Nonlinear Quantum Electrodynamics In The Focus Of A High Peak Power Laser[1]

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We have constructed a $\lambda = 1.053\mu$m laser system which delivers 2J, 1.5ps pulses, focussed down to a 1.4 times diffraction limited, $50\mu\text{m}^2$ spot size. When 46.6GeV electrons are brought into approximately head-on collision with an $\sim 10^{18}\text{W/cm}^2$ laser pulse at the Stanford Linear Accelerator Center (S.L.A.C.), they see, in their own rest frame, a Lorentz transformed intensity $I' \sim 4\gamma^2 I > 10^{28}\text{W/cm}^2$, where $\gamma \sim E_e/m_e$. In such circumstances, multiphoton Compton scattering up to at least fourth order has been observed, and a limit for multiphoton Breit-Wheeler pair production has been established. Type II KDP crystals are used for frequency doubling, efficiencies as high as 55% have been observed. This lowers the number of laser photons required to conserve relativistic energy and momentum in pair production.

The laser system was designed and built with three primary goals: high intensity, high repetition rate, and phase stability. Our system uses Chirped Pulse Amplification to generate high peak power pulses.[1] The flashlamp pumped Nd:Glass slab that serves as the system's final amplifier, delivers 1 terawatt pulses at a 0.5Hz repetition rate, with good focussability.

It is important to maintain spatial and temporal overlap of the laser pulses and electron bunches. The laser pulse area at the focus is $\sim 50\mu\text{m}^2$, whereas the electron bunch area is significantly larger. A Mach-Zender Interferometer monitors the pointing of the laser. The FWHM lengths of the pulse and bunch are 1.5 and 3.0ps respectively. Temporal overlap of the laser pulses with the electron bunches that are generated $\sim$ 4km away is achieved by driving a low Q, intracavity mode locker synchronously with the accelerating RF. The 12th subharmonic of the accelerator's klystron frequency (2.856GHz) is transported to the laser room via an optical fiber. It is decoded, divided down to 59.5MHz, and sent into a Lightwave Technologies stabilizer. The stabilizer output is fed into the

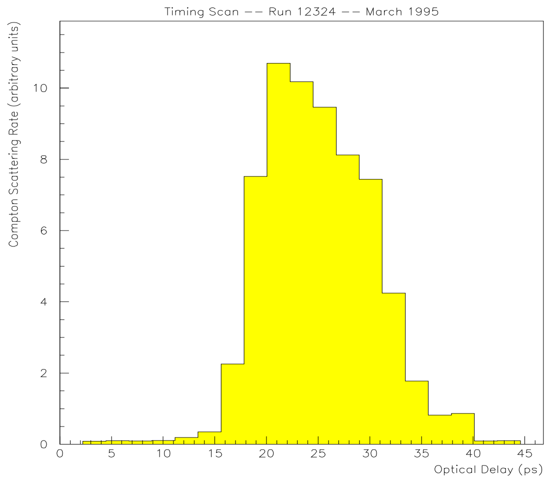

Figure 1: Scattering Rate versus Optical Delay

module which drives the acousto-optic mode locker crossed by the lasing axis of our Nd:YLF Oscillator. A photodiode monitors the Oscillator's output and its signal is fed into the stabilizer. The stabilizer performs a phase comparison between the photodiode and the aforementioned Master RF subharmonic. This signal is used for phase feedback, locking the laser pulses to the electron bunches with a jitter measured to be less than 1.5ps.

The jitter reported is derived from bunch/pulse collision data. The Compton scattering rate is proportional to the overlap of the pulse and bunch. An optical delay line with femtosecond resolution is used to temporally scan the laser pulse through the electron bunch. Since the bunch and pulse lengths are known, deconvolving the interaction rate (measured as a function of optical delay) gives a measure of the instantaneous jitter. Repeated time scans give information about long term drift. Figure 1 shows the scattering rate as a function of optical delay.

The oscillator output is sent through a fiber/grating expansion stage where it is chirped and stretched. A 1nJ pulse is selected from the 119MHz pulse train and used to seed a Nd:Glass regenerative amplifier. A single 1mJ pulse is selected from the train transmitted through the cavity's 50% output coupler. It is sent through a 1.5:1 air spatial filter and, in twice traversing a

[1]This paper has been accepted for presentation at the 1995 IEEE Lasers And Electro-Optics Society Annual Meeting.

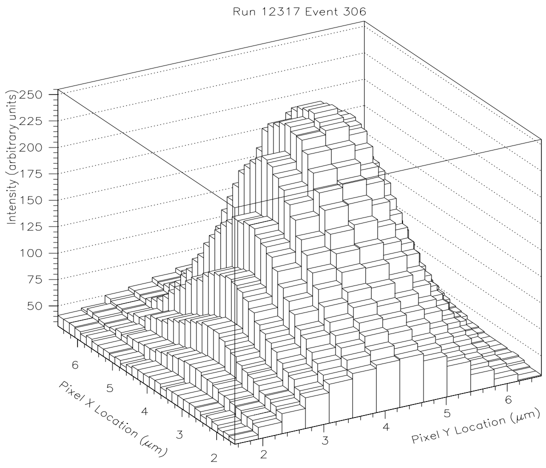

Figure 2: Laser Pulse Intensity Profile Showing a $50\mu\mathrm{m}^2$ Focal Spot Size

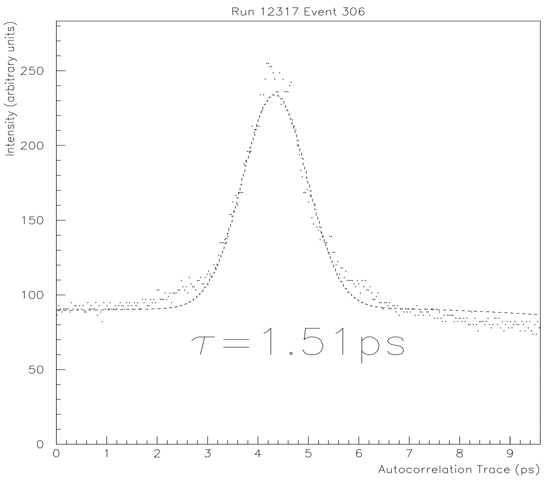

Figure 3: Laser Pulse Autocorrelation Trace Showing a 1.5ps FWHM Pulsewidth

second Nd:Glass rod amplifier, is boosted to 15mJ; high spatial frequency components are removed in a 1:1 vacuum spatial filter.

Emerging from the spatial filter, the pulse is steered through a set of four prisms which expand the horizontal width of the pulse by a factor of ~ 4.4. The elliptical beam is further expanded in a 2:1 Galilean telescope before being sent into the 1.1×6.5cm clear aperture of the Nd:Glass slab. The pulse traverses the slab three times in a bow tie pattern making 12 bounces per pass, 8 of which occur in the slab's 20.3cm pumped length. Small signal gains on the order of 600 have been measured, and 15mJ pulses have been amplified to over 3.5J.

The slab output is recircularized by a pair of cylindrical lenses. It is further up-collimated in a second Galilean telescope and a second vacuum spatial filter before being sent into the grating pair compressor, set in a double pass configuration. The compressed pulse is steered by the gratings into the beam transport line. For operation in the green, the doubler is inserted just prior to the beam transport line. The $\sim$ 10m transport line steers the beam through the radiation shielding to the interaction point. An off-axis paraboloid focuses the pulse into the interaction region. A second off-axis paraboloid recollimates the beam and directs it back to the laser room where it enters a diagnostic line. This line contains a pyroelectric Joulemeter, a CCD camera (from which a real-time fit to the focussed pulse intensity profile derives the effective focal spot area), and single shot autocorrelators sensitive to $\lambda = 1.053\mu$m and $\lambda = 527$nm light. Figures 2 and 3 show the focal spot profile and autocorrelation trace for a 500mJ, 1.51ps, $50\mu m^2$ pulse recorded in the March 1995 run.

Large multiphoton Compton scattering rates have been measured. Computer simulations which predict relative rates of generation of recoil electrons, positrons, and gammas for given outgoing particle momentum, bunch characteristics, and pulse characteristics are in excellent agreement with our data. Analysis of the complete sample is underway.

Acknowledgments

This work was supported by the U.S. Dept. of Energy under contract No. DE-FG02-91ER-40685 and performed by the $E-144$ collaboration, comprised of members from The University of Rochester, Princeton University, S.L.A.C. , and The University of Tennessee.

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