Experimental determination of the positron source emittance for a crystal target

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Abstract

Investigations on positron sources, using channeling of ultrarelativistic electrons in axially oriented crystals, are carried out in Europe and Japan. Recently, an experiment (WA 103) has been worked out in CERN, using 6 and 10 GeV incident electrons impinging on tungsten crystals along the $< 111 >$ axis. Crystals 4 and 8 mm thick and compound target made of a 4 mm crystal followed by a 4 mm amorphous disk were used. The positron trajectories, in the horizontal plane, were reconstructed in a drift chamber partially immersed in a magnetic field. The positron momentum and its emission angle were, thus, determined. The momentum spectrum as well as angular distribution were obtained for each target and comparisons were made for crystal and amorphous targets of the same thickness. The experimental data has also been used to study the transverse phase space of the crystal sources. Comparison were operated with thick amorphous targets and the accepted yields, in usual matching conditions for a linear collider, have been derived for both kind of targets.

1 INTRODUCTION

In order to achieve high luminosities at the interaction point of a linear collider, very powerful positron sources with high intensity and low emittance are needed. Conventional positron sources, using a high intensity electron beam impinging on a thick amorphous target with high Z, even if optimized as was done for the SLC, present a high rate of energy deposition in the target which induces serious heating problems; mechanical stresses and target failures may, hence, occur. The target thickness can be significantly reduced if instead of generating bremsstrahlung radiation by interaction of the incident electron with individual atoms, we allow the incident electron to interact coherently with a set of ordered atoms as it happens when the electron trajectory is aligned with an axial or planar direction of a crystal. In that case, channeling radiation and coherent bremmstrahlung produce a large number of photons and, correspondingly, a large number of e^+e^- pairs [1, 2, 3]. Having, for the same yield, a much thinner target leads to less energy deposition in crystal sources. Theoretical investigations as intensive simulations predicted enhancement of photon and positron yields when the beam direction is aligned with a crystal axis. Tungsten crystals have been chosen for the high field available on the atomic strings. Proofs of principle, followed by specific tests were worked out by european and japanese teams [4, 5, 6, 7]. The encouraging results led to a dedicated experiment carried out recently at CERN [5]. The 6–10 GeV tertiary electron beam of the SPS was sent on crystal targets and the emitted positrons were measured. We report, here, some results of this experiment, recently analysed.

2 THE EXPERIMENTAL SET-UP

The experiment used tertiary electron beams of the SPS (with almost 99% of electrons) having energies between 5 and 40 GeV. The electrons after crossing profile monitors (delay chambers) and counters impinge on the targets. Photons and e^+e^- pairs are produced in these targets. These particles come mainly in the forward direction and cross the magnetic spectrometer consisting of the drift chamber and positron counters inserted between the poles of a magnet. The most energetic particles leaving the magnet in the forward direction are swept by a second magnet whereas the photons reach the photon detector made of a preshower and a calorimeter. The channeling condition requires an incident electron angle, with respect to the atomic rows, smaller than the Lindhard critical angle,

$$\Psi = \sqrt{2U/E},$$

where U represents the potential well depth of an atomic row and E the incident energy. For 10 GeV and $< 111 >$ axis of the tungsten crystal, the critical angle is of 0.45 mrad. In order to fulfil it, we installed a trigger system made of scintillation counters with an acceptance angle of 0.75 mrad, slightly larger than the critical angle, taking into account crystal effects at angles larger than Ψ. The targets, installed on a 0.001 degree precision goniometer consisted in:

- 4 and 8 mm thick tungsten crystals oriented along their $< 111 >$ axis,
- a compound target made of 4 mm crystal followed by 4 mm thick amorphous disk,
- a 20 mm amorphous disk for checking the reconstruction efficiency with a similar number of positrons as for the 8 mm crystal

The mosaic spreads of the crystals are less than 0.5 mrad. The main part of the detection system consists in a drift chamber (DC) made of hexagonal cells and filled with a gas mixture $He(90\%) + CH_4(10\%)$; the first part of the DC is outside of the magnetic field and allows the measurement of the exit angle of the positrons, while the second part, submitted to the magnetic field, allows the measurement of the positron momentum. Two values of the magnetic field are chosen (1 and 4 kGauss) to cover the energy domain. The spatial resolution is of 500 micrometers.The maximum horizontal angle being accepted is about 30 degrees.The vertical acceptance is of ± 1.5 degree. Counters placed on two sides of the chamber allow precise definition of the vertical acceptance and rapid indication of the positron yield. The photon detector is made of:

- a preshower giving the photon multiplicity,
- a "spaghetti" calorimeter providing the amount of radiated energy [8].

The experimental set-up is represented on figure 1.

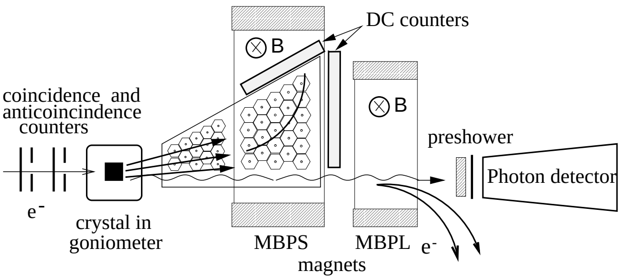

Figure 1: Experimental set-up.

2.1 The experimental conditions

The incident electron beam, used mainly at 6 and 10 GeV, had an intensity of some thousands of e^- in a burst of 3.2/5.2 seconds duration with a repetition rate of 14.4/16.8 seconds. Beam dimensions were controlled just before the target with delay chambers; typical values were 3–4 mm FWHM, for H and V widths.

3 THE RESULTS

The reconstruction of the positron trajectories in the drift chamber, allowing their identification in terms of emission angle and momentum, provided the results on energy spectrum and angular distribution.

The measured occupancy (number of hitted wires per event) was almost the same for the 8 mm thick crystal and for the 20 mm thick amorphous targets. These targets are, hence, comparable. The measured energy spectra and angular distribution were in good agreement with the simulations for the 20 mm amorphous target, which indicates that the reconstruction process was operating correctly. The resolution was between 2 and 5 % and of 0.2 degree for the energy and angle, respectively. The global efficiency (geometrical acceptance and track reconstruction) was between 5 and 10 %.

3.1 Measurements on the 8 mm thick target

The energy spectrum and angular distribution obtained with a 10 GeV incident beam are represented on figure 2 for the crystal and amorphous target, both 8 mm thick. The associated simulations are also represented on the same figure. For energy spectra and angular distributions, the energy bin width was 5 MeV and the number of e^+ were calculated up to 30° and 100 MeV, respectivly. We can

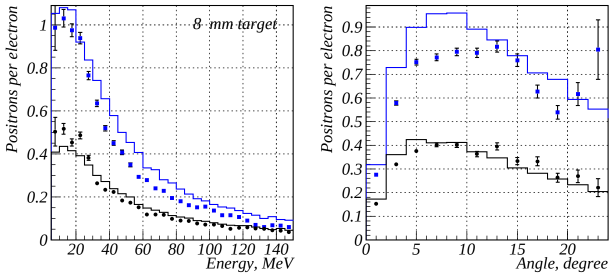

Figure 2: The energy and angular spectra corrected by efficiency for the 8 mm target. $E^- = 10$ GeV. Boxes — crystal, points — amourphous target. Histograms — corresponding simulation.

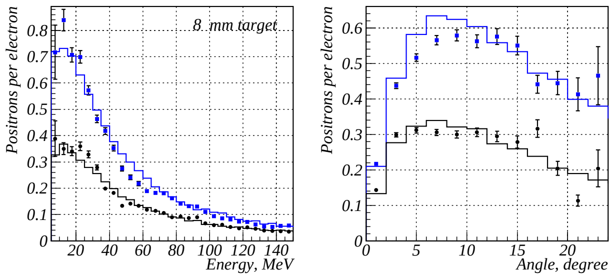

Figure 3: The energy and angular spectra corrected by efficiency for the 8 mm target. $E^- = 6$ GeV.Boxes — crystal, points — amourphous target. Histograms — corresponding simulation.

observe that:

- the simulations agree quite well with the measurements,
- the crystal target gives a number of positrons larger, by more than a factor 2, with respect to the amorphous target.

The same kind of observations can be made for a 6 GeV incident beam (figure 3) where the enhancement obtained with the crystal target , with respect to the amorphous one, is close to 2. The measured distributions (energy, angle) for the compound target and the 8 mm crystal are almost identical, allowing the substitution of one for another.

3.2 Measurement on the 4 mm thick target

The results (energy spectrum and angular distribution) for a 10 GeV incident beam have been represented on figure 4. We may observe a strong enhancement (more than 3.5) when using a crystal target.

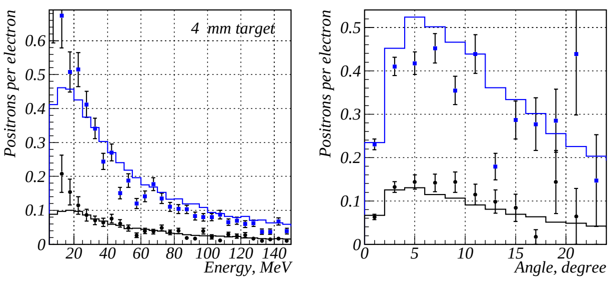

Figure 4: The energy and angular spectra corrected by efficiency. 4 mm target. $E^- = 10$ GeV. Boxes — crystal, points — amourphous target. Histograms — corresponding simulation.

3.3 Measurement on 20 mm amorphous target

We represent on figure 5 the energy spectrum and angular distribution of positrons generated by a 10 GeV e- beam in an amorphous tungsten target 20 mm thick.

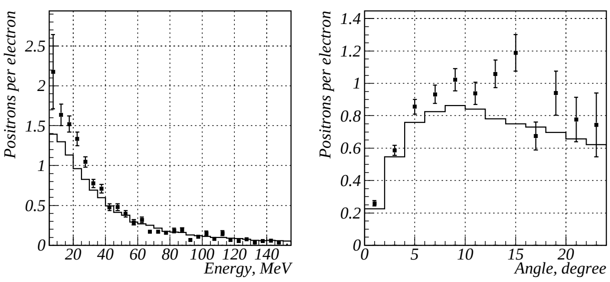

Figure 5: The energy and angular spectra corrected by efficiency for the 20 mm amorphous target. $E^- = 10$ GeV. Points — experimental data, histogram — simulation.

3.4 Comparison of the 8 mm thick crystal target with an amorphous target 20 mm thick

Yield: the number of positrons contained in the following domain:

$$5 < E^+ < 30 MeV$$

$$p_T < 7.5 MeV/c$$

$$\theta(\text{emission angle}) < 30\ degrees,$$

has been determined for both targets. For the 8 mm crystal, the experimental value is of 4 e^+/e^-, whereas the simulation predicted 4.1. The 20 mm amorphous target gives a somewhat higher value in the experiment (6 e^+/e^-) and for the simulation (about 5 e^+/e^-). The acceptance conditions considered here are usual for Linear Collider positron sources and correspond to an adiabatic matching lens with a magnetic field tapering from 8 teslas to a tenth of this value and with an S-Band positron accelerator. Transverse momentum distributions are shown on fig. 6.

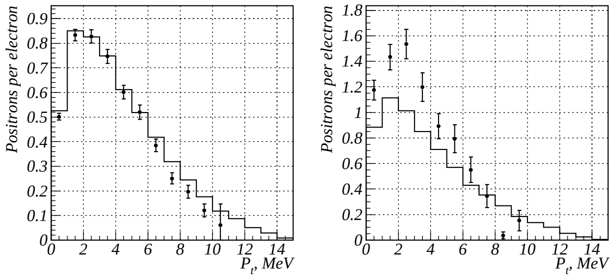

Figure 6: The transverse momentum spectra for 8 mm crystal (left) and 20 mm amorphous (right). Only positrons with energy from 5 to 30 MeV were taken into account. Points is experimental data, histogram — simulation.

4 SUMMARY AND CONCLUSIONS

This experiment provided us with the main characteristics of crystal positron sources with different thicknesses. Energy spectra and angular distributions have been compared to those of amorphous positron sources and the yields in usual acceptance conditions for a linear collider have been determined. The obtained yields make these crystal sources competitive with the conventional ones (amorphous) for such application. The peculiarity of such crystal sources appear when comparing crystal and amorphous targets of the same thickness: the enhancements on positron yield when the incident electron beam is impinging on the W crystal along the $< 111 >$ axis, is of: a factor of 3.5, at least for a 4 mm crystal, at $E^- = 10GeV$, a factor of more than 2 for a 8 mm crystal, at $E^- = 10GeV$ and slightly below 2 for $E^- = 6$ GeV. These enhancements are related to a smaller radiation length for the crystal leading to thinner targets than the amorphous one, for the same operating conditions and the same yield. Such characteristics is important, as less deposited energy is present referring to the simulations [9].

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