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RADIATION FROM THE CHANNELING OF 10 GeV POSITRONS BY SILICON SINGLE CRYSTALS

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A new type of radiation accompanying the electron (positron) channeling exhibits the properties different from ordinary bremsstrahlung, coherent bremsstrahlung and transition radiation. This type of radiation was predicted by Kumakhov[1] and has been recently detected in the experiments at SLAC[2] with the participation of physicists from YerPhI and ChPhTI and others[3,4].

The goal of our experiment was to study in detail the radiation emitted by the 10 GeV positrons channeling in a plane of a silicon single crystal.

The experimental setup was similar to that described in Ref.[5] and used previously at the 10 GeV Dubna Synchrophasotron in experiments on the deflection of relativistic protons by a bent silicon crystal. The apparatus was moved to an electron/positron beam at the 76 GeV Serpukhov accelerator.

The system was redesigned to include the spectrometers for photon and positron identification and measurement (Fig.1). Scintillation counters S1, S2, S3 and veto counters A1, A2, A3 formed an event trigger. Drift chamber modules DC1, DC3 and DC4 each consisting of 4-X and 4-Y planes and DC2 consisting of 2-X and 2-Y planes were used to record the positron coordinates. Positron identification was provided by the lead glass Čerenkov counter array. The positron momentum was measured by bending magnet M3. The energy of photons originated in the silicon crystal was measured by a 150 mm x 230 mm CsI(Tl) photon spectrometer. This spectrometer was protected by lead shielding and was surrounded by anti-counters A4-A12 to reduce the background events.

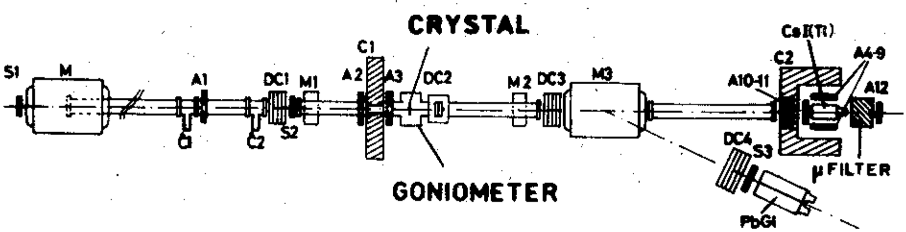


Fig.1. Experimental apparatus.

Anti-counters A4 and A12 were also used to form a muon trigger for calibration of the CsI(Tl) spectrometer by measuring the muon ionization energy losses during data taking. The muon trigger was every 10th one.

The CsI(Tl) spectrometer was calibrated using Cs, Co and Po(Be) γ-ray sources. The energy resolution (f.w.h.m.) of the detector obtained by unfolding the calibration spectra was found to be around 8% in the energy region of 1 MeV.

The sources of background radiation were diminished as much as possible by minimizing the mass of radiating material along the positron beam path. In addition, steering magnets M1 and M2 were installed on the beam for deflection of the positron trajectory to separate upstream photon background sources. Therefore only the photons produced in the crystal or in the second drift module DC2 passed through the aperture of the photon spectrometer. For the same reason the drift chamber module DC2 had the lowest possible pressure (150 Torr). It contributed only a 3×10^{-4} radiation length to the background radiation. The transport system from M1 to M2 was held under vacuum except for DC2 itself.

Photons from the π^0 decay emerged from a targeting system in an internal beam of the accelerator were converted by a radiator placed outside the accelerator. The positron beam contained 10^5 particles per 10^{12} protons incident on the production target. The hadron contamination of the positron beam was measured to be less than 0.5%.

The silicon single crystal was manufactured from a silicon wafer 26 mm in diameter and 500 μm thick by etching on both sides of the central section of the wafer 18 mm in diameter up to 90 μm in thickness. This crystal has a ring of stoffness. The crystal was packed up in a totally depleted E transmission silicon detector ring 0.9 mm thick that served to center the crystal in the beam. The preliminary alignment of the crystal was made by reflection laser light from the polished surface. The axis <111> was perpendicular to the crystal surface up to 0.2°. The precision orientation of the crystal and identification of the crystallographic axes relative to the beam direction were made by rotating the crystal located in the goniometer and by counting the intensity of γ-rays in the CsI(Tl) spectrometer.

The positron beam was directed along the (110) crystal plane, the <111> axis was displaced by 0.5 degrees horizontally relative to the beam direction to avoid the axial channeling of the positrons.

The valid events were recorded on magnetic tape whenever a) the energy of the positron was greater than 8 GeV, b) there was a proper signal in the lead glass array and c) the γ-ray energy absorbed in the CsI(Tl) spectrometer was above a threshold of 5 MeV. For each event the incident positron angle relative to the (110) plane, the photon energy and the secondary positron energy were measured.

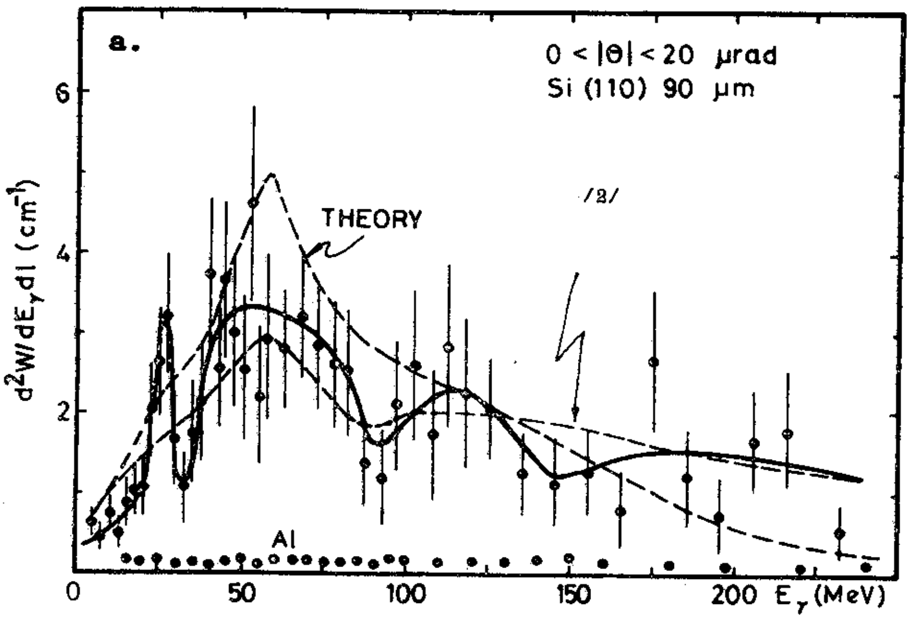
Figure 2a presents the spectral density of the radiation normalized per one incident positron. The data were taken for the incident positron angles lying within 20 microradians of the (110) plane. For 10 GeV positrons planar channeling in the silicon crystal the critical angle is about 65 microradians. The broken line in this figure corresponds to Kumakhov's approach. The dotted line is obtained from fitting the data of the experiment [2], the energy scale was properly transformed from a diamond crystal to a silicon one. In the figure the bremsstrahlung spectrum obtained in our experiment for an amorphous aluminium radiator is also plotted. The radiation length for aluminium is different from the silicon one only by 1%. The solid line through the experimental points is drawn to guide the eye.

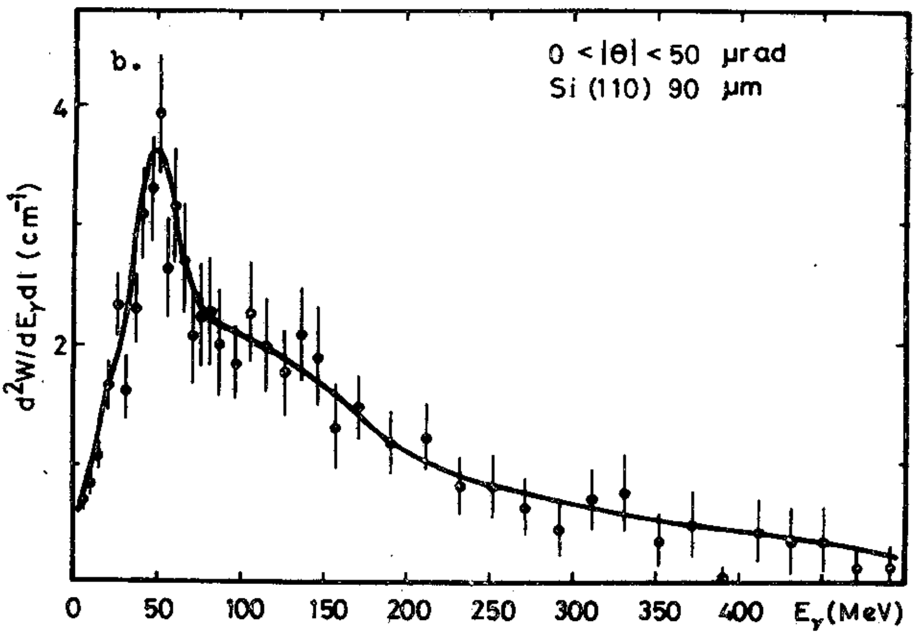
Overall, Kumakhov's prediction matches the data fairly well. In particular, the radiation due to the channeling is of the order of fifty times more intense than ordinary bremsstrahlung radiation, it is much more narrowly peaked in energy, and the energy of the main peak near 50 MeV corresponds closely to Kumakhov's prediction.

Below 50 MeV our data are distinctly different from both the Kumakhov theory and from data of ref. [2]. There is an evidence for a narrow statistically significant peak in the γ-ray spectral energy distribution in the vicinity of 25 MeV.

The γ-ray radiation intensity is strongly dependent on the positron angle relative to the (110) plane of the crystal. Figure 2b shows the γ-ray spectral density for the case when the positron angle lies inside the crytical angle, and Figure 2c shows the one for the positron angle lying around a critical angle of 65 microradians. The apparent periodic structure exhibited in Figure 2c, in general, seems to be consistent with the structure predicted by Kumakhov for the radiation of the positron with ultra relativistic energy. However, our experimental results show more strong modulations.

The radiation probability of the γ-radiation is also dependent on the incident positron angle relative to the (110) plane of the crystal. Figure 3a illustrated the angular distribution of the incident positrons transversing the silicon crystal. Figure 3b illustrates the same but for the γ-rays in an energy range of $30<E_\gamma<80$ MeV, i.e.,in the region of the prominent γ-peak in Figure 2a. The width of the distribution about 65


a.
0 < |θ| < 20 μrad
Si (110) 90 μm
THEORY
/2/
Al
d²W/dE_γdl (cm⁻¹)
0
2
4
6
50
100
150
200
E_γ (MeV)


b.
0 < |θ| < 50 μrad
Si (110) 90 μm
d²W/dE_γdl (cm⁻¹)
2
4
0
50
100
150
200
250
300
350
400
E_γ (MeV)

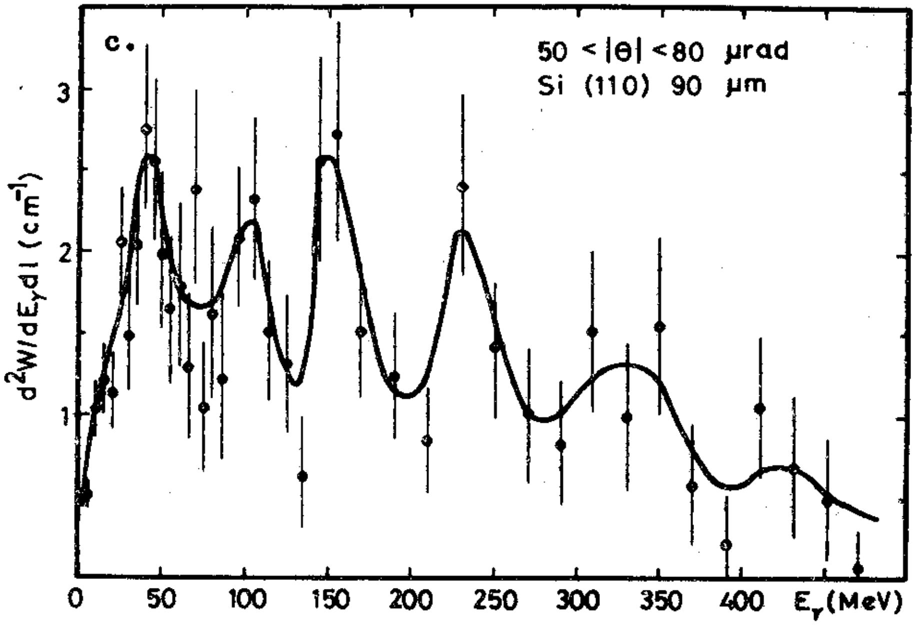


Fig.2. Spectral density of the radiation due to channeling positrons for the incident positron angles: a. $0<\Theta<20$ microradians; b. inside the critical angle; c. includes the region near the critical angle.

microradians is approximately equal to the critical channeling angle. This is an evidence that the events in the peak of γ-ray spectral density (Figure 2a) are generated by positrons incident on the crystal inside the critical channeling angle. Furthermore, the angular distribution of the incident positrons producing the γ-rays in an energy range of $600<E_\gamma<1000$MeV displays a picture expected for the bremsstrahlung nature, as is seen in Figure 3c.

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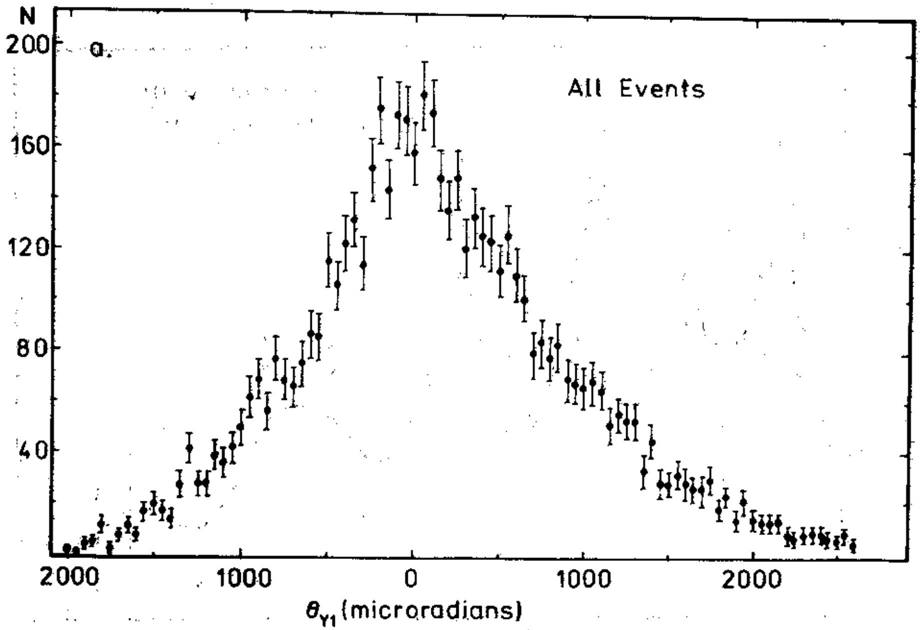
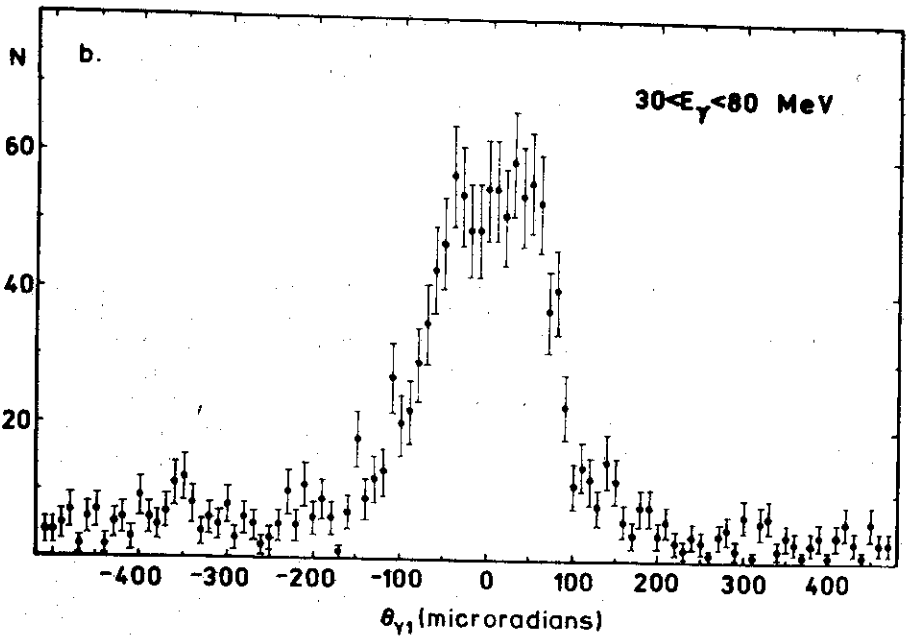

N
200
160
120
80
40
a.
All Events
2000
1000
0
1000
2000
θY1 (microradians)


N
60
40
20
b.
30<Eγ<80 MeV
-400
-300
-200
-100
0
100
200
300
400
θY1 (microradians)

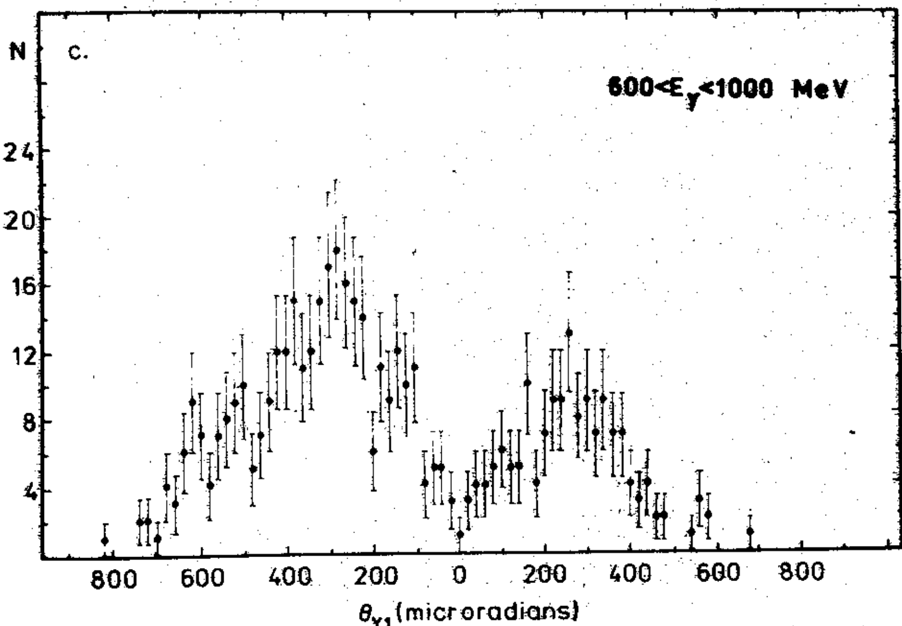


Fig.3. Incident angular distribution for positrons: a. within the aperture of the spectrometer; b. producing a photon in a region $30<E_\gamma<80$ MeV; c. producing a photon in a region $600<E_\gamma<1000$ MeV.

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