POSITRON-PRODUCTION EXPERIMENT IN TUNGSTEN CRYSTAL USING 4 AND 8-GEV CHANNELING ELECTRONS AT THE KEKB INJECTOR LINAC

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Abstract

A series of positron-production experiments with crystal tungstens hit by 4 and 8-GeV single-bunch electron beams were carried out at the KEKB 8-GeV injector linac. Three tungsten crystals (<111> axis) with different thicknesses (2.2, 5.3 and 9.0 mm) and those combined with amorphous tungsten plates were tested on a precise goniometer. The positron-production yields were measured with a magnetic spectrometer in the positron momentum (P_{e^+}) range from 5 to 20 MeV/c. The results show that the enhancements of the positron yield from crystal targets compared to amorphous targets of the same thickness at P_{e^+}=20 MeV/c are from 1.5 to 3.7 and from 1.8 to 5.1, depending upon the target thickness for 4 and 8-GeV electrons, respectively.

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 because of a heat load on the target. One promising method utilizing a crystal target was proposed by Chehab *et al.* [1] in 1989. The benefit of this method is on its 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. It is also expected that the thin target relaxes the problem of the 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 tungsten crystal target using a 1.2-GeV electron beam [2]. This new scheme was tested at the positron station of the KEKB injector linac. The result indicates that, when a hybrid target made of 1.7-mm-thick tungsten crystal and 7.0-mm-thick amorphous plate is used and the <111> crystal axis is oriented along the 3-GeV electron beam direction, the positron yield is enhanced by 40% compared with that for the disoriented case [3]. Chehab *et al.* also studied the positron yield from the crystal target for 5-40 GeV electrons at CERN-SPS [4]. Although a positron enhancement is observed, there have so far been only a few experimental results over a wide energy range of a primary electron beam. Thus, more systematic and precise experimental data could help us to understand the complicated mechanism of these elementary radiation processes and to design a high-intensity positron source. A series of experiments [5] to investigate the positron yields using various crystal targets are underway for incident electron energies lower than 8 GeV.

2 EXPERIMENTAL SETUP

2.1 Electron beam

An electron beam with a pulse width of 10 ps impinged on a tungsten crystal target at a repetition rate of 25 and 2 Hz with the energy of 4 and 8 GeV, respectively. The beam charge (0.2 nC/bunch) was measured by a wall-current monitor for each pulse. The transverse profile of the electron beam at the target was monitored by a 100-μm-thick fluorescent screen monitor during the experiment. The transverse beam size was 1 to 1.5 mm (FWHM) in diameter. The angular spreads of the electron beam were measured with a wire scanner to be about 123 (23) and 121 (41) μrad in the horizontal and vertical directions to the beam axis for the 4 (8)-GeV electrons, respectively. While the electron beam impinged on the target after passing through a vacuum window made of 100-μm-thick stainless steel, the angular spread of the electron beam at the target was estimated to be 0.2 (0.1) mrad in total at 4 (8) GeV by taking into account multiple scattering. These angular spreads were less than the critical angles (0.61 and 0.43 mrad) of the channeling condition at 4 and 8 GeV, respectively.

2.2 Tungsten mono-crystalline target

Three tungsten mono-crystalline targets (W_c) with different thicknesses (2.2, 5.3 and 9.0 mm) were tested either

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alone or in combination with an amorphous tungsten plate (W_a). The surface mosaicities of these crystals on both sides were measured by an X-ray scattering method to be 1.5, 0.5 and 0.5 mrad for 2.2, 5.3 and 9.0-mm-thick crystals, respectively. W_a's with different thicknesses from 3 to 18 mm with 3 mm steps were also installed on a horizontal movable stage to the beam axis at 82.5 mm behind the crystal target. They were used for combined targets. Several other W_a's with thicknesses of up to 28 mm were also mounted on a crystal target holder, which made it possible to calibrate the positron yield.

2.3 *Positron spectrometer*

Figure 1 shows a schematic drawing of the experimental setup. This comprises a positron-production target mounted on a precise goniometer and a positron spectrometer. The positrons emitted from the target in the forward

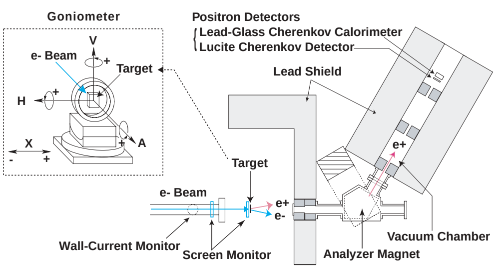

Figure 1: Schematic drawing of the experimental setup.

direction were momentum-analyzed by the magnetic field in a momentum range lower than 20 MeV/c, where the deflection angle was 60° from the beam axis. The positron trajectories were determined by five collimators installed before and behind the momentum-analyzer magnet. They were kept in a vacuum at a pressure level of 10^{-1} Pa. The momentum-analyzed positrons were detected with a 5-mm-thick transmission-type lucite Cherenkov detector and a 20-mm-thick total-absorption-type lead-glass calorimeter with photomultiplier tubes. The lead blocks surrounding the detectors suppressed any background caused by electromagnetic showers generated upstream of the beam line by off-momentum electrons, and caused by electromagnetic showers generated at the collimators. The acceptance of the positron spectrometer was obtained by using the detector simulation code GEANT3 [6] at each positron momentum. The typical geometrical and momentum acceptances are about 1 msr and 2.4% ($\Delta P/P$, FWHM) at P_{e+} =20 MeV/c.

2.4 *Data-acquisition system*

Since the emitted positrons were 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 wall-current monitor were sent to a data-acquisition system using a PC/Linux-based CAMAC/ADC, where all signal charges were simultaneously digitized and recorded. The goniometer could rotate the crystal target around two axes (the horizontal (H) and vertical (V) axes) by pulse motors. The angular resolutions of the goniometer were 10.5 and 34.9 μrad/pulse in the H and V axes, respectively. The <111> crystal axis with respect to the electron beam was determined by changing the relative rotational angles around the two axes with steps of 2 mrad.

3 EXPERIMENTAL RESULTS

3.1 *Rocking curves*

A rocking curve was measured as a function of the goniometer rotational angle around the H axis while the angle around the V axis was fixed to the angular position giving the peak yield. Twenty beam-pulse measurements were performed at the same H angle. The data corrections were made for pedestals in positron charge measurements, for backgrounds, and for the electron-beam intensity. The beam-associated background data were also measured under the condition with the magnetic field off and with the target away. The background data were carefully subtracted from the raw data. The results of rocking-curve measurements for the W_c's at P_{e+}=20 MeV/c are shown in figs.2. Figures 2 (a) and (b) show the results for the 2.2-mm-thick W_c at E_{e-}=4 and 8 GeV, and for the 5.3 and 9.0-mm-thick W_c's at E_{e-}=4 GeV, respectively. These curves clearly indicate that the width of the rocking-curve peak is much larger than the critical angle of the channeling electrons, and broadens with the thickness of the crystal target. These broad widths of the rocking curves indicate that coherent bremsstrahlung is the predominant process over the channeling radiation process in this energy region.

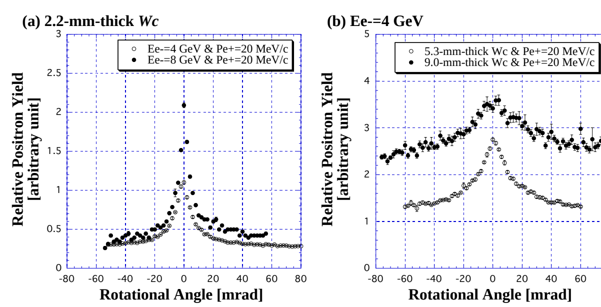

Figure 2: Rocking curves measured at P_{e+}=20 MeV/c (a) for the 2.2-mm-thick W_c at E_{e-}=4 and 8 GeV, and (b) for the 5.3 and 9.0-mm-thick W_c's at E_{e-}=4 GeV as a function of the goniometer rotational angle around the H axis.

3.2 *Enhancement of the positron yield*

An enhancement of the relative positron yield was obtained from the rocking curves. Here, the enhancement is defined by the ratio of the peak yield (on-axis) to the yield at the base region (off-axis) 50 mrad apart from the crystal axis in the H scan. The observed enhancements at P_{e+}=20 MeV/c for both of the W_c's and the combined targets as a function of the target thickness are shown in figs.3. Here, the total thickness of the target was used for the combined targets. The result shows that the enhancement factor is much reduced with an increase of the total target thickness, and no crystal effect enhances the positron yield at a target thickness larger than 14 mm in total, which is almost the same as the optimum thickness of a W_a target at E_{e^-}=4 GeV. The momentum dependence of the enhancement for the crystal targets was also measured in the momentum range of 5-20 MeV/c. The result shows that the momentum dependence of the enhancement is not very strong in the present measurement.

Table 1: Momentum dependence of the positron-yield enhancement for the crystal targets

P_{e+}	E_{e^-}=4 GeV		
(MeV/c)	2.2mm W_c	5.3mm W_c	9.0mm W_c
5	3.3 $\pm$ 0.1	2.2 $\pm$ 0.1	1.5 $\pm$ 0.2
10	3.6 $\pm$ 0.3	2.3 $\pm$ 0.1	1.5 $\pm$ 0.2
15	3.5 $\pm$ 0.1	2.2 $\pm$ 0.1	1.7 $\pm$ 0.3
20	3.7 $\pm$ 0.1	2.2 $\pm$ 0.1	1.5 $\pm$ 0.1
P_{e+}	E_{e^-}=8 GeV		
(MeV/c)	2.2mm W_c	5.3mm W_c	9.0mm W_c
5	5.0 $\pm$ 1.5	2.9 $\pm$ 0.5	2.1 $\pm$ 0.3
10	6.5 $\pm$ 0.6	3.4 $\pm$ 0.7	2.3 $\pm$ 0.4
15	6.2 $\pm$ 0.8	3.2 $\pm$ 0.5	2.0 $\pm$ 0.2
20	5.1 $\pm$ 0.5	3.0 $\pm$ 0.5	1.8 $\pm$ 0.2

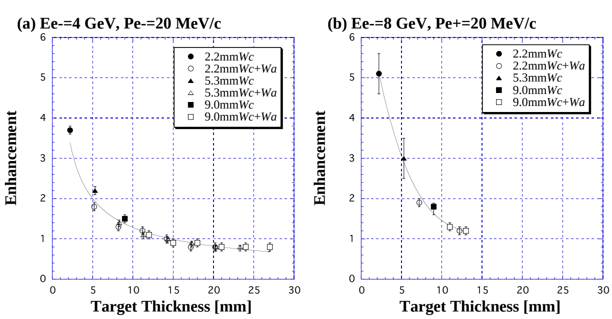

Figure 3: Variations in the enhancement of the positron yield at P_{e+}=20MeV/c (a) for E_{e^-}=4 GeV and (b) for E_{e^-}=8 GeV as a function of the target thickness. The solid curves drawn through the data are only for the eye's guide.

3.3 *Positron production efficiency*

The absolute values of the measured positron yields were calibrated by using the data for the W_a targets. The positron production efficiencies for the different W_a target thicknesses were calculated by using the GEANT3 code in which all of the geometry of the experimental setup was taken into account. Here, the positron production efficiency is defined as the ratio of the number of detected positrons to the number of incident electrons. The experimental data points normalized to the calculations at a W_a thickness of 9 mm are shown in figs. 4 (a) and (b) with P_{e+}=20 MeV/c at E_{e^-}=4 and 8 GeV, respectively. Also shown in solid curves are the results of calculations, which reproduce quite well the experimental data points over the wide range of the W_a target thicknesses. The maximum positron yields for the 9.0-mm-thick crystal target were obtained with an enhancement of 20% with respect to the W_a targets with the optimum thickness (14 and 18 mm) at P_{e+}=20 MeV/c for E_{e^-}=4 and 8 GeV.

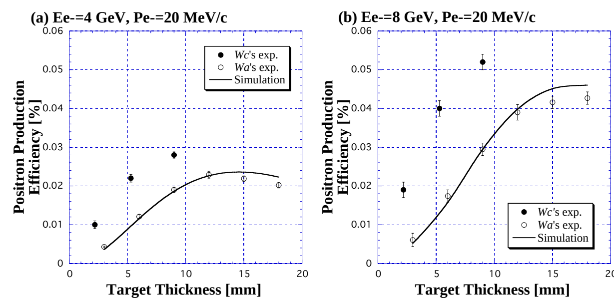

Figure 4: Positron production efficiencies measured for the crystal targets at P_{e+}=20 MeV/c (a) for E_{e^-}=4 GeV and (b) for E_{e^-}=8 GeV. The solid curves drawn through the data are based on a simulation.

4 CONCLUSIONS

The positron production efficiencies from the crystal targets by 4 and 8-GeV electrons were measured as a function of the target thickness and as a function of the positron momentum. The results show that when the <111> crystal axis was aligned along the incident electron beam direction, a large positron yield enhancement was observed. The enhancement factor decreases as the target thickness increases. The maximum positron yields for the crystal targets were enhanced by 15 and 18% on the average with respect to the optimum yields obtained for the amorphous target with the momentum range of 5-20 MeV/c at E_{e^-}=4 and 8 GeV, respectively. This new scheme using the crystal target indicates that the heat load in the crystal part of the target could be considerably reduced due to a small amount of the energy loss in total.

5 REFERENCES

[1] R. Chehab, *et al.*, PAC'89, Chicago, IL, Mar. 1989, p.283.

[2] K. Yoshida, *et al.*, Phys. Rev. Lett. 80, 1437 (1998).

[3] M. Inoue, *et al.*, NIM B173 (2000) p.104.

[4] R. Chehab, *et al.*, RREPS'01, Lake Aya, Altai Mountains, Russia, September 2001, to be published in NIM B.

[5] H. Okuno, *et al.*, RREPS'01, Lake Aya, Altai Mountains, Russia, September 2001, to be published in NIM B.

[6] CERN Program Library Long Writeup W5013, CERN, Geneva, 1994.