Office of
Science

Office of Project Assessment
CD-3A/Status Review Report on the

Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) Project

at Thomas Jefferson National Accelerator Facility

January 2023

EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) status review of the Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) Major Item of Equipment (MIE) project, located at the Thomas Jefferson National Accelerator Facility (TJNAF) was conducted on January 10-12, 2023. The review was conducted by the Office of Project Assessment (OPA) at the request of Timothy J. Hallman, Associate Director of Science for Nuclear Physics (NP). The review was chaired by Alex Bachowski, OPA.

The purpose of this review was to assess the project team's preparedness for CD-3A and its current status, including technical, cost, schedule, management, and environment, safety and health, and quality assurance. The project is ready for Critical Decision (CD) 3A after updating cost estimates, risks, and the contingency analysis (for the CD-3A scope). Overall, the project is progressing well and the CD-3A/status review was generally successful. However, the project has significant work to do in preparation for a CD-2/3 review later this year. Most notably, the project needs to elaborate the installation schedule to provide more granular detail; this is not a trivial endeavor. Also, the project must fill open vacancies, notably the Deputy Project Manager, Infrastructure Control Account Manager (CAM), Risk Manager, and Quality Assurance Manager, in order to adequately prepare for the CD-2/3 review.

Target and Spectrometer

The project made significant progress in the spectrometer and target, and window design, with various prototypes under test with promising results. The project provided a strong justification for planned CD-3A advance procurements in terms of schedule, cost, and risk. In consultation with vendors, the project should consider adjusting the deadlines to exercise fixed price options for spectrometer coils and power supplies to reflect timeline of prototype fabrication and testing. The installation schedule of linked planning packages in Primavera (P6) was shown. This is sufficient for the present state of the project. For CD-2/3 a more granular, resource loaded schedule with staffing plan needs to be developed. This would include installation drawings. The present workforce allocation in this area appears light.

Detectors, Data Acquisition, and Infrastructure

The independent Final Design Review (FDR) that was conducted in December 2023 was very thorough. Some of the recommendation tracker's deadlines and estimated completion dates that were well past due would benefit from a review by the project team. Staging detectors at The College of William & Mary will help with overall schedule risk. Since the funding is available and to reduce supply chain risks, the project would benefit from purchasing electronic parts as soon as possible. Leveraging the existing Data Acquisition (DAQ) architectures from Parity and Super Bigbite Spectrometer (SBS) experiments has significantly reduced a great deal of design risk. Access to the Idaho Accelerator 8 MeV electron beam has been a significant help in testing components for radiation hardness. Establishing a permanent, non-interim CAM for infrastructure before procurement starts is critical. Completing infrastructure drawings by early summer 2023 appears feasible.

Cost and Schedule

The Inflation Reduction Act (IRA) has benefited the project by improving the available funding and advancing the pre-baseline schedule by one year; however, the project team needs to continue to refine cost and schedule estimates to be ready for CD-2/3. The project team has implemented an effective Earned Value Management System that allows them to track progress. This is commendable at this phase of the project. The contingency assigned to the CD-3A scope, as presented, is not adequate. The cost and schedule uncertainty that is associated with part of the CD-3A scope should be evaluated and appropriately accounted for in the project's Risk Register. A bottom-up, risk-based contingency should then be developed for the CD-3A scope. The float to CD-4 should be evaluated based on a risk analysis and set prior to the CD-2 baseline.

Project Management and ES&H

MOLLER has a strong team that can deliver the project; however, the bench is not deep. The project and TJNAF would benefit from a full-time, experienced Deputy Project Manager. Filling out the project team (Deputy Project Manager, Infrastructure CAM, Risk Manager, Quality Assurance Manager) to execute the construction phase is critical for CD-2/3 readiness. Communication across the institutions contributing to the project is effective. The project benefits from a committed group of collaborators. The Key Performance Parameters (KPPs) are fully defined and mature, but they depend on delivery of in-kind contributions and scope from TJNAF infrastructure projects. These risks should be appropriately reflected in the project's schedule risk analysis and should be documented in an assumptions document. A formal agreement with TJNAF could provide a means of formalizing roles and responsibilities for contributions from the Laboratory that are necessary to successfully complete the project. The project should consider referencing As Low As Reasonably Achievable (ALARA) standards. Neither the shielding engineering presentation nor the Hazard Analysis Report (HAR) addressed ALARA; this should be addressed prior to the CD-2/3 review. In lieu of the Construction Project Safety and Health Plan, the project should consider an ESH Installation Plan for the beamline and detector prior to CD-2/3.

Key Recommendations

- Proceed to CD-3A after updating cost estimates, risks, and the contingency analysis (for the CD-3A scope).
- Work with TJNAF management to identify a full-time, experienced deputy Project Manager as soon as possible and address the other open positions. Report on progress to the DOE Nuclear Physics Program Office by April 2023.
- Before the CD-2/3 review:
  - Develop further the installation plan with finer granularity, to include staffing plan and preliminary installation drawings.
  - Complete the planned prototype detector tests.
  - Proceed with hire(s) into the DAQ group.
  - Prepare an assumptions document.

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Appendices

1. INTRODUCTION

The Office of Nuclear Physics is funding the Measurement of a Lepton-Lepton Electroweak Reactions (MOLLER) Major Item of Equipment (MIE) at the Thomas Jefferson National Accelerator Facility (TJNAF) (Figure 1-1). MOLLER will provide the ability to measure parity violating asymmetries in Møller scattering at an unprecedented level of precision. Even small departures from the theoretical value could signal the presence of electron-electron scattering not accounted for in the Standard Model. As the most sensitive low energy measurement of a flavor-conserving purely leptonic interaction in the world, MOLLER will also be a significant component of the global strategy to discover signatures of a variety of physics that could escape detection at the Large Hadron Collider (LHC).

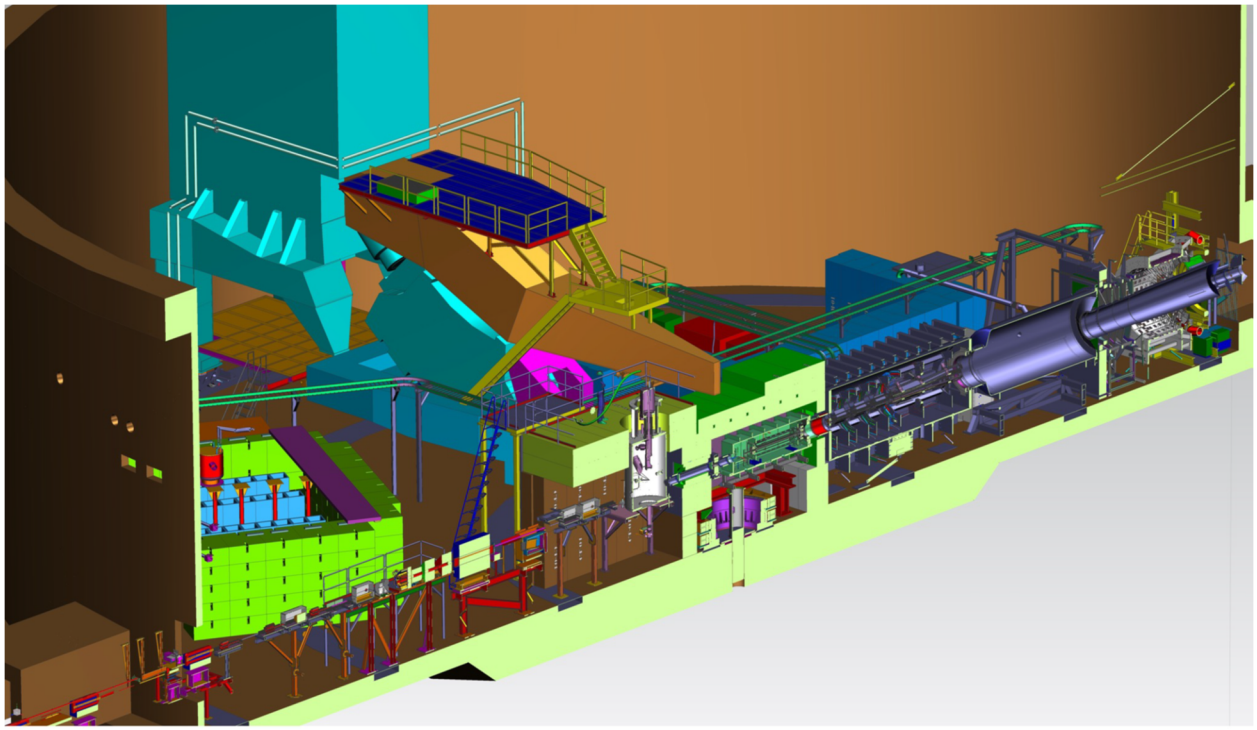


Figure 1-1. MOLLER, to be sited in Hall A at TJNAF, consists of its polarized target, spectrometer, tracking detectors, integrating detectors, data acquisition, and infrastructure modifications. It will measure a key symmetry property with unprecedented precision through Møller scattering in collisions between two electrons.

The specific measurements enabled cannot be carried out in any other existing or planned facility. The science goals of MOLLER have been peer reviewed and endorsed both by the Nuclear Science Advisory Committee (NSAC) and by an independent external panel of experts. MOLLER received approval of Critical Decision (CD) 1, Approve Alternative Selection and Cost Range, on December 15, 2020.

In an October 11, 2022, memorandum (Appendix A), Dr. Timothy J. Hallman, Associate Director of the Office of Science for Nuclear Physics, requested that Kurt Fisher, Director,

Office of Project Assessment (OPA), Office of Science (SC), conduct a review of the MOLLER MIE, which was held with both in-person and remote participation on January 10-12, 2023. The purpose of this review was to assess the overall status of MOLLER—technical, cost, schedule, management, and Environment, Safety and Health (ESH) and Quality Assurance (QA)—and to determine if the project is positioned to execute CD-3A, Approve of Long-lead Procurements. Alex Bachowski, OPA, chaired the Review Committee (Appendix B).

Committee members were chosen based on their technical and/or project management expertise, and experience with building large scientific research facilities, as well as their independence from the project. The chairperson organized the Committee into several subcommittees, each assigned to evaluate a particular aspect of the project corresponding to members' areas of expertise. The MOLLER MIE team and DOE/SC Headquarters staff jointly developed the agenda (Appendix C). Comparison with similar projects was the primary method for assessing technical requirements, cost estimates, schedules, and adequacy of the management structure.

2. TECHNICAL SYSTEMS EVALUATIONS

2.1 Target and Spectrometer

2.1.1 Findings

A list of CD-3A items were shown and their relevance discussed: Toroid Magnets; Magnet Power Supplies; Beam Pipes and Bellows; Liquid Hydrogen Target Chamber; MOLLER Polarimeter Collimator. The main justification for CD-3A procurements is risk reduction for potential extended vendor production schedules for the majority of items.

Target

Time-depended target flow simulations were shown. Using improved high performance computing resources 18 seconds of beam time have been simulated. Results show that the optimized design meets requirements. QWeak measurements are being used to validate the design and simulations.

The target chamber design is being revised for value engineering, using two half-length sections, avoiding the need for new expensive tooling at the vendor. Review of design calculations to incorporate this change is expected to be completed shortly.

The current cryogenic plant only supports 1.4kW cooling power, plant 2 is needed for beam operation at full power. A second unit, built by TJNAF, is expected to be available from September 2024.

The target is designed following a standard TJNAF process:

- TJNAF Pressure Safety Supplement.
- Independent review of fire protection was performed.
- Custom lifting fixtures are done to code.
- Detailed Quality Assurance (QA) requirements.
- Safety Systems are specified.

Most designs are finished including 2D fabrication drawings. Drawings are kept in TeamCenter and UpChain.

The QWeak heat exchanger will be reused.

The H2 pump is based on the QWeak design. The drive motor will be outside of the cryostat.

The slow control system design is 90% complete.

Spectrometer

A new Control Account Manager (CAM) will be joining the project in January 2023.

The present design fulfills the physics requirements. Key design requirements and fabrication/ installation tolerances are derived from the physics simulations.

Tracking studies through the magnetic field were performed. Minor tweaks resulting from features of the coil prototypes will be included in a later iteration. No changes to the results are expected.

Alignment tolerances were studied, and the design is acceptable even in worst case scenarios of correlated misalignment of 3 mm. The expected alignment is better than +/- 0.5 mm.

Radiation tests of epoxy resin (CTD 403) were completed. Results show that the epoxy system is adequate in the operating temperature range of interest. Further cross-checking dose calculations from FLUKA vs GEANT is planned to confirm that irradiation levels applied during the test are well understood.

Installation

A new CAM for Installation (WBS 1.08) joined the project recently. A draft Installation System Requirements Document was recently revised. The installation schedule of linked planning packages in Primavera (P6) was shown. Risk 8.01 Staging space for pre-assembly and survey of equipment remains "high" though spaces have been identified that could alleviate the problem. Risk 8.02 Installation Man Power Deficit remains "medium".

2.1.2 Comments

The project made significant progress in spectrometer, target, and window design, with various prototypes under test with promising results.

All design aspects, and in particular those relevant to the CD-3A scope, were covered in detail at the Final Design Review (FDR) held in December 2022.

The project provided a strong justification for planned CD-3A advance procurements in terms of schedule, cost, and risk.

The project incorporated recommendations from CD-3A Director's review, in particular by adding power supplies to the CD-3A scope.

Comments and recommendations from the recent FDR are being addressed.

Following the significant progress in the design and completion of FDR, the project is ready to proceed with the proposed CD-3A scope.

Several steps need to be completed in the next two to three months (by end of March) before proceeding with CD-3A procurement contracts: approve and release remaining drawings, complete test of prototype power supply, complete characterization, and preliminary testing of prototype coils.

In consultation with vendors, the project should consider adjusting the deadlines to exercise fixed price options for spectrometer coils and power supplies to reflect timeline of prototype fabrication and testing.

The installation schedule of linked planning packages in P6 was shown. This is sufficient for the present state of the project. For CD-2/3 a more granular, resource loaded schedule with staffing plan needs to be developed. This would include installation drawings. The present workforce allocation in this area appears light.

2.1.3 Recommendations

1. Proceed to CD-3A.

2. Prior to CD-2/3, develop a more granular, resource loaded installation schedule including staffing plan.

3. Prior to CD-2/3, provide preliminary installation drawings.

2.2 Detectors, Data Acquisition, and Infrastructure

2.2.1 Findings

First revisions of all System Requirement Documents (SRDs) and Interface Control Documents (ICDs) have been completed and signed.

The Bill of Materials (BOMs), for both TJNAF and non-TJNAF designs, are being periodically reviewed for lead times and obsolescence.

Detector

The Gas Electron Multiplier (GEM) production orders have not been placed yet. University of Virginia (UVA) and Stony Brook University (SBU) have places “in the queue” with CERN and have prior experience obtaining GEMs from CERN and building detectors from them.

GEM electronics in the Super Bigbite Spectrometer (SBS) are being actively monitored for failure rate. Further units are being procured. GEM support structure is still in the design phase. Stiffness is improved.

The Pion detector has gone through a significant redesign. Segmentation now matches that of ShowerMax, aiding background reduction. The timeline to have a final pion detector design is late spring 2023.

Materials for light guides are tested and a preferred type selected. Materials for long pass filters on photomultiplier tubes (PMTs) selected and rad-qualified, but still need to make final wavelength pass-band choice.

Pre-production models of all integrating detector types are being tested, with specifications met. All different types of shapes have been built. The manufacturing method for frames is chosen, the quartz radiator is finalized, and the PMT and base are chosen and tested. The PMT lifetime (total charge at anode) is within acceptable limits for the duration of the experiment. Shower max detectors are at the stage of testing prototypes.

Trigger detectors have chosen a scintillator type and shape, wavelength shifter (WLS) readout using a specific WLS fiber, PMT and base design, and are assembling a prototype.

Data Acquisition

Field programable gate array (FPGA) firmware to readout the analog to digital converter (ADC) and Trigger Interface (TI) is 90% complete.

Full Data Acquisition (DAQ) chain testing has not started yet, but the MOLLER team plans to start it in the next six months.

Full 16-channel integrating ADC board is now available.

A noise study of long ADC cabling has been done at the University of Manitoba.

Pre-baseline schedule and cost variances are due to a shortage of DAQ staff at TJNAF.

The baseline Beam Charge Monitor (BCM) electronics is the legacy TJNAF design. New BCM electronics are being designed by TJNAF and not in scope of MOLLER.

The University of Manitoba already has all the ADC and FPGA parts in hand.

HVMAP DAQ integration work has not started yet.

Infrastructure

One of the three identified barite loaded concrete vendors has informed the project that they will provide a budgetary quote by the end of January 2023.

Electrical work in Hall A is required to provide additional distribution of power.

A majority of the infrastructure cost is shielding.

Cable tray and cable support designs are still in progress. Cables and connectors are expected to be regular stock items with normal delivery times.

2.2.2 Comments

The Independent Final Design Review (FDR) conducted in December 2023 was very thorough.

Some of the recommendation tracker's deadlines and estimated completion dates are well past due and would benefit from a review.

All groups demonstrated cognizance of JLab ES&H and QA/QC expectations.

Staging detectors at William & Mary Hi-Bay will help with overall schedule risk.

Detector

The strong relationship with Idaho State University has made the radiation testing go smoothly. Access to the Idaho Accelerator 8 MeV electron beam has been a significant help. Extensive spectrometer data on wavelength dependence at various radiation dose levels has been obtained and analyzed.

The strong relationship with U. Manitoba electronics group is important for electronics work and High Voltage Monolithic Active Pixel Sensors (HVMAPS) implementation.

Good progress on the main detector mechanical structure has been made. The latest revision of the structure still needs to get simulated.

Lead times for GEM frames were not clear.

Data Acquisition

The FPGA has significant headroom with respect to resource utilization to support any new minor features that might arise.

Since the funding is available and to reduce supply chain risks, the project would benefit from purchasing as much of the electronic parts as possible and as soon as possible. BOMs are being monitored regularly for lead times, but industry-wide these lead times remain uncertain.

Leveraging the existing DAQ architectures from Parity and SBS experiments has significantly reduced a lot of design risk.

Infrastructure

Establishing a permanent, non-interim CAM before procurement starts is going to be critical. Finishing all drawings for infrastructure by early summer 2023 appears doable. RadCon is very much involved in the shield design process. Shielding physics design makes good and extensive use of knowledge base from the PREX/CREX series of experiments.

2.2.3 Recommendations

Complete the following prior to CD-2/3:

4. Complete the planned prototype detector tests.

5. Proceed with hire(s) into the TJNAF DAQ group.
6. Develop further the installation plan with finer granularity.
7. Proceed to CD-3A.

3. COST and SCHEDULE, PROJECT MANAGEMENT and ENVIRONMENT, SAFETY and HEALTH

3.1 Findings

PROJECT STATUS (November 2022)		
Project Type	MIE	
CD-1	Planned:	Actual: October 2020
CD-3A	Planned: Q2FY23	Actual:
CD-2/3	Planned: Q4FY23	Actual:
CD-4	Planned: Q4FY27	Actual:
TPC Percent Complete	Planned: 21%	Actual: 19%
TPC Cost to Date	$ 9.35M	
TPC Committed to Date	$ 10.00M	
TPC	$ 48.66M*	
TEC	$ 47.10M	
Contingency Cost (w/Mgmt Reserve)	$ 11.38M	100% to go
Contingency Schedule on CD-4	17 months	
CPI Cumulative	0.99*	
SPI Cumulative	0.92*	

**Project is not yet baselined; values based on pre-baseline plan*

The presented cost of the CD-3A scope is $5.8 million. The cost breakdown is:

- Toroid Magnets ($2.88 million)
  - Upstream magnet conductor and coil fabrication with associated hardware
  - Upstream collimators, blocker and two-bounce shield (tungsten)
  - Downstream magnet coils and associated hardware
  - Downstream collimators (tungsten)
  - Downstream magnet enclosure
- Magnet Power Supplies ($1.00 million)
- Beam Pipes and Bellows ($1.08 million)
- Liquid Hydrogen Target Chamber ($0.56 million)
- Moller Polarimeter Collimator ($0.02 million)
- Contingency ($0.26 million)

The presented contingency on the CD-3A scope is about 5% of the CD-3A scope. Justification for CD-3A scope is to reduce schedule risk to ensure physics results on a competitive schedule and to fit into the CEBAF accelerator schedule.

The project plans to implement additional Level 2 milestones for completion of CD-3A scope, as well as charge codes for each control account.

CD-3A is expected to be achieved by third quarter FY 2023, CD-2/3 by first quarter FY2024, and CD-4 by fourth quarter FY 2027.

The management team has experienced some turnover and a few CAM positions are currently filled by acting CAMs. A CAM was hired for WBS 1.03 with an expected start date of January 17, 2023. There is still a CAM opening for Infrastructure (WBS 1.06). The project plans to hire a QA lead and Risk Manager to fill open positions prior to CD-2/3.

The project cost range is $45.8-55.4 million. The project is currently funded at $48.66 million and has a point estimate of $37.3 million. The project has a funding profile that was significantly improved thanks to forward funding of $31.12 million through the Inflation Reduction Act (IRA). FY 2023 is the last year of project funding, with the project expecting $4 million.

Cost contingency has increased from the CD-1 value of $10.9 million to $11.4 million, which is 32% of the Total Estimated Cost (TEC) or 38% of the TEC to go.

MOLLER has two significant in-kind contributions from the National Science Foundation (NSF) and from the Canadian Foundation for Innovation (CFI). The contributions are for the detectors and the data acquisition system and represent about 20% of the cost of the full MOLLER scope.

Both contributions are fully funded and allow these scope elements to advance to construction independent of DOE funding authorization.

An International Cooperative Research and Development Agreement (ICRADA) exists between TJNAF and University of Manitoba for the CFI scope.

Memorandums of Understanding (MOU) between TJNAF and the various universities performing project work exist and have all been signed by the project. About half have been signed by the universities.

NSF is providing reporting on university progress to DOE that allows the project team to properly track the MIE Cost and Schedule Performance Indices (CPI/SPI).

The project team has processed 20 Baseline Change Proposals (BCPs) to date and 13 in the past year. Baseline Change Requests (BCRs) can be initiated by the relevant CAM or by the Project Manager. All BCRs are tracked in the change request log.

A BCR was implemented to account for the increase in material costs in FY 2023 dollars. The project plans to issue a BCR to update the labor rates to FY 2023 in the near future. Currently the plan reflects FY 2019 labor rates.

The project expects to have a budgetary estimate for the barite concrete by the end of January after receiving information back on the request for information (RFI).

TJNAF's certified Earned Value Management System (EVMS) and change control process have been in use for over a year by the project.

The project utilizes Primavera (P6) as their scheduling software. P6 and the Laboratory's cost system, Costpoint, are integrated into Deltek Cobra.

NSF scope has been integrated into P6 and status meetings are held monthly. The CFI scope is not yet fully integrated into P6. The project plans to complete integration of the CFI scope into P6 in FY 2023.

TJNAF provides a project management qualification course to new CAMs. Currently there is one project controls professional who supports the project. Two contract specialists are assigned to the project, as well as the contracts lead.

The remaining individual project procurements are all estimated to be less than $1 million, below the $3 million threshold for site office review.

Contracts and project controls take part in updating the procurement register.

Requirements and interfaces are complete and under revision control.

The Technical Design Report is complete. The last FDR was completed in December 2022. The project team requested that the Committee evaluate the FDR review committee makeup and results to offer thoughts concerning perceived independence and whether another review is needed prior to CD-2/3.

Overall design maturity is greater than 90%.

The Hazard Analysis Report, Acquisition Strategy, Quality Assurance Plan, Risk Management Plan and Security Vulnerability Assessment Report have been updated, reviewed, and approved.

KPPs are fully defined.

The critical path for construction runs through toroid procurement.

Critical path from the start of installation flows through infrastructure and target.

The DOE project is responsible for installation of the full project scope including in-kind contributions.

Installation depends on completion of the existing Hall A physics program followed by Hall A cleanout. The project team has identified three months float between MOLLER readiness and the SBS Hall A clean-out.

TJNAF will be implementing the Experimental Readiness Review (ERR) process for the installation planning in Hall A.

The project currently has 17 months of schedule contingency to CD-4.

The Project Manager flashed through the installation sections of the P6 schedule to demonstrate the level of detail that currently exists.

The Laboratory has a Lessons Learned database that is shared with other Laboratories. The project Risk Register captures high-level risks from in-kind partners. These risks are mapped to individual activities in the integrated P6 schedule.

The Safran program is utilized to perform the project risk analysis Monte Carlo.

The 80% confidence level risk value from the Monte Carlo yields a finish date of March 2027 and a cost value of $44.7 million.

The MOLLER project plan includes features to protect equipment; however, this is not documented in an Equipment Protection Plan.

Environment, Safety and Health

The Hazard Analysis Report (HAR) was updated in October 2022 to include the electrical program updates, address the COVID-19 pandemic, and the November 2021 DOE/SC review comments.

The HAR references and links to ES&H Manual Chapter 3210 Work Planning, Control, and Authorization Process including the Task Hazard Analysis Worksheet. The HAR indicates that an outside Fire Protection consultant was retained to analyze the hydrogen target. The HAR addresses the beamline reconfiguration work to be performed in Hall A. The HAR indicates that a hydrogen leak could possibly create an oxygen deficiency hazard (ODH). This risk is identified in the MOLLER MIE Hazard Assessment Matrix (Table 1).

The ESH presentation included a link to a flow chart for Designing, Fabricating, Procuring, and Shipping equipment for use at TJNAF.

The ESH presentation addressed the laboratory's process for accepting non-NTRL equipment.

The Quality Assurance Program (QAP) defines performance/inspection and acceptance testing and provides several criterions. The QAP addresses design control, reviews, interfaces and verification.

3.2 Comments

MOLLER has a strong team that can deliver the project; however, the bench is not deep. The project and TJNAF would benefit from a full-time, experienced deputy Project Manager.

Communication across the institutions contributing to the project is effective. The project benefits from a committed group of collaborators.

The contingency assigned to the CD-3A scope is not adequate. There is some cost and schedule uncertainty associated with a part of the CD-3A scope that should be evaluated and appropriately accounted for in the project's Risk Register. A bottom-up, risk-based contingency should then be developed for the CD-3A scope.

The float to CD-4 should be evaluated based on a risk analysis and set prior to the CD-2 baseline.

A separate presentation describing the installation plan should be part of the agenda at the CD-2/3 review.

The project would be wise to plan for an independent review of the installation plan at an appropriate time.

Filling out the project team (Deputy Project Manager, Infrastructure CAM, Risk Manager, QA Manager) to execute the construction phase is critical for CD-2/3 readiness.

The university MOUs should all be signed by the CD-2/3 review.

The KPPs are fully defined and mature, but they depend on delivery of in-kind contributions and scope from Laboratory infrastructure projects. These risks should be appropriately reflected in the project's schedule risk analysis and should be documented in an assumptions document.

A formal agreement with TJNAF could provide a means of formalizing roles and responsibilities for contributions from the Laboratory that are necessary to successfully complete the project.

Detailed plans for removing the existing experiment in Hall A do not yet exist, but TJNAF has experience in this area.

The project team has implemented an effective EVMS system that allows progress to be appropriately tracked. This is commendable at this phase of the project.

The project team is dealing with longer than normal lead times and limited vendors. These risks must be appropriately accounted for in project planning.

The IRA benefited the project by improving the available funding and improving the schedule by one year; however, the project team needs to continue to refine cost and schedule estimates to be ready for CD-2/3.

A draft of a Transition to Operations plan should be available by the CD-2/3 review.

The project Risk Register needs to be updated on a regular basis. A rigorous risk workshop should be held prior to the CD-2/3 review.

MOLLER can profit from an Equipment Protection Plan document. Such a document could reveal aspects associated with ESH that were not previously considered.

Environment, Safety and Health

The project should verify whether there is a risk of fire or explosion from a release of hydrogen in the HAR (Hazard Assessment Matrix; Table 1). If this is addressed in the Fire Protection

consultant's analysis then, this should be incorporated into the HAR or as an attachment (appendix). This should be addressed prior to the CD-2/3 review.

The project should modify the HAR to address Natural Phenomena as listed in DOE Guide 413.3-12, Chg. 1 prior to the CD-2/3 review.

The project should verify whether the Fire Protection Consultant's analysis needs to be addressed in the Security Assessment Document (SAD) as part of the Hall A beamline reconfiguration. This should be addressed prior to the CD-2/3 review.

The project should verify that the HAR does in fact contain the COVID-19 paragraph that appears in the change log revision table.

The project should consider referencing As Low As Reasonably Achievable (ALARA) standards. Neither the Shielding Engineering presentation nor the HAR addressed ALARA. This should be addressed prior to the CD-2/3 review.

In lieu of the Construction Project Safety and Health Plan, the project should consider an ESH Installation Plan for the beamline and detector prior to the CD-2/3 review.

The project should consider separate presentations dedicated to Quality Assurance and incorporation of Lessons Learned prior to the CD-2/3 review.

3.3 Recommendations

8. Update the cost estimates, risks, and contingency analysis for the CD-3A scope prior to ESAAB.

9. Prepare an assumptions document by the CD-2/3 review.

10. Work with TJNAF management to identify a full-time, experienced Deputy Project Manager as soon as possible and also address the other open positions. Report on progress to the program office by April 2023.

11. Proceed to CD-3A after updating the contingency analysis.

Appendix A Charge Memo

United States Government **Department of Energy**

memorandum

DATE: 10/11/22

REPLY TO ATTN OF: Office of Nuclear Physics, SC-36

SUBJECT: Project Review of MOLLER

TO: Kurt Fisher, Director
Office of Project Assessment, SC-23

I request your Office conduct a Department of Energy (DOE) Office of Science (SC) Independent Project Review of the Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) Major Item of Equipment (MIE) project located at the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF), January 10-12, 2023. The purpose of this review is to assess the overall status of MOLLER – technical, cost, schedule, management, and Environment, Safety, & Health (ES&H) and Quality Assurance (QA) – and to determine if it is positioned to execute Critical Decision-3A (CD-3A), "Approve of Long-lead Procurements."

In carrying out its charge, the review panel is requested to consider the following main topics:

1. Is the project team effectively executing the work? Are technical issues appropriately and proactively being addressed? Are the proposed CD-3A long-lead procurements appropriate?
2. Are the cost and schedule estimates credible? Do they include adequate scope, cost, and schedule contingency? Are the estimates for the proposed CD-3A long-lead procurements appropriate and can these procurements be properly tracked?
3. Is environment, safety, and health (ES&H) and quality being properly addressed given the project's current stage of development?
4. Is the project being properly managed? Are risks being effectively managed? Is the management team in place to successfully execute the CD-3A scope?
5. Is the project appropriately addressing the recommendations from the prior DOE SC reviews?
6. Is the project ready for CD-3A approval?

The Office of Nuclear Physics' Program Manager, Elizabeth Bartosz, who is responsible for oversight of MOLLER, will work closely with you as necessary to plan and carry out this review. I would appreciate receiving your panel's report within 30 days of the review's conclusion.

Timothy J. Hallman
Digitally signed by Timothy J. Hallman
Date: 2022.10.11 13:53:49 -04'00'

Timothy J. Hallman
Associate Director of the Office of Science
for Nuclear Physics

cc: Kurt Fisher, SC-23
P. Mantica, SC-36.2

Appendix B Review Committee

DOE/SC CD-3A/Status Review of the
Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) Project at TJNAF
January 10-12, 2023

Alex Bachowski, DOE/OPA, Chairperson

SC1
Target and Spectrometer

* *GianLuca Sabbi, LBNL*
Carsten Hast, SLAC
Peter Wanderer, retired BNL

SC2
Detectors, DAQ, and Infrastructure

* Larry Ruckman, SLAC
Glenn Young, BNL

SC3
ESH, Cost and Schedule, Project Management

* Ron Ray, FNAL
Kurt Fisher, DOE/OPA
Whitney Hughes, PNNL
Sergio Zimmerman, LBNL
Jim Niehoff, FNAL (ESH)

Observers

Paul Mantica, DOE/NP
Elizabeth Bartosz, DOE/NP
David Cinabro, DOE/NP
Bryan Foley, DOE/TJSO
Alfredo Galindo-Uribarri, NSF

LEGEND

SC Subcommittee
* Chairperson
ITA Remote Participation

Count: 11 (excluding observers)

Appendix C Review Agenda

DOE/SC CD3A/Status Review of the
Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) Project at TJNAF
January 10-12, 2023

AGENDA

	Day 1: Tuesday, January 10, 2023	**Presenter**	**Location**
8:30 - 9:00	Breakfast & Coffee		Atrium
9:00 - 10:00	Executive Session	Committee	B207
10:00 - 10:15	Introduction from JLab Management	Stuart Henderson	F113
10:15 - 10:45	MOLLER Science Overview	Krishna Kumar	F113
10:45 - 11:00	Break		Atrium
11:00 - 12:00	MOLLER Project Overview	James Fast	F113
12:00 - 13:00	Lunch / Executive Session	Committee	B207
13:00 - 14:00	MOLLER Technical Elements	Kent Paschke	F113
14:00 - 14:40	MOLLER MIE Cost and Schedule	James Fast	F113
14:40- 14:55	Break		Atrium
14:55 - 15:15	CD-3a Scope	James Fast	F113
15:15 - 15:45	CAM Presentation WBS 1.02 Target	Silviu Covrig Dusa	F113
15:45- 16:15	CAM Presentation WBS 1.03 Spectrometer	James Fast	F113
16:15 - 16:30	Break		
16:30 - 18:00	Executive Session	Committee	B207
18:00	Adjourn		

	Day 2: Wednesday, January 11, 2023	Presenter	Location
08:30 - 09:00	Breakfast & Coffee		Atrium
09:00 - 09:45	Response to homework		F113
09:45 - 10:15	CAM Presentation WBS 1.04/1.05 Detectors	Carl Zorn	F113
10:15 - 10:45	CAM Presentation WBS 1.06 Infrastructure	Robin Wines	F113
10:45 - 11:00	Break		Atrium
11:00 - 11:30	CAM Presentation WBS 1.07 Trigger / DAQ	Robert Michaels	F113
11:30 - 12:00	CAM Presentation WBS 1.08 Installation	Vladimir Berdnikov	F113
12:00 - 13:00	Lunch / Executive Session	Committee	B207
	Breakout (Parallel Sessions)		
	SC1: Management		F113
13:00 - 13:40	Topic 1: Systems Engineering	Robin Wines	
13:40 - 14:10	Topic 2: Schedule Development	Lisa Loewus	
14:10 - 14:30	Break		
14:30 - 15:00	Topic 3: EH&S and QA	Ed Folts	
15:00 - 15:30	Topic 4: Risk Analysis	James Fast	
	SC2: Target and Infrastructure		TED 561 A/B
13:00 - 13:40	Topic 1: Target Physics Design	Silviu Covrig Dusa	

13:40 - 14:10	Topic 2: Target Engineering	Dave Meekins	
14:10 - 14:25	Break		
14:25 - 15:05	Topic 3: Shielding Physics Design	Ciprian Gal	
15:05 - 15:20	Topic 4: Shielding Engineering	Ryan Biraben	
15:20 - 15:45	Topic 5: Hall A Infrastructure	Robin Wines	
	SC3: Spectrometer and Beam Pipes		F324/325
13:00 - 13:25	Topic 1: Spectrometer Physics Design	Juliette Mammei	
13:25 - 14:15	Topic 2: Toroid Engineering Overview	Dave Kashy	
14:15 - 14:30	Break		
14:30 - 15:00	Topic 3: US Toroid Engineering	Ernie Ihloff	
15:00 - 15:20	Topic 4: Magnet Power Supplies and I&C	Brian Eng	
15:20 - 15:45	Topic 5: Beam Pipes and Bellows	Eric Sun	
	SC4: Detectors, Trigger, and DAQ		F224/225
13:00 - 13:30	Topic 1: Main Detectors and Test Beam	Michael Gericke	
13:30 - 14:00	Topic 2: ShowerMax and Irradiation Study	Dustin McNulty	
14:00 - 14:20	Topic 3: Detector Mechanics	Larry Bartoszek	
14:20- 14:35	Break		

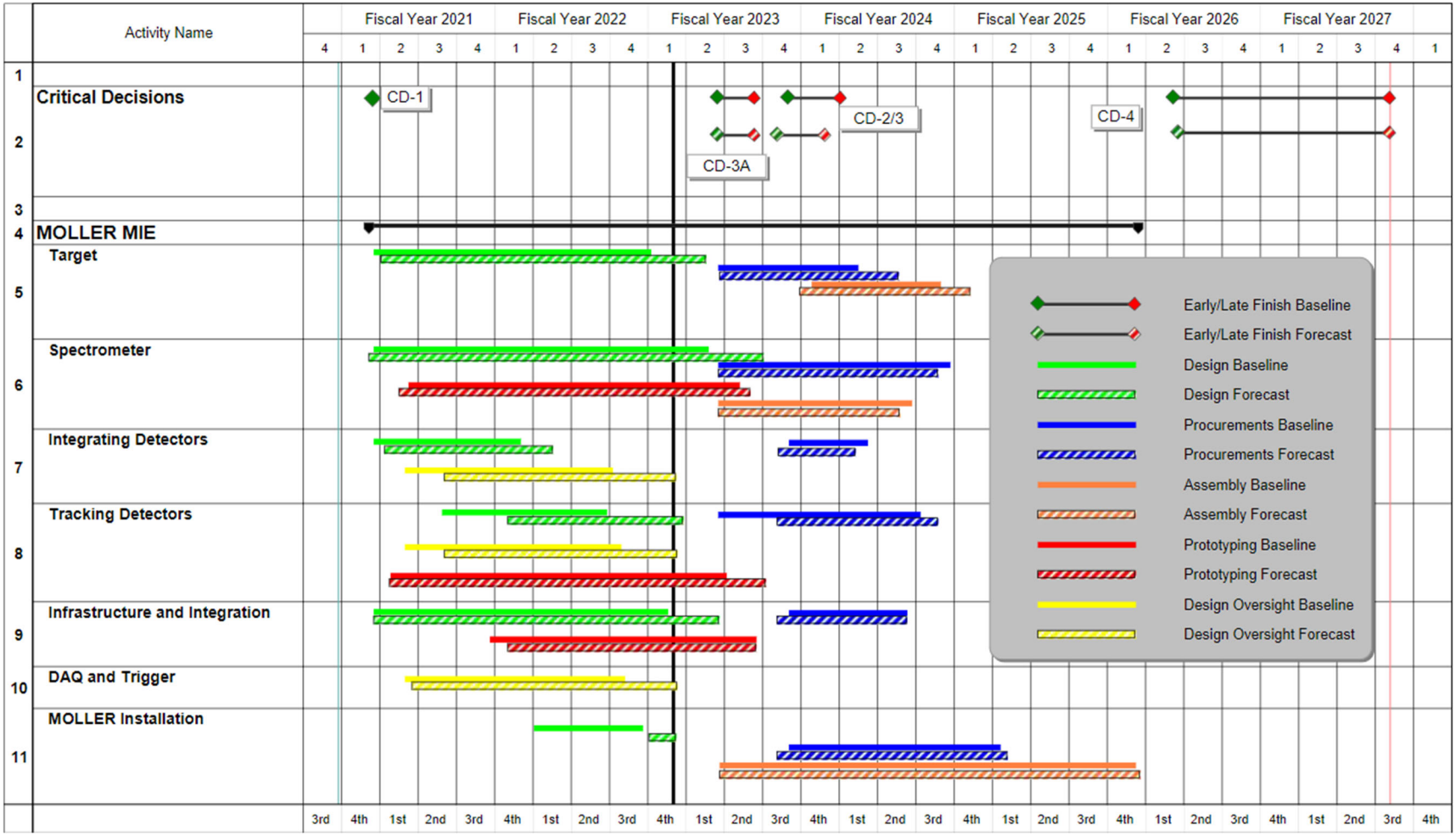
14:35 - 15:05	Topic 4: Tracking Detectors	Dave Armstrong	
15:05 - 15:25	Topic 5: Trigger / DAQ System Design	Robert Michaels	
15:25 - 15:45	Topic 6: Trigger / DAQ Development and Prototyping	Paul King	
15:45 - 16:00	Break		
16:00 - 17:00	Executive Session	Committee	B207
17:00-19:00	Reception	All	Atrium

	Day 3: Thursday, January 12, 2023	**Presenter**	**Location**
08:30 - 09:00	Breakfast & Coffee		Atrium
09:00 - 10:00	Executive Session / Report Writing	Committee	B207
10:00 - 10:15	Fact check with MOLLER team	Committee and MOLLER	Breakout Rooms F224/225, TED 2561A/B , F324/325, and F326/327
10:15 - 10:30	Break		Atrium
10:30 -11:00	Executive Session / Prep for Closeout	Committee	B207
11:00 - 12:00	Closeout	All	F113

Appendix D MOLLER Cost Chart

Table 2: Project Cost Summary			
WBS	**WBS Title**	**Total AY $K**	
1.01	Project Management	$	4,231
1.02	Liquid Dydrogen Target	$	3,894
1.03	Spectrometer	$	14,116
1.04	Integrating Detectors	$	842
1.05	Tracking Detectors	$	1,019
1.06	HALL A Infrastructure and Integration	$	6,832
1.07	DAQ and Trigger	$	605
1.08	MOLLER Installation	$	4,203
	Direct TEC	**$**	**35,742**
	TEC Contingency (32%)	$	11,358
	TEC	**$**	**47,100**
1.13.01	R&D and CDR	$	1,407
1.13.02	Project Closeout	$	111
	Direct OPC	**$**	**1,518**
	OPC Contingency (38% of ETC)	$	42
	OPC	**$**	**1,560**
TPC TOTAL (AY M$)		**$**	**48,660**

Appendix E MOLLER Schedule



Appendix F MOLLER Management Chart