Study of Exotic *S=+1* Baryon States in Exclusive Photo-production with CLAS.

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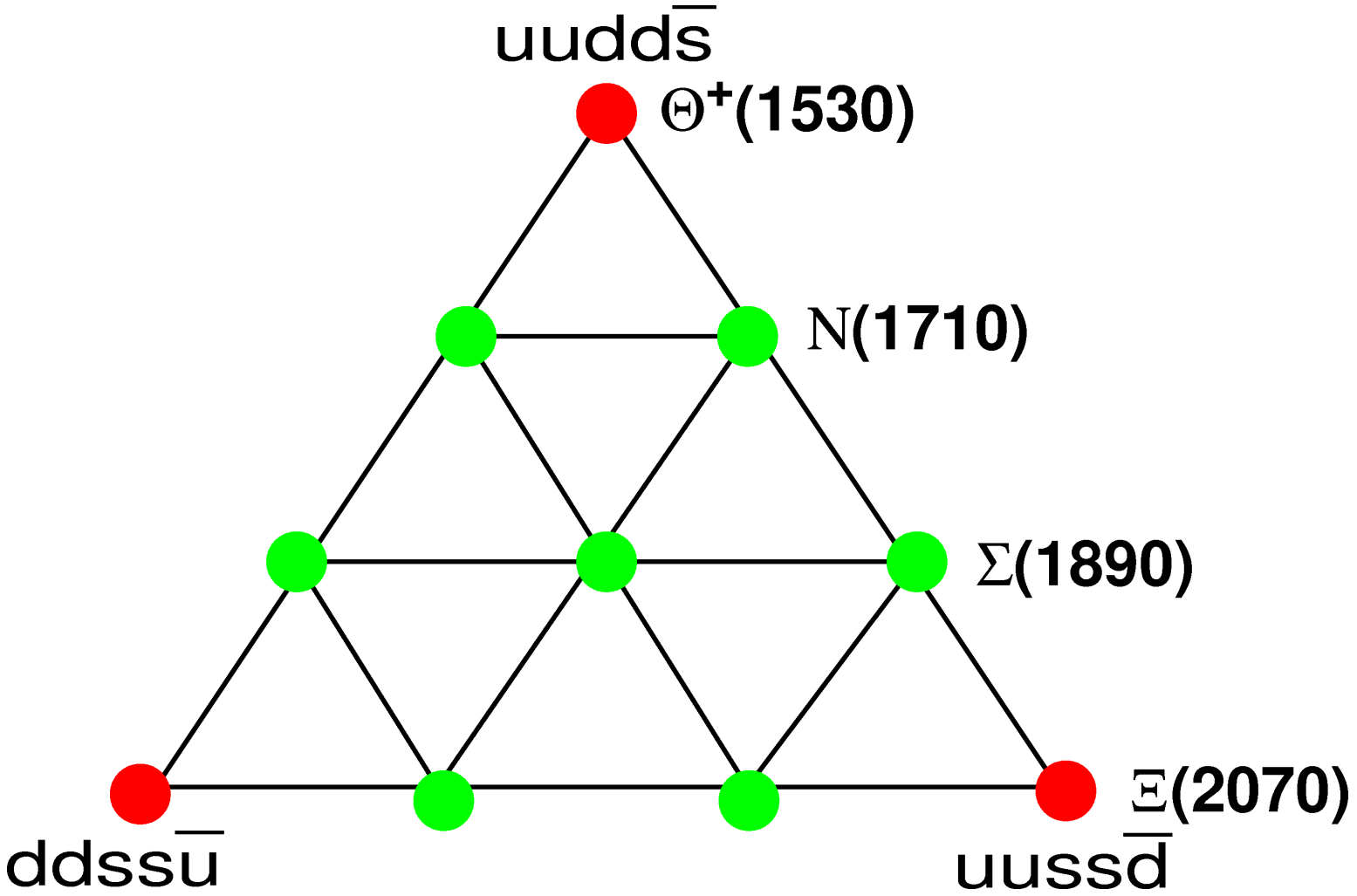
for the CLAS Collaboration

- Introduction
- Evidence for Θ^+ on deuterium $\gamma d \rightarrow p K^- K^+ n$
- Evidence for Θ^+ on hydrogen $\gamma p \rightarrow \pi^+ K^- K^+ n$
  $\gamma p \rightarrow \overline{K}^0 K^+ n$
- Search for Θ^{++} $\gamma p \rightarrow K^- K^+ p$
- Summary and Outlook

The Anti-decuplet in the Chiral Soliton Model

D. Diakonov, V. Petrov, M. Polyakov, Z.Phys.A359, 305 (1997)



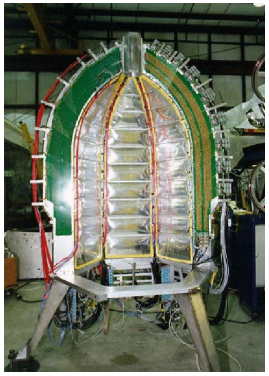
JLab accelerator CEBAF

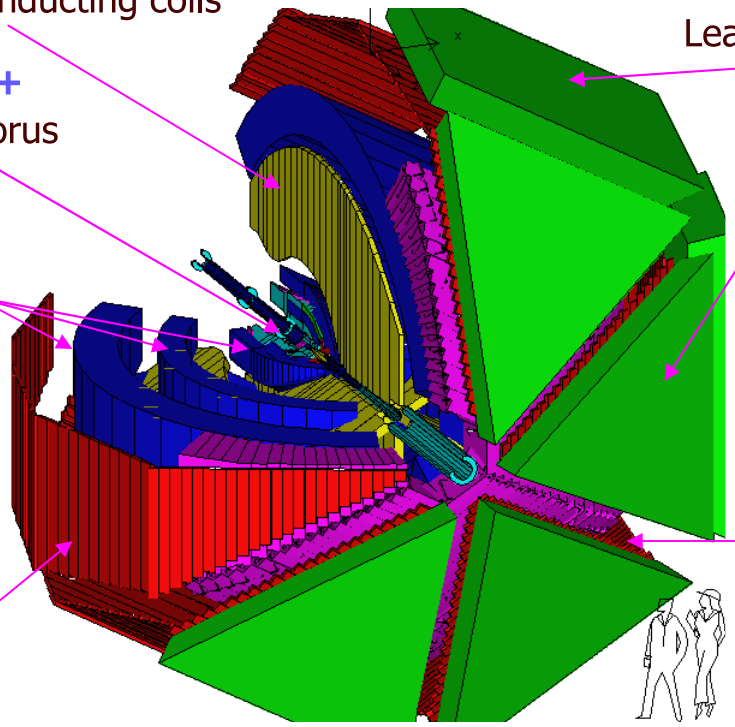
CEBAF Large Acceptance Spectrometer

Torus magnet
6 superconducting coils

Liquid D_2 (H_2)target +
γ start counter; e minitorus

Drift chambers
argon/CO_2 gas, 35,000 cells



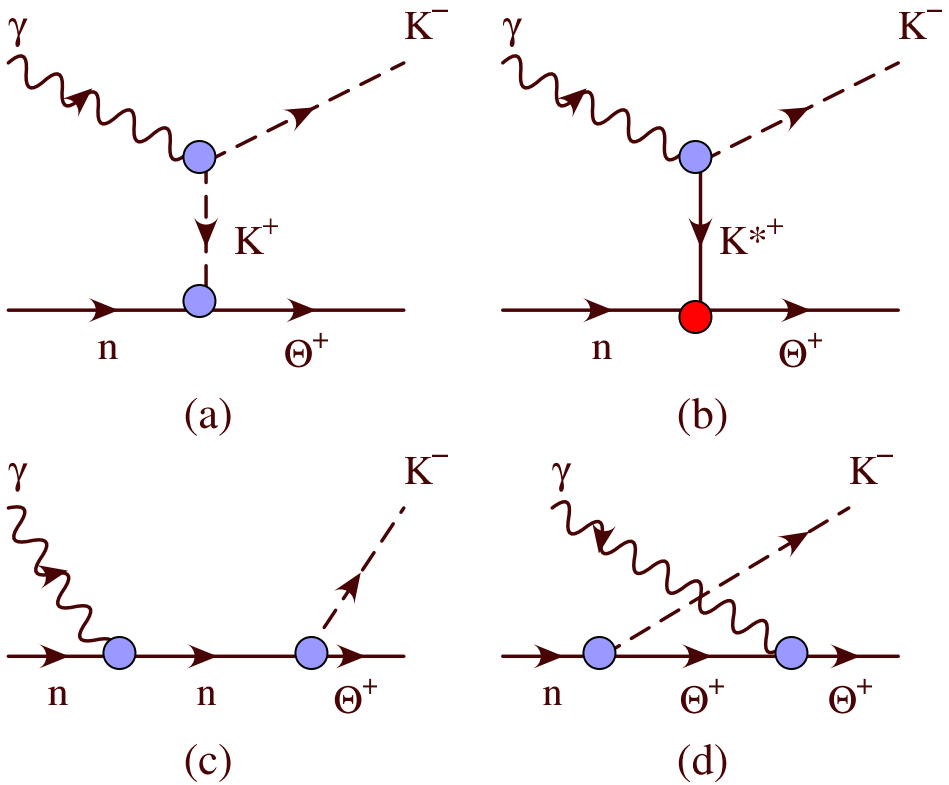


Electromagnetic calorimeters
Lead/scintillator, 1296 photomultipliers

Gas Cherenkov counters
e/π separation, 256 PMTs

Time-of-flight counters
plastic scintillators, 684 photomultipliers

Possible Θ^+ production mechanisms in the reaction $\gamma n \to K^- \Theta^+$



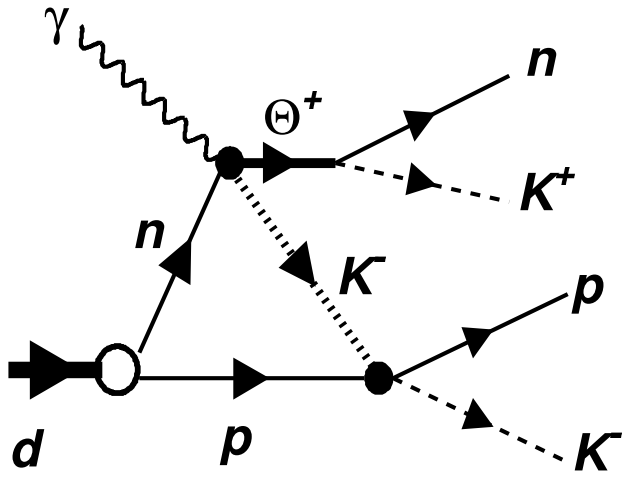
W. Liu, C.M. Ko, nucl-th/0309023
S.I. Nam, A. Hosaka, H.C. Kim, hep-ph/0308313
Y. Oh, H. Kim, S.H. Lee, hep-ph/0310019

Effective interaction Lagrangian theory
Calculation of the total and differential cross sections

Exclusive Photoproduction on Deuterium

- Reaction of interest: $\gamma d \rightarrow pK^-K^+(n)$:
  P, K^+ and K^- were detected in CLAS, neutron is identified in MM
- We did not find the signal in the inclusive reaction possibly due to the limited acceptance of CLAS for forward going negative particles.
- In the exclusive reaction a final state interaction is required inside the deuteron;

  - K^- scatters at larger angles
  - Kinematics is fully defined, no need for Fermi corrections.

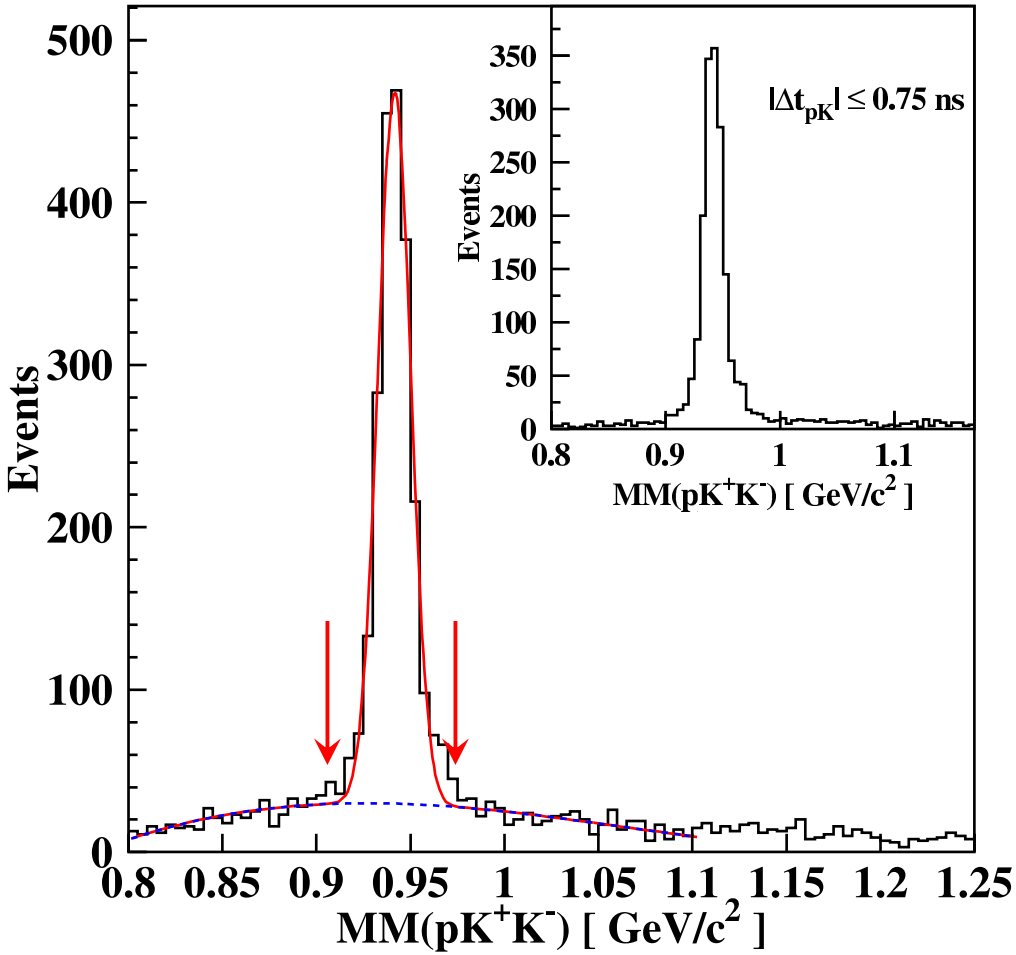


a)

  - Experimental data from 1999 run (g2a)
  - Data taking 14 days
  - Tagged photons with up to 3 GeV energy;
  - Target: 10 cm long liquid deuterium;

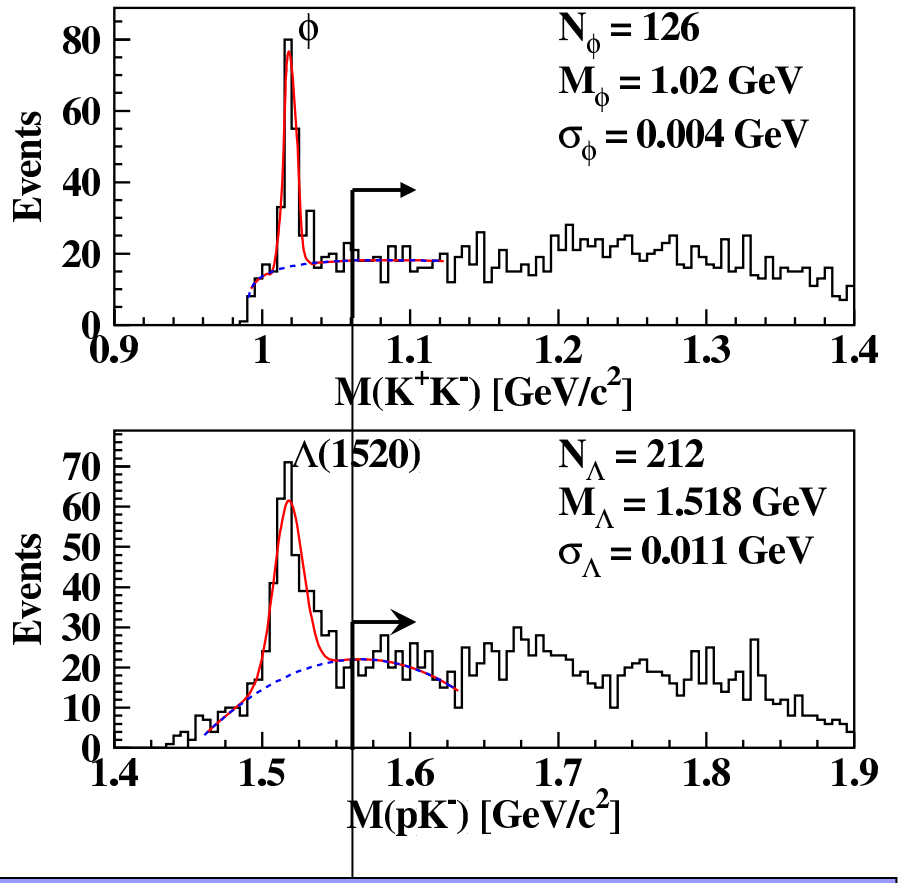
Reaction $\gamma d \rightarrow pK^+K^-(n)$

- Clear peak at neutron mass.
- 15% non pKK events within ±3σ of the peak.
- Almost no background under the neutron peak after event selection with tight timing cut.



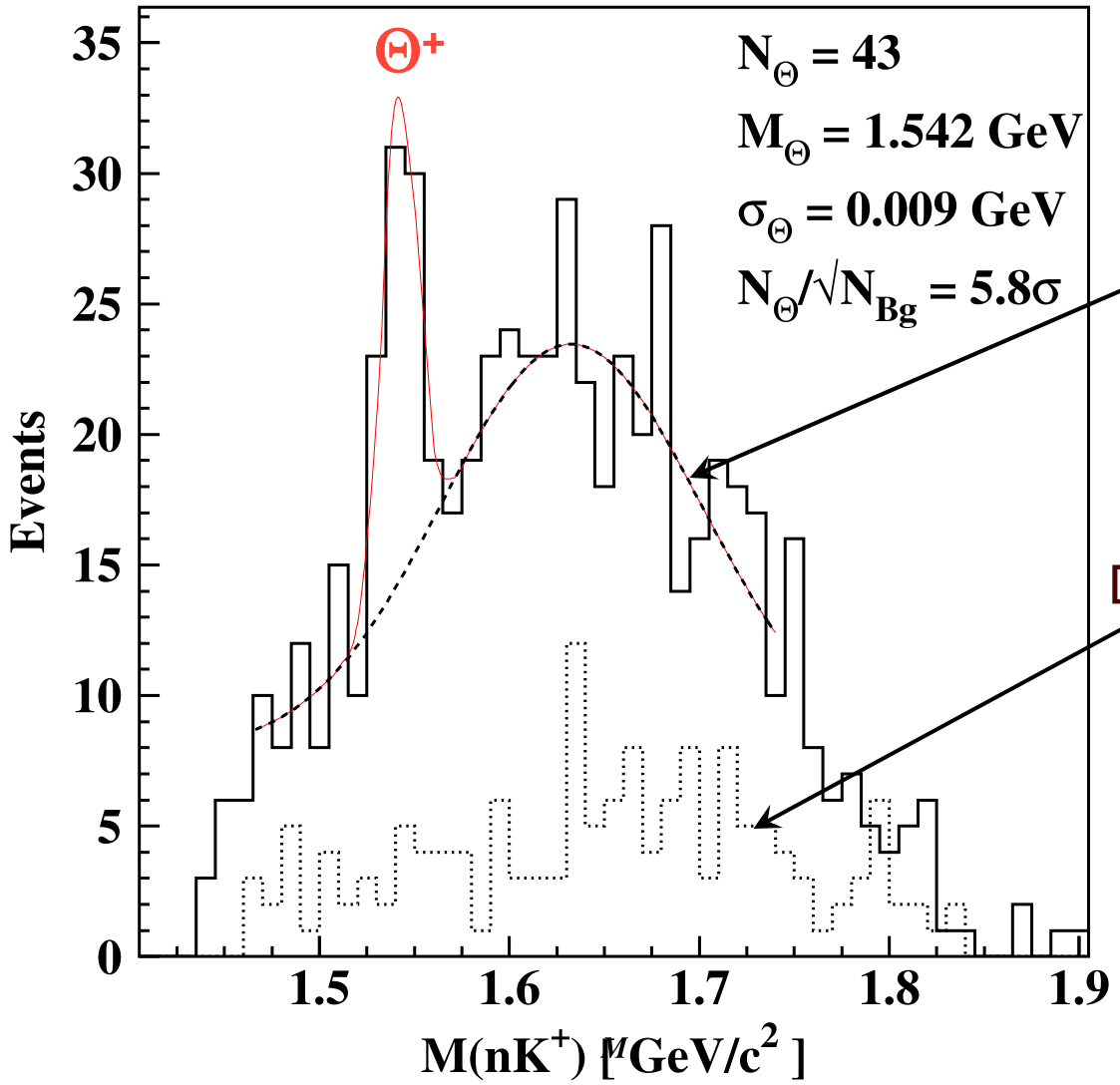
Removal of known resonances

- Several known processes can contribute to $pK^+K^-(n)$ final state
  1. $\gamma d \rightarrow \phi p(n)$, $\phi \rightarrow K^+K^-$
  2. $\gamma d \rightarrow \Lambda(1520)K^+(n)$, $\Lambda(1520) \rightarrow pK^-$
- Both resonances are produced predominantly on the proton (the neutron is a spectator).



Events above these regions are used for further analysis.

nK^+ invariant mass distribution



Background

Distribution of Λ(1520) events

Estimate of total cross section

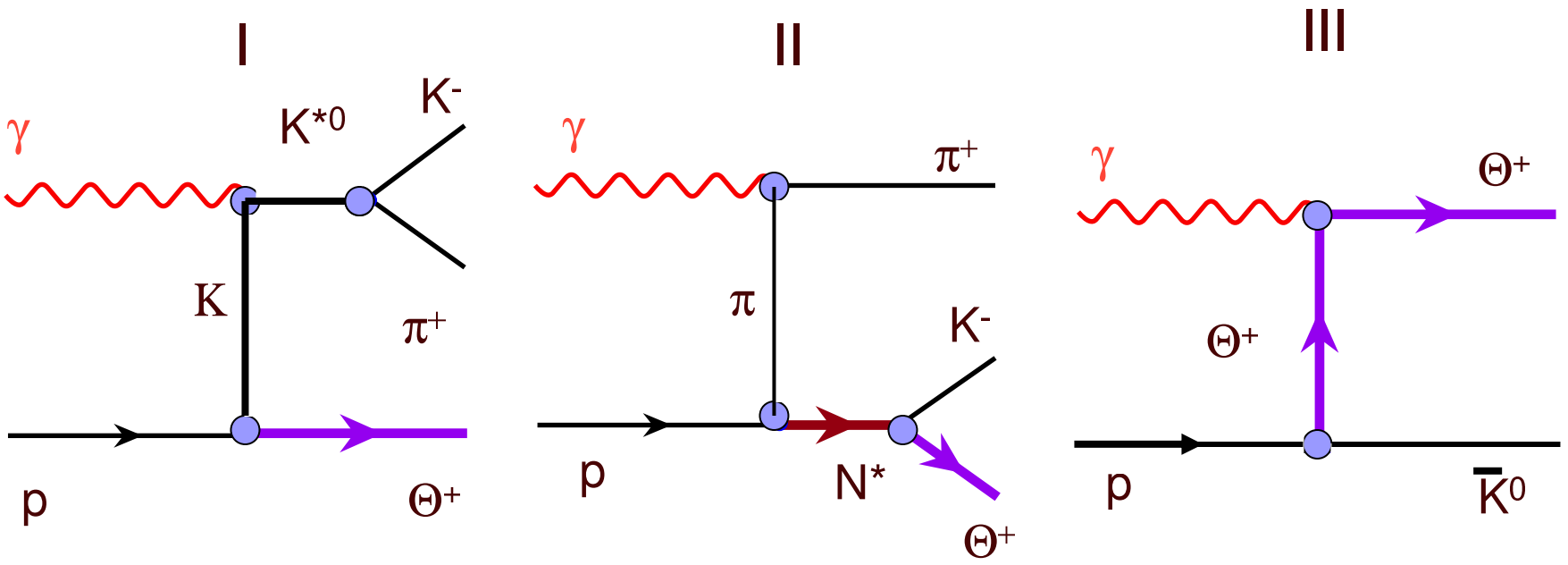
$$\gamma n \to K^- \Theta^+$$

- The total cross section was estimated with the assumption that the Q^+ photoproduction on nucleon proceeds the same way as the L(1520) production.
- 3 body phase space was used for the acceptance calculations.
- There are no data on elastic K^+n scattering cross section. Approximation was made to estimate it from the total cross section
- Baryon rescattering from the spectator nucleon was not taken into account
- σ ~ **60-160 nb (rough estimate)**

Θ^+ Production from Protons

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

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

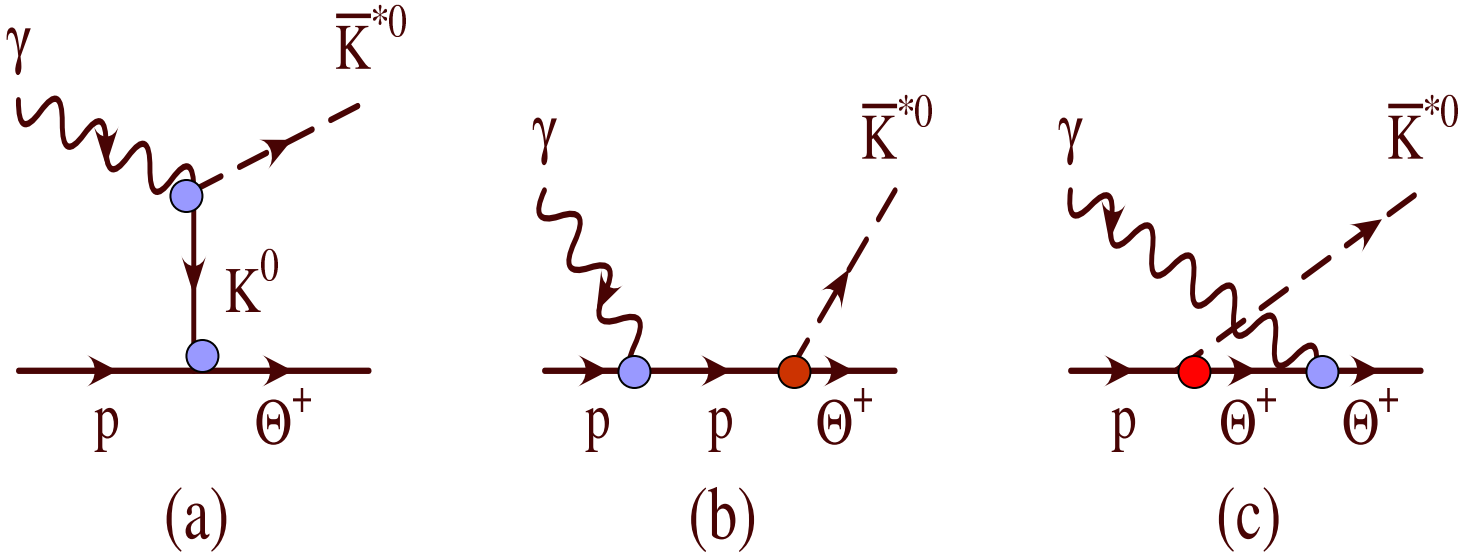


Photoproduction on hydrogen

Reaction type I

- Experimental data from 1999 and 2000 runs (g6a,b)
- Data taking ~ one month
- Tagged photons with 3-5.25 GeV energy
- Target: 18 cm long liquid hydrogen
- Reaction of interest: $\gamma p \rightarrow \pi^+ K^- K^+ (n)$
  - *π+, K+ and K- were detected in CLAS, neutron is identified in MM*

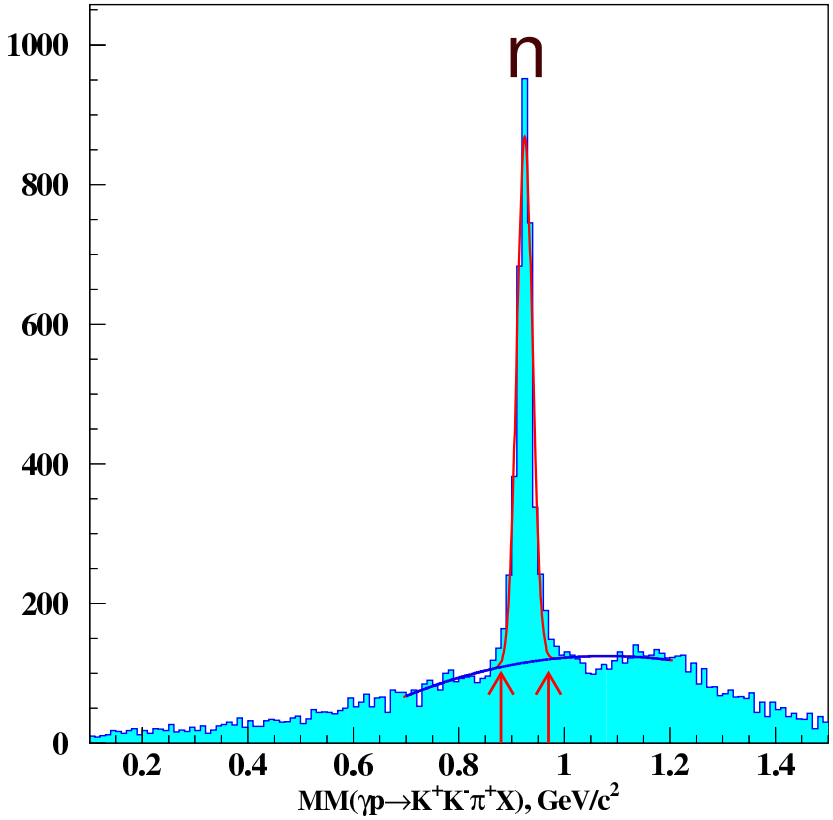
Possible Θ^+ production mechanisms in the reaction $\gamma p \to K_0^* \Theta^+$



W. Liu, C.M. Ko, V. Kubarovsky, nucl-th/0310087

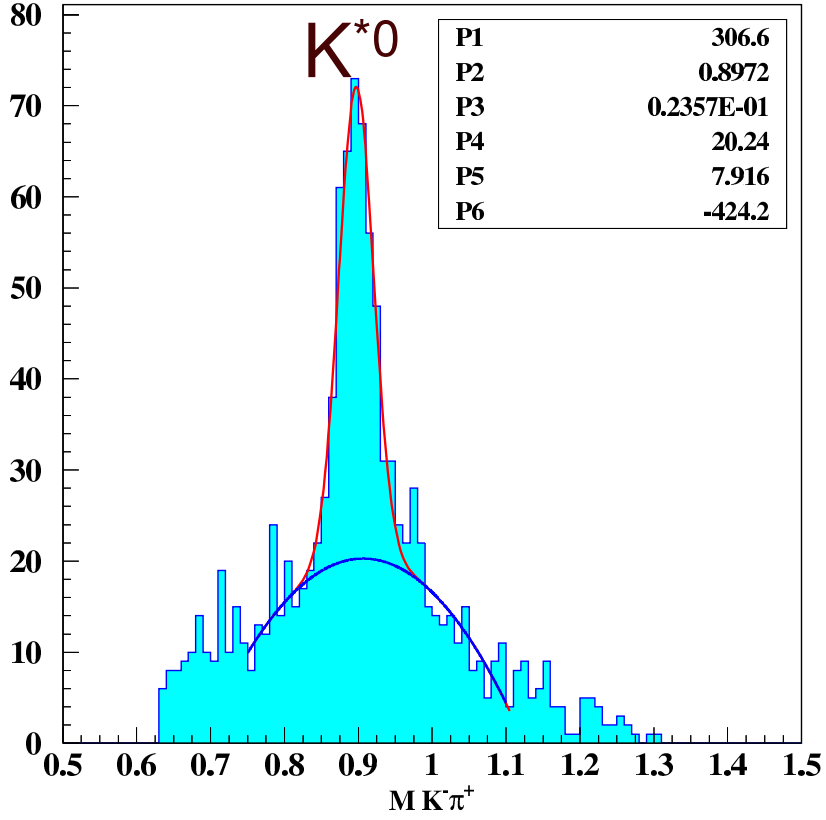
Final state $\pi^+K^-K^+(n)$

After PID



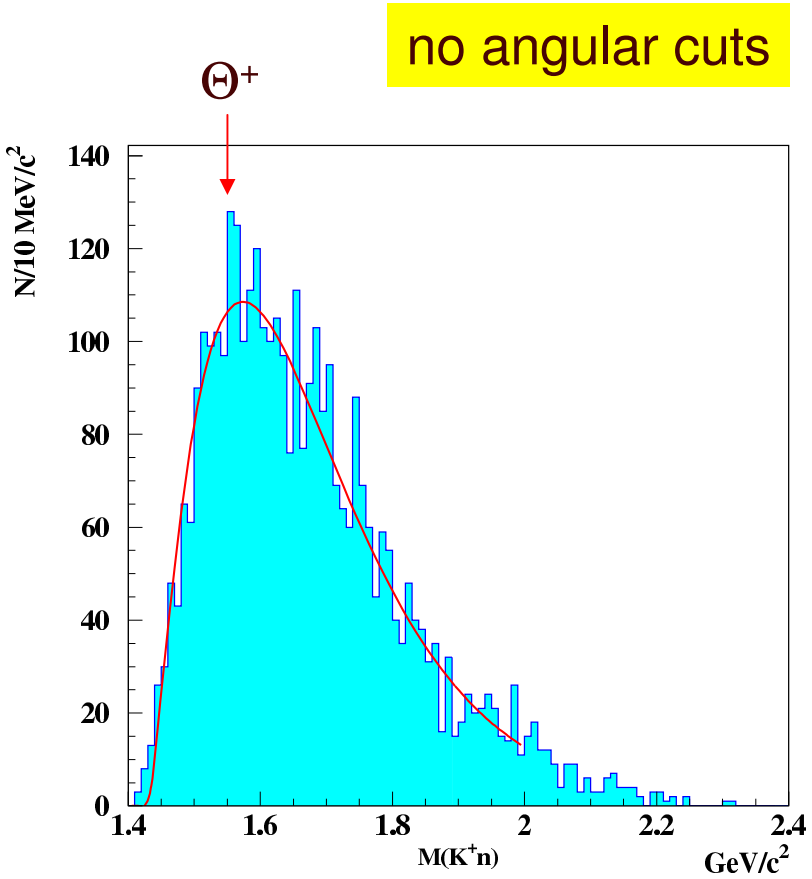
$$MM^2 = P_\gamma^2 + P_p^2 - P_{\pi+}^2 - P_{K+}^2 - P_{K-}^2$$

After cut on neutron mass



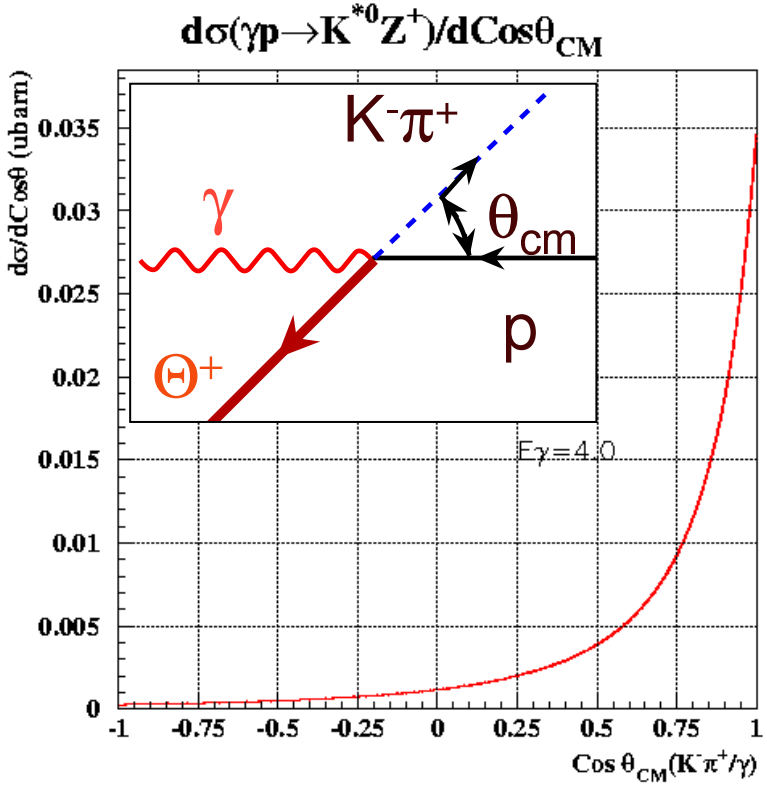
$$M = P_{\pi+}^2 + P_{K-}^2$$

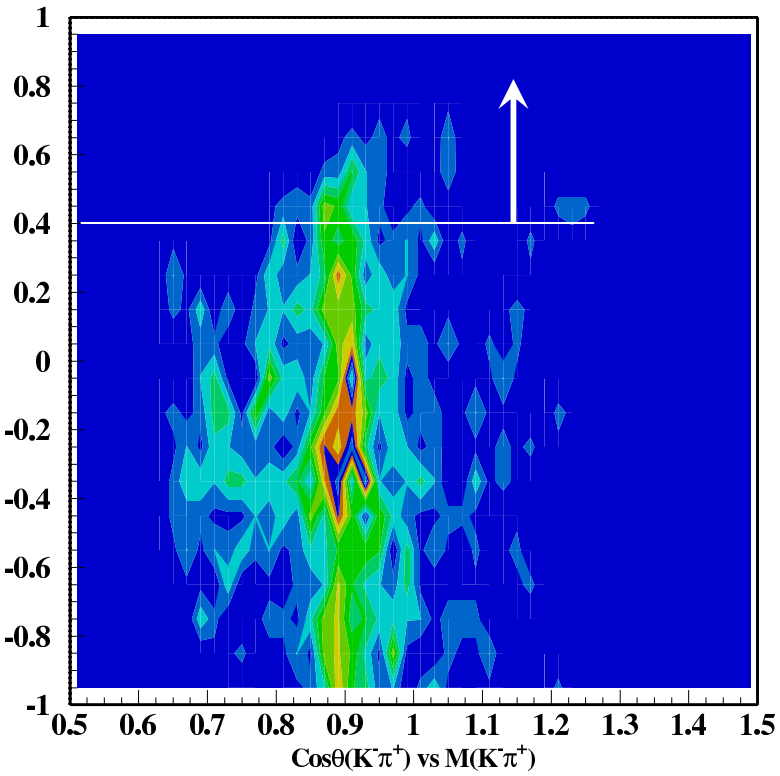
nK^+ invariant mass



Production kinematics

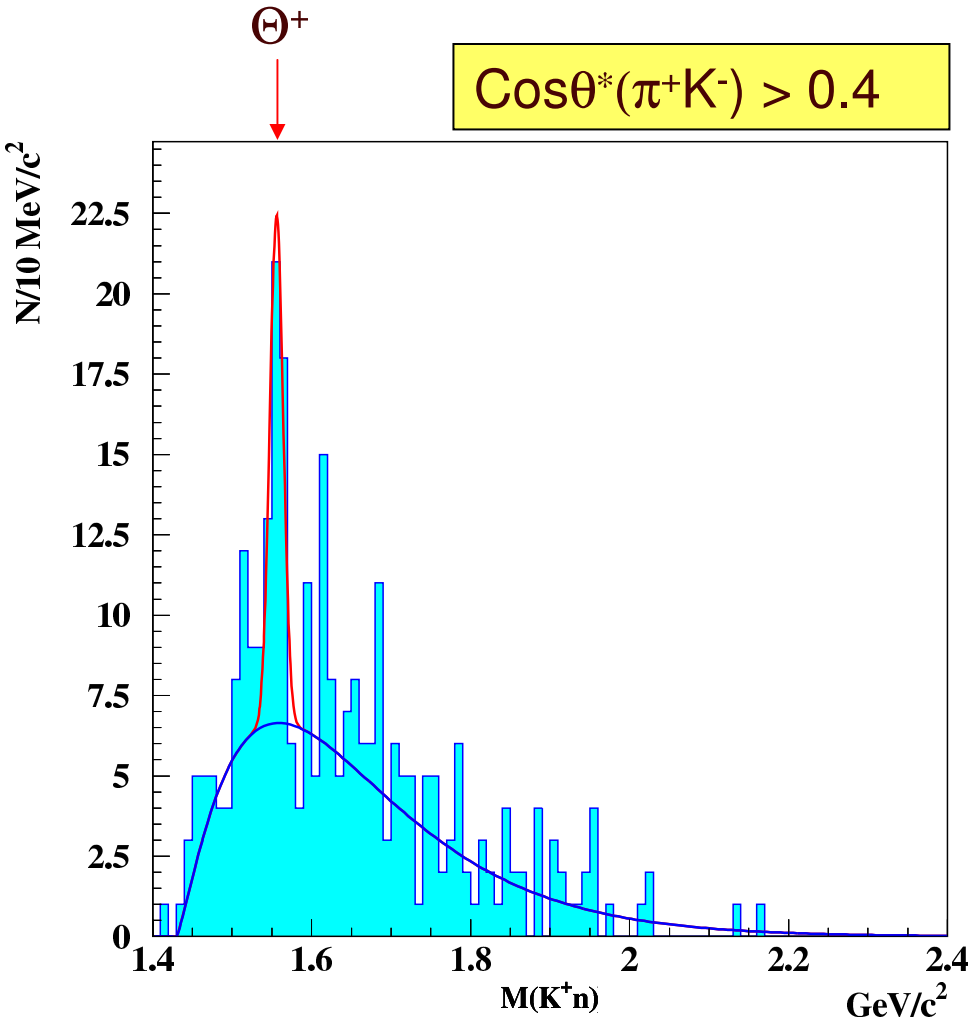
- Production of Θ^+ is dominated by forward production of π^+K^- system
- Cut $\cos\theta(\pi^+K^-)$ to enhance the forward production.





M. Polyakov, private communication

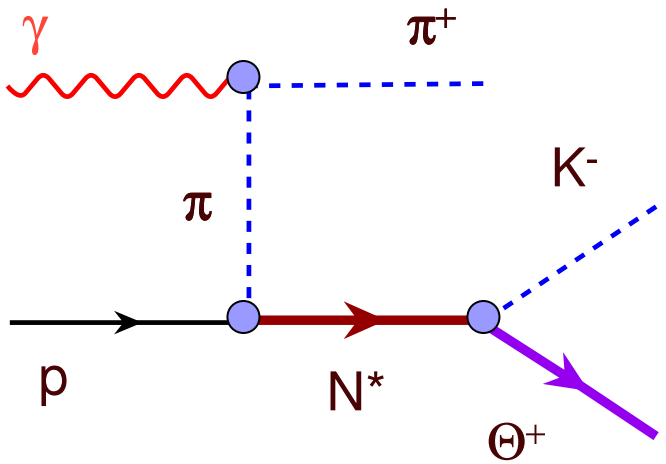
nK+ invariant mass



- Events ~ 31
- M = 1556 MeV
- Γ < 19 MeV

Θ+ Production via N* decays

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



Experimental conditions

3 data runs:

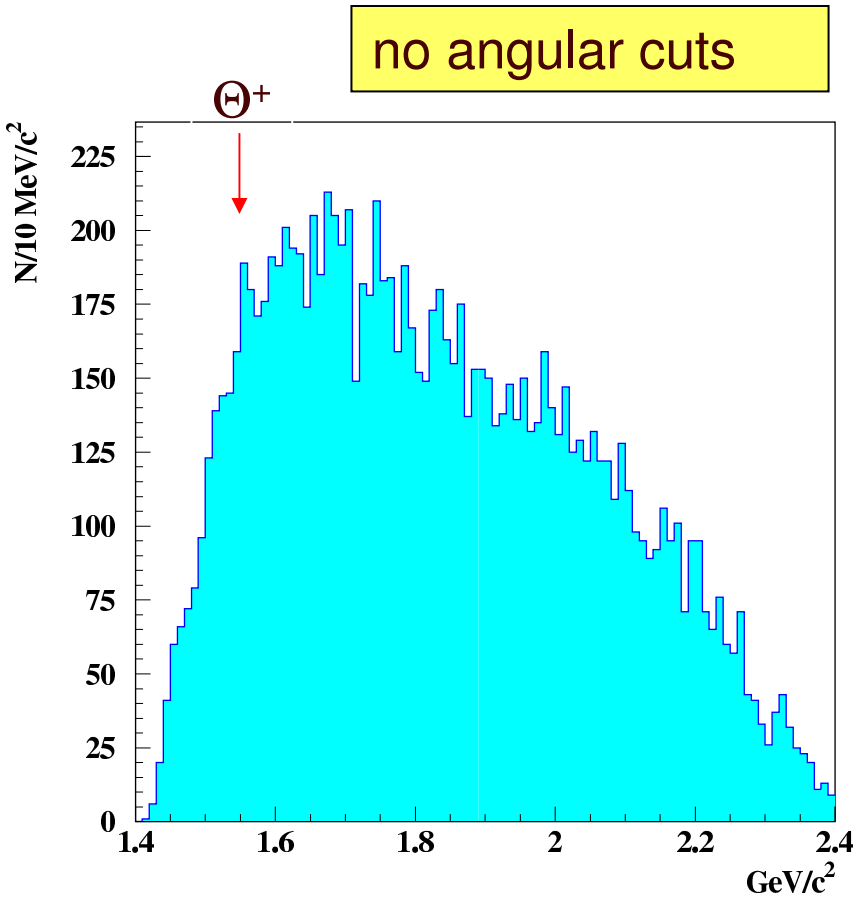
- a. E_γ = 3.2 - 4.0 GeV
- b. E_γ = 3.0 - 5.25 GeV
- c. E_γ = 4.8 - 5.47 GeV

  Target was moved upstream by 1 m

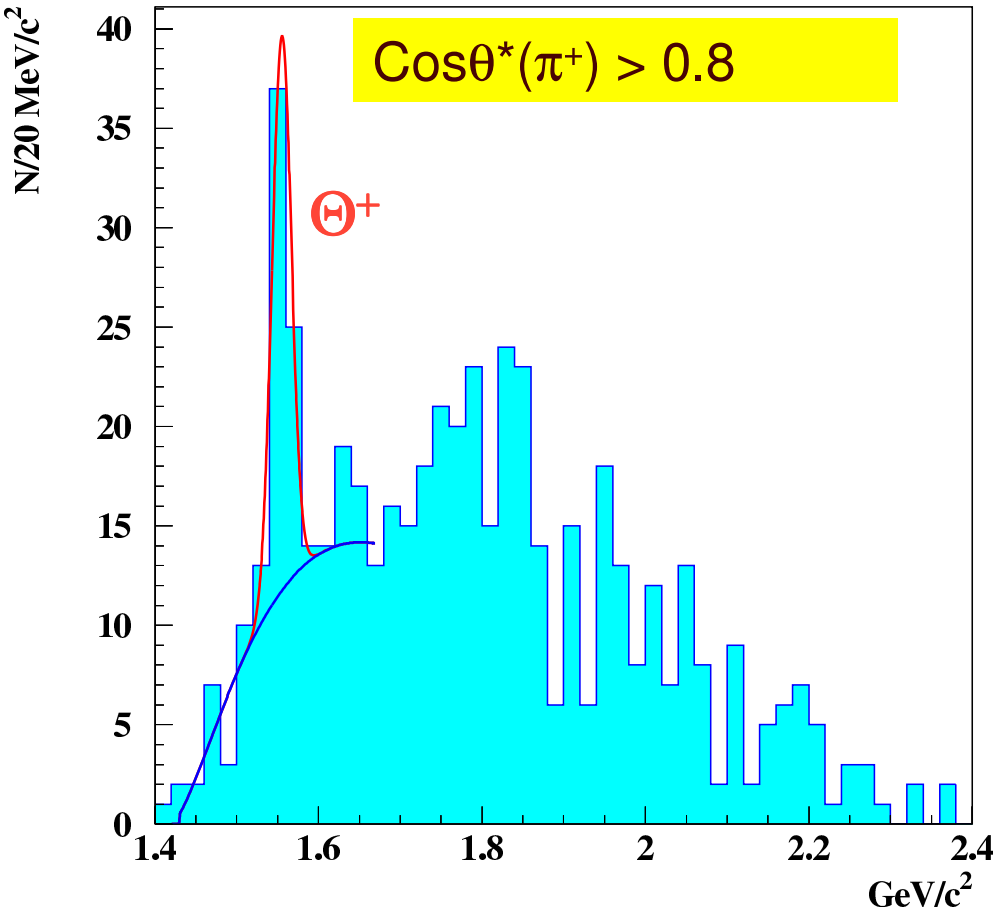
  Toroid magnetic field was reduced by a factor of 2

  to improve acceptance for forward going particles

nK+ invariant mass

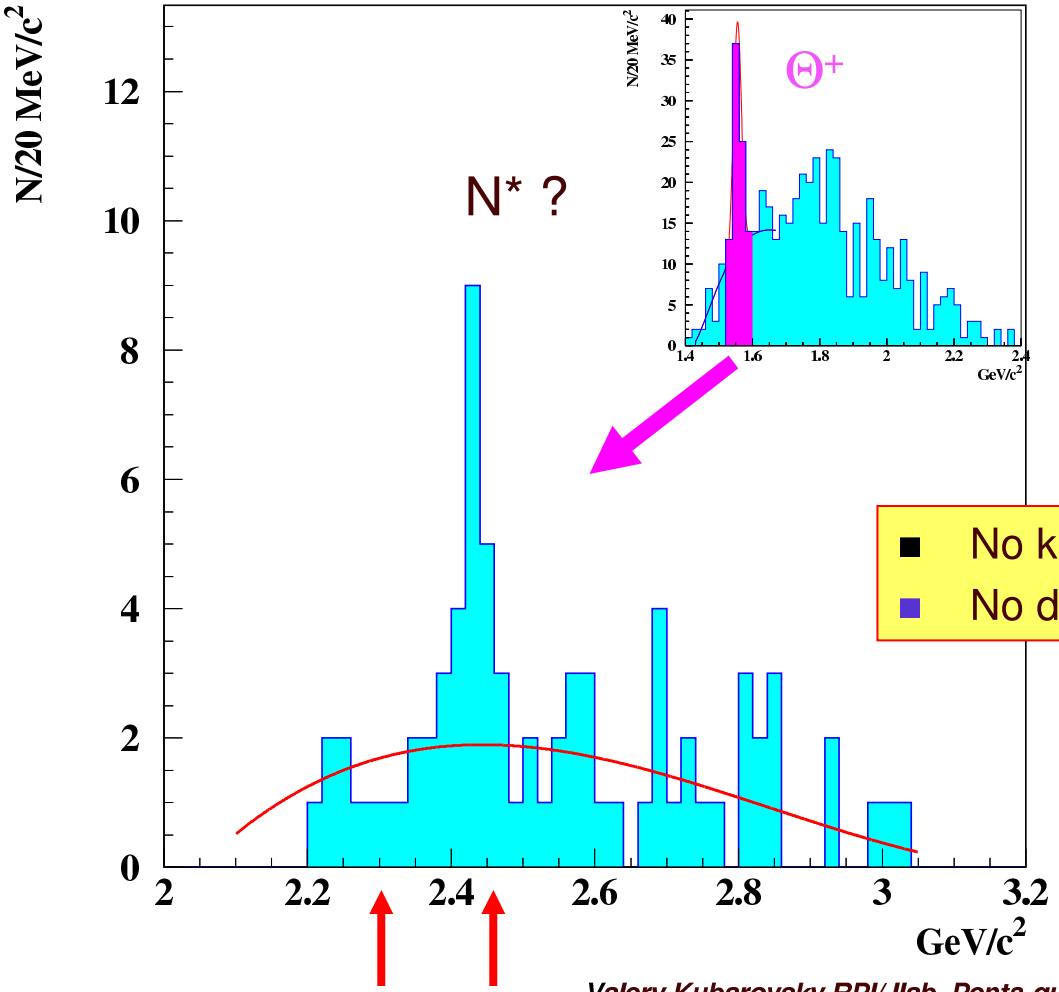


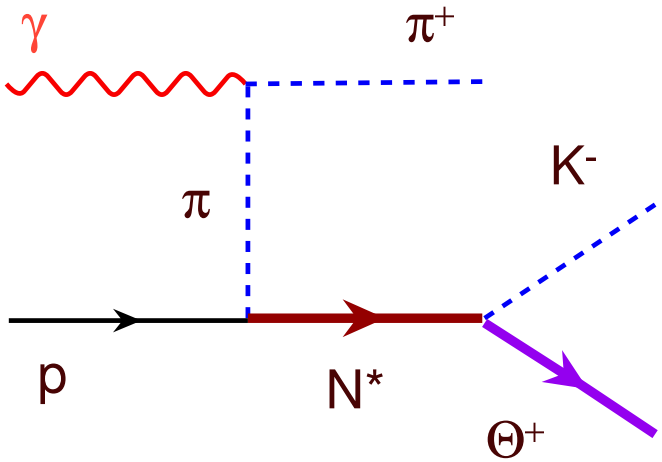
nK^+ invariant mass



- Events ~ 41
- M = 1555 MeV
- Γ < 28 MeV
- Estimated significance 7.8 +/- 1.0 σ

Indications of Θ^+ production from heavy N*(2430)





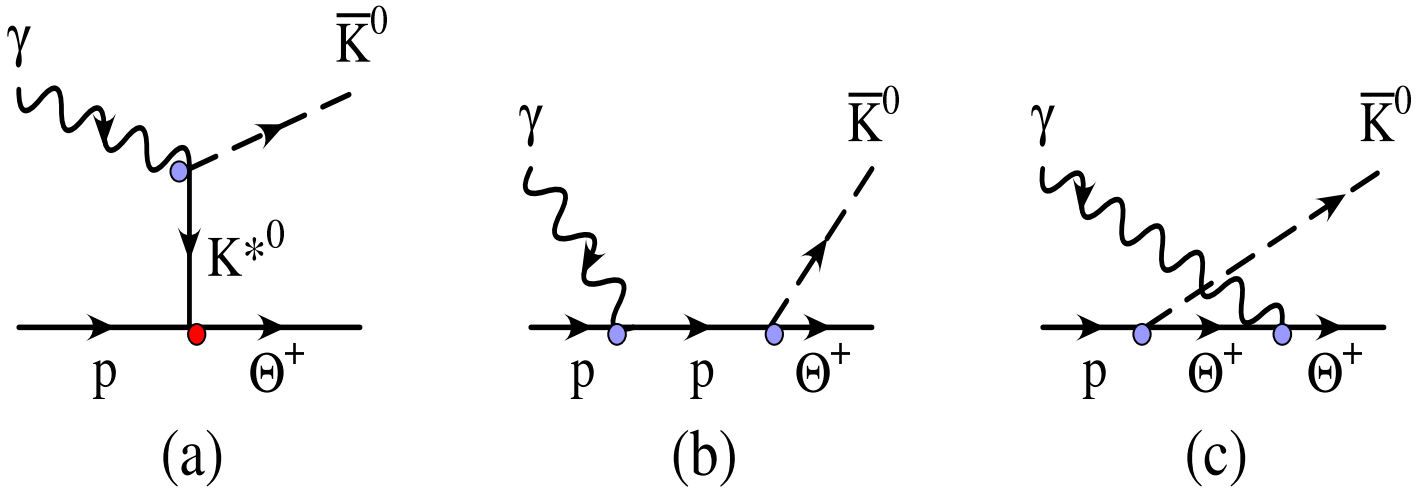
- No known N* resonances in PDG
- No data on elastic scattering in this region

M Θ+K-

Search for pentaquark in the reaction $\gamma p \to \bar{K}^0 \Theta^+$

$\bar{K}^0 \to \pi^+ \pi^-$

$\Theta^+ \to n K^+$



M. Battaglieri , R. De Vita INFN Genova

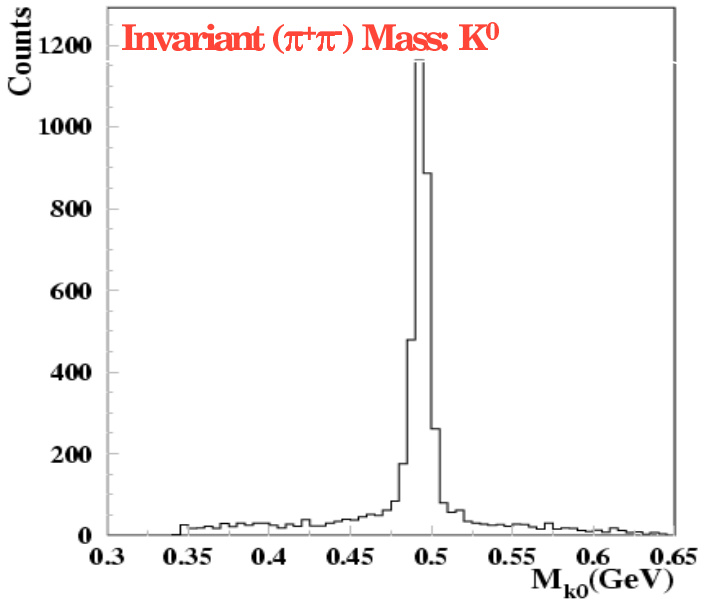
$$\gamma\, p \rightarrow \Theta^{+} K^{0} \rightarrow K^{+} n\, \pi^{+} \pi^{-}$$

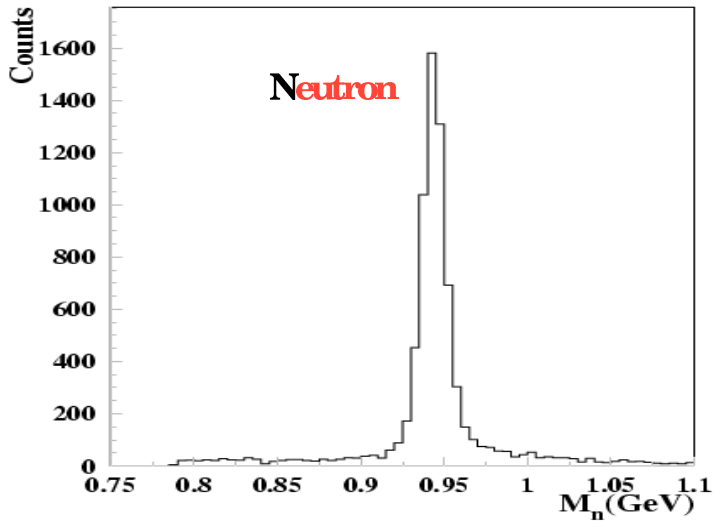
$$\bar{\Theta}^{+} \rightarrow K^{+} \bar{n} \qquad K^{0} \rightarrow K_S^{0} \rightarrow \pi^{+} \pi^{-}$$

Red: detected particles

General Cuts

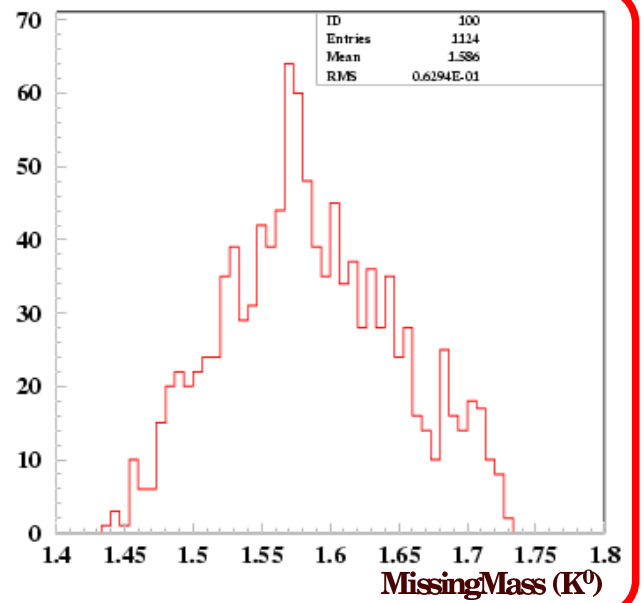
- $abs(T_{Tag} - T_{STart}) < 1$
- $1.8 < E_{\gamma} < 2.3$
- $abs(M_{K+} - 0.494) < 0.04$
- $abs(M_{\pi+\pi-} - 0.494) < 0.01$
- No other charged particles





- Θ^+ should show up as a peak in the $\overline{K^0}$ missing mass

All angles

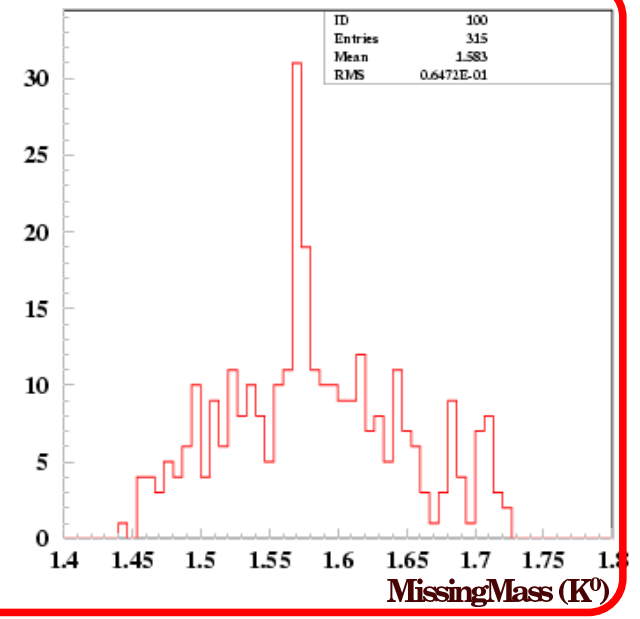


$\gamma\ p \rightarrow \overline{K^0}\ K^+ n$

M(nK^+)

- The peak is enhanced when the $\overline{K^0}$ is selected at backward angles in the C.M.

$cos_{CM}(K^0) < -0.5$



M(nK^+)

- Cutting at $cos_{CM}(K^0) < -0.5$ the peak is identified at:

M = 1571 +/- 4 MeV	FWHM ~ 9 MeV

- statistical significance of 6.4 σ

- Full MC simulations (phase space + signal) indicate:
  - no peaks are expected in that mass spectrum (bg only)
  - the CLAS resolution is compatible with the observed peak width

- We extracted a total cross section ranging from σ_{tot} = 11 to 24 nb

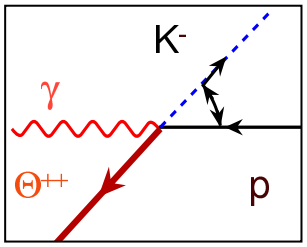
Search for doubly charged X^{++} with positve strangeness.

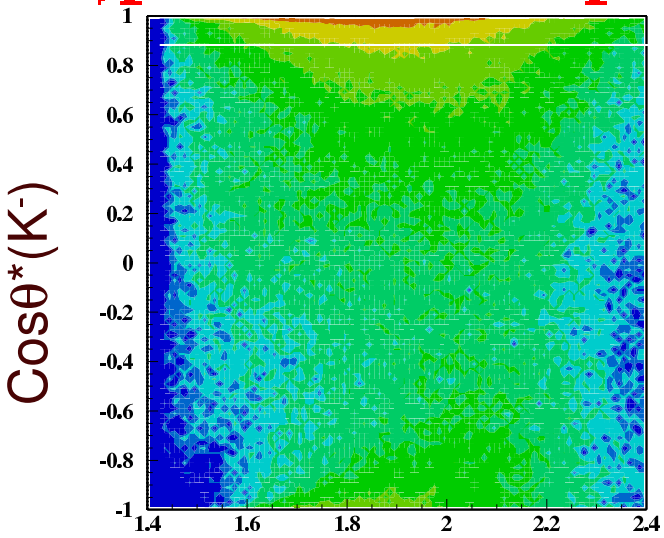
$$\gamma p \to K^- X^{++}, \quad X^{++} \to K^+ p$$

- Isospin 0 and 1 are both possible for Θ^+.
- Isotriplet Θ^0, Θ^+, Θ^{++}
- Isoquintet – charges from -1 to +3.
- The reaction is $\gamma p \to K^- X^{++}, \quad X^{++} \to K^+ p$
- Cut ϕ-mesons $\gamma p \to p\phi, \quad \phi \to K^+ K^-$
- Cut $\Lambda(1520)$ $\gamma p \to K^+ \Lambda(1520), \quad \Lambda \to K^- p$
- 136K events was taken for the further analysis

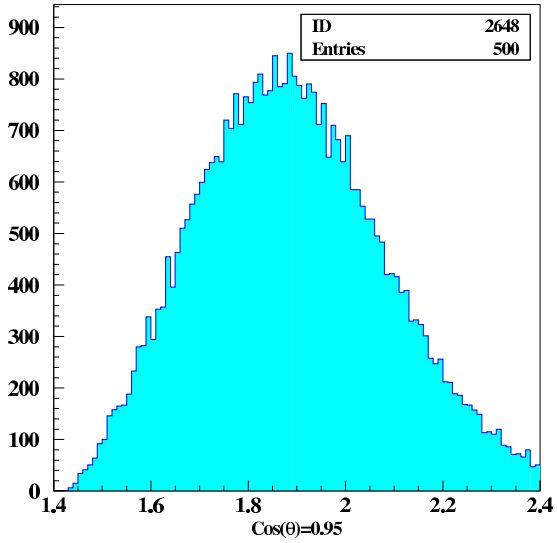
Search for Θ++ → pK+

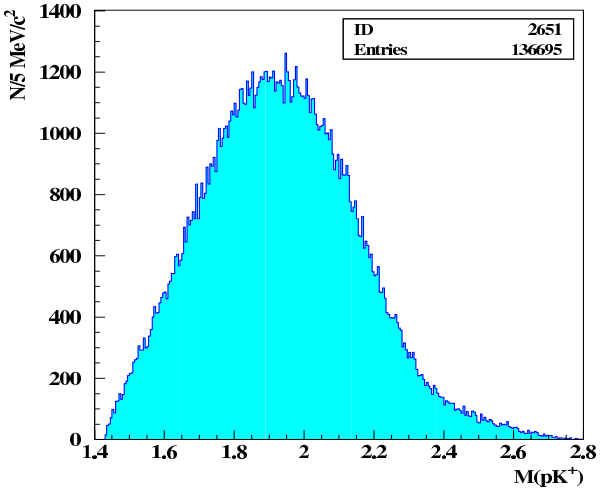
$\gamma p \rightarrow K^- K^+ p$



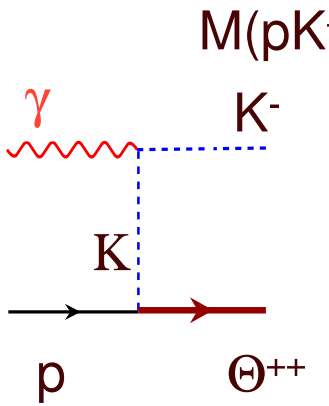


Cosθ*>0.9



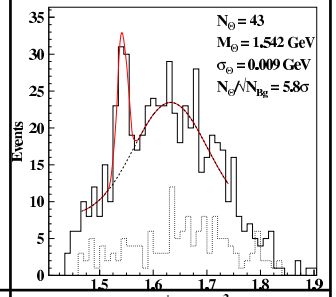
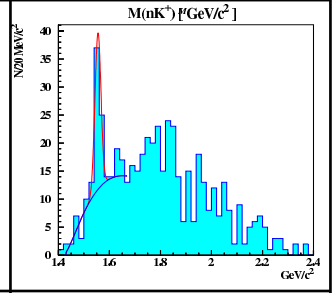
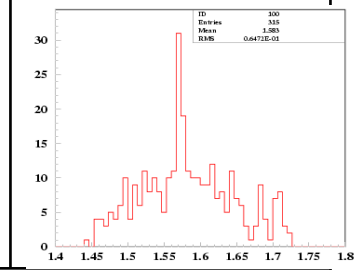


M(pK+)



Summary

CLAS Evidence for Exotic S=+1 Baryon States

Reaction	E_γ	σ (nb)	Mass	Width	
$\gamma d \to p K^- K^+ n$	1.7-3	60-160 $\gamma n \to K^- \Theta^+$	1542(5)	< 21	
$\gamma p \to \pi^+ K^- K^+ n$	3-5.4	?	1555(10)	< 28	
$\gamma p \to K^0 K^+ n$	1.8-2.3	11-24	1571(?)	< 9	

Outlook

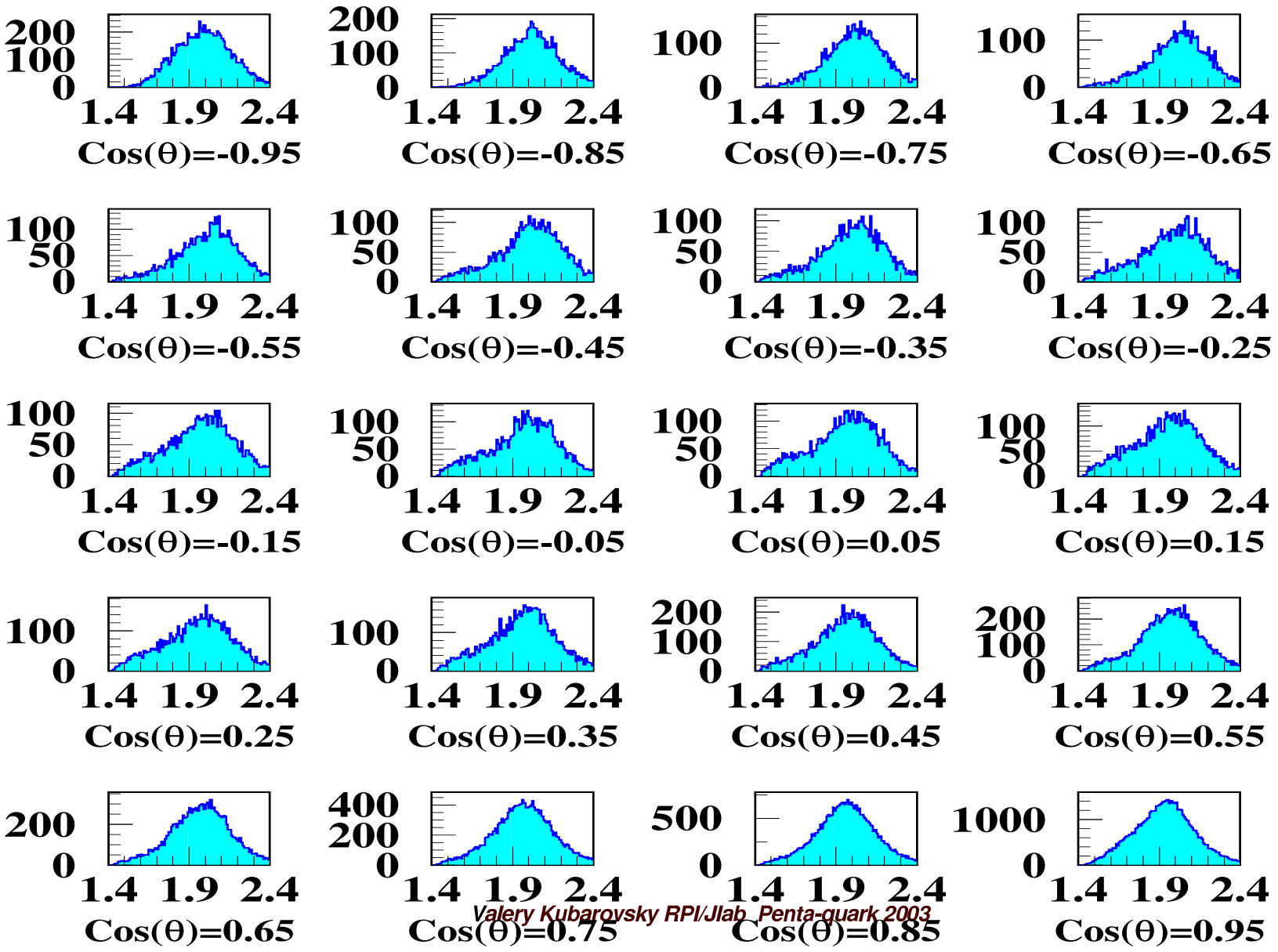
- Run (30 PAC days) on deuterium target scheduled for early next year.

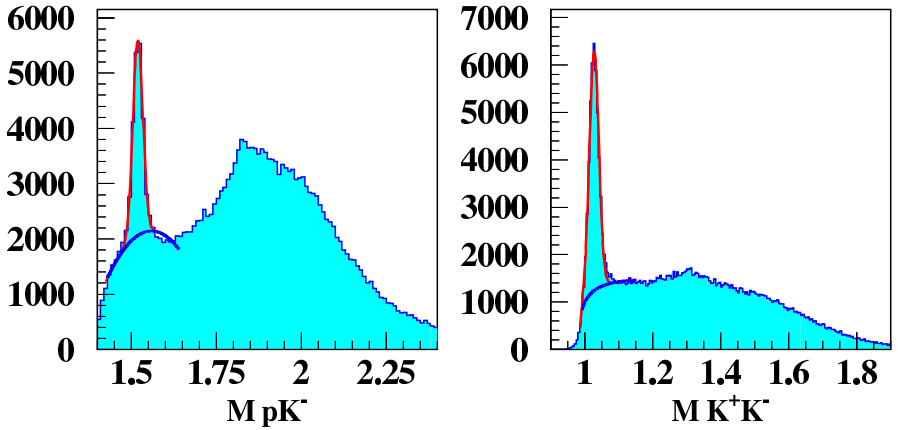
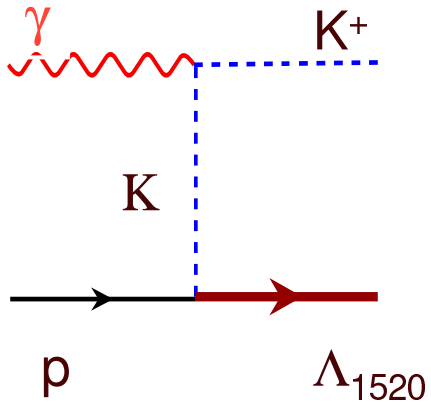
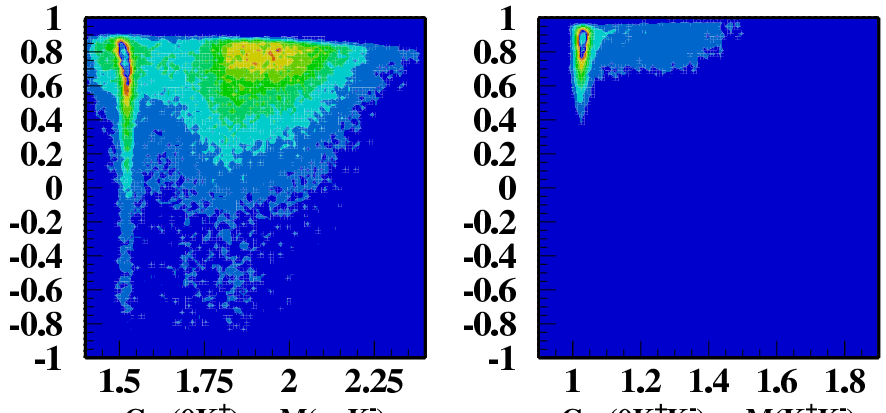
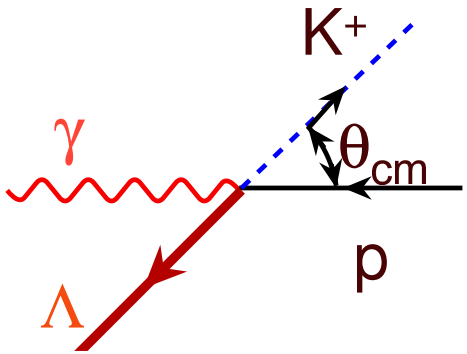
- New proposals are being discussed
  - Ξ^{--} searches
  - Higher statistics data on hydrogen

- Important issues are the determination of the Θ^+ spin and parity isospin, width, cross sections, production mechanisms …

- Search for other members of the pentaquark anti-decuplet.

$M(pK^+)$


200
100
0
1.4 1.9 2.4
Cos(θ)=-0.95
200
100
0
1.4 1.9 2.4
Cos(θ)=-0.85
100
0
1.4 1.9 2.4
Cos(θ)=-0.75
100
0
1.4 1.9 2.4
Cos(θ)=-0.65
100
50
0
1.4 1.9 2.4
Cos(θ)=-0.55
100
50
0
1.4 1.9 2.4
Cos(θ)=-0.45
100
50
0
1.4 1.9 2.4
Cos(θ)=-0.35
100
50
0
1.4 1.9 2.4
Cos(θ)=-0.25
100
50
0
1.4 1.9 2.4
Cos(θ)=-0.15
100
50
0
1.4 1.9 2.4
Cos(θ)=-0.05
100
50
0
1.4 1.9 2.4
Cos(θ)=0.05
100
50
0
1.4 1.9 2.4
Cos(θ)=0.15
100
0
1.4 1.9 2.4
Cos(θ)=0.25
100
0
1.4 1.9 2.4
Cos(θ)=0.35
200
100
0
1.4 1.9 2.4
Cos(θ)=0.45
200
100
0
1.4 1.9 2.4
Cos(θ)=0.55
200
0
1.4 1.9 2.4
Cos(θ)=0.65
400
200
0
1.4 1.9 2.4
Cos(θ)=0.75
500
0
1.4 1.9 2.4
Cos(θ)=0.85
1000
0
1.4 1.9 2.4
Cos(θ)=0.95

$\gamma p \to K^- K^+ p$

$\gamma p \to K^+ \Lambda(1520), \quad \Lambda \to K^- p$ $\qquad$ $\gamma p \to p\phi, \quad \phi \to K^+ K^-$