

α_s extraction from the Bjorken sum rule at ePIC early running

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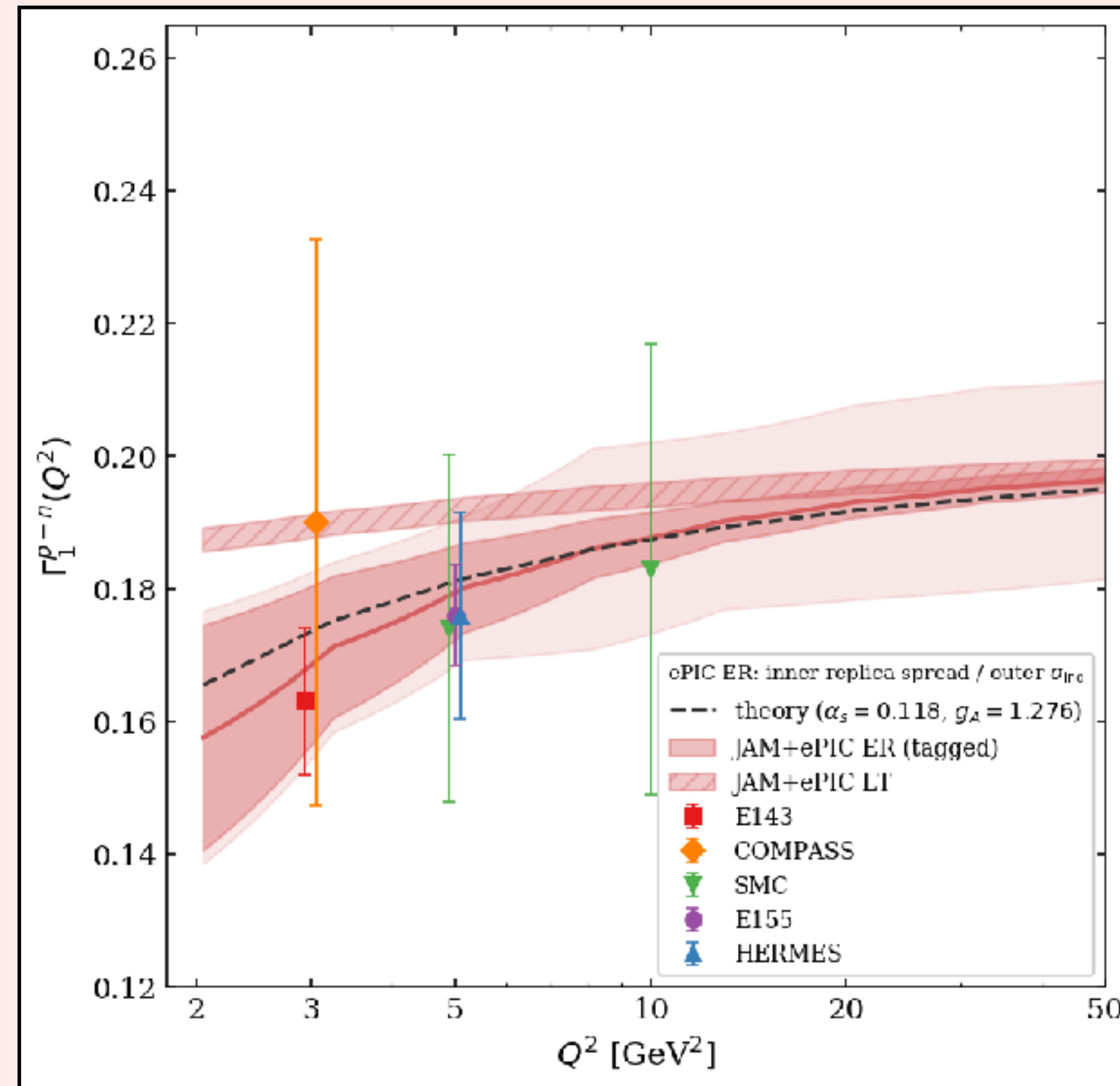
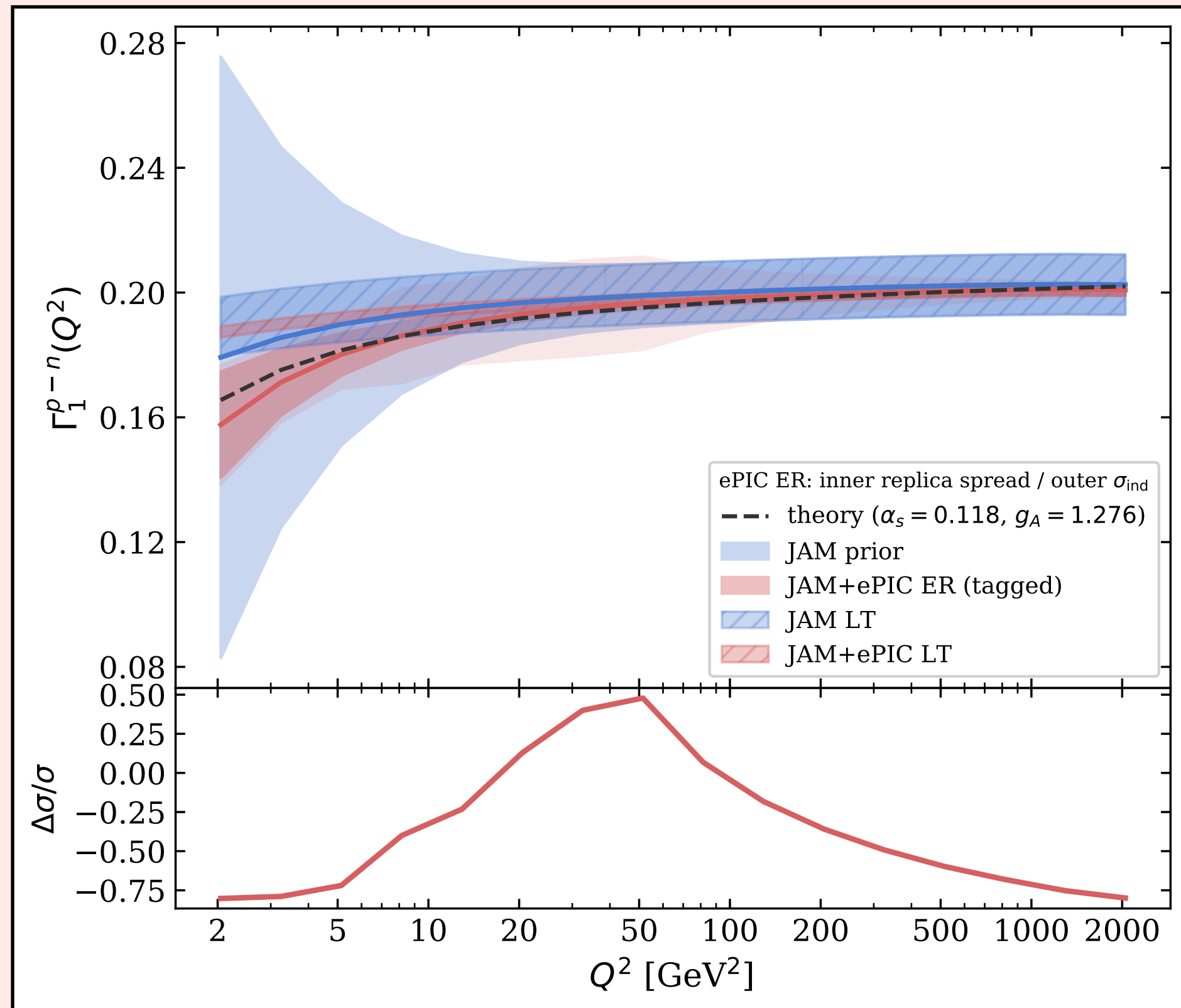
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The Bjorken Sum Rule

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- At leading twist: $\Gamma_1^{p-n} \equiv \int_0^1 [g_1^p(x, Q^2) - g_1^n(x, Q^2)] dx = \frac{g_A}{6} C_{\text{ns}}(\alpha_s, Q^2)$
- N⁴LO: $C_{\text{ns}} = 1 - \frac{\alpha_s(Q^2)}{\pi} - 3.58 \left(\frac{\alpha_s(Q^2)}{\pi} \right)^2 - 20.22 \left(\frac{\alpha_s(Q^2)}{\pi} \right)^3 - 175.7 \left(\frac{\alpha_s(Q^2)}{\pi} \right)^4$



Assume all are $A_{\parallel}$ measurements:

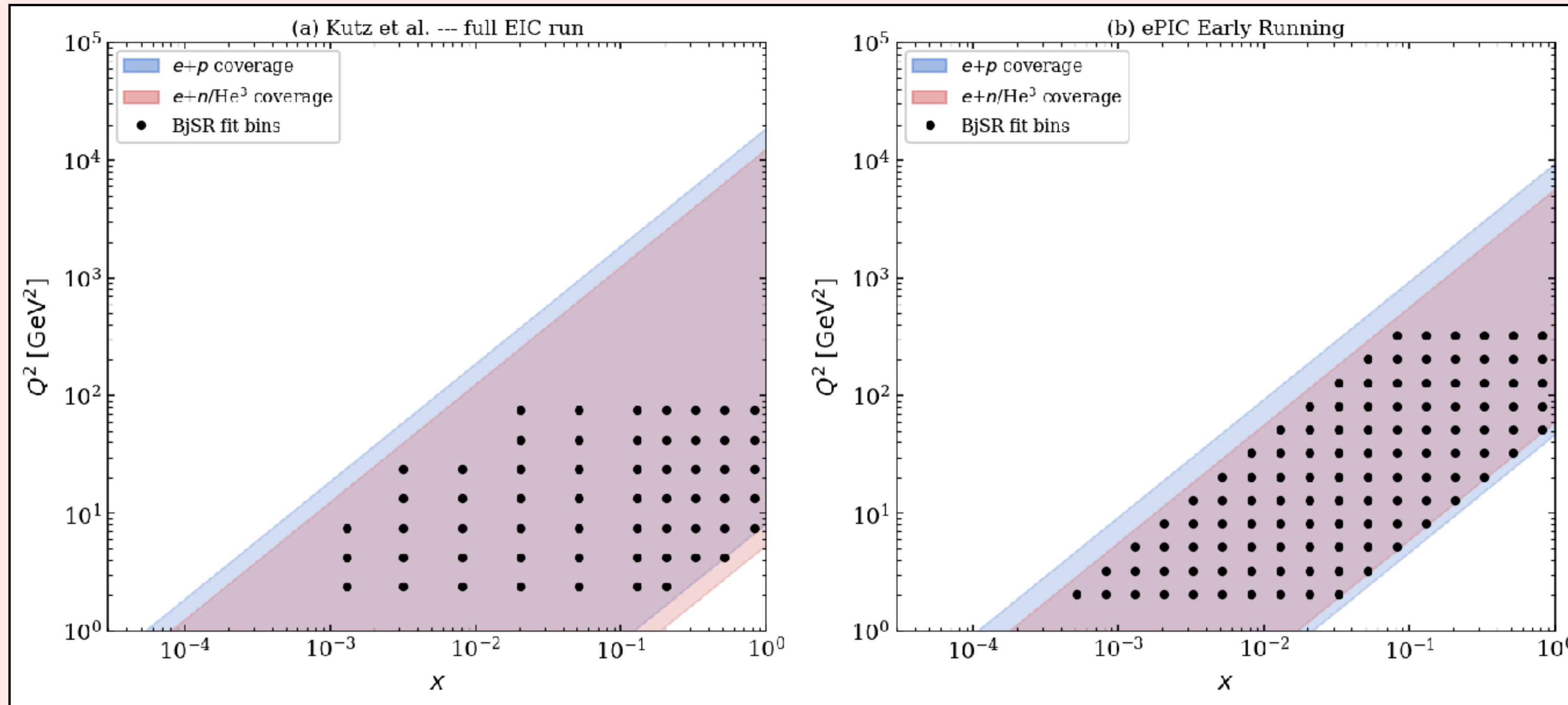
- ep 9x275 GeV, 2.5 fb⁻¹
- ep 9x130 GeV, 1.0 fb⁻¹
- eHe3 9x166 GeV, 1.5 fb⁻¹, tagged

$$\sigma_{\text{ind}}(Q^2) = \sqrt{d_{\text{uncorr}}^2(Q^2) + \sigma_{\text{shape}}^2(Q^2)}$$

$\sigma_{\text{shape}}^2(Q^2)$: 1 std of replica spread

$d_{\text{uncorr}}^2(Q^2)$: uncorrelated unc. from $A_{\parallel}$

- ▶ Kutz et al. (2024) [10.1103/PhysRevD.110.074004](https://arxiv.org/abs/10.1103/PhysRevD.110.074004): ECCE projection for full EIC running
- ▶ New fit follows the similar fitting procedures, but use JAM global analysis to model unmeasured regions and different uncertainty estimates



Bjorken sum construction

Decompose the integral to three parts:

$$\Gamma_1^{p-n} = \underbrace{\int_0^{x_{\min}} (g_1^p - g_1^n) dx}_L + \underbrace{\int_{x_{\min}}^{x_{\max}} (g_1^p - g_1^n) dx}_M + \underbrace{\int_{x_{\max}}^1 (g_1^p - g_1^n) dx}_H$$

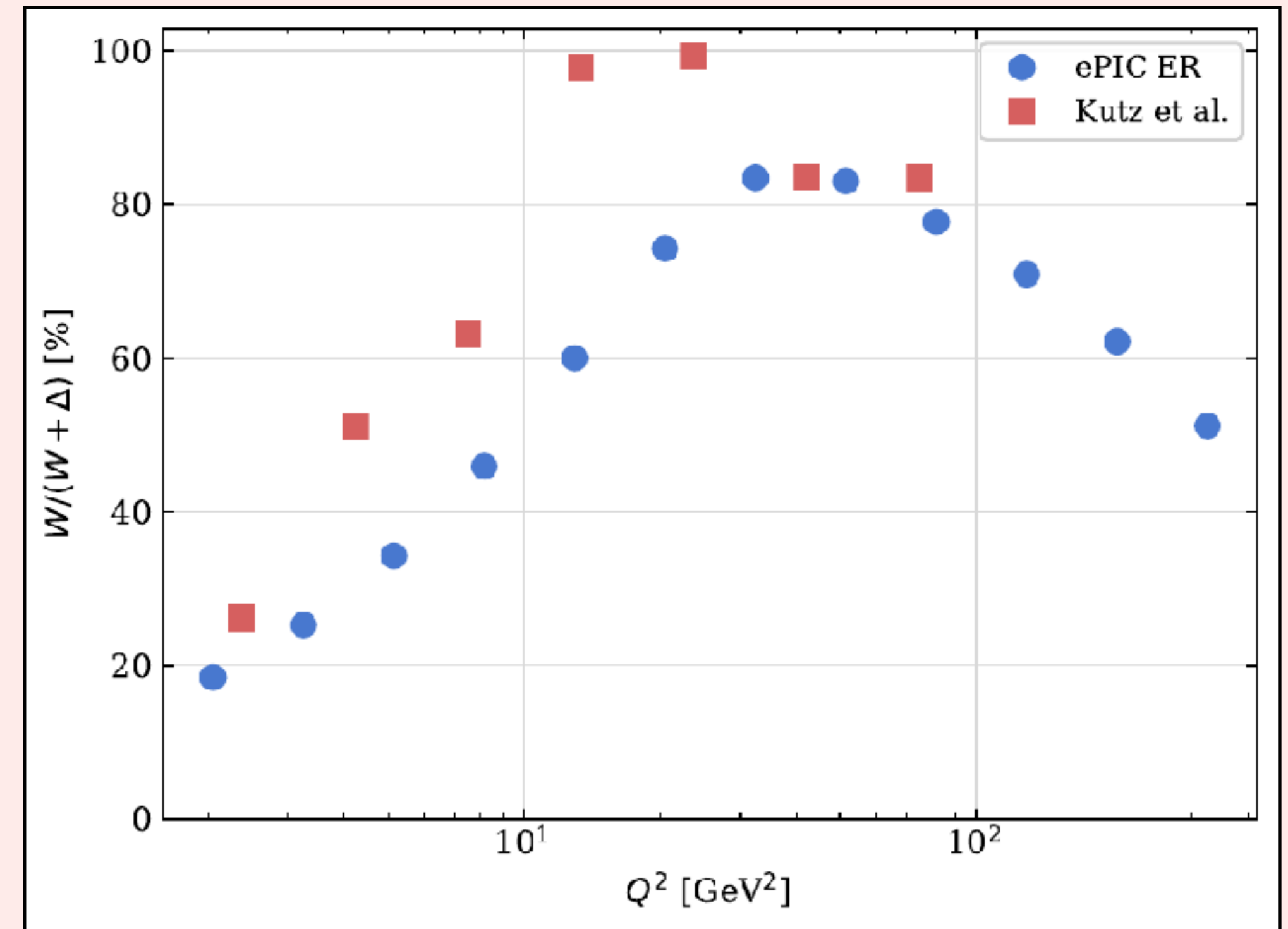
unmeasured low x measured region unmeasured high x

Kutz et al.

- M from ECCE full EIC running projection
- H from parameterizations of existing data
- L from N^4 LO Bjorken prediction at a reference α_s , by subtracting $M+H$; its uncertainty is estimated separately

New fit

- M from ePIC early running simulation
- $\Delta = L + H$ supplied by JAM replica ensemble, constrained by the JAM global analysis



New fit

- Build covariance matrix for data fluctuation

$$C_{\text{total}} = C_{\text{ePIC}} + C_{\text{completion}}$$

$$C_{\text{ePIC}} = \text{diag}(d_{\text{uncorr}}^2) + d_{\text{corr}} d_{\text{corr}}^T \text{ from } A_{\parallel} \text{ simulation}$$

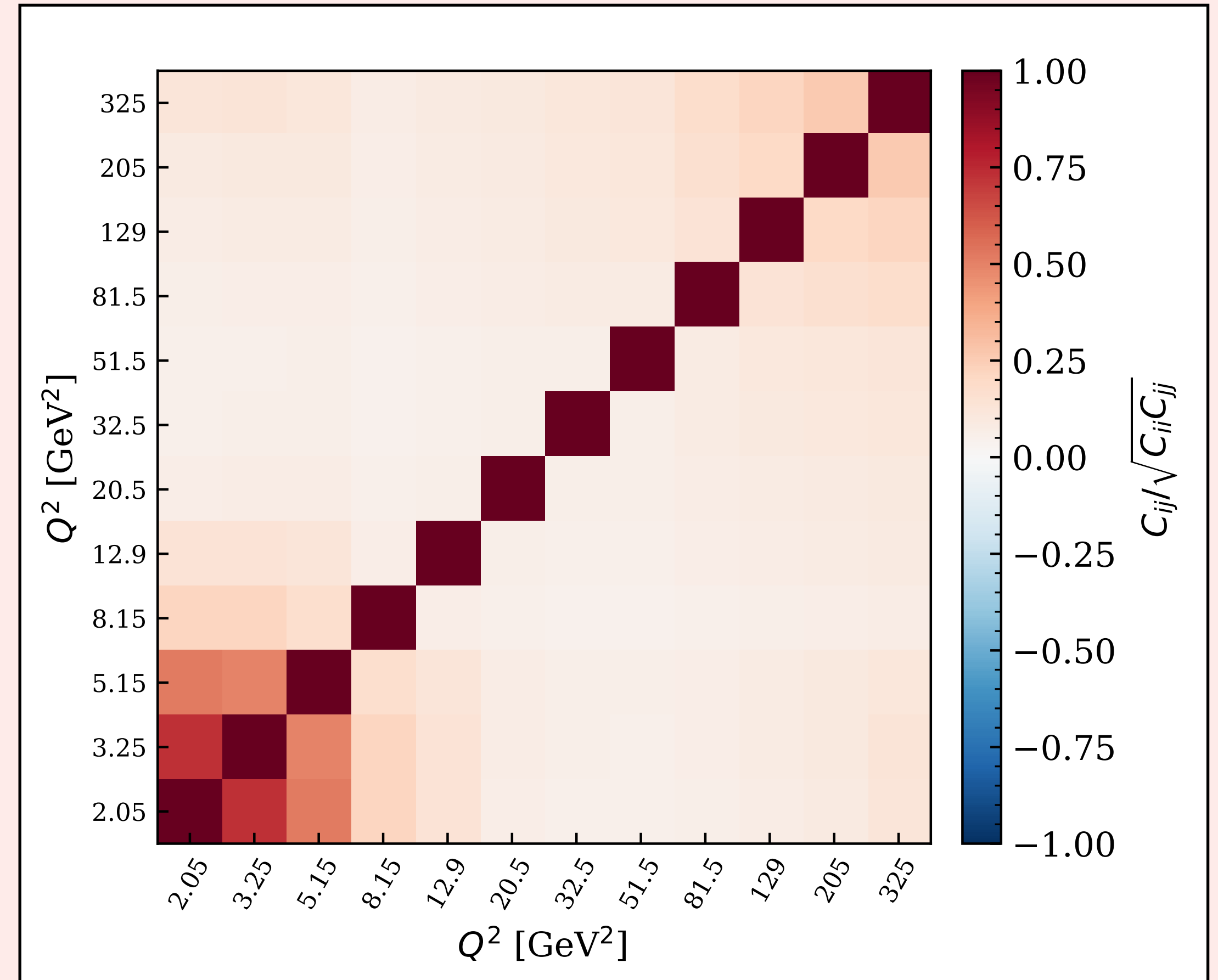
$$C_{\text{completion},ij} = \text{cov}_r \left(\Delta_r(Q_i^2), \Delta_r(Q_j^2) \right) \text{ from replica spread}$$

- Renormalization scale & HT uncertainty are examined later

Kutz et al.

- separate the projected uncertainty into several pieces:
 - Exp. uncorrelated unc. on the projected moments
 - beam-polarization uncertainty from pseudo experiments
 - low x and parameterization uncertainties
 - perturbative truncation uncertainty from the N⁴LO to N⁵LO shift
 - neglect higher-twist effects

Correlation matrix of the total projected $\Gamma_1^{p-n}(Q^2)$ covariance



$$C_{ij} = \delta_{ij} d_{\text{uncorr},i}^2 + d_{\text{corr},i} d_{\text{corr},j} + C_{\text{completion},ij}$$

- N⁴LO Bjorken coefficient function and five-loop QCD running with heavy-quark threshold crossings for the coupling
- Kutz et al.: fit Λ_s , convert to $\alpha_s(M_Z)$, neglect HT in the nominal high Q^2 fit
- New fit: fit $\alpha_s(M_Z)$ directly, include the JAM completion response, and test non-LT effects because the fit extends to lower Q^2

$$\alpha_s(M_Z), g_A \longrightarrow \alpha_s(Q_i^2) \longrightarrow \Gamma_{i,\text{LT}}^{p-n} \longrightarrow \Gamma_{i,\text{pred}} \longrightarrow \chi^2$$

For each trial $\alpha_s(M_Z), g_A$, run the coupling to every Q_i^2 bin

↓

Calculate N⁴LO Bjorken prediction, $\Gamma_{i,\text{LT}}^{p-n} = \frac{g_A}{6} C_{\text{ns}}(\alpha_s(Q_i^2))$

↓

Add JAM completion response, $\Gamma_{i,\text{pred}} = \Gamma_{i,\text{LT}}^{p-n} + s_i [\alpha_s(M_Z) - 0.118]$

$s_i = \frac{d\bar{\Delta}_i}{d\alpha_s(M_Z)}$ slope from JAM refits at five different $\alpha_s(M_Z)$

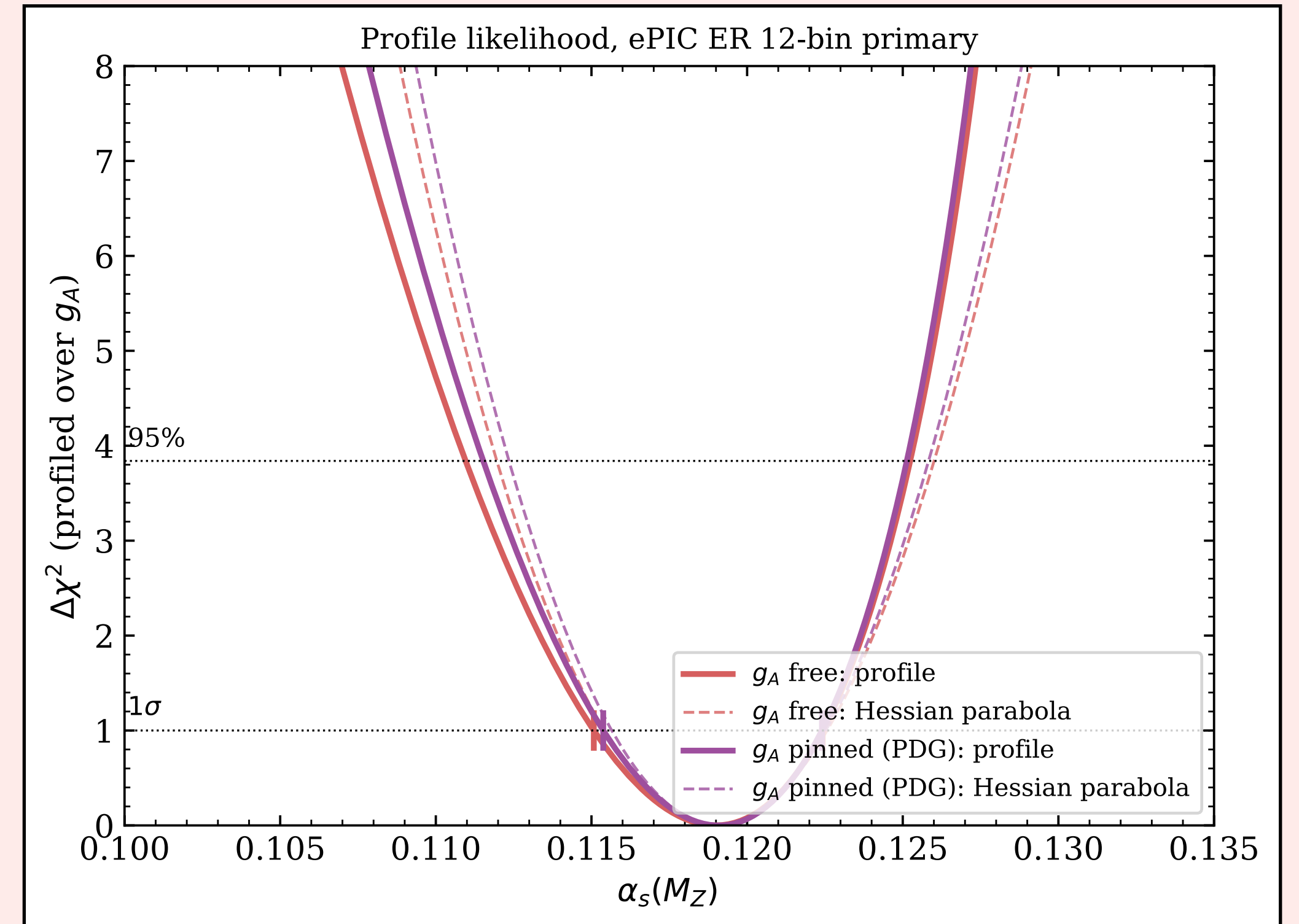
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compare prediction with projection point using the full covariance matrix,

$$\chi^2 = (\Gamma_{\text{data}} - \Gamma_{\text{pred}})^T C^{-1} (\Gamma_{\text{data}} - \Gamma_{\text{pred}})$$

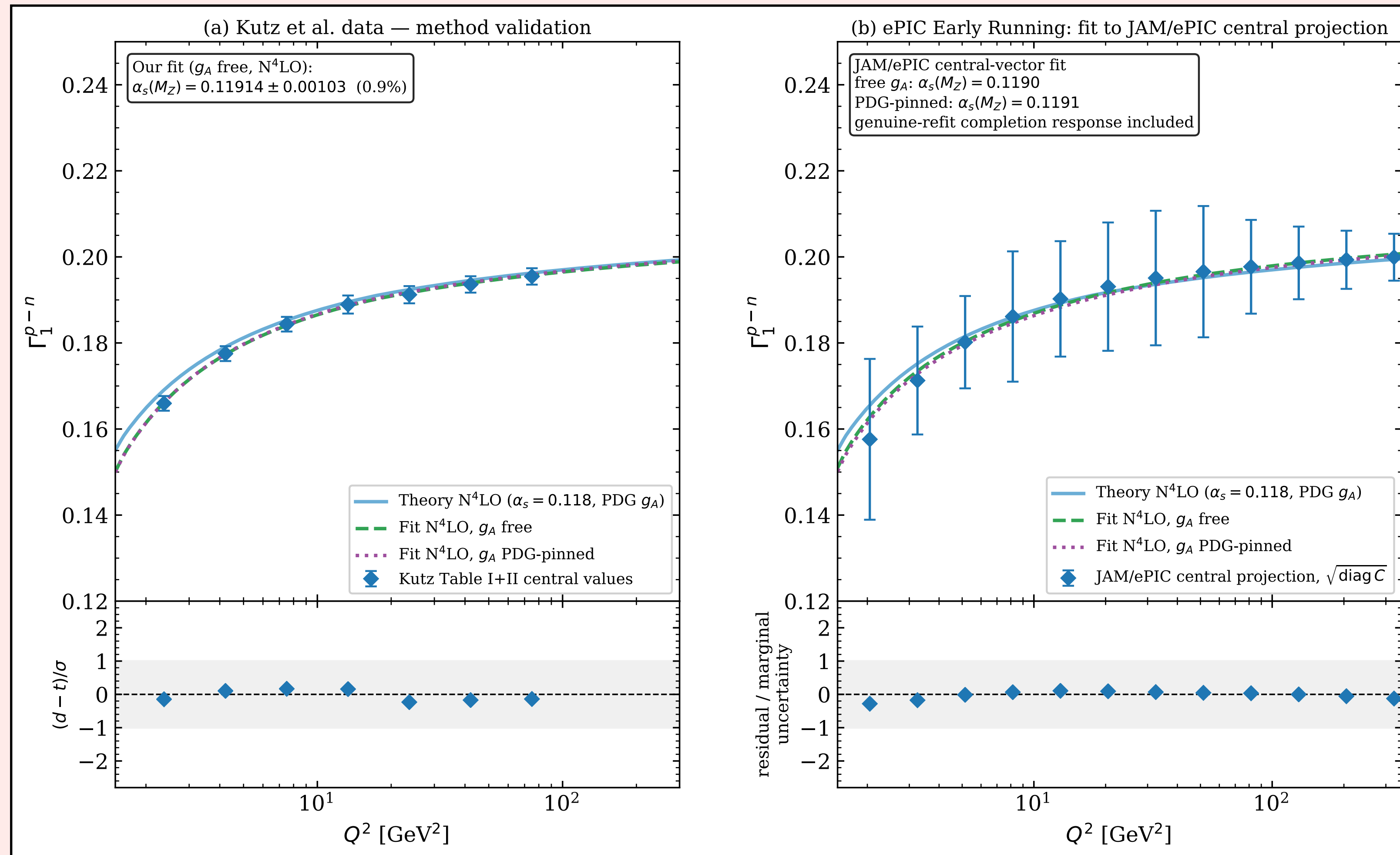
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Minimize χ^2 and determine uncertainties from profile of $\alpha_s(M_Z)$



Fits to projected central moments

- ▶ N⁴LO Bjorken coefficient function and five-loop QCD running with heavy-quark threshold crossings for the coupling
- ▶ Kutz et al.: fit Λ_s , convert to $\alpha_s(M_Z)$, neglect HT in the nominal high Q^2 fit
- ▶ New fit: fit $\alpha_s(M_Z)$ directly, include the JAM completion response, and test non-LT effects because the fit extends to lower Q^2



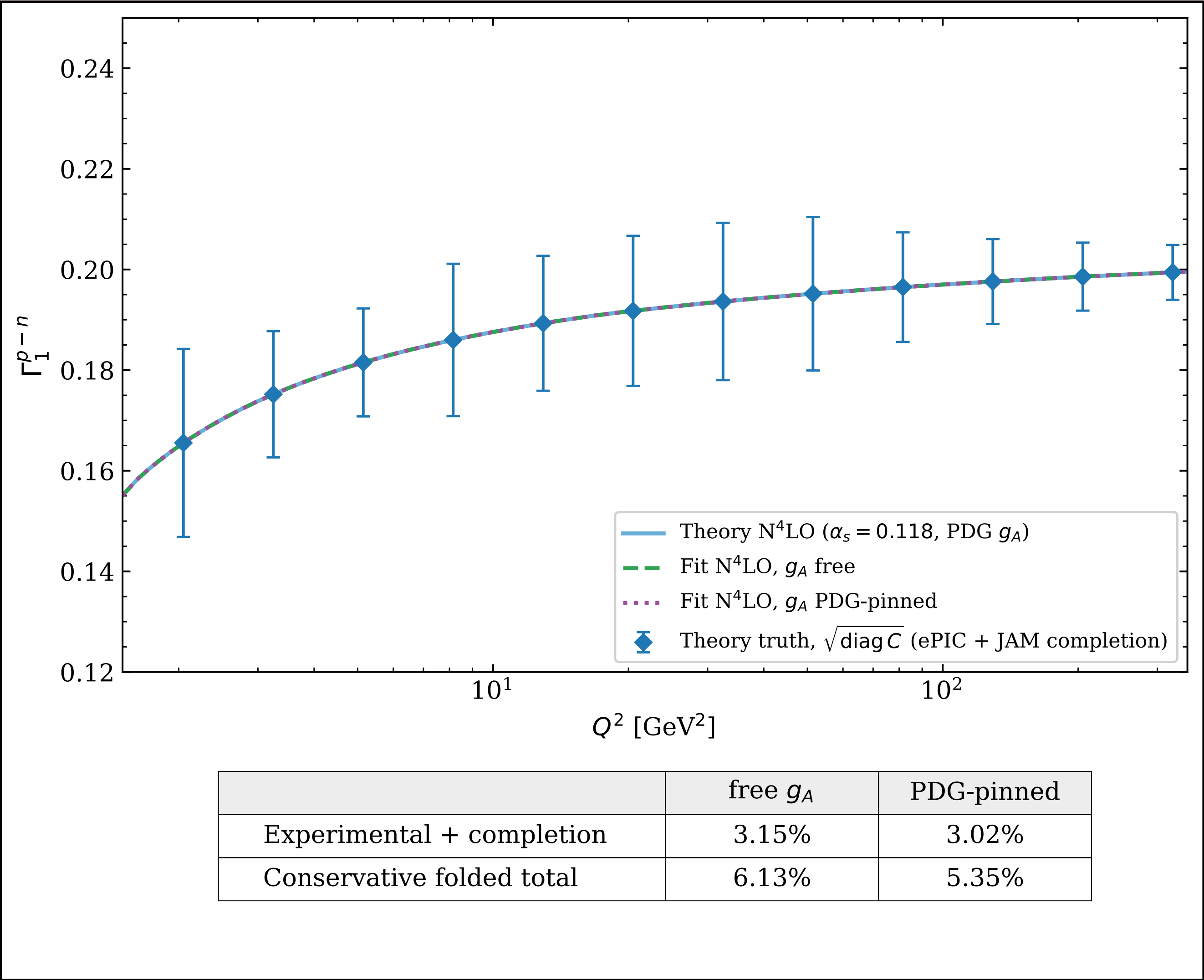
- ▶ Point centers are generated from $\alpha_s(M_Z) = 0.118$,
 $g_A = 1.2762$
- ▶ Same covariance $C = C_{\text{ePIC}} + C_{\text{completion}}$
- ▶ $\Gamma_{i,\text{pred}} = \Gamma_{i,\text{BjSR}}(\alpha_s, g_A) + s_i [\alpha_s(M_Z) - 0.118]$

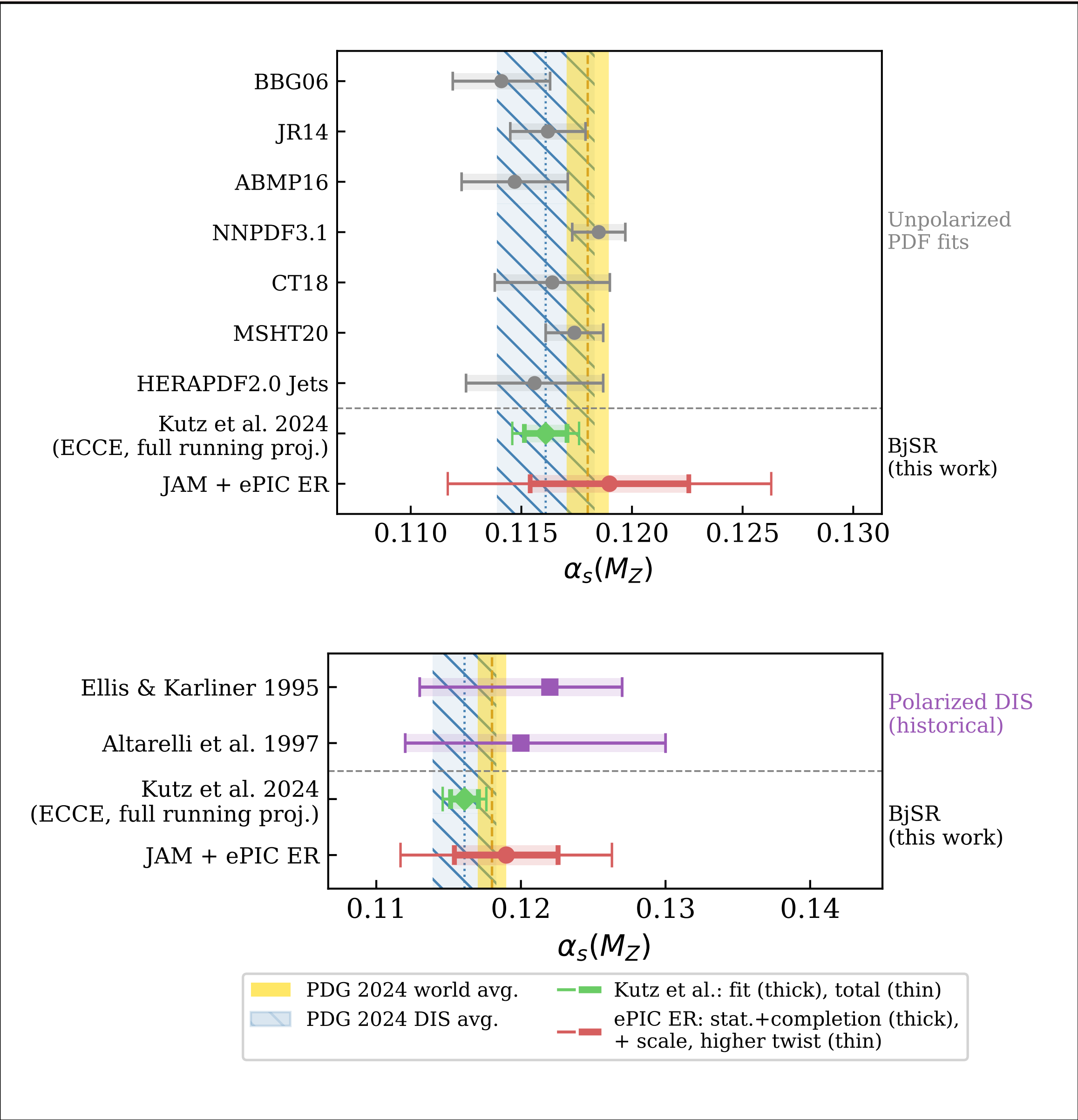
The analysis repeats the fit under:

- ▶ renormalization-scale variations $Q^2/2$ and $2Q^2$
- ▶ higher-twist/non-LT variations based on the full-minus-LT JAM moment

Folded total conservative uncertainty:

$$\sigma_{\text{total}} = \sqrt{\sigma_{\text{Hessian}}^2 + \sigma_{\text{scale}}^2 + \sigma_{\text{HT}}^2}$$





	free g_A	PDG-pinned
Experimental + completion	3.15%	3.02%
Conservative folded total	6.13%	5.35%

- ▶ Result reflects projected α_s precision with JAM model and ePIC early running data
- ▶ Projected precision improves on historical polarized DIS Bjorken extractions
- ▶ Early running data along might not be competitive with existing world data
- ▶ Will repeat study for full running scenario, which should produce more competitive result as indicated by Kutz et al.