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OBSERVATION OF ENHANCED PAIR CREATION OF 50-110 GeV
IN AN ALIGNED Ge CRYSTAL

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Abstract

An increase of the e^+e^- pair creation rate above the Bethe-Heitler rate has been observed for photons incident along the $\langle 110 \rangle$ axis of a Ge crystal at 100 K. The enhancement increases with increasing energy and the rate is more than doubled at 100 GeV. The observed features appear to be consistent with the theory of crystal-assisted pair creation, but the magnitude is less than predicted. Pair creation enhancement is also observed off-axis and this is attributed to coherent pair creation.

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We have observed an increase in the rate of e^+e^- pair creation by 50 - 110 GeV photons when the incident photon beam was directed along the $\langle 110 \rangle$ axis of a cooled Ge crystal. The enhancement depends on the photon energy, being absent at energies less than 50 GeV and yielding more than double the normal Bethe-Heitler (BH) rate at energies above 100 GeV. The strongest effect occurs at alignment and exhibits an angular width of ~ 50 μ rad. The e^+ energy distribution is peaked in contrast to the BH shape observed off-axis. Additional enhancement was seen at larger angles (~ 400 μ rad). The large on-axis enhancement may well be the first observation of the recently predicted "crystal-assisted pair creation" [1], while the off-axis enhancement can be attributed to "coherent pair creation" [2].

The experiment was performed in the CERN North Area H2 beam line, using a 150 GeV ($\Delta p/p \sim 0.2\%$) electron beam of low intrinsic angular divergence ($\Delta\theta \sim \pm 30$ μ rad). The beam was separated from hadrons by synchrotron radiation. The maximum electron intensity was $\sim 10^4$ e^- /burst. The photon beam was derived from the bremsstrahlung radiation in a 0.5 mm Pb foil. The tagged photons had a 50 - 110 GeV energy range. The Ge crystal (provided by Cristal-Tec, Grenoble, France) was 1.4 mm thick, and 2cm x 2cm in area, and its mean curvature was measured to be < 30 μ rad. It was mounted on a two axis goniometer which could rotate in steps of 1.7 μ rad and was equipped with a cooling system. All data were taken with the crystal at 100 K. The system used to tag 50-110 GeV photons consisted of a deflection magnet, a scintillator and a lead glass calorimeter. A similarly constructed bispectrometer was used to detect the created e^+ and e^- in the 15 - 110 GeV energy range. Further downstream, lead glass detectors allowed the measurement of the total radiated energy in the beam direction when the pair spectrometers are removed.

The data acquisition system was triggered whenever scintillators indicated a coincidence between a tagging e^- and a created e^+ . If E_t is the energy of the tagging electron, E_+ and E_- the energies deposited in the two parts of the pair spectrometer, the sum $E_t + E_+ + E_-$ has to be 150 GeV. Events for which this sum was not sufficiently close to 150 GeV were eliminated off-line as background.

Initial alignment of the crystal was done with the 150 GeV e^- beam, by monitoring the radiation which is known to be enhanced on axis. Along $\langle 110 \rangle$ we observed more than one order of magnitude increase in the radiative power corresponding to an effective radiation length much smaller than the crystal thickness (0.06 of the BH radiation length). The characteristics of this radiation will be described in a forthcoming paper. We have checked that the alignment was unchanged with the photon beam by measuring the tilt angle dependence of the secondary photon emission from the e^+e^- created colinearly with the incident photons. The intense secondary photon emission on-axis complicates the observation of the pair creation.

Measured enhancement of the total e^+e^- rates for an aligned over a non-aligned [3] crystal is shown in fig. 1 as a function of the photon energy. An instrumental cut off eliminates events for which the e^+ has $E_+/\hbar\omega < 0.16$, where $\hbar\omega$ is the photon energy. The relative increase shows an energy threshold around 50 GeV.

An additional evidence for the crystal-assisted mechanism can be found in fig. 2 which shows the e^+ energy spectra obtained in aligned and random directions. The selected photon energy range (80 - 110 GeV) for on-axis data is above the threshold observed for the effect whereas it extends over a wider energy range (50 - 110 GeV) in the random case in order to improve statistics. The energy scale is expressed in units of $E_+/\hbar\omega$ where $\hbar\omega$ is the tagged photon energy. In random orientation the distribution is in reasonable agreement with the BH prediction. The on-axis distribution differs from the BH theory. However, it is peaked at $E_+/\hbar\omega$ 0.7 rather than at the predicted [1] value of $\sim .5$. This can be explained by the fact that radiation is also recorded by the pair spectrometer, and by assuming that the created e^- dissipates a large part of its energy by radiation. With the e^+ and e^- spectrometers receiving about the same amount of radiated energy, nearly half of the converted e^- energy is added to the e^+ signal, and this produces a shift towards higher energy of the on-axis e^+ peak. The width of the peak, ~ 0.4 , is in good agreement with the predicted value just above the threshold [4].

Data have also been acquired on the crystal angle dependence of the pair creation. Measurements averaged over a large incident energy range (80 to 110 GeV) are shown in fig. 3 as a function of the angle between the $\langle 110 \rangle$ axis and the photon beam. The point near 400 μ rad represents averaging over several runs at a variety of angles (the range is indicated by horizontal bar). The data point in the valley near 40 μ rad suggests that the range of angles over which crystal-assisted pair creation extends may be very narrow. The theoretical estimate [4] of the angular width for the crystal-assisted pair creation peak (about 77 μ rad and 52 μ rad at 50 and 110 GeV photon energy, respectively) is consistent with our data. Due to our angular resolution, the on-axis measured enhancement should be interpreted as a lower limit for the true magnitude of crystal-assisted pair creation. The data point near 400 μ rad is the result of coherent pair creation, which should be distinguished from the crystal-assisted pair creation observed on-axis.

The theoretical prediction of the crystal-assisted pair creation rate, scaled down by 3, is shown in fig. 1. The calculation assumes that, in addition to the normal BH process, pair creation is produced by the crystal fields averaged along an axial direction [5]. These fields were obtained from a thermally averaged superposition of Doyle-Turner approximations to Hartree-Fock potentials. We note that the predictions are sensitive to the form of the string potential, and reasonable alternative choices can give different results.

The theory of coherent pair creation yields predictions which differ radically from the crystal-assisted pair creation theory. This alternative approach emphasizes the periodicity of the lattice potential, and predicts a maximum in the pair creation rate in directions near the crystal axis, but a minimum for perfect alignment. The two approaches are not really different theories, but alternative approximations to a single theory. The crystal-assisted approach emphasizes the strong crystal fields, and is appropriate when particles can be contained by these fields. It becomes invalid at large angles when particles move rapidly in the transverse direction and the lattice periodicity becomes important. The theory of coherent pair production incorporates this periodicity, but, being based on the plane-wave Born approximation, it assumes that the crystal fields are not too large. This approach is appropriate for large angles, where the

e^+e^- pairs are created with transverse kinetic energies much larger than the averaged crystal potential, but its validity is questionable for nearly perfect alignment [6]. A correct calculation should include the results of these two approaches as limiting cases. Our data suggest that the enhanced pair creation can be described as a superposition of the two effects (see curves in fig. 3): a crystal enhanced pair creation peak at small angles (sketched below 80 μ rad), and a broader coherent peak at larger angles (Born-approximation calculation above 170 μ rad). Of course, the true answer must await further research.

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The continuous curve in fig. 1 and the dashed one in fig. 3 take into account this unpublished correction
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FIGURE CAPTIONS

- Fig. 1 Relative enhancement $(W_A - W_{NA})/W_{NA}$ of the pair creation rate in a $\langle 110 \rangle$ Ge crystal. W_A and W_{NA} are the pair creation rates for aligned and non-aligned directions, respectively. The enhancement is shown as a function of incident photon energy and compared with the crystal-assisted theory.
- Fig. 2 Energy spectra, measured with the e^+ detector, averaged over incident photon energies from 80 to 110 GeV for the aligned crystal and from 50 to 110 GeV for the non-aligned crystal. The two spectra are normalized to the same number of e^+ .
- Fig. 3 Angular scan of the total pair creation rate in a geometrical plane containing the $\langle 110 \rangle$ axis and making an angle of 0.1 rad with respect to a (110) plane. This plane has been chosen in order to optimize the production of coherent pairs. θ_{TILT} is the angle of the beam relative to the $\langle 110 \rangle$ axis. The solid curve is a prediction of the coherent theory of pair creation (scaled by 0.6), while the dashed curve is a guide to the eye which is qualitatively consistent with the crystal-assisted theory.

FIG. 1

FIG. 2

FIG. 3