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The SLAC Polarized Electron Source Laser System*

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Abstract:

The Stanford Linear Collider (SLC)[1] has operated a polarized photocathode electron source and titanium sapphire laser for high energy physics collisions for over 6500 hours of nearly continuous operation. The laser system for the source has demonstrated >98.5% total uptime for the duration of the experiment. The laser system uses a pair of titanium sapphire oscillators pumped by frequency doubled YAG lasers to produce 2ns, 250μJ pulses at wavelengths from 740nm to 870nm.

Source Requirements:

The SLC uses a 3 kilometer linac to produce a 50GeV electron beam for high energy physics experiments. The electron source[2] uses a DC high voltage photocathode electron gun driven by a pulsed laser, and subharmonic bunchers to produce a pair of electron bunches. After both bunches are damped (in 1 GeV storage rings), the first bunch is sent to the high energy collision point, the second is used to generate positrons. The positrons are damped (in a second ring) and then injected into the main linac to be accelerated and then collide with the electron bunch at the high energy collision point.The photocathode gun and source laser have the following operating parameters (based on 1994 performance except where indicated).

Photocathode type	Strained GaAsP - GaAs, 1.5 cm^2 area.
Cathode QE at 845nm (operating λ)	0.1% (after cesiation)
Gun high voltage	120 kV DC
Maximum charge each pulse (after cesiation)	8×10^{10} e^- (13nC)
Pulse length	2ns FWHM
Pulse Structure	2 pulses, 62 nsec separation
Repetition Rate	120 Hz

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Electron polarization	≈80%
Cathode QE lifetime (1/e)	≈ 1500 Hours
Cathode operating hours (1993 run)	≈ 5000
Laser operating wavelength	740nm - 870nm each bunch
Laser pulse energy	250μJ each bunch, 125μJ to cathode
Laser transverse profile	TEM_{00}
Pulse timing stability and timing jitter	<50 picoseconds RMS
Laser intensity Stability	< 1.5% RMS
Laser pointing Stability	<5% Spot radius
Laser operating Hours to date	≈ 5000 hours, in 1993, ≈ 1500 in 1994
Laser unscheduled downtime	<0.5%
Laser total downtime including maintenance	<1.5%

System Design:

Titanium doped sapphire $Ti^{3+}:Al_2O_3$ (Ti:Sapphire)[3] was chosen as the active material due to its large tuning range, and relatively wide scale use in industry. Frequency doubled Neodymium Yttrium Aluminum Garnet $Nd^{3+}:Y_3Al_2O_{12}$ (Nd:YAG)[4], was chosen as the pump source. When this system was developed, commercial Nd:YAG lasers with the required energy (>10mJ) were only available at repetition rates of up to 60Hz. We used a pair of Nd:YAG lasers, operating interleaved as a pump source.

The charge limit effect[5] in the photocathode limits the amount of charge which can be extracted, and produces a coupling between the first and second bunches. The SLC only requires that the first bunch be polarized, allowing us to use a shorter wavelength for the second bunch to provide a larger charge limit. We use independent Ti:Sapphire cavities for the first and second bunches to allow independent tuning.

The output beams from the Ti:Sapphire cavities are chopped to the required 2ns width, and have their intensities adjusted to produce the required electron beam current. The output beams from each cavities can be independently steered and focussed. The overall configuration is given in figure 1.

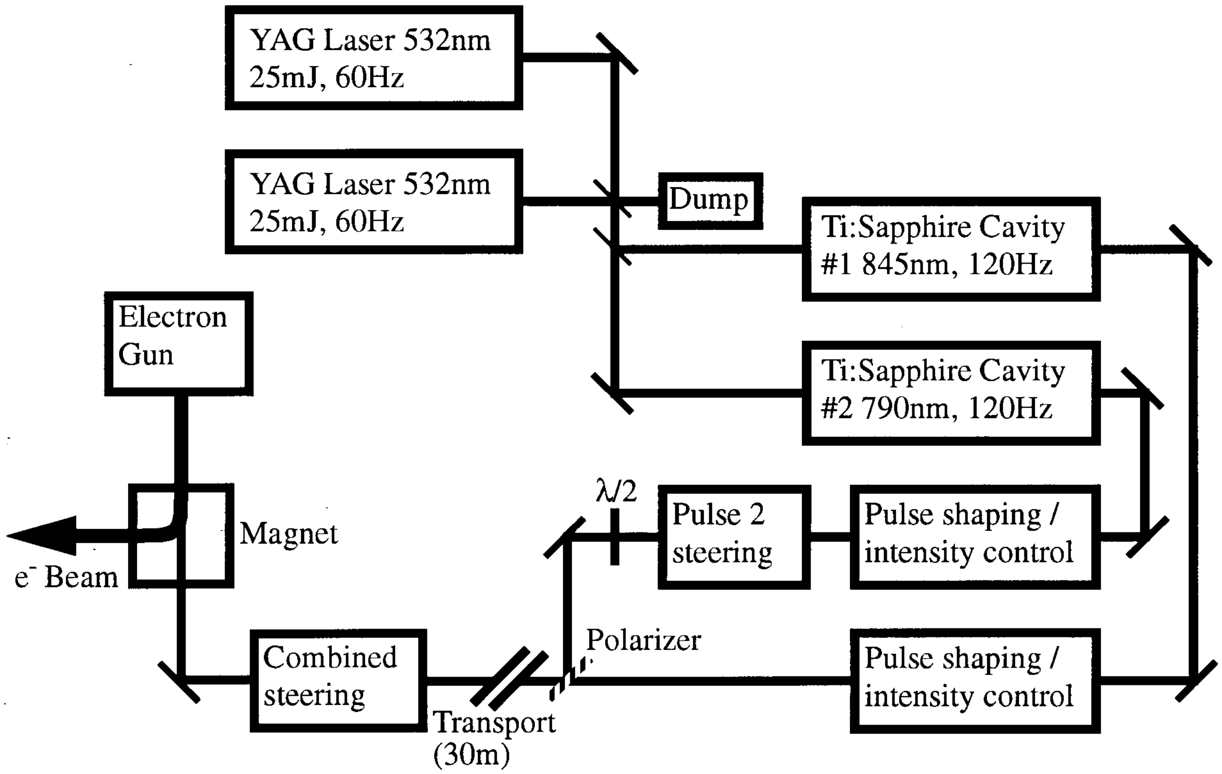

figure 1.

The pump YAG lasers are commercial flash lamp pumped, frequency doubled systems. Although designed for 60mJ, they are operated at 25mJ at 532nm to provide longer component, especially flashlamp, lifetime. They are not injection seeded and therefore produce an output pulse with substantial mode beating in 6ns FWHM pulses. Output beam pointing drift is compensated by imaging the YAG rods onto the Ti:Sapphire crystals. The output intensity jitter is approximately 3%RMS. We typically obtain a flashlamp lifetime of 2 months (3×10^8 shots). The pump chambers last 4-6 months.

The Ti:Sapphire cavities (figure 2) are stable resonators approximately 50cm long. The crystals are end pumped by imaging the YAG rods to a peak energy density of $1.8J/cm^2$. Gain is approximately 50%/pass, overall efficiency is $\approx$15%. A pair of Brewster angle polarizers, one in transmission, one in reflection are used to tune the cavity and allow Q-switching[6] with the intra-cavity Pockels cell. Out coupling is through one of the Polarizers when the Pockels cell is used to cavity-dump[7] the system.

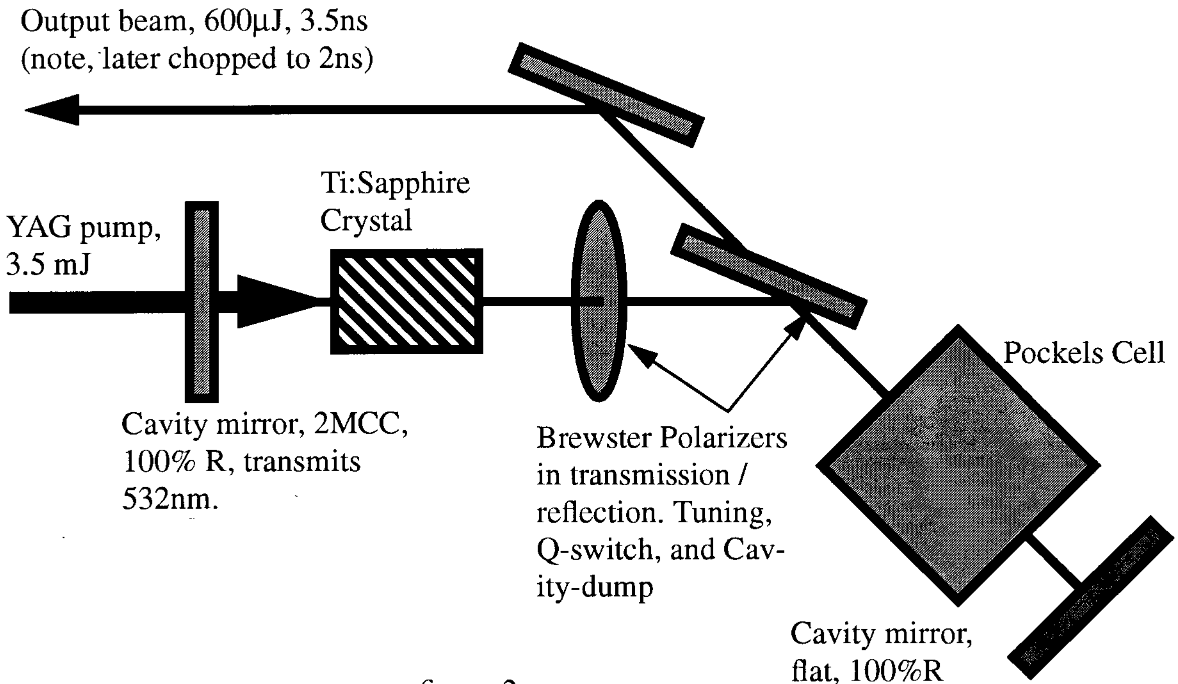

figure 2.

The Ti:Sapphire cavities (figure 2) are operated in a Q-switched, cavity-dumped mode. First a high voltage (2kV) pulse is applied to the Pockels cell before the YAG pump pulse arrives to temporarily prevent lasing. After a few hundred nanoseconds, the high voltage pulse ends, and lasing begins to develop in the cavity. Near the peak of the intracavity power, a high voltage pulse is again applied to the Pockels cell. This pulse dumps the intra-cavity circulating power through the cavity polarizer to the output. The resulting pulse has a length which is the round trip optical transit time of the cavity (about 3.5 nanoseconds). This pulse is later chopped to the required 2 nanosecond FWHM. A timing diagram for the laser system is shown in figure 3.

The output beams from the Ti:Sapphire cavities are sent to fast Pockels cell choppers which use avalanche transistor drivers to produce a 100ps rise time, 2ns FWHM, 3kV electrical pulses. These pulses are sent on a 50Ω transmission line to a Pockels cell. The pulse reflection from the

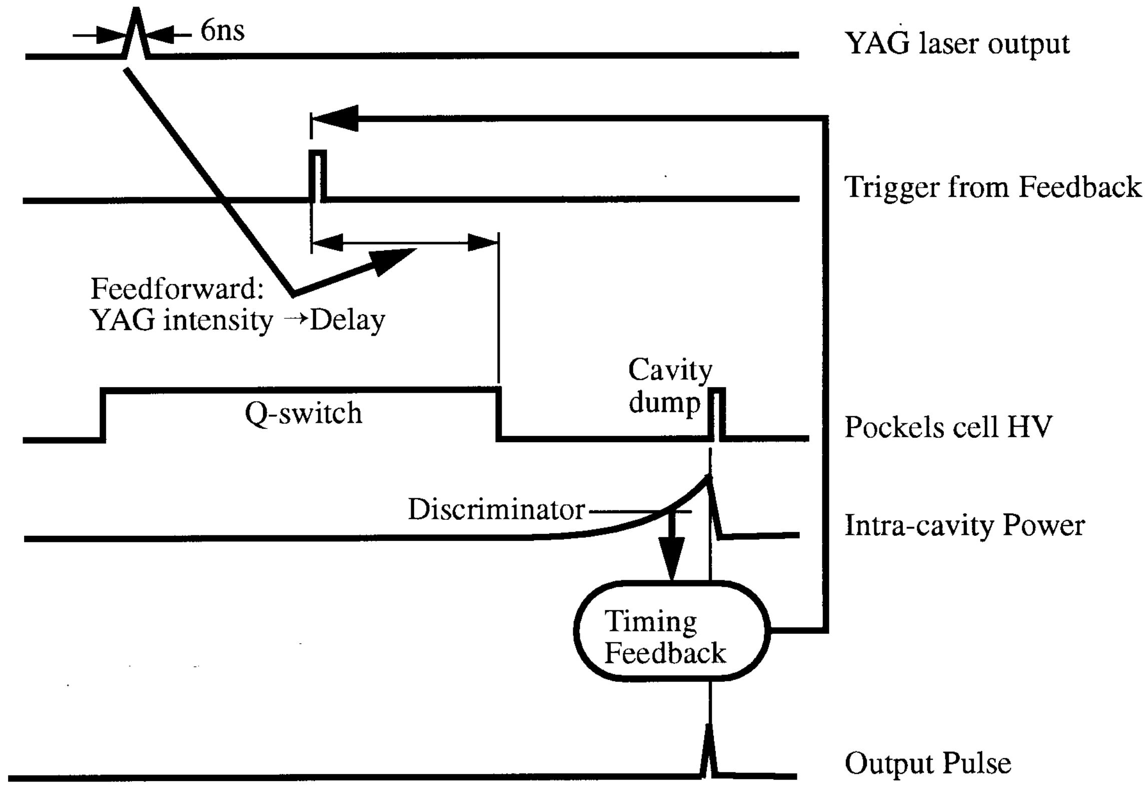

figure 3.

Pockels cell doubles the voltage to 6kV as required for a $\lambda/2$ phase shift to chop the optical pulse. The resulting optical pulse has a risetime of about 750ps. A slower (30ns) adjustable amplitude pulser is used to drive an additional Pockels cell to control the output laser beam intensity.

The Ti:Sapphire cavities are stable resonators and produce pure TEM_{00} beams. A remote controlled telescope is used to steer and focus the beam from the second cavity. A separate telescope is used after the beams are combined to control the position and size of both pulses. Remote readout of energy, pulse shape and wavelength are provided in to the accelerator control system.

Feedback system:

One of the most stringent requirements on the laser system is that it operate with good stability for long periods of time without adjustment. The controls and diagnostics for the laser system are connected to the SLAC accelerator control system which provides software feedbacks for stabilization. Additionally hardware feedforwards are used to improve pulse to pulse stability.

Each YAG laser has its output energy stabilized by a feedback which controls the high voltage to the laser flashlamps. An adjustable hardware limit prevents the feedback from accidently driving the high voltage high enough to cause damage. Typically over the two month lamp lifetime, the high voltage is adjusted from 1100V to 1250V.

The time for the end of the Q-switch pulse in each Ti:Sapphire cavity is controlled by a feedback which monitors a photodetector which measures the intracavity power. This feedback stabilizes the time at which the intracavity power builds up. The cavity dump time for the laser is fixed by the accelerator requirements, so this feedback ensures that dumping occurs near the peak of the laser pulse.

The output energy after the pulse shaping is monitored by photodetectors. Feedbacks then adjust the voltage on the intensity control pulsers to stabilize the energy at the required level. The set-points for these loops are adjusted by a low bandwidth loop which monitors the electron beam current from the gun, and adjusts the laser power as required to compensate for the changing quantum efficiency.

Feedforward system:

The primary source of intensity instability in the Ti:Sapphire laser is changes in gain causing variation in the build-up time of the intra-cavity power. Since the cavity dump time is fixed, these changes in build-up time produce intensity fluctuations. With no compensation, the gain changes resulting from the 3% RMS YAG intensity variation would produce approximately 12% RMS output jitter. By using the timing feedback (described above) to control the build-up time to allow dumping near the peak intensity, the jitter is reduced to approximately 4%. This remaining jitter is uncorrelated pulse to pulse.

The feedforward system measures the YAG output energy on each pulse, and then on the same pulse (while the Q-switch is preventing the Ti:sapphire cavities from lasing), adjusts the timing of the end of the Q-switch pulse. Increases in YAG energy cause the Q-switch time to move later to compensate for the increased gain. The timing is set so that the cavity dump occurs on the trailing edge of the intracavity pulse. By correctly adjusting the feedforward, the output is made first order invariant in the pump energy. With 3% RMS pump fluctuations, we typically obtain <1.5%RMS output (often < 0.8%RMS).

System operational experience:

This laser system was used on the SLC linac for the 1993 physics run, and is currently in use for the 1994 physics run. It has operated approximately 6500 Hours with less than 1.5% total downtime. During the 1993 run, 50,000 Z_0s[8] with an average source electron polarization of approximately 65% were delivered to the SLD detector for high energy physics. During the 1994 run, it is expected that 100,000 Z_0s will be delivered with approximately 80% polarization.

References:

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[3] A. Sanchez, "Crystal Growth, Spectroscopy, and Laser Characteristics of Ti^{3+}:$Al_2 0_3$", IEEE J. of Quantum Electronics, vol. 24, no. 6 (1988) 995

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[5] M. Woods et al. "Observation of a charge limit for semiconductor photocathodes" Journal of Applied Physics V 73 (1993) 8531

[8] The SLC Collaboration "Precise Measurement aof the Left-Right Cross Ssection Asymmetry in Z Boson Production by e^+e^- Collisions" SLAC-PUB-6456 (1994), sumitted to Physical Review Letters.