October 20-22, 2005
Jefferson Lab
Newport News, VA USA

Search for pentaquarks in $\gamma\ p \rightarrow\ \Theta^{+}\ \bar{K}^{0}$ in high statistics experiments at CLAS

M. Battaglieri R. De Vita V. Kubarovsky

and the CLAS Collaboration

- **The g11 experiment**
- $\gamma\ p \rightarrow \bar{K}^{0}\ \Theta^{+} \rightarrow \pi^{+}\ \pi^{-}\ K^{+}\ (n)$
- $\gamma\ p \rightarrow \bar{K}^{0}\ \Theta^{+} \rightarrow \pi^{+}\ \pi^{-}\ p\ (K^{0})$ New result!

POSITIVE vs. NEGATIVE

12 (almost-all) 'low-energy' experiments found evidence of a possible pentaquark state

- Different probes/targets
- Different Labs
- Some have high statistical significance

- Structures have few counts in peaks
- Mass difference
- Background shape not known
- Strong cuts to enhance the signal
- Kinematical reflections
- Some of them do not tag Strangeness

10 high-energy experiments did not find any signal

- Production mechanisms?
- Background reactions ?
- Different reactions/kinematics
- Spectra affected by different acceptance

- high statistics
- set upper limit

To solve the controversy about the existence of the $\Theta^+(1540)$ pentaquark is needed definitive confirmation from dedicated low energy experiments

- **high statistics**
- **high resolution**

Search for Pentaquarks at JLab

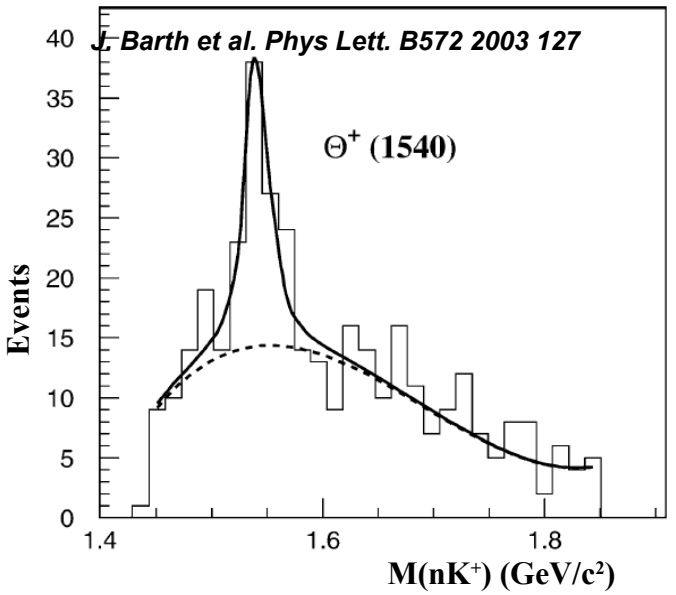
A comprehensive program to search for pentaquarks with high statistics and high resolution electro and photoproduction experiments is in progress at Jefferson Lab

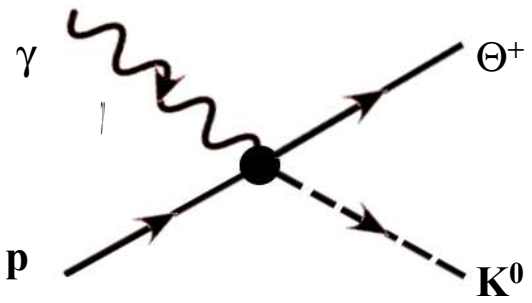
New experiments seeking evidence of pentaquarks in Hall A and B (CLAS) were approved in 2003-2004 with the goal of confirming previous results and explore new kinematics with at least a factor 10 increase in statistics

g10	deuteron	$E_\gamma \sim 1.0\text{-}3.5$ GeV	data taking completed in 2004
g11	proton	$E_\gamma \sim 1.6\text{-}3.8$ GeV	data taking completed in 2004
eg3	deuteron	$E_\gamma \sim 4.0\text{-}5.4$ GeV	data taking completed in 2005
Super-g	proton	$E_\gamma \sim 3.8 - 5.7$ GeV	planned for 2006
HAll-A	proton/deuteron	$E_e \sim 5.0$ GeV	planned for 2006

Θ^+ Search in Exclusive Photoproduction off the proton

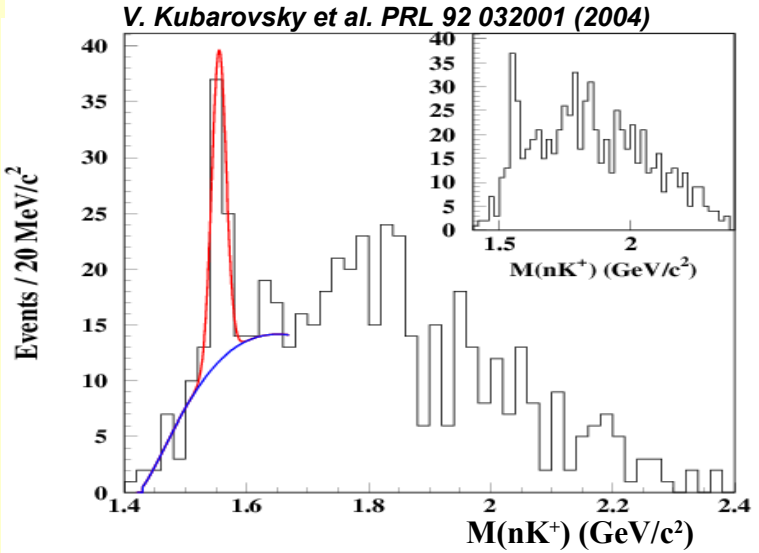
SAPHIR - Bonn

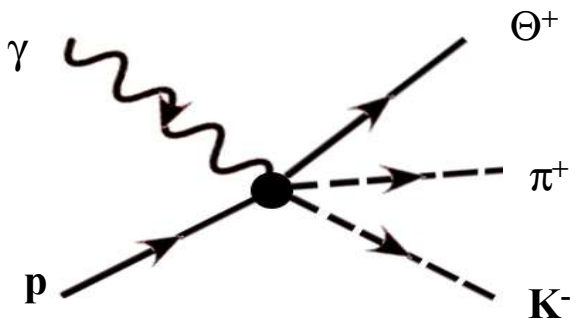




$E_\gamma \sim 1.6\text{-}2.6$ GeV

CLAS - JLab





$E_\gamma \sim 3.0\text{-}5.4$ GeV

To be tested in dedicated experiment (Super-g)

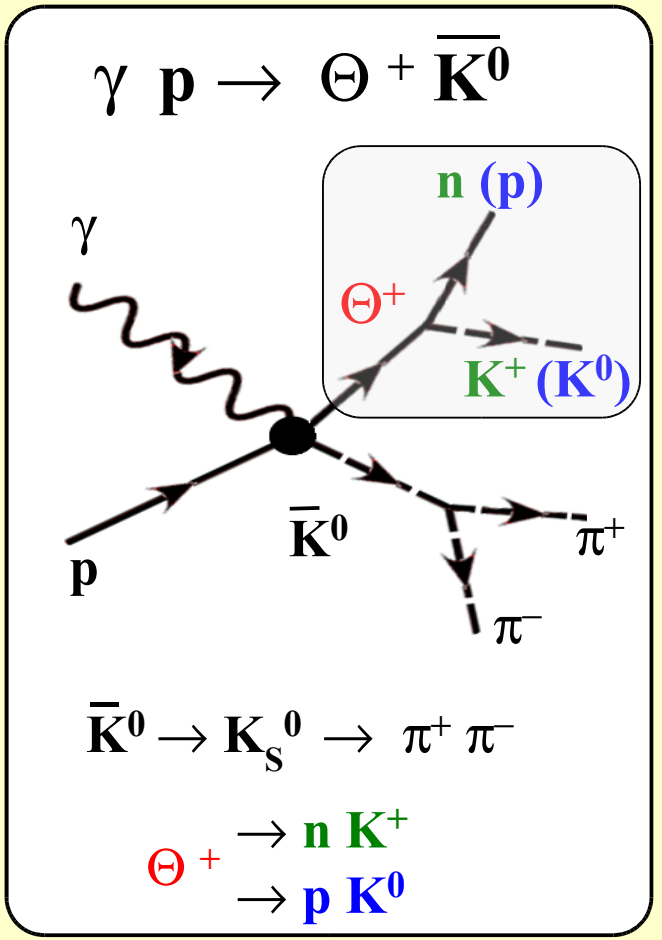
g11@JLab

Spectroscopy of Exotic Baryons with CLAS: Search for Ground and First Excited States

M. Battaglieri R. De Vita V. Koubarovsky
and the CLAS Collaboration

Proposed measurement and Primary Goals:

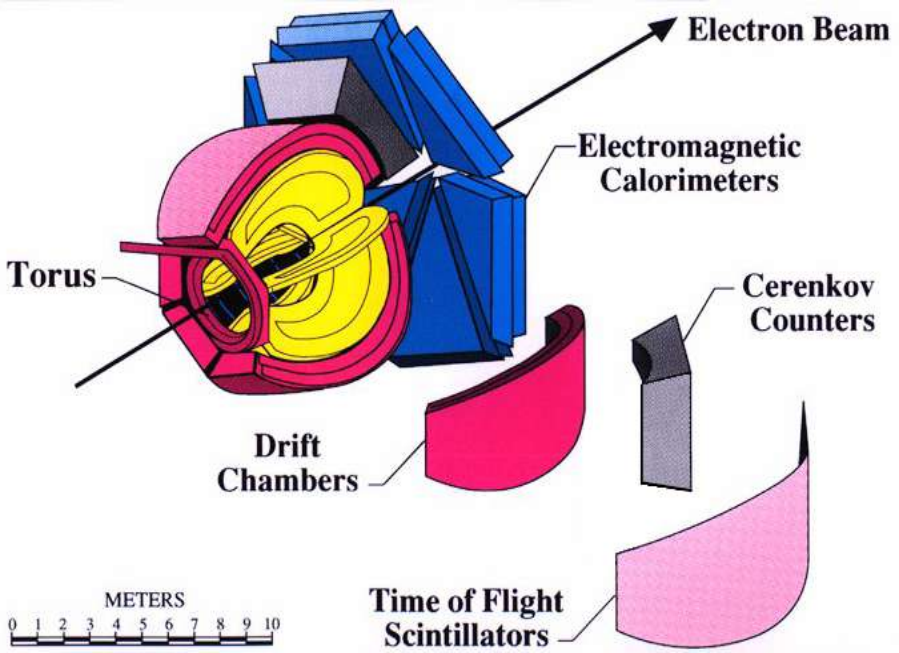
- Search for $\Theta^+(1540)$ and possible excited states in γ-p interaction above threshold (E_γ = 1.6 – 3.8 GeV)
- Collect more than 10 times the statistics of previous measurements in the same kinematics
- Establish the mass of any observed peak with 2 MeV acc.
- Determine total and differential cross section

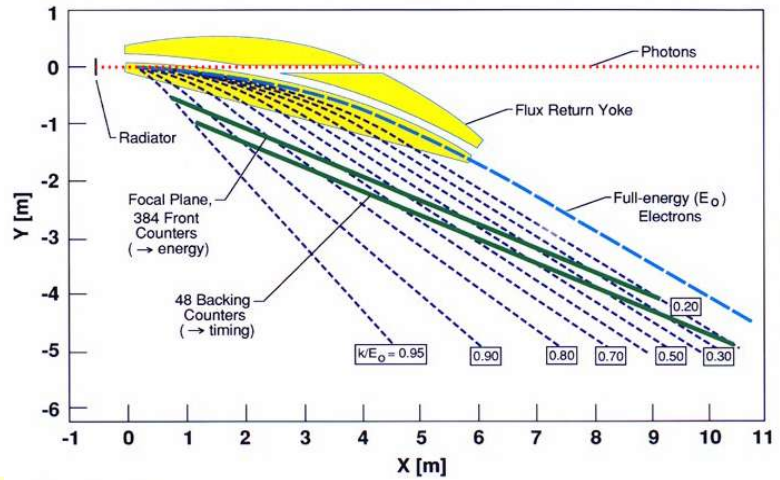


Status of the experiment

- New experiment approved by JLab PAC25 in January 2004
- Run in May-July 2004, with a total of $7 \cdot 10^9$ triggers recorded (Luminosity ~70 pb^{-1})
- Data calibration and processing completed in January 2005
- Results for this reaction

The CEBAF Large Acceptance Spectrometer
CLAS



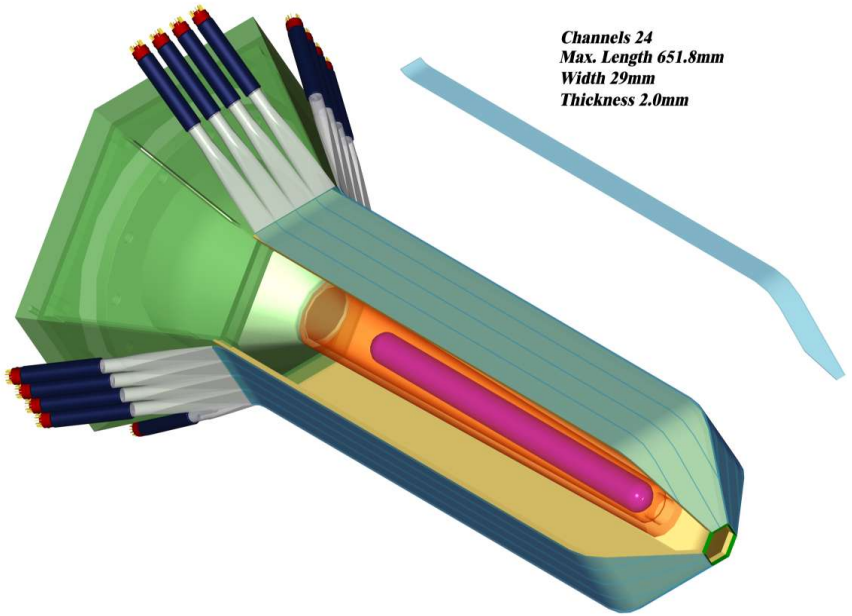


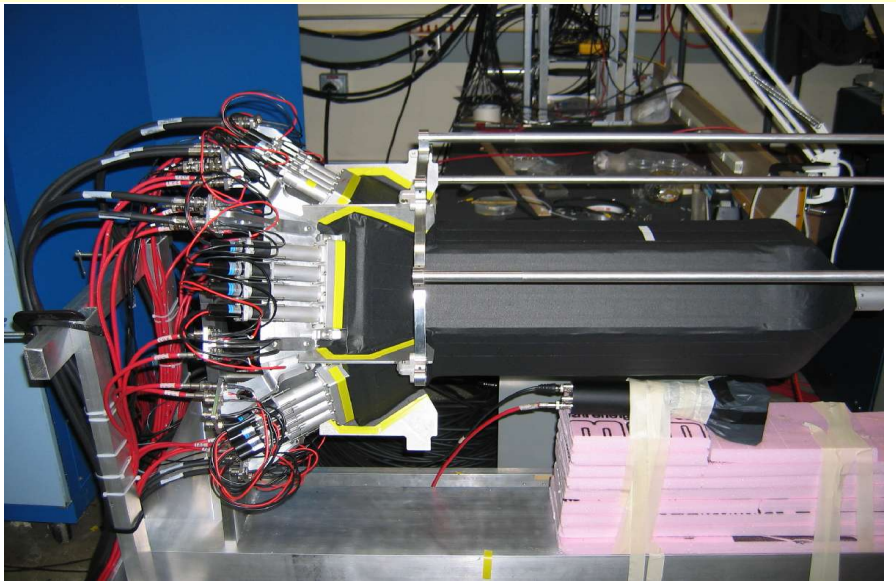
Performance

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

New Equipment For High Luminosity Run

New Start Counter for Vertex Time Reconstruction





New 40 cm Hydrogen Target

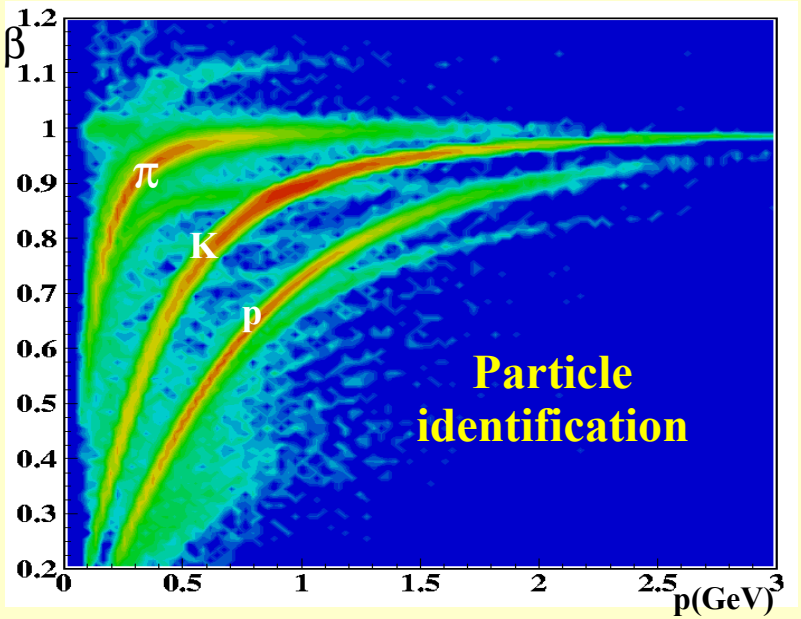
New Target

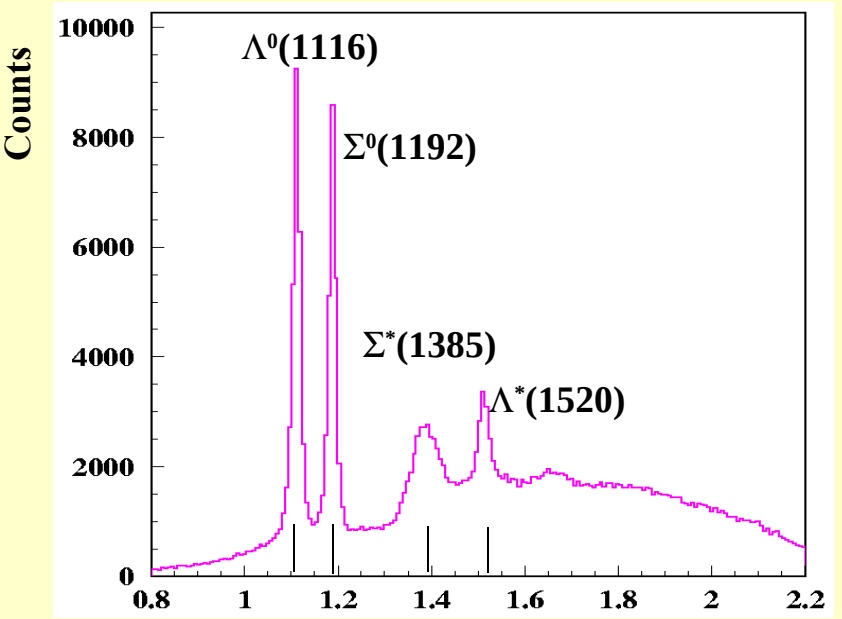
- Extended 40 cm cell
- 40mm radius
- tapered shape to reduce bubbles
- modified beam-pipe

New Start Counter

- Extended target cell coverage (40 cm)
- 2mm thick scintillator + light guide
- Higher azimuthal segmentation (4 x 6)
- Time resolution < 1ns (<300 ps in rec)

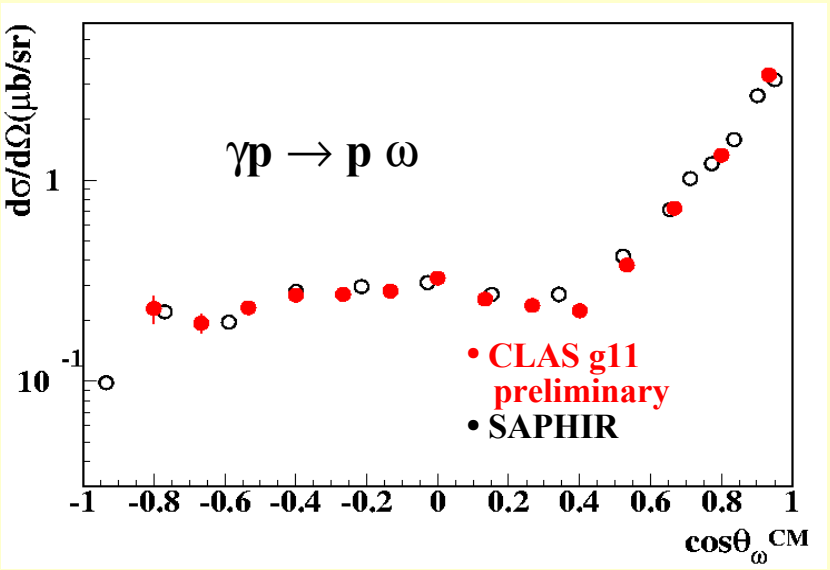
g11 data quality

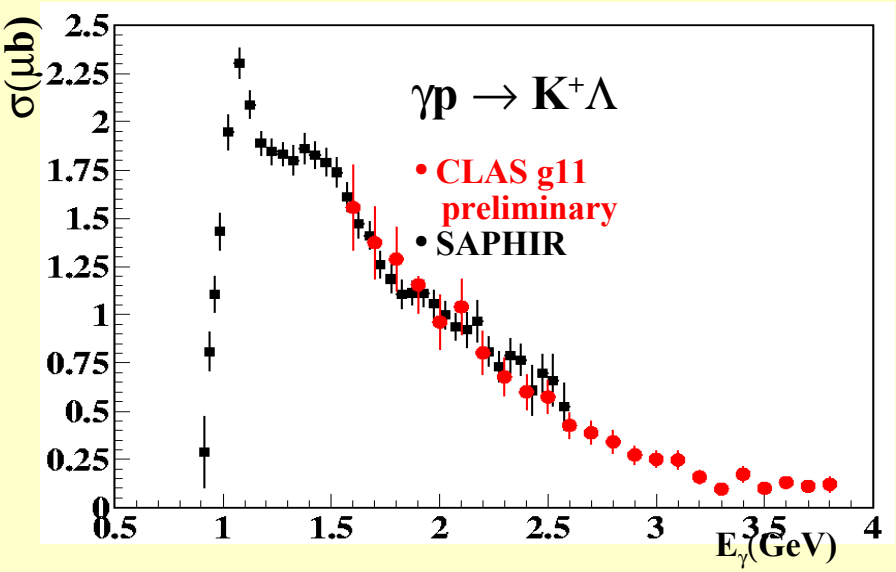




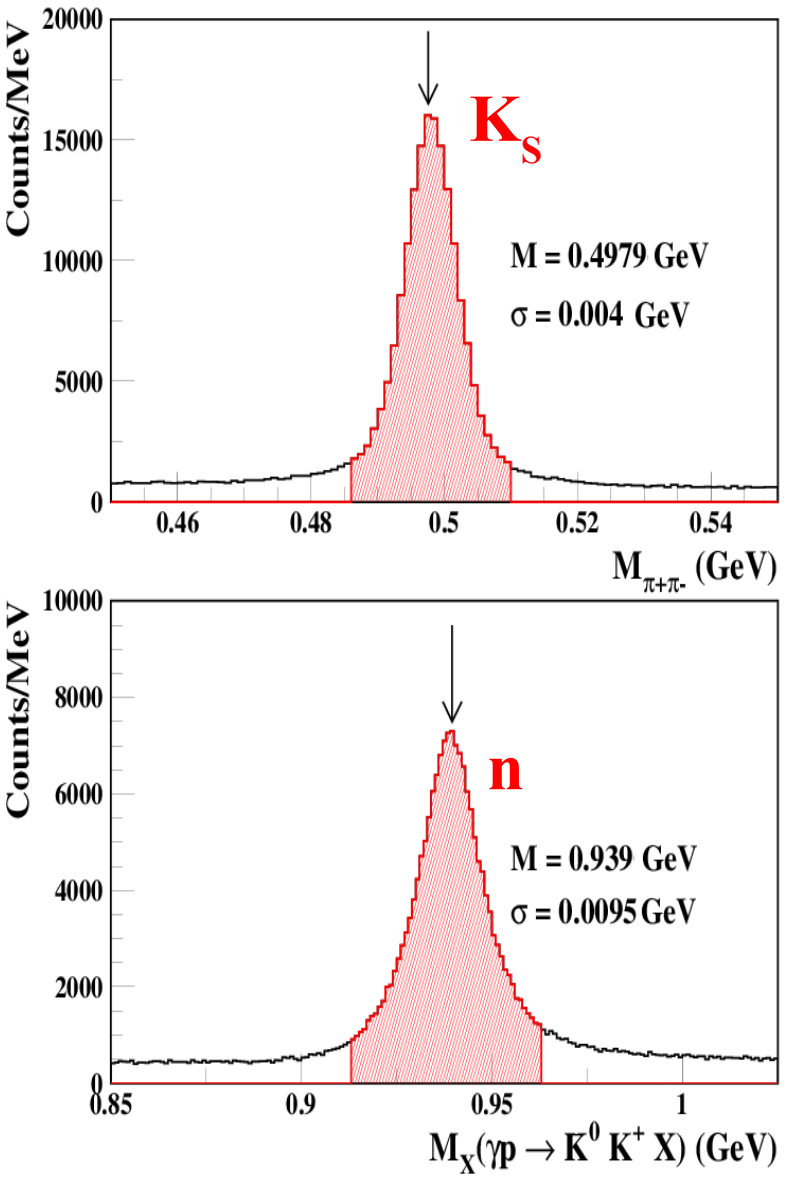
- Different final states are measured simultaneously in the CLAS detector

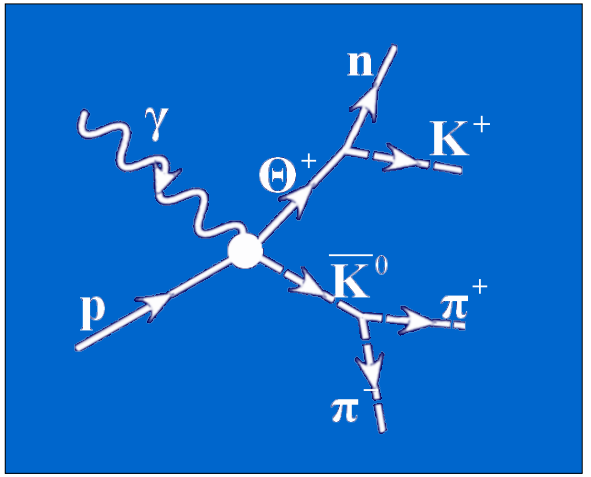
- Cross section for known reactions





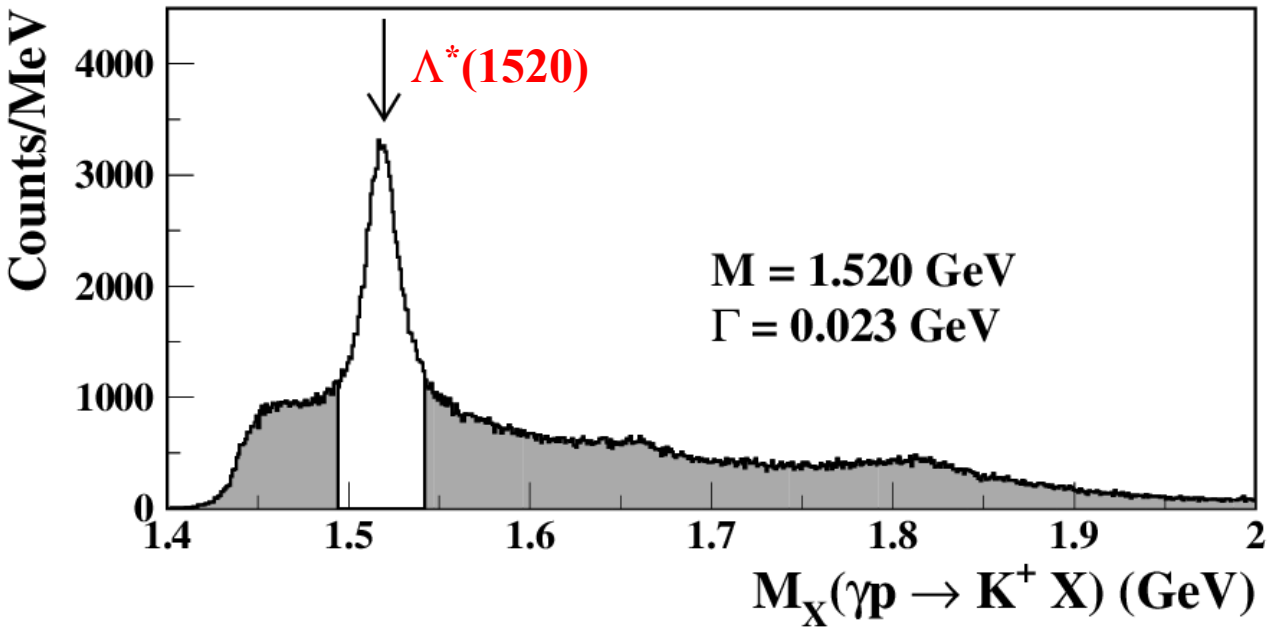
The reaction $\gamma\ p \rightarrow \bar{K}^0\ \Theta^+ \rightarrow \pi^+\ \pi^-\ K^+\ (n)$





- the K^0 is detected via its K_S component decaying into $\pi^+\ \pi^-$
- final state is identified using the missing mass technique
- strangeness is tagged detecting the K^+
- using the full statistics (70 pb^{-1}) a total of ~350K events are selected

★ **Background of known hyperons decayingin the same final state is rejected**

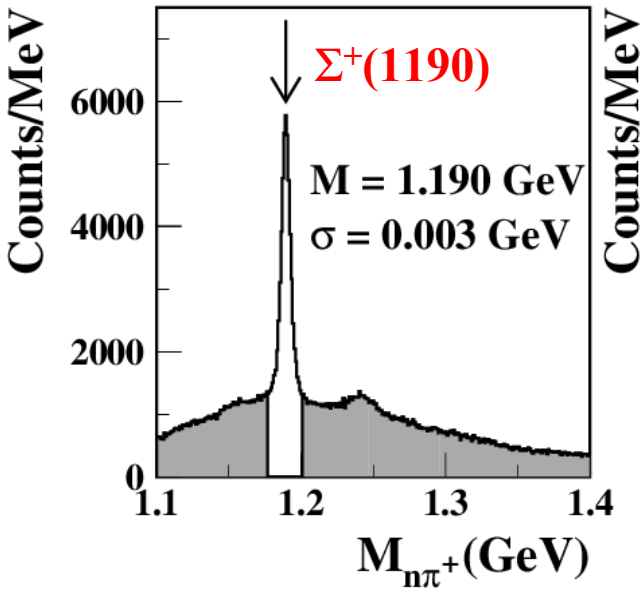


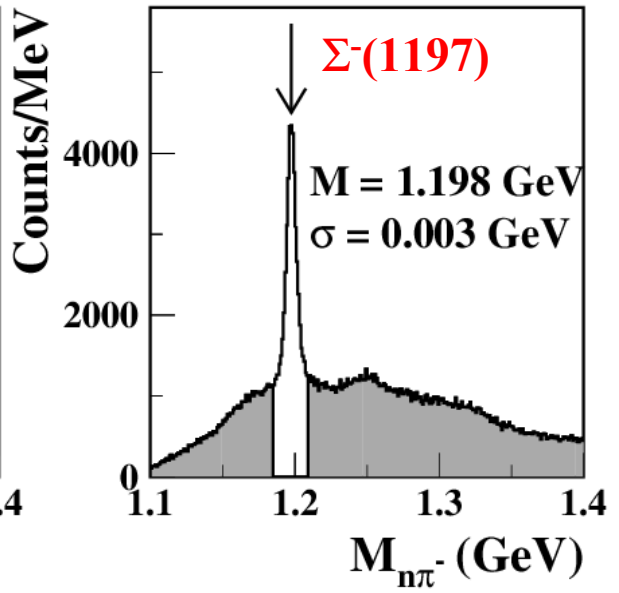
$\gamma\ p \rightarrow \Lambda^*(1520)\ K^+$

$\Lambda^*(1520) \rightarrow n\ K^0$

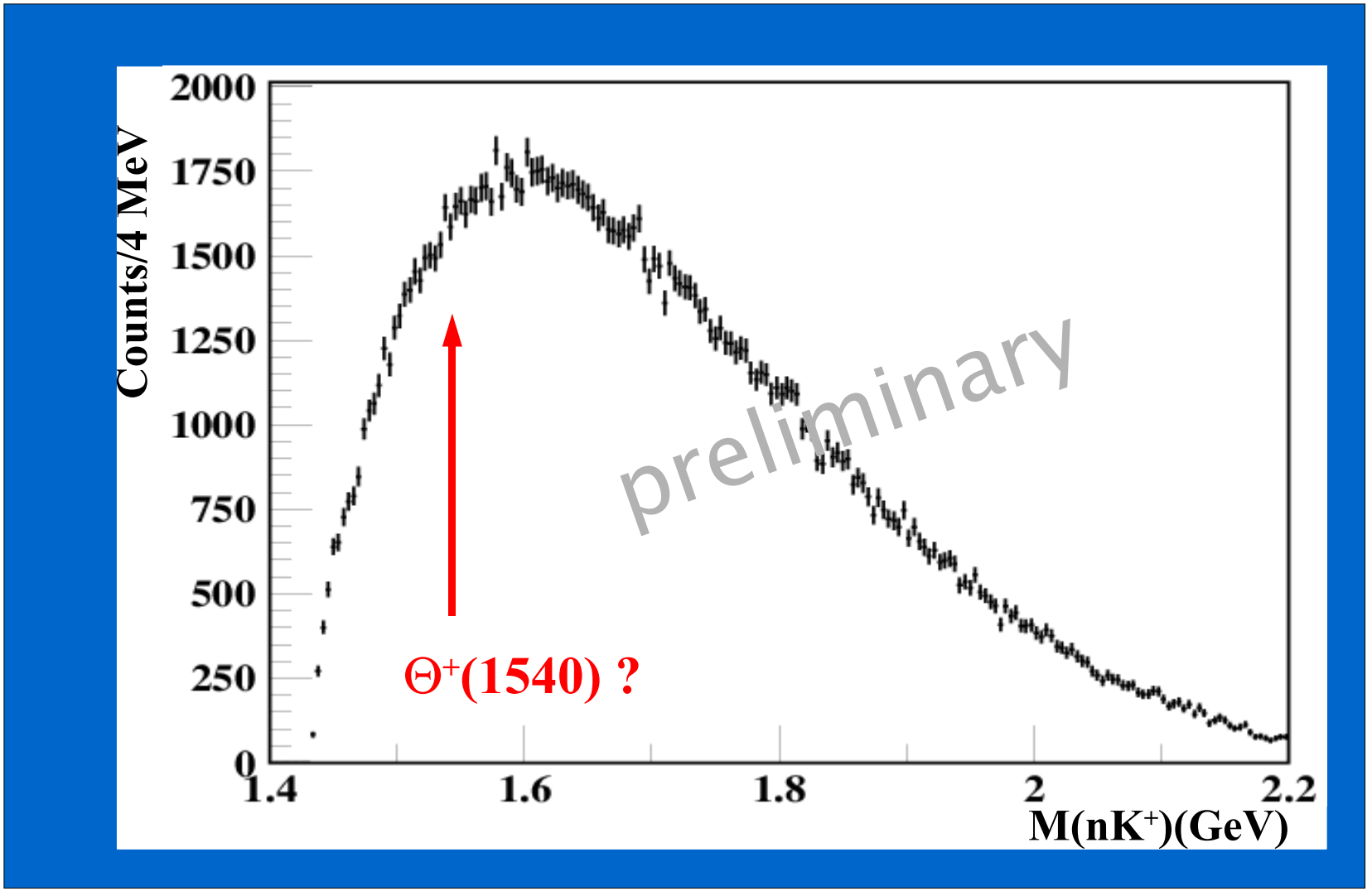
$\gamma\ p \rightarrow \Sigma^{+(-)}\ \pi^{-(+)}\ K^+$

$\Sigma^{+(-)} \rightarrow n\ \pi^{+(-)}$



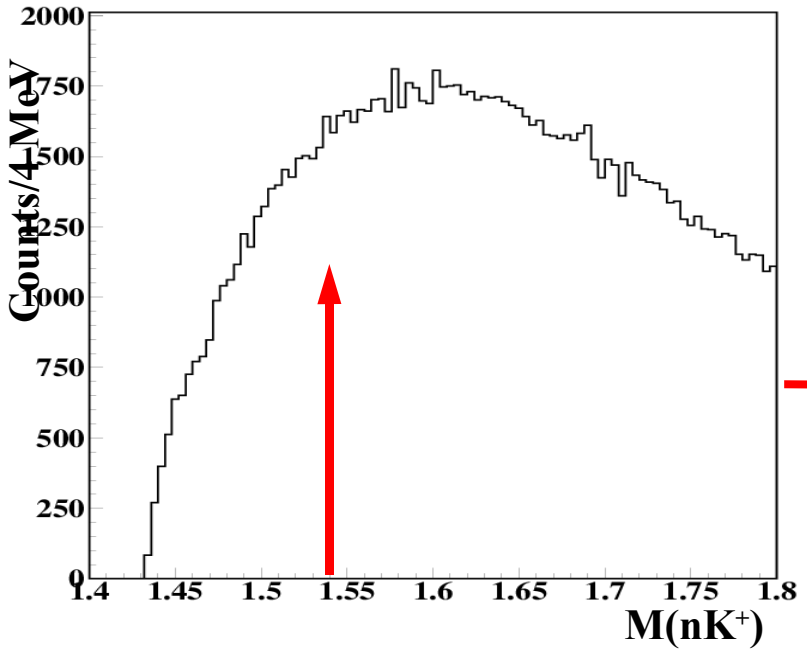


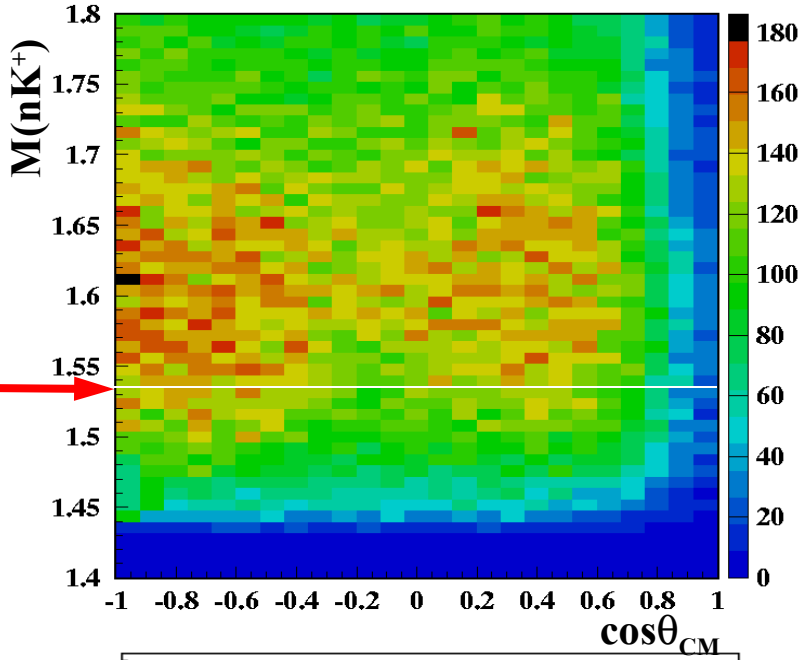
nK^+ Mass Spectrum

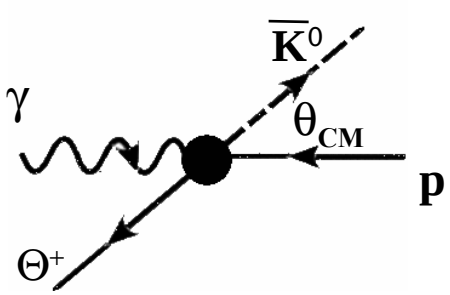


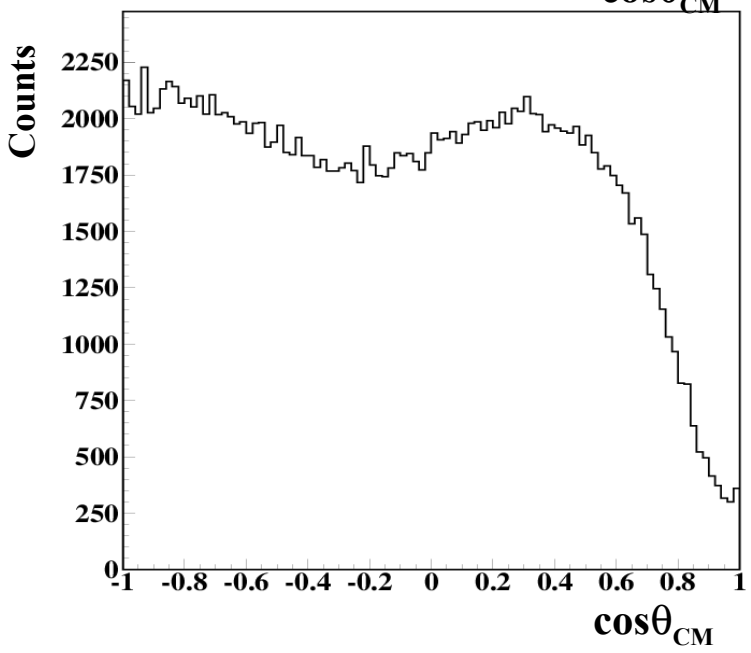
- the nK^+ mass spectrum is smooth
- no structure is observed at a mass of ~1540 MeV

nK^+ Mass Spectrum





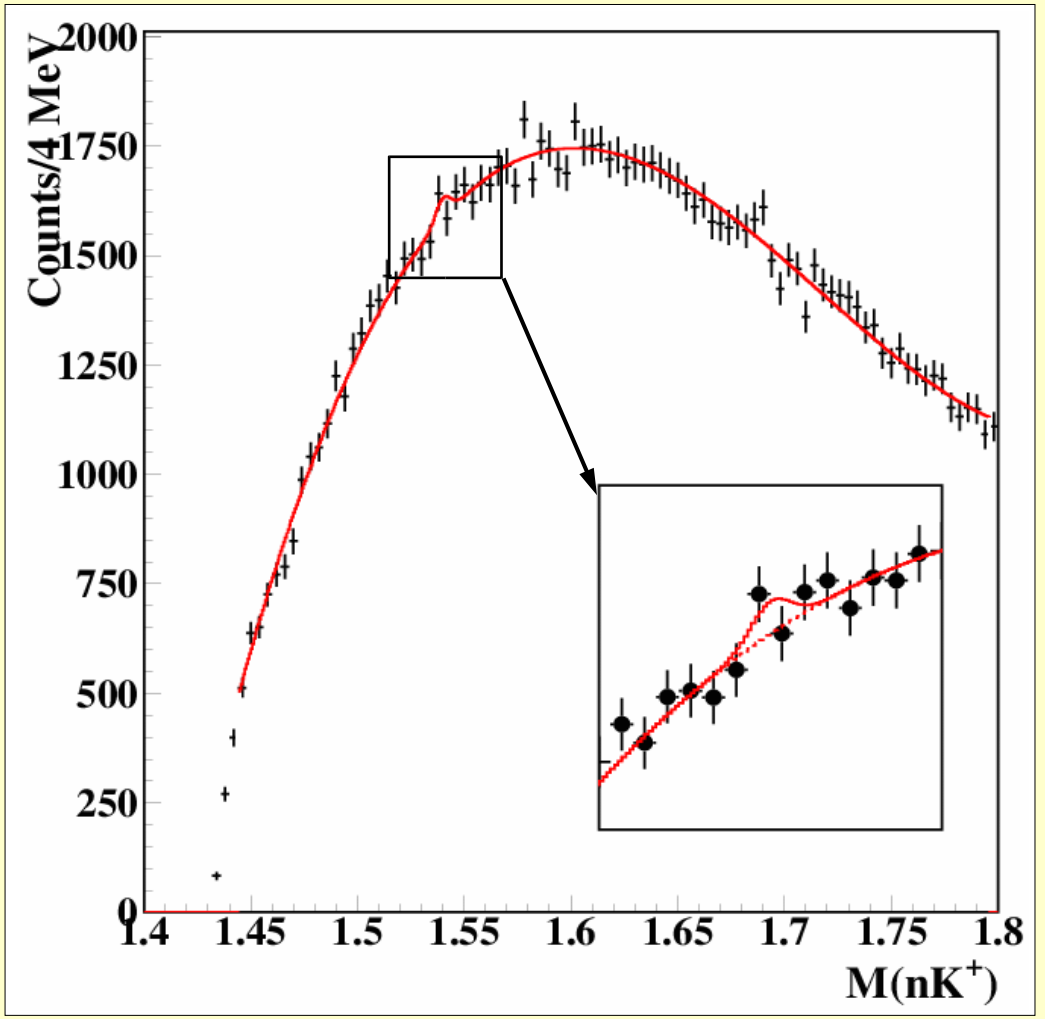




- mass vs. CM angle distribution shows coverage of the whole kinematics
- no evidence for a structure is found for different CM angle ranges

Evaluation of an Upper Limit on the Θ^+ Yield

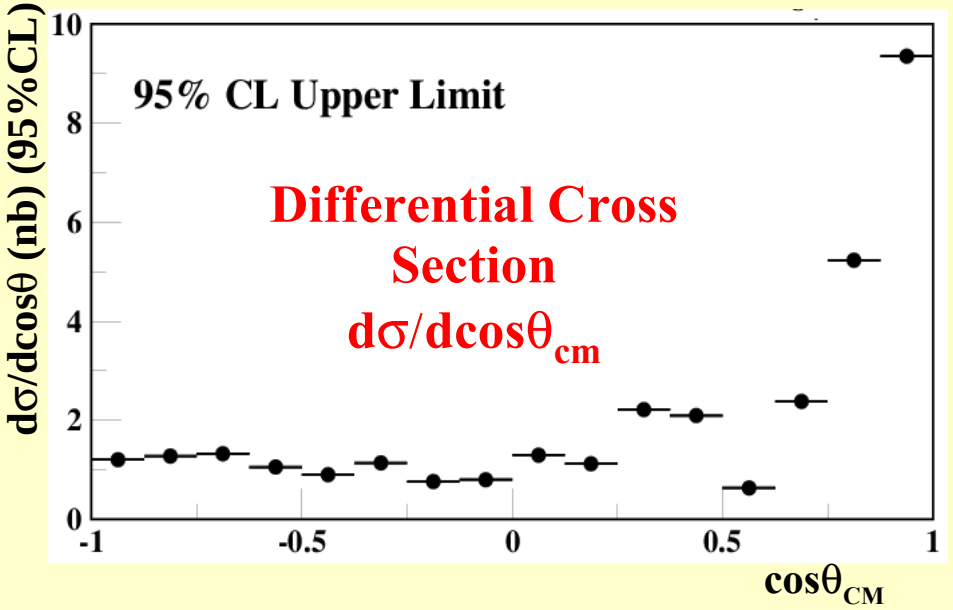
- Θ^+ is searched for as narrow resonance over a smooth background in the (nK^+) spectrum (integrated and in angular bins)
- Resonance width inferred from MC simulations, assuming a negligible intrinsic width
- Signal and background yields extracted fitting: binned/unbinned spectra including/excluding Θ^+ mass region
- M(nK^+) range (1520 - 1600 MeV) scanned in 5 MeV steps
- Upper limit derived using Feldman and Cousins approach

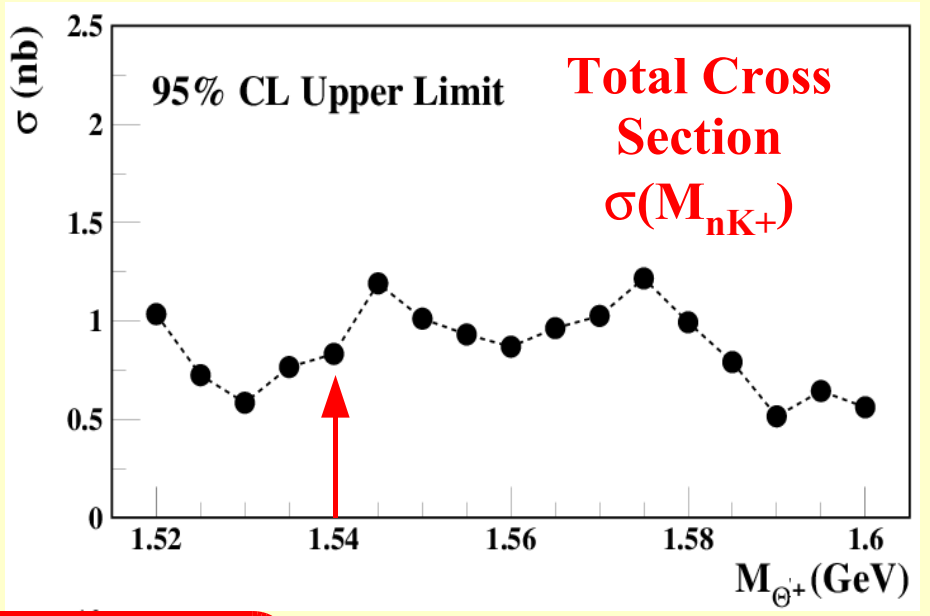


Upper Limit on the $\gamma\ p \to\ \Theta^+\ \bar{K}^0$ Cross Section

$$\sigma(95\%CL) \propto \frac{\text{Yield}(95\%CL)}{\text{efficiency}\ \ \text{luminosity}\ \ BR(\Theta^+ \to nK^+)}$$

- Absolute cross section measurement
- BR ($\Theta^+ \to nK^+$)=50%
- CLAS detection efficiency evaluated using different Θ^+ production models
- Three independent analyses give consistent results





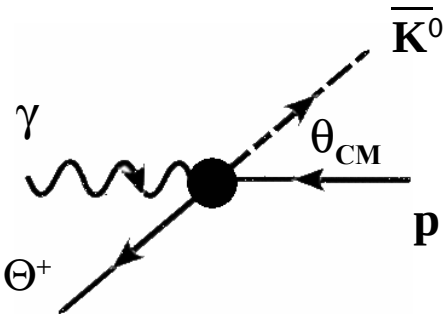
Upper limit (95% CL)

$$\sigma_{\gamma p \to \Theta^+ K^0} < 0.5 - 1.2\ \text{nb}$$

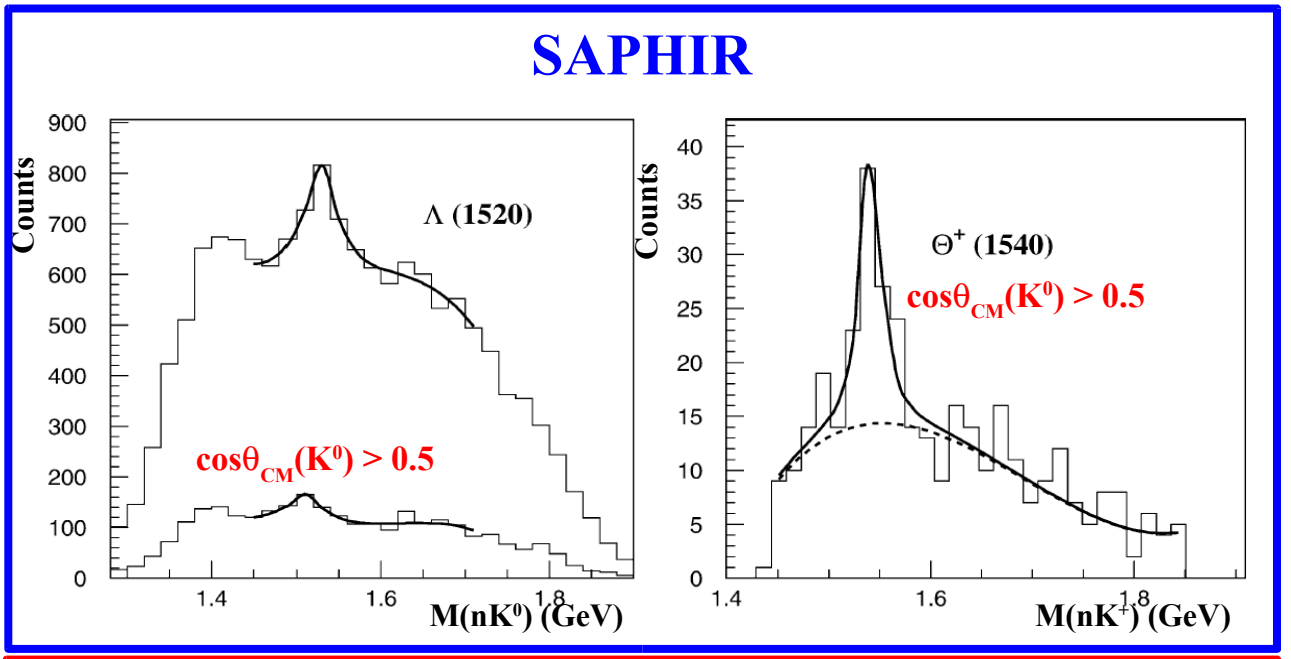
Comparison with SAPHIR results

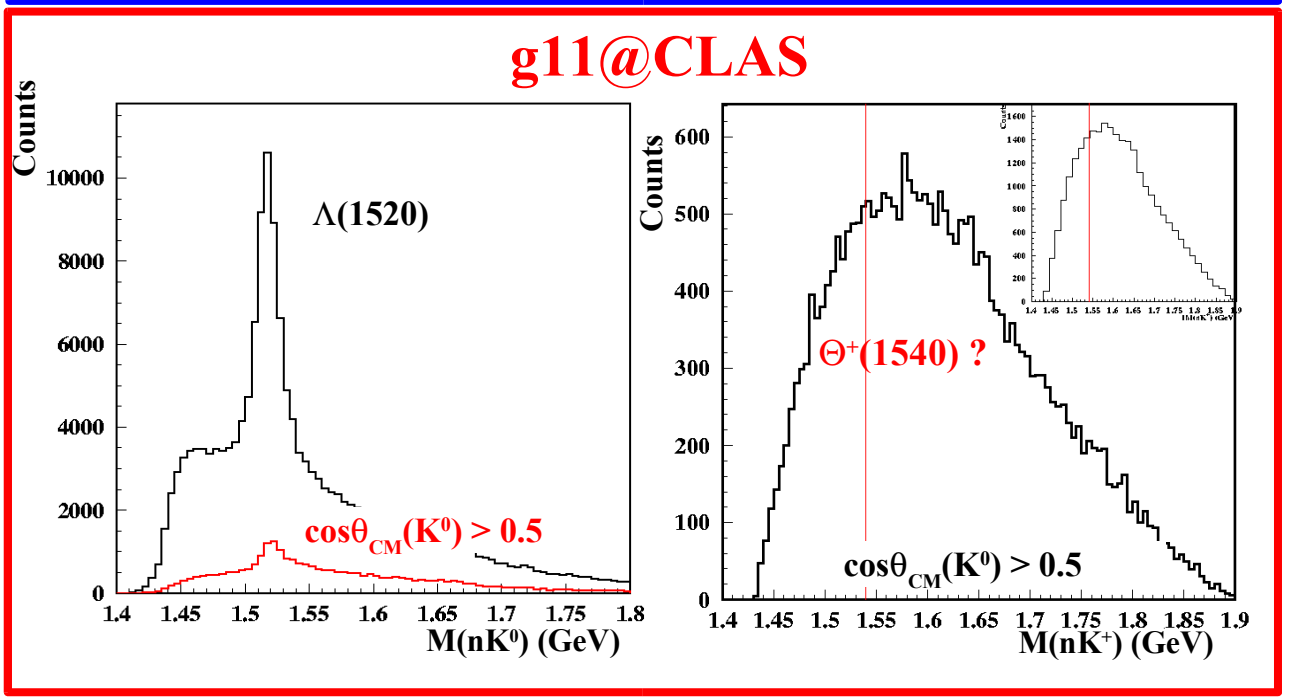
Kinematics

- Selection of forward angles of the K^0 in the γ–p center of mass



- Energy limited to 2.6 GeV
- no hyperon rejection





Comparison with SAPHIR results

Observed Yields

SAPHIR

$N(\Theta^+)/N(\Lambda^*) \sim 63/630 \sim 10\%$

CLAS

$N(\Theta^+)/N(\Lambda^*) < 100/53000 < 0.2\%$ (95%CL)

Cross Sections

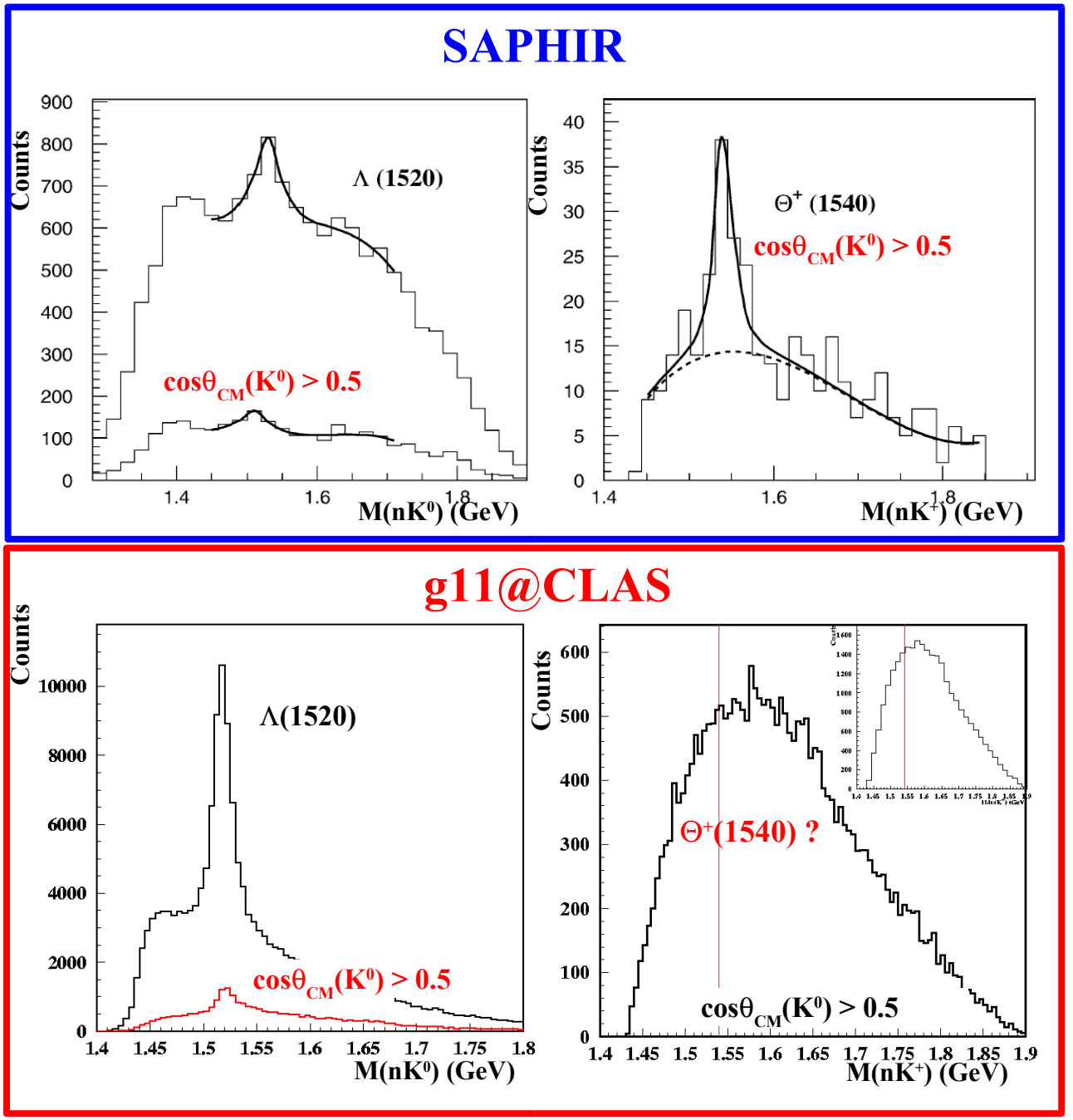
SAPHIR

$\sigma_{\gamma p \to \Theta^+ K^0} \sim 300$ nb

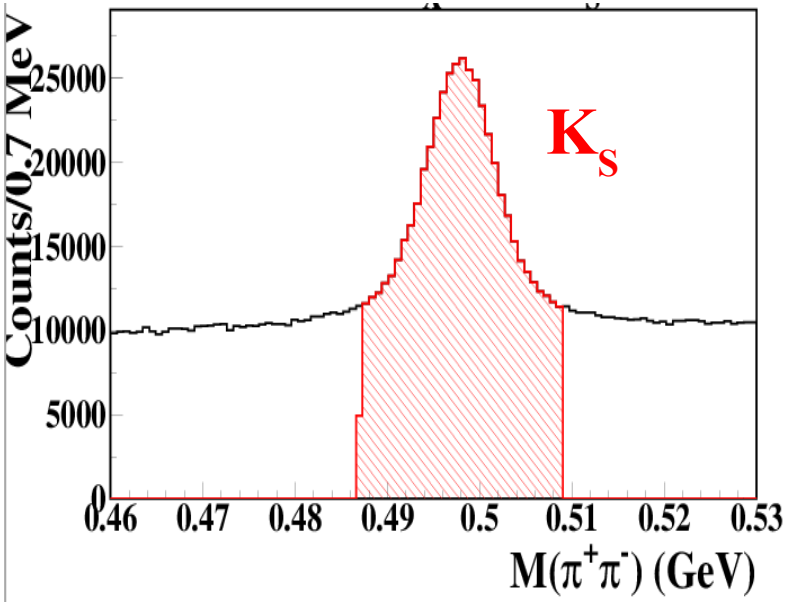
reanalysis 50 nb

CLAS

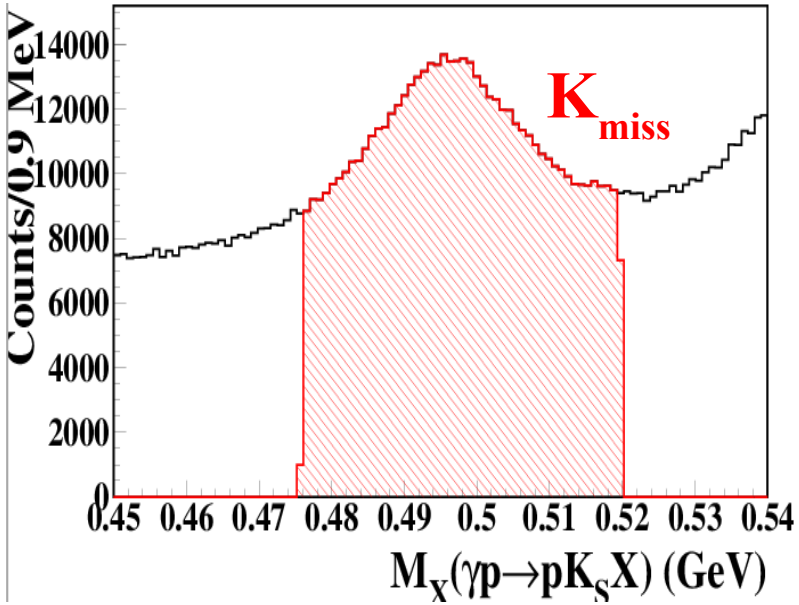
$\sigma_{\gamma p \to \Theta^+ K^0} < 0.8$ nb



The reaction $\gamma\ p \rightarrow \bar{K}^0\ \Theta^+ \rightarrow \pi^+\ \pi^-\ p\ (K^0)$



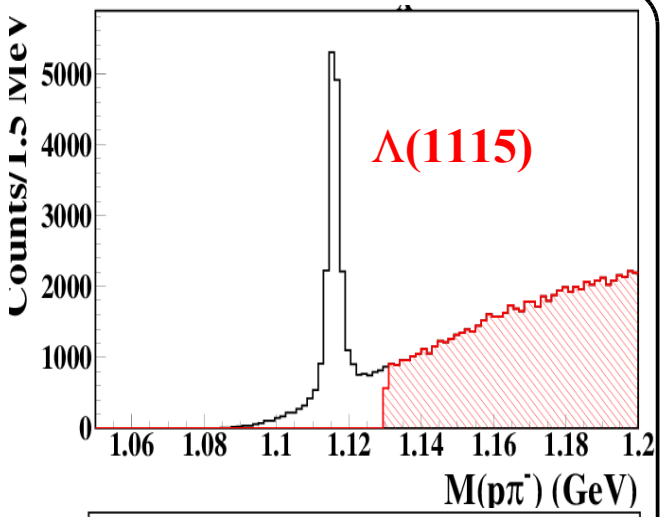
- one K^0 is detected via its K_S component decaying into $\pi^+\ \pi^-$
- final state is identified using the missing mass technique
- Detected K_S can be either from the Θ^+ decay or from the $\bar{K}^0$



- Background of known hyperons decaying in the same final state is rejected

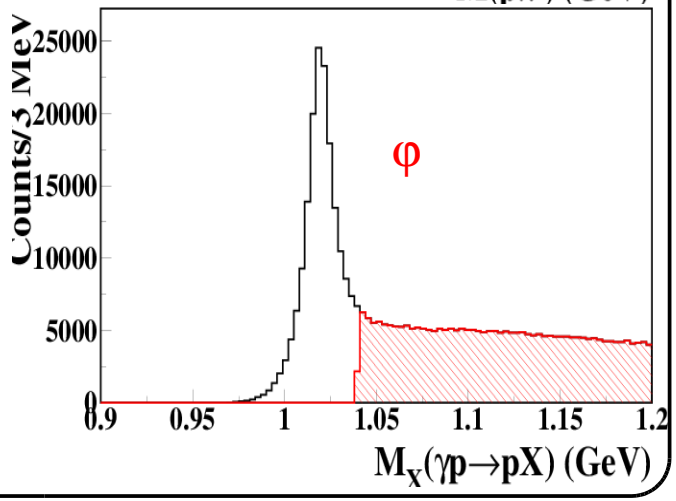
$\gamma\ p \rightarrow \Lambda(1115)\ \pi^+\ X$

$\Lambda \rightarrow p\ \pi^-$



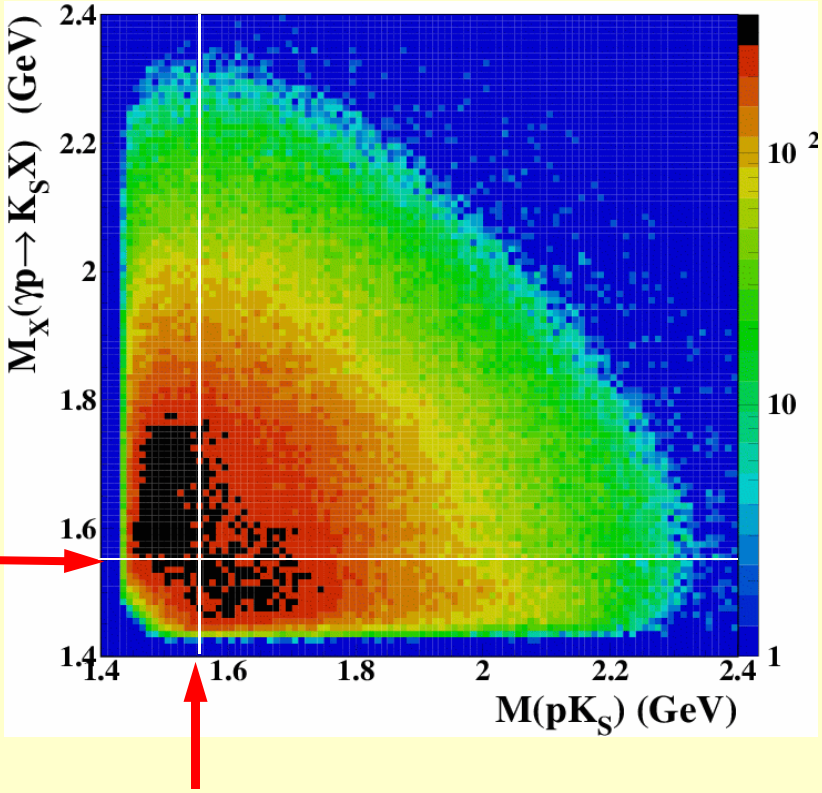
$\gamma\ p \rightarrow p\ \varphi$

$\varphi \rightarrow K_L\ K_S$



Θ^+ should show up in measured and missing K^0 spectra

- pK_S Invariant Mass
- K_S Missing Mass



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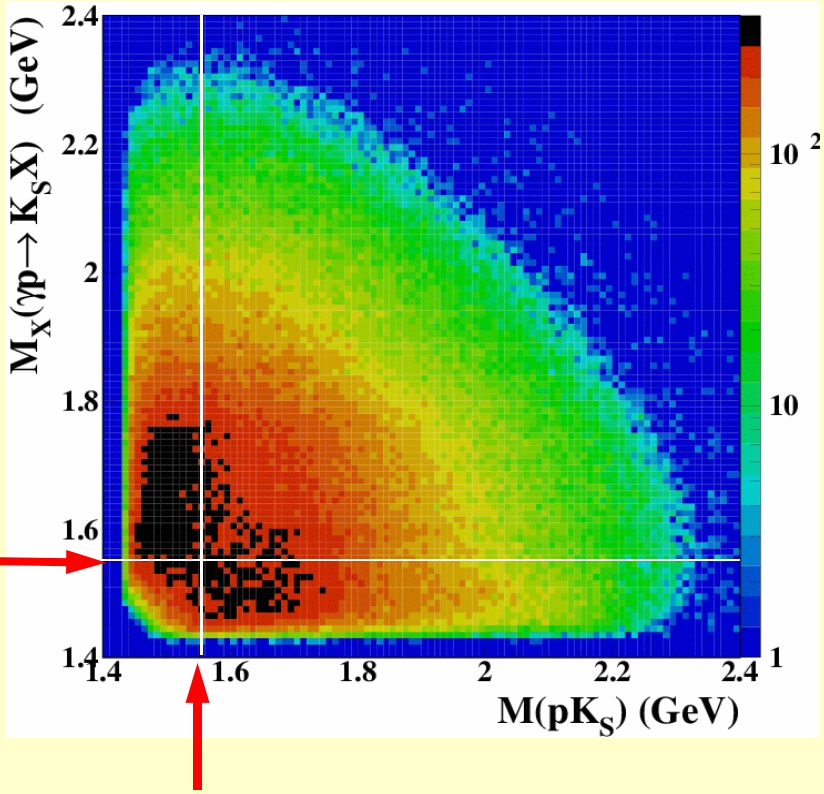
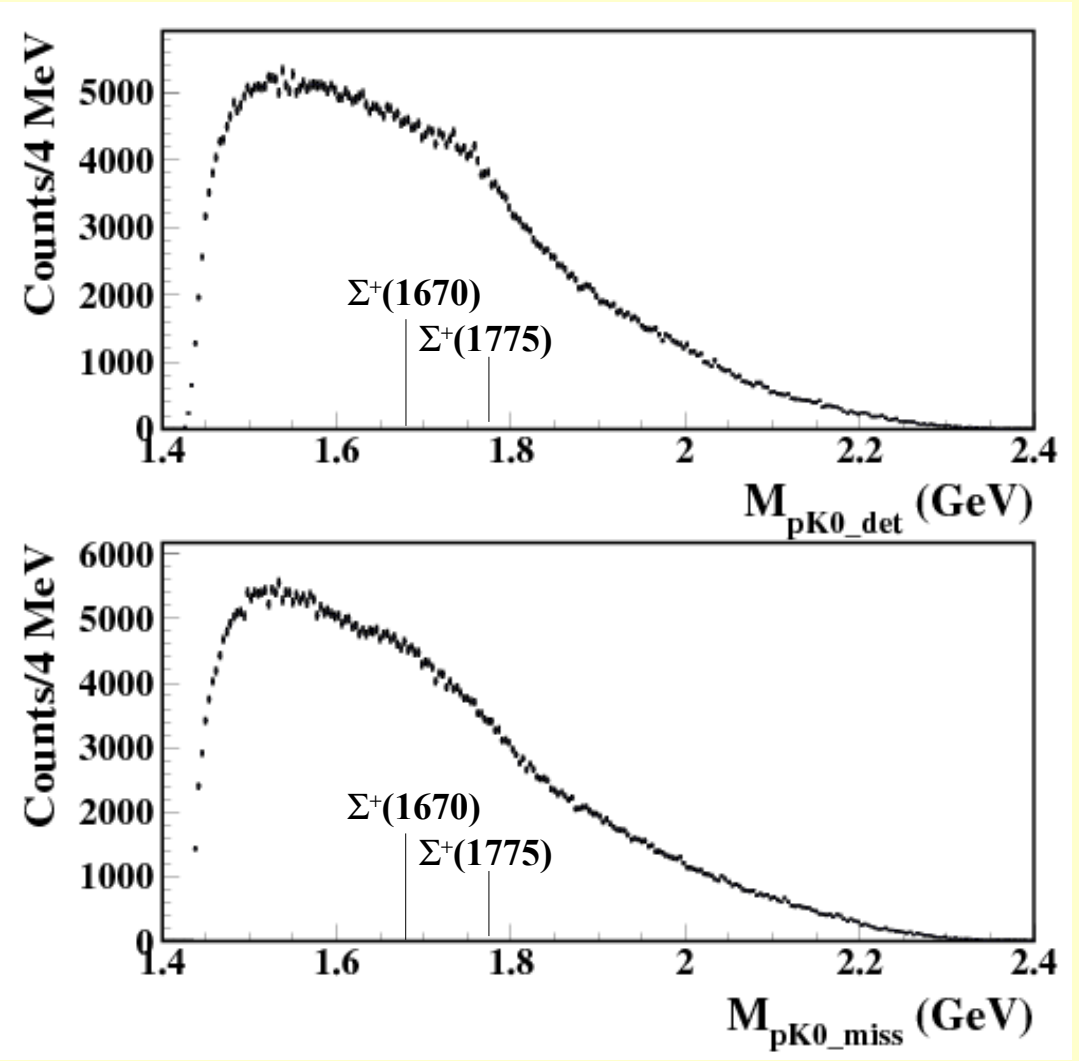
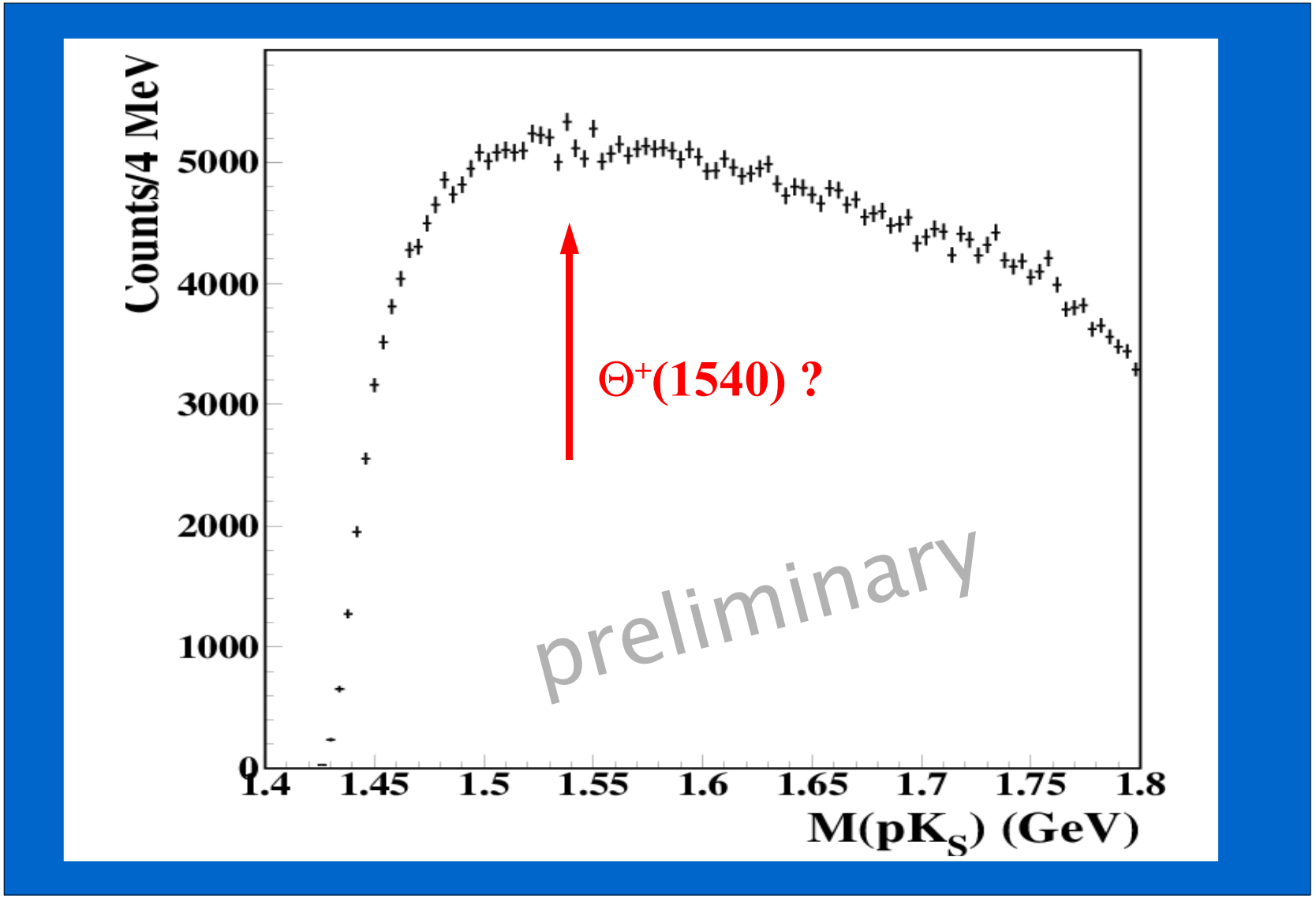




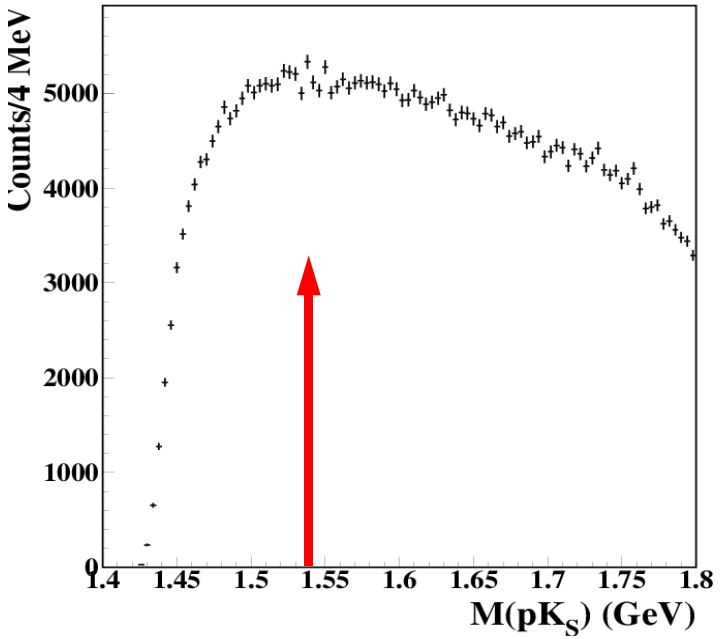
- Events corresponding to the two projections can be considered almost independent and combined together doubling the statistics
- We only show upper limits derived from pK_S Invariant mass spectrum

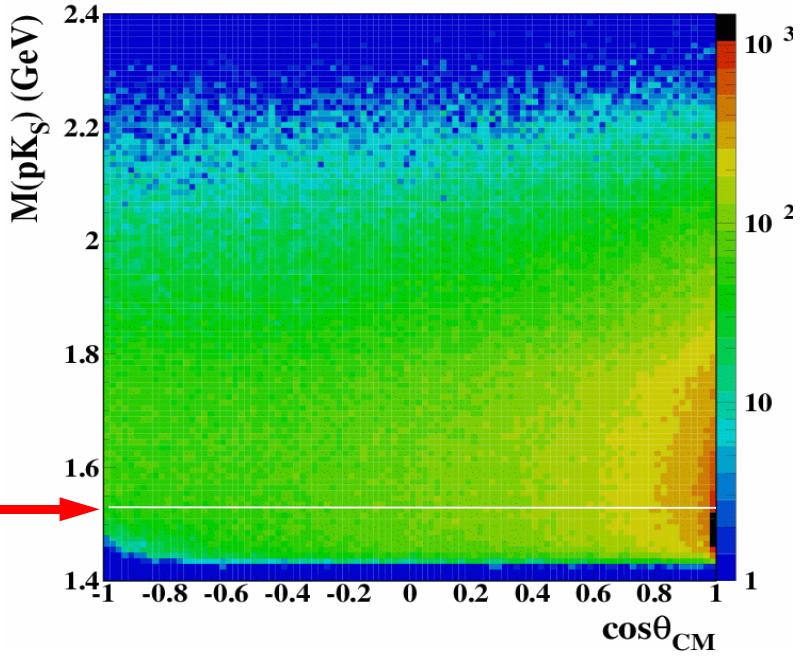
pK_S Mass Spectrum

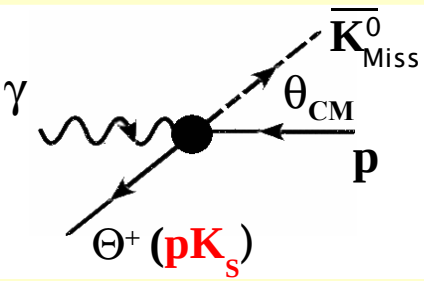


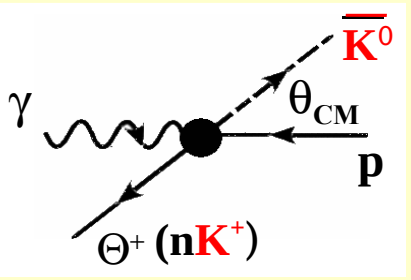
- the pK_s mass spectrum is smooth
- no structure is observed at a mass of ~1540 MeV

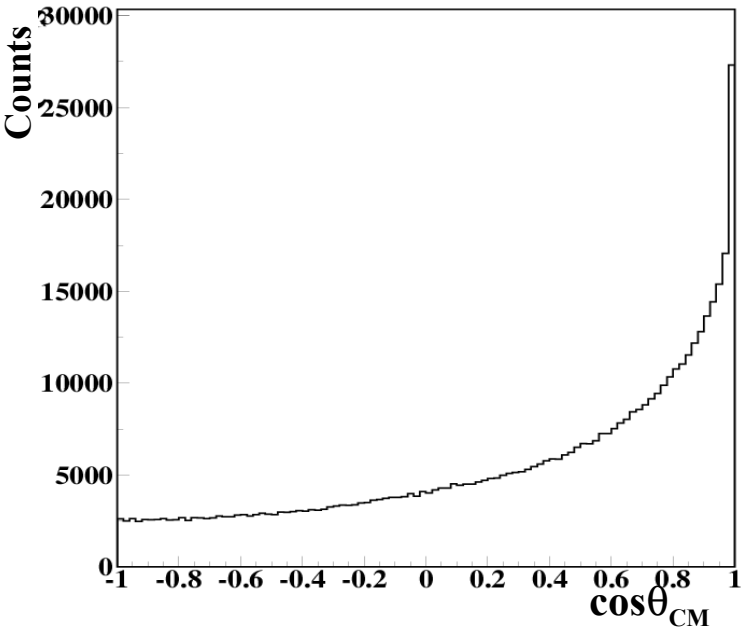
pK_S Mass Spectrum









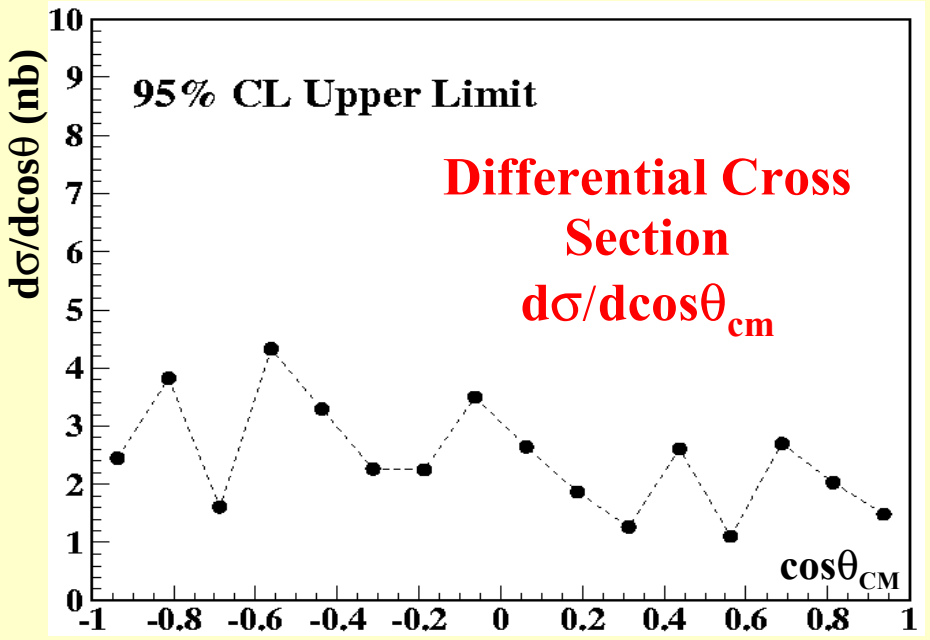


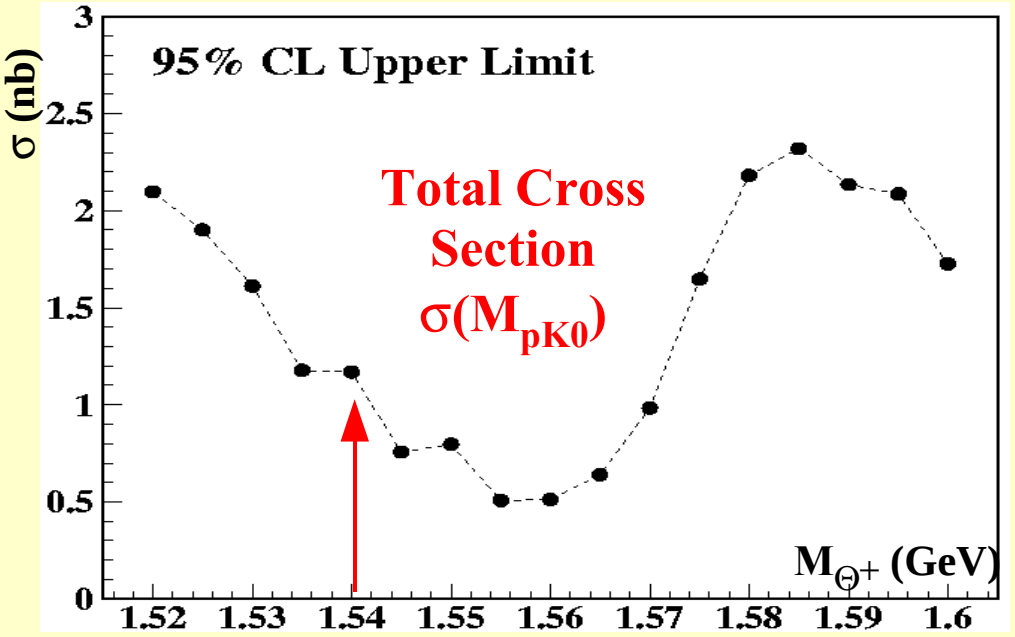
- Kinematics complementary to the other decay mode ($\Theta^+ \rightarrow K^+ n$)
- mass vs. CM angle distribution shows coverage of the whole kinematics (especially at forward angles)

Upper Limit on the $\gamma\ p \to\ \Theta^+\ \bar{K}^0$ Cross Section

$$\sigma(95\%CL) \propto \frac{\text{Yield}(95\%CL)}{\text{efficiency}\ \ \text{luminosity}\ \ BR(\Theta^+ \to pK^0)}$$

- Absolute cross section measurement
- BR ($\Theta^+ \to pK^0$)=50%
- CLAS detection efficiency evaluated using different Θ^+ production models





Flat UL differential xsec

UL (95% CL) $\sigma_{\gamma p \to \Theta^+ K^0} < 1 - 2$ nb

Upper limit on Γ_{Θ^+} from CLAS Results

S.Stepanian - V.Burkert

Theoretical cross section are for Γ_{Θ^+}=1 MeV

Publication	Reaction	J^π				Experimental width
		$1/2^-$	$1/2^+$	$3/2^-$	$3/2^+$	Γ_{Θ^+}
M. Guidal et al.,	$\gamma p \to \bar{K}^0\Theta^+$	0.01nb	0.22nb			**<3.6 MeV**
hep-ph/0507180	$\gamma n \to K^-\Theta^+$	0.2nb	1nb	55nb	10nb	< 4 MeV
S. Nam et al.,	$\gamma p \to \bar{K}^0\Theta^+$		(2.7)nb	8nb	(1)nb	**<0.3 MeV**
hep-ph/0505134	$\gamma n \to K^-\Theta^+$		2.7nb	200nb	25nb	< 1.7 MeV
Y. Oh et al., NP A745	$\gamma p \to \bar{K}^0\Theta^+$	~0.4nb	~1.6(100)nb			**<0.5 MeV**
hep-ph/0412363	$\gamma n \to K^-\Theta^+$	~1.7nb	~8.7(75)nb			< 0.5 MeV
C.M. Ko and W. Liu	$\gamma p \to \bar{K}^0\Theta^+$		15(30)nb			**<0.05 MeV**
nucl-th/0410068	$\gamma n \to K^-\Theta^+$		15(30)nb			< 0.25 MeV
W. Roberts	$\gamma p \to \bar{K}^0\Theta^+$	2nb	5.2(~10)nb	15.4nb	1.8nb	**<0.15 MeV**
nuc-th/0408034	$\gamma n \to K^-\Theta^+$	3.5nb	11.2(~20)nb	48nb	4.nb	< 0.4 MeV

( ) – with K* exchange

$\sigma \propto \Gamma$

g11

($\sigma^{\gamma p}$<0.8 nb

$\sigma^{\gamma n} < 4nb$

Conclusions

- Negative results casted doubts about the existence of the widely observed narrow state (<20MeV) with Strangeness +1 (Θ^+ pentaquark)
- Direct comparison of different experiments is difficult
- Need new generation of dedicated experiments in the same kinematic of positive results with:

High statistics

High precision

g11@JLab

- JLab (CLAS) has a comprehensive physics program to search for evidence of pentaquark states in photon induced reactions
- The photoproduction on proton (g11 experiment) ran in May-July 2004 accumulating a total integrated luminosity of 70 pb^{-1} in the photon energy range 1.6-3.8 GeV
- Preliminary results for the reactions $\gamma p \rightarrow \Theta^+ \bar{K}^0$ studied in both decay modes ($\Theta^+ \rightarrow nK^0$ and $\Theta^+ \rightarrow pK^0$) show no indication of a narrow resonance
- An upper limit of 0.8 nb ($\Theta^+ \rightarrow nK^0$) and 1nb ($\Theta^+ \rightarrow pK^0$) on the total cross section were derived
- Due to the complementary kinematics of the two decay modes, the combined CLAS efficiency is smooth and providing a flat upper limit on the differential cross section
- Analysis of other reactions searching for the Θ^+ and Θ^{++} are in progress

See Valery's talk!

A letter is ready to be submitted to PRL

Search for $\Theta^+(1540)$ pentaquark in high statistics measurement of $\gamma p \to \bar{K}^0 K^+ n$ at CLAS

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(The CLAS Collaboration)

Check Arxiv next days!