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Crab Crossing in a Gamma-Gamma Collider

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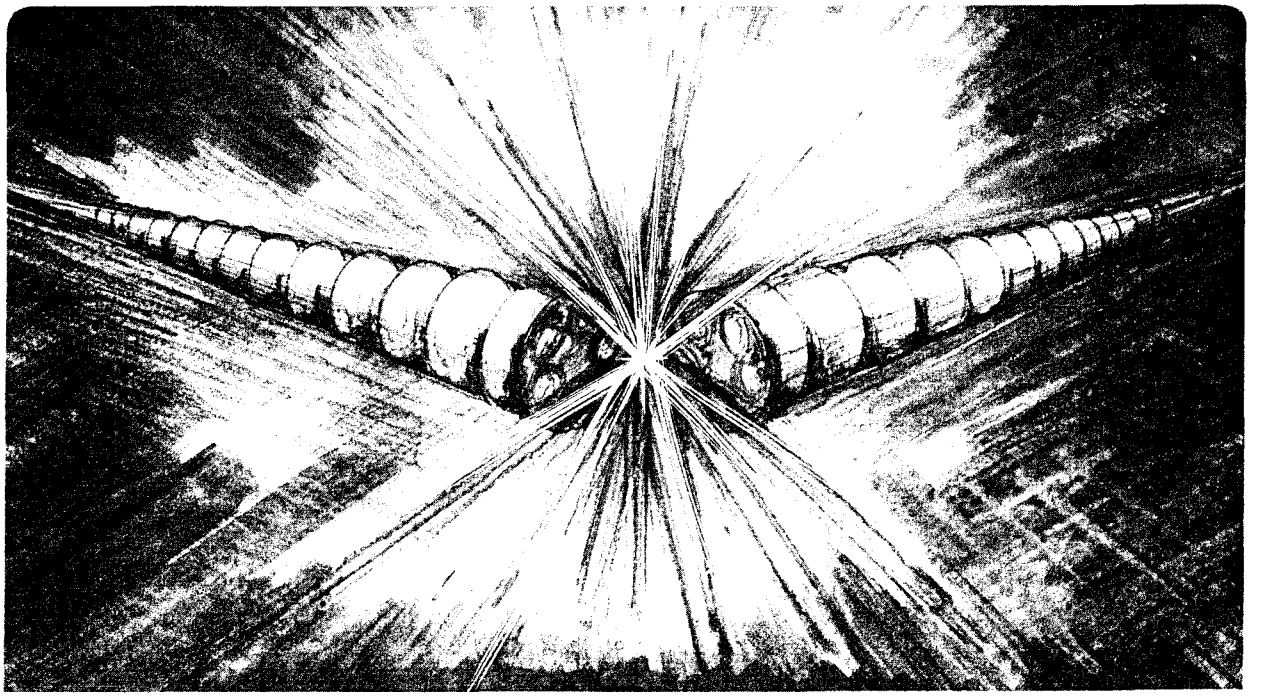
August 1994



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Crab Crossing in a Gamma-Gamma Collider*

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Abstract

The crabbing of an incident photon beam from a laser, and the electron beam with which it interacts at the conversion point, is shown to have the same efficiency as in head-on Compton scattering, but with the advantages of a crossing geometry. The resulting γ-ray beam is also crabbed, which allows for a crossing collision point, while maintaining the luminosity at the same value it would have in a head-on collision.

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I. Introduction

The crabbing of electron and photon beams allows the conversion efficiency of photons into γ-rays to remain as high as it would be in head-on Compton scattering. In order to achieve this it is required to crab both the photon and electron beams. These aspects of the scheme are addressed in the next two sections of this paper.

If the electron beam is crabbed the resulting γ-ray beam is crabbed, without regard to the incident photon beam. Thus it is possible to have the crossing of γ-rays at an angle. This is highly advantageous for the collider in two regards. Firstly, the γ-ray crossing allows the debris of the crossing to go to one side. This is the same advantage as in e^+-e^- colliders. The second advantage, special to γ-γ colliders, is that there need be no holes made in the laser mirrors either for the opposing beam or for the collision debris, in order to arrange for a head-on Compton scattering.

A schematic, showing the layout for the proposed configuration, is presented in Fig.(1). The basic idea, that of "crabbing" of an electron beam was due to Robert Palmer [1], introduced first for linear colliders, and subsequently taken over for storage rings [2]. It has been noted that a similar approach can be applied to the γ-γ collision [3]. In this paper, we extend the idea of crabbing further to photon beams and provide some relevant formulae.

II. Crabbing of the Electron Beam

The luminosity for two unequal bunches of Gaussian shape colliding with a crossing angle 2θ is (see Fig.(2))

$$L(\theta) = \frac{N_1 N_2 f}{2\pi\sqrt{(\sigma_{y1}^2+\sigma_{y2}^2)[(\sigma_{z1}^2+\sigma_{z2}^2)\theta^2+(\sigma_{x1}^2+\sigma_{x2}^2)]}} \quad . \tag{1}$$

Here f is the collision frequency, N_i is the number of the particle in the bunch i, and σ_{xi}, σ_{yi} and σ_{zi} are the rms bunch dimensions of the bunch i in the x-, y- and z-direction respectively. We assume that the bunches are not crabbed, i.e. the bunch axis lies in the direction of motion, that the collision is taking place in the x-z plane, that all particles within each bunch are parallel to each other and that the bunch velocity in the x-direction is non-relativistic, i.e., $\theta << 1$.

From Eq.(1), we obtain the reduction due to the crossing angle as follows:

$$\frac{L(\theta)}{L(0)} = \frac{1}{\sqrt{1 + (\theta/\theta_0)^2}} \quad , \tag{2}$$

where

$$\theta_0 = \sqrt{\frac{\sigma_{x1}^2+\sigma_{x2}^2}{\sigma_{z1}^2+\sigma_{z2}^2}} \quad . \tag{3}$$

In order to avoid a significant reduction in the luminosity, the crossing angle θ needs to be smaller than θ_0.

There are several schemes for crabbing of the electron beam. One way is to use transversely deflecting cavities [1], such as an RF cavity working in the transverse mode TEM_{110}. Such a scheme is schematically shown in Fig.(3). Another scheme is called dispersive crabbing [5]. In this scheme, an RF cavity is used to introduce an energy chirping along the beam, and due to dispersion of the beam transport system the beam will be tilted in transverse angle.

III. Crabbing of the Photon Beam

The geometrical reduction in Compton scattering efficiency due to a crossing angle is given by the same equations, Eq.(2) and Eq.(3). For typical parameters for a γ-γ collider, θ_0 is of the order of 1 mrad for γ-γ collision, and 10 mrad for Compton scattering. Since the crossing angle may need to be as large as 30 mrad [4], it is desirable to crab the laser beam as well as the electron beam, as shown in Fig.(1).

The crabbing of the photon beam from a laser may also be done in a number of ways. One way that is analogous to the dispersive crabbing mentioned above for the electron beam is shown in Fig.(4). In this scheme, a chirping in frequency is produced along the bunch length. Then by passing the chirped pulse through a dispersive optical element, such as a grating pair, the bunch will be tilted as well as compressed longitudinally.

In the geometrical optics approximation, the crabbing angle from the arrangement in Fig.(4) is straightforward to work out. The grating should be blazed for high efficiency operation in first order, with the grating equation $\cos\alpha - \cos\beta = g\lambda$, where α and β are respectively the grazing angle of the incident and outgoing beams, and g is the number of grooves per unit length. Let ℓ be the initial laser pulse length, d be the separation of the

two gratings, and $\Delta\lambda = \lambda_2 - \lambda_1$ be the wavelength variation across the pulse. The pulse, after the grating pair, is shortened by a length $(\Delta\ell)_z = dg^2\lambda\Delta\lambda/\sin^3\beta$, and crabbed with a transverse dimension $(\Delta\ell)_T = dg\Delta\lambda\sin\alpha/\sin^3\beta$. Then the crabbing angle θ_c is given by

$$\tan\theta_c = \frac{(\Delta\ell)_T}{\ell - (\Delta\ell)_z} \quad . \tag{4}$$

This expression is valid for the case $(\Delta\ell)_T$ is larger than the transverse size of the laser pulse. As an example, consider the case $\lambda = 1\ \mu m$, $\Delta\lambda/\lambda = 1\ \%$, $g = 100$ grooves/mm, $\alpha = 45°$, $\beta = 52.6°$, $d = 1$ cm, $\ell = 500\ \mu m$. We obtain $(\Delta\ell)_T = 14\ \mu m$, $(\Delta\ell)_z = 2\ \mu m$. Thus we have $\theta_c = 28$ mrad, which is in the correct order of magnitude.

Conventional laser systems producing high power, short pulse beams contain chirping and dispersive elements. The crabbed laser beam can simply be obtained by adjustments of these elements. In the case of free-electron lasers, on the other hand, the crabbing can be done externally.

IV. Conclusions

It is seen that crab crossings can be devised for a γ-γ collider at both conversion and collision points without reduction in either conversion efficiency or luminosity, and with no more difficulty than for an electron-positron collider.

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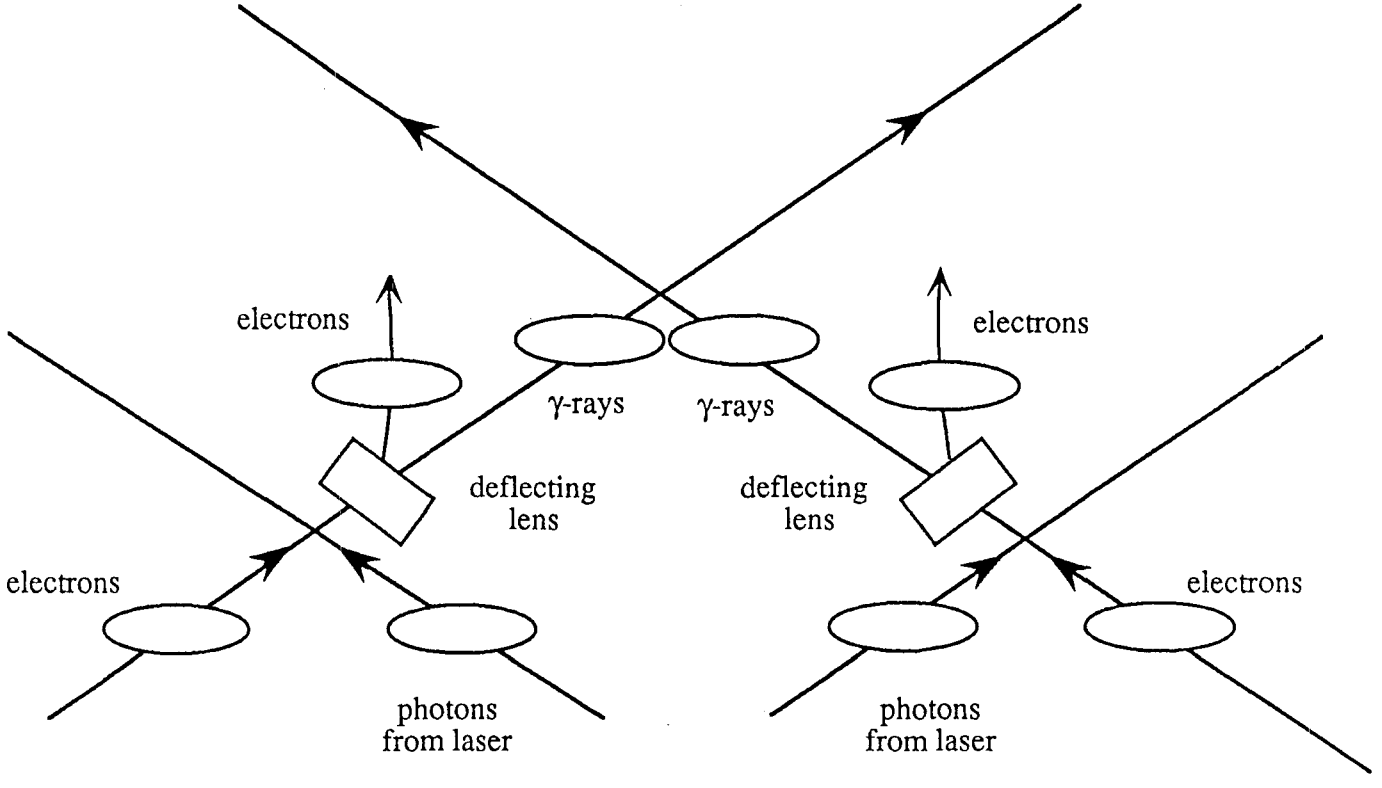


Fig. 1 Schematic of the conversion point and the collision point for a crabbed γ-γ collider

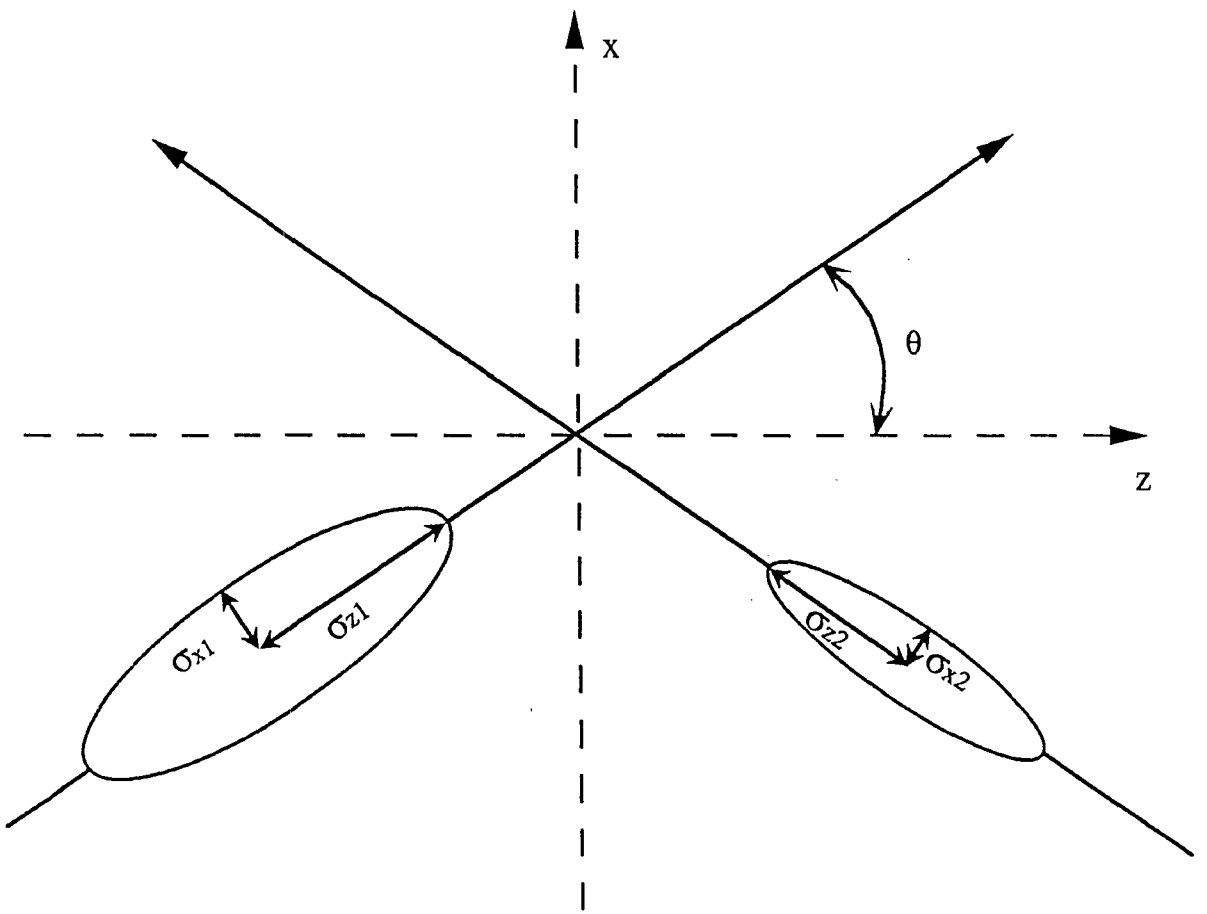
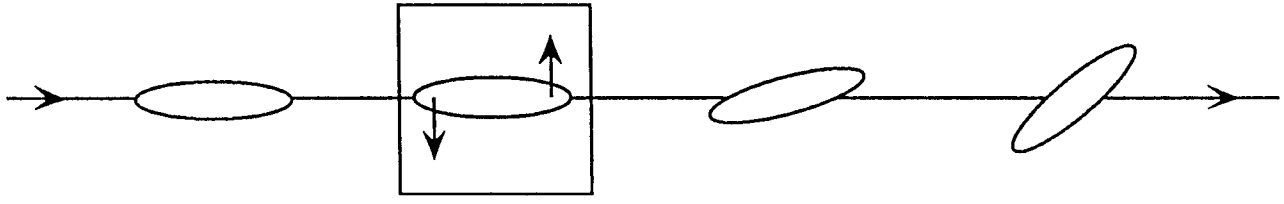


Fig. 2 Schematic of two beam collision with a crossing angle



RF cavity TM_{110} Mode

Fig.3 Schematic of electron beam crabbing

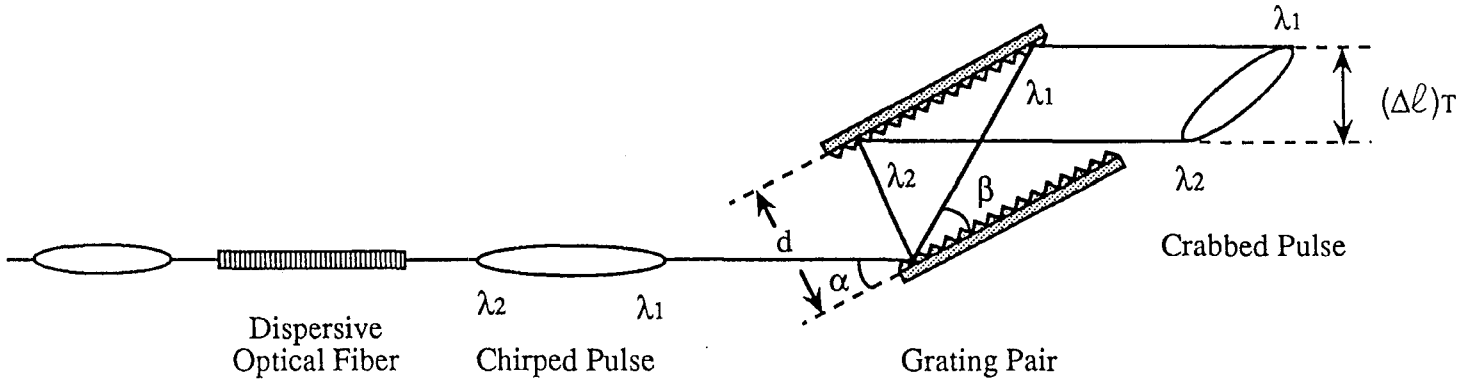


Fig.4 Schematic of photon beam crabbing