

EVIDENCE FOR AN EXOTIC, $S=+1$, BARYON STATE IN PHOTOPRODUCTION REACTIONS WITH CLAS

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V.Kubarovsky, RPI INT - Seattle, July 21-25, 2003

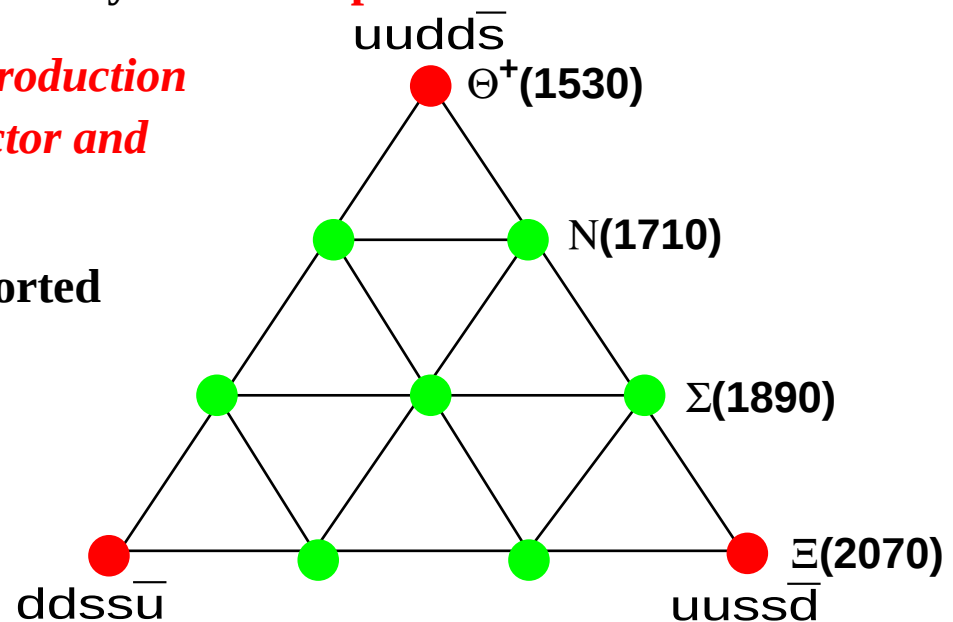
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Introduction

- 5-quark resonances have been predicted and search for many years. Recently more quantitative predictions have been made within chiral soliton model (Diakonov et al, Z.Phys. A359 (1997) 305). Using $P_{11}(1710)$ as the “anchor” for the masses of the anti-decuplet, an exotic, $I=0$ and $S=+1$ state, Θ^+ (Z^+), is predicted with **$M=1.53$ GeV** and a narrow width of **15 MeV**, decaying predominantly to **nK^+** or **pK^0** .

Suitable for a search in photoproduction reactions using the CLAS detector and at energies available at JLAB.

- Two experiments have reported evidence for $\Theta^+(1530)$ in $\gamma^{12}\text{C}$ (LEPS, Spring-8), and $K^+\text{Xe}$ (DIANA, ITEP) interactions.



CEBAF Large Acceptance Spectrometer

Charged particles:

$$p > 0.2 \text{ GeV}/c$$

$$8^\circ < \theta < 140^\circ$$

$$\sigma_p/p \sim 0.5\% \quad (\theta < 30^\circ)$$

$$\sigma_p/p \sim 1-2\% \quad (\theta > 30^\circ)$$

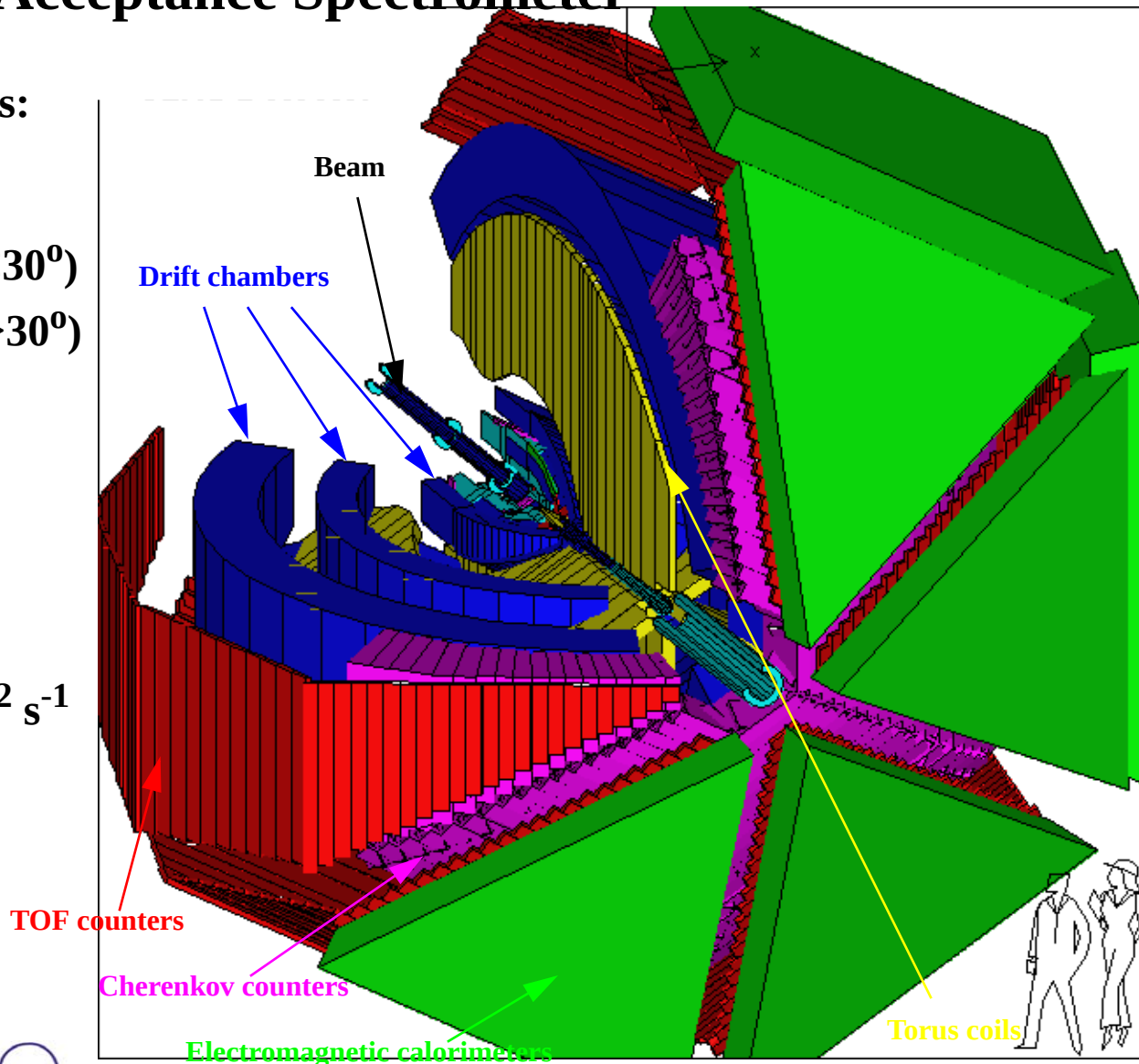
$$\sigma_\theta = 1 \text{ mrad}$$

$$\sigma_\phi = 4 \text{ mrad}$$

$$\sigma_t = 100-250 \text{ ps}$$

Beams: e^-/γ

$$L_\gamma = 5 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$$



Data samples

❑ Photoproduction data on deuterium (CLAS/g2 run, 1999):

Tagged photons with energies up to 3 GeV and liquid deuterium target. Single charged particle trigger.

Reaction of interest $\gamma d \rightarrow p K^+ K^- (n)$. Detected final state $(p K^+ K^-)$.

❑ Photoproduction data on hydrogen (CLAS/g6, 1999):

Tagged photons with energies up to 5.2 GeV and liquid hydrogen target. Two charged particle trigger.

Reaction of interest $\gamma p \rightarrow \pi^+ K^- K^+ (n)$. Detected final state $(\pi^+ K^+ K^-)$.

In both cases neutron is identified via missing mass.



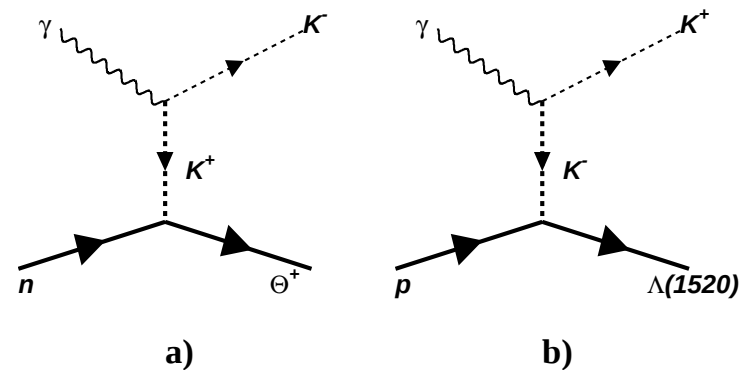
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Photoproduction on deuterium: $\gamma d \rightarrow K^+ K^- X$

Analysis assuming $\gamma n \rightarrow n K^+ K^-$ with corrections for Fermi smearing (*the technique used by LEPS collaboration*) did not yield statistically significant result.

□ Production on a single nucleon proceeds via t-channel kaon exchange (similar to the Λ production)

□ The t-channel meson, K^- in the case of Θ^+ , is emitted predominantly in the forward direction.



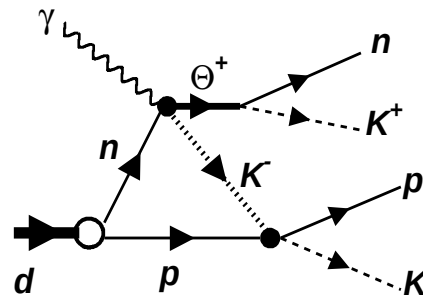
The limited forward acceptance of CLAS for negatively charged particles is unfavorable for the direct photoproduction of Θ^+ in this reaction.

Photoproduction on deuterium: $\gamma d \rightarrow p K^+ K^- (n)$

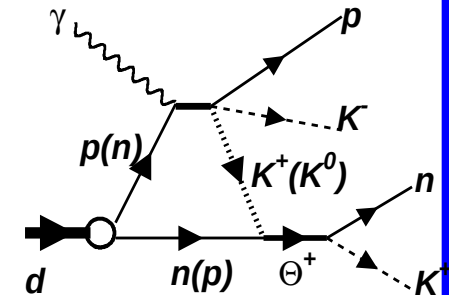
Exclusive reaction requires FSI: *both nucleons should be involved in the reaction* ($P_N > \bar{P}_F$).

☐ Reactions with FSI will produce K^- at larger angles.

☐ In exclusive kinematics no correction for Fermi smearing is needed.



a)

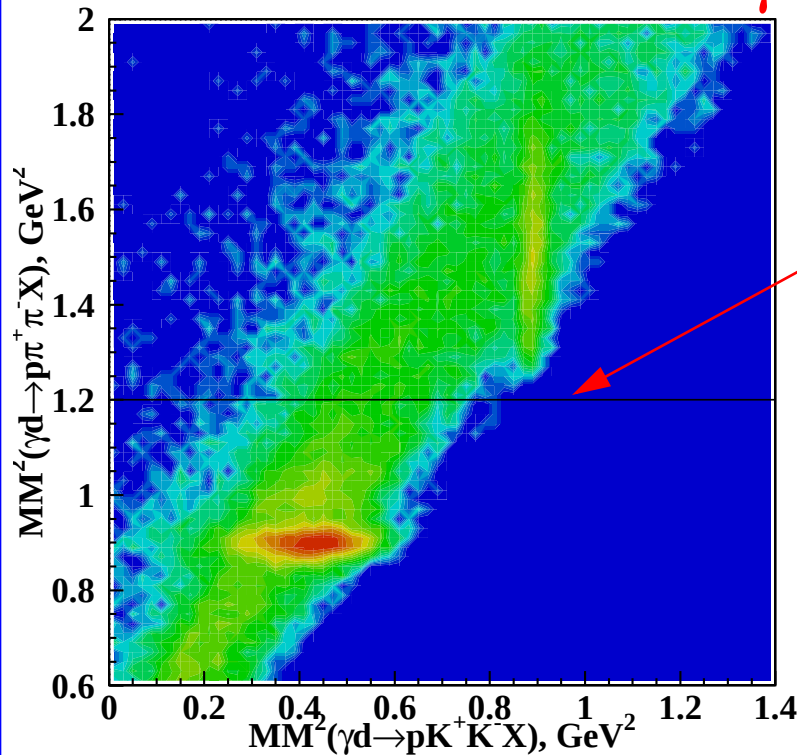


b)

Production of $\Lambda(1520)$ on deuterium suggests the existence of large FSI.

In ~50% of Λ events, both nucleons in final state have $P_N > 0.2$ GeV/c.

Reaction $\gamma d \rightarrow p K^+ K^- n$

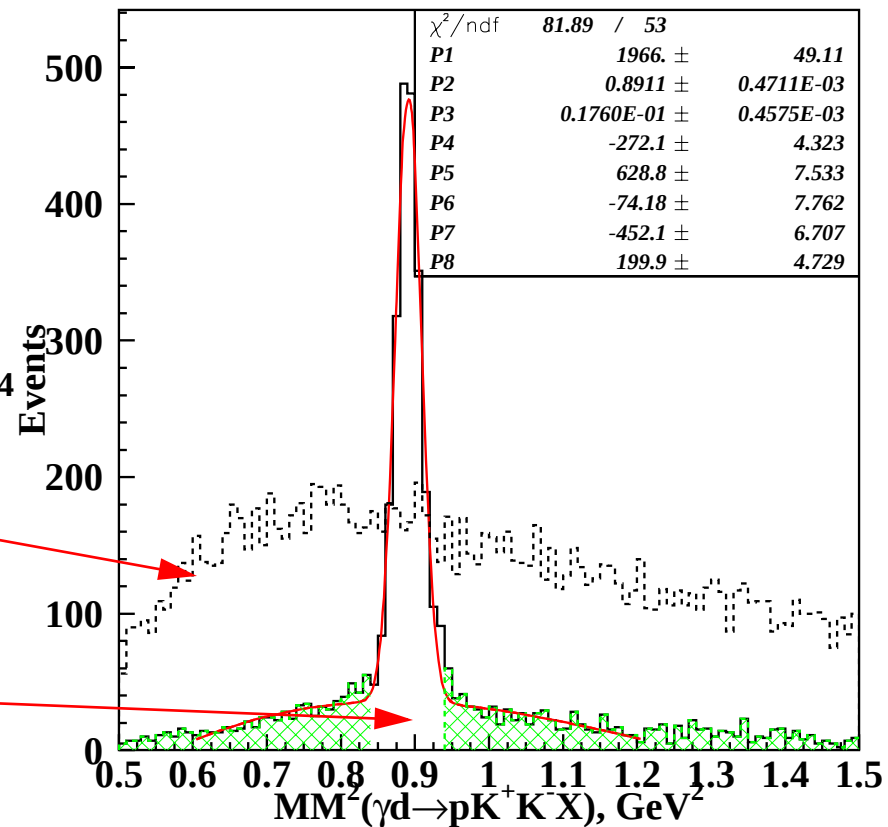


□ Clean separation of $\gamma d \rightarrow p\pi^+\pi^-X$ and $\gamma d \rightarrow pK^+K^-X$ events.

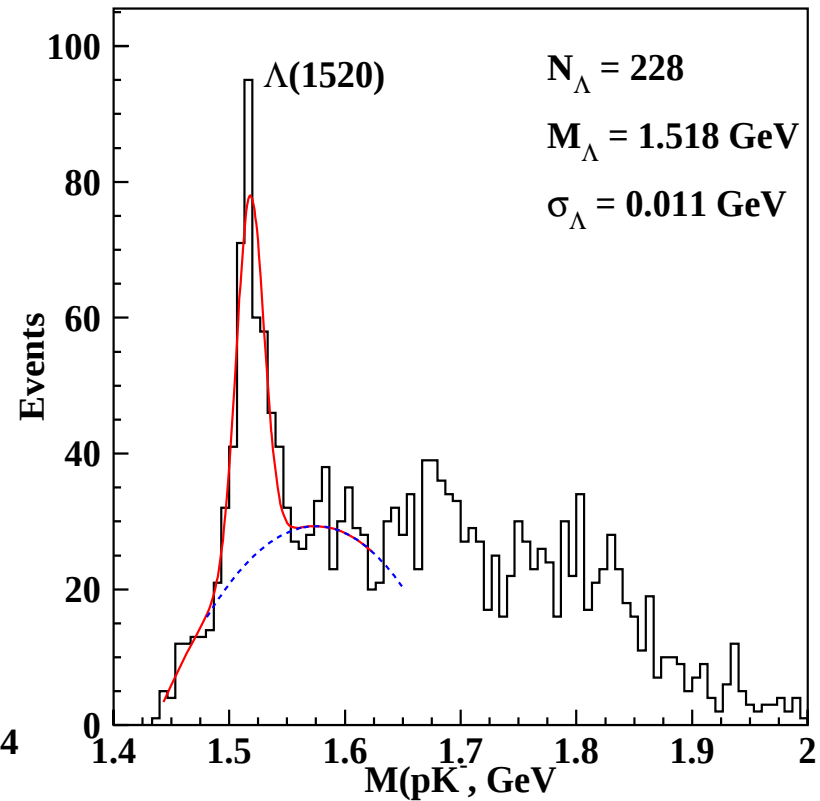
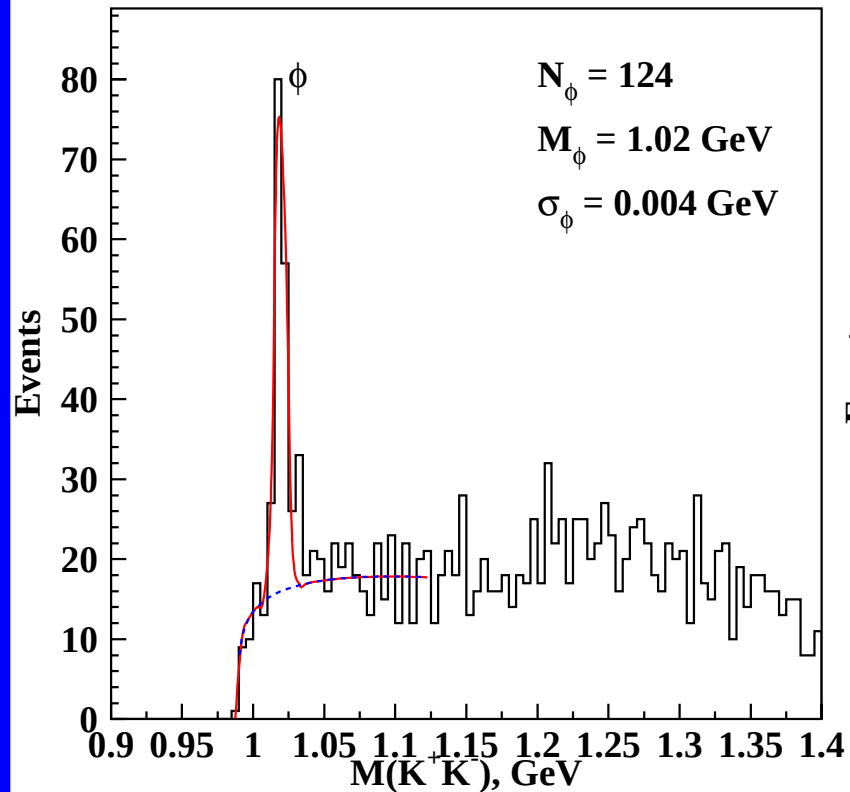
Events with $MM^2(\gamma d \rightarrow p\pi^+\pi^-) < 1.2 \text{ GeV}^2$ are rejected.

□ No pK^+K^-n events are cut out (dashed histogram).

□ 15% non pK^+K^-n events in a $\pm 3\sigma$ range.



Production of ϕ and $\Lambda(1520)$ in the reaction $\gamma d \rightarrow p K^+ K^- n$



These resonances contribute to the background.



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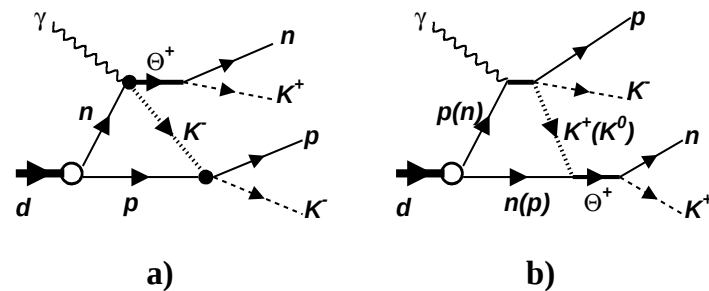
Kinematical cuts used to reduce background

- ❑ $M(K^+K^-) > 1.07 \text{ GeV}$: eliminates ϕ 's.
- ❑ $P_n > 0.07 \text{ GeV/c}$: momentum of both nucleons should be greater than the average Fermi momentum (detected protons have $P_p > 0.25 \text{ GeV/c}$)
- ❑ $P_{K^+} < 1 \text{ GeV/c}$: from 3-body ($\gamma d \rightarrow p K^- \Theta^+$) phase space simulations.
- ❑ Exclude production of Λ' using cuts on $M(pK^-)$.

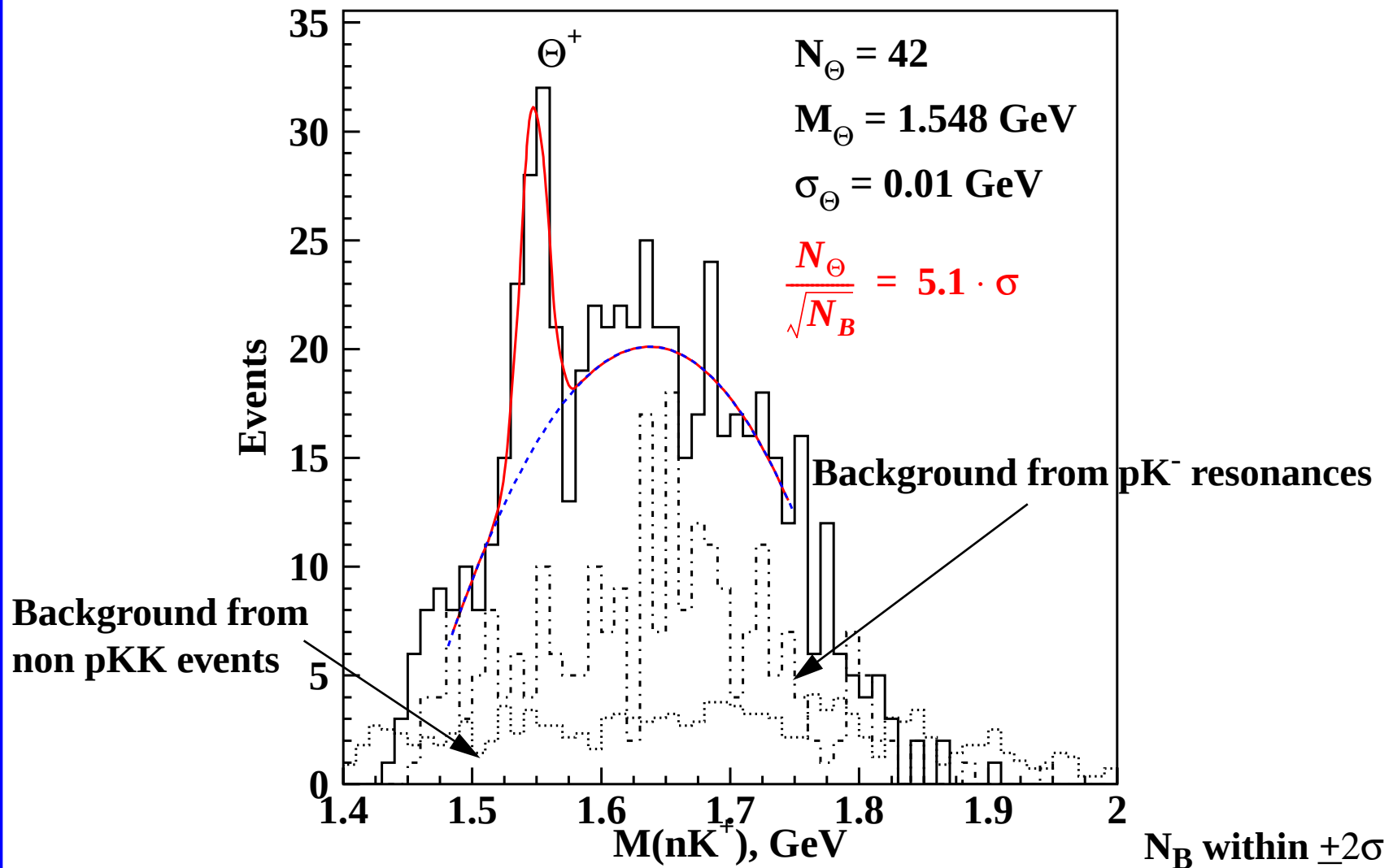
Θ^+ signal is expected in the invariant mass of nK^+ system.

$$M(nK^+) \equiv MM(\gamma d \rightarrow p K^- X)$$

No corrections for Fermi smearing are necessary.



Distribution of $M(nK^+)$ for remaining events

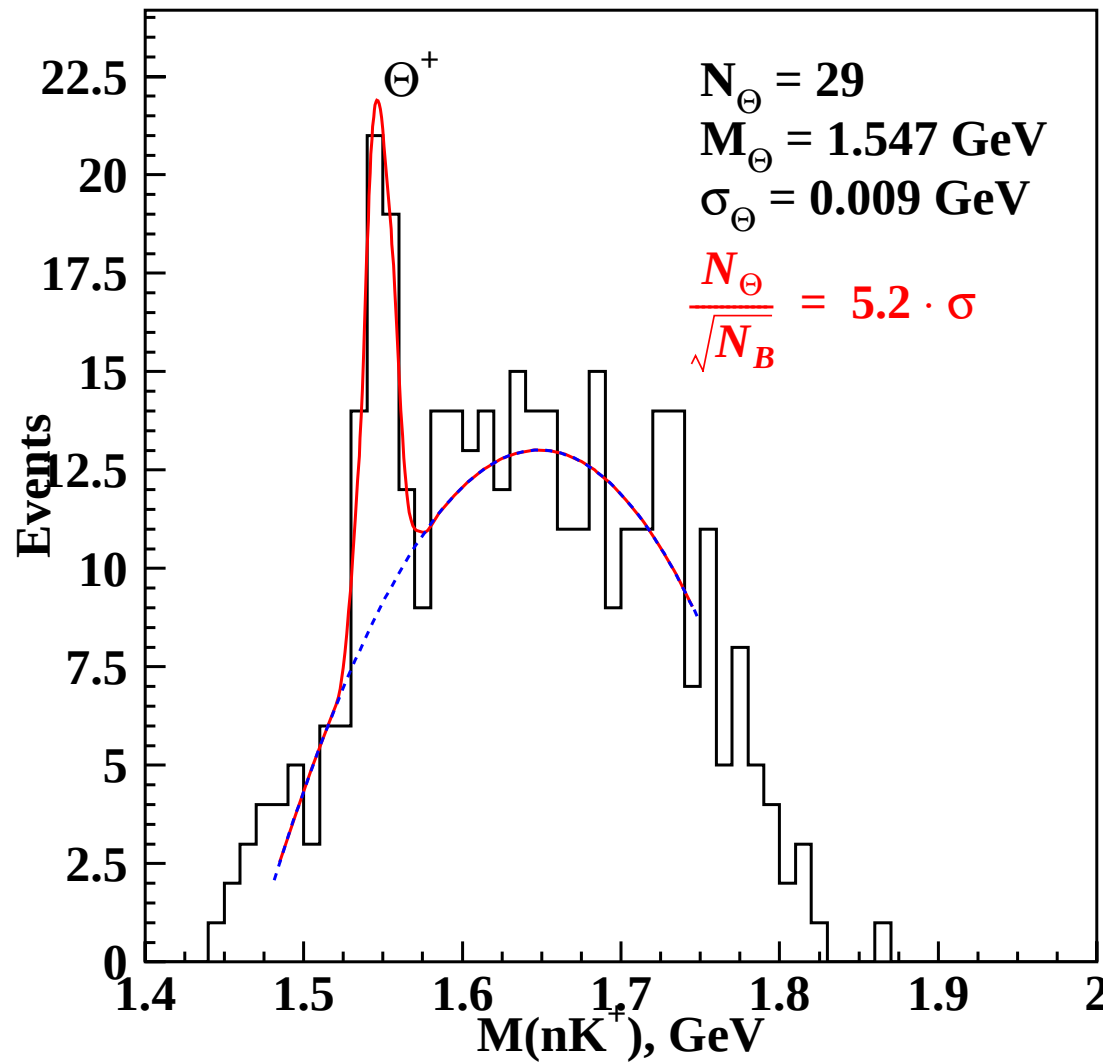


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Distribution of $M(nK^+)$ after tight cut $|\Delta t(pK)| < 0.75\text{ns}$



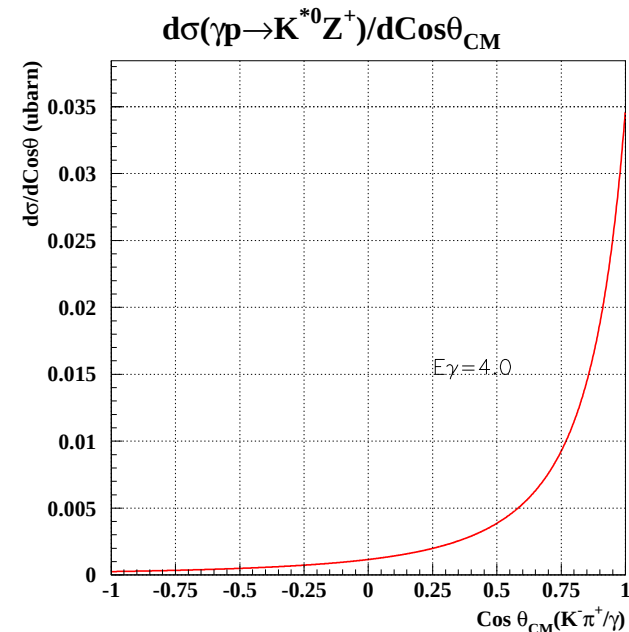
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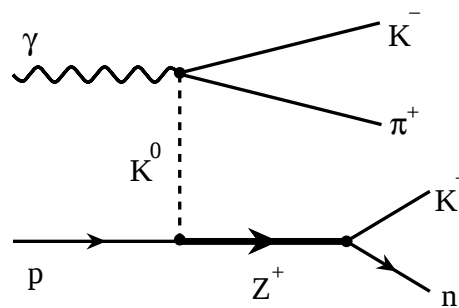
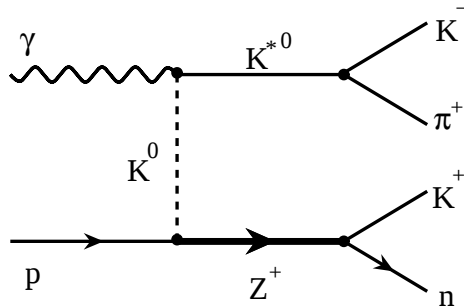
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Photoproduction on hydrogen: reaction $\gamma p \rightarrow \pi^+ K^- K^+ n$

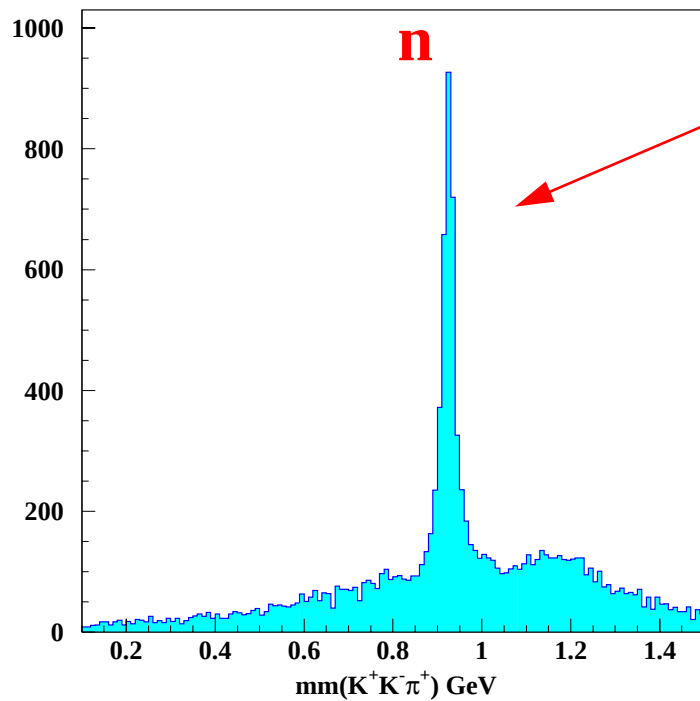
- ❑ Production via t-channel K^0 exchange.
- ❑ Produced t-channel mesonic system, $\pi^+ K^-$, is emitted predominantly in the forward direction (cross section is large at small t).
- ❑ Both diagrams have been considered in the final analysis.



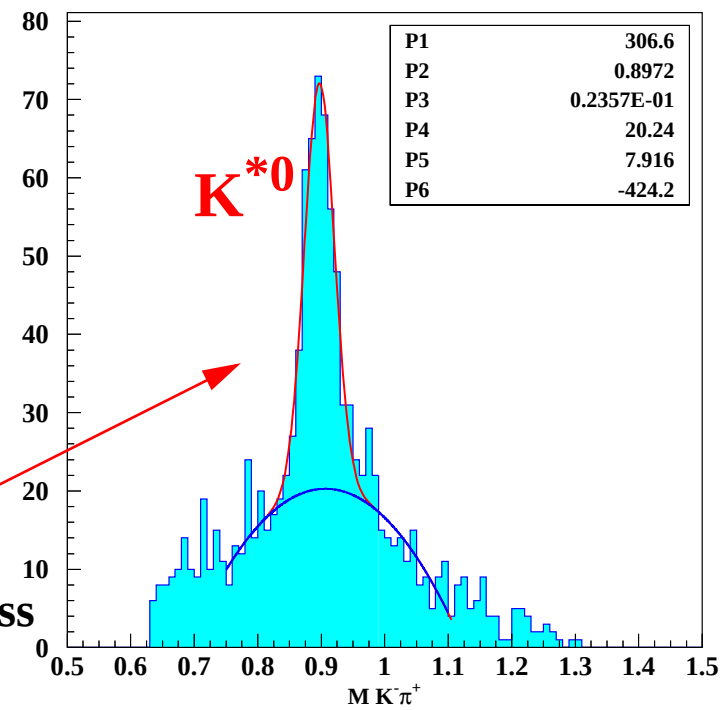
Calculations by Polyakov.



Missing mass distribution of $\gamma p \rightarrow \pi^+ K^- K^+ X$

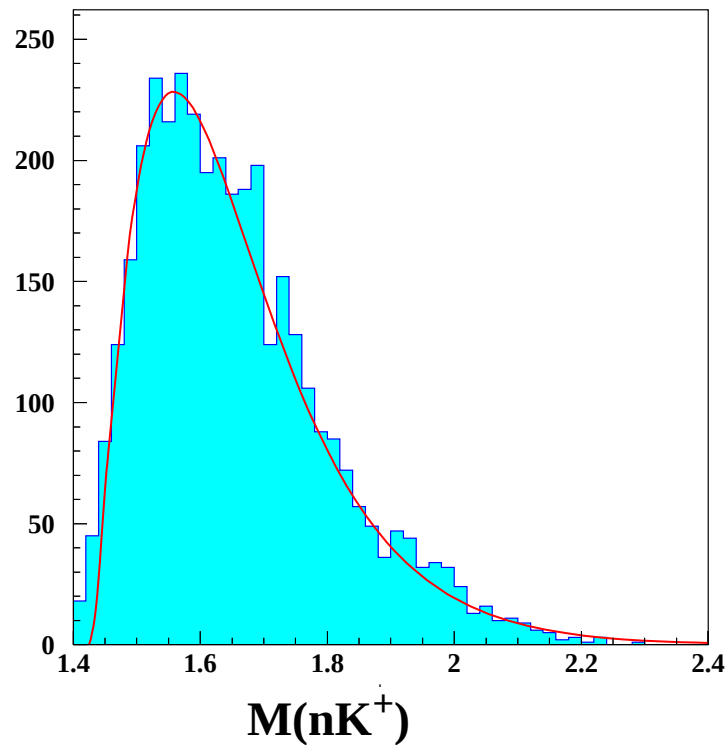


Invariant mass of $\pi^+ K^-$



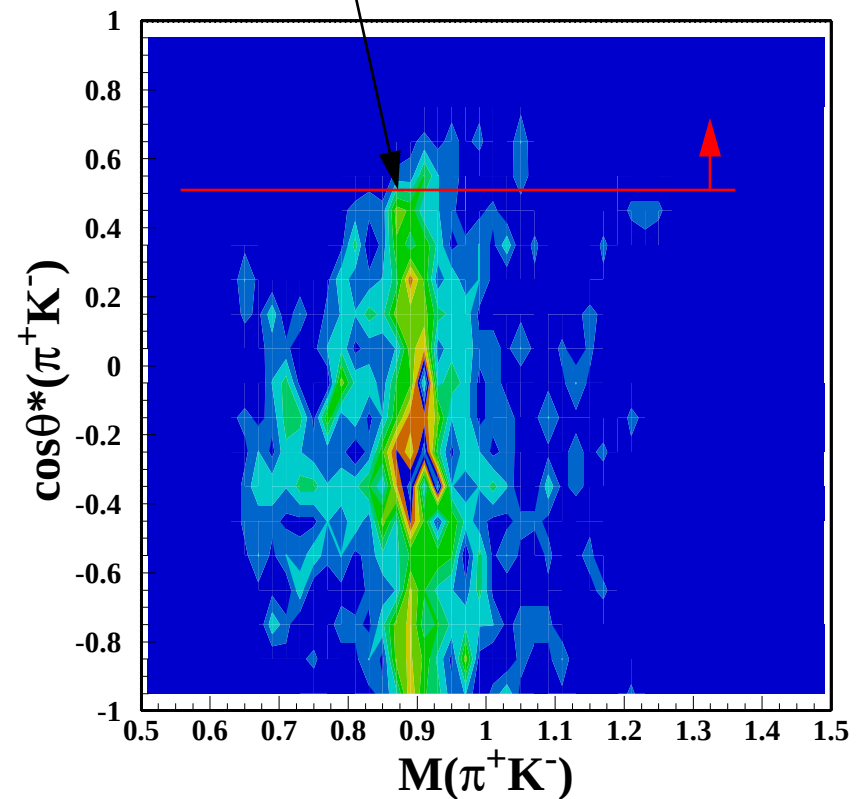
After cut on the missing neutron mass

Invariant mass of nK^+

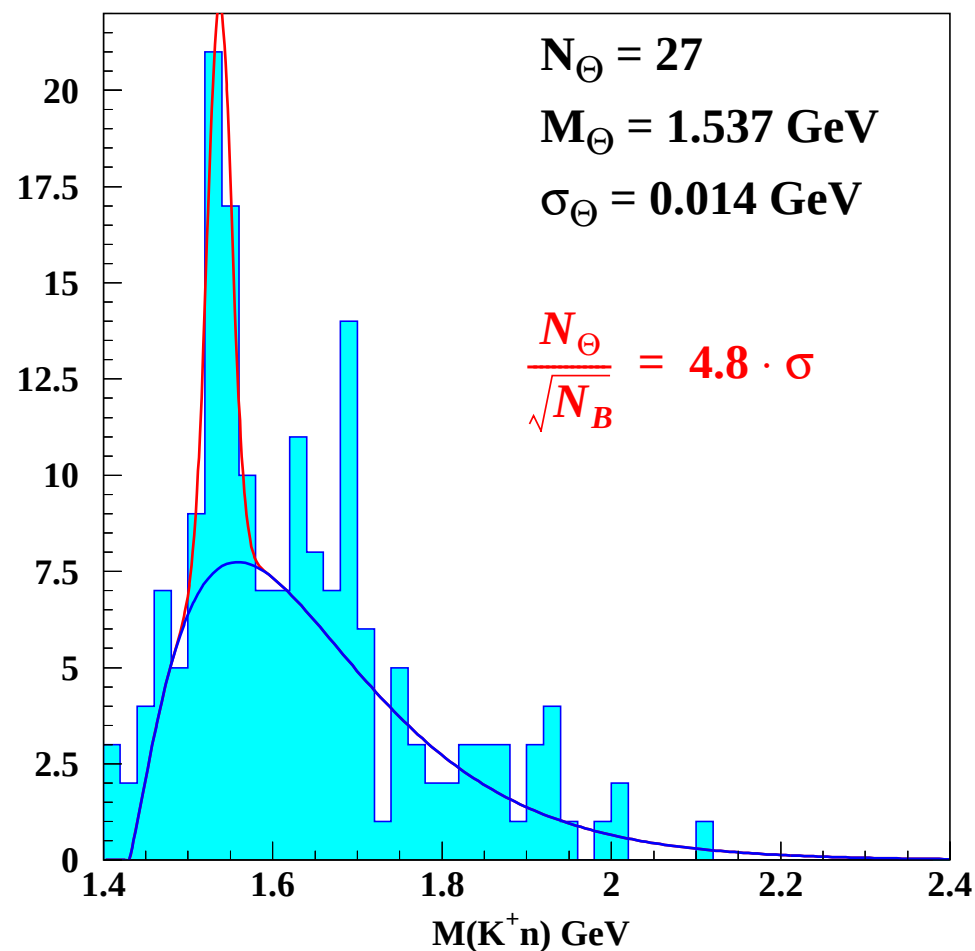


$$M(nK^+) \equiv M(\gamma p \rightarrow \pi^+ K^- X)$$

Cut to enhance forward production



Distribution of nK^+ invariant mass after $\cos\Theta^*(\pi^+K^-)>0.5$



Background shape taken from the fit to the distribution without $\cos\Theta^*(\pi^+K^-)$ cut.



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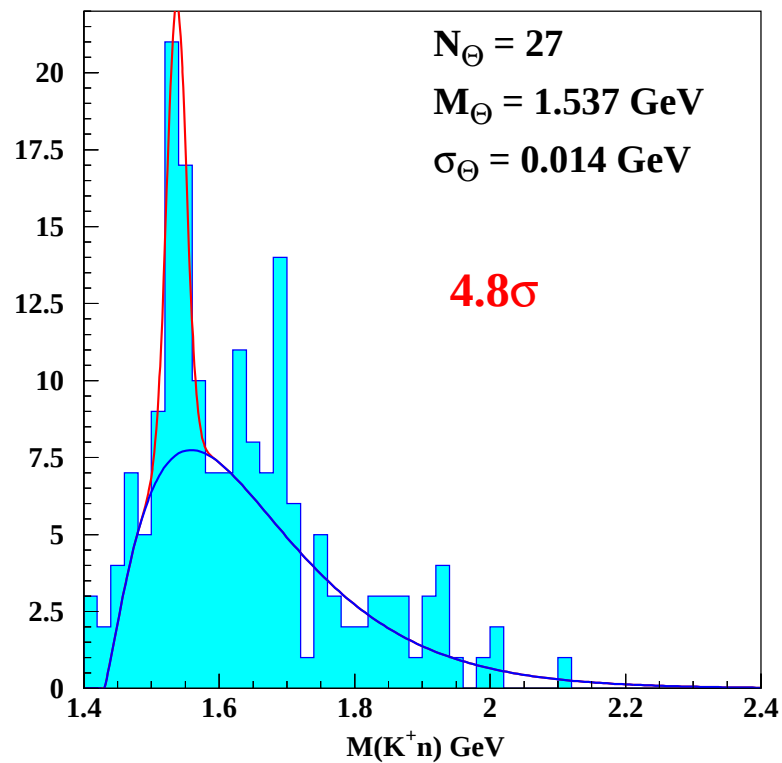
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Summary

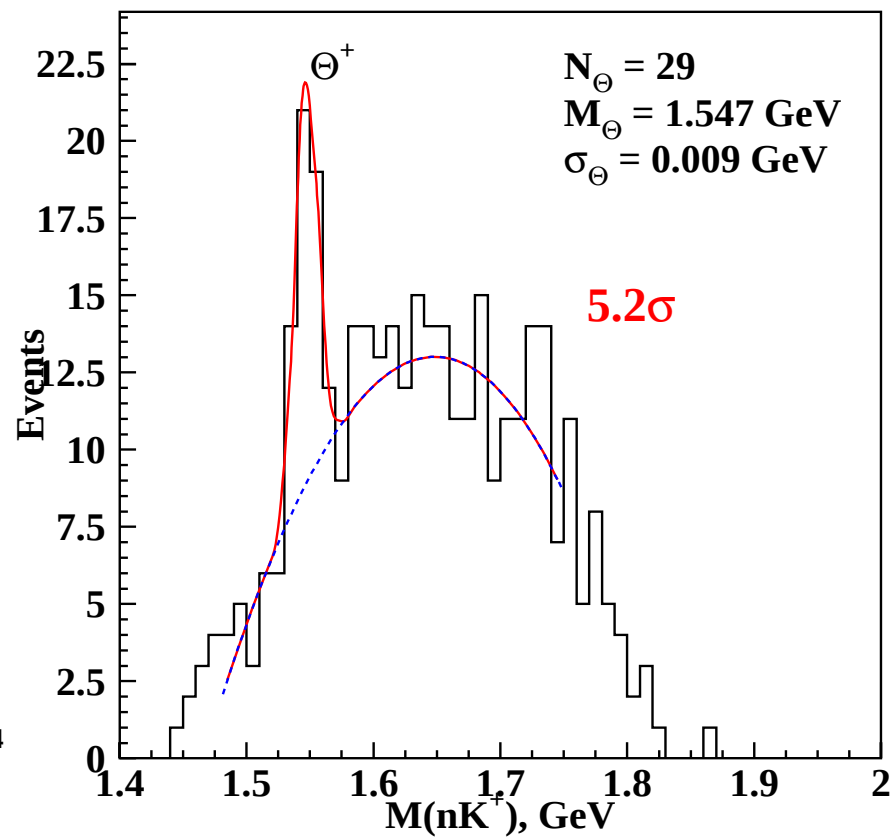
- ❑ Analyses of CLAS photoproduction data firmly establish the existence of a narrow $S=+1$ exotic resonance state in the nK^+ system with a mass approximately at 1.54 GeV . Statistical significance of the peak in the invariant mass distribution of nK^+ is 4.8σ in the analysis of reaction $\gamma p \rightarrow \pi^+ K^- K^+ n$, and is 5.2σ in the analysis of reaction $\gamma d \rightarrow p K^+ K^- n$.
- ❑ These results are consistent with the $S=+1$ resonance reported by LEPS (Spring-8) and DIANA (ITEP) collaborations, and with the 5-quark ($uudds$) exotic state, Θ^+ , predicted in the chiral soliton model.
- ❑ Proposal for a new experiment for 30 days of running has been submitted to JLAB PAC24. New measurements will allow to study properties of Θ^+ as well as $N(1710)$, the “anchor” for the anti-decuplet masses.



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



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

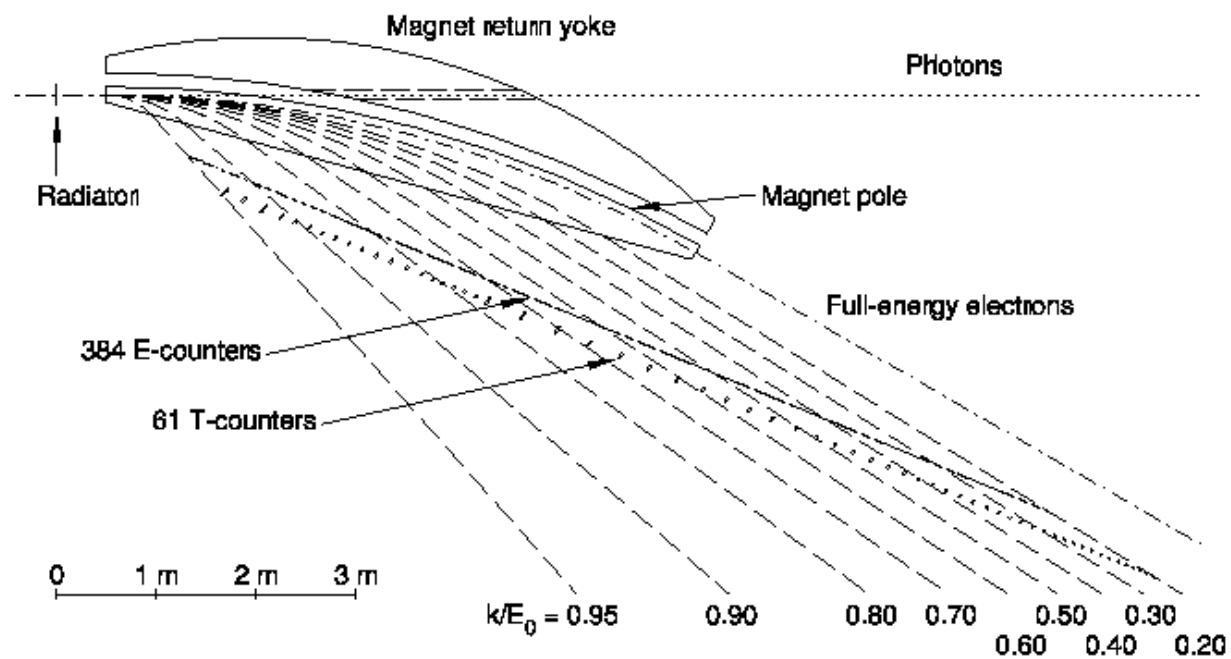


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CLAS photon tagger



$$\Delta E = 3 - 5 \text{ MeV}$$

TAGGER.PLT
D. Soder 23-Feb-99



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