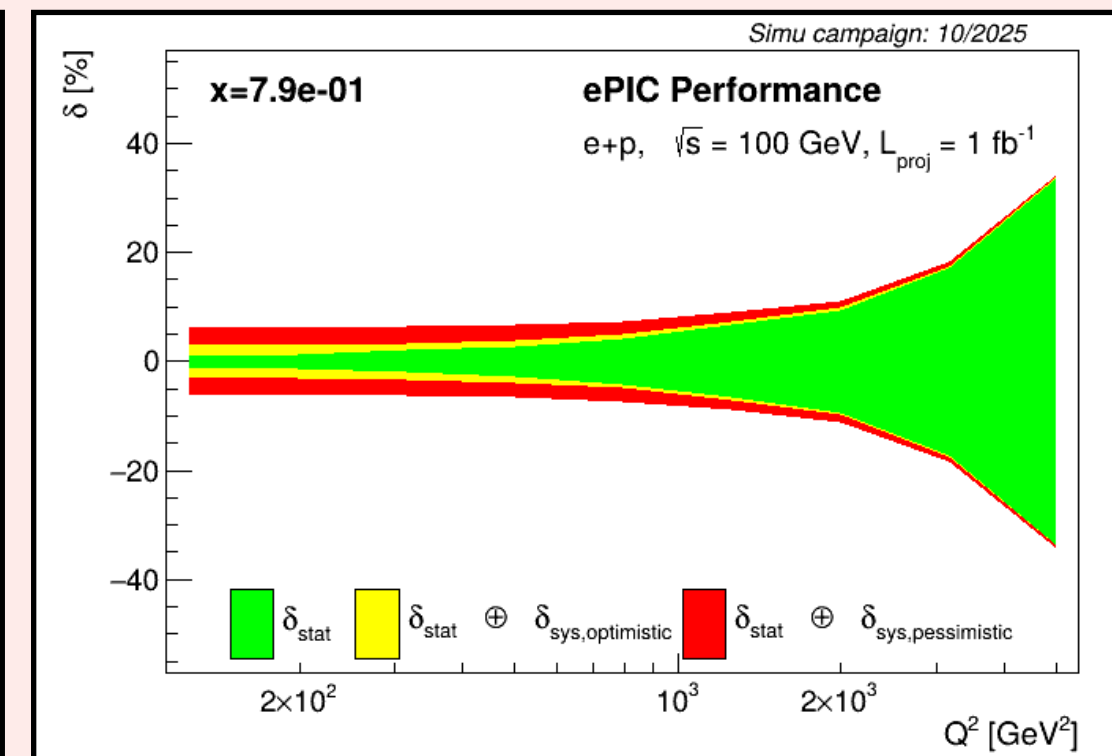
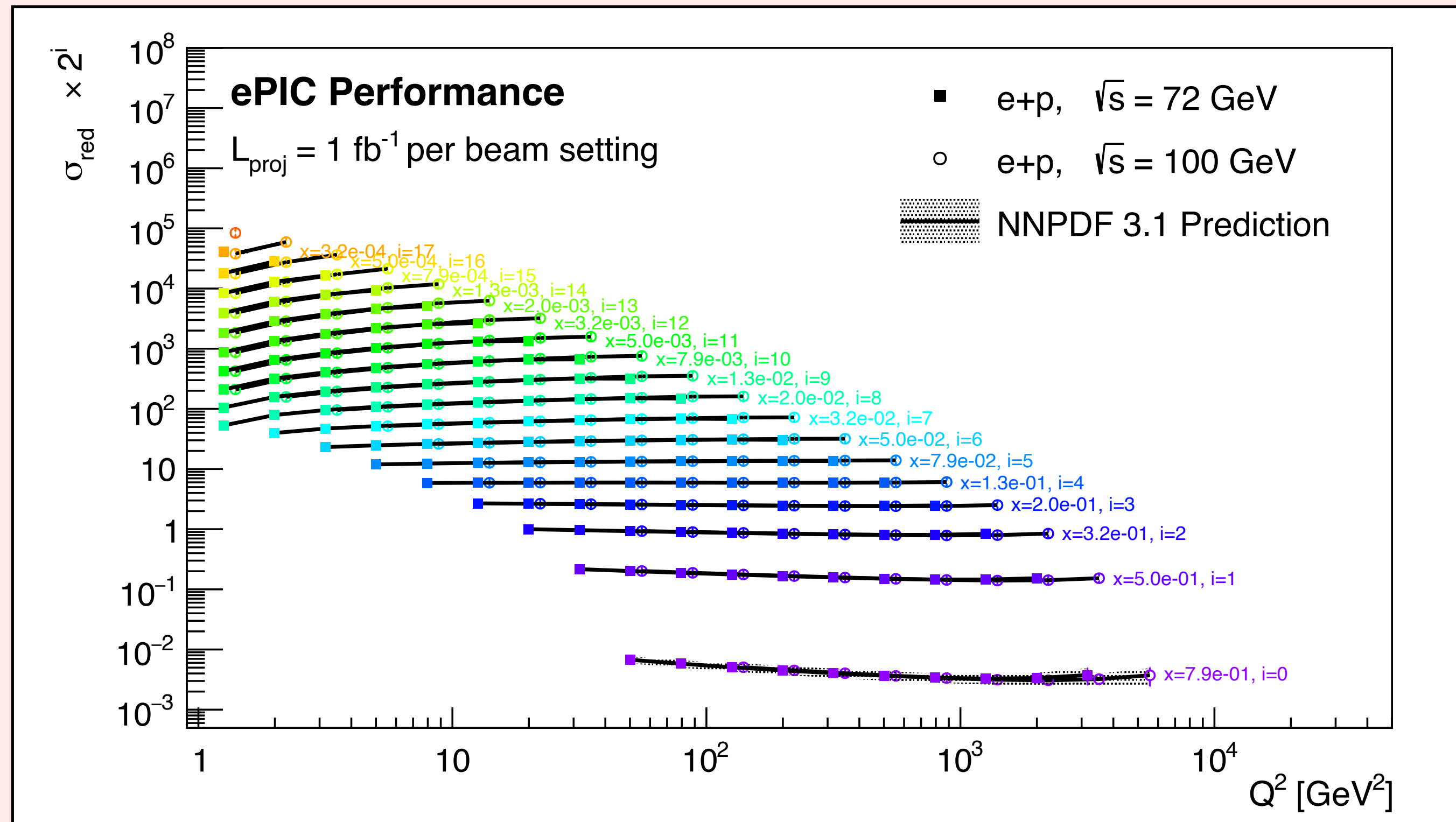
* Some ep/eA studies in this talk use 10×130 & 10×250 GeV beam energy configurations

How are quarks and gluons distributed inside the proton?

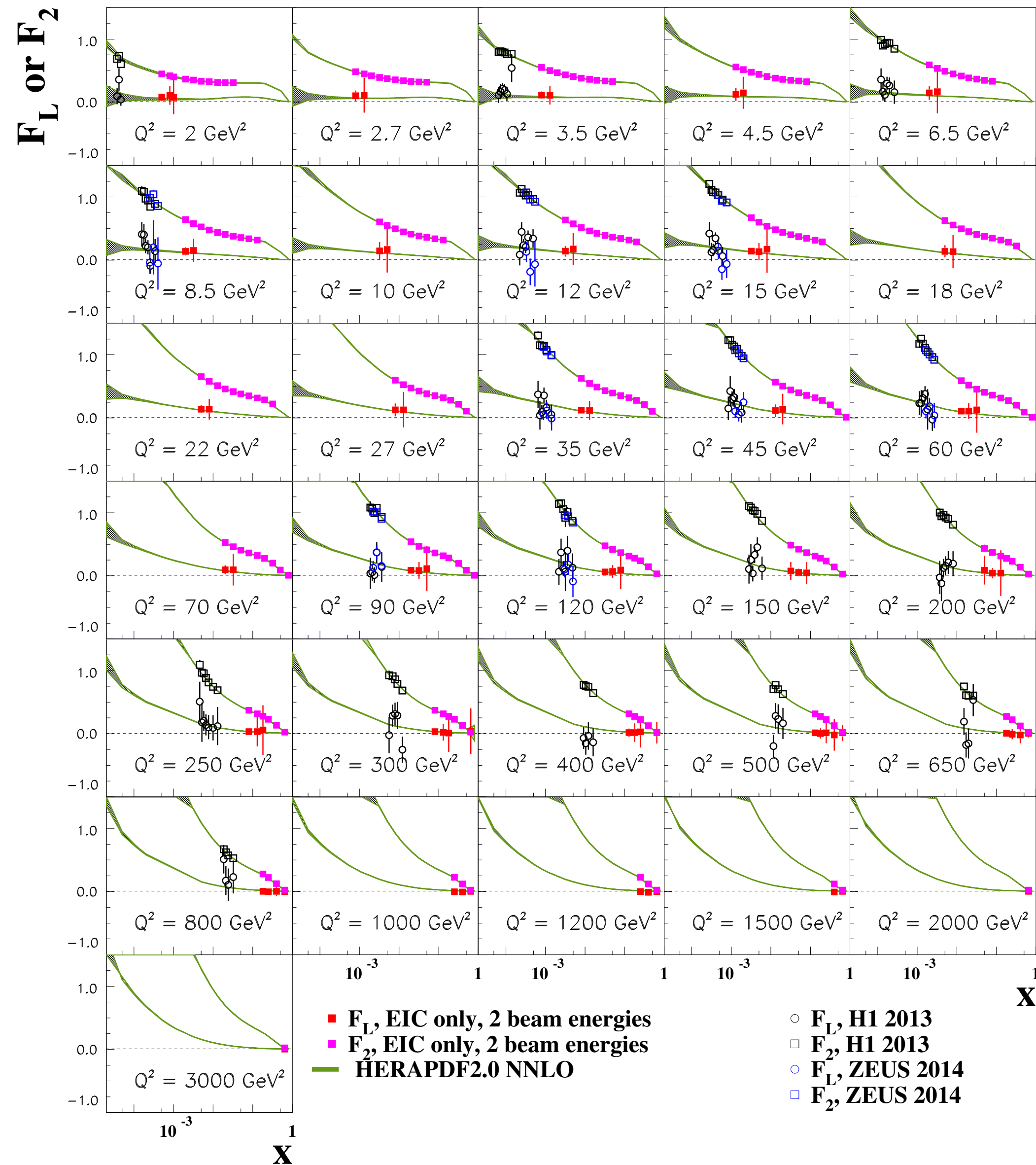


Statistics in this region are relatively limited at HERA since the cross section falls rapidly as Q^2 increases

- ▶ Existing fixed target and collider data establish a strong proton structure baseline, but leave gaps in x and Q^2 coverage
- ▶ Early ePIC data will bridge the gap, enabling high precision measurements across a broad range of kinematics
- ▶ Multiple beam energies provide the lever arm needed for structure function measurements



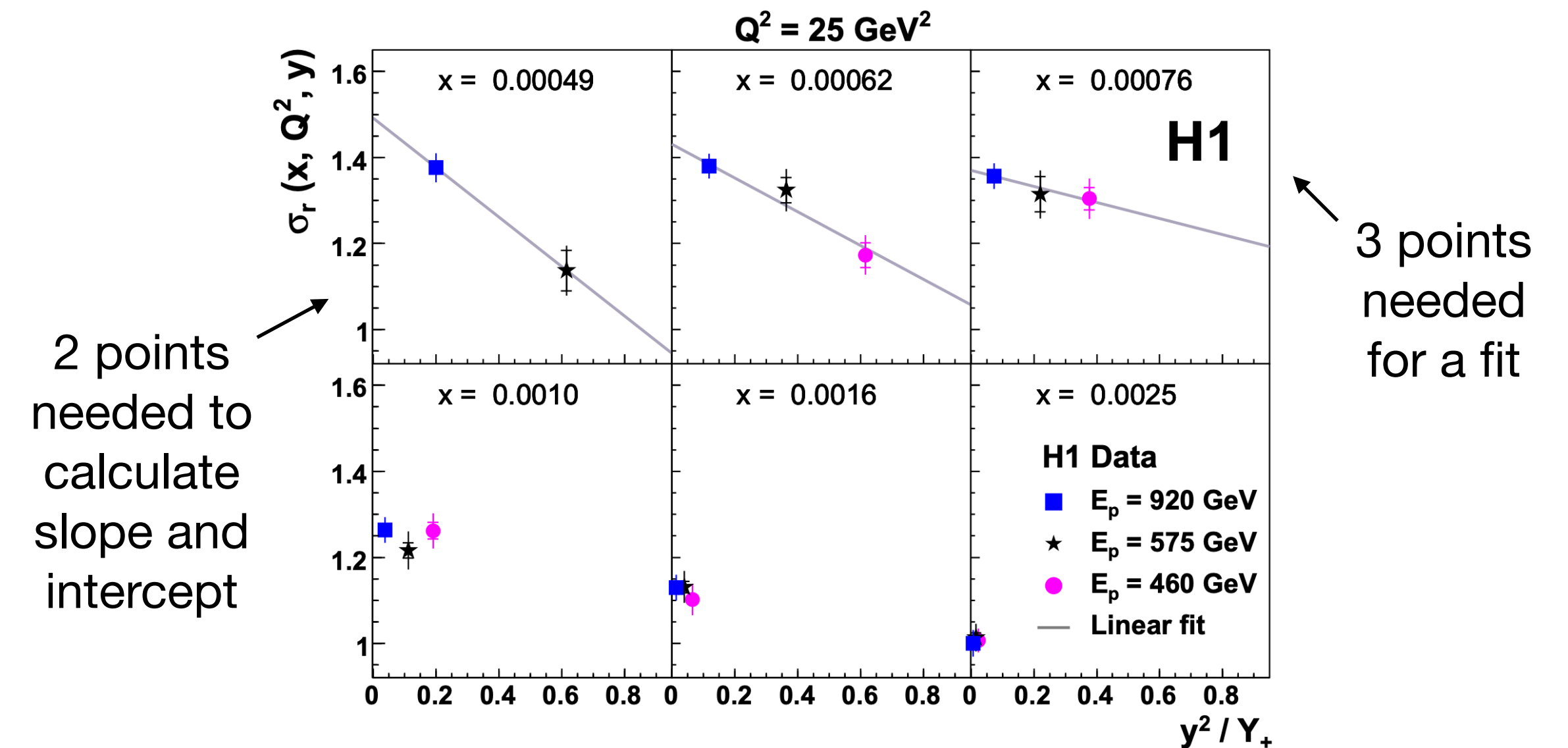
- ▶ Cross sections provide the basis for unpolarized proton structure function and collinear proton/nuclear PDF studies
- ▶ Statistical uncertainties and binning from full simulation
- ▶ Systematics derived from Yellow Report estimates
 - ▶ 1.9% point-to-point (1% radiative correction, 1.6% bin migration, detector efficiency, charge symmetric background)
 - ▶ 3.4% normalization (1.5% luminosity, 3% electron purity & detector effect)
- ▶ Measurement uncertainties are dominated by systematic uncertainties

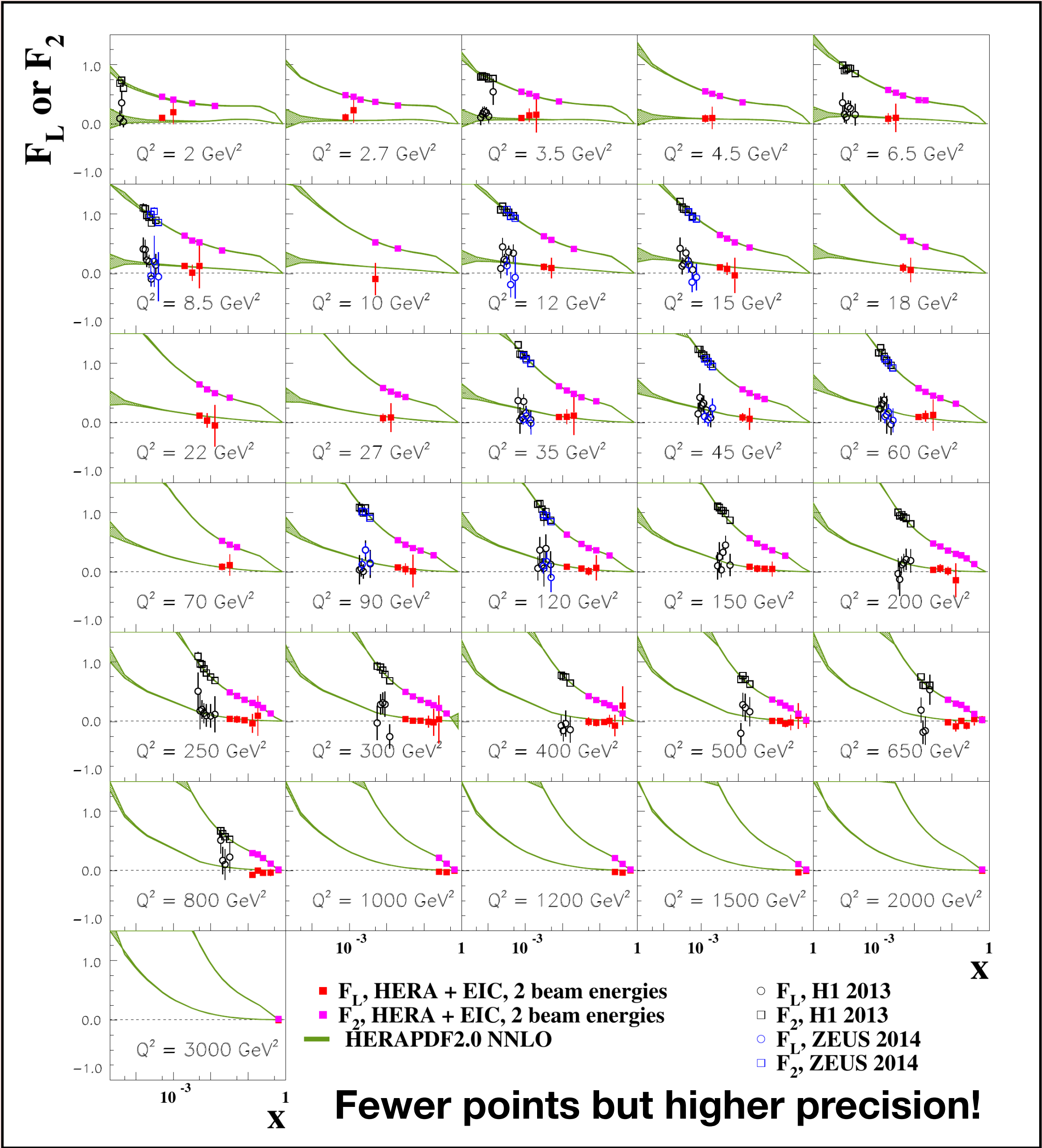


$$\sigma_r(x, Q^2, y) = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2)$$

$$Y_+ = 1 + (1 - y)^2 \quad y \approx \frac{Q^2}{sx}$$

- Measurements at different energies enable a model independent separation of F_2 and F_L

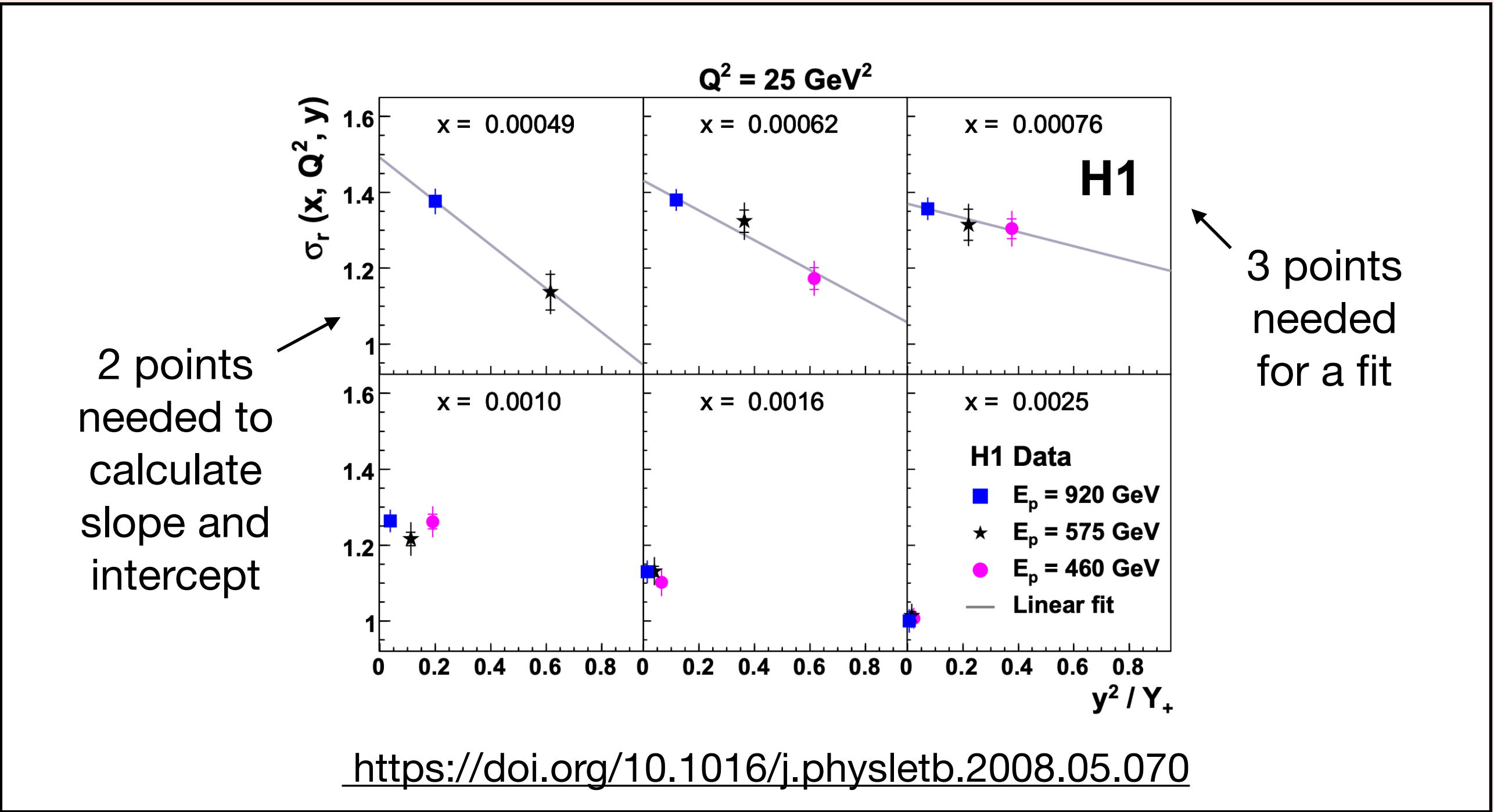


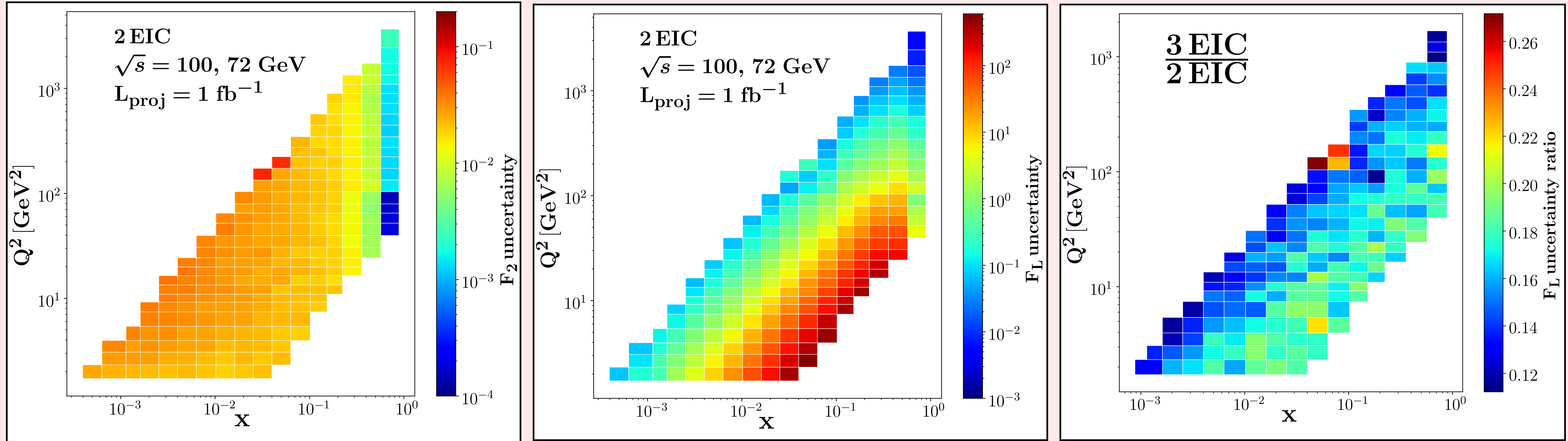


$$\sigma_r(x, Q^2, y) = F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2)$$

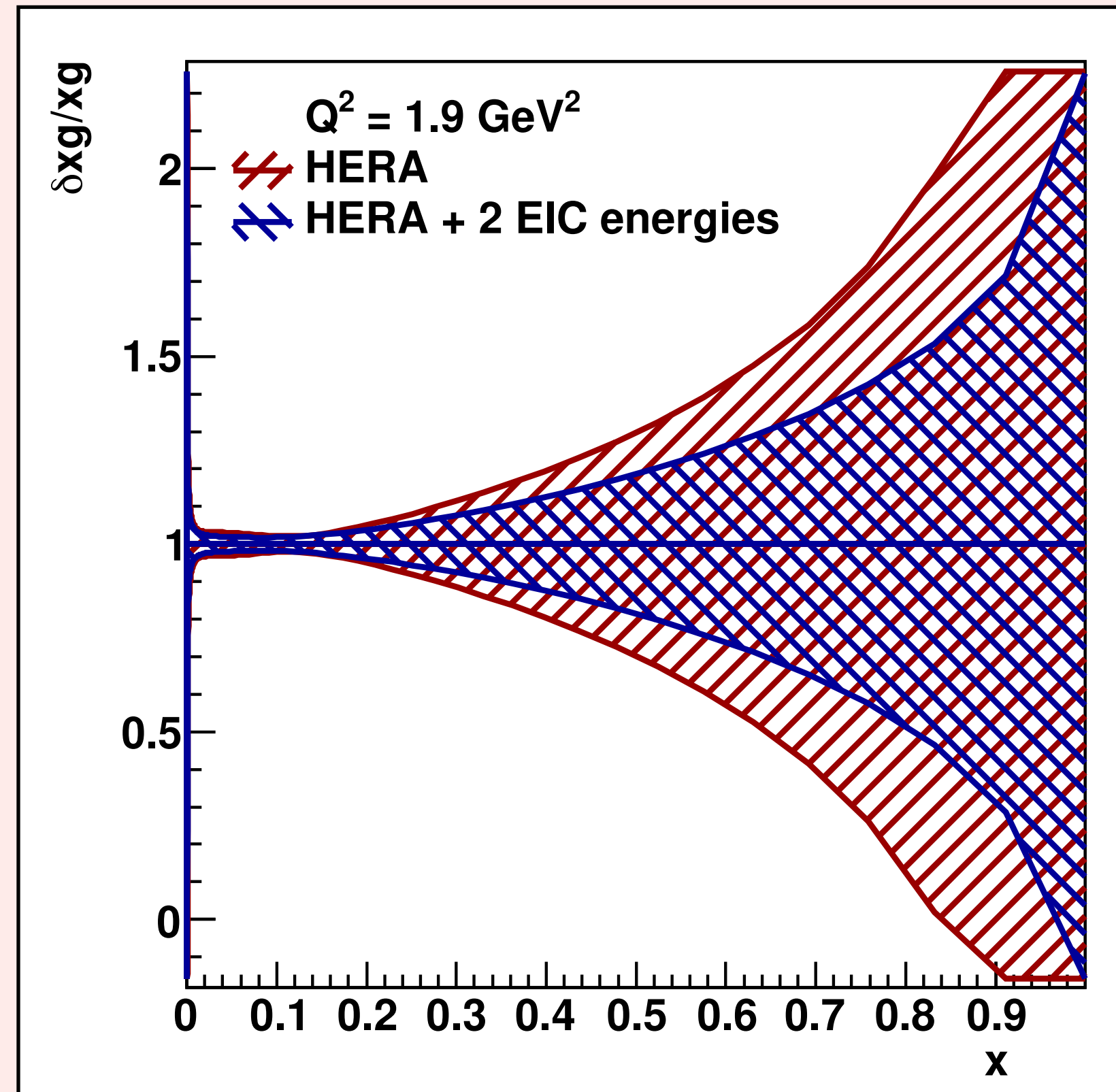
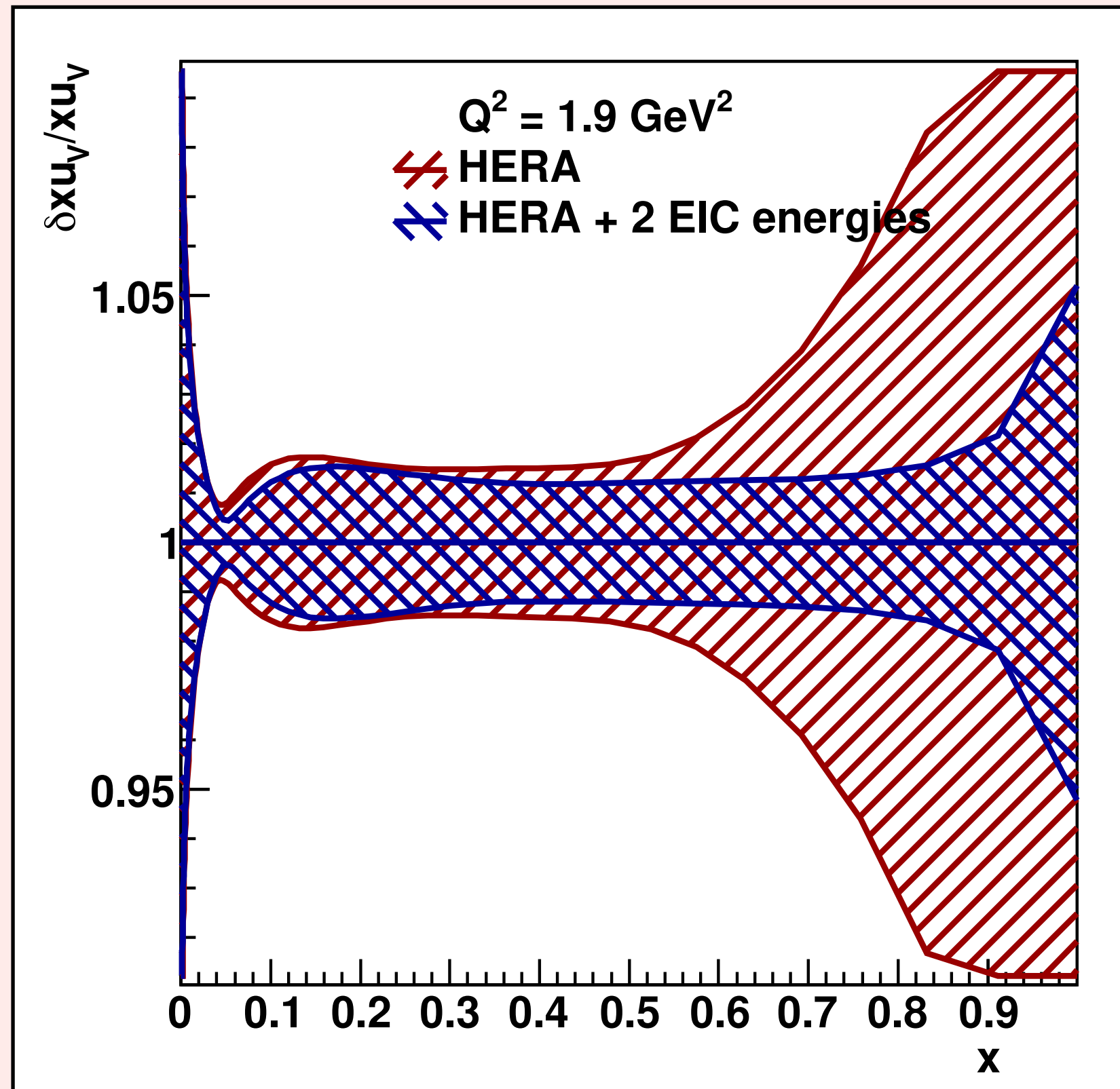
$$Y_+ = 1 + (1 - y)^2$$

- Measurements at different energies enable a model independent separation of F_2 and F_L





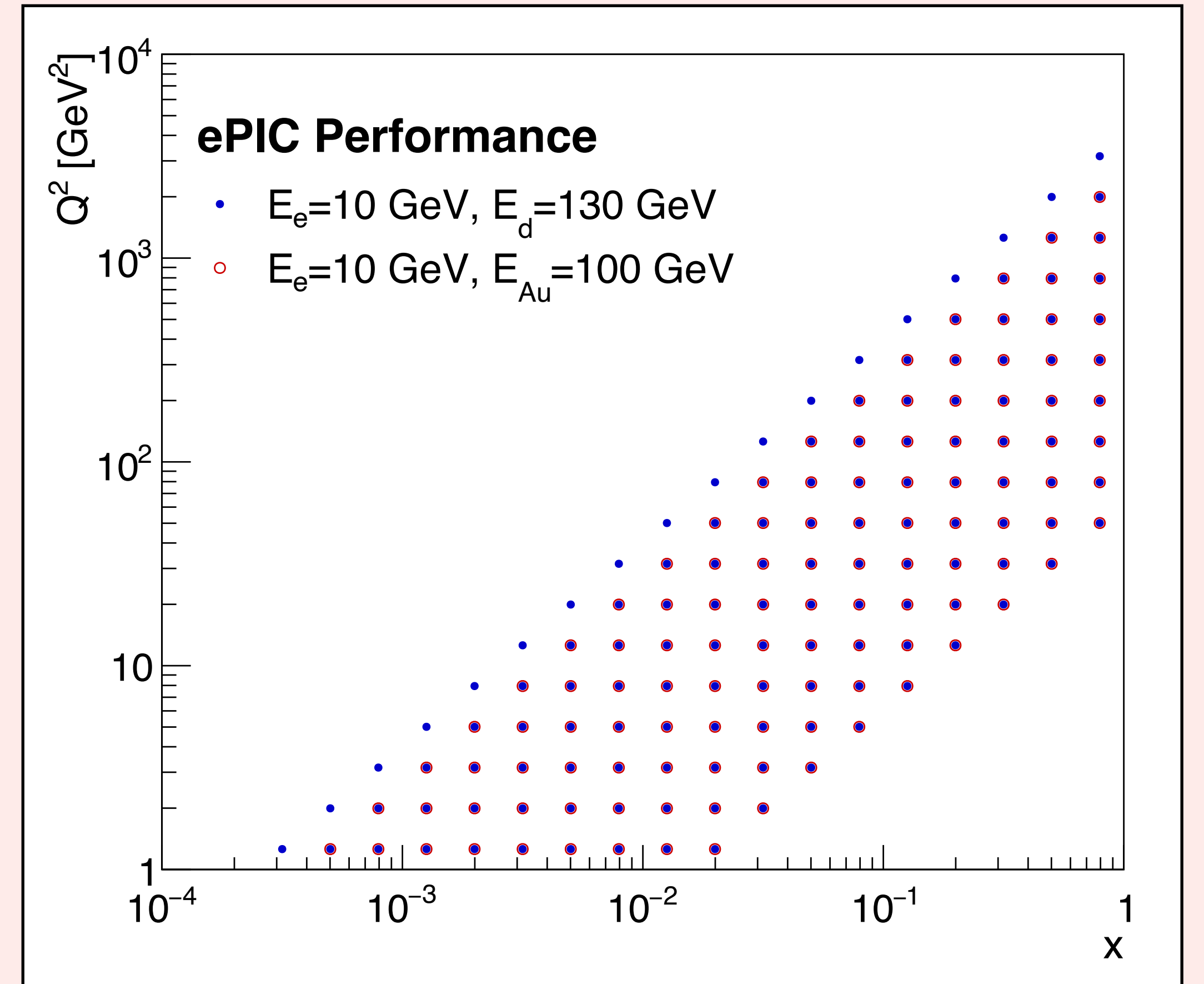
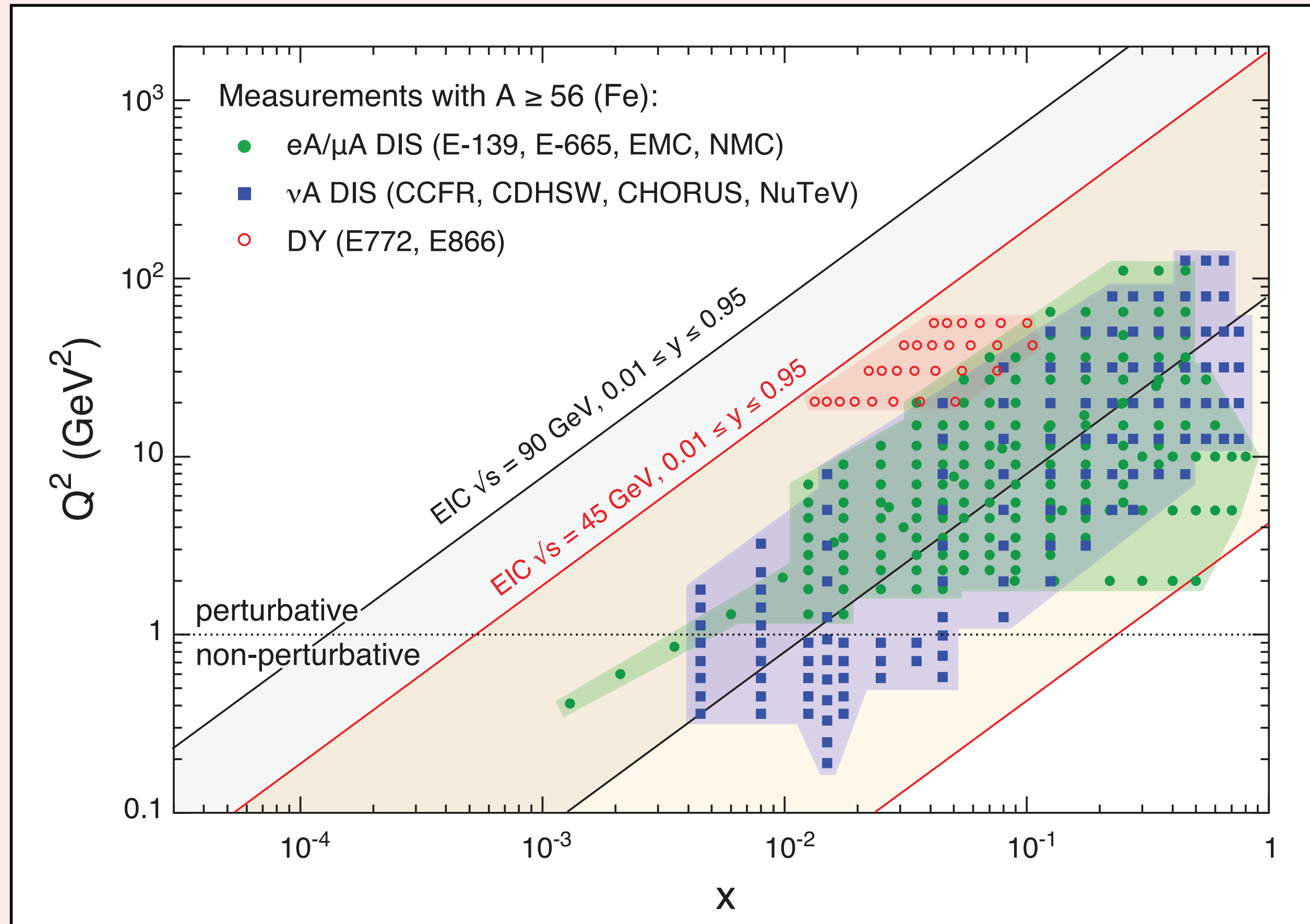
- ▶ F_L extraction is more challenging and needs more y^2/Y_+ lever arm
- ▶ Precision on F_L benefits from high y , so lower center of mass beam configurations are needed
- ▶ Potentially a third beam configuration (5x130 GeV) will also be available during early running
- ▶ F_L uncertainties could improve by roughly a factor of 5 - 8 with three beam energy configurations



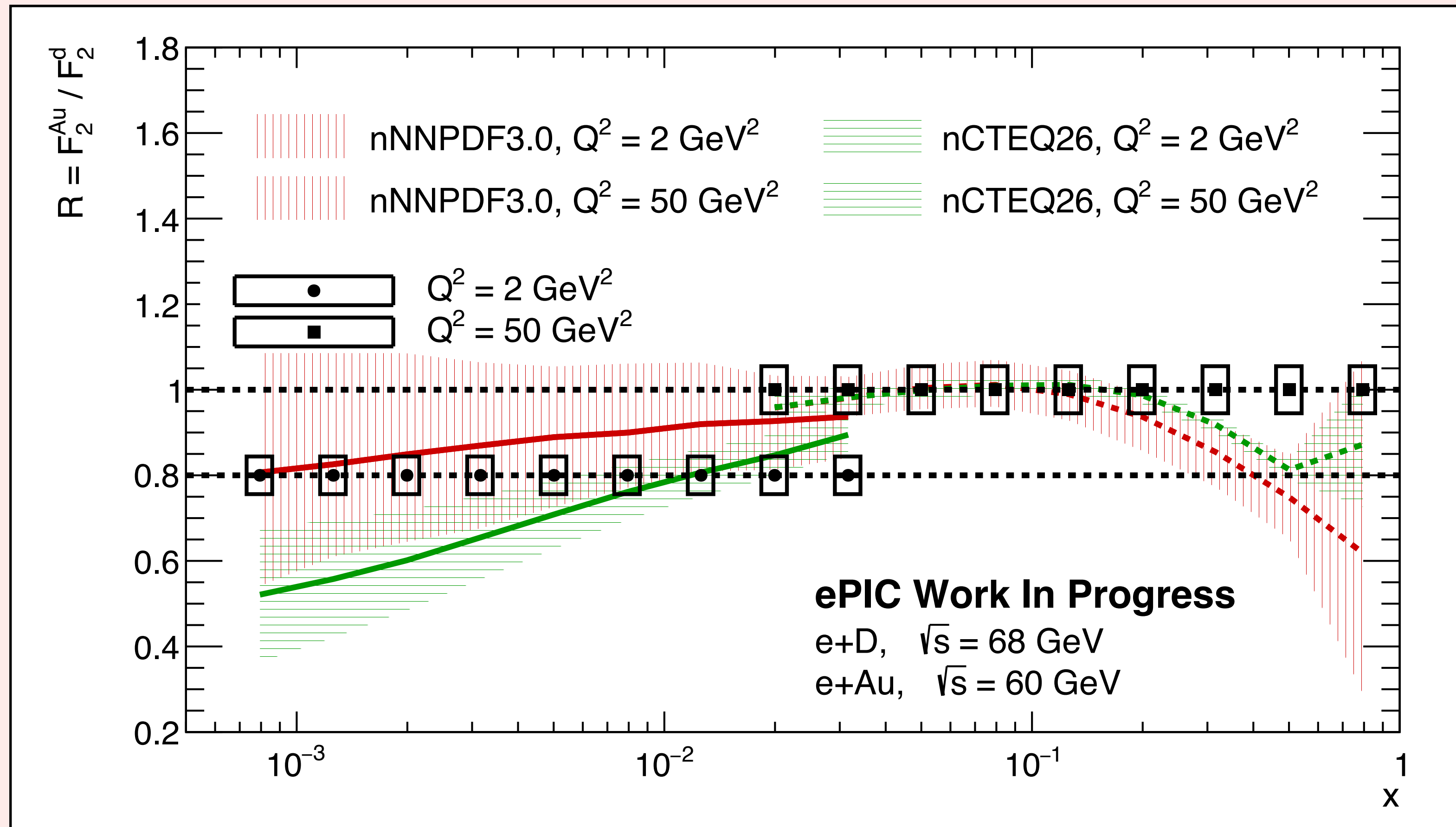
For 9x130 & 9x275 GeV config.

- ▶ NNLO fit in HERAPDF framework using xFitter with HERA data and EIC pseudodata
- ▶ Shown is comparison between HERA data only versus HERA + EIC early running data
- ▶ Mainly impact up valence quark and gluon PDFs
- ▶ Stronger impact at high x where HERA data are statistically limited

How does a nuclear environment modify parton distributions?

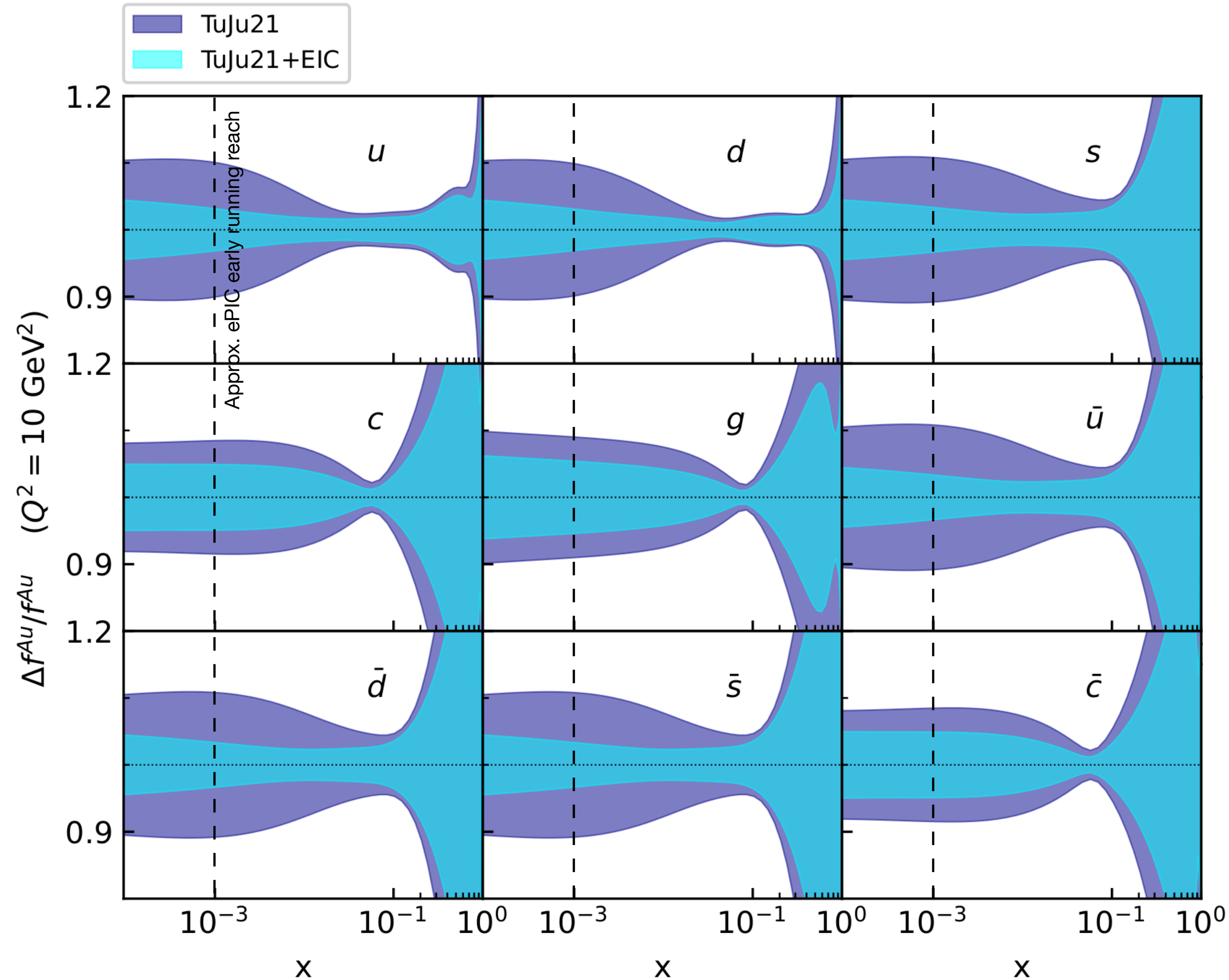


- ▶ Nuclear PDFs, especially the gluon distribution, are still uncertain
- ▶ ePIC will have significant overlap in xQ^2 phase space for ed and eAu/eAg
- ▶ Can measure nuclear modification of F_2 over wide range in x and Q^2



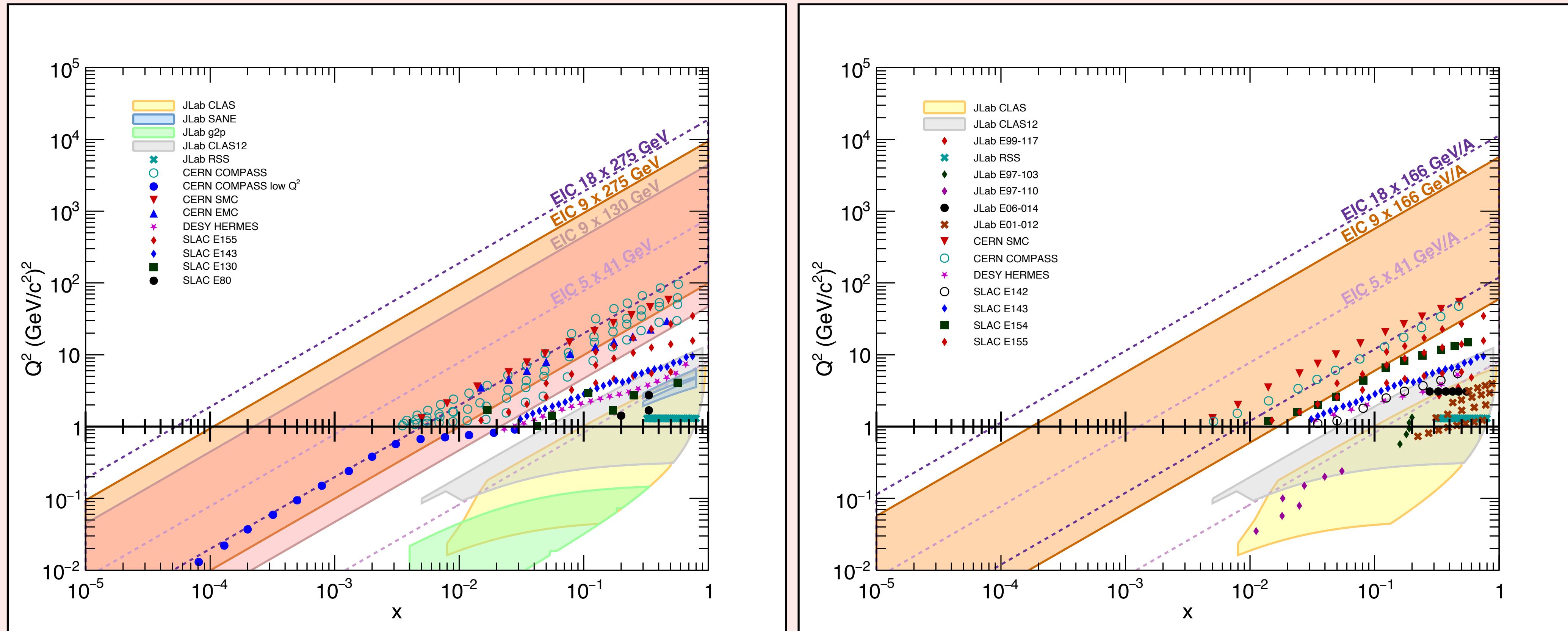
* bands show 90% confidence level

- ▶ Shown is pessimistic estimate of systematic uncertainties. Statistical uncertainties are expected to be small except at large x
- ▶ The F_2^A / F_2^d ratio probes quark nuclear modifications down to $x \sim 10^{-3}$
- ▶ Its new x and Q^2 dependence adds new constraint on nuclear PDFs



- ▶ Impact of eAu pseudo data on TUJU21 gold nPDF
- ▶ Evaluated using Bayesian reweighting procedure with single $e\text{Au}$ early science configuration
- ▶ Extend DIS data for heavy nuclei down to $x \sim 10^{-3}$
- ▶ Significant improvement at low- x for all parton species

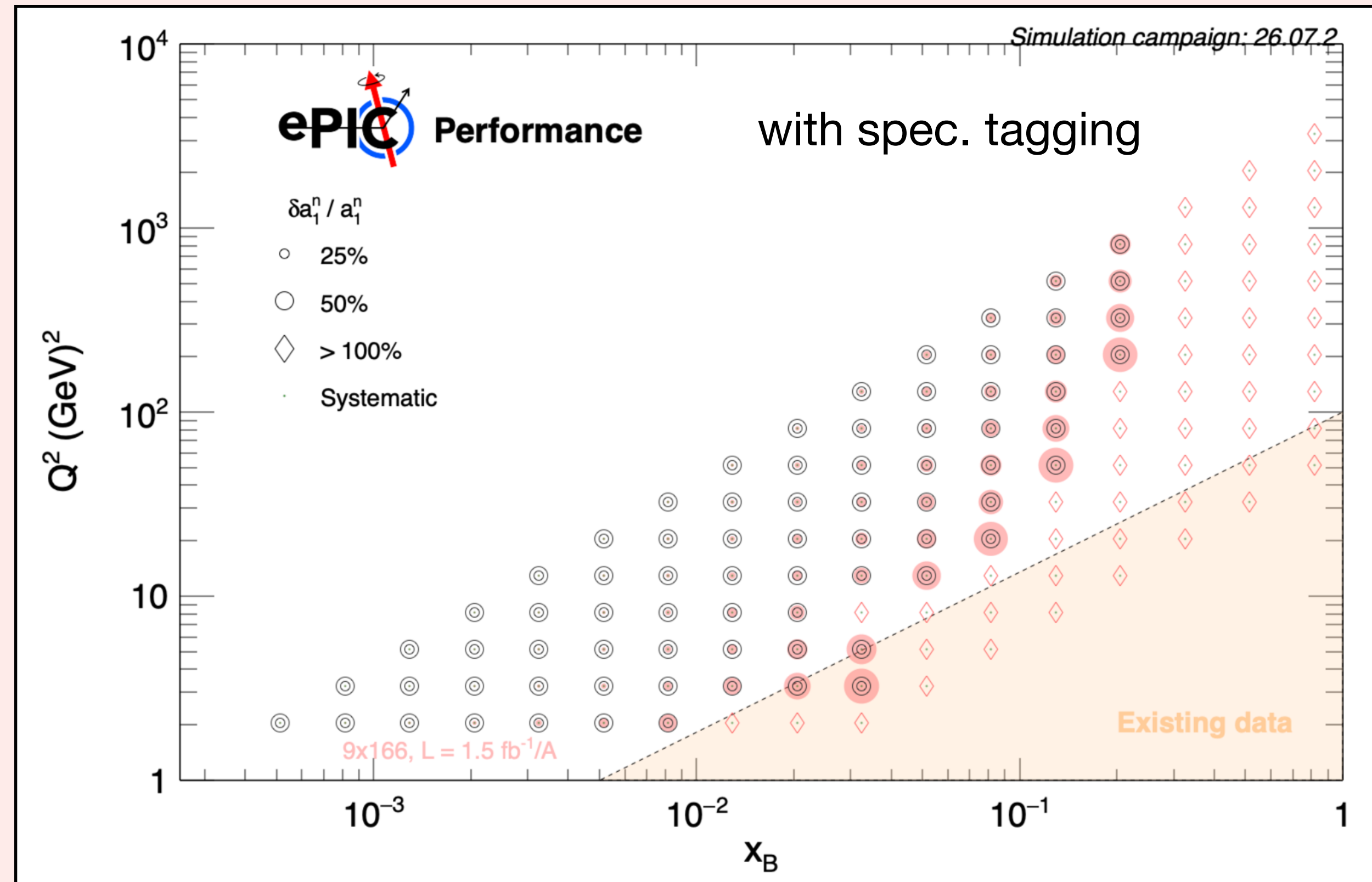
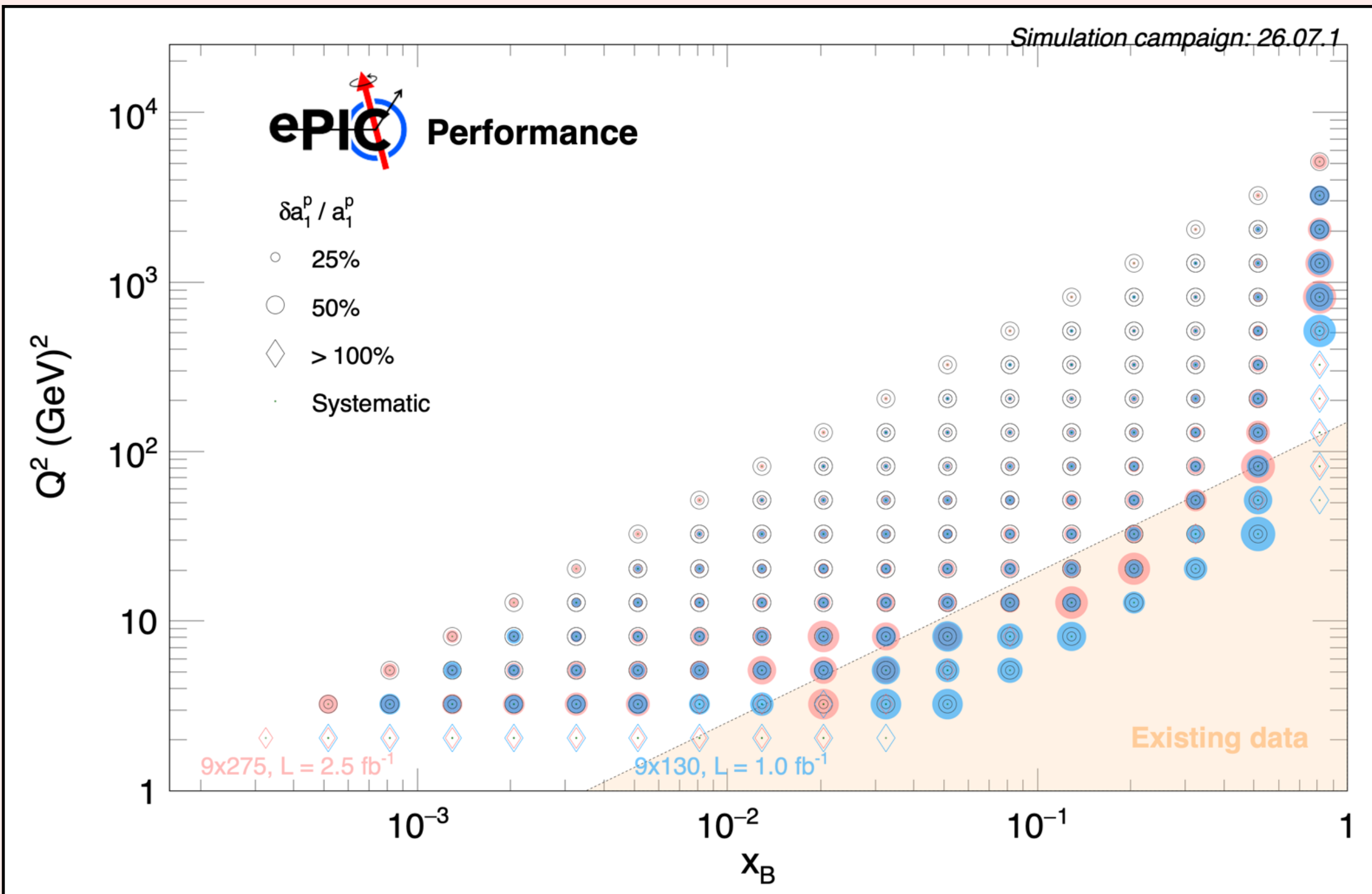
How are quark and gluon spins distributed inside the nucleon?



- ▶ Low x spin measurements are currently limited
- ▶ ePIC data will extend spin measurements into a wider unexplored space and reach much lower x
- ▶ Proton and neutron measurements provide complementary views of nucleon spin.

A1 double spin asymmetry

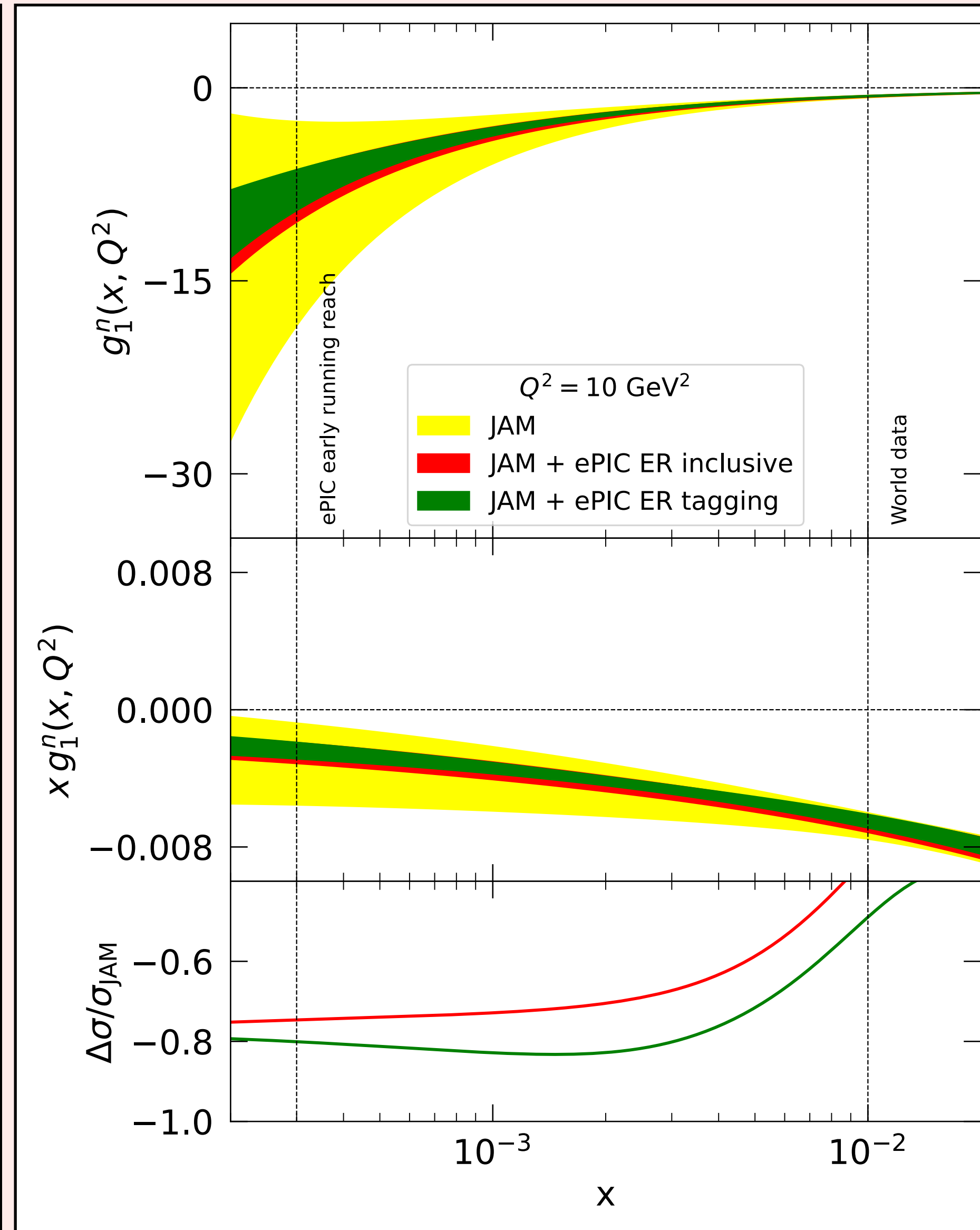
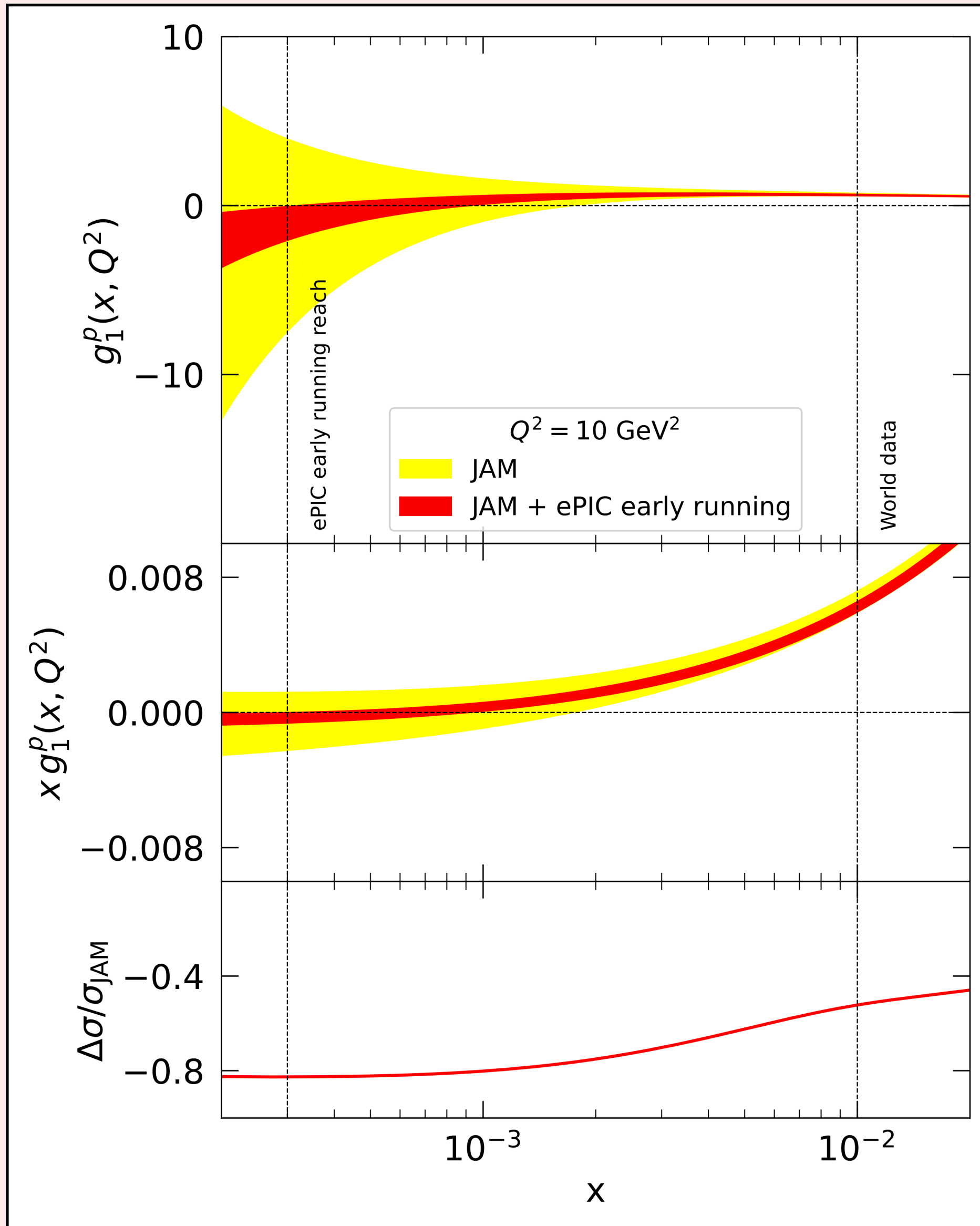
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- Proton and neutron data will both be available. Neutron A_1 can be measured from fully inclusive and spectator tagging measurements
- Beam polarizations are assumed to be 70%. Systematics estimate includes 3.4% uncorrelated and 1.5% correlated uncertainties
- Measurement uncertainty is dominated by statistical uncertainties
- New data will have low x reach and cover wide range of new phase space

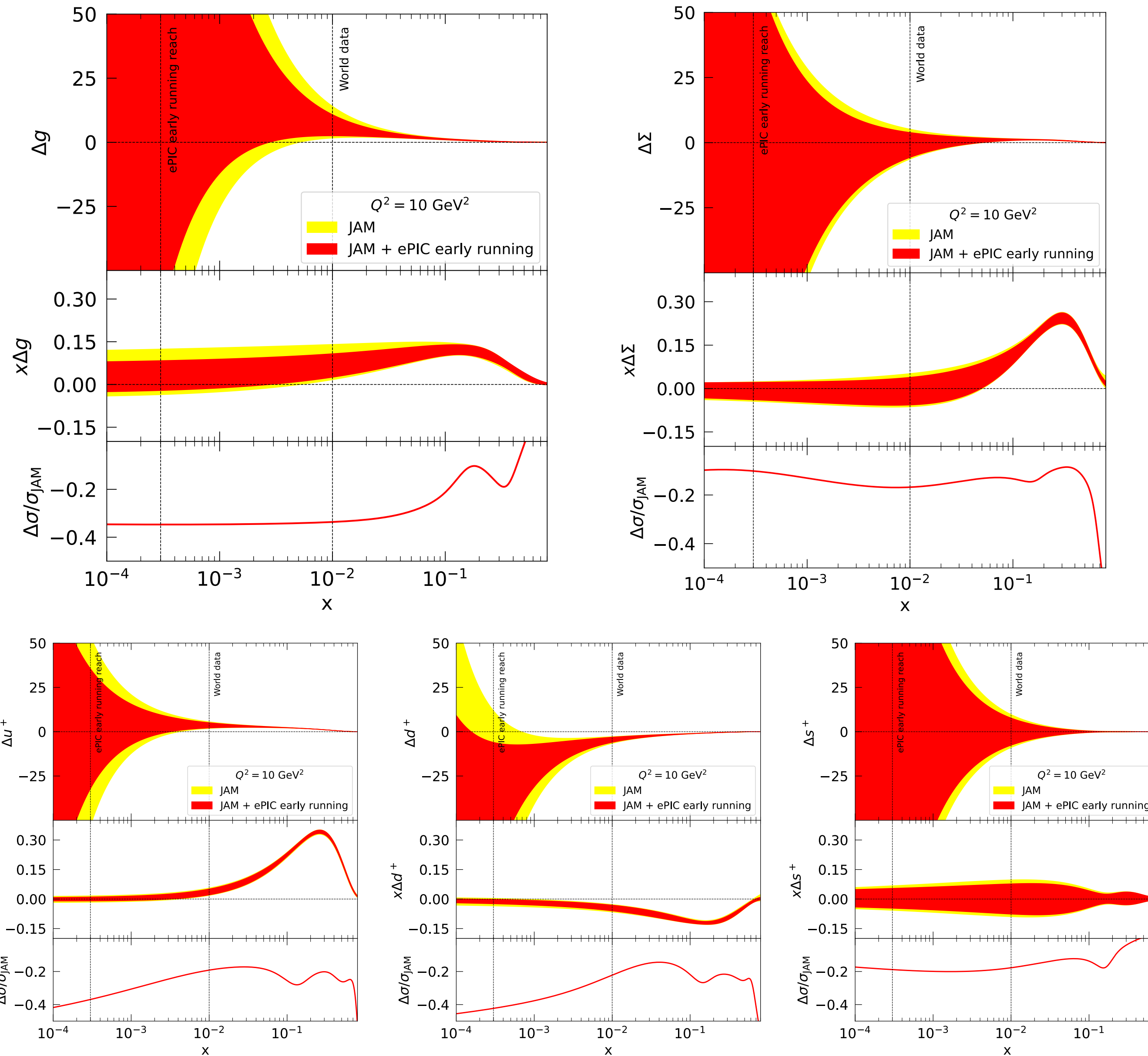
$$A_1(x, Q^2) \equiv \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{A_{\parallel}}{D(1 + \eta\xi)} - \frac{\eta A_{\perp}}{d(1 + \eta\xi)}$$

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



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

- Shown is impact on global fit using JAM analysis
- Extrapolation uncertainties to low x will be significantly reduced
- Ambiguity in sign of g_1^p and how fast g_1^n drops at low x will be resolved
- Spectator tagging will provide additional uncertainty improvement for g_1^n

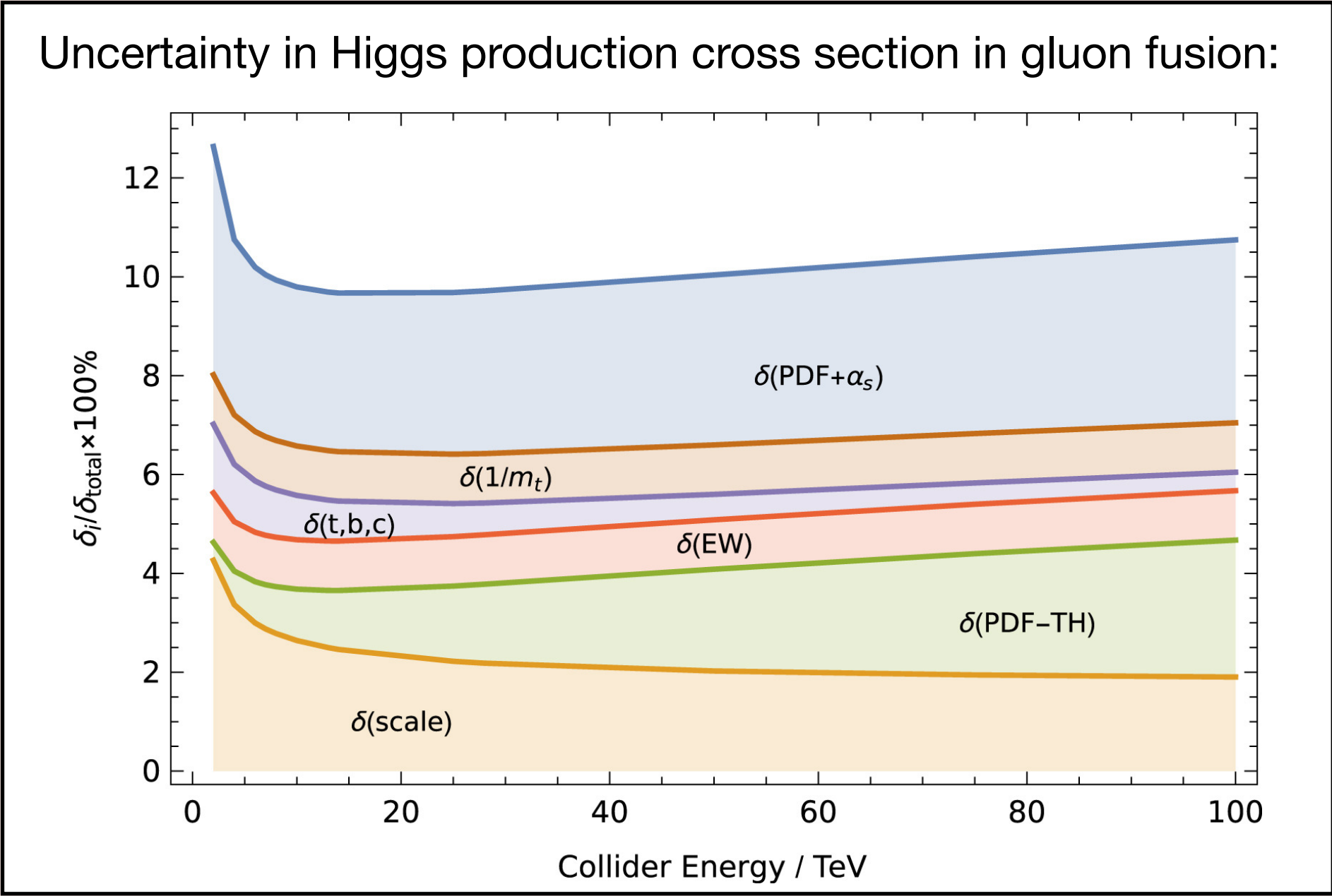


- ▶ Global fits translate g_1 measurements into quark and gluon helicity constraints
- ▶ Neutron data help with flavor separation in inclusive data
- ▶ Early data are projected to improve low x uncertainties
- ▶ SIDIS data will further constrain the uncertainties

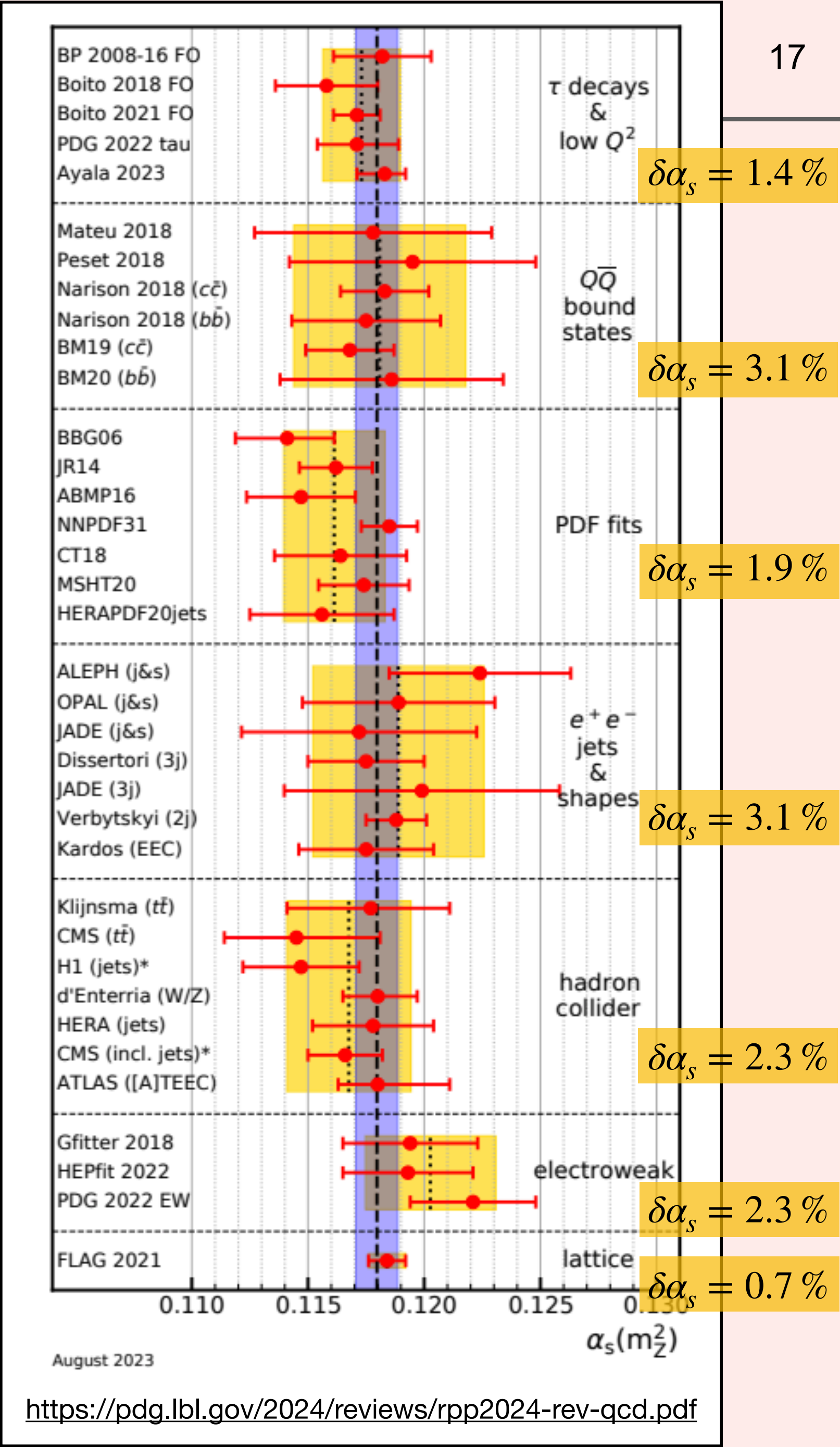
α_s extraction

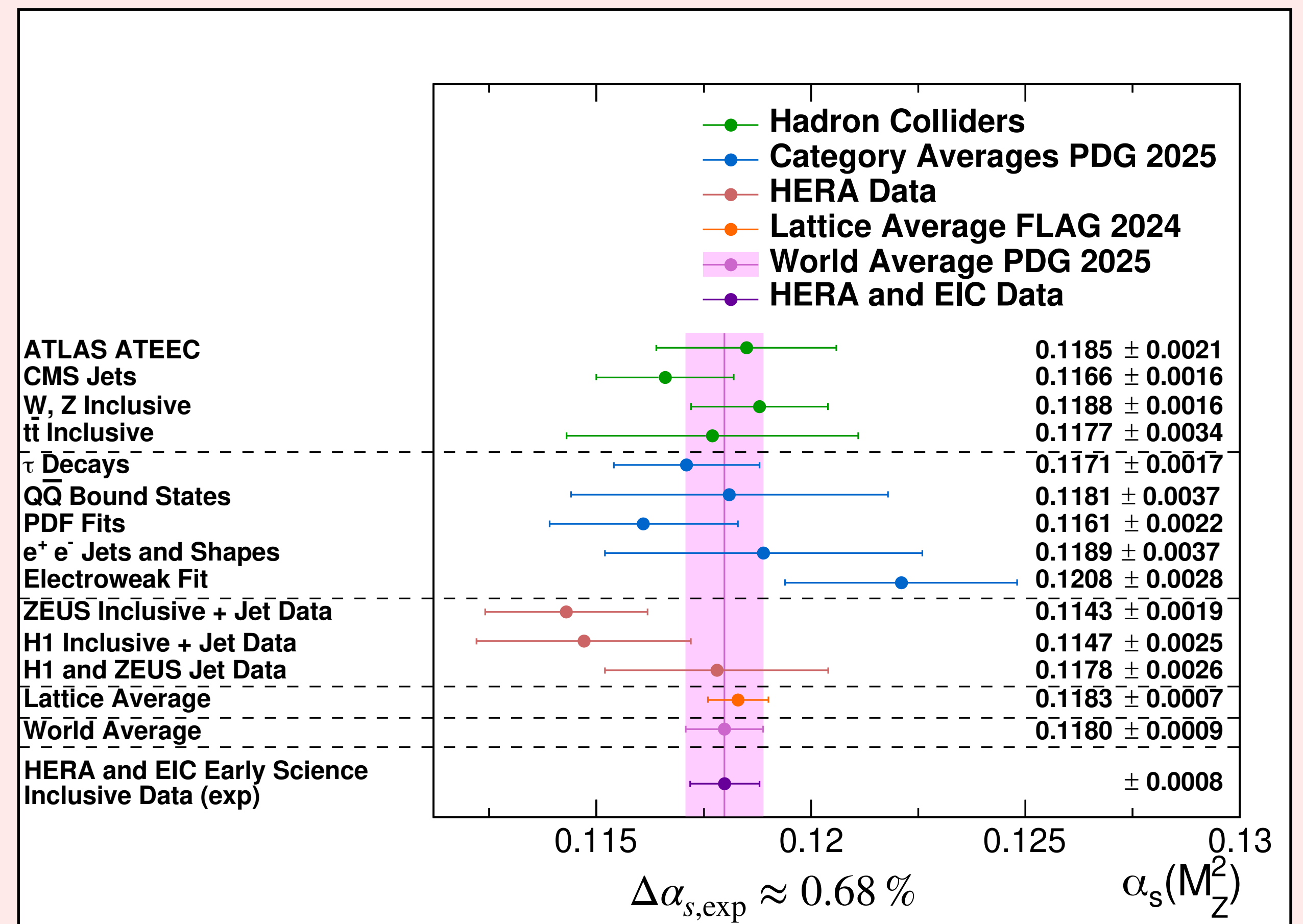
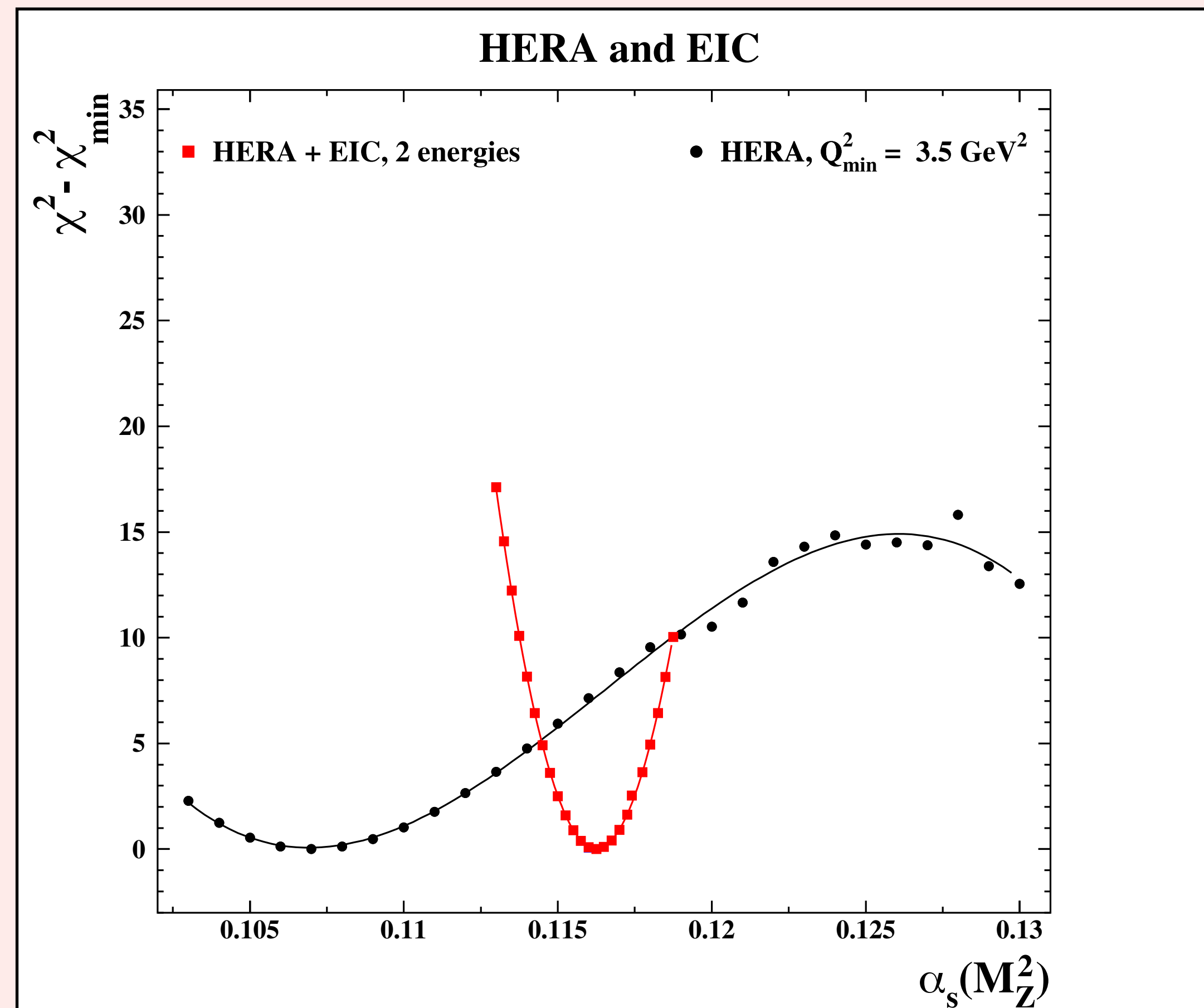
- ▶ α_s is currently the least precisely known coupling constant
- ▶ Important for pQCD, SM and BSM tests
- ▶ ePIC will have multiple ways to extract α_s and reduce its experimental uncertainty

Strong	Electromagnetic	Weak	Gravity
$\Delta\alpha_s/\alpha_s = 8 \times 10^{-3}$	$\Delta G_N/G_N = 2.2 \times 10^{-5}$	$\Delta G_F/G_F = 5.1 \times 10^{-7}$	$\Delta\alpha/\alpha = 1.5 \times 10^{-10}$

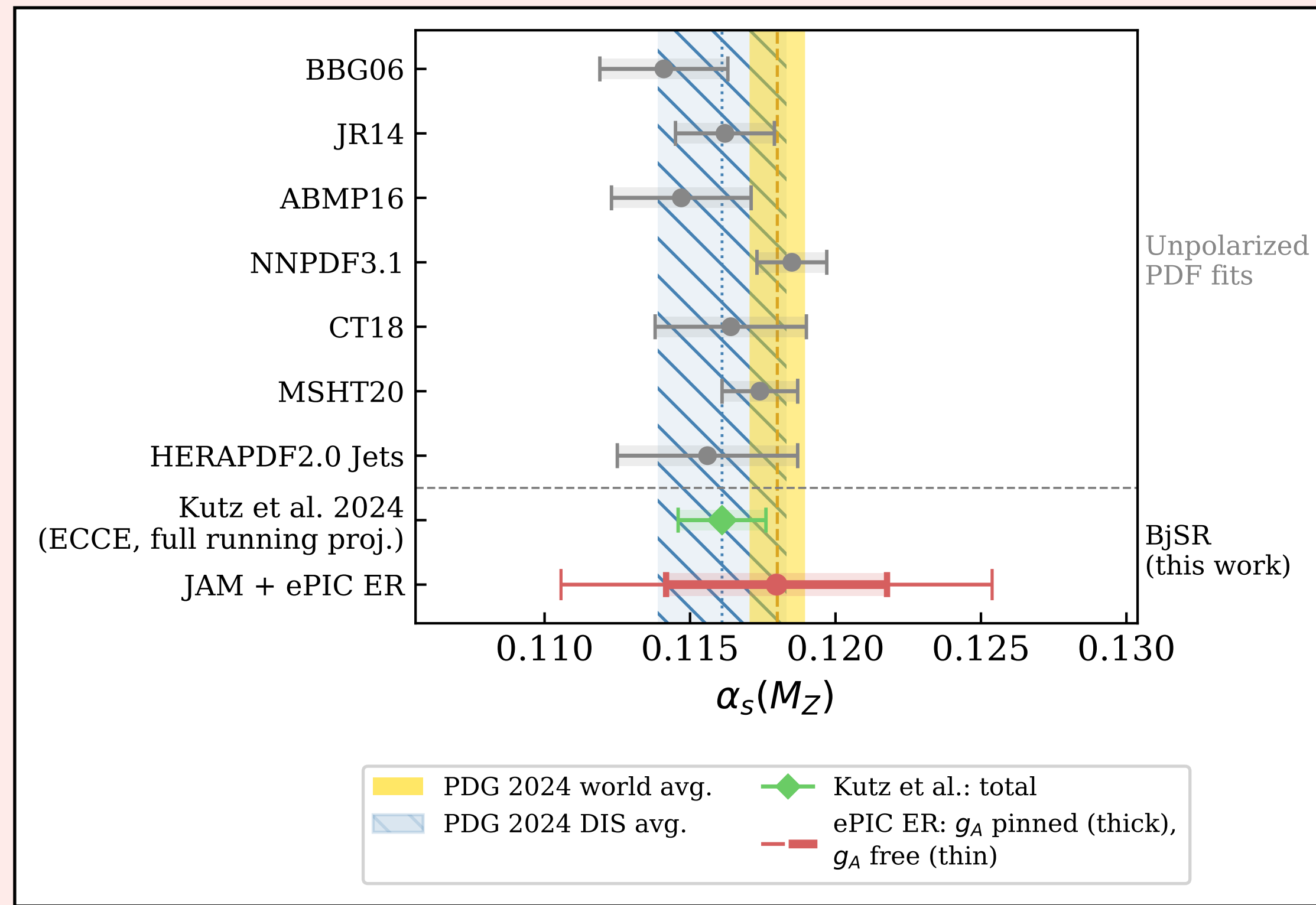
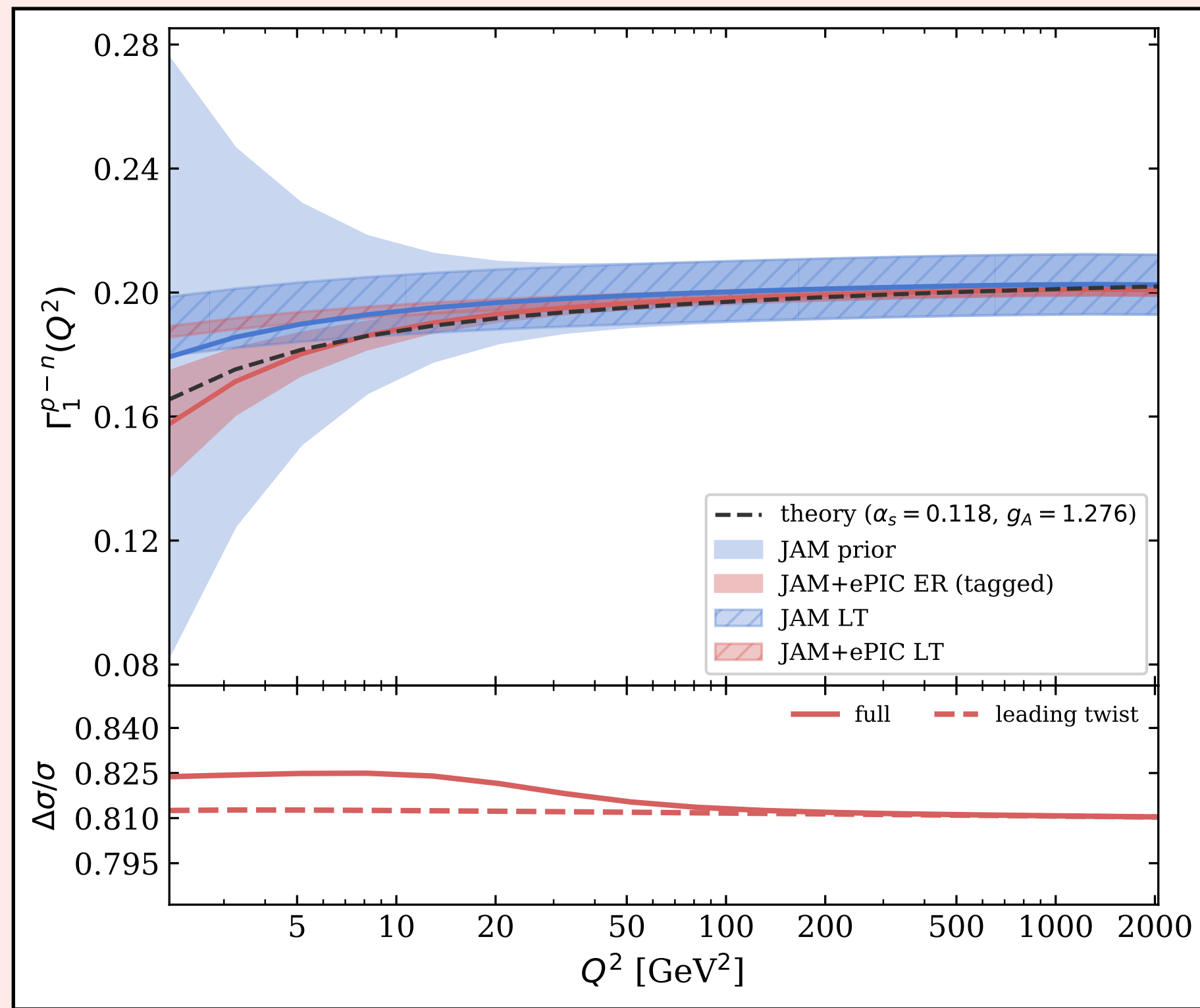


<https://doi.org/10.1016/j.cpc.2018.06.025>





- ▶ Extraction by simultaneous fit of PDFs and α_s
- ▶ HERA + early EIC inclusive data could determine α_s with high experimental precision
- ▶ Model and PDF parameterization uncertainties are expected to be small
- ▶ Treatment and impact of theory uncertainties are under active study.

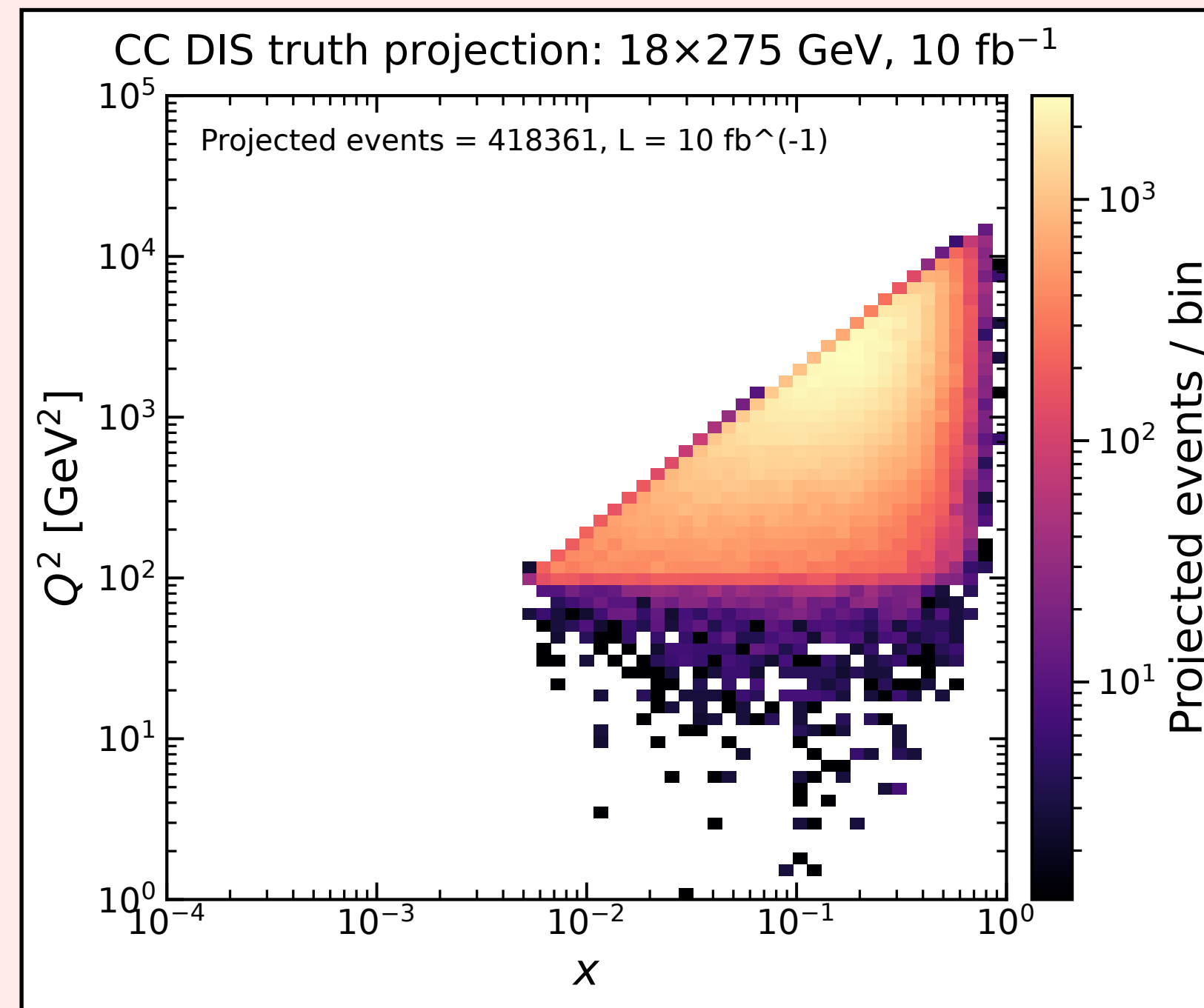
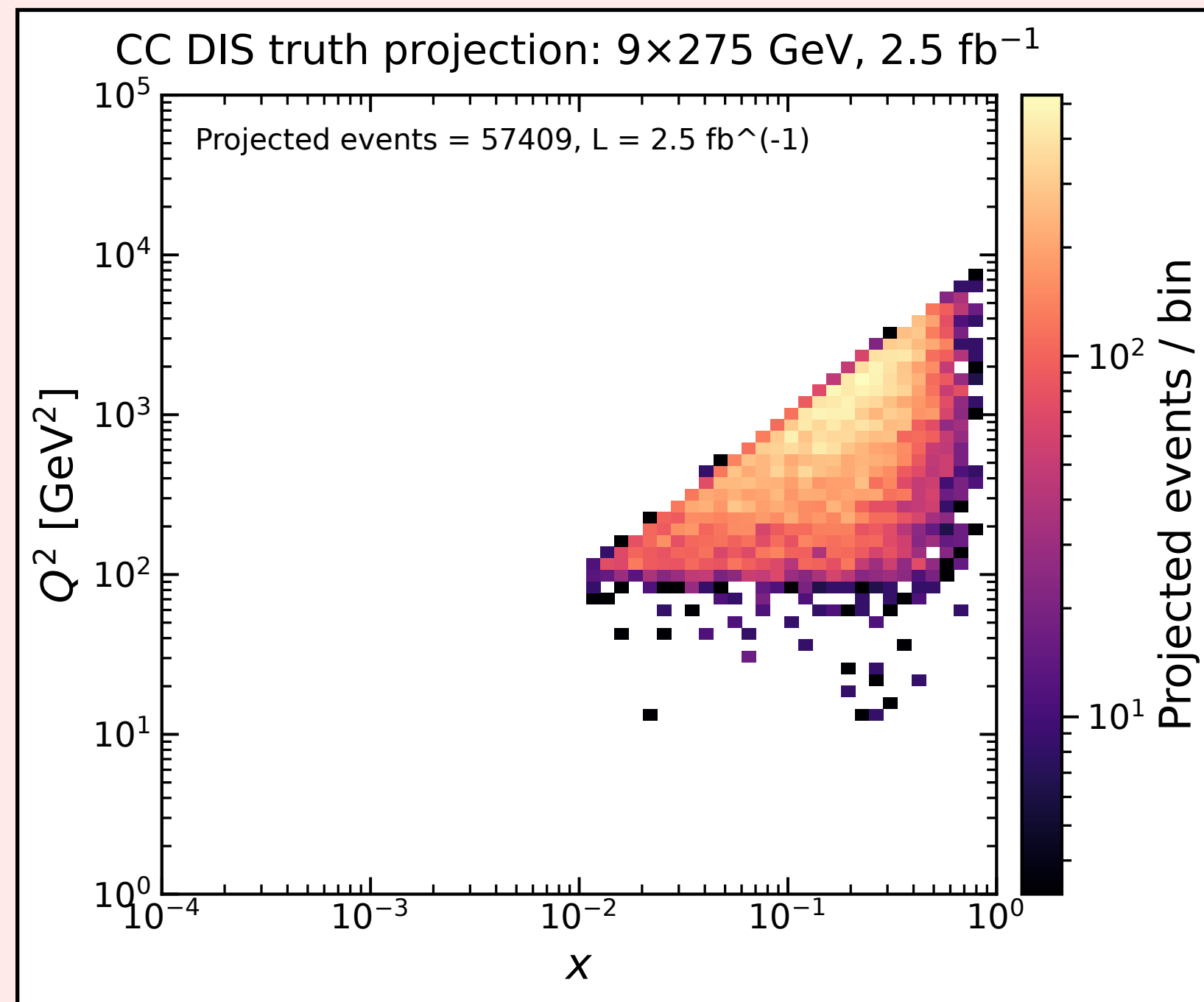


$$\Delta\alpha_s(g_A \text{ pinned}) \approx 3.22 \%$$

- ▶ $\Gamma_1^{p-n} \equiv \int_0^1 [g_1^p(x, Q^2) - g_1^n(x, Q^2)] dx = \frac{g_A}{6} C_{ns}(\alpha_s, Q^2)$ (Leading twist)
- ▶ Early polarized data will help test the Bjorken sum with significantly improved precision
- ▶ The Q^2 dependence of Bjorken sum provides complementary α_s measurement
- ▶ Full EIC running could potentially yield a more precise α_s determination than current PDF fit

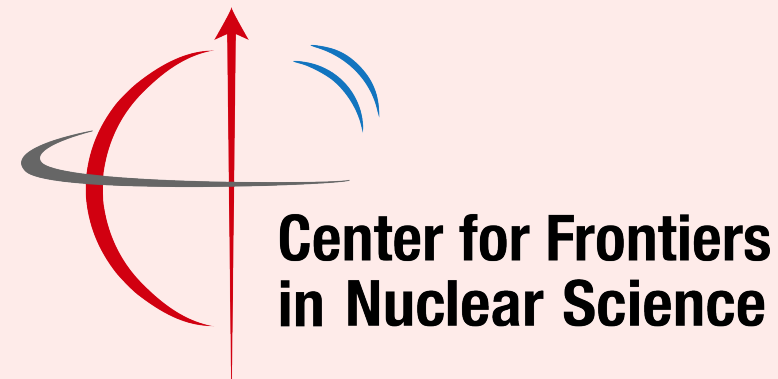
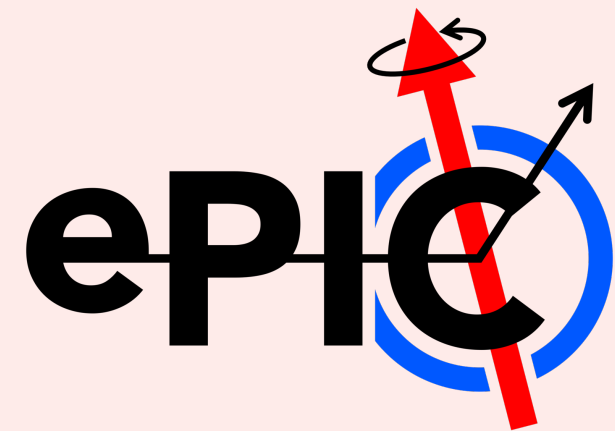
More inclusive physics opportunities are available, including:

- Charge current interactions



- Proton and neutron g_2
- Parity violating structure functions
 - g_3^{cc} and g_5^{cc}
 - $F_1^{\gamma Z}$, $F_3^{\gamma Z}$, $g_1^{\gamma Z}$, $g_5^{\gamma Z}$

- ▶ Early EIC running will already provide broad new kinematic coverage for studies of nucleon and nuclear structure, including spin
- ▶ The ePIC inclusive program spans unpolarized and polarized ep and en DIS, as well as eA DIS, with projected impact on PDFs, low x spin structure, and α_s extraction
- ▶ Together, these measurements target high priority questions identified in the NAS science pillars



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& MARY

Thank you! :)