Hadron Spectroscopy and fragmentation at HERA

Moriond 2006 QCD, La Thuile, Italy 18-25 March 2006

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On behalf of the H1 and ZEUS collaborations

- Introduction/Motivations
- Results: charmed hadrons, η/ω, f_0/f_2, strange and charmed pentaquarks
- Conclusions

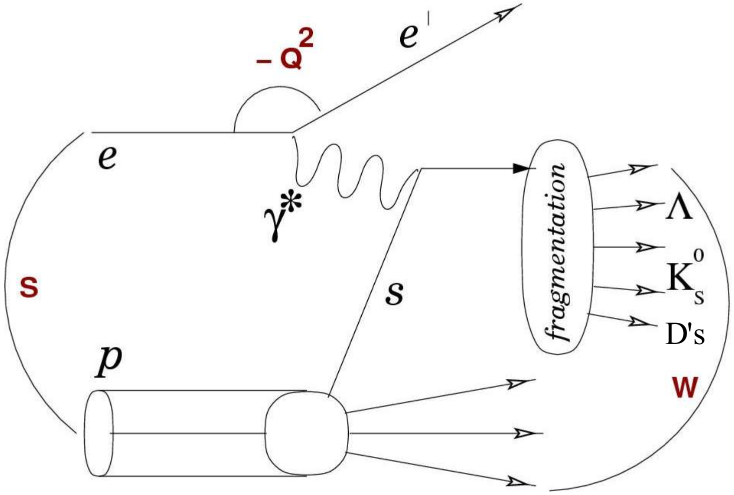
Introduction

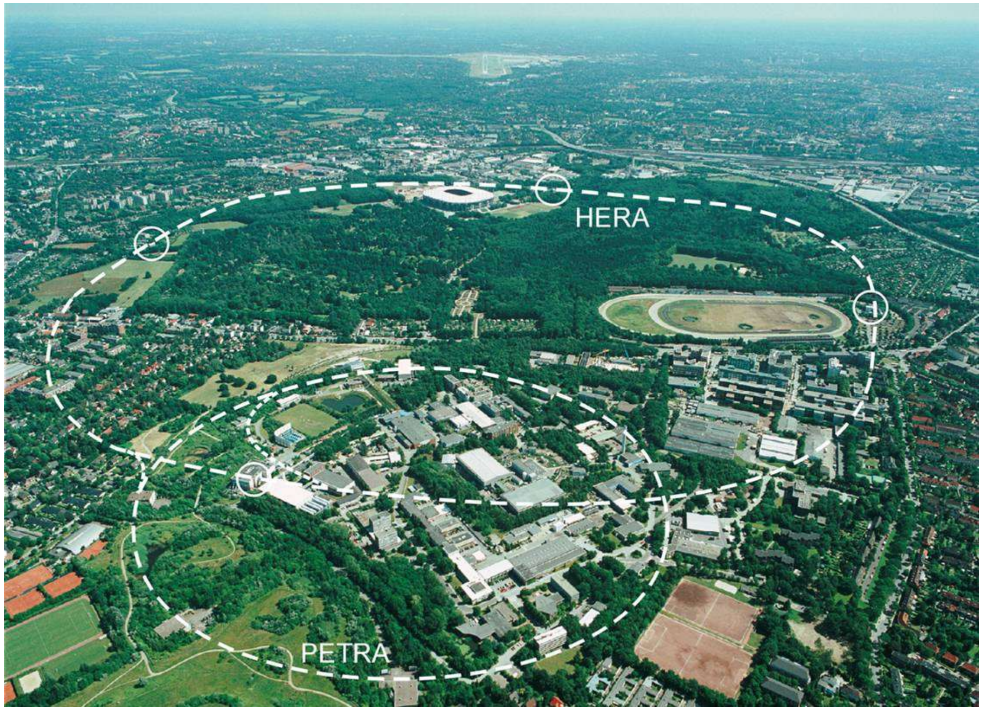
The process by which coloured quarks and gluons convert to colourless hadron is one outstanding problem in particle physics
Example: production of a hadron

$$\sigma(p) = \int dz\, dp_{parton}\, \sigma(p_{parton})\, D_H^{parton}(z)\, \delta(p - zp_{parton})$$

- pQCD not applicable to fully calculate the fragmentation functions $D_h^{parton}(z)$
- Phenomenological models based on laws of thermodynamics often used
- Are these models and $D_h^{parton}(z)$ universally applicable?
- High energy collisions ⇒ large multiplicities of particles with low transverse momentum ⇒ opportunity to study hadronisation and to measure the various $D_H^{parton}(z)$

HERA Collider

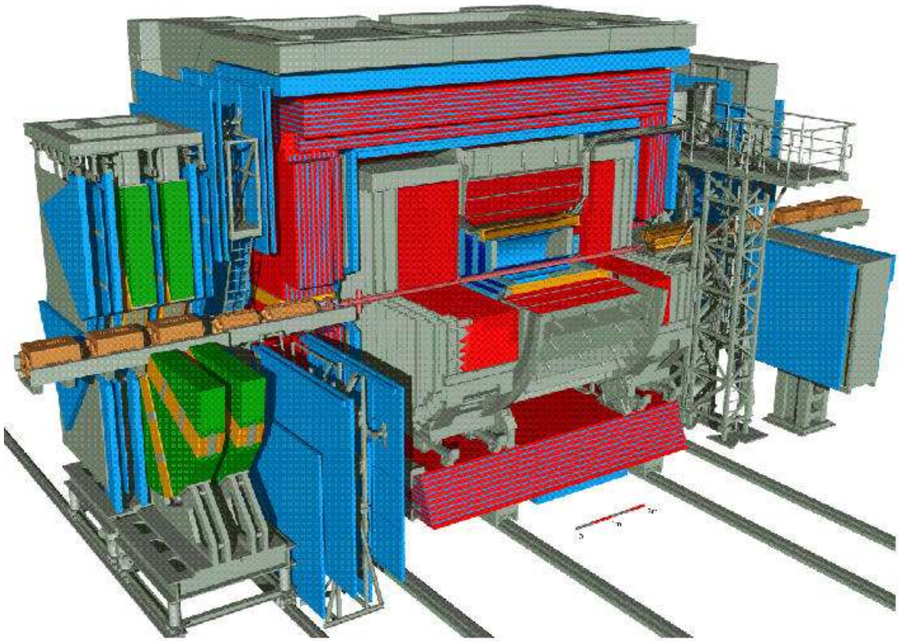


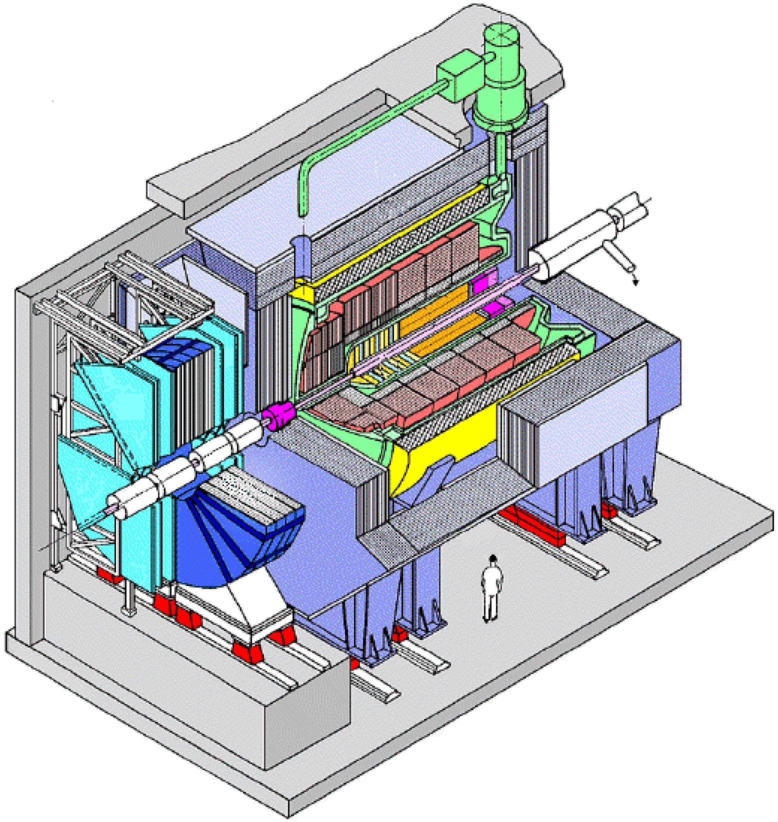


ep kinematics

photon virtuality Q^2
energy c.m. $\sqrt{s}$=300-320 GeV
hadronic energy W=m($\gamma*$p)
inelasticity $y=Q^2/(x_{Bj}\, s)$
two regimes: $Q^2 \approx 0$ GeV^2 -- photoproduction
$Q^2 > 1$ GeV^2 -- electroproduction (DIS)

ZEUS and H1 detectors





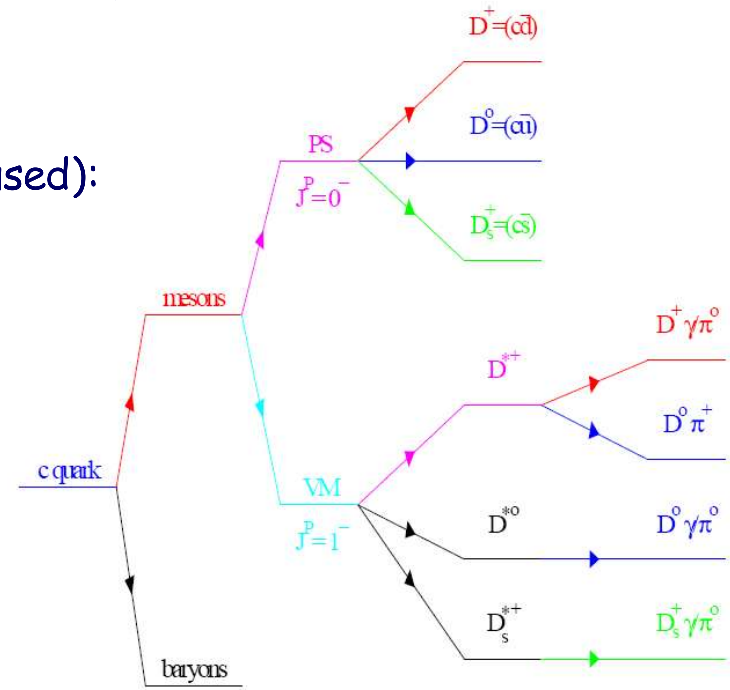
ZEUS **H1**

- Tracking ⇒ momentum measurement, particle ID
- Calorimetry ⇒ energy measurement

Charm fragmentation fractions and fragmentation ratios

Into which hadrons does the charm quark hadronize?

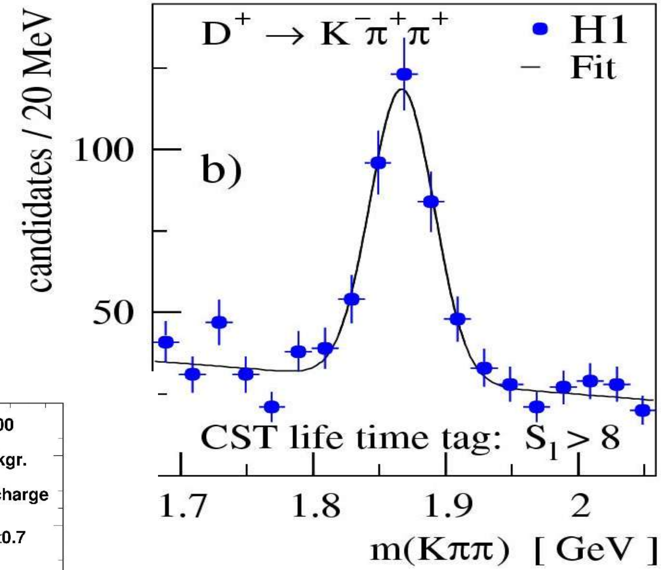
- Fragmentation fractions (total cross sections used):
  - $$f(c \to H) = \frac{\sigma(H)^{tot}}{\sigma(c)^{tot}}$$
- Fragmentation ratios (direct cross sections used):
  - $$R_{u/d} = \frac{\sigma(c\bar{u})_S^{dir} + \sigma(c\bar{u})_V^{dir}}{\sigma(c\bar{d})_S^{dir} + \sigma(c\bar{d})_V^{dir}}$$
  - $$P_V^d = \frac{\sigma(c\bar{d})_V^{dir}}{\sigma(c\bar{d})_S^{dir} + \sigma(c\bar{d})_V^{dir}}$$
  - $$P_V^{u+d} = \frac{\sigma(c\bar{d})_V^{dir} + \sigma(c\bar{u})_V^{dir}}{\sigma(c\bar{d})_S^{dir} + \sigma(c\bar{d})_V^{dir} + \sigma(c\bar{u})_S^{dir} + \sigma(c\bar{u})_V^{dir}}$$
  - $$\gamma_S = 2\frac{\sigma(c\bar{s})_S^{dir} + \sigma(c\bar{s})_V^{dir}}{\sigma(c\bar{d})_S^{dir} + \sigma(c\bar{d})_V^{dir} + \sigma(c\bar{u})_S^{dir} + \sigma(c\bar{u})_V^{dir}}$$

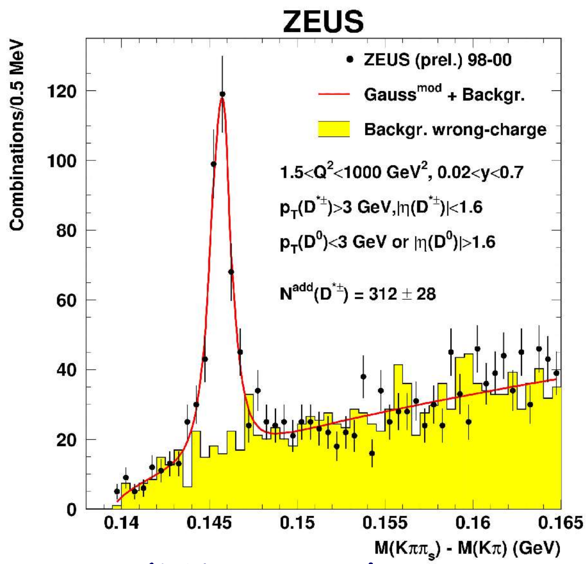


FF and FR of D^+, D^0, D^* and Λ_c

Tracks from Central Detector used:

- $D^0 \rightarrow K\pi$ with π_s from D^*: $\sigma^{tag}(D^0)$
- $D^0 \rightarrow K\pi$ without π_s from D^*: $\sigma^{untag}(D^0)$
- $D^{*\pm} \rightarrow D^0\pi_s \rightarrow K\pi\pi_s$ without vis. D^0: $\sigma^{add}(D^{*\pm})$
- $D^\pm \rightarrow K\pi\pi$: $\sigma(D^\pm)$
- $D_s^\pm \rightarrow \varphi\pi \rightarrow KK\pi$: $\sigma(D_s^\pm)$
- $\Lambda_c^\pm \rightarrow Kp\pi$: $\sigma(\Lambda_c^\pm)$





reflections subtracted, then signal + background shape fitted to invariant mass distribution (H1 uses also secondary vertexes)

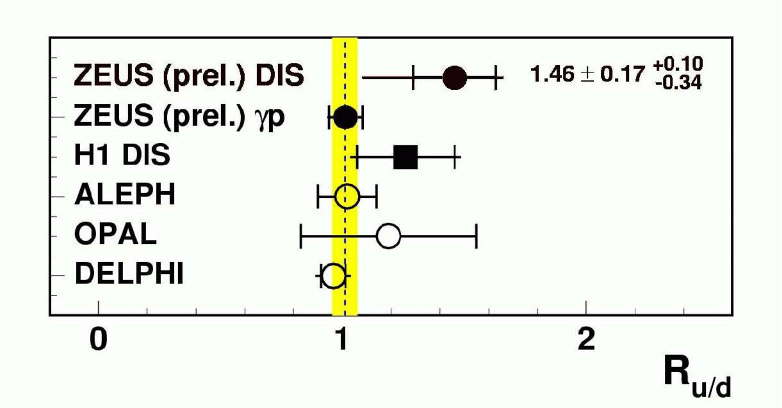
Results: $R_{u/d}$ and γ_s

H1:

$$R_{u/d}=\frac{f(c\to D^0)-f(c\to D^{*+})BR(D^{*+}\to D^0\pi)}{f(c\to D^+)+f(c\to D^{*+})BR(D^{*+}\to D^0\pi)}$$

ZEUS:

$$R_{u/d}=\frac{\sigma^{untag}(D^0)}{\sigma(D^{\pm})+\sigma^{tag}(D^0)}$$

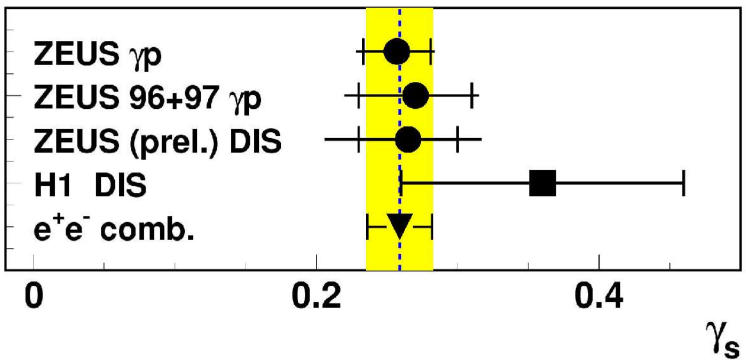


H1:

$$\gamma_s=2\frac{f(c\to D_s^+)}{f(c\to D^+)+f(c\to D^0)}$$

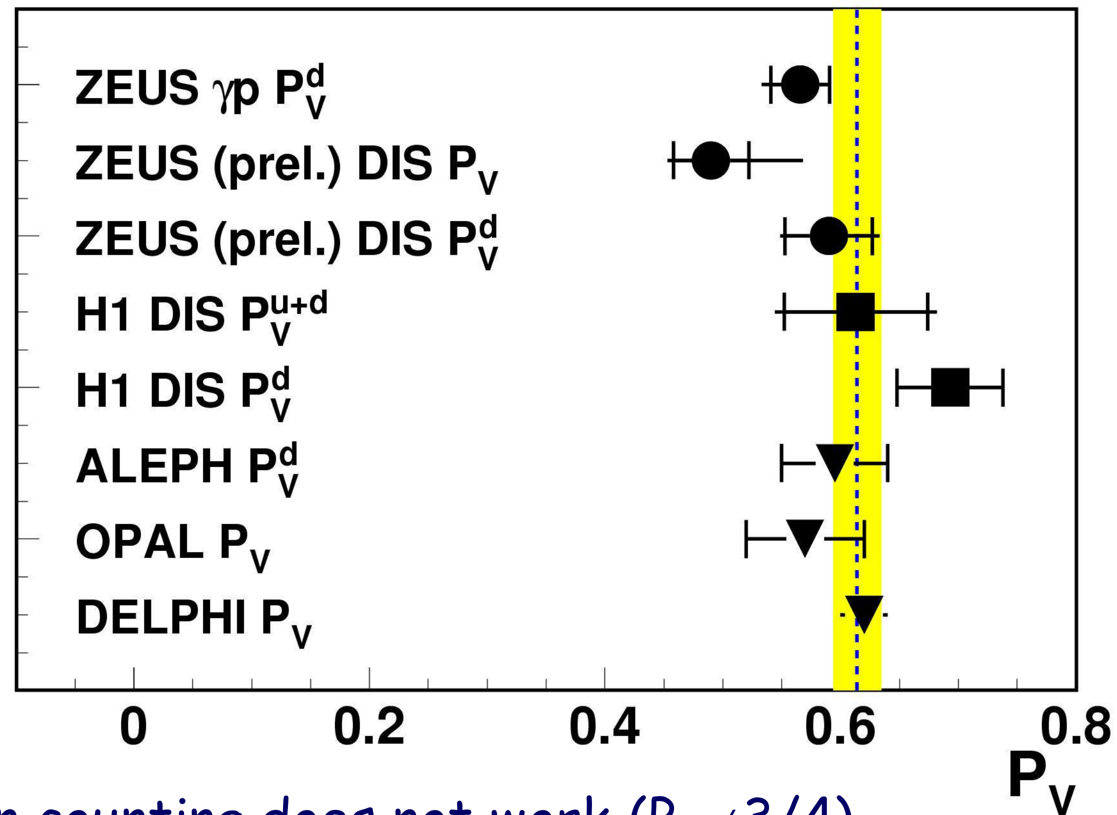
ZEUS:

$$\gamma_s=2\frac{\sigma(D_s^{\pm})}{\sigma(D^{\pm})+\sigma^{tag}(D^0)+\sigma^{untag}(D^0)+2\sigma^{add}(D^{*\pm})}$$



In agreement with each other, expectation and world average

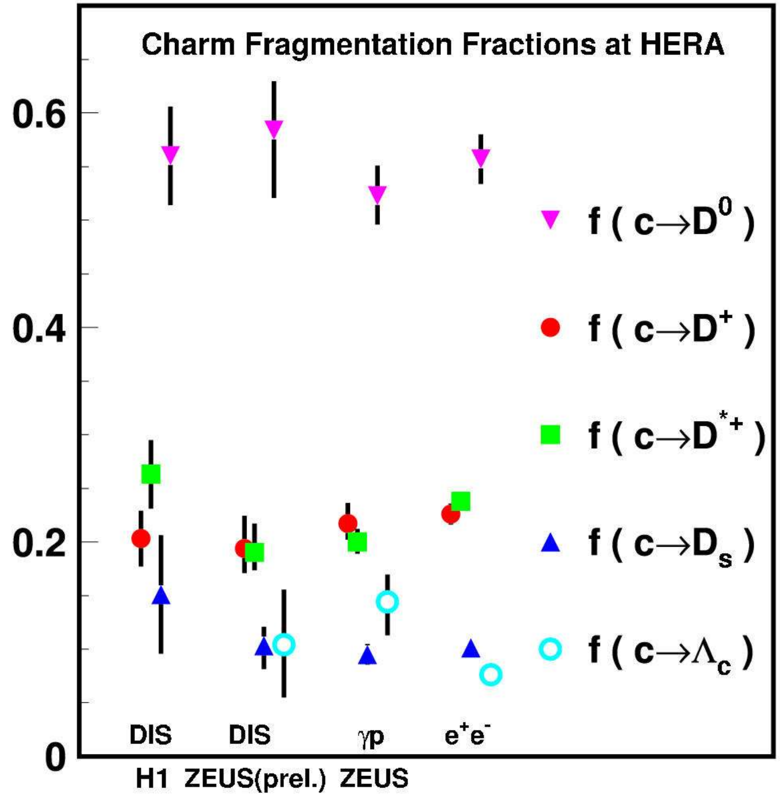
Results: P_V and P_V^d



Naïve spin counting does not work ($P_V \neq 3/4$)

In agreement with world average

Results: fragmentation fractions



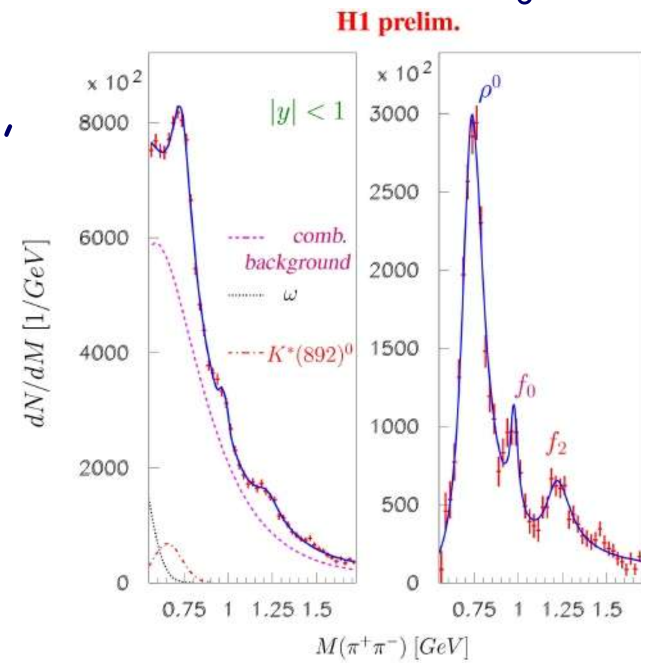
All fragmentation fractions are in agreement with world average and support assumption of universality

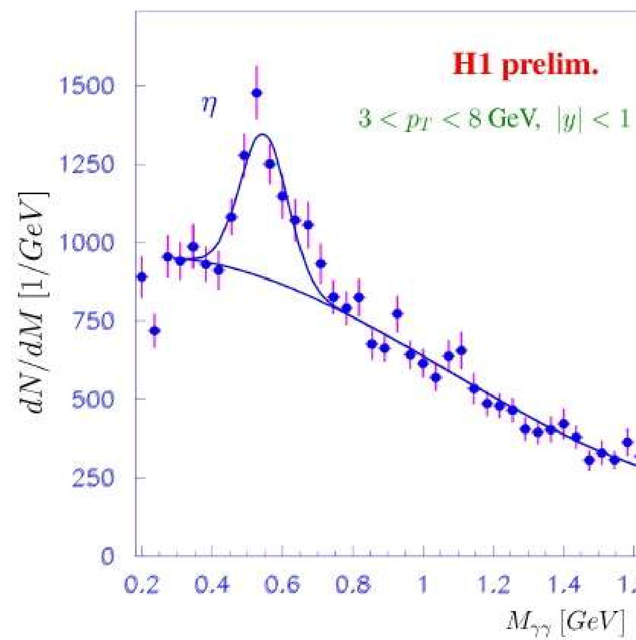
Non-charmed particle productions

In ZEUS and H1 production of well-known hadrons are measured: pions, K^0_s, Λ, protons, charmed mesons, J/ψ...

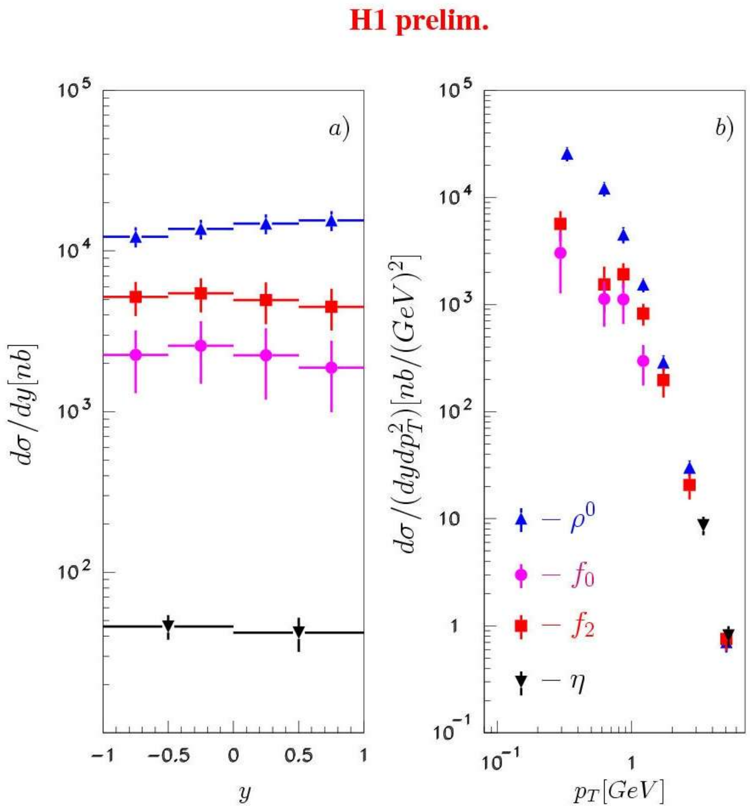
Latest result is the cross section measurement of:

- Inclusive photoproduction of η, ρ^0, $f_0(980)$ and $f_2(1270)$ meson at H1, Photoproduction, 38.7 pb-1, W=210 GeV

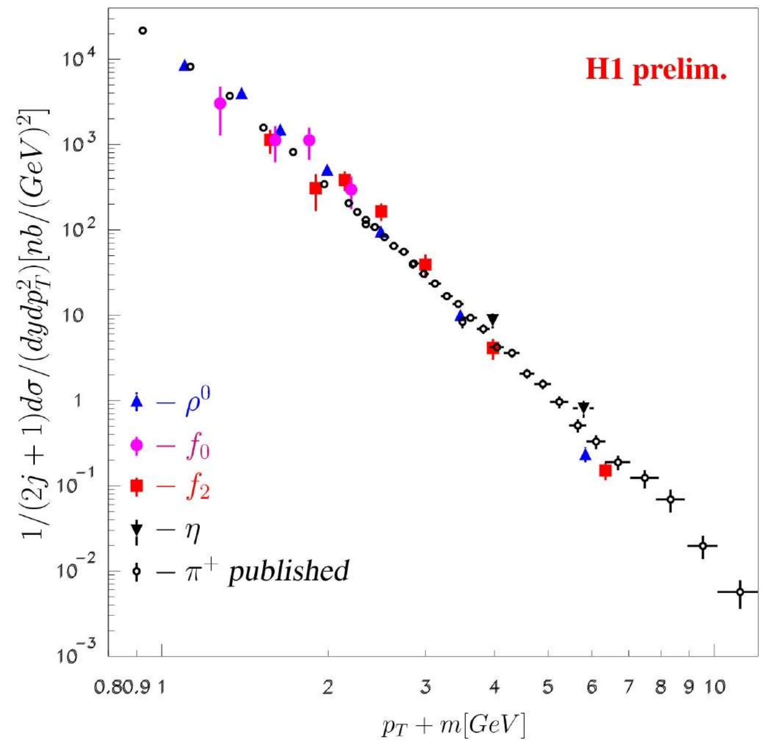




η, ρ^0, $f_0(980)$ and $f_2(1270)$ meson at H1



Flat distribution
in rapidity space

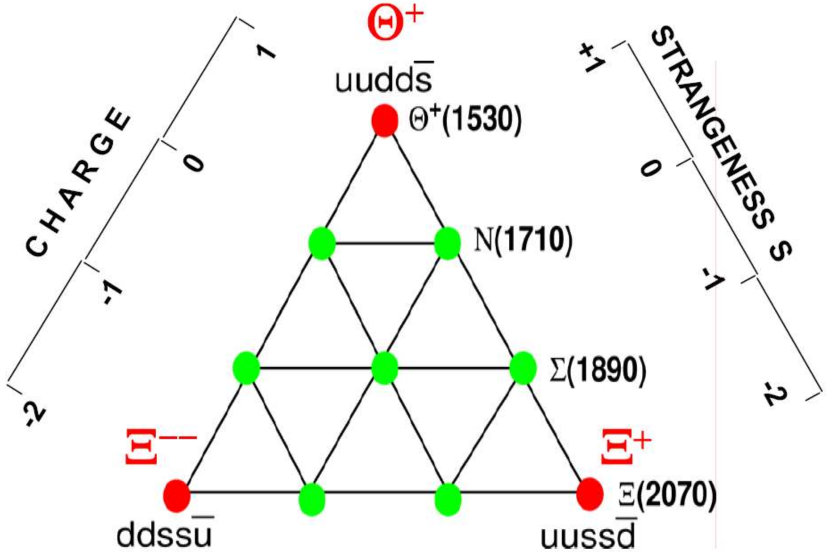


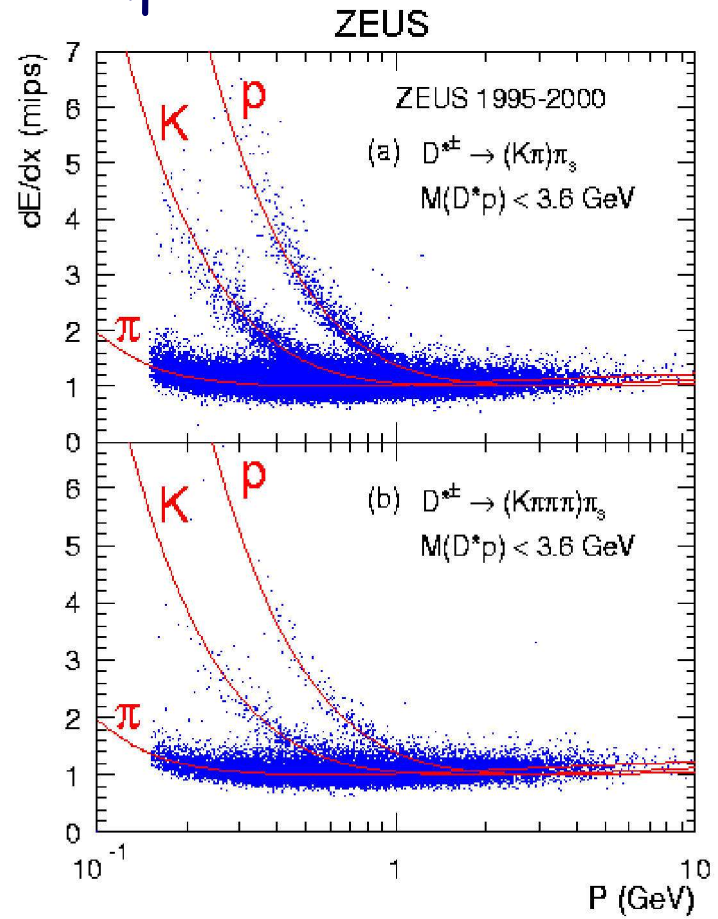
The universal behaviour
of hadrons is observed

Pentaquarks states Theory

The strange Pentaquark anti-decouplet

➢Proposed by Diakonov, Petrov, Polyakov in 1997:
➢3 exotic baryons at corner
➢Prediction of a width less than 15 MeV for the $\theta^{+}(1520)$ state

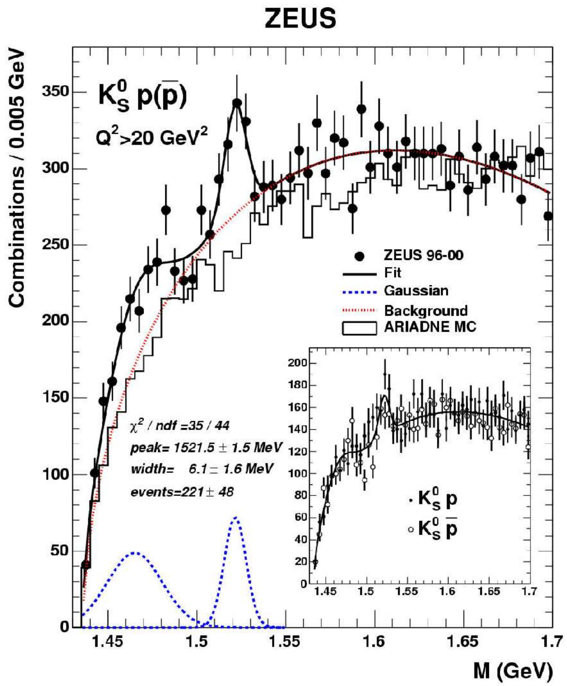


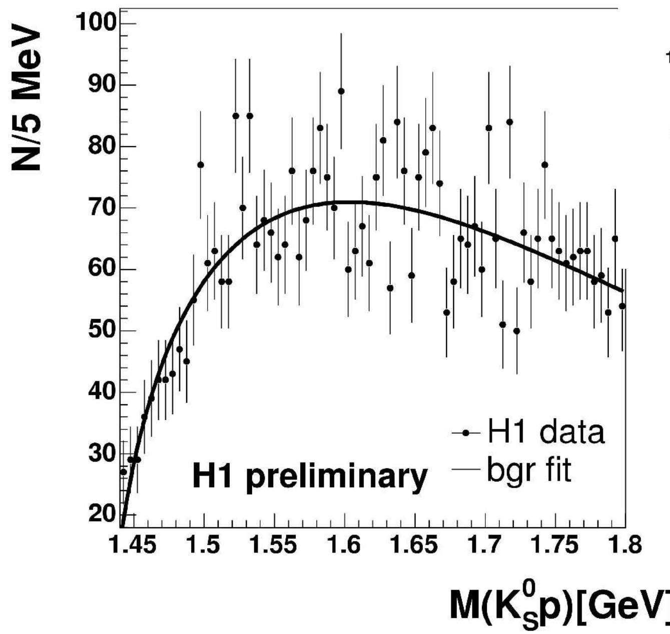


Search for $\theta^{\pm}$

Search for $\theta^{+} \to pK^{0}_{s}$ / $\theta^{-} \to \bar{p}K^{0}_{s}$

- ZEUS:
  - candidate signal produced in forward pseudorapidity region
  - visible cross section measured in DIS
- H1:
  - No peak visible from H1
  - Upper limits on cross section set, do not exclude ZEUS observation





Search for Double Strange $\Xi^{--}_{3/2} \to \Xi^- \pi^-$

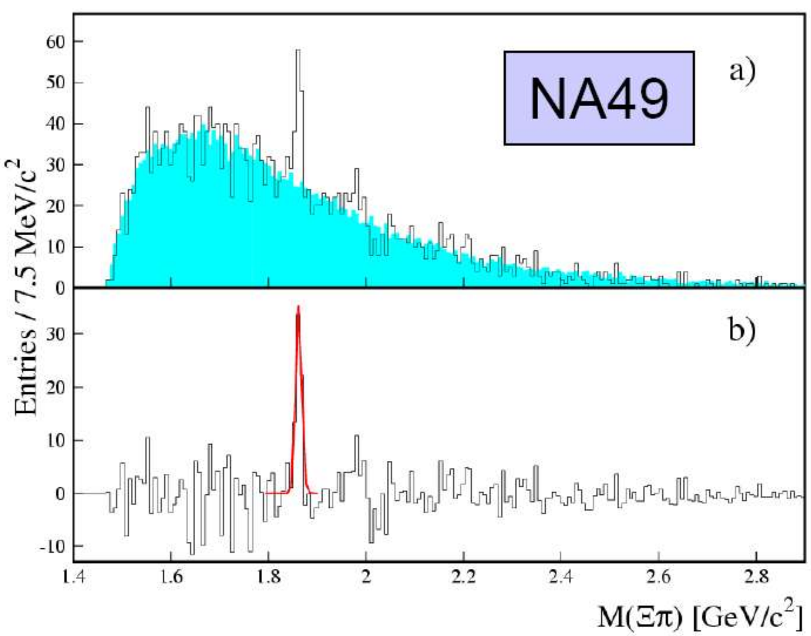
NA49 search for $\Xi^{--}_{3/2} \to \Xi^- \pi^-$

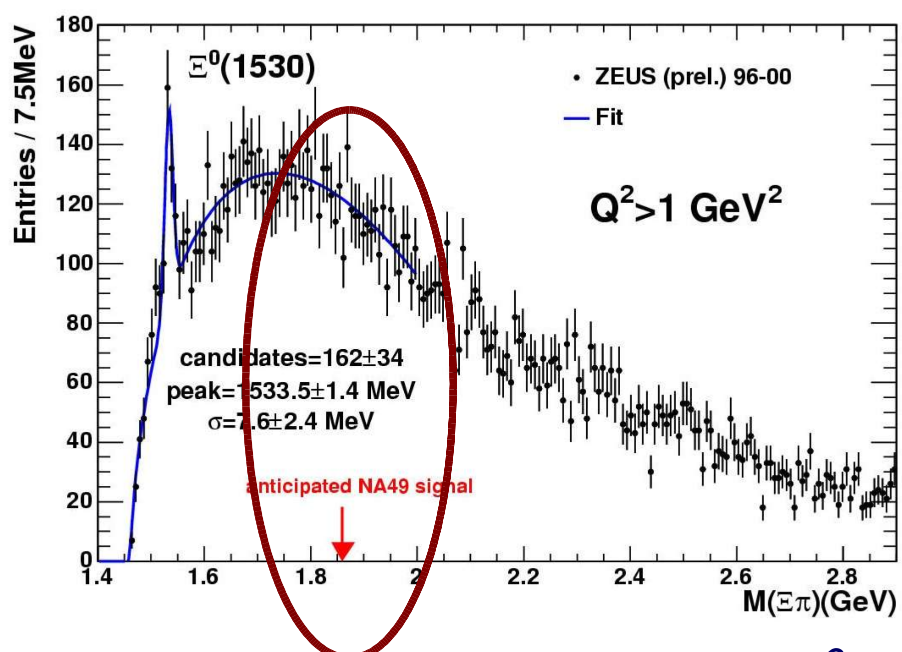
M=1862 ± 2 MeV

width < 18 MeV, ~3σ

Similar analysis of NA49 repeated using ZEUS DIS data

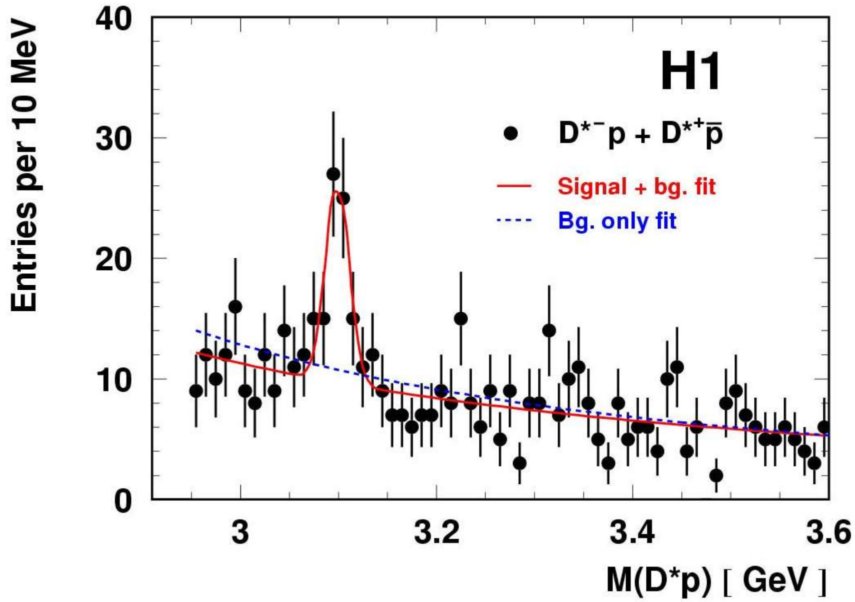
$\Xi^{--}_{3/2} \to \Xi^- \pi^- \to \Lambda^0 \pi^- \pi^- \to p \pi^- \pi^- \pi^-$



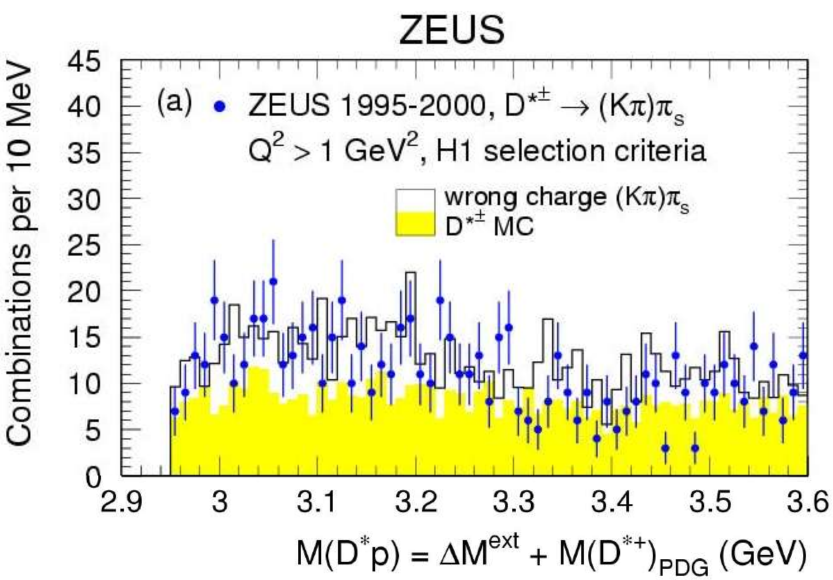


ZEUS: clean $\Xi^0(1530)$ but no pentaquark signal for $Q^2>1$ and $Q^2>20$ GeV^2, not observation due to different phase space?

Search for $\theta_c \to D^* p$



Comparison of H1 and ZEUS in similar phase space region



ZEUS do not observe θ_c signal in a DIS data sample 1.7 times of H1 data sample
(H1 see the signal also in PHP, ZEUS neither in photoproduction)

Acceptance corrected $R_{cor}(D^*p(3100)/D^*)$

H1:

kinematic region: $1<Q^2<100$ GeV^2 and $0.05<y<0.7$

in the visible D^*p range: $p_T(D^*p)>1.5$ GeV, $-1.5<\eta(D^*p)<1.0$

and visible D^* range: $p_T(D^*)>1.5$ GeV, $-1.5<\eta(D^*)<1.0$

$R_{cor}(D^*p(3100)/D^*)=(1.59 \pm 0.33(stat)\ ^{+0.33}_{-0.45}(syst))\%$ prel

ZEUS:

kinematic region: $Q^2>1$ GeV^2 and $y<0.957$

phase space: $p_T(D^*)>1.5$ GeV, $-1.5<\eta(D^*)<1.0$

95% C.L. upper limit:

$R_{cor}(D^*p(3100)/D^*)<0.59\%$ ($<0.51\%$ for both D^0-decay channels)

ZEUS: full kinematic region (DIS+photoproduction)

95% C.L. upper limit:

$R_{cor}(D^*p(3100)/D^*)<0.47\%$ ($<0.39\%$ for both D^0-decay channels)

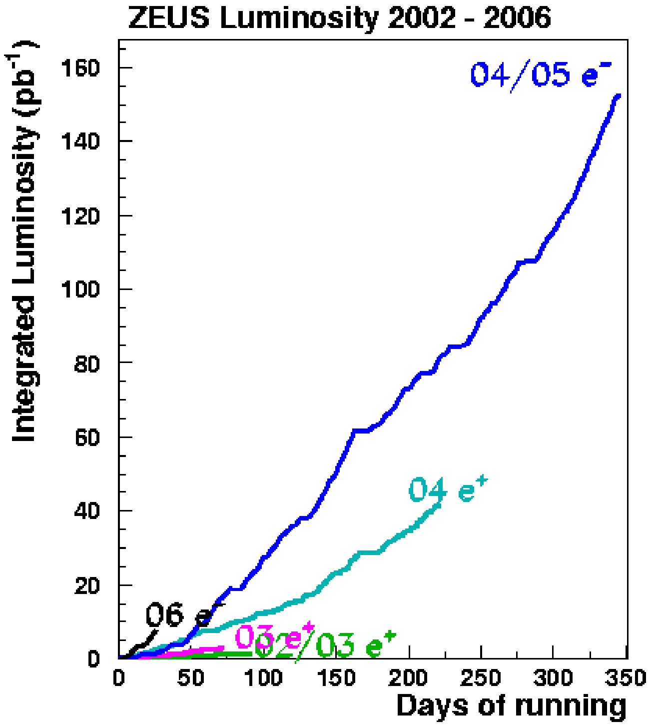
Observation of ZEUS and H1 are not compatible

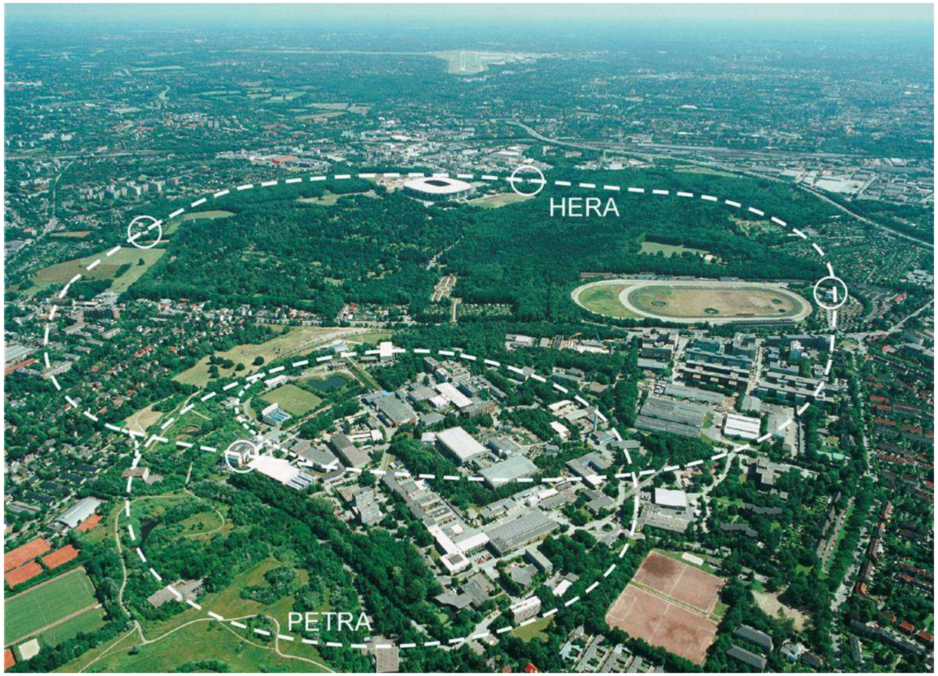
Conclusions

Precise measurements in wide kinematic ranges have been presented

- inclusive cross sections of $D^{\pm}$, D^{0}, D^{*} and Λ_c , were measured in DIS and photoproduction
- extracted fragmentation ratios and fractions support assumption of universality
- η, ρ^{0}, $f_0(980)$, $f_2(1270)$: inclusive cross-section for hadronic resonances has the same behaviour as observed for long-lived hadrons
- $\theta^{+}(1530)$: evidence for a narrow state (ZEUS). H1 does not observe this state but upper limit does not exclude ZEUS observation
- $\Xi^{-}(1860)$: no evidence for the NA49 signal at 1862 MeV (ZEUS)
- $\theta^{0}_{c}(3100)$: evidence from H1 for the narrow resonance, ZEUS with larger statistic does not see this signal
- Need more statistics (HERA2) to confirm or exclude the observations

HERA Collider





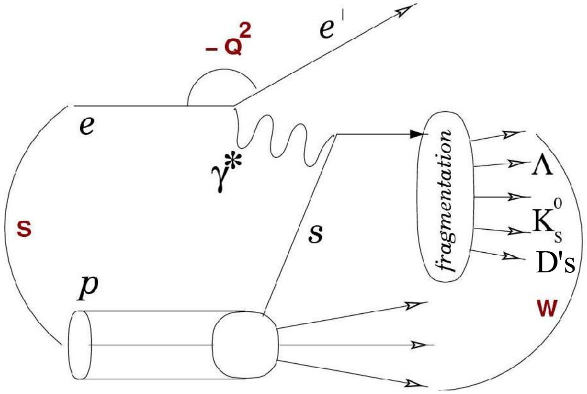
ep kinematics

photon virtuality Q^2

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

$Q^2 \approx 0$ GeV^2 -- photoproduction

$Q^2 > 1$ GeV^2 -- electroproduction (DIS)



Kinematics

$e(k)p(P) \rightarrow e(k')V(v)p(P')$

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

$s = (k+P)^2$

$W^2 = (q+P)^2$

$y = (P \cdot q)/(P \cdot k)$

$x = Q^2/(2P \cdot q)$