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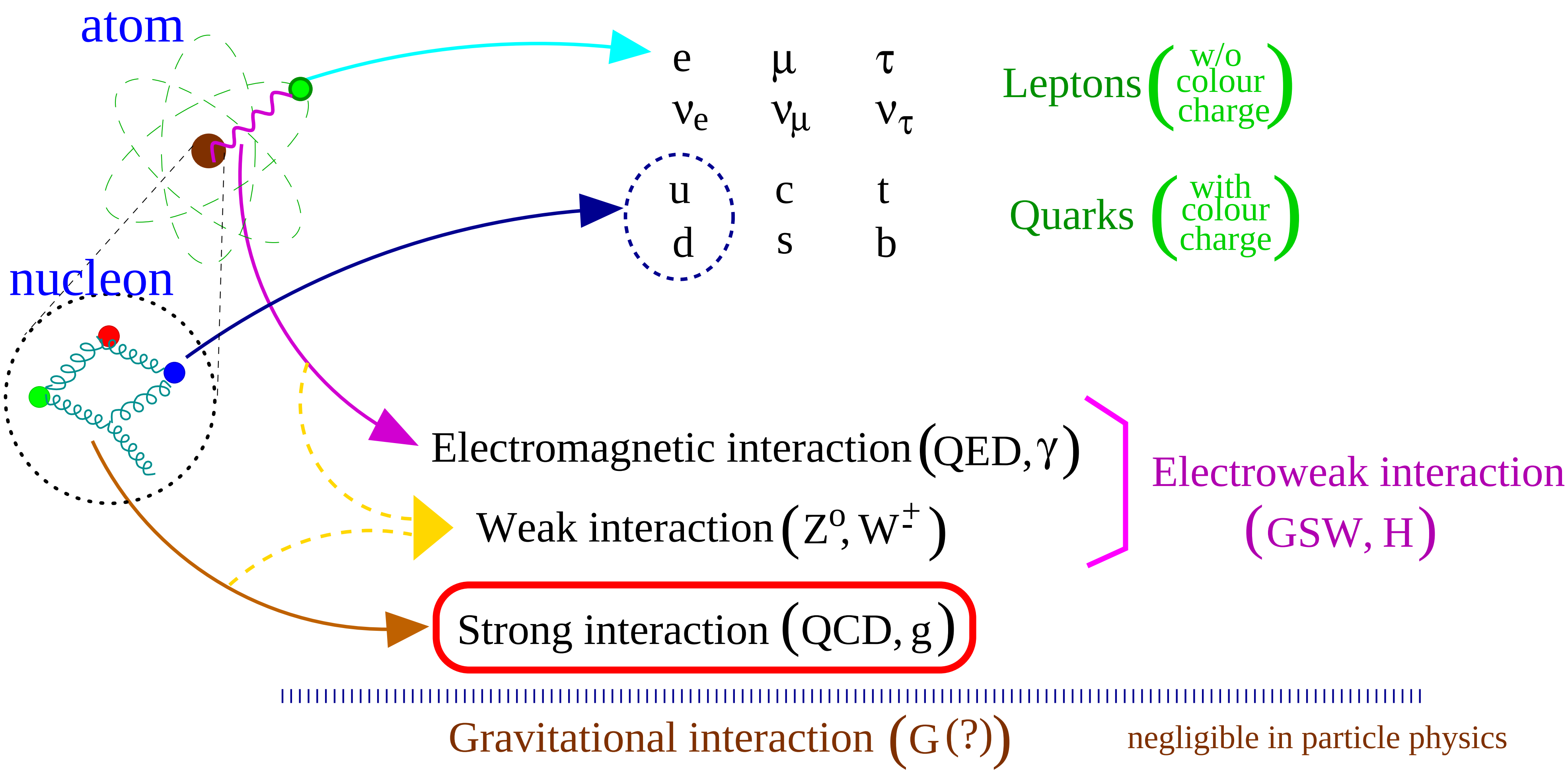
Tests of QCD and precise determinations of α_s at HERA

- Introduction and motivations
- QCD and jet physics in DIS
- Experimental setup
- Description of the analyses
- Results and determination of α_s

Particles and interactions in Nature

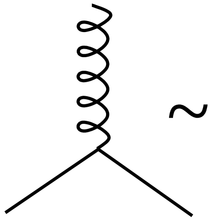
- The Standard Model of fundamental interactions is, at present, the most succesful theory to describe the experimental results in terms of the most fundamental constituents of the Universe.



QCD ⇔ Strong Interaction

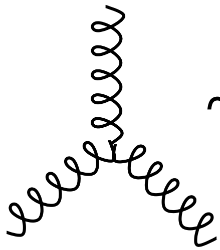
→ QCD describes the interaction between quarks and gluons
through a "colour" charge whose intensity is given by α_s.

In the same way as QED:

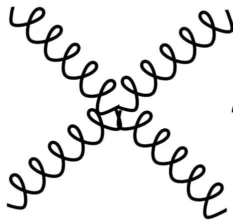


$\sim \frac{4}{3}\alpha_s$

But gluons carry COLOUR CHARGE:



$\sim 3\alpha_s$



$\sim \alpha_s^2$

This makes differences wrt QED

→ α_s decreases with increasing energy scale ←

and this dependence is used to "explain" the behaviour of the strong interaction:

- at high energies
  - → asymptotic freedom ($\alpha_s \to 0$)
  - → Perturbative approach applicable
  - → Hard processes
- at low energies
  - → confinement ($\alpha_s > 1$)
  - → Perturbative approach no longer correct
  - → Partons confined inside hadrons

Motivations to measure α_s

α_s has to be determined from experiment

Once the value of α_s is known, it is possible to make predictions with (perturbative) QCD and compare with other experimental measurements

and also to estimate the SM predictions for other processes which involve any QCD contribution

Theoretical predictions in QCD

even for studies not directly related to QCD: Higgs searches, Grand unification

The uncertainties in QCD calculations are relatively large. Thus, individual determinations of α_s are not as accurate as desired. To compensate this it becomes interesting to make independent determinations

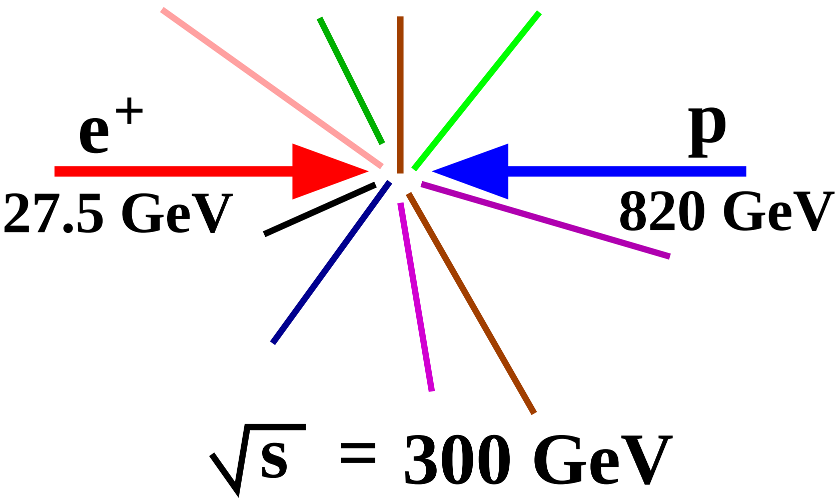
... as many as possible.

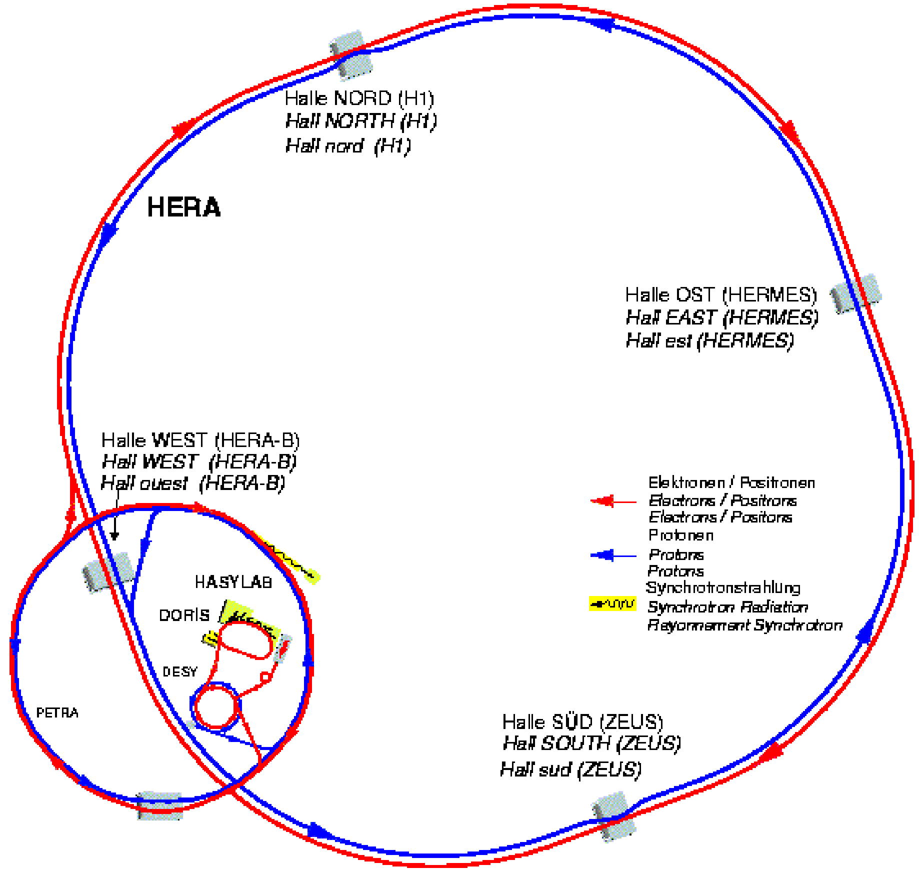
... and as precise as possible.

The HERA collider

Ring accelerator in DESY (Hamburg)

→ $e^{\pm}$ (27.5 GeV) and p (820/920 GeV)



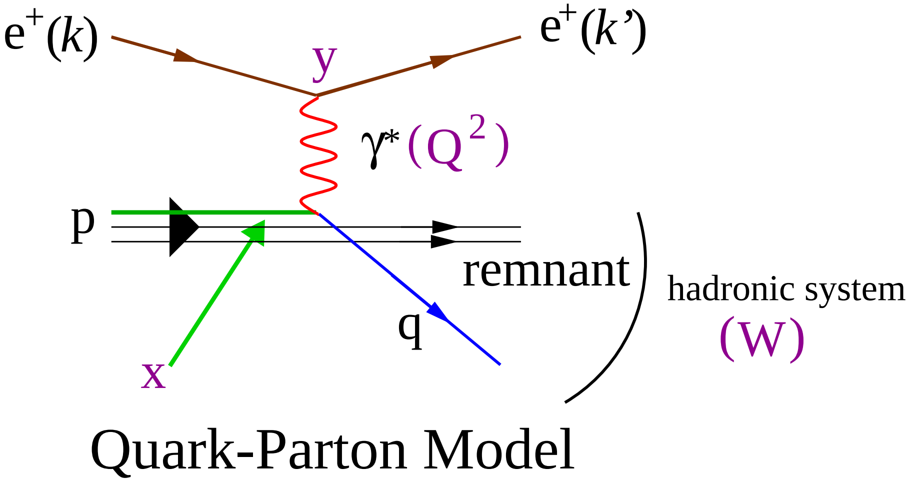


There are 4 interaction points where the experiments are located

- H1 and ZEUS: ep interactions
- HERMES: Polarised e's are scattered on a fixed target (Nucleon spin studies)
- HERA-B: p's are scattered on a fixed target (study of B mesons)

ep interactions and kinematic variables

In the Standard Model the most important contribution to the inelastic interactions between protons and positrons is given by the diagram



and the variables commonly used to describe the process are

$$\mathbf{q} \equiv k - k' \Longrightarrow Q^2 = -q^2$$

$$\mathbf{s} = (p+k)^2$$ (center-of-mass energy²)

$$\left.\begin{array}{l} y \equiv \dfrac{p \cdot q}{p \cdot k} \\ x \equiv \dfrac{Q^2}{2p \cdot q} \end{array}\right\} \Longrightarrow Q^2 = sxy$$

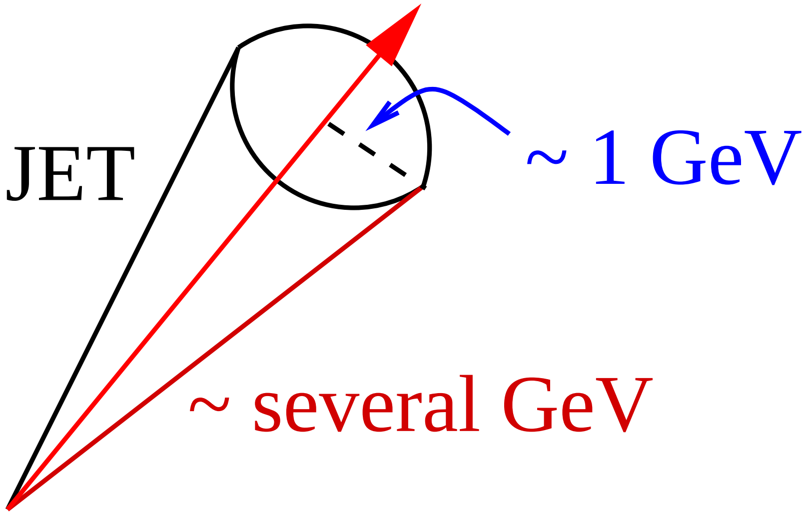
In the deep inelastic scattering regime, the exchanged boson is virtual, i.e.

$$Q^2 >> 1 \text{ GeV}^2$$

Jet production

For high energy partons, the observed final-state hadrons are very collimated since the hadronisation process involves low-energy transfers.

collimated set of hadrons ⇔ jets



Thus:

- We can define jets
- and identify jets $\sim$ partons

Jets provide a "natural" way to study parton dynamics

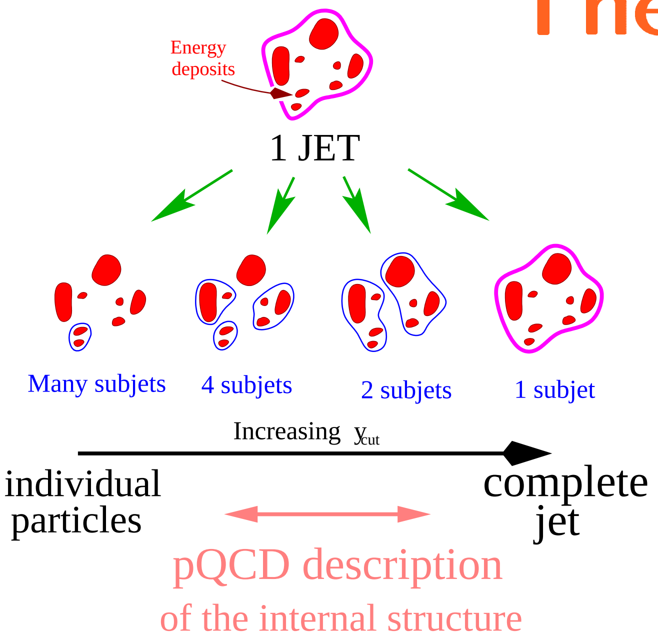
For quantitative studies $\rightarrow$ formal definition: jet algorithm

The internal structure of jets

Jet ⇒ set of hadrons ⇒ internal structure

The internal structure of jets informs on the transition from partons to hadrons

The subjet multiplicity



Subjets are jet-like objects within a jet

When hadronisation effects are small enough, the following relations are qualitatively established:

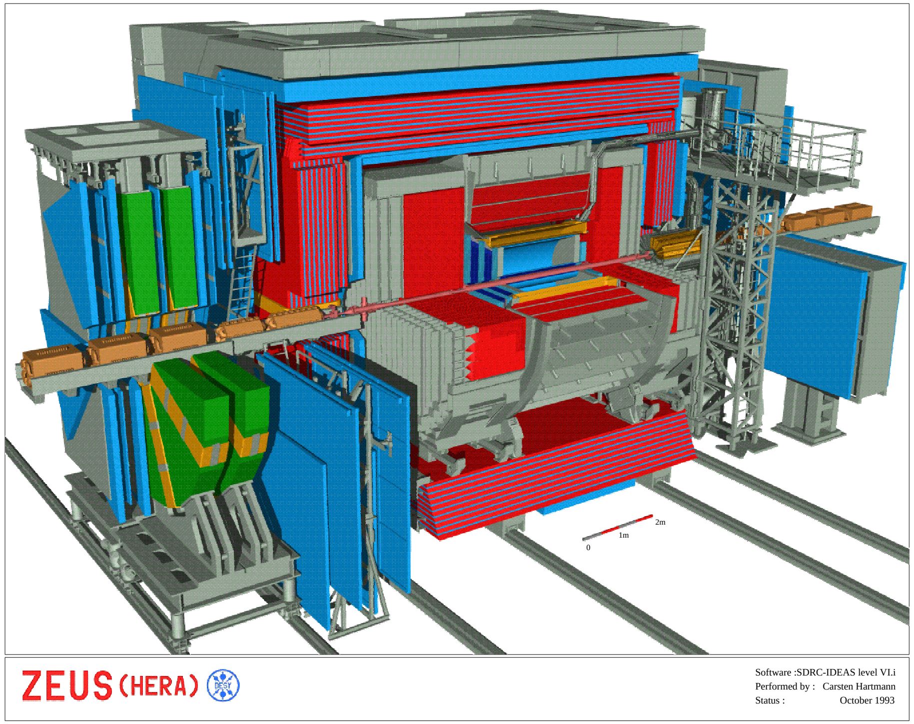
Jets → partons in the hard process

Subjets → partons in the jet

Tests of QCD and phenomenological models

The ZEUS detector at HERA

ZEUS is a multipurpose detector designed to study the high energy interactions between electrons (positrons) and protons.



The most important components of the detector for the analyses are

The Central Tracking Detector (CTD)

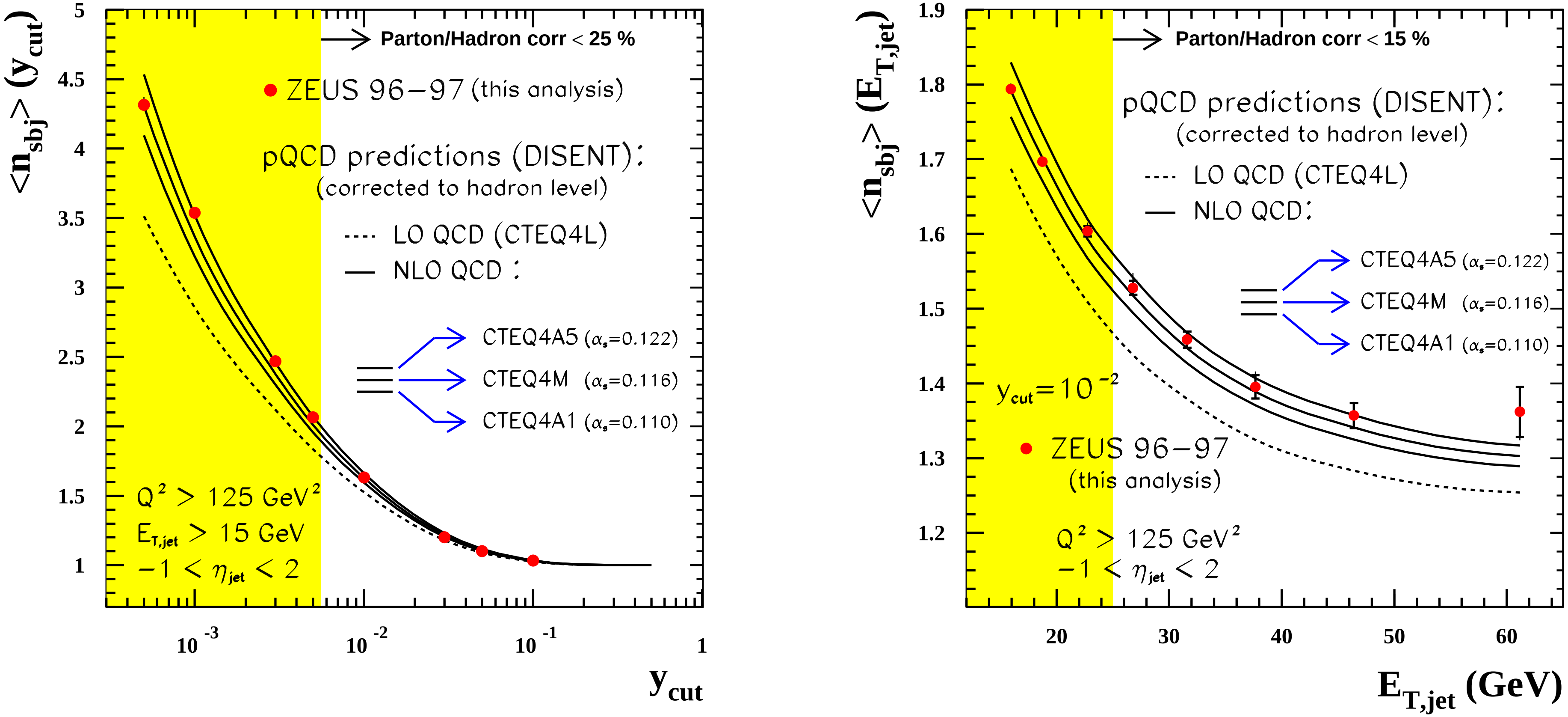
- Trajectories of charged particles
- Vertex of the interaction

The Uranium Calorimeter (UCAL)

- Energies of the particles (kinematics)
- Particle identification (scattered e)

Mean subjet multiplicity in NC DIS

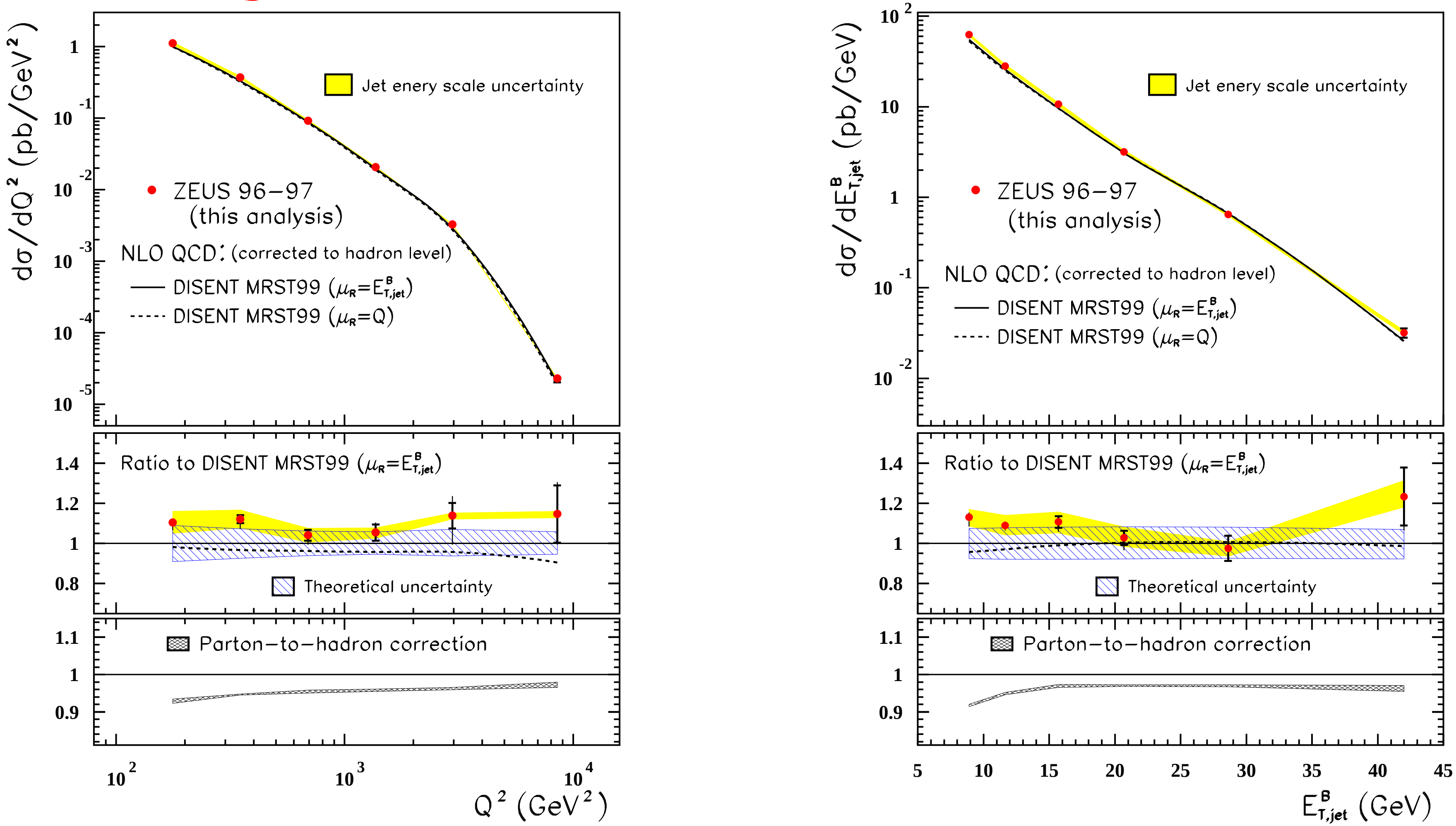
The theoretical calculations are compared to the measured values in the data



- Good description of the data by NLO QCD calculations
- LO QCD is not enough to describe the measured multiplicities

Next step: Determination of α_s

Inclusive jet cross sections in the Breit frame

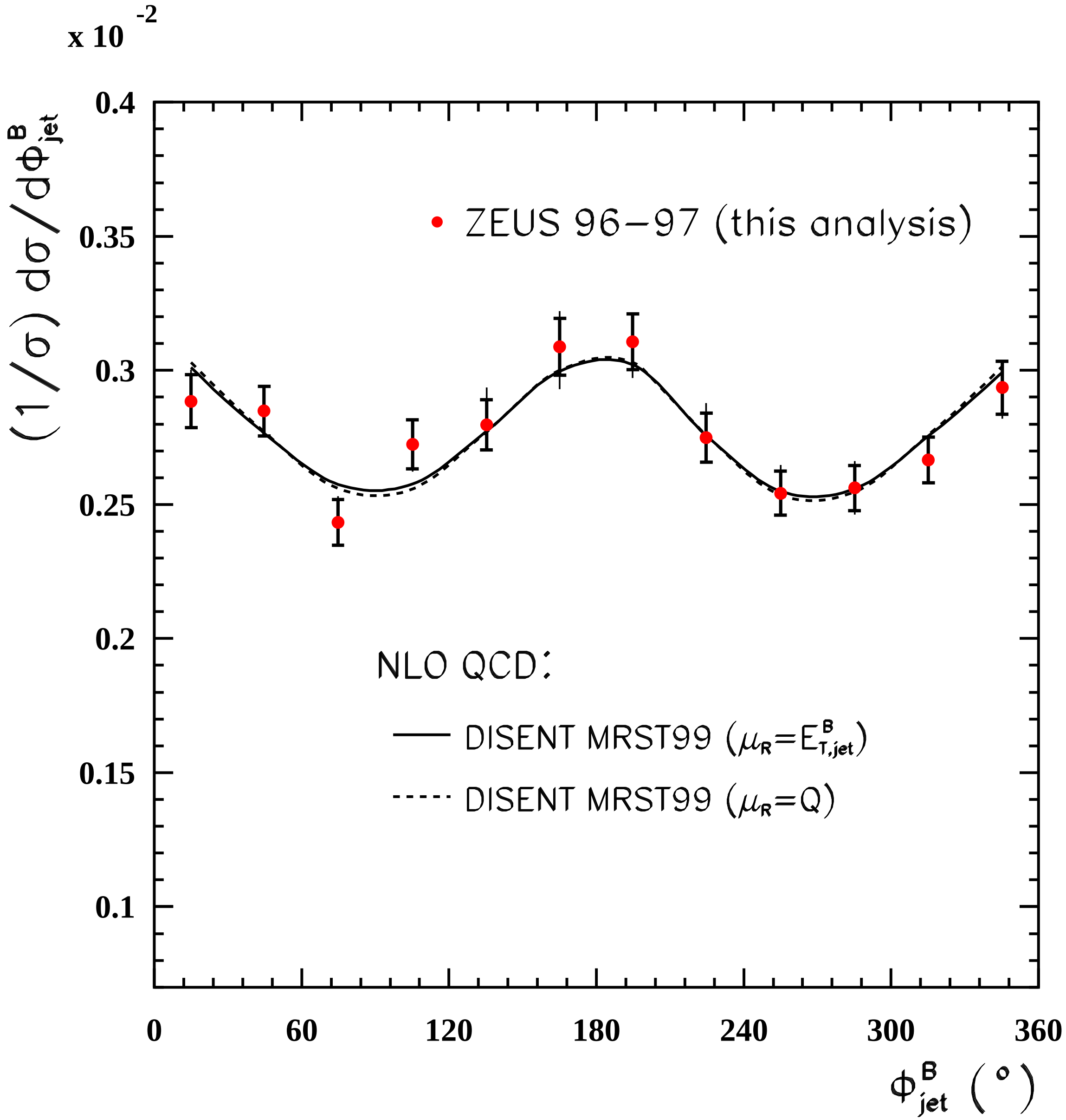


- Reasonable description of the data by NLO QCD calculations.
- Discrepancy of 10-15% comparable to the theoretical uncertainty.

Determination of α_s

The azimuthal asymmetry

An asymmetry is clearly observed and in good agreement with the NLO QCD prediction.



FOR THE FIRST TIME USING JETS

Extraction of α_s

- Both analyses were used to extract the strong coupling constant

⇒ Good agreement with world average.

⇒ The uncertainties are comparable to those of the best determinations of α_s.

⇒ Very precise determination of α_s from the measures inclusive jet cross section at high-Q^2:

$$\alpha_s(M_Z) = 0.1212 \pm 0.0017\ (\text{stat.})^{+0.0023}_{-0.0031}\ (\text{syst.})^{+0.0028}_{-0.0027}\ (\text{th.})$$

⇒ Determination of α_s from the measurements of the internal structure of jets in NC DIS (for the first time):

$$\alpha_s(M_Z) = 0.1187 \pm 0.0017\ (\text{stat.})^{+0.0024}_{-0.0009}\ (\text{syst.})^{+0.0093}_{-0.0076}\ (\text{th.})$$