

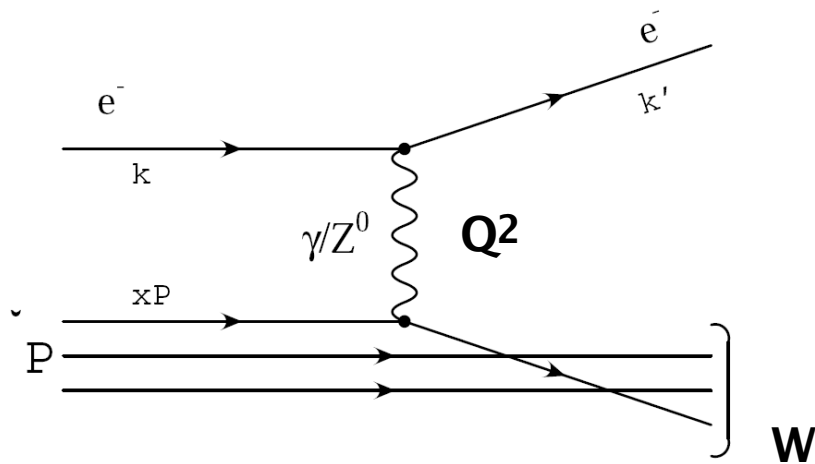


Energy dependence of the charged multiplicity and scaled momenta in DIS

On behalf of the ZEUS Collaboration

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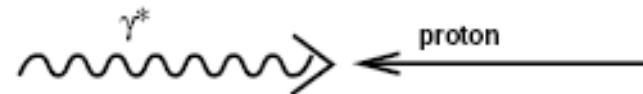
University of Warsaw, Poland

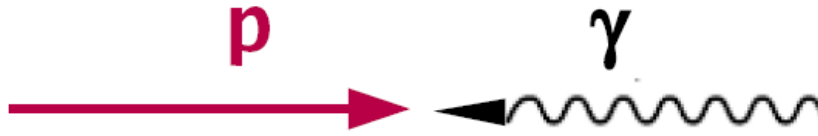


- Energy of ~ 300 GeV in ep CMS
- Neutral current (NC)

Outline

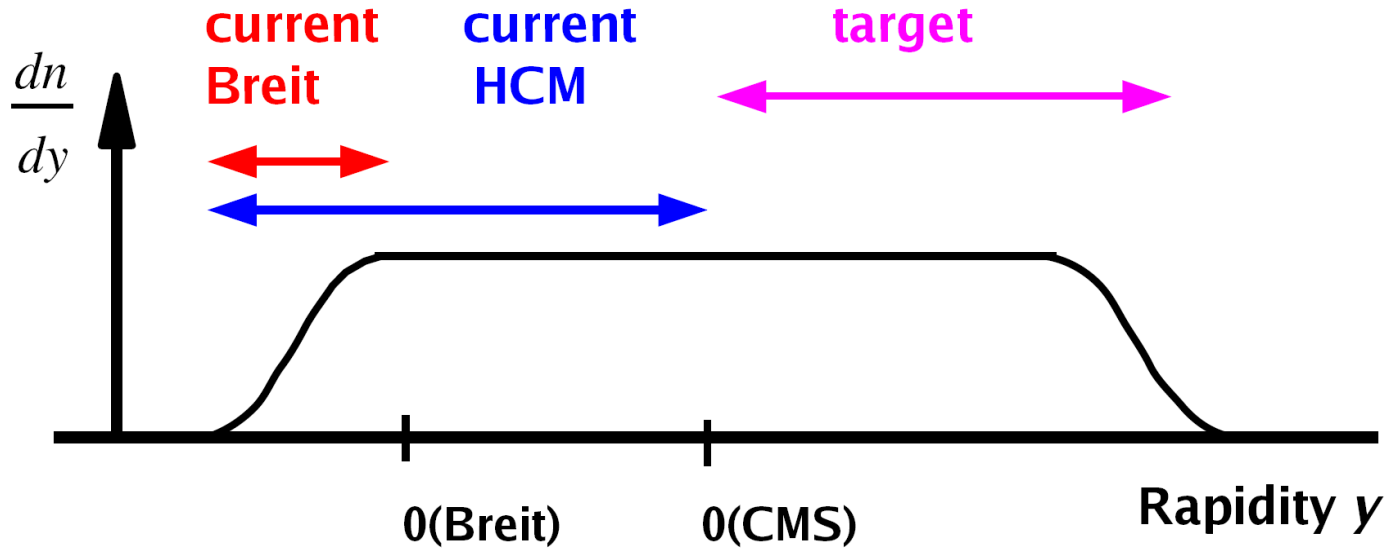
- Motivation
- KNO scaling
- Scaled momenta compared with e^+e^- data

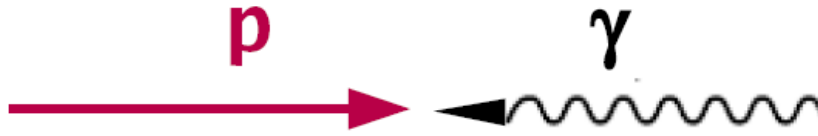




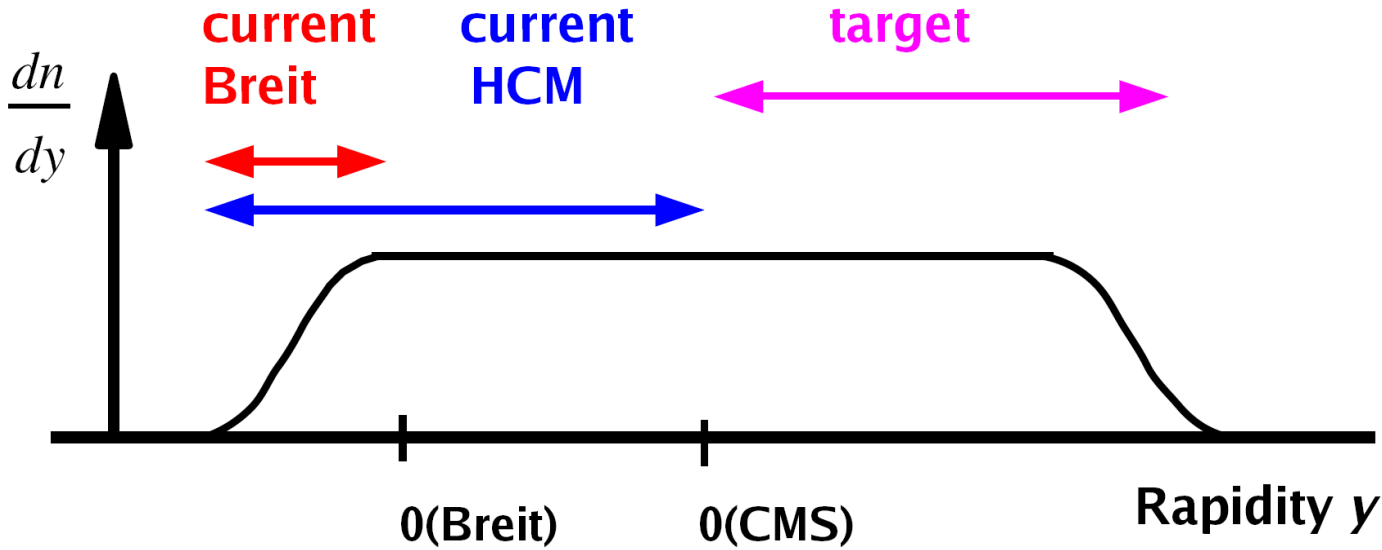
Rapidity of particles defines their expected features,

Similar to e^+e^-





Similar to e^+e^-



$Q, 2E_B^{cr}, M_{eff}$

W, M_{eff}

$$M_{eff}^2 = \left(\sum_i^n E_i \right)^2 - \left(\sum_i^n P_{Xi} \right)^2 - \left(\sum_i^n P_{Yi} \right)^2 - \left(\sum_i^n P_{Zi} \right)^2$$

Data and motivation

Luminosity 38.6 pb^{-1} collected in 1996-7
with $E_{\text{proton}} = 820 \text{ GeV}$ and $E_{e^+} = 27.5 \text{ GeV}$

NC DIS events with $Q^2 > 25 \text{ GeV}^2$
 $70 < W < 225 \text{ GeV}$

Comparison with $e^+ e^-$ in previous studies in Breit frame :

- a reasonable agreement at $Q > 8 \text{ GeV}$
- no agreement at $Q < 8 \text{ GeV}$
explained by the asymmetric nature of $\gamma^* p$

Alternative energy scales to Q :

- the invariant mass of hadronic system $M_{\text{eff}}^{\text{Breit}}$ and $M_{\text{eff}}^{\text{HCM}}$
- the available energy in the current region
of Breit frame E_B^{Cr} or of HCM $E_{\text{HCM}}^{\text{Cr}} \approx W/2$

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Predictions

Monte Carlo models

ARIADNE 4.12 — colour dipole model

LEPTO MEPS — matrix element + parton shower

fragmentation — the Lund string model

HERWIG — cluster hadronisation model

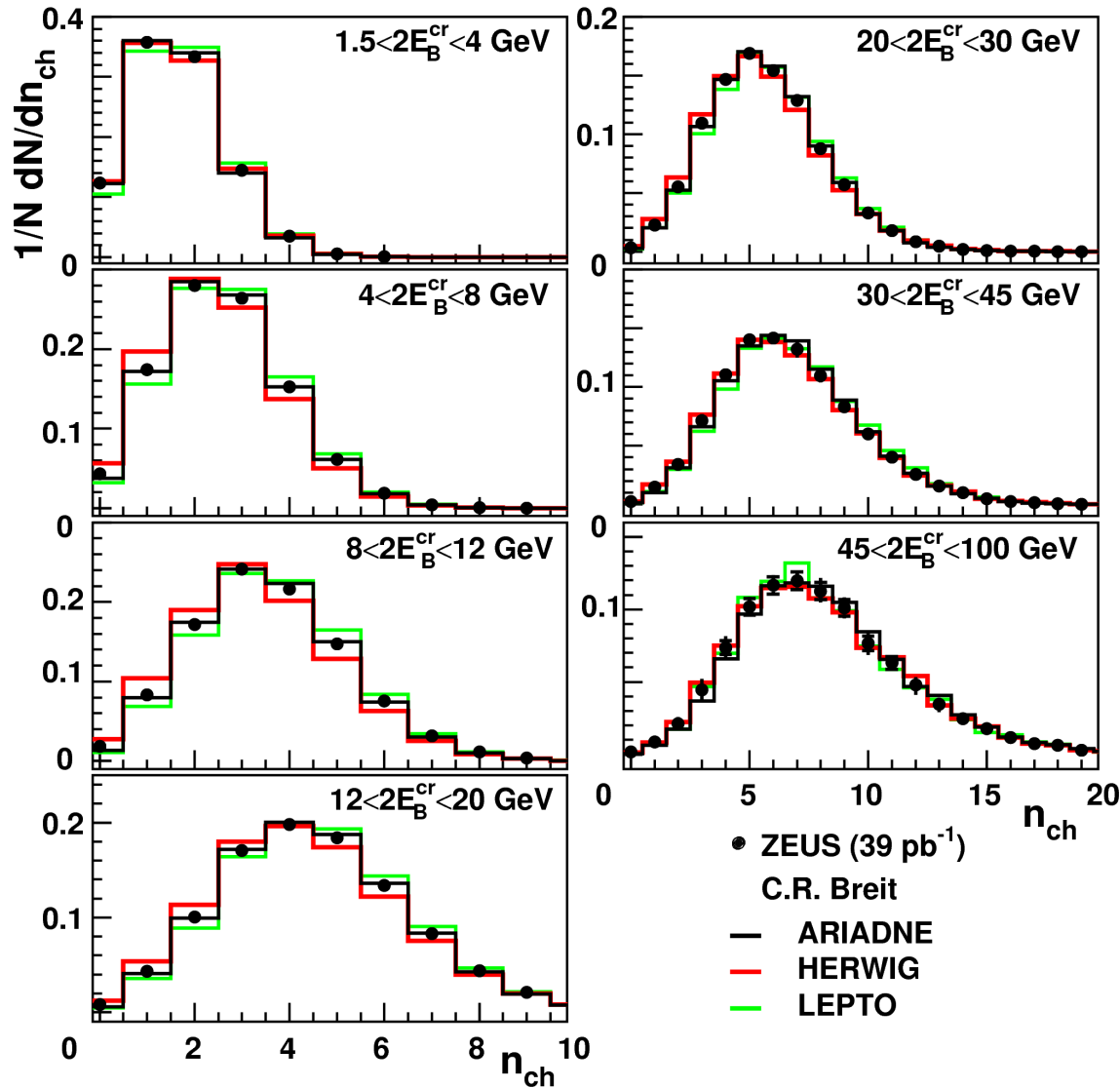
Hadrons taken with lifetime $> 3 \cdot 10^{-10}$ s

Next step:

comparison with data for different scales

Multiplicity in 2 E_B^{cr} bins in the Breit frame

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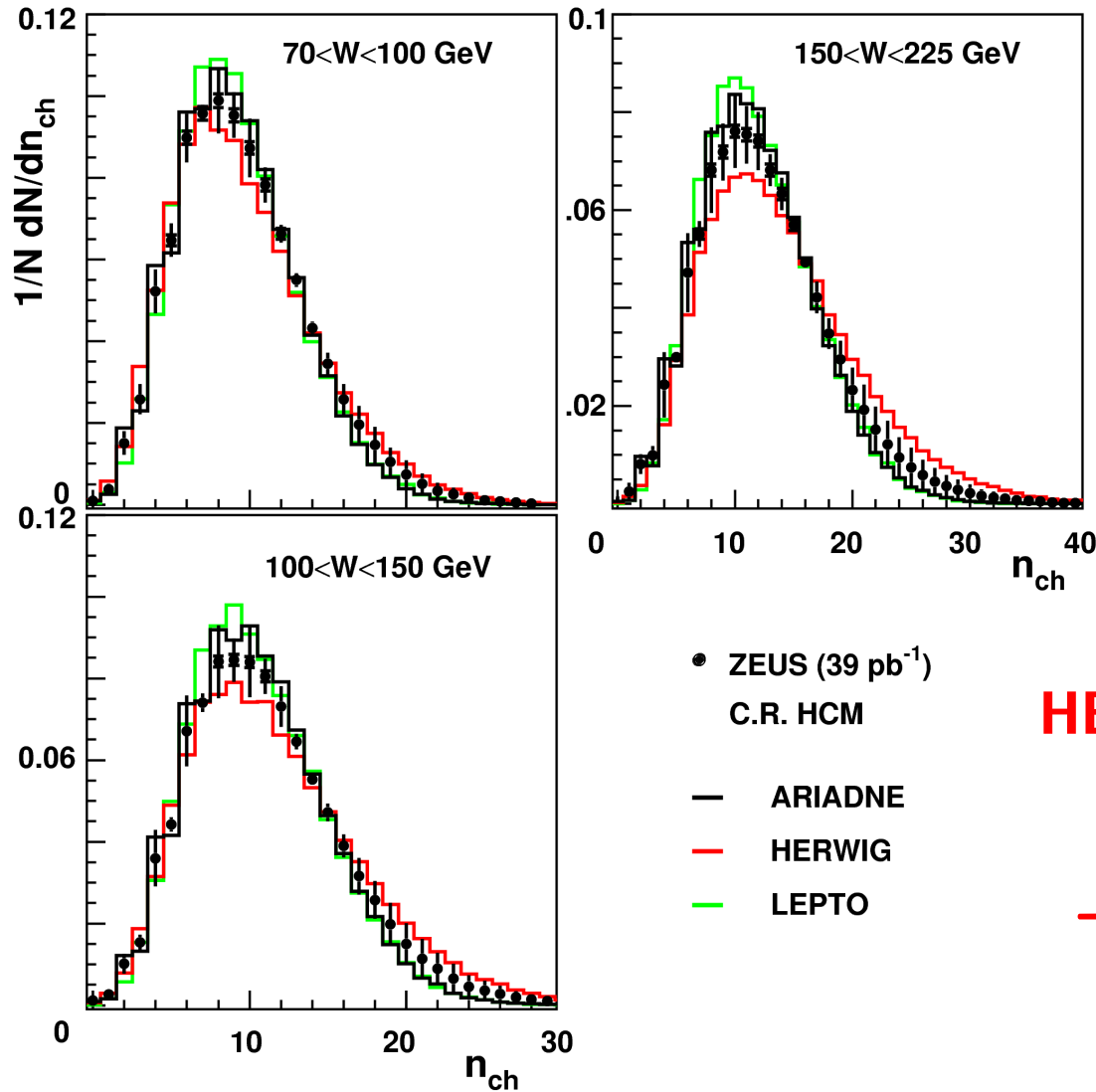


E_B^{cr} — the available energy
in the current region
of Breit frame

All the MC models
→ good descriptions
but ARIADNE is the best

Multiplicity in W bins in the HCM frame

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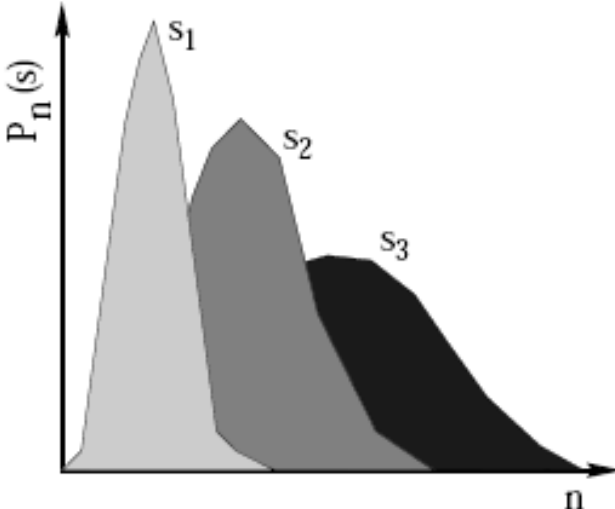
W — total energy in γ^* p centre of mass

HERWIG — longer tails for multiplicities

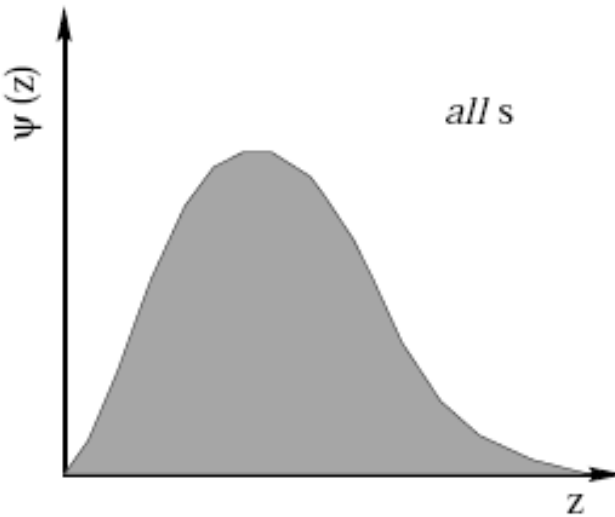
→ increase of sys. uncertainties

KNO scaling

Z.Koba,H.B.Nielson,P.Olsen
 N.P. B40(1972)317



⇓ rescaling



$P(n_{ch})$ the probability distribution of multiplicity n_{ch}

$\langle n_{ch} \rangle$ the average multiplicity

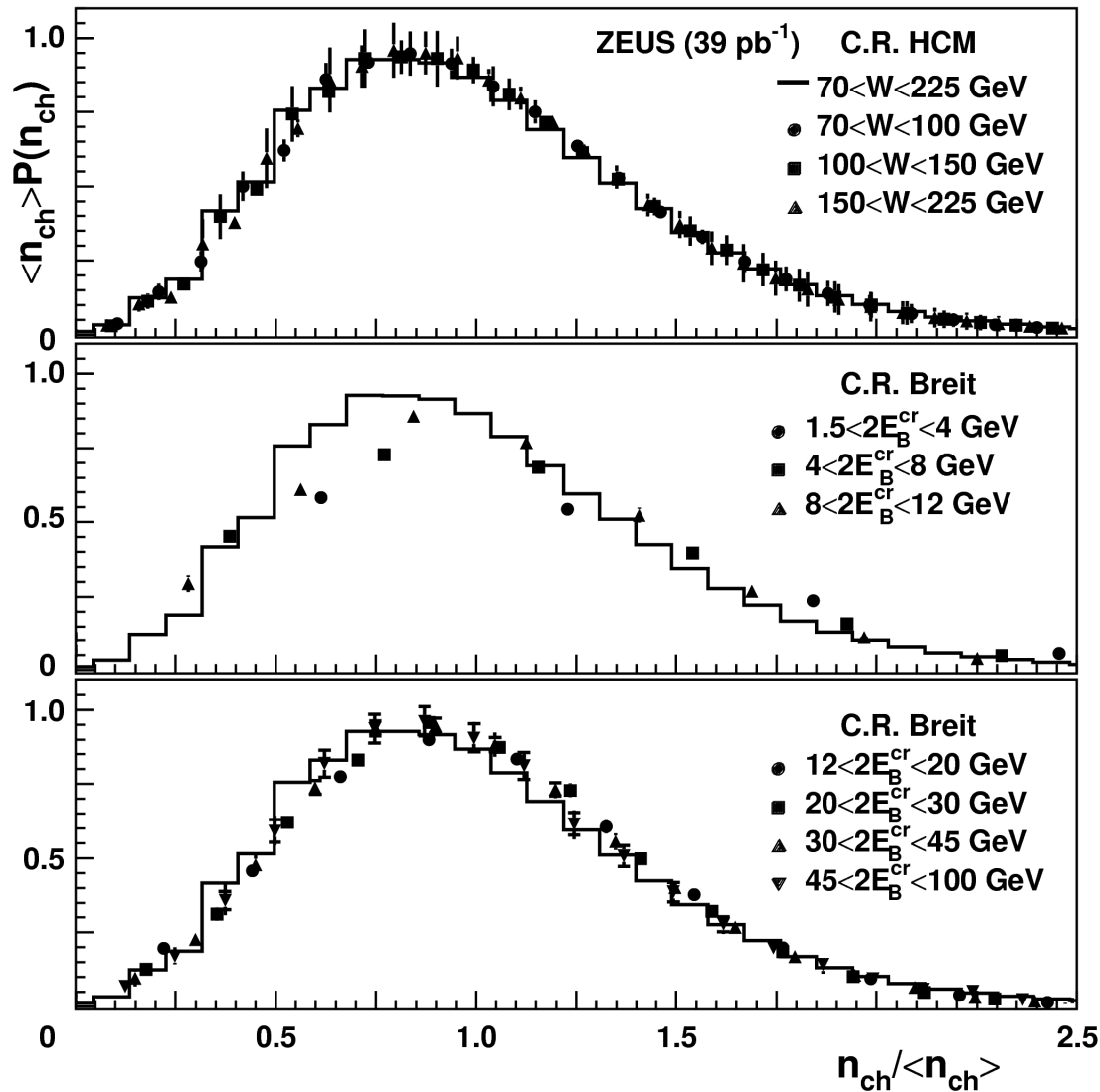
at high enough energies s
 → asymptotic behaviour

$$\langle n_{ch} \rangle P(n_{ch}) \sim n_{ch} / \langle n_{ch} \rangle$$



KNO scaling in W and E_B^{cr} bins

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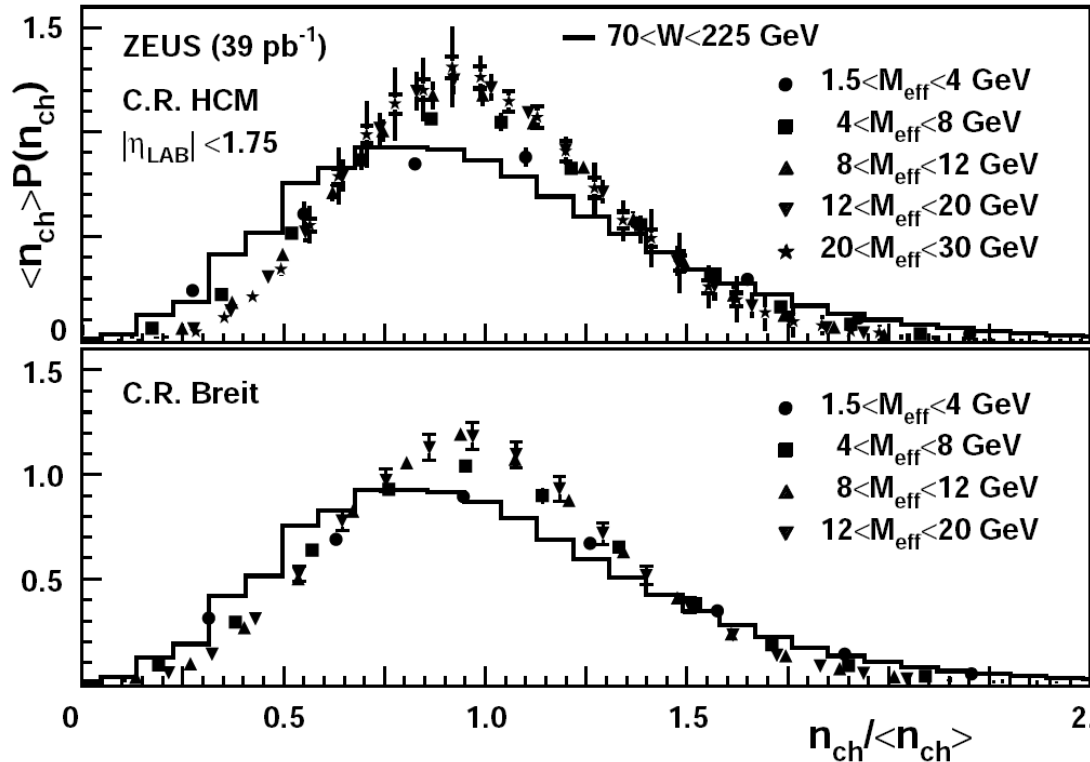
Product of $P(n_{ch}) \langle n_{ch} \rangle$
the multiplicity distribution
and the average multiplicity

— reference distribution
average distr. 70 < W < 225 GeV

bins	agreement
2 $E_B^{cr} < 12$ GeV	No
2 $E_B^{cr} > 12$ GeV	OK

KNO scaling in M_{eff} bins

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HCM frame

Breit frame

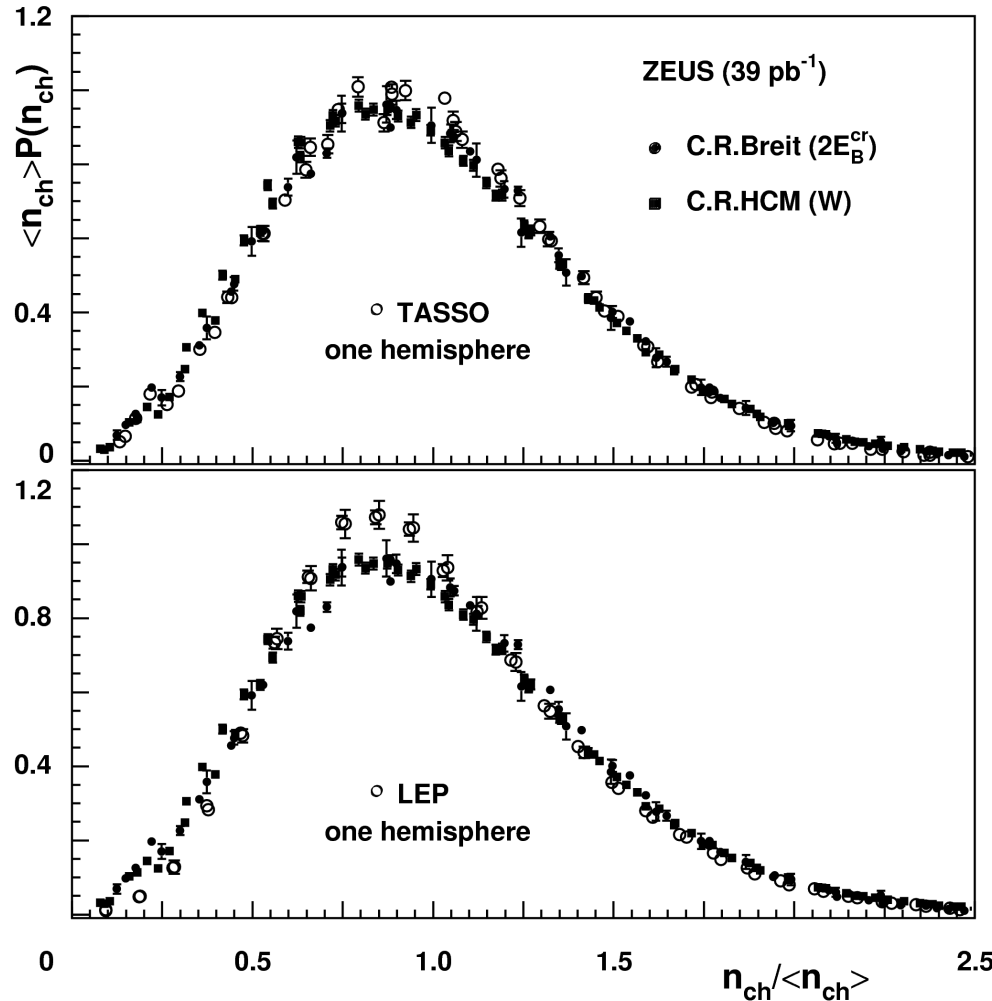
no agreement with
the reference plot

Scaling behaviour observed for HCM and Breit

except $M_{\text{eff}} < 4 \text{ GeV}$

KNO scaling (e⁺e⁻ vs ep)

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ep in bins

$$2 \frac{E_B^{cr}}{W}$$

if $2 E_B^{cr} > 12 \text{ GeV}$

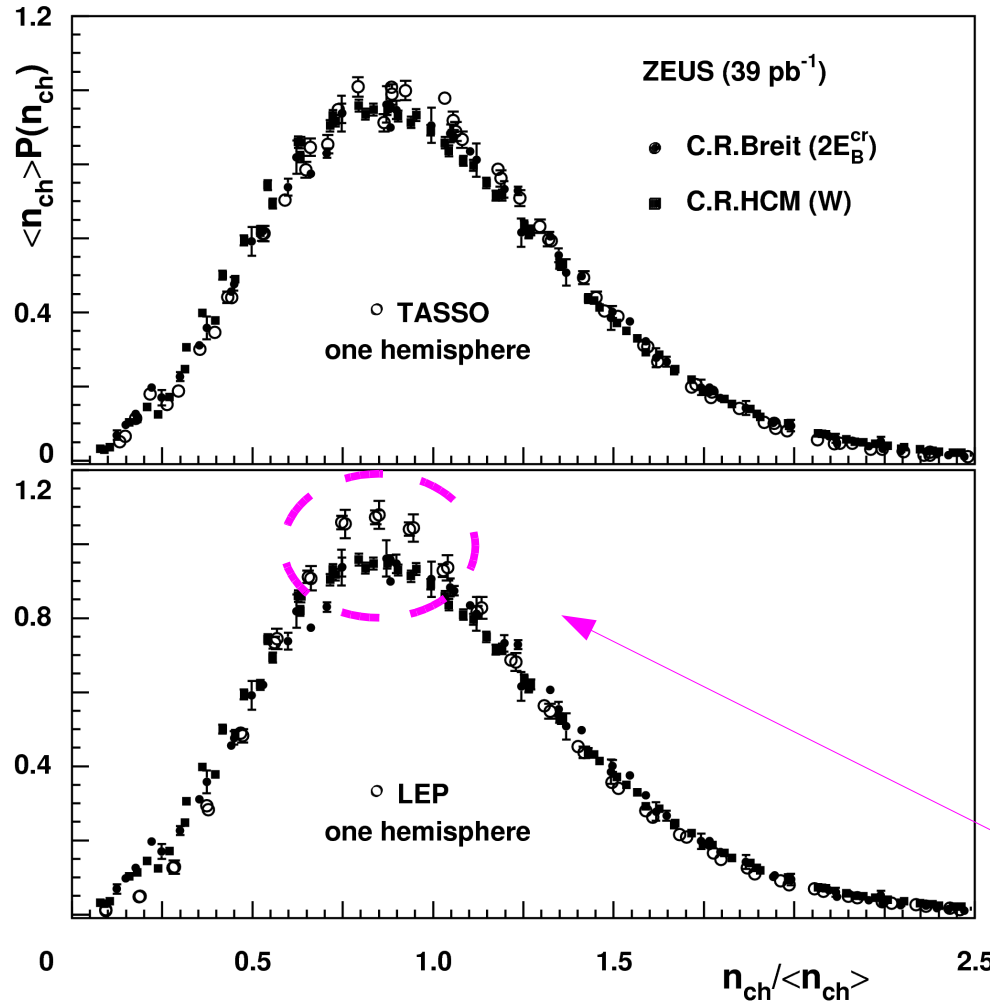
e⁺e⁻ data from **one hemisphere**
LEP (DELPHI, OPAL) at Z⁰
PETRA (TASSO)

acceptable agreement
for PETRA and LEP

except LEP at peak

KNO scaling (e⁺e⁻ vs ep)

ZEUS



ep in bins

$$2 \frac{E_B^{cr}}{W}$$

if $2 E_B^{cr} > 12 \text{ GeV}$

e⁺e⁻ data from

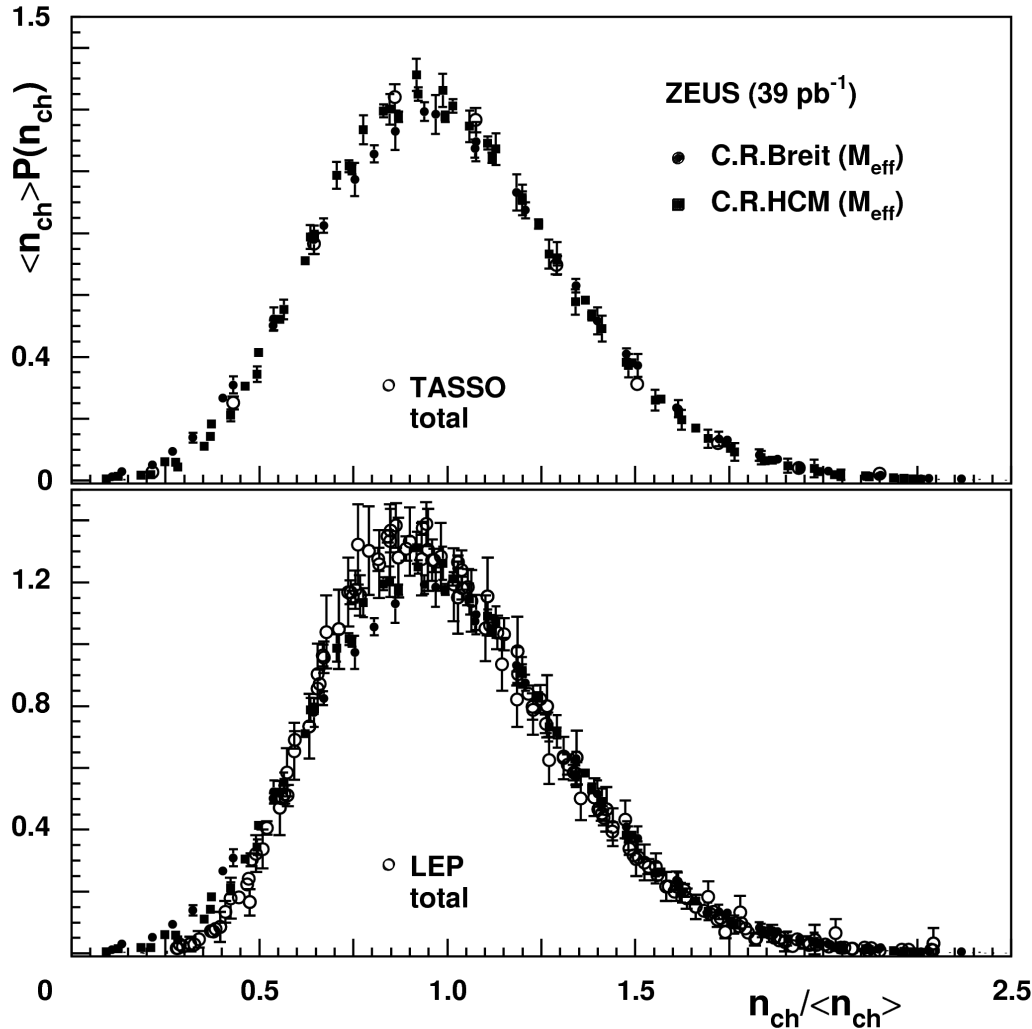
LEP (DELPHI, OPAL) at Z⁰
PETRA (TASSO)

acceptable agreement
for PETRA and LEP

except LEP at peak

KNO scaling (e^+e^- vs ep in M_{eff} bins)

ZEUS



ep with $M_{\text{eff}} > 8 \text{ GeV}$

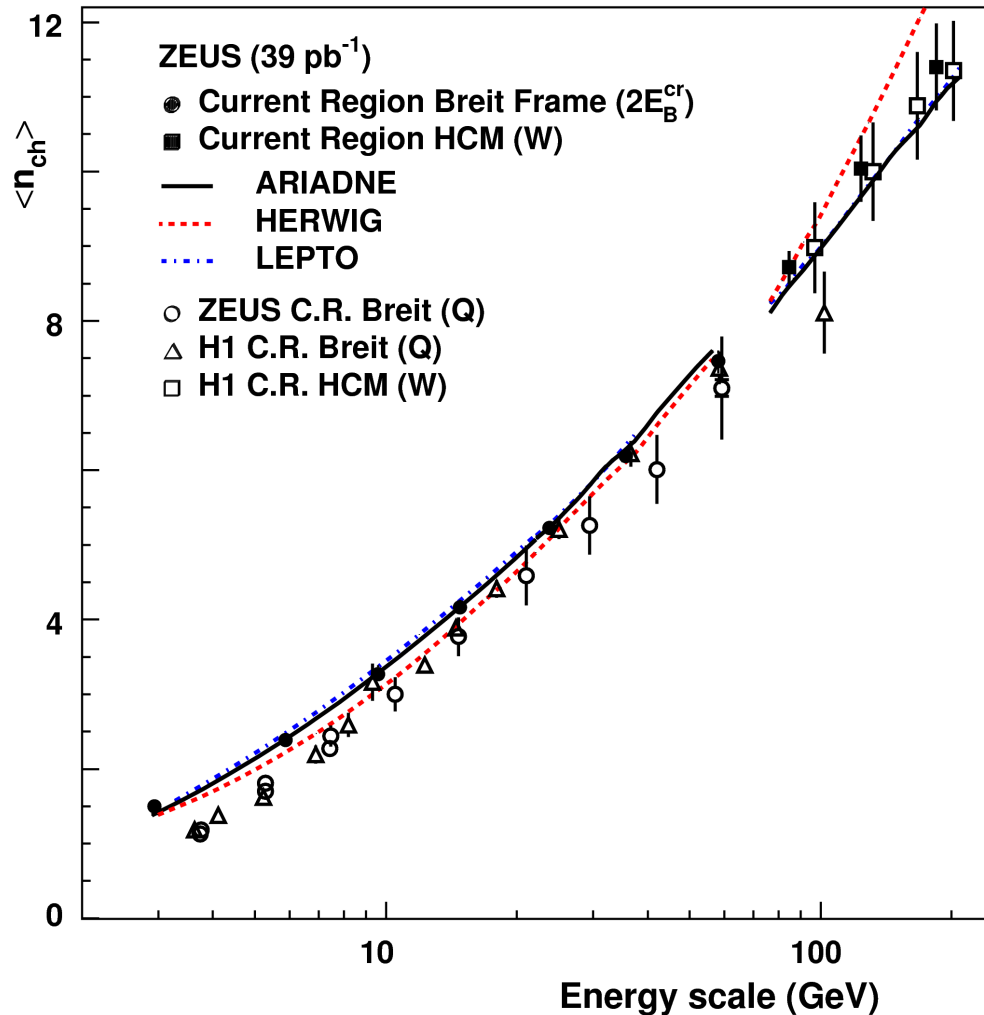
e^+e^- data for **2 hemispheres**

- LEP $91.2 < \sqrt{s} < 209 \text{ GeV}$
(DELPHI, OPAL, L3, ALEPH)
- PETRA (TASSO)

Good agreement

Average multiplicity as $f(2 \cdot E_B^{cr})$ and $f(W)$

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Data are in good agreement
with LEPTO and ARIADNE

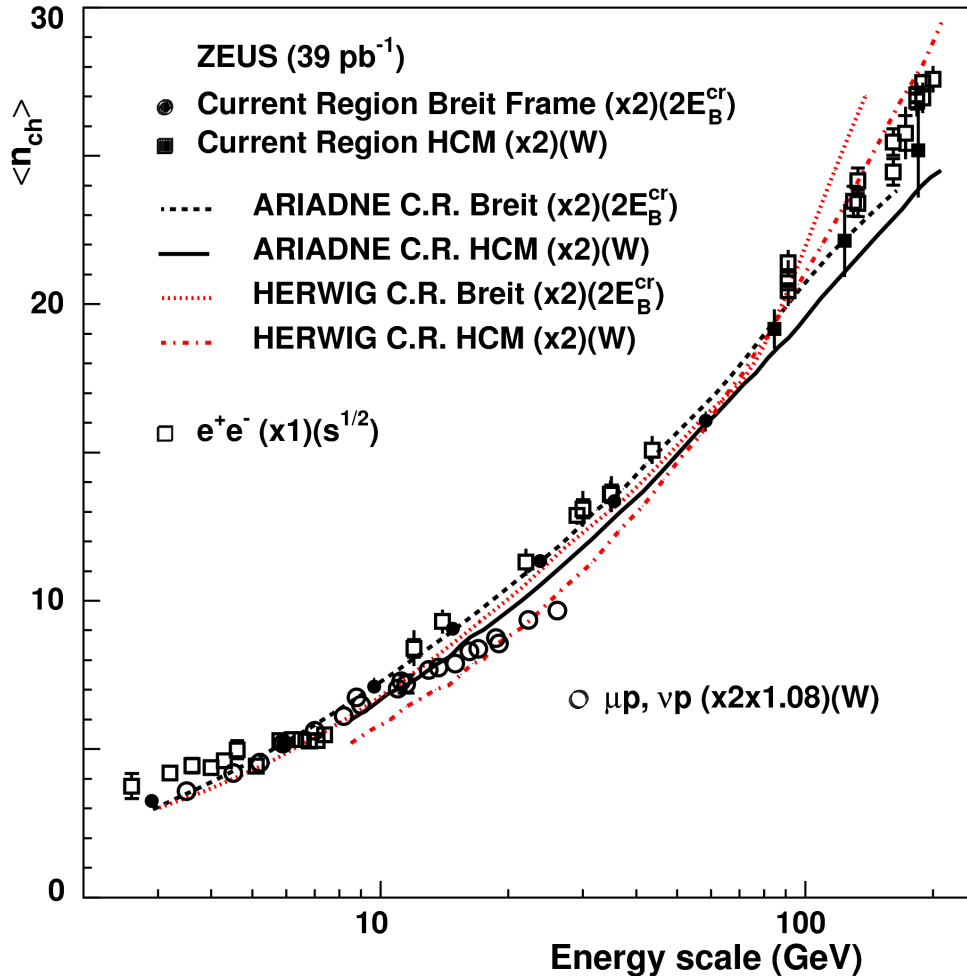
not with **HERWIG**

At low energy scales
differences if $2E_B^{cr}$ or Q

At high scales
good agreement

Multiplicity (e^+e^- vs ep & fixed target)

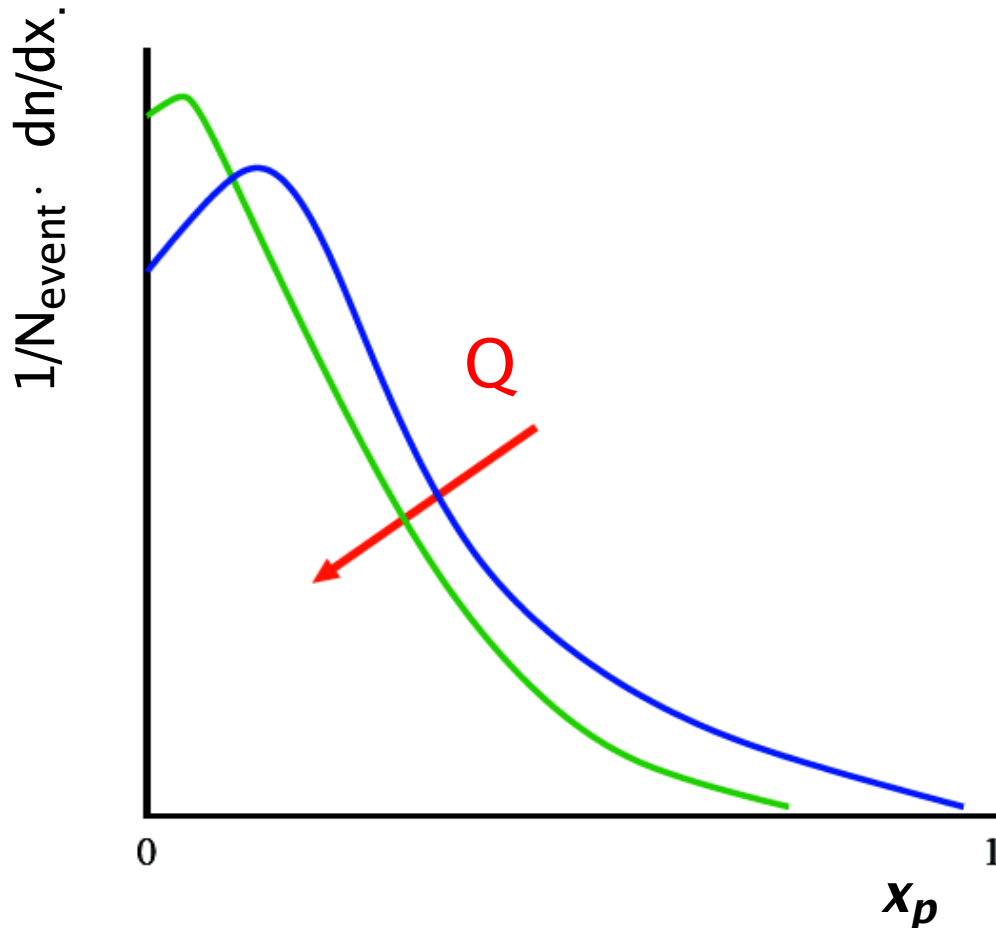
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- At low scales E_B^{cr} gives better agreement with e^+e^- than Q
- Fixed target data deviate from the observed energy dependence above 15 GeV
- ARIADNE - the best description but data are systematically above predictions in HCM
- HERWIG deviates from data
- LEP data above ep data in HCM at scale >100 GeV

Scaled momentum $x_p = \frac{(2 P_h)}{Q} = \frac{P_h}{E_{beam}}$

For ep and e^+e^-



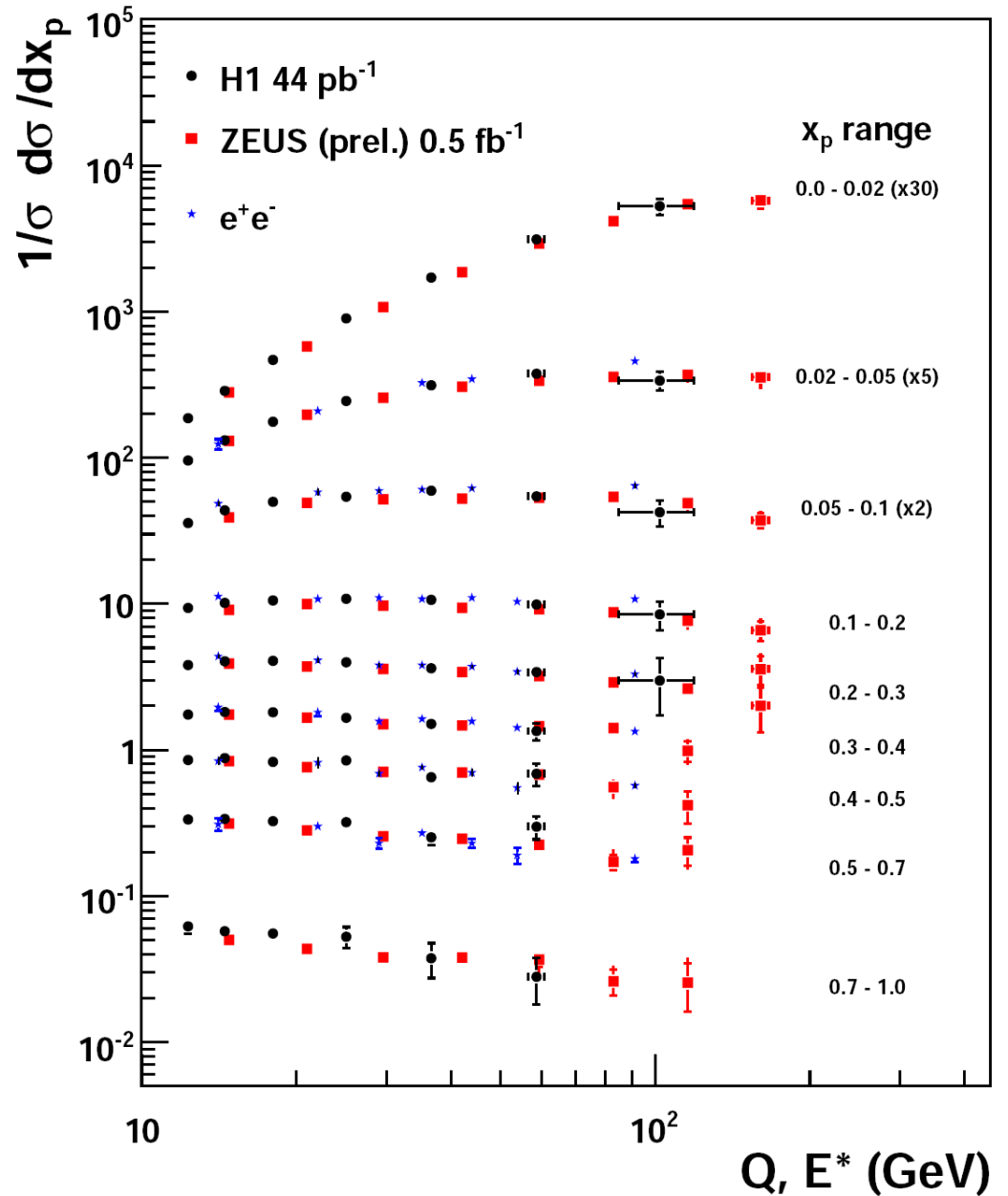
P_h – momentum of charged particles in current region of the Breit frame.

With Q increasing dn/dx_p is softer, i.e. more particles with smaller fraction of energy $Q/2$.

Comparison ep with e⁺e⁻

- supports the concept of quark fragmentation universality.
- scaling violation is observed

ZEUS data (prel), 0.5 pb⁻¹, 1996-2007
 H1 data, Phys.Lett. B654(2007)148
 ee data from TASSO, MARK II, AMY,
 DELPHI PL,B311(1993)408
 $E^* = 2 E_{\text{beam}}$

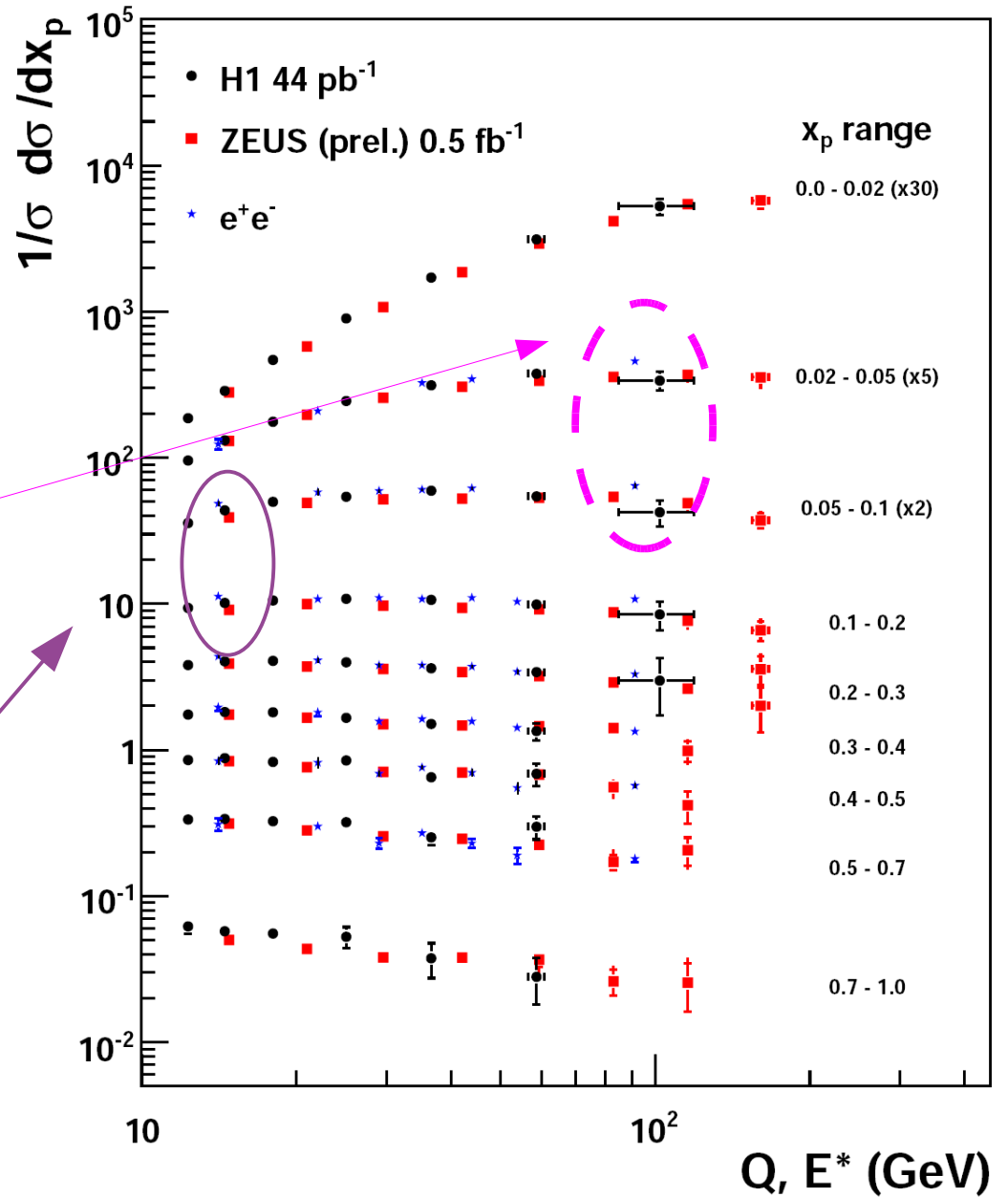


Comparison ep with e^+e^-

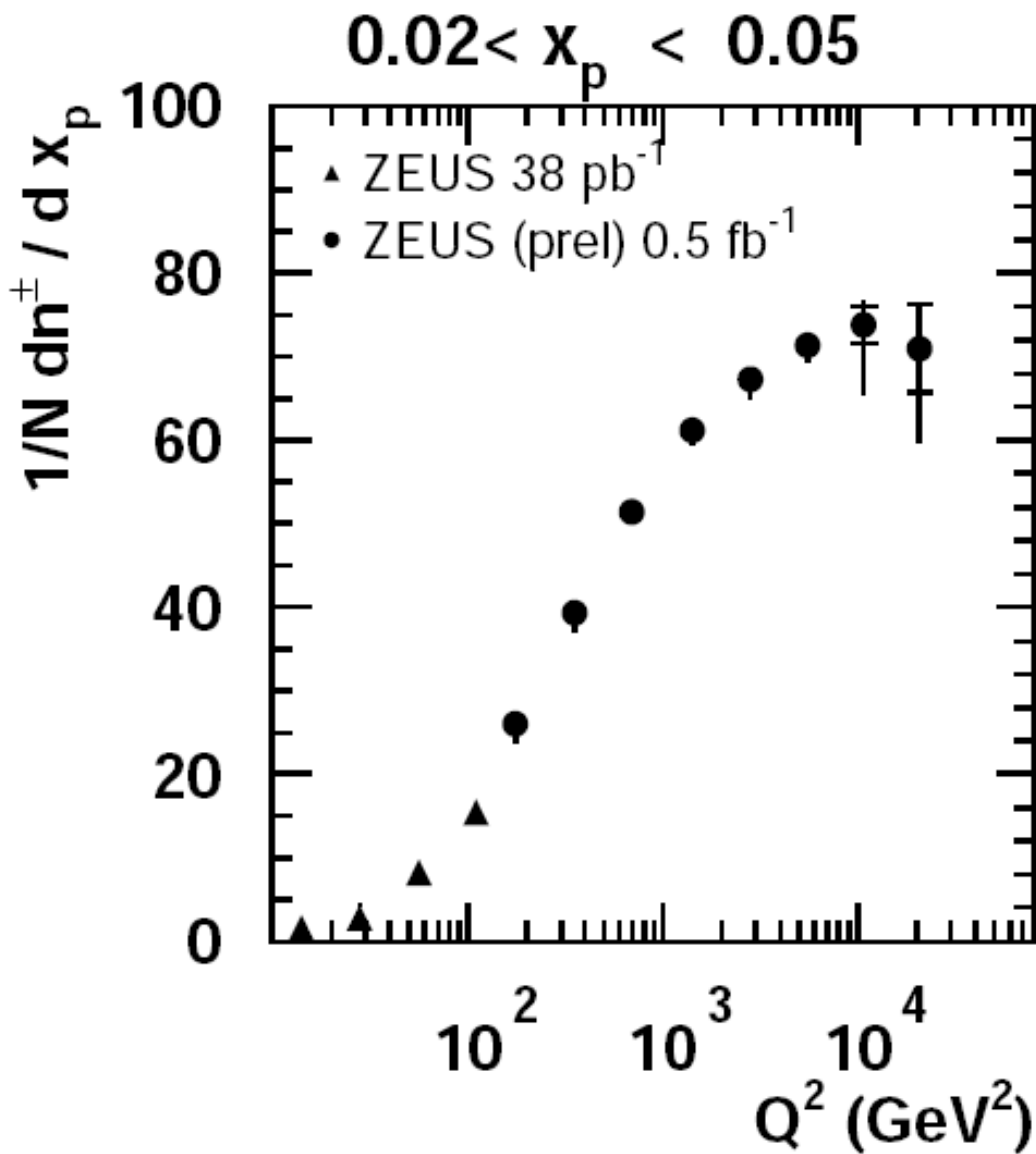
- supports the concept of quark fragmentation universality.
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LEP (DELPHI)

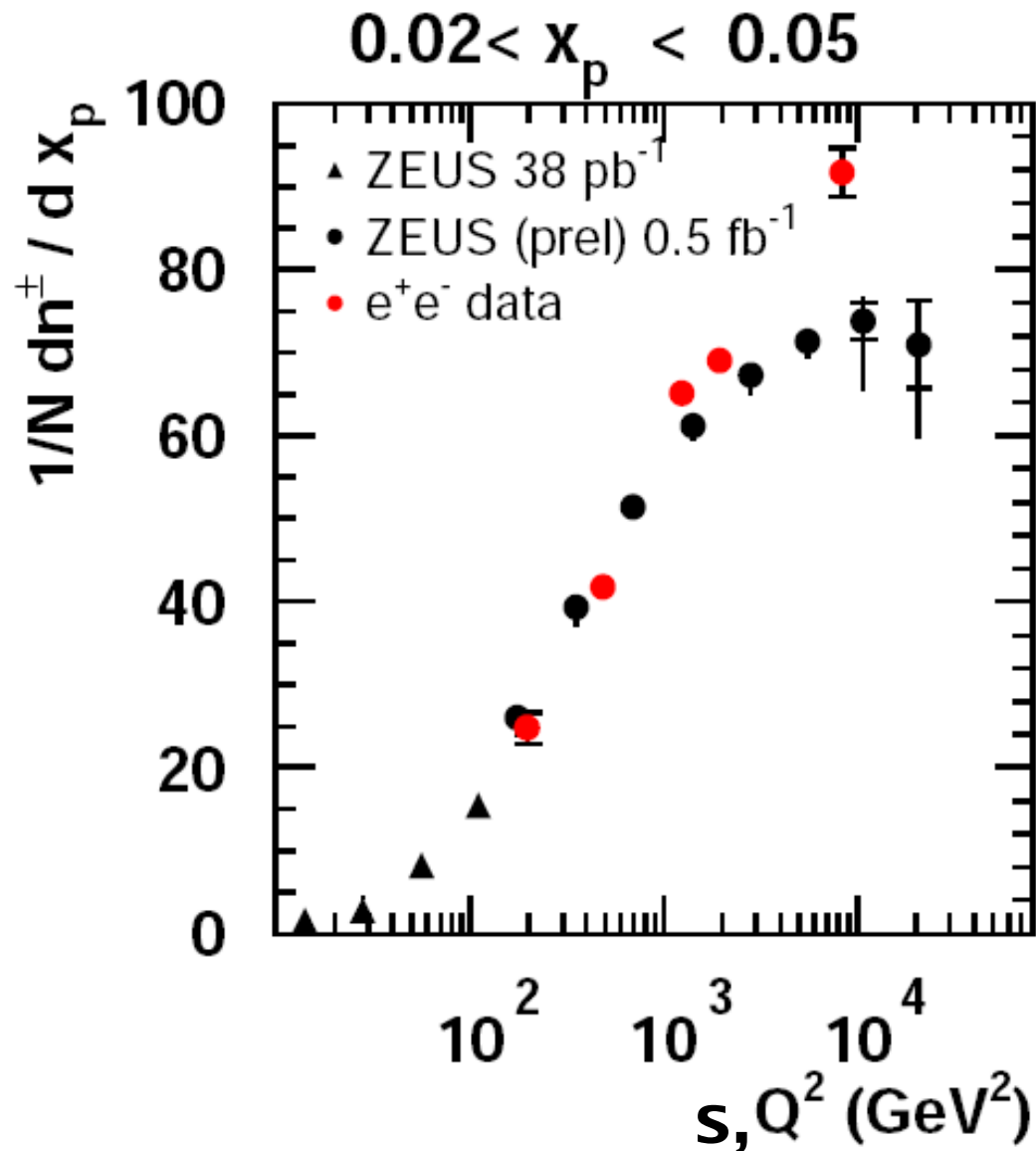
PETRA (TASSO)



Scaled momenta in x_p bins



Scaled momenta in x_p bins



e^+e^- data imposed with
 $s=4E_{\text{beam}}^2$

Summary and conclusions

Charged hadron multiplicities are investigated in current region of Breit and HCM frames for different energy scales: $2E_B^{cr}$, W , M_{eff} , Q

- Mean charge multiplicity as a f ($2E_B^{cr}$) agrees better with e+e- than as a f(Q),
- Usage of W and $2 E_B^{cr}$ gives a consistent comparison of ep with e+e- and with the previous DIS data
- KNO scaling for ep is similar to
 - one hemisphere of e+e- if W and $2 E_B^{cr}$ are used
 - total multiplicity if M_{eff} is used

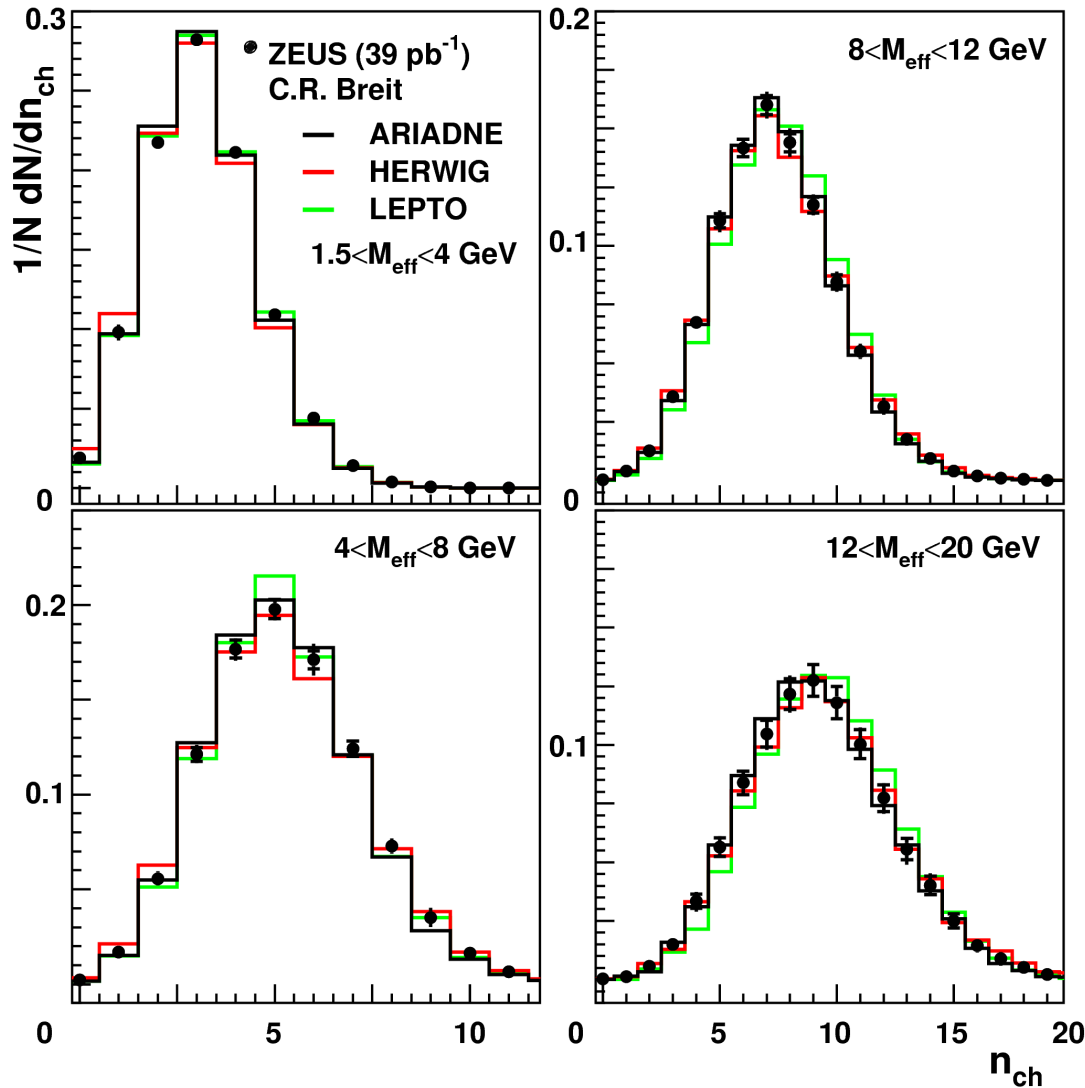
Scaled momenta in current region of ep Breit frame compared with e+e-

- general trends are the same (the scaling violation is observed)
- some differences are seen for e.g. small x_p at LEP energies

Thank you for your attention.

Multiplicity in M_{eff} bins in the Breit frame

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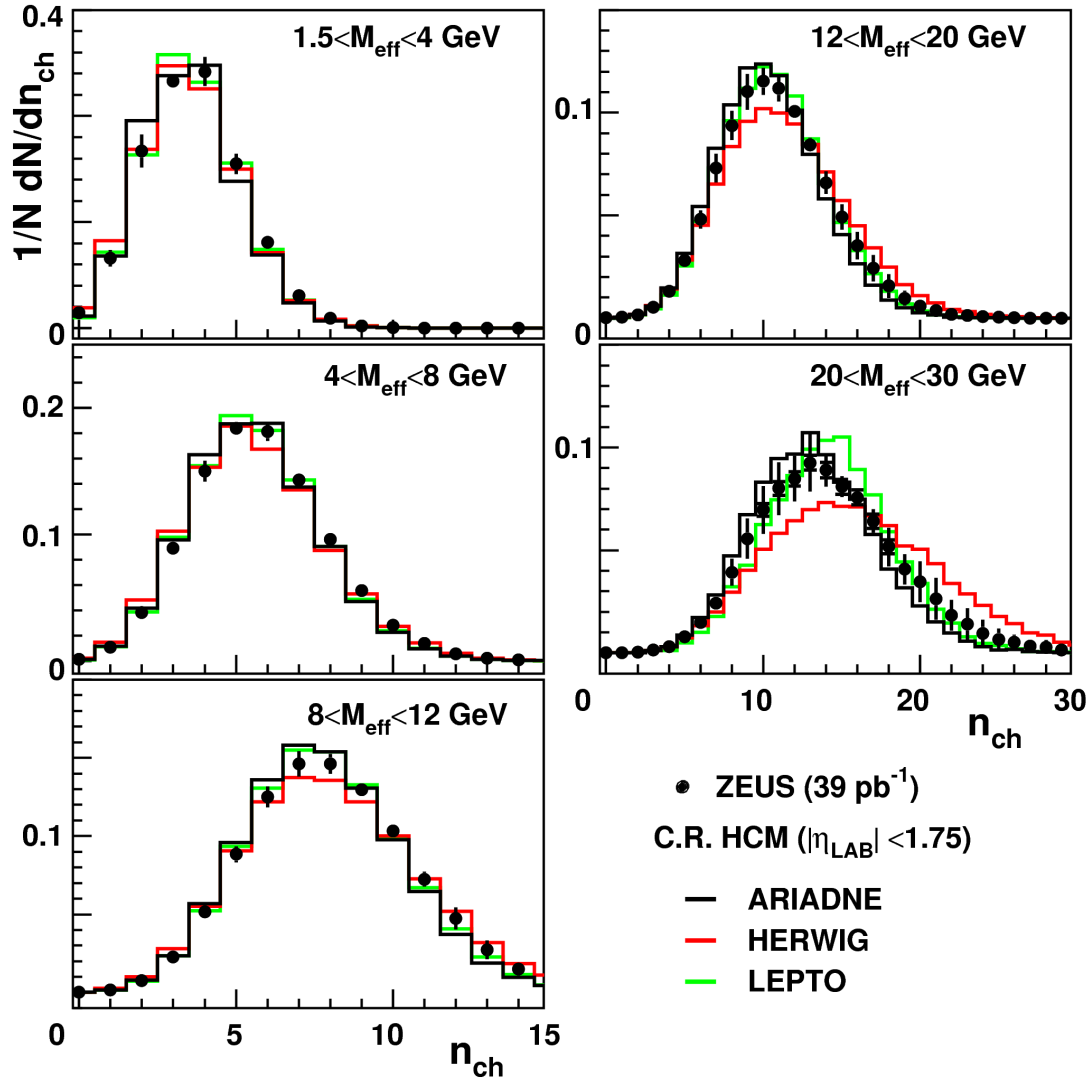


M_{eff} — the invariant mass
of hadronic system
in the Breit frame

All the MC models
→ good descriptions

Multiplicity in M_{eff} bins in the HCM frame

ZEUS

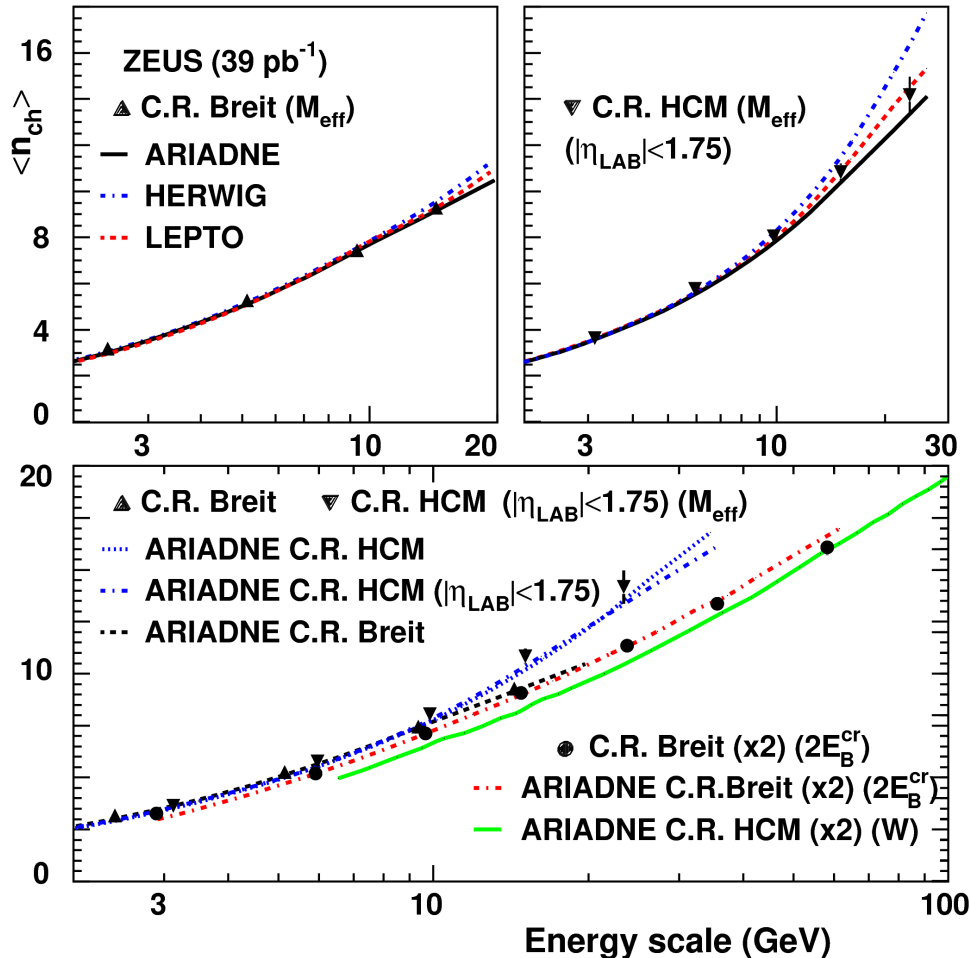


M_{eff} — the invariant mass
 of hadronic system
 in $\gamma^* p$ centre of mass

None of models gives
 a good description,
 in particular at higher M_{eff}

Average multiplicity as f (M_{eff})

ZEUS



Data agree with
LEPTO and ARIADNE

At energy scales $M_{\text{eff}} < 10 \text{ GeV}$
 $\langle n_{\text{ch}} \rangle$ in Breit and HCM agree
 at higher scales
 $\langle n_{\text{ch}} \rangle$ rises faster in HCM