Utilizing relativistic mirrors for photon-photon scattering

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Photon-photon scattering is a fundamental theoretical prediction of quantum electrodynamics [1]. However, so far only an upper bounds on the cross section at photon energies of eV levels has been achieved due it's extremely small value [2-4] (see Fig. 1). Since for photon energies much less than the electron rest mass energy the scattering cross section increases as the sixth power of the photon energy, measuring photon-photon scattering at higher energies (~keV levels) is advantageous. To generate these high energy photon beams we propose using laser pulses (called source pulses from here on) reflected and frequency up-shifted by mirrors moving at relativistic velocities [5-7]. In these schemes the mirror is from a driver laser generating a breaking plasma wave, relativistic flying mirror (RFM) [5], a spherically focused driver laser generating a spherically breaking plasma wave, spherical flying mirror (SFM) [6], by a thin foil accelerated to relativistic velocities in the radiation

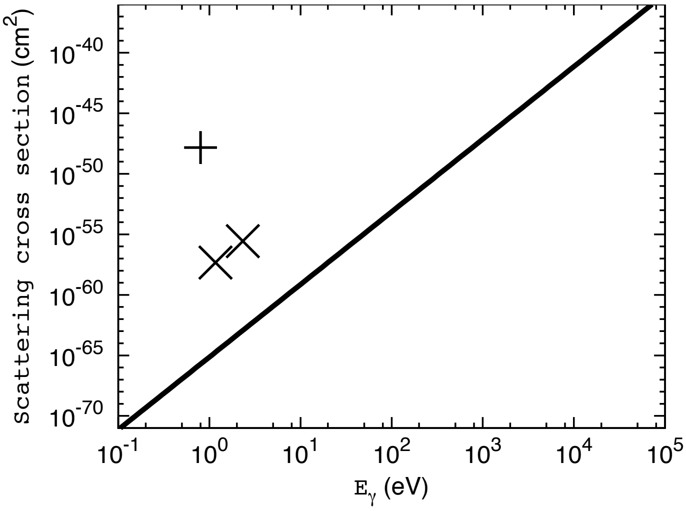

Figure 1. Photon-photon scattering cross section versus photon energy. The cross shows the measurement of [2,3] and X's show measurements of [4].

pressure dominant regime by an ultra-high intensity driver laser pulse, double-sided relativistic mirror (DSRM) [7], or by a spherically shaped thin foil accelerated to relativistic velocities by a spherically focusing ultra-high driver intensity laser pulse, double-sided spherical mirror (DSSM) (suggested in [8]). The reflected source laser pulses due to the double Doppler effect can have high photon energy (keV levels), extremely short duration (atto-second order) and coherency [5-7]. In addition the shape of the mirror can be used to focus the photon beams to very small spots [5,6]. It is known that the photon-photon scattering can be enhanced by stimulated emission induced by colliding three photon beams simultaneously [9]. Figure 2 shows the scalings we obtain for the different schemes with three photon beams colliding. We have calculated this considering a total input source laser energy of 30 mJ (10 mJ for each laser pulse), low laser source amplitude on the relativistic mirror surface, and only the first harmonic, although high harmonics occur [7]. In the DSRM and DSSM schemes we took for the parameters of the thin foil for a source pulse laser wavelength of 800 nm: thickness of 200 nm, density of 8.4x10^{23} cm^{-3}, initial source laser spot size of 8000 nm. The drop off in scattered photons number at higher photon energy for the DSRM scheme can be attributed to the fact that in the other schemes the decrease in reflectivity is compensated by a smaller focus spot, however, in the DSRM scheme the focus spot is unchanging. In addition it should be noted that to get higher photon energy the driver laser pulse energy needs to be increased. Although the DSRM and DSSM schemes have a high number of scattered photons, the driver laser energy necessary to generate such mirrors is quite large. Therefore, we consider the SFM scheme for specific parameters. The scattered photon number at 1 keV for the SFM scheme can be achieved if we use two 200 TW driver lasers with wavelengths of 800 nm

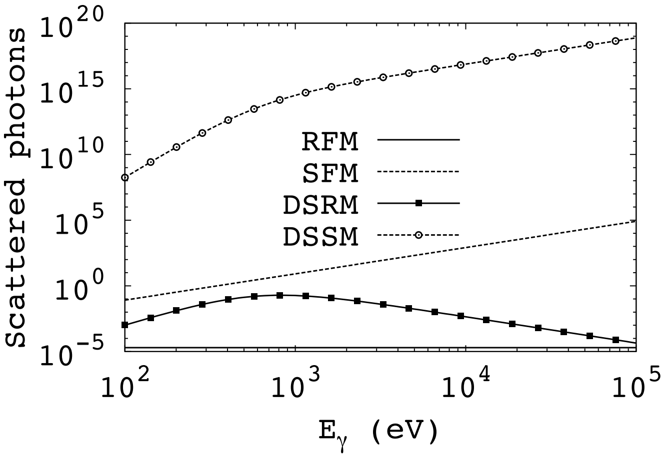

Figure 2. Photon-photon scattering event rate for the various relativistic mirror schemes where three beams are collided.

which are spherically focusing in a plasma of density 2x10^{19} cm^{-3}. To generate wakefields the pulse durations should be less than ~ 12 fs. The SFM will have a radius of 240 nm. One source laser pulse will reflect off one mirror and the other two source laser pulses will reflect off another mirror. We take the source pulse duration to be 100 fs which results in an intensity of 1.1x10^{17} W/cm^2 on the mirror surface. Due to this pulse duration we may need to rely on multiple mirrors generated behind the driver laser pulses reflecting the pulses due to the collapse time of the mirror. This can happen due to multiple breaking waves behind the driver laser pulse. We will take our scattering estimate to be an upper bounds. The focused source spot size will be ~1.2 nm. The focused source intensity is ~10^{25} W/cm^2 which is results in an insignificant number of electron-positron pairs generated [10]. The resulting number of scattered photons is ~8 assuming three photon beams of energy 10 mJ each are shown onto the relativistic mirrors. This represents a fair number of scattered photons, which could be detected.

In conclusion we have presented a scheme whereby the theoretically predicted photon-photon scattering could be measured using relativistic mirrors to upshift laser photons to keV energy levels where the cross section is much higher. At these levels scattering could be achieved with a much fewer number of photons than that at the eV level. Based on each relativistic mirror configuration we have shown through the scaling of each scheme with photon energy that a fair number of photons could be scattered using three colliding upshifted laser pulses. We have given specific parameters for the SFM case and have shown that a fair amount of scattering could be obtained with present day lasers. Near future and next generation laser systems [11] will make feasible other schemes such as DSRM and DSSM. Further examination of the problem is necessary, however, such as achieving precise alignment for the collisions, noise filtering, and optimization of the laser-plasma interaction.

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