**MOLLER Director’s Review – 2016**

# I. Overview

A Director’s Review of the MOLLER experiment, E12-09-005, was held at JLab on Dec. 15/16, 2016. This report summarizes the Review Committee’s findings. The agenda, Director’s charge and Committee membership can be found in the Appendix; the charge elements are repeated in the body of the report.

The scientific case for the experiment remains as strong as ever, retaining, in the 13 TeV LHC era, unique sensitivity to certain scenarios for beyond the standard model physics. It is particularly important to retain a variety of tools to investigate this physics given the absence of any strong indications of new physics at the weak scale. The two loop radiative correction calculations planned for the near future will further enhance the case for the impact of any deviations from the standard model measured in this experiment.

The Committee would like to commend the collaboration for the excellent work they have done to advance the experiment as a whole since the time of the last Director’s review in 2010. There has been noteworthy progress in virtually all areas. The key elements necessary to measure the 35 ppb Moller asymmetry include a high intensity, highly polarized and very well-characterized electron beam, a thick target and a well-understood spectrometer with large acceptance at small laboratory scattering angles. We note the excellent start on quantifying the risks associated with various contributions to both the statistical and systematic uncertainties.

We note progress on the polarized beam and monitoring and are particularly encouraged by the small helicity-correlated beam asymmetries measured in the QWeak experiment—these nearly meet the systematic error contributions required for MOLLER. The development by the collaboration of Pockels cell crystals with faster time response is very important to achieve the necessary statistical uncertainties. It will be important to continue these bench tests to development with the polarized source to be sure the current, excellent helicity-correlated beam properties are retained. A pair of polarimeters is being developed; the agreement between a similar pair in Hall C at the 0.7% level is very encouraging.

Progress on understanding high power liquid hydrogen targets has been outstanding. The ability to calculate the overall density reduction for a variety of such targets, and the ongoing work to simulate the (more important for these experiments) density fluctuations is very encouraging and suggests that a target with twice the power handling capability of the QWeak target is within reach.

The spectrometer has progressed substantially since the last Director’s review. The novel design for the downstream toroid has now been tested and refined in Monte Carlo simulations and found to provide good separation of the Moller events from the various backgrounds. The focal region has a range of detectors to effectively measure the main signal as well as the various backgrounds with good granularity. A set of diagnostic detectors has also been developed, in part to provide critical cross checks of the main integration mode data acquisition. Continued development of background simulations, which have produced an impressive report on the e-p and e-Al contributions, will be critical to the success of the experiment.

In summary, the Committee finds that the substantial progress since the last Director’s Review suggests that the experiment is ready to move to the next stage. As a result of our consideration of the charge elements, we have a number of recommendations in both technical and management areas that we hope will facilitate the progress of the experiment. We recognize that the collaboration has been focused on technical rather than management issues; accordingly, we have more suggestions for the approach to the project phase. Indeed, the report contains numerous recommendations; their number should be taken only as a sign of the enthusiasm of the committee for the experiment. It will be important for the collaboration to move forward with the remaining R&D tasks to reduce project risk, and this will require significant resources. Taking the next step in advancing the precision of parity-violating electron scattering experiments that the MOLLER experiment represents will require sustained effort of both the collaboration and the laboratory.

The structure of the remainder of this document is as follows. Section II comprises five subsections that group elements of the charge (Appendix A) according to “subsystem”:

1. Science reach, technical feasibility, systematic errors
2. Magnet systems
3. Detector systems
4. Target system
5. Project management, cost, schedule, ESHQ

The subsections, in turn, have the Findings/Comments/Recommendations format. The committee membership is listed in Appendix B.

**II. Response to the charge**

*II.1. Science reach, technical feasibility, systematic errors* (charge elements a, b)

FINDINGS:

Measurements of parity violating electron scattering (PVES) have played a central role in establishing the Standard Model of electroweak interactions. With the proposed precision on the APV in electron-electron scattering, translating into a 0.1% extraction of the weak mixing angle, the MOLLER experiment will probe quantum effects in the Standard Model at unprecedented levels and will be sensitive to a broad array of new physics scenarios.

Within the framework of the Standard Model, MOLLER will provide the most precise low-energy measurement of the weak mixing angle. With precision at the same level of the Z-pole measurements, MOLLER would allow for a stringent test of the energy dependence of the weak mixing angle predicted by Standard Model quantum corrections. Consistently with current low-energy data, a ten-sigma discrepancy from the Standard Model prediction could be observed by MOLLER – a non trivial discovery window.

At the same time, MOLLER has a “broad band” sensitivity to physics beyond the Standard Model, as it probes both high-scale new physics and light, weakly interacting sectors. For heavy new physics, the projected precision implies sensitivity to an effective scale of 10 TeV and to a specific direction in coupling space that was inaccessible at LEP and will be inaccessible even at future electron-positron colliders. For light and weakly coupled sectors, MOLLER has unique sensitivity to the so-called dark Z boson. This broad sensitivity to new physics puts MOLLER in the same class as other high profile low-energy precision measurements.

Finally, it is important to establish the relevance of MOLLER in light of ongoing searches for new physics at the Large Hadron Collider (LHC). Here the outlook is positive, as well. On the one hand, should the LHC find evidence of new physics, MOLLER will play an important role in constraining the form of possible new interactions, given its sensitivity to scales of O(10) TeV. On the other hand, if new physics is not seen at the LHC, MOLLER still has chances to probe new effects to which LHC would be blind, namely “lepto-philic” interactions mediated by very heavy particles (for which the competition would only be next generation electron-positron colliders), and dark sectors.

This will be the most precise measurement on electron parity violation. The effort pushes the state-of-art in technology in all aspects of the hardware. The MOLLER experiment at JLab aims to measure the parity-violating asymmetry of about 35ppb in the scattering of 11GeV longitudinally polarized electrons off unpolarized electrons in a 150cm long liquid hydrogen target to an overall fractional (in-)accuracy of 2.4%.

MOLLER proposes to achieve this accuracy with an allocation of 344 PAC days spanning three running phases, which are currently foreseen to achieve results of similar relative accuracy as the E158 result (~10%, phase I), an improvement by a factor of about two over E158 (phase II), and the final accuracy (phase III).

The quantity of interest is the electron's electroweak charge, Qwe. It is related, by a kinematic factor and the Fermi coupling constant, to the parity violating, single-helicity asymmetry in the scattering of electrons. This asymmetry is observed as the longitudinal single (electron beam-) spin asymmetry in elastic scattering off atomic electrons. The observed asymmetry is to be corrected for any helicity-correlated beam properties (position, charge/intensity, energy, angle, size) and to be normalized by the absolute polarization of the electron beam.  It is diluted by any experimental background that will also introduce an offset if the underlying processes have a parity-violating asymmetry.

The 2.4% uncertainty has a statistical component of 2.1%. The collaboration has identified and quantified ten sources of systematic uncertainties. They contain contributions from the uncertainty in the (energy) scale, the measurement of absolute beam polarization, beam characteristics for the different helicity states, multiple sources of physics background, and effects from (residual) transverse beam polarization components. Their total amounts to 1.1%.

COMMENTS:

Convincing progress was presented towards demonstrating that the measurement accuracy will, with an appropriate and staged run-plan and timely analysis follow-up, ultimately be achievable.

An excellent start was made on an initial table to address technical risk for reaching the stated uncertainties based on commonly used project criteria.

The contributions to the systematic uncertainty can be considered uncorrelated as presented, despite internal correlations among beam parameters on the one hand, and internal correlations in backgrounds due to inelastic e+p scattering.

The collaboration proposes staged running, but did not present a worked-out run-plan or agreed-on criteria to arrive at such a plan. The pursuit of fast turn-around analyses, well beyond quality assurance to the level of results of near-publishable quality, are deemed likely to be an essential component of such a plan.

One possible contribution to the systematic uncertainty was identified in addition to those quantified in the written materials submitted prior to the review, namely that from the effect(s) of the coupling of detector acceptance with possible single-spin asymmetries in the re-scattering of polarized electrons in the final state off detector materials. The collaboration discussed this effect as part of the Q&A session. It presented a preliminary assessment that puts its size among the smaller contributions to the systematic uncertainty and expressed intent to refine this estimate.

The collaboration should investigate the effect of spectrum distortions induced by radiative corrections, including careful consideration of thick target bremsstrahlung. State-of-the art radiative corrections should be included in the simulation of both “Moller” and “background” events, especially the one from ep elastic scattering, which result in a large subtraction of ~6.6%.

We now address broad questions of experimental feasibility by subsystem (see also specific sections below), and conclude with comments on recommendations from previous reviews

i. High-power target

The work on designing a high-power target, capable of receiving 5kW, is progressing well. The main concern is the beam-induced density fluctuations (due to boiling); empirically, this effect can be suppressed by increasing the helicity reversal frequency.

ii. Beam control (energy, position, spot size):

The success of the MOLLER experiment hinges on the ability to control the helicity-correlated beam asymmetries. These stringent beam specifications have been pushed by the most recent PV experiments (Qweak and PREX-I). The energy asymmetry has exceeded that required by the MOLLER experiment, although the effect of realistic residual dispersion at the target must still be addressed. Other beam qualities still yet to be improved: the intensity asymmetry needs to be a factor of 3 smaller; the position difference needs to be 40% smaller; the angular difference needs to be a factor of 2 smaller, and the spot size difference to be a factor of 10 smaller. The strategy of slow spin reversal (with a Wien filter) and g-2 precession will be used to further suppress these asymmetries. Currently these beam requirements have been demonstrated with the 6 GeV beam. There are good prospects to anticipate that the 11GeV beam can exceed these requirements, as the adiabatic damping should increase and synchrotron radiation in the accelerator is expected to wash out the helicity correlated beam asymmetries in the delivered beam.

Towards improving the beam properties, the collaboration has been testing a promising solution, the RTP crystal as the material for the Pockels cell to reverse the electron helicity. Due to its lack of the piezo-electric effect, the RTP crystal could help to reduce settling time after reversal. It is a high priority in the collaboration to test the new Pockels cell and extract polarized electron beam in the coming year.

Work on improving the beam current monitor resolution has been in progress; the collaboration identified the source of limiting noise floor from the oscillator used in the beam monitor. The feasibility of using a lower noise local oscillator should be pursued and its full impact on the charge measurements must be understood. While brute force averaging of 5 BCMs is a potential solution to the intensity noise problem (provided that the residual noise is uncorrelated between monitors so that it can be reduced through statistical combination), it limits flexibility in doing systematic studies. The proposed beam monitors measure the beam position, but are not sensitive to the beam size. No R&D was identified or proposed towards a direct measurement of beam size and possible correlation with helicity.

iii. Detectors and background control

The novel hybrid magnet design achieves the goals to (1) focus the Moller signal and (2) separate the dominant noise from elastic e-p scattering. The work to move the magnet from a conceptual into an engineering design is progressing well. The latest background study has demonstrated the ability to control the dominant background (e-p elastic, e-p inelastic, e-Al scattering) by a simultaneous fit using the test data collected in different group of radial and azimuthal detectors. It is possible to increase the power to resolve these backgrounds by optimizing the detector segmentation.

Due to the space limitation, the beam dump is somewhat close to the detector assembly. The shielding design will need to be finished to ensure no excess noise from the secondary particle productions in the beam dump.

iv. Lessons from Qweak

The top challenges from the Qweak experiment, including the beamline background caused by asymmetric halo, the transverse analyzing power of detector radiators, and the steering of low energy beam electrons downstream of the target by a slightly asymmetric torus, may also impact the MOLLER experiment. The combination of small angle detectors and diffuse background detectors has been successful in monitoring the beamline background, and the MOLLER collaboration plans to use the same technique. While a good case was made that the L-R asymmetry from the radiator scattering will be small in the main MOLLER detector, full Monte-Carlo studies will be needed to demonstrate that it can be controlled to the 0.1 ppb level. The collaboration also needs to finish the particle tracking study under a magnetic field with realistically broken torus symmetries to ensure there is no excessive scattering from the beamline.

Recommendation #1 of the 2014 DOE/NP-led MOLLER science review (“Complete the full two loop calculations of radiative corrections in order to document the theoretical prediction and submit a report to the Office of Nuclear Physics by September 15, 2016.”) has not been fully addressed. While the goal of completing the two-loop calculation in both “minimal subtraction” and “on shell” schemes within two years was overly optimistic, to date only partial two-loop results in the on-shell scheme appear. The report submitted to DOE on September 15, 2016 outlines a plan that suggests the completion of the relevant calculations in the next three years.

The background assessment on the e-p inelastic and Al elastic background seems to be adequate. The study demonstrates that a simultaneous fit using the test data collected in different group of radial and azimuthal detectors is sufficient to separate the dominant backgrounds, while preserving the resolution of the signal in the main Moller ring.

RECOMMENDATIONS:

* In order to maximize the physics reach of the proposed measurement, it is critical that the theory uncertainty on the PV asymmetry be brought below the 1% level. We recommend that the relevant two-loop calculations be completed within the next three years. The MOLLER collaboration leadership should take the needed steps to facilitate this development.
* The technical risk assessment, using accepted technological readiness levels, for reaching the stated statistical and systematic uncertainties should be completed.
* A run-plan that addresses the interleaving of the counting and flux measurement modes and (other) needs for data dedicated to systematic uncertainties should be developed.
* Rapid analysis feedback should be pursued to ensure the level of near-publication quality results (i.e., asymmetries corrected for all known factors) for the initial running period(s).
* Test the new Pockels cell and extract polarized electron beam.
* Demonstrate the noise level of the beam monitors in combination. In particular, continue to investigate the sources of noise in the BCMs including, but not limited to, that from the local oscillator.

*II.2 Magnet systems* (charge elements b, c, d, e)

We first provide summary comments in response to the charge elements, following by Findings/Comments/Recommendations.

b.   Have the recommendations of the previous MOLLER reviews (the 2010 MOLLER Director’s Review and the 2014 DOE/NP-led MOLLER science review) been properly addressed?

Yes, on the magnets a significant effort was made to develop a realistic magnet design that provides some confidence of feasibility for the spectrometer. The team also made significant progress on evaluating infrastructure needs.

c. The feasibility and effectiveness of the pre-conceptual design for meeting the technical performance requirements. Is the high precision achievable or are there outstanding technical risks?

The team has made significant progress in developing a pre-conceptual design that appears feasible and that should meet the technical performance requirements, pending validation of key features.

d.   The status of the proposed technical design, including the feasibility and merit of the technical approach; the completeness of the technical design and scope

The technical designs are progressing and are appropriate for this stage of the project. Further effort should be made to categorize and quantify the technical risks, and to develop a clear phased plan to address them; these plans should be fully in place and tracked by CD-1.

e.   Are the cost and schedule estimates credible and realistic for this stage of the pre-project planning?  Do they include adequate scope, cost and schedule contingency?

The cost and schedule are not very advanced, but that is not unexpected at this stage of the project. Serious effort should be applied to further develop and clarify the WBS, identify owners of each of its element, and enforce a consistent bottoms-up approach to cost and schedule. Management should insist on a cost and schedule strategy for each level-II that clearly identifies risks, provides a milestone-based development phase that addresses the risks, and that results in a cost and schedule designed for success. This should be in place for CD-1.

COMMENTS and FINDINGS:

* Significant progress has been made on developing a realizable spectrometer magnet.
* A first tolerance analysis has been performed related to single hybrid coil position, which serves as an example for further tolerance analysis.
* Coil tolerances must be assessed broadly, including, but not limited to the impact on the physics (would a full field map mitigate this problem, e.g., in the context of integrating detectors) and on transport of the 1 MW of electron beam after it goes through the target.
* The Hall A will require a 1MW upgrade to its power capacity, as well as an increase of LCW capacity to 2MW and 500 gallons per second. Furthermore, a feedline from ESR-II for cryogens will be required.
* The projects effort to leverage the experience from the MIT team is commendable, and has resulted in a conceptual design that provides credibility to the project.
* The technical requirements should be further developed/communicated so there is clarity in the figure of merit(s) of the various technical components and what constitutes acceptable.
* A systematic study of possible tolerance requirements needs to be developed, including elements such as a) individual coil position (x, y, z) and angle requirements (already partially done); b) temperature control requirements; c) power supply temporal stability requirements, etc
* A magnetic measurement plan should be developed that takes into account real project needs and the technical issues associated with accurate probe positioning over such a large magnet.
* An evaluation of material irradiation and activation vs experimental time needs to be developed so that a plan can be developed for access/handling.
* The radiation requirements should be clearly identified early in the project so that appropriate fabrication materials can be selected. This is important, for example, for the magnet epoxy selection. Although the project appears to be aware of this, no systematic procedure/documentation is in place to guarantee that the issue is addressed consistently.
* Radiation impact on long-term magnet performance should be evaluated, e.g. possible impact on, in particular, the mechanical and electrical stability of the epoxy used to pot the coils, other mechanical supports/positioning systems, as well as on resistivity and hence power and temperature stability.
* The pre-conceptual design and manufacturing effort suggested a plan to design, build and test a full prototype magnet. This is commendable; however it should be part of a clear, systematic and complete project plan for the magnet system.
* For CD-1, the project needs to show that alternative design concepts have been or are being evaluated to ensure that cost, schedule and technical risks are being minimized.
* The cost estimates for the hybrid magnet appear to be based on engineering experience on somewhat similar kinds of magnets. The 40% contingency is too low at this early stage in the design.
* The Hall A spectrometer cost estimates presented did not have sufficient granularity to determine if there were sizeable items missing. For example it is not clear if the detailed costs of the closed-loop chiller anticipated for the spectrometer solenoid dedicated LCW system were included. (Note added: after the review, the collaboration clarified that the estimate did include the cost of the chiller.)
* The hybrid spectrometer magnet design utilizes a high current density compared to traditional resistive magnets. Variations in water temperature, e.g. due to variations in the ambient temperature, may result in coil size change that introduces systematic errors into the experiment. Cu resistivity can be impacted due to high radiation dose, which would result in increased resistive heating over time. The thermal stability should be evaluated in terms of potential impact on the science figure of merit, and if need be the design should include cooling water temperature control so that the magnet temperature remains constant despite resistivity changes.
* Using TOSCA for the hybrid spectrometer magnet design and basic tracking, using the Biot-Savart mode, is appropriate. If iron perturbations are to be analyzed TOSCA may not be effective; a boundary element code such as Radia would be more appropriate.
* The plan moving forward for the hybrid spectrometer includes designing and fabricating a single coil prototype, which would be extremely valuable in addressing the technical risk while improving the cost estimate for that element of the project.
* The design approach being pursued for the collimators is critical to the project and should be continued so that a robust baseline layout is in place prior to CD-1.
* Vacuum vessel (housing the hybrid magnet) installation, alignment, and removal must be evaluated in detail. Consideration should be made for handling the radiation exposed heavy vacuum vessel.
* The project would benefit from a sensitivity table of the various elements (beam size variation, beam current variation, polarization, etc.) to identify highest risk/benefit elements. Furthermore, some effort should be made to identify how, and to what degree, these elements are coupled.
* The Hall A infrastructure needs for the Moller experiment is at an appropriate stage for the project, but will need to be further along for CD-1. In particular a “baseline” layout is needed that is compatible with existing floor loading and that allows the experiment to be assembled/disassembled or moved as needed by the Hall A experimental schedule.
* We suggest the project prepare to carry out an Operational Mode and Effect Analysis (OMEA) along with Failure Modes and Effect Analysis (FMEA) to guide risk identification and mitigation planning.
* The cost breakdown for the magnets shows a 4.8M$ cost, plus 40% contingency, and a two-year schedule. This does not appear credible without a significant development phase performed in advance. The team should develop a robust development and qualification plan, including for example a) sample conductor qualification and b) prototype magnet design, fabrication and test, prior to final magnet production. The development phases could be aligned to provide technical feedback in advance of CD-1 and CD-2, respectively, providing confidence in the cost and schedule at those critical milestones.

RECOMMENDATIONS:

* The potential effects of radiation damage on the epoxy-potted spectrometer magnet coils should be assessed
* Develop a robust project schedule, including development/technology readiness elements, with sufficient detail and milestones to address primary technical risks in a timely manner.
* Develop a consistent and actionable approach to sensitivity analysis for both backgrounds and helicity-correlated effects, and associated specification derivation, such that technical designs can be evaluated, manufacturing tolerances specified, and resulting hardware measured.

*II.3 Detector systems* (charge elements b, c, d, e)

*b.     Have the recommendations of the previous MOLLER reviews (the 2010 MOLLER Director’s Review and the 2014 DOE/NP-led MOLLER science review) been properly addressed?*

FINDINGS and COMMENTS:

Comments and recommendations from prior reviews called for detailed Monte Carlo simulation. Effort has been devoted here, for the most part successfully. Backscatter effects were less crisply discussed.

Cost estimates were described as ‘sketchy’ in the 2010 review. There has been a firming up of costs for detector elements. The estimates are based on quotes obtained for the major cost elements like the fused silica plates, photomultipliers. Costs developed for the trackers are based on recent experience in building similar GEMs. It is likely that the contingency, at 20%, is too low. The team expects that construction of the detector will require 3 years, with an additional year of float contingency.

The team was asked to devote particular attention to background detectors. Pion detectors have been planned which use acrylic Cerenkov counters with GEM tracking planes.

Prototypes have been built for the detector elements. Some of these have already undergone an extensive set of beam tests at Mainz.

RECOMMENDATIONS:

None.

*c.     The feasibility and effectiveness of the pre-conceptual design for meeting the technical performance requirements. Is the high precision achievable or are there outstanding technical risks?*

RECOMMENDATIONS:

* The detector sensitivities to helicity correlated beam parameter differences do not yet include the effect of realistic residual beam energy dispersion at the target. A specification for allowable residual dispersion at the target should be determined.
* The optics of the Hall A beamline should be examined to ensure there are adequate knobs to obtain a satisfactory waist in the Compton collision region while limiting residual dispersion at the target. (Note added: after the review, the collaboration clarified the status of the beamline design: there is an existing design that includes the required Compton waist and minimizes the dispersion at the target.)
* The impact of mu+mu- pair production in the target on the pion detector asymmetry measurements should be simulated.
* Splashback from the Shower Max Detector should be simulated to see the impact on the Thin Detector ring signals.
* Cross-talk between detector regions due to showering in the support structure of the Thin Detector should be simulated. If a straightforward aluminum frame turns out to be problematic, a more expensive and challenging carbon frame option could be investigated.
* The specification for alignment and symmetrization of the spectrometer coils should include clean transport of nearly 1 MW of the main beam along the beamline.
* Carry out full Monte-Carlo studies of the Mott-scattering in the full MOLLER geometry.
* Adjust the quartz detector segmentation to optimize the resolving power relative to the dominant backgrounds, including the e-p elastic, e-p inelastic, e-Al scattering, and diffuse backgrounds.
* Simulations of the combined apparatus and hall are needed, for example, to assess backscattering backgrounds from the dump in the pion detectors.
* Complete the shielding studies around the beam dump to ensure there is no excessive noise in the main MOLLER detectors.

*d.     The status of the proposed technical design, including the feasibility and merit of the technical approach; the completeness of the technical design and scope.*

FINDINGS and COMMENTS:

The Quartz Cerenkov Detector has been extensively prototyped and tested, including completion of six rounds of beam tests. The GEM tracker relies on experience gained by the team in constructing such detectors for another experiment. The Shower Max Detector (Quartz/Tungsten) is at prototype stage, with beam test to follow.

Mechanical design of the support systems for these detector elements is notional. The expectation is that finished detector components will be delivered to JLab where these elements will be assembled onto support structures that will be developed by the Hall A team.

Long equipment down-times due radiation damage are a serious risk to reaching the precision goal. In the context of the main detector, this means that all components in the scattered beam envelope (radiators, light-guides, support structure) should show negligible damage up to 50 MRad. All components outside of the beam envelope (PMTs, bases, connectors, cables, switch) should be rad hard to something conservative like 1 MRad. Corrosion due to nitric acid formation in humid air is harder to quantify, but it has been an issue for air lightguides in very high dose rate environments.

Rad damage tests to at least 50 MRad are needed to qualify a source of fused silica for use in the thin detector. The selected Spectrosil 2000 should be adequate. The Idaho accelerator may be able to deliver the large dose required, at least to small pieces.

RECOMMENDATIONS:

* Conduct radiation damage tests to at least 50MRad to qualify fused silica for use in the thin detector.

*e.     Are the cost and schedule estimates credible and realistic for this stage of the pre-project planning?  Do they include adequate scope, cost and schedule contingency?*

FINDINGS and COMMENTS:

The cost estimates for the individual detector items are realistic for this stage of pre-project planning. The schedule appears to be a top down estimate of three years. Because many of the estimates are based on quotes, the team has assigned a top down contingency on the costs of 20%. This contingency is too low for this stage of the experiment. The team recognizes that there may be inadequate schedule contingency, and suggests an extra year should be assigned for this. This is commendable.

RECOMMENDATIONS:

* Develop Bases of Estimates for Detectors (WBS 1.4, 1.5), including un-costed (physicist) manpower needs. Develop bottom-up contingencies using standard methodologies. Update the cost estimate.
* Develop a detailed detector fabrication schedule that links into the Hall A MOLLER detector integration schedule.

*II.4 Target system* (charge elements b, c, d, e)

*b.     Have the recommendations of the previous MOLLER reviews (the 2010 MOLLER Director’s Review and the 2014 DOE/NP-led MOLLER science review) been properly addressed?*

FINDINGS and COMMENTS:

Yes, the collaboration has done an admirable job addressing the target-related recommendations of previous review committees. With the assistance of the JLab Target Group, the Moller collaboration has performed an extensive labor and cost estimate for the design and construction of the liquid hydrogen (LH2) target. The labor estimate ($2.5M) is somewhat lower than that predicted by the 2010 review, but in line with the design and construction of the QWeak target, which was built at JLab in 2009.

Extensive effort to characterize and compare the performance of the Qweak and other LH2 targets has been made utilizing Computational Fluid Dynamics (CFD). The agreement lends strong credibility to the collaboration’s dependence on CFD to guide the MOLLER target design.

A new cryogenic plant, ESR2, is planned for the MOLLER project, but has not yet received funding. The new plant is expected to provide sufficient refrigeration capacity for the MOLLER LH2 target, about 5 kW. A new 200 foot long liquid helium transfer line between Hall A and ESR2 has been included in the MOLLER cost estimate presented at this review.

As is standard practice at JLab for such systems, the LH2 target will receive a separate review focusing on EH&S, performance, and operability design aspects.

RECOMMENDATIONS:

None.

*c.     The feasibility and effectiveness of the pre-conceptual design for meeting the technical performance requirements. Is the high precision achievable or are there outstanding technical risks?*

FINDINGS and COMMENTS:

Based on the success of the QWeak target, the performance requirements for the MOLLER target are probably achievable. However, as was pointed out at the review, there is no clear way to fully test the target system prior to the experiment.

A CFD simulation was presented that indicates that the required statistical boiling width could be met in a 150 cm long, longitudinal flow LH2 cell. The simulations indicated that little or no density fluctuations would occur in the bulk fluid at a flow rate of 1.8 kg/s. Some boiling is however expected to occur at the cell’s aluminum entrance and exit windows, which will enlarge the parity violating asymmetry width.

An estimate of the PV asymmetry width due to target boiling was made by scaling the performance of the G0 target, a 20 cm cryotarget with mostly longitudinal flow at 0.3 kg/s, and was predicted to be 26 ppm. The dependency of the helicity reversal rate, *f-0.38* in this scaling, was taken from QWeak data. Here the target was 35 cm long, with 1 kg/s transverse flow. No explanation for this unusual rate dependence was offered, and there are concerns that it may depend on target and flow geometry. Efforts to better understand this dependence would lend greater confidence in the scaling.

Further CFD refinement of the target cell should continue in order to reduce boiling at the windows as much as possible.

RECOMMENDATIONS:

None.

*d.     The status of the proposed technical design, including the feasibility and merit of the technical approach; the completeness of the technical design and scope.*

FINDINGS and COMMENTS:

The status of the technical design is appropriate for the pre-project stage of this project. The proposed design is based on an existing target system which was successfully used for the E158 experiment at SLAC. As an aid to developing a more mature target design, a detailed cooling budget, including viscous heating, pump losses, etc. should be developed in the near future.

Continued, close communication with the JLab Cryogenics Group, regarding the operating parameters of the ESR2 refrigeration plant, will be critical to the design of the target’s helium/hydrogen heat exchanger.

RECOMMENDATIONS:

* Pursue a more realistic, detailed cell window design and check/refine with CFD. Work with JLab engineers and designers to ensure that the design remains technically feasible.
* Specify the number, location, and beam current requirements for all solid targets.
* Calculate the radiation load on nearby scattering chamber components for the purpose of estimating the o-ring and vacuum pump and gauge lifetimes.
* It will be important to assess the effect of irradiated beamline components on the plans to move the experiment in and out of the beamline.

*e.     Are the cost and schedule estimates credible and realistic for this stage of the pre-project planning?  Do they include adequate scope, cost and schedule contingency?*

FINDINGS and COMMENTS:

The cost and schedule estimates provided for this review were developed in conjunction with the JLab Target Group and are believed to be credible and realistic.

The collaboration’s blanket 40% contingency was applied to this estimate, which is probably a reasonable value.

The collaboration commissioned and received a workforce schedule from the JLab Target Group, assuming a three-year timeline to design and construct the MOLLER target. No schedule contingency was provided, but it will undoubtedly be strongly coupled to the Target Group’s additional workload.

It was mentioned that the E158 scattering chamber might be appropriate for use in MOLLER as a cost-saving measure. The collaboration is reminded that the cost-savings associated with re-using existing equipment can sometimes be negative.

RECOMMENDATIONS:

* Perform a cost-benefit analysis for the target scattering chamber, comparing the E158 chamber with one purpose-built for the proposed MOLLER experiment.

*II.5 Project Management, Cost, Schedule, ESHQ* (charge elements e, f, g)

We reiterate here that we appreciate the collaboration focus on technical issues at this stage; the recommendations in this section (II.5) are intended to help the collaboration move toward CD-1.

*e. Are the cost and schedule estimates credible and realistic for this stage of the pre-project planning?  Do they include adequate scope, cost and schedule contingency?*

FINDINGS:

* No CD-0 yet, so no initial funding profile defined/communicated.
* Cost estimate has been revised since initial estimate in 2011. Base cost has gone up from $16.4M to $19.7M.
* WBS 1.5 includes integration (design of structures, cabling, etc.), utility upgrades, and installation
* The project personnel stated that they believe 4 years is adequate for total project duration.
* No integrated and resource loaded schedule was developed to date.
* Several key WBS elements have developed preliminary schedules
* High level cost estimates were developed for each subsystem
* Both cost and schedule estimates are “top down” estimates.
* Initial thought is that this will be a 4 year construction project
* Some area costs (WBS 1.1 Target) are based on some engineering design drawings, prior experience, etc. These have 40% contingency (like most)
* A uniform cost contingency % is assigned top down for each subsystem. Most subsystems use 40% for contingency. Two subsystems have 20-33% contingency.
* Some subsystems’ cost estimate includes the cost for commissioning.
* For 1.3.3 Integrating Detectors – there are labor and material contributions from Canada and from Germany. There is a request for funds from Canadian Government, but costs presented are for materials in case Canadian funds don’t come through. (Canadian effort will occur even without new funding.)
* DAQ – estimates of JLab engineering were stated at $80K/yr. Estimator assumed an inaccurate labor rate for engineering resources.
* Technical, schedule and resource risk is not yet included in the contingency analysis.

COMMENTS:

* For CD-1, the project needs to show that alternative design concepts have been or are being evaluated to ensure that cost, schedule and technical risks are being minimized.
* The project must have preliminary guidance on the funding profile from DOE NP prior to defining a schedule. What was presented was a technically limited schedule, but that’s all. Many DOE projects are funding limited, not technically limited.
* The project needs to develop a schedule that includes getting through CD gates as well as funding profile constraints.
* The project will need to provide guidelines/guidance to be used by each Subsystem in developing their revised cost estimate/schedules. This may include guidance of “cost range” – high and low estimates. Options (best case vs worst case), etc. It should also include guidance on application of labor rates by institution, overhead rates by institution, escalation rates (labor and materials), etc.
* An output of CD-1 is a defined cost range for the project. The Resource Loaded Schedule is a “point estimate”. How does this point estimate relate to the cost range? Is there optional scope that can be added to define the top end of the range?
* Nearly universally utilized 40% contingency may be light in some WBS areas at this stage. The project needs revised guidance to Subsystem Mgrs. The two subsystems with 20-33% contingency are too low for this stage of cost development.
* Will need to move to an integrated, resource-loaded schedule shortly – this is a large and complex process – do not underestimate it. There are tool requirements to meet EVMS guidelines. MS Project for example will not meet these. Primavera P6 does but has a large overhead associated with it.
* Early cost estimate (even with seemingly large contingency) should not be used to establish an upper limit on DOE TPC.
* Subsystem Managers must be on board (appointed) prior to development of cost estimate ranges for CD-1. They must be responsible for these estimates (or they won’t be responsible for the ultimate outcome).
* In addition to cost estimate contingency, the Project should develop a methodology for accounting for technical, resource (funding, people) & schedule risk. DOE now expects contingency to include technical and other risk elements as well as cost-estimate risk.
* The assumptions for schedule estimates are not clear. For example, in estimating the design schedule, was the time needed for prototype and testing considered? Was the time needed for QA taken into account?
* The high level schedule presented appears to be overly optimistic.
* The overly optimistic high level schedule estimate could result in insufficient estimate of manpower needs in completing the project
* Cost and schedule impacts of those technical risks should be considered, and linked to contingency evaluation.
* All parts of project rely on JLab engineering and design at some level. When developing the schedule the project needs to account for availability and resources of JLab.
* WBS 1.7, 1.10 and 1.11 which are labeled as “dependencies” for the Lab need to have a cost/schedule. Also, an agreement with JLab to achieve these WBS items needs to be written with clear milestones.

RECOMMENDATIONS:

* Prior to CD-1, a fully integrated and resource loaded project schedule will need to be developed. This can be done at a more “summary level” for CD-1 and refined further prior to CD-2. The impacts of funding profile as well as the CD gate constraints should be integrated into the schedule. The resource costs should include all appropriate overheads as well as the effects of escalation as the funding profile and schedule will be in At-Year $.
* Develop and communicate written guidelines for project’s bottom up cost/schedule development, risk assessment and contingency analysis. It will help ensure uniformity in these areas, which is expected for successful CD reviews.
* The Basis of Estimate for each subsystem/deliverable should be developed in conjunction with the resource loaded schedule
* Plan an approach for defining the “cost range” needed at CD-1.
* Develop a contingency approach that relates to the understanding of scope as well as maturity of the development of each subsystem. At this stage of planning, it is better to give higher % range in contingency estimate due to the uncertainties. Additional contingency could be added for identified high risk items.
* Develop risk evaluation metrics and a risk register that tracks all technical, cost, funding and schedule risks, with identified risk owner, risk response plan
* The project needs to come up with a plan and decision point for down-select of options in design and technical choices.

*f. Are the plans to manage the foreseen MOLLER project appropriate at this stage?  Is there a capable team in place to produce a credible technical, cost and schedule baseline in the next phase?*

FINDINGS:

* Subcontracts will be handled through the JLab MOLLER Project Office.
* The membership of the Technical Board has not yet been fully defined.
* The Executive Board will include the Deputy Spokesperson + Canadian & German PI’s plus 4 elected representatives.
* Lab Management has begun communicating advice and constraints regarding the management organization.
* The Collaboration does not yet have a clear understanding of these organizational requirements.
* There will be internal design reviews organized by the Project Manager (PM/CE)
* Some subsystem level Key Performance Parameters (KPPs) have been documented.
* Some high-level subsystem requirements have been developed.
* Most subsystems have identified contributing institutions. The work scope division for institutions below Level 2 has not been clearly defined yet.
* Three Level-3 items in WBS 1.3 have overlaps with other WBS.
* All subsystems have identified major technical risks and show good understanding of these risks. However no risk evaluation metrics were presented. Cost and schedule impact of the risks were not presented.
* There is not yet a Project WBS Dictionary. Nor are there clear and complete scope and interface definitions between the subsystems.

COMMENTS:

* In project phase, 1 FTE to do monthly reporting, EVMS, subcontracts + managing the construction project, is likely inadequate. This will require a small team many of whom will be paid on project.
* The KPP’s need to be carefully developed and should be “measureable”. While “Installed” is measureable, it is somewhat weak... The project should not aim for too many KPPs as these define project completion. In the modern KPP approach, there will be both *objective* and *threshold* versions for each KPP. Drafts of these will be required at CD-1.
* The project will need to develop a WBS Dictionary to define scope and interfaces for each subsystem (to L3). This is a good communication tool to define responsibilities and interfaces. The project may also want to go the direction of a simple WBS Dictionary combined with detailed Interface Control Documents (ICDs). These ICD’s would provide precise detail of the interfaces.
* The project will need to further refine the organization and appoint Subsystem Managers in coordination with JLab management. In some cases, physics coordinators can be coupled with someone at JLab to ensure all requirements are met. Subsystem Managers should largely form the membership of the Tech Board (plus safety officer, chief engineer, project controls officer, etc).
* The project will need to define a risk management process (plan). A Risk Registry should be used to capture all technical, cost, schedule, funding, resource, etc, risks.
* Clearly defined work scope for each institution at the lower level of WBS is necessary for further development of the project plan.
* Any overlap of responsibility between different WBS’s may cause difficulty in managing the project. In addition, it causes difficulty in setting up a control account structure that meets EVMS requirements.

RECOMMENDATIONS:

* Fill the Project Manager and Subsystem Manager positions well before CD-1. The PM and subsystem managers should play a large roll in defining and filling L3 positions as well as in developing the schedule and cost for their subsystems.
* Reconsider the structure of the WBS items that have overlap to make sure the there is no overlap in responsibility, with the interface clearly defined. Each WBS element at L3 or L4 must be uniquely assigned to an institution, with clearly defined work scope.
* Develop a WBS Dictionary and begin to refine subsystem interfaces.
* Develop a risk based contingency analysis approach. Technical, funding and schedule risks should be considered in the contingency analysis.
* In preparing for CD1, the project should start developing the complete set of project documents, such as the Project Execution Plan (PEP), risk management plan, Hazard Assessment (HA), etc.
* Develop a simple set of project level KPPs that are measureable. There will be both threshold and objective (goal) KPPs. Begin discussing these with the NP Program manager once one is identified.
* A clear and agreed upon understanding of who is providing what must be developed. Mechanisms for accomplishing this include MOUs, Collaborative Agreements or Subcontracts.

*g. Is ES&H being properly addressed given the current stage of development and planning?*

FINDINGS:

* The project will follow Lab ES&H guidelines and ISM principles will be applied.
* Will follow Physics Division Experiment Readiness Review process (ERR).
* Technical Design Reviews have been held on spectrometer, etc., but insignificant design effort to date on other elements.
* There will be design reviews that will occur lead by lead/chief engineer, etc. (WBS 1.5).
* Work by outside institutions will be reviewed and coordinated within WBS 1.5.
* Will utilize Lab screening program for vendors (QA).
* WBS 1.5 personnel will perform Hazard Analyses.
* No QA planning documents were made available to the committee during the review.
* Most subsystems acknowledged the plan to follow ES&H procedures needed for their deliverables.
* One subsystem showed consideration for QA.

COMMENTS:

* Consider possible ODH issues in the bunker surrounding the target.
* The project will need to recruit and appoint a Project Safety Officer to participate in the safety aspects of project development – including Hazards Analysis, the safety component in design reviews, to act as a liaison between the Collaboration and JLab EHS personnel, etc.
* A Project QA plan document should be developed prior to CD-1. This should include within it the key elements of QA planning and JLab QA processes.
* The current overall ES&H plan for the project appears appropriate.

RECOMMENDATIONS:

* QA process considerations should be included in schedule estimate
* Project should develop QA guidelines in similar fashion to the existing ES&H guidelines.

# Appendix A: Charge

Assess all aspects of the pre-conceptual design and associated plans to successfully execute a MOLLER experiment—scientific, technical, cost, schedule, management, and environment, safety and health (ES&H). The following main topics will be considered at the review:

a.     The significance and merit of the scientific goals of the MOLLER experiment

b.     Have the recommendations of the previous MOLLER reviews (the 2010 MOLLER Director’s Review and the 2014 DOE/NP-led MOLLER science review) been properly addressed?

c.     The feasibility and effectiveness of the pre-conceptual design for meeting the technical performance requirements. Is the high precision achievable or are there outstanding technical risks?

d.     The status of the proposed technical design, including the feasibility and merit of the technical approach; the completeness of the technical design and scope

e.     Are the cost and schedule estimates credible and realistic for this stage of the pre-project planning?  Do they include adequate scope, cost and schedule contingency?

f.      Are the plans to manage the foreseen MOLLER project appropriate at this stage?  Is there a capable team in place to produce a credible technical, cost and schedule baseline in the next phase?

g.     Is ES&H being properly addressed given the current stage of development and planning?

h.     Are there other issues relating to the foreseen MOLLER project.

# Appendix B: Committee Membership

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