arXiv:2307.01183[hep-ph]

Extraction of the strong coupling with HERA and EIC inclusive data

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ePIC Collaboration Meeting 2023

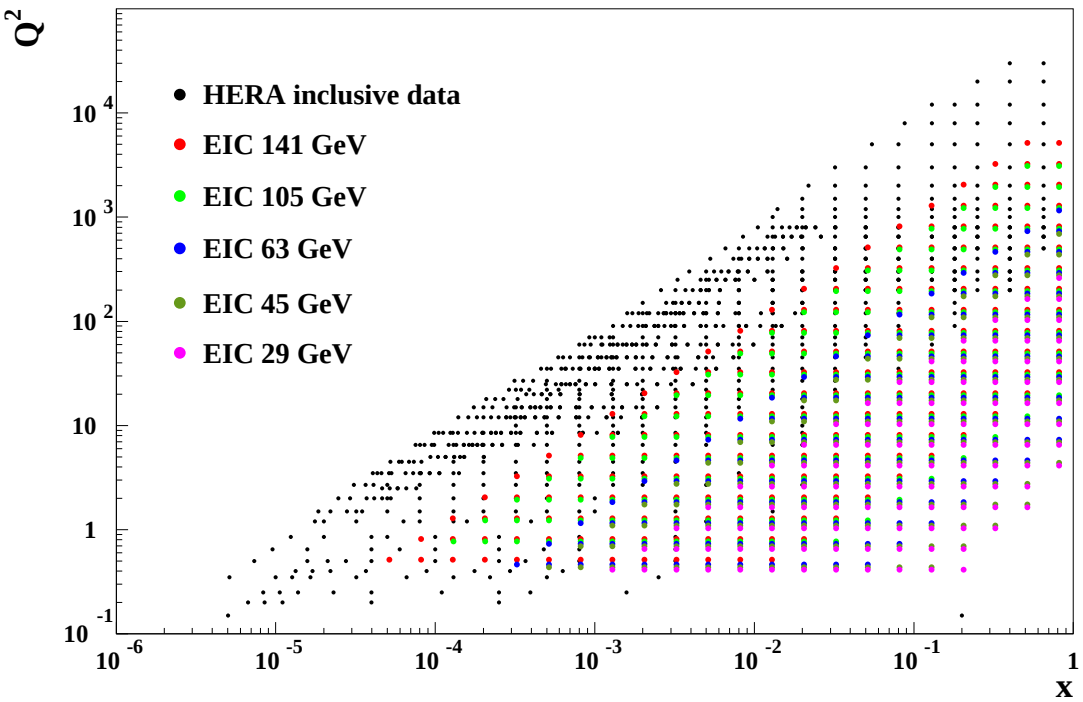
28 Jul, 2023

Motivation

- Physics scopes of HERA and EIC differ but have significant overlap.
  - Inclusive DIS cross sections will be measured to high precision in a phase space region that will be complementary to HERA.
- The strong coupling, α_s, is the least well constrained.
  - Essential ingredient of SM cross section calculations, as well as constraints on new physics and grand unification scenarios.
- Inclusive DIS cross section is sensitive to α_s through F_2 and F_L.

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[Y_+F_2(x,Q^2) - y^2F_L(x,Q^2) \mp Y_-xF_3(x,Q^2)]$$

HERA and EIC kinematic phase-space



Analysis Method

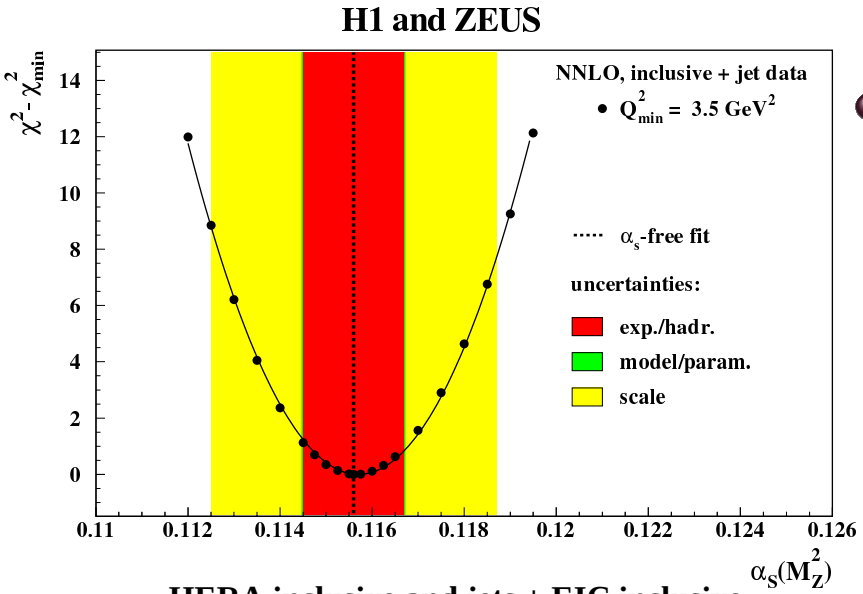
- Final combined H1 and ZEUS inclusive DIS NC and CC cross sections
  - $\sqrt{s} = 320, 300, 251, 225$ GeV
  - Total integrated luminosity: 1fb^{-1}
  - NC: $0.045 \leq Q^2 \leq 50000$ GeV^2, $6{\cdot}10^{-7} \leq x_{B_j} \leq 0.65$, $0.005 \leq y \leq 0.95$
  - CC: $200 \leq Q^2 \leq 50000$ GeV^2, $1.3{\cdot}10^{-2} \leq x_{B_j} \leq 0.40$, $0.037 \leq y \leq 0.76$
- EIC pseudodata are produced by considering the studies performed in the ATHENA framework.
  - NC pseudodata are produced for five different CMEs. $0.001 < y < 0.95$, $Q^2 > 1$ GeV^2

e-beam energy (GeV)	p-beam energy (GeV)	$\sqrt{s}$ (GeV)	Integrated lumi (fb^{-1})
18	275	141	15.4
10	275	105	100
10	100	63	79.0
5	100	45	61.0
5	41	29	4.4

  - CC pseudodata are produced for only $\sqrt{s}$ = 141 GeV.
- Based on the QCD fit → the HERAPDF theoretical framework, PDF parameterisations and model parameter choices.
- Used HERAPDF20_NNLO_ALPHAS_116 LHAPDF set.
- The `xFitter` framework is used.

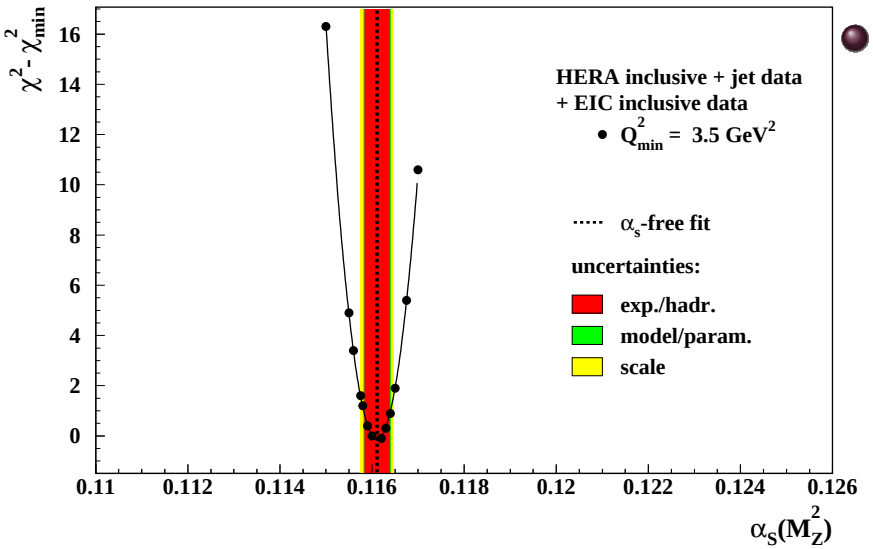
QCD fits with EIC inclusive and HERA inclusive+jet data

- A simultaneous NNLO fit is performed to extract the PDFs and $\alpha_s(M_Z^2)$ from HERA inclusive and jet data and EIC inclusive data.



- **HERA inclusive + jet data, NNLO:** (EPJC82(2022)243)

$$\alpha_s(M_Z^2) = 0.1156 \pm 0.0011\ (\text{exp})\ ^{+0.0001}_{-0.0002}\ (\text{model} + \text{param}) \pm 0.0029\ (\text{scale})$$

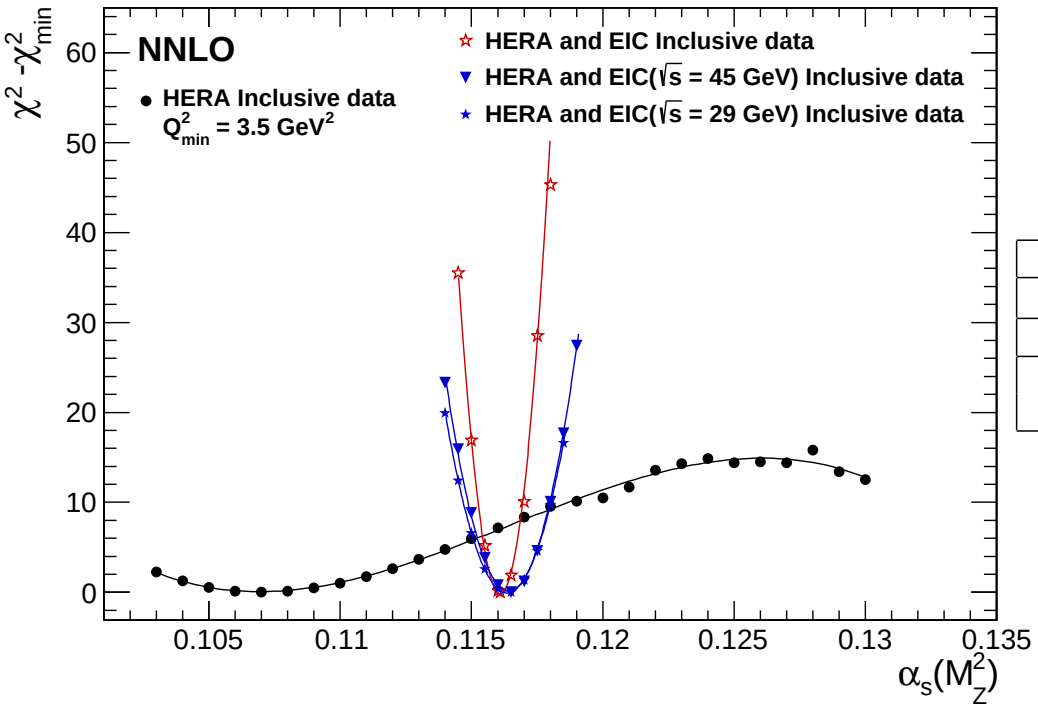


- **EIC inclusive data and HERA inclusive + jet data, NNLO:**

$$\alpha_s(M_Z^2) = 0.1161 \pm 0.0003\ (\text{exp})\ \pm 0.0001(\text{model} + \text{param})\ ^{+0.0002}_{-0.0001}\ (\text{scale})$$

QCD fits with HERA and EIC inclusive data only

- A simultaneous NNLO fit is performed to extract the PDFs and $\alpha_s(M_Z^2)$ from HERA and EIC inclusive data.



Central values of model input parameters and their one-sigma variations.

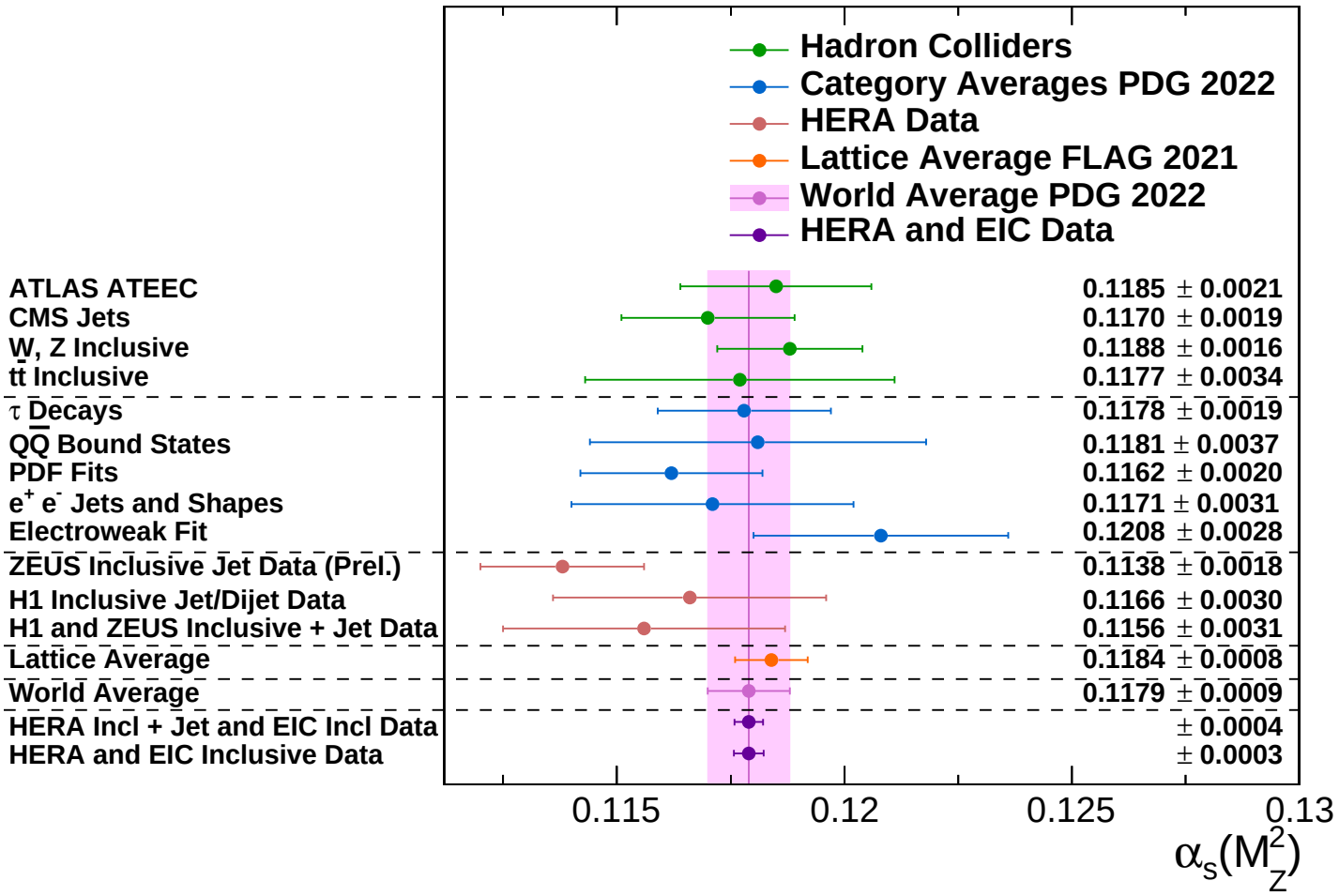
Parameter		Central val.	Downwards var.	Upwards var.
Q^2_{min}	[GeV^2]	3.5	2.5	5.0
f_s		0.4	0.3	0.5
M_c	[GeV]	1.41	1.37	1.45
M_b	[GeV]	4.20	4.10	4.30

No scale variations are made for the inclusive data

- **EIC and HERA inclusive data, NNLO:**

$$\alpha_s(M_Z^2) = 0.1161 \pm 0.0003\ (\mathrm{exp})\ \ \pm 0.0001\ (\mathrm{model + param})$$

Comparison to other $\alpha_s(M_Z^2)$ results



- With using only inclusive DIS data from HERA and EIC, we are able to determine the $\alpha_s(M_Z^2)$ with potentially world-leading precision in a simultaneous fit of PDFs and $\alpha_s(M_Z^2)$ at NNLO.

Conclusion

- The estimated total uncertainty on $\alpha_s(M_Z^2)$ when including EIC DIS pseudodata is better than 0.3% → Improves the precision of the present world experimental and lattice averages.
- We are working with global fitting experts to assign a meaningful scale uncertainty to our result, due to missing higher order contributions beyond NNLO in the theory.
- Adding inclusive jet and dijet EIC pseudodata to the QCD analysis can improve the $\alpha_s(M_Z^2)$ precision.

Acknowledgements

- We are very grateful to
  - many colleagues in the EIC experimental community for their immense effort in working on all aspects of the project over many years.
  - Néstor Armesto, Andrea Barontini, Thomas Cridge, Stefano Forte, Lucian Harland-Lang, Anna M. Staśto and Robert S. Thorne for their very valuable discussions about the theory uncertainties.
  - Valerio Bertone and Francesco Giuli for their help with the `APFEL` program.
  - Christopher Schwan for his help with the `PineAPPL` tool.

THANK YOU!

Backup

Fit settings for $\alpha_s(M_Z^2)$ fit

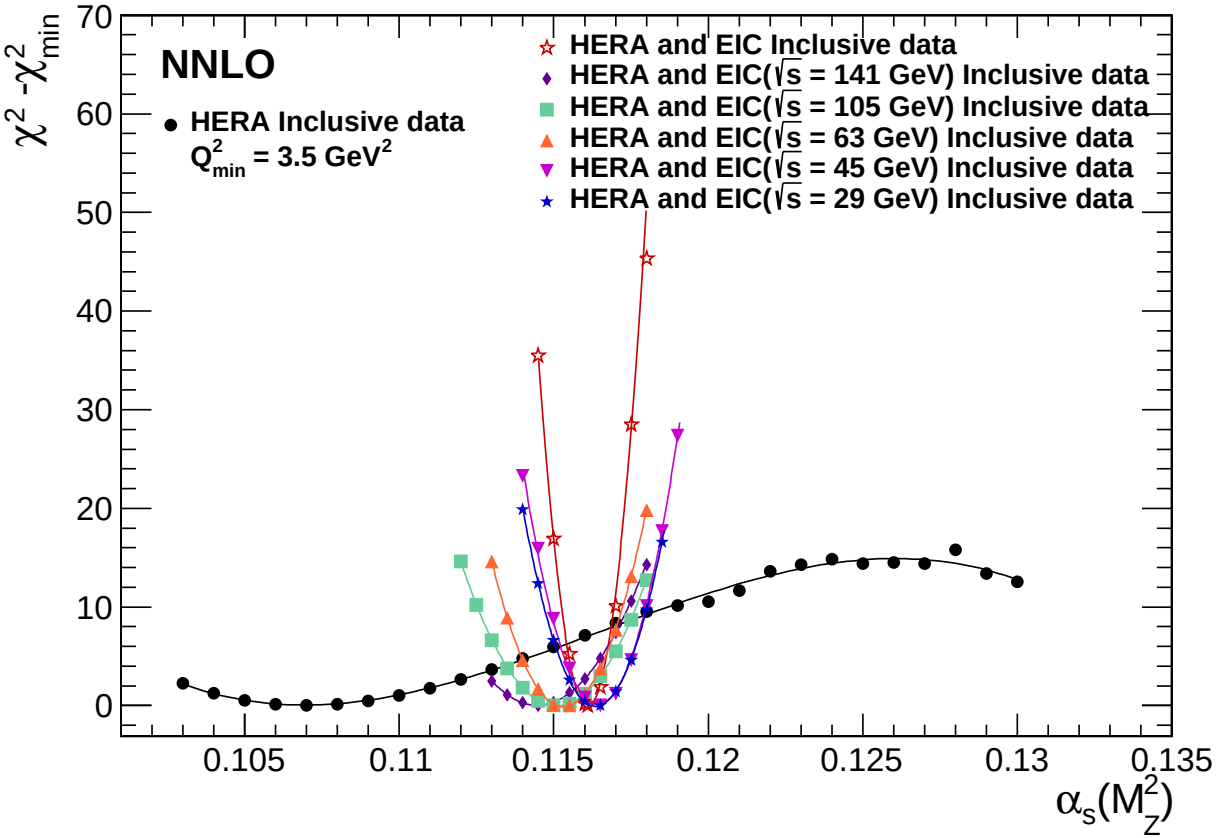
- The PDF parameterisation (following the HERAPDF2.0 approach):

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{25}; \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}\left(1+E_{u_v}x^2\right); \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}}; \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}}\left(1+D_{\bar{U}}x\right); \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}.
\end{aligned}
$$

- PDFs are parameterised at a starting scale for QCD evolution of $\mu_{f0} = 1.9$ GeV^2.
- Strangeness fraction: $f_s = x\bar{s}/(x\bar{d} + x\bar{s}) = 0.4$
- The theory settings and their variations:
  - Central scales: $\mu_r^2 = \mu_f^2 = Q^2$ for the inclusive DIS data, $\mu_r^2 = \mu_f^2 = Q^2 + p_T^2$ for inclusive jet data and $\mu_r^2 = \mu_f^2 = Q^2 + < p_T >_2^2$ for dijets.
  - Scale variations: μ_r, μ_f scales are varied up and down by a factor of 2.

QCD fits with HERA and EIC inclusive data only

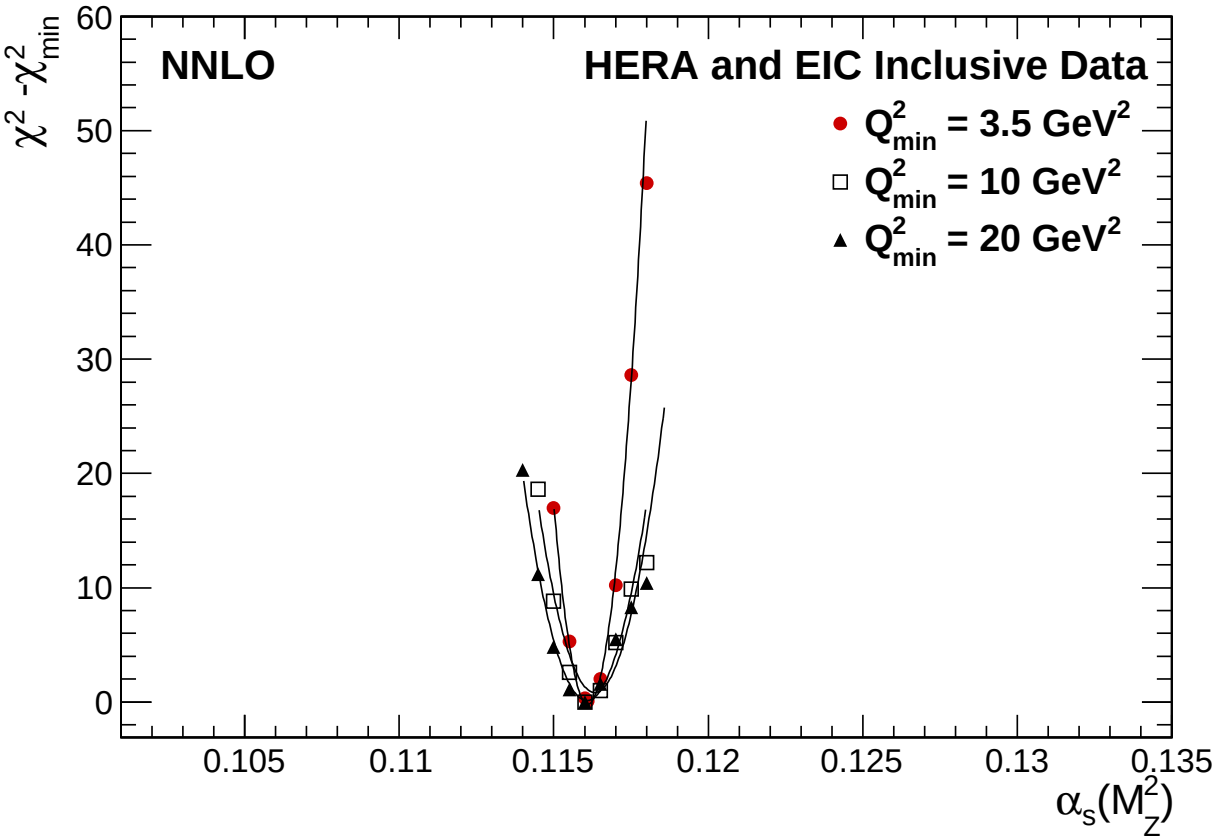
- A simultaneous NNLO fit is performed to extract the PDFs and $\alpha_s(M_Z^2)$ from HERA and EIC inclusive data.



$\Delta\chi^2 = \chi^2 - \chi^2_{min}$ vs. $\alpha_s(M_Z^2)$ for the NNLO fits to HERA data on inclusive ep scattering only (black), and also with the addition of simulated EIC inclusive data for all five $\sqrt{s}$ values together (red) or for only one $\sqrt{s}$ value.

Sensitivity to minimum Q^2 cut

- The analysis is repeated with the Q^2_{min} cut increased from 3.5 GeV^2 to 10 GeV^2 or 20 GeV^2.
- The distinct minima still observed, with only a small dependence on Q^2_{min} (below 0.1%).



$\Delta\chi^2 = \chi^2 - \chi^2_{min}$ vs. $\alpha_s(M_Z^2)$