(A New Proposal to Jefferson Lab PAC26)

High resolution search for exotic resonances in nK^+ system near 1540 MeV

J. P. Chen, E. Chudakov, C. DeJager, P. Degtyarenko, R. Feuerbach, M. Jones, J. Gomez, O. Hansen, D. W. Higinbotham, J. LeRose, R. Michaels, S. Nanda, B. Reitz, A. Saha, B. Wojtsekhowski (contact and spokesperson)
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606

J. Arrington, K. Hafidi, R. Holt, P. E. Reimer(co-spokesperson), D. Potterveld, E. Schulte, X. Zheng
Argonne National Laboratory, Argonne, IL 60439

G. Cates(co-spokesperson), D. Day, A. Deur, R. Lindgren, N. Liyanage, V. Nelyubin(co-spokesperson)[†], B. E. Norum, J. Singh, R. Snyder, W. A. Tobias, K. Wang
University of Virginia, Charlottesville, VA 22901

D. Nikolenko, I. Rachek
Budker Institute, Novosibirsk, Russia

. D. J. Magaziotis .
California State University LA, CA

G. B. Franklin, B. Quinn, R. Schumacher, C. Meyer
Carnegie Mellon University, Pittsburgh, PA 15213

L. Pentchev
College of William and Mary, Williamsburg, VA 23185

P. Markowitz, J. Reinhold
Florida International University, Miami, FL 33199

E. Cisbani, F. Cusanno, F. Garibaldi, S. Frullani, G. M. Urciuoli, M. Iodice
INFN, Rome, Italy

R. De Leo, L. La Gamba
INFN, Bari, Italy

A. Asratyan, G. Davidenko, A. Dolgolenko, G. Dzyubenko, V. Evdokimov, V. Goryachev, M. Kubantsev, I. Larin, V. Matveev, A. Sitnikov, V. Verebryusov, V. Vishnyakov
Institute of Experimental and Theoretical Physics, Moscow, Russia

O. Gayou, Y. Qiang
Massachusetts Institute of Technology, Cambridge, MA 02139

Ya. Azimov
PNPI of Russian Academy of Science, Gatchina, Russia

V. Kubarovsky*, P. Stoler
Rensselaer Polytechnic Institute, Troy, NY 12180-3590

R. Gilman, K. McCormick
Rutgers, The State University of New Jersey, Piscataway, NJ 08854

P. Souder, R. Holmes, H. Benaoum .
Syracuse University, Suracuse, NY 13244

E. Piasetzky
Tel Aviv University, Israel

W. Briscoe, R. Arndt, I. Strakovsky, R. Workman
Center for Nuclear Studies, Department of Physics
The George Washington University, Washington DC 20052

S. Dhamija, W. Korsch
The University of Kentucky, Lexington, KY 40506

J. Annand, D. Ireland, J. Kellie, K. Livingston, G. Rosner
University of Glasgow, Glasgow, Scotland

A.M. Nathan
University of Illinois, Champaign-Urbana, IL 61801

K. Kumar, K. Paschke, L. Kaufman
University of Massachusets, Amherst, MA

J. Calarco, W. Hersman
University of New Hampshire, Durham, NH 03824

K. Egiyan, S. Mayilyan, V. Mamyan, A. Shahinyan, H. Voskanyan
Yerevan Physics Institute, Yerevan, Armenia

and **The Hall A Collaboration**
† on leave from PNPI of Russian Academy of Sciences, Gatchina, Russia
* also TJNAF, Newport News, VA 23606

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Abstract

An experiment is proposed to search for and measure the parameters of a narrow exotic baryonic state in reaction $\mathrm{Be}(e, nK^+K^-)X$ in the mass range from 1500 to 1600 MeV. The data will determine the resonance mass and width with a detector resolution (FWHM) of 2.9 MeV. The width will be determined with accuracy of 0.7 MeV.

The experiment utilizes a 5.0 GeV electron beam in Hall A, High Resolution Spectrometer (left) with a septa magnet, the BigBite spectrometer, and a large neutron detector. This equipment exists or is under construction for the approved experiment E02013. With 550 hours of beam-time for this measurement, resonances whose widths as small as 1 MeV may be observed unambiguously. Such a measurement will dramatically increase our experimental confidence in the parameters of the exotic state Θ^+ and its nature.

1 Introduction

Evidence supporting a new baryon resonance (Θ^+) has been observed in nK^+ and pK^o_S decays by several independent experiments [2, 3, 4, 5, 6, 7, 8, 9]. Because of its positive strangeness and baryon number, the Θ^+ is explicitly exotic, and its minimal quark content is $uudd\bar{s}$. Such a state was predicted as a member of an antidecuplet of the flavor group $SU(3)_F$ [1]. This unitary identification assumes zero isospin of the Θ^+, and continues to be favored [11, 12, 13]. As discussed below, a careful examination of the experimental evidence points increasingly to a resonance that is quite narrow, probably a few MeV or less.

The existence of the Θ^+ would have profound effects on our understanding of strong interactions and hadrondic structure, and ramifications that could well be felt beyond nuclear physics. There is probably nothing in medium energy physics that has captured such wide attention in many years, and it is essential that JLab take a leadership position in resolving questions regarding the Θ^+ in as rapid a manner as is reasonable. We propose here the only experiment of which we are aware that has the potential to observe the width of the Θ^+. The experiment would look at the reaction $\mathrm{Be}(e, n\,K^+, K^-)\mathrm{X}$, something that is quite close to the reaction $\gamma\, n \rightarrow K^-\,\Theta^+ \rightarrow K^-\,K^+\,n$ that was studied at SPring-8, with the obvious caveat that the photon in our case is virtual. As we will explain, the exquisite resolution is the fortuitous result of experimental equipment that has been developed for other experiments, including the Hall A septum magnets, Bigbite, and the E02013 G^n_E neutron detector. The design of our experiment also makes it possible to observe several reactions that will serve as excellent calibrations and convincing checks of our resolution. Finally, we want to emphasize strongly that under the assumption that the Θ^+ is quite narrow, our experiment is likely to have the greatest statistical significance of any experiment under consideration.

1.1 The current experimental picture

The present experiments find a mass for the $\Theta^+$of around 1540 MeV, with a range of 1526-1555 MeV (see Tab. 1). This is quite close to the predicted mass of 1530 MeV [1]. The spin of the Θ^+ is unknown, though there is weak evidence that $J = 1/2$ is preferred, as was predicted [1]. The parity of the state is also unknown. Many models predict a positive parity but constituent quark model predicted a negative one [14]. It is interesting that a $uudd\bar{s}$ positive parity state requires at least one unit of orbital angular momentum in the quark configuration.

Perhaps the most intriguing property of the Θ^+ is its width. The original theoretical prediction had $\Gamma_{\Theta^+} < 15$ MeV [1]. Existing experiments cannot resolve Γ_{Θ^+}, however they place upper limits based upon the experimental resolution. Most experimental publications give an upper boundary of 20 MeV, larger than expected by theory. The Xenon bubble chamber data, corresponding in essence to the charge exchange $K^+n \rightarrow K^0p$, provide a tighter limit of 9 MeV [3]. An indirect data treatment [15], using the published K^+d total cross section data, leads to a stronger limitation $\Gamma_{\Theta^+} < 6$ MeV. The partial-wave analysis of available KN (elastic and charge exchange) scattering data appear to exclude even widths above 1 MeV [16]. If the width is indeed so small, it is natural to expect that other members of the same multiplet should have comparable widths. Such an expectation is supported by recent evidence for another exotic state Ξ^{--} also having a narrow width [18]. A width on the level of few MeV will indicate that the Θ^+ has very different structure than known baryons. A narrow width also has important implications regarding the optimal design for experiments

Approach/ Collaboration	Beam/Target	Channel	Mass (MeV)	Width (MeV)	Events in Signal/Background	Ref.
Theoretical Predictions						
Chiral soliton			1530	<15		[1]
Experimental Observations						
LEPS	$\gamma^{12}C$	nK^+	1540±10	<25	19/17	[2]
DIANA	K^+Xe	pK°_S	1539±2	<9	29/44	[3]
CLAS/γn	γD	nK^+	1542±5	<21	43/54	[4]
CLAS/γp	γH	nK^+	1555±16	<26	41/28	[5]
ELSA	γH	nK^+	1540±4±2	<25	55/56	[6]
ITEP/ν	$\nu H, D, Ne/H$	pK°_S	1533±5	<20	26/15	[7]
HERMES	eD	pK°_S	1528±2.6±2.1	17±9±3	74/145	[8]
COSY	pp	$K^\circ p\Sigma^-$	?	<18	62/112	[9]
SVD	pA	$K^\circ pX$	?	<15	50/78	[10]
Limits based on *Non*-Observations						
USC	K^+d		1543	<6	—	[15]
GWU	K^+n		1540−1550	≤1	—	[16]
Jülich	K^+n		1545	<5	—	[17]
Approved experiments and some proposals						
Approach/ Collaboration	Beam/Target	Channel	Mass (MeV)	Expected resolution	Events in Signal/Background	Ref.
LEPS D run	γD	nK^+K^-	—	10-15	100 2/1	[20]
CLAS, g10	γD	nK^+	—	10-20	1000 2/1	[21]
CLAS, g11	γH	nK^+	—	10-20	1000 2/1	[22]
M2-HallA	eD	epK^-	—	2.8	520(50nb) 4/1	[23]
M1-HallA	eBe	nK^+K^-	—	2.9	500(4.5nb) 2/1	this proposal

Table 1: Theoretical predictions, experimental observations and limits based on non-observation for the production of the Θ^+.

that would resolve outstanding questions regarding the Θ^+'s existence and properties.

1.2 A quick snapshot of the proposed experiment

The proposed experiment will be performed using one of the JLab Hall A spectrometers (to detect the K^-), the new Bigbite spectrometer (to detect the K^+) and the new large neutron detector that is being built for E02-013 to measure G_E^n at high Q^2[19]. The Hall A spectrometer will be used in conjunction with one of the new septum magnets, allowing the K^- to be detected at 6° The value of the Θ^+ mass will also be accurately measured with use of several methods for calibration of the detector system. The angular distribution of the decay products will be measured and may allow for the determination of the resonance spin.

This proposal used as a starting point the experimental scheme developed for the "M1" portion of our previous proposal [23] to PAC25. In relation to our earlier proposal, we have been able to increase our event rate by a factor of 3-4 (when making equivalent assumptions about the production cross section as were in the first proposal). We have also established that our background will be about half of what we first assumed. The sensitivity of our experiment is thus about 6-8 times better than was implied by our last submission. We also include with this proposal additional analysis to address concerns expressed by PAC25 [24]

about the sensitivity of the proposed scheme to the model of the production mechanism. We note also that our simulations indicate that the detector system will collect data on electro production of the Θ^+ without any additional beam time. Finally, we note that the higher rate of the proposed scheme may allow a photo-production experiment with a polarized ^{3}He target [25], where polarization observables would allow us to identify the quantum numbers of the Θ^+. The feasibility of the polarized experiment will need to await better information on the width and cross section of the Θ^+.

1.3 The impact of this experiment

While evidence for the Θ^+ has been seen in about dozen experiments, there is still considerable controversy regarding its existence. Naively, looking at Table 1, it would seems that the statistical significance of the collective observations is quite good. It is well known, however, that it is surprisingly easy to inadvertently create "bumps" when searching for resonances, even when trying to be cautious. What is needed is an experiment that will see evidence for the Θ^+ that is so overwhelming that little room will be left for error. Designing such an experiment, however, is difficult when the properties of the suspected resonance are still uncertain.

In the scenario in which the Θ^+ is a narrow resonance ($\Gamma_{\Theta^+} \leq 3\,\mathrm{MeV}$), and has $J^P_\Theta = 1/2^+$, we believe our experiment is likely to have overwhelmingly the greatest sensitivity. There are several arguments to support this claim. For instance, most of the experiments that have been performed thus far have fairly similar backgrounds, and have ratios of signal to background of around 1:1. Our resolution, however, is around 3-10 times narrower than has previously been the case, naively implying a ratio of signal to background from around 3:1 to 10:1. Given our expected background rates, such an argument would suggest that our experiment would have a superior statistical significance to anything that is presently planned. Of course, a careful comparison of experiments would need to include information and details that are not at present available to us. Some of these detail, however, might work in our favor. On one point, we note that in our proposal $-t = 0.25 \pm 0.1\mathrm{GeV}^2$, which is probably a bit smaller (by roughly a factor of two?) than either SPring-8 or CLAS. If the dependence on $-t$ is in accordance with the trend found in the calculation of Guidal, Polyakov, and Vanderhaeghen[40], this is a good thing. Our low $-t$ is possible because we are able to look at quite forward angles. The event rates we are expecting in this experiment, which are consistent with the calculation of Guidal, Polyakov, and Vanderhaeghen[40], lead to a signal to background ratio of roughly 2:1.

Again considering the calculation of Guidal, Polyakov, and Vanderhaeghen[40], we expect a total photo-production cross section of 4.5 nb for the case of a width of 3 MeV given our distribution (discussed later) of virtual photon energies. In this scenario, we expect to accumulate around 25 events/day, or around 500 events over the course of the experiment. With the expectation of around 150 background events, this implies a signal/noise (S/N) of around $S/N = 500/\sqrt{500+150} = 20$. If the width were as small as 1 MeV, we would still have around $500/3 = 167$ events, and a $S/N = 167/\sqrt{167+150} = 9.4$. There is no proposed experiment that can come close to this sensitivity under the assumption of a narrow width. We note also that even with the width of around 1 MeV the proposed experiment should be able to determine the width with an error of around 0.7 MeV. Finally, because our experiment utilizes spectrometers with reasonably well understood acceptances, we determine the production cross section with certain caveats on the assumed spin.

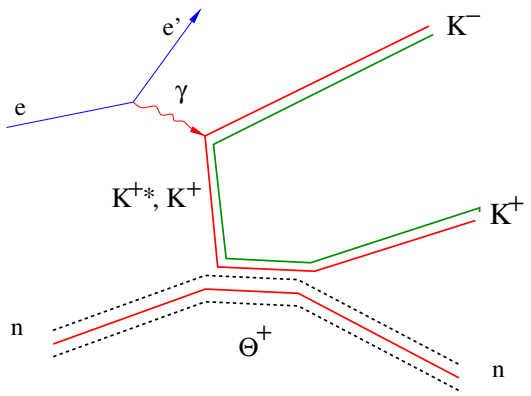

Figure 1: The diagram of the Θ^+ production process.

With our high resolution, clean signal, and relatively low $-t$, we believe that our experiment has the best sensitivity of any that is being proposed. At the very least, it will compliment well the other experiments that are either running or being considered. For instance, even if Hall B does not see an effect in their current run, that could easily be because the Θ^+ is simply too narrow, and our experiment could still see it with impressive statistical significance. We believe it would be unfortunate for the JLab community to delay the only experiment in the world that is capable of studying the Θ^+ with high resolution. With preparation for E02013 proceeding rapidly, and the world's largest neutron detector expecting to be completed within the year, we would like to run quickly.

1.4 The organization of this proposal

The proposal is organized as follows. In section 1 we present the physics motivation and the goals of the proposed experiment. Section 2 introduces the kinematics of the proposed measurements. In section 3 we describe essential features of both the standard and the specialized equipment. Section 4 deals with calculations and recent experimental data on single rates on the detectors. Section 5 presents a Monte Carlo simulation study. Section 6 presents the details of proposed measurements, the resulting mass resolution, event rates and analysis. Section 7 presents the detailed plan of the equipment calibration based of several independent schemes. Expected results and a beam time request are shown in section 8. Finally the proposal is summarized in section 9.

2 Kinematics

The diagram of the reaction is shown in Fig. 1. The quasi-real photons are produced by electron scattering. A pair of kaons is produced through the diffractive mechanism with t-channel dominance. The virtual kaon interaction with a neutron results in the Θ^+. The Θ^+ state decays into a neutron and a K^+. The narrow width of the Θ^+ means that its decay is most likely to happen at a large distance from the target nuclei. The reaction is characterized by forward angle between negative kaon and photon momenta. The dominant exchange particles are the pseudo-scalar K^+ and, less important, the much more massive vector K^{+*}.

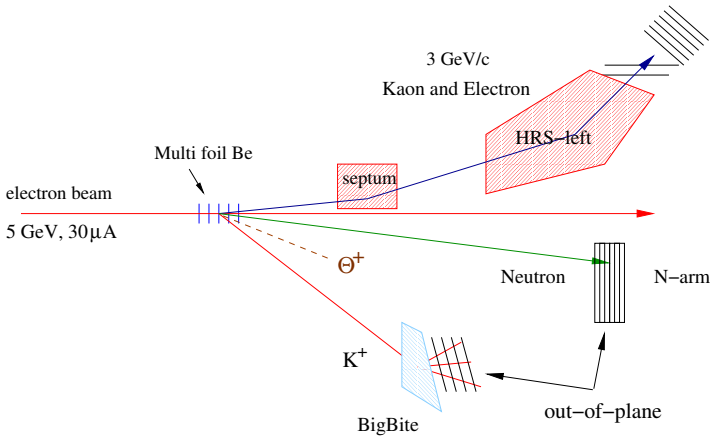

Figure 2: The experimental setup in this experiment.

As illustrated in Figs. 2 this experiment will study production of the Θ^+ from a Be target. The high-energy negative kaon (or electron) will be detected in the Left High Resolution Spectrometer (HRS-left) at a central angle of 6° with a septum magnet. The electron (a negative kaon in the parasitic electro production measurement) will remain undetected. Both decay products of the Θ^+ will be detected and provide full information about the Θ^+ four-momentum. The positive kaon will be detected in the BigBite spectrometer at horizontal/vertical angles 18.4°/-20°, and the neutron will be detected in the large neutron detector at horizontal/vertical angles 18.4°/+20° (see Fig. 2). Distance from the target center to the BigBite iron is of 2.4 m, which is larger that standard distance of 1.07 m. Distance from the target center to the neutron detector is of 12 m as it will be in GEN experiment.

An electron beam with a current of 30 μA at an energy of 5.0 GeV will be used. The Be target of total thickness 1.5 mm will be made of 20 foils with spacing of 25 mm. Such configuration allows effective rejection of the accidental events from different targets and minimization of the multiple scattering in the target.

HRS-left is selected for kaon detection because it is equipped with threshold Čerenkov counters for pion rejection at the trigger level and the state-of-the art RICH detector for identifying the kaon [26]. High momentum kaon leads to a slowdown of the Θ^+ particle and better resolution for its mass. The direction of the Θ^+ particle is about 18°. The relatively small momentum of the produced Θ^+ (of 1 GeV/c) and low energy yield in its decay to the nK^+ channel leads to a large angle between K^+ and neutron. The forward direction of the Θ^+ leads to positioning the detectors in a place with high background rate, especially if the detectors are located in the same plane as the negative kaon. So, we plan to put both detectors for decay products out-of-plane. The BigBite will be installed in the Θ^+ direction down by 20° and the neutron detector in the Θ^+ direction up by 20°. Such an arrangement has a relatively large angle between the beam line and detectors (20-35°) and also a large range of angles between the Θ^+ momentum and decay products (due to the favorable aspect ratio of the acceptance in BigBite and the neutron detector) which is very important for determining the resonance spin. The choice of 5.0 GeV electron beam energy (0.5 GeV higher than in the proposal [23]) allows for the parallel study of the electro production of the Θ^+ state.

item	value
central momentum range, p_c [GeV/c]	0.3-4.3
momentum acceptance, $\Delta p/p_c$ [%]	$\pm$ 4.5
momentum resolution, σ_p/p	$1.1 \cdot 10^{-4}$
minimum angle for the central trajectory	6° with septum
solid angle for the point target [msr]	6.2(4.3 with septum)
coverage for scattering angle	3.1°
extended target acceptance, Y [cm]	$\pm$ 5
θ_{disp} angular resolution (rms) [mr]	1.5
$\theta_{nondisp}$ angular resolution (rms) [mr]	2.0
target vertex Y resolution, $\sigma_{_Y}$ [mm]	1.5
path from the target to the trigger [m]	25.0
detector area (front chamber), [cm x cm]	200 $\times$ 15
trigger segmentation	16
time resolution, $\sigma_{_{ToF}}$ [ns]	0.15

Table 2: The parameters of the HRS spectrometer.

3 Experimental Setup

The experiment will be performed in Hall A, where most of equipment needed in this proposed experiment already exists or will be ready soon for experiment E02-013, preliminary scheduled run in the fall of 2005.

3.1 The CEBAF electron beam

The beam energy of 5.0 GeV with relatively low beam current of 30 μA will be used in this experiment.

3.2 The target

The experiment will utilize a standard Hall A solid target ladder with Be target and a 4 cm long liquid hydrogen cell (with current of 30 μA) for calibration measurements. The Be target will consists of twenty 75 μm foils spaced by 25 mm. Made of 5 mm wide vertical strips such a target provides a thickness of 275 mg/cm^2. Because of large length it allows effective rejection of the accidental coincidence events between HRS and BigBite by using a target vertex test and at the same time the small thickness in the way of particles allows low momentum kaons to be detected without significant multiple scattering.

3.3 The High Resolution Spectrometer-left

Basic parameters of the HRS-left are given in Tab. 2. The spectrometer has very good momentum and angular resolutions and moderate momentum and angular acceptances.

In this experiment for PID in the HRS-left, we are going to use a combination of the RICH, the gas threshold Čerenkov counter, two layer shower detector, and time-of-flight (ToF) on 25 meter path from the target to the S2m scintillator plane. The gas Čerenkov counter filled with either C_4F_{10} or freon-114 will have very good pion rejection at momentum above 2.8 GeV/c. Electrons will be identified by a large signal in the shower detector or in the gas Čerenkov counter with efficiency of 99.9%. The expected few percent pion contamination

item	value
nominal momentum coverage (at H=9 kG) [MeV/c]	200-900
momentum resolution, σ_p/p [%]	0.5
solid angle for the point target [msr]	96
θ angular resolution [mr]	4.0
target vertex resolution, σ_{Y} [mm]	5
path from the target to the trigger [m]	4.0
detector area (front chamber), [cm x cm]	140×35

Table 3: The generic parameters of the BigBite spectrometer [27].

in the electron event sample will be reduced by the shower counter by a factor 30-50. Kaons will be identified by absence of the signal in the gas Čerenkov counter, a small signal in the shower detector and correct value of the Čerenkov angle in the RICH detector [26]. Difference in ToF between the pions and the kaons at 3.0 GeV/c momentum is about 1.1 ns, which provides an additional pion (and electron) rejection factor of 5 for ToF resolution (sigma) of 0.30 ns, which has already been achieved.

3.4 The BigBite spectrometer

The BigBite spectrometer consists of a 20 ton dipole magnet and its detector system, which includes planes of drift chambers and trigger/PID counters. The concept of such a spectrometer was developed and realized at NIKHEF [27]. The parameters observed for the detection of scattered electrons at NIKHEF are given in Tab. 3. For operation in Hall A at higher luminosity, the original detector system is being modified. The new detector has a set of high resolution drift chambers. The particle path from the target to the front wire chamber of BigBite will be in vacuum. MC studies have been done for the geometry of the present proposal for the detection of the K^+. For 600 MeV/c momentum kaon, the relative momentum resolution was found to be 0.6% and an angular resolution of 2 mr.

3.4.1 The BigBite particle identification

BigBite is equipped with a two-layer scintillator trigger plane, which provide 0.20 ns ToF resolution and $\Delta E/E$ information. Two layers segmented Čerenkov counters with a water radiator (similar to that built for HKS [28]) and the aerogel radiator (n = 1.055, similar to the A2 detector in HRS-left) will be added to the BigBite detector package. Table 4 shows the calculated number of photo-electrons in the Čerenkov counters and the ToF difference between kaon and pion for different momenta. The water Čerenkov detector will be used for off-line positive identification of kaons at momenta above 600 MeV/c. Protons with momenta below 600 MeV/c will be rejected using ToF. Particle identification in the proposed counters in BigBite was also studied by using GEANT-3 MC code.

3.5 The neutron detector

The large neutron detector is under construction for experiment E02013 [19]. The detector test assembly will be done in spring 2005. It consists of 244 neutron bars and 184 veto paddles. They are arranged in seven(six) layers with the iron converters and two veto planes.

momentum	average number of photo electrons					Δ ToF
[MeV/c]	p in water	K in water	K in aerogel	π in water	π in aerogel	$K-\pi$ [ns]
200	0	0	0	150	0	23.8
400	0	0	0	340	0	15.9
600	0	50	0	370	15	8.5
800	0	200	0	380	22	5.2
1000		270	0	390	24	3.5

Table 4: The light collection (the average number of photo-electrons) in the Čerenkov counters and the difference between ToF for K and π in BigBite.

Figure 3 shows the schematic view of the detector cross section. The detector efficiency for neutron in energy range of present proposal is about 24%, which takes into account a significant loss of neutrons from interactions in the front shielding and interactions which fire the veto counters. Each neutron bar is viewed by two PMTs, so the ToF resolution (rms) is better then 0.30 ns. Because the neutron energy in the proposed experiment is much less than in GEN the trigger threshold will be reduced from 50 MeV to 20 MeV. We also plan to reduce thickness of the steel plates (neutron converters), which also hold the plastic bars, from 1 inch to 0.5 inch. The detector efficiency as calculated with a GEANT-4 based code is shown in Fig. 4 for different threshold levels.

A trigger scheme of the neutron arm is based on summing the signals from all counters of four vertical layers (total 32 bars) as shown in Fig. 3. The PMT signals in each two layers are summed together (denoted as SS1-15) and then used for the overlapping sums (denoted as S1-14). The output signals from S1-14 units will be discriminated and form the neutron arm trigger.

4 Inclusive electro-production

In this section the inclusive reactions, which define the singles rates of electrons, pions, kaons and protons in the spectrometers, are presented. In both the BigBite and the neutron arm detectors the rates dominate in the low energy part of the particle spectra. We used a DINREG-based code [29] for the calculation of the low energy part of the inclusive spectra ($E_{hadron} << E_{beam}$). DINREG reproduced published neutron and proton yields in electro-nuclear reactions [30]. DINREG-based calculations for the wire chamber rates were found to be in agreement with measurements in Hall A [32].

The HRS-left will be used to detect negatively charge particles with a momentum of about 3.0 GeV/c. Electron yield was found from a DIS parametrization and checked relatively to direct measurement in Hall A. The yields of negative pions and kaons were calculated by using the parametrization from Wiser's thesis [34] and checked relatively results from DESY and SLAC measurements of inclusive photo-production [35, 36, 37].

4.1 Kinematics and definitions

The kinematic quantities of electro-production are presented in Fig. 5.

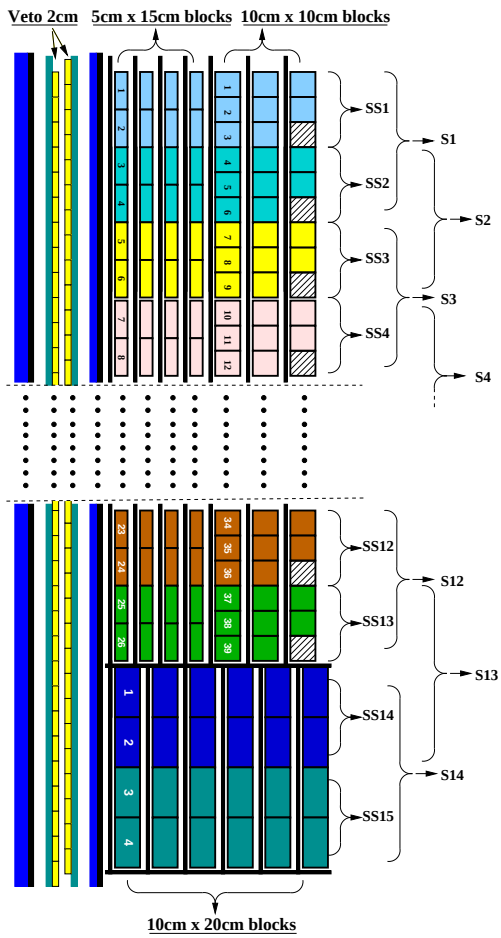

Figure 3: The scheme of the neutron detector and the groups of the counters whose signals will be summed for use in the trigger.

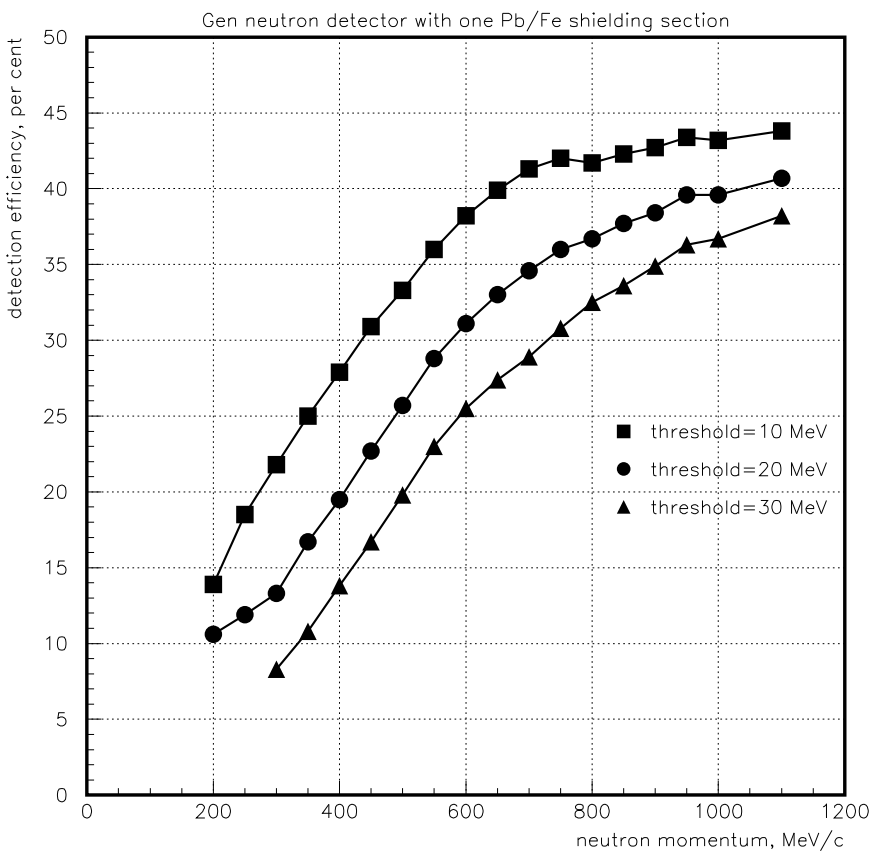

Figure 4: The efficiency of the neutron detector for different threshold levels.

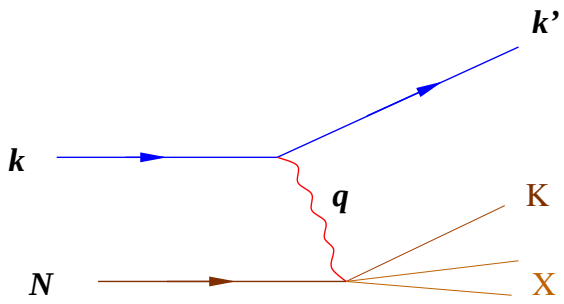

Figure 5: Kinematics quantities for description of electron-nucleon scattering: k and k' are the four-momenta of incoming and outgoing electrons, N is the four-momentum of a nucleon with mass M. The exchange photon transfers four-momentum $q = k - k'$ to the target.

The definitions of the kinematical variables are given for the reaction $e + N \rightarrow e' + K + X$. The five four-momenta involved are:

$$\begin{gathered} k = (E, \vec{k}), \text{ for the incident electron} \\ k' = (E', \vec{k}'), \text{ for the scattered electron} \\ N = (M, \vec{P}), \text{ for the target nucleon} \\ K = (E_{_K}, \vec{p}_{_K}), \text{ for the produced kaon} \\ X = (E_{_X}, \vec{p}_{_X}), \text{ for the residual system} \end{gathered}$$

A few kinematic variables are defined below as:

$$\begin{gathered} q^2 = (k - k')^2 = -Q^2, \\ \nu = E - E', \\ \epsilon = \left[1 + 2\frac{\nu^2+Q^2}{Q^2} tan^2\frac{\theta_e}{2}\right]^{-1}, \\ s = (q + N)^2 = W^2, \\ t = (q - K)^2, \\ x_{_F} = p^{cm}_{K,z}/p^{cm}_{K,z\,max}, \text{ the Feynman variable} \end{gathered}$$

The differential cross section of inelastic eN scattering processes is written in the usual notation as

$$\frac{d^2\sigma}{dE'd\Omega_{e'}} = \frac{\alpha^2}{4E^2 sin^4(\frac{\theta}{2})}\left[W_2(q^2,\nu)cos^2(\frac{\theta}{2}) + 2W_1(q^2,\nu)sin^2(\frac{\theta}{2})\right].$$

In the approximation of $E, E' >> M_N$ and finite q^2, ν we will use

$$\frac{d^2\sigma}{dE'd\Omega_{e'}} \approx \frac{\alpha^2}{4E^2 sin^4(\frac{\theta}{2})}\frac{F_2(q^2,\nu)}{\nu}.$$

The differential cross section for the electro-production of hadron a can be presented as:

$$\frac{d^3\sigma}{dE'd\Omega_{e'}d\Omega_{_K}} = \Gamma \cdot \frac{d\sigma_{\gamma^*,K}}{d\Omega_{_K}},$$

where Γ is the virtual photon flux factor, given by:

$$\Gamma = \frac{\alpha}{2\pi^2}\frac{E'}{E}\frac{s-M^2}{2MQ^2}\frac{1}{1-\epsilon},$$

Field of 9 kG	e^-	$\pi^\pm$	kaon	proton
rate [MHz]	0.5	8.2	0.02	3.3

Table 5: The singles rates in BigBite at $\mathcal{L}_{eN}$ of $3 \cdot 10^{37}$ cm^{2}s^{-1}.

and $\frac{d\sigma_{\gamma^*,K}}{d\Omega_K}$ is the cross section for kaon production by the virtual photon. At small scattering angle, where $Q^2 << \nu^2$, the transverse terms of the cross section are dominate, so we will use the form:

$$\frac{d\sigma_{\gamma^*,K}}{d\Omega_K} = \frac{d\sigma_T}{d\Omega_K} + \epsilon \frac{d\sigma_{TT}}{d\Omega_K} cos(2\phi),$$

where ϕ is the angle between the electron scattering plane and the Θ^+ production plane.

4.2 Singles rates in the HRS

In the present experiment the HRS will be at 6° and the central momentum at 3.0 GeV/c. The kinematics for the beam energy of 5 GeV corresponds to Q^2 of 0.15 (GeV/c)^2. An electron rate is of 120 kHz for the luminosity of $\mathcal{L}_{eN}$ of $3 \cdot 10^{37}$ cm^{2}s^{-1}. Pion rate expected on the level less than of 5% of the electron rate. An estimate of the negative kaon rate was made by using Wiser's parametrization of experimental data [34]. It is about 90 Hz. The effective photon energy range for the process from 3.85 to 4.75 GeV. The kaon rate at the trigger detector is approximately 30 Hz due to kaon decay.

4.3 Singles rates in the BigBite

The proposed configuration of the detectors was analyzed for singles rates, which defined the maximum usable luminosity and possible production rate. This section deals with the calculation and measurement of the singles rate in the BigBite spectrometer.

Figure 6 shows the expected rate of electrons at different momenta. The proton rates are shown in Fig. 7. To cross check these calculations we made a measurement of the counting rate of a multi-wire proportional chamber located behind BigBite at 65° and a distance of 8 m from the target. During measurements the beam energy was 4.2 GeV. The observed rate was found to be about half the calculated rate [32]. In the analysis below we used the calculated rate as a conservative estimate of the background.

For this experiment, BigBite will be installed out of plane at average polar angle 27°, at larger than the nominal distance from the target, so the solid angle will be 38 msr. The rates integrated over the acceptance are shown in the Tab. 5. The kaon rate shown in the table includes a decay factor.

4.4 Singles rate in the neutron detector

In the proposed experiment we will use the neutron detector N-200, which is under preparation for the GEN experiment E02013 [19]. It will be installed at distance of 12 m from the target at average polar angle of 27 degree relatively beam line.

In 2002 we built a 10% segment of the full detector (20 neutron bars and 8 veto paddles) and used it for measurement of the singles rates and trigger rates at a distance of 8 m from

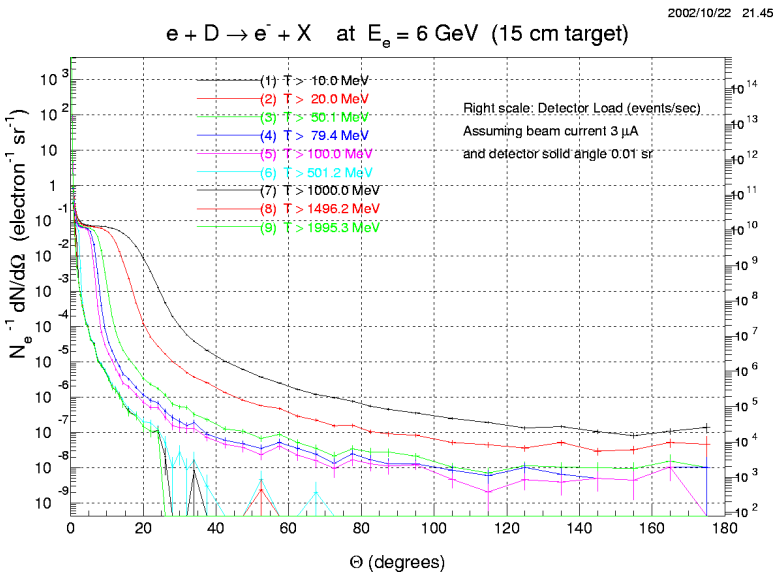

Figure 6: Electron rate at $\mathcal{L}_{eN}$ of $2.75 \cdot 10^{37}$ cm^{2}s^{-1}. The detector solid angle is 0.01 sr in this plot.

	veto paddle	N-bar PMT, above 5 MeVee	trigger, above 20 MeVee
rate [MHz]	1.2	0.06-0.18	5.7

Table 6: The rates in the neutron detector at $\mathcal{L}_{eN}$ of $3 \cdot 10^{37}$ cm^{2}s^{-1}.

the target and 25° from the beam line. Rates were found to be in good agreement with DINREG-based calculations [31].

Figure 8 shows the expected rate of pions at different momenta, which contribute to the rate in N-200. The rate of neutrons is shown in Fig. 9. Table 6 shows the expected detectors rates in N-200 during proposed measurement.

5 Monte Carlo simulation of the experiment

There are following main parameters obtained from the MC simulation:

- the resolution for an invariant mass of the nK^+ system;
- the probability to detect decay products of Θ^+ state in N-arm and BigBite;
- the probability to detect a negative kaon in the HRS in events, when the Θ^+ particle was produced;
- the photon energy range corresponding to a negative kaon in the HRS momentum acceptance; and
- the probability to detect decay products of a system produced, when K^- is registered in HRS: a non-resonance background.

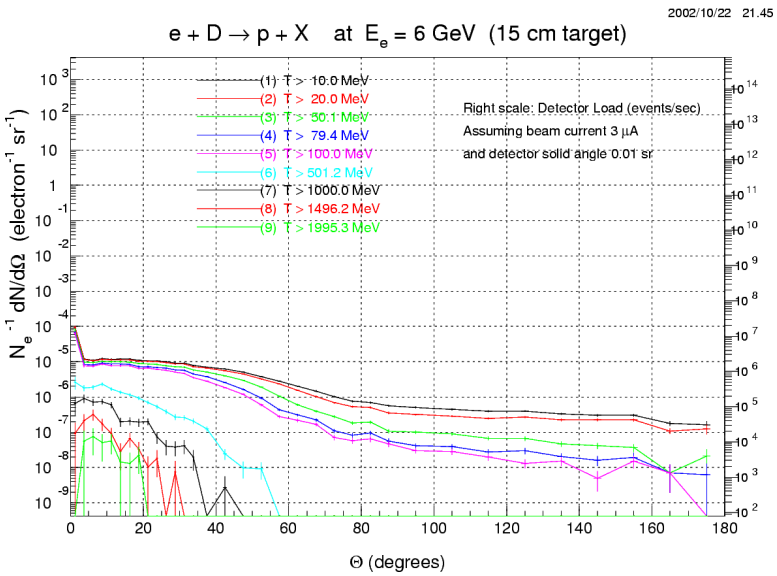

Figure 7: Proton rate at $\mathcal{L}_{eN}$ of $2.75 \cdot 10^{37}$ cm^{2}s^{-1}. The detector solid angle is 0.01 sr in this plot.

The MC code for this experiment is written under GEANT-3. The HRS spectrometer is represented by its acceptance and resolution in configuration with the septum magnet as shown in Tab. 2. Decay of the kaon on the path to the HRS detector was calculated separately. The BigBite geometry was described in many details, including geometry of the magnet and every detector. The resolution was found from additional MC study of the optics reconstruction matrix. The neutron detector was represented by its front face. N-arm detection efficiency was calculated by a separate code [33] (see Fig. 4).

5.0.1 The mass resolution and detection probability for the Θ^+

In the MC a photon generates an event from the nucleon, which contains a negative kaon (uniformly in the acceptance of the HRS) and a system with a mass of 1540 MeV. The system decays to a neutron and a positive kaon with isotropic distribution in its cms. Resulting event distributions are shown in Fig. 10 and Fig. 11. The mass resolution (FWHM) was found of 2.9 MeV. Figure 11 presents distributions Θ^+ events over the incident photon energy, the resonance momentum, the neutron momentum, and the correlation of the neutron and kaon momenta.

The probability for detection was found to be $f_{nK^+}^{N*BB-accept} = 1.67 \cdot 10^{-3}$ for a mass of 1.54 GeV . The detection probability for different resonance mass defines an acceptance range of the experiment. To do this the mass of produced system was generated uniformly in range from 1.4 to 1.7 GeV. The smooth background in Fig. 10 presents also a shape of acceptance in this experiment for different mass of nK^+ system.

5.0.2 The probability to detect negative kaon in HRS

This very important parameter was calculated by using two ways: a first is a model of the Θ^+ photo production from a neutron [40] and a second is an experimental shape of the

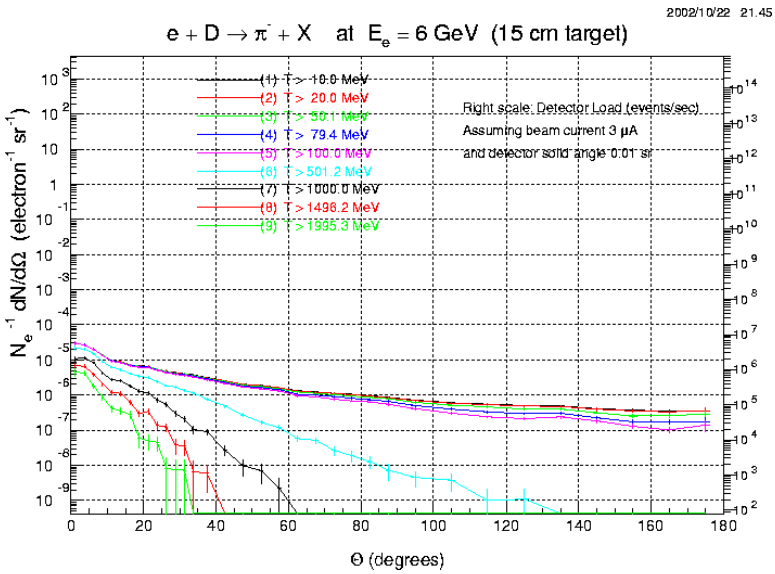

Figure 8: Pion rate at $\mathcal{L}_{eN}$ of $2.75 \cdot 10^{37}$ cm^{2}s^{-1}. The detector solid angle is 0.01 sr in this plot.

K^+ distribution in the photo production of $\Lambda(1520)$ [41], shown in Fig. 12. The fraction of the total cross section, which corresponds to the HRS acceptance, was calculated from

$$f_{\gamma,K^-}^{HRS-accept} = \left[\frac{d\sigma}{dt}|_{-t=0.24} \times \Delta t \times \frac{\Delta\phi}{2\pi} \right] / \sigma_{total}$$

where $\Delta t = 0.15$ (GeV/c)^2 is a range of t momentum transfer, which was found by the MC according to HRS acceptance, and $\Delta\phi = 0.87$ is the HRS azimuthal angle coverage. The value of $f_{\gamma,K^-}^{HRS-accept}$ was calculated by using results [40] (see Fig. 13). For positive parity the $f_{\gamma,K^-}^{HRS-accept}$ is of 0.063 and for negative parity it is 1.5 times less. The second approach with the $\Lambda(1520)$ leads to the $f_{\gamma,K^-}^{HRS-accept} = 0.032$. Thus we are expecting that the fraction for Θ^+ state would be somewhere within 0.032-0.063 range and used the average value of $f_{\gamma,K^-}^{HRS-accept} = 0.048$ for an estimation of the Θ^+ counting rate.

5.0.3 Non-resonance background

A starting point for the analysis is a rate of K^- in the HRS focal plane, which was found of 30 Hz (see Sec. 4). The production of K^- is associated with the production of the kaon and hadron system. At low end of the photon energy (about 3.8 GeV) such a system is a kaon and a nucleon (nK^+ or pK°). For a photon energy above 4 GeV the acceptance for three body system of a kaon, a nucleon, and a pion, opens up. The probability to have a neutron and a K^+ in the acceptance of N-arm and BigBite for the γ, K^- event has contributions from the production of both two body nK^+ and three body $nK^+\pi$ final states. The accepted fractions are $f_{nK^+}^{N*BB-accept} = 1.67 \cdot 10^{-3}$ and $f_{nK(\pi)}^{N*BB-accept} = 0.28 \cdot 10^{-3}$ (these numbers are for 100 MeV range of nK^+ mass). However, we don't know the ratio between these two channels. We can make estimates for two extreme scenarios. In the first one the two body system is responsible for all K^- events. Final number of events per 1 MeV in invariant

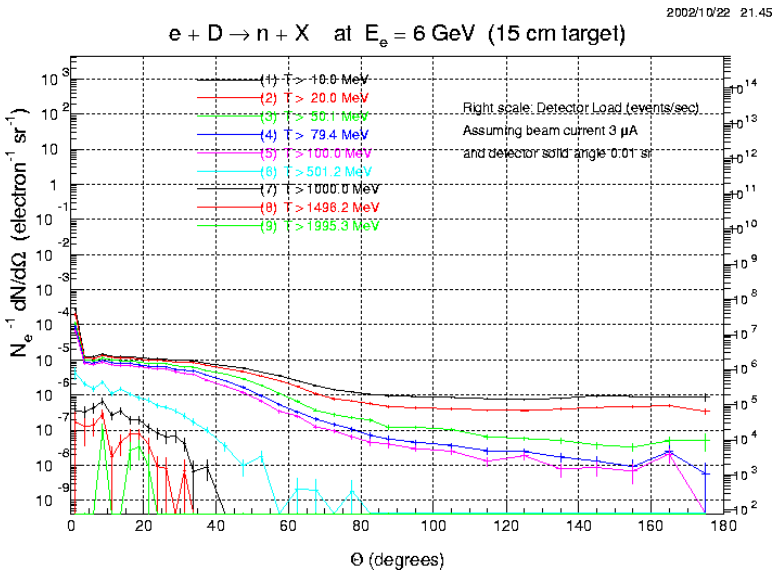

Figure 9: Neutron rate at $\mathcal{L}_{eN}$ of $2.75 \cdot 10^{37}$ cm^{2}s^{-1}. The detector solid angle is 0.01 sr in this plot.

mass spectra is of 34 for the 20 days experiment. In the second scenario the three body system produced in all K^- events. It allows for only 9 events per MeV in final spectra because of smaller acceptance and twice the number of possible channels ($nK^+\pi^\circ$, $nK^\circ\pi^+$, $pK^\circ\pi^\circ$, $pK^+\pi^-$). We assumed a 50:50 branching ratio between nK^+ and pK°, which could be effected by dynamics of the production process. We also assumed a 25% branching ratio to $nK^+\pi^\circ$ in three body final state, which again could be effected by dynamics. Resulting non-resonance background is of 34 ± 25 events per MeV.

5.0.4 The photon energy range

The luminosity of Θ^+ production experiment is proportional to the photon energy range for which negative kaon could be detected by HRS and Θ^+ decay products in N-arm and BigBite. For present kinematics we found this range is from 3.8 to 4.1 GeV as shown in the upper left plot of Fig. 11.

6 Proposed measurement

A measurement is proposed which will allow observation of a narrow Θ^+ state in an invariant mass spectrum with sensitivity of 1 MeV wide resonance. Experiment will measure a mass and width of the state. Experiment will also measure an angular distribution of the decay products. If the width is about 10 MeV, which leads to a large production cross section, more events will be obtained from electro production data, which covers large range of four momenta of virtual photon as well as large range of momentum transfer to negative kaon.

The key experimental elements of the present proposal are

- a high resolution spectrometer HRS in Hall A;

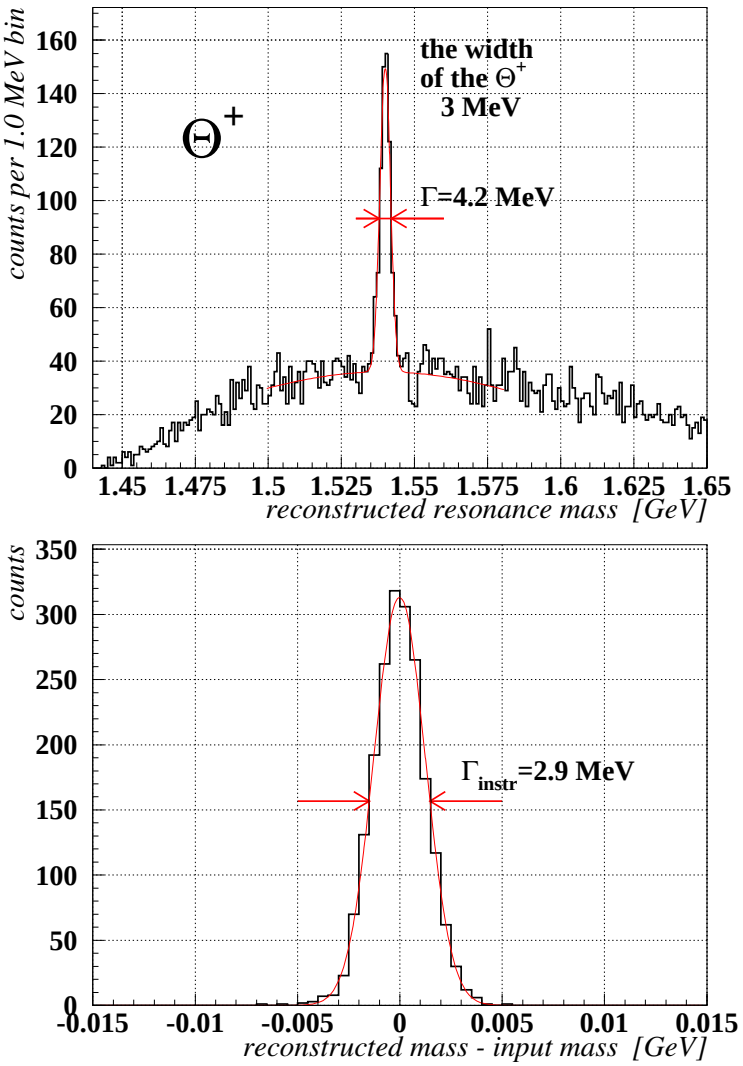

Figure 10: The acceptance and resolution for invariant mass of the nK^+ system. Statistics in this plot corresponds to the production cross section of 4.5 nb at photon energy 4 GeV.

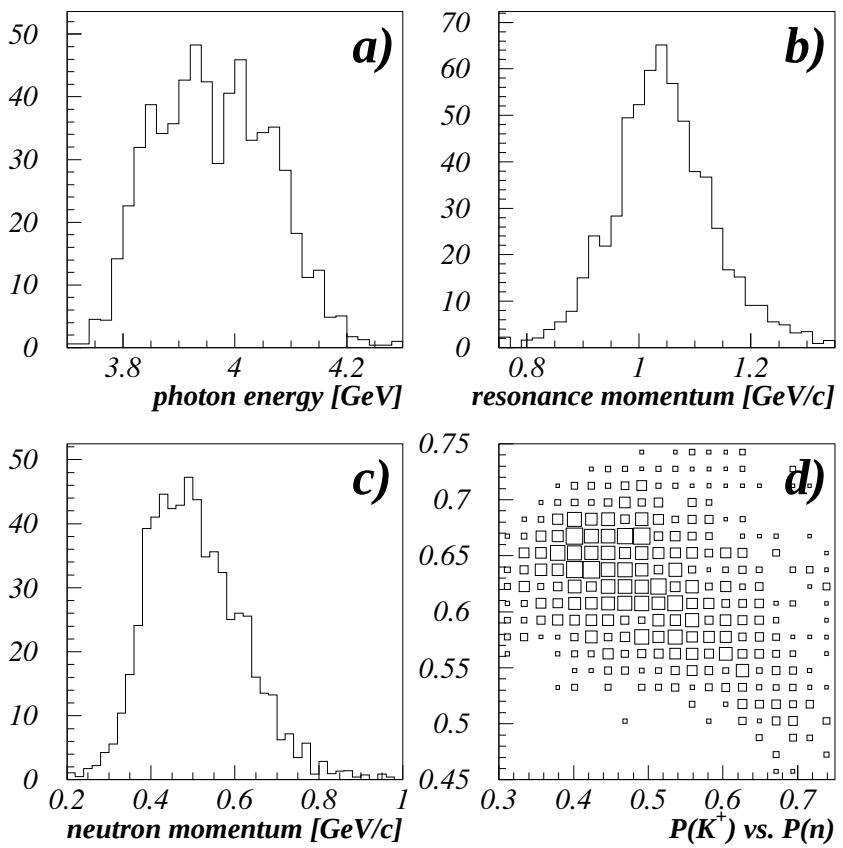

Figure 11: The event distributions for Θ^+ production a) the photon energy; b) the Θ^+ momentum; c) the final neutron momentum; and d) the correlation between the neutron and kaon momenta.

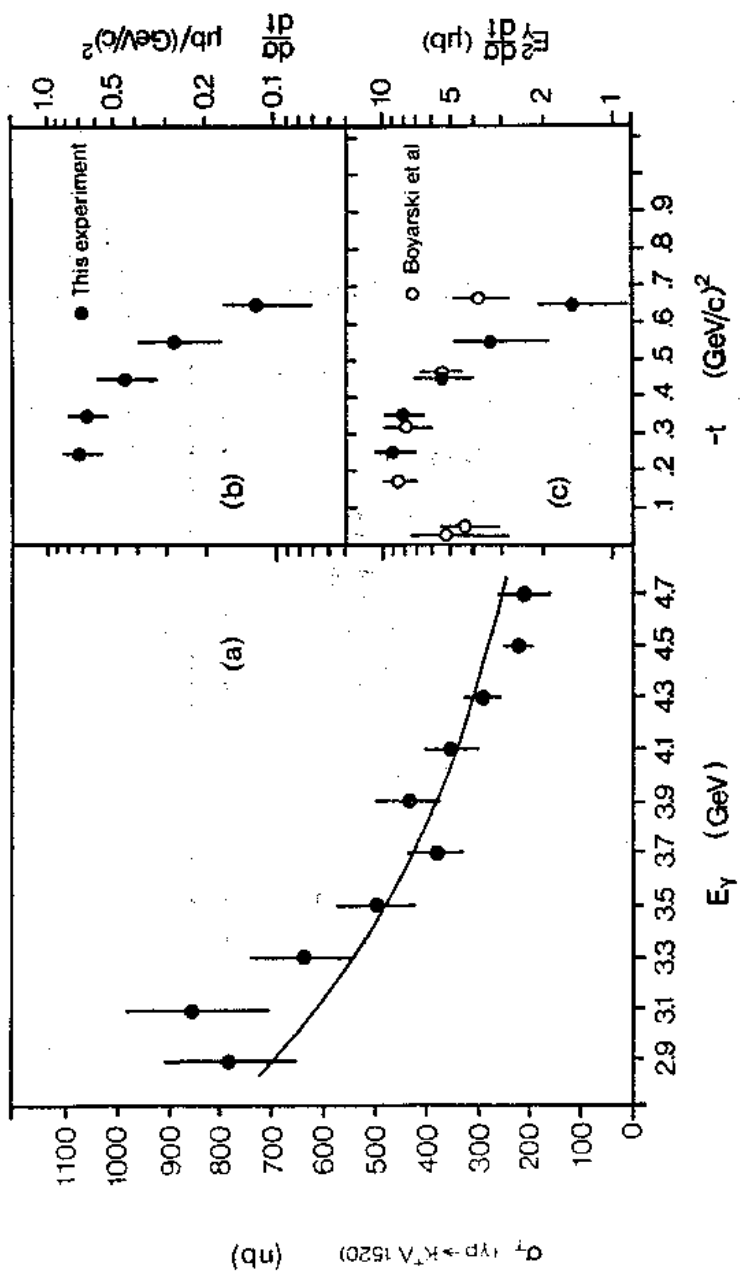

Figure 12: The total and differential cross section for photo production of $\Lambda(1520)$ from proton [41].

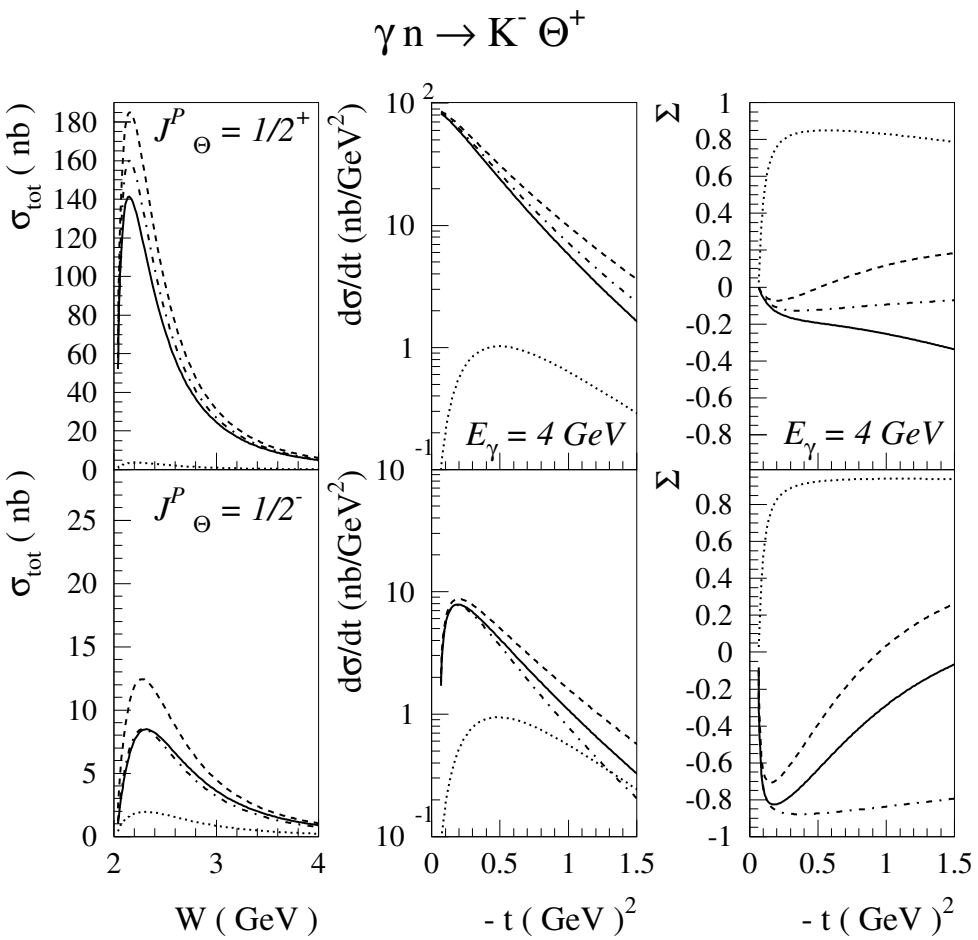

Figure 13: The total and differential cross section for photo production of Θ^+ according to [40].

- a septum magnet for HRS, which allows detection of particles for the central trajectory in each spectrometer at an angle of 6°;
- a large acceptance magnetic spectrometer BigBite, with a high resolution detector package under construction for the GEN experiment;
- a large array of the neutron counters, which is also a part of the GEN experimental setup;
- a 50 cm long multi foil Be target; and
- a set of threshold Čerenkov counters for PID in BigBite.

The primary goal of proposed experiment will be realized by using photo production by quasi-real photons. The flux of quasi real photons may be calculated [36], which will allow for the determination of the production cross section, which is still undertermind in spite of dozen published observations of the Θ^+ state. The high energy forward negative kaon presents a very important **tag**, which reduces dramatically the contribution of competing reactions into K^+-neutron event sample and selects sample of slow Θ^+ , which allow for the accurate measurement of its mass. Exact photo-production mechanism of the Θ^+ is unknown. However, it is logical to expect that it is similar to the t-channel dominated process for producing the $\Lambda(1520)$. The important parameters in this case are the total cross section and its t-dependent slope. In the calculation of the acceptance we used a predictions [40] and an experimental shape of the differential cross section from the process $\gamma p \to K^+\Lambda(1520)$.

The electro production measurement, which does not require extra beam time and, as a result, is not discussed in details in this text, could be quite useful in case Θ^+ has large width and production cross section. The post-target tagging approach, often used in hyper-nuclei experiments, is a low Q^2 electro-production study of photo-production processes. Because the HRS spectrometer momentum resolution (rms) is about $1.1 \cdot 10^{-4}$ such tagging has very good energy resolution. The effective flux of photons is also much higher than achievable with a tagged real photon beam if the electron scattering angle is sufficiently small. The cross section may also have large a $\sigma_{_{TT}}$ term, where the ratio to the $\sigma_{_T}$ is related to the Σ photon polarization observable and can be estimated from parasitic electro production experiment because of significant out-of-plane acceptance. For small scattering angles the effective degree of linear photon polarization can be presented as $(1 + E_\gamma^2/(2E_e^i E_e^f))^{-1}$ which is ≈80% for the conditions of this measurement.

6.1 The experiment parameters

We are going to study the reaction $\mathrm{Be}(e, nK^+K^-)X$. The concept of the measurement is shown in Fig. 2. An electron beam with a current of 30 μA at an energy of 5.0 GeV will be used. The negative kaon (or scattered electron) will be detected in the magnetic spectrometer HRS-left at a central angle of 6° with a septum magnet. The positive kaon will be detected in the BigBite spectrometer at horizontal/vertical angles 18.4°/-20°, and the neutron will be detected in the large neutron detector at horizontal/vertical angles 18.4°/+20°. The invariant mass resolution (FWHM) for nK^+ is about 2.9 MeV.

6.1.1 The calculation of the Θ^+ production rate

We assumed the resonance width (FWHM) of 3 MeV. In calculating the Θ^+ production rate we used the value of the total photo-production cross section of 4.5 nb motivated by analysis [40], where at 4 GeV photon energy such cross section corresponds to the width of the resonance Γ of 3 MeV. The calculations for the production and background are made for the electron-nucleon luminosity $\mathcal{L}_{eN}$ of $3 \cdot 10^{37}$ cm^{-2}s^{-1}. The photon-neutron luminosity was calculated as (see definitions in Sec. 4)

$$\mathcal{L}_{\gamma n(eutron)} = \frac{N}{A} \cdot 0.015 \cdot \frac{\Delta E_\gamma}{E_\gamma} \cdot \mathcal{L}_{eN} \approx 6.8 \cdot 10^{-4} \cdot \mathcal{L}_{eN} \; = \; 2.0 \cdot 10^{34} \text{ cm}^{-2}\text{s}^{-1},$$

where E_γ and ΔE_γ are defined by the kaon momentum and its range accepted in HRS-left, $\langle E_\gamma \rangle = 4.0$ GeV and $\Delta E_\gamma = 0.325$ GeV; $\mathcal{L}_{eN}$ is the electron-nucleon luminosity, $\mathcal{L}_{eN} = 3 \cdot 10^{37}$ cm^{-2}s^{-1}. Such a value of $\mathcal{L}_{\gamma n(eutron)}$ is about 10^4 times higher than what one can obtain with real-photon tagging. This leads to the production rate

$$\nu^{\Theta^+}_{\gamma,K^-nK^+} = \mathcal{L}_{\gamma n} \cdot \sigma^{\Theta^+}_{\gamma n} \cdot f^{HRS-accept}_{\gamma,K^-} \cdot f^{decay}_{K^-} \cdot f^{N*BB-accept}_{nK^+} \cdot \eta_n \cdot b_{nK^+} \; = \; 25 \text{ events per day},$$

where $\sigma^{\Theta^+}_{\gamma n}$ is the cross section of 4.5 nb; the $f^{HRS-accept}_{\gamma,K^-}$ is a fraction of K^- associated with Θ^+ production within HRS angular acceptance, it is $\approx$0.048; $f^{decay}_{K^-} = 0.33$ is the survival probability of a K^- after a 25 meter path in the HRS; $f^{BB*N-accept}_{nK^+}$ is a fraction of Θ^+ events when both decay products are in angular acceptance of N-arm and BigBite detectors, $f^{BB*N-accept}_{nK^+}$ is $\approx 1.67 \cdot 10^{-3}$; $\eta_n = 0.24$ is the detection efficiency of the neutron; and b_{nK^+} is the branching ratio for Θ^+ decay to nK^+, $b_{nK^+} = 0.5$.

By using this rate and expected non-resonance (see below) one can find a sensitivity of 20 day experiment to resonance with cross section of 1.5 nb. Random origin of similar bump will require 5 sigma statistical fluctuation. Another words the experiment will collect of 20 events per nb of the cross section, when we referring to the cross section at its maximum near 2 GeV photon energy.

6.1.2 Trigger rate and event analysis

The DAQ trigger will use a coincidence between HRS and BigBite. At forward angle and 3 GeV/c central momentum of HRS a pion rate is less than few percent of the electron rate, which is about 120 kHz at proposed luminosity. A rejection factor of the electrons and pions in HRS-left is on the order of 10^4 based on use of the gas Čerenkov and shower counters. After RICH information analysis the event sample will have less than 10% pions, the rest being kaons. The raw scintillator rate at BigBite expected to be about 12.5 MHz mainly pions and protons. On-line veto from a thin scintillators allows for the rejection of protons with kinetic energy below 100 MeV. A BigBite trigger (segmented into 24 scintillators and 24 aerogel cells) will have rate of 100 kHz, when we assumed an on-line rejection factor of 100 with two layer Čerenkov counters (see Sec. 3). Within 120 ns coincidence time window these rates lead to comfortable for DAQ accidental coincidence rate of 15 Hz.

Off-line analysis of PID detectors should bring the rejection factor for protons and pions to the level of 10^4. Most of remaining accidental events will be between a negative kaon in HRS and a positive kaon in BigBite, which has a rate of 0.05 Hz. Analysis of the event vertex (HRS-left vs BigBite) allows us to cut this accidental rate by an additional factor of 10-20 to the level of 0.005 Hz.

With 6 MHz rate of neutrons and 24% detection efficiency we expecting about 1.4 MHz rate of triggers in the N-arm after applying veto cut. It leads to 11% probability of accidental hit in 75 ns time interval, where we are expecting a neutron with momentum from 0.3 to 0.7 GeV/c. The distribution of accidental events in nK^+ invariant mass has a width of 300 MeV resulting to accidental background of very low level level of $2 \cdot 10^{-6}$ Hz/MeV or 3 event/MeV in final invariant mass spectra (after 20 days experiment).

A tracking system of BigBite has three planes of wire chambers, which are designed to handle the track rate on level of 10 MHz. For 150 ns maximum drift time we are expecting to have 1.5 extra tracks per events. Three wire chambers located in field free area allow to identify hits related to individual tracks. Tracks unrelated to the trigger will have large mismatch in drift time for left and right cells, so can be removed with a factor of 10-15. In addition a correlation of the track position and the hit position in the segmented trigger plane allow to reduce false track background by a factor of 20.

6.1.3 The correlated rates

The correlated rate due to real coincidences between the HRS-left, BigBite, and the neutron detector in principle has contribution from the following two reactions

- production of heavy hyperons Λ and Σ which have about 20% probability of decay in nK^+; and
- production from neutron of the ϕ meson, which decay to K^+K^- and direct production of K^+K^- pair.

However, large momentum of the negative kaon yields non-zero probability only for direct production of nK^+K^-. The MC simulation logic for the background was discussed in Sec. 5.

7 Calibration of the mass scale and resolution

Several calibration methods will be used. The list of reactions applicable in our experiment includes:

- Elastic electron scattering.
- Electro disintegration of the Deuterium - $D(e,e'n)p$ with reconstruction missing proton mass. Reconstruction of the missing neutron mass in $H(e,e'\pi^+)n$ reaction and $H(e,e'n)\pi^+$ with reconstruction missing pion mass.
- Reconstruction of the missing mass of $\Lambda(1116)$, $\Lambda(1520)$ and $\Sigma^\circ(1193,\ 1385)$ in reaction $H(e,e'K^+)X$. Reconstruction of the invariant mass of $\Sigma^+(1189)$ in reaction $H(e,e'n\pi^+)\overline{K}$. Reconstruction of the missing neutron mass in reaction $D(e,e'n\pi^+)n$ and Σ^- invariant mass in $D(e,e'n\pi^-)K^+p$. Reconstruction of the $\Lambda(1116)$ in $n\pi^\circ$ invariant mass in reaction $H(e,e'nK^+)\pi^\circ$ and a missing mass in reaction $H(e,e'K^+)\Lambda(1116)$.

During these measurements the positions of spectrometers will be the same as in the main part of the experiment. Multi-foils Be target will be used for calibration of the optics for both spectrometers. Hydrogen and Deuterium target will be used to do calibration with K^+/π^+ in several reactions.

The first method of calibration is based on elastic electron scattering from carbon and hydrogen and allows calibration of the momentum and angles reconstruction of HRS-left and BigBite. The beam with energy of one pass will be used for BigBite calibration. The expected rate is about 5 kHz luminosity of $\mathcal{L}_{eN} = 1 \cdot 10^{35}$ cm^{-2}s^{-1}. The beam with energy of 3 GeV pass will be used for HRS calibration. Here expected rate is about several kHz at the same luminosity. Absolute beam energy will be measured by using EP system with precision of 2×10^{-4} [42].

For the neutron arm similar initial calibration of the Time-of-Flight (ToF) will be achieved by using a prompt gamma production. This calibration will be done in single arm DAQ mode as well as for main body of collected data, where N-arm trigger will be not used for on-line event selection.

The second method will check calibration of the neutron arm via reconstruction of the missing proton mass. We plan to take data for 4 hours during 0.8 GeV running conditions with HRS-left momentum adjusted to 0.5 GeV/c. The rate of 100 Hz will allow detailed test and calibration of the N-arm.

The third group of calibrations will use electro production of the hyperons. We plan to take data for 4 hours for K^+ electron production with beam energy of 3 GeV and HRS-left momentum adjusted to 1.7 GeV/$c$for detecting scattered electron. Additional calibrations will be done with beam of 5 GeV for total of 40 hours of beam time. During 5 GeV calibration run we will use several HRS settings. A setting of 3.7 GeV/c provides data on the Σ^+ invariant mass.

We present below the MC result for the process - $H(e, e'K^+)\Lambda(1116)$ The distributions shown in Fig.14 are generated from MC simulated data. The missing mass resolution (FWHM) of 5.8 MeV will test the BigBite performance for detecting K^+.

The Σ^+ production will provide a very detailed test through the reconstruction of invariant its mass. The difference in masses between the Θ^+ and Σ^- resonances is 350 MeV, which is close to mass difference between a kaon and a pion. The data taking will be done for HRS momentum of 3.7 GeV/c. The momentum and mass distributions are shown in Fig.15. Such level statistics will be collected in 12 hours of beam time. The invariant mass resolution (FWHM) is 2.7 MeV.

8 Expected results and beam time request

8.1 Search for narrow resonances

This experiment has unique sensitivity in the search of narrow resonances decaying to nK^+ in mass range 1500-1600 MeV. The resonance with the width of 1 MeV (total photo production cross section of 7 nb at 2 GeV photon energy) will be observed as a signal five times larger statistical fluctuation. The expected search example is shown in Fig. 16.

8.2 The mass and width of the Θ^+ state

The systematic accuracy of mass measurement of 0.5 MeV was estimated from systematics of calibration which will be done by using several methods with large statistics for Λ and Σ resonances. With 500 events, which are expected for the 3 MeV width of the resonance, will allow for 0.2 MeV uncertainty.

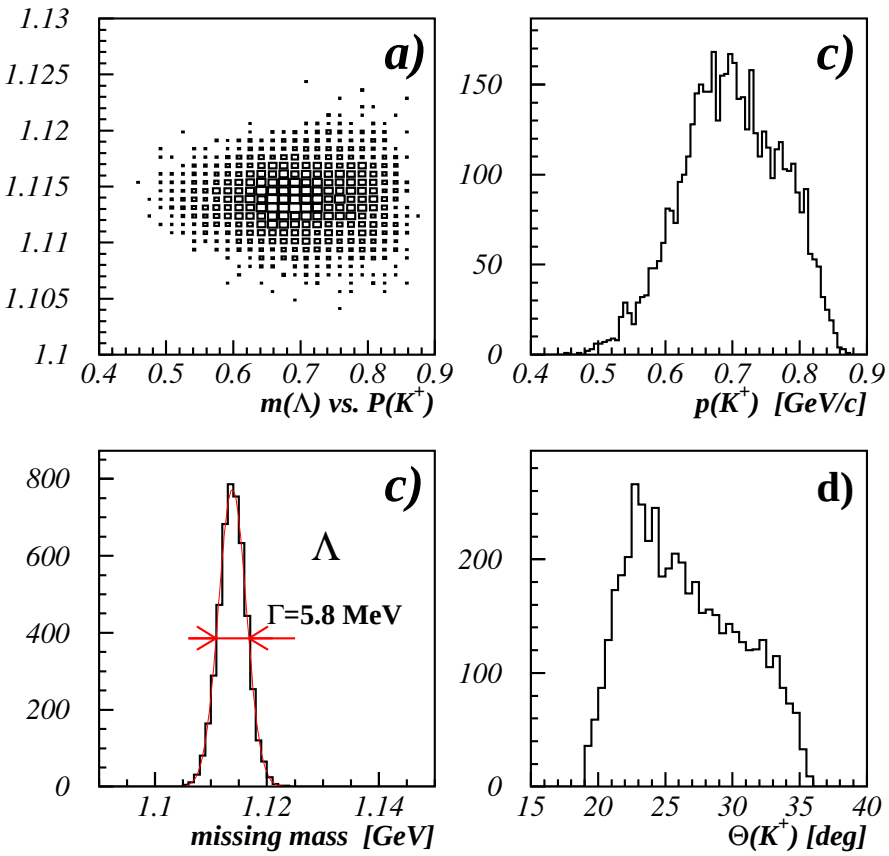

Figure 14: The event distributions from K^+ production run with missing $\Lambda(1116)$.

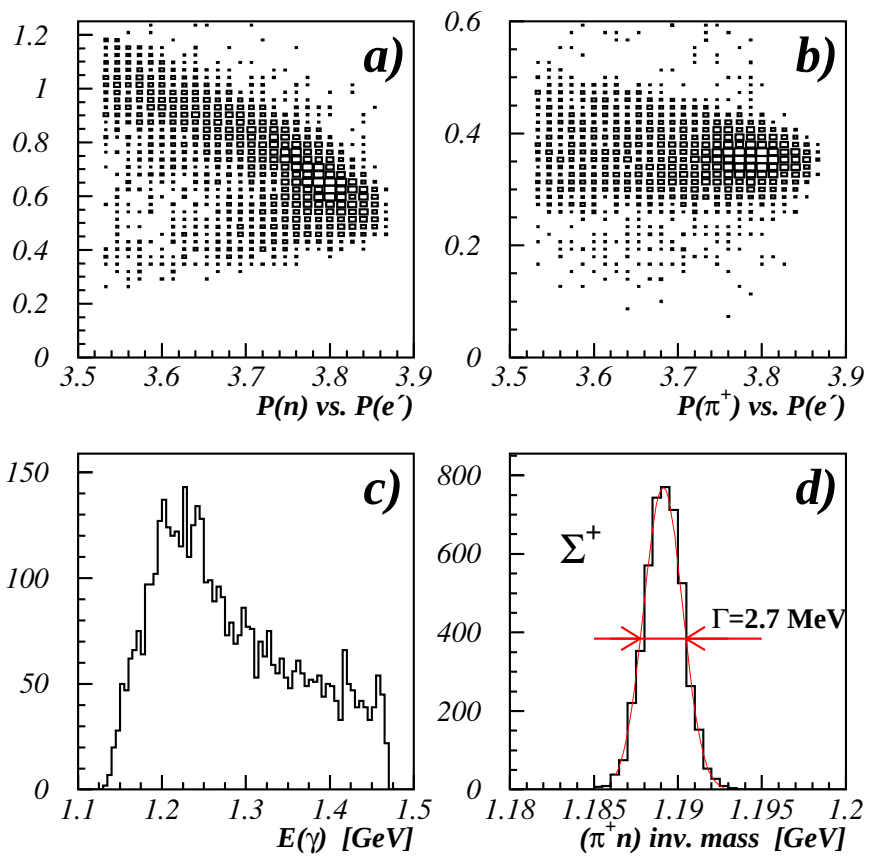

Figure 15: The event distributions for Σ^+ production a) the neutron momentum vs the final electron momentum; b) the π momentum vs the final electron energy; c) a photon energy spectra; and d) a Σ peak in the invariant mass spectra of $n\pi^+$.

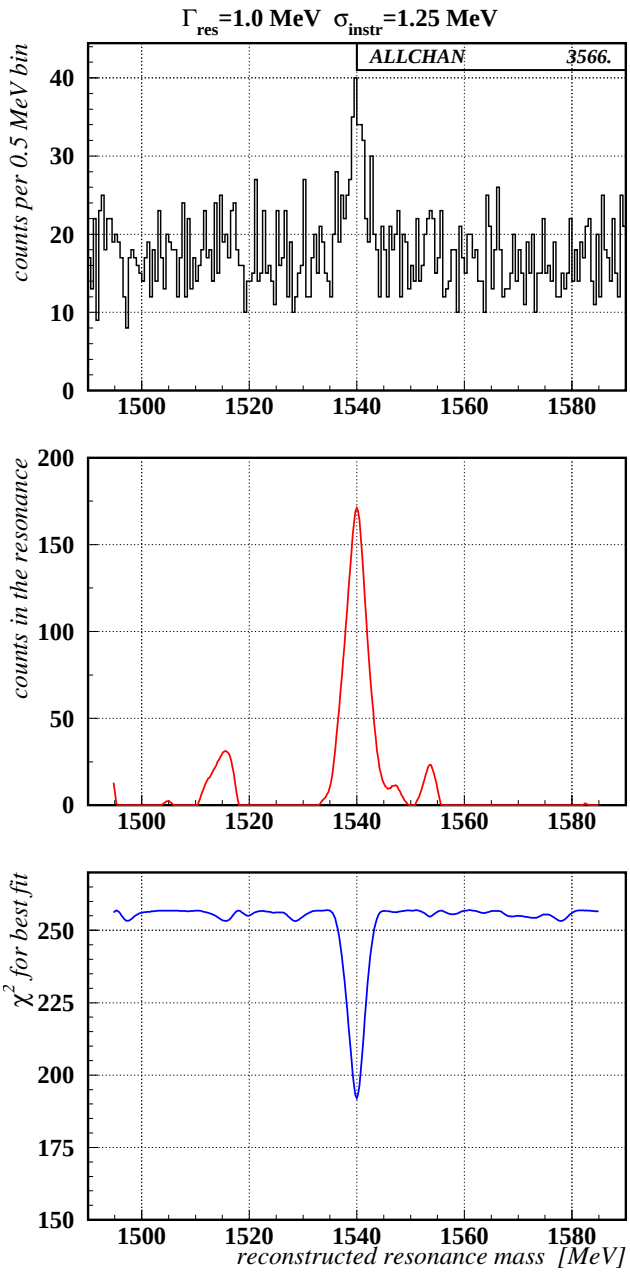

Figure 16: The MC data and a search for 1 MeV wide resonance. A top panel shows the data. A middle panel shows the amplitude of the peak which allow best χ^2. A bottom panel shows the value of χ^2 when position of resonance scan through the region.

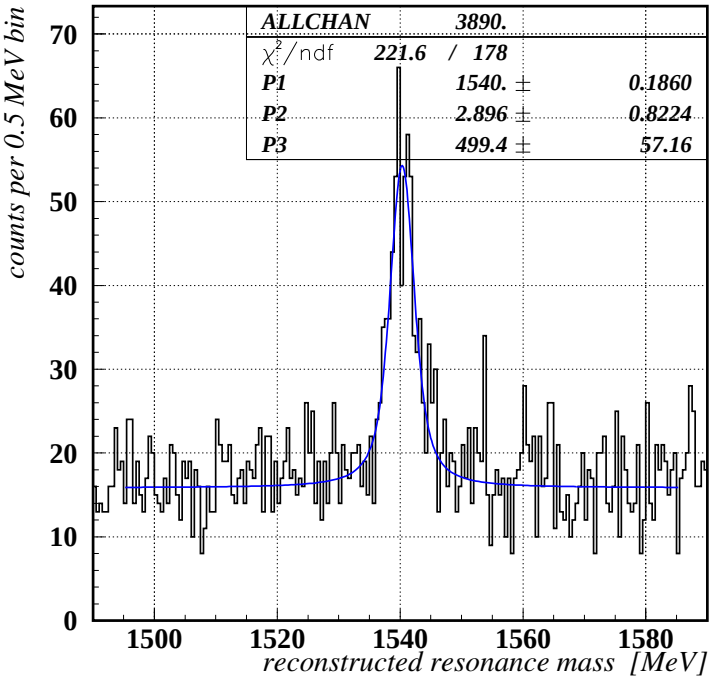

Figure 17: The MC data and a fit for 3 MeV wide resonance.

For the width $\Gamma_{res} = 3$ **MeV the experimental result will be** 3.0 ± 0.7 **MeV**. The expected mass distribution is shown in Fig. 17.

8.3 Beam time request

The purpose of this experiment is to search for and measure the parameters of the the Θ^+ state. The experiment will be performed at beam energy 5.0 GeV, with currents up to 30 μA. Table 7 summarizes the beam time requirements. The measurement needs installation of the detectors constructed for experiment E02013 [19] in out-off-plane configuration. In total we request 23 days of beam-time to perform the proposed measurements.

9 Conclusions

We request 550 hours of beam-time to search for the resonances and measure their mass and width in reaction $\mathrm{Be}(e, nK^+K^-)X$ at photon energy of 4 GeV. Collected data will allow also us to conduct a study of the Θ^+ electroproduction in reaction $(e, e'nK^+)$. Measurement of the width with an instrumental resolution (FWHM) of 2.9 MeV will reveal the state's width and enhance our understanding of the nature of Θ^+ exotic state. The value of the mass will be established with an accuracy of 0.5 MeV. Furthermore, the proposed experiment will collect a sample of about 500 Θ^+ events (for an assumed 3 MeV resonance width) and investigate the resonance properties. We propose an experiment which can firmly establish the resonance even if its width of 1 MeV (which corresponds to the total photo production

item	type of measurement	current [μA]	energy [GeV]	time [hr]
1	BigBite and N-arm calibration	30	0.8	12
2	beam energy measurement	1	3.0	4
3	HRS and BigBite(K) calibration	30	3.0	8
4	beam energy measurement	1	5.0	6
5	mass resolution calibration	30	5.0	40
6	Θ^+ production run	30	5.0	480
total				550

Table 7: The time allocation assuming 100% efficiency.

cross section of 7 nb at its maximum near 2 GeV photon energy). The status of the equipment needed in the proposed measurements should permit the experiment to be realized in a time scale of one year. Additional resources may allow a reduction in preparation time. All known experiments have at least several times lower mass resolution and sensitivity than this proposal.

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