Strange particle production at HERA

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on behalf of the ZEUS and H1 Collaborations

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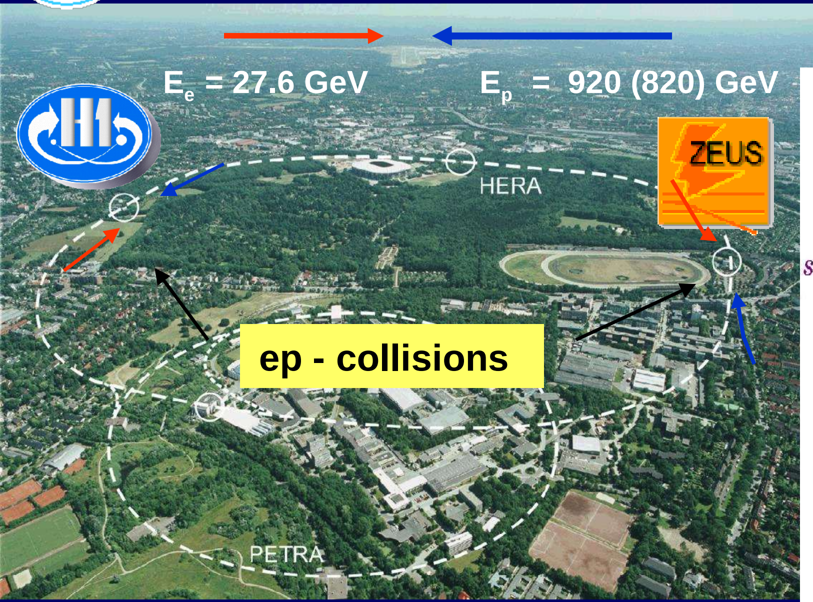
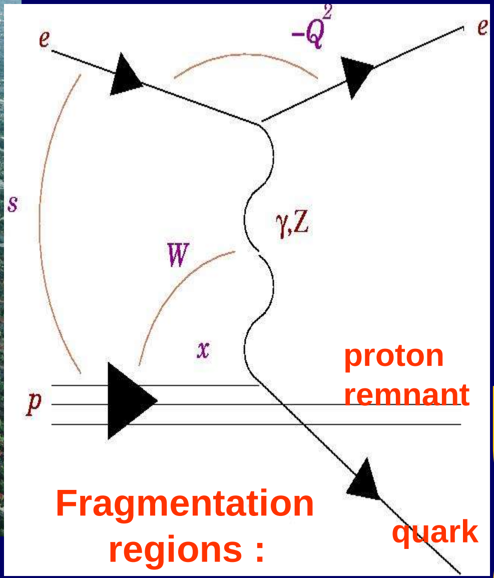
- Motivation
- Inclusive strange particle production
- Bose - Einstein correlations
- Pentaquarks
- Summary

HERA - Hamburg

ep – collisions → hard and soft processes





Hadronisation :
non- perturbative process

Multihadron (including strange particles) description:

Analytical QCD +
LPHD hypothesis approach
Monte Carlo QCD based models :
ARIADNE + JETSET / PYTHIA
HERWIG

Data:

- identified separate hadrons and resonances
- multihadron production

Inclusive Deep Inelastic Scattering at HERA:
$ep \to e' X$

Kinematics of DIS

s : e-p c.m. energy , $\sqrt{S} \approx$ **300 – 318 GeV**
Q^2 : = $-q^2$, 4-momentum transfer squared
x : fraction of p momentum carried by quark
y : inelasticity parameter
W : γ-p c.m. energy

Q^2 ~ 0 : photoproduction

Soft processes can be studied in:

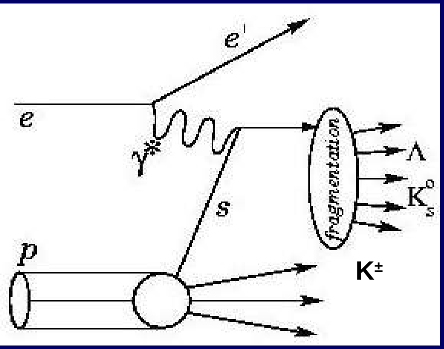
- photoproduction
- hadronisation

Strange particle studies in DIS

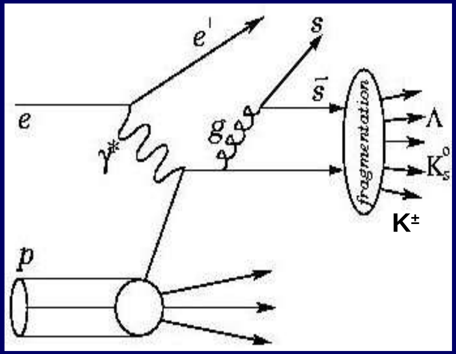
- Strange hadron production in particularly baryons - not well understood
- Universal strange particle fragmentation ?
  - → ratio baryon to meson production
  - → baryon and antibaryon production difference
- Comparison with other particle interaction processes
- Is the strangeness suppression factor different in e^+e^- and ep interactions ?
- If the space - time characteristics of emission source are different for strange particles ?
- Does radius of emission volume depend on hadron mass ?

Strange particle production

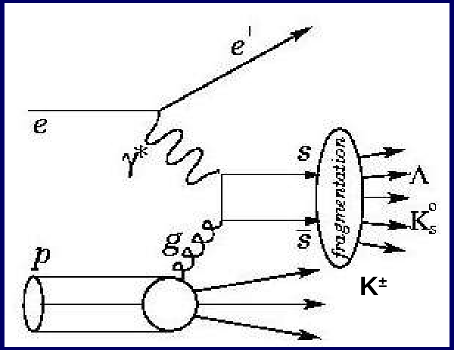
Strange quark production : possible mechanisms



Flavour excitation - hard scattering of sea quark

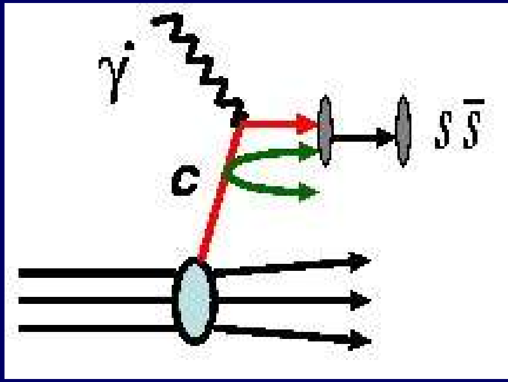


Gluon- splitting



Boson - gluon fusion

and



Heavy quark decay

Probably other ...

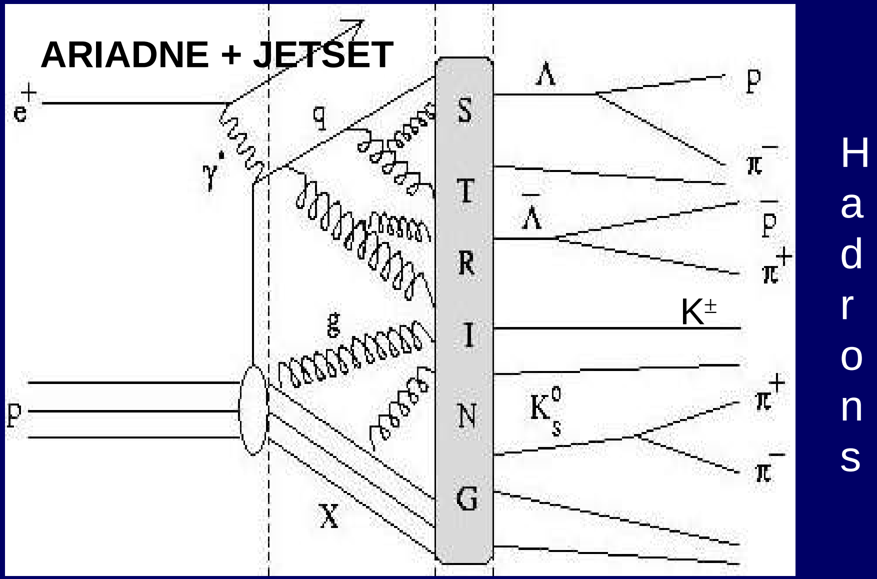
Next step : fragmentation to hadrons - non perturbative process

Fragmentation models

ARIADNE plus JETSET

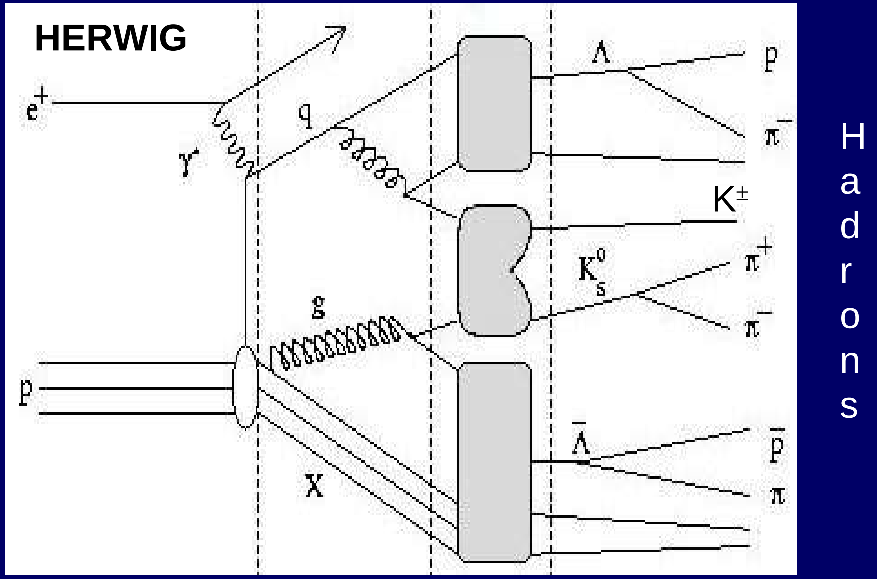
- QCD parton cascade: Color Dipol Model
- Lund string fragmentation

Strangeness suppression factor :
λ_s = P(s) / P(u) ; P(u) = P(d)



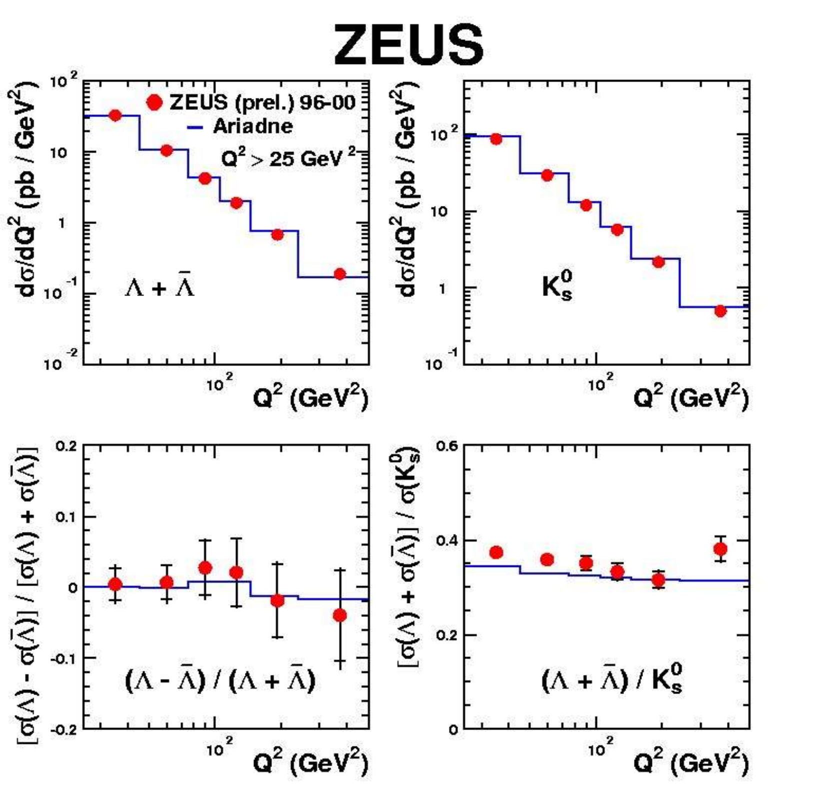
HERWIG

- Parton shower
- Production and decay colour singlet clusters

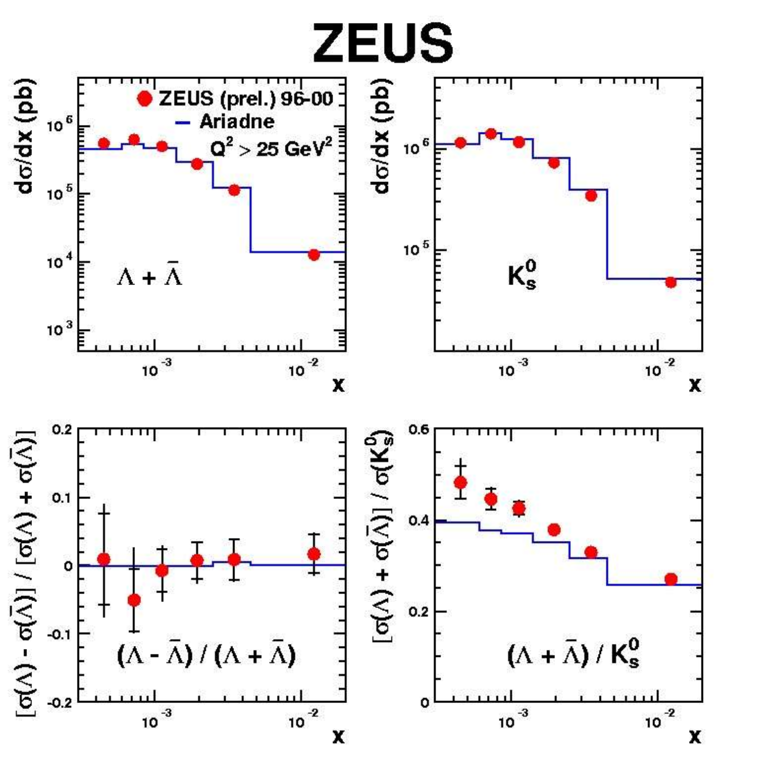


Neutral strange particles

- Differential cross sections
- Baryon to antibaryon production asymmetry
- Baryon to meson ratio



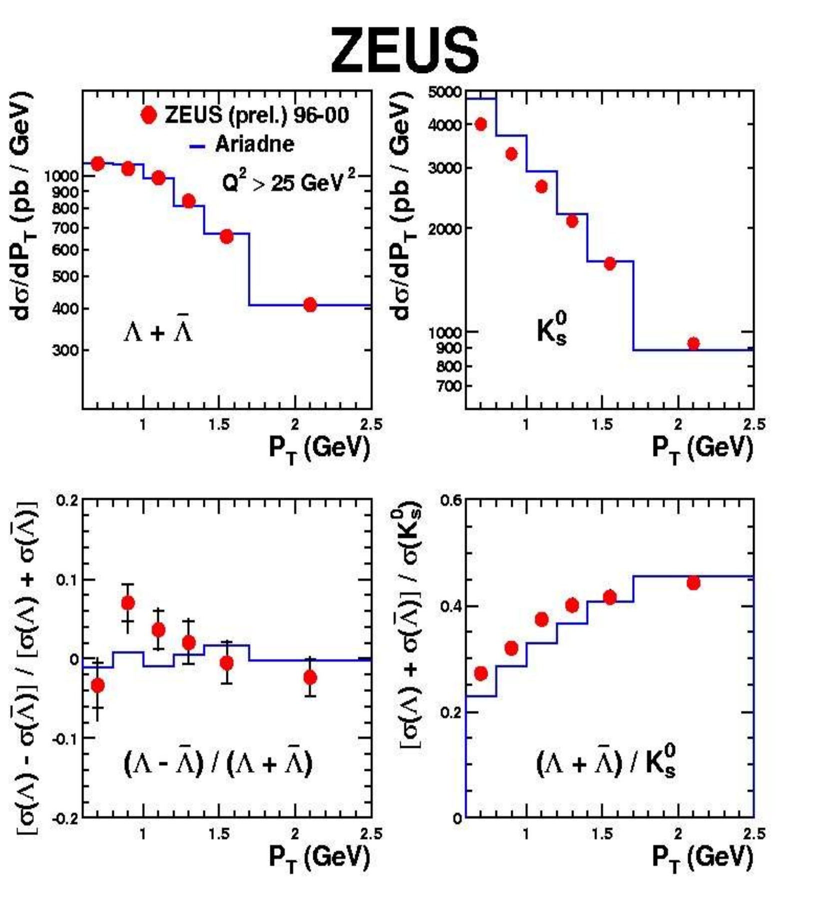
Reasonable description of x-sections by ARIADNE

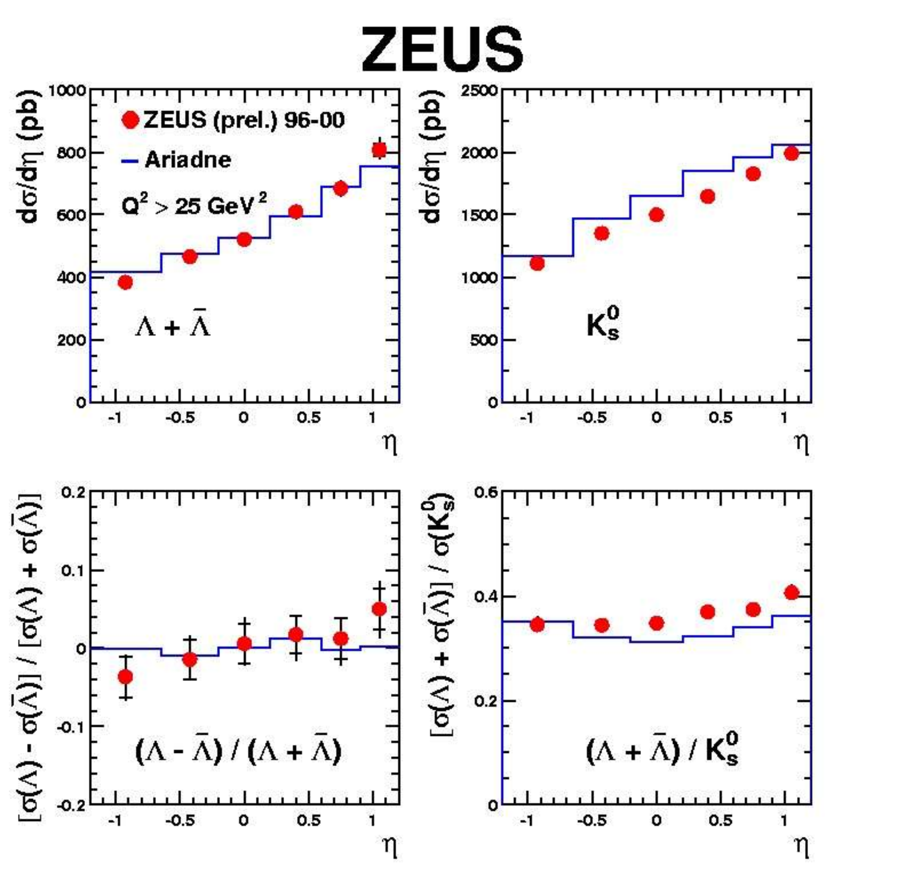


- No baryon anti-baryon asymmetry
- Small access in baryon to meson ratio over the ARIADNE at small Q^2

- No baryon antibaryon asymmetry
- Rise of baryon to meson ratio for decreasing x
- ARIADNE underestimates low x region

Cross sections : p_T and η dependence – Lab frame





- ARIADNE overestimates K_S^0 rate for small p_t

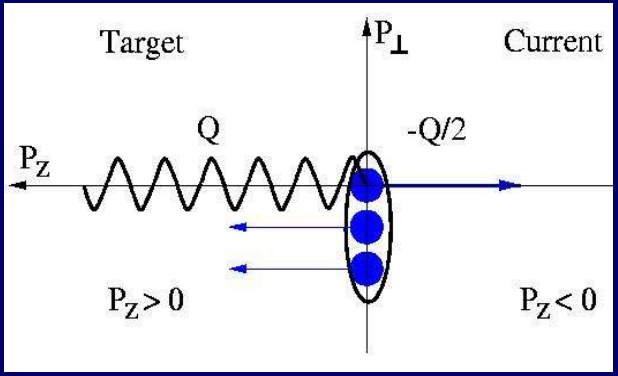
$\rightarrow$ ratio baryon / meson underestimated in MC

- No significant baryon - antibaryon asymmetry

- ARIADNE overestimates K_S^0 production
- No baryon - antibaryon asymmetry
- Baryon to meson ratio: some rise in forward (proton fragmentation) region ?

Strange particles - Breit frame fragmentation studies

Breit frame

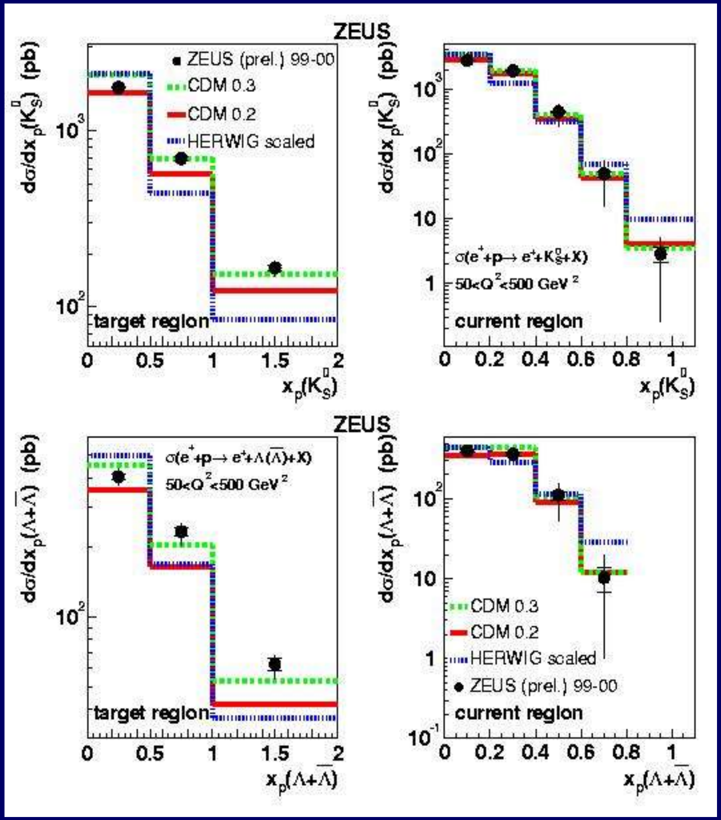


Separates struck quark (current hemisphere) and proton remnant (target hemisphere)

Fragmentation studies based on scaled momentum distribution **$x_p = 2\,p\,/\,Q$**

Current region is analogous to single hemisphere of e^+e^- annihilation

Studies: comparison **x_p** distributions for Λ , $\bar{\Lambda}$ and **K_S^0** with different MC - **Ariadne (CDM)** - for different λ_s and **HERWIG**



HERWIG fails to descibe the cross section behaviour

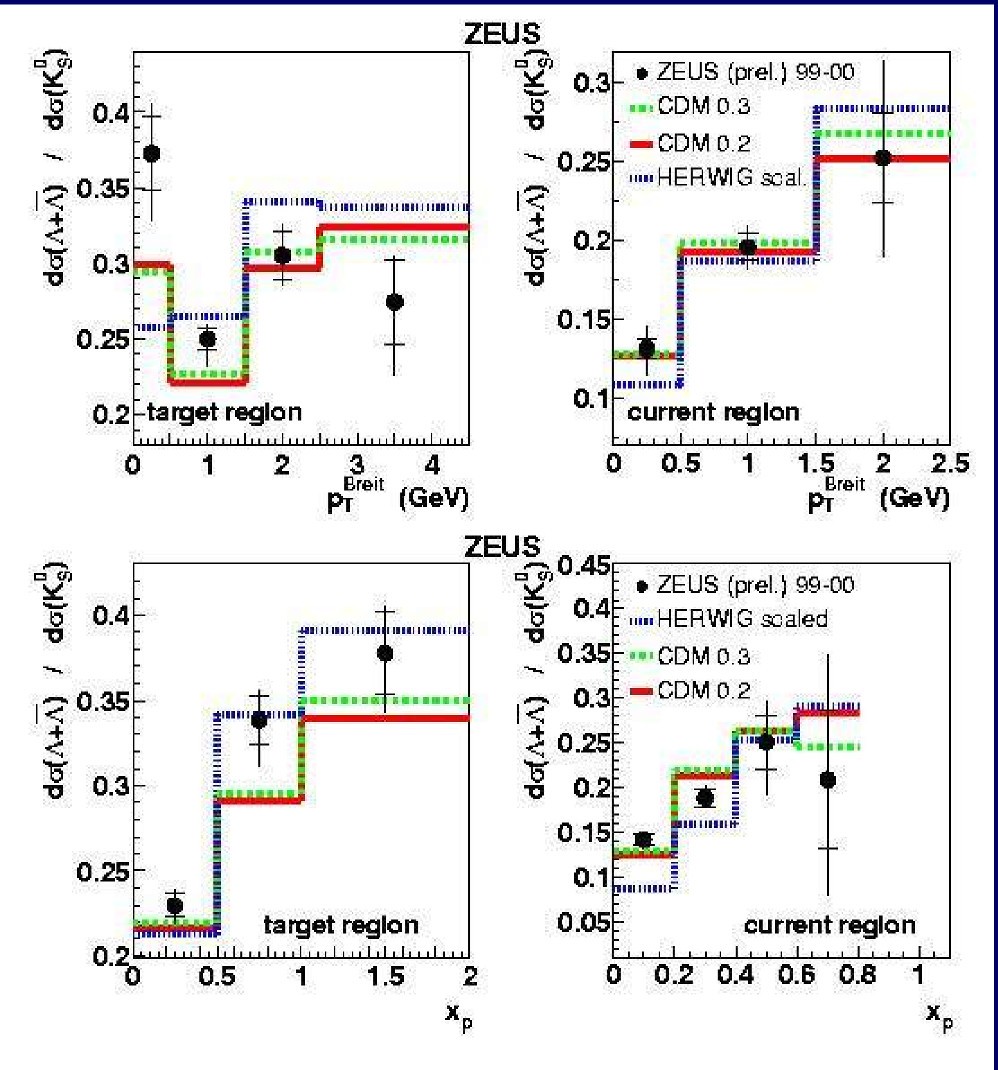
For current region agreement with **CDM** is reasonable already for **λ_s = 0.2**

For target region CDM distribution closer to data for **λ_s = 0.3**

CDM is more sensitive for changes of λ_s

Strangeness suppression related to gluon density in the proton remnant?

Breit frame - ratio Λ / K^0_S measurements



In current region :

reasonable agreement with ARIADNE (CDM) Monte Carlo for $\lambda_S = 0.2$

different behaviour for HERWIG

In target region :

problem with description of the ratio as function of p_T^{Breit} - an effect of reconstructed Λ in Lab ?

similar trend for x_p dependence in data and ARIADNE MC - but smaller values
Larger value : $\lambda_S \approx 0.3$ is expected

More statistics is necessary

Bose-Einstein correlations in $K^{\pm}$ and $K^0_S K^0_S$ pairs

BE effect for pairs of identical bosons : symmetrization wave-function –> interference effect – enhancement in the bosons production with similar momenta.

BE effect :

- related to the space-time characteristic of the particle emission source
- gives information about hadronisation process
  - emission volume measured in different reactions: ee ep hh AA
  - radius dependence of the emission volume on the produced hadron mass

Experimentally : BE correlation function can be measured from two-particle distribution **R** :

$R(Q_{12}) = P(Q_{12}) / P_{ref}(Q_{12})$ as function of the 4 - momenta difference of the two particles : $Q_{12} = \sqrt{-(p_1 - p_2)^2}$

P / **P**

Standard parametrisation of **R** : **Goldhaber parametrization**: $R(Q_{12}) \propto (1+\lambda \exp(-r^2 Q_{12}^2))$

(assuming spherical emitting souce)

extraction from fit to data: **r** - radius of the emitting source

λ - strength of the effect - degree of incoherence

(0 –fully coherent, 1 fully incoherent)

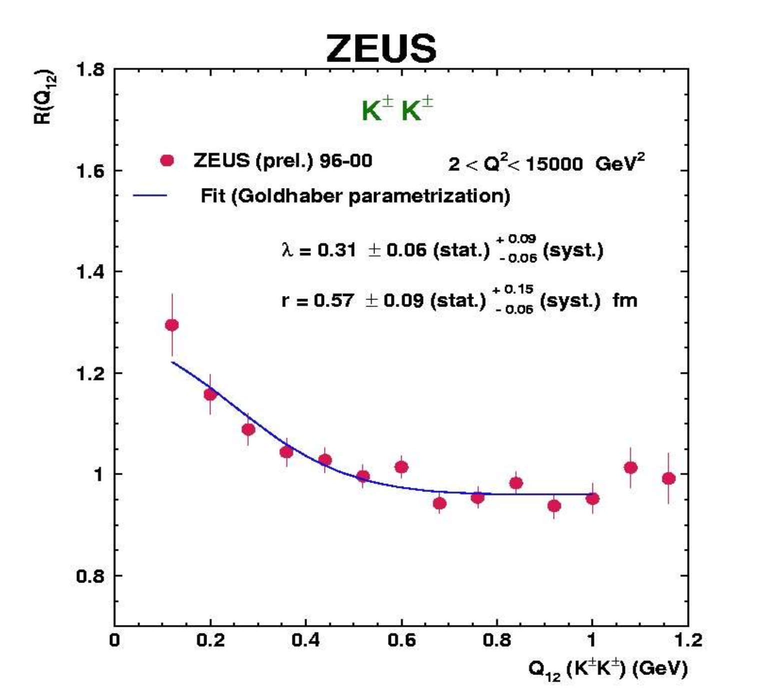
BEC - charged $K^{\pm}$

Use double ratio method with mixed sample pairs of Kaons from different events

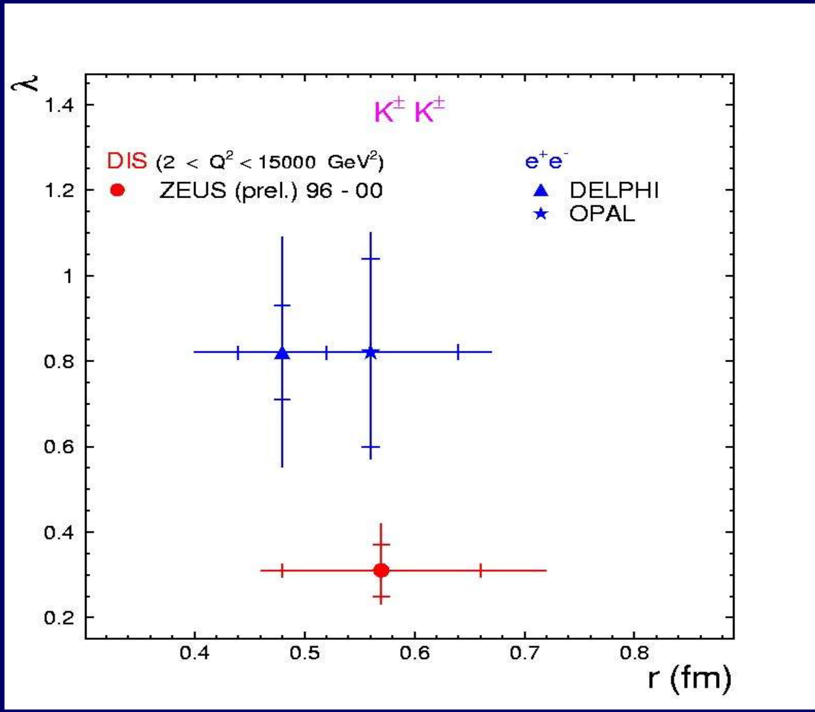
$$R(Q_{12}) = P(Q_{12})_N^{data} \;/\; P(Q_{12})_N^{MCnoBEC}$$

$$P(Q_{12})_N^{data} = P(Q_{12})^{data} \;/\; P_{mix}^{data}(Q_{12})$$

$$P(Q_{12})_N^{MCnoBEC} = P(Q_{12})^{MC} \;/\; P_{mix}^{MCnoBEC}(Q_{12})$$



$\lambda = 0.31 \pm 0.06$ $+ 0.09 \;\; - 0.06$ (syst.)

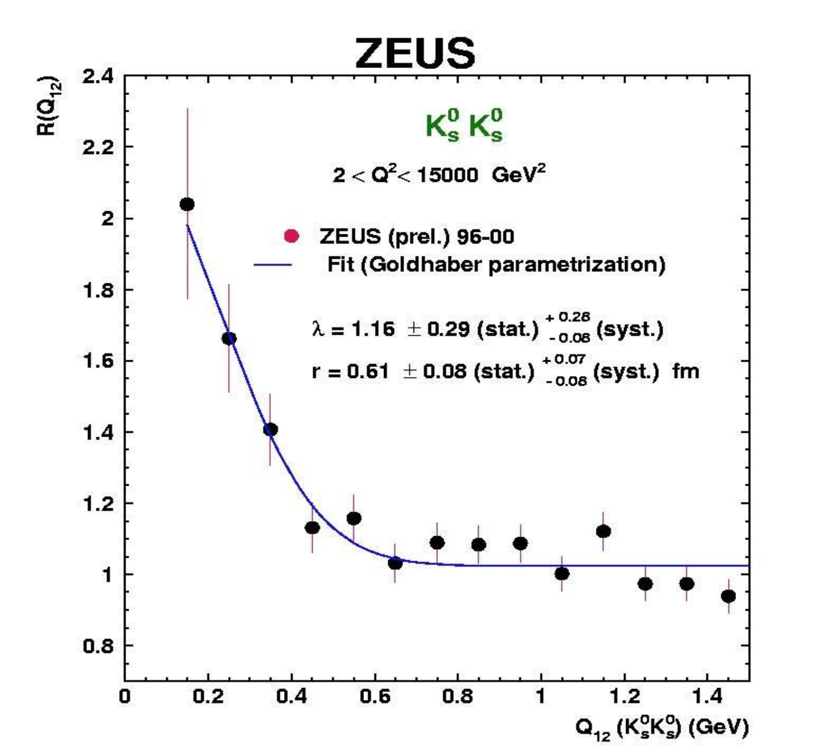


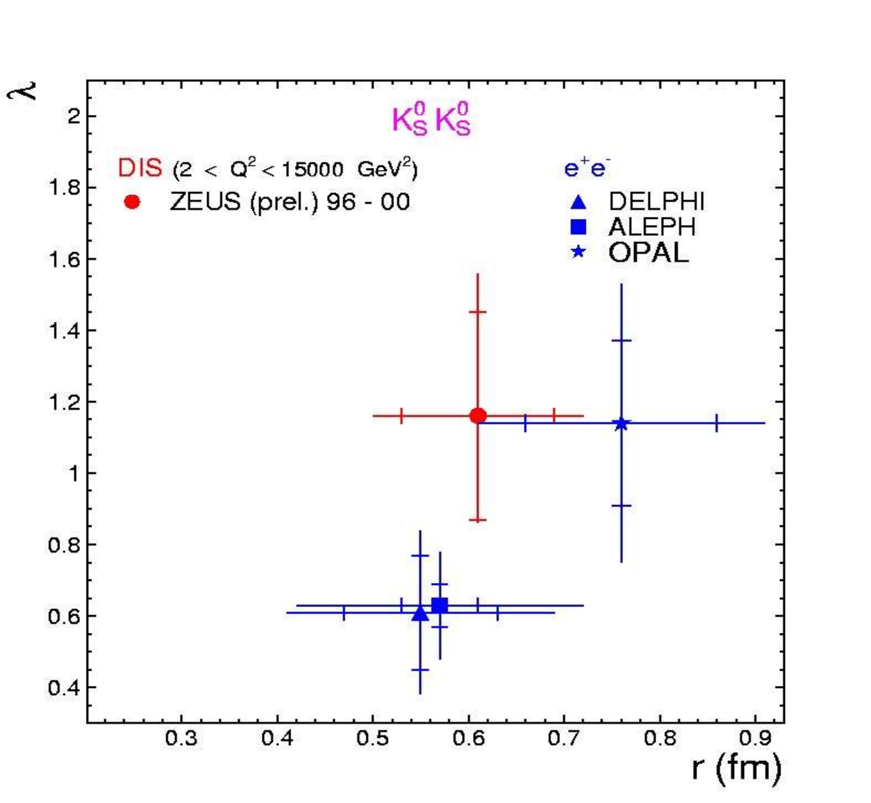
Smaller λ in comparison to e^+e^- $\rightarrow$ data populate mostly proton remnant fragmentation region

$r = 0.57 \pm 0.09$ (stat.) $+0.15 - 0.06$ (syst.)
similar to previous ZEUS result for charged pions :
$r_\pi = 0.666 \pm 0.009$ (stat.) $+0.022 - 0.036$ (syst.)

Strong signal of φ^0**(1020)** resonance in data $\rightarrow$ it is possible that at least one kaon in pairs coming from φ^0

BEC - $K^0_S K^0_S$ pairs





BE effect cleary visible

r = 0.61 ± 0.08 + 0.07 - 0.08 (syst.)
λ = 1.16 ± 0.29 + 0.28 -0.08 (syst.)

r value for K_S^0 in good agreement with $K^\pm$

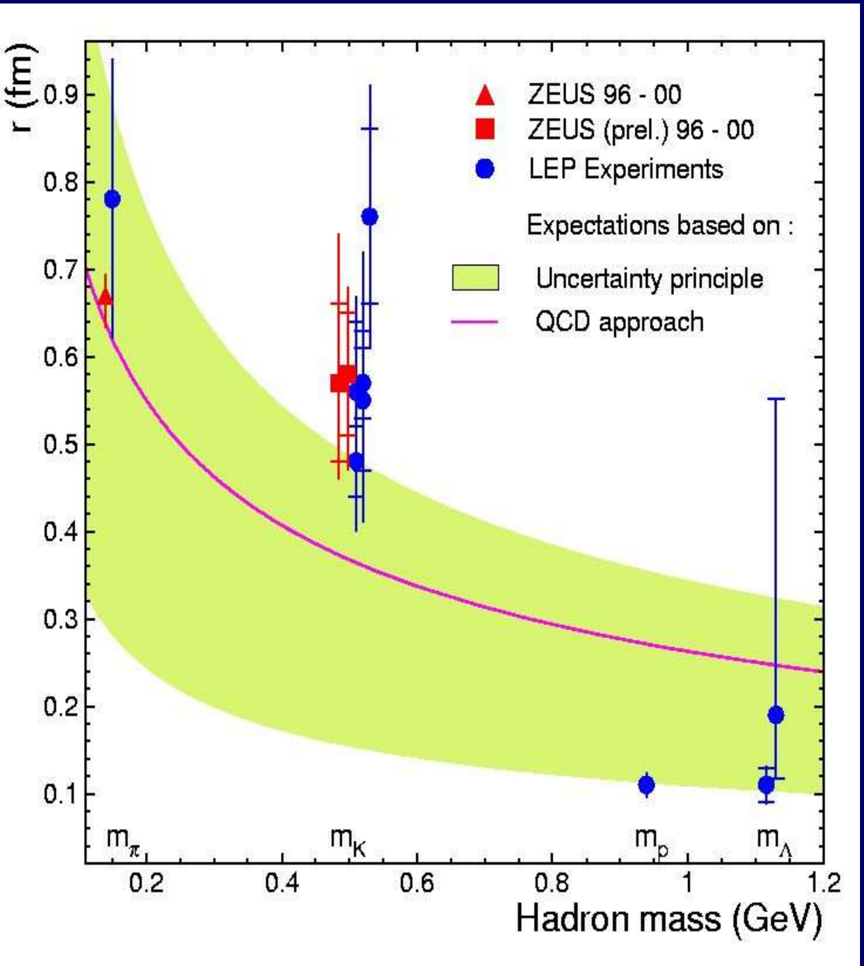
large λ → low Q_{12} affected mainly by **f⁰(980)** resonance which not well descibed by simulation.

Agreement with **e^+e^- (LEP)** for **radius**

λ value larger than for **ALEPH** and **DELPHI** and more similar to **OPAL**

Influence of **f⁰(980)** :
removed by **ALEPH** and **DELPHI**

Dependence of BEC radius on hadron mass



Experimental indication:

$$r(m_\pi) > r(m_K) > r(m_p) > r(m_\Lambda)$$

Theory [123]:

- LUND model does not predict such dependence of r(m)

however

- Heisenberg uncertainty relations and QCD via virial theorem can describe such mass dependence

But the situation is not so clear :

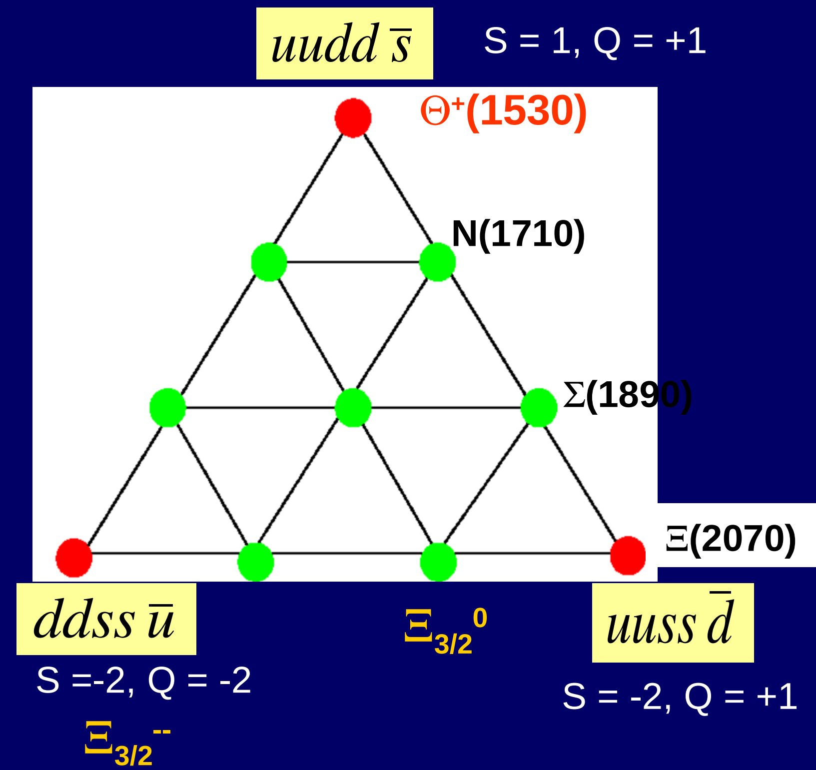
r values for pions and kaons are not so different and the effect comes from heavier particles $\rightarrow$
more precise measurements from different processes are necessary

HERA results on protons and Λ will be available soon

1 G. Alexander et al., Phys. Lett. B452 (1999) 159
2 G. Alexander, Rep. Prog. Phys. 66 (2003) 481
3 B. Anderson, Phys. Rep. 97 (1983) 31

Search for pentaquarks

QCD allows for **5–quarks** hadronic states
These exotic states so-called **pentaquarks** with
4 q + $\bar{q}$ can be produce as bound " stable ''
(colourless) particles



Support from Theory - an example :
Chiral quark soliton model → antidecuplet pentaquarks

D. Diakonov et al. (**Z. Phys. A.359 (1997) 305**) : lightest member: narrow (Γ < 15 MeV) exotic state
This so-called Θ^+ pentaquark has mass ≈ 1530 MeV and includes an anti-strange quark *$uudd\bar{s}$*
Possible decays : Θ^+ **(1530)** → **K^+n** or **K^0p**

Other possible 5-quarks states:

- two strange quarks like $\Xi_{3/2}^{-}$ (**$ddss\bar{u}$**) and $\Xi_{3/2}^{0}$ decaying into Ξ and charged pions

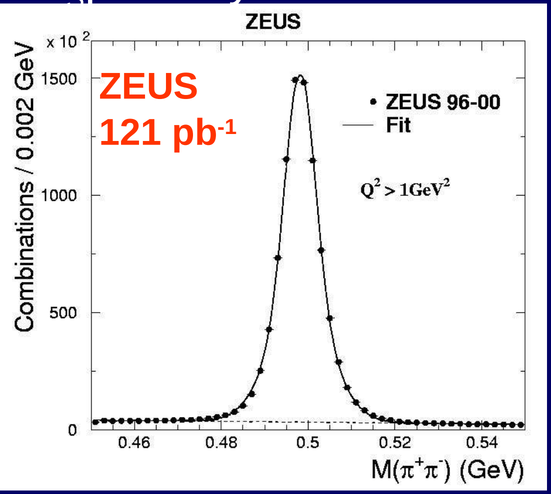
Search for pentaquarks in high energy **ep** collisions by ZEUS / H1

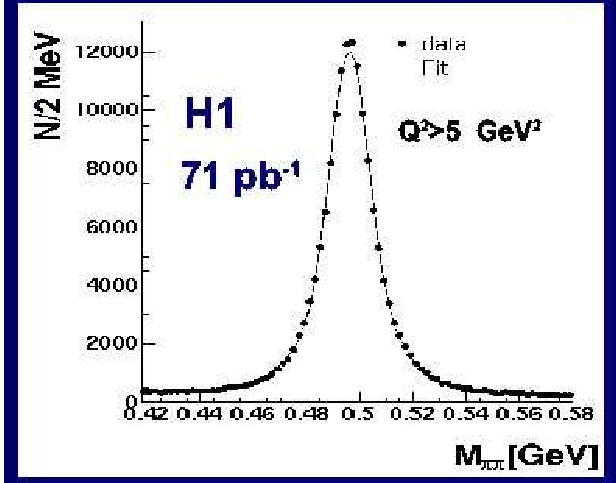
Strange pentaquark Θ^+ - DIS / photoproduction studies

$e^\pm p \rightarrow e^\pm \Theta^+ X \rightarrow e^\pm K^0 p X$

ZEUS / H1 : reconstructed $K_S^0 p (\bar{p})$ invariant mass distribution :

$K^0_S p$ decay mode : well reconstructed K^0_S and proton

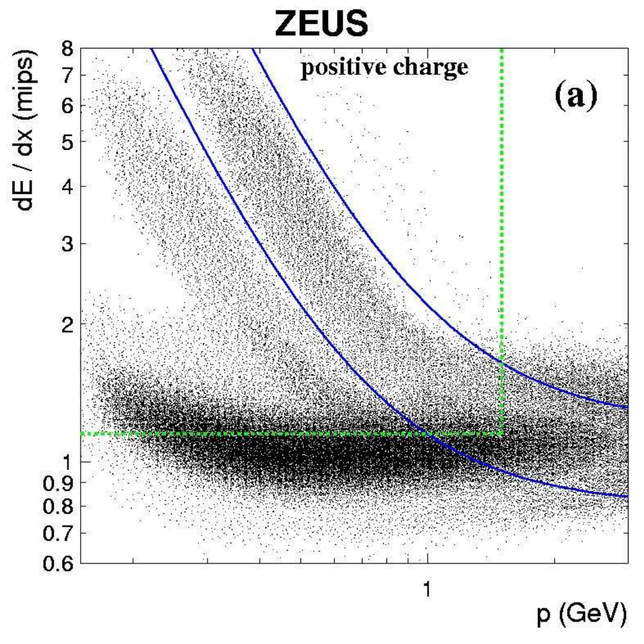




K^0_S reconstruction:

- $K^0_S \rightarrow \pi^+\pi^-$ using secondary vertex
- $p_T(K^0_S) > 0.3$ GeV , $|\eta(K^0_S)| < 1.5$
- remove Dalitz e^+e^- pairs and Λ's

An example : band method



Proton reconstruction :

- tracks from primary vertex
- dE/dx identification :

  ZEUS - band method and
  cuts : dE/dx>1.15, p < 1.5 GeV

  H1 - likelihood method - dE/dx -
  momentum can be > 1.5 GeV

Mass resolution for $K^0_S p$: ZEUS - 2.4 MeV
H1 - 5 MeV

Positive results for Θ^+

V. D Burkert , LP2005

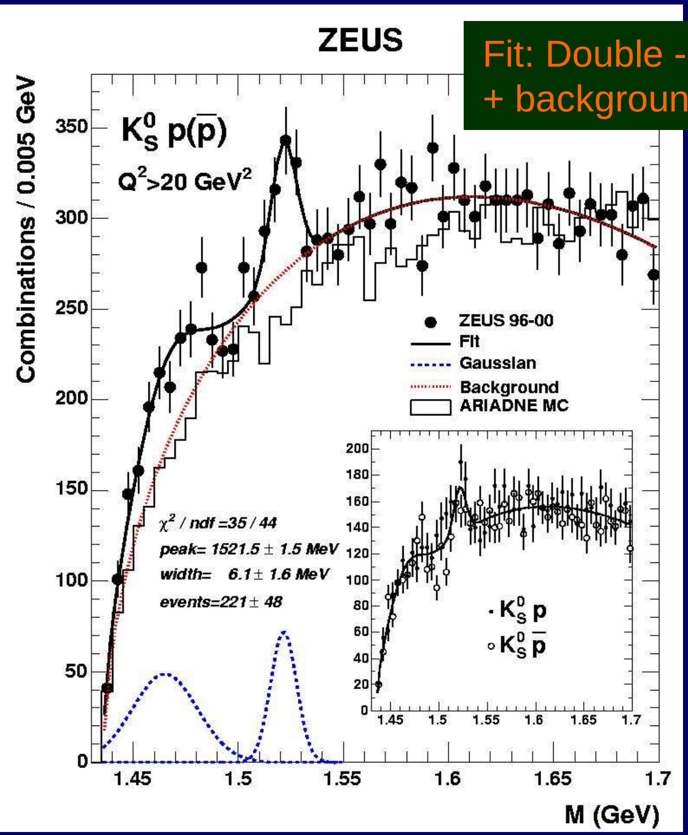
Group	Reaction	Mass	Width	σ s
LEPS	$\gamma C \to K^+K^- X$	1540 +- 10	< 25	4.6
DIANA	$K^+Xe \to K^0p X$	1539 +- 2	< 9	4.4
CLAS	$\gamma d \to K^+K^- p(n)$	1542 +- 5	< 21	5.2
SAPHIR	$\gamma p \to K^+K^0(n)$	1540 +- 6	< 25	4.8
ITEP	$\nu A \to K^0p X$	1533 +- 5	< 20	6.7
CLAS	$\gamma p \to \pi^+K^-K^+(n)$	1555 +- 10	< 26	7.8
HERMES	$e^+d \to K^0p X$	1528 +- 3	13 +- 9	~5
ZEUS	$e^+p \to e'K^0p X$	1522 +- 3	8+-4 (5)	~5
SVD	$pA \to K^0pX$	1526 +- 3	< 10	5.5
COSY	$pp \to K^0p\Sigma^+$	1530 +- 5	< 18	4-6

But also negative results from many experiments :

BES , Belle , BaBar , HERA-B , CDF , PHENIX , SPHINX , HyperCP, CLAS, H1

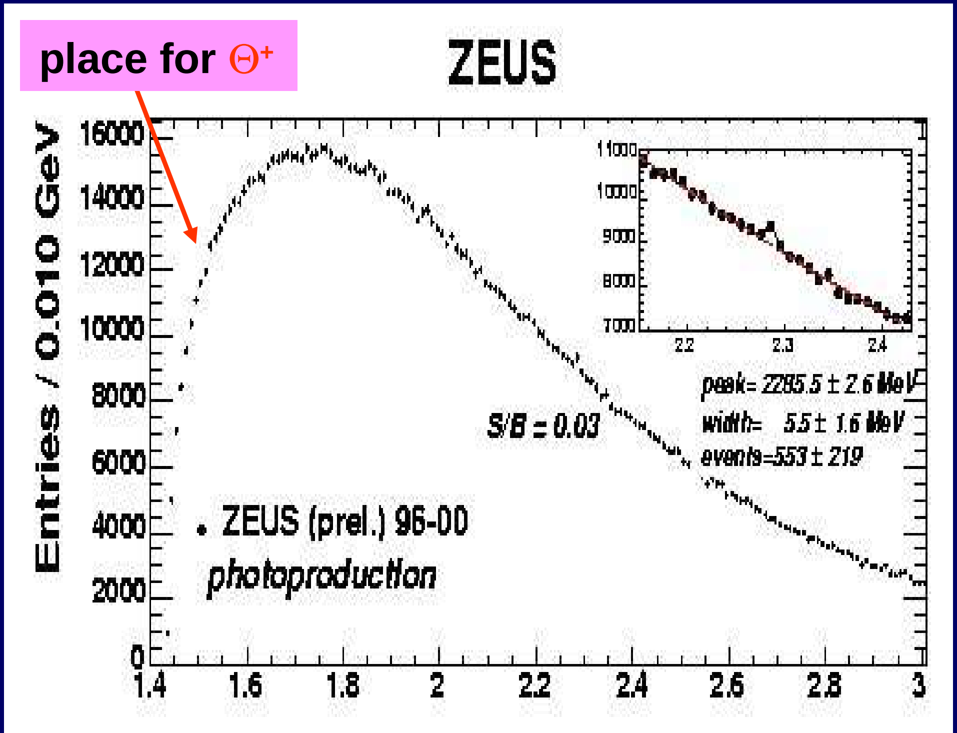
new results - final conclusion ? - important for understanding physics of strong inter.

Θ^+ - ZEUS :



Fit: Double -Gaussian + background function

Use $\Lambda_C^+ \to K^0_S\, p$ peak (2285) for photoproduction and DIS to calculate signal to background ratio



DIS : Q^2 > 20 GeV^2

evidence for narrow peak near 1522 MeV (4.6 σ signal) with Γ = 8 ± 4 MeV

ZEUS Collaboration - Phys. Lett. B591 (2004) 7

Photoproduction : Θ^+ is absent $\to$

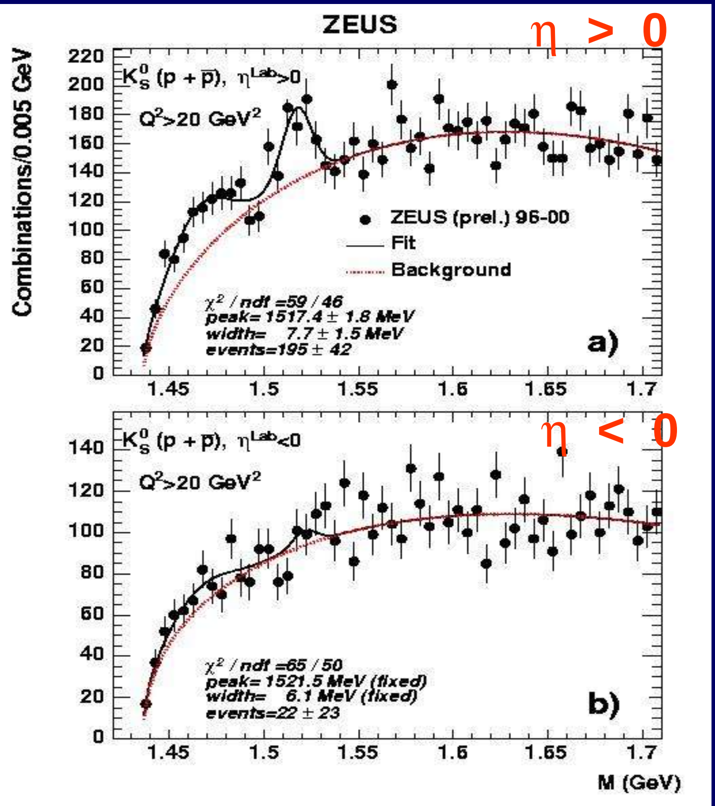
significant combinatorial background and multiplicity can lead to small ratio S / B

For DIS this ratio was 10 times larger

Θ^+ production properties : Θ^+ and Λ (1520)

Negative result from e^+e^- may indicate that ZEUS signal is related to proton fragmentation

Check : studies in different pseudorapidity regions : forward and rear , comparison of $K^0_s p$ signal with reconstructed $\Lambda(1520)$ from u,d,s fragmentation

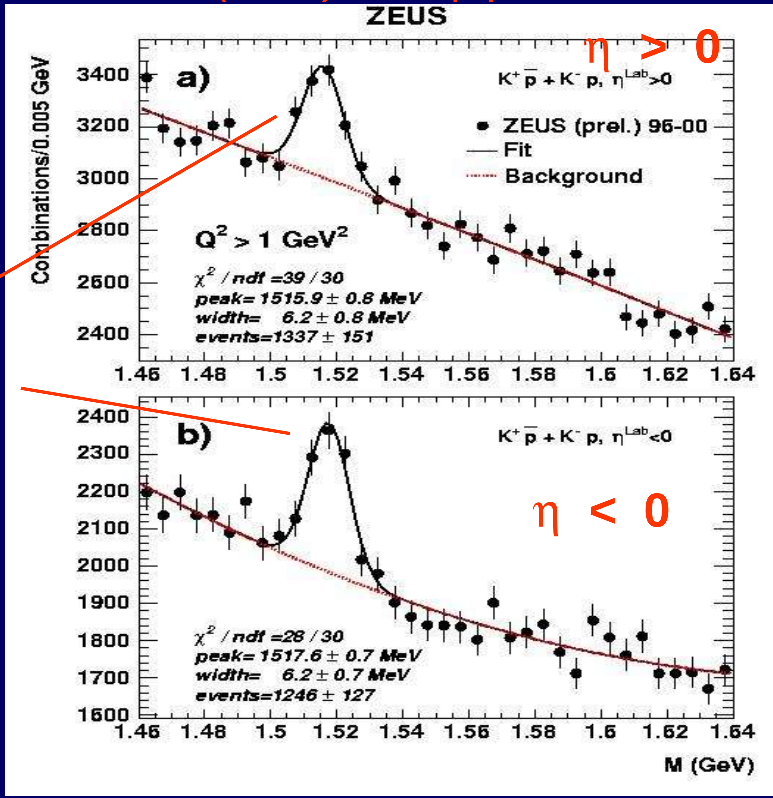


Region with significant proton remnant fragmentation

similar numbers

Region dominated by pure fragmentation

$\Lambda(1520) \to K^\pm \bar{p}\, p$



Θ^+ - produced mostly at forward rapidity hemisphere $\eta_{LAB} > 0$ and $Q^2 > 20$ GeV^2 - $\Lambda(1520)$ behaviour is different

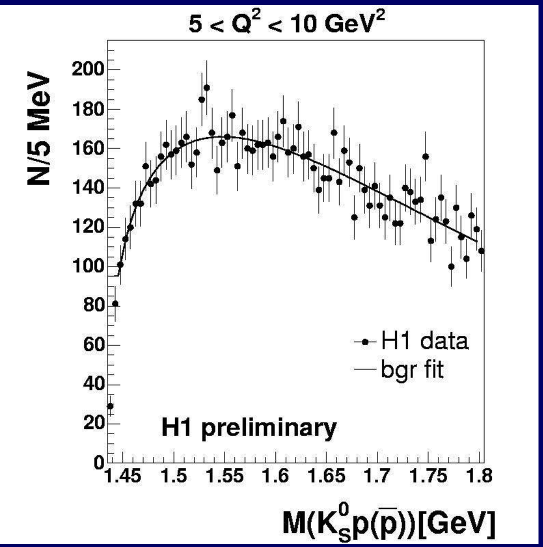
Does the production of Θ^+ involve the diquark fragmentation mechanism [1] ?

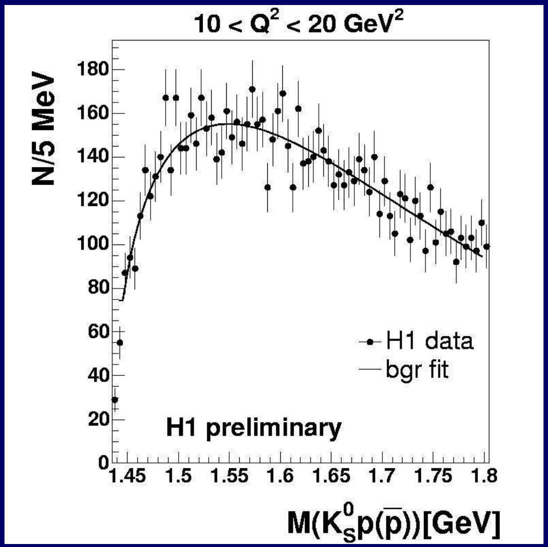
1. S. Chekanov, hep-ph/0502098

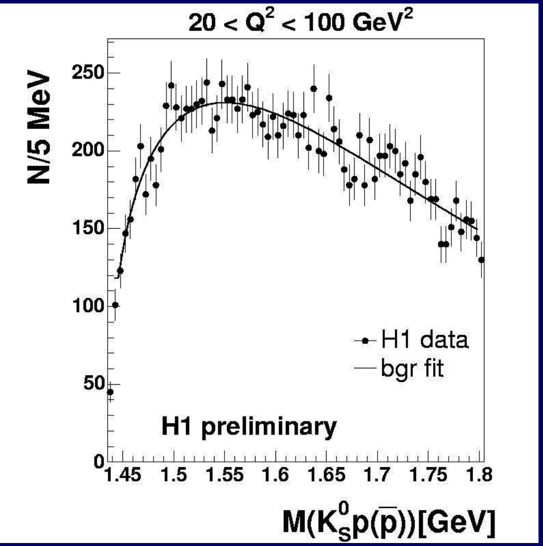
Θ^+ - H1

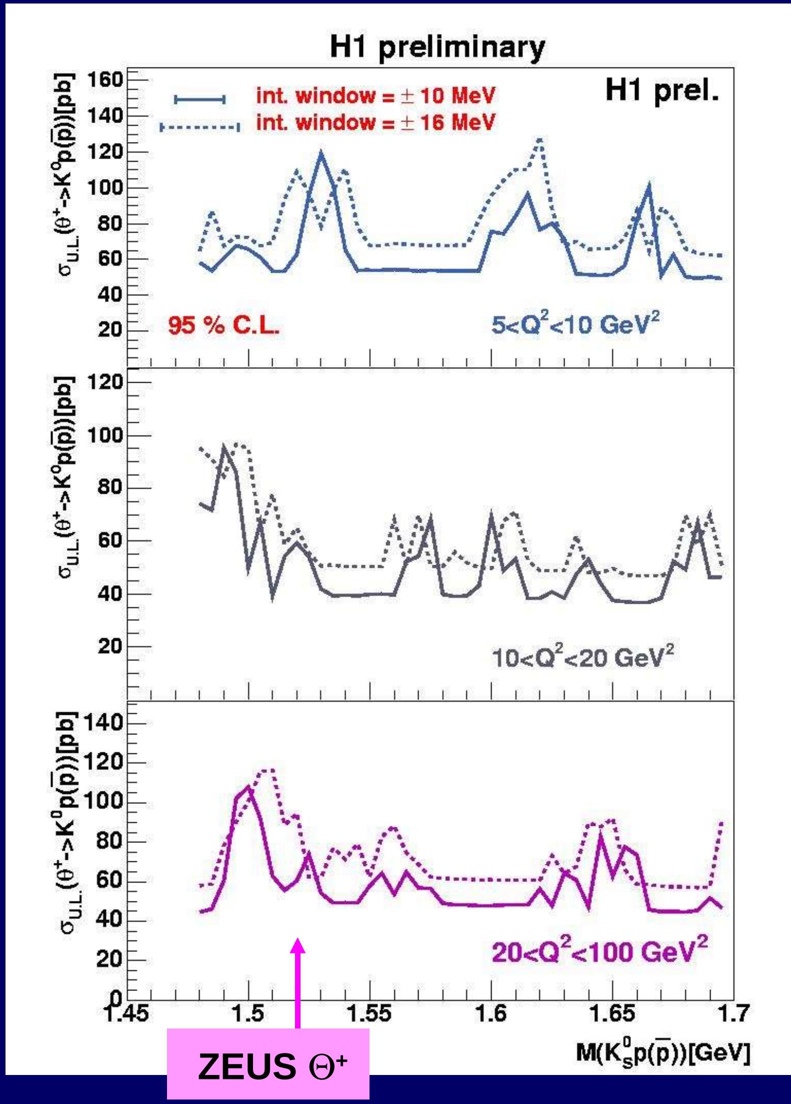
H1 : $Q^2 > 5$ GeV^2 , $0.1 < y < 0.6$
ZEUS : $0.01 < y < 0.95$

Visible range:
$p_T(K_S^0 p) > 0.5$ GeV , $|\eta(K_S^0 p)| < 1.5$





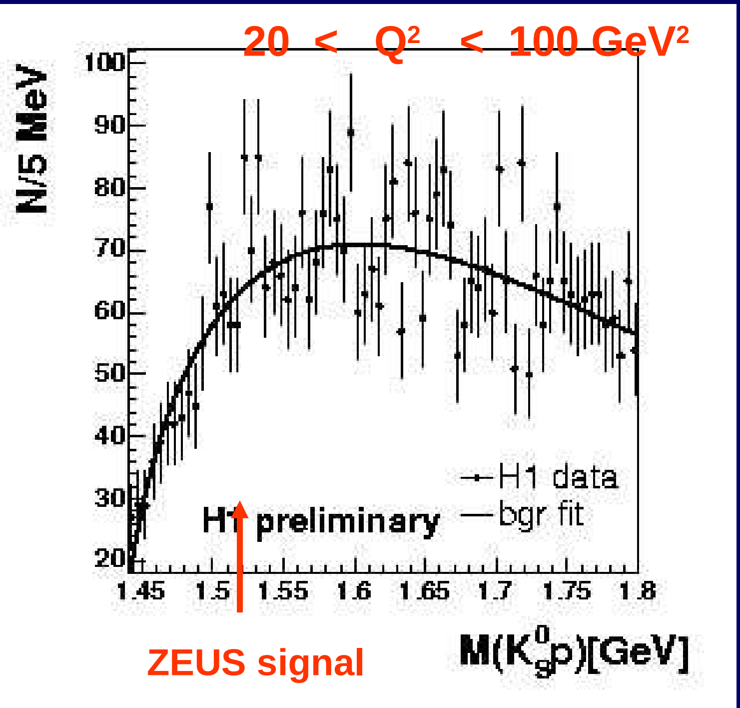


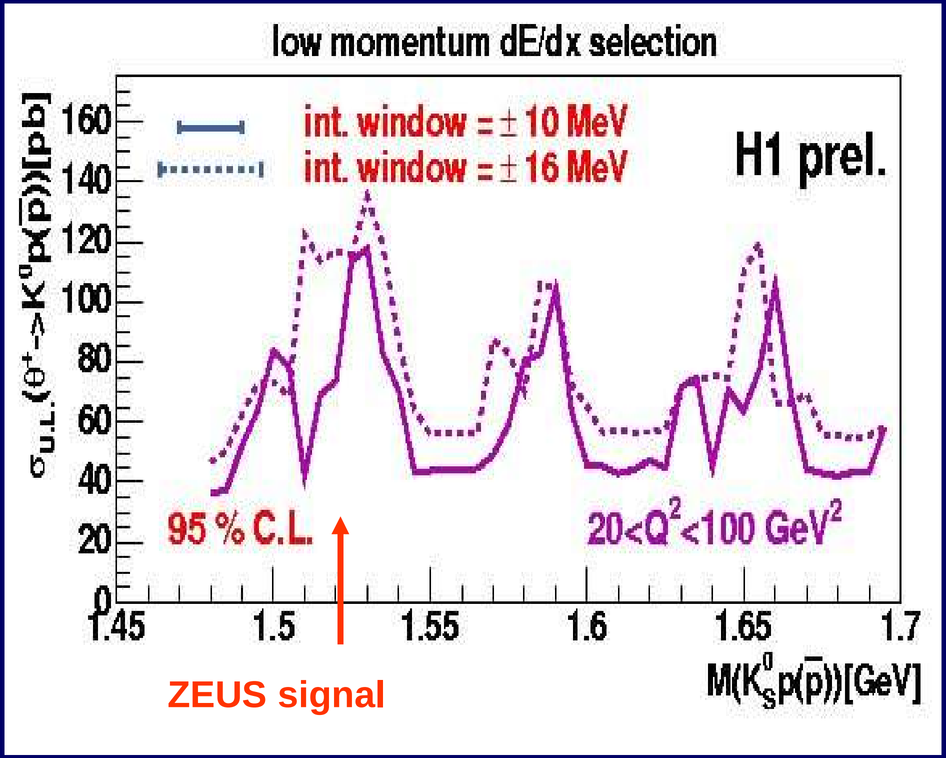


No signal - upper limit on $\sigma(\Theta)$ assuming quark fragmentation of Θ^+

Θ+ - H1 analysis for low momentum proton

In other analysis low - momentum protons (< 1.5 GeV as in ZEUS) were used - better proton purity





Still negative result

- statistics lower than in ZEUS
- more data is needed

Upper limit on Θ^+ cross section for $20 < Q^2 < 100$ GeV^2

- does not contradict to the ZEUS observation: $\sigma(\Theta^+) \sim 120$ pb for $Q^2 > 20$ GeV^2

Heavy strange PQ ?

ZEUS results:

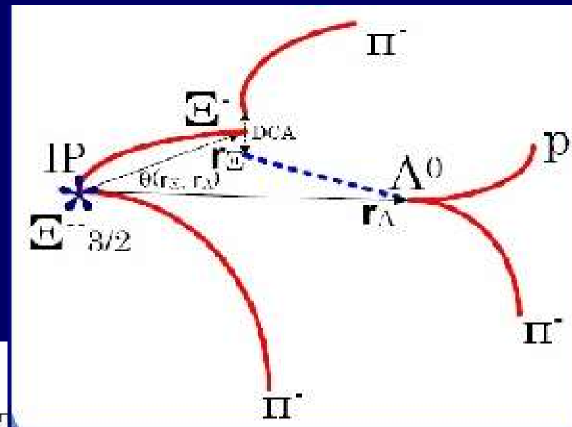
search for $\Xi^{--}_{3/2}$ (ddssū)

decaying to $\Xi^- \pi^-$ ($\Xi^- \pi^+$)

Na49 – observation :

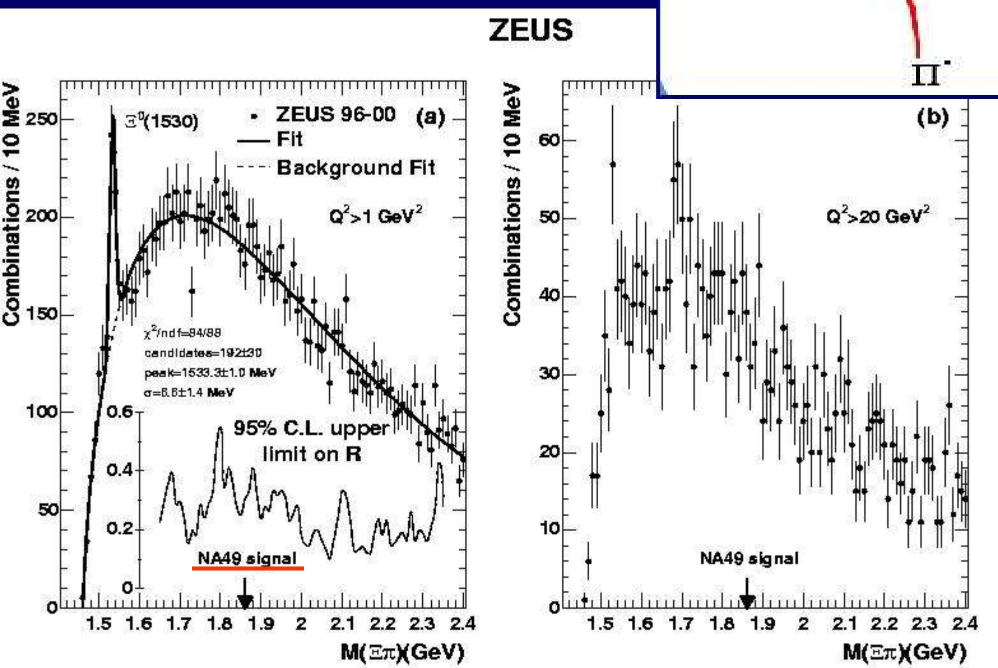
narrow peak at 1862 ± 2 MeV

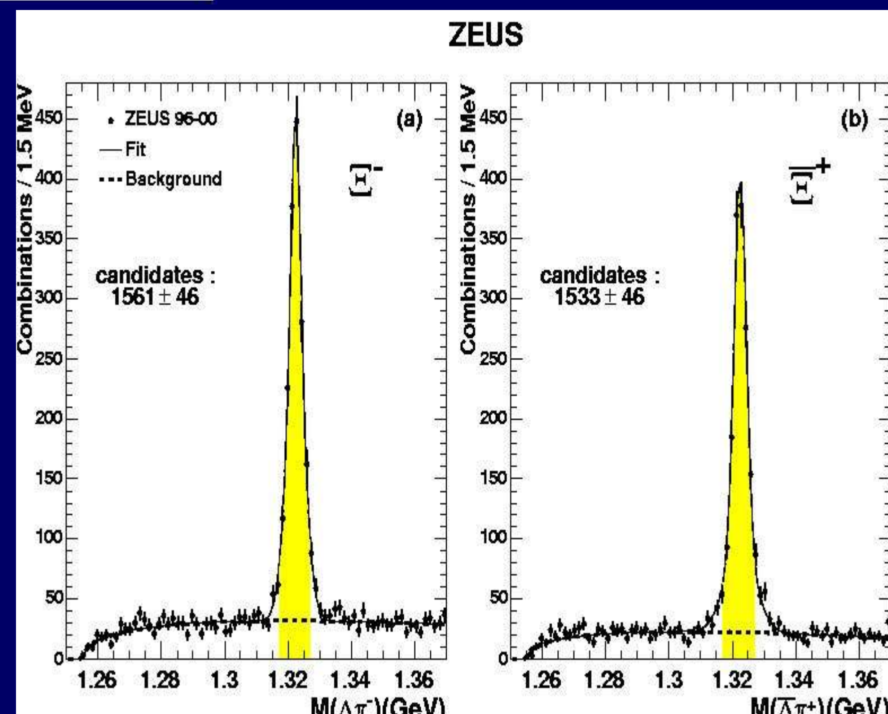
Γ < 18 MeV



Reconstuction of candidate:

- Λ (secondary vertex)
  - + tracks with small DCA from Λ
- Ξ + pions from primary vertex





No evidence for NA49 pentaquark

Upper limit : R = $\Xi_{3/2}^{--(0)}$ / $\Xi^0(1530)$ ~ 0.2 - 0.5

Summary

Strange particles provide good test of hadronization models :

- HERWIG does not descibe the shape of the measured cross sections
- ARIADNE provides better description of the data but fails for some kinematic regions:
  - underestimates the baryon -to- meson ratio at lower x and in the target region of the Breit frame
  - overestimates pseudorapidity distribution of K^0_S in almost whole η region
- For quark fragmentation region data suggests a smaller λ_S value than for target region where Monte Carlo desciption is not good
- No significant baryon antibaryon asymmetry was found
- The radius of the particle emission volume for kaons is consistent with pions and with LEP
- measurements for heavier particles are necessary to clarify the r dependence on the hadron mass

Pentaquarks

- Search for signal of the exotic narrow state was positive for Θ^+ strange pentaquark for ZEUS and negative for H1
- No evidence for heavy strange pentaquark was found by ZEUS

Hoping to solve this puzzle with help of high statistics expected for HERA II

Thank you

Charm pentaquark Θ_c^0 - H1:

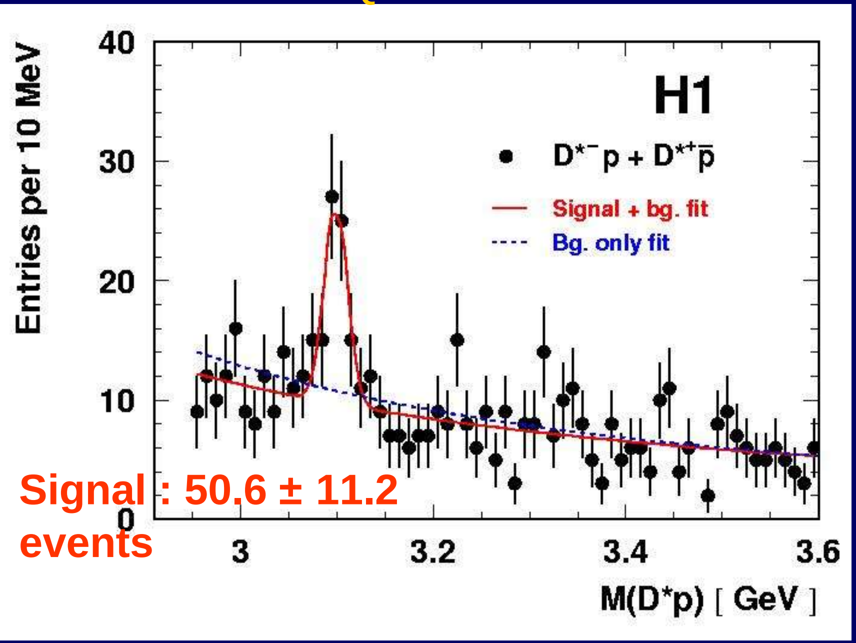
$\Theta_c^0 = uudd\bar{c}$

Searches in effective mass
$M(D^{*-} p)$ (+ c.c.) spectra

$D^{*-} \to D^0 \pi_S^- \to K^+\pi^- \pi_S^-$ (+ c.c.)

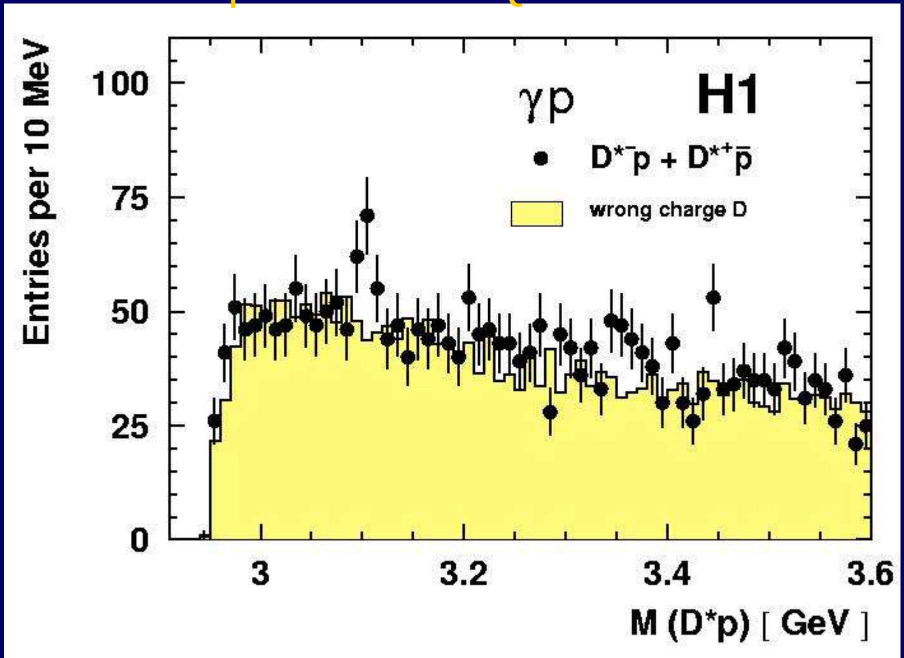
H1 data sample : 75 pb^{-1}
proton candidate - likehood method - dE/dx energy lost

DIS : $1 < Q^2 < 100\ GeV^2$



Signal : 50.6 ± 11.2 events

Photoproduction : $Q^2 \leq 1\ GeV^2$



Narrow resonance seen in DIS and photoproduction events

Mass = 3099 ± 3 (stat) ± 5 (syst.) , the measured Gaussian width : 12 ± 3 (stat.)

A. Atkas et al., Phys. Lett. B588 (2004) 17

Θ_c^0 – H1 : fragmentation investigations

Posssible production of $D^* p(3100)$: photon-gluon fusion PGF process

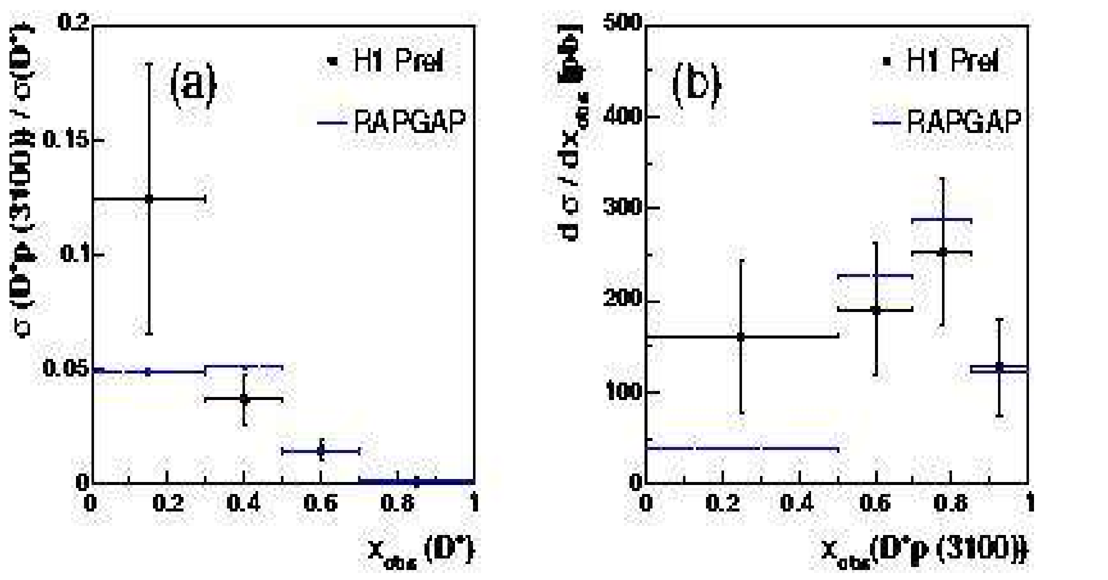
Baryon to meson $\sigma(D^* p) / \sigma(D^*)$ ratio :

- well described by RAPGAP MC as function of event kinematics (Q^2,W, subsys. energy)
- indication for suppression baryon production $D^* p$ relative to D^* in central rapidity region

Fragmentation study: use the similar method as for charm fragmentation function : in $\gamma^* p$ frame particles projected into plane perpendicular to γ^* direction; divide the event into 2 hemisphere defined by D^* direction and calculate in hemisphere the hadronisation variable

$x_{obs} (D^* p, D^*) = (E-p_z)(D^* p, D^*) / \Sigma_{hem}(E-p_z)$

An example :

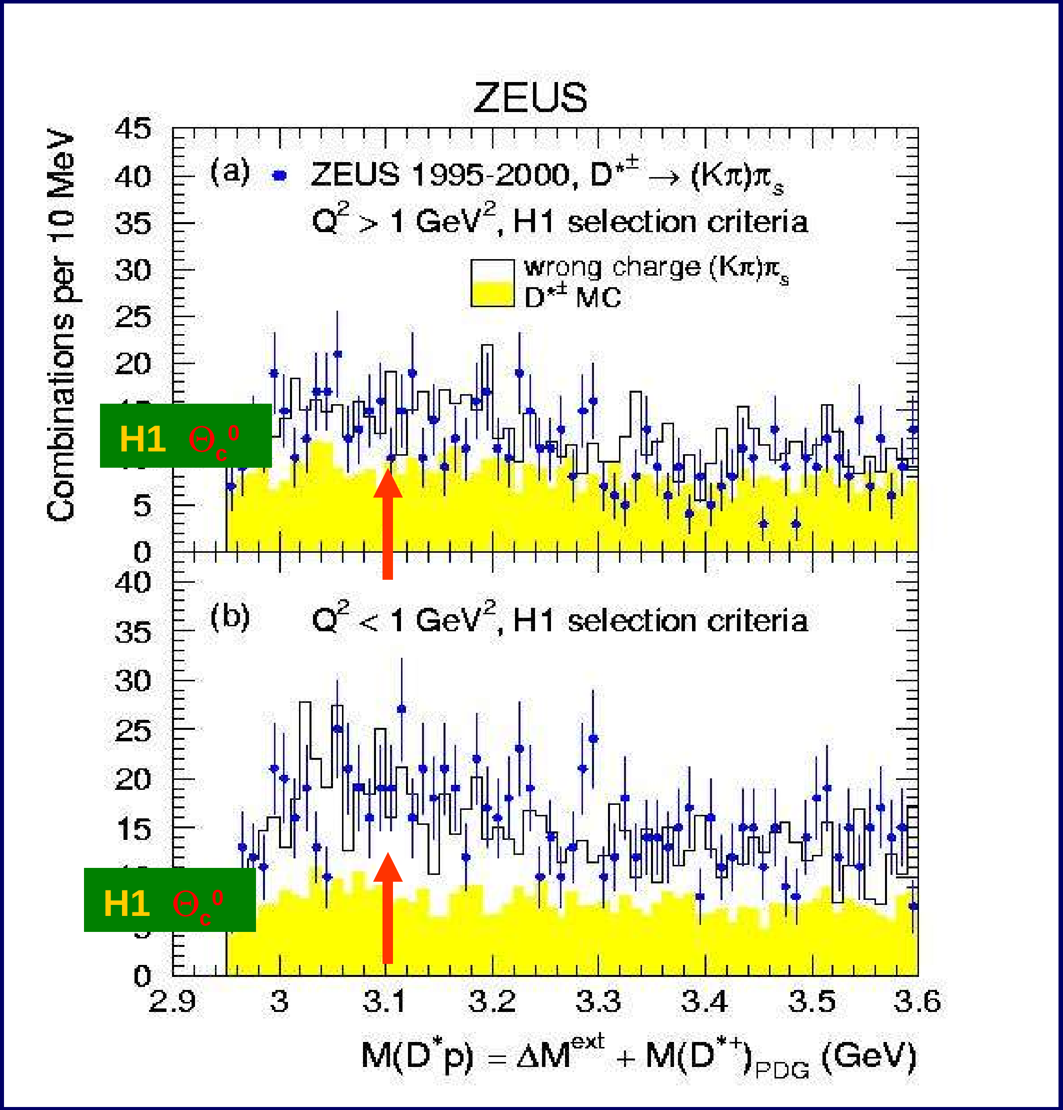


Rise for decreasing x_{obs} → meson D^* originating from $D^*p(3100)$ softer than inclusive D^* expected for decay of real particle D^*p

The $D^*p(3100)$ fragmentation function is rather hard - behaviour expected for charmed hadrons

Θ_c^0 - ZEUS :

Search in $D^{*\pm} p \bar{p}$ invariant-mass spectrum



DIS

Photoproduction

No evidence for Θ_c^0 was found in more than 60000 D^* candidates

also after application the H1 selection criteria