POSITRON-PRODUCTION EXPERIMENT USING 8-GEV CHANNELING ELECTRONS IN A CRYSTAL-TUNGSTEN TARGET

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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 using a single-bunch beam (10 ps width) from the KEKB injector linac. In this experiment 2.2mm-thick and 9mm-thick crystal tungsten targets were tested either alone or in combination with an amorphous tungsten target (2.0 and 4.0mm-thick). Positrons emitted from the target in the forward direction were momentum-analyzed by a magnetic spectrometer in a momentum range lower than 20 MeV/c and were detected with a 3mm-thick acrylic Cherenkov counter and a lead-glass calorimeter. Since the produced positrons were shortly bunched, the number of positrons per bunch was measured as a pulse charge from each detector. The positron yields have been measured for each target as a function of the rotational angle of a goniometer and as a function of the positron momentum. For the 2.2mm-thick and 9mm-thick crystal targets, 5.1-times and 1.7-times enhancements of the positron yield were observed, respectively, when the crystal axis, <111>, was oriented to the incident electron beam. This paper describes the results 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 X_0 (radiation length) for a 4-8 GeV electron beam. In this case, 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 was proposed by Chehab *et al.*[1] in 1994.

The benefit of this method is its high positron-production efficiency due to channeling radiation (CR)[2] 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. It is also expected that the thin target relaxes its heat load, and that the spatial spread of positrons due to multiple scattering in the target is reduced. Yoshida *et al.* demonstrated a clear enhancement of the positron yield in a crystal tungsten target using a 1.2-GeV electron beam[3]. This new scheme was tested at the positron station of the KEKB injector linac[4]. The result indicates that, when a hybrid target made of 1.7mm-thick crystal tungsten and 7.0mm-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[5]. Chehab *et al.* also studied the positron yield from the crystal target for 5-40 GeV electrons at CERN-SPS[6]. Although a positron enhancement is expected, there have so far been only a few experimental studies over a wide energy range of primary electron beams. Theoretically unified treatments by taking into account both processes of 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 design a high-intensity positron source.

A series of experiments[7-9] to investigate the positron yields under various crystal target conditions are underway for an incident electron energy of 8 GeV.

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 (see Fig.1). An electron beam with a pulse width of 10 ps and with an energy of 8 GeV 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 beam charge was measured by a wall-current monitor for each pulse. The transverse profile of the electron beam at the target was monitored by a screen monitor during the experiment. The transverse beam size was about 1 mm (FWHM) in diameter. The angular spreads of the electron beam were expected to be about 72 and 15 mrad in the

horizontal and vertical directions, respectively. However, since the electron beam impinged on the target after passing through a vacuum window made of 100mm-thick stainless steel (SUS304), the angular spread of the electron beam at the target was estimated to be 0.1 mrad in total by taking into account the multiple scattering. This angular spread was less than the critical angle (0.43 mrad) of the channeling condition at 8 GeV.
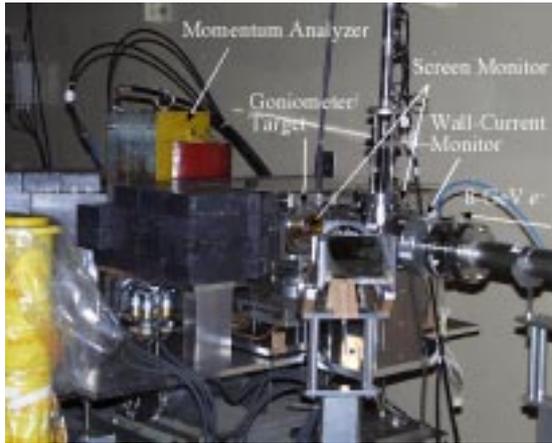

Figure 1: Photograph of the beam line and the experimental setup viewed from the electron beam.

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 (a lead-glass calorimeter and an acrylic Cherenkov counter). All of the collimators and detectors are installed in a vacuum chamber kept at a vacuum pressure of 10^{-3} Torr. In this experiment, 2.2mm-thick and 9mm-thick crystal tungstens (W_c) were tested either alone or in combination with an amorphous tungsten target (W_a) (2.0 and 4.0mm-thick). The positrons emitted from the target in the forward direction were momentum-analyzed in a momentum range lower than 20 MeV/c by the magnetic field, where the deflection angle was 60º from the beam axis. The positron trajectory was determined by five collimators installed before and behind the magnetic spectrometer. The geometrical acceptance and momentum acceptance were about 1 msr and 3% at a positron momentum of 20MeV/c, respectively. The momentum-analyzed positrons were detected with a 3mm-thick acrylic Cherenkov counter and a lead-glass calorimeter 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 electrons, 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 mrad/pulse in the H and V axes, respectively. The crystal axis, <111>, was determined 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.
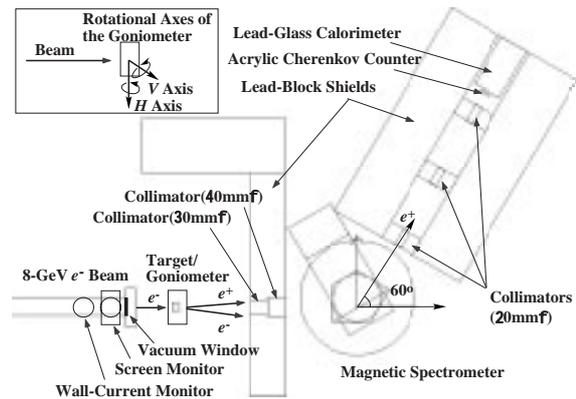

Figure 2: Schematic drawing of the experimental setup.

3 EXPERIMENTAL RESULTS

3.1 Results for the Tungsten Crystals

The enhancement of the positron yield was measured by changing the V and H angles of the goniometer for the two crystal tungsten targets. Figure 3 shows the results ((a) 2.2mm-thick W_c and (b) 9mm-thick W_c) of the relative positron yield (rocking curve) measured by the acrylic Cherenkov counter at a momentum of 20 MeV/c. Each data point shows the average value and its errors obtained by twenty beam-pulse measurements at the same rotational angle. Corrections were made for pedestals in the charge measurements, for backgrounds, and for the electron-beam intensity. The beam-associated background data were also measured under the condition without a magnetic field. The data measured by the lead-glass calorimeter and the acrylic Cherenkov counter were consistent with each other within the experimental uncertainty.

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 enhancements and the angular widths (FWHM) of the rocking curve were 5.1 ± 0.1 and 9.0 mrad, and 1.7 ± 0.1 and 39.2 mrad for the 2.2mm-thick and 9mm-thick W_c, respectively. The momentum dependence of the positron enhancement was also measured in the same way in the momentum range of 10-20 MeV/c. The results are summarized in Table 1.

Table 1: Measured enhancements of the positron yields depending upon the positron momentum.

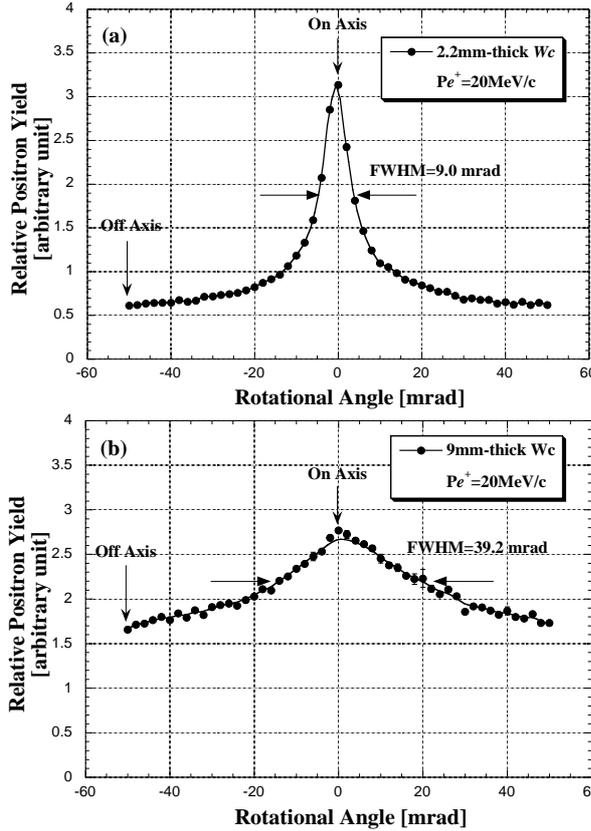| Momentum [MeV/c]	Enhancement (2.2mm W_c)	Enhancement (9mm W_c)
10	6.6 ± 0.1	1.9 ± 0.1
15	6.1 ± 0.1	1.7 ± 0.1
20	5.1 ± 0.1	1.7 ± 0.1

Figure 3: Relative positron yields (a) for the 2.2mm-thick W_c and (b) for the 9mm-thick W_c as a function of the goniometer rotational angle around the H axis while the angle around the V axis is fixed to the position giving the yield peak. The solid curves are only for the eye's guide.

3.2 Calibration for the Positron Yield

The measured positron yields were calibrated by using amorphous tungsten targets with different thicknesses of 3 mm to 18 mm. Figure 4 shows the positron-production efficiency with a momentum of 20 MeV/c. The data for the crystal targets are also shown for a comparison. The experimental data were normalized by using the simulated data point of 8mm-thick W_a. The thickness-dependence of the positron yield from W_a in the momentum range of 10-20 MeV/c agrees with simulation results using the EGS4 code[10] within the experimental uncertainty. A full simulation with the GEANT3 code[11] taking into account all geometry of the experimental setup showed good agreement with that of the EGS4 simulation[8]. For the crystal target, a more sophisticated simulation code

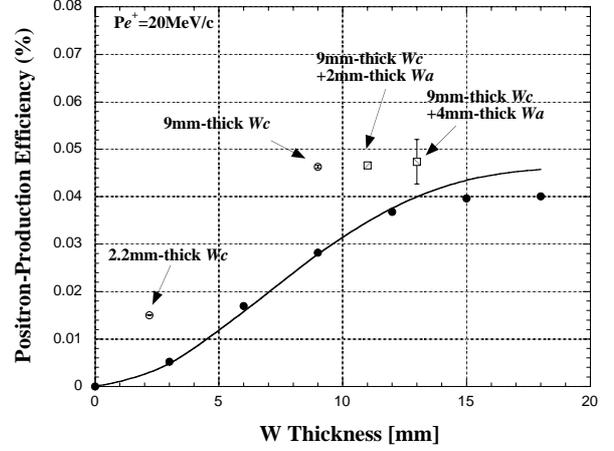including CR and CB radiation processes is under development.

Figure 4: Positron-production efficiency measured for crystal and amorphous tungsten targets at the momentum of 20 MeV/c. The positron-production efficiency is defined as the ratio of the number of the detected positrons to an electron injection. A solid curve based on the EGS4 simulation drawn through data points is also shown.

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 5.1 ± 0.1 times and 1.7 ± 0.1 times for targets with the 2.2mm-thick and 9mm-thick crystal tungsten at a momentum of 20 MeV/c, respectively, when the crystal axis, <111>, was oriented to the incident electron beam.

It is interesting to note that the measured positron yield for 9mm-thick crystal is slightly larger than the maximum yield attainable for the 15mm-thick amorphous target by the 8-GeV electron beam.

5 REFERENCES

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