Specifications for Beam Parameters for HAPPEX-II and HAPPEX-He

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This document provides a reference for various beam parameter specifications for the HAPPEX-II and HAPPEX-He experiments. Included is a summary table for each experiment, a list of special considerations for requirements from the beam and related accelerator systems, and an appendix containing a brief description of the reasoning that has led to each parameter.

We welcome feedback on the feasibility on these requirements, as well as any guidance on which items can be better defined from the accelerator perspective.

1 Requirements Summary

The beam property requirements for each experiment are summarized below. For each beam property, we list requirements in the several categories, described below (many of these categories, and their descriptions, are taken directly from a similar table submitted by the G0 collaboration, 12-17-2001). *For most parameters, values averaged over approximately one day ("slug" averages) will be the most important performance indicator.* Corrective action will be necessary if these averages are too large or if they show a systematic offset over several days.

- **Nominal Value:** This is the usual desired central value of the beam property.
- **Maximum (DC) deviation from nominal:** This is how far the "DC" central value of the beam property, averaged over several seconds, can drift before corrective action is required.
- **Maximum 30 Hz Noise:** Operationally, we integrate the signal for a given beam property over a 33 msec time period, and form differences between two successive 33 msec periods. The standard deviation of the distribution for those differences is what we refer to as "30 Hz noise."
- **Maximum Noise at other frequencies:** This is the upper limit on random noise at frequencies other than 30 Hz, for example, 60 Hz and higher harmonics.

- **Maximum Run-averaged helicity-correlation:** This refers to the maximum value of the helicity-correlated (HC) difference (or asymmetry) that can be tolerated after averaging over the entire 700 hour run. These difficult specifications will be achieved primarily with careful configuration of the polarized source, active feedback in the source, and maintaining a well-matched setup in the accelerator to maximize the benefits from adiabatic damping.
- **One-day "slug" average:** Due to statistical noise, it is not possible to tell in a short measurement whether a systematic offset exists which will make it impossible to reach the run-averaged HC goal. Averaging beam parameters over approximately one day provides a convenient benchmark for convergence to the run-averaged HC goals, with enough statistical precision to perceive systematic offsets. These one-day average specifications are made with the assumption that the averages are statistically distributed, with no measurable offset. *If the one-day averages are not distributed around a negligible systematic offset, immediate corrective action will be necessary in order to assure convergence to the run-averaged goals.*

HAPPEX-II

Beam Property	Nominal Value	Maximum Deviation from Nominal (DC)	Maximum 30Hz Helicity Non-correlated Noise	Maximum Noise at other frequencies	Maximum Run-averaged Helicity-correlation	HC One-day ("slug") Average
Energy	3.2 GeV	10^{-3}	$\frac{\Delta E}{E} \leq 80$ ppm	800 ppm	$\langle\frac{\Delta E}{E}\rangle \leq 13$ ppb	100 ppb
Energy Spread $\frac{\sigma_E}{E}$	$< 10^{-3}$	10^{-3}	4×10^{-4}	-	-	-
Average Current $\langle Q\rangle$	100 μA	10 μA	1000 ppm (> 200 ppm)	1%	600 ppb	< 4.5 ppm
Position (x and y) at target	0	±0.2mm	12 μm	120 μm	$\langle\Delta x\rangle = 2$ nm	< 15 nm
Angle ($x\prime$ and $y\prime$) at target	0	±0.2mrad	12 μrad	120 μrad	$\langle\Delta x\prime\rangle = 2$ nrad	< 15 nrad
Beam Spot Size (rms) at target	radius: > 100μm < 1000μm	20% (area)	3%* (area)	10%* (area)	5 ppm* (area)	40 ppm* (area)
Polarization	> 70%	-	-	-	-	-
Halo	100 Hz/μA @ 3mm †	-	-	-	-	-

* See "Special Considerations", note 11.

† See “Special Considerations”, note 4.

HAPPEX-He						
Beam Property	Nominal value	Maximum deviation from nominal (DC)	Maximum 30Hz Noise	Maximum Noise at other frequencies	Maximum run-averaged helicity-correlation	One-day (“slug”) average
Energy	3.2 GeV	10^{-3}	$\frac{\Delta E}{E} < 120$ ppm	1200 ppm	$\langle \frac{\Delta E}{E} \rangle < 20$ ppb	< 150 ppb
Energy Spread $\frac{\sigma_E}{E}$	$< 10^{-3}$	10^{-3}	4×10^{-4}	-	-	-
Average Current $\langle Q \rangle$	100 μA	10 μA	1000 ppm (≥ 200 ppm)	1%	600 ppb	< 4.5 ppm
Position (x and y) at target	0	±0.2mm	18 μm	180 μm	$\langle \Delta x \rangle = 3$ nm	< 23 nm
Angle ($x\prime$ and $y\prime$) at target	0	±0.2mrad	18 μrad	180 μrad	$\langle \Delta x\prime \rangle = 3$ nrad	< 23 nrad
Beam Spot Size (rms) at target	radius: ($> 100\mu$m) $< 1000\mu$m	20% (area)	3%* (area)	10%* (area)	5 ppm*	40 ppm*
Polarization	$> 75\%$	-	-	-	-	-
Halo	100 Hz/μA @ 3mm †	-	-	-	-	-

* See “Special Considerations”, note 11.
† See “Special Considerations”, note 4.

2 Special Considerations

1. **Priority in source configuration:** Like other parity-violation experiments, HAPPEX-II and HAPPEX-He will require priority in the source configuration (centering on the Pockels cell, etc.). In order to tune the source to minimize HC beam systematics, it will also be necessary to control setpoints for common devices such as the Insertable Halfwave Plate, Rotating Waveplate, and Pockel cell voltages. (Changes to these setpoints can be made without significant impact on most experiments, for example, with negligible effect on beam polarization.) Other requirements for the source configuration may be negotiated with the Electron Gun Group.

2. **Time for source configuration:** Dedicated study of the source, using Hall A beam only and lasting 1-2 shifts, will be necessary in order to optimize the source configuration. This study will need to be repeated if there are any major changes to the polarized source, for example, a gun switch.

3. **Wien angle optimization:** It is necessary that the Wien filter be set to minimize transverse beam polarization for Hall A.

4. **Beamtune and halo acceptable for Compton polarimeter:** In order to meet the precision goals of the experiment, it will be necessary to have reliable data from the Compton polarimeter continuously during production. It is therefore necessary that the beam be suitable for the use of the Compton polarimeter.

   A suitable criteria for operation of the Compton is a counting rate of 100 Hz/μA in the Compton photon detector, with the Compton laser off. The halo restriction is such that the Compton detector is the only instrument available at CEBAF which is suitable for monitoring this parameter at this level, so it will be the duty of Hall A personal operating the Compton to communicate the status of this parameter to accelerator. This specification matches the requirement for use of the Compton system during portions of E97-110, running April-May, 2003.

5. **Hall C charge asymmetry:** Experience during previous parity runs at Jefferson Lab have demonstrated that a significant helicity correlation in intensity for one hall can induce helicity-correlated intensity, position, or energy differences in another. HAPPEX-II and HAPPEX-He may require a real-time readout of the charge asymmetry in Hall C in order to monitor this potential problem. In addition, it is desirable that the intensity asymmetry in Hall C be limited by using an independent feedback mechanism at the source, controlled by either Hall C or Accelerator division.

6. **Current Leakage:** It is necessary that the contribution of Hall B and C beams in the Hall A beam does not measurably degrade the Hall A helicity-correlated beam parameters or beam polarization.

7. **Electron Beam Transmission:** Significant clipping of the electron beam between the photocathode and the target can create excessive charge jitter or helicity correlated systematics on the beam. In particular, such clipping can create a helicity-correlated intensity asymmetry from helicity-correlated position differences. This can confuse diagnostics of the source, and cause mis-corrections, using source optics, of problems created in beam transport. To avoid such problems, it may be necessary to take brief measurements of the Hall A beam alone (with lasers from other halls turned off) to verify that there are not helicity-correlated effects from transport. Such measurements, if necessary, would be very brief (on order of 10 minutes) and might occur as frequently as once per shift.

8. **Beam Modulation:** Air core steering coils in the Hall A beamline and the energy vernier in SL20 will be used to modulate beam position, angle, and energy in order to measure sensitivity to those parameters. These modulations will be slow, but they may be performed nearly continuously during the run. The amplitude of modulation will be approximately $\pm$1mm, $\pm$1mR, and $\pm$1MeV. The position and angle modulation affect the beam in Hall A only, while the energy modulation would affect beam in all halls.

9. **Energy and Position Locks:** It will be necessary to find a way to make the beam modulation system described above compatible with the energy and position locks (FFB), or to turn FFB off during production running. Even if FFB is turned off for the bulk of production running due to incompatibilities with the beam modulation system, it will be regularly used (approximately 2 hours each day) to check for systematic errors in the Compton polarimeter due to the improvement in Signal-to-Noise during FFB operation.

10. **BPM Autogain Disabled:** It is expected that these experiments will be performed with the Hall A SEE BPM electronics set to Forced Gain.

11. **Helicity-Correlated Beam Spot Size:** It is recognized that no direct method exists to measure 30-Hz and helicity-correlated differences in the beam spot size, so these requirements are expressed only to note the potential importance of this parameter. These specifications are generated using a "worst-case" estimate of luminosity changes due to helicity-correlated changes in spot size, based on limited empirical data. It is expected that a careful configuration of the source will achieve these goals and that no intervention by accelerator operators will be required.

    If a large HC spot-size asymmetry exists, and if the experiment is sensitive to it, the net effect will be measurable in luminosity monitors designed for this purpose. This indirect measurement is expected to provide the only indication of a suitably small HC spot-size asymmetry.

3 APPENDIX: Criteria Leading to Specifications

3.1 HAPPEX-II

HAPPEX-II will measure a scattering asymmetry of around 1 ppm to a precision of 50 ppb (5%). Approximately 60 days of production beam time are approved, corresponding to approximately 38×10^6 pairs. For most parameters, the Maximum (DC) Deviation from Nominal is constrained by the general requirement of stable running conditions for high-precision parity-violation experiments, and the Maximum Noise at Non-30-Hz Frequencies is taken to be approximately $10\times$ larger than the non-helicity-correlated 30-Hz noise ceiling to limit nonlinear effects.

- **Energy:** Mean energy fixed by choice of Q^2, and slow deviations from the setpoint should be $< 10^{-3}$ to maintain the centering of the elastic stripe on the detector and avoid edge effects. The expected energy sensitivity is $\partial A/\partial\frac{\Delta E}{E} \approx 4$ ppb / ppb, so to keep the correction on order of 50 ppb, we need to keep a run-averaged $\langle\frac{\Delta E}{E}\rangle < 13$ ppb. In order to converge to this small energy difference, it is necessary to have a 30 Hz jitter of < 80 ppm, and a slug average of < 100 ppb. The energy spread (and the noise on the energy at other frequencies, to the extent that these are separate specifications) is constrained to $< 10^{-3}$ by the need to avoid edge effects on the detector. Because energy spread is not expected to significantly affect the detected signal when constrained at that level, a tight constraint on 30 Hz jitter or helicity-correlated (HC) offset of the energy spread is not necessary.

- **Current:** HAPPEX-II expects to run with 100 μA beam current. The integrated charge for each helicity window should jitter by less than 1000 ppm, to avoid introducing significant noise though detector or beam monitor non-linearity. It is also necessary that this jitter not be too small (> 200 ppm) so that the range of measurement is large enough to study non-linearity in helicity-correlated charge asymmetry corrections. With an expected 3% non-linearity in charge asymmetry correction, a 600 ppb run-averaged HC correction will give an acceptable systematic error of 18 ppb. In order to achieve this run-averaged number, the "slug" average must be below 4.5 ppm.

- **Position and Angle:** Nominal positions centered through the target BPMs are chosen to center on the beamline monitors, the target, and through the Compton polarimeter. The run-averaged HC position differences for both x and y must be < 2 nm, to allow reasonably small systematics from the ~ 20 ppb/nm sensitivity for both detector segments. In order to achieve this number, the one-day HC average must be < 15 nm, and the non-HC 30 Hz jitter in position must be $< 12\mu$m. The angle sensitivities (in units of ppm/μrad) are very similar to the position sensitivities (in units of ppm/μm), so in these units the requirements are similar quantities.

- **Beam Spot:** The beam spot must be large enough to avoid stimulating boiling (density fluctuation) of the cryotarget. There is a lack of empirical data to guide this specification, as a novel cryotarget design is to be employed for HAPPEX-II. Data taken with previous cryotargets suggests that the intrinsic (non-rastered) beam spot should have an area comparable to a circle with radius 100μm. The beam spot should not be larger than 1mm radius.

  It is recognized that no direct method exists to measure 30 Hz systematics in the spot size, so these requirements are expressed only to note the potential importance of this parameter. Again, there is a lack of empirical data to guide this specification. Some limited data suggests that the bulk density change as a function of spot size change must be less than 5% density loss per factor of 10 change in spot-size area. In this worst-case, the HC spot-size asymmetry would need to be smaller than 5 ppm to keep the contribution to systematic error less than 25 ppb.

If a large HC spot size asymmetry exists, and if the experiment is sensitive to it, the net effect will be measurable in luminosity monitors designed for this purpose. This indirect measurement is expected to provide the only indication of a suitably small HC spot-size asymmetry.

- **Beam Halo:** The Compton polarimeter sets this requirement. At 3 GeV, the photon detectors are brought to a position only 3mm from the beam. The expected count rate from Compton scattering in these detectors is $\sim$1 kHz/μA. It is desirable to achieve a signal/background ratio near 10, which implies a count rate in these detectors of 100 Hz/μA with the Compton laser off.

  The Compton is the only instrument capable of measuring this tight restriction for Hall A. In the April/May run period, Hall A will attempt to use the Compton polarimeter with a 3 GeV beam, which will provide a benchmark for the ability of the accelerator to meet this goal.

3.2 HAPPEX-He

HAPPEX-He will measure a scattering asymmetry of around 8 ppm to a precision of about 160 ppb (2%). The total beam time (and the number of helicity window pairs) is approximately the same as for HAPPEX-II. The smaller fractional error for this measurement places tighter requirements on beam systematics relative to the final precision than might otherwise be expected when comparing to HAPPEX-II. For most parameters, considerations are as above for HAPPEX-II. Exceptions are noted before.

- **Energy** The expected energy sensitivity is $\partial A/\partial\frac{\Delta E}{E} \approx 8$ ppb / ppb, so to keep the correction on order of 160 ppb, we need to keep a run-averaged $\langle\frac{\Delta E}{E}\rangle < 20$ ppb. In order to converge to this small energy difference, it is necessary to have a 30 Hz jitter of < 120 ppm, and a slug average of < 150 ppb.

- **Current** HAPPEX-He expects to run with 100 μA beam current. It is desirable to achieve HC charge asymmetry corrections comparable to HAPPEX-II.

- **Position and Angle** The run-averaged HC position differences for both x and y must be < 3 nm, to allow reasonably small systematics from the ≈ 35 ppb/nm sensitivity for the combined detector segments. In order to achieve this number, the one-day HC average must be < 23 nm, and the non-HC 30 Hz jitter in position must be $< 18\mu$m. The angle sensitivities (in units of ppm/μrad) are very similar to the position sensitivities (in units of ppm/μm).

- **Beam Spot** The beam spot must be large enough to avoid stimulating significant density fluctuation of the cryogenic gas He target.