Particle production and spectroscopy at HERA

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Low x Meeting, Ischia, September 12, 2009

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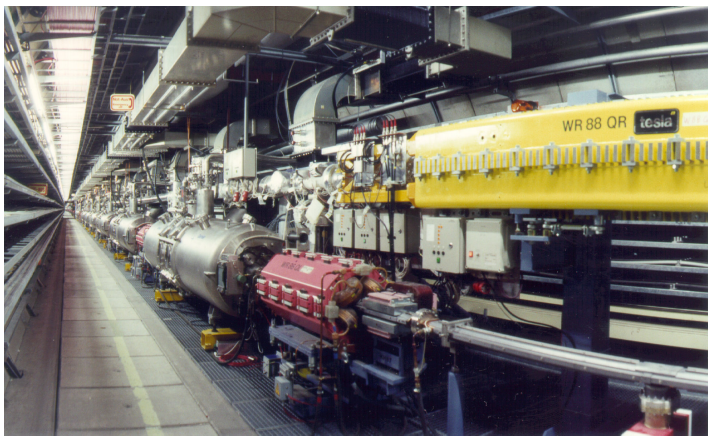
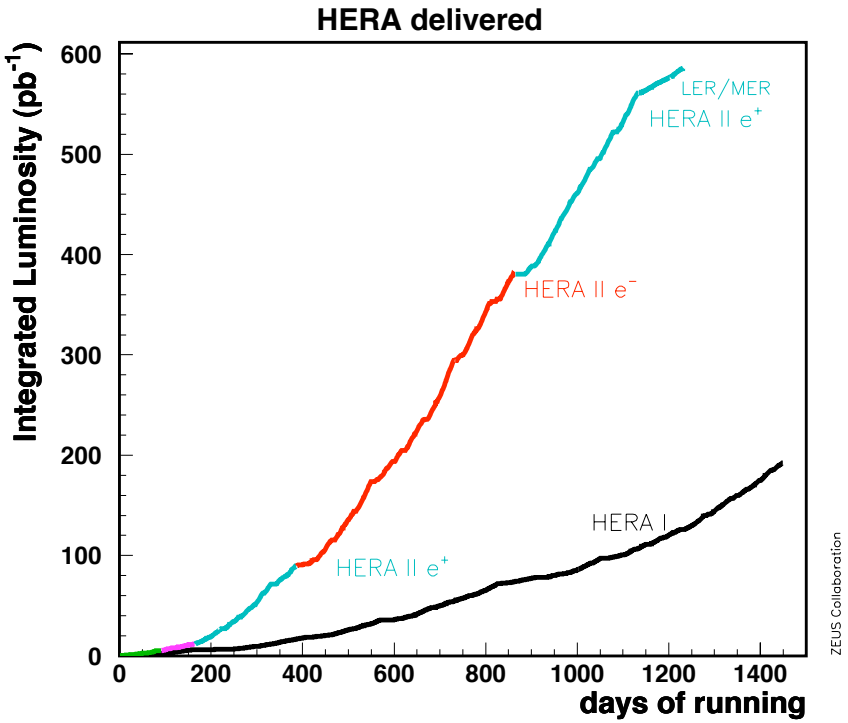
2. Multiplicity studies
3. Scaled momentum studies
   - Photoproduction (PH)
   - Deep Inelastic Scattering (DIS)
4. Spectroscopy
   - ρ^0, K^{*0} and ϕ mesons in PH
5. Summary

HERA accelerator at DESY



- $E_{protons} = 920$ GeV
- $E_{electrons} = 27.5$ GeV

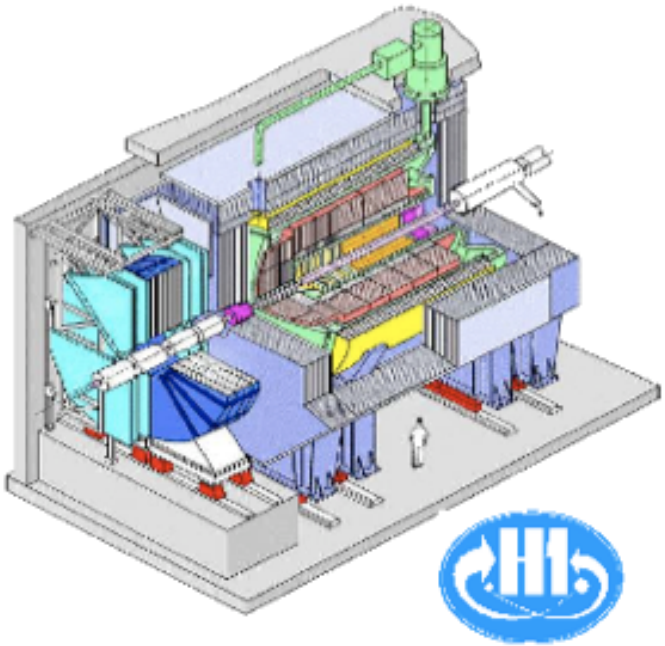


HERA I 1994-2000 about 100pb^{-1} collected per experiment, mainly e^+p data
HERA II 2002-2007 about 400pb^{-1} per experiment, polarized lepton beams

Results presented in this talk: HERA I and/or HERA II data

ZEUS and H1 detectors

H1

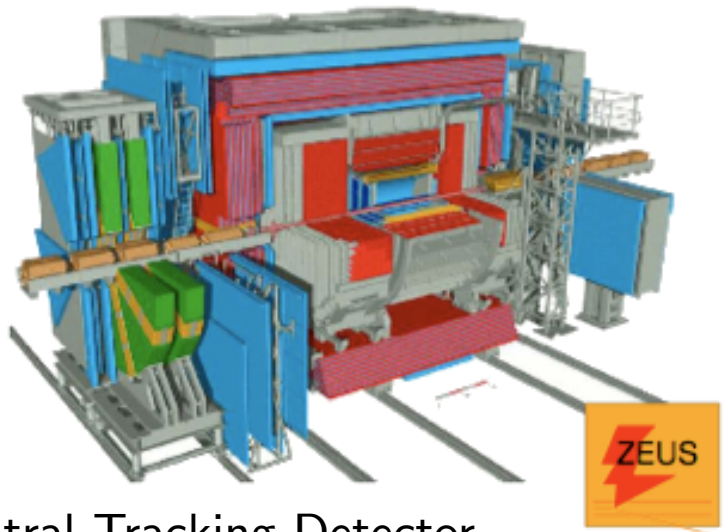


Central Tracking Detector
$20^o < \theta < 165^o$

silicon vertex detector
$30^o < \theta < 150^o$

$\sigma(p_T)/p_T \approx 0.006 p_T[\text{GeV}] \oplus 0.02$

ZEUS



Central Tracking Detector
$15^o < \theta < 164^o$

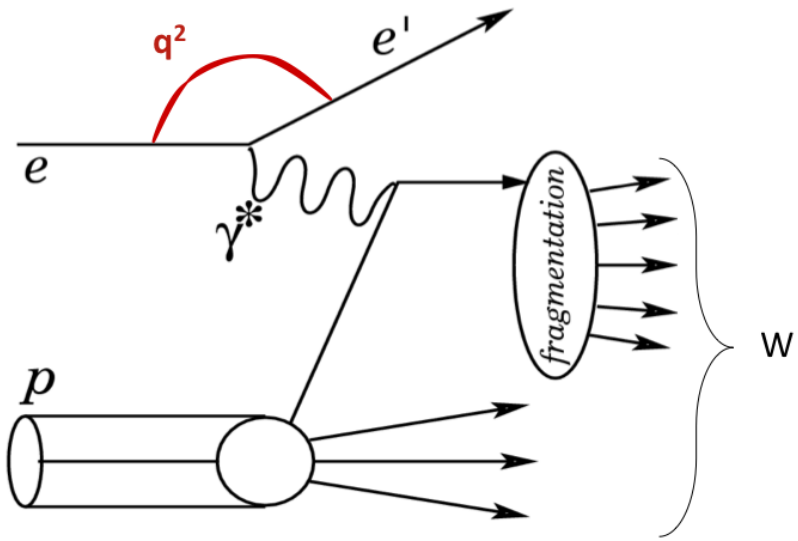
microvertex detector
$7^o < \theta < 150^o$

straw-tube tracker
$5^o < \theta < 25^o$

Hadron production

Kinematic variables

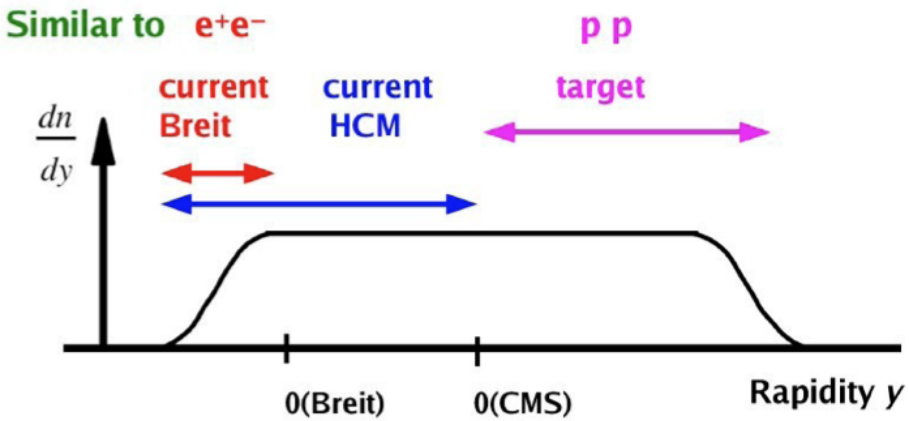
- $Q^2 = -q^2$, where q is the 4-momentum of photon
- $s = (P + e)^2$ is the ep center of mass energy
- $W^2 = (P + q)^2$ is the hadronic energy for $\gamma^* p$ system



Two regimes

- $Q^2 \approx 0$ GeV^2 Photoproduction
- $Q^2 > 1$ GeV^2 Deep Inelastic Scattering

Multiplicity studies – characteristics of events

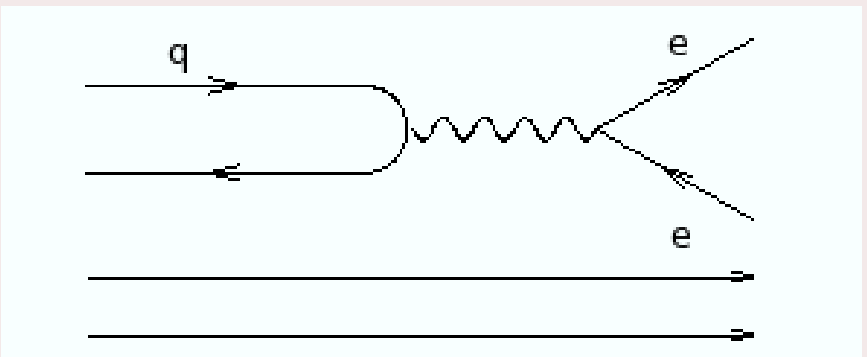


Appropriate frame of reference

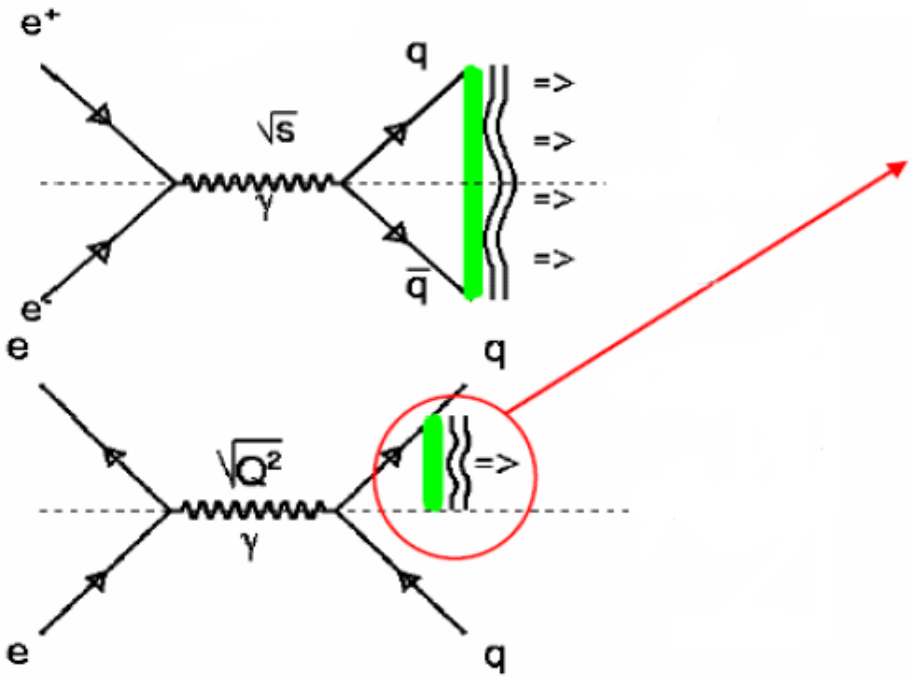
– Hadronic Center of Mass HCM
– Breit Frame

The Breit frame is defined by two conditions:

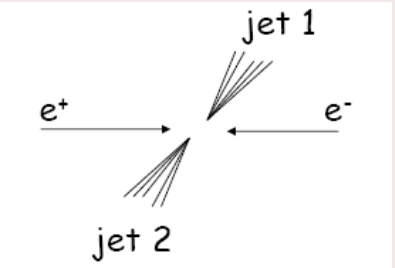
– proton and virtual photon are moving collinearly;
– virtual photon doesn't carry the energy, only momentum.

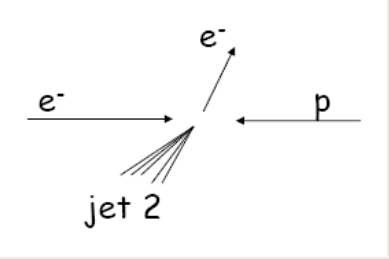


Comparison ep and e^+e^-

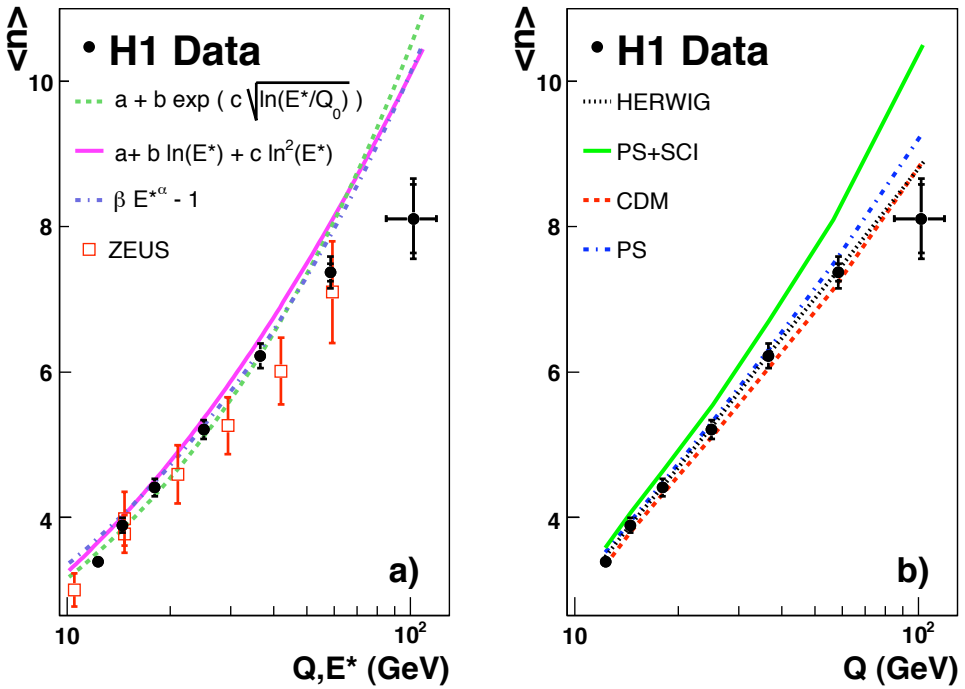


Current region in the Breit frame in ep is similar to one hemisphere in e^+e^-.





Multiplicity distributions in DIS



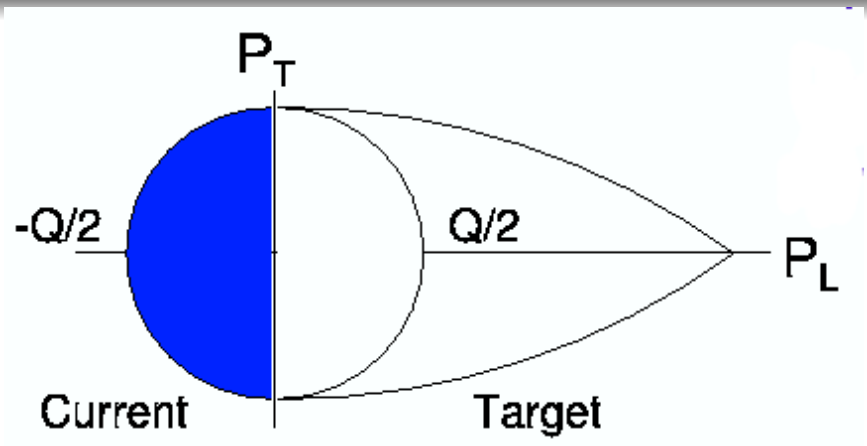
agreement with ZEUS data and parametrisations from e^+e^-
logarithmic energy dependence of average charged multiplicity

Scaled momentum spectra

Definitions

$$x_p = \frac{2P^{Breit}}{Q}$$

$$\xi = \ln(\frac{1}{x_p})$$



Momentum space in the Breit frame

- x_p is the particle momentum measured in the Breit frame scaled by $\frac{Q}{2}$ so by max available momentum (effects connected with internal k_T of quark in proton are ignored)

QCD predictions for x_p distributions are based on:
$f(x, Q^2) \otimes \sigma_{NLO} \otimes D(x_p, Q^2)$

MLLA QCD model

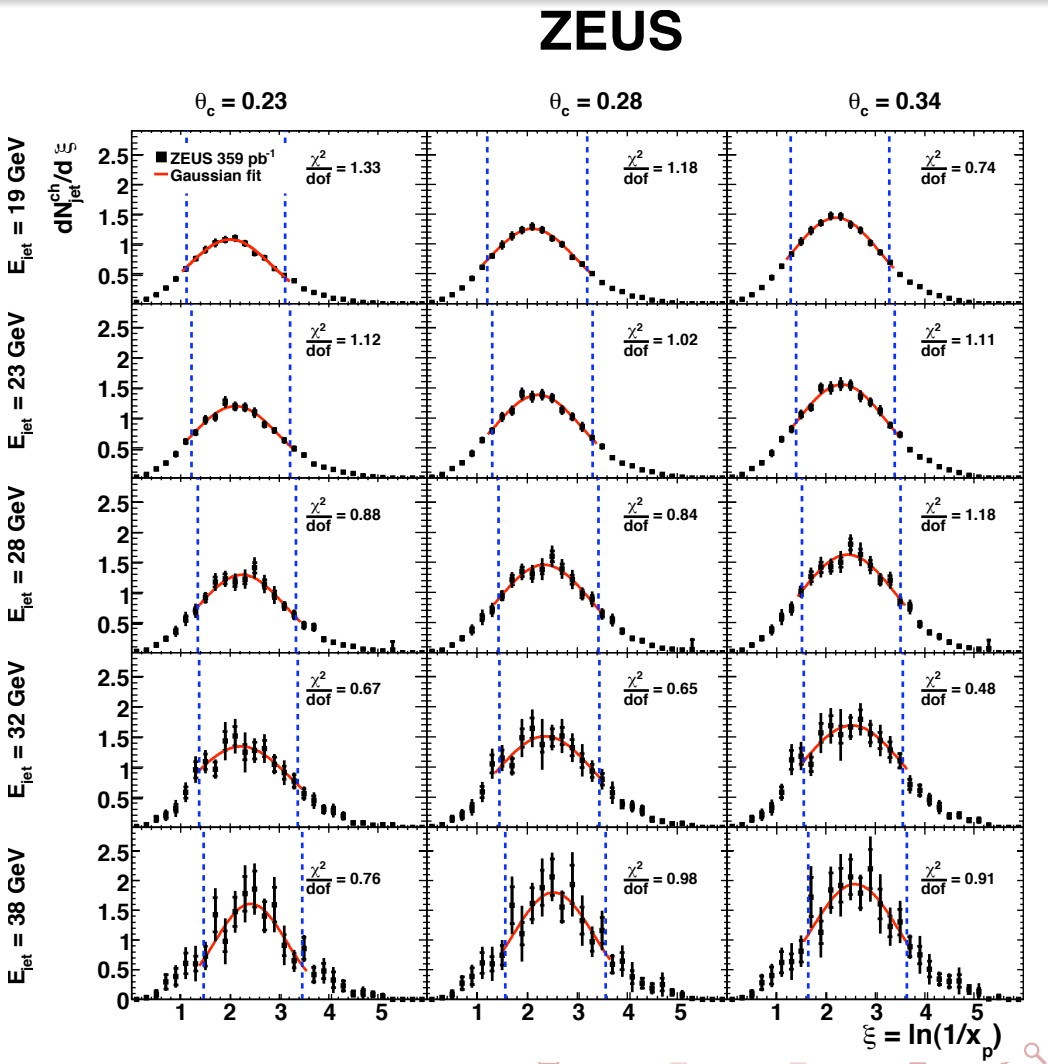
- Modified Leading Log Approximation (MLLA):
  – describes parton production in terms of a shower evolution
  – includes colour coherence and gluon interference effects
- According to MLLA predictions, the function $D(\xi(x_p))$ is roughly Gauss distribution.
- LEP data have been fitted with 2 free parameters: $\Lambda_{eff} = Q_0$ and K_h.
- **From LEP I – LEP II fits:**
  – $\mathbf{\Lambda_{eff} = 270 \pm 20\ MeV}$
  – $\mathbf{K_h = 1.31 \pm 0.03}$
  V.Khoze, S.Lupia, W.Ochs (Phys.Lett. B386 (1996) 451-457)

Photoproduction in ZEUS analysis

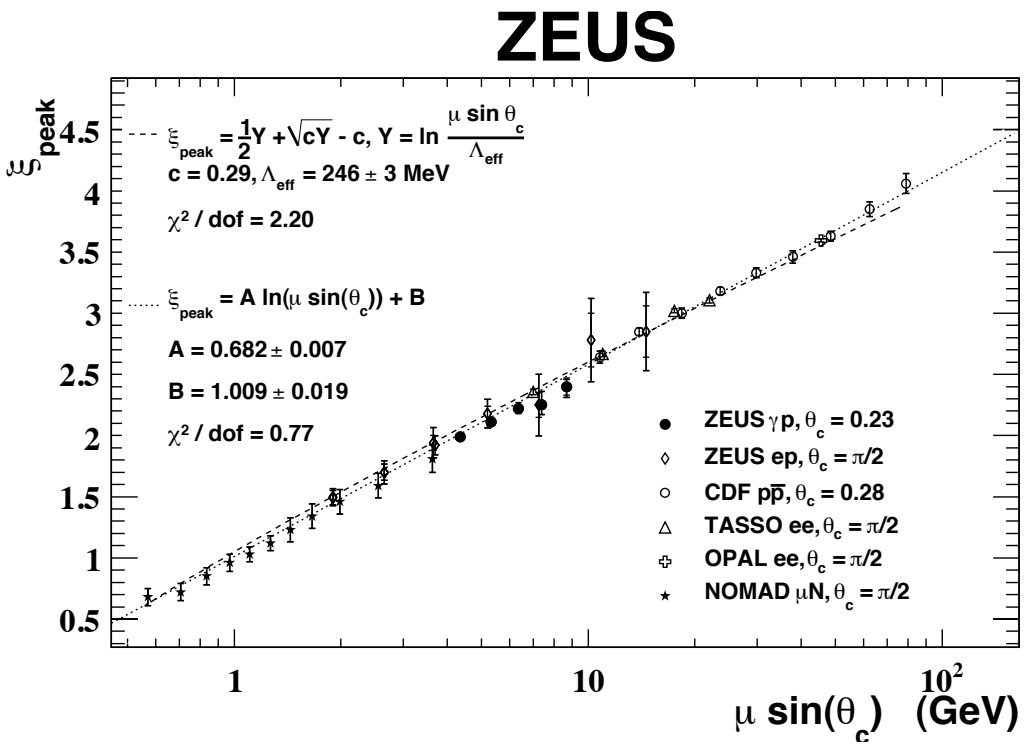
- only two reconstructed jets events
- energy scales in the range 19 to 38 GeV

Extraction of Λ_{eff}

- fit gaussian distribution ± 1 around the arithmetic mean of the ξ distribution
- fit dependence of the peak position on energy scale

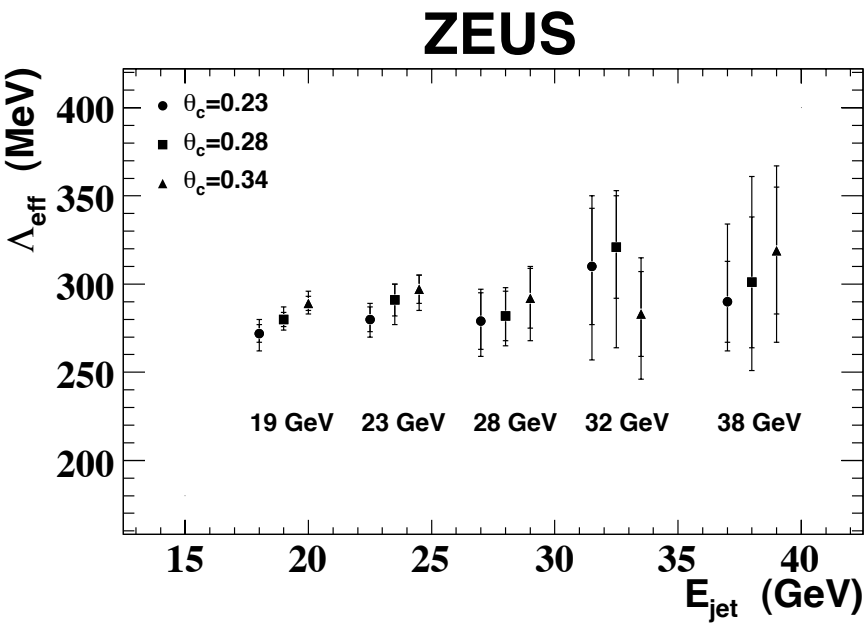


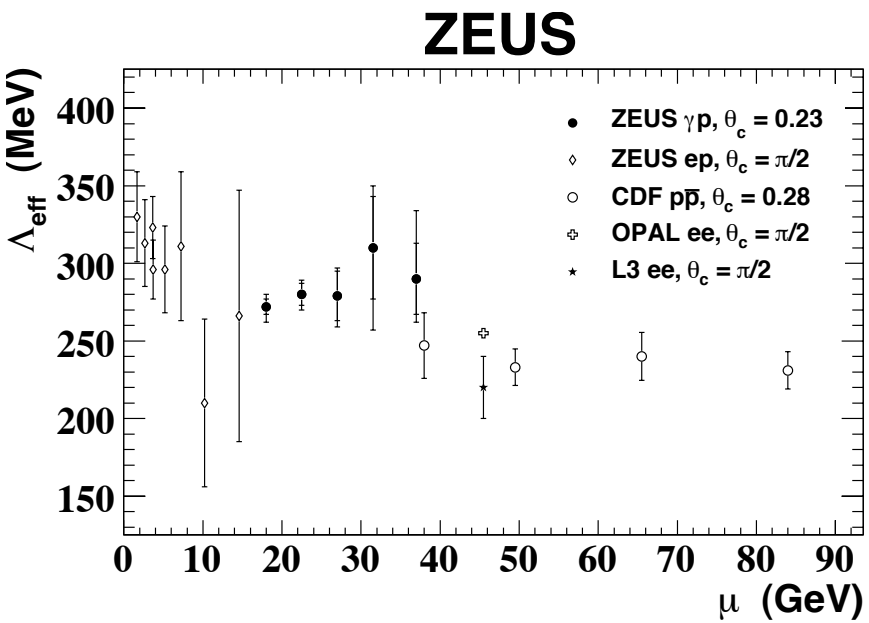
Scaled momentum studies – Λ_{eff} extraction



Extraction of Λ_{eff}:
fit dependence of the peak position on energy scale

$$\Lambda_{eff} = 275 \pm 4(stat.)^{+4}_{-8}(syst.)\ \text{MeV}$$





Λ_{eff} extracted from Gauss

— at 5 E_{Jet} points using 3 θ_c values
— Λ_{eff} has a weak dependence on θ_c,
— no dependence on E_{Jet} is observed

Λ_{eff} as a function of μ

— μ is the energy scale for each process
— ZEUS data fills the gap 19 – 38 GeV
— first measurements of Λ_{eff} from γp

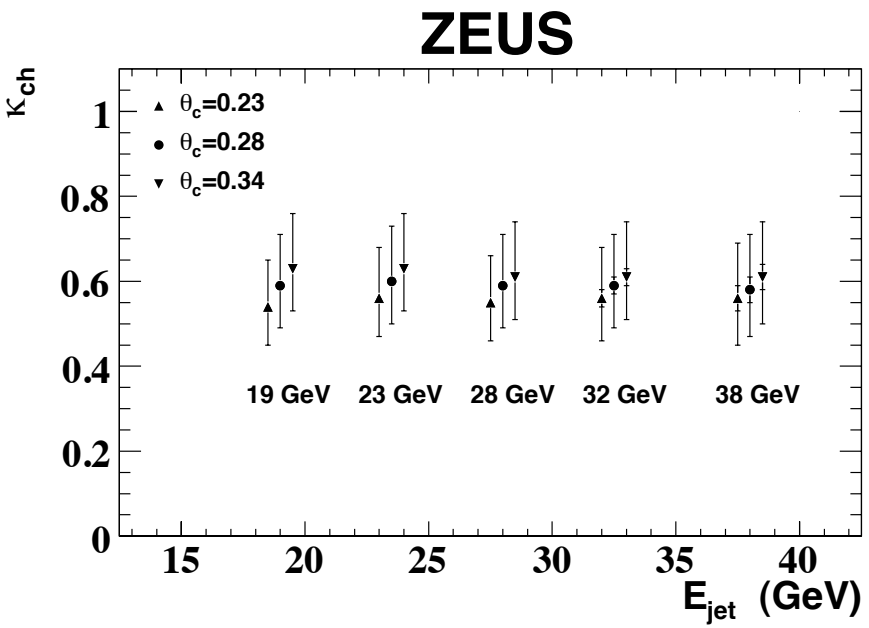
Λ_{eff} and κ_{ch} measurements

MLLA fit method

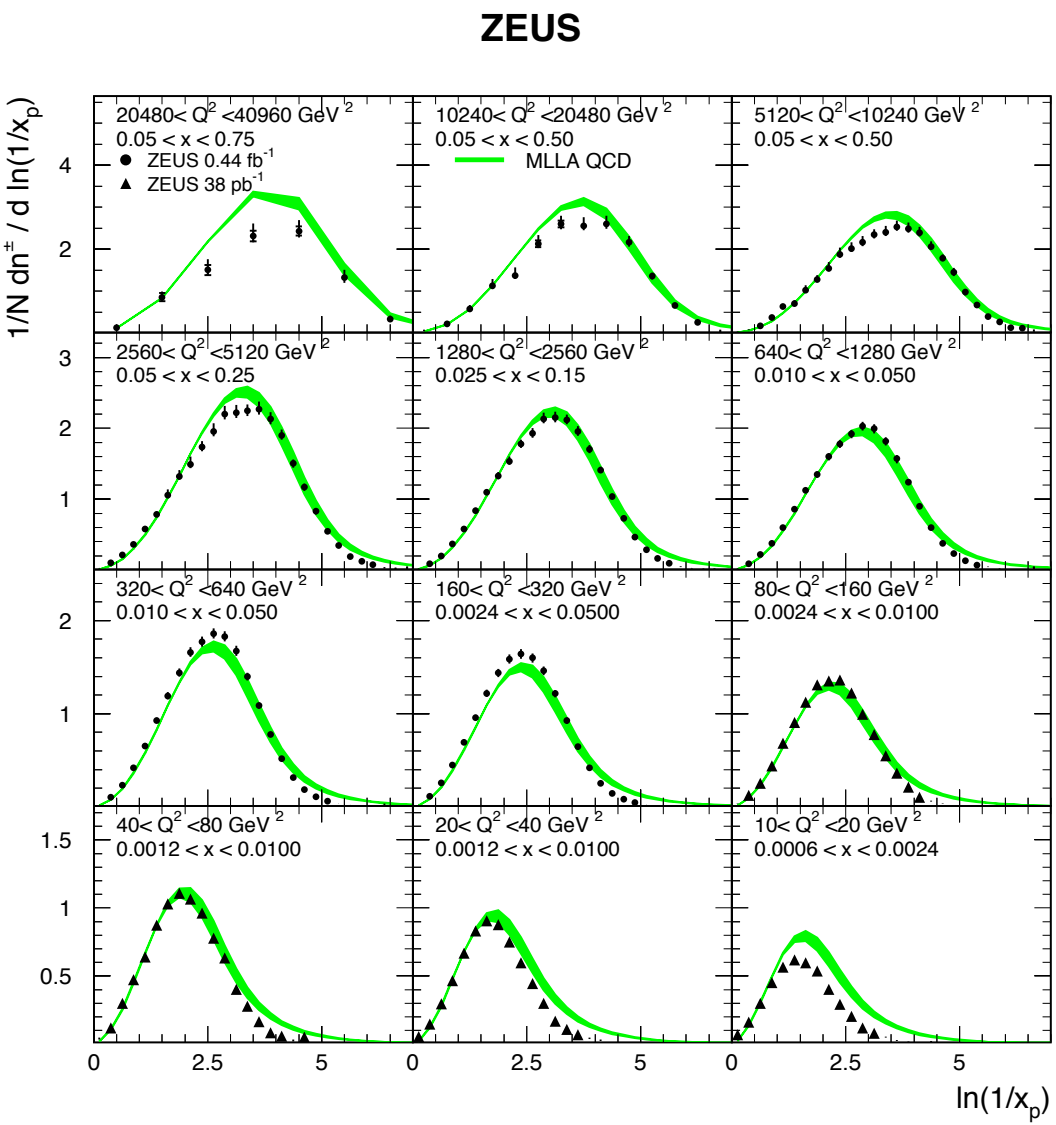
— for $\theta_c = 0.23$ and averaged over E_{Jet}:
$\Lambda_{eff} = 304 \pm 6(stat.)^{+8}_{-32}(syst.)$ MeV

$\kappa_{ch} = 0.55 \pm 0.01(stat.)^{+0.03}_{-0.02}(syst.)^{+0.11}_{-0.09}(th.)$

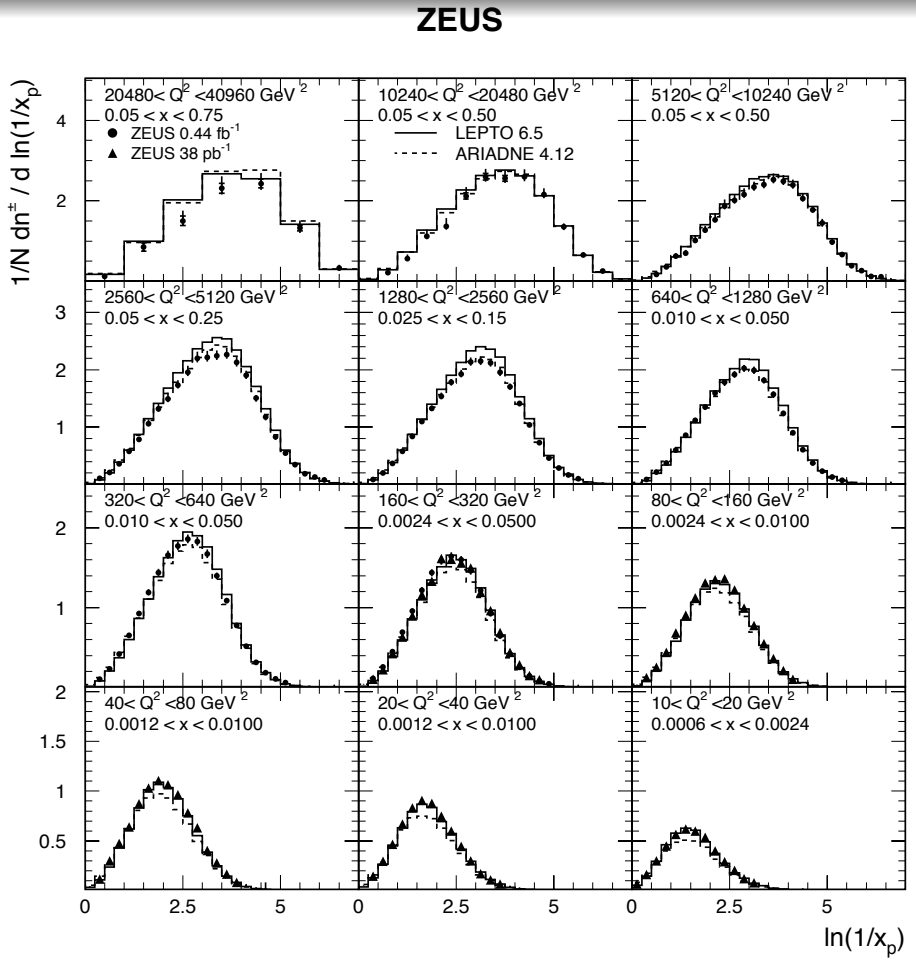
— κ_{ch} has a weak dependence on θ_c
— κ_{ch} is consistent with CDF:
$\kappa_{ch} = 0.56 \pm 0.05(stat.) \pm 0.09(syst.)$
— data support the assumption that
κ_{ch} is universal.

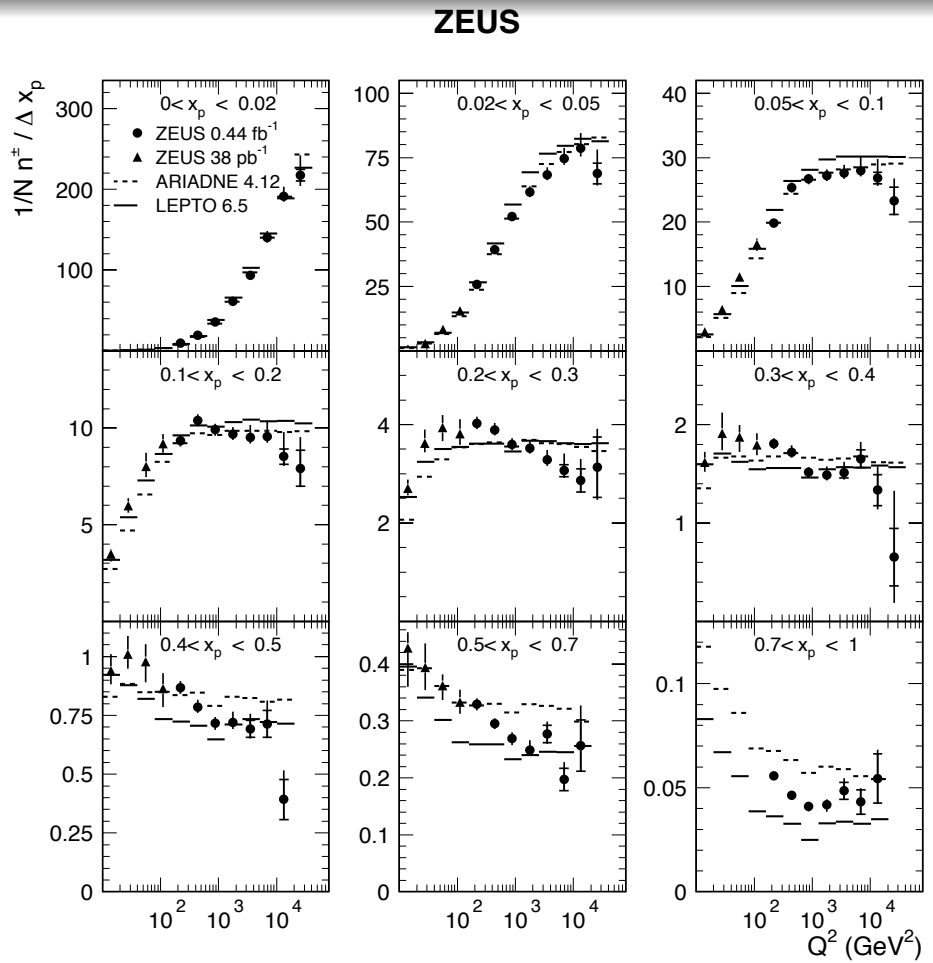


DIS in ZEUS analysis



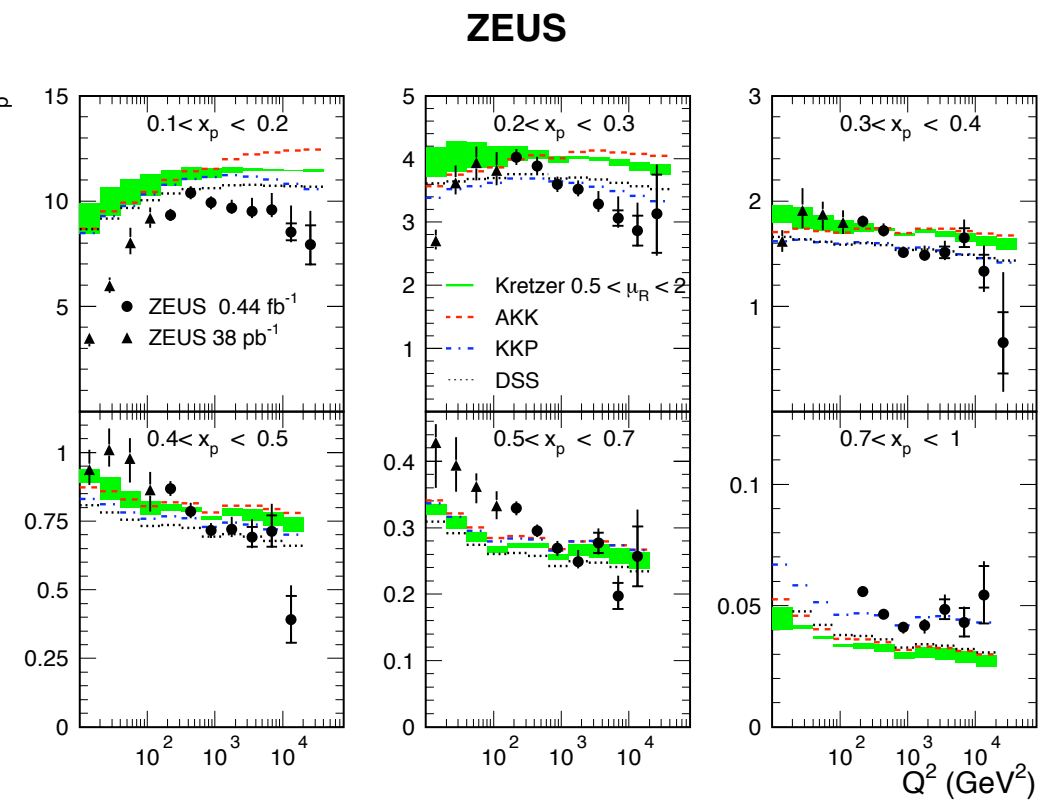
- Parameters used from LEP fits (MLLA + LPHD).
- Λ_{eff} value agrees with the value $\Lambda_{eff} = 275 \pm 4(stat.)^{+4}_{-8}(syst.)$ MeV deduced from a ZEUS analysis of scaled momenta in dijet photoproduction.
- The long tails come from mass corrections.
- low Q^2 – large differences; medium Q^2 – small differences although BGF contribution is big; high Q^2 – large differences again;





The data are not reproduced by LEPTO and ARIADNE in the entire range of Q^2 and x.

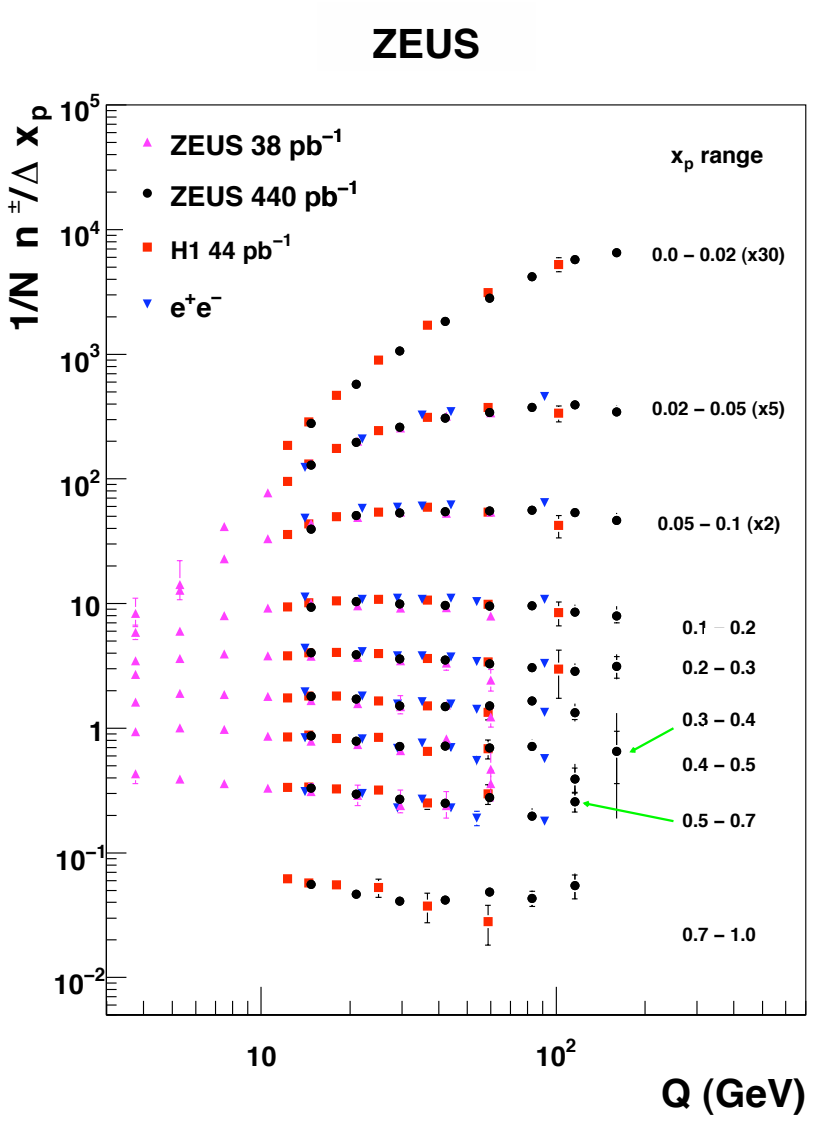
Comparison with Fragmentation Functions



- "Kretzer FF" (2000)
- "KKP FF" (Kniehl, Kramer, Pötter) (2000)
- "AKK FF" (Albino, Kniehl, Kramer) (2005)
- "DSS FF" (De Florian, Sassot, Stratmann)(2007)

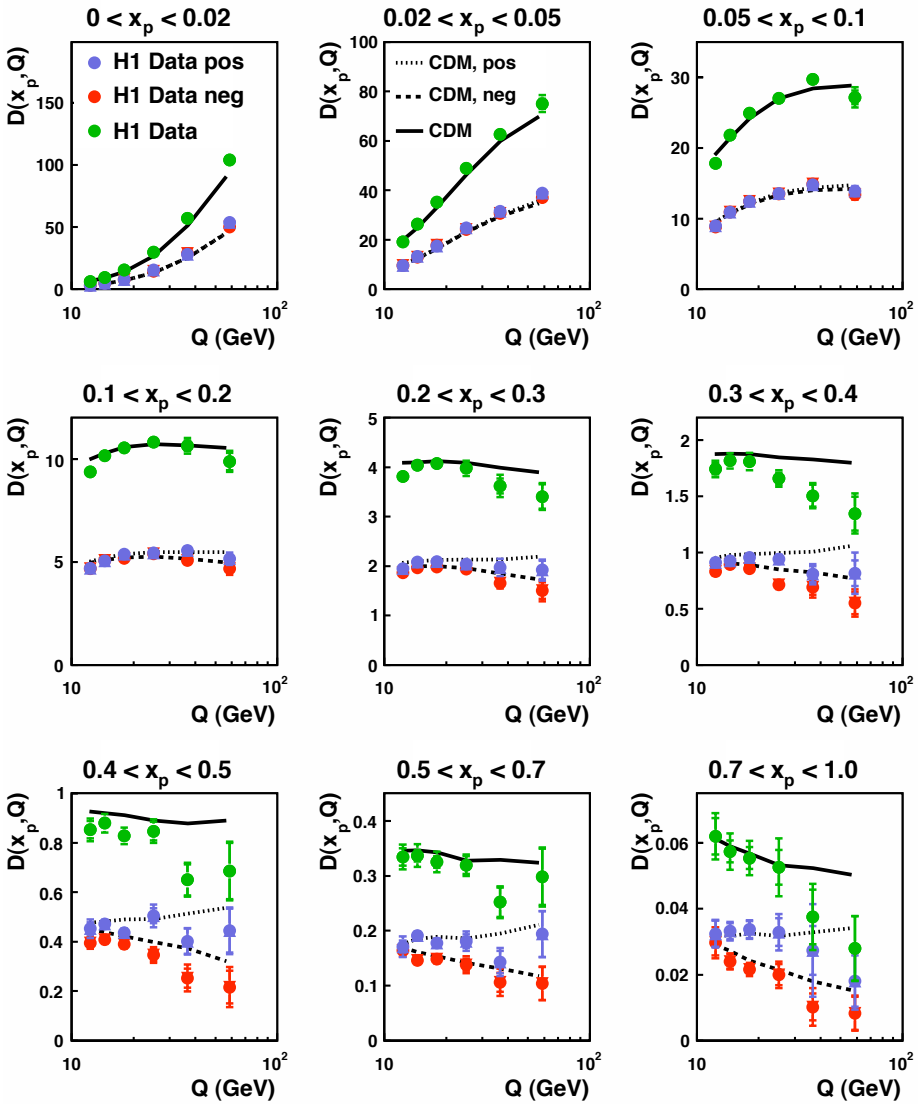
- NLO+FF cannot fully describe the data for the entire x_p range.
- Measured scaling violation larger than predicted.

Scaling violation for ZEUS, H1 and e^+e^- data



- ep data compared with e^+e^- annihilation data and H1 experiment
- the agreement supports fragmentation universality

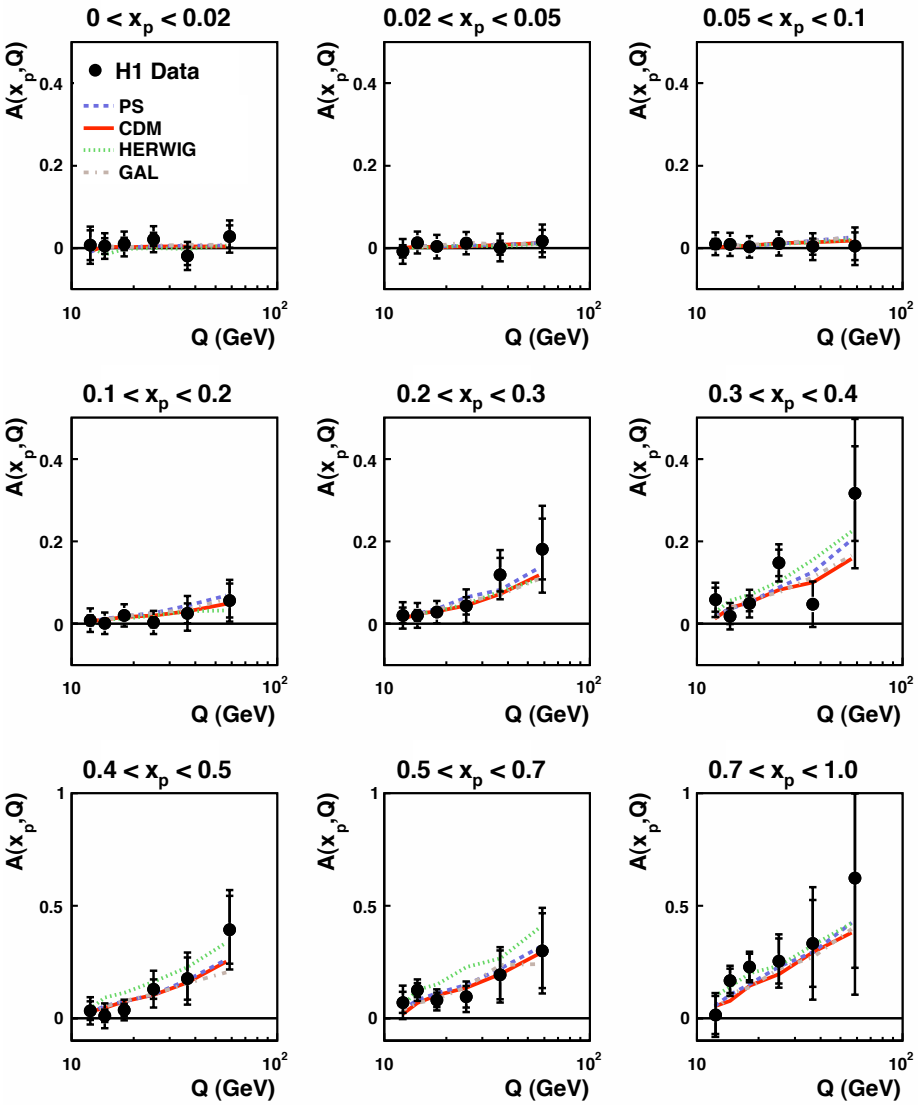
Hadronic final state charge asymmetry



H1 experiment

- differences between negative and positive particles exp. for higher x_p
- the asymmetry is directly related to the valence quark content of the proton
- data well described by MC
- largest $A(x_p, Q) \approx 0.4$ in the highest Q and x_p intervals

Hadronic final state charge asymmetry



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Inclusive photoproduction of ρ^0, K^{*0} and ϕ Meson

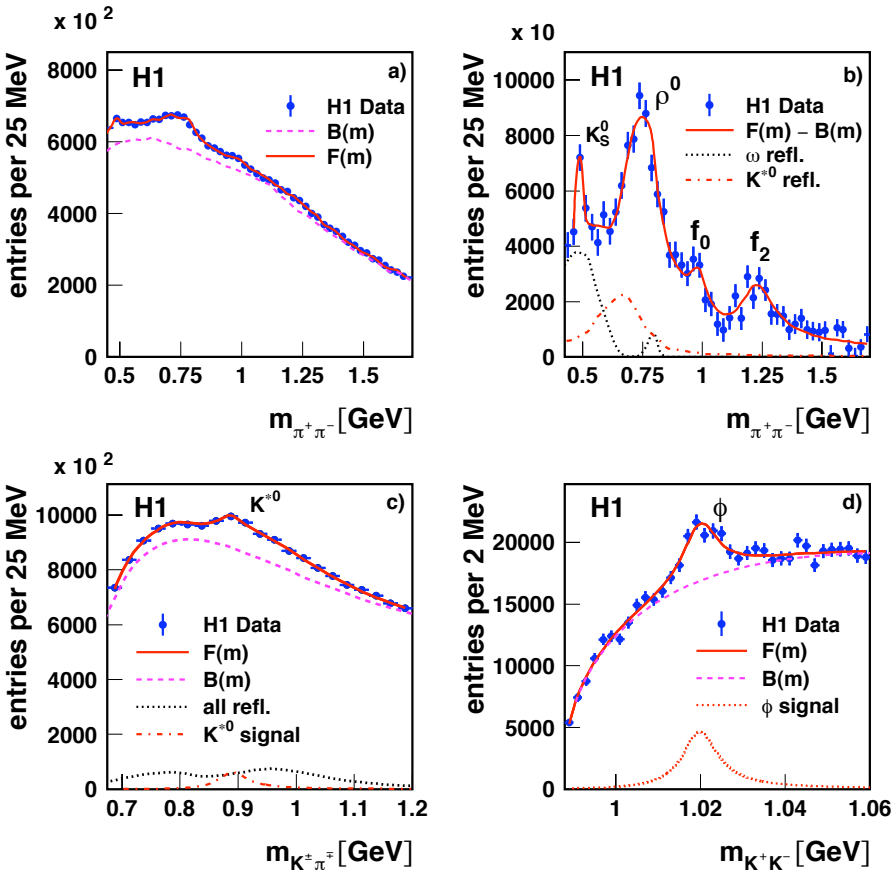
Main selection criteria for photoproduction events:

- H1 data for inclusive non-diffractive photoproduction events
- $\rho^0(770), K^{*0}(892), \phi(1020)$ mesons production

Meson identification

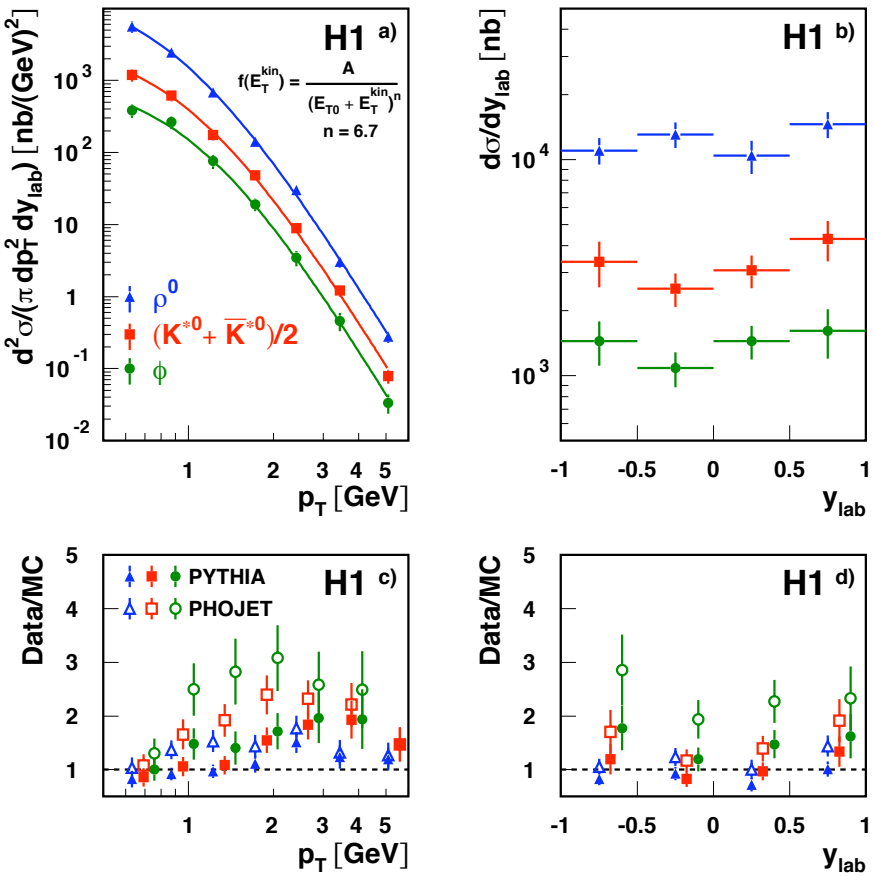
$\rho^0 \to \pi^+\pi^-$ $\quad$ $K^{*0} \to K\pi$ $\quad$ $\phi \to K^+K^-$

ρ^0, K^{*0} and ϕ signals



- clear signals for mesons are observed
- Fit function:
  F(m) = S(m) + R(m) + B(m), where
  — S(m) is signal
  — R(m) is reflection
  — B(m) is comb. background

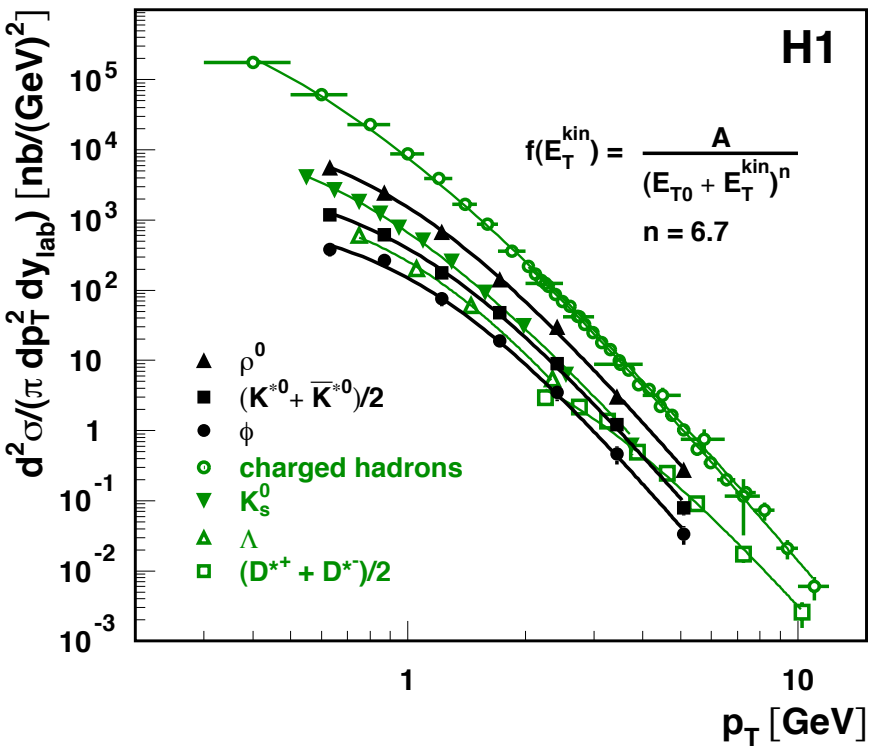
ρ^0, K^{*0} and ϕ differential cross sections



PHOJET10: DPM
PYTHIA6.2: LO QCD ME with PS and Lund string model

— models do not describe the shape of the measured p_T spectrum

ρ^0, K^{*0} and ϕ p_T distributions



the invariant cross section expressed as a function of meson's p_T and its rapidity y_{lab}
data well described by parametrisation with a power law distribution

Summary

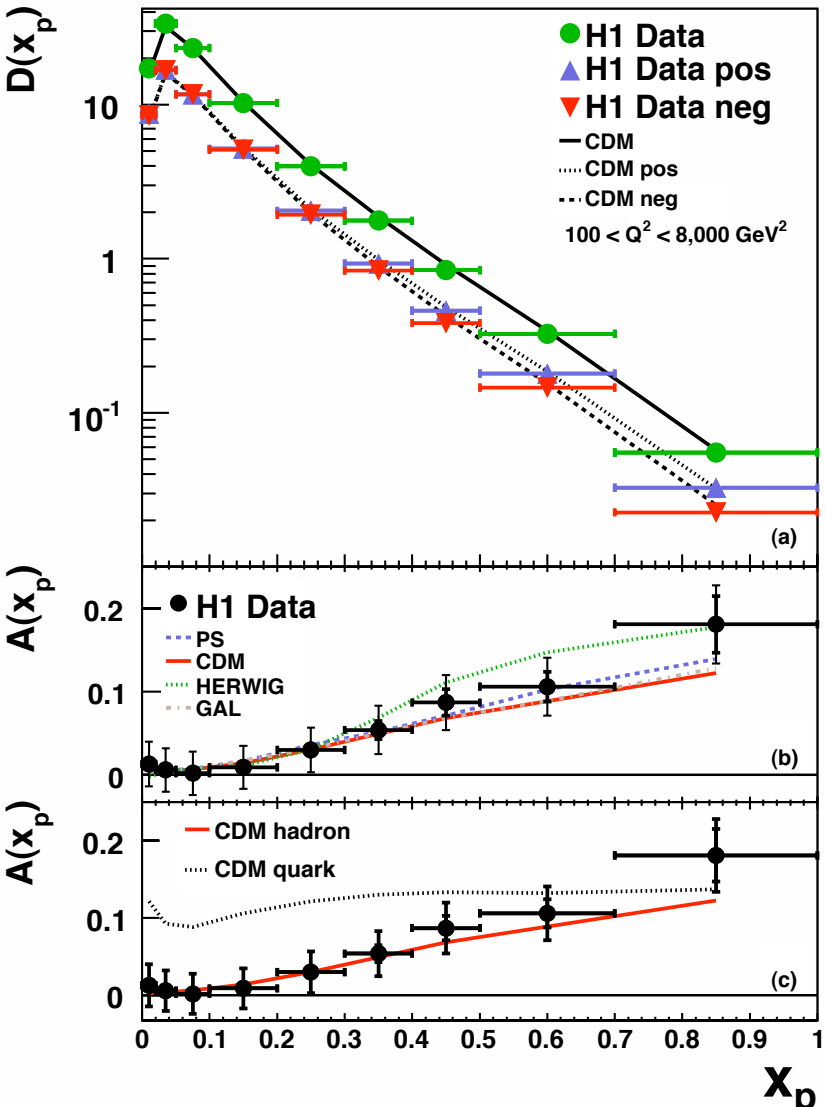
- **Multiplicities in NC DIS**
  - average charged multiplicity scaling with the energy
- **Scaled momentum studies**
  - scaled momentum spectra were measured for $0 < Q^2 < 41000$ GeV^2
  - Λ_{eff} and κ_{ch} were extracted
  - observation of the hadronic final state charge asymmetry
- **Spectroscopy**
  - first measurements of the inclusive non-diffractive photoproduction of $\rho(770)^0$, $K^*(892)^0$ and $\phi(1020)$ mesons

Conclusions

- HERA provides with high precision measurements of multiplicity and momentum spectra in wide kinematical range.
- Theoretical calculations and MC simulations give qualitative description of the data, but they can not describe the data in all details.
- Full understanding of particle production at HERA can be very useful for LHC studies.

Thank you for your attention

Hadronic final state charge asymmetry



CDM before and after hadronisation. Hadrons at low x_p are dominantly produced by fragmentation while hadrons at high x_p retain the memory of the charge of the scattered quark from hard interaction.
Sea quarks and gluons will produce a charge symmetric hadronic final state.