ACHIEVING BEAM QUALITY REQUIREMENTS FOR PARITY EXPERIMENTS AT JEFFERSON LAB*

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Abstract

Measurement of asymmetry between alternating opposite electron polarization in electron-nucleon scattering experiments can answer important questions about nucleon structures. Such experiments impose stringent condition on the electron beam quality, and thus the accelerator used for beam creation and delivery. Of particular concern to such "parity" experiments is the level of correlation between beam characteristics (orbit, intensity) and electron polarization that can obscure the real asymmetry. This can be introduced at the beam forming stage, created due to scraping, or not damped to desired level due to defective transport. Suppression of such correlation thus demands tight control of the beam line from cathode to target, and requires multi-disciplined approach with collaboration among nuclear physicists and accelerator physicists/engineers. The approach adopted at Jefferson Lab includes reduction of correlation source, improving low energy beam handling, and monitoring and correcting global transport. This paper will discuss methods adopted to meet the performance criteria imposed by parity experiments, and ongoing research aimed at going beyond current performance.

PARITY EXPERIMENTS AT JEFFERSON LAB AND THEIR REQUIREMENTS

Parity-violation (**PV**) experiments aimed at high precision measurement of nucleon quark structure are an important part of the physics program at Jefferson Lab. Major recent and ongoing PV experiments include HAPPEX-I in 1999, G0 in 2003-04, HAPPEX-HE and HAPPEX-II in 2004, all dedicated to measuring various aspects of nucleon strangeness form factors, and future Lead and Qweak experiments. These experiments take advantage of the CEBAF accelerator to deliver CW electron beam with high polarization and low noise in intensity and orbit, but also have tight specifications on helicity-correlated (**HC**) systematics to minimize contribution of "false-asymmetry" to the final result.

The PV experiments at CEBAF measure difference in electron nucleon elastic scattering cross-sections between alternating polarized electron states, or helicity, each lasting 33 ms.. Alternating polarization is essential in eliminating effects of machine-induced false correlation to helicity and allowing the asymmetry on the level of a few parts per million (**ppm**) to be resolved. This is realized by flipping the voltage of the Pockels cell, which controls the polarization of the laser light on the photocathode and in turn the polarization of the emitted electrons, at 30 hz. A quartet flipping pattern in some experiments further suppresses signals occurring at sub-harmonics of 30 hz.

Despite major false asymmetry elimination as described, more demanding PV experiments require that small intrinsic asymmetry of HC beam parameters be controlled to even finer degrees. This includes:

- Intensity: This can be caused by quantum efficiency (**QE**) anisotropy in the photocathode. Beam scraping at tight apertures in the presence of HC orbit can also create intensity variation with helicity.
- Orbit: This can be generated from transverse gradients of linear laser polarization. The finite analyzing power of the photocathode, a measure of dependence of emitted electron property on the laser polarization, is another factor contributing to HC orbit. HC orbit on the cathode is typically at micron level.

Table 1 gives an overview of the intrinsic physics asymmetries and requirements on HC beam properties by various experiments at Jefferson Lab.

In the following description of the CEBAF accelerator at Jefferson Lab will be given in the context of PV experiments, followed by methods developed to reduce helicity correlated beam properties.

OPERATING CEBAF FOR PV EXPERIMENTS

Figure 1 gives a functional view of the CEBAF accelerator and the process of electron beam generation and delivery. For each experimental hall (A/B/C) 100 keV KE electron beam is generated from the photocathode gun by incident laser after passing through the Pockels cell. Flipping the voltage across Pockels cell at 30 hz results in the alternating helicity described earlier. The electron beam then goes through a chopping system to define the longitudinal extent of the pulse for each hall, as well as longitudinal capture and bunching for preacceleration to 55 MeV, followed by injection into the main accelerator. The latter consists of a 5 pass re-

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Table 1: Specs on Experiment-Averaged HC Parameters

Experiment	Physics Asym. (ppm)	Intensity (ppm)	Position on Target (nm)	Angle on Target (nrad)
HAPPEX-I	13	1.0	10	10
G0	2-50	1.0	20	2
HAPPEX-He	8	0.6	3	3
HAPPEX-II	1.3	0.6	2	2
Qweak	0.3	0.1	20	100
Lead	<1	0.1	1	1

circulating linac, at 1 GeV per pass, with spreaders and recombiners on either end to handle multiple beams at different momenta. Final RF separation system directs each beam to its destination experimental hall.

For PV experiments a feedback system was developed to reduce HC parameters. Special beam current monitor (BCM) and beam position monitor (BPM) electronics are used to monitor such parameters in the Injector up to 5 MeV, and in the experimental halls. The actuators consist of the intensity attenuator cell (IA) and the piezo-electric transducer-controlled mirror (PZT) in step with the helicity flipping pattern to control HC intensity and orbit. The feedback system takes into account cross coupling between IA and PZT on intensity and orbits. For such a feedback model to be effective, the stability of the cathode-to-target transport is important.

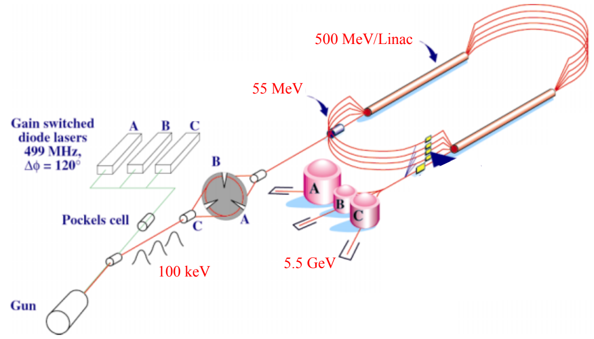

Figure 1: CEBAF Conceptual Layout

PARITY QUALITY BEAM MOTIVATED IMPROVEMENTS

Intense activities have been undertaken at Jefferson Lab aimed at making CEBAF an optimal source of parity quality beam for PV experiments. This is mainly focused on 2 fronts: Minimizing the source of HC beam properties, and optimizing global transport to realize theoretically expected adiabatic damping of HC orbits. Progress was also made towards improving stability of the global transport and ability to optically fine-tune the contribution of HC orbit to false asymmetry on target.

Electron Source

Electron source for PV experiments must strive to achieve high QE, high polarization, and low QE anisotropy in the photocathode, the latter for minimizing HC beam properties. In addition the phase noise of the laser system must be small. For the G0 experiment titanium sapphire laser on strained GaAs photocathode was used, achieving phase noise of a few ps., 75% polarization, and 10% QE anisotropy. For ongoing HAPPEX experiment a superlattice GaAs photocathode is used to achieve even better performance in terms of polarization (85%) and QE anisotropy (2-3%).

Injector Configuration and Setup

Significant progress has been made in 2003-04 to improve the performance of the CEBAF Injector system in support of parity quality beam. This includes:

- Ambient field coil: To minimize optical aberration from beam steering away from center of solenoids by earth field, leading to defective optics and transmission, a low field magnetic coil was installed 1 foot from the beam line encompassing the 100 keV region. This has resulted in improved optics and transmission.
- Setup procedure: A revised orbit setup procedure taking advantage of solenoid-dithering software ensured minimized optical aberration from the solenoids, as well as improved transmission and reproducibility. This and the ambient field coil improved the global transport stability, and the helicity feedback. They also improved the reliability of the optical model discussed below.
- 4-dimensional model: Knowledge of transport optics in the Injector, with a 150-fold momentum gain, is crucial for achieving desired damping of HC orbits. The use of solenoid lenses made 4D modeling necessary. Transverse single particle optics was subjected to beam based verification, resulting in beam-calibrated elements and a working optical model.
- 30 hz PZT: A dedicated diagnostic PZT mirror was built. This mirror is capable of dithering the laser spot at 30 hz on the cathode in both planes, with its response picked up at all BPM's throughout the accelerator. This allowed examination of the global propagation of HC orbits, and is invaluable in isolating problem areas.

Global Transport: Monitoring and Correction

In the main accelerator (55 MeV to 5.5 GeV) the focus is on achieving theoretically expected damping of transverse phase space area in each plane, and on betatron matching to eliminate envelope blowup. A well-tested procedure has been applied to quantify these properties and implement corrections section-by-section [1]. Phase space damping in the main accelerator was demonstrated to be within 1% of theoretical expectation, and typical betatron mismatch factor in either plane can be controlled to within 20%, or envelope blowup by the same fraction, which is adequate over this 60-fold energy increase.

The next step in this program is to further sub-divide the sections where this procedure is applied, with the advantage of eliminating long-range mismatch cancellation that can lead to transport sensitivity.

As a byproduct of this effort, 4×4 transfer matrices based on difference orbit data became available from the cathode to the target over momentum increase by a factor of over 10^4. It was further shown that the difference orbit data over this entire range is in very close agreement with a 4-dimensional linearly symplectic transport. This leads to the conclusion that CEBAF cathode-to-target single particle transport displays 100% momentum damping in 4D phase space, all observed orbit blowup can be attributed to linear XY coupling and linear betatron mismatch, and correction by linear elements (quadrupoles and skew-quadrupoles) alone can fix all deviation from damping.

Improving Feedback Performance

The helicity feedback system as described earlier requires optimization of the physical setup, basically amounting to conditioning the response matrix to make it as non-degenerate as possible. Work in this direction has improved the performance of the feedback system:

- Degeneracy between position and intensity actuators is minimized via a procedure minimizing the baseline intensity asymmetry before feedback.
- Improved alignment procedure of the IA cells greatly reduced its effect on beam position, thus the cross-coupling of the feedback [2].
- Switching from single-responder to multiple-responder input to the feedback system improved its robustness and desensitized it to global optical drift.
- Final PZT response before the target became controllable through optical tuning. This was made possible by the new diagnostic 30 hz PZT, which maps out the detail of its responses at all locations of the accelerator.

Finally the improved global transport stability also contributed to the performance of the feedback.

PERFORMANCE FOR G0

The G0 experiment recently concluded at Jefferson Lab certified that all requirements on HC beam parameters have been achieved based on run-averaged analysis [2,3]. Figure 2 shows HC beam parameters for the entire G0 run, with red and blue representing 2 opposite polarization schemes of the Pockels cell for controlling systematics. The HC intensity and orbit are seen to meet the specs of Table 1 for G0. This has been achieved with the feedback system running on intensity and X/Y positions on target.

PLANS FOR IMPROVEMENTS

As more demanding PV experiments come on line now and in near future, work is in progress to further improve the quality of CEBAF transport and machine control tools. This consists of the following.

Injector Transmission Improvement

Careful analysis of beam envelope in the Injector indicated that by adding focusing elements to restore axial symmetry in the Injector, transmission through some tight apertures can be vastly improved. New elements have been installed and are being tested.

Fixing Injector Transport

As pointed out earlier, the cathode-to-target transport is consistent with 100% momentum damping in 4D phase space. However due to limited modeling information in the acceleration components up to 55 MeV, XY coupling and betatron mismatch resulted in about a factor of 10 orbit blowup. Work is underway to empirically determine the transport in these components and arrive at a solution to reclaim the missing damping in orbit amplitudes.

Phase Trombone

For some of the PV experiments such as HAPPEX, an optical manipulation, known as phase trombone, that trades off the impacts between position and angle on the detector can be employed to further reduce orbit related false asymmetry. At CEBAF such a scheme using 8 quadrupoles has been developed. Preliminary test was encouraging.

New Helicity Feedback System

To fully separate intensity correlation with position feedback and control, a set of 4 actuators were implemented in the 5 MeV line, after the aperture limited 100 keV region, with controls electrically isolated to avoid cross-talk false asymmetries. Testing is in progress.

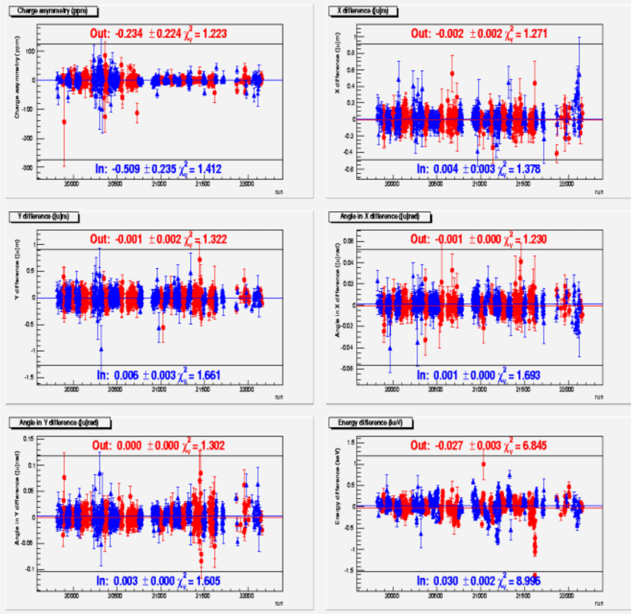

Figure 2: G0 Parity Quality: Left-to-right and top-to-bottom: Intensity (ppm), X-position (µm), Y-position (µm), X-angle (µrad), Y-angle (µrad), Energy (keV).

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