QCD at HERA

R. Yoshida
Argonne National Laboratory
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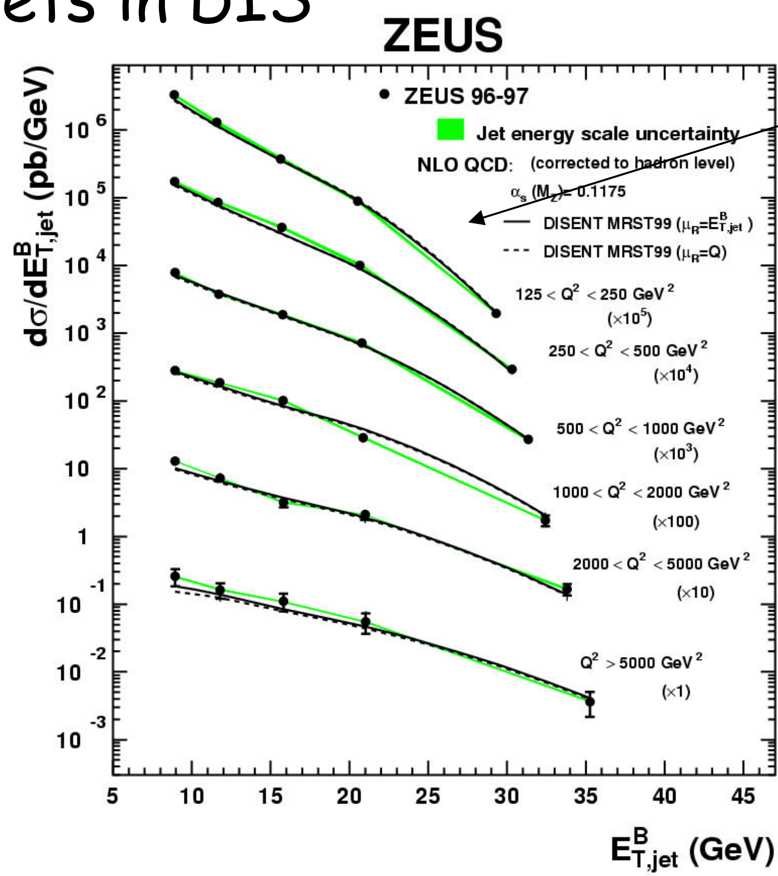
Outline

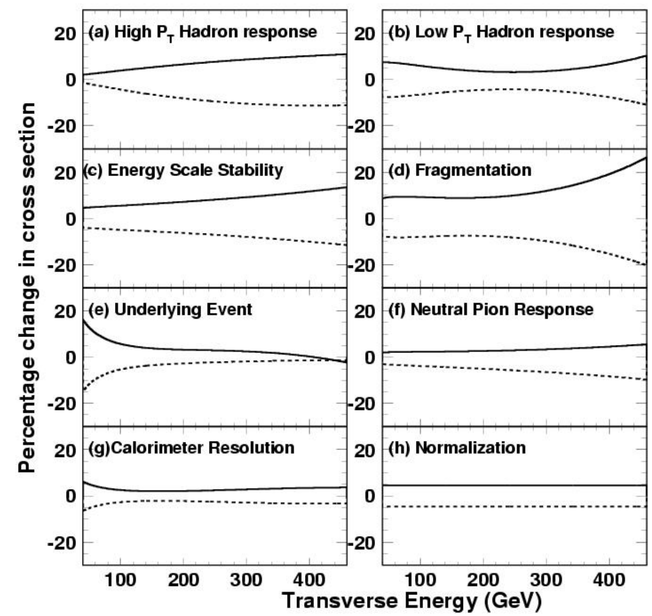
- Jet measurements and α_s
- Parton distributions from structure function measurements.
- Parton distributions and α_s from structure functions and jets.

Jet measurements at HERA

jets in DIS



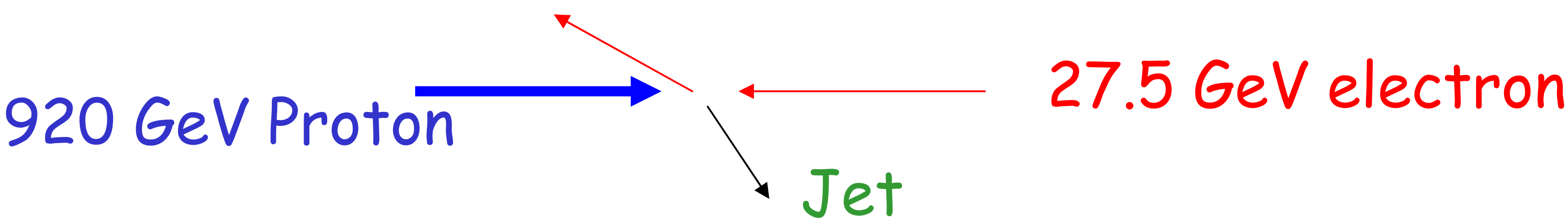
Jet measurements at HERA has typical uncertainty ~5%.



Compare to ~60% at Tevatron

Jet measurements at HERA

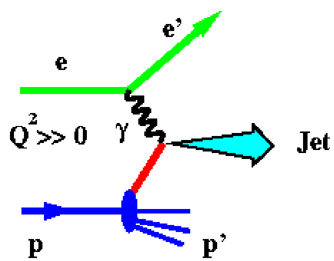
- HERA jet energies can be calibrated using the energy balance with the scattered electron--achieve 1-2% energy uncertainty for jets.



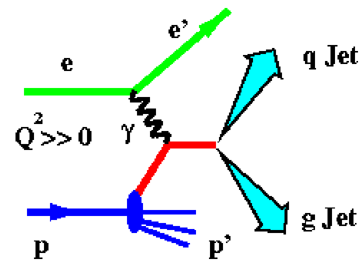
- HERA jets are reconstructed using the theoretically robust algorithms (typically k_t rather than cone)—comparison to QCD theory does not suffer from large hadronization uncertainties.

Jet production processes at HERA

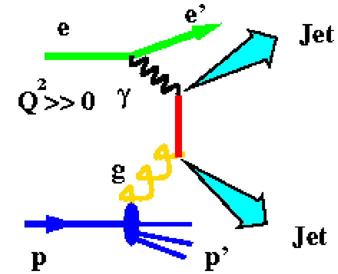
DIS



LO

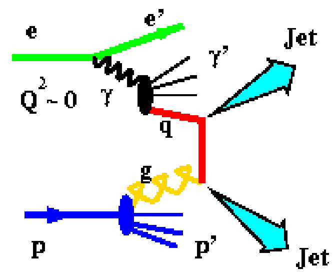


QCD-COMPTON

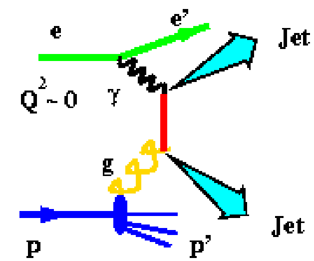


BGF

Photoproduction



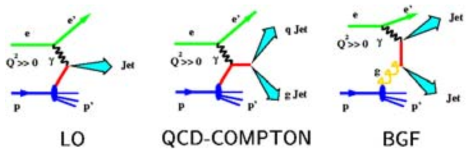
RESOLVED

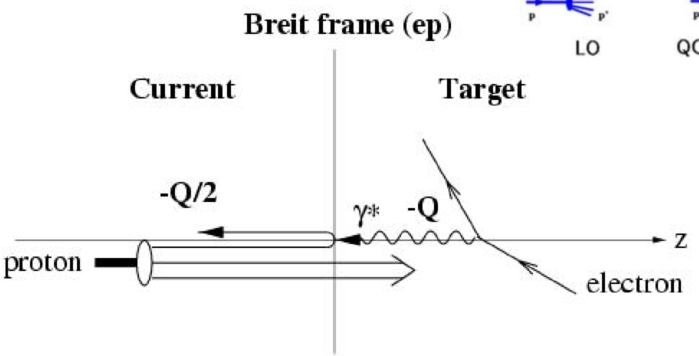


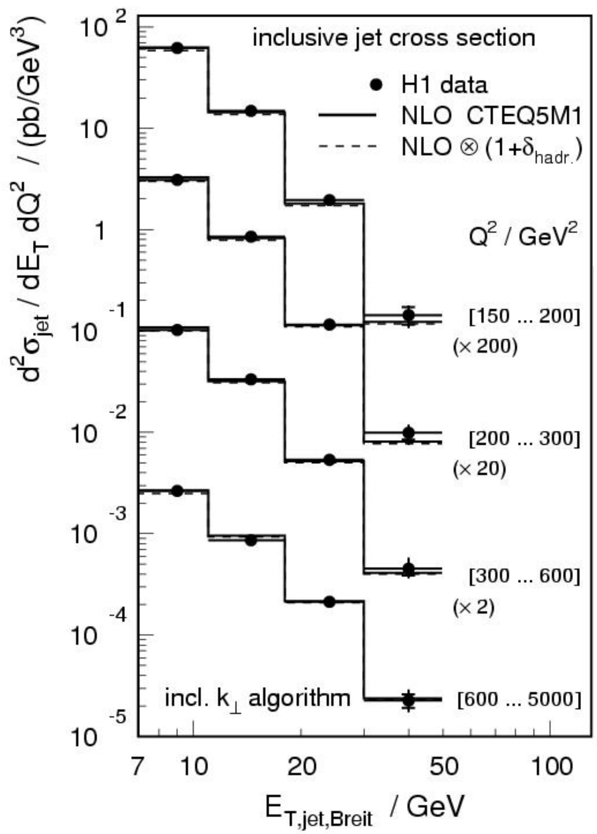
DIRECT

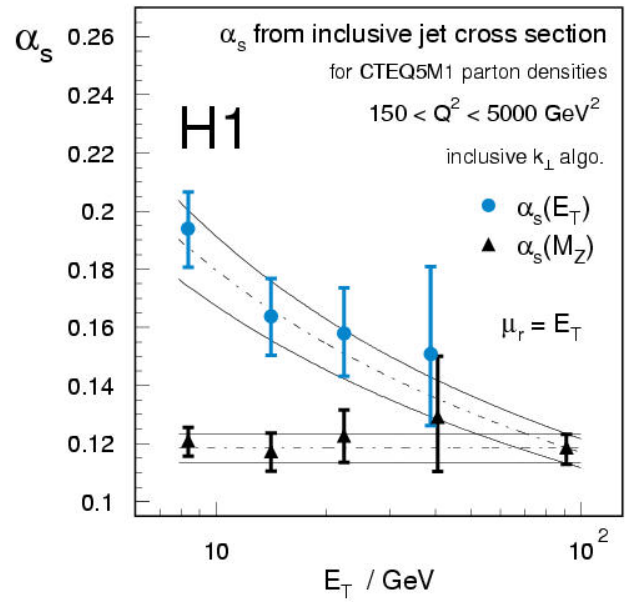
Jet measurements and α_s

Example: DIS jets in Breit frame



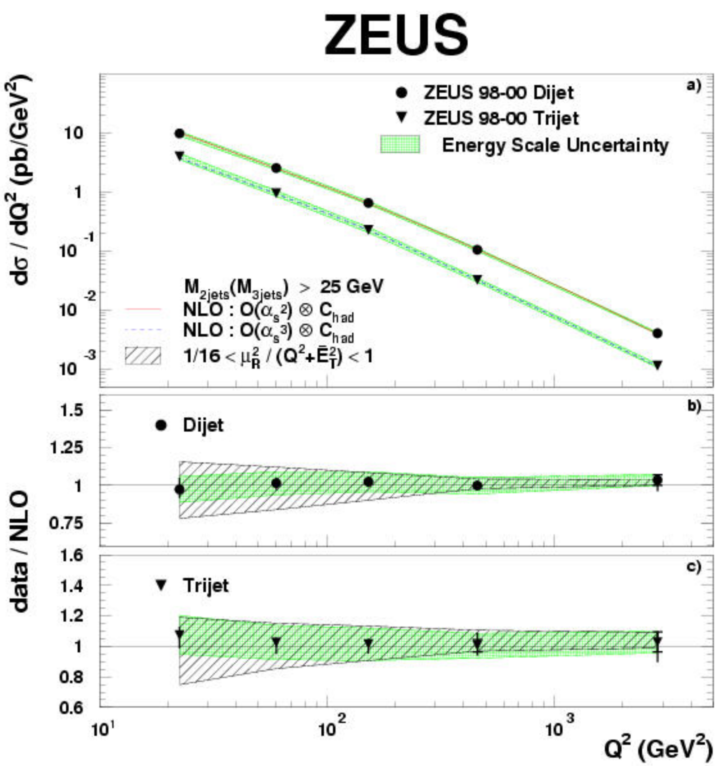


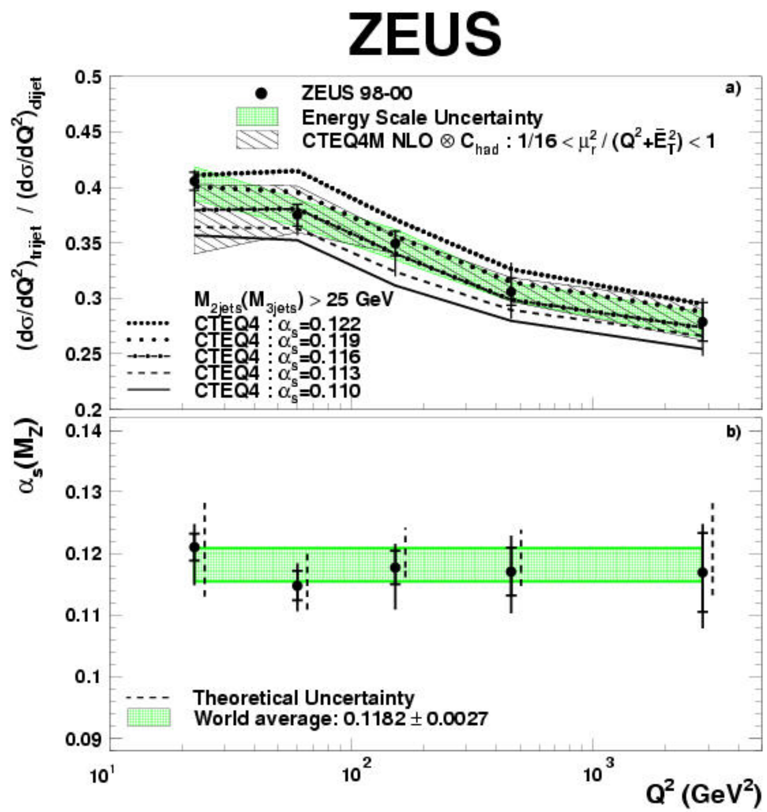




Jet measurements and α_s

Example: 3 to 2 jet rate ratio
pdf uncertainty tends to cancel



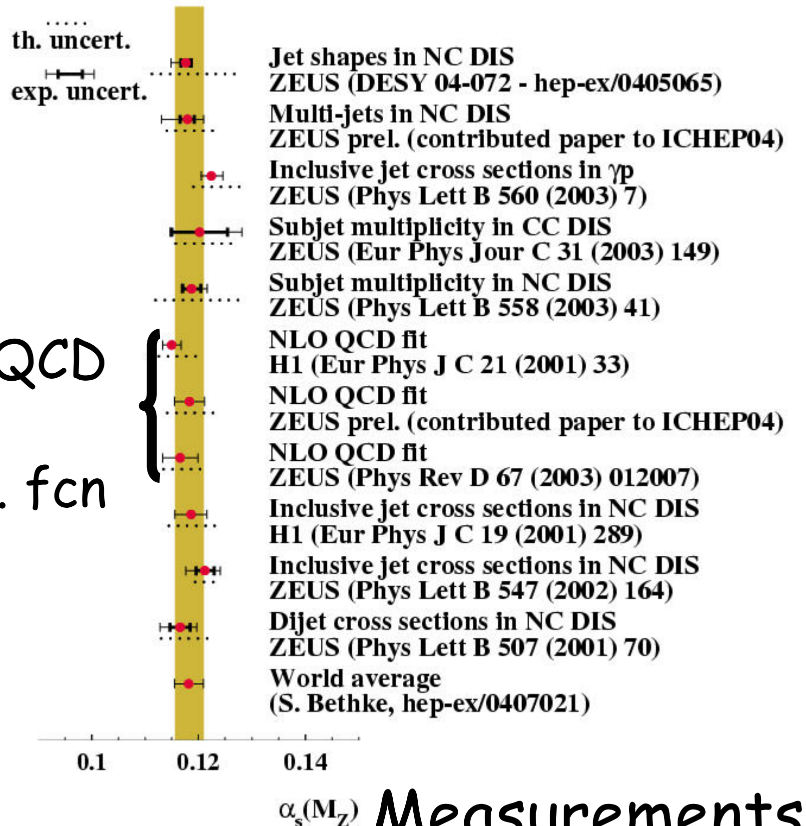


Jet measurements and α_s

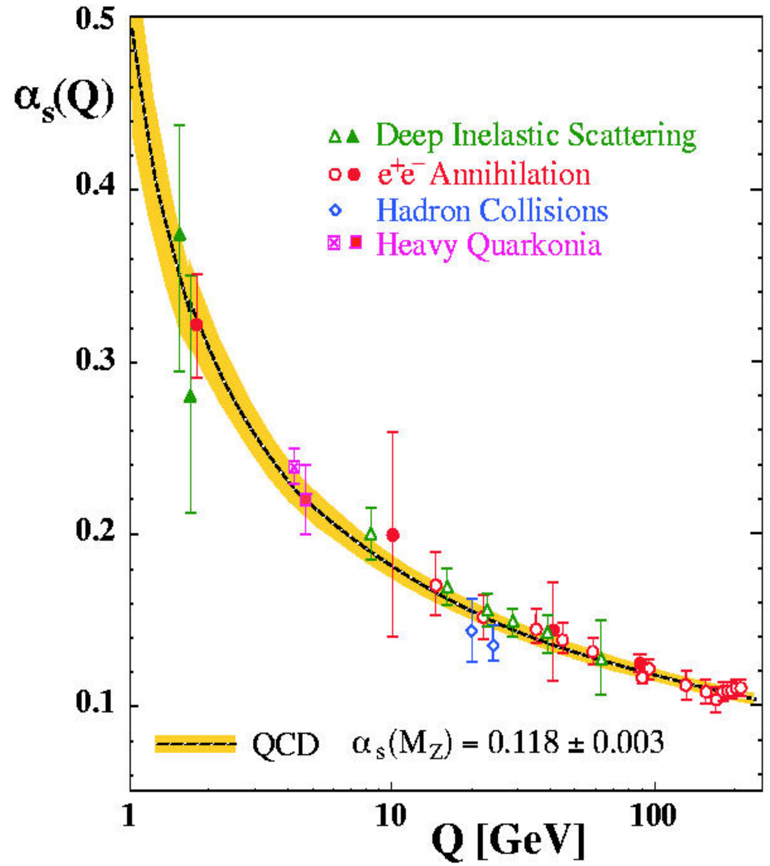
Correlations between pdf and α_s

- Pdfs are extracted assuming some value of α_s (or determines the value of α_s)
- Jet cross-sections at HERA depends on pdfs
- α_s from jets is extracted taking this correlation into account.
- In effect the value of α_s is varied simultaneously in pdf and cross-section calculations when fitting data to optimum α_s —this is done using a set of pdfs determined at various values of α_s .

Jet measurements and α_s



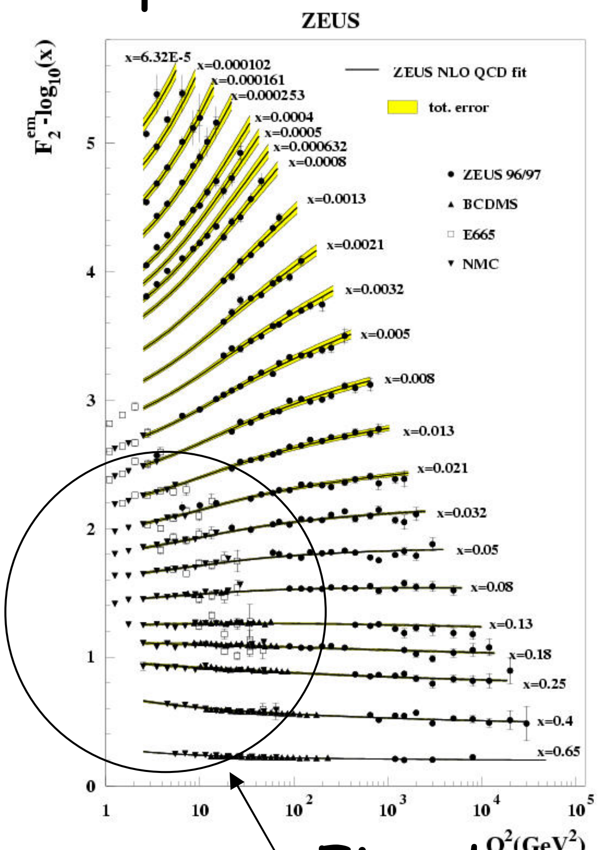
NLOQCD fits to st. fcn

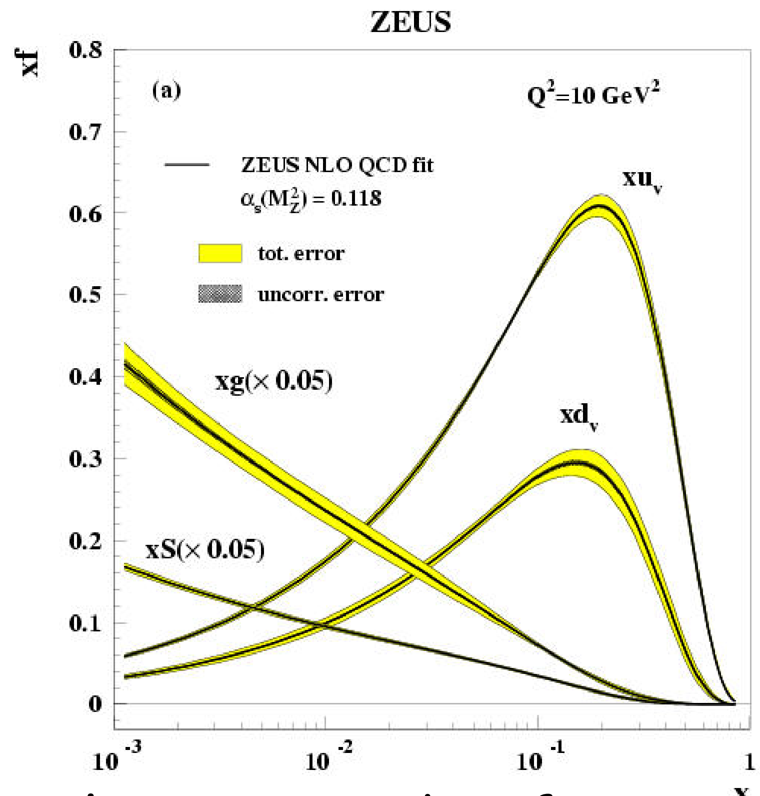


Measurements combined (C. Glasman et al.) →

Structure functions and pdf

Example: ZEUS NLO QCD fit (similar results for H1)

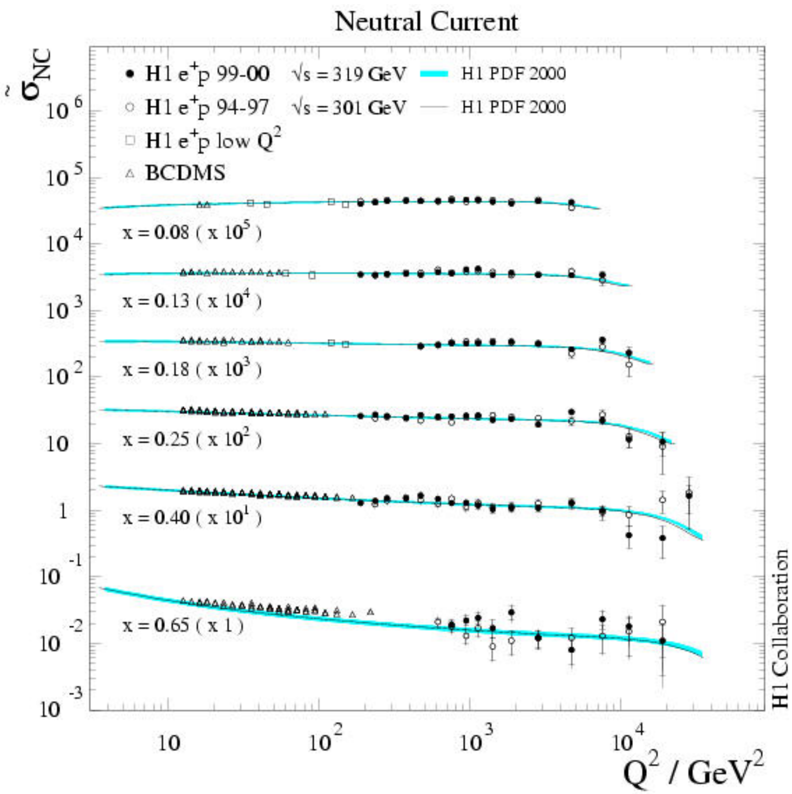


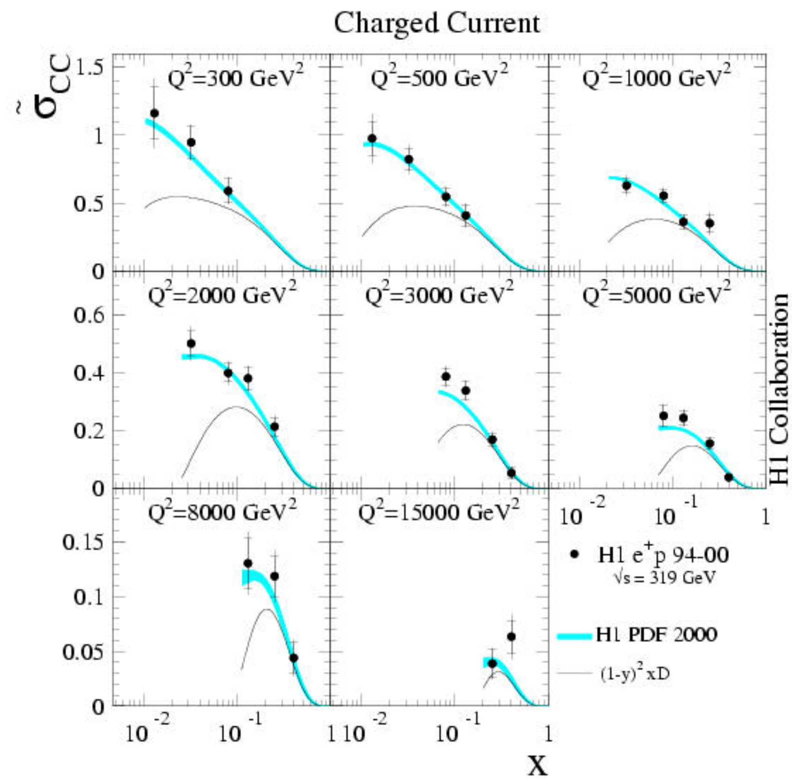


Fixed target results are used in fit to fix the high x pdf

Structure functions and pdf

Use all of HERA I data (>100 pb-1) to replace fixed target experiments in the fit

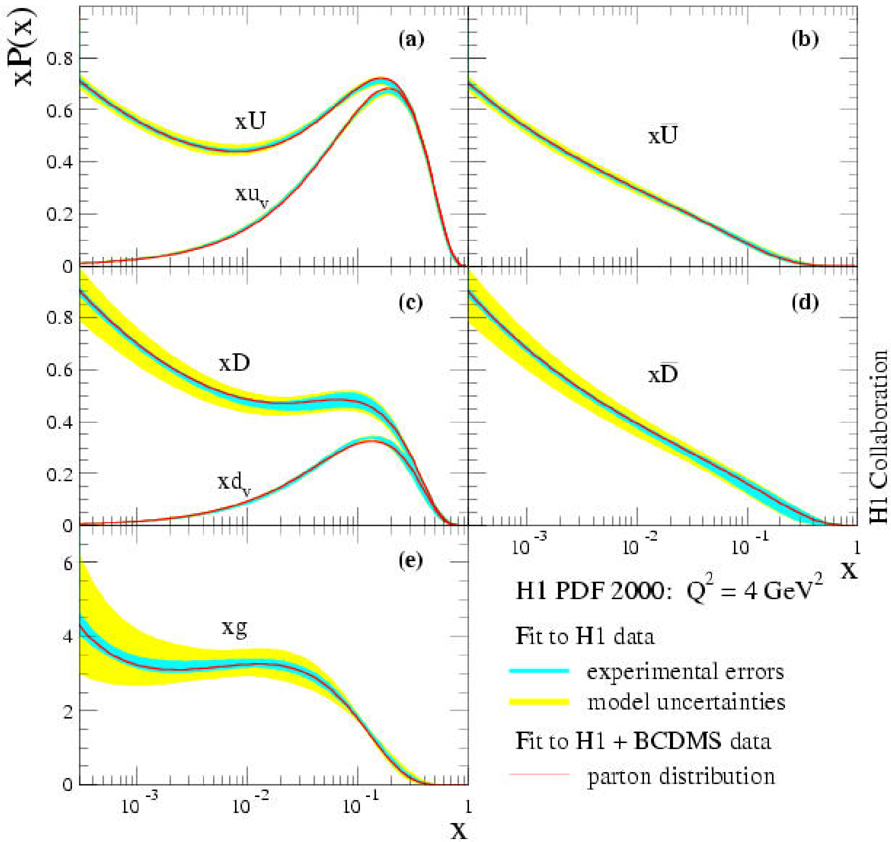




H1 data: similar for ZEUS

No low Q2, heavy target corrections.

Structure function and pdf



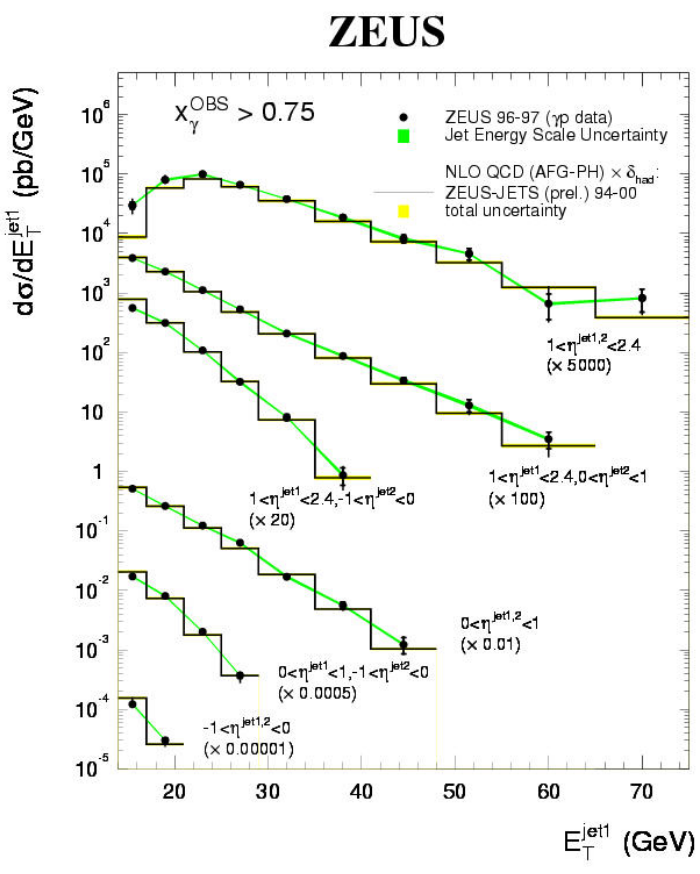
HERA only fit:
H1 results
similar for ZEUS

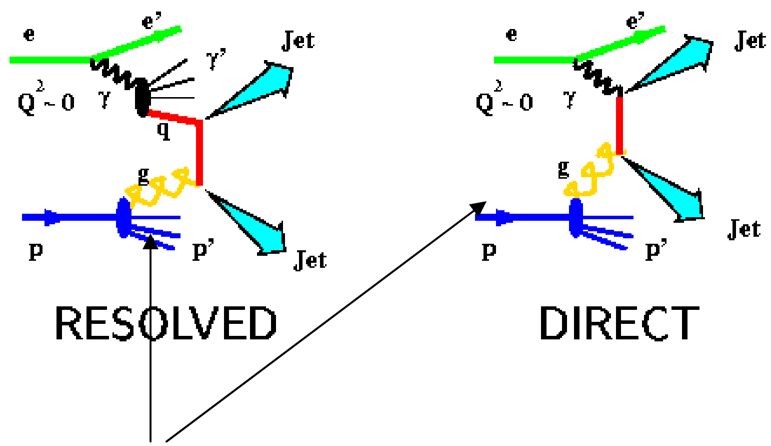
High x statistics dominated

α_s weakly constrained

note: α_s enters multiplied by the gluon density at lower x where HERA has high precision data.

Jet measurements and pdf





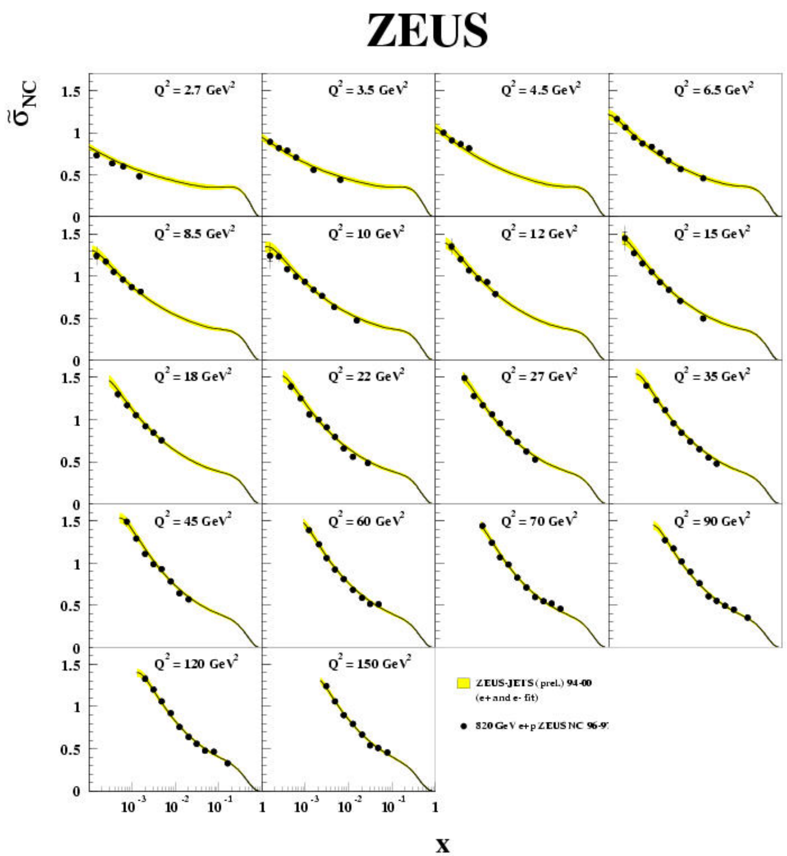
Sensitivity to the gluon

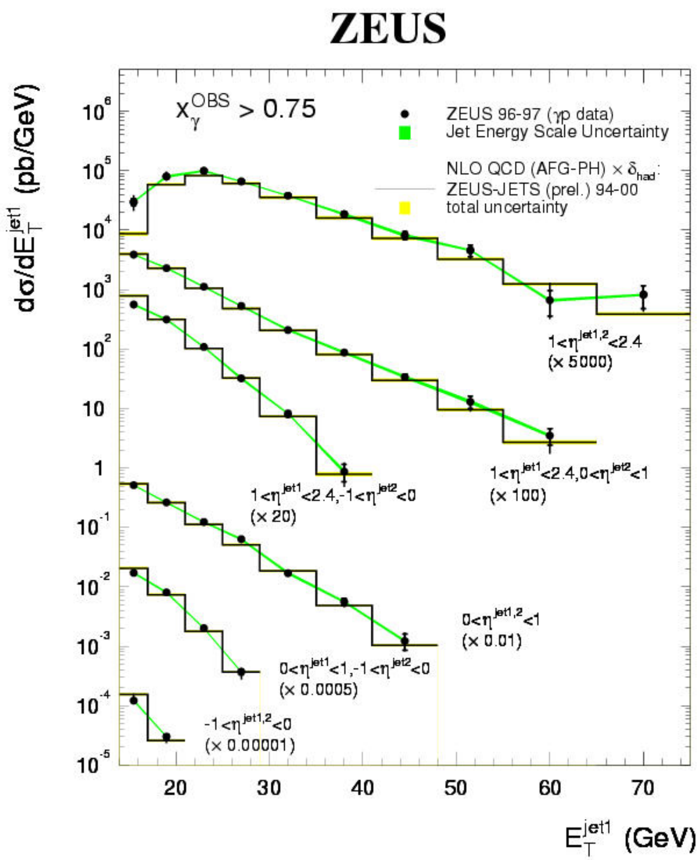
Note: cross-section is directly proportional to gluon. For structure function Q2 slope is proportional.

Jet measurements and QCD fit

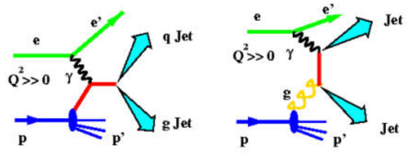
- Up to now, no QCD fit made rigorous use of jet data. CTEQ, MRST global fits use LO + k-factor for their jet descriptions.
- Although NLO jet calculations exist (DISENT, PHOJET, NLOJET etc.), their use in an iterative fitting procedure is not possible due to prohibitive computing time requirements.
- ZEUS collaboration has pioneered a fast calculation method (basically putting the cross-sections on a grid) which enables the use of jet data to be put rigorously into a NLO fit.
- This makes possible, for the first time, a rigorous use of jet data in NLOQCD fits to parton distributions of the proton.
- This enables, for example, a consistent simultaneous extraction of precision α_s (mainly based on jets) and pdfs taking all correlated uncertainties into account.

ZEUS-JETS QCDNLO fit results

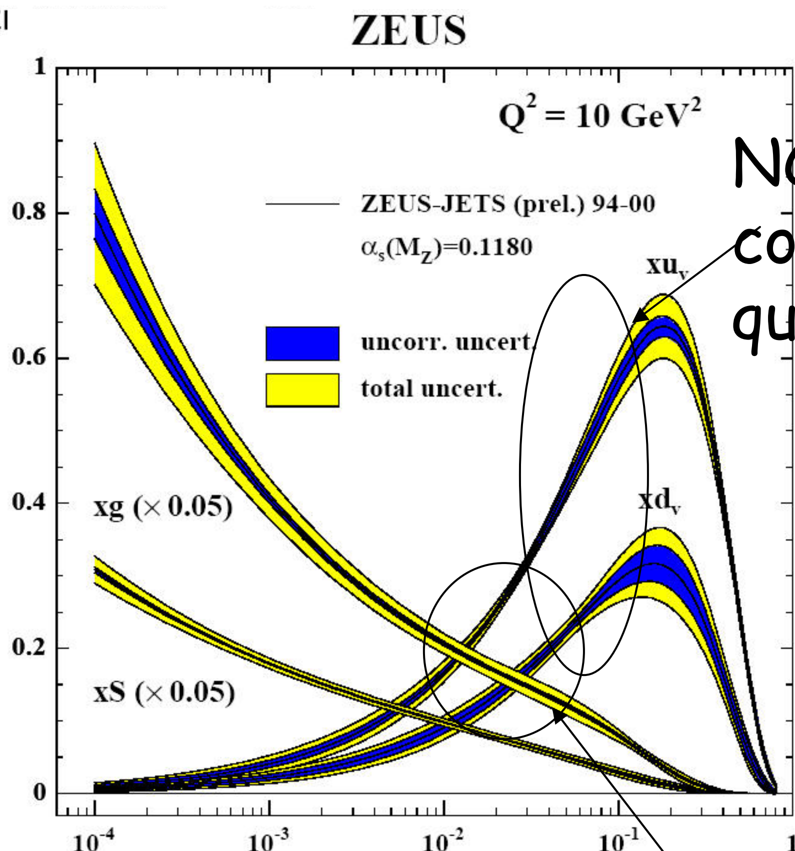




ZEUS-JETS NLOQCD fit results

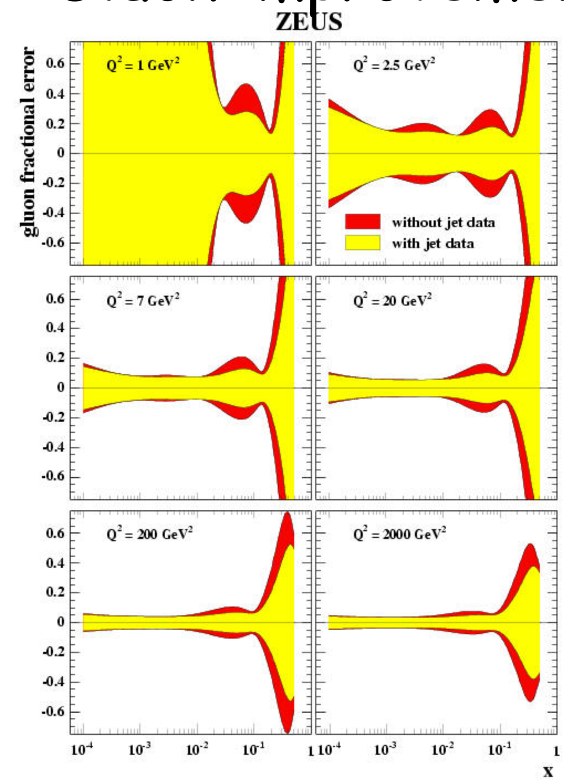


QCI



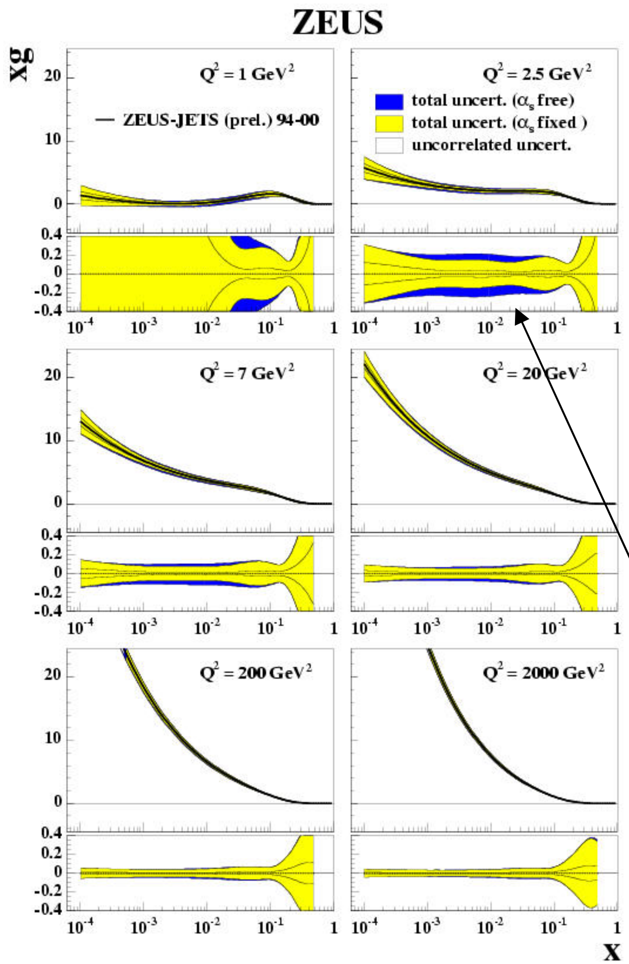
NC and CC constrain quarks

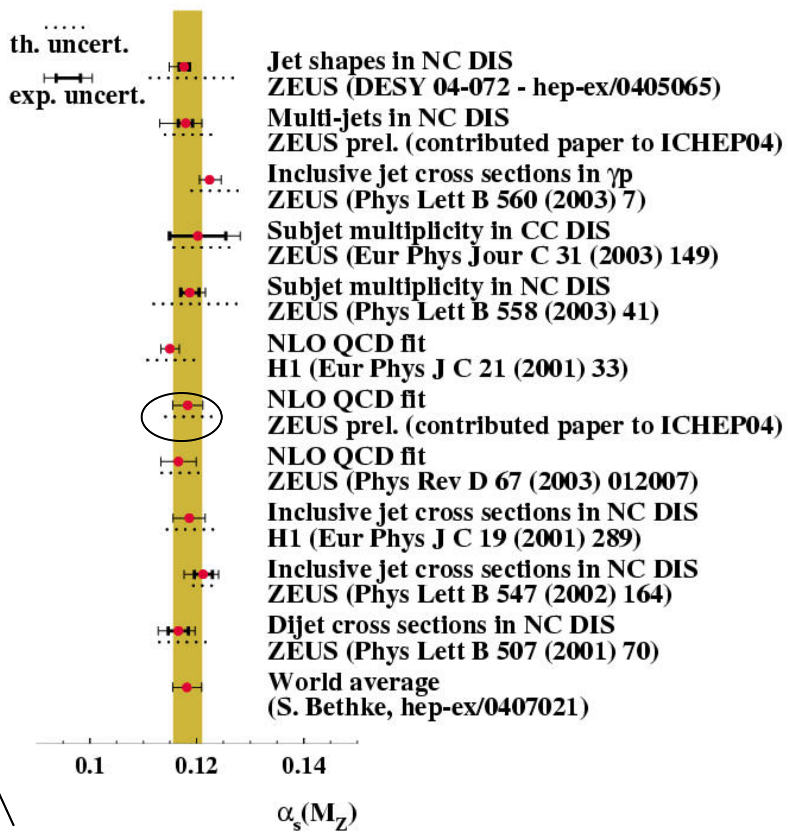
Gluon improvement



Jet data constrain the medium x gluon

ZEUS-JETS simultaneous fit to pdf and α_s





Gluon does not become unconstrained when α_s freed.

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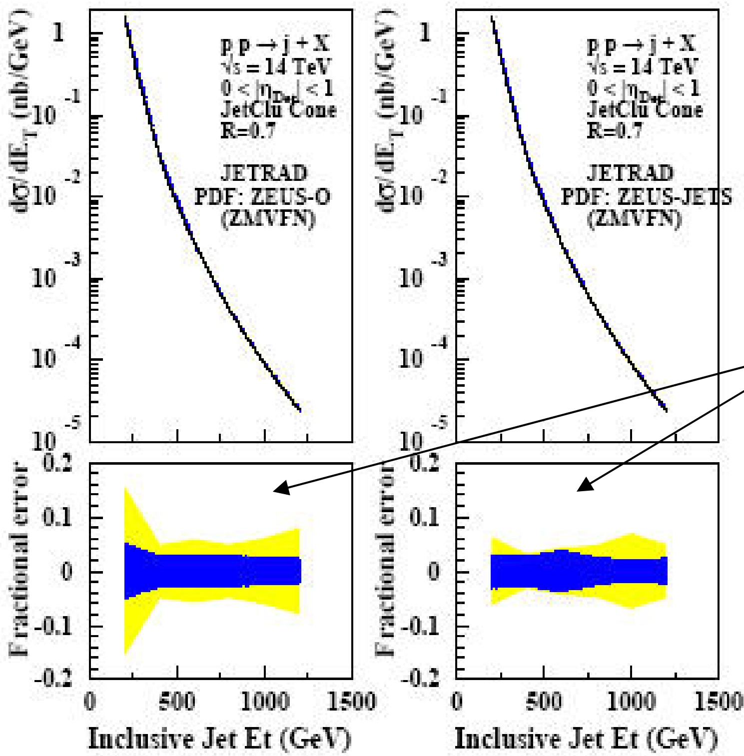


Predictions of LHC jet cross-sections

Improvement due to inclusion of ZEUS jet data

Prediction for LHC Inclusive jet production using ZEUS-ONLY 2004 and ZEUS-JETS 2004 PDFS in the JETRAD programme- uncertainties in the prediction are smaller using the PDFs which include HERA jet infromation

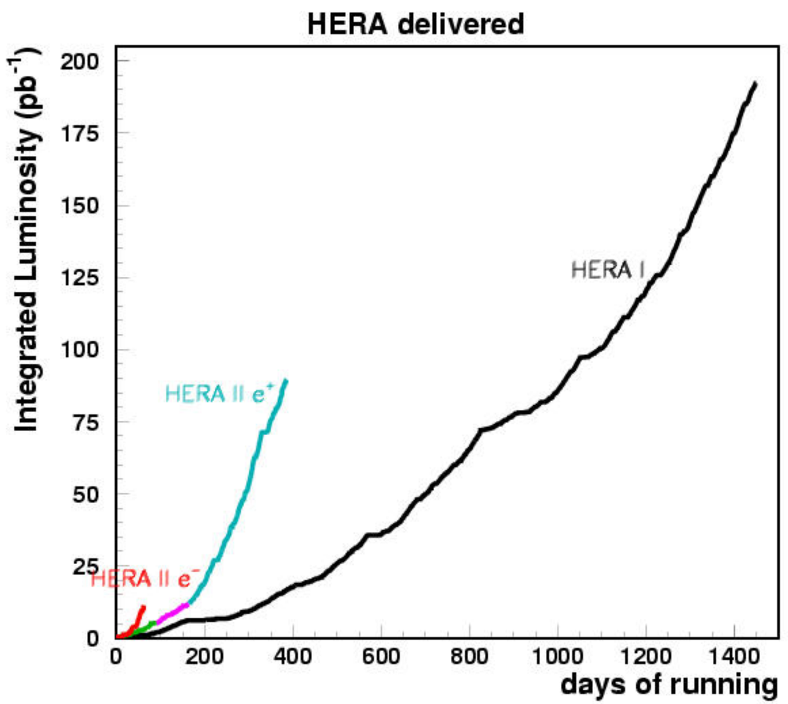
work by: K. Nagano, KEK

ZEUS-JETS fit: possible extensions

- Use charm production data: still has some theoretical issues; also experimental systematic uncertainties are a little too large.
- Use other jet data: use e.g. 2 to 3 jet ratio, subjet multiplicity etc.
- Use “resolved” photoproduction jet data and constrain photon pdfs simultaneouly.
- …

Impact of HERA II

- HERA II (x5 increase in luminosity compared to HERA I
- Planned to run to middle of 2007
- 500-1000 pb-1 data using both e+ and e- beams. (also e polarization)
- Currently taking data
- Impact on these fits?



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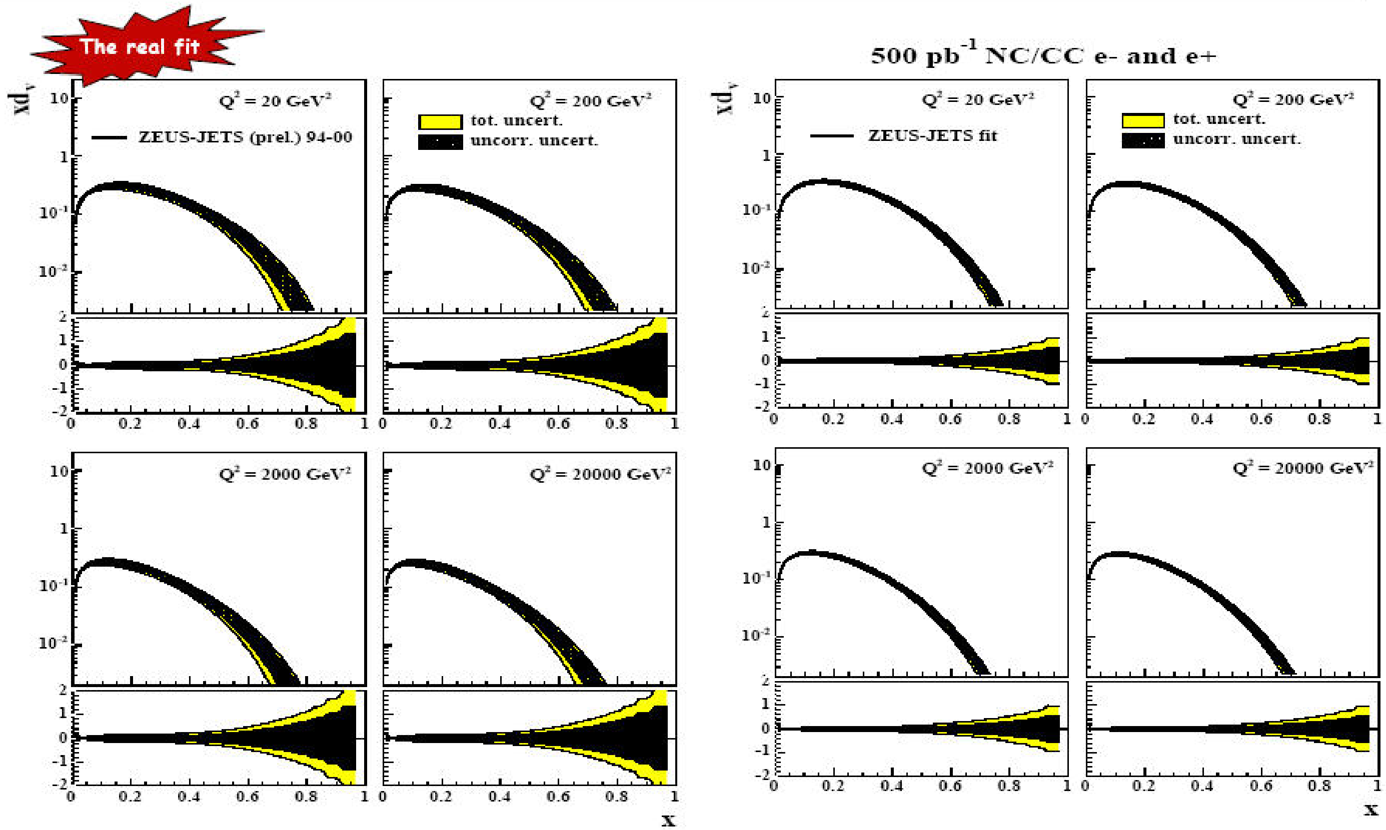
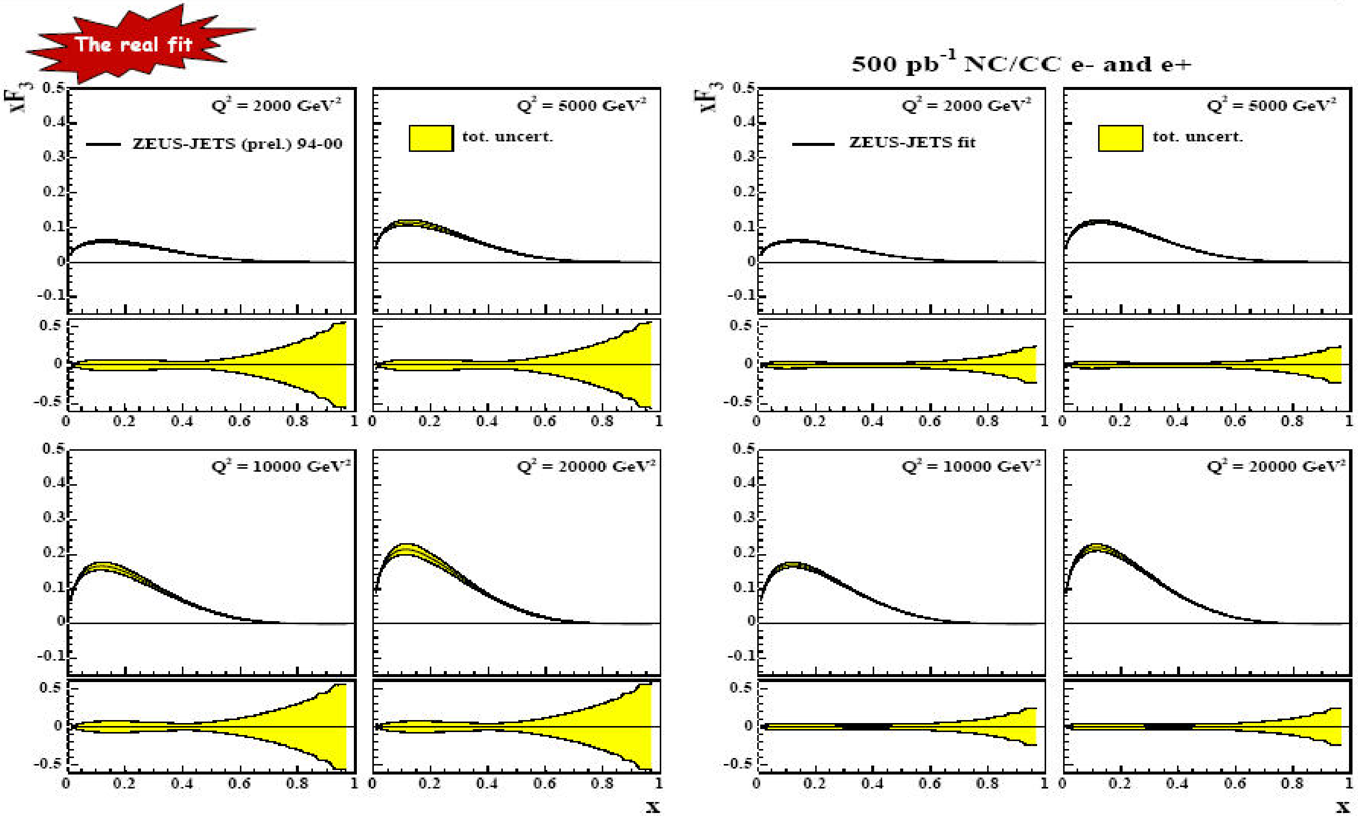
Impact on d-valence distribution



- Maximum uncertainty reduced from over 200% to 100%

(C. Gwenlan, Oxford)

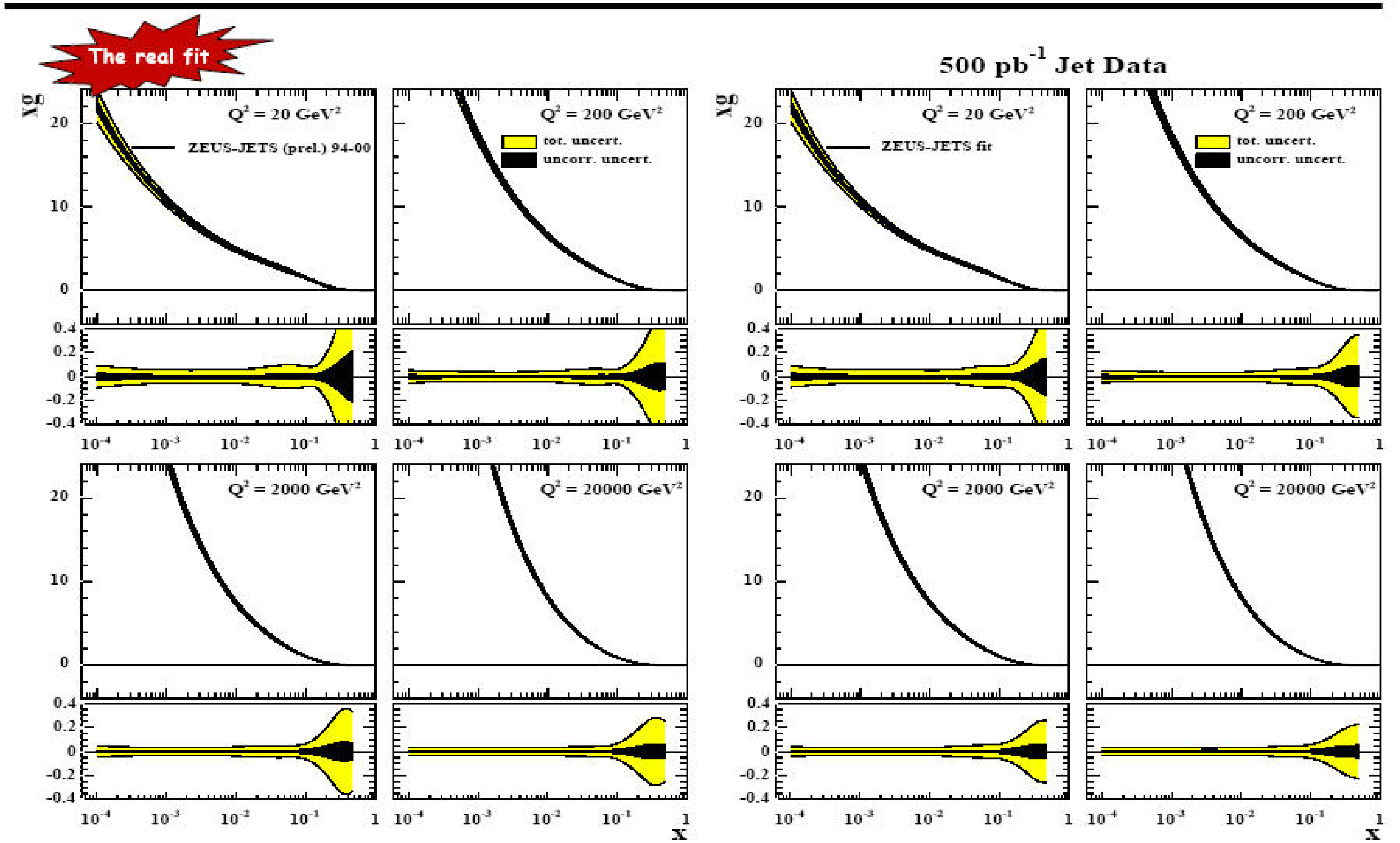
Impact on xF3 ~ Σx(q-qbar)



- Significant improvement in xF3 uncertainties (max. uncert. goes from ~60-20%)

(C. Gwenlan, Oxford)

Impact on the gluon distribution



- Impact at mid-to-high-x, uncertainties are further reduced

(C. Gwenlan, Oxford)

Conclusions

- HERA jet measurements are precision data (~5% uncertainty).
- α_s has been measured at HERA from jets, running, over an order of magnitude in scale, and at a precision at the level of the world average. The uncertainties are dominated by theoretical ones.
- ZEUS has developed a method to do a rigorous combined fit at NLO with structure function and jet measurements to extract pdfs and α_s. The precision of the gluon determination improve markedly; a precision α_s is extracted.
- The new HERA II data will lead to much improved pdfs at high x.

Extras

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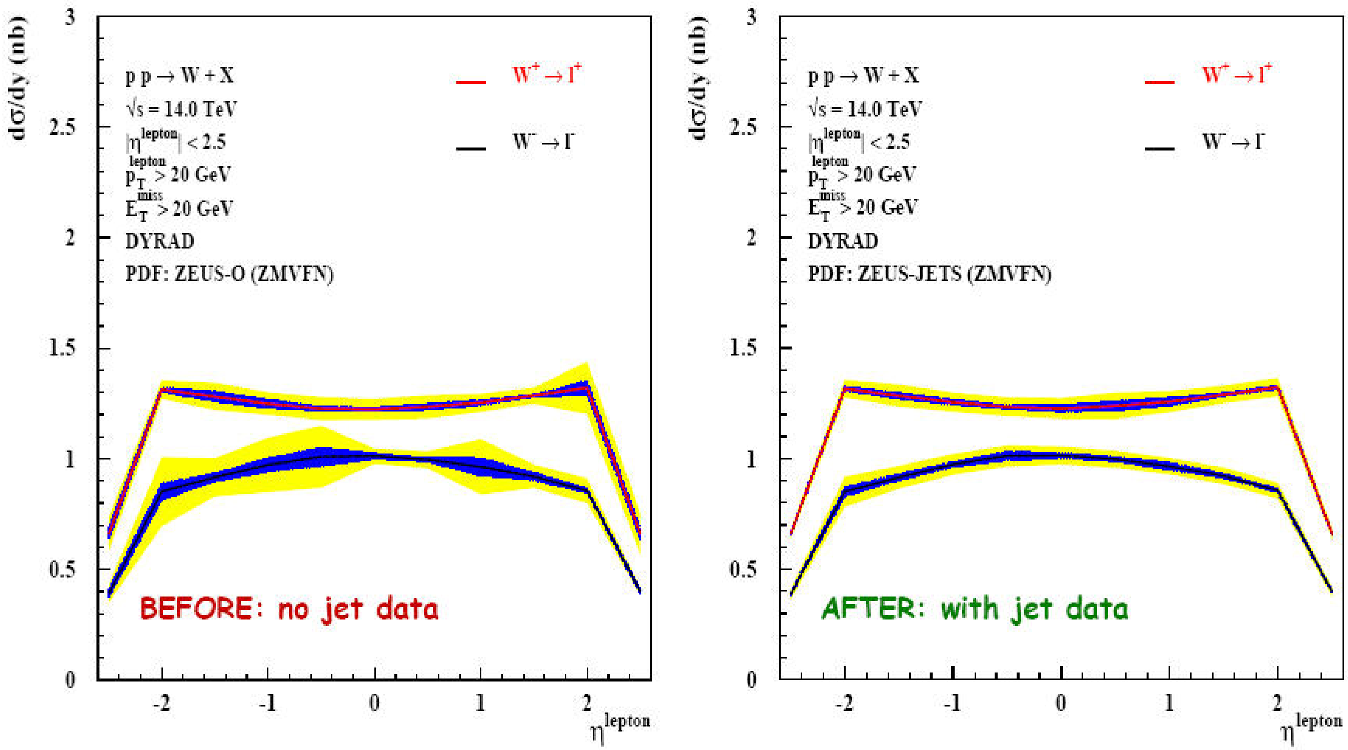
Impact on the LHC (an example)

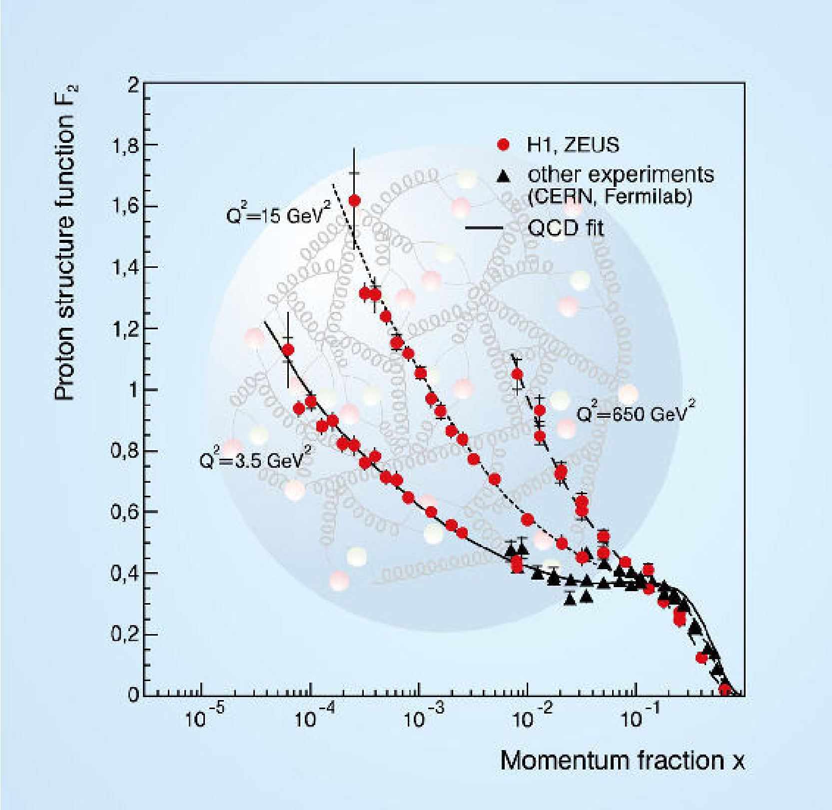
$W^{\pm}$ production (plots from Kunihiro Nagano)

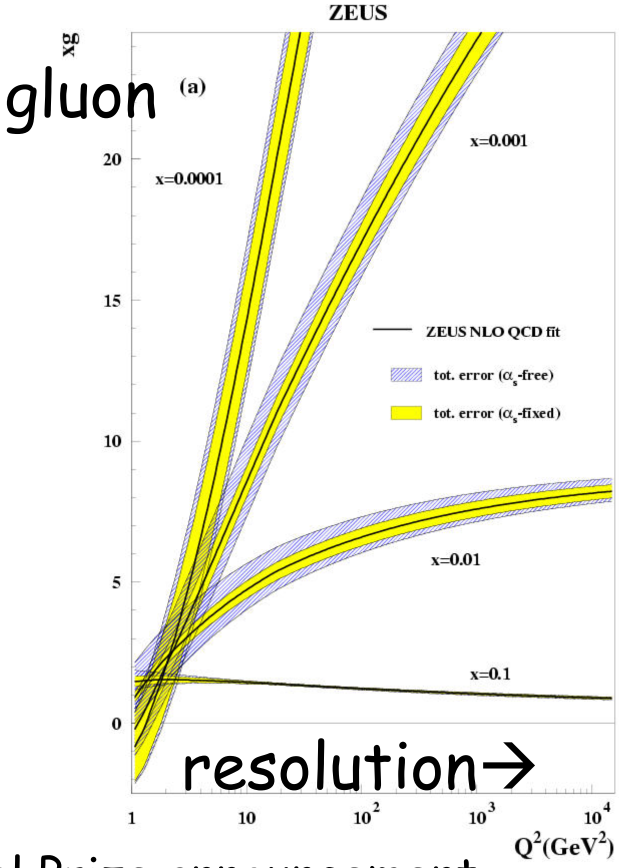


- Smaller uncertainties from improved knowledge of gluon from jet data

(K. Nagano, KEK)

Triumph of perturbative QCD





A part of Wilczek's comments upon the Nobel Prize announcement

proposed specific experimental tests of our ideas. In the fourth paper some technical objections to the theory were cleared up, and in the fifth and sixth papers further experimental consequences, regarding the pointwise evolution of structure functions, were derived. The most dramatic of these, that protons viewed at ever higher resolution would appear more and more as field energy (soft glue), was only clearly verified at HERA twenty years later.

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2. Comparison of ZEUS/H1 public analyses

Both ZEUS (2004) and H1 (2003) now make PDF fits to their own data. Where does the information come from in a HERA only fit compared to a global fit ?

	Global	HERA Only
Valence	Predominantly fixed target data (ν-Fe and μD/μp)	High Q^2 NC/CC $e^{\pm}$ cross sections
Sea	Low-x from NC DIS High-x from fixed target Flavour from fixed target	Low-x from NC DIS High-x less precise Flavour ?(need assumptions
Gluon	Low-x from HERA $dF_2/dlnQ^2$ High-x from momentum sum	Low-x from HERA $dF_2/dlnQ^2$ High-x from momentum sum

Mostly uv → (Global valence)
some dv → (HERA Only valence)
Tevatron jet data? → (Global gluon high-x)
HERA jet data? → (HERA Only gluon high-x)

ANALYSES FROM HERA ONLY …

— Systematics well understood
  - measurements from our own experiments !!!

— No complications from heavy target Fe or D corrections

(A. Cooper-Sarkar, Oxford)

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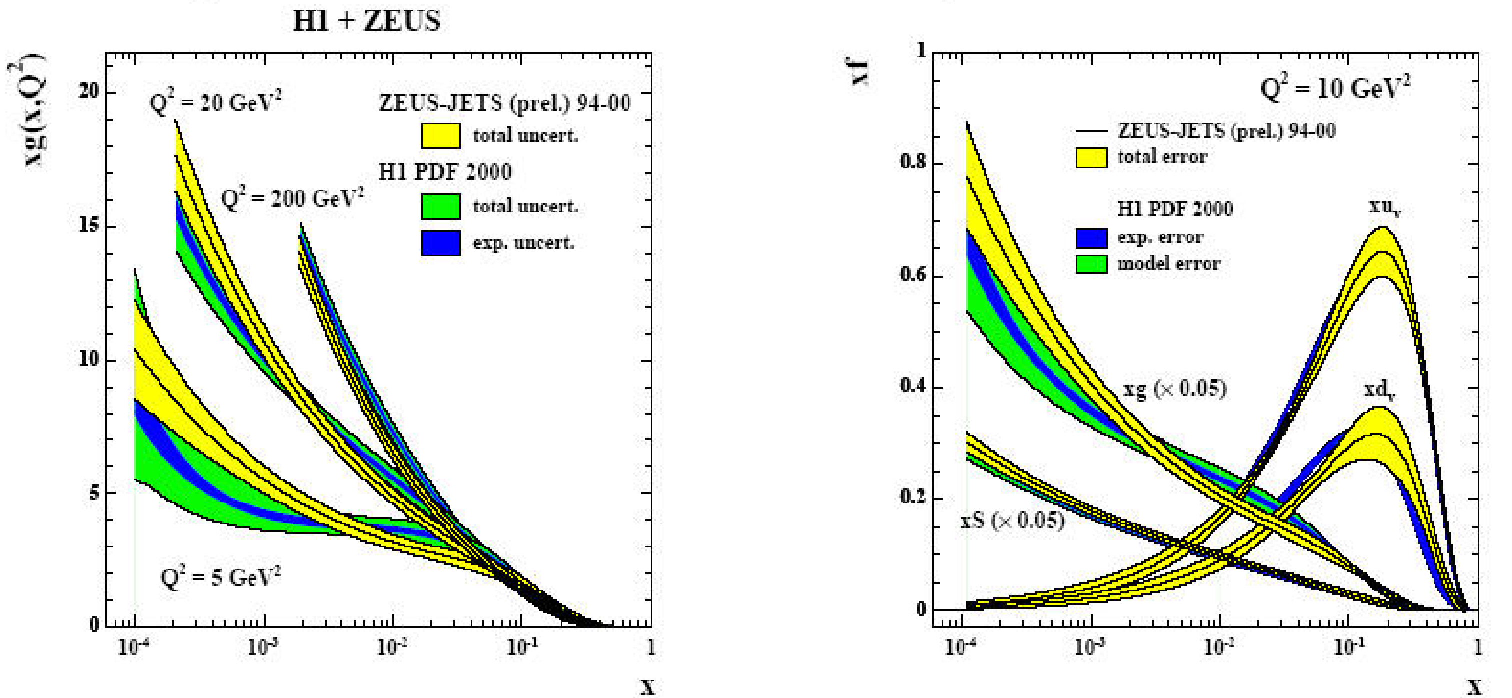
Comparison of ZEUS 2004 and H1 2003 analyses



Both collaborations include model errors – variations on assumptions at Q^2_0. These are large compared to the HESSIAN exp. errors of H1, and small compared to the OFFSET exp. errors of ZEUS. Comparison with model errors included gives similar size of errors

But valence PDFs cannot really be compared this way because H1 do not fit in terms of valence PDFs and model errors cannot be easily evaluated- recall that the H1 parametrization puts a strong constraint on the shape of the valence PDF

(A. Cooper-Sarkar, Oxford)

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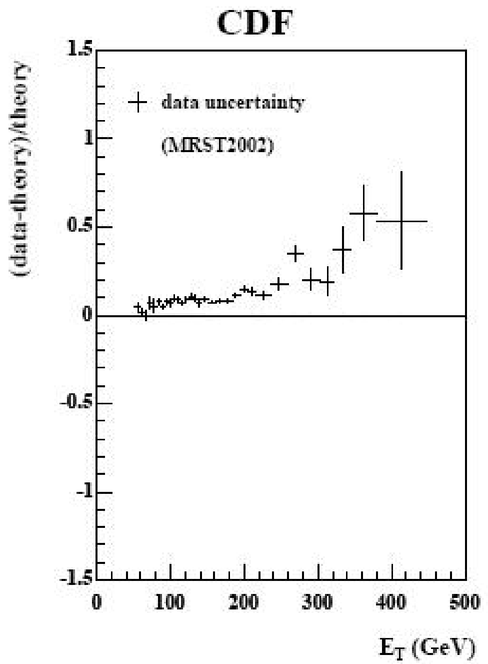
I have also made predictions for CDF jet data

-And I obtain **χ2 of 63 for 31** data points for **MRST2002** PDFs

-Whereas I obtain **χ2 of 51 for 31** data points for **ZEUS-S 2002 central PDFs**

I,e we are actually BETTER at predicting CDF jets!



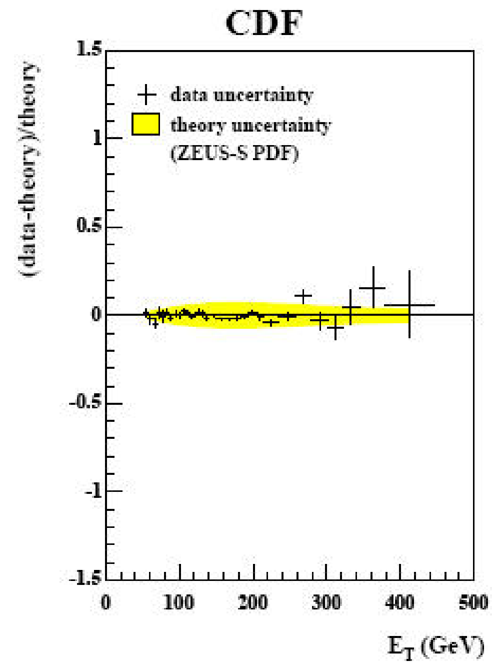
MRST2002

This figure shows (data-theory)/theory

And the error bars represent the size of the experimental error

Whereas the shaded area represents the PDF error-larger than exp error until high ET

IF the PDF error is included in the χ2 we get χ2 = 13 for 31 d.p.



ZEUS-S 2002

(A. Cooper-Sarkar, Oxford)

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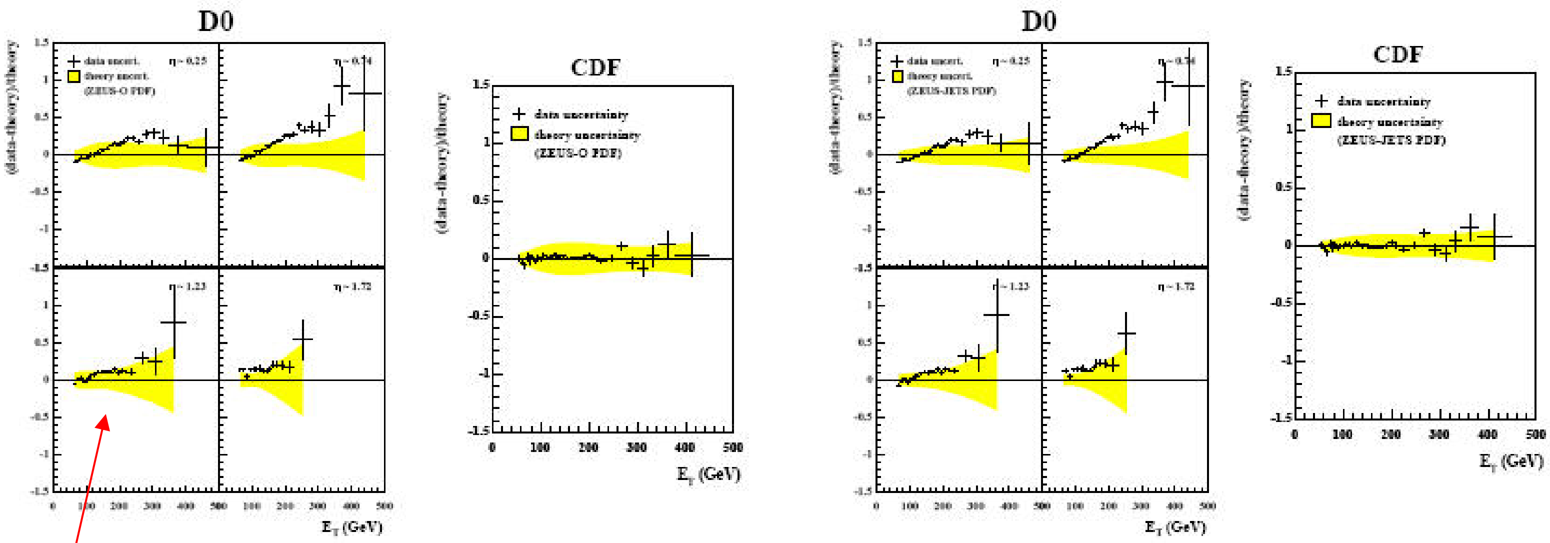
We would also like to investigate these things for the ZEUS PDFs 2004 both the ZEUS-ONLY (no jets) PDFs and the ZEUS-JETS PDFS



ZEUS-ONLY nojets χ2=122 for central PDF χ2=26 if PDF error accounted

ZEUS-ONLY nojets χ2=49 for central PDF χ2=8 if PDF error accounted

ZEUS-JETS χ2=118 for central PDF χ2=34 if PDF error accounted

ZEUS-JETS χ2=49 for central PDF χ2=10 if PDF error accounted

(A. Cooper-Sarkar, Oxford)

Note: CDF and D0 data have large (up to 60%) systematic uncertainties not shown on the plots: in case of the CDF data systematics are "shifted" to optimal values in the course of the fit. This is not possible for the D0 data since the relevant information is not available