Pentaquark searches in high statistics experiments on deuterium with CLAS

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Introduction

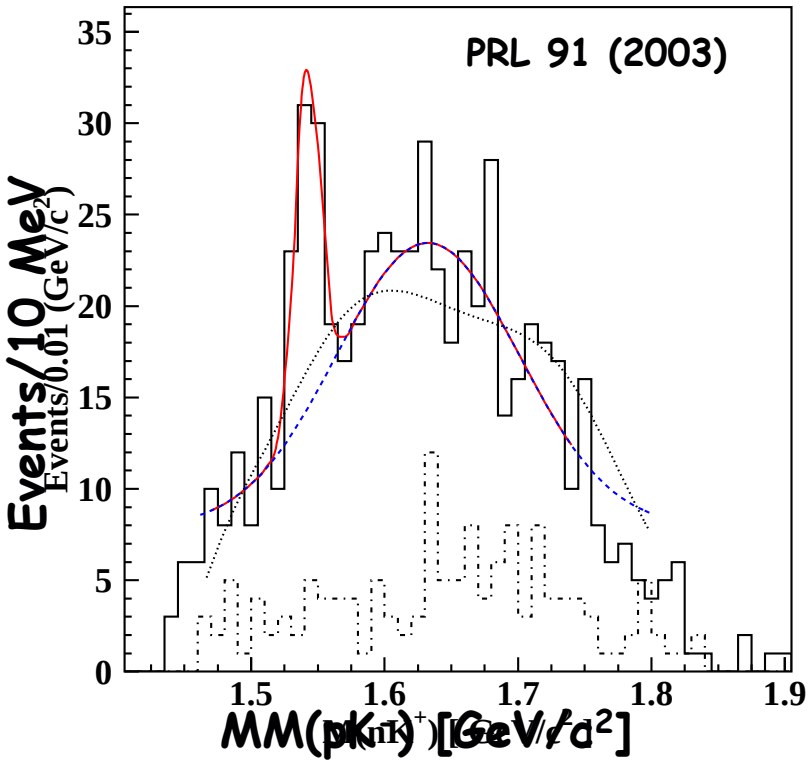
Reactions for Θ^+ searches

Comparison with published data

Cross section upper limits

Summary

Published deuterium data (G2a): $\gamma d \rightarrow pK^-K^+n$



- Re-analysis of the experimental data from 1999 run. Tagged photon energy range < 3GeV.
- Search for the Θ^+ signal in the nK^+ decay mode.
- Simple cuts:
  - PID and event selection (neutron MM cut)
  - Exclude $\phi(1020)$ and $\Lambda(1520)$ events
  - Spectator momentum >0.08 GeV/c
  - K^+ momentum <1 GeV/c
- Only ~40 events in the mass peak around 1.54 GeV/c^2. Estimated statistical significance 4.6σ to 5.8σ, depending on the fitted background shape.

CLAS statement - 06/30/2004

"Improved analysis of this data finds that the significance of the observed peak may not be as large as indicated."

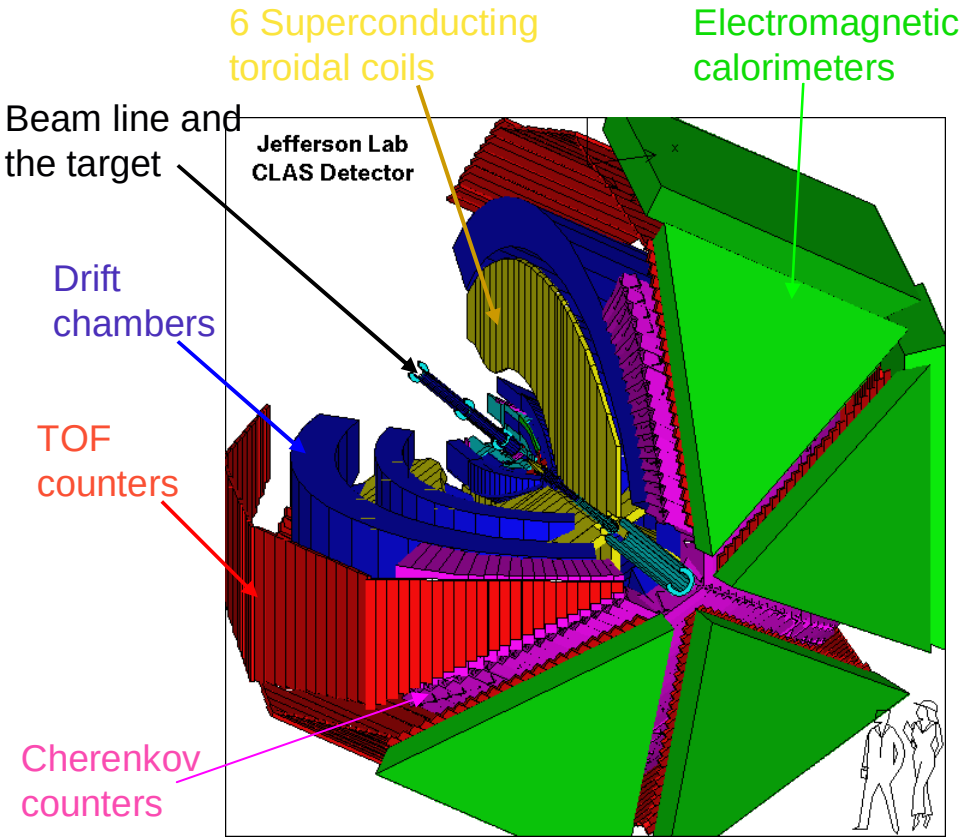
New experiments for the pentaquark searches with CLAS

- Photoproduction on deuterium at **E_γ<3.7 GeV**, E03-113 (G10).
  - Goals of the experiment:
    - increase statistics in the published reaction $\gamma d \rightarrow pK^-K^+(n)$ by x10;
    - Θ^+ mass determination with 2 MeV accuracy;
    - search for the Θ^+ signal in different production and decay modes.
  - Run conditions:
    - data taking in March – May 2004;
    - tagged photon beam energy range - 1 GeV to 3.6 GeV;
    - two settings of the CLAS toroidal magnet: I_T=2250 A and 3375 A;
    - at each setting integrated luminosity is ~10 times higher than in published data.
  - Special measurements for Hall B tagged photon beam energy calibration.

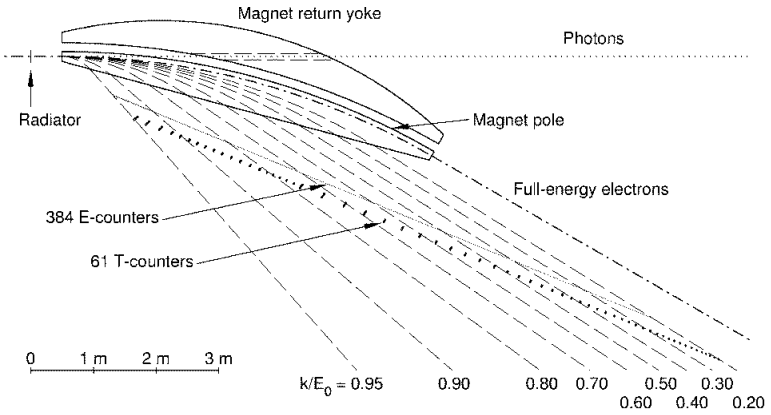
- Photoproduction on deuterium at **E_γ<5.7 GeV**, E04-010 (EG3). Search for Φ^{--} (Ξ^{--}) in the reaction $\gamma n \rightarrow K^+K^+\Phi^{--}$, $\Phi^{--} \rightarrow p\pi^-\pi^-\pi^-$. Reversed torus polarity to increase detection efficiency for negative particles in the forward region: favorable setting for the reaction $\gamma n \rightarrow K^-\Theta^+$. (*See H. Egiyan's talk in this afternoon).*

Hall B at JLAB

CEBAF/Hall B CLAS Detector



Bremsstrahlung tagged photon facility, photon energy resolution ~0.2%



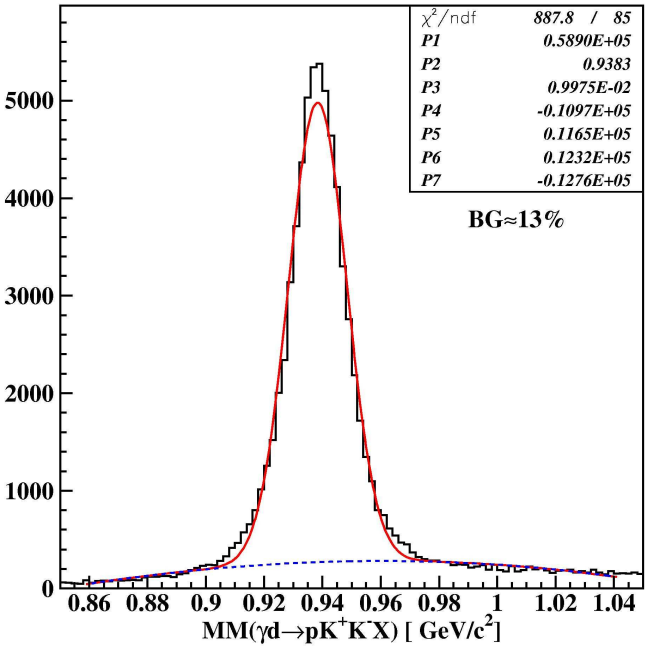
G10 analysis

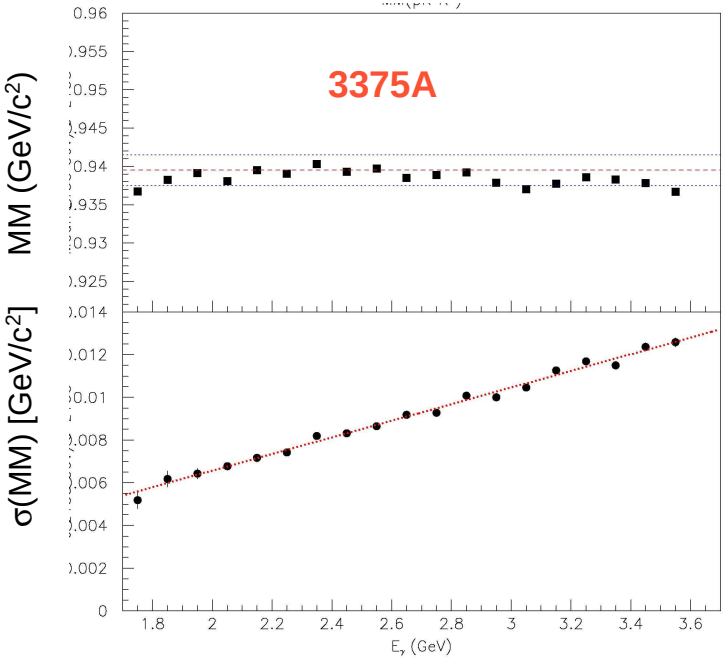
Analysis group: Dan Carman, Ken Hicks (Ohio), Dave Tedeschi, Nathan Baltzell (USC), Bryan McKinnon (Glasgow), Silvia Niccolai (ORSAY), Patrizia Rossi, Marco Mirazita (INFN), Stepan Stepanyan (JLAB).

Independent analysis of several reactions by different groups -

		Detected final state	
$\gamma + d \to p + K^- + K^+ + (n)$	$\Theta^+ \to nK^+$	pK^-K^+	
$\gamma + d \to \Lambda^0 + K^+(K_s^0) + n(p)$	$\Theta^+ \to nK^+(pK_s^0)$		Talk by S. Niccolai
$\gamma + "n" \to p + K^0 + K^-$	$\Theta^+ \to pK^0$	$p\pi^-\pi^+K^-$	Talk by D. Tedeschi
$\gamma + d \to \Lambda(1520) + X$		pK^-	Talk by T. Mibe

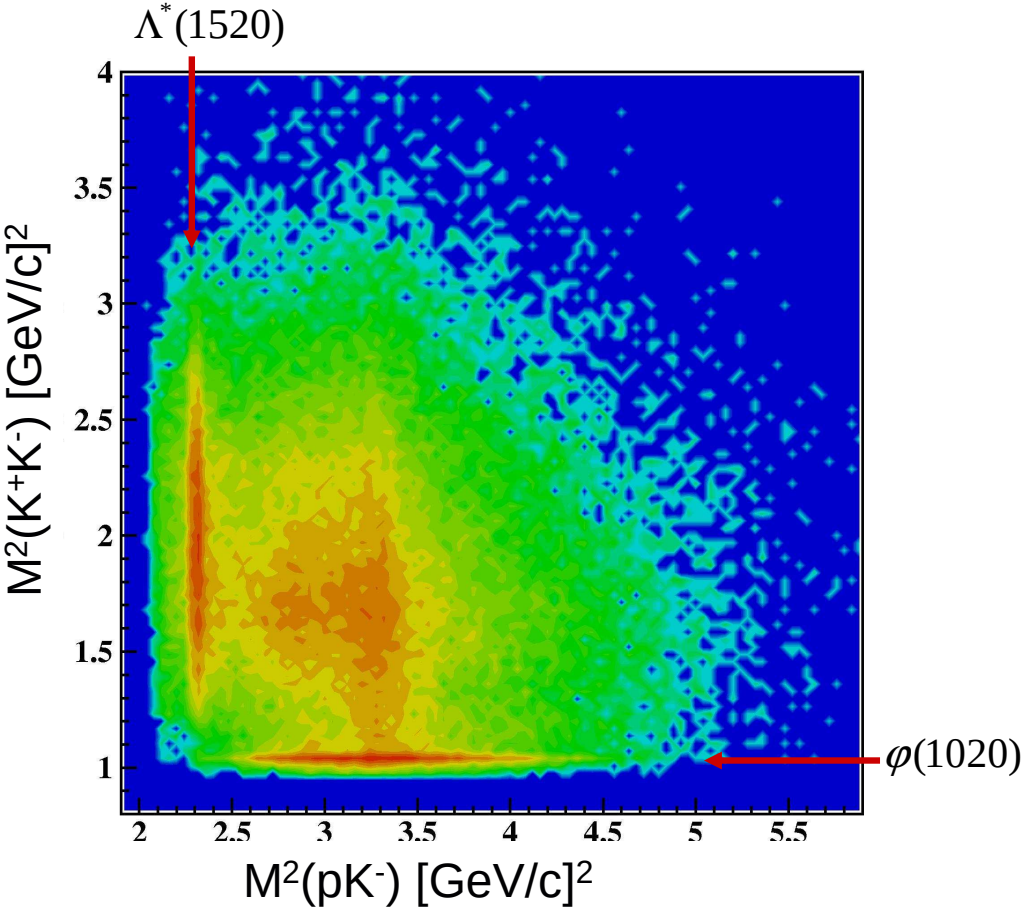
Reaction $\gamma d \rightarrow pK^+K^-(n)$

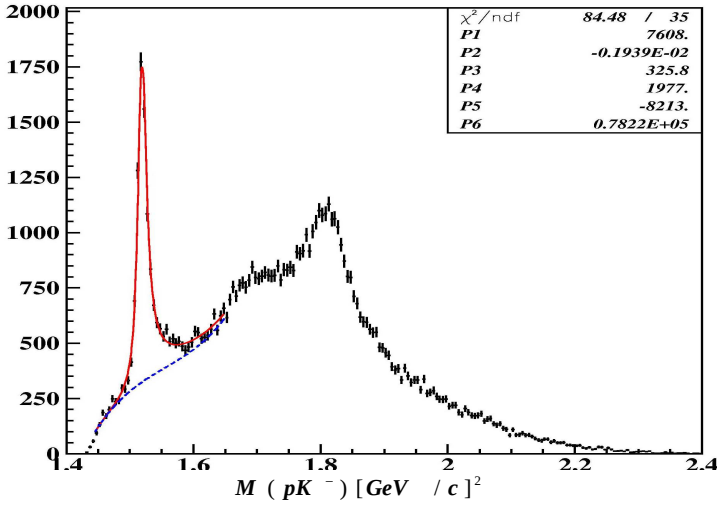


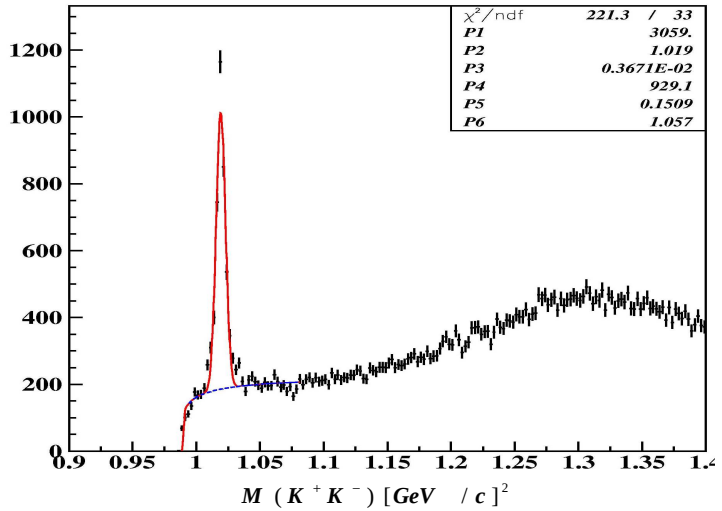


- Independent derivation of momentum and energy corrections:
  - Energy loss – checked with GEANT simulations;
  - tagger energy – independent measurements with Pair Spectrometer;
  - beam energy - measurements from Hall A and $pp\pi^-$ reaction;
  - momentum in CLAS - using invariant mass $K^0 \rightarrow \pi^+\pi^-$ and fully exclusive reactions.

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

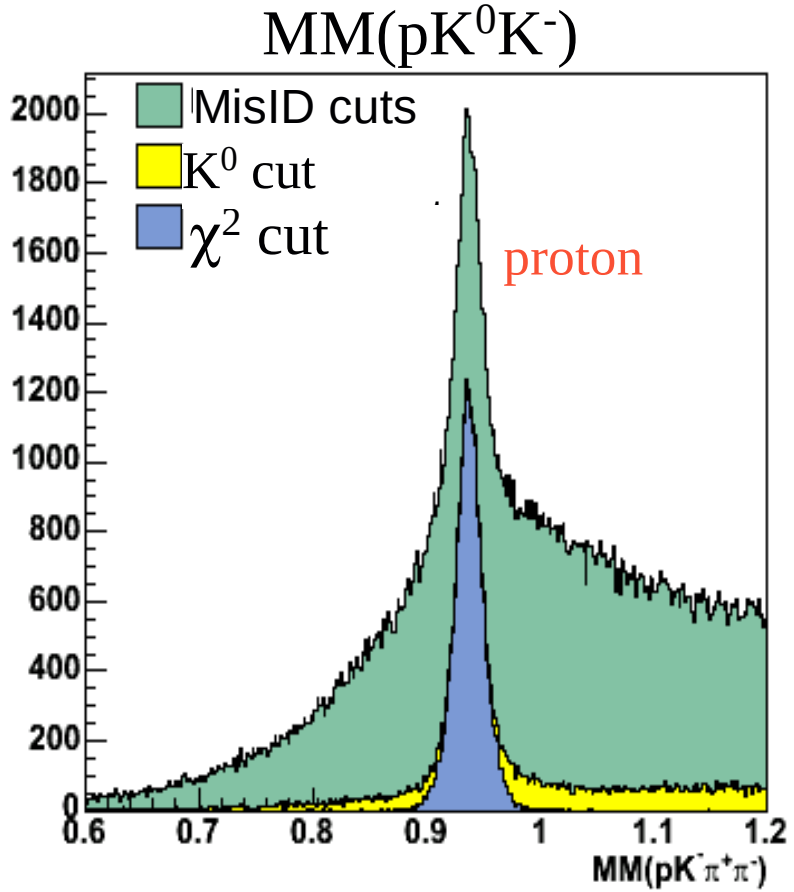


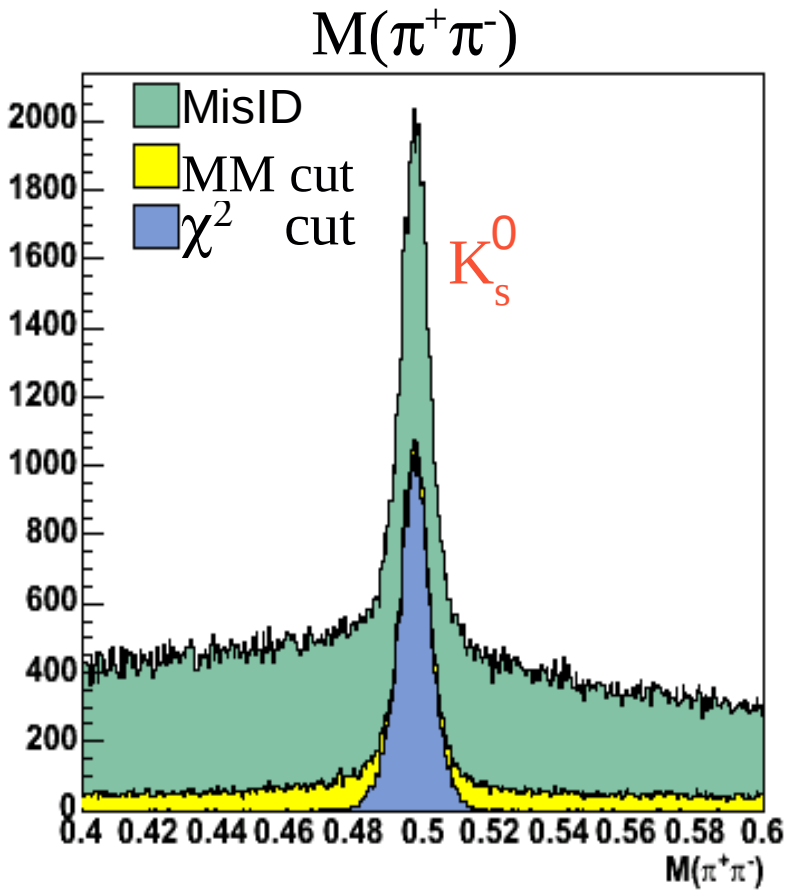




Reaction $\gamma d \rightarrow pK_sK^-(p)$

N. Baltzell, D. Tedeschi (USC)

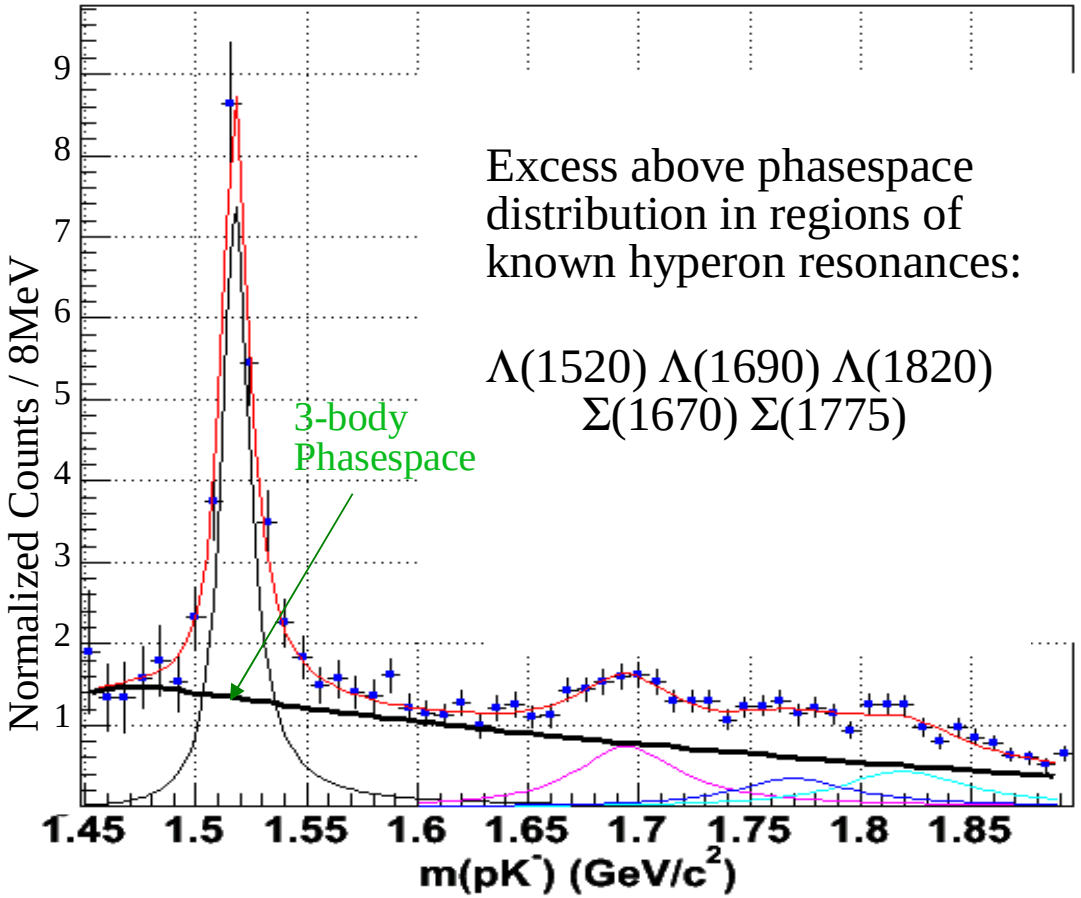




$\gamma n \rightarrow Y^* K^0$

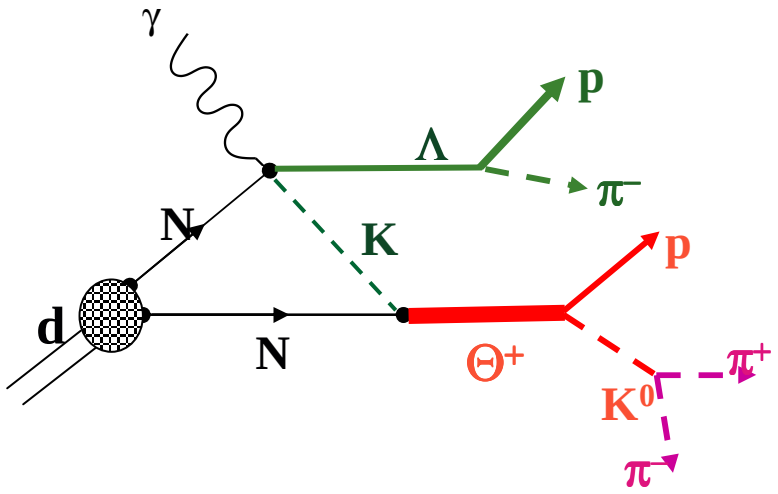
$\Lambda(1520)$ Yield ≃ 2,000

N. Baltzell, D. Tedeschi (USC)



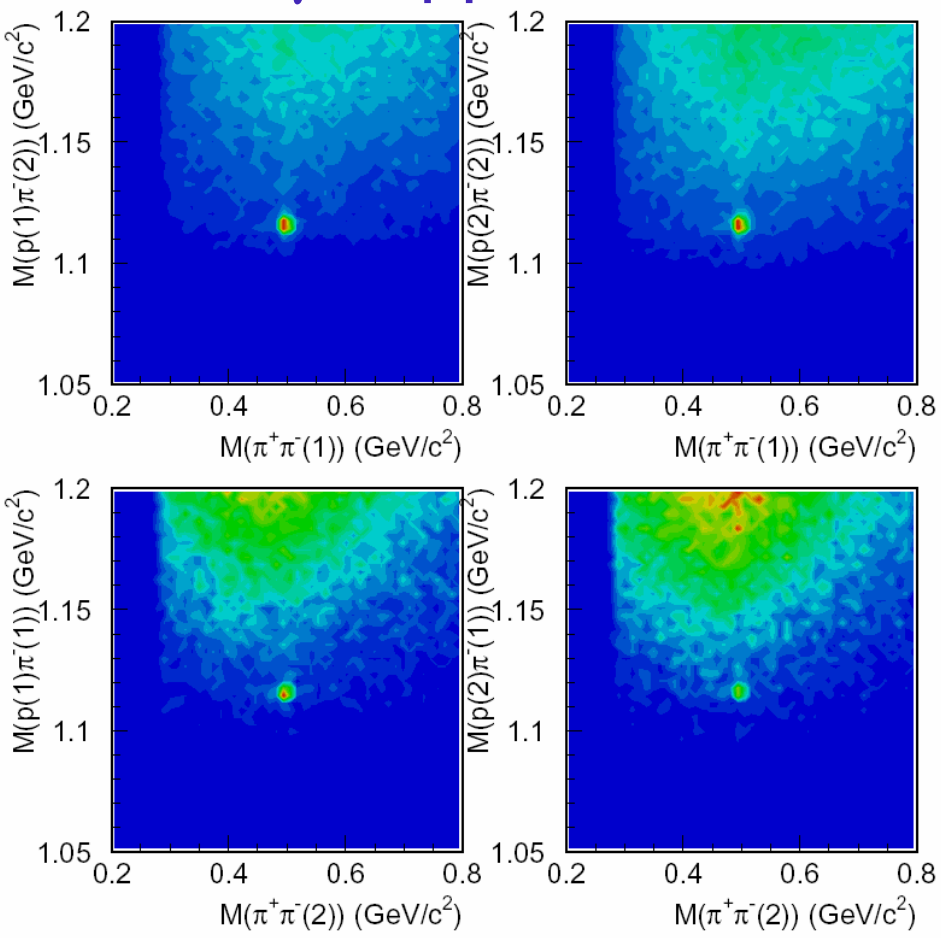
Reaction $\gamma d \to \Lambda^0 \Theta^+$

S. Niccolai



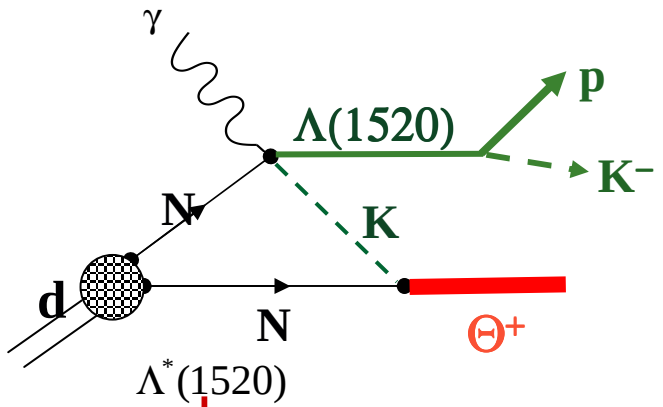
- Search for the Θ^+ in the nK^+ and pK_s decay modes.
- Studies of several different topologies.

$\gamma d \to pp\pi^+\pi^-\pi^-$

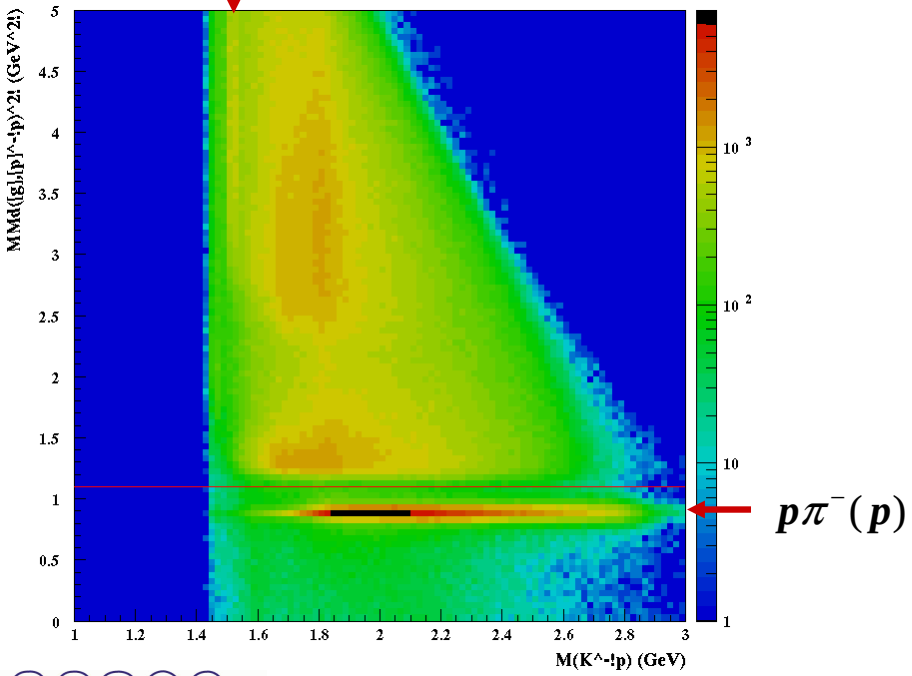


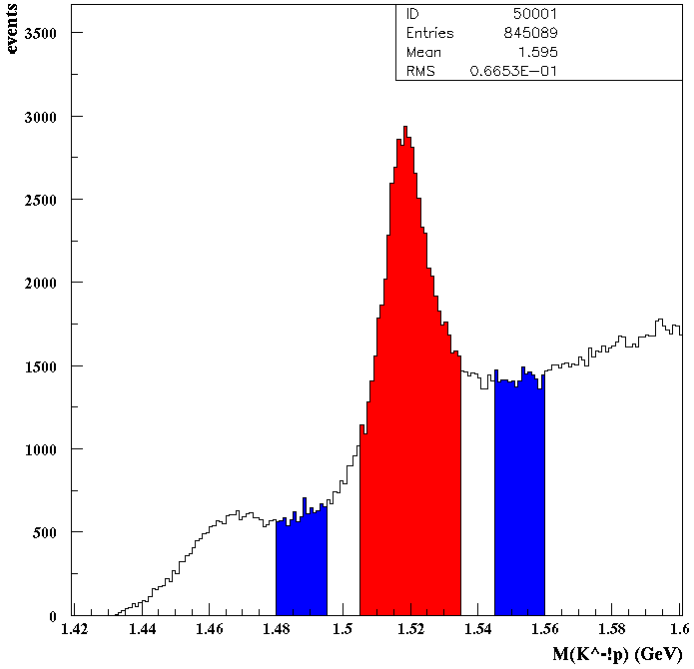
Reaction $\gamma d \rightarrow \Lambda(1520)X^+$

T. Mibe



- Search for the Θ^+ in the missing mass distribution of pK^-.





Comparison with published data

- The same photon beam energy spectrum as for g2a.
- The same set of cuts:
  - excluding $\phi(1020)$ and $\Lambda(1520)$ events;
  - missing momentum cut > 0.08 GeV/c;
  - cut on K^+ momentum < 1 Gev/c.

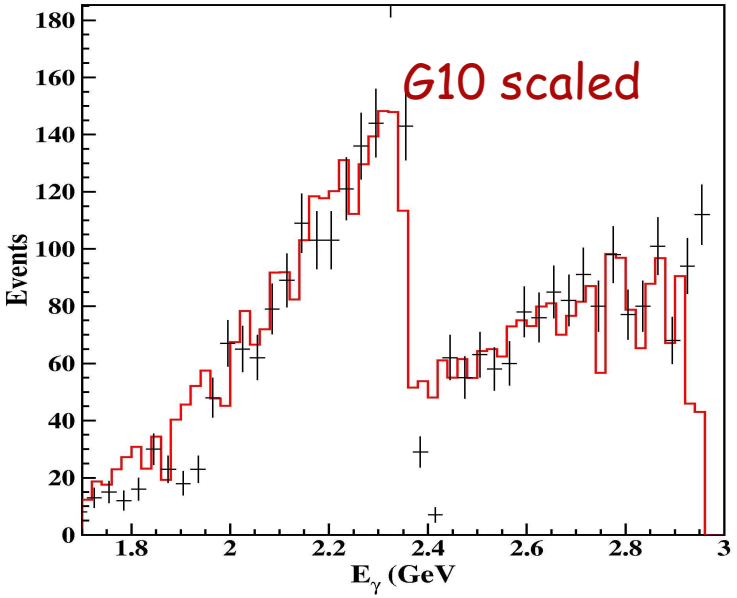
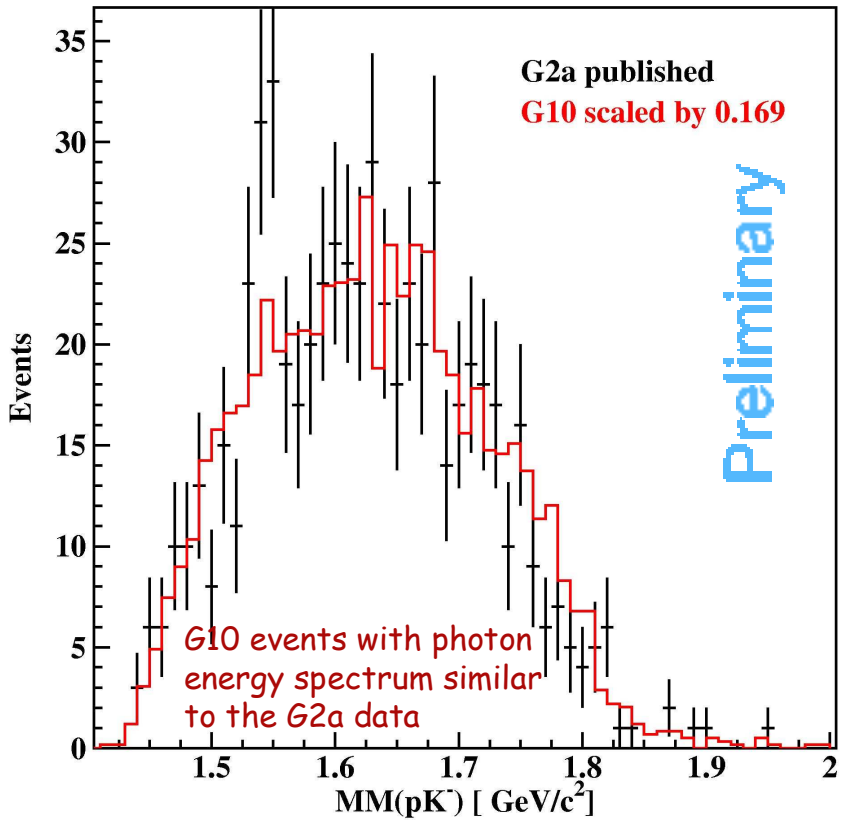


Table 1: Reaction $\gamma d \to pK^+K^-(n)$, cut on K^- acceptance to match to g2a.

Particle	g10 2.5:1 for $E_\gamma < 2.35 : 2.96$ GeV				g2				
	N	N_{Bg}	Mean (GeV)	σ (GeV)	N	N_{Bg}	Mean (GeV)	σ (GeV)	ratio
neutron	13100 ±118	1200	0.939	0.0082	1977 ±49	124	0.9341	0.0085	6.6 ±0.2
$\Lambda(1520)$[1] $M(pK^-)$	2078 ±74		1.520		330 ±34	90	1.518	0.008	6.3 ±0.5
$\phi(1020)$ $M(K^+K^-)$	992 ±38		1.019	0.0034	126 ±16	45	1.02	0.004	7.8 ±1
Final # of events	3650				620				5.9

Missing mass distributions

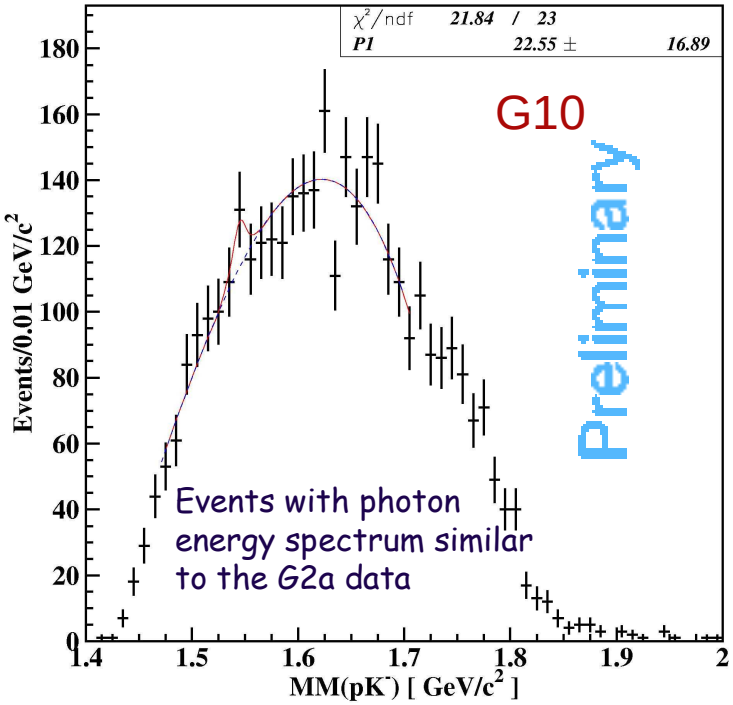


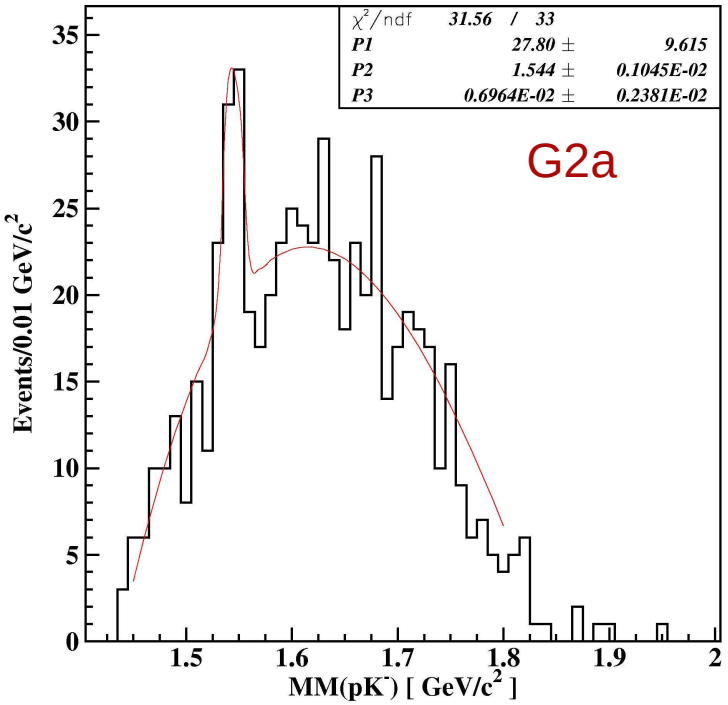
- Two distributions are statistically consistent with each other:
  - 26% c.l. for null hypothesis from the Kolmogorov test (two histograms are compatible).
  - Reduced χ^2=**1.15** for in the mass range from 1.47 to 1.8 GeV/c^2
- Published results on the Θ^+ from the analysis of the G2a data cannot be reproduced in the analysis of the high statistics G10 data.

Fit to the MM(pK$^-$) distributions

- Fit to the G10 MM distribution with smooth function (3rd degree polynomial, P_3).
- Use P_3 as a shape of the background to extract fluctuations into a Gaussian with fix mean, and the experimental mass resolution as a width, σ.
- The only fit parameter is the number of events in the Gaussian peak, N_G.

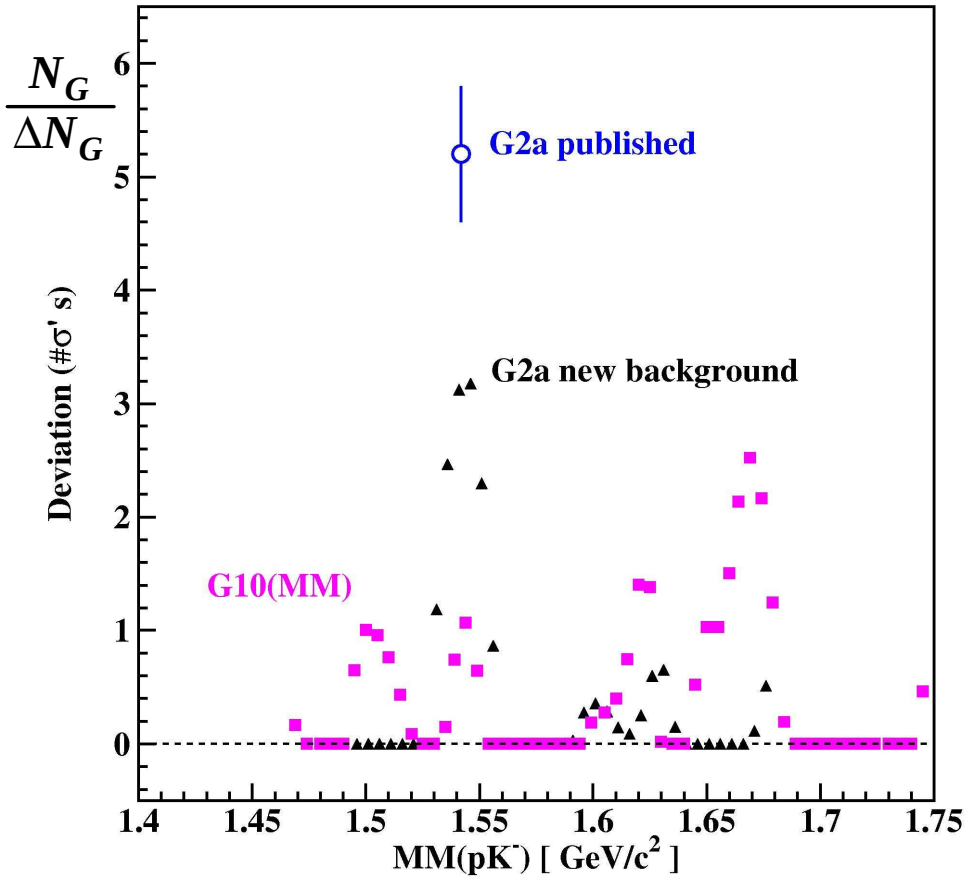
$$F(MM) = \sum p_i MM^{i-1} + \frac{N_G}{\sqrt{2\pi\sigma}} e^{-\frac{(MM-m)^2}{2\sigma^2}}$$





Statistical fluctuations with the new background

$$F(MM) = \sum p_i MM^{i-1} + \frac{N_G}{\sqrt{2\pi}\sigma} e^{-\frac{(MM-m)^2}{2\sigma^2}}$$

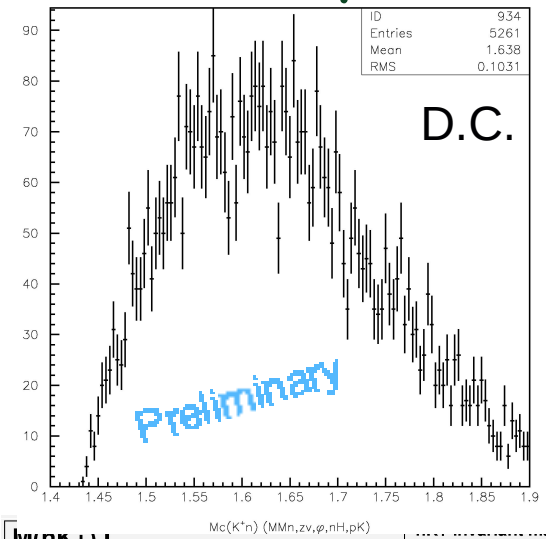


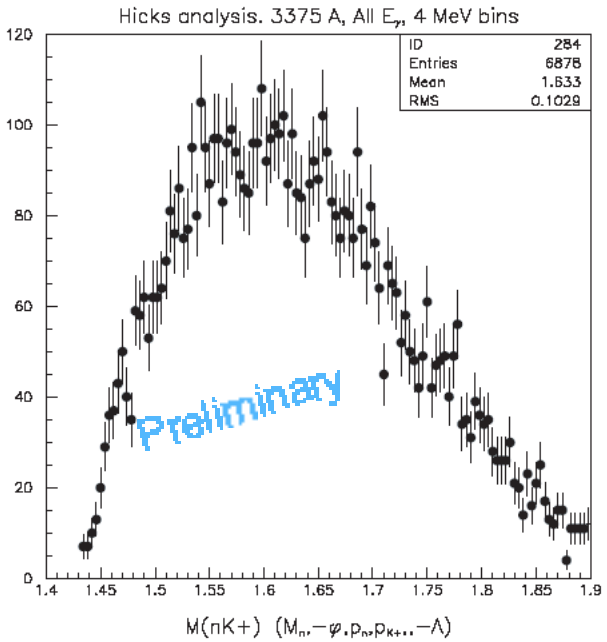
We cannot find any reason for the observed peak (with 3σ) other than a statistical background fluctuation.

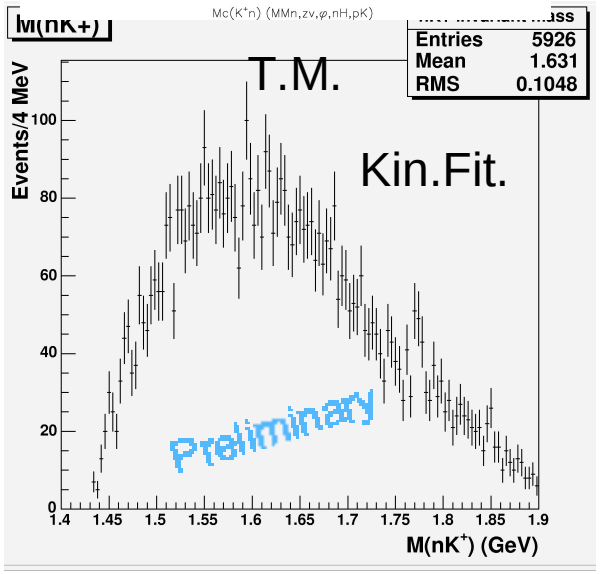
The originally quoted significance of 5.2 ±0.6σ would then be the result of the underestimated background combined with a statistical fluctuation in the 1.54 GeV/c^2 mass region.

Preliminary results from $\gamma d \rightarrow pK^+K^-(n)$ analysis

- Photon beam energy $E_\gamma < 3.6$ GeV.
- Missing neutron momentum $P_n > 0.2$ GeV/c.
- Invariant mass M(nK+) with constraned neutron mass.
- Kinematical fit.

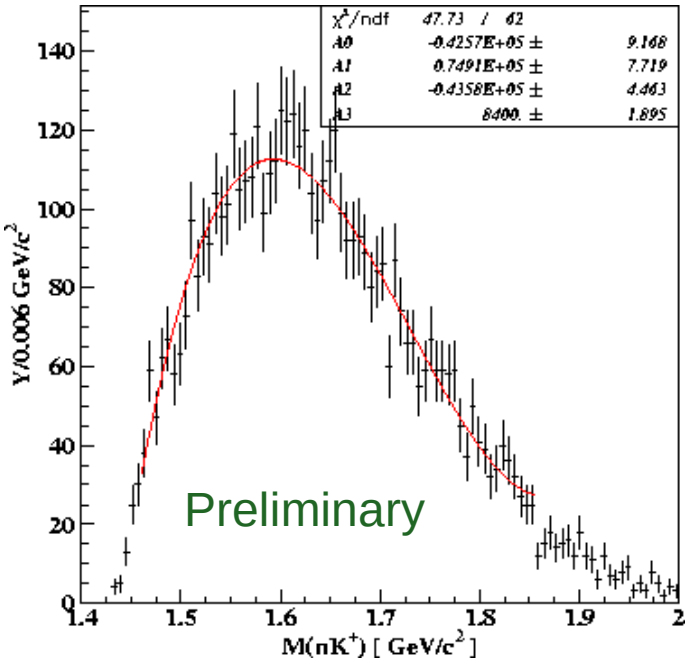






Fit to the M(nK$^+$)

First fit to the mass distribution with smooth function, P(M)

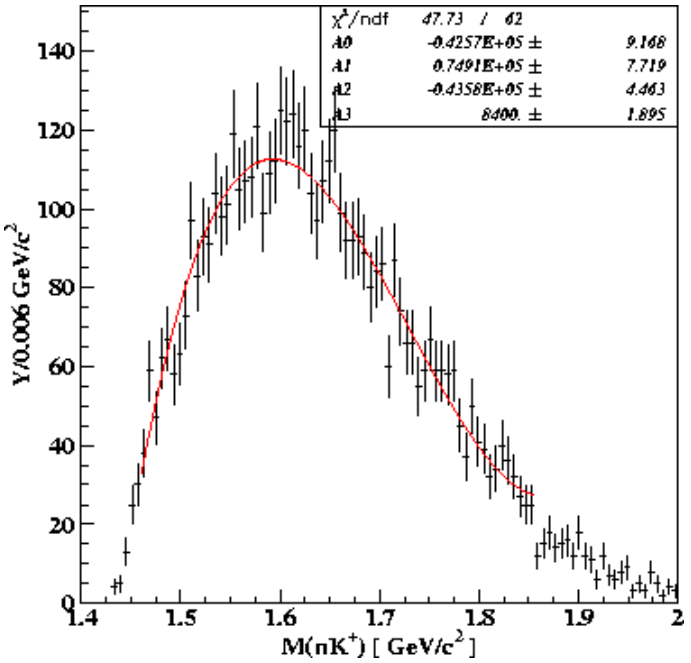


Two different background functions:

$$P(M) = \sum p_i M^{i-1} \quad \& \quad P(M) = p_1 (M - M_0)^{p_2} e^{-(p_3 M + p_4 M^2)}$$

Fit with the fixed background, $P(M)$, and a Gaussian (σ ex. resolution, several values of m).

$$F(M) = P(M) + \frac{N_G}{\sqrt{2\pi}\sigma} e^{-\frac{(M-m)^2}{2\sigma^2}}$$

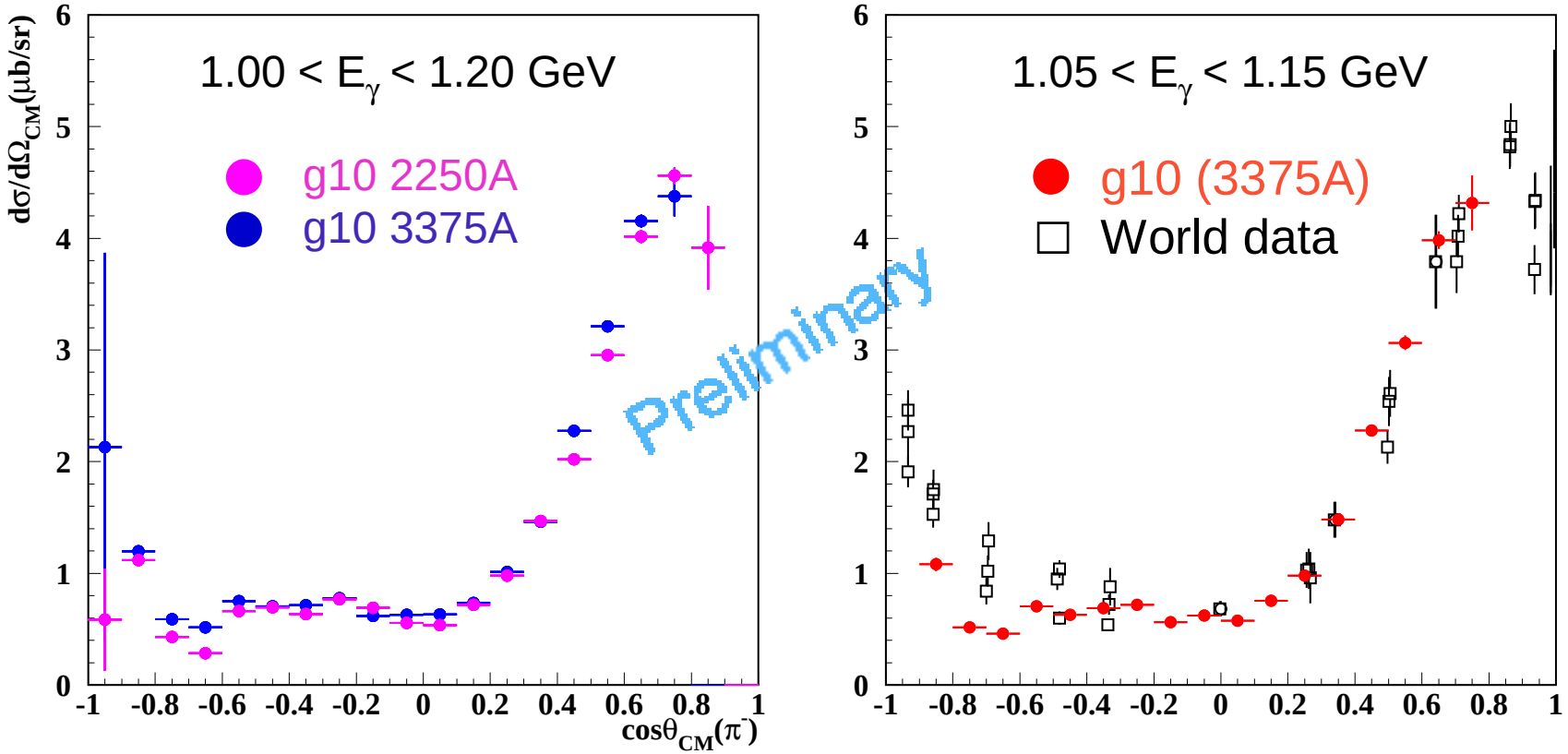


Cross section upper limit :

$N_{\Theta+}=N_G+2\Delta N_G$ (95% c.l.)

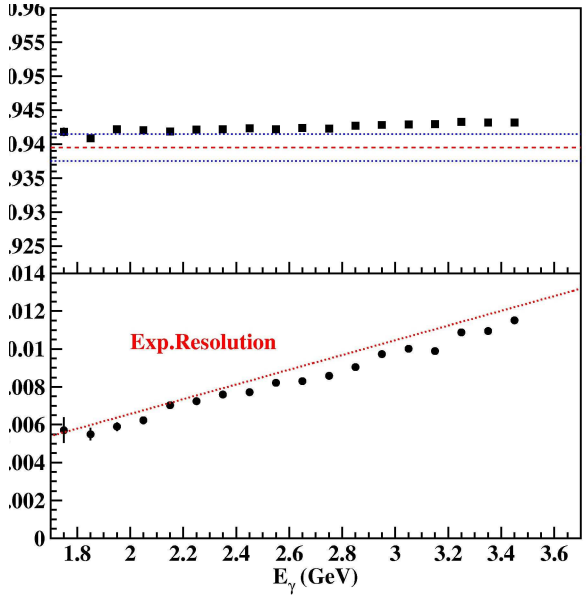
Cross section of the reaction $\gamma d \rightarrow p\pi^- (p)$

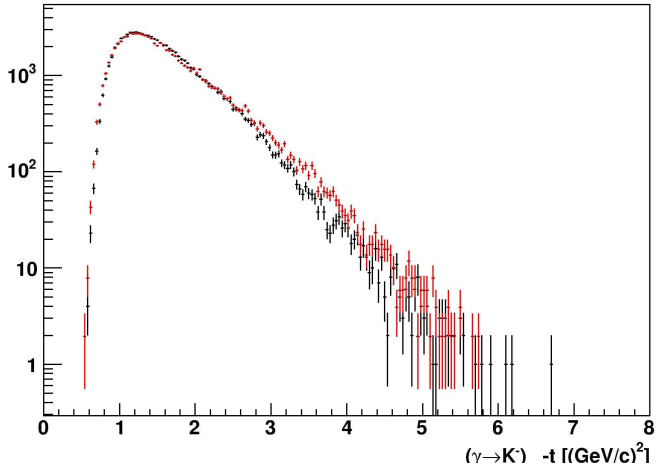
Only 0.5% of the G10 statistics is used

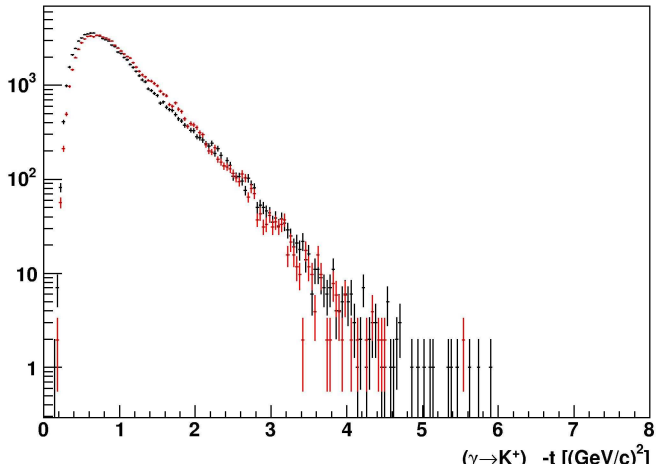


Acceptance simulations

- Phase-space event generator with weighted t-dependences for the K^+ and the K^-. Reproduces the experimental distributions quite well.
- GEANT simulation of the CLAS detector.
- Full reconstruction chain as for the experimental data .





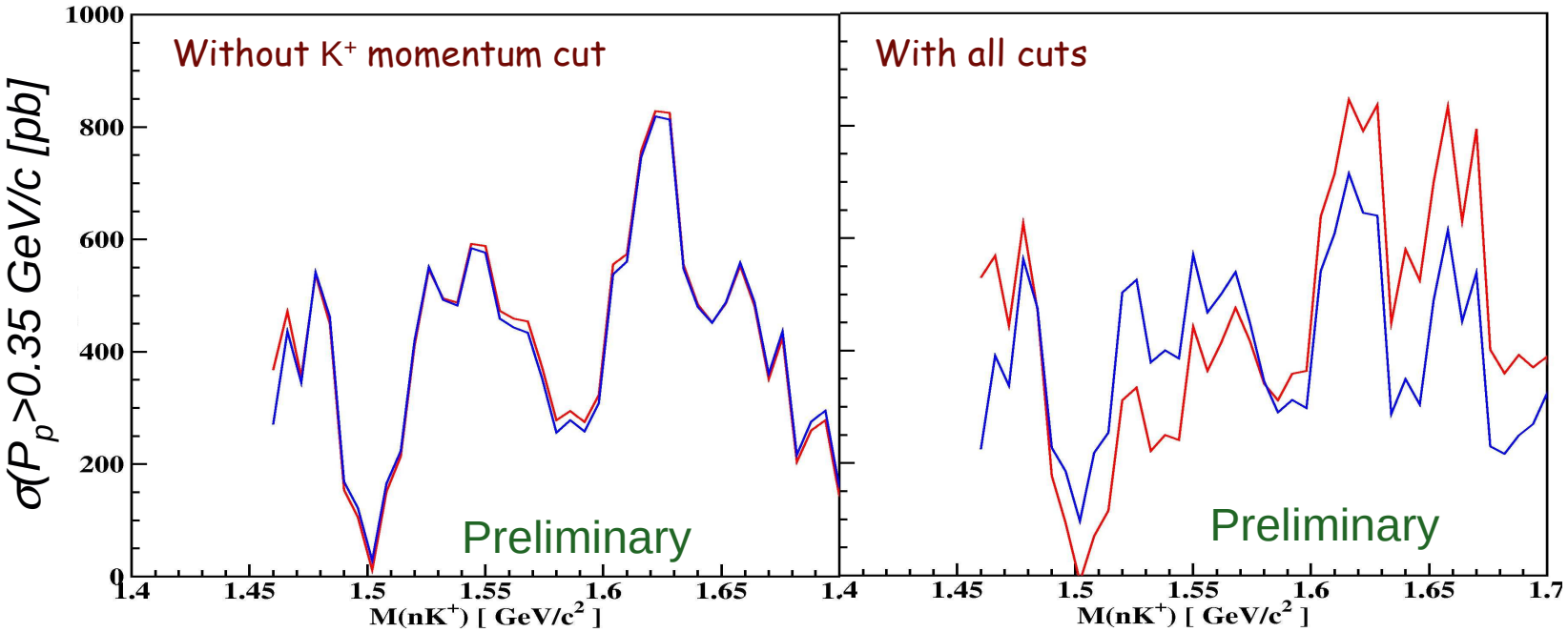


Cross section upper limit for the $\gamma d \rightarrow p K^- \Theta^+$

Upper limit (95% c.l.) integrated over E_γ and transferred momentum.

$P(M)=\Sigma p_i M^{i-1}$

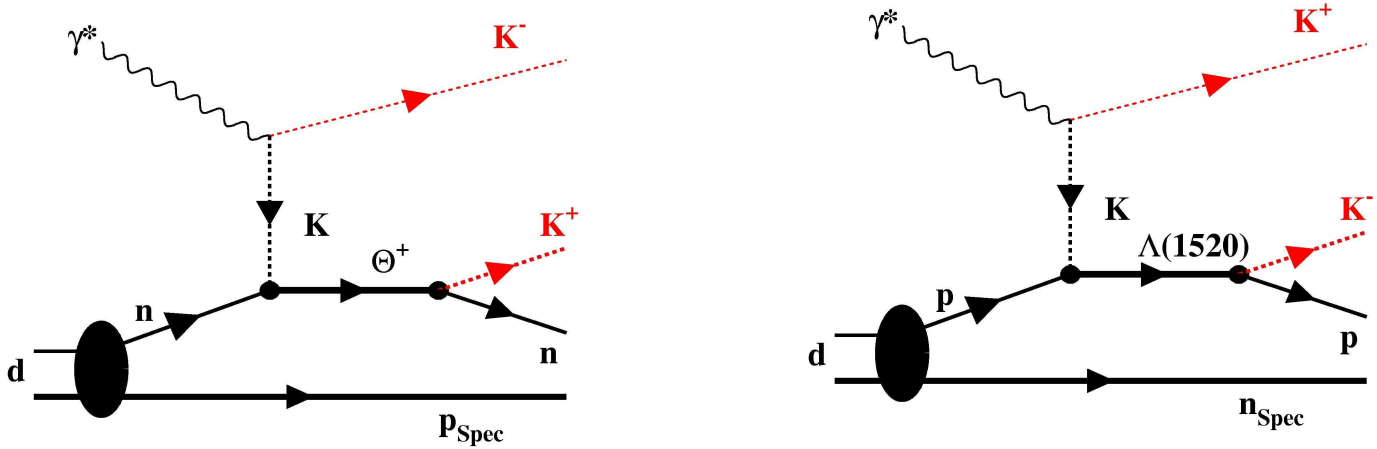
$P(M)=p_1(M-M_0)^{p_2}e^{-(p_3 x+p_4 * x * x)}$



For the cross section of the elementary process $\gamma n \rightarrow \Theta^+ K^-$, detection of the high momentum spectator (p) should be taken into account.

K^+K^- final state

- In the reaction $\gamma d \rightarrow pK^-K^+n$ the Θ^+ is produced on the neutron and the proton is a spectator.
- In the same reaction $\Lambda(1520)$ is produced on the proton and the neutron is a spectator.

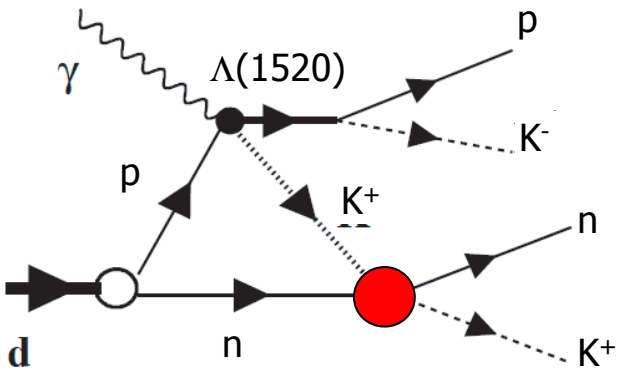


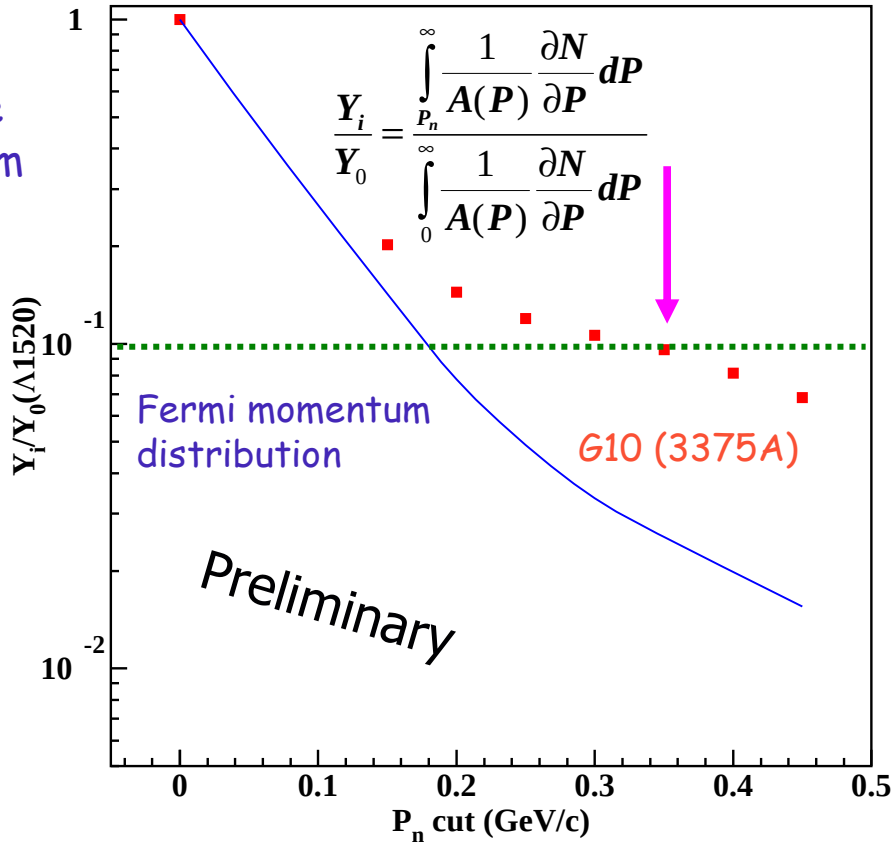
- Detecting a high momentum spectator, the proton, in the case of the Θ^+ production, and the neutron, in the case of the $\Lambda(1520)$, requires re-scattering (or FSI).

Yield of the $\Lambda(1520)$

- The Fermi momentum tail can account only for 20% of the $\Lambda(1520)$ yield in the reaction $\gamma d \rightarrow \Lambda(1520)K^+(n)$ with spectator momentum $P_n > 0.35$ GeV/c.

FSI between (K^+n) and [$\Lambda(1520)n$] are the main source of the high momentum spectator.

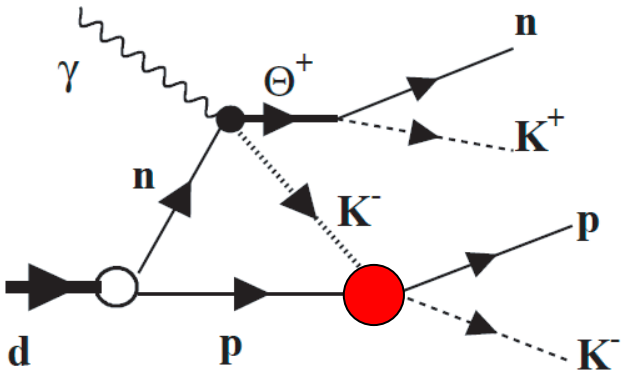


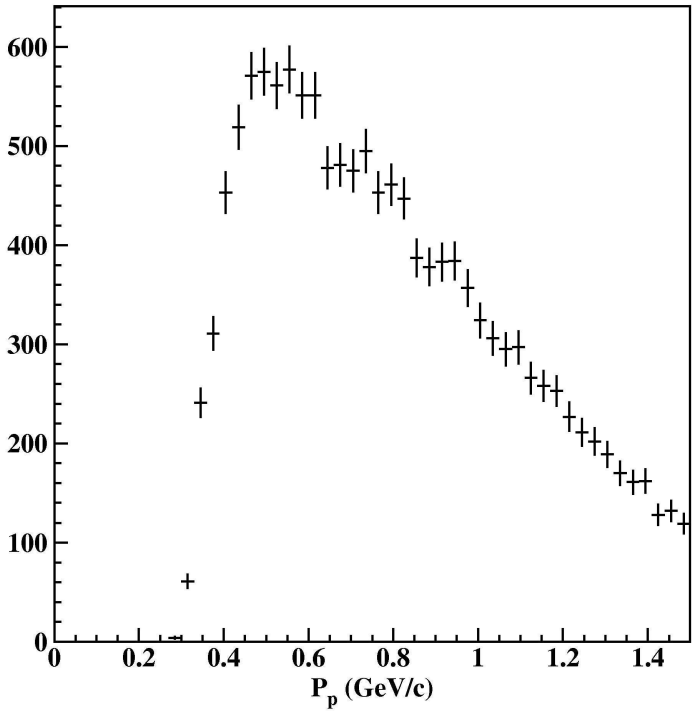


Elementary cross section: $\gamma n \to \Theta^+ K^-$

- Minimum momentum of protons in CLAS >0.35 GeV/c.
- If the Fermi momentum is the only source for a high momentum spectators, than the cross section upper limit is ~20 nb.
- If we take $\Lambda(1520)$ production as a guide, the cross section upper limit is 4-5 nb, $Y/Y_0(0.35)=0.1$ (model dependent).

$$\sigma(\gamma n) = (Y_0 / Y)\sigma(\gamma d)$$





Experimental upper limit on Γ_{Θ^+}

Theoretical cross sections 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			<5.7 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	<(0.5) 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			< 0.8 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			< 0.08 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	< 0.24 MeV
nuc-th/0408034	$\gamma n \to K^-\Theta^+$	3.5nb	11.2(~20)nb	48nb	4.nb	< 0.4 MeV

$\sigma \propto \Gamma$

$\sigma^{\gamma p} < 1.25 nb$

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

( ) – with K* exchange

Summary

The status and the preliminary results from comprehensive searches for the Θ^+ pentaquark from the high statistics, high precision photoproduction experiments on deuterium with CLAS have been presented.

- High statistics data did not confirm previously observed peak in the reaction $\gamma d \rightarrow pK^-K^+n$ ($\Theta^+ \rightarrow nK^+$).
- Estimated cross section upper limit for the elementary process $\gamma n \rightarrow \Theta^+ K^-$ is ~4-5 nb, model dependent.
- Analyses of several other reaction channels from G10 data are in progress, and will be released soon.
- Analysis of the new data (EG3) from high statistics deuterium run at high energy to search for the excited cascades as well as for the Θ^+ expected to start by the end of the year.