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Experimente

Polarization Measurement of the 6 GeV Coherent Bremsstrahlung from the Hamburg Electron Synchrotron

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High energy bremsstrahlung produced in a suitably oriented monocrystal is expected to be highly polarized, 1) - 5). We report an experiment in which in agreement with these predictions linear polarizations up to 70 % were measured.

The essential parts of the experimental setup were two diamonds, each adjustable in angular orientation by a high precision goniometer. The first one - inside the synchrotron vacuum chamber - ~~chamber~~produced the photons from the circulating electron beam. The photon beam was collimated and cleaned from charged particles twice by broom magnets before hitting the second diamond, which converted part into electron pairs. This diamond was mounted with its goniometer inside a spectrometer magnet. Symmetric electron pairs were momentum analysed with 2 % resolution and detected by means of two scintillation counter telescopes. A quantameter was used to monitor the photon beam. From the point of view of polarization the first crystal must be regarded as the polarizer, the second one as the analyser.

The spectrum produced by the first diamond as shown in fig. 1a, was chosen by adjusting the orientation such that it had one major peak at 2 GeV, the high energy edge being at 6 GeV. We reported in ref. 5) that such "one point" spectra in which the dominating peak is due to the contribution of the lattice plane (2$\bar{2}$0), defined in Miller indices, are expected to show particularly high polarizations. The orientation of the diamond is best described by giving the position of the electron momentum $\vec{p}_0$, which coincides with the photon beam axis, in the coordinate frame of the crystal axes: [110], [001], [110]. For the spectrum in fig. 1a Θ_1 = 50,5 mrad is the angle of $\vec{p}_0$ against the polar axis [110], and α = 49,6 mrad is the azimuthal angle measured against the plane [110], [001]. The experimental points in fig. 1a represent coincident counts of electron pairs converted in a 20 μ Au foil in which the cross section is independent of polarization. The points were normalised to the theoretical curve - shown as dashed line - at the high energy end of the spectrum. The solid curve is derived from the theoretical curve by taking into account the angular averaging effects in the same way as described in ref. 5), the only difference being that a more rigid collimation was used here. The collimation angle as seen from the radiator was only ± 0,05 mrad. This explains that there is little difference between the dashed and the solid curves. The intensity of the collimated photon beam was limited to 2.10^9 effective quanta per minute in order to keep the accidental coincidence counts lower than 10 % of the true ones.

Our method of measuring the polarization has first been proposed by Barbiellini et al 6). It is based on the fact that the pair production cross section in crystals depends on the direction of the polarization vector of the incoming photon on the one hand and the preferred recoil direction of the crystal as given by its specific orientation on the other hand. This circumstance is expressed by the "asymmetry ratio" R of pair production, which is defined for completely polarized photons by:

$$(1) \qquad R = \frac{J_\perp - J_\parallel}{J_\perp + J_\parallel} ,$$

Where $J_\perp$, $J_\parallel$ are the cross sections for pair production in diamond from photons with their electric vector perpendicular and parallel, respectively, to some reference plane Π, which will be fixed further down. R depends on k, the photon energy, and Θ_2 and α_2. These angles correspond to Θ_1 and α_1 if $\vec{p}_0$ is replaced by $\vec{k}$. The asymmetry ratio depends strongly on Θ_2 and α_2 and has characteristic discontinuities like the bremsstrahlung intensity. R is completely analogous to the polarization P for bremsstrahlung which is given by the definition

$$P = \frac{I_\perp - I_\parallel}{I_\perp + I_\parallel} \, , \tag{2}$$

where $I_\perp$, $I_\parallel$ denote the photon intensity with electric vector $\vec{\varepsilon}$ perpendicular and parallel respectively to the plane Π, for which we choose the plane [110], [001].

In the experiment we observed the number of counts $N_\perp$ with photons of polarization perpendicular to the reference plane Π, and - after rotating the analyser crystal around the beam axis $\vec{k}$ by 90° - we observed the counting rate $N_\parallel$ respectively. The polarization is now determined by the relation

$$P = (1/R) \cdot \frac{N_\perp - N_\parallel}{N_\perp + N_\parallel} \, , \tag{3}$$

where R is regarded as known from the theory. It is evident from (3) that the statistical error for P is the smaller the larger R is. Therefore the orientation of the analyser crystal must be chosen such that R is as large as possible. We found that if we oriented the analyser crystal to be on the high intensity edge of the $(02\bar{2})$ discontinuity, already known from the bremsstrahlung spectrum, the asymmetry has not only the largest value, but also is the peak intensity intensitive against small angular misalignments$^{7)}$. It is therefore not difficult to find the peak intensity experimentally. With the help of its goniometer the analyser diamond could be rotated around two axes perpendicular to $\vec{k}$, fixing Θ_2 and α_2. In addition, because the direction of polarization was held fixed, there was a third axis by which the analyser could be rotated around $\vec{k}$ by 90° without changing Θ_2 and α_2. The angular accuracy of the goniometer was ± 0.1 mrad.

The experimental points for the polarization are shown in fig. 1b. They confirm the expected high polarization of the peak of the spectrum. The dashed line is again calculated for ideal experimental conditions, while the solid curve is the result of averaging exactly with the same angular distribution that had been used for the spectrum above.

The statement that we in equ. (3) consider R as known deserves some further explanation. One may argue that if R is regarded as known theoretically the same should hold for P because both come out of the same theory. The difference lies, however, in the experimental realisation of the theoretical assumptions. There can be imperfections in the crystal as mosaic structure, and the directions of the particles are smeared out by multiple scattering and beam divergence. These influences result in a reduction of the intensity of bremsstrahlung and its polarization by angular averaging, which cannot be calculated in all cases accurately. The pair production, however, is to a large extent insensitive to such angular averages because the angles of orientation are much larger than for bremsstrahlproduction at comparable energies. Also the photons are not submitted to multiple scattering in the target. We have collected experimental evidence that the angular dependence of the pair production cross section in diamond agrees within a few percent well with the theoretical prediction by studying it with unpolarized photons. Hence we regard R well determined in the sense that if there were a source for completely polarized photons one would measure R with good precision. As far as this point of view is accepted the measurement yields absolute values of P.

Equ. (3) shows further that the measurement of a number of points with varying values of P fixes the ratio between them, $P_1:P_2:P_3...$ The experimental points show that the method adopted is consistent with the theoretical expectation. We therefore conclude that: (I) The pair production in crystals can be considered a precise tool for the determination of photon polarization and (II) that in accordance with the theory of coherent bremsstrahlung production photon beams with a high degree of linear polarization can be obtained.

Figure caption

Fig. 1. Spectrum and polarization from a 6 GeV electron beam hitting a diamond crystal at $\Theta_1 = 50.5$ mrad, $\alpha_1 = 49.6$ mrad. The bremsstrahlung intensity, $k \cdot (d\sigma/dk)$, is given as a multiple of $\bar{\sigma} = (Z^2e^4)/(137\ m^2c^4) = 2.09 \cdot 10^{-26}\ \text{cm}^2$.

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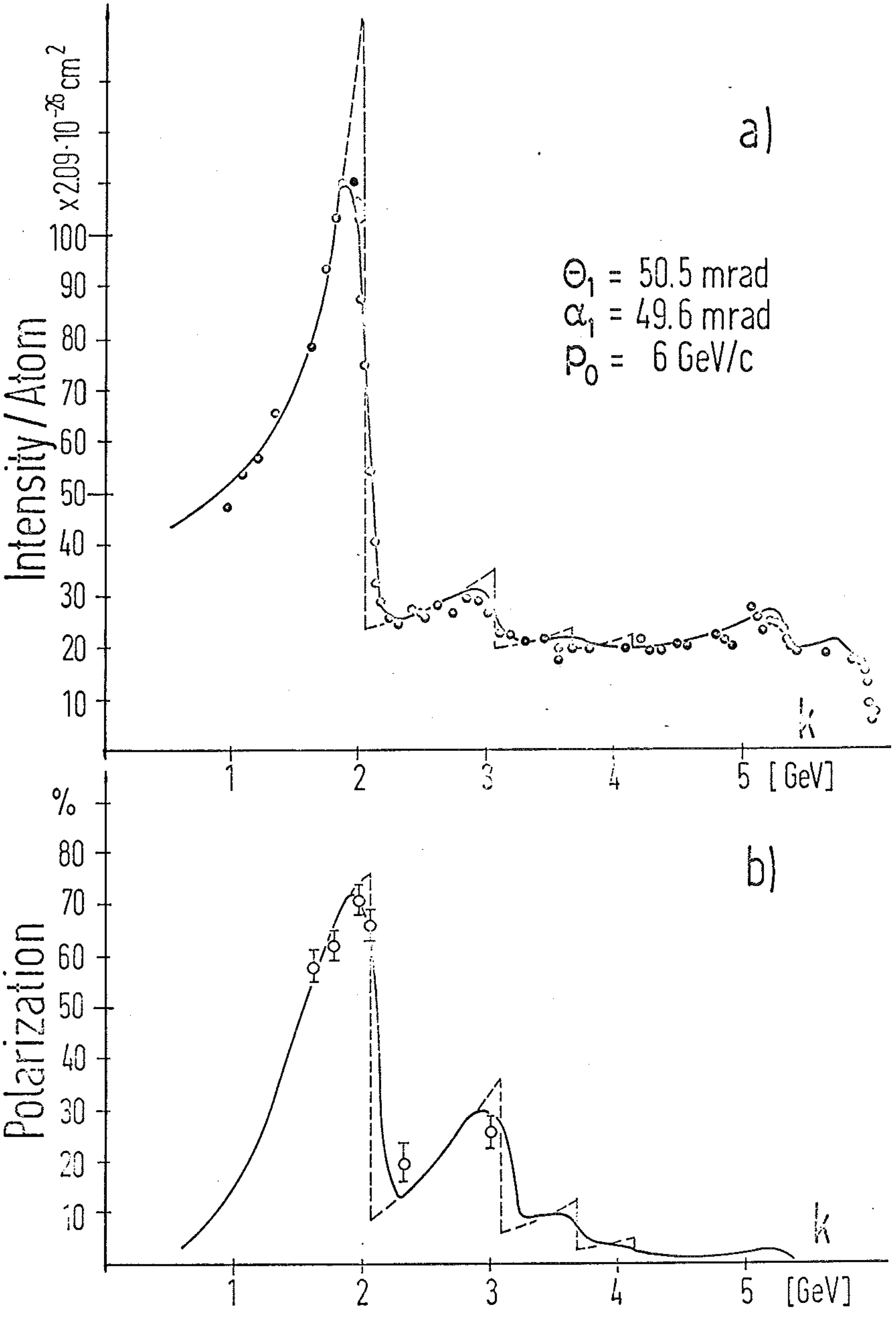
a)
Intensity / Atom
x 2.09·10⁻²⁶ cm²
10
20
30
40
50
60
70
80
90
100
Θ₁ = 50.5 mrad
α₁ = 49.6 mrad
p₀ = 6 GeV/c
k
1
2
3
4
5
[GeV]
b)
Polarization
%
10
20
30
40
50
60
70
80
k
1
2
3
4
5
[GeV]

Fig.1

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ERRATUM

$a_1 = 49,6$ mrad has to be replaced by the correct value:

$a_1 = 23,1$ mrad

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Abstract

This report describes the measurement of photon polarization by the method of asymmetric coherent pair production in crystals. The polarized photon beam was produced in a diamond. Polarization as high as 70 % was measured.