Search for Pentaquarks at CLAS in Photoproduction from Proton

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April Meeting

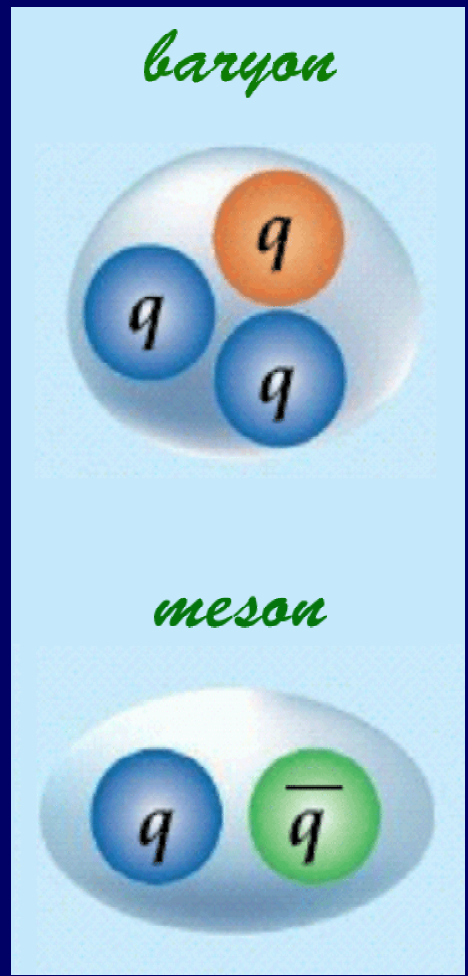
Quarks and QCD

quarks are among the few known elementary particles

quarks interact by the strong force through the exchange of gluons forming hadrons, the building blocks of ordinary matter

known quark configurations are baryons (3q) and mesons ($q\bar{q}$)

Quantum Chromo Dynamics allows hadronic states with different quark configuration (4q, 5q, 3qg)



Exotics and Pentaquarks

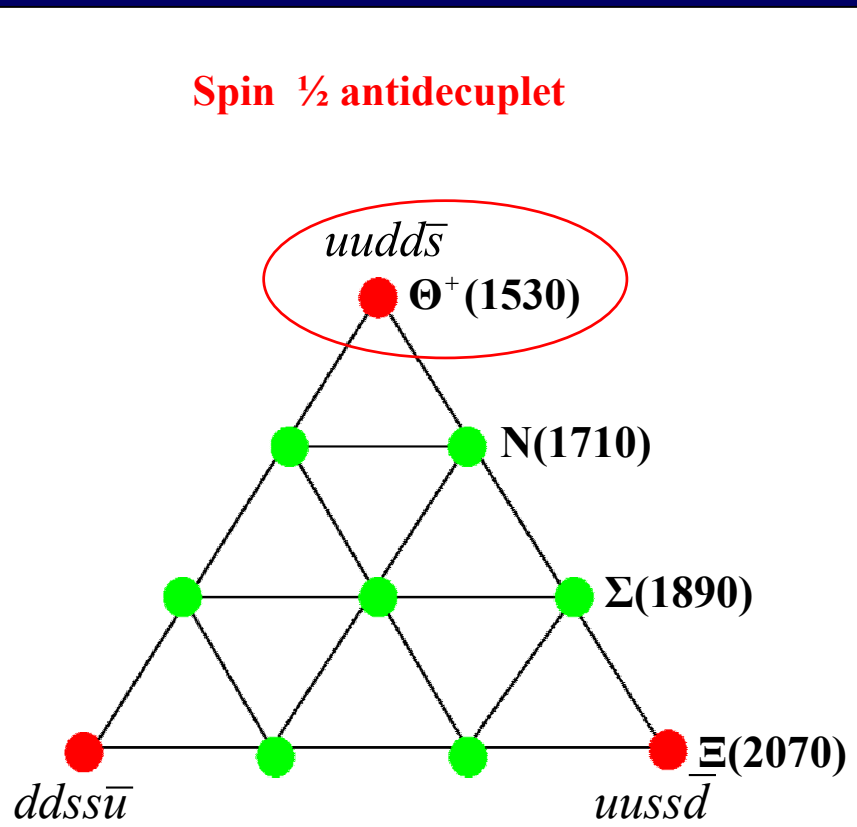
Pentaquarks are hadronic states with minimal quark content of 5 quarks

$$4q+\bar{q}$$

When the antiquark has a different flavor than the other 4 quark, the pentaquark has "exotic" quantum numbers

Example: $uudd\bar{s}$
Strangeness = 0 + 0 + 0 + 0 + 1 = +1

An antidecuplet of pentaquarks with masses of 1.5–2.1 GeV was predicted by D. Diakonov et al.



D.Diakonov et al. Z. Phys A359, 1997, 305
D. Diakonov, V. Petrov, Phys. Rev. D69, 2004, 094011

Evidence for Pentaquark States

- First evidence for a possible $\Theta^+(1540)$ was reported by the LEPS/Spring-8 Collaboration in photoproduction off nuclei
- Corroborated by several experiments (CLAS, COSY-TOF, DIANA, HERMES, JINR, NOMAD, νBC, SAPHIR , SVD-2, ZEUS) using different probes and targets
- Positive results have limited event samples in the observed structures
- Comparison of results from different experiments shows discrepancies in the observed masses
- Null results have been recently presented (ALEPH, BABAR, BELLE, BES, CDF, COMPASS, DELPHI, E690, FOCUS, HERA-B, PHENIX, SPHINX)

Definitive confirmation from high statistics/ high resolution experiments is needed to resolve the controversy about the existence of the $\Theta^+(1540)$ pentaquark

Search for Pentaquarks at CLAS

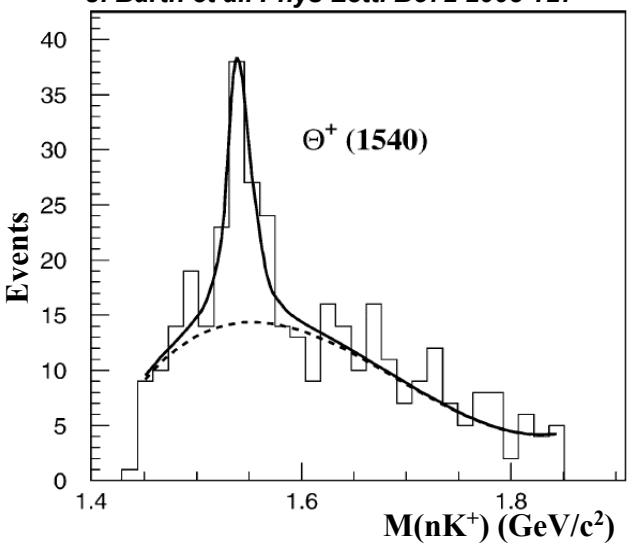
A comprehensive program to search for pentaquarks with high statistics and high resolution photoproduction experiments is in progress at Jefferson Lab

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

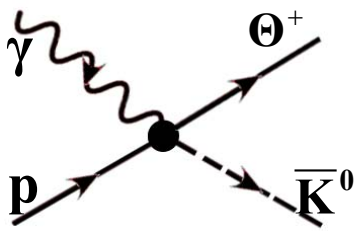
g10	deuteron	$E_\gamma \sim 1.0$-3.5 GeV
	data taking completed in 2004	
g11	proton	$E_\gamma \sim 1.6$-3.8 GeV
	data taking completed in 2004	
eg3	deuteron	$E_\gamma \sim 4.0$-5.4 GeV
	data taking completed in 2005	
Super-g	proton	$E_\gamma \sim 3.8$ - 5.7 GeV
	planned for 2006	

Θ^+ Search in Exclusive Photoproduction off the proton

J. Barth et al. Phys Lett. B572 2003 127

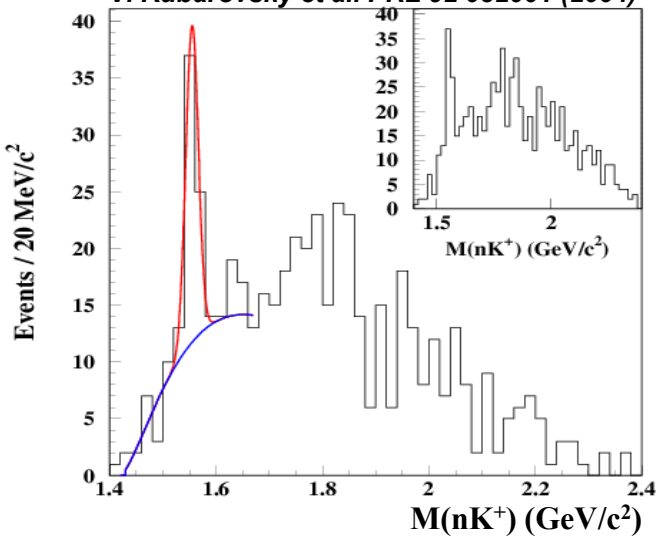


$$\gamma p \rightarrow \Theta^+ \overline{K}^0$$



$E_\gamma = 1.6 - 2.6$ GeV

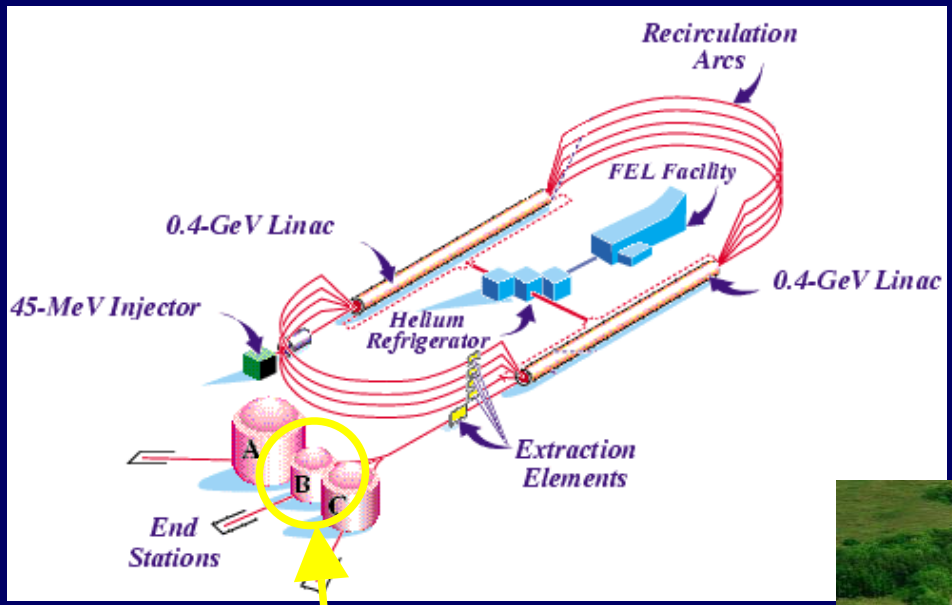
V. Kubarovsky et al. PRL 92 032001 (2004)



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

to be tested by a dedicated experiment (Super-g) planned for 2006

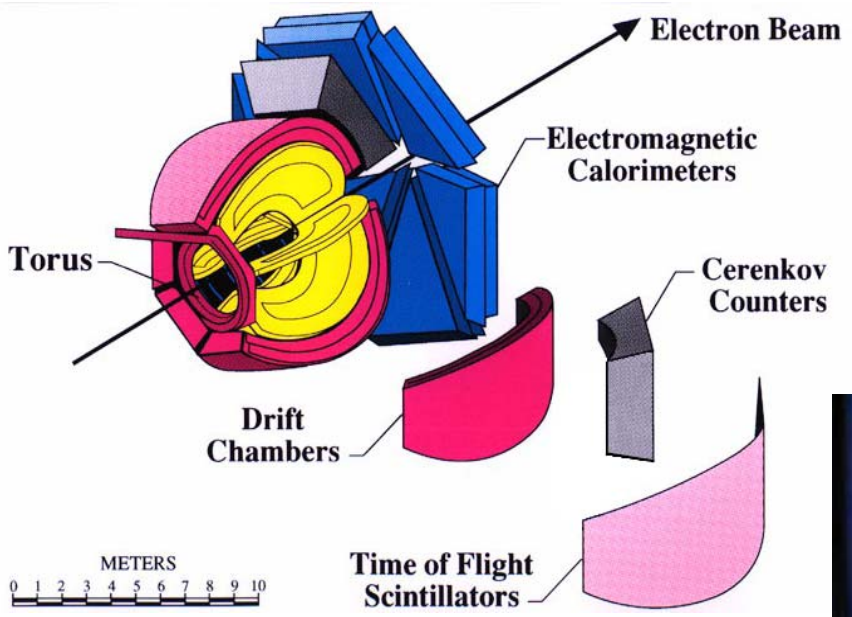
Jefferson Lab

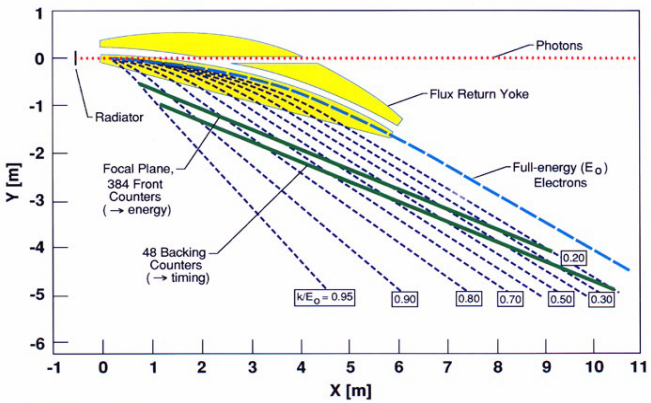


E_{max} ~ 6 GeV
I_{max} ~ 200 μA
Duty Factor ~ 100%
σ_E/E ~ 2.5 10^{-5}
Beam P ~ 80%
E_γ ~ 0.8– 5.7 GeV

CLAS

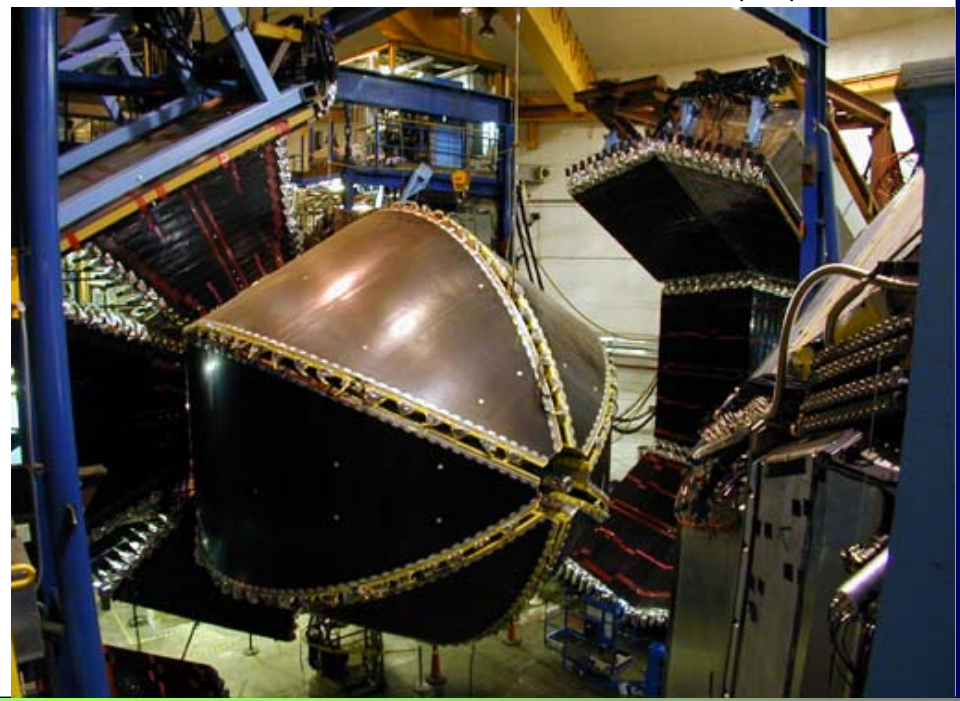
The CEBAF Large Acceptance Spectrometer CLAS





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 ($\Delta E_\gamma/E_\gamma \sim 10^{-3}$)



g11@JLab: Spectroscopy of Exotic Baryons with CLAS Search for Ground and Excited States

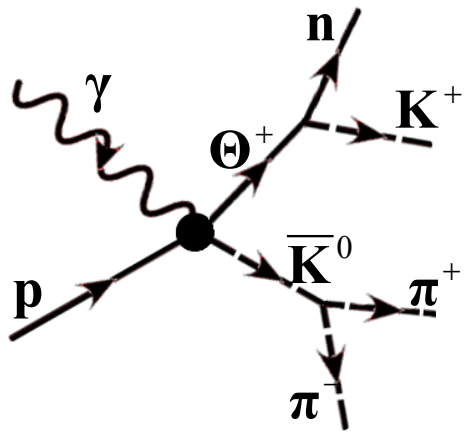
Proposed measurement and Primary Goals:

- 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 accuracy
- 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
- Preliminary results for this reaction

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

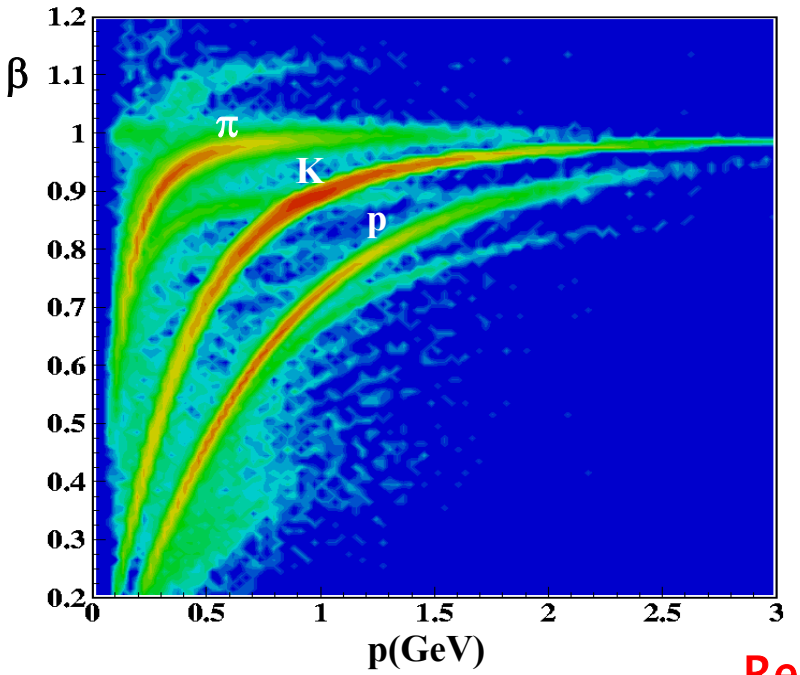


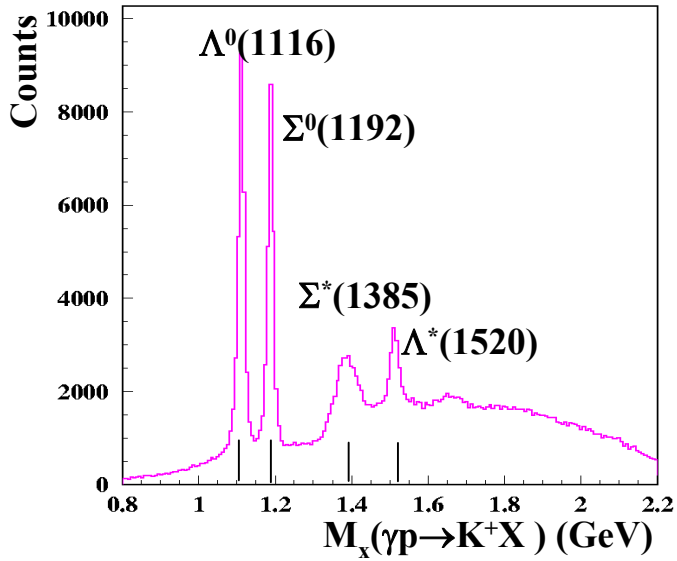
$$\Theta^+ \rightarrow nK^+$$

$$\overline{K}^0 \rightarrow K_S \rightarrow \pi^+\pi^-$$

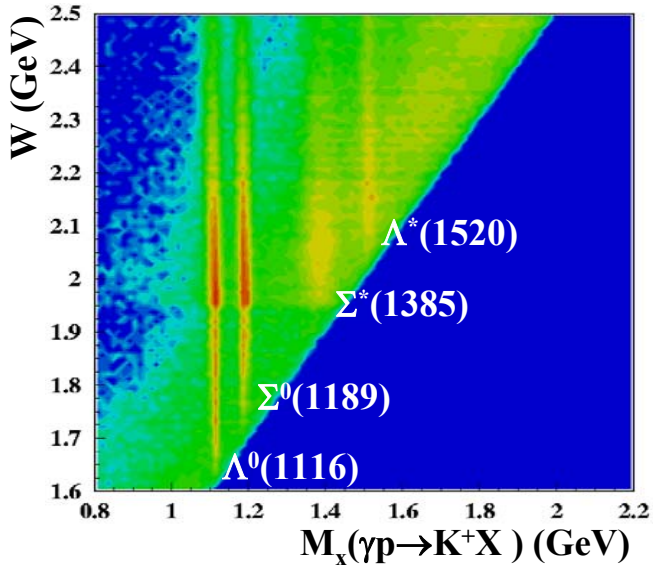
g11 data quality

Particle identification





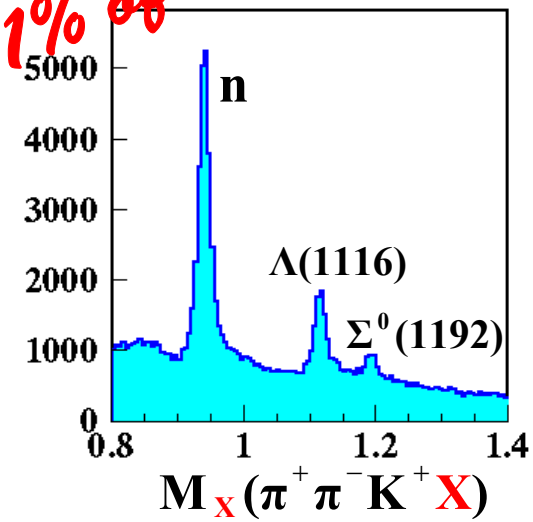
Reaction identification and kinematical coverage

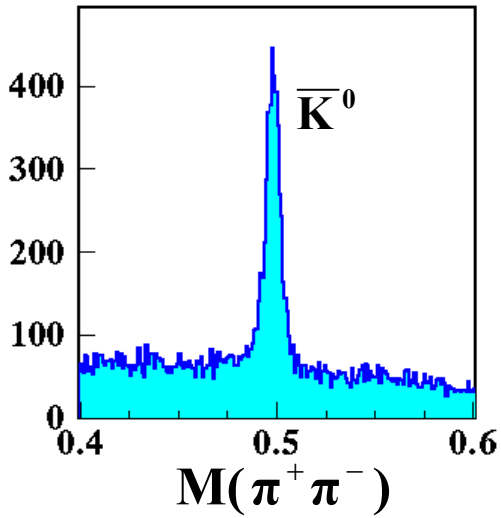


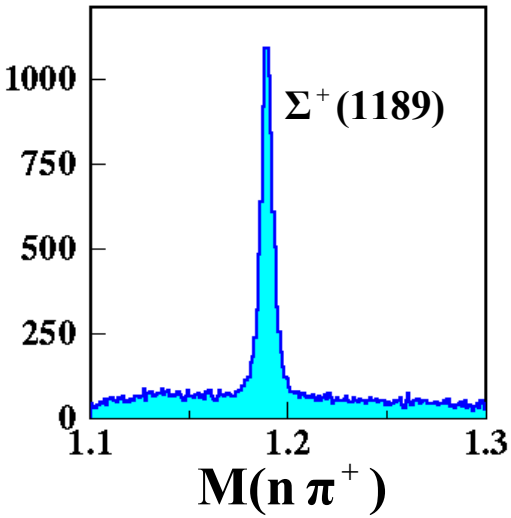
1% of statistics

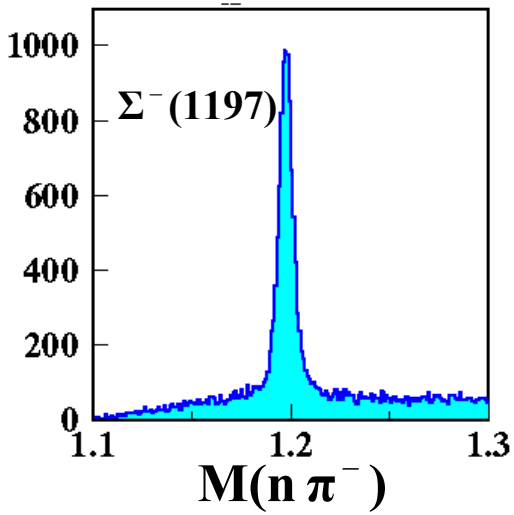
$\gamma p \rightarrow \pi^+ \pi^- K^+ n$

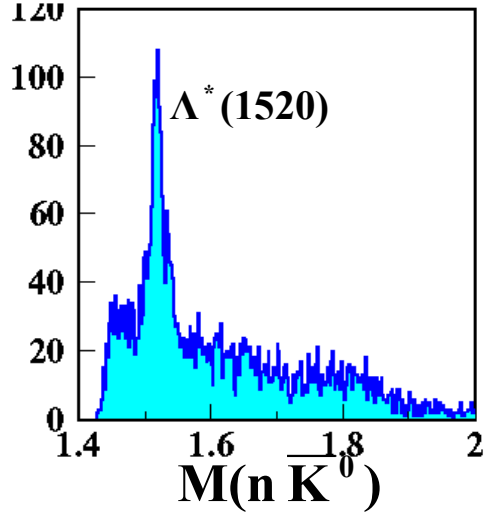
g11@JLab

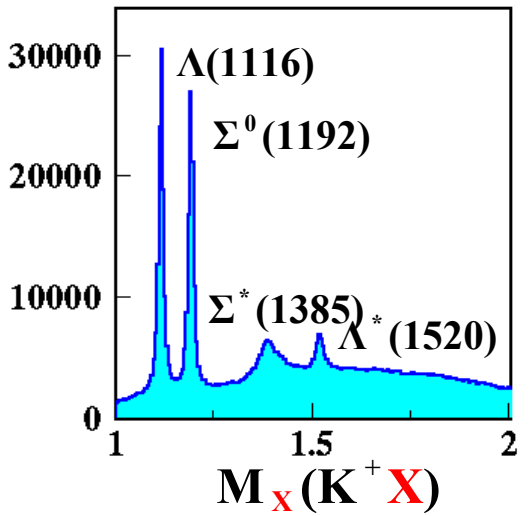






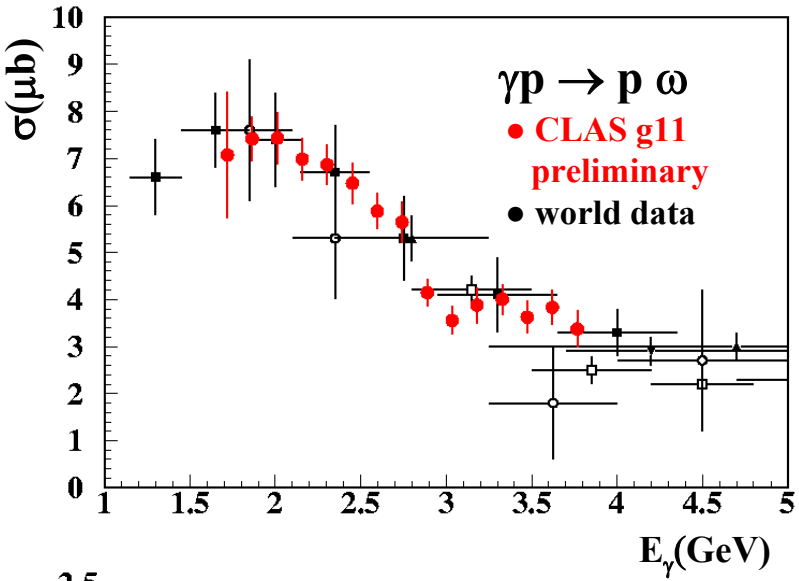


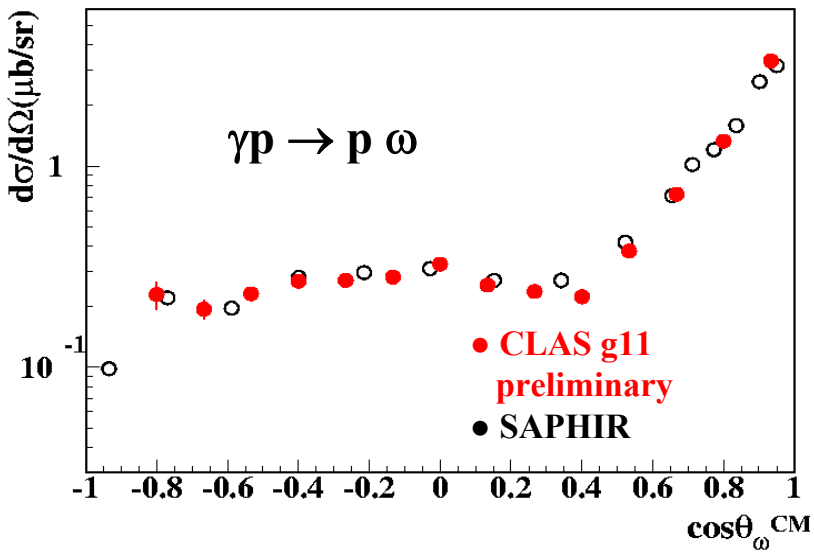


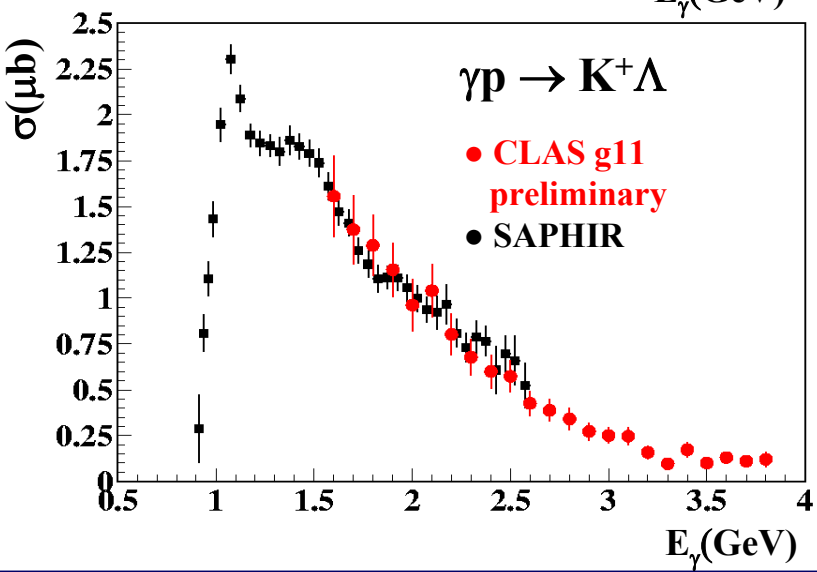


Cross Section Extraction

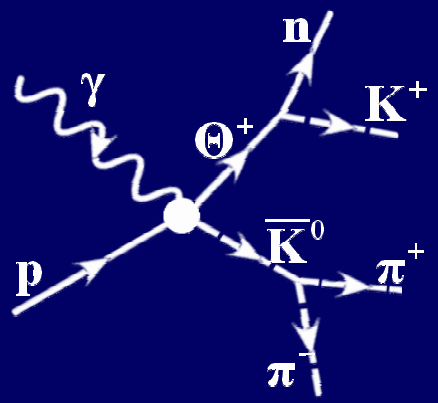
- Different final states are measured simultaneously in the CLAS detector
- Cross section for known reactions have been extracted to test the accuracy of the analysis procedure
- 1% of statistics



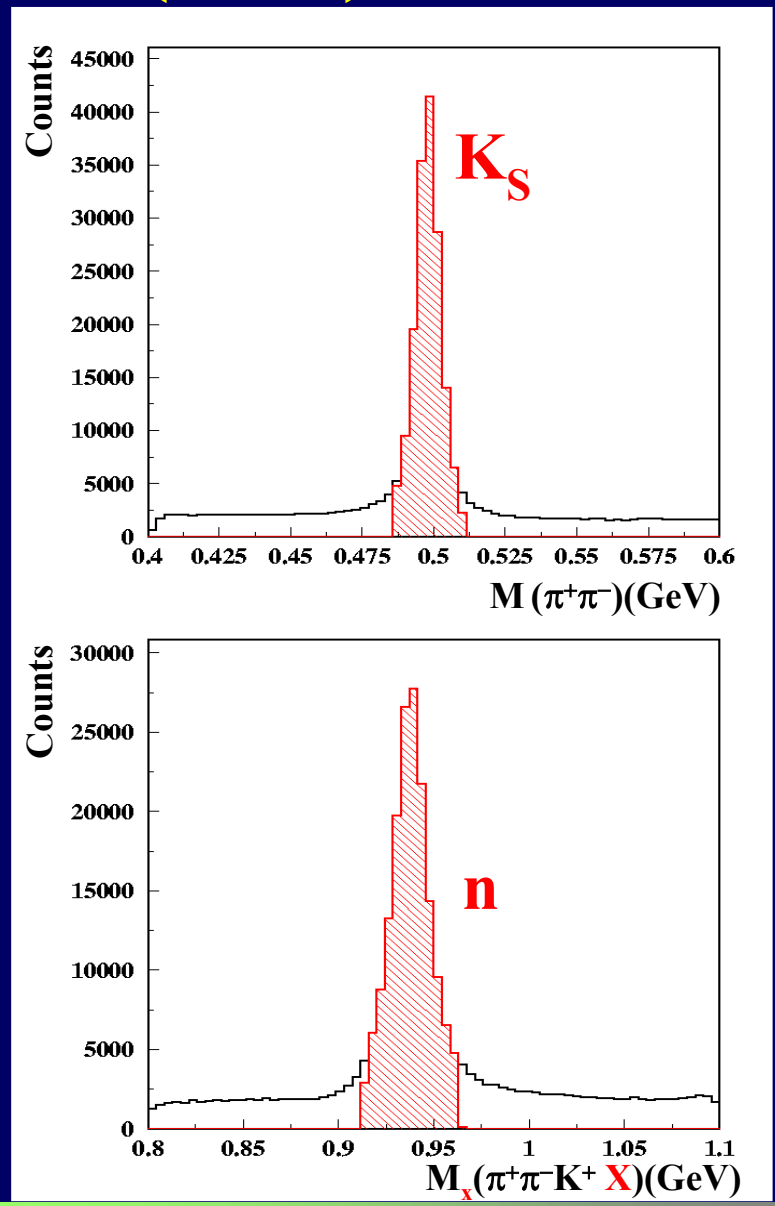




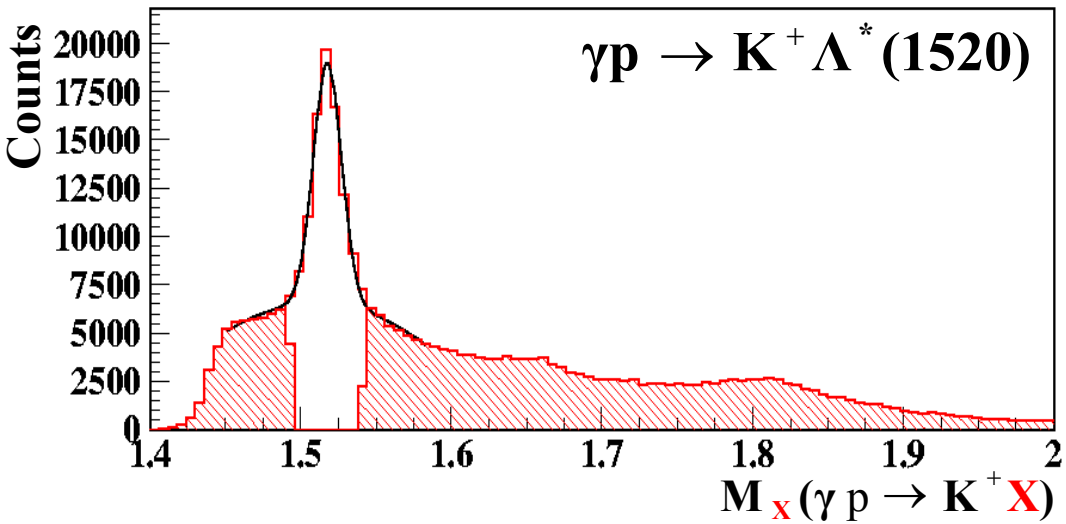
Search for the $\Theta^+(1540)$

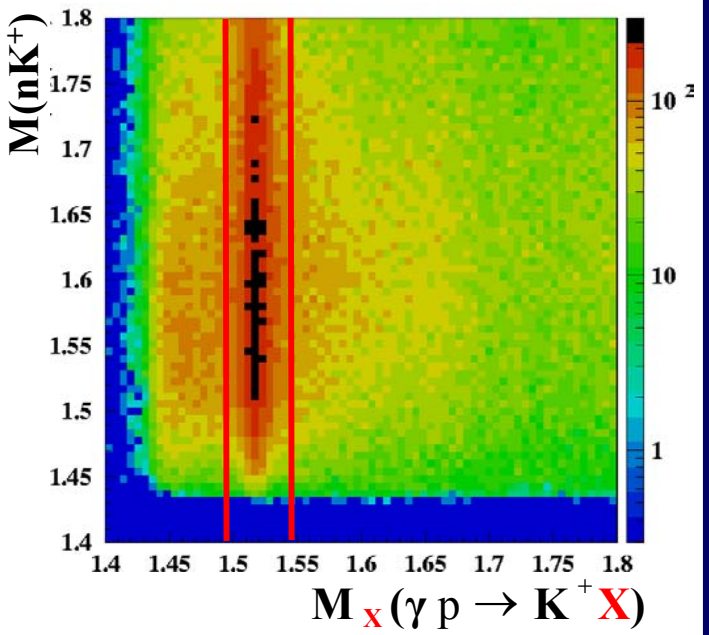


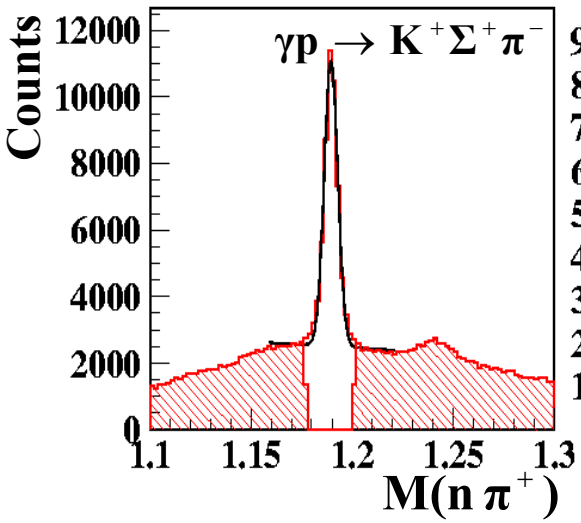
- the K^0 is detected via its K_S component decaying into $\pi^+ \pi^-$
- final state is identified using the missing mass technique
- strangeness is tagged detecting the K^+
- using the full statistics (70 pb^{-1}) a total of ~120000 events are selected

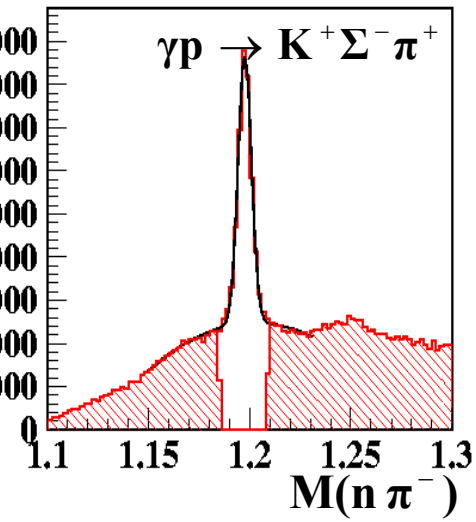


Hyperon Production







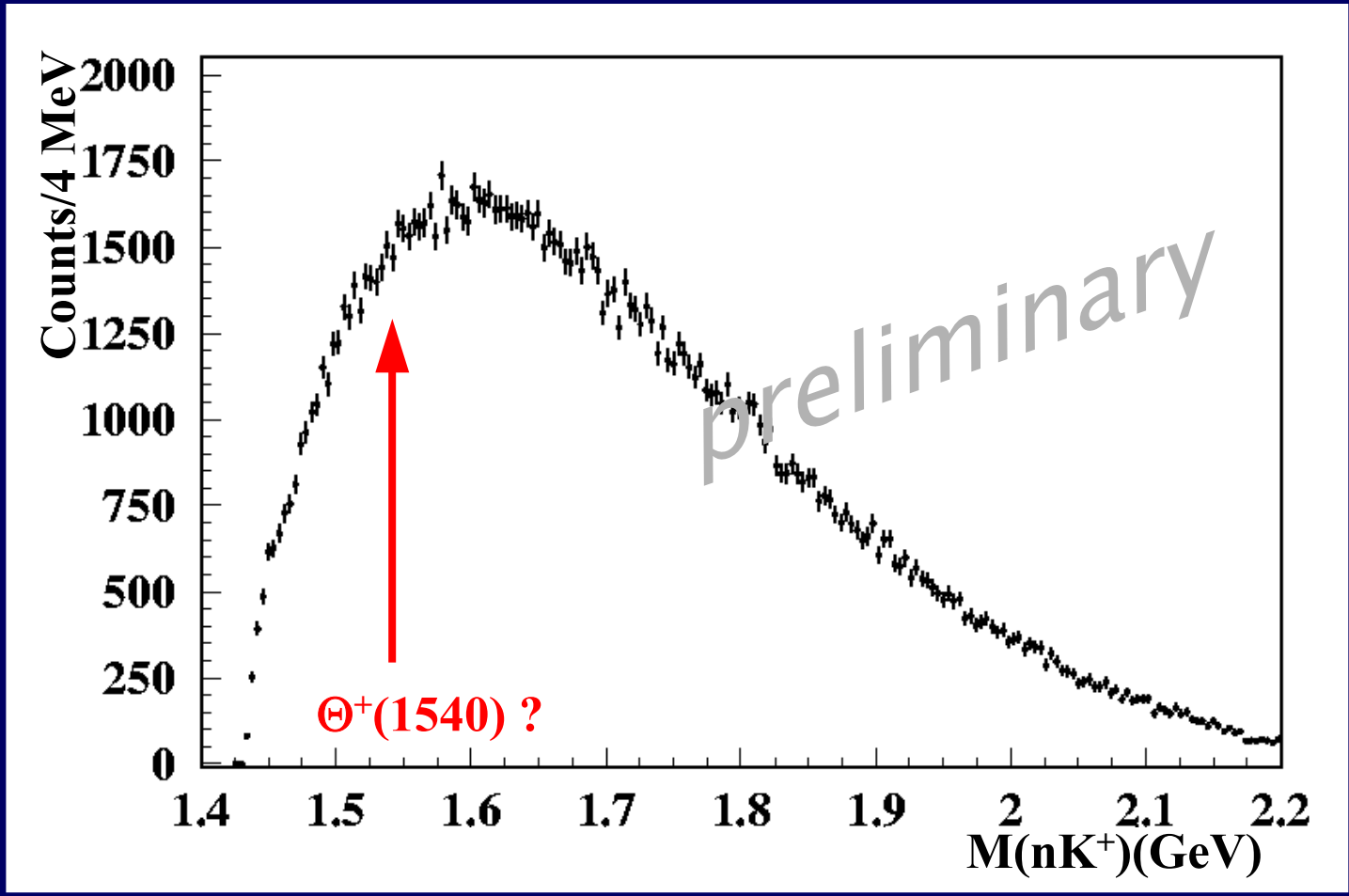


$N_\Lambda = 91300$

$N_{\Sigma+} = 36200$

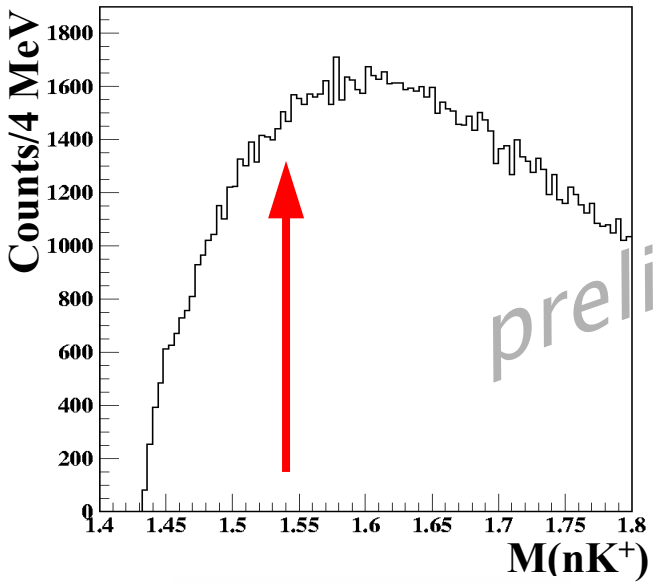
$N_{\Sigma-} = 26800$

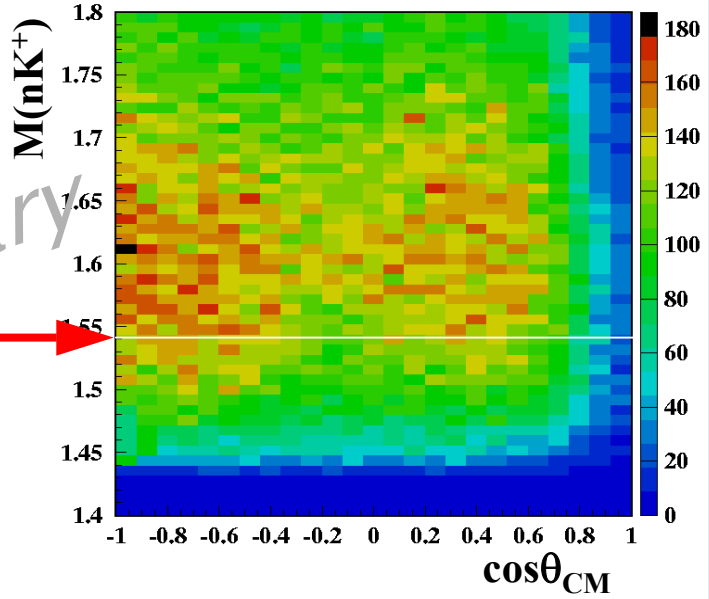
nK^+ Mass Spectrum

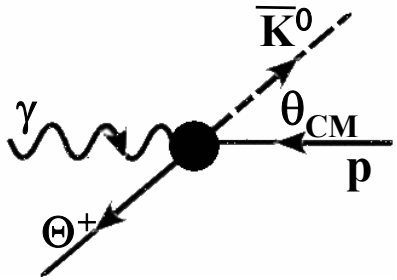


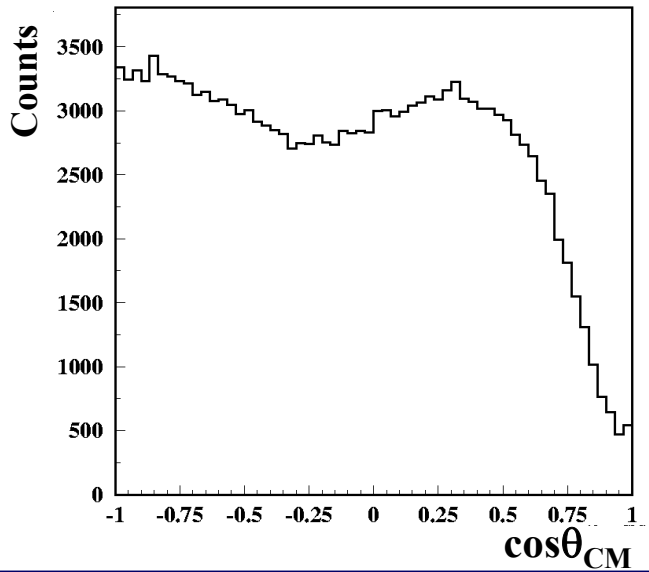
- the nK^+ mass spectrum is smooth
- no structure is observed at a mass of ~1540 MeV

nK⁺ Mass Spectrum







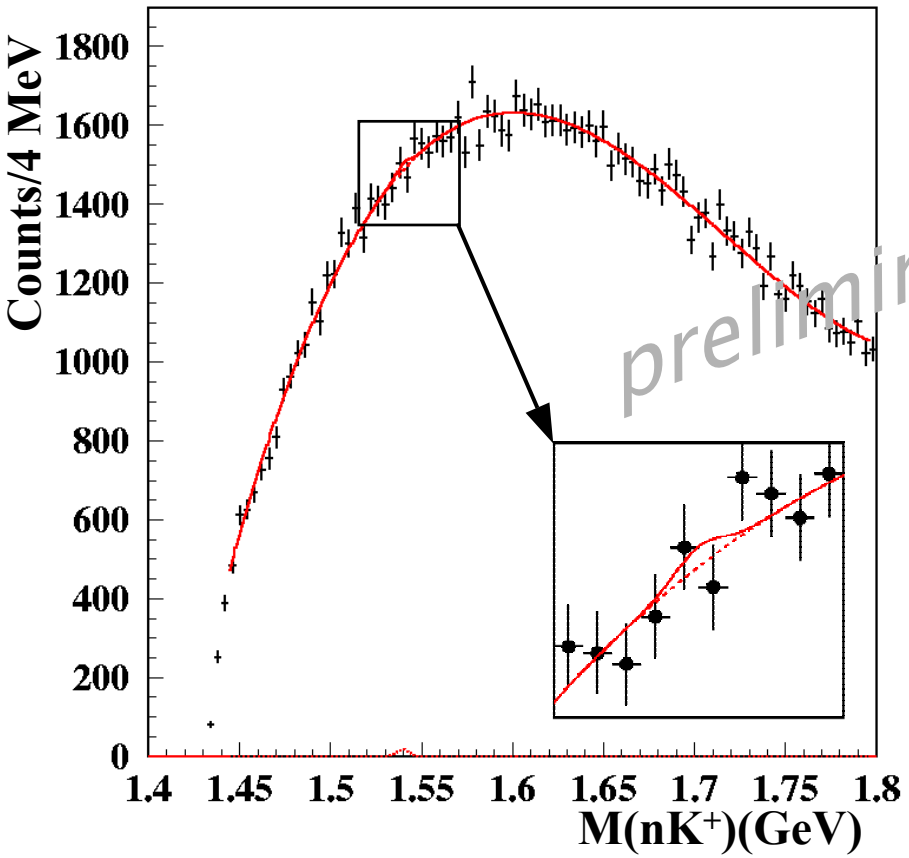


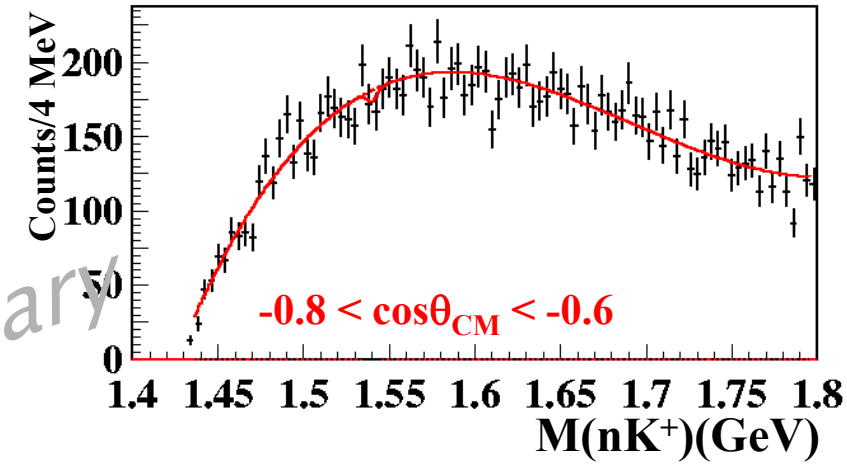
- mass vs. CM angle distribution shows coverage of the whole kinematics
- no evidence for a structure is found for different CM angle ranges

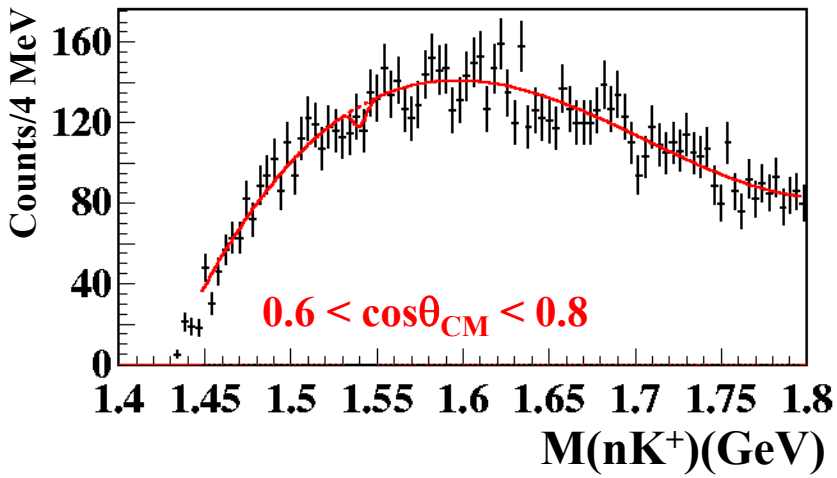
Evaluation of an Upper Limit on the Θ^+ Cross section

- Θ^+ signal is searched for as narrow resonance over a smooth background in the (nK^+) spectrum
- Resonance width inferred from MC simulations, assuming a negligible intrinsic width
- Background described as 5^{th} order polynomial
- 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

Evaluation of an Upper Limit on the Θ^+ Yield

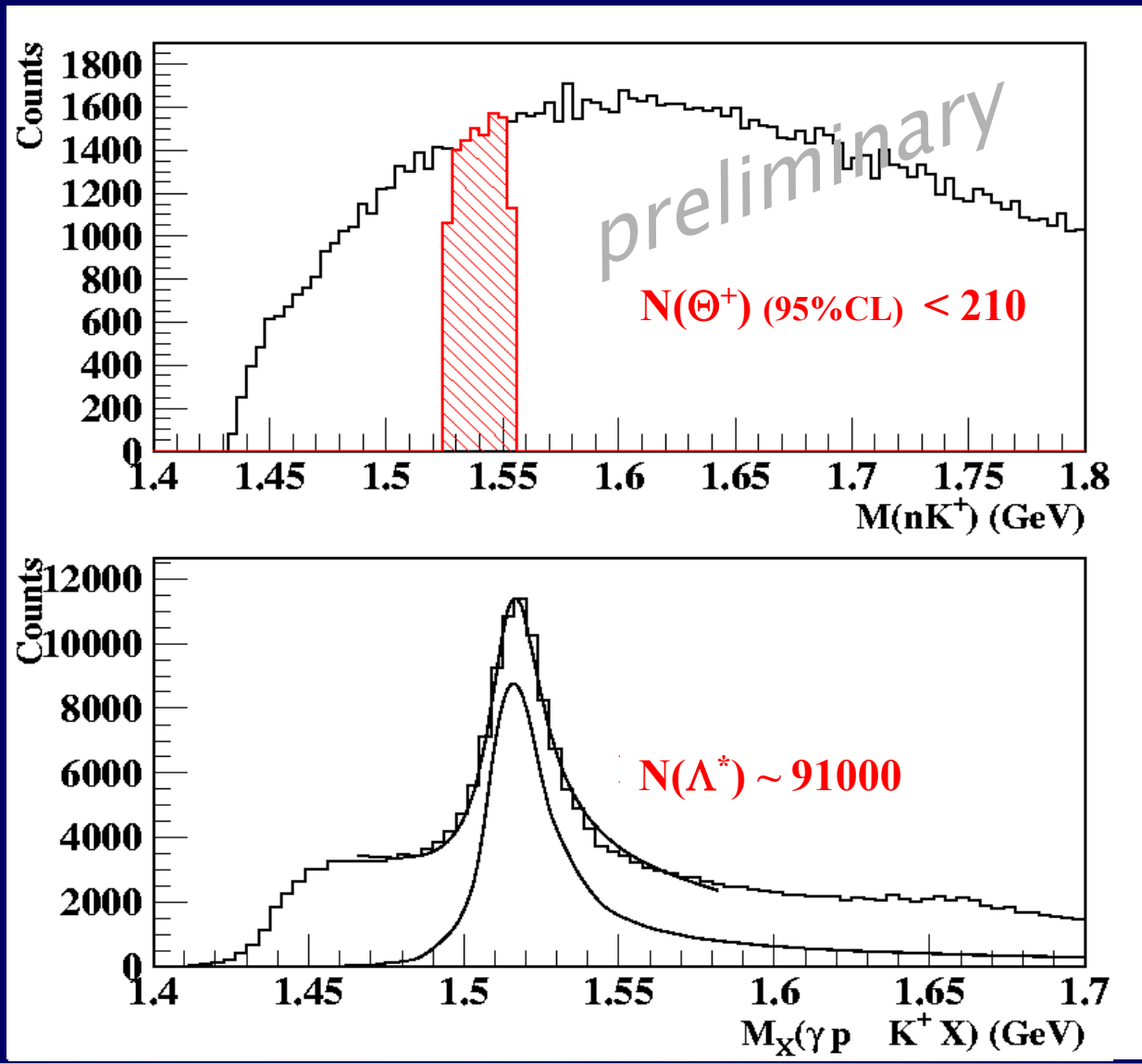






$\Theta^+(1540)/\Lambda^*$ Yields

$$\frac{N(\Theta^+)}{N(\Lambda^*)} < 0.2\%$$

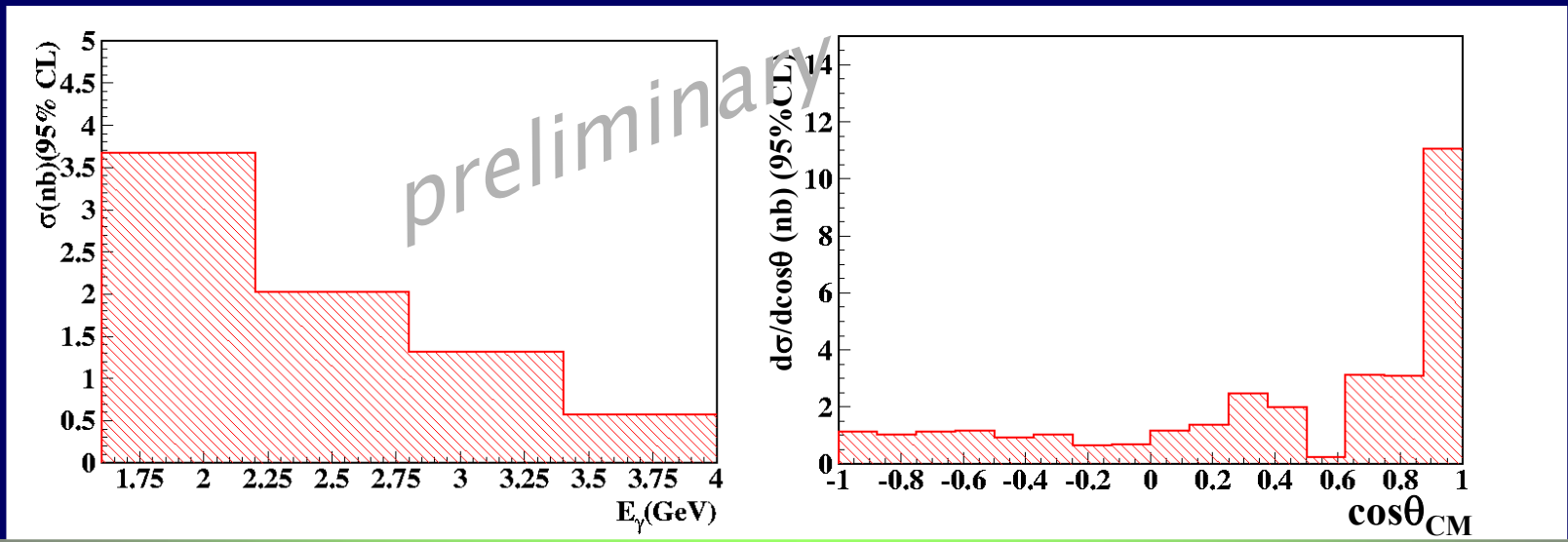


Upper Limit on the $\Theta^+(1540)$ Cross section

energy and angular dependence

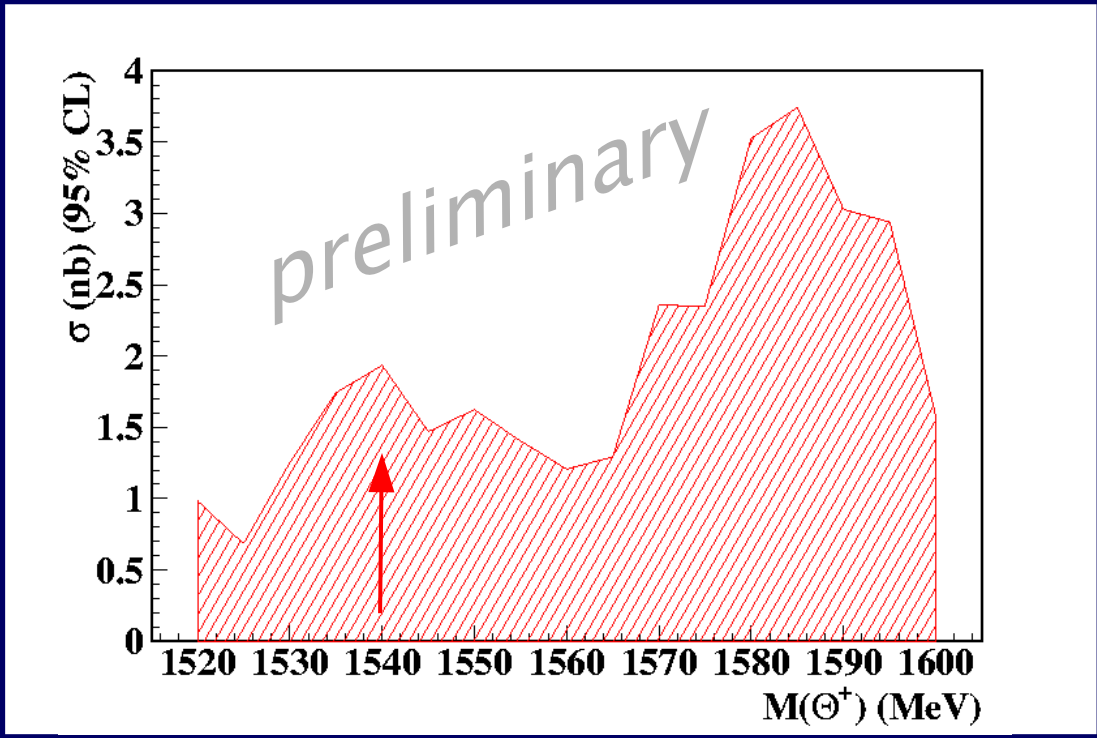
$$\sigma(95\%CL) \propto \frac{\text{Yield}(95\%CL)}{\text{efficiency} \cdot \text{luminosity} \cdot BR(\Theta^+ \rightarrow nK^+)}$$

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



Upper Limit on the Θ^+ Cross section

mass dependence



Upper limit (95% CL)

$\sigma_{\gamma p \to \Theta^+ K^0} < 1\text{–}4$ nb

Comparison with SAPHIR results

Observed Yields

SAPHIR

$N(\Theta^+)/N(\Lambda^*) \sim 9\%$

CLAS

$N(\Theta^+)/N(\Lambda^*) < 0.5\%$ (95%CL)

Cross Sections

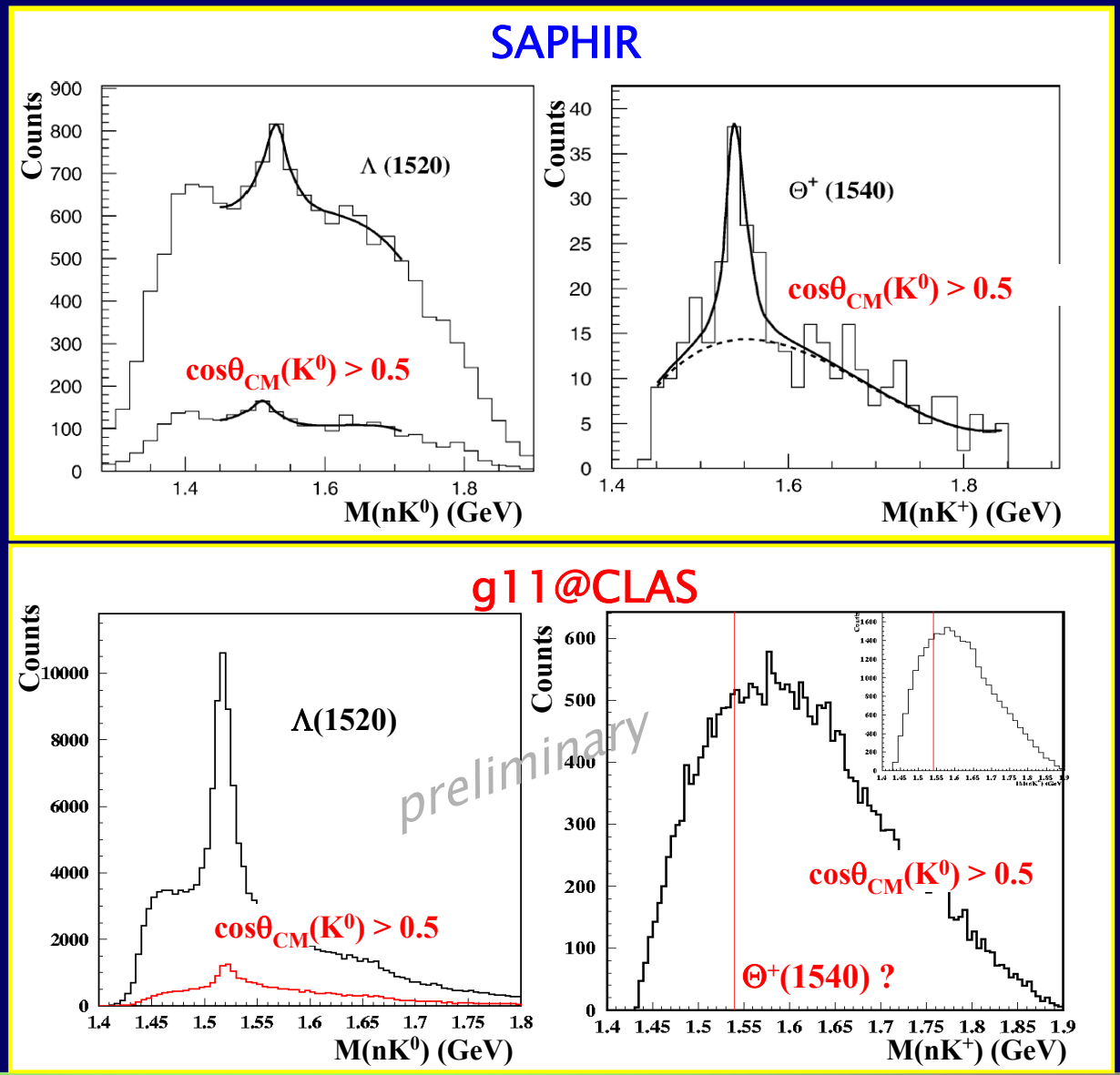
SAPHIR

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

reanalysis 50 nb

CLAS

$\sigma_{\gamma p \to \Theta^+ K^0} < 1\text{-}4$ nb



Summary and Outlook

- The CLAS Collaboration at JLab has a comprehensive physics program to search for evidence of pentaquark states in photon induced reactions
- g11 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 reaction $\gamma p \rightarrow \Theta^+ \bar{K}^0$ show no indication of a narrow resonance in this channel
- An upper limit of 1–4 nb on the total cross section for this reaction was derived in contrast to the SAPHIR results
- Analysis of other reactions searching for the Θ^+ and Θ^{++} are in progress
- A second experiment at higher energy designed to verify our previously published results in the reaction $\gamma p \rightarrow \Theta^+ K^- \pi^+$ is planned