

Search for Pentaquark States on Proton Target at CLAS

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for the CLAS Collaboration

International Workshop
PENTAQUARK04
July 20-23, 2004 at SPring-8, Japan
URL: <http://www.rcnp.osaka-u.ac.jp/~penta04/>
E-mail: penta04@rcnp.osaka-u.ac.jp

Organizers
Hiroshi Toki (Chair, RCNP, Osaka)
Atsushi Hosaka (Scientific Secretary, RCNP, Osaka)
Schin Date* (SPring-8)
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Tomoaki Hotta (RCNP, Osaka)
Ken-ichi Inai (Kyoto)
Noritaka Kumagai (SPring-8)
Takashi Nakano (RCNP, Osaka)
Yuji Ohashi (SPring-8)
Makoto Oka (Tokyo Inst. Tech.)

Workshop Site
SPring-8, Harima Science Garden
City, Hyogo prefecture
<http://www.spring8.or.jp/>

Hosted by
RCNP
JASRI at SPring-8
Supported by Inoue foundation



The diagram shows a proton target on the left, composed of three quarks (two up, one down) and gluons. An energetic photon strikes the proton, leading to the production of a pentaquark particle (u⁺) and a neutron. The pentaquark particle is shown as a cluster of five quarks (two up, two down, one strange) and gluons. A kaon meson is also shown as a cluster of two quarks (one up, one strange) and gluons.



An aerial photograph of the SPring-8 facility, showing the large circular synchrotron ring and the surrounding Harima Science Garden. In the background, a traditional Japanese castle is visible.

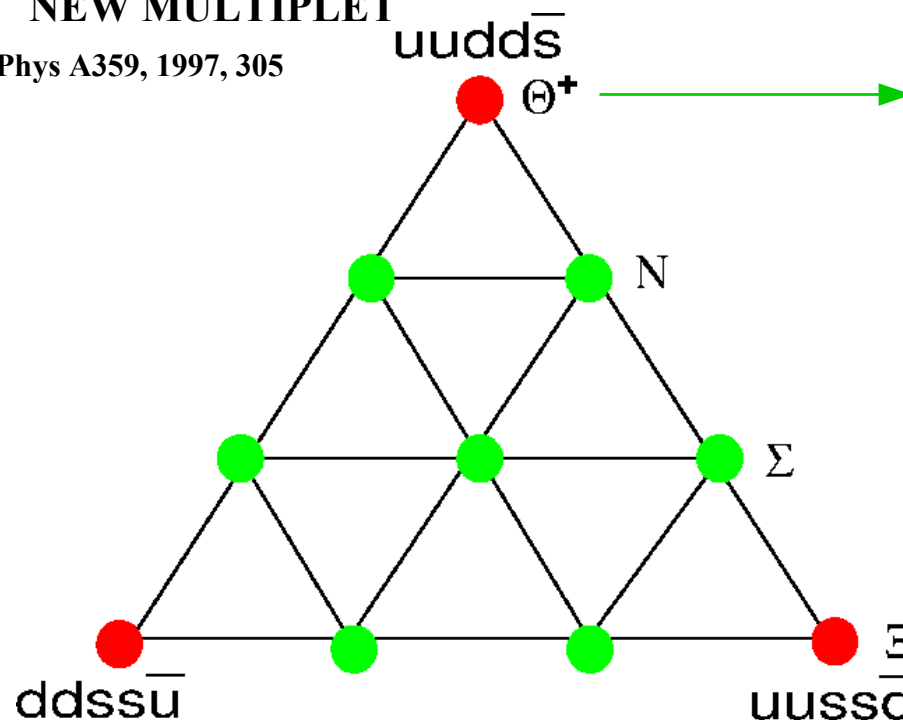
- ◆ **Physics Motivation**
- ◆ **Experimental Setup**
- ◆ **Analysis of existing data**
- ◆ **New experiments and future perspectives**

Physics Motivation

- ◆ QCD does not forbid the existence of **pentaquark states**
- ◆ Theoretical and experimental activity started several decades ago
- ◆ Interest renewed by *Diakonov et al.* Soliton Model predictions

$[\bar{10}]$ Spin = $\frac{1}{2}$ NEW MULTIPLET

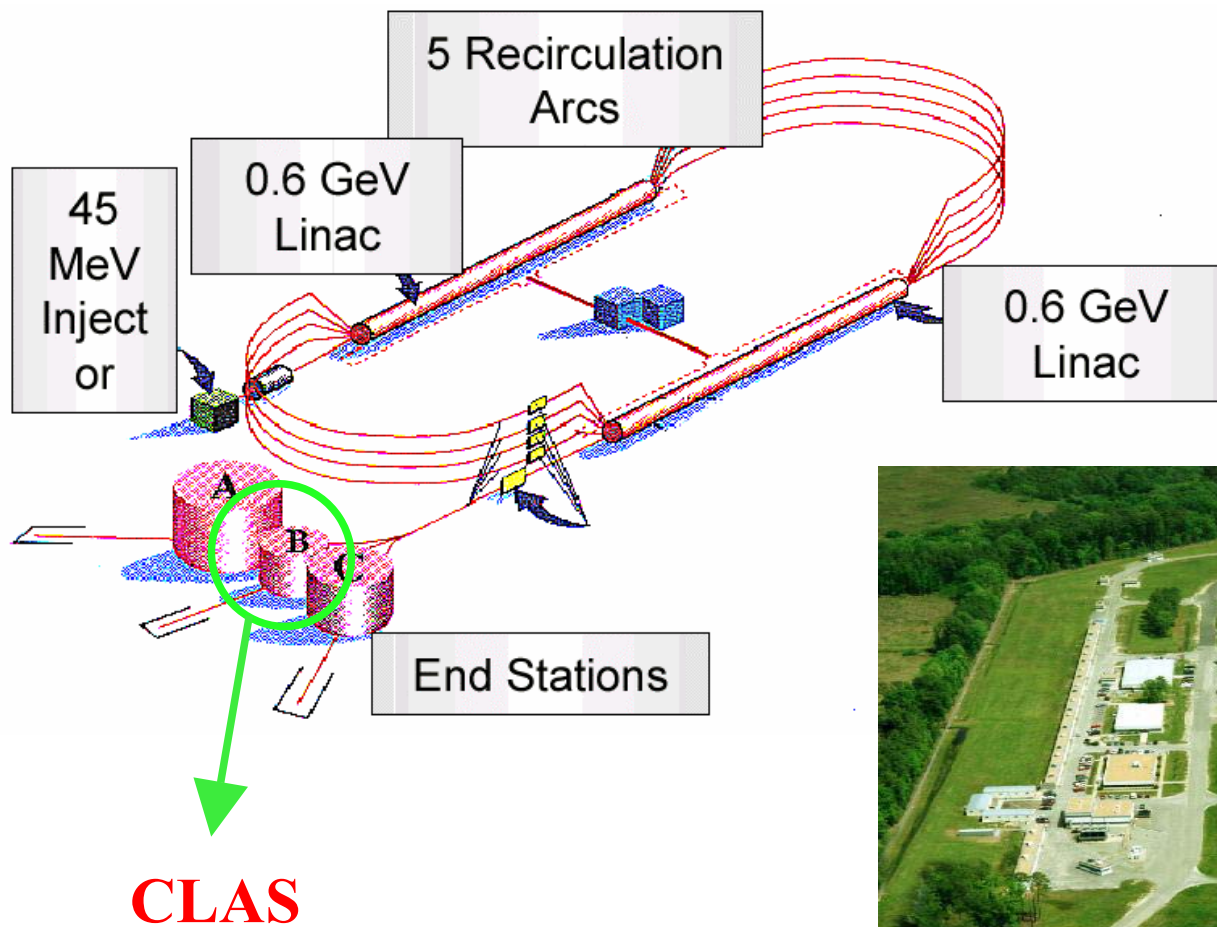
D.Diakonov et al. Z. Phys A359, 1997, 305



Isospin = 0
Strangeness = +1
 Mass ~ 1.530 MeV
 $\Gamma \sim 15$ MeV

- ◆ First experimental evidence for the Θ^+ found by the Spring-8/LepS collaboration on nuclear target
- ◆ Results confirmed by several experiments using different probes and targets (DIANA, CLAS, CERN/FNAL, SAPHIR, HERMES, SVD-2, ZEUS, COSY,...) with statistical significance of 4-6 σ

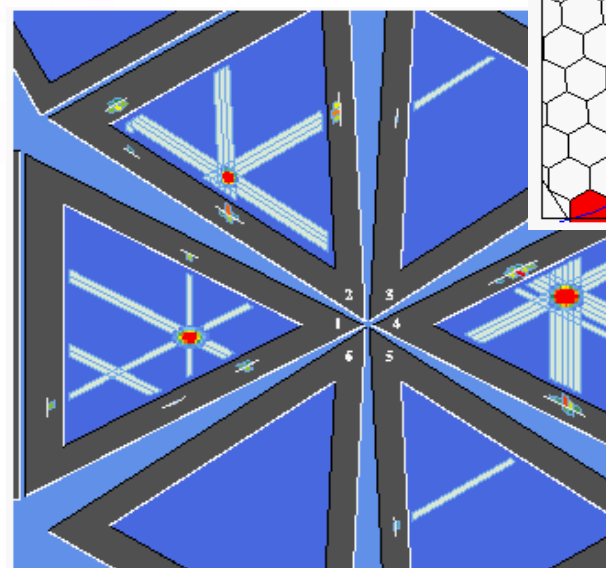
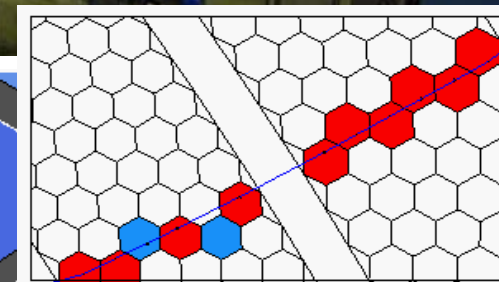
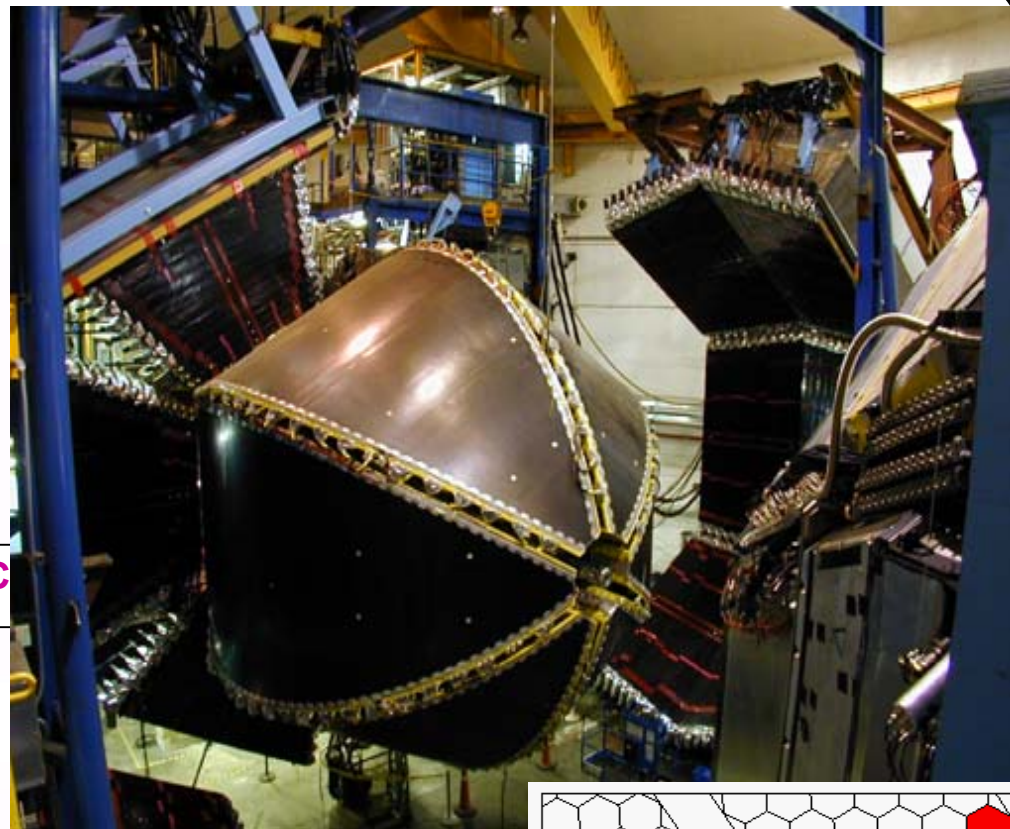
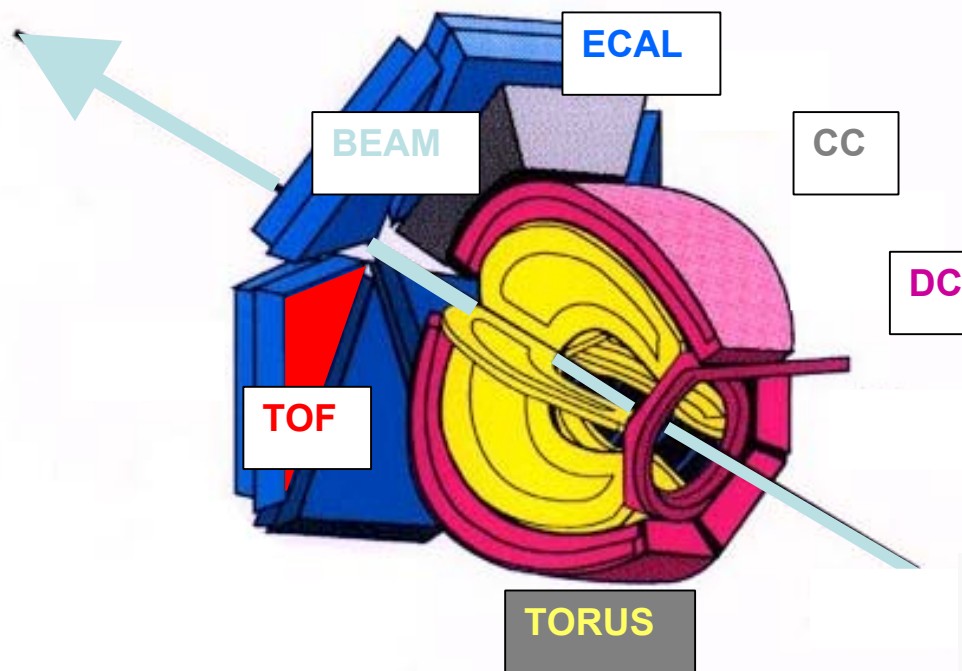
Jefferson Lab



E_{\max}	$\sim 6 \text{ GeV}$
I_{\max}	$\sim 200 \mu\text{A}$
Duty Factor	$\sim 100\%$
σ_E/E	$\sim 2.5 \cdot 10^{-5}$
Beam \mathcal{P}	$\sim 80\%$
$E_\gamma(\text{tagged})$	$\sim 0.8\text{-}5.5 \text{ GeV}$



The CEBAF Large Acceptance Spectrometer CLAS



- Performance**
- 6 independent sectors
 - $\sim 4\pi$ acceptance
 - $L = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
 - $\int B \, dl = 2.5 \text{ T m}$
 - $\Delta p/p \sim 1 \%$

**Best suited for
multihadron final
states
(p, π , K)**

Analysis of Exclusive Reactions on Proton Target

High Energy:

3 data runs:

- a. $E_\gamma = 3.2 - 4.0$ GeV, 1999
- b. $E_\gamma = 3.0 - 5.25$ GeV, 2000
- c. $E_\gamma = 4.8 - 5.47$ GeV, 2001



results published in 2004: V. Kubarosky et al. PRL 92 032001 (2004)

Low Energy:

1 data run:

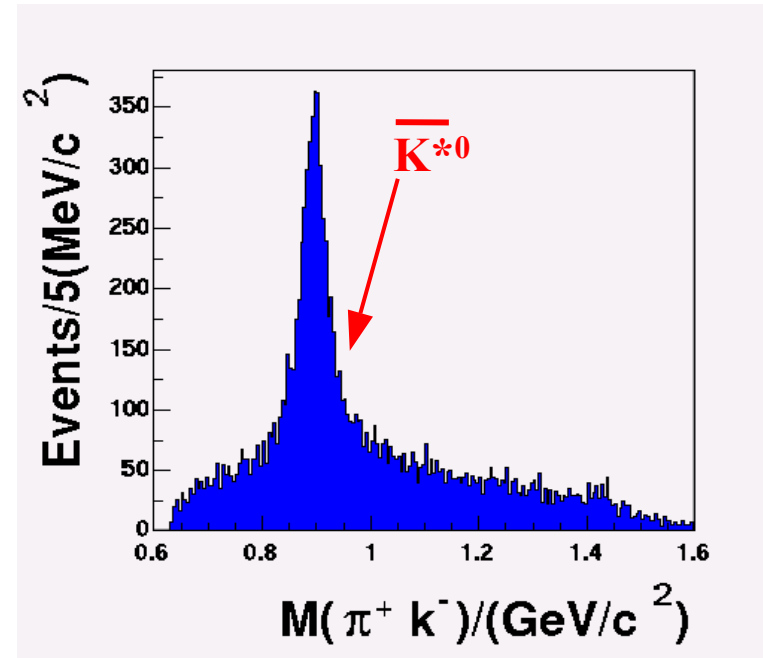
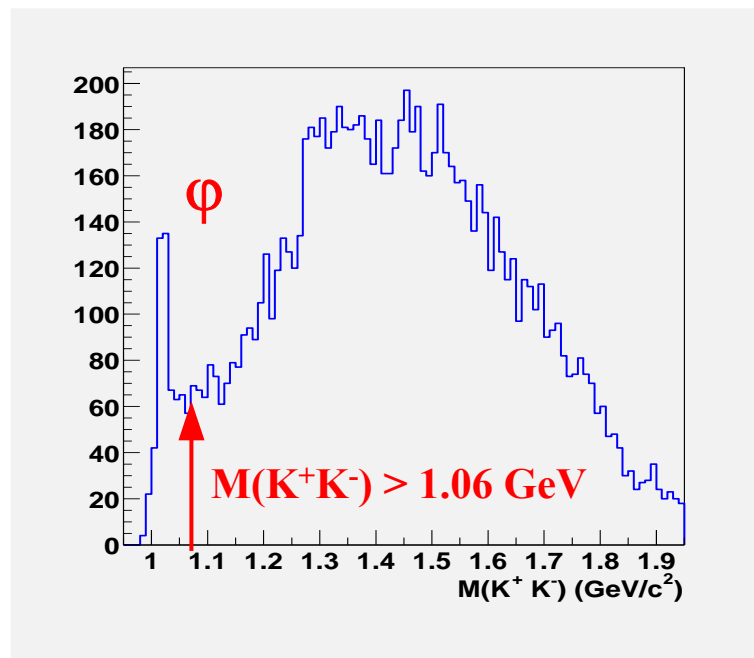
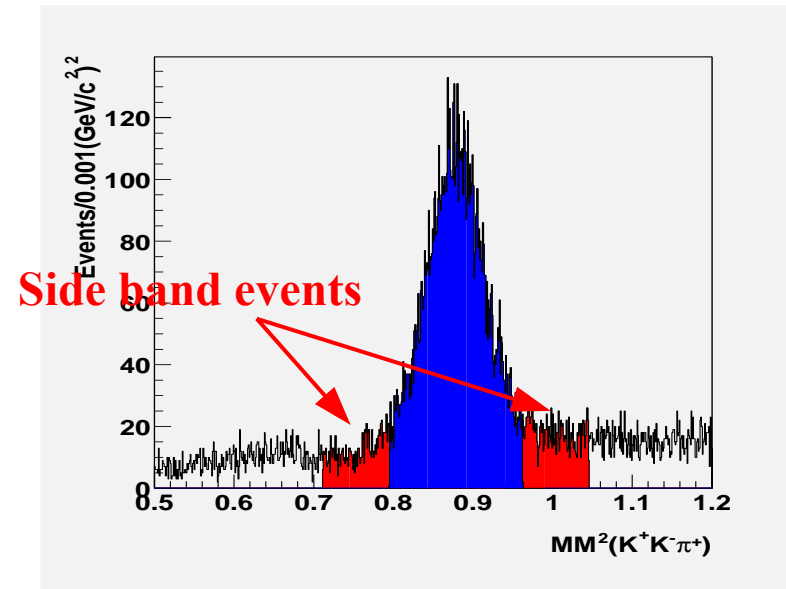
- $E_\gamma = 0.4 - 3$ GeV, 1999



analysis in progress

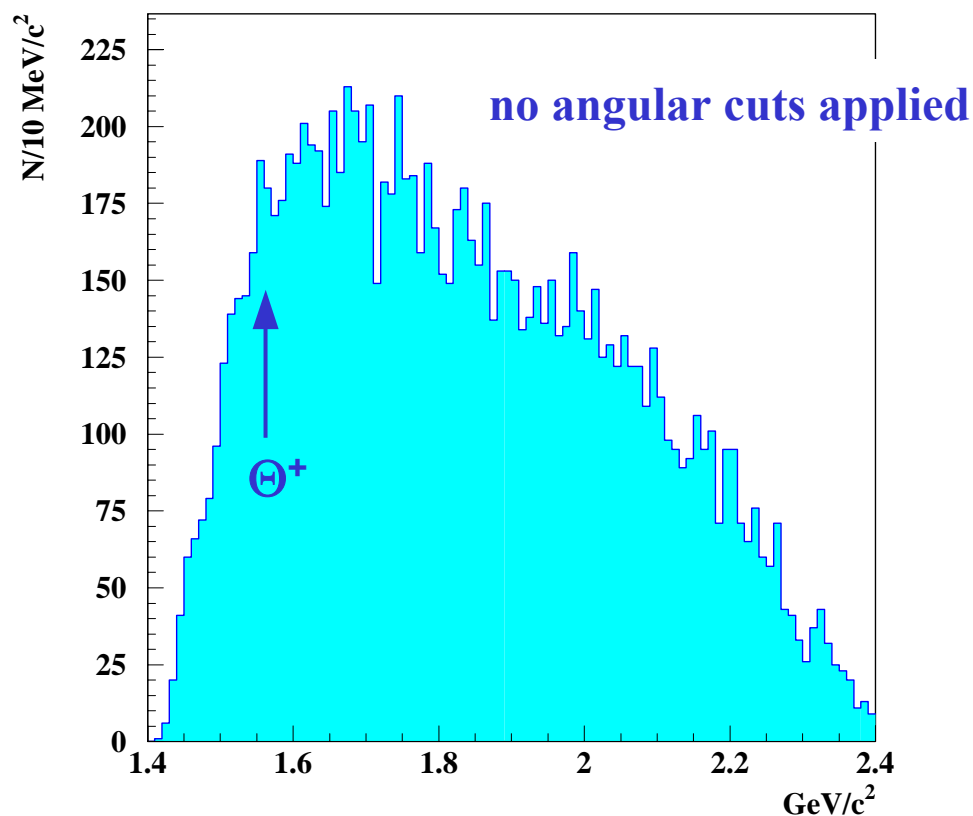
High Energy Photon Analysis: $\gamma p \rightarrow \pi^+ K^- \Theta^+$

- ◆ reaction is selected using missing mass technique:
 - π^+, K^+, K^- are detected in CLAS and the neutron is selected with a $\pm 2\sigma$ cut around the neutron peak
- ◆ known hyperon production rejected applying cuts on the appropriate mass



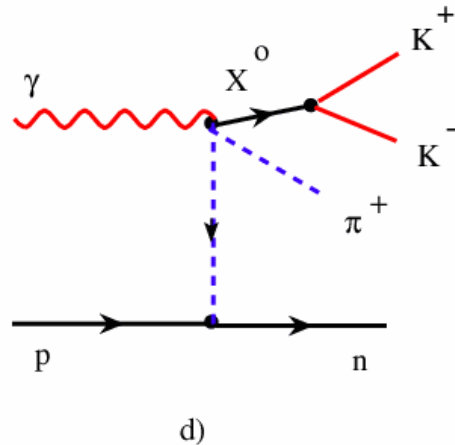
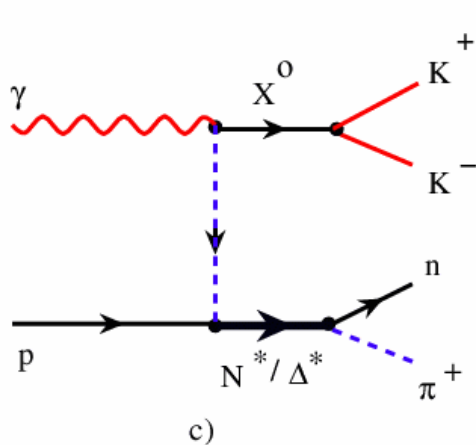
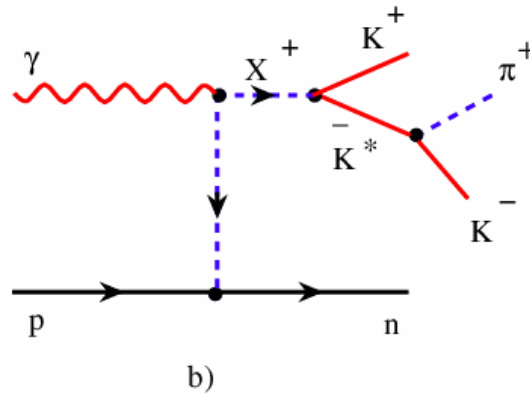
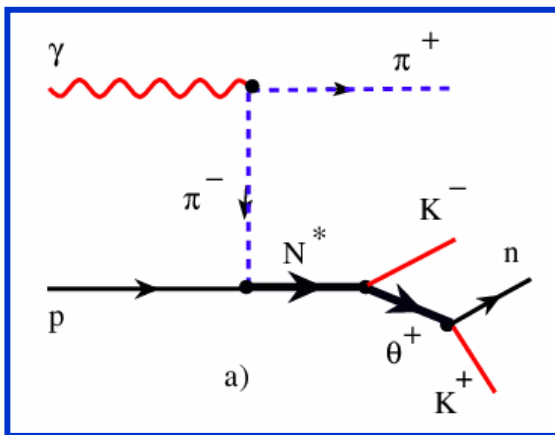
High Energy Photon Analysis: $\gamma p \rightarrow \pi^+ K^- \Theta^+$

- ◆ after selection of the final states and rejection of known background sources the (nK^+) invariant mass is constructed
- ◆ no obvious structures are visible at this level of the analysis
- ◆ large background contribution from meson production
- ◆ hypothesis on Θ^+ production mechanism as well as on the backgrounds need to be made to try to understand this spectrum



High Energy Photon Analysis: $\gamma p \rightarrow \pi^+ K^- \Theta^+$

Possible production mechanism



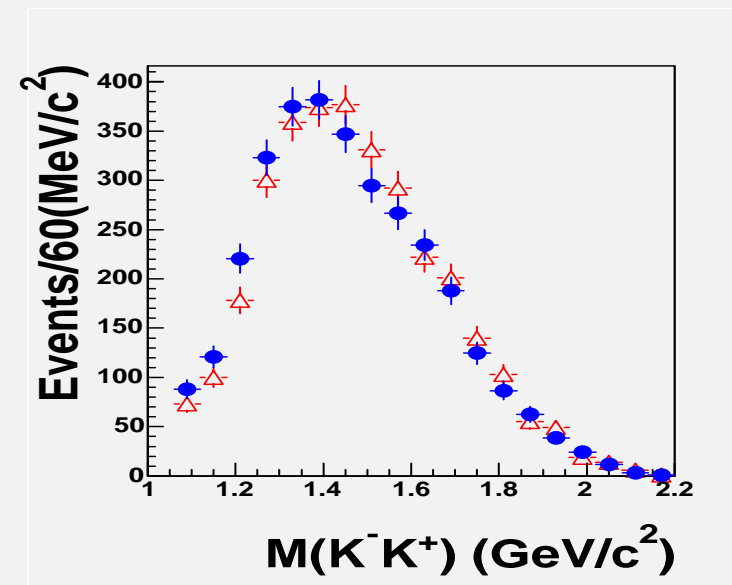
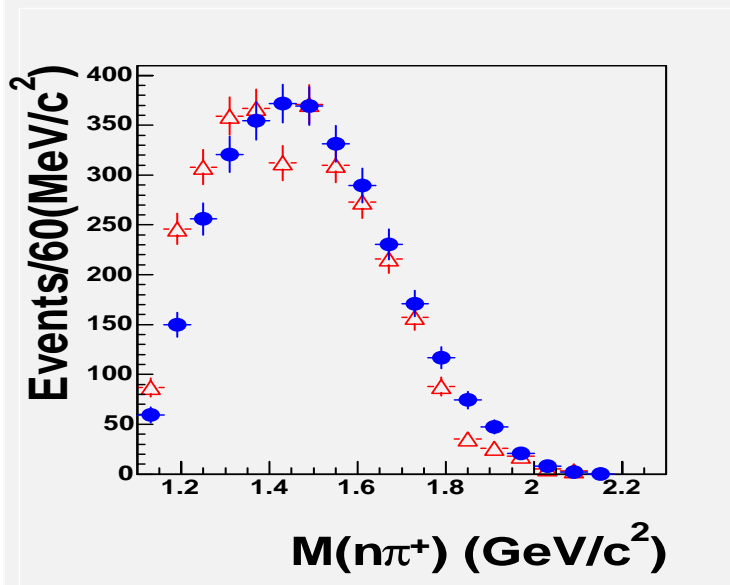
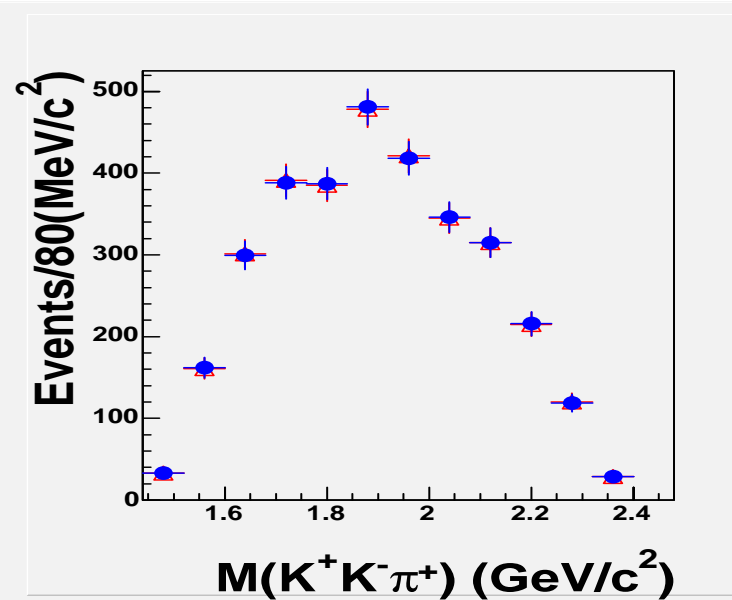
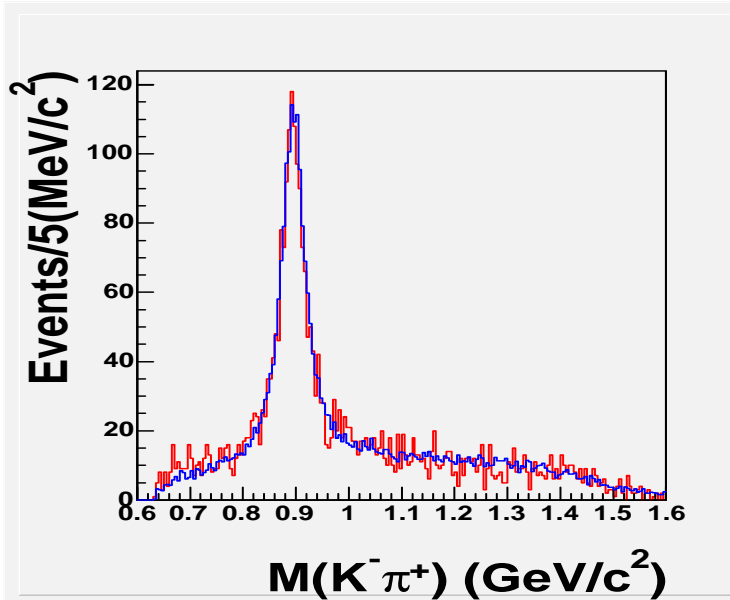
Select t-channel process
by tagging forward π^+
and reducing K^+ from t-
channel process

$$\cos\theta_{\pi^+}^* > 0.8$$

$$\cos\theta_{K^+}^* < 0.6$$

in CM frame

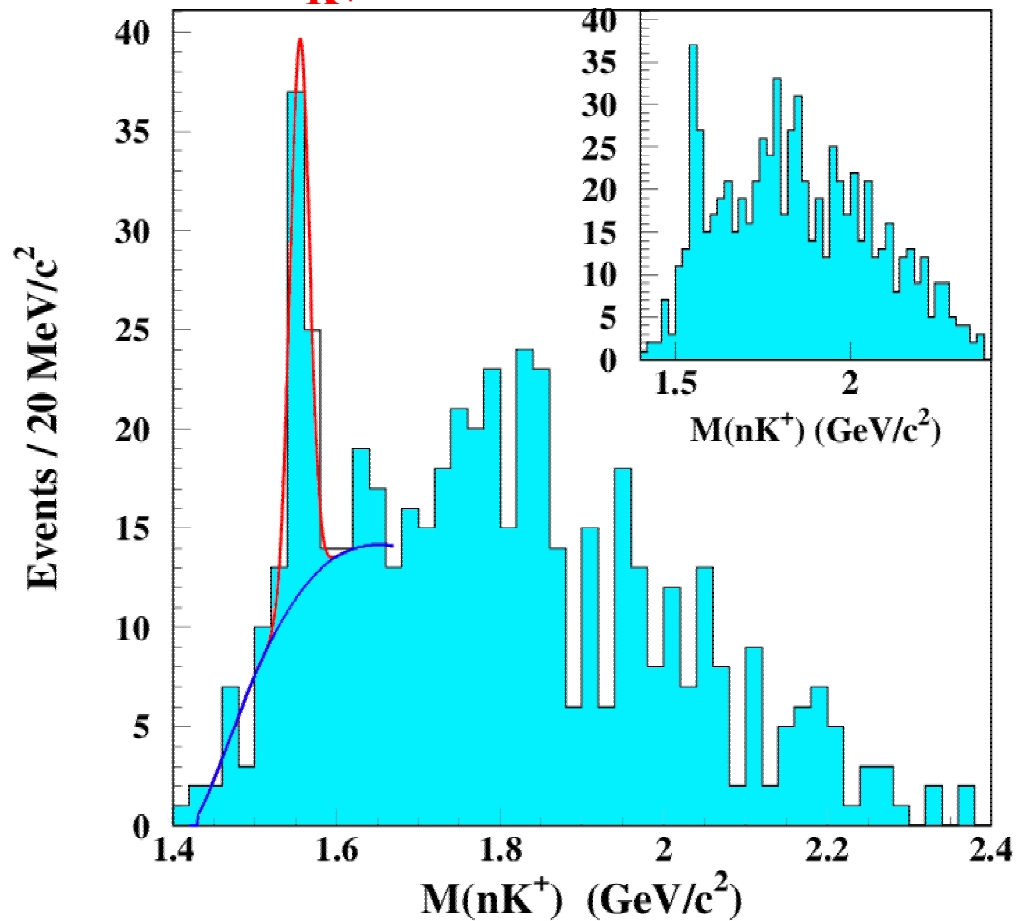
Background from Partial Wave Analysis



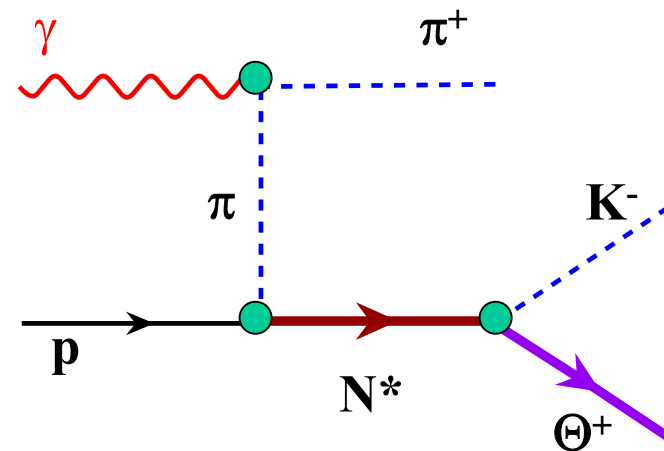
High Energy Photon Analysis: $\gamma p \rightarrow \pi^+ K^- \Theta^+$

$$\cos\theta_{\pi^+}^* > 0.8$$

$$\cos\theta_{K^-}^* < 0.6$$

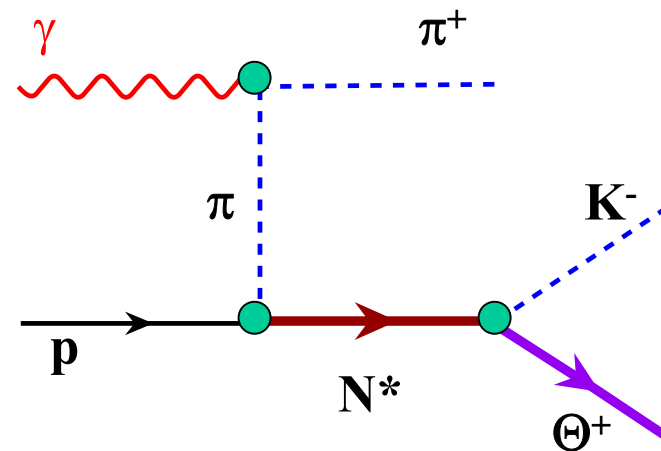
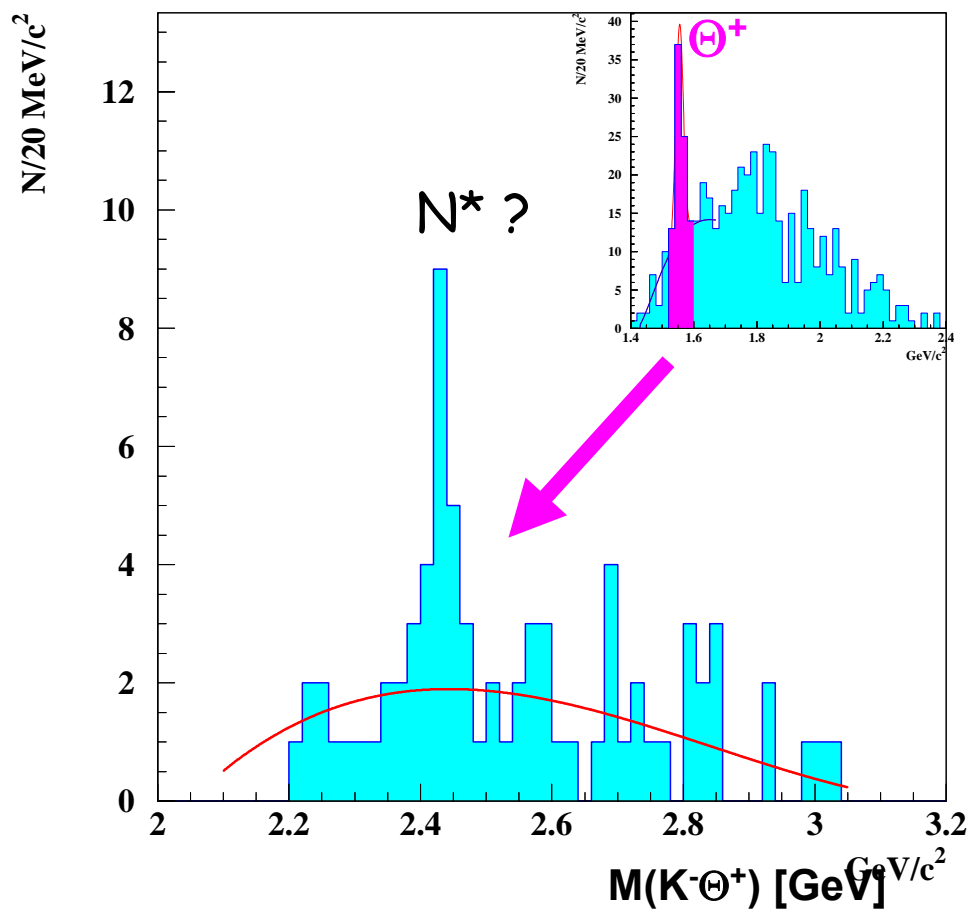


- Fitted mass **1.555 GeV**
- $\Gamma < 28$ MeV consistent with detector resolution
- Estimated significance **7.8 σ**



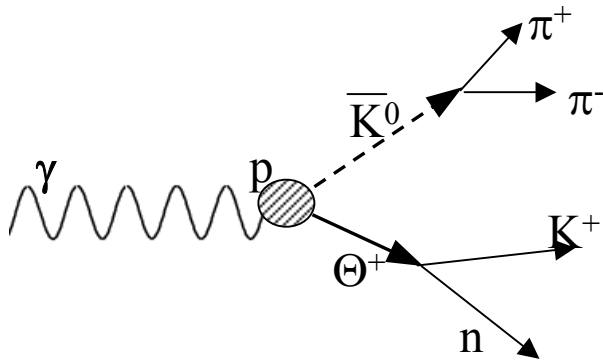
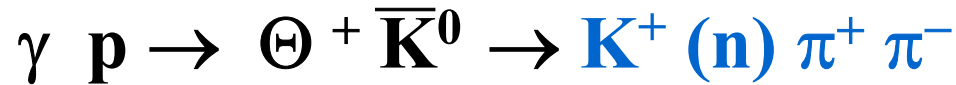
$$\gamma p \rightarrow \pi^+ K^- \Theta^+$$

Indication for a heavy $N^*(2430)$?



No πN scattering data in the relevant energy range to confirm or reject this hypothesis

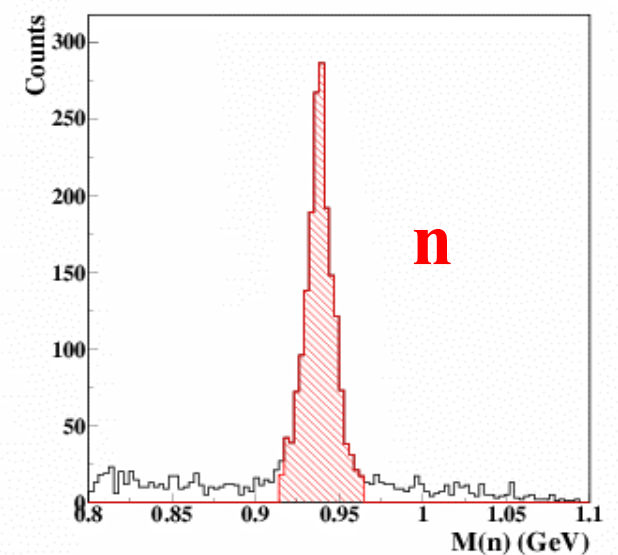
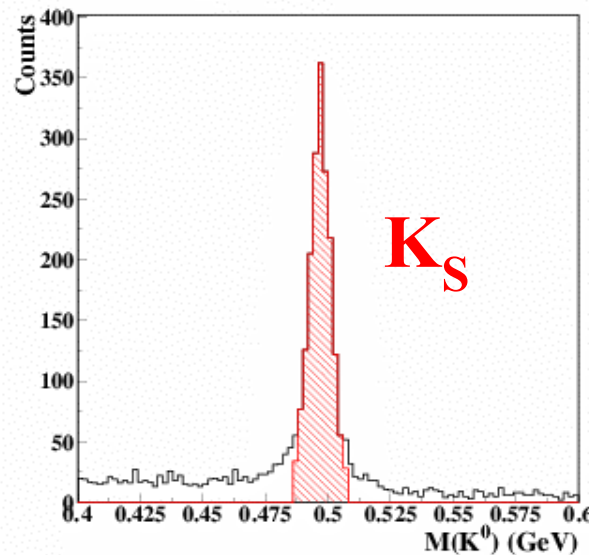
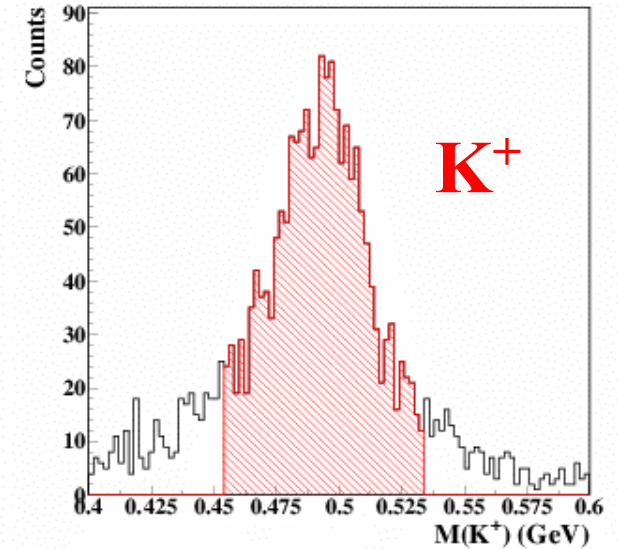
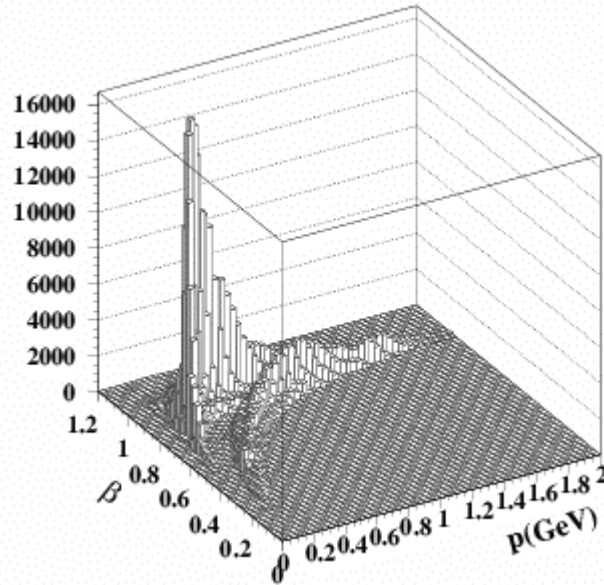
Low Energy Photon Analysis



✓ the Θ^+ is searched in the $n K^+$ decay mode

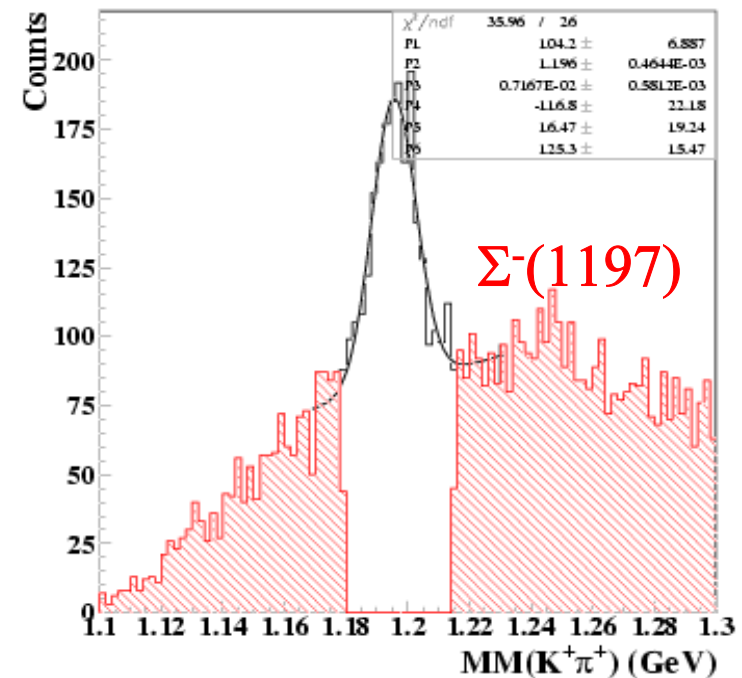
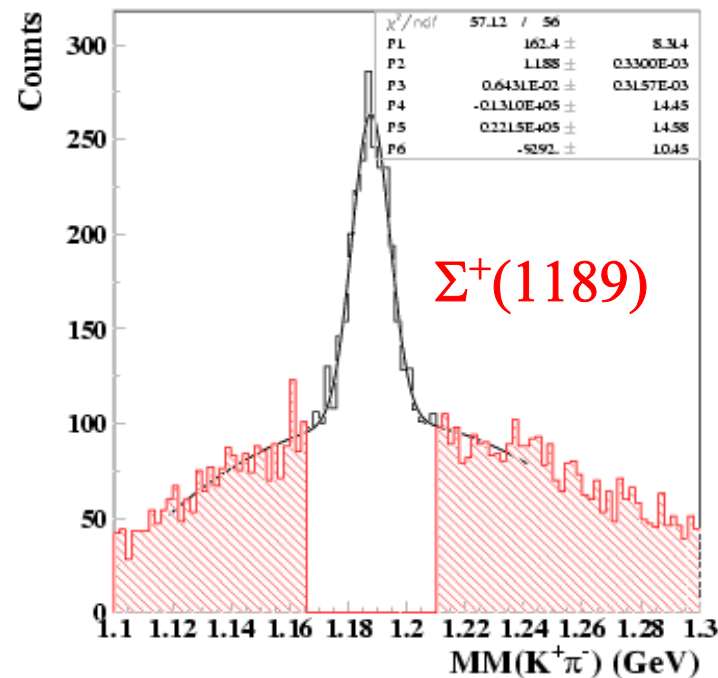
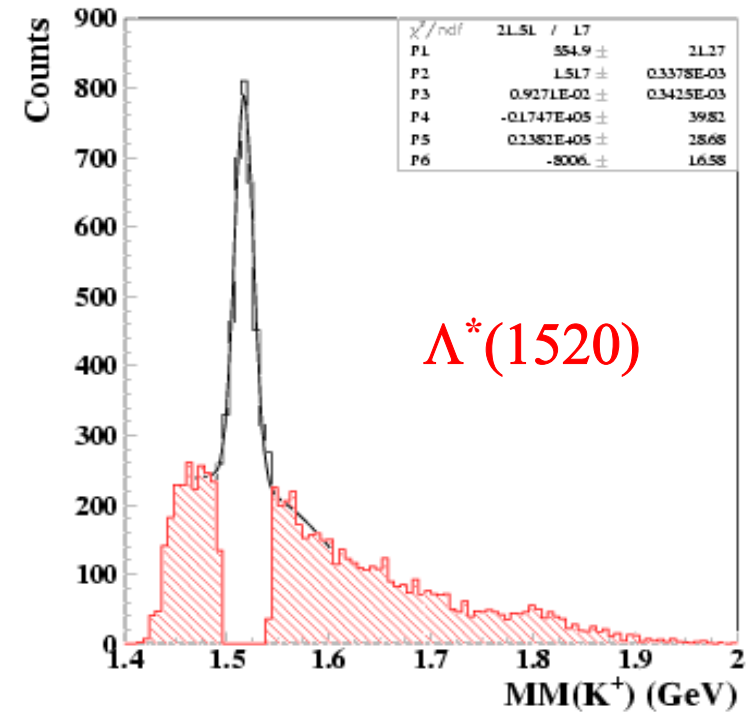
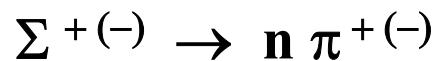
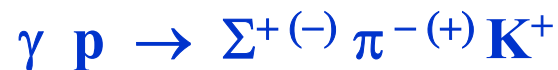
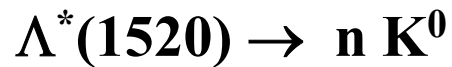
✓ the \bar{K}^0 is detected via its K_S component decaying into $\pi^+ \pi^-$

✓ the final state is identified detecting the **three charged particles** and using the missing mass technique



Background Rejection

Background due to production of known hyperons decaying to this same final state was rejected by cutting on the corresponding masses

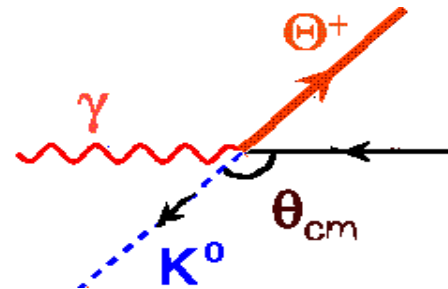


Low Energy Photon Analysis



Analysis still in progress

- From a preliminary analysis there are some indications of possible narrow structures at 1.523 ± 5 MeV and 1.573 ± 5 MeV in nK^+ invariant mass and 1.579 ± 5 MeV in the (pK^+) invariant mass
- Angular cut selecting K_S^0 at backward angles in γ -p center of mass
- Limited statistical significance
- Parallel analysis on the same data set shows that statistical fluctuations using different selection cuts are not negligible



Request for a high statistics experiment

presented at JLab Jan 2004 PAC-25

g11

Approved with maximum rate

Present Status

- ◆ Several collaborations reported evidence for pentaquark signals

“ there are substantial indications that something interesting is being observed” (PDG2004)

but

“ it is reasonable to have some reservation about the existence of this state based on the present evidence” (PDG2004)

- ◆ null results have been recently presented
- ◆ positive results have limited statistics significance and few events in the observed structures
- ◆ comparison between different experiments shows discrepancies in mass position, ...

**these results need to be confirmed by
high statistics/ high resolution experiments**

Future Projects

a long and comprehensive program to search for pentaquark signals in high statistics and high resolution experiment has started in Hall B at Jefferson Lab

g10	$\gamma d \rightarrow \Theta^+ K^- p$ $\gamma d \rightarrow \Theta^+ \Lambda^0$	E_γ 1.-3.6 GeV	data taking completed
g11	$\gamma p \rightarrow \Theta^+ \bar{K}^0$ $\gamma p \rightarrow \Theta^+ K^- \pi^+$ $\gamma p \rightarrow \Theta^{++} K^-$	E_γ 1.5-3.8 GeV	presently running
eg3	$\gamma d \rightarrow \Xi_5^{--} X$ $\gamma d \rightarrow \Xi_5^- X$	$E_\gamma \sim 1.5 - 5.4$ GeV	scheduled for Fall 2004
Super-g	$\gamma p \rightarrow \Theta^+ \bar{K}^0$ $\gamma p \rightarrow \Theta^+ K^- \pi^+$ $\gamma p \rightarrow \Theta^{++} K^-$ $\gamma p \rightarrow \Xi_5 X$	$E_\gamma \sim 1.5 - 5.4$ GeV	to be scheduled

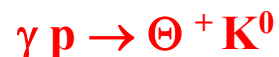
G11 run on proton target

talk by M. Battaglieri

▶ 25 days of data taking on hydrogen target with
 $1.5 < E_\gamma < 3.8$ GeV

▶ two reaction channels

two decay modes

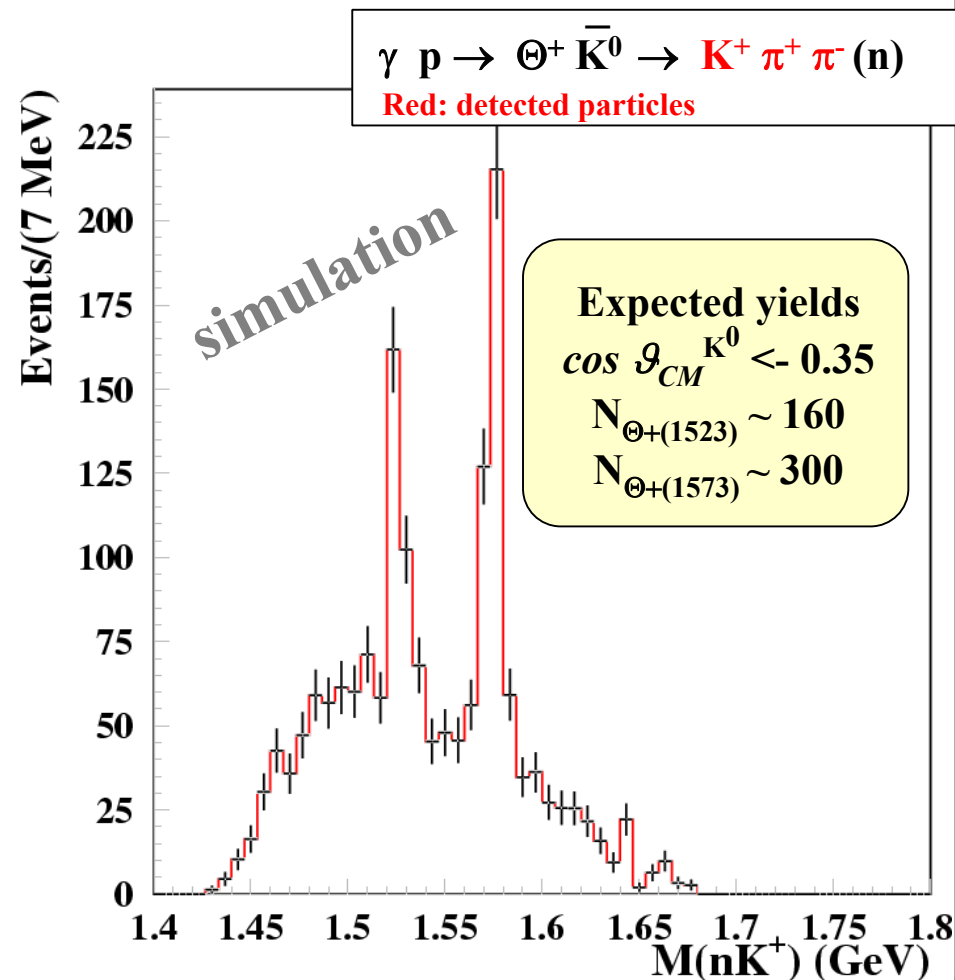


▶ search for Θ^+ ground and excited states

▶ search for isospin partners

▶ collecting more than 10 times the present statistics

▶ started in May 2004, ending on July 28th



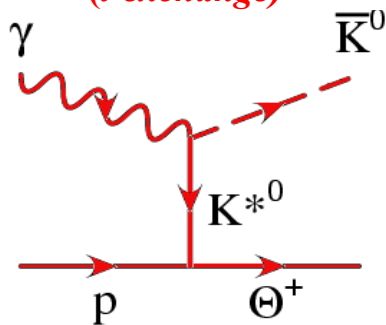
Statistical Accuracy:

Differential Cross Section

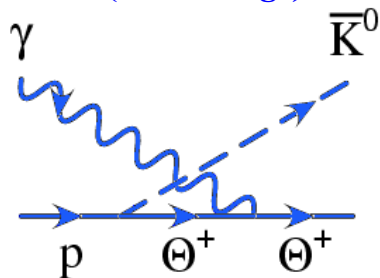
Projected results for
 $E_\gamma < 2.2 \text{ GeV}$
300 events in the $\cos \vartheta_{CM}^{K^0} < -0.35$ range

Sensitivity to different
production mechanisms

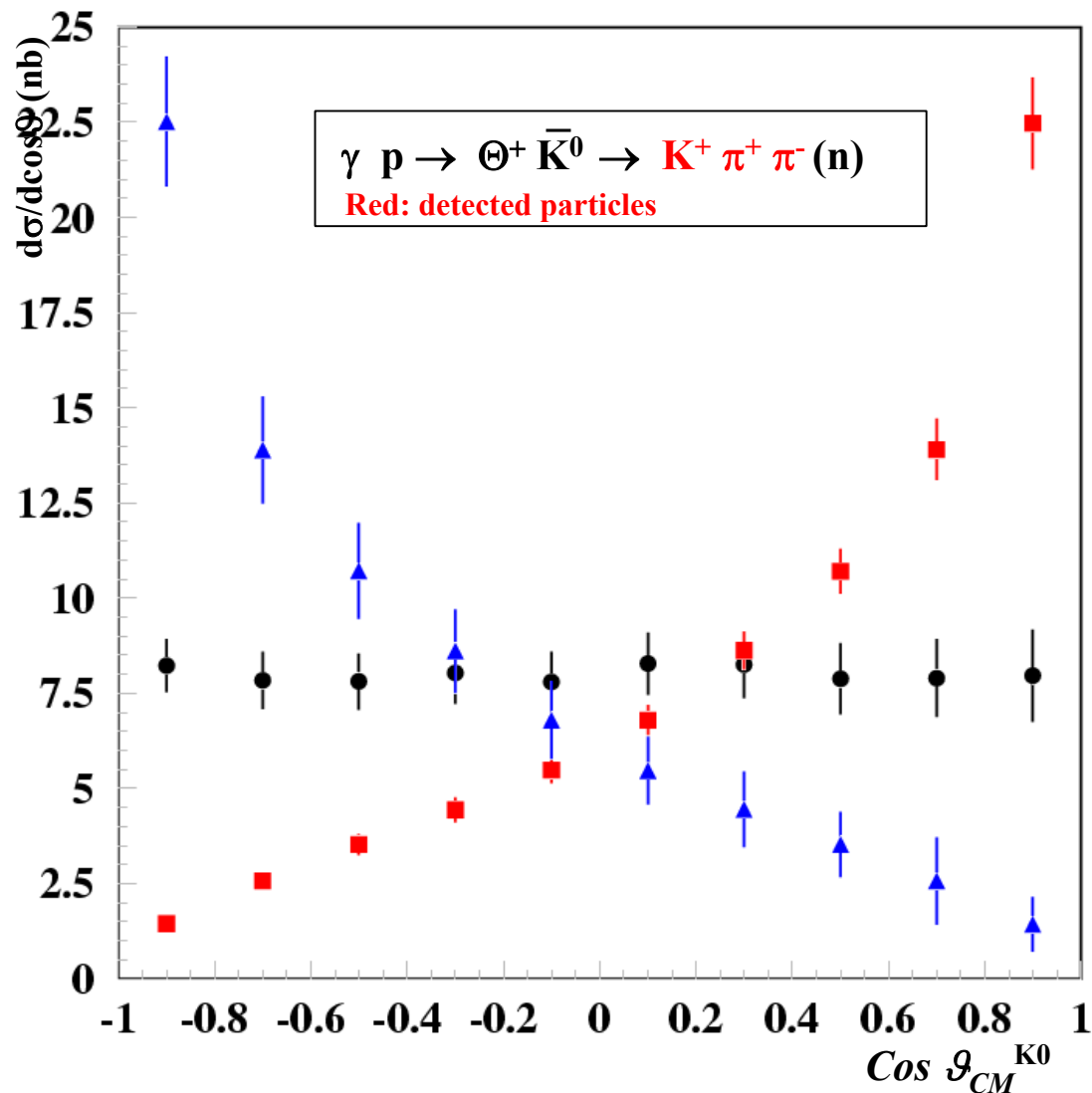
Red = forward production
(*t*-exchange)



Blue = backward production
(*u*-exchange)

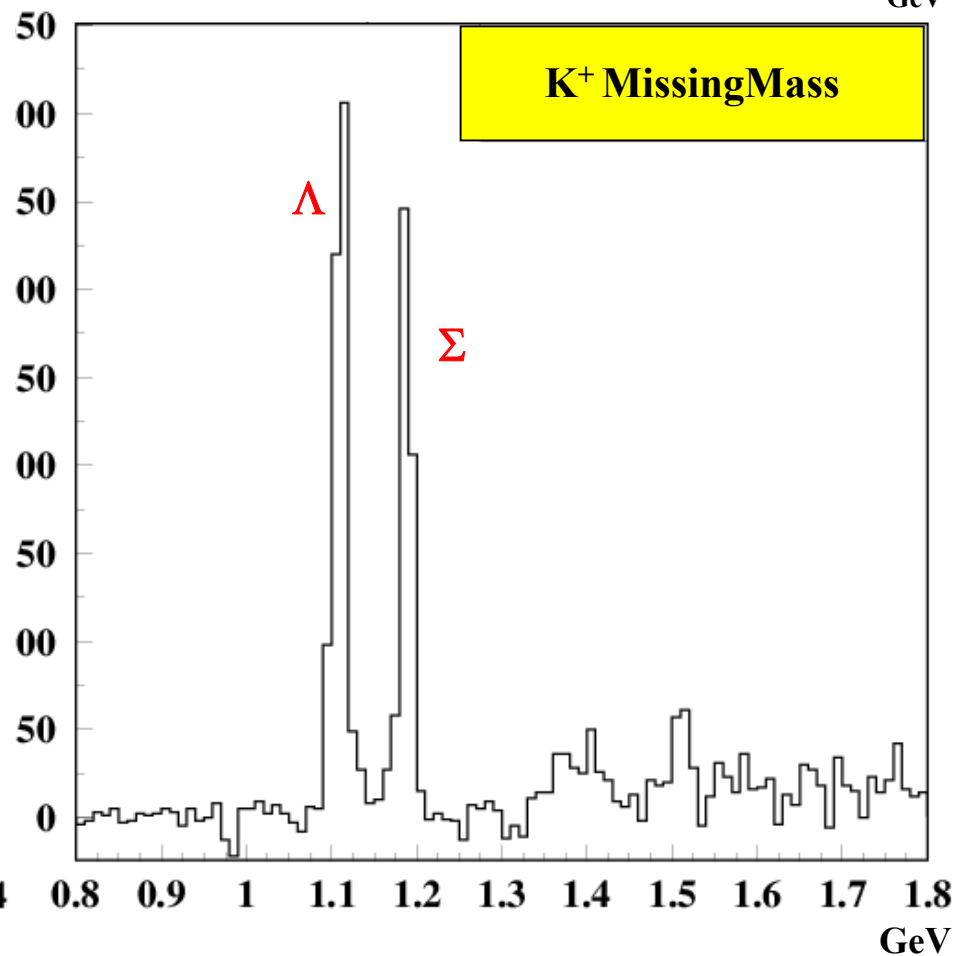
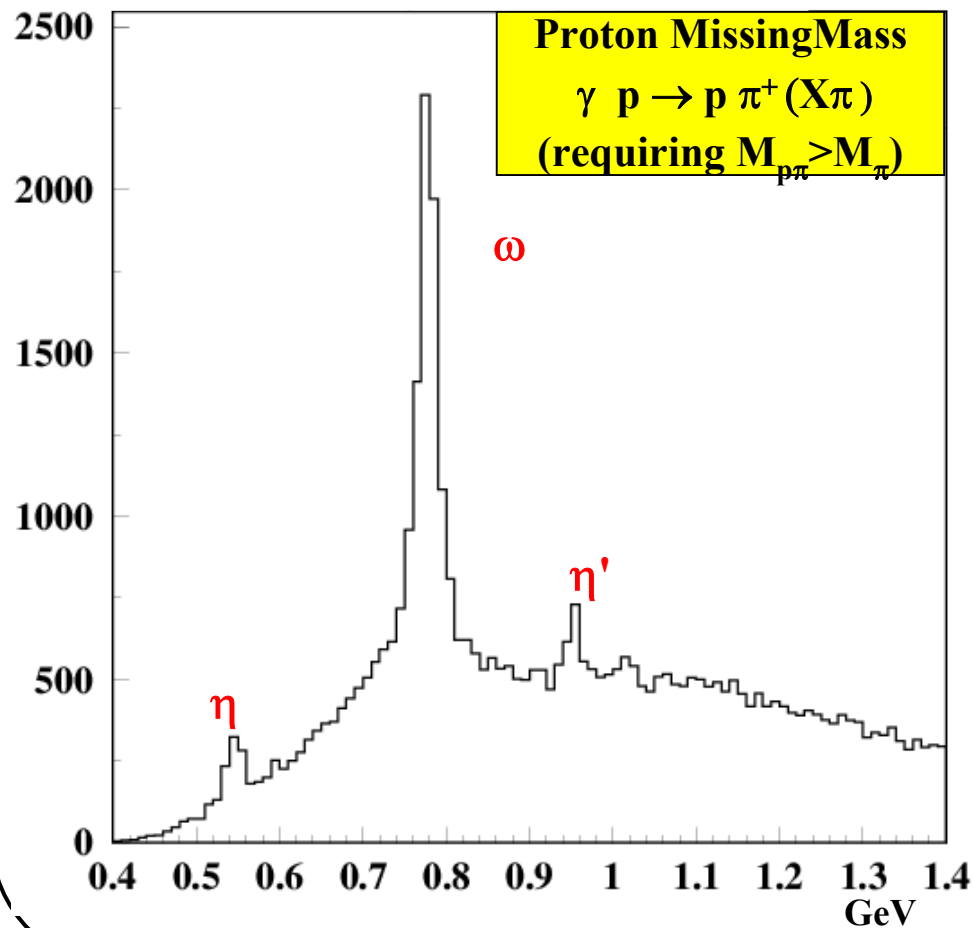
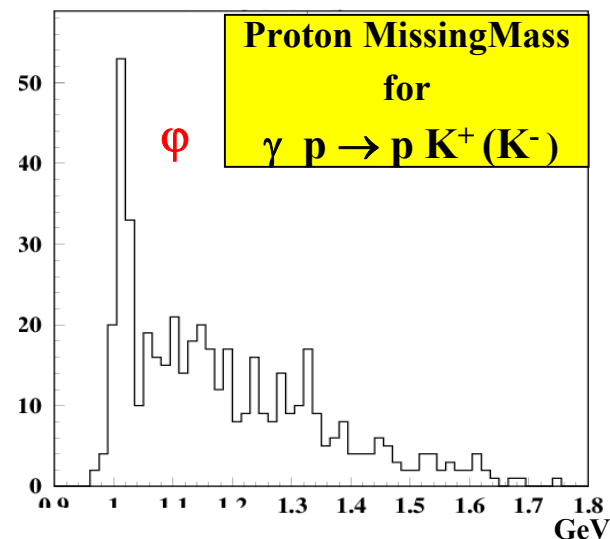


Black = uniform distribution in the cm



First glance at g11 data

Missing mass spectra for 20' of data taking



Conclusions

- ▶ **The CLAS Collaboration is making a significant effort in the search of pentaquark states**
 - ▶ several data sets and reactions channels analyzed
 - ▶ highest significance so far on proton target
 - ▶ other analyses in progress, search of possible excited states and isospin partners
- ▶ **Near term program in pentaquark searches**
 - ▶ firmly establish the existence of the Θ^+ in different reaction channels
 - ▶ determine the Θ^+ mass with accuracy < 2 MeV
 - ▶ confirm/ improve the limit $\Gamma < 8-9$ MeV
 - ▶ search for narrow excited states of the Θ^+
 - ▶ search for isospin partners of the Θ^+
 - ▶ search for other members of antidecuplet