A HIGH-INTENSITY HIGHLY-POLARIZED ELECTRON BEAM FOR HIGH-ENERGY PHYSICS

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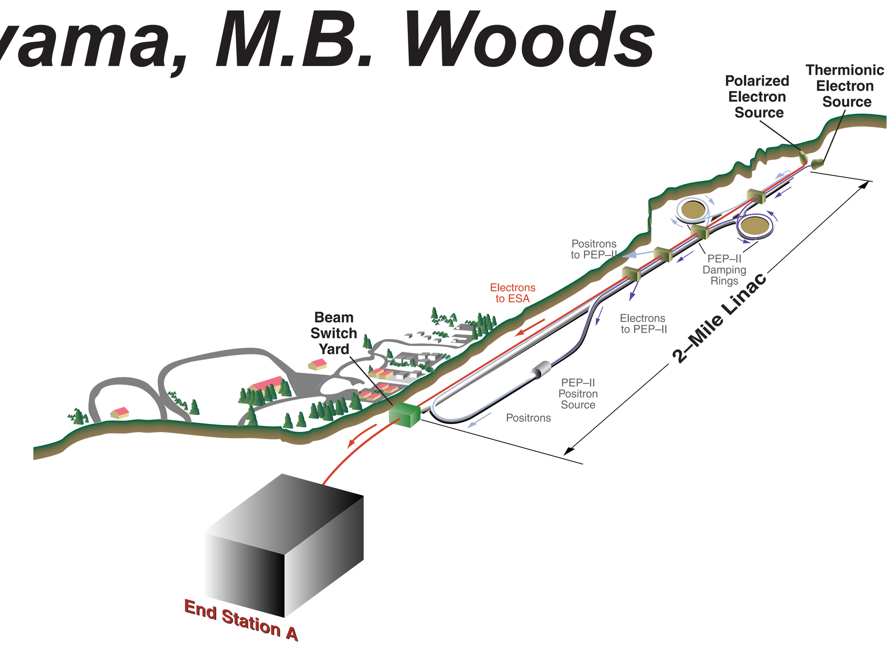

INTRODUCTION

The E158 parity violation experiment requires a high power (1/2 MegaWatt), highly polarized electron beam with low jitter and minimal helicity correlations. Beam parameters achieved for E158 are summarized in table 1.

Table 1 Beam achieved for E158 and needed for NLC

	E158	NLC
Intensity/pulse	$6x10^{11}$	$14.4x10^{11}$
Rep. Rate	120 Hertz	120 Hertz
Intensity jitter	0.5%	0.5%
Energy	45 GeV	250 GeV
Energy jitter	0.02%	0.3%
Pulse Train	270 nanoseconds	267 nanoseconds
Microbunch spacing	0.35 nanoseconds	1.4 nanoseconds
e- Polarization	~80%	80%
Transverse jitter	5% of spotsize	22% sigma x, 50% sigma y
Energy spread	0.15%	0.25%

THE SOURCE

- No evidence of charge limit [4] for a cathode developed for NLC at SLAC [1] (figure 1)
- Unique capability of delivering high intensity high polarization beam This
- High intensity facilitates shaping of the pulse temporal profile to compensate for beam loading and achievment of a small energy spread.
- Peak polarization of cathode (figures 2 and 3) occurs near the maximum of the gain curve of the SLAC-built ultra-stable Ti:Sapphire laser (Laser operates at 805 nm; Peak emission for Ti:Sapphire is 790 nm [5])
- Cathode quantum efficiency is maintained by a three day cesiation cycle (figure 4)

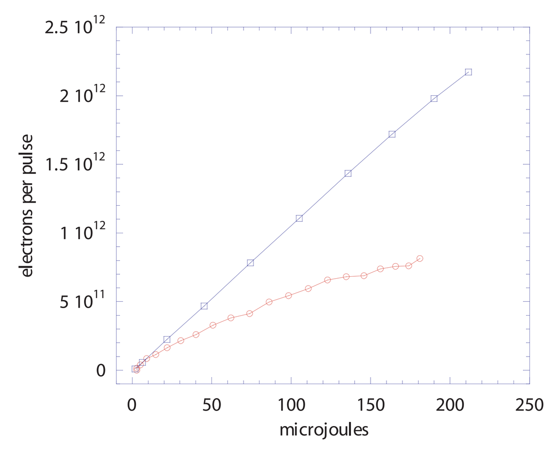

Figure 1: Top curve is the charge in 100 nanosecond long train from the new cathode with high surface doping plotted versus laser intensity. Lower curve is the charge in an even longer 350 nanosecond train from the previous cathode, a standard strained GaAs with $5x10^{18}/cm^3$ uniform doping.

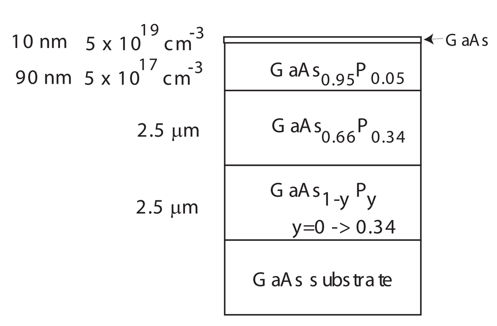

Figure 2: Structure of the strained GaAs photo cathode

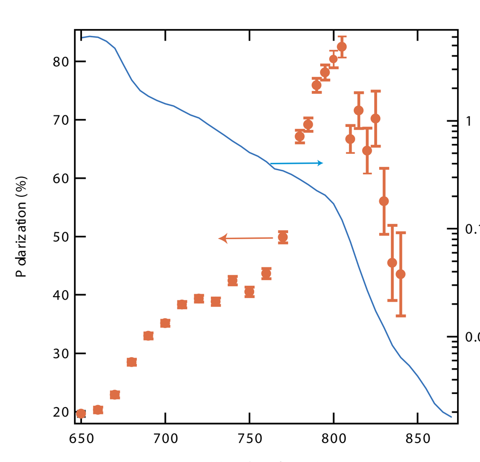

Figure 3: Quantum efficiency and e- polarization of the photo cathode vs. laser wavelength

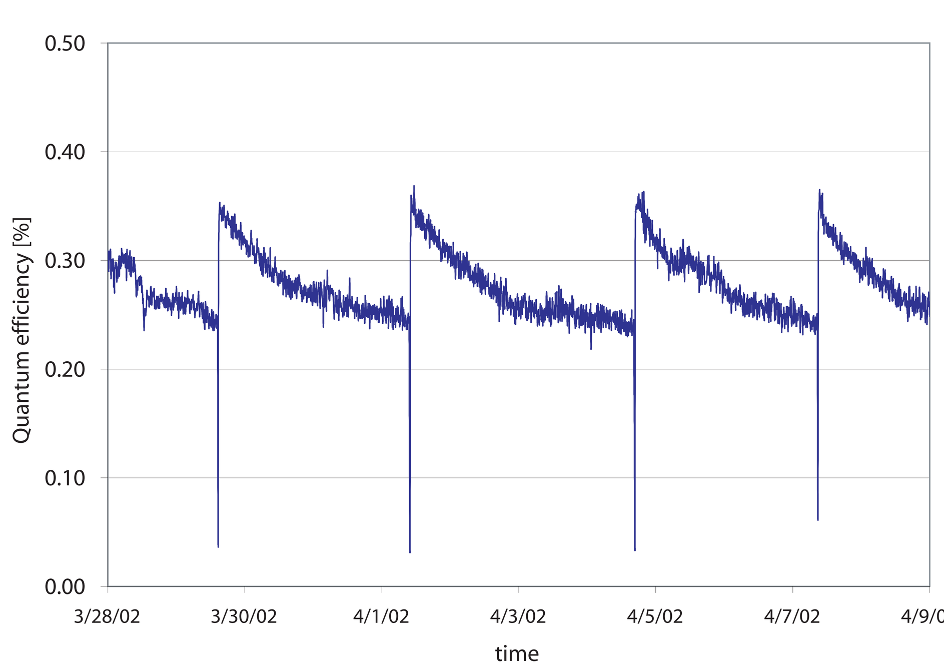

Figure 4: Cathode lifetime and cesiation cycle

- Laser cavity is optimized for maximum power and maximum peak to peak stability [5]
- The multimodal laser beam profile is depicted in figure 5.
- The temporal laser pulse shape and jitter are shown in Figure 6 (jitter is based on the rms for 100 consecutive samples).
  The minimum 0.8% jitter achieved includes electronics noise in the photodiode measurement.
- Jitter observed in the electron beam is 0.5% rms.
- Source intensity capability a factor 7 greater than required by E158 due to Laser and cathode improvements
- Optimized source laser system minimizes helicity-correlated effects in the resulting electron beam parameters (Q, E, x, x', y, y') [6]. Such effects can be large due to strain anisotropies of the cathode that cause a quantum efficiency dependence on residual linear polarization of the laser light [7].
- The laser beam incident on the cathode is circularly polarized, helicity control is achieved by a linear polarizer followed by a pair of Pockels cells
- The corresponding left-or right-voltages are selected by a pseudo-random algorithm

Abstract

A new high-energy parity violation experiment at SLAC as well as particle-physics experiments using future e+e- colliders (such as NLC) operating at energies above the scale of unification of the electromagnetic and weak interactions require a highly-polarized electron beam with intensity requirements previously unachievable due to a surface charge limit effect at the cathode of the polarized electron source. Using a GaAs(0.95)P(0.05)/GaAs(0.66)P(0.34) single layer photocathode with high surface doping that was recently developed at SLAC as part of the NLC R&D effort[1], a beam with >2x1012 e- per 100 ns of pulse length (and up to 3 A/cm2) has been produced at the electron source of the SLAC 3-km linac, limited only by the available laser energy. This is considerably more charge per unit pulse length than required for the NLC macropulse. The polarization measured in the laboratory is ~80%. The present PV experiment (E-158) at SLAC requires 8x1011 electrons in a ~300 ns pulse (350 mA). Consequently there is sufficient head room to shape the pulse temporal profile to allow the necessary energy compensation for the linac beam loading to limit the energy spread at 48.7 GeV to ~0.3% rms. The intensity stability required for stable machine operation is determined by the source laser stability. After recent improvements [2], the SLAC-built flashlamp-pumped Ti:Sapphire laser [3] now has an energy stability of 0.5% rms. Temporal pulse shaping is performed on the laser beam using an improved pulse shaper. Details of the beam generation, energy compensation, and linac performance recently achieved for E-158 will be discussed.

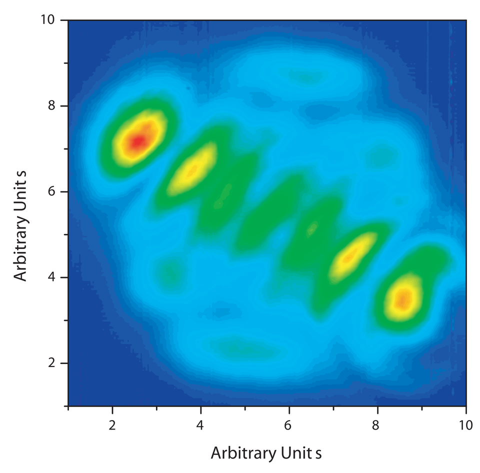

Figure 5: Laser beam profile showing the dominant higher order TEM's essential for required temporal pulse shape

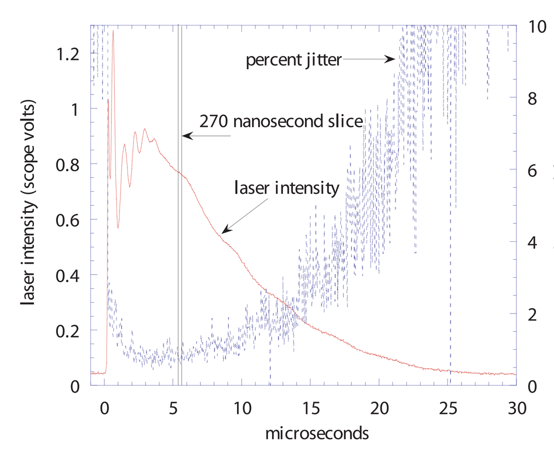

Figure 6: Laser intensity in arbitrary units and jitter in percent. Note the low jitter at the point where a 270 nanosecond slice is made.

BEAM LOADING COMPENSATION

- Temporal profile of the laser pulse is shaped using a fast high voltage Pockels cell / polarizer pair, to thereby shape the electron pulse (figure 7).
- This is necessary to utilize a unique solution [8] whereby on the high gradient RF curve utilized at SLAC, (from SLAC Linac Energy Doubling - SLED, that is the energy from the energy doubled klystrons) summed with the energy removed by beam loading achieves a remarkably small energy spread over the length (270 nanoseconds) of the electron pulse.
- The shaped electron pulse must travel through about 15 meters of flat, non-doubled RF to 170 MeV and traverse a non-isochronous chicane before transmission on the "SLEDed" RF.
- The beam loading compensation scheme for the un-SLEDed RF is a mixture one modeled, and one experimentally developed. The solution calls for the timing of 2 of the 5 flat-top RF klystrons to turn on late (see figure 8), having the last 200-300 nanoseconds of their ~800ns risetime concurrent with the beam passing through.
- Additionally, a 180 degree phase shift (note the downward notch in the top picture of figure 9) through 4/5 of the sections is timed critically to reduce energy spread at the end of the train. This scheme achieves an energy spread of 0.3% full width (see figure 9 bottom).

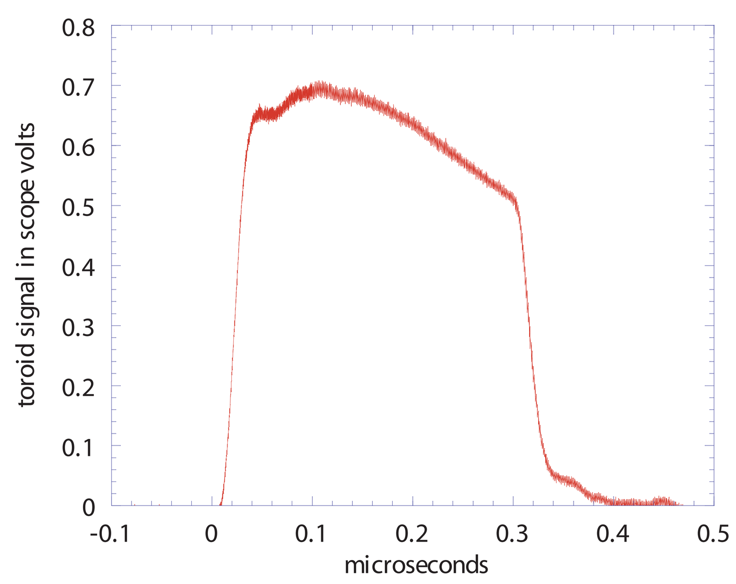

Figure 7: Toroid oscilloscope trace in envelope mode, showing the pulse shape and intensity jitter of 16 consecutive pulses.

OTHER EFFECTS

Single Bunch Effects

The chicane gives the equivalent of about 1.2 degrees of RF in time of flight variation per MeV. This requires the beam loading compensation as well as the single bunch energy spread to be good to the 0.3% level. While this is achievable, there are gains in the single bunch energy spread at the experiment which are achieved by time of flight bunching through the chicane. The beam is run 8 degrees off crest of the RF upstream of the chicane, creating a correlation of energy to longitudinal position in a single bunch, resulting in bunch compression through the chicane. Though a new bunching diagnostic looking around ~13 GHz has improved the tuning of longitudinal bunching parameters upstream near the source, this additional time-of-flight scheme is also employed.

Multibunch Effects

A source of jitter is transverse wakefields over the 270 nanosecond train. RF beam position monitors, located at 1.19 GeV beam energy, with integration are used [6] as a real-time transverse wakefield diagnostic. Another measurement used is with strip-line beam position monitors looking at the falling (trailing) edge of the pulse. The rms motion of the tail of the pulse, due to wakefield effects as well as residual dispersion, can be quickly viewed in a z-plot of beam position monitors down the linac; the orbit can then be tuned to minimize tail jitter.

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INJECTOR OPTICS

Other beams produced for the operation of the PEP-II B-Factory are interleaved with this high power beam. A second, short pulse laser [2] is combined optically to provide beams for PEP-II. The lower current PEP-II beams have relatively no beam loading effects to consider. This makes the energy profiles of the high power beam and the PEP-II beam somewhat different from the Gun to the 1.19 GeV point. Optical matching of the various beams in this area is not a problem for transmission to PEP-II or E158 due to a high bandpass lattice optimized to reduce chromatic effects. This was done using a new version of the optics program MAD[9] which includes linear acceleration and structure end focussing.

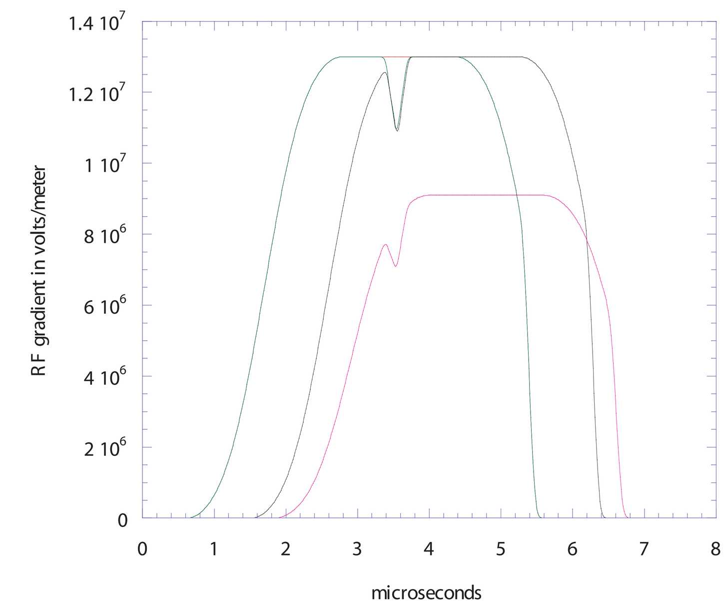

Figure 8: Energy profile of 5 individual sections powered by 5 klystrons. A 180 degree phase shift is given to all but one klystron

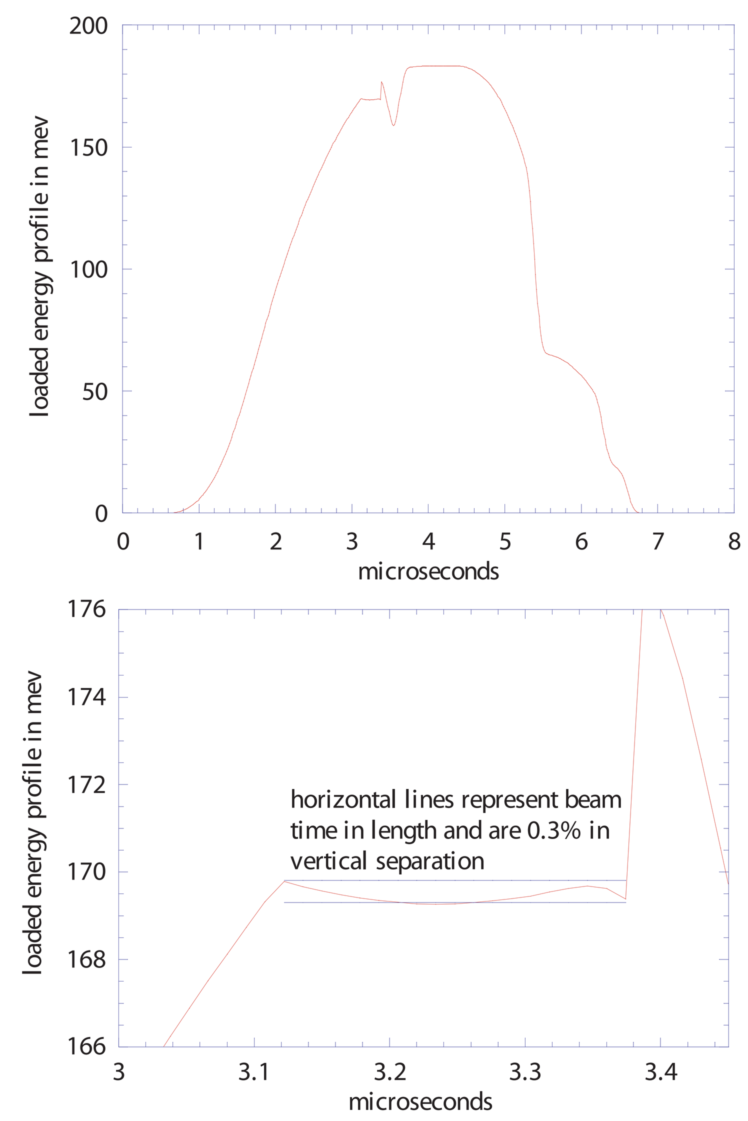

Figure 9: Simulated beam loaded energy profile at the non-isochronous chicane. Top picture is the full energy profile from the sum of 5 accelerator sections, 2 of which are staggered in time and the beam, bottom is the top left corner of the top picture. Lines indicate 0.3% full width energy spread where the 270ns-long pulse occurs.

SUMMARY

- Source capability of high current, high polarization, low jitter, and low energy spread.
  -> Key to the success of the E158 experiment is the The recent cathode development at SLAC
- Capability of high current, both by elimination of the charge limit effect for NLC
- Optimization of source laser allows low jitter, high polarization and high brightness performance
- Linac produces a stable beam with a heavily beam-loaded gradient.
- A solution for energy spread minimization with "SLEDed" RF and flat top RF has been found.
- Electron intensity is shaped in time for the "SLEDed" case and novel use of phase shifts and timing are used to solve the flat top RF case loaded by the shaped beam.
- Added intensity overhead due to cathode development allows for pulse shaping

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