

# Summary of beam parameter requirements for MOLLER

This note provides a listing and summary of requirements for the beam performance for the MOLLER experiment. In some cases, these requirements exceed the nominal 12 GeV performance parameters.

1. **Run averaged helicity-correlated beam asymmetries.** The goals for run-averaged helicity-correlated beam asymmetries are listed in Table 1. As discussed in a separate document (DocDB:402), 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 imposes requirements on the *jitter* (random noise) in the beam properties. These goals are shown in the Table 1. These requirements will be achieved assuming that the beam jitter properties are similar for the 12 GeV upgraded machine as for 6 GeV operations. Some recent initial experience with 11 GeV beam in Hall A suggests that the beam jitter properties for 15 Hz window pairs are similar to the 6 GeV machine.
3. **Match to Design Beam Optics** It will be necessary to have the accelerator optics “well matched” during the MOLLER experiment. In particular, helicity-correlated beam asymmetries are exacerbated if beam optics do not match design throughout the injector and linacs. Additionally, if the beam

Beam Property	Required 1 kHz random fluctuations	Required cumulative helicity-correlation
Intensity	< 1000 ppm	< 10 ppb
Energy	< 108 ppm	< 0.7 ppb
Position	< 47 $\mu\text{m}$	< 1.2 nm
Angle	< 4.7 $\mu\text{rad}$	< 0.12 nrad

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

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. A factor of 100 in suppression of transverse orbit amplitude is desired, a factor of 10 in suppression is required.

4. **Fast Feedback:** The fast feedback system for position and energy lock will be needed. The ability to pause the feed-forward data collection and feedback on both the position and energy will be required for correction sensitivity monitoring (see beam modulation).
5. **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. 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%.
6. **Phase Advance:** The successful use of the beam modulation system requires a significant phase advance between the modulation magnets and the monitors used to characterize the beam motion, so that independent motions spanning the beam phase space can be observed. The MOLLER collaboration will work with accelerator to design optics with sufficient phase advance between modulation magnets.
7. **Beam Energy** The MOLLER figure-of-merit is proportional to the beam power, and the experiment is designed for 11 GeV beam energy at 60  $\mu$ A beam current. If beam energy is less than design, this will correspond to a loss of figure of merit corresponding to  $\sqrt{\Delta E/E}$ .
8. **RF trip rate and recovery time** The MOLLER run planning is assuming a beam uptime of 90% during steady production running. The expected ramp time on the production target will be about 25 seconds. It is assumed that the average recovery time before beam can return is 40 seconds, implying that  $< 6$  beam trips per hour is required to achieve the goal of 90% efficiency.
9. **Helicity Reversal Frequency** MOLLER will require the helicity reversal frequency to be selectable to be 1920 Hz or 960 Hz. A multiplet of 64 windows (for 1920Hz) or 32 windows (for 960Hz) will need to be used to cancel 60 Hz line noise. This will require new firmware and control software for the JLab helicity board, but it is not expected that this will require new hardware. The helicity flip rate will need the option of either locking to the 60Hz line phase (with any variation in timing occurring during the settle period) or running from an internal clock, asynchronous with the line phase. The settle time between integration windows should be variable between 10  $\mu$ s and 30  $\mu$ s.
10. **Polarization Orientation** MOLLER is highly sensitive to transverse polarization components. The experiment will require regular corrections for both

vertical and horizontal transverse polarization. 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. The expected corrections at this time scale will be approximately  $1^\circ$  in spin launch angle, in both the horizontal and vertical directions.

11. **Priority in source configuration:** MOLLER will require 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, and Pockel cell voltages.
12. **Time for source configuration:** Dedicated time for configuration of the laser optics of the source will be required. 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. It is assumed that 3 dedicated shifts may be required in the injector for any significant change in the source configuration.
13. **Control of helicity-asymmetries on other source lasers** MOLLER will require 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.
14. **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 to be  $< 10^{-4}$ , with a safety margin to account for reasonable models of photocathode non-uniformity. Additionally, we expect an 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.
15. **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 will use the spin flip from the injector spin rotation with a period of about one week. The configuration time should be short enough to maintain high efficiency - the collaboration has assumed this process would be accomplished in 2 hours. This injector spin manipulation will also be used for small, daily corrections to the spin launch angle to preserve a minimized transverse polarization for the MOLLER measurement.

16. **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 no clear evidence to tie this effect to a specific technical definition of “halo”. Studies will continue during the upcoming PREX and CREX runs to attempt to characterize halo. Currently, there is no halo requirement specified for MOLLER.
  
17. **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. The primary challenge is transmission through the 1 cm apertures at the laser cavity in the Compton chicane.  
  
The nominal criteria for operation of the Compton is a counting rate of 100 Hz /  $\mu\text{A}$  in the Compton photon and electron detector with the Compton laser off. This specification matches the requirement for use of the Compton system for most of the operational lifetime of the system and has already been achieved in the photon detector at 11 GeV. It is expected that MOLLER experimenters will be closely collaborating with accelerator personnel to optimize the Compton photon background counting rates.
  
18. **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. This is an important slow reversal, and must be done frequently. MOLLER aims at changing at performing 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.
  
19. **Beam Energy Slow Reversal** At 11 GeV, the total number of  $g2$  spin rotations will be large, on the order of  $120\pi$ . 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. (For a symmetric linac configuration change, the beam energy change needed is  $\sim 93$  MeV.)  
  
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 detailed consultation with the Accelerator and Physics Divisions.
  
20. **Full transverse polarization calibration** MOLLER is planning to calibrate the detector using several periods, each lasting 2 to 3 shifts, of 100%

transverse polarization in Hall A. This will provide a sensitive test of systematics. These measurements would be best performed at the time of each beam energy change for  $g - 2$  slow reversal.

21. **Duty factor during steady running** During steady running periods when all hardware is working, there are expected interruptions in beam delivery from periodic RF trips and planned configuration changes. The experiment assumes that the total duty factor is  $> 88\%$  when accounting for RF trips and recovery time, laser optics slow reversals, and injector spin manipulation slow reversals.
22. **Efficiency on configuration change** There are many configuration changes that will be required during the course of running. These include beam line optics changes for measurements with the Møller polarimeter (weekly), injector spin manipulation slow reversal (weekly), energy-change slow reversal (every 10 weeks), transverse polarization studies (every 10 weeks), and low current calibration studies (every 10 weeks). An efficient transition between these configurations is anticipated.
23. **Low Current (tracking mode) beamline operation** While MOLLER takes most data at high currents, low currents (about 100 nA) will be required during calibration runs for tracking detectors to measure the spectrometer properties. The beam will need to be steady, with trajectory controlled at the 100  $\mu\text{m}$  level, during these tracking calibration periods.