Study of Multiplicity and Event Shapes using ZEUS detector at HERA

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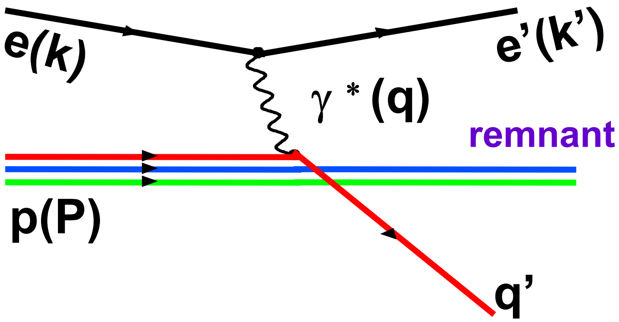
HERA description & DIS kinematics

- 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:



$$Q^2 = -q^2 = -(k - k')^2$$ *Virtuality of photon*

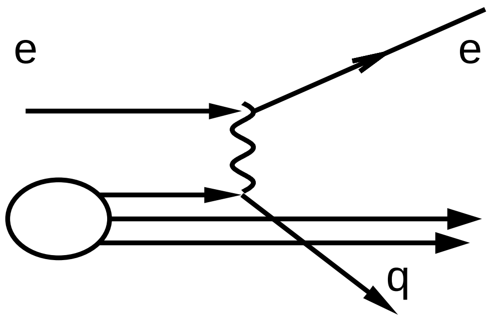
$$y = \frac{p \cdot q}{p \cdot k}$$ *Inelasticity 0 ≤ y ≤ 1*

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

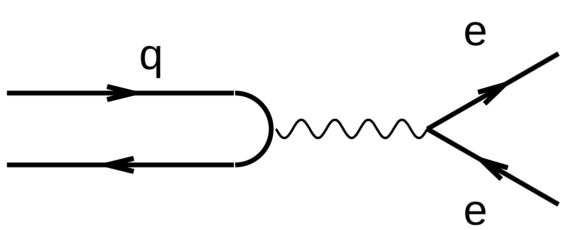
e^+e^- & ep : Breit Frame

DIS event

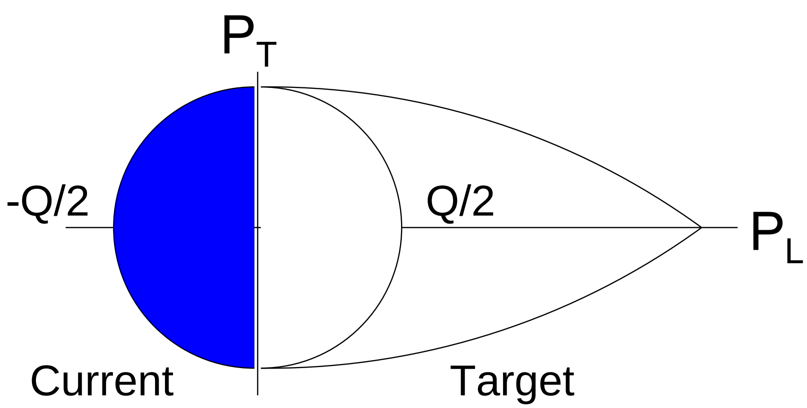
Lab Frame



Breit Frame



Breit Frame



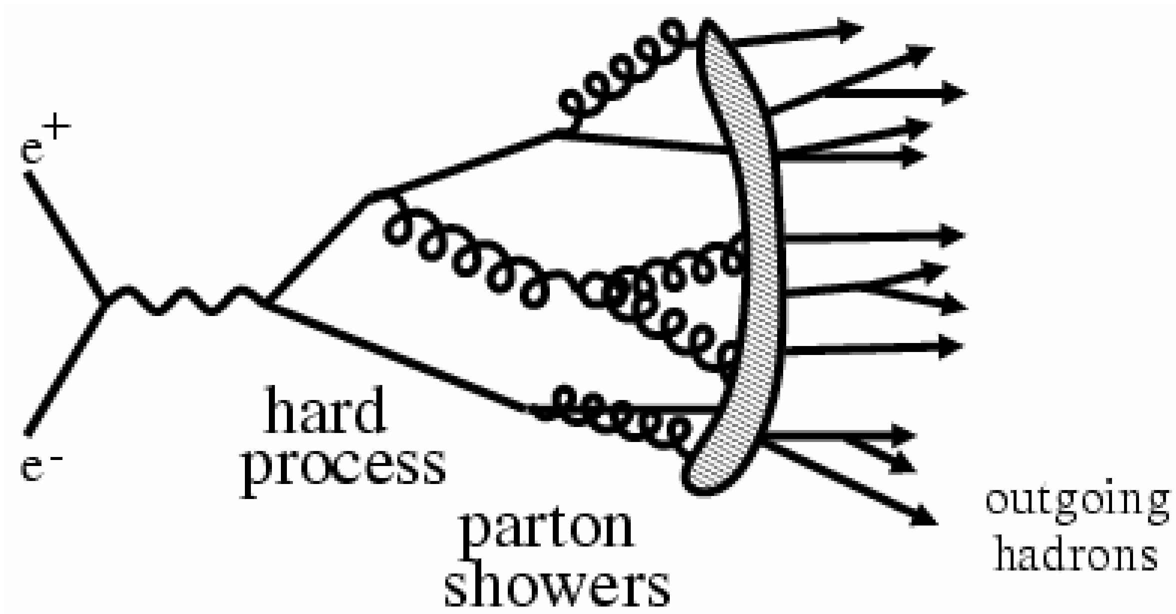
- **Breit Frame definition:**

$$2xP + q = 0$$

- **"Brick wall frame" incoming quark scatters off photon and returns along same axis.**

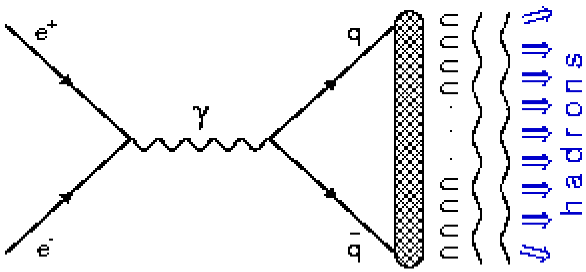
- **Current region of Breit Frame is analogous to e^+e^-.**

Hard and soft processes

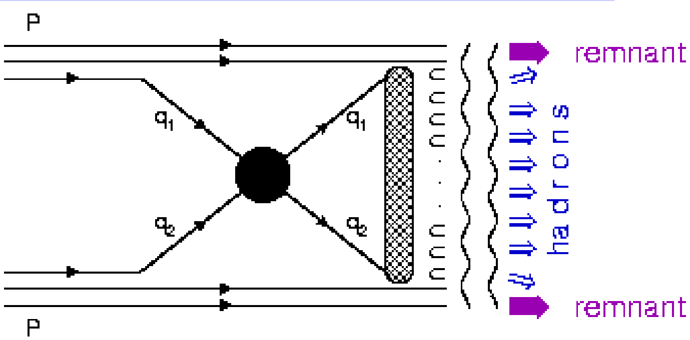


- **Hard processes: perturbative QCD**
- **Soft processes: (hadronization) non-perturbative QCD**

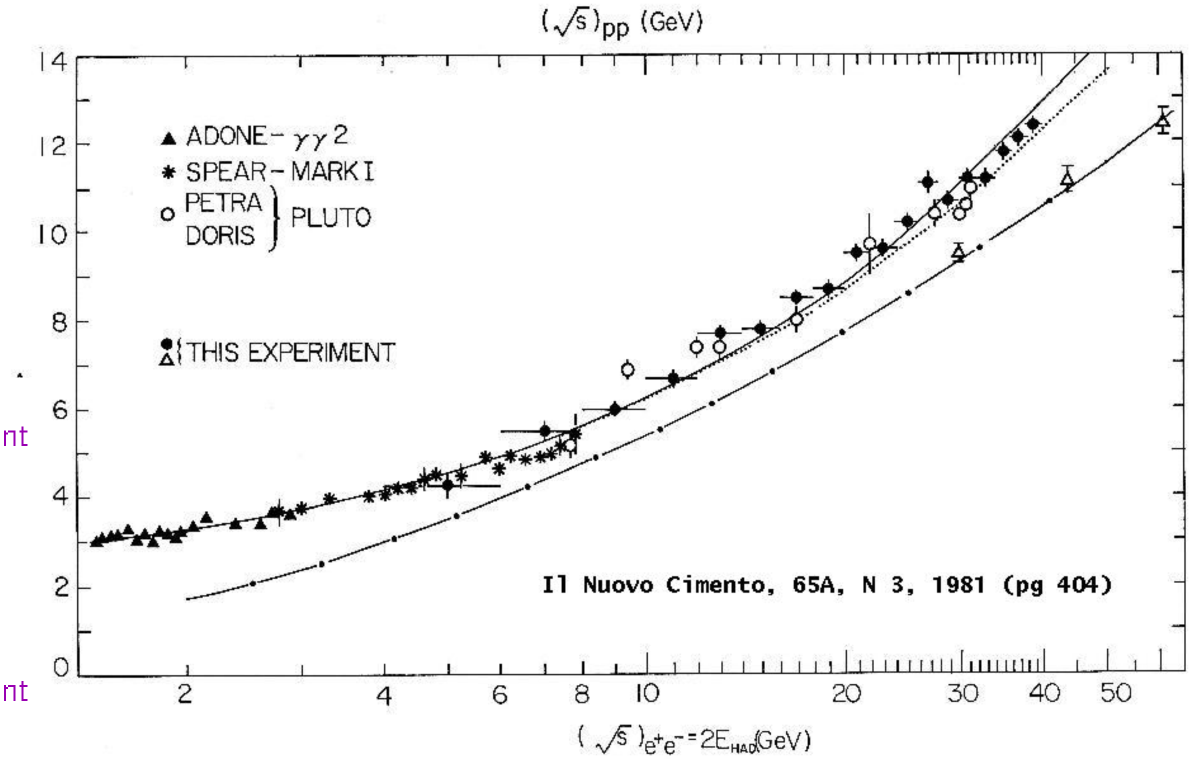
Mean multiplicity: e^+e^- and pp



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



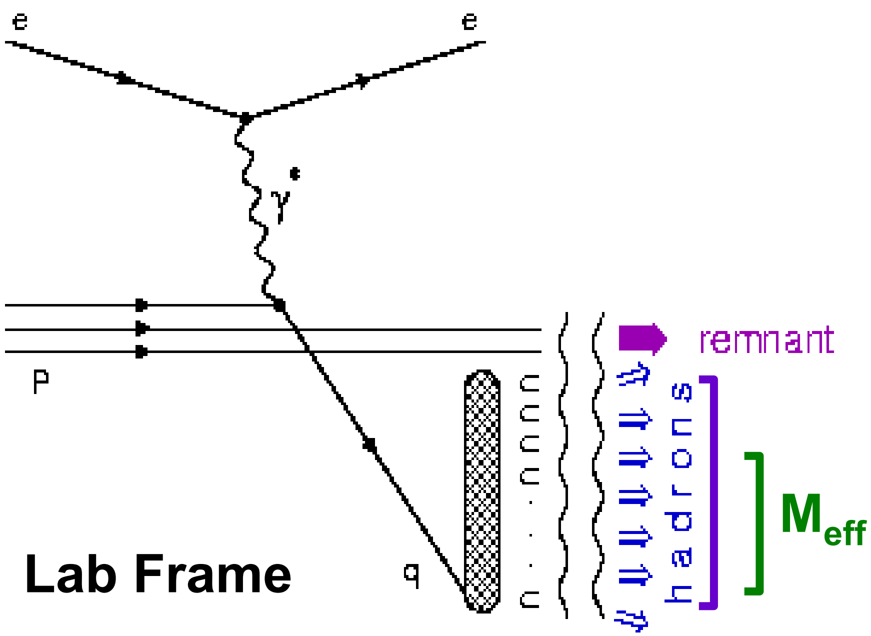
$$\sqrt{s_{pp}} = \sqrt{\left(p_p + p_p\right)^2}$$



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

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

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



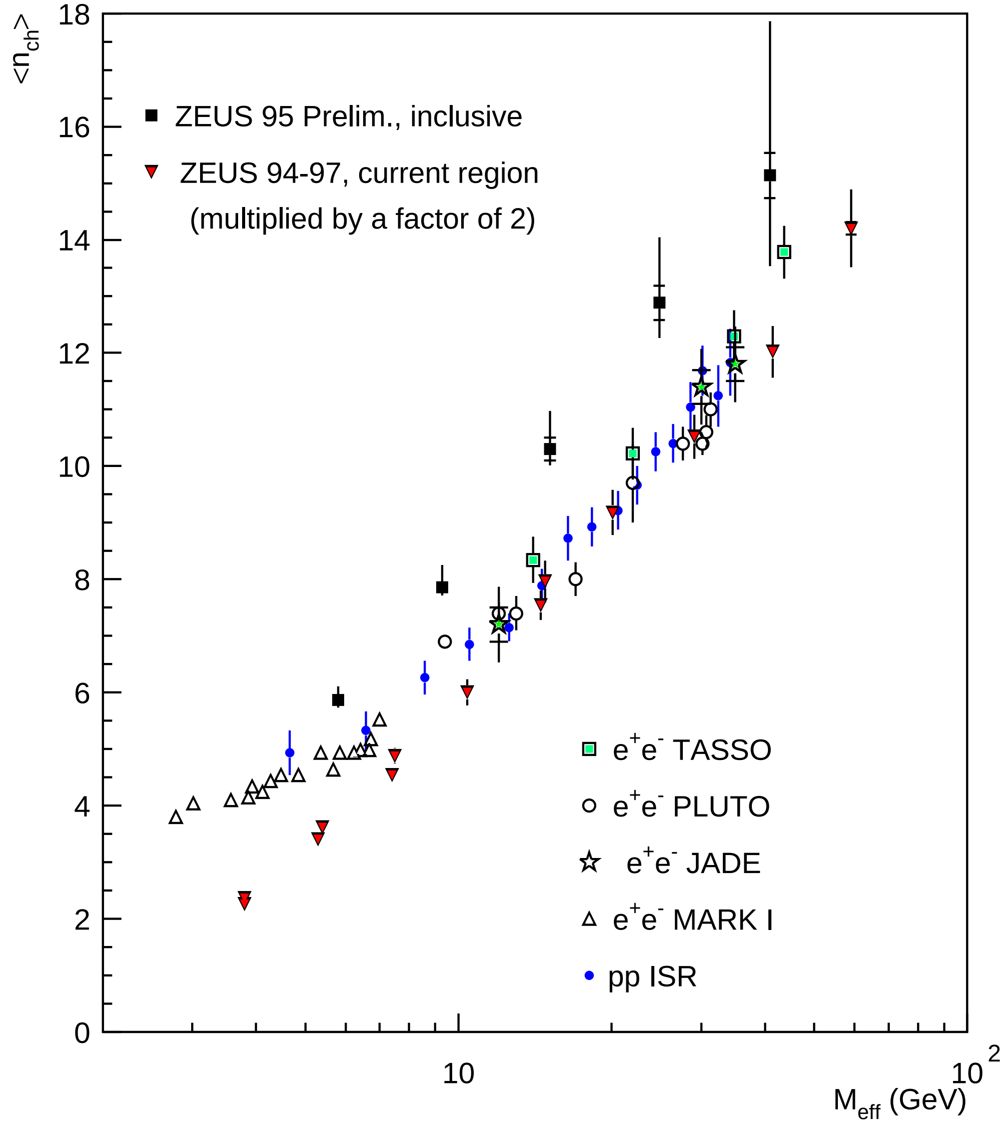
- Analogous to the pp study: want to measure the dependence of $\langle n_{ch} \rangle$ of on the invariant mass of the system
- Boost in proton direction => proton remnant & fraction of string escape down the beam pipe
- Can measure only a fraction of string: assume $\langle n_{ch} \rangle$ vs. invariant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

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

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

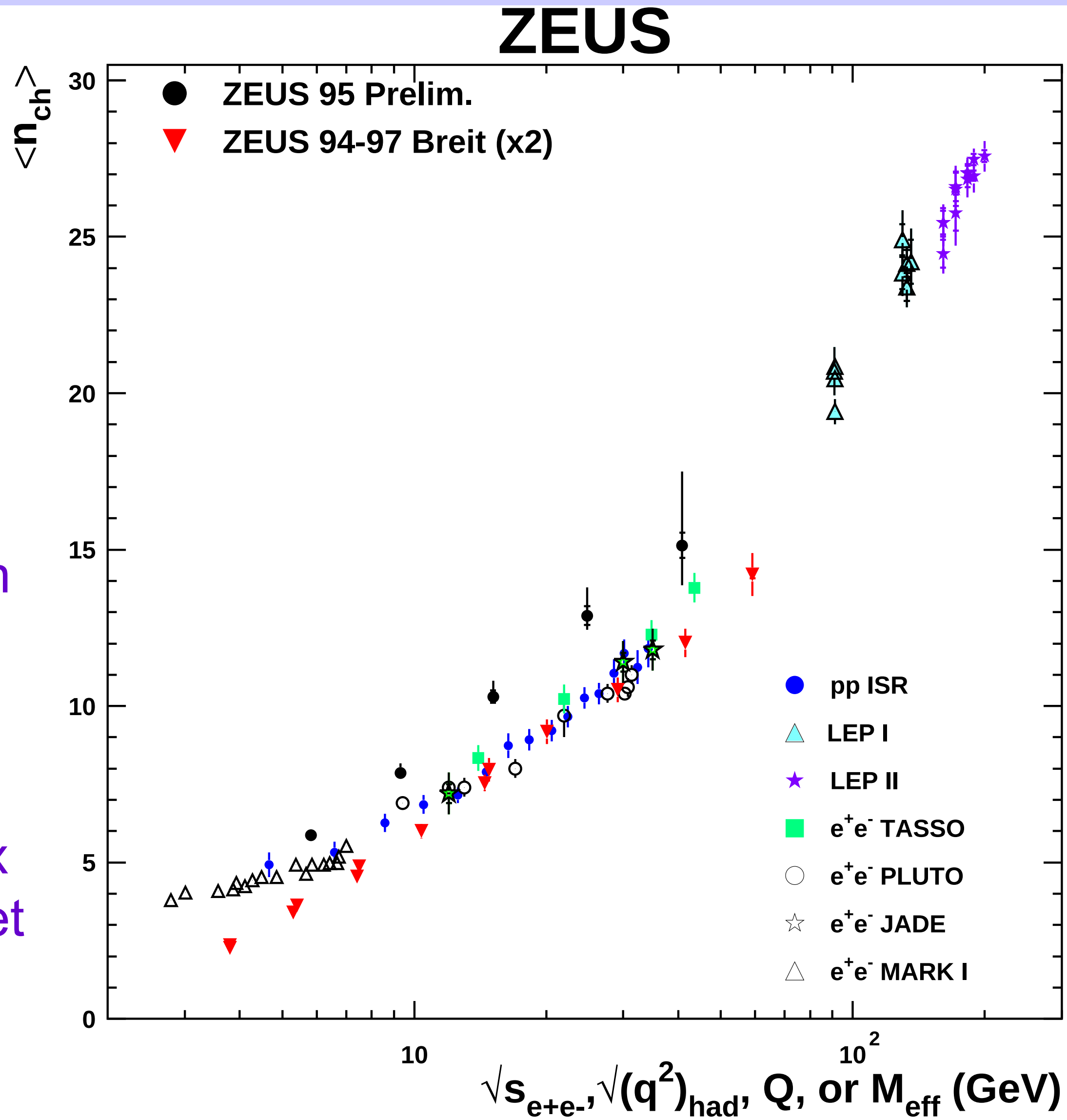
Comparison of multiplicity for ep, with e^+e^- & pp

- mean charged multiplicity, $<n_{ch}>$, for different energy scales: e^+e^- ($\sqrt{s}$), pp ($\sqrt{q^2}$) and ep (M_{eff})
- Excess in $<n_{ch}>$ 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

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

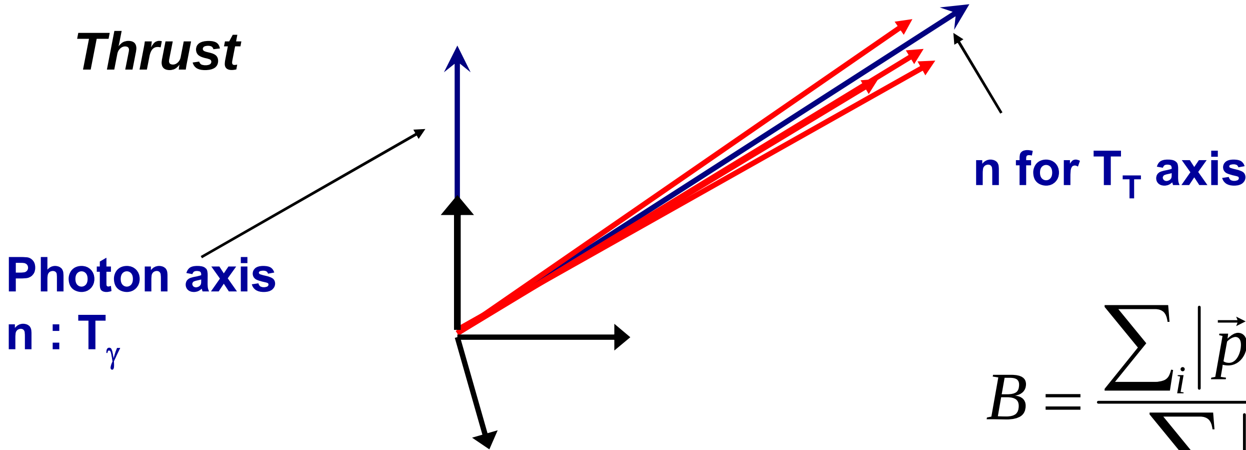
$$\langle F \rangle_{pow} = a_F \frac{16}{3\pi} \frac{\mu_I}{Q} \ln^P \frac{Q}{\mu_I} \bullet \left[\overline{\alpha_0}(\mu_I) - \alpha_s(Q) - \frac{\beta_0}{2\pi}\left(\ln \frac{Q}{\mu_I} + \frac{K}{\beta_0} + 1\right)\alpha_s^2(Q) \right]$$

$\overline{\alpha_0}$ = **"non-perturbative parameter"**

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

Event Shape Variables

Thrust



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

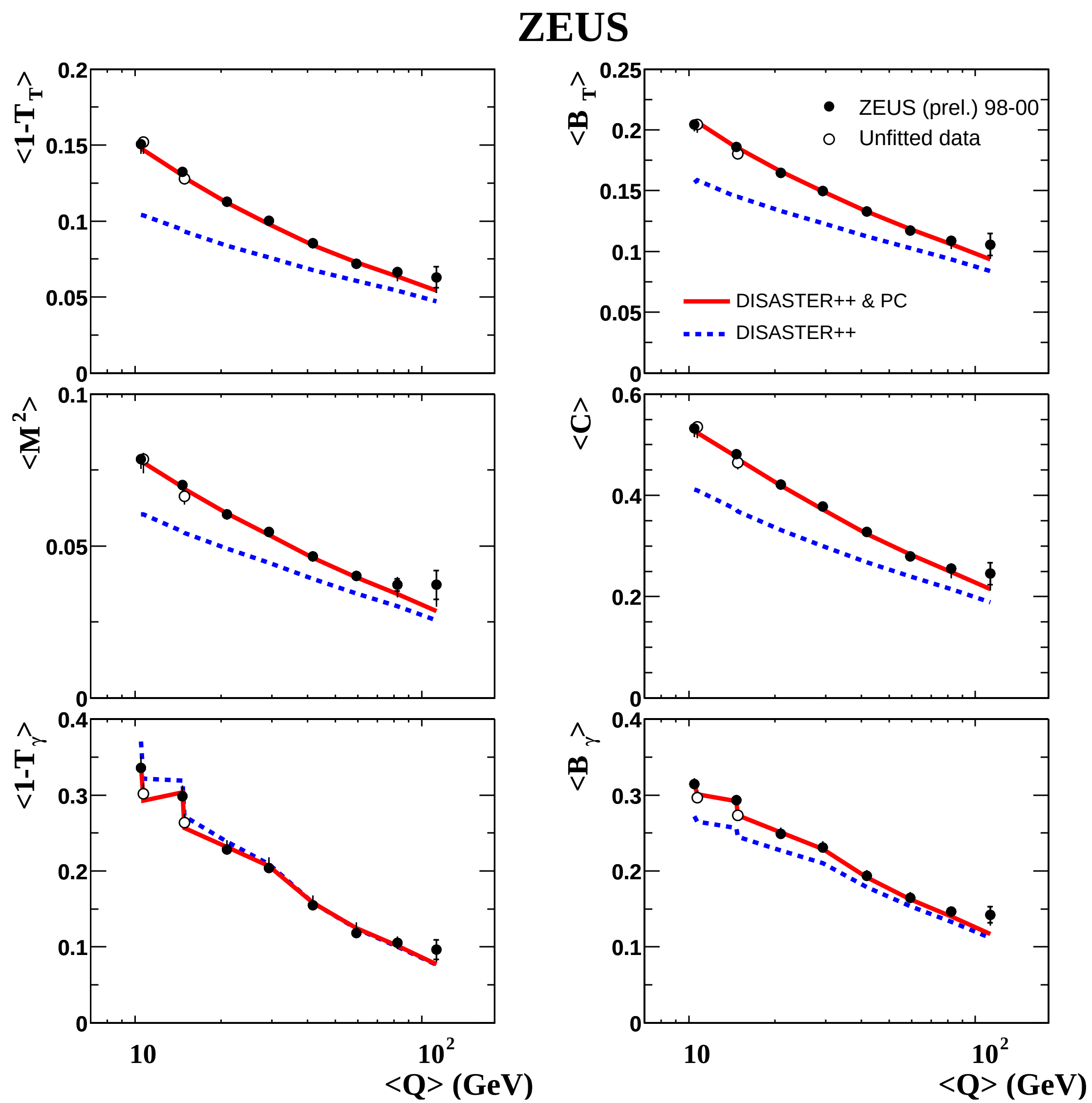
$$B = \frac{\sum_i \left| \vec{p} \times \vec{n} \right|}{\sum_i \left| \vec{p} \right|} \qquad M^2 = \frac{\left(\sum_i p^\mu \right)^2}{\left(2 \sum_i E \right)^2}$$

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

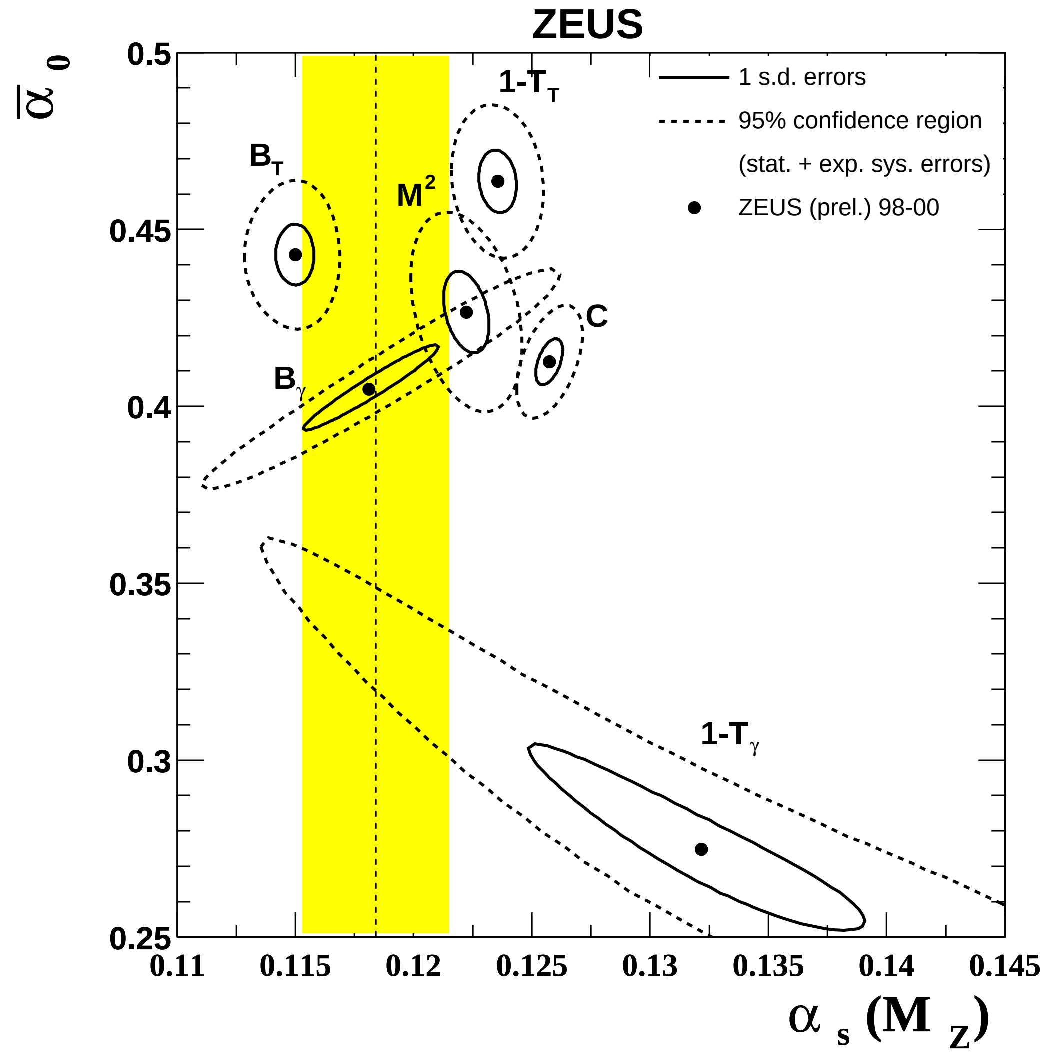
- Thrust: longitudinal momentum sum
- Broadening: transverse momentum sum
- Measured with n set to the thrust axis, and photon axis
- Jet Mass and C parameter: correlations of pairs of particles
- Sum over all momenta in current region of Breit frame.

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



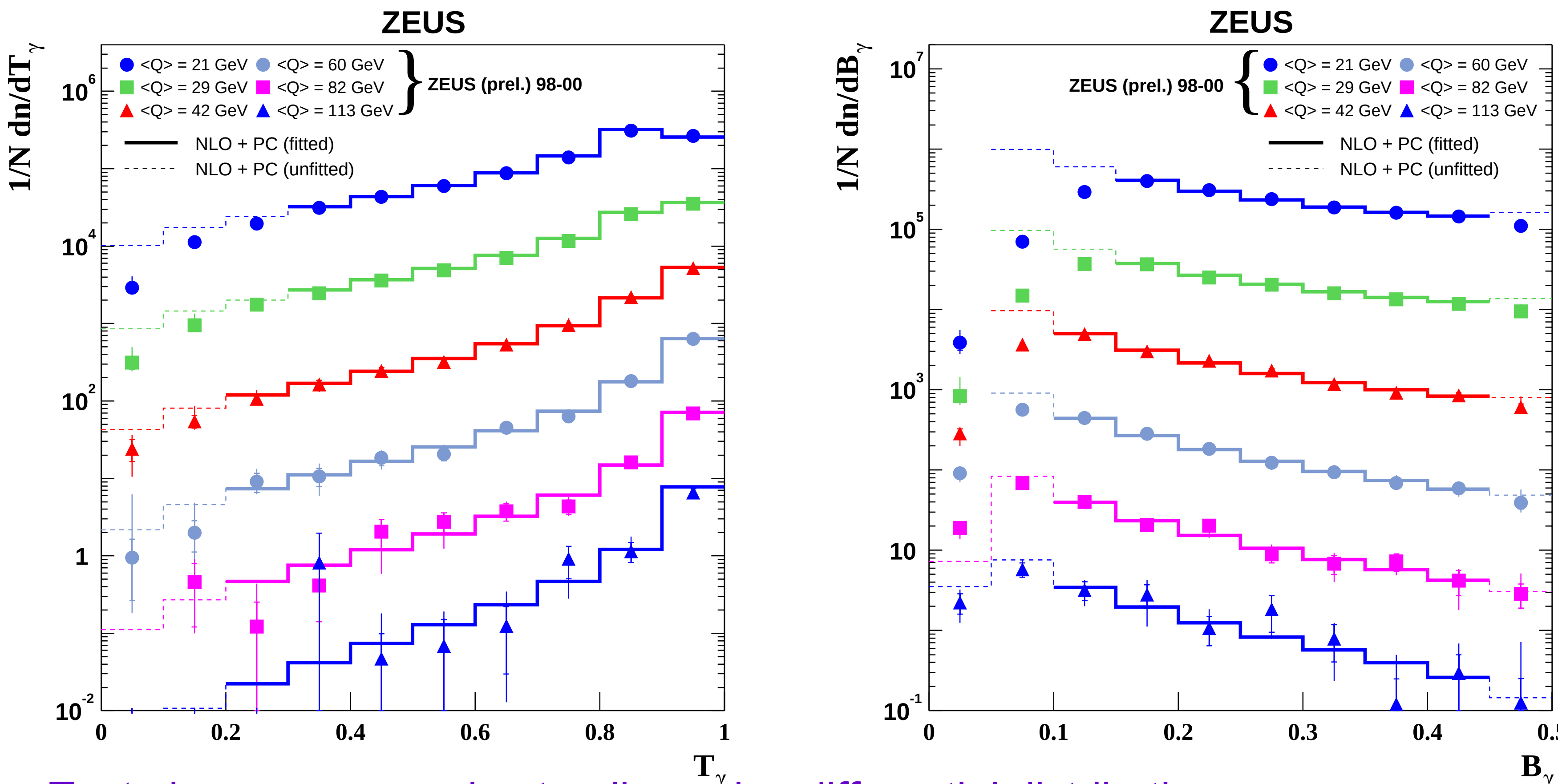
Extraction of α_0 and α_s from NLO + PC fits to means



- Not all variables give same α_s and α_o.
- 1 – Tγ fit poorly defined -large systematic errors
- Extracted parameters: $\alpha_o \approx 0.45$, $\alpha_s \approx 0.12$

Differential distributions

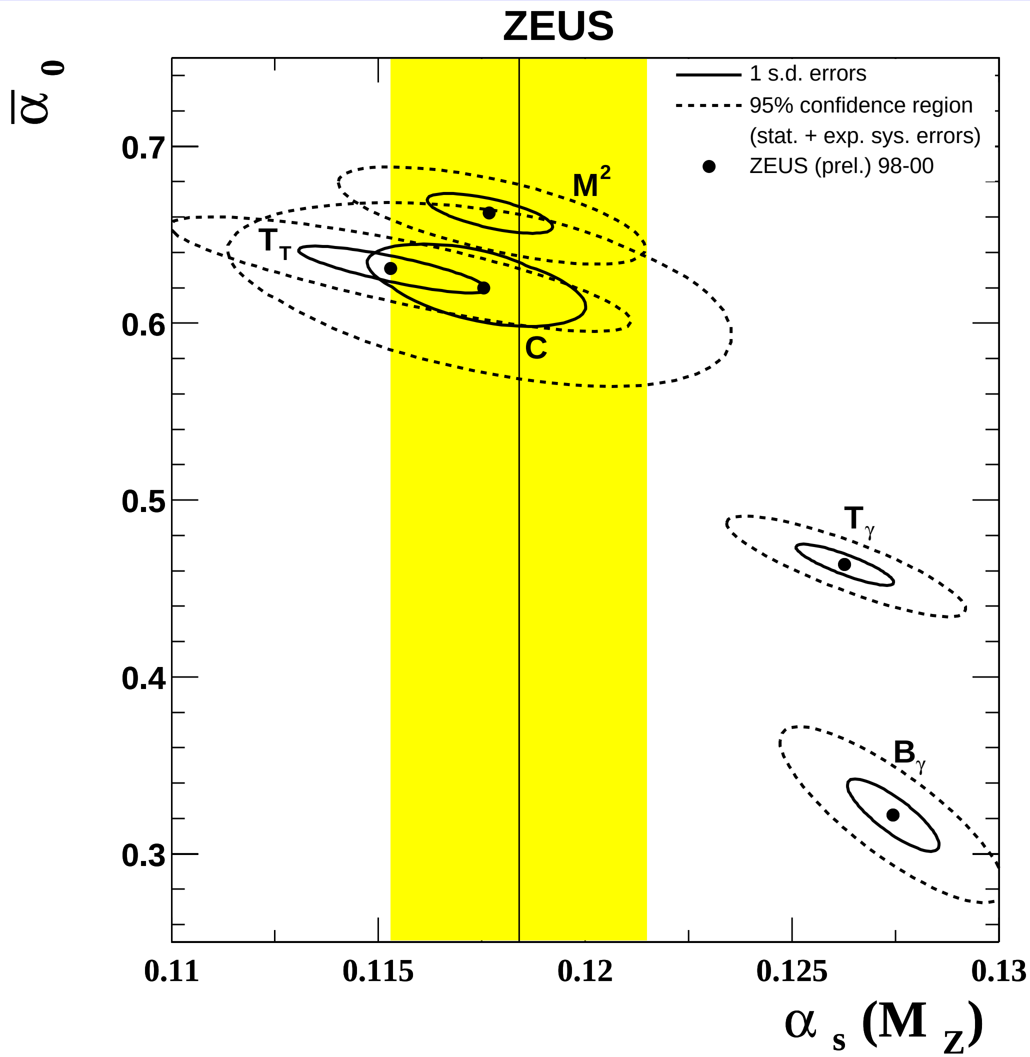
NLO+PC Fits to Differential Distributions



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

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

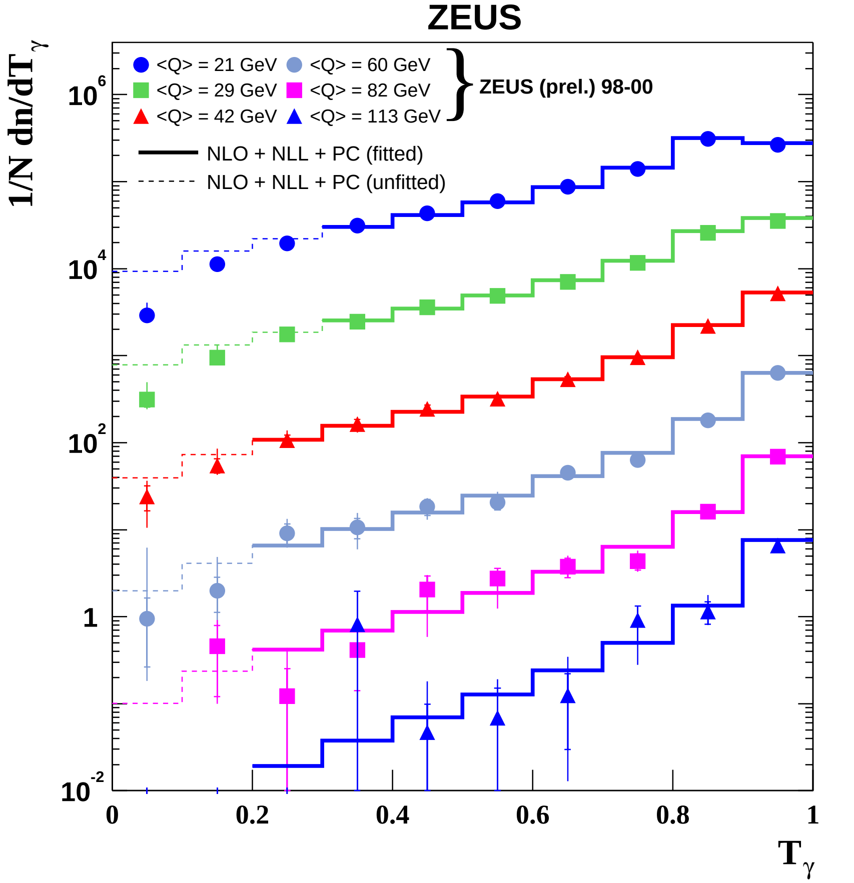
Extraction of α_0 and α_s from fits to differential distributions

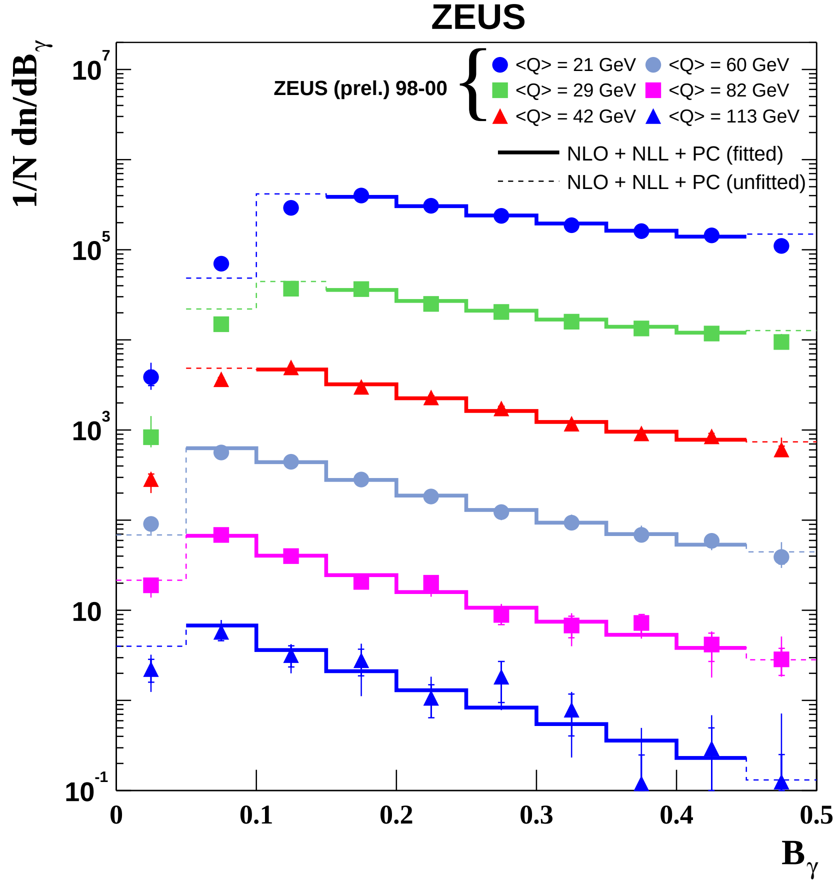


- Photon axis variables fit with high α_s, but other variables consistent with each other in α_s and α_o
- Fits α_o somewhat high compared to that from means
- Extracted parameters: $\alpha_o \approx 0.65$, $\alpha_s \approx 0.12$
- Method a little unstable, try adding NNLO effects-resummations

Differential distributions: with resummation

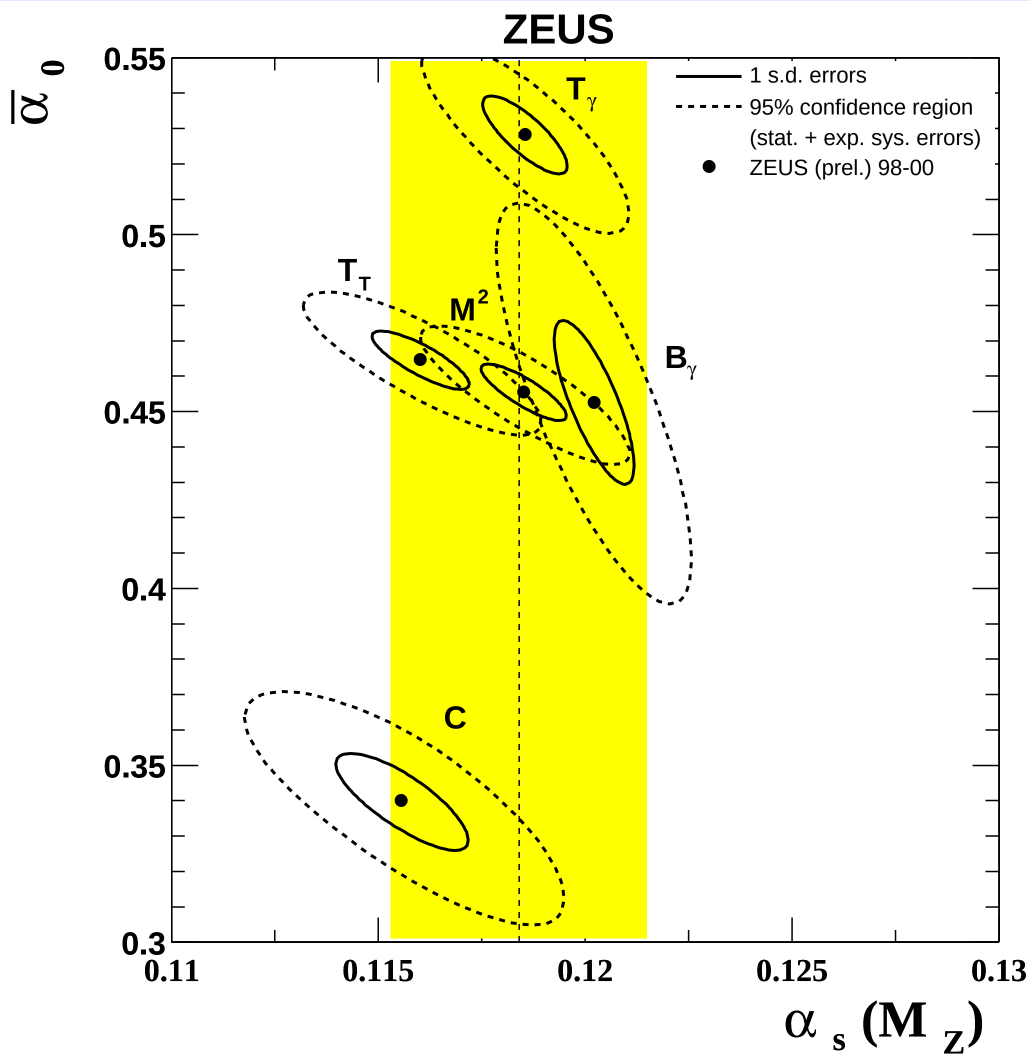
NNLO+NLO+PC Fits to Differential Distributions



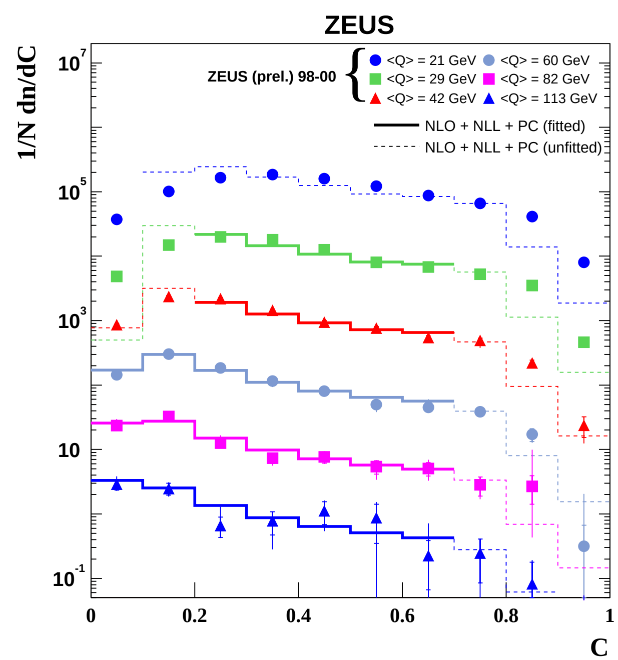


Calculation describes data better; able to enlarge range of fit

Extraction of α_0 and α_s from fits to differential distributions



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



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_o 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)