Fragmentation and particle production in DIS and photoproduction

On behalf of the H1 and ZEUS Collaborations

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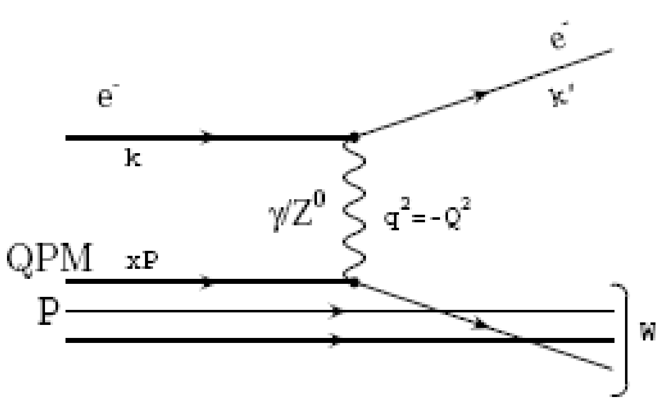
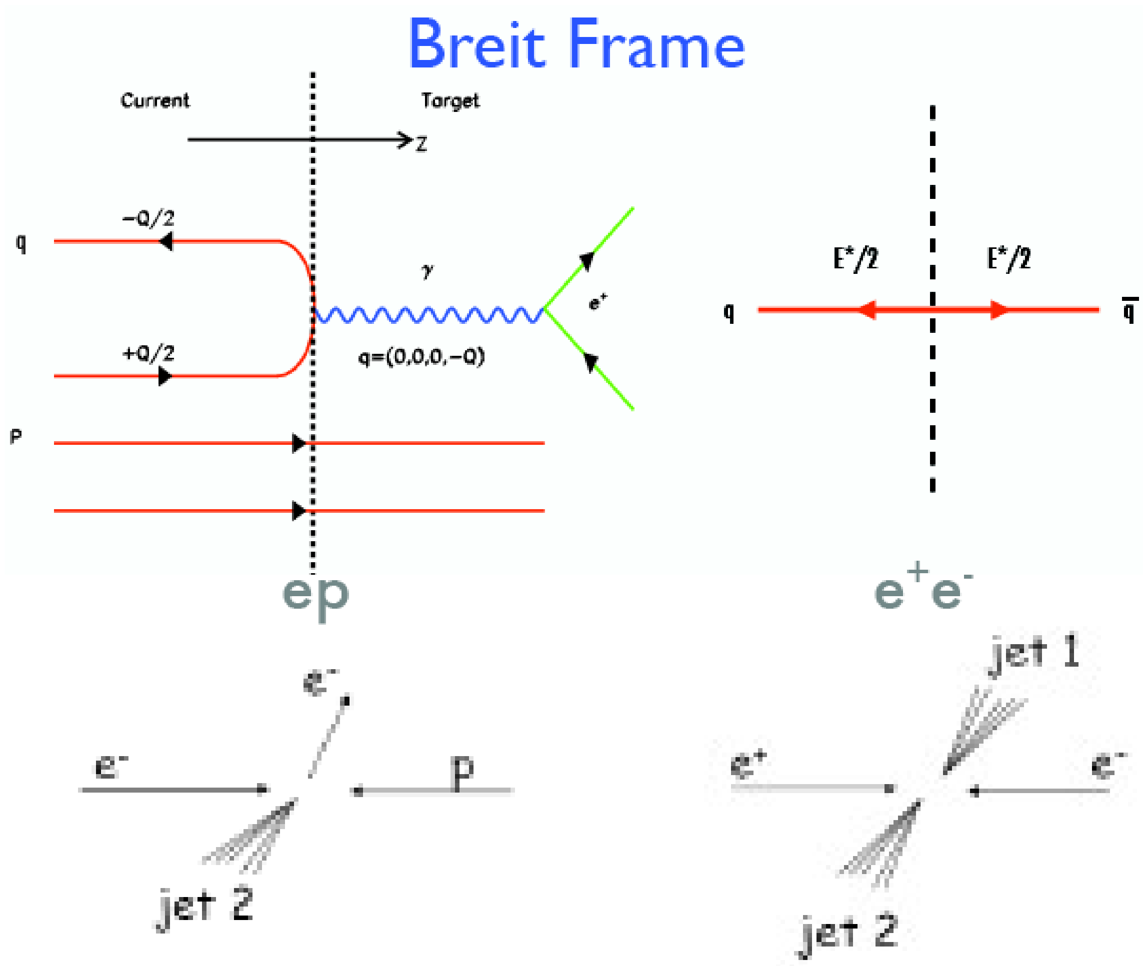
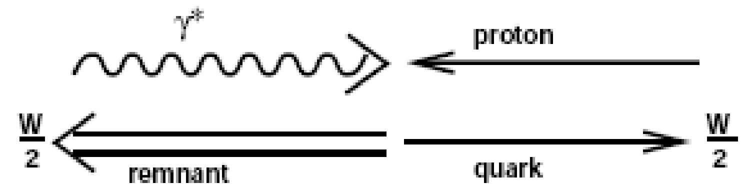


- **Energy of~300 GeV in ep CMS**
- **neutral current (NC)**

Reference frames



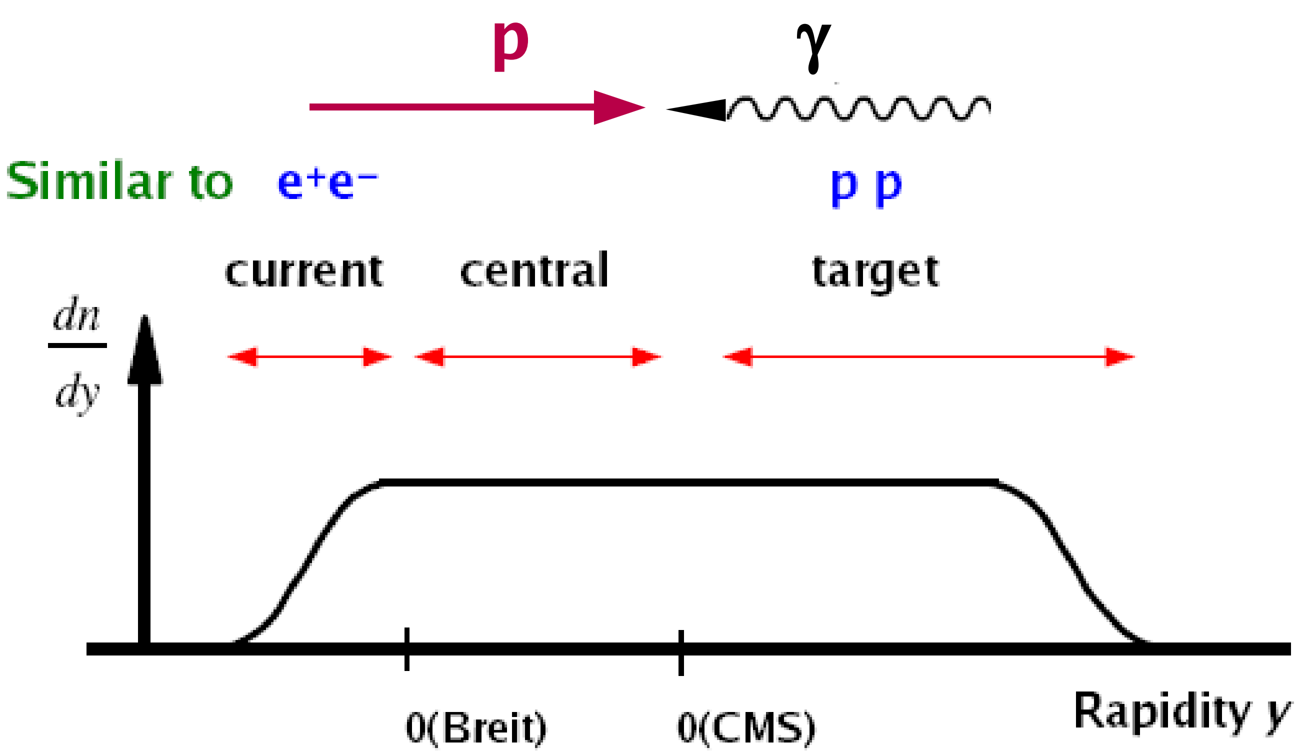
Hadronic Centre of Mass
or CMS γp

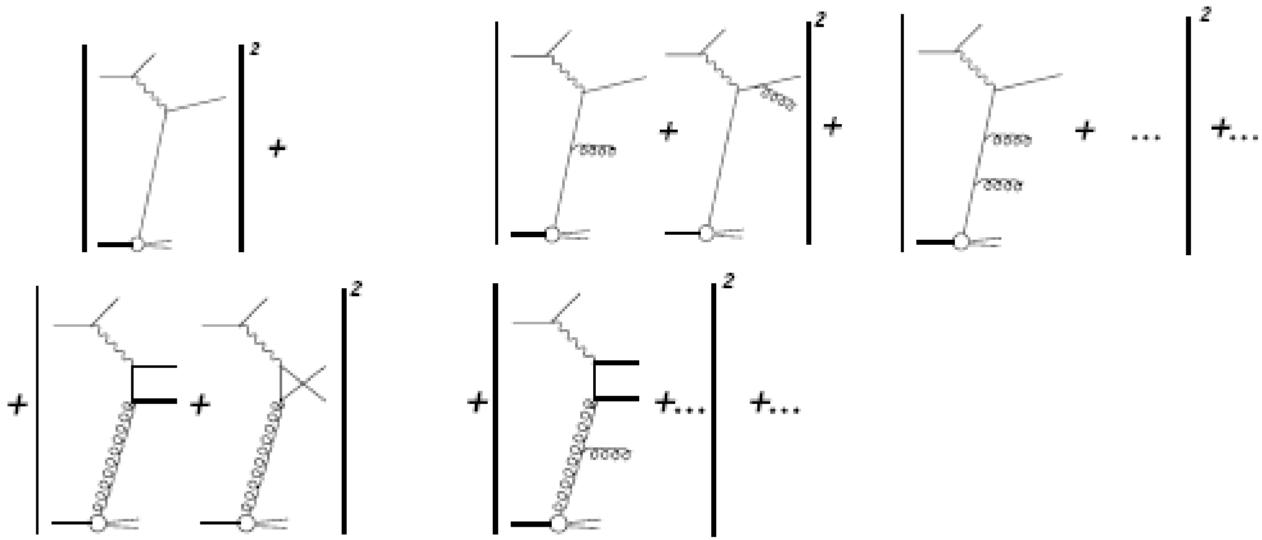


Photon virtuality, Q, is related to momentum of scattered quark.

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,





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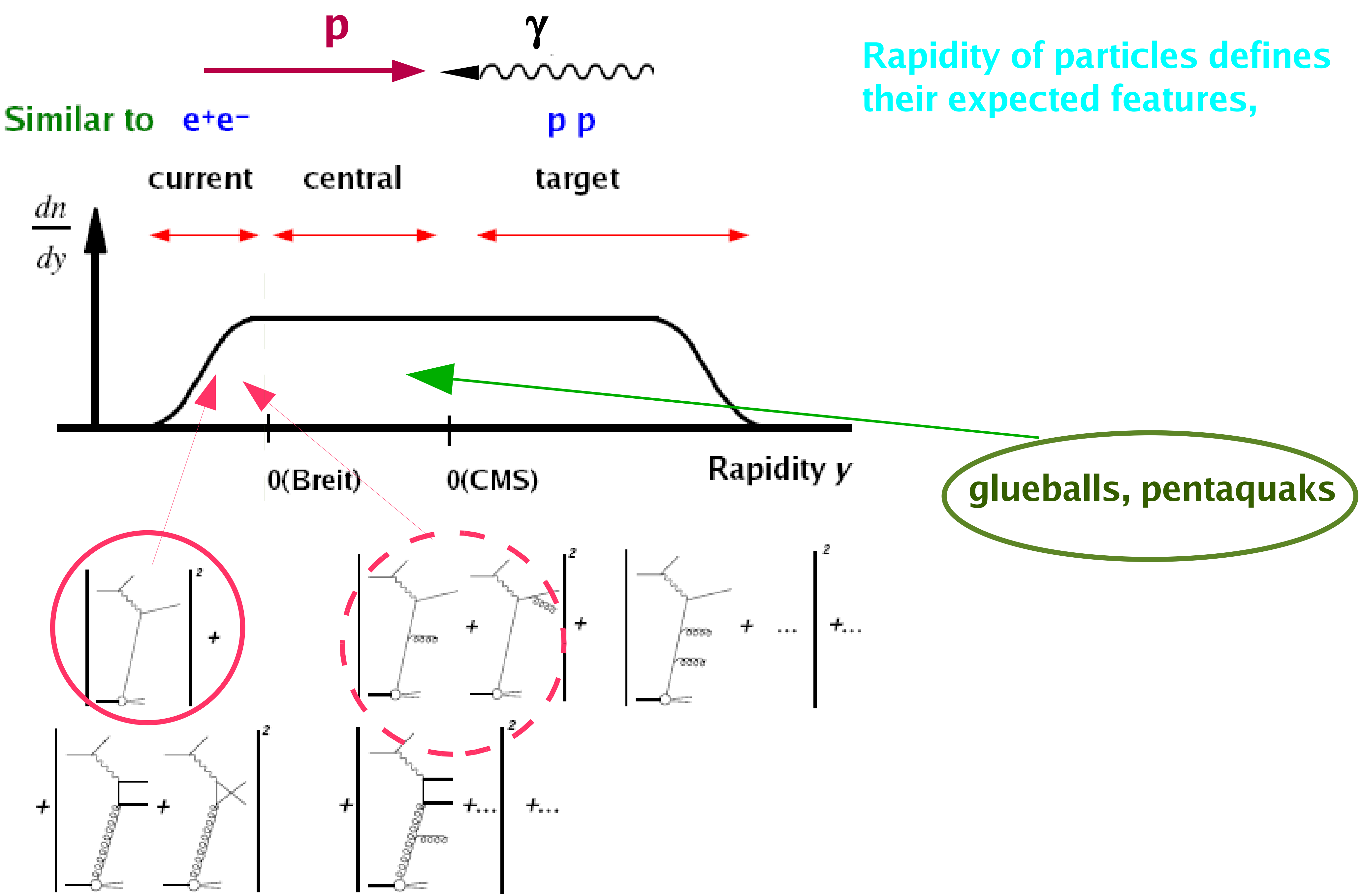

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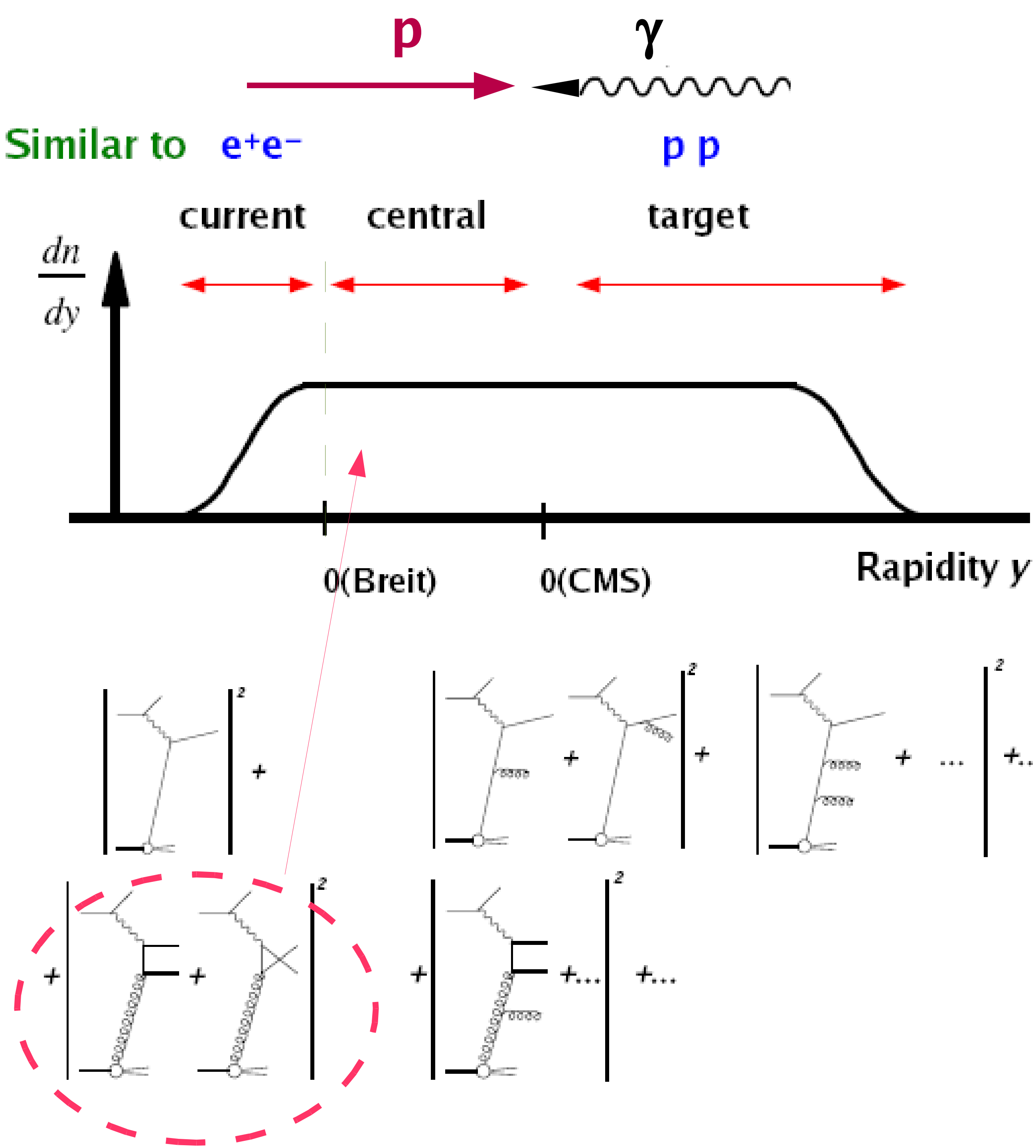

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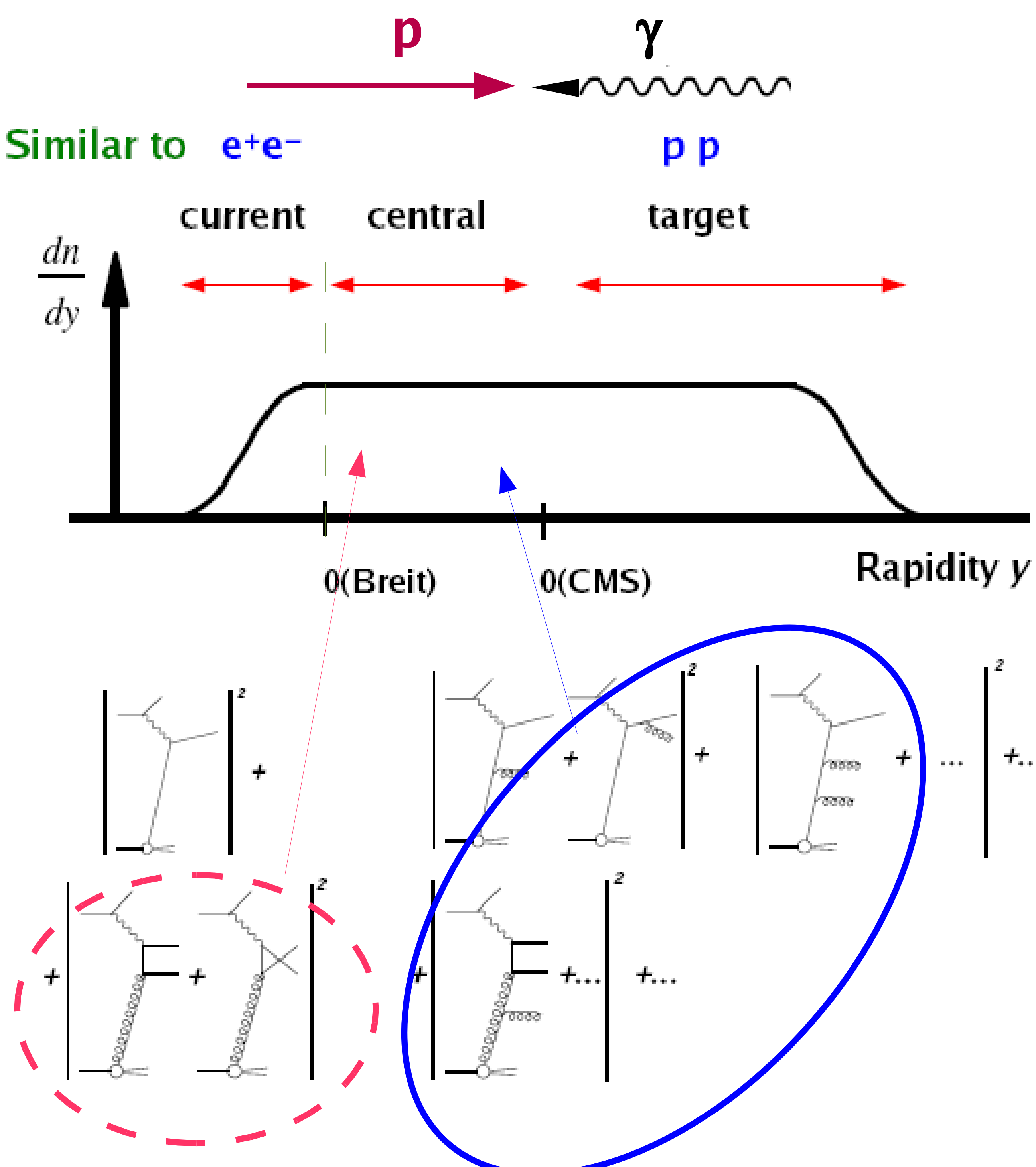
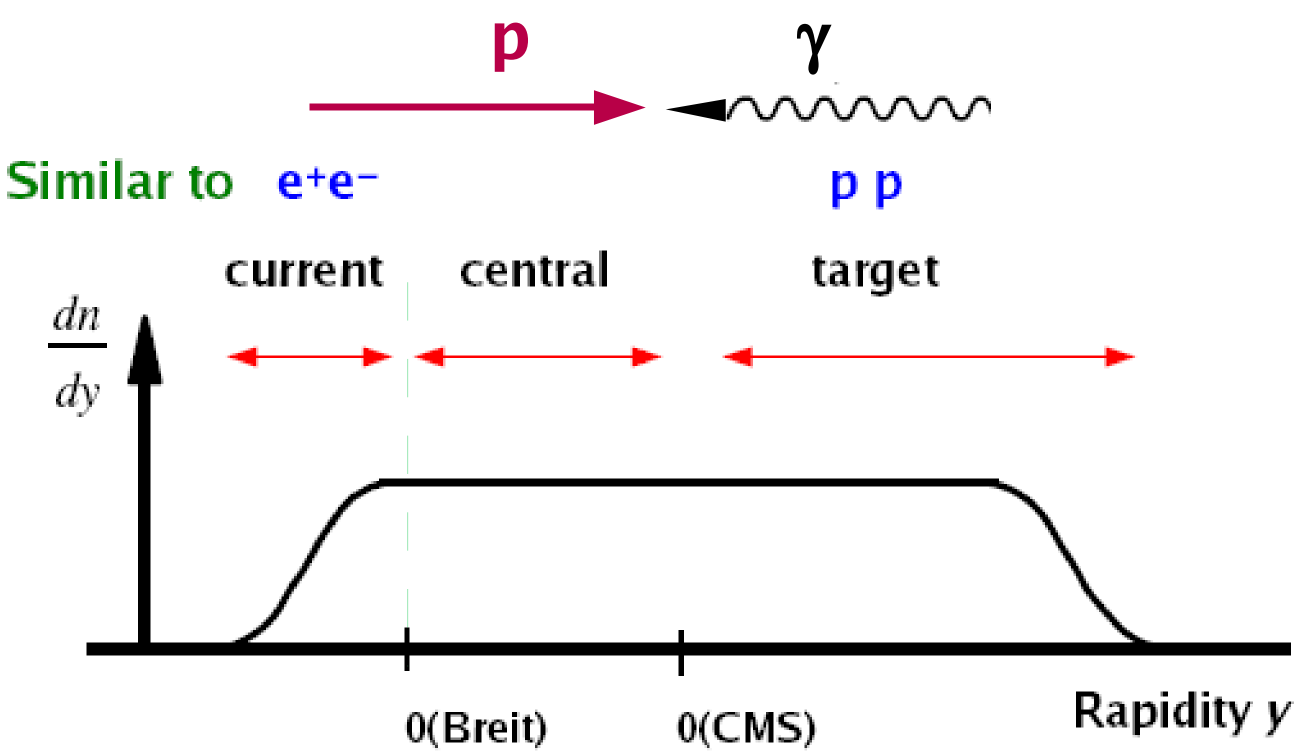


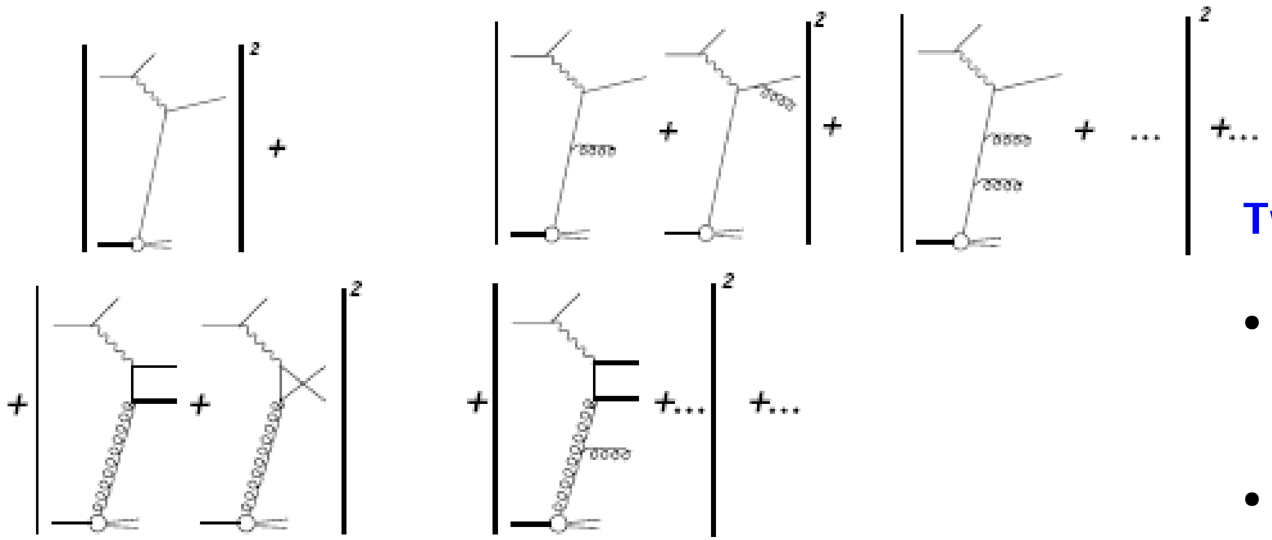


Rapidity of particles defines their expected features,

Outline:

- fragmentation in DIS (scaled momenta)
- particle production (size of their sources)

- fireball-like events in photoproduction



Two similar analyses on fragmentation:

- H1 Collaboration, DESY 07-065, Phys.Lett. (luminosity 44 pb^{-1})

- ZEUS Collaboration,(Preliminary) (luminosity 0.5 fb^{-1})

Monte Carlo Models

Our best knowledge is stored in MC models including hadronisation:

Colour dipole model	— ARIADNE 4.12	}	DIS
MEPS	— LEPTO		
	— PYTHIA		γp

strangeness suppression factor $\lambda_s = P(s) / P(u)$

Assumption for fragmentation process

Particle definition:

- Charged particle only; no cuts,
- Medium lifetime, i.e. all particles with a lifetime larger than 0.01 ns
- Stable particles include: $\Lambda, \Sigma^{\pm}, \Omega, K^0$

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

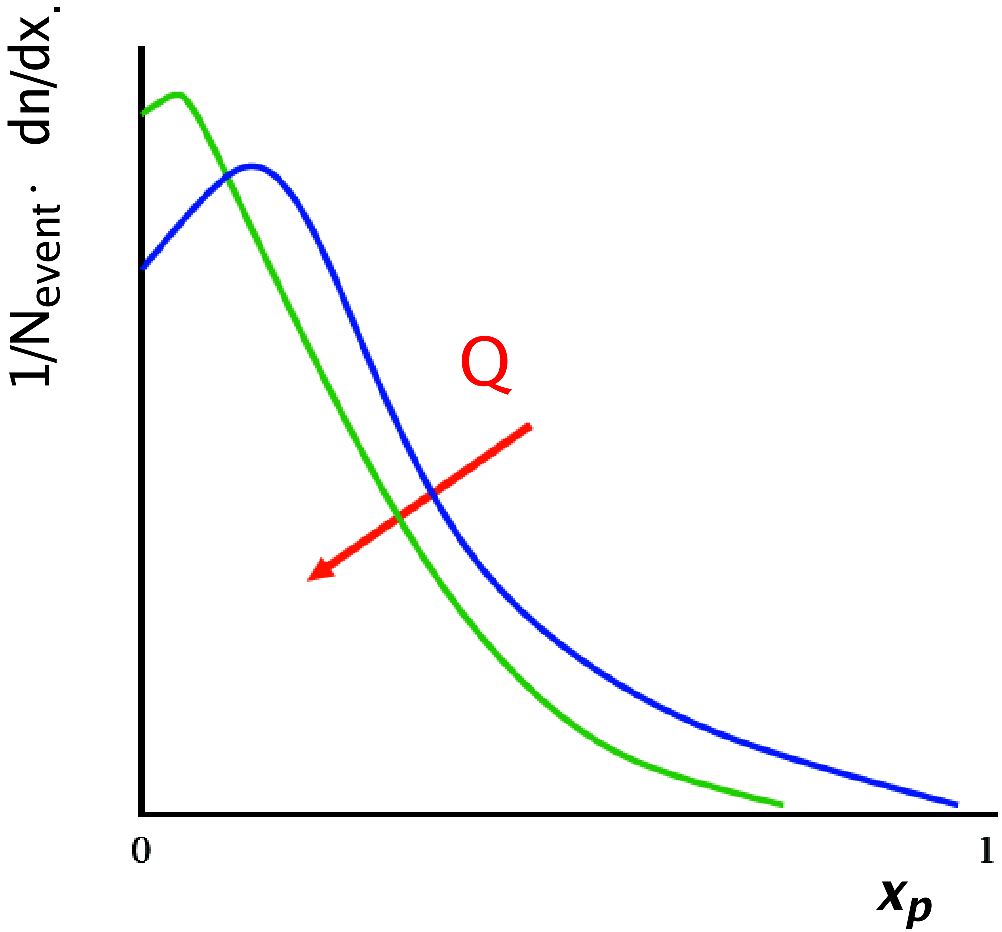
parton cross section (NLO,..)

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^-***

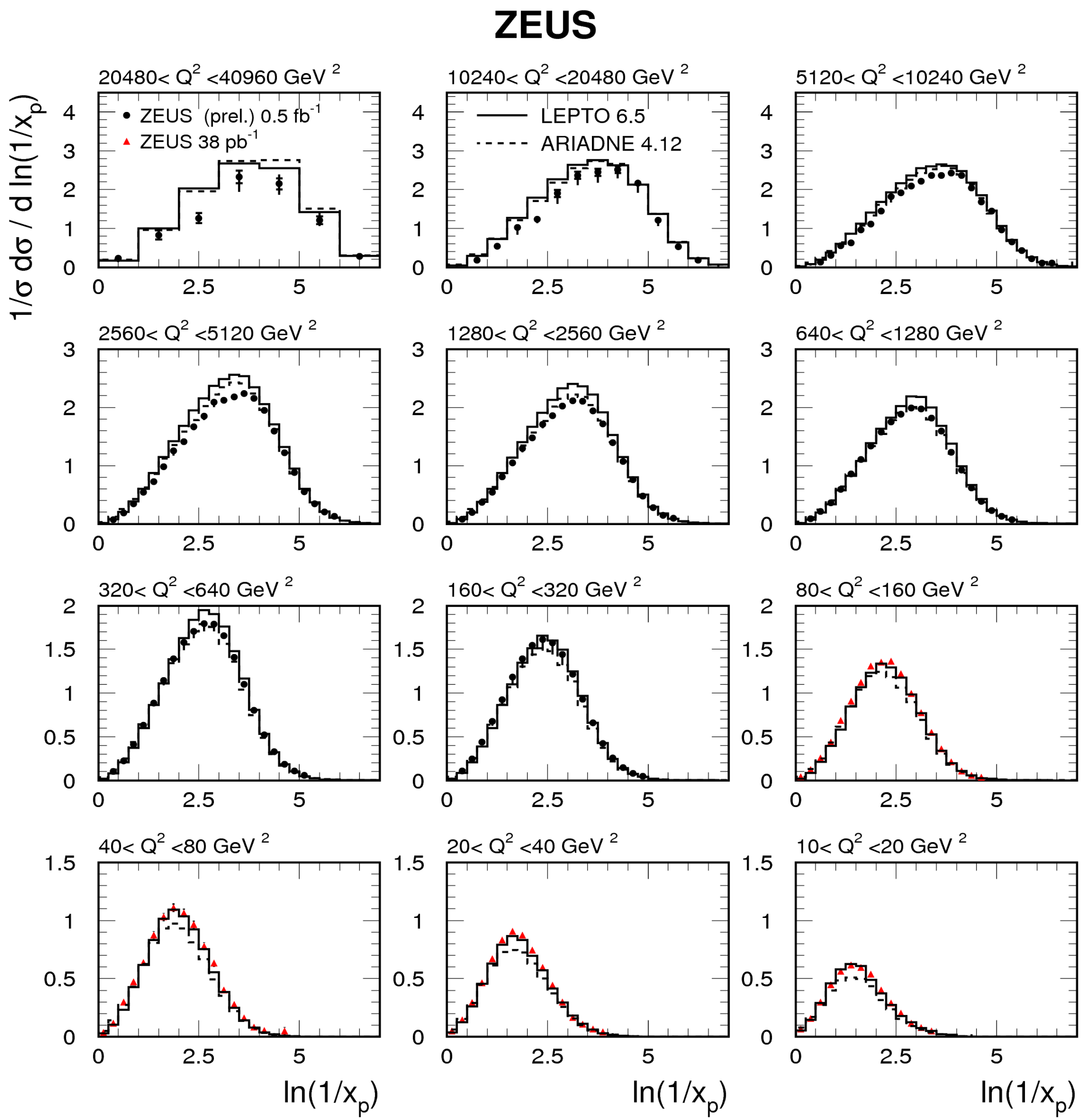


P_h **– momentum of charged particles in current region of the Breit frame.**

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

$\ln(1/x_p)$

Comparison with MC models in Q^2 intervals

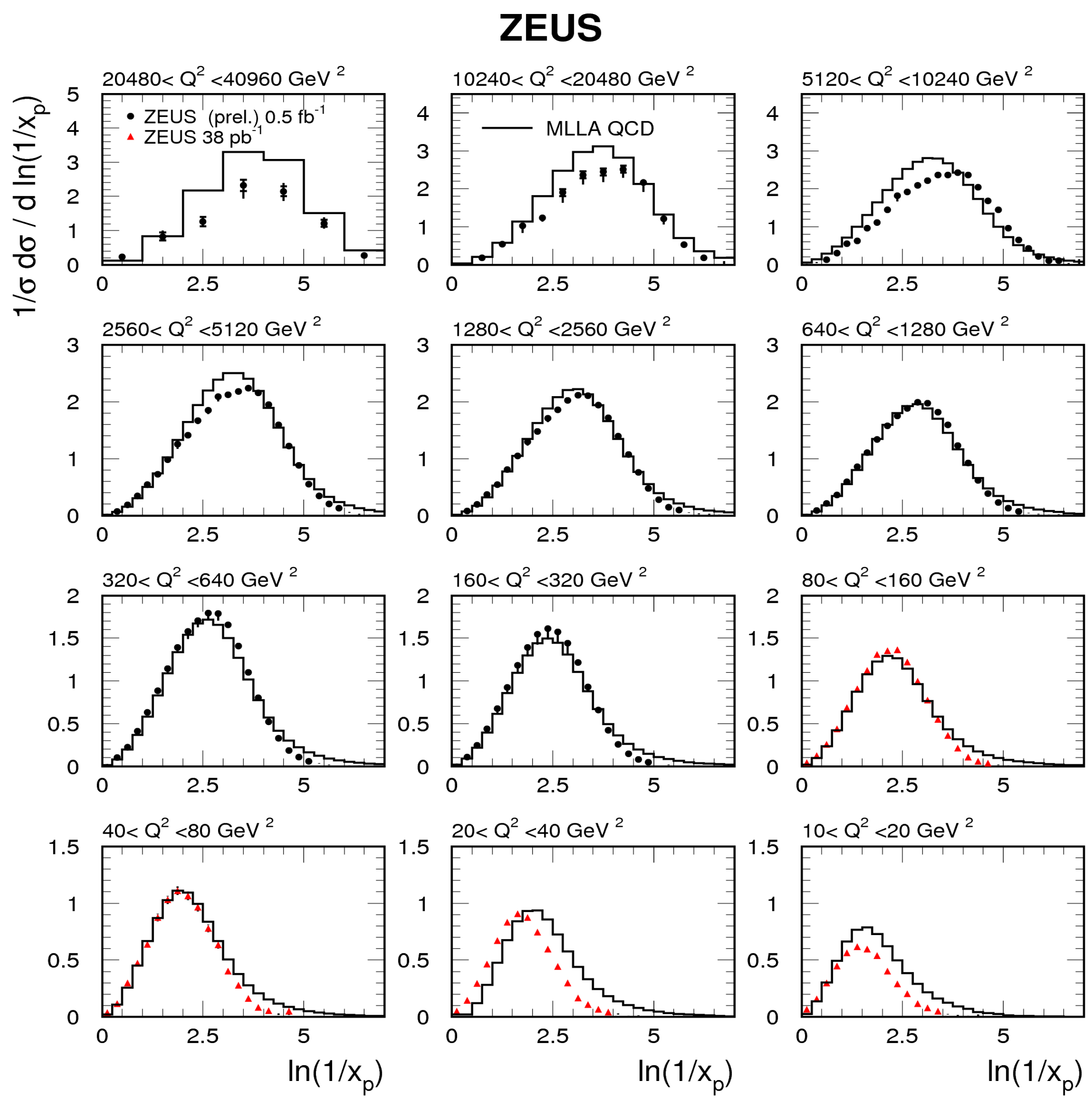


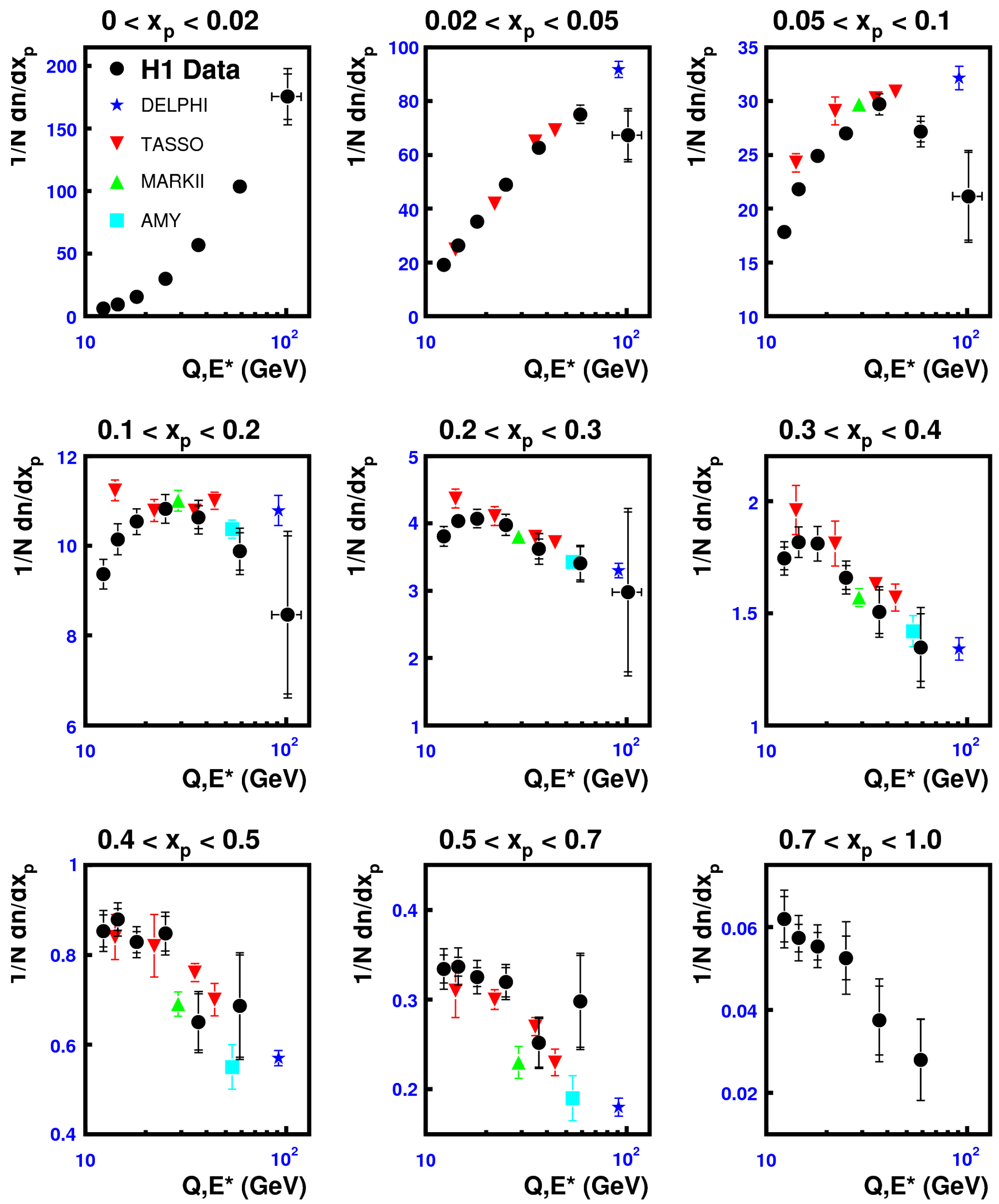
Both LEPTO and ARIADNE, MC models reproduce main features failing in normalisation at the highest Q^2

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





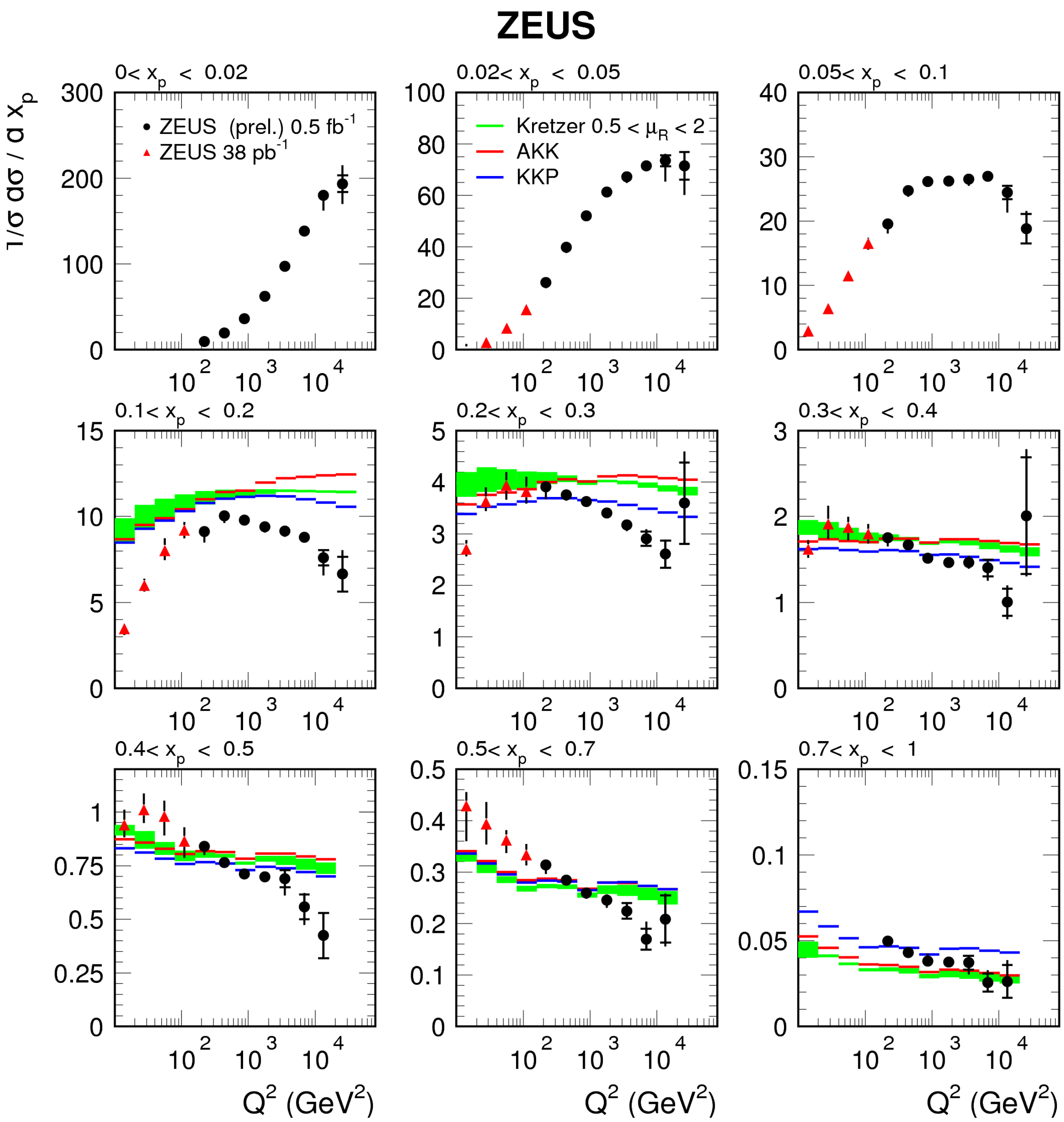
Scaling violation in x_p intervals

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



Fragmentation functions (FF):

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

Full NLO matrix element + partonic FF proposed by:

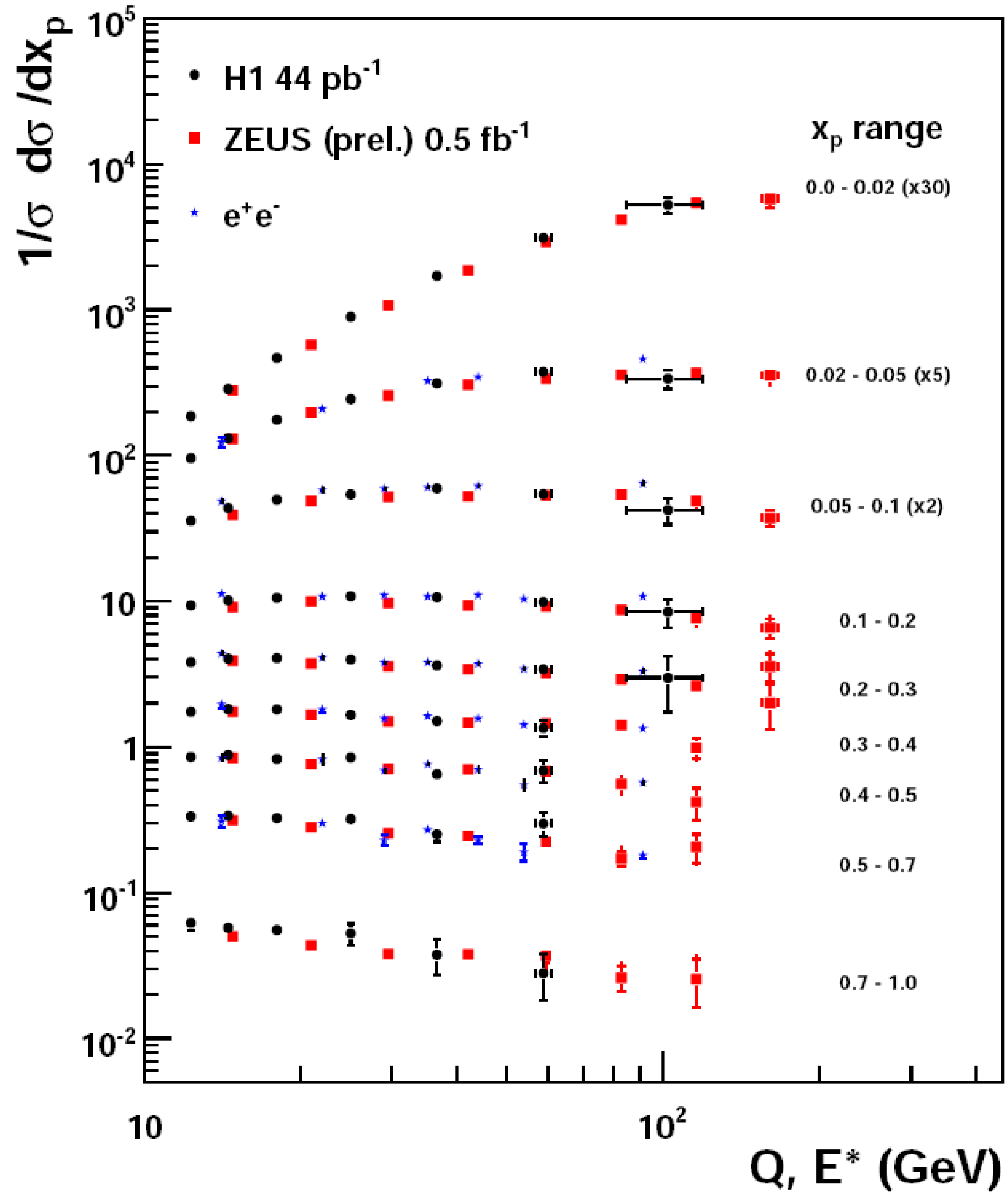
- **Kretzer** (2000) at Z^0pole data ALEPH, SLD, low-en. TPC
- **KKP** (Kniehl,Kramer,Poetter) (2000) at Z^0pole data ... + DELPHI, 3jet OPAL
- **AKK** (Albino,Kniehl,Kramer) (2005) update of KKP (d,s)

Comparison *ep* with e^+e^-

- supports the concept of quark fragmentation universality.

Summary:

- MC models and analytical 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).



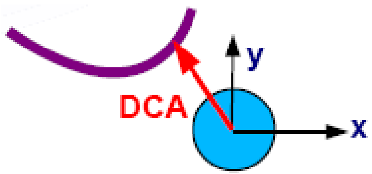
Particle production

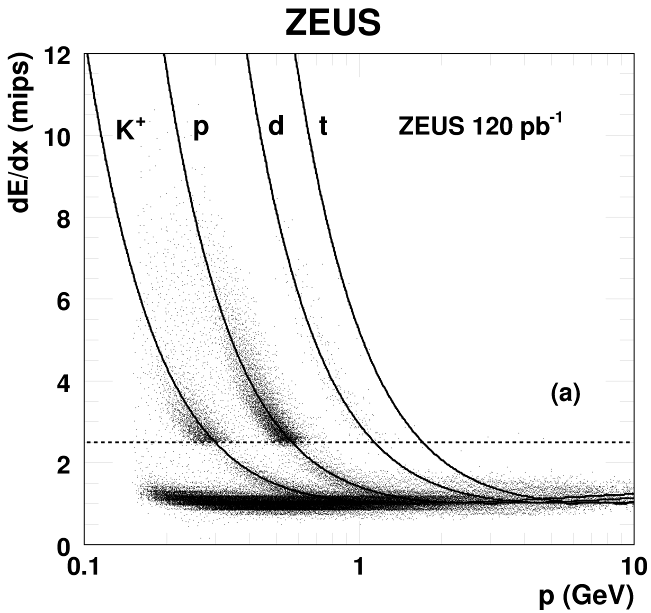
Selection criteria:
- 120 pb^{-1} (HERA I)
- $Q^2>1$ GeV

ZEUS Coll. DESY 07-070
H1 Coll. DESY 04-032
ZEUS Coll. DESY 07-063
ZEUS Coll. DESY 06-226

Need for:
- for modelling production of hadrons at high energy,
- for testing the mechanism for baryon production and baryon transport along the rapidity axis,

Measurements done:
- differential cross sections,
- baryon-to-meson ratio,
- ratio of strange-to-light hadrons,
- transverse spin polarisation of Λ,
- size of the emitting source.





Investigated particles:

$$K^{\pm}K^{\pm}, K_s^0, \Lambda(\bar{\Lambda}), p(\bar{p}), d(\bar{d})$$

Method of identification:
- dE/dx
- Distance of closest approach DCA

Deuteron and anti-deuteron

Bound state of two nucleons or multi-quark particle ?
In elementary collisions — overlap of wave function in the final state,

- **Not included in the standard hadronisation model , i.e. JETSET type**
- **Anti-d was observed in e^+e^- by ARGUS, OPAL, ALEPH, CLEO**

- **Observation of anti-d in ep photoproduction (H1)**
- **First measurement of d and $\bar{d}$ in DIS (ZEUS)**
  (high background— beam-gas, beam-wall, secondary interactions)

The coalescence model gives the cross section for formation of an object with A nucleons

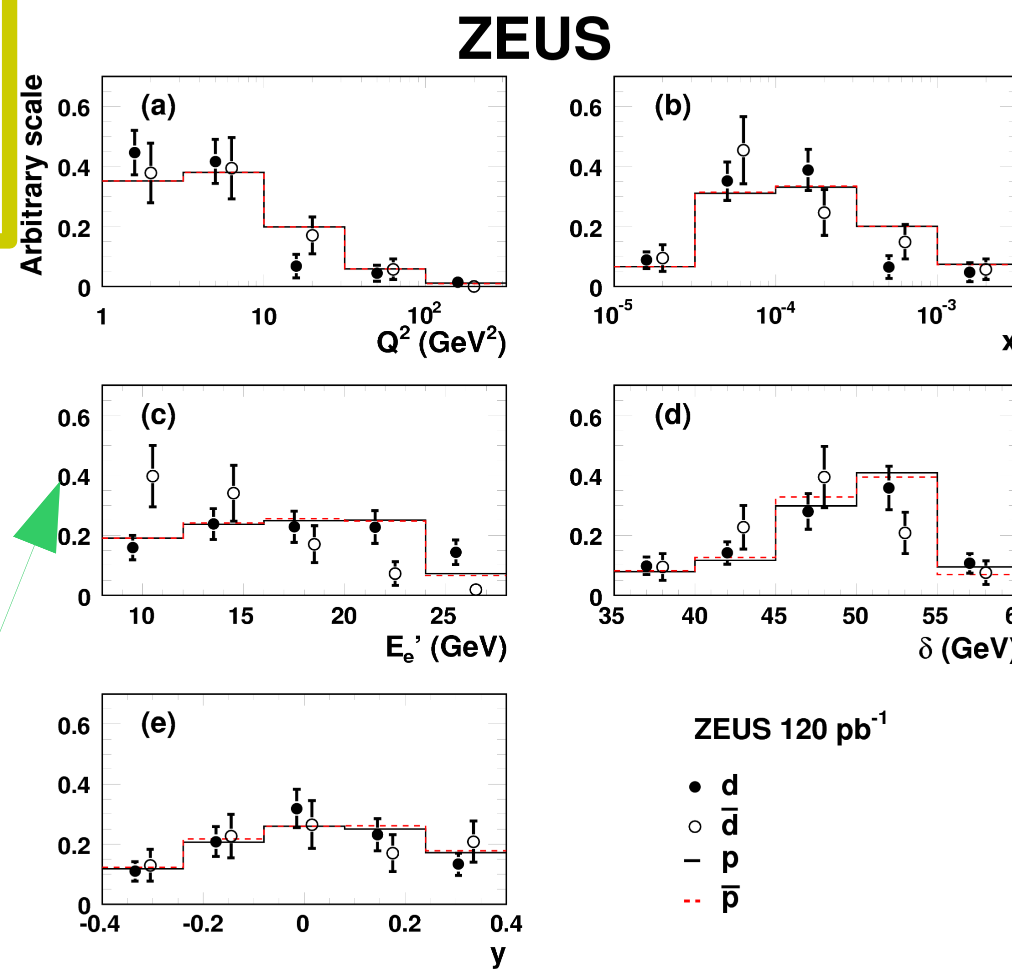
$$\frac{E_A}{\sigma_{tot}}\frac{d^3\sigma_A}{d^3P_A} = B_A\left(\frac{E_N}{\sigma_{tot}}\frac{d^3\sigma_N}{d^3p_N}\right)^A \qquad p_N = P_A/A \qquad A = 2$$

The coalescence parameter $B_2 \propto \frac{1}{V} \propto \frac{1}{R^3}$ **where *R* – source radius**

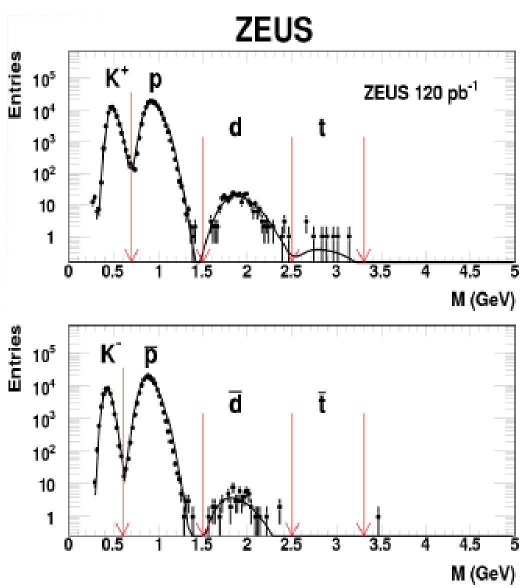
Number of events:

p	1.52 10^5
$\bar{p}$	1.62 10^5 ← tracking efficiency
d	177 ± 17
$\bar{d}$	53 ± 7

Deuteron yield is suppressed by a factor of ~1000 w.r.t. protons



No d($\bar{d}$) is found in current region of Breit frame in agreement with low rate in e^+e^-.
Only 2.5% of p($\bar{p}$) is emitted in this region.

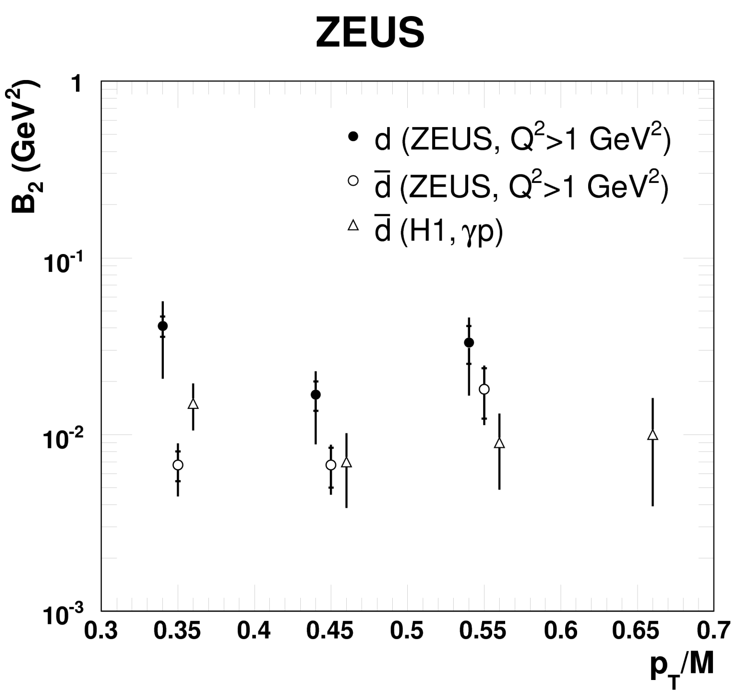


d($\bar{d}$) distributions are consistent with those for p($\bar{p}$) except anti-d as function of scattered electron energy (E_e') (related to W.)

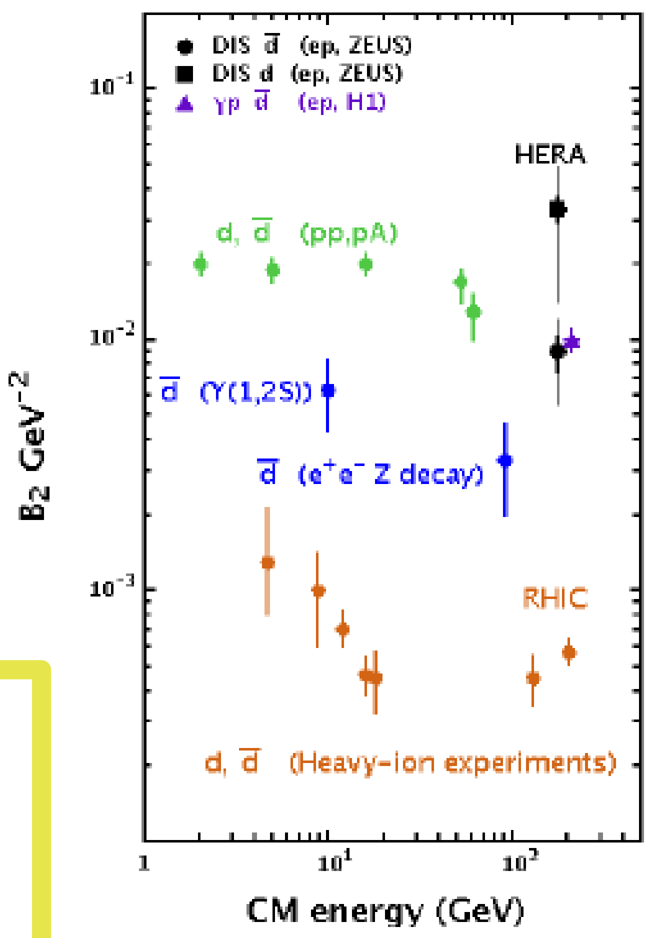
The coalescence parameter B_2

- larger for d than for anti-d
- similar for DIS and for photoproduction

$$\frac{E_d}{\sigma_{tot}} \frac{d^3\sigma_d}{d^3P_d} = B_2 \left(\frac{E_p}{\sigma_{tot}} \frac{d^3\sigma_p}{d^3p_p} \right)^2$$



World data



Source radius
$R^3 \sim 1/B_2$

small

large

the source volume is different for d and anti-d, and different than in e^+e^-.

Bose-Einstein correlation

$$R(Q_{12}) = \frac{P(Q_{12})^{data}}{P_{mix}(Q_{12})^{data}} \cdot \left[\frac{P(Q_{12})^{MC,nBEC}}{P_{mix}(Q_{12})^{MC,nBEC}}\right]^{-1}$$

ZEUS Coll. DESY 07-063

$$Q_{12} = \sqrt{-(p_1 - p_2)^2}$$

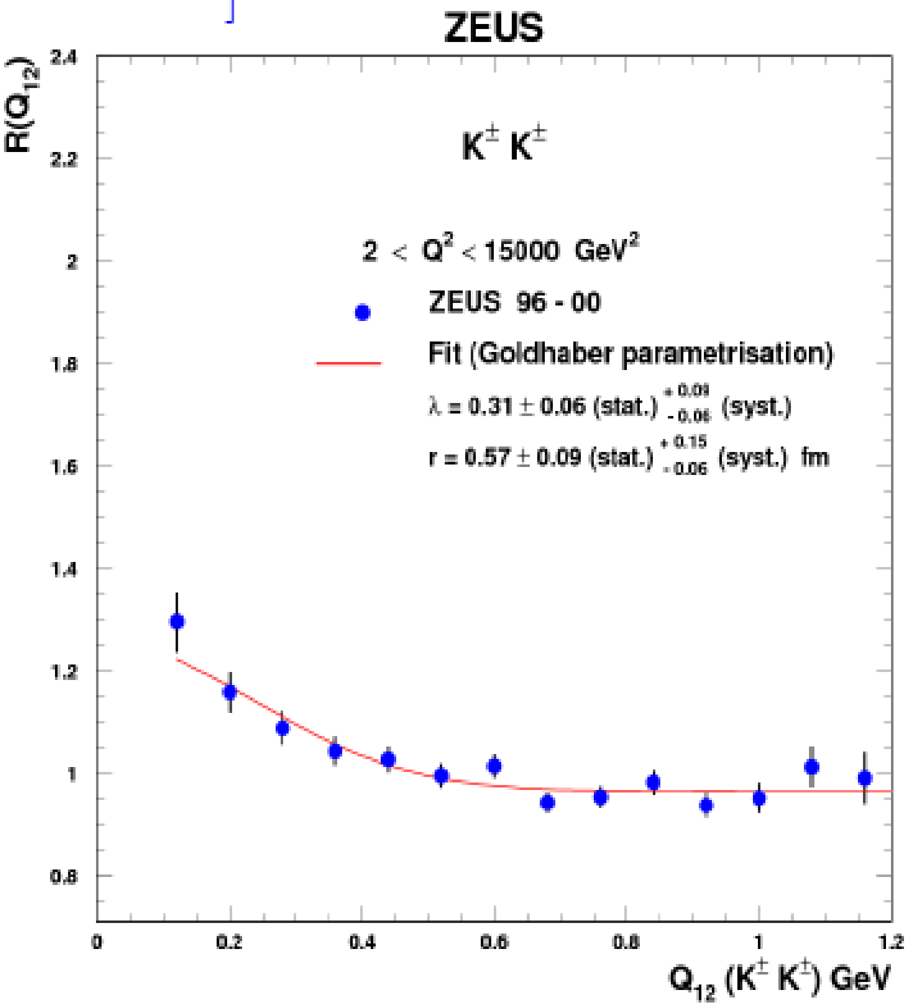
Luminosity 121 pb^{-1}

$Q^2 > 2$ GeV^2 and $p_K < 0.9$ GeV

K^+K^+ and K^-K^- pairs: 55522

Goldhaber parametrisation:

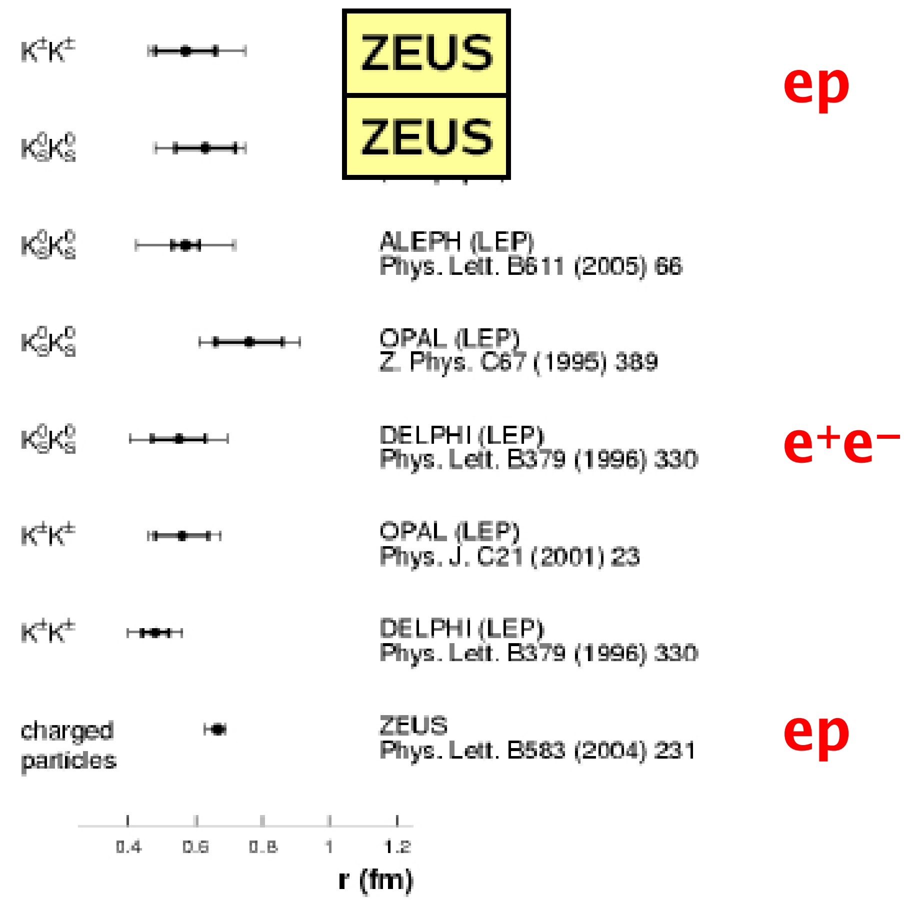
$$R(Q_{12}) = 1 + \lambda \exp(-r^2\, Q_{12}^2)$$



Comparison of DIS and LEP results

Results for KK pairs are sensitive to resonances decaying into KK pairs,

in particular for $K^0 K^0$ the λ parameter which describes the strength of BE correlation:



		corrected
$\lambda=1.16 \pm 0.29$	$\rightarrow$	0.70 ± 0.19
$r=0.61 \pm 0.08$		0.63 ± 0.09

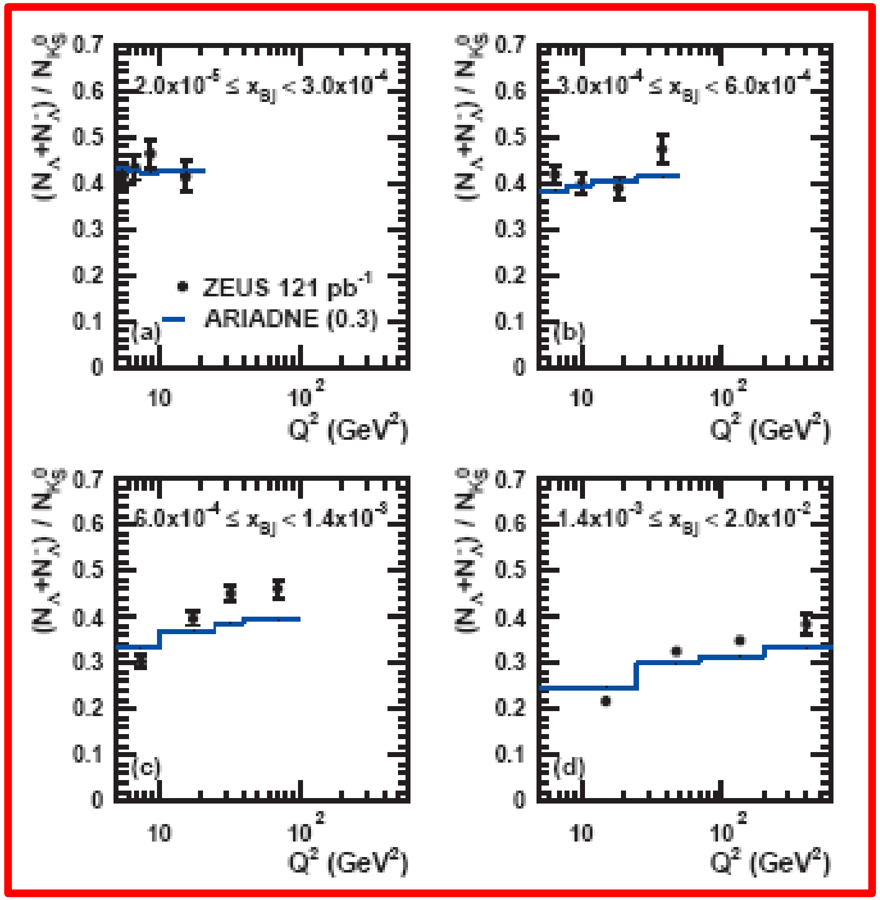
Conclusions:

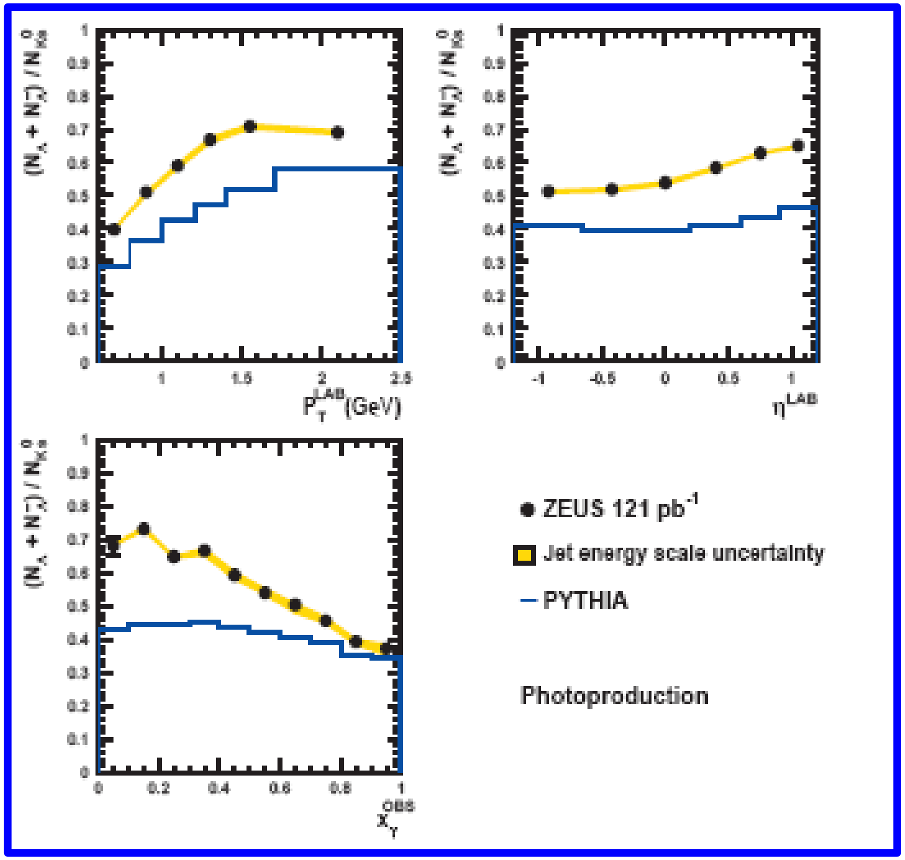
BE correlation — the same for ep and e^+e^-

Strange particle production

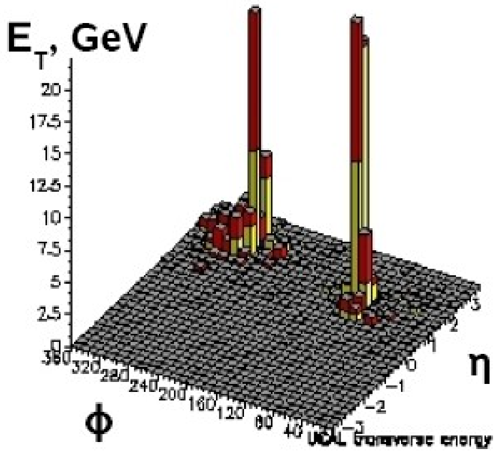
Baryon-to-meson ratio $$\frac{N(\Lambda)+N(\bar{\Lambda})}{N(K_s^0)}$$

well described by MC for DIS and direct photoproduction but not for resolved photons or 'fireball' type of events.

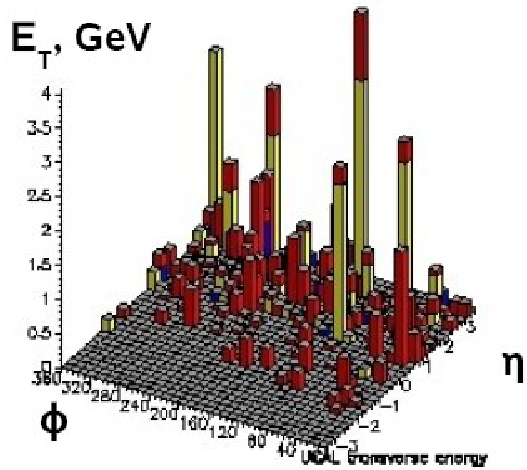




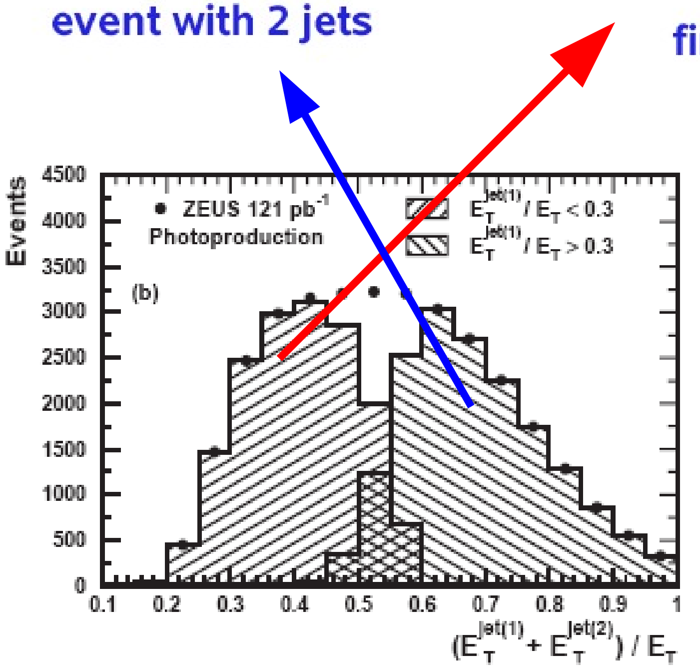
Strange particle production in “fireball-like” events



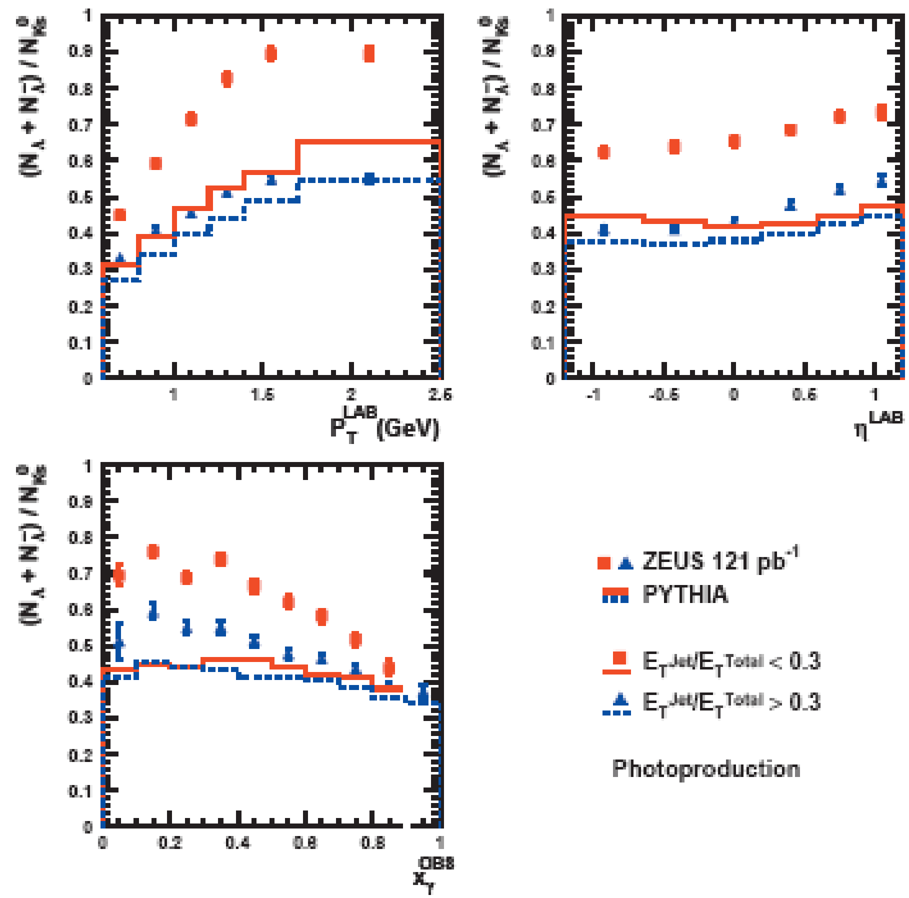
event with 2 jets



fireball-like event



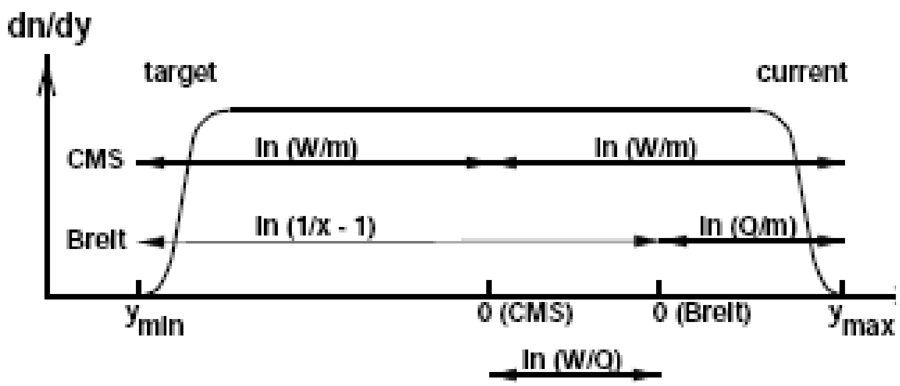
“FIREBALL”



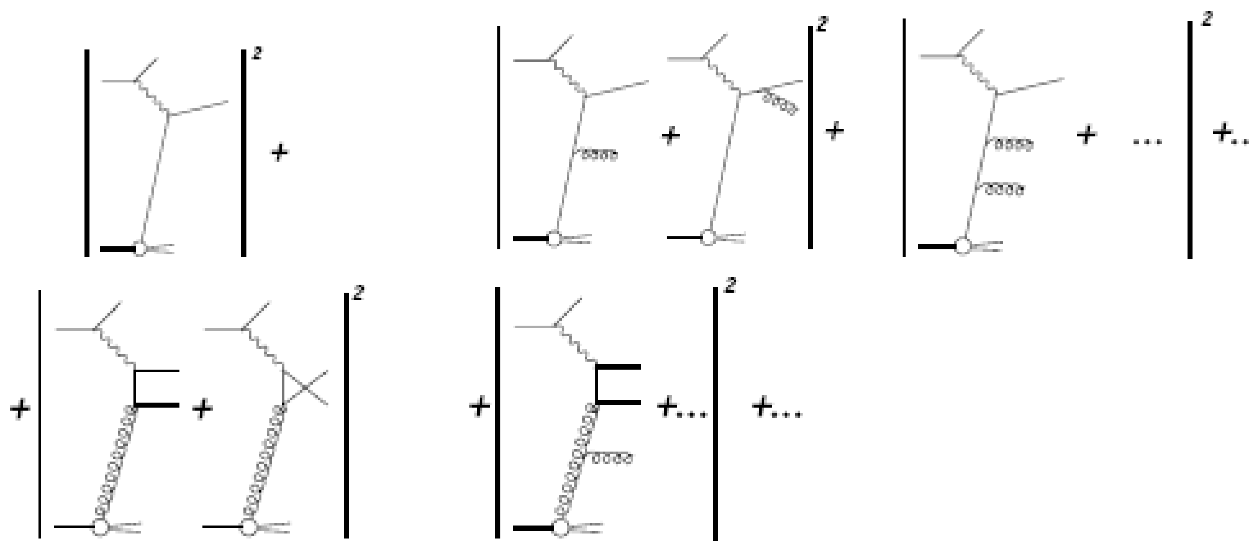
Summary and conclusions

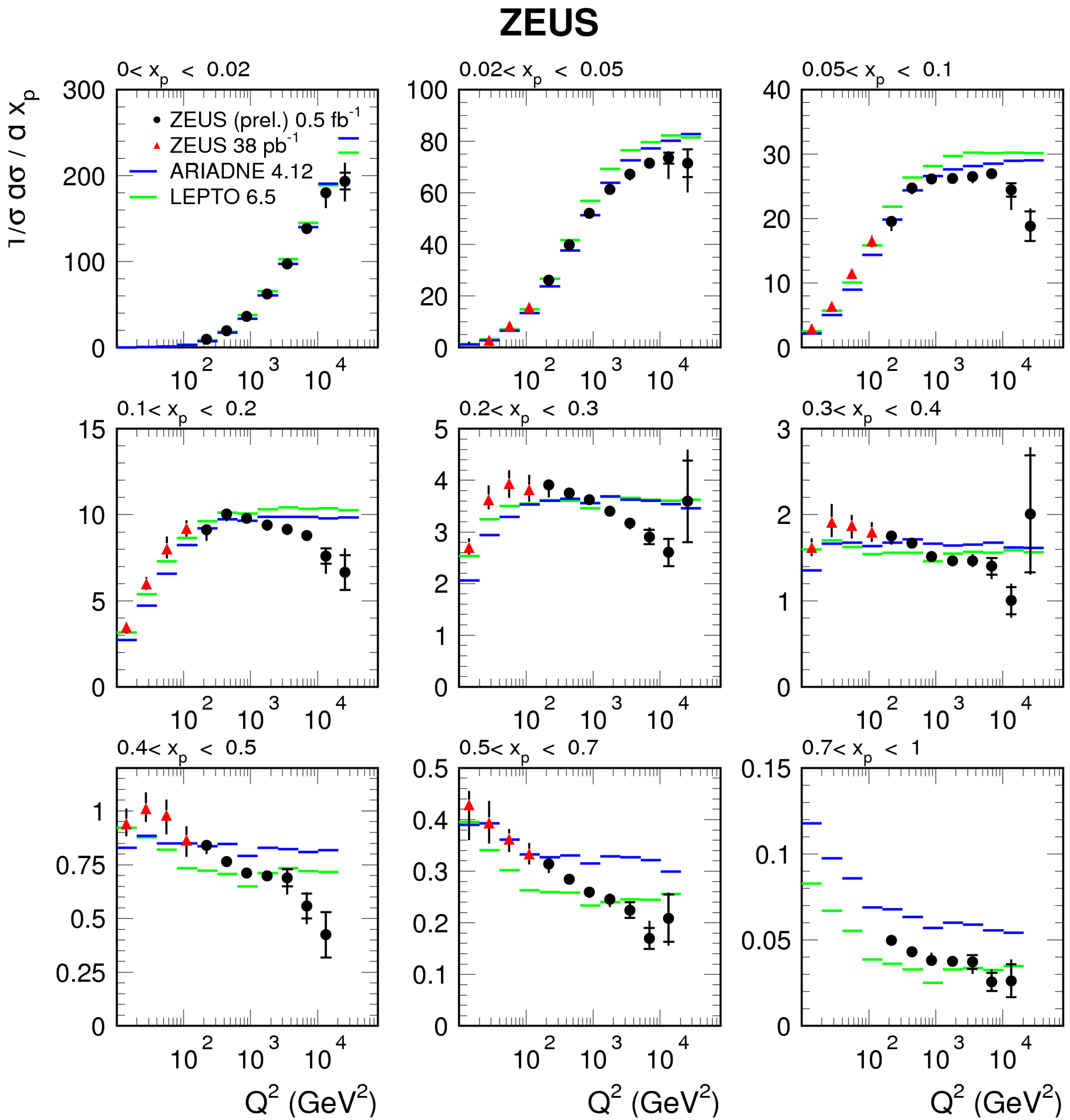
- HERA provided a wealth of high precision hadronic data,
- Hadron scaled momentum x_p distributions support the concept of quark fragmentation universality, but NLO + FF predictions based on e^+e^- data fail to describe the distributions as a function of Q^2,
- First observation of d and anti-d in DIS
  - rate of d is three order of magnitude smaller than for p,
  - rate of d is three times larger than for anti-d
  - coalescence model : smaller production volume than AA and e^+e^- cross section (or B_2) the same for DIS and γp,
- Size of particle production volume from Bose-Enstein correlation is similar to those estimated from e^+e^- data,
- In resolved photon region the ratio of baryon-to-meson larger than expected.

Additional plots


dn/dy
target
current
CMS
ln (W/m)
ln (W/m)
Breit
ln (1/x - 1)
ln (Q/m)
y_{min}
0 (CMS)
0 (Breit)
y_{max}
ln (W/Q)

rapidity





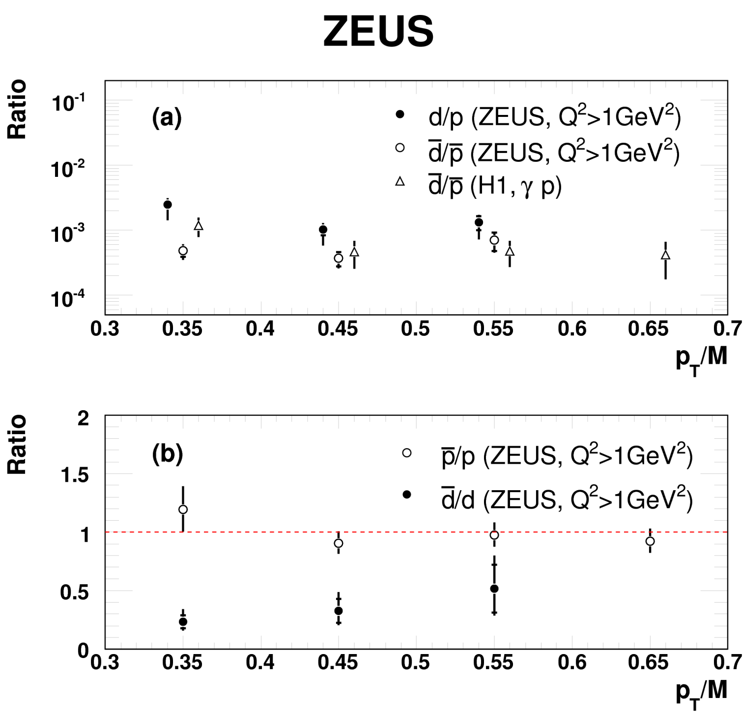
Scaling violation in x_p intervals

Both LEPTO and ARIADNE fail to describe the data for the entire Q^2 region.

Energy (Q^2) increases more soft particles are produced.

At higher Q^2 and higher x_p data fall faster than predicted by leading order MC models.

particle-to-particle yields



$\bar{p}/p = 1$

$\bar{d}/d \neq 1$

Summary:

- first observation of d production, of anti-d in DIS,
- rate of anti-d is smaller than d,
- rate of p is consistent with anti-p, no chance to investigate small baryon-antibaryon asymmetry,

- if the coalescence model is used the source volume is different for d and anti-d, and different than in e^+e^-.