STRANGENESS PHOTOPRODUCTION AND THE GDH EXPERIMENTS AT LEPS

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Strangeness production in the few GeV region has been investigated with a linearly polarized photon beam at LEPS. Our motivation is mainly a search for various exotic states. The status of our recent data, especially on ϕ meson and Θ^+ baryon production, and the preparation status of the GDH experiment are presented.

1. Introduction

SPring-8 is an 8 GeV electron storage ring dedicated as a synchrotron light source. When the Research Center of Nuclear Physics (RCNP) at Osaka University started planning a new facility in relation to this 8 GeV electron ring, Jefferson Laboratory was almost ready to run experiments at 4 GeV. Our decision was to construct a multi-GeV real photon facility with Backward-Compton scattering (BCS).[1] To be a competitive facility, we considered to produce linearly polarized photons of the highest energy among the BCS photon facilities.[a] Our physics motivation was focussed on the near threshold production of ϕ mesons in the forward region. The ϕ meson is a vector meson and has a sharp forward production peak, and a gradual increase of the total cross section with energy is understood by the Pomeron exchange at high energies.[2–5] Although the available experimental data are poor in the near threshold, they seem to disagree with the conventional theoretical view. Since meson exchange processes are suppressed by the OZI rule, the introduction of a second Pomeron or a scalar glueball was proposed.[6] One of the merits of using a BCS photon beam is a reach of extreme forward angles close to a beam. As mentioned in the next section, the BCS photon beam has a relatively flat energy spectrum

[a] GRAAL at European Synchrotron Radiation Facility, LEGS at National Synchrotron Light Source, etc.

compared to the Bremsstrahlung photon beams which have a $\sim 1/E_\gamma$ dependent rise at the low energy side. Precise data are seriously awaited for further theoretical understanding of the ϕ production process.

Construction of the beam line named LEPS (Laser-Electron Photon at SPring-8)[10] started in 1997, and was completed in 1999. Installation of the LEPS spectrometer was completed in the spring of 2000, and the first experiment started in the fall of 2000. First physics result appeared in 2002 on the observation of the Θ^+ baryon[11] from a complementary analysis of the ϕ production data.

Characteristics of the photon beam and spectrometer of the LEPS facility, the physics program including future plans, and a status of the GDH experiment are described below.

2. LEPS facility

The photon beam is produced by BCS of laser photons on electrons circulating in the 8 GeV storage ring. The maximum energy of the BCS photon is expressed by

$$E_\gamma^{max} = \frac{4kE_e^2}{m_e^2 + 4kE_e}\,, \tag{1}$$

where k is the energy of the laser photon, E_e is the electron energy, and m_e is the electron mass. It is 2.4(1.9) GeV when a 351(550) nm Ar laser is used. The incident photon beam energy is determined by analyzing the momentum of the scattered electron with a tagging counter, and its resolution of 15 MeV in RMS is limited mainly by the energy and angular spread of the electron beam. The minimum energy required for tagging is 1.5 GeV in order for the scattered electrons to escape from the beam chamber. The

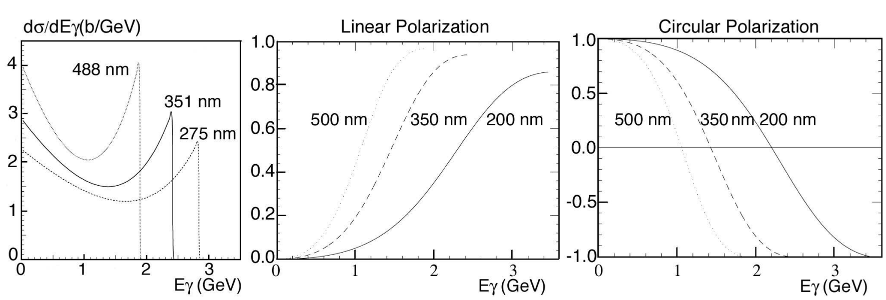

Figure 1. Energy spectrum(a), linear(b) and circular(c) polarization of the BCS photons for 3 different wave lengths at an electron energy of 8 GeV.

energy spectrum of the photon beam is relatively flat as shown in Fig. 1(a). BCS photons can be highly polarized by polarizing the laser photons, see Fig. 1(b),(c). A photon polarization of greater than 90 % is easily obtainable, and the polarization direction is also easily manipulated by changing the laser polarization. The photon beam size in RMS is 2.5 mm vertically and 3.6 mm horizontally at the target position about 70 m downstream of the BCS region. A typical tagged photon flux is 1×10^6 γ/sec. The smallness of the beam emittance in the storage ring is essential to keep the BCS rate high over the straight interaction region and is important to make the photon beam size small on the target. The horizontal beam emittance is set to 6 nm·rad[b] currently, and the corresponding electron beam divergence of a few tens of μrad is comparable to the angular spread of BCS photons. This implies that the collimation technique which is commonly used at the relatively low energy BCS facilities to select the photon beam energy can not be applied at high energy BCS facilities like LEPS.

The basic LEPS detector was designed to optimize the acceptance of ϕ meson production at forward angles. Photons hit a liquid hydrogen or deuterium target 5 or 15 cm thick after passing through a charged particle veto counter. The charged particle spectrometer consists of a start trigger counter (SC), a silica aerogel Cherenkov counter (AC), a silicon-strip vertex detector, an upstream and two downstream drift chambers, a 0.7 T (1.0 T at maximum) dipole magnet, and a time-of-flight scintillator array (TOFS) as shown in Fig. 2. The detector acceptance covers forward angles of ± 0.4 and ± 0.2 rad in the horizontal and vertical directions, respectively. Typical detector resolutions in RMS for momentum, time-of-flight, and mass (momentum dependent) are 0.006 GeV/c at 1 GeV/c, 150 psec for a flight length of $\sim$4 m from the target to the TOFS, and 0.01 GeV/c^2 for a 1 GeV/c kaon, respectively. e^+e^- pairs produced in the very forward angles are blocked by horizontal lead bars which were set in the median plane inside the magnet gap. The trigger simply requires a hadron event by applying a tagging counter hit, no charged particles before the target, charged particles after the target, no signal in the AC, and at least one hit on the TOFS. The AC fires for electrons and positrons, and for pions with momentum higher than 0.6 GeV/c by the choice of a refractive index of 1.03. Good π/K separation is obtained as shown in the mass spectrum in Fig. 3. A typical trigger rate is about 20 events/sec for 5 cm thick liquid hydrogen target.

[b]The vertical emittance is $\sim$10 times smaller than the horizontal one.

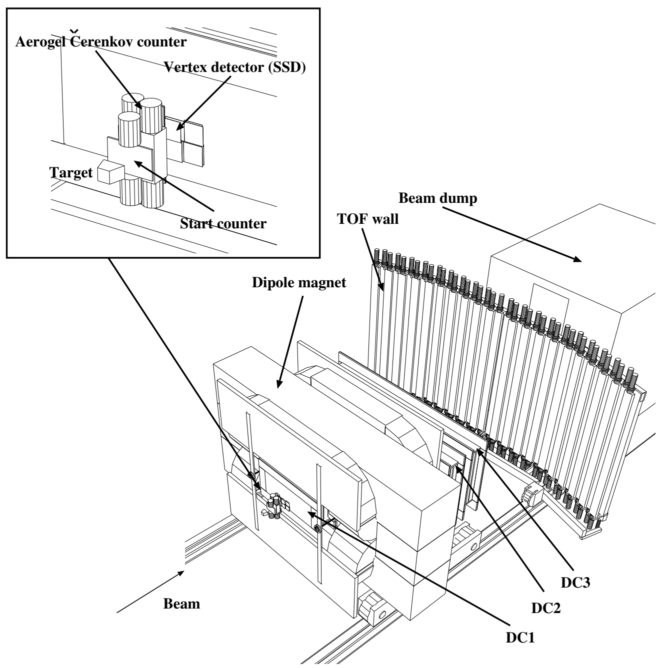

Figure 2. The LEPS spectrometer.

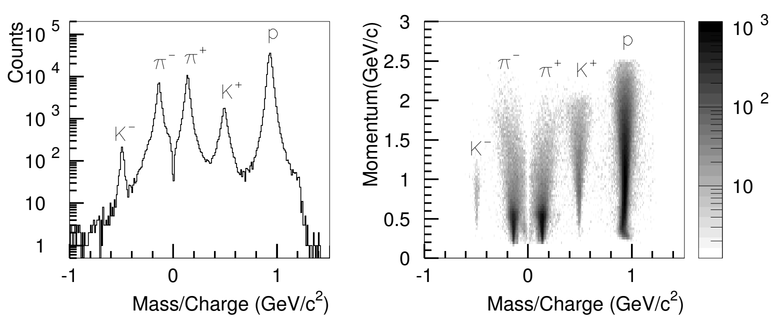

Figure 3. The measured mass distribution.

3. Experimental programs

3.1. *ϕ meson production*

The differential cross section at t=t_{min} is barely reproduced by single Pomeron[2] and meson exchanges at the near production threshold, and it has been discussed that a second Pomeron(scalar glueball, 0^+) may play a key role.[6–9] The reaction $\gamma p \to \phi p \to K^+K^-p$ was studied from the threshold to 2.4 GeV. A linearly polarized photon beam has the great advantage to extract parity information on the exchanged particles when the decay angular distribution of the ϕ meson is measured. The Gottfried Jackson (GJ) frame is suited for the analysis of t-channel exchange mechanism. The z-axis is defined as the incident photon direction in the ϕ meson rest frame, and the x-axis is defined so that the ϕ meson production plane lies in the x-z plane. Various angle variables are defined in Fig. 4. The K^+K^- decay plane is oriented preferably parallel (perpendicular) to the photon polarization for natural (unnatural) parity exchange.

ϕ meson events are identified by reconstructing at least two particles out of the K^+K^-p final state. After subtracting the background contribution from the $\Lambda(1520)$ and non-resonant K^+K^-p final state, the differential cross section was obtained by applying detector acceptance and efficiency corrections and normalization. Data points were fit by an exponential function n_0e^{bt} to get the cross section at t = t_{min}. The energy dependence of the differential cross section shows an unexpected local peak around E_γ = 2 GeV as shown in Fig. 5. The solid curve shows the model prediction including Pomeron and pseudo scalar meson exchanges.[9] It seems difficult to explain the peaking behavior by the pseudo scalar exchanges only.

The Decay angular distribution shows a dominance of natural parity exchange with some contamination of unnatural parity exchange as in Fig. 6(b). The curves show the model prediction including the Pomeron and pseudo scalar meson exchanges.[9] As pseudo scalar exchange (unnatural parity) dominates over the Pomeron exchange (natural parity) near the production threshold, our result suggests the presence of additional natural parity exchange processes.

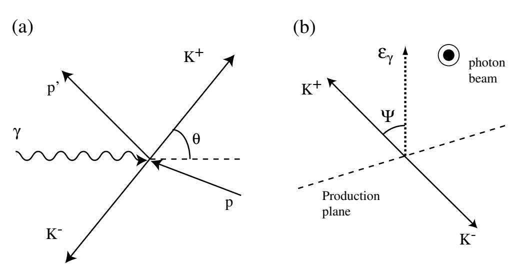

Figure 4. Gottfried-Jackson frame. θ, ϕ and Ψ are the K^+ polar angle, K^+ azimuthal angle, and azimuthal angle of the photon polarization relative to the ϕ-meson production plane, respectively.

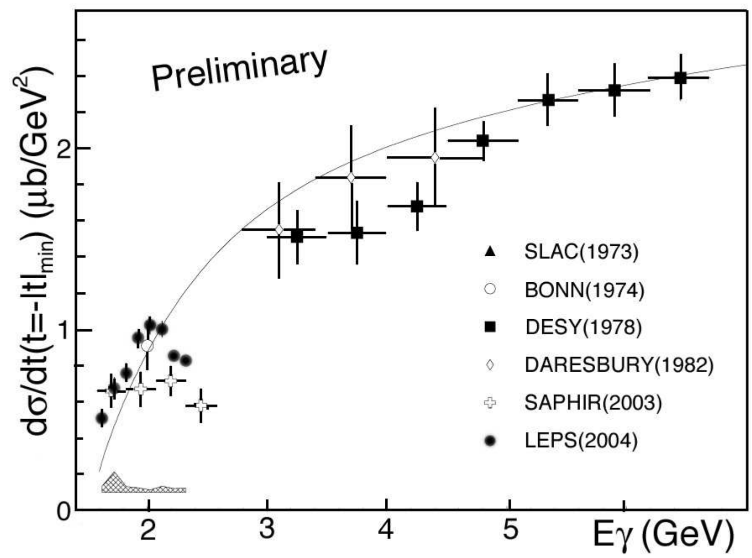

Figure 5. Differential cross section at 0°. Systematic errors are indicated in hatched histogram.

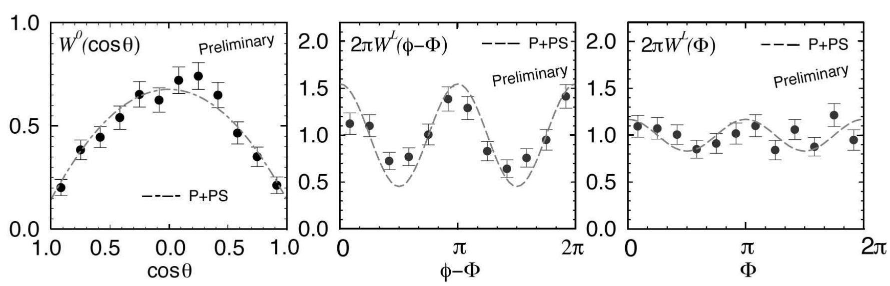

Figure 6. The decay angular distribution for $t >$ -0.2 GeV^2 in the energy region 2.173< E_γ <2.373 GeV. Statistical errors only.

3.2. Θ^+ *baryon production*

In the past, Z^* searches were guided by the bumpy structures seen in the K^+N total cross section data. On the other hand, the Θ^+ baryon (formerly named Z^+) search was motivated purely by theory[12]. The first observation of the Θ^+ baryon[11] was derived from the analysis of events from the neutrons in the carbon nuclei in the plastic scintillator SC. K^+K^- events were reconstructed as in the ϕ analysis. After subtraction of proton events, and known states as the ϕ and $\Lambda(1520)$, a peak was observed at

1.54 GeV/c^2 with a Gaussian significance of 4.6 σ. Proper Fermi motion correction is essential in the analysis. As soon as we noticed the evidence, we began dedicated data taking from October 2002 to June 2003 with a liquid deuterium target to reduce the Fermi motion effect. We applied strict cuts to reduce background in the previous analysis, however, we applied rather loose cuts in the present analysis to see cut dependences. Cuts are summarized as follow, 1) a 4σ cut on the $K^+/K^-/p$ identification, 2) a vertex cut, 3) a ϕ exclusion cut of $M_{K^+K^-}$ >1.03 GeV/c^2, 4) neutron (missing) mass between 0.89 and 0.99 GeV/c^2, and 5) E_γ <2.35 GeV. We examined two different methods in the missing mass correction. The Fermi motion corrected missing mass is obtained as

$$MM^c_{\gamma K^-} = MM_{\gamma K^-} - MM_{\gamma K^+K^-} + M_n\,, \qquad (2)$$

$$(MM^c_{\gamma K^-})^2 = (MM_{\gamma K^-})^2 - \frac{P_{(K^+n)}}{P_n}(MM_{\gamma K^+K^-} - M_n)^2\,, \qquad (3)$$

where $MM_{\gamma K^-}$ and $MM_{\gamma K^+K^-}$ are the missing masses of the γK^- and γK^+K^- systems, respectively, M_n is the neutron mass, and $P_{(K^+n)}$ and P_n are momenta of the K^+n and n systems, respectively, assuming P_n is the missing momentum. The preliminary result is shown in Fig. 7. As the same data set is used for both plots and the events from the proton target are not separated, both Θ^+ and $\Lambda(1520)$ are seen. It was verified that the tightening of any cuts did not degrade the signal or enhance the signal in most cases. Our conclusion is that the Θ^+ peak was reconfirmed with

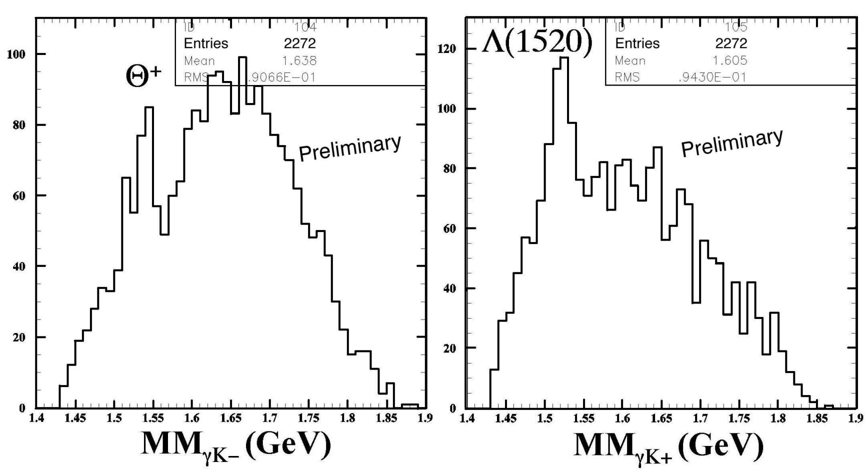

Figure 7. Missing mass distributions of K^- and K^+ for the same data set.

several times more statistics than previously. The peak is not likely due to a fake one or to background contamination, according to our study of the cut dependences. Although about 10 experiments at relatively low energies confirmed the Θ^+ baryon, negative results appeared from high energy experiments.[13] A consistent understanding does not exist at this moment why data from different experiments contradict each other. Planning of the following experiments is affected by this controversy, and the first priority is given to experiments to solve whether the Θ^+ baryon exists or not.

3.3. *Other programs*

Some of the nucleon resonances which were predicted by the quark model may strongly couple to strange channels[14] and are missing in the particle data listing. The $D_{13}(1960)$[15] among them was investigated through the $\gamma p \rightarrow K^+\Lambda^0$, $K^+\Sigma^0$ reactions measured simultaneously with the ϕ, Θ^+ production experiment. The result of photon beam asymmetries was published elsewhere[16]. The partial wave analysis must be revised together with the differential cross section data which will be finalized soon.

A multi-π^0 production experiment was carried out from October till December of 2003 as the second major experiment. The detector consisted of a forward calorimeter with 252 PWO crystals and a backward calorimeter with 208 lead-scintillating-fiber bricks. The physics goal is an investigation of σ and ω meson production.

The $\Lambda(1405)$ state may have a meson-baryon hybrid structure as $\Sigma\pi$, and the decay spectrum is predicted to be mode dependent.[17,18] An experiment to detect $\Lambda(1405) \rightarrow \pi^-\Sigma^+$, $\pi^+\Sigma^-$ is under way since February 2004 as the third major experiment. A superconducting solenoid magnet with a time-projection chamber (TPC) was installed in the basic LEPS spectrometer to detect a kink from $\Sigma^\pm \rightarrow \pi^\pm n$.

Our future plans depend on the progress of the Θ^+ experiments. Our plan in the next year is to take a different approach from the past ones, and it may be an invariant mass measurement, i.e., the TPC makes K^0 and K^* detections possible with an E_γ upgrade to 2.8 GeV. The decay angle distribution from K^* provides parity information of the exchanged particles. A polarized target is indispensable for the next phase of LEPS experiments, beyond the quantum number determination of the Θ^+ baryon. The tentative schedule for 2006 foresees the installation of a polarized target, and the first experiment will likely be the GDH sum rule measurement on both the proton and the neutron as described in the next section.

4. GDH experiment

As the motivation and goal of the GDH experiment have been discussed during this and the past GDH symposiums, we skip an introduction and give the status of our GDH experiment. The ELSA-GDH reported a plan to complete both proton and neutron measurements up to 3 GeV at the previous GDH symposium. So there was not very strong support internally until recently, although the proposal was officially approved in 2001. There was a drastic change in the past year as the necessity of a polarized target was seriously discussed in relation with the determination of the quantum numbers of the Θ^+ baryon. The importance of a neutron GDH measurement has re-emerged because of the discontinuation of the neutron program at the ELSA-GDH as presented in this symposium.[19] The description of our GDH experiment was basically presented at the previous GDH symposium.[20] The most crucial equipment to run a GDH experiment is a polarized target, and the required modification of the KEK's dilution refrigerator has been almost completed. Cooling and polarizing tests are expected in the near future. The remaining crucial equipment is a $\sim 4\pi$ calorimeter with charged particle detection surrounding the polarized target; it will be provided by the collaboration of UCLA-Melbourne-Yamagata. One year of running is expected for the confirmation experiment on Θ^+ production starting from the spring of 2005. Installation of the polarized target is planned during the long shutdown period of the SPring-8 accelerators scheduled in summer. The LEPS-GDH experiment will cover the E_γ range between 1.8 and 2.8 GeV, and is expected to run from October 2006 as the first experiment using a polarized target.

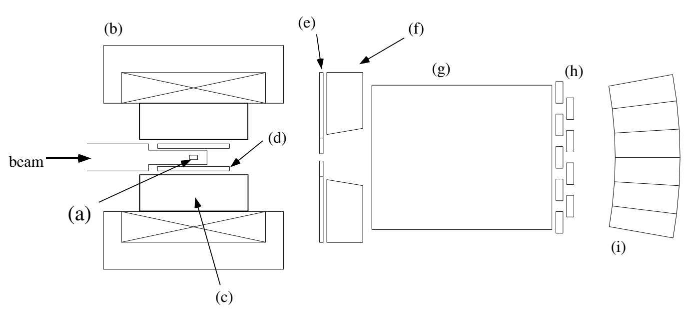

Figure 8. The setup of the GDH experiment at LEPS: (a)polarized target (b) solenoid magnet (c),(f),(i) gamma detectors (d),(e) charged particle detectors (g) gas Cherenkov counter (h) forward detector(TOFS).

5. Summary

The accessibility of the BCS photon experiments to extreme forward angles near the beam has been successfully demonstrated in ϕ meson production at LEPS. The linearly polarized photon beam plays an essential role in identifying the exchange processes. The Θ^+ baryon searches reminded us of the importance of a real photon beam.

We have measured various strangeness production processes. The ϕ meson production was investigated near the production threshold in the small t-region. An unexpected peak was observed around 2 GeV in the differential cross section at $0°$. It suggests the possibility of an additional contribution of natural parity exchange processes. A very preliminary analysis reconfirmed the Θ^+ baryon with statistics several times higher than the previous result. Although the highest priority is on the Θ^+ baryon program, the LEPS-GDH experiment became realistic to run in a few years.

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