Jets in Deep Inelasic Scattering at HERA

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On behalf of H1 AND ZEUS Collaborations

- **Inclusive Jets, Dijets, Trijets in Deep Inelastic Neutral Current e^+p scattering**
- **Comparison with QCD predictions**
- **Extraction of α_s**

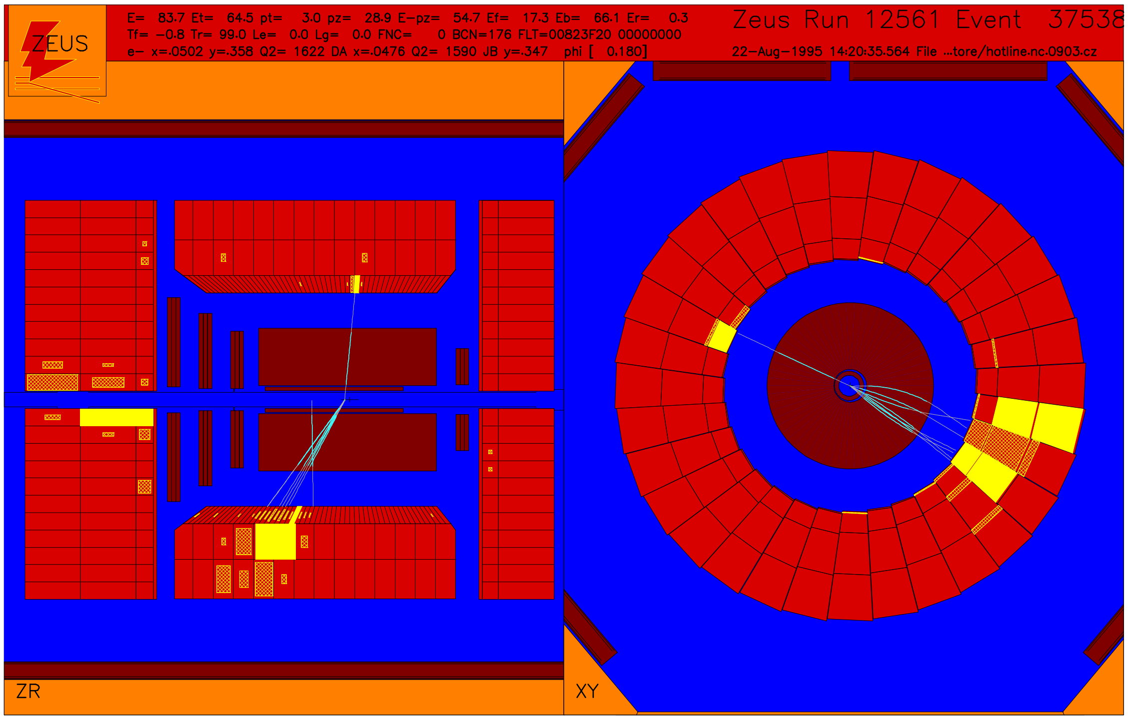
Neutral Current Single Jet events at HERA

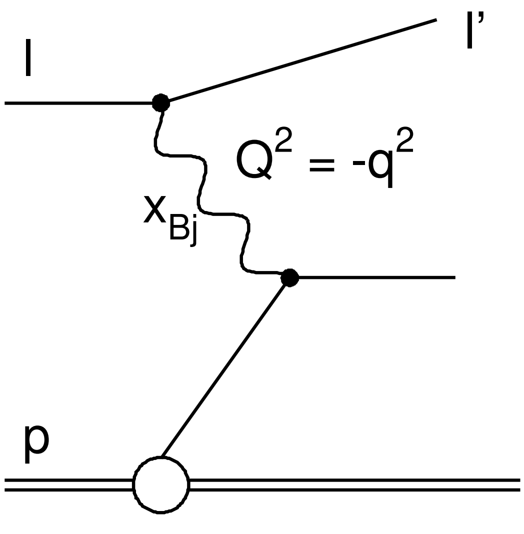
HERA : $E_e = 27.5 GeV, E_p = 820 GeV$, $s = Q^2_{max} = 10^5 GeV^2$

Most probable final state structure in High Q^2 DIS at HERA :

$$e^+ p \rightarrow e^+ + jet + X$$

Single Jet Event (ZEUS Detector)



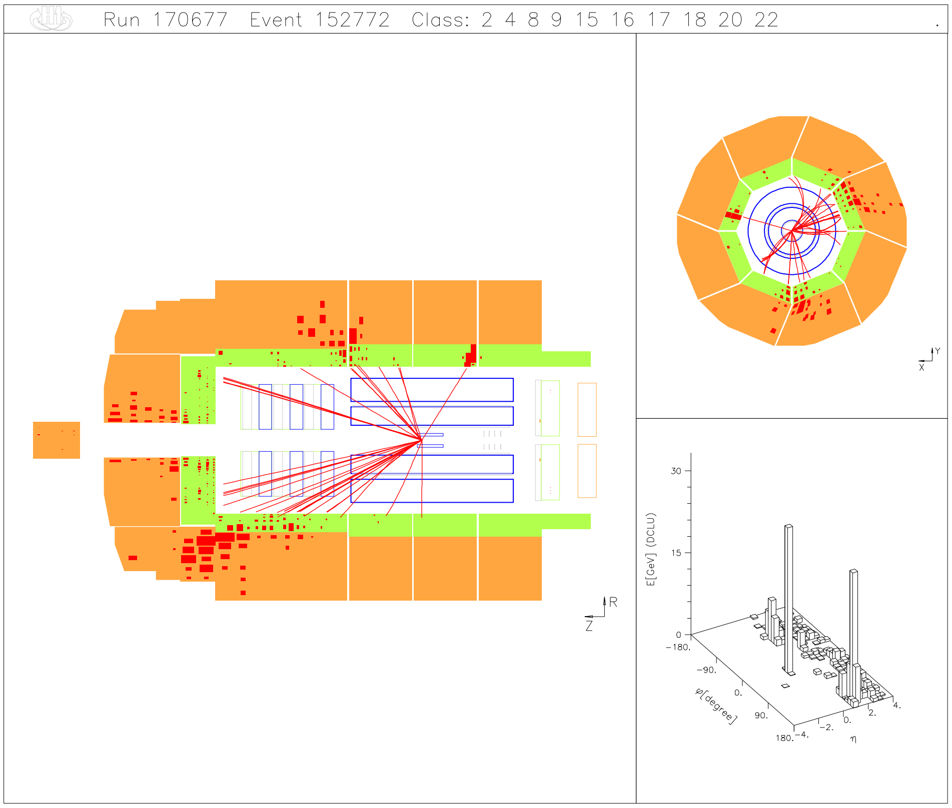


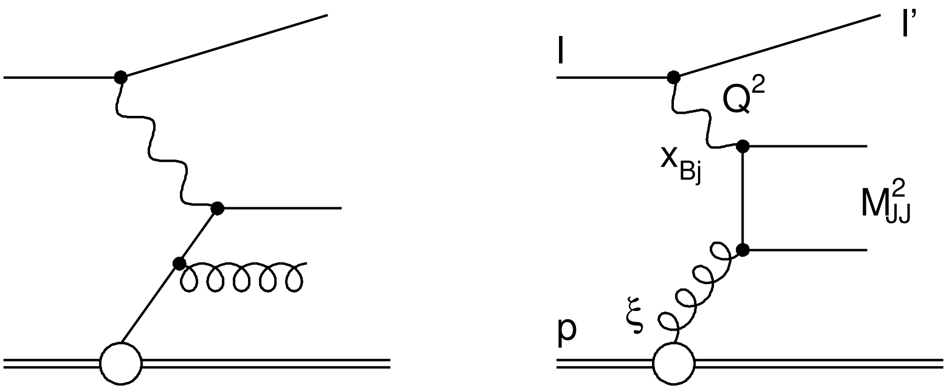
QPM Diagram

Dijet events at HERA

$$e^+p \to e^+ + jet_1 + jet_2 + X$$

Dijet event (H1 Detector)





$O(\alpha_s)$ Diagrams : QCD- Compton and Boson-Gluon-Fusion

Sensitive to α_s and proton-pdf's

High E_T^{jet} and Q^2 reachable at HERA

Inclusive Jet Analysis

Measurement of the differential cross sections for inclusive jet production in

$$e^+p \rightarrow e^+ + jet(s) + X$$

ZEUS Analysis

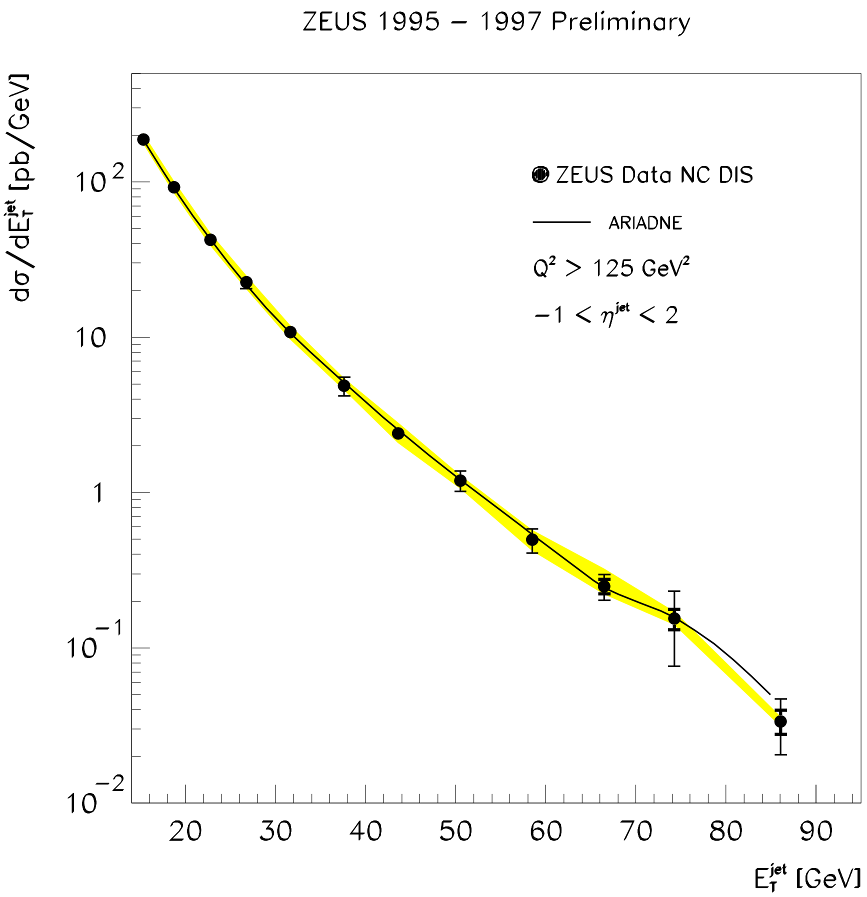
- 1995-1997 data, Luminosity $= 43pb^{-1}$
- Isolated positron , $Q^2 > 125GeV^2$
- Jets searched in Lab.system with longitudinally invariant k_T algorithm

Count jets with $E_T > 14GeV$ and pseudorapidity $-1 < \eta < 2$

$(\eta = -ln(tan(\theta/2)), \theta$ w.r.t proton-direction)

Inclusive Jet Cross Section : E_T Dependence

Full Q^2 range



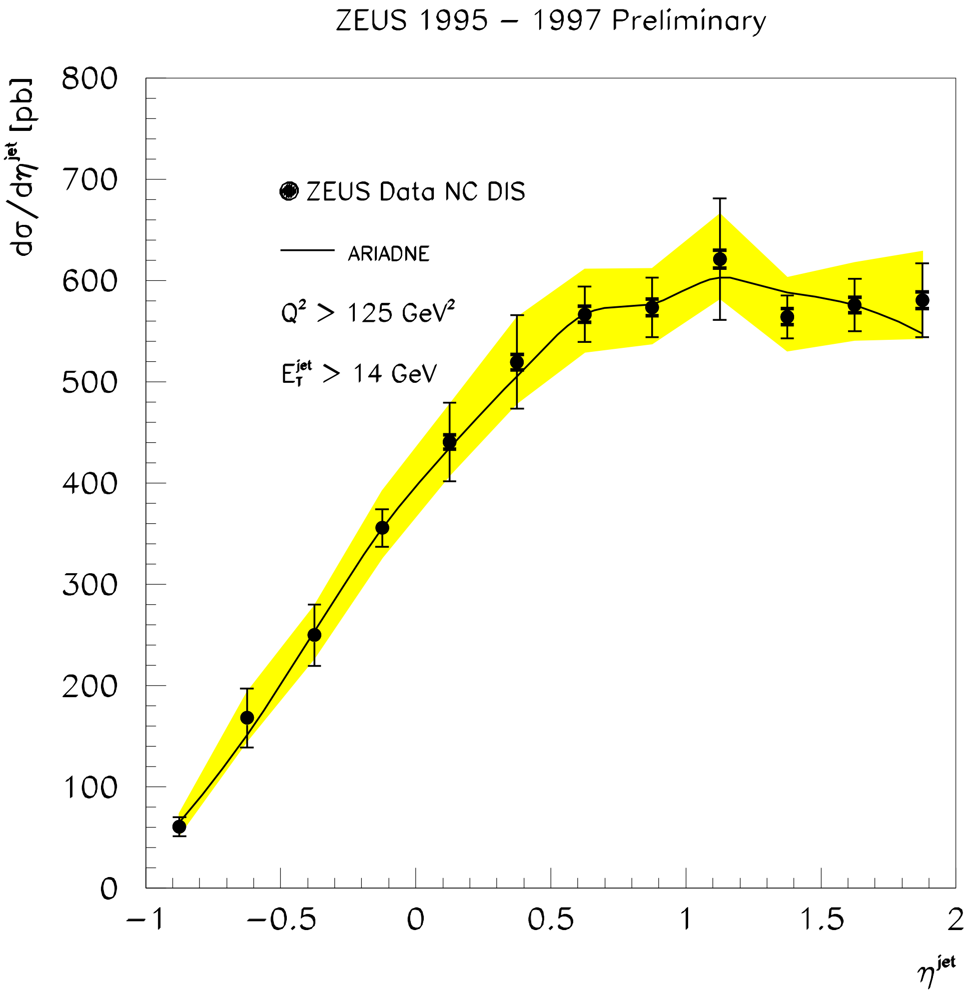
Compared with Standard Model calculation :

- Photon and Z_o exchange
- First order electroweak radiative corrections
- $O(\alpha_s)$ QCD calculations plus parton showers (color dipole model : ARIADNE MC)
- CTEQ4 proton pdf's

Data over 4 orders of magnitude well described

Inclusive Jet Cross Section : η_{Jet} Dependence

Full Q^2 range



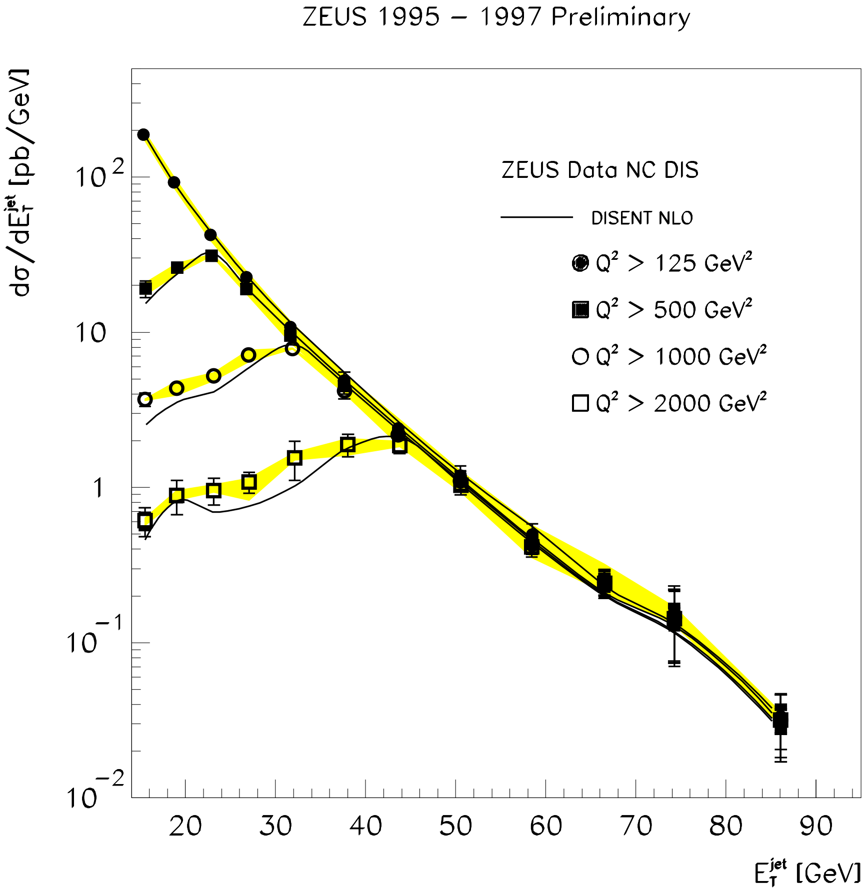
Compared with Standard Model (Ariadne MC) :

Data over full measured range in η_{Jet} well described

The agreeement between data and Standard Model (ARIADNE MC) expectation is for the E_T and η_{Jet} distributions always better than 10%

Inclusive Jet Cross Section : E_T Dependence for different Q^2 regions

Measurements of $d\sigma/dE_T^{Jet}$ for $Q^2 > 125, 500, 1000, 2000 GeV^2$



Compared with Standard Model :

- LO and NLO QCD calculations at parton level using the DISENT program
- CTEQ4 proton pdf's
- Factorisation/Renormalisation scales = Q^2
- corrected for Z_0 exchange and electroweak radiative effects

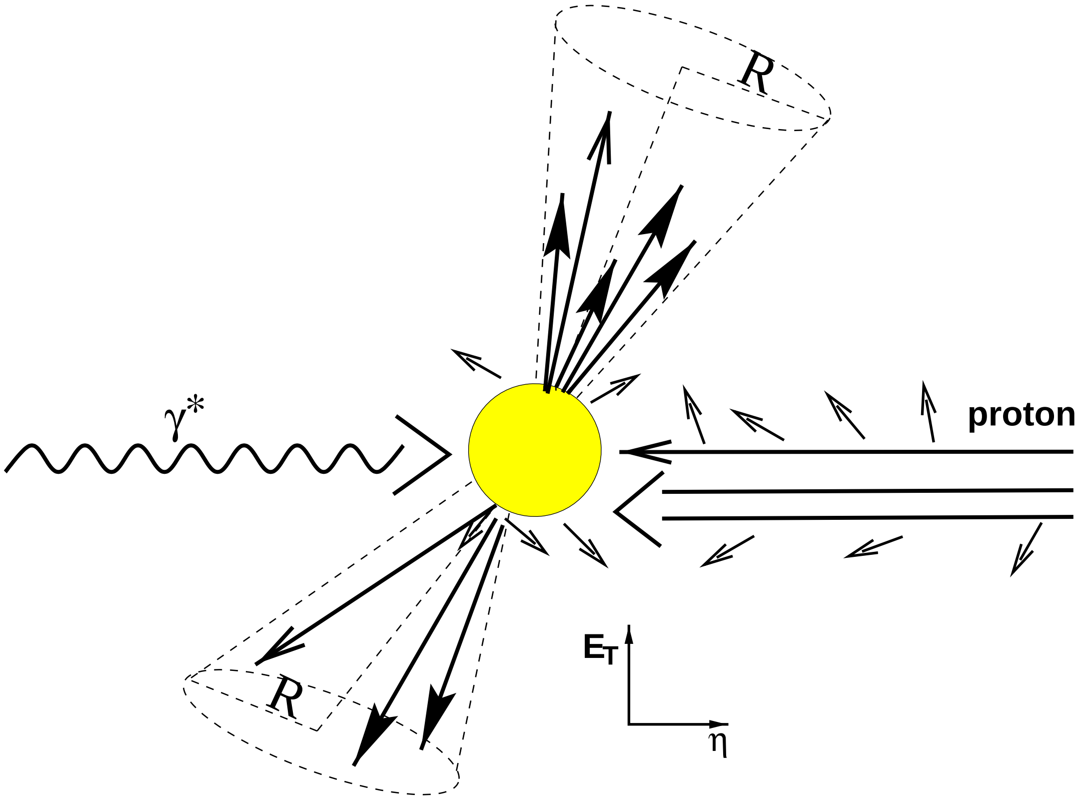
Hadronization corrections smaller than 5%

Tendency in the data to be above expectation for $Q^2 > 1000 GeV^2$ at lower E_T values

NLO correction is 50% at $E_T = 20 GeV$ for $Q^2 > 1000 GeV^2$! Improved QCD calculations needed.

Inclusive jet search in Breit frame (H1)

H1 searched for Jets in the Breit frame (virtual photon collides head-on with the proton) using the inclusive k_T algorithm. A cut on E_T^{jet} in this frame suppresses QPM events.

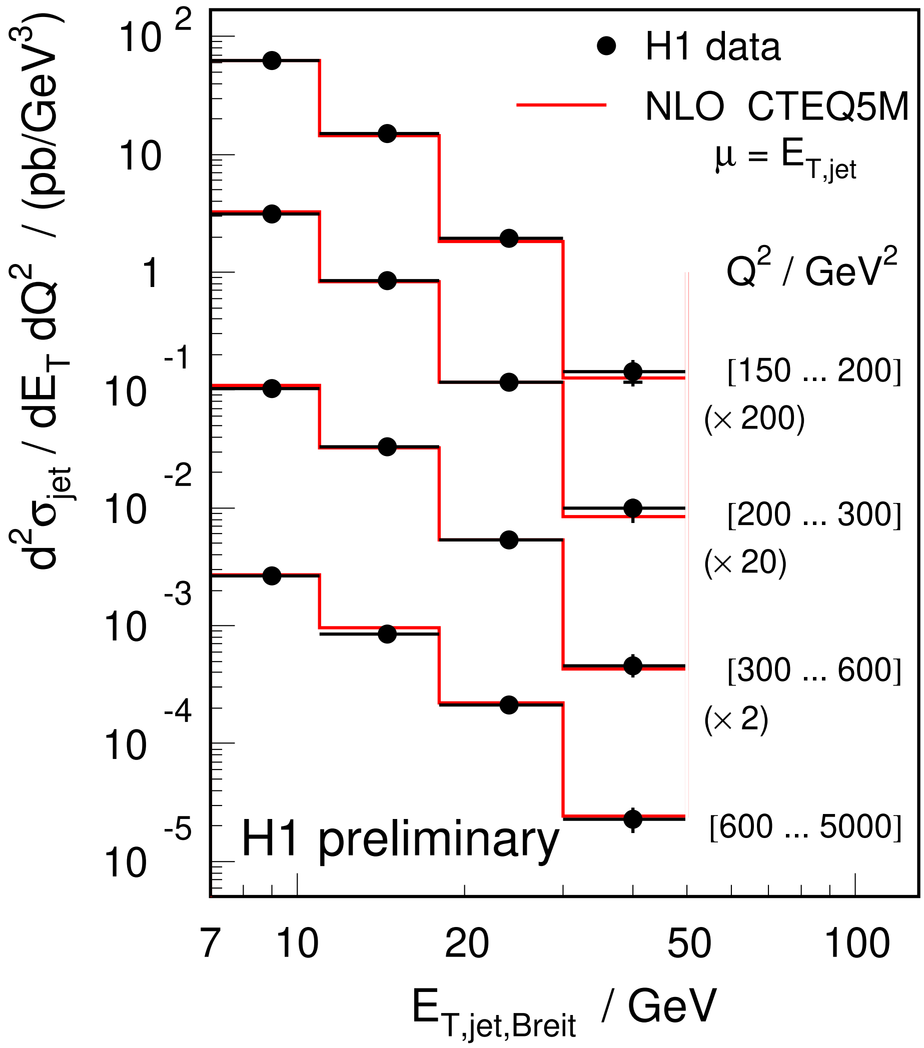


Q^2 describes the resolution of the probe
E_T describes the 'hardness' of the QCD process

What is the relevant scale ? Q^2 ? E_T^2 ?

Inclusive jet search in Breit frame (H1)

H1 Selection : $150 < Q^2 < 5000 GeV^2, 49 < E^2_{T_{jets(s)}} > 2500 GeV^2$



Good description by NLO-QCD (DISENT) using CTEQ5M pdf's

Hadronization corrections small (3 - 10 %), decreasing with E_T

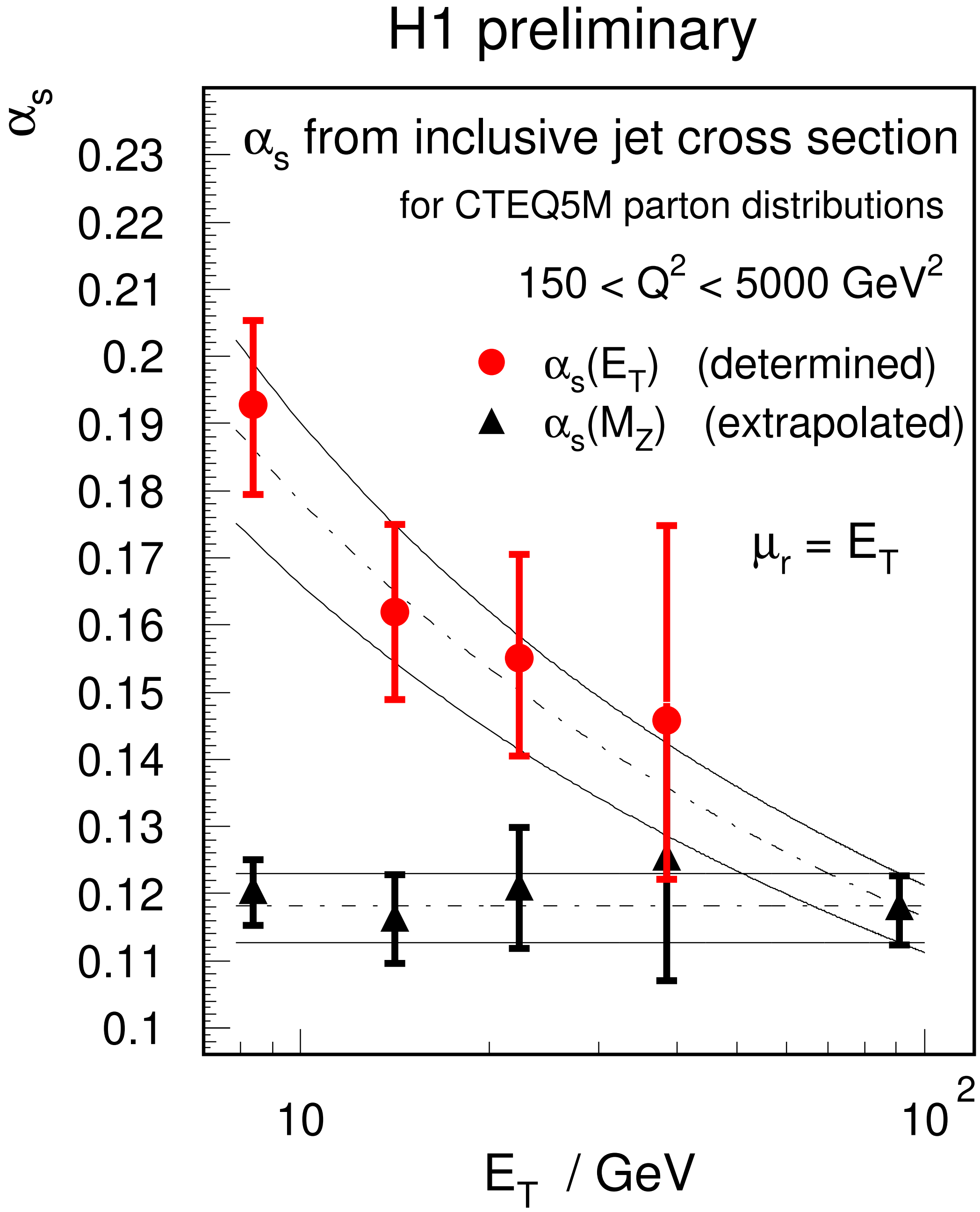
$\rightarrow$ Extract α_s from the E_T and Q^2 dependence of the inclusive jet cross section

$\alpha_s(E_T)$ from Inclusive Jet Cross Section

Take (E_T) as the relevant renormalization scale

$\alpha_s(E_T)$ has been extracted at 4 values of E_T for 4 Q^2 regions
Q^2 : $150 - 200, 200 - 300, 300 - 600, 600 - 5000 GeV^2$

Consistent result in all four Q^2 regions $\rightarrow$ Combine all Q^2 regions

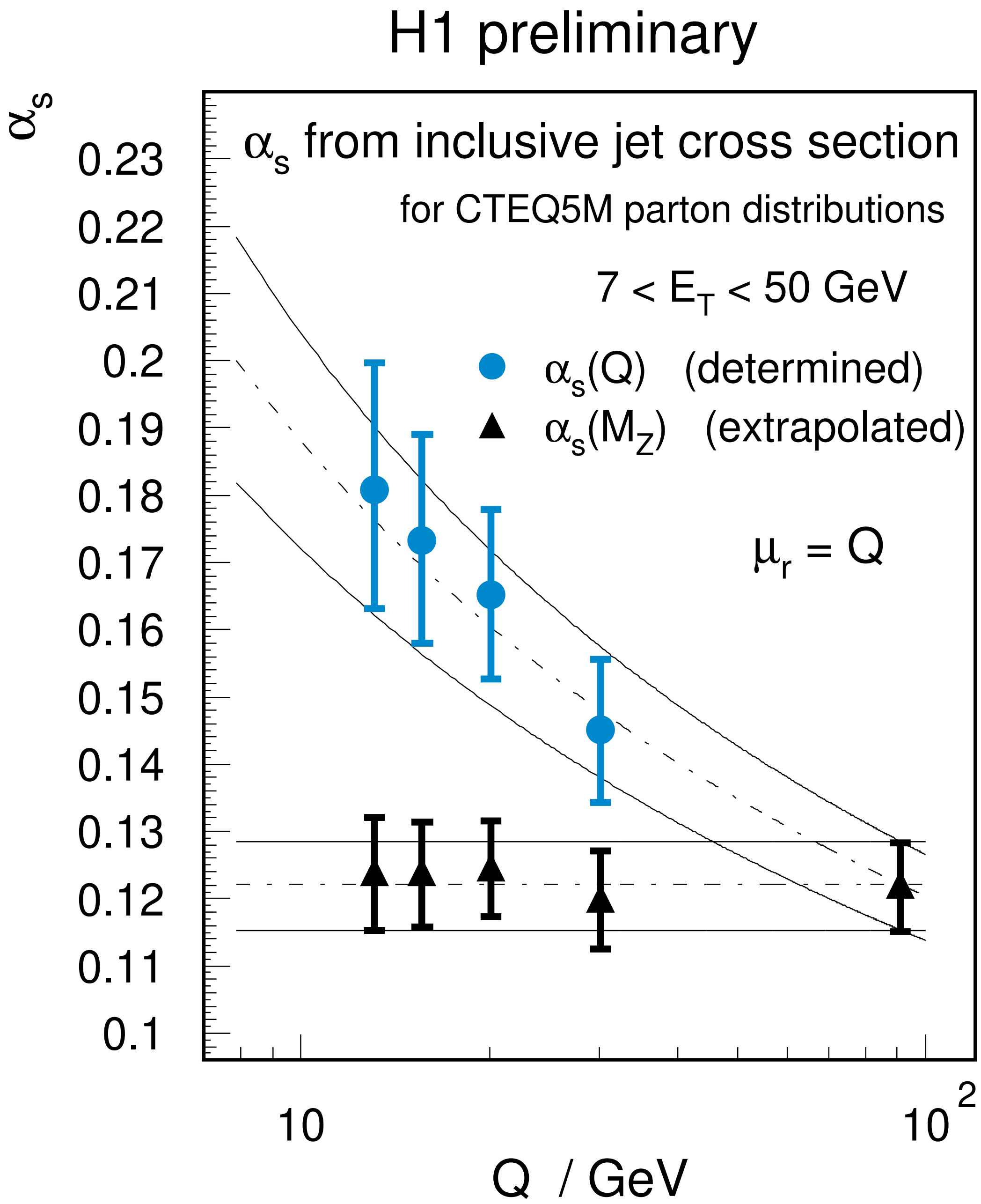


For $\mu_{ren} = E_T$

$\alpha_s(M_Z) = 0.1181 \pm 0.0030(exp)^{+0.0039}_{-0.0046}(theo)^{+0.0036}_{-0.0015}(pdf)$

$\alpha_s(Q)$ from Inclusive Jet Cross Section

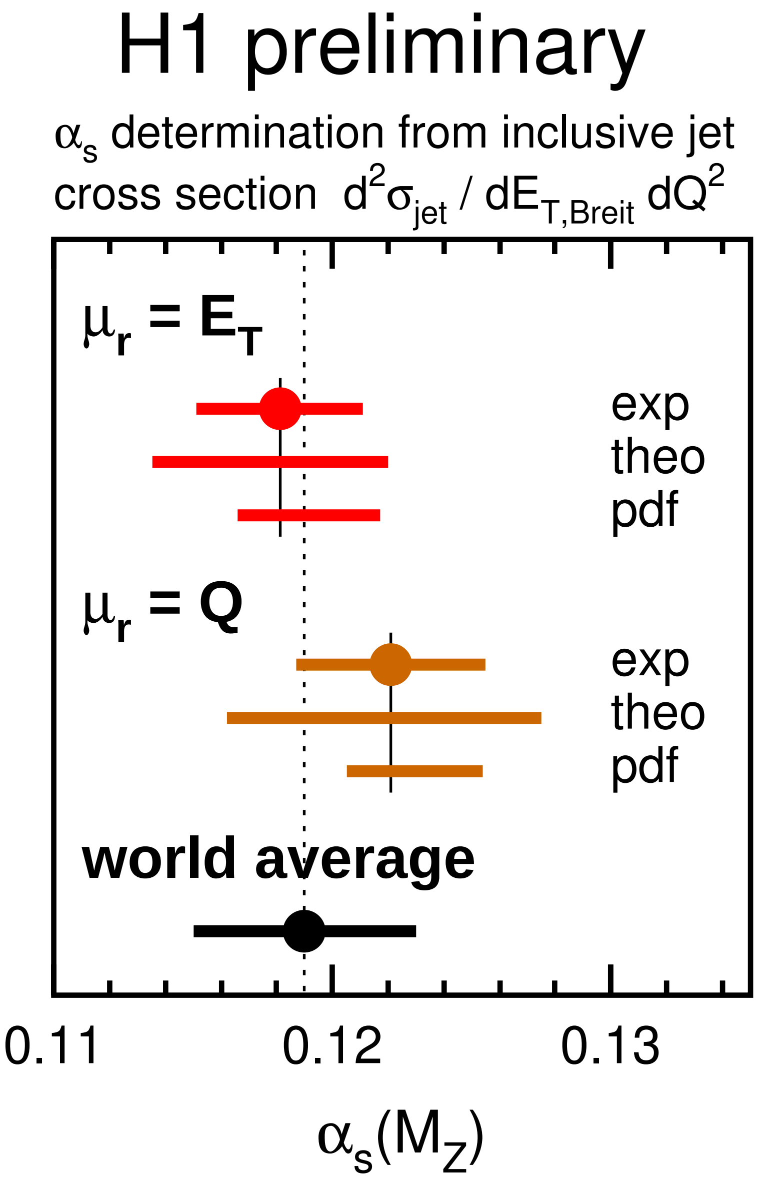
Take Q as the relevant renormalization scale



For $\mu_{ren} = Q$

$$\alpha_s(M_Z) = 0.1221 \pm 0.0034(exp)^{+0.0054}_{-0.0059}(theo)^{+0.0033}_{-0.0016}(pdf)$$

α_s from Inclusive Jet Cross Section

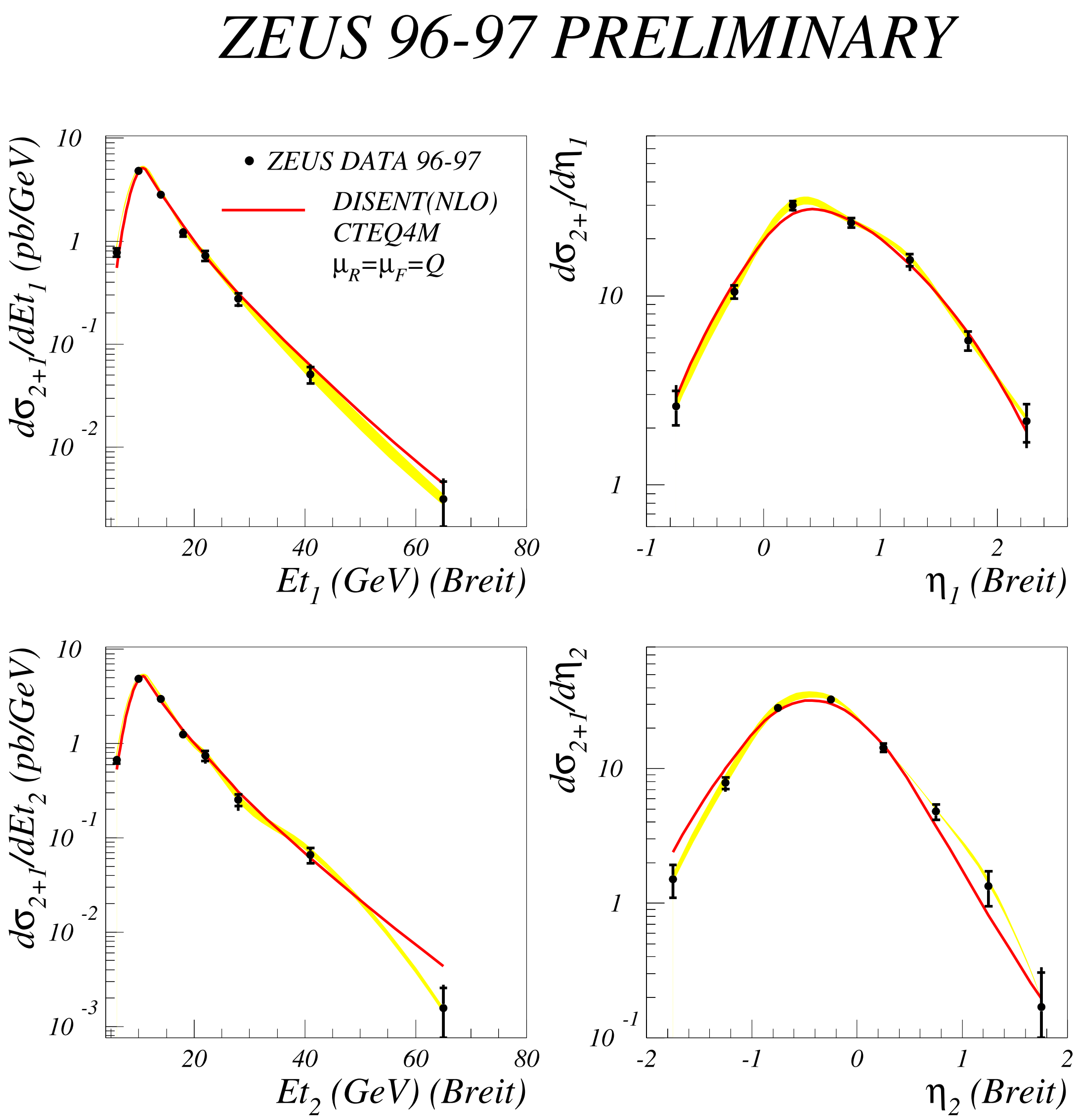


The dependence of α_s on the α_s-value used in the pdf - determinations has been studied in detail and found to be small.

Dijets (ZEUS)

Phase space : $470 < Q^2 < 20000 GeV^2$
Jets defined with long. invariant K_T algorithm in Breit frame
$E_{T1} > E_{T2} > 5GeV; E_{T1} + E_{T2} > 17GeV$

E_T and η spectra for both jets :

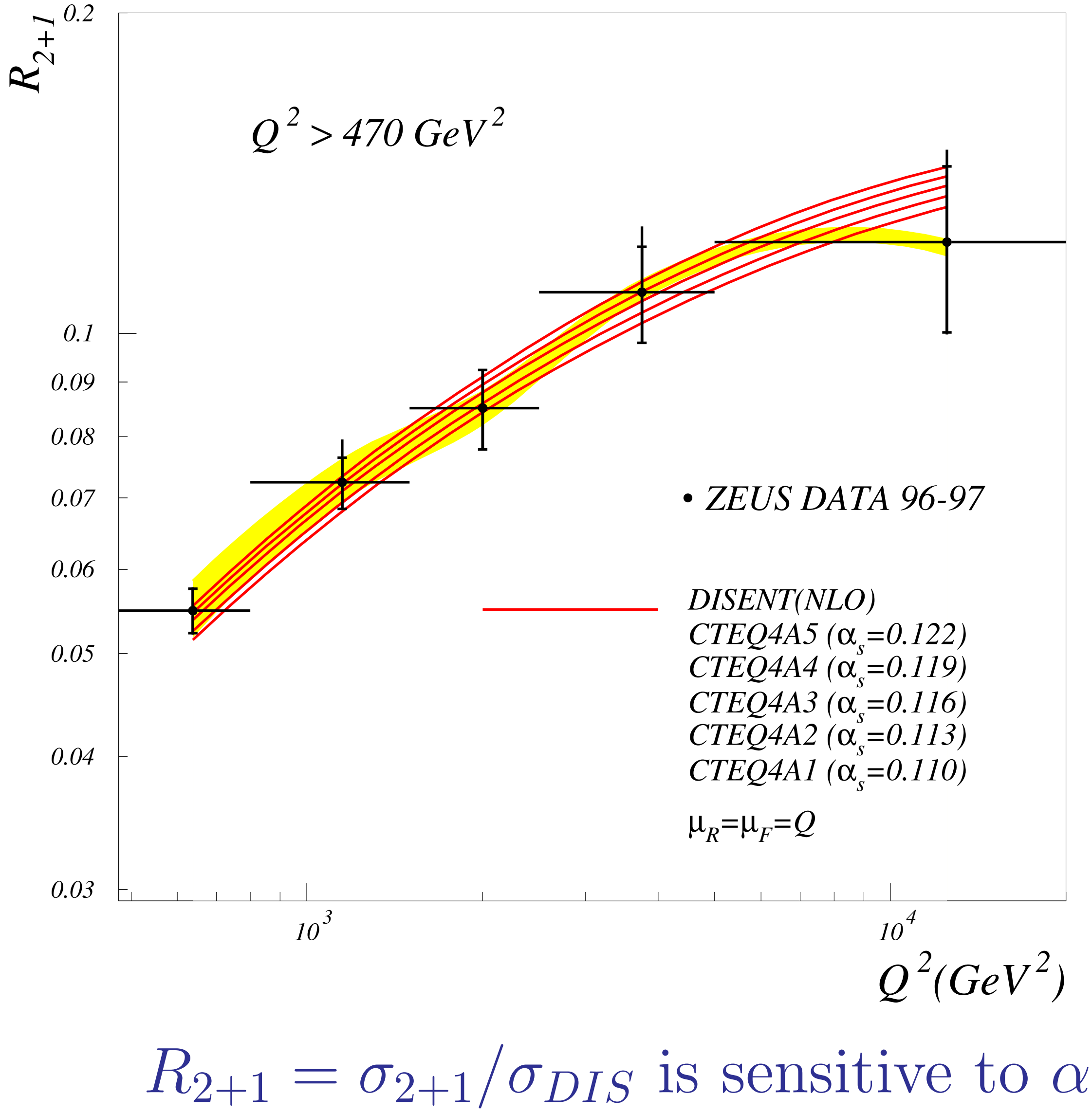


Data are corrected for detector, electroweak effects and hadronisation

Good description by NLO-QCD (DISENT)

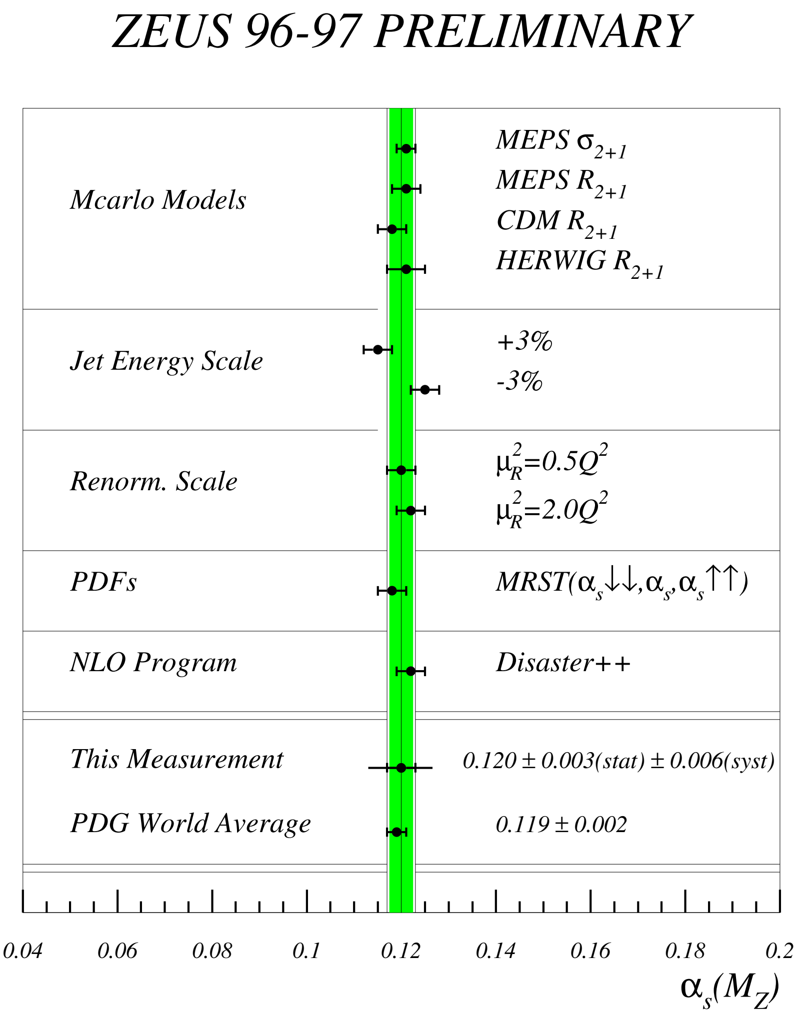
Relative Dijet rates at High Q^2

ZEUS 96-97 PRELIMINARY



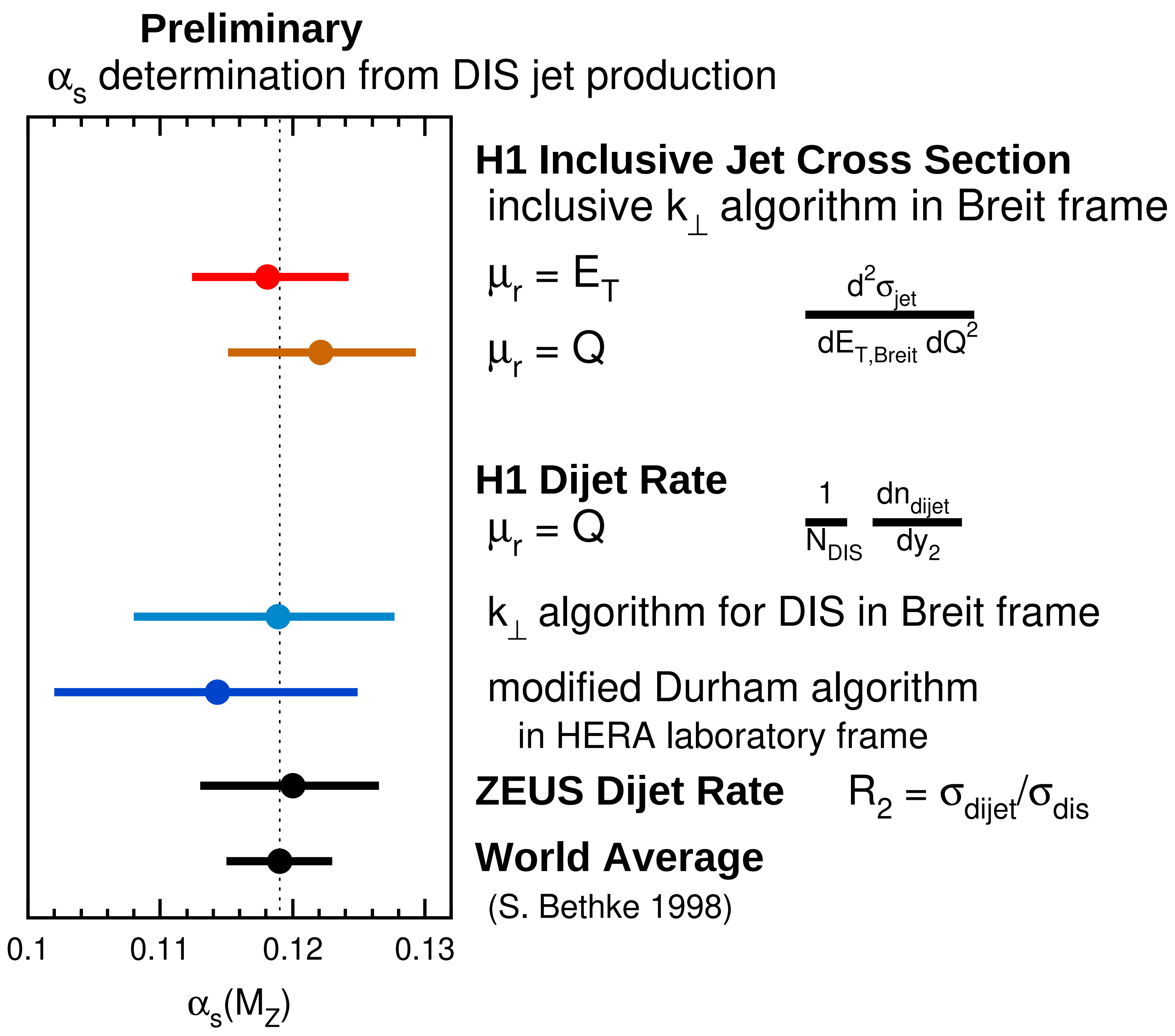
$R_{2+1} = \sigma_{2+1}/\sigma_{DIS}$ is sensitive to α_s

α_s from fit to Dijet rates (ZEUS)



$$\alpha_s(M_Z) = 0.120 \pm 0.003(stat)^{+0.005}_{-0.006}(exp)^{+0.003}_{-0.002}(theo)$$

Summary α_s from Jets at HERA



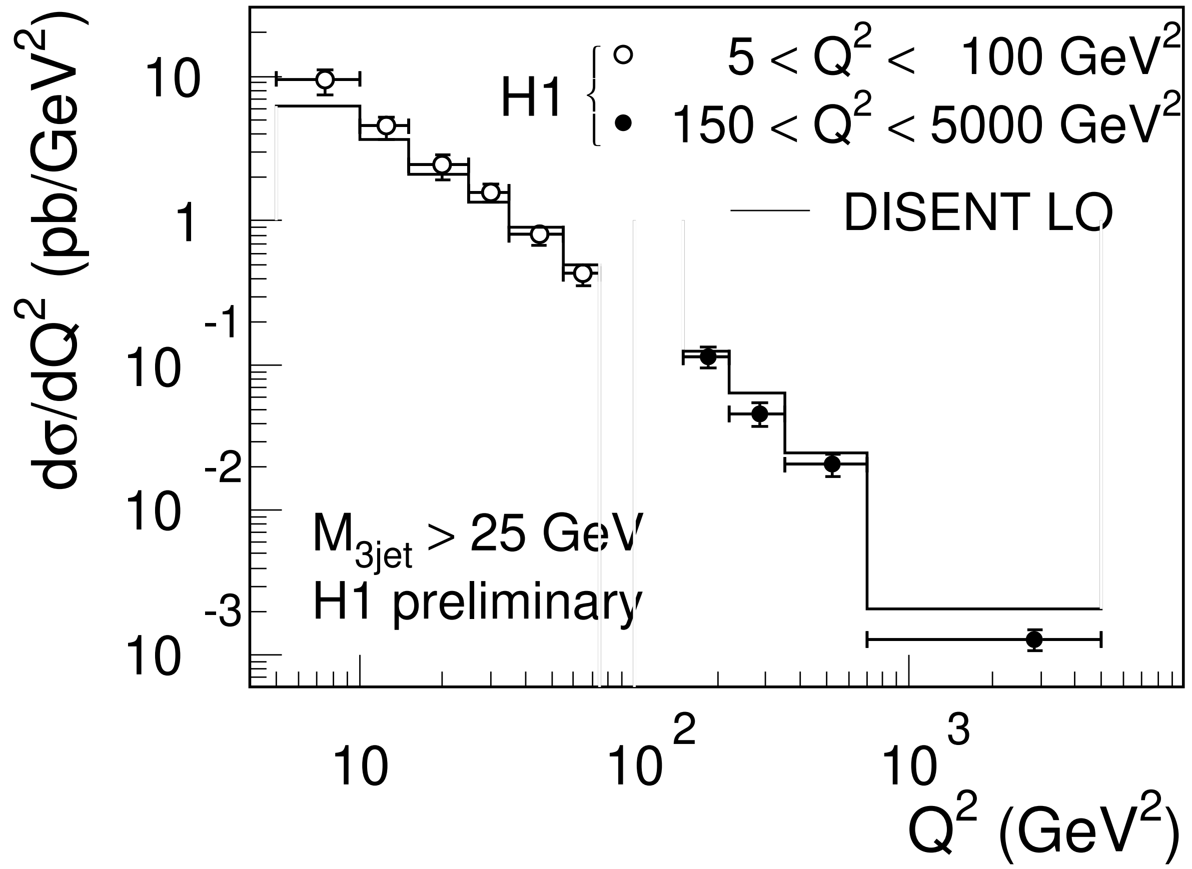
Very competitive measurements !

Three-jet production in DIS

The large center-of-mass energy at HERA allows the study of multi-jet production e.g.

$$e^+p \rightarrow e^+ + 3jets + X$$

H1 analysis : $5 < Q^2 < 100 GeV^2$ and $150 < Q^2 < 5000 GeV^2$
Jets defined by K_T algorithm in Breit frame
Demand three jets with $E_T > 5 GeV$ each



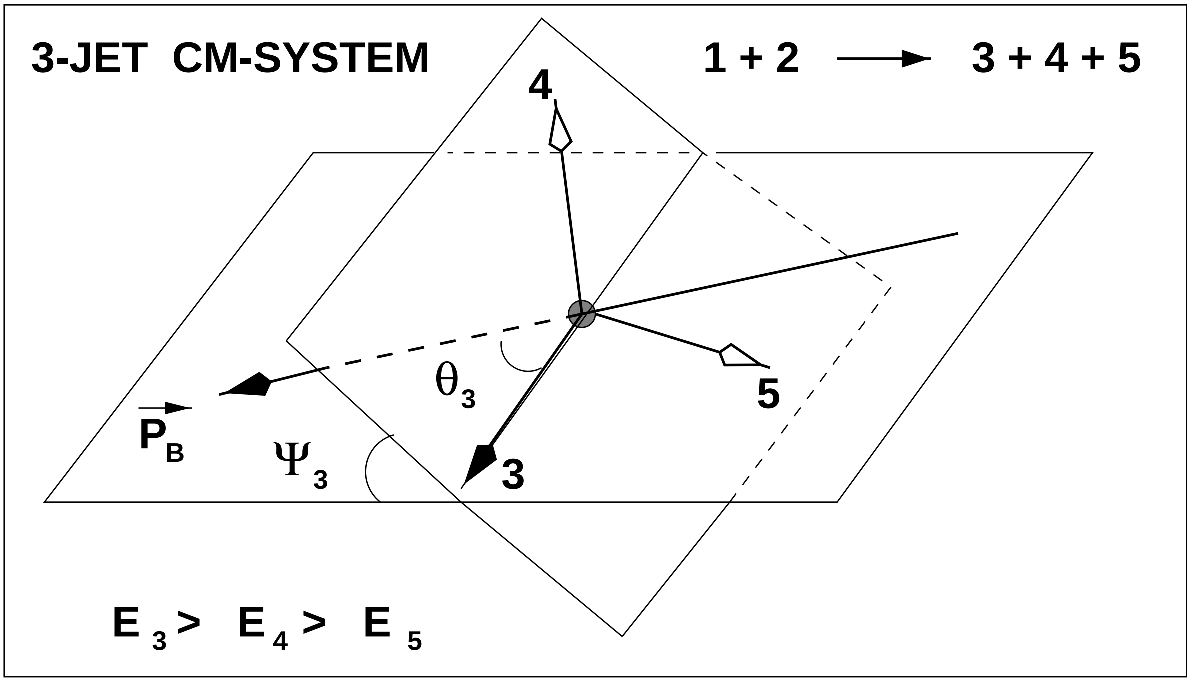
Data compared with LO QCD ($O(\alpha_s^2)$ for three-parton final states) calculations using the DISENT program with CTEQ5L proton pdf's. (Hadronisation corrrections would lower the predictions by 20 - 30 %).

$\rightarrow$ Fair description of data apart from lower Q^2 region

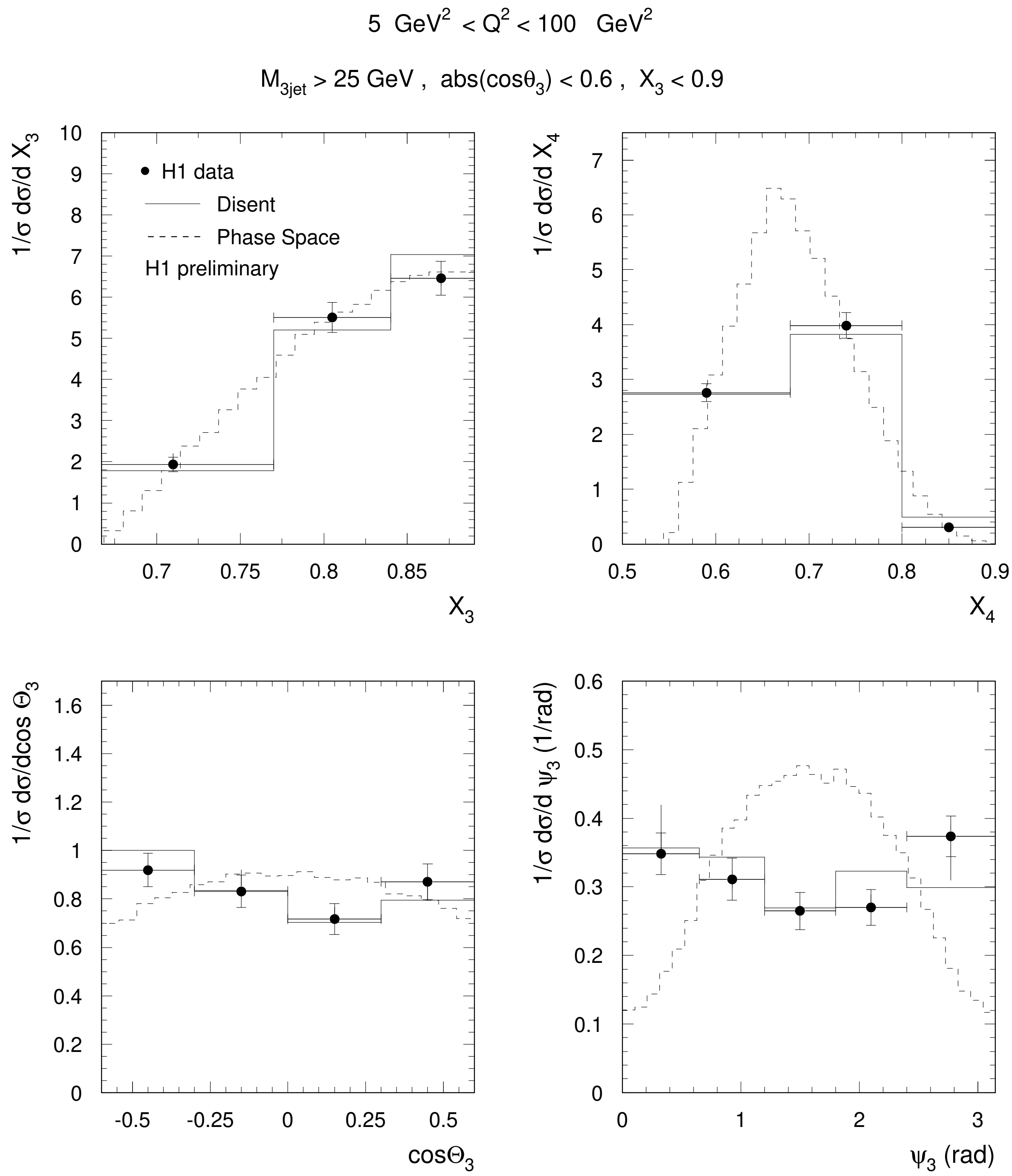
Three-jet topology

Topology of 3-jet events in their CM-System has been studied in terms of the following variables :

- Three-jet invariant mass M_{3jet}
- Scaled jet energies ($E_3 > E_4 > E_5$)
  $X_3 = 2E_3/M_{3jet}, X_4 = 2E_4/M_{3jet}$
- Polar angle of leading jet Θ_3
- Orientation of the 3-jet plane wrt the plane containing the beam direction and the leading jet Ψ_3



Three-jet topology



Shapes well described by LO QCD calculation (DISENT)

Depletion near $\Psi_3 \sim 0$ and π expected due to jet-cuts.

Data behave in opposite way, in agreement with QCD (initial state radiation pole)

Summary

- The high CM energy of HERA made it possible to study jet production in NC-DIS over a wide range in Q^2 and jet transverse momenta E_T
- The inclusive jet distributions as well as the dijet distributions are well described by $O(\alpha_s^2)$ QCD calculations
- This fact allowed determinations of the strong coupling constant α_s with different methods (inclusive jets, dijets) and different jet-algorithms
  - The variation of α_s with the renormalization scale taken as Q^2 or E_T^2 gives consistent results
  - For both choices the 'running of α_s' is seen
  - The results extrapolated for $\alpha_s(M_Z)$ are compatible and competitive with the world average value
- First measurements of the 3-jet final state in DIS have been performed. The data are in fair agreement with the LO QCD calculation.

  The measured jet angular distributions show enhanced radiation close to the proton beam direction as predicted by QCD due to the initial-state radiation pole