NEW RESULTS FROM JET PHYSICS AT HERA

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OVERVIEW

- HARD JETS AT HERA
- ZEUS: INCLUSIVE JETS AT HIGH Q^2 and α_S.
  … and the positive effect on the PDFs
- H1: INCLUSIVE JETS AT HIGH Q^2 and α_S.
- ZEUS: DIJETS AT HIGH Q^2 (and the PDFs)
- H1: MULTIJETS AT HIGH Q^2 and α_S
- H1: DIJETS IN PHOTOPRODUCTION
- SUMMARY ON α_S FROM JETS AT HERA
- THE (HERA) JET PHYSICIST'S WISH-LIST

HARD JETS AT HERA

"why, what and how" ...

Cross-sections

Perturbative QCD, collinear factorization:

$$\sigma = \sum_{m=1}^{2} \alpha_s^m(\mu_r) \sum_{a=q,\bar{q},g} f_a(\eta,\mu_f) \otimes \hat{\sigma}(x_{Bj}/\eta,\mu_r,\mu_f)$$

Series expansion in powers of α_S; coefficients are convolutions of PDFs with hard scattering matrix elements.

Access to …

– underlying gauge group
– parton distributions, universality
– effect of exchanged boson
– parton dynamics in the proton

– strong coupling
– factorization
– concept of pQCD

Typically: assume factorization, pQCD, dynamics → get α_S, PDFs

Tools

– k_T jet algorithm (safe, small corrections, ...) on cells or energy flow objects (in Breit frame for DIS analysis)
– NLO theory corrected to hadron level with parton shower models
– latest PDFs like CTEQ6 ...
– data corrected for detector and QED effects with MC models
– excellent understanding of jet energy scale (1-3%)
– many measurements dominated by theoretical errors

Remember

– Importance of jet physics for LHC (background to all searches, understanding of detector/calibrations/tools etc.)

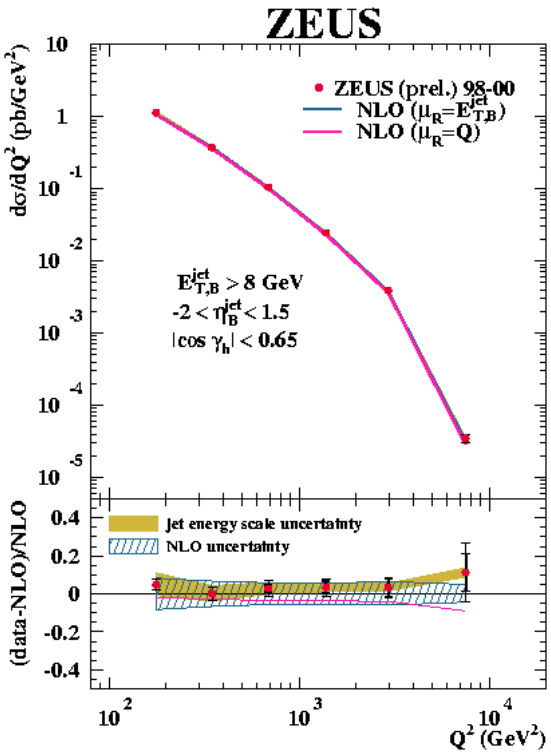
ZEUS INCLUSIVE JETS AT HIGH Q^2

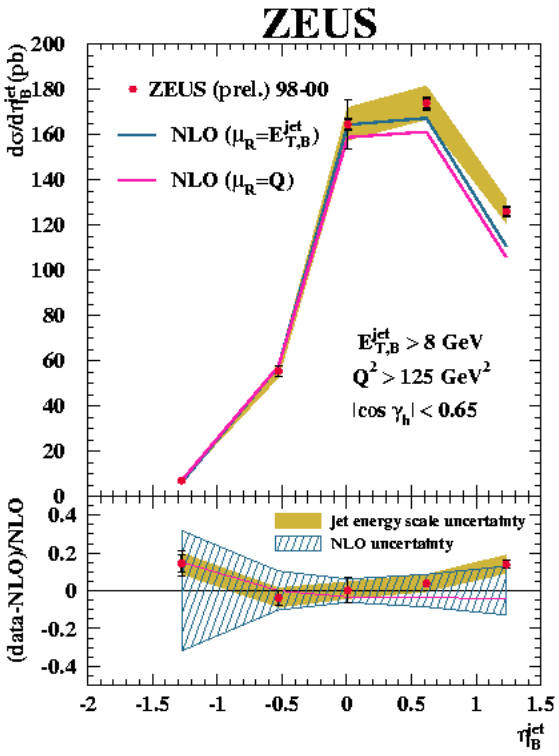
`Simple' measurement – take PDFs/α_S as given

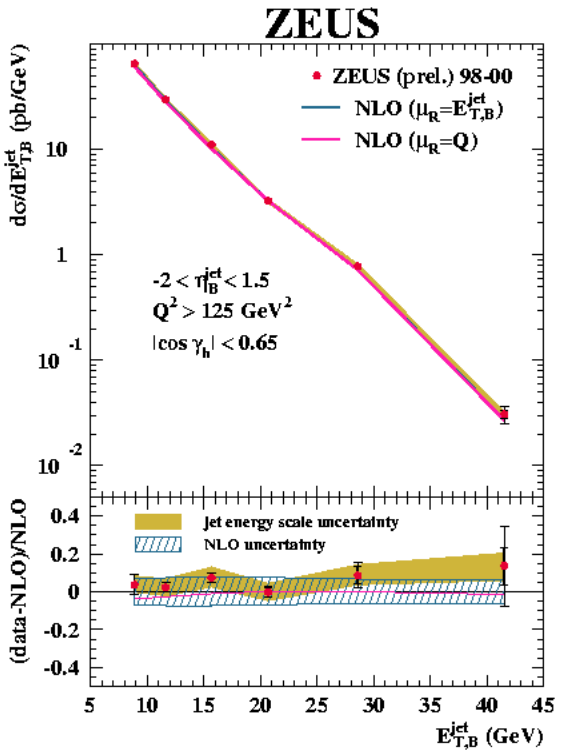
Tests – factorisation, – pQCD, – PDF universality $\hat{\sigma}$

Selection – ~82pb^{-1} from 98-00; – $Q^2 > 125$ GeV^2; – $E_T > 8$ GeV (Breit)

Aims – strong coupling; – use in QCD fits



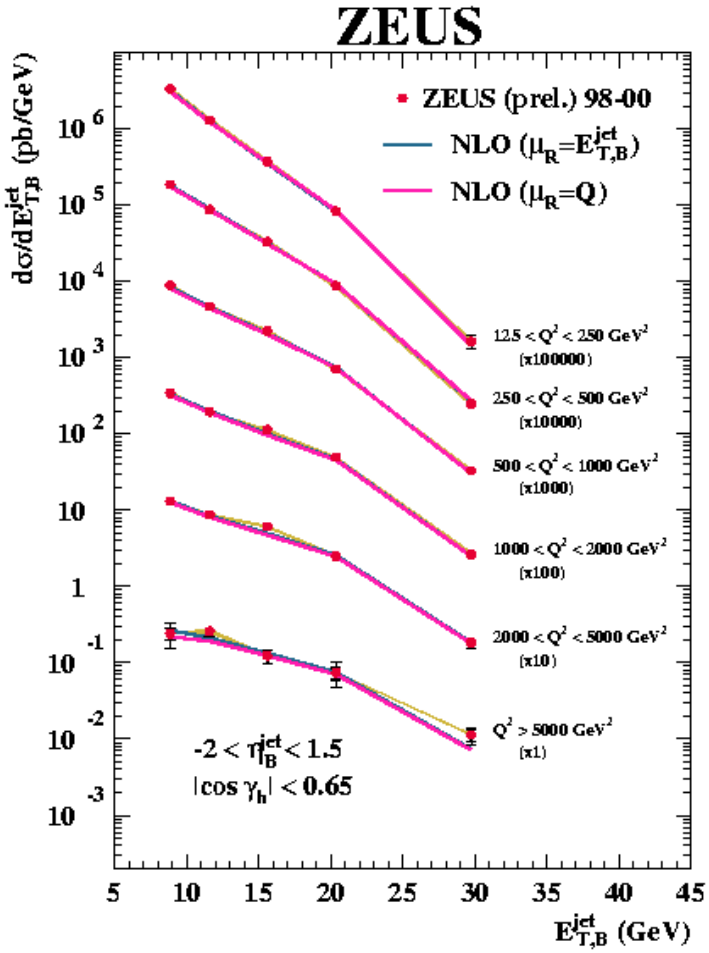


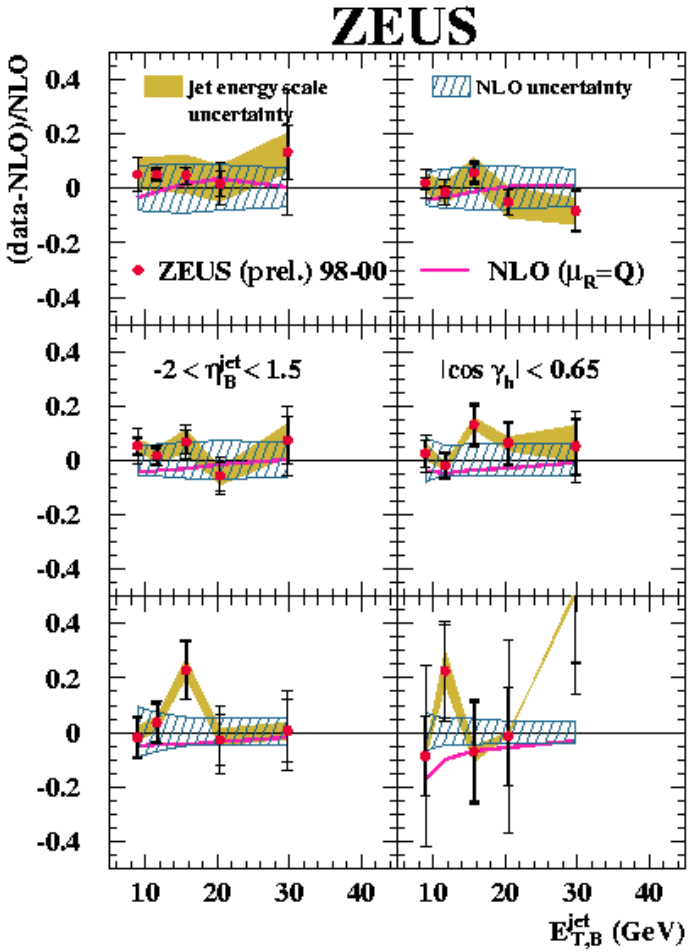


Data well described by NLO theory; errors mostly dominated by scale variation effect.

ZEUS INCLUSIVE JETS

Also double-differentially, comparison to NLO



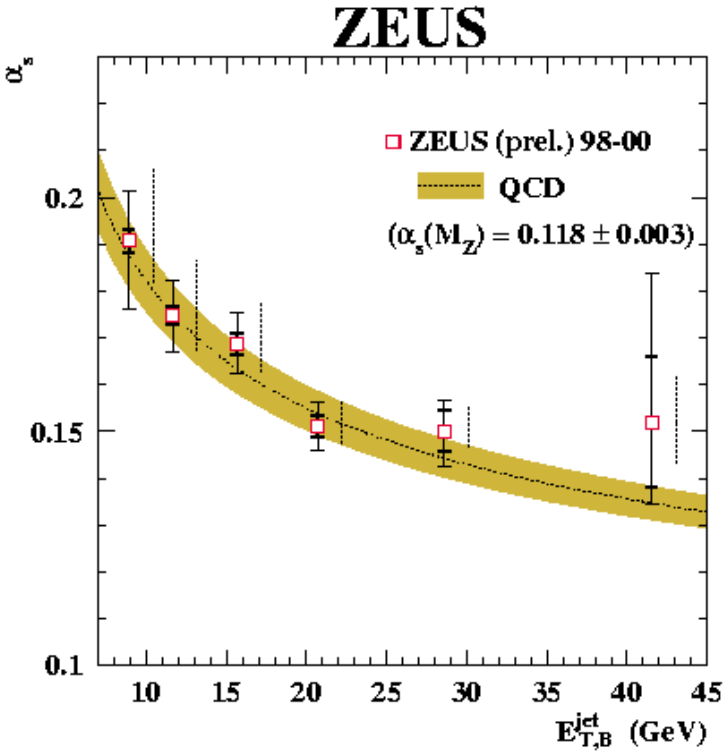


¶ E_T and Q^2 dependence → PDF information (use data in QCD fits as 96/97 measurement)

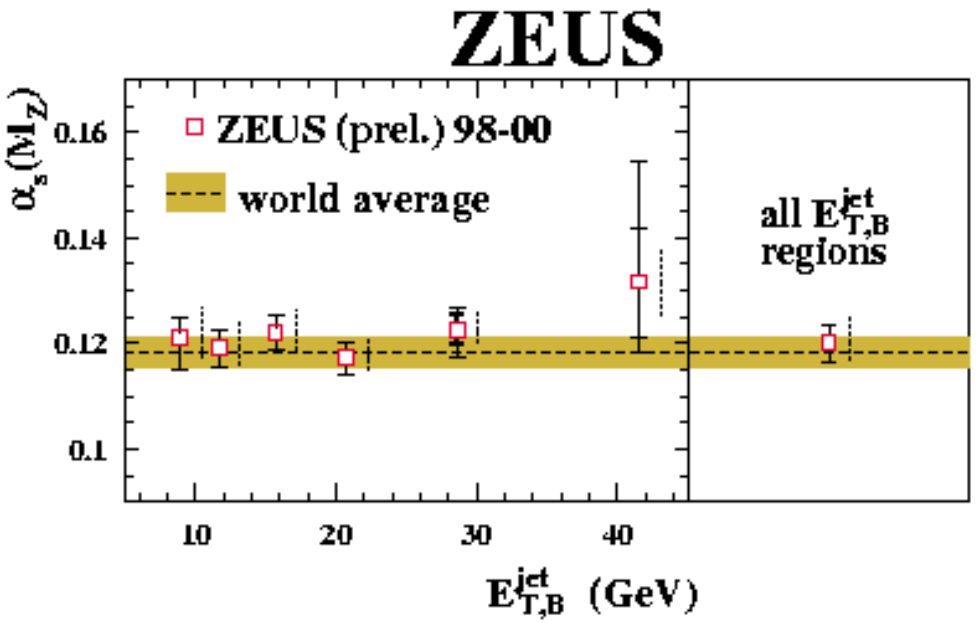
¶ Ratio with NLO: data well described by NLO QCD

α_s FROM ZEUS INCLUSIVE JETS

in bins of transverse energy and combined



Demonstration of running coupling.



All points compatible with world average.

ZEUS inclusive jets: $\alpha_s(M_Z) = 0.1196 \pm 0.0025(exp) \pm 0.0023(theo)$

World average: $\alpha_s(M_Z) = 0.1187 \pm 0.0020$

H1 inclusive jets: $\alpha_s(M_Z) = 0.1197 \pm 0.0016(exp) \pm 0.0047(theo)$

REMINDER: PDFs VIA INCL. JETS

Aim: reduction of gluon error via BGF process

– Structure functions alone leave large uncertainty of PDFs (specially gluon) at high momentum fractions.

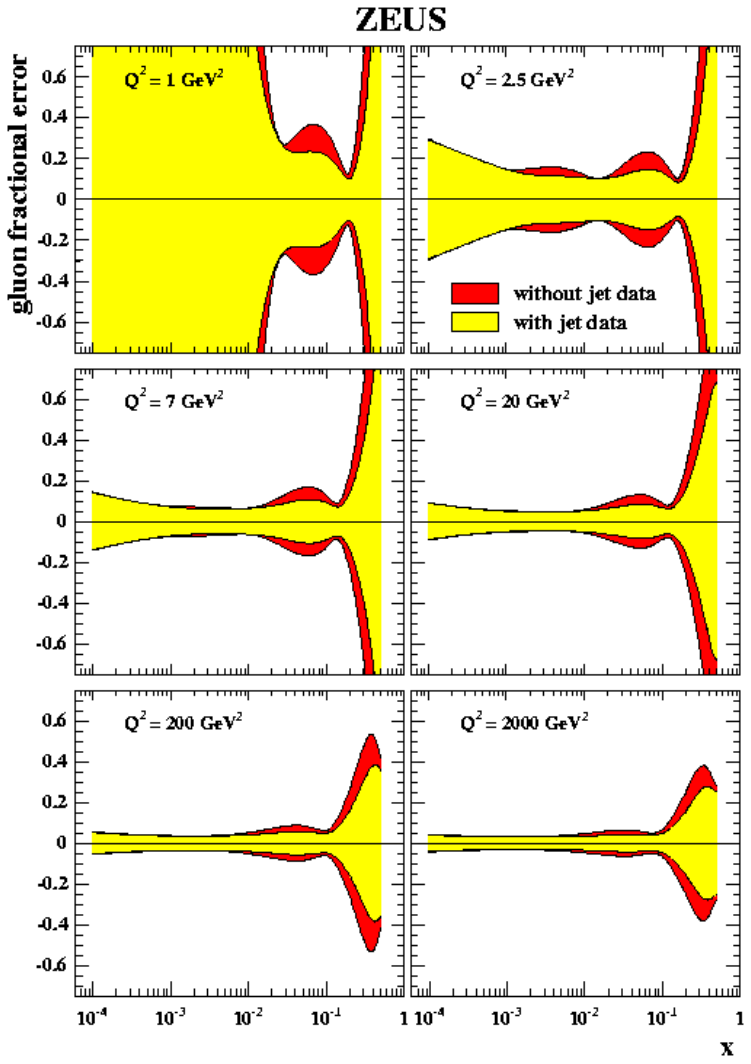
– Jet data provide access to this kinematic regime.

– (Technically demanding) inclusion of jet data in QCD fits leads to massive improvement of gluon uncertainty at medium and high momentum fractions. (used here: inclusive jets

– Data sets used here:
  – ZEUS inclusive jets (predecessor to this analysis) from 96/97.
  – ZEUS dijets from photoproduction.

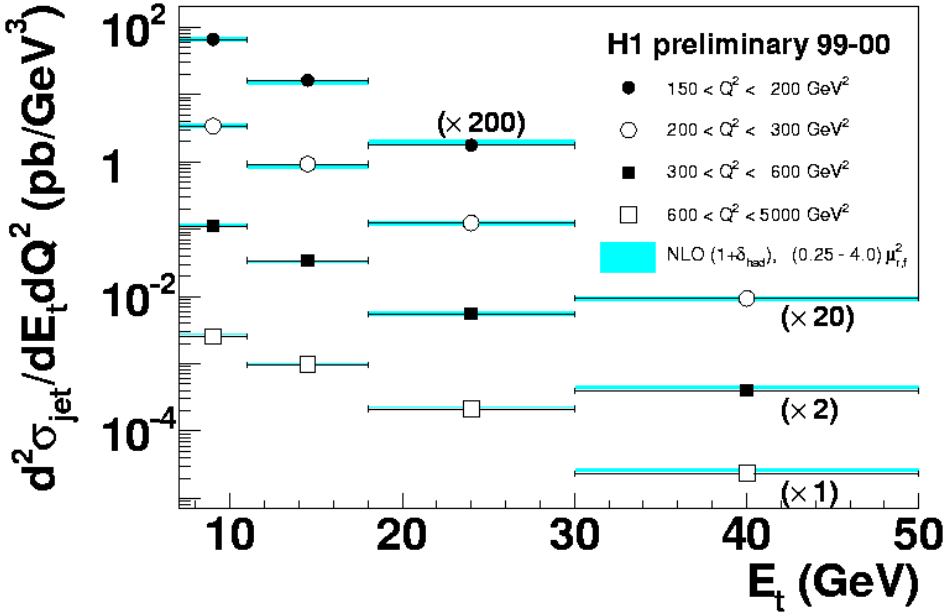
– Future plans: use ZEUS inclusive and dijet data from high Q^2 from 98-00 data.

– Programs like FASTNLO provide systematic way of using jet data in fits.

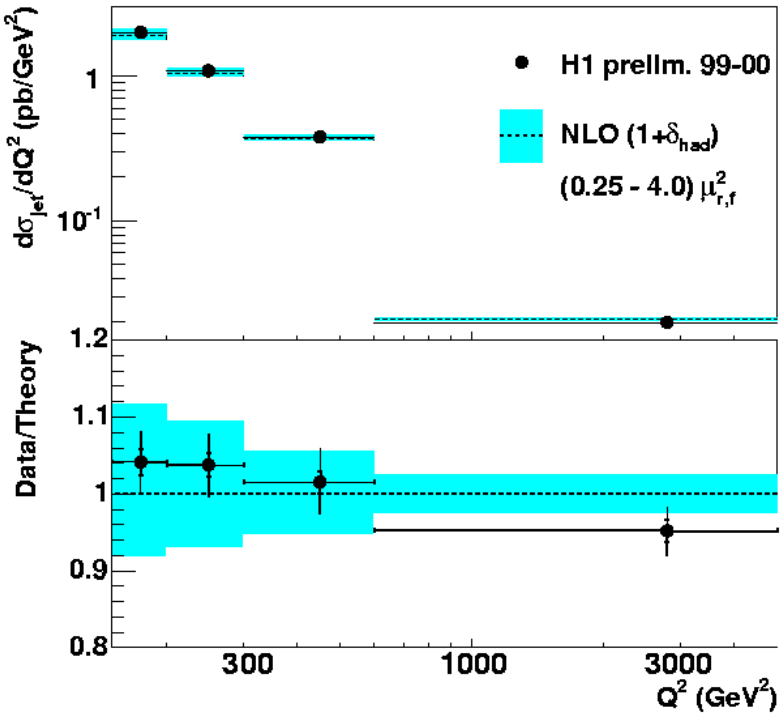


H1 INCLUSIVE JETS AT HIGH Q^2

As function of E_T in bins of Q^2.



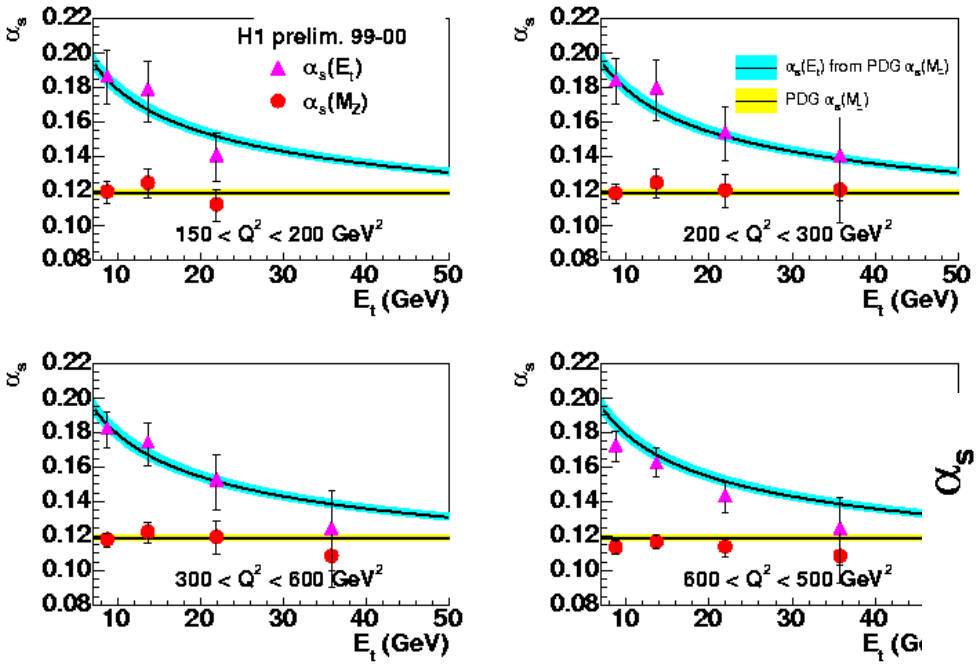
– 61pb^{-1} from 99-00 data
– double-differential measurement in E_T (Breit frame, > 7 GeV) and Q^2 (> 150 GeV^2);
– similar phase-space as ZEUS analysis; similar precision.



– Very good agreement of data and theory within all errors;
– uncertainty dominated by theory (scale variation effect; missing higher orders).

H1 INCLUSIVE JETS

extraction of strong coupling



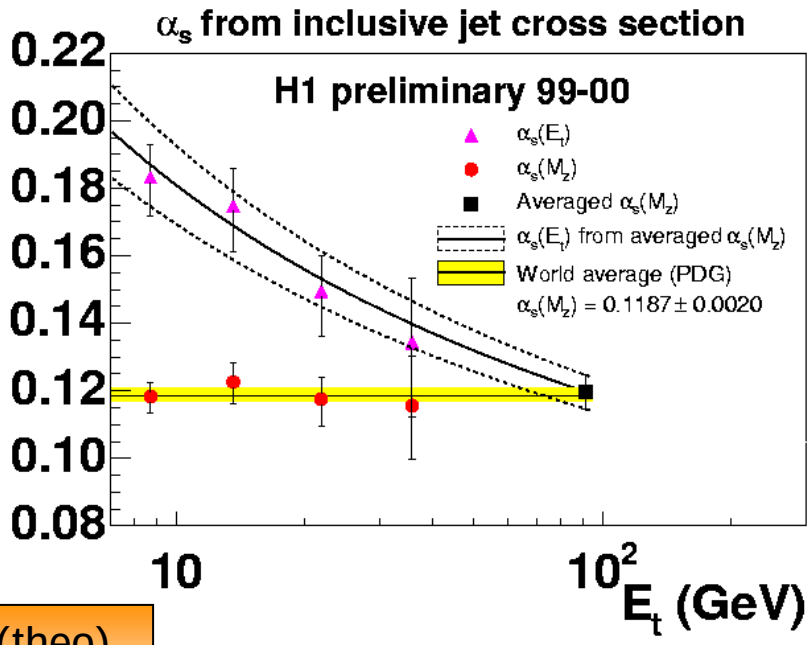
¶ Coupling extracted from 15 data points.

¶ All single measurements consistent.

¶ Combination of all points in one value.

¶ Result consistent with world average and ZEUS inclusive jets.

¶ Theory error dominates (effect of higher orders)



H1 inclusive: $\alpha_s(M_Z) = 0.1197 \pm 0.0016(\text{exp}) \pm 0.0047(\text{theo})$

(ZEUS inclusive: $\alpha_s(M_Z) = 0.1196 \pm 0.0025(\text{exp}) \pm 0.0023(\text{theo})$)

ZEUS DIJETS AT HIGH Q^2

Motivation

Idea:

¶ PDFs characterized by variables Q^2 and ξ (proton momentum fraction)

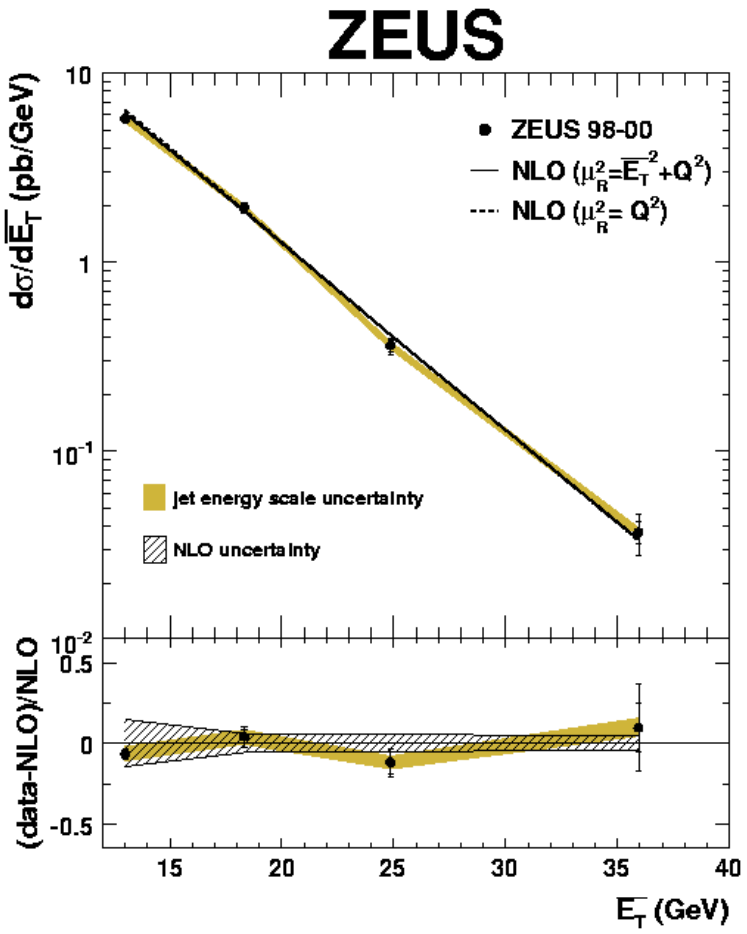
¶ In dijet events:

$$\xi = x_{Bj} \cdot \left(1 + \frac{M_{jj}^2}{Q^2}\right)$$

→ Use dijets at high Q^2 from large 98-00 data sample (82pb^{-1}) to obtain theoretically safe and precise information about PDFs (g at high ξ!).

Example

¶ Mean E_T of dijets, well described by NLO!



Analysis

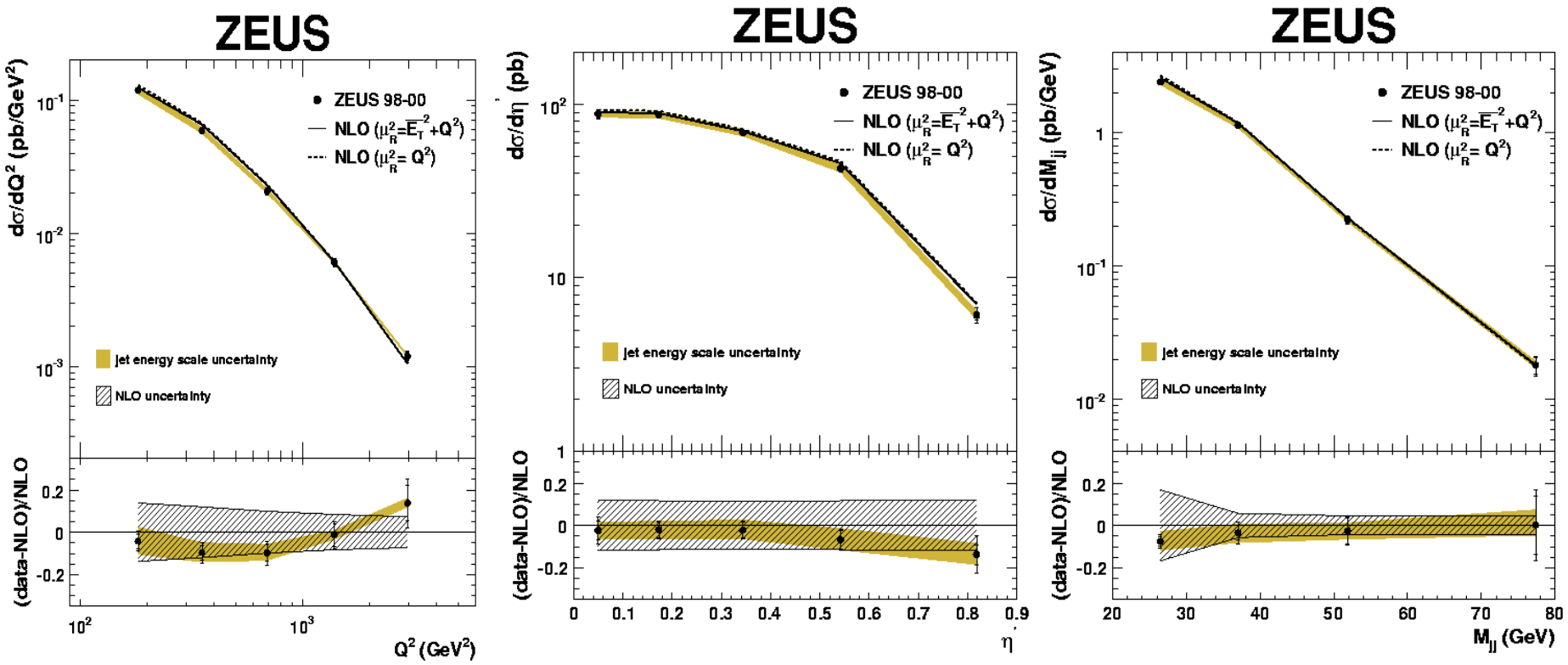
¶ Phase-space selection:
- $125 < Q^2_{DA} < 5000$ GeV^2
- $|\cos\gamma_{had}| < 0.65$

¶ Jet selection:
- $-2 < \eta_{Breit} < 1.5$
- $E_{T,1(2)} > 12$ (8) GeV

¶ Compare to NLO QCD (DISENT, CTEQ6)

ZEUS DIJETS AT HIGH Q^2

More single-differential results

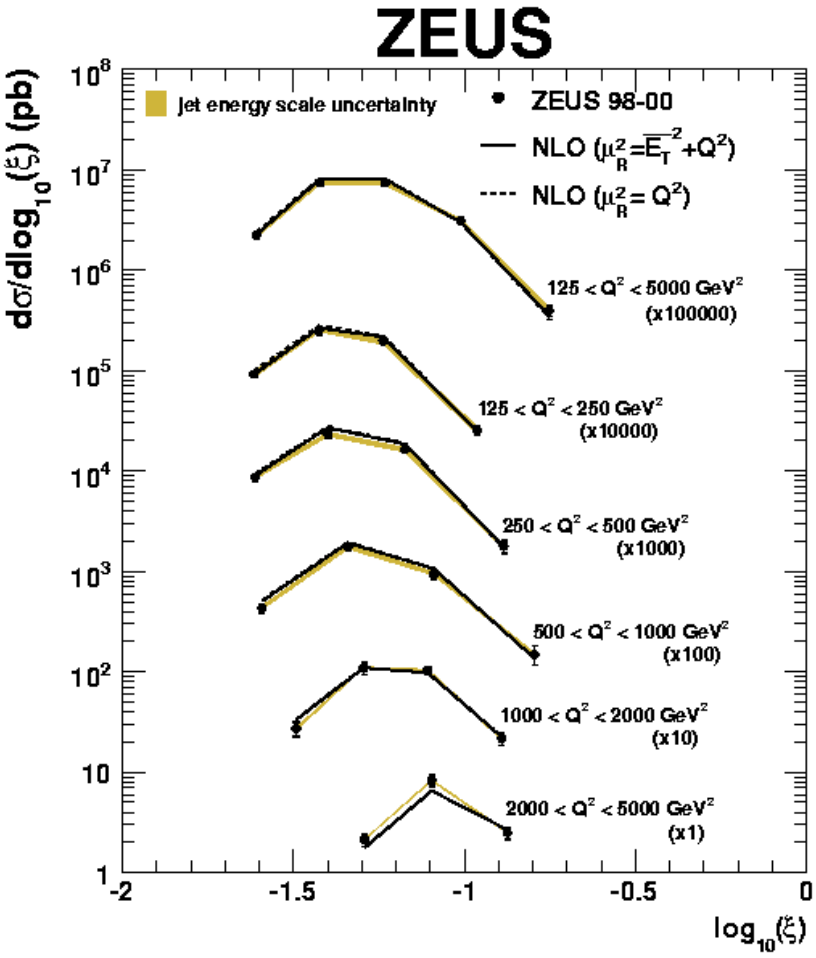


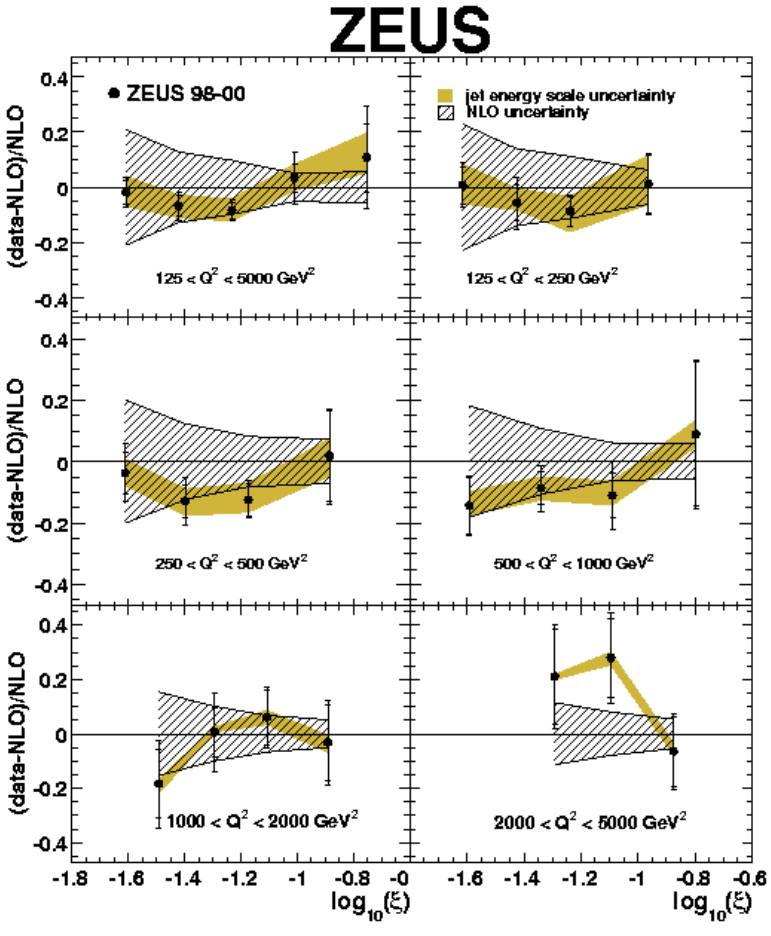
¶ Data nicely described by NLO theory corrected to hadron level.

¶ Theoretical uncertainties almost everywhere larger than experimental errors. Dominating contribution from scale variation to estimate higher-order effects.

ZEUS DIJETS AT HIGH Q²

double-differential measurement: log(ξ) in Q^2 bins



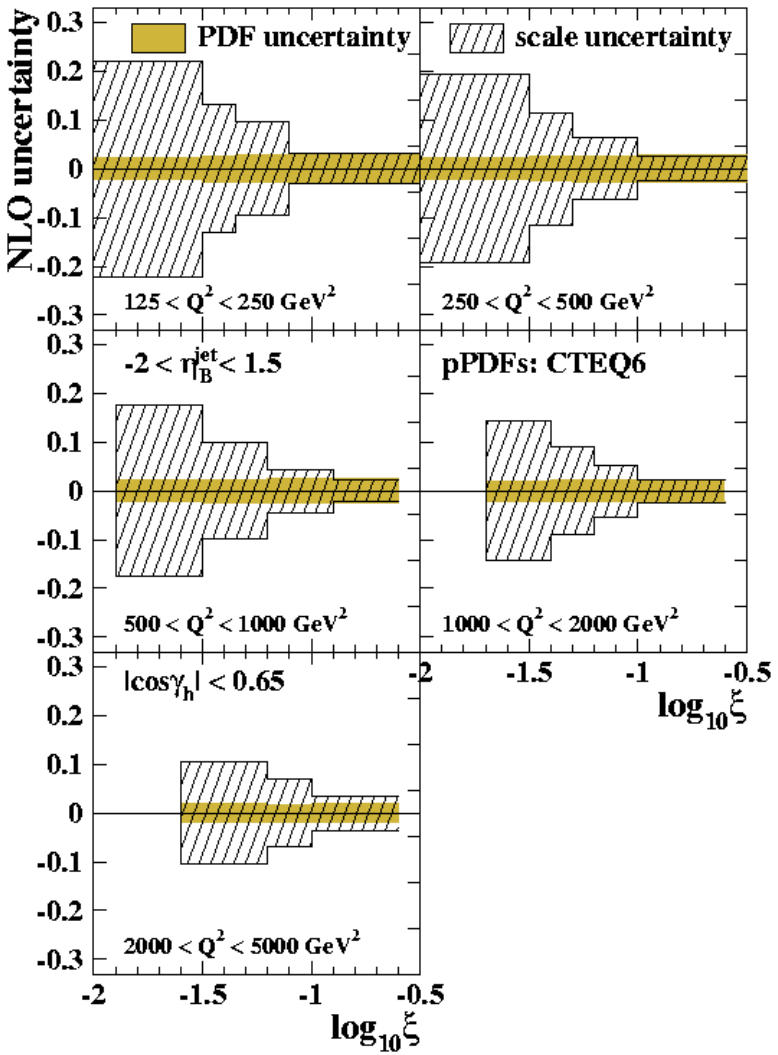


¶ Also double-differential data well described by NLO.

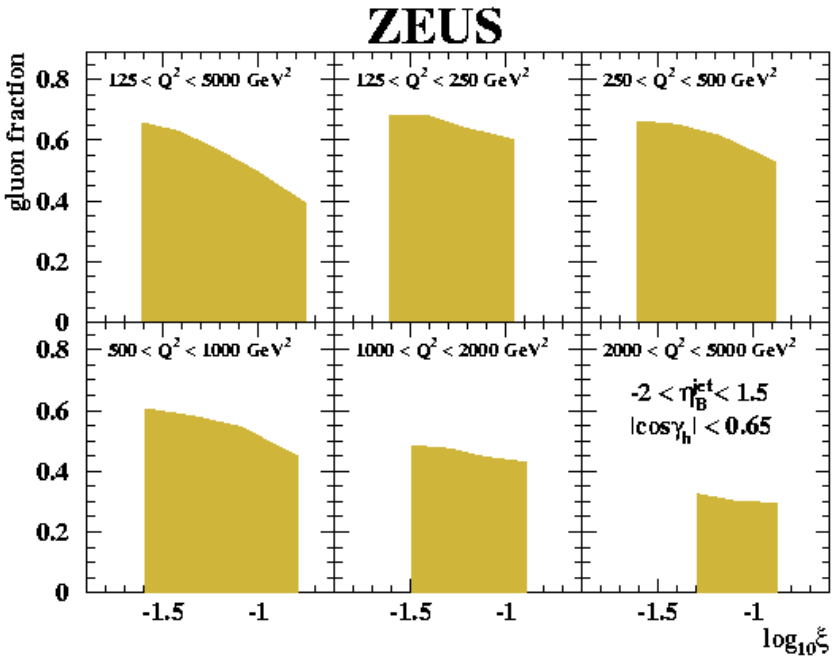
¶ Still large theoretical uncertainties; at high Q^2 statistics getting low.

ZEUS DIJETS

theory uncertainty and gluon fraction



– scale uncertainty 5-20%, large at small ξ.
– PDF uncertainty ≤3%, significant at high ξ.

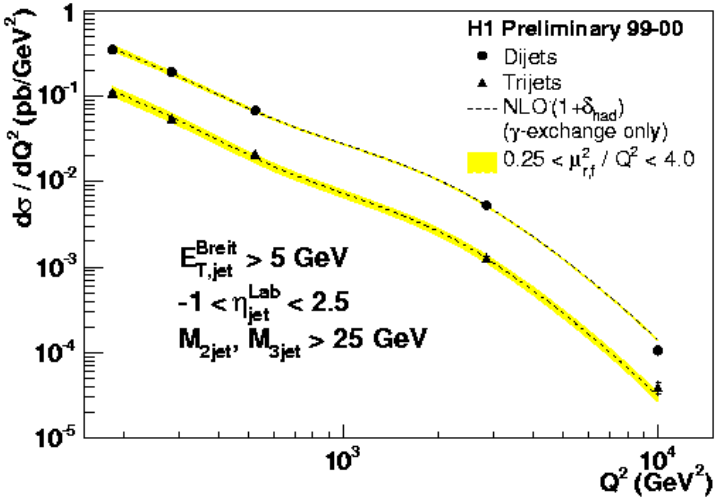


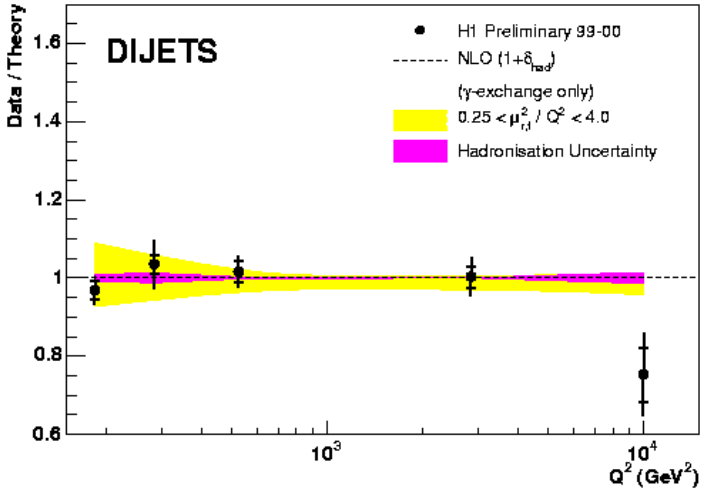
- gluon fraction decreases with increasing ξ and Q^2.
- still substantial gluon contribution → use in NLO QCD fits of PDFs.

H1 MULTIJETS AT HIGH Q^2

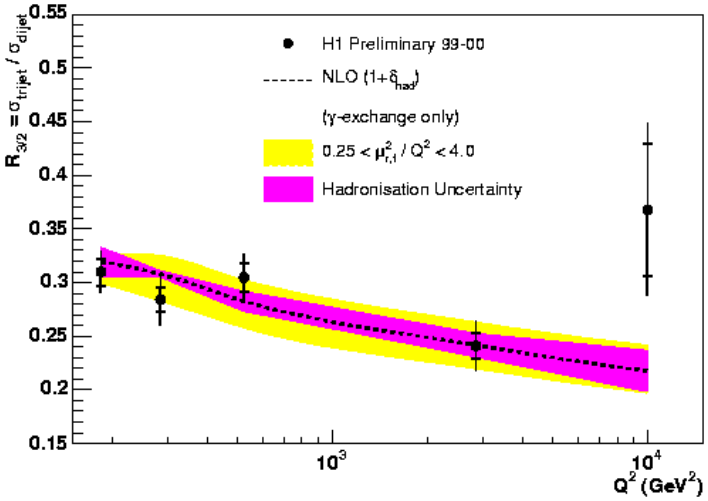
Di- and trijets from 99-00 data

¶ Analysis of di- and trijet events in large data sample from 99-00 (pb^{-1}).
¶ Analysis similar to ZEUS DESY-05-019.
¶ Rather soft E_T(Breit) cut of 5 GeV – but cut on invariant 2(3)-jet mass M > 25 GeV.
¶ NLO QCD provides excellent description:



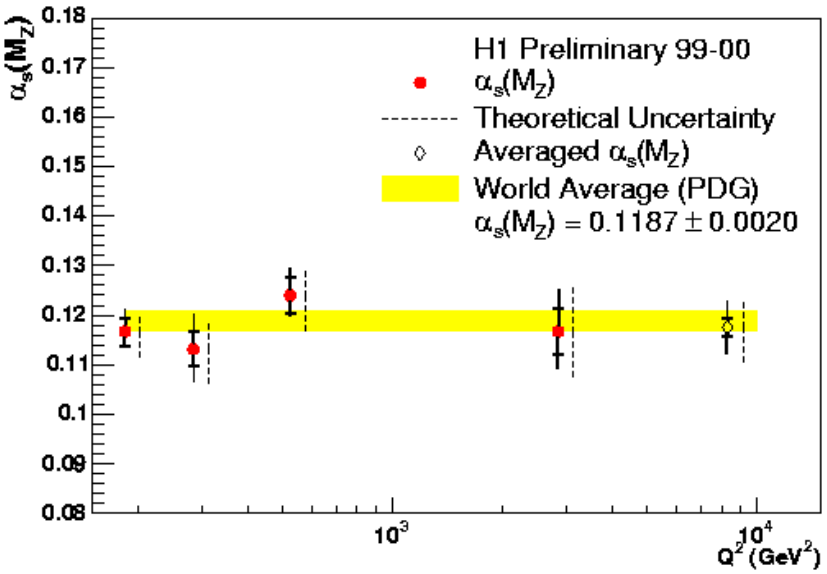


¶ Good description of data → extraction of strong coupling seems useful.
¶ In 3/2-jet ratio theo.+ exp. uncertainties cancel (partly) → use this quantity!



H1 MULTIJETS AT HIGH Q^2

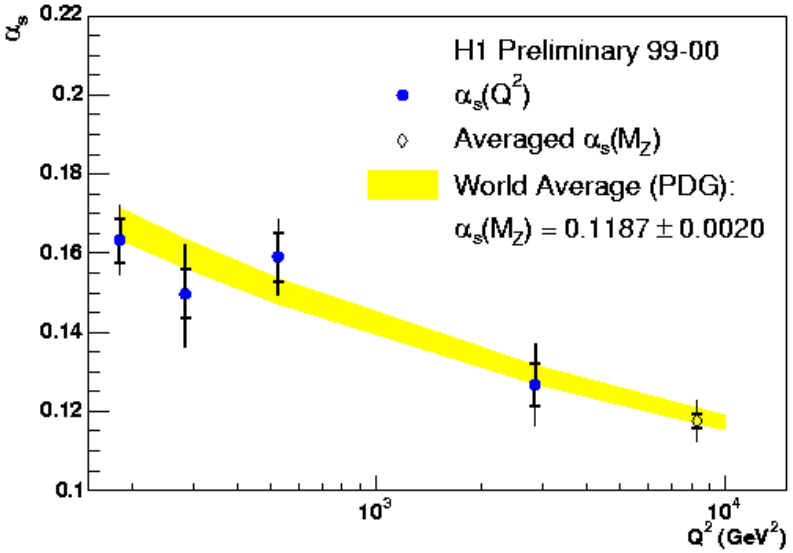
Strong coupling from di- and trijets



¶ 3/2-jet ratio as function of Q^2.

¶ Single data points are compatible with each other and with world average.

¶ Nice demonstration of running coupling.



¶ Resulting value for coupling:

$$\alpha_s(M_Z) = 0.1175 \pm 0.0017(\text{stat}) \pm 0.0050(\text{sys}) \pm 0.0061(\text{theo})$$

¶ Substantially larger than for inclusive jets.

¶ Systematics and theory closer than for (H1) inclusive jets

H1 DIJETS IN PHOTOPRODUCTION

precise multi-differential test of QCD

¶ Concentrate on high-E_T to define perturbatively safe regime.
$E_{T,max}$> 25 GeV, $E_{T,2}$ > 15 GeV

¶ Data set of 66pb^{-1} from 99-00; large statistics allow differential measurement (14k events).

¶ Data might be used to exploit sensitivity to photon and proton PDFs.
- direct and resolved regimes via x_γ.
- proton momentum fractions x_p up to 0.7
- disentangling gluon- and quark-initiated processes (BGF at low x_p).

$$x_\gamma = \left(E_{T,1}e^{-\eta_1} + E_{T,2}e^{-\eta_2}\right)/2yE_e$$
$$x_p = \left(E_{T,1}e^{\eta_1} + E_{T,2}e^{\eta_2}\right)/2E_p$$

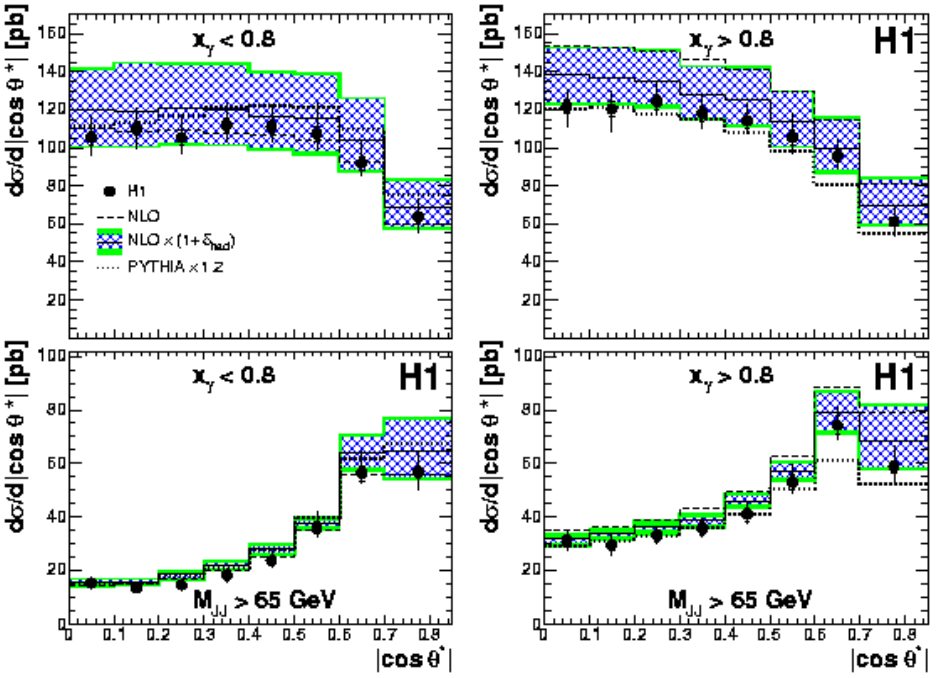
¶ Overall excellent demonstration of power of pQCD; exp. uncertainty dominated by had energy scale (known to 1.5-8%)

¶ Measurement in cosθ* gives access to dynamics of hard interaction → tests of pQCD.

$$\left|\cos\theta^*\right| = \left|\tan(\eta_1 - \eta_1)/2\right|$$

¶ High-E_T cuts suppress cross section at high cosθ*, for high M_{jj} closer to ME expectations.

¶ Faster rise in resolved than in direct reflects gluon/quark propagator spin.



H1 DIJETS IN PHOTOPRODUCTION

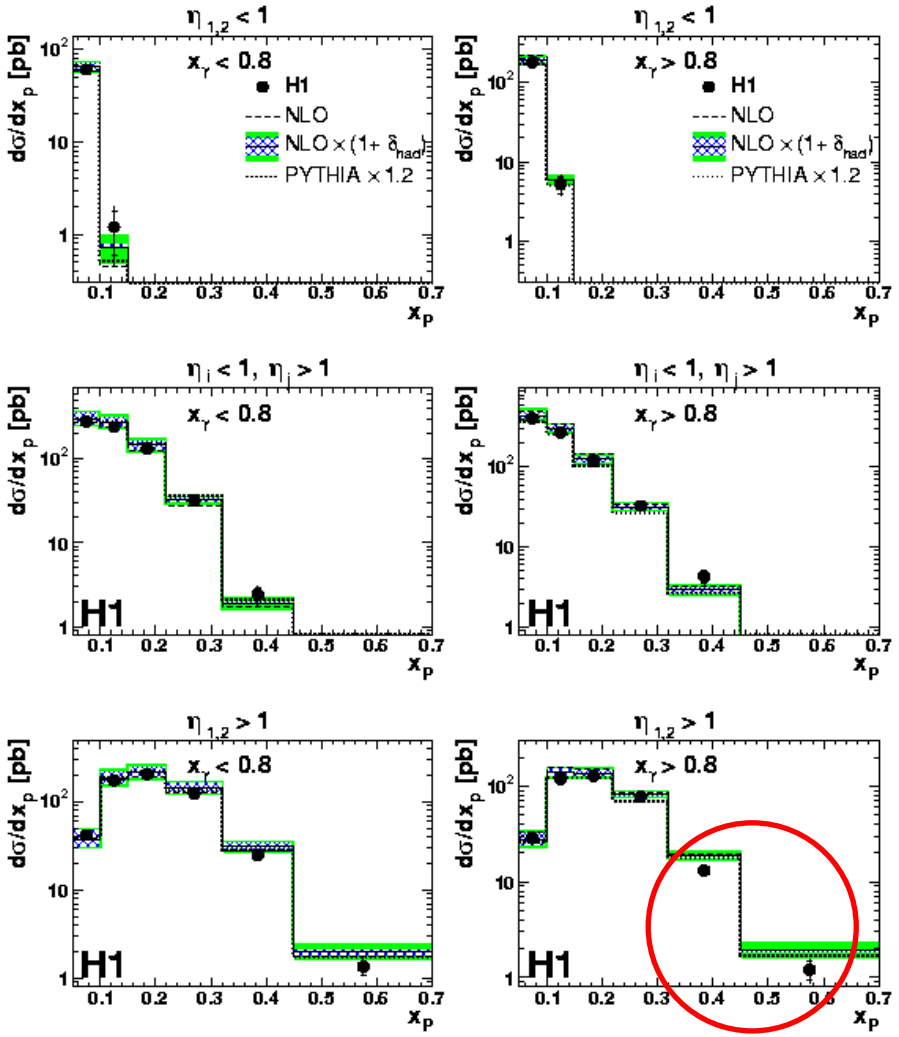
exploiting the dijet event topology

¶ Pseudorapidities of jets reflect momentum distributions of incoming partons
- → measure x_p for both jets back/forward and for one jet forward/backward separately for resolved and direct.
- → learn about PDFs/dynamics?

¶ Data are well described in all phase space regions except for highest x_p point in direct sample for both jets forward:
- – insufficient parton dynamics in DGLAP-based NLO theory?
- – underestimated PDF uncertainty at high momentum fractions?

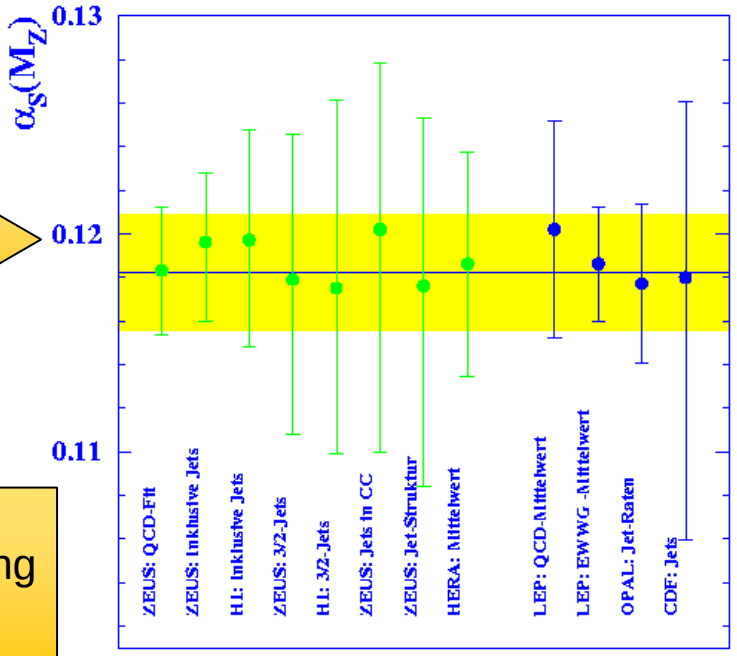
¶ Data might be very useful in global fits for the proton parton densities;

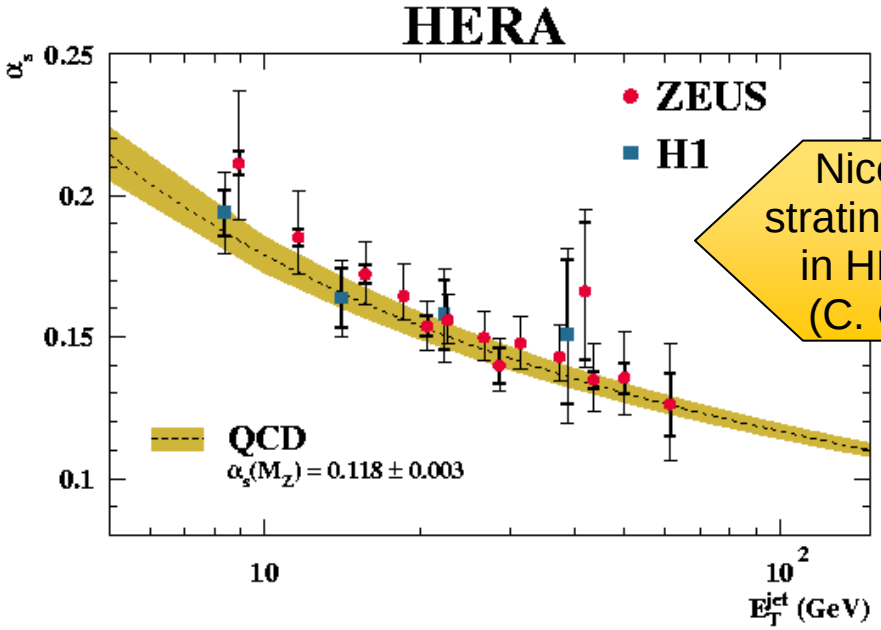
how large is the sensitivity to the γ PDFs?



SUMMARY ON HERA α_s

Consistency of HERA/ LEP/Tevatron results is an important check!





Nice demon-strating of running in HERA data. (C. Glasman)

Summary of new determinations of $\alpha_s(M_Z)$:

H1 inclusive:

$\alpha_s(M_Z) = 0.1197 \pm 0.0016(exp) \pm 0.0047(theo)$

H1 3/2 jets:

$\alpha_s(M_Z) = 0.1175 \pm 0.0017(stat) \pm 0.0050(sys) \pm 0.0061(theo)$

ZEUS inclusive:

$\alpha_s(M_Z) = 0.1196 \pm 0.0025(exp) \pm 0.0023(theo)$

HERA : $\alpha_S(M_Z)=0.1186 \pm 0.0011(exp.) \pm 0.0050(th.)$

Bethke: $\alpha_S(M_Z)=0.1182 \pm 0.0027$

(HERA) JET PHYSICIST'S WISHLIST

or "conclusion and outlook"

Achieve-ments

¶ Excellent understanding of pQCD demonstrated; concepts of factorisation and PDF universality work very well.

¶ Very precise parameter extraction:

– clear reduction of gluon uncertainty at medium/high x via use of jet data.

– HERA average: $\alpha_S(M_Z)=0.1186\pm0.0011(\text{exp.})\pm0.0050(\text{th.})$

Experi-mental wishes

¶ not much to wish for really:

– we have large samples → in most fields statistics not an issue

– experimental errors well under control (lumi, energy scale, ...)

¶ Some questions would profit from more data and multi-differential analyses (parton dynamics)

¶ Clearly (wo)manpower will be an issue – people are leaving HERA!

Theoretical wishes

¶ ... some wishes here:

– often scale uncertainty dominating source of uncertainty (low Q^2, E_T, M_{jj})

→ higher orders (NNLO) would really help (coupling, PDFs).

→ but also question important: Which is "true" scale (BML, ...)

– hadronisation corr. of NLO theory done with LO MC programs

→ want NLO+PS for better consistency + as approach to NNLO

→ MC@NLO? (standard answer: e^+e^- easy, pp important ...)

... but remember: HERA can provide important input to LHC!

– DGLAP-BFKL question: Easy-to-use BFKL program would help experimentalists a lot ...

– ...