SOME RESULTS ON WA 103

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Abstract

This addendum is concerning the experiment WA 103, based on the use of channeling of high energy electrons in crystals, to improve the photon production and correspondingly the number of positrons resulting from the materialization of these photons. This experiment has been carried out during the summer of 2000. The first part of this addendum is related to the data gathered during the run and on their analysis as resulting from the positron track reconstruction. We present, in the second part, the programme of measurements associated to a run asked for this year.

INTRODUCTION

The objective of the experiment is to measure the enhancement in positron production when the incident electron beam is in channeling conditions - at glancing angles to the rows in a crystal. For such orientation, the number of radiated photons along the major axes of the crystal is much higher than in the amorphous target of the same thickness. Correspondingly, the number of pairs due to the photon materialization is also larger. Up to now, Tungsten crystals 4 and 8 mm thick have been used. The main physics observable are the emission angle and the momentum of the positrons. These quantities are needed to determine the phase space of such positron source for a comparison with the conventional ones in the framework of a possible use in the future e⁺e⁻ linear colliders. The interest for such sources is somewhat growing due to some peculiar features as a large number of soft photons giving correspondingly a large number of soft positrons easily captured by the known optical matching devices and a thinner thickness for the targets leading to less energy deposition. The difficulties encountered by the conventional devices, where excessive heating and mechanical stresses are met in linear collider working conditions, brings some additional interest to this alternative method. That motivated also the research effort on crystal positron sources in Japan. The aim of the CERN experiment is to reach a better understanding and a reliable description of this kind of sources, before proposing them for the use in a linear collider project. We present, in the first part, the present status of our experiment and, in the second part, our request for a beam run, this year, on the X5 transfer line of the SPS.
1 PRESENT STATUS OF WA 103

1.1 The experimental conditions

An experiment has been carried out during two weeks in July—August 2000, after a calibration run at the end of May 2000. The experiment installed on the X5A transfer line of the SPS provided data on the positrons and photons created in the tungsten targets:

- a 4 mm thick crystal,
- a 8 mm thick crystal,
- a compound target made of a 4 mm crystal followed by a 4 mm thick amorphous disk.

The electron incident energy was taken in the range 5 to 40 GeV with a particular effort at 10 GeV, for which half of the beam time was devoted. The positrons were measured in a magnetic spectrometer made of a Drift Chamber partially immersed in a magnetic field; two values of the magnetic field were used: 1 and 4 kGauss. These field values allowed to investigate the energy domain up to 80—100 MeV. Data has been taken on:

- the Drift Chamber (DC),
- the positron counters installed on two lateral walls of the DC, with a specific domain of acceptance for each of them, with respect to the positron energy,
- the preshower and the calorimeter for the photons.

1.2 The preliminary results

The preliminary results based on the measurements provided by the counters and by a rapid analysis of the data gathered on the Drift Chamber have been summarized in an “Appendix to Addendum CERN/SPSC 2000-044” (SPSC/P309 ADD.2). The results from the Drift Chamber have been obtained through a simplified track reconstruction procedure, which showed enhancements in positron as in photon production, on the crystal axis.

1.3 The results obtained with reconstructed positron tracks

A reconstruction process, taking into account the actual magnetic field distribution in the Drift Chamber, has been operated.

1.3.1 The reconstruction process.

The magnetic field varies from 0 to the maximum value $B_0$ (1 or 4 kG) inside the volume of the Drift Chamber (DC). In case of the real map of the magnetic field a sequence of a straight line and an arc of circle does not describe accurately the positron track. The reconstruction procedure has been modified to take into account this fact. A template method for the track reconstruction was chosen.
Figure 1: Set of positron tracks with energy 20 MeV and angle 10° simulated by GEANT. Magnetic field is 1 kG.

Figure 2: Sketch of the DC with the positron counters and the cells near to the lateral walls.

Figure 1 shows a set of positron tracks with given energy $E_1^+ = 20$ MeV and angle $\theta_1^+ = 10^\circ$, simulated in GEANT. One can see, that the influence of the different processes, especially multiple scattering, on the low energy positron track is quite strong. Nevertheless, the ideal geometrical track, which can be obtained when all the interaction processes in the medium are switched off, passes through the DC as an average track from the set. A set of ideal reference tracks corresponding to positrons and electrons with energies $E_1^\pm$ from 5 MeV to 150 MeV (step 1 MeV) and angles $\theta_1^\pm$ from $-5^\circ$ to $55^\circ$ (step $0.5^\circ$) originated from the target center were calculated. The trajectories in the DC were parametrised by 9-degree polynomial $y(x)$ and the coefficients were stored in the database.

For each event the reconstruction program makes the maps of the functions $L_0$ and $L_2$ representing the distance between the simulated reference tracks of known initial angle and energy and the hit wire of the DC. It calculates the values $L_0$ and $L_2$ for each track of positron or electron with energy $E_i^\pm$ and angle $\theta_i^\pm$ using the following formulae:

$$L_0(E_i^\pm, \theta_i^\pm) = \frac{1}{N_1 + N_2} \sum_{n}^{N_1+N_2} \exp\left(-\frac{|d_n-r_n|}{\lambda}\right), \quad (1)$$

$$L_2(E_i^\pm, \theta_i^\pm) = \frac{1}{N_2} \sum_{n}^{N_2} \exp\left(-\frac{|d_n-r_n|}{\lambda}\right), \quad (2)$$

where indexes 1 and 2 mean DC1 (part of the DC outside of the magnetic pole) or DC2 (part of the DC inside of the magnetic pole), $N$ — number of hit wires, $\lambda = 1$ cm — coefficient characterizing the dimension of the DC cells, $d_n$[cm] — distance between the track $(E_i^+, \theta_i^+)$ and the $n$-th wire, $r_n$[cm] — the radius calculated from TDC value of the $n$-th wire. The values $L_0$ are used for the tracks with $\theta_i^\pm > \theta_{lim} = 5^\circ$ and $L_2$ — for others. For tracks with $\theta_i^\pm < \theta_{lim}$, the information from the DC1 is difficult to use due to its acceptance. Peaks on the maps $L_0/2(E_i^\pm, \theta_i^\pm)$ (Fig. 3) correspond to the real tracks and therefore
Figure 3: Distribution $L_{0,2}(E_{\pm}, \theta_{\pm})$ for two simulated positron tracks: (57 MeV, 8°), (71 MeV, 15°).

the local maxima are taken for the further analysis as candidates for the good tracks, which should have also hit the wires near to the lateral walls of the DC (Fig. 2). The track should have also a minimum number of the hit wires and the distances between them should be less than a chosen value. The minimum number of the hit wires on the track and the maximum distance between them are determined as a compromise between the reconstruction efficiency and the number of “false” tracks. The wires which belong to the good track are then excluded from the further analysis. The search of the good tracks starts from the largest local maximum. A map of the reconstructed positron tracks is shown in figure 4. Now we present the positron spectra at the energy limits [25 MeV, 100 MeV] for 4 kGs magnetic field and [5 MeV, 50 MeV] for 1 kGs magnetic field and at the angular limits from 0 to 15°, where the efficiency is more simply defined. The angular limits can be extended after some study. Figure 5 shows an example of the track reconstruction.

Full simulation of the events under study was prepared using GEANT subroutines. It gave the opportunity to study the influence of scattering and energy losses on the reconstruction efficiency and the number of “false” tracks.

To determine the reconstruction efficiency the positrons irradiated from the
target with vertical (perpendicular to the DC plane) angle less than 25 mrad are selected. In case of a magnetic field of 4 kGs their tracks can be reconstructed with an efficiency of about 90% (for example, the efficiency for 4 mm axially oriented crystal is 90%, for 8 mm — 87%). In the case of a magnetic field of 1 kGs this efficiency decreases to ~ 80% (33% for 4 mm, 76% for 8 mm). The reconstructed track is called “false” if there is no simulated positron from the target with similar energy and horizontal angle, which passed through the DC regardless of its vertical angle. The “false” track contribution is changing from 14% for 4 kGs magnetic field up to 36% for 1 kGs magnetic field. Mainly the “false” tracks originate from the secondary positrons and the positrons, which lost energy.

1.3.2 The results for a 10 GeV incident electron beam and a 4 mm target

The experimental and simulated data were analysed using the reconstruction procedure described above. The presented spectra are normalized on the number of the incident electrons with a divergence less than 0.75 mrad. To exclude the false triggers from the experimental data a requirement on the signal coming from the calorimeter was added (Fig. 6). This selection can affect the track multiplicity and the systematic error due to this selection is about 5%. This results from a calculation on the simulated spectrum (Fig. 6) when changing the threshold position. Improvement is expected with additional study of the simulated calorimeter spectra. Figure 7 shows the spectra at the side positron counter.

To understand the systematic errors and make some corrections one can use the positron spectra obtained with the amorphous target (Fig. 8, 9). The agreement for the magnetic field of 1 kG is worse than for the field of 4 kGs due to a large number of “false” tracks. The angular spectra show that mainly the “false” tracks are found, when the DC2 alone is used.
Figure 6: Spectra at the calorimeter for the experimental and simulated data. The used threshold at the experimental spectrum is shown. $E_{\gamma} = 18$ GeV, $W_{\text{Rand}} = 4$ mm.

Figure 7: Spectra at the side positron counter for the experimental and simulated data. The used threshold is shown. $E_{e^{-}} = 10$ GeV, $W_{\text{Rand}} = 4$ mm, $P = 4$ kGα.

Comparison of positron spectra obtained from the experimental data and the simulation shows qualitative agreement for the crystal target (Fig. 10, 11).

The figures 12, 13 show clear enhancement in the positron yield for the crystal target in comparison with the amorphous one.
Figure 8: Positron energy and angular spectra for the experimental (points with error bars) and simulated (histogram) events. $E_{e^-} = 10$ GeV, $W_{Rem,d} = 4$ mm, $F = 1$ kGs.

Figure 9: Positron energy and angular spectra for the experimental (points with error bars) and simulated (histogram) events. $E_{e^-} = 10$ GeV, $W_{Rem,d} = 4$ mm, $F = 4$ kGs.
Figure 10: Positron energy and angular spectra for the experimental (points with error bars) and simulated (histogram) events. $E_\gamma = 10$ GeV, $W_{\text{Xtal}} = 4$ mm, $F = 1$ kGs.

Figure 11: Positron energy and angular spectra for the experimental (points with error bars) and simulated (histogram) events. $E_\gamma = 10$ GeV, $W_{\text{Xtal}} = 4$ mm, $F = 4$ kGs.
Figure 12: Experimental positron energy and angular spectra for the crystal axis (empty histogram) and the random position (filled histogram). $E_{e^-} = 10$ GeV, $W = 4$ mm, $F = 1$ kGs.

Figure 13: Experimental positron energy and angular spectra for the crystal axis (empty histogram) and the random position (filled histogram). $E_{e^-} = 10$ GeV, $W = 4$ mm, $F = 4$ kGs.
1.3.3 The results for a 10 GeV incident electron beam and a compound target (4 mm crystal followed by a 4 mm amorphous disk)

The positron spectra were obtained also for the compound target.

Figure 14: Positron energy and angular spectra for the experimental (points with error bars) and simulated (histogram) events. $E_{e^-} = 10$ GeV, $W_{Xtal} = 4 + 4$ mm, $F = 1$ kGs.

Figure 15: Positron energy and angular spectra for the experimental (points with error bars) and simulated (histogram) events. $E_{e^-} = 10$ GeV, $W_{Xtal} = 4 + 4$ mm, $F = 4$ kGs.
Figure 16: Positron energy and angular spectra for the experimental (points with error bars) and simulated (histogram) events. $E_{e^-} = 10$ GeV, $W_{Ran,d} = 4 \times 4$ mm, $F = 1$ kGs.

Figure 17: Positron energy and angular spectra for the experimental (points with error bars) and simulated (histogram) events. $E_{e^-} = 10$ GeV, $W_{Ran,d} = 4 \times 4$ mm, $F = 4$ kGs.
Figure 18: Experimental positron energy and angular spectra for the crystal axis (empty histogram) and the random position (filled histogram). $E_{e^-} = 10$ GeV, $W = 4 \pm 4$ mm, $F = 1$ kGs.

Figure 19: Experimental positron energy and angular spectra for the crystal axis (empty histogram) and the random position (filled histogram). $E_{e^-} = 10$ GeV, $W = 4 \pm 4$ mm, $F = 4$ kGs.
Comparison of the 4 + 4 mm compound target and the 8 mm crystal target shows good agreement (Fig. 20).

Figure 20: Experimental positron energy and angular spectra for the axis position of the 4 + 4 mm compound target (points with error bars) and the 8 mm crystal target (histogram). $E_{\alpha} = 10$ GeV, $\beta = 1$ kG.

It is interesting to compare the 4 mm crystal target with the 8 mm amorphous one. The theory predicts equal multiplicities of the positrons from these targets. The experiment confirms this prediction (Fig. 21, 22). The energy and angular spectra look very similar, but the 2-dimensional distributions can reveal some small differences (Fig. 23, 24).

Figure 21: Experimental positron energy and angular spectra for the axis position of the 4 mm crystal target (points with error bars) and the 8 mm amorphous target (histogram). $E_{\alpha} = 19$ GeV, $\beta = 1$ kG.
Figure 22: Experimental positron energy and angular spectra for the axis position of the 4 mm crystal target (points with error bars) and the 8 mm amorphous target (histogram). $E_p = 10$ GeV, $F = 4$ kGs.

Figure 23: Two-dimensional distribution for the positrons from the 8 mm amorphous target. $E_p = 10$ GeV, $F = 1$ kGs.
Figure 24: Two-dimensional distribution for the positrons from the 4 mm crystal target. $E_{e^-} = 10$ GeV, $B = 1$ kGs.

1.3.4 The remaining analysis for the data of the 2000 run
The spectra presented above are based on 10 – 20% of the data collected during the 2000 run. To have the good accuracy for the 2-dimensional distributions one needs to analyze the total statistics. There is also data for other energies of the incident electron beam: 5 GeV, 20 GeV and 40 GeV, but the data with 5 GeV electron beam are rather poor.

2 BEAM REQUESTS FOR 2001
2.1 The programme
The running programme should consist of:

- a rapid checking of the detection system with a thin target (4 mm) and at 10 GeV (Energy of reference)
• a test at 10 GeV, incident energy, of an amorphous tungsten target ≈ 29 mm thick, giving the same amount of positrons as the 8 mm crystal; this test will allow us to compare the respective yields at a given energy acceptance and would help in testing the influence of the multiplicity on the track reconstruction.

• a study of positron production with W crystal at a lower incident energy, 6 geV, which corresponds to one of the incident energies considered for the conventional source of a linear collider project.

• a rapid measurement at 60 GeV, with the counters; the interest is related to the expected enhancement in pair production occurring in the whole crystal target.

2.2 The requested beam

In the framework of an installation on the X5A transfer line, the required intensity would be of some 10^14 electrons per spill just before our set-up. Our trigger will select electrons with divergence less than 0.75 mrad to fulfill (roughly) the channeling conditions. The energy will be varied between 6 and 90 GeV. The main part of the measurements being made with incident electrons of 6 and 10 GeV. We shall start using the beam at 10 GeV, continue with the beam at 6 GeV and end our programme by a rapid test at 60 GeV with the counters.