Multiplicity and momentum distributions of hadrons in deep inelastic scattering at HERA energies

On behalf of the H1 and ZEUS Collaboration

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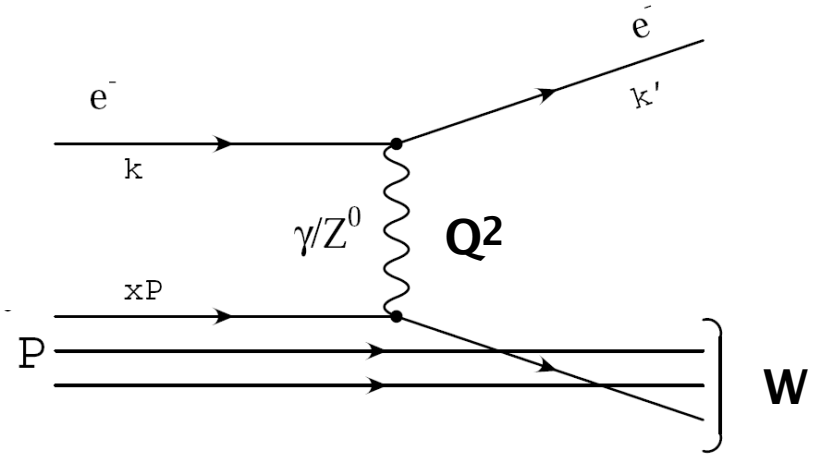
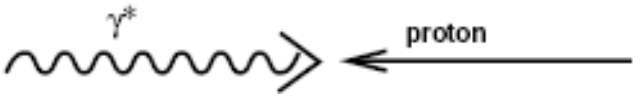


- Energy of~300 GeV in ep CMS
- Neutral current (NC)

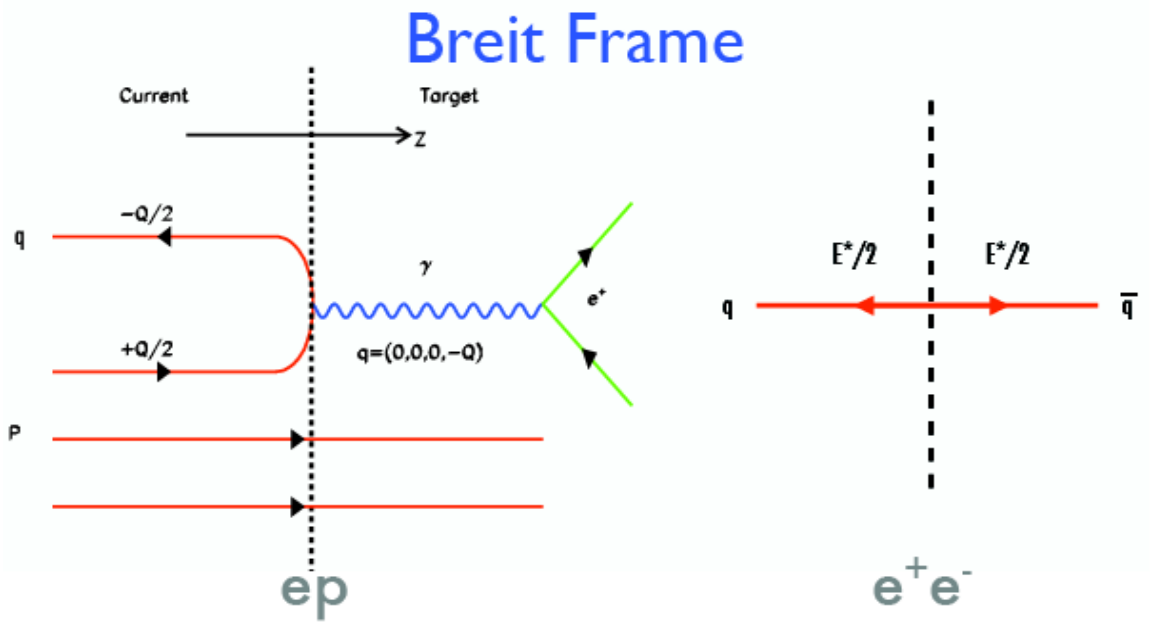


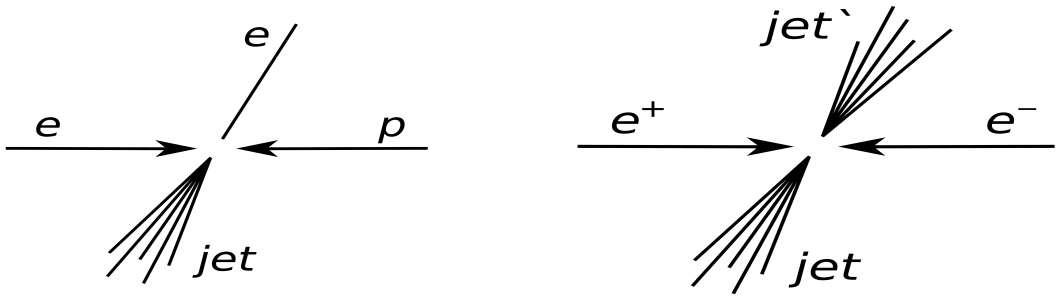
Multiplicity and momentum distributions of hadrons in deep inelastic scattering at HERA energies

Outline

- **Motivation:**
  - **scaling with energy**
  - **comparison with $e^+ e^-$**
- **Multiplicity of charged hadrons**
- **Scaled momenta distributions of charged hadrons**
- **Summary and conclusions**

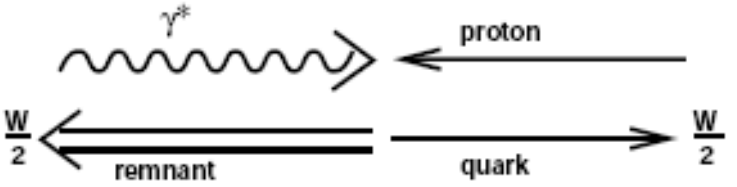
Reference frames





Photon virtuality, Q, is related to momentum of scattered quark.

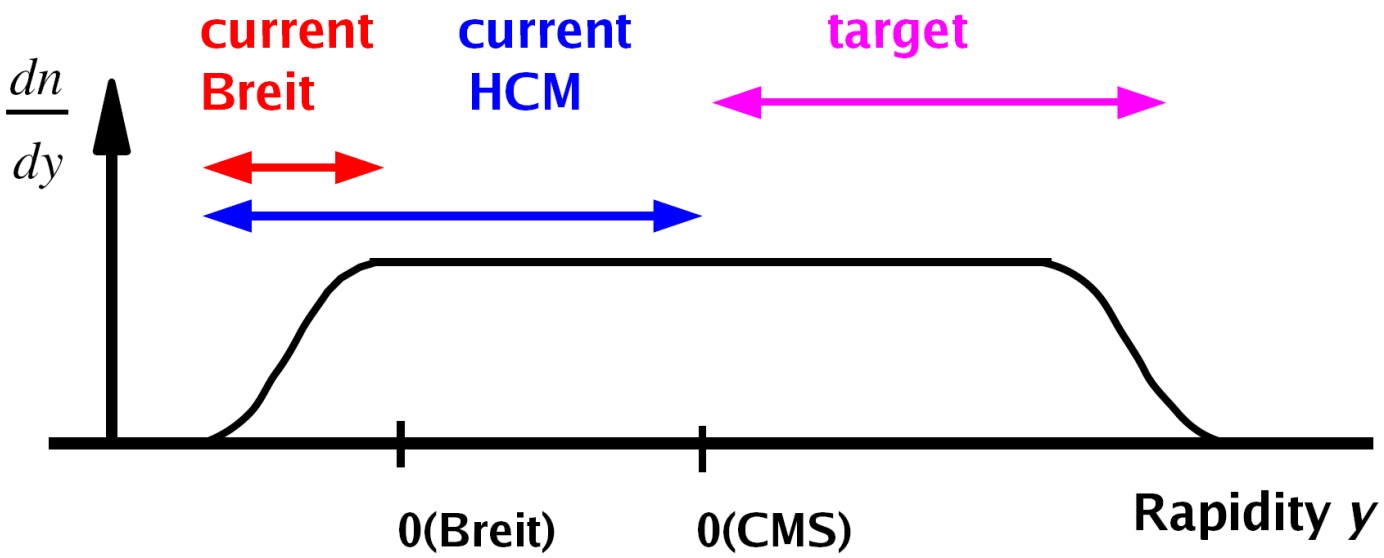
Hadronic Centre of Mass or CMS γp



Knowledge of particle rapidity is important for understanding of underlying processes and for comparison with e^+e^- or pp.

Rapidity of particles defines their expected features,

Similar to e^+e^- p p



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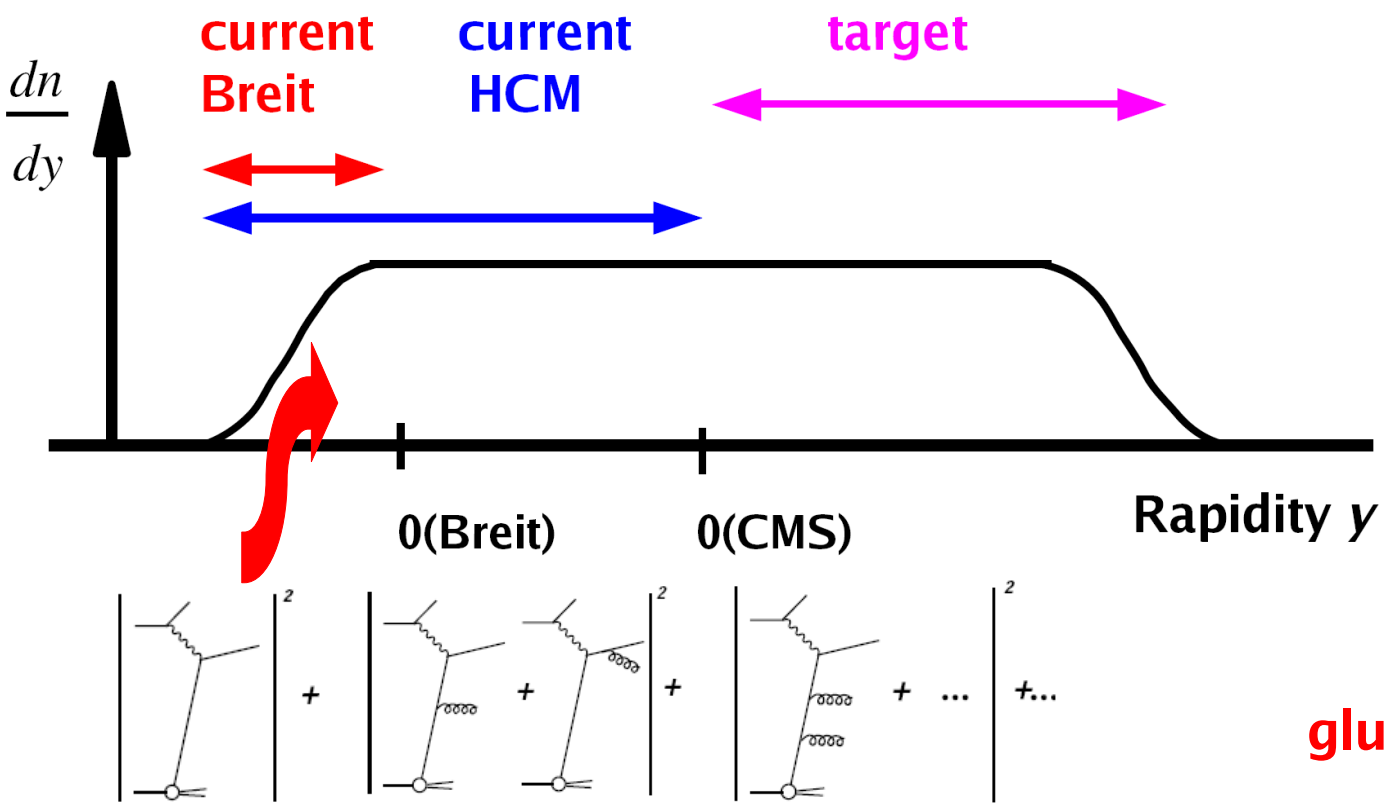

gluon emission

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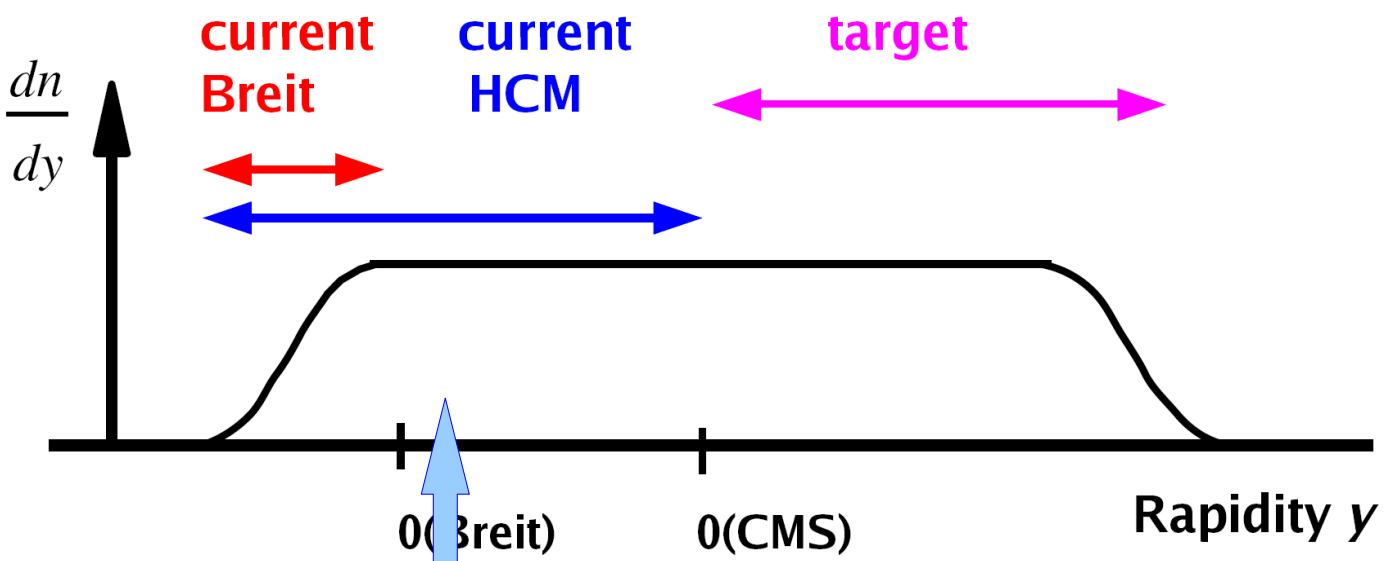
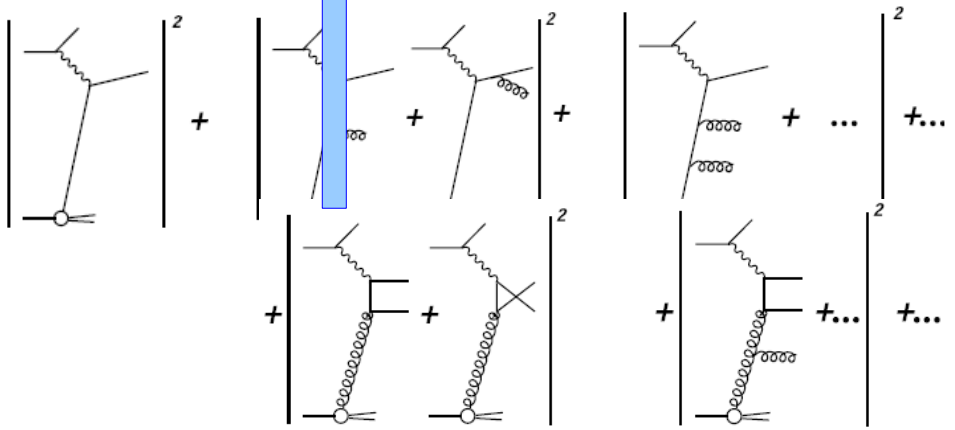
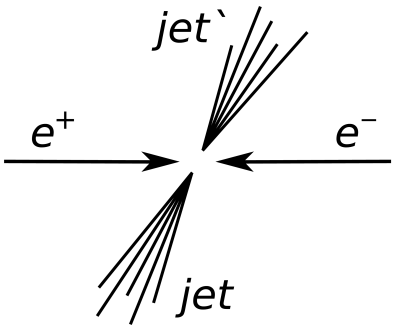




gluon emission

boson-gluon fussion



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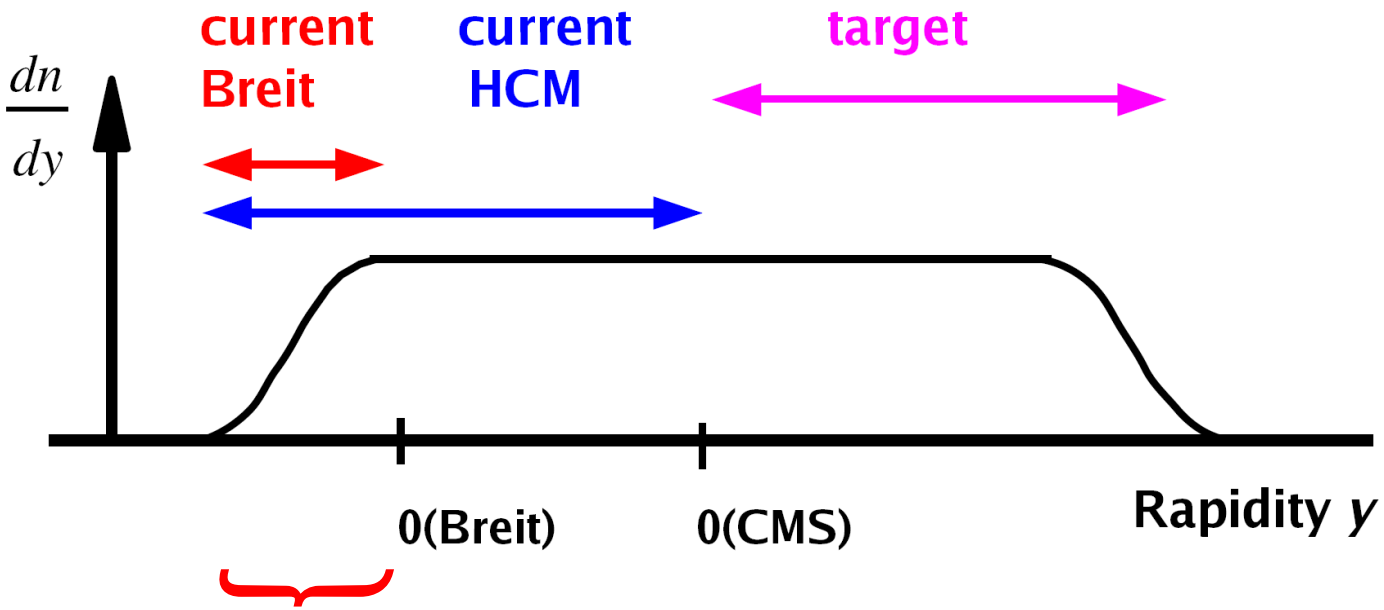
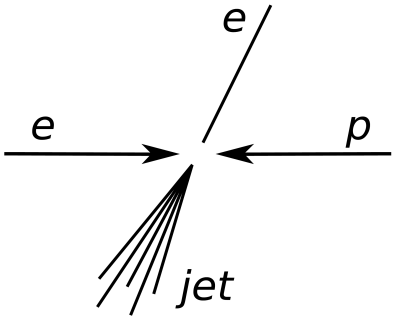




Q, $2E_B^{cr}$, M_{eff}

W, M_{eff}

$$2E_B^{cr} = 2\left(\sum_i^n E_i\right)$$

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

Discussed HERA DIS data

ZEUS Coll.,	Eur.Phys.J. C11(1999)251	(luminosity 38 pb^{-1})
H1 Coll.,	Phys.Lett. B654(2007)148	(luminosity 44 pb^{-1})
ZEUS Coll.,	JHEP06 (2008) 061	(luminosity 39 pb^{-1})
ZEUS Coll.,	Preliminary	(luminosity 0.5 fb^{-1})

Predictions

Monte Carlo models

ARIADNE 4.12 — colour dipole model

LEPTO MEPS — matrix element + parton shower ~~(PS+SCI)~~

fragmentation — the Lund string model

HERWIG — cluster hadronisation model

Charged hadrons taken with lifetime > $3 \cdot 10^{-11}$ s

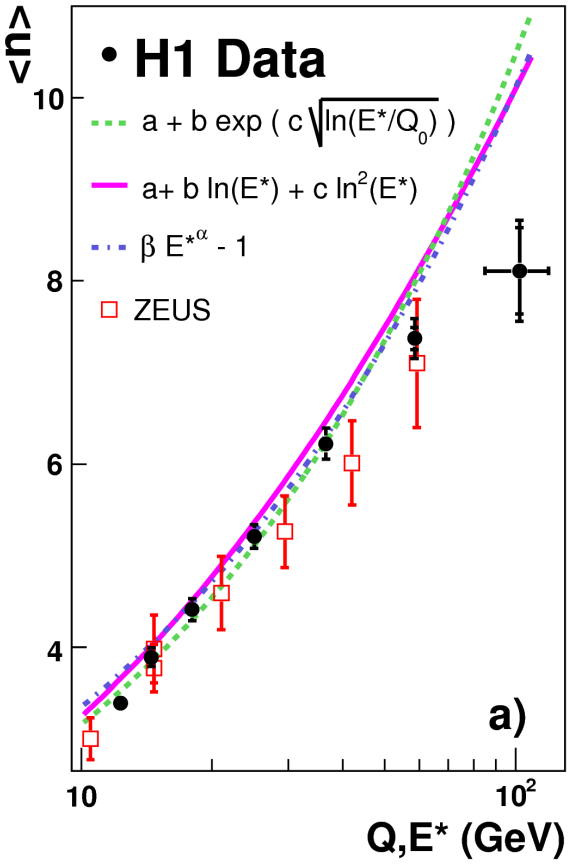
stable particles include: Λ, $\Sigma^{\pm}$, Ω, K^0

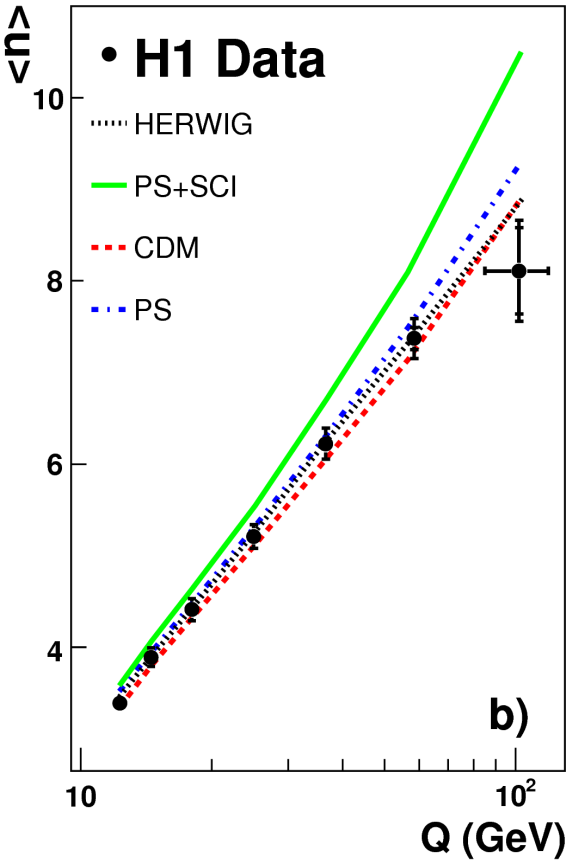
Average multiplicity as f (Q) (e^+e^- vs ep)

Luminosity 44 pb^{-1}
collected in 2000
with E_{proton} = 920 GeV
and E_{e+} =27.5 GeV

$100 < Q^2 < 20000$ GeV^2
$0.05 < y < 0.6$

e^+e^- is represented by parameterisations ,
$E^* = 2\,E_{beam}$





<u>Conclusions:</u>

- Good agreement with e^+e^- except at highest Q^2
- Good agreement with predictions except at LEPTO (PS+SCI)

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

$$2E_B^{cr} = 2\left(\sum_i^n E_i\right)$$

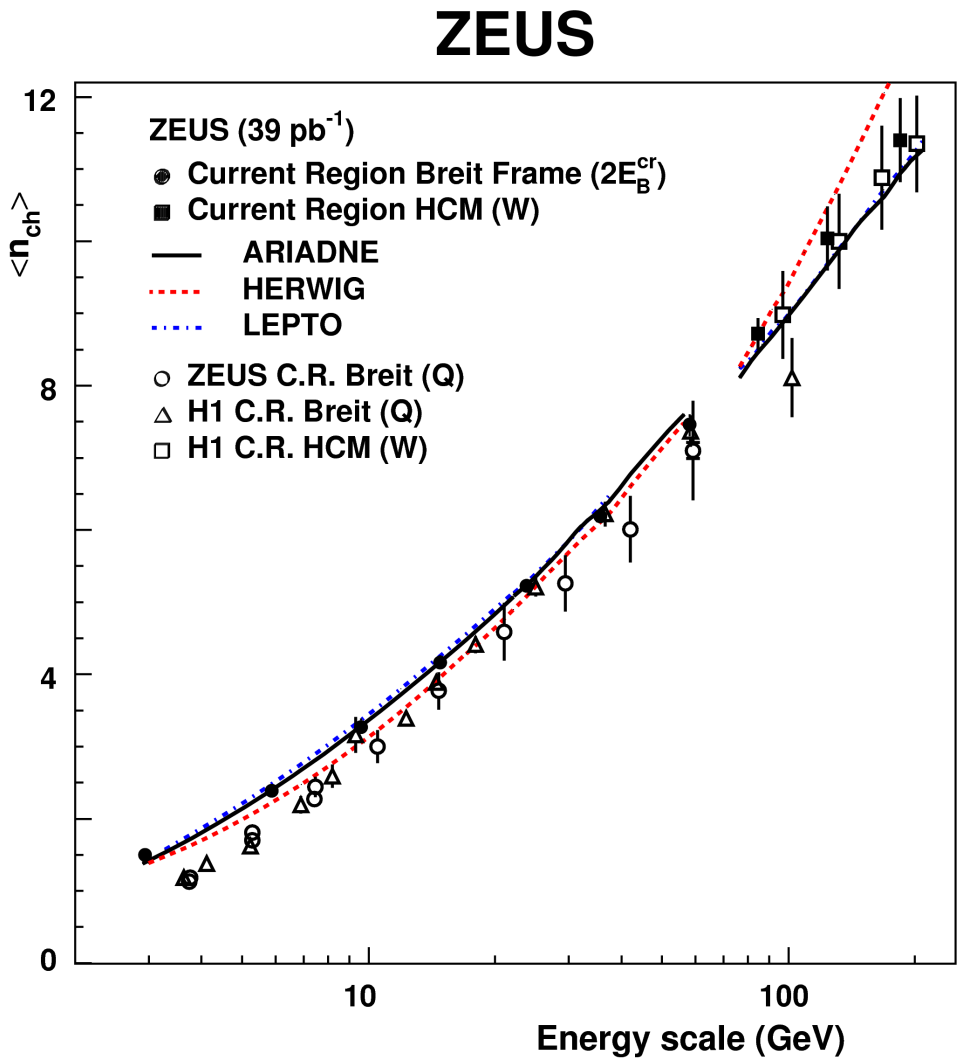
Luminosity 38.6 pb^{-1}
collected in 1996-7
with E_{proton} = 820 GeV
and E_{e+} =27.5 GeV

$Q^2 > 25\ GeV^2$
$70 < W < 225$ GeV

Alternative energy scales to Q

Conclusions

- good agreement
  with LEPTO and ARIADNE
  not with HERWIG
- differences at low energy scales
  but not at high scales



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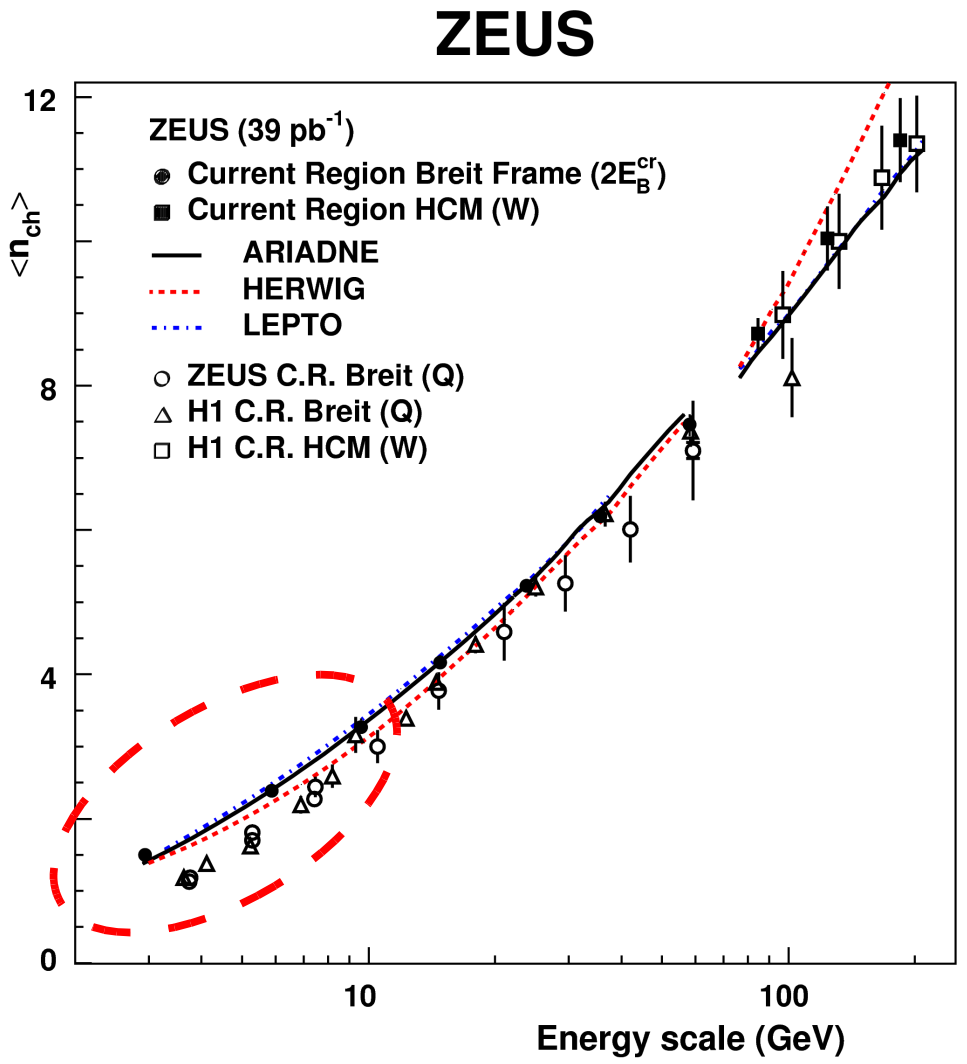
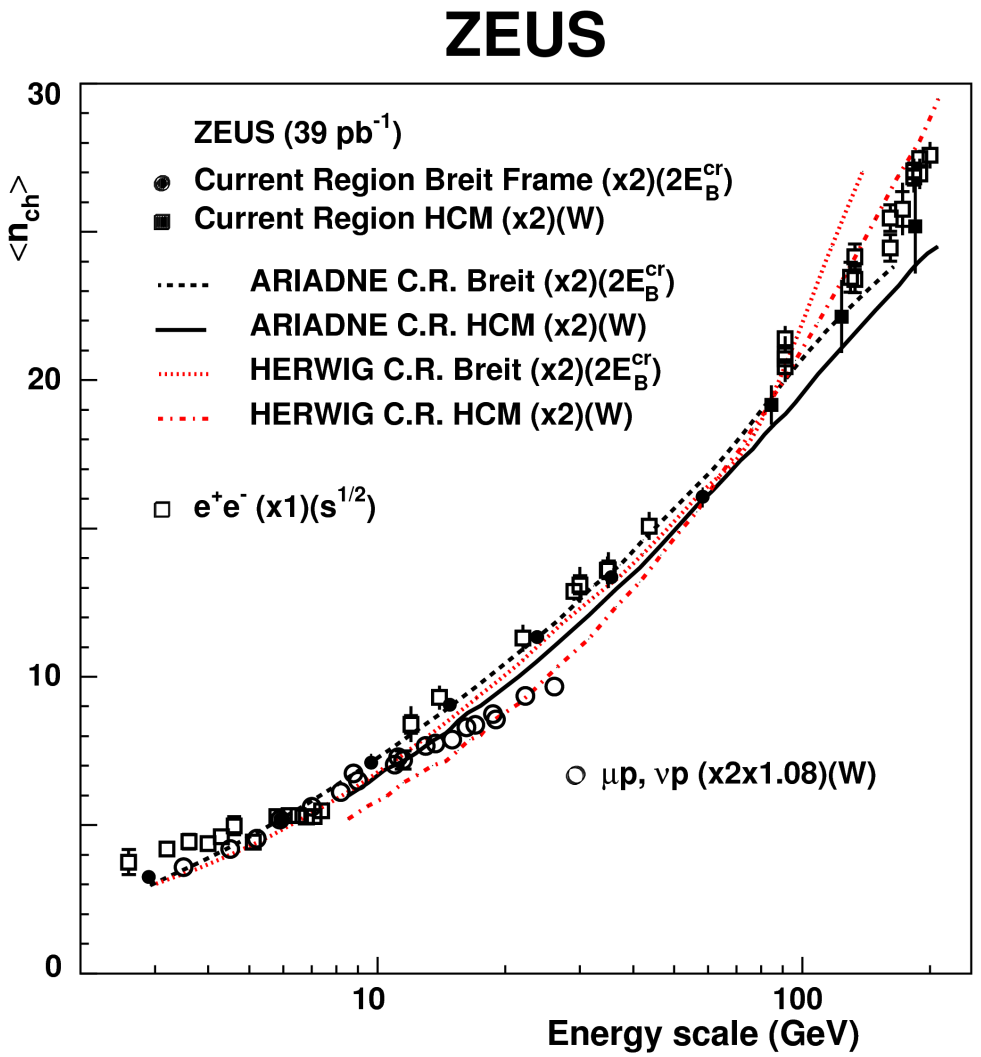


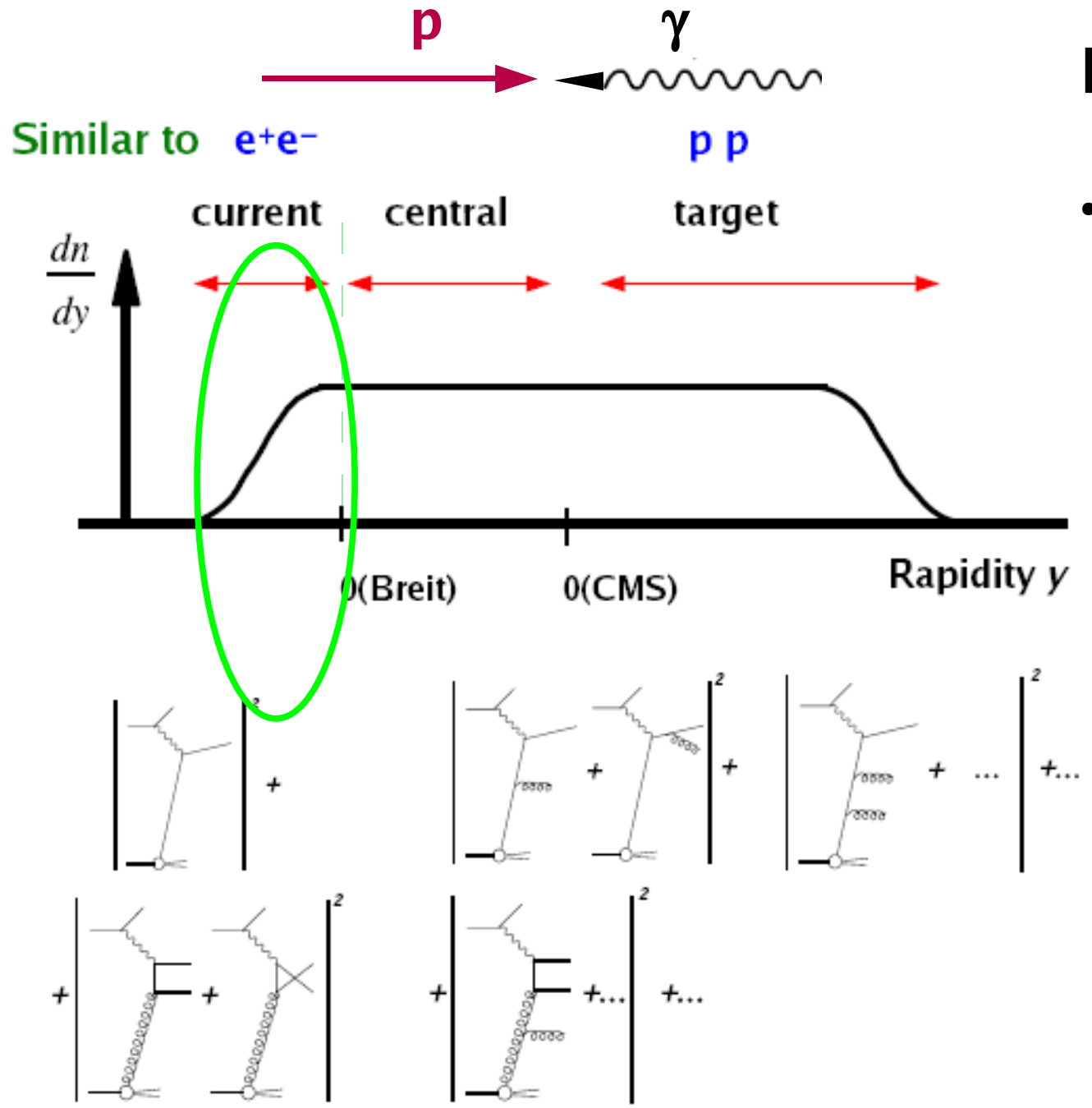
Multiplicity (e^+e^- vs ep & fixed target)



- At low scales $2E_B^{cr}$ gives better agreement with e^+e^- than Q
- 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
- Fixed target data deviate from the observed energy dependence above 15 GeV

Fragmentation in DIS

- **hadron spectra in the Breit frame**



Fragmentation functions $D(z,Q^2)$

Hadron spectra in ep hard scattering

$$f(x,Q^2) \otimes \sigma(Q^2) \otimes D(z,Q^2)$$

Parton density

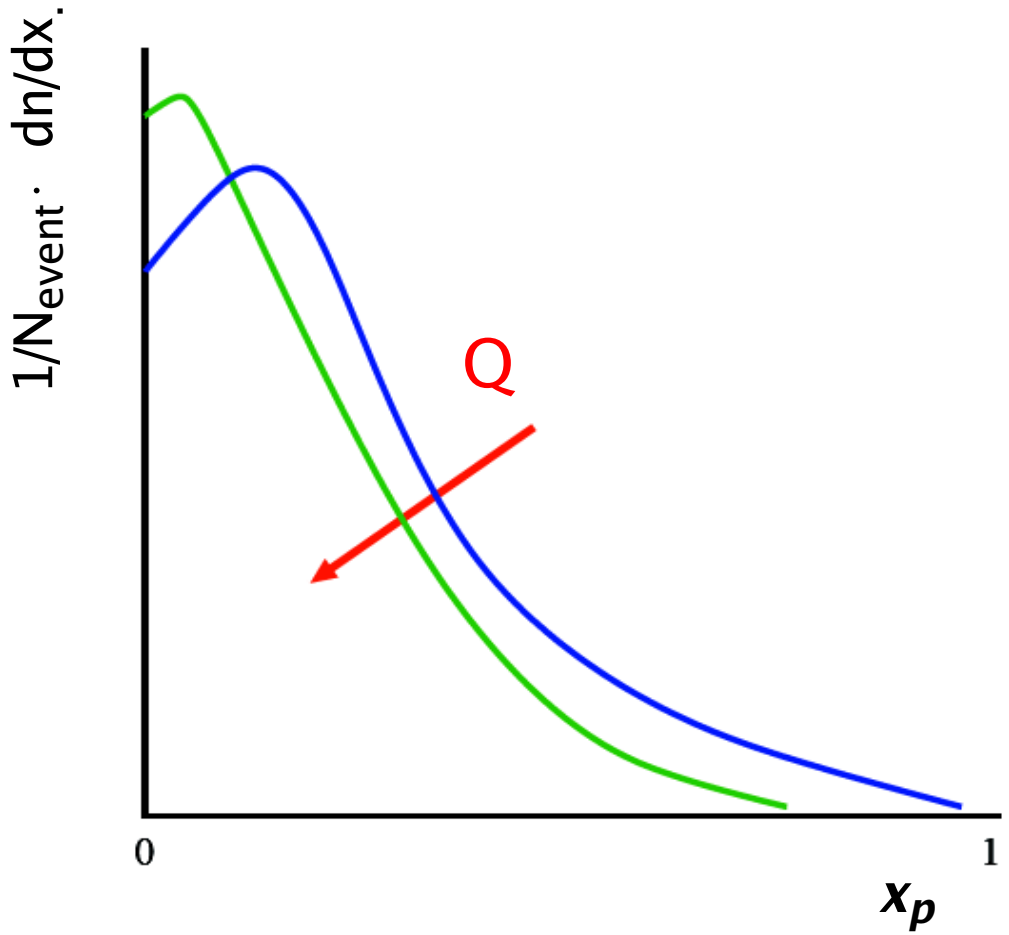
parton cross section (NLO,..)

probability for a parton to fragment into a hadron carrying a given fraction z of the parton energy

- **Evolution of FF given by DGLAP**
- **FF are universal (from factorisation theorem)**
- **Scaling violation in the Q^2 evolution permits to determine α_s**

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.

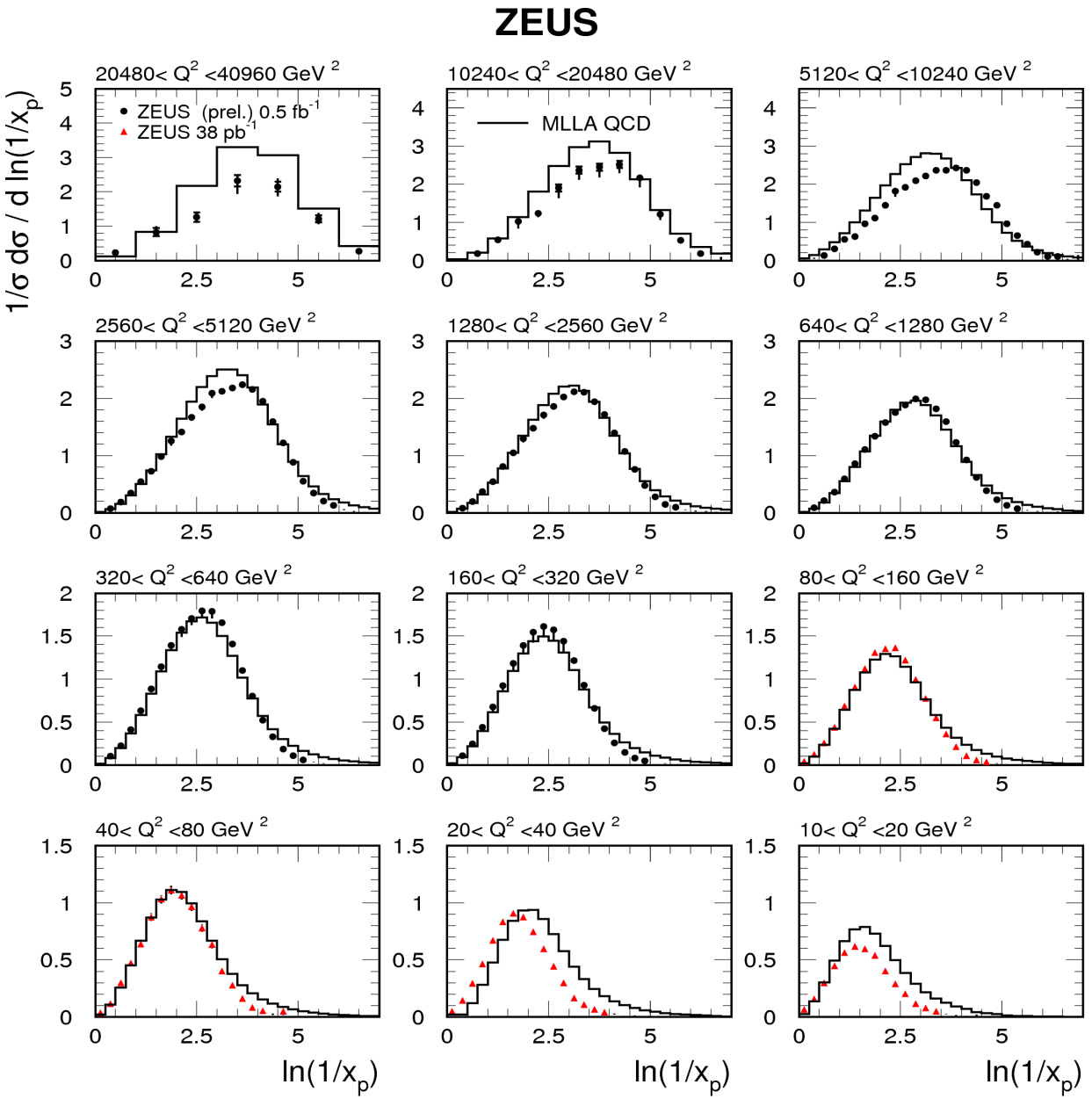
With Q increasing dn/dx_p is softer,
i.e. more particles with smaller fraction of energy Q/2.

$\ln(1/x_p)$

Modify Leading Log Approximation (MLLA)

The limiting spectra described by MLLA (+LHPD) are given
Λ_{QCD}=270 MeV
K_h=1.31 (from e^+e^-).

At low Q^2 migration from target region



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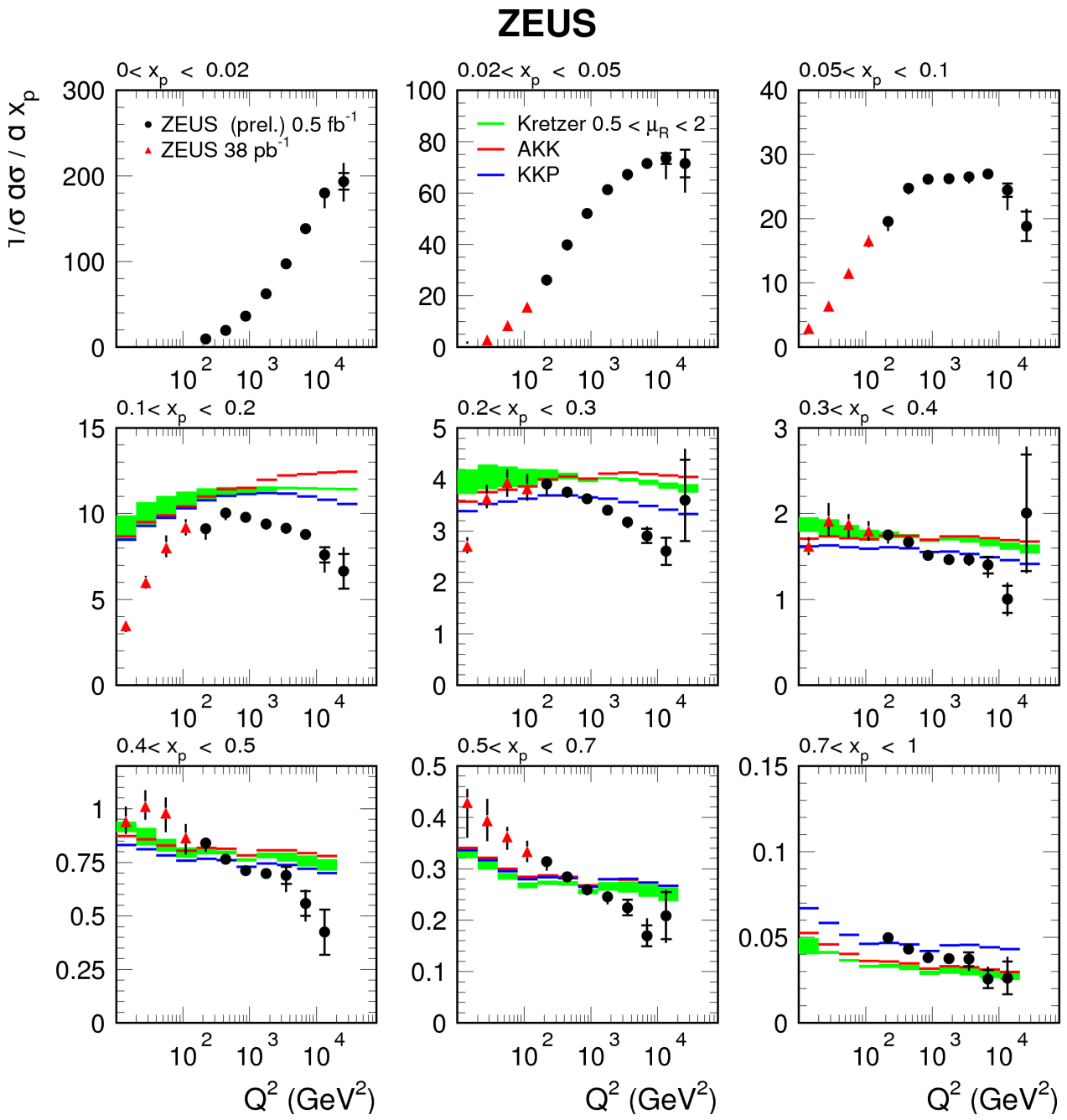


Fragmentation functions (FF):

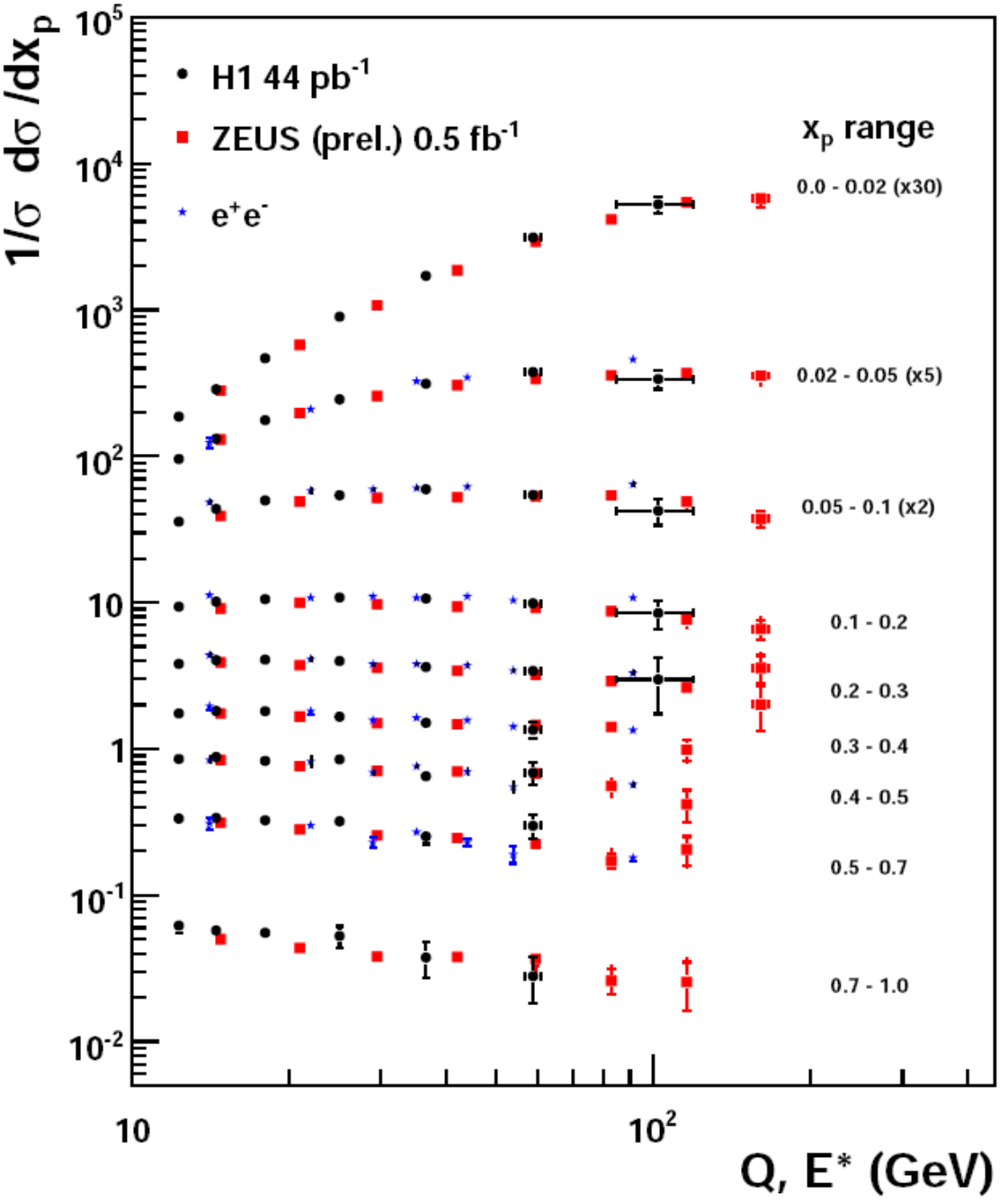
NLO QCD predictions implemented in CYCLOPS (PDF: CTEQ6M, $\Lambda_{\overline{MS}}^{(5)}=266$ supported by S.Albino)

Full NLO matrix element + partonic FF proposed by:

- **Kretzer (2000) at Z^0pole data ALEPH, SLD, low-en. TPC**
- **KKP (Kniehl,Kramer,Poetter) (2000) at Z^0pole data ... + DELPHI, 3jet OPAL**
- **AKK (Albino,Kniehl,Kramer) (2005) update of KKP (d,s)**

Comparison ep with e^+e^-

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



ee data from TASSO, MARK II, AMY, DELPHI PL,B311(1993)408

$E^* = 2\ E_{beam}$

Summary and conclusions

- HERA provided a wealth of high precision hadronic data.

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

- Available energy for hadronisation defined by $2E_B^{cr}$ agrees better with e+e- than as Q.

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

- general trends are the same — the scaling violation is observed for both

but

- perturbative QCD calculations do not reproduce the ep data in entire range of Q^2 and x_p.

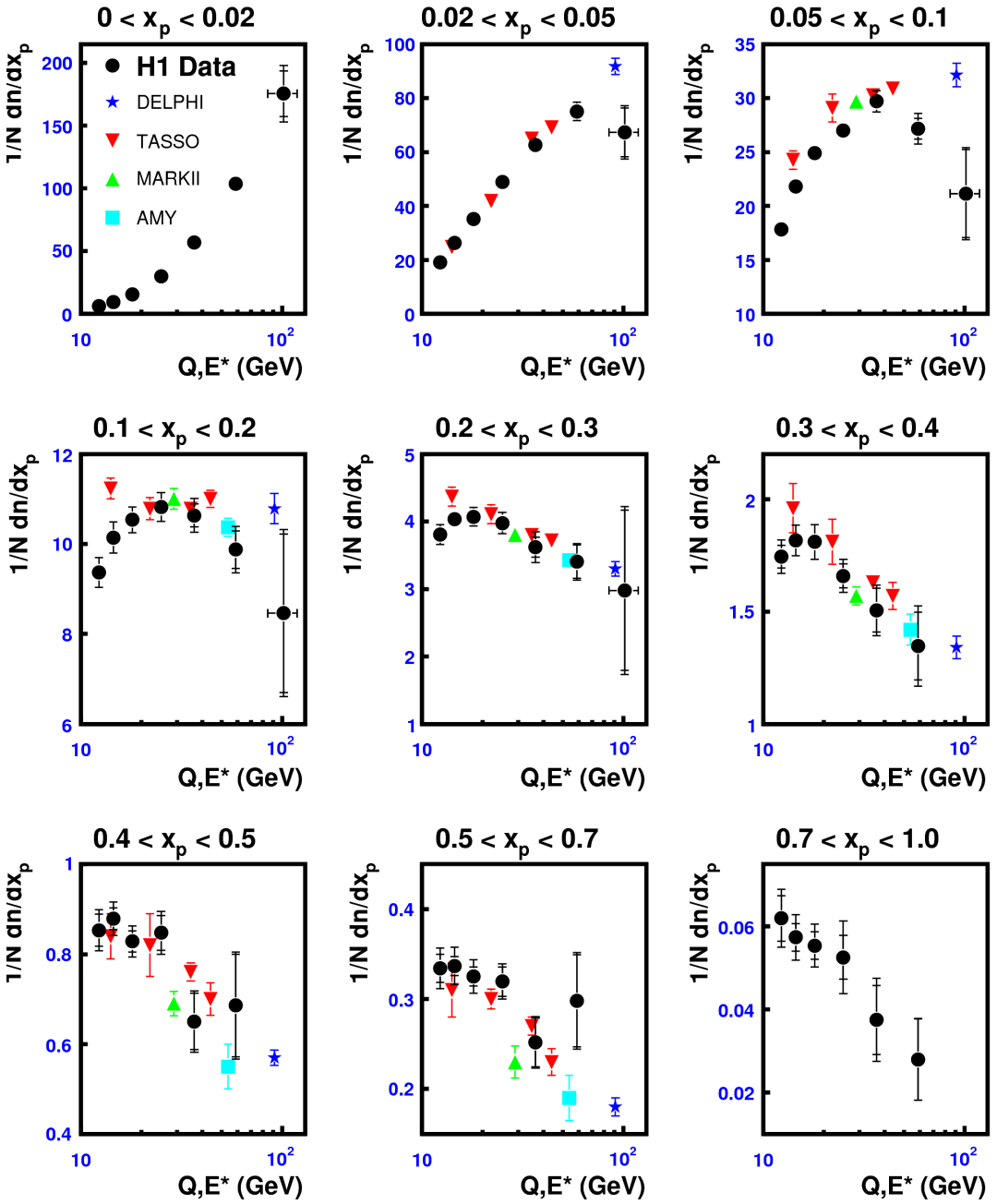
Thank you for your attention.

Thank you for coming.

You could have been in a nicer place

Conclusions

- MLLA+LPHD QCD calculations do not reproduce the ep data in entire range of Q^2 and x_p ,
- NLO + FF based on e^+e^- fail to describe x_p distribution as a function of Q^2 (small differences between different FFs).



Scaling violation in x_p intervals

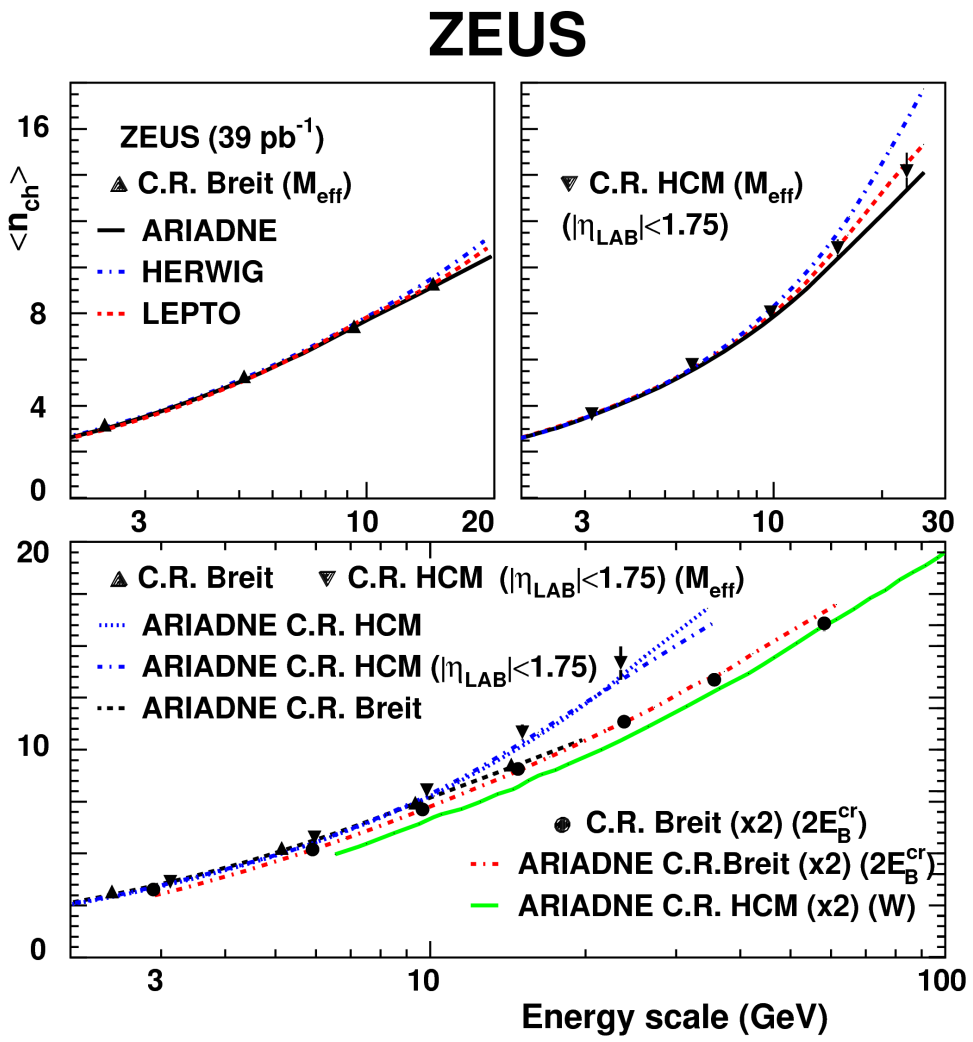
H1 data

e^+e^- data

Good agreement between *ep* and e^+e^-, except:

- higher Q^2 and small x_p
- BGF contribution
  - low Q^2 and mid x_p
  - kinematics depopulates current region

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