Particle production at HERA

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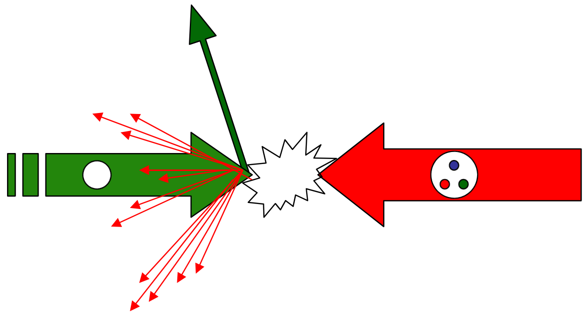
On behalf of H1 and ZEUS Collaborations

- Introduction
- Inclusive neutral strange particle production
- Bose-Einstein correlations between charged/neutral Kaons
- Anti-Deuteron production and a search for heavy stable charged particle
- Azimuthal asymmetry of final hadrons
- Summary

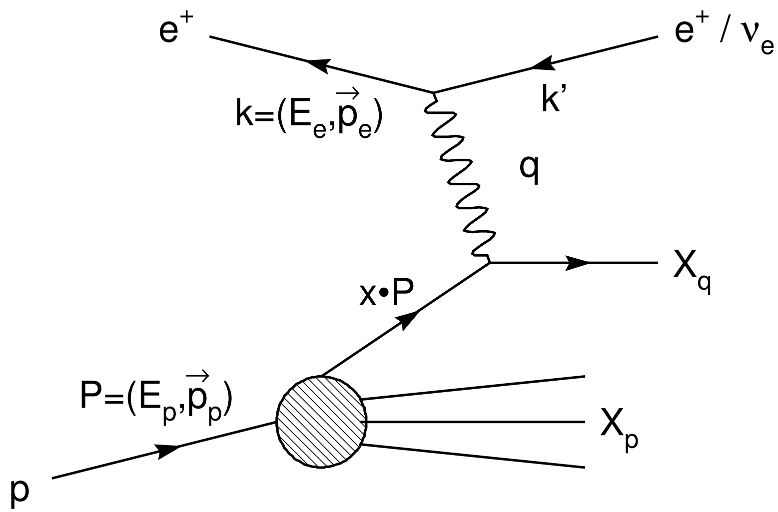
HERA collider

- HERA, ep collider with high enough energy to allow a deeper insight of the nature of the strong interactions and lead to an enriched production of the hadronic final states which makes it a valuable field of studies.



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

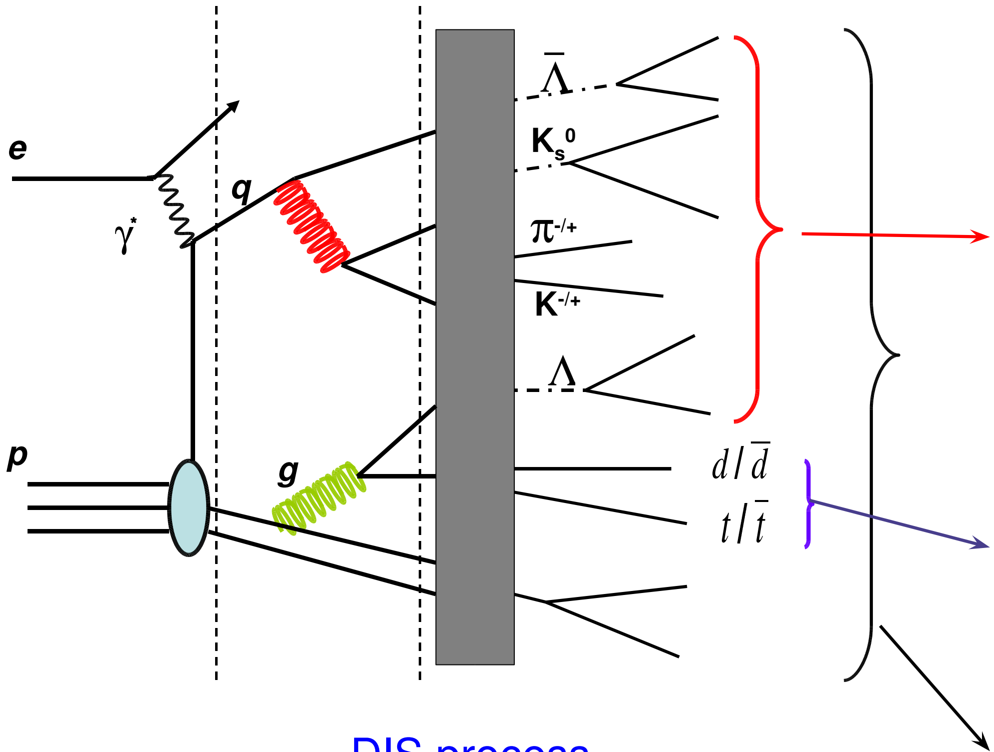
$\sqrt{s}$ = 300 - 318 GeV



- DIS kinematics:

$$q = k - k' \qquad Q^2 = -q^2$$
$$x = \frac{Q^2}{2p\cdot q} \qquad y = \frac{p\cdot q}{p\cdot k}$$

Motivation



DIS process

Can λ_s = 0.3 describe strange particle production in ep as well as in LEP?

$\Lambda/\bar{\Lambda}$ asymmetry, polarisation?

Bose-Einstein effect to explore the space-time characteristic of emission source, mass dependence of the size?

$d/\bar{d}$ and more heavier nuclei production?

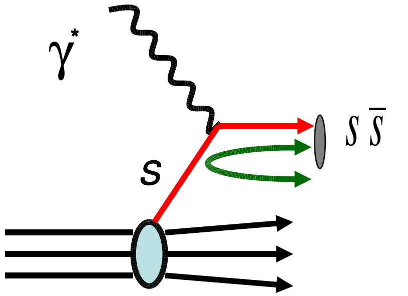
A new method was applied to measure the angular asymmetry of final hadrons?

Neutral strange particle production

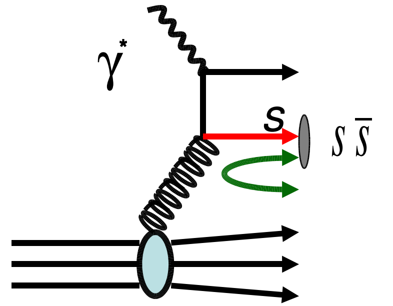
Ref. abstract 366

NOT the Tower of Belem,Lisbon!

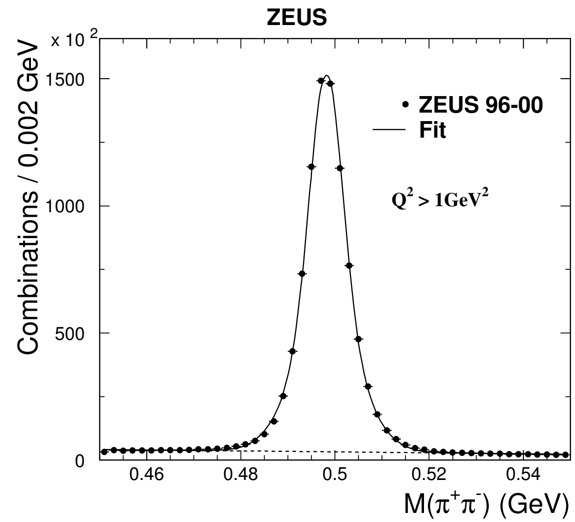
Strange production mechanisms in ep

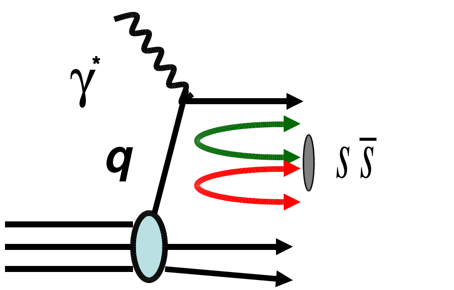


a) Hard scattering of *s* sea quark

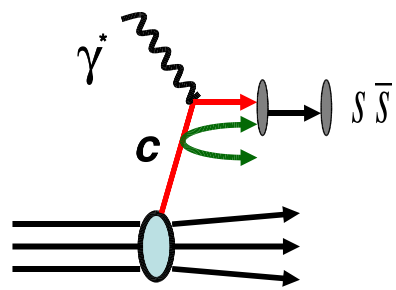


b) Boson-gluon fusion (BGF)

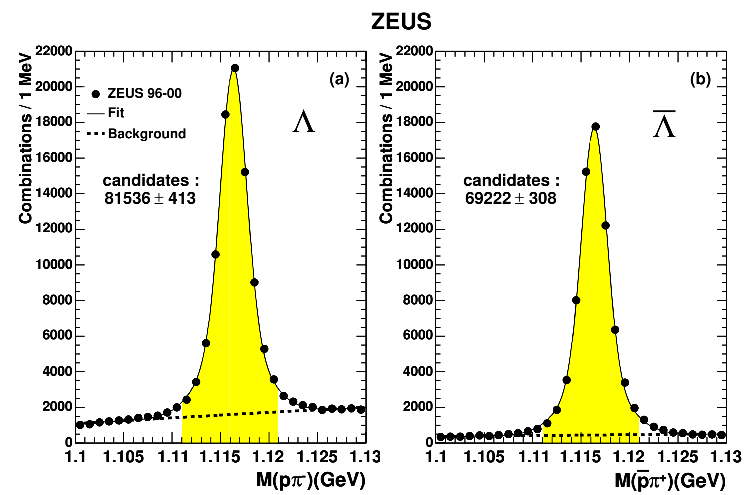




c) Parton pure fragmentation

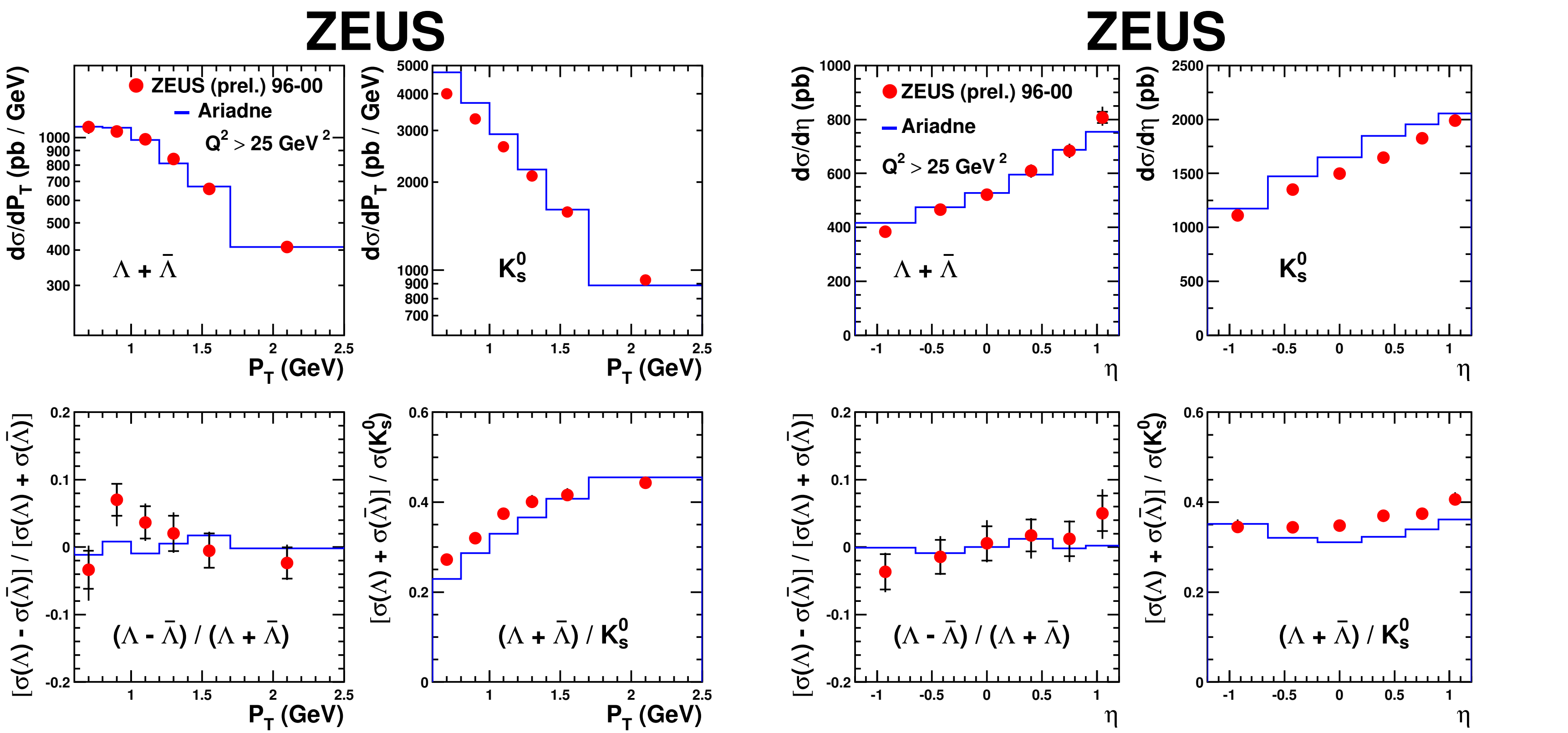


d) Heavy quark decay



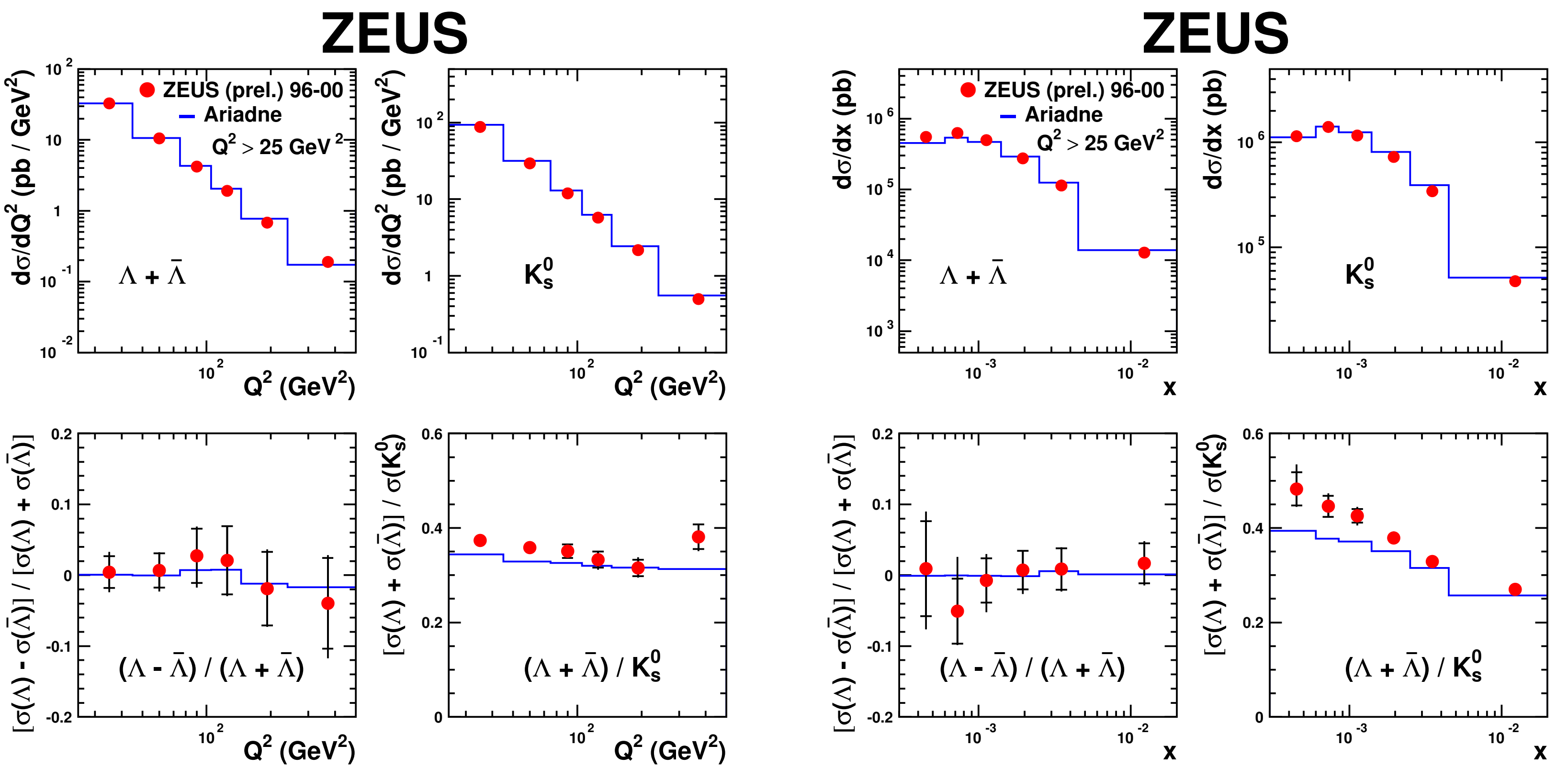
Neutral strange particle production

ZEUS 96-00 data, 120 pb^{-1}, $Q^2 > 25GeV^2$, $0.02 < y < 0.95$, 0.6< P_T <2.5 GeV, | η |<1.2



- Ariadne(CDM) generally describes the data well, but excess is found at lower P_{T} and the whole η region for K_S^0. Smaller λ_s value(0.22)?.
- $\Lambda/\bar{\Lambda}$ asymmetry is consistent with zero.

Neutral strange particle production

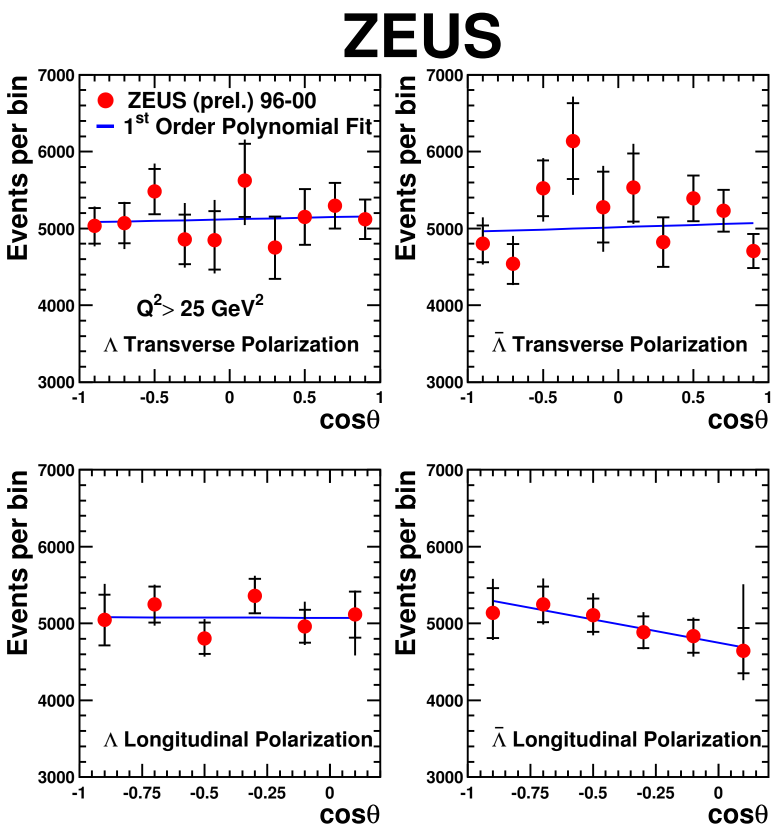


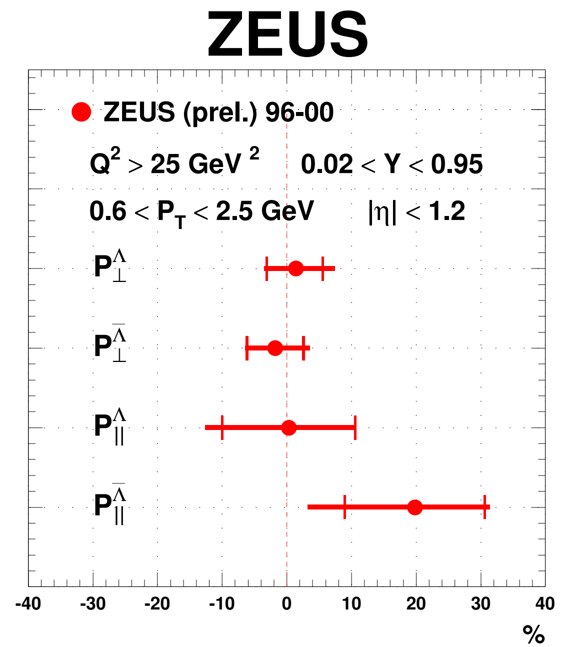
- Ariadne fails to describe the $(\Lambda + \bar{\Lambda})/K_S^0$ in lower-x region.
- No baryon-antibaryon asymmetry was observed

Λ / $\bar{\Lambda}$ polarization

Λ polarisation was measured via the angular distributions of $p(\Lambda \rightarrow p + \pi^-)$ in Λ rest frame.

$$\frac{dN}{dcos\theta} \propto \frac{1}{4\pi}(1 + \alpha P cos\theta) \quad \alpha = 0.642$$





- No Λ and $\bar{\Lambda}$ polarisation (96-00 unpolarised beams)
- HERA II provides longitudinally polarised electron beam, could we see $\Lambda/\bar{\Lambda}$ polarisation?

Bose-Einstein Correlations in DIS

Ref. abstract 368

Bose-Einstein Correlations

- Bose-Einstein effect is an enhancement in the production of identical bosons with similar momenta. A tool to study the space-time structure of the particle source
- Previous ZEUS publication shows BEC is independent of Q^2.
- Correlation function:

$$R(p_1, p_2) = \frac{\rho(p_1,p_2)}{\rho(p_1)\rho(p_2)} = 1 + \mid f(p_1 - p_2) \mid^2$$

$\rho(p_1)$,$\rho(p_2)$ single particle density distribution functions

$\rho(p_1, p_2)$ two particle density distribution function

f(q) is the Fourier transform of the space-time density distribution of the source.

Fit with standard Goldhaber-like function to extract emission source radius r and coherence strength factor λ

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

- Reference sample:

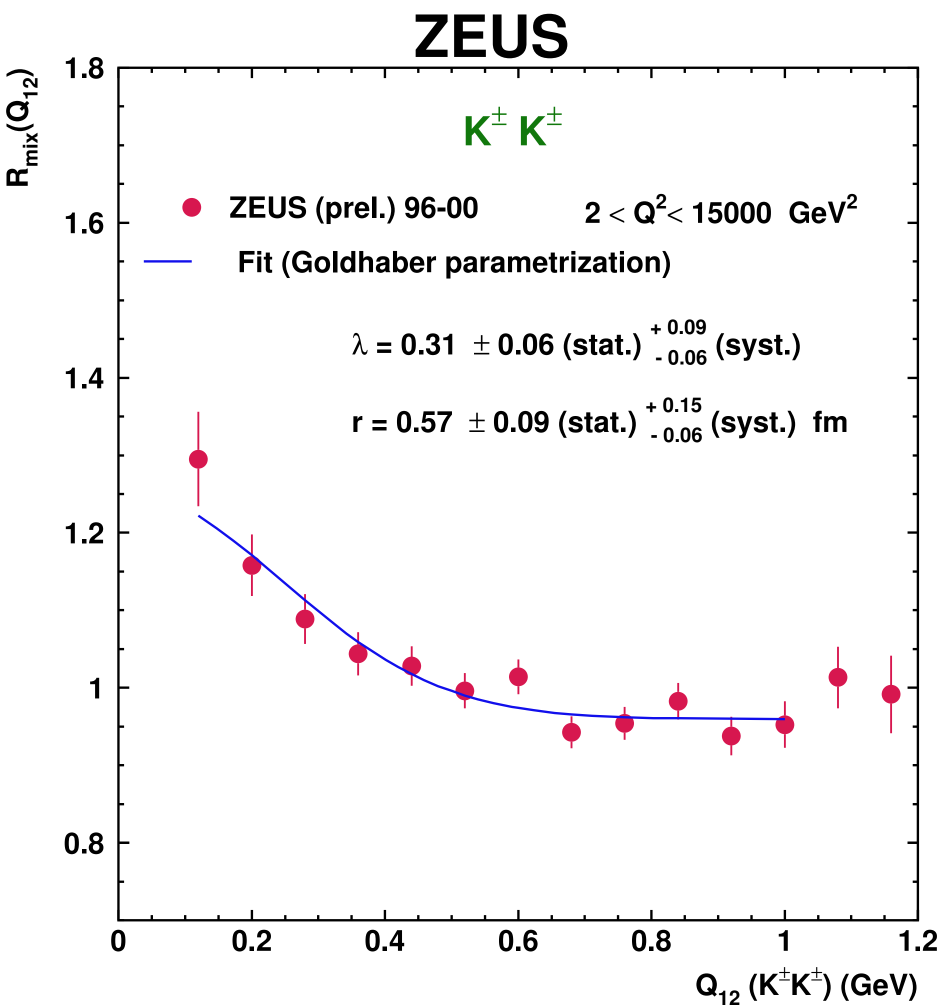
Correlation function $R(Q_{12})$ is measured using double ratio method

$$R(Q_{12}) = \frac{P(Q_{12})^{data}}{P_{mix}(Q_{12})^{data}} / \frac{P(Q_{12})^{MC,noBEC}}{P_{mix}(Q_{12})^{MC,noBEC}}$$

mixed event sample from Data

MC correction to remove non-BEC

Bose-Einstein Correlations - $K^{\pm}K^{\pm}$



96-00 ZEUS data, 121 pb^{-1}

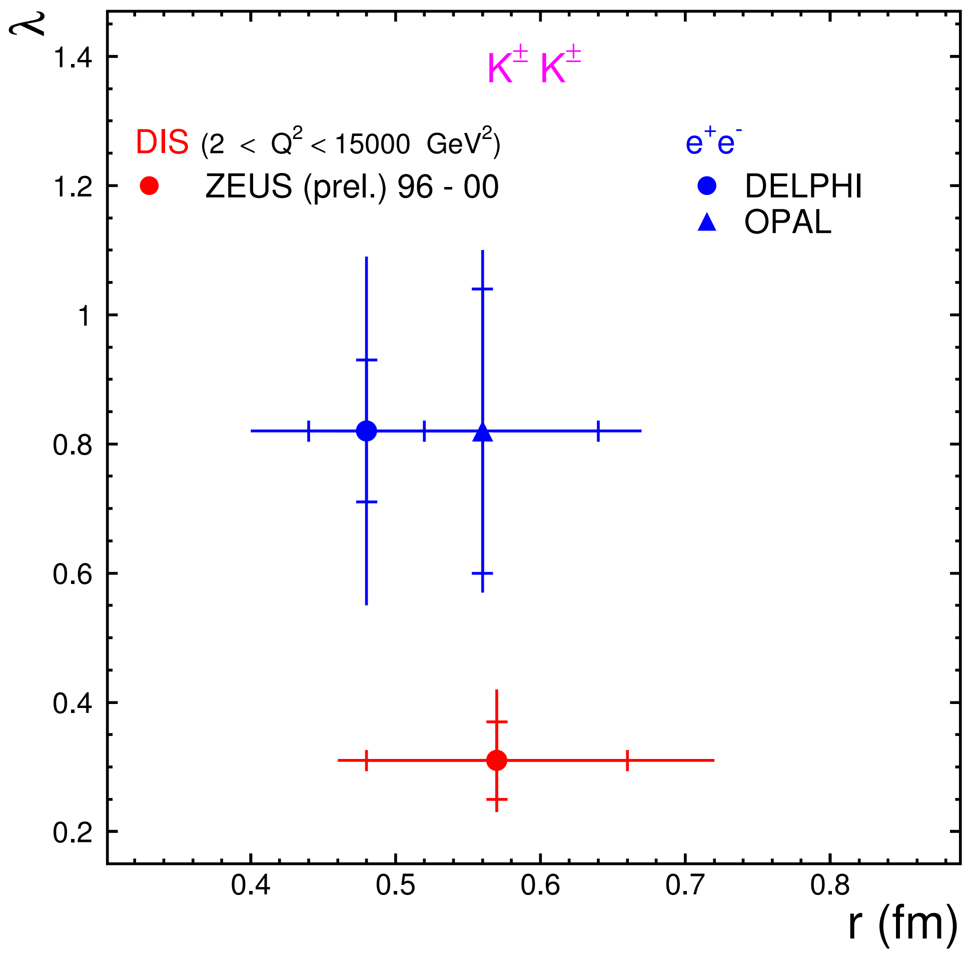
Visible BE effect as the momentum difference of two bosons is small

r value for charged kaons is similar to charged pions

ZEUS: Phys. Lett. B 583, 231(2004)

Charged pion: $r = 0.666 \pm 0.009^{+0.022}_{-0.036}$ fm

Bose-Einstein Correlations - $K^{\pm}K^{\pm}$



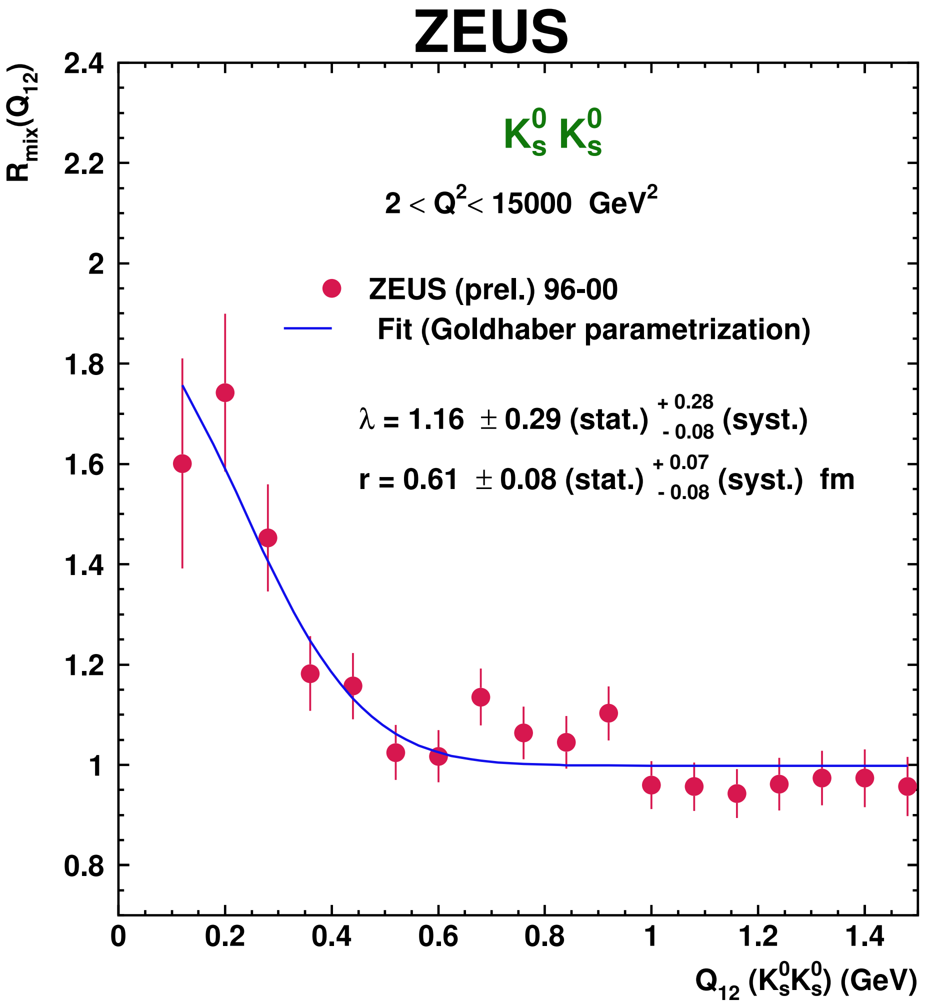
The result on the radius is in a good agreement with LEP result

But λ value in DIS is smaller than for e^-e^+.

Possible explanations

- Different fragmentation processes in e^-e^+ and ep.
- Kaon production from ϕ_0(1020) decay in proton fragmentation region decreases λ.

Bose-Einstein Correlations - $K_s^0 K_s^0$



Clear visible BE effect

LEP: a hierarchy in radius of the BE sources.

$$r(\pi^\pm) > r(K^\pm) > r(\Lambda)$$

ZEUS: $r(K_0^s)$, $r(K^\pm)$ and $r(\pi^\pm)$ are similar.

Charged pions: $r = 0.666 \pm 0.009^{+0.022}_{-0.036}$ fm

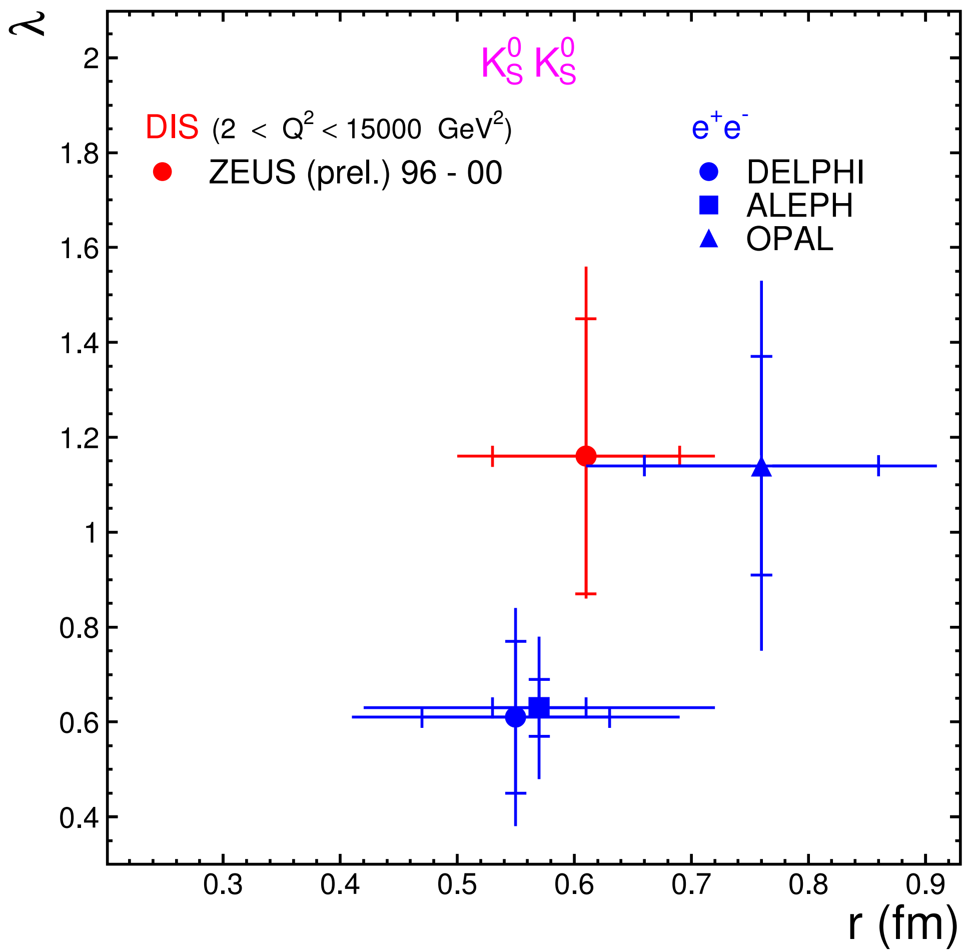
Charged kaons: $r = 0.57 \pm 0.09^{+0.15}_{-0.06}$ fm

Neutral kaons: $r = 0.61 \pm 0.08^{+0.07}_{-0.08}$ fm

Situation with mass dependence is still not clear

→ more studies are needed

Bose-Einstein Correlations - $K_s^0 K_s^0$



BE radius is in a good agreement with LEP results

But λ value in DIS is larger than for $e^- e^+$.

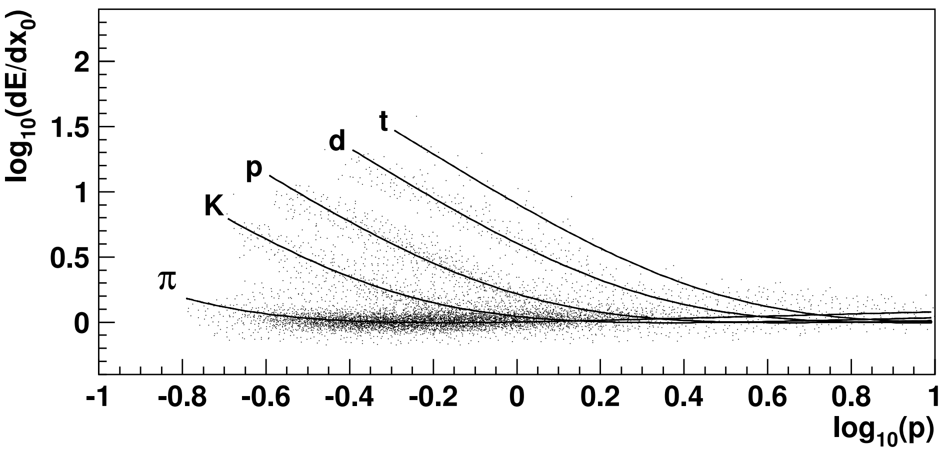
Possible explanations

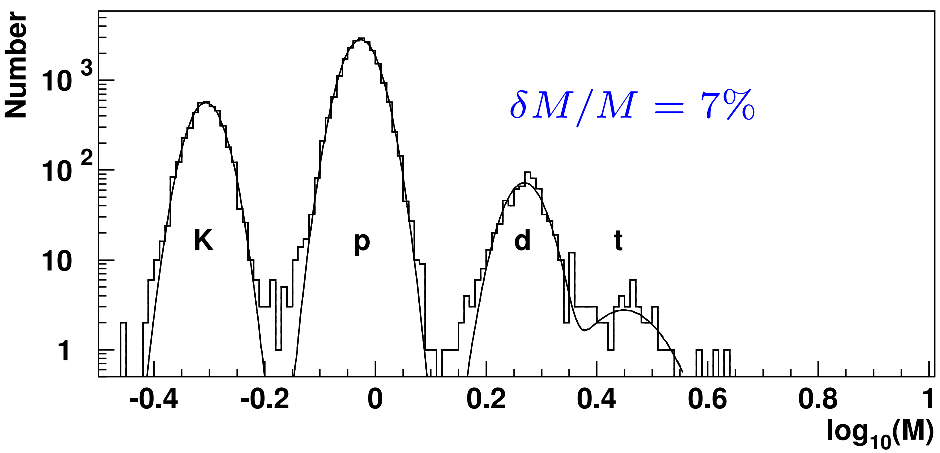
- paired K_s^0 production from $f_0(980)$ resonance decay significantly affects λ in low Q_{12}, and not well described in MC.
- LEP (ALEPH,DELPHI) removed influence of $f_0(980)$.

Measurement of Anti-Deuteron production

Ref. abstract 602

Anti-Deuteron and heavy particles search

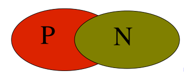


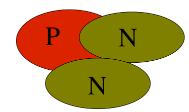


Particle identification is performed using P and $\frac{dE}{dX}$

H1 publication:

Eur. Phys. J.C36(2004) 413-423

Production of 

, 

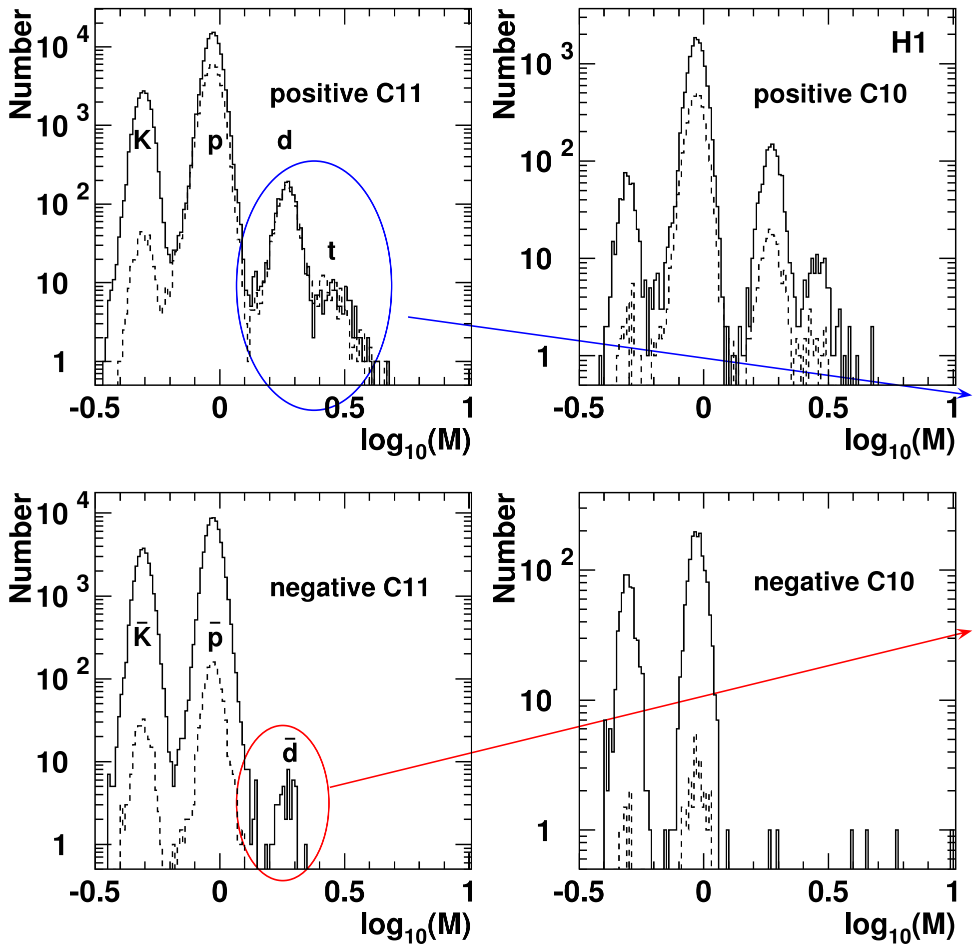
and their anti-partners is not understood in ep and $p\bar{p}$ collisions.

Heavy stable particle $\Rightarrow$ physics beyond the Standard quark fragmentation.

Some models exist and attempt to describe these particles production.

Coalescence model

Anti-Deuteron and heavy particles search



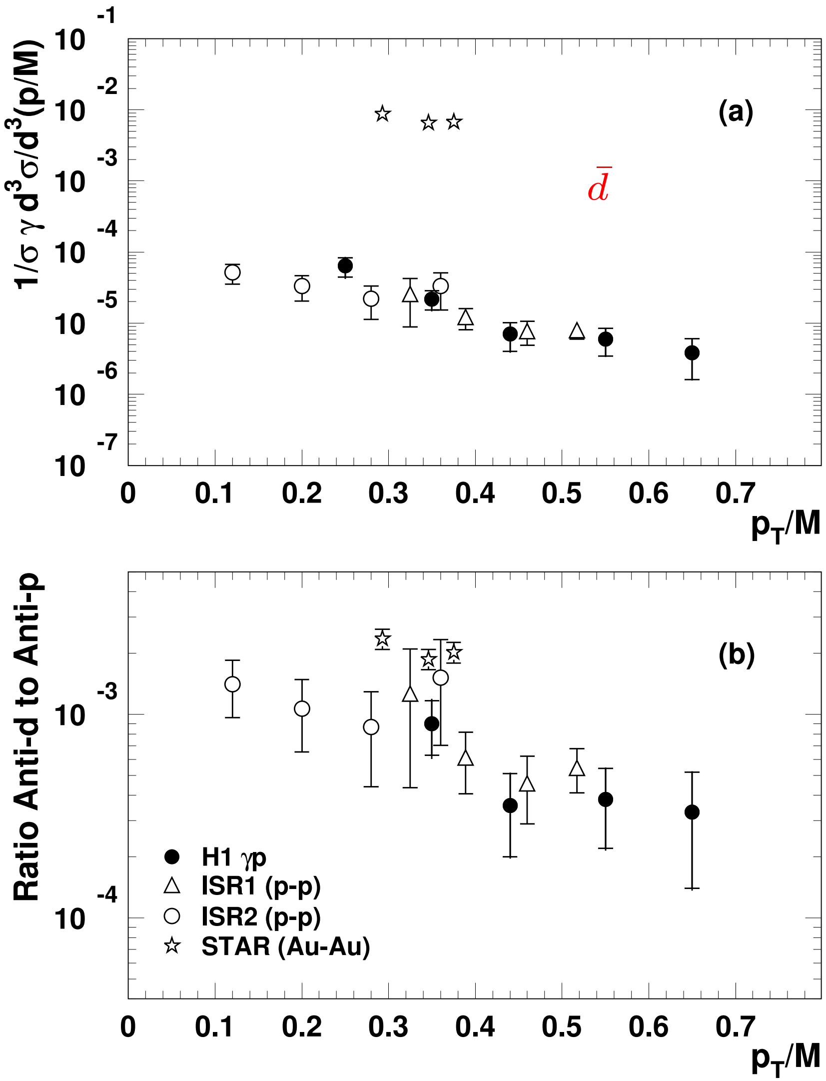
$< W_{\gamma p} >$=200 GeV
$0.2 < p_t/M <$0.7, $| y_{lab} |< 0.4$

Deuterons and tritons are difficult to separate from the backgrounds (beam-gas interaction and material background).

45 anti-deuterons @ 5.5 pb^{-1} H1 data
0 antitritions.

No negative particles heavier than anti-deuterons and no positive particles heavier than tritons are observed.

Anti-Deuteron and heavy particles search



$\sigma(\bar{d})$ = 2.7 $\pm$ 0.5 $\pm$ 0.2 nb

$\sigma(M_{-/+} > M_{\bar{d}/t}) < 0.19$ nb @ 95% C.L.

0.2$<p_t/M<$0.7, $|\ y_{lab}\ |$<0.4

Normalised invariant $\bar{d}$ cross sections obtained in γp and pp collisions are in good agreement, however much lower than in Au-Au collisions.

$\bar{d}$ to $\bar{p}$ ratio is slightly smaller in elementary particle collisions than in heavy ion collisions.

Anti-Deuteron and heavy particles search

Coalescence model:

$\frac{1}{\sigma}\frac{d^3\sigma(d)}{d^3p} = B_2(\frac{1}{\sigma}\frac{d^3\sigma(p)}{d^3p})(\frac{1}{\sigma}\frac{d^3\sigma(n)}{d^3p})$

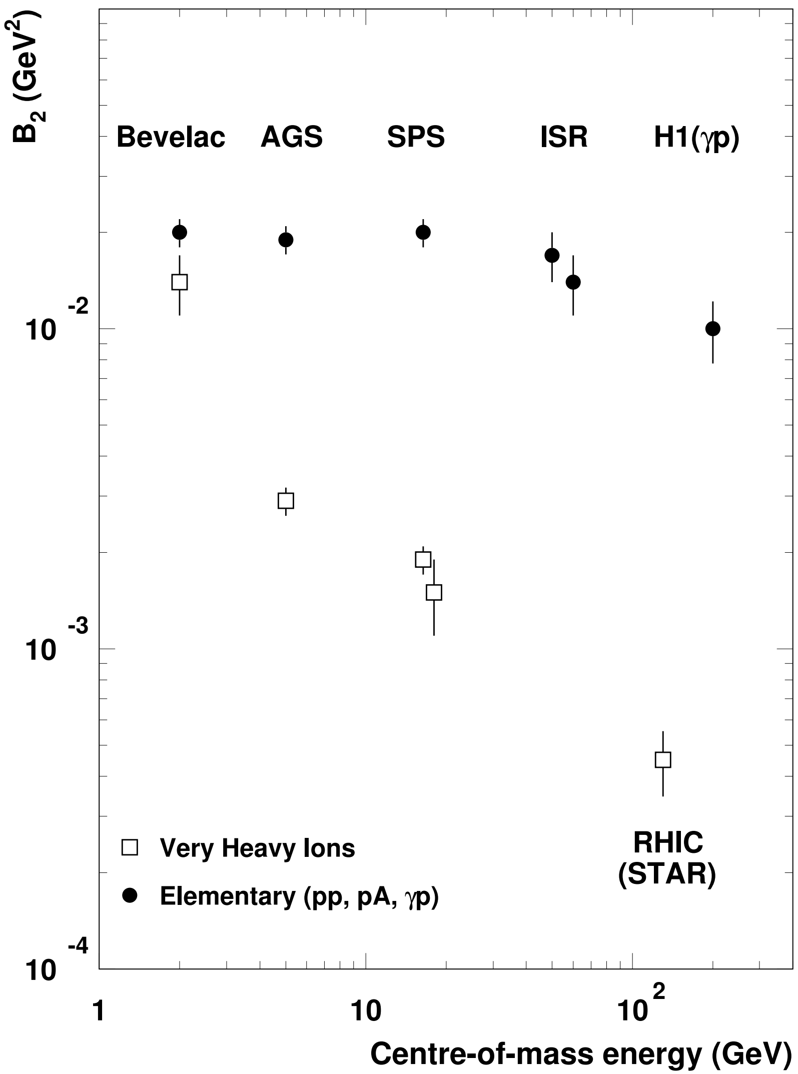
B_2 is inversely proportional to the size of interaction region.

The measured B_2 in photoproduction is

$B_2 = 0.010 \pm 0.002 \pm 0.001$

B_2 value in γp is similar to the values in pp and pA at lower c.m.s energy, but by an order of magnitude larger than in Au-Au collisions.

Very heavy ions:
Bevelac (Ne-Au), AGS(Au-Pt), SPS(Pb-Pb)



Azimuthal asymmetry in DIS

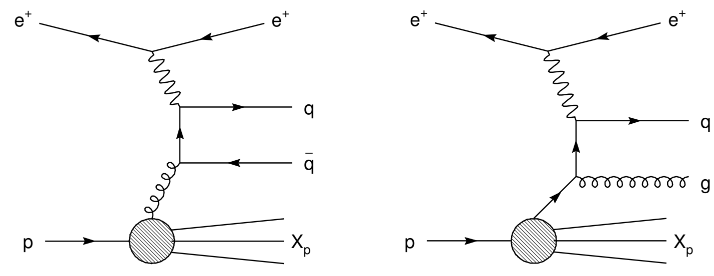
Ref. abstract 365

Azimuthal asymmetry with energy flow method

- pQCD prediction:

$$\frac{d\sigma^{ep \to ehX}}{d\phi} = A + Bcos(\phi) + Ccos(2\phi) + Dsin(\phi) + Esin(2\phi)$$

- Azimuthal asymmetry comes from
  - BGF and QCDC
  - Boson polarization
  - Longitudinally polarized electron beam
  - Final hadron polarization
  - Parity violating weak interactions
  - Intrinsic parton momentum in the proton



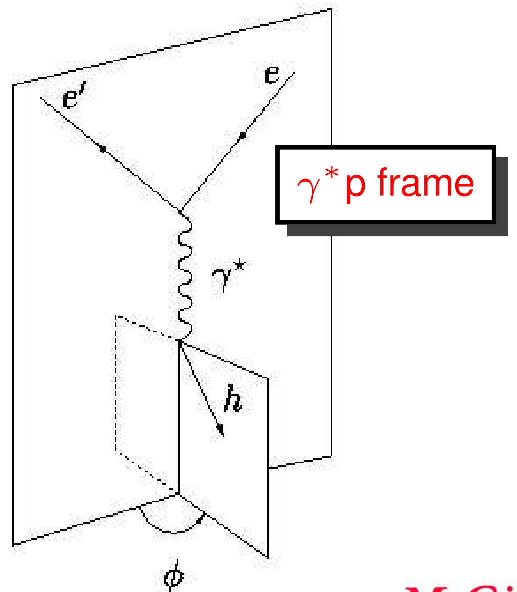
- Experimentally, we measure the 1st moments

$$\langle cos(n\phi)\rangle = \frac{\int d\sigma cos(n\phi)}{\int d\sigma} \qquad n = 1, 2$$

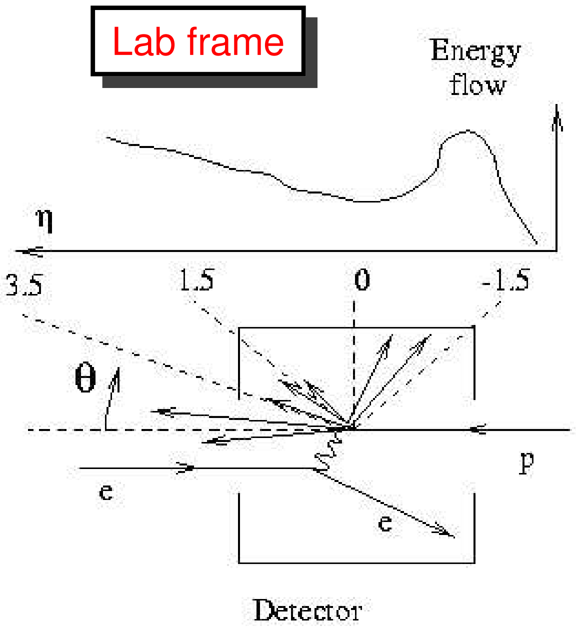
$\Longrightarrow$ means:

$$\langle cos(\phi)\rangle = \frac{B}{2A} \qquad \langle cos(2\phi)\rangle = \frac{C}{2A}$$

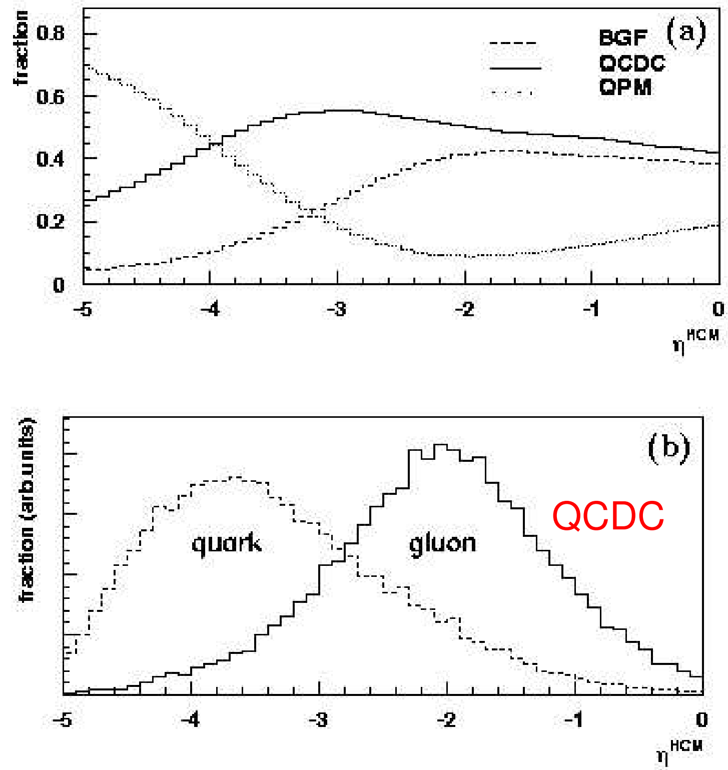
$$\langle sin(\phi)\rangle = \frac{D}{2A} \qquad \langle sin(2\phi)\rangle = \frac{E}{2A}$$



Energy flow method + pseudorapidity



- Calorimeter and tracking detector information → charged and neutral hadrons investigated
- Particle direction is weighted with its transverse energy → enhance hard partons (larger E_T^*) contributions
- Mean value → CAL energy scale and uncertainties cancel out

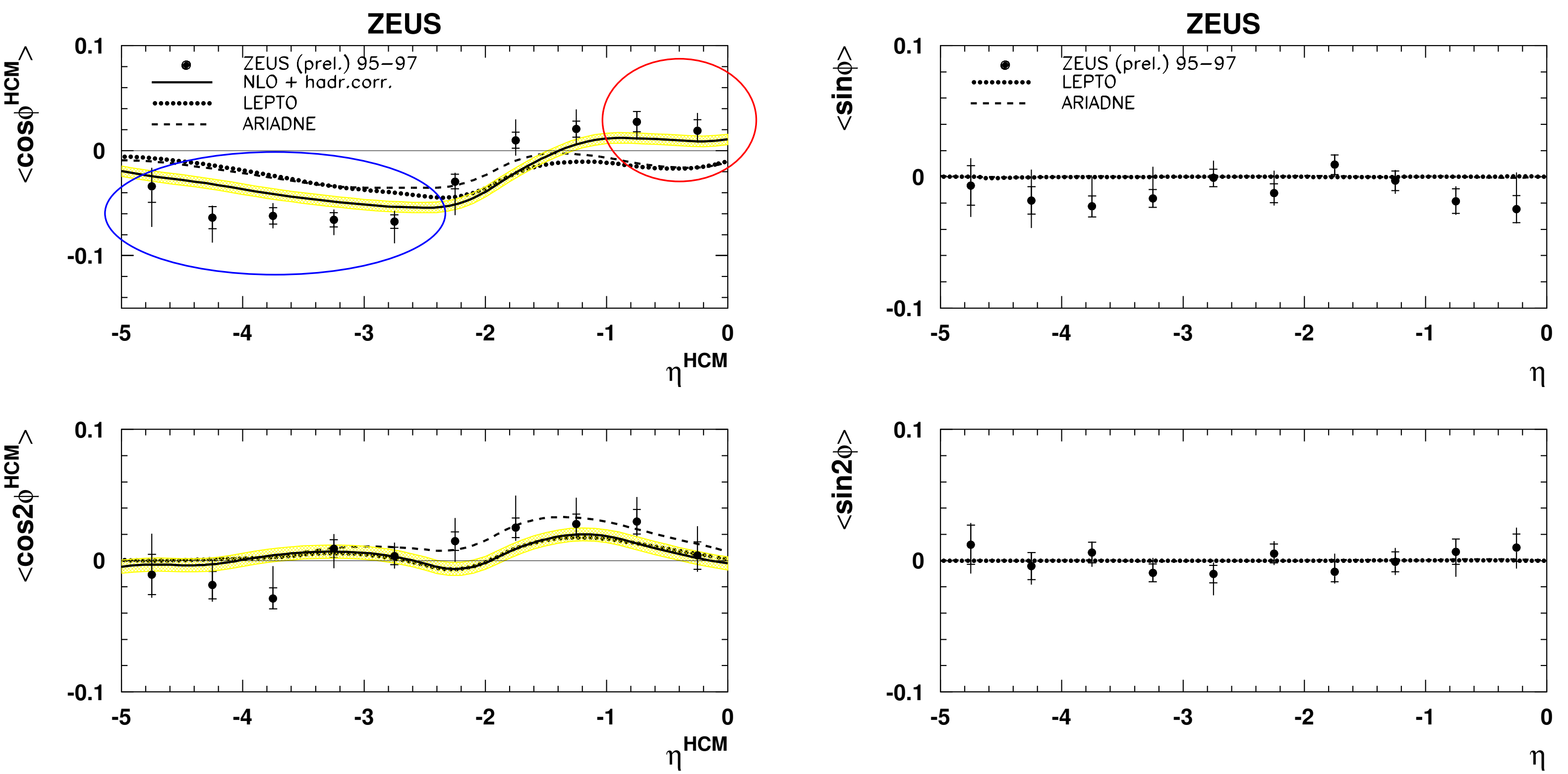


Why as a function of pseudorapidity?

- separation of BGF and QCDC
- separation of hadrons from q and g
- hadrons nearby in the HCM($\gamma^* p$) frame → nearby in Lab

Azimuthal asymmetry - results

ZEUS 95-97 data, 45 pb^{-1}, $100 < Q^2 < 8000 GeV^2$, $0.01 < x < 0.1$, $\mathrm{P_T^{Lab}} > 150$MeV



- $\langle cos\phi \rangle$: The NLO predictions describe the data better than the LO QCD.
- $\langle cos2\phi \rangle$: Consistent with zero for $\eta^{\mathrm{HCM}} < -2$ and positive for higher η^{HCM}
- $\langle sin\phi \rangle$ and $\langle sin2\phi \rangle$: Consistent with zero

Summary

- Strange particle production
  - ep data suggests a smaller λ_s for fragmentation processes
  - No $\Lambda/\bar{\Lambda}$ asymmetry and no $\Lambda(\bar{\Lambda})$ polarisation was observed
  - Bose-Einstein correlations of charged/neutral kaons were measured in DIS and compared to LEP experiments

- Anti-deuteron production in photoproduction was measured. No significant production of particles heavier than deuteron is observed

- Azimuthal asymmetry was measured in DIS using energy flow. The data is consistent with the pQCD predictions but the NLO contributions are not negligible.