Alphas from HERA

Voica Radescu
(Physikalisches Institut Heidelberg)
on behalf of the H1 and ZEUS Collaborations

Outline:

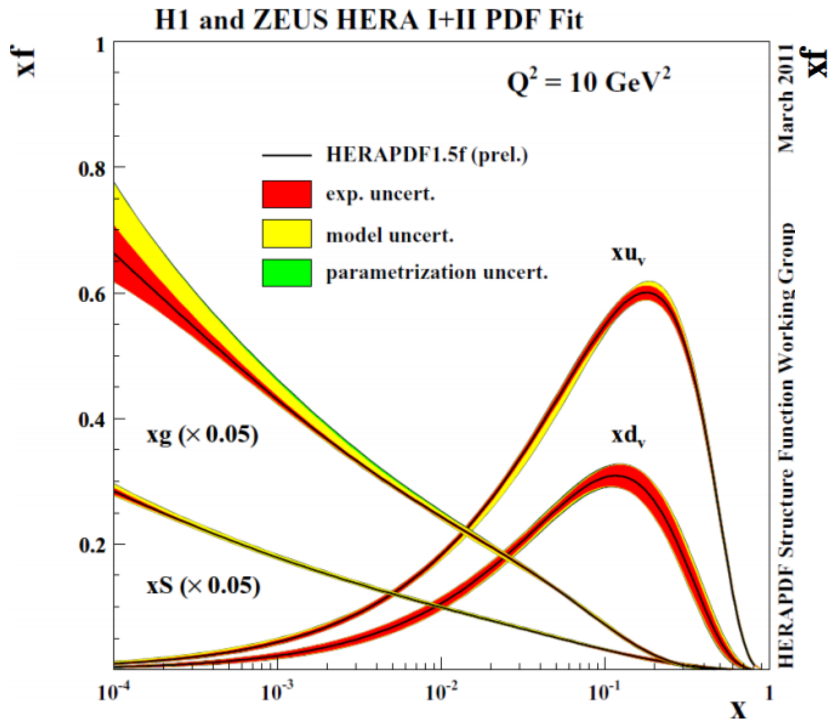
- Impact of inclusion of Jet Data in the HERAPDF fits
- New preliminary Jet measurements from HERA and their impact on alphas
- Summary

HERAPDF1.5f with free alphas (no jets)

- The strong coupling is tightly correlated to the gluon PDF in fits to inclusive data where gluon is determined from the scaling violations:
  - Comparison of the PDFs (fixed alphas) and PDF+alphas fit using DIS inclusive data only:

NO JETS, just inclusive HERA I+II data, HERAPDf1.5f:

Fixed alphas=0.1176 (no jets)



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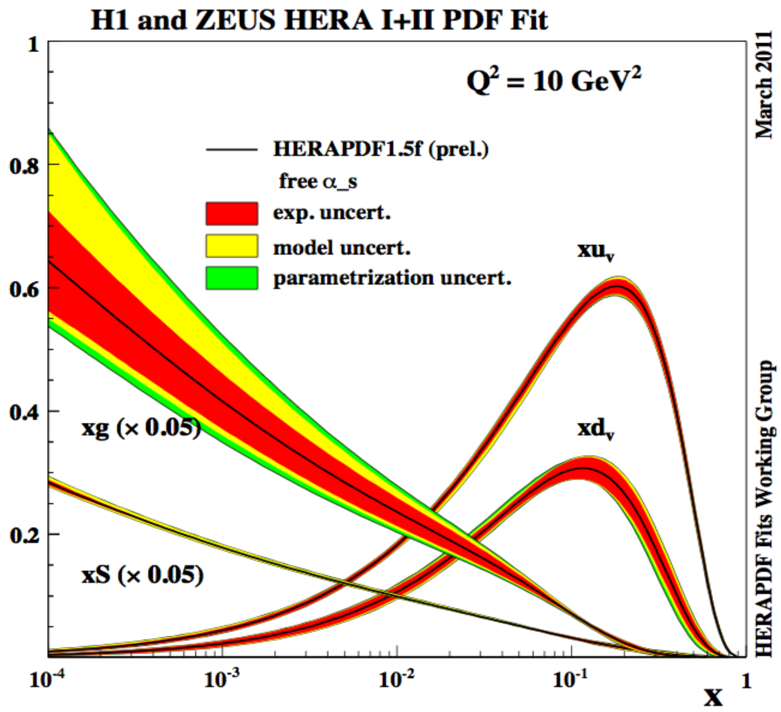

What HERA jet data in PDF+alphas fits?

- Only Inclusive Jet ep data have been used in the simultaneous PDF+alphas fits:
  - High Q^2 (Q^2>125 GeV^2) inclusive jet production from ZEUS (HERA I)

    [PLB547,164(2002)] 38/pb 1996-1997

    [NPB765,1(2007)] 82/pb 1998-2000
    - Scale of the jet measurement: E_T of the leading jet
    - Experimental uncert: ~15 % uncorr, 5% corr
    - Theoretical error:~5-10%
  - Low Q^2 (100>Q^2>5) inclusive jet production from H1 (HERA I)

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    - Scale of the jet measurement: sqrt((E_T^2+Q^2)/2)
    - Experimental uncert: ~9% uncorr, 8% corr
    - Theoretical uncert:~10-30%
  - High Q^2 (Q^2>150) normalised jet cross-sections from H1 (HERA I+II)

    [EPJC65,363(2010)] 395/pb 1999-2007
    - Scale of the jet measurement: sqrt((E_T^2+Q^2)/2)
    - Experimental error ~6% uncorr, 3% corr
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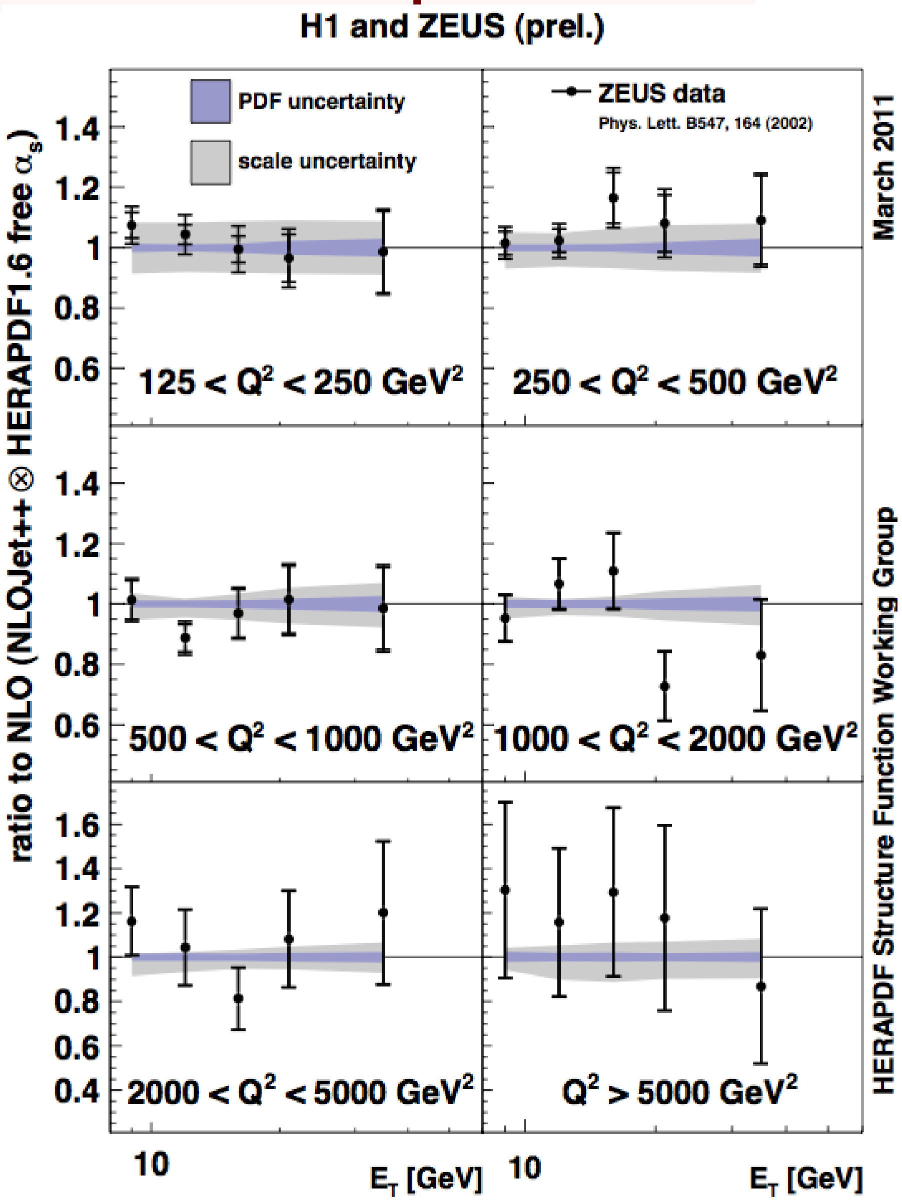
- NLOJet++/FastNLO used for the fast evaluation of the jet cross-sections



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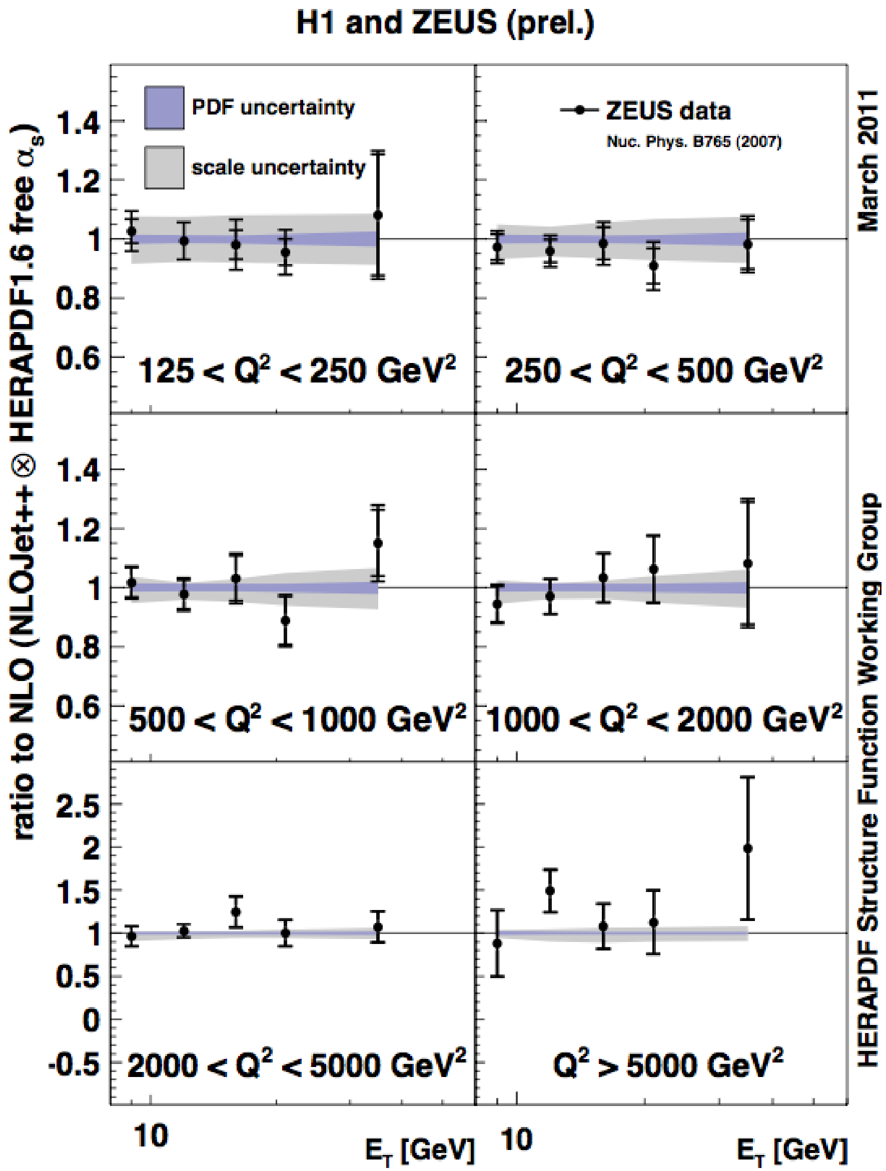

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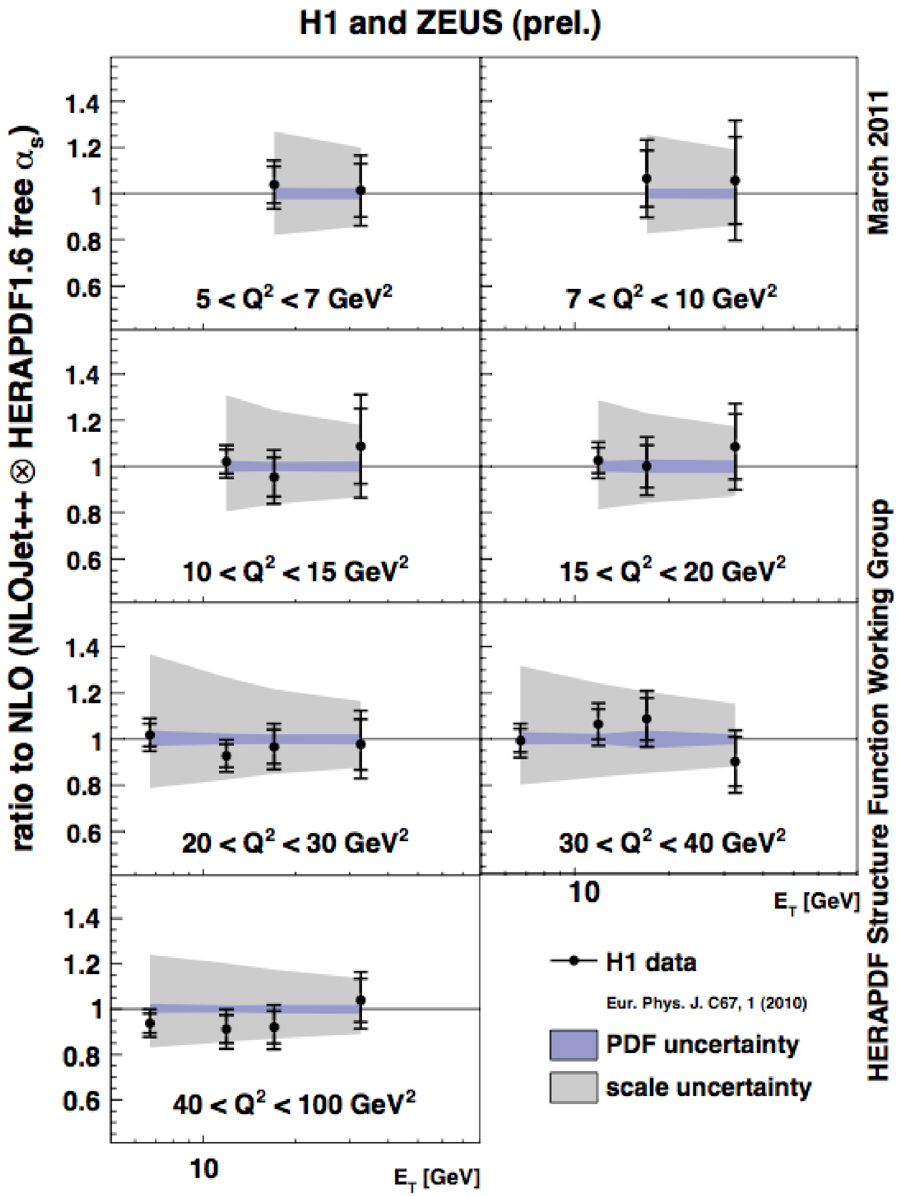

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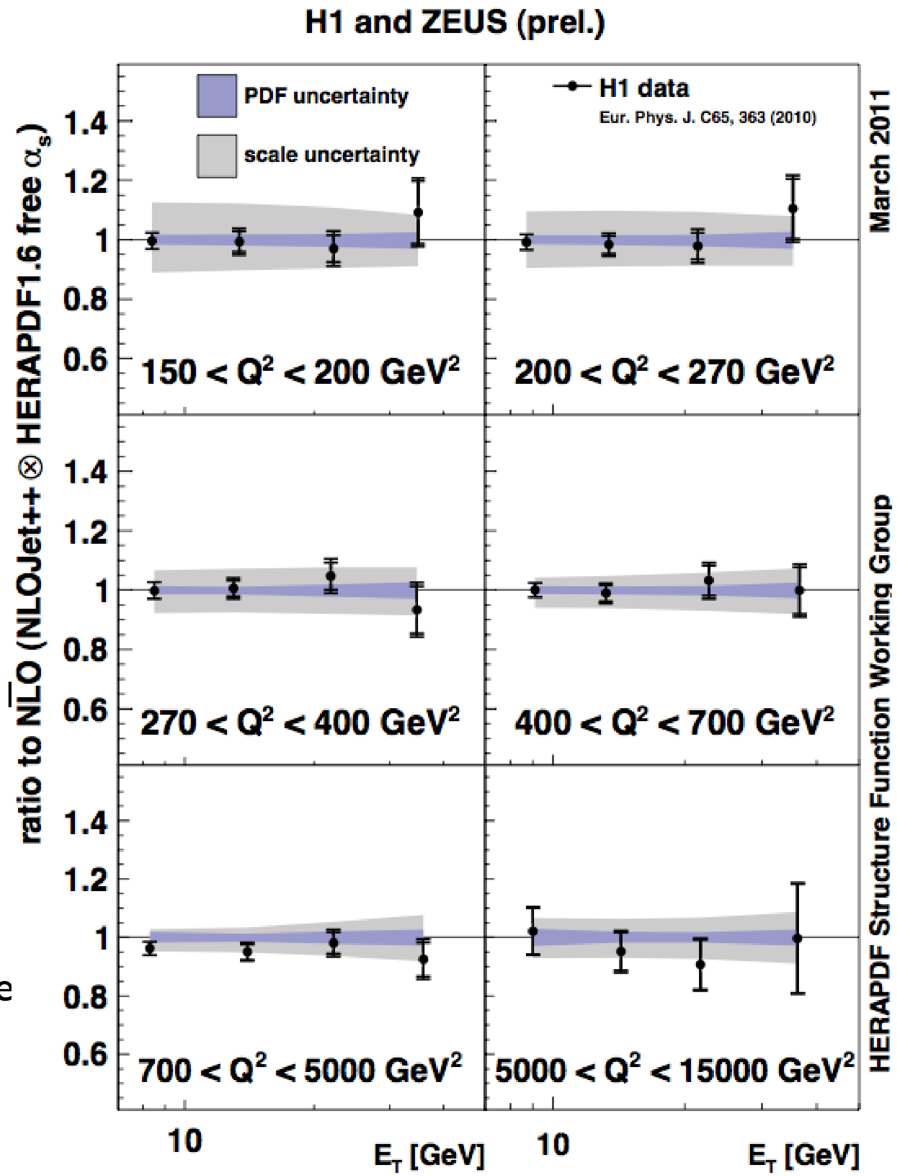
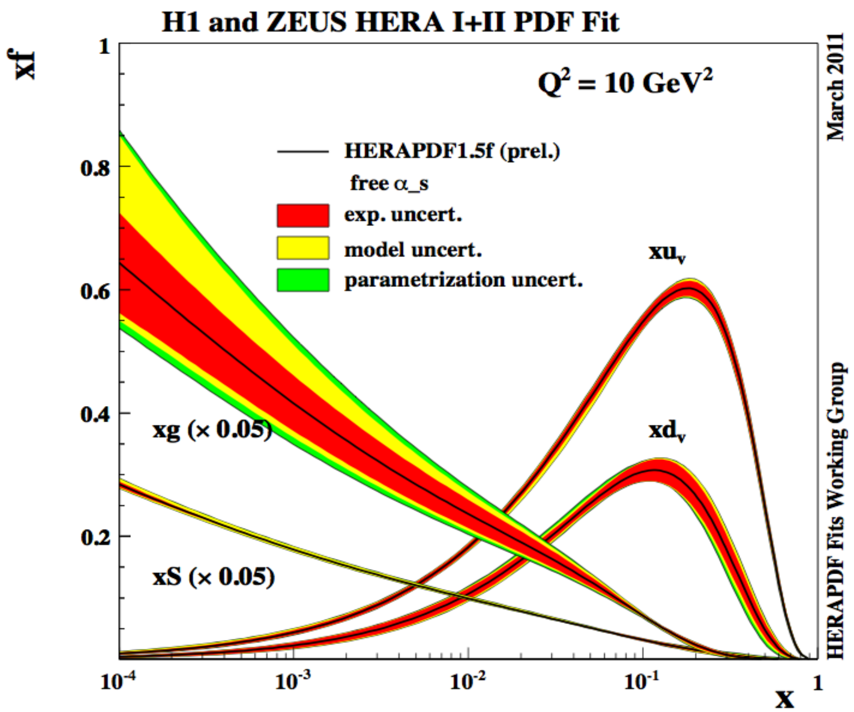


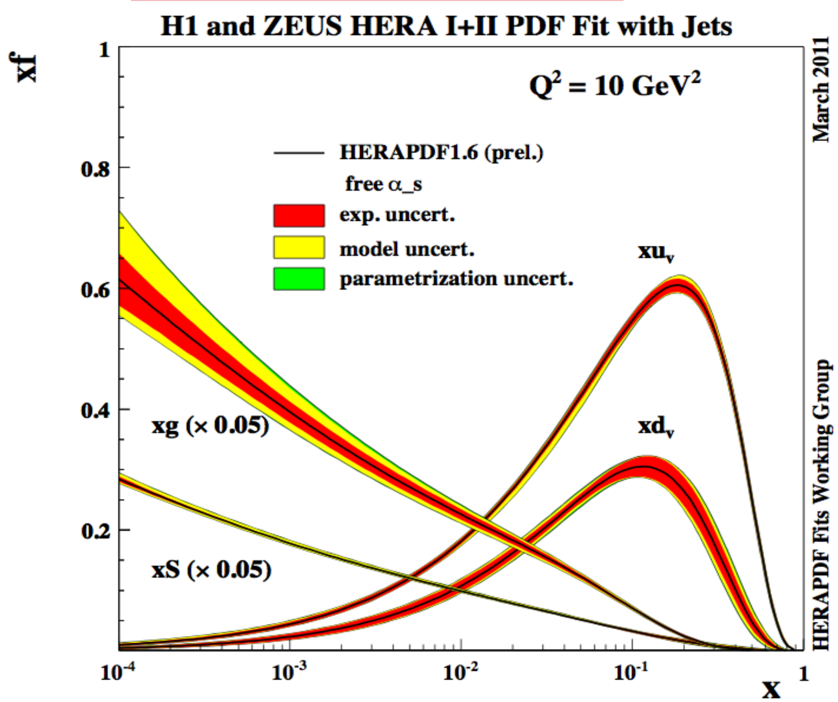
Including Jets: HERAPDF1.6

- The strong coupling is tightly correlated to the gluon PDF in fits to inclusive data where gluon is determined from the scaling violations
- Addition of the HERA Jet cross section data (NLOJet++/fastNLO) into the fits allows to constrain simultaneously alphas and gluon [not yet combined jet data, H1 and ZEUS]
  - Comparison of the PDFs with free alphas fit with and without Jet data

Free alphas (no jets)



Free alphas (with jets)



- The uncertainty on the low-x gluon is reduced dramatically once Jet data is included in the fit:

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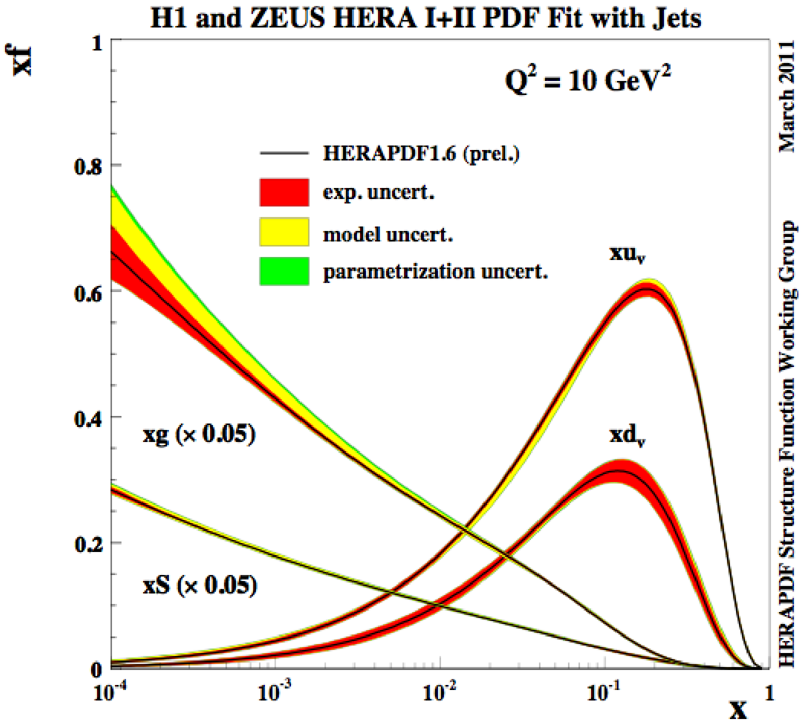
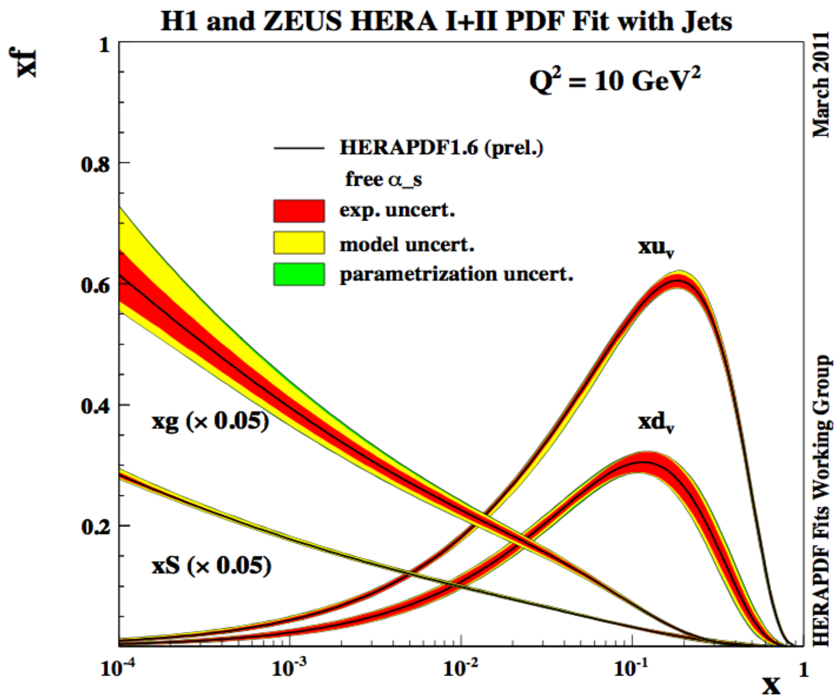
Fixed alphas (with jets)



Free alphas (with jets)



Including Jets: HERAPDF1.6

HERAPDF1.6 $\alpha_S(M_Z)$ =0.1176 fixed

HERAPDF1.6	χ2	ndp
All data	811.5	780
Inclusive cross sections	730.2	674
Jet cross sections	81.3	106

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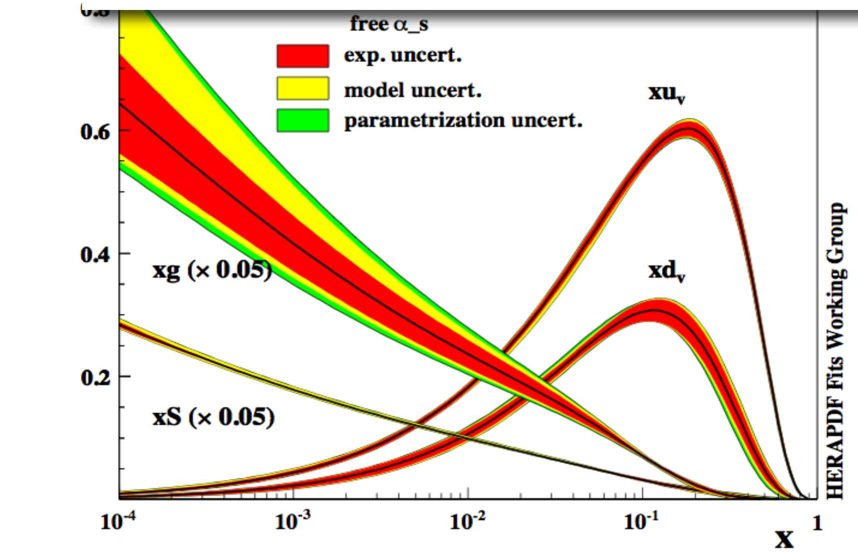
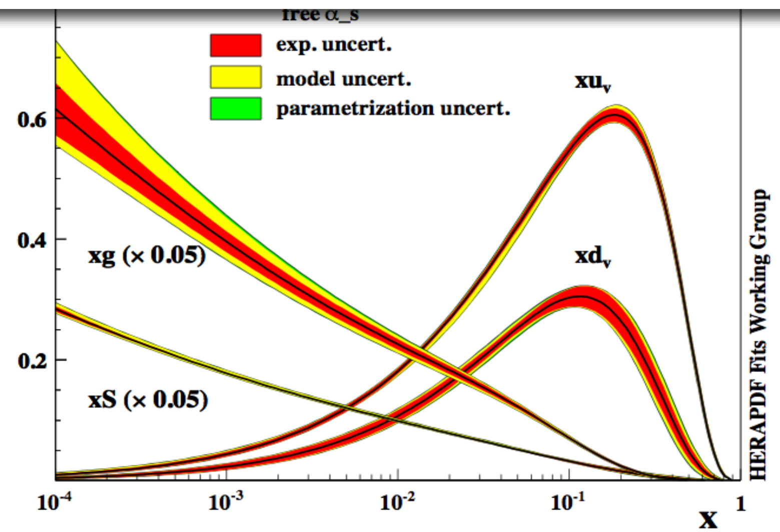


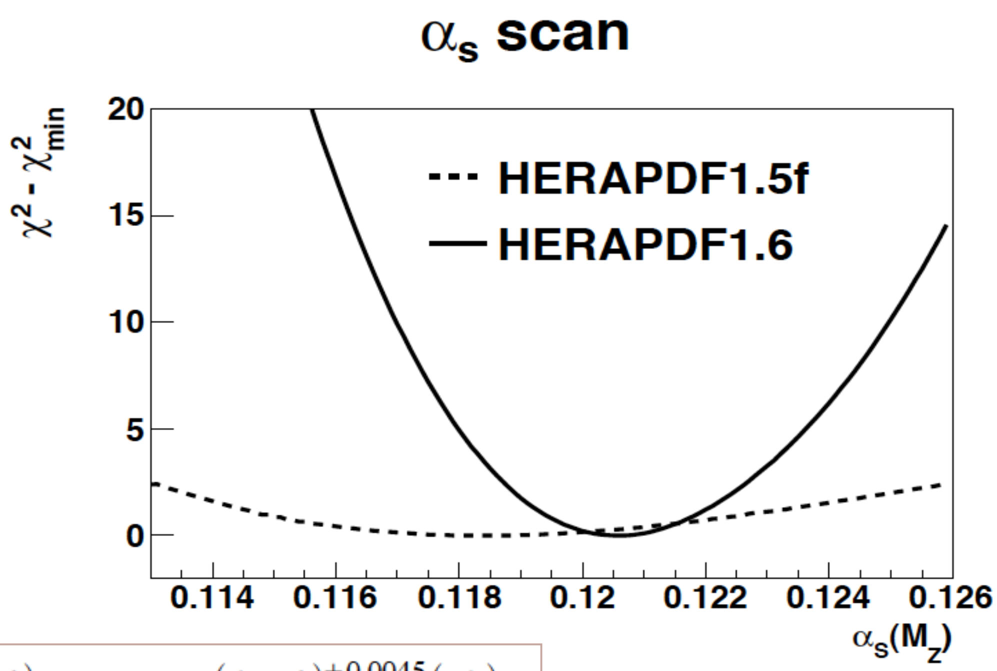


- The uncertainty on the low-x gluon is reduced dramatically once Jet data is included in the fit:

Impact of the jet data on α_S

- Comparison of the chisquare scan versus strong coupling for:
  - HERAPDF1.5f - no jet data
  - HERAPDF1.6 - with jets

- Without jet data the chisquare has only a shallow dependence on strong coupling

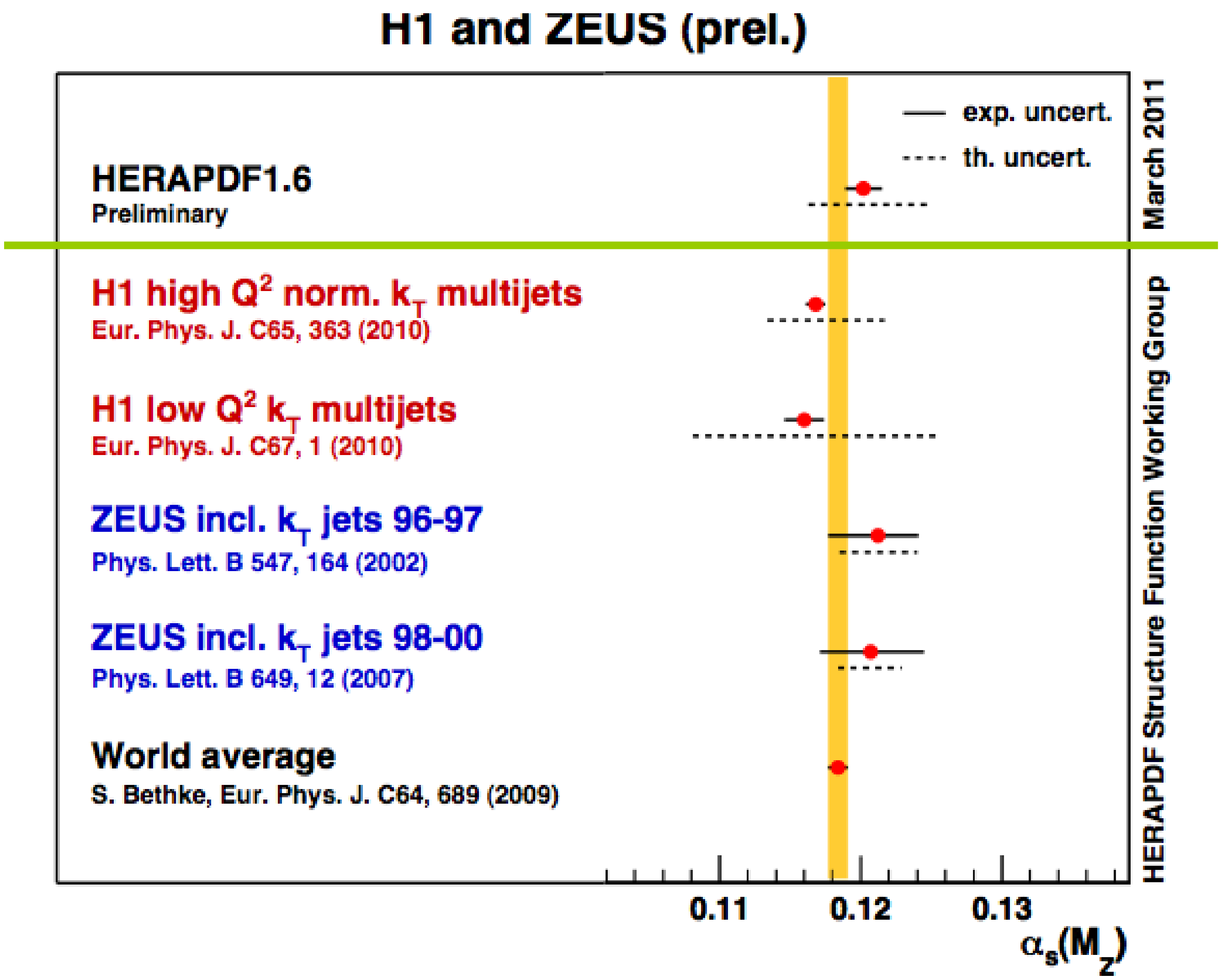


$\alpha_S(M_Z)$ = 0.1202 ± 0.0019 ± scale error

$$\alpha_s = 0.1202 \pm 0.0013\,(\exp) \pm 0.0007\,(mod) \pm 0.0012\,(had)^{+0.0045}_{-0.0036}\,(th)$$

- Jet data have non negligible correlated errors (~5%) which are treated fully correlated
- Predictions for jet cross sections need hadronisation corrections and the uncertainties of the hadronisation corrections are evaluated by OFFSET method (for now)
- The uncertainty due to missing higher orders in the perturbative calculations is estimated by changing the renormalisation and factorisation scales of both the inclusive and jet data by a factor 2.

Summary comparison plot

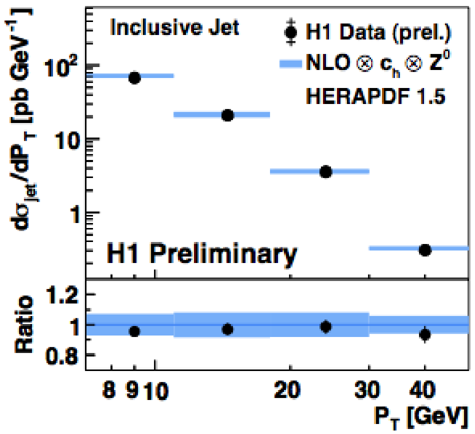


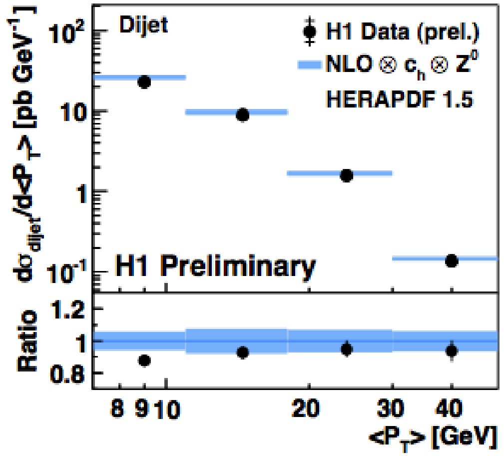
- For HERAPDF1.6
  - PDF uncertainty is part of the experimental uncertainty
- For H1:
  - PDF uncertainty is part of the theoretical uncertainty
- For ZEUS:
  - PDF uncertainty is part of the experimental uncertainty

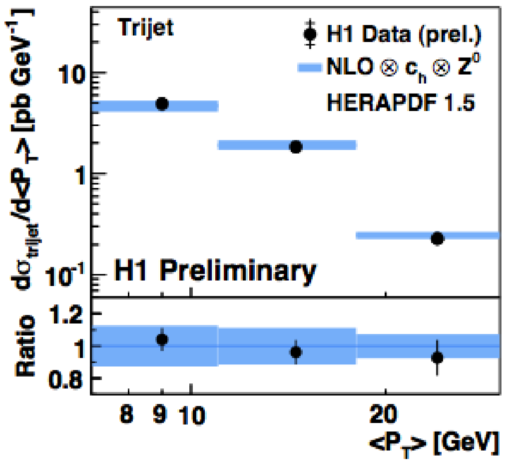
New preliminary measurements from H1

- From H1 in DIS regime:
  - Multijet Cross Section at High Q^2 (Q^2 >150 GeV^2) based on HERA II data
    - **Inclusive, Dijet, Trijet**
    - **Single** and double differential
  - Main experimental uncertainties
    - Acceptance corrections: 1.5~8%
    - JES:2-5%
    - Lumi:2.5%
  - Hadronisation corrections:
    - Inclusive and Dijet (0.94-0.98)
    - Trijet (0.8-0.9)
  - Theoretical uncertainty obtained by varying the scale by a factor 2

- NLO calculations based on NLOJet++ using HERAPDF1.5 and scale of the jet measurement: sqrt((E_T^2+Q^2)/2)







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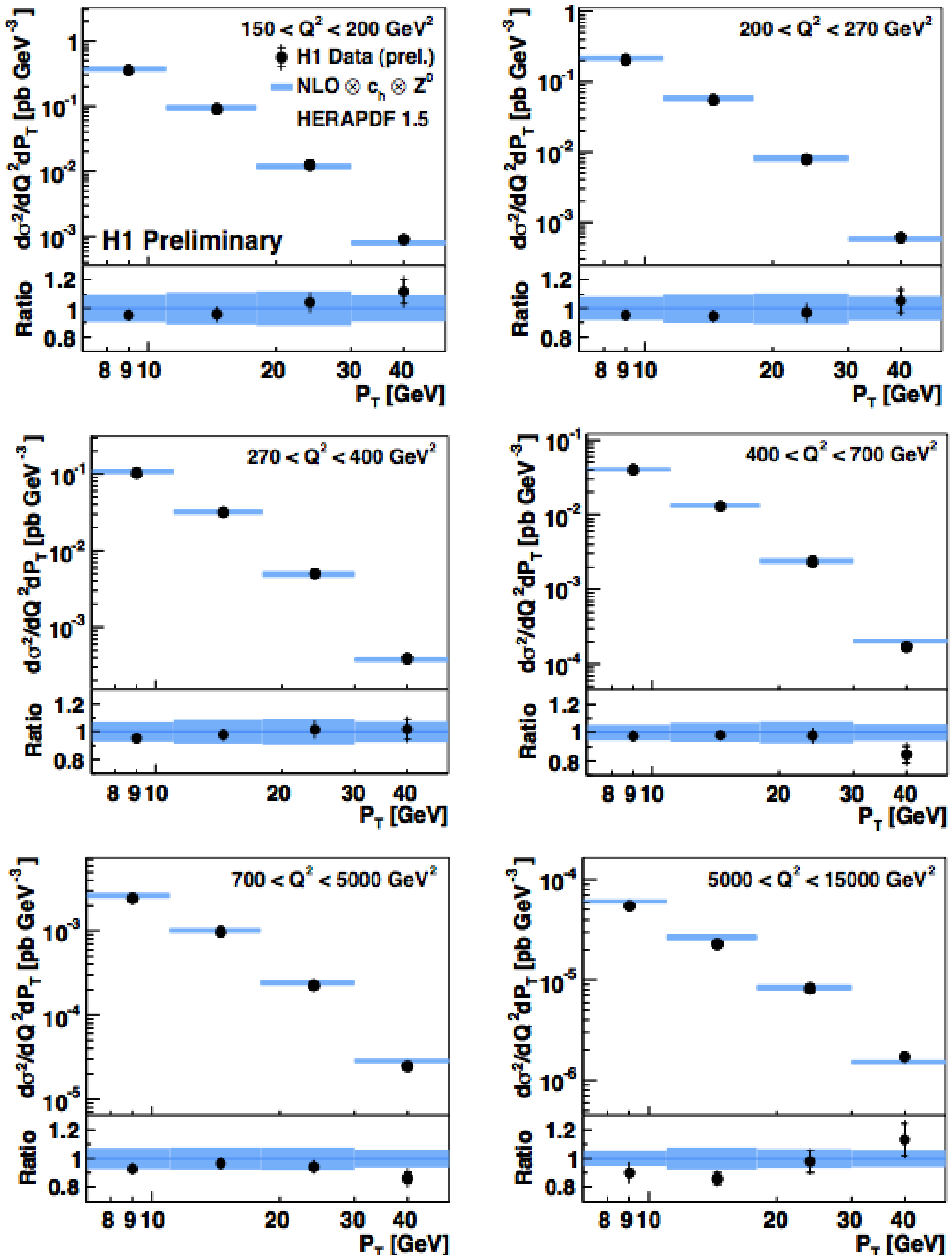


- NLO calculations based on NLOJet++ using HERAPDF1.5 and scale of the jet measurement: sqrt((E_T^2+Q^2)/2)

Determination of alphas from Multijet Cross sections

- NLO calculations depend on PDFs and alphas(Mz)
  - H1 analyses used CT10 PDF fixed and fit for alphas(Mz) assigning an additional error due to PDF uncertainty
  - Results:

Inclusive Jet:

$$\alpha_s(M_Z) = 0.1190 \pm 0.0021 \text{ (exp.)} \pm 0.0020 \text{ (pdf)} \ ^{+0.0050}_{-0.0056} \text{ (th.)}$$

Dijet:

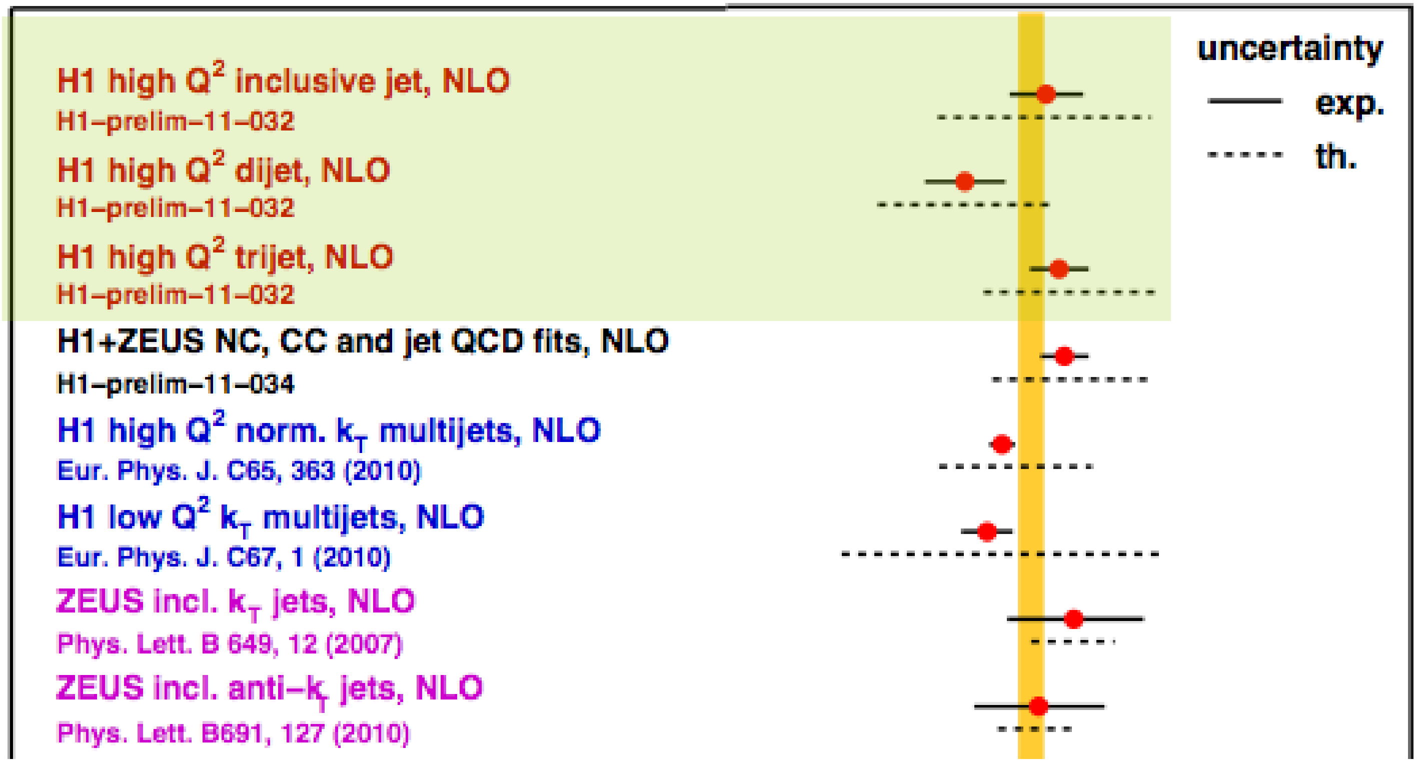
$$\alpha_s(M_Z) = 0.1146 \pm 0.0022 \text{ (exp.)} \pm 0.0021 \text{ (pdf)} \ ^{+0.0044}_{-0.0045} \text{ (th.)}$$

Trijet:

$$\alpha_s(M_Z) = 0.1196 \pm 0.0016 \text{ (exp.)} \pm 0.0010 \text{ (pdf)} \ ^{+0.0055}_{-0.0039} \text{ (th.)}$$

- Theoretical uncertainty dominates
- Alphas from trijet measurements yields the most precise experimental result

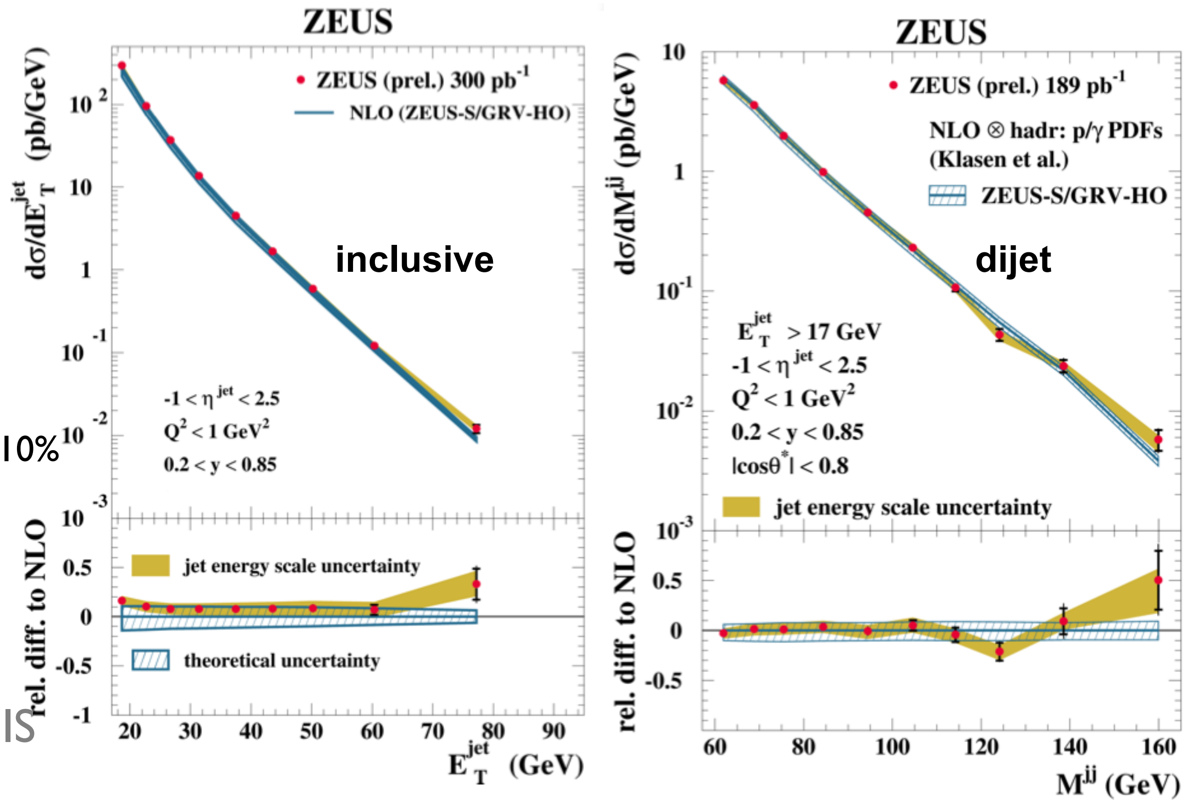
New summary comparison of the individual determination of alphas



- Alphas from jet measurements at HERA are in good agreement among each other and with world average
- Main uncertainty arises from the theoretical uncertainty: need improvement (calculations beyond NLO terms)

New preliminary measurements from Zeus

- Inclusive jets and dijets in the Photoproduction regime ($Q^2 < 1 GeV^2$):
  - Experimental uncertainties:
    - Uncorrelated: ~4%
    - Correlated (JES): 5-10%
  - Theoretical uncertainties:
    - Higher order corrections:~7-10%
    - Photon PDFs: 2-10%
    - Proton PDFs: 1-5%
    - Hadronisation: <2.5%
    - Alphas: <3.7%



- Inclusive jets and dijets in the DIS regime ($Q^2 > 500 GeV^2$):
  - Experimental uncertainties:
    - Uncorrelated: ~3-7% (inclusive)
      ~2-6% (dijets)
    - Correlated: 2-5%
  - Theoretical uncertainties:
    - Dominated by the scale for inclusive, negligible for dijets
    - PDF: ~4% for dijets <3% for inclusive

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- Inclusive jets and **dijets** in the DIS regime ($Q^2>125$ GeV^2):
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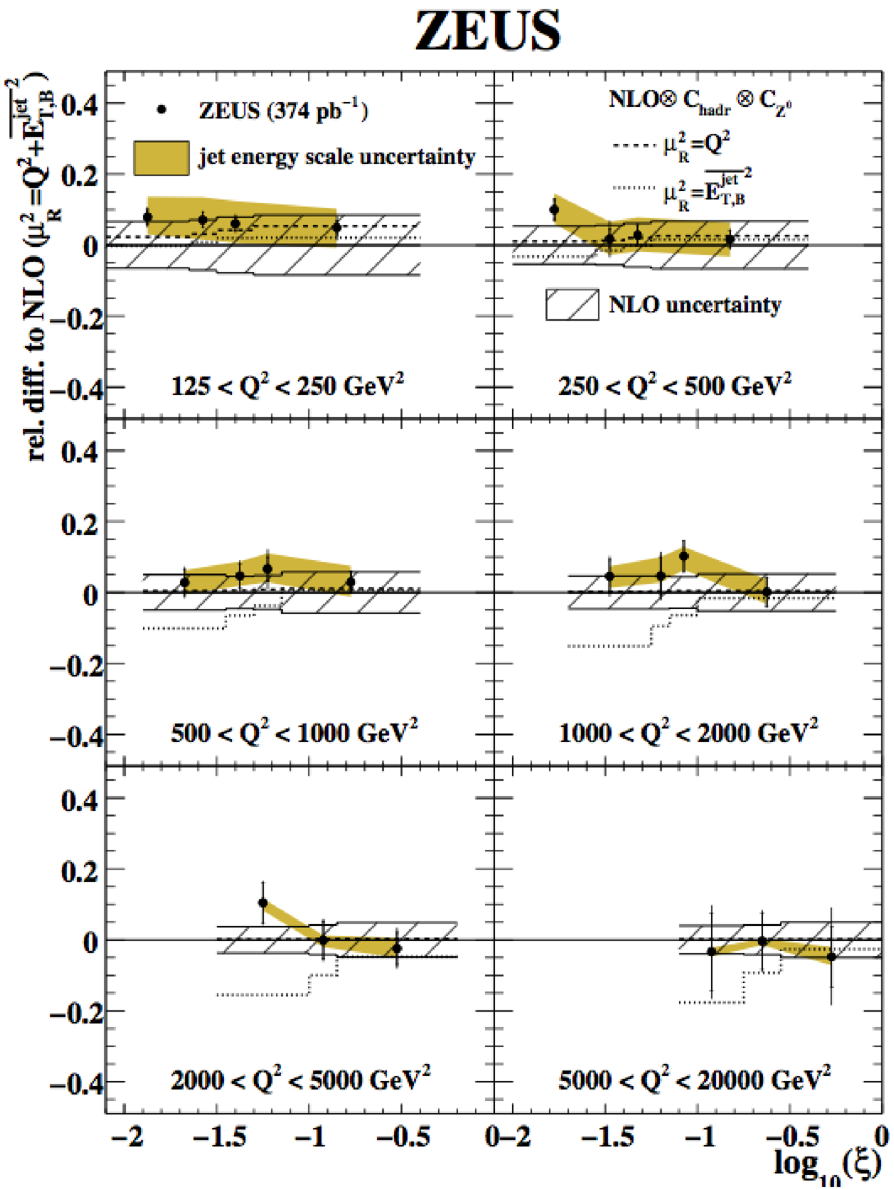

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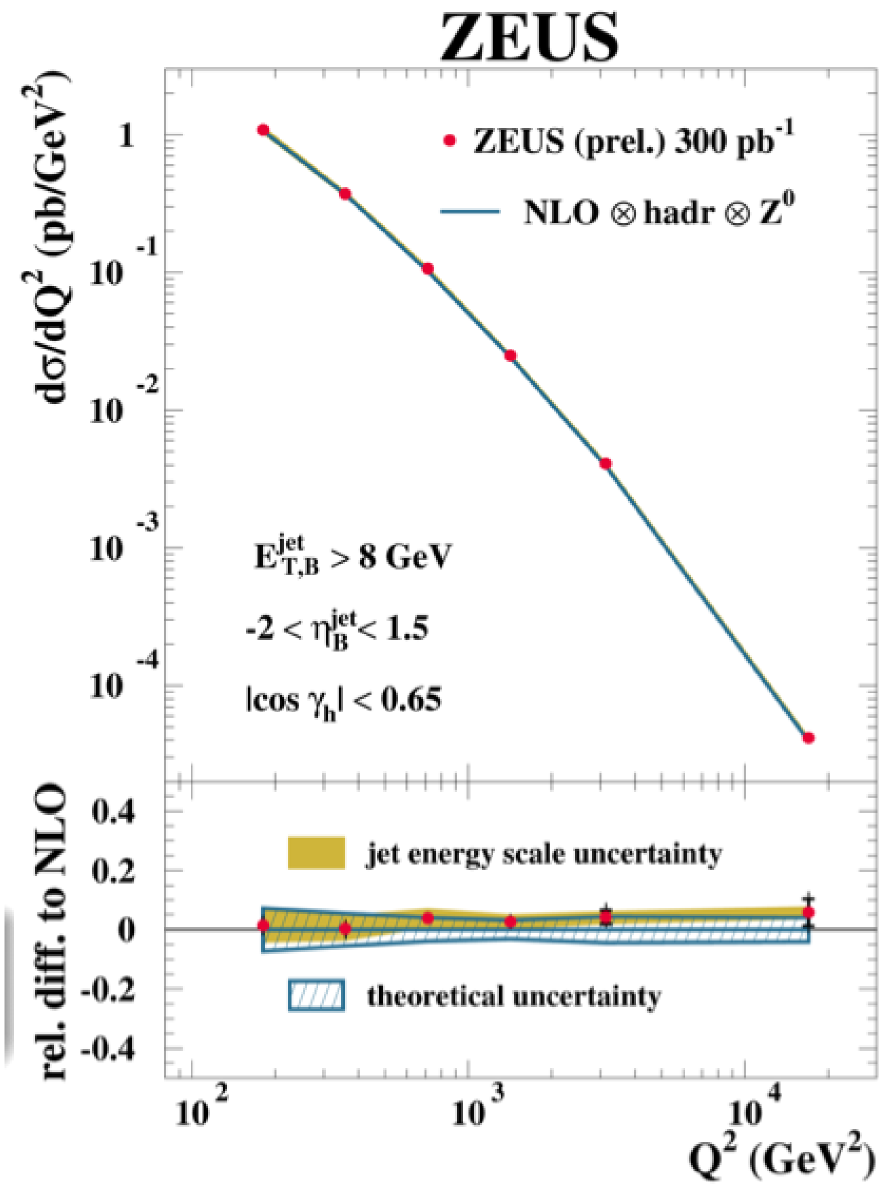


Determination of alphas from inclusive jets at ZEUS

Inclusive Jets in ...	NC DIS	PHP
phase space:	$Q^2 > 500$ GeV yields smaller α_s uncertainty	$21 < E_T^{\text{jet}} < 71$ GeV
theoretical uncertainty dominated by terms beyond NLO:	$\pm 1.5\%$	$\pm 2.5\%$
experimental uncertainty ruled by jet energy scale:	$\pm 1.9\%$	$\pm 1.8\%$

NC DIS:

$\alpha_s\,(M_Z) = 0.1208^{+0.0037}_{-0.0032}(\text{exp.}) \pm 0.0022(\text{th.})$

→ **total uncertainty:** $\pm 3.5\%$

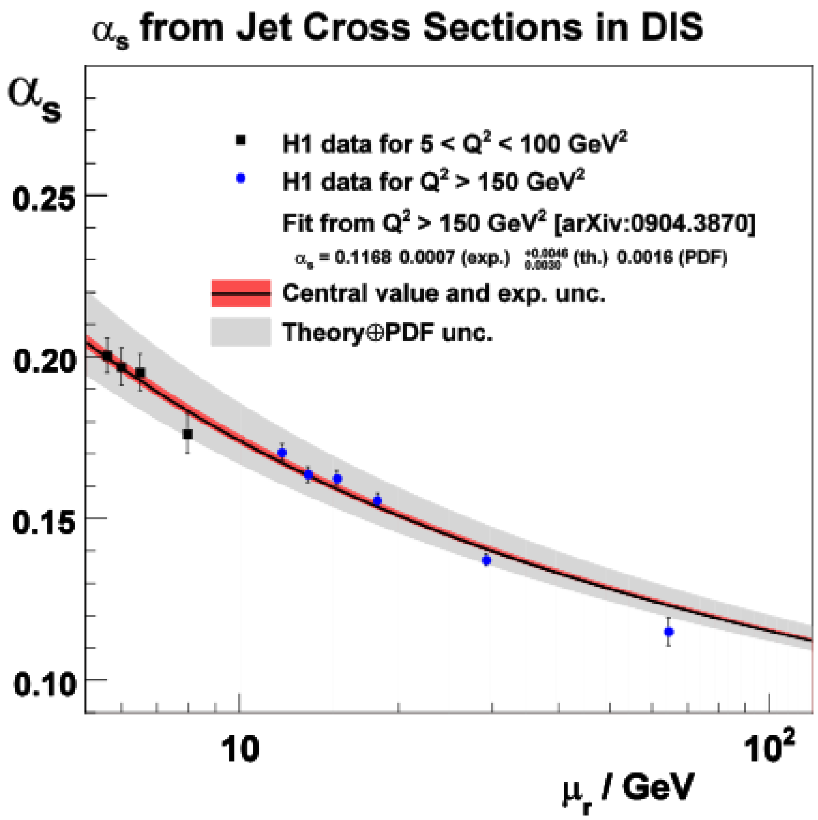
PHP:

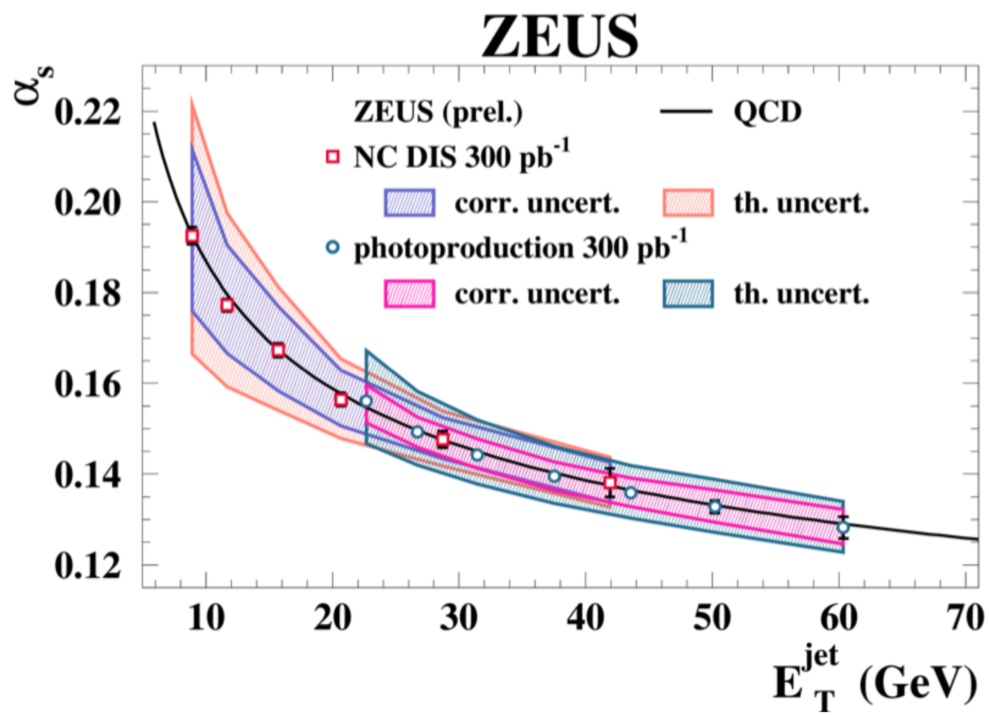
$\alpha_s\,(M_Z) = 0.1206^{+0.0023}_{-0.0022}(\text{exp.})^{+0.0042}_{-0.0033}(\text{th.})$

→ **total uncertainty:** $\pm 4.0\%$

Running of strong coupling

H1





- Extrapolating theoretical and experimental uncertainties from the high to low Q2 region observe good agreement between extraction of the alphas at low and high Q2.

- Predicted alphas running agrees well with data

Summary

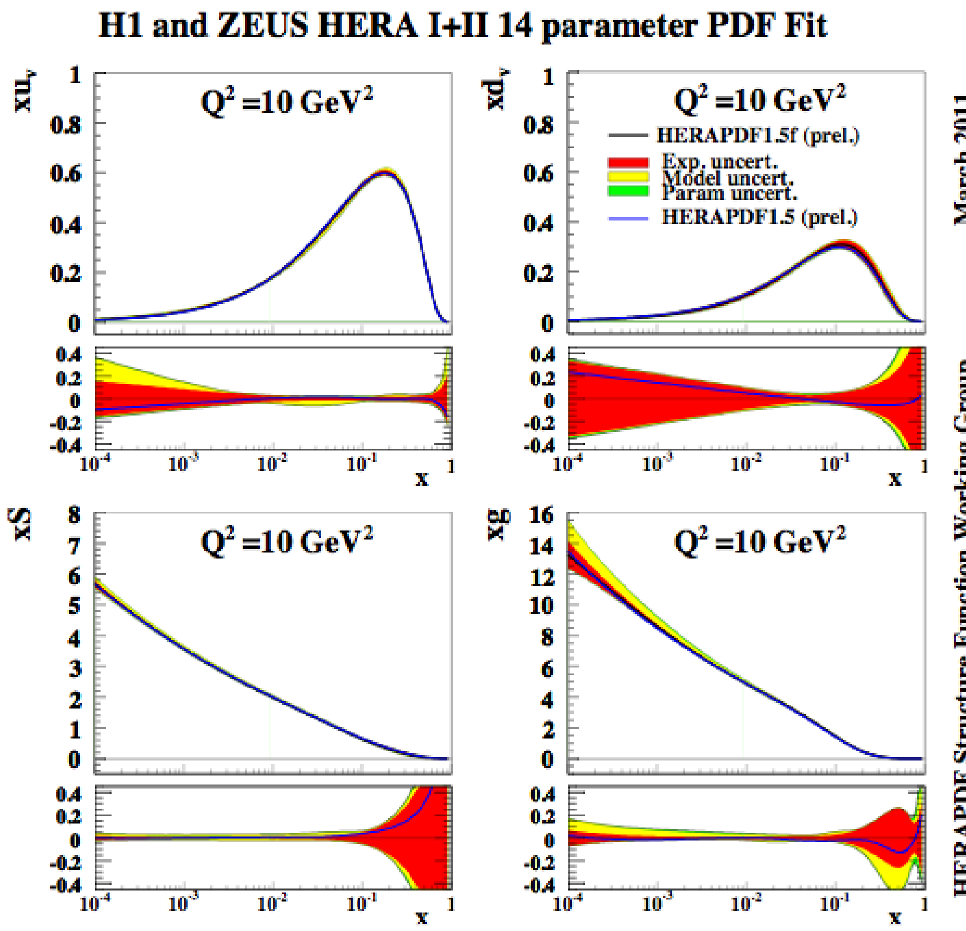
- Inclusion of the jet data allows for simultaneous constrain of gluon and strong coupling:
  - HERAPDF1.6

- New preliminary jet measurements from both H1 and ZEUS experiments:
  - H1: High Q2 Multijet Cross sections in DIS
  - ZEUS: Inclusive and Dijet measurements in Photoproduction and DIS

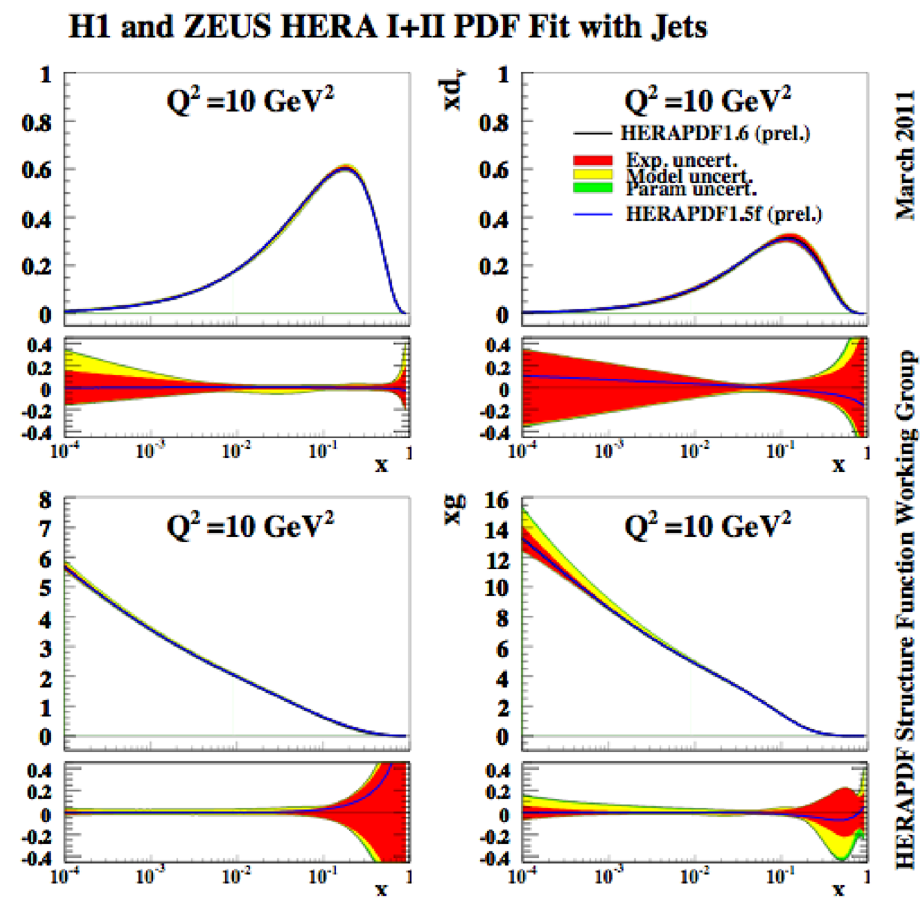
  - Individual fixed PDF fits to alphas yield competitive alphas extractions which are in agreement with eachother and with world average
    - However, theoretical uncertainty dominates and there is need for an improvement

  - New measurements have the potential to further constrain alphas and gluon in the PDF fits

Effect of jet inclusion

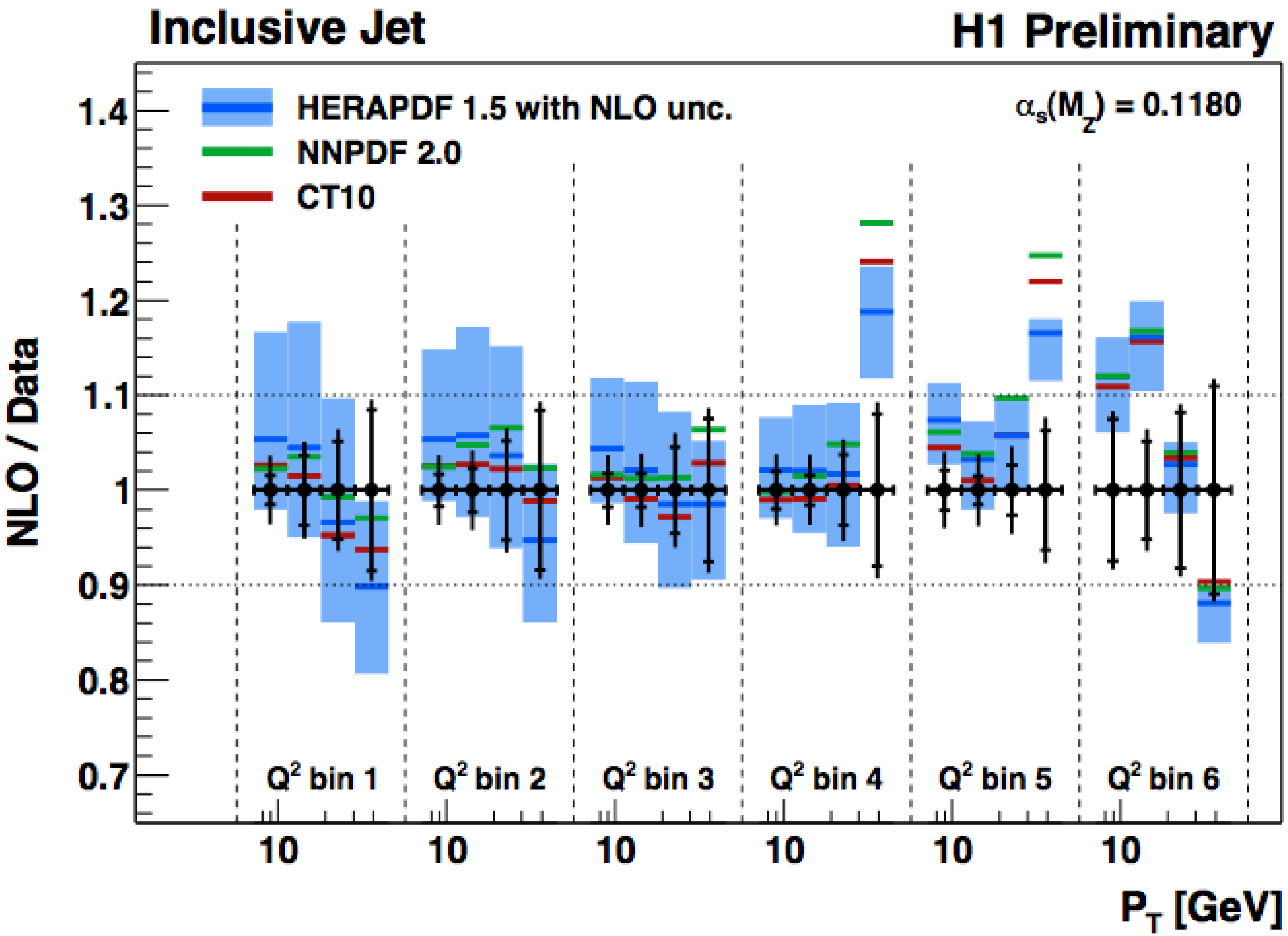


No jets



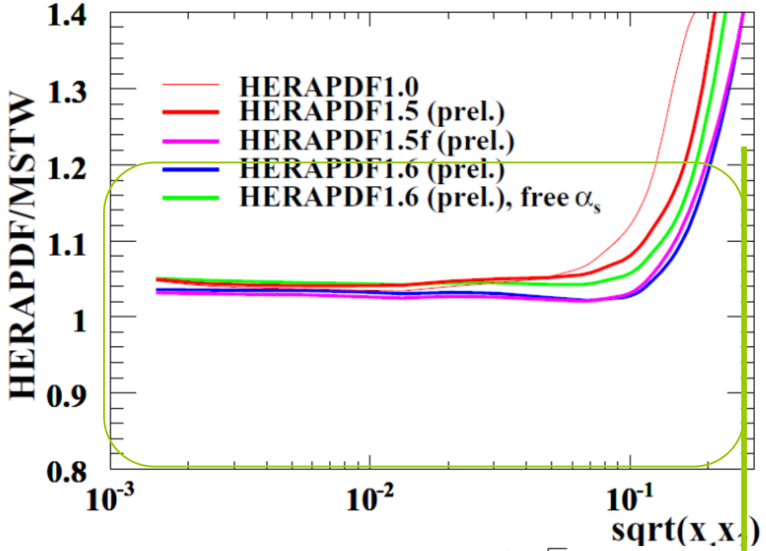
With jets

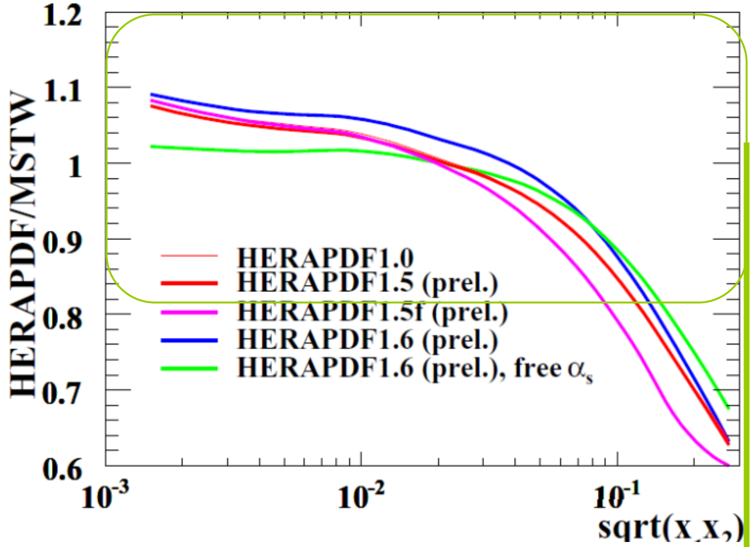
Comparison with other PDFs

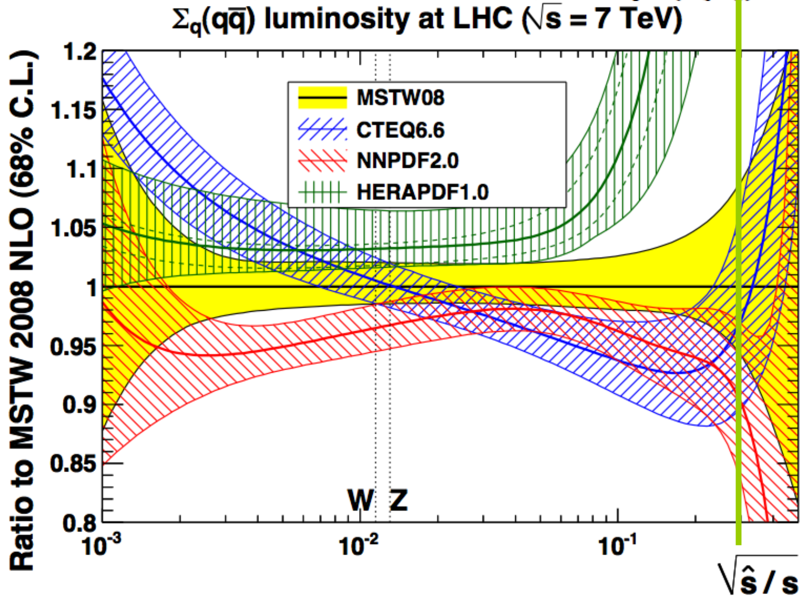


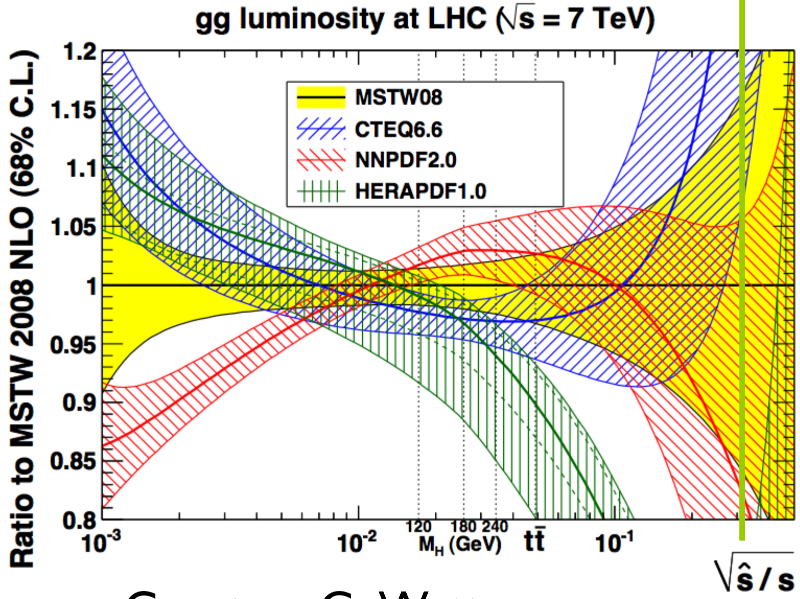
Luminosity plots for 7 TeV

- q-qbar luminosity at NLO (for W,Z) g-g luminosity at NLO (for





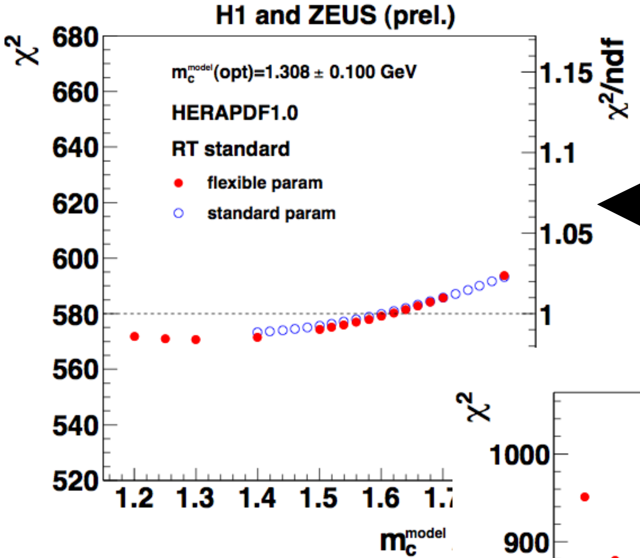




Courtesy G. Watt

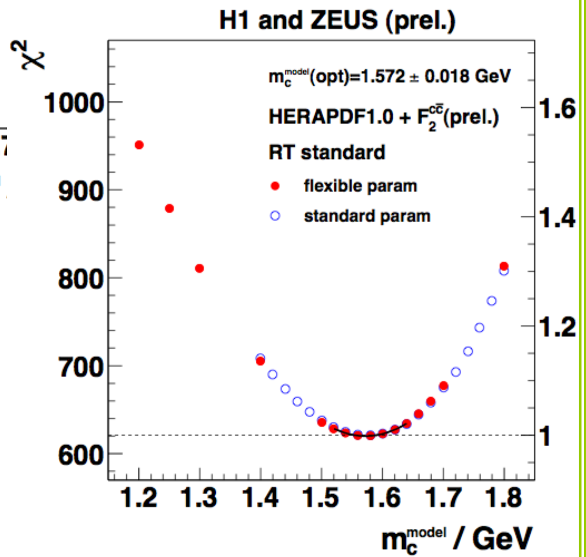
Extra studies at HERA using charm and low energy data

- Addition of the HERA combined F_2 charm data can help reduce model uncertainty of m_c(1.35-1.65):
  - Inclusive data has no sensitivity, while addition of the charm data does.

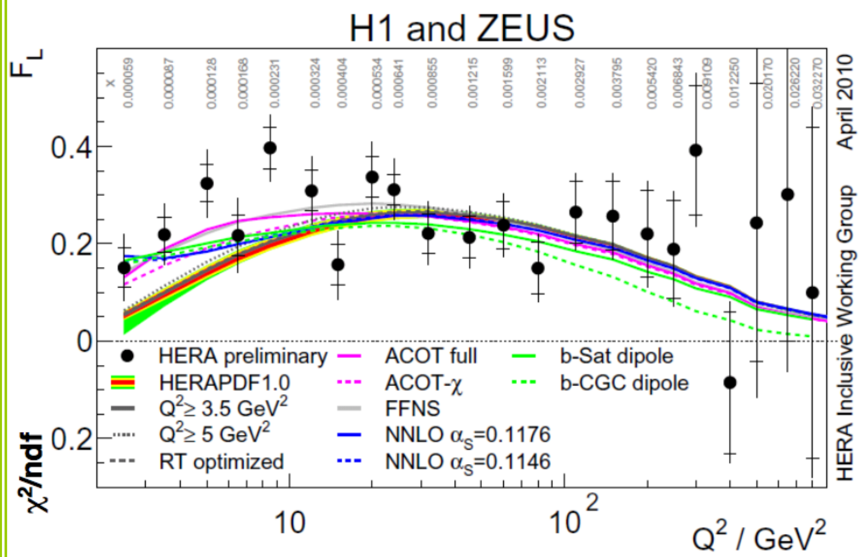


without charm data

Including charm data



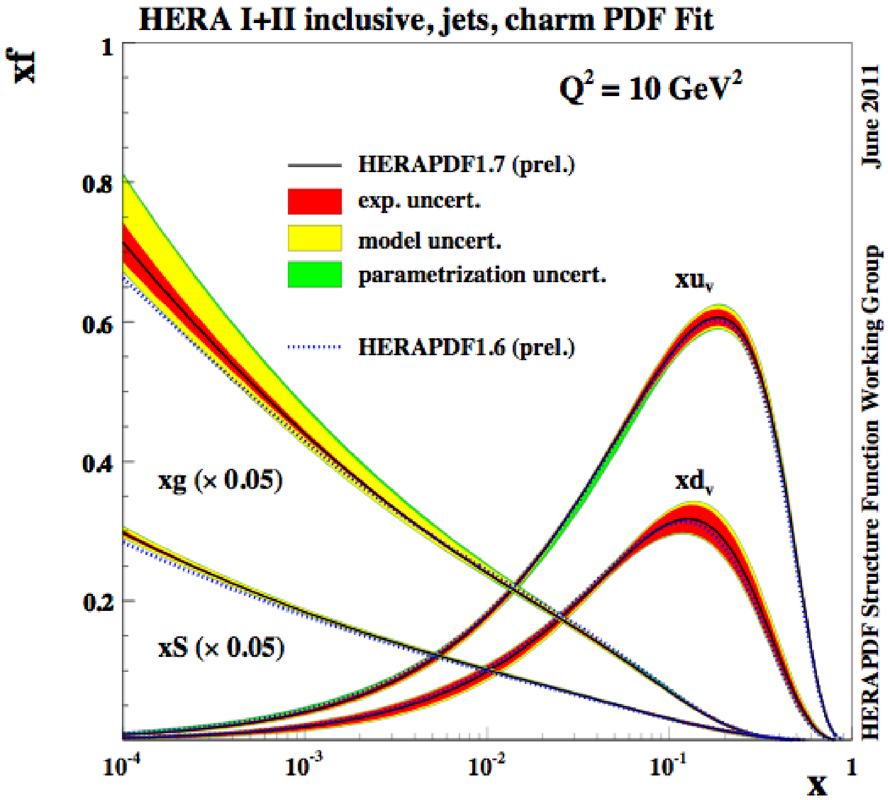
- Addition of the HERA combined lower proton energy data provides more sensitivity to the gluon PDFs at low x, low Q^2



What happens when we put all data together?
DIS inclusive, Jets, Charm, LEN
HERAPDF1.7

HERAPDF1.7 (NLO)

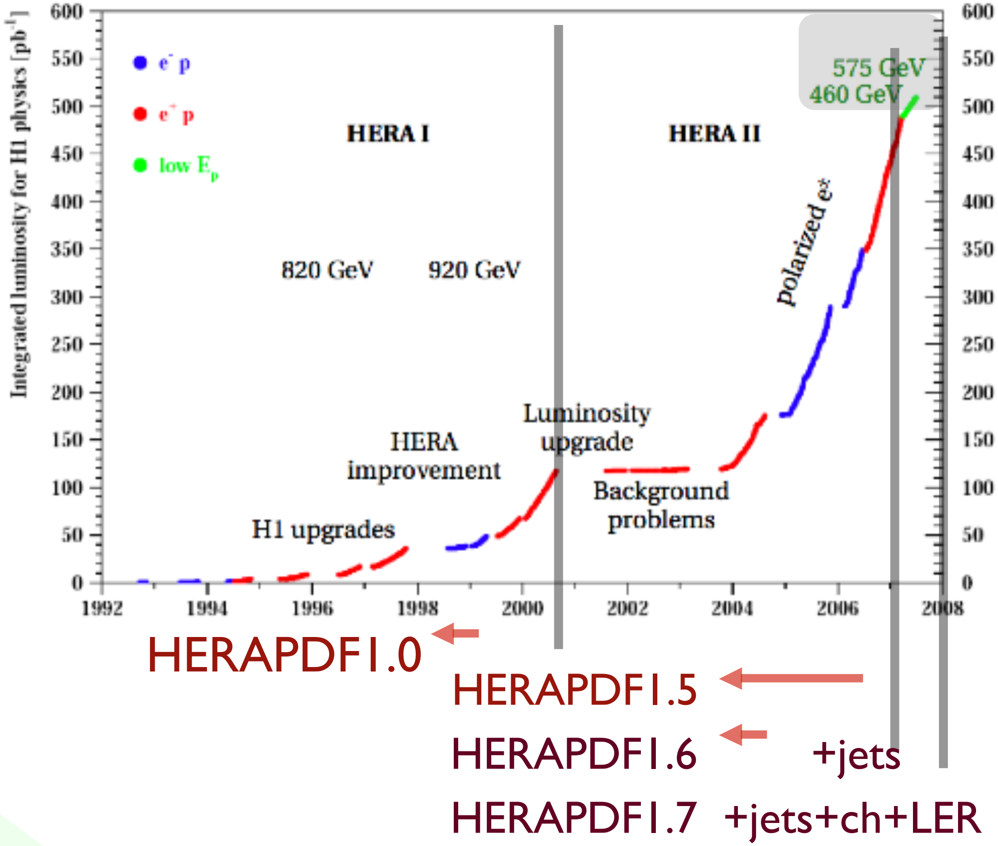
- Data Sets:
  - Combined HERA I+II data (prelim)
  - Combined HERA Charm data (prelim)
  - Combined HERA II low energy data
  - Separate H1 and ZEUS jet data
- Adjustments of the settings:
  - Use extended parametrisation
  - Use RT optimised version with its prefered value of mc=1.5 GeV
    - From the studies based using charm data
  - Raise the value of strong coupling from 0.1176 to 0.1190
    - From the studies using jet data



Input Data from HERA into the HERAPDF fits

- Combined HERA I inclusive data
[JHEP01(2010) 109]
  - HERAPDF1.0 NLO (full errors) and NNLO
  - Data used in NNPDF2.0(1), CT10, AB(K)M

- Combined HERA I+high Q^2 HERA II Data [prelim]:
  - Accurate measurements in high Q^2 region
    - Sensitivity to valence quarks
  - HERAPDF1.5*, HERAPDF1.5f (full errors)
    - NLO (full errors)
    - NNLO (full errors)
- HERA I + Combined Charm F_2 data [prelim]:
  - Provides constraints on charm mass
  - Accounts for some differences among PDFs
- Low Energy Data HERA II [EPJ(2011)71]:
  - Accurate measurement in $Q^2 \geq 1.5$ GeV^2 range, sensitive to structure function F_L
  - Investigate the low Q^2 region
- HERA(I+II) +H1 and ZEUS DIS Jet data:
  - HERAPDF1.6 NLO (full errors)
  - Determination of strong coupling



Using all these data sets: HERAPDF1.7
- provides consistency check

* HERAPDF1.5 (NLO and NNLO) in LHAPDF5.8.6

PDF determination at HERA

- HERA PDFs are determined from QCD Fits to solely HERA data of $Q^2>3.5$ GeV^2
- The QCD settings are optimised for HERA measurements of proton structure functions (dominated by gamma exchange) $F_2(x,Q^2) = \frac{4}{9}(xU + x\overline{U}) + \frac{1}{9}(xD + x\overline{D})$

  - NLO (and NNLO) DGLAP evolution equations, RT-VFNS (as for MSTW08)
  - PDF parametrised at the starting scale Q_0^2: $xg, xu_{val}, xd_{val}, x\bar{U} = x\bar{u}(+x\bar{c}), x\bar{D} = x\bar{d} + x\bar{s}(+x\bar{b})$

    Q_0^2 = 1.9 GeV^2 (below m_c)
  - Simple Functional form: $xf(x,Q_O^2) = Ax^B(1-x)^C(1+Dx+Ex^2)$
    - It describes the shape of PDFs with few input parameters
    - The number of free parameters is reduced by the physics constraints

- A - normalisation
- B - low x behaviour
- C - high x behaviour
- D,E - medium x tuning

  - Imposing momentum sum rules:

$$\int_0^1 dx \cdot (xu_v + xd_v + x\bar{U} + x\bar{D} + xg) = 1$$

$$\int_0^1 dx \cdot 2u_v = 2 \qquad \int_0^1 dx \cdot d_v = 1$$

Additional Constraints:

$x\bar{s} = f_s x\bar{D}$ strange sea is a fixed fraction f_s of $\bar{D}$ at Q_0^2

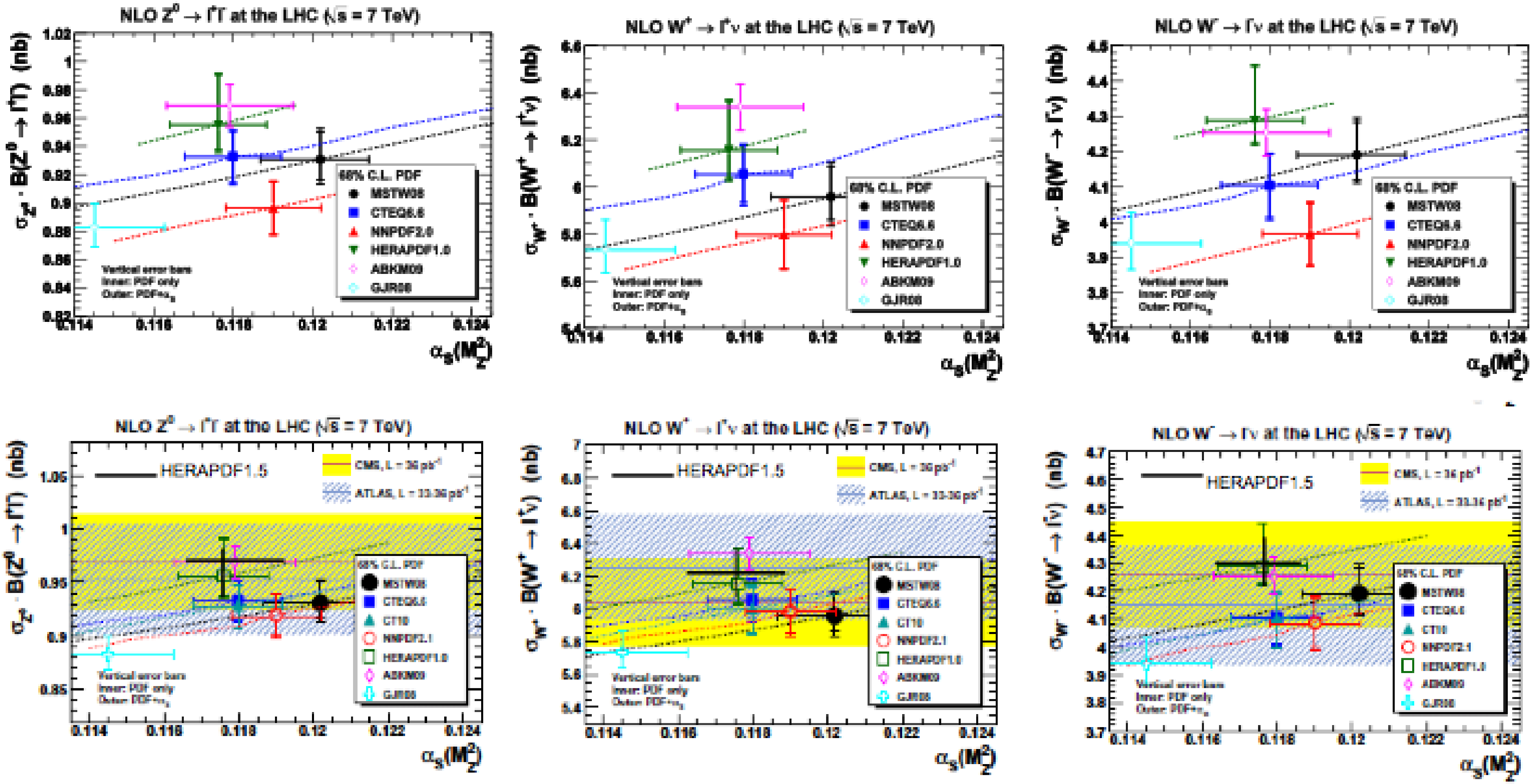
$B_{Ubar} = B_{Dbar}$
sea = 2 x (Ubar +Dbar)
Ubar = Dbar at x=0

In 10p fit: Buv=Bdv

  - The best fit results in:
    - 10 free parameters (for HERA I data)
    - 13 free parameters (for HERA I+II data)

NNPDF2.0 has been updated to NNPDF2.1 using FONLL VFN

CTEQ6.6 to CT10 ABKM09 to ABM11 HERAPDF1.0 to HERAPDF1.5



The use of the VFN scheme puts NNPDF2.1 closer to MSTW,

CT10 and CTEQ6.6 are very similar, HERAPDF1.5 is a little higher than 1.0 for W+,Z