International Conference
on
High Energy Physics

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PentaQuark Searches in H1

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for the H1 Collaboration

Strange PentaQuarks

Mesons and baryons from u,d,s

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$3 \otimes 3 \otimes 3 = 10 \oplus 8 \oplus 8 \oplus 1$$

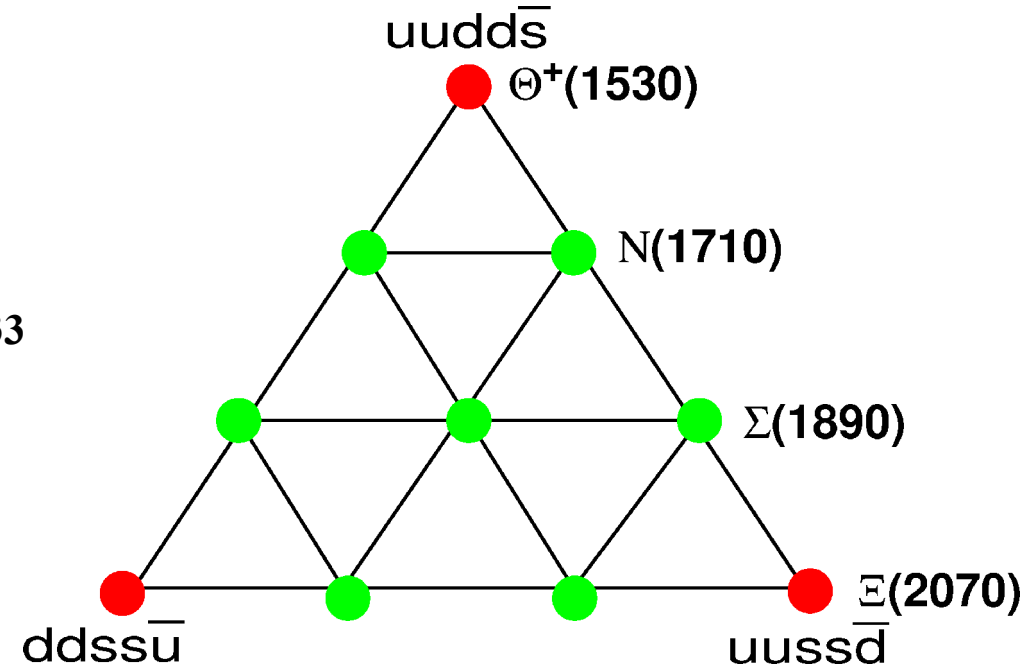
Baryon $\otimes$ Meson

$$8 \otimes 8 = 27 \oplus 10 \oplus \overline{10} \oplus 8 \oplus 8 \oplus 1$$

Anti-decuplet $qqqq\bar{q}$

Theory:

Diakonov, Petrov, Polyakov Z.Phys. A359 (1997) 305
Jaffe, Wilczek Phys.Rev.Lett. 91 (2003) 23
Karliner, Lipkin Phys.Lett. B575 (2003) 249
Cheung hep-ph/0308176
Capstick, Page, Roberts Phys.Lett. B570 (2003) 185
Walliser, Kopeliovich J.Exp.Theor.Phys. 97 (2003) 433
Kahana, Kahana hep-ph/0310026
Shuryak, Zahed hep-ph/0310270
Hoegaasen, Sorba Nucl.Phys. B145 (1978) 119
Strottman Phys.Rev. D20 (1979) 748
Roisnel Phys.Rev. D20 (1979) 1646
.....



$\Theta^+(1530)$

Seen by many experiments, in various experimental environments

Table 1: Published experiments with evidence for the Θ^+ baryon.

Reference	Group	Reaction	Mass (MeV)	Width (MeV)	σ's*
[1]	LEPS	$\gamma C \to K^+K^-X$	1540 ± 10	< 25	4.6
[2]	DIANA	$K^+Xe \to K^0pX$	1539 ± 2	< 9	4.4
[3]	CLAS	$\gamma d \to K^+K^-p(n)$	1542 ± 5	< 21	$5.2 \pm 0.6^\dagger$
[4]	SAPHIR	$\gamma d \to K^+K^0(n)$	1540 ± 6	< 25	4.8
[5]	ITEP	$\nu A \to K^0pX$	1533 ± 5	< 20	6.7
[6]	CLAS	$\gamma p \to \pi^+K^+K^-(n)$	1555 ± 10	< 26	7.8
[7]	HERMES	$e^+d \to K^0pX$	1526 ± 3	13 ± 9	~ 5
[8]	ZEUS	$e^+p \to e^+K^0pX$	1522 ± 3	8 ± 4	~ 5
[9]	COSY-TOF	$pp \to K^0p\Sigma^+$	1530 ± 5	< 18	4-6
[10]	SVD	$pA \to K^0pX$	1526 ± 5	< 24	5.6

Table 2: Published experiments with non-observation of the Θ^+ baryon.

Reference	Group	Reaction	Limit	Sensitivity?
[11]	BES	$e^+e^- \to J/\Psi \to \Theta\Theta$	$< 1.1 \times 10^{-5}$ B.R.	No [68]
[12]	BaBar	$e^+e^- \to \Upsilon(4S) \to pK^0X$	$< 1.0 \times 10^{-4}$ B.R.	Maybe
[13]	Belle	$e^+e^- \to B^0\bar{B}^0 \to p\bar{p}K^0X$	$< 2.3 \times 10^{-7}$ B.R.	No
[14]	LEP	$e^+e^- \to Z \to pK^0X$	$< 6.2 \times 10^{-4}$ B.R.	No?
[15]	HERA-B	$pA \to K^0pX$	$< 0.02 \times \Lambda^*$	No?
[16]	SPHINX	$pC \to K^0\Theta^+X$	$< 0.1 \times \Lambda^*$	Maybe
[17]	HyperCP	$pCu \to K^0pX$	$< 0.3\%\ K^0p$	No?
[18]	CDF	$p\bar{p} \to K^0pX$	$< 0.03 \times \Lambda^*$	No?
[19]	FOCUS	$\gamma BeO \to K^0pX$	$< 0.02 \times \Sigma^*$	Maybe
[20]	Belle	$\pi + Si \to K^0pX$	$< 0.02 \times \Lambda^*$	Yes?
[21]	PHENIX	$Au + Au \to K^-\bar{n}X$	(not given)	Unknown

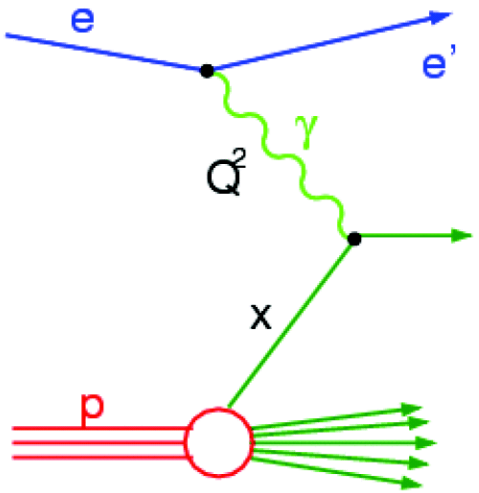
and also not seen by many other experiments...

Tables borrowed from K.H. Hicks, hep-ex/0504027 v2

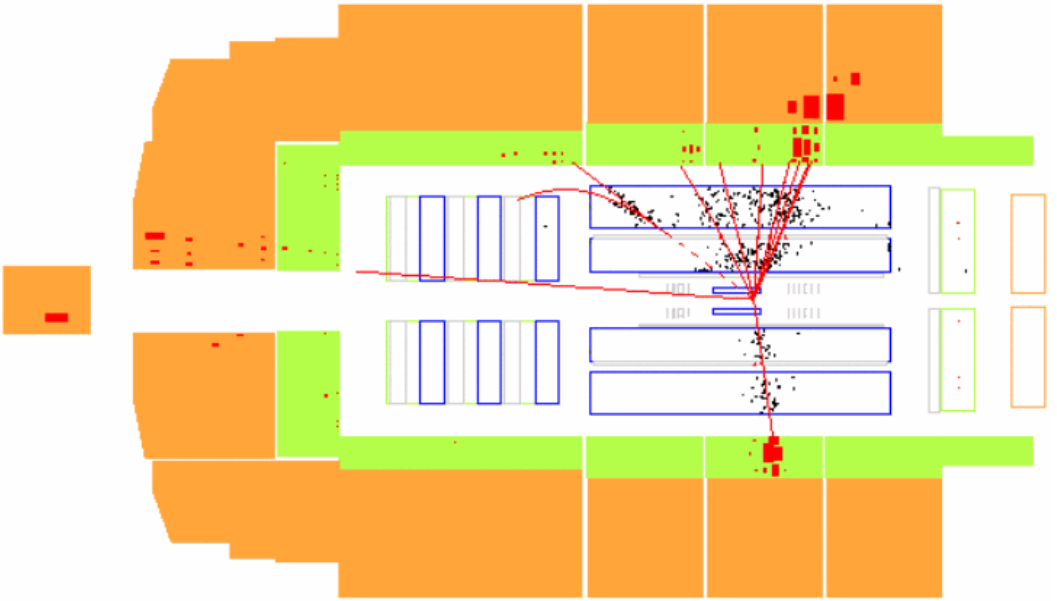
HERA and H1

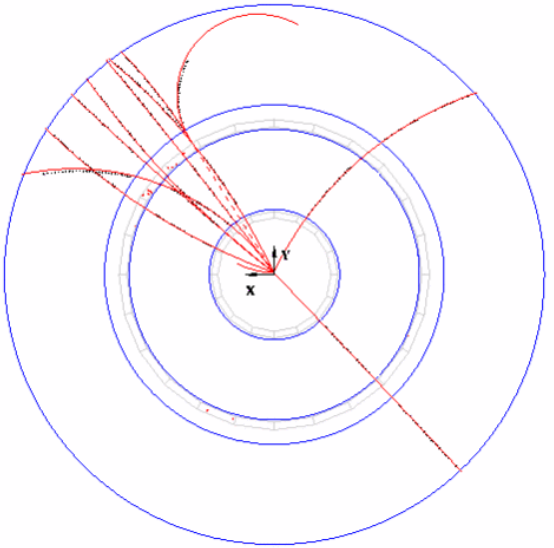
300-318 GeV

e (27.6 GeV) p (820-920 GeV)



H1 Detector





HERA-1 data
1996-2000
75 – 100 pb^{-1}
1 < Q² < 120 GeV²

Search for the $\Theta^+(1530)$ Pentaquark

Event Selection

HERA-I data, 75 pb^{-1}

$5 < Q^2 < 100$ GeV^2

$0.1 < y < 0.6$

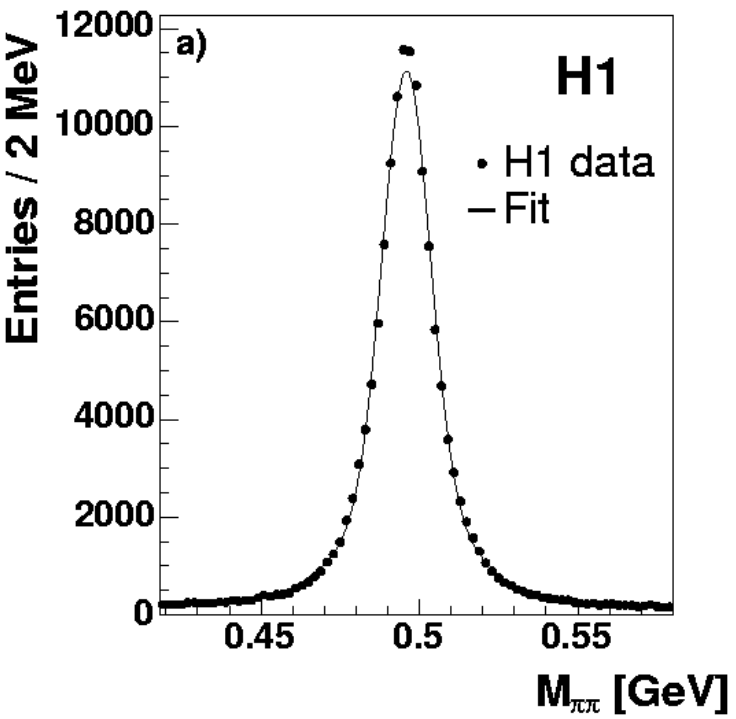
$35 < E - p_z < 70$ GeV

$\Theta^+(1530) \rightarrow p\, K^\circ_S \rightarrow p\, \pi^+\pi^-$

K°_S Selection

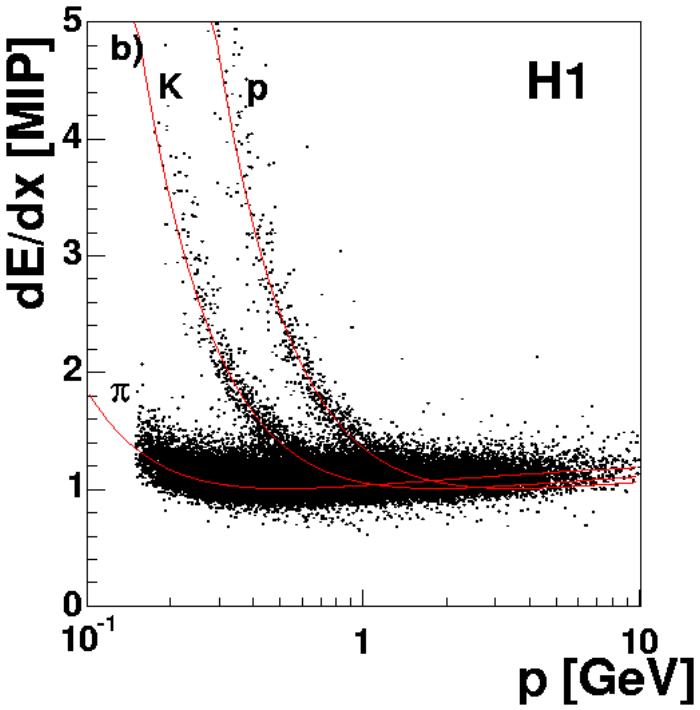
- Secondary $\pi^+\pi^-$ vertex
- $p_{t,\pi\pi} > 0.3$ GeV, $|\eta_{\pi\pi}| < 1.5$
- Remove background from Λ and γ-conversions

$\Longrightarrow \sim 132000\, K^\circ_S$, $\sim 3\%$ background

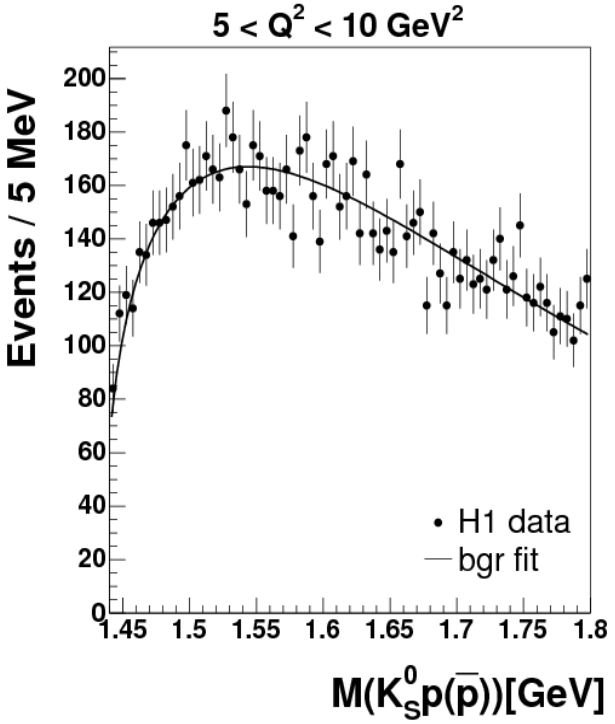


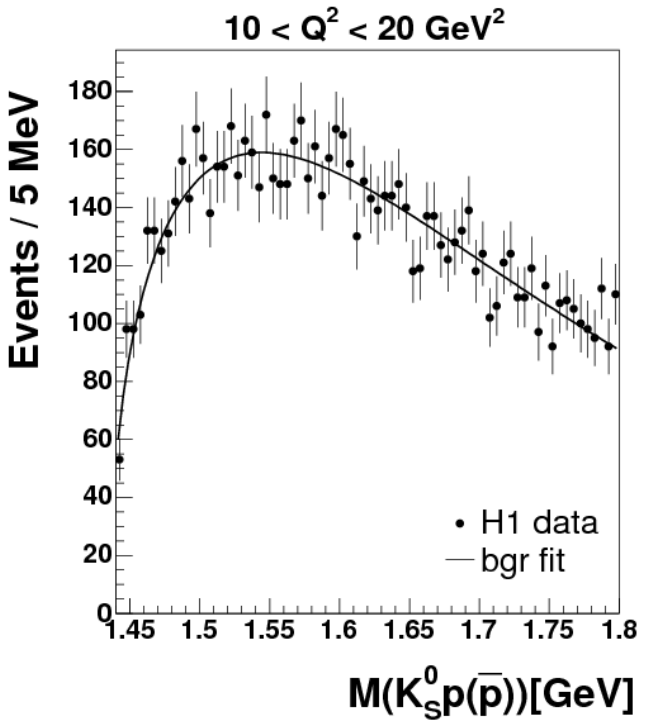
proton (and antiproton) Selection

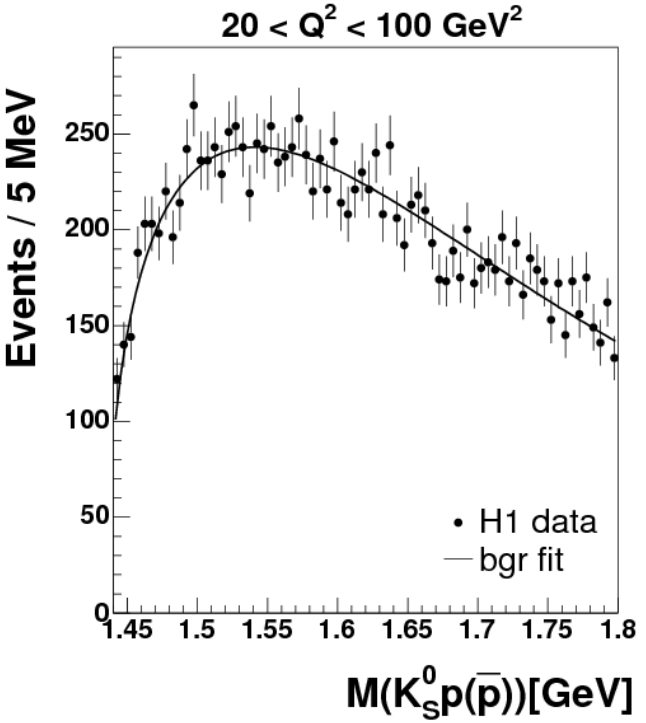
- dE/dx, resolution $\sim 8\%$
- Parameterisation based on Bethe-Bloch
- proton separation by likelihood approach
- No cut on proton momentum
- Efficiency 65 - 100%, well described in MC



Search for the $\Theta^+(1530)$ Pentaquark



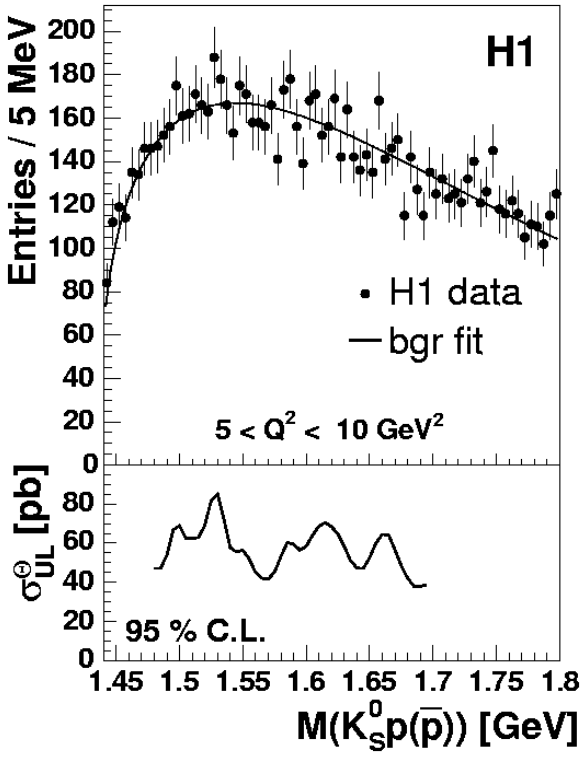


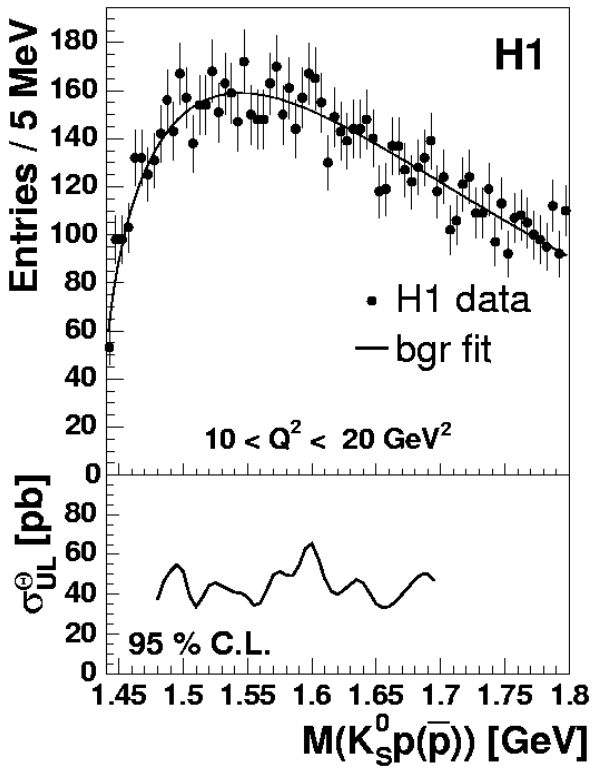


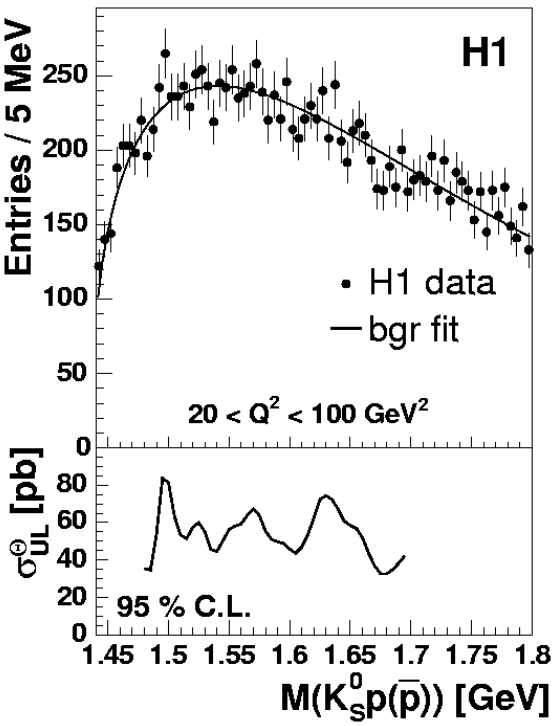
$$\textit{Background}: \quad \alpha(M_{K^\circ_S p} - M_{thr})^{\beta} \cdot e^{-\gamma(M_{K^\circ_S p} - M_{thr})} \qquad M_{thr} = M_p + M_{K^\circ_S}$$

No significant signal seen !

Search for the $\Theta^+(1530)$ Pentaquark







Upper Limit on cross section, given for the process:

$$e\,p \rightarrow e\,\Theta\,(\overline{\Theta})\,X, \quad \Theta \rightarrow K^{\circ}\,p\ \ (\overline{\Theta} \rightarrow \overline{K^{\circ}}\,\overline{p})$$

Θ approximated with narrow Gaussian in range 1.48 - 1.7 GeV

Modified Frequentist approach, based on likelihood ratios

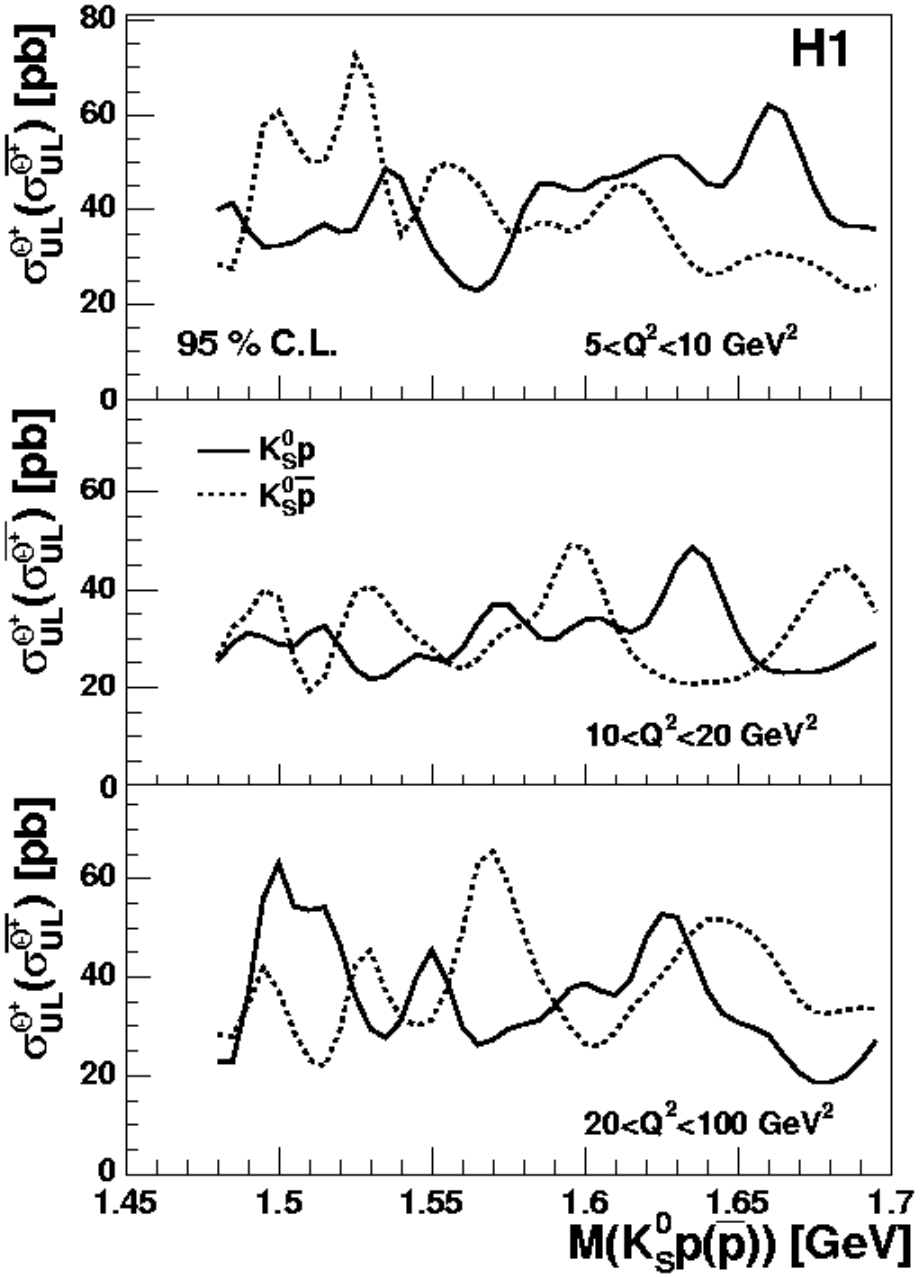
Nucl.Inst.Meth. A434 (1999) 435

Upper limits in range 30-90 pb

Search for the $\Theta^+(1530)$ Pentaquark

Separate distributions

for $K^0_S p$ and $K^0_S \bar{p}$



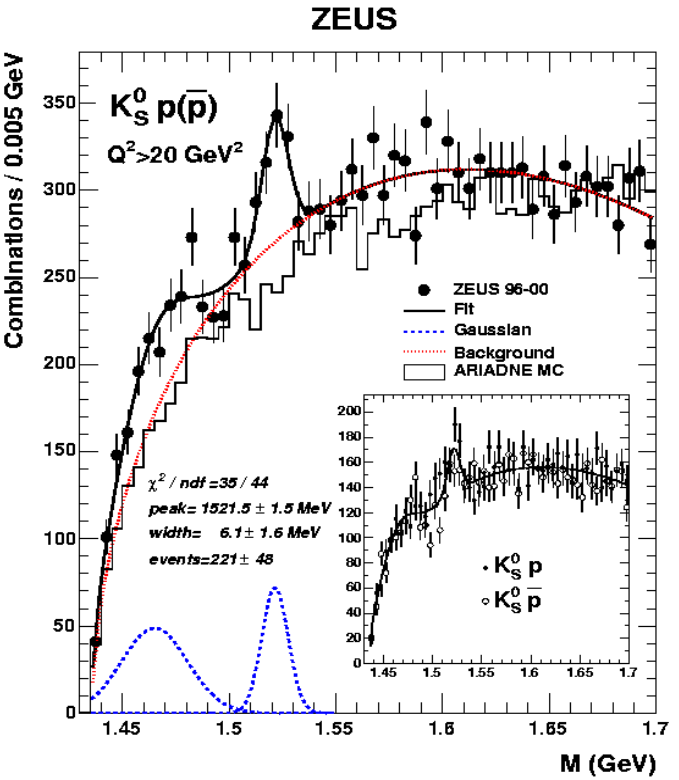
No signal observed at the same mass

Upper limits comparable in size

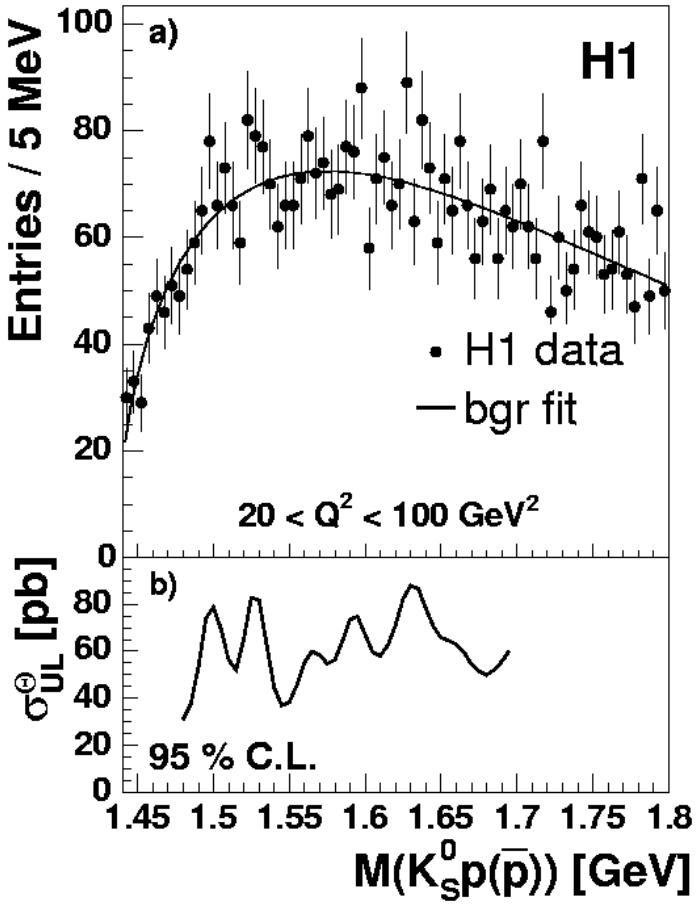
Search for the $\Theta^+(1530)$ Pentaquark

Compare with the ZEUS analysis

$p(p) < 1.5$ GeV
$Q^2 > 20$ GeV^2



H1 data with "ZEUS cuts"



H1:

$\sigma(M{=}1.52) < 72\ pb\ (95\%\ C.L.)$

When extrapolated to ZEUS y-range

$\sigma(M{=}1.52) < 100\ pb\ (95\%\ C.L.)$

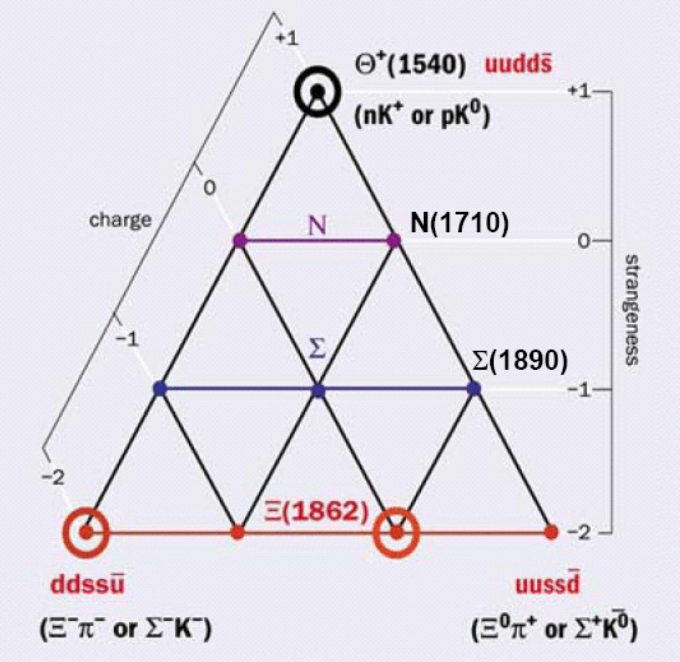
ZEUS Prel.:

$\sigma = 125 \pm 27\,^{+36}_{-28}\ pb$

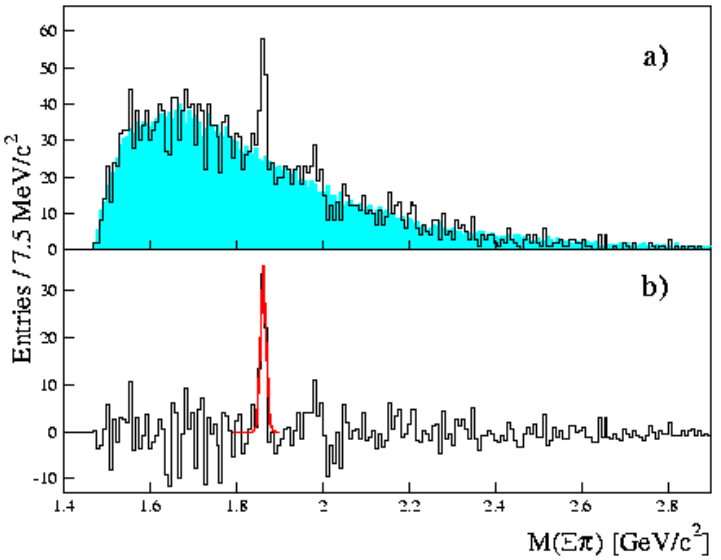
H1 does not confirm the ZEUS result

Search for the $\Xi(1862)$ Pentaquark

S = -2 PentaQuark



Reminder: the NA49 signal



$5.6\,\sigma$ combined signal at 1862 ± 2 MeV

Ξ° and Ξ^{--} both seen

Decay modes:

$$\Xi^{--} \to \Xi^- \pi^- \to (\Lambda \pi^-)\pi^- \to (p \pi^-)\pi^-\pi^-$$

$$\Xi^{--} \to \Sigma^- K^- \to (n\pi^-)K^-$$

So far, this resonance is not seen by any other experiment (WA89, ALEPH, BES, HERA-B, ZEUS ...)

H1 Preliminary:
Search for the $\Xi^{--}(1862)$

Data from HERA-1 1996-2000
~102.5 pb^{-1}

Search for the $\Xi(1862)$ Pentaquark

Event Selection

$2 < Q^2 < 120$ GeV^2

$0.05 < y < 0.7$

$E_{e'} > 8$ GeV

$35 < E - p_z < 70$ GeV

Λ Selection

3-dim. Vertex fit

$p_{t,p\pi} > 0.3$ GeV

Decay Length > 0.75 cm

Background from K^0_S rejected

no dE/dx cut

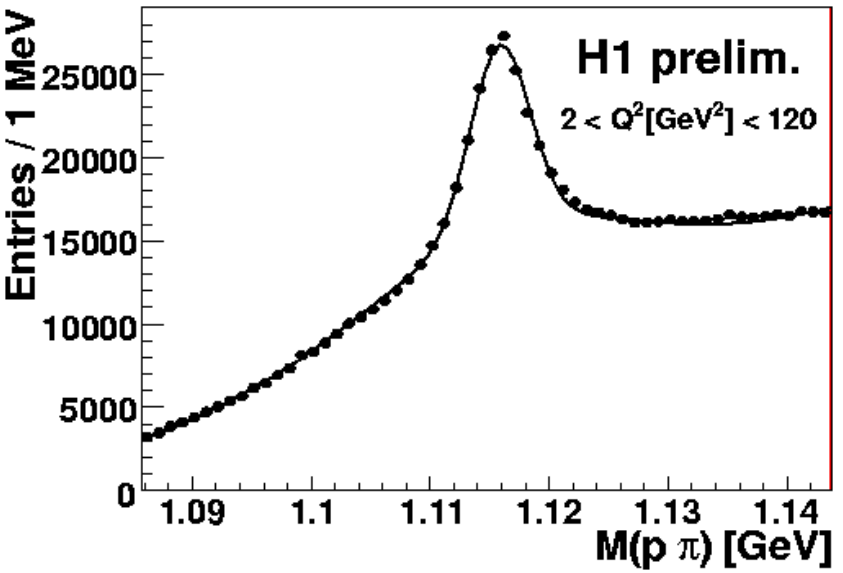
$\Xi(1321)$ Selection

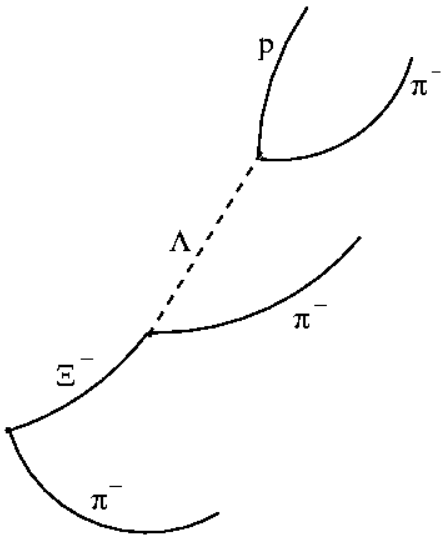
Λ mass window 8 MeV

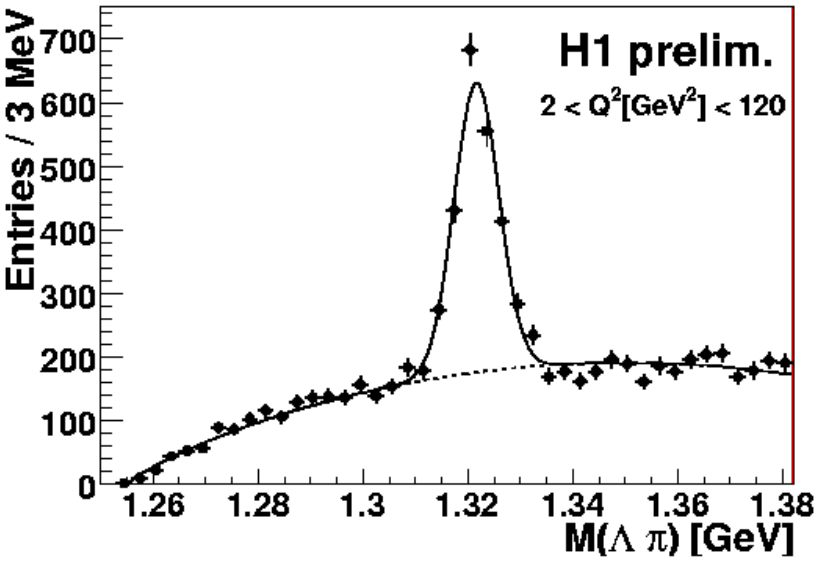
3-dim. Vertex fit

$DCA_{\Lambda\pi} < 2.5$ mm

$\theta_{2D}(\Lambda, \Lambda\pi) < 0.6$ rad.





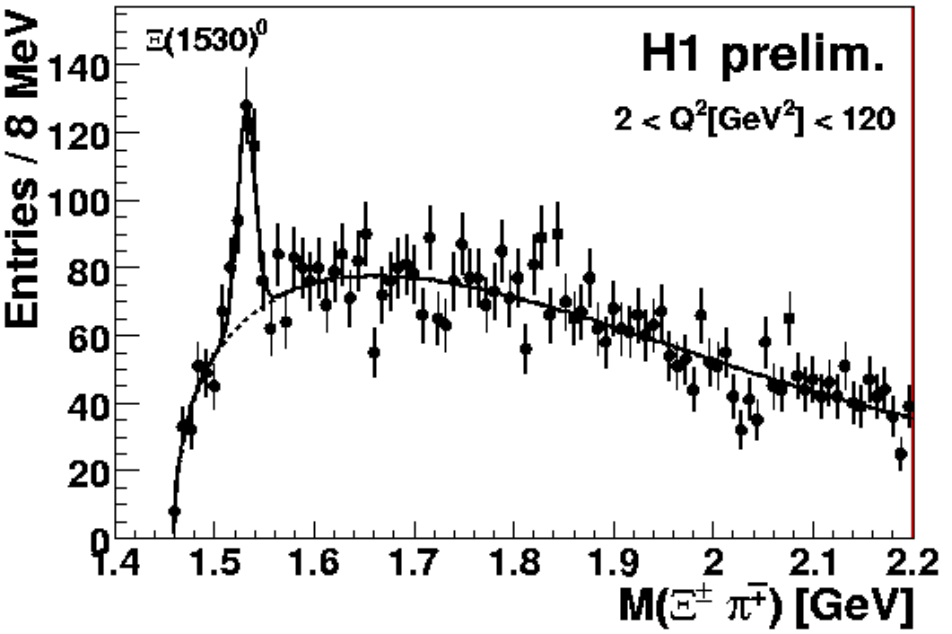


Clear signals of Λ and Ξ

$\sim 158000\ \Lambda$, $\sim 1650\ \Xi(1321)$

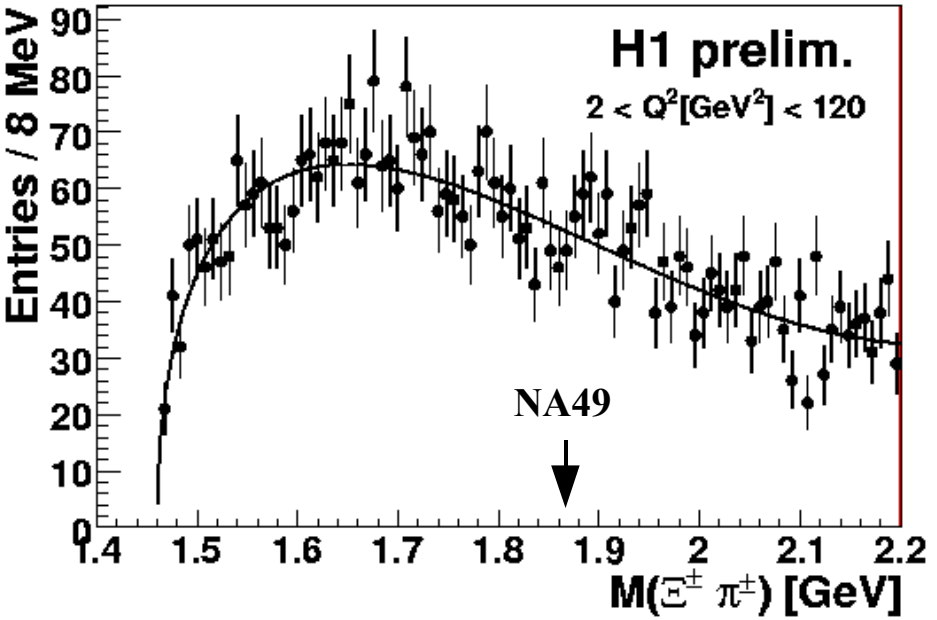
Search for the $\Xi(1862)$ Pentaquark

Further Cuts:
$\Xi(1321)$ mass window ± 15 MeV
$p_{t,\Xi\pi} > 1$ GeV
π originates at main vertex



Neutral combinations $\Xi^{\pm}\pi^{\mp}$

Clear Signal of $\Xi(1530)$
$\sim$ **170 events**

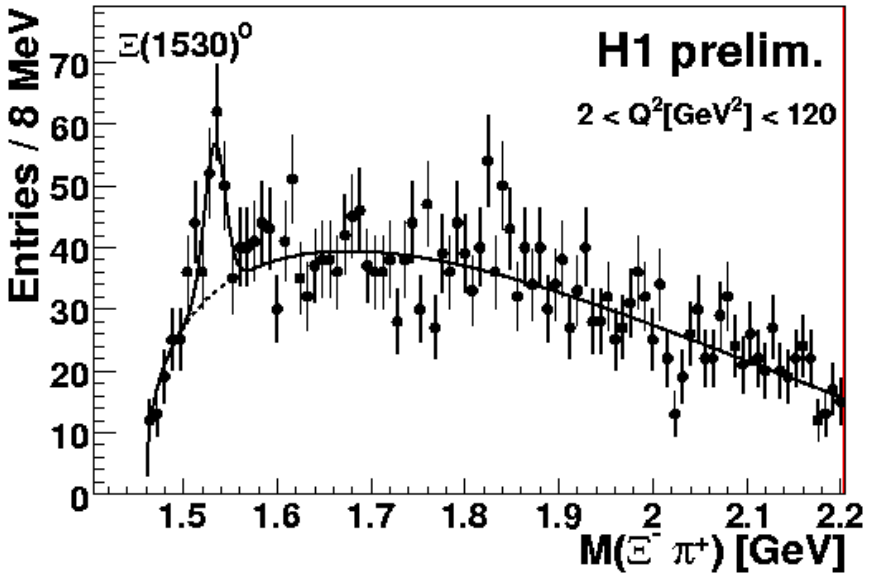


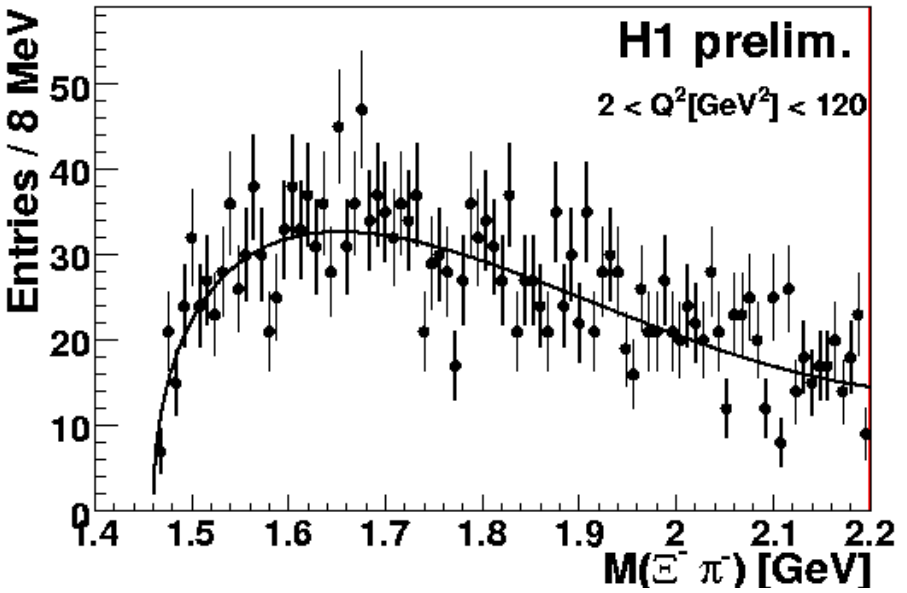
Doubly charged combinations $\Xi^{\pm}\pi^{\pm}$

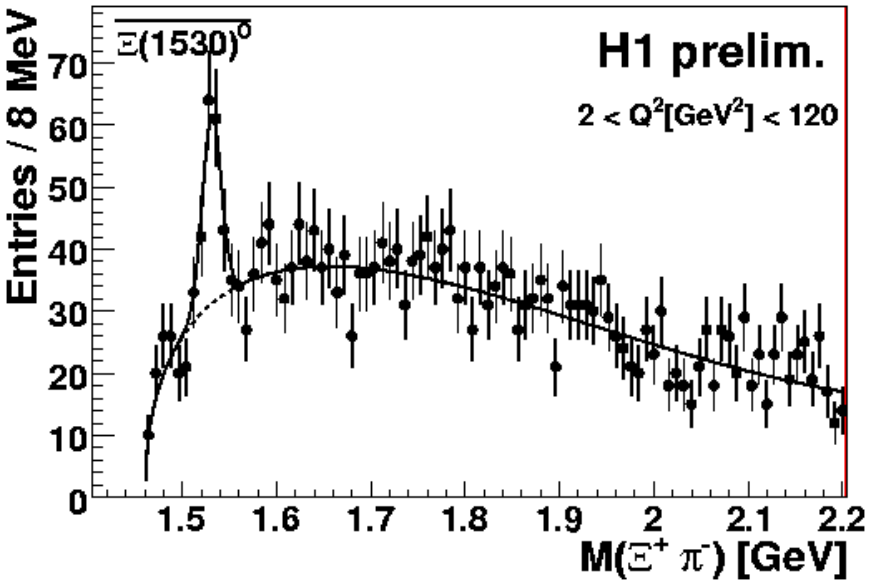
No significant signal

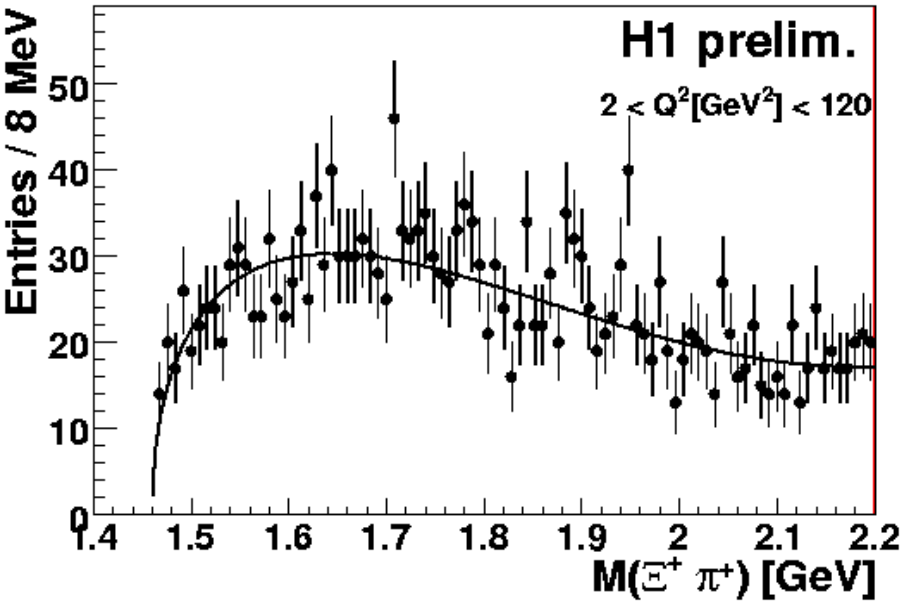
No sign of the NA49 resonance at 1862 MeV

Search for the $\Xi(1862)$ Pentaquark







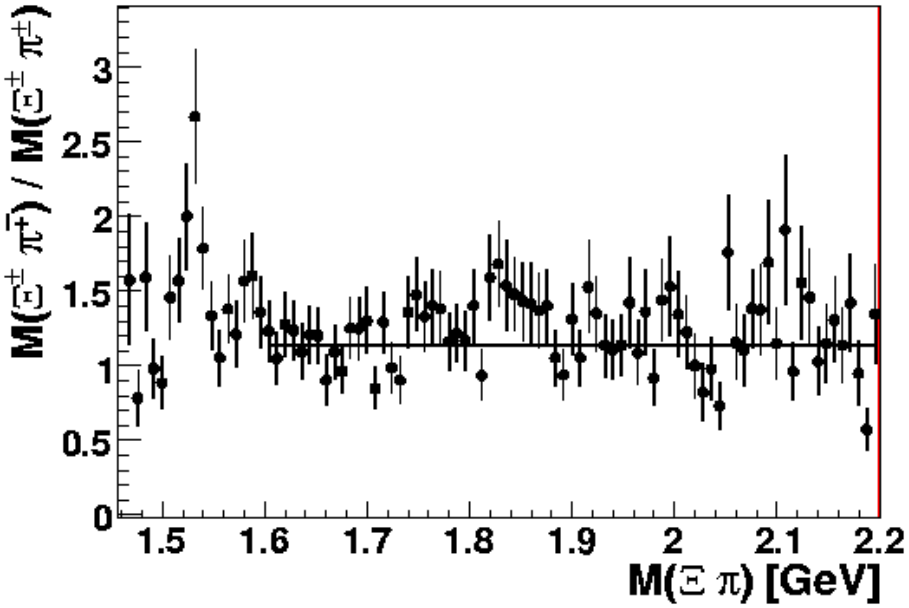


Extract upper limits on Ξ^{--} production

Search for the Ξ(1862) Pentaquark

Ratio of
Neutral to Doubly Charged combinations

Practically flat
==> use common background
relative normalisation ~1.1



- **Upper limit given for Mass dependent Ratio:**

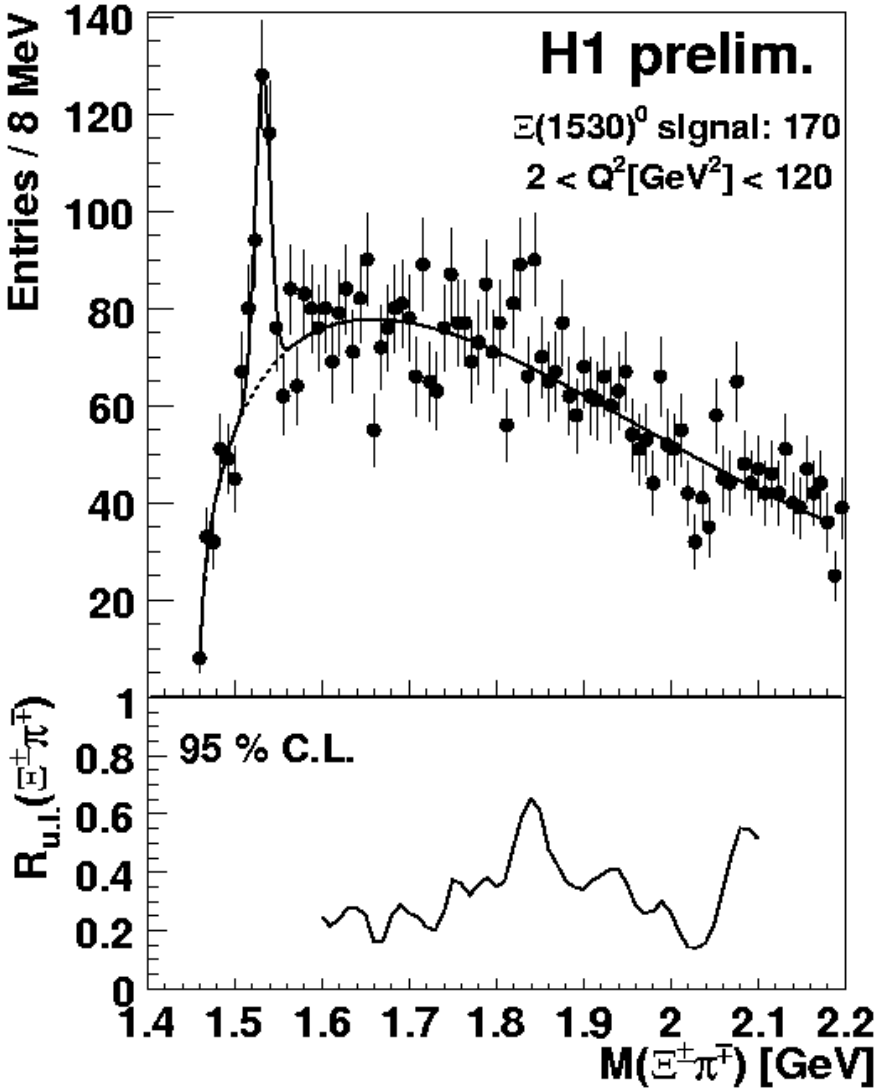
$$R_{U.L.}(M) = \frac{dN_{U.L.}(\Xi\pi)/dM}{N(\Xi(1530)^{\circ})}$$

- **Modified frequentist approach**
- **Narrow Gaussian for the possible signal, in range 1.6 - 2.1 GeV**
- **Common background function,**

$$a \cdot (x - M_{\Xi} - M_{\pi})^{b} \cdot (c + d \cdot x + e \cdot x^{2})$$

- **Separate limits for Neutral and Doubly Charged combinations, and for their sum**

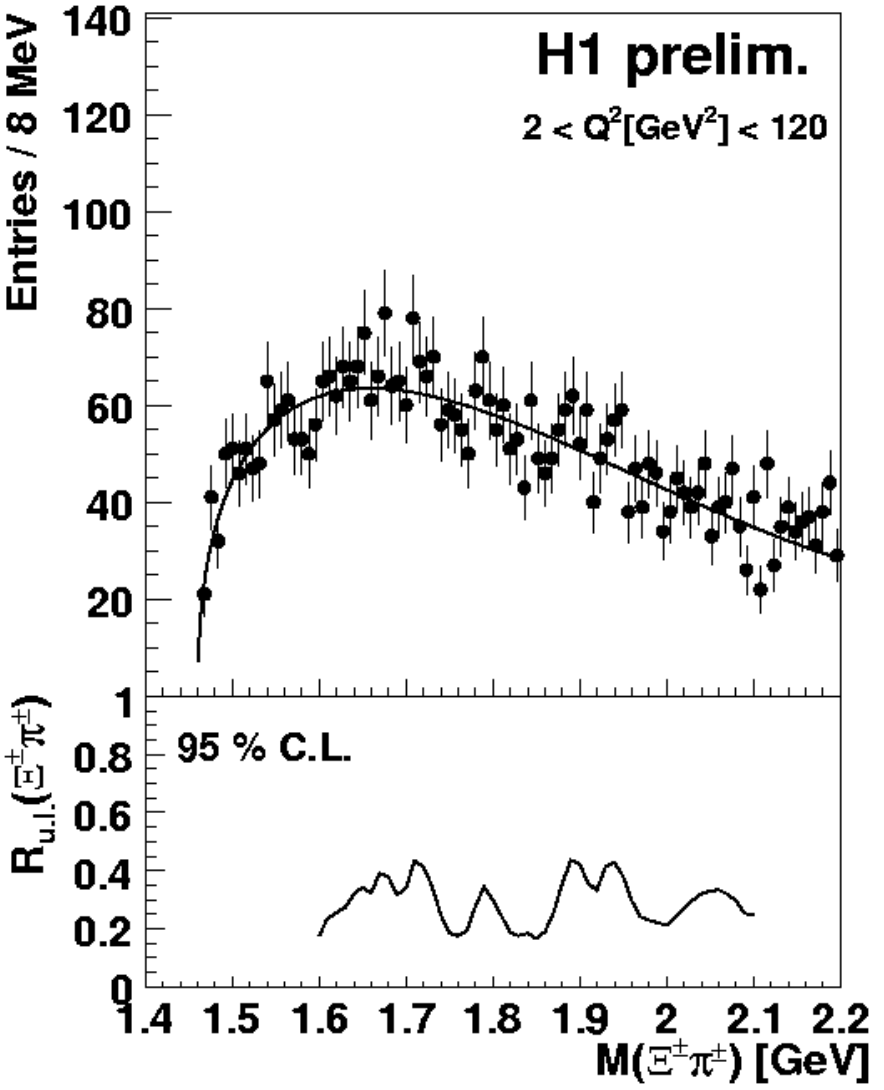
Search for the Ξ(1862) Pentaquark



Neutral Combinations

$R_{U.L.}$ in range 0.15 – 0.6

$R_{U.L.}(1860) \sim 0.5$



Doubly Charged Combinations

$R_{U.L.}$ in range 0.15 – 0.5

$R_{U.L.}(1860) \sim 0.2$

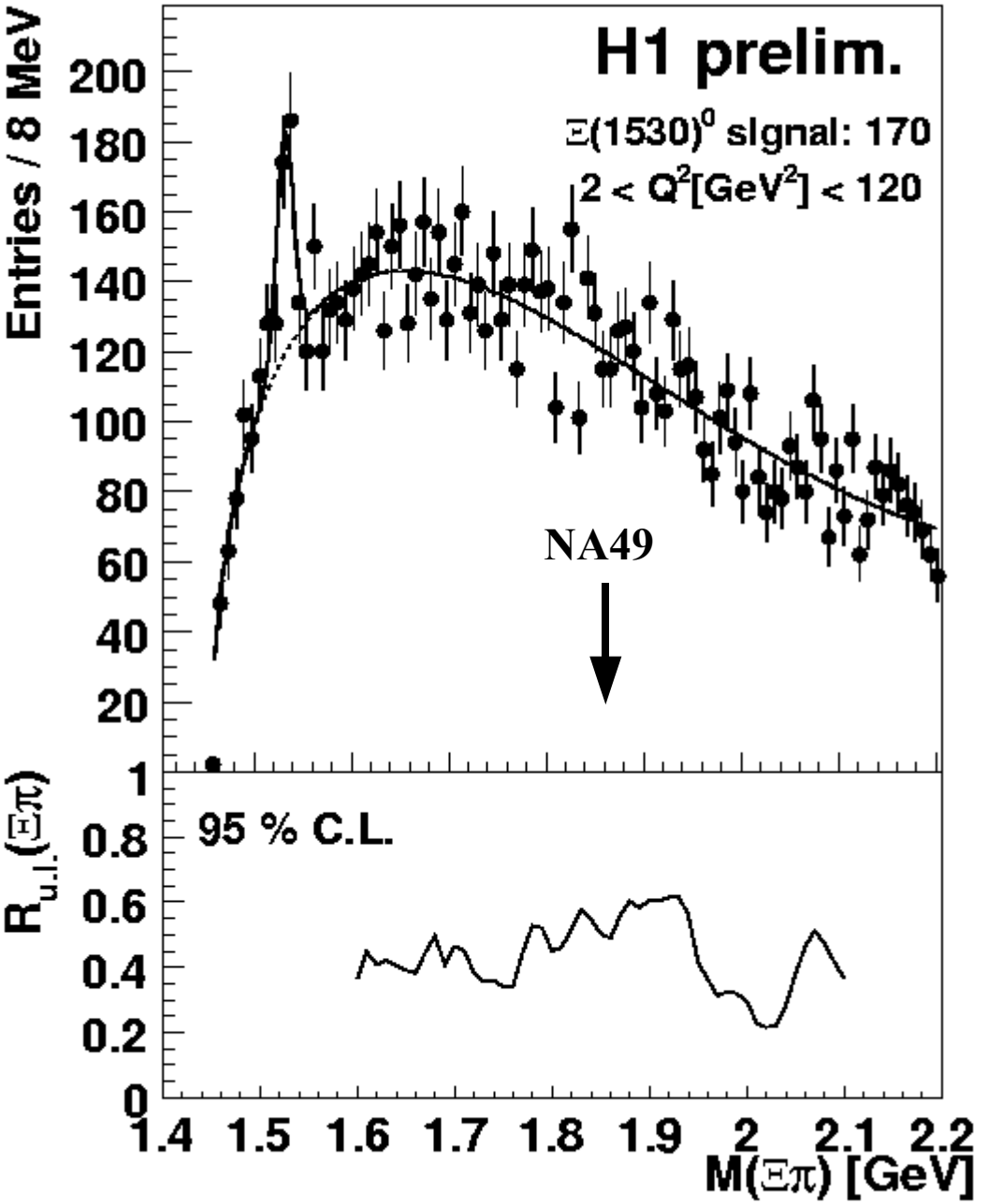
Search for the Ξ(1862) Pentaquark

All Combinations
$R_{U.L.}$ in range 0.2 – 0.6
$R_{U.L.}(1860) \sim 0.5$

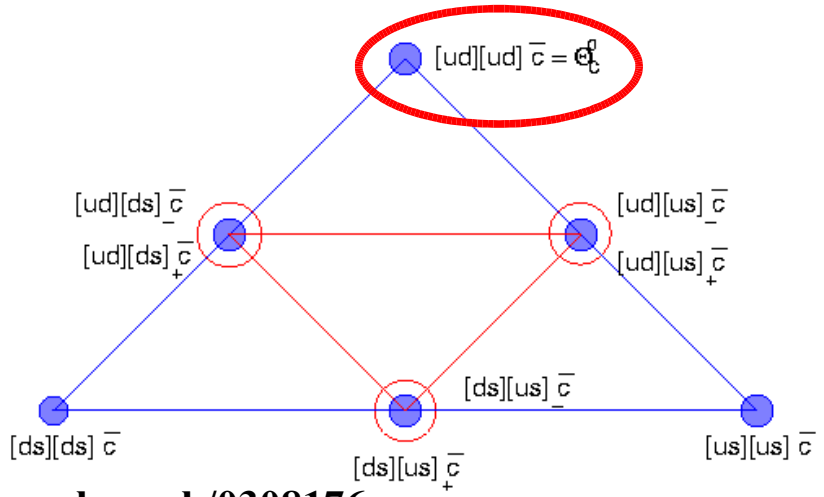
Comparison with ZEUS

All Combinations
$R_{U.L.}$ in range 0.1 – 0.5
$R_{U.L.}(1860) \sim 0.29$

(some differences in the Q^2 range, Selection cuts, ...)



Anticharmed Pentaquark Θ_c° $(D^*p(3100))$



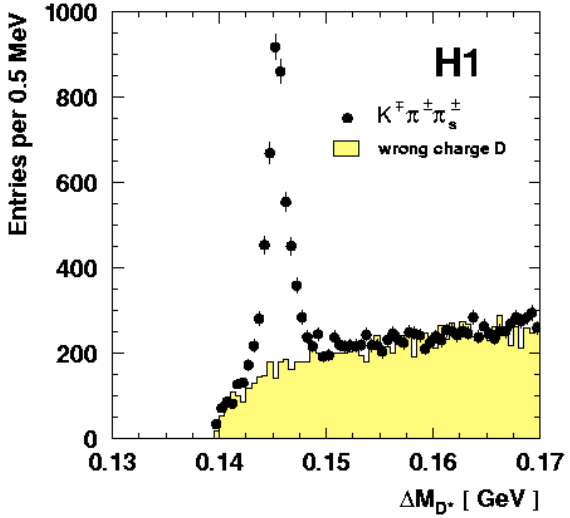
Cheung hep-ph/0308176

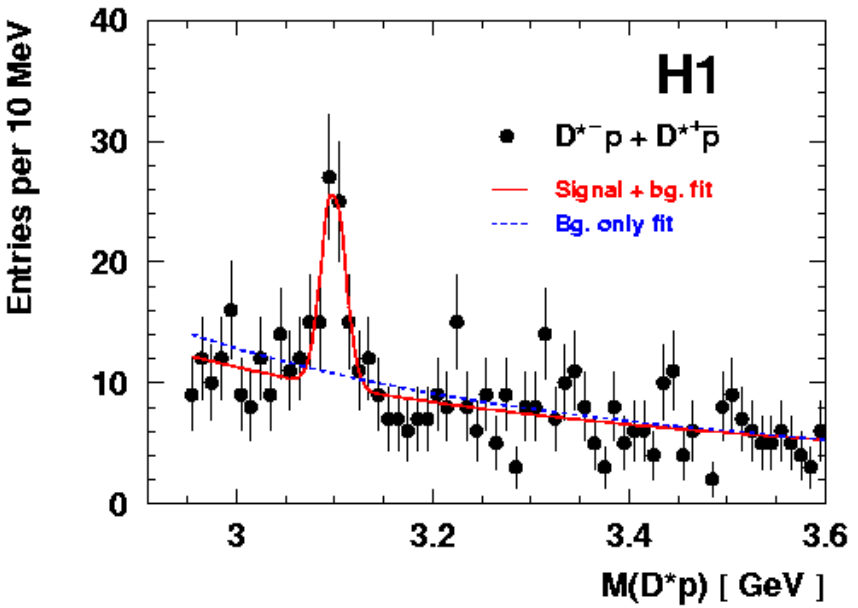
Predicted mass: ~ 3 GeV

Possible Decays:

$$\Theta_c^\circ \to D^- p, \quad \Theta_c^\circ \to \overline{D^\circ} n$$

If heavy enough, decay to $D^{*-} p$ possible





Evidence published
Phys.Lett. B588 (2004) 17

So far, no other experiment could confirm this signal

Here: Acceptance corrected yields ratios, differential distributions (H1 Prel.)

$D^*p(3100)$

$D^*p(3100)$: **Acceptance corrected yields ratios, relative to inclusive D^* production**

Visible range:

D^* : $p_t > 1.5$ GeV, $|\eta| < 1.5$, $z > 0.2$

$D^*p(3100)$: $p_t > 1.5$ GeV, $-1.5 < \eta < 1$

Acceptance correction, using RAPGAP:

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

This ratio can be compared with the upper limit found by ZEUS:

$$R_{cor}(D^*p(3100)/D^*) < 0.51\,\%\ \text{(95\% C.L.)}$$

Implement "fragmentation production" model in RAPGAP

$D^*p(3100)$ **produced like inclusive D^*, but with zero width and isotropic decay**

Extrapolating to full D^* phase space

$\Longrightarrow$ **visible cross section ratio**

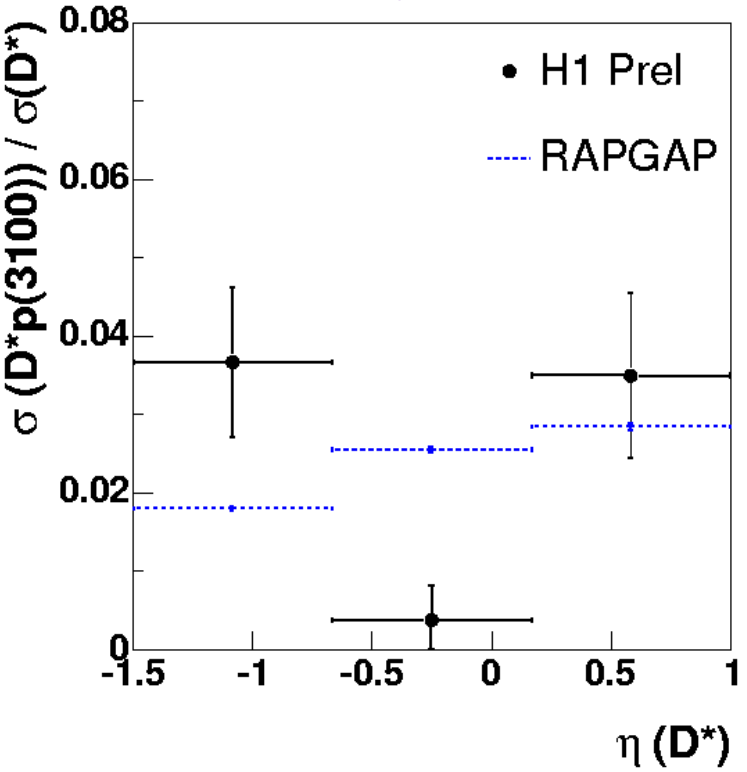
$$\sigma_{vis}(D^*p(3100))/\sigma_{vis}(D^*) = 2.48 \pm 0.52\,^{+0.85}_{-0.64}\,\%$$

$D^*p(3100)$

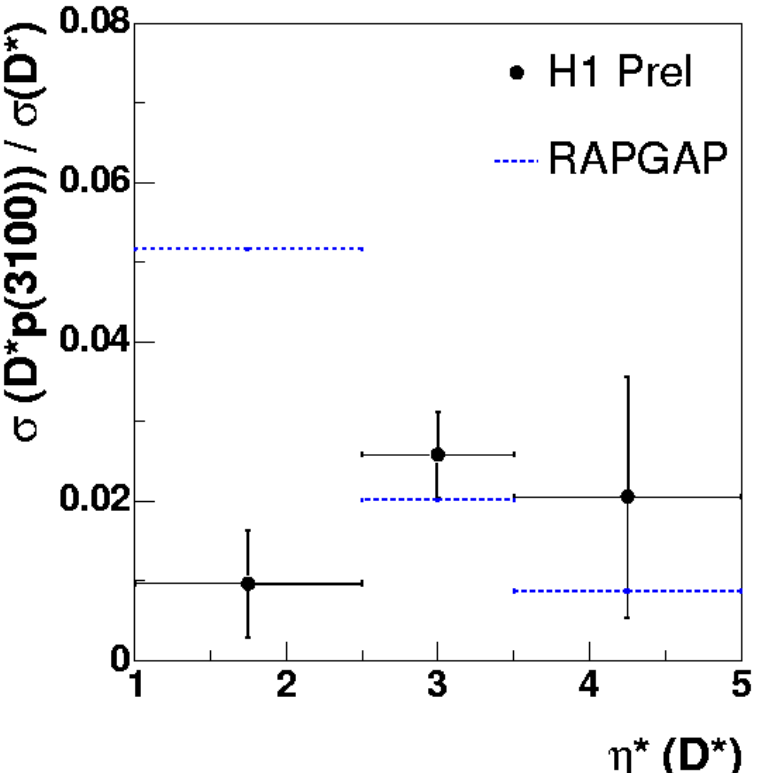
Differential distributions of the cross section ratio $\sigma(D^*p(3100))/\sigma(D^*)$

Compare to RAPGAP with "fragmentation production" of $D^*p(3100)$

Lab system



Hadronic system

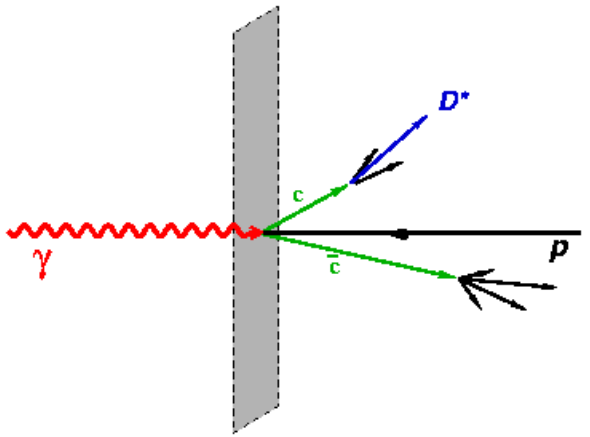


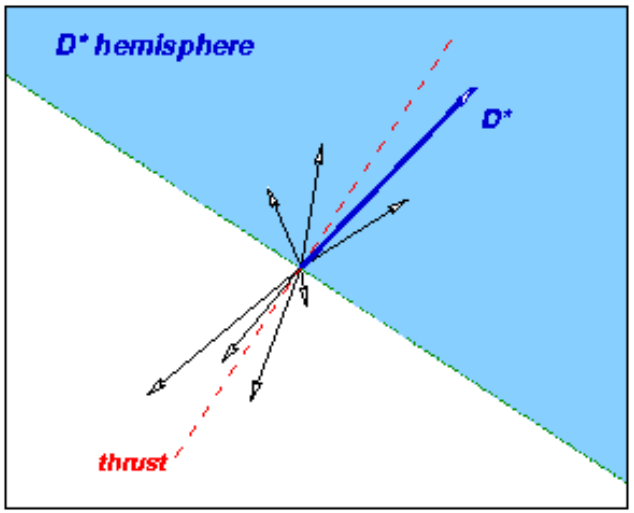
$D^*p(3100)$ production:

Suppressed in the central region

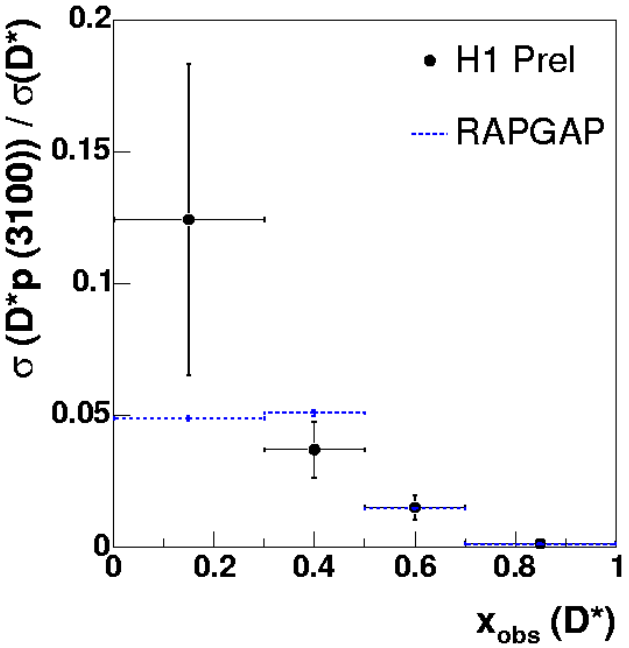
Closer to the photon direction than inclusive D^* production

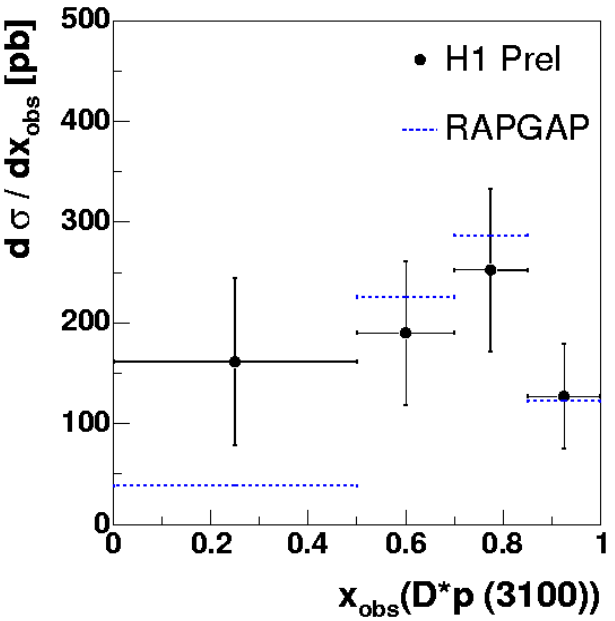
$D^*p(3100)$





Dependence on x_{obs}





Fragmentation Variable

$$x_{obs}(charm) = \frac{(E - p_z)_{charm}}{\sum_{h \in hemi} (E - p_z)_h}$$

D^*'s from $D^*p(3100)$ decays:
softer than inclusive D^*'s

$D^*p(3100)$ fragmentation function:
harder than fragmentation of inclusive D^*'s

SUMMARY

Strange PentaQuarks:

$\Theta^+(1530)$

- Not observed in the decay mode $\Theta^+(1530) \rightarrow K^\circ_S p$
- Upper limits on cross section in mass range 1.48 – 1.7 GeV
- No confirmation of the ZEUS evidence

$\Xi(1862)$

- Not seen by H1, decay mode $\Xi(1862) \rightarrow \Xi\,\pi \rightarrow \Lambda\,\pi\pi \rightarrow p\,\pi\pi\pi$
- Upper limits on the Production Ratio $N(\Xi^{\pm}\pi^{\pm})/N(\Xi^{\circ}(1530))$ obtained in the mass range 1.6 – 2.1 GeV. Agreement with ZEUS

$D^*p(3100)$

- Acceptance corrected yields ratio $R_{cor}(D^*p(3100)/D^*) = 1.59 \pm 0.33\,^{+0.33}_{-0.45}\,\%$ (Not confirmed by ZEUS)
- Production close to the photon direction, suppressed in fragmentation region
- D*p(3100) fragmentation harder than inclusive D* fragmentation
- D*'s from D*p(3100) decays are softer than inclusive D*'s

Outlook: HERA-2 data from H1 and ZEUS should resolve the open questions!

BACKUP SLIDES

Search for the Ξ(1862) Pentaquark

$Q^2 > 20\ GeV^2$

Comparison H1 and ZEUS