Different quark-antiquark production mechanism of $u\bar{u}$ from $d\bar{d}$ and $s\bar{s}$ studied by linearly polarized high energy photon beams at BL33LEP

We carried out meson (quark-antiquark) and baryon (three quarks) production experiments from a proton target using high energy photon (γ) beams of 1.5-2.95 GeV. According to the well-known formula $E = mc^2$ of Einstein, the high energy photon beams produce masses. In our experiments, lepton-antilepton(e^-e^+) or quark-antiquark($u\bar{u}$, $d\bar{d}$, and $s\bar{s}$) pairs are produced. We would like to clarify the structure of mesons and baryons and understand the production mechanisms of quark-antiquark pairs. At forward meson angles, we measured differential cross sections and photon beam asymmetries for the γ+proton → (a) $\pi^-+\Delta^{++}$ [1], (b) π^++neutron [2], and (c) $K^+ + \Lambda$ [3] reactions at SPring-8 **BL33LEP**. There are six types of quarks: u, d, s, c, b, and t, and six types of antiquarks: $\bar{u}$, $\bar{d}$, $\bar{s}$, $\bar{c}$, $\bar{b}$, and $\bar{t}$. On the basis of the quark model, the proton, Δ^{++}, neutron, and Λ baryons are composed of uud, uuu, udd, and uds quarks, and the π^-, π^+, and K^+ mesons are composed of $d\bar{u}$, $u\bar{d}$, and $u\bar{s}$ quark-antiquark pairs, respectively. These reactions produce pure (a) $u\bar{u}$, (b) $d\bar{d}$, and (c) $s\bar{s}$ pairs in the final state. We compare the results of these quark-antiquark productions precisely for the first time, which is essential to understand how mesons and baryons are produced.

Figure 1 shows the missing mass of the γ + proton → π^- + X reaction. The missing mass is calculated from the photon beam energy and the momenta of π^- in the x, y, and z directions. The law of conservation of momentum and energy is assumed. The Δ^{++} peak is predominantly observed and is fitted with a relativistic Breit-Wigner shape to obtain the yield. The contributions from 2π, 3π, and ρ productions and electron contamination in the π^- selection are considered as the background under the Δ^{++} peak.

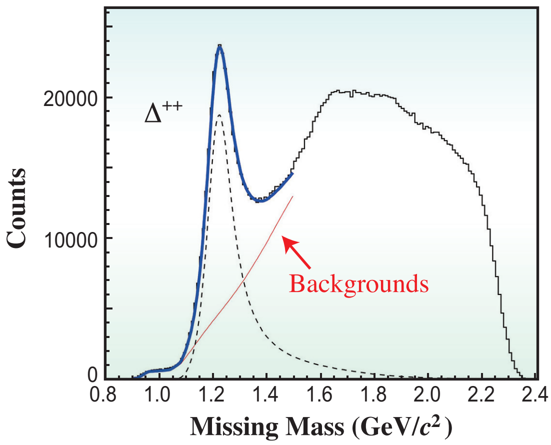

Fig. 1. Missing mass of the γ+proton → π^-+X reaction for E_γ = 1.5-2.95 GeV [1]. The thick solid curve is the result of the fit. The dashed curve is the Δ^{++} contribution.

Figure 2 shows the first-ever high statistics differential cross sections for the γ+proton → $\pi^-+\Delta^{++}$ reaction [1]. As the photon energy increases, the cross sections decrease gradually. The result of the theoretical calculations by Nam [4] well reproduces the data for the photon energies above 1.9 GeV. Since the calculations do not introduce a nucleon or Δ resonance in the intermediate state, the bump (1.5-1.8 GeV) might be due to a contribution from the resonance.

The photon beam asymmetries measured by using linearly polarized photon beams are sensitive to quark-antiquark production mechanisms. When mesons are produced at forward angles, meson exchanges are dominant in the production mechanisms. Figure 3 shows the asymmetries for the γ+proton → $\pi^-+\Delta^{++}$ [1], π^++neutron [2], and $K^+ + \Lambda$ [3] reactions. The π^+ + neutron and $K^+ + \Lambda$ reactions have positive asymmetries, which suggests the dominance of ρ-meson and K^*-meson exchanges, respectively, in the production mechanisms. In other similar meson productions, such as π^0+proton, η+proton, and $K^+ + \Sigma^0$, positive asymmetries were also observed. On the other hand, the $\pi^-+\Delta^{++}$ reaction is found to have negative asymmetries, which suggests the dominance of π-meson exchange. The result of the theoretical calculation by Nam [4] reproduces the negative asymmetries for the $\pi^-+\Delta^{++}$. It is quite interesting that only the $u\bar{u}$ production seems to have a different production mechanism from the $d\bar{d}$ and $s\bar{s}$ productions.

The π^++neutron reaction exchanges a u-quark in a proton(uud) for a d-quark, producing a neutron(udd). The $K^+ + \Lambda$ reaction also exchanges a u-quark for an s-quark, which produces a Λ(uds) baryon. Only the $\pi^-+\Delta^{++}$ reaction exchanges a d-quark for a u-quark and produces a Δ^{++} (uuu) baryon. The author's naive interpretation is that the spatial distribution of the d-quark might be different from that of the u-quark in the proton. The ρ-meson and K^*-meson have relatively heavy masses of 770 and 890 MeV/c^2, respectively. The well-known theory by Yukawa suggests that the interaction of these heavy mesons is limited to short distances, for example, a few 0.1 fm. The π-meson has a low mass of 140 MeV/c^2 and its interaction can reach large distances of 1-2 fm, which are comparable

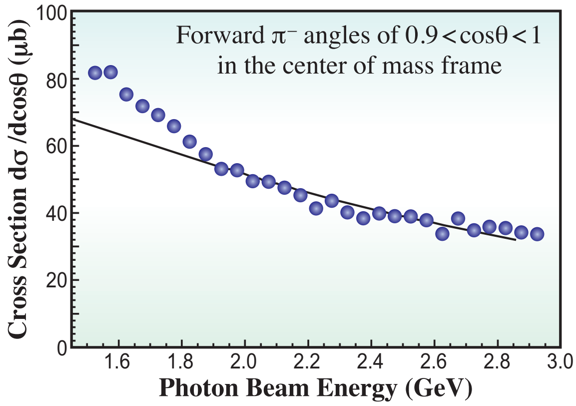

Fig. 2. Differential cross sections for the γ+proton $\rightarrow \pi^-+\Delta^{++}$ reaction [1]. The solid curve is the theoretical calculation by Nam [4].

to the proton's radius of ~1 fm. Since we detected the mesons at forward angles of 0.9<cosθ<1, the reactions are inferred to occur on the surface of the proton. If we assume that the *u*-quark is located near the surface and the *d*-quark remains in the central region of the proton, these asymmetry results are reasonably explained.

We are developing polarized HD (hydrogen-deuteride) targets. Longitudinally and transversely polarized proton targets are used in combination with circularly and linearly polarized photon beams. Many polarization observables for various reactions can be measured. We expect that new measurements will provide us with further interesting understanding of the proton structure and the quark-antiquark production mechanisms.

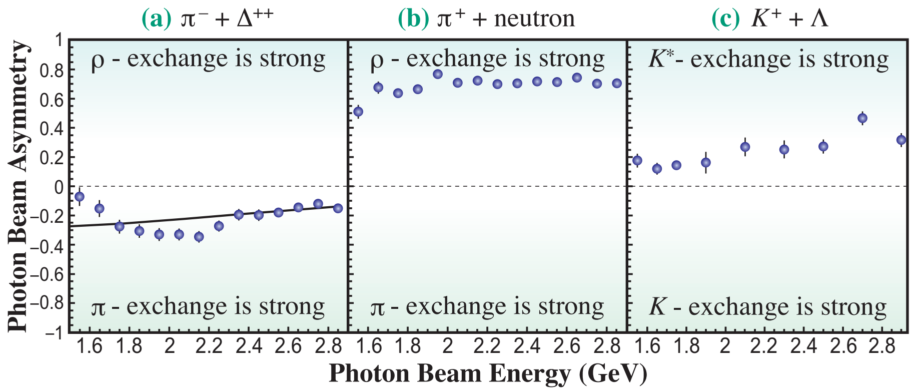

Fig. 3. Photon beam asymmetries for the γ+proton $\rightarrow$ **(a)** $\pi^-+\Delta^{++}$ [1], **(b)** π^++neutron [2], and **(c)** $K^+ +\Lambda$ [3] reactions for forward meson angles of 0.9<cosθ<1. The solid curve in (a) is the theoretical calculation by Nam [4].

Hideki Kohri for the LEPS collaboration

Research Center for Nuclear Physics,
Osaka University

Email: kohri@rcnp.osaka-u.ac.jp

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