THE STATUS OF GALLIUM ARSENIDE PHOTOEMISSION GUNS AT JEFFERSON LAB

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Highlights of the polarized beam program at CEBAF at Jefferson Lab will be presented. These include successful completion of portions of parity violation experiments G0 Forward Angle and HAPPEX-II. Experience with commercial modelocked Ti-Sapphire lasers and high polarization strained-superlattice GaAs photocathodes will be discussed. Finally, gun charge lifetime measurements made over the course of many years following charge extraction of nearly 3000 C will be presented.

1. Parity Violation Experiments

The past year has seen the successful completion of scheduled portions of the parity violation experiments HAPPEX-II and G0 Forward Angle. These experiments were demanding from a polarized source perspective, requiring new lasers, new laser-table optical devices, new pockels cell alignment procedures, new injector beamline settings and new software tools to map and set the beam envelope through the machine [1]. Rigorous monitoring of beam properties was required throughout each experiment to maintain consistent and reliable results. For both experiments, the helicity-correlated beam asymmetries were maintained within acceptably small limits (see Table 1).

Table 1. Preliminary run-averaged helicity-correlated beam asymmetries for parity violation experiments recently conducted at CEBAF. Numbers may change slightly as data reduction continues. Error bars are forthcoming.

Experiment	Intensity	Position X	Position Y	Energy
G0 Forward Angle	0.14 ppm	3 +/- 4 nm	4 +/- 4 nm	10 ppb
HAPPEX-II He	0.4 ppm	3 nm	2 nm	2.6 ppb
HAPPEX-II H	0.2 ppm	2.2 nm	2.3 nm	2 ppb

The two experiments faced different challenges. The G0 Forward Angle experiment was lengthy, consisting of two preliminary stages of beam delivery (engineering and commissioning runs) followed by production running. Although production running was only

~ 8 weeks, the total calendar time for all stages of this experiment was over 12 months. The G0 Forward Angle experiment relied on time-of-flight detection which necessitated low duty factor beam at the bunch repetition rate of ~ 31 MHz, which is the sixteenth sub-harmonic of standard 499 MHz CW beam delivered to each experiment hall. Two styles of modelocked Ti-Sapphire lasers were constructed at Jefferson Lab to meet this beam specification however, both lasers proved inadequate. Each laser was ~ 5 m long, with numerous folding mirrors to provide a relatively small footprint. The first version used an intra-cavity acousto-optic modulator (AOM) to initiate modelocked operation. Unfortunately, optical pulses were too long (~ 300 ps) to provide adequate electron beam transmission through the CEBAF injector chopper with 111 ps acceptance. This was likely a result of difficulty obtaining a large depth of modulation (i.e., high absorbed rf power) within the AOM. The second version was seeded with light from a gain-switched diode laser with a pulse repetition rate of 31 MHz [2]. This laser produced 150 ps pulses but the output was contaminated with low-level light at multiples of 31 MHz. In addition, both homemade lasers were "free running", i.e., without active cavity length stabilization. As a result, the phase of the electron beam produced by these lasers would vary by small amounts over time, effecting transmission and beam orbit through the machine in subtle ways. These minor cavity length changes would probably have gone unnoticed by many experiments but they were problematic for a parity violation experiment, where it is extremely important that conditions remain constant. The third and final version of the G0 laser was purchased from commercial vendor Time-Bandwidth Products. This laser also had a ~ 5 m cavity length but modelocked operation was obtained using a saturable absorber mirror [3]. The laser proved to be very reliable with output power 300 mW and active cavity length stabilization to produce an optical pulse train with very low timing jitter. Options were purchased that allowed operation at two wavelength ranges centered at 780 nm and 845 nm and with four different optical pulsewidths between 10 and 70 ps.

The G0 Forward Angle experiment required only $40 \mu\text{A}$, a modest value by CEBAF standards, however it proved to be a difficult matter to deliver this beam to the G0 target because bunch charge was much higher than usual. Transporting $40 \mu\text{A}$ at 31 MHz repetition rate was equivalent to delivering $640 \mu\text{A}$ at the normal pulse repetition rate of 499 MHz, in terms of equivalent bunch charge. Space charge induced emittance growth caused the G0 electron bunches to rapidly expand in space and time and it was impossible to deliver the requested beam current using injector settings that had been adequate for normal CEBAF operations. This is obvious in Figure 1, where 100 kV electron bunch length grows from ~ 100 ps at $0.5 \mu\text{A}$ to ~ 350 ps at $40 \mu\text{A}$. The transverse beam profile also grew as a function of beam current and significant aberrations could be seen at high current. Eventually, injector settings were empirically determined that provided $40 \mu\text{A}$ beam to the endstation with $\sim 80\%$ transmission. The biggest adjustments were made to the laser spot size at the photocathode, solenoid focusing magnet settings and prebuncher amplitude.

High bunch charge and associated less-than-unity injector transmission created problems for parity-quality beam delivery during G0 Forward Angle. Helicity-correlated beam parameters - position, charge and energy - are coupled. For example, helicity-correlated po-

Fig 1. G0 electron bunchlength measured at 100 kV beam energy using the injector chopper. Individual pulse heights were scaled to provide equal area under each curve.

sition asymmetry at the photocathode creates helicity-correlated charge asymmetry downstream of apertures. And helicity-correlated charge asymmetry produces rf-beam loading at accelerating cavities which in turn produces helicity-correlated position and energy asymmetry at the target. Consequently, it was important to eliminate helicity-correlated asymmetries as early in the machine as possible, i.e., at the photocathode. The G0 collaboration used a rotating halfwave plate downstream of the pockels cell to obtain a "coarse minimum" of helicity-correlated position and charge asymmetry. Helicity-correlated charge asymmetry was further reduced by modulating laser power at the photocathode using a device referred to as the IA cell, which consists of a waveplate, a pockels cell driven at low voltage and a fixed linear polarizer. A pzt-driven mirror was used to actively minimize position asymmetry. Typical results are shown in Figure 2, where the plots indicate helicity-correlated beam parameters approach zero as the feedback algorithms take effect.

The HAPPEX-II collaboration hoped to conduct their experiment without using position feedback. To this end, they spent considerable time in advance of the experiment studying pockels cell behavior to develop a test regiment to identify cells with small birefringence gradient and an alignment procedure that placed the laser beam at the precise geometric center of the cell, a location that provides the smallest helicity-correlated laser beam steering [4]. The small helicity-correlated beam asymmetries identified in Table 1 suggests this work was worth the effort. The run-averaged position asymmetries were small and within specifications, without using active position feedback.

There were however, complications associated with HAPPEX-II, which consisted of measurements using two target materials, helium and hydrogen. The intended beam current for this experiment was 80 μ A but radiation heating of the superconducting spectrometer magnets limited beam current to ~ 40 μ A. This made it difficult to obtain reasonable statistical accuracy during the allotted time period for the experiment. To help overcome this shortcoming, strained-superlattice GaAs photocathode material from commercial vendor SVT Associates [5, 6] was installed in one of the CEBAF photoguns. This material pro-

Fig 2. Clockwise from top left; helicity correlated charge, position, energy and angle asymmetries as feedback algorithms take effect.

vided $\sim 86\%$ beam polarization, considerably higher than what is typically obtained from strained-layer GaAs (between 75 and 78%) and the highest value yet measured at CEBAF. Stable beam properties were observed while helium was studied and other halls were not requesting much beam. However, when the collaboration switched to hydrogen and a neighboring hall began to receive high current beam, it was discovered that photocathode lifetime was very poor. To maintain requested beam currents at all halls, the laser spot was moved to "fresh" photocathode locations daily. The rapidly decaying QE and slightly different beam orbits through the injector from each photocathode location created subtle variations in the injector transmission that made it difficult to obtain stable beam conditions on a parity-scale. As a result, the collaboration requested that measurements with the hydrogen target be completed using beam from the other gun, with lower polarization but longer operating lifetime. Figure 3 shows position asymmetry plotted versus run number for beam obtained from each of the CEBAF guns, first using strained-superlattice GaAs and then strained GaAs. Position asymmetries were stable and close to zero while operating from "gun2", the gun with longer operating lifetime.

Both collaborations will return in 2005 and 2006 to complete additional portions of their experiments; HAPPEX will continue their experiment to obtain more accuracy and G0 will conduct backward scattering-angle measurements. The lessons learned during 2004 should make future efforts go smoothly. Other collaborations have taken note of recent success. As a result, it is likely more demanding parity violation experiments will receive approval

Fig 3. Helicity-correlated position asymmetry plotted versus run number for insertable halfwave plate IN and OUT (red boxes, blue triangles). Left side of plot for beam from strained superlattice GaAs and gun with poor lifetime, right side of plot for beam from strained GaAs and gun with long lifetime.

for beam time at CEBAF, for example Qweak and Lead Parity.

2. Gun Charge Lifetime

On a note unrelated to parity violation experiments, a dedicated effort has been made to accurately monitor the charge lifetime of each gun at the CEBAF injector over the past four years, with nearly 3000 C extracted from the guns. Photocathode QE is measured at least daily and plotted as a function of extracted charge. An exponential fit is applied to the data and charge lifetime is defined as the amount of charge that can be extracted from the photocathode before QE falls to $1/e$ of the initial value. The results for measurements obtained with both guns using the Hall C laser are shown in Figure 4. There is considerable scatter to the data, likely due to the fact that conditions were not constant during this long period of time. For example, gun, photocathode material, laser wavelength and laser spot size at the photocathode were often changed to best suit the needs of the experiment program. Despite this lack of control of important experimental variables, there are sections of the plot that reveal interesting trends. During 2003, "gun2" charge lifetime was observed to steadily decrease from ~ 250 C to < 100 C. To address this problem the non-evaporable getter pumps were replaced and the gun re-baked. The charge lifetime steadily increased throughout 2004, achieving a value exceeding 500 C, suggesting new NEG pumps and subsequent vacuum recovery following the bakeout had significantly improved the vacuum within the gun. This observation suggests NEG pumps have a limited lifetime, at least under CEBAF operating conditions, i.e., relatively high average current with guns vented and re-baked frequently compared to load-locked guns.

Fig 4. Gun charge lifetime measured over four years with nearly 3000 C extracted charge. The period of time between 2003 and 2004 is of interest and is described in the text.

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