PDF/$\alpha_S(M_Z)$ relevant results from HERA

A M Cooper-Sarkar

Low-x 2021

1. HERAPDF2.0Jets NNLO
   H1prelim-19-041
   ZEUS-prel-19-001

2. Study of proton parton distribution functions at high x using ZEUS data

   I. Abt *et al.* (ZEUS Collaboration)
   Phys. Rev. D **101**, 112009 – Published 26 June 2020

3. **Measurement of the 1-jettiness event shape observable in deep-inelastic electron-proton scattering at HERA**

   H1prelim-21-032

TOPIC 1: Updating HERAPDF2.0Jets with **NNLO predictions for jets** from NNLOJET (Gehrmann et al) as implemented in the ApplFast system

Jet Data sets used in the present NNLO analysis
Strong overlap with those used in the NLO analysis

Data Set	published	Q^2[GeV^2] range from	to	$\mathcal{L}$ pb^{-1}	e^+/e^-	$\sqrt{s}$ GeV	norma-lised	all points	used points
H1 high Q^2 HERA I incl. jets	2007	150	15000	65.4	e^+p	301	yes	24	24
H1 low Q^2 HERA I dijets	2010	5	100	43.5	e^+p	301	no	22	16
H1 high Q^2 HERA II incl. jets	2014	150	15000	351	e^+p/e^-p	319	yes	24	24
H1 high Q^2 HERA II dijets	2014	150	15000	351	e^+p/e^-p	319	yes	24	24
H1 low Q^2 HERA II incl. jets	2016	5	80	290	e^+p/e^-p	319	yes	48	32
H1 low Q^2 HERA II dijets	2016	5	80	290	e^+p/e^-p	319	yes	48	32
ZEUS incl. jets HERA I	2002	125	10000	38.6	e^+p	301	no	30	30
ZEUS dijets HERA I and II	2010	125	20000	374	e^+p/e^-p	318	no	22	16

These data sets are new and were not used in the 2015 NLO analysis

However as well as adding new data sets we have to subtract some data

- Trijets- there are no NNLO predictions
- Data at low scale μ = (pt^2 +Q^2) < 13.5 fro which scale variations are large (~25% NLO and ~10% NNLO)
- 6 Dijet data points at low pt for which predictions are unreliable

There is a choice of scales to be made for the jets.

Factorisation scale

At NLO we used factorisation scale= Q^2 but this is not a good choice for low Q^2 jets, we have many more low Q^2 jet data points now – from the H1 2016 data- so we move to a choice factorisation scale $=(Q^2+pt^2)$ for all jets- this makes almost no difference to high Q^2 jets

Renormalisation scale

For HERAPDF2.0Jets NLO we chose renormalisation $=(Q^2+pt^2)/2$

For HERAPDF2.0Jets NNLO jets a choice of renormalisation $=(Q^2+pt^2)$

Results in a lower $\chi2$, $\Delta\chi2\sim -15$

In fact the 'optimal' scale choice for NLO and NNLO is different – if optimal is defined by lower $\chi2$. At NLO $\Delta\chi2\sim -15$ for the old scale choice.

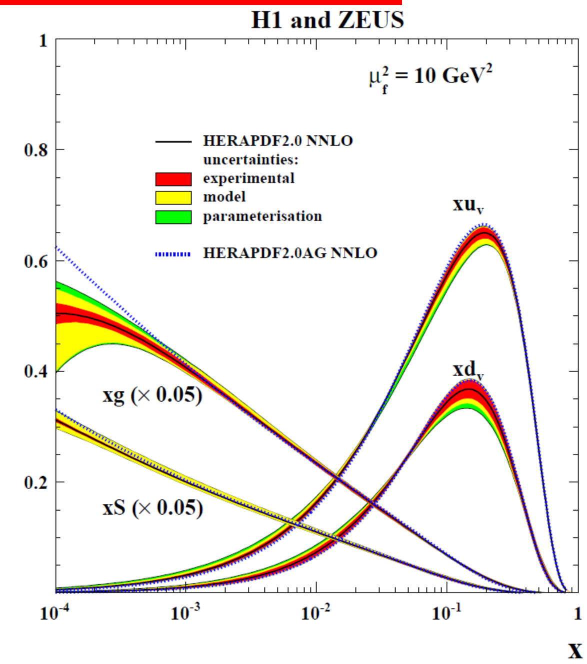
We also explore the consequences of scale variation.

HERAPDF specifications: sources of uncertainty

Experimental
Hessian uncertainties: 14 eigenvector pairs, evaluated with $\Delta\chi 2 = 1$
Cross checked uncertainties evaluated from the r.m.s. of MC replicas

Model: Variation of input assumptions
Variation of charm mass and beauty mass parameters is restricted using HERA charm and beauty data

Variation	central	Upper	lower
f_s size and shape	0.4	0.5	0.3
M_c (NLO) GeV	1.43	1.49	1.37
M_c (NNLO) GeV	1.47	1.53	1.41
M_b GeV	4.5	4.25	4.75
Q^2_{min} GeV^2	3.5	2.5	5.0



Parametrisation
Variation of $Q^2_0 = 1.9 \pm 0.3\ GeV^2$ and addition of 15th parameters

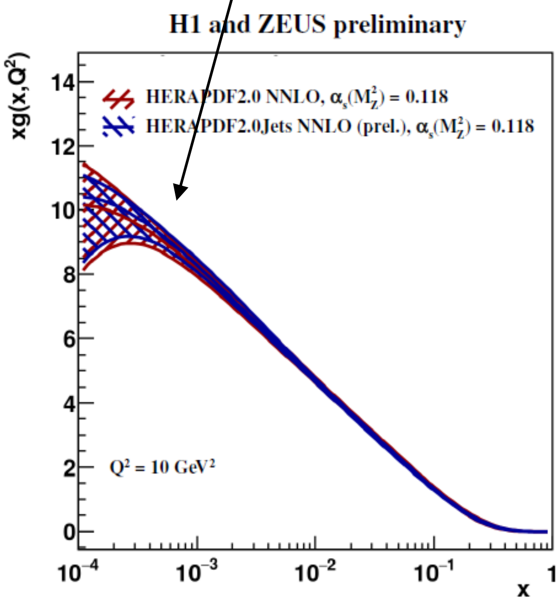
When jets are included we also evaluate a hadronisation uncertainty from offsetting the corrections given for each jet data set

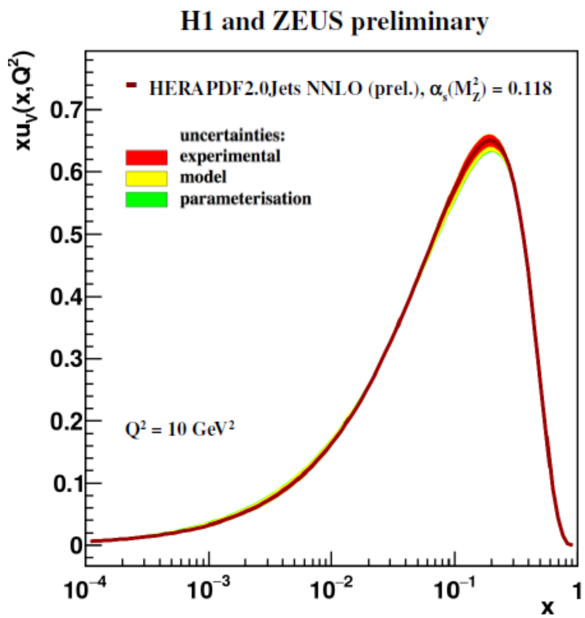
First we determine PDFs by making fits with the fixed value of

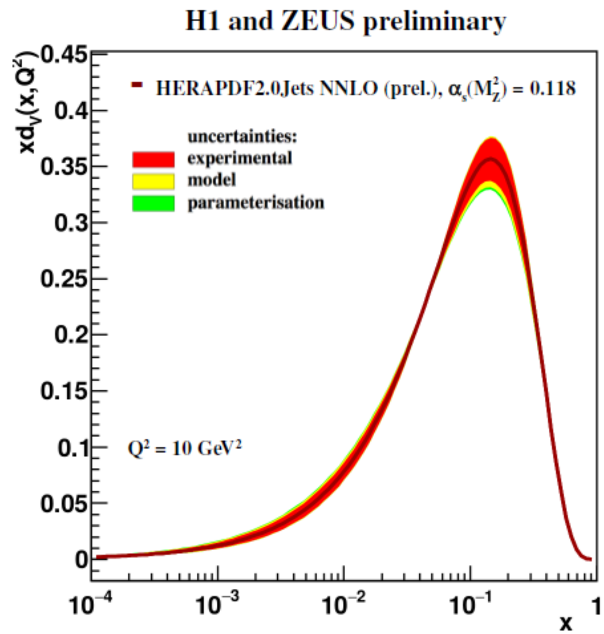
$\alpha_s(M_Z) = 0.118$

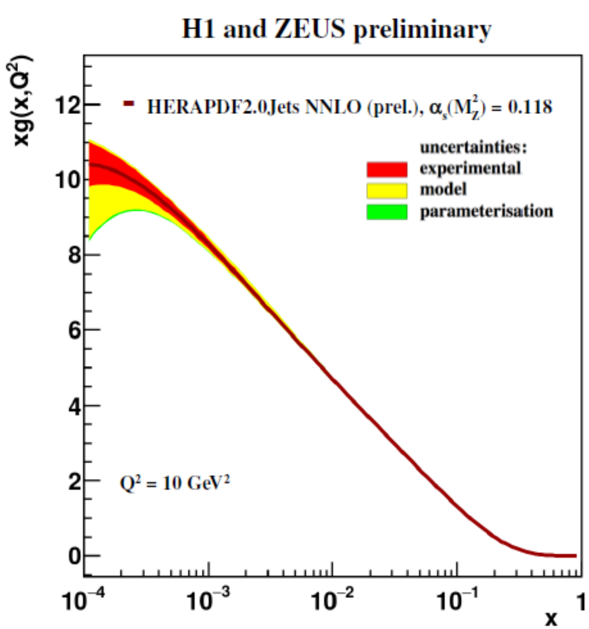
HERAPDF2.0Jets NNLO

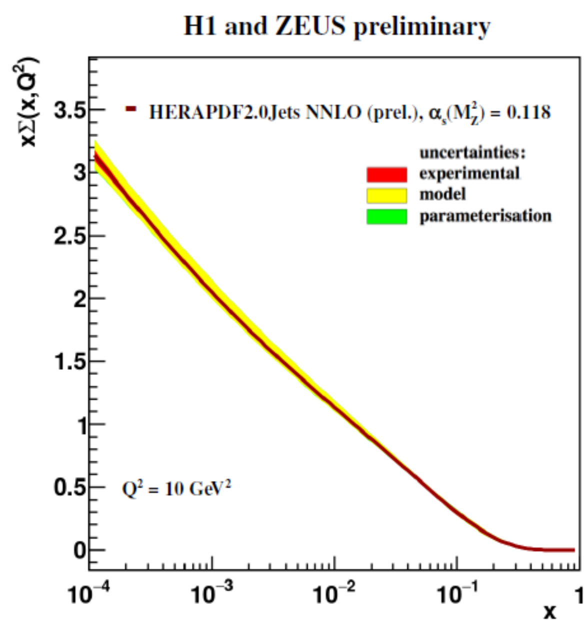
Uncertainties on the gluon are reduced when compare to HERAPDF2.0NNLO



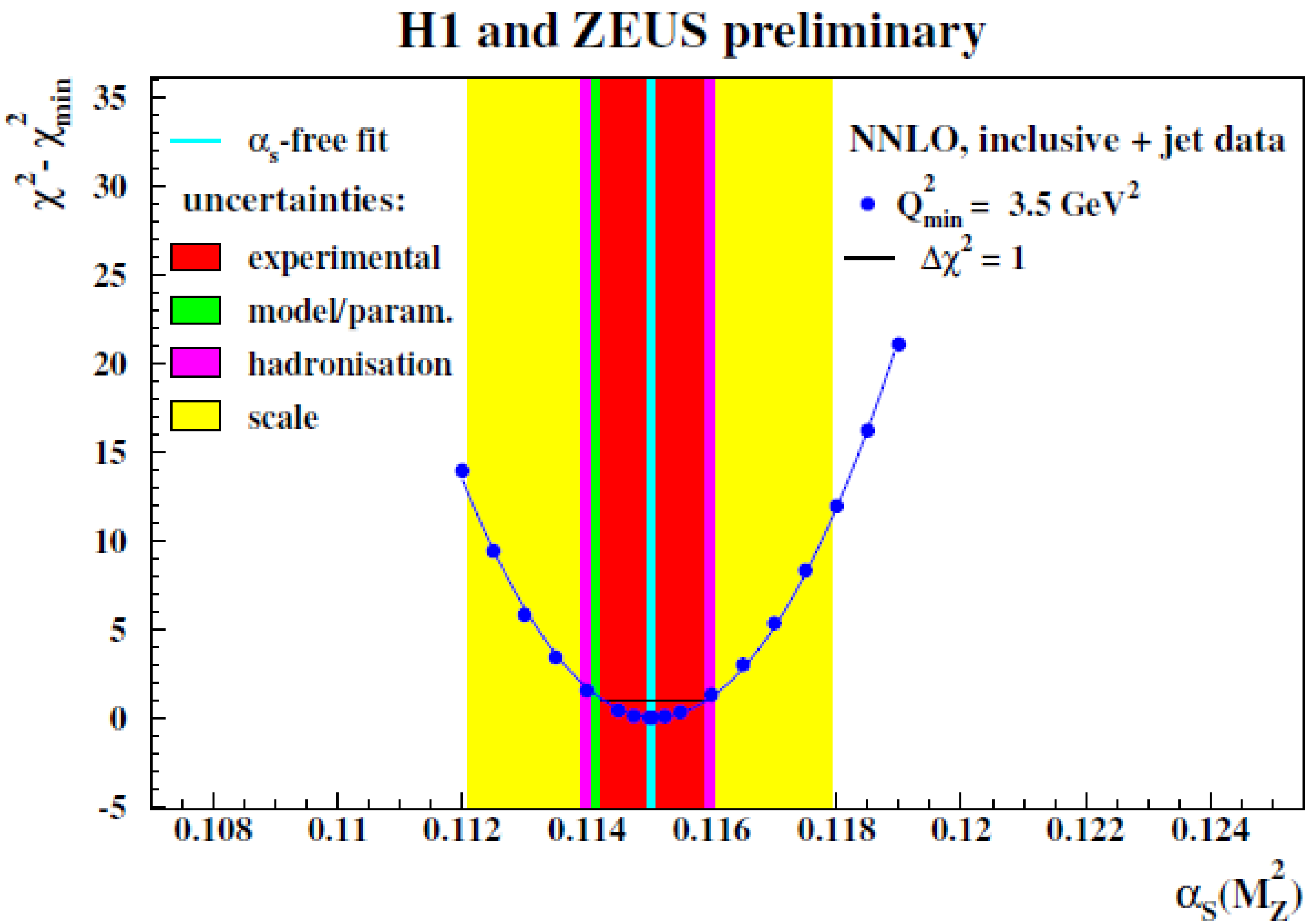








The standard value of $\alpha_s(M_Z)$ for HERAPDF fits is $\alpha_s(M_Z)$ =0.118 but we also perform fits with free $\alpha_s(M_Z)$, since the jet data enable us to constrain it.



$\alpha_s(M_Z)=0.1150 \pm 0.0008_{(exp)} {}^{+0.0002}_{-0.0005(model/param)} \pm 0.0006_{(had)} \pm 0.0027_{(scale)}$

The fitted experimental uncertainty is not the whole story.

The experimental, model, parametrisation and hadronisation uncertainties are also determined for these fits.

In addition, in fits with free $\alpha_s(M_Z)$ scale uncertainty becomes important:

Scale uncertainty is determined from the usual procedure

This was to vary factorisation and renormalisation scales both separately and simultaneously by a factor of two taking the maximal positive and negative deviations. These are assumed to be 50% correlated and 50% uncorrelated.

This gives scale uncertainty $^{+0.0026}$ / $_{-0.0027}$ by far the largest uncertainty.

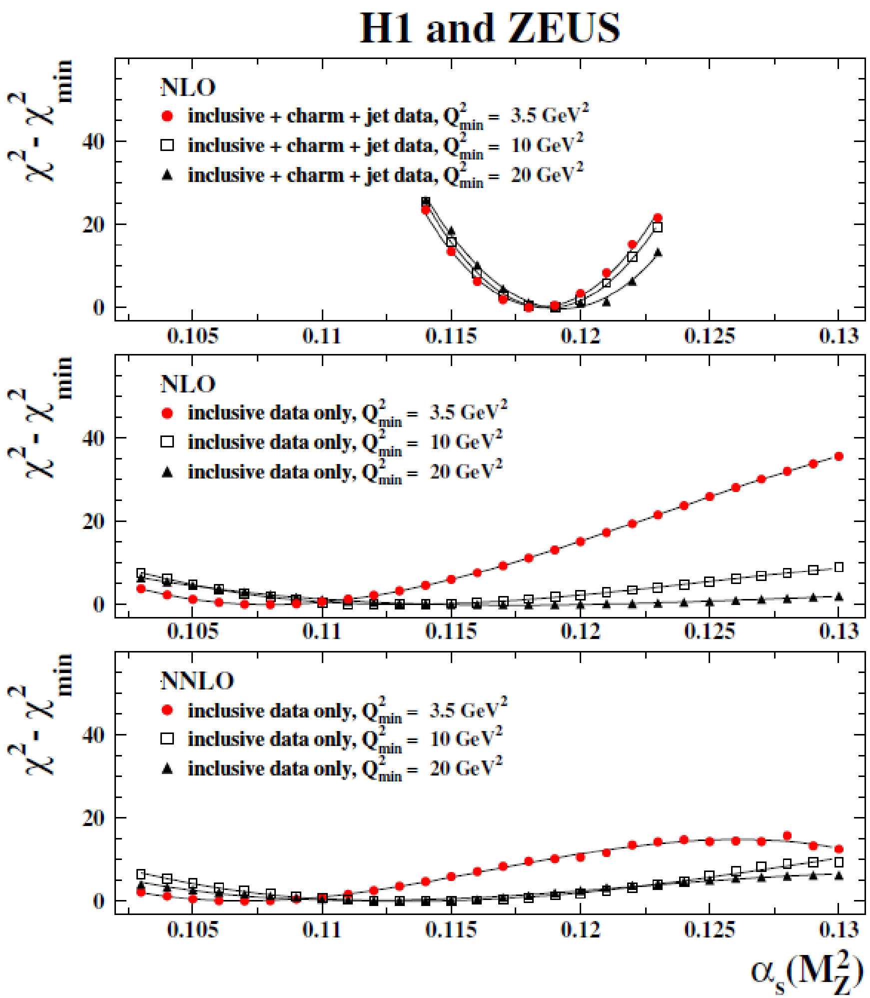
To summarise the value of $\alpha_s(M_Z)$ determined from these fits with all uncertainties is:

$$\alpha_s(M_Z)=0.1150 \pm 0.0008_{(exp)}\ {}^{+0.0002}_{-0.0005(model/param)} \pm 0.0006_{(had)} \pm 0.0027_{(scale)}$$

$\chi2$=1599 for free $\alpha_s(M_Z)$ fit, using1343 data points, 1328 degrees of freedom

$\chi2$/d.o.f =1.203

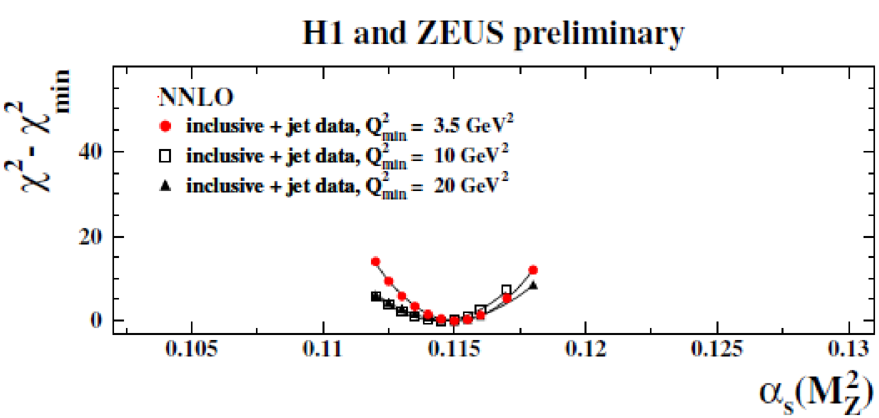
Compare $\chi2$/d.o.f =1.205 for HERAPDF2.0NNLO (with only 1131 degrees of freedom)



These scans over the NNLO inclusive +jet data are compared to the published scans done at NLO and to the corresponding scans using only inclusive data.

Just as at NLO the jet data help to constrain $\alpha_s(M_Z)$. There is a similar level of accuracy at NNLO and NLO and $\alpha_s(M_Z)$ clearly moves lower at NNLO –

But note we are using a different scale now– our scale uncertainty studies show that with the old scale choice used at NLO the NNLO result would be even lower → $\alpha_s(M_Z) \sim 0.1135$.
So this IS a systematic shift.

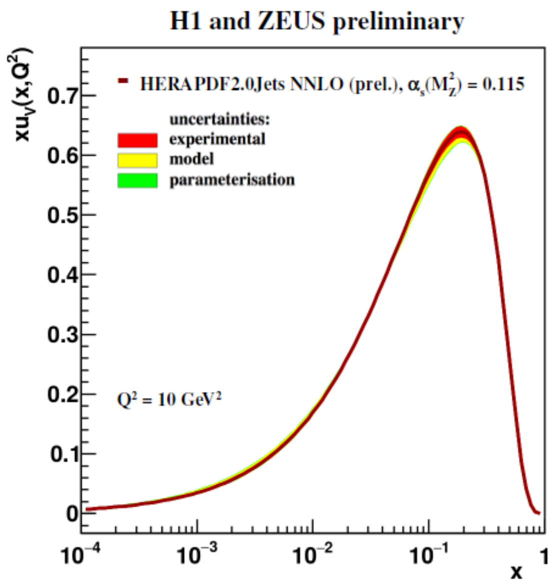


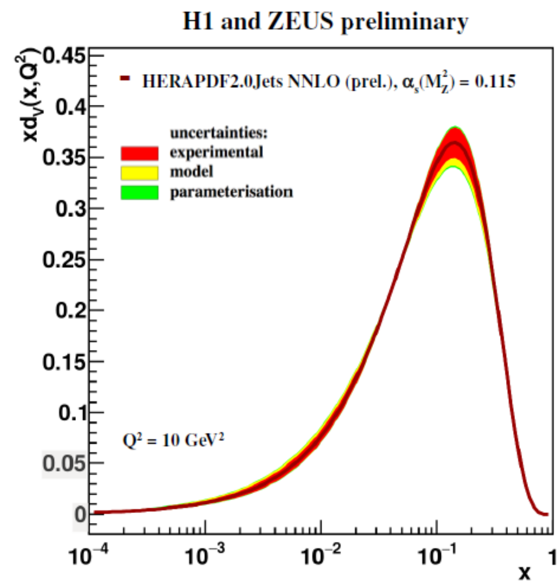
The NNLO result is:
$\alpha_s(M_Z)=0.1150 \pm 0.0008_{(exp)} {}^{+0.0002}_{-0.0005(model/param)} \pm 0.0006_{(had)} \pm 0.0027_{(scale)}$

Compare the NLO result
$\alpha_s(M_Z)=0.1183 \pm 0.0009_{(exp)} \pm 0.0005_{(model/param)} \pm 0.0012_{(had)} {}^{+0.0037}_{-0.0030(scale)}$

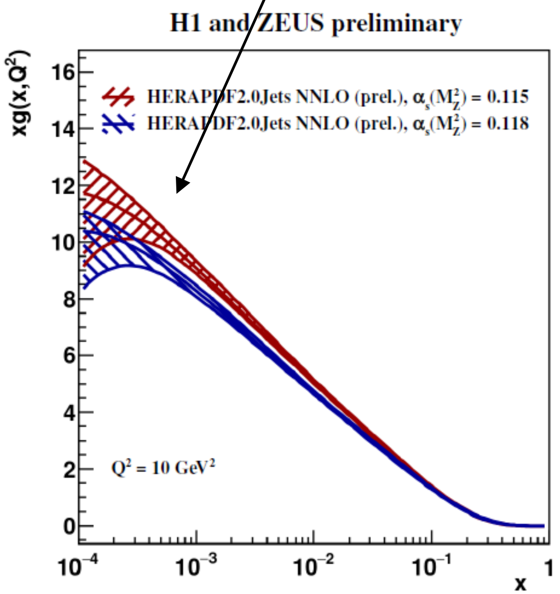
So now produce PDFs with the fixed value

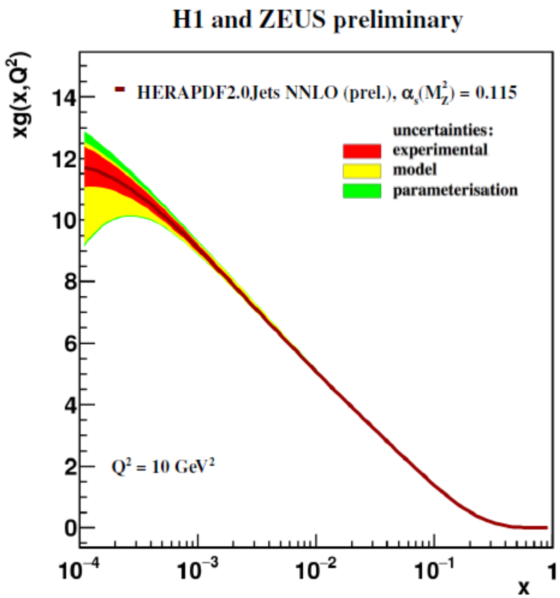
$\alpha_s(M_Z) = 0.115$

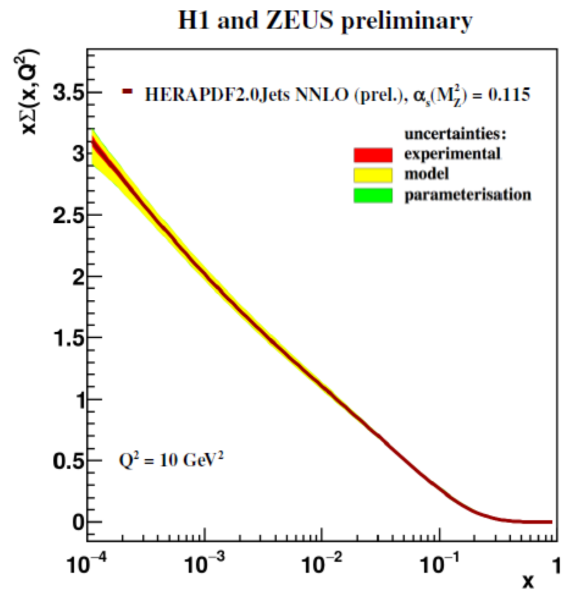




Compare PDFs for $\alpha_s(M_Z) = 0.115$ and $\alpha_s(M_Z) = 0.118$
Only different in the gluon







Conclusions: TOPIC 1

We have completed the HERAPDF2.0 family by performing an NNLO fit including jet data.
This results in two new PDF sets:
HERAPDF2.0JetsNNLO $\alpha_s(M_Z)$ =0.118 – the PDG value
HERAPDF2.0JetsNNLO $\alpha_s(M_Z)$ =0.115 – The value favoured by our own fit

The Jet data allow us to constrain $\alpha_s(M_Z)$. Our NNLO value is

$$\alpha_s(M_Z)=0.1150 \pm 0.0008_{(exp)} {}^{+0.0002}_{-0.0005(model/param)} \pm 0.0006_{(had)} \pm 0.0027_{(scale)}$$

Compare the NLO result

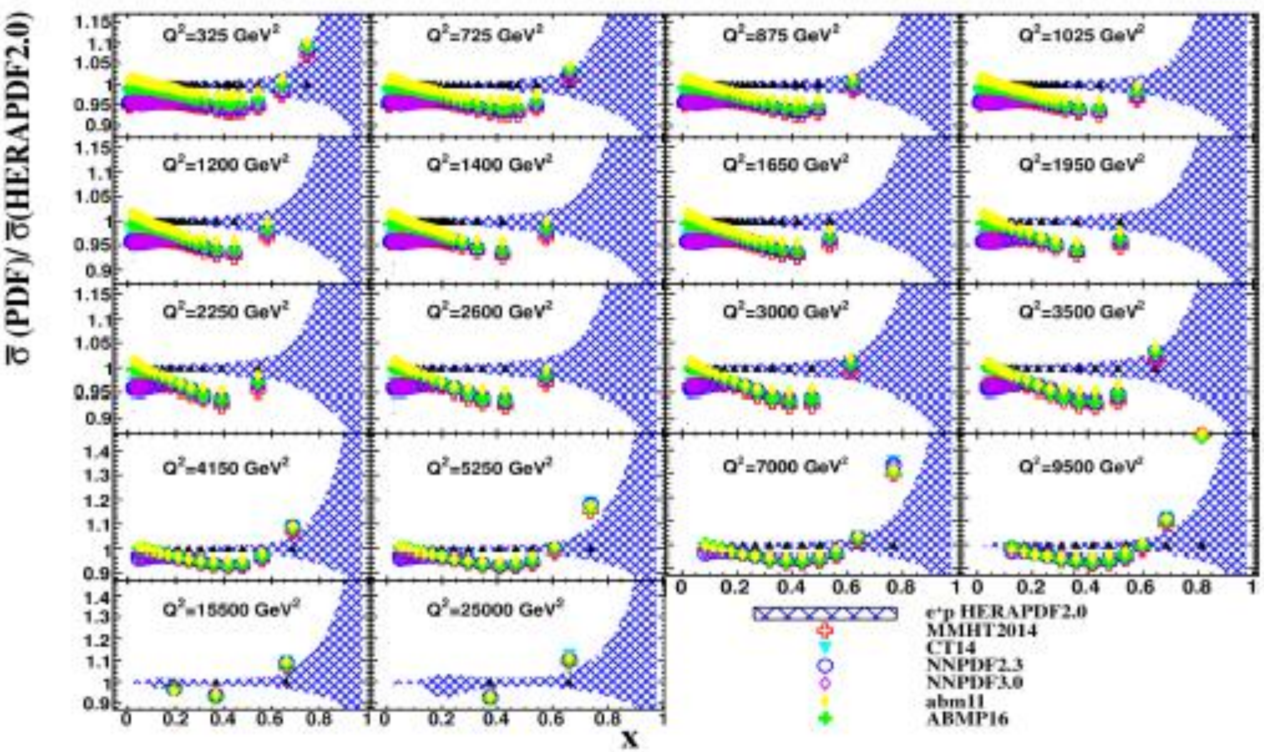
$$\alpha_s(M_Z)=0.1183 \pm 0.0009_{(exp)} \pm 0.0005_{(model/param)} \pm 0.0012_{(had)} {}^{+0.0037}_{-0.0030(scale)}$$

There is a systematic shift downwards at NNLO even taking scale variation into account

TOPIC 2: high-x ZEUS data

I. Abt *et al.* (ZEUS Collaboration)
Phys. Rev. D **101**, 112009 – Published 26 June 2020

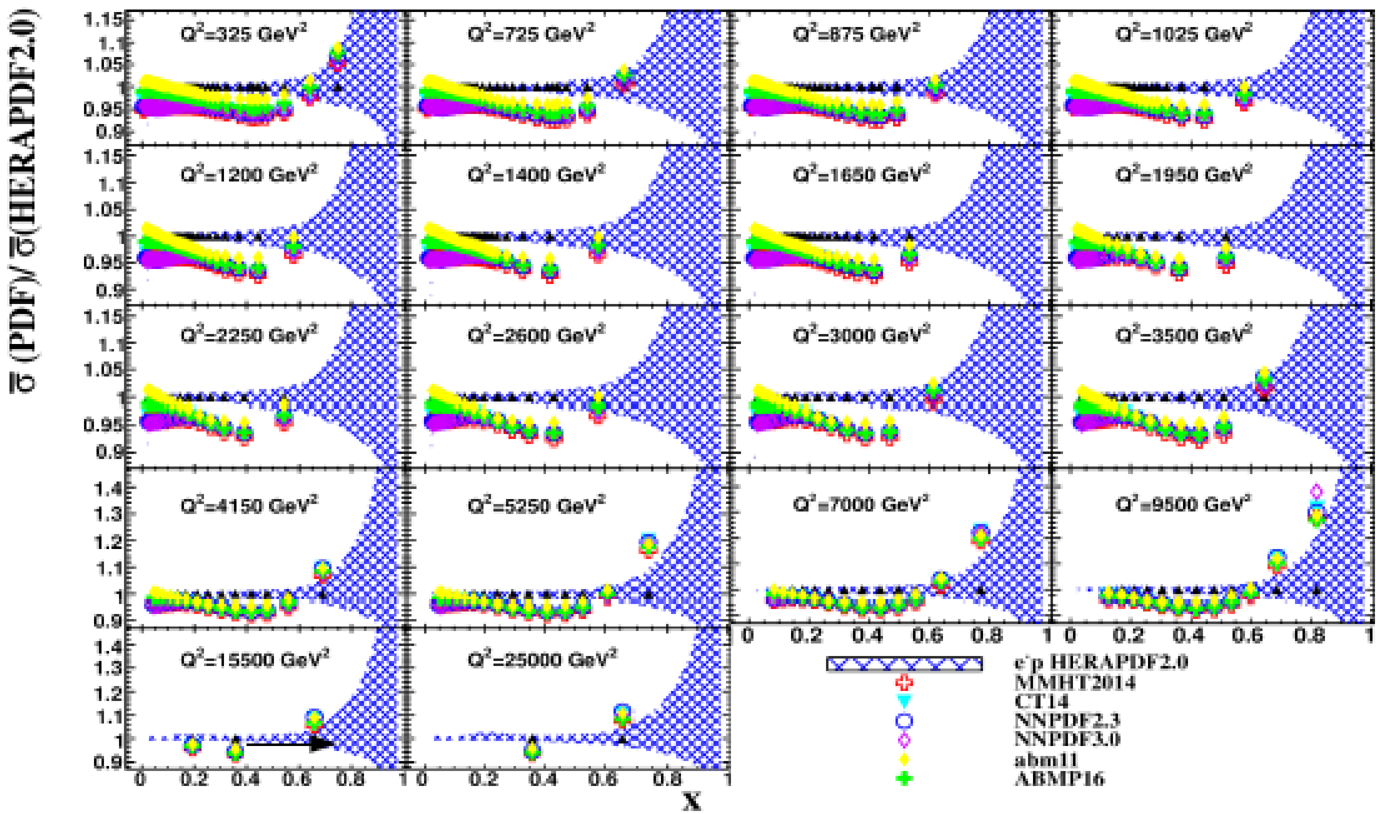
Ratio of generated level cross sections in different PDFs (at NLO) to HERAPDF2.0NLO for M bins (e+p)



Where $\overline{\sigma}$ is the total integrated cross section in a given x-Q² bin

There is a shape difference between HERAPDF & other PDFs, approaches 10% at x ~ 0.4.

Ratio of generated level cross sections in different PDFs (at NLO) to HERAPDF2.0NLO for M bins (e-p)

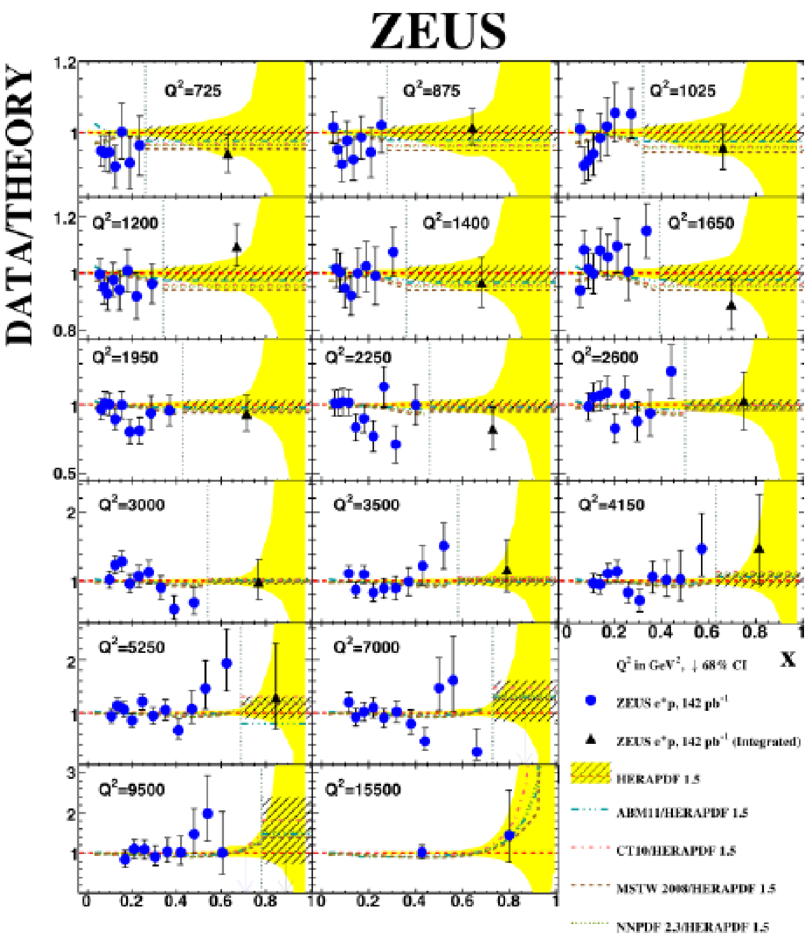


There is a shape difference between HERAPDF & other PDFs, approaches 10% at x ~ 0.4.

You won’t often see this since plots are usually in ln(x)
But it is worrying for BSM physics

ZEUS has some measurements at very high-x that are not in the HERAPDF—or indeed in any PDF

H. Abramowicz *et al.* (ZEUS Collaboration)
Phys. Rev. D **89**, 072007 – Published 8 April 2014



But there are very few events at high-x
So these are not suitable for input to the PDF fits in the usual way

Transfer Matrix for the detector is developed using which number of events reconstructed in data can be predicted from any PDF as below.

- Get a prediction for the generator/hadron level number of events, which is luminosity x radiative corrections x Born cross section.

i.e. $\nu_{i,k} = \mathcal{L} K_{ii} \sigma_{i,k}$

- Apply transfer matrix a_{ij} to get the number of events in a bin j.

$$\nu_{j,k} \approx \sum_i a_{ij} \nu_{i,k}$$

L : data luminosity
K_{ii} : Radiative corrections (calculated using HERACLES)
$\sigma_{i,k}$: born level cross sections in i[th] bin for k[th] PDF
$\mathbf{a}_{ij}$ has all detector and analysis effects
(probability of an event reconstructed in j[th] bin to come from i[th] true bin)

2) *Comparison at reconstructed level* from different PDFs : Convolute M with Transfer Matrix to get a prediction of number of events in the cross section Bins (ν) from different PDFs

- ν from different PDF is compared to observed events from data and Poisson statistics is used to probe how well given PDF is defining the data.

- p-value is determined for different PDFs

- Comparison of p-values in high-x and lower-x range is shown for different PDFs

Probability for explaining high-x data from different PDFs

PDF	e^-p	e^+p
$HERAPDF2.0$	0.05	0.5
$CT14$	0.002	0.8
$MMHT2014$	0.002	0.8
$NNPDF2.3$	0.00007	0.6
$NNPDF3.0$	0.0002	0.7
$ABMP16$	0.01	0.8
$ABM11$	0.001	0.6

p-value for e-p and e+p data sets are shown on comparison to different PDFs
(includes only statistical fluctuation from Poisson probabilities).

Probability for explaining high-x data from different PDFs in differen x-ranges

	e^-p		e^+p	
PDF	$x < 0.6$	$x \geq 0.6$	$x < 0.6$	$x \geq 0.6$
HERAPDF2.0	0.06	0.2	0.6	0.1
CT14	0.0008	0.2	0.7	0.6
MMHT2014	0.00003	0.1	0.6	0.6
NNPDF2.3	0.00007	0.2	0.6	0.6
NNPDF3.0	0.00003	0.2	0.6	0.6
ABMP16	0.01	0.2	0.8	0.5
ABM11	0.03	0.3	0.7	0.4

p-value for e-p and e+p data sets are shown on comparison to different PDFs for two different x ranges.

Perhaps unsurprisingly the HERAPDF does best, but it I still not great

- **Disagreement comes primarily from lower x in e-p**

+1.8 %				
	e^-p		e^+p	
PDF	$x < 0.6$	$x \geq 0.6$	$x < 0.6$	$x \geq 0.6$
HERAPDF2.0	0.02	0.1	0.2	0.3
CT14	0.02	0.3	0.8	0.5
MMHT2014	0.008	0.2	0.8	0.5
NNPDF2.3	0.009	0.3	0.8	0.4
NNPDF3.0	0.008	0.3	0.8	0.4
ABMP16	0.04	0.3	0.6	0.4
ABM11	0.03	0.3	0.4	0.2
−1.8 %				
	e^-p		e^+p	
PDF	$x < 0.6$	$x \geq 0.6$	$x < 0.6$	$x \geq 0.6$
HERAPDF2.0	0.03	0.3	0.8	0.2
CT14	0.0	0.08	0.4	0.6
MMHT2014	0.0	0.04	0.2	0.6
NNPDF2.3	0.0	0.08	0.2	0.6
NNPDF3.0	0.0	0.08	0.2	0.6
ABMP16	0.0003	0.1	0.7	0.6
ABM11	0.004	0.2	0.7	0.5

Dominant systematics : due to error in normalization of data quoted as 1.8 %

Conclusions :

- **p-values from different PDFs change differently**
- **Similar behavior as when using only statistical fluctuations.**

Systematic uncertainties can also be accounted
The dominant one is normalisation

The overall picture is the same as when using only statistical uncertainties

CONCLUSION TOPIC 2: There is further unused information at high-x.
Work is ongoing to develop a Bayesian fitting code to incorporate these high-x data into PDF fits.

TOPIC 3: H1 measurement of an event shape variable: 1-jettiness with sensitivity to PDFs/$\alpha_S(M_Z)$, resummation and hadronisation effects

Neutral current deep-inelastic scattering

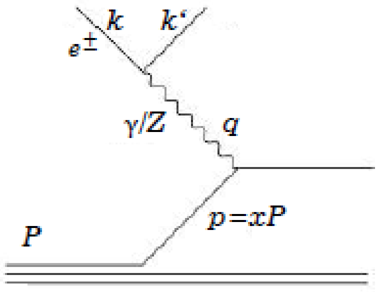
- Process $ep \to e'X$
- Electron or positron scattering

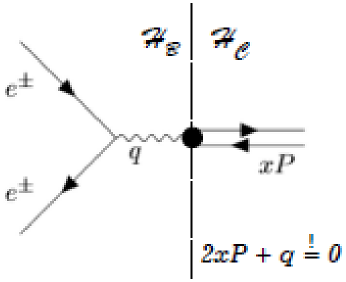
Kinematic variables

- Virtuality of exchanged boson Q^2
  $Q^2 = -q^2 = -(k - k')^2$
- Inelasticity, Bjorken-x and centre-of-mass energy
  $y = \frac{p \cdot q}{p \cdot k} \qquad Q^2 = x_{Bj} \cdot y \cdot s$

Breit frame

- Exchanged boson completely space-like
- Collides head-on with parton (brick-wall frame)





1-jettiness

- Axes incoming parton and $q + xP$:

$$\tau_1^b = \frac{2}{Q^2} \sum_{i \in X} \min\{xP \cdot p_i, (q + xP) \cdot p_i\}$$

- Infrared safe and free of non-global logs
- Sensitive to strong coupling α_s and PDFs

DIS thrust normalised to boson axis

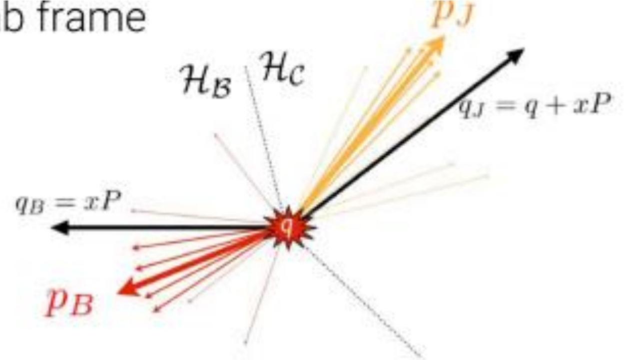
- Normalisation with $Q/2$ of the event:

$$\tau_Q = 1 - \frac{2}{Q} \sum_{i \in \mathcal{H}_C} P_{z,i}^{Breit}$$

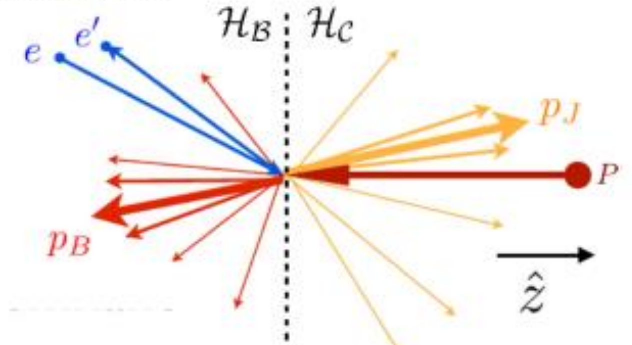
- Only particles in the current hemisphere contribute

Equivalence follows from momentum conservation:

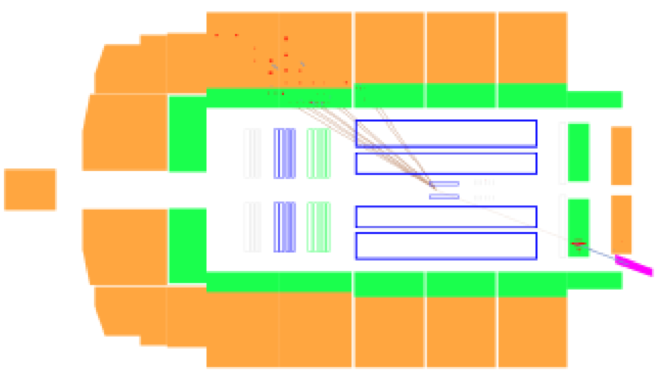
Lab frame

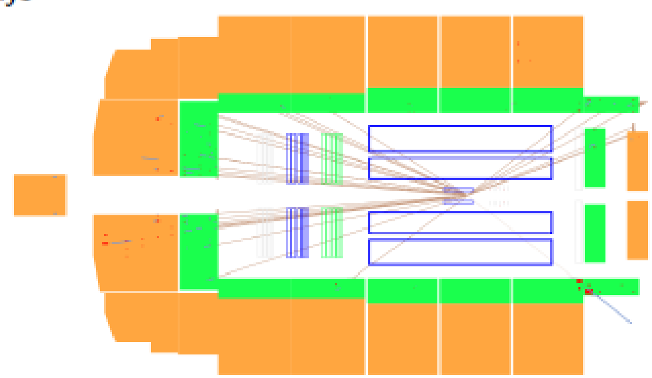


Breit frame



Visualisation of the 1-jettiness with event displays





- DIS 1-jet configuration
- Most HFS particles collinear to scattered parton
  → Small τ_1^b

- Dijet event
- More and larger contributions to the sum over the HFS
  → Large τ_1^b

Single differential cross section

- Unfolded using bin-by-bin method
- Corrected for electron QED radiative effects
- Divide by τ_1^b-bin width
- Stat. & syst. uncertainties smaller than marker size

Comparison with MC models

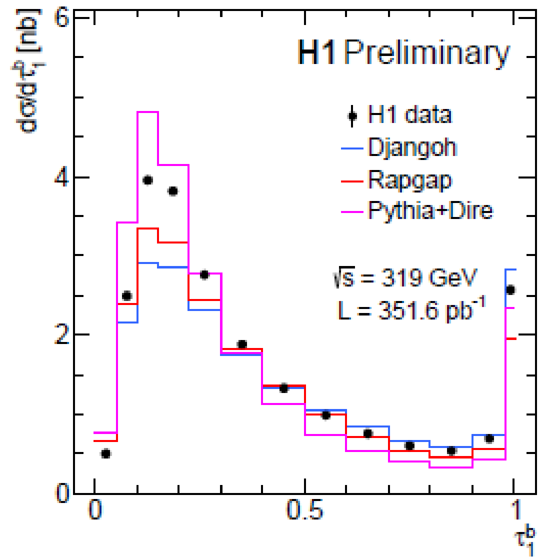
- Djangoh 1.4: Colour-dipole-model
- Rapgap 3.1: ME + parton shower
- Pythia 8.3 + Dire

Dire Parton Shower

- Dipole-like shower
- Inclusive NLO DGLAP corrections to the shower evolution are included

Phase space

- $150 < Q^2 < 20.000\ \text{GeV}^2$
- $0.2 < y < 0.7$



Peak region (resummation region)

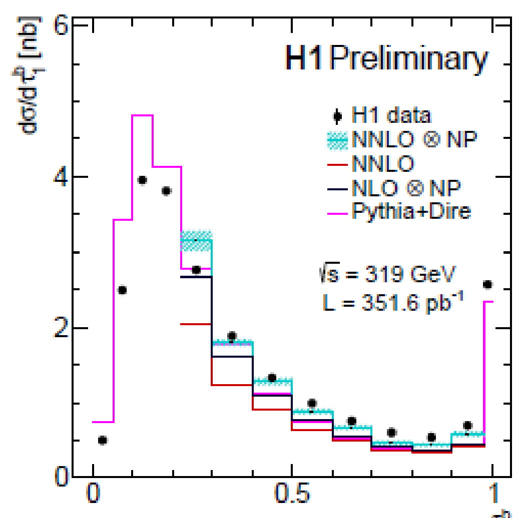
- Not well described by the models

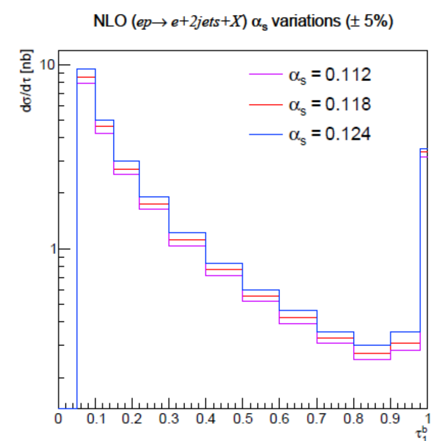
Tail region (fixed order region)

- Djangoh and Rapgap perform well
- Pythia+Dire underestimates the data

$\gamma p \rightarrow 2$ jets+X NNLO prediction form NNLOJET

- NP corrections from Pythia 8.3 (sizeable)
- NNLO provides a reasonable description of fixed-order region
- NNLO improves over NLO



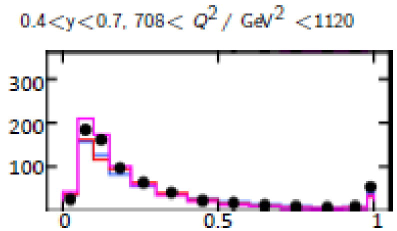


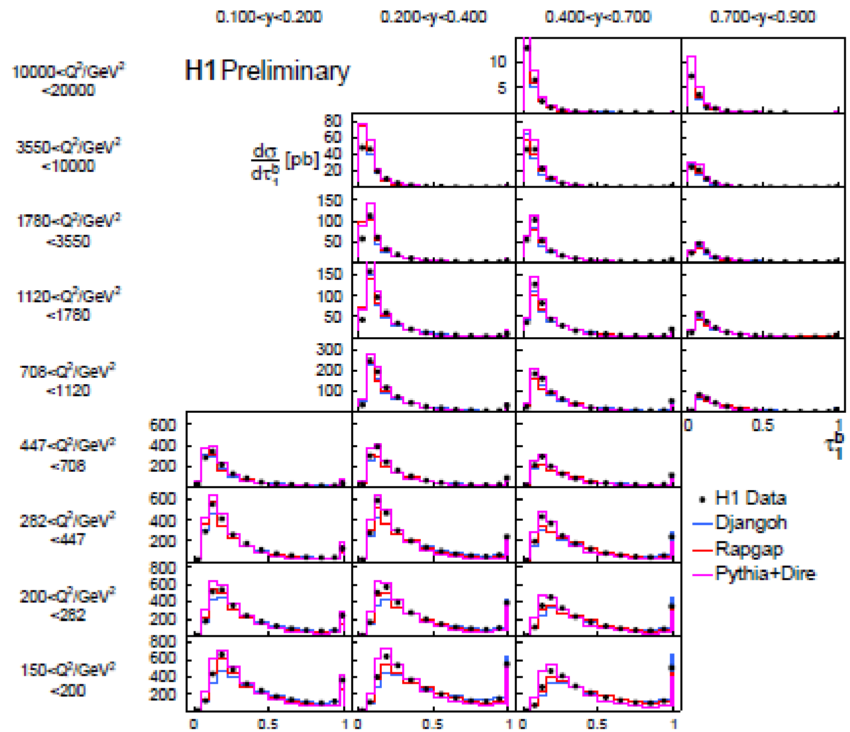
Triple differential cross sections

Large cross section and sizeable data
→ Triple-diff. cross sections as a function of Q^2, y, τ

3D cross sections

- increasing Q^2
  → Peak moves to lower τ
  → Tail region lowers
- Increasing y
  → $\tau = 1$ becomes enhanced

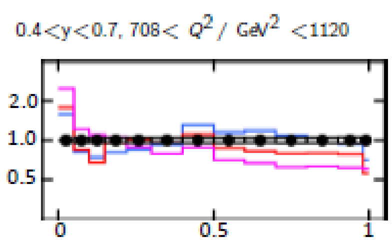


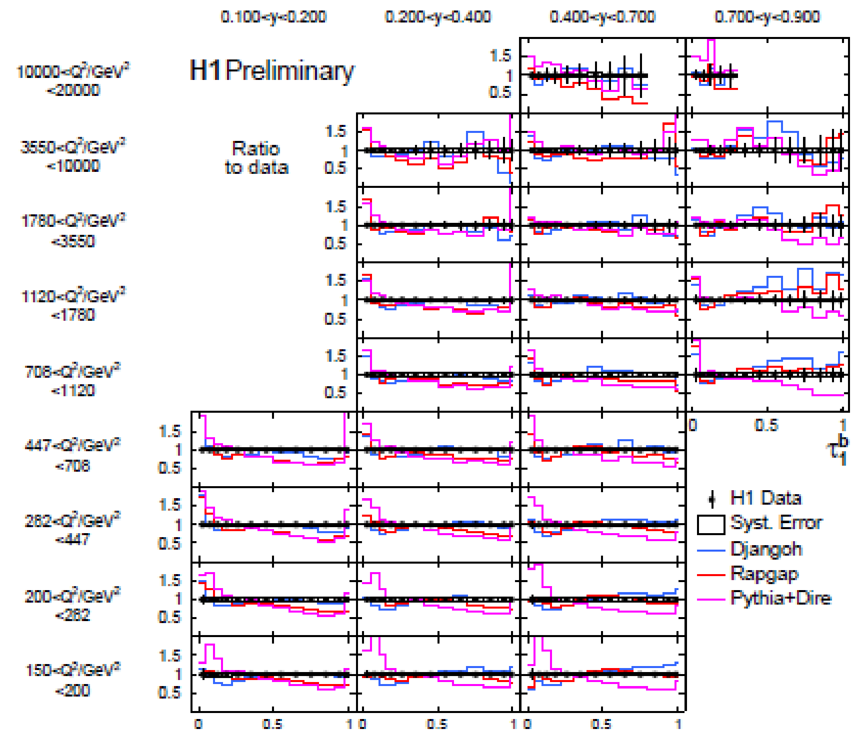


Ratio to data

- Stat. uncertainties of a few to $O(10\%)$
- Syst. uncertainties are in the range of 5%

→ 'Classical' MC models perform reasonably well over entire phase space
→ Pythia+Dire similar to Rapgap at low y, but too large at low τ

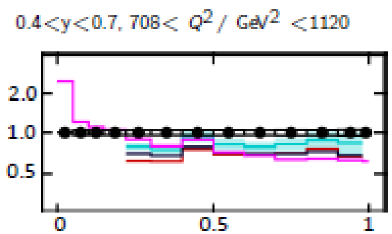


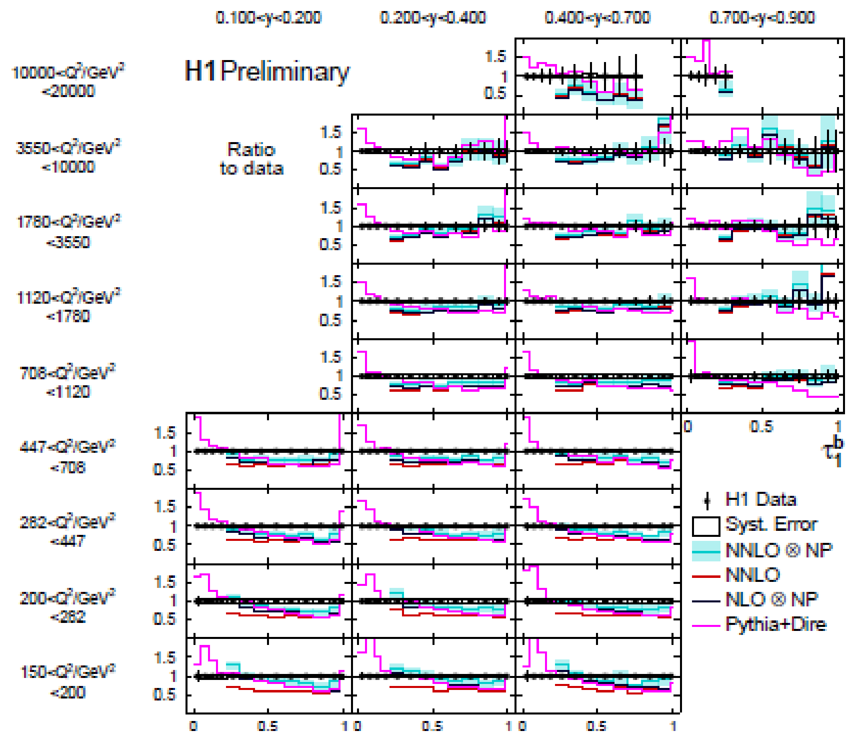


NNLO pQCD ($ep \to$2 jets+X)

- Reasonable description in entire phase space
- Improved description with increasing Q^2
- Small scale uncertainties

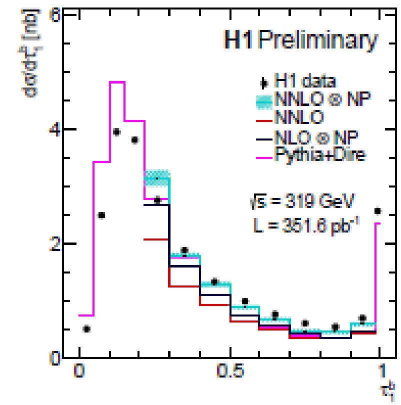
$\to$ Altogether: NNLO improves over NLO but NP corrections are sizeable

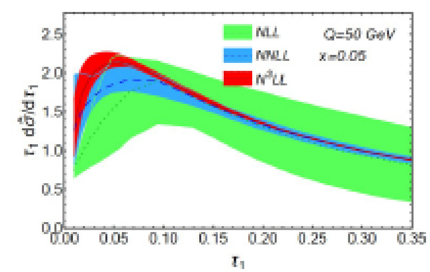




CONCLUSION: Topic 3

- A first measurement of the 1-jettiness event shape observable in NC DIS was presented
- 1-jettiness is equvalent to DIS thrust normalised with $Q/2$
- Classical Monte Carlo provides a good description of the data
- Modern Monte Carlo performs reasonably well
- NNLO fixed order predictions ($ep \to 2$ jets) provide good description in the region of validity, but hadronisation corrections are large
- H1prelim-21-032
  https://www-h1.desy.de/psfiles/confpap/EPSHEP2021/H1prelim-21-032.pdf





Kang, Lee, Stewart, [PoS DIS2015 (2015) 142]

Outlook

- N3LL and NNLO+PS predictions need to be confronted with data
- Sensitivity to α_s and PDFs needs to be explored
- Data will become useful for improving (DIS) MC generators

Back-up

Note on NNLOJet predictions for DIS jets

A bug was found in August2020

This has led to two errata on papers published by NNLOJet and H1 which used these grids in the extraction of $\alpha_S(M_Z)$

V. Andreev *et al.* [H1 Collaboration], Eur. Phys. J. C **77**, 791 (2017), [Erratum: Eur. Phys. J. C 81, 738 (2021)], [1709.07251].

D. Britzger *et al.* [NNLOJet and Applfast Collaboration], Eur. Phys. J. C **79**, 845 (2019), [arXiv:1906.05303].

We are wor ... grids.

We present ... esults are

essentially ...

V. Andreev *et al.* [H1 Collaboration], Eur. Phys. J. C **77**, 791 (2017), [Erratum: Eur. Phys. J. C 81, 738 (2021)], [1709.07251].

D. Britzger *et al.* [NNLOJet and Applfast Collaboration], Eur. Phys. J. C **79**, 845 (2019), [arXiv:1906.05303].

The PDFs do not change visibly

The extracted value of $\alpha_S(M_Z)$ could be marginally larger, see for example:

The H1 value extracted in a similar manner, with a joint PDF and $\alpha_S(M_Z)$ fit, changed from 0.1142 to 0.1147 with an experimental uncertainty of 0.0011

The HERAPDF approach uses only HERA data

The combination of the HERA data yields a very accurate and consistent data set for 4 different processes: e^+p and e^-p Neutral and Charged Current reactions and for e^+p Neutral Current at 4 different beam energies

The use of the single consistent data set allows the usage of the conventional $\chi2$ tolerance $\Delta\chi2 = 1$ when setting 68%CL experimental errors

NOTE the use of a pure proton target means no need for heavy target/deuterium corrections.

d-valence is extracted from CC e^+p without assuming d in proton= u in neutron

All data are at high W (> 15 GeV), so high-x, higher twist effects are negligible.

HERAPDF evaluates model uncertainties and parametrisation uncertainties in addition to experimental uncertainties

HERAPDF2.0 is based on the new final combination of HERA-I and HERA-II data which supersedes the HERA-I combination and supersedes all previous HERAPDFs

HERAPDF2.0Jets fits add HERA Jet data to this.

HERAPDF specifications: parameterisation and χ2 definition

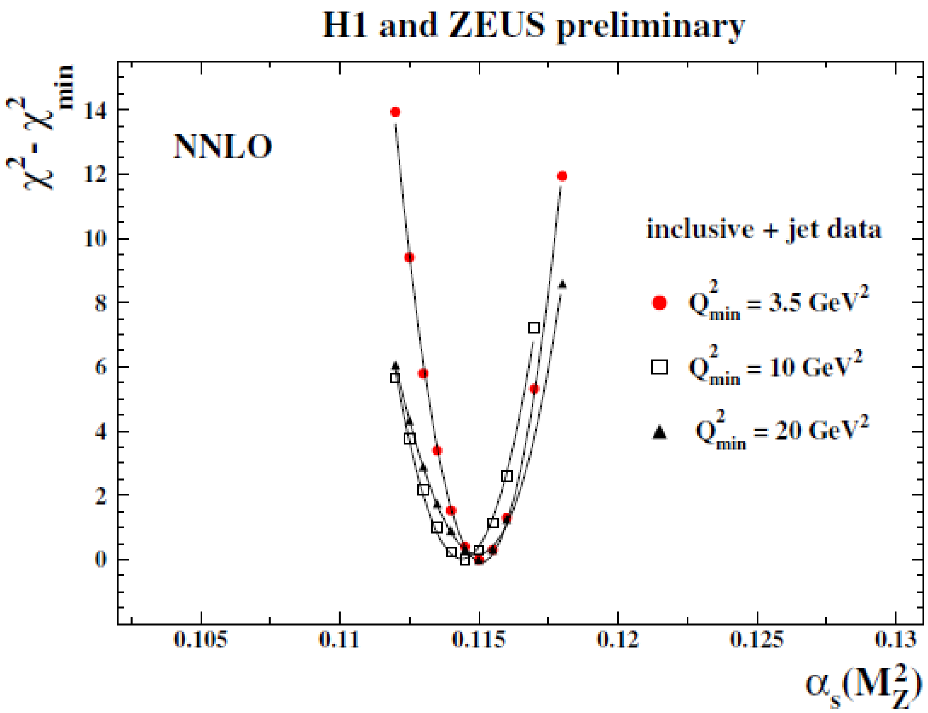
For the NLO and NNLO fits the central parametrisation at $Q^2_0 = 1.9$ GeV^2 is

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

QCD sum-rules constrain A_g, A_{uv}, A_{dv}
$x\bar{s} = f_s x\bar{D}$ sets the size of the strange PDF and the constraints $B_{\bar{U}} = B_{\bar{D}}$ and $A_{\bar{U}} = A_{\bar{D}}(1-f_s)$ ensure $x\bar{u} \rightarrow x\bar{d}$ as $x \rightarrow 0$.

- There are 14 free parameters in the central fit determined by saturation of the χ2
- But extra D and E parameters are added to all flavours of PDF for parametrisation uncertainty plus Ag'=0 for no negative gluon term is also checked.
- $\alpha_S(M_Z)$ = 0.118, 0.115, free $\alpha_S(M_Z)$
- PDFs are evolved using the DGLAP equations using QCDNUM and convoluted with coefficient functions to evaluate structure functions and hence measurable cross sections
- Heavy quark coefficient functions are evaluated by the Thorne Roberts Optimized Variable Flavour Number scheme – this is the standard, unless otherwise stated
- Jet predictions from NNLOJet (T.Gehrmann et al) via Applfast

Since it is well known that HERA data at low x and Q^2 may be subject to the need for ln(1/x) resummation or higher twist effects we also perform χ2 scans with harder Q^2 cuts



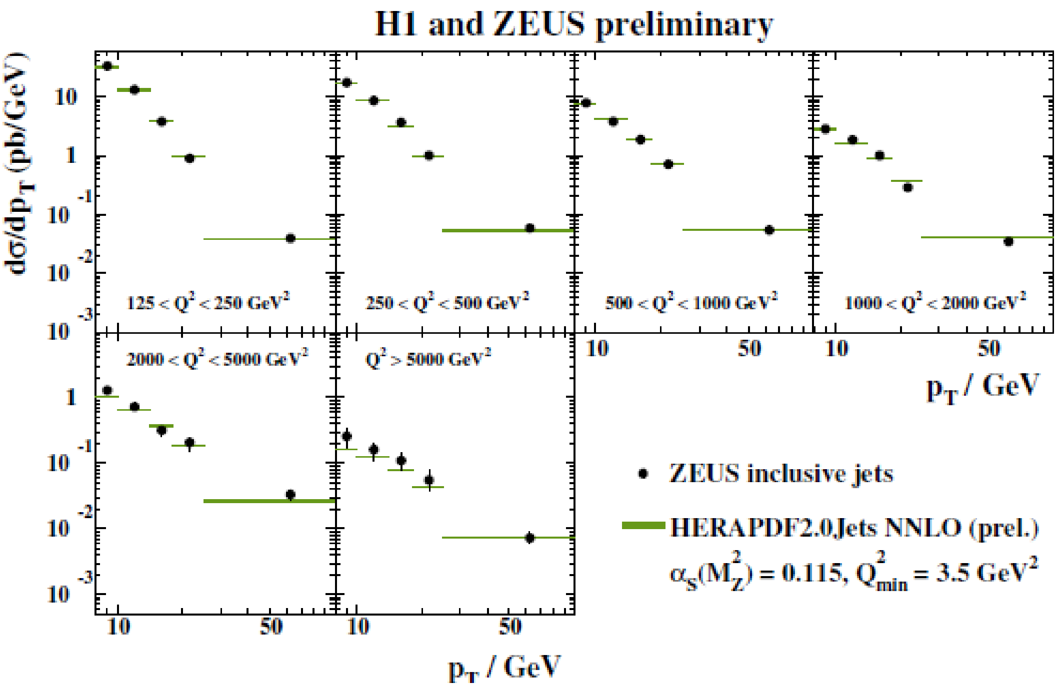
The Q^2 cuts do not result in any significant change to the value of $\alpha_s(M_Z)$ that is determined

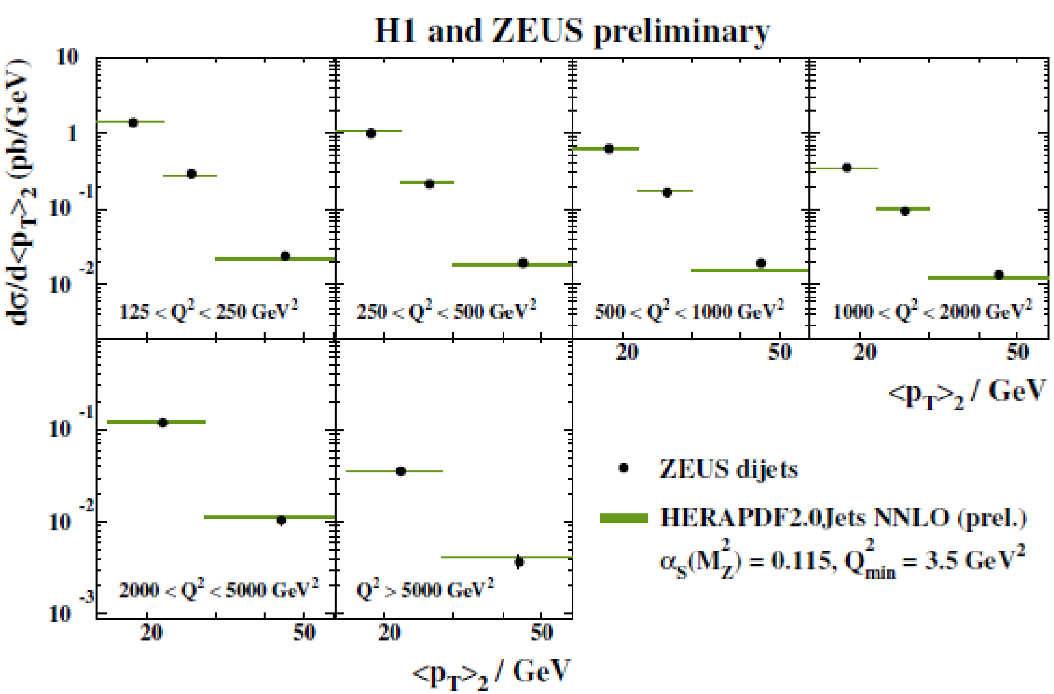
The central values from the three scans are:

$\alpha_s(M_Z) = 0.1150 \pm 0.0008$ $Q^2 > 3.5$ GeV^2

$\alpha_s(M_Z) = 0.1144 \pm 0.0010$ $Q^2 > 10$ GeV^2

$\alpha_s(M_Z) = 0.1148 \pm 0.0010$ $Q^2 > 20$ GeV^2





Now compare the HERAPDF2.0 Jets NNLO fit with $\alpha_s(M_Z)=0.115$ to the jet data

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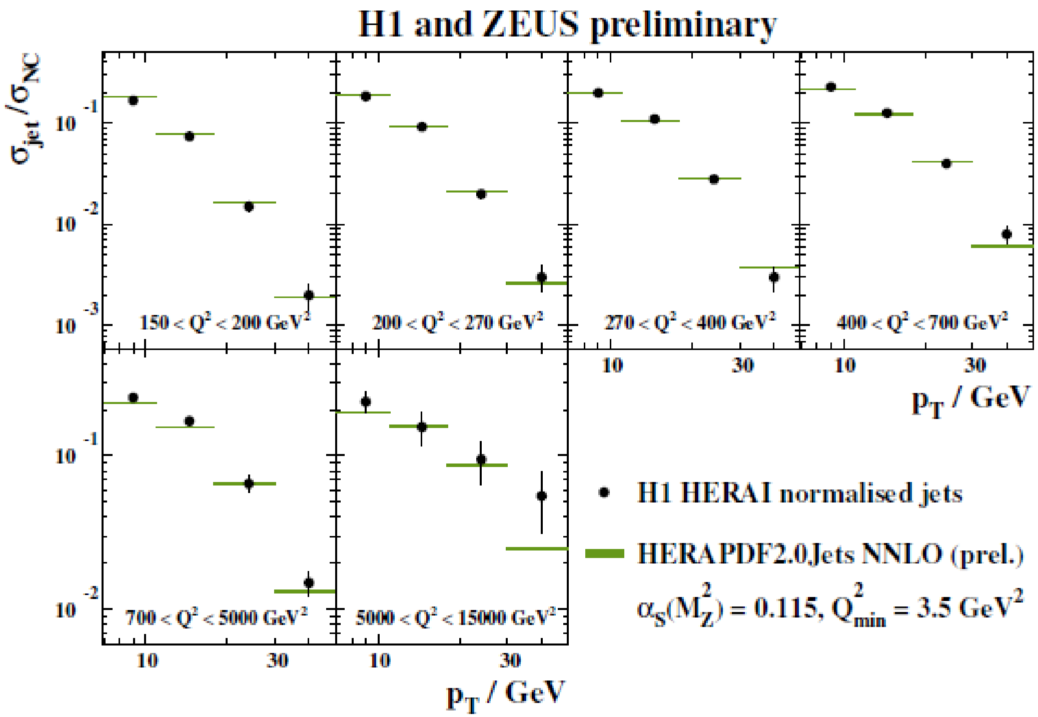

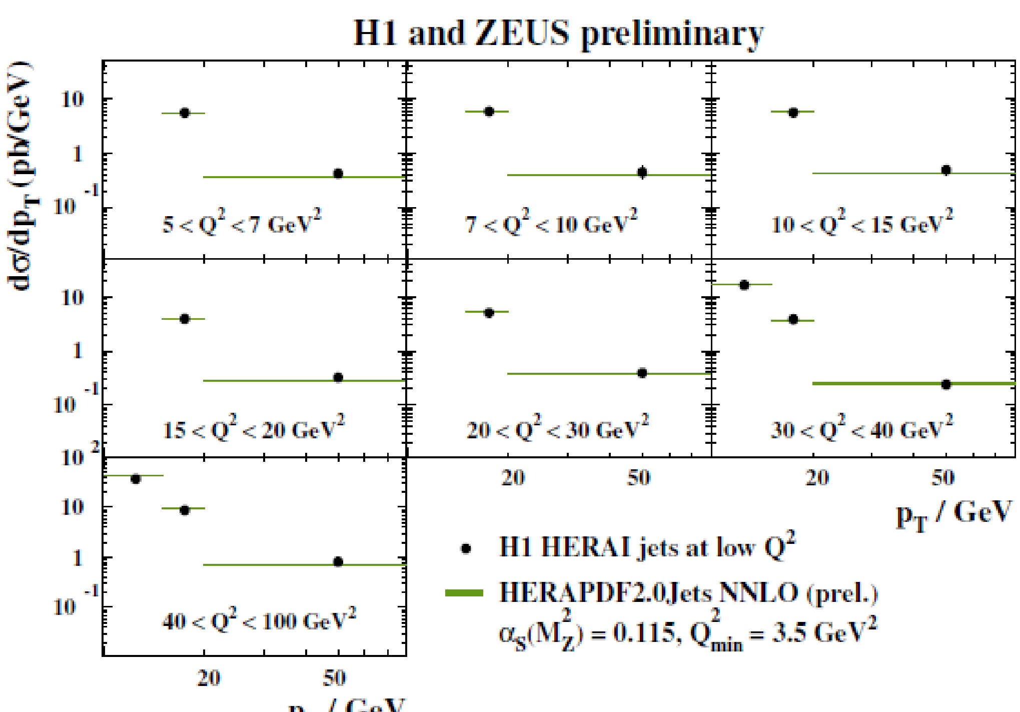

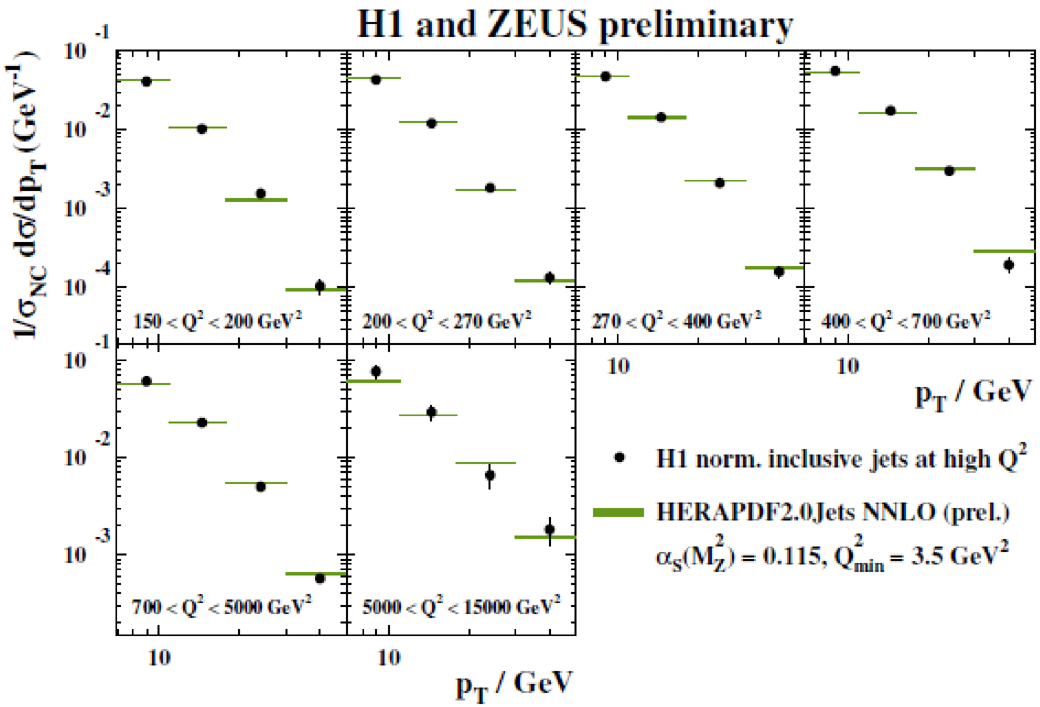

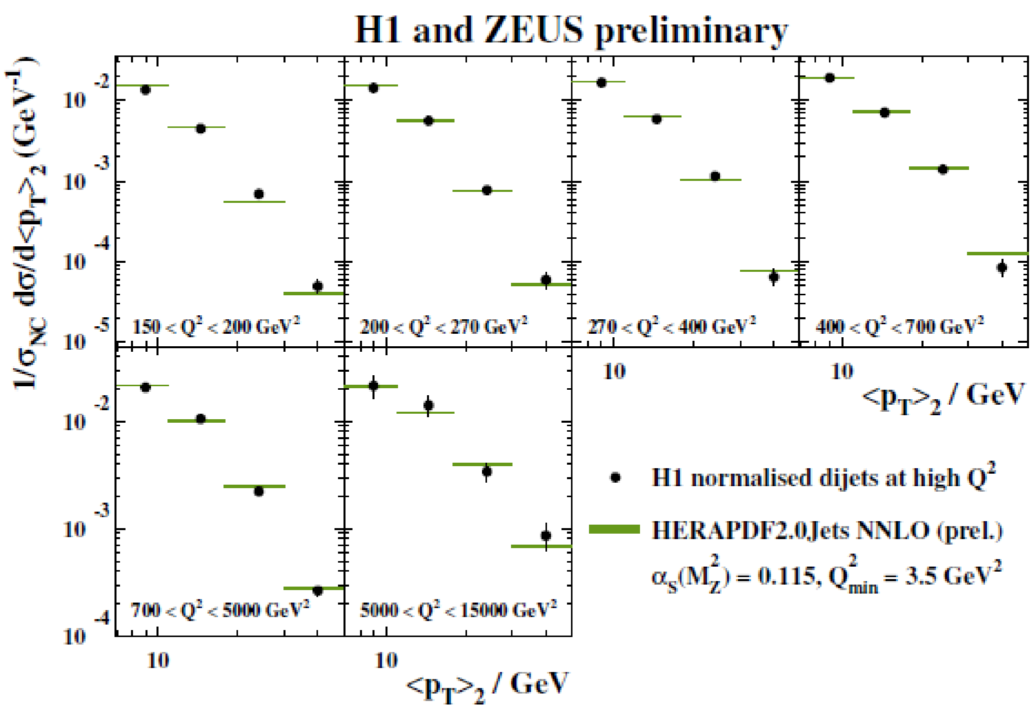

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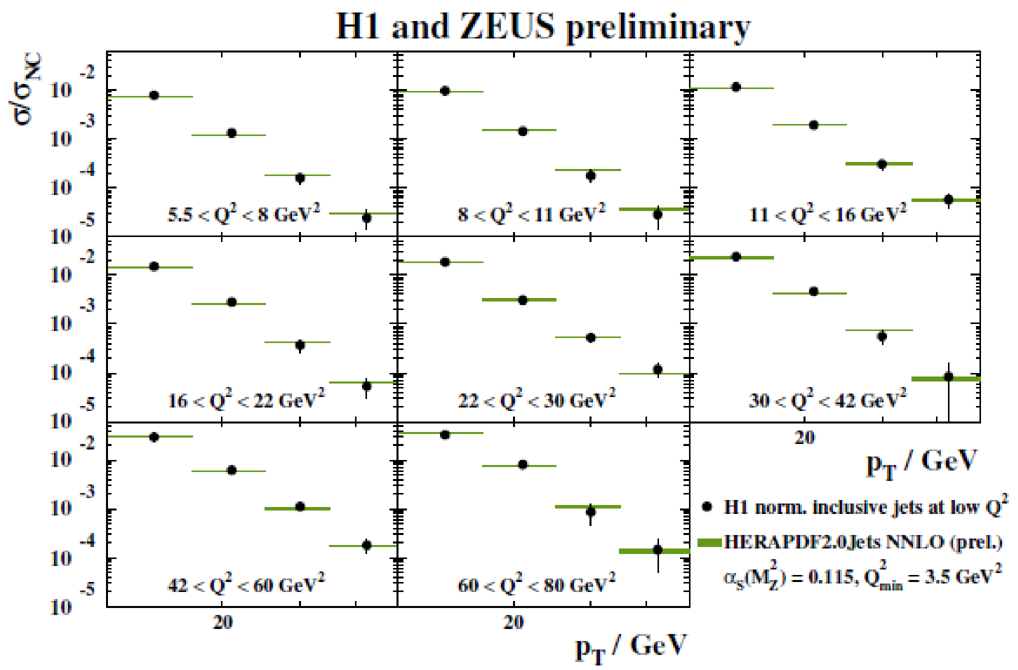
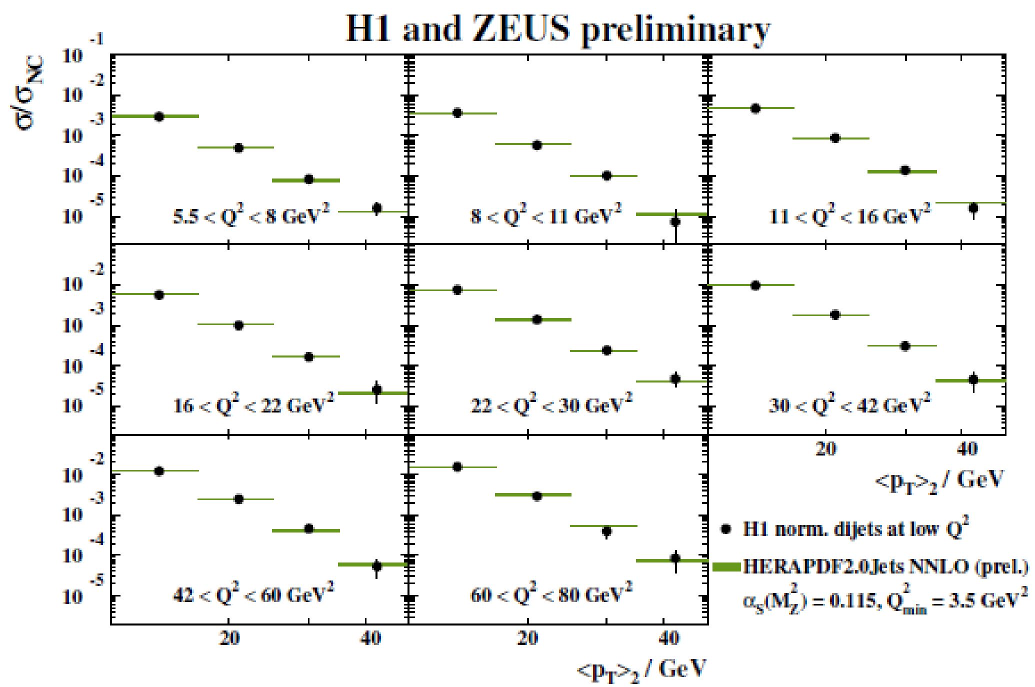
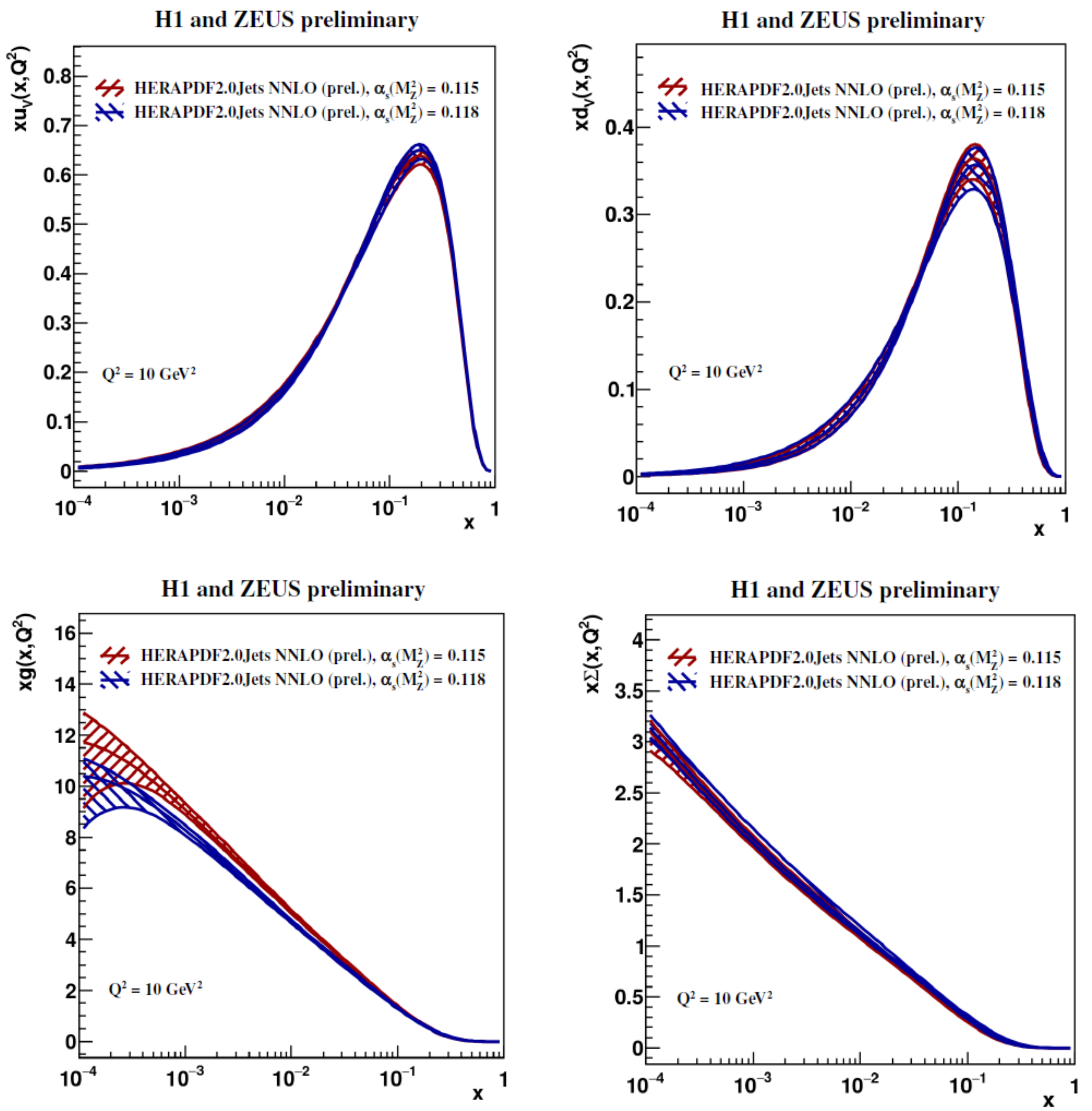




Compare PDFs for

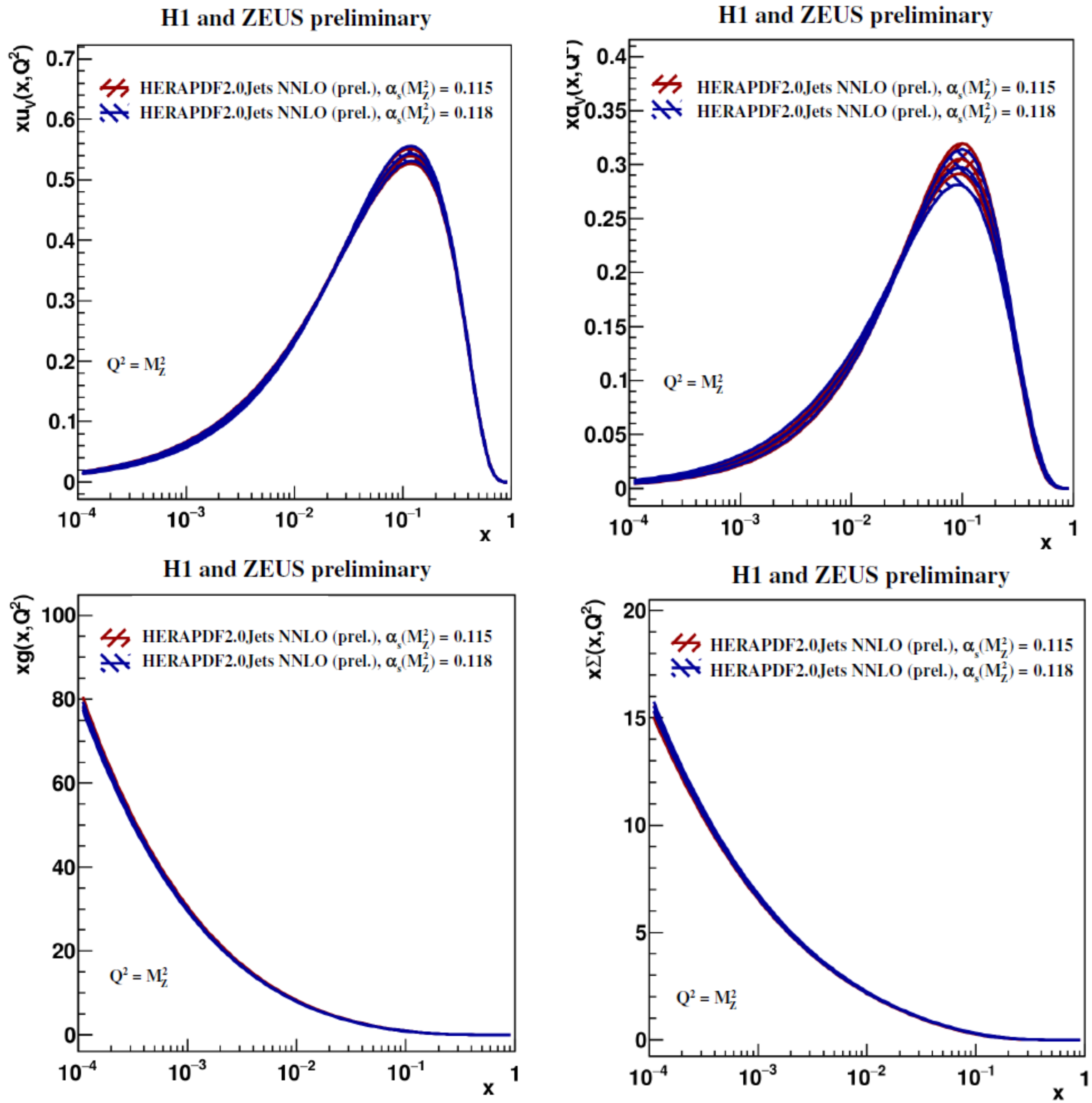
$\alpha_s(M_Z)$ =0.115 and
$\alpha_s(M_Z)$ =0.118



Compare PDFs for

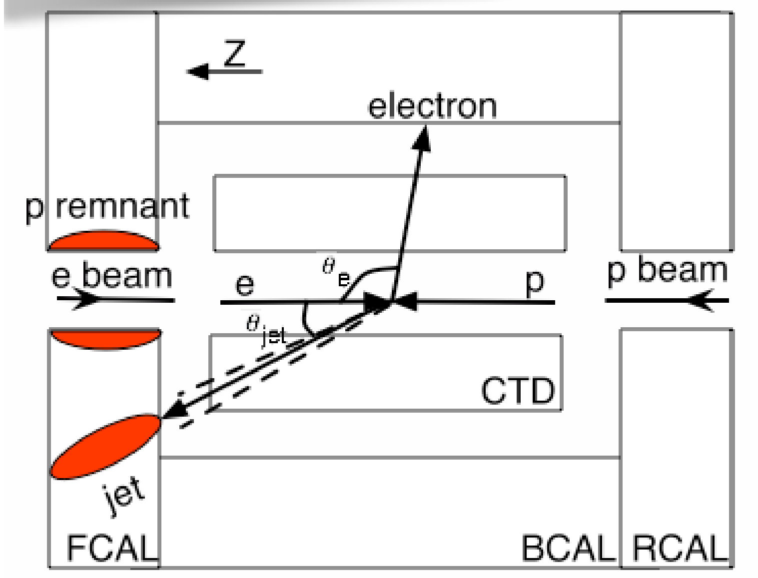
$\alpha_s(M_Z)$ =0.115 and
$\alpha_s(M_Z)$ =0.118

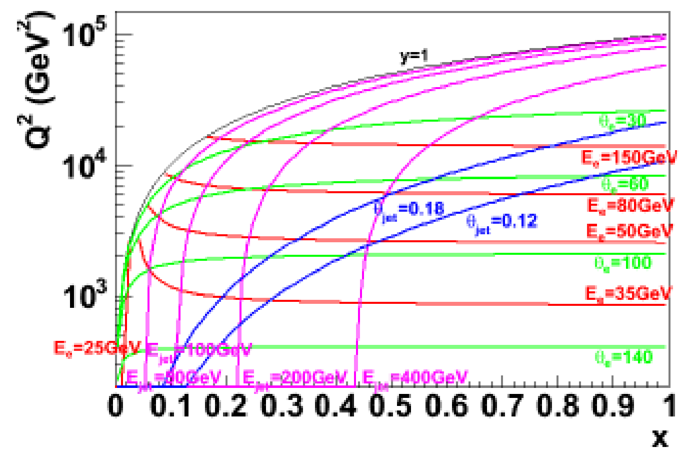
At high scale $Q^2 = M_Z^2$



Measurement of neutral current $e^{\pm}p$ cross sections at high Bjorken x with the ZEUS detector

H. Abramowicz *et al.* (ZEUS Collaboration)
Phys. Rev. D **89**, 072007 – Published 8 April 2014





At high Q^2, scattered electron seen with ≈100% acceptance
For not too high x, measure x from jet and measure in small bins
For $x > x_{Edge}$, measure integrated cross section to x=1

4

Transfer Matrix : Probability of an event reconstructed in j^{th} bin to come from i^{th} true bin

Tracing back the path of MC reconstructed events in the generated x-Q^2 phase space

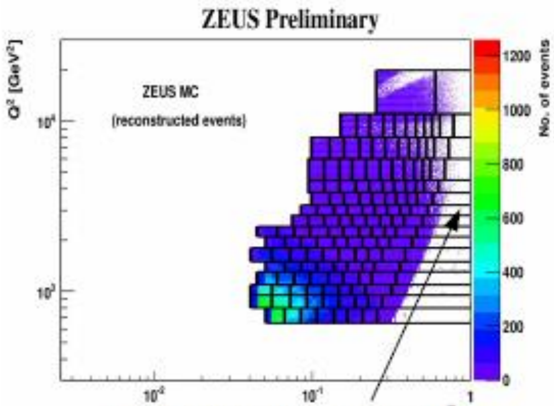
$$a_{ij} = \frac{\sum_{m=1}^{M_i} \omega_m I(m \in j)}{\sum_{m=1}^{M_i} \omega_m^{MC}}$$

a_{ij} = probability of an event reconstructed in j^{th} bin to come from i^{th} bin

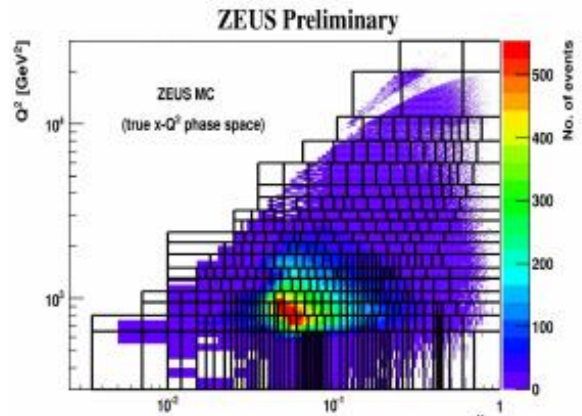
ω_m = MC weights given to m^{th} event in bin i

I = 1 if m^{th} event is reconstructed in bin j, else = 0

M_i = total events generated in i^{th} bin



Reconstructed MC events in xsection binning 'N' (total 153 bins)



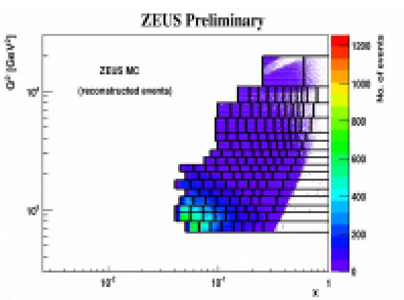
Generated distribution of these events in extended binning 'M' (total 429 bins)

Using Transfer matrix to predict no. of events reconstructed in a given cross section bin

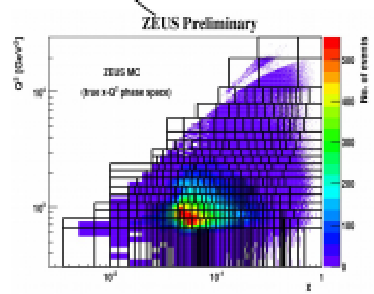
N = T M

Transfer Matrix

(153 X 429 elements)



Predicted x-Q2 events in Cross section binning
(153 elements in N Vector = number of cross section bins)



Generated x-Q2 events in Extended binning

(429 elements in M Vector = number of generated bins)

HERA-II data

- High-Q^2 region: $Q^2 > 150\ \mathrm{GeV}^2$
- Luminosity: $L = 351\ \mathrm{pb}^{-1}$

Signal Monte Carlo models

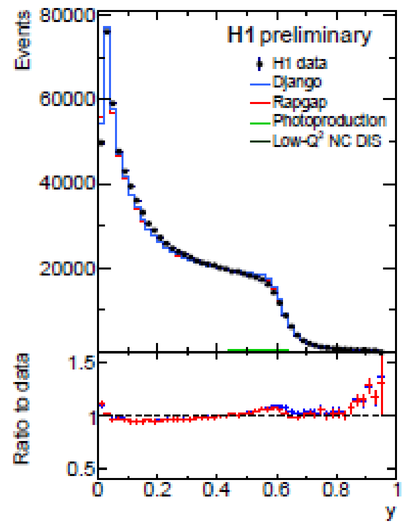
- Rapgap (ME + PS)
- Djangoh (CDM)

Little background in incl. DIS

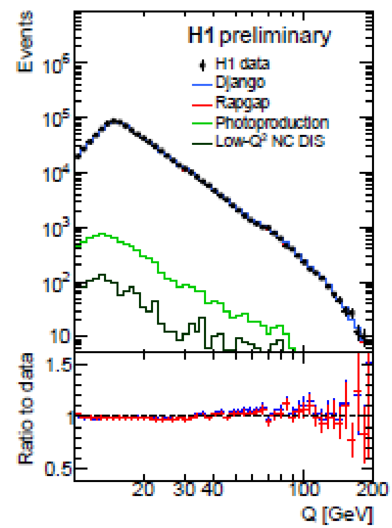
- Photoproduction
- Low-Q^2 NC DIS
- Other sources are negligible (QEDC, CC DIS, di-lepton production)

Reconstruction

- Use the IΣ method → Independent of electron ISR



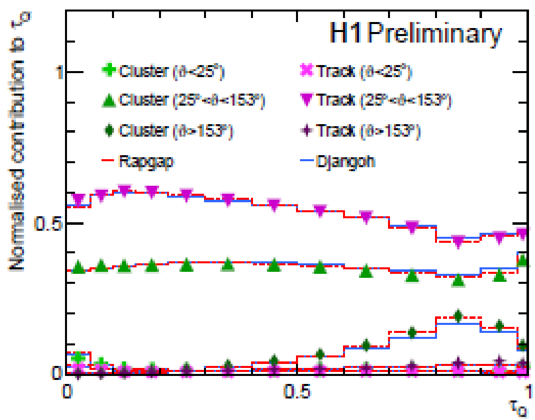
$$y = y_\Sigma = \frac{\Sigma}{\Sigma + E_{e'}(1 - \cos\vartheta_{e'})}$$

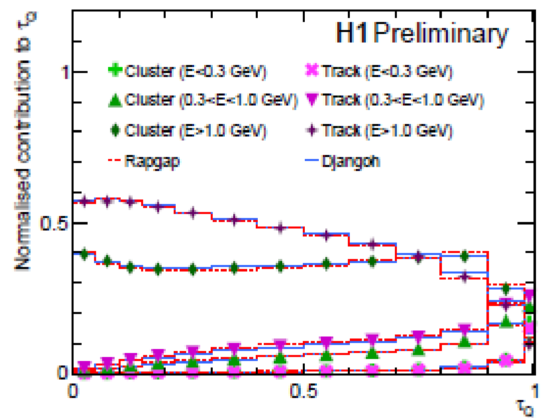


$$Q^2 = Q^2_\Sigma = \frac{E^2_{e'}\sin\vartheta_{e'}}{1 - y_\Sigma}$$

DIS thrust - a 4π observable

- All particle candidates in all DIS events contribute $\left(\tau_Q = 1 - \frac{2}{Q}\sum_{i\in\mathcal{H}_C} P_{z,i}^{Breit}\right)$
- Normalised contribution to τ_Q for different ranges in polar angle ϑ and energy



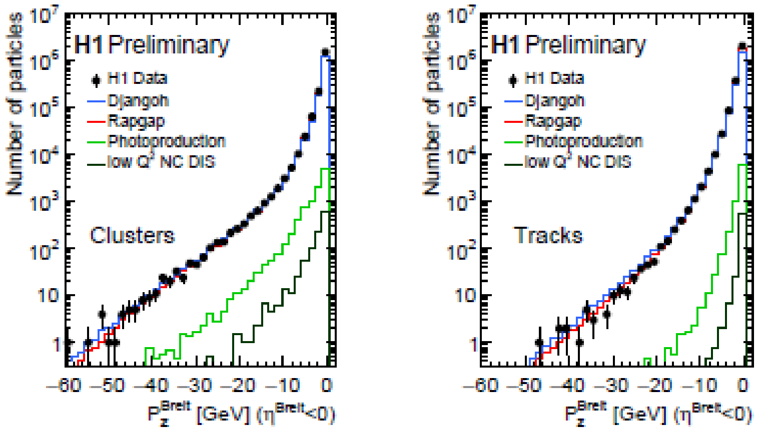


- Mainly tracks and clusters in the central part of the detector contribute ($25^\circ < \vartheta < 153^\circ$)
- Mainly particles with high energy contribute ($E > 1$ GeV)
  $\Rightarrow$ Well measured particles dominate in τ_Q

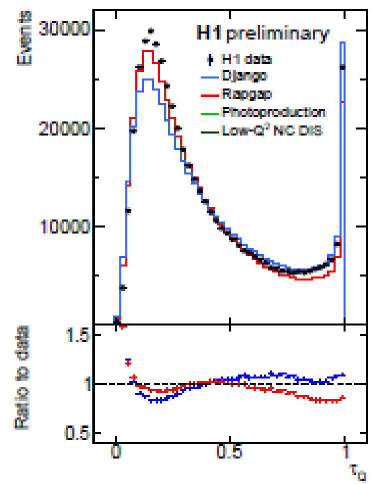
1-jettiness - DIS thrust

DIS thrust: Sum of longitudinal momenta

- Longitudinal momentum distribution of single particles in the current hemisphere
- Particles are well modelled by simulation for clusters and tracks



- $\tau_Q \to 0$: DIS 1-jet events
- $\tau_Q \to 1$: Dijet events
- $\tau_Q = 1$: Dijet event, both jets in beam hemisphere



- Reasonable agreement between data and MC
- Full τ_Q range measurable