Charged Particle Multiplicity Distributions

- **Abstracts covered:**

LEP2
- Charged particle multiplicities in heavy and light quark initiated events above the Z0 peak
  - (OPAL, 5-0511)

LEP1
- Charged particle multiplicity in three jet events and two-gluon systems
  - (DELPHI, 5-0437, new results)

LEP1
- Measurement of charged-particle multiplicity distributions and their Hq moments in hadronic Z decays at LEP
  - (L3, 6-0237)

HERA
- Multiplicity distributions in deep inelastic scattering at HERA
  - (ZEUS, 6-0272, new results)

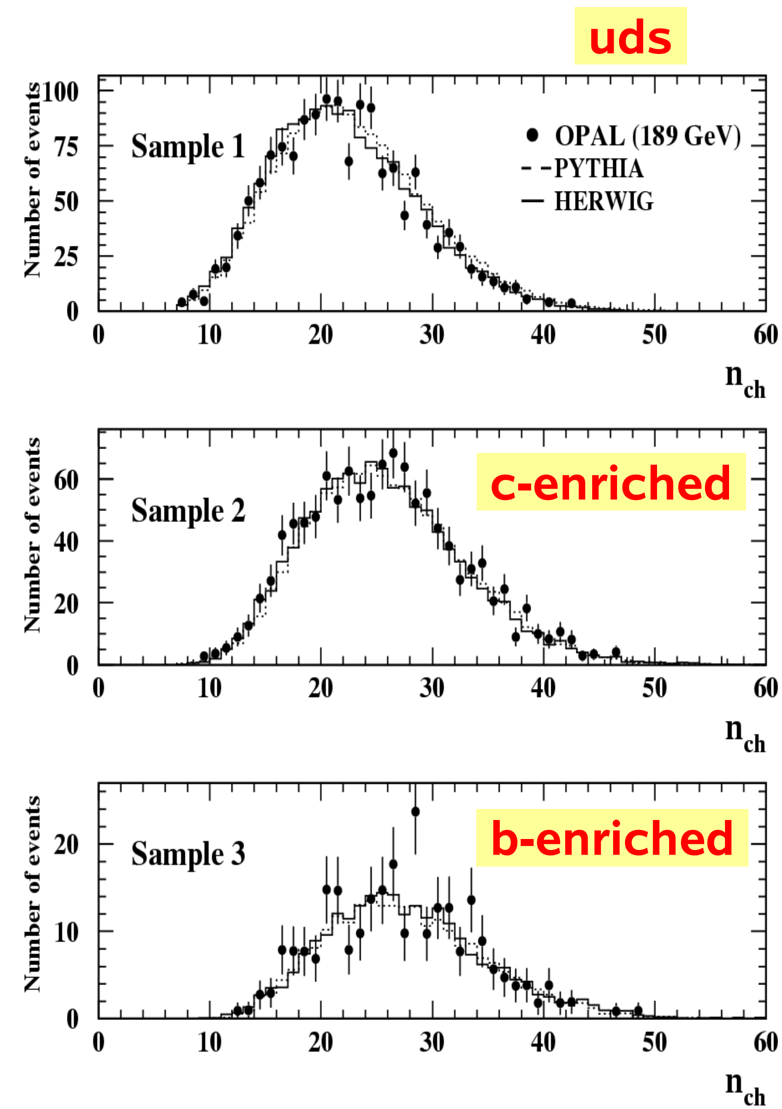
(Brief) Introduction

- **What can we learn from multiplicity distributions?**
  - Difference between b- and uds-events, energy dependence?
    - naive model: decreasing difference at higher energies
    - MLLA and other models: constant with energy
  - Difference between quark- and gluon-jets?
    - can be used to extract Colour Factor ratios
  - Shape of multiplicity distributions?
    - analysis of higher factorial moments sensitive to particle production correlations
  - Compare average multiplicities in e^+e^-, pp and ep data
    - basic fragmentation properties identical?
- **Basic hypothesis**
  - Local Parton Hadron Duality (LPHD)
    - hadron multiplicity is directly related to parton multiplicity via simple normalization factor, can be calculated perturbatively

Energy Dependence of δ_{bl}

(OPAL 5-0511)

- $\delta_{bl} = \langle N_b \rangle - \langle N_{uds} \rangle$
- **LEP2 data $e^+e^- \rightarrow$ hadrons from 130 - 206 GeV**
- **3 independent samples**
  based on event likelihood, mainly b-tag
  - ➔ b-enriched, c-enriched (slightly), uds
- **unfolding procedure**
  based on PYTHIA/HERWIG predicted b,c,uds fractions/sample
- **largest sys. errors**
  - ➔ PYTHIA/HERWIG model dependence, track resolution



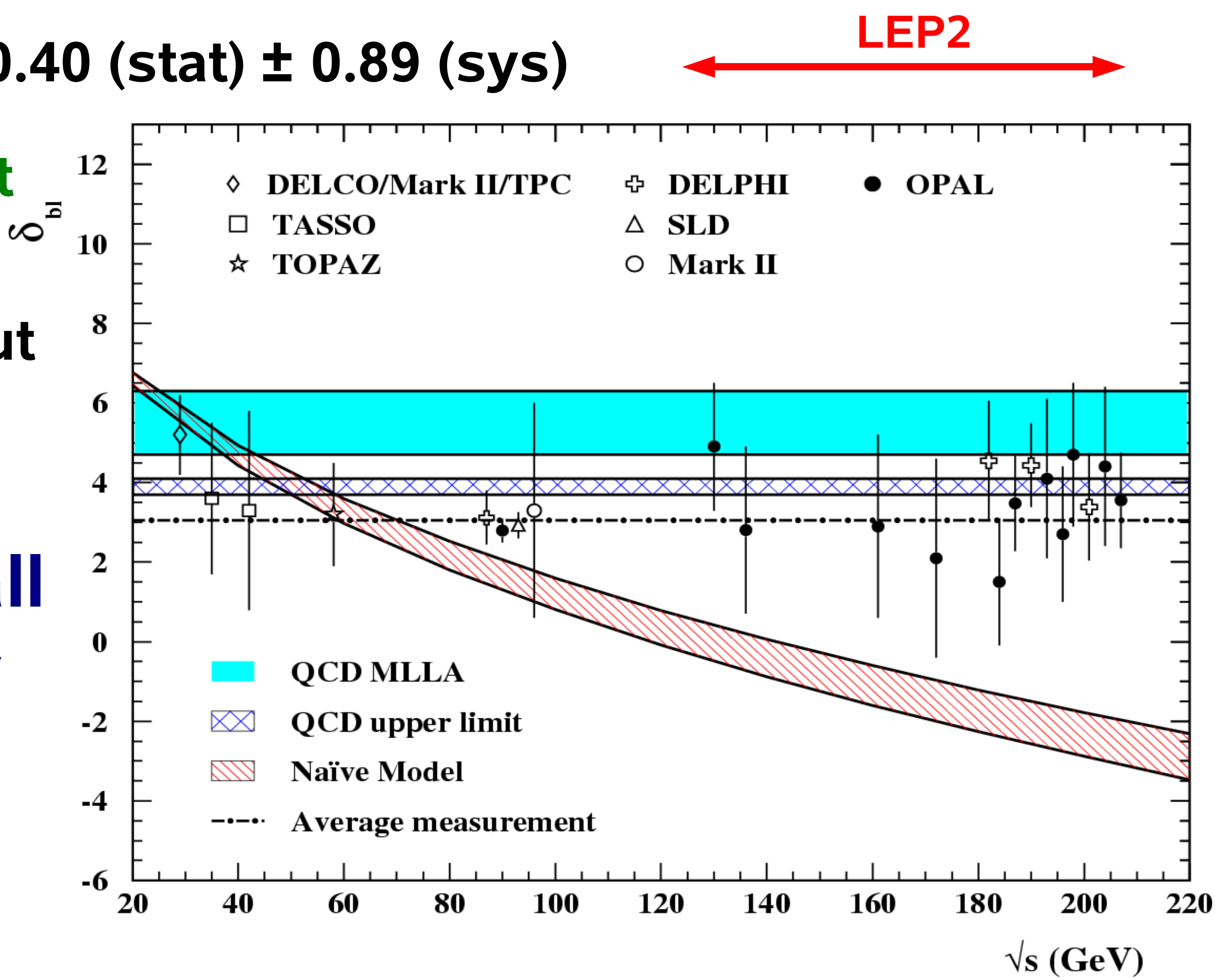
Theoretical Predictions for $\delta_{bl}(E)$

- **Naive model:**
  - same multiplicity of light hadons in uds-jets and b-jets (at same energy) + additional b-hadron multiplicity
  - expect decreasing δ_{bl} with higher energy
- **Pertubative QCD:**
  - soft gluon radiation suppressed inside cone of $\Theta_0 = M_q/E_q$
  - expect significant differences between gluon radiation in light and heavy quark jets
  - LPHD + Modified Leading Log Approximation (MLLA) expects no energy dependence:
    - constant $\delta_{bl} = 5.5 \pm 0.8$ ($\pm$ ~1 due to missing higher order corrections)
- **Other QCD calculations**
  - predict constant $\delta_{bl} = 3.7 - 4.1$ (depending on m_b)

Naive Model ruled out by LEP2

- **Results**
  - linear fit to 130 - 206 GeV data (11 points):
    → (no) slope = 0.000 ± 0.018 (χ^2/dof = 0.59)
  - average δ_{bl} = 3.44 ± 0.40 (stat) ± 0.89 (sys)
  - Earlier DELPHI result (3 points) confirmed
  - Naive model ruled out (wasn't obvious without LEP2 data)
- **Average δ_{bl} over all data, 27 - 206 GeV**
  (low E, LEP1, LEP2)

  δ_{bl} = 3.05 ± 0.19



3-jet events and 2-gluon systems

(DELPHI 5-437, new results)

- **LEP1 data $e^+e^- \rightarrow$ hadrons**
  - reject b-events (anti b-tag)
  - force reconstruction of 3-jets (opening angles Θ_1, Θ_2, Θ_3)
    (angular ordered Durham algorithm, cross-checks with Cambridge and Luclus)
- **Get multiplicity distributions for each Θ_1,Θ_3 -bin**
- **Fit multiplicity distributions by negative binominal**
  - get average 3-jet multiplicity $N_{q\bar{q}g}$
- **Recent predictions by Eden, Gustafson, Khoze**

$$N_{q\bar{q}g} = N_{q\bar{q}}(L_{q\bar{q}}, \kappa_{\mathrm{L}u}) + \frac{1}{2} N_{gg}(\kappa_{\mathrm{L}e})$$

Eden A

3-jet multiplicity — 2-quark multiplicity — 2-gluon multiplicity

L = kinematic variables

κ = cut-offs

$$N_{q\bar{q}g} = N_{q\bar{q}}(L, \kappa_{\mathrm{L}u}) + \frac{1}{2} N_{gg}(\kappa_{\mathrm{L}u})$$

Eden B

Colour Factor Ratios C_A/C_F

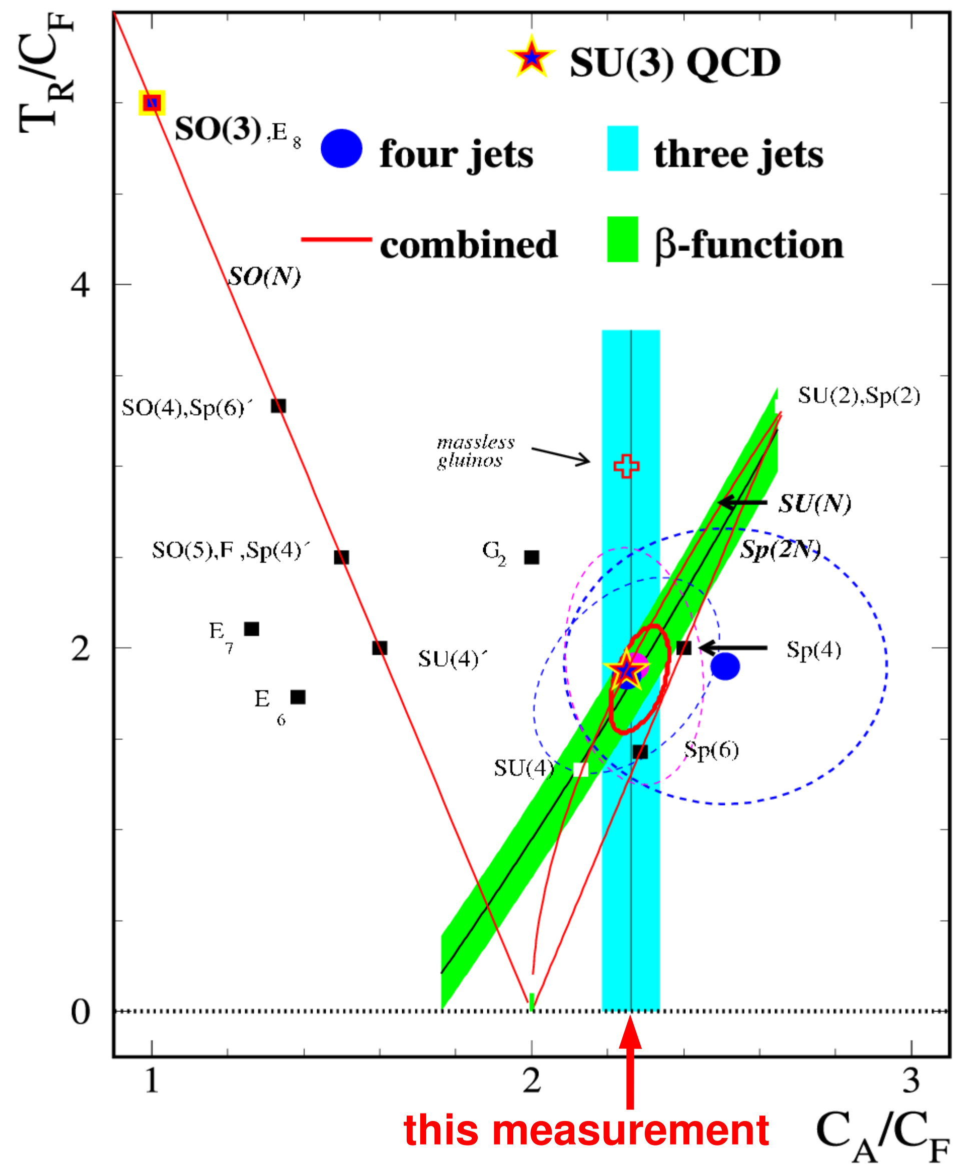
- Eden A + B equations can be used to fit colour factor ratios C_A/C_F
- Naive expectation for 2-quark / 2-gluon ratio contains colour factors

$$r = \frac{N_{gg}}{N_{q\bar{q}}} = r_0[1 - r_1\gamma_0 - r_2\gamma_0^2 - r_3\gamma_0^3]$$

$$r_0 = C_A/C_F \qquad \gamma_0 = \sqrt{\frac{2C_A\alpha_s}{\pi}}$$

➜ C_A/C_F = 2.261 ± 0.014 (stat.)
± 0.036 (syst.)
± 0.052 (theor.)
± 0.041 (clus.)

agrees with earlier OPAL result



in agreement with SU(3) expectation of QCD

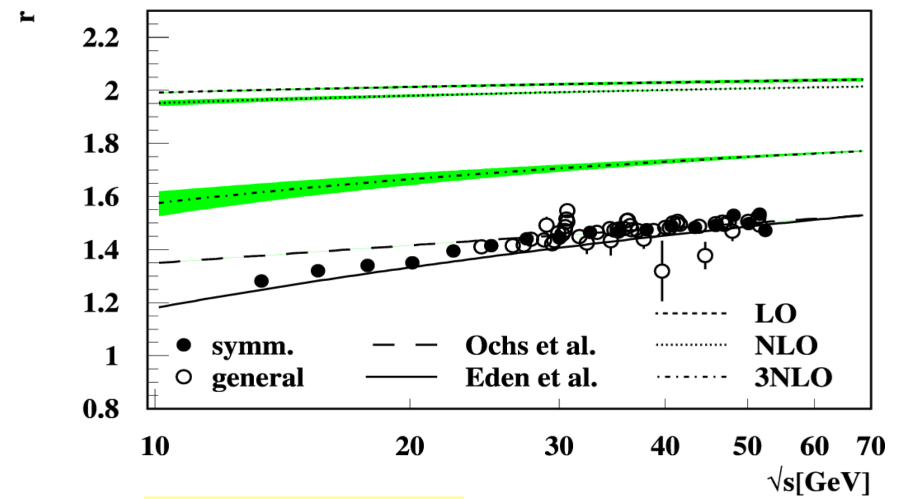
Gluon/Quark Multiplicity Ratios

- Eden A equation can also be used to extract 2-gluon multiplicity N_{gg} from N_{qqg} (using MLLA prediction for N_{qq})
- Ratio r = N_{gg}/N_{qq} subject of large corrections, better use

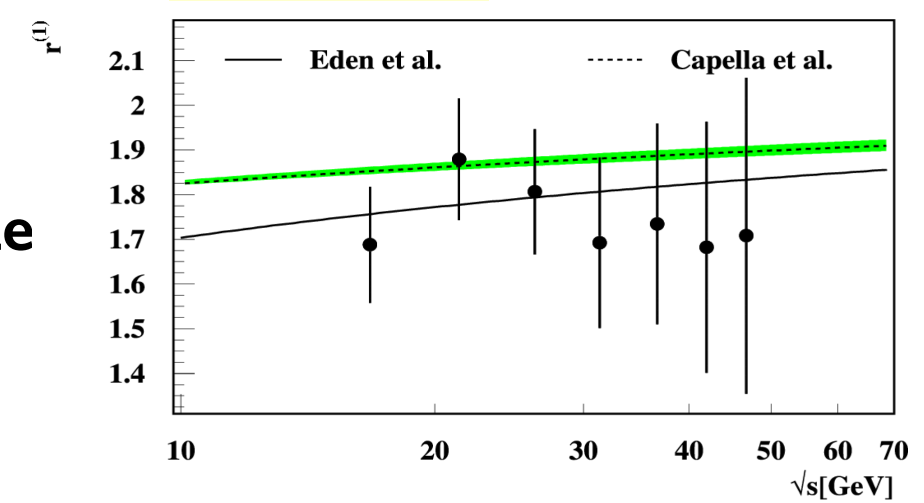
$$r^{(1)} = \frac{dN_g/ds}{dN_q/ds}$$

- Results
  - lower order calculations oversize r (as lower the order as more oversizing)
  - agreement with Eden et al. and similar calculations and earlier OPAL result

r = N_{gg}/N_{qq}



$$r^{(1)} = \frac{dN_g/ds}{dN_q/ds}$$



H_q Moments
(L3 6-0237)

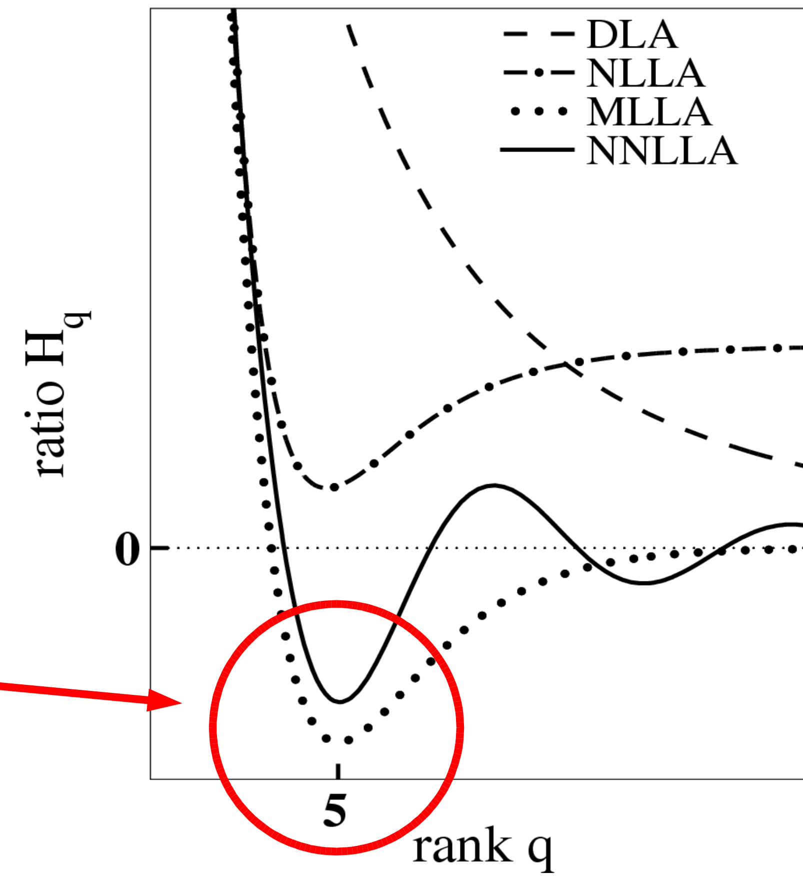
- **Shape of multiplicity distribution is fundamental tool to study particle production correlations**
  - Independent production → Poissonian distribution
  - any deviations → correlations!
- **Use H_q moments up to rank q**

$$H_q = \frac{|K_q|}{F_q}$$

$|K_q|$: normalized factorial moments
F_q: normalized factorial cumulants

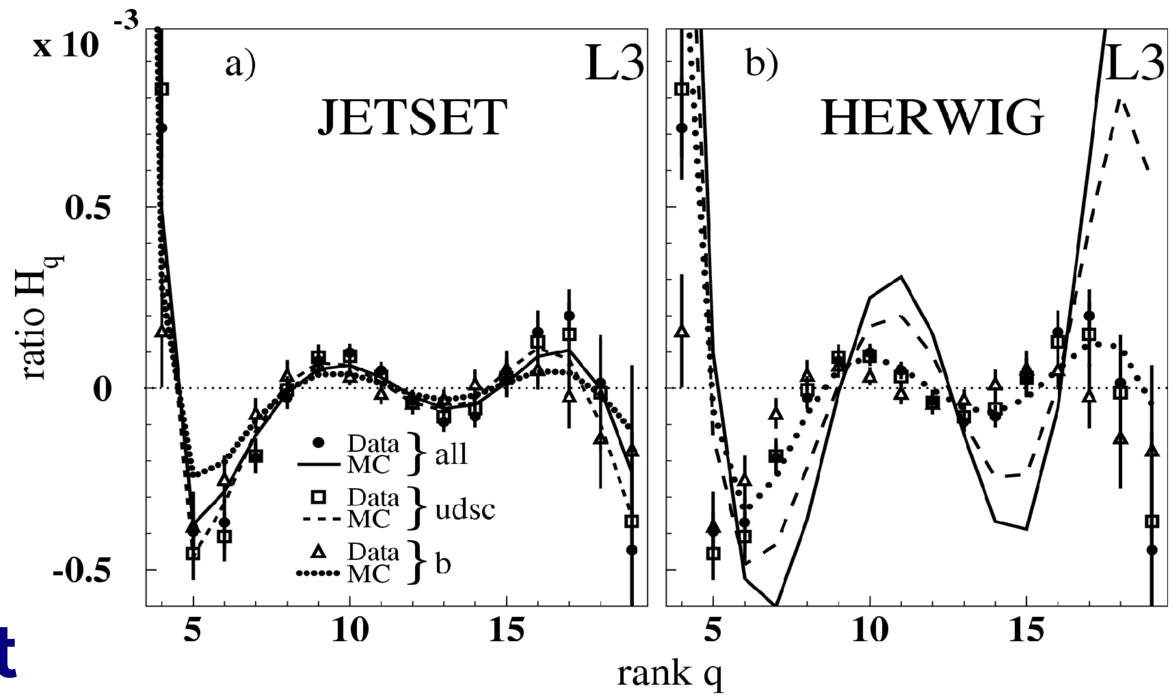
H_q have same order of magnitude over large range of q

- **MLLA and NNLLA predict minimum at q = 5**
  - NNLLA even predicts oscillations, e.g. maximum at q ≈ 8



H_q Truncation

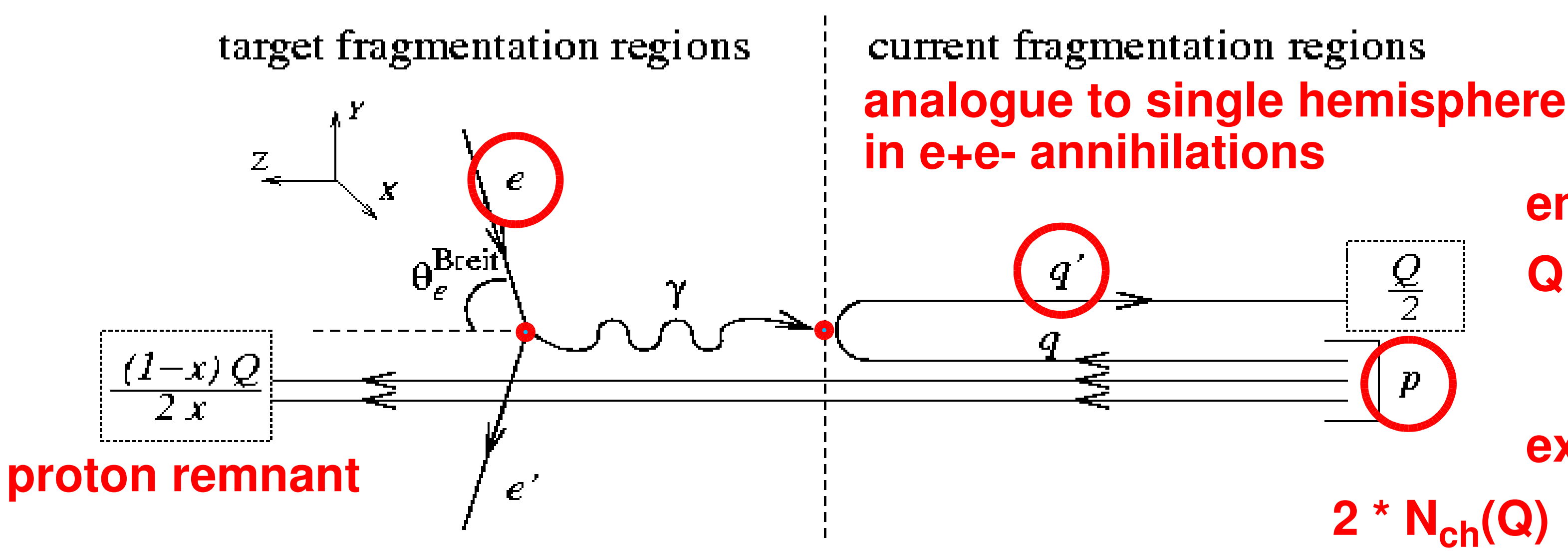
- Problem: H_q sensitive to low statistics at high multiplicities → need truncation (introduce bias?)
- L3 used LEP1 data (b-tagged events + udsc-events)
  - truncation around rank q ≈ 50 (criteria: relative stat. error > 50%)
- Results
  - Minimum at q = 8 seen
    - confirms MLLA + NNLLA
  - quasi-oscillations for higher q visible
  - JETSET agrees well, HERWIG doesn't



- MC studies suggest
  - need > 10^7 events to detect maximum at q = 8 (here: 1.5 x 10^6 ev. used)
    (Could be in reach with LEP combination?)

Multiplicity in Deep Inelastic Scattering
(ZEUS 6-0272, new results)

- More difficult to study multiplicity in ep collisions
  - highly asymmetric beam conditions
  - large part of hadronic system outside detector acceptance
  - only visible part of hadronic system (M_{eff}) can be used
  - Study in lab frame and current + target regions of Breit frame
    - Assign final state hadrons after Breit frame transformation according to p_Z:
    - if $p_Z > 0$ → assign to current region, otherwise assign to target region



energy scale:

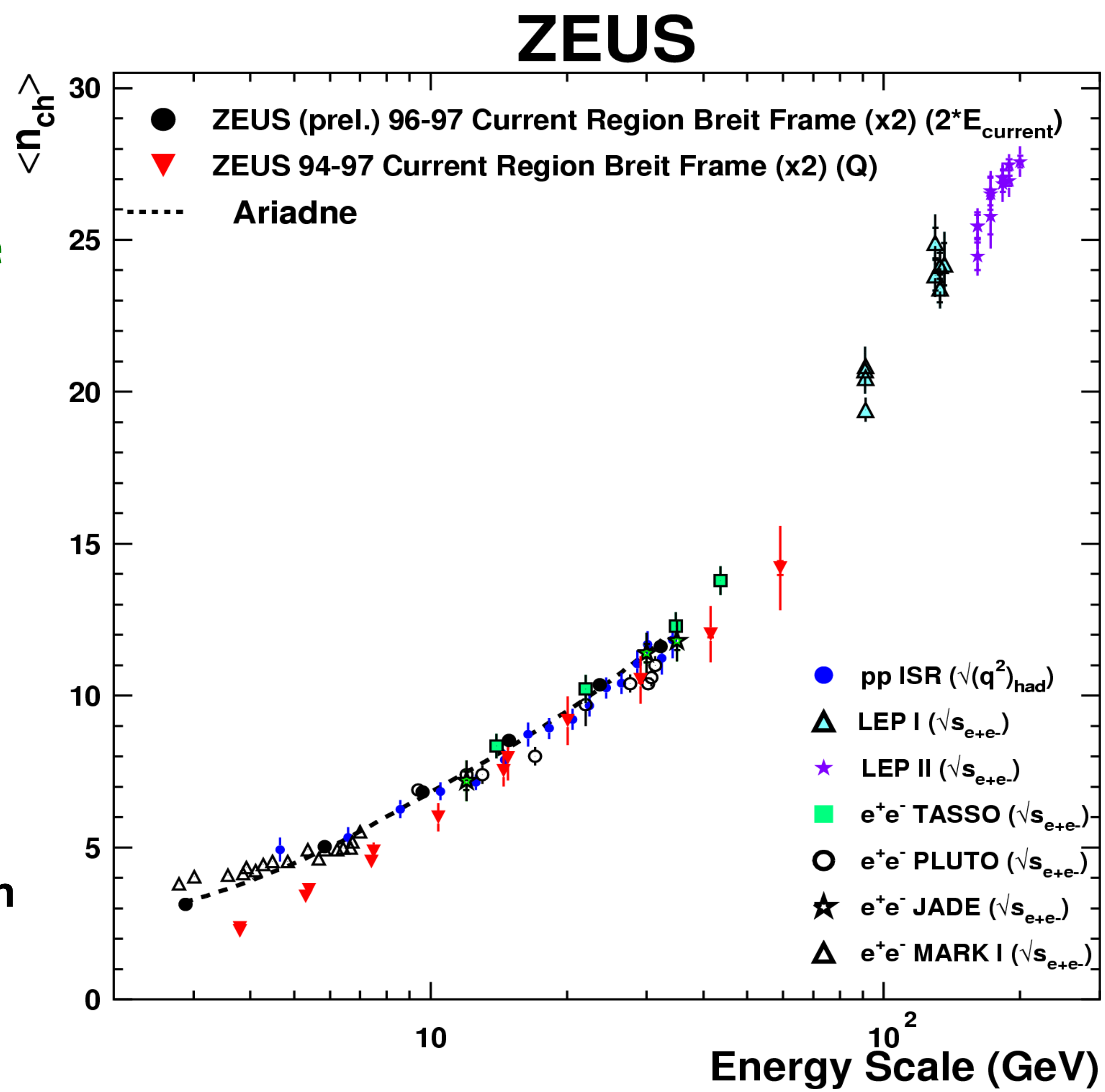
$Q = \sqrt{s_{e^+e^-}}$

expect:

$2 * N_{ch}(Q) \approx N_{ch}(\sqrt{s_{e^+e^-}})$

Comparison with e^+e^- and pp Data

- ZEUS e^+p data from 1996-97, 38.6 pb^{-1}, 735k events
- Results:
  - Good agreement with e^+e^- and pp data above 10 GeV
  - Data as function of Q lower for < 10 GeV
  - Better agreement of data as function of $E_{current}$ for < 10 GeV
    - where: $E_{current}$ = energy of all particles in current region



Summary of Charged Multiplicities

- **Average δ_{bl} constant with energy (27 - 206 GeV)**
  - average δ_{bl} = 3.05 ± 0.19 (OPAL LEP2+ DELPHI LEP2 + lower E)
  - naive model ruled out
- **Study of 3-Jet Events and 2-Gluon Systems (DELPHI)**
  - Fit to Color Factor ratios C_A/C_F agrees with SU(3) expectation
  - Ratios $r = N_{gg}/N_{qq}$ and $r^{(1)}$ agree with predictions by Eden et al.
- **Analysis of H_q moments (L3) sensitive to particle production correlations**
  - MLLA and NNLLA expected minimum at rank q = 5 confirmed
- **DIS ep multiplicity data (ZEUS) in current Breit frame agree with e^+e^- and pp data**