Jets and α_s

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Outline of talk

QCD processes and partons

Jets

Measurement of α_s

Some brief theoretical notes.

(much indebted to Giulia Zanderighi's talk at ICHEP)

We are comparing various jet cross sections to QCD calculations. What is the status here?

1) LO calculations all possible and done where needed.

2) $2 \rightarrow 2$ NLO all done

$2 \rightarrow 3$ NLO nearly all done

$2 \rightarrow 4$ not much done

3) NNLO not much done apart from Drell-Yan, 3 jets in e^+e^-.

and a few others

Jets are the means by which we observe the partons….

Two approaches, cone and clustering.

Cone is well defined but has some IR problems.
Clustering (k_T) has better theoretical properties.
Cluster two objects if
$d^2_{ij} = \min(E^2_i , E^2_j).[(\eta_i - \eta_j)^2 + (\varphi_i - \varphi_j)^2] < R$

Mid-point algorithm helps the cone IR problem, but is not perfect.

Now we have SIScone (seedless) which is much better still.

Anti-k_T algorithm, aims at well defined jets for LHC

Both of the latter are IR and collinear safe

TASKS for EXPERIMENT

1) Measure jet cross sections using a theoretically well defined technique, i.e. one that can be reliably compared with theory.

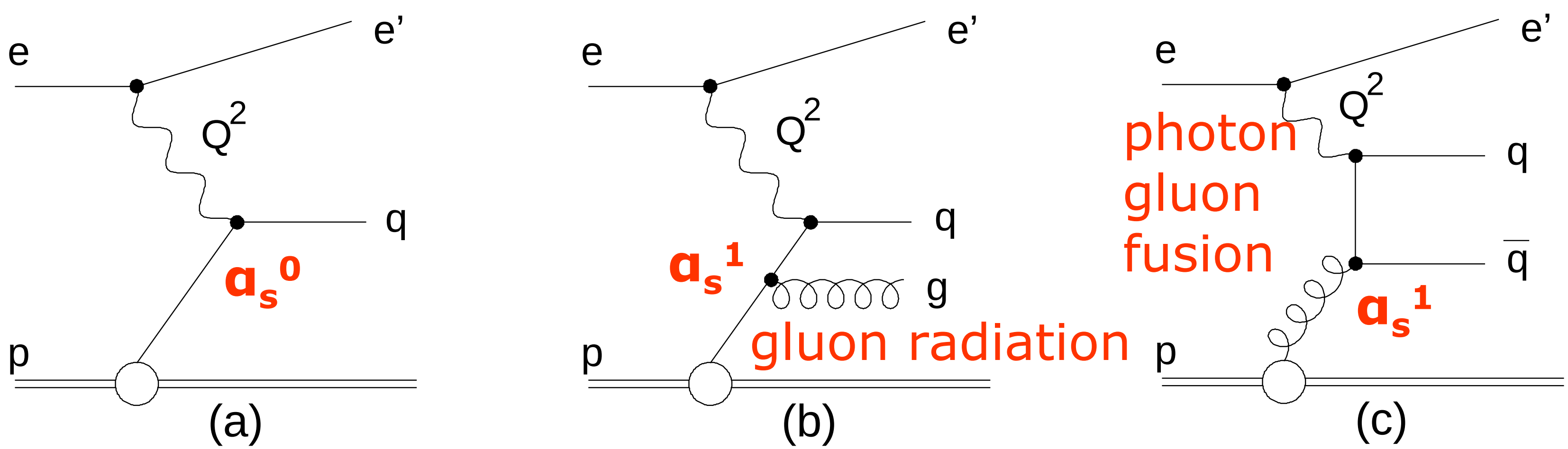
2) Check that distributions agree with QCD

3) Check that PDFs used are giving good results. Data may be suitable for evaluation of new PDFs.

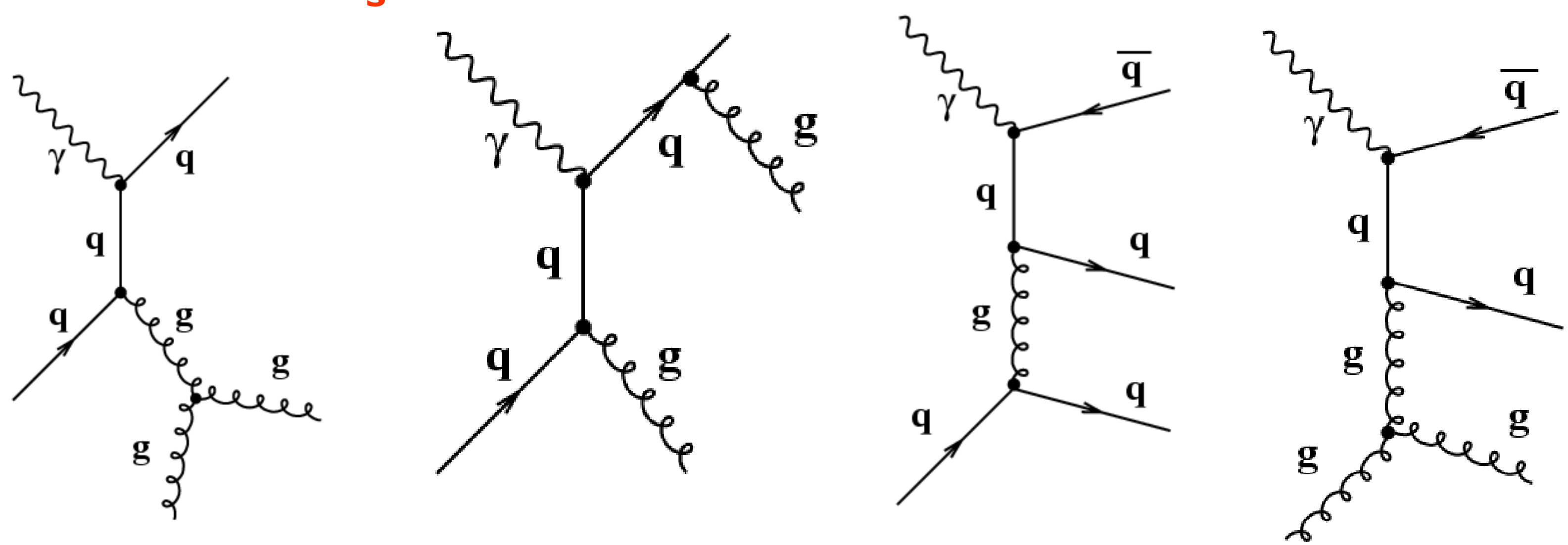
4) Use data if possible to verify that α_s is OK and maybe to evaluate a new and better value of α_s .

These tasks may not be completely separable.

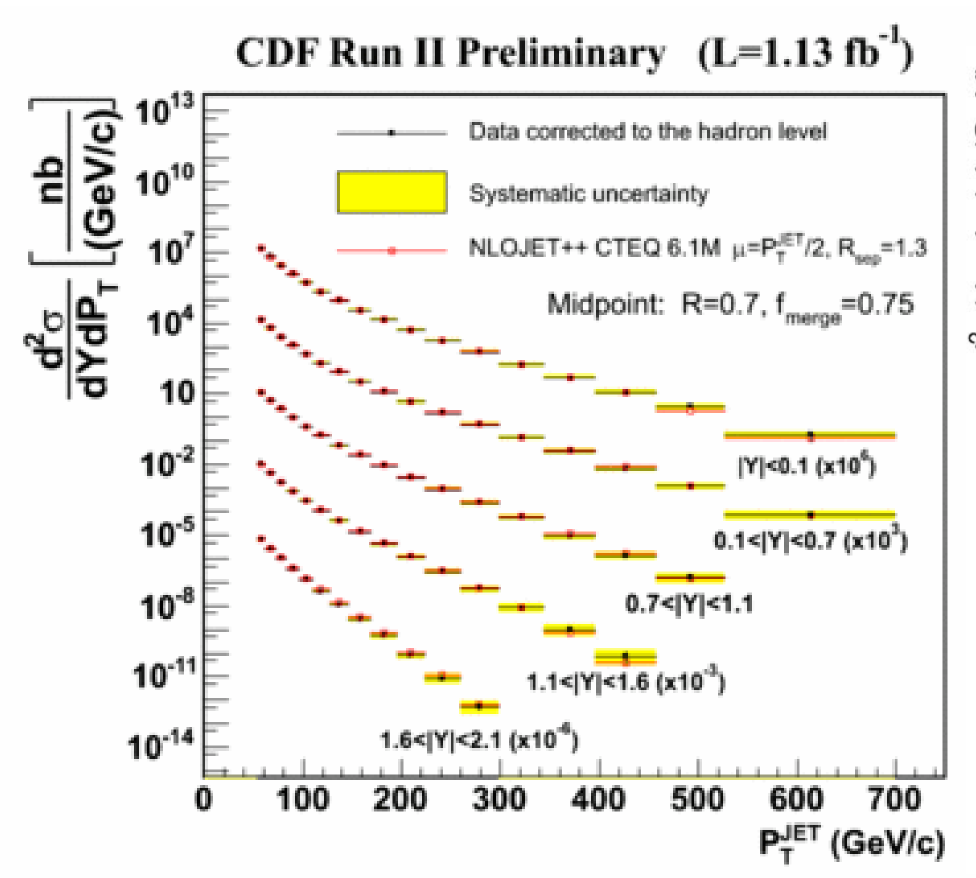
Diagrams of different order in α_s in NC DIS

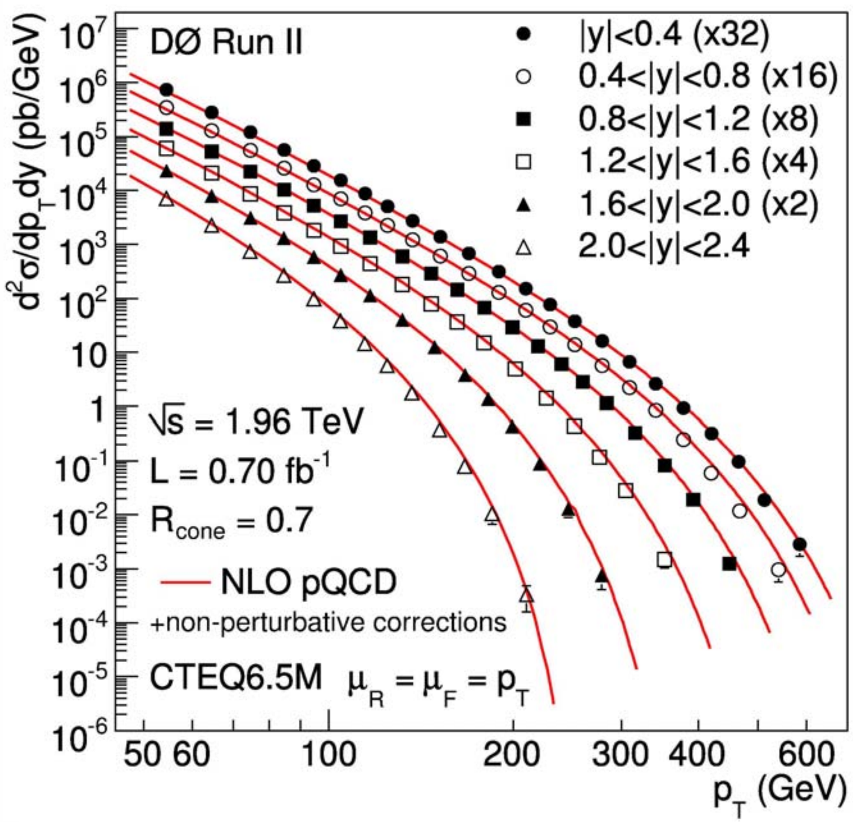


And more: α_s^2



CDF and D0 inclusive jets up to 700 GeV/c.

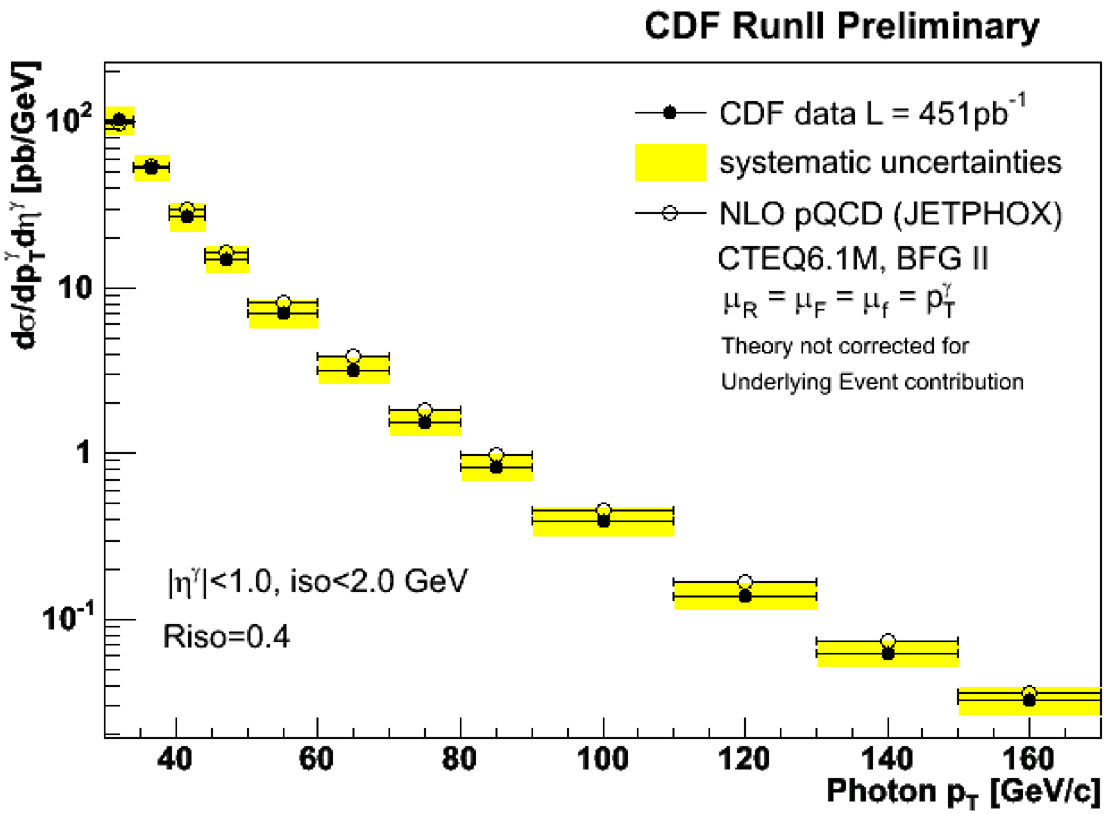




Cone jets using midpoint algorithm R=0.7 are used in both cases.

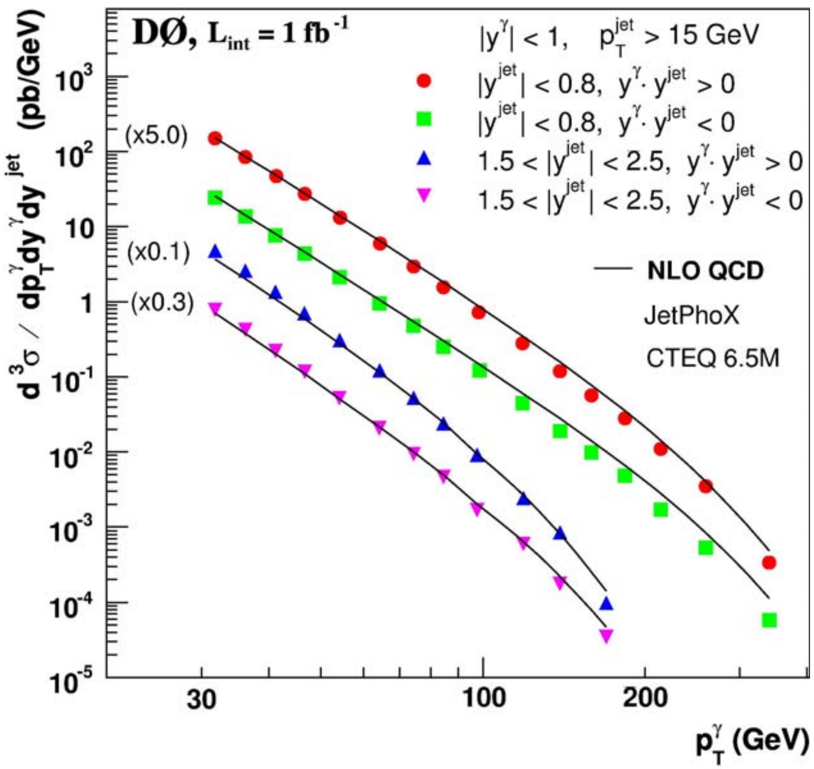
Good agreement with NLO QCD

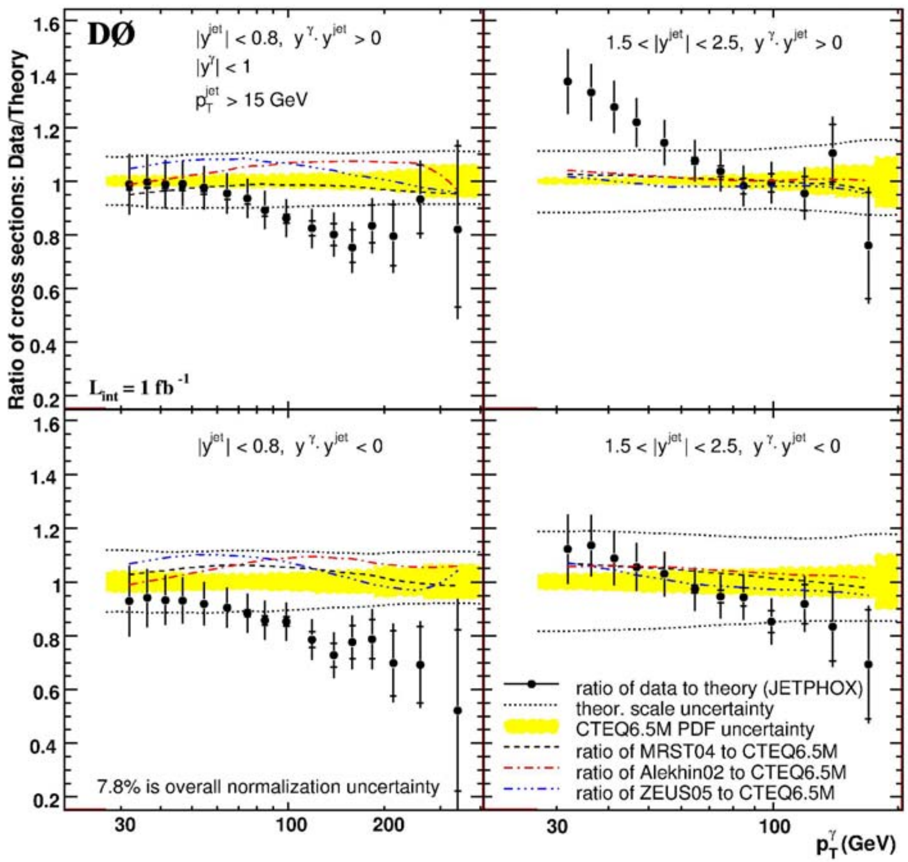
Inclusive photons (CDF)



NLO calculations (JETPHOX) are fine.

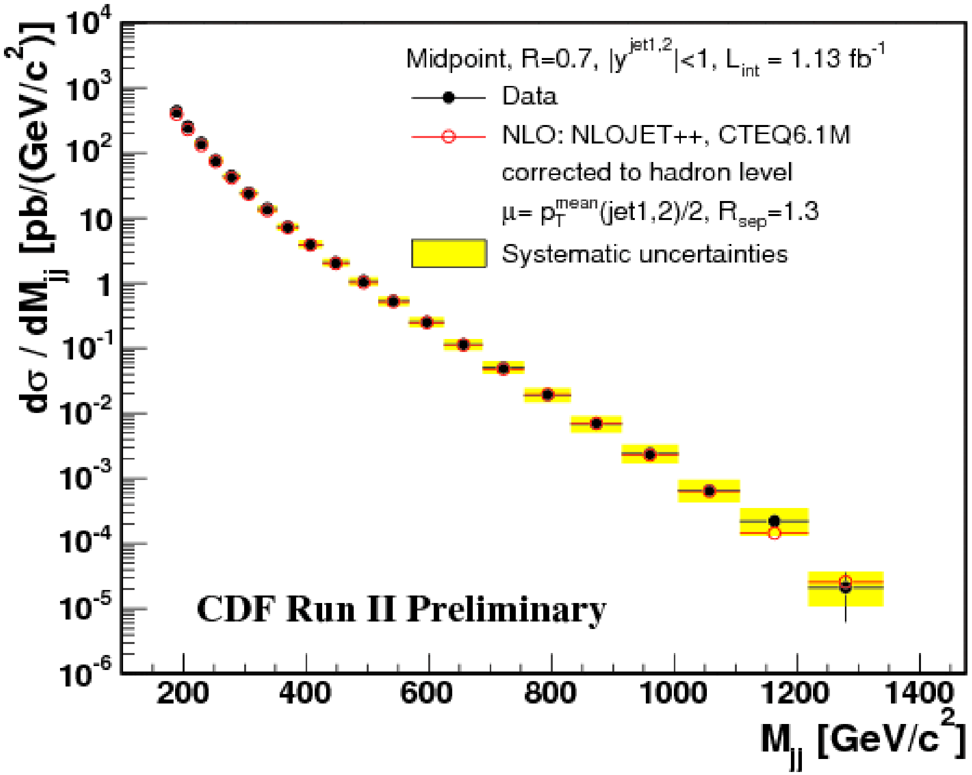
D0 photon + jet. Triple differential X sections

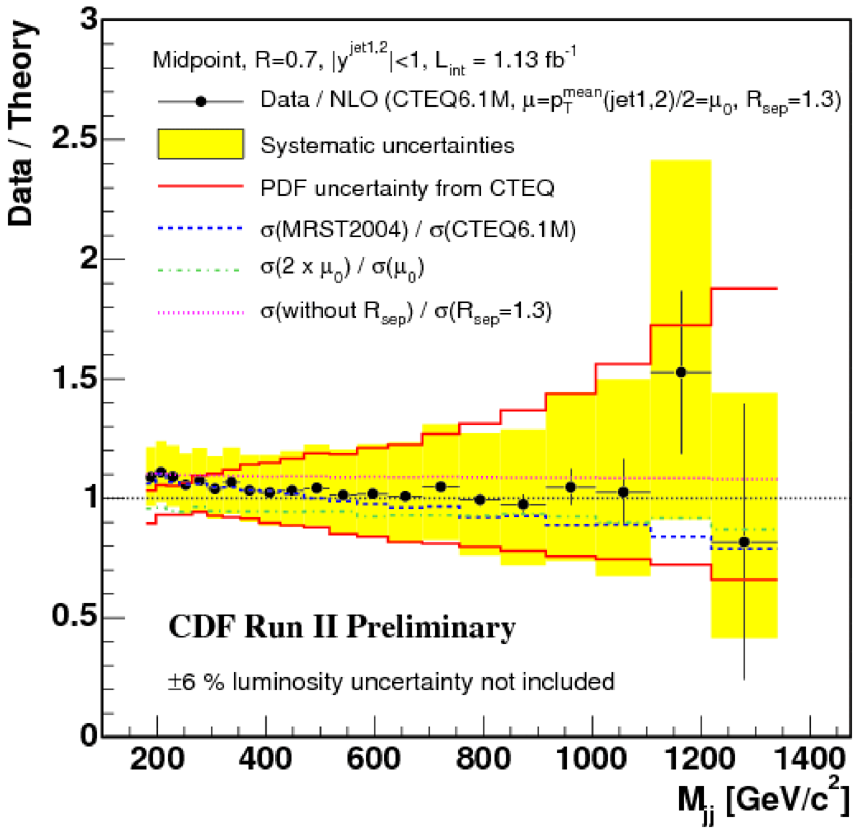




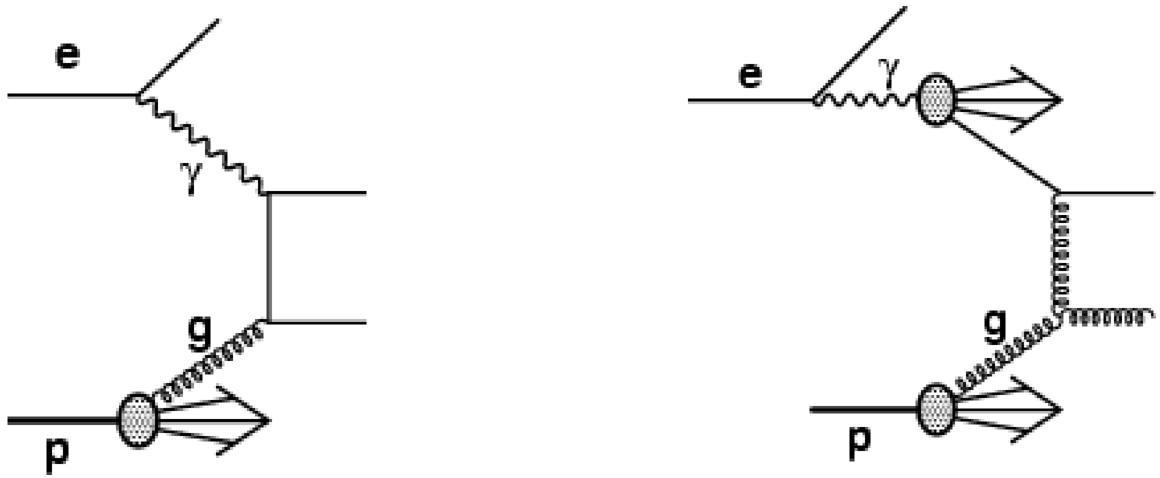
There are some discrepancies, which need theoretical attention!

CDF dijets. No sign of mass structure, all OK with NLO QCD



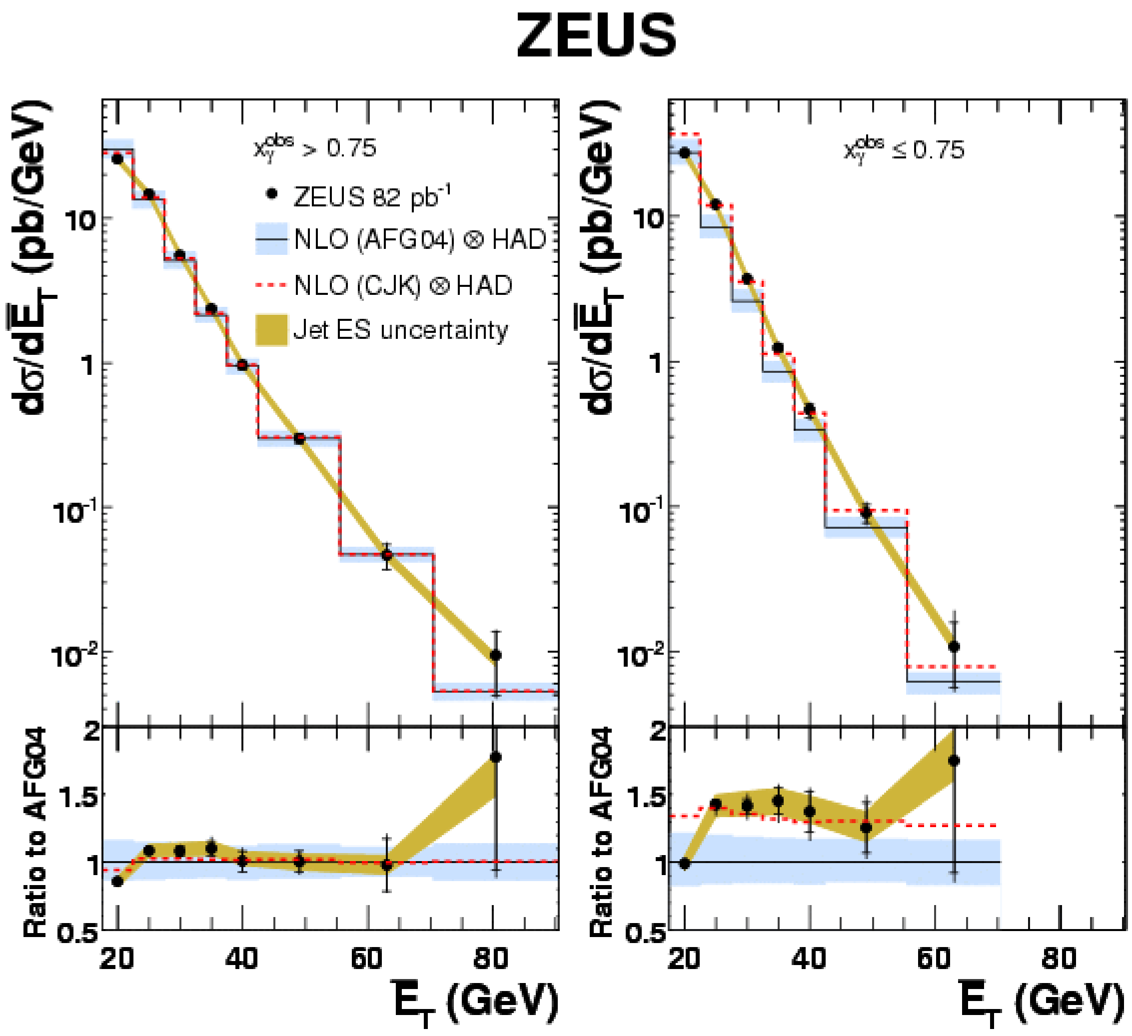


ZEUS dijets in photoproduction



Examples of direct and resolved events at LO

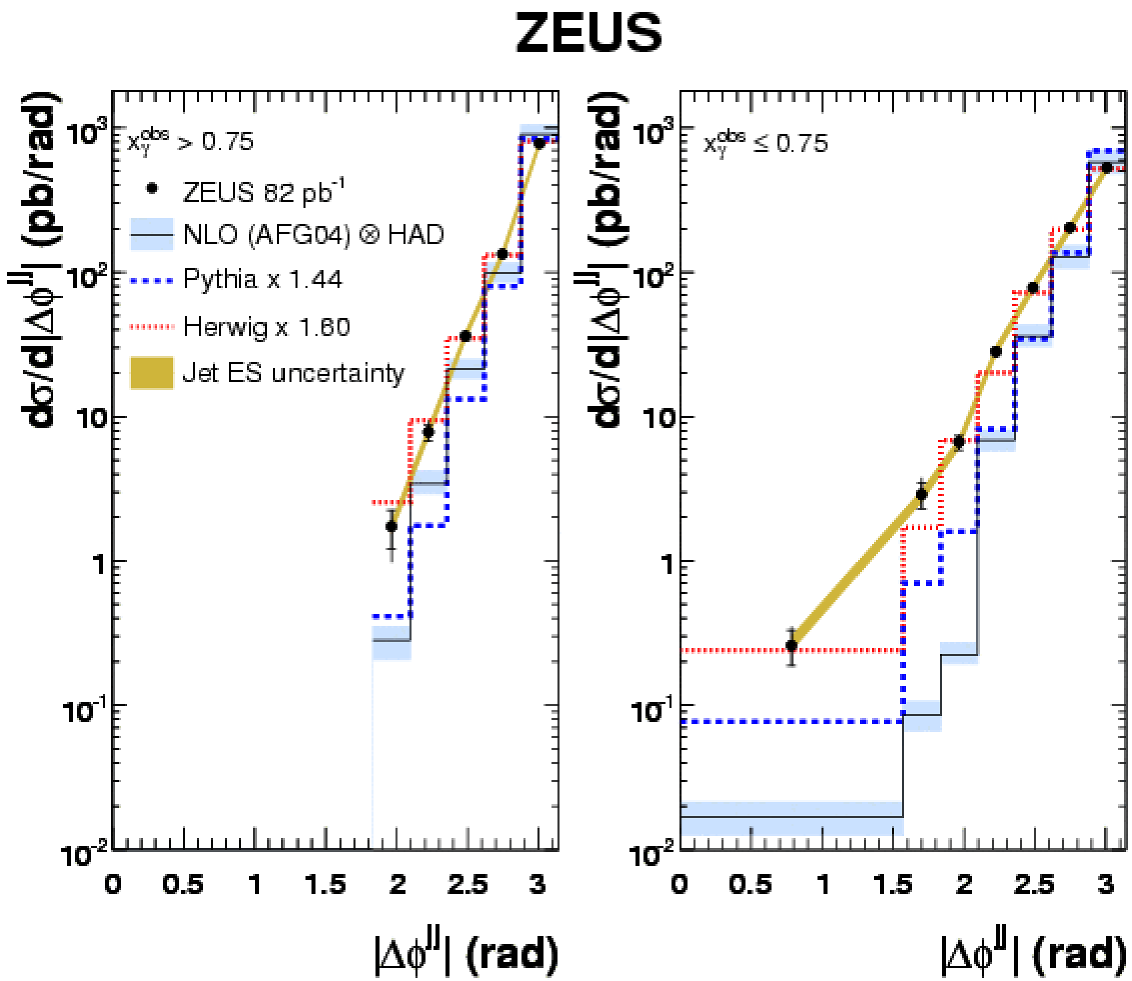
ZEUS dijets in photoproduction



All is OK.

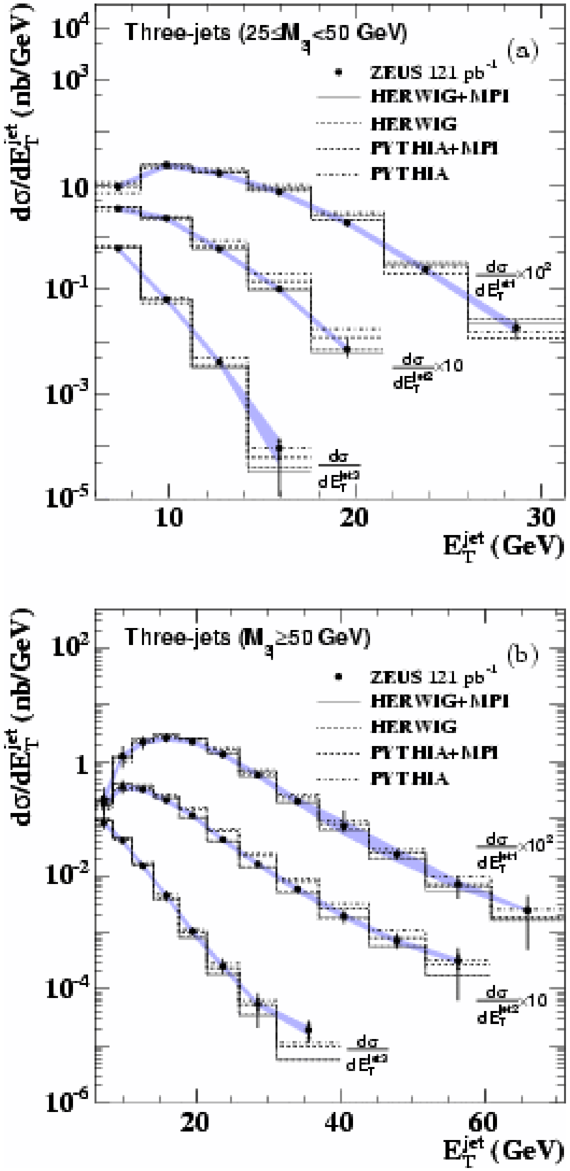
ZEUS dijets in photoproduction

At LO $\Delta\varphi = \pi$



Sensitivity to higher order effects. HERWIG seems to do it best! However note that there is scope for retuning of PYTHIA.

ZEUS



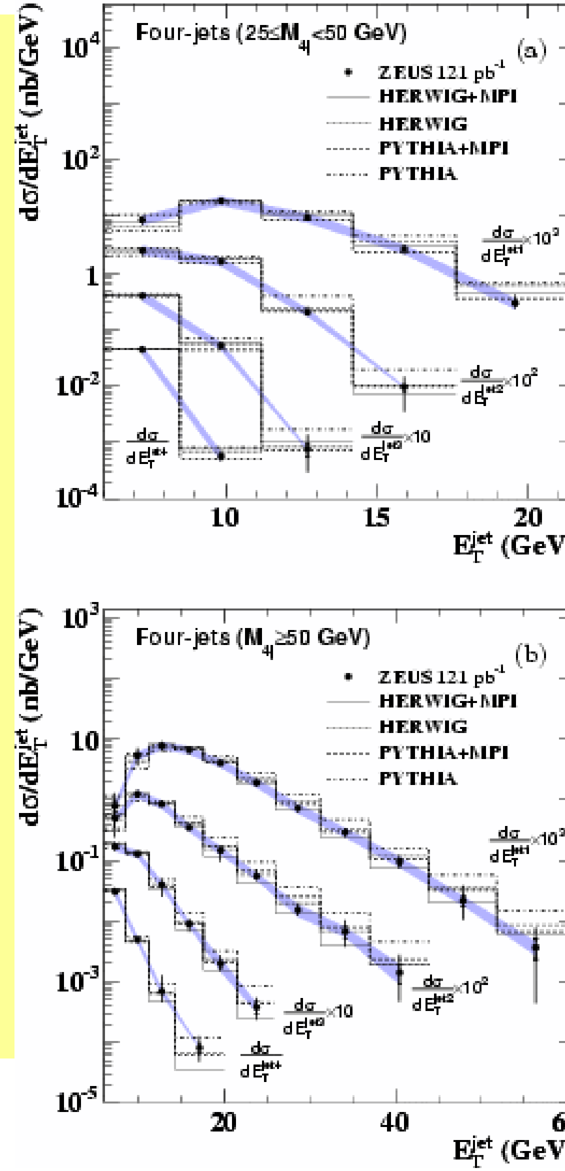
ZEUS

3-jet and 4-jet photoproduction cross sections

Reasonable agreement with PYTHIA
and HERWIG

"Overall, it helps to include the Multi Parton Ints"

ZEUS



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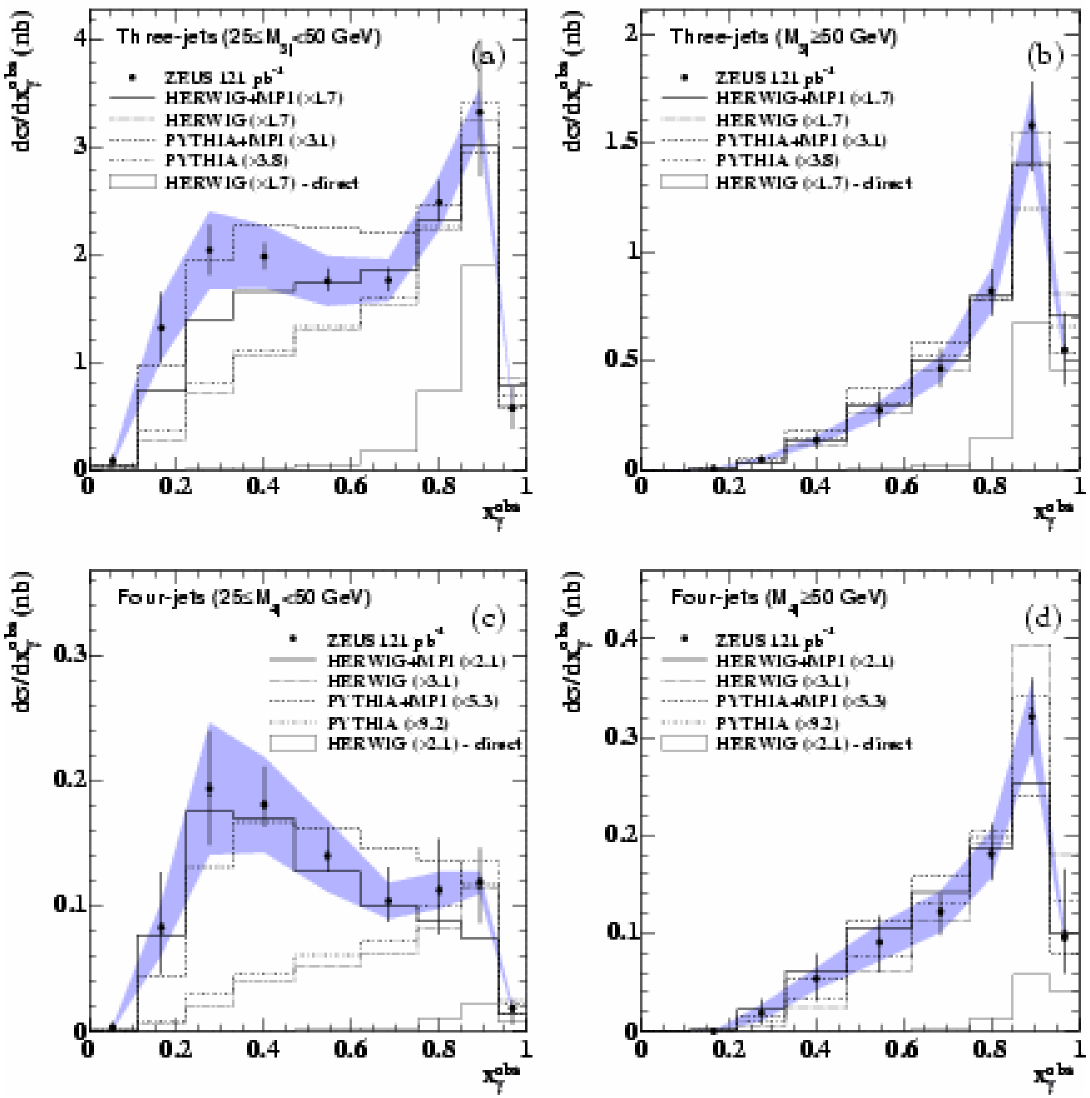
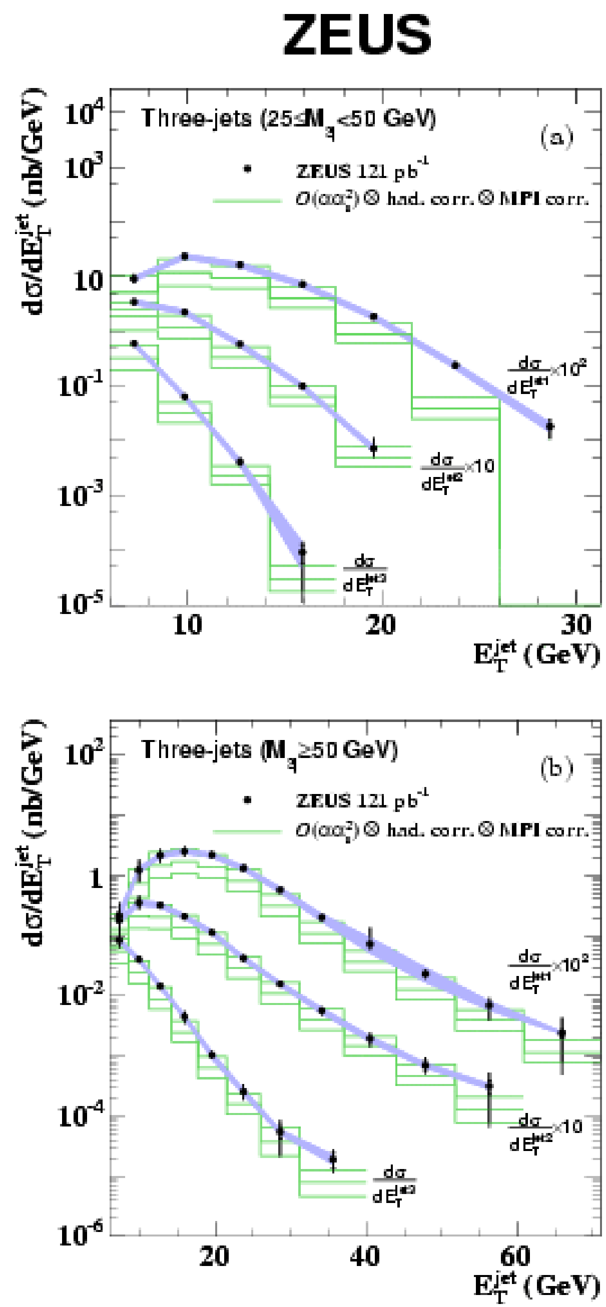


However x_γ plots do seem to suggest MPI is helpful

Now take the 3-jet data and compare with $O(\alpha\alpha_s^2)$ pQCD with corrections applied for hadronisation and MPI.

Low-mass is a little problematic in places, high mass seems OK.



ZEUS – 3-jet correlations in photoproduction and DIS

Definitions of some angular correlation quantitites.

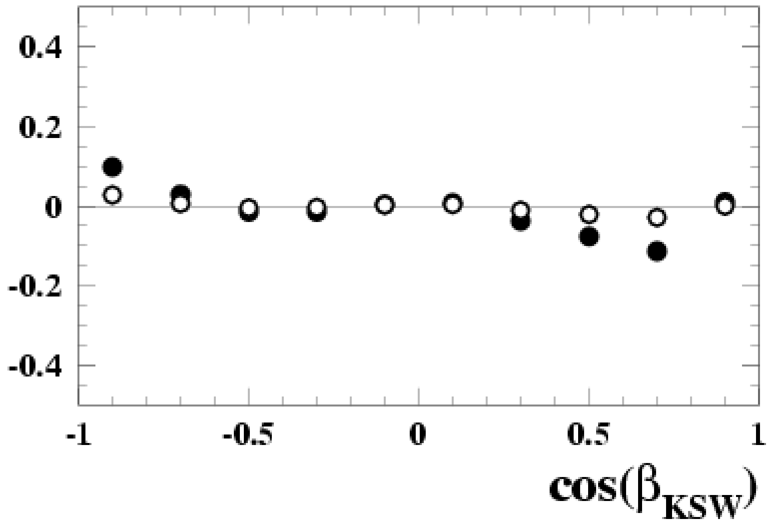
θ_H = angle between plane of highest energy jet and beam,
and plane of two lowest energy jets

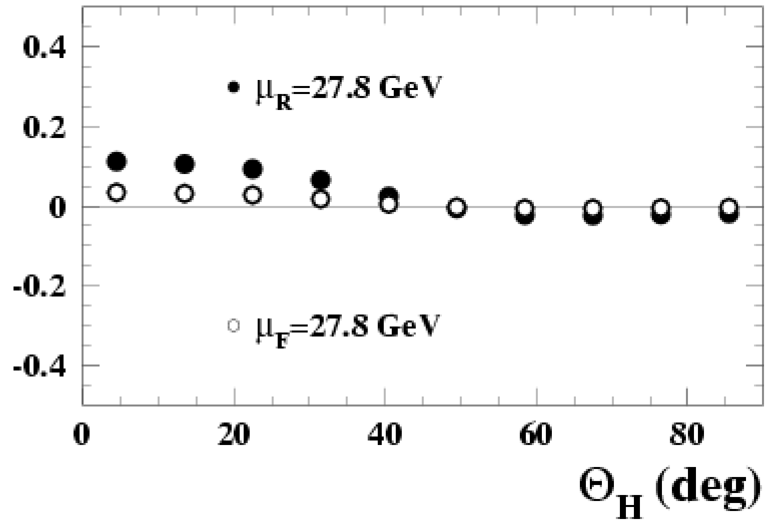
α_{23} = angle between two lowest energy jets

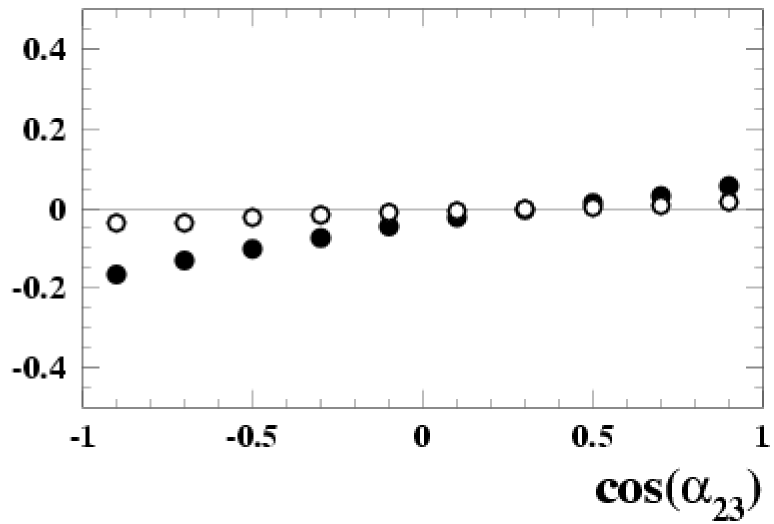
β_{KSW} = Körner-Schierholz-Willrodt type angle
(based on cross products of jet momentum vectors)

η^{jet}_{max} = maximum pseudorapidity of the three jets

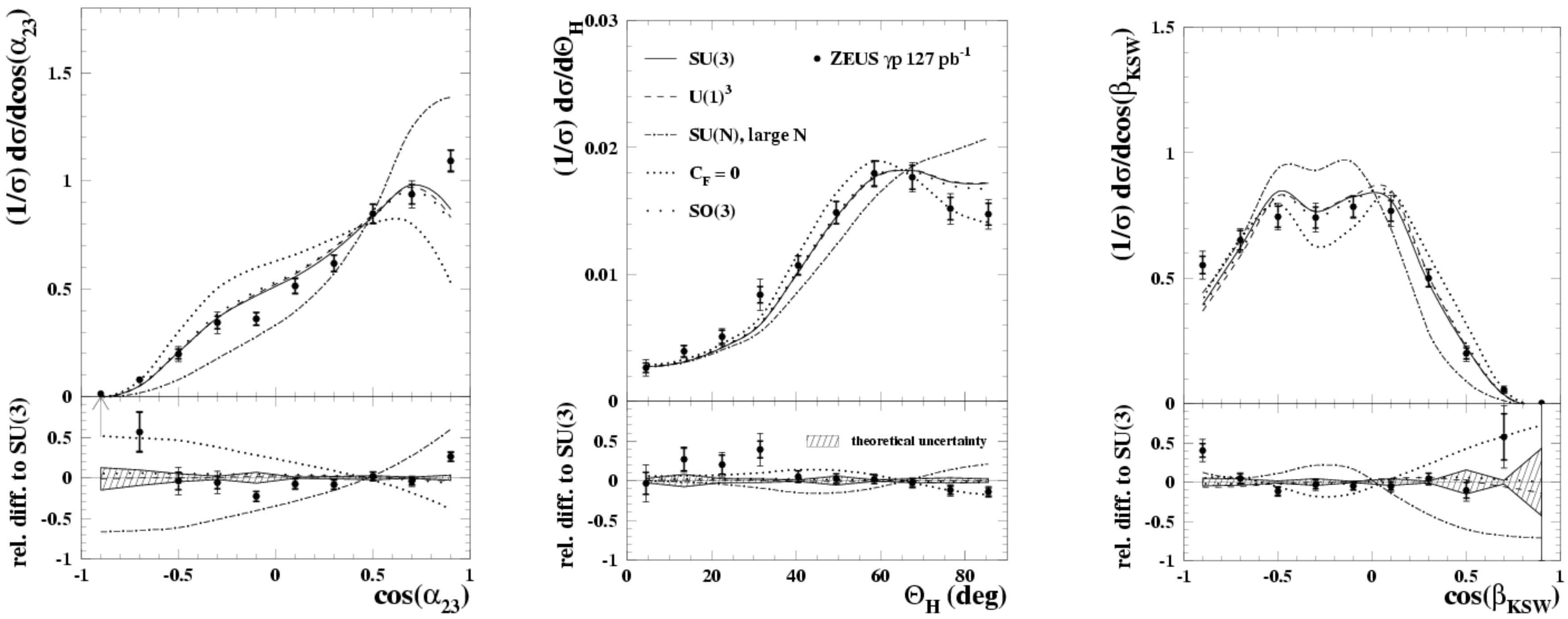
Differences beween calculations varying scales





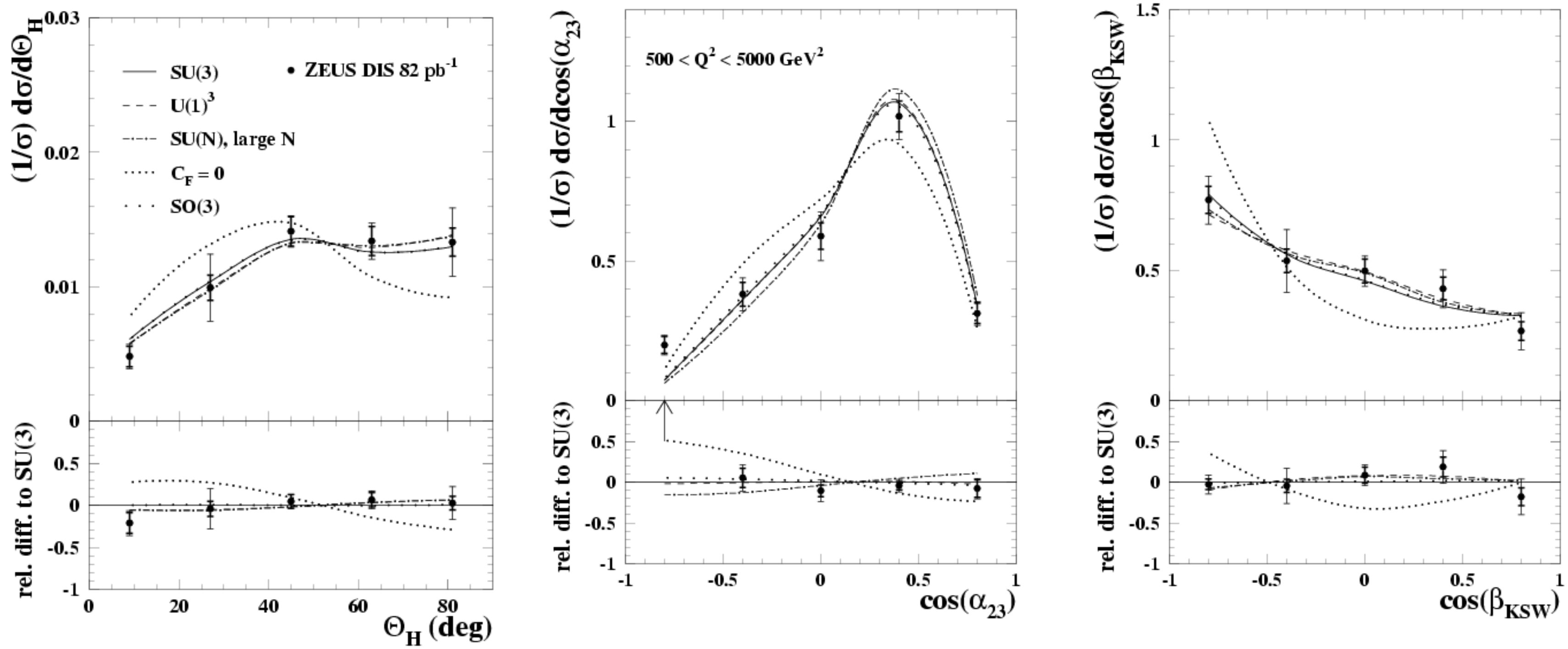


ZEUS photoproduction



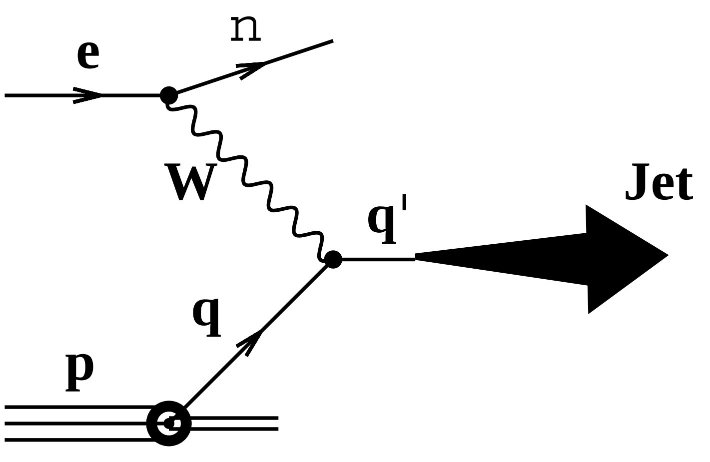
Use these distributions to distinguish standard QCD based on SU(3) from other mathematical possibilities such as SU(N) and $U(1)^3$ (no triple gluon coupling) SO(3).

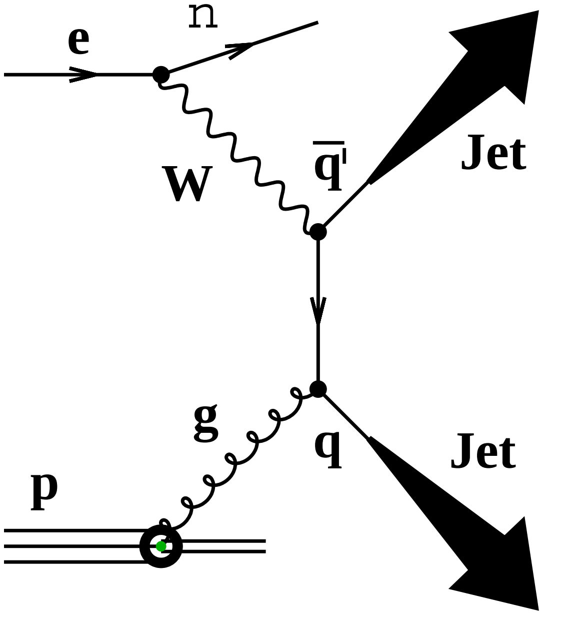
ZEUS DIS 500 < Q² < 5000 GeV²

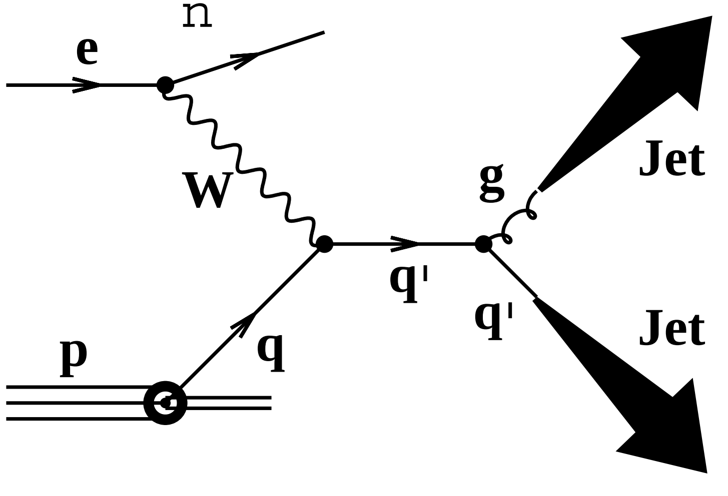


Conclusion: standard SU(3) gives best agreement.

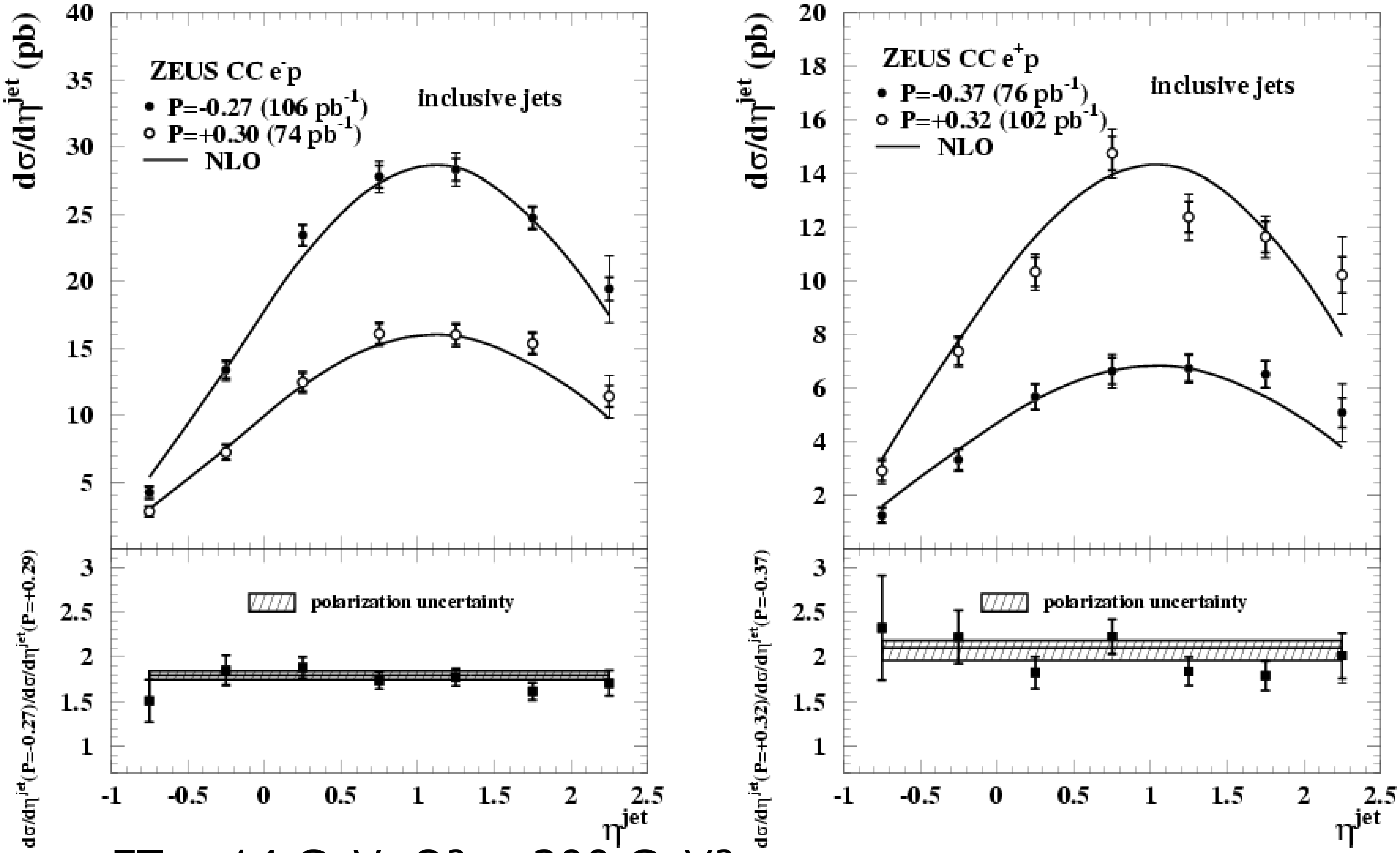
Diagrams of different order in α_s in CC DIS





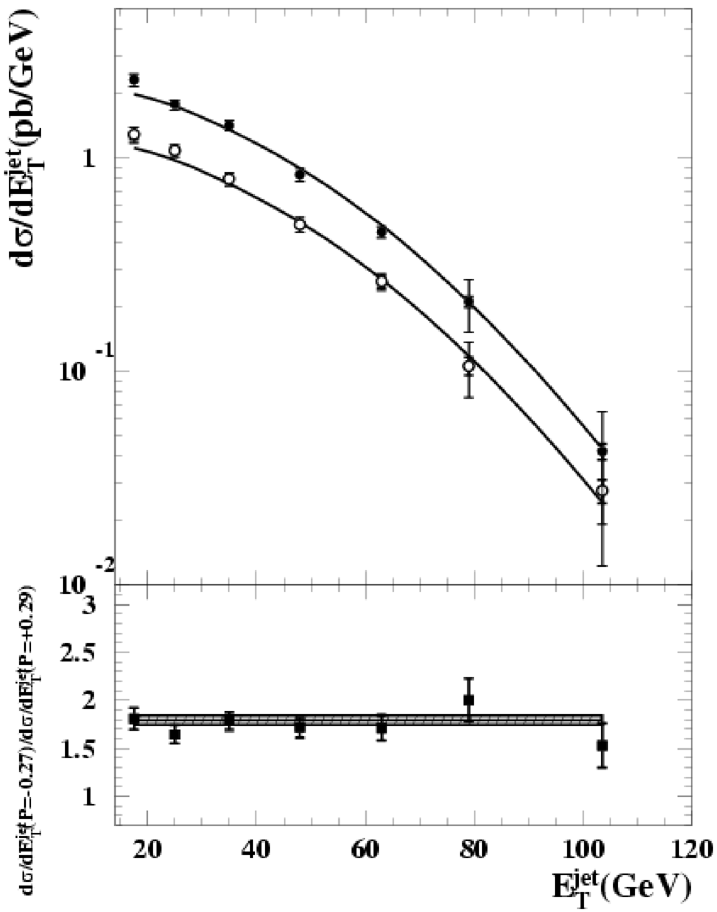


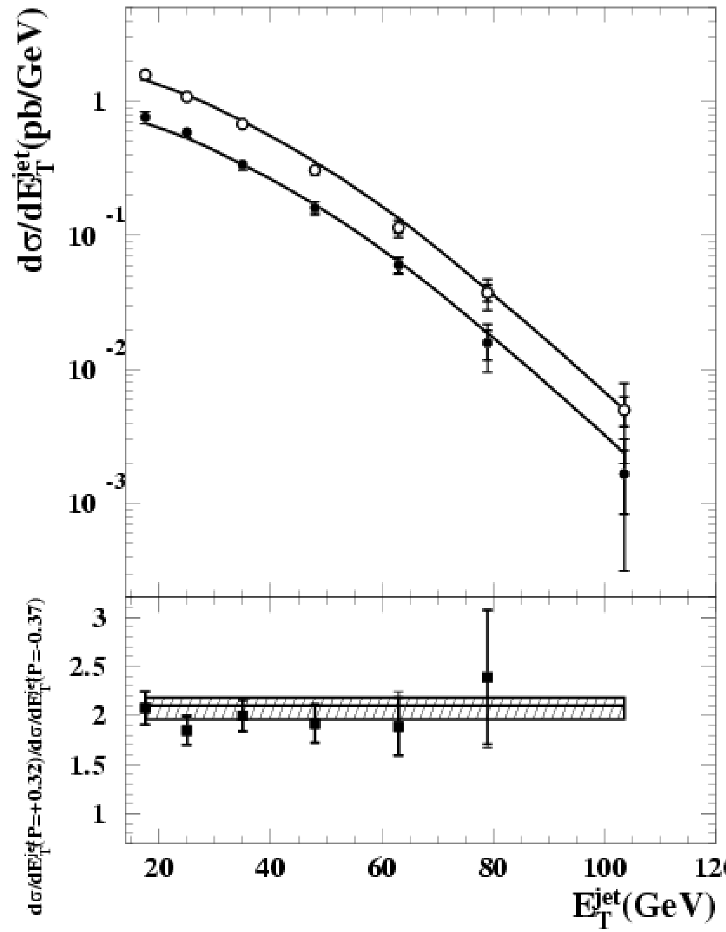
HERA II data, e- and e^+, polarised beams. Inclusive jets.



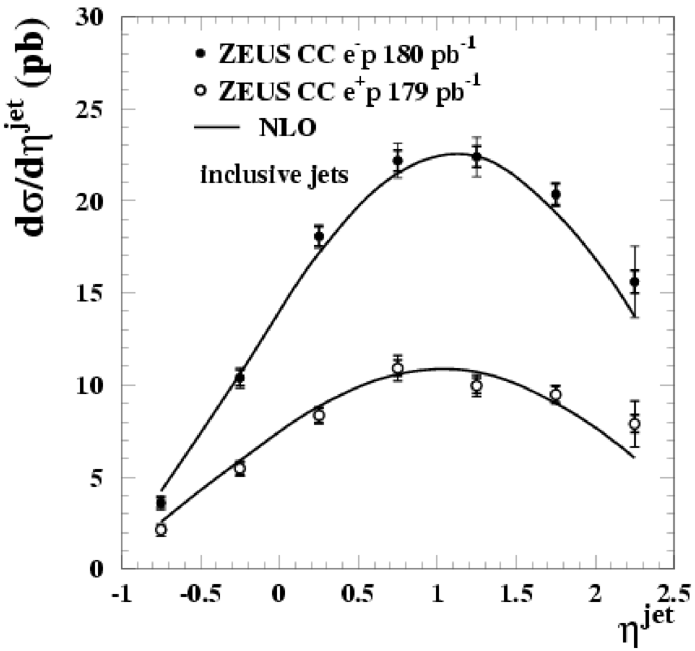
ET > 14 GeV, $Q^2 > 200$ GeV²

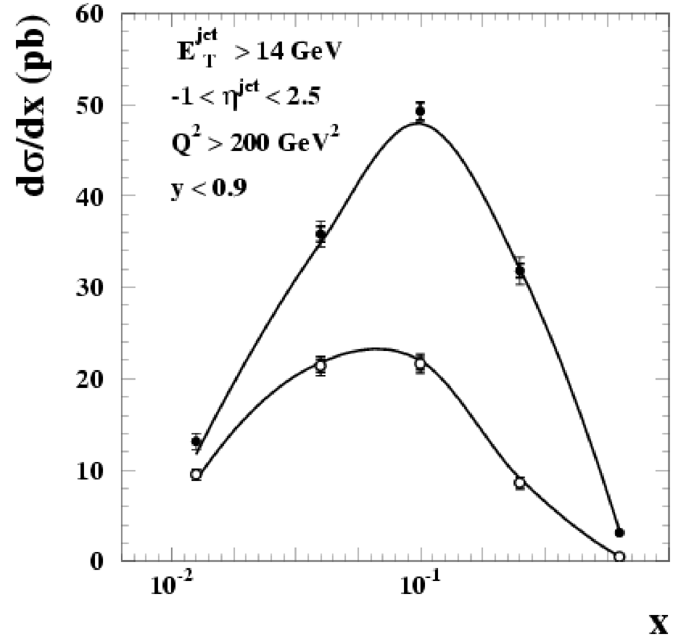
ET distributions





Predictions are fixed order QCD based on MEPJET and are $O(\alpha_s)$ for inclusive jet and $O(\alpha_s^2)$ for 2, 3-jet, equivalent to NLO (LO for 3-jet case).

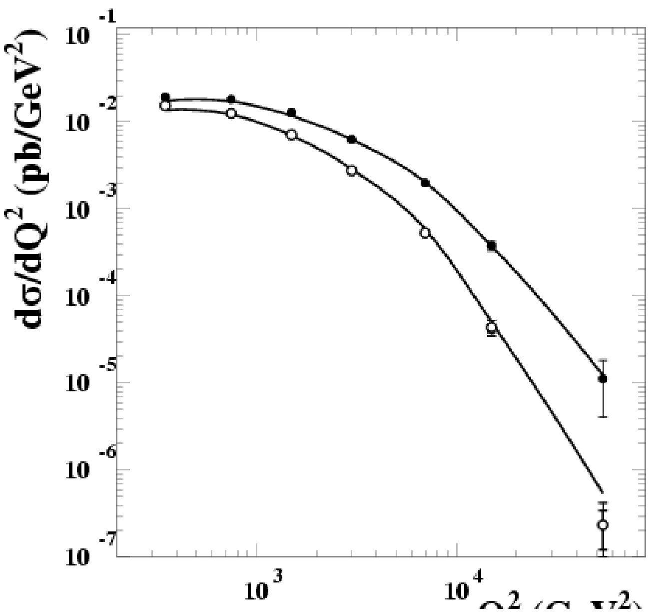


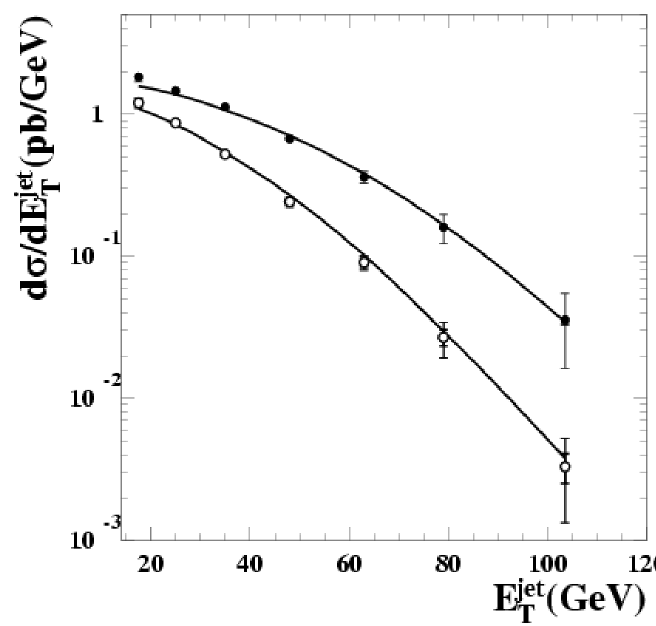


Unpolarised
inclusive
jet
cross
sections

compared
to NLO QCD

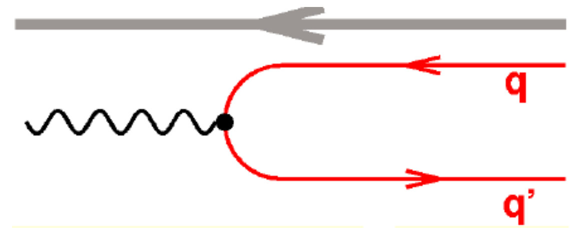
Agreement
Is OK.





H1 jet production at high Q^2 and determination of α_s

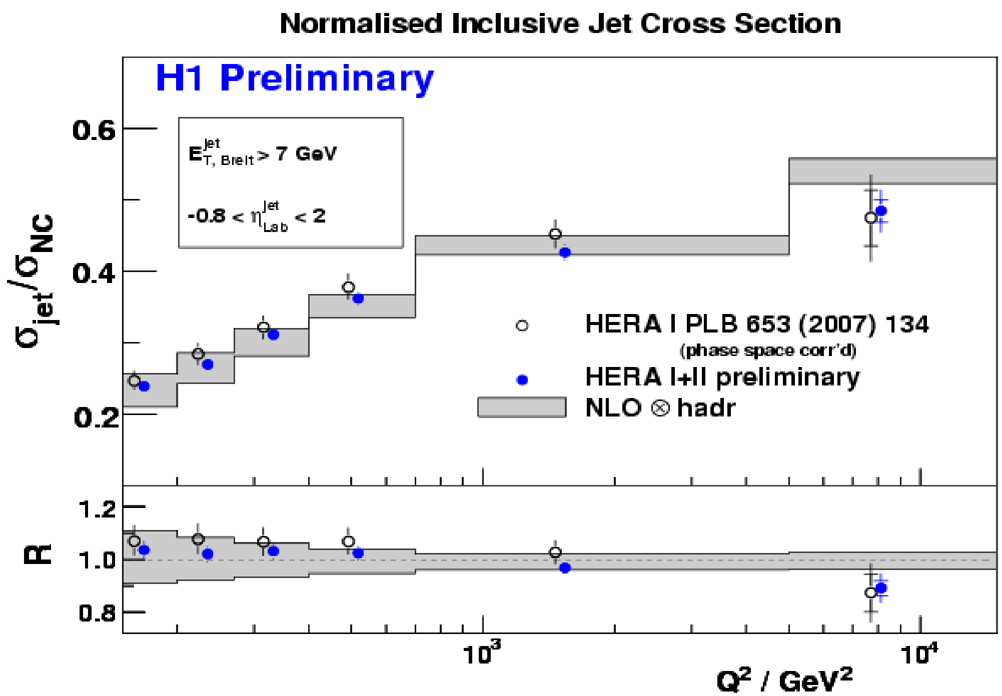
([Full HERA data](), 2008, $Q^2 > 150$ GeV^2)

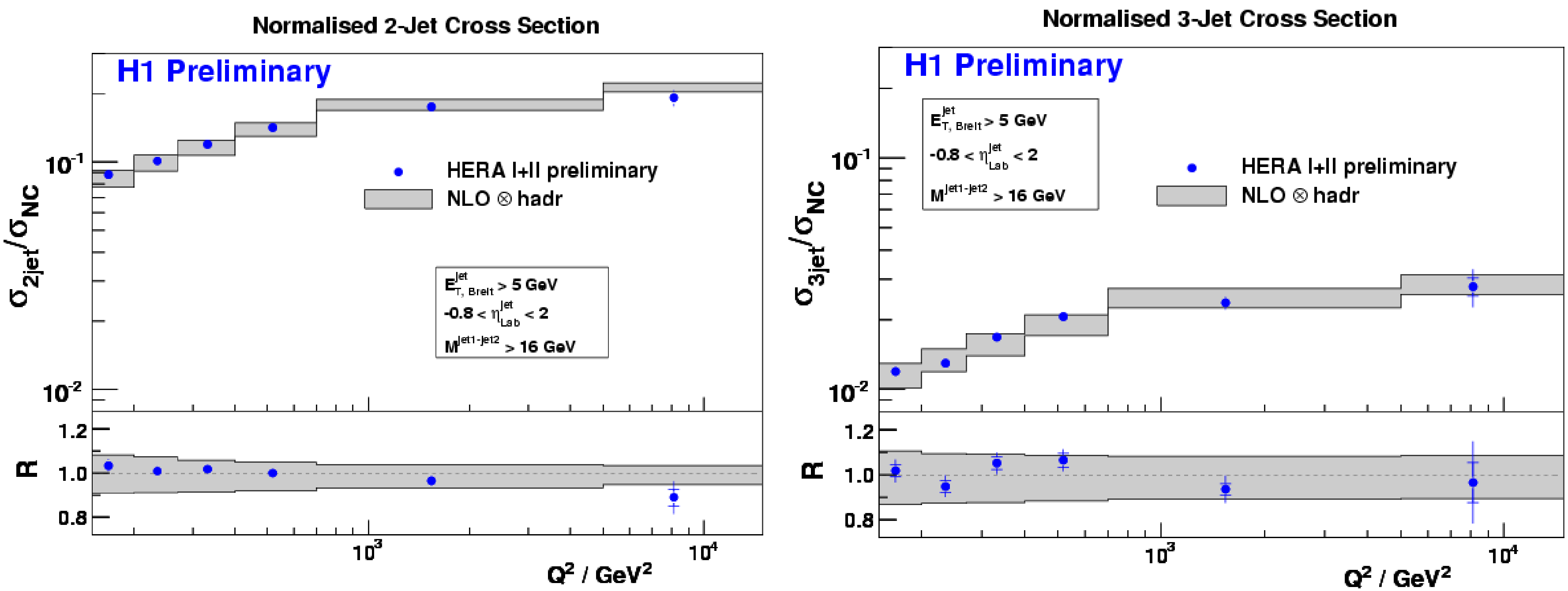


Jets are found in the Breit frame (k_T clus).
E_T in the Breit frame > 7 GeV, but a laboratory rapidity cut is imposed.
Numbers of 2- and 3-jet events are measured.

Cross sections quoted as ratio
σ(n-jet)/σ(NC)

referring to the DIS cross section





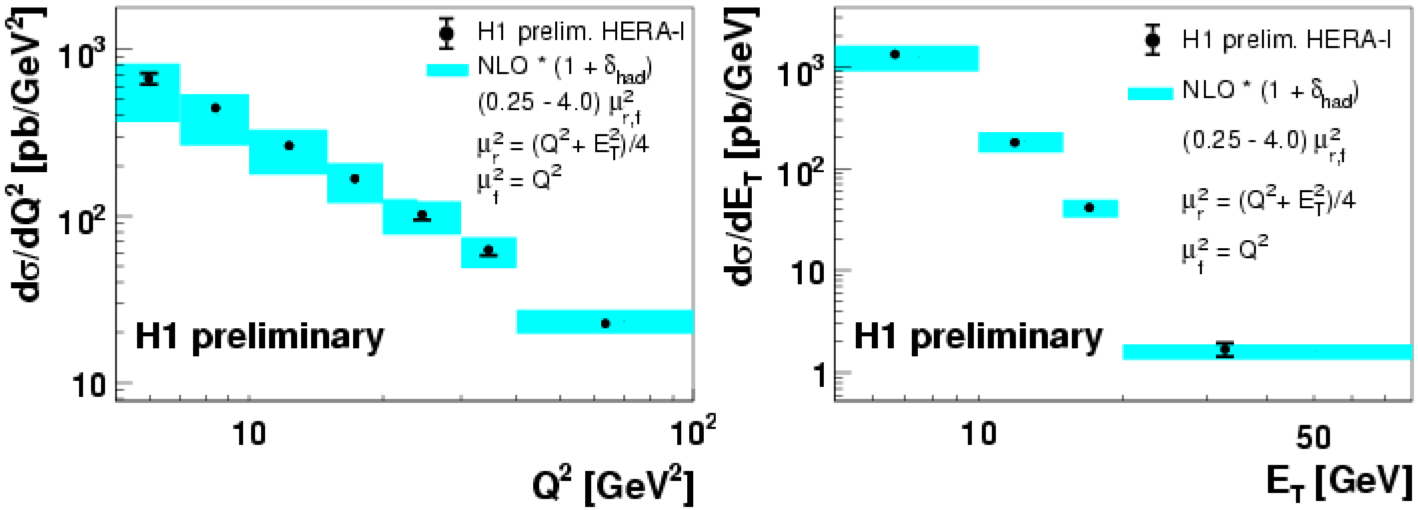
Normalised 2 and 3 jet cross sections.

These and other control plots give excellent agreement in shape with the NLO QCD predictions

A complementary analysis was performed by H1 at less high values of Q2   (5 – 100 GeV2)

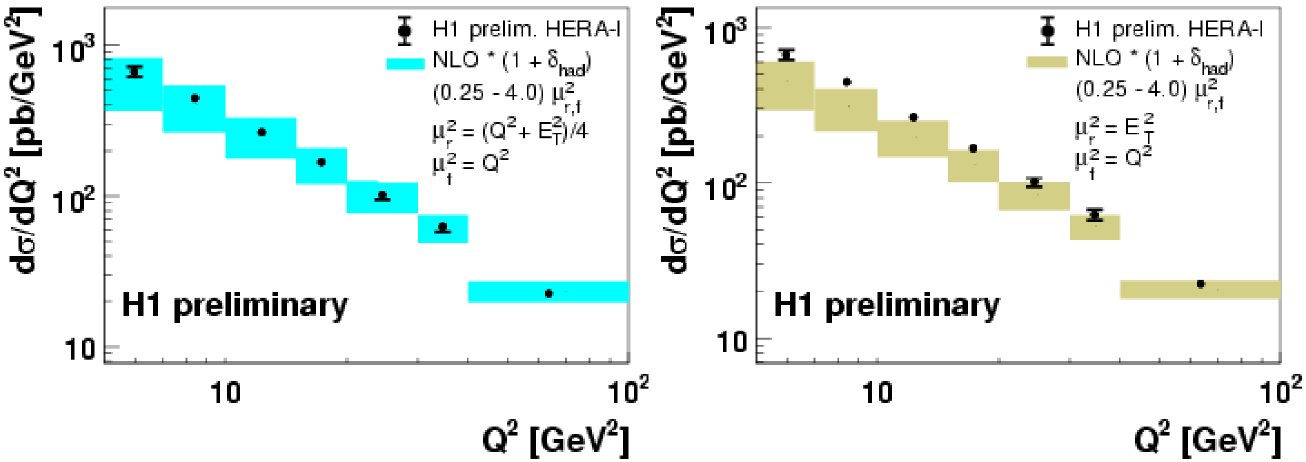
Again in Breit frame. E_T > 5 GeV and 0.2 < y < 0.7 applying Lab rapidity cuts to define jet acceptance

Inclusive Jet Cross Sections $\frac{d\sigma}{dQ^2}$ and $\frac{d\sigma}{dE_T}$

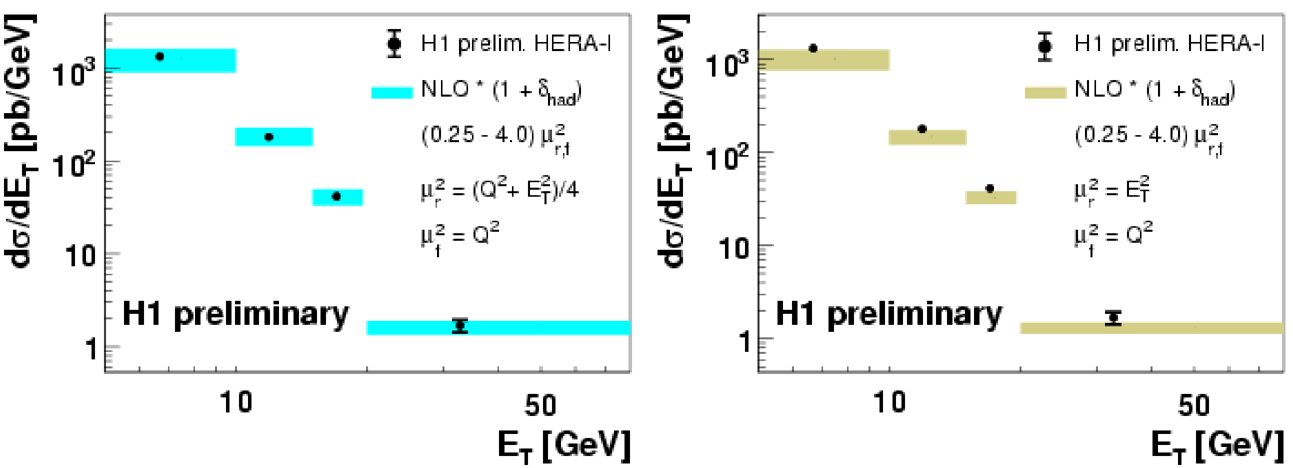


General kinematic features are fine.

Inclusive Jet Cross Sections $\frac{d\sigma}{dQ^2}$



Inclusive Jet Cross Sections $\frac{d\sigma}{dE_T}$



Vary the renormalisation scale

from

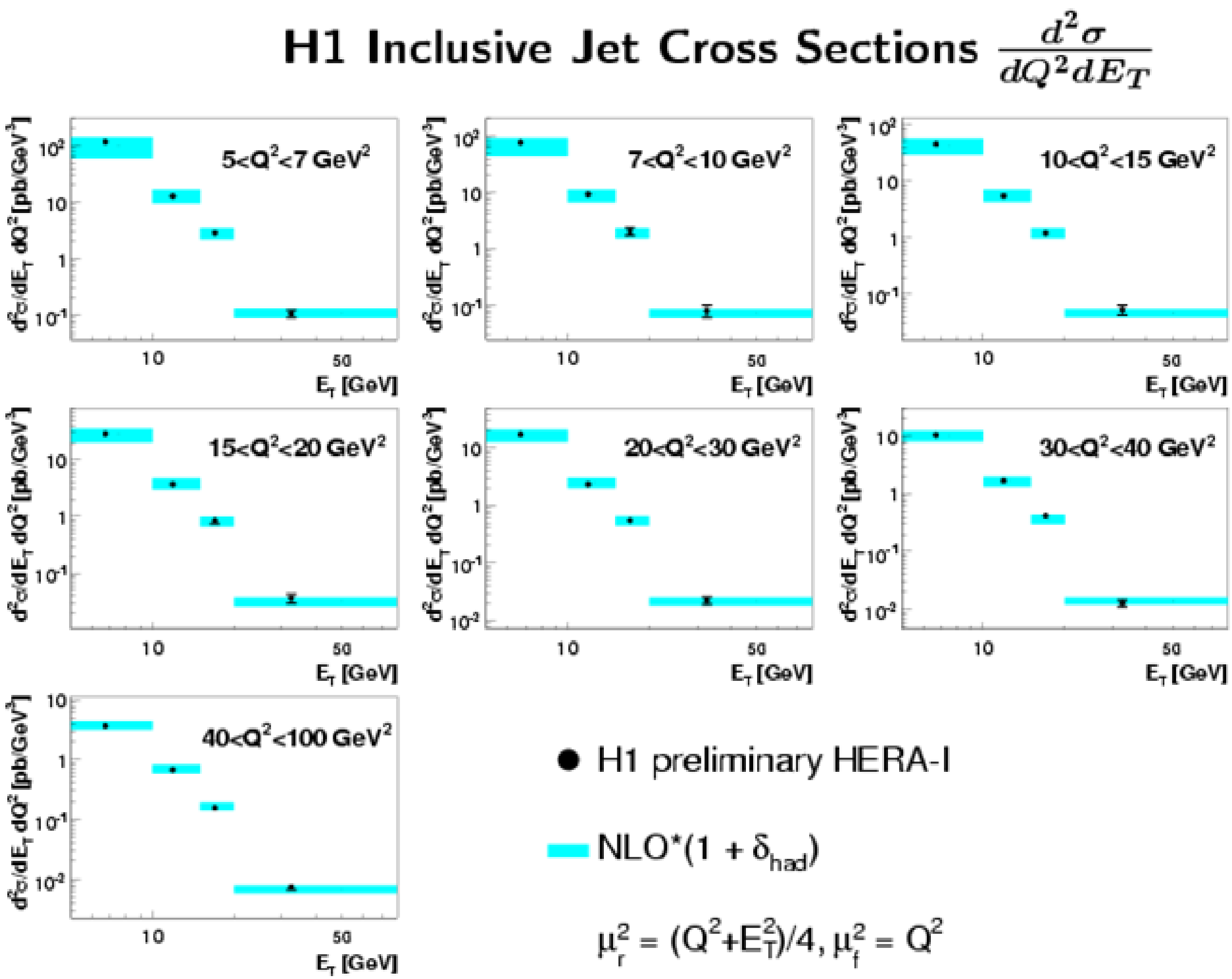
$(Q^2+E_T^2)/4$

to

E_T^2

Clearly the first choice is better

Set of double differential cross sections, at better ren. scale



Now we come to consider α_s in more detail.

The competition from LEP:

Fit to LEP event shapes has attained

$$\alpha_s(M_z^2) = 0.1240 \pm \underset{\text{(stat)}}{0.0008} \pm \underset{\text{(exp)}}{0.0010} \pm \underset{\text{(had)}}{0.0011} \pm \underset{\text{(theo)}}{0.0029}$$

(Gehrmann, Luioni, Stenzel 2008)

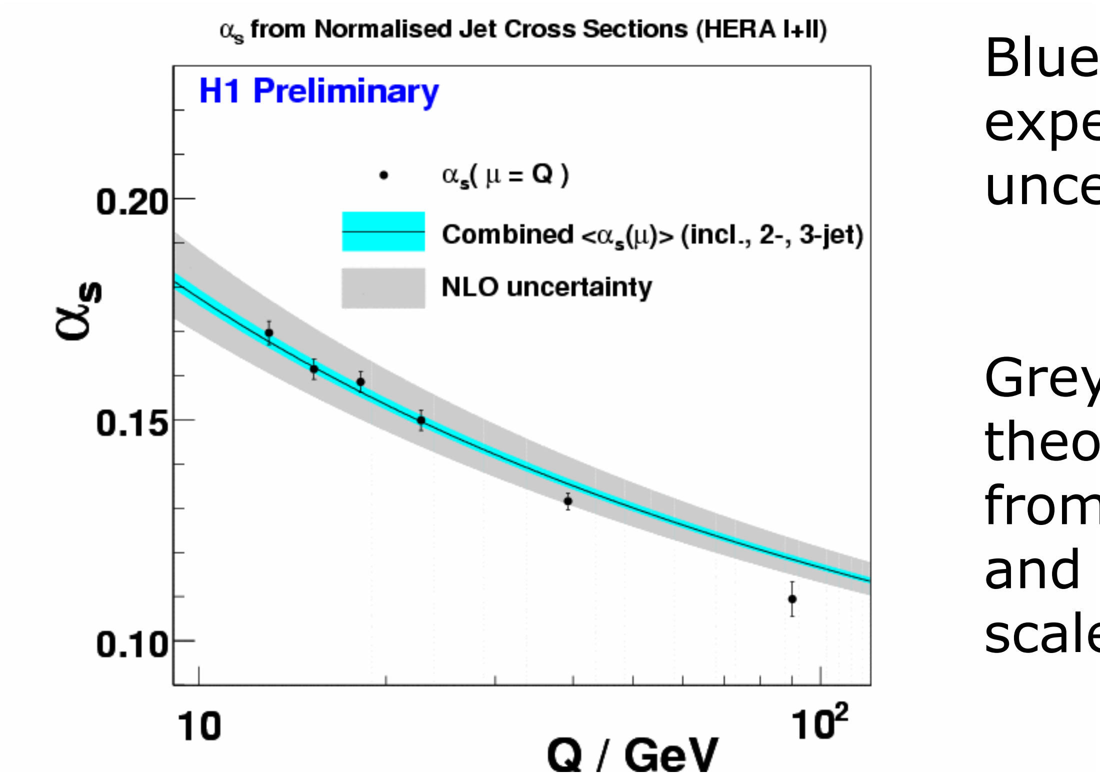
But

$$\alpha_s(M_z^2) = 0.1172 \pm \underset{\text{(stat)}}{0.0020} \pm \underset{\text{(exp)}}{0.0008} \pm \underset{\text{(had)}}{0.0012} \pm \underset{\text{(theo)}}{0.0012}$$

(Becher, Schwarz 2008)

We shall see what HERA can do!

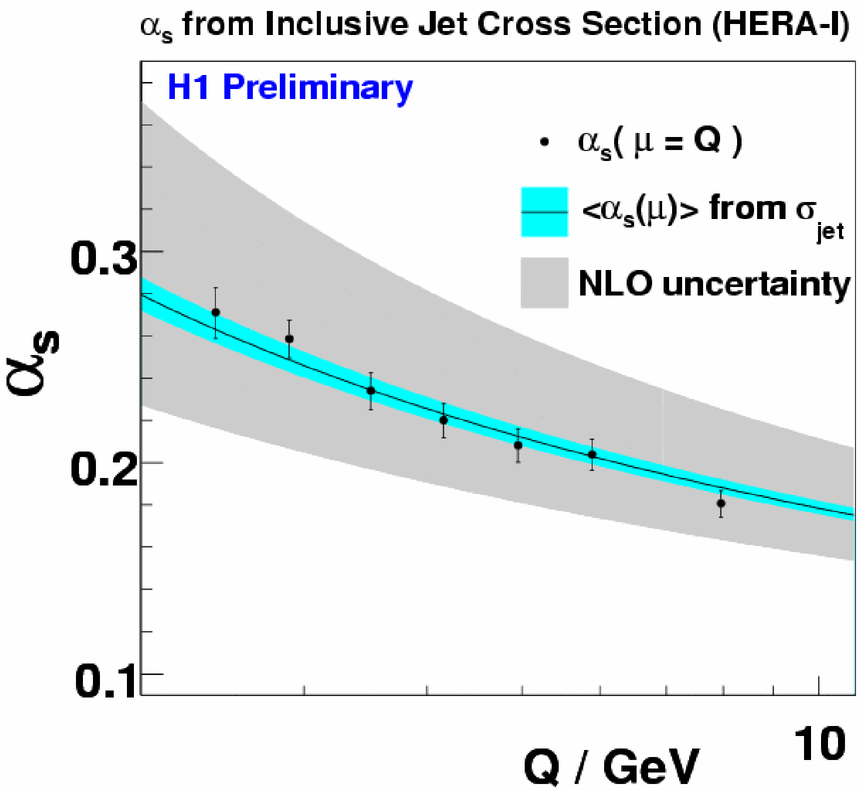
The value of α_s from H1 high-Q^2 is fitted from the 2-jet and the 3-jet data in a number of ET and Q^2 bins and a combined fit is performed

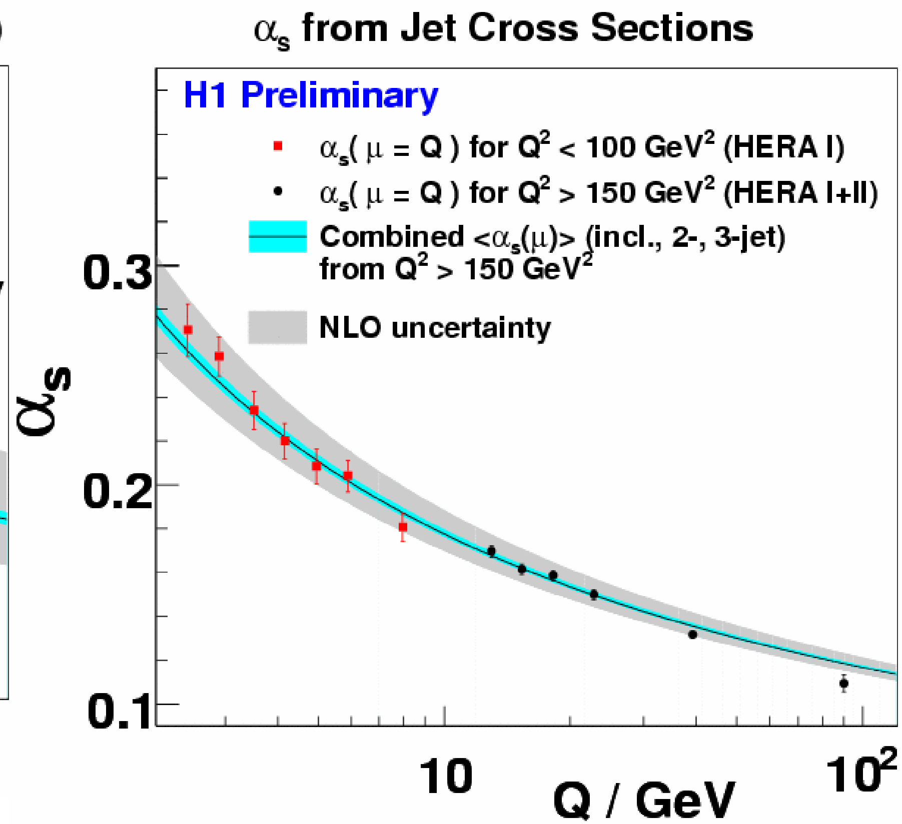


Blue band = experimental uncertainties.

Grey band = theory uncertainties from PDFs, renorm and factorisation scales etc.

Fit for α_s





In the r.h plot the fit is for $Q^2 > 150$ GeV^2 with the results extrapolated into the lower Q^2 range.

The low range gives $\alpha_s = 0.1186 \pm 0.0014 \,^{+0.0132}_{-0.0101} \pm 0.0021$

The high range gives $\alpha_s = 0.1182 \pm 0.0008 \,^{+0.0041}_{-0.0031} \pm 0.0018$

(exp) (theory) (pdf)

ZEUS photoproduction,

inclusive jets at high ET.

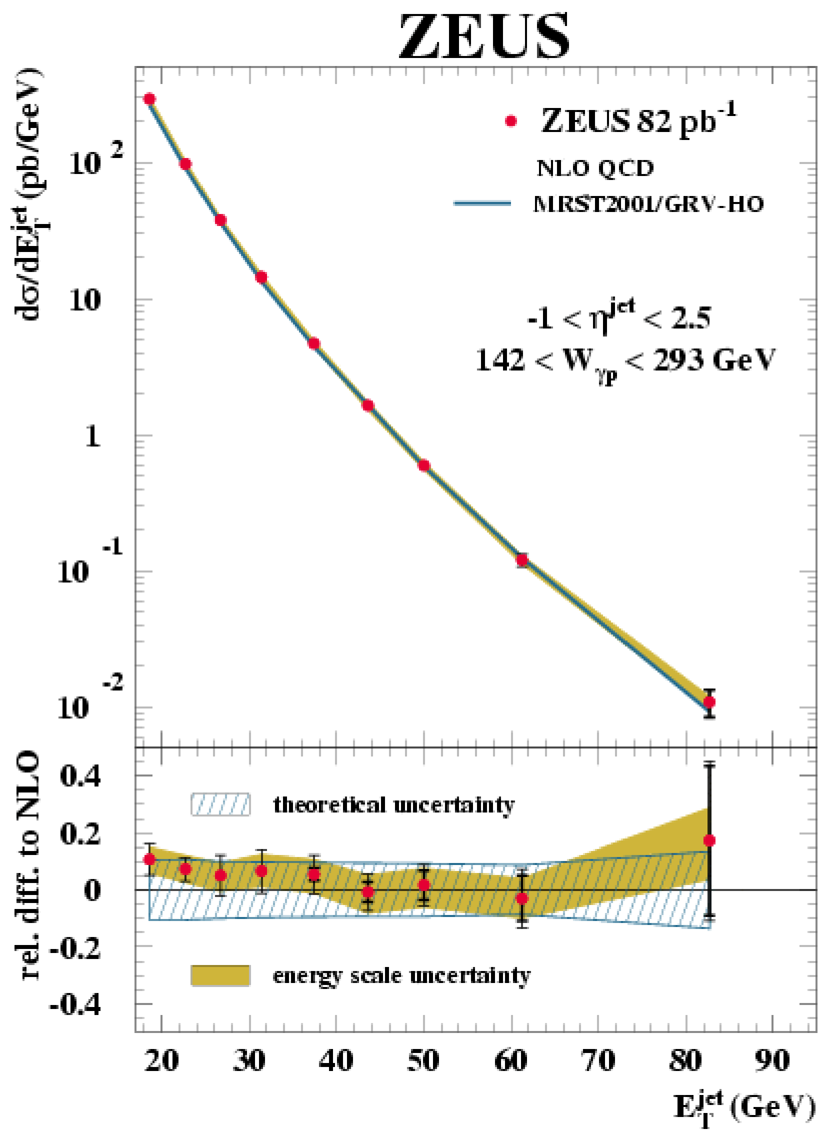
E_T(jet) > 17 GeV

MRST2001/GRV-HO

R = 1.0

Fit for α_s

0.1223 ± 0.0022 ± 0.0030
(exp) (th)



Combined H1 and ZEUS fit for α_s

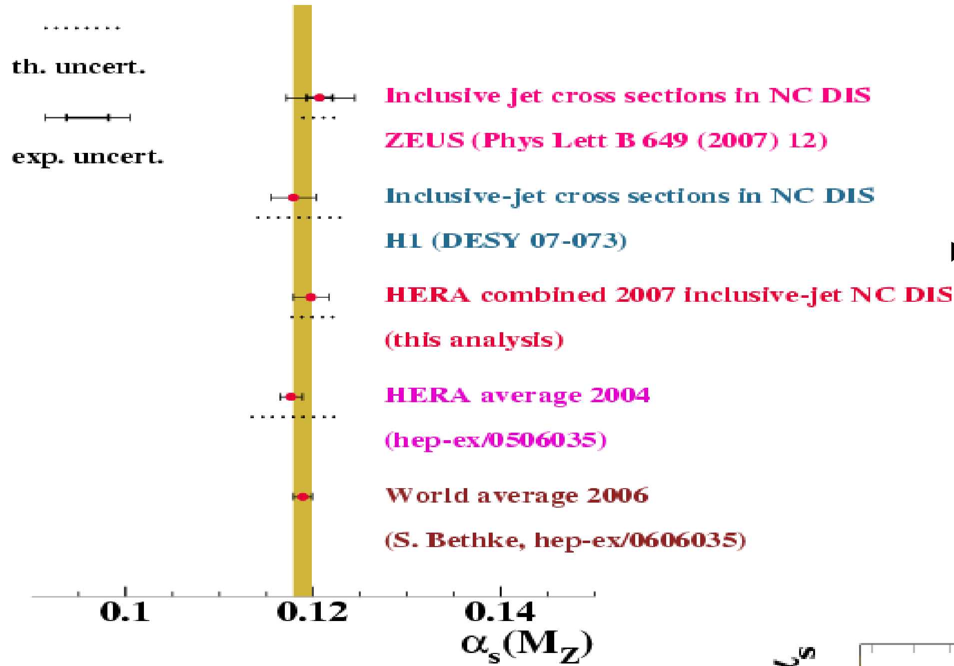
Fit uses:

- inclusive jet cross sections as function of ET and Q^2 from H1. 24 points with $150 < Q^2 < 15000$ GeV

-inclusive jet cross sections as a function of Q^2 from ZEUS. 6 points with $125 < Q^2 < 100000$GeV

Calculate pQCD cross sections with NLOJET++
Factorisation scale = Q, normalisation scale = ET of jet
Use MRST2001 PDFs
Running of em coupling with Q2 is included

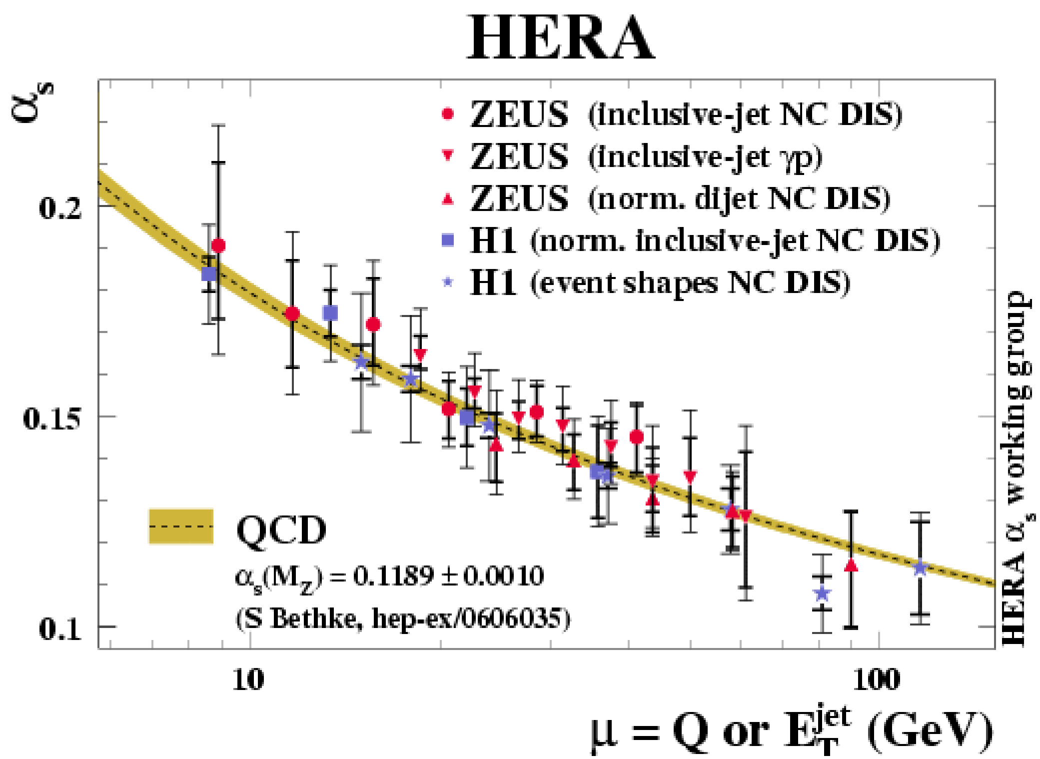
Define a χ^2matrix and minimise using Hessian method.



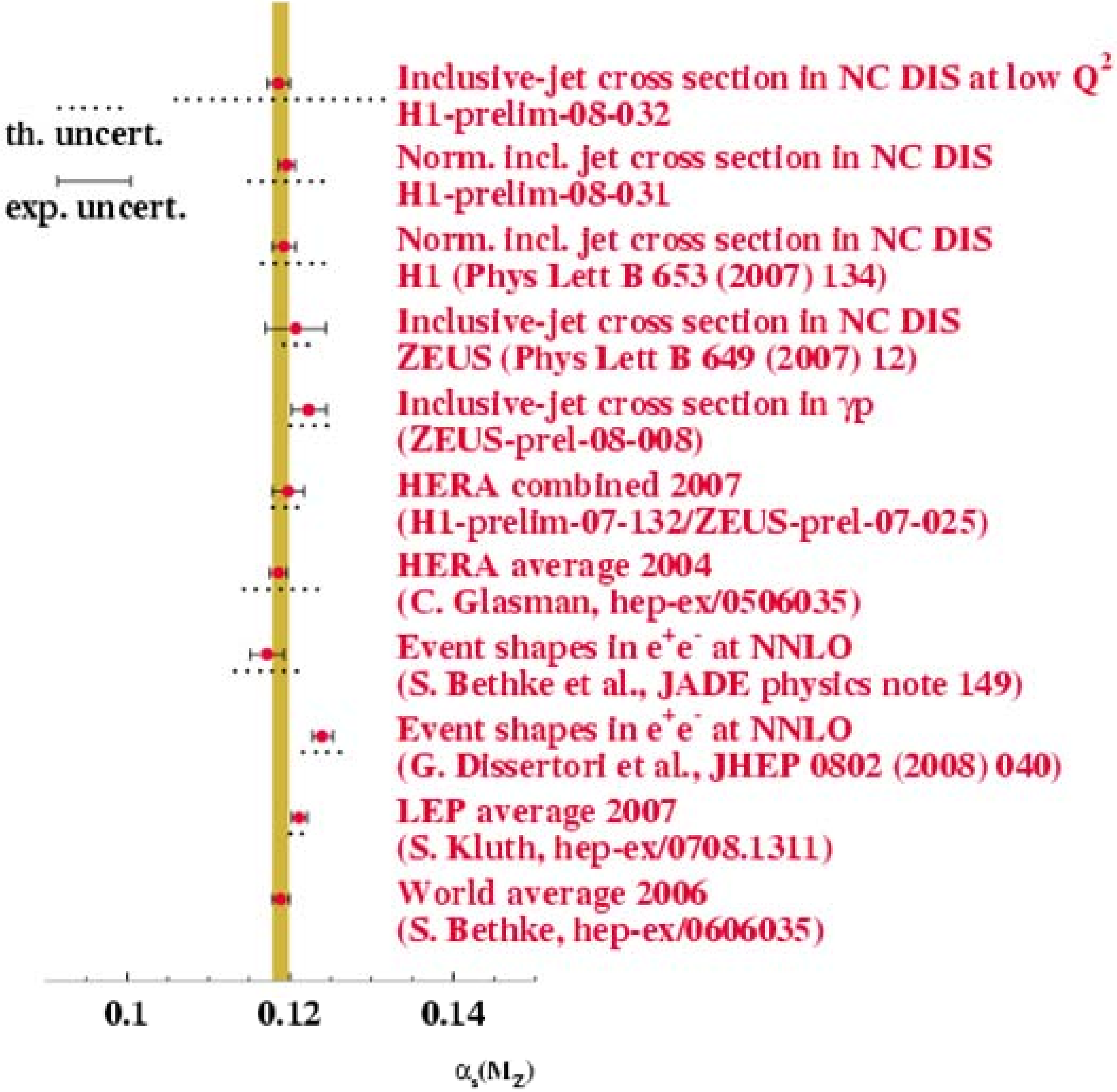
Result:
$\alpha_s = 0.1198 \pm 0.0019 \pm 0.0026$
(exp) (th)

Theoretical uncertainties no longer taken as fully correlated.

Vary renorm, fac scales. (0.0021, 0.0010), PDFs (0.0010), hadronisation correction. (0.0004)



List of recent values:



Conclusions

Progress continues in calculating the relevant diagrams.

Progress in improved jet cone algorithms especially relevant for LHC.

HERA produces more and more accurate data

Measurements of α_s continue to improve as data and theory both become more precise.