Particle scattering by two colliding laser pulses*

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Abstract

Consider the motion of charges before and after the arrival of (i) a single or (ii) a pair of short (or long) laser pulses traveling into opposite directions. A mathematical analysis combined with computer simulation reveals the effect of these pulses on the motion of a gas of such charged particles. Measurements of their velocities constitutes a novel and very sensitive indicator of collisions between the pair of optical pulses.

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1 Motivation

The motivation behind this report is the direct interaction of ultra-intense lasers with matter. Indeed, during the past decade a confluence of advances in laser science has opened the door to the study of laser-matter interaction as the new frontier of the 21st century. The extraordinarily high intensity (petawatt) of the laser pulses have pushed the relativistic, and hence nonlinear, nature of laser-matter interactions to the forefront of science. These processes are characterized by ultra-relativistic velocities and accelerations of such extreme violence that relativistic physics and mathematics is not merely optional but mandatory.

At present there is a considerable amount of highly visible experimental activity whose purpose is to grasp the properties and the nature of these extreme laser processes. However, a mathematically solid understanding in the form of principles, formulations, equations, etc., is sorely lacking. This lack extends from the laser-driven mechanics of particles, to that of plasmas, and onto that of fluids.

*Based on a physics "FEMTO meeting" talk *"Optical alignment: particle dynamics in the presence of two colliding laser pulses"* given 12/1/2005

Our present focus is on the mechanics of particles. They are the fundamental building blocks of matter, and as such their interactions with ultra-intense laser radiation plays a fundamental role in physics. The nature of these interactions, which manifests itself through the mechanical trajectories of test particles, is controlled by the externally given laser-radiation field.

2 Scattering by a Pair of "Colliding" Laser Pulses

Consider a set of charged particles scattered by two counter propagating ("colliding") laser pulses. The amplitude profile of each pulse is

$$\frac{q}{m}A_x = \frac{qE}{m\omega c}e^{-((t\pm z)/L)^8}\sin\omega(t\pm z) \quad \text{(super-Gaussian pulse)} \qquad (1)$$

which for

$$\begin{aligned} \omega &= 1 && \text{(optical frequency)} \\ L &= 2\pi && \text{("pulse width")} \\ \frac{qE}{m\omega c} &= 1 && \text{(impulse factor)} \end{aligned}$$

is depicted in Figure 1. The process of these particles passing through the e.m.

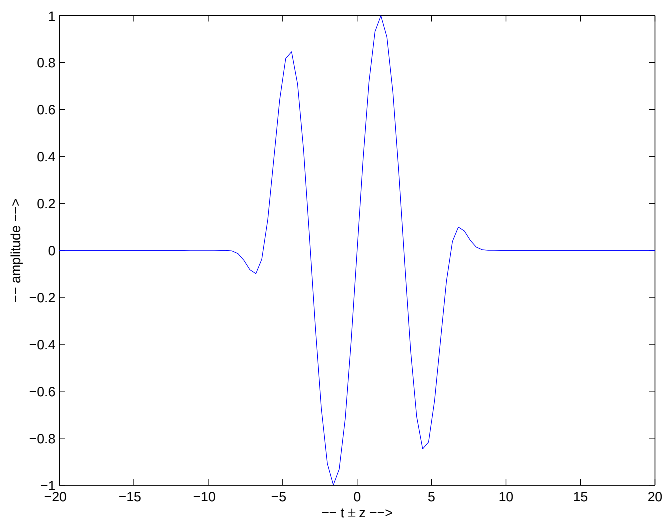

Figure 1: Amplitude profile of the super-Gaussian pulse, Eq.(1).

field of this pair of pulses is a scattering process. The region where the two pulses pass each other ("collide") is an instantaneous scattering center in space and time. The domain for the scattering is two-dimensional – space and time (z and t in the lab).

The spacetime region where the two pulses collide separates the 2-d spacetime into an "IN-region" and an "OUT-region". They are the causal past ("asymptotic past") and the causal future ("asymptotic future") of the spacetime region where the two pulses pass through each other. These regions form the setting for a scattering experiment.

By following the process of N charges being scattered by the colliding pulses, one finds that the final velocities have a distribution whose form is given by the shape and the intensity of the two colliding pulses. Figure 2 is a MATLAB generated histogram of N=200 000 particles being scattered by the two colliding pulses in Figure 1.

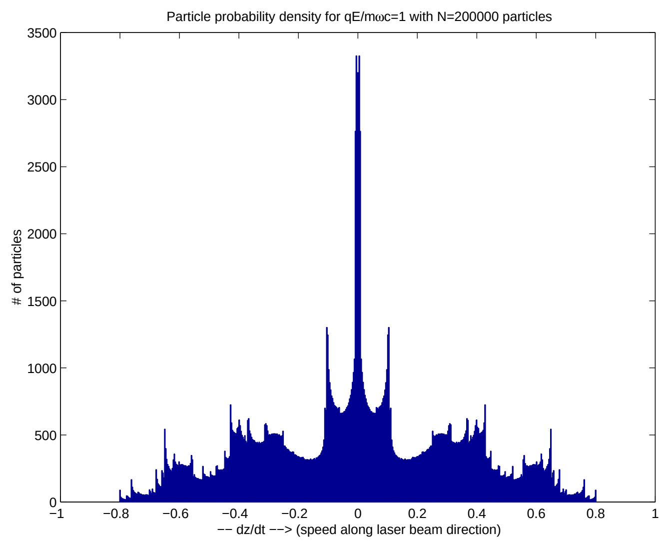

Figure 2: Histogram of 200,000 particles scattered by a pair of colliding laser pulses, each of $\sim$ two cycles as in Figure 1 and each having an intensity of $\sim 10^{18}$ watts/cm^2 (i.e. $qE/\omega mc = 1$). *Nota bene:* The spacetime world line of each particle was determined separately by integrating the classical Lorentz equations of motion 200,000 times. Using a MATLAB code of about one page, this process took $\sim$24 hours.

The causal relationship between this histogram distribution and the "collision" establishes a correspondence between the two. It is clear that for a given pair of pulses there is a unique outgoing particle distribution (like Fig. 2). However, it is not known whether this correspondence is one-to-one. If it were, then this distribution function would be a very sensitive tool for measuring the shape and the intensity of "colliding" laser pulses.