

Study of Multiplicity and Event Shapes using ZEUS detector at HERA

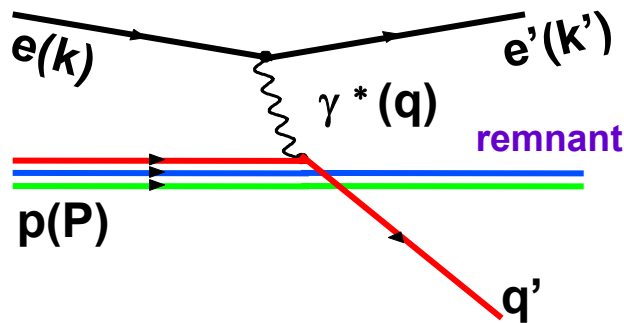
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HERA description & DIS kinematics

- 920 GeV p^+ (820 GeV before 1998)
- 27.5 GeV e^- or e^+
- 318 GeV cms (300 GeV)
- Equivalent to a 50 TeV Fixed Target
- DIS Kinematics:



$$Q^2 = -q^2 = -(k - k')^2 \quad \textit{Virtuality of photon}$$

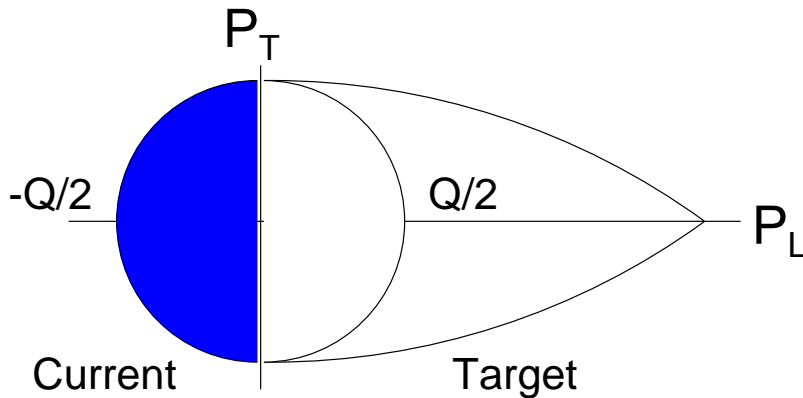
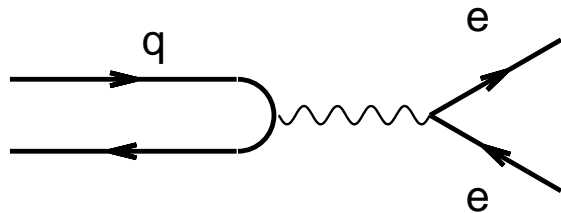
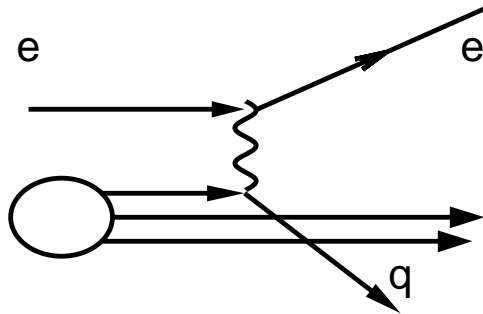
$$y = \frac{p \cdot q}{p \cdot k} \quad \textit{Inelasticity } 0 \leq y \leq 1$$

$$x = \frac{Q^2}{2q \cdot p} \quad \textit{Fraction of } p \textit{ momentum carried by struck parton}$$

e^+e^- & ep : Breit Frame

DIS event

Lab Frame
Breit Frame
Breit Frame

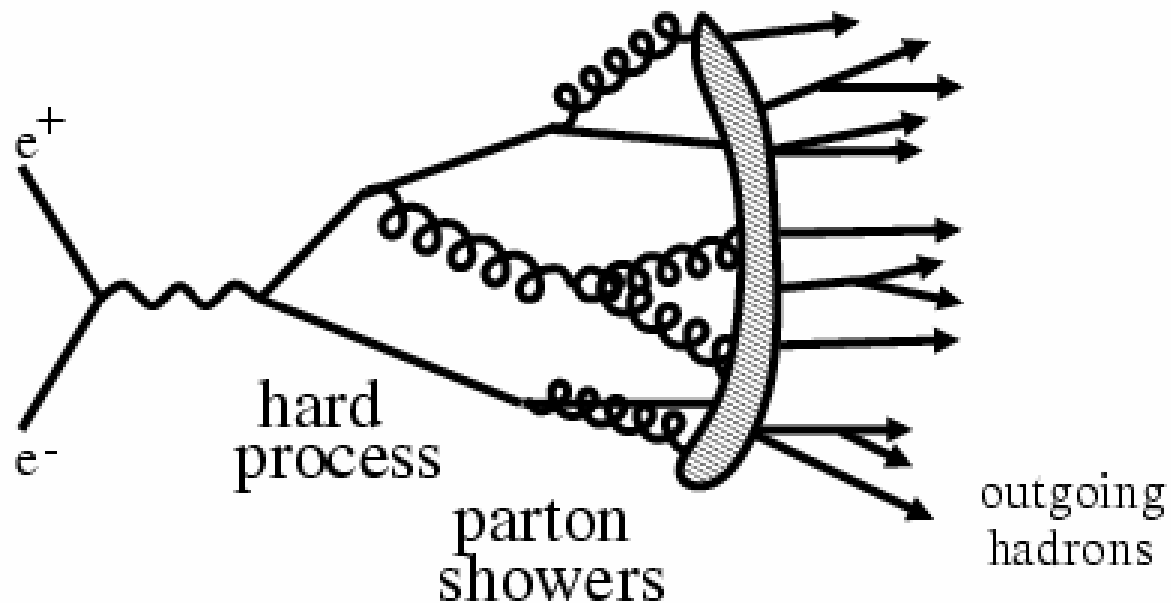


- Breit Frame definition:

$$2xP + q = 0$$

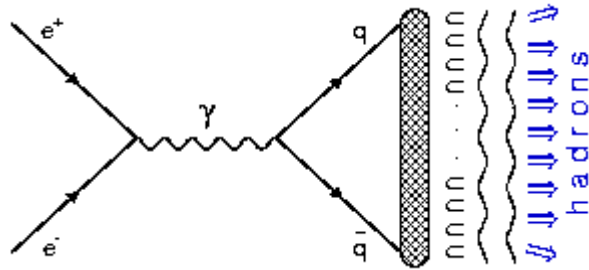
- “Brick wall frame” incoming quark scatters off photon and returns along same axis.
- Current region of Breit Frame is analogous to e^+e^- .

Hard and soft processes

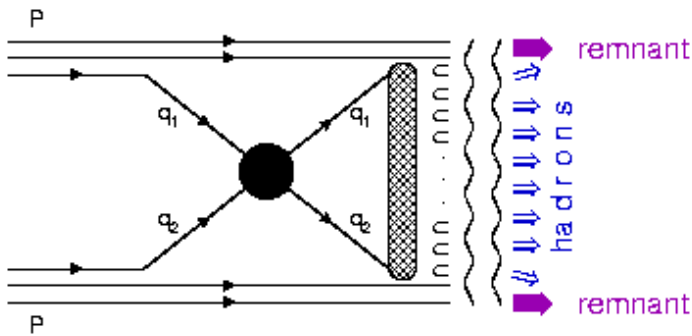


- Hard processes: perturbative QCD
- Soft processes: (hadronization) non-perturbative QCD

Mean multiplicity: e^+e^- and pp

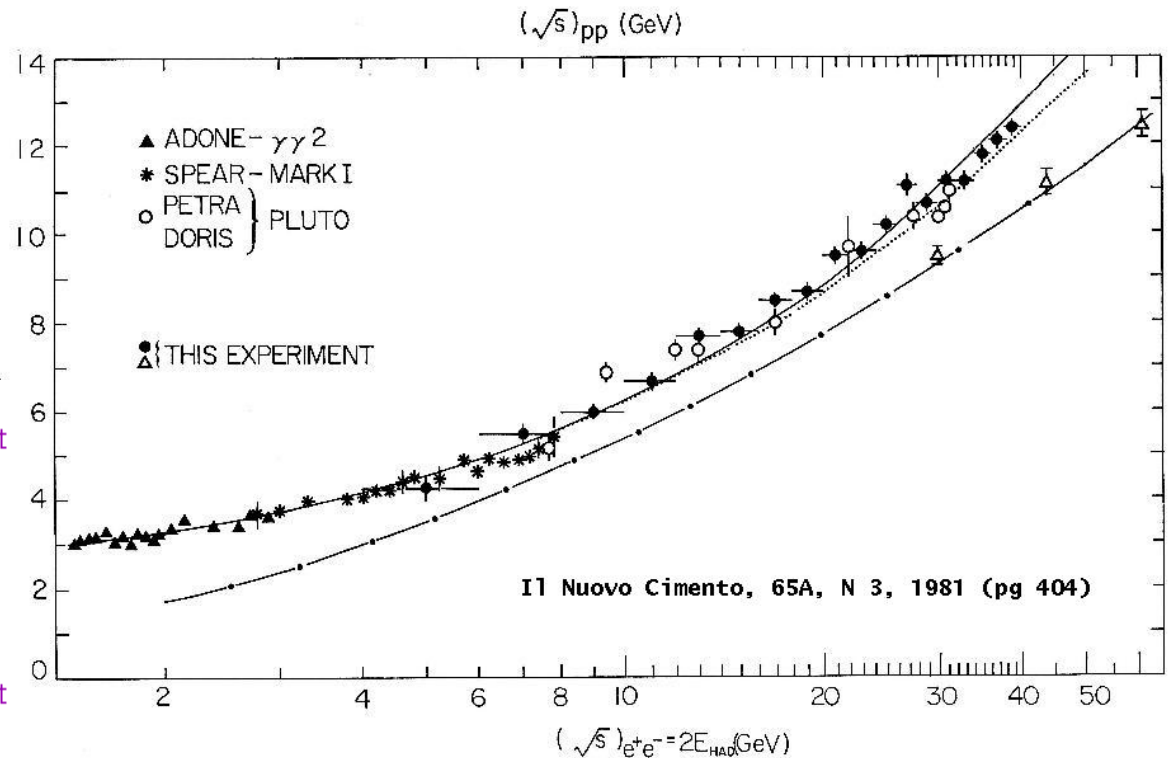


$$\sqrt{s_{e^+e^-}} = \sqrt{(p_{e^-} + p_{e^+})^2}$$



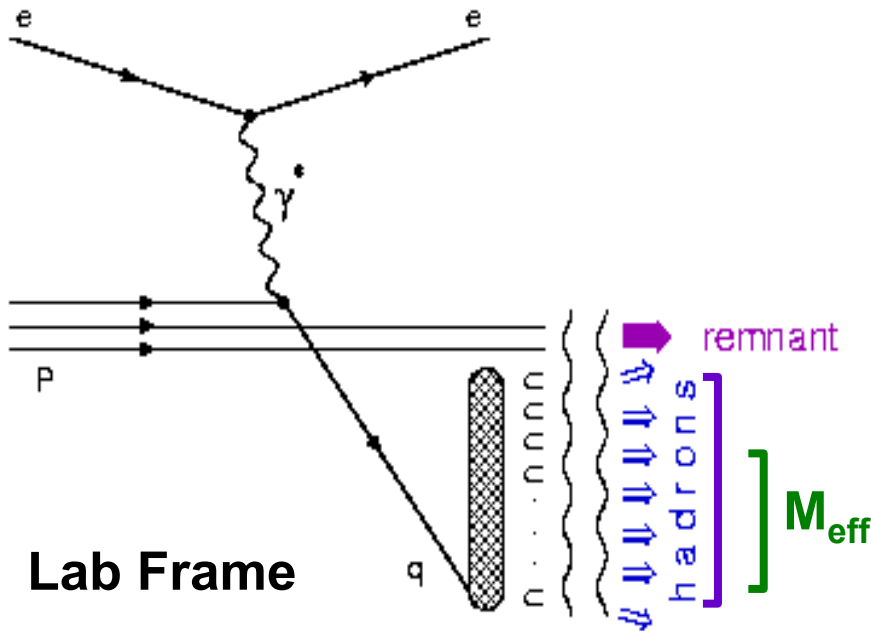
$$\sqrt{s_{pp}} = \sqrt{(p_p + p_p)^2}$$

$$\sqrt{(q_{tot}^{had})^2} = \sqrt{\left[(q_1^{inc} - q_1^{leading}) + (q_2^{inc} - q_2^{leading}) \right]^2}$$



Multiplicity vs. invariant mass of system is universal for pp & e^+e^-

Motivation for the use of M_{eff} as energy scale



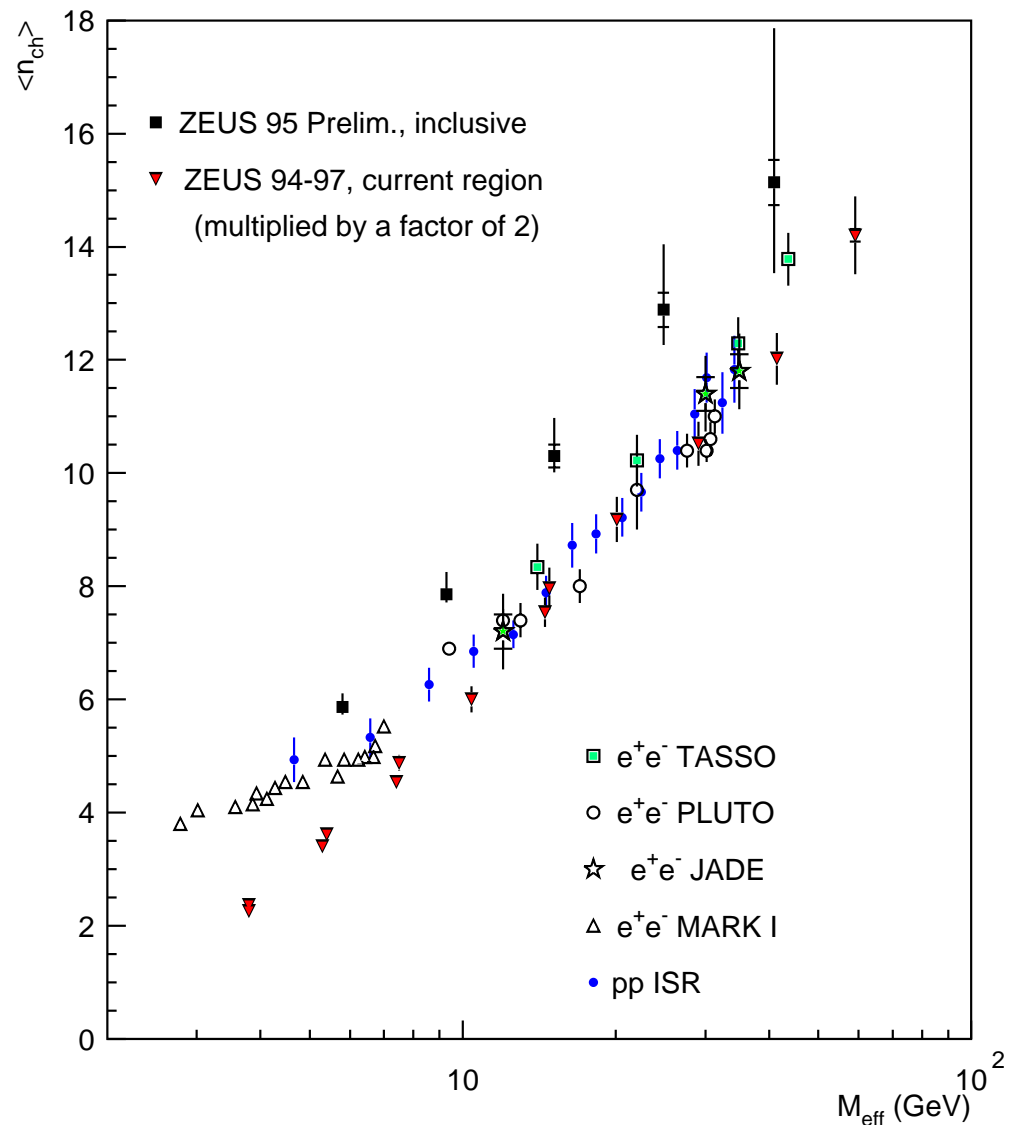
- Analogous to the pp study: want to measure the dependence of $\langle n_{\text{ch}} \rangle$ of on the invariant mass of the system
- Boost in proton direction => proton remnant & fraction of string escape down the beam pipe
- Can measure only a fraction of string: assume $\langle n_{\text{ch}} \rangle$ vs. invariant mass is universal, can compare to pp data
- Use M_{eff} as a scale

$$M_{\text{eff}}^2 = \left(\sum_{i \neq e'} E^i \right)^2 - \left(\sum_{i \neq e'} p_x^i \right)^2 - \left(\sum_{i \neq e'} p_y^i \right)^2 - \left(\sum_{i \neq e'} p_z^i \right)^2$$

M_{eff} : HFS measured in the detector where the tracking efficiency is maximized

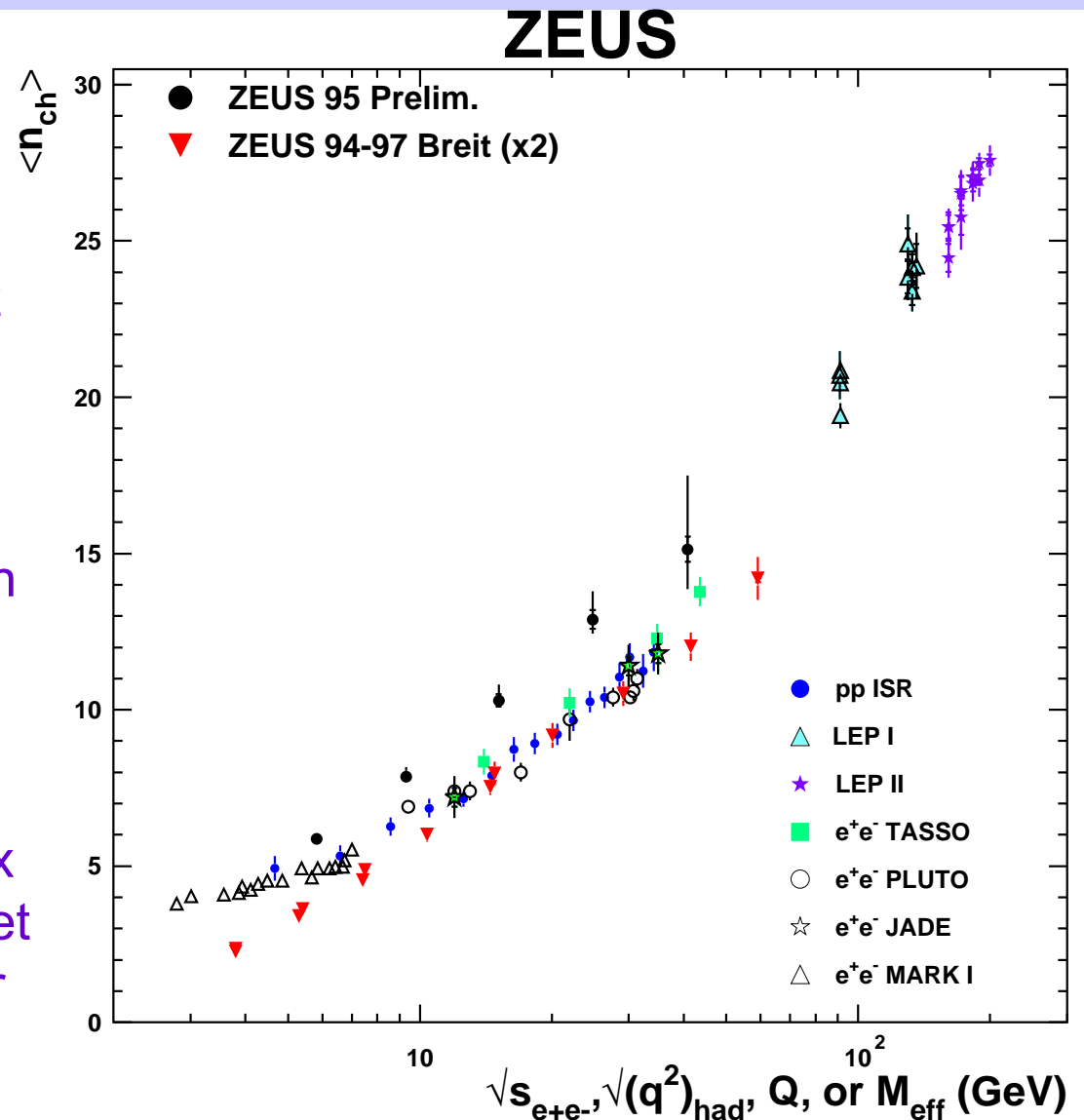
Comparison of multiplicity for ep, with e^+e^- & pp

- mean charged multiplicity, $\langle n_{ch} \rangle$, for different energy scales: e^+e^- (\sqrt{s}), pp ($\sqrt{q^2}$) and ep (M_{eff})
- Excess in $\langle n_{ch} \rangle$ observed for ep data
- Possible explanations: Different contributions from gluons (HERA can reach smaller x than pp)



Compare to LEP data

- LEP data at higher energy: should have contribution from gluons
- Can't conclude from this plot, it seems both ep and pp data could meet LEP points
- $\langle n_{ch} \rangle$ vs. Q for ep in current region of Breit frame agrees with e^+e^- and pp data, for high Q
- Working on improving this measurement using more statistics, and spitting data into x and Q^2 bins, in current and target region aiming for new results for ICHEP 2004.



Study Hadronization using Event Shapes

- Event shape variables measure aspects of the topology of the hadronic final state
- Event shapes in DIS should allow investigation of QCD over a wide range of energy scales, though hadronization corrections are large for these variables
- ***Power Correction:*** analytical calculation suggested by Dokshitzer & Webber to describe the effect of hadronization for these variables
- Event shape analysis is done in current region of the Breit frame

Power corrections: an analytical approach

- Power correction is used to calculate hadronization corrections for any infrared safe event shape variable, F
- Mean event shape variables are sum of perturbative and non-perturbative (power correction) parts
- The power correction depends on two parameters, α_0 and α_s

Used to determine the hadronization corrections

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

$$\langle F \rangle_{\text{pow}} = a_F \frac{16}{3\pi} \frac{\mu_I}{Q} \ln^P \frac{Q}{\mu_I} \bullet \left[\overline{\alpha_0}(\mu_I) - \alpha_s(Q) - \frac{\beta_0}{2\pi} \left(\ln \frac{Q}{\mu_I} + \frac{K}{\beta_0} + 1 \right) \alpha_s^2(Q) \right]$$

$\overline{\alpha_0}$ = “non-perturbative parameter”

-(Dokshitzer, Webber Phys. Lett. B 352(1995)451)

Event Shape Variables

Thrust

Photon axis
 $n : T_\gamma$

n for T_T axis

$$T_k = \max_{\hat{n}_k} \frac{\sum_i |\vec{p}_i \cdot \hat{n}_k|}{\sum_i |\vec{p}_i|}$$

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

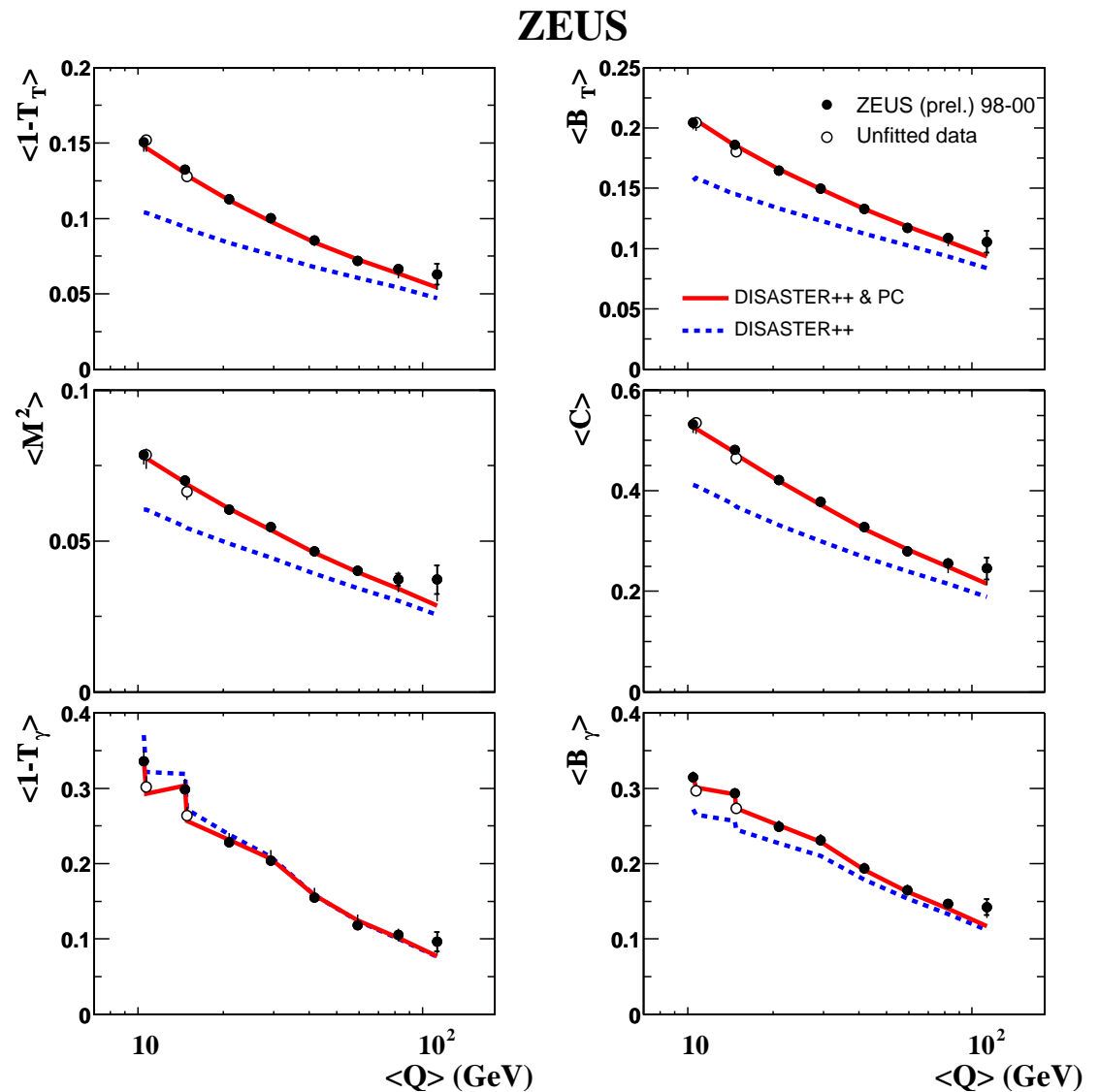
$$M^2 = \frac{(\sum_i p^\mu)^2}{(2 \sum_i E)^2}$$

- Thrust: longitudinal momentum sum
- Broadening: transverse momentum sum
- Measured with n set to the thrust axis, and photon axis
- Jet Mass and C parameter: correlations of pairs of particles
- Sum over all momenta in current region of Breit frame.

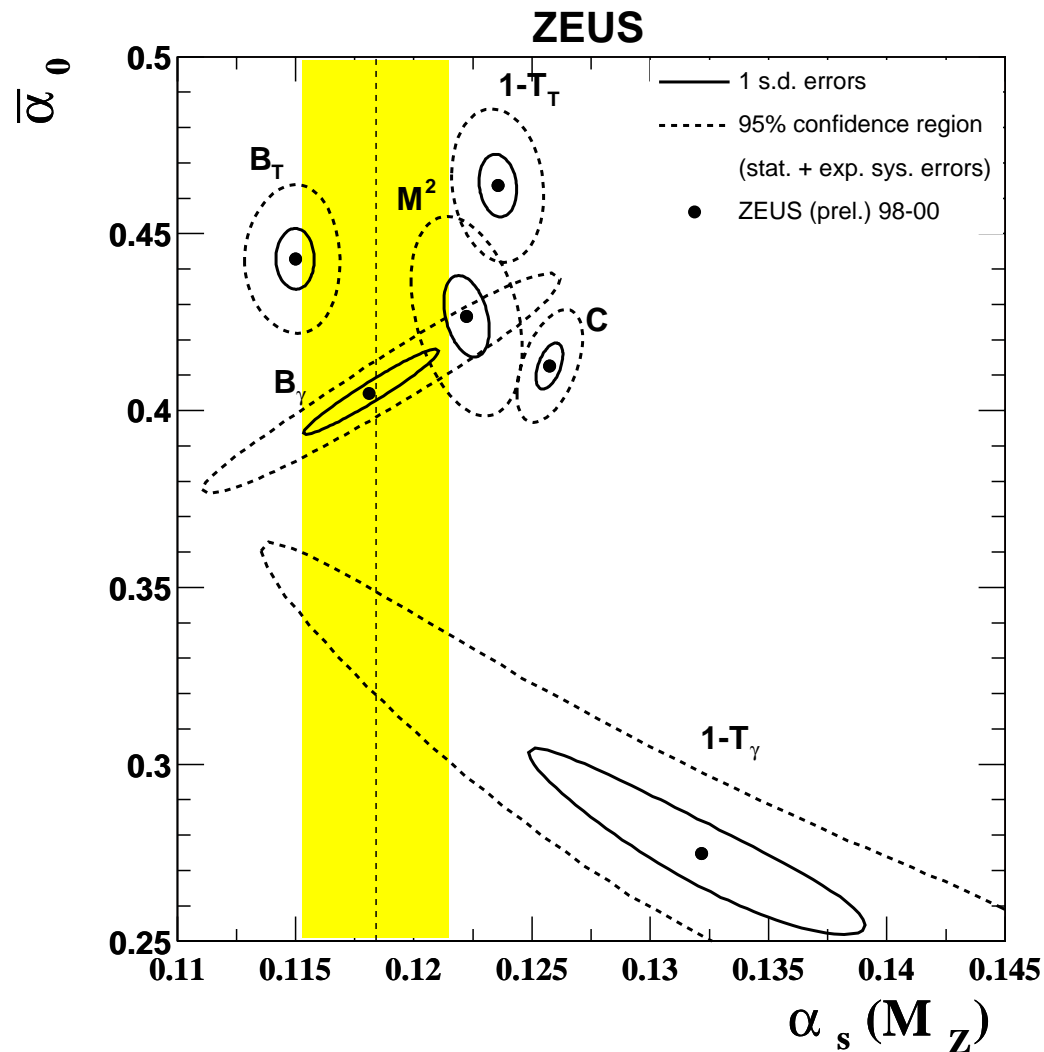
$$C = \frac{3 \sum_{ij} \vec{p}_i \vec{p}_j \sin^2(\theta_{ij})}{2 \sum_{ij} \vec{p}_i \vec{p}_j}$$

Mean event shape variables

- NLO + Power correction fits to means measured in bins of X and Q^2
- High x points (open circles) not fitted
- All variables fitted with a good χ^2
- Photon axis variables ($1-T_\gamma$) show large x -dependence
- $1-T_\gamma$ correction very small and negative
- Model describes data well



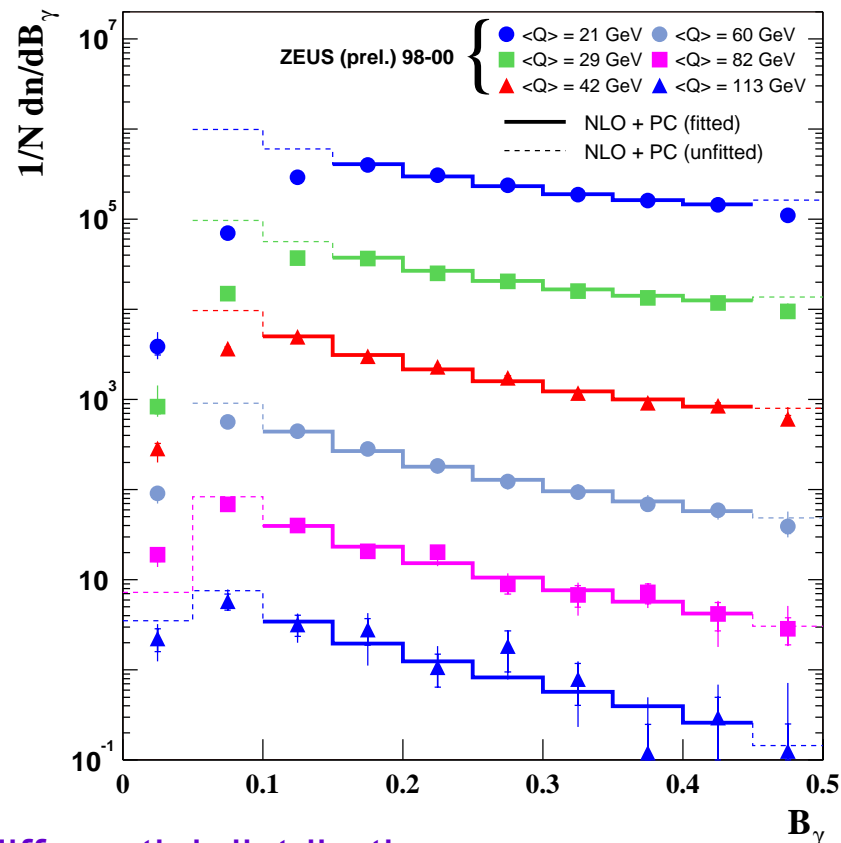
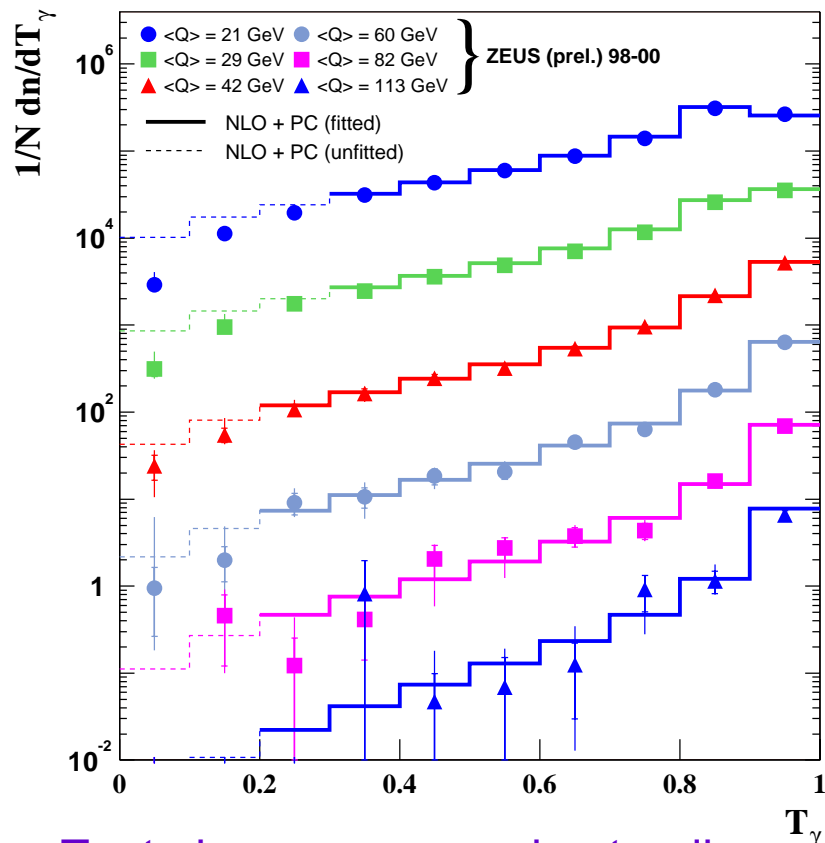
Extraction of α_0 and α_s from NLO + PC fits to means



- Not all variables give same α_s and α_0 .
- $1 - T_\gamma$ fit poorly defined -large systematic errors
- Extracted parameters:
 $\alpha_0 \approx 0.45$, $\alpha_s \approx 0.12$

Differential distributions

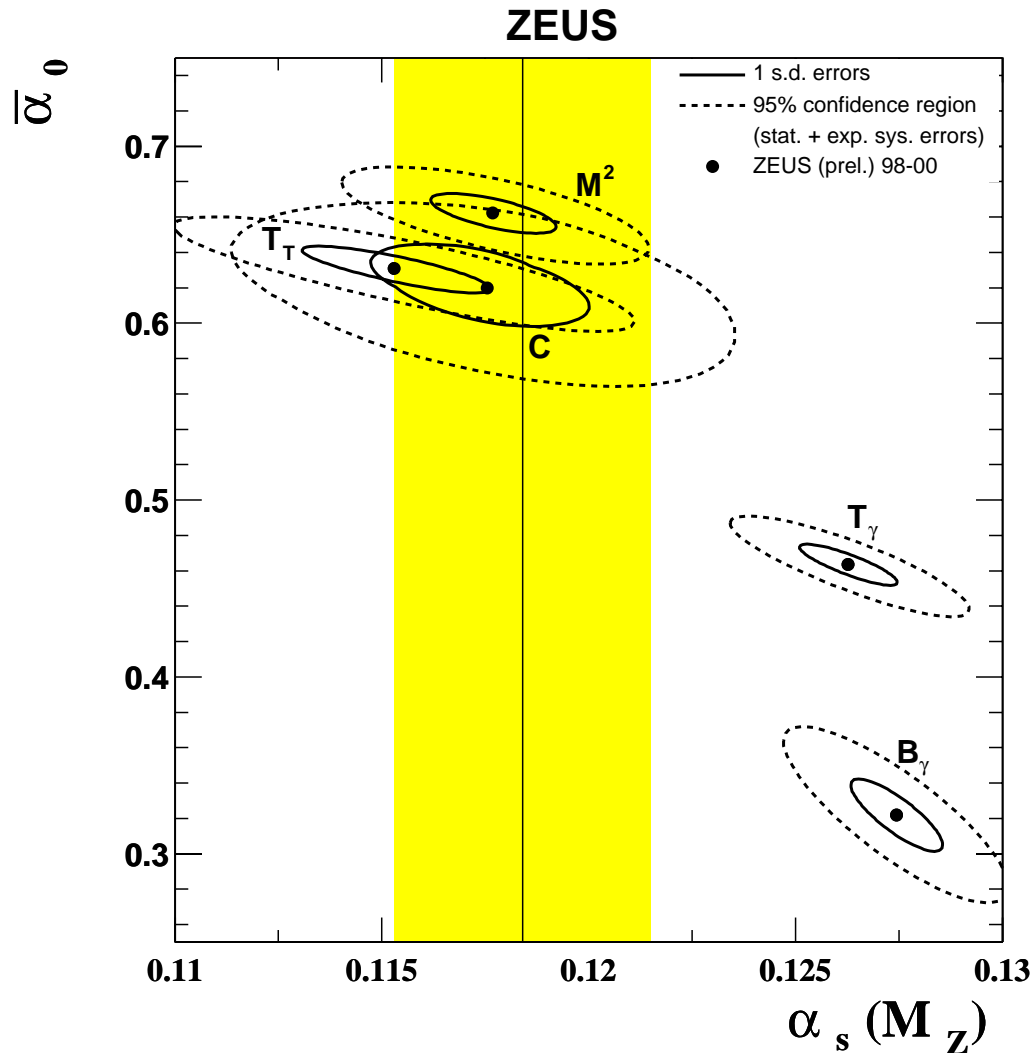
NLO+PC Fits to Differential Distributions ZEUS



- Try to improve our understanding using differential distributions
- Power correction is interpreted as a 'shift' in the NLO distribution

$$\frac{1}{N} \frac{dn}{dF}(F) = \frac{1}{N} \frac{dn_{NLO}}{dF}(F - F_{pow})$$

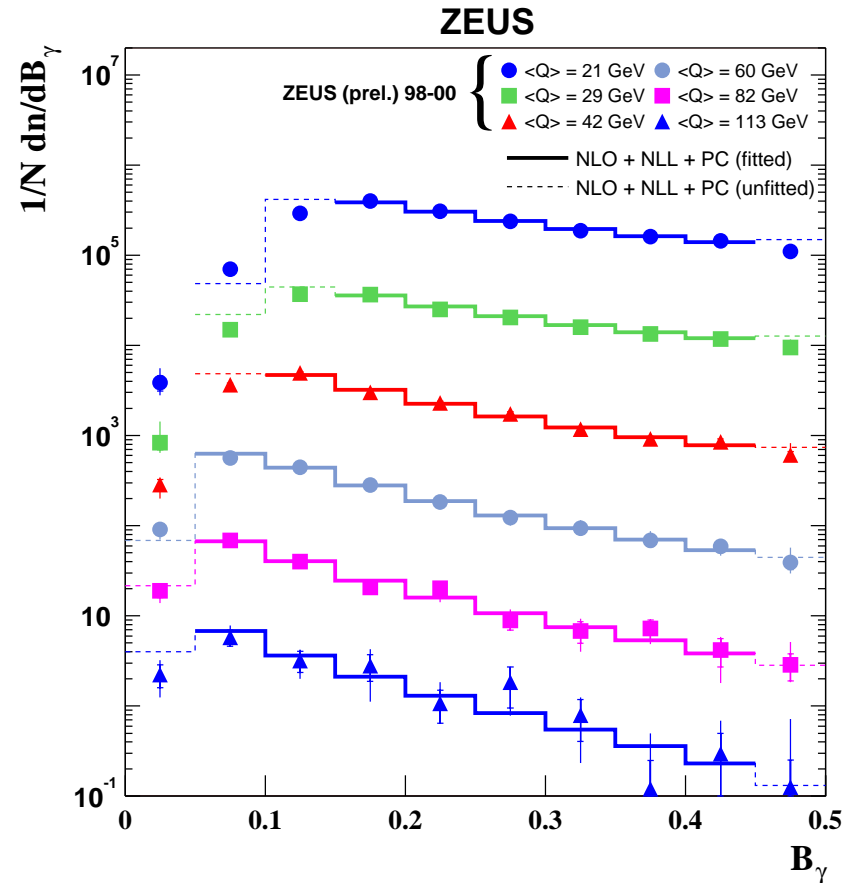
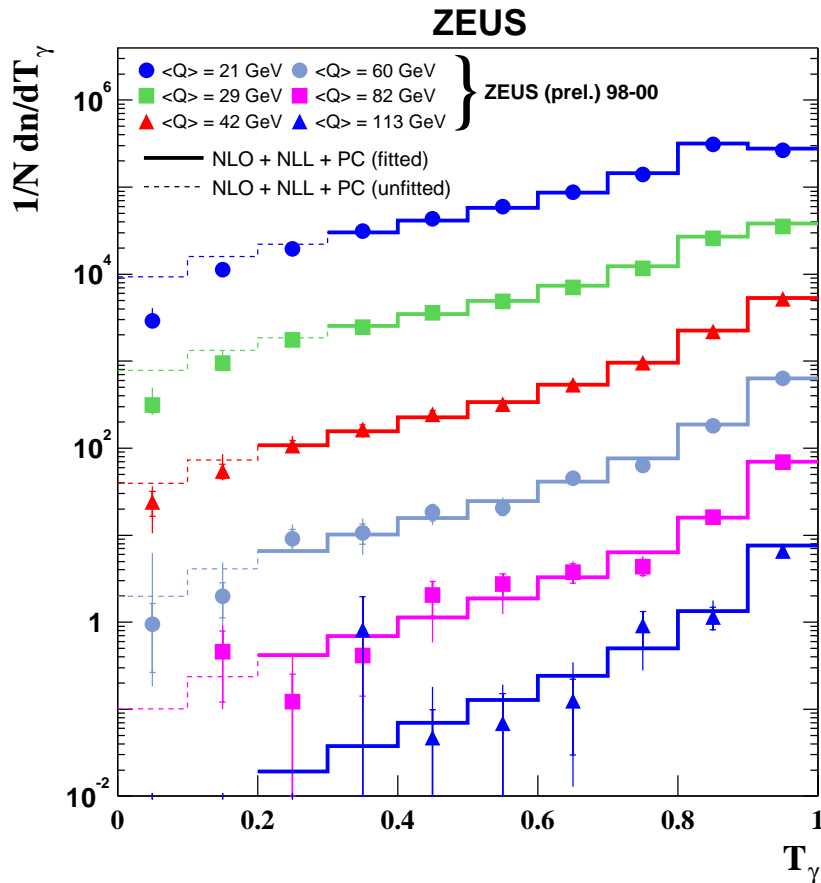
Extraction of α_0 and α_s from fits to differential distributions



- Photon axis variables fit with high α_s , but other variables consistent with each other in α_s and α_0
- Fits α_0 somewhat high compared to that from means
- Extracted parameters:
 $\alpha_0 \approx 0.65$, $\alpha_s \approx 0.12$
- Method a little unstable, try adding NNLO effects-resummations

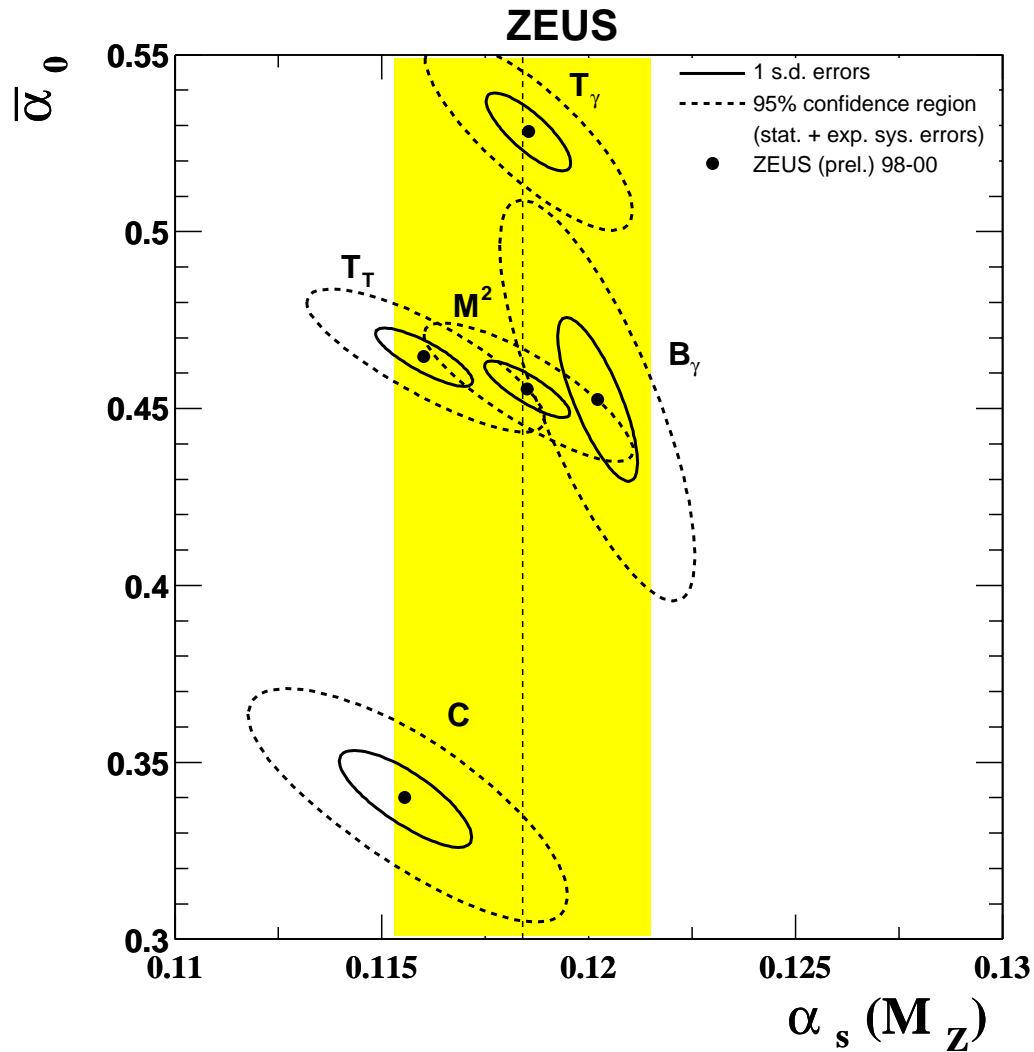
Differential distributions: with resummation

NNLO+NLO+PC Fits to Differential Distributions

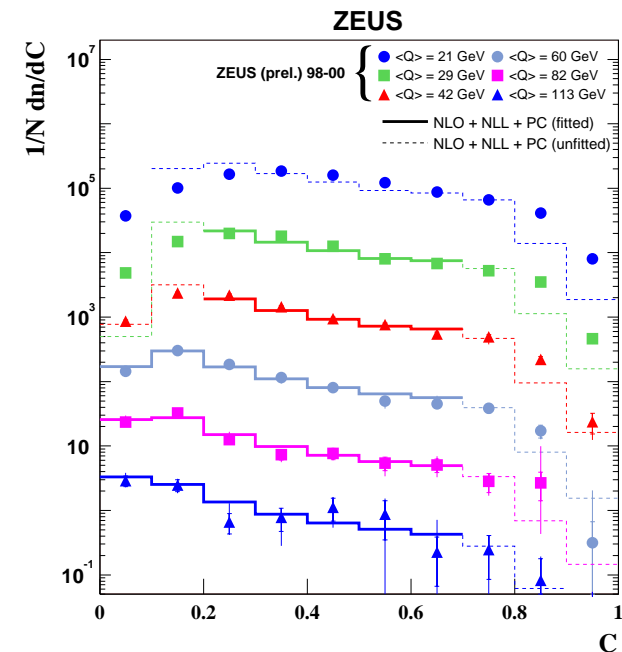


Calculation describes data better; able to enlarge range of fit

Extraction of α_0 and α_s from fits to differential distributions



- C is consistent in α_s but low in α_0 . C result very sensitive to fitted range: under investigation
- α_0 consistent with results from fit to means. Extracted parameters: $\alpha_0 \approx 0.118$, $\alpha_s \approx 0.5$



Summary

Showed results for two methods of investigating hadronization:

•Multiplicity:

- Mean charged multiplicity vs. effective mass was measured for ep and compared to e^+e^- and pp. Multiplicity shows excess in data for ep.
- Current study aiming for higher precision using new data

•Event Shapes:

- NLO + power correction has been fitted to the mean event shape data, $\alpha_s \approx 0.12$, $\alpha_0 \approx 0.45$. Consistent with published results. Photon axis variables poorly determined
- NNLO Resummed calculations give better results than NLO + power correction only, with $\alpha_s \approx 0.118$, $\alpha_0 \approx 0.5$. Resummation gives consistent α_s, α_0 for all event shape variables, but C fit dependant on range
- Current investigation of new event shape variables & new methods. (K_{out} for events with 2 or more jets, 2 jets can fix the NLO predictions better)