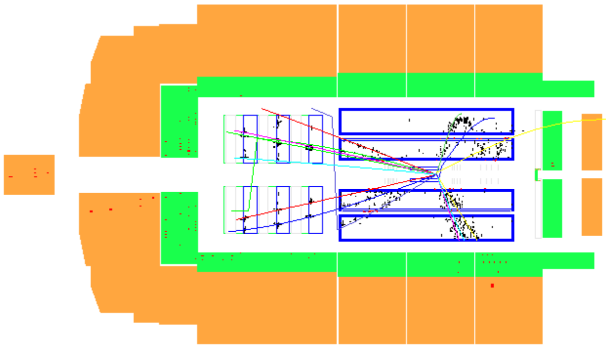
Frascati Spring School 2007

14. – 18. May 2007

Search for Baryonic States $X \to \Xi \pi$ in DIS at H1



THE H1 EXPERIMENT AT HERA
H1 Collaboration at DESY, Notkestr.85, D-22607 Hamburg, Germany

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Overview

- Introduction: Pentaquarks (PQ)
- Experimental search for new baryonic states at H1, e.g. PQ $\Xi^{--/0}$
- Conclusion

Pentaquarks: first observation

- In 2003 first observation of a narrow resonance with flavour exotic quantum numbers (B = +1, S = +1) by the LEPS Collaboration:
- Reaction: γ n → K^-K^+n
- minimal quark content: $udud\bar{s} \rightarrow \Theta^+(1540)$
- Successively confirmed by 10 experiments in various reactions:

Experiment	Reaction	Energy (GeV)	Mass (MeV/c^2)	significance
LEPS	$\gamma^{12}C \rightarrow K^- X$	$E_\gamma \approx 2$	1540 ± 10	4.6σ
DIANA	$K^+ Xe \rightarrow p K_s^0 X$	$E_{K^+} < 0.5$	1539 ± 2	4σ
CLAS(d)	$\gamma d \rightarrow p K^- K^+ n$	$E_\gamma < 3.8$	1542 ± 5	5.2
SAPHIR	$\gamma p \rightarrow K_s^0 K^+ n$	$E_\gamma < 2.65$	$1540 \pm 4 \pm 2$	4.4σ
CLAS(p)	$\gamma p \rightarrow \pi^+ K^- K^+ n$	$E_\gamma = 4.8 - 5.5$	1555 ± 10	7.8σ
νBC	$\nu A \rightarrow p K_s^0 X$	range	1533 ± 5	6.7σ
ZEUS	$ep \rightarrow ep K_s^0 X$	$\sqrt{s} = 320$	1522 ± 1.5	4.6σ
HERMES	$ed \rightarrow p K_s^0 X$	$E_e = 27.6$	$1528 \pm 2.6 \pm 2.1$	5.2σ
COSY	$pp \rightarrow \Sigma^+ p K_s^0$	$P_p = 3$	1530 ± 5	3.7σ
SVD	$pA \rightarrow p K_s^0 X$	$E_p = 70$	$1526 \pm 3 \pm 3$	5.6σ
NA49	$pp \rightarrow \Xi^- \pi^- X$	$E_p = 158$	1862 ± 2	4σ
H1	$ep \rightarrow D^{*-} p D^{*+} \bar{p} X$	$\sqrt{s} = 320$	$3099 \pm 3 \pm 5$	5.4σ

Adapted from V.D.Burkert, hep-ph/0510309

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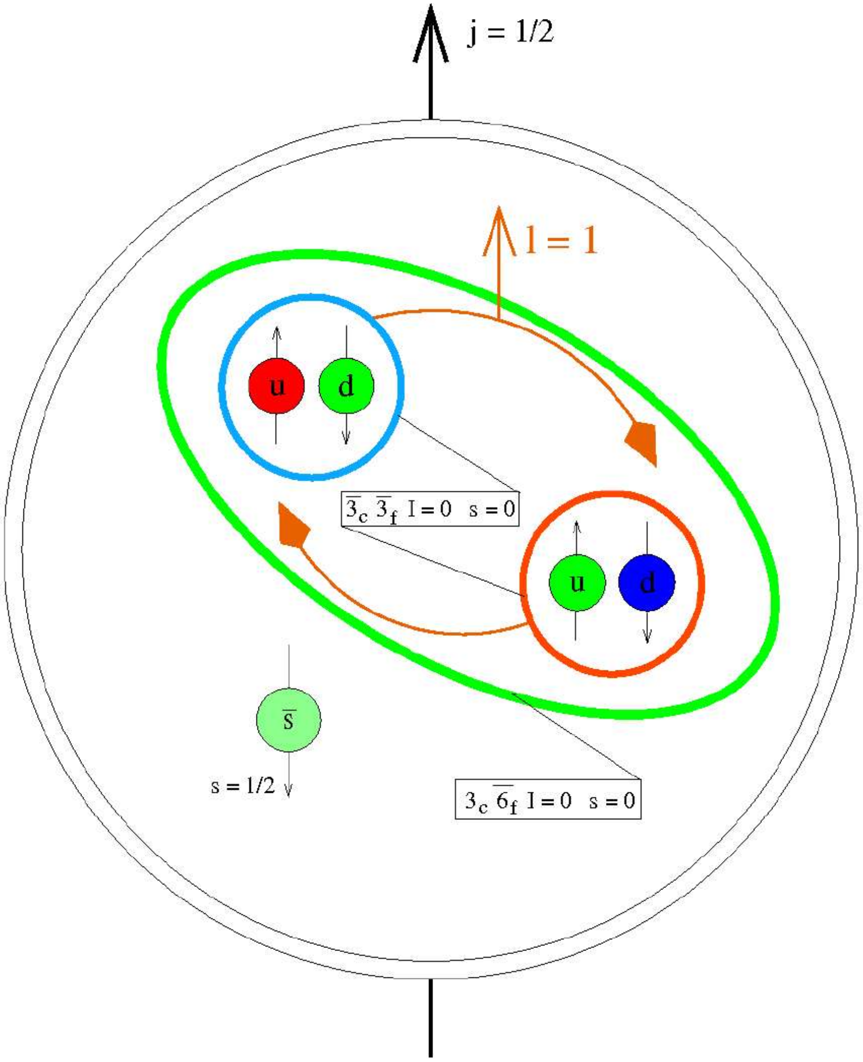
but also several negative results

Group	Reaction
BES	$e^+e^- \to J/\Psi \to \bar{\Theta}\Theta$
BaBar	$e^+e^- \to \Upsilon(4S) \to pK^0 X$
Belle	$e^+e^- \to B^0 \bar{B}^0 \to p\bar{p}K^0 X$
LEP	$e^+e^- \to Z \to pK^0 X$
HERA-B	$pA \to K^0 pX$
SPHINX	$pC \to K^0 \Theta^+ X$
HyperCP	$pCu \to K^0 pX$
CDF	$p\bar{p} \to K^0 pX$
FOCUS	$\gamma BeO \to K^0 pX$
Belle	$\pi + Si \to K^0 pX$
PHENIX	$Au + Au \to K^- \bar{n} X$

K. Hicks, hep-ph/0504027

Pentaquarks: models

- Hypothetical 5 quark state: $4q\bar{q}$
- Various theoretical models:
  - Jaffe Wilczek diquark model:
    PQ = $\bar{q}$ (qq) (qq)
  - Karliner Lipkin triquark model:
    PQ = (qq)($qq\bar{q}$)
    - Both models predicts
      $8_f \oplus \overline{10}_f$ for the light PQ
    - and for the heavy PQ: $\bar{6}_f \oplus 3_f$
  - Chiral soliton model (Diakonov *et al.*)
  - Lattice QCD, …

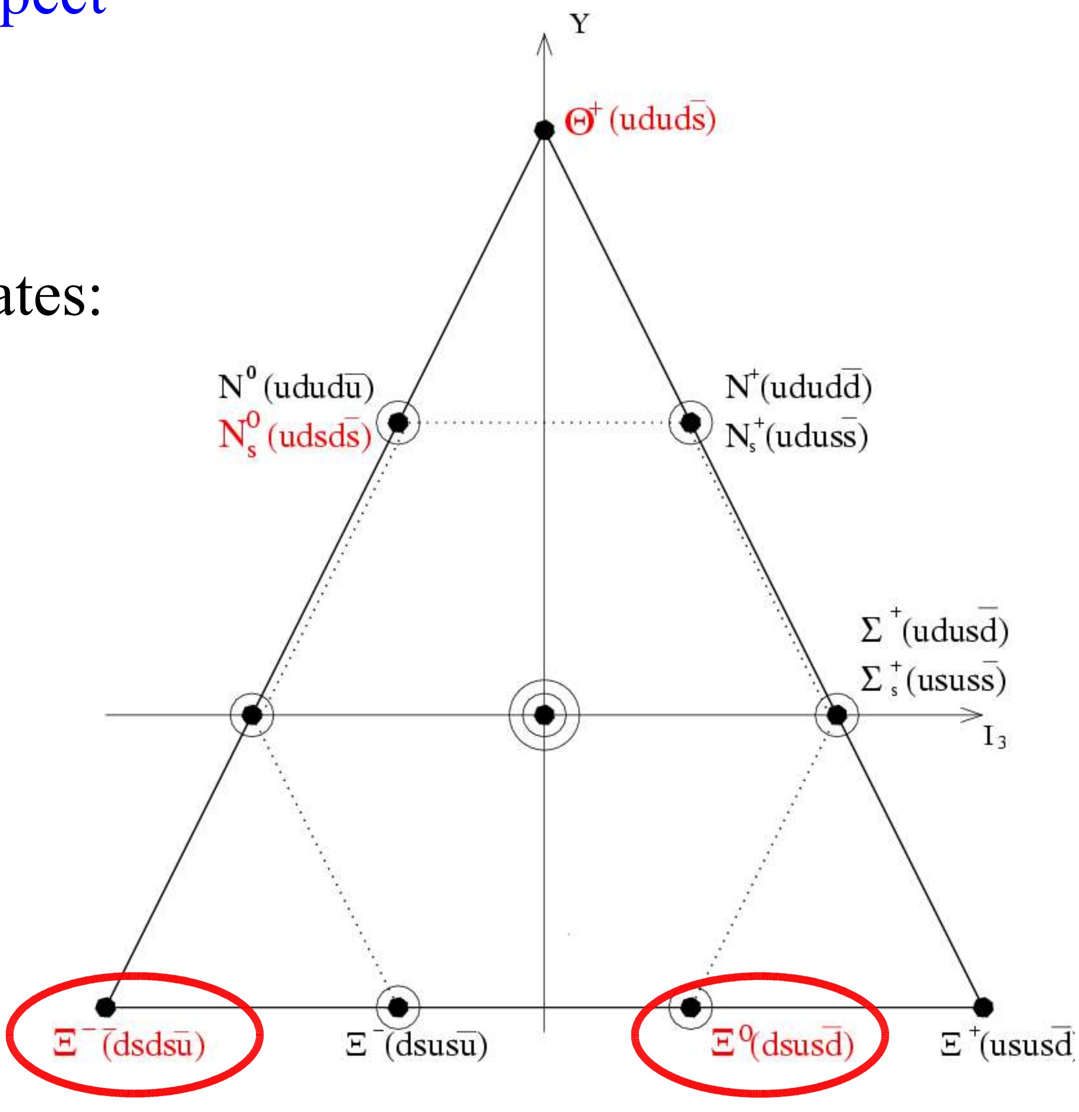


The $\Theta^+(1540)$ in the JW model

Representation of light PQ's

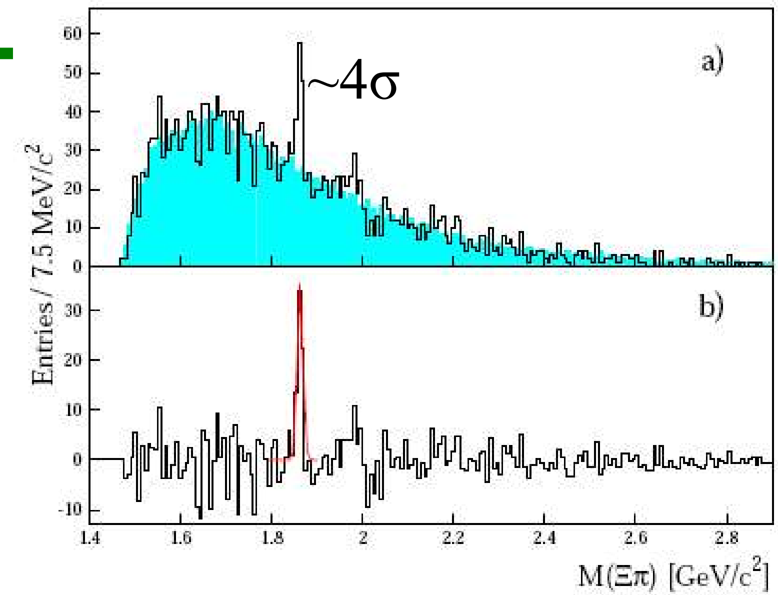
- If the $\Theta^+(1540)$ really exists → expect several other states

- Other possible pentaquark candidates:
  - $\Xi^{--/0}$ seen only by NA49 in the decay channel $\Xi\ \pi$
  - STAR Collab. has seen a possible candidate for the N^0_s in the decay channel $K^0_s\Lambda$



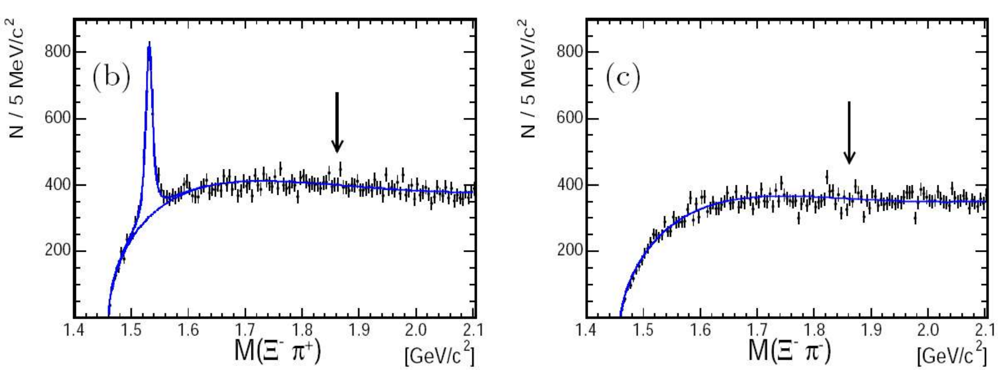
Remarks on the PQ signals $\Xi^{--/0}$

- The NA49 signal $\Xi_{5q} \rightarrow \Xi\,\pi$:

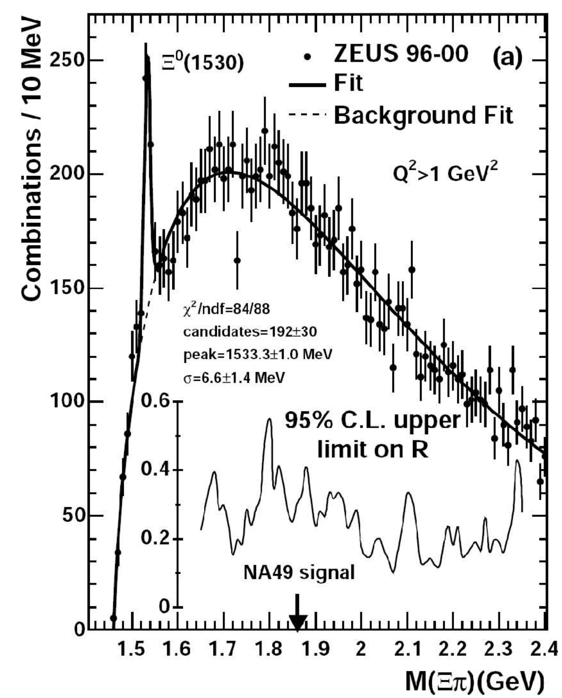


m ≈ 1860 MeV
Γ < 18 MeV

- FOCUS and COMPASS experiment close to kinematics of NA49 →No signal observed
- CDF do not see a signal too



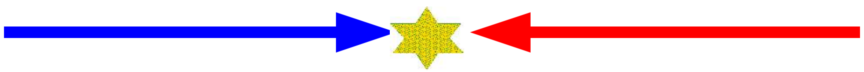
- Neither ZEUS



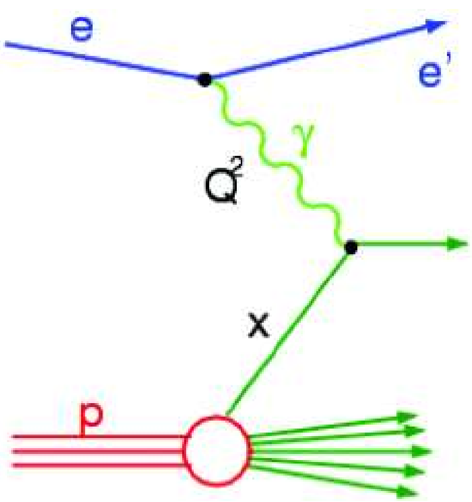
- Introduction: Pentaquarks (PQ)
- **Experimental search for new baryonic states at H1, e.g. PQ $\Xi^{--/0}$**
- Conclusion

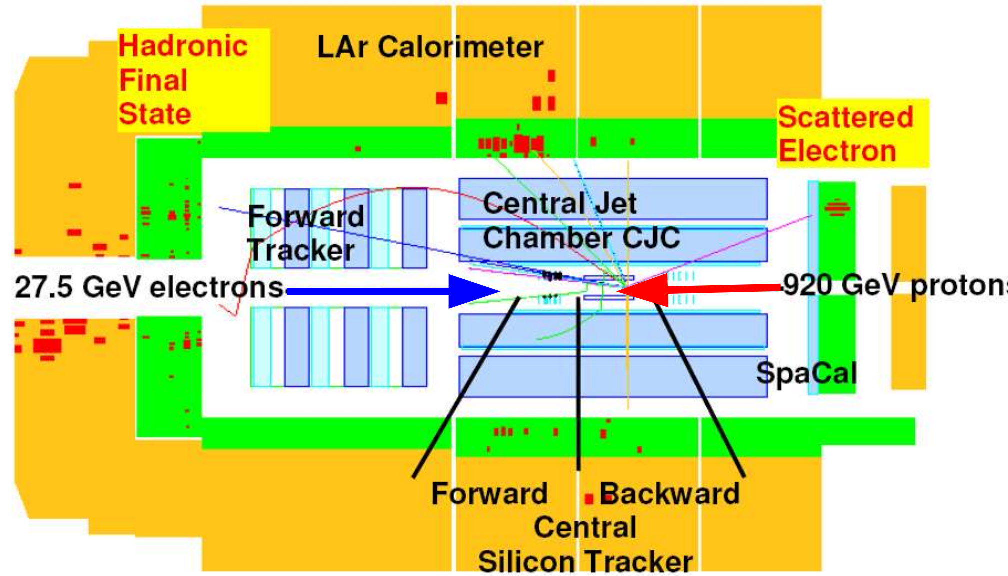
HERA and H1

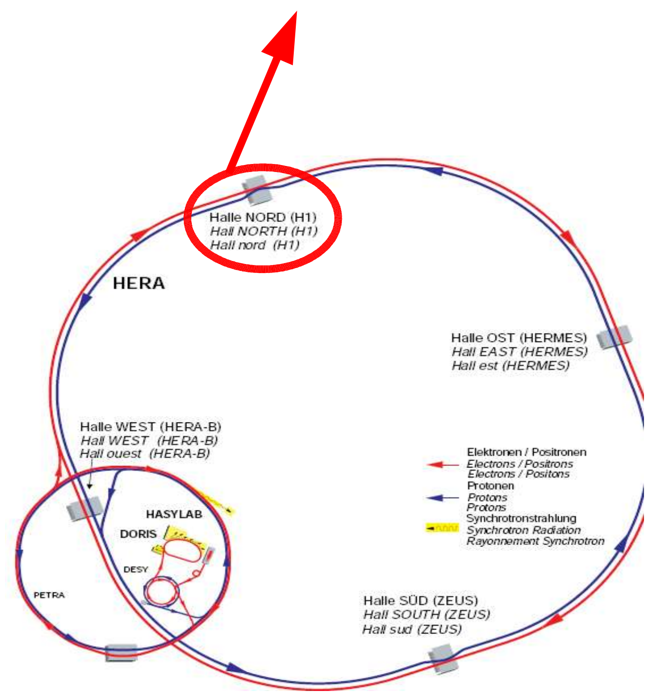
300 – 318 GeV



$e^{+/-}$(27.6 GeV) p (820 – 920 GeV)







HERA I Data: 1996 – 2000
101 pb^{-1}

Search for new baryonic states @ H1

DIS-selection:

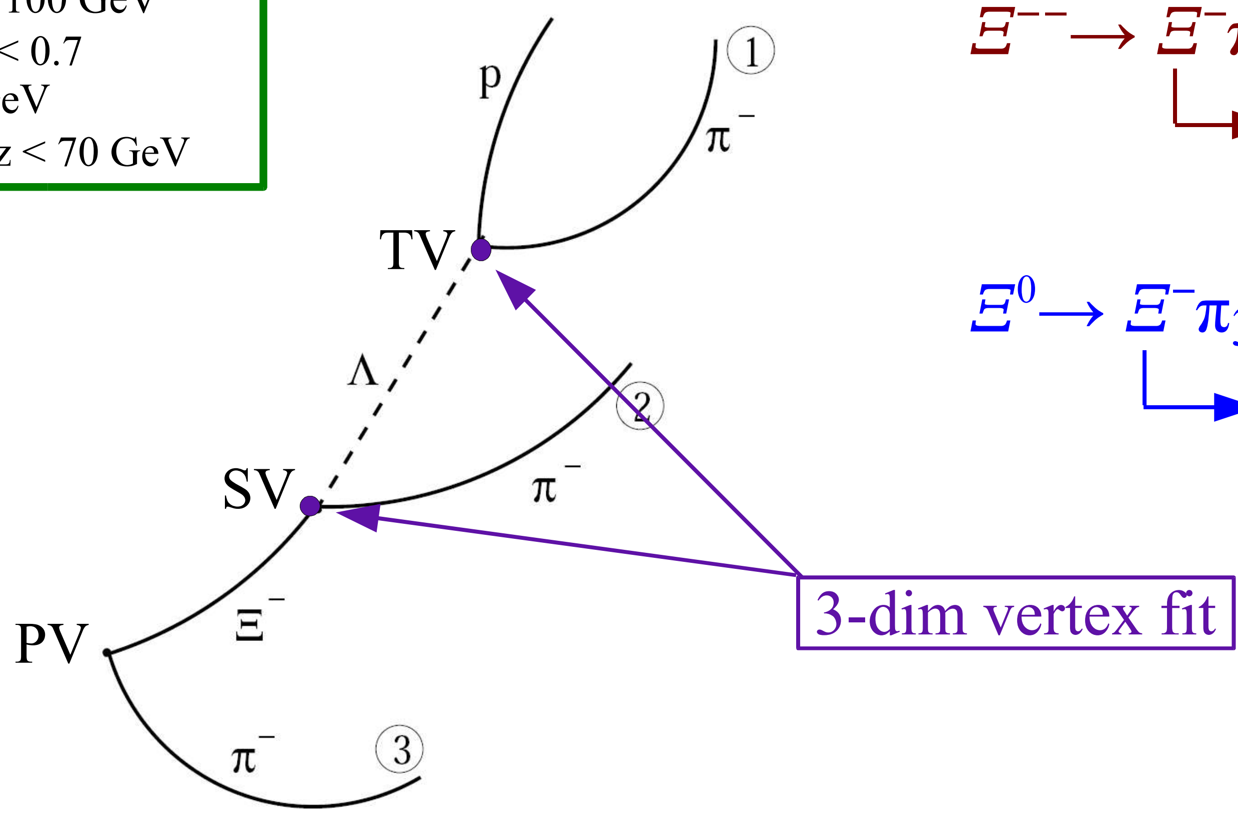
Scat. e in SpaCal

$2 < Q^2 < 100$ GeV^2

$0.05 < y < 0.7$

$E_e' > 8$ GeV

$35 < E\text{-}pz < 70$ GeV



Reconstruction of full decay chain:

$\Xi^{--} \to \Xi^- \pi_3^-$

$\quad \hookrightarrow \Lambda \pi_2^-$

$\quad\quad \hookrightarrow p \pi_1^-$

$\Xi^0 \to \Xi^- \pi_3^+$

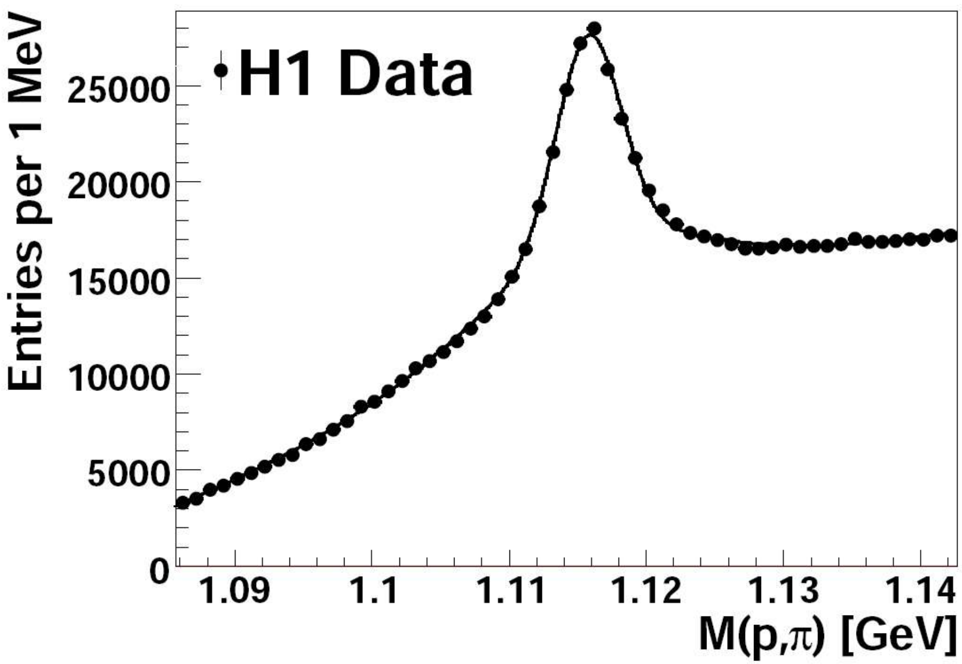
$\quad \hookrightarrow \Lambda \pi_2^-$

$\quad\quad \hookrightarrow p \pi_1^-$

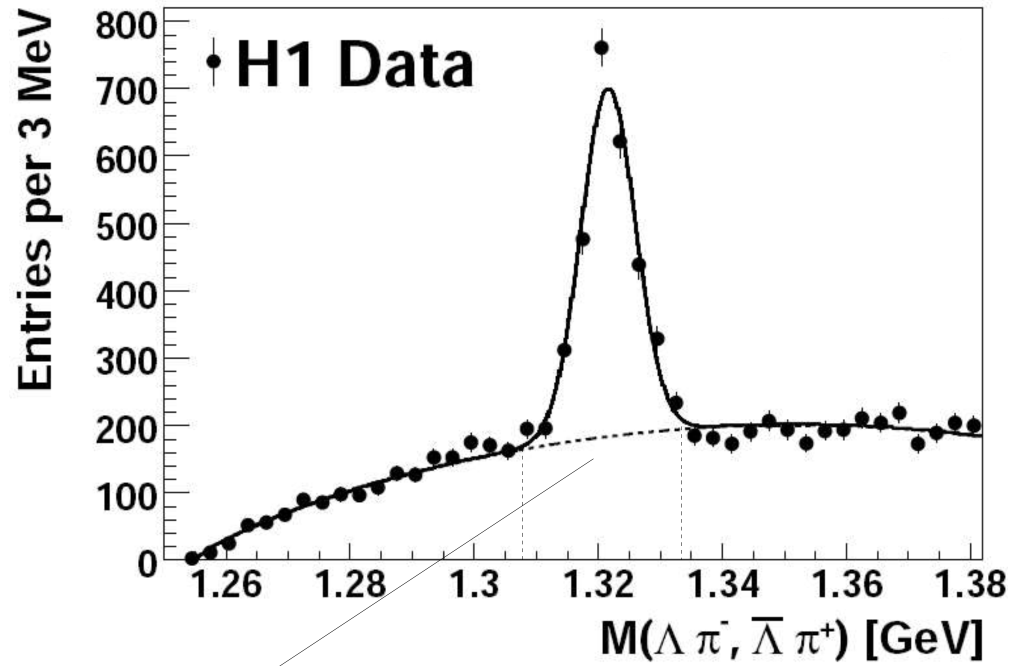
Particle	Mass [GeV]	Decay	BR [%]	Lifetime [cm]
Λ	1.116	$p\,\pi^-$	63.9	7.9
Ξ^-	1.321	$\Lambda\,\pi^-$	99.9	4.9
$\Xi(1530)^0$	1.532	$\Xi\,\pi$	100	0

Search for new baryonic states @ H1

$\Lambda \rightarrow p\pi^-$

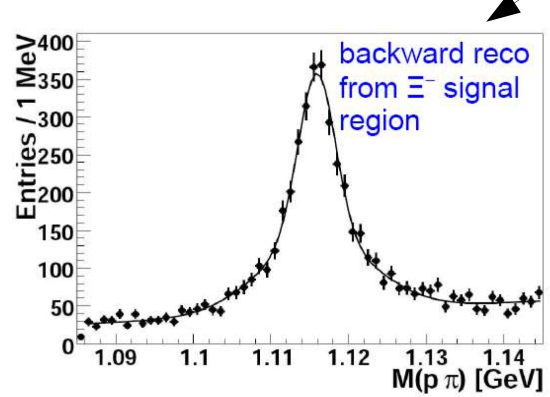


$\Xi^- \rightarrow \Lambda\pi^-$



150k reconstructed Λ:

$m = 1115.8$ MeV
$\sigma \approx 5$ MeV
$c\tau = (7.6 \pm 0.9)$ cm



1870 reconstructed Ξ^-:

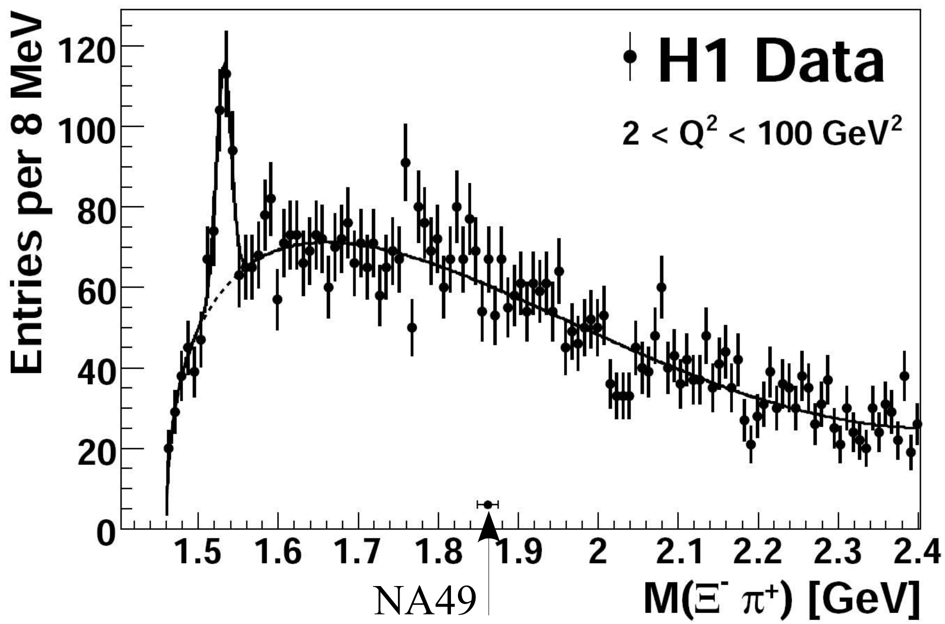
$m = 1321.6$ MeV
$\sigma \approx 4.3$ MeV
$c\tau = (5.1 \pm 0.3)$ cm

→ PDG compliant

Search for new baryonic states @ H1

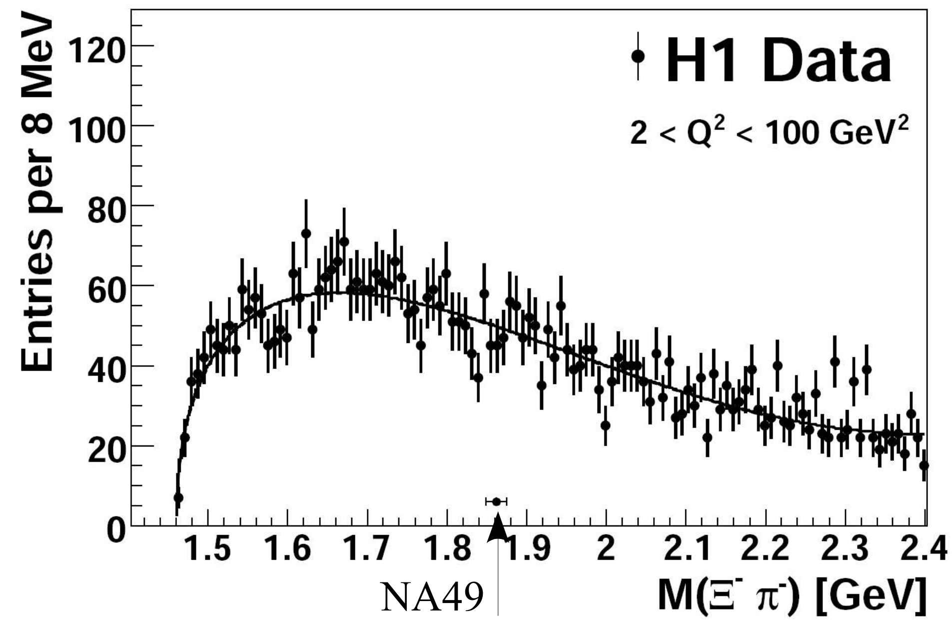
Combine Ξ^- candidates with additional (primary vertex-fitted) track assumed to be π

neutral combinations:
$\Xi^-\pi^+$ and $\bar{\Xi}^+\pi^-$



Clear signal of $163 \pm 24\ \Xi(1530)^0$
$m = (1532.1 \pm 1.6)$ MeV
$\sigma = (9.4 \pm 1.5)$ MeV

charged combinations:
$\Xi^-\pi^-$ and $\bar{\Xi}^+\pi^+$

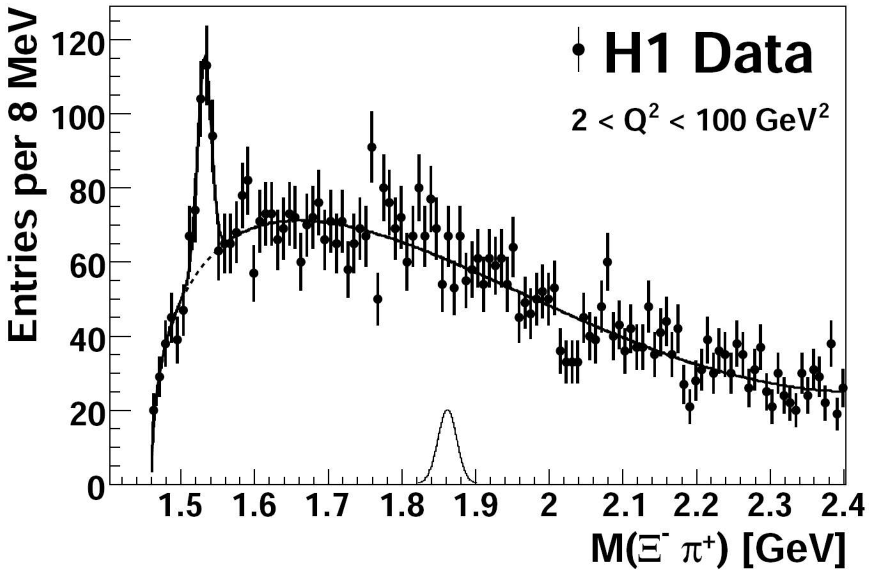


No significant signal
→ **no hint for the NA49 resonance**

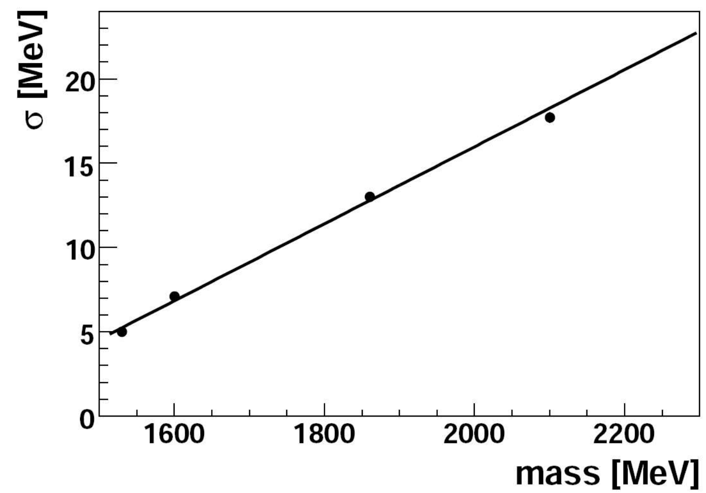
Limit calculation

- Modified frequentist approach (T.Junk)
- Assumptions:
  - BR($X \rightarrow \Xi\pi$) = 100 %
  - Small width
  - Production similar to $\Xi(1530)^0$
- Mass-dependent upper limit for possible $\Xi^-\pi^\pm$ signal at 95 % C.L.: $N_{u.l.}(\Xi^-\pi^\pm)$
- Normalise upper limit wrt number of $\Xi(1530)^0 \rightarrow$ systematics mostly cancel
- Correct for small differences in efficiency (mass-dependent):

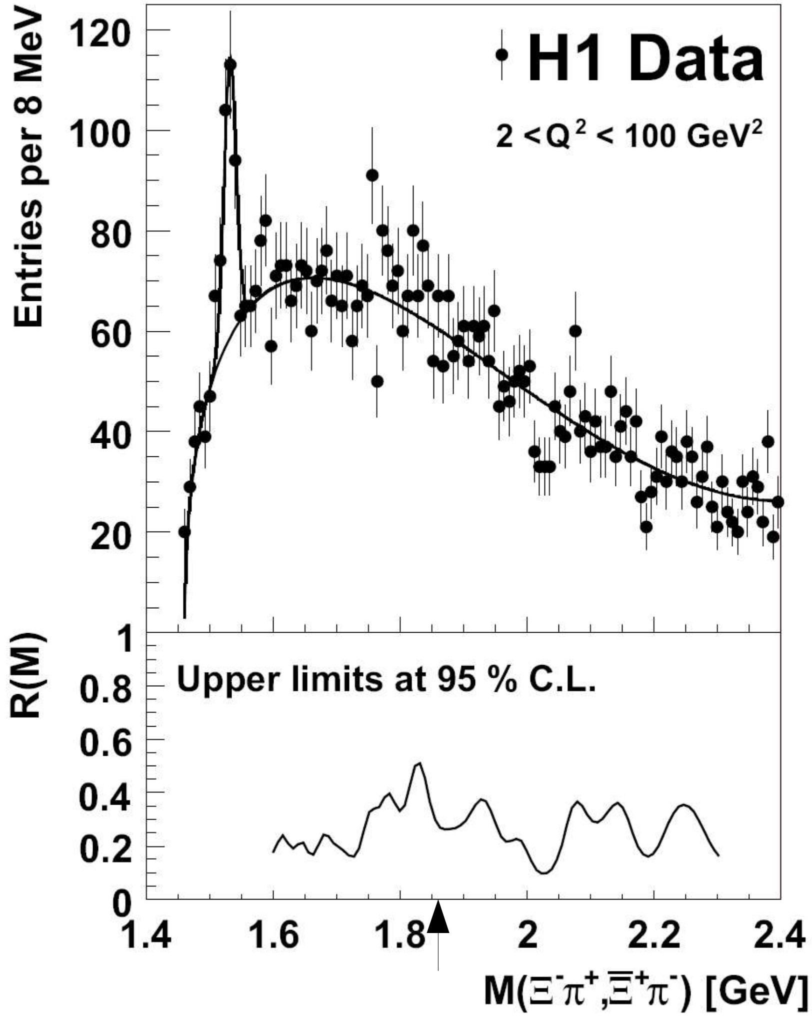
$$R_{u.l.}(M) = \frac{N_{u.l.}(\Xi^-\pi^\pm)}{N(\Xi(1530)^0)} \frac{\epsilon(\Xi(1530)^0)}{\epsilon(M, q)}$$

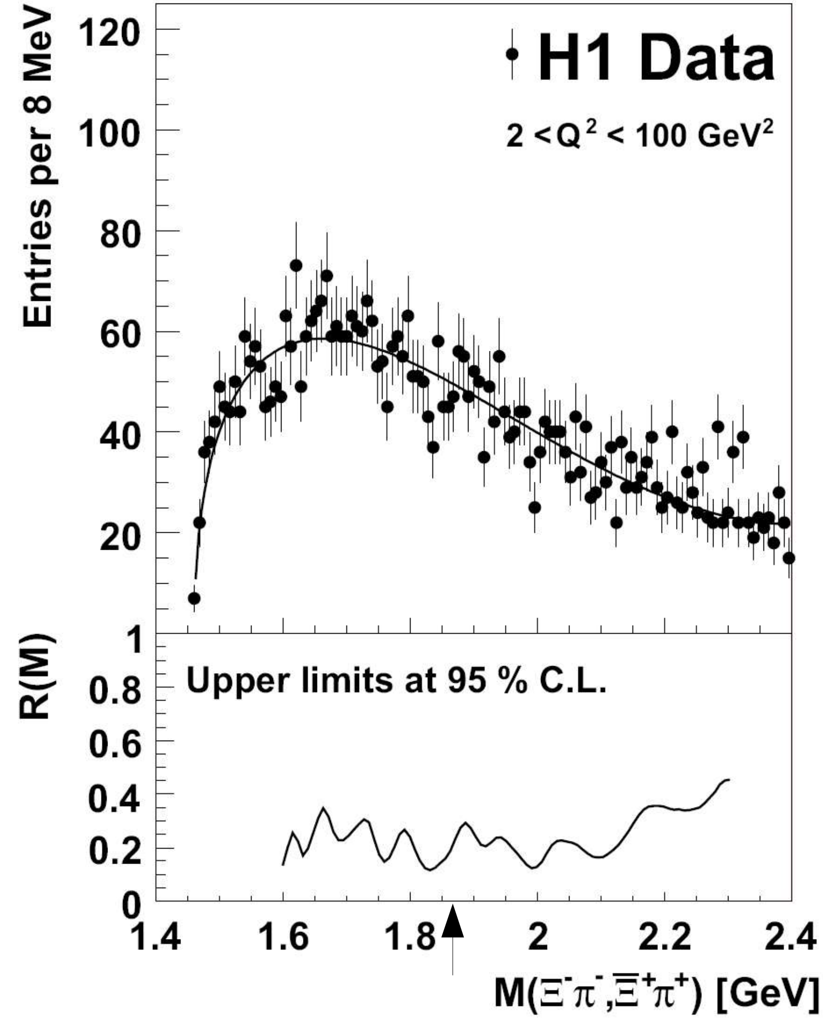


resolution



Invariant ($\Xi\pi$) mass and limit-results





Neutral combinations:
$0.1 < R_{u.l.} < 0.5$
$R_{u.l.}(1860) \approx 0.3$

Charged combinations:
$0.1 < R_{u.l.} < 0.45$
$R_{u.l.}(1860) \approx 0.15$

Conclusion

- The invariant mass spectrum $\Xi\pi$ was studied using DIS data recorded with the H1 detector at HERA
- In spite of similar statistics as NA49, their signal could not be confirmed at H1
- Upper limits at 95 % C.L. were set on the ratio of new, narrow baryonic states to the well established $\Xi(1530)^0$:

$$0.1 < R_{u.l.}(M) < 0.5$$

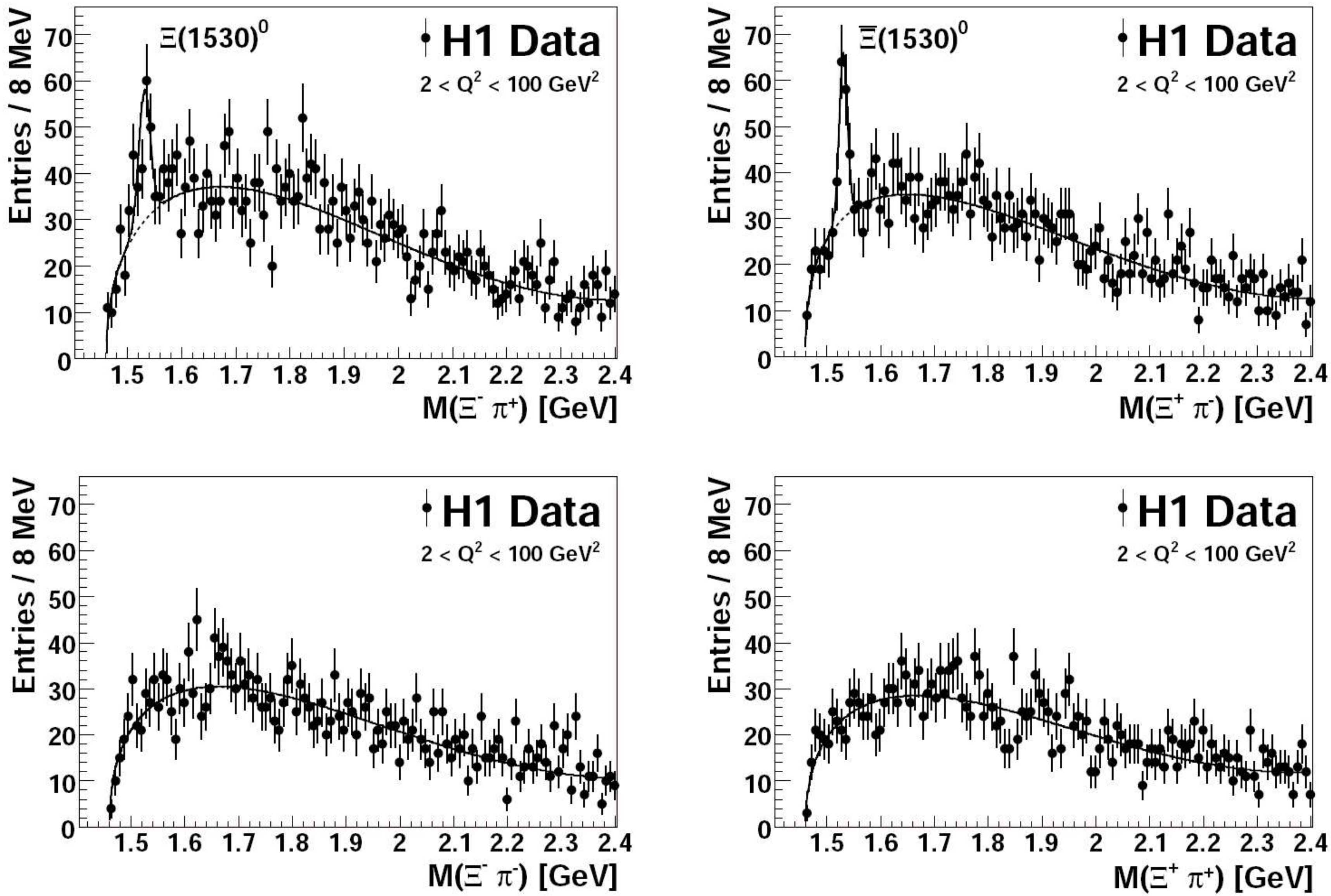
- Similar limits were derived from the ZEUS experiment
- To be published soon
  (available at arXiv:0704.3594)

Additional material

Search for the $\Xi^{--/0}(1860)$ pentaquark

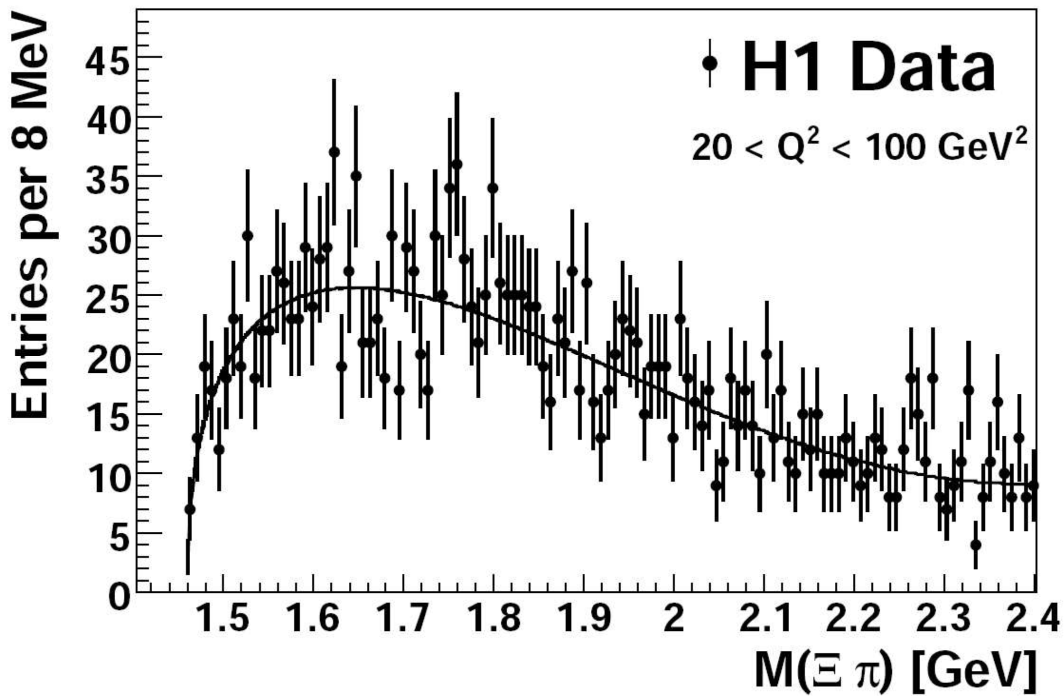
neutral comb.

charged comb.



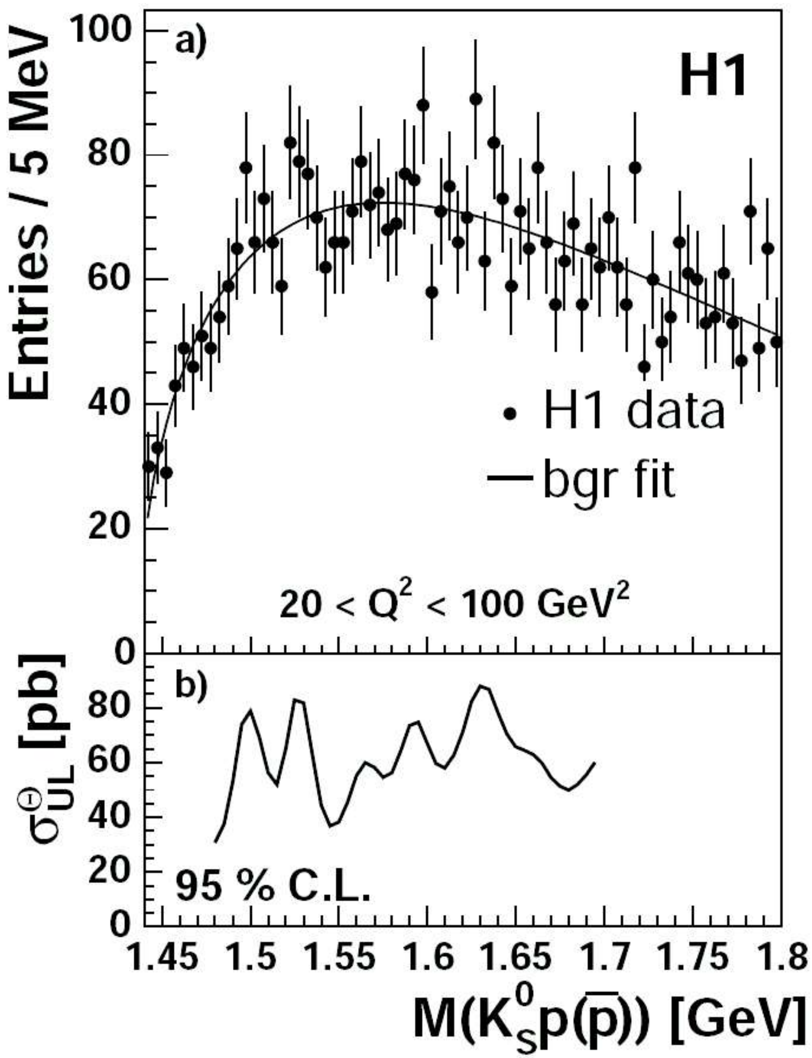
Search for the $\Xi^{--/0}(1860)$ pentaquark

All charge combinations, $20 < Q^2 < 100$ GeV^2

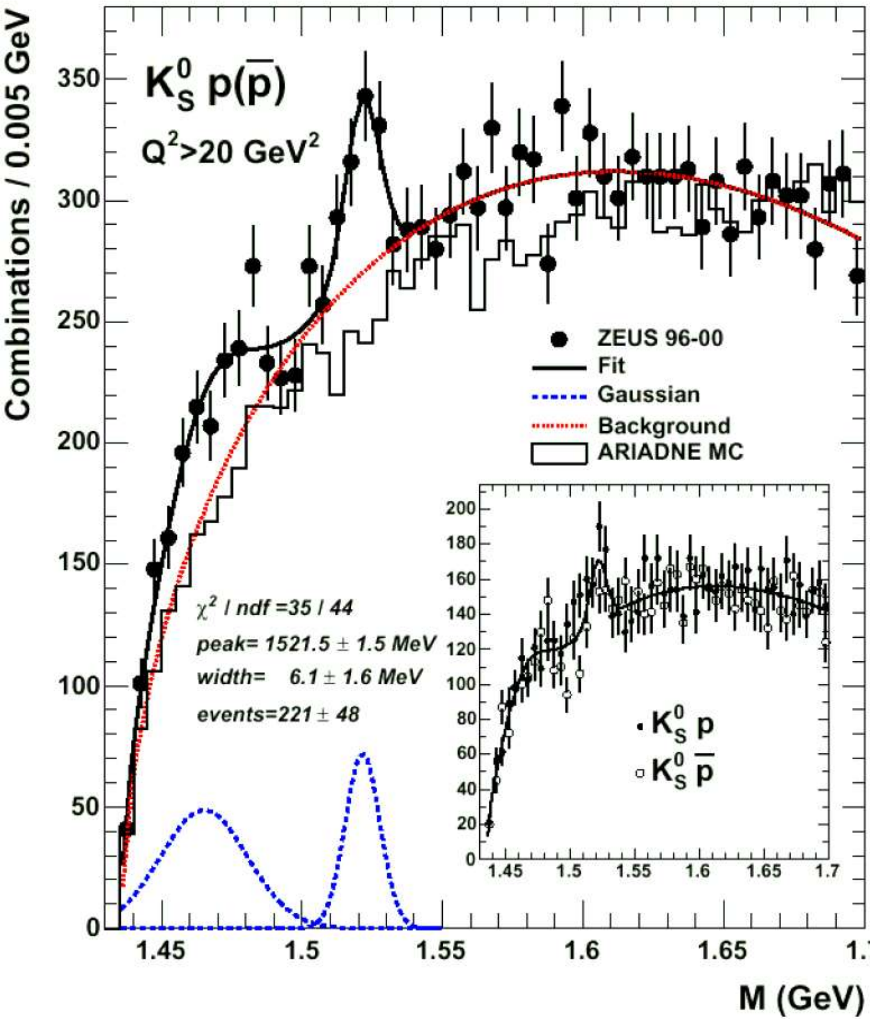


Situation at H1 and ZEUS: $\Theta^+(1540)$

H1



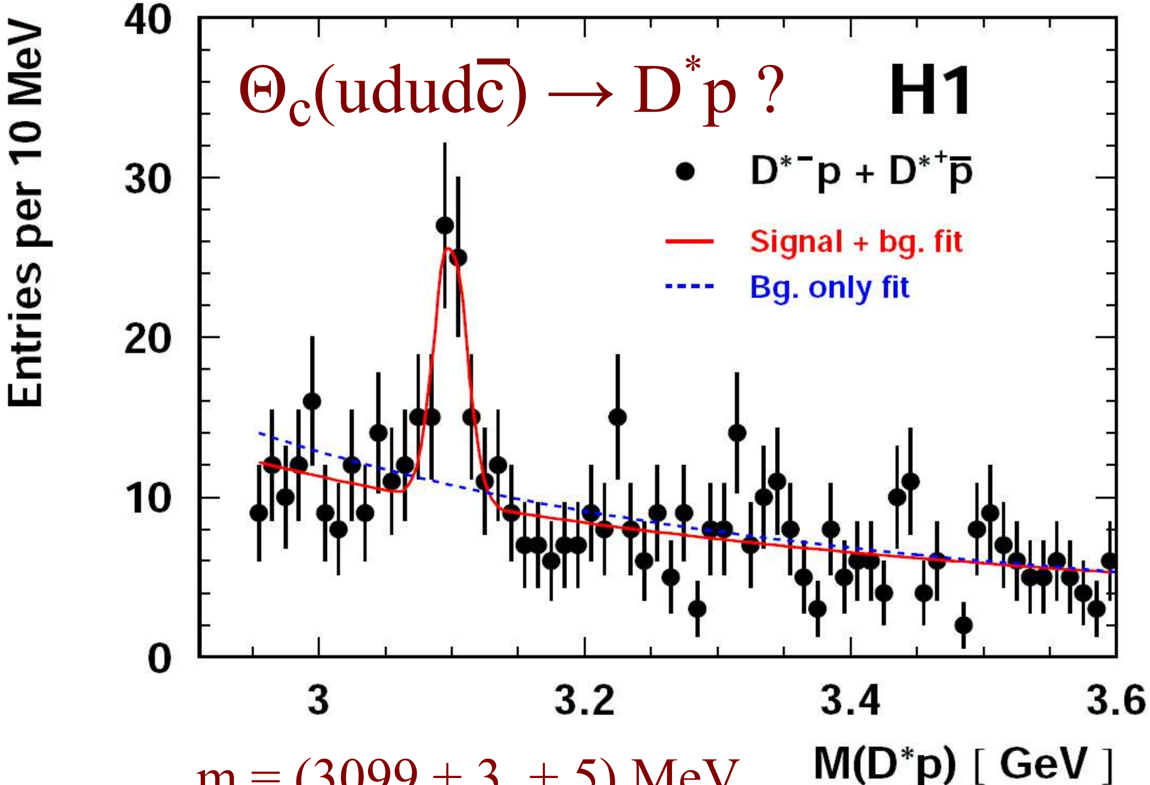
ZEUS



→ "controversial"

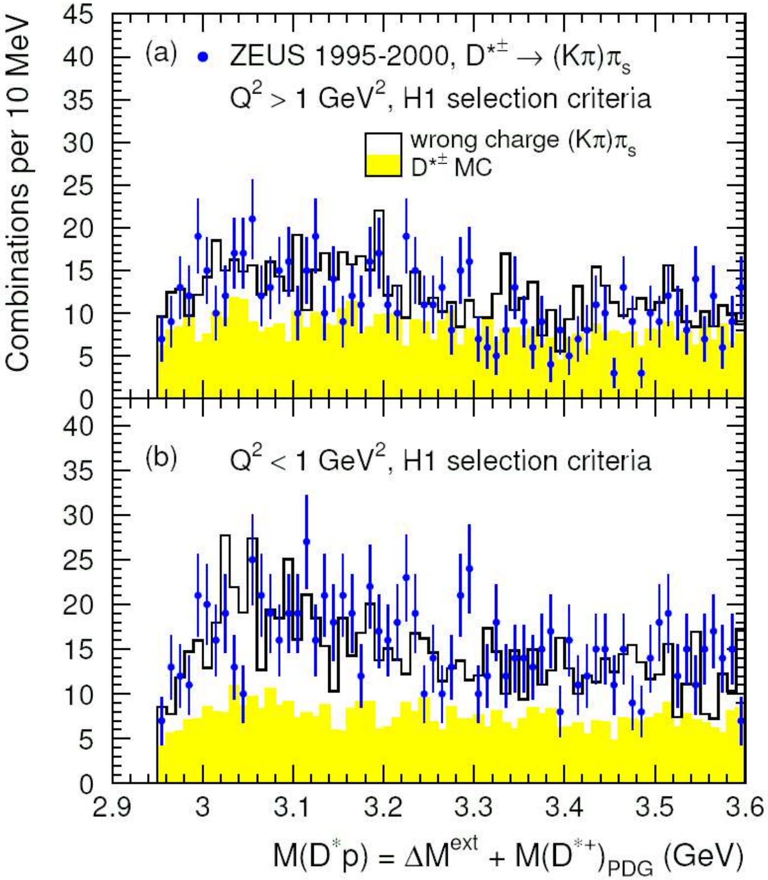
Situation at H1 and ZEUS: Θ_c

H1



m = (3099 ± 3 ± 5) MeV
σ = (12 ± 3) MeV
N_S = 50.6 ± 11.2
N_B ≈ 45 - 51 (± 2σ)
Significance: 5.4 – 6.2 σ

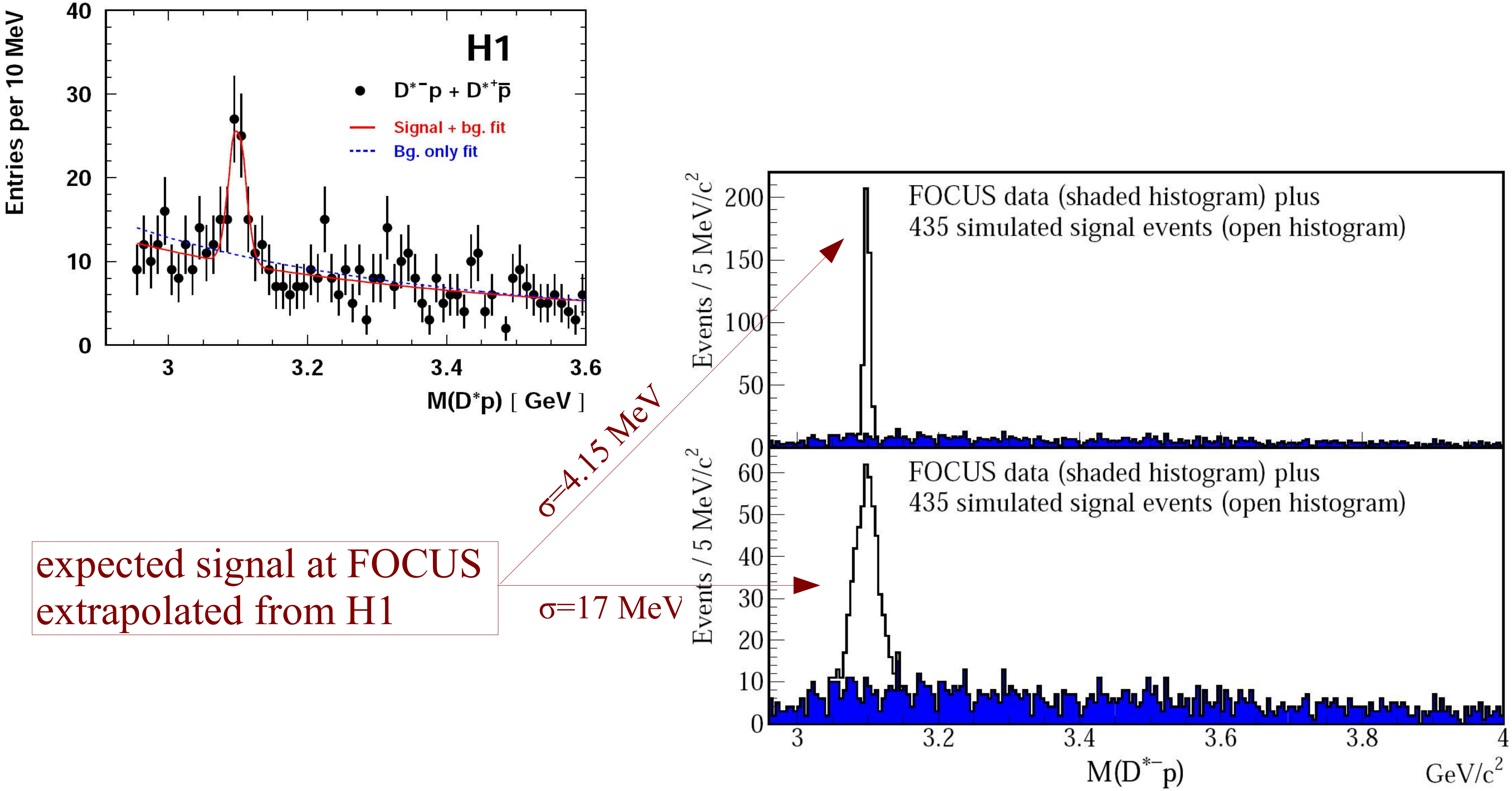
ZEUS



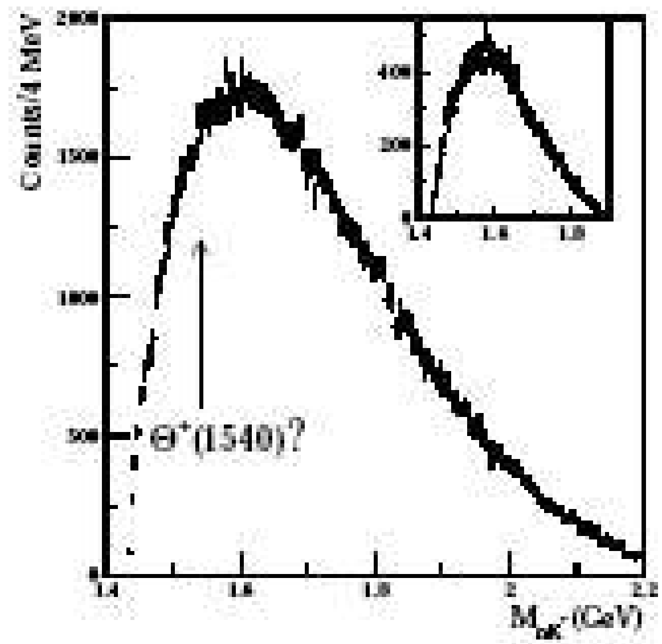
→ controversal!

The Θ_c at H1 and FOCUS

- The H1 signal $\Theta_c \rightarrow D^*p$:
  - ZEUS and FOCUS claimed incompatibility



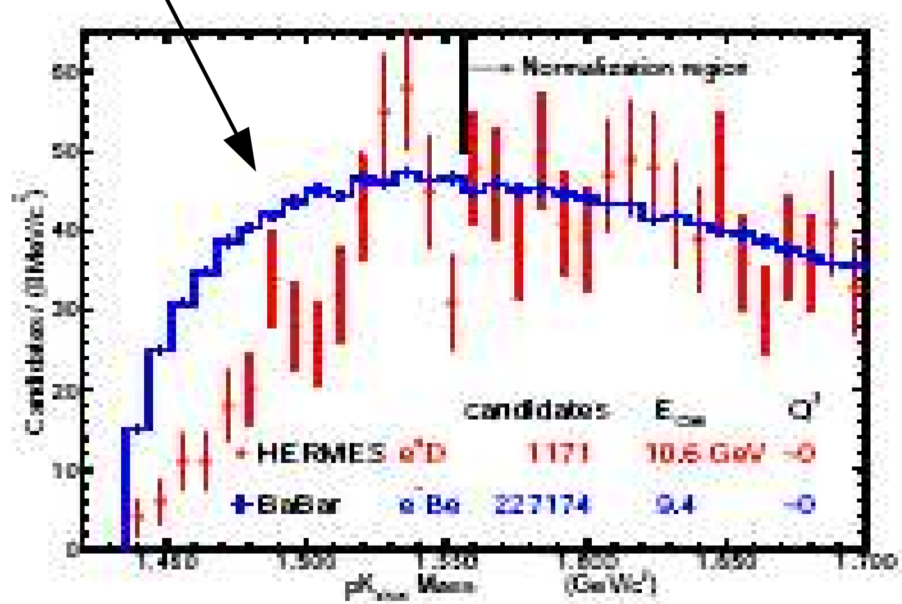
The new CLAS experiments



- $\gamma p \rightarrow K^0_s K^+ (n)$
  - No Signal observed
  - Upper limit on production cross section: (0.85-1.3)nb at 95% CL and m ≈ 1.54GeV
  - Contradicts SAPHIR experiment by two orders of magnitude (300nb)
  - Implies very small coupling of Θ^+ to NK*; but in many models major source of Θ^+ production
- $\gamma d \rightarrow p K^- K^+ (n)$
  - Previous CLAS results claimed ~ 5 σ for Θ^+ in the same channel and same energy
  - New high statistics results see no hint for a Θ^+ state!
  - Clearly contradicts the previous data
  - New fit of old data with improved BG (from new data) yields a significance of only 3 σ, previous: (5.2 ± 0.6) σ
  - The new CLAS data leaves room only for a Θ^+ state with intrinsic width of less than 0.5 MeV

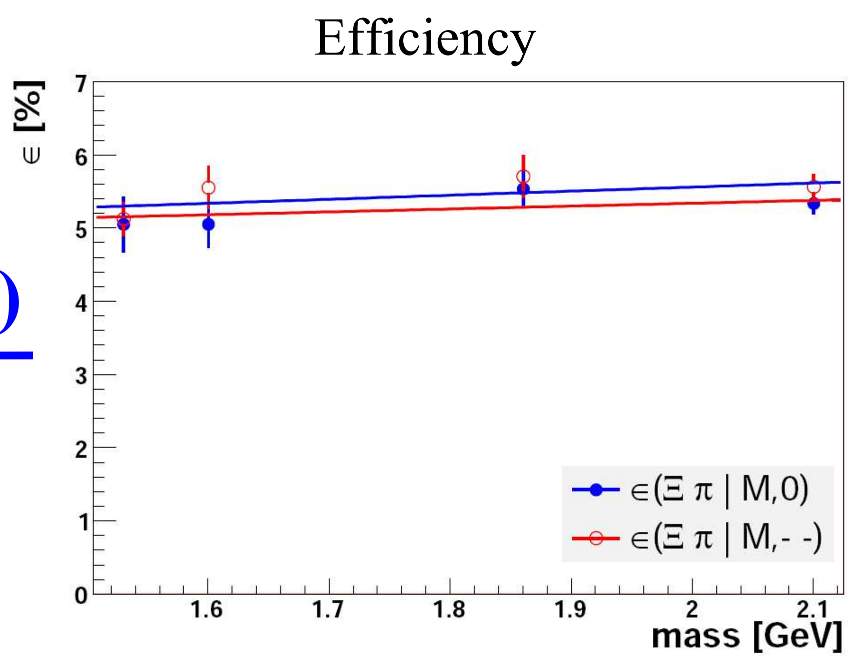
The BaBar experiment

- $e + Be \rightarrow p\, K^0_s + X$
  - Energy of electron: ~ 9 GeV
  - No Signal observed
  - Can be compared with HERMES data (quasi real photoproduction)
  - Potential loss of acceptance at HERMES for small masses
  - Peak could be result of acceptance rising up just below Θ^+ mass



Limit calculation II

- Correct $R^*_{u.l.}$ for small differences in efficiency (mass-dependent):



$$R_{u.l.}(M) = R^*_{u.l.}(M) \bullet \frac{\epsilon(\Xi(1530)^0)}{\epsilon(M, q)}$$

- Uncertainties considered:
  - Number of $\Xi(1530)^0$: 15% (from fit
  - Width of signal: 5% (diff $\sigma\,(\Xi(1530)^0)$ data-MC)
  - Efficiency correction factor: 8%
  - BG: 2% (performing BG determination under different assumption)