Spectral Narrowing of Backscattered Photons in Electron-Laser Collisions under a Strong Magnetic Field

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Abstract

We studied an electron-laser collisions, for the first time, at a bending section of a compact storage ring to study an effect of the magnetic field. The observed backscattered photon spectrum showed an unexpectedly narrow band width without any collimation. We were only able to reproduce this phenomenon by assuming that the scattering occurs within the electron orbital plane. Conservation of the total angular momentum may become important when a strong magnetic field is applied to an electron-laser collision.

1 Introduction

The Compton backscattering method is adopted as a quasi-monochromatic and tunable gamma- or x-ray source. AURORA is a compact electron storage ring that has no straight sections [1]. We have studied electron-laser collisions in a strong magnetic field.

Figure 1 shows our experimental setup, the electron-laser interaction region was set in the strong magnetic field of AURORA, which was operated at various electron energies. The 50-W CO_2 laser was set so the polarization would be parallel to the electron orbital plane of the ring. The laser beam was focused by a set of ZnSe lenses on the electron orbit. A 4-mm thick Si mirror was used to reflect laser light and to extract x-ray beams. No x-ray collimating apparatus was used except an opening for the 1×0.5 cm vacuum chamber and 1.23×1.23 cm a hole on the Si mirror mount in both horizontal and vertical directions, respectively. X-rays were detected by a 2"ϕ x2" NaI scintillator with a 50-μm thick Be window. In this setup, the materials that absorb x-rays were the 4-mm thick Si mirror and 2-mm thick Al_2O_3 vacuum window. In this experiment, to keep analog digital converter dead time below 10 %, we limited the electron beam current to the order of 10 mA.

In order to make a quantitative comparison, we made the following corrections on the theoretically calculated spectrum: the opening hole on the Si mirror mount, the absorption of x-rays by the vacuum window, Be window and Si mirror, and the response function of the NaI scintillator. In order to estimate the absolute number of collisions, we have experimentally obtained the density distribution of a laser beam at the focusing point, and carefully estimated the overlap volume of the photon and electron beams. In the calculation we have taken a picture that the laser density is distributed uniformly along the laser trajectory, and that the electrons pass periodically inside the laser beam. Effects of absorption and detector response on the energy spectrum were corrected. The convolution of theoretical spectrum due to the response function of the NaI scintillation detector was made with close approximation by Gaussian distribution.

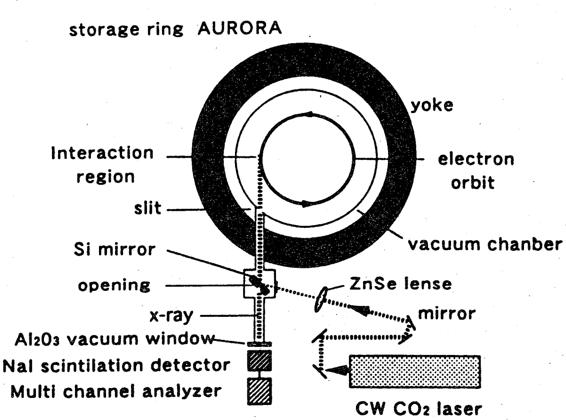

Fig. 1. Schematic view of the electron-laser collision experimental setup using the exact circular electron storage ring.

Figure 2 shows the observed energy spectra of the backscattered photons when the electron energies were 288, 315, and 366 MeV, respectively. Here that x-ray peak energy increases as electron energy increases. These peak energies are quite consistent with calculations from kinematics of the head-on collision. Contrary to our expectations, however, the observed energy spectra all exhibited very narrow band widths. We think the collimation effect that is usually introduced to select scattered photon energy is useless to explore this narrowing.

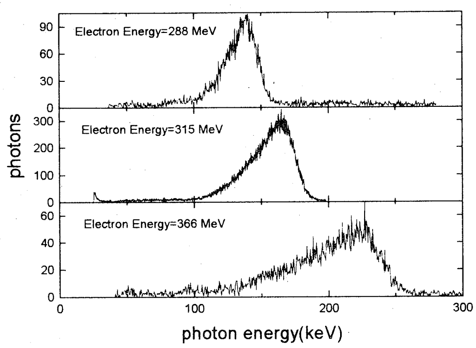

Fig. 2. Observed scattered x-ray energy spectra corresponding to electron energies of 288, 315 and 366 MeV.

2 Quantitative conparison of energy spectrum

Figure 3 shows corrected theoretical calculations and observed spectra. In this figure these corrected theoretical spectra(dashed lines) are compared with the observed ones(solid line) in an absolute value. The calculated spectra reproduce the increasing Compton edge as the electron energy increases. The edge in the low energy side appears due to the absorption and slit. However, great deviations from the obtained data are apparent. None of these corrections was able to introduce band width narrowing. We think the collimation effect that is usually introduced to select scattered photon energy is useless to explore this narrowing. In the following discussion, we will focus on how narrow the observed x-ray energy spread is compared to a standard calculation known to give good agreement with experiments performed at the straight section of storage rings[2-5].

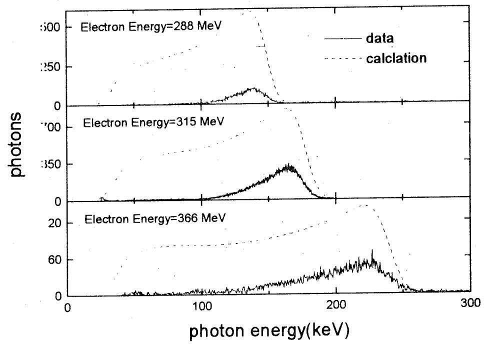

Fig. 3. Corrected theoretical calculations are compared with observed spectra in absolute intensity.

3 Effect of the vertical slit

In order to figure out the unknown effect that resulted in this band width narrowing, we have studied the effect of the vertical slit on the theoretical calculation. This examination corresponds to confining the scattering angle to near the electron orbital plane. When we narrow the spacing of the vertical slit, the band width narrows, as shown in this Figure, but it was impossible to reproduce present experimental distribution even with 0.46 mrad slit. From this examination we can easily imagine that some kind of intrinsic selection mechanism is involved in this phenomenon. We think the collimation effect that is usually introduced to select scattered photon energy is useless to explore this narrowing.

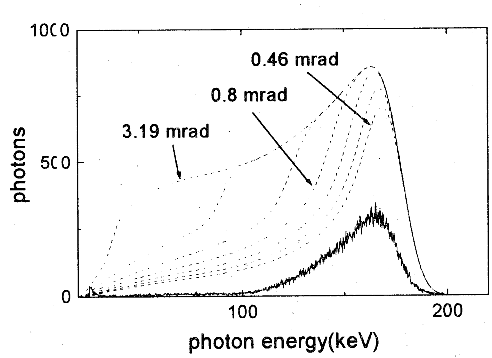

Fig. 4. Spectral shapes calculated for various vertical acceptance half angles.

4 Extreme case spectrum

The cross-section of backscattered photons was calculated according to Compton backscattering theory [6-7]. The laboratory differential cross-section is given by transforming to the laboratory system in the scattered photon energy and by integrating it over an azimuthal angle with regard to the head-on collision,

$$\frac{d\sigma}{d\varepsilon_x}=\int_0^{2\pi}\frac{d^2\sigma}{d\varepsilon_x d\varphi}d\varphi$$
$$=\frac{\pi r_0^2}{2\varepsilon_L\gamma^2}\left[\frac{\gamma m}{\gamma m-\varepsilon_x}+\frac{\gamma m-\varepsilon_x}{\gamma m}-1+\left(\frac{m^2}{2\varepsilon_L(\gamma m-\varepsilon_x)}-\frac{m}{2\varepsilon_L\gamma}-1\right)^2\right]. \qquad (1)$$

We have calculated an extreme case in which, instead of integrating the azimuthal scattering angle from 0 to 2π as ordinary Laboratory spectrum, we have limited the scattering angle to the electron orbital plane. We have obtained the formula:

$$\frac{d\sigma}{d\varepsilon_x}=\left.\frac{d^2\sigma}{d\varepsilon_x d\varphi}\right|_{\varphi=0}$$
$$=\frac{r_0^2}{4\varepsilon_L\gamma^2}\left[\frac{\gamma m}{\gamma m-\varepsilon_x}+\frac{\gamma m-\varepsilon_x}{\gamma m}-2+2\left(\frac{m^2}{2\varepsilon_L(\gamma m-\varepsilon_x)}-\frac{m}{2\varepsilon_L\gamma}-1\right)^2\right]. \qquad (2)$$

Figure 5 shows the corrected spectra(dashed lines) are again compared with the observed spectra in an absolute intensity. When x-ray absorption and response function corrections are made to the extreme case theoretical spectrum, most of the low energy peak disappears and a little peak, caused by the absorption, remains. We think here rather good agreement between theoretical and experimental spectra. In the high energy section, the spectral shapes are beautifully reproduced. Even the absolute intensities are in a good agreement. However, in the low energy section, the peaks are not seen in the experimental spectra, although the amount is small. We think carefully that the low energy peak near the discrimination level can easily disappear due to a decrease of detection efficiency caused by a nature of electronics. This correction is not introduced to the theoretical spectrum. As a consequence, the new formalism, extreme case cross section is useful for reproducing the present experimental results. This implies that the photon scattering angle is confined to the electron orbital plane, apparently due to a strong magnetic field.

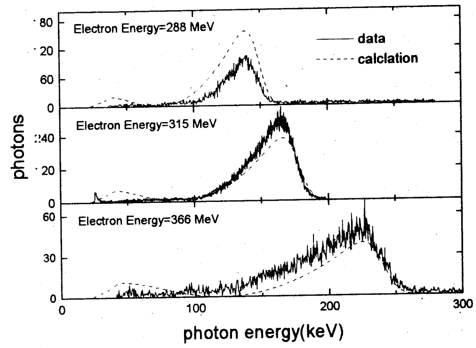

Fig. 5. The corrected theoretical spectra based on Eq. (2) and the observed spectra in absolute intensity.

5 Summary

The Observed energy spectra all exhibited very narrow band widths without any collimaton. If we assume the scattering occur within a orbital plane, we obtained rather good agreement. The electron-photon interaction must occur within the electron orbital plane. This narrowing would be caused by a strong magnetic field. A conservation of the total angular momentum may take an important role in this phenomena

Ackowledgements

Yamada as a former member of PRESTO gratefully acknowledges the financial support by the Research and Development Corporation of Japan throughout this study.

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