Recent results on multiplicity from ZEUS

Michele Rosin

University of Wisconsin, Madison

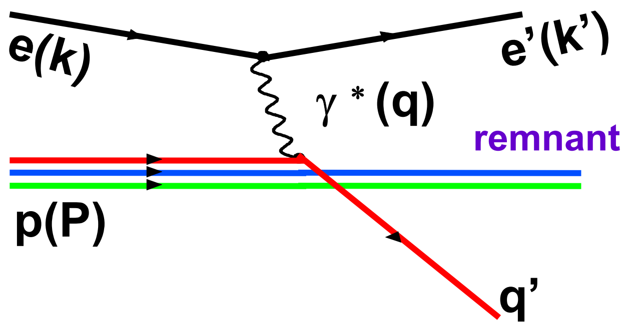
on behalf of the ZEUS Collaboration

Hadron Structure 2004
September 1, 2004

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:



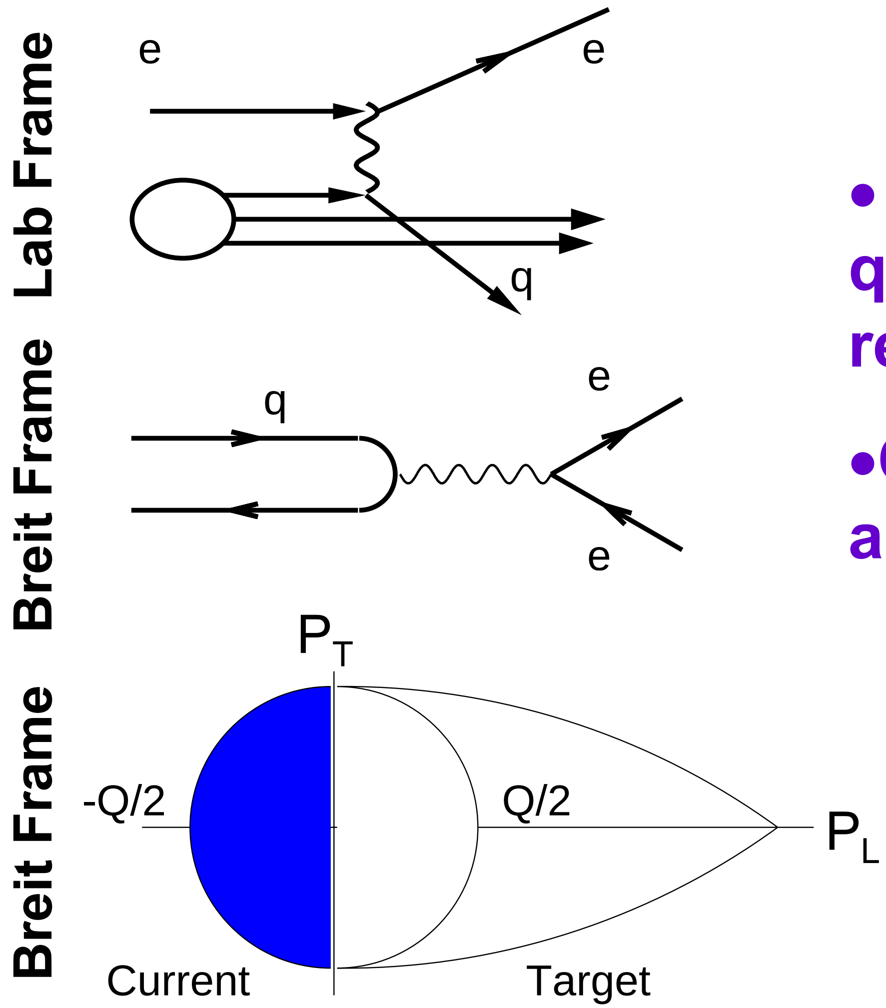
$$Q^2 = -q^2 = -(k-k')^2$$ *Virtuality of photon*

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

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

e^+e^- & ep : Breit Frame

DIS event



- **Breit Frame definition:**

$$2xP + q = 0$$

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

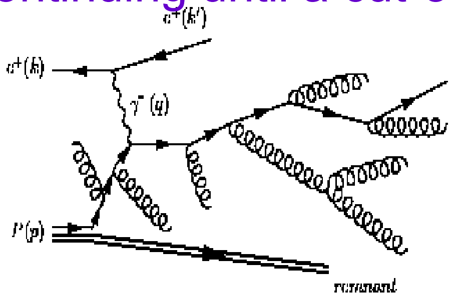
- **Current region of Breit Frame is analogous to e^+e^-.**

Monte Carlo models: parton cascades and hadronization

Models for parton cascades:

Parton Shower Model:

- cascade of partons with decreasing virtuality continuing until a cut-off

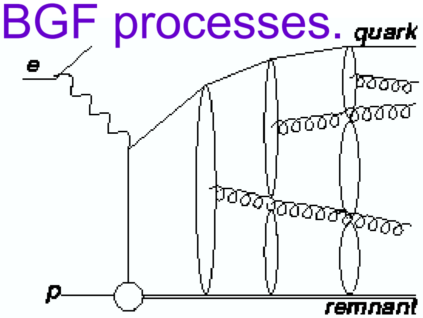


LEPTO
HERWIG

Color Dipole Model:

- Gluons are emitted from the color field between quark-antiquark pairs, supplemented with BGF processes.

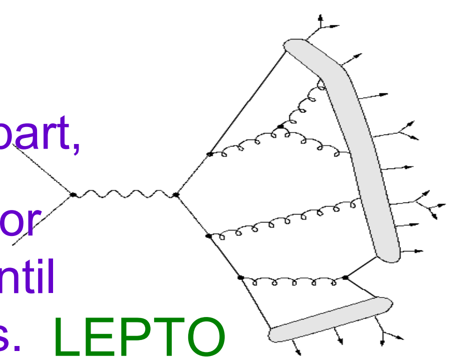
ARIADNE



Hadronization models:

Lund String Model:

- color "string" stretched between q and q moving apart,
- string breaks to form 2 color singlet strings, and so on until only on-mass-shell hadrons.

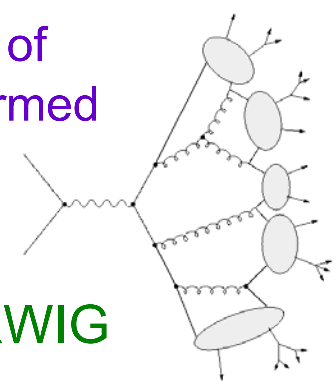


LEPTO
ARIADNE

Cluster Fragmentation Model:

- color-singlet clusters of neighboring partons formed
- Clusters decay into hadrons

HERWIG



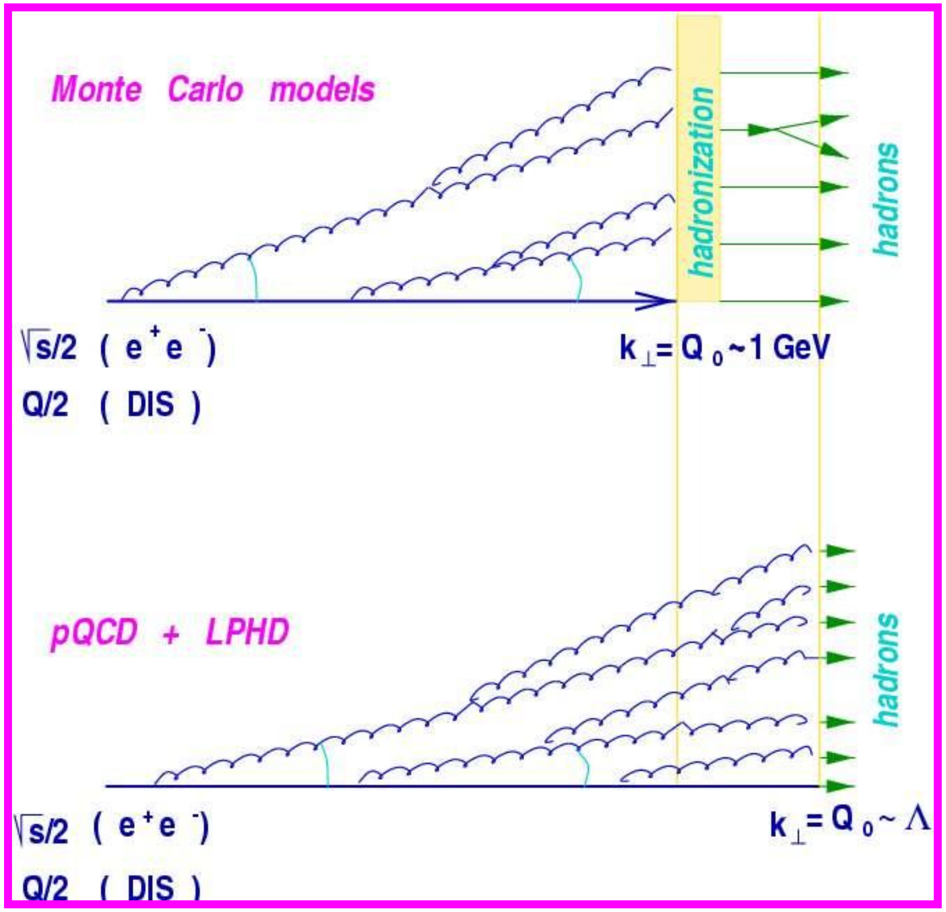
Local Parton-Hadron Duality

- Local Parton Hadron Duality (LPHD): cut off parton shower at mass of pion, distribution of final partons is same as final hadrons.

- Successful concept for most inclusive observables (e+e-, ave. multiplicities, single particle inclusive spectra)

- Attempt to check LPHD using Normalized Factorial Moments: (NFM)

$$F_q(\Omega) = \frac{\langle n(n-1)\ldots(n-q-1)\rangle}{\langle n\rangle^q} \qquad q = 2,3,\ldots$$



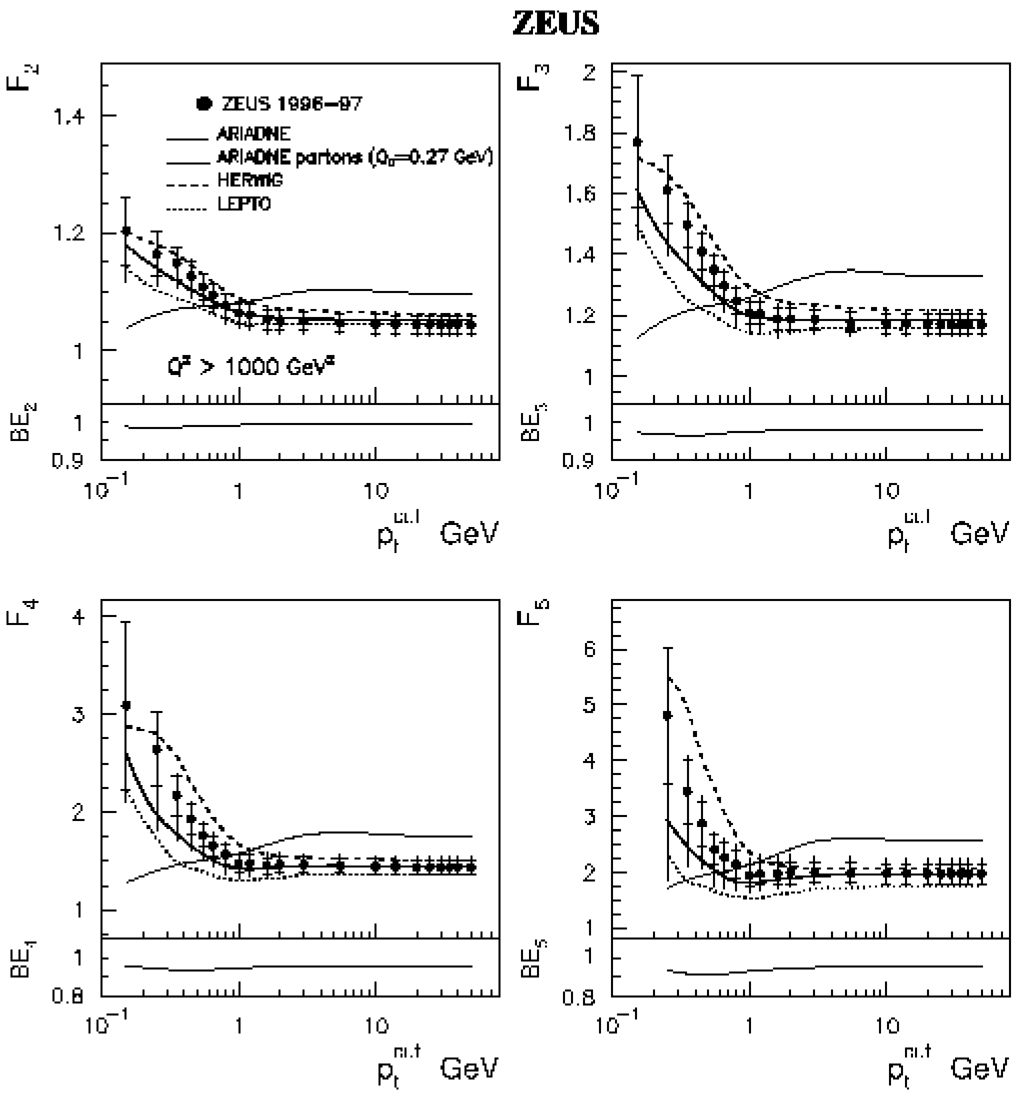
- Particle multiplicities are studied in terms of NFMs for a specified phase space region of size Ω.

- Compare data to MC with and without hadronization

Phys. Lett B 510 (2001) 36-54

Factorial Moments vs. p_T

- Multiplicity moments of order q=2,…,5 in current region of Breit frame
- LHPD doesn't describe our data in soft part of the spectrum
- Understanding hadronization is essential



1996-97 data, 38 pb^{-1}

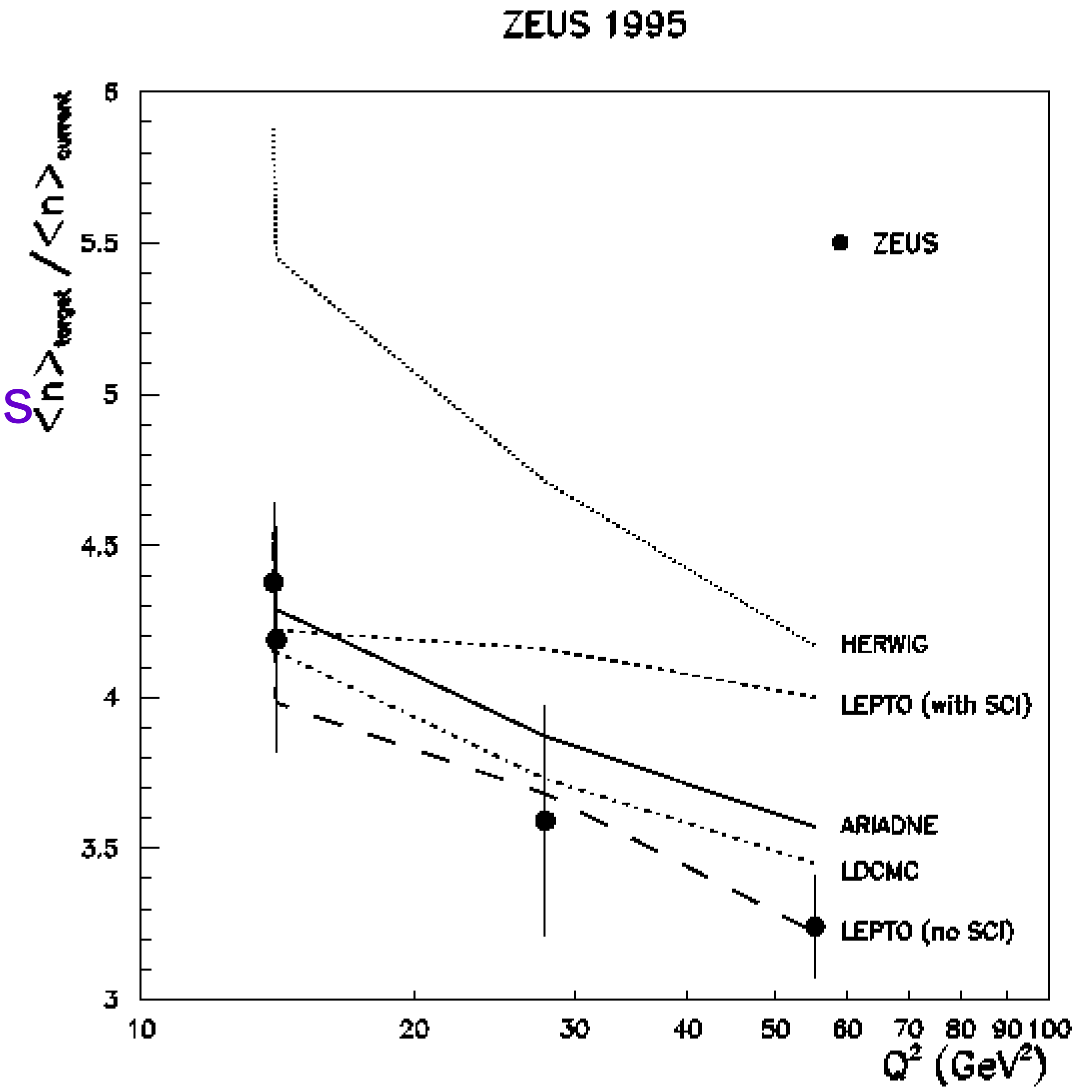
Q^2>1000 GeV^2

Multiplicity in Current and Target regions of Breit Frame

- Measurement of multiplicities in Breit Frame vs. Q^2
- Ratio of mean multiplicities in current and target regions vs. Q^2 show higher multiplicity in target region.
- Is Q^2 the proper scale for target region?
- Behavior described by MC

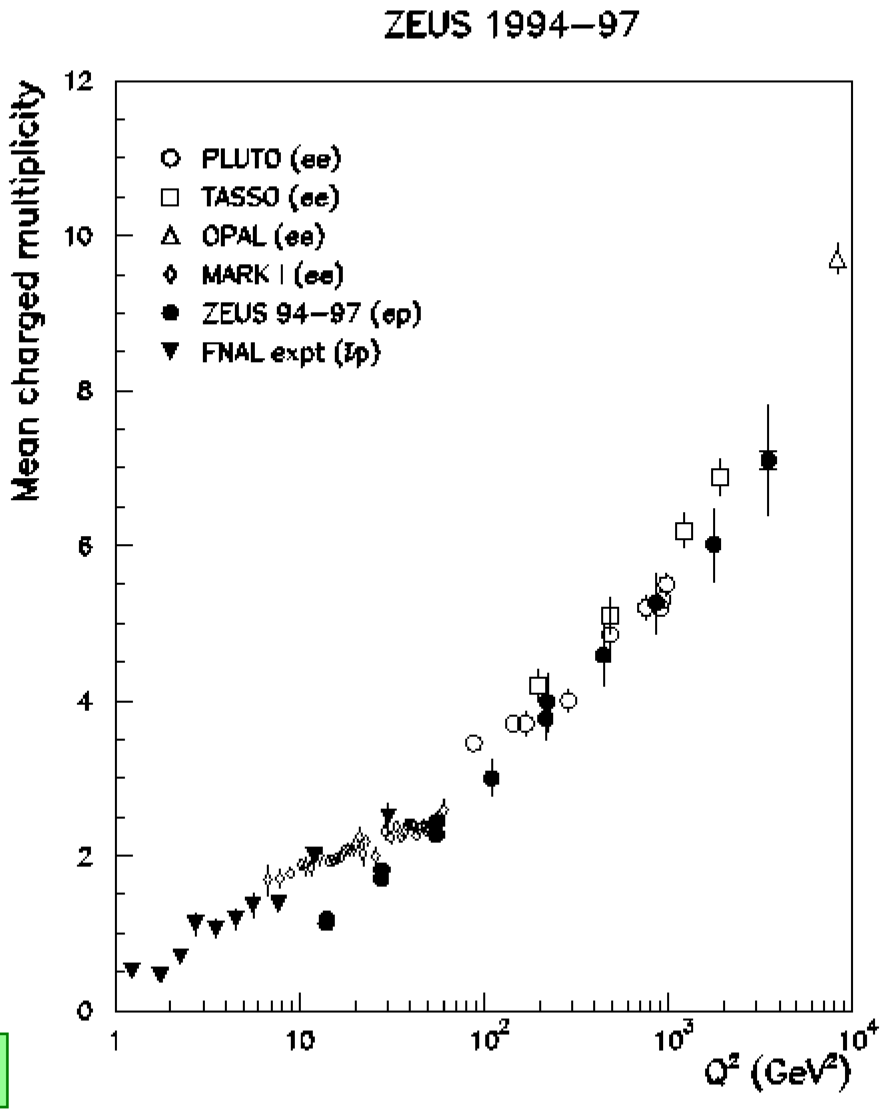
1996-97 data, 38 pb^{-1}

Q^2>10 GeV^2



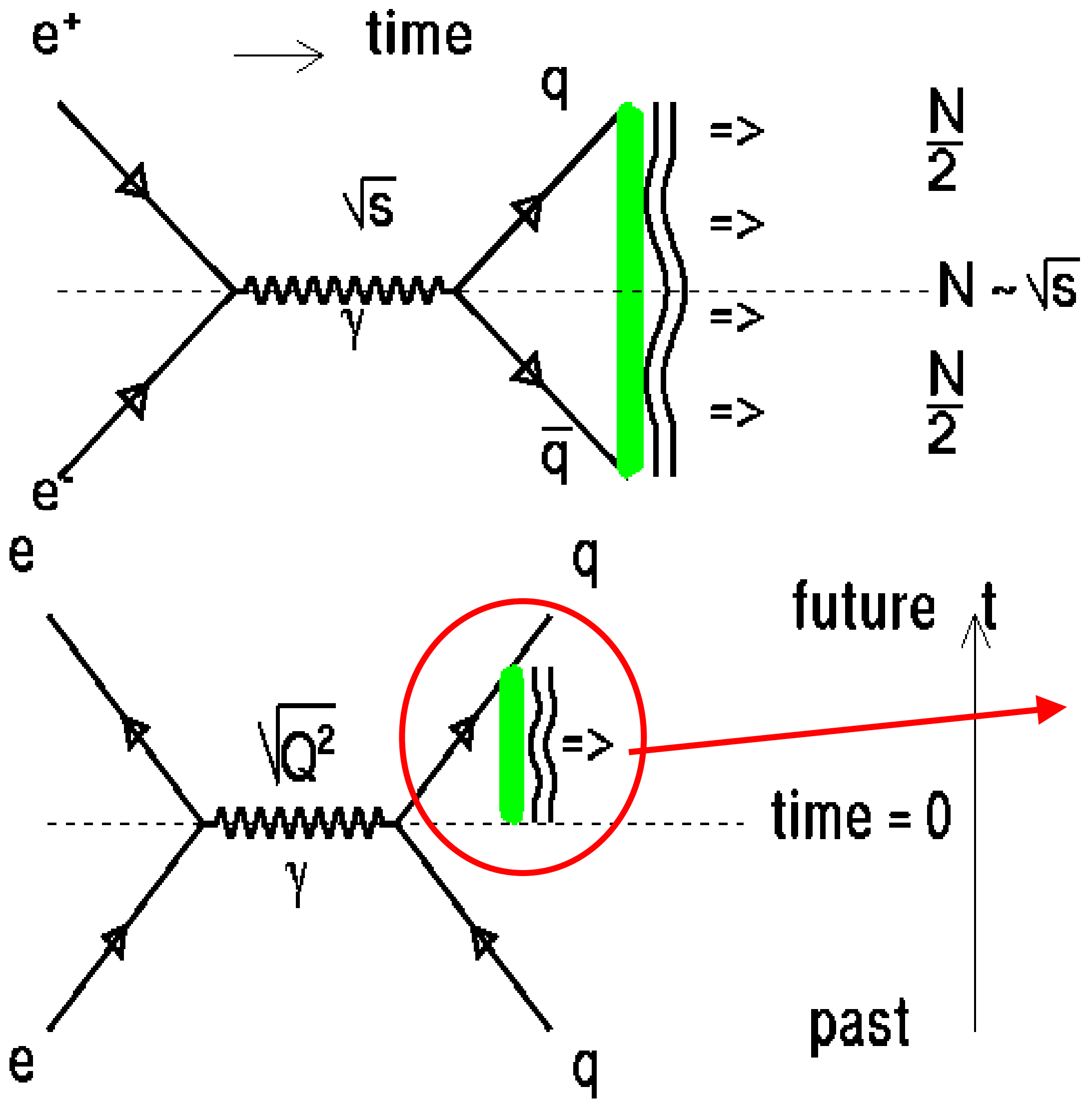
Measurement vs. Q

- Consistent with e+e- data for high Q^2
- Disagreement at low Q^2 may be attributed to gluon radiation
- Idea of current analysis: Understand current and target multiplicity and compare to e+e-



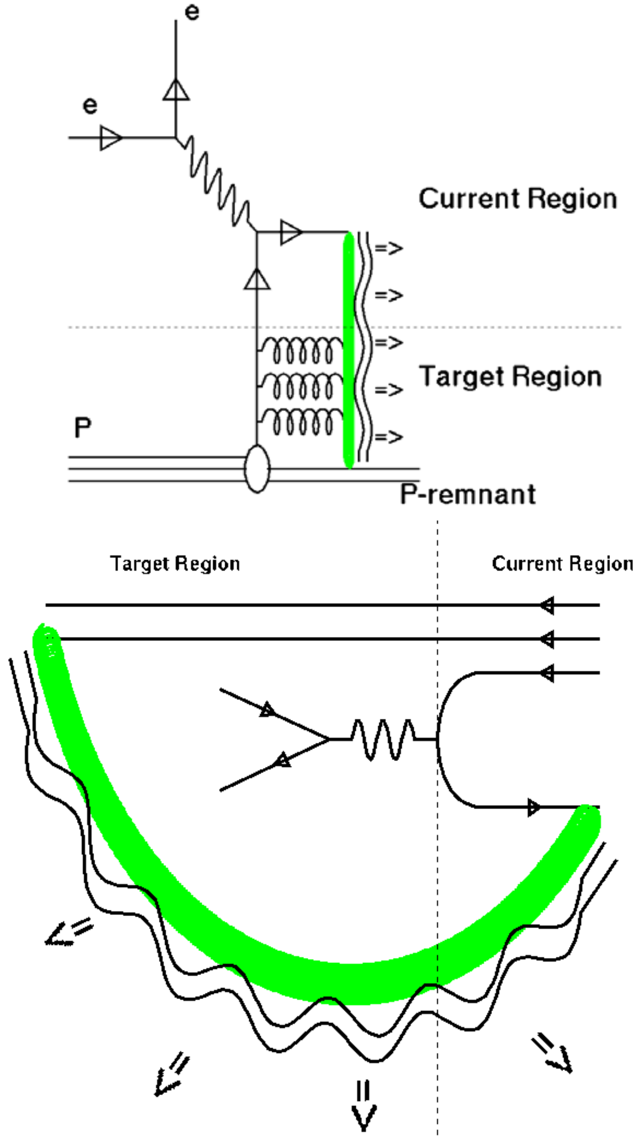
European Physics Journal C11 (1999) 251-270

Multiplicity: ep vs. e^+e^- (1)



- e+e-: boson with virtuality $\sqrt{s}$ produces 2 quarks & hadronization is between 2 colored objects q and $\bar{q}$
- ep: boson with virtuality Q produces 1 quark: the 2nd quark comes from the interaction between the photon and the proton
- current region of Breit frame for ep similar to one hemisphere of e+e-
- If we use Q as scale to compare to e+e-, multiply hadrons by 2

Multiplicity: ep vs. e^+e^- (2)

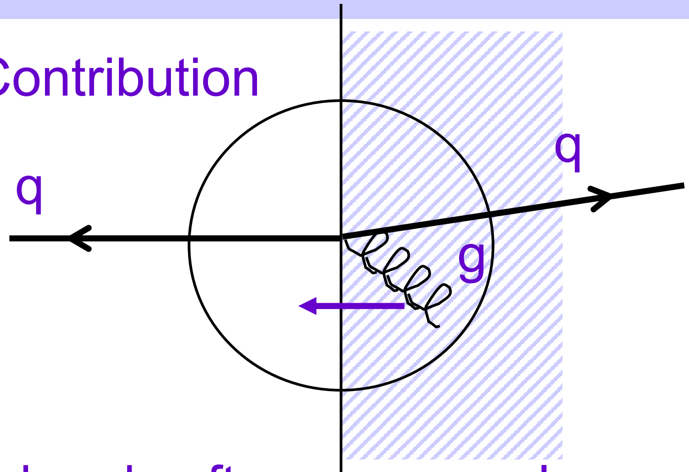


- ep: Split into Current and Target Region – one string two segments.
- In ep we have a color field between 2 colored objects the struck quark and the proton remnant
- When we use Q2 as a scale we are assuming the configuration is as symmetric as it is in e+e-, but it isn't
- This asymmetric configuration leads to migration of particles from the current region to the target region

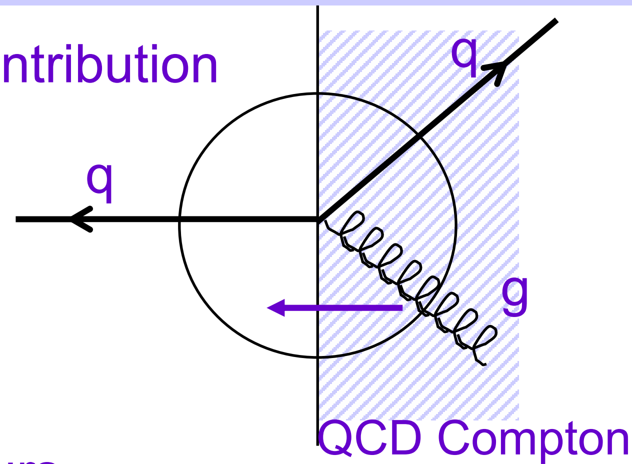
Breit Frame diagram

Gluon radiation, Q, and 2*E_{Breit}

Soft Contribution



Hard Contribution



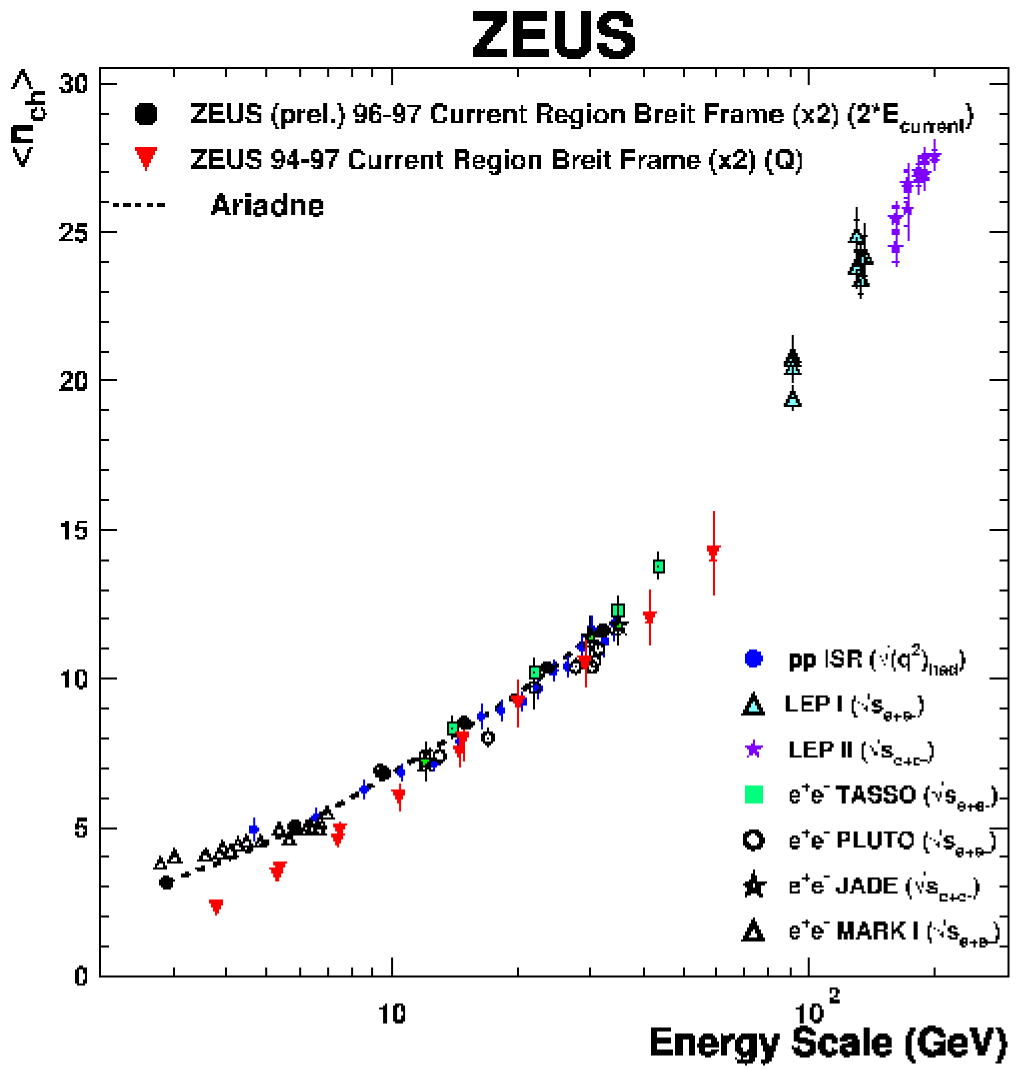
- In hard and soft processes gluon radiation occurs
- These gluons can migrate to target region
- Total energy in the current region of Breit frame and multiplicity are decreased due to these migrations (Q^2 is not)
- Effect is more pronounced for low Q^2 : more low energy gluons
- Must use 2*E_{Breit} and 2*N_{ch} for comparing with e+e-

No migrations: $E_{Breit} = \frac{\sqrt{Q^2}}{2}$

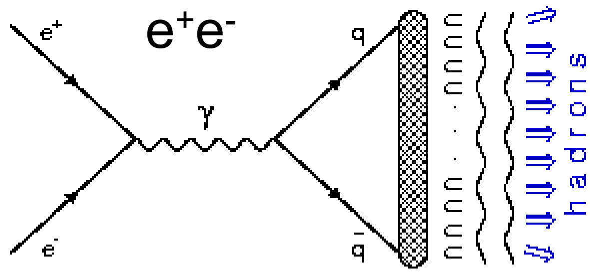
With migrations: $\begin{cases} N < N_{expected} \\ E_{Breit} < \frac{\sqrt{Q^2}}{2} \end{cases}$

Multiplicity vs. 2^*E_{breit}

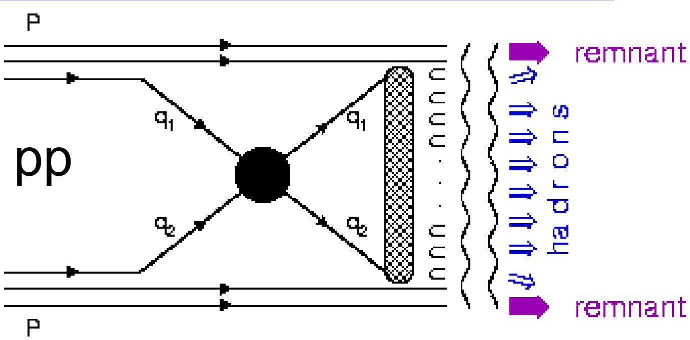
- Measure multiplicity dependence on 2^*E_{Breit} and compare to previous ZEUS measurement vs. Q, and to e+e-
- Points agree with the e^+e^- points
- This approximation of invariant mass partially takes into account the real distribution of the particles.
- Current region understood, would like to use some energy scale to compare target region for ep to e+e-..



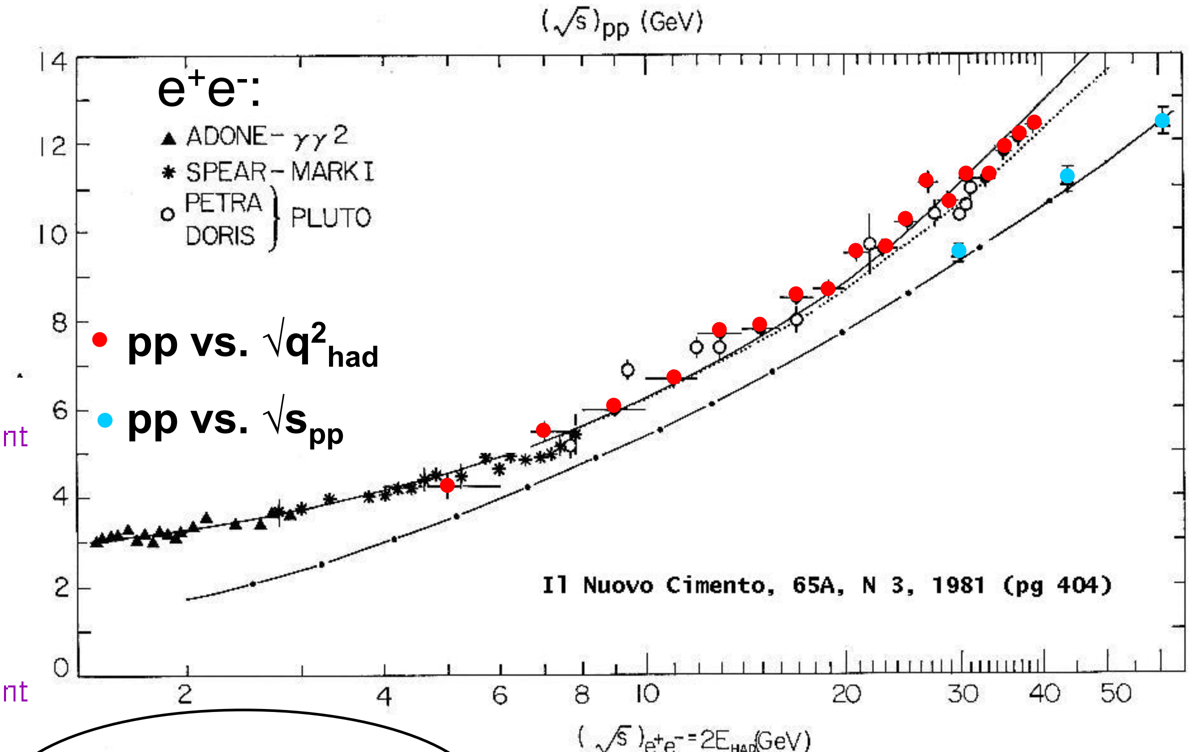
Multiplicity e^+e^- and pp



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



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



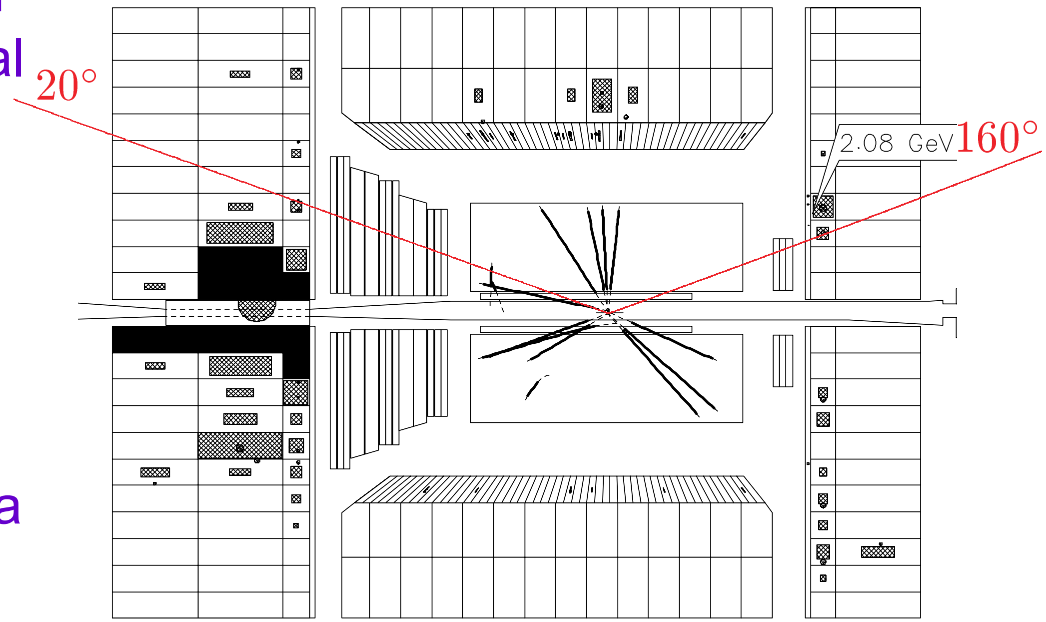
Invariant mass of pp

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

- Agreement between e^+e^- and pp plotted vs. pp invariant mass

Charged Hadrons & Effective Mass: experimental method

- Measure hadronic final state within $\Delta\eta$ for best acceptance in the central tracking detector (CTD)
- Measure # charged tracks, reconstruct number of charged hadrons
- Measure invariant mass of the system (Meff) in corresponding delta eta region.
- Energy is measured in the Calorimeter (CAL)



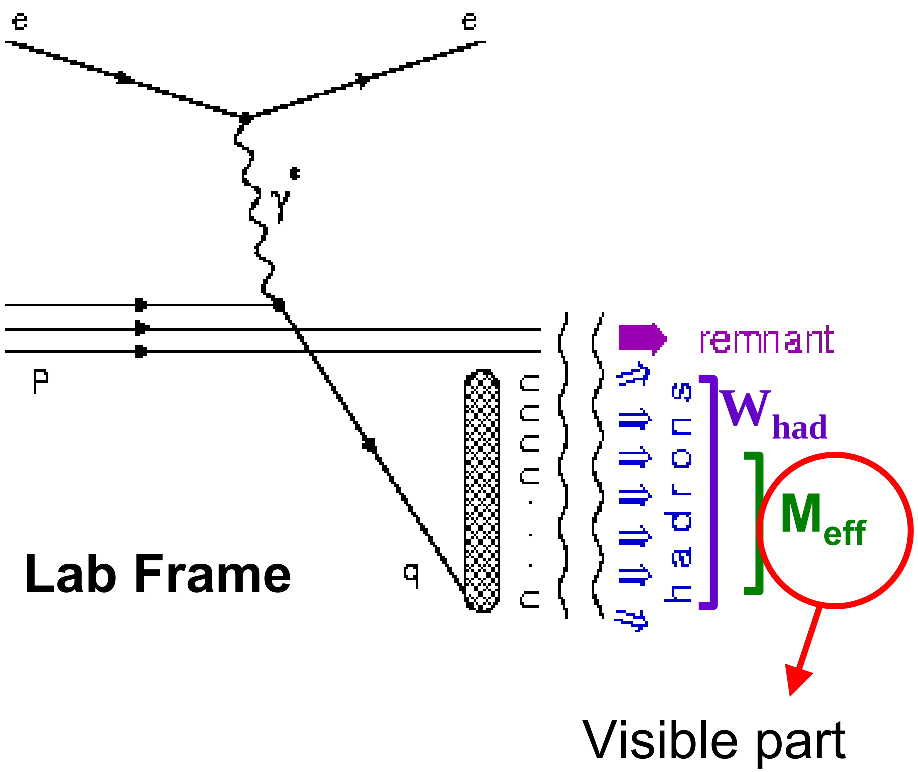
$$M_{eff}^2 = \Big(\sum_{i \neq e'} E^i\Big)^2 - \Big(\sum_{i \neq e'} p_x^i\Big)^2 - \Big(\sum_{i \neq e'} p_y^i\Big)^2 - \Big(\sum_{i \neq e'} p_z^i\Big)^2$$

Study: $\langle n_{ch} \rangle$ vs. M_{eff}

CTD

CAL within the CTD acceptance

The use of M_{eff} as energy scale



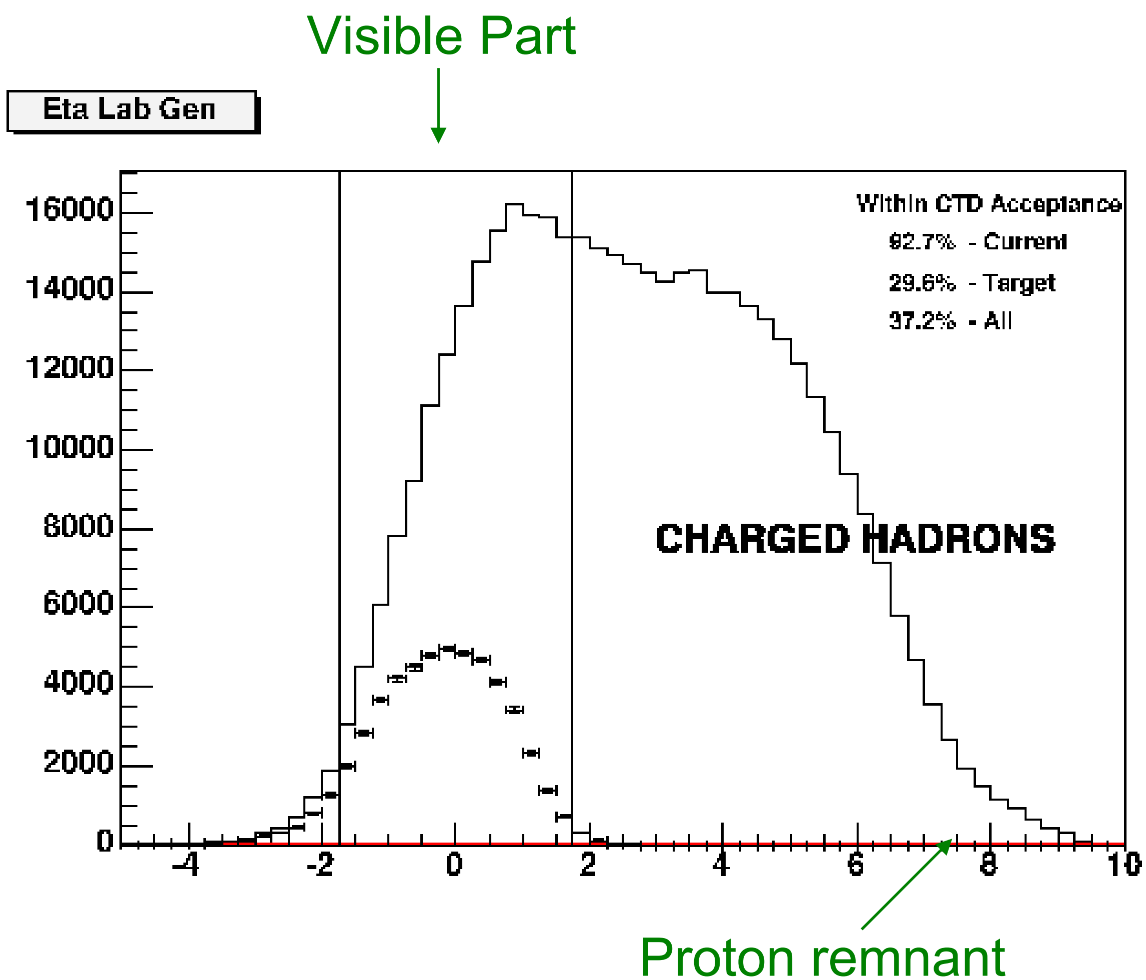
- Previously shown in e+e- and pp that the number of charged particles vs. invariant mass of the system is universal
- For ep in lab frame, measure visible part of <nch> vs. visible part of energy available for hadronization: Meff

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

Detector acceptances for current and target regions

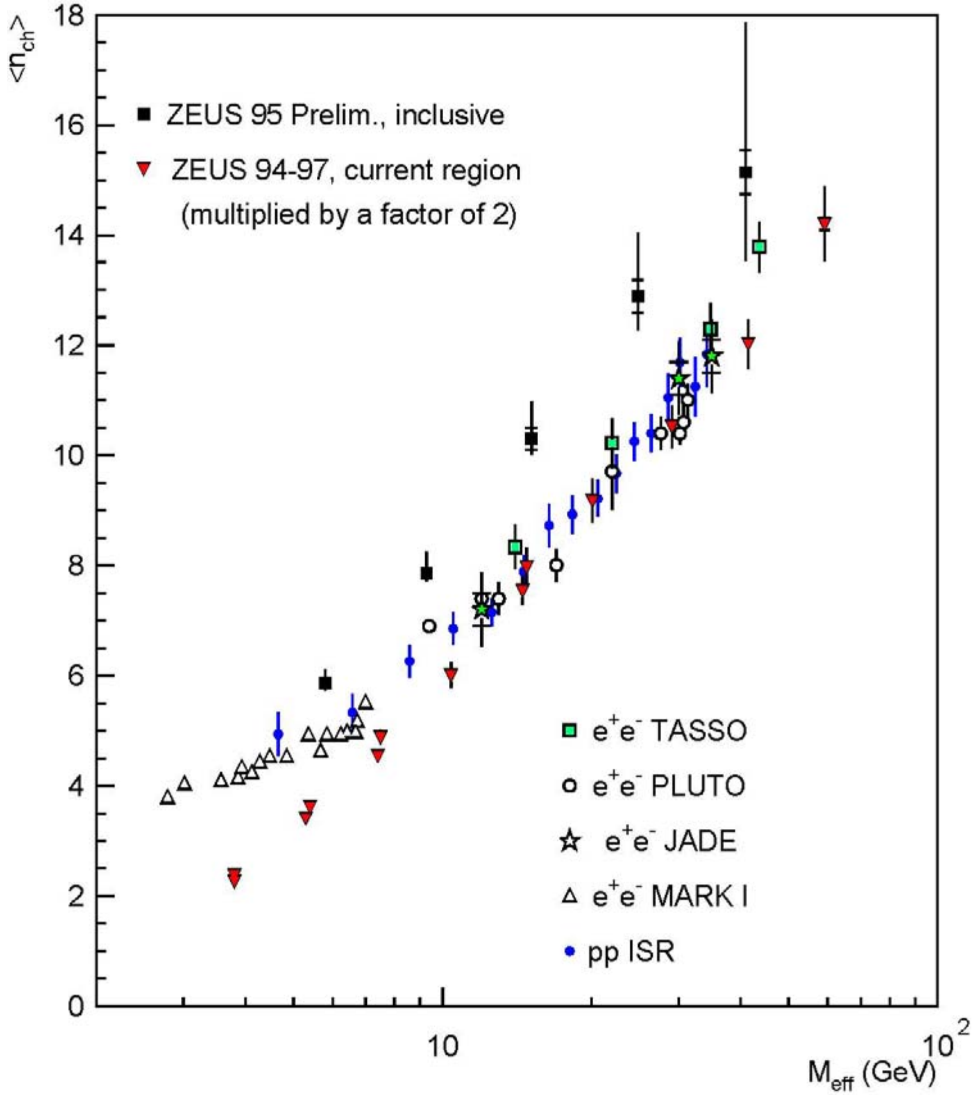
The visible part of the multiplicity is very different for the current and target region of the Breit Frame.

- Observed portion of hadrons from total number generated is 90% for current region & only 30% for target region.
- When comparing visible part of the current and target regions we compare total current region with only the part of the target region that is far from the proton remnant



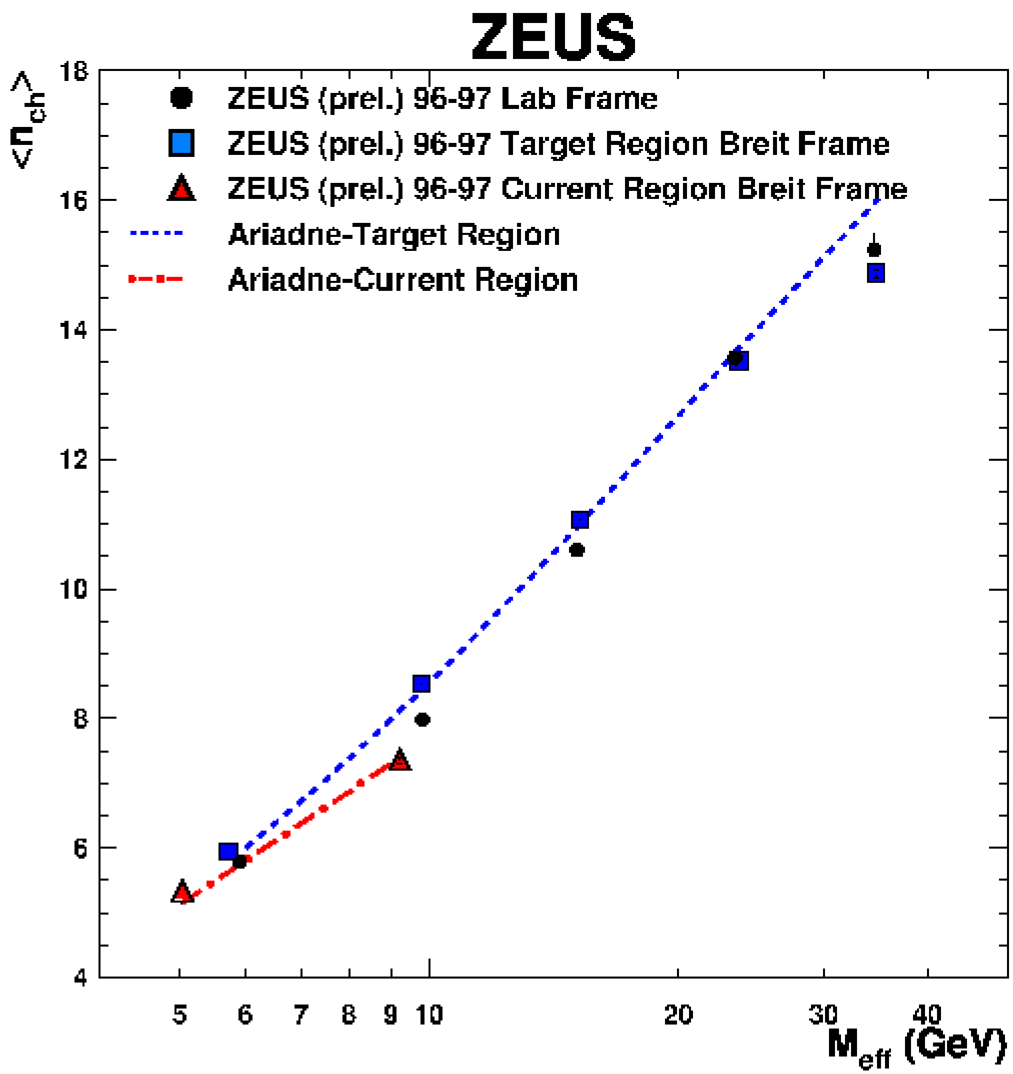
Previous results in lab frame: $\langle n_{ch} \rangle$ vs. M_{eff}

- 1995 preliminary results
- $\langle n_{ch} \rangle$ plotted vs. M_{eff} for ep, vs. q_{had} for pp and vs. √s for e+e-.
- $\langle n_{ch} \rangle$ for ep is ~15% higher than that for e+e- and pp.
- Investigate this difference: look at visible charged multiplicity vs. M_{eff} for current and target regions of the Breit frame.



Breit frame vs Meff

- Similar dependence in multiplicity for visible parts of current and target regions of the Breit frame as a function of their respective effective mass
- Target multiplicity is higher than current multiplicity and can reach higher values of Meff
- combined current and target region show same behavior as target region
- Multiplicity and M_{eff} are Lorentz invariant so can move to the lab frame

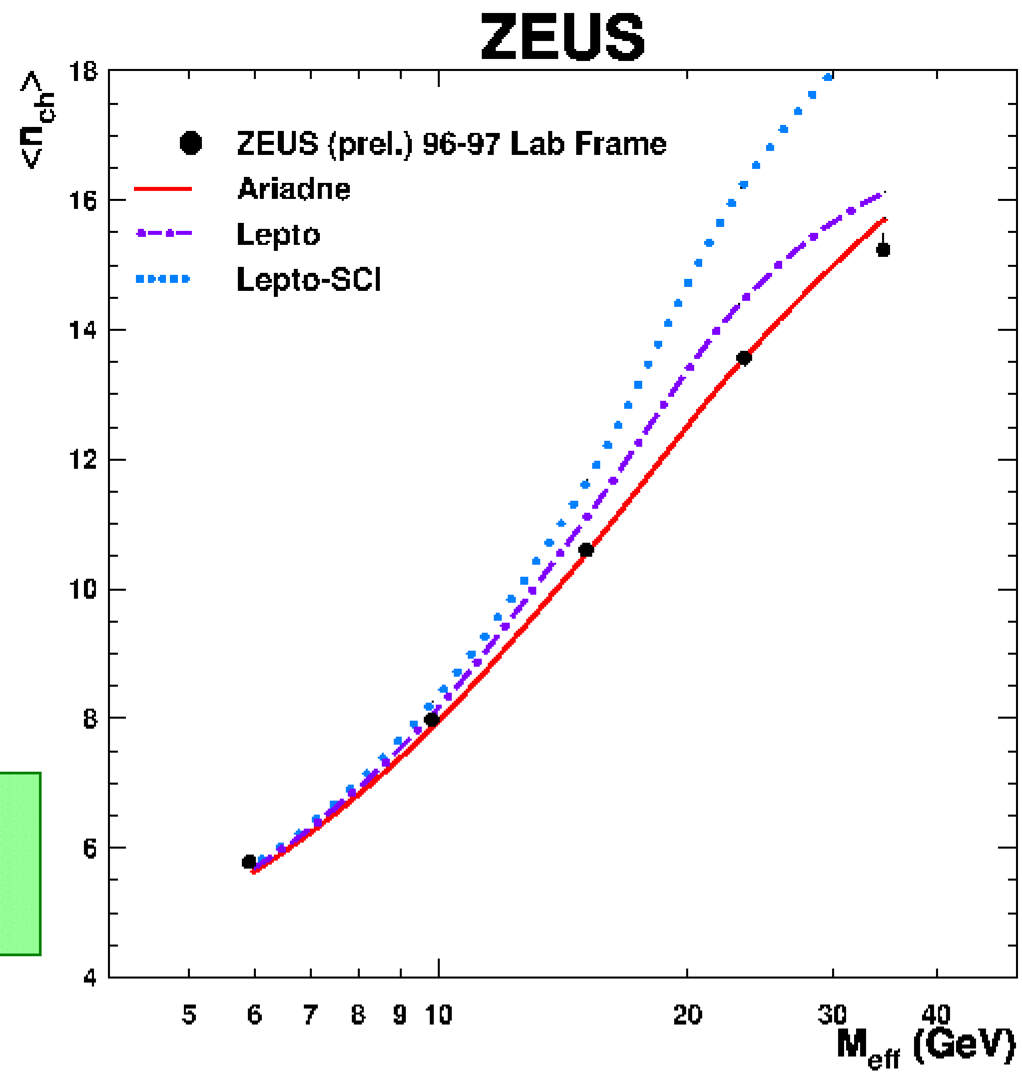


Current lab frame measurement

- Agreement between data and ARIADNE
- LEPTO also describes data but when including the soft color interactions LEPTO-SCI deviates from data

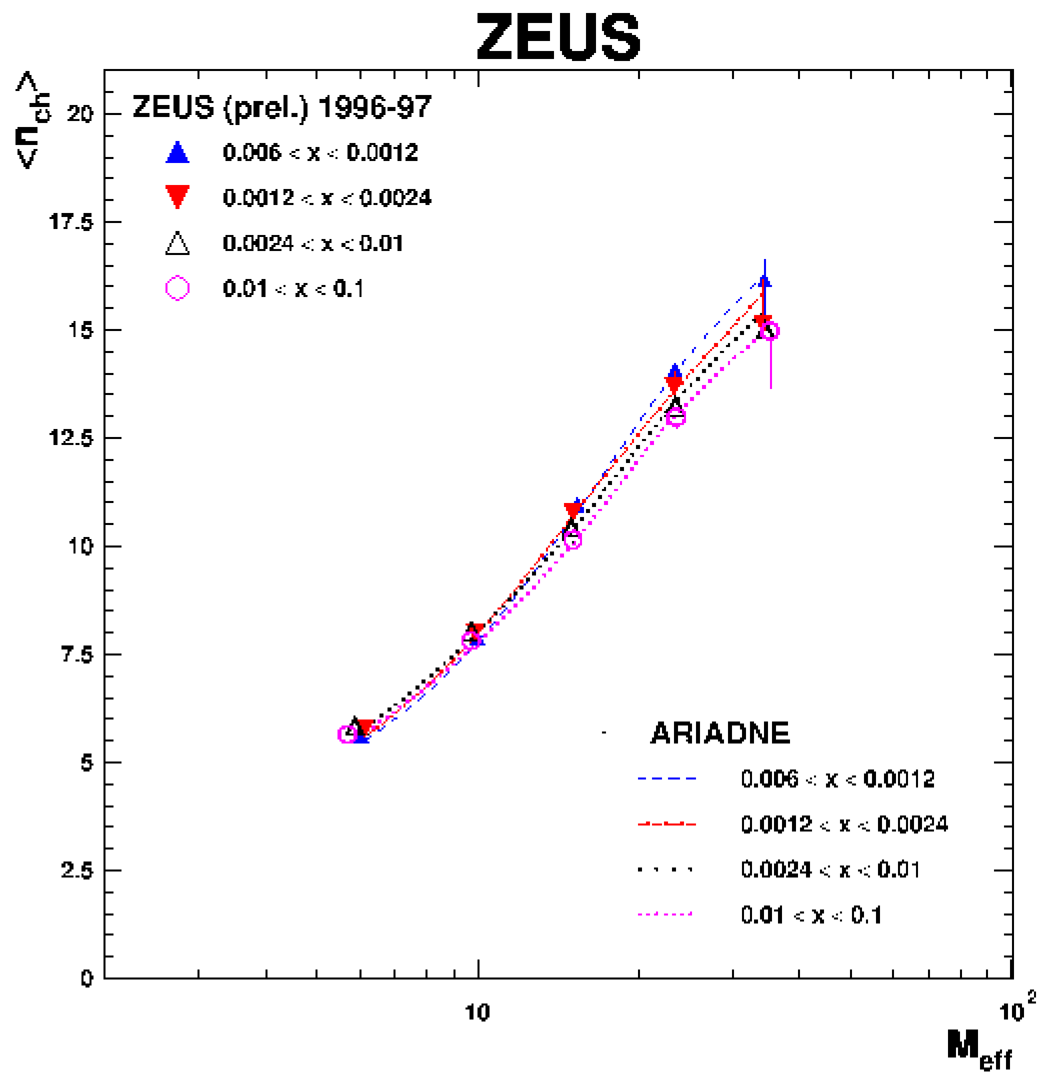
1996-97 data, 38 pb^{-1}

$Q^2>20\ GeV^2$



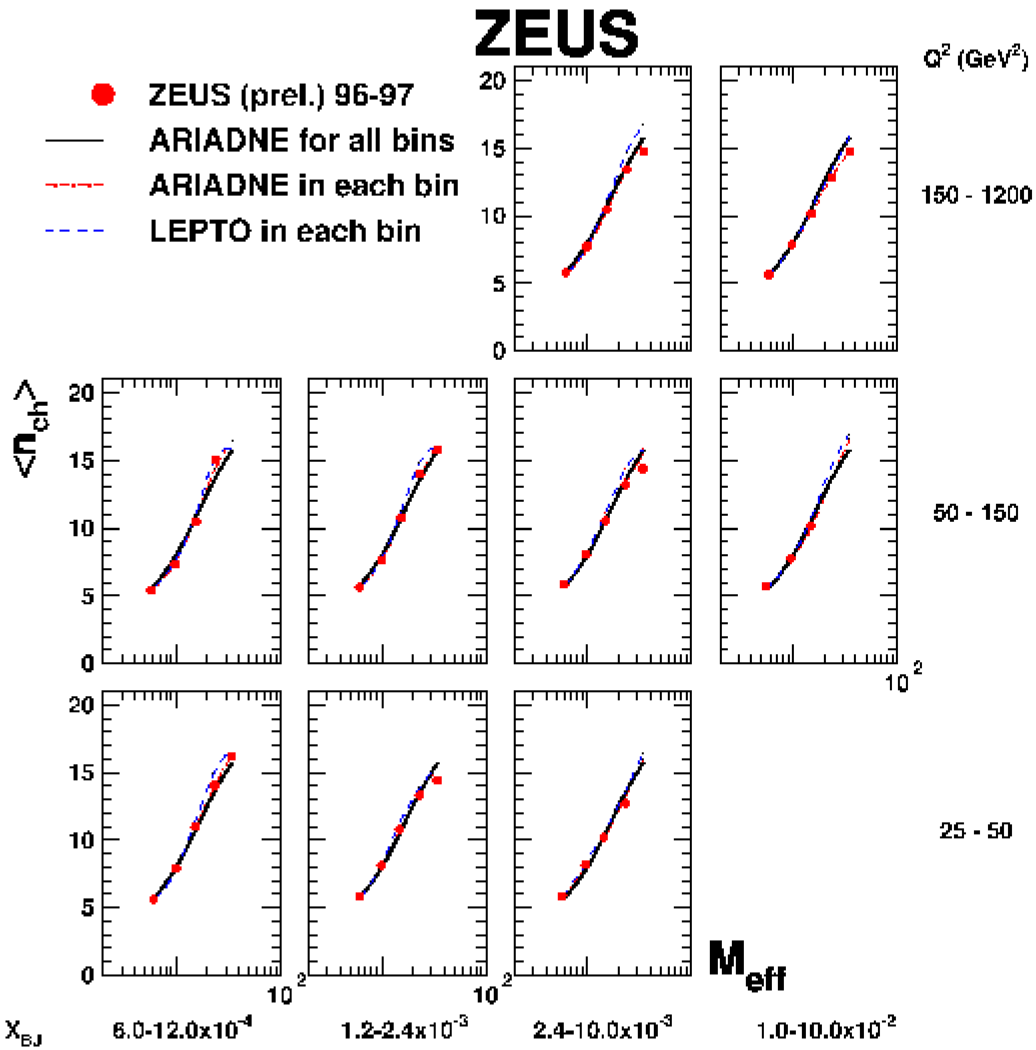
Lab frame: <n_{ch}> vs. M_{eff} in x bins

- Would also like to study x and Q^2 dependence
- x range split into similar bins as in previous multiplicity paper.
- weak x dependence in both data and MC observed not sufficient to explain difference
- Q^2 dependence? => next page



Lab frame: x and Q^2 bins

- Data described by ARIADNE
- LEPTO above data
- No Q^2 dependence observed
- Dependence of the $\langle n_{ch} \rangle$ on M_{eff} doesn't change with x & Q^2 enough to explain observed difference between ep and e+e-



Summary

- The hadronic final state has been investigated in DIS ep scattering in terms of the mean charged multiplicity and respective invariant mass of the charged and neutral particles, M_{eff}
- Measurement in current region of the Breit frame show same dependence as e+e- if $2^*E_{current}$ is used as the scale
- Similar dependence observed in multiplicity for visible part of the current and target regions of the Breit frame as a function of their respective effective mass
- Lab frame measurements show no strong dependence on x or Q^2
- Full comparison of current and target region is still underway, the main problem being that visible part of the target region is only 30% of the total, and MC studies expect that the multiplicity behavior changes when we go closer to the proton remnant.