First Results concerning a Crystal Radiator dedicated to Positron Production by Photons from Channeled Multi-Gev Electrons

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Abstract

Starting from extensive simulations of photon emission by channeled electrons in tungsten crystals, a test experiment has been proposed. It concerns a 2 GeV electron beam impinging on a 1 mm tungsten crystal oriented along its $< 111 >$ axis. Radiation measurements are ensured by a preshower detector followed by a lead-plexiglas calorimeter. Channeling data are compared to those obtained for random incidence. They can be associated with simulations using shower codes (GEANT) for estimating performances of positron sources based on this principle.

I INTRODUCTION

Extrapolation of conventional positron sources to the parameters required for linear colliders led to the utilization of high energy electron beams impinging on thick targets. Adequate set-up (high gradient RF sections, damping rings) is necessary to minimize longitudinal and transverse phase space extensions. Moreover thermic effects are important and represent serious limitations[1, 2]. A different way to generate positrons has been initiated for VLEPP colliders and adopted in the DESY-THD linear collider project: they use intense photon beams created in helical wigglers by very energetic electron beams, to produce electron-positron pairs in thin targets[3, 4]. Such a method, though bringing lower emittance and weaker power deposition in the target, requires a very high energy beam (100-250 GeV) and a very long wiggler (50-150 m). Instead of using a magnetic wiggler we may use an atomic wiggler of millimeter scale to generate the powerful photon beam to be sent onto the pair generation target. Channeling of multi-Gev electrons in oriented crystals could produce enough photons to reach the expected value of more than one accepted positron per incident electron which represents the current design value for linear colliders[5, 6].

Channeling radiation may be more intense than classical Bremsstrahlung in a given crystal thickness for specific incident energies. For a tungsten crystal oriented along the $< 111 >$ axis, the ratio between the intensities due to channeling and bremsstrahlung reaches unity for an energy of 0.7 GeV and a value of 2 at 2 GeV.

A test experiment using the 2 GeV Orsay linac with a 1 mm thick tungsten crystal, oriented on its $< 111 >$ axis has been proposed; the first results are presented hereafter.

II PRELIMINARY SIMULATIONS

The fundamental physical process on which the proposed set-up is grounded, i.e. photon generation produced by channeled electron in a crystal, has been simulated by a Monte-Carlo code[7]. From calculated electron trajectories in a given crystal lattice the photon emission probabilities and their complete kinematics are computed according to the quasi-classical Baier-Katkov formula for radiation in a non uniform field[8]. The multiple scattering is taken into account.

Simulation was done in the software environment usual in High Energy Physics. The detector simulation code GEANT[9] was adopted as the basis for working out the needed calculations. In this framework the code simulating channeling was introduced as event generator. The main physical processes involving electrons, positrons and photons were taken into account.

Considering an electron beam having normal distribution with rms value of 1 mm (radial) and 0.5 mrad (angular) simulations on photon production have been worked out. Photon yield as well as radiated intensities were evaluated in the energy domain 2 - 20 GeV and systematically

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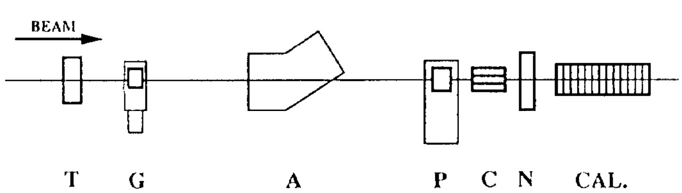
compared for a crystal and an amorphous target of the same thickness[6]. Enhancement above 3 for the photon yield and 2 for the radiated intensity were reported simulating the experimental conditions. Equivalent positron yield increase was evaluated when putting an amorphous tungsten (1 mm thick) located after the crystal [6].

III EXPERIMENTAL SET-UP

The lay-out, represented on figure 1, comprises the following elements:

- **The tungsten crystal** was grown at the Stuttgart Max-Planck Institute für Metallforschung. Mosaic spread controlled by γ - diffractrometry is no more than 0.5 mrad; this value is lower than the Lindhard critical angle, 1 mrad for 2 GeV beam on $< 111 >$ axis.
- **The goniometer** from Microcontrole, has an angular resolution of 10^{-3} degree. Rotation around two perpendicular axes and translation are controlled by a microcomputer.
- **The detection of photons** transmitted through a 2 cm diameter collimator is provided by a scintillator - for photon counting - and a lead-plexiglas calorimeter.
- **Electron beam diagnostics** for intensity and transverse profile are provided
- **Bending magnet** is used for electron beam sweeping before the detector.



T:induction monitor
G:goniometer-crystal
A:bending magnet
P:profile monitor (SEM grid)
C:collimator
N:scintillator
CAL:calorimeter

Figure 1: Lay-out of the experiment

Step by step goniometer motion as measurement data gathered on the scintillator (number of photons) and the calorimeter (radiated energy) are processed by two microcomputers. Beam pulse number and integrals of elementary goniometer steps could be chosen; angular limits of motions are also usually fixed before starting an angular scan. Multiscale spectra for photon number, radiated energy and incident electron beam intensity allow full observation of these parameters during the angular scans. Moreover, photon data normalization by incident electron beam intensity will ensure efficient monitoring.

IV EXPERIMENTAL RESULTS

A Experimental conditions

Recalling that efficient channeling needs an angular divergence for the electron beam smaller than 1 mrad, particular attention was given to this problem. Two collimators with $4 \times 4mm^2$ aperture and distant 60 meters apart allowed maximum divergence better than 0.1 mrad. Electron beam dimensions were controlled through a multiwire secondary emission profile monitor[10]. Typical FWHM values were about 1.5 mm; crystal lateral dimensions being 6 mm. Additional emittance monitoring using Optical Transition Radiation at the crystal location is installed.

B Results

Angular scans for both rotation axes (vertical Z and horizontal Y) are registered. Crossing of the electron beam along the chosen $< 111 >$ axis in the crystal requires that the beam direction be perpendicular to the entrance face (111). This condition is met for particular values of the rotation angles around the axes. At rather large angular distance ($\sim$ 1 degree) from these values, the crystal is seen as a disordered structure (amorphous) by the beam.

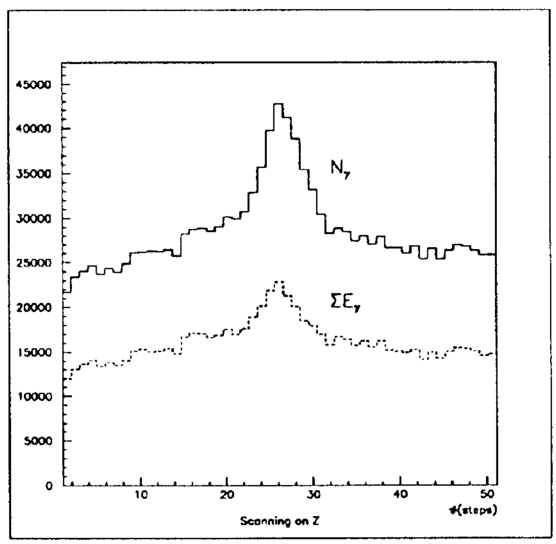


Figure 2: Angular scan around Z axis for scintillator (N_γ) and calorimeter (ΣE_γ)

Scanning around the vertical axis, for this particular value of the rotation angle around the horizontal axis, is shown on figure 2 which gives the relative number N_γ of photons detected by the scintillator. On this figure, angular steps represent 0.05 degree. Enhancement by a factor $2 \div 2.5$ may be observed when comparing the peak value (channeling conditions) and the quasi constant value (amorphous). Corresponding enhancement ($\sim$ 1.8) for radiated energy ΣE_γ is also observed for the same angular parameters (figure 2). From these results, we can obtain the average photon energy,

$$< E_\gamma >= \frac{\Sigma E_\gamma}{N_\gamma},$$

the orientation dependence of which is presented on figure 3. One observes that this average energy exhibits a minimum in alignment conditions.

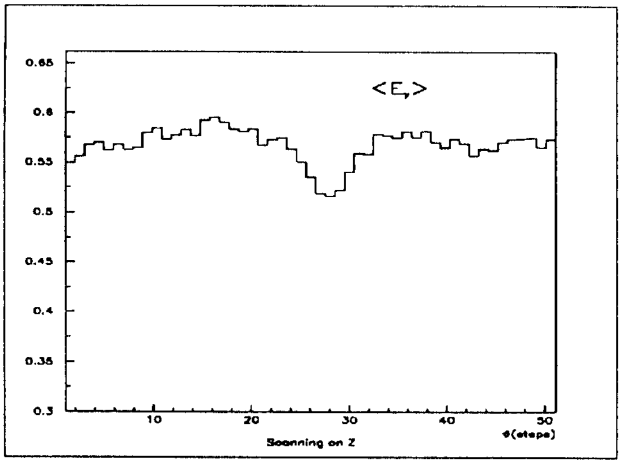


Figure 3: Angular scan of the average energy of photons

A convenient representation may also be observed on figure 4. Scanning on both vertical and horizontal axis shows the maximum for the relative number of photons.

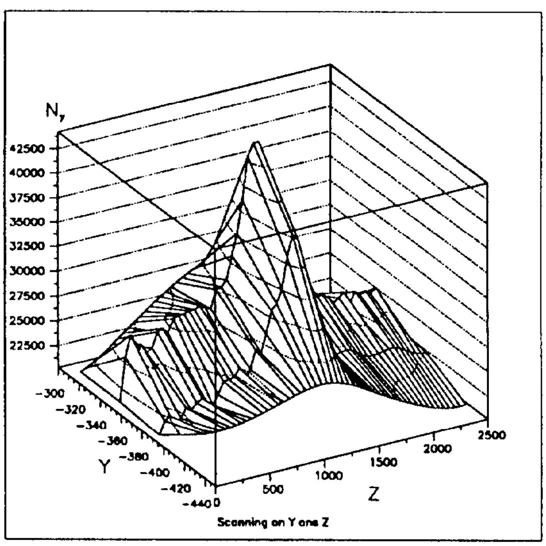


Figure 4: Angular scans around axes Z and Y of the photon yield

V COMMENTS ON THE RESULTS

Maxima in relative photon number and radiated energy as well as minimum of average photon energy occur for the same crystal orientation corresponding to channeling.

FWHM value of the angular scans corresponds to 6 mrad when collimating the photon beam before the detector with ± 1 mrad. Photon enhancement persists beyond the nominal Lindhard angle for 2 GeV (1 mrad). This is connected mainly with the contribution to the radiation process of above-barrier particles, i.e. slightly beyond channeling conditions. This has been previously observed in other experiments [11].

Enhancement in photon production is slightly below computed estimates.

These first results constitute quite encouraging observations concerning the photon radiation. They could be improved in the future particularly by background subtraction.

Nevertheless, the enhancement of the photon yield allows equivalent improvement in positron production if one refers to shower simulations.

A rough estimate of the cumulated number of incident particles on the crystal shows a total fluence of $\sim 10^{15} electrons/mm^2$. No radiation damage is observed.

Further measurements are foreseen.

VI ACKNOWLEDGMENTS

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