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Event Shapes and Power Corrections Results from HERA

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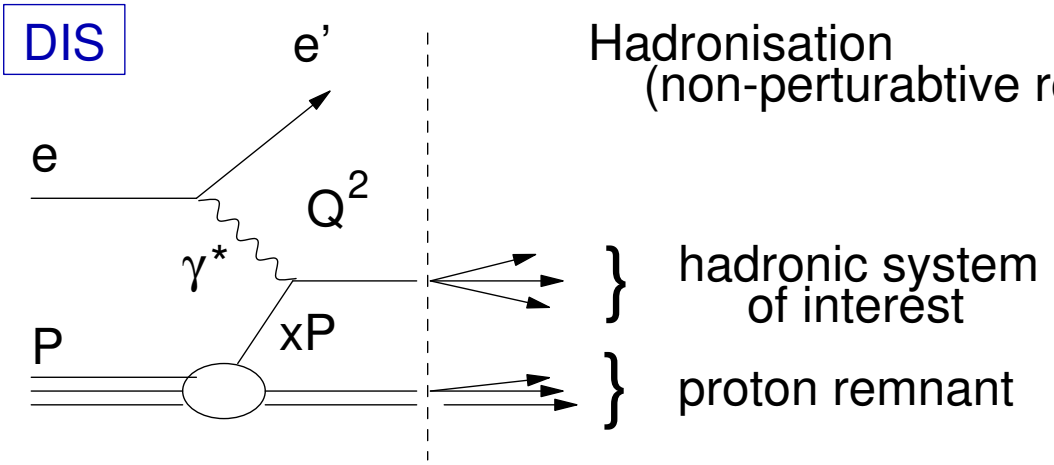
Overview

- **Introduction**
  - Deep Inelastic Scattering (DIS)
  - Event shape definitions
- **Event Shape Results**
  - Differential event shapes
  - Mean event shapes
- **Power Correction Fit Results**
- **Conclusions**

Event Shape Definitions

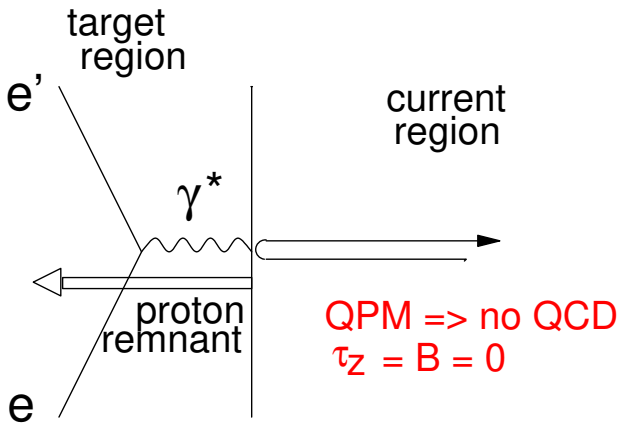
DIS



Perturbative QCD

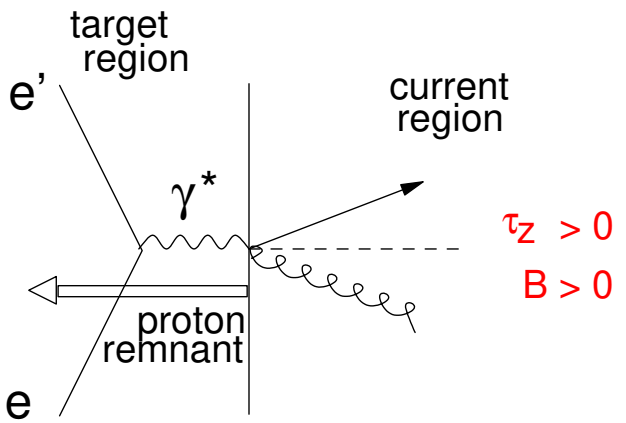
NLO predictions available eg. DISENT

Breit Frame



$$\tau_z = 1 - \frac{\Sigma p_z}{\Sigma |p|}$$

$$B = \frac{\Sigma p_t}{\Sigma |p|}$$



=> QCD effects

broadening of hadronic system

Event Shape Definitions

- **Analogy between current region in DIS and one hemisphere of an e^+e^- event.**

$$\tau_m = 1 - \max_{n'} \frac{\sum_i |n' \cdot p_i|}{\sum_i |p_i|} = 1 - \frac{\sum_i |n^T \cdot p_i|}{\sum_i |p_i|}$$

$$\rho = \frac{M^2}{(2E_{tot})^2} = \frac{\left[(\sum |E|)^2 - (\sum p_x)^2 - (\sum p_y)^2 - (\sum p_z)^2\right]}{4\left(\sum_i |E|\right)^2}$$

$$C = \frac{3}{2\left(\sum_i |p_i|\right)^2} \sum_{ij} |p_i||p_j| \sin^2 \theta_{ij}$$

Don't want to be sensitive to soft particles migrating from the target region:

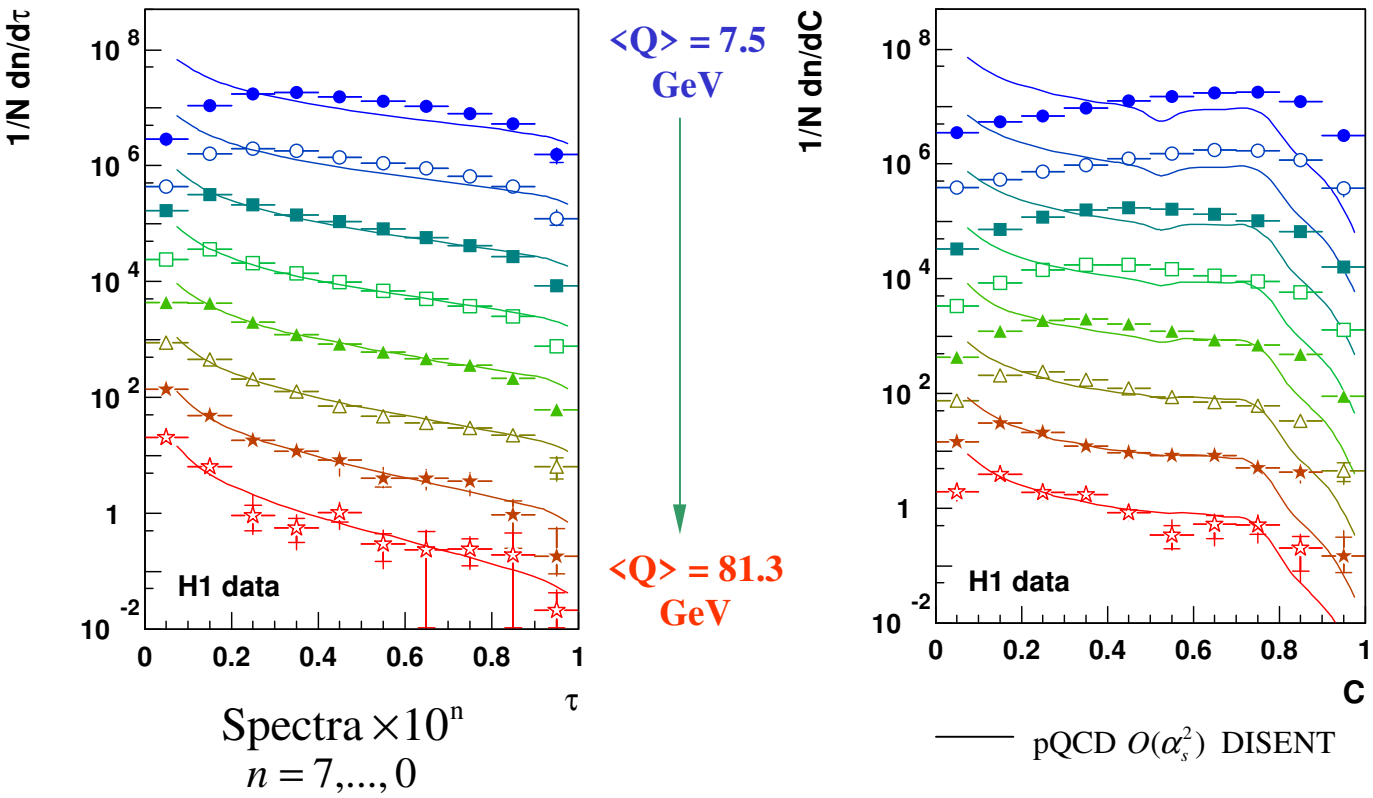
$$E_{\text{Current Region}} > 0.1Q$$

$$E_{\text{Current Region}} > 0.03Q$$

Results are not sensitive to exact value of the cut

Normalised Differential Event Shapes

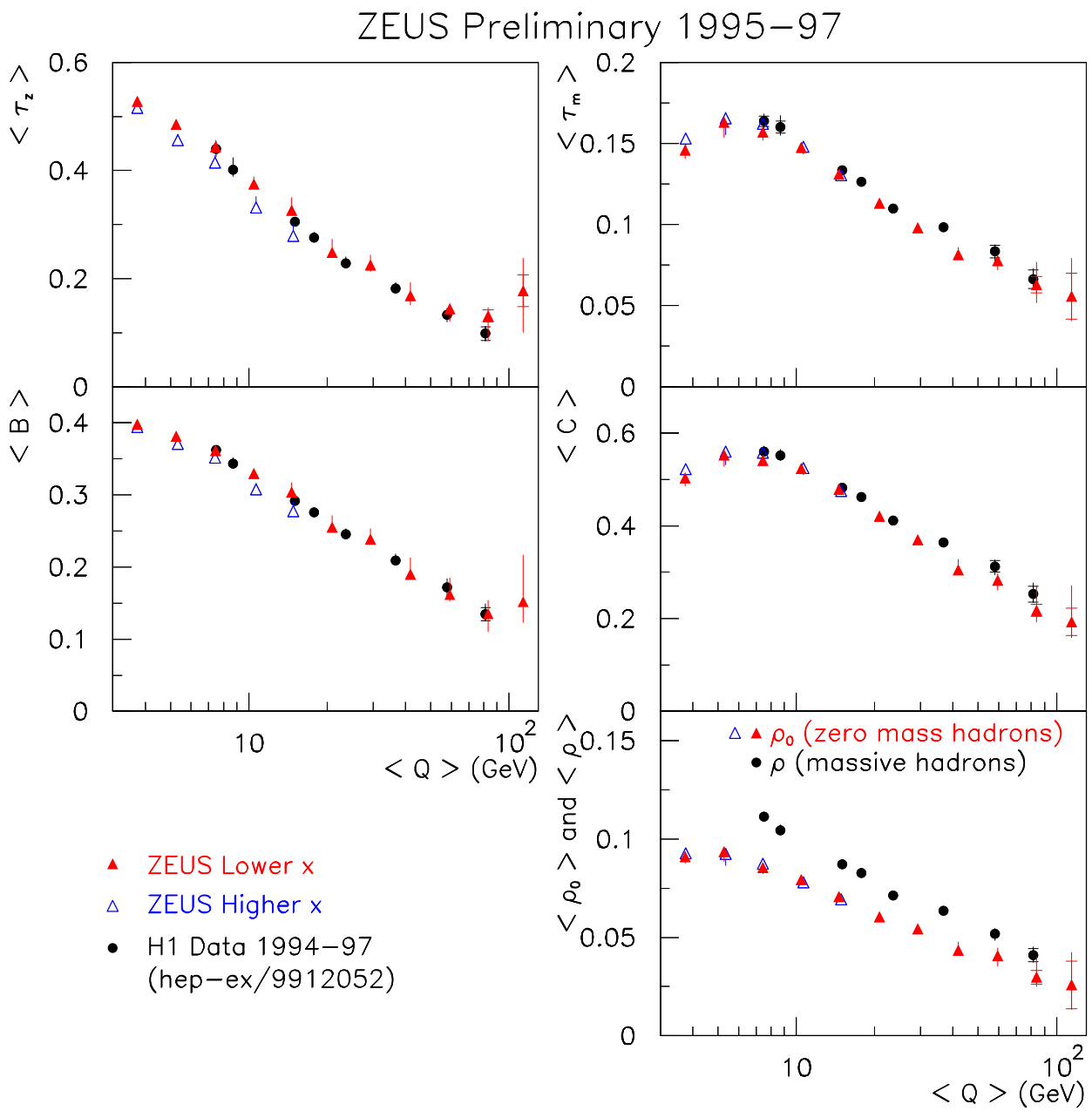
H1 1994-97 (hep-ex/9912052)



- **Measured in increasing bins of momentum transfer Q**
- **Events become more collimated as Q increases**
- **Discrepancies between measured hadrons and pQCD predictions (DISENT), especially at low Q**

  ⟶ **Hadronisation corrections important!**

Mean Event Shapes



- **Events more collimated with increasing Q**
- **Reasonable agreement between data sets**
- **Different definition of jet-mass ρ**
- ***x*-dependence apparent in ZEUS data**
  ⟶ ZEUS bin explicitly in *x*

$1/Q^P$ Hadronisation Corrections

- **Assume leading corrections to perturbative QCD predictions have form ~ $1/Q^P$**

and try

$$\langle F \rangle_{DATA} = \langle F \rangle_{\text{pQCD}} + \langle F \rangle_{\text{Power Corr.}}$$

Try simple fits of form:

$$\langle F \rangle_{\text{Power Corr.}} = \frac{\lambda_1}{Q} \quad \textbf{and} \quad \langle F \rangle_{\text{Power Corr.}} = \frac{\lambda_2}{Q^2}$$

H1 1994-97 (hep-ex/9912052)

$\langle F \rangle$	$\lambda_{1,F}$/ GeV	χ^2/dof	$\lambda_{2,F}$/ GeV^2	χ^2/dof	$\alpha_s(M_Z)$	χ^2/dof
$\langle \tau \rangle$	0.71 ± 0.03	2	7.2 ± 0.3	23	0.131 ± 0.001	1
$\langle B \rangle$	0.55 ± 0.02	1	5.2 ± 0.2	28	0.134 ± 0.001	24
$\langle \tau_C \rangle$	0.73 ± 0.01	29	7.1 ± 0.2	212	0.152 ± 0.001	2
$\langle \rho \rangle$	0.54 ± 0.01	38	5.2 ± 0.1	283	0.160 ± 0.001	1
$\langle C \rangle$	2.33 ± 0.03	66	20.8 ± 0.4	327	0.148 ± 0.001	5
$\langle y_{fJ} \rangle$	-0.13 ± 0.01	2	-1.2 ± 0.1	7	0.113 ± 0.001	1
$\langle y_{k_t} \rangle$	-0.32 ± 0.02	7	-3.1 ± 0.3	21	0.110 ± 0.001	9

- **Neither simple form can describe the data well**

Dasgupta, Dokshitzer, Salam,Webber et al Power Corrections

Attribute 1 / Q^P form to behavior of strong coupling at small scales:

$$\langle F \rangle_{\text{PowerCorr.}} = a_F \frac{16M'}{3\pi p}\left(\frac{\mu_I}{Q}\right)^p \times \left[\bar{\alpha}_{p-1}(\mu_I) - \alpha_S(Q) - \frac{\beta_0}{2\pi}\left(\ln\frac{Q}{\mu_I} + \frac{K}{\beta_0} + \frac{1}{p}\right)\alpha_S{}^2(Q)\right]$$

$\bar{\alpha}_{p-1}(\mu_I)$ - nonperturbative fit parameter, universal?

μ_I - Infrared matching scale, $\mu_I = 2\,\text{GeV}$

$M' = \frac{2}{\pi}M \approx 0.95$ - Milan factor from 2-loop correction

p - power. $p = 1$ (except y_{kt} where $p = 2$)

a_F - Calculable *constant* for each variable

Except B, $a_F \propto \underbrace{1/\sqrt{\alpha_s} + const.}$ $+ O(1)$

Just fit with these terms

x-dependent terms omitted (hep-ph/9812487)

Fits à la Dokshitzer, Webber et al.

1) ZEUS data fitted well for e^+e^- type variables

→ **ZEUS preliminary plots x-dependence in data**

Varying renorm. scale : $\mu_R^2 = 4Q^2$, $\mu_R^2 = \frac{1}{4}Q^2$

2) H1 data fitted well for by model

H1 1994-97 (hep-ex/9912052)

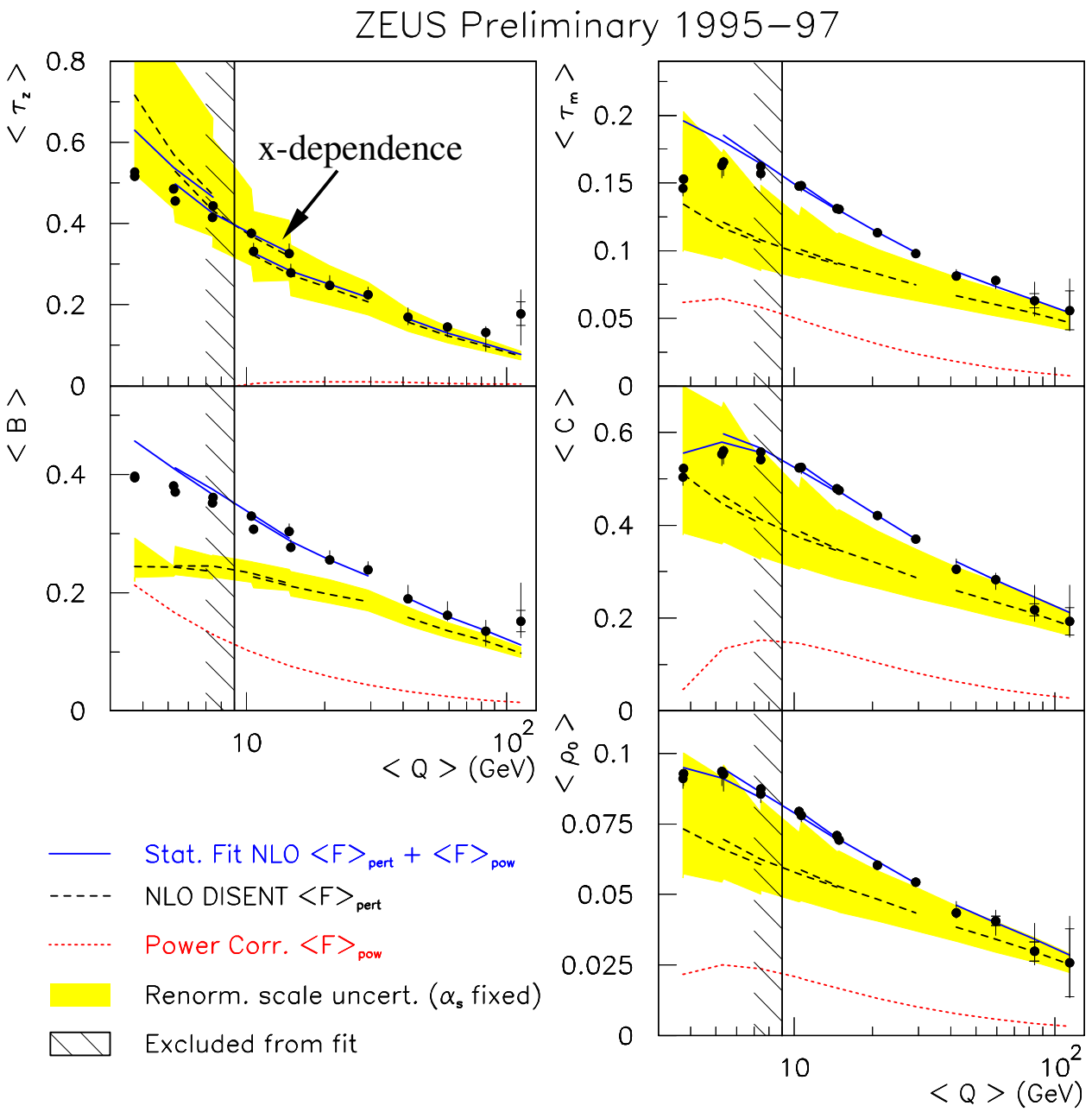
$\langle F \rangle$	a_F	p	$\overline{\alpha}_{p-1}(\mu_I = 2\,\mathrm{GeV})$	$\alpha_s(M_Z)$	χ^2/dof	$\kappa/\%$
$\langle \tau \rangle$	1	1	$0.503\ ^{+0.043}_{-0.053}\ ^{+0.053}_{-0.068}$	$0.1190\ ^{+0.0075}_{-0.0054}\ ^{+0.0073}_{-0.0069}$	0.5	−98
$\langle B \rangle$	$1/2 \cdot a'_B$	1	$0.537\ ^{+0.017}_{-0.012}\ ^{+0.028}_{-0.039}$	$0.1113\ ^{+0.0036}_{-0.0028}\ ^{+0.0049}_{-0.0051}$	0.7	−69
$\langle \rho \rangle$	1/2	1	$0.597\ ^{+0.009}_{-0.010}\ ^{+0.050}_{-0.057}$	$0.1374\ ^{+0.0024}_{-0.0032}\ ^{+0.0110}_{-0.0096}$	1.1	−32
$\langle \tau_C \rangle$	1	1	$0.503\ ^{+0.008}_{-0.010}\ ^{+0.043}_{-0.047}$	$0.1310\ ^{+0.0023}_{-0.0028}\ ^{+0.0098}_{-0.0089}$	1.2	−22
$\langle C \rangle$	$3\pi/2$	1	$0.447\ ^{+0.005}_{-0.007}\ ^{+0.032}_{-0.038}$	$0.1301\ ^{+0.0016}_{-0.0020}\ ^{+0.0103}_{-0.0091}$	0.8	+36

→ **H1 contour plot**

Theory uncertainties of 5-10%

Varying renorm. scale : $\mu_R^2 = 2Q^2$, $\mu_R^2 = \frac{1}{2}Q^2$

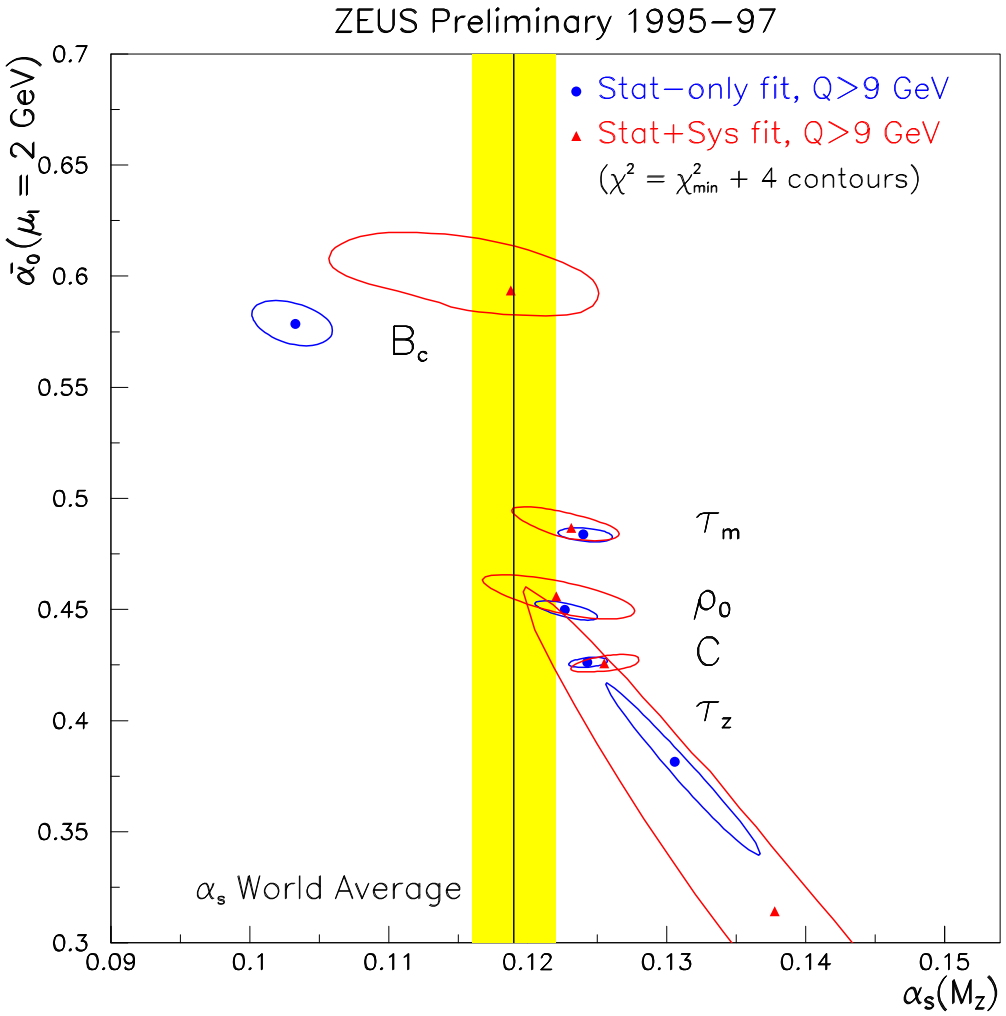
Fits à la Dokshitzer, Webber et al.



- **e^+e^- type variables (C, τ_m, ρ_0) fit well**
- **ZEUS data highlight problems with the x-dependence in DIS specific variables (B and τ_z)**
- **Large scale uncertainties**

ZEUS contour plot

Stat-only fit and Fit with systematic errors



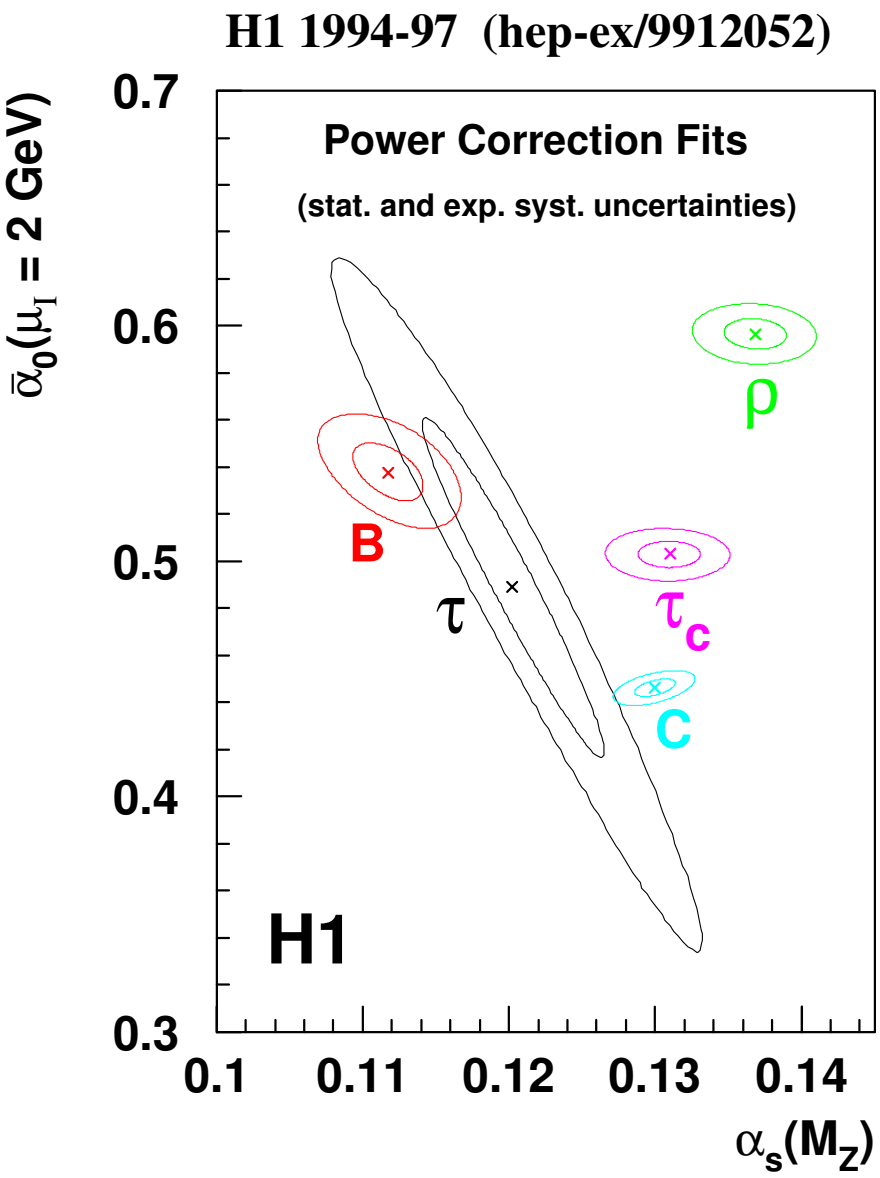
- **~20% spread in α_0 around 0.5**
- **e^+e^- type variables (C, τ_m, ρ_0) fit common α_s**
- **Spread of α_s for the other variables**

→ **Missing higher order QCD corrections or influence of *x*-binning?**

cf. large renormalisation scale uncertainties

Note: Differing definition of ρ from H1!

H1 contour plot

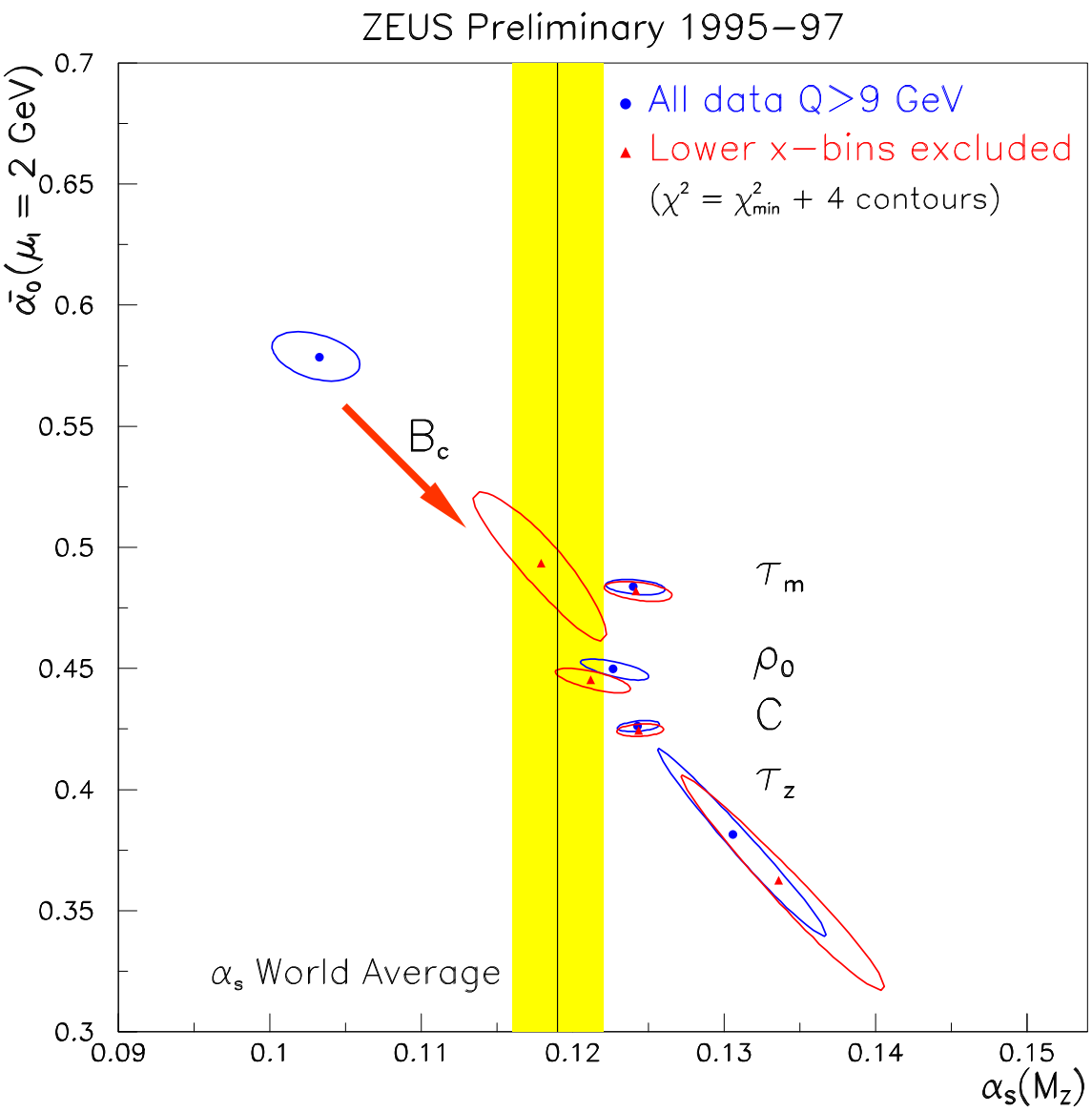


- ~20% spread in α_0 around 0.5
- e^+e^- variable close in α_s
- Spread in α_s for the other variables

→ Missing higher order QCD corrections?

cf. typical theory uncertainties of 5-10%
(renormalisation scale and PDF)

x-dependence in broadening



For B, $a_F \propto \underbrace{1/\sqrt{\alpha_s} + const.}_{\text{Just fit with these terms}} + O(1)$

Just fit with these terms

• x-dependence observed in ZEUS data

these omitted x-dependent terms are important!

(n + 1) jets searched for in current *and* target regions of Breit Frame

(+1 is the proton remnant)

Two distance measures used to combine particles into jets:

1) Durham or k_t algorithm

$$y_{kt} = \frac{2\min(E_i^2, E_j^2)(1-\cos\theta_{ij})}{Q^2}$$

2) Factorizable JADE algorithm

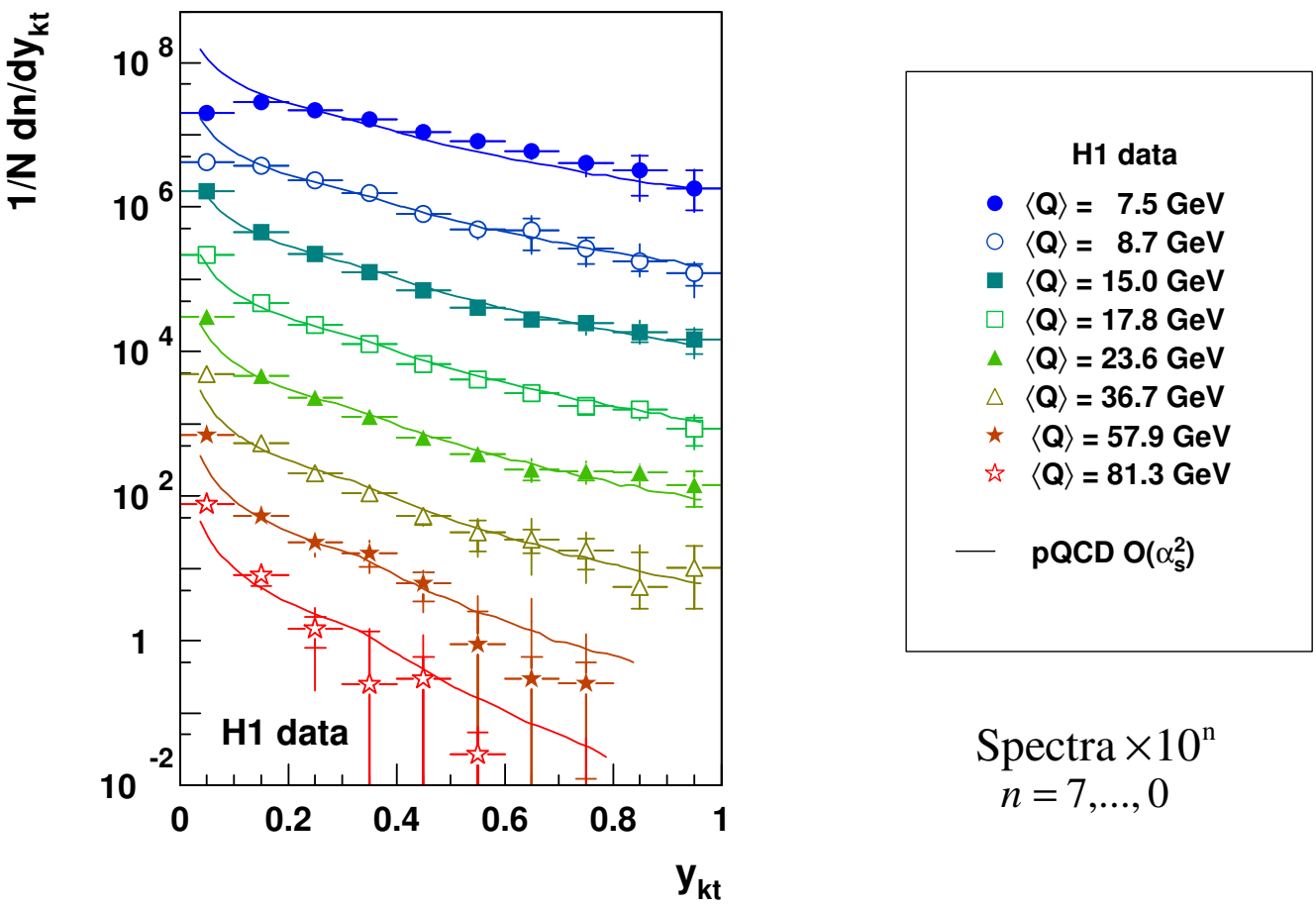
$$y_{fj} = \frac{E_i E_j (1-\cos\theta_{ij})}{Q^2}$$

Event shape y is defined as the y-value at which the transition

$(2+1) \rightarrow (1+1)$ jets **occurs**

Normalised Differential Event Shapes

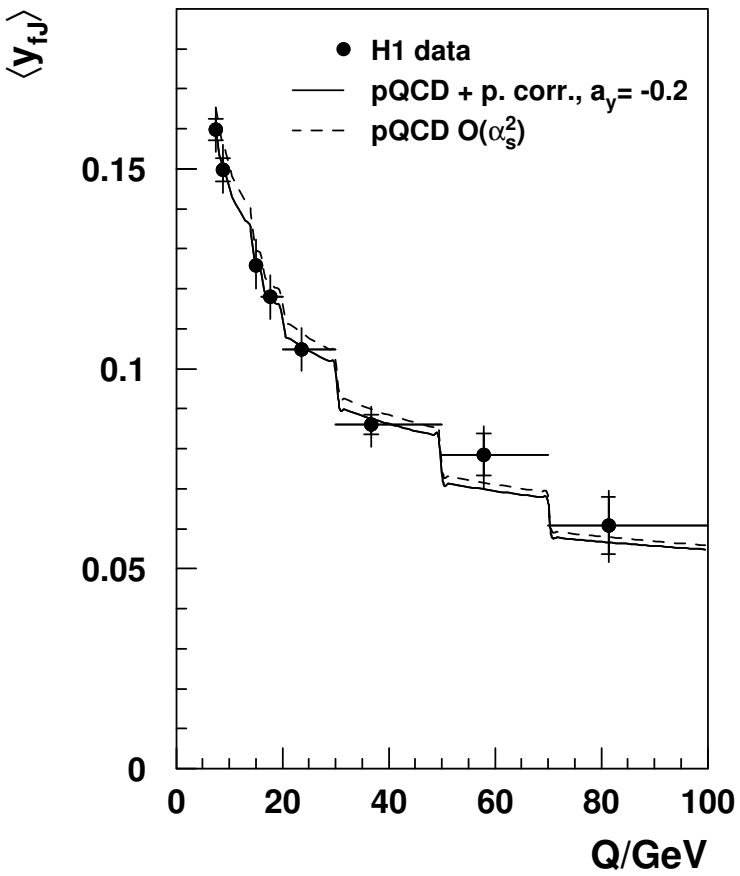
H1 1994-97 (hep-ex/9912052)



- **Measured in increasing bins of momentum transfer Q**
- **Hadronisation corrections are smaller for the event shapes, y_{fj} and y_{kt}**

H1 Event shape fits, y_{fj}

H1 1994-97 (hep-ex/9912052)



<y> Factorisable JADE algorithm

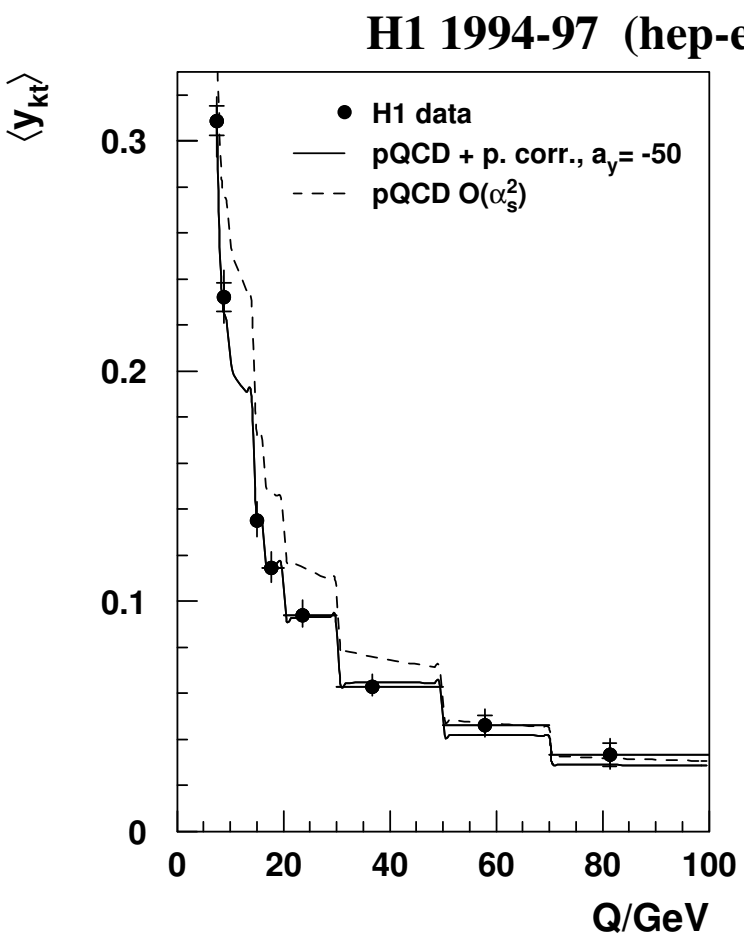
- **Acceptable fit, but unreasonably low values of α_0 and α_s with given a_{fJ} coefficient**

$\langle F \rangle$	a_F	p	$\overline{\alpha}_{p-1}(\mu_I = 2\,\mathrm{GeV})$	$\alpha_s(M_Z)$	χ^2/dof
$\langle y_{fJ} \rangle$	1	1	$0.28\ ^{+0.02}_{-0.02}$	$0.105\ ^{+0.005}_{-0.006}$	0.8
$\langle y_{fJ} \rangle$	-0.2^*	1	$0.37\ ^{+0.20}_{-0.21}$	$0.116\ ^{+0.008}_{-0.009}$	0.6

- **More consistent fit obtainable by varying the a_{fJ} coefficient to -0.2**

→ **Negative power corrections**

H1 Event shape fits, y_{kt}



<y> K_t algorithm

- **Power correction expected as ~ 1 / Q^2**

H1 data exclude a 1 / Q dependence!

a_{kt} coefficients are unknown ...

… fit is *consistent* with 1 / Q^2 power corrections, but these hadronisation corrections to y_{kt} are small

→ **Need calculation of a_{kt} ...**

→ **...and more experimental precision!**

Conclusions

• HERA data on event shapes are precise and consistent.

• Simple $\langle F \rangle_{pQCD} + \lambda/Q$ and $\langle F \rangle_{pQCD} + \lambda/Q^2$ fits cannot describe data well

• τ_z, B, ρ, τ_m, and C have large power corrections y_{fJ} and y_{kt} have small negative power corrections

• Both ZEUS and H1 data see ~universal $\alpha_0 \sim 0.5 \pm 20\%$

• e^+e^- type variables (C, ρ, τ_m) in ZEUS and H1 see ~common value of α_s

• DIS specific variables (B and τ_z) in ZEUS and H1 see uncomfortable spread of α_s

- **Model has problems describing *x*-dependence seen in ZEUS DIS specific variables**

• H1 see *negative* power corrections are required for y-event shapes.

- **Data consistent with $1/Q^2$ form for y_{kt}**
- **More theory input on the y_{kt} variable**

• H1 and ZEUS analyses support basic concept of ~universal power corrections!