DIS Workshop

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ZEUS

Determination of α_s using subjet multiplicities in NC DIS

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For the ZEUS Collaboration

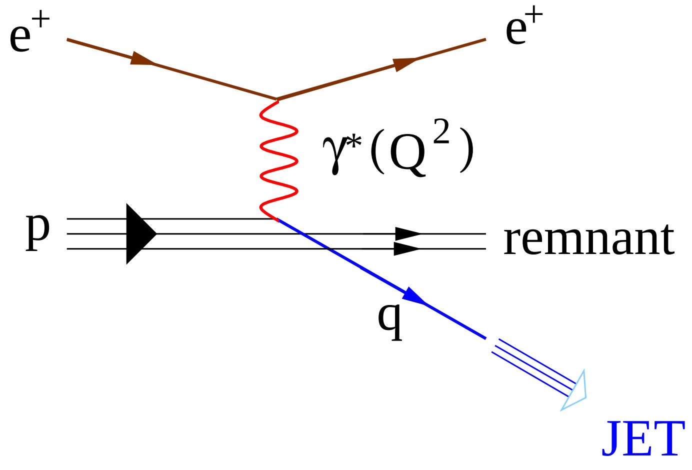
- Introduction and motivations
- Description of the analysis
- Measurements corrected to hadron level
- Obtaining NLO QCD predictions
- DATA vs NLO QCD
- Extraction of α_s

Jet production in Neutral Current DIS

In HERA the main contribution for producing jets of hadrons in the process

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

is given by the QPM diagram



To study the kinematics, the following variables are used:

Q^2 is the virtuality of the exchanged boson

s is the squared center-of-mass energy

x is Bjorken's x

Jet algorithm

- The jet search is performed in the laboratory frame using the inclusive k_T cluster algorithm.

- To define the jets we need the following variables:

  → The transverse energy (E_T) with respect to the z-axis defined by the colliding particles

  → The pseudorapidity (η) defined as the following function of the polar angle (angle wrt z-axis):

$$\eta_{jet} = -\ln\left(\tan\frac{\theta}{2}\right)$$

  → The azimuthal angle (ϕ)

- The jet search is performed in the $\eta - \phi$ plane (laboratory frame) using the inclusive k_T cluster algorithm to assign the particles to each jet.

- In this algorithm, jets are identified by successively combining nearby pair of particles

$$d_{ij} = min(E_{T,i}, E_{T,j})^2 \cdot [\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2]$$

until a jet is complete ($d_i = E_{T,i}^2$).

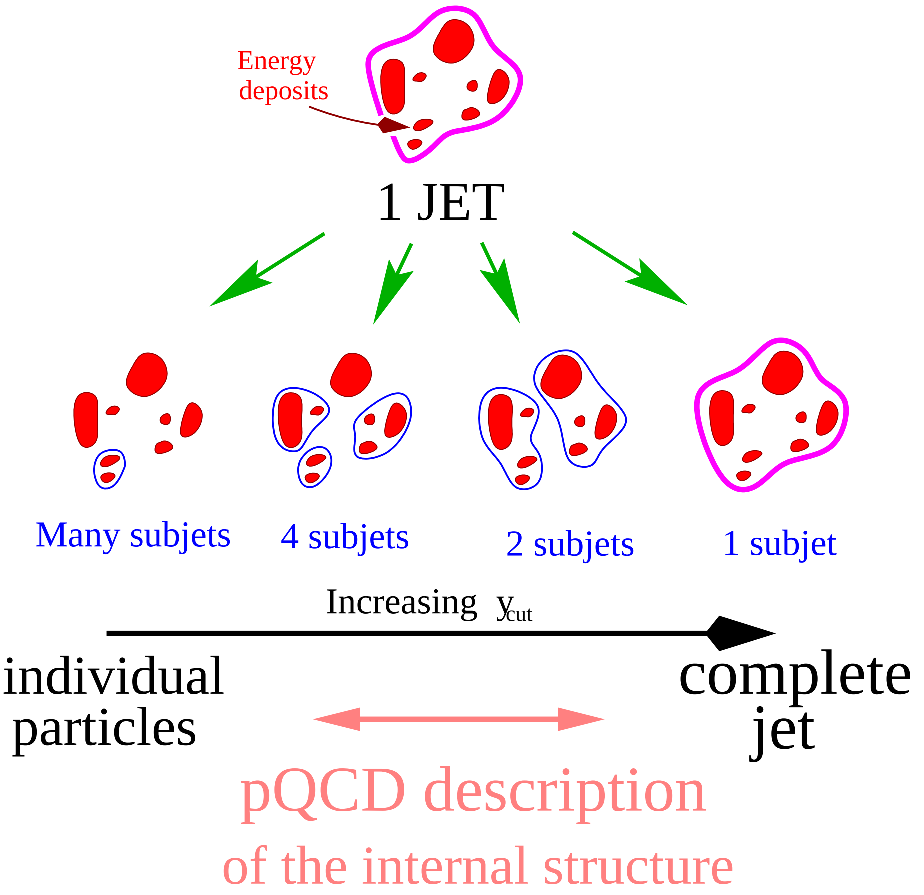
- The jet variables are then reconstructed using the following expressions:

$$E_{T,jet} = \sum_i E_{T,i} \;\; ; \;\; \eta_{jet} = \frac{\sum E_{T,i} \cdot \eta_i}{E_{T,jet}} \;\; ; \;\; \phi_{jet} = \frac{\sum E_{T,i} \cdot \phi_i}{E_{T,jet}}$$

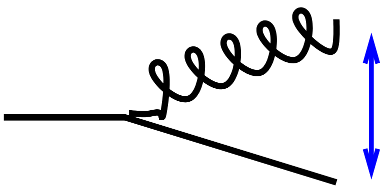
where the sums are made over all the particles in the jet.

Definition of subjets

The "subjets" are jet-like structures within a given jet.



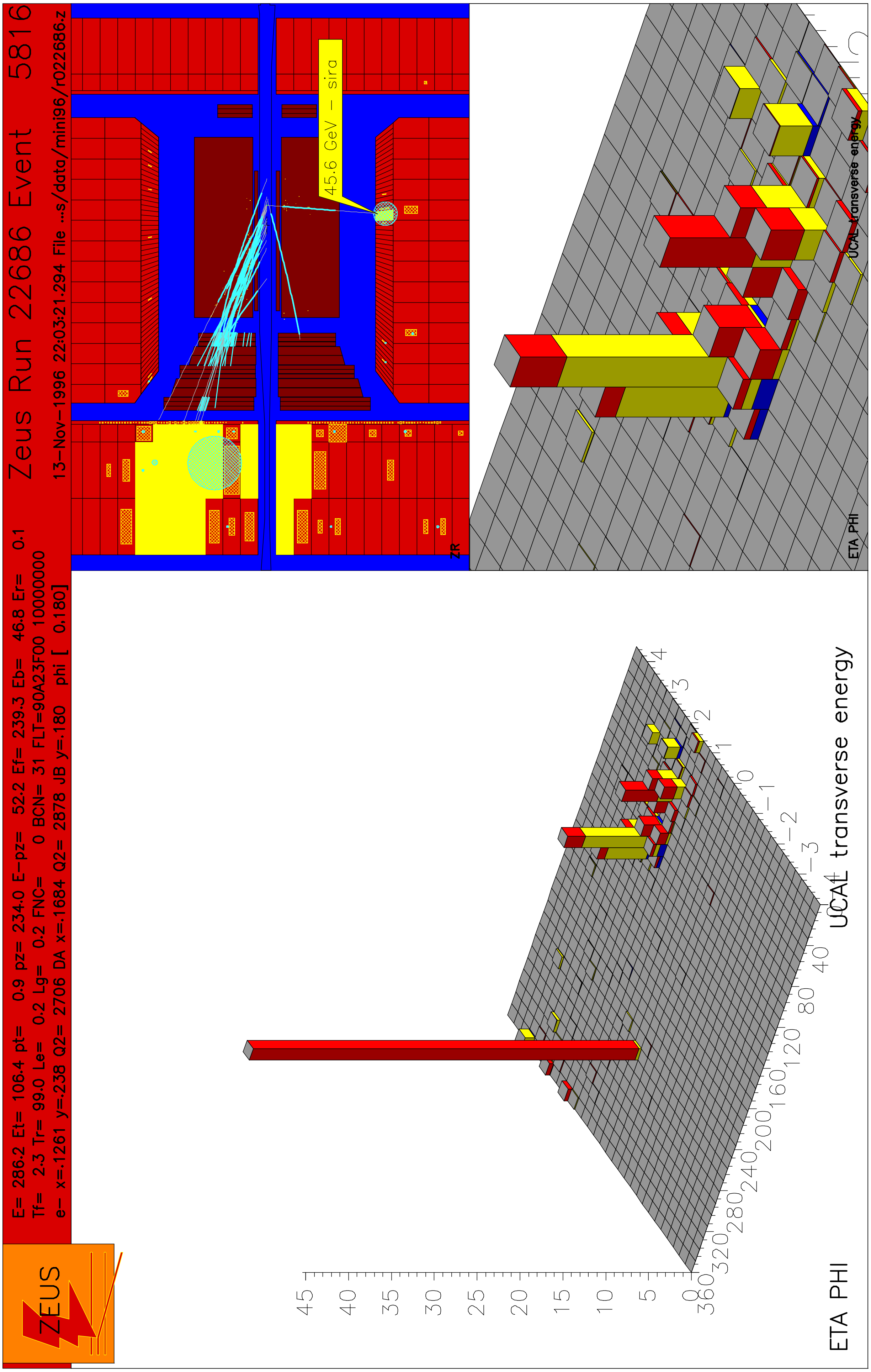
For not too small y_{cut} we are resolving parton radiation hard enough to avoid non-perturbative effects:



$$p_T \sim \sqrt{y_{cut}}\, E_{T,jet}$$

$\rightarrow$ "hard" processes ($p_T \gtrsim 1$ GeV)

- Comparison to pQCD calculations


Zeus Run 22686 Event 5816
13-Nov-1996 22:03:21.294 File ...s/data/mini96/r022686.z
E= 286.2 Et= 106.4 pt= 0.9 pz= 234.0 E-pz= 52.2 Ef= 239.3 Eb= 46.8 Er= 0.1
Tf= 2.3 Tr= 99.0 Le= 0.2 Lg= 0.2 FNC= 0 BCN= 31 FLT=90A23F00 10000000
e- x=.1261 y=.238 Q2= 2706 DA x=.1684 Q2= 2878 JB y=.180 phi [0.180]
ZEUS
45.6 GeV - sira
ZR
ETA PHI
UCAL transverse energy
ETA PHI
UCAL transverse energy

Motivations for the analysis

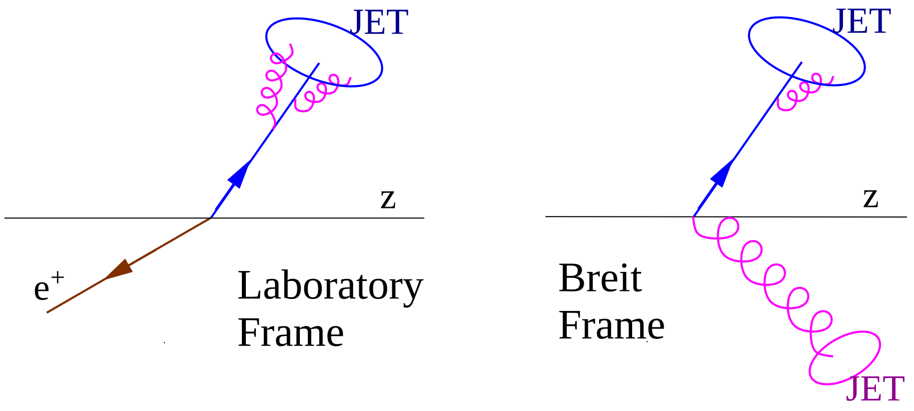
The study of the jet's internal structure using subjets has several theoretical advantages:

- Measurements are infrared-safe to all orders

  $\rightarrow$ Useful tool to test QCD beyond LO

  $\Rightarrow$ Extraction of α_s

The extraction of α_s is at present only possible using jets defined in the Laboratory Frame since NLO QCD calculations are needed:



- In the Breit (or HCM), NLO for the interaction is related to LO for jet substructure.

- In the Laboratory Frame, NLO for the interaction is related to NLO for jet substructure.

Description of the analysis

Analysis using ZEUS data (96-97) with 38 $\mathbf{pb^{-1}}$

- Isolated positron candidate with $E_{e'} > 10$ GeV

- Kinematics are reconstructed using the Double Angle method

$$\boxed{Q^2 > 125 \text{ GeV}^2}$$

- **Jet selection**:

  k_T cluster algorithm (inclusive mode)

  $E_T^{Lab} > 15$ GeV

  $-1. < \eta^{Lab} < 2.$

The measured values are corrected for the detector effects using Monte Carlo samples generated with two different models for the parton radiation:

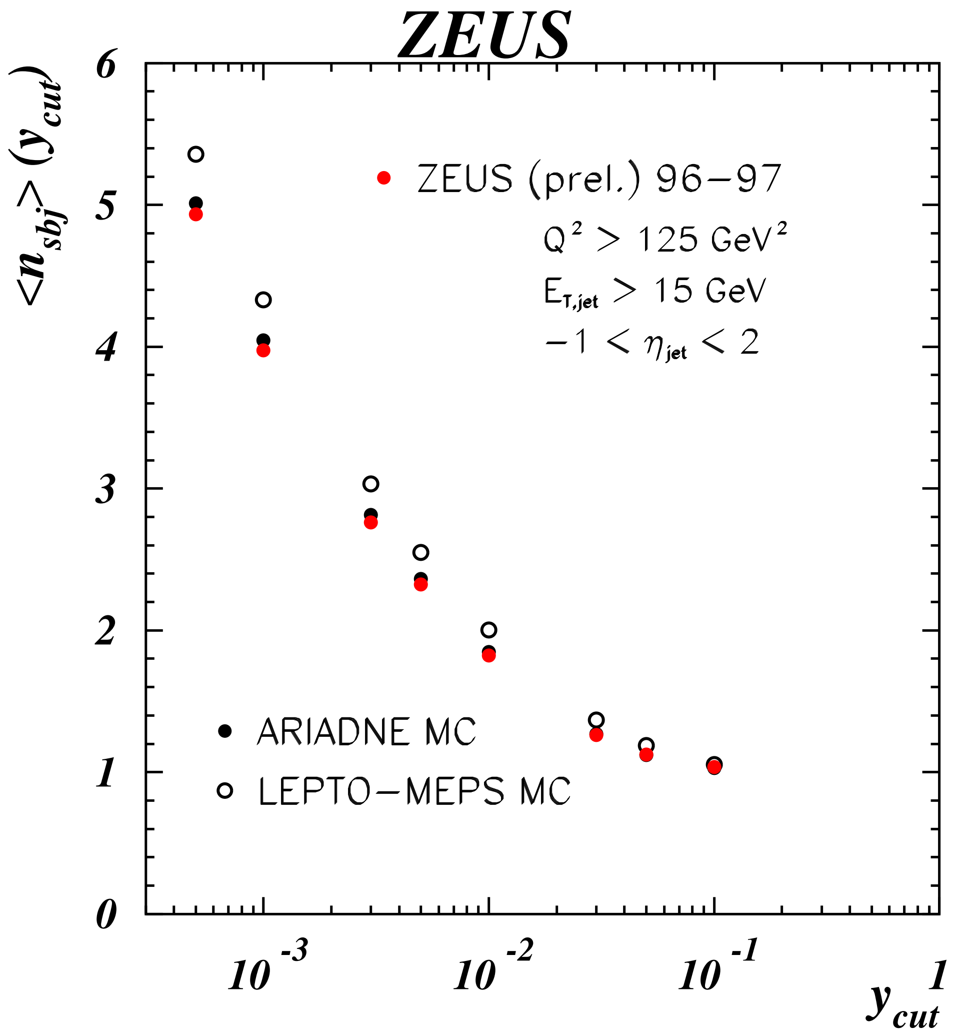
Colour Dipole Model (ARIADNE)

Matrix element + parton showers (LEPTO-MEPS)

Measurements at detector level

We measure the mean value of the number of subjets for the inclusive jet sample:

$$< n_{sbj} >= \frac{1}{N_{jet}} \sum_{k=1}^{N_{jet}} (n_{sbj})_k$$

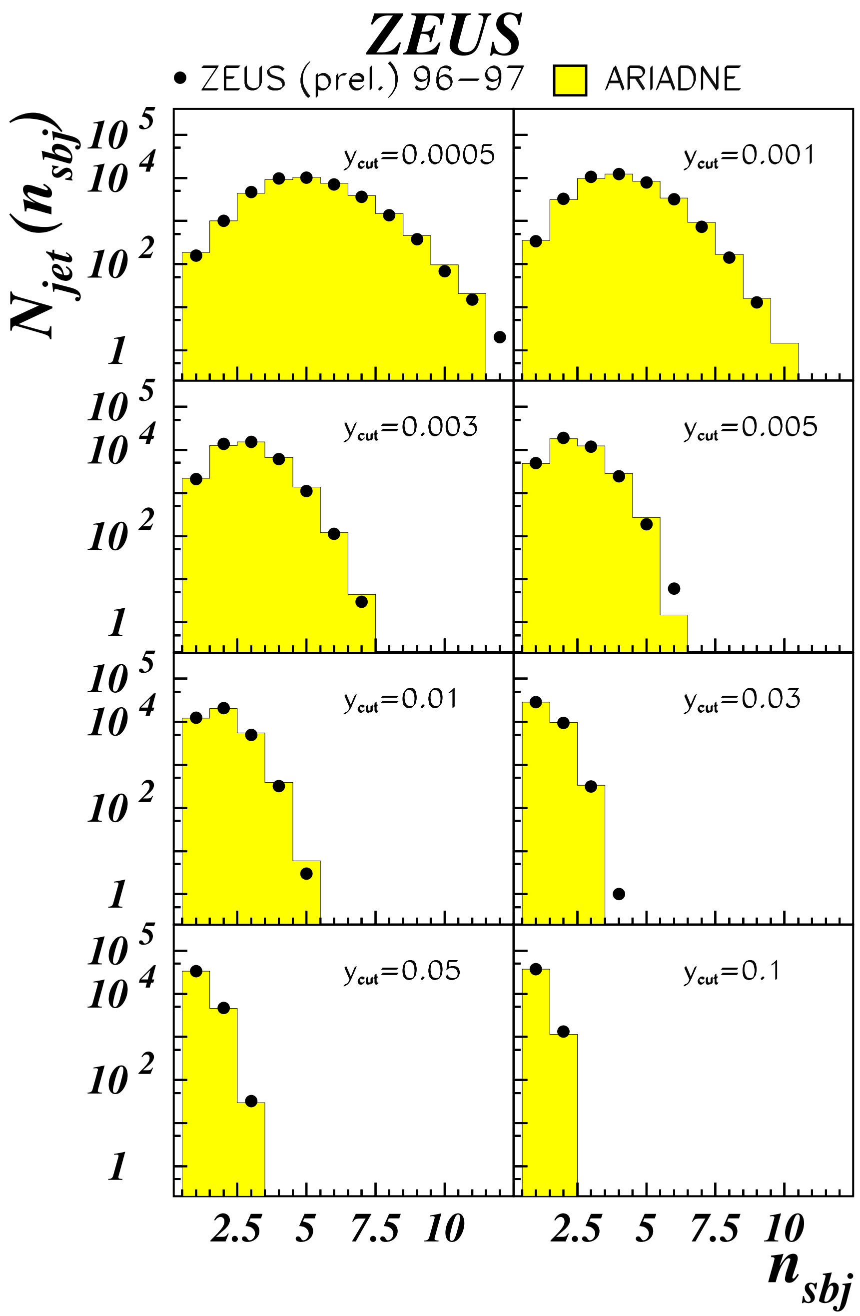


- Reasonable description by ARIADNE MC
- LEPTO-MEPS is clearly above DATA points

Subjet multiplicity distributions

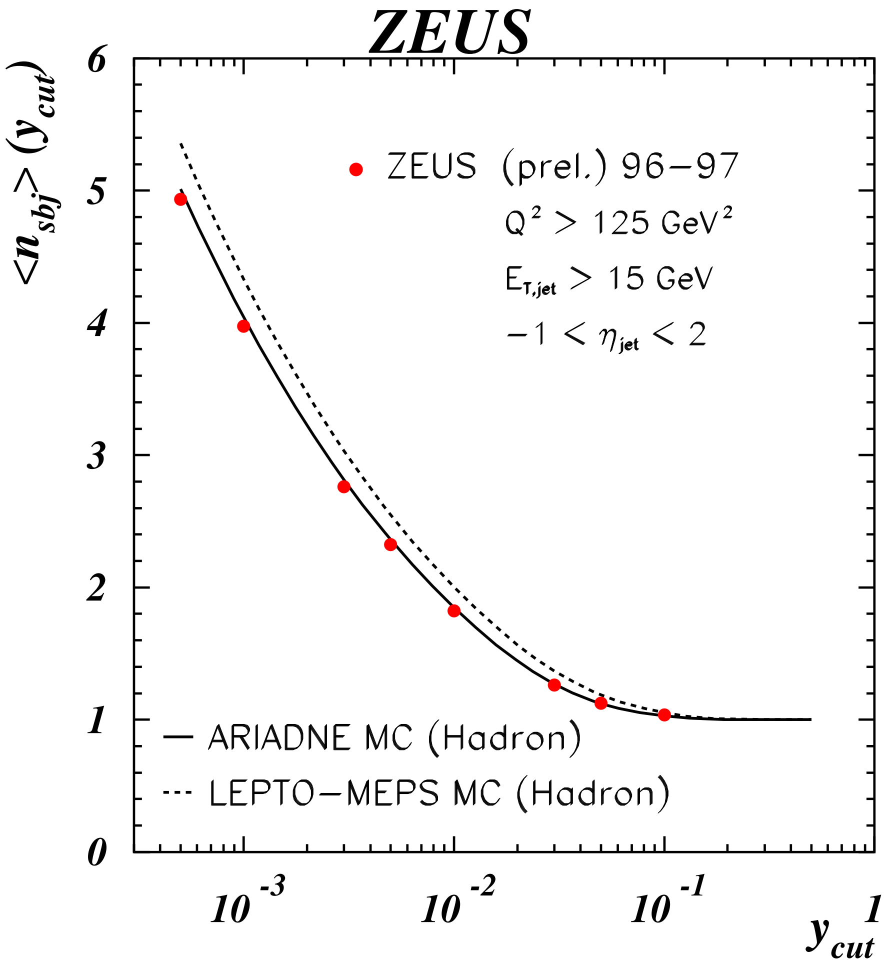
Distributions for $n_{sbj}(y_{cut})$ at detector level

MC predictions area normalized to the data



→ Good description by ARIADNE MC

Corrected mean subjet multiplicity as a function of y_{cut}



→ ARIADNE MC describes well the data

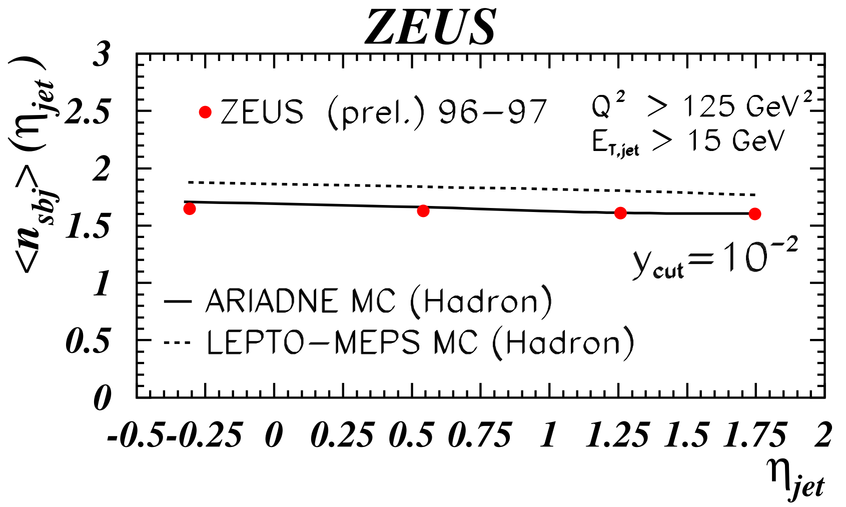
→ LEPTO-MEPS predicts more subjets than in the data.

The most important systematics:

→ Model dependence (LEPTO-MEPS vs ARIADNE): 2-3%

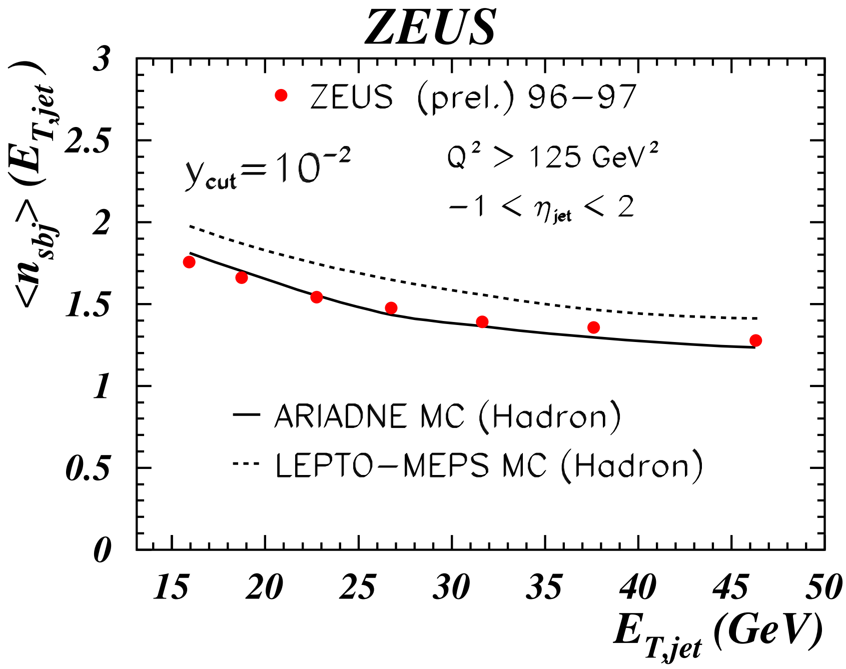
→ Jet energy scale ($\pm 3\%$): 1-2%

Fixing y_{cut} we have studied the dependence of $< n_{sbj} >$ wrt the jet variables



$\rightarrow$ $< n_{sbj} >$ has no η_{jet} dependence

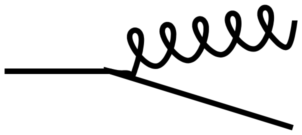
Consistent with quark-initiated jet dominance



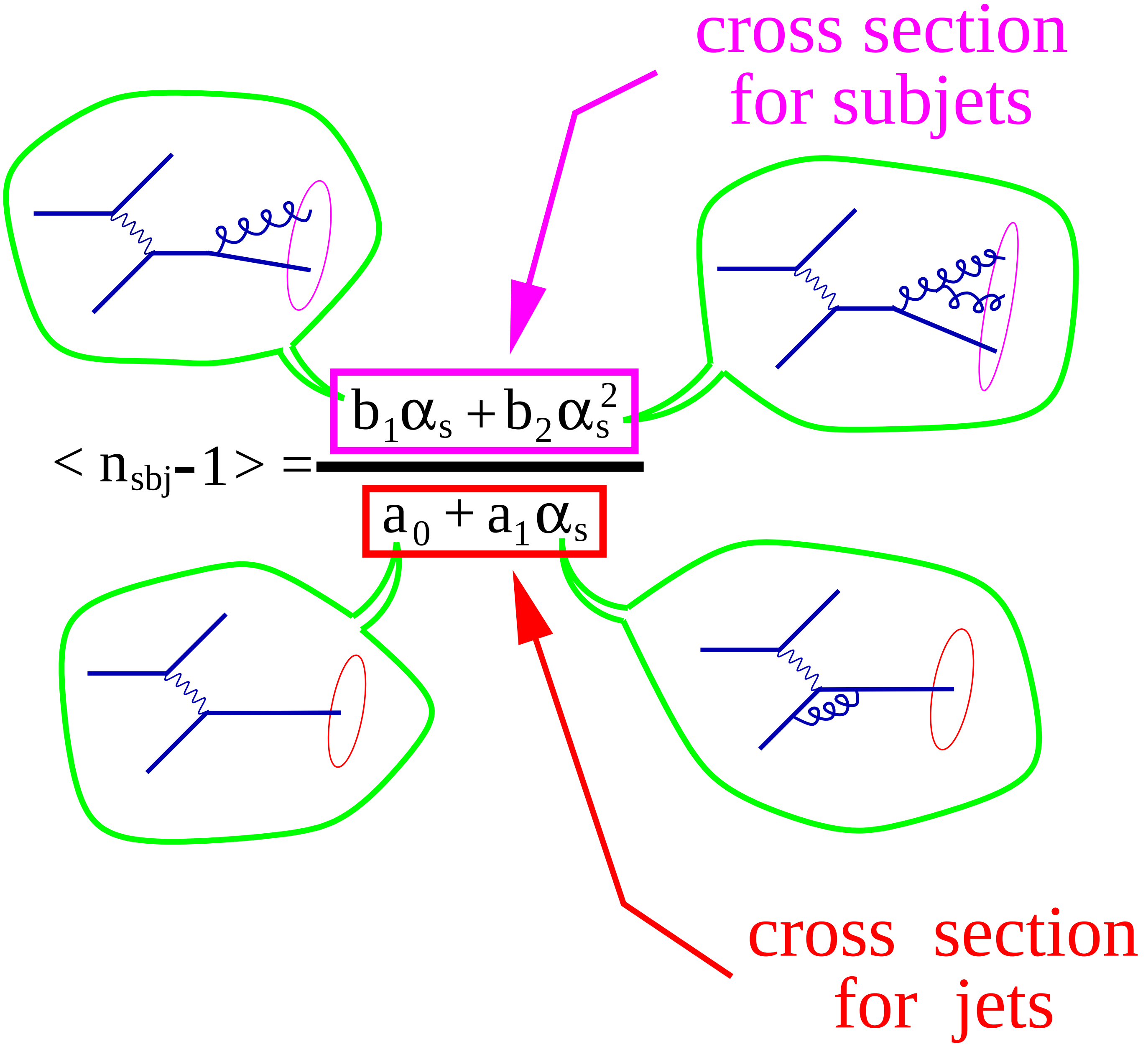
$\rightarrow$ $< n_{sbj} >$ decreases as $E_{T,jet}$ increases

$\rightarrow$ The jets become more collimated as $E_{T,jet}$ increases

NLO QCD calculations

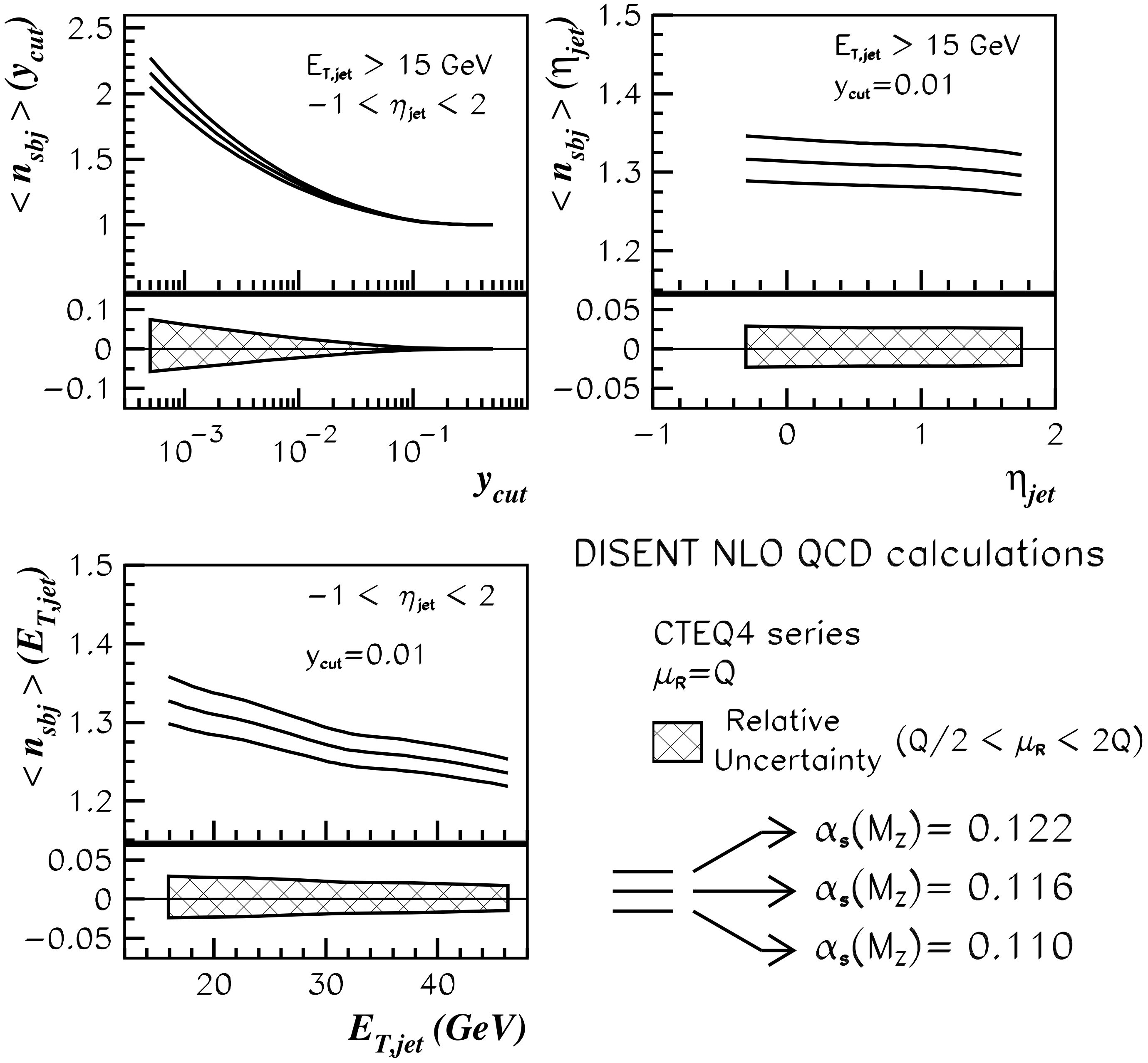
$< n_{sbj} - 1 > \Rightarrow$  $\Rightarrow$ proportional to α_s

To make a meaningful determination of α_s,
the next-to-lowest order calculations are needed:



$$< n_{sbj} - 1 > = \frac{\boxed{b_1 \alpha_s + b_2 \alpha_s^2}}{\boxed{a_0 + a_1 \alpha_s}}$$

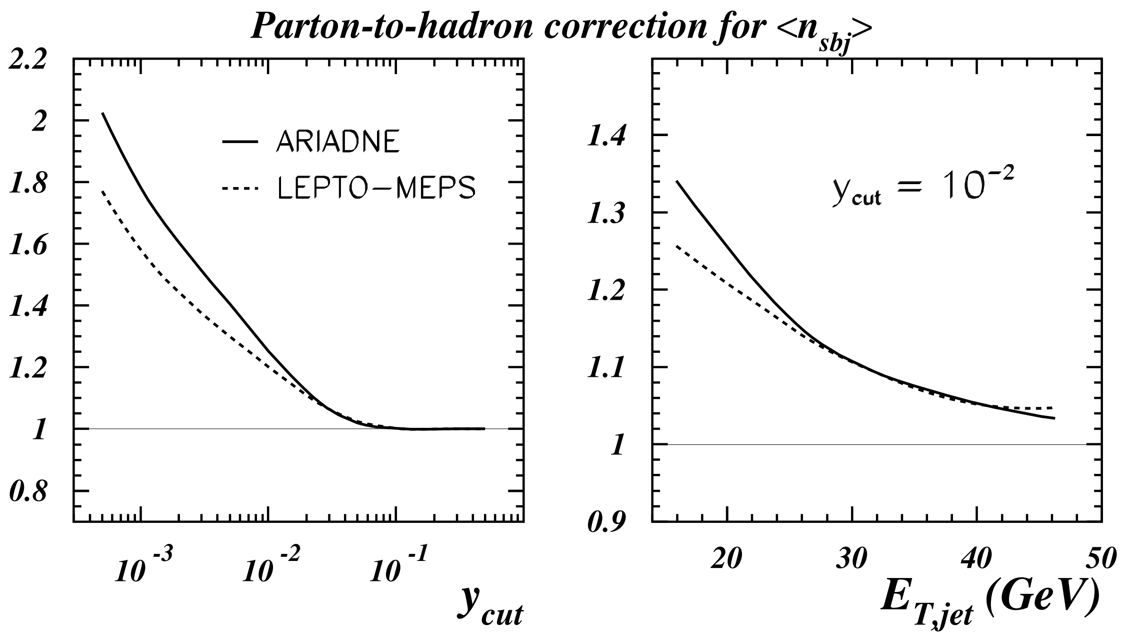
NLO QCD calculations



Clear α_s dependence of $< n_{sbj} >$ at NLO

Parton-to-hadron correction

The NLO QCD calculations have been corrected to the hadron level



→ Corrections calculated with ARIADNE MC and LEPTO-MEPS are compared.

→ The correction decreases as y_{cut} or $E_{T,jet}$ increase

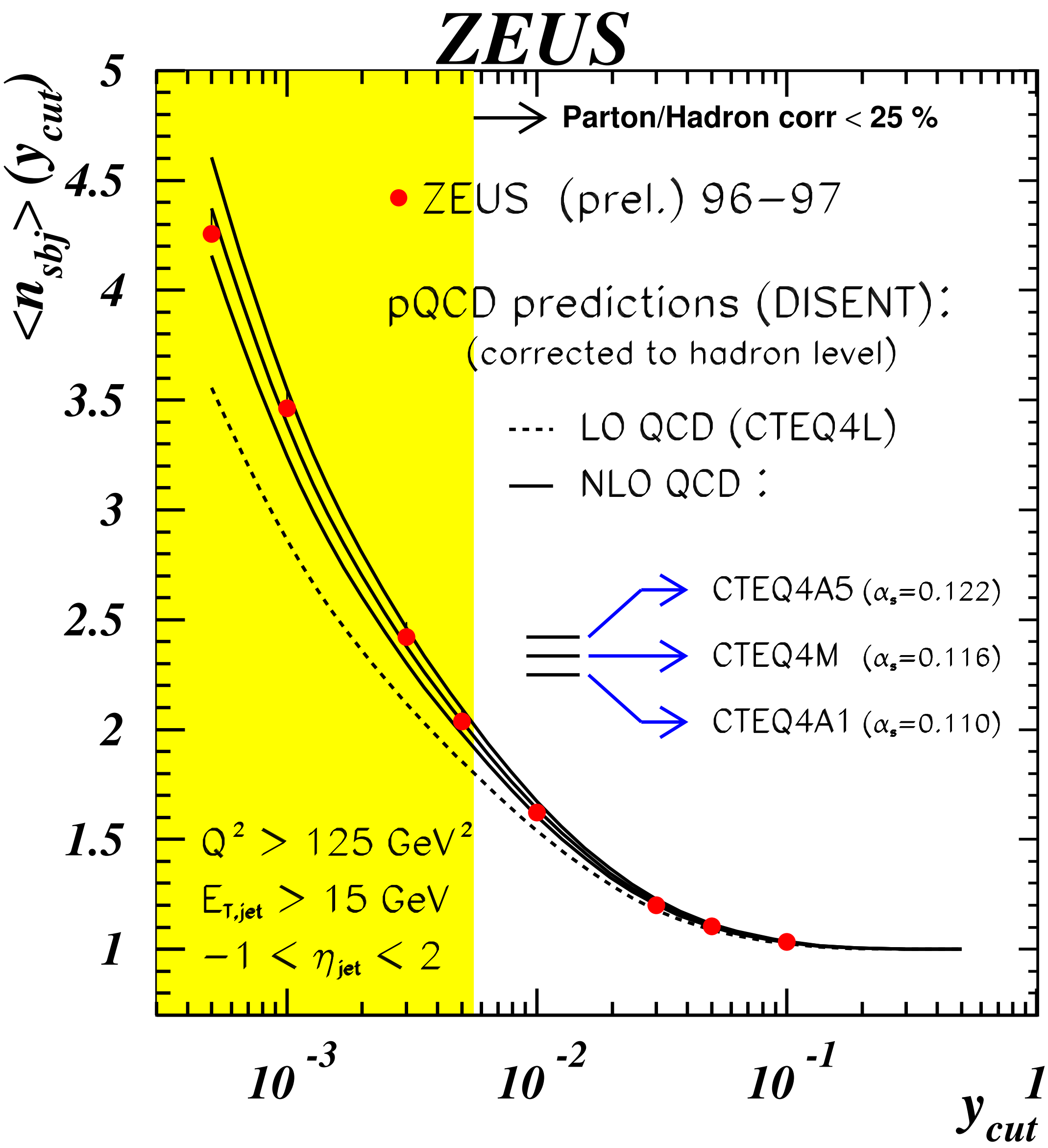
→ Uncertainty in hadronization correction is small for high y_{cut} and $E_{T,jet}$.

Theoretical uncertainties

- Variation of the renormalization scale: $Q/2 < \mu_R < 2Q$
- Using $\mu_R = E_{T,jet}$ of the leading jet $\Rightarrow$ Negligible
- Sensitivity to the gluon content of the proton $\Rightarrow$ Negligible
- Use of MRST98 to cross-check the result $\Rightarrow$ Similar results

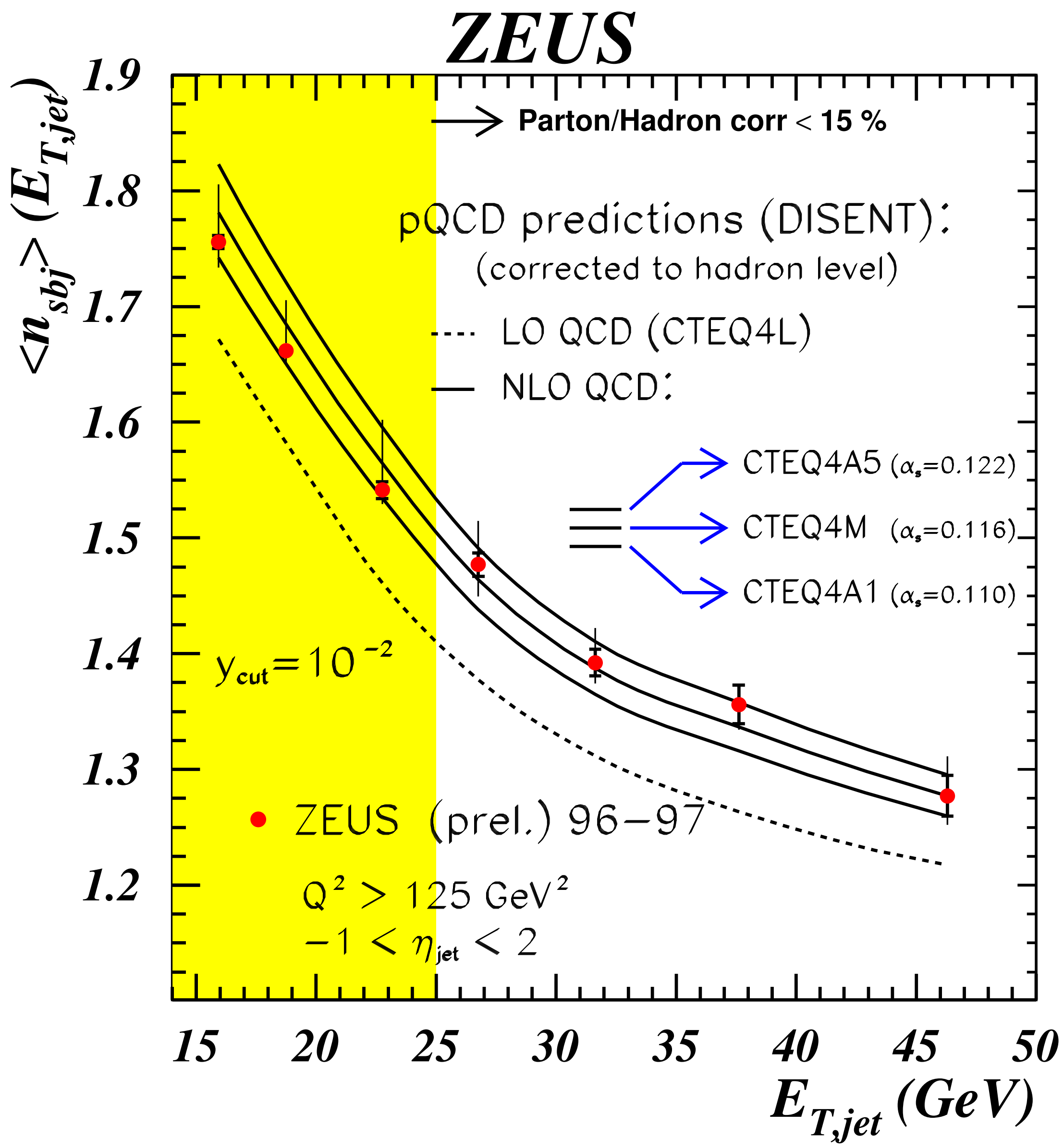
Comparison of the DATA with NLO QCD predictions

→ Comparison at hadron level



- NLO QCD describes the data.

Comparison of the DATA with NLO QCD predictions (2)

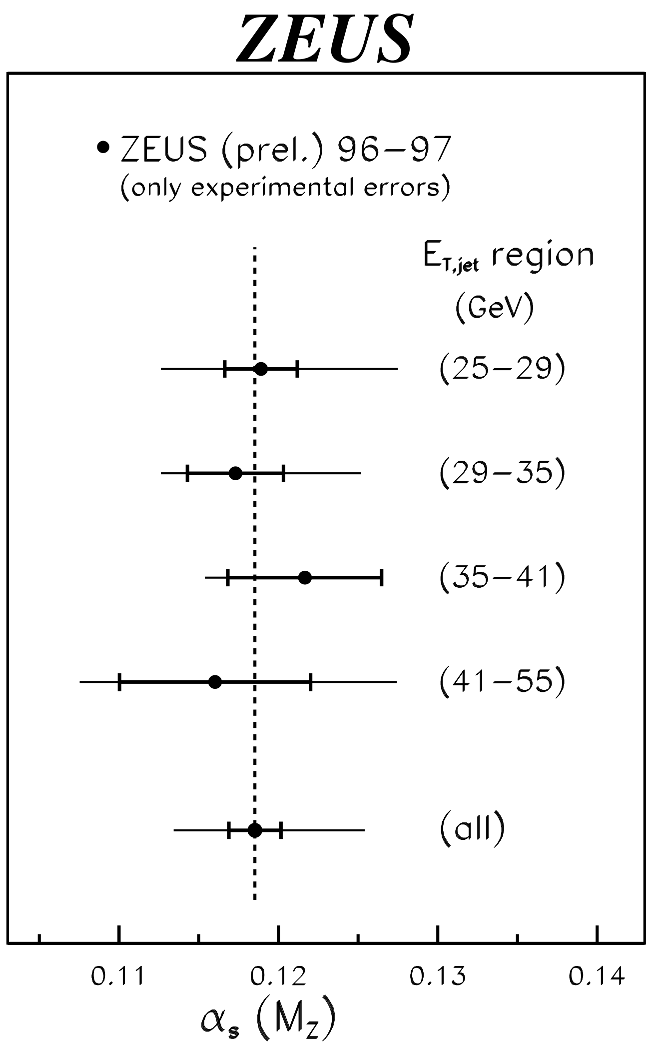


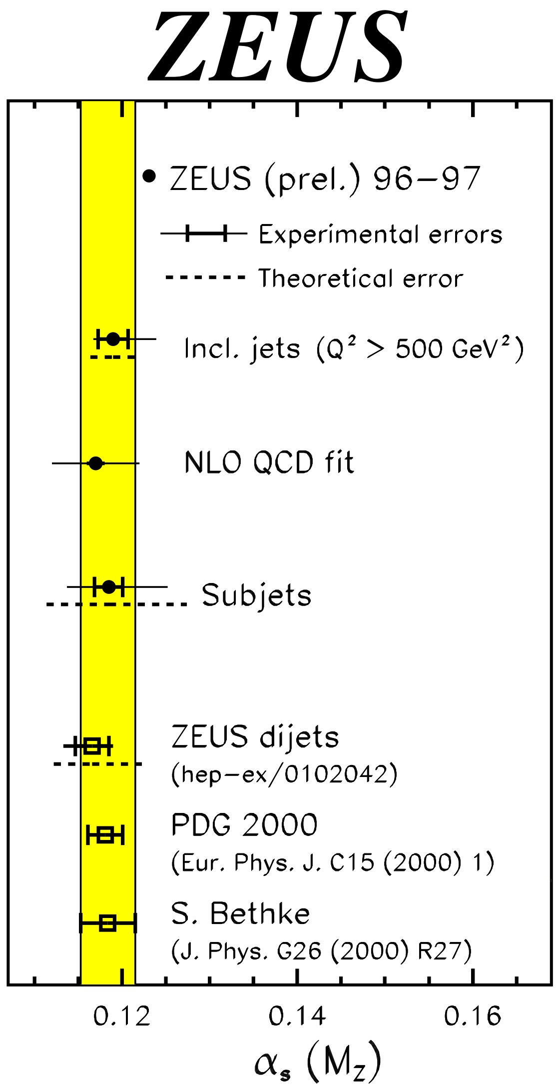
- The measurements are sensitive to α_s

We extract α_s using the data with $E_{T,jet} > 25$ GeV

determination of α_S

A value is extracted in each $E_{T,jet}$ region (only where parton-to-hadron corrections are smaller than 15%)





And the combined value is:

$$\boxed{\alpha_s(M_Z) = 0.1185 \pm 0.0016\ (\text{stat.})^{+0.0067}_{-0.0048}\ (\text{syst.})^{+0.0089}_{-0.0071}\ (\text{th.})}$$

in good agreement with the world average value.

Summary

- Measurements of the mean subjet multiplicity in an inclusive sample of jets produced in NC DIS ($Q^2 > 125$ GeV^2) have been presented.

- It is observed that the mean subjet multiplicity in NC DIS has no dependence on the jet pseudorapidity,

- and it decreases as the transverse energy of the jet increases.

- NLO QCD calculations corrected to hadron level describe very well the data.

- α_s has been extracted using the subjet multiplicity in NC DIS for the first time:

$$\alpha_s(M_Z) = 0.1185 \pm 0.0016\ (\text{stat.})^{+0.0067}_{-0.0048}\ (\text{syst.})^{+0.0089}_{-0.0071}\ (\text{th.})$$