“Grenoble bridge from HERA to EIC”
by W. Turner

K. Wichmann

Extraction of the strong coupling with HERA and EIC inclusive data

Salim Cerci[1], Zuhal Seyma Demiroglu[2,3], Abhay Deshpande[2,3,4], Paul R. Newman[5], Barak Schmookler[6], Deniz Sunar Cerci[1], Katarzyna Wichmann[7]

[1] *Adiyaman University, Faculty of Arts and Sciences, Department of Physics, Turkiye*
[2] *Center for Frontiers in Nuclear Science, Stony Brook University, NY 11764, USA*
[3] *Stony Brook University, Stony Brook, NY 11794-3800, USA*
[4] *Brookhaven National Laboratory, Upton, NY 11973-5000, USA*
[5] *School of Physics and Astronomy, University of Birmingham, UK*
[6] *University of California, Riverside, Department of Physics and Astronomy, CA 92521, USA*
[7] *Deutsches Elektronen–Synchrotron DESY, Germany*

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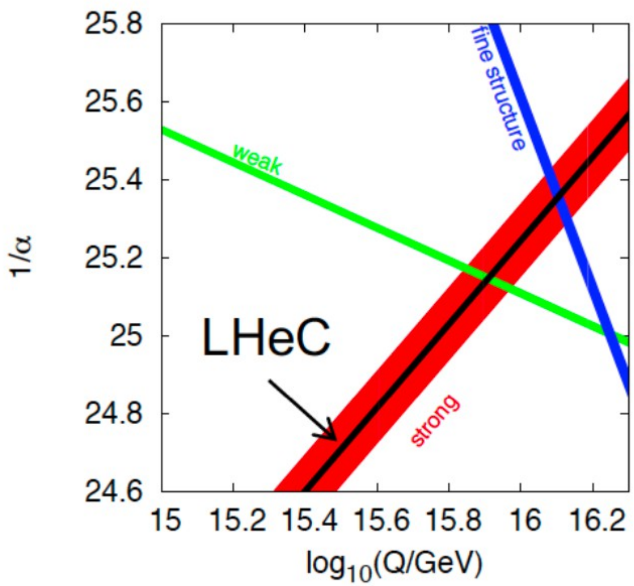
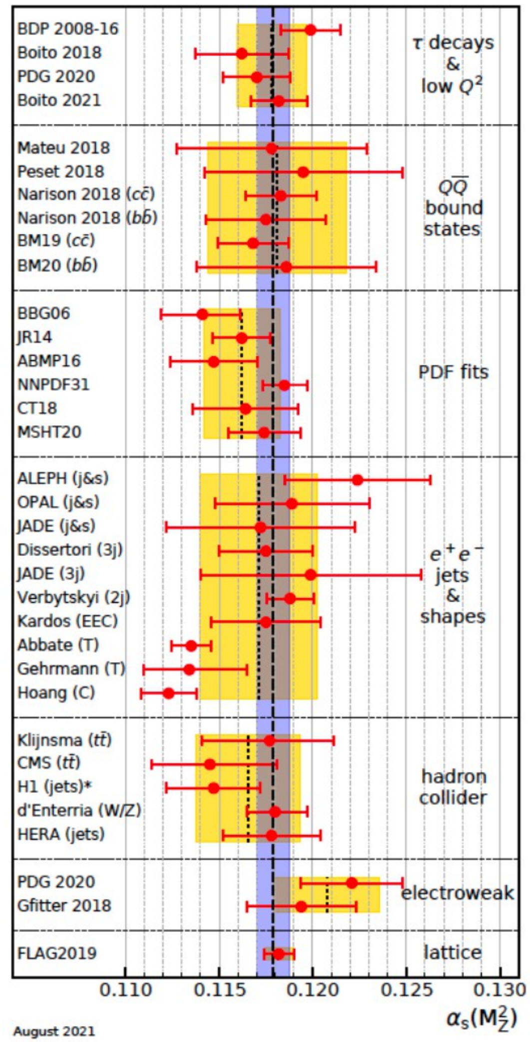
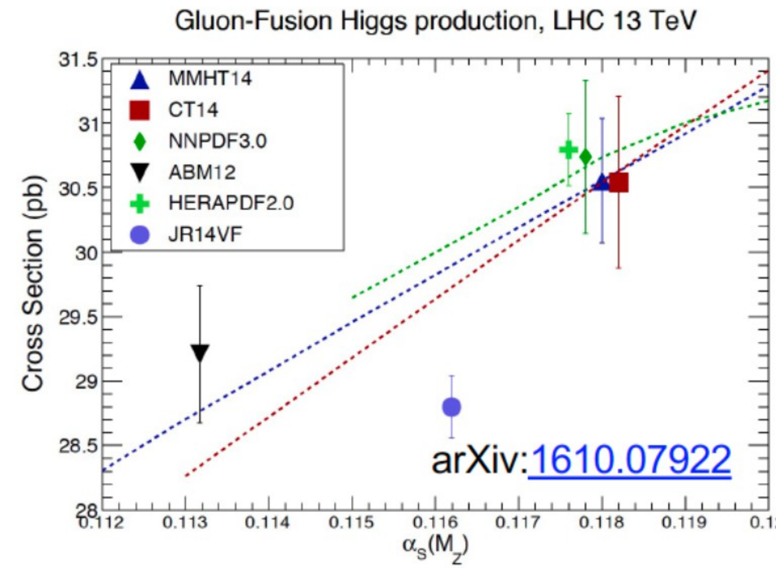
Why look at α_s?





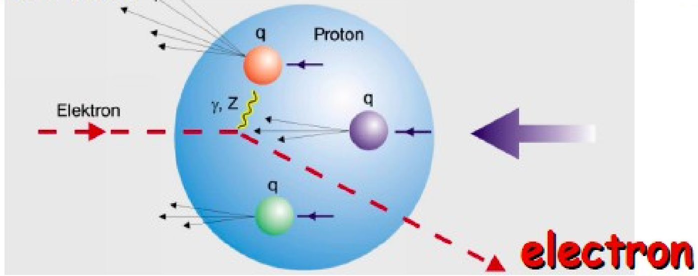


- **αs** is least known coupling constant;
  needed to constrain GUT scenarios; cross section predictions, including Higgs;
  …

PDG21: αs = 0.1175 ± 0.0010 (w/o lattice)

- **PDFs** and/or **αs** limit:
  precision SM and Higgs measurements, BSM searches, …

- what is true **αs** central value and uncertainty?
  new precise determinations have important role to play

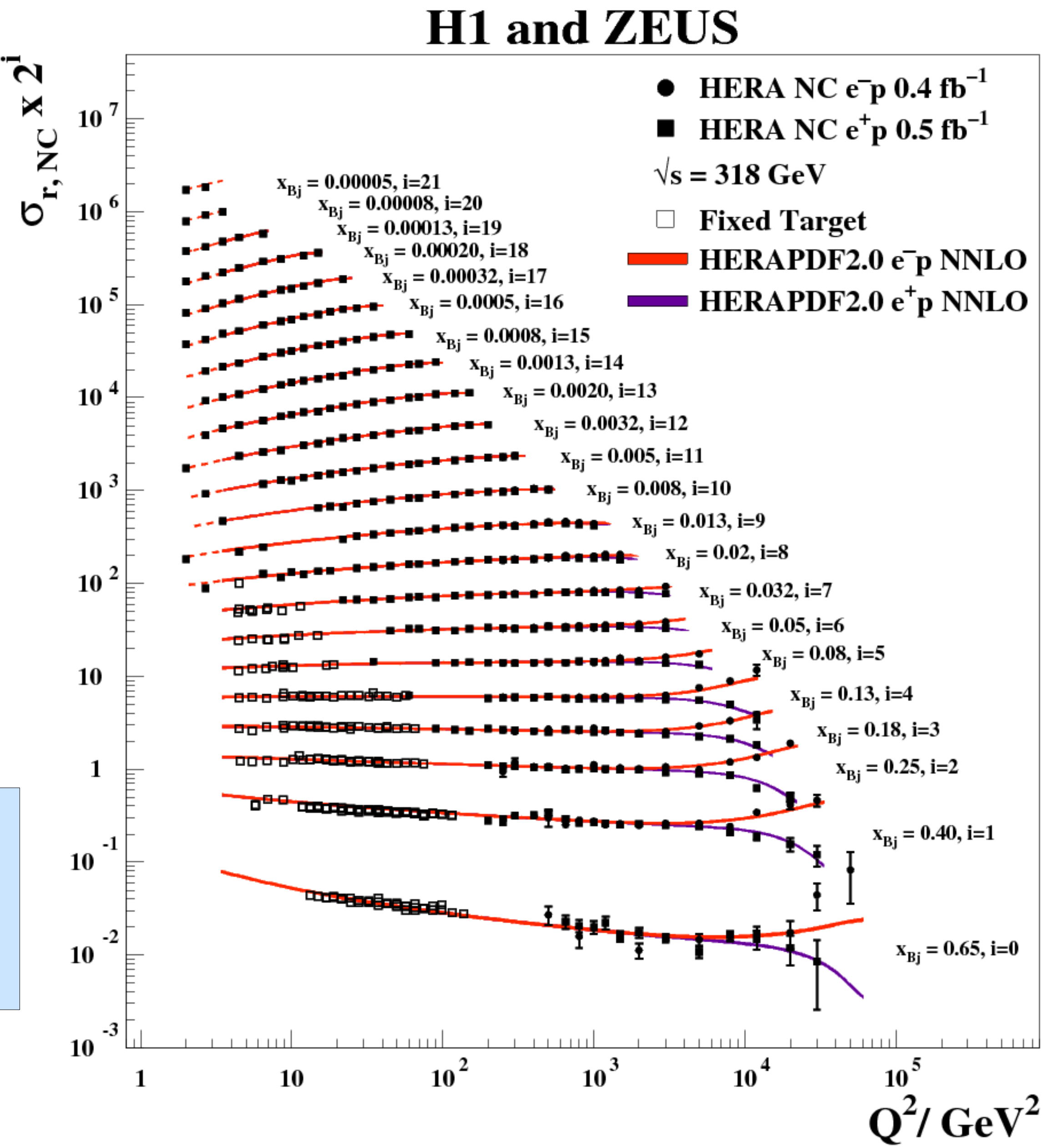


HERA combined inclusive DIS

HERA DIS is core of every PDF extraction

 HERAPDF philosophy

HERAPDF approach uses only HERA data in global QCD fit



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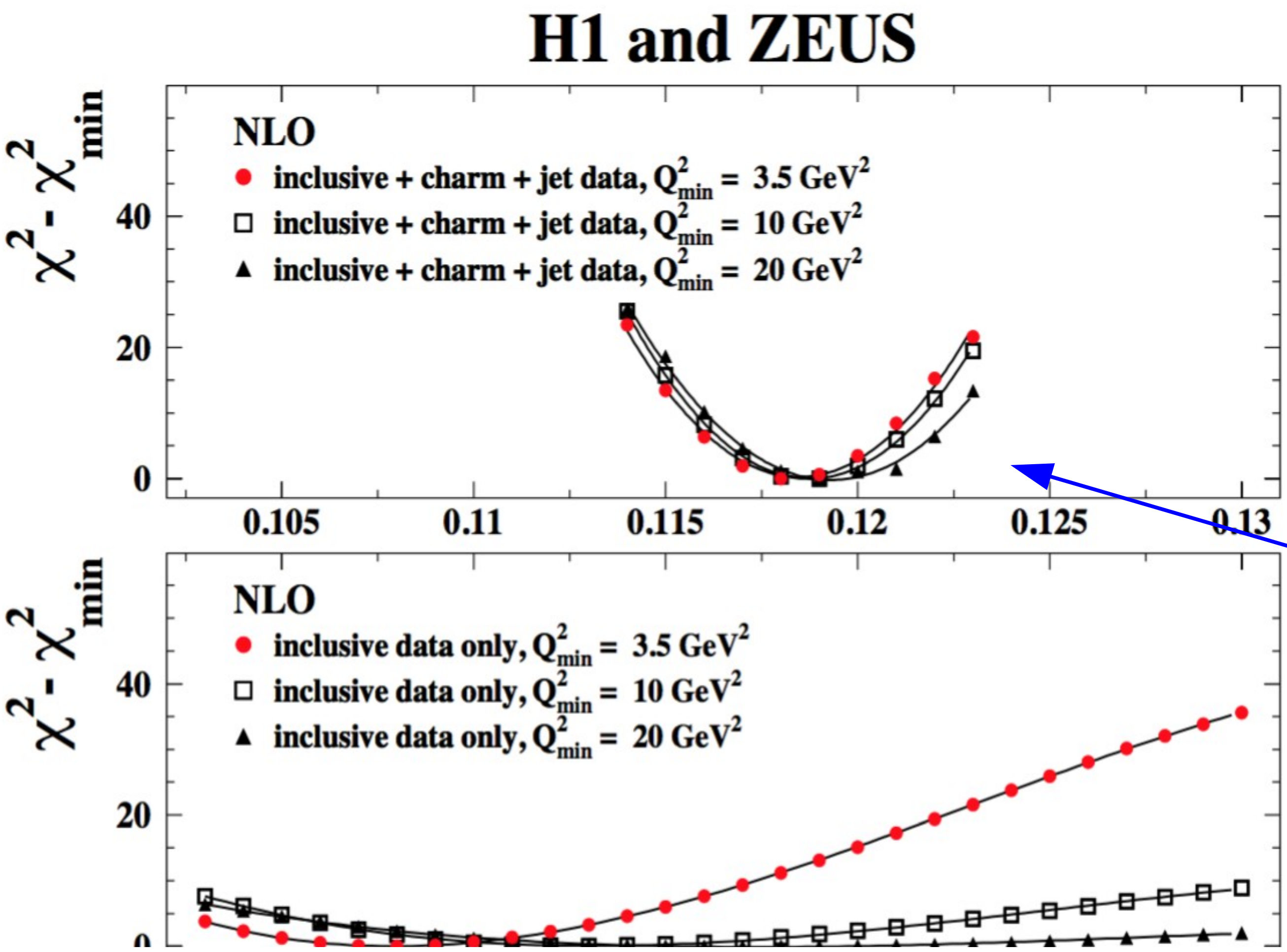
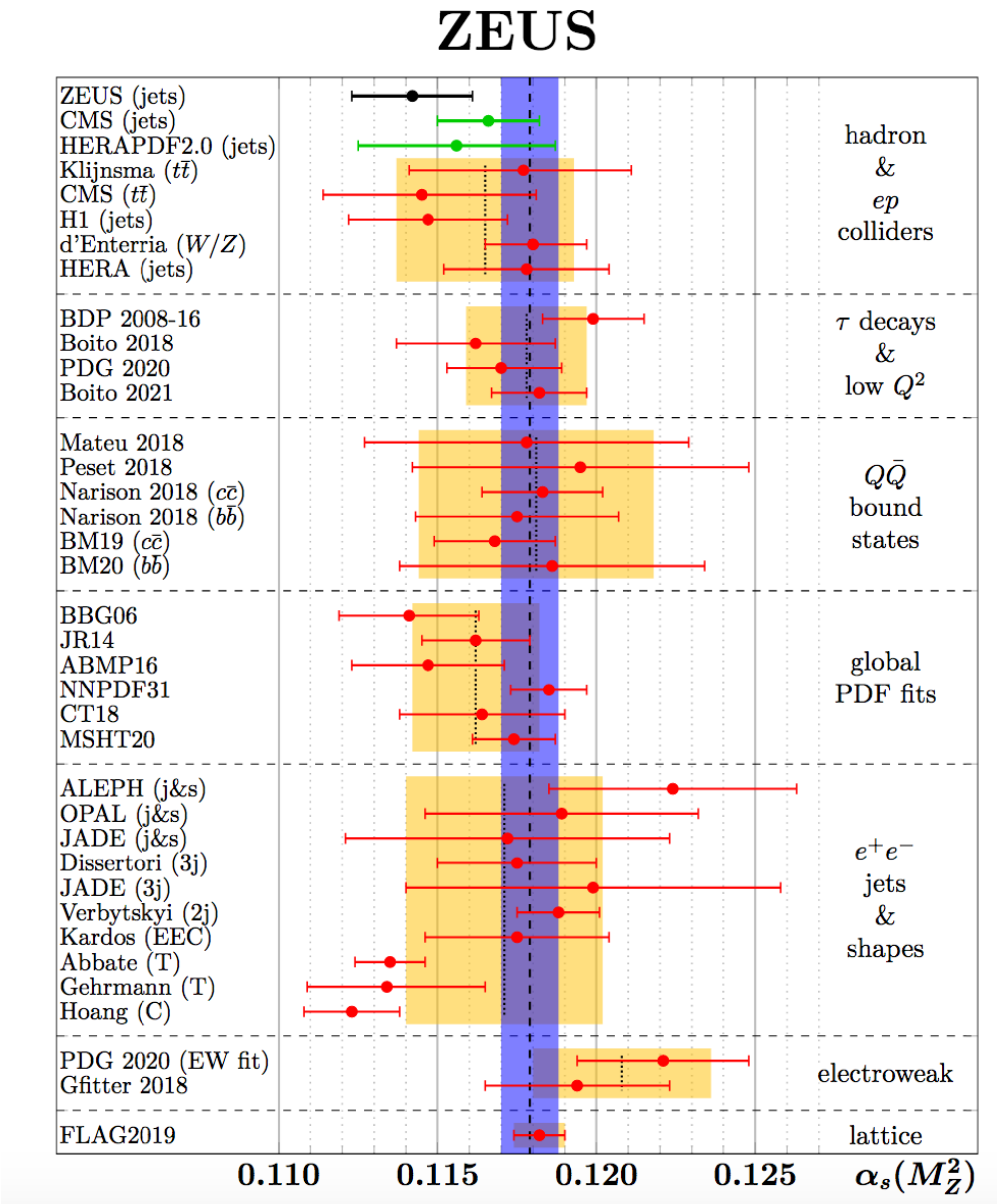
Is DIS @ HERA enough for α_s estimation?

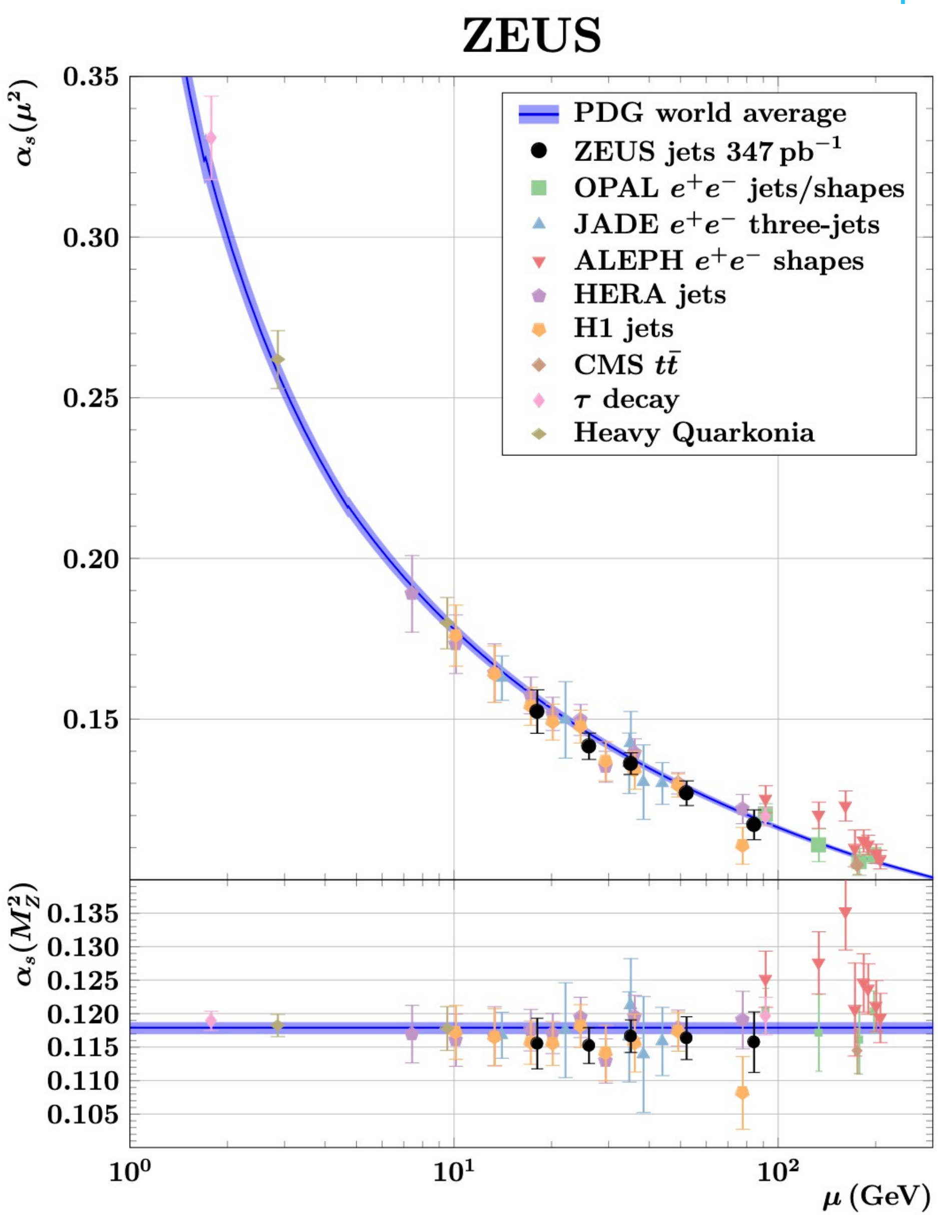


- HERA inclusive data carry little information on $\alpha_s(M_Z)$
- Jet data sensitive to $\alpha_s(M_Z)$
   adding jets meands large theory scale uncertainties

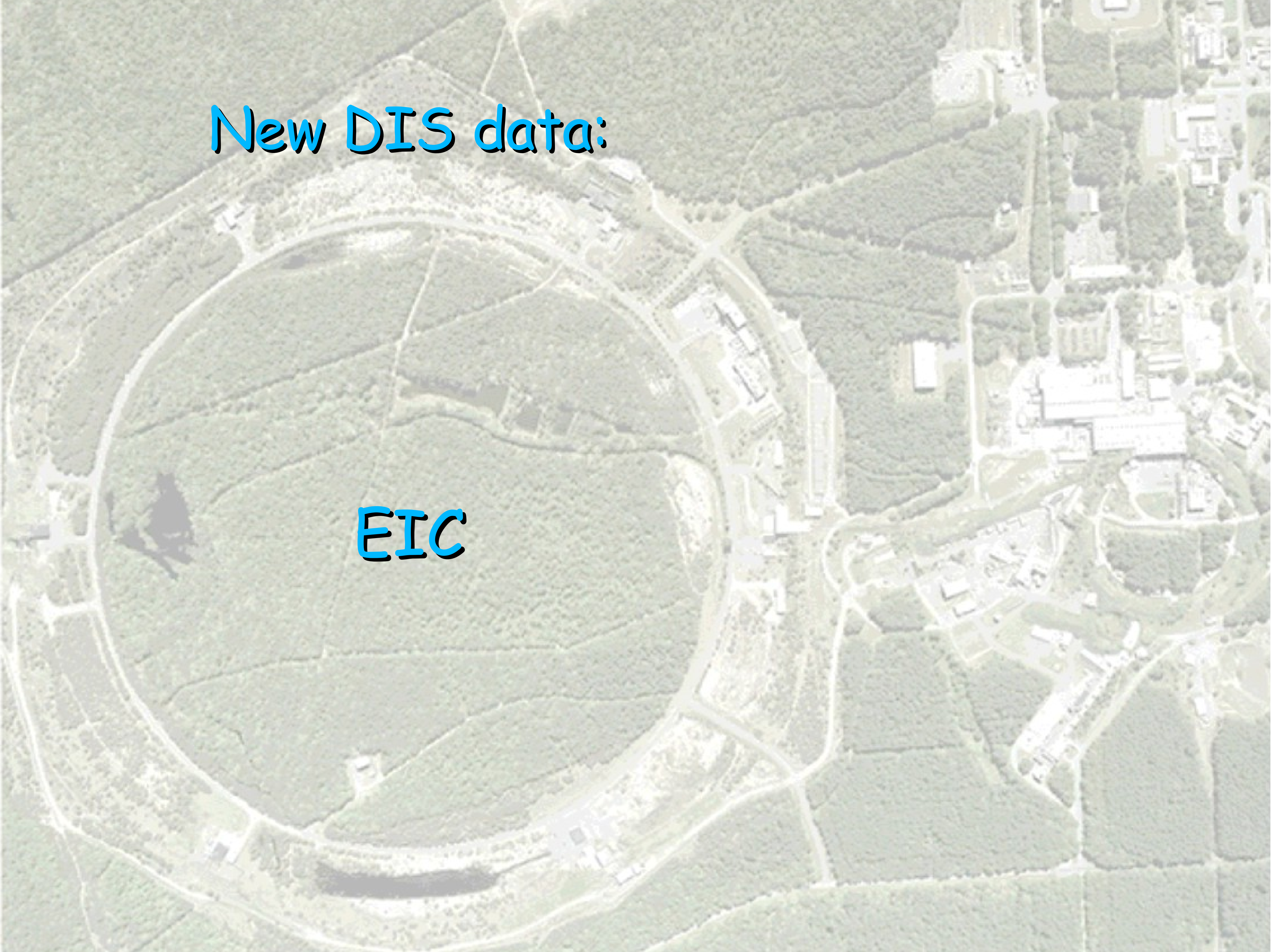
 Possible simultaneous determination of PDFs and $\alpha_s(M_Z)$ at NNLO

Recent examples from HERA



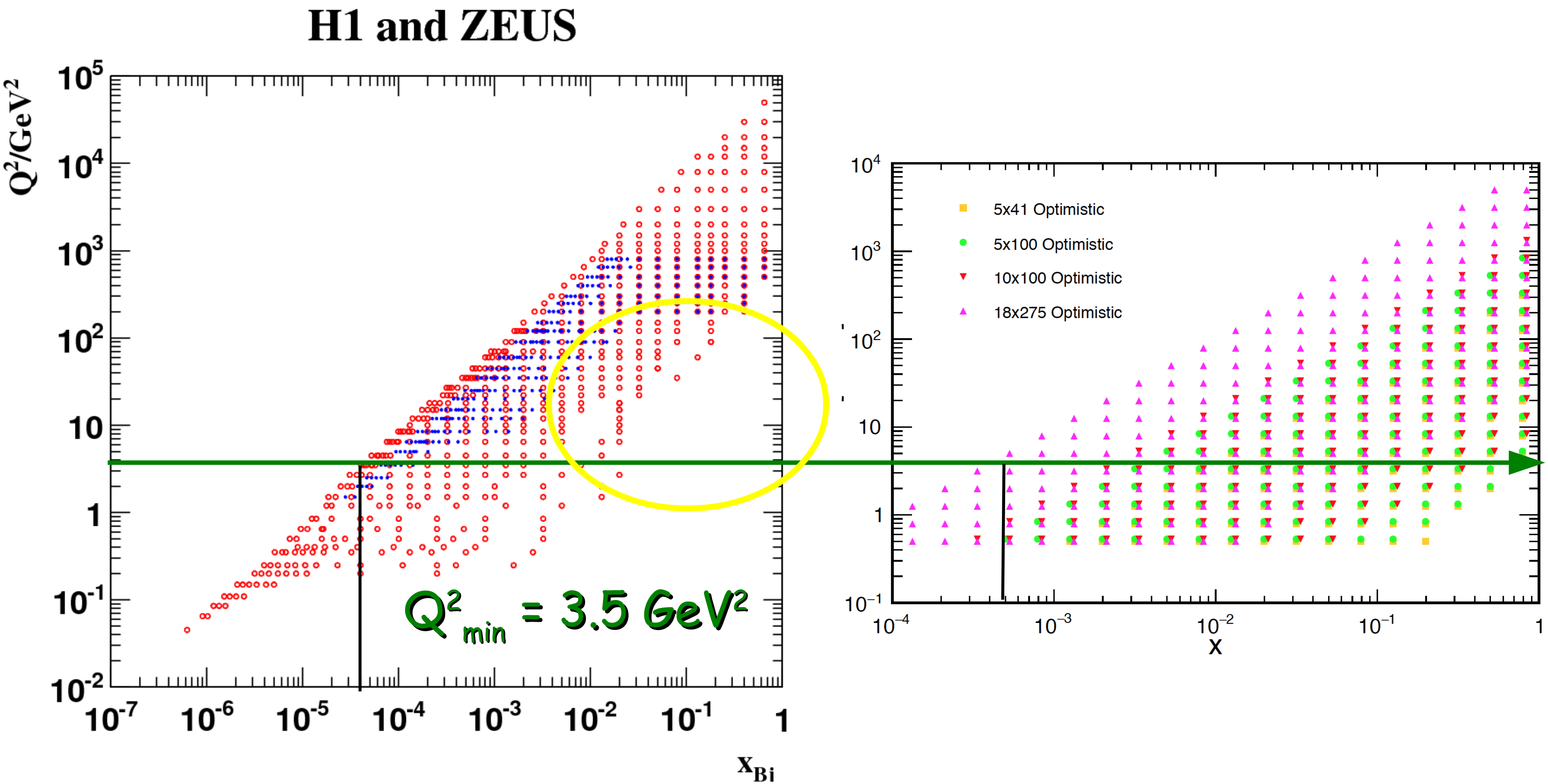


New DIS data:



EIC

HERA & ATHENA phase-space



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

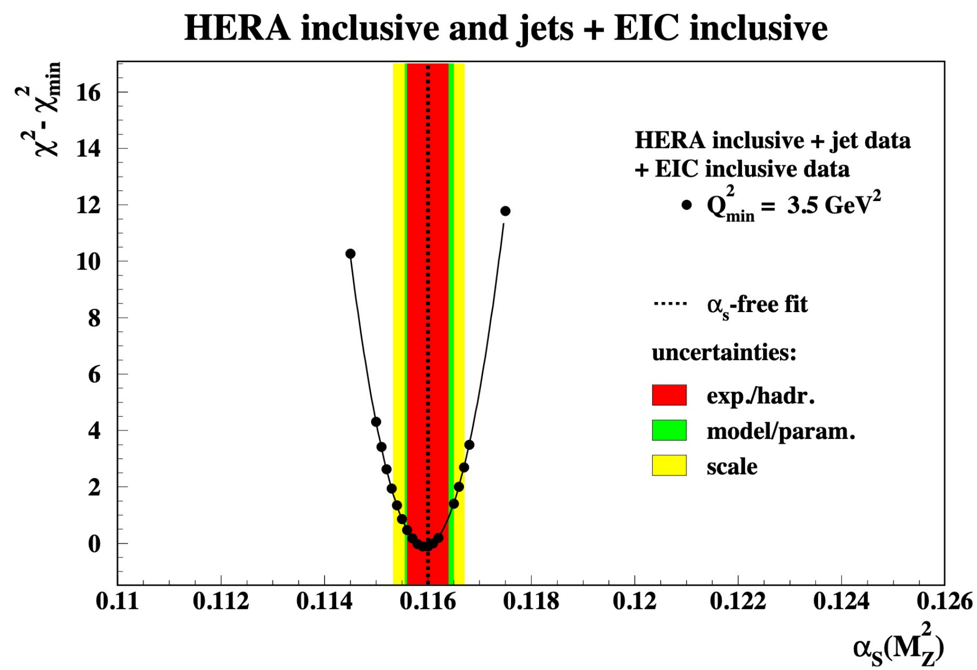
NNLO QCD analysis details

- EIC pseudo-data created using HERAPDF2NNLO with $\alpha_s(M_Z) = 0.116$
- HERAPDF procedure used
- Cuts
  - $Q^2 > 3.5$ GeV^2
  - $W^2 = Q^2(1-x)/x > 10$ GeV
  - $0.001 < y < 0.95$

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

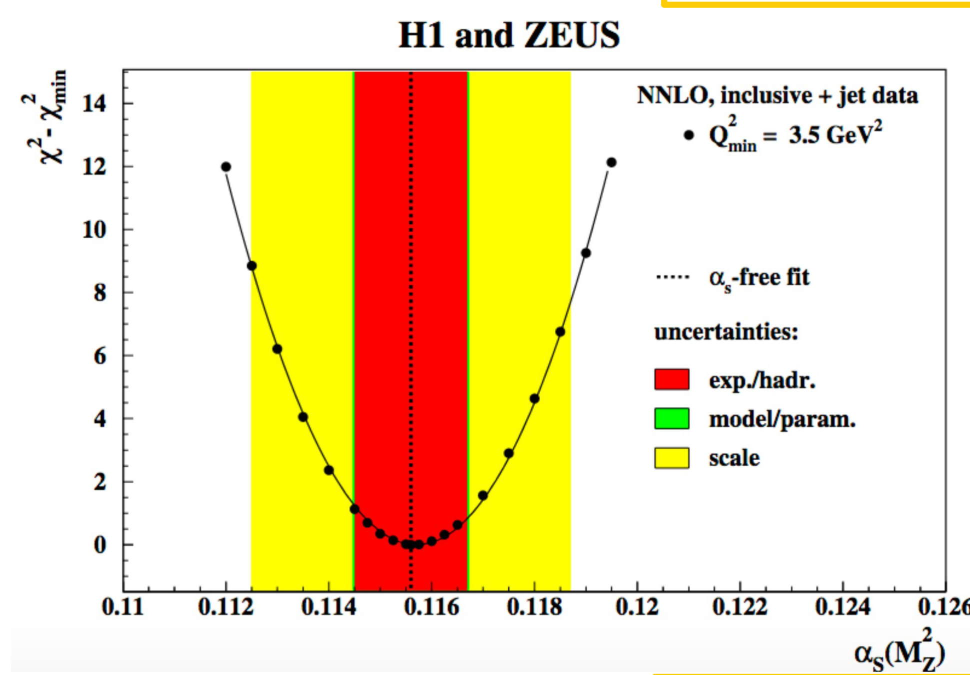
- Pseudodata uncertainties
  - Most data points have uncorrelated systematic uncertainty of 1.9%, extending to 2.75% at lowest y values
  - Additional normalisation uncertainty of 3.4% taken to be fully correlated between data at each CME, and fully uncorrelated between different CMEs

Simultaneous PDF and α_s fits with HERA DIS+jets and EIC DIS



$$\alpha_s(M_Z^2) = 0.1160 \pm 0.0004\ (\text{exp})\ {}^{+0.0003}_{-0.0002}\ (\text{model} + \text{parameterisation}) \pm 0.0005\ (\text{scale})$$

 stunning improvement in uncertainties, also in scale uncertainty!



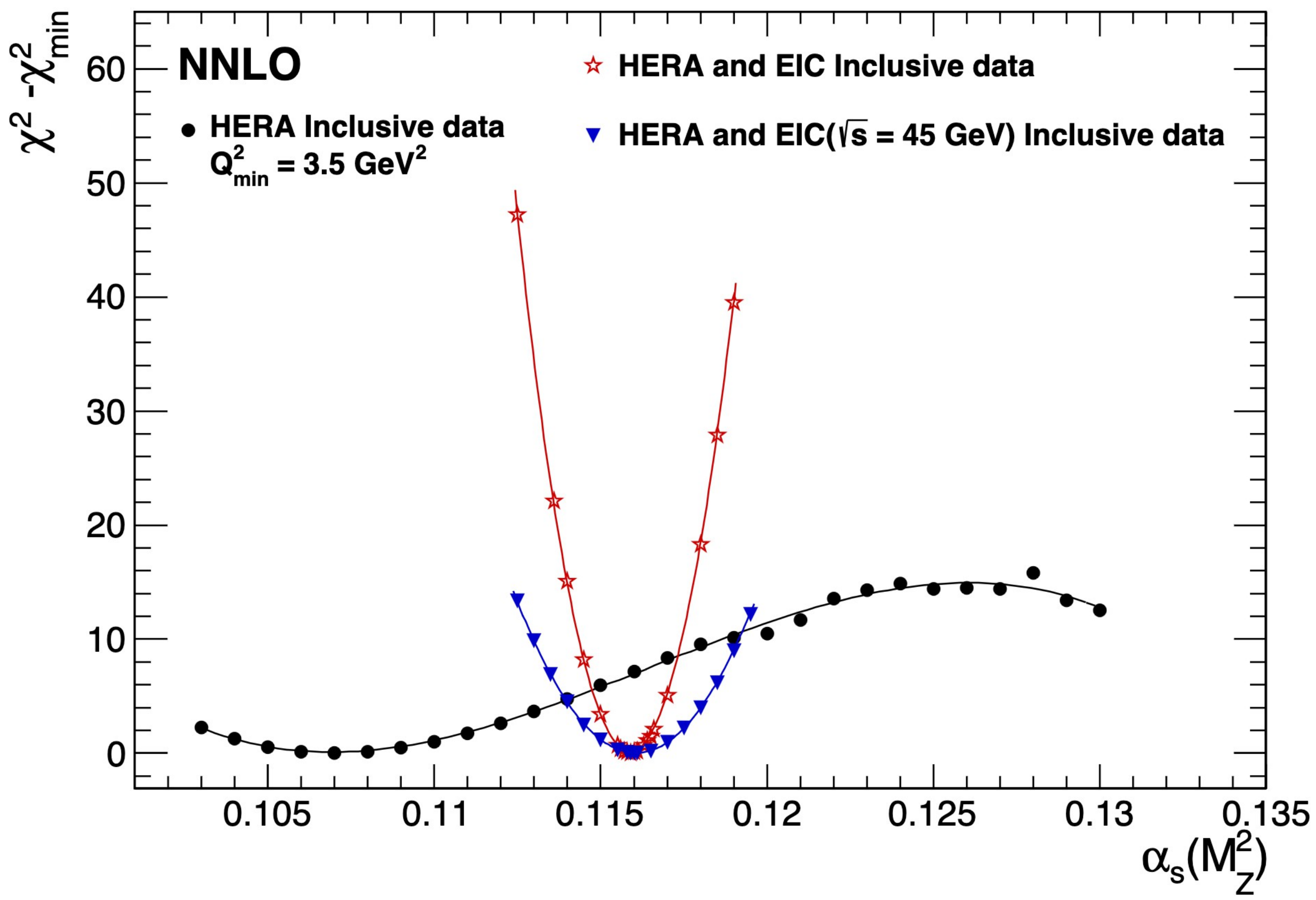
$$\alpha_s(M_Z^2) = 0.1156 \pm 0.0011\ (\text{exp})\ {}^{+0.0001}_{-0.0002}\ (\text{model} + \text{parameterisation}) \pm 0.0029\ (\text{scale})$$

Note:

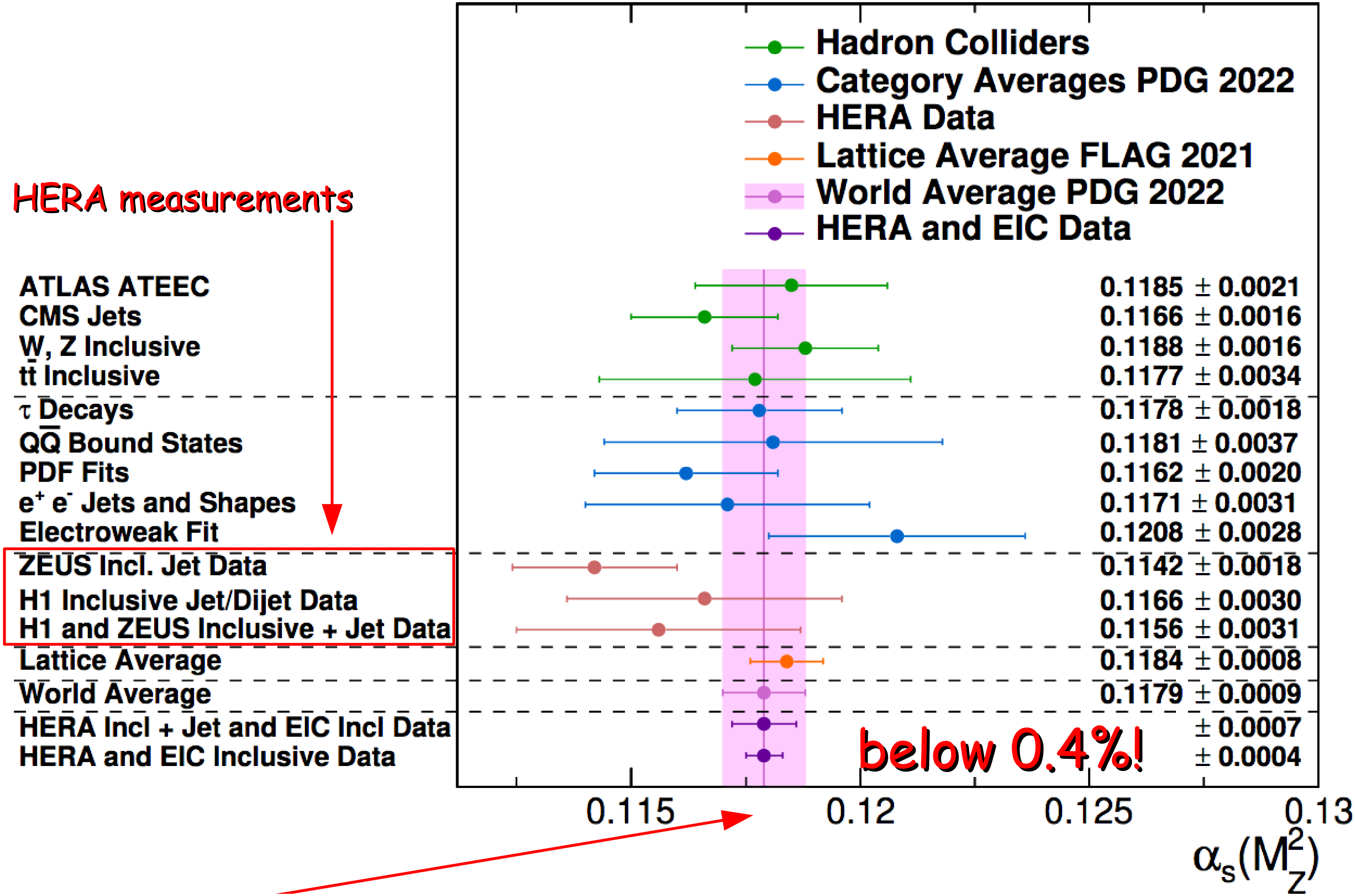
scale uncertainty much reduced when including EIC data
 HERA jet data carry less wight

So how about no jets at all? ...

Simultaneous PDF and α_s fit with only inclusive data from HERA and EIC



- Inclusive data only sensitive to α_s due to EIC kinematic phase-space and high-x quark evolution



$$\alpha_s(M_Z^2) = 0.1159 \pm 0.0004\ (\text{exp})\ {}^{+0.0002}_{-0.0001}\ (\text{model} + \text{parameterisation})$$

→ stunning improvement!

→ no scale uncertainty for DIS data → studies needed

K. Wichmann @ DIS 2024

Checking robustness of results

- Restricting data range by imposing Q^2_{min} (or x_{min}) cuts has only very small impact on result

  ⇒ EIC impact traceable to the large x, moderate Q^2 region

- There is some sensitivity to W^2 cut:
  - Default (> 10 GeV^2) yields experimental precision 0.004
  - Switching to > 15 GeV^2 leads to experimental precision 0.006
  - ⇒ Important to avoid sensitivity to higher twist or resummation effect
- Looking at “only” 1 fb^{-1} of EIC data
  - Precision is only a factor ~2 worse when fitting only one low $\sqrt{s}$ EIC beam energy

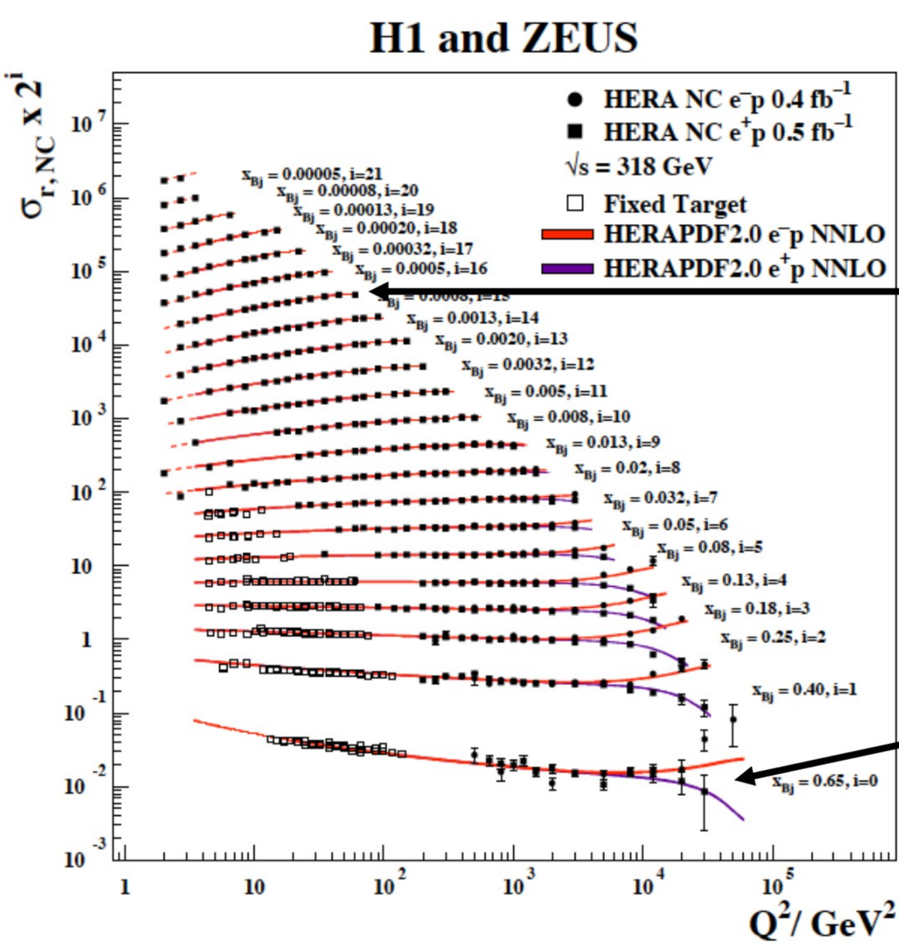
    ⇒ result achievable in ~1 year of early data taking

  - Doubling <u>uncorrelated</u> systematic uncertainties: 0.4% ⇒ 1.7%

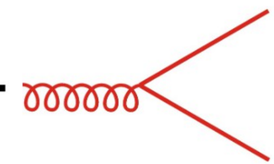
    ⇒ important to understand systematics early on

Origin of EIC impact

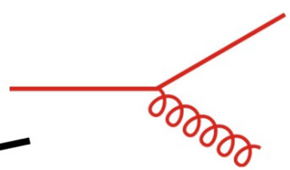
- EIC impact traceable to large x, moderate Q^2 region
  - Why does large x, intermediate Q^2 data improve precision so much?



$$\frac{d\sigma_r}{dQ^2} \sim \frac{\alpha_s}{2\pi}\left[P_{qg} \otimes g + P_{qq} \otimes q\right]$$



At low / intermediate x, scaling violations are driven by $g \rightarrow gg$, $g \rightarrow q\bar{q}$
[most sensitive to α_s.g(x)]



At largest x, scaling violations are driven by $q \rightarrow qg$
[most sensitive to α_s.q(x)]

Precision high x data decouple α_s from gluon density

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Few words on theory uncertainties

- 'Scale' uncertainties uncertainties due to missing higher orders beyond NNLO in the theory
   Expected to be small for inclusive data, and covariances with other uncertainties have to be considered (hence generally omitted in global fits)
- Moving the machinery to N^{3}LO will make them even smaller
  - One possible way to estimate these uncertainties
- Ongoing work by global fitting groups (eg NNPDF arXiv:1906.10698) to develop a consistent framework based on correlation matrices
  - outcomes eagerly awaited
  - may become very important in EIC era

Message to take away

- Using EIC DIS data will make tremendous difference in $\alpha_s(M_Z)$ determination
- Can be further improved by
  - Adding inclusive jet and dijet EIC data to the QCD analysis
  - Adding other observables: event shapes, jet substructure, jet radius parameters
  - Investigating impact of EIC data in global QCD fits, including data from the LHC and elsewhere