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

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Abstract

A new high-energy parity violation (PV) 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 intensities previously unachievable due to a surface charge limit (SCL) effect at the cathode of the polarized electron source. A newly developed photocathode which allows these high intensities is being used for the SLAC PV experiment E-158. The intensity stability required for stable machine operation is determined by the source laser stability, which has been reduced to 0.5%. 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 the SLAC parity violation experiment E-158 are discussed.

1 INTRODUCTION

Using a strained 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 $>2\times10^{12}$ e^- per 100 ns of pulse length has been produced at the electron source of the SLAC 3-km linac with no evidence of the SCL [2]. See Fig. 1. This is more charge per unit pulse length than required for the NLC. The polarization measured in the laboratory and confirmed at high energy is ~80%. The parity violation experiment (E-158) at SLAC requires 6×10^{11} electrons in a pulse of ~300 ns at high energy, which is readily achieved with the new cathode. Using the new cathode for E-158, there is now sufficient head room to shape the laser pulse temporal profile to allow the necessary energy compensation for the beam loading of the electron bunch in the linac to limit the energy spread at high energy. Beam parameters achieved for E158 are summarized in table 1.

2 THE SOURCE

The cathode is a variant of the standard SLC strained GaAs/GaAsP structure [3], but with the addition of an extremely high dopant density (~5×10^{19} cm^{-2}) in the final few nanometers of the epilayer. The remainder of the epilayer has some added P to match the band gaps, which keeps the quantum efficiency high, while the substrate P is also increased to maintain the lattice mismatch and thus the strain. The high polarization is achieved both by the strain and by lowering the dopant density in the bulk of the epilayer to 5×10^{17} cm^{-2}.

Table 1 Beam achieved for E158 and needed for NLC

	E158	NLC
Intensity/pulse	6×10^{11}	14.4×10^{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 ns	267 ns
Microbunch spacing	0.35 ns	1.4 ns
e- Polarization	~80%	80%
Transverse jitter	5% of spotsize	22% sigma x, 50% sigma y
Energy spread	0.15%	0.25%

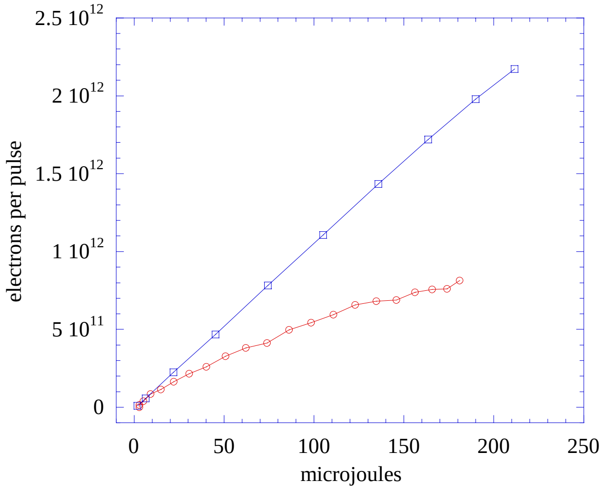

Figure 1 Top curve is the charge in 100 nanosecond long train from the new cathode with high surface doping plotted versus laser intensity. Lower curve is the charge in an even longer 350 nanosecond train from the previous cathode, a standard strained GaAs with 5×10^{18}/cm^3 uniform doping.

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An additional beneficial characteristic of this cathode is that the wavelength required for peak polarization is shifted down near the peak emission wavelengh of the SLAC-built ultra-stable Ti:Sapphire laser. Peak emission for Ti:Sapphire is 790 nm [4], and peak polarization for this cathode is about 805 nm.

Recent changes in the laser cavity [5], have resulted in increased power and lower intensity jitter. The laser pulse shape and jitter are shown in Figure 2. The jitter results quoted are based on the rms for 100 consecutive samples. The minimum 0.8% jitter achieved includes electronics noise in the photodiode measurement. The jitter observed in the electron beam is 0.5% rms.

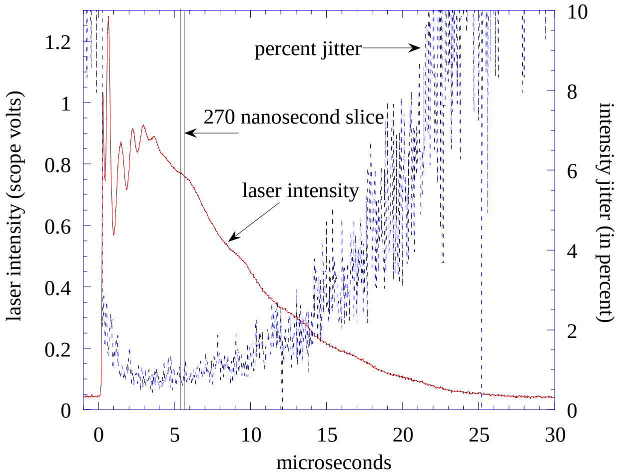

Figure 2 Laser intensity in arbitrary units and jitter in percent. Note the low jitter at the point where a 270 nanosecond slice is made.

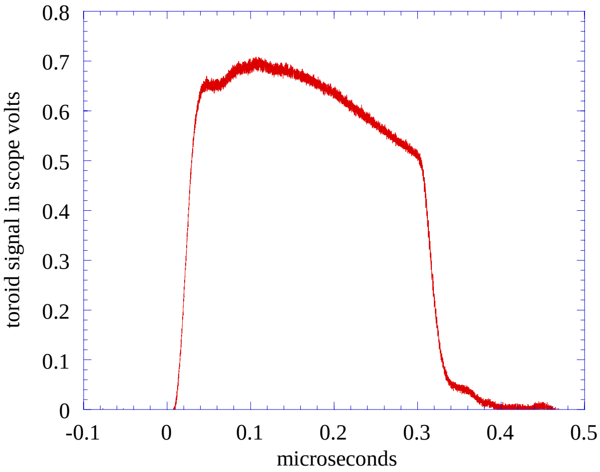

Figure 3 Toroid oscilloscope trace in envelope mode, showing the pulse shape and intensity jitter of 16 consecutive pulses.

The laser improvements, together with the improved cathode, give a source intensity capability a factor 7 greater than required by E158. Much effort is put into the source laser system to minimize 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 is circularly polarized by a linear polarizer followed by a pair of Pockels cells. Its helicity is determined by the Pockels cell voltages applied. The corresponding left- or right-voltages are selected by a pseudo-random algorithm pulse-by-pulse.

3 BEAM LOADING COMPENSATION

The light is shaped using a fast high voltage Pockels cell / polarizer pair, to thereby shape the electron pulse (see figure 3). 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. This 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 4), having the last 200-300 nanoseconds of their ~800ns risetime concurrent with the beam passing through.

In addition, there is a 180 degree phase shift (note the downward notch in the top picture of figure 4) through 4/5 of the sections timed critically to reduce energy spread at the end of the train. This scheme achieves an energy spread of 0.3% full width.

4 OTHER EFFECTS

4.1 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 .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 degress 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.

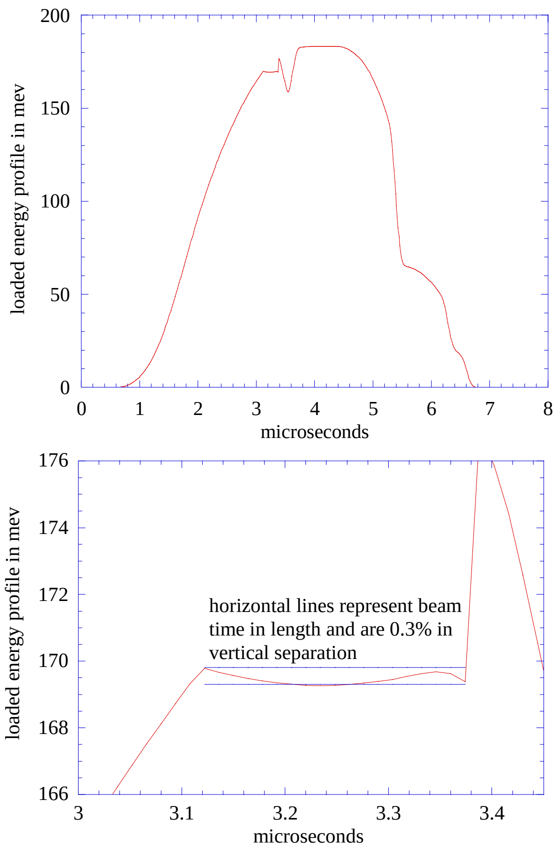

Figure 4 Simulated beam loaded energy profile at the non-isochronous chicane. Top picture is the full energy profile from the sum of 5 accelerator sections, 2 of which are staggered in time and the beam, bottom is the top left corner of the top picture. Lines indicate .3% full width energy spread where the 270ns-long pulse occurs.

4.2 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.

5 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 [5] 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.

6 SUMMARY

Key to the success of the E158 experiment is the source capability of high current, high polarization, low jitter, and low energy spread. The recent cathode development at SLAC for NLC has given the capability of high current, both by elimination of the charge limit effect, and changing the optimum laser wavelength to be near the optimum for Ti:Sapphire along with high polarization. Laser development over the past year has given very low jitter while going to the higher brightness. This low jitter is necessary for stable beam operation with a heavily beam-loaded gradient. Lastly, a solution for energy spread minimization with “SLEDed” RF and flat top RF have been simultaneously solved. 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. The shaping would not have been possible without the added overhead due to cathode development.

7 ACKNOWLEDGEMENTS

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