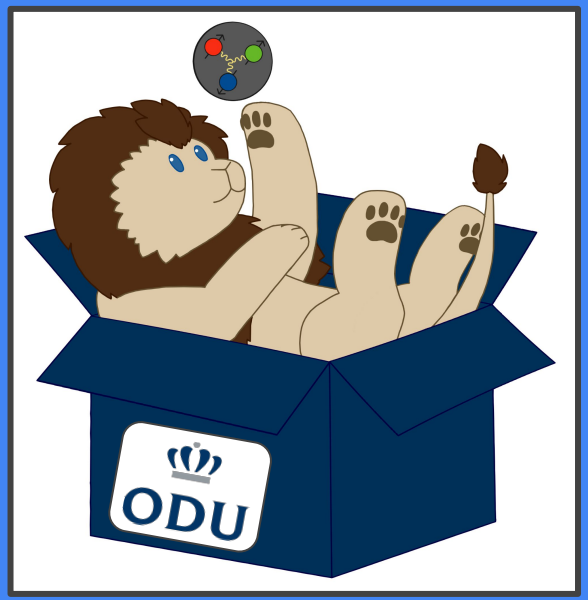
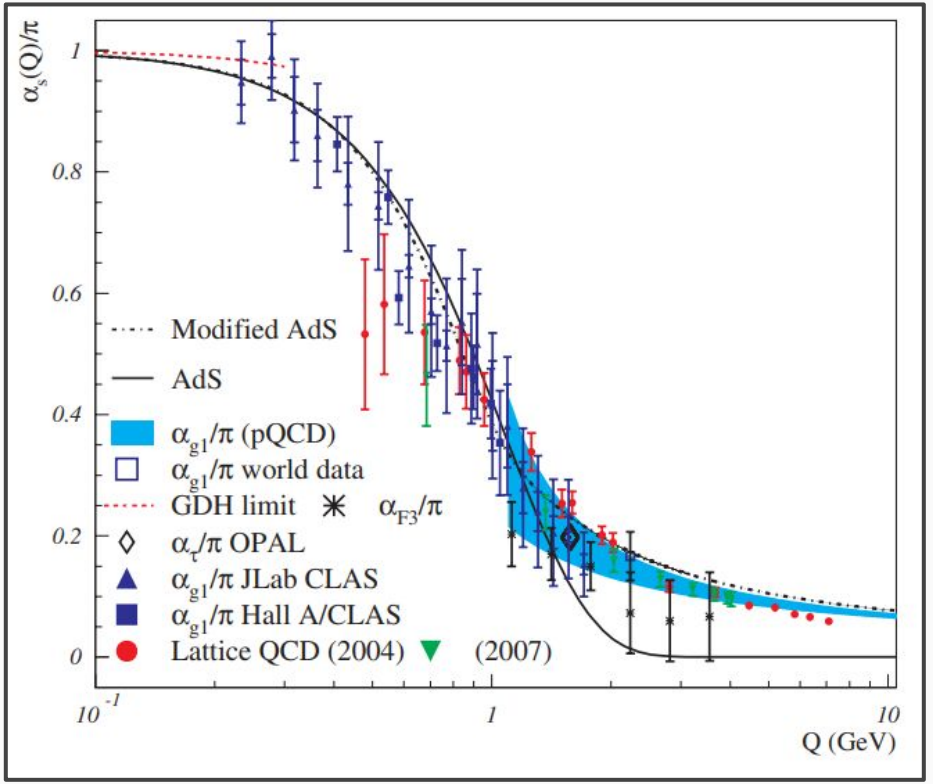
Measuring Strong Coupling at the Future EIC

Darren W Upton



How Strong is Strong?

- Strong coupling is scale-dependent
- Extractions by experiment & global analysis with theory models
- Spin sector offers special access



S. Brodsky et al, PRD 81, 096010 (2010)

High precision measurements of α_s at the future EIC

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High precision measurements of α_s at the future EIC

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How Do You Find α_s?

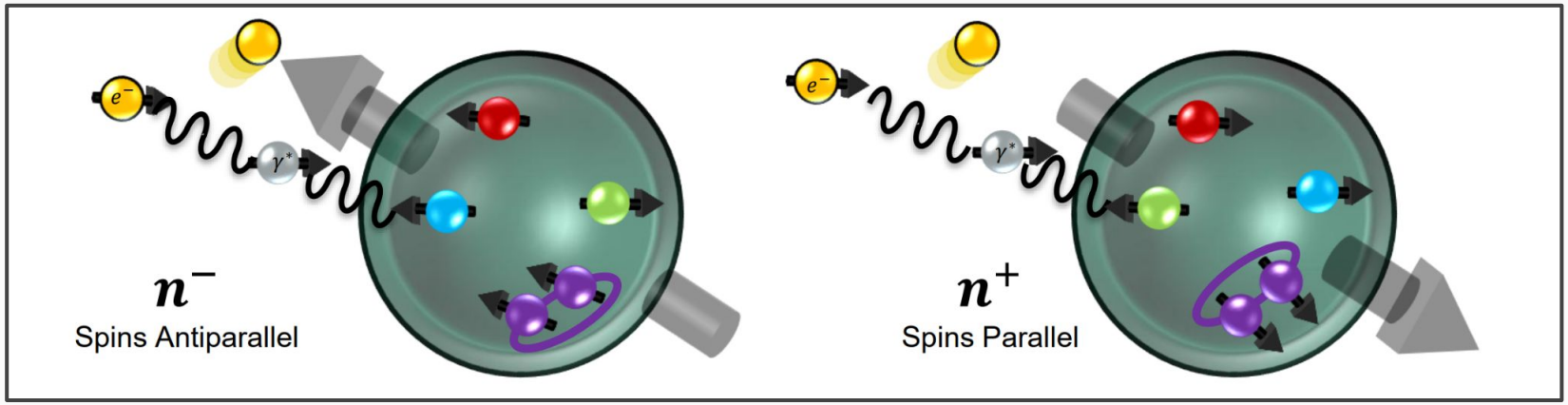
Bjorken Sum Rule

- Hadronic observable Γ_1 from spin structure moments
- Γ_1 related α_s via axial coupling x pQCD series

$$\overline{\Gamma}_1(Q^2) = \int_0^{1^-} g_1(x, Q^2)dx$$

$$\Gamma_1^{\mathrm{p-n}}(\alpha_s) = \Gamma_1^{\mathrm{p-n}}(Q^2) = \sum_{\tau>0} \frac{\mu_{2\tau}^{\mathrm{p-n}}(\alpha_s)}{Q^{2\tau-2}} = \frac{g_{\mathrm{A}}}{6}\left[1 - \frac{\alpha_s(Q^2)}{\pi} - 3.58\left(\frac{\alpha_s(Q^2)}{\pi}\right)^2 - 20.21\left(\frac{\alpha_s(Q^2)}{\pi}\right)^3 - 175.7\left(\frac{\alpha_s(Q^2)}{\pi}\right)^4 - (\sim 893.38)\left(\frac{\alpha_s(Q^2)}{\pi}\right)^5 + \mathcal{O}\left((\alpha_s)^6\right)\right] + \sum_{\tau>1} \frac{\mu_{2\tau}^{\mathrm{p-n}}(\alpha_s)}{Q^{2\tau-2}},$$

Spin-Polarized Lepton Scattering

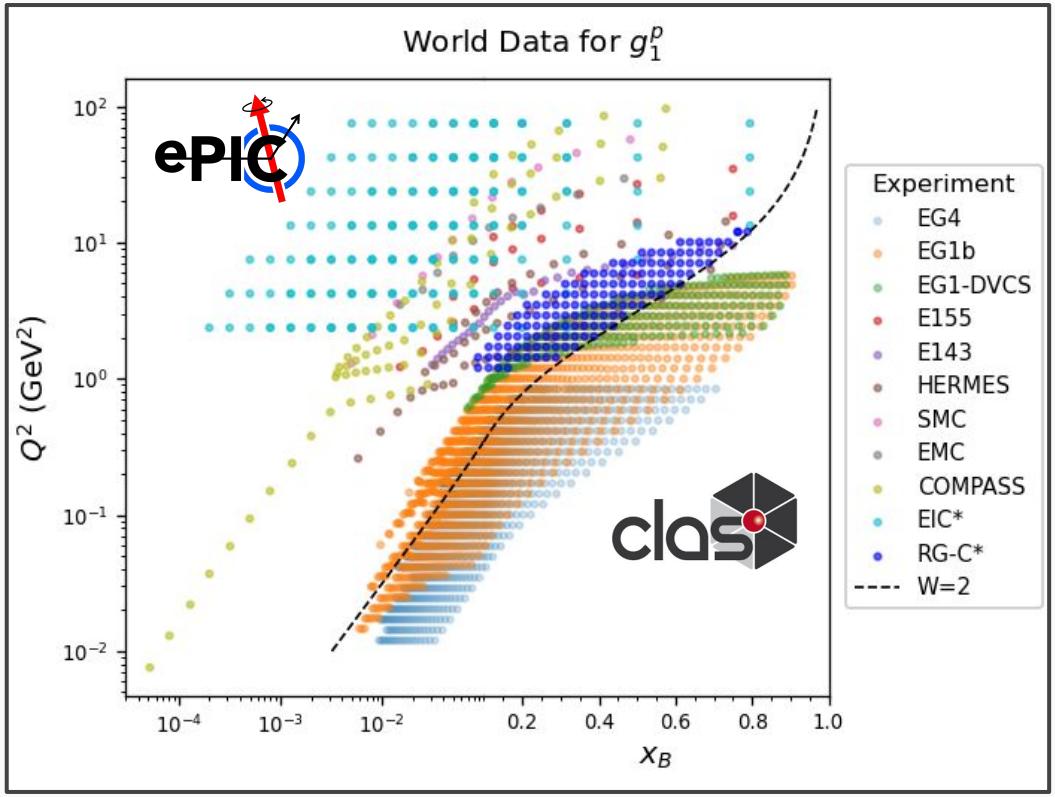


$$A_{||}(x,Q^2) = \frac{n^- - n^+}{n^- + n^+} = D\left(A_1(x,Q^2) + \eta A_2(x,Q^2)\right)$$

$$A_1(x,Q^2) \propto \frac{g_1(x,Q^2)}{F_1(x,Q^2)} = \frac{\Sigma_i e_i^2 \Delta q_i(x,Q^2)}{\Sigma_i e_i^2 q_i(x,Q^2)}$$

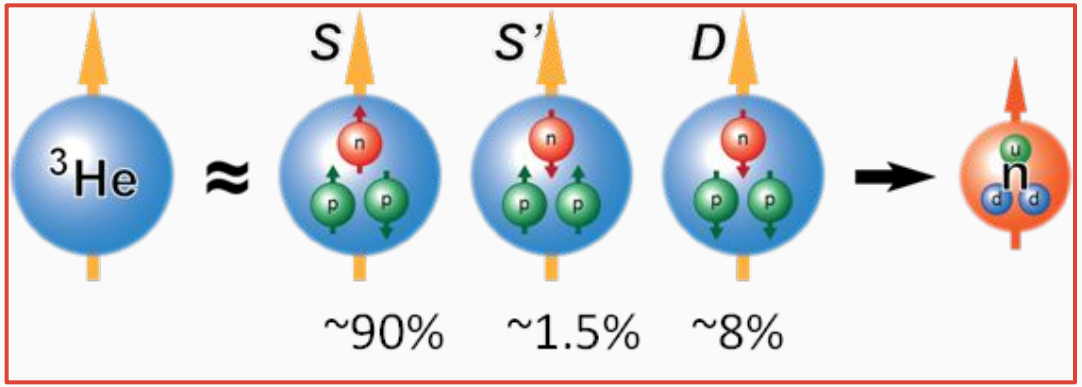
Why do we need the EIC?

- Need for *really* low-x data at high Q^2 to improve precision of moments



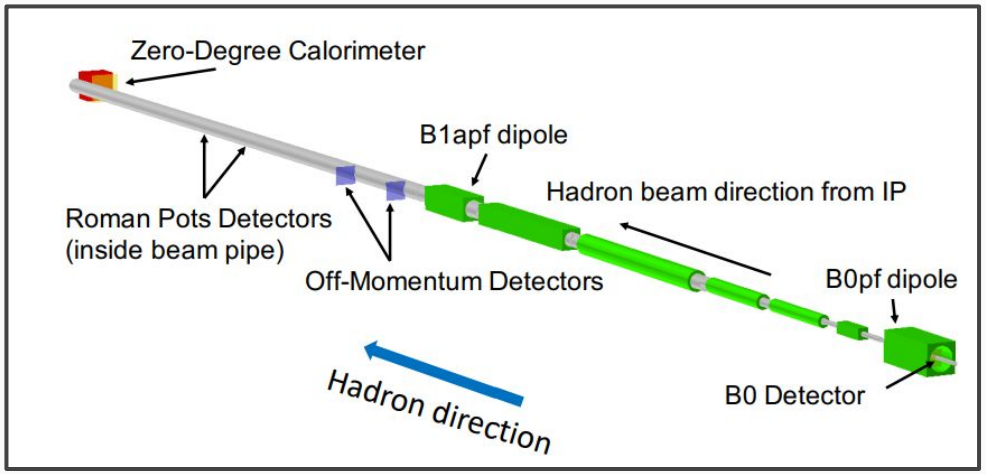
DIS on the “Neutron”

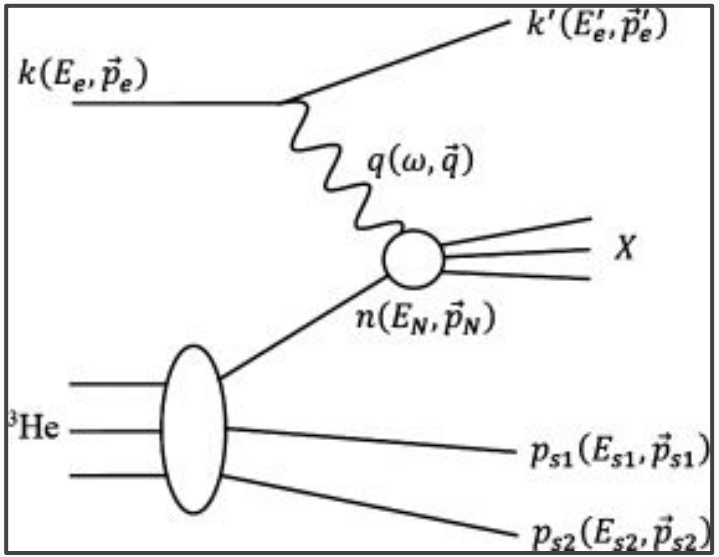
- Free neutron target is a fairy tale
- Current methods use polarized deuteron or ^{3}He targets
- In S-state of ^{3}He, proton spins cancel -> “semi-free polarized neutron”
  - ➢ Sizeable systematic uncertainties from nuclear effects



Doubly-Tagged DIS at the EIC

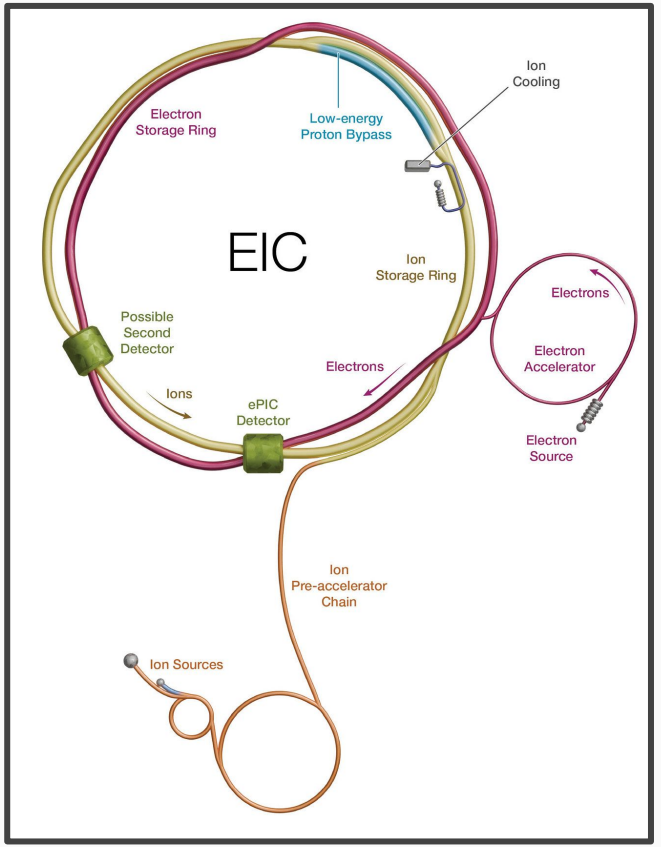
- Measure protons from ^{3}He break-up
- Minimize systematics coming from nuclear corrections to 3He
  - ➢ Select scattering from quasi-free neutron
- Accomplished by detector stack in far-forward region





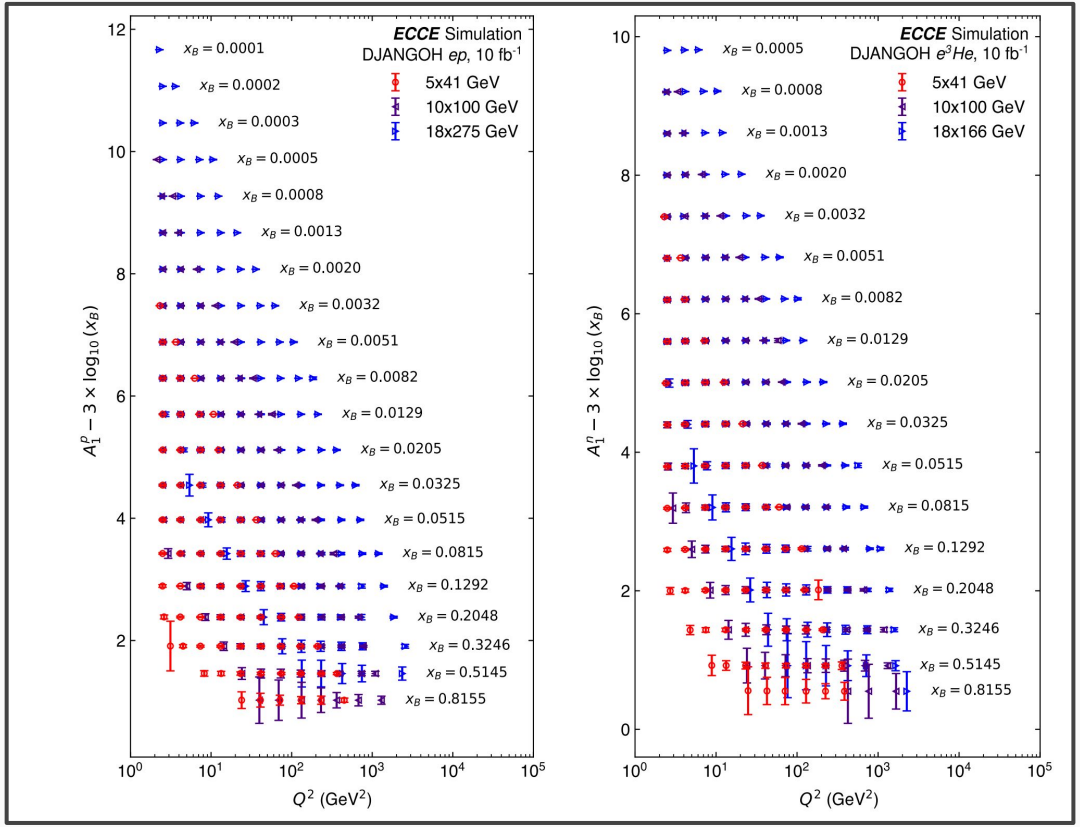
Future EIC (Assumed)

- Three energy settings for *ep* and *e-^{3}He*
- Beam polarizations ~70%
- Projections from simulation of ECCE
- Far-Forward detectors for tagged DIS of ^{3}He



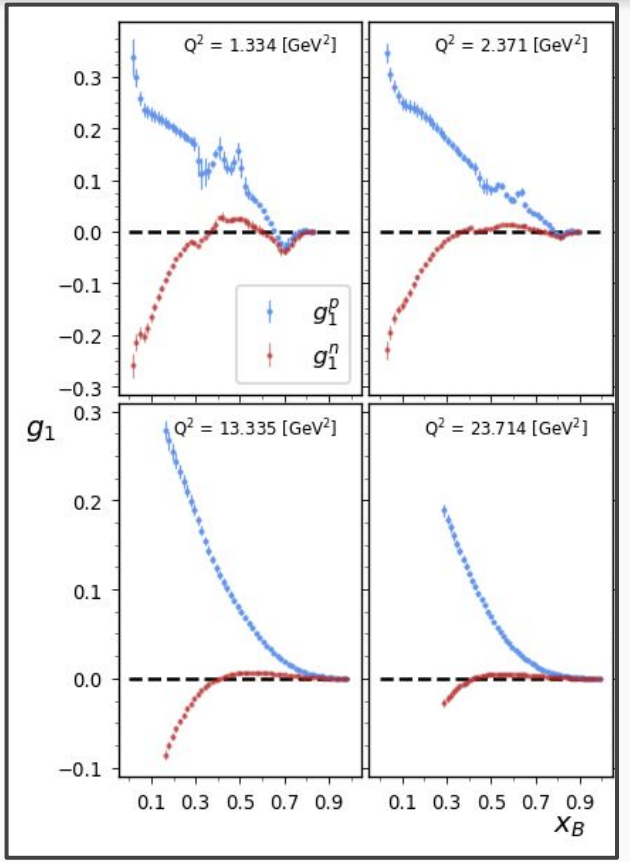
A_1 - Projections

- DJANGOH to generate events in simulated in ECCE
- Systematics from unfolding, Rad Corr, etc
- $A_1F_1 \sim g_1$
- Not full coverage of *x*



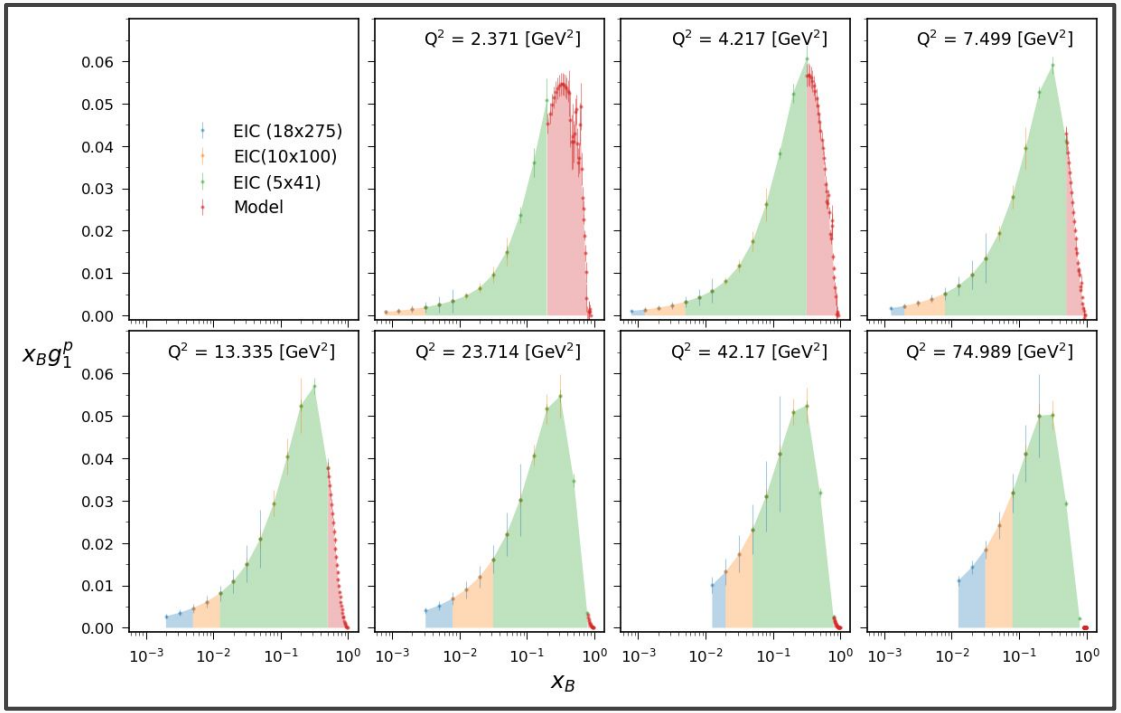
World Fits of g_1 for Large x_B

- "Hall B Model" uses world data for longitudinal scattering on proton, deuteron, & neutron
  - Covers resonance through DIS
  - Fit uncertainties are shown with error bars
- Model precision will be improved by my thesis data from CLAS12 Run Group - C & A1n JLab12 experiment in Hall C



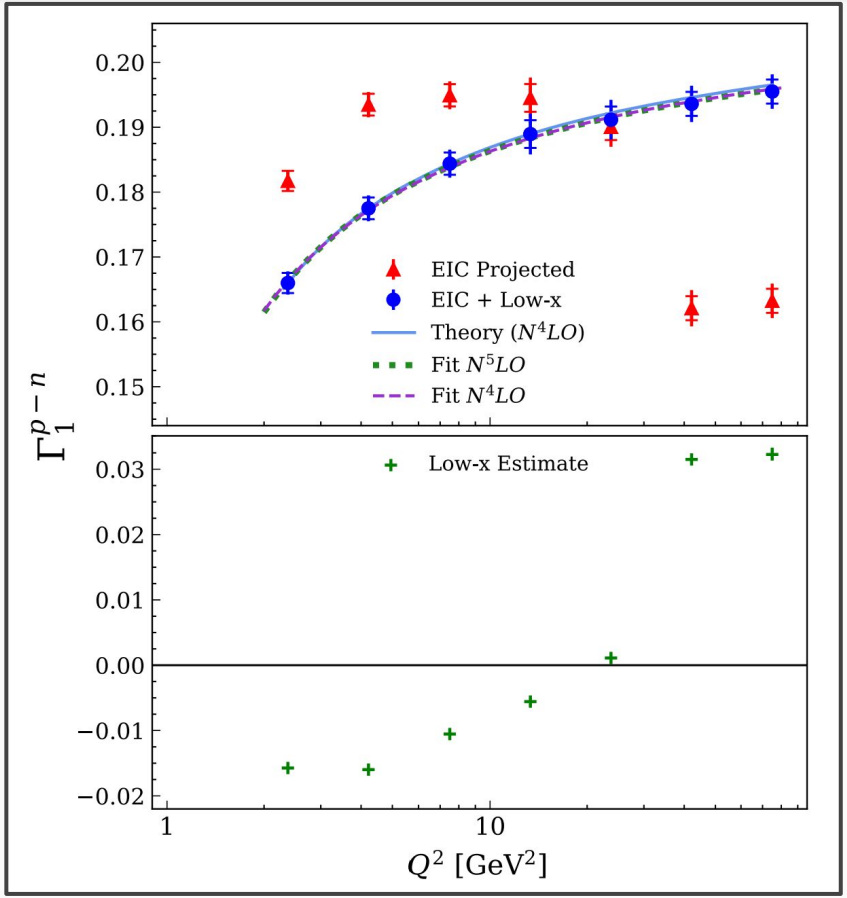
Stitch Projections & Model

- Using model to fill-in coverage at large *x*
- Color is associated with region with best precision



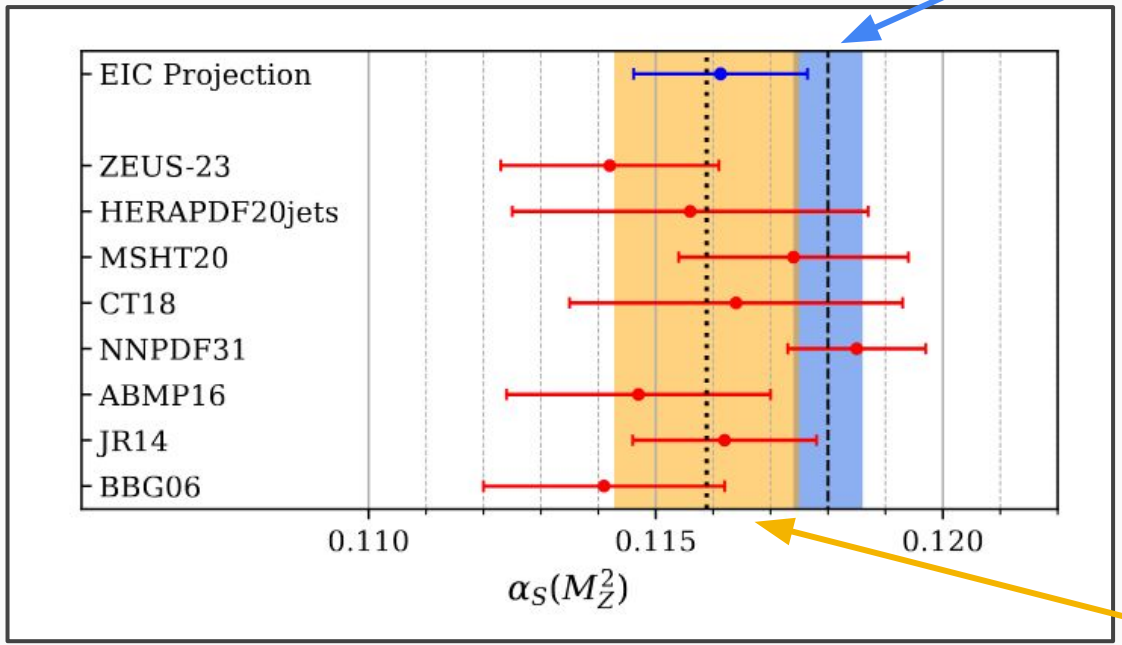
Moments & Fitting for α_s

- Integration over *x* provides Γ_1
- Fit projections at N^xLO
- Estimation for missing low-*x* comes from Regge theory



How does this Compare?

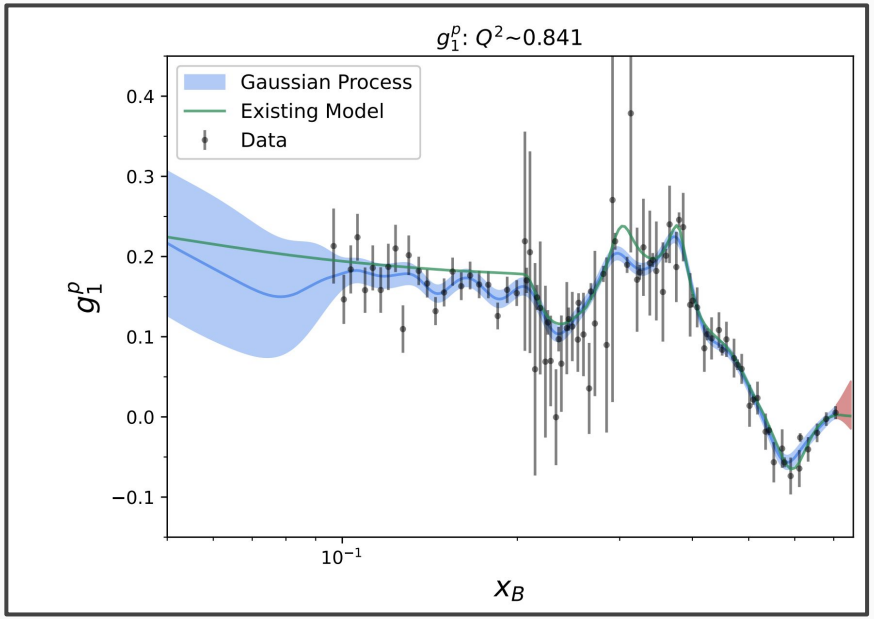
- EIC precision is competitive against existing *global analyses*

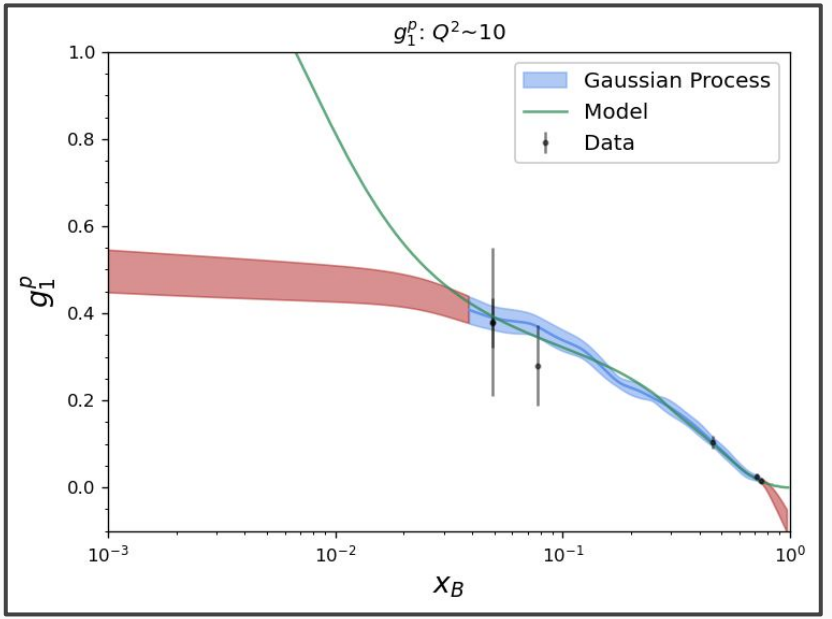


What Else Can Help?

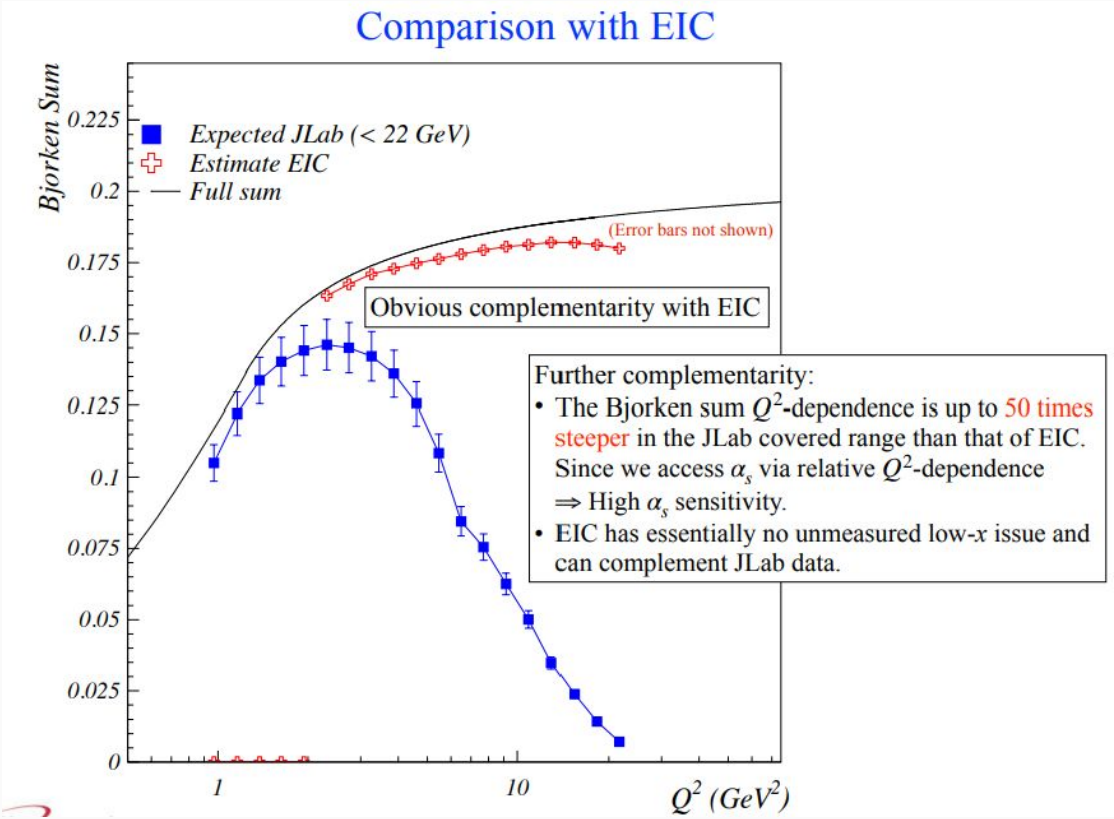
Updating World Fits using ML

- Model full spectrum using flexible ML modeling techniques
- Gaussian Process (GP) provides flexible models with UQ





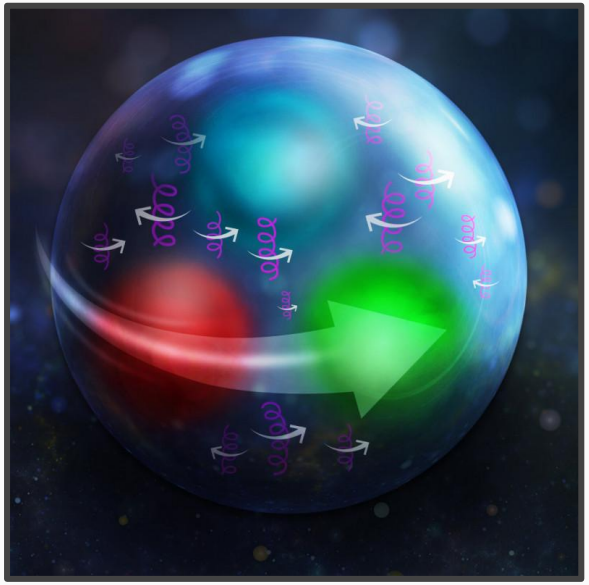
Synergy with JLab 22 GeV



A. Deur, JLab 22 GeV Open Discussion (2023)

Closing Thoughts

- EIC offers unique opportunities for spin physics via tagged DIS
- Using projections we show a competitive extraction of α_S
- Excellent complementarity between EIC & JLab



Questions & Comments

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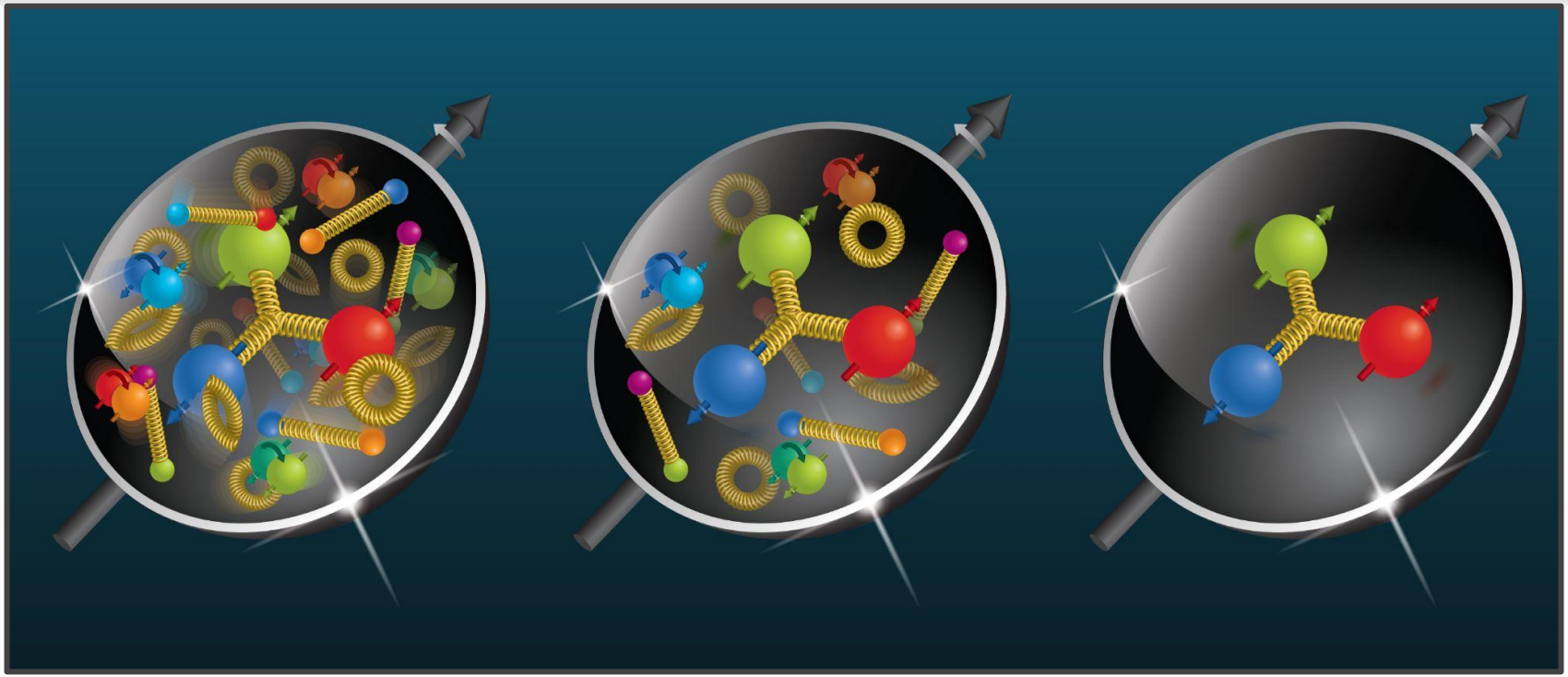
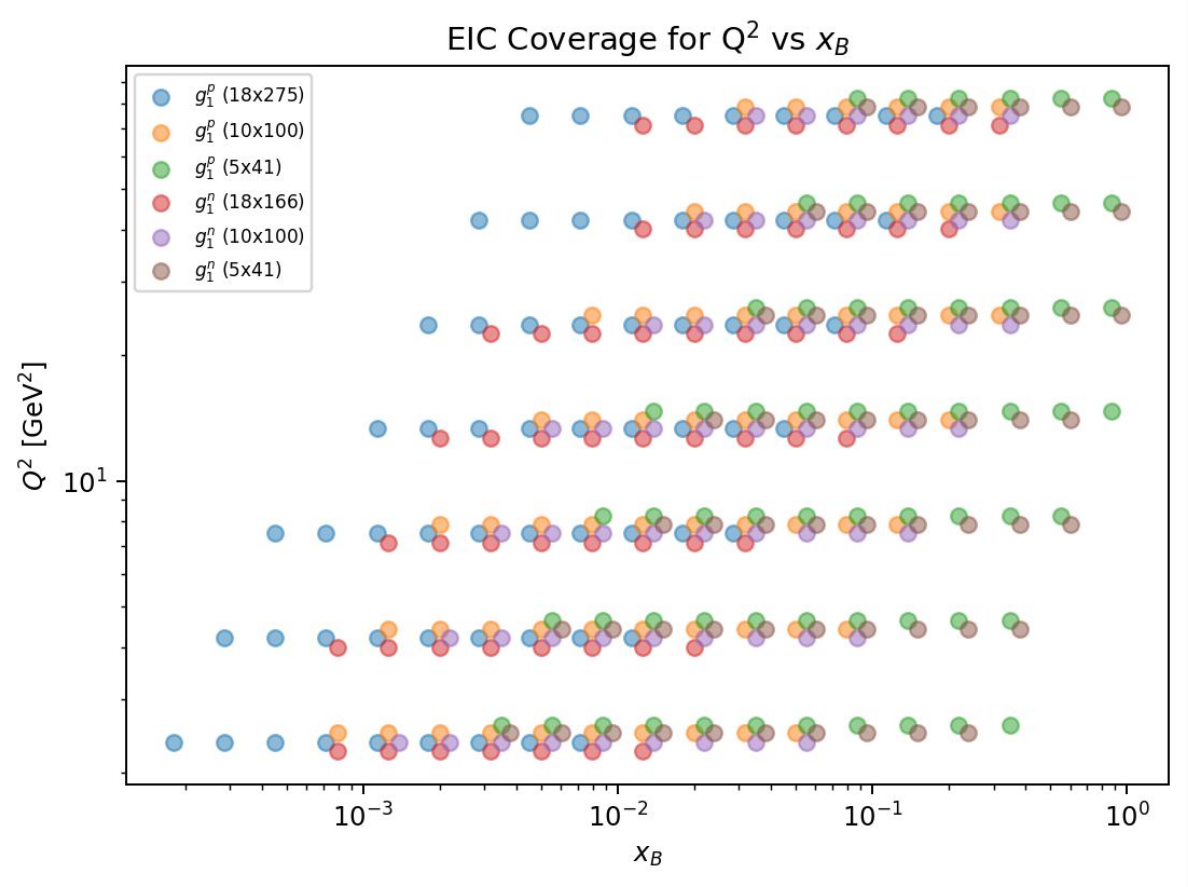
Backup Slides

Understanding the Evolution in x_B

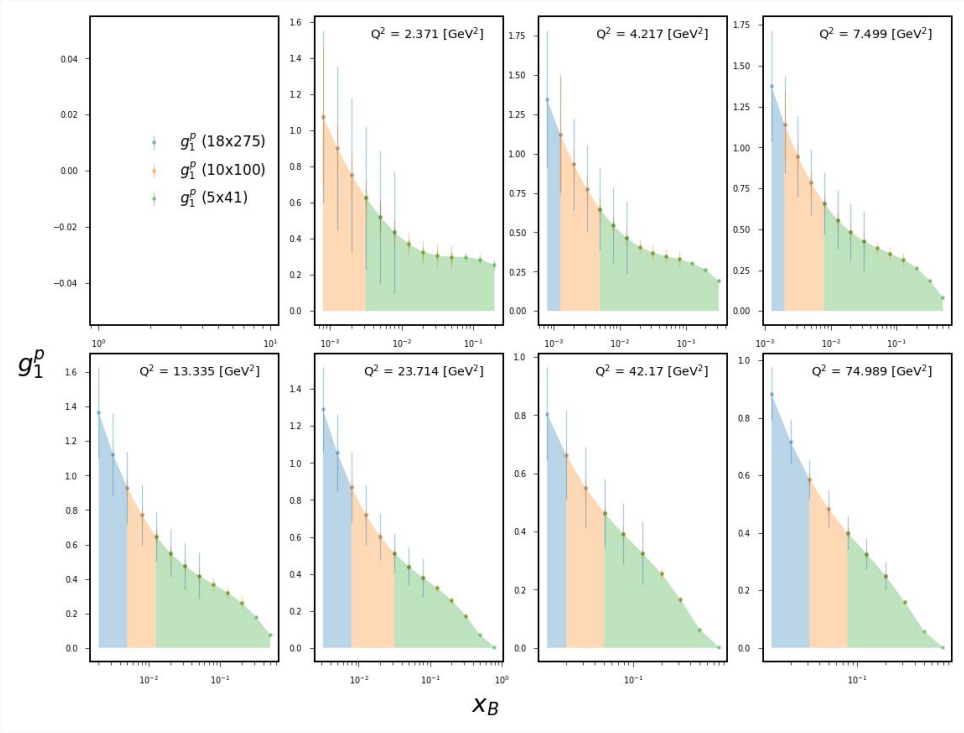


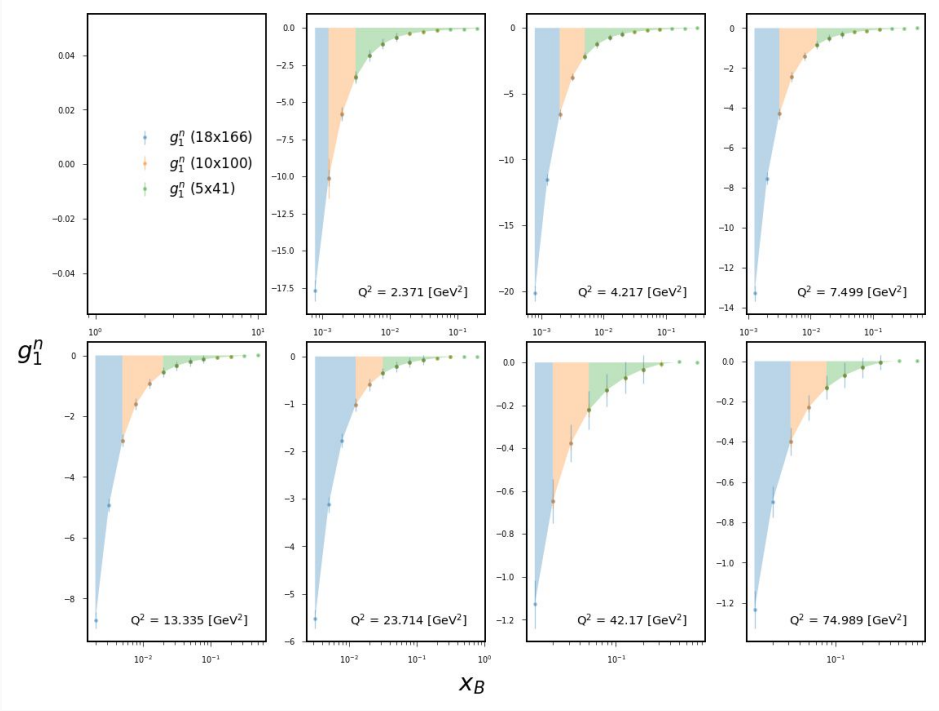
Increasing *x*

EIC Kinematic Coverage



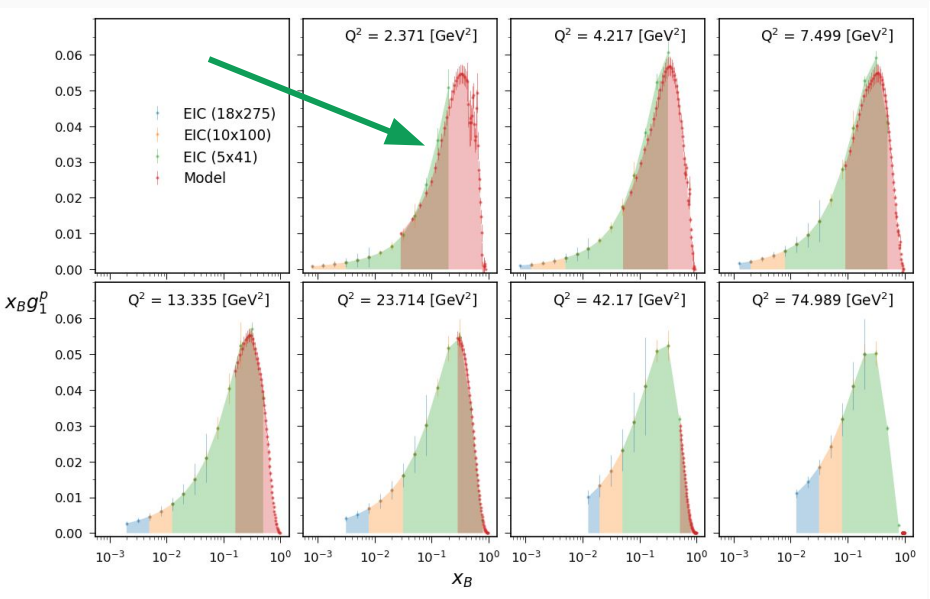
Projections for g1

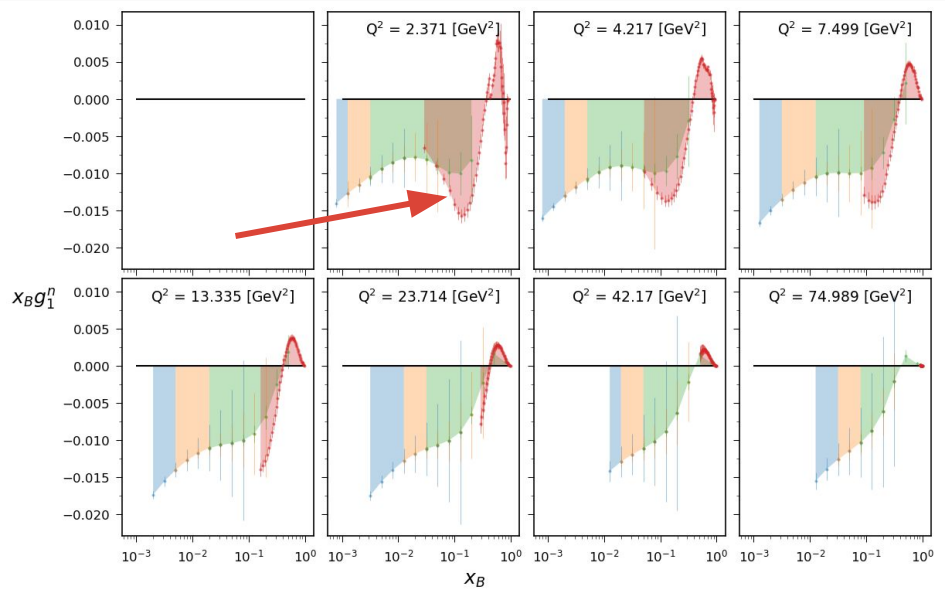




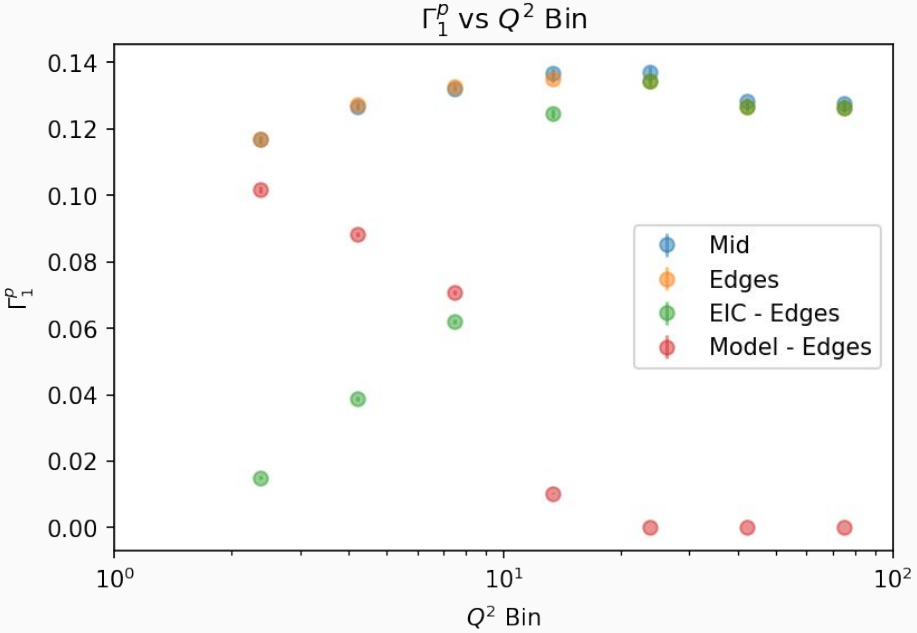
Stitched Version (Overlap)

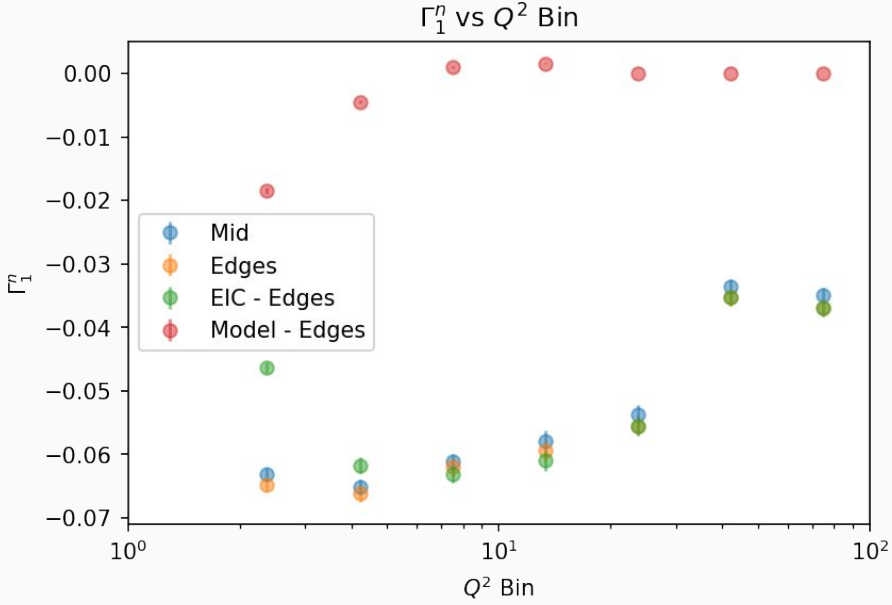
- EIC g1p is too high & EIC g1n is too low



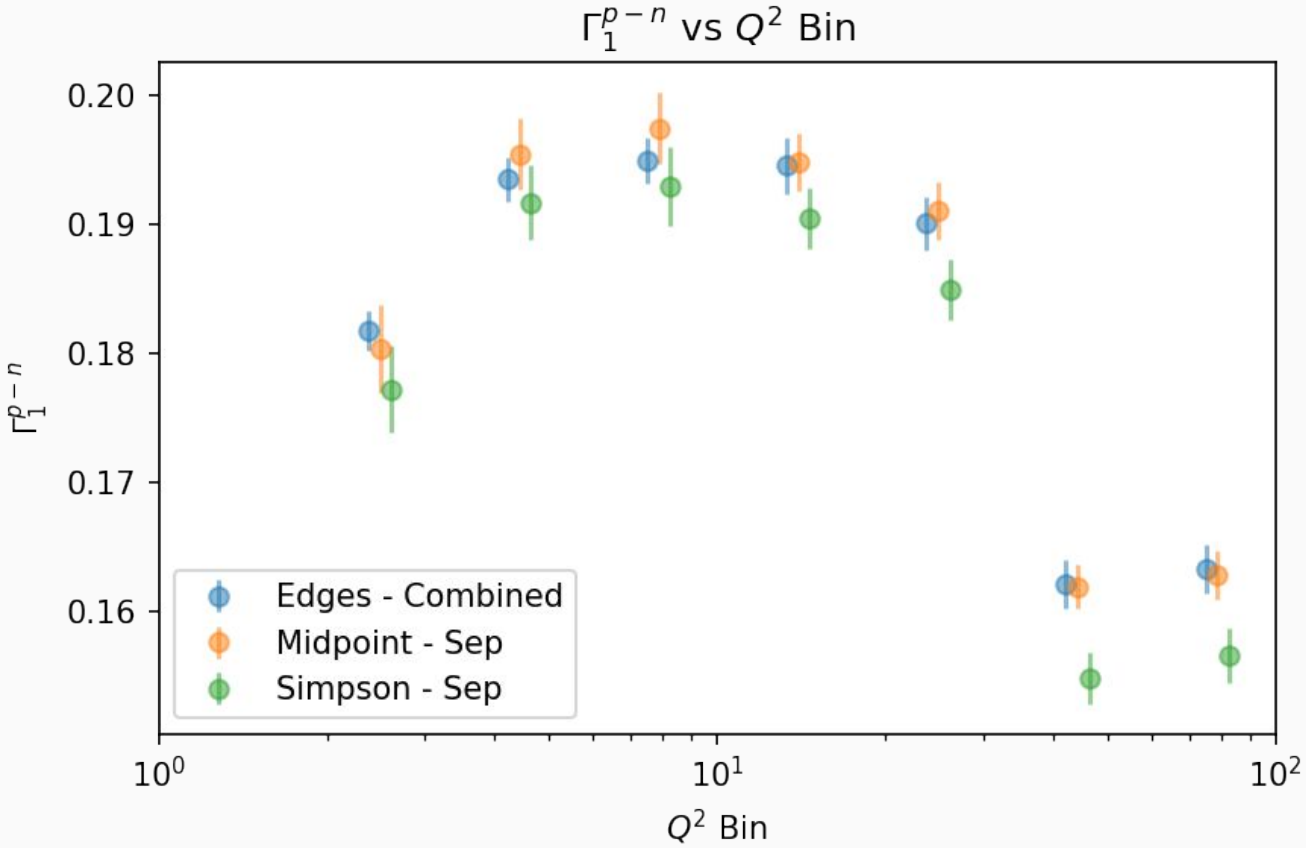


Moments


Γ_1^p vs Q^2 Bin
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Γ_1^p
10^0
10^1
10^2
Q^2 Bin
Mid
Edges
EIC - Edges
Model - Edges

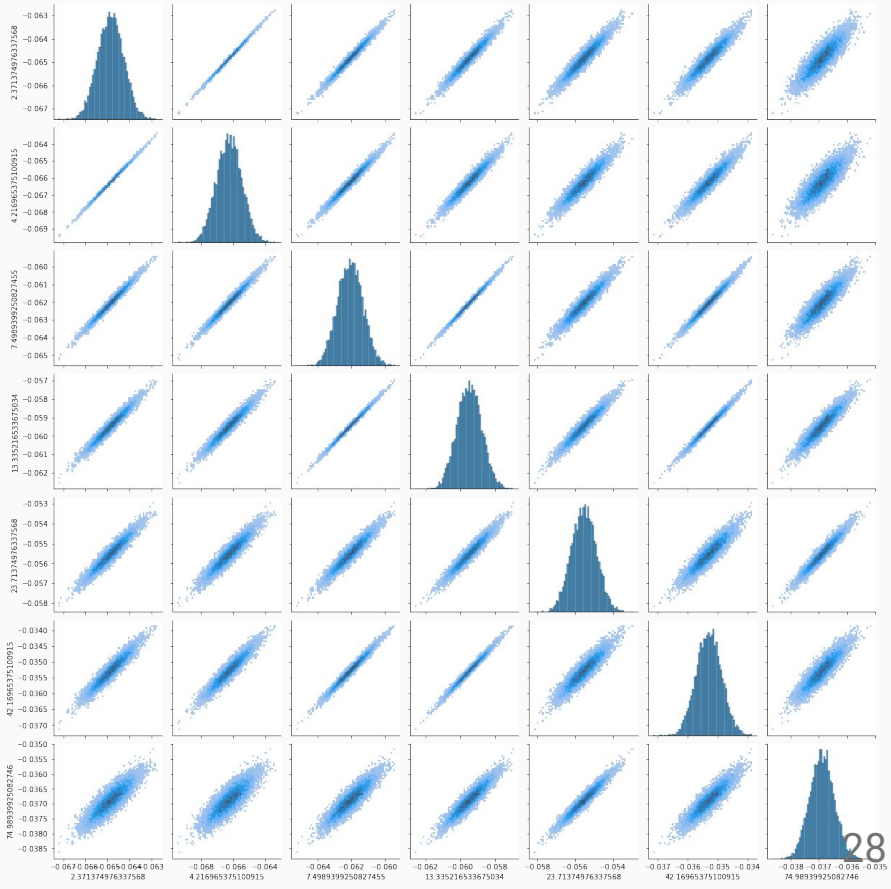

Γ_1^n vs Q^2 Bin
0.00
−0.01
−0.02
−0.03
−0.04
−0.05
−0.06
−0.07
Γ_1^n
10^0
10^1
10^2
Q^2 Bin
Mid
Edges
EIC - Edges
Model - Edges

Integration Methods



Beam Polarization Uncertainty

- Order of magnitude estimation from MC approach
- Generate pseudo-data at each energy by varying overall g_1 normalization by σ=2% per setting



Moments from ML World Fits

- Integrated over x for GP model
- Comparable to world data