The CUP experiment is a first important step of a more ambitious project that investigates the feasibility to create new powerful sources of high-frequency monochromatic electromagnetic radiation: crystal undulator and γ-laser based on channeling of positrons in crystals. In this report the main goal of the CUP experiment and the results of theoretical studies on positron/electron both channeling and channeling radiation (CR) in mono and complex crystals performed in 2009 will be presented.

1 The CUP Experiment

The final objective of the CUP experiment (Crystal Undulator for Positrons) is to study the features of radiation emitted by positron channeling in a crystal. For our investigation the positron beam of the DAΦNE Beam Test Facility, the transfer line of which is presented by Fig. 1, will be used.

As known, the BTF facility provides electrons and positrons with energy ranging from 20 to 800 MeV (750 MeV for positrons). Working around the nominal DAΦNE energy of about 500 MeV, we expect to identify in a silicon monocrystal the radiation at (110) channeling of positrons having a peak at a photon energy of 1 MeV. The DAΦNE BTF is the unique European Facility that at present time is able to deliver positron beams in the energy range of interest for the CUP experiment. In fact, according to well accepted CR theories a strong photon peak with energy

![Figure 1: Transfer line of the DAΦNE Beam Test Facility.](image)
from 20 KeV up to 1.5 MeV should appear for the (100) plane of a single crystal at a positron beam energy of about 600 MeV. At BTF this peak could be detected and its intensity should be investigated as a function of several parameters (crystal thickness, angle of incidence of impinging beam, etc). Unfortunately, the high background around the crystal in the experimental hall of the DAΦNE BTF has represented a strong limit to detectability of the signals we are looking for. Anyway important upgrade on the shielding structure along the BTF transfer line (part of which had been implemented soon after our measurement tests) and the use of suitable magnets to redirect the positrons at the transfer line exit could solve most of the problems we have met. These technical solutions are discussed in the following.

2 The DAΦNE BTF Facility

The DAΦNE Beam Test Facility is an electron/positron transfer line, by which the beam accelerated from the Linac, is transported to an experimental hall where the beam tests as well as the experiments can be performed. The facility can provide e-/e+ beam in a wide range of intensity: from single particle per bunch up to $10^{10}$ particles per pulse. The BTF is operating since 2002: during these years, tens of high energy physics experiments from all over Europe have been hosted. The main applications of the facility are: high energy detector calibration, low energy calorimetry, low energy electromagnetic interaction studies, detector efficiency and aging measurements, tests of beam diagnostic devices.

3 Experimental Setup

The aim of the first measurements at the DAΦNE BTF was to identify and investigate the intense radiation at (110) channeling of 500 MeV positrons in a plane silicon single crystal, for which a peak at photon energy of 1 MeV is expected.

In Fig. 2 the experimental-setup used for the BTF measurements campaign has been shown. The beam spot diameter at the target position was approximately 10 mm with a maximum angular divergence of 1 mrad according to the Linac parameters.

![Figure 2: The end part of the DAΦNE BTF and the experimental setup for CUP.](image)
As a conclusion, the most important thing we learnt from this measurement campaign was that it is mandatory to reduce the background level by at least one order of magnitude if we want to detect positron planar channeling. The latter requires upgrading of the BTF transfer line by multiple shielding. In addition, a possible solution could consist in installing a magnetic chicane in the straight line after the last 45° bending magnet as shown in Fig. 3.

![Figure 3: Proposed scheme of chicane solution for separation of positron beam and CR.](image)

It should deflect the beam after the target into a dump. The detection device for recording the CR would be mounted after the last magnet in a straight line from the target chamber (as reference take in mind that we follow the particle motion). This setup offers several advantages:

- it is comparatively inexpensive;
- full advantage can be taken of the existing and optimized beamline to produce an adequate beam spot in the target chamber;
- with the slit systems the emittance can be reduced, the momentum spread of the linac positron beam be handled and, in turn, hopefully a high quality positron beam be generated with the required beam divergence of 0.2 mrad at a spot size of less than 10 mm diameter;
- the intensity can be adapted to make counter experiments feasible. Because the detector has in this geometry not anymore a direct line of sight into the region of the background producing slit systems, the background should be strongly reduced. Furthermore, it is also of great importance that the detectors could be shielded sufficiently well from the radiation produced in the beam dump.

The results of the first test we have done at BTF proved that we have high background, due to which it is difficult to resolve positron channeling and CR peaks. In 2009 we continued with upgrading our experimental layout and exploiting the advantages of the multiple shielding along the transfer line that is going to reduce of at least an order of magnitude the background level in the experimental hall. Multiple advantages can also be derived by a magnetic chicane that is going to be installed at the end of the BTF transfer line.
4 Theoretical Studies on Moderate Energy Electron/Positron Channeling

When electrons or positrons are planar channeled in a crystal, the spectrum of bound energy states forms and one can observe so-called CR. The intensity of CR depends on populations of bound energy levels. These populations change during projectiles motion through a crystal that, in turn, influences the CR intensity. During 2009 we have developed a theoretical model and computer codes to investigate the bound energy spectra of planar-channeled electrons and positrons and to obtain the initial populations of bound states. Solving the kinetic equations and using some approximations we explore the dynamics of bound state populations. The simple approximations used allow analytical solutions of kinetic equations to be obtained. Presented models have been applied to describe planar channeling of 80 MeV electrons and positrons along (220) planes in Si crystal.

Spectral distributions of CR by 20-800 MeV electrons in different planes of a thin 4H polytype silicon carbide crystal were obtained. We demonstrated that channeling in 4H SiC with hexagonal structure has some new features not available in other structures. Using Doyle-Turner approximation to the atomic scattering factor and taking into account thermal vibrations of atoms, the continuum potentials for different planes of 4H polytype SiC single crystal were calculated. In the frame of quantum mechanics, the theory of CR has been applied to calculate the transverse electron states in the continuum potential of the planes and to study transition energies, linewidths, depth dependence for population of quantum states and spectral radiation distributions. At electron energies higher than 100 MeV the spectral distributions of radiation are calculated by classical calculations and successfully compared with quantum mechanics solutions. Specific properties of planar CR in 4H polytype SiC were additionally revealed.

Fig. 4 shows the continuum potential along with eigenvalues and Bloch bands for 200 MeV electrons channeled along the (112\(\bar{0}\)) plane of SiC. At this energy 10 states are bound and it seems that channeling has classical character. In order to calculate the spectral angular distribution of CR for electrons of energies 200 MeV we have calculated the trajectories, velocities and acceleration of electrons obtained by numerical solution of the equation of motion in the (112\(\bar{0}\)) potential of SiC calculated within Doyle-Turner approximation.

![Figure 4: The channeling quantum states for 200 MeV electrons in SiC (112\(\bar{0}\)).](image)

In practice, a beam of electrons hints a crystal surface forming different initial conditions for
various electrons. Therefore, one has to find the spectral distribution of radiation for all points of incidence (possible trajectories). The total observed spectra obtains by averaging over partial spectral distributions. Fig. 5 shows the averaged spectral angular distribution of CR emitted in the forward direction by 200 MeV electrons in a 5 µm thick SiC crystal. In this intermediate energy region, however, for some specific cases CR is described with the same accuracy by both classical and quantum methods. In order to compare the classical calculations with quantum ones the spectral angular distribution of CR for 200 MeV energy electrons is simulated by a quantum method (Fig. 6). As seen, the energy distributions of both spectra (Figs. 5 and 6) are nearly the same but line structure is still seen for quantum approximation. In quantum mechanical model if one can assume that higher states have a shorter coherence lifetime and, therefore, bigger linewidth then classical and quantum methods give the same results.

Figure 5: CR spectrum for 200 MeV electrons in SiC (1120) in classical approximation.

Figure 6: CR spectrum for 200 MeV electrons in SiC (1120) in quantum approximation.

In order to analyze the dechanneling processes for electrons and positrons of moderate energies we have developed special code for solving the Fokker-Planck equation for planar channeled particles. The algorithm allows studies on the diffusion coefficients for various scattering processes under the channeling conditions for relativistic light particles. First results have proved the correctness of the model used. Presently, it is under next step of development.
5 Conferences, Seminars


References


