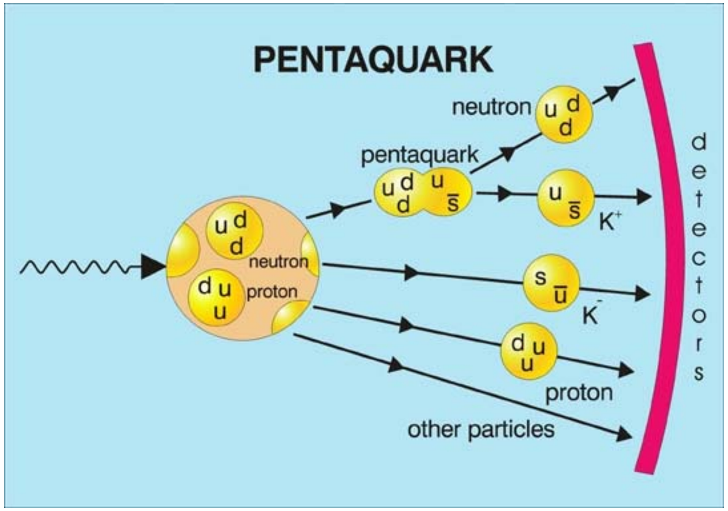
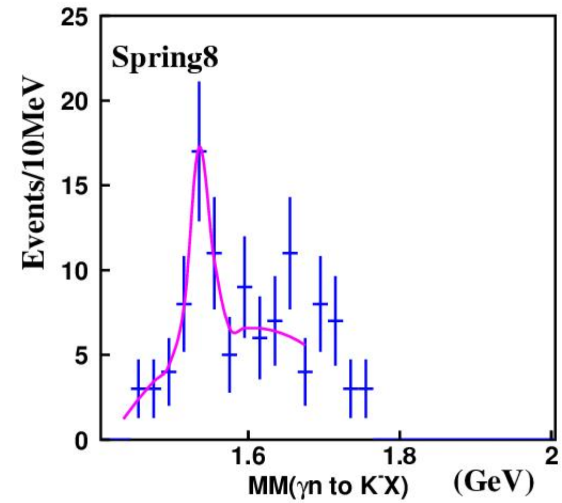
Pentaquarks: An Experimental Overview

Curtis A. Meyer

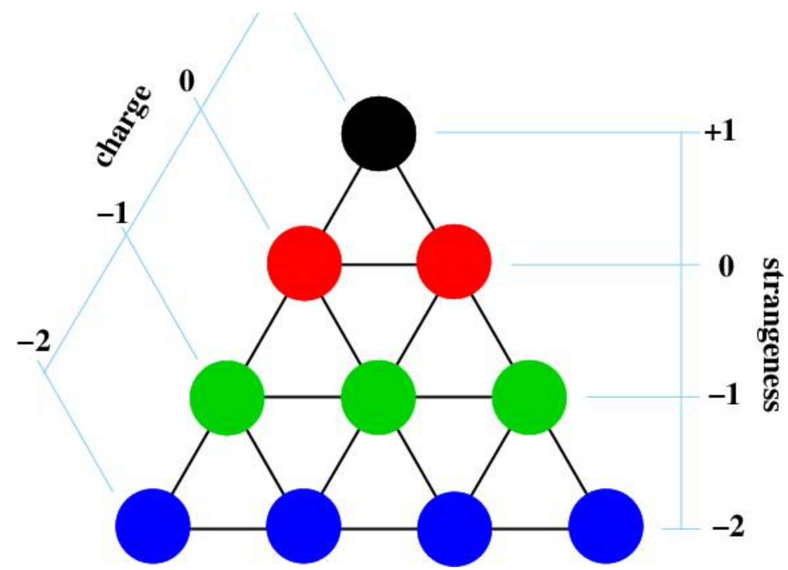
Based, in part, on work carried out with Alex Dzierba and Adam Szczepaniak





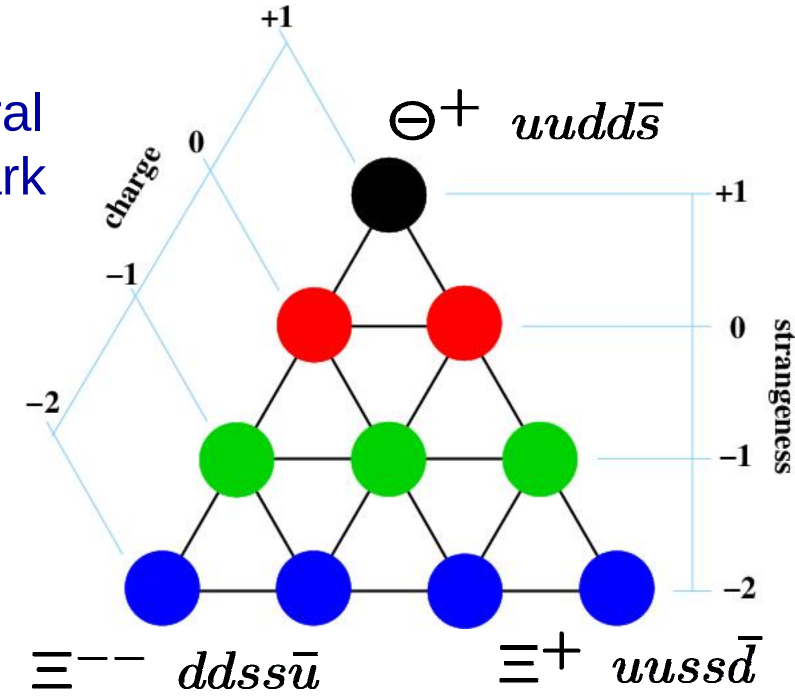
Before 2003 …. searches for flavor exotic baryons showed no evidence for such states.

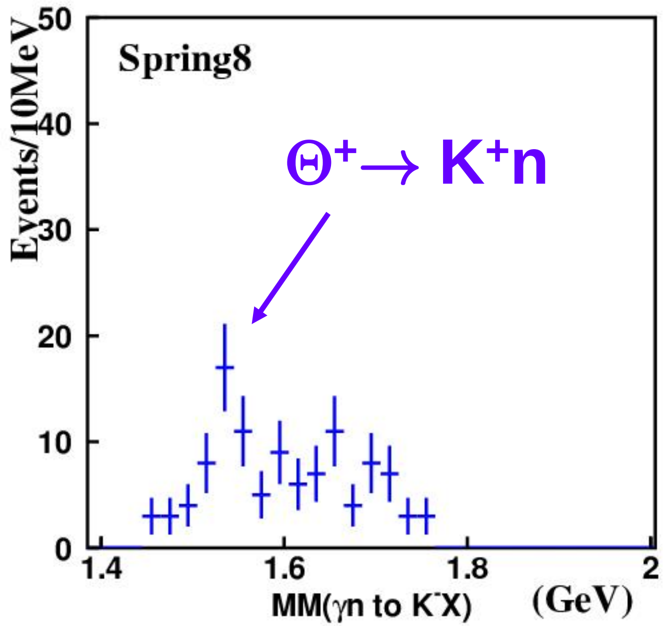
Since 2003 …. Hadronic Physics has been very interesting.



Spectacular Development

1997: Diakonov, Petrov and Polykov use a chiral soliton model to predict a decuplet of pentaquark baryons. The lightest has S=+1 and a mass of 1530 MeV and expected to be narrow.
Zeit. Phys. A359, 305 (1997).





2003: T. Nakano *et al.* γ n $\rightarrow$ K^+K^-n on a Carbon target.
Phys. Rev. Lett. 91, 012002, (2003)

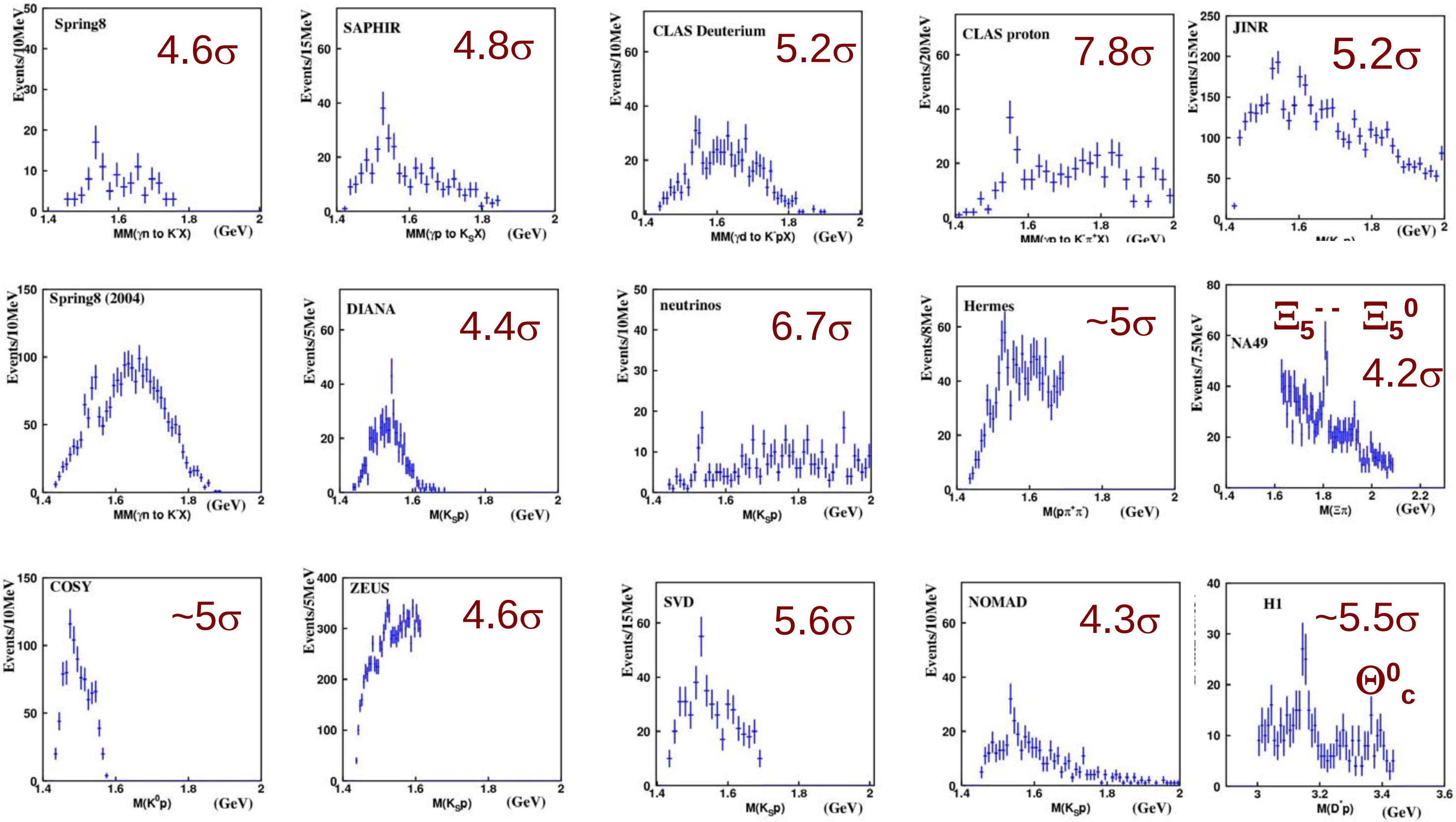
The Dam Breaks ….

Positive Sightings

Experiment	Reaction searched / publication	Claim	Decay
LEPS	$\gamma\, C_{12} \to K^- K^+ n$ **PRL 91 (2003) 012002**	Θ^+	K^+n
CLAS	$\gamma\, d \to K^+ K^- np$ $\gamma\, p \to \pi^+ K^- K^+ n$ **PRL 91 (2003) 252001, PRL 92 (2004) 032001**	Θ^+	K^+n
SAPHIR	$\gamma\, p \to K^0_S K^+ n$ **Phys.Lett B572 (2003) 127**	Θ^+	K^+n
COSY	$pp \to \Sigma^+ K^0_S p$ **Phys.Lett.B595 (2004) 127**	Θ^+	$K^0_S p$
DIANA	$K^+Xe \to K^0_S X'$ **Phys.Atom.Nucl.66(2003)1715**	Θ^+	$K^0_S p$
JINR	$p{+}C_3H_8 \to K^0_S pX$ **hep-ex/0401024**	Θ^+	$K^0_S p$
SVD	$pA \to pK^0_S X$ **hep-ex/0401024**	Θ^+	$K^0_S p$
ν	$\nu\, A \to K^0_S pX$ **BC at CERN & FNAL** **hep-ex/0309042**	Θ^+	$K^0_S p$
HERMES	$ep \to e'pK^0_S X$ (quasi-real photoproduction) **Phys.Lett.B585(2004) 213**	Θ^+	$K^0_S p$
ZEUS	$ep \to e'pK^0_S X$ **Phys.Lett.B592(2004)7**	Θ^+	$K^0_S p$
NA49	$pp \to \Xi\pi\ X$ **PRL 92(2004)042003**	Ξ_5	
H1	$ep \to e'pD^{*-}X$ **Phys.Lett.B588(2004)17**	Θ^0_c	

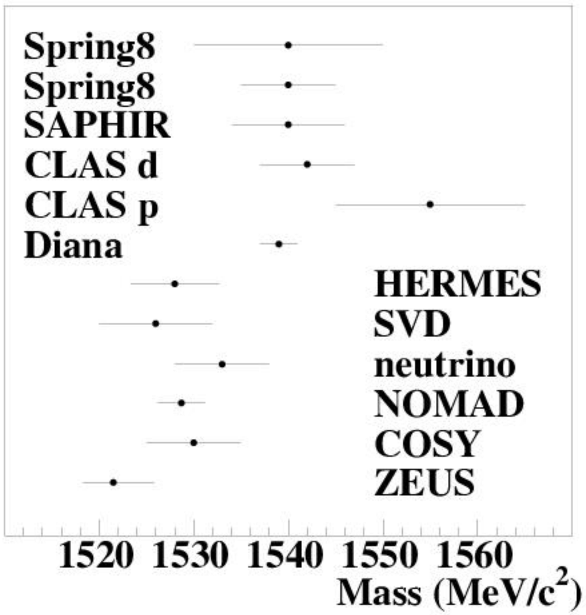
The Data

Reported Significance



Summary of Results

Θ^+



A narrow structure whose width is less than experimental resolution

Old data constrain Γ_Θ<1MeV

Ξ_5^{--} Ξ_5^0

Na49: Mass: 1862 MeV
Width < Resolution

Θ_c^0

H1: Mass : 3100 MeV
Width ~10 MeV

Statistics

$$\xi_1 = \frac{s}{\sqrt{b}}$$

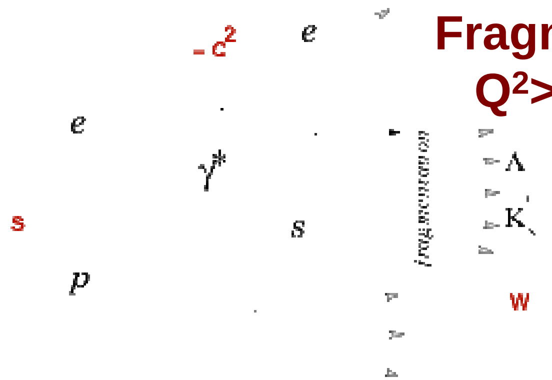
$$\xi_2 = \frac{s}{\sqrt{s+b}}$$

$$\xi_3 = \frac{s}{\sqrt{s+2b}}$$

Experiment	Signal	Background	Significance			
			Publ.	ξ_1	ξ_2	ξ_3
Spring8	19	17	4.6σ	4.6	3.2	2.6
Spring8	56	162		4.4	3.8	2.9
SPAHIR	55	56	4.8σ	7.3	5.2	4.3
CLAS (d)	43	54	5.2σ	5.9	4.4	3.5
CLAS (p)	41	35	7.8σ	6.9	4.7	3.9
DIANA	29	44	4.4σ	4.4	3.4	2.7
ν	18	9	6.7σ	6.0	3.5	3.0
HERMES	51	150	4.3-6.2σ	4.2	3.6	2.7
COSY	57	95	4-6σ	5.9	4.7	3.7
ZEUS	230	1080	4.6σ	7.0	6.4	4.7
SVD	35	93	5.6σ	3.6	3.1	2.4
NOMAD	33	59	4.3σ	4.3	3.4	2.7
NA49	38	43	4.2σ	5.8	4.2	3.4
NA49	69	75	5.8σ	8.0	5.8	4.7
H1	50.6	51.7	5-6σ	7.0	5.0	4.1

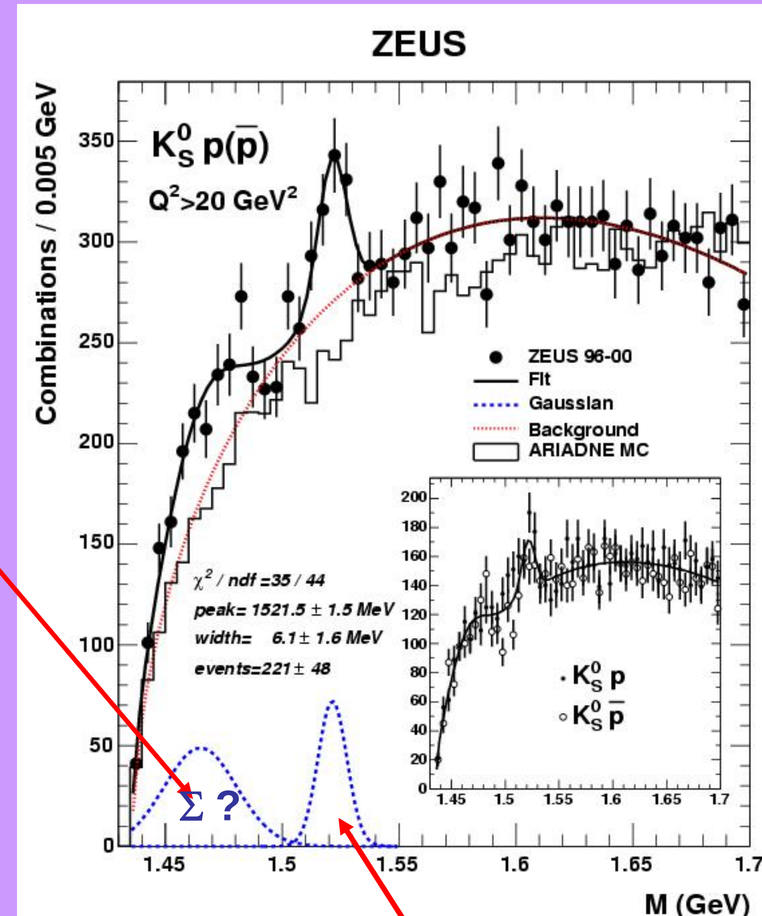
Zeus Result

Phys. Lett. B591 (2004) 7.



Fragmentation, $Q^2>20GeV^2$

Mass=1465
Width=15
368 Events



Interesting Result

~6000 Λ
~200 Λ(1520)
230 Θ^+

fragmentation is a good source of Θ^+!

What does Λπ look like?
(many $\Sigma \rightarrow \Lambda\pi$)

Observe: Θ^+
mass=1.521 GeV width=6.1 MeV
230 Events on 1080 Background

No Signal for: Ξ_5 , Θ^0_c

(U.Karshon, Pentaquark-04)

Negative Reports

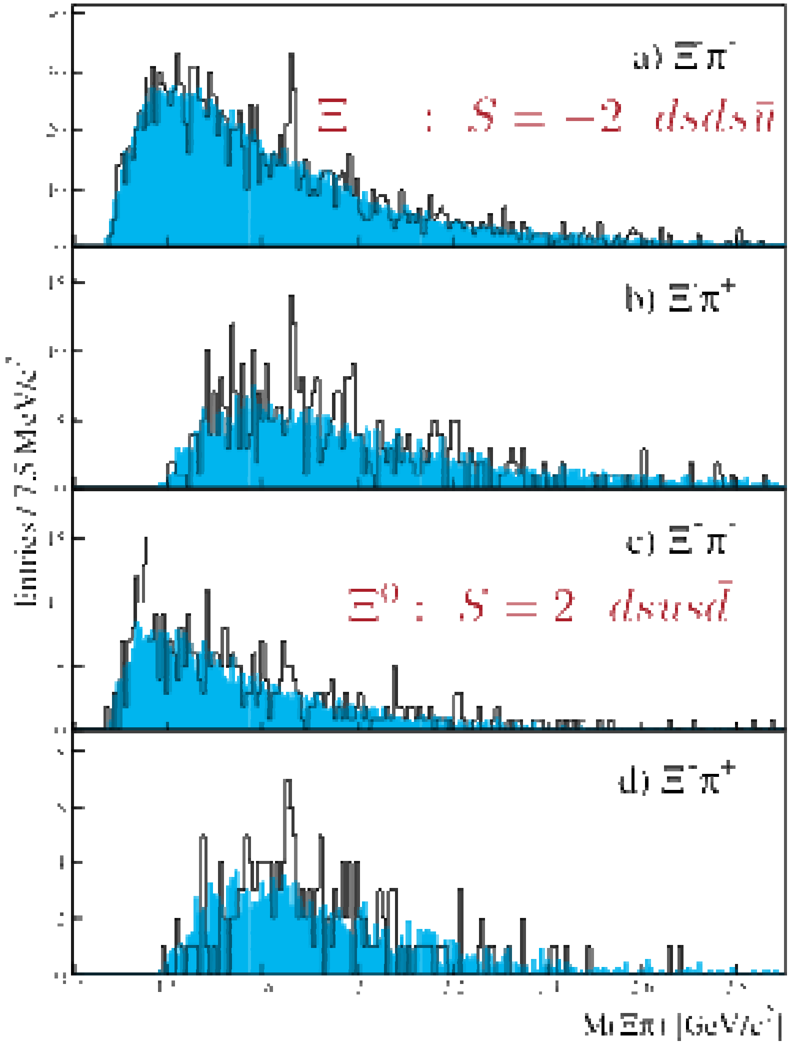
CDF	$p\bar{p} \rightarrow PX$ **hep-ex/0408025,0410024**	Θ^+ Θ_c^0 Ξ_5	**ALEPH**	**Hadronic Z decays** Submitted to **Phys. Lett. B**	Θ^+ Θ_c^0 Ξ_5
HyperCP	**(π^+,K$^+$,p)Cu $\rightarrow$ PX** **hep-ex/0410027**	Θ^+	**DELPHI**	**Hadronic Z decays** **hep-ex/0410080**	Θ^+
SELEX	**(π,p,Σ)p$\rightarrow$ PX** Quark Confinement 2004	Θ^+	**L3**	$\gamma\gamma \rightarrow \Theta\overline{\Theta}$ **hep-ex/0410080**	Θ^+
FOCUS	**γ p$\rightarrow$ PX** **hep-ex/0412021**	Θ^+ Θ_c^0 Ξ_5	**WA89**	**Σ^-N$\rightarrow$ PX** **hep-ex/0410029**	Ξ_5
E690	**pp$\rightarrow$ PX** QNP2004 -	Θ^+ Ξ_5	**ZEUS**	**ep$\rightarrow$ PX** **hep-ex/0410029**	Θ_c^0 Ξ_5
BES	**e$^+$e$^-$$\rightarrow$ J/ψ (ψ(2S)** **PRD 70 (2004) 012004**	Θ^+	**HERA-B**	**pA$\rightarrow$ PX** **PRL 93 (2004) 212003**	Θ^+ Ξ_5
BELLE	**KN$\rightarrow$ PX** **hep-ep/0411005**	Θ^+ Θ_c^0	**SPHINX**	**pC(N)$\rightarrow$ θ K X** **EPJ A21 (2004) 455**	Θ^+
BaBar	**e$^+$e$^-$$\rightarrow$ Υ (4S)** **hep-ex/0408064**	Θ^+ Ξ_5	**PHENIX**	**AuAu$\rightarrow$ PX** **J.Phys.G 30 (2004) S1201**	Θ^+
COMPASS		Θ^+ Ξ_5			

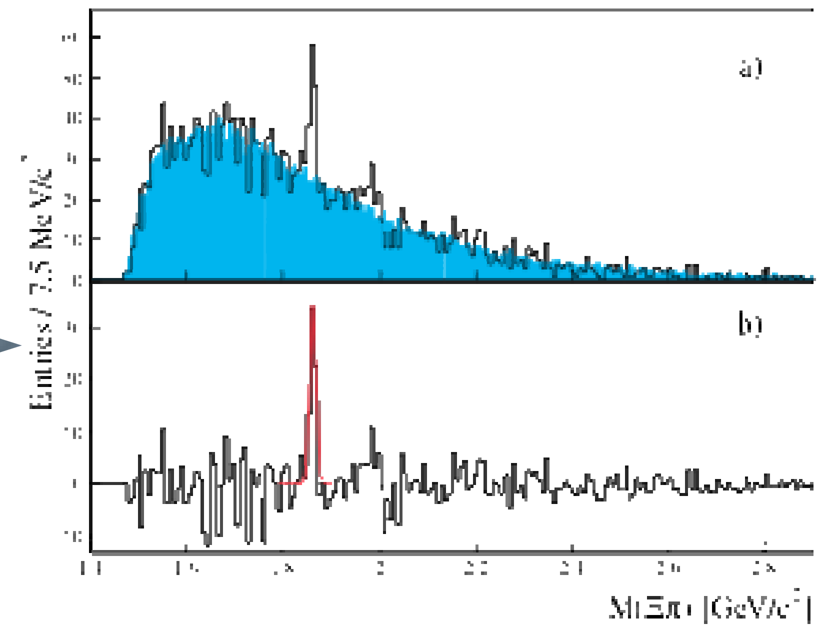
(Table by Alex Dzierba)

NA49 $\Xi_5(1860)$

fixed target experiment at CERN - spectrometer
158 GeV/c proton beam

$$\Xi^{--}(1862) \to \Xi^-\pi^-$$
$$\Xi^{0}(1862) \to \Xi^-\pi^+$$



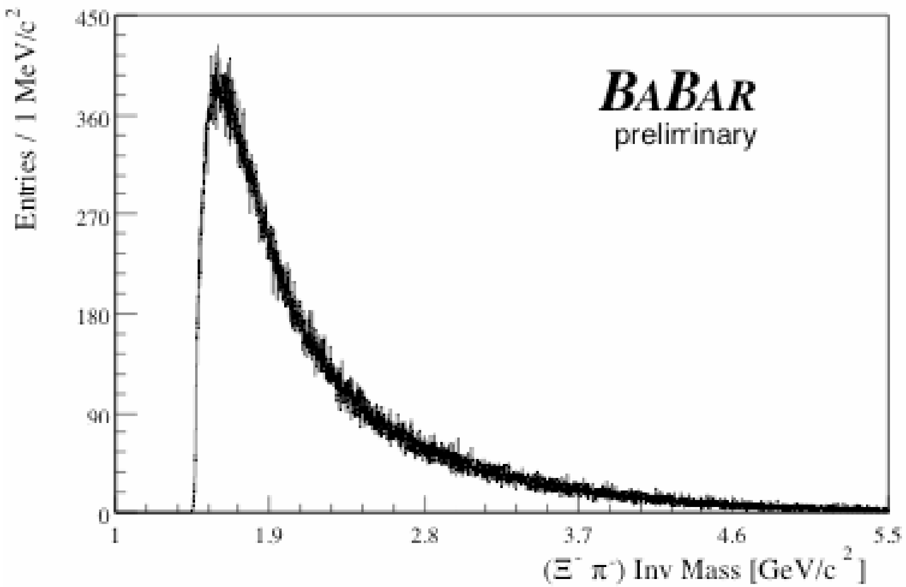


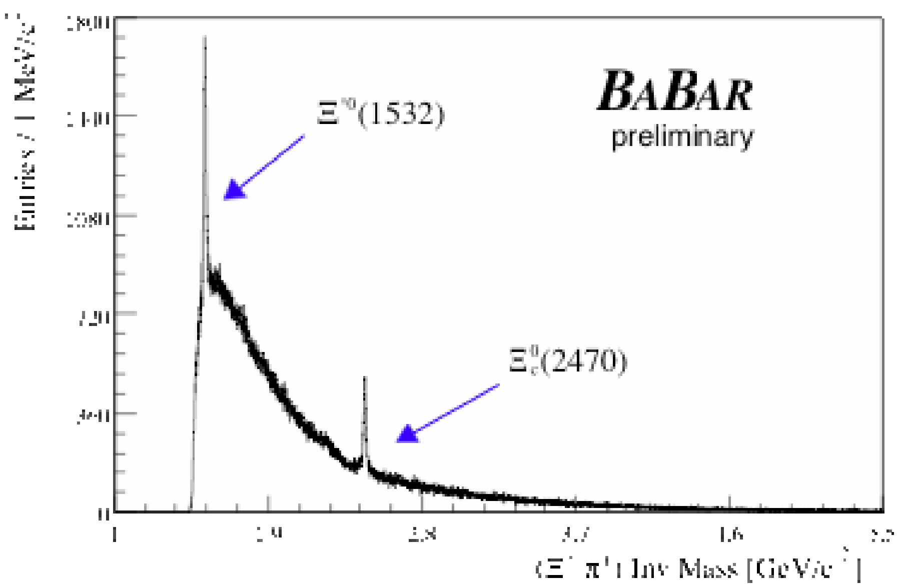
$M = 1.862\ GeV/c^2$

width is below detector resolution

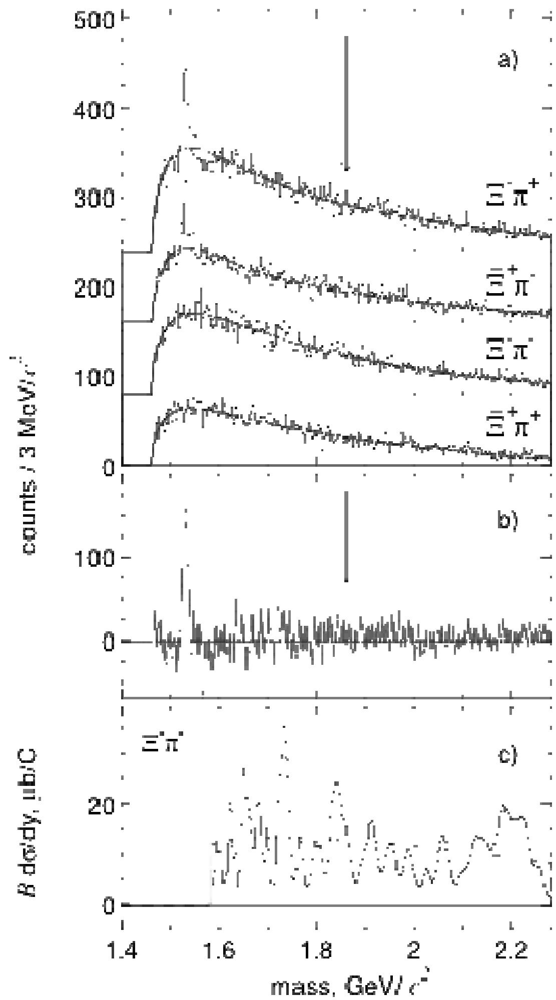
Null Results $\Xi_5(1860)$

$$\Xi^{--}(1862) \to \Xi^- \pi^-$$
$$\Xi^0(1862) \to \Xi^- \pi^+$$



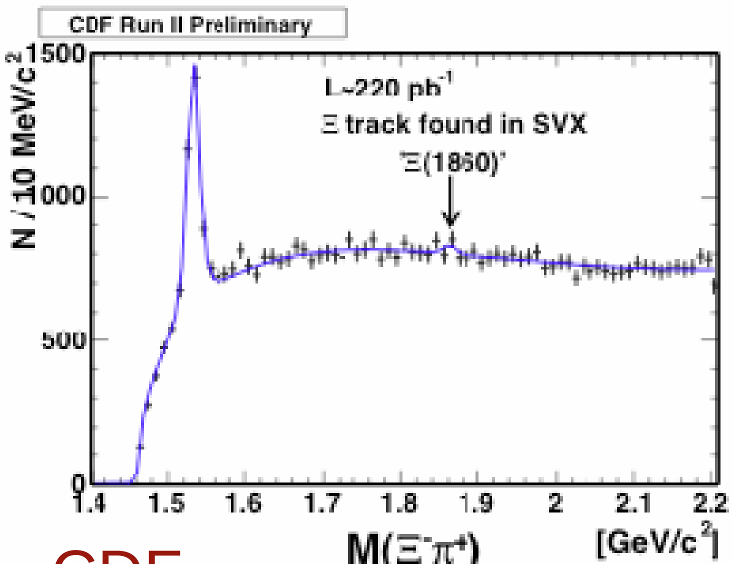


HERA-B

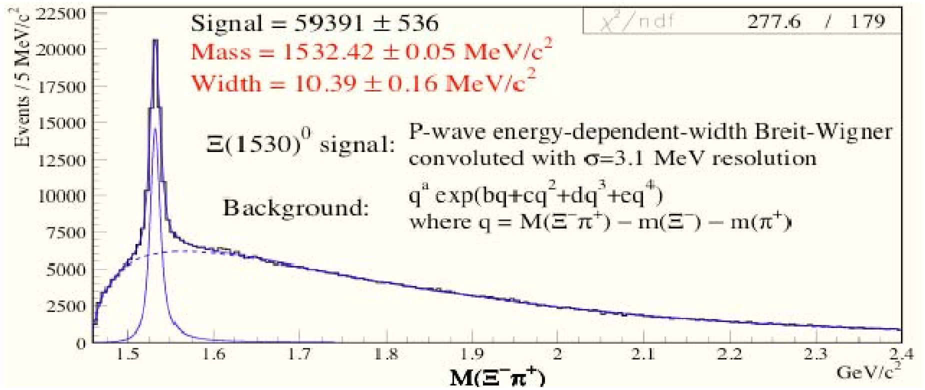


Null Result $\Xi_5(1860)$

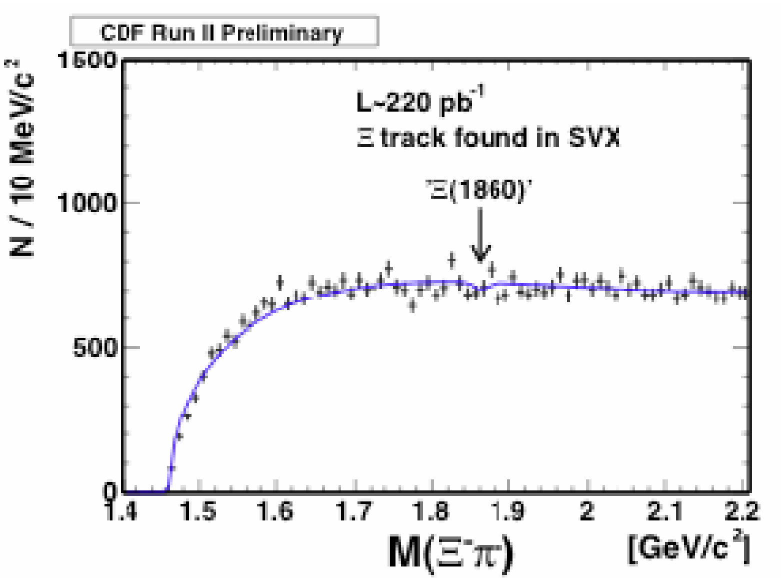
$$\Xi^{--}(1862) \rightarrow \Xi^-\pi^-$$
$$\Xi^0(1862) \rightarrow \Xi^-\pi^+$$



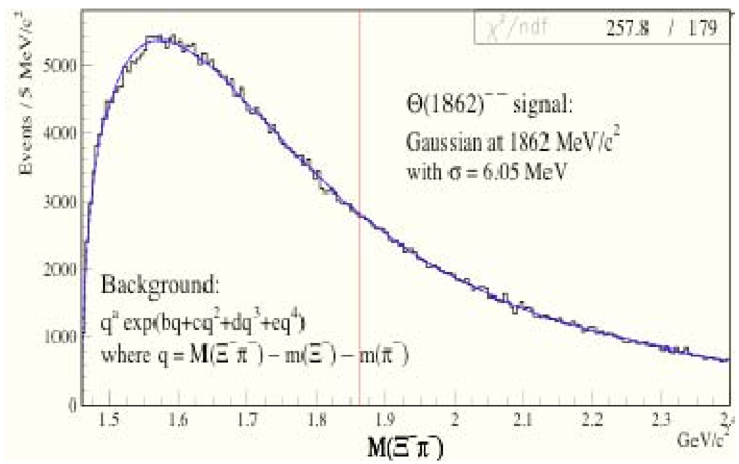
ALEPH and ZEUS also null result



CDF



FOCUS



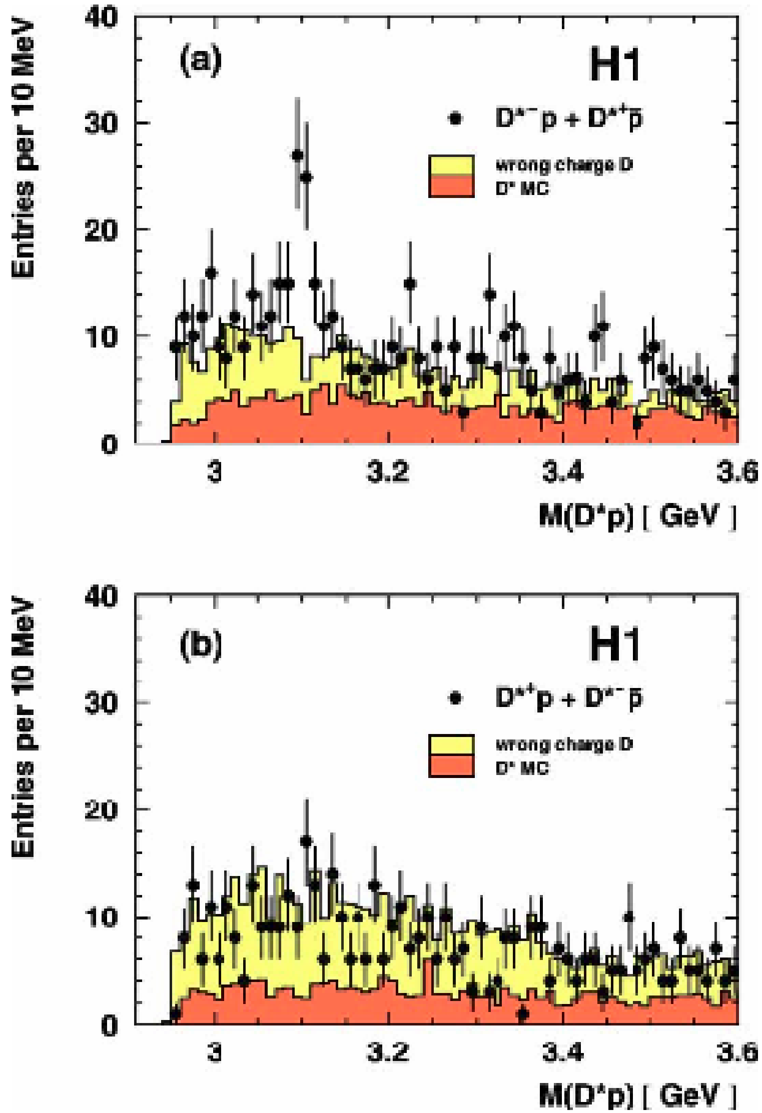
H1 at HERA

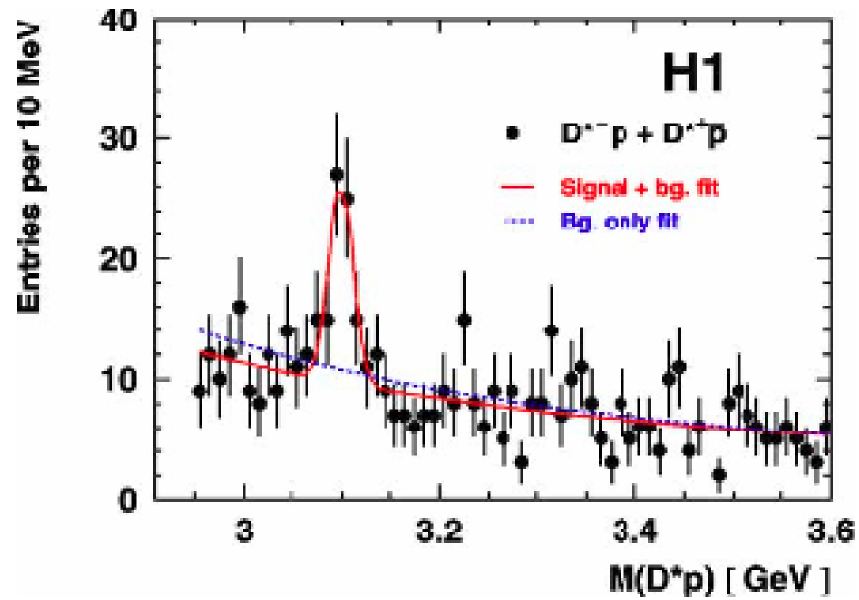
$\theta_c(3100) \rightarrow D^{*-}p$

Evidence for a narrow anti-charmed baryon state

H1 Collaboration

Physics Letters B 588 (2004) 17–28

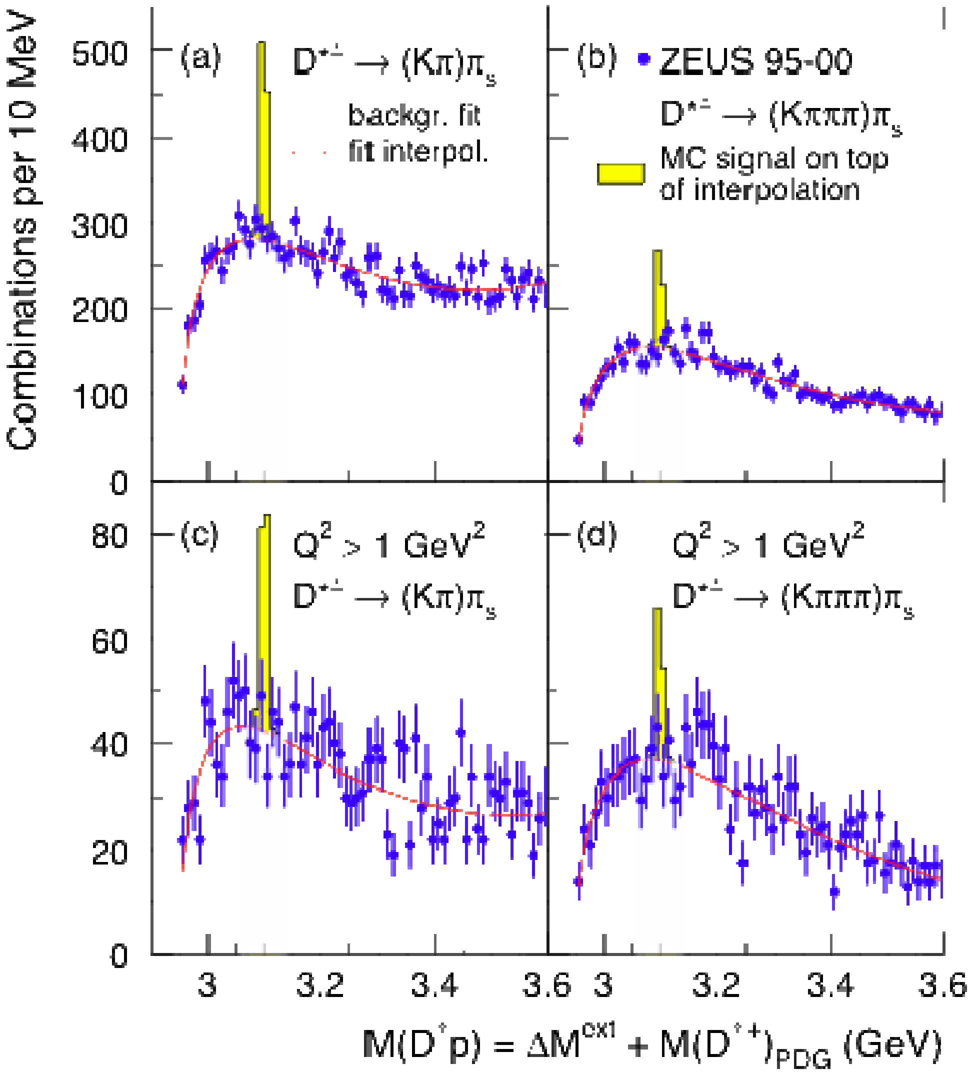




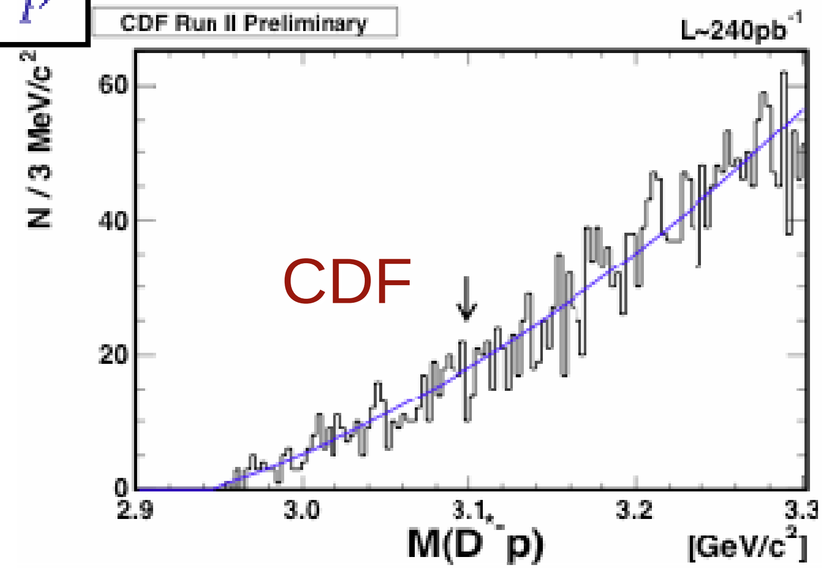
Sample	Mass (MeV)	Gaussian width (MeV)	N_s
$D^{*+}\bar{p} + D^{*-}p$	3099 ± 3	12 ± 3	50.6 ± 11.2
$D^{*-}p$	3102 ± 3	9 ± 3	25.8 ± 7.1
$D^{*+}\bar{p}$	3096 ± 6	13 ± 6	23.4 ± 8.6

Null Results $\theta_c(3100) \rightarrow D^{*-}p$

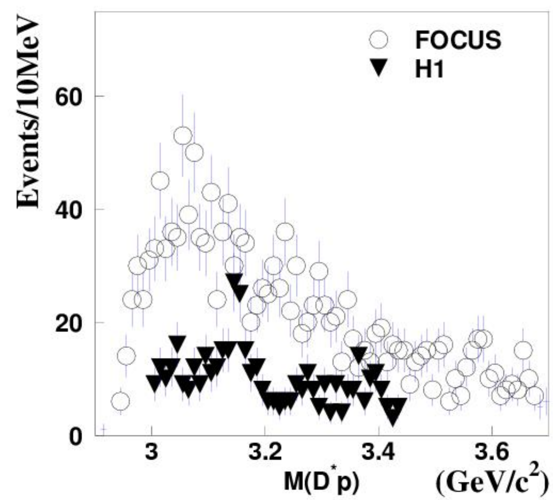
ZEUS



CDF

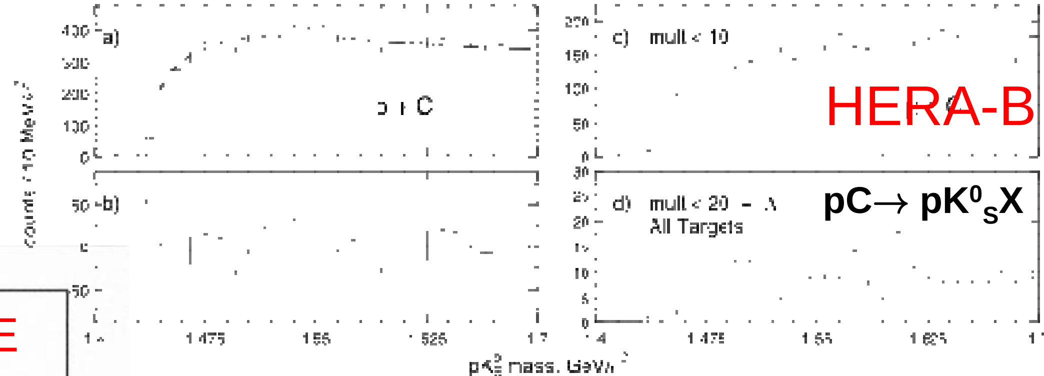


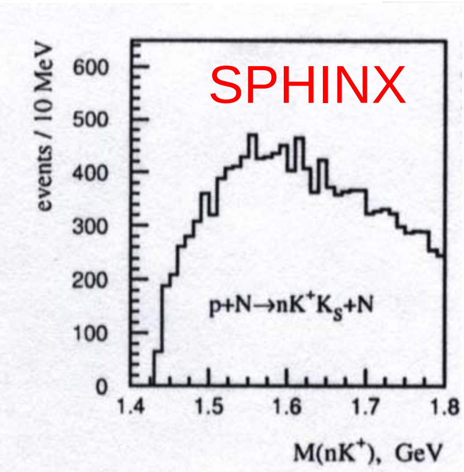
FOCUS

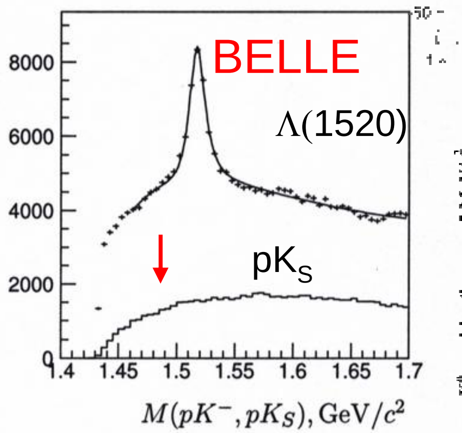


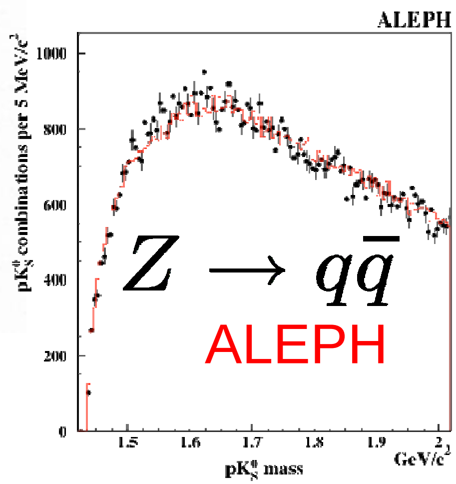
Negative Results

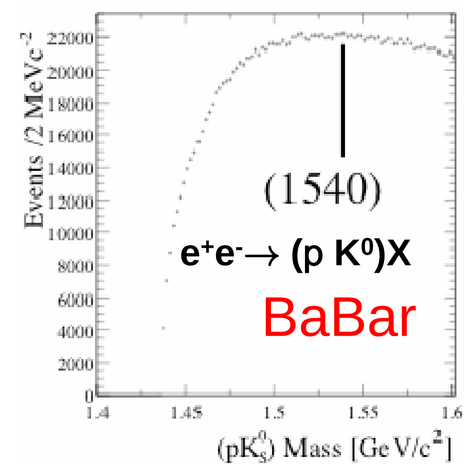
$\Theta^+(1540)$

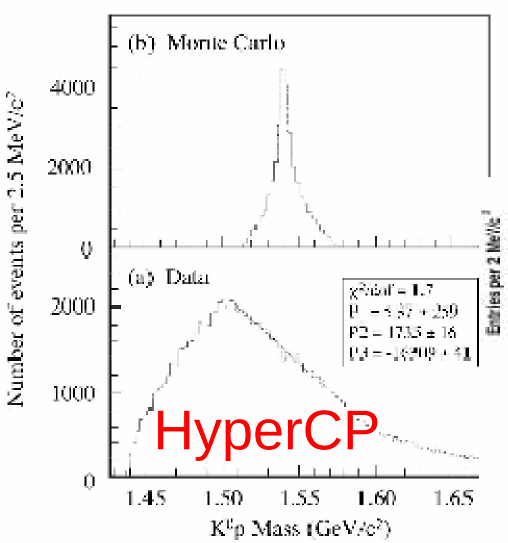


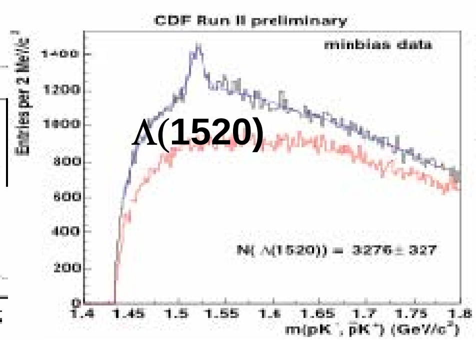


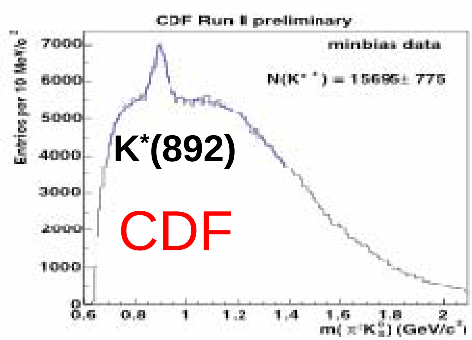


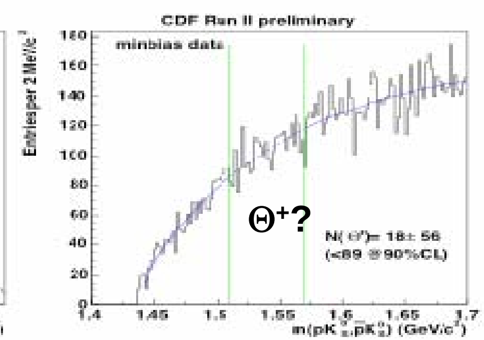






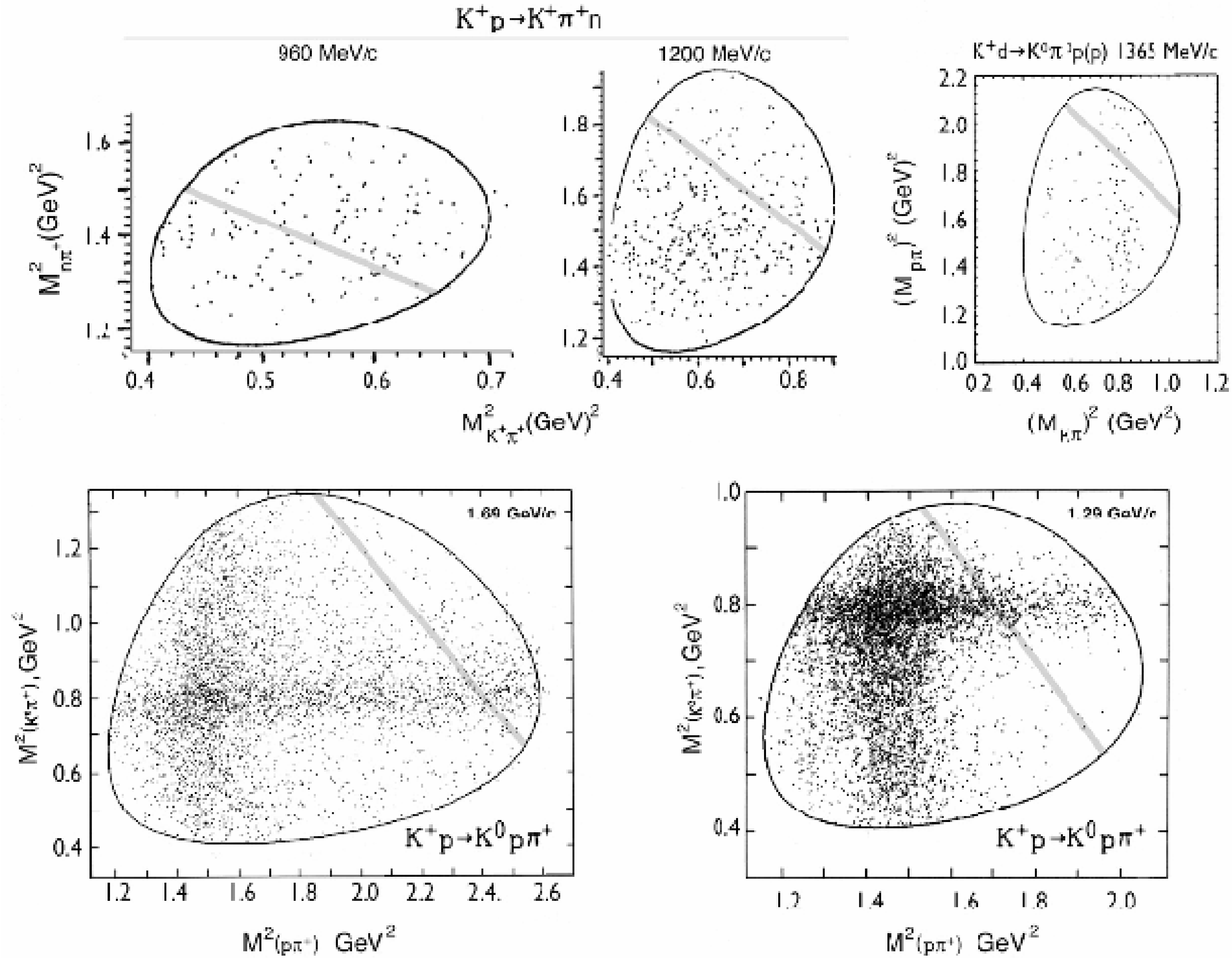






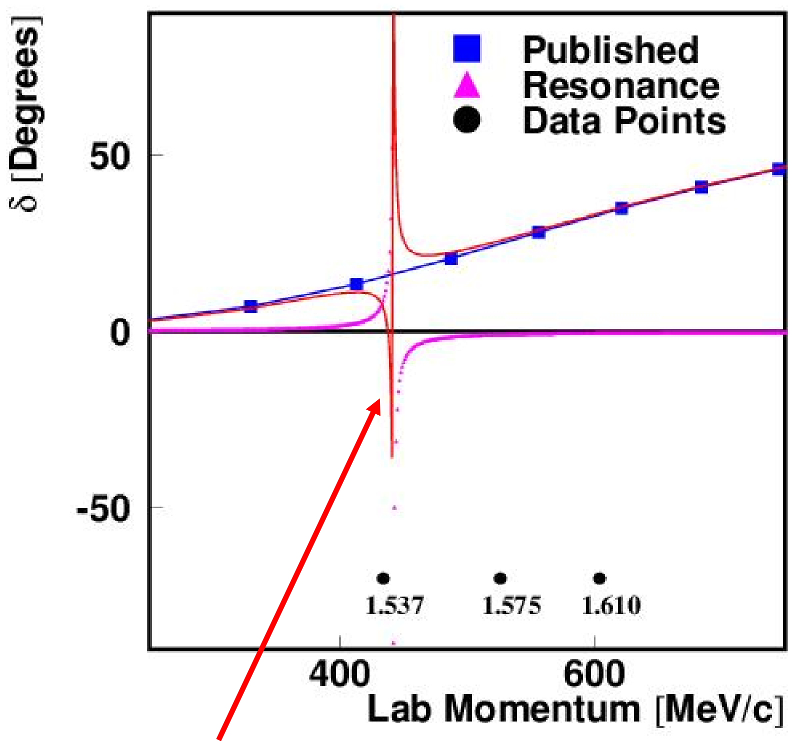
Bubble Chamber

No signals in the Dalitz Plots



Scattering Data

K⁺n P-wave Phase Shifts

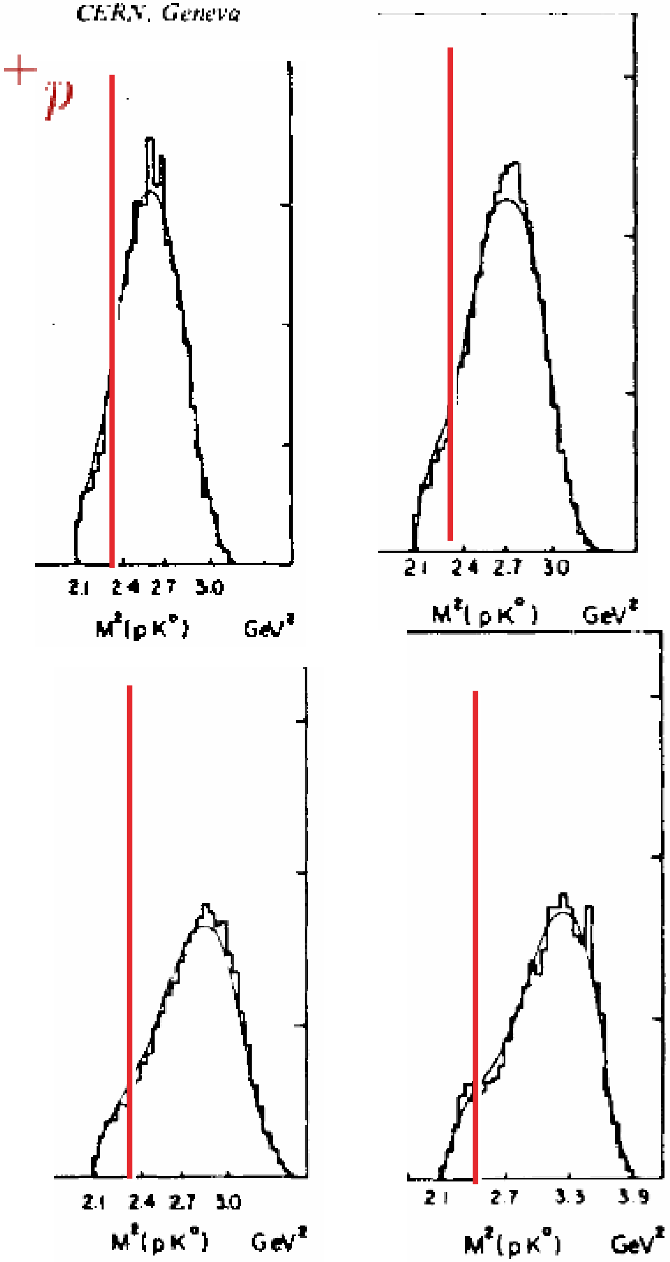


1MeV wide resonance at 1540

PROPERTIES OF THE INELASTIC K⁺p REACTIONS BETWEEN 1.2 AND 1.7 GeV/c

A. BERTHON, L. MONTANET, E. PAUL, P. SAETRE‡ and D.M. SENDALL
CERN, Geneva

$$K^+p \rightarrow K^0_S \pi^+ p$$



The Numbers

Positive Results

Experiment	s	b	Λ	Λ(1520)	ϕ
Spring 8	19	17		25	
Spring 8	56	162		180	
SAPHIR	55	56		530	
CLAS(d)	43	54		212	126
CLAS(p)	41	35			
DIANA	29	44	1152		
ν	19	8			
HERMES	51	150		850	
COSY	57	95			
ZEUS	230	1080	5700*	193	
SVD	35	93	260		
NOMAD	33	59			

	s	b	Ξ	D*
NA49	38	43	1640	
H1	50	52		3000

* Estimate from cross section

Some Negative Results

Experiment	Λ	Λ(1520)	ϕ
E690		5000	
ALEPH		2800	
CDF		3300	16000
BaBar	10000000	100000	
HERA-B	5000	3000	50000
SPHINX	5500	23700	12000
HYPERCP			
COMPASS			
BELLE		15520	

	Ξ	Ξ(1530)	D	D*
E690		15000		
ALEPH	3350	200	25000	
CDF	36000	1000	3000000	536000
BaBar	258000	17000		
HERA-B	18000			
ZEUS	2600	160		
WA89	676000			
FOCUS			84000	36000

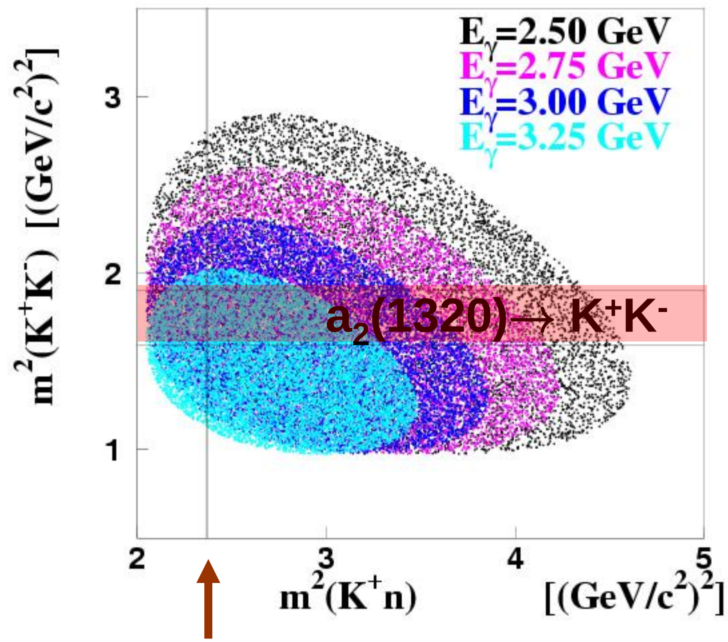
Low Energy Experiments

Produce a spin-2 or spin-3 resonance that decays to K^+K^-.

Have non-uniform populations of |m|=0,1,2,…

Produces a broad enhancement near 1.5

Kinematic Reflections



RAPID COMMUNICATIONS

PHYSICAL REVIEW D 69, 051501(R) (2004)

The evidence for a pentaquark signal and kinematic reflections

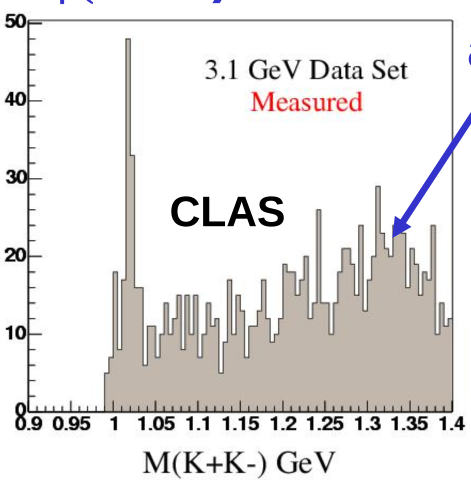
A. R. Dzierba, D. Krop, M. Swat, and S. Teige
Department of Physics, Indiana University, Bloomington, Indiana 47405, USA

A. P. Szczepaniak
Department of Physics and Nuclear Theory Center, Indiana University, Bloomington, Indiana 47405, USA

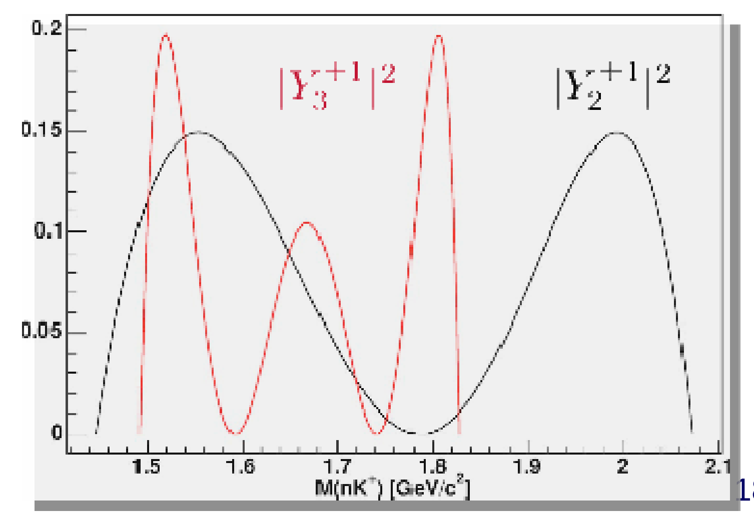
(Received 14 November 2003; published 25 March 2004)

$\phi(1020)$

$a_2(1320)$



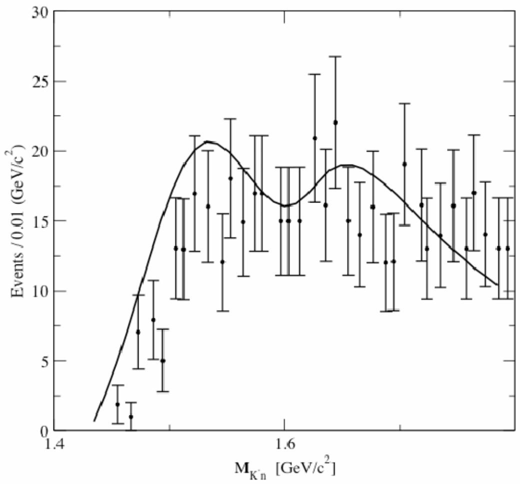
$\Theta^+(1540)$



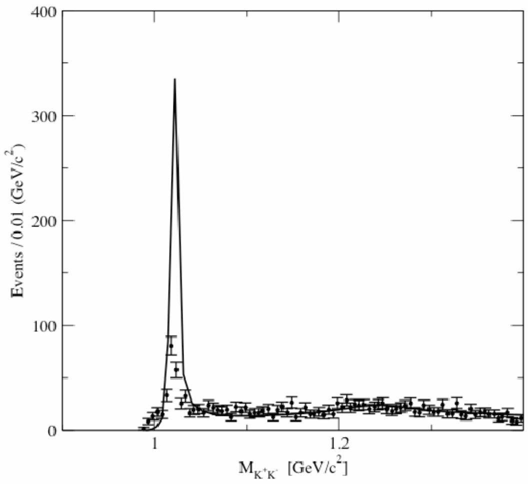
Kinematic Reflection?

The CLAS γ d $\rightarrow$ p n K^+K^- Data

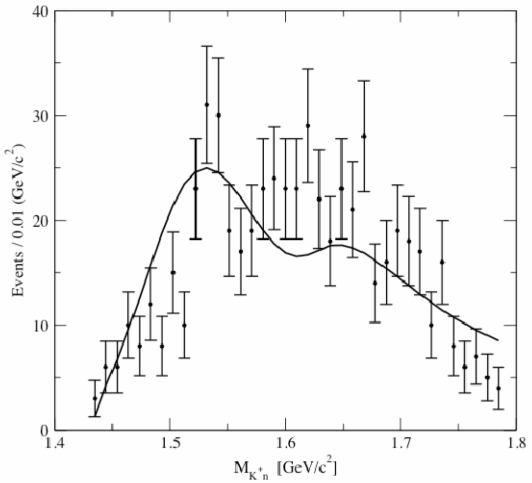
Mass (K^-n)



Mass (K^+K^-)



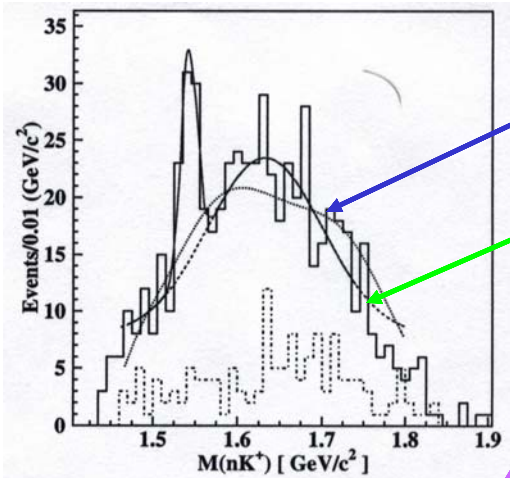
Mass (K^+n)



Solid lines are predicted using K^+K^- resonances

Statistical Fluctuation

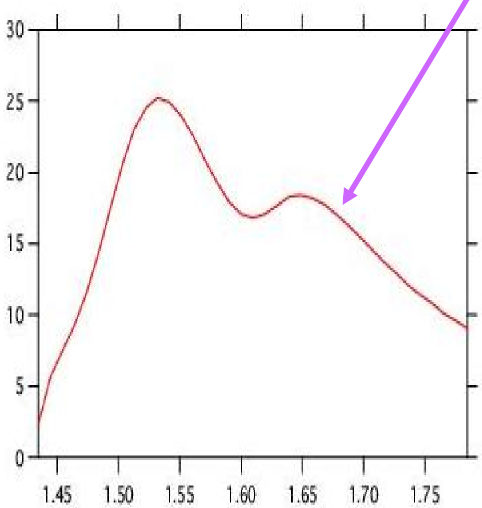
CLAS Published



Simple Physics Background

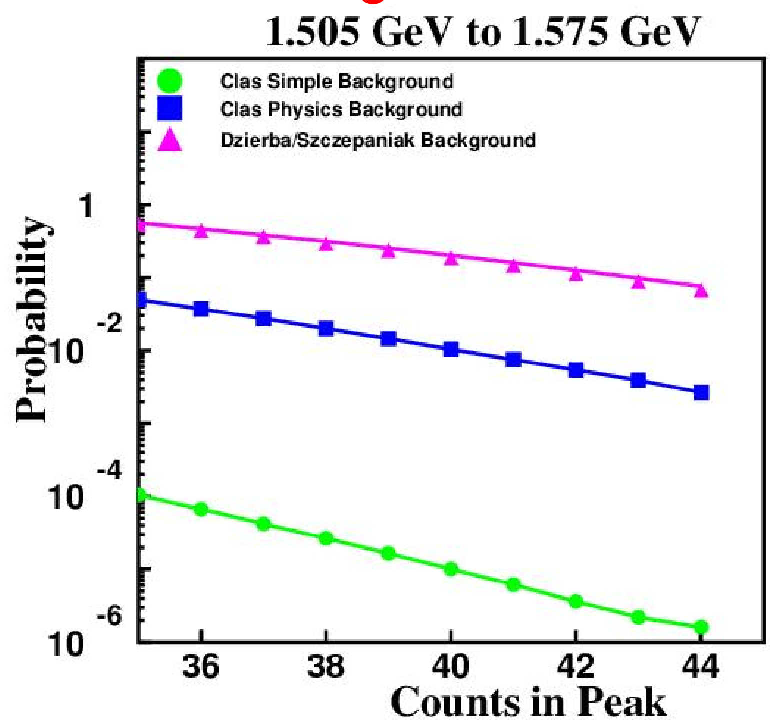
Naïve Background

Dzierba Background



You need to understand your background to claim a new discovery!

Chance of the Background Fluctuating into the observed signal

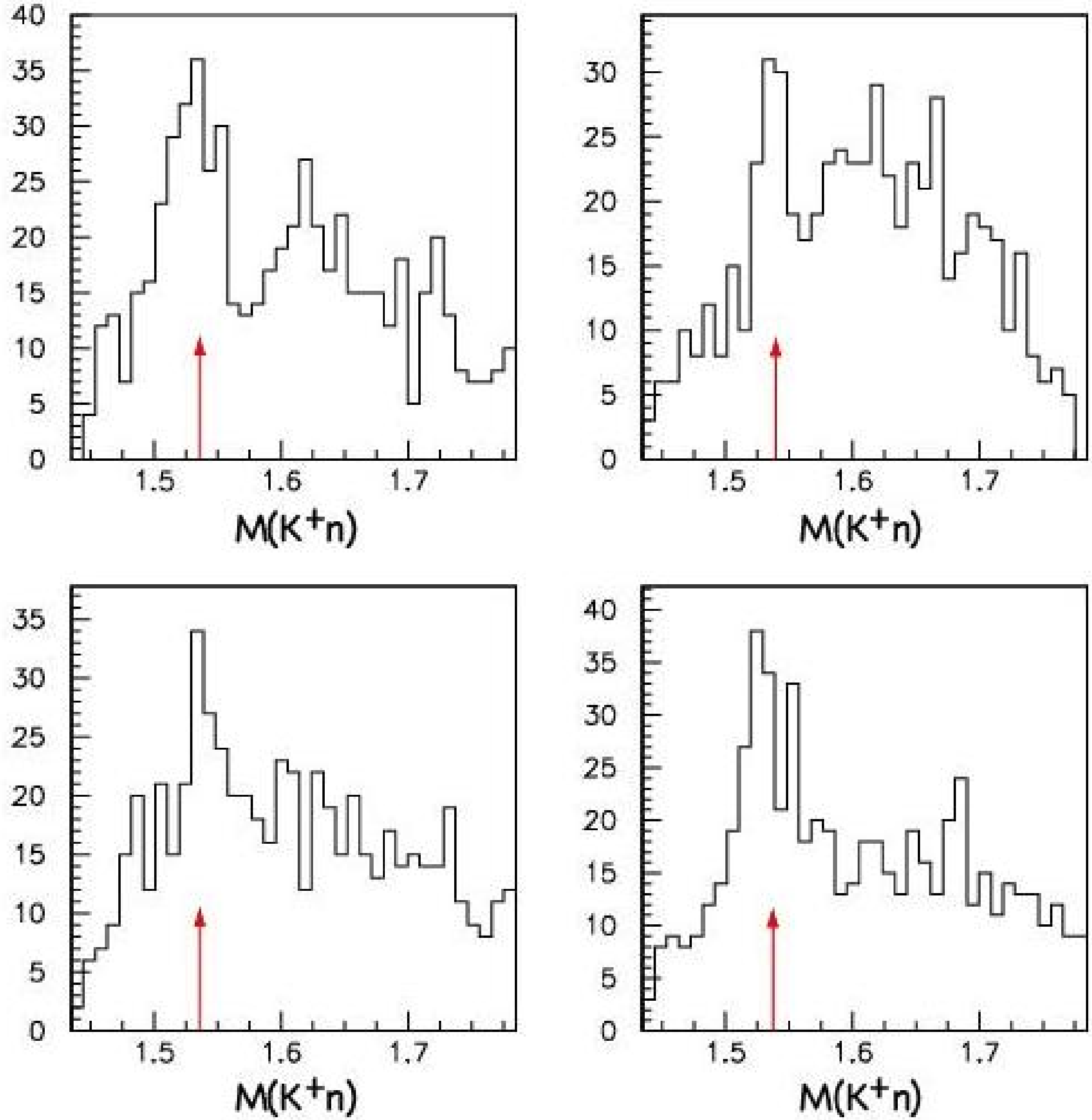


Games

Use Dzierba Background

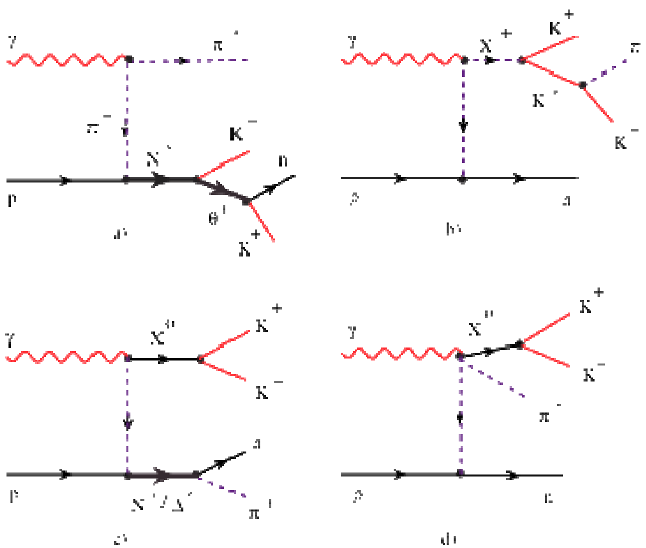
Generate 40 random spectra

3 are Fake
1 is CLAS



Severe Cuts

$\gamma\, p \rightarrow \pi^+ K^+ K^- (n)_{missing}$

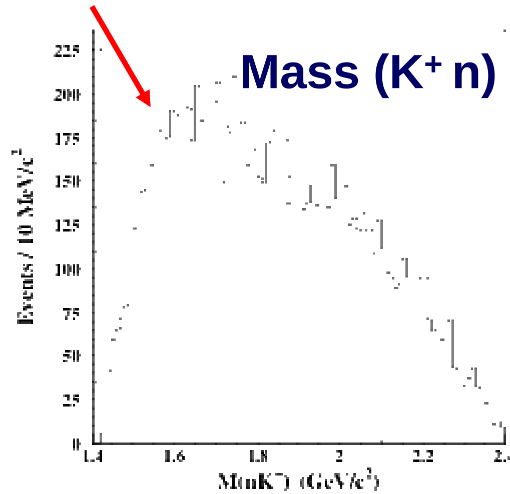


Design cuts to remove diagrams (b), (c) and (d)

$|t_{\gamma\rightarrow\pi^-}| < 0.28\ GeV^2$

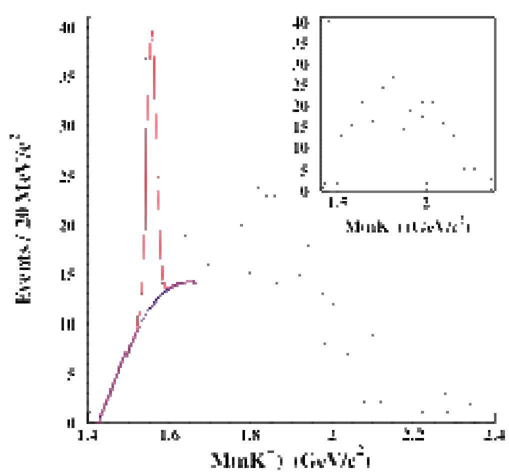
$\cos\theta^*_{K^+} < 0.6$

Mass (K^+ n)

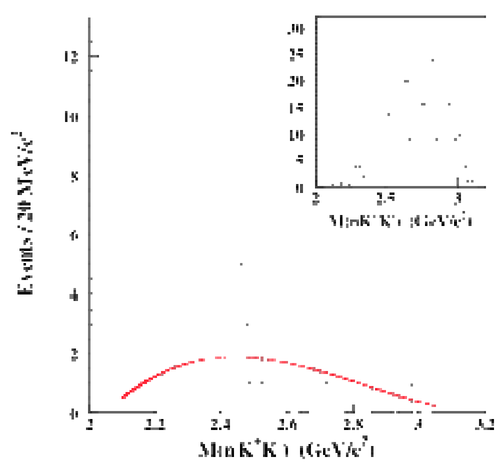


Uncut Spectrum

Mass (K^+ n)



Mass ($K^- K^+$ n)

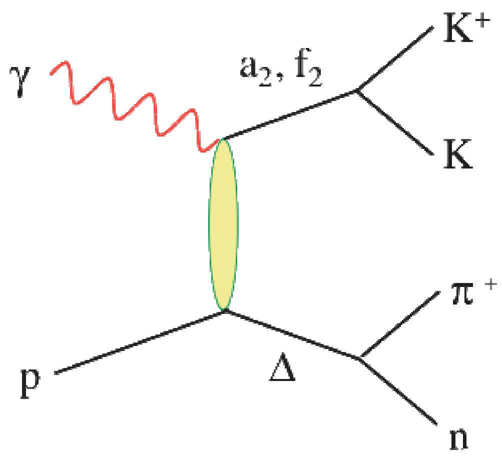


After Cuts

CLAS: Phys. Rev. Lett. 92, 032001,(2004)

Monte Carlo Study

$\gamma\, p \rightarrow \Delta\, a_2/f_2$ a_2 or $f_2 \rightarrow K^+K^-$

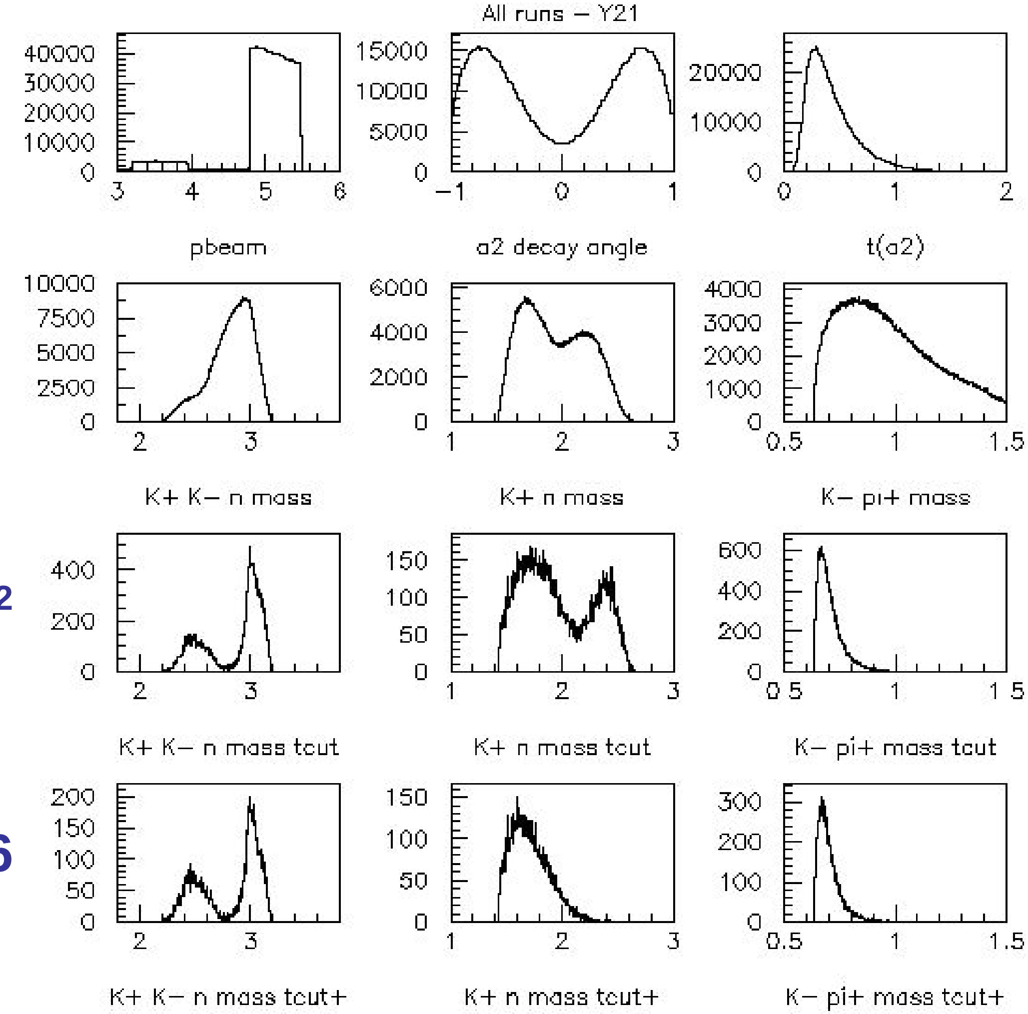


$| Y^M_L(\cos\theta, \phi) |^2$ Y^1_2

Raw

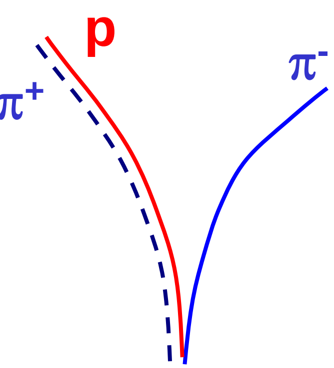
$| t_{\gamma\rightarrow\pi^-}| < 0.28$ GeV^2

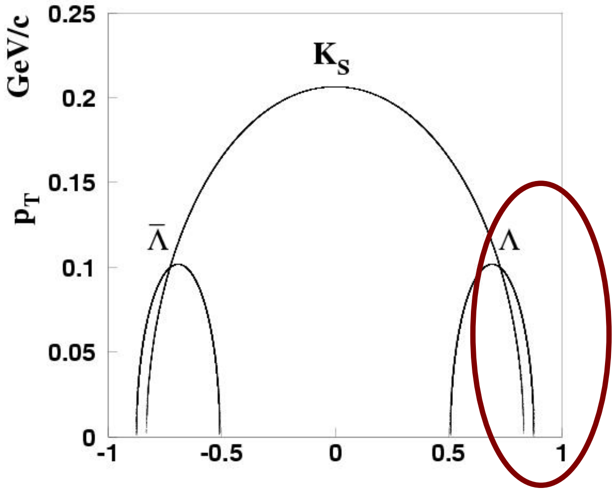
and $\cos\theta^*_{K^+} < 0.6$

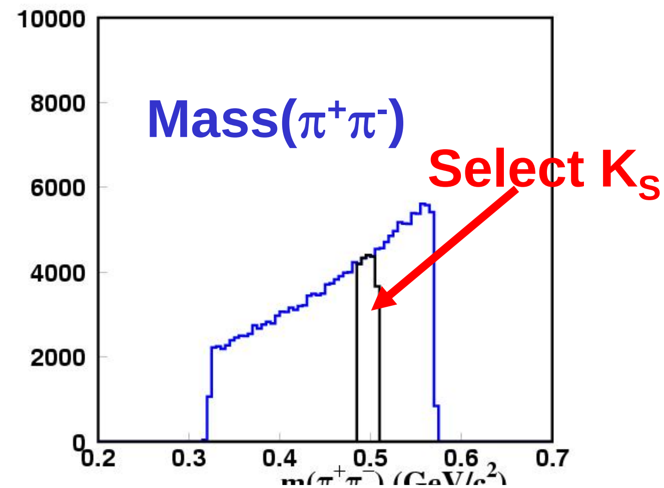


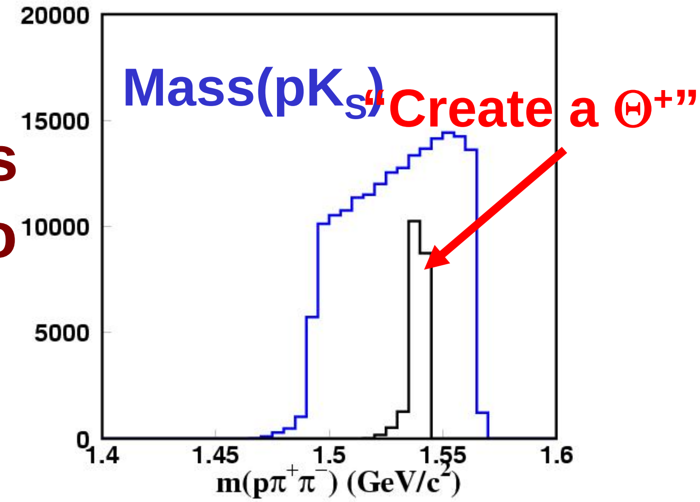
Ghost Tracks

Λ (p>2GeV/c)$\rightarrow$ pπ^-









It is easy to manufacture narrow peaks in the data near 1.5GeV that appear to decay to p K_S .

(M. Longo QNP 2004)

Ξ_5 Pentaquark

One low statistics report by NA49

Nine negative results.
Null results in both similar and different production mechanisms.
1-2 orders of magnitude more data in known resonances.

Θ_c Pentaquark

One low statistics report by H1

Five negative results.
Null results in both the same and different production mechanisms.
Factor of 10 to 1000 times for data in known resonances.

Θ^+ Pentaquark

11 low-statistics reports near 1500 MeV

Low-energy reports suffer from some combination of the following:
(a) Fermi motion effects.
(b) Severe cuts whose effects may not have been adequately studied.
(c) Insufficiently constrained reactions.
(d) Kinematic reflections.

15 new high-statistics searches in a number of reactions with excellent resolution that have come up empty.
Bubble chamber data from decades ago show no evidence.
KN scattering data severely limit this

The Zeus result is interesting.
It suggests that fragmentation is a good way to produce the Θ^+.

Not really consistent with ALEPH, BaBar, BELLE, CDF, …
What does H1 have to say on this?

PDG 2004

$\Theta(1540)^+$ MASS

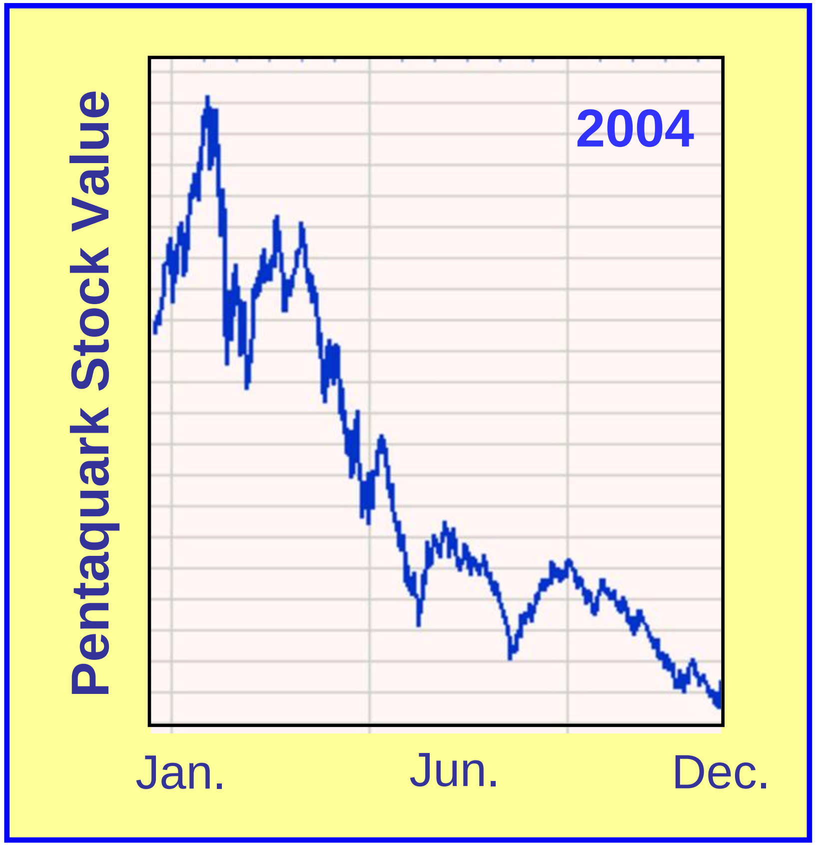
As is done through the *Review*, papers are listed by year, with the latest year first, and within each year they are listed alphabetically. NAKANO 03 was the earliest paper.

It is difficult to deny a status of three stars and a place in the Summary Tables for a state that six experiments claim to have seen. Nevertheless, as discussed in the above note, we believe it reasonable to have some reservations about the existence of this state on the basis of the present evidence.

VALUE (MeV)			*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1539.2±	**1.6 OUR AVERAGE**						
1533	+ 5		27	[1] ASRATYAN	04	BC	ν, $\overline{\nu}$ in p,d,Ne, BEBC and 15-ft
1555	+ 10		41	[2] KUBAROVSKY	04	CLAS	$\gamma p \to \pi^+ K^- K^+ n$
1539	+ 2		29	[3] BARMIN	03	XEBC	$K^+ Xe \to K^0 p Xe$
1540	+ 4	+ 2	63	[4] BARTH	03	SPHR	$\gamma p \to n K^+ K^0_S$
1540	+ 10		19	[5] NAKANO	03	LEPS	$\gamma\, ^{12}C \to K^+ K^- n X$
1542	+ 5		43	[6] STEPANYAN	03	CLAS	$\gamma d \to K^+ K^- p n$

Conclusions

The possible existence of pentaquarks is still very much an experimental question, and the data do not look very convincing.



If they exist, they not only have exotic quantum numbers, but **very exotic** production and decay modes.

I hope that the issue can be settled soon – but I am not buying stock.