Proton Antiproton Pair Production in Two Photon Collisions

Hiroshi Hamasaki
Institute of Applied Physics,
University of Tsukuba
Tsukuba, Ibaraki 305, Japan
(VENUS collaboration)

Abstract
A measurement of the cross section for $\gamma\gamma \rightarrow \bar{p}p$ was made at two-photon center-of-mass energies ($W$) between 2.2 and 3.4 GeV. This results were obtained using $e^+e^- \rightarrow e^+e^-\bar{p}p$ events selected from data samples for an integrated luminosity of $190.2\text{pb}^{-1}$ taken with the VENUS detector at the TRISTAN.

There is a marked contrast in the angular distribution of the cross section between at the high $W$ range ($2.2 < W < 2.5$ GeV) and at the low $W$ range ($2.5 < W < 3.0$ GeV). The integrated cross section ($|\cos \theta^*| < 0.6$) is in good agreement with previous measurements.

1 Introduction

It is considered that proton and antiproton pair production in two photon collision is one of the simplest processes in the reaction of baryon production.

Measurements of this process have been presented by several groups [1, 2, 3, 4, 5]. One of the measured results is the invariant mass dependence of the cross section. The cross section $\gamma\gamma \rightarrow \bar{p}p$ has been calculated within the framework in which many of the non-purturbative components may be absorbed in the proton wave function [6]. Calculations incorporating the wave function which use the QCD sum rules [7] are generally in agreement...
with experimental measurements such as the proton's magnetic form factor and the decay rate for $J/\psi \to \bar{p}p$. The experimental results are in general agreement but disagree with the prediction of the QCD sum rules by one order of magnitude. A recent calculation by the diquark model [8, 9, 10] agrees quite well with data. The both predictions by QCD and the diquark model are applicable to the high invariant mass region ($W > 2.5$ GeV), but in this region the data are quite limited. Thus, statistically significant data samples are necessary even to test the diquark model.

The angular dependence of the cross section has been also measured. Interestingly, in the high $W$ range of 2.5 to 3.0 GeV there is a good agreement in the angular distribution between the shapes of theoretical curves and the experimental data. On the other hand, there is a marked contrast in the angular distribution between in the high $W$ range and in the low $W$ range of 2.0 to 2.5 GeV. In spite of this very interesting fact, no explanation was found in the earlier experimental reports. Therefore, it is interesting to study this process by the VENUS detector.

2 Analysis

We used the data samples at the center-of-mass energy $\sqrt{s} \approx 58$ GeV in the present analysis which were collected by the VENUS detector at the TRISTAN and the corresponding integrated luminosity is 190.2 pb$^{-1}$.

2.1 Event Selection

The anti-tag event samples were selected by using the following selection criteria.

1. We selected events with exactly two oppositely charged good tracks in the CDC.

2. To reject cosmic ray events, the time difference of the TOFs was required to be less than 5 ns.

3. The sum of the energy clusters in the LG and the LA was required to be less than 10.0 GeV to reject single photon annihilation events and a two photon tagged events.
4. For both tracks, $|p| < 1.5 \text{ GeV}/c$, $\text{prob.}(\text{proton}) > 0.01$ and $|\text{Mass}_{\text{proton}} - \text{Mass}_{\text{measured}}| < 0.1 \text{ GeV}/c^2$, in order to identify the proton and the antiproton. The parameter, $\text{prob.}(\text{proton})$ is the relative probability of the proton (or antiproton) given by

$$\text{prob.}(\text{proton}) = \exp \left[ -\frac{1}{2} \frac{(\text{TOF}_{\text{mea.}} - \text{TOF}_{\text{exp.}})^2}{\sigma_{\text{TOF}}} \right] \quad (1)$$

where $\text{TOF}_{\text{mea.}}$ is the measured time-of-flight and $\text{TOF}_{\text{exp.}}$ is the expected time-of-flight for the proton with the same path length measured. $\sigma_{\text{TOF}}$ is the time resolution of the TOF.

5. In order to reject non-exclusive production of $p\bar{p}$ pair events, the vector sum of $p_t$ was required to be less than 0.2 GeV/c. This cut also rejects the events produced by highly virtual photons.

After these event selections, the total number of candidate events is 206.

### 2.2 Efficiency

Using Monte Carlo simulation, we obtain the detection efficiency for the present process. Since the efficiency is a function of both $W$ and $\cos \theta^*$, MC events were first generated using a uniform angular distribution. Then we calculated by dividing the event samples into two-dimensional bins of these two variables. The variable $W$ is the invariant mass of two charged particles which are assumed to be protons, while $\theta^*$ is the angle between the proton momentum and the electron beam direction in the photon-photon center-of-mass frame. The generated events were run through a full detector simulator for the VENUS, VMONT and were selected by the same cuts as the real data. For the present estimation of the efficiency we generate 1,000 MC data for each two-dimensional bin $(W, \cos \theta^*)$. Fig. 1 shows the detection efficiency as a function $W$ (a) and as a function of $|\cos \theta^*|$ for $W = 2.5$ GeV (b).

### 2.3 Background

Background sources of the present reaction are considered and listed in Table 1.
Figure 1: Detection efficiency: (a) as a function of $W$; (b) as a function of $|\cos \delta^*|$. 

<table>
<thead>
<tr>
<th>Final state</th>
<th>Misidentification</th>
</tr>
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<tbody>
<tr>
<td>Non-exclusive production</td>
<td>$\gamma \gamma \rightarrow p(p)(X^+)X^-$</td>
</tr>
<tr>
<td>Beam-gas beam-pipe</td>
<td>$\gamma \gamma \rightarrow pX^-$</td>
</tr>
<tr>
<td>Single photon annihilation</td>
<td>$\gamma \gamma \rightarrow \bar{p}X^+$</td>
</tr>
<tr>
<td>Two photon process</td>
<td>$\gamma \gamma \rightarrow X^+X^-$</td>
</tr>
</tbody>
</table>

$d \rightarrow \bar{p}p$
$\gamma \gamma \rightarrow \bar{p}p(X)$
$\rightarrow \bar{p}p$
$ee \rightarrow \bar{p}p$

Table 1: Background sources of $\gamma \gamma \rightarrow \bar{p}p$
In this table, X indicates a particle other than the proton or antiproton namely pion or kaon or gamma and () indicates the undetected particles by
the detector. The non-exclusive production of $\bar{p}p$ pairs is the events which have other products in addition to $\bar{p}p$.

(a) The contribution in which both tracks are misidentified, is estimated by studying $\gamma\gamma \rightarrow X^+X^-$ events. The result is $2.3 \pm 1.1 \%$. (b) The events including $\bar{p}$ from misidentification ($\rightarrow pX^-$) are considered mainly to come from the beam-gas and beam-wall events. The number of these background events is estimated by using the $Z_{\text{mis}}$ distribution. The result is $5.7 \pm 1.7 \%$. In the other method, this contribution is estimated by studying the $pX^-$ samples. The result is $5.5 \pm 1.6 \%$. (c) The events including a proton from misidentification ($\rightarrow pX^+$) are considered to come from reactions involving non-exclusive production of $\bar{p}p$ pairs. This contribution are estimated by studying $pX^+$ samples. The result is $3.8 \pm 1.4 \%$. (d) There are more contributions from non-exclusive production, $\gamma\gamma \rightarrow p\bar{p} + nX$ in which $nX$ are undetected. This contribution is estimated by using $p_t$ balance. Fig. 2 shows the vector sum of $p_t$ distributions for the real data and the MC data. In order to estimate $\gamma\gamma \rightarrow p\bar{p} + nX$ contribution, we fitted the real data by the sum of the MC data of $\gamma\gamma \rightarrow \bar{p}p$ and $\gamma\gamma \rightarrow \bar{p}pnX$. Because this MC data of the non-exclusive production is considered to include the background events from misidentification, we subtract the previously estimated background from the MC data of the non-exclusive production. We set the cut value of 0.2 GeV/c and the shaded area corresponds to the background contribution. It is estimated to be $9.58 \%$ for the background contribution only from $\gamma\gamma \rightarrow p\bar{p}nX$ contribution.

Contaminations from other processes such as $\bar{p}p$ production from beam-gas and beam-wall and from single photon annihilation ($ee \rightarrow \bar{p}p$) are considered to be very small and these contributions are neglected.

2.4 Results

The differential cross section was evaluated by using

$$ \frac{d\sigma(W,|\cos\theta^*|)}{d|\cos\theta^*|} = \frac{N(W,|\cos\theta^*|)}{\eta(W,|\cos\theta^*|)} \cdot \frac{1}{L_{\gamma\gamma}(W) \cdot f \cdot Ldt \cdot \Delta W \cdot \Delta|\cos\theta^*|} $$ (2)
where $N$ is the number of candidate events after subtracting background events, $\eta(W, |\cos\theta^*|)$ is the detection efficiency, $L_{\gamma\gamma}(W)$ is the photon luminosity function and $\int L dt$ is the integrated luminosity. We include a correction for the form factor effect for virtual photons using the mass scale of the $\rho$ meson in the calculation of $L_{\gamma\gamma}$. Fig. 3 shows the results of the differential cross section. Fig. 3 (a) is for the $W$ range of 2.2 to 2.5 GeV and Fig. 3 (b) is for the $W$ range of 2.5 to 3.0 GeV.

The invariant mass dependence of the cross section is given by integration over the angular range $|\cos\theta^*| < 0.6$:

$$
\sigma(W) = \int_{0.0}^{0.6} \frac{d\sigma(W, |\cos\theta^*|)}{d|\cos\theta^*|} d|\cos\theta^*| \\
\approx \sum_{|\cos\theta^*| = 0.1}^{0.5} \frac{d\sigma(W, |\cos\theta^*|)}{d|\cos\theta^*|} 
$$

(3)

Fig. 4 is results of the measured cross section and two theoretical curves. The dashed curve is based on the leading order QCD calculation, and the
Figure 3: Measured differential cross section for $\gamma\gamma \rightarrow \bar{p}p$: (a) $2.2 < W < 2.5$ GeV; (b) $2.5 < W < 3.3$ GeV.

solid curve is a result of calculations performed in the context of a diquark model.

3 Conclusion

We measured the invariant mass dependence of the cross section for $\bar{p}p$ pair production in two photon collisions. The VENUS result is in good agreement with the previous measurements. In the higher invariant mass region, our data is statistically significant compared with the previous results and it is in good agreement with the CLEO results.

The angular dependence of the cross section was also measured. The present data have the same behavior as those of the previous measurements, that is, in the high invariant mass region measured differential cross section increases at small angles, while in the low invariant mass region it enhances near 90°.
Figure 4: Measured cross section for $\gamma\gamma \rightarrow \bar{p}p$.

References