Summary of beam parameter specifications for MOLLER

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This note provides a listing and summary of specifications for the beam performance for the MOLLER experiment.

1. **Run averaged helicity-correlated beam asymmetries.** The goals for run-averaged helicity-correlated beam asymmetries are listed in Table 1. As discussed in the MOLLER TDR, it is expected that these are achievable given the plans for the new Pockels cell, expected improved matching optics, and slow-reversals.

2. **Random Beam Position and Intensity Noise at Target** The goal for the accuracy of beam corrections implies specifications on the maximum "jitter" (random noise) in the beam properties. These goals, shown in the Table 1, have been met in recent 11 GeV operations.

3. **Match to Design Beam Optics** It will be necessary with have the accelerator optics "well matched" during the PREX experiment. In particular, the helicity-correlated beam asymmetries are exacerbated if beam optics do not match design throughout the injector and linacs. If the beam is not matched through the BSY and into the hall, then beam spot sizes and beta-function phases are not well described by the optics model, and the various constraints on the beam line optics are more difficult to meet. It is therefore expected that matching must be done from the injector through delivery into Hall A early in the PREX commissioning period. A factor of 100 in suppression of transverse orbit amplitude is desired, but in any case at least a factor of 10 suppression will be needed in order to achieve experimental goals.

4. **Fast Feedback:** The fast feedback system for position and energy lock will be needed. The ability to pause the data collection and feedback on both the position and energy will be required for correction sensitivity monitoring (beam modulation).

5. **Beam Energy** The MOLLER figure-of-merit is proportional to the beam power, and the experiment is designed for 11 GeV beam energy at 65 μA beam current. Beam energy > 10.6 GeV can be used, with loss of statistical power corresponding to $\sqrt{\Delta E/E}$ and therefore an increase in run-time by $\Delta E/E$.

6. **Helicity Reversal Frequency** MOLLER expects to use the helicity reversal frequency at either 1920 Hz or 960 Hz depending on performance. A multiplet of 64 windows (for 1920Hz) or 32 windows (960Hz) will need to be used to cancel 60 Hz line noise. For low (diagnostic) flip rates, timing should be selectable for locking to 60Hz line phase (with timing variations contained in the settle period) or using an internal clock asynchronous to line phase. This functionality is currently supported by the JLab helicity control board.

Beam Property	Required 1 kHz random fluctuations	Required cumulative helicity-correlation
Intensity	< 1000 ppm	< 10 ppb
Energy	< 110 ppm	< 1.4 ppb
Position	< 50 μm	< 0.6 nm
Angle	< 10 μrad	< 0.12 nrad

Table 1: *Goals for run-averaged values and 1 kHz differential noise in helicity-correlated beam asymmetries.*

7. **Laser optics slow reversal:** A waveplate in the injector is used to change the helicity of the beam relative to the voltage on the Pockels cell and the helicity reporting signal. MOLLER aims to perform this reversal every 2-4 hours. This change would take less than 1 minute if performed using an automated script, however, it must be coordinated with other experimental halls who must correct their record of the beam helicity. A process should be designed to make this process efficient, with a goal of a 2 minute change to occur approximately every 2-4 hours.

8. **Injector Spin Reversal** Spin rotation in the injector provides a method for a convincing "helicity flip" which does not interfere with the beam profile or mechanisms which might lead to a spot size asymmetry or other helicity-correlated beam asymmetries. MOLLER expects to use a spin rotation with a period of about 5-7 days. The new double-Wien system planned for installation in the injector will be used to provide this helicity flip, as well as make the regular small corrections to the spin launch angle to preserve a minimized transverse polarization for the MOLLER measurement.

9. **Beam Energy Slow Reversal:** At 11 GeV, the total number of g-2 spin rotations will be large, on the order of 120π. It will be possible to flip the spin orientation, while maintaining very similar beam optics properties, by changing the energy of the accelerator by about 100 MeV. This interval is small enough to not require invasive reconfiguration of the experiment: backgrounds, spectrometer optics, etc. will remain very similar. This type of reversal is expected to be very effective in that all sources of HCBAs will be reversed under this operation. However, since this method is disruptive to other halls, MOLLER expects to only employ a g-2 reversal a few times over the duration of the entire run. Over the duration of all the production running, a total of 10 energy flips are planned, with at least one such flip during run I, 3 flips in run II and 6 flips in run III, or effectively a configuration change every 10 weeks during production running. The exact frequency and the nature of the configuration change would be chosen after consultation with the Accelerator and Physics Divisions.

10. **Polarization Orientation** MOLLER is highly sensitive to components of transverse polarization, such that experiment will require fully longitudinal polarization and regular correction for residual vertical and horizontal transverse polarization components. These polarization components will be measured continually in the experimental hall, with corrections for drifts envisioned to occur daily during regular running, or in a shorter time scale after any significant linac energy rebalancing.

11. **Full transverse polarization calibration:** MOLLER is planning to calibrate the detector using 2 to 3 shifts of 100% transverse polarization in Hall A during the first experimental run.

12. **Low Current (tracking mode) beamline operation** While MOLLER takes most data at high currents, some periods of very low current (about 0.5-1 nA) will be needed during calibration runs for tracking detectors to measure the spectrometer properties. Other low current running will use between 5-100 nA beam currents. For currents greater than 5 nA, the beam will need to be steady, with trajectory measured with a precision of 1 mm averaged over several seconds.

13. **Priority in source configuration:** Consistent with common practice during past parity-violation measurements at JLab, MOLLER will need priority in the source configuration (centering on the Pockels cell, etc.). In order to tune the source to minimize HC beam asymmetries, it will also be necessary to control setpoints for common devices such as the insertable halfwave plate, rotating waveplate, Pockels cell, and helicity magnets, or other critical configuration parameters (*e.g.* cathode analyzing power orientation).

14. **Helicity-correlated feedback using injector correctors** It is likely to be necessary to use feedback on helicity-correlated position in order to reduce random noise sufficiently to achieve the MOLLER precision goals. This can be accomplished using helicity-correlated magnets in the injector or (with smaller dynamic range) setpoints on the RTP Pockels cell, with a slow update time (1 hour or more). The position transfer function between the injector and the hall will need periodic re-calibration, depending on the rate of drifts in beam optical properties. If beam jitter is somewhat smaller than expected, then this feedback may not be needed.

15. **Beam Modulation:** Air core steering coils in the Hall A beamline and the energy vernier (presumably in SL20) will be used to modulate beam position, angle, and energy in order to measure sensitivity to those parameters. It will be necessary to "pause" position lock and energy lock during these modulation periods. This calibration cycles will be run every few minutes during data taking, with a total duty cycle between 5-15%. We may also scan the set points of the Pockels cell and the helicity magnets.

16. **Phase Advance:** The successful use of the beam modulation system requires sufficient phase advance between the modulation magnets and between the monitors used to characterize the beam motion, so that independent motions spanning the beam phase space can be observed. The beamline optics designed for the MOLLER experiment will satisfy this specification.

17. **Intensity Modulation** Mechanism for intensity modulation below 30 Hz frequency with amplitude less than 1%, used for calibration of intensity and position dependent corrections to the MOLLER asymmetry. This would be used similar to the beam position and energy modulation system.

18. **Efficiency on configuration change** There are a number configuration changes that will be needed during the course of running. These include beam line optics changes for measurements with the Møller polarimeter, injector spin manipulation slow reversal, energy-change slow reversal, and low current calibration studies. An efficient transition between these configurations is anticipated.

19. **RF trip rate and recovery time** The expected ramp time for restoring beam on the production target will be about 25 seconds, and while the detector system will need a similar period of time to stabilize after a beam trip. MOLLER will be unable to make use beam until the target and detector stabilization is complete. It is assumed that the average recovery time before beam can return is 40 seconds, such that a goal of 90% operation efficiency during steady beam delivery would imply < 6 beam trips per hour.

20. **Time for source configuration:** Dedicated time for configuration of the laser optics of the source will be needed at the start of experimental runs. This includes time to configure and characterize laser optics on the laser table, and then several shifts to characterize and calibrate the source configuration using the electron beam. As many as 3 dedicated shifts may be needed in the injector to calibrate after any significant change in the source configuration.

21. **Control of helicity-asymmetries on other source lasers** MOLLER expects to use feedback mechanisms to control the helicity-correlated charge asymmetry of the Hall B and Hall D lasers (measured before the slit) and the Hall C laser. This has typically been accomplished with IA cells on each laser beamline.

22. **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 misguided corrections, using source optics, of problems created in beam transport. It is thought that clipping can also create higher moments of helicity-correlated asymmetries, such as spot-size asymmetries, and conditions with poor injector transmission have been seen to lead to high background rates in the Compton. To avoid such problems, MOLLER will need very clean electron transmission from source to target with minimal beam interception. As a general rule, changes in mean value of the charge asymmetry should be kept to less than 20 ppm, and the width change less than 50 ppm, through the injector and into the hall (transmission of 95% can typically achieve this).

23. **Helicity-Correlated Beam Spot Size:** No direct method exists to measure helicity-correlated differences in the beam spot size. The possible helicity-correlated spot-size asymmetry will be bounded on the laser beam, with a safety margin to account for reasonable models of photo-cathode non-uniformity, to be $< 10^{-4}$, with an expected order-of-magnitude suppression through injector spin reversal for a final expected value of $< 10^{-5}$. It is also expected that the helicity-correlated spot size asymmetry at the experimental target will be further suppressed by adiabatic damping from the injector combined with the addition of stochastic noise from synchrotron radiation.

24. **Halo** The Qweak experiment saw a significant false asymmetry that was ascribed to a helicity-correlated change in the beam distribution on target. This is often referred to as a “halo” effect. It should be noted that there is not clear evidence to tie this effect to a specific technical definition of “halo”. Studies will continue to attempt to characterize halo. There is not currently a halo specification for MOLLER.

25. **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. A commonly-used criteria for operation of the Compton is a counting rate of 100 Hz/μA in the Compton photon and electron 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. This specification is unchanged from past operation of the Compton polarimeter system.

Changelog: November 20, 2025

- Added intensity modulation
- Added injector position feedback mechanism
- Updated low-current running parameters
- Removed redundant ”efficiency in operation” bullet
- Some bullets modified to reflect current state of hardware or beam experience.
- Some language modified to stress ”specification”, avoiding mis-interpretation of ”requirement”, other minor edits for brevity.