Energy dependence of the charged multiplicity and scaled momenta in DIS

On behalf of the ZEUS Collaboration

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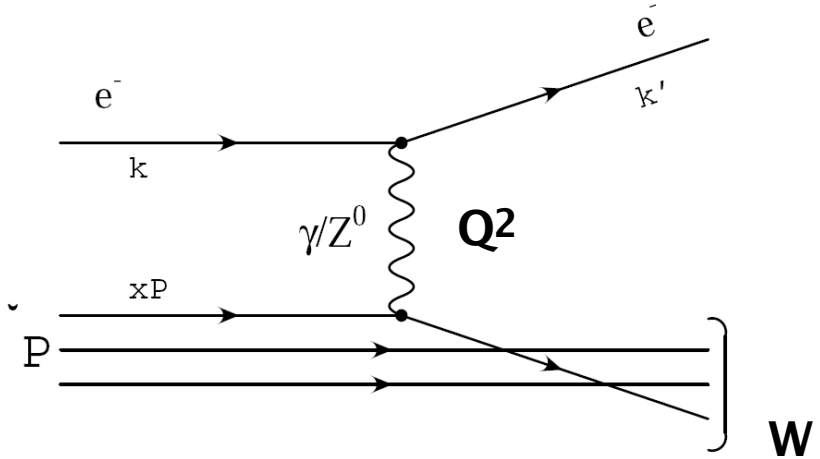
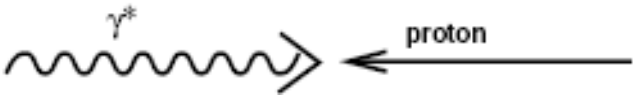


- Energy of~300 GeV in ep CMS
- Neutral current (NC)

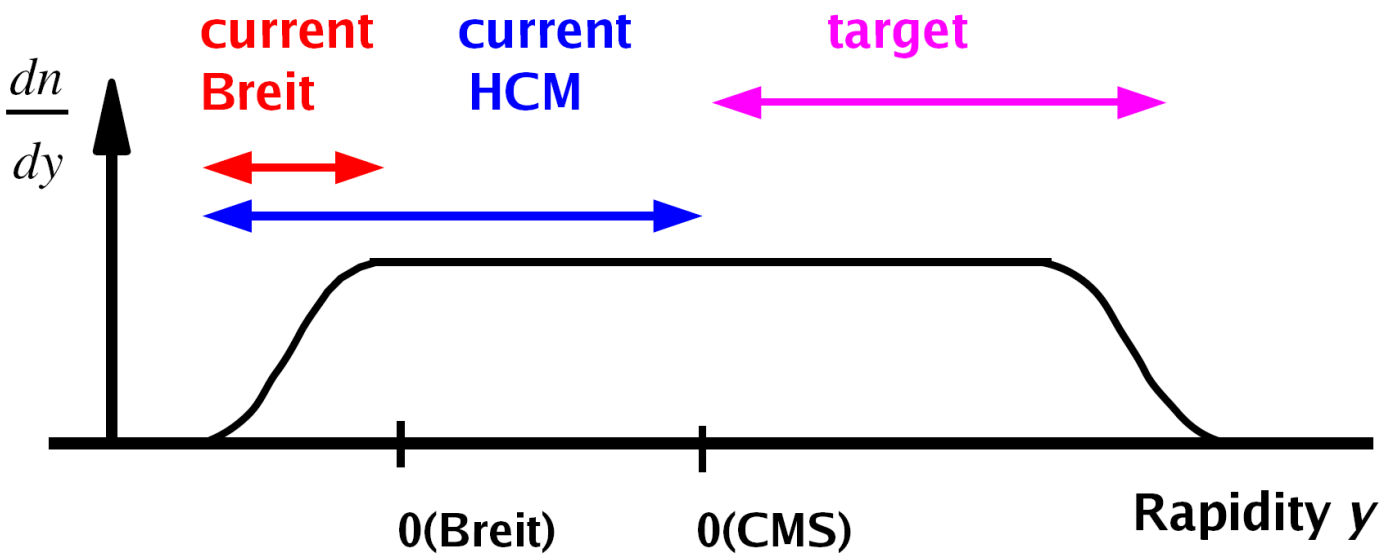


Outline

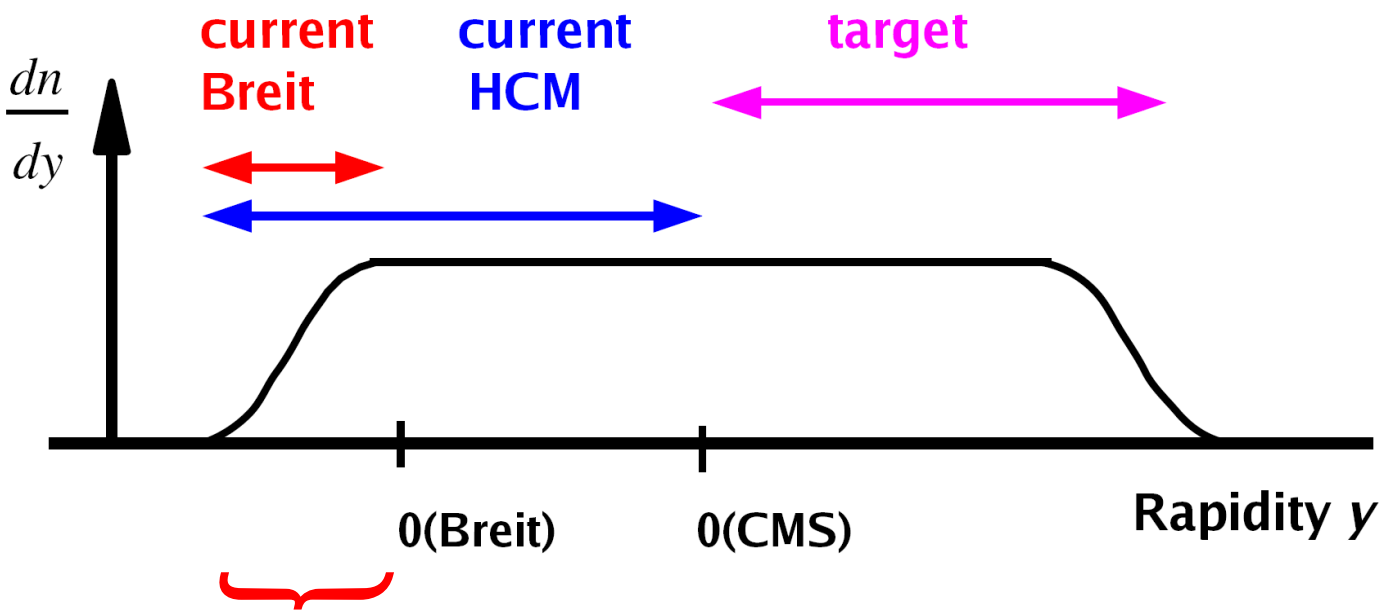
- Motivation
- KNO scaling
- Scaled momenta compared with e^+e^- data

Rapidity of particles defines their expected features,

Similar to e^+e^- p p



Similar to e^+e^- p p



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

$W,\ M_{eff}$

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

Data and motivation

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

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

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

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

Alternative energy scales to Q:

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

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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

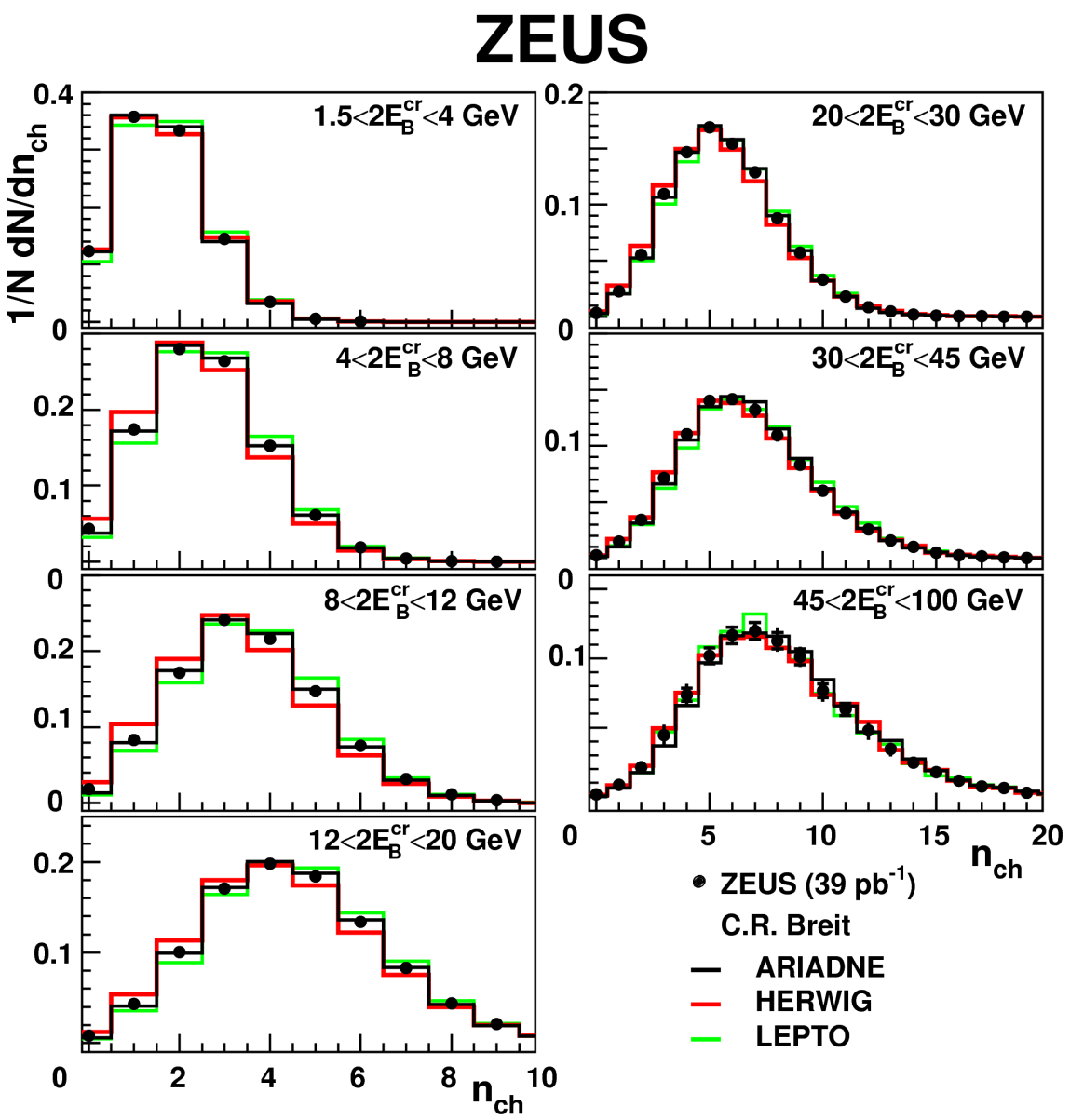
HERWIG — cluster hadronisation model

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

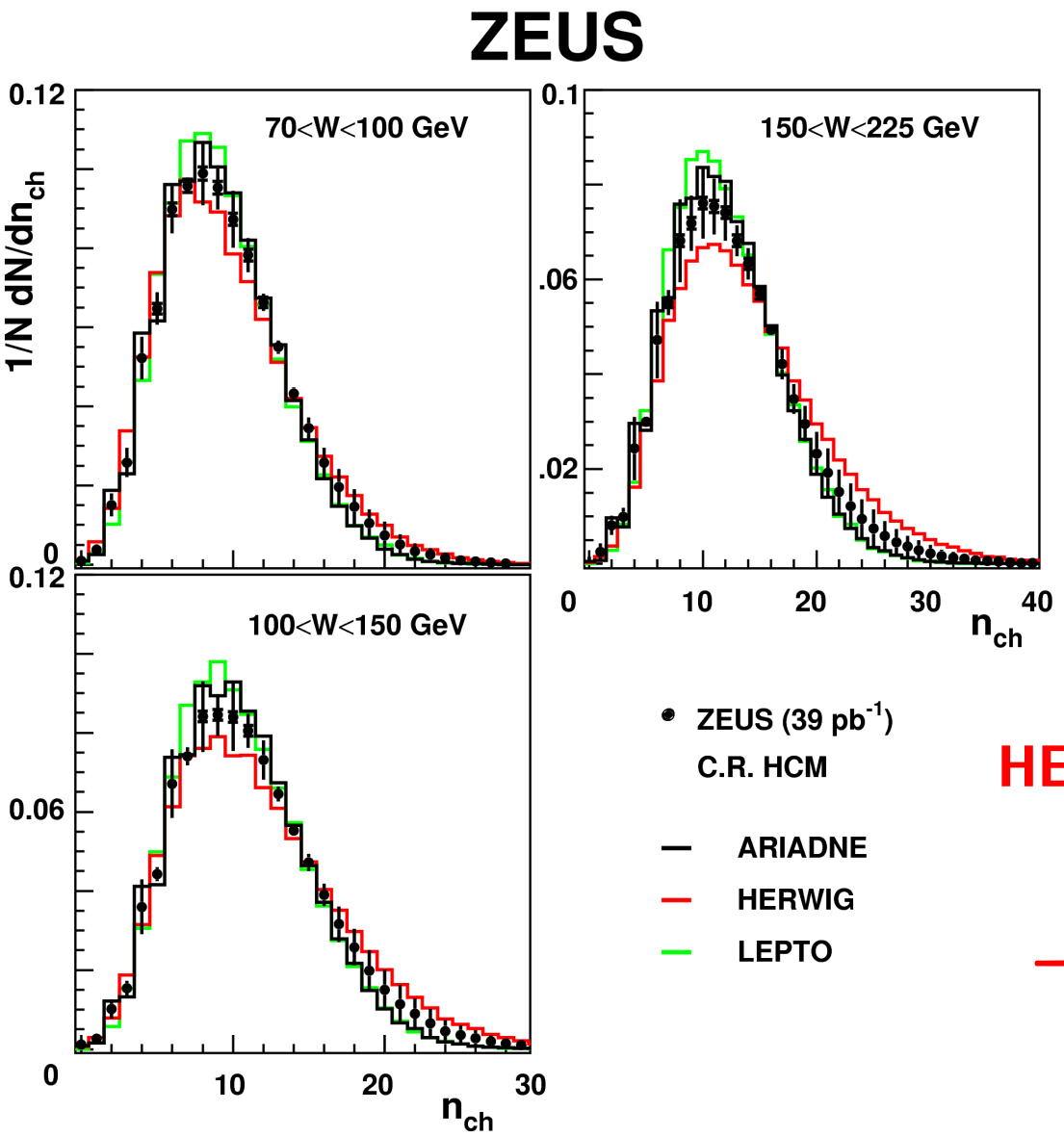


E_B^{cr} — the available energy in the current region of Breit frame

All the MC models → good descriptions

but ARIADNE is the best

Multiplicity in W bins in the HCM frame

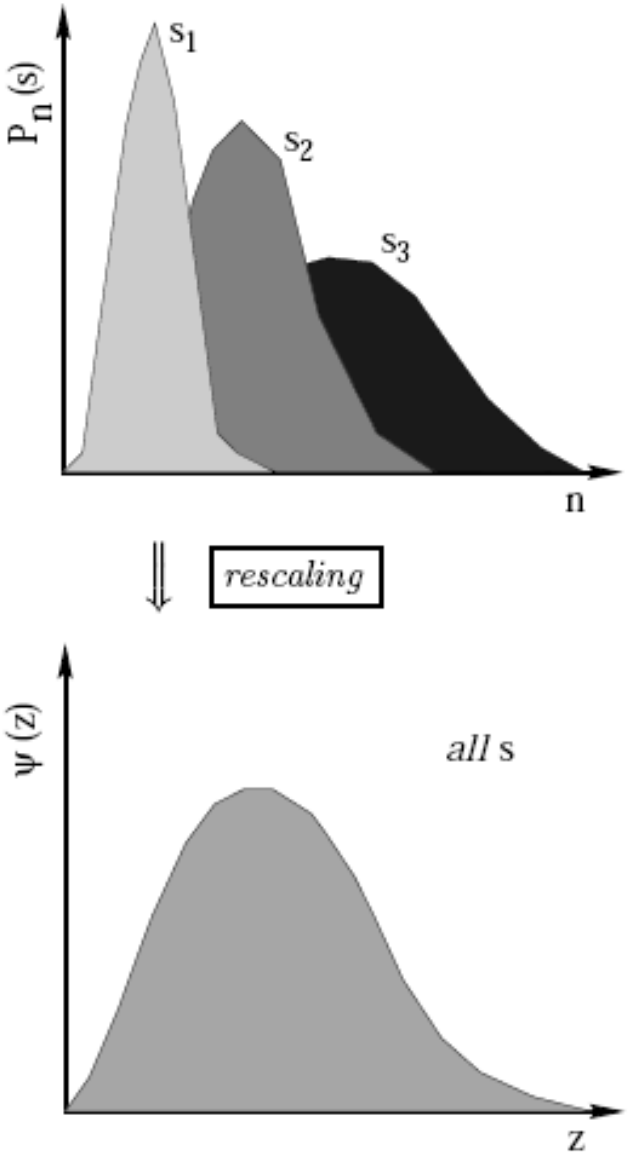


W — total energy in $\gamma^* p$ centre of mass

HERWIG — longer tails for multipliciities

→ increase of sys. uncertainties

KNO scaling



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

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

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

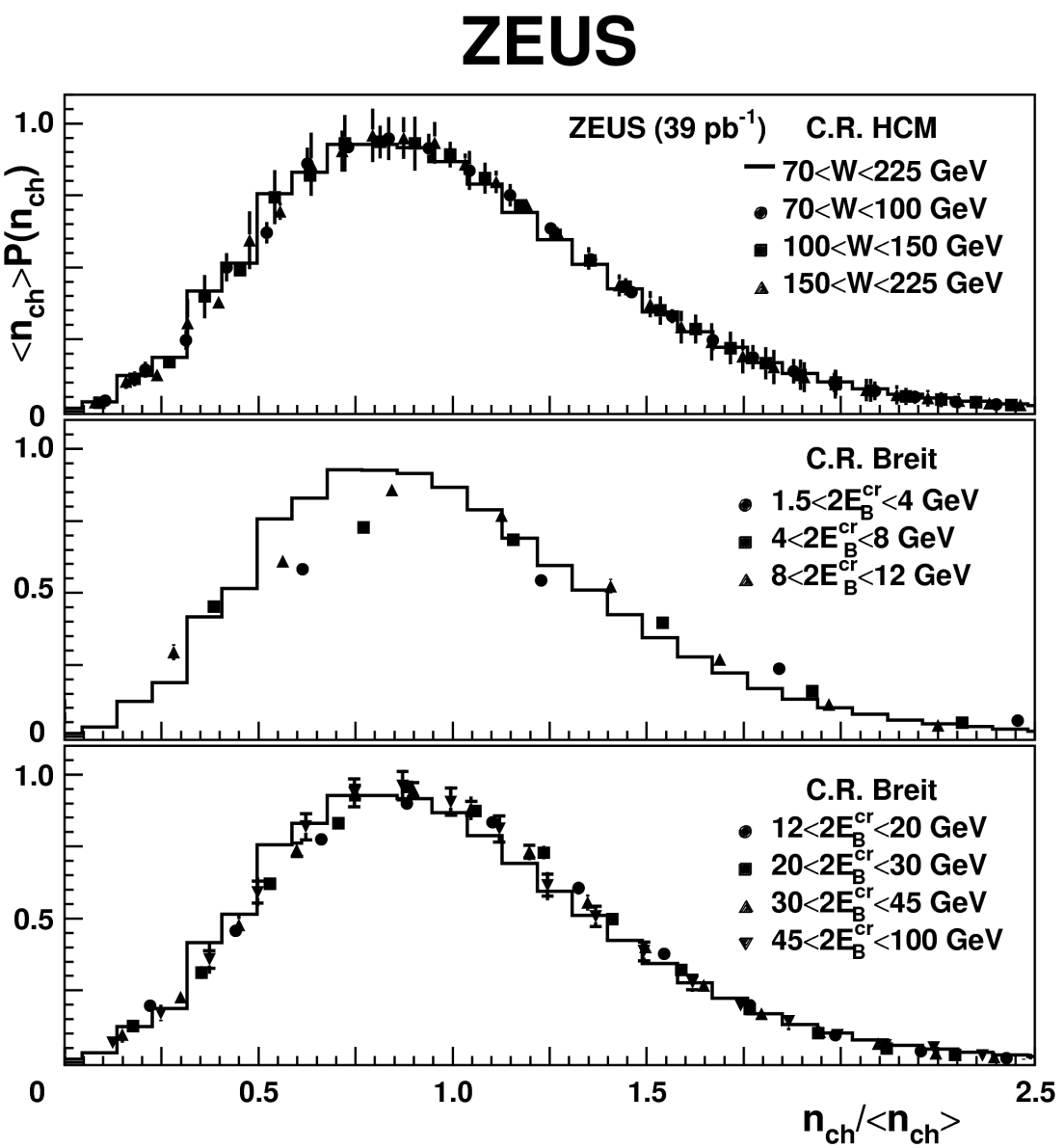
at high enough energies s → asymptotic behaviour

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

$$\uparrow \qquad \uparrow$$

$$\psi(z) \qquad z$$

KNO scaling in W and E_B^{cr} bins

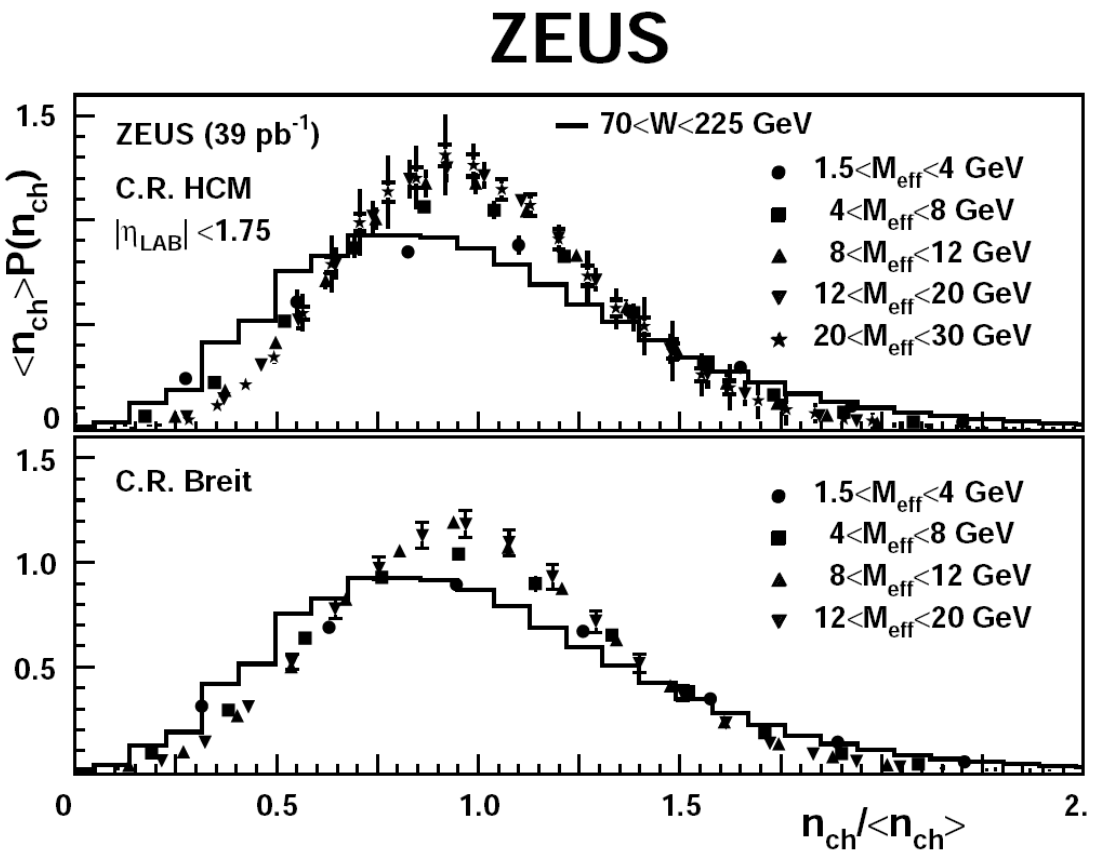


Product of $P(n_{ch})\ \langle n_{ch}\rangle$
the multiplicity distribution
and the average multiplicity

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

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

KNO scaling in M_{eff} bins



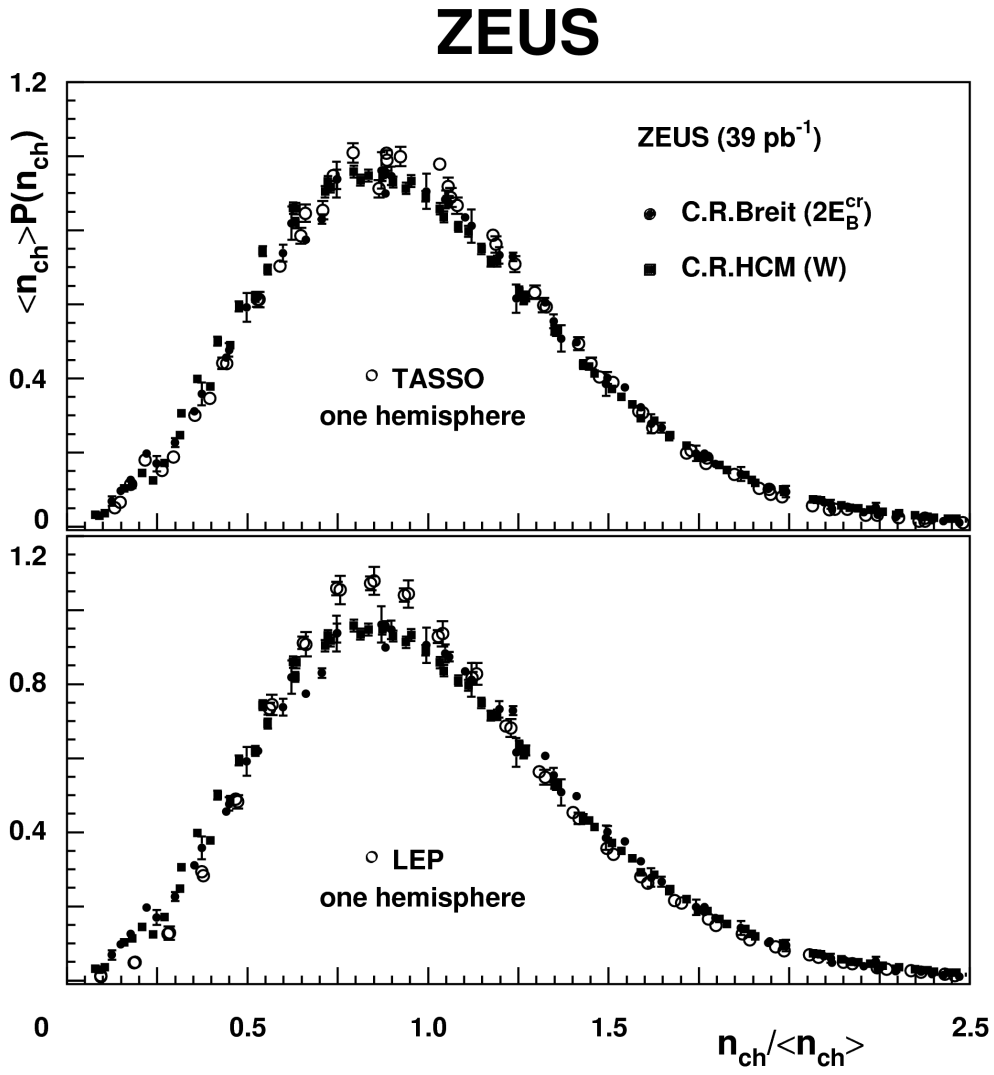
HCM frame

Breit frame

no agreement with the reference plot

Scaling behaviour observed for HCM and Breit except M_{eff} < 4 GeV

KNO scaling (e^+e^- vs ep)



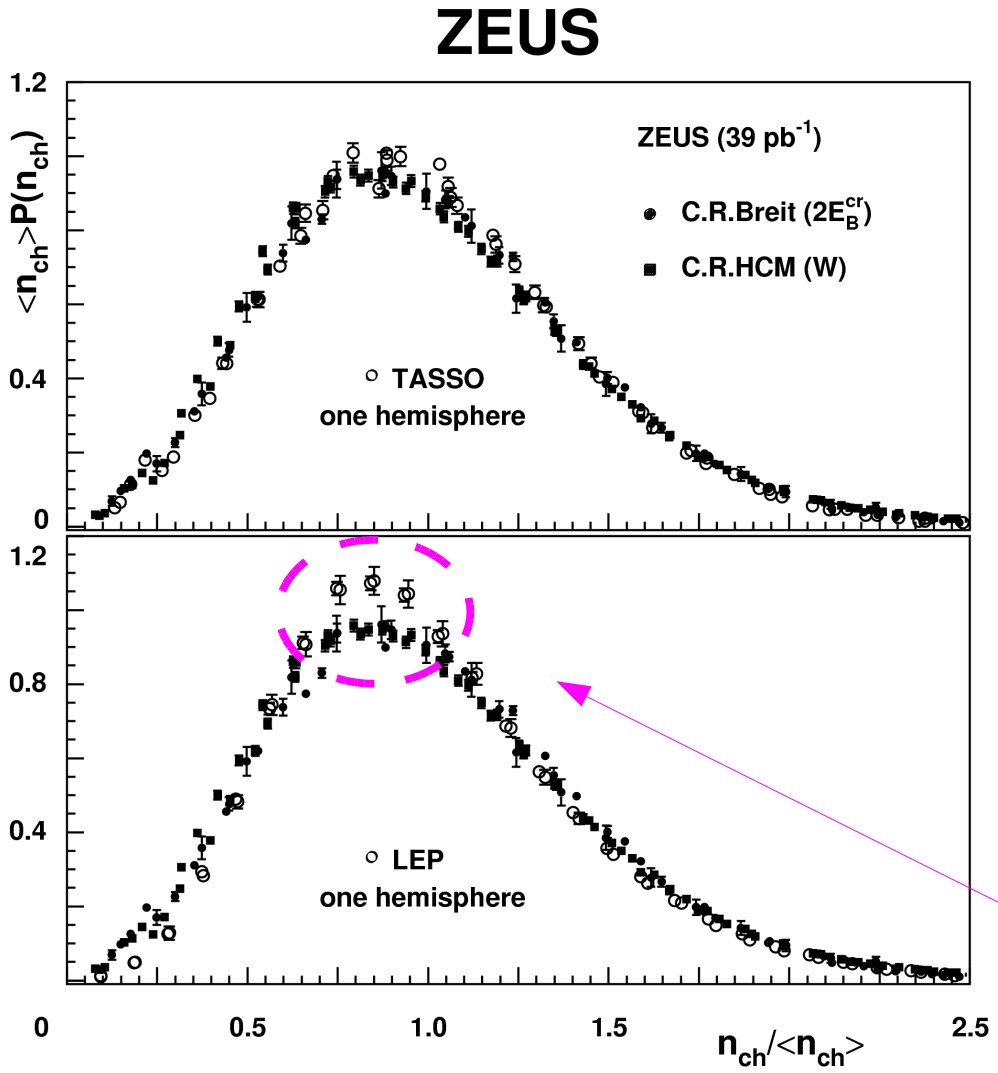
ep in bins $2E_B^{cr}$ / W if $2E_B^{cr} > 12$ GeV

e+e− data from one hemisphere
LEP (DELPHI, OPAL) at Z^0
PETRA (TASSO)

acceptable agreement
for PETRA and LEP

except LEP at peak

KNO scaling (e+e− vs ep)



ep in bins $2E_B^{cr}$ if $2E_B^{cr} > 12$ GeV

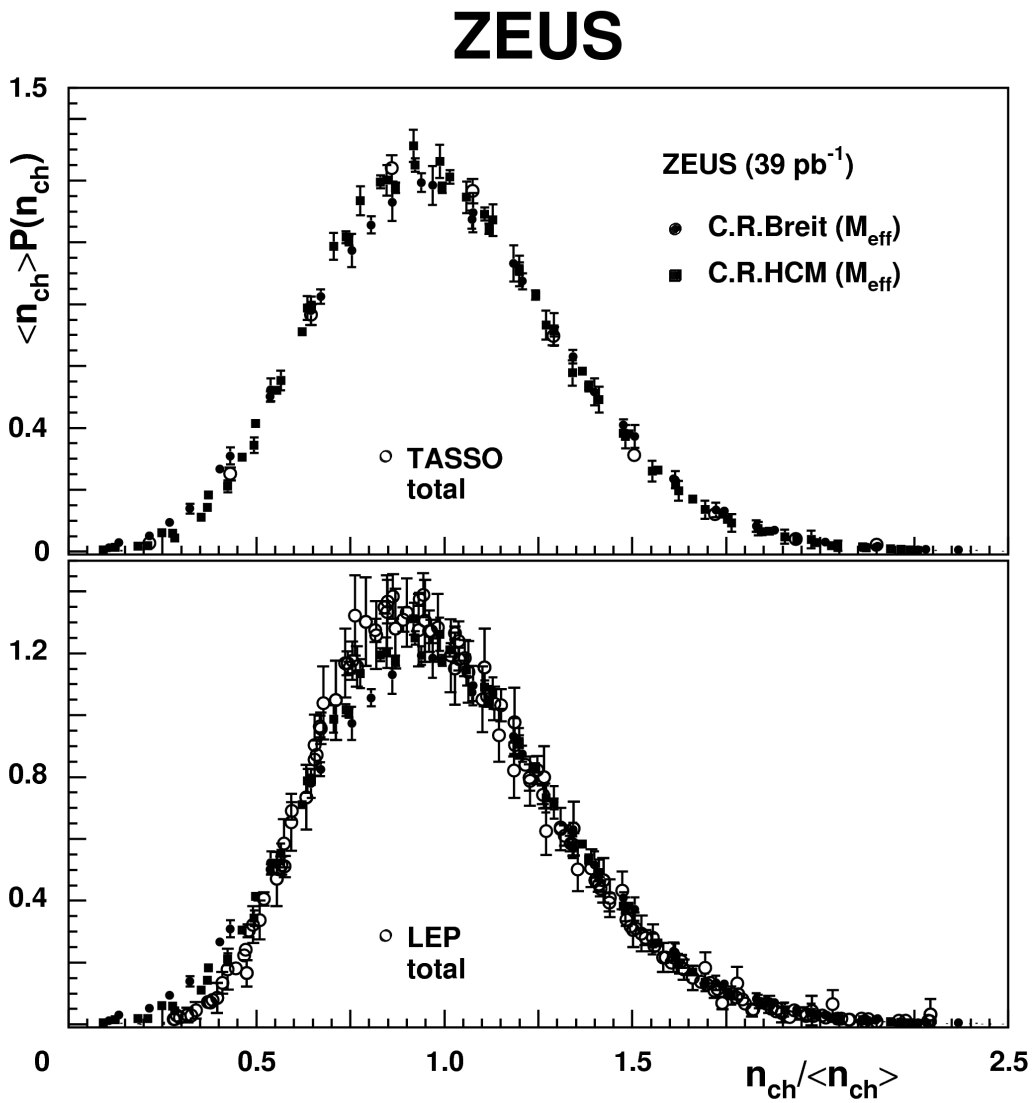
W

e+e− data from
LEP (DELPHI, OPAL) at Z^0
PETRA (TASSO)

acceptable agreement
for PETRA and LEP

except LEP at peak

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



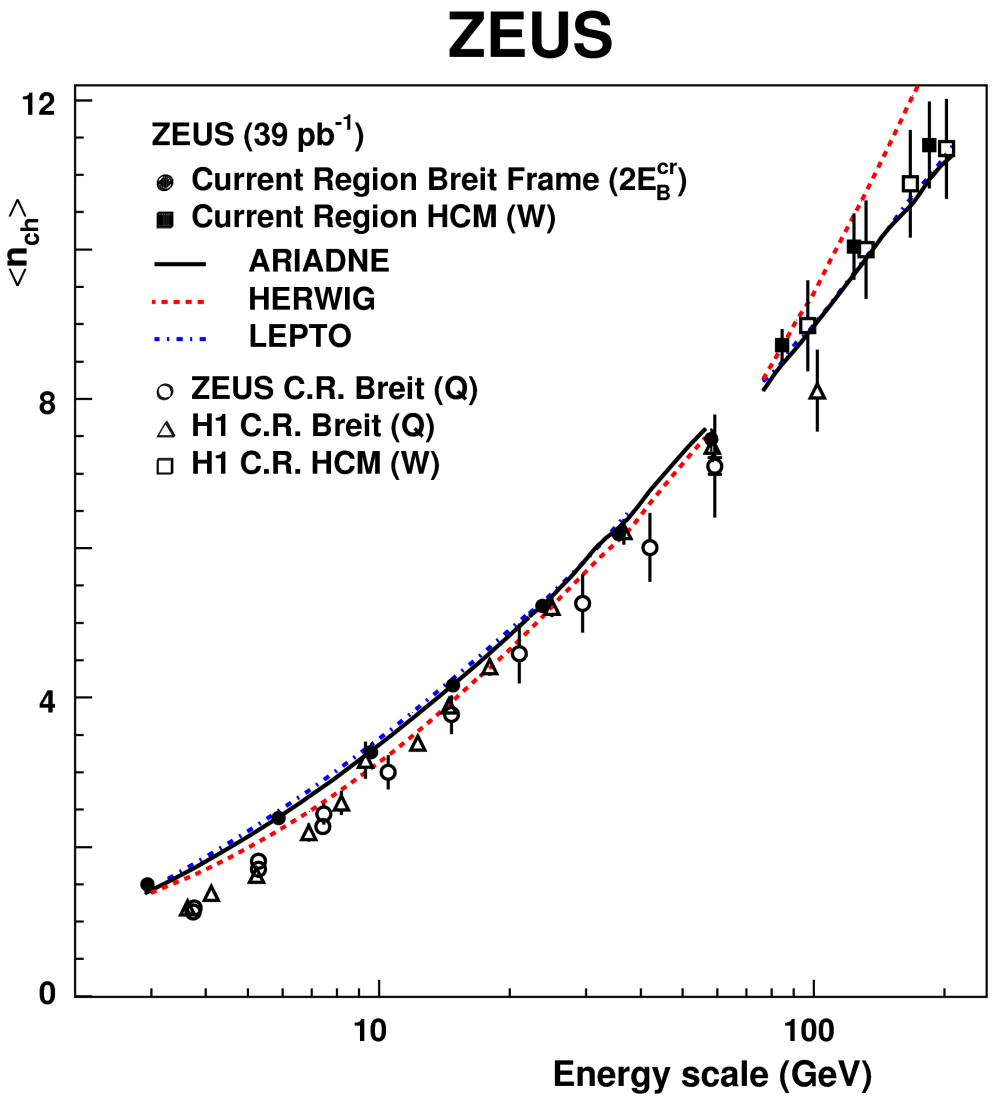
ep with M_{eff} > 8 GeV

e+e− data for 2 hemispheres

- LEP 91.2 < √s < 209 GeV
  (DELPHI, OPAL, L3, ALEPH)
- PETRA (TASSO)

Good agreement

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



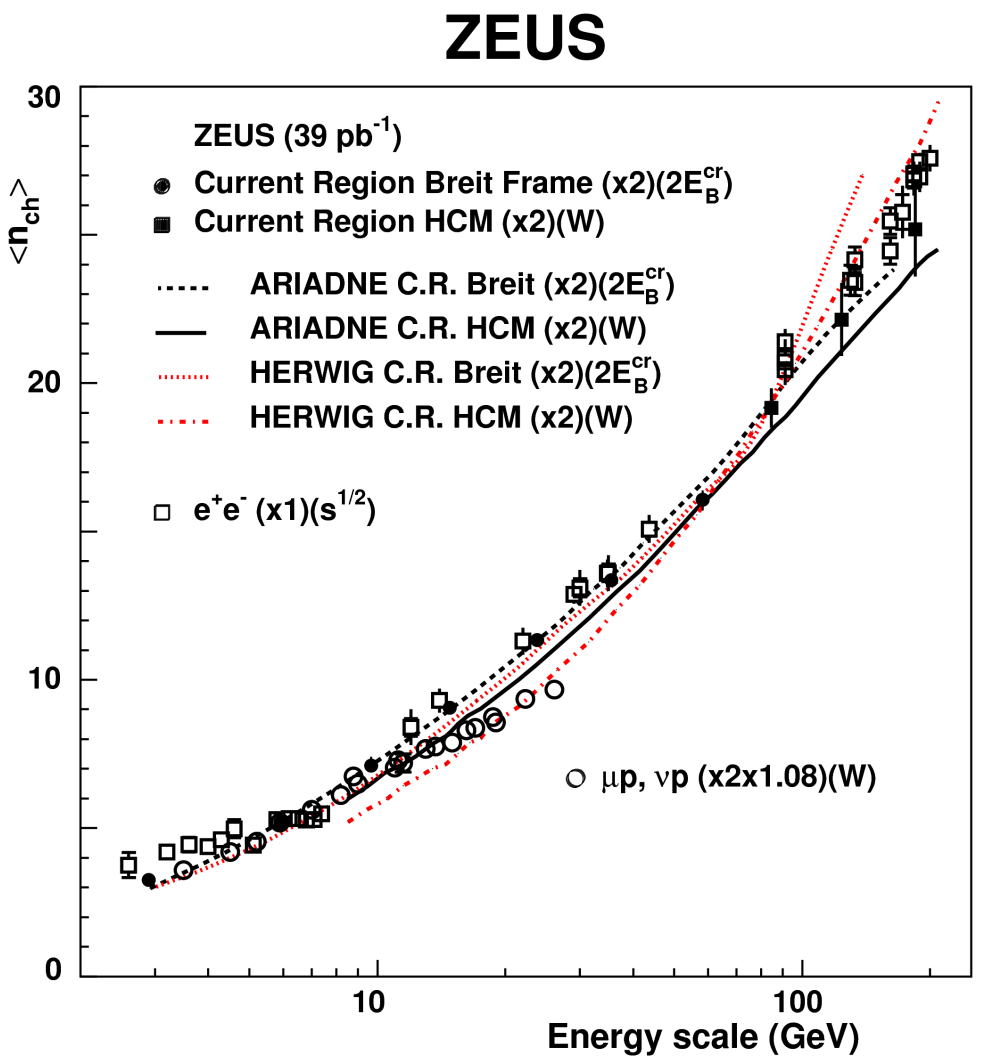
Data are in good agreement with LEPTO and ARIADNE

not with HERWIG

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

At high scales good agreement

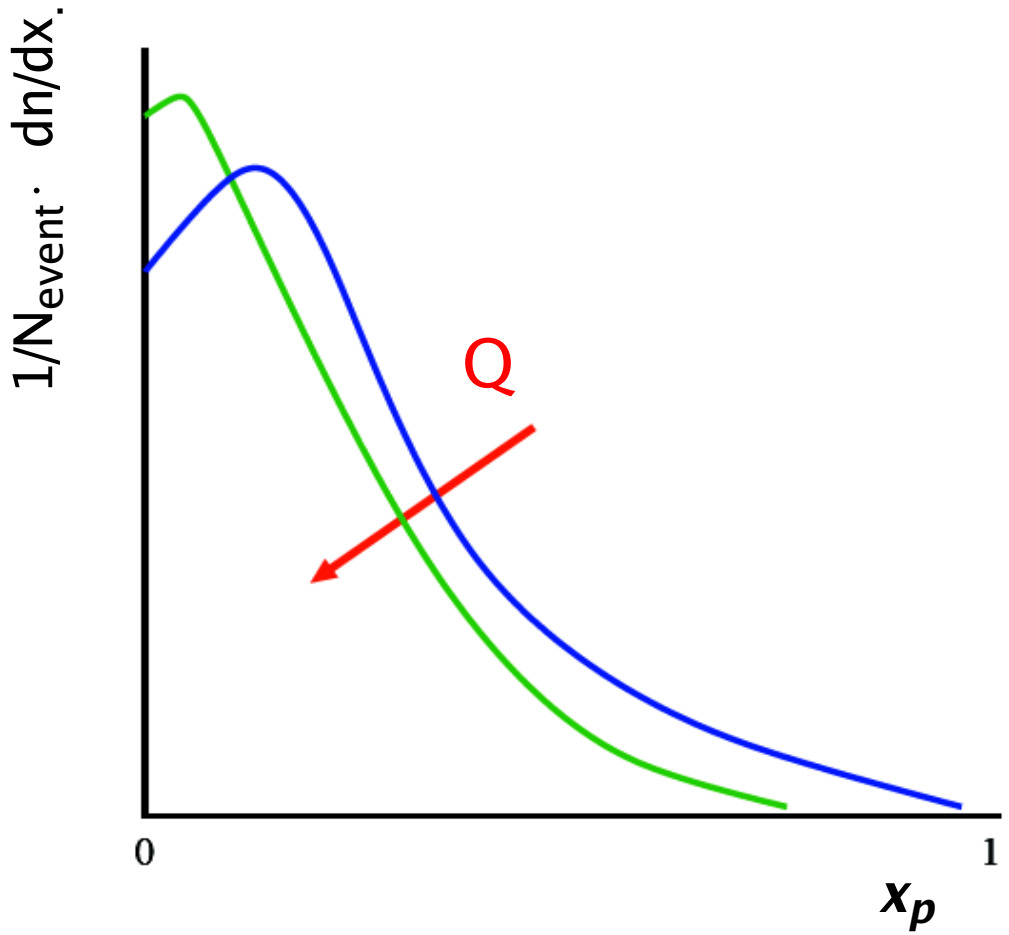
Multiplicity (e^+e^- vs ep & fixed target)



- 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^-

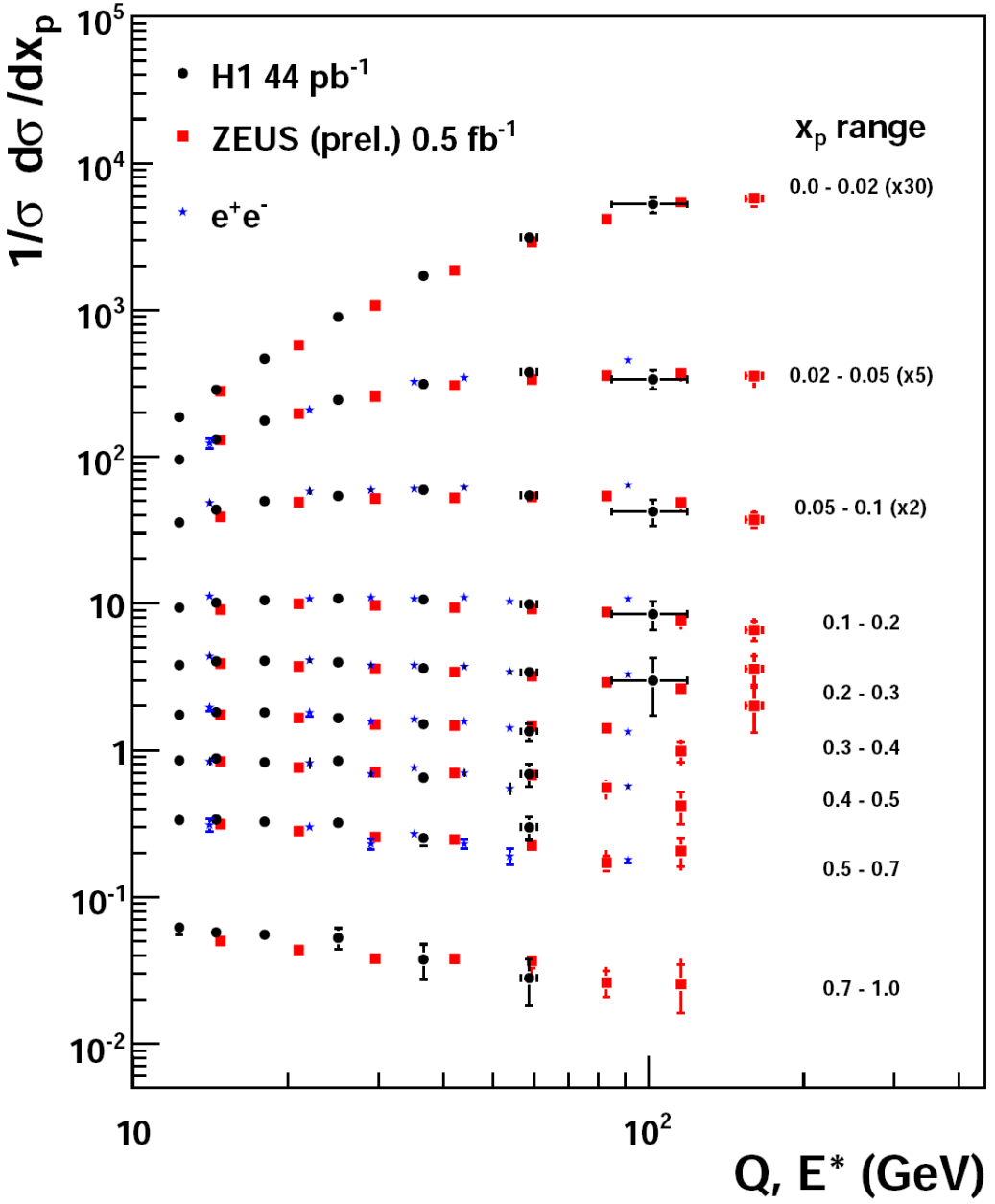


P_h – momentum of charged particles in current region of the Breit frame.

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



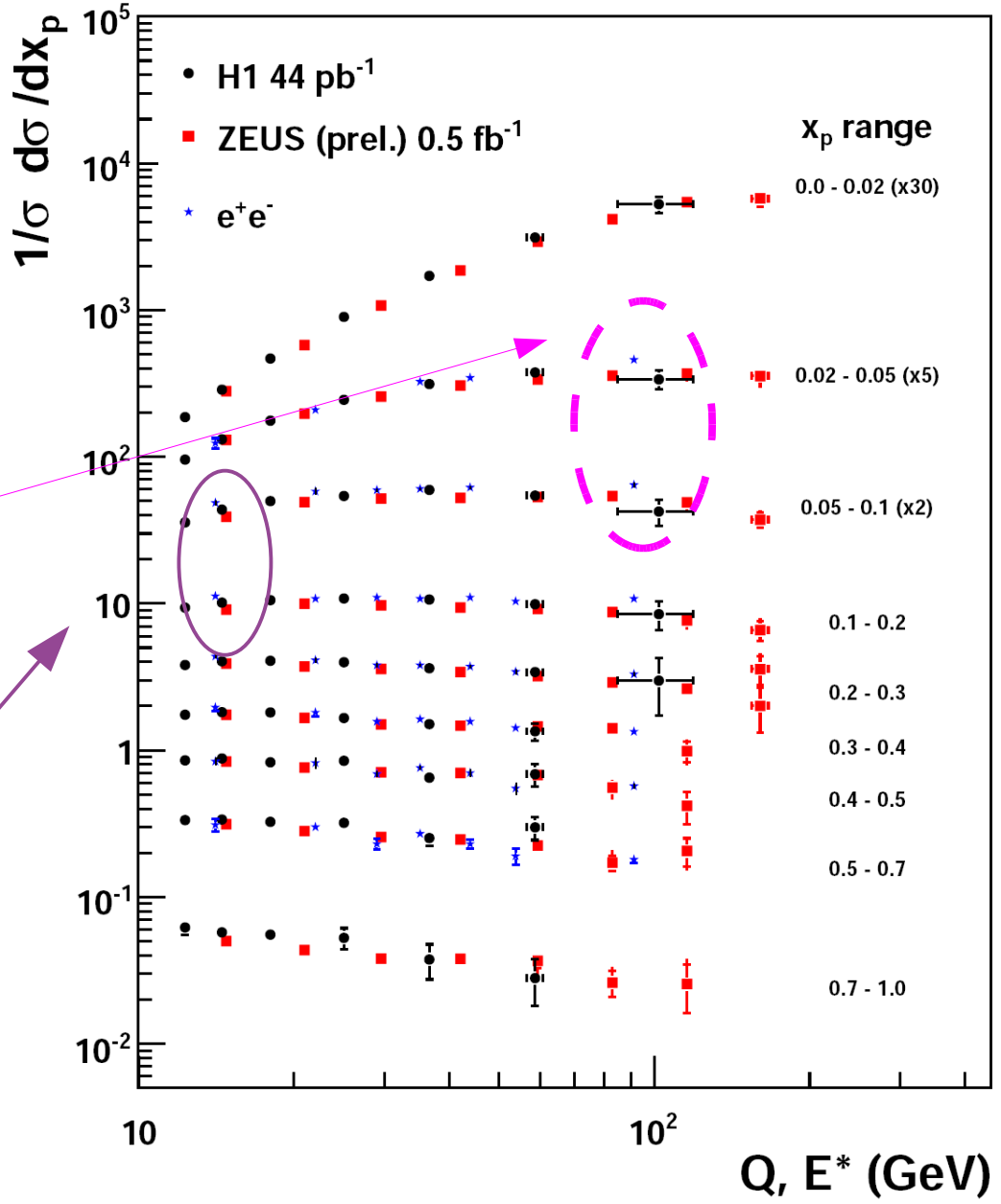
ZEUS data (prel), 0.5 pb^{-1}, 1996-2007
H1 data, Phys.Lett. B654(2007)148
ee data from TASSO, MARK II, AMY,
DELPHI PL,B311(1993)408
$E^* = 2\ E_{beam}$

Comparison ep with e^+e^-

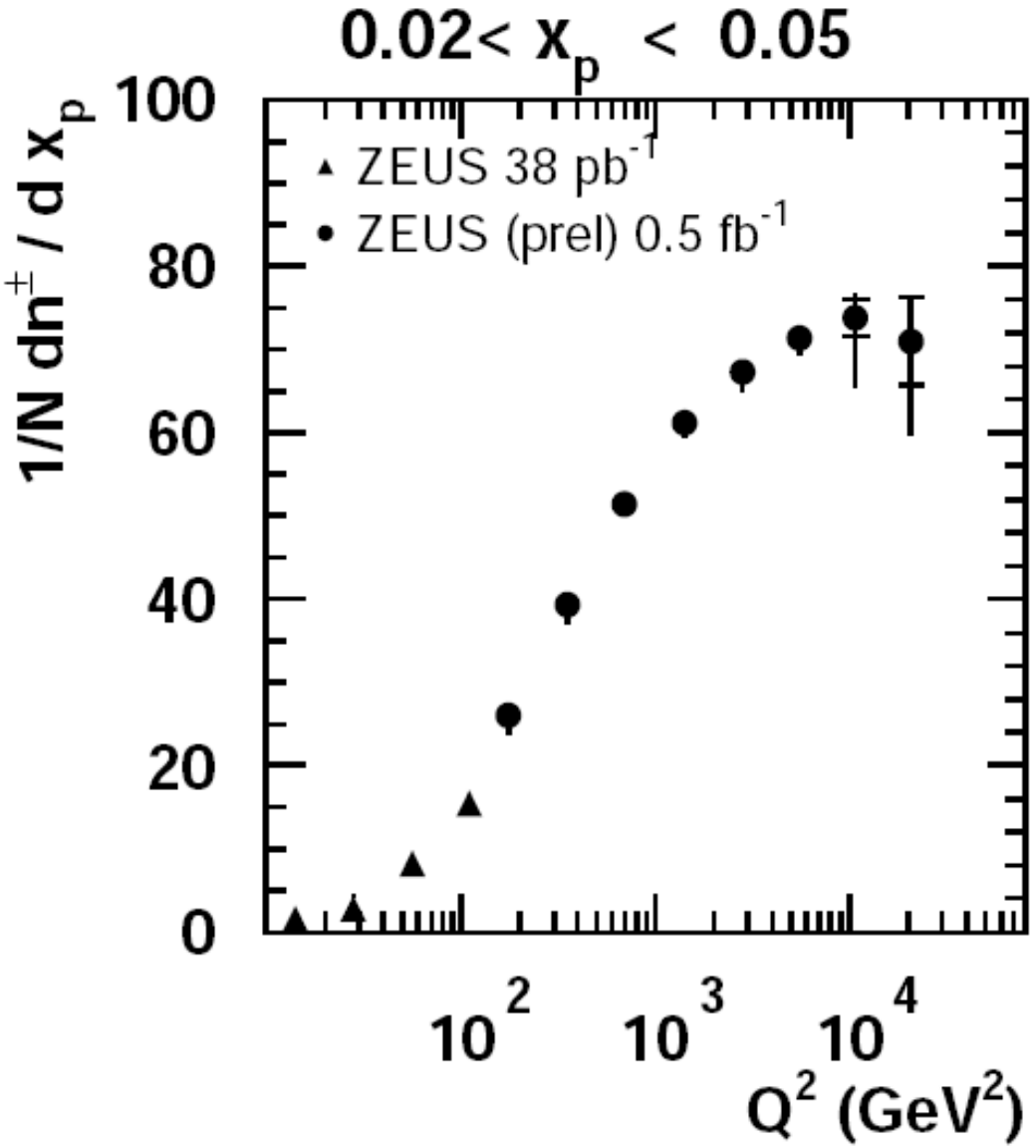
- supports the concept of quark fragmentation universality.
- scaling violation is observed

LEP (DELPHI)

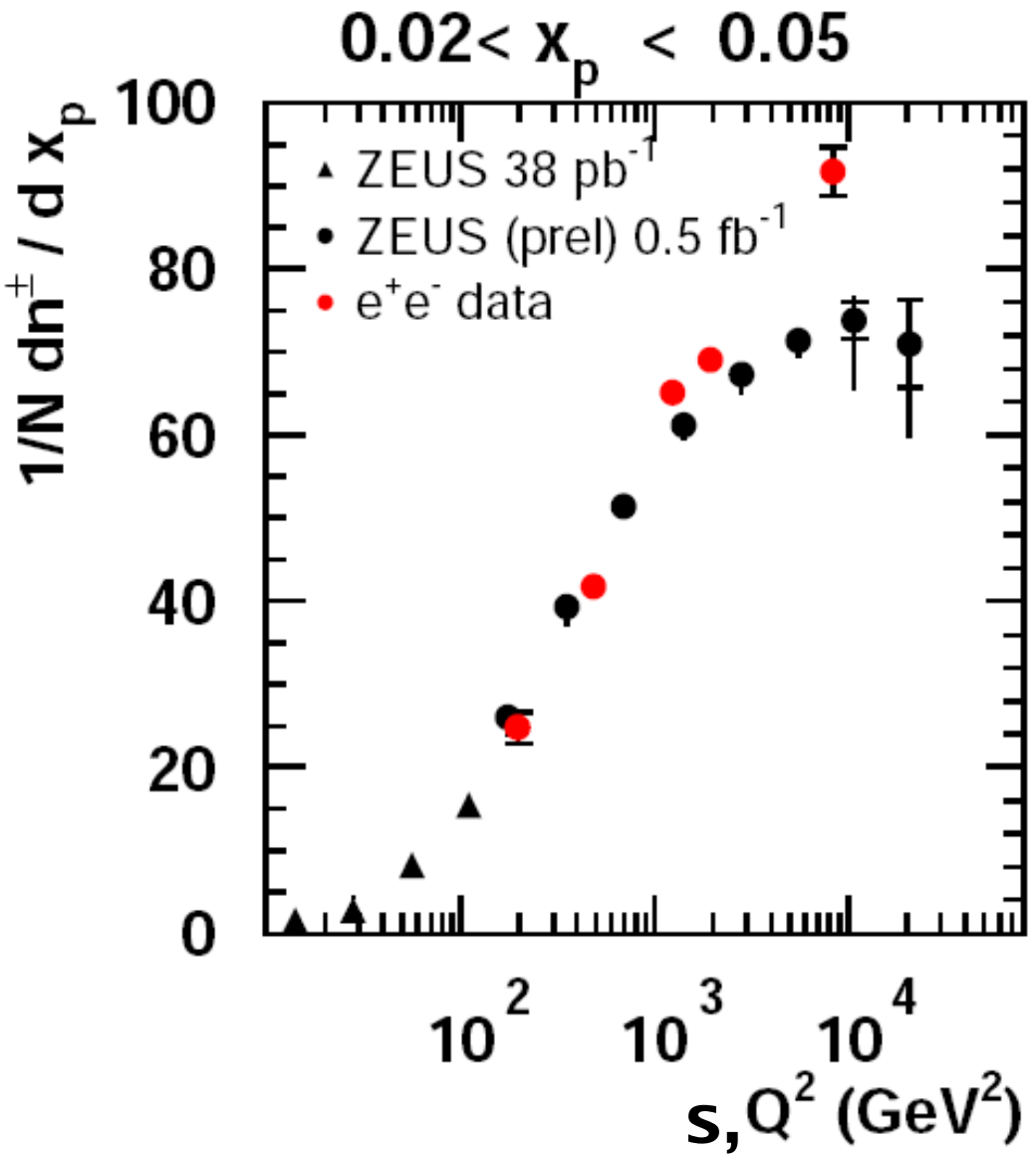
PETRA (TASSO)



Scaled momenta in x_p bins



Scaled momenta in x_p bins



e^+e^- data imposed with $s=4E^2_{beam}$

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

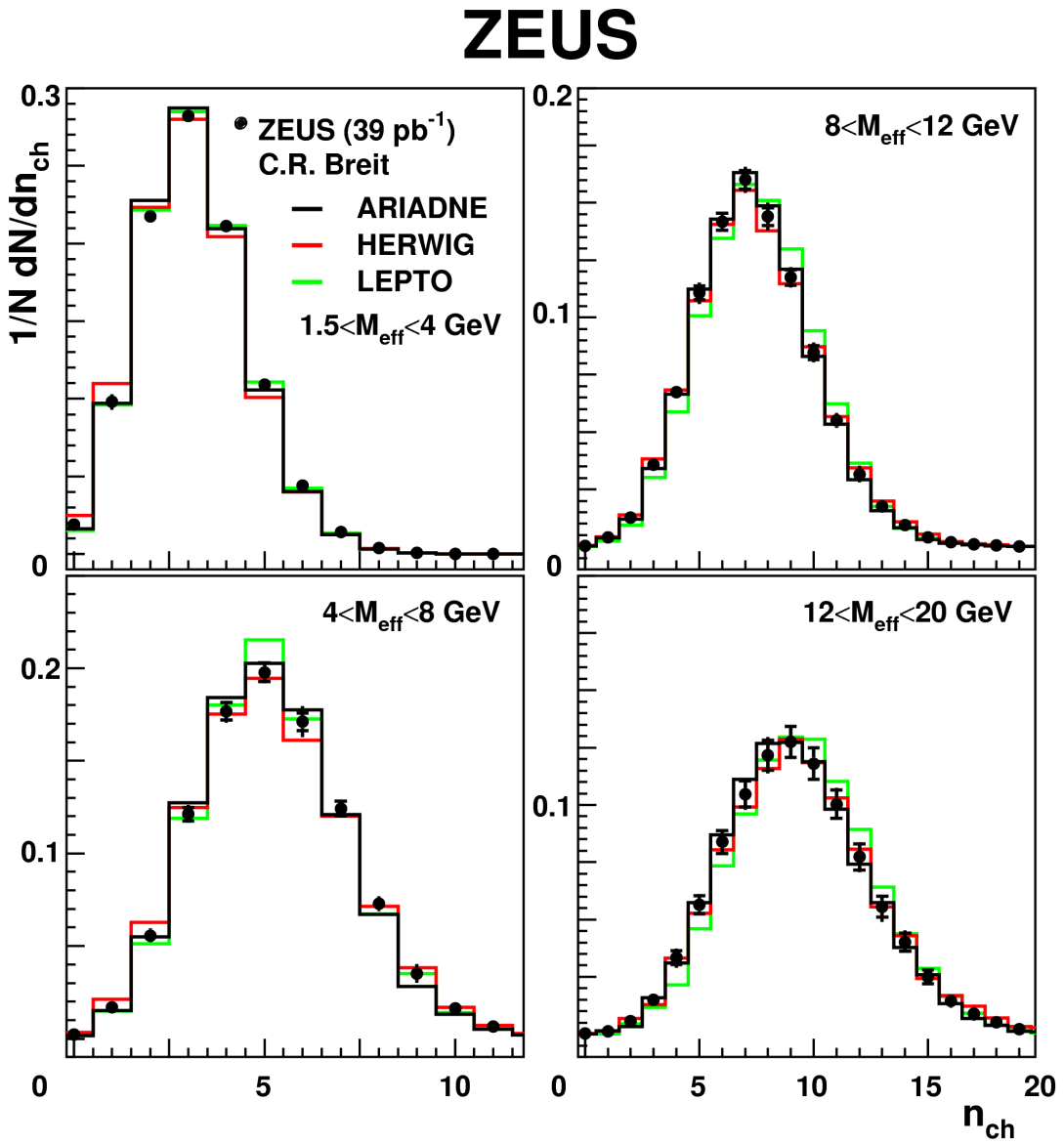
- Mean charge multiplicity as a f ($2E_B^{cr}$) agrees better with e+e- than as a f(Q),
- Usage of W and $2E_B^{cr}$ gives a consistent comparison of ep with e+e- and with the previous DIS data
- KNO scaling for ep is similar to
  - one hemisphere of e+e- if W and $2E_B^{cr}$ are used
  - total multiplicity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

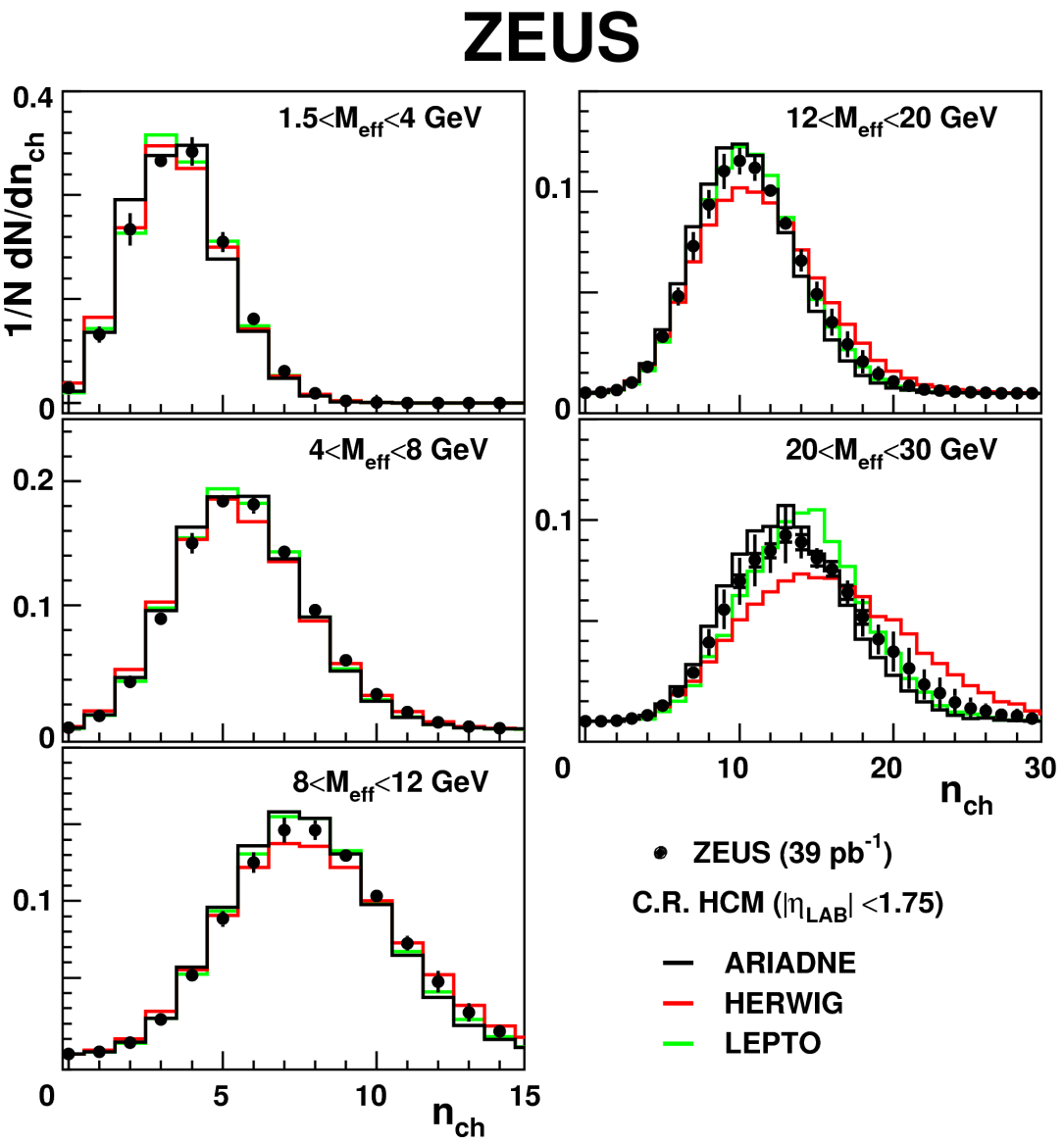
Multiplicity in M_{eff} bins in the Breit frame



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

All the MC models → good descriptions

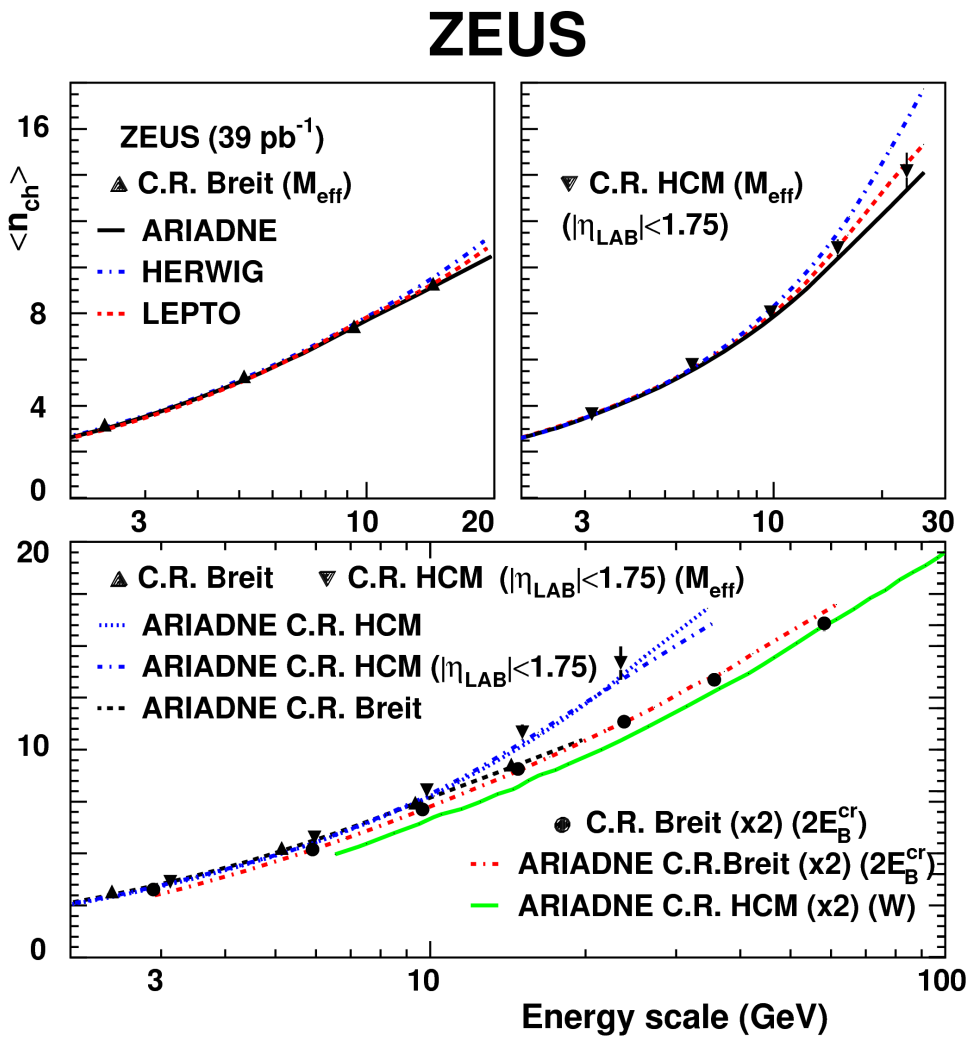
Multiplicity in M_{eff} bins in the HCM frame



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

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

Average multiplicity as f (M_{eff})



Data agree with
LEPTO and ARIADNE

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