PROPOSAL FOR EXPERIMENT AT LEPS BEAM LINE

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(ver. 1)

Measurement of π^0 polarizabilities

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RUNNING TIME:

- 2 days for tuning and calibration
- 10 days for data acquisition

BEAM:

- Type of Polarization: Linearly polarized LEPS beam
- Beam Intensity: $\geq 5 \times 10^6$ *photons/s* for $E_\gamma \geq 1.5$ GeV

DETECTOR:

- Forward γ-detector (252 PWO detector blocks) + α

TARGETS:

- a Pb target ($\sim 0.1X_0$)

Summary of the Proposal

We propose an experiment measuring the electromagnetic polarizabilities of π^0 with multi-GeV Laser-Electron Photons at SPring-8 (LEPS). The measurement will be made by utilizing Primakov production of $2\pi^0$. This is a new method which nobody has ever tried in the study of the two-photon process $\gamma\gamma \to \pi^0\pi^0$. The π^0 polarizabilities can be measured by measuring the cross section $\sigma(W)$ at very forward angles of $2\pi^0$ Primakov production, where W is the energy of the $2\pi^0$ system.

There is only one set of data available to provide the π^0 polarizabilities. That is given by the Crystal Ball experiment[1]. There are some separate analyses for the Crystal Ball data. Kaloshin and Serebryakov get the value[2] of $(\overline{\alpha}_{\pi^0} - \overline{\beta}_{\pi^0})$ and $(\overline{\alpha}_{\pi^0} + \overline{\beta}_{\pi^0})$ out of the Crystal Ball data as

$$\overline{\alpha}_{\pi^0} - \overline{\beta}_{\pi^0} = (-1.1 \pm 1.7) \times 10^{-4}\ fm^3$$

and

$$\overline{\alpha}_{\pi^0} + \overline{\beta}_{\pi^0} = (1.00 \pm 0.05) \times 10^{-4}\ fm^3,$$

respectively. Thus the π^0 polarizabilities are not well determined. The data themselves are sparse[1] and other independent experiments are needed.

We are planning to employ a forward γ detector system which consists of 252 PWO crystals. The detector covers the forward angular region from 3° to 20°. All crystals have been tested with a radio-active source. The energy resolution and the position resolution have been measured by utilizing a Bremsstrahlung beam at SPring-8 and are

$$\frac{\sigma_E}{E} \simeq \frac{0.03}{\sqrt{E(GeV)}}$$

and

$$\sigma_x \simeq \frac{2.8\ mm}{\sqrt{E(GeV)}}$$

for a set of nine PWO crystals with a slightly different size.

The event rate is estimated to be about 200 events/day under the conditions of

- cross section: $\sigma_p(\pi^0\pi^0) = 1\ \mu b$
- beam intensity: $N_b = 5 \times 10^6\ photons/s$ for $E_\gamma > 1.5 GeV$
- target thickness: $N_t(Pb\ 0.1X_0) = 1.8 \times 10^{21}$
- acceptance: $\eta = 0.3$.

where $\sigma_p(\pi^0\pi^0)$ is the cross section of $2\pi^0$ Primakov production.

1 Proposed Experiment at LEPS

1.1 *General Description of the Experiment*

In general the electromagnetic polarizability is a fundamental property of a particle and measures its deformation in an external electromagnetic field. The electric polarizability $\overline{\alpha}_M$ and the magnetic polarizability $\overline{\beta}_M$ characterize the induced electric dipole moment $\boldsymbol{d} = \overline{\alpha}_M \boldsymbol{E}$ and the magnetic moment $\boldsymbol{m} = \overline{\beta}_M \boldsymbol{B}$ of the particle M in an external electric and magnetic field, respectively. Here we are planning to measure the electromagnetic polarizability of π^0, making use of Primakov production of $2\pi^0$ at extremely forward angles. In this case the target should have a large Z number in order to provide a strong electric field in the vicinity of the target. Thus an incident real photon interacts with a virtual photon of the electric field of the target nucleus and $2\pi^0$ come out at forward angles. In this case the energy of the incident photon is extremely high compared with that of the virtual photon coming from the target. Therefore this interaction happens like $\gamma\gamma \to \pi^0\pi^0$, which is approximately regarded as a two real-photon interaction in the center of momentum system of the initial two photons. We can investigate both the polarizabilities of $\pi^\pm$ and π^0 by this method. We will concentrate here on the π^0 polarizability. That is because it will provide a unique testing ground for the loop structure and higher-order effects since there exists no Born term and therefore the one-loop contribution is dominant for the $\gamma\gamma \to \pi^0\pi^0$ process.

The cross section for the reaction $\gamma\gamma \to \pi^0\pi^0$ is given by

$$\frac{d\sigma(\gamma\gamma \to \pi^0\pi^0)}{d\Omega} = \frac{\alpha^2}{4s}\sqrt{\frac{s-4m_\pi^2}{s}}|f_{\pi^0}(s)|^2 \tag{1}$$

and $f_{\pi^0}(s)$ is written by

$$f_{\pi^0}(s) = \frac{2}{3}\{f_0(s) - f_2(s)\} \tag{2}$$

where $f_0(s)$ and $f_2(s)$ are the helicity-conserving S-wave amplitudes for the isospin 0 and 2 of the $\pi^0\pi^0$ state, respectively. Donoghue and Holstein gave the $\gamma\gamma \to \pi^0\pi^0$ amplitudes[4] with the electromagnetic polarizabilities of π^0 as

$$f_{\pi^0}(s) = \frac{m_\pi}{4\alpha}(\overline{\alpha}_{\pi^0} - \overline{\beta}_{\pi^0})s + O(s^2, sm_\pi^2). \tag{3}$$

The electric and magnetic polarizability terms always appear in the combination $\overline{\alpha}_{\pi^0} - \overline{\beta}_{\pi^0}$ in this case unlike the case of Compton scattering since the initial two photons are colinear in the center of momentum system. But the sum of the polarizabilities is well determined by a dispersion relation sum rule[5]

$$\overline{\alpha}_{\pi^0} + \overline{\beta}_{\pi^0} = \frac{1}{2\pi^2}\int_0^\infty \frac{dW\sigma_{tot}(W)}{W^2}, \tag{4}$$

so that we can deduce both the polarizabilities, where W is the energy of the system given as the invariant mass of two outgoing π^0s. The measurement of the π^0 polarizabilities will be made by measuring the cross section $\sigma(W)$ at very forward angles because of Primakov production.

This experiment is closely related to the scalar σ meson in the study of the $\sigma \to \gamma\gamma$ process. The observation of the $\sigma \to \gamma\gamma$ process is very much important in search for the σ meson. However, it is difficult to observe the process because of two reasons. First, the branching ratio is estimated to be so small as the order of 10^{-5}. In addition to that, the total width of σ is too large to be observed in a huge background coming from $\pi^0 \to \gamma\gamma$. A direct measurement of this process is kind of the next generation experiment.

In such a case as a meson decays into a channel with a small branching ratio, the inverse process is of great advantage in the study of the decay channel of the meson under consideration. In the present case we can make use of the Primakov effect to produce the σ meson in the inverse process, $\gamma\gamma \to \sigma$. Namely, 2γs in the initial channel are an incident photon and a virtual photon of the electric field of the target nucleus. The differential cross section for Primakov production of a meson is well known and given with the partial decay width as follows:

$$\frac{d\sigma_P}{d\Omega} = \Gamma_{\gamma\gamma}\frac{8\alpha Z^2}{m^3}\frac{\beta^3 E_\gamma^4}{Q^4}|F_{em}(Q)|^2 \sin^2\theta. \quad (5)$$

Here $\alpha = 1/137$ is the fine structure constant, Z the charge number of the target nucleus; E_γ is the incident photon energy; m, β, and θ are the mass, velocity, and the direction of the meson; Q is the momentum transfer to the nucleus; $F_{em}(Q)$ is the electromagnetic form factor. $\Gamma_{\gamma\gamma}$ denotes the partial decay width to the $\gamma\gamma$ channel. Eq. (5) shows a strong dependence of E_γ, Q and m on the cross section. The lower limit of Q decreases as E_γ goes up when the meson mass produced in this process is set to be a certain value. We apply Eq. (5) for σ production with a large mass width. The Breit-Wigner formula is assumed to represent the mass with this non-negligible width. Fig. 1 shows the differential cross section $d\sigma_P/dW$ of σ Primakov production as a function of W for the final state of $2\pi^0$, where W denotes $\sqrt{s}$ of the outgoing 2π system. Here the mass and the width are set to be 600 MeV and 500 MeV, respectively, and the partial decay width of the $\sigma \to \gamma\gamma$ process is assumed to be 5 keV for the whole σ mass region. As shown in Fig. 1, the cross section drastically decreases as the mass increases in the case of Primakov production which takes place in a small momentum-transfer region like $|t| < 0.01$ GeV^2. But we can reach the energy up to ~ 500 MeV of the 2π system by this method.

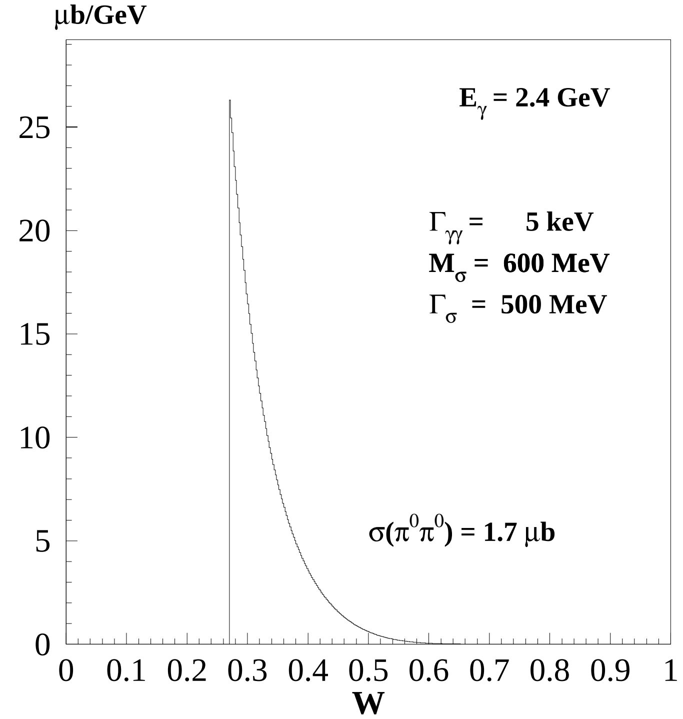

Figure 1: The W dependence of the cross section of Primakov production with a Pb target at 2.4 GeV.

1.2 *Experimental Data on π^0 Polarizabilities*

There are only one data available from the Crystal Ball experiment[1] to provide the π^0 polarizabilities. Babusci *et al.* gave the value of the polarizability[3]

$$|\overline{\alpha}_{\pi^0}| = (0.69 \pm 0.07 \pm 0.04) \times 10^{-4}\ fm^3,$$

but Donoghue and Holstein pointed out that it was too precise. Nowadays the π^0 polarizabilities deduced from the Crystal Ball data are converging to the values given by Kaloshin and Serebryakov[2] as

$$\overline{\alpha}_{\pi^0} - \overline{\beta}_{\pi^0} = (-1.1 \pm 1.7) \times 10^{-4}\ fm^3,$$

$$\overline{\alpha}_{\pi^0} + \overline{\beta}_{\pi^0} = (1.00 \pm 0.05) \times 10^{-4}\ fm^3.$$

However the data are rather sparse and other independent measurements are necessary to obtain reliable polarizabilities of π^0

1.3 γ *Detector*

We employ a forward γ detector system for measuring outgoing $2\pi^0$. The detector system comprises 252 PWO crystal detectors covering the forward angular region from 3° to 20°. Fig. 2 shows what the detector system looks like. The size of the crystals is $22 \times 22 \times 180\ mm^3$ corresponding to 19.5 radiation lengths(X_0). Each crystal is viewed a

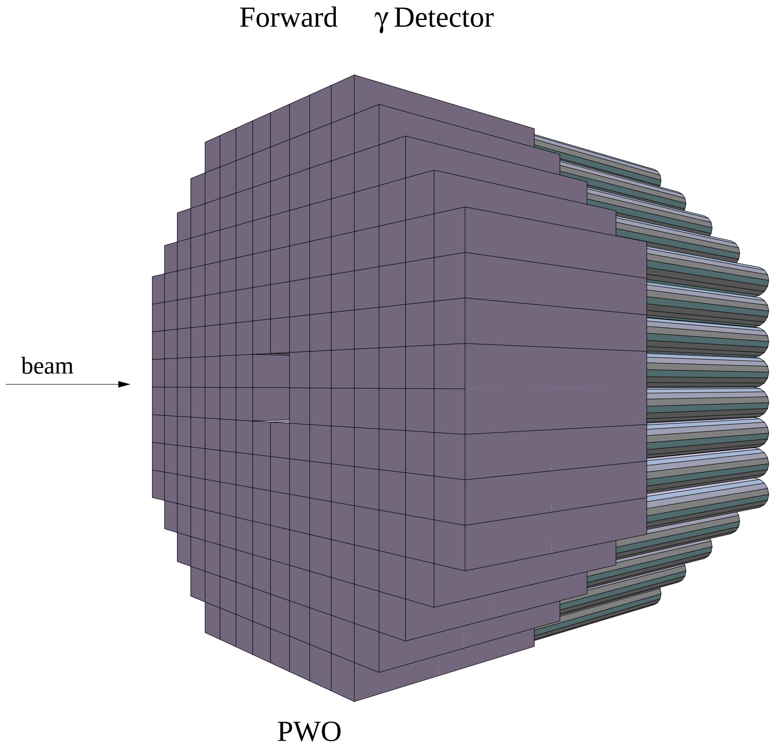

Figure 2: Drawing of the forward γ-detector system consisting of 252 PWO crystal scintillators.

photomultiplier tube with a Cockcroft-Walton type divider.

The energy resolution and the position resolution are obtained so far as

$$\frac{\sigma_E}{E} \simeq \frac{0.03}{\sqrt{E(GeV)}} \tag{6}$$

and

$$\sigma_x \simeq \frac{2.8mm}{\sqrt{E(GeV)}} \tag{7}$$

for a set of nine PWO crystals with a slightly different size of $20 \times 20 \times 200\ mm^3$. Therefore the mass resolution of the $2\pi^0$ system is expected to be about 5% for the mass region 280 MeV $< M_{\pi^0\pi^0} <$ 500 MeV.

All PWO crystals have been tested with a radio-active source and are ready for being assembled into the forward γ detector system as shown in Fig. 2. The average acceptance is simulated to be more than 0.3 for the events in the Primakov region of $|t| < 0.01\ GeV^2$.

1.4 *Data Statistics*

Here is an estimation of the data statistics expected in the proposed experiment. We assume the following parameters:

- cross section: $\sigma_p(\pi^0\pi^0) = 1\ \mu b$
- beam intensity: $N_b = 5 \times 10^6\ photons/s$ for $E_\gamma > 1.5 GeV$
- target thickness: $N_t(Pb\ 0.1X_0) = 1.8 \times 10^{21}$
- acceptance: $\eta = 0.3$.

Then we have the yield Y given by

$$Y = N_b \cdot N_t \cdot \sigma(\pi^0\pi^0) \cdot \eta = 2.7 \times 10^{-3}/s \tag{8}$$

which corresponds to the number of events of about 200 events/day.

References

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