Search for Pentaquark States at CLAS

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for the CLAS Collaboration

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Search for Pentaquarks

- QCD allows for hadronic states other than qqq and $q\bar{q}$, like $qqqq\bar{q}$ (pentaquarks), $qq\bar{q}\bar{q}$ (tetraquarks), …

- Idea of a five-quark state first mentioned in the '60s:
M. Gell-Mann, PLB 8 (1964) 214; H.J. Lipkin, PLB45 (1973) 267;
R.L. Jaffe et al, PLB60 (1976) 20; …

- Experimental activity started several decades ago with the search for a state with M>2 GeV and large width. Eventually dropped because of lack of convincing evidence.

1986, Particle Data Group:

"The general prejudice against baryons not made of three quarks and the lack of any experimental activity in this area make it likely that it will be another 15 years before the issue is decided"

Exotics and Pentaquarks

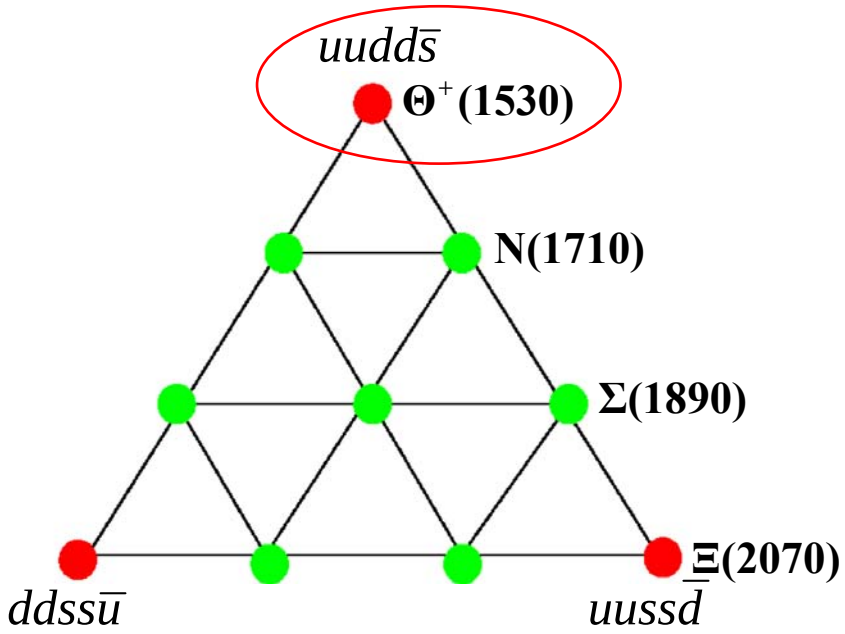
Chiral Quark Soliton Model (D.Diakonov et al.) predicts an antidecuplet of pentaquarks:

- low mass (1.5–2.1 GeV)
- narrow (≤ 30 MeV)
- exotic quantum numbers (S=+1)

Existence of pentaquark states can be explained within different theoretical approaches

Experimental searches focused on lower mass state, the Θ^+ ($uudd\bar{s}$)

Spin ½ antidecuplet

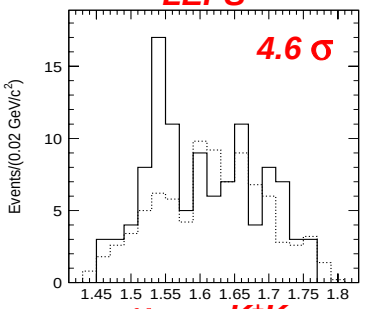


D.Diakonov et al. Z. Phys A359, 1997, 305

D. Diakonov, V. Petrov, Phys. Rev. D69, 2004, 094011

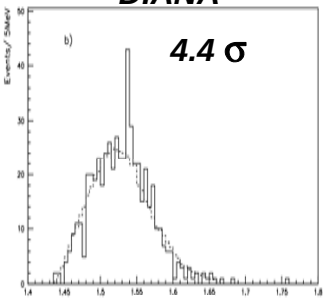
Evidence for Θ^+ ("1st generation")

LEPS



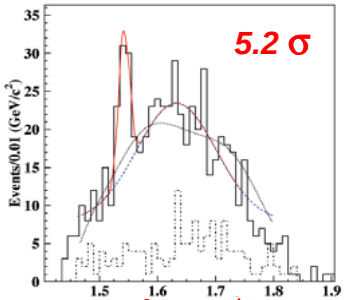
$\gamma n \rightarrow nK^+K^-$

DIANA



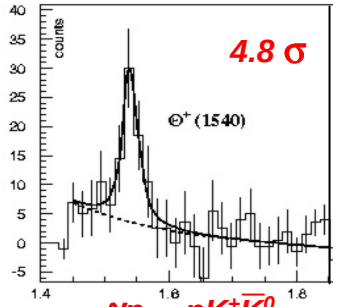
$K^+Xe \rightarrow pK^0X$

CLAS-d



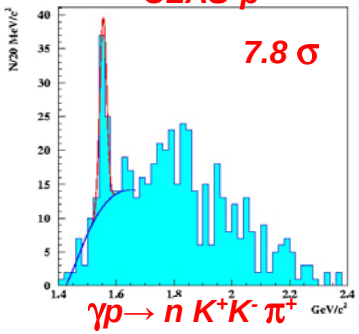
$\gamma d \rightarrow nK^+K^-p$

SAPHIR



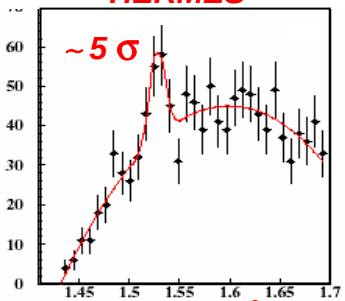
$\gamma p \rightarrow nK^+\overline{K^0}$

CLAS-p



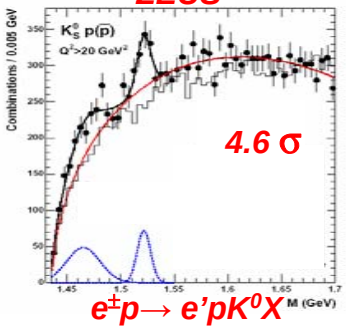
$\gamma p \rightarrow n K^+K^- \pi^+$

HERMES



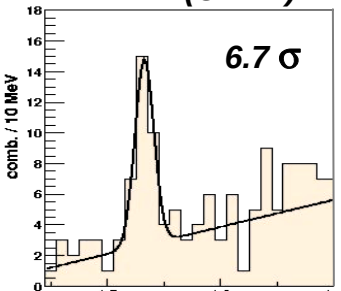
$ep \rightarrow e'pK^0X$

ZEUS



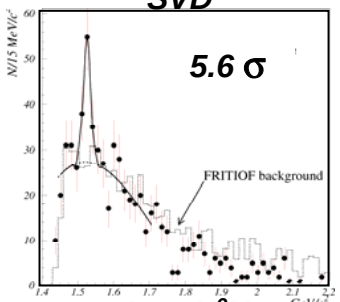
$e^{\pm}p \rightarrow e'pK^0X$

ITEP (CERN)



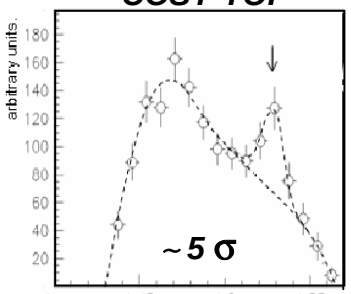
$\nu p,d,Ne \rightarrow pK^0X$

SVD



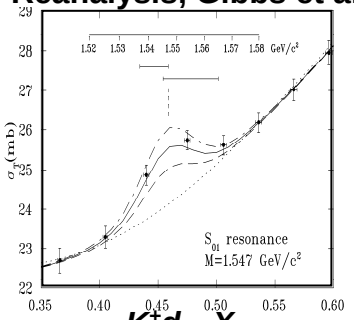
$pA \rightarrow pK^0X$

COSY-TOF



$pp \rightarrow \Sigma^+pK^0$

Reanalysis, Gibbs et al.



$K^+d \rightarrow X$

- eletromagnetic interaction
- other...

Evidence for Pentaquark States

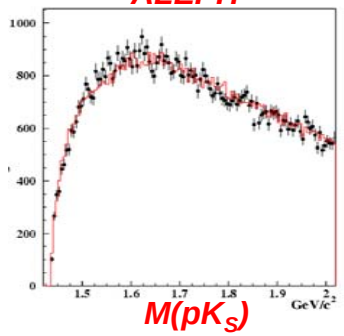
- Evidence for the Θ^+ pentaquark reported by 11 experiments in different reactions
- Evidence for the Ξ^{--} pentaquark reported by the NA49 Collaboration
- Signal of an anticharmed pentaquark observed by the H1 Collaboration
- First evidence for the Θ^{++} found by STAR
- New analyses by LEPS, SVD-2, DIANA confirm initial results

but:

- Positive results have limited event samples in the observed structures
- Comparison of results from different experiments shows discrepancies in the observed masses
- Observations in the pK^0 decay do not tag the strangeness
- Null results reported by several Collaborations

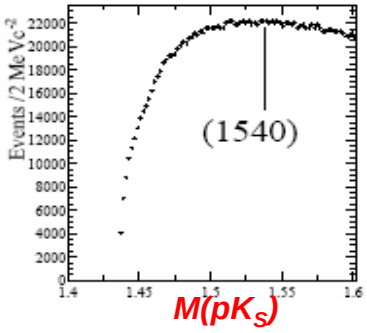
Null Results

ALEPH



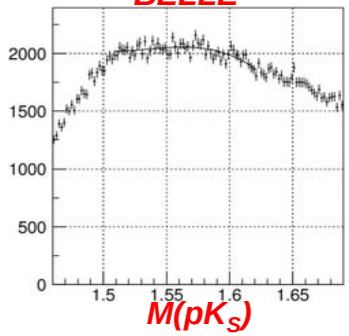
$M(pK_S)$

BABAR



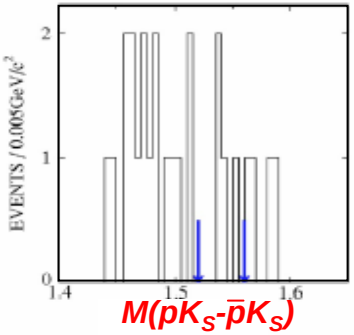
$M(pK_S)$

BELLE



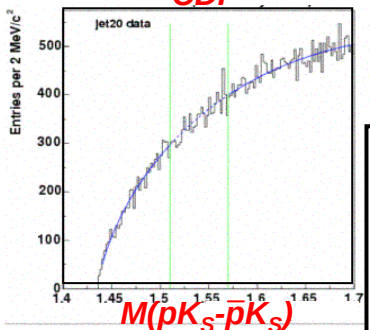
$M(pK_S)$

BES



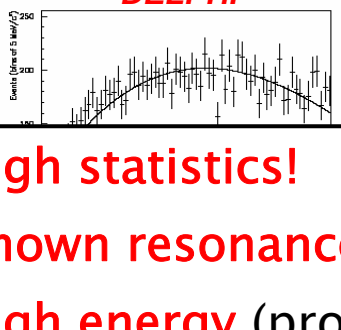
$M(pK_S\text{-}\bar{p}K_S)$

CDF

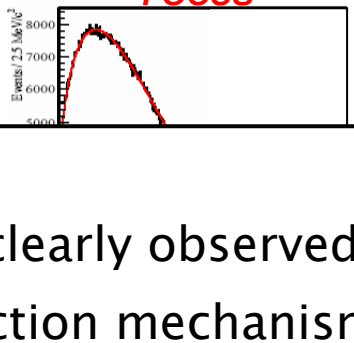


$M(pK_S\text{-}\bar{p}K_S)$

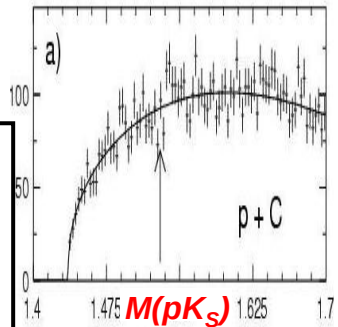
DELPHI



FOCUS

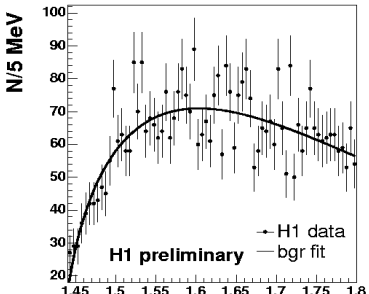


HERA-B

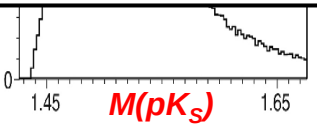


$M(pK_S)$

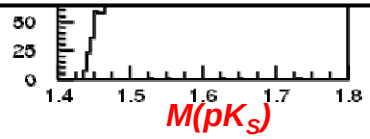
H1



$M(pK_S)$



$M(pK_S)$



$M(pK_S)$

- High statistics!
- Known resonances clearly observed
- High energy (production mechanism?)
- Semi-inclusive production
- Difficult comparison between different experiments

+ more

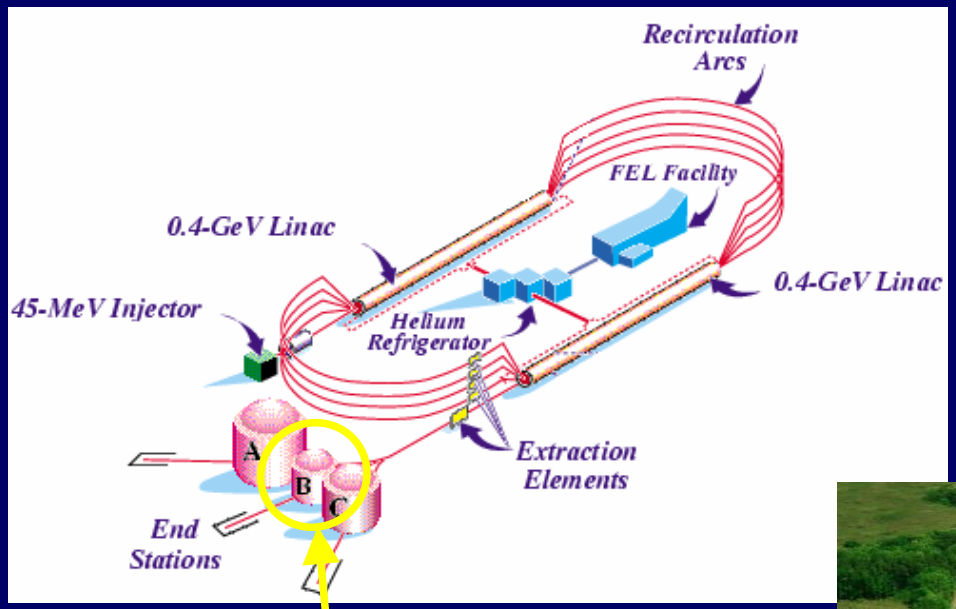
Search for Pentaquarks at CLAS

A comprehensive program to search for pentaquarks with high statistics and high resolution photoproduction experiments is in progress at Jefferson Lab

New experiments seeking evidence of pentaquarks with the CLAS detector were approved in 2003-2004 with the goal of confirming previous results and explore new kinematics with at least a factor 10 increase in statistics

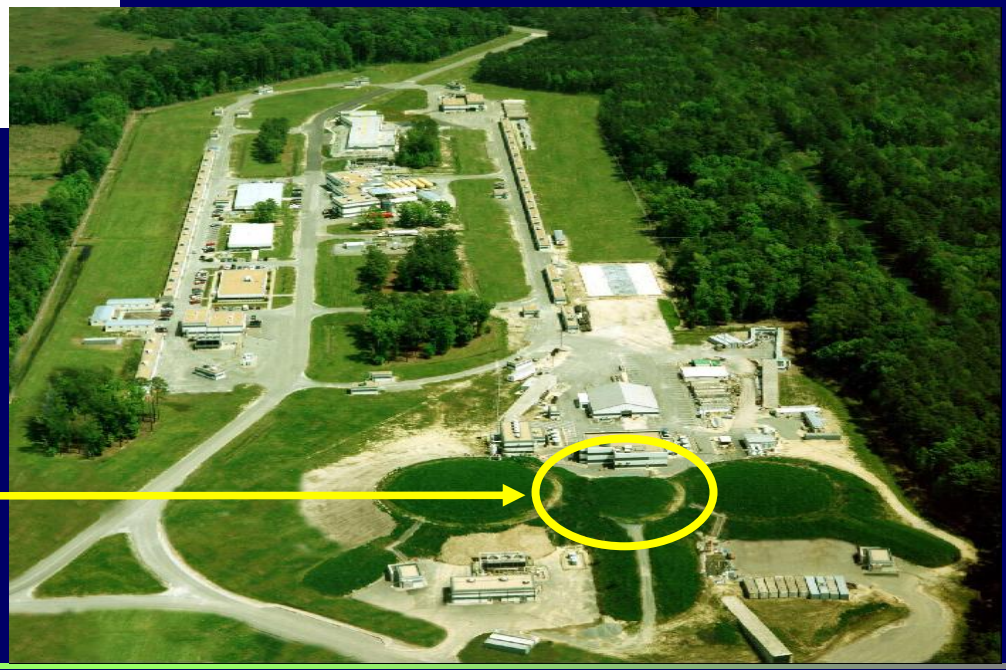
g10	deuteron	$E_\gamma \sim 1.0$–3.5 GeV
	data taking completed in 2004	
g11	proton	$E_\gamma \sim 1.6$–3.8 GeV
	data taking completed in 2004	
eg3	deuteron	$E_\gamma \sim 4.0$–5.4 GeV
	data taking completed in 2005	
Super-g	proton	$E_\gamma \sim 3.8$ – 5.7 GeV
	planned for 2007-8	

Jefferson Lab

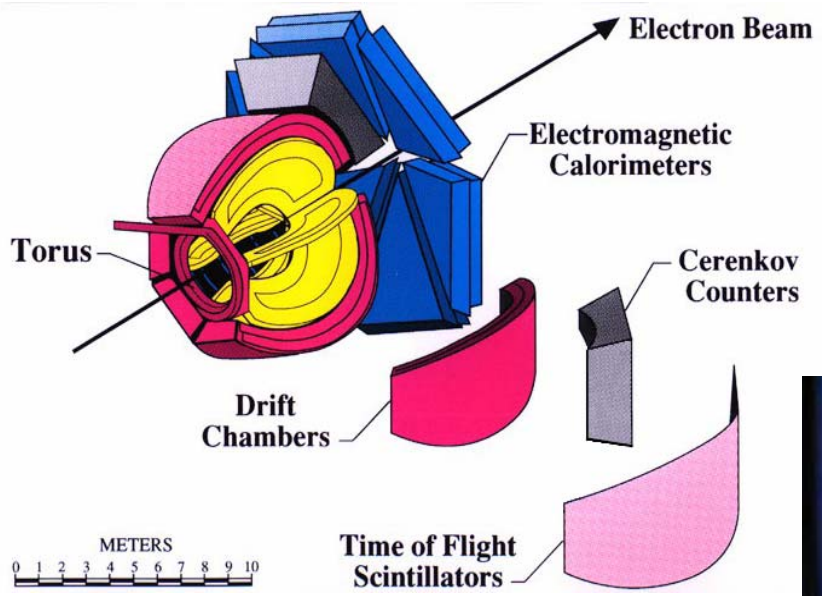


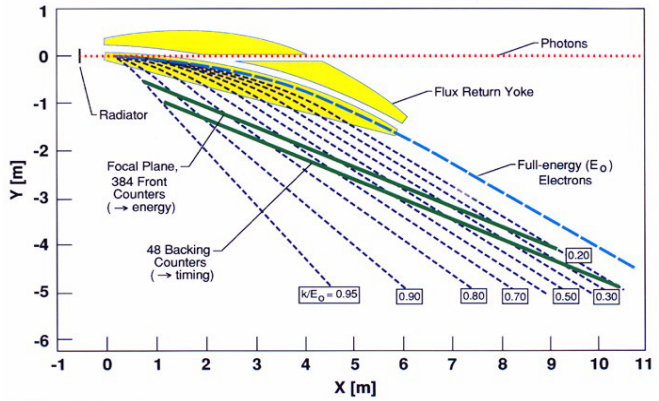
E_{max} ~ 6 GeV
I_{max} ~ 200 μA
Duty Factor ~ 100%
σ_E/E ~ 2.5 10^{-5}
Beam P ~ 80%
E_γ ~ 0.8– 5.7 GeV

CLAS



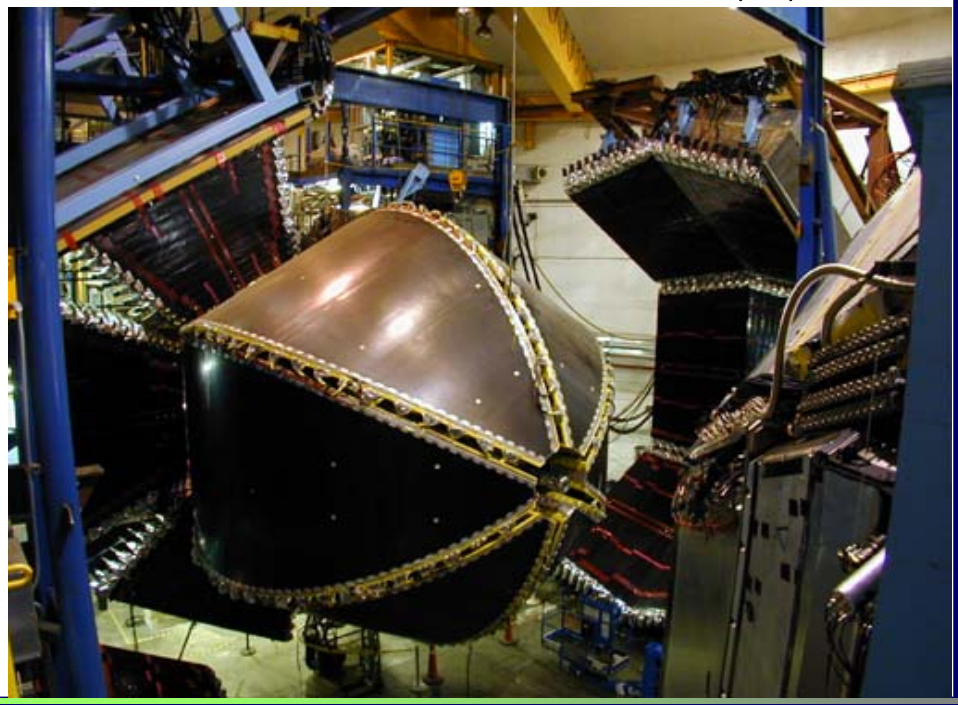
The CEBAF Large Acceptance Spectrometer CLAS





Performance

- $L = 10^{34}\ cm^{-2}\ s^{-1}$
- $\int B\ dl = 2.5\ T\ m$
- $\Delta p/p \sim 0.5\text{–}1\ \%$
- $\sim 4\pi$ acceptance
- Best suited for multiparticle final states
- Bremsstrahlung Photon Tagger ($\Delta E_\gamma/E_\gamma \sim 10^{-3}$)

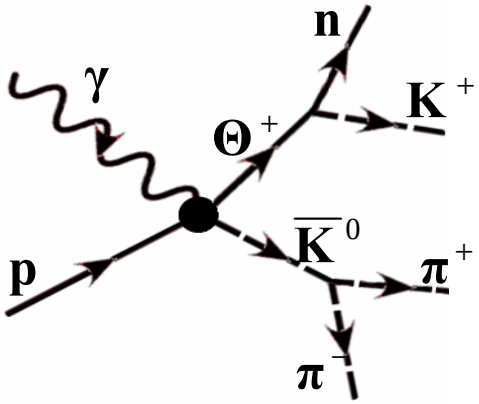


Search for Pentaquarks at CLAS

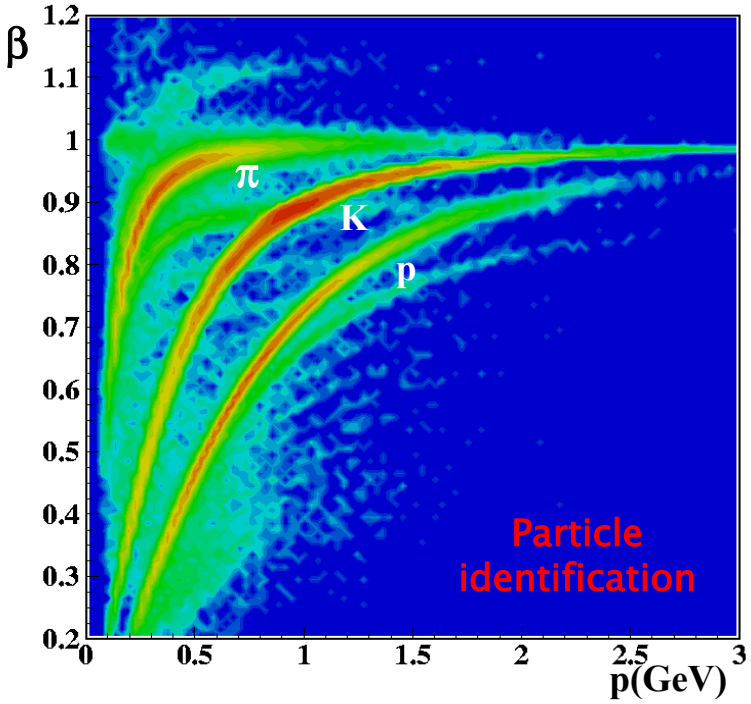
- Θ^+ pentaquark searches
  - $\gamma p \rightarrow \Theta^+ \bar{K}^0, \quad \Theta^+ \rightarrow nK^+, pK^0$
  - $\gamma d \rightarrow \Theta^+ K^- p$
  - $\gamma d \rightarrow \Theta^+ \Lambda(1116)$
- Θ^{++} pentaquark search
  - $\gamma p \rightarrow \Theta^{++} K^-$
- Φ^- (Ξ^- (1860)) pentaquark search
  - $\gamma d \rightarrow \Phi^{--} X, \quad \Phi^{--} \rightarrow \Xi^- \pi^- \rightarrow \Lambda^0 \pi^- \pi^-$

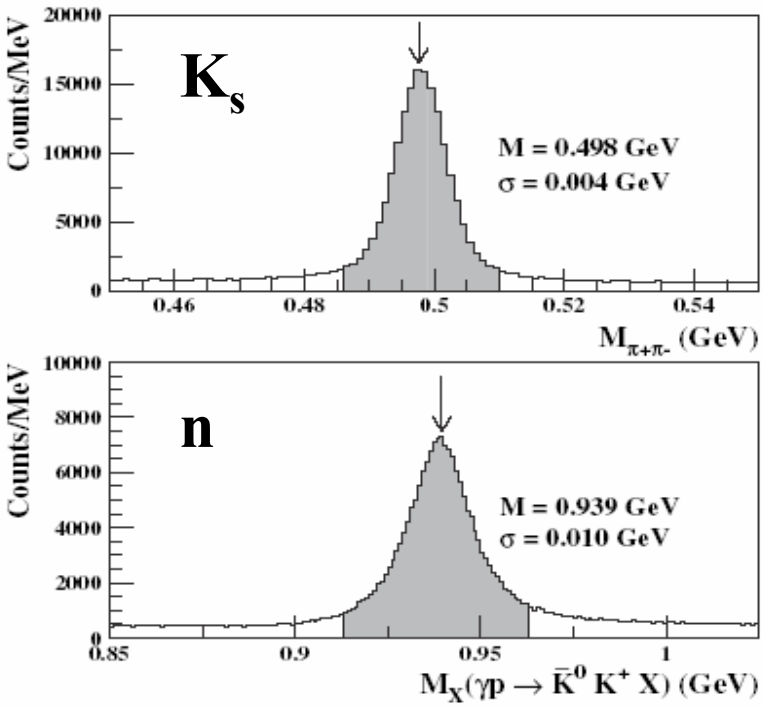
CLAS data analysis

$\gamma p \rightarrow \Theta^+ \overline{K}^0$

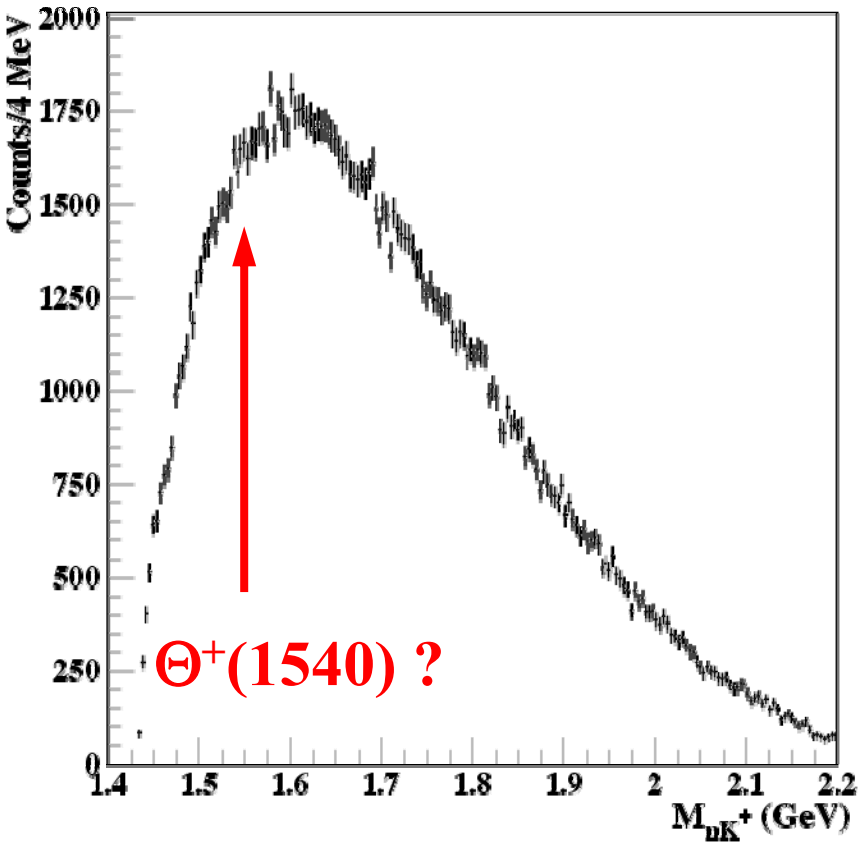


- charge particles detected in CLAS
- missing mass technique is used to identify the exclusive reaction

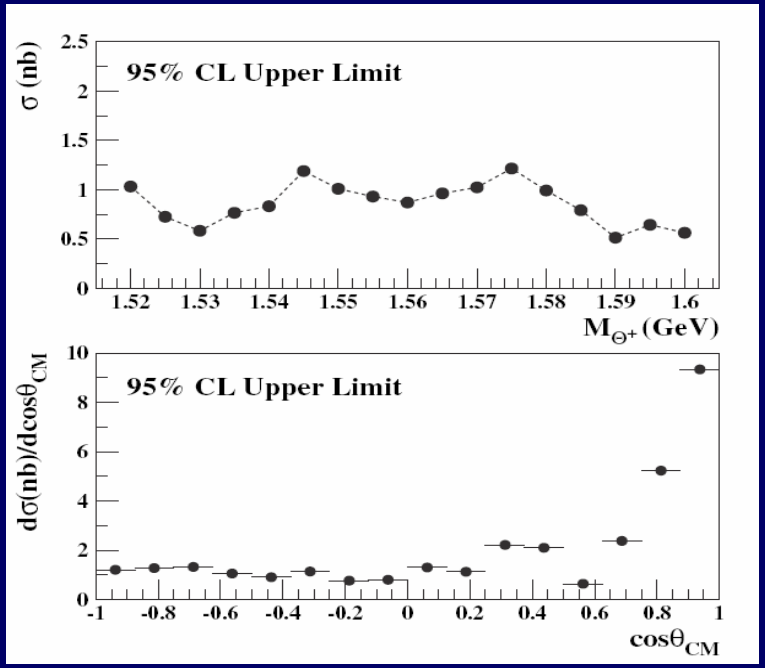




$\gamma p \rightarrow \Theta^+ \overline{K}^0, \quad \Theta^+ \rightarrow nK^+$

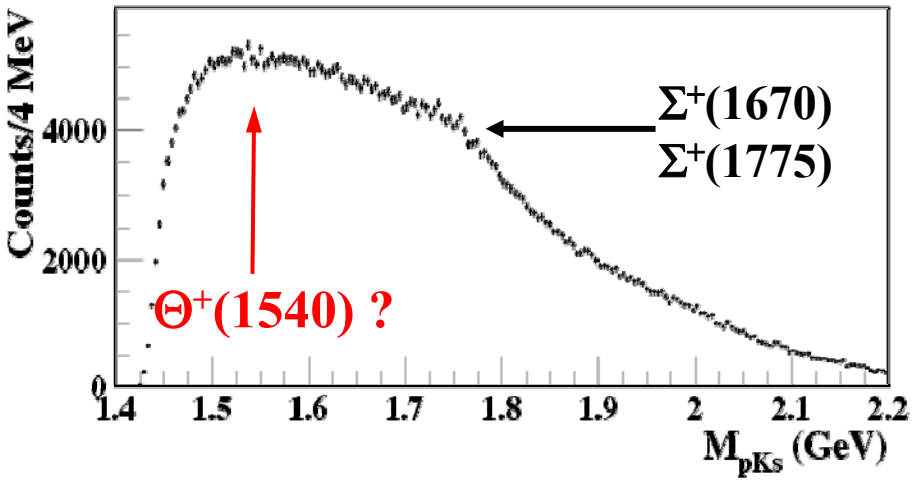


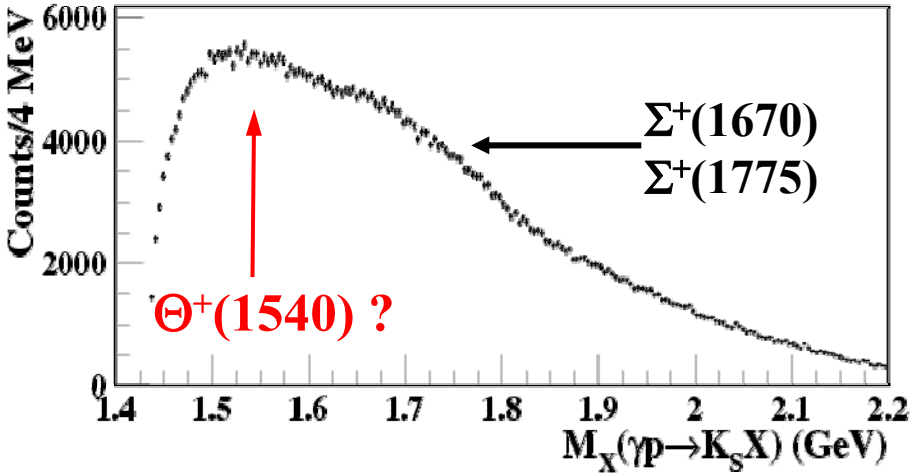
M. Battaglieri et al.,
Phys. Rev. Lett. 96, 042001 (2006)



- no indication of a narrow resonance in the nK^+ spectrum
- σ (95% CL) < 0.5–1.2 nb
- Θ^+/Λ^* (95% CL) <0.22 %
- CLAS result contradicts SAPHIR
  ($\sigma \sim 50$ nb, $\Theta^+/\Lambda^* \sim 9\%$)

$\gamma p \rightarrow \Theta^+ \overline{K}^0$, $\Theta^+ \rightarrow p K^0$

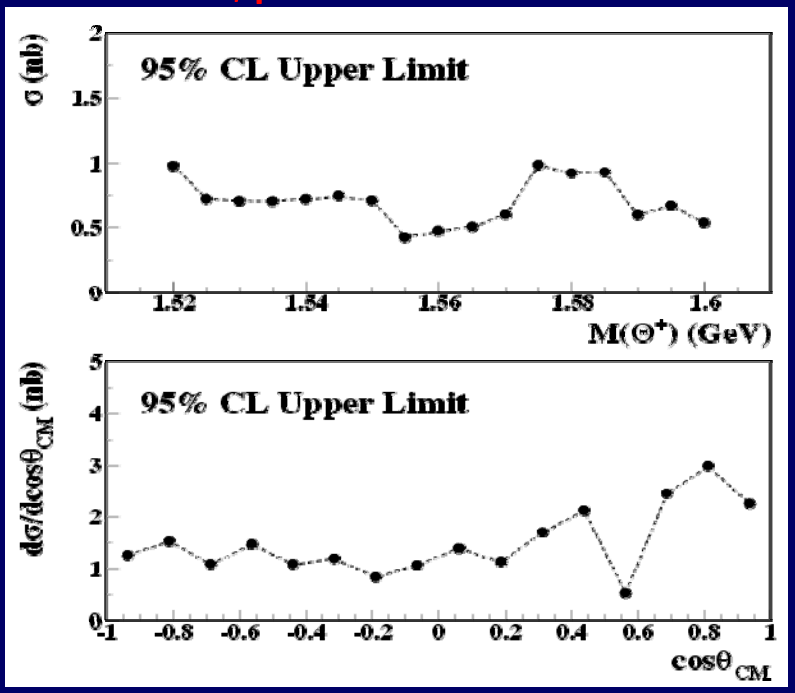




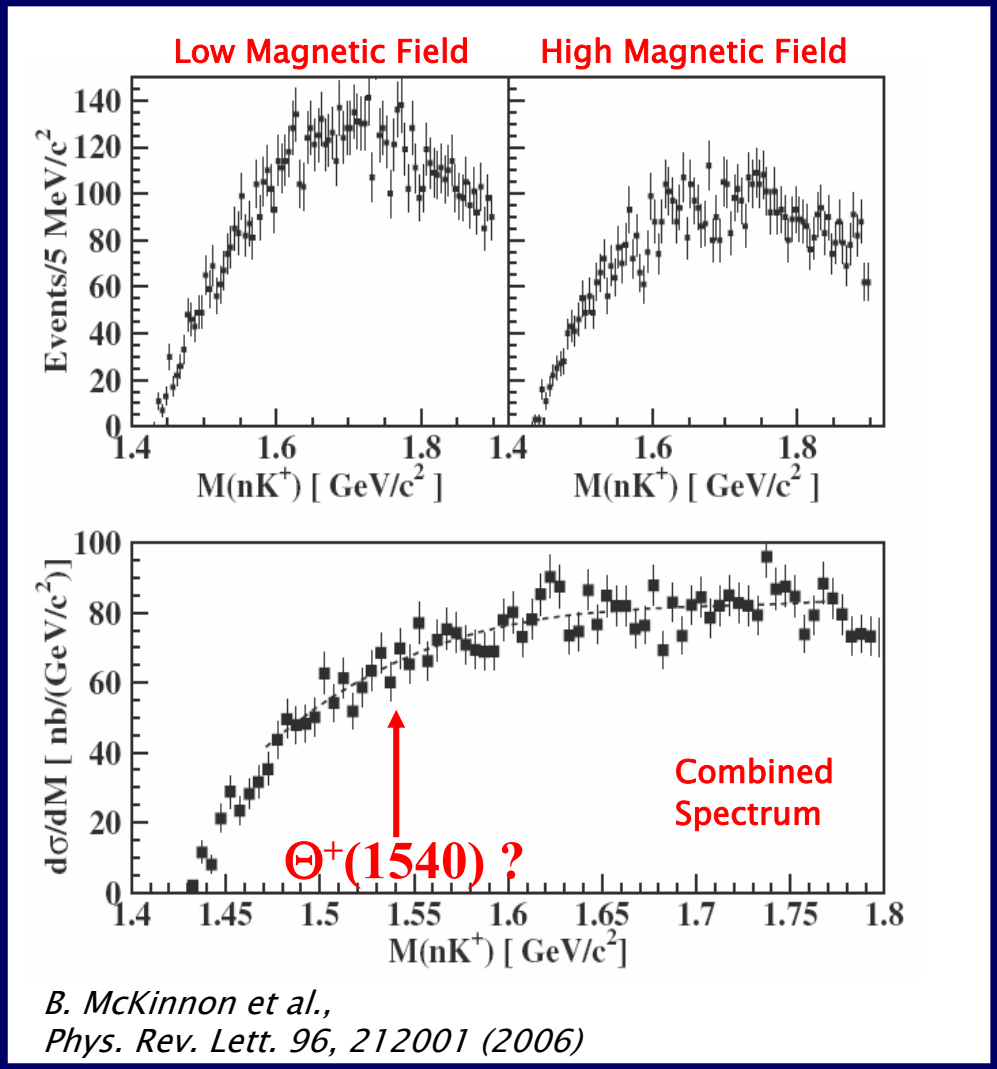
R. De Vita et al.,
hep-ex/0606062, Submitted to PRD

- same production channel but different decay mode
- large acceptance at forward angles, complementary to the nK^+ decay
- no signal observed

nK^+/pK^0 combined results

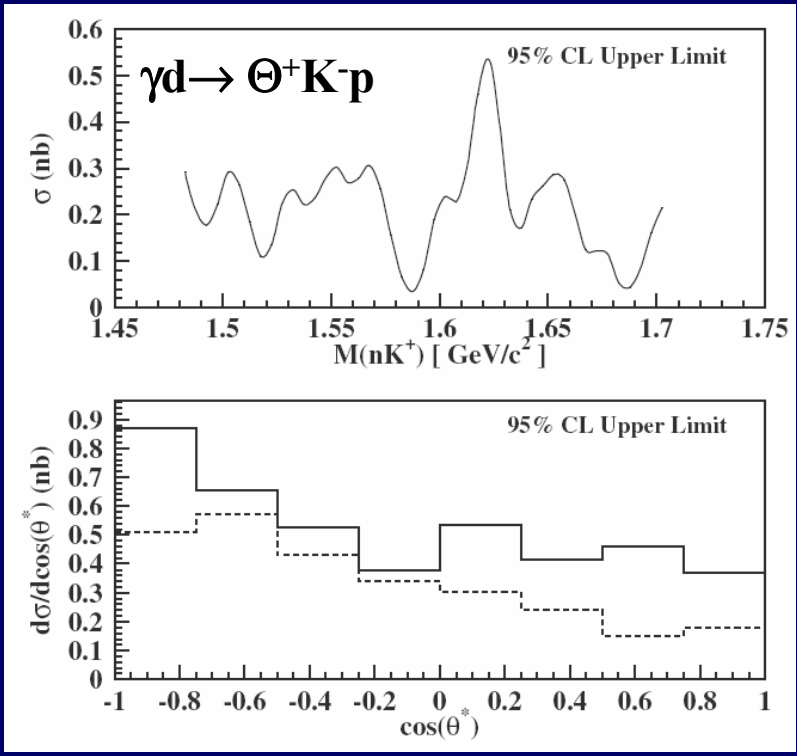


$\gamma d \rightarrow \Theta^+ K^- p, \quad \Theta^+ \rightarrow n K^+$

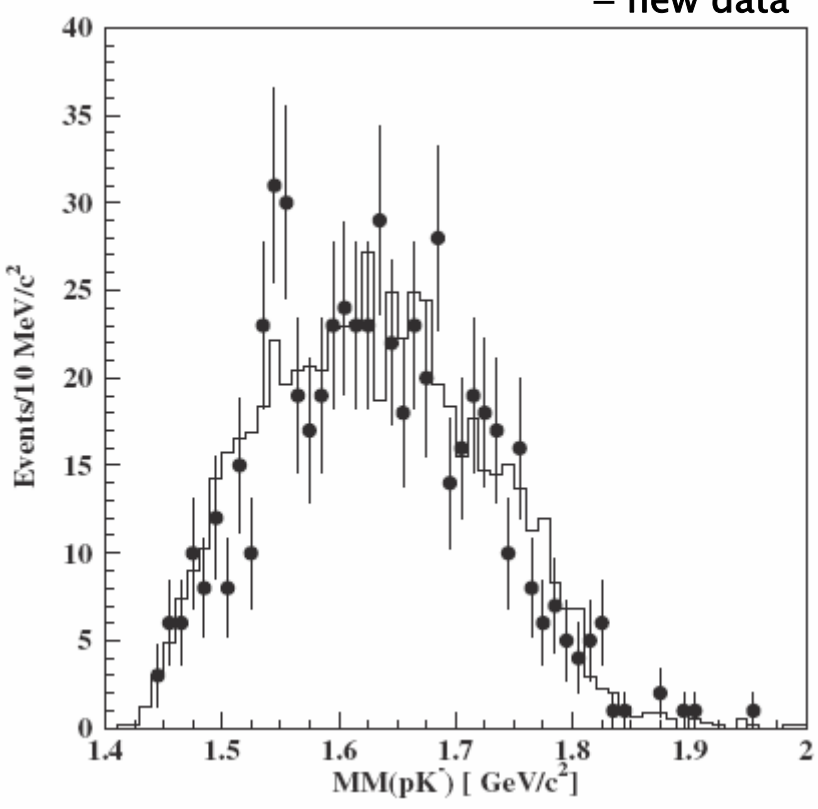


B. McKinnon et al.,
Phys. Rev. Lett. 96, 212001 (2006)

- no evidence of a narrow structure si found in the nK^+ spectrum
- 95% CL upper limit on the cross section for the elementary process $\gamma n \rightarrow \Theta^+ K^-$ of ~ 3 nb



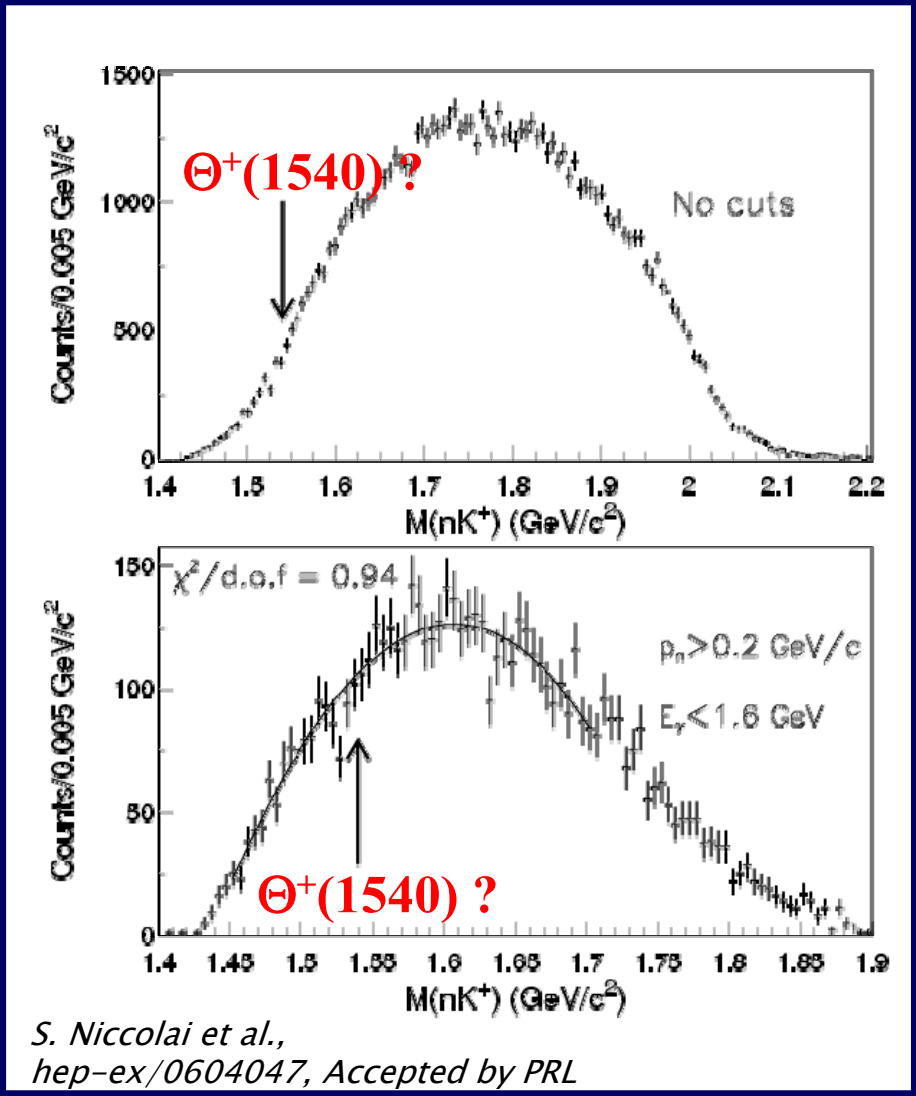
$\gamma d \rightarrow \Theta^+ K^- p, \quad \Theta^+ \rightarrow n K^+$



B. McKinnon et al.,
Phys. Rev. Lett. 96, 212001 (2006)

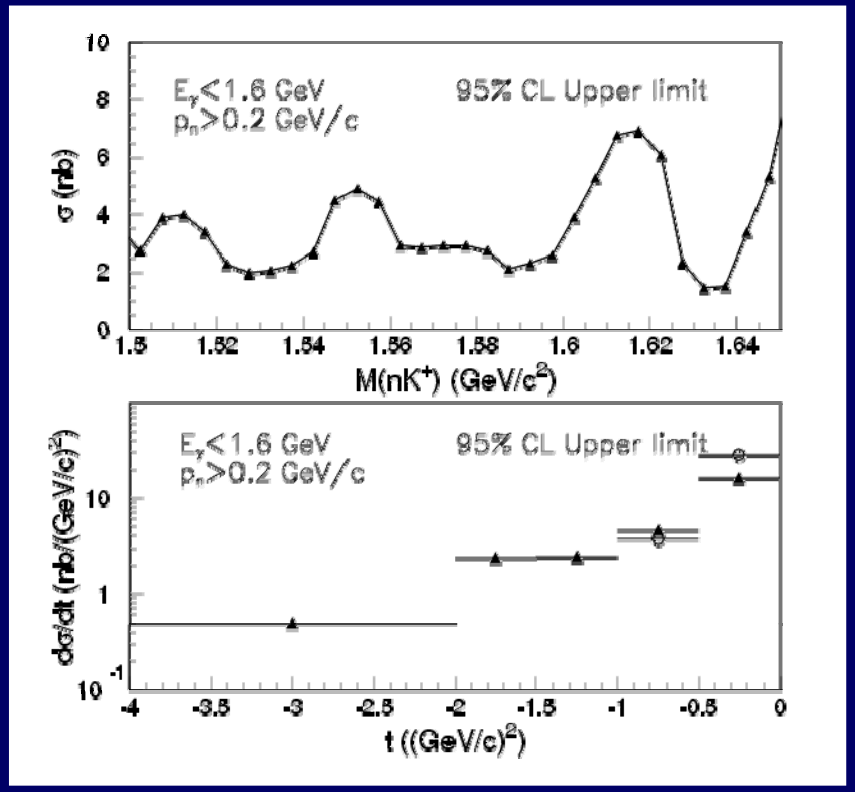
- Same reaction and same experimental conditions as previous CLAS result on deuteron but much higher statistics
- Previously observed structure could not be reproduced under similar conditions
- Statistical significance of old result is reduced from 5.2 to 3.1 when new mass spectrum is used as background

$\gamma d \rightarrow \Theta^+ \Lambda(1116)$

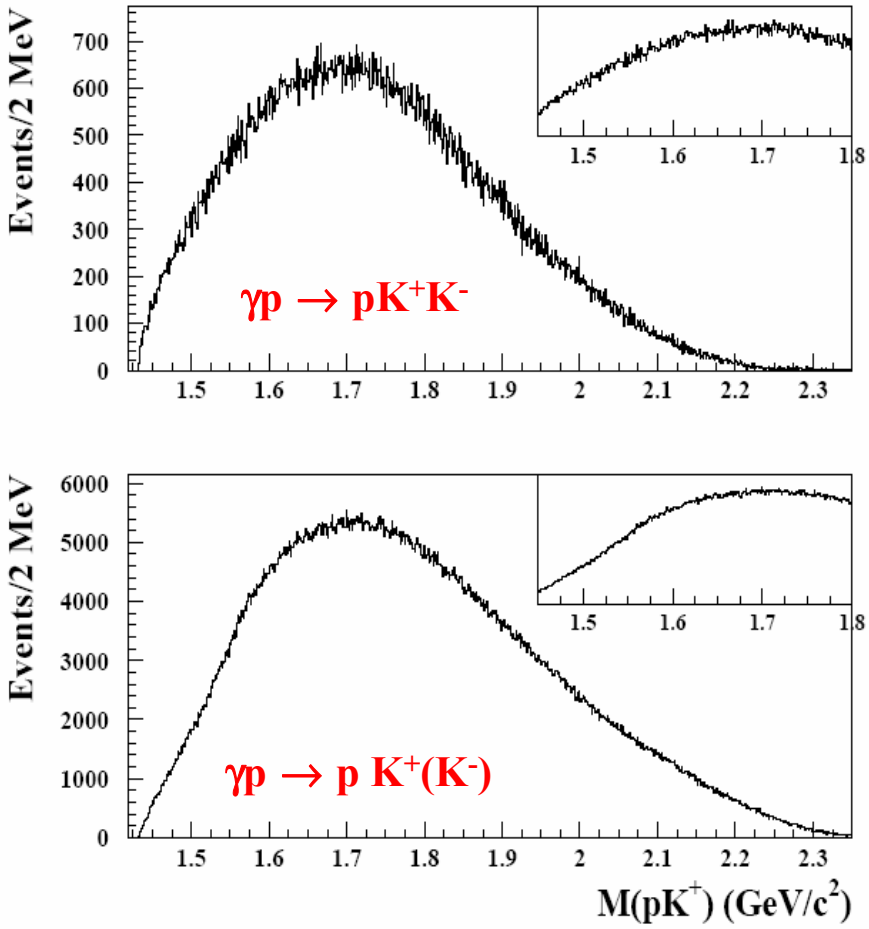


S. Niccolai et al., hep-ex/0604047, Accepted by PRL

- Two body process, i.e. no kinematic reflection from meson production
- Λ detection provides a strangeness tag
- Reaction proposed by V. Guzey (PRC, 065203 (2004))



$\gamma p \rightarrow \Theta^{++}K^{-}$ $\Theta^{++} \rightarrow pK^{+}$

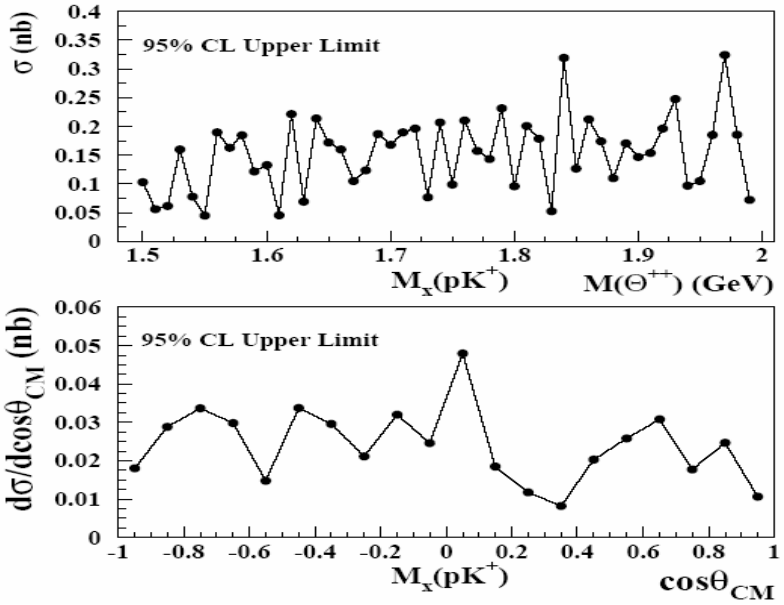


V. Kubarosky et al.,
hep-ex/0605001, Submitted to PRL

- Reaction studied in two event topologies (3 particles or 2 particles detected)
- No signal is found for masses 1.45–2 GeV
- 1 000 000 Λ^* observed
- 95% CL upper limit

$\sigma < 0.15$ nb $\Leftrightarrow$ $\Gamma < 0.1$ MeV

$\sigma(\Theta^{++})/\sigma(\Lambda^*) < 2.3\times10^{-4}$



$\gamma d \rightarrow \Phi^{--}X$

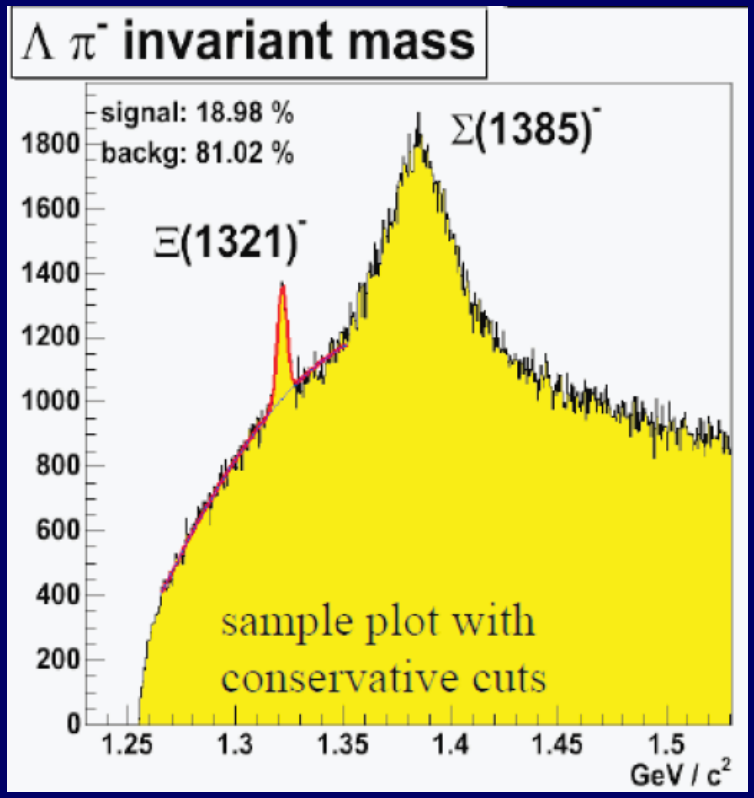
- Evidence for the Φ^{--}pentaquark searched for by reconstructing its decay products:

$$\Phi^{--} \rightarrow \Xi^{-}\pi^{-}$$
$$\rightarrow \Lambda^{0}\pi^{-}\pi^{-}$$
$$\rightarrow p\,\pi^{-}\pi^{-}\pi^{-}$$

- Cuts on the Ξ^{-} and Λ^{-} decay vertices used to suppress the background

- Preliminary analysis shows clear peaks for the X ground and first excited states

- Analysis still in progress



Upper limit on Γ_Θ from CLAS

Theoretical predictions for $\Gamma_\Theta = 1$ MeV

Publication	Reaction	J^π				Experimental Width
		1/2 −	1/2 +	3/2 −	3/2 +	
H.Kwee et al.	$\gamma p \to \Theta^+ \bar{K}^0$	0.01 nb	0.22 nb			<3.2 MeV
PRD 72, 054012(2005)	$\gamma n \to \Theta^+ K^-$	0.2 nb	1 nb	55 nb	10 nb	< 3 MeV
S. Nam et al.	$\gamma p \to \Theta^+ \bar{K}^0$		~3 nb	8 nb	1 nb	<0.23 MeV
PL B633, 483(2006)	$\gamma n \to \Theta^+ K^-$		~3 nb	200 nb	25 nb	< 1 MeV
Y. S. Oh et al.	$\gamma p \to \Theta^+ \bar{K}^0$	0.4 nb	100 nb			<0.01 MeV
PRD 69, 014009(2004)	$\gamma n \to \Theta^+ K^-$	2 nb	75 nb			<0.04 MeV
C. M. Ko and W. Liu	$\gamma p \to \Theta^+ \bar{K}^0$		15 nb			<0.05 MeV
nucl-th/0410068	$\gamma n \to \Theta^+ K^-$		35 nb			<0.09 MeV
W. Roberts	$\gamma p \to \Theta^+ \bar{K}^0$	3.4 nb	6.9 nb	17.7 nb	3.2 nb	<0.1 MeV
PRC 70, 065201(2004)	$\gamma n \to \Theta^+ K^-$	3.5 nb	11.5 nb	48 nb	4.2 nb	< 0.3 MeV

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Summary and Outlook

- Experimental situation concerning the existence of pentaquark states is still highly controversial (14 positive results challenged by negative evidence)
- Positive results have limited statistics
- Direct comparison of experimental results is very difficult because of the different conditions (energy range, production mechanism, kinematics, ...)
- A definitive conclusion can be obtained only by high statistics experiments that directly test positive evidences
    - A comprehensive physics program to search for evidence of pentaquark states in photoproduction reactions is in progress at Jefferson Lab with the CLAS detector
    - Analyses of several reactions on proton and deuteron targets show no evidence of pentaquarks states setting upper limits on the production cross sections of few nb
    - Further searches for pentaquark states in wider kinematic range are planned for the near future