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UCRL-TR-222530

Comparison of Techniques to Reduce Bremsstrahlung Background Radiation from Monoenergetic Photon Beams

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June 30, 2006

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Comparison of Techniques to Reduce Bremsstrahlung Background Radiation from Monoenergetic Photon Beams

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INTRODUCTION

An important applied technology is a tunable mono-energetic photon source [1]. These sources are made of relativstic electron accelerators coupled to low-energy lasers, which produce high-energy, mono-energetic γ-rays.

One challenge associated with systems such as this is a continuum of bremsstrahlung background created when an electron beam passes through an aperture of some sort and the electron bunch or its halo impinges on the aperture pictured in figure 1. For instance, in the current T-REX [1] design for the interaction point between the laser- and electron-beam, the electron-beam passes through the center of a mirror used to reflect the laser. There is a potential with this design that bremsstrahlung radiation may be produced at the edges of the mirror openings and contaminate the mono-energetic photon beam. Certain applications [2] may be sensitive to this contamination.

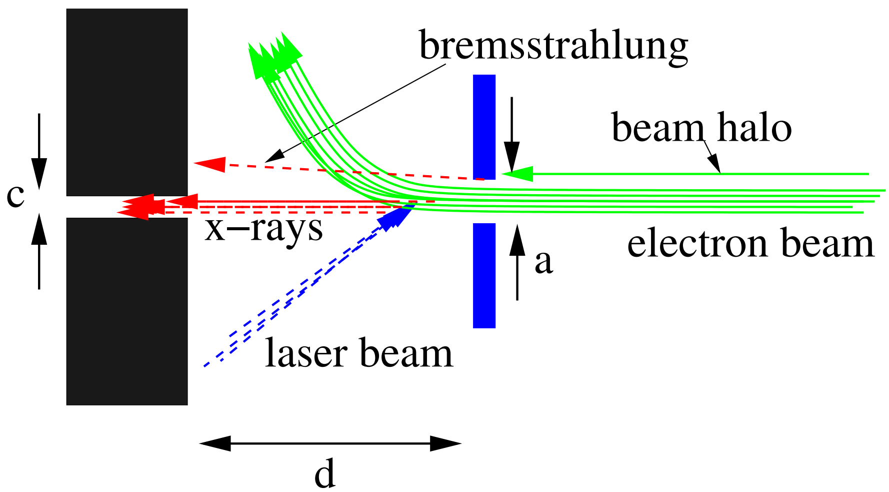

FIG. 1: T-REX schematic: Electron beam from accelerator enters from the right. Electron beam passes through an aperture (middle). Laser beam interacts with the electron beam and produces hard x-rays (γ-rays) in the direction of the electron beam. These γ-rays then pass through a collimator (left). Also shown is a beam halo electron which strikes the edge of the aperture. The resultant braking produces bremsstrahlung radiation. The goal is to use the collimator to prevent the bremsstrahlung radiation from mixing with the desired γ-ray beam.

To reduce the bremsstrahlung contaminate a collimator (thickness$\sim$$24in.$ (calculated from XCOM database [3]) to attenuate by a factor of 10^{-3} the $112MeV$ photons expected in the T-REX demonstration [1]) is situated between the aperture and target. To maximize the brightness of the photon-beam, the collimator opening must be no less than the size of the photon-beam spot size expected to be about $1mm$. This fixes the collimator opening. *a priori* the aperture size must be greater than the collimator opening and is a function distance between the aperture and collimator. In this paper we focus on two approaches to estimate the aperture size, given a collimator and a target whose sizes and distances from the aperture are given. In the next section we will discuss these approaches.

TECHNIQUES

The first approach we explore is to choose an aperture size, a, such that the mean angle of emission (also known as the characteristic angle, $\gamma^{-1} = m_e/E_e$ (see Ref. [4])) from the edge of the aperture is subtended by the collimator wall as pictured in figure 2.

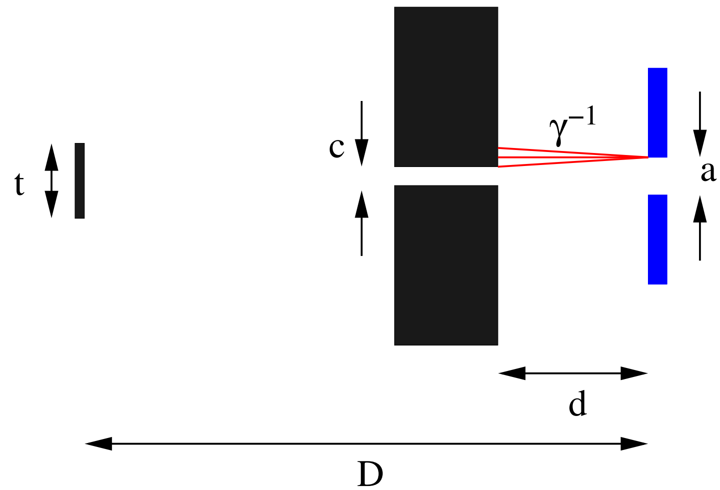

FIG. 2: Bremsstrahlung radiation from aperture (right) is emitted from the closest point to the beam axis. The aperture is chosen so that γ-rays within the mean emission angle γ^{-1} are subtended by the collimator (left).

The second approach to determine the aperture size, a, requires that there be no direct line-of-sight from the aperture to the target. This is accomplished by requiring that the collimator is placed at a distance upstream of the focal point where the separation between the two rays from opposite edges of the aperture opening to opposing edges on the target is greater than the collimator opening, demonstrated in figure 3.

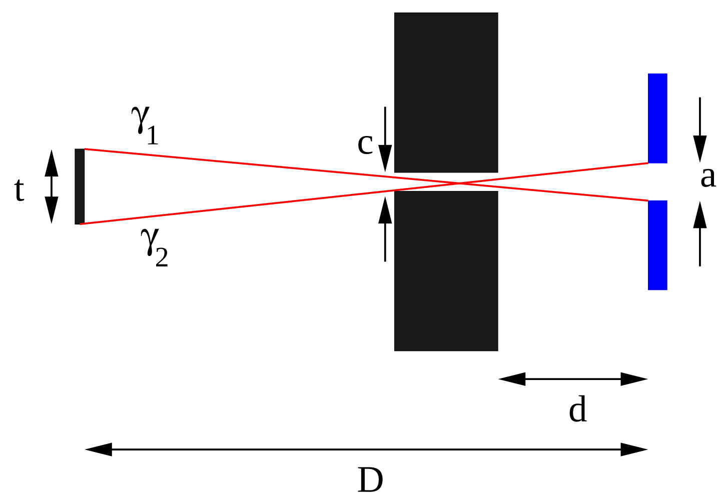

FIG. 3: Bremsstrahlung from aperture (right) propagates via straight lines to the target (left). These lines must be subtended by the collimator (center). The aperture size in this figure drawn small to illustrate the challenge.

ANALYSIS

Using the characteristic angle approach we calculate the aperture size so that γ-rays emitted at the charactristic angle ($\gamma^{-1} = m_e/E_e$) are subtended by the solid part of the collimator. From this the following condition must be met:

$$\gamma^{-1} \leq |a - c|/2d \tag{1}$$

where we have made a small angle assumption for the right-hand-side. It is then a trivial matter to solve for the aperture size, a:

$$a \geq 2d\gamma^{-1} + c \tag{2}$$

Using the line-of-sight principle, we begin by drawing two rays, one from the aperture top to the target bottom, and vice-versa for the other ray (see Fig. 3). These rays are written in the following manner: $y_1 = m_1 x + b_1$ and $y_2 = m_2 x + b_2$, where by symmetry $m_1 = -m_2$. The focal point is the intersection of the two rays and is $f = Dt/(a+t)$. To prevent direct line-of-sight, the collimator must be placed upstream of the focal point by an additional distance such that the following two equivalent conditions must be met:

$$|y_2(f + x_m) - y_1(f + x_m)| \geq c, \tag{3}$$

(where x_m is the minimum distance upstream from the focal point where the above equality holds true, $x_m = cD/(a+t)$)

$$D - d \geq f + x_m. \tag{4}$$

Substituting the focal point, f, and x_m and solving for a yields the expression:

$$a \geq (c + td/D)/(1 - d/D). \tag{5}$$

CONCLUSION

The minimum requirements for aperture size have been calculated using two different approaches: characteristic angle and line-of-sight. The result are two expressions: Eq. 2 and 5. We note here that the opening angle using the characteristic angle is greater than the opening angle using the line-of-sight principle 5, using typical values for the T-REX application (e.g. $E_e/m_e \sim$220, $D \sim 12m$, $d \sim 5m$, and $c \sim$beamspot$\sim 1mm \pm .5mm$ (electron jitter consistent with PLEIADES[5]), see Ref[1]). Therefore, a conservative estimate for the aperture size in this application is equation 2.

For equation 5 we note that if $t \sim 0$ and $D \gg d$ then the aperture size goes like the collimator size to zeroth order. The first order correction is cd/D. And for $t \gg c$ the aperture size goes like td/D to zeroth order with a first order correction of td^2/D^2.

[1] C. P. J. Barty and F. V. Hartemann, UCRL-TR-206825 (2004).

[2] D. P. McNabb and J. Pruet, UCRL-TR-210052 (2005).

[3] M. J. Berger et al., *XCOM: Photon Cross Section Database*, National Institute of Standards and Technology, NBSIR 87-3597 (1998).

[4] J. D. Jackson, *Classical Electrodynamics, Second Edition* (John Wiley and Sons, New York, 1975).

[5] **PLEIADES P**ico-second **L**aser-**E**lectron **I**nter-**A**ction for the **D**ynamical **E**valuation of **S**tructures (LLNL).