Potential α_s measurement via polarized e+^{3}He scattering

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eA study group meeting
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Stony Brook University

Center for Frontiers in Nuclear Science

ePIC

Extract α_s via A_1^p and A_1^n

- Extract α_s via double spin asymmetry measurement on e + ^{3}He scattering at EIC

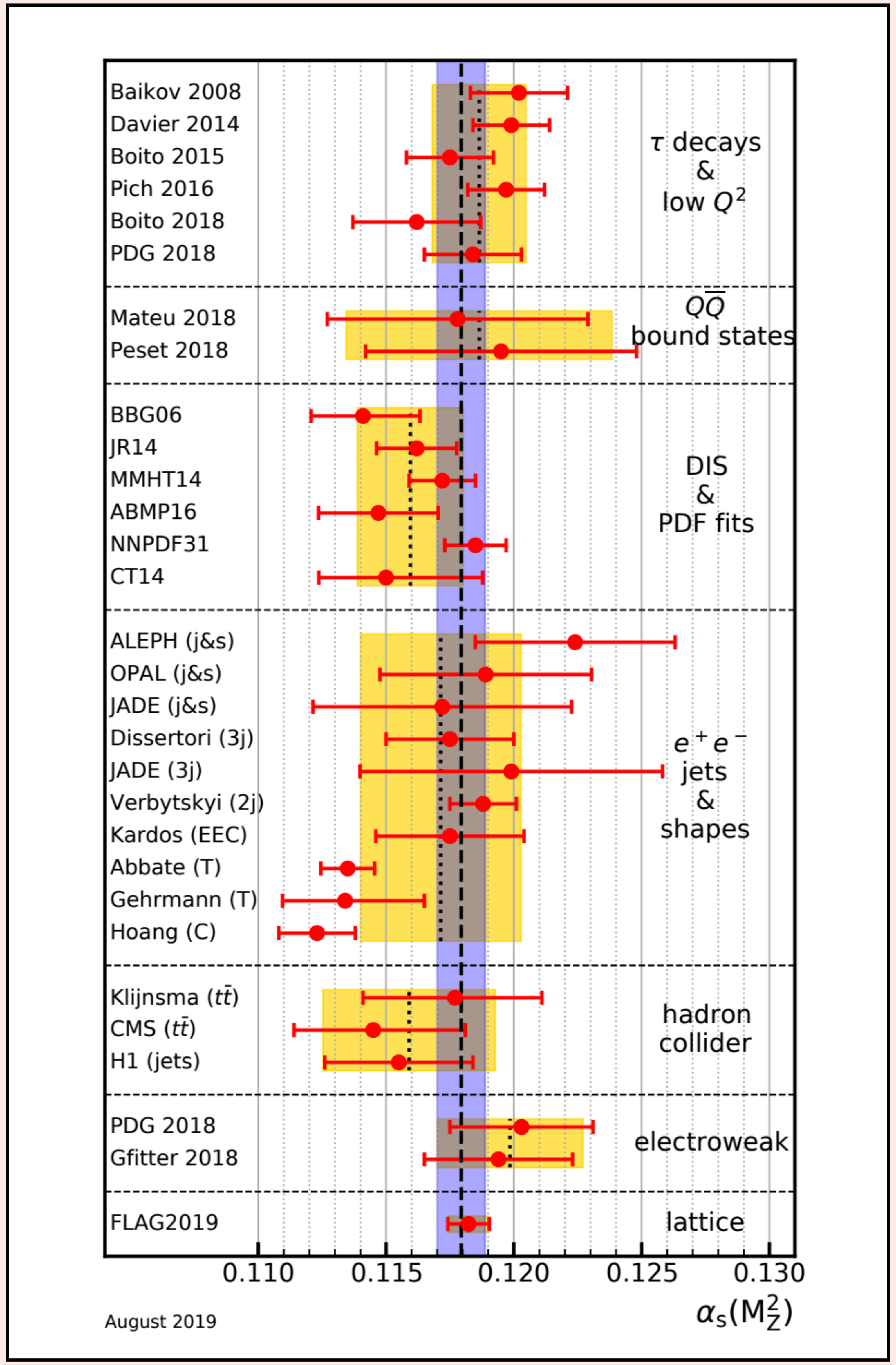
Strong: $\frac{\Delta \alpha_S}{\alpha_S} = 8 \times 10^{-3}$ ← Least precisely known

Important for calculating pQCD, testing SM and exploring BSM physics

Electromagnetic: $\frac{\Delta \alpha}{\alpha} = 1.5 \times 10^{-10}$

Weak: $\frac{\Delta G_F}{G_F} = 5.1 \times 10^{-7}$

Gravity: $\frac{\Delta G_N}{G_N} = 2.2 \times 10^{-5}$



P. A. Zyla *et al.* (Particle Data Group), Review of Physics Particle Physics. *PTEP 2020*

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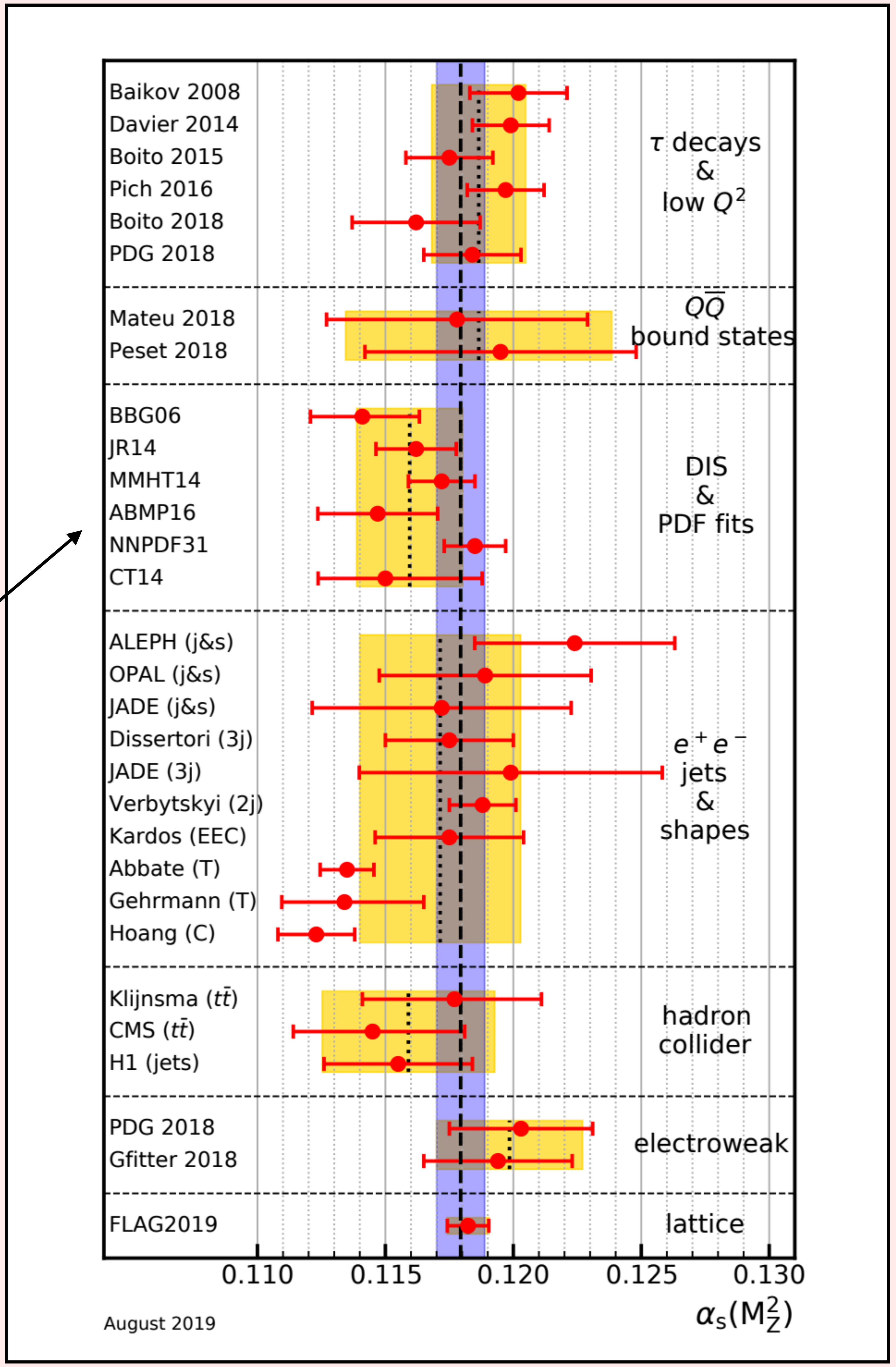
EIC can be a significant contributor to the global extraction of α_s:

- Global PDF fits

  Cerci *et al.* Extraction of the strong coupling with HERA and EIC inclusive data. *Eur. Phys. J. C 2023*

- Using BJSR

  Kutz *et al.* High precision measurements of α_s at the future EIC. *Phys. Rev. D 2024*



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Bjorken integral: $\Gamma_1^{\mathrm{p-n}} \equiv \int_0^{1^-} (g_1^p - g_1^n)\, dx$

At finite Q^2 values:

$$\Gamma_1^{\mathrm{p-n}}(\alpha_S) = \Gamma_1^{\mathrm{p-n}}(Q^2) = \sum_{\tau>0} \frac{\mu_{2\tau}^{p-n}(\alpha_S)}{Q^{2\tau-2}}$$

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

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- Extract α_s via double spin asymmetry measurement on e + ^{3}He scattering at EIC

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

where

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

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

$$A_2 = \frac{2\sigma^{\mathrm{TL}}}{\sigma_{1/2} + \sigma_{3/2}}$$

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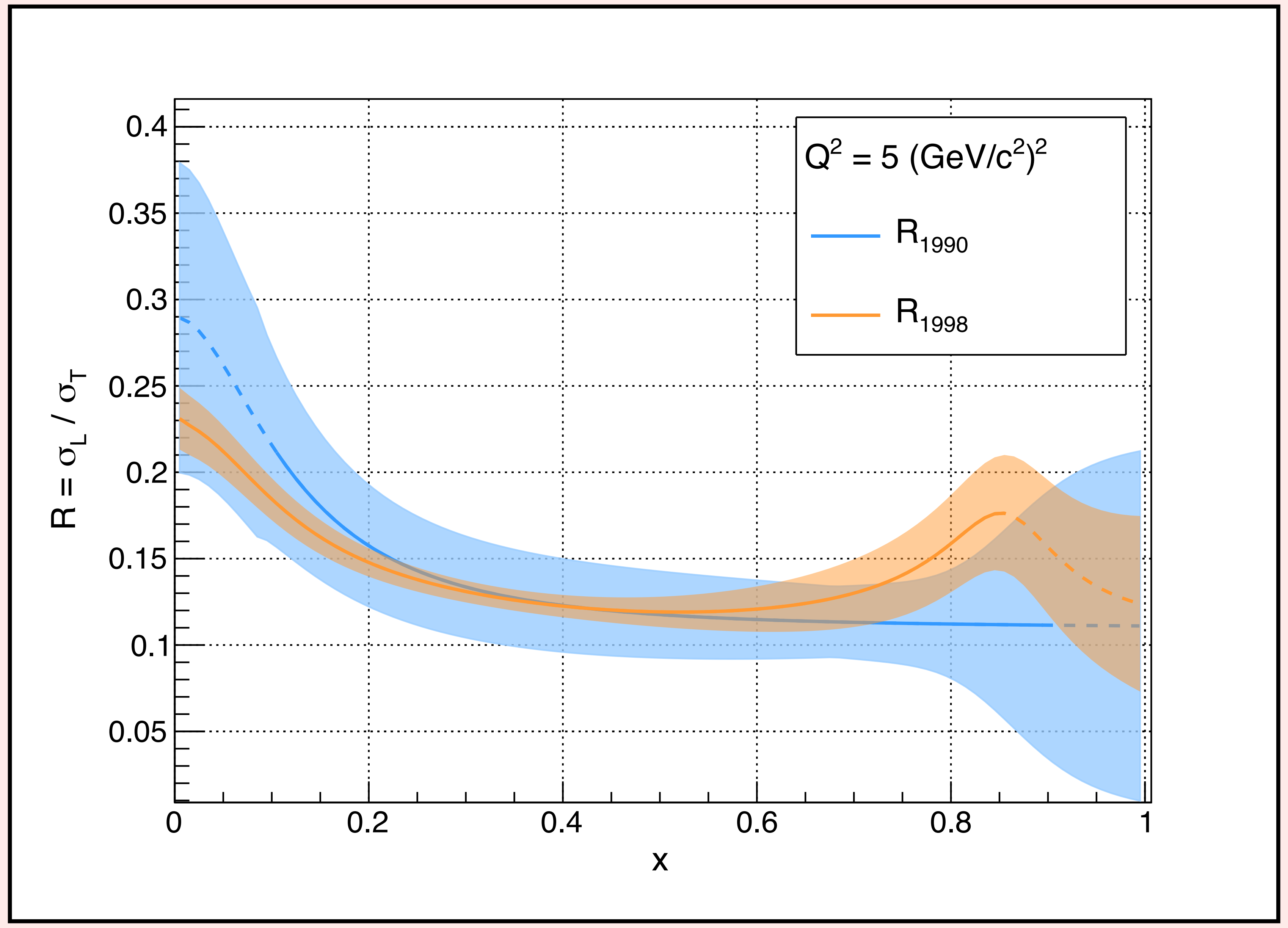
$R \equiv \dfrac{\sigma_L}{\sigma_T}$: ratio of the longitudinal to transverse virtual photon absorption cross sections



Precise Measurements of the Proton and Deuteron Structure Functions from a Global Analysis of the SLAC Deep Inelastic Electron Scattering Cross Sections, *L. W. Whitlow et al.*

Measurements of $R = \sigma_L/\sigma_T$ for 0.03 < x < 0.1 and Fit to the World Data, *K. Abe et al.*

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The rest are kinematic variables:

$$D = \frac{y(2-y)(2+\gamma^2 y)}{(2(1+\gamma^2)y^2 + (4(1-y) - \gamma^2 y^2)(1+R))} \tag{7}$$

$$\gamma = 4M^2x^2/Q^2 \tag{8}$$

$$d = \sqrt{4(1-y) - \gamma^2 y^2} D/(2-y) \tag{9}$$

$$\eta = \gamma(4(1-y) - \gamma^2 y^2)/(2-y)/(2+\gamma^2 y) \tag{10}$$

$$\xi = \gamma(2-y)/(2+\gamma^2 y)\ , \tag{11}$$

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$$\delta A_{\parallel,\perp} = \frac{1}{\sqrt{N P_e P_N}} \longrightarrow \delta\alpha_S$$

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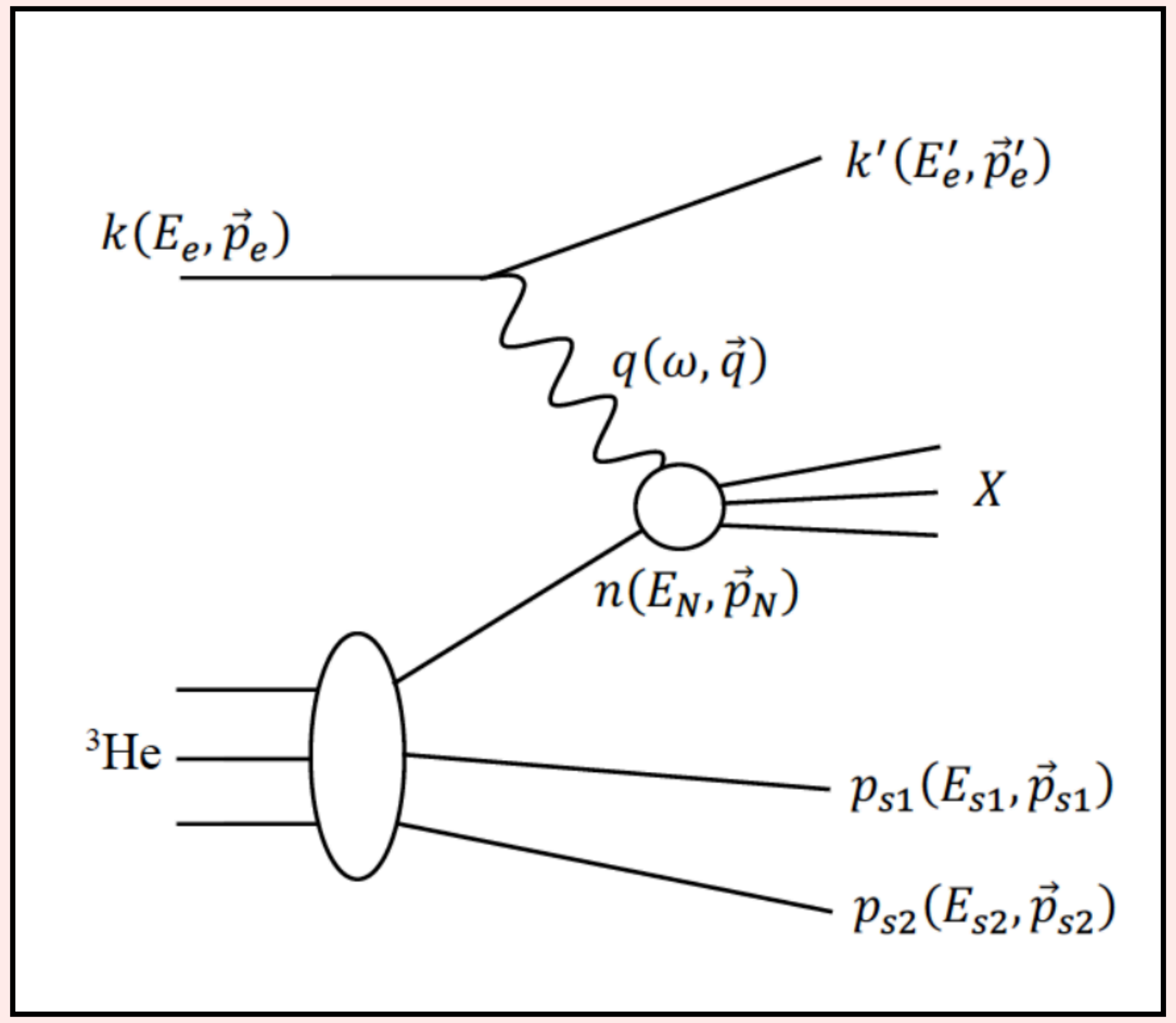
e + ^{3}He DIS scattering

- e+^{3}He scattering with double spectator tagging will have less model dependence in extracting the neutron structural functions
  - Currently, A_1^n is deduced from $A_1^{^3\mathrm{He}}$ where the systematic uncertainties are dominated by the model in the extraction

Diagram of the DIS process:



Rest frame of ^{3}He:

"Free" neutron

"Low momentum" protons

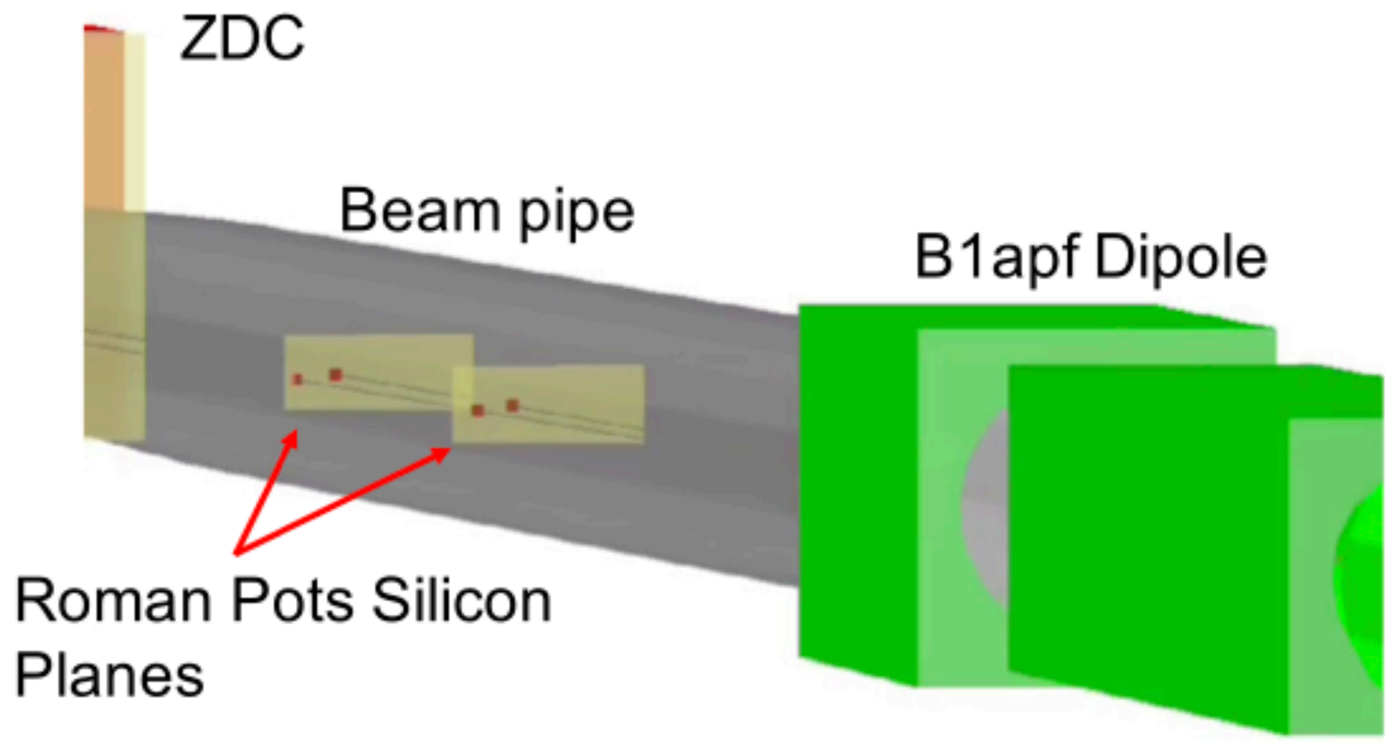


Fig. 3. Zoomed-in image of a 3BBU-MF e+^{3}He with both protons tagged in the Roman Pot silicon detector planes. The beam pipe was made semi-transparent in order to see the event. The off-momentum detectors are omitted from the figure to make the event easier to view.

Friščić et al. Neutron Spin Structure from e-^{3}He Scattering with Double Spectator Tagging at the Electron-Ion Collider. *Phys. Lett. B* 2021

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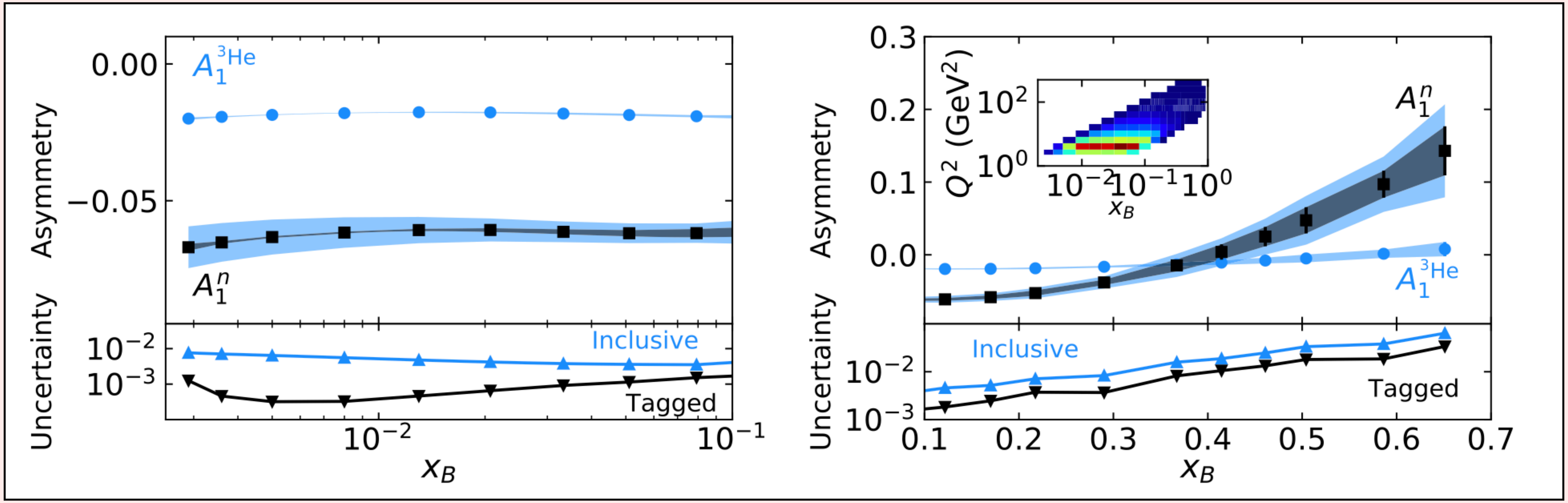
Comparison of A_1^n extracted from inclusive (blue band) vs tagged (black square) measurements:



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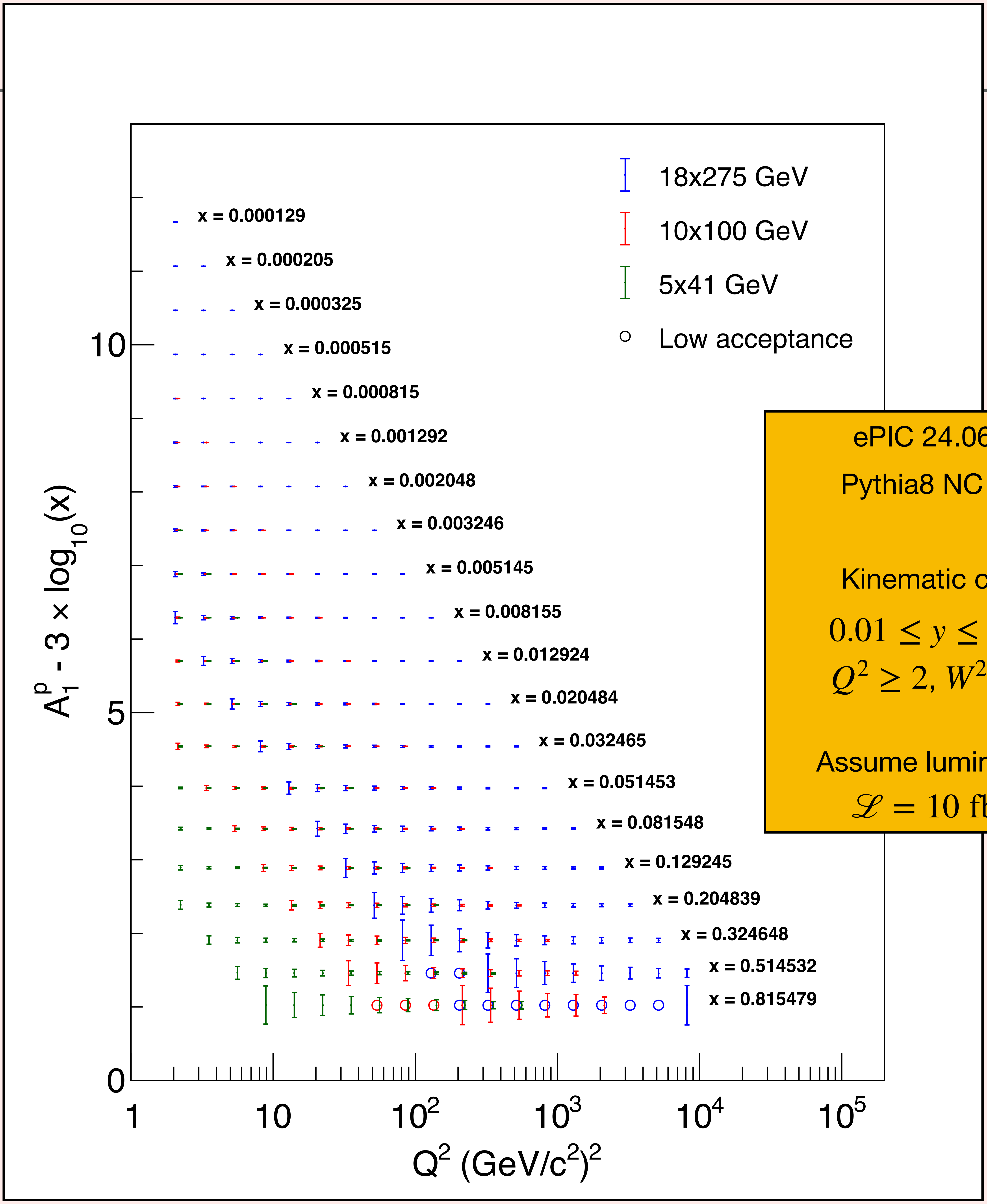
A_1^p from ep simulation

- $A_1(x, Q^2) \equiv \dfrac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \dfrac{A_\parallel}{D(1+\eta\xi)} - \dfrac{\eta A_\perp}{d(1+\eta\xi)}$
- $\delta A_{\parallel,\perp} = \dfrac{1}{\sqrt{N} P_e P_N}$
- Assume half of the events give $A_\parallel$ and half give $A_\perp$, $P_e = P_p = 70\,\%$
- A_1 for each bin is calculated using parameterization from: X. Zheng, Doi: 10.2172/824895
- R (for calculating D) is taken from: https://doi.org/10.1016/S0370-2693(99)00244-0. Uncertainties from this fit are not included



ePIC 24.06.0,
Pythia8 NC DIS

Kinematic cuts:
$0.01 \le y \le 0.95$
$Q^2 \ge 2,\ W^2 \ge 4$

Assume luminosity:
$\mathscr{L} = 10\ \text{fb}^{-1}$

* Calculated using bin center x and Q^2

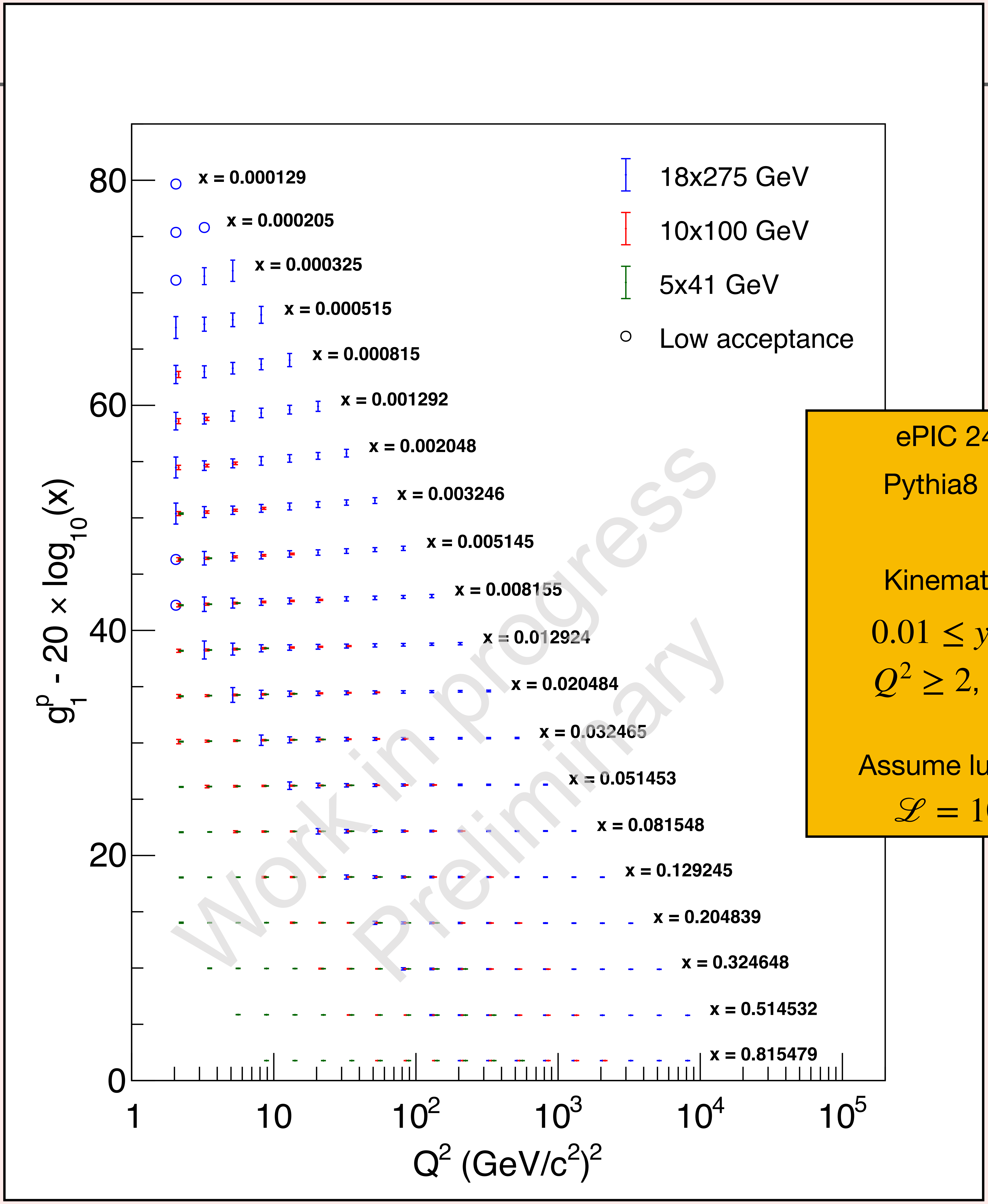
* ignore bin if calculated y is <= 0.01 or >= 0.95

g_1^p from ep simulation

A₁ is calculated using parameterization from: X. Zheng, Doi: 10.2172/824895

$$A_1^p \approx g_1^p / F_1^p$$

Using HERAPDF20_LO_EIG for F_1^p



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Event generator for e + ^{3}He study..

- Using BeAGLE to generate e + ^{3}He scattering events
- Use eicsmear and hepmc3ascii2root to convert data format
- epic simulation:

  epic_craterlake, Initialization time: 309.589417869 s, Per event time: 6.24880 s
- eicrecon error …

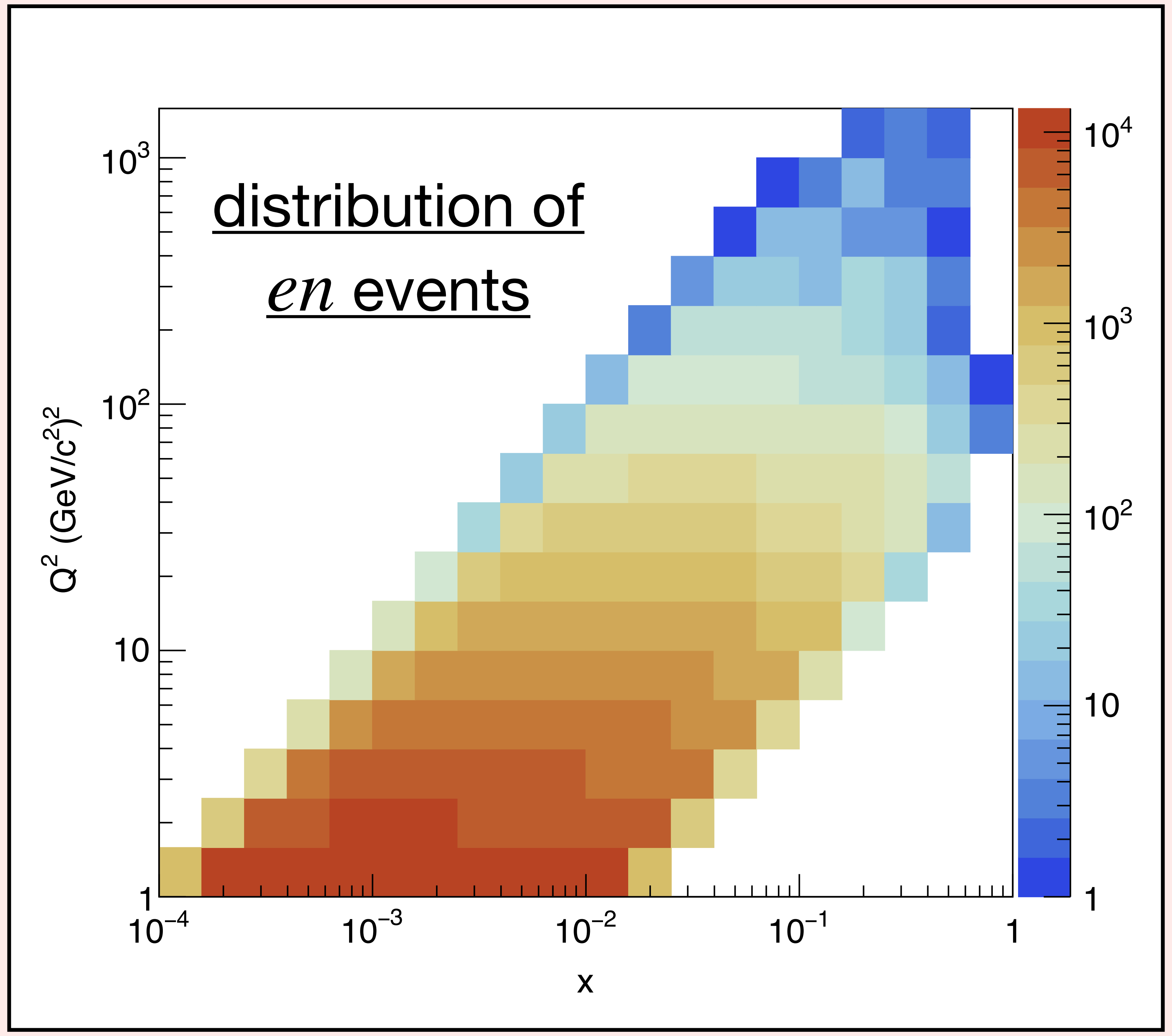
  [WARN] Status: 58 events processed at 0.0 Hz (0.4 Hz avg)

  [WARN] Status: 59 events processed at 1.0 Hz (0.4 Hz avg)

  [FOFFMTRK:ForwardOffMRecParticles] [error] No beam protons to choose matrix!! Skipping!!

  [RPOTS:ForwardRomanPotRecParticles] [error] No beam protons to choose matrix!! Skipping!!
- (Send request to the simulation team to generate large data set)
- Analysis to reconstruct events (next step after resolving the eicrecon error)

BeAGLE e + ^{3}He:



Total of 1M e + ^{3}He events (33.3% are *en*)

$$0.01 \leq y \leq 0.95$$