Event Shapes, Jet Substructure and α_s Measurements at HERA

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On Behalf of the H1 and ZEUS Collaborations

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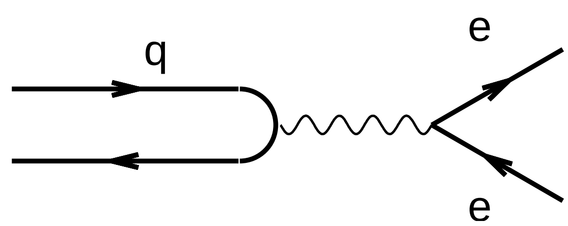
HERA Kinematic Variables

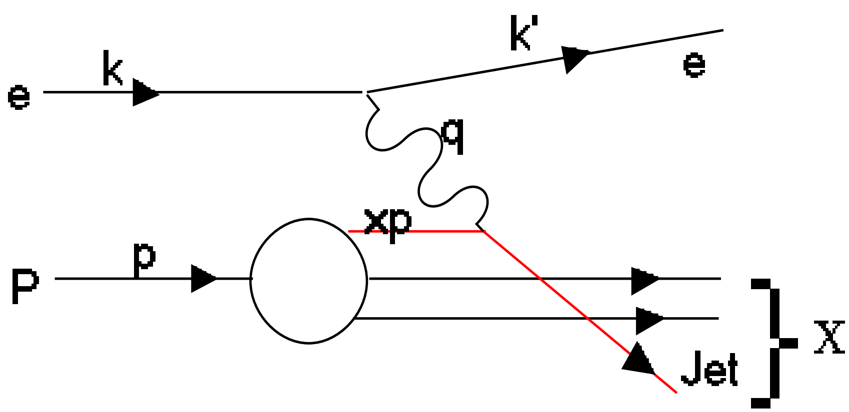
- 920 GeV p^+

  (820 GeV before 1999)
- 27.5 GeV e^- or e^+
- 318 (300) GeV cms

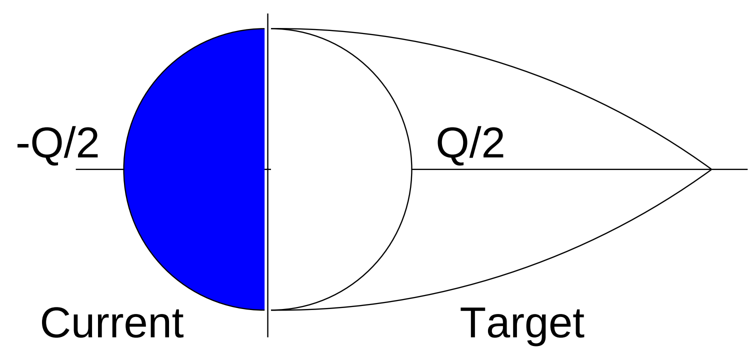
Breit Frame Definition:

$$q + 2x_B P = 0$$





Q^2, x_{Bj}, y



Similar to hemisphere in e^+e^-

Particle and Energy Flow

Combination of the hard and soft scales

Axis Dependent:

Thrust

$$T = \frac{\sum_i |\vec{p}_i \cdot \hat{n}|}{\sum_i |\vec{p}_i|}$$

T_T, B_T

T_γ, B_γ

Broadening

$$B = \frac{\sum_i |\vec{p}_i \times \hat{n}|}{\sum_i |\vec{p}_i|}$$

Axis Independent:

C Parameter

$$C = \frac{3\sum_{ij} |\vec{p}_i||\vec{p}_j| \sin^2(\theta_{ij})}{2\left(\sum_i |\vec{p}_i|\right)^2}$$

C, M^2

Jet Mass

$$M^2 = \frac{\left(\sum_i p_i^\mu\right)^2}{\left(2\sum_i E_i\right)^2}$$

Sums are over all momenta in the current hemisphere of the Breit frame

Approach to Non-perturbative Calculations

pQCD prediction → measured distribution

- **Correction factors for non-perturbative (soft) QCD effects**

Proposed theory*: Use power corrections to correct for non-perturbative effects in infrared and collinear safe event shape variable, F:

Used to determine the hadronization corrections

$$\langle F \rangle = \langle F \rangle_{perturbative} + \langle F \rangle_{power\ correction}$$

$$\langle F \rangle_{pow} = a_V \frac{3MA_1(\alpha_s, \overline{\alpha}_0)}{\pi Q}$$

Valid for event shape means and differential distributions

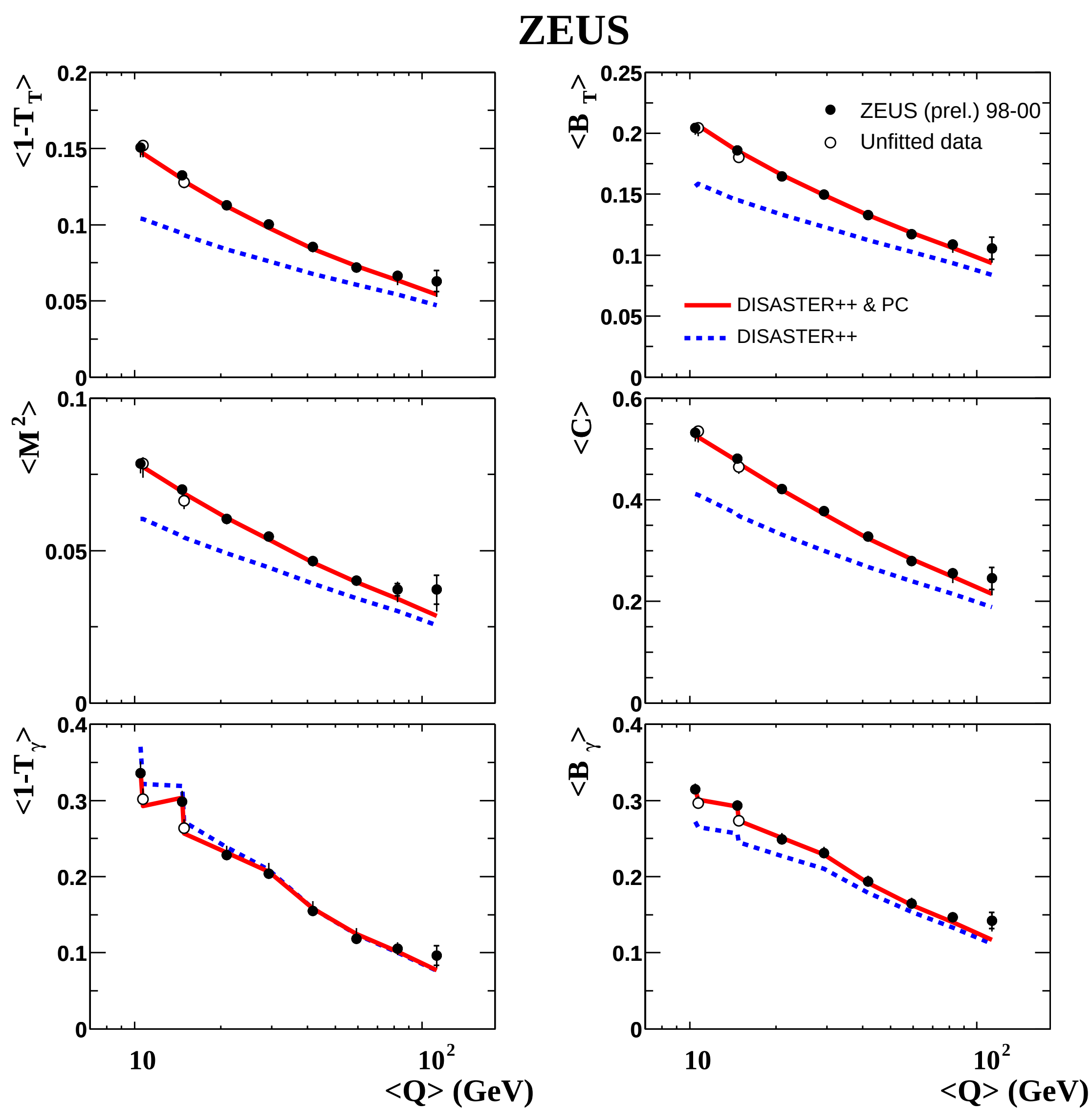
Power correction

- **Independent of any fragmentation assumptions**

$\overline{\alpha}_0 =$ **Univeral "non-perturbative parameter"**

*** – (Dokshitzer, Webber, phys. Lett. B 352(1995)451)**

Shape Means



2-parameter fit

- **Simultaneous fit for α_s and α_0**
- **Each shape fit separately**

Fits use Hessian method for statistical and systematic errors

All variables: good χ^2

NLO calculation: DISASTER++

ZEUS 98-00 (82.2 pb^{-1})

$80 < Q^2 < 2 \cdot 10^4$ GeV^2

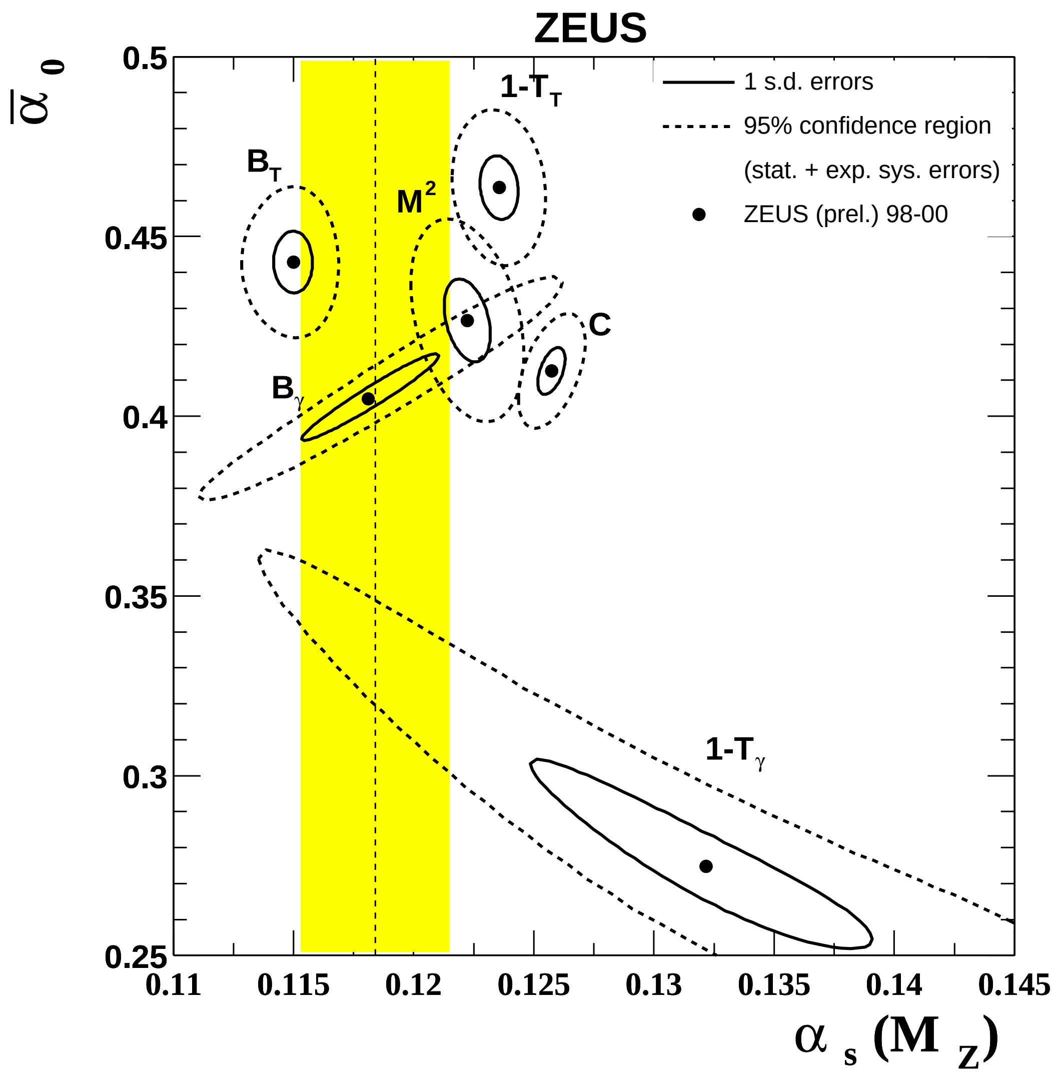
$2 \cdot 10^{-3} < x < 0.6$

Mean Parameters

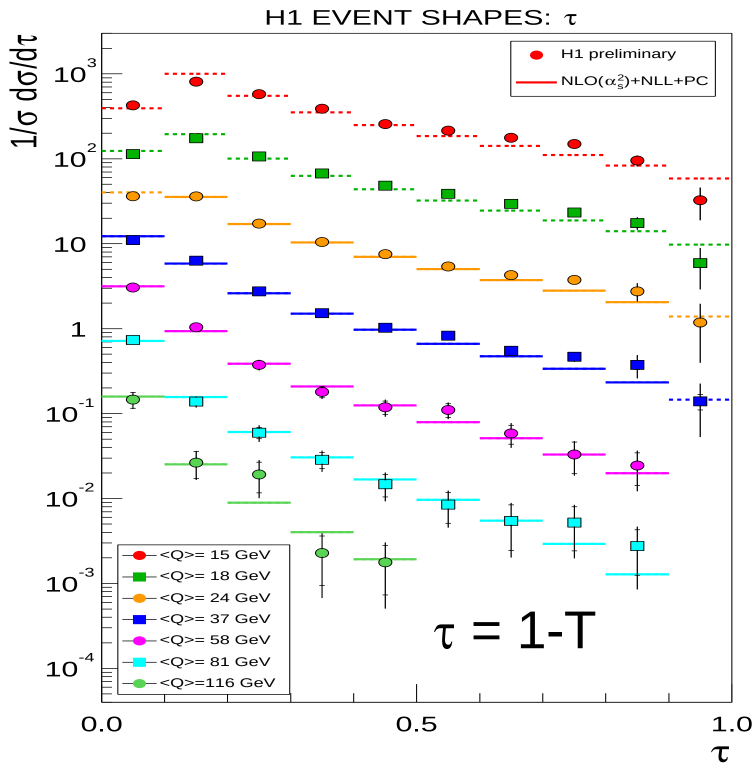
Extracted parameters for each shape

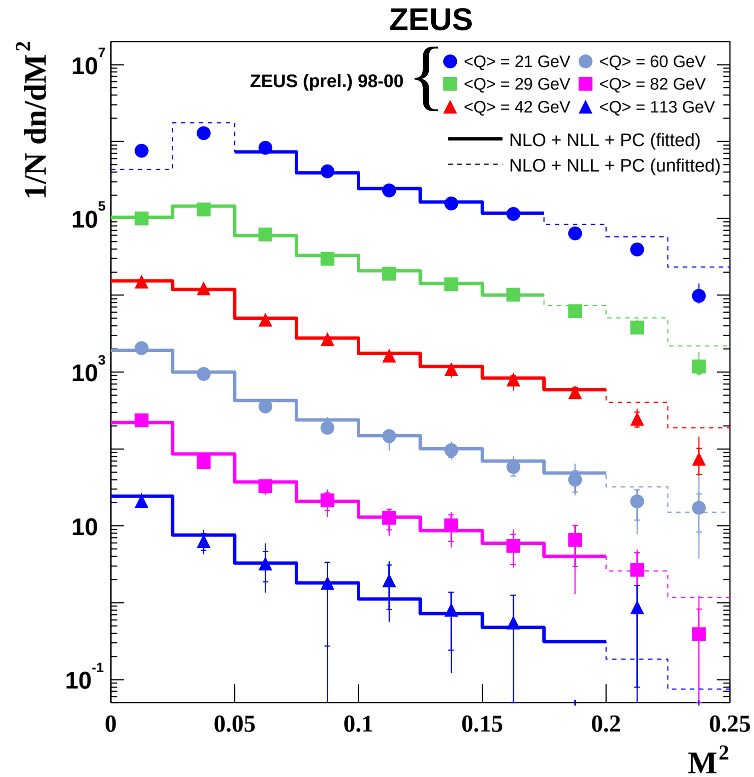
- **Fitted α_s values consistent to within 5%**
- **Fitted $\alpha_0 \approx 0.45$ to within 10%**

Theory errors dominate, except for γ axis shapes



Shape Distributions





H1 (112 pb^{-1})

14 < Q < 200 GeV

0.1 < y < 0.7

Fit differential distributions over a limited range.

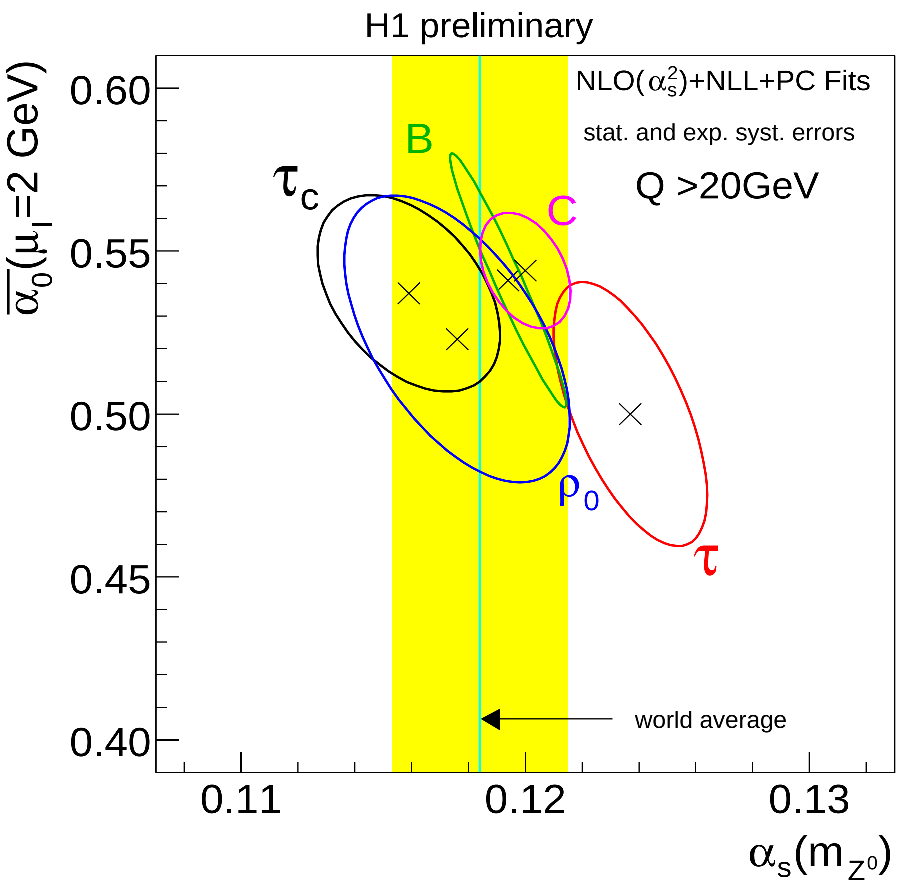
- **Bins for which theoretical calculations are expected to be questionable are omitted from fit.**
- **Resummation is applied with DISRESUM.**

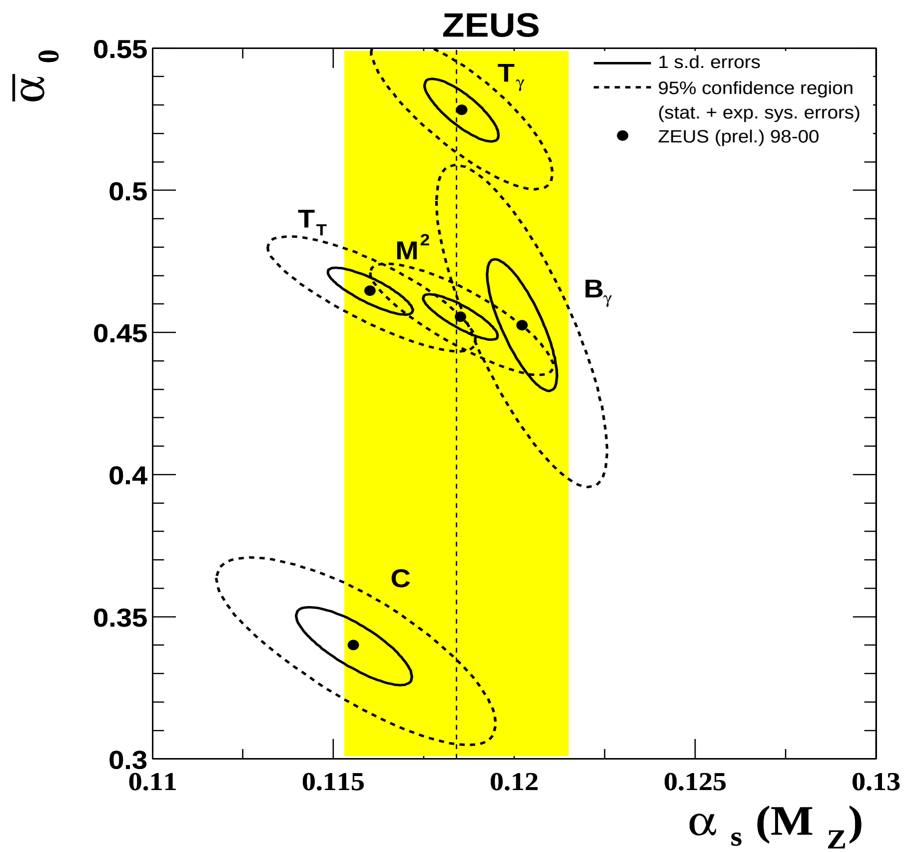
ZEUS 98-00 (82.2 pb^{-1})

9 < Q < 141 GeV

2*10^{-3} < x < 0.6

Distribution Parameters





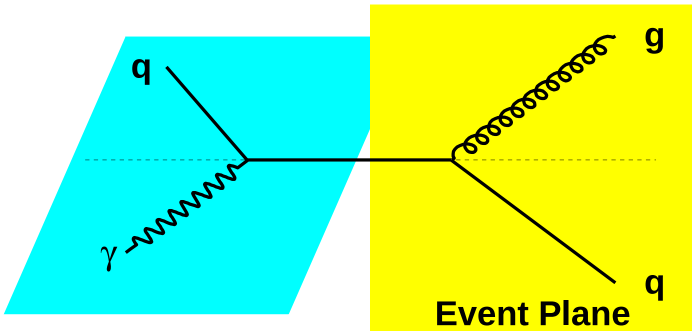
Fits use Hessian method for statistical and systematic errors.

All variables with a good χ^2.

Fits are sensitive to matching method.

α_S agrees with world average $\alpha_0 \approx 0.5$.

Event Shapes With Jets



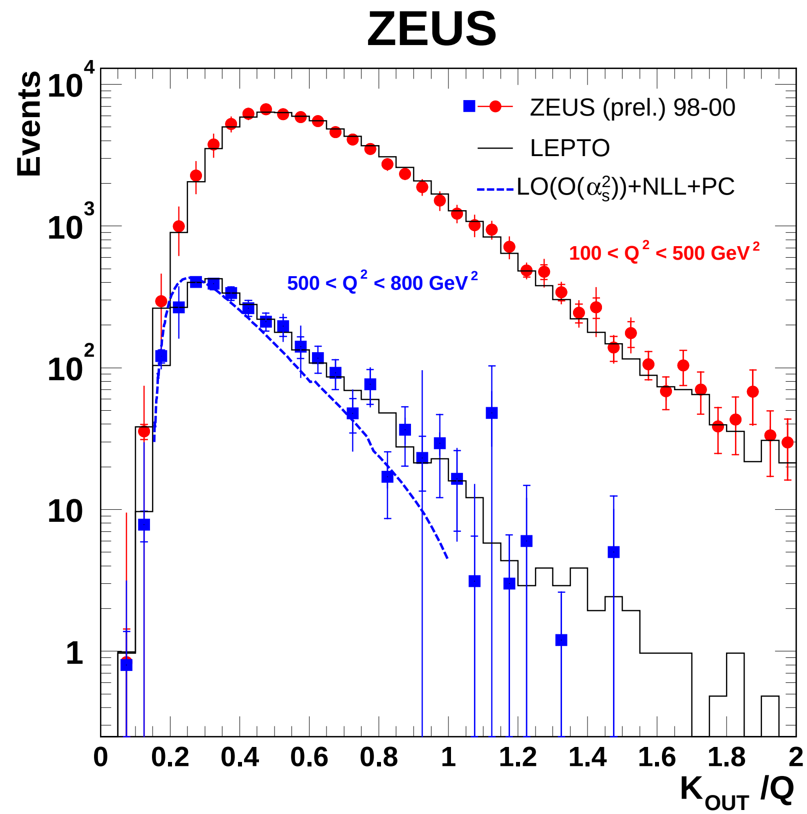
Momentum out of plane

$$K_{out} = \sum_i \left| \vec{p}_i \right|$$

Energy flow out of event plane:

- **Sensitive to perturbative & non-perturbative contributions**
- **Dijet event:**
  - Perturbative physics: in plane
  - Non-perturbative physics: out-of-plane momentum

Measured by H1 and ZEUS



First comparison with LO+NLL+PC shown

- $\alpha_s(M_Z) = 0.118$
- $\alpha_0 = 0.52$

ZEUS 98-00 (82.2 pb^{-1})

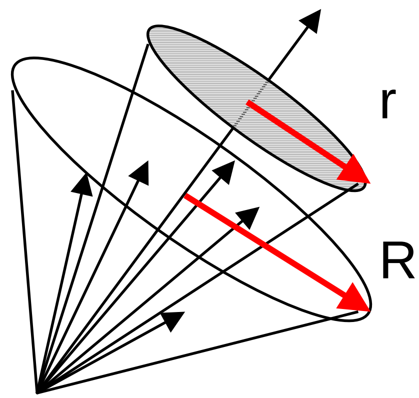
$100 < Q^2$

Jet Substructure

Jet substructure depends mainly on type of primary parton and to lesser extent on the particular hard scattering process

Gluon initiated jets are broader than quark initiated jets

Jet Shape $\psi(r)$: fraction of the jet E_T inside a cone in the η-φ plane of radius r

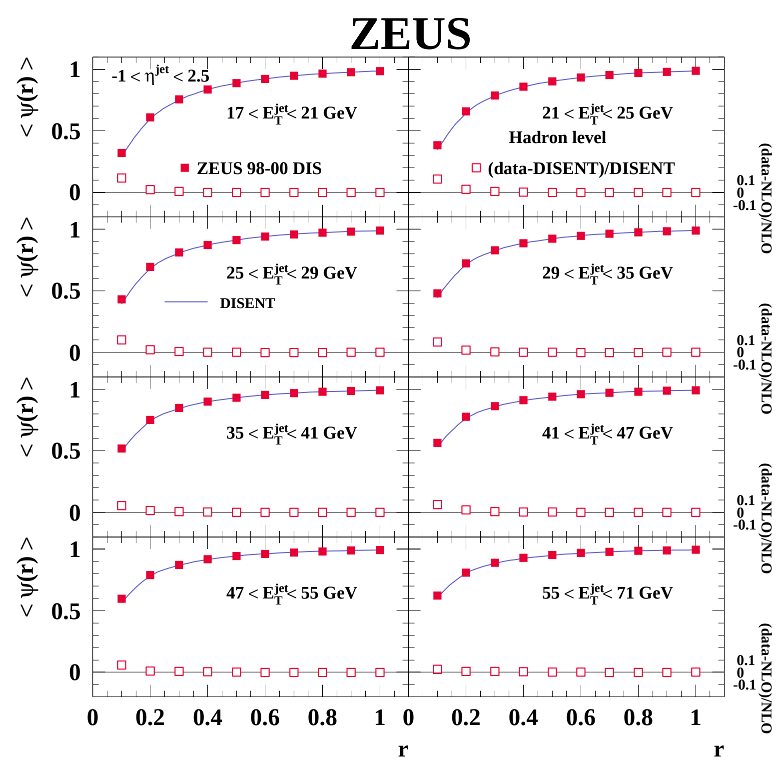


ZEUS 98-00 (82.2 pb^{-1})

Jets found in LAB frame

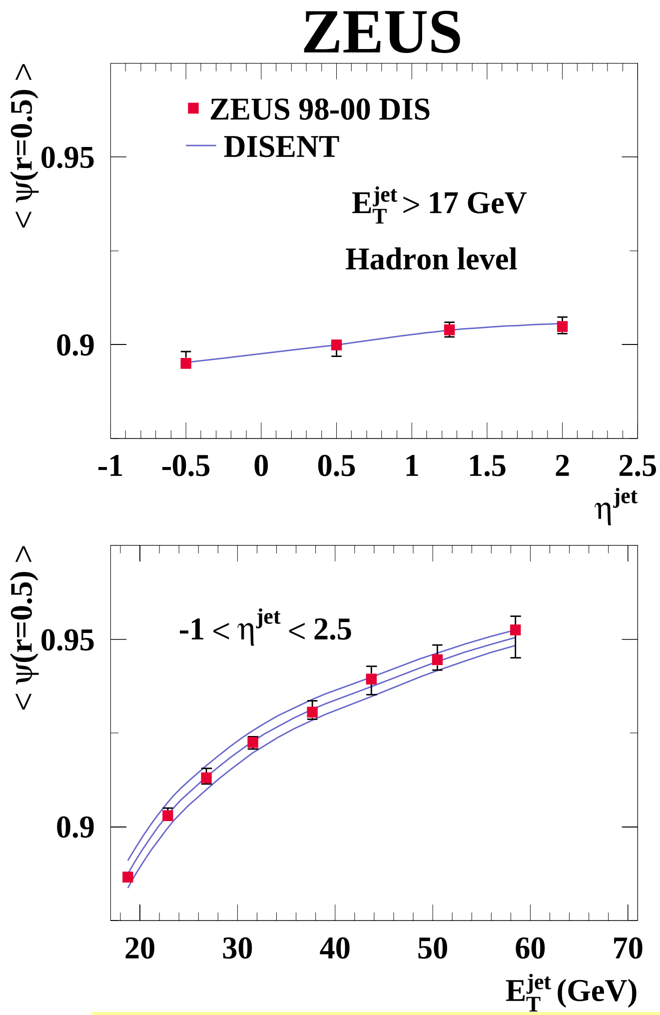
$Q^2 < 125$ GeV^2

$E_t^{jet} > 17$ GeV $-1 < \eta^{jet} < 2.5$



First time studied in photoproduction

Using Jet Substructure to Study the Hard Subprocess



E_t^{jet} dependence:

- DIS and γp: jets become narrower as E_T^{jet} increases

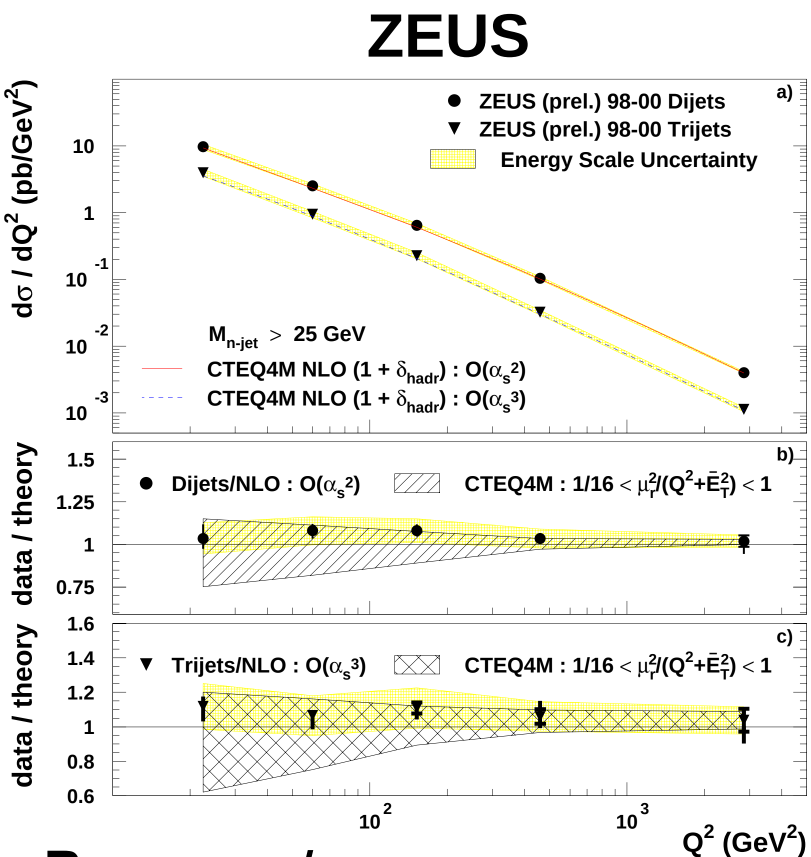
α_S=0.1225

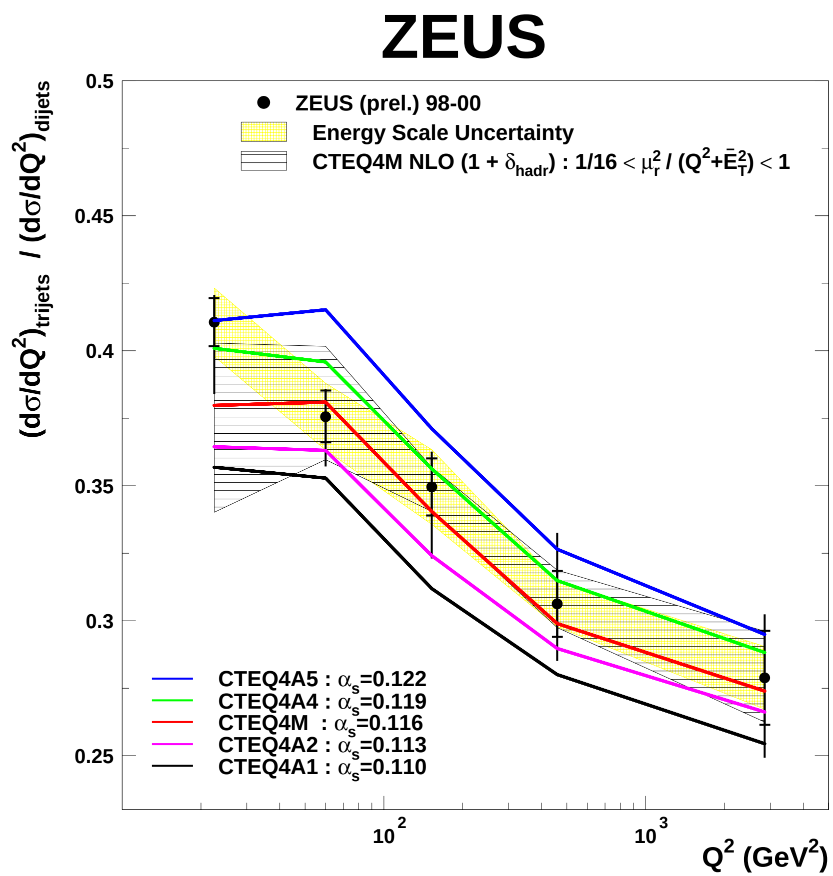
α_S=0.1175

α_S=0.1125

$$\alpha_s(M_z) = 0.1176 \pm 0.0009\,(stat.)^{+0.0009}_{-0.0026}(\exp.)^{+0.0091}_{-0.0072}(th.)$$

Multijet Test of QCD





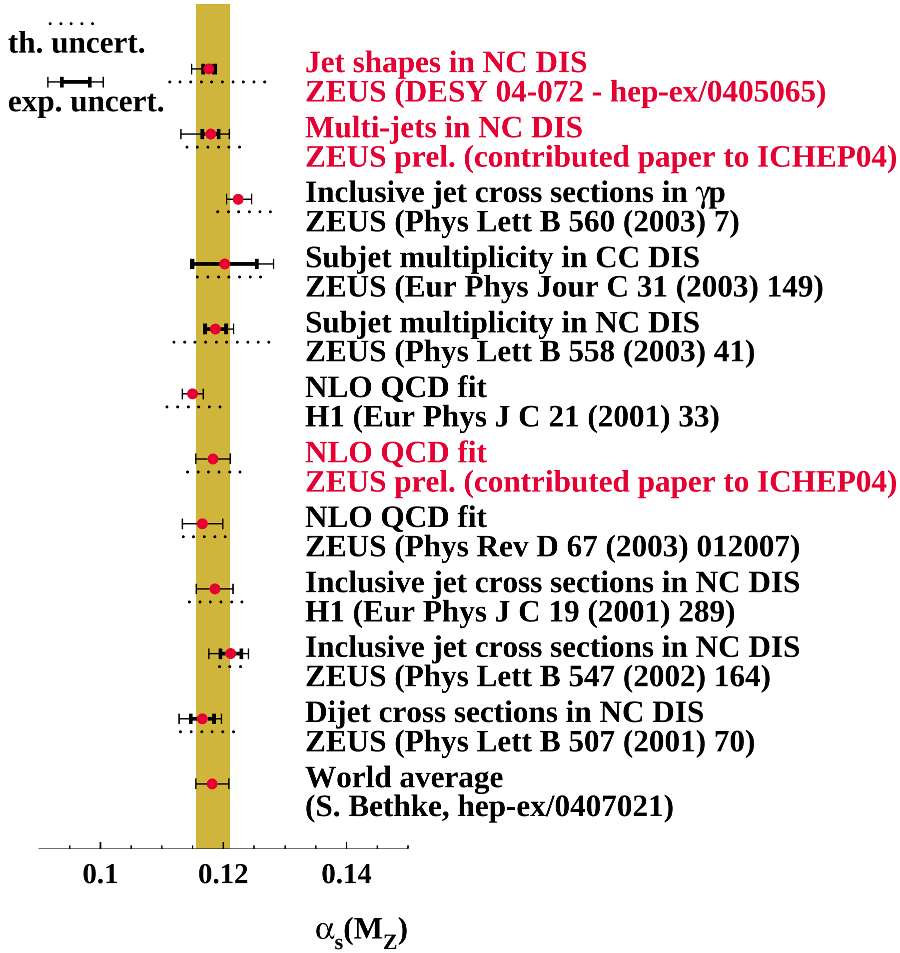
$R_{3/2} = \sigma_{trijet}/\sigma_{dijet}$

Systematic uncertainties substantially reduced

Very sensitive test of QCD calculation

$$\alpha_s(M_z) = 0.1179 \pm 0.0013(stat.)^{+0.0028}_{-0.0046}(syst.)^{+0.0061}_{-0.0047}(th.)$$

Summary



- **Good experimental measurement of event shapes**
  - Means, Differential Distributions, and new event shapes for jet events
  - Need some theoretical input for higher order calculations and resummations for the event shapes in jet events
- **Jet substructure, jet rates, and jet ratios demonstrate the validity of the description of the internal structure of jets by QCD**
  - Using $R_{3/2}$ cross section ratio gives possibility to measure α_S at very low Q^2