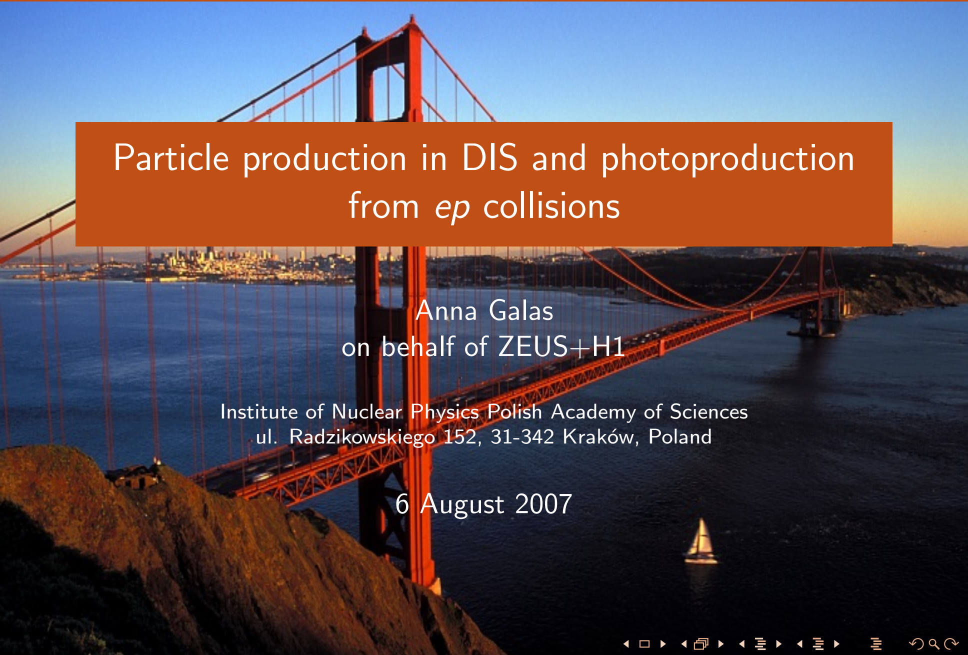

Particle production in DIS and photoproduction from *ep* collisions

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6 August 2007

Presented results

Measurement of K^0_S, Lambda, Antilambda Production at HERA

hep-ex/0612023, European Physical Journal C 51 (2007) 1-23

Bose-Einstein Correlations of Charged and Neutral Kaons in Deep Inelatsic Scattering at HERA

hep-ex/0706.2538, published online in Physics Letters B

Charged Particle Production in High Q^2 Deep Inelastic Scattering at HERA

hep-ex/0706.2456, submitted to Physics Letters B

ep collisions at HERA

$ep \rightarrow e'X$ collisions at HERA give informations about soft and hard processes.

@ HERA:

$e^{\pm}$ $(27.6\ GeV) + p\ (820/920\ GeV)$

$\sqrt{s} = \sqrt{4E_eE_p} = 300/318\ GeV$

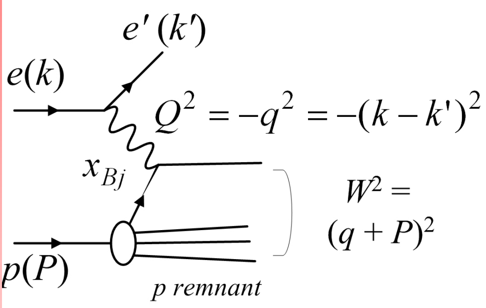
where E_e, E_p are energies of e and p beams.

Tha data presented here were taken during: 1996-2000 ($L = 121\ pb^{-1}$) using ZEUS and in 2000 ($L = 44\ pb^{-1}$) using H1 detector.

Soft QCD processes @HERA can be measured using:

- hadronization (DIS) $Q^2 > 1\ GeV^2$
- photoproduction (PHP) $Q^2 \sim 0\ GeV^2$

DIS kinematic variables for $ep \rightarrow e'X$



P/k the initial-state four momenta of the proton and electron/positron

$s = (P+k)^2$ the cms energy squared of the ep system

$W = (P+q)^2$ the cms energy of the γ^* virtual-photon-proton system

DIS processes:

- $ep \rightarrow e'X$ (Neutral Current) - exchange γ^*, Z^0
- $e^+(e^-)p \rightarrow \nu(\bar{\nu})X$ (Charged Current) - exchange W^+, W^-

where X - hadronic final state

The photon virtuality Q^2 and Bjorken variables are defined as:

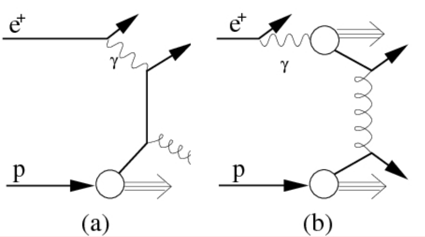
$$Q^2 = -q^2 = -(k-k')^2$$

$$x_{B_J} = \frac{Q^2}{2P\cdot q} \qquad y_{B_J} = \frac{P\cdot q}{P\cdot k}$$

$$Q^2 = s\cdot x_{B_J} y_{B_J}$$

Photoproduction processes

PHP processes are characterized by quasi-real exchange photon, γ, and very small four-momentum-transfer: $Q^2 \sim 0 \ GeV^2$



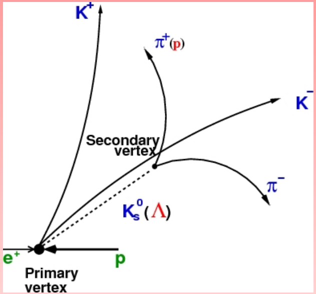
Examples of leading order diagrams in PHP: (a) direct PHP and (b) resolved PHP.

- direct PHP - γ interacts directly with a parton in the proton
- resolved PHP - γ behaves as a source of partons, one of which takes part in the interaction with the proton

$$x_\gamma^{OBS} = \frac{\sum_{jets} E_T^{jet} e^{-\eta^{jet}}}{2 y_{J_B} E_e}$$

- $x_\gamma^{OBS} = 1$ direct PHP
- $x_\gamma^{OBS} < 1$ resolved PHP

K_S^0, Λ and $\bar{\Lambda}$ identification



Particle	Mass [GeV]	Decay Length [cm]	Main decay
K_s^0	0.497	2.68	π^+, π^-
Λ	1.112	7.89	p, π^-
$\bar{\Lambda}$	1.112	7.89	$\bar{p}$, π^+

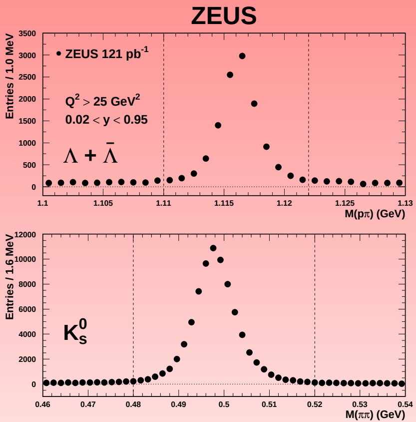
Event requirements:

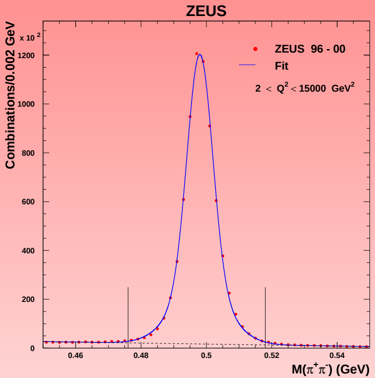
- primary and secondary vertices well separated
- two secondary vertex tracks with opposite charges

Selection criteria:

- $|\eta(K_s^0, \Lambda, \bar{\Lambda})| < 1.2$
- $0.6 < p_T(K_s^0, \Lambda, \bar{\Lambda}) < 2.5\ GeV$
- $M(e^+e^-) > 0.05\ GeV$
- $K_s^0 : M(p\pi) > 1.125\ GeV$
- $\Lambda/\bar{\Lambda} : M(\pi^+\pi^-) < 0.475\ GeV$

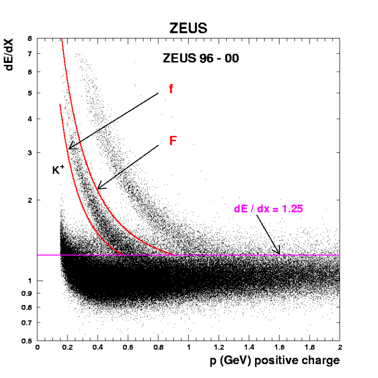
K_S^0 and $\Lambda + \bar{\Lambda}$ signals





- background: $\sim 3\%$ for K_s^0, $\sim$ 6% for $\Lambda + \bar{\Lambda}$
- background: $\sim 4\%$ for K_s^0 BEC
- clear signal, large statistics, low background

$K^{\pm}$ identification



We used different cuts on $\frac{dE}{dx}$ to select charged kaons and minimalize background from pions.

An example of K^+ selection method

- The tracks were accepted if $f < \frac{dE}{dx} < F$, where f, F are functions motivated by Bethe-Bloch equations:
  $$\left.\begin{aligned} f &= \frac{0.08}{p^2} + 1 \\ F &= \frac{0.17}{p^2} + 1.03 \end{aligned}\right\} \text{for } K^+$$
  where p is the total track momentum.
- $\frac{dE}{dx} > 1.25$ to minimize background from π
- $p < 0.9\ GeV$ to compromise between purity and momentum range (trouble in particle separation for large p)

K_s^0, Λ and $\bar{\Lambda}$ cross-sections

The cross-section were calculated in the following kinematic regions:

- $Q^2 > 25\ GeV^2$ and $0.02 < y_{B_J} < 0.95$
- $5\ GeV^2 < Q^2 < 25\ GeV^2$ and $0.02 < y_{B_J} < 0.95$

$\Bigg\} + \begin{array}{l} |\eta^{K_s^0,\Lambda,\bar{\Lambda}}| < 1.2 \\ 0.6 < p_T^{K_s^0,\Lambda,\bar{\Lambda}} < 2.5\ GeV \end{array}$

- $1\ GeV^2 < Q^2$ and $0.02 < y_{B_J} < 0.85$ (PHP)

$\Big\} + \begin{array}{l} |\eta^{jet}| < 2.4 \\ E_T^{jet} > 5\ GeV \end{array} + 2\ jets$

$$\frac{d\sigma}{dY}^{K_s^0,\Lambda,\bar{\Lambda}} = \frac{N}{A \cdot \alpha \cdot B \cdot \Delta Y}$$

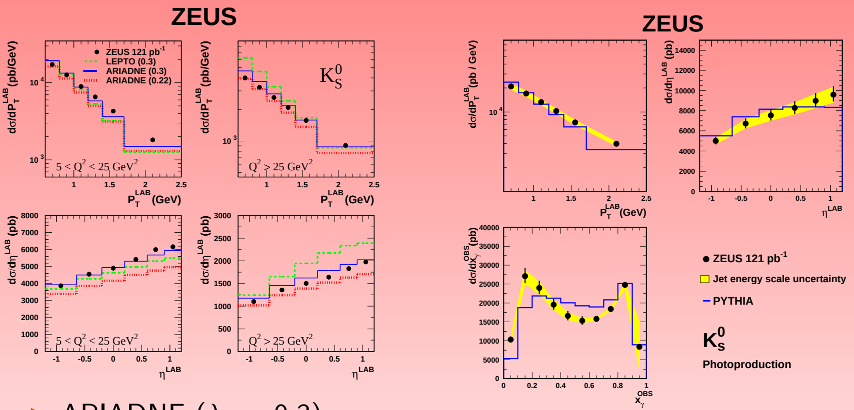
where:

N - number of $K_s^0, \Lambda, \bar{\Lambda}$ in a bin of width ΔY, α - luminosity, A - acceptance and B - branching ratio

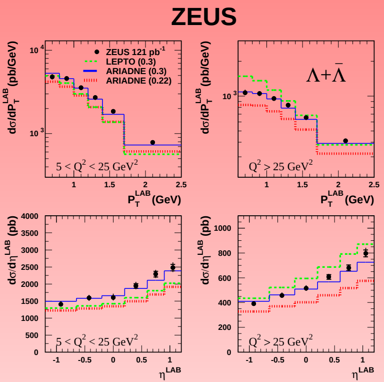
The differential cross-sections were measured as functions of:

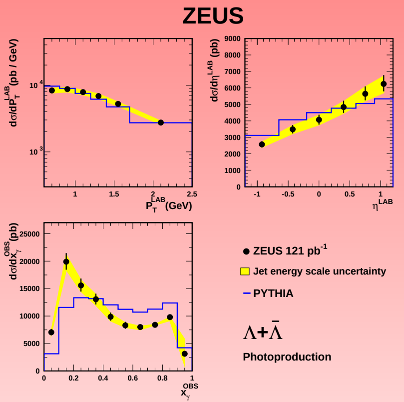
- DIS: $p_T^{K_s^0,\Lambda,\bar{\Lambda}}$, $\eta^{K_s^0,\Lambda,\bar{\Lambda}}$, x_{B_J}, Q^2
- PHP: $p_T^{K_s^0,\Lambda,\bar{\Lambda}}$, $\eta^{K_s^0,\Lambda,\bar{\Lambda}}$, x_γ^{OBS}

Differential K_s^0 cross-sections



- ARIADNE ($\lambda_s = 0.3$) describes data reasonably well
- ARIADNE ($\lambda_s = 0.22$) and LEPTO describe the data less satisfactory
- PYTHIA describes the data well

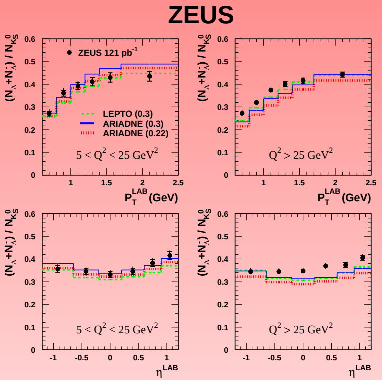


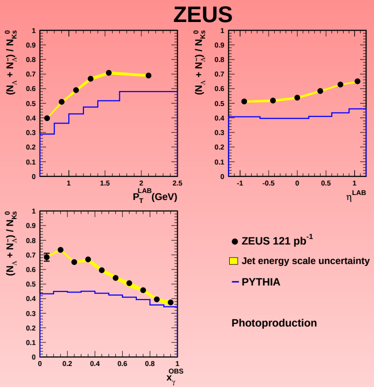


- ARIADNE ($\lambda_s = 0.3$) describes the data reasonably well
- ARIADNE ($\lambda_s = 0.22$) and LEPTO do not describe the data well

- PYTHIA describes the data well

Baryon to meson ratio





- ARIADNE ($\lambda_s = 0.3$) follows the shape of the data
- Baryon to meson ratio increases at low x_γ^{OBS} up to 0.7, not predicted by PYTHIA
- For $x_\gamma^{OBS} = 1$, same baryon to meson ratio as in DIS and e^+e^-

BEC between $K_s^0 K_s^0$ and $K^\pm K^\pm$

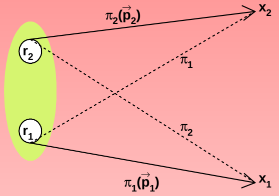
Bose-Einstein effect is an enhancement in the production of identical bosons with similar momenta.

BE effect is related to the time-space characteristic of the particle emission source.

In experiment: $\boxed{R(Q_{12}) = \frac{P(Q_{12})}{P_{ref}(Q_{12})}}$

where $Q_{12} = \sqrt{-(p_1 - p_2)^2} = \sqrt{M^2 - 4m^2_{boson}}$

Two bosons with momenta $\vec{p_1}$, $\vec{p_1}$ produced at points r_1 and r_2



π_1, π_2 - bosons

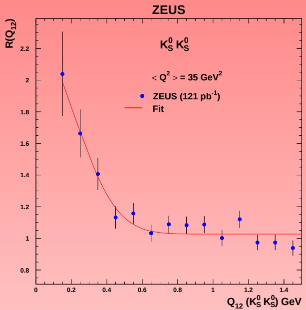
Standard parametrisation of $R(Q_{12})$ is Goldhaber-like parametrisation:

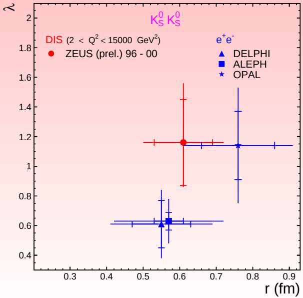
$$\boxed{R(Q_{12}) = \alpha(1 + \lambda e^{-Q_{12}^2 \mathbf{r}^2})(1 + \delta Q_{12})}$$

The correlation function $R(Q_{12})$ is measured using double ratio method:

$$\boxed{R(Q_{12}) = \frac{P(Q_{12})_{data}}{P_{mix}(Q_{12})_{data}} \Big/ \frac{P(Q_{12})_{MCnoBEC}}{P_{mix}(Q_{12})_{MCnoBEC}}}$$

BEC between $K_s^0 K_s^0$





- $96 - 00\ e^{\pm}p$ ZEUS data sample $\Rightarrow L = 121\ pb^{-1}$
- DIS events sample: $2 < Q^2 < 15000\ GeV^2$
- BE effect clearly visible
- r value for $K_s^0 K_s^0$ is similar to $\pi^{\pm}\pi^{\pm}$

$$\left.\begin{aligned} \lambda &= 1.16 \pm 0.29(stat)^{+0.28}_{-0.08}(sys) \\ r &= 0.61 \pm 0.08(stat)^{+0.07}_{-0.08}(sys) fm \end{aligned}\right\} \quad K_s^0 K_s^0 \text{ (ZEUS)}$$

$$\left.\begin{aligned} \lambda &= 0.475 \pm 0.007(stat)^{+0.011}_{-0.003}(sys) \\ r &= 0.666 \pm 0.009(stat)^{+0.022}_{-0.036}(sys) fm \end{aligned}\right\} \quad \pi^{\pm}\pi^{\pm} \text{ (ZEUS)}$$

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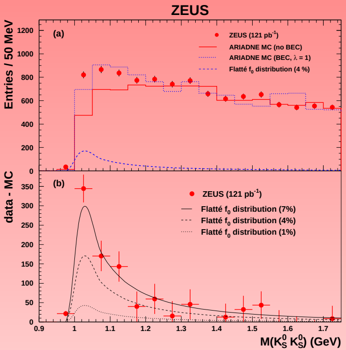
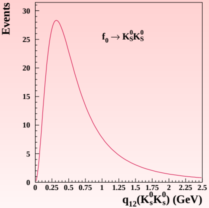
- good agreement with LEP for r
- higher λ value than for ALEPH, DELPHI
- the $f_0(980)$ resonance is expected in the same low Q_{12} region where BEC are measured
- small contribution of $f_0(980)$ in data can significantly change λ value

λ corrections for $K_s^0 K_s^0$





- low Q_{12}, $M(K_s^0 K_s^0)$ regions are affected by $f_0(980)$ resonance, not well simulated by ZEUS MC
- the $f_0(980)$ is expected in the same Q_{12} region where BEC are measured
- the shape of the enhancement in data over MC_{noBEC} is well described by Flatté
- the difference between MC_{noBEC} and MC_{BEC} ($\lambda = 1$, $r = 0.45\ fm$) indicates 4% contribution of $f_0(980)$ in data
- using Breit-Wigner distribution we subtracted 4% contribution of $f_0(980)$ from data sample

$$\left.\begin{array}{l}\lambda = 0.70 \pm 0.19(stat)^{+0.28}_{-0.08}\ ^{+0.38}_{-0.52}(sys) \\ r = 0.63 \pm 0.09(stat)^{+0.07}_{-0.08}\ ^{+0.09}_{-0.02}(sys) fm\end{array}\right\} \ 4\%\ f_0(980)$$

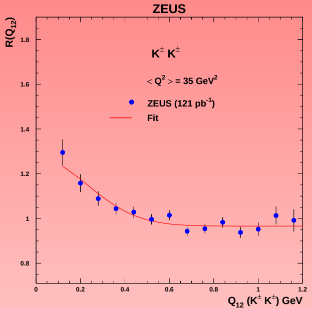
- good agreement with LEP for r
- good agreement with LEP for λ
- ALEPH and DELPHI took into account f_0 contribution in theirs studies

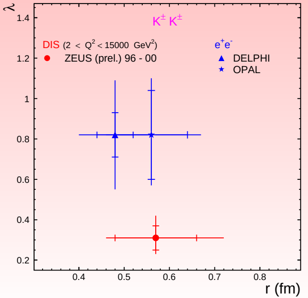
where f_0:
derived from Breita-Wignera distribution proposed by Flatté[a]:

$$\frac{d\sigma}{dm_{KK}} = \frac{N_F \cdot m_0^2 \cdot \Gamma_{KK}}{(m_0^2 - m_{KK}^2)^2 + (m_0 \cdot (\Gamma_{\pi\pi} + \Gamma_{KK}))^2}$$

[a] Phys. Lett. B63 (1976) 224

BEC between $K^{\pm}K^{\pm}$





- $96-00$ $e^{\pm}p$ ZEUS data sample $\Rightarrow L = 121\ pb^{-1}$
- DIS events sample: $2 < Q^2 < 15000\ GeV^2$
- BE effect clearly visible
- r value for $K^{\pm}K^{\pm}$ is similar to $K^0_sK^0_s$ and $\pi^{\pm}\pi^{\pm}$

$$\left.\begin{aligned}\lambda &= 0.37 \pm 0.07(stat)^{+0.09}_{-0.08}(sys)\\ r &= 0.57 \pm 0.09(stat)^{+0.15}_{-0.08}(sys)fm\end{aligned}\right\} \quad K^{\pm}K^{\pm}\ \text{(ZEUS)}$$

$$\left.\begin{aligned}\lambda &= 0.475 \pm 0.007(stat)^{+0.011}_{-0.003}(sys)\\ r &= 0.666 \pm 0.009(stat)^{+0.022}_{-0.036}(sys)fm\end{aligned}\right\} \quad \pi^{\pm}\pi^{\pm}\ \text{(ZEUS)}$$

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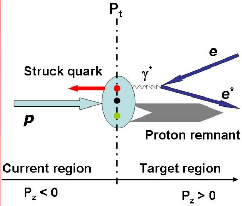
- good agreement with LEP for r
- smaller λ value than for OPAL, DELPHI
- different fragmentation processes in $e^{\pm}p$ (ZEUS) and e^+e^- (ALEPH, DELPHI, OPAL) collisions
- ZEUS data populate mostly proton fragmentation region - we expect proton influence
- high probability that at least one kaon in kaon-pair is produced in $\phi(1020) \rightarrow K^+K^-$ decay - strong signal in data

Charged particles studies in Brait Frame



- separetes struck quark and proton remnant
- $e^{\pm}p$ current region is analogous to one hemisphere of $e^{+}e^{-}$ annihilation
- scaled momentum $x_p = \frac{2 \cdot p_h}{Q}$ in $e^{\pm}p$ current region of Breit Frame (QPM model)

  where p_h - momentum of charged tracks
- in $e^{+}e^{-}$ annihilation $\Rightarrow x_p = \frac{2 \cdot p_h}{E^*}$

scaled momentum distribution $D(x_p, Q) = \frac{1}{N}\frac{dn}{dx_p}$

where:

N - total number of selected events

dn - total number of charged tracks with x_p in the interval dx_p

average charged multiplicity $< n >$

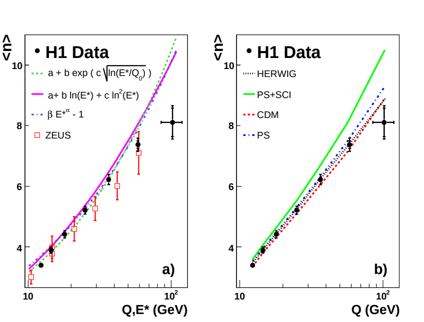
defined as an average number of charged particles in the current region of Brait Frame per event

Charged multiplicity $< n >$

2000 e^+p H1 data sample $\Rightarrow L = 44pb^{-1}$

Charged particle selection

- $100 < Q^2 < 20000\ GeV^2$
- $0.05 < y < 0.6$
- $p_T > 0.12\ GeV$
- $20^o < \theta < 165^o$



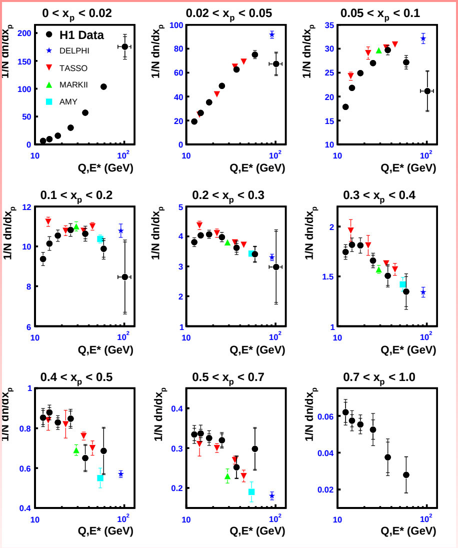
(a)

- the ZEUS results are in agreement with H1
- in low Q region the data are slightly below the e^+e^- parametrisation
- for highest Q the H1 data are clearly below the e^+e^- parametrisation

(b)

- good agreement between different models of hadronisation and parton cascade
- soft colour interactions model overestimates the multiplicity $< n >$

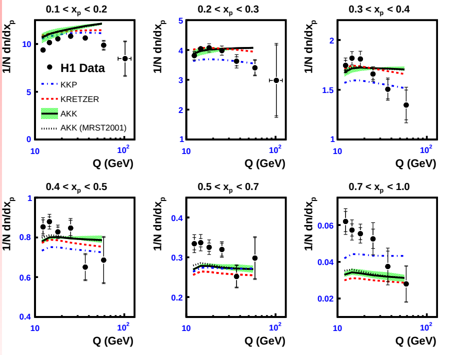
Scaled momentum distribution $D(x_p, Q)$



- quite good agreement between e^+p and e^+e^-
- at low x_p significant increase in the number of hadrons from low to high Q
- at high x_p the number of hadrons decreases with $Q \Rightarrow$ this corresponds with less tracks observed in e^+p data than in e^+e^-
- middle x_p and low Q region affected by high order QCD processes (BGF, ICQCD) which occur as a part of hard interactions in e^+p but not in e^+e^-

Scaled momentum distribution $D(x_p, Q)$

Scaled momentum distribution $D(x_p, Q)$ in comparison with Next-to-Leading order NLO QCD CYCLOPS for three different fragmentation functions obtained from fits to e^+e^- data (KKP, KRETZER, AKK).



- all three fragmentation function parametrisations give diffrent results
- none of them can describe the scaling violations seen in H1 data

Summary

- The measurements of K_s^0, Λ, $\bar{\Lambda}$ production have been made at ZEUS
- In high and low Q^2 DIS, ARIADNE generally describes the cross-sections
- PYTHIA describes cross-sections in PHP well, except the x_γ^{OBS} dependence
- ARIADNE follows the shape of the ratio of baryons to mesons
- The baryon to meson ratio increases up to 0.7 at low x_γ^{OBS}, not predicted by PYTHIA
- The BEC of $K_s^0 K_s^0$ and $K^\pm K^\pm$ were measured and compared to LEP results
- The radius value for $K_s^0 K_s^0$ is consistent with $K^\pm K^\pm$ and with $\pi^\pm \pi^\pm$
- The radius value is compatible with LEP results
- λ value for $K_s^0 K_s^0$ is high due to the $f_0(980)$ influence in low Q_{12} region
- Smaller λ for $K^\pm K^\pm$ in comparison with LEP due to proton influence
- The average charged multiplicity $< n >$ and scaled momentum distribution $D(x_p, Q)$ of charged hadrons at high Q^2 in Breit Frame at H1 and compared with e^+e^- and diffrent MC models
- The results broadly support quark fragmentation universality in e^+p and e^+e^-
- A small multiplicity depletion is observed at low Q due to high order QCD processes occurring as part of hard interaction in e^+p scattering but not in e^+e^- annihilation
- At high Q a large depletion is observed
- NLO fails to describe the scaling violations seen in H1 data