POSITRON-PRODUCTION EXPERIMENT BY 8-GeV CHANNELING ELECTRONS IN CRYSTAL TUNGSTEN AT THE KEKB INJECTOR LINAC

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Abstract

An experiment to study the positron production efficiency by 8-GeV electrons hitting an axially oriented tungsten monocrystalline target was carried out by using a single-bunch beam (10 ps width) from the KEKB injector linac. In this experiment a 2.2-mm-thick crystal tungsten is tested either alone or in combination with an amorphous tungsten (5.0 and 10.0 mm thick). Positrons emitted from the target in the forward direction are momentum-analyzed by a magnetic spectrometer in the momentum range 10-30 MeV/c and are detected with a 3-mm-thick acrylic Cherenkov counter and a lead-glass calorimeter. Since produced positrons are shortly bunched, the number of positrons per bunch are measured as a pulse charge from each detector. The positron yields have been measured for each target as a function of the rotational angles of a goniometer. For the 2.2-mm-thick crystal target, a five-times enhancement of the positron yield was observed when the crystal axis, <111>, was oriented to the incident electron beam. For the combined-type target, the positron yield enhancement decreased depending on the thickness of the amorphous part. This paper describes the first result of this series of experiments.

1 INTRODUCTION

For future e^+e^- linear colliders and high-luminosity B-factories, it is critically important to develop a high-intensity positron source. In a conventional method using an amorphous heavy-metal target, the target thickness is optimized by taking into account the electromagnetic shower process and the positron capture efficiency in the succeeding acceleration section. The optimum thickness is 4-5 radiation length for the 4-8 GeV electron beam. The only possibility to increase the positron intensity is to increase the incident electron intensity. However, the electron intensity is limited due to a heat load on the target. One promising method utilizing a crystal target has been proposed by Chehab *et al.*[1] in 1994. The benefit of this method is a high positron-production efficiency due to channeling radiation (CR) and coherent bremsstrahlung (CB), since CR and CB increase low-energy photons in the radiation process. This results in a thinner target compared with the conventional method, which is due to high-intensity low-energy photons originating from the CR and CB. It is also expected that the thin target relaxes its heat load, and the spatial spread of positrons due to multiple scattering in the target is suppressed. Yoshida *et al.* demonstrated a clear enhancement of the positron yield in a crystal tungsten target using a 1.2-GeV electron beam[2]. This new scheme was tested at the positron station of the KEKB injector linac[3,4]. The result indicates that, when a hybrid target made of 1.7-mm-thick crystal tangsten and 7.0-mm-thick amorphous one is used and the crystal axis, <111>, is oriented to the 3-GeV electron beam, the positron yield is enhanced by 40% compared with that for the disoriented case. Chehab *et al.* have also studied the positron yield from the crystal target for 5-40 GeV electrons at CERN-SPS[5]. Although the positron enhancement is expected, there have been so far only a few experimental researches over a wide energy range of primary electron beams and, thus, theoretically unified treatments taking into account both processes of the CR and CB have not yet been established. More precise experimental data will help us to understand the complicated mechanism of these elementary radiation processes and to realize the high-intensity positron source.

A series of experiments to investigate the positron yields under various crystal target conditions are planned for an incident electron energy below 8 GeV.

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2 EXPERIMENTAL SETUP

2.1 Beam Line

Our experiment was performed at the energy analyzer line in the beam switchyard of the KEKB 8-GeV injector linac. The 8-GeV electron beam with a pulse width of 10 ps impinged on a tungsten target at a repetition rate of 2 Hz. The beam intensity in this experiment was 0.2 nC/bunch, which was limited mainly by the radiation safety condition. The electron beam charge was measured by a wall-current monitor pulse-by-pulse. The transverse beam sizes and the positions of the electron beam at the target were monitored by a screen monitor during the experiment. The transverse beam size was about 3 mm (FWHM) in diameter. The normalized transverse emittance was about 120 πmm•mrad, and the angular spread of the electron beam was expected to be less than 5 μrad. Since the electron beam impinged on the target after passing through a vacuum window made of 100-μm-thick stainless steel (SUS304), it was expected that the angular spread of the electron beam would be 0.1 mrad in total, taking into account multiple scattering. This angular spread was less than the critical angle (0.43 mrad) of the channeling condition at 8 GeV.

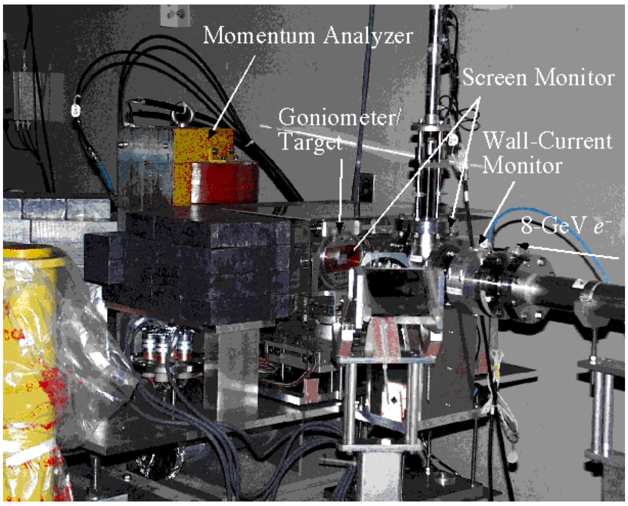

Figure 1: Photograph of the beam line and the experimental setup viewed from the electron beam.

2.2 Experimental Setup

Figure 2 shows a schematic drawing of the experimental setup. This comprises a positron-production target mounted on a precise goniometer, a magnetic spectrometer, collimators, and two kinds of positron detectors. In this experiment, a 2.2-mm-thick crystal tungsten (W_c) was tested either alone or in combination with an amorphous tungsten (W_a) (5.0 and 10.0 mm thick). Positrons emitted from the target in the forward direction were momentum-analyzed by the magnetic field, which deflects positrons at 60° from the beam axis in a momentum range less than 30 MeV/c. The positron trajectory was determined by the collimators installed before and behind the magnetic spectrometer. The momentum-analyzed positrons were detected with a 3-mm-thick acrylic Cherenkov counter and a lead-glass calorimeter well shielded by lead blocks. The lead blocks suppressed any background caused by electromagnetic showers generated upstream of the beam line due to the off-momentum electron beam, and caused by electromagnetic showers generated at the collimators. Since the emitted positrons were also shortly bunched, the number of positrons per bunch was measured as a pulse charge from each detector. Signals from the positron detectors and the signal of the electron beam charge were sent to a data-acquisition system using a PC-based CAMAC/ADC system, where all signal charges were simultaneously digitized. The goniometer could rotate the crystal target around two axes (the horizontal(H) and vertical(V) axes) by a pulse motor. The angular resolutions of the goniometer were 10.5 and 34.9 μrad/pulse in the H and V axes, respectively. The crystal axis, <111>, was searched by changing the relative rotational angles around the two axes with a step of 2 mrad. The positron yields were measured for each target as a function of the rotational angle of the goniometer and as a function of the positron momentum.

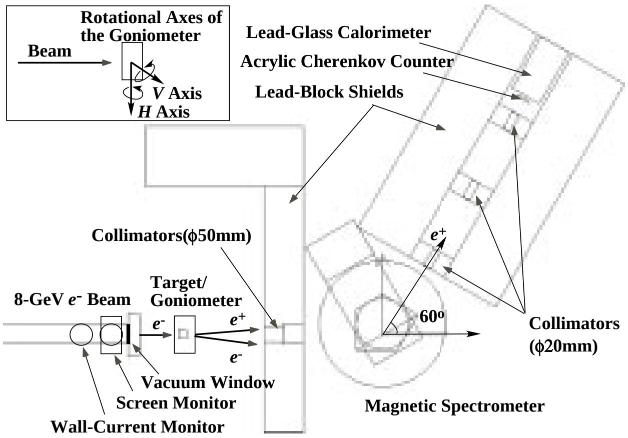

Figure 2: Schematic drawing of the experimental setup.

3 EXPERIMENTAL RESULTS

3.1 Result for the Tungsten Crystal

After a linearity check for two positron detectors, the enhancement of the positron yield was measured by changing the V and H angles of the goniometer for the 2.2-mm-thick crystal tungsten target (W_c). Figure 3(a) shows the result of the relative positron yield (rocking curve) measured by the lead-glass calorimeter at a momentum of 20 MeV/c. Each data point shows the average value and the standard deviation measured twenty times at the same rotational angle after correcting the pedestals of the detectors, subtracting the backgrounds, and normalizing by the electron-beam intensity. The pedestal data of the detection system were measured under the conditions: (1) without an electron beam, (2) without the following RF power of the end klystron, and (3) without a magnetic field. The beam-associated background data were also measured under the condition without a magnetic field. The enhancement of the relative positron yield is defined by the ratio of the peak yield (on-axis) to the yield at the base region 50 mrad apart from the crystal axis in the *H* scan. The observed enhancement was 5.0 and the FWHM of the rocking curve was 7.6 mrad. The momentum dependence of the positron enhancement was also measured in the same way in the 10-30 MeV/c region. No appreciable dependence was observed.

3.2 Results for the Combined Targets

Enhancement measurements were also performed for combined targets, that is, the same W_c with a 5.0-mm-thick amorphous tungsten (W_a) and W_c with a 10.0-mm-thick W_a. The W_a's were mounted just behind the W_c target. The results at a positron momentum of 20 MeV/c are shown in Figs.3 (b) and 3 (c). It is noted that the vertical axis of the figures indicates a relative positron yield in arbitrary unit and only the enhancement factors are meaningful in the results. Three experimental data are summarized in Table 1.

Table 1: Measured enhancements of the positron yields for three target combinations.

Target type	Enhancement	FWHM (mrad)
(a) 2.2-mm-thick W_c	5.0 ± 0.1	7.6
(b) W_c+5-mm-thick W_a	1.9 ± 0.1	10.0
(c) W_c+10-mm-thick W_a	1.2 ± 0.1	15.5

4 CONCLUSIONS

Positron-production experiments by 8-GeV electrons hitting an axially-oriented tungsten monocrystalline target were carried out using single-bunch beams at the KEKB injector linac. The enhancements of the positron yields were 5.0 ± 0.1, 1.9 ± 0.1, and 1.2 ± 0.1 for targets with 2.2-mm-thick crystal tungsten, two combinations with 5-mm-thick and 10-mm-thick amorphous tungsten at a momentum of 20 MeV/c, respectively, when the crystal axis, <111>, was oriented to the incident electron beam. The angular width of the rocking curve varied, depending on the total thickness of the target. The results indicate that the angular width is mainly due to the contribution from the coherent bremsstrahlung and multiple scattering at the target since the critical angle of the channeling radiation is much less than it.

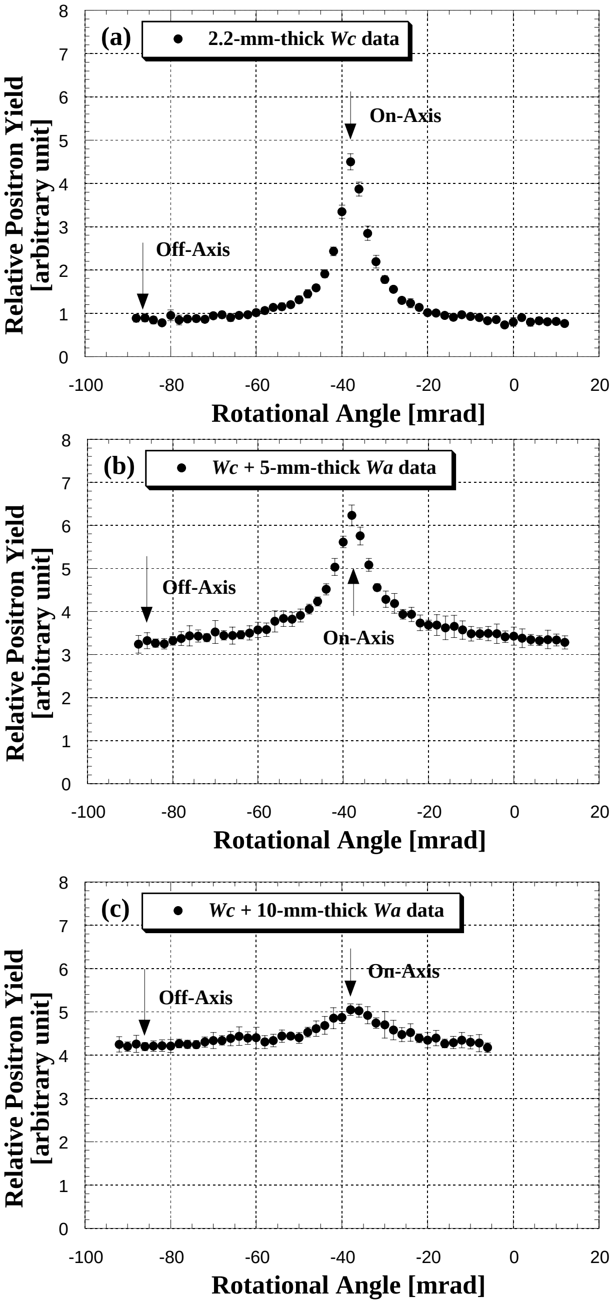

Figure 3: Relative positron yields as a function of the goniometer rotational angle around the H axis for three target combinations. The angle around the V axis is fixed to the position giving the yield peak. The positron momentum: 20 MeV/c, and the positron emission angle: 0 degree.

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