EXPERIMENTAL ACTIVITIES ON HIGH INTENSITY POSITRON SOURCES USING CHANNELING

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Abstract

The positron source under investigation is using channeling radiation of multi-GeV electrons in a tungsten crystal. The radiated photons are impinging on the amorphous targets creating e^+e^- pairs. A dipole magnet between the crystal-radiator and the amorphous-converter allows the charged particles to be swept off and only emitted photons to generate e^+e^- pairs in the converter. Granular targets of different thicknesses, made of small tungsten spheres, have been recently investigated as a target-converter. This paper is describing the experimental studies conducted at the KEKB linac with such device. After the description of the experimental set-up and beam parameters, the measurement methods and preliminary results are presented.

INTRODUCTION

Positron sources are critical components of the future linear or circular collider projects. The intensity required for the positron source at such facilities is a few orders of magnitude higher than that delivered by the existing ones based on a conventional scheme using an intense electron beam on a thick target. Therefore, it would be difficult to consider it, mainly due to the high heat load in the target and the Peak Energy Deposition Density (PEDD). Recent investigations led to the concept of a hybrid scheme based on the intense photon production by the GeV electrons channeled along a crystal axis [1–3]. This allows the reduction of the deposited power and PEDD in the target-converter. A new option of the hybrid positron source implying the replacement of the compact converter by a granular one, made of tungsten spheres is under study. Granular target can provide better heat dissipation and a better resistance to the shock waves. Several experiments have been performed in the past to study the positron production based on the hybrid scheme [2, 4]. The current experiment is a continuation of the long term collaboration with KEK. In this paper we report on the experimental activity performed at the KEK-B linac to study positron production and target heat load with the hybrid scheme using granular converter. The experimental set-up as well as the preliminary results are presented and discussed.

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EXPERIMENTAL SETUP

KEKB Injector Linac as e- Drive Beam

The experiment has been performed at the beam switchyard of the KEKB injector linac. The linac was operated at 7 GeV in a single bunch mode with a repetition rate of 1–50 Hz. The bunch intensity was measured to be 1–2 nC and the normalised beam emittance was measured with a wire scanner to be about 149.9 (H)/63.1 (V) π mm mrad. A detailed layout of the experiment can be found elsewhere [4]. During the experiment, the transverse beam profile at the targets has been monitored by the thin fluorescent screens attached to the target surface. The pulse-by-pulse bunch intensity was measured by the Wall Current Monitor installed just before the 30 μm vacuum window through which the electron beam is sent to the crystal or amorphous targets (see Fig. 1). To ensure the axial channeling conditions, the angular spread of the incident electron beam has to be smaller than the critical angle, which is about 0.5 mrad for the tungsten crystal oriented on its $\langle 111 \rangle$ axis and 7 GeV electron beam energy. For the experiment, the angular spread of the electron beam was estimated to be well bellow 0.1 mrad taking into account the multiple scattering in the vacuum window.

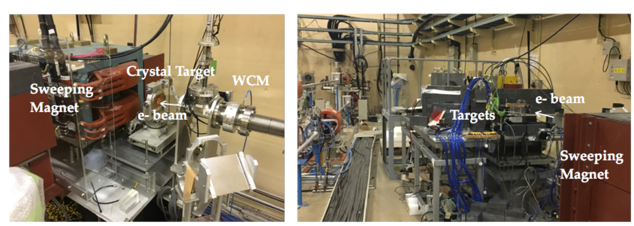

Figure 1: Experimental layout. Left: photo shows a crystal target mounted on a goniometer and a sweeping magnet. Right: photo shows the target-converters mounted on a translation stage and a detection system.

Hybrid and Conventional Schemes

Mainly two positron production schemes have been investigated during this experimental campaign. The hybrid scheme implies the use of the crystal target as a radiator and amorphous target (bulk or granular) as a converter. A 1 mm thick tungsten crystal was installed on the 2-axes goniometer allowing the electron beam to be aligned with the ⟨111⟩ axis of the tungsten crystal. The photons produced in the crystal were sent to the target-converter. Between the two targets a dipole magnet (so-called sweeping magnet) was installed to sweep out the charged particles exiting the crystal target. Three granular targets having 4-, 6-, and 8-layers together with the 8 mm thick bulk target, served as a reference, were tested. The granular targets are made of spheres of 1.1 mm radius arranged in staggered layers with alternation of the layers having even and odd number of spheres. This ensures more compact packaging with a central sphere at the converter exit. All targets have been installed on the translation stage (see Fig. 2) in order to place a given target remotely on the beam during the experiment. The conventional positron

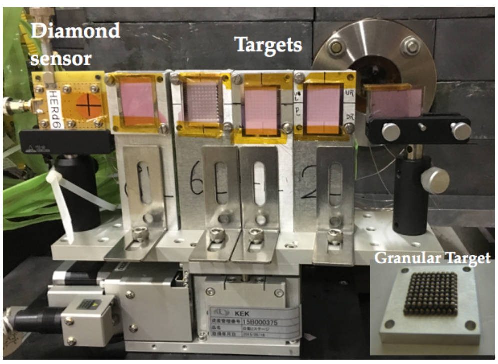

Figure 2: Translation stage with the bulk/granular targets and a diamond sensor.

production scheme, where the electron beam directly hits the granular/bulk targets has been employed for a comparison with the hybrid scheme performance and for positron yield calibration. The temperature rise measurements of the target-converter were conducted in both schemes for the sake of comparison.

Diamond Detector: γ-rays Measurement

This time, it was decided to measure the enhancement factor of the photons produced by the electron beam going through the axially oriented crystal compared to the situation when the crystal axis is not aligned with the incident electron beam.

Single crystal CVD diamond detector of 500 μm thickness from Cividec [5] was mounted inline with five targets on the same translation stage (see Fig. 2). Keithley 2410 power meter was used to apply 400 V to one of the electrodes of the Diamond Sensor (DS) in order to create external electric field in the DS for charge collection. Other electrode (collecting) was connected to the Lecroy oscilloscope by 50 Ohm coaxial cable of about 40 m long through the 30 dB attenuator.

We used GEANT4 to simulate the interaction of high energy photons (up to 7 GeV) with the 500 μm thick DS. Our simulation shows that the interaction efficiency of γ-rays with the DS is about 0.3% with the most probable energy deposition of 0.1 MeV. Thus, DS can be used to measure the photon flux of about 10^{11} expected in our experiment. Moreover, measurement of the direct photon flux made it possible to perform the angular 2D scan of the crystal in a more efficient way.

Positron Detection System

The positrons produced in the target-converter have been analyzed by a spectrometer made of 60° bending magnet (so-called analyzing magnet). The accepted positrons were detected by 5 mm thick lucite Cherenkov detector. The signal measured by the detector is proportional to the number of incident positrons. Thus, the positron yield measurements were performed at four values of positron momenta: 5, 10, 15 and 20 MeV imposed by the analyzing magnet. A set of collimators was installed along the detection chain to improve momentum resolution and reduce the background. The positron detection system was kept under the vacuum $\sim 10^{-2}$ Torr to reduce the multiple scattering of low momentum positrons.

The detection system was simulated by using the GEANT4 toolkit [6]. The detector acceptances at different positron momenta (5–20 MeV) have been calculated being very close to previous obtained values by using the simulation code GEANT3 [7]. In such a way, a typical momentum acceptance is 2.6% (FWHM) at the positron momentum 20 MeV/c. Whole detection system is shielded by the thick lead blocks in order to reduce/suppress the effect of the beam associated background on the positron measurements.

Temperature Measurement

In order to measure the temperature of the target-converter, the standard K-type thermocouples were attached to the backside (with respect to the beam direction) of the targets (see Fig. 3). In total, nine thermocouples having dimensions smaller than 1 mm^2 were glued by an epoxy thermal conductive paste to the tungsten spheres (granular target) or the back surface (8 mm thick bulk target) keeping the same configuration/distance between the thermocouples. The output from the thermocouples has been calibrated and sent by a 40 m long extension cables to the experimental room. Dy-

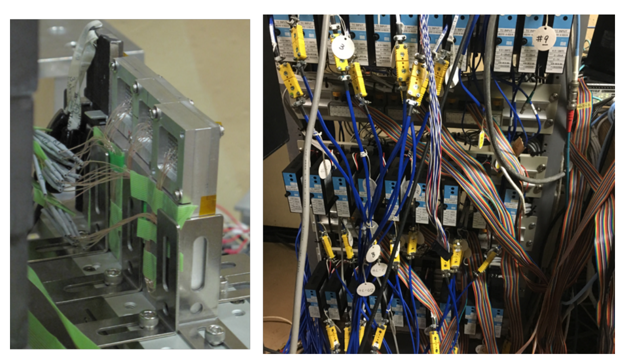

Figure 3: Measurement of the target temperature. Left: photo shows the targets with the thermocouples. Right: photo shows the thermocouple signal readout system.

namic range of the thermocouple signal transformers used this time was limited to 0 –100°C which made it possible

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to measure the bunch-by-bunch temperature rise more precisely. The temperature data were acquired continuously by a data logger with a sampling rate of 1 kHz.

PRELIMINARY RESULTS

Rocking Curve: Enhancement Factor

To align the ⟨111⟩ crystal axis with respect to the electron beam, a 2D angular scan has been performed. A dedicated program was developed to automate the scanning procedure which reduced the scanning time. Fig. 4 shows a typical 1D angular scan, so-called rocking curve, where an enhancement of photon production in the crystal at the specific angle can be observed. This photon enhancement in channeling

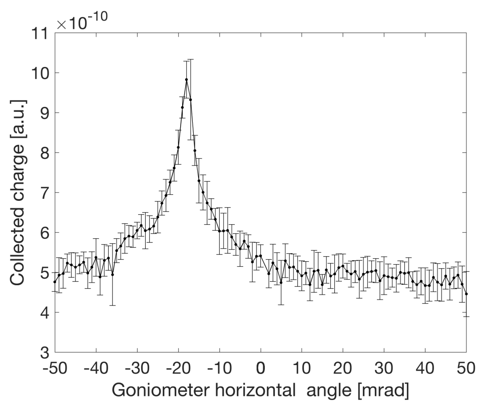

Figure 4: Rocking curve measured by the diamond sensor. Collected charge by the diamond sensor is plotted as a function of the goniometer rotational angle.

conditions with respect to random orientation of the crystal (50 mrad apart from the crystal axis) is called an enhancement factor. The experimental results indicate that the 1 mm thick crystal provides an increase by a factor of two in the photon production. However, the simulations and further analysis of the background which can strongly affect the final results are under way to fully describe the experimental data. The analogous dependencies have been also measured by using the positron production as an observable.

Positron Yield

Once the crystal axis was aligned with the electron beam, positron yield has been measured systematically for various conditions in hybrid and conventional schemes. To describe the experiment a full GEANT4 simulation had been performed. A FOT code [8] is used to simulate the interaction of electrons with the aligned crystal. Fig. 5 illustrates the positron yield measured at four different positron momenta in the conventional scheme for both reference 8 mm thick and 6-layers granular target. In this figure we also plot the simulated positron yields for the same conditions. Given that the positron detector used in the experiment does not provide us with the absolute calibration, positron production efficiency will be calibrated based on the GEANT4 simulations in the conventional positron production scheme.

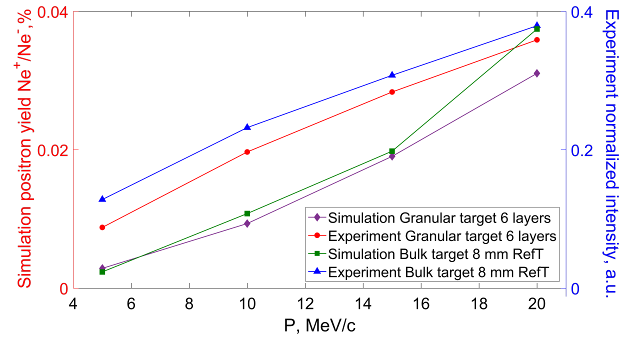

Figure 5: Momentum dependence of the positron yield in the conventional positron production scheme for the 8 mm thick bulk and 6-layers granular targets.

Measurement of the Temperature Rise

Along with the positron yield measurements, the temperature measurements of the target-converter have been performed in order to estimate the heat load in the bulk and granular converters. In Fig. 6 we show the temperature variations on the bunch-by-bunch basis. The determination of the

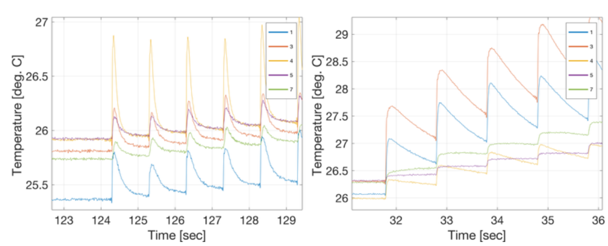

Figure 6: Bunch-by-bunch temperature rise measured in the bulk 8 mm thick (Left) and 6-layers granular (Right) targets. Different colours correspond to the different thermocouples.

temperature rise with the tungsten spheres and, in particular, with the central sphere on the exit face of the converter will allow the computation of the deposited energy and PEDD. The experimental data will be compared to the simulations.

SUMMARY

We have successfully tested the hybrid positron source with the bulk and granular target-converters. The enhancement in photon and, thus, the positron production by using the axially oriented crystal has been clearly observed. The experimental results show different behaviour of the granular and bulk targets in what concerns the adiabatic heating and heat dissipation. The positron production as well as the target heat load have been measured for the hybrid and conventional schemes for the sake of comparison. The data analysis and simulations of the various conditions of the experiment are ongoing. The final performance of the hybrid positron source using granular converter will be described elsewhere [9]. The experimental activities at KEK are very important for the hybrid positron source studies in general and for the high intensity positron source of the future linear/circular colliders in particular.

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