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Results on Event Shapes in DIS

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(for the H1 Collaboration)

1. The Breit Frame
2. Definition of the Event Shape Variables
3. Data Selection
4. QCD Calculations and Power Corrections
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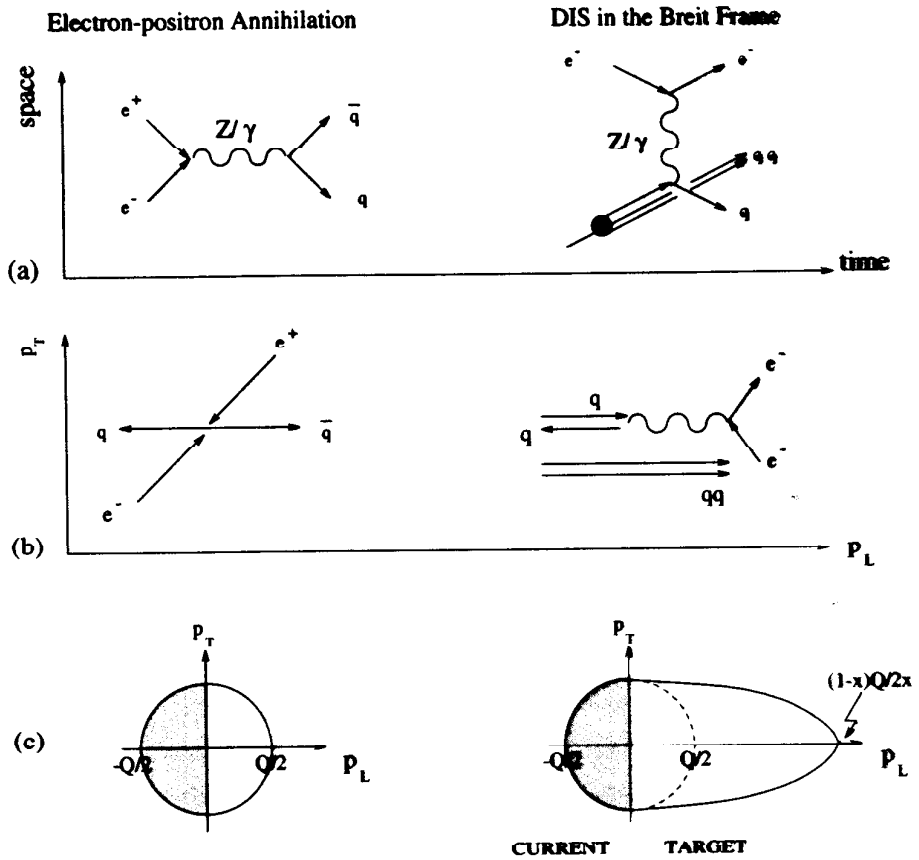
1. The Breit Frame



- **Phase Space in the Current Hemisphere of the Breit Frame for $e\,p \to e\,X$ Events:**

$$Q/2$$

- **Phase Space in one Hemisphere of $e^+e^- \to q\,\bar{q}$ Events:**

$$\sqrt{s}/2$$

$\Rightarrow$ **Is there a relation between**

$$e\,p \text{ Scattering} \leftrightarrow e^+e^- \text{ Annihilation}$$

concerning Event Shapes at a Scale

$$Q_{\mathrm{DIS}} = \sqrt{s_{\mathrm{ee}}}\ ?$$

2. Definition of the Event Shape Variables

Define infrared safe Variables, calculable in NLO QCD:

- **Sums extend over all hadrons h with four-momenta $p_h = \{E_h, \mathrm{p}_h\}$ in the Breit Current Hemisphere:**

$$\cos(\mathrm{p}_h \cdot \mathrm{n}) > 0,$$

where the Axis n coincides with the γ/Z direction:

1. Thrust T_C:

$$T_C = \max \frac{\Sigma_h |\mathrm{p}_h \cdot \mathrm{n}_T|}{\Sigma_h |\mathrm{p}_h|} \qquad \mathrm{n}_T \equiv \text{Thrust Axis}$$

2. Thrust T_Z:

$$T_Z = \frac{\Sigma_h |\mathrm{p}_h \cdot \mathrm{n}|}{\Sigma_h |\mathrm{p}_h|} = \frac{\Sigma_h |\mathrm{p}_{z\,h}|}{\Sigma_h |\mathrm{p}_h|} \qquad \mathrm{n} \equiv \gamma/Z \text{ Axis}$$

3. Jet Broadening B_C:

$$B_C = \frac{\Sigma_h |\mathrm{p}_h \times \mathrm{n}|}{2\,\Sigma_h |\mathrm{p}_h|} = \frac{\Sigma_h |\mathrm{p}_{\perp h}|}{2\,\Sigma_h |\mathrm{p}_h|} \qquad \mathrm{n} \equiv \gamma/Z \text{ Axis}$$

4. Jet Mass ρ_C:

$$\rho_C = \frac{M^2}{Q^2} = \frac{(\Sigma_h\, p_h)^2}{Q^2}$$

3. Data Selection

• Data Samples

low Q sample	1994 $e^+ p$ data	$\mathcal{L} \simeq 2.9\ pb^{-1}$
high Q sample	1994 – 1996 $e^\pm p$ data	$\mathcal{L} \simeq 11.7\ pb^{-1}$

• Event Selection Criteria

variable	$Q = 7 \div 10$ GeV	$Q = 14 \div 100$ GeV
event vertex	$\lvert z_{vtx} - \langle z \rangle \rvert < 35$ cm	
isolated lepton	$R_e = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.5$	
lepton energy	$E'_e > 10$ GeV	
lepton polar angle	$157° < \theta_e < 173°$	$30° < \theta_e < 150°$
hadron polar angles	$5.7° < \theta_h < 170°$	
$E - p_z$ conservation	$30\ \text{GeV} < \sum_h E_h (1 - \cos\theta_h) < 65\ \text{GeV}$	
hadr. energy, Breit CH	$\sum_h E^c_h > 0.1\, Q$	
kinematic variables	$0.05 < y_e < 0.80$ and $0.05 < y_h$	

• Kinematic variables for Breit frame transformation

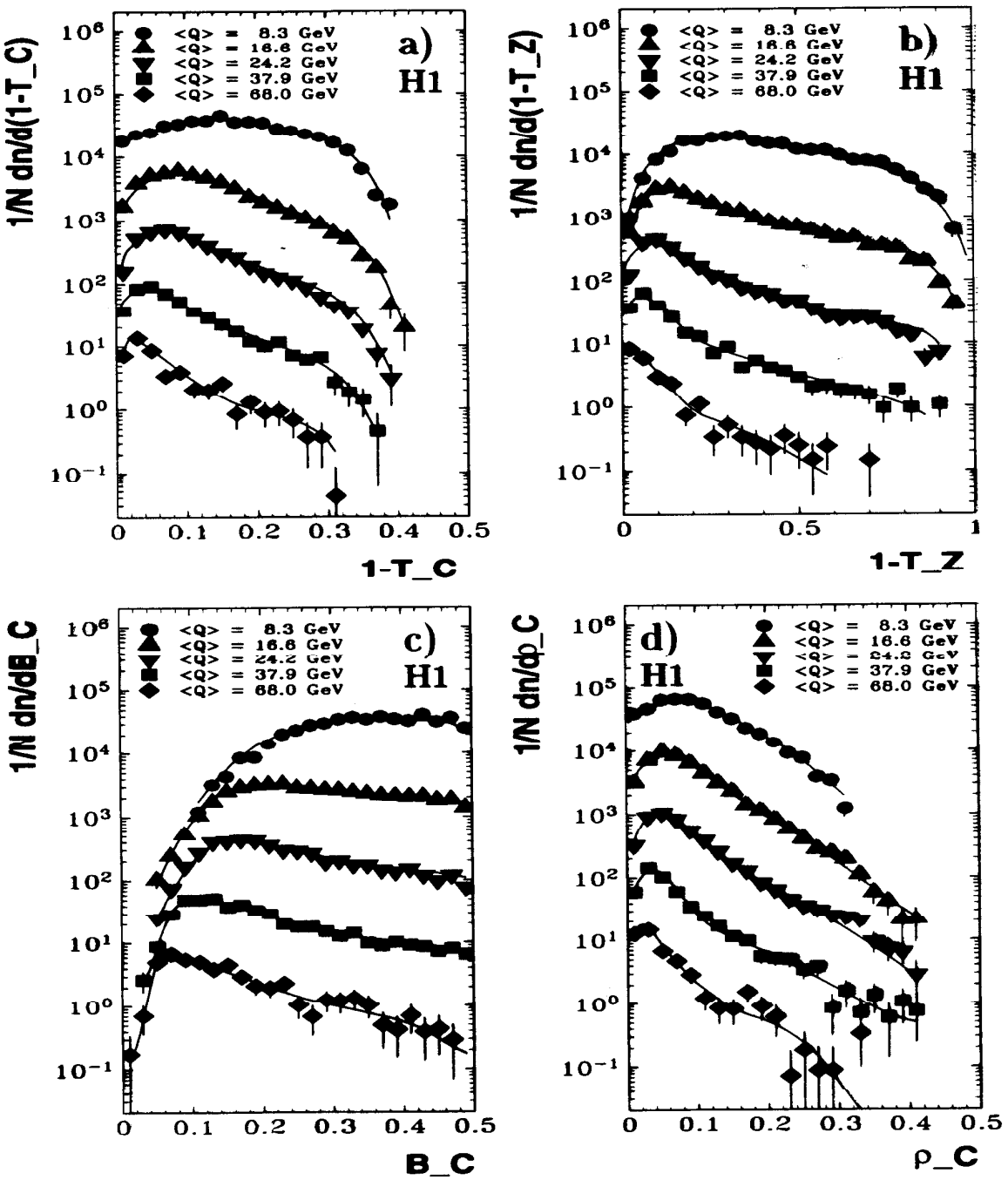
calculated from the electron (E'_e, θ_e)
and from the hadrons (E_h, θ_h)

$$Q^2 = 4\, E_e\, E'_e \cos^2 \frac{\theta_e}{2}\,,$$

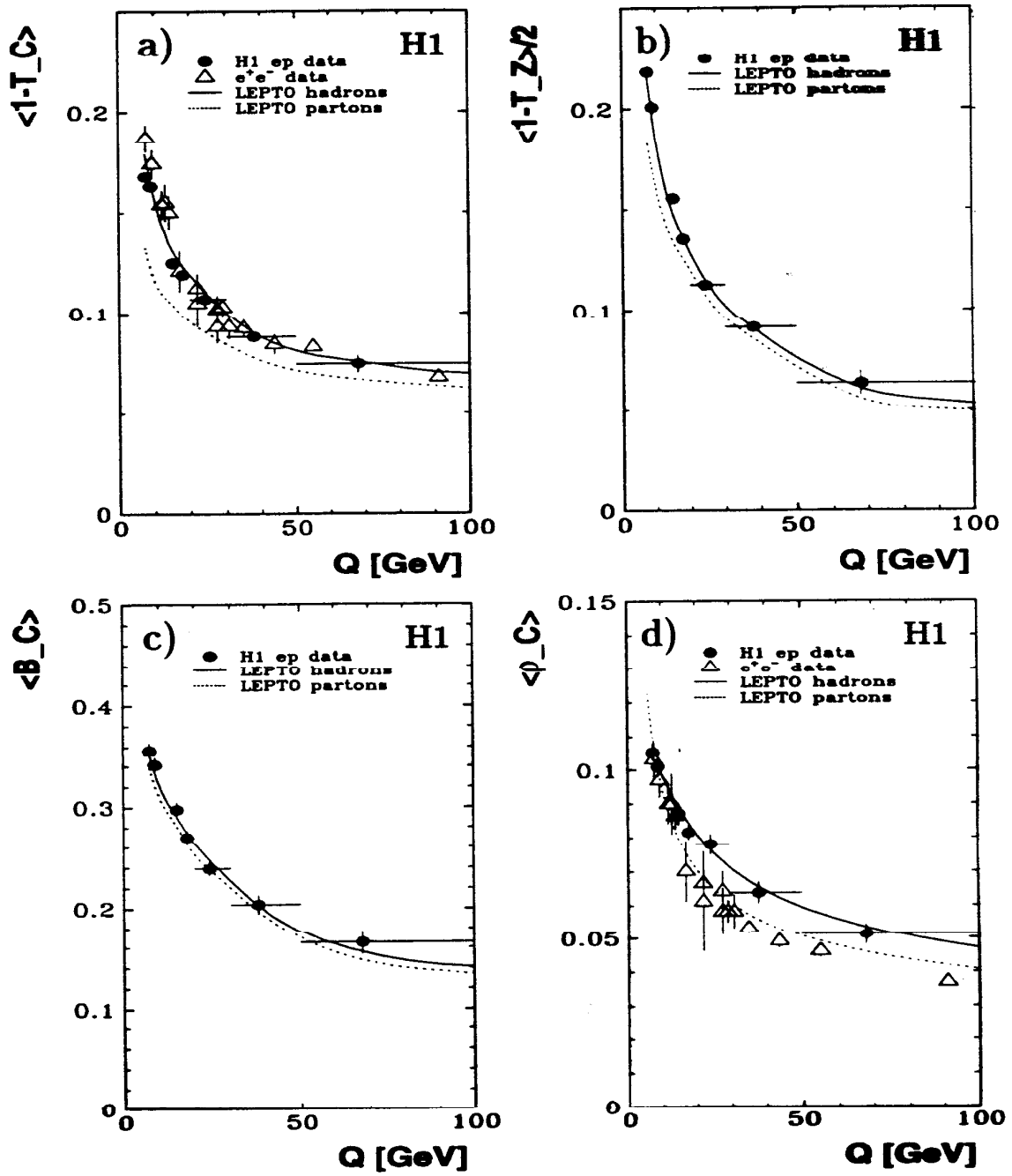
$$y = y_e = 1 - \frac{E'_e}{E_e} \sin^2 \frac{\theta_e}{2} \qquad \text{for} \quad y_e > 0.15\,,$$

$$y = y_h = \frac{\sum_h E_h (1 - \cos\theta_h)}{2\, E_e} \qquad \text{for} \quad y_e < 0.15$$

H1 differential event shape spectra (full symbols) in comparison with LEPTO hadrons (full lines):



Q dependence of H1 event shape means (full symbols) in comparison with e^+e^- data (open triangles), LEPTO hadrons (full lines) and partons (dotted lines):



4. QCD Calculations and Power Corrections

- **Event Shape Means exhibit a strong Q or Energy Dependence due to**

  1. the Variation of the Strong Coupling Constant

  $$\alpha_s(Q) \propto 1/\ln(Q/\Lambda)$$

  2. Power or so-called 'Hadronisation' Corrections

  $$\propto 1/Q^n$$

- **According to recent theoretical developments (s. e.g. Yu.L. Dokshitzer, B.R. Webber;** Phys. Lett. B 352 (1995) 451**) this Dependence can be written for any infrared safe Event Shape Variable $\langle F \rangle$, where e.g.**

  $$F = 1 - T_C,\ 1 - T_Z,\ B_C,\ \rho_C,$$

  as:

$$\langle F \rangle = \langle F \rangle^{\text{pert}} + \langle F \rangle^{\text{pow}}$$

$$\langle F \rangle^{\text{pert}} = c_1\, \alpha_s(Q) + c_2\, \alpha_s^2(Q) + \ldots$$

$$\langle F \rangle^{\text{pow}} = a_F \frac{16}{3\,\pi} \frac{\mu_I}{Q} \ln^p \frac{Q}{\mu_I} \cdot \left[\bar{\alpha}_0(\mu_I) - \alpha_s(Q) - \frac{\beta_0}{2\,\pi} \left(\ln \frac{Q}{\mu_I} + \frac{K}{\beta_0} + 1 \right) \alpha_s^2(Q) \right.$$

introducing

1. a new 'infrared matching' Scale μ_I where

$$\Lambda_{\text{QCD}} \ll \mu_I \ll Q$$

2. a new universal (?) non-perturbative parameter $\bar{\alpha}_0(\mu_I)$

- **The perturbative Part $\langle F \rangle^{\text{pert}}$ may be obtained to $\mathcal{O}(\alpha_s^2)$ via**

$$\langle F \rangle^{\text{pert}} = \frac{\int_0^{F_{\max}} F \frac{d\sigma}{dF} dF}{\int_0^{F_{\max}} \frac{d\sigma}{dF} dF} = \frac{1}{\sigma_{\text{tot}}} \int_0^{F_{\max}} F \frac{d\sigma}{dF} dF ,$$

where the total cross section needs only be known to first order QCD.

Currently two NLO programs are available for this task:

1. MEPJET: **E. Mirkes, D. Zeppenfeld;**
   Phys. Lett. B 380 (1996) 205
2. DISENT: **S. Catani, M. Seymour;**
   Phys. Lett. B 378 (1996) 287

Due to the integration method applied in MEPJET, however, a lower cut in F, such that

$$0 < F_{\text{cut}} < F \leq F_{\max}$$

has to be used.

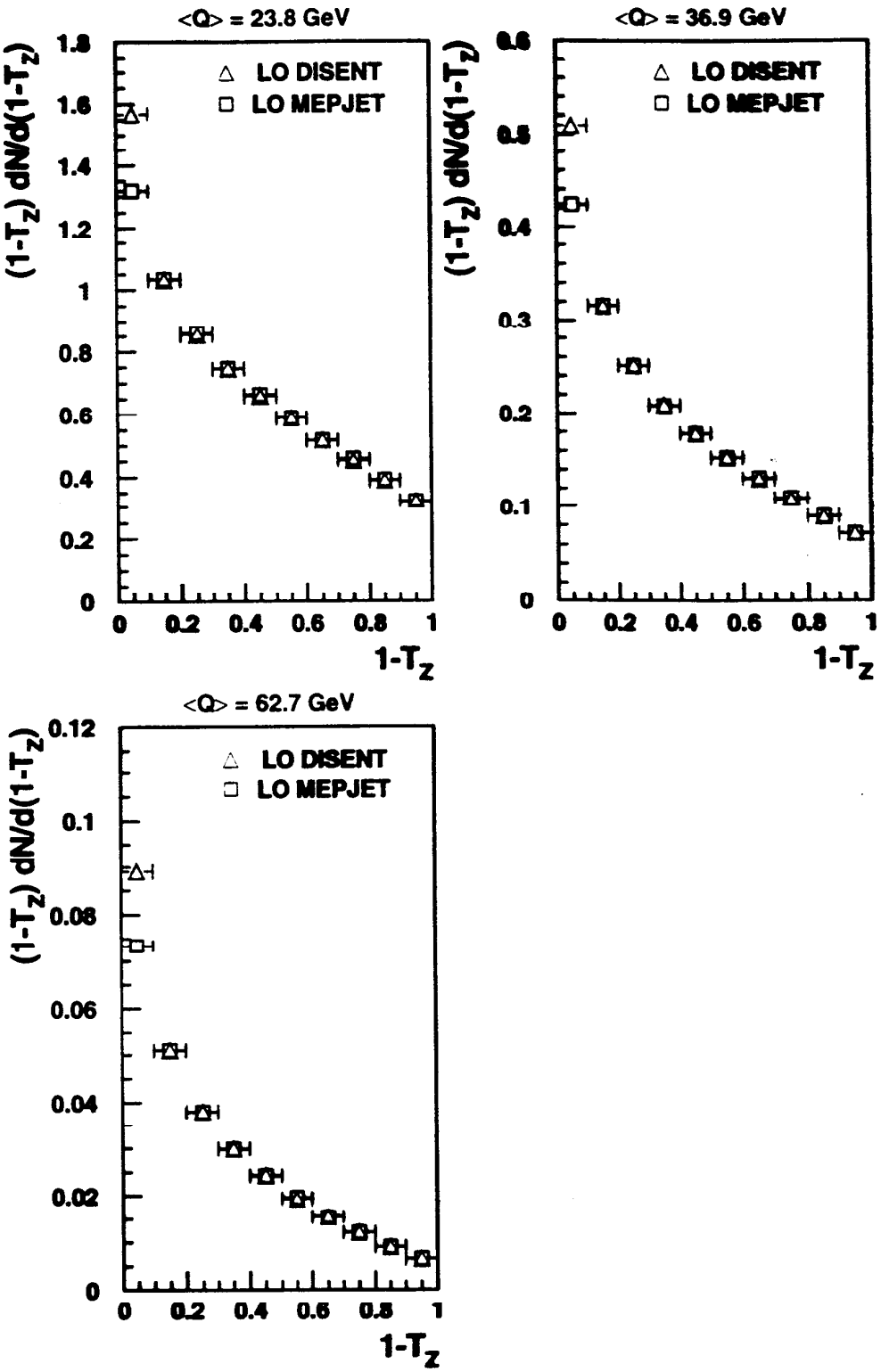
In DISENT special care has been taken concerning the numerical integration of $F\, d\sigma/dF$, which still contains integrable singularities for $F \to 0$.

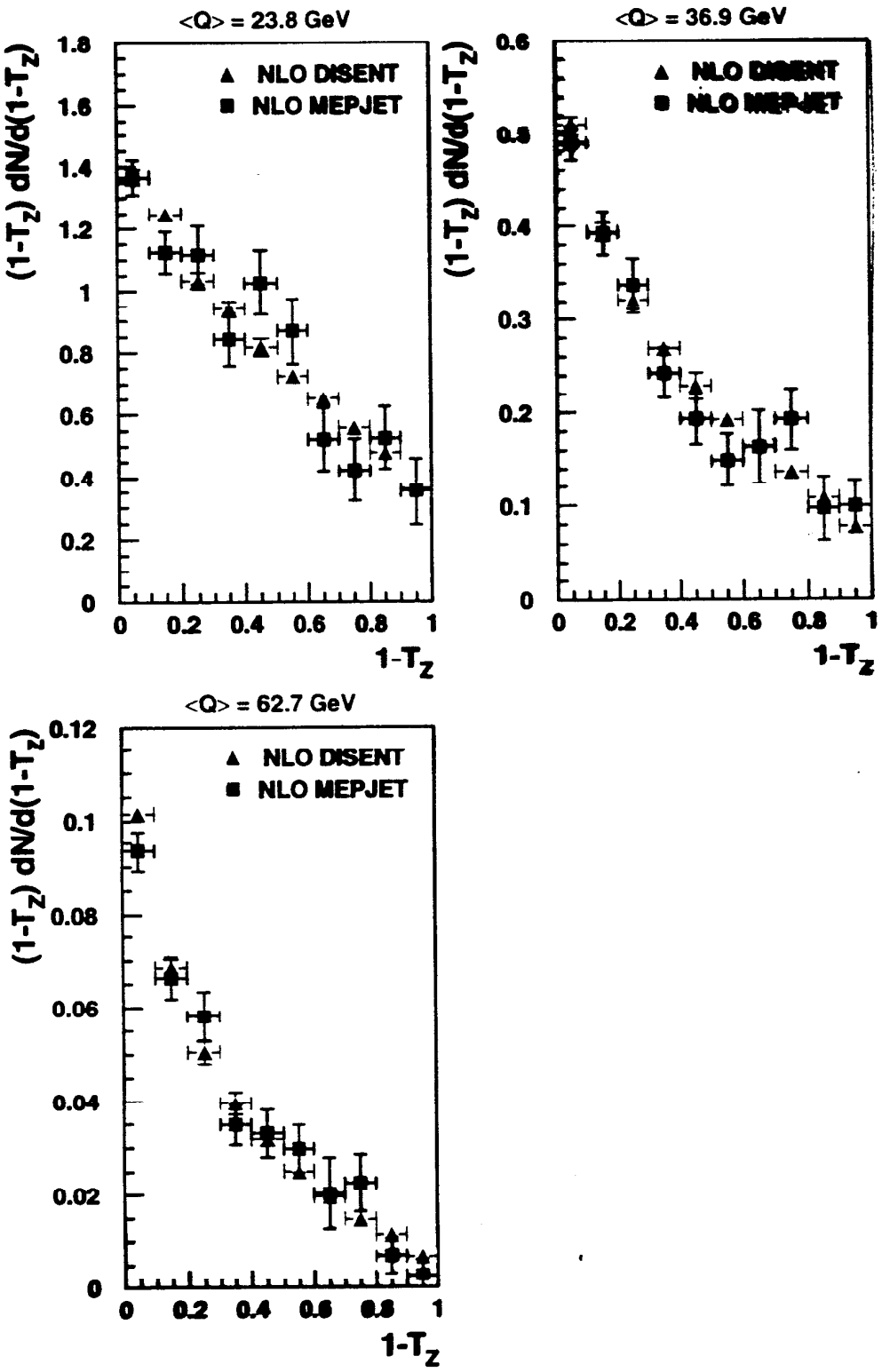
$\Rightarrow$ It is allowed to use the complete phase space

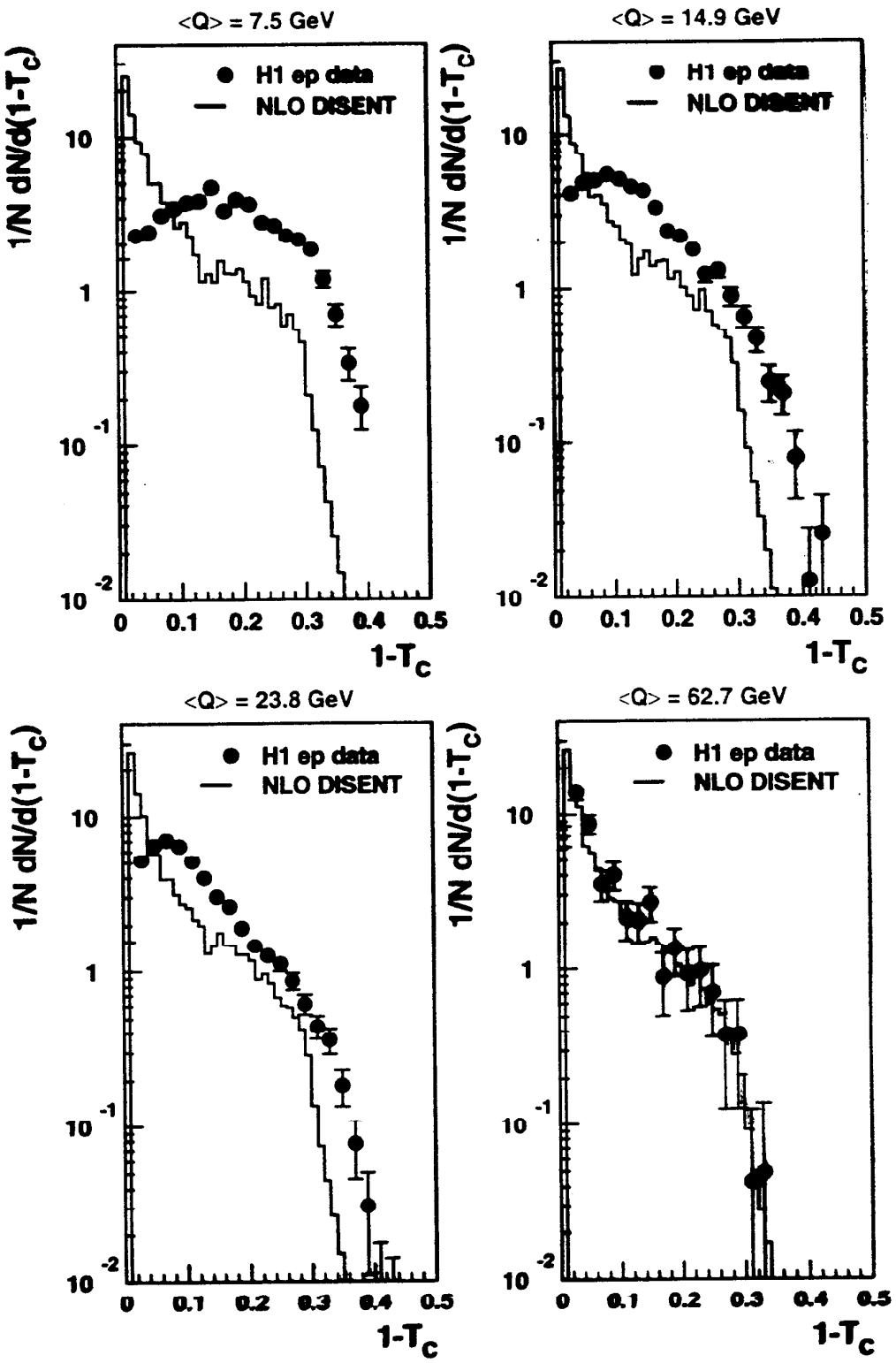
$$0 \leq F \leq F_{\max}.$$

$\Rightarrow$ DISENT results are used in the analysis.

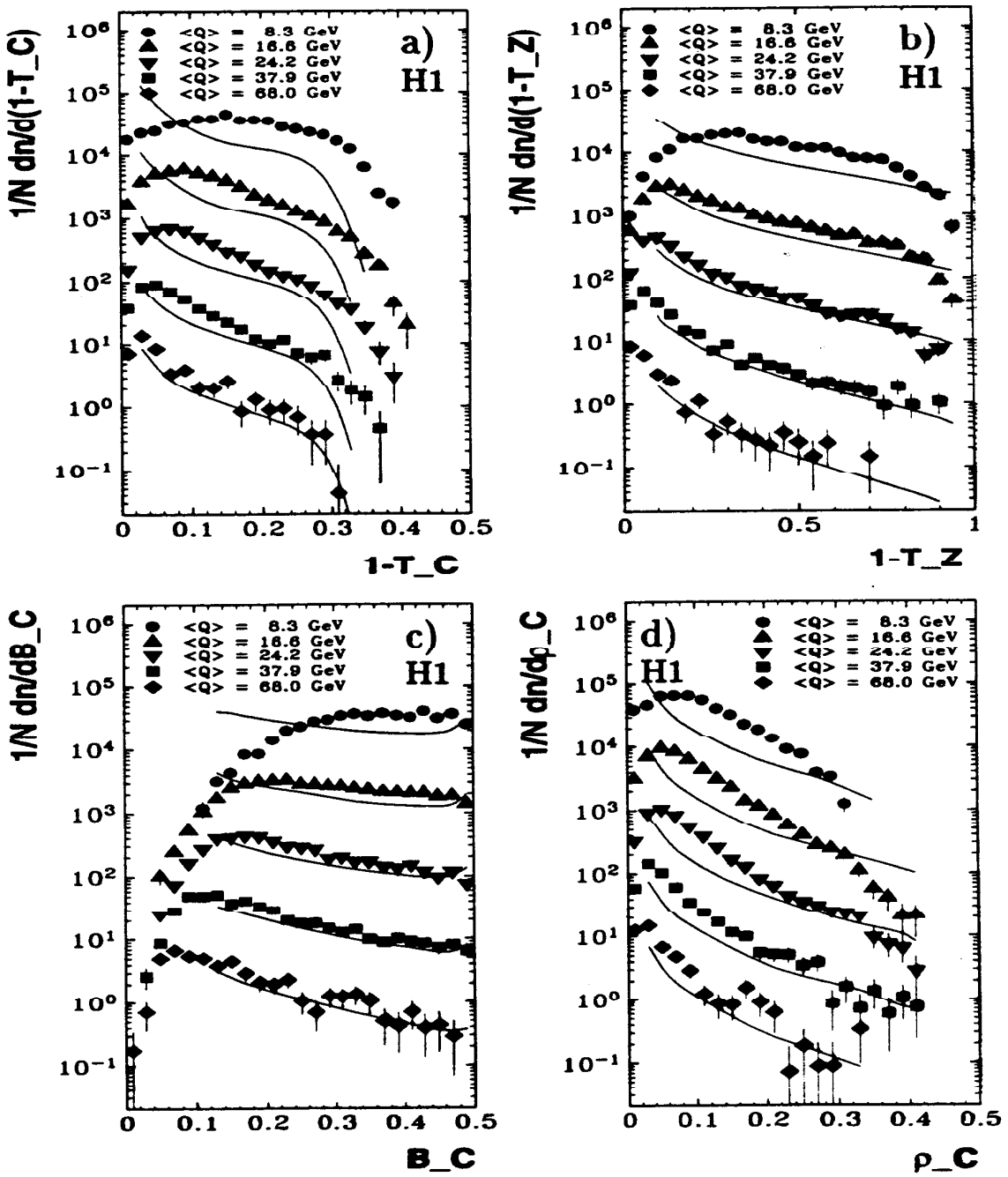
In the overlapping phase space MEPJET and DISENT agree to $< 1\,\%$ in $\mathcal{O}(\alpha_s)$ and $\sim 3\,\%$ $\mathcal{O}(\alpha_s^2)$.


<Q> = 23.8 GeV
LO DISENT
LO MEPJET
(1-T_Z) dN/d(1-T_Z)
1-T_Z
<Q> = 36.9 GeV
LO DISENT
LO MEPJET
(1-T_Z) dN/d(1-T_Z)
1-T_Z
<Q> = 62.7 GeV
LO DISENT
LO MEPJET
(1-T_Z) dN/d(1-T_Z)
1-T_Z


<Q> = 23.8 GeV
NLO DISENT
NLO MEPJET
(1-T_Z) dN/d(1-T_Z)
1-T_Z
<Q> = 36.9 GeV
NLO DISENT
NLO MEPJET
(1-T_Z) dN/d(1-T_Z)
1-T_Z
<Q> = 62.7 GeV
NLO DISENT
NLO MEPJET
(1-T_Z) dN/d(1-T_Z)
1-T_Z


<Q> = 7.5 GeV
<Q> = 14.9 GeV
<Q> = 23.8 GeV
<Q> = 62.7 GeV
H1 ep data
NLO DISENT
1/N dN/d(1-T_C)
1-T_C
10
1
10^-1
10^-2
0
0.1
0.2
0.3
0.4
0.5

H1 differential event shape spectra (full symbols) in comparison with DISENT NLO calculations (full lines):



- **The Power Correction Part**

$$\langle F \rangle^{\text{pow}} = a_F \frac{16}{3\pi} \frac{\mu_I}{Q} \ln^p \frac{Q}{\mu_I} \cdot$$

$$\left[\bar{\alpha}_0(\mu_I) - \alpha_s(Q) - \frac{\beta_0}{2\pi} \left(\ln \frac{Q}{\mu_I} + \frac{K}{\beta_0} + 1 \right) \alpha_s^2(Q) \right]$$

$$\propto a_F \frac{\mu_I}{Q} \ln^p \frac{Q}{\mu_I}$$

contains in addition to the new Scale μ_I and the non-perturbative parameter $\bar{\alpha}_0(\mu_I)$ two coefficients a_F and p, that are calculable and depend on F.

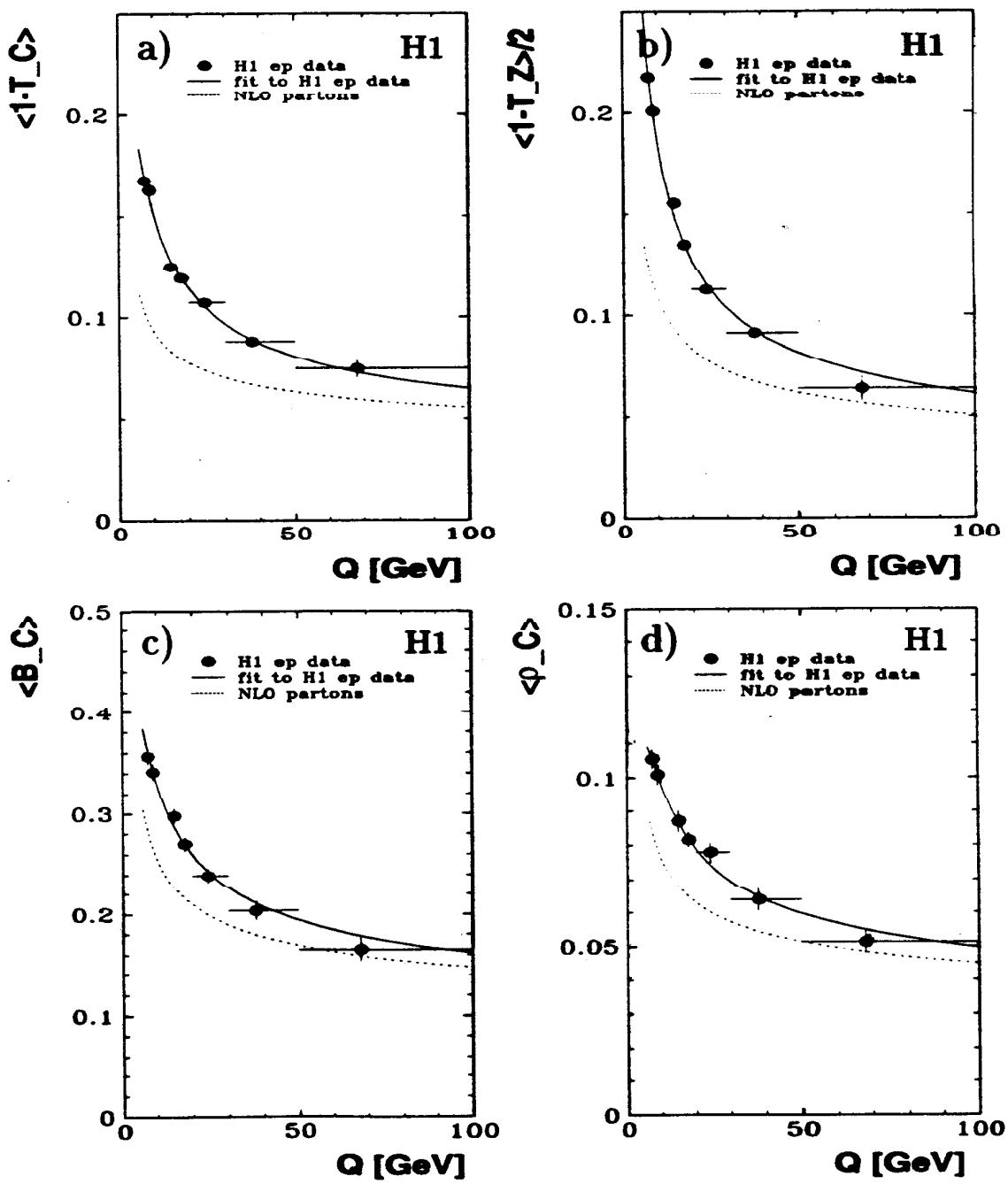
All Power Corrections investigated are $\propto 1/Q$, resp. $p = 0$, except for B_C, where $p = 1$. In our fits, however, the conjectured behaviour of $\langle B_C \rangle$ could not be verified and p was taken to be 0!

- **c_1, c_2 and a_F coefficients used in the QCD fits ($p = 0$ always):**

Observable	c_1	c_2	a_F
$\langle 1 - T_C \rangle$	0.384 ± 0.033	0.57 ± 0.21	1
$\langle 1 - T_Z \rangle / 2$	0.053 ± 0.033	3.45 ± 0.23	1
$\langle B_C \rangle$	0.990 ± 0.121	2.39 ± 0.86	2
$\langle \rho_C \rangle$	0.359 ± 0.048	-0.05 ± 0.30	1/2

5. Fit Results

Q dependence of H1 event shape means (full symbols), DISENT NLO calculations (dotted lines) and power correction fits (full lines):



Error Consideration:

- **Experimental Errors (statistical and systematical):**

$$\delta\bar{\alpha}_0 \simeq \pm 0.007 \qquad\qquad \delta\alpha_s \simeq \pm 0.003$$

- **Theoretical Uncertainties:**

1. NLO Calculations: $\boldsymbol{c_1 \pm \delta c_1,\ c_2 \mp \delta c_2}$

$$\delta\bar{\alpha}_0 \simeq \pm 0.002 \qquad\qquad \delta\alpha_s \simeq \pm 0.001$$

2. **Renormalization Scale:** $\boldsymbol{0.8\,Q < \mu_R < 1.5\,Q}$

$$\delta\bar{\alpha}_0 \simeq \pm 0.06 \qquad\qquad \delta\alpha_s \simeq {}^{-0.005}_{-0.004}$$

The interplay between non-perturbative ($\boldsymbol{\mu_I}$) and perturbative ($\boldsymbol{\mu_R}$) regions is problematic.

Recall: $\Lambda \ll \mu_I \ll \mu_R$
for a range in $\langle Q \rangle$ **of** $7.5 - 68$ GeV

Lower value: **require** $3\,\mu_I < \mu_R$

3. 'Infrared Matching' Scale: $\boldsymbol{\mu_I = 2.0 \pm 0.5}$ **GeV**

$$\delta\bar{\alpha}_0 \propto \mu_I \qquad\qquad \delta\alpha_s \simeq \pm 0.002$$

$\Rightarrow$ **Total error is dominated by theoretical uncertainties.**

- **Results on $\bar{\alpha}_0$ and $\alpha_s(M_Z)$ from fits to the Q dependence of the event shape variables (first error experimental, second error theoretical uncertainties):**

Observable	$\bar{\alpha}_0(\mu_I = 2\ \mathrm{GeV})$	$\alpha_s(M_Z)$	χ^2/ndf
H1 ep data			
$\langle 1 - T_C \rangle$	$0.497 \pm 0.005\ ^{+0.070}_{-0.036}$	$0.123 \pm 0.002\ ^{+0.007}_{-0.005}$	5.0/5
$\langle 1 - T_Z \rangle / 2$	$0.507 \pm 0.008\ ^{+0.109}_{-0.051}$	$0.115 \pm 0.002\ ^{+0.007}_{-0.005}$	8.5/5
$\langle B_C \rangle$	$0.408 \pm 0.006\ ^{+0.036}_{-0.022}$	$0.119 \pm 0.003\ ^{+0.007}_{-0.004}$	5.3/5
$\langle \rho_C \rangle$	$0.519 \pm 0.009\ ^{+0.025}_{-0.020}$	$0.130 \pm 0.003\ ^{+0.007}_{-0.005}$	3.1/5
Common fit without B_C, ignoring correlations!			
$T_C + T_Z + \rho_C$	$0.491 \pm 0.003\ ^{+0.079}_{-0.042}$	$0.118 \pm 0.001\ ^{+0.007}_{-0.006}$	39/19
e^+e^- data			
$\langle 1 - T_{ee} \rangle$	$0.519 \pm 0.009\ ^{+0.093}_{-0.039}$	$0.123 \pm 0.001\ ^{+0.007}_{-0.004}$	10.9/14
$\langle M_H^2/s \rangle$	$0.580 \pm 0.015\ ^{+0.130}_{-0.053}$	$0.119 \pm 0.001\ ^{+0.004}_{-0.003}$	10.9/14

$\Rightarrow$

- **All investigated Event Shape Means exhibit consistently a $1/Q$ behaviour, no $1/Q^2$ terms are needed.**
- **The theoretical ansatz with $p = 1$ for $\langle B_C \rangle$ does not fit to the data.**
- **The concept of a 'universal' Power Correction parameter $\bar{\alpha}_0$ in DIS ep scattering and e^+e^- annihilation is supported.**

6. Conclusions

- **First Analysis of DIS Event Shape Parameters $1 - T_C$, $1 - T_Z$, B_C, ρ_C in the Breit Current Hemisphere**
- **Coverage of a large Range in $Q = 7 \div 100$ GeV in a Single Experiment**
- **The Event Shapes**
  - **become more collimated with rising Q as expected.**
  - **give consistent results.**
  - **are compatible with a Universal Power Correction Parameter $\bar{\alpha}_0 \approx 0.5$ within $\pm 20\,\%$.**
- **Using $\mathcal{O}(\alpha_s^2)$ computations of DISENT and MEPJET and applying the Power Correction Model $\bar{\alpha}_0$ and $\alpha_s(M_Z)$ are simultaneously determined independent of Fragmentation Models.**
  Large theoretical uncertainties emphasize the need for higher order calculations!
- **Comparison with e^+e^- Experiments:**
  - **Q Dependence of Mean Thrust and Jet Masses in Gross Agreement despite Differences in the underlying Physics and the Analysis Methods**
  - **Same Power Correction Parameters $\bar{\alpha}_0$ within $\pm 20\,\%$ of $e\,p$ Results**