MOLLER Project Final Design Review
Detectors, DAQ - December 7 - 8, 2022

Review Committee:
Elton Smith (William & Mary), Jeff Cherwinka (UW-PSL)
Chris Cuevas, Alexander Camsonne, David Abbott (JLab)

The Review Committee would like to commend the MOLLER team for good progress on detector development. The presentations provided a comprehensive review of the project and were clear. The quality, knowledge and responsiveness to questions and requests for additional information from the committee has been appreciated.

Charge to the Review Committee

1. Are the science goals and physics requirements adequately defined and addressed by the subsystem designs and specifications?

    Yes, but it would be helpful for future reviews to have a single document with a table that make summarized this for the entire detector

2. Are the designs technically adequate and sufficiently advanced for a project at this stage?

    Yes.

    a. Are they sufficiently mature to support fabrication? Some are ready to start procurement, seem to be on track for fabrication in the next few months, and understand what is left to do.
        i. Thin Quartz - Finalizing details and further testing planned
        ii. Shower Max - Ready
        iii. GEMs - Finalizing production methods
        iv. Pion Detector - Design is not complete
        v. Scintillators - Design is not complete
        vi. DAQ & Electronics - Mostly ready, but HVMAPS needs more work
        vii. Scatter Beam Monitoring Detectors - Finalizing details
    b. Are any remaining design options properly identified and documented? No major remaining open design options were presented for the detectors. The BCMs & BPMs electronics decision is not on project but is needed.
    c. Are there plans in place for completion to allow the start of procurements and fabrications within 4-6 months after FDR? Yes (see 2a).

3. Are subsystem interfaces addressed?

    Yes, but more details are needed on cables and gas utilities.

4. Have the subsystems addressed JLab standards of EHS&Q?

    Yes.

5. Are recommendations from Preliminary Design Reviews sufficiently addressed?

Yes.

General

Findings:

1. The majority of the MOLLER Detectors and DAQ are being funded by NSF and CFI. There is some funding for these systems by DOE, but it is not part of DOE CD-3a list.
2. The detector resolution of 25% is estimated to contribute 21 ppm and the electronic noise is estimated to contribute 10 ppm to the statistical pair width of 91 ppm.
3. The uncertainty budget for A_PV includes knowing the normalizing kinematic factor of < 0.5%, which in turn puts requirements on the thickness and resolution of the tracking detectors.
4. All MOLLER project activities from the DOE, NSF and CFI scopes, are loaded into a P6 resource-loaded schedule, except for NSF and CFI labor.
5. There is a plan to measure pulse pair asymmetry reasonably quickly for comparison with previous experiment results. [SLAC E158]

Comments:

1. Establishing potential radiation sensitivity for the PMT base electronics as soon as possible (and before procurement and production) is highly advisable.
2. The Project should come up with a plan for responding to and closing out all review recommendations.
3. We commend all design groups for their careful attention to ES&H best practices.

Recommendations:

1. Design, procurement, fabrication, quality assurance, routing, and support for cables is a significant effort. This work naturally lags detector development, but it seems underdeveloped compared to the state of the rest of the detector. In the next 4 to 6 months clarify the cabling for the major detector subsystems including end to end cable list with responsible party and preliminary routing layout.
2. Design, procurement, fabrication, quality assurance, routing, and support for gas supply and distribution systems is a significant effort. This work naturally lags detector development, but it seems underdeveloped compared to the state of the rest of the detector. In the next 4 to 6 months clarify the gas systems for the major detector subsystems including manifold layout.
3. Identify and evaluate multi-pin twinaxial connectors for the PMT readout signals.

Thin Quartz Detectors

Findings:

1. The thin quartz detectors generate the primary signals for the MOLLER measurement and can be operated in both Integrating and Counting modes.
2. The system includes 224 detector modules, which consist of a 3" Electron Tube 9305QKB photomultiplier tube with a quartz window and a quartz plate that generates Cerenkov light that is collected via an air light guide. The base allows switching between Integrating and Counting modes.
3. The preamplifiers and mode switching PMT base circuitry has been tested thoroughly.
4. Assessment of issues from radiation effects on PMT electronics has been evaluated with positive results.
5. The photomultiplier tube will be run with anode currents of less than 10 uA, which will result in a gain loss of about 2 (one lifetime) during the whole experiment (1 year of PAC days). The asymmetry is not directly sensitive to the pmt gain as long as it has a linear response over this range.
6. The housings have been produced with 3D printers and verified for geometric tolerances.
7. The assemblies will be flushed with dry air to cool the electronics and fill the air guide with a controlled gas mixture.
8. The resolution requirement of $\sigma_E/E < 25\%$ requires collecting an average of more than 25 photoelectrons.
9. Beam tests in May of 2022 have demonstrated that the design can achieve its desired goals.
10. The internal cabling of the modules inside their container is defined, but the cabling from the container to the readout electronics still needs to be worked out
11. The concept of using a robot to install the thin quartz detector segments into the support structure has been replaced with rotating rings. A jib crane was added to hall infrastructure to support this installation.
12. Alignment of thin quartz subassemblies and segments is now achieved with precision of manufacturing instead of adjustability.
13. Thin quartz subassemblies will be installed into segments and aligned at William and Mary. They will be transported to JLab ready for installation.
14. The work on radiation testing of 3D printed materials and quartz is very impressive.
15. High Voltage and Low Voltage multi-pin connectors have been specified and are available. Very good details presented as response to review panel 'homework' questions.

Comments:

1. Continue studies of material choices for the module structure for radiation hardness, stability under temperature changes, and sensitivity to a dry air environment.
2. The complete cabling scheme from detectors to the electronics must be designed and tested to verify that it does not degrade the detector performance.
3. Material for some 3D printed parts are made from Nylon. The dry gas flow could dehydrate the nylon making it brittle. This should be considered and tested as part of material selection.
4. The radiation studies looked really well done.
5. The thin quartz support structure drive chain, sprockets and motor could be removed after segment installation is complete to eliminate the iron from the experiment region. The main ring could be locked in position with a bolt on plate and/or the brakes presented.
6. Consider a temporary X frame between the main rings to control racking and fine tuning of ring alignment until enough segments are installed.
7. The motion control systems for the Quartz support rings and the GEMs rotator need to support any required unbalanced load from free rotation in the event of a power failure or single component failure (chain, shaft key, motor...). This may require adding enough friction to the system to resist rotation or using counterbalance to control torque. A test of the effectiveness of the design with a dummy load would ensure design assumptions are met.

Recommendations:

NONE

Shower Max Detectors

Findings:

1. The Shower Max detectors provide a complementary measurement of the asymmetry from Ring 5 and can be operated in both Integrating and Counting modes.
2. The system includes 28 quartz/tungsten sampling calorimeters, with a 3” Electron Tube 9305QKB photomultiplier tube coupled to four layers of a quartz/tungsten sandwich via an air light guide. The base allows switching between Integrating and Counting modes.
3. The mechanical assemblies have been prototyped and tested successfully in a test beam at MAMI.
4. The beam data agrees favorably with the Monte Carlo simulation.
5. The expected radiation doses range between 0.15 and 1.3 Grad. It is planned to use long-pass filters to eliminate low-energy photons to the photomultiplier.
6. Extensive tests at the Idaho Accelerator Center for quartz radiation hardness have been completed.
7. Tests of the effects of radiation on the mechanical structures are ongoing and will help assess the materials used for the supports of the main detectors.
8. Clear and specific EH&S processes were presented.

Comments:

1. The committee agrees that the shower max subsystem is ready for production.

Recommendations:

NONE

Pion Detectors

Findings:

1. The pion detectors measure the (background) asymmetry from pions. The contamination is small (0.13%) but may lead to a correction of order 1 ppb.
2. The system includes 28 modules, which consist of a piece of lucite directly coupled to a 1” pmt. The detectors are shielded by 45 X0 (shower max + lead donut) which range out all Moller electrons.
3. Tests of preliminary designs were conducted at MAMI and results are under analysis.
4. The specific pmt choice is still to be made.
5. The group is studying the advantages of adding three scintillators (pion exit scintillators) at three locations immediately downstream of the pion detectors for redundant pion measurements.
6. Acrylic detectors have been studied with beam at MAMI [Mainz beam facility]

Comments:

1. Complete analysis of beam test data and final design selections for detector elements.
2. Evaluate benefits of pion exit scintillators.
3. Evaluate design requirements for transposer circuit board to accommodate amplifier circuit normally designed for a 3” PMT base
4. Select 1” PMT vendor and prepare for acceptance testing.

Recommendations:

NONE

GEM Detectors

Findings:

1. Four wheels, each holding 7 sectors of triple GEM detectors (total 28) are being built for MOLLER.
2. GEM production is being split between two groups. The University of Virgina (UVA) is building 4 sectors per wheel, and Stony Brook (SBU) is building 3 sectors per wheel.
3. GEM thickness planned is 0.93X0, thicker than SBS GEM but even in this case the required tracking resolution of 1mm position and 1mrad angular is expected to be reached.
4. New APVs and MPDs were bought specifically for Moller, some remaining channels will be borrowed from SBS, the large number of SBS channels available should be able to provide the remaining channels and spares.
5. A plan for counting data taking was presented, the goal to reach 0.5% accuracy on the kinematic factor seems reachable with the expected performances from the GEM
6. Rate capability of the MPD system seems sufficient to do the study quickly as most time is used by overhead (~15 minutes data taking runs)
7. The readout is based on the APV-25 card. Long cables attached to the cards creates high noise in the first 5 channels of each card. The current plan is to not use the first 8 noisy channels of the APV card. The noise levels were measured for 23 m cables, but MOLLER runs may require the cables to be up to 30 m long.
8. Assembly and testing facilities are available at UVa and Stony Brook.
9. GEM frame machining is currently sole sourced. Investigation of alternative vendors is underway. Engaging machine shop supervisors for various members of the collaboration could help with this process.
10. Full readout chain was explained in sufficient detail with performance results from SBS experience, the scale of the system is a bit less than the BigBite GEMs setup which were extensively used during GMn and GEn experiments.
11. The rotation range of the frame will be 51.4 degrees.

Comments:

1. Confirm that the physics requirement on measuring the normalizing kinematic factor can be met with the proposed thickness of the GEM detectors.
2. The committee agrees the project is ready to order the foils from CERN.
3. Coordination between UVA and SBU should continue to maximize the efficiency and consistency of the GEM production between their groups.
4. Prototype needed to finalize the cabling plan, special care will be given to the GEM HDMI cable connection.

5. The changes to the design have greatly improved stability and reduced risk.
6. Careful attention is needed to the installation of the detectors and in particular where people will need to be for that work. It may be useful to increase the angular travel of the rings to ease installation.
7. The motion control systems for the GEMs rotator need to support any required unbalanced load from free rotation in the event of a power failure or single component failure (chain, shaft key, motor...). This may require adding enough friction to the system to resist rotation or using counterbalance to control torque. A test of the effectiveness of the design with a dummy load would ensure design assumptions are met.
8. The radial motion of the GEM chambers needs to stop the chamber in the correct position and ensure overtravel is prevented. One way to do this is to use a limit switch (proximity sensor, roller switch, etc) with adjustable position that can be set for a soft stop at the correct position in conjunction with a hard stop that can react the maximum torque of the motor and stop the drive without damage. The drive system should not allow motion if there is a power failure.

Recommendations:

1. Perform readout testing with the proposed 30m HDMI cables to measure performance and verify FIR filter solution for APV25 signal levels.
2. Evaluate strain relief devices and include these in the GEM frame support design. There may be details that impact G10 frame machining.

HVMAPS detector

Findings:

1. Total of 84 pixel readout modules mounted behind each of the quartz tiles in Ring 5 of the Main detector.
2. Readout will use CERN based lpGBT/VTX+ fiber link for control/config and data readout. This is a mature design.
3. HVMAPS detectors will be used as part of the Counting Mode DAQ and as an independent data stream in Integrating Mode.
4. The detector is not essential for success of Moller but would complement the mapper and provide quick diagnostics giving a real time distribution of the Moller events in the detectors
5. Jefferson Lab's FEDAQ group has experience with the proposed Arista 7130 FPGA-based network switch.

Comments:

1. The project needs to develop a plan (scheduling and resources) to integrate this system into MOLLER DAQ.

Recommendations:

NONE

SAM, LAM, DBM, Scanner

Findings:

1. Air core light guide and Hamamatsu R375 PMT have been evaluated thoroughly and there is ample experience with this PMT.
2. Safety factor is large with 8pe expected and 1pe required

Comments:

1. These are relatively small systems that are adequately developed.

Recommendations:

NONE

Trigger Scintillators

Findings:

1. There are 14 trigger scintillators, 7 upstream of the GEMs and 7 downstream.
2. The design requires timing resolution of less than 2 ns, efficiency > 98%, 1.3 MHz rate capability and a thickness of < 2% X0.
3. The proposal is to use a grooved EJ-208 scintillator with wavelength-shifting fibers Kuraray Y-11.
4. The detectors were simulated, and one prototype constructed. The scintillator wrapping for the prototype was mylar with 90% reflectance, which resulted in poor detection efficiency.
5. The wrapping will be replaced with 3M DF2000MA material with reflectivity >99%.
6. The ET 9181SB photomultiplier with a quartz window has been considered for readout, but no decisions have been made.

Comments:

1. Verify that wrapping with improved reflectivity achieves the required efficiency over the entire scintillator area.
2. The radiation hardness of the DF2000MA should be evaluated, possibly tested at the Idaho Accelerator.
3. Photomultipliers with normal glass windows should be considered for this project as they are located in a low radiation environment.
4. The 1.3 MHz rate capability will be challenging and must be considered as part of the selection of the photomultiplier.

Recommendations:

NONE

Counting and Integrating DAQ System Overview:

Findings:

1. The plan is to implement a JLAB CODA-based DAQ system for all MOLLER detector subsystems. Detector subsystems will be present both in the experimental hall and in the Injector area of the accelerator.
2. A 15 Msps 18 bit 16 channel ADC board has been developed and is being tested
3. Each integrating ADC board will host a CODA readout controller running on the SOC, a software TI will be implemented to interface with standard CODA TD module for trigger distribution and synchronization and data is sent through the network through a dedicated 10 gigE ethernet port.
4. GEM readout electronics are a replica of the BigBite/SuperBigBite DAQ system.
5. No failures of the APV25 or MPD modules have been attributed to radiation dose.
6. Experience with BB/SBS GEM DAQ issues was explained sufficiently and diagnostics are in place to identify problems.
7. Fiber optic routing options for trigger signaling between Injector Service Building [ISB] and HallA were presented.

Comments:

1. The overall DAQ system is reasonably well defined and should accommodate all the operating modes proposed.
2. Evaluate and decide on Power-Over-Ethernet [PoE] or external 48VDC supply for integrating ADC boards.
3. Using single mode fiber with the JLAB trigger distribution systems should be considered and verified as soon as possible.
4. Online computing resources proposed are reasonable for the expected data and trigger rates.
5. Consider performing online data evaluation using the existing JLab farm.

Recommendations:

NONE

Beam Parameter Readout for BCM/BPM

Findings:

1. Two systems are available for BCM : JLab and Berkeley. The JLab design has applications for all experimental halls and is the only system available for BPM readout.
2. The experiment would like to have both systems available for redundancy to make sure the noise goal is achieved
3. Work to integrate digital readout of both systems in CODA is ongoing
4. Grounding for all instrumentation devices on the detector has been evaluated and a plan for implementation has been developed for installation.

Comments:

1. The review committee recognizes that the beam instrumentation devices are off project and we encourage the evaluation of both the JLab and Berkeley electronics. We strongly suggest that the experimenters work closely with the project management to implement both solutions.

Recommendations:

NONE

DAQ and detector timetable :

December 7th, 2022

Time	Subsystem	Presenter
8:00 - 9:00	Welcome Review Committee (Closed Session)	
9:00 - 9:40	Overview of Experiment and Requirements	Mark Pitt
9:40 - 9:50	Program Overview	Jim Fast
9:50 - 10:00	Interface Control	Robin Wines
	DETECTORS PAGE HERE	
10:00 - 10:15	Break	
10:15 - 11:00	Thin Quartz	Michael Gericke
11:00 - 11:45	Shower Max	Dustin McNulty
11:45 - 12:15	Pion Detector	David Armstrong
12:15 - 1:15	Lunch (Committee Lunch F224)	
1:15 - 2:00	Thin Quartz, Shower Max support/mechanics	Larry Bartoszek
2:00 - 2:30	Scattered Beam Monitors and Scanners	Mark Pitt
2:30 - 2:45	Break	

2:45 - 3:55	GEM Design, Readout Electronics, UVA Prototyping	Nilanga Liyanage
3:55 - 4:30	SBU Prototyping	Klaus Dehmelt
4:30 - 6:00	Review Committee (Closed Session)	

December 8th, 2022

Time	Subsystem	Presenter
8:15 - 8:45	Response to Questions	
	DETECTORS PAGE HERE	
8:45 - 9:15	GEM Rotator Wheel Frame, Support, Motion System	Chandika Annasiwatta
9:15 - 9:45	Trigger Scintillators	Rakitha Beminiwatta
9:45 - 10:00	Break	
	DAQ PAGE HERE	
10:00 - 10:45	Overview, Counting DAQ System and Integrating DAQ System HW Q6 Response	Paul King
10:45 - 11:15	Integrating ADCs	Paul King

11:15 - 11:30	HVMAPS Readout	Paul King
11:30 - 11:45	Beam Parameter Readout, JLab/Berkeley Systems	Bob Michaels
11:45 - 12:15	EHS&Q Wrapup, Remaining Questions	Bob Michaels
12:15 - 1:30	Lunch (Committee Lunch F224)	
1:30 - 3:00	Review Committee (Closed Session)	
1:30 - 2:30	Meeting with JLab Integration and Pre -ERR	
3:00 - 3:15	Break	
3:15 - 3:45	Response to Questions	
3:45 - 5:00	Review Committee (Closed Session)	
5:00 - 6:00	Closeout	