Q024

LEPS proposal for Q-PAC
Title : Backward-meson photoproduction up to 3 GeV

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Collaborator list

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Beam running time: 60 days

Requirements for the beam condition and experimental equipment:

Linearly polarized photon beam with 1.5 GeV−3.0 GeV energies

Liquid hydrogen target (for TPC, 15 cm)

LEPS forward spectrometer

Contents

1 Summary of proposal

Recently, the LEPS collaborators measured the π^0, η, η', and ω photoproductions at backward angles with photon energies from 1.5 GeV to 2.4 GeV (1.9 GeV – 2.3 GeV in the total energy). A strong angular dependence, unexpected s-dependence, and resonance-like bump structures have been observed for these reactions. The data are a good mean to investigate baryon resonances in s-channel, and the u-channel nucleon exchange process. However, these structures have not been understood. In order to provide more information for these structures, and have good understanding for meson photoproduction, we would like to propose an experiment of backward meson photoproduction with photon energies from 1.5 GeV to 3.0 GeV (W = 1.9 – 2.55 GeV).

In this experiment, we will measure ρ^0 and ϕ photoproductions which were hard to be observed in the previous experiment due to the wide width of ρ^0 mesons, and a small yield for ϕ production in contrast to huge backgrounds. In addition to the cross section measurement, we will obtain photon beam asymmetries for $\pi^0, \eta, \eta', \omega, \rho^0$, and ϕ photoproductions. The measurement of photon asymmetries was very difficult in the previous experiment due to many background reactions and difficulty of estimation of the effect. In order to do the measurement, we will install side detectors additionally to define particles from mesons and multi-pion background events.

2 Physics motivation

2.1 Baryon resonances

Many baryon resonances were found, and their characteristics were determined by experiments with an induced pion beam. However, there are still a large number of baryon resonances which are predicted in the constituent quark models but have not been observed experimentally [1]. Identification of these missing resonances is important to understand whether the quark-model calculations are valid or not. Some of these resonances may not couple to a pion channel strongly but couple to other channels. So that we realize that pion induced reactions are limited to search for such missing resonances furthermore.

The photon beam is a good mean to search for missing resonances because it is possible to investigate various channels in a final state. Many facilities like, LEPS, CLAS, ELSA and GRAAL, have recently obtained data for pion, Kaon, η and η' photoproductions [2, 3, 4, 5, 6, 7, 8], and those data are analyzed connecting with N* or Δ^* resonances [9, 10]. But we do not yet have a conclusion on missing resonances for any new photoproduction data. This is partly because some weakly excited resonances are obscured due to other strong resonances which have large decay widths, making it difficult to demonstrate their existence only from a specific channel or only from cross section data. Therefore, it must be useful to look at various channels at a time at the same kinematical range. Alternatively, polarization observables are useful to extract missing resonances because of interference between resonances. In order to provide a strict requirement for studies of baryon resonances, we would like to measure differential cross sections and photon beam asymmetries for $\pi^0, \eta, \eta', \omega, \rho^0$, and ϕ photoproductions at the same kinematical region, with photon energies, E_γ = 1.5 – 3.0 GeV (W = 1.9 – 2.55 GeV).

The LEPS collaborators obtained differential cross sections and photon beam asymmetries for π^0 photoproduction with $E_\gamma = 1.5 - 2.4$ GeV (W = 1.9 – 2.3 GeV in the total energy). A strong angular dependence in the photon asymmetry, and a change of s-dependence of differential cross sections above W = 2.1 GeV were observed [8]. However, we do not yet have any conclusion for these structures. By extending the photon energy up to $E_\gamma = 3.0$ GeV, we will provide more information for these structures. These structures should disappear at higher energies, if these structures are due to resonances.

We also have obtained differential cross sections for η, η' and ω photoproductions with $E_\gamma = 1.5 - 2.4$ GeV. The data indicate resonance-like structures above W $\sim$ 2.0 GeV for η and η' photoproductions, but no structure for ω photoproduction [11]. By looking at data for these channels at a time, a restriction is given to theories because theoretical models need to explain those structures simultaneously. Therefore, it is very interesting to measure various channels at the same kinematical range up to $E_\gamma = 3.0$ GeV.

2.2 u-channel process at backward angles

At very backward angles, the production mechanism is dominated by u-channel contributions where a proton or a nucleon resonance is exchanged. In general, differential cross sections of meson photoproduction are well described using a simple equation of $s^{2\alpha(u)-2}$ on basis of the Regge theory at high energies [12, 13]. Unfortunately, the applicability of Regge theory is not well demonstrated at lower energies because of the lack of experimental data at backward angles. The LEPS collaborators have obtained the s-dependence of differential cross sections, $\mathrm{d}\sigma/\mathrm{d}u$ with the total energies, W = 1.9 – 2.3 GeV. Figure 1 shows the results of the s-dependence from LEPS and Daresbury [14]. The s-dependence from the LEPS data is different from the s-dependence from the Daresbury data with W = 2.5 – 3.1 GeV which is well explained by nucleon Regge pole [14]. So that it is very interesting to measure ω photoproduction up to W = 2.55 GeV, and see how the LEPS data connect to the Daresbury data.

2.3 $s\bar{s}$ knockout process from proton

The unpolarized cross section and photon beam asymmetry for ϕ photoproduction at backward angles will be obtained. These observables may help to understand a contribution from the

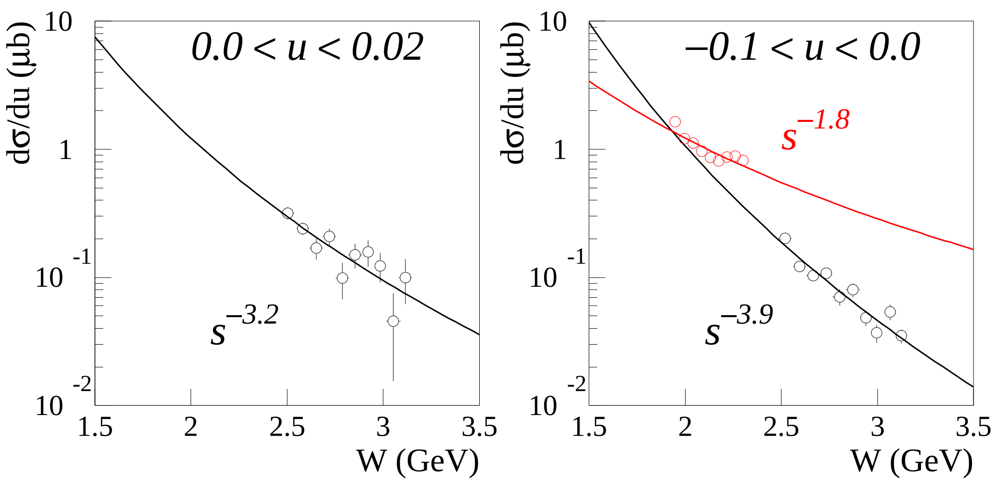

Figure 1: $\sqrt{s}$(=W) dependence of differential cross sections, dσ/du. Open black circles and open red circles are the data from Daresbury [14] and LEPS, respectively. The solid curves are results by fitting a s-dependence function to the data.

$s\bar{s}$ direct knockout process from a proton [15]. A experiment of double polarization observables (beam-target) for ϕ photoproduction is planed, and the polarized target is now under construction [16]. The double polarization observables are very sensitive to the strangeness content of a proton because these observables can distinguish the knockout process with other processes [15]. The proper energy for the double polarization measurement will be known by obtaining the energy dependence of differential cross sections at backward angles.

2.4 Meson photoproduction from the LEPS standard setup

Figure 2 shows the missing mass spectrum for the $\gamma p \rightarrow pX$ reaction obtained by detecting protons with the LEPS forward spectrometer. The data were taken with E_γ = 1.5 GeV – 2.4 GeV in 2002 and 2003. The total number of tagged photons are 2.5 $\times 10^{12}$. Peaks due to π^0, η, η', and ω are clearly identified. However, it is very hard to see peaks due to ρ^0 and ϕ events because of the wide width of ρ^0 and a large background of multi-pion events under the peaks.

It is very difficult to obtain photon asymmetries for these meson photoproductions except for π^0 photoproduction, because there are many background events from more than one reaction. It is difficult to estimate the effect from mixed background reactions on measured photon asymmetries.

We need to reduce the background level to observe ρ^0 and ϕ events, and measure photon asymmetries. New detectors will be installed surrounding the target to detect decay particles from mesons and multi-pion events.

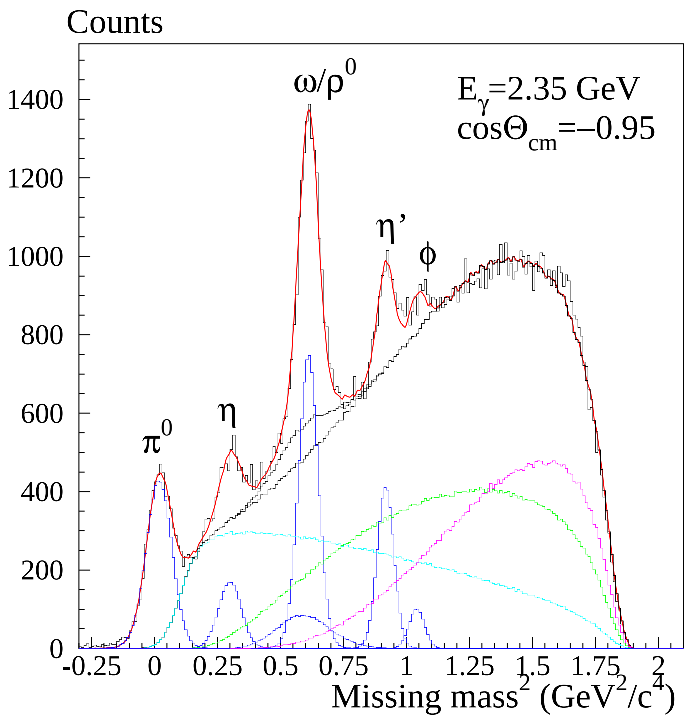

Figure 2: Missing mass spectrum of MM(p). Solid-black curve shows the data from the LEPS standard experiment. Red curve shows a fitting result by using background shapes made by MC simulation. Lightblue, green and pink curves are a shape for 2π, 3π and 4π production, respectively. Black-dotted curve indicate the sum of these multi-pion reactions and ρ^0 production.

3 Experimental method

The LEPS forward spectrometer will be used to detect protons at forward angles, $\pm$ 20 degree in x-direction and in $\pm$ 10 y-direction. Mesons will be identified by a missing mass technique. By detecting protons at forward angles, backward meson photoproductions will be measured. The angular coverage of cosΘ_{cm} of meson photoproduction is from –1 to –0.6. Background events from multi-pion (non-resonant) productions of $2\pi, 3\pi, 4\pi$ events will be removed, and the ρ^0/ω separation will be done by using new detectors surrounding the target.

3.1 Existing equipments

- The LEPS forward spectrometer will be used in this experiment. We will use the SVTX, DC1, DC2, DC3, and TOF wall for a momentum and time-of-flight measurement. The silica aerogel counter will be removed to make a space for new detectors. Instead of the aerogel counter, a plastic scintillation bar (e^+e^- veto bar) will be installed behind the DC3 to reject e^+e^- events in median plane on the trigger level. The veto bar with the hight of 4 cm was used for the K* experiment [17]. The hight in y-direction will be changed to be 7 cm, which is a little smaller than the hight corresponding to an acceptance of the e^+e^- lead blocker in the dipole magnet. The dipole magnet will be excited to be 0.7 T at the center of the magnet. Operation condition of the available equipments will be the same as the standard LEPS experiment. Since we will not require any particle selection at the forward spectrometer in the trigger level, charged pions, Kaons, and protons are all accepted unless a particle goes through the region of e^+e^- veto bar.

- The liquid hydrogen target contained in the cell, which is used for the TPC experiment, will be used. The cell is cylindric shape. The length is 15 cm, and the diameter is 4cm. The target will be positioned at z = –990 mm (the position of the center of magnet is z=0). This position is close to the position of the LEPS standard setup for the long LH2/LD2 target, z = –998 mm.
- Linearly polarized photon beam with 1.5 – 3.0 GeV energies will be used. We expect that the beam intensity of tagged photons is 500 kcps with 2 laser beams. Currently we have 250 kcps with an injection of one laser of 257 nm wave length.
- The trigger will be made by a coincidence signal of signals from the tagging system, Start counter, and TOF wall with a veto signal from the e^+e^- veto bar. We will not use any signal from new detectors placed around the target. The trigger rate is expected to be about 300 Hz with the tagger rate of 500 kcps. The expected dead time is about 20%.
- 50 ADC and TDC channels will be needed additionally for new detectors.

3.2 Angular and momentum distributions

Figure 3 and 4 show angular and total momentum distributions for decay particles from ρ^0, ω, and ϕ mesons, and background reactions obtained by the MC simulation. These distributions are for events detecting protons at the forward spectrometer. Most of Kaons for the $\phi \to K^+K^-$ reaction are scattered in $\Theta_{lab} < 60°$. On the other hand, multi-pion events have more broad angular distribution. This can be used for the ϕ selection with a small background.

3.3 Side detectors

Figure 5 shows a experimental setup of this experiment. Plastic counters and lead-scinti sandwich counters will be installed surrounding the target to define charged particles and γ rays from π^0's, respectively. Table 1 shows a list of the number of charged particles, and the detection of γ rays for each reaction. According to the number of charged particles and finding a hit in γ counters, reactions are organized to groups (modes).

3.3.1 Plastic counters

The number of charged particles will be counted by plastic counters. 16 plastic scintillators will be installed covering 60° – 170° in scattering angles, Θ_{lab}. The size of the counter is 5 mm thick, 30 mm wide and 430 mm long. Other 16 counters will be installed covering $\Theta_{lab} = 20°$

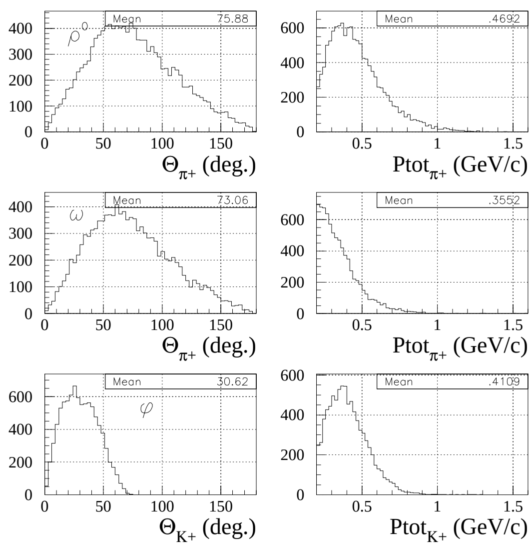

Figure 3: Scattering angles, Θ_{lab}, and total momentum, Ptot of charged pions or Kaons from ρ^0, ω, and ϕ with MC simulation.

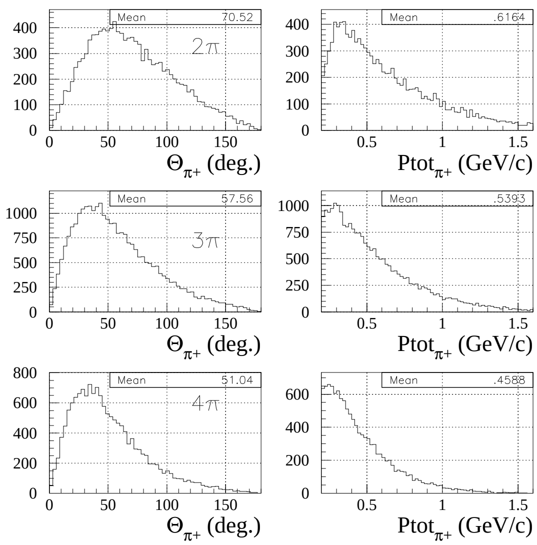

Figure 4: Scattering angles, Θ_{lab}, and total momentum, Ptot of charged pions from background reactions of $2\pi, 3\pi$, and 4π with MC simulation.

– 60°. The size of the counter is 5 mm thick, 30 mm wide and 180 mm long. 4 counters will placed in a front of the target to detect particles going to forward angles. These front counters will be used as the start counter.

Particles at $\Theta_{lab} < 60°$ will be separated with particles at $\Theta_{lab} > 60°$ by two sets of counter arrays. The S/N ratio for ϕ events will be improved by requiring charged particles at forward angles since K^+'s and K^-'s from ϕ events are scattered in $\Theta_{lab} < 60°$ (see Figure 6).

Another option is using counters with a 600 mm long covering 20° – 170°. A z-position of a hit will be determined by a time difference between a timing from PMTs attached to the both sides.

The acceptance is about 99% for any reaction, but a part of events are lost by making a mistake to count the number of particles when more than one particle make a hit in one segment. Taking the effect into account, the acceptance is about 90% with 16 segments.

3.3.2 γ counters

Lead and fiber-scintillator sandwich detector will be placed at outer side of plastic counters to detect γ rays from π^0's. The coverage is from 30° to 160°, and from 160° to 170° by other peace of detectors. The shape is cylindrical, and 750 mm long. The thickness is 25 mm. The detector will be segmented to be 18 by bundling some fibers. Signals are read out from fibers at both side, downstream and upstream. When the resolution of a time difference is good, we will measure a z-position of γ rays. The efficiency is expected to be 96%. The geometrical

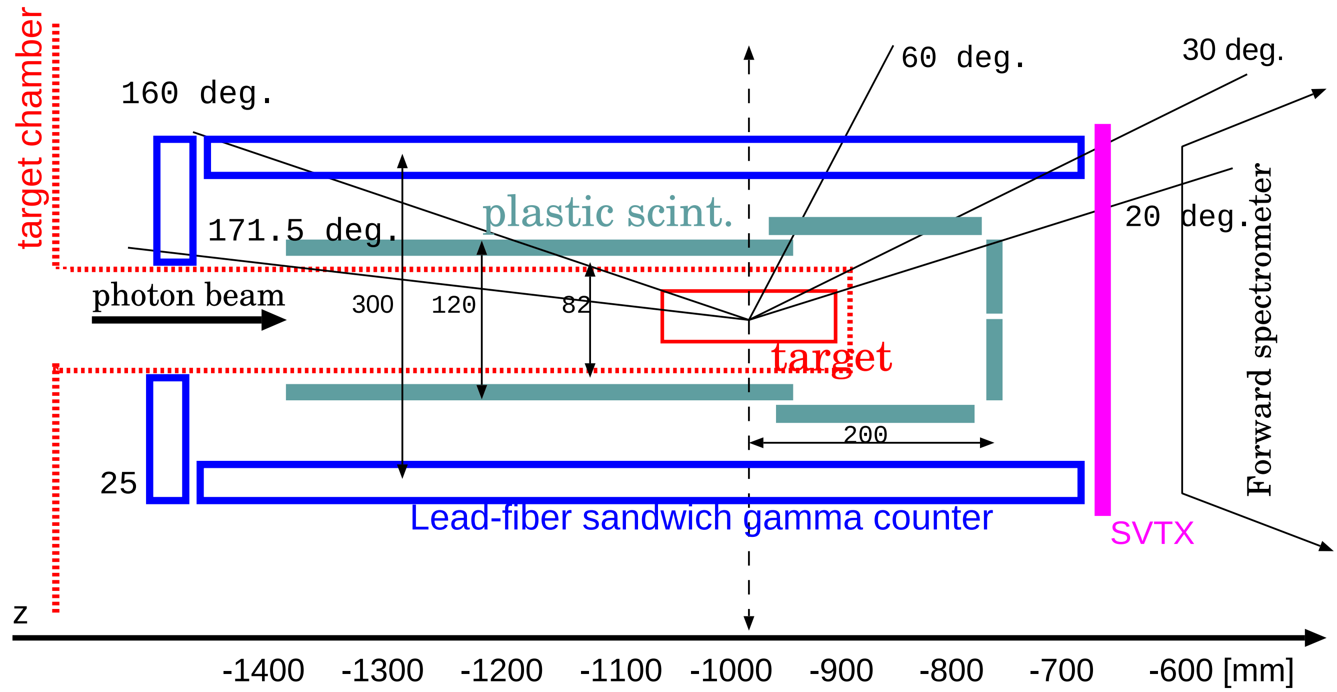

Figure 5: Experimental setup, side view.

acceptance depends on a reaction mode, and is about 90% for a requirment having more than one hit.

3.3.3 Selection of modes

By detecting charged particles and γ rays, a reaction mode in Table 1 is identified. Missing mass spectra will be obtained in each mode. Figure 6 shows an expected spectrum for mode A, B and C.

For the A mode, a requirement is not to find any charged particle. Then a spectrum will be obtained like the top plot in Figure 6. Background events under the π^0 and η peaks are from $2\pi^0$ only. There are events from $2\pi^0$ and $4\pi^0$ under η'. When the number of γ rays is counted efficiently by γ detectors, The events from $4\pi^0$ are rejected. A photon beam asymmetry for η production will be obtained by using a side band method. There is only one background reaction of $2\pi^0$ events. By measuring a photon asymmetry for $2\pi^0$ events (we expect it is zero.) in $0.5 < \mathrm{MM(p)} < 0.75$ and taking a yield ratio of $2\pi^0$ to η events into account, we will calculate the photon asymmetry for η photoproduction. In the same way, we will obtain photon asymmetry for η' photoproduction, but there are two kine of background reactions of $2\pi^0$ and $4\pi0$, and we need to estimate those effect.

For the B mode, a requirement is not to find any γ ray, and to find 2 charged particles. The events from ρ^0, ϕ (decay into K^+K^-, 49.2%) and 2 charged π ($2\pi^c$) remain shown in the middle plot in Figure 6. When events in $\Theta < 60°$ are selected, most of ρ^0 events and $2\pi^c$ events are rejected, and the ϕ peak is more clearly seen (red curve in Figure 6). A photon

Table 1: list of modes. $2\pi^0$, and $2\pi^c$ means $\pi^0\pi^0$, and $\pi^+\pi^-$,respectively. $4\pi^0$, $4\pi^c$ and $4\pi^{c0}$ means $\pi^0\pi^0\pi^0\pi^0$, $\pi^+\pi^-\pi^+\pi^-$, and $\pi^+\pi^-\pi^0\pi^0$,respectively.

Reaction	charged	γ (hits)	Mode	BG
$\pi^0 \to 2\gamma$	0	Y	A	$2\pi^0, (4\pi^0)$
$\rho^0 \to \pi^+\pi^-$	2	N	B	$2\pi^c$
$\omega \to \pi^+\pi^-\pi^0$	2	Y	C	$3\pi, 4\pi^{c0}$
$\eta \to 2\gamma, 3\pi^0$	0	Y	A	$2\pi^0, (4\pi^0)$
$\eta' \to \pi^+\pi^-\eta, \rho^0\gamma, 2\pi^0\eta$	2/0	Y	A/C	$2\pi^0, 4\pi^0/3\pi, 4\pi^{c0}$
$\phi \to K^+K^-$	2	N	B	$(2\pi^c)$, $\theta < 60°$
$(2\pi^c)\pi^+\pi^-$	2	N	B	
$(2\pi^0)\pi^0\pi^0$	0	Y	A	
$(3\pi)\pi^+\pi^-\pi^0$	2	Y	C	
$(4\pi^{c0})\pi^+\pi^-\pi^0\pi^0$	2	Y	C	
$(4\pi^c)\pi^+\pi^-\pi^+\pi^-$	4	N	D	
$(4\pi^0)\pi^0\pi^0\pi^0\pi^0$	0	Y	A	

beam asymmetry for ρ^0 and ϕ photoproductions will be obtained by using a side band method. There is only one background reaction of $2\pi^c$ events.

For the C mode, ω and η' events and background events from 3π and 2 charged π and 2 neural π ($4\pi^{c0}$) are seen in the bottom plot in Figure 6. If the photon asymmetry for the background events is zero, it is easy to obtain photon asymmetry for ω photoproduction.

3.4 Another option for side detectors

Another option is using a time-projection chamber (TPC) to detect charged particles. The size of the TPC in the LEPS facility is 800 mm long. The inner radius is 70 mm, and the outer radius is 230 mm. For this experiment, we may use the TPC without solenoid (no magnetic field). We need the number of charged particles, and it can be done by the TPC without the solenoid. A measurement of a vertex point by a line-fitting for a track is a big benefit because the vertex resolution with the forward detectors becomes worse at smaller scattering angles. When the TPC is operated with the solenoid magnet, the γ detectors cannot be used because of no space for them.

The LEPS collaborators have taken data with the TPC and the solenoid magnet together with the forward spectrometer. Pions are clearly identified, and its momentum is measured by the TPC. Figure 7 shows missing mass spectra (MM(p)) for the $\gamma p \to pX$ reaction obtained by the forward spectrometer from the TPC experiment. The missing mass spectrum (MM(p$\pi^+\pi^-$)) for the $\gamma p \to p\pi^+\pi^-X$ reaction is calculated by detecting p, π^+ and π^-, and measure momenta with the TPC. In order to select events of the $\omega \to \pi^+\pi^-\pi^0$, and $\eta' \to \pi^+\pi^-\eta$ reaction, MM(p$\pi^+\pi^-$) is used. When a proper cut by MM(p$\pi^+\pi^-$) is applied for MM(p), the S/N ratio is improved and the peaks due to ω and η' are clearly seen. At the TPC experiment, a hit in plastic counters at the side of the target was required for the trigger, so that π^0 and

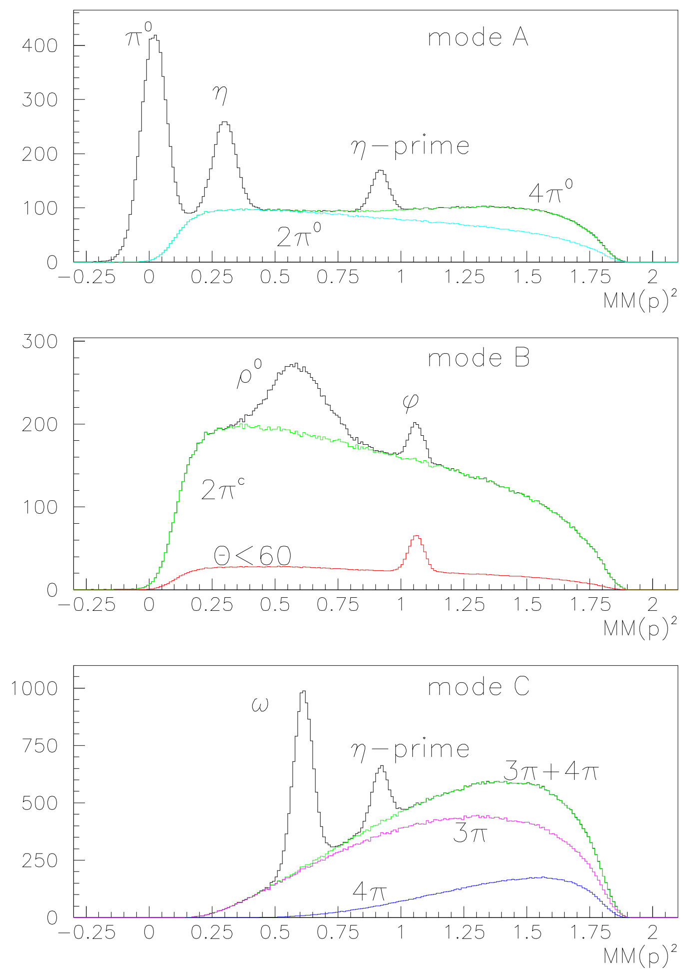

Figure 6: Expected missing mass spectra for each mode with side detectors.

η events were not detected. The angular coverage for forward protons in the TPC experiment was smaller than that in the standard LEPS experiment because the target was positioned to more upstream in the TPC experiment. When we use the TPC in this experiment, the target and the TPC will be moved to downstream to be close to the forward spectrometer. A hit in plastic counters at the side of the target will not be required for the trigger.

4 Request for beam

4.1 Estimation of the beam time requested

The cross section for ϕ photoproduction is expected to be smallest in $\pi^0, \eta, \eta', \omega, \rho^0$, and ϕ channels. The cross section is estimated to be 0.01 μb/sr from the small ϕ peak seen in Figure 2, which is consistent with a theoretical calculation [15]. The yield can be estimated as follows:

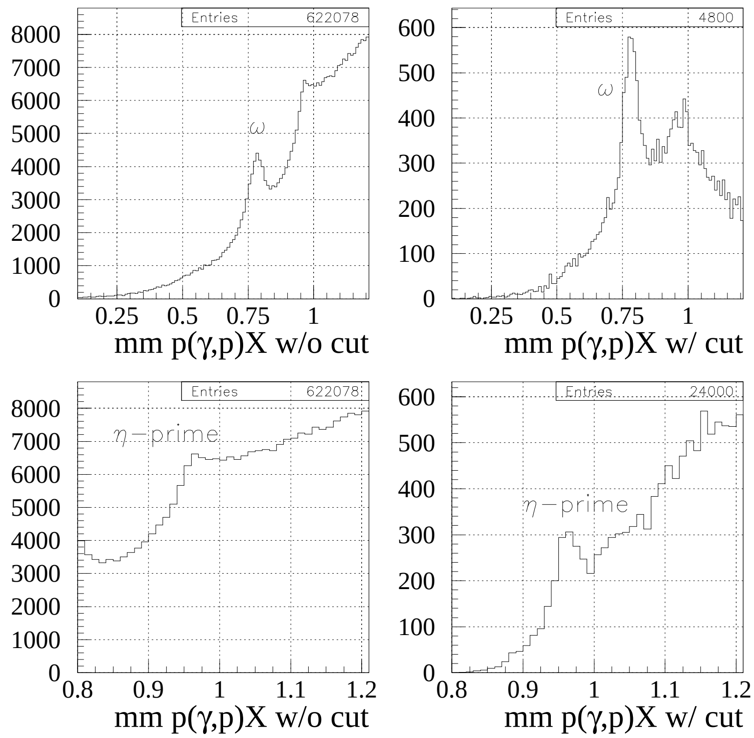

Figure 7: Experimental data from the TPC experiment. Top-left:Missing mass for ω. Top-right:Missing mass for ω with a cut of the TPC. Bottom-left:Missing mass for η'. Bottom-right:Missing mass for η' with a cut of the TPC.

$$Yield = \frac{d\sigma}{d\Omega} \times A \times B \times N_p \times N_\gamma \times T \times 0.4 \times 2\pi \qquad (1)$$

$$= 0.01 \times 10^{-30} \times 0.5 \times 0.492 \times 6.8 \times 10^{23} \times 5 \times 10^5 \times 0.4 \times 2\pi \sim 1 \times 10^{-3} \text{ events/s.} \qquad (2)$$

A is the acceptance of the forward spectrometer for protons, and it is about 0.5 for the range of $0.6 < \cos\Theta^p_{cm} < 1.0$. B is a branching ratio for $\phi \to K^+K^-$, 0.492. N_p is the number of protons in the target, 6.768 $\times 10^{23}$. N_γ is the number of tagged photons, 500 kcps, and T is a transmission for the photon beam, 0.5. The solid angle for proton detection is 0.4 of $0.6 < \cos\Theta_{cm} < 1.0$.

This yield is for $E_\gamma = 1.5 - 3.0$ GeV and $-1 < \cos\Theta_{cm} < -0.6$. When we use a bin size of $d\cos\Theta_{cm} = 0.1$ and $dE_\gamma = 0.1$ GeV, we will have 1.8 $\times 10^{-5}$ event/s = 1.5 events/bin/day.

We will have about 90 ϕ events in each bin for 60 days beam time. This is enough to determine differential cross sections. We will use wider binning for a measurement of photon asymmetries. We will expect more yields for other channels, $\pi^0, \eta, \eta', \omega$, and ρ^0.

4.2 Experimental schedule

We require a three-day beam time for a preparation of side detectors and study of the trigger in addition to 60 days for physics run.

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