The MOLLER Experiment

Measurement Of Lepton Lepton Elastic Reactions

An Ultra-precise Measurement of the Weak Mixing Angle using Møller Scattering

E12-09-005

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Abstract

The upgraded 11 GeV CEBAF polarized electron beam presents a compelling opportunity to measure a weak neutral current amplitude to unprecedented precision at $Q^2 \ll M_Z^2$. The result would yield a precise measurement of the weak mixing angle $\sin^2 \theta_W$, a fundamental parameter of the electroweak theory. The experimental goal of $\delta(\sin^2 \theta_W) \sim 0.1\%$, matching the accuracy of the two single best measurements by e^+e^- colliders at the Z resonance, would be accomplished by a precise measurement of the parity-violating asymmetry in fixed-target Møller scattering. The quantitative goals, the measurement strategy, and the major parameters of the experimental design in the original proposal remain unchanged, and we will refer to it frequently in this document. The original proposal document can be found at

`http://hallaweb.jlab.org/12GeV/Moller/moller_final.pdf`.

After presenting a brief overview of the experiment, we address a few aspects of the experimental design that have seen progress in recent months, both due to dedicated studies as well as due to technical accomplishments in other related projects. We conclude with a projection of the required beam time to achieve the proposed accuracy for the measurement.

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Chapter 1

Introduction and Motivation

Since the SU(2)$_L$×U(1)$_Y$ gauge theory of electroweak interactions was established more than three decades ago as a cornerstone of the Standard Model, experiments have been searching for clues to address the model's many shortcomings. Compelling theoretical arguments point to pursuing measurements that are sensitive to various kinds of new dynamics at the TeV scale in two broad thrusts: hadron and lepton colliders at the highest possible center of mass energies on the one hand, and targeted precision electroweak measurements at low energy on the other.

One class of accelerator-based low energy measurements focus on electroweak observables that can be calculated with high accuracy and aim to achieve sufficient precision so that indirect effects of new dynamics at the TeV scale might become manifest. In this document, we update the status of the MOLLER project (proposal E09-005), a new electroweak measurement that can potentially be the most sensitive such low energy measurement, at least as far as flavor-diagonal neutral current interactions are concerned.

We propose to measure the parity-violating asymmetry A_{PV} in the scattering of longitudinally polarized 11 GeV electrons from the atomic electrons in a liquid hydrogen target (Møller scattering). In the Standard Model, A_{PV} is due to the interference between the electromagnetic amplitude and the weak neutral current amplitude, the latter being mediated by the Z^0 boson. A_{PV} is predicted to be 35.6 parts per billion (ppb) at our kinematics. Our goal is to measure A_{PV} to a precision of 0.73 ppb. The result would yield a measurement of the weak charge of the electron Q_W^e to a fractional accuracy of 2.3% at an average Q^2 of 0.0056 (GeV/c)^2.

Within the context of the Standard Model, the Q_W^e measurement yields a determination of the weak mixing angle $\sin^2 \theta_W$ with an uncertainty of ± 0.00026(stat) $\pm$ 0.00013(syst), similar to the accuracy of the single best such determination from high energy colliders. Thus, our result could potentially influence the central value of this fundamental electroweak parameter, a critical input to deciphering signals of any physics beyond the Standard Model that might be observed at the Large Hadron Collider (LHC).

1.1 Physics Motivation Summary

A model-independent way to quantify the sensitivity of a low energy electroweak measurement is in the context of 4-Fermi contact interactions, as described in Sec. 1.4 of the proposal (Eqn 1.4). The proposed accuracy of the measurement provides access to an energy scale of 7.5 TeV (Eqn 1.5), better than the sensitivity of any previous measurement of a flavor-diagonal amplitude at fixed target or at colliders.

Within any new physics scenario, such as Supersymmetry models or models with new massive Z' bosons, the 7.5 TeV limit can be converted to a model-dependent limit on specific of physics amplitudes involving electrons in the initial and final state. Such limits will take on added significance should any new physics anomalies be discovered at the Tevatron or the LHC. It is likely that low energy measurements will become a necessary ingredient in unfolding the nature of the new dynamics that might be directly observed in high energy collisions. The original proposal referred to extensive literature on this issue; here we point out two new publications that reflect the growing interest of the potential measurement in phenomenological analyses of future LHC and low energy precision data [1, 2].

As described in Sec. 1.3 of the proposal, the proposed measurement will be significant even in the case that the Tevatron or LHC validates the minimal Standard Model with the discovery of a low mass Higgs boson. The prediction of a Higgs boson in range 110-160 GeV is based on an electroweak global fit of precision low energy data. However, the two most precise inputs to the fit are measurements of $\sin^2 \theta_W$ that disagree with each other by more than 3 standard deviations. Taken at face value, each measurement implies very different values for the mass of the Higgs boson. The proposed measurement of Q_W^e, given that it is designed to have an accuracy comparable to the above-mentioned measurements, will become a significant new input in future precision analyses of the internal consistency of the electroweak theory.

In summary, the proposed measurement will have a significant impact on electroweak physics in the timescale of 5 to 10 years, within a variety of outcomes of other precision measurements at high energy as well as low energy experiments. It will be a particularly robust input since it is a unique purely leptonic reaction at $Q^2 \ll M_Z^2$ with little theoretical uncertainty, and unlikely to be superceded by any other measurement proposed for new facilities in the coming decade.

Chapter 2

Experimental Design Update

The conceptual design of the experimental apparatus was described in Chapter 2 of the original proposal document, with additional details provided in a series of appendices. The design chapter followed up in Chapter 3 with a detailed discussion of potential systematic errors and the proposed strategies to control them. In this document, we focus on aspects of the design that have developed since the original proposal document was written. We once again relegate details to a new set of appendices [3]. A recent CAD rendition of the apparatus is shown in Fig. 2.1.
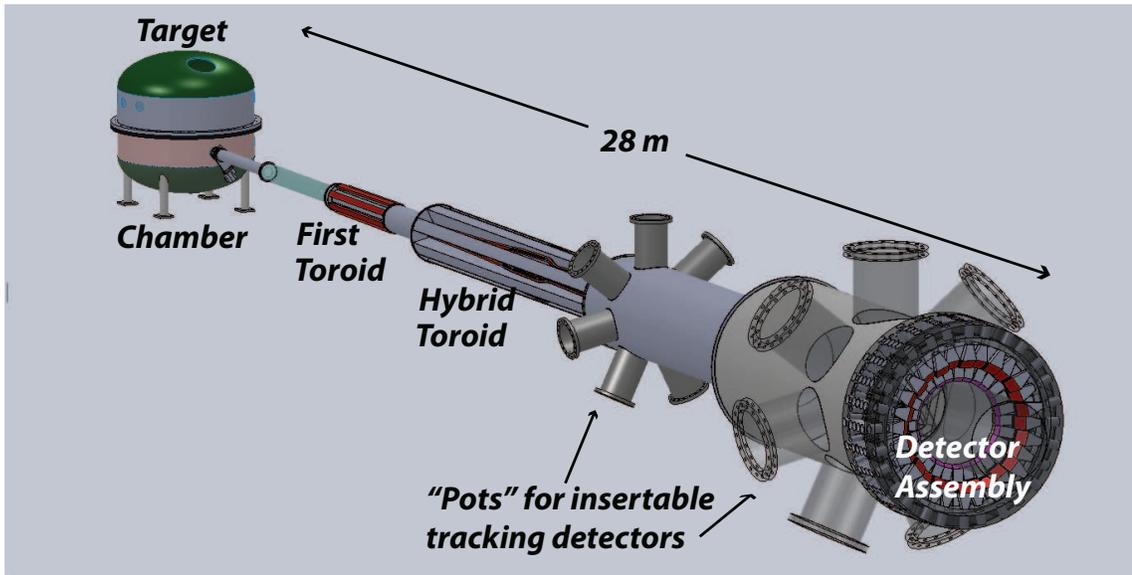

Figure 2.1: *Schematic Overview of the Experimental Apparatus.*

2.1 Design Overview

2.1.1 Polarized Beam

The preparation and control of the polarized electron beam is obviously a critical component of the apparatus and has been dealt with in detail in the original proposal (Secs 2.1, 3.1 and App. A). Our collaboration continues to gain experience in beam operation during data collection of the PREX and Qweak experiments. In collaboration with the JLab Electron Gun Group (EGG), we are learning to achieve consistently better control of beam helicity correlations at the target. In the process, incremental improvements are being accomplished towards the challenging beam parameters required for MOLLER, which are spelled out in App. A of the proposal document. For example, just before the PREX experiment, helicity-correlated laser spot-size asymmetries were measured for the first time in the JLab polarized source. The results showed that spot-size effects on the laser spot were controlled at the desired level of about 10^{-4}.

For multiple reasons, MOLLER proposes to flip the beam helicity at a rate of 2 kHz; Qweak is currently successful taking data with a 1 kHz flip rate. However, it has proven difficult to push the transition of the Pockels cell to be shorter than 60 μs, and to keep the cell optical properties stable after the shock of the fast transitions. Although carefully tuning the HV pulse sent to the cell may reduce the problem, it now appears unlikely that the KD*P cell, as it is presently used at JLab, will be sufficient for the MOLLER experiment, unless we are willing to accept a dead time loss of 12%. The collaboration is exploring other options, including the use of RTP Pockels cells (which are not piezoelectric and therefore do not experience mechanical shock on transition), and Kerr cells.

2.1.2 Liquid Hydrogen Target

The electron beam will impinge on a 150 cm long liquid hydrogen target, dissipating ~ 5 kW to generate the required signal rate of ~ 150 GHz. Even with a 2 kHz flip rate, one of the many technical challenges will be to control target density fluctuations to be small compared to the statistical fluctuations (~ 80 ppm). The success of the target design is predicated on several novel ideas which are being tested for the first time with the Qweak design and operational experience. In addition, the cooling power needed for MOLLER has been carefully considered and the required solutions are being incorporated into the lab's planning. These considerations are discussed in detail in App. A [3]. The main conclusion is that the technical risk associated with the target and related cryogenic systems has been greatly mitigated since the proposal document was written.

2.1.3   Spectrometer System

Another technically challenging aspect of the experiment is the spectrometer and collimator system that will spatially separate Møller-scattered electrons from background. As described in detail in the original proposal (Sec. 2.3-4, App. B), the heart of the experiment is a set of two warm toroidal magnets systems, consisting of seven coils each. Over the past year, our focus has been on validating the spectrometer design and addressing the technical challenges to achieve realistic engineering designs. A Magnet Advisory Committee was formed to advise the collaboration on the technical feasibility and to move us towards solutions that would lead to ease of fabrication. The committee members are: George Clark (TRIUMF), Ernie Ihloff (MIT-Bates), Vladimir Kashikhin (Fermilab), Jim Kelsey (MIT-Bates), Dieter Walz (SLAC) and Robin Wines (JLab)

We present here a summary of recent accomplishments and future plans. The details can be found in App B [3].

1. The TOSCA package was used to verify the proposal model for the 3-D field map of the hybrid toroid. The two field maps matched in great detail and gave very similar results in GEANT4 simulations of signal and background rates.

2. A first-pass realistic model of the hybrid toroid coil using actual conductors was made and presented to the Magnet Advisory Committee. The committee members concurred that there were no show-stoppers and made many suggestions for improvements

3. A new design incorporating these suggestions has recently been completed and is being reviewed by JLab technical staff for the first attempts at designs for structural support and water cooling.

4. The latest design has somewhat degraded performance for background rejection and "optics tweaks" are being pursued to regain the performance of the proposal field map.

5. The final tweaks must incorporate a detailed model for collimation and shielding from neutral background and so this effort will now be launched in parallel.

2.1.4   Integrating Detectors

We have taken a first pass at laying out the quartz and light guides in a CAD program. The goal is to develop sufficient detail so that engineers and designers can evaluate the complexity of the mechanical assembly. In the process a framework for realistic background simulations will also be developed. Figure 2.2 shows two views of the integrating detector layout. In this model, the air light guides are perpendicular to the charged particle trajectories, which leads to a relatively simpler
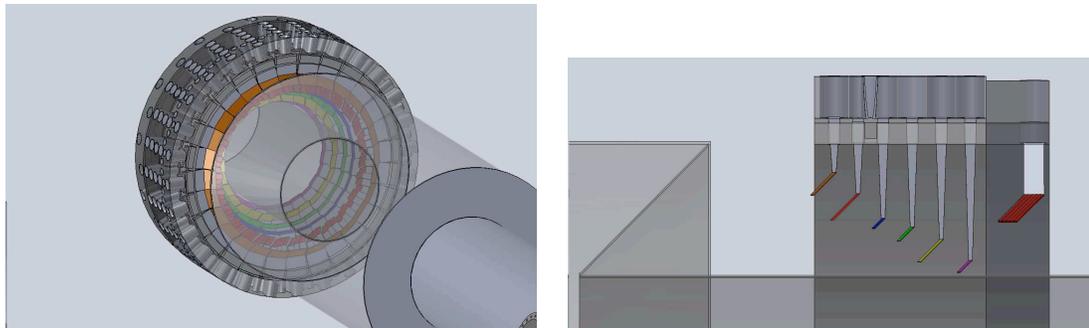
Figure 2.2: *A perspective view of the integrating detector assembly is shown on the left. On the right is shown a plan cutaway view. Note that two back-to-back detectors (thin quartz and quartz/tungsten sandwich) will simultaneously measure the flux of the Møller peak.*

mechanical assembly. Also shown is a new "shower-max" quartz/tungsten sandwich detector that will provide a second independent measurement of the flux in the main Møller "peak". This detector will be less sensitive to soft photon and charged hadron backgrounds.

The detectors have been set in six radial bins that have been optimized to measure the main Møller scattering asymmetry as well as the asymmetries in the background processes of elastic and inelastic scattering from target protons. A discussion of this optimization can be found in Sec. 2.2. We are also investigating a mechanical assembly model with light guides that are parallel to the Cherenkov photons, i.e. at 45° to the charged particles. Ultimately, the most important criterion is the efficiency of delivering photons to the photocathode, so the final decision will be based on a detailed Monte Carlo study comparing the two light guide designs.

2.1.5 Tracking Detectors

We have made some progress in defining the parameters of a charged-particle tracking system which will be used to verify the spectrometer optics, measure the absolute value of Q^2, and study backgrounds. The basic concept is to have three planes of trackers downstream of the two toroids. Two of these planes would be in the drift region in the vacuum space, as shown in Fig. 2.1. A third plane would be in air right after the charged particles exit from the angled vacuum window (see Fig. 2.2) and before the quartz detectors. This space could also hold a scanning device for a quick check of the spectrometer tune. These considerations are discussed in detail in App. D [3].

2.2 Backgrounds Update

A detailed discussion of backgrounds, their suppression, and potential systematic errors were discussed in Sec. 3.5 of the original document. Here we expand on two potential sources of backgrounds that will cause negligible dilution but might still require significant systematic corrections, expanding on discussions in Secs. 3.5.2 and 3.5.3 of the original proposal.

2.2.1 Inelastic e-p Scattering

There is a small ($\sim 0.5\%$) dilution from electrons that arrive in the vicinity of the Møller peak after having scattered inelastically off protons. As discussed in the proposal, the parity-violating asymmetry in inelastic scattering involves unknown vector couplings which can potentially be significantly bigger than the weak vector charge of the proton. We have done a preliminary study of the optimization of the radial segmentation of the integrating detectors so that we will be able to measure the relevant combination of vector couplings so as to make a reliable correction to the raw Møller asymmetry.

In Fig. 2.2, the quartz is color-coded. The Møller electrons hit the red quartz while the elastic e-p electrons predominantly hit the yellow quartz. The two detectors in between (green and blue) are the relevant ones that will yield the measurements to be used to make a reliable correction. The considerations that are relevant for this analysis are discussed in App. C [3], and a careful analysis validates our estimate in the proposal for the systematic error in the correction.

2.2.2 Pions from Weak Decays

A challenging background to monitor and correct for is a fractionally tiny flux of pions or muons from weak decays of heavy hadrons produced by electro- or photo-production in the target. If there is sufficient polarization transfer, the potentially large analyzing power in weak decays might lead to a sizable correction. This was discussed briefly in Sec. 3.5.3 in the original proposal, where we proposed to monitor the size of such an effect by deploying a "pion" detector downstream of the primary integrating detectors.

The Director's Review committee (see Sec. 3) shared our concerns for improving our estimates for such a background correction. They also suggested that we start thinking about contingency plans should the background asymmetry be significantly higher than anticipated. We have launched a comprehensive study of hadron electro- and photo-production. A more careful estimate of the background since the review validates the conservative upper limit of a 0.5 ppb correction assumed in the proposal document. The details of this, and our future plans, are described in App. C [3].

2.3   Polarimetry

In order to reach a robust 0.4% accuracy in beam polarimetry, we have proposed to develop two separate, continuous polarimeters for the current proposal: one based on Compton scattering from polarized laser light and the other on Moller scattering from trapped atomic hydrogen. Plans for these systems are described in the original proposal, in App. F and G.

Recent activity with Compton polarimetry at Jefferson Lab has largely focussed on the challenge of achieving high-precision at low beam energies (∼1 GeV). The Hall A polarimeter was upgraded to use a green laser cavity as the photon target. The change in photon energy provides a higher scattering asymmetry and higher scattered photon energies which are essential for low energy operation, and will be helpful at higher energies. A new Compton polarimeter has been constructed in Hall C, and is presently being commissioned.

The collaboration is considering new design concepts for the laser system to be used at 12 GeV. One of the largest challenges to operating the JLab Compton polarimeters has been bremsstrahlung photons scattering from narrow beam apertures, which are required by the small electron-laser crossing angle. At 12 GeV, beam emittance growth driven by synchrotron radiation in the arcs of the higher passes might exacerbate this problem, and force a re-engineering of the Compton interaction region.

In order to maintain high luminosity at a larger electron-photon crossing angle (and therefore larger beam apertures), a concept for a new laser system has been proposed. This concept is based on a mode-locked Fabry-Perot cavity storing coherently-pumped "bunches" of laser power. The collaboration is also evaluating other options for the laser system that will maintain sufficient statistical power while increasing electron beam apertures, and reducing systematic errors.

2.4   Hall A Infrastructure Issues

We have made significant progress in thinking through some of the major issues regarding situating the experiment in Hall A. The early focus is on figuring out modifications and relocation of existing Hall equipment and also identifying utilities that need upgrading to service the needs of the experimental apparatus. This exercise will help quantify the resources and funding needed above and beyond the design and construction of the experimental apparatus and also help plan for how MOLLER can co-exist and interleave its running with other experimental programs in Hall A. In App. E [3], we list the major items on which progress has been made since the original proposal was written.

Chapter 3

Director's Review

A Director's review of the MOLLER experiment was held on January 14-15, 2010. The review was chaired by Charles Prescott (SLAC) and the other members of the committee were Doug Beck (UIUC), Dave Hertzog (UIUC), Bob Kephart (Fermilab), Bill Marciano (BNL), Matt Poelker (JLab), Michael Schmitt (Northwestern), Glenn Young (JLab) and John Weisend (SLAC). The committee reviewed the scientific relevance of the project and focussed on technical issues with the intention of establishing feasibility and impact on JLab. The full report is available [4], along with the detailed presentations by collaboration members [5].

We highlight some important quotes from the report. The primary recommendation was as follows: **The Review Committee unanimously recommends that the Director undertake planning for MOLLER now, to be ready for the 12 GeV Upgrade era**. The report also endorsed the motivation for the experiment: *Thus MOLLER, by exploiting the best qualities of the Jefferson Lab electron beam, brings new information to bear on, and to constrain interpretations of, any new physics that may result at the LHC and elsewhere.* The committee provided an endorsement of the technical feasibility of the proposed design: *The Committee could find no technical reasons the goals of MOLLER could not be reached.*

The committee report also contains a number of detailed suggestions. The need to involve engineers in the design of the spectrometer and the need for the collaboration to make early progress on its technical design was stressed. The report also pointed out the need for a careful study of the cryogenic needs of the project by JLab. The need for a detailed R&D plan, especially to achieve the challenging goals for systematic control, and a more careful study of potentially large background corrections from rare charged current processes was also pointed out. There has been progress on all these fronts, as has been highlighted in the previous chapter and the associated documentation.

Chapter 4

Beamtime Request

While the MOLLER apparatus is being designed for a beam current of 85 μA at 11 GeV, we have assumed a beam current of 75 μA and a beam polarization of 80% to formulate the beam time request. If higher beam current and/or higher beam polarization are considered routine, the request can correspondingly be reduced using the appropriate P^2I factor. In order to ensure the technical success of this challenging measurement, we are proposing to take data in three separate run periods. These run periods have been optimized so that not only important technical milestones are met, but also that each run will provide publishable results and will significantly add to our knowledge of electroweak physics to date.

One important criterion for gauging the amount of running time required is to estimate how close one can approach counting statistics in the instantaneous raw asymmetry measurement. From our Monte Carlo simulation, we estimate that pure counting statistics for a 1 kHz pulse-pair is 83 ppm. Considering the various sources of additional fluctuations such as target density and electronics noise, an aggressive but realistic goal for final production running is 90 ppm. However, it will be challenging to achieve the final goal for the width in early running, so we will assume 100, 95 and 90 ppm respectively for the three running periods.

Another important criterion is overall efficiency. Generally, once parity experiments have been properly commissioned, the up-time should be 90% for the experimental apparatus, since stable run conditions are required over extended periods of time. Coupled with an accelerator efficiency of 70%, the final running should yield an effective efficiency greater than 60%. Again however, we are unlikely to achieve this in the early going. So, we have assumed total efficiencies of 40, 50 and 60% respectively for the three running periods.

We summarize our estimated beam time in the Table 4.1. The total request is for 344 PAC days for production running and 13 commissioning weeks over the three running periods. In the following, we summarize the goals of each run and then discuss special considerations that must be part of the discussion with both the scheduling committee and accelerator operations before final beam time allocation.

Run Period	1kHz Width (ppm)	% Stat. Error	Stat. Error (ppb)	PAC Days (Prod.)	Eff. %	Calendar Weeks (Prod.)	Comm. Weeks	Total Weeks
I	100	11.0	2.88	14	40	5	6	11
II	95	4.04	1.05	95	50	27	3	30
III	90	2.43	0.63	235	60	56	4	60
		2.05	0.53	**344**			**13**	101

Table 4.1: *Summary of the Estimated Beam Time (75 μA, $P_e = 80\%$).*

4.1 The Three Runs

4.1.1 Run I

The primary goal of the first run will be to commission the principal subsystems of the apparatus. The focus will be on validating the target design, the spectrometer optics, rejection of background and the demonstration that detector fluctuations are dominated by statistics. Once this is established, a reasonable goal would be to achieve a statistical error better than or equal to the E158 result, which we conservatively estimate can be done in 5 calendar weeks. The duration of production running also allows enough sensitivity to demonstrate that there are no anomalously large background asymmetries from charged current processes.

4.1.2 Run II

The primary goal of the second run is to get more than 25% of the proposed statistics so that one is able to achieve $\delta(\sin^2 \theta_W) \sim 0.0005$. This would be the single-best such measurement at $Q^2 \ll M_Z^2$, which could already potentially have a major impact on TeV-scale physics depending on the status of LHC data anomalies. The control of beam helicity correlations must be fully commissioned to achieve $\delta(A_{raw}) \sim 1$ ppb. The fractional statistical error of 4% will require modest but not the ultimate systematic control of absolute normalization errors such as the beam polarization. We have assigned 3 weeks for recommissioning of the apparatus. We will also strive to achieve better than 50% overall efficiency for data collection.

4.1.3 Run III

This run must have all aspects of the apparatus to be working to its full scope. We must also have enough diagnostics in place and sufficient trained personnel within the collaboration so that high quality data can be collected with the best possible efficiency. We are targeting 60% total efficiency. The full control of normalization errors such as the absolute value of Q^2 and the beam polarization at the level of

0.4-0.5% must be achievable. The long duration of this run likely means that it must be split between two fiscal running cycles, and we have assigned 2 weeks of commissioning for each period.

4.2 Special Beam Considerations

Systematic control is one of the most important considerations that must govern various decisions on the design as well as running conditions for the experiment. Two important aspects of this are the methods of "slow helicity reversals" (passive sign flips of the raw asymmetry), and controlled changes to the degree of transverse beam polarization.

4.2.1 Transverse Polarization Running

The large vector analyzing power A_T for Møller scattering (ranging from 5 to 15 ppm at our kinematics) presents a unique opportunity to test the complete apparatus and its capability for absolute normalization at the fraction of a percent level, including detector acceptance, background corrections, azimuthal imperfections, radiative corrections, absolute value of Q^2 and the longitudinal beam polarization. This is because A_T is known theoretically at the 0.1% level. The Møller apparatus is capable of measuring A_T with a fractional statistical error of $\sim 0.2\%$ in a matter of 8 hours at full luminosity. We are therefore planning to request several periods, each lasting 2 to 3 shifts, of 100% transverse polarization in Hall A for a sensitive test of systematics. The periods can likely be synchronized with a change of beam energy that we also plan to request (see Sec. 4.2.4 below).

4.2.2 Wien Angle "Tweaks"

The large A_T value also represents a challenge in terms of systematic control. As discussed in Sec. 3.3 of the original proposal, in order to ensure a negligible systematic error at the fraction of a ppb level due to a coupling between residual transverse components of the electron beam polarization with azimuthal imperfections in the apparatus, it will be required to make periodic corrections to the polarization launch angle at the polarized source. We estimate that changes at the level of 1° to the launch angle might be requested once a day during production running. Assuming the launch angle was set correctly given the sensitivity of the available diagnostics, over many days the total change to the launch angle should average out to zero to high precision. We expect that these changes will be small enough to have no impact on the average longitudinal polarization that will be seen in any of the Halls that happen to be running at the same time.

4.2.3   The Double-Wien

The "Double-Wien" filter at the front end of CEBAF was commissioned during the PREX run. The system accomplishes a full flip of the beam polarization direction with a aid of two Wien filters and a solenoid lens. The method is very effective because the flip is achieved with a relatively minor change to the beam optics at the front end of the machine. This is a very powerful and crucial way to cancel subtle systematic errors. It would be good to get 50 to 100 flips by this method over the duration of the full set of runs. This might require a configuration change once every 5 to 7 days during production running.

4.2.4   Beam Energy

Over the next two years, as the detailed design of the MOLLER apparatus evolves and depending on discussions with the Accelerator Division, the exact beam energy for MOLLER (somewhere in the range of 10.5 to 11 GeV) will be chosen and used to fix the geometry of the spectrometer and the associate collimation. Once this energy is chosen, we will immediately investigate what minimum configuration change would accomplish a beam polarization sign flip either by slightly reducing the total energy of the machine or moving from symmetric to slightly asymmetric energies in each of the two linacs.

For a symmetric linac configuration change, the beam energy change needed is ~ 93 MeV. This is a small enough fractional change in the total beam energy that the MOLLER apparatus can be designed to accommodate both energies for production running with no other changes. Of course, if an asymmetric linac configuration can be found that will maintain the total energy to be the same while accomplishing a polarization sign flip, that would be desirable. However, we do not believe this is a necessary constraint, especially if it complicates other aspects of beam quality.

Over the duration of all the production running, a total of 10 energy flips would be desirable, with at least one such flip during run I, 3 to 4 flips in run II and 6 to 8 flips in run III, or effectively a configuration change every 6 to 10 weeks during production running. The exact frequency and the nature of the configuration change would be chosen after detailed consultation with the Accelerator Division. Since the requested frequency for the configuration change is similar to that required for transverse running, it might well be optimal to schedule the required 100% transverse running in the period in which an energy configuration change is being made.

Bibliography

[1] Y. Li, F. Petriello and S. Quackenbush, Phys. Rev. D **80**, 055018 (2009) [arXiv:0906.4132 [hep-ph]].

[2] W. F. Chang, J. N. Ng and J. M. S. Wu, Phys. Rev. D **79**, 055016 (2009) [arXiv:0901.0613 [hep-ph]].

[3] Link for MOLLER PAC37 Update Appendices: https://hallaweb.jlab.org/wiki/index.php/MOLLERReview

[4] Link for MOLLER Director's Review Report: https://hallaweb.jlab.org/wiki/index.php/MOLLERReview

[5] Link for MOLLER Director's Review Presentation Slides: http://hallaweb.jlab.org/12GeV/Moller/review/index.html

[6] I. Cohen *et al.*, Phys. Rev. Lett. **40**, 1614 (1978).

[7] A. Boyarski *et al.*, Phys. Rev. **D14**, 1733 (1976).

[8] M. Alekseev *et al.*, Eur. Phys. J. **C64**, 171 (2009).

[9] P. Gutierrez, C. Hodges, K. Morgan and D. Schinzel, Nucl. Instrum. Methods **248**, 354 (1986).

[10] J. Bosser, K. Gnanvo, J. Spanggaard, G. Tranquille, Proc. 9th European Particle Accelerator Conference (EPAC 2004), preprint: CERN-AB-2004-089.