



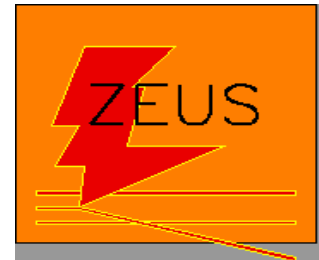
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ITEP/DESY



Spectroscopy and Fragmentation results from HERA



On behalf of the H1 and ZEUS Collaborations



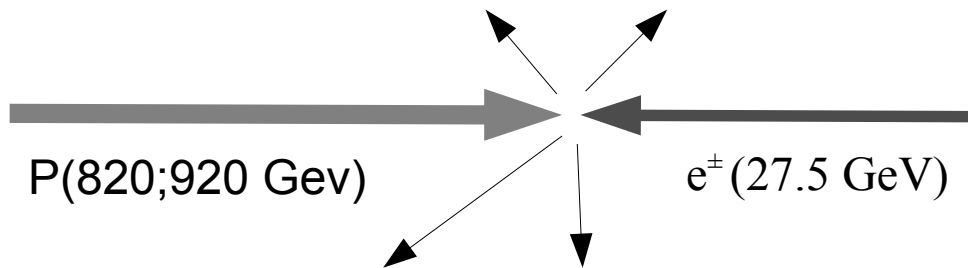
Charged particle production

D* fragmentation

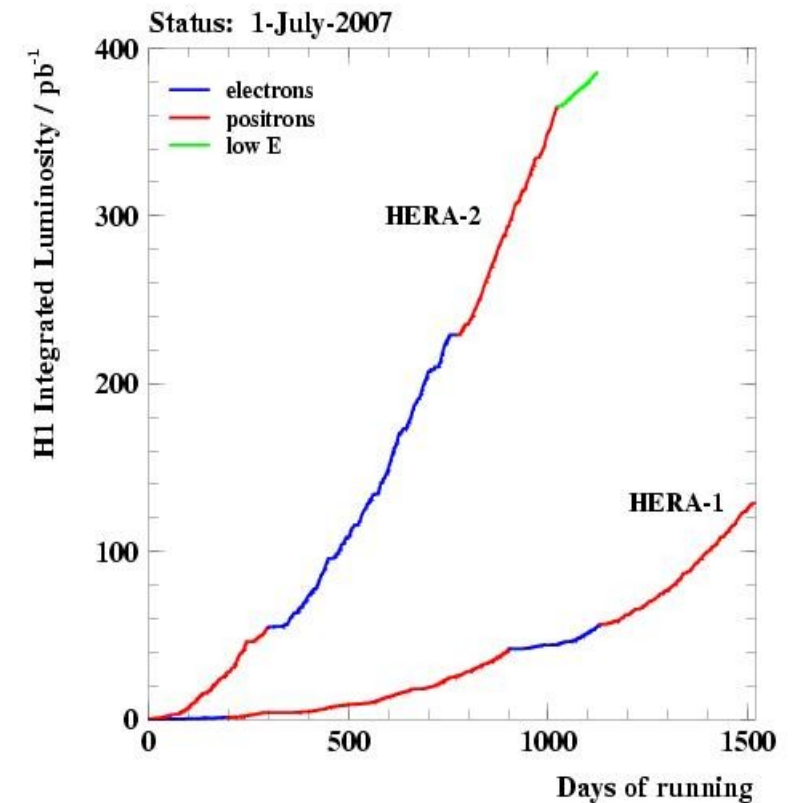
Strangeness production

Production of multi-quark states

HERA



Data taking periods:
HERA I : 1992-2000
HERAII : 2002-2007



$\sim 0.5 \text{ fb}^{-1}$ per experiment

$e^\pm p$ - Kinematics

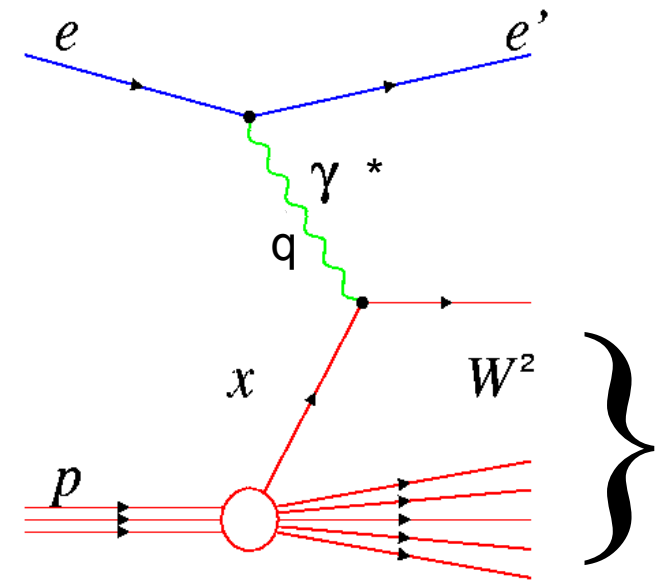
c.m. energy : $s^{1/2} = 301\text{-}319 \text{ GeV}$

hadronic energy : $W = m(\gamma^* p)$

photon virtuality : $Q^2 = -q^2$

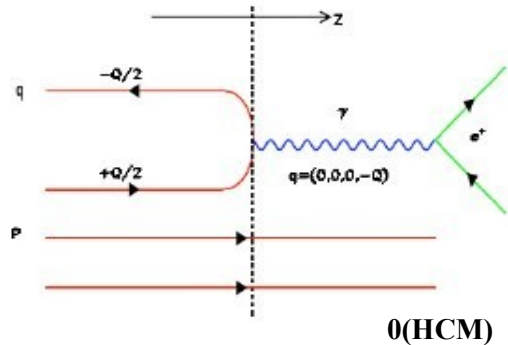
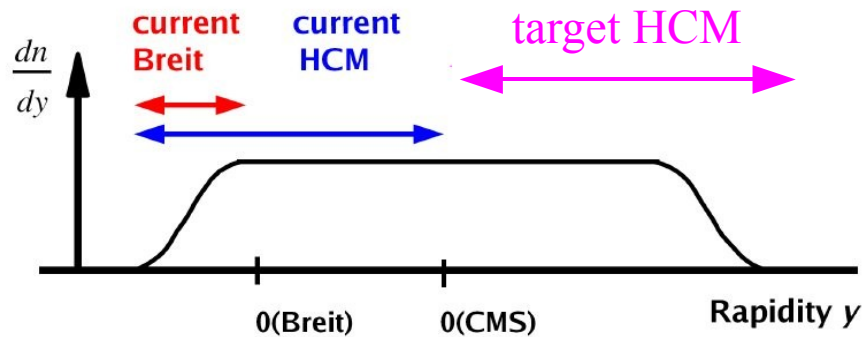
inelasticity : $y = Q^2 / (x_{\text{Bj}} s)$

two regimes : $Q^2 \approx 0 \text{ GeV}^2$: **Photoproduction**
 $Q^2 > 1 \text{ GeV}^2$: **Electroproduction (DIS)**



Fragmentation

HCM Frame
(hadronic centre-of-mass)



Breit Frame

Similarity expected between e^+e^- and ep in current regions of Breit or HCM Frames. Target regions should look more like in pp collision.

To see the similarity you need to choose the proper variables:

$$e^+e^- : s^{1/2}$$

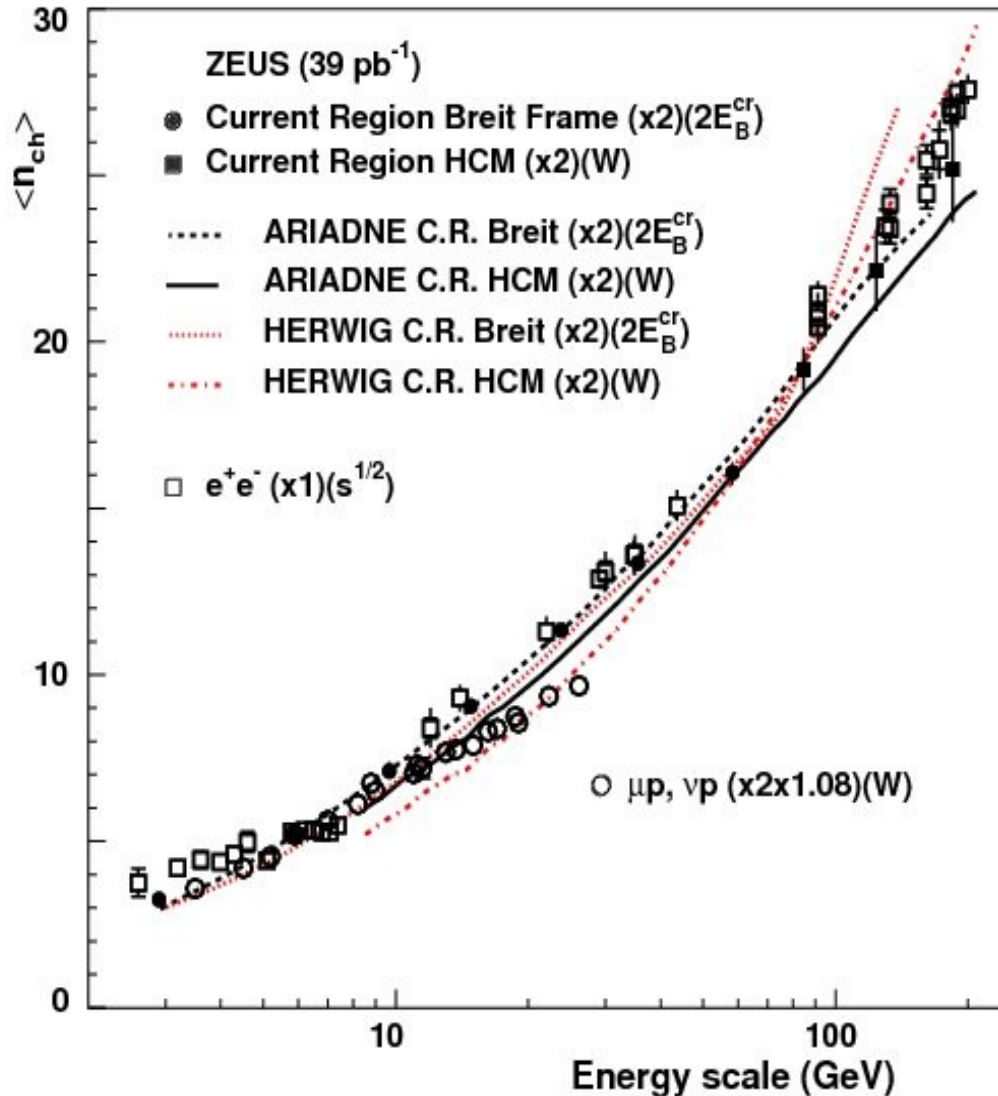
$$\text{ep (HCM)} : W$$

$$\text{ep (Breit Frame)} : E_B^{\text{cr}} \text{ (available energy in the current region of Breit Frame)}$$

$$\text{Scaled momentum : } x_p = 2p_h/Q \text{ in ep} \\ (p_h/E_{\text{beam}} \text{ in ee)}$$

Charged Particle Multiplicities

ZEUS



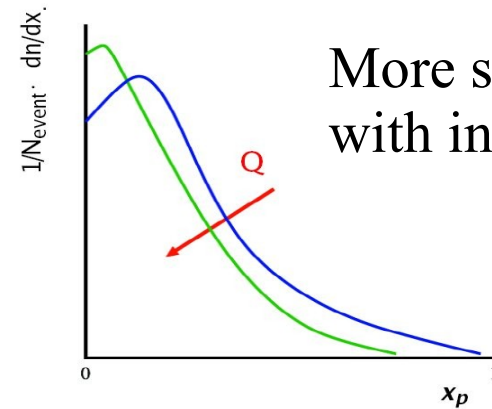
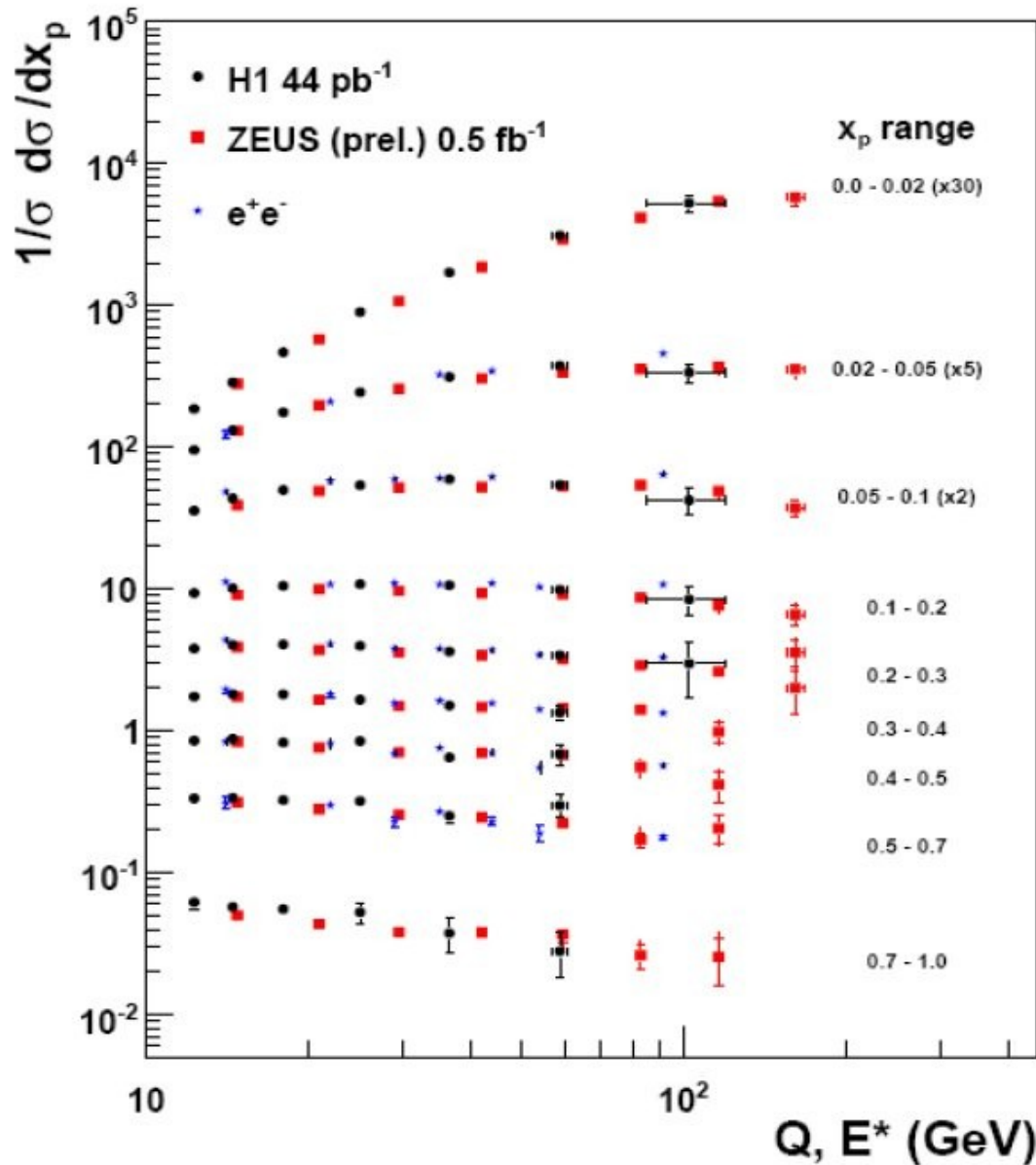
Breit Frame:

Good agreement between e⁺e⁻ and ep data when 2*E_B^{cr} is used as energy scale

HCM Frame:

overall good agreement with e⁺e⁻ and fixed target experiments when W is used as energy scale

Scaled Momentum Distributions

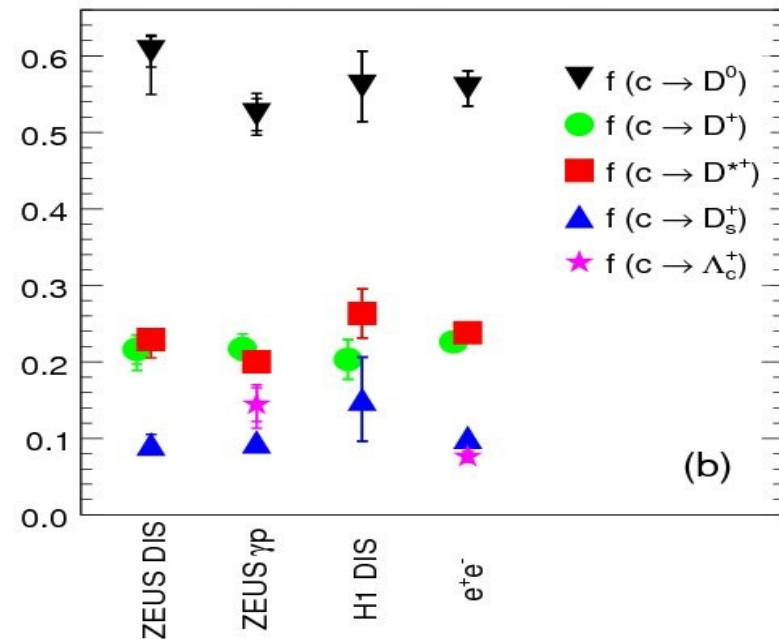
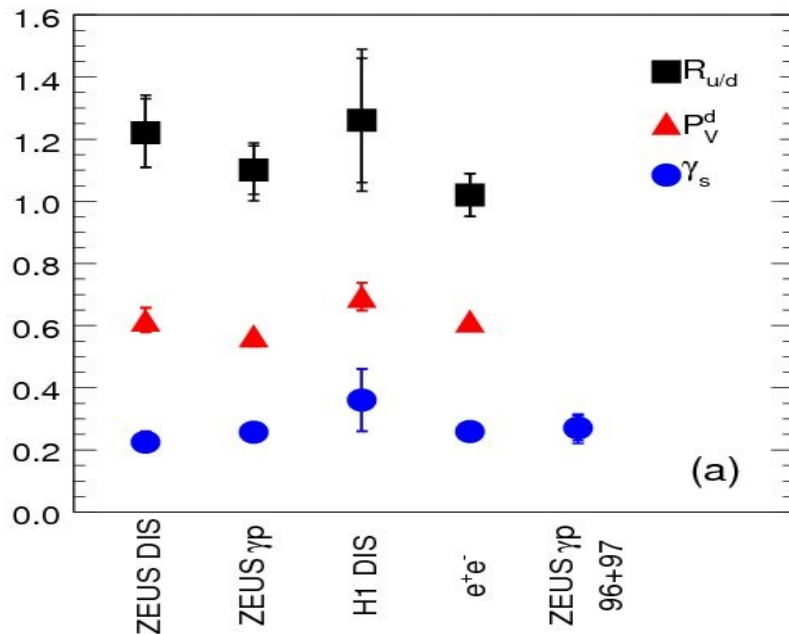


More softer particles
with increasing energy

Agreement between e⁺e⁻ and ep:
supports the concept
of quark fragmentation
universality

Scaling violation is observed

Fragmentation of Charm Quarks I



Fragmentation ratios:

$$R_{u/d} = (c\bar{u})/(c\bar{d})$$

$$P_v = V/(V+PS)$$

$$\gamma_s = (2c\bar{s})/(c\bar{d}+c\bar{u})$$

Fragmentation fraction

$$f(c \rightarrow D) = \sigma(D)/\sigma(c)^{\text{tot}}$$

Measurements support universality of charm fragmentation

Fragmentation of Charm Quarks II

z – fraction of the D^* momentum with respect to the charm quark.

for the $e^+e^- - x_p$

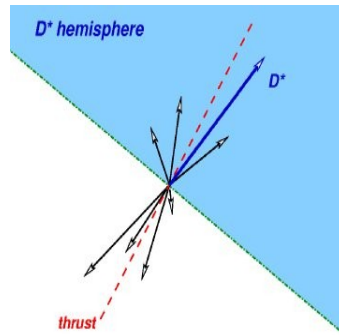
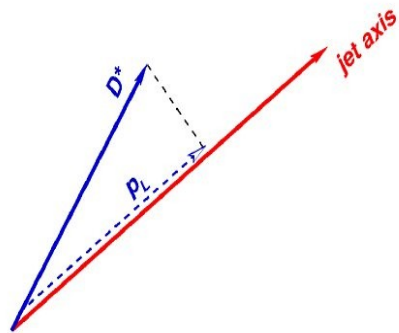
for ep two methods:

“jet”

$$z_{\text{jet}} = \frac{(E+p_L)_{D^*}}{(E+p)_{\text{jet}}}$$

“hemisphere”

$$z_{\text{hem}} = \frac{(E+p_L)_{D^*}}{\sum_{\text{hem}} (E+p)_i}$$



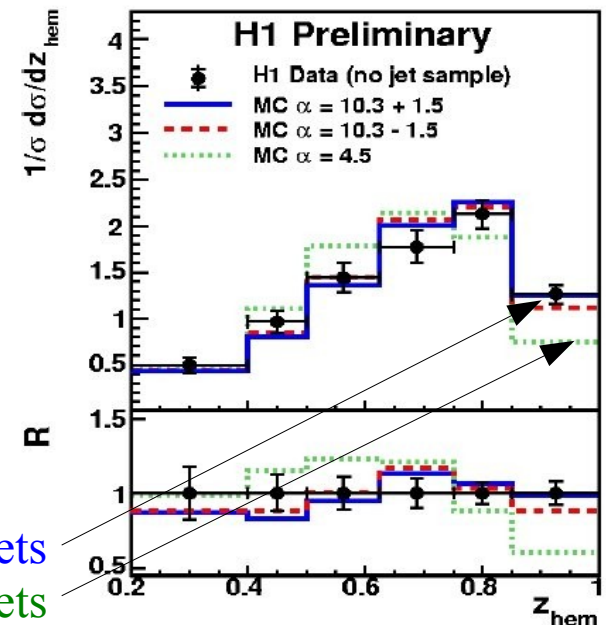
needs jet in the event

Applicable also to events without jet

Distributions for two methods are different, but resulting FF the same

Extracted parameter value agrees with e^+e^- : supports universality of FF

For events without hard scale in the event (no jet): different FF needed

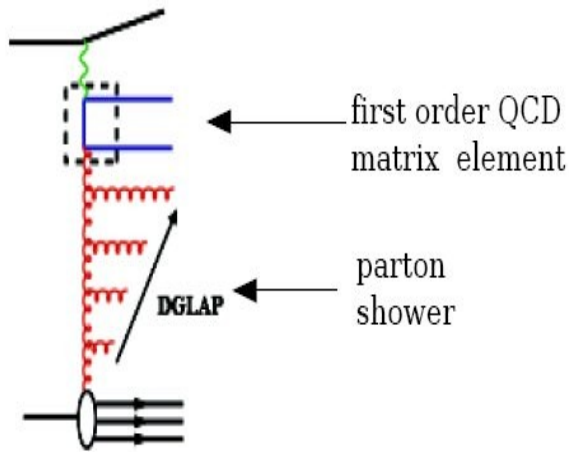


$D_Q^H(z) \propto z^\alpha (1-z)$ Kartvelishvili *et al.* parametrisation

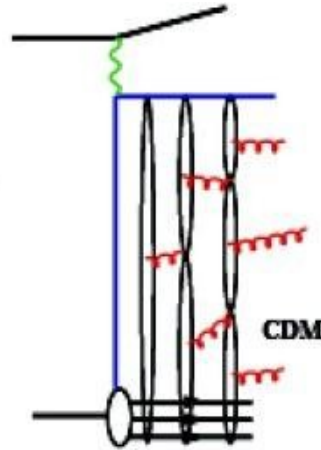
FF for events without jets
FF for event with jets

Strangeness production

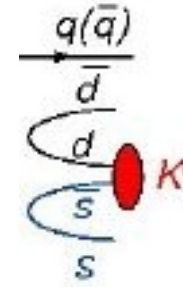
Matrix Element Parton Shower (MEPS)



Color Dipole Model (CDM)

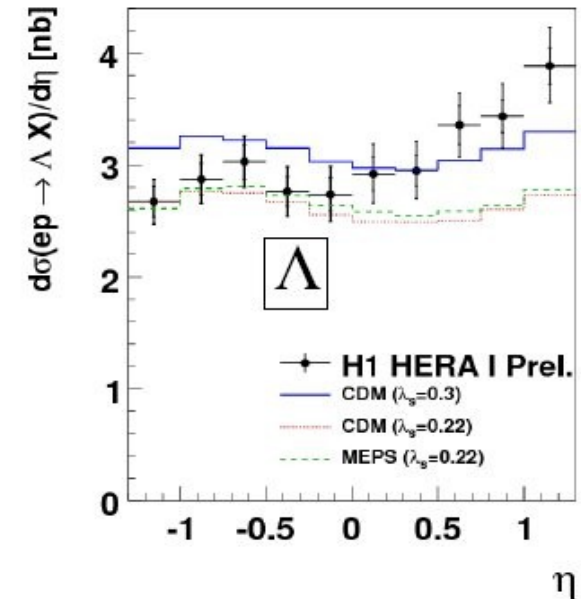
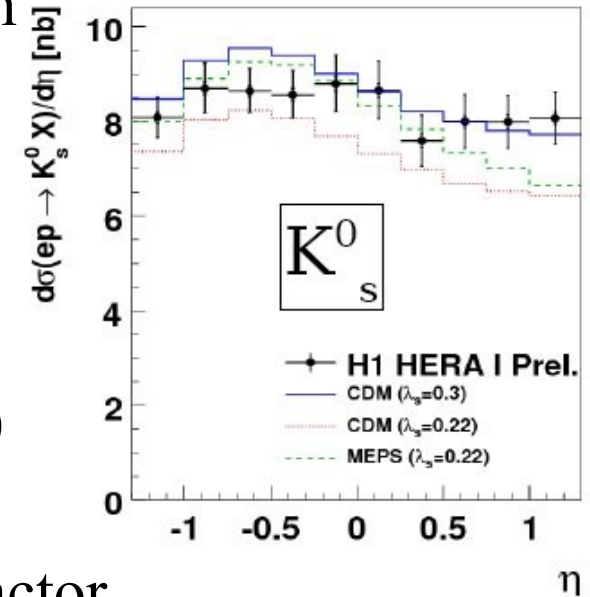


Hadronisation



$$\lambda_s = P(s)/P(u)$$

strangeness
suppression factor



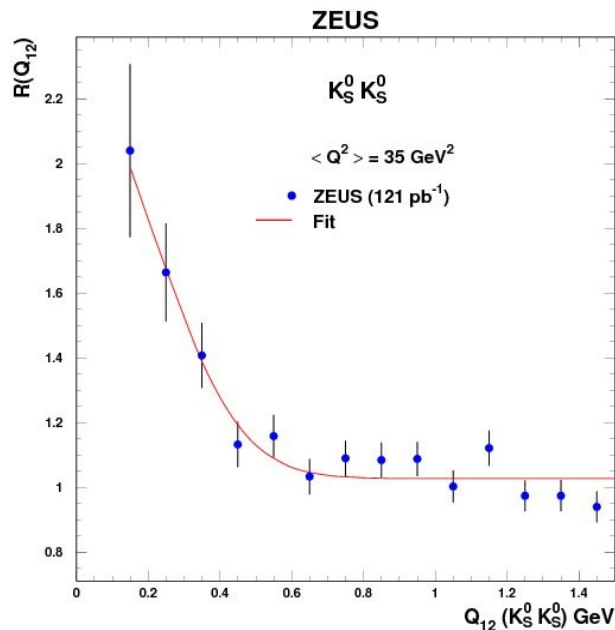
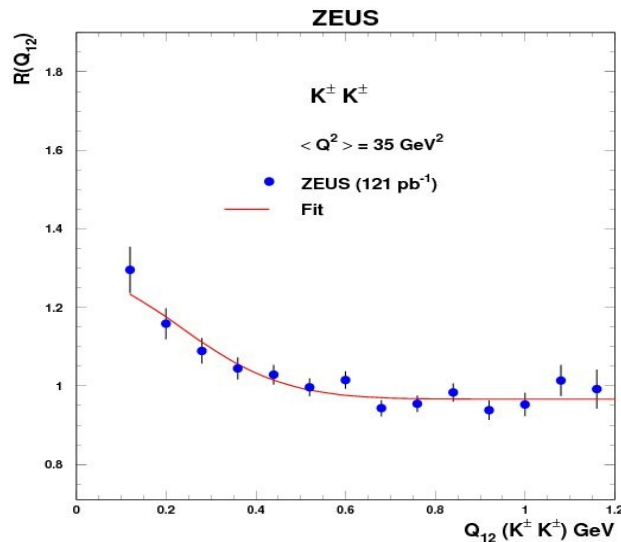
Neither MEPS nor CDM can describe the data with a single value of the λ_s parameter

MEPS + ($\lambda_s=0.22$) – reasonable description of K^0 (and ratio of K^0 to charged particles)

MEPS + ($\lambda_s=0.3$) – close to Λ data

CDM + ($\lambda_s=0.3$) – K^0, Λ , but fails in details

Bose-Einstein Correlation in KK system



$$R(Q_{12}) = P(Q_{12}) / P_0(Q_{12})$$

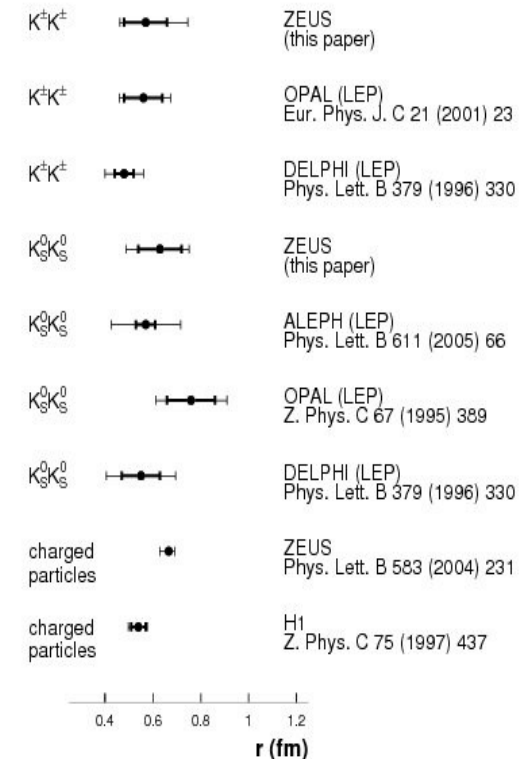
$$Q_{12}^2 = -(p_1 - p_2)^2 = (M_{KK}^2 - 4M_K^2)$$

$$\text{Fit: } R(Q_{12}) = 1 + \lambda \cdot \exp(-r^2 Q_{12}^2)$$

λ – strength of BEC

r – size of the source

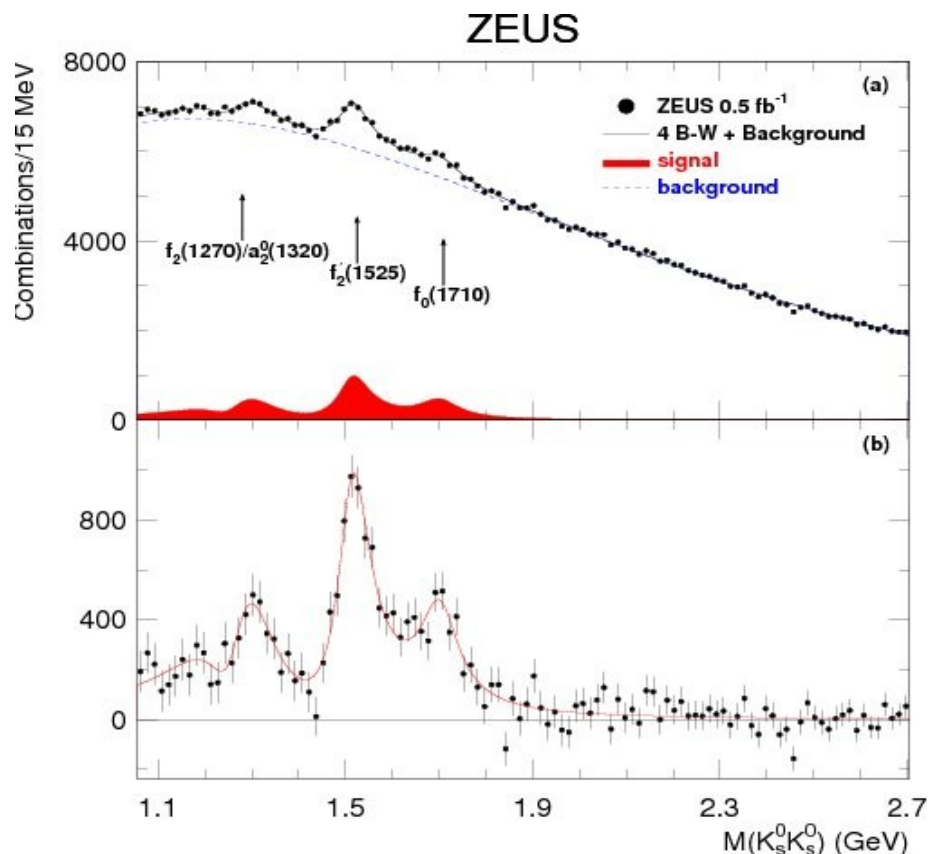
Measure $R(Q_{12})$ using
 event-mixing procedure
 (corrected with MC)



Consistent with the measurement
 of BEC for charged particles in DIS
 and kaons in e^+e^-

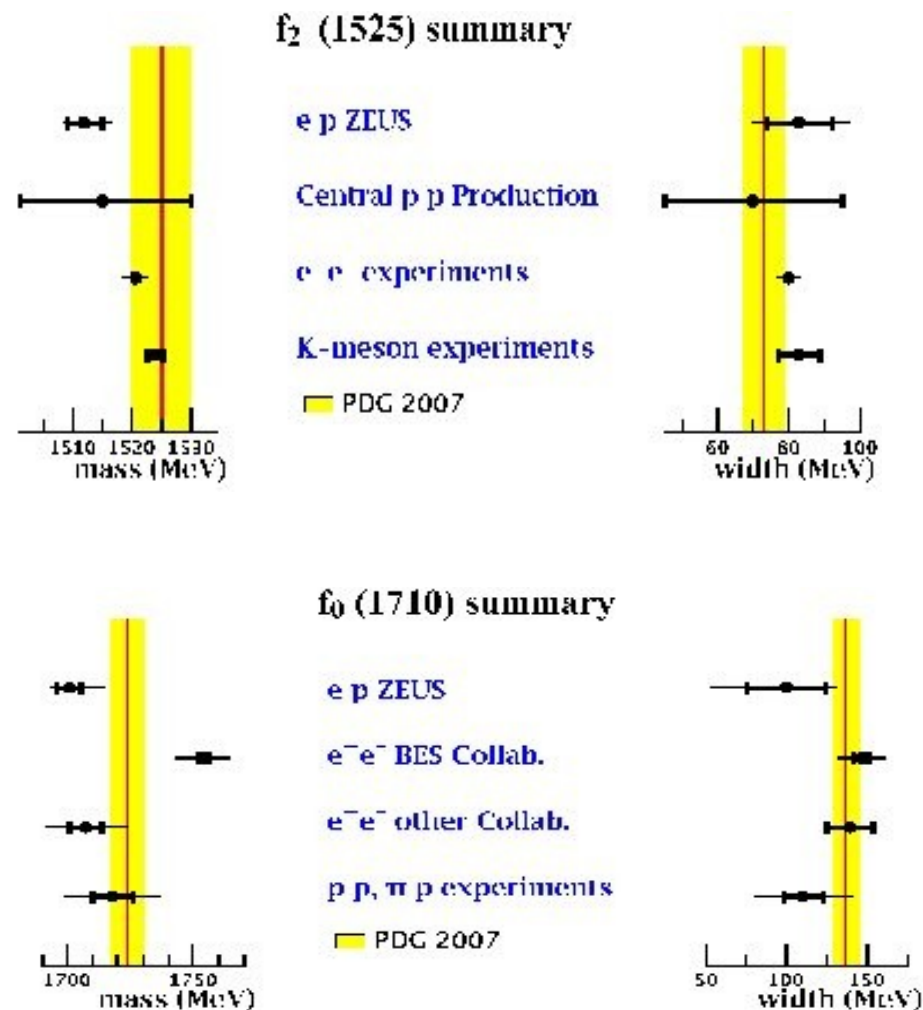
Spectroscopy

$K^0\bar{K}^0$ - resonances



3 enhancements corresponding to $f_2(1270)/a_2(1320)$, $f_2'(1525)$ and $f_0(1710)$

$f_0(1710)$ (5 σ significance) is the glueball candidate. (If not the same particle as observed in $\gamma\gamma \rightarrow K^0\bar{K}^0$ (TASSO, L3))



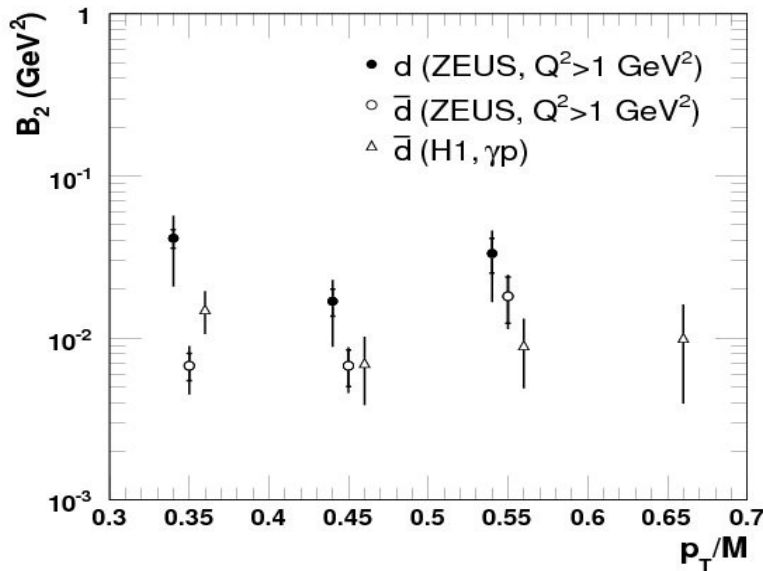
$\bar{d}/d, \bar{p}/p$ production

Coalescence model:

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

$$B_2(d) = B_2(\bar{d}) - \text{expected}$$

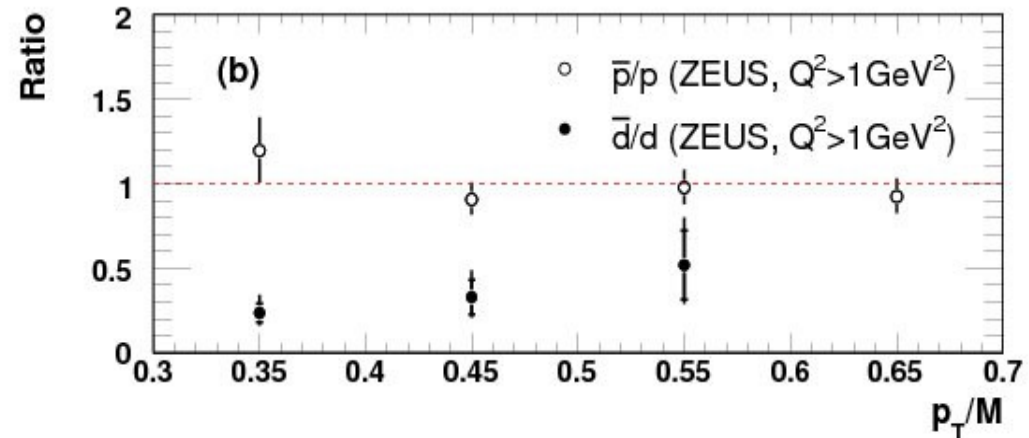
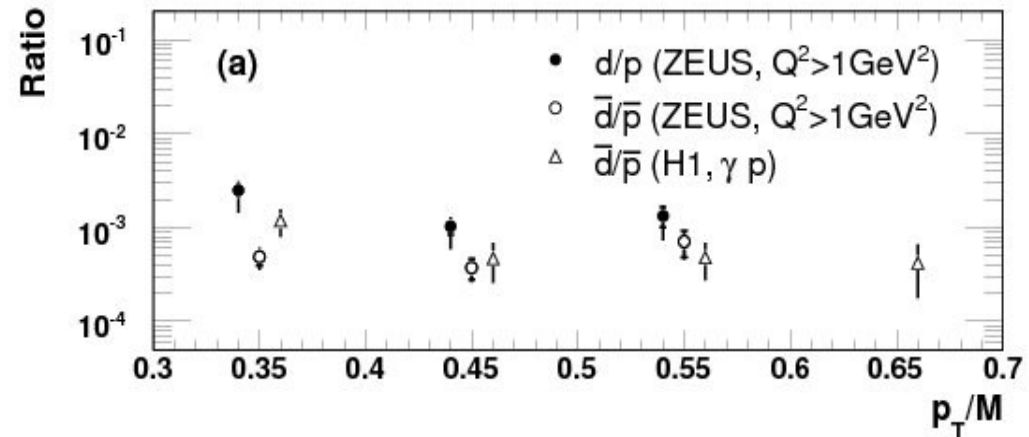
ZEUS



$$B_2(d) = (3.32 \pm 0.34^{+1.13}_{-1.55}) \cdot 10^{-2}$$

$$B_2(\bar{d}) = (0.89 \pm 0.14^{+0.19}_{-0.20}) \cdot 10^{-2}$$

ZEUS



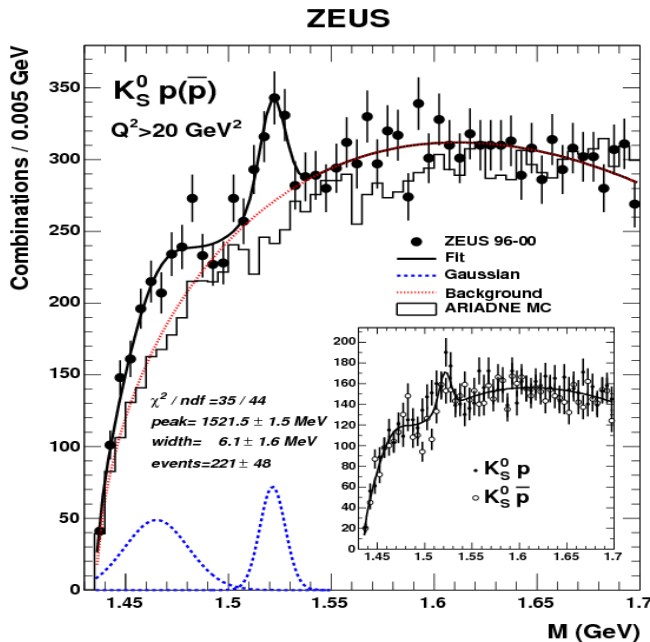
Enhanced production of multi-quark states?

Strange Pentaquark Θ^+

2004

HERA I data

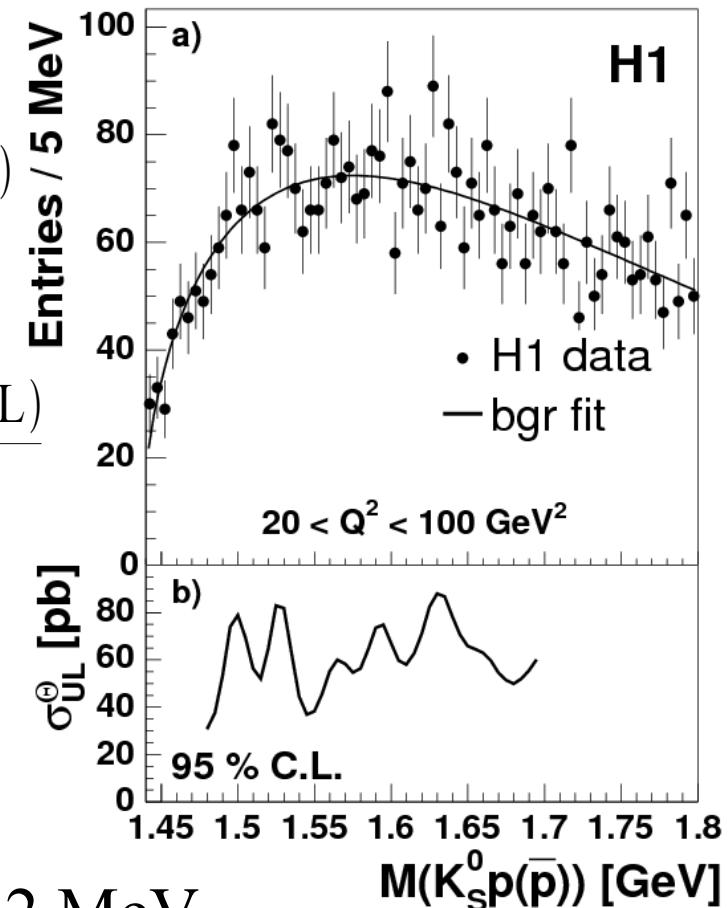
2006



ZEUS : $Q^2 > 20.0 \text{ GeV}^2$, $0.04 < y < 0.95$

$$\sigma(e p \rightarrow e \theta X \rightarrow e K^0 p X) = 125 \pm 27 (\text{stat})^{+38}_{-28} (\text{syst}) \text{ pb}$$

H1:
 $20.0 < Q^2 < 100.0 \text{ GeV}^2$
 $0.1 < y < 0.6$
 $\sigma(M = 1.52 \text{ GeV}) < 72 \text{ pb} (95\% \text{ CL})$
 (extrapolated to ZEUS
 y-region):
 $\sigma(M = 1.52 \text{ GeV}) < 100 \text{ pb} (95\% \text{ CL})$



Positive signal in ZEUS data at 1522 MeV

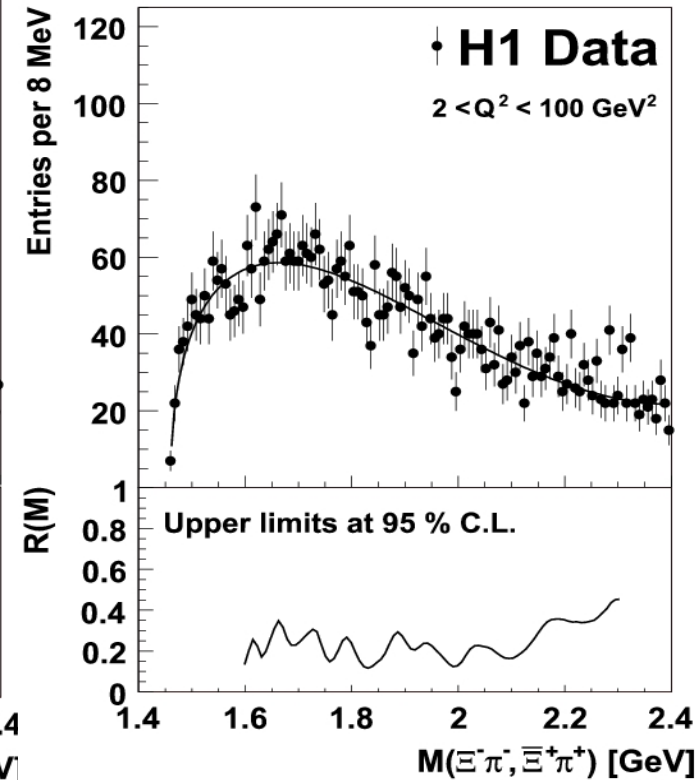
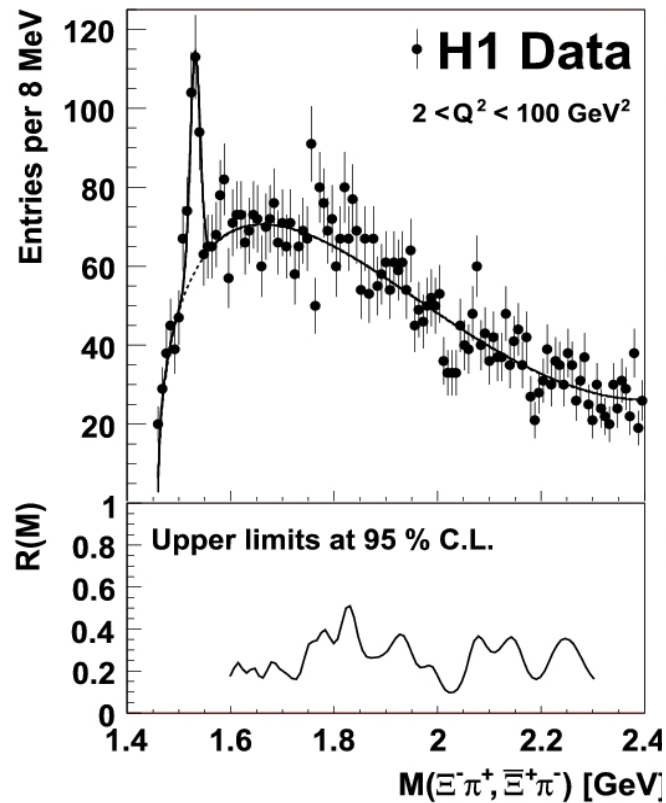
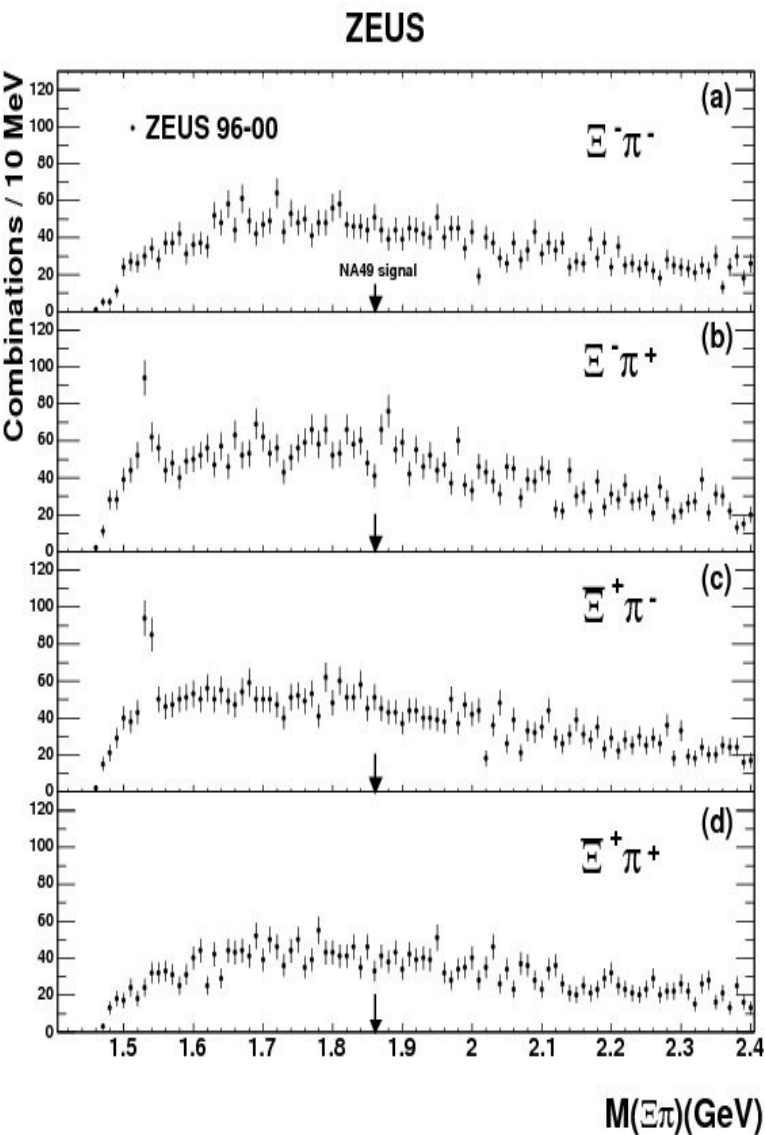
No signal in H1, upper limit does not support ZEUS evidence

HERA II data will clarify this issue

Double Strange Pentaquarks Ξ_{5q}

2007

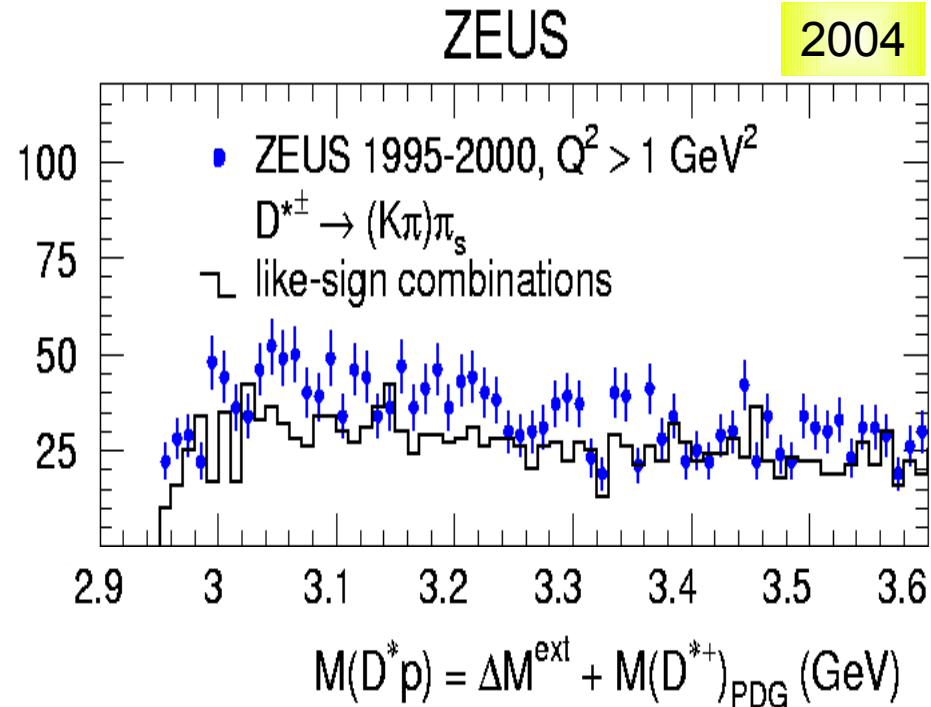
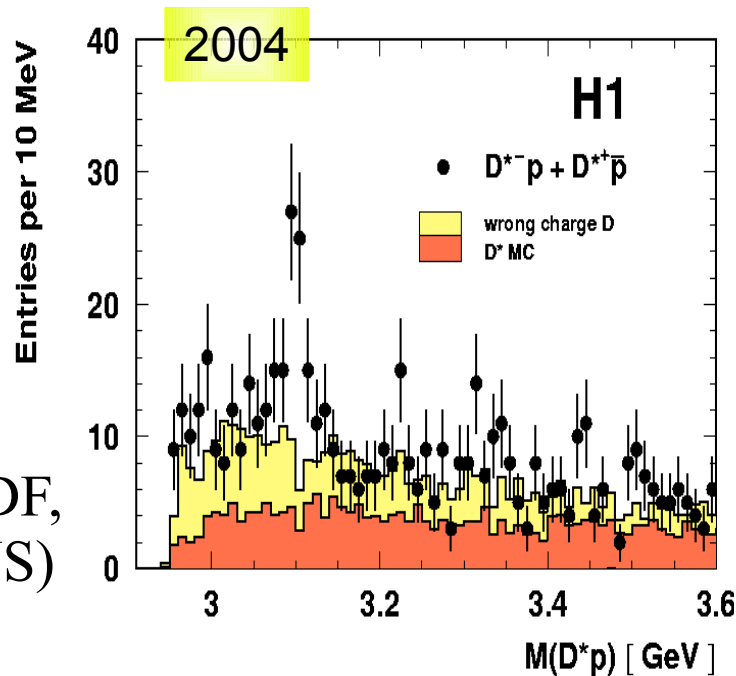
2005



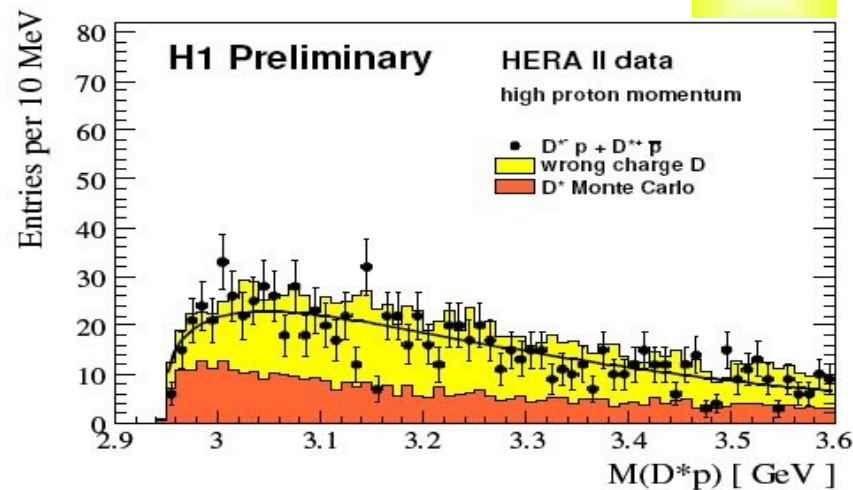
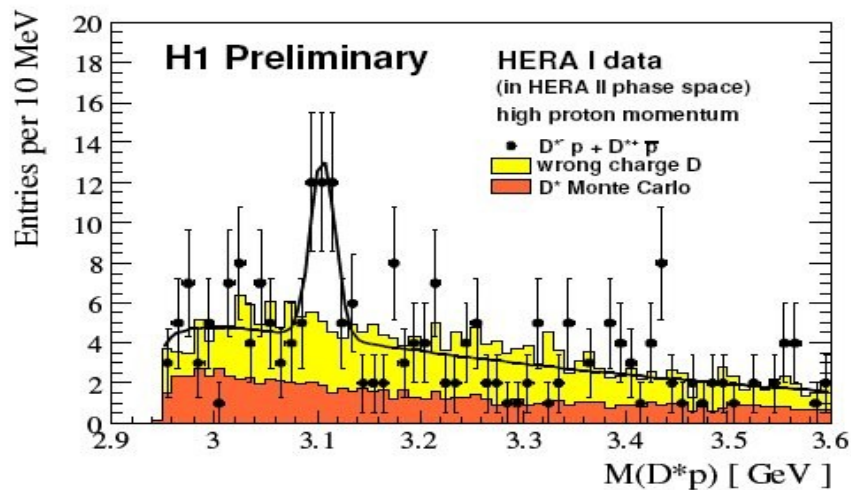
Known resonant state $\Xi(1530)$ clearly seen
 No signal at 1860 (NA49).
 Upper limit relative to $\Xi(1530)$

D* \bar{p} resonance (charm PQ)

HERA I:
charming
resonance
in H1 data
no signal
in ZEUS data
(and BaBar, CDF,
ALEPH, FOCUS)

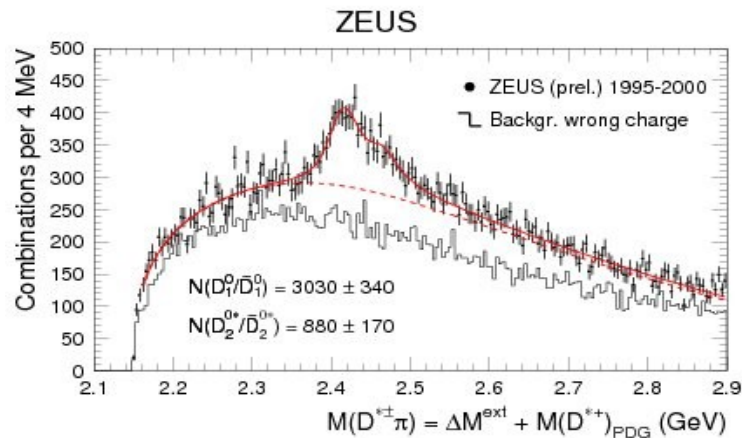


new analysis from H1 using HERA II data:

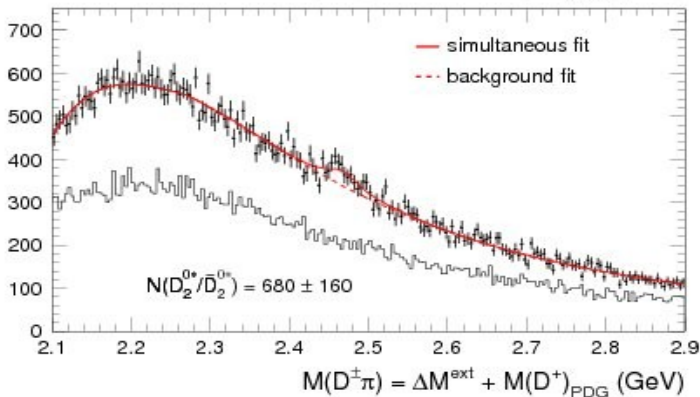


No excess
in HERA II
data

Excited charm and charm-strange mesons



$D_1(2420)^0$ and $D_2^*(2460)^0$
in $D^{*+}\pi^-$



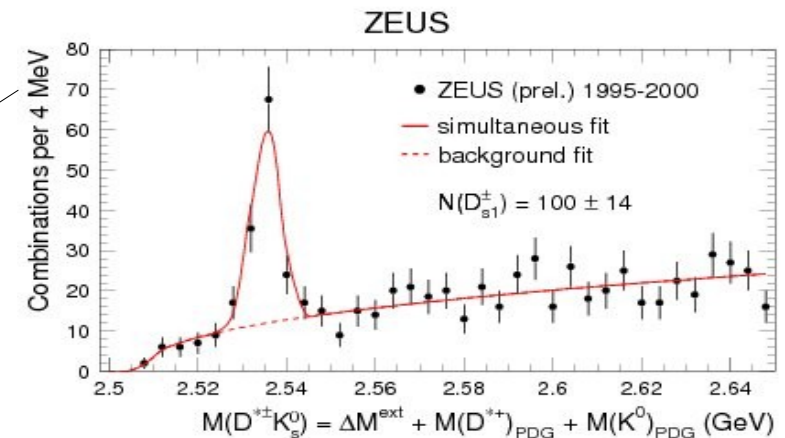
$D_2^*(2460)^0$
in $D^+\pi^-$

$$f(c \rightarrow D_1^0) = 3.5 \pm 0.4^{+0.4}_{-0.6} \pm 0.2\%$$

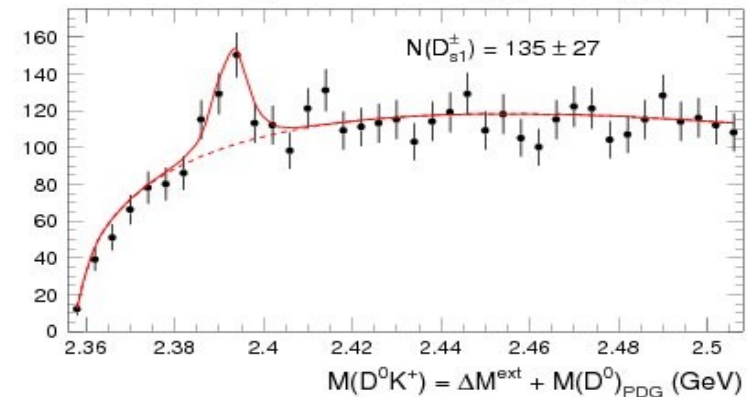
$$f(c \rightarrow D_2^{*0}) = 3.8 \pm 0.7 \pm 0.6 \pm 0.2\%$$

$$f(c \rightarrow D_{s1}^+) = 1.1 \pm 0.2 \pm 0.1 \pm 0.1\%$$

Consistent with the e^+e^- measurements



$D_{s1}(2536)^\pm$
in $D^{*+}K_s^0$



$D_{s1}(2536)^+$
in $D^0 K^+$

Helicity measurements:

$$R(D_1^0) = 6.1 \pm 2.3^{+2.0}_{-0.8} \quad \text{HQET:} +3$$

$$R(D_{s1}^+) = -0.74^{+0.23+0.06}_{-0.17-0.05}$$

hardly consistent with 0

(CLEO conclusion)

Summary

Fragmentation:

Many similar features/consistent picture with e^+e^- but some striking differences:

- charm fragmentation at threshold
- no simple picture for strangeness production
- enhanced production of deuterons

Spectroscopy:

Competitive with other world measurements:

- glueball candidate
- excited charm mesons
- pentaquarks (none in recent analyses, unfortunately)

Further exciting results in near future, with the HERA II data.