MOLLER Project Final Design Reviews
Target, Spectrometer, Infrastructure - December 5-6, 2022

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The Review Committee would like to commend the MOLLER team for thorough and comprehensive design analyses and presentations. 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. Detailed presentations on the Target and Spectrometer state the components meet the specifications. In addition, the physics requirements flow down to the component specifications.

2. Are the designs technically adequate and sufficiently advanced for a project at this stage?
   Yes.
   a. Are they sufficiently mature to support fabrication? Yes for some, but not all components are ready for procurement. It is expected all components will be ready for procurement by CD2/3.
   b. Are any remaining design options properly identified and documented? No major remaining open design options were presented and the design appears finalized.
   c. Are there plans in place for completion to allow the start of procurements and fabrications within 4-6 months after FDR? Yes.

3. Are subsystem interfaces addressed?
   Yes, for CD-3A components. Components with outstanding interface determinations are expected to be complete in the next few months.

4. Have the subsystems addressed JLab standards of EHS&Q?
   Yes. The application of Jefferson Lab ESH&Q requirements were provided for the Target chamber, spectrometer, magnets and beampipes.

5. Are recommendations from Preliminary Design Reviews sufficiently addressed?
   Yes.

Findings:

1. The MOLLER experiment is scheduled to run for three years at 50% duty cycle.
2. PDR held for 1.06 Infrastructure on 8-June-2022.
3. The hydrogen target and system is similar to other experiments run at JLAB, QWeak, etc. The target cell is longer and the beam power on the target is higher and requires a higher flow. Therefore a new system is required with only the heat exchanger being reused. Lessons learned from previous experiments have been incorporated.
4. There are 11 Interface Control Documents which have been completed and are being used.
5. The LH2 target design capitalizes on a lot of experience gained from the Qweak experiment.
6. The use of CFD was benchmarked for the QWeak experiment. The goal is to have lower density fluctuations for the Moller experiment and calculations thus far support this.
7. The design calculations for the target was for 4.5 KW with a max of 3.3 KW planned. The design calculations used a 4x4 mm raster with a 5x5 mm raster planned. Sufficient margin has been added for all of the design calculations.
8. All hydrogen reliefs will be vented outside of the experimental hall. A N2 purge will be maintained on the vent system to limit potential contamination to the system.
9. Conservative material properties have been assumed for many of the mechanical analyses. For example,
    a. The target scattering chamber was analyzed as 6061-T6 while the actual material will be the stronger alloy 7075.
    b. The downstream detector “top hat” and other weldments were analyzed as 6061-0 while they will naturally age to the -T4 condition shortly after welding.
10. System controls, and interlocks for the target system are based on previous experiments and are in good shape for this stage of the project.
11. Modifications to the existing beamline and spectrometers are needed. Most of the beamline items are ready to be procured. Plans for the rest of the system are in good order. Detailed installation planning with safety measures is still to be done. The new water system design is done with cost optimization underway.
12. The shielding calculations appear to be in good shape with the shielding designs essentially done and in final design. There is some worry over the cost and lead time for the concrete delivery.
13. The window into the target chamber is designed to be a beryllium window E-beam welded into an aluminum flange.
14. The coil belly plate design for the spectrometer is a new requirement so this design has not been started.
15. A prototype magnet support frame has been purchased and an assembly with at least one coil will be started soon. There is a preliminary assembly plan for one of the DS magnets assemblies that can be used and vetted.
16. The DS coils are being received and QC of the coils thus far have met specifications.

17. The routing of the US coil leads may create a field distortion. It appears that this distortion is not significant to the physics.
18. Collimator 1-2 is a complicated braze assembly. It is planned to fabricate this assembly early which should give time to recover if there are problems.
19. There are some large vacuum loads on some of the chambers that are restrained by the alignment links. Having a redundant mechanism to carry the load in case of a failure in the primary load path would be a good safety measure.
20. The photon scraper is mounted to one of the vacuum chambers and final alignment will be done after assembly of the vacuum chamber.
21. First article power supply has been ordered. FAT is scheduled for March and delivery in June.
22. Some designs have taken consideration of the supply chain issues and revise the design using available components. For example, in the interlock and protection system, the design team replaced Allen-Bradley PLC with Siemens PLC because AB could not provide a delivery schedule.

Comments:

1. The project appears to be doing a commendable job with sharing and deconflicting CAD data among the multiple engineering teams which are using various different CAD softwares.
2. Sprocket engagement of the drive chain of the target's vertical lifter system may be less than manufacturer's recommended minimum. Previous experience may mitigate this discrepancy.
3. Installation of upstream beamline components will be beneficial and should be prioritized appropriately.
4. Removal of 30% of the utility platform is expected to be labor intensive and have a high impact on operations.
5. Engineering peer review/validation of the target chamber calculations should be complete prior to procurement action.
6. The 95% efficiency requirement for the power supply sounds optimistic. Lowering the efficiency requirement to 90-92% would be more reasonable. This could impact the current draw of the power supply which would impact the power feed requirements and switchgear.
7. Proper positioning of the downstream magnets depends upon the flatness of the mating faces of the bottom and top enclosure assemblies. Post-weld machining will be required on the "top hat" assembly to ensure this required flatness. The review committee is also concerned that vibrational effects during transport could cause the weldment to distort, leading to unacceptable magnet alignment.
8. Many braze joints need to be made to the completed and installed coils for electrical and cooling connection. The process to make these joints and the quality control need careful attention.
9. The requirements and design of the solid target system are still TBD. The solid target is planned to be a bolt on to the LH2 target. The requirements need to be supplied in time to complete the system design.

10. It was mentioned that some of the interface requirements for the US coil assembly and vacuum chamber were still being firmed up. These need to be defined in time to support the final spectrometer design.
11. The assembly and alignment plan for the upstream coils in the vacuum chamber is still TBD. This needs to be finalized in order to proceed with the detailed design.
12. The presented power supply current accuracy +/-50 ppm which will be challenging to achieve and may require a calibrated independent measurement system. The committee was told that the spec has been significantly relaxed to 1000 ppm or more. The new spec should be finalized and documented in the official requirement document.
13. Review LCW requirements with Facilities to ensure the existing plant can supply adequate LCW to MOLLER and support other Hall operations. This may require consultation with the Physics division regarding future experiments.
14. The beryllium window may be difficult to source. An all aluminum window is a backup option. Consider preparing a drawing/specification for an all-aluminum window in the event that the planned beryllium window cannot be sourced.
15. Water velocity of 12 ft/sec are high for copper coils. Jlab has experience with up to 15 ft/sec. The short 3 year duration of the experiment relieves concern about erosion.
16. The LH2 pump is a unique design developed and tested with Qweak. The MOLLER version will rework the bearings and move the motor outside the vacuum. Planning for maintenance including having many spares is important.
17. It would be good to review any requirements for fall restraint tie off during all installation operations to ensure there is adequate infrastructure for access.
18. There is a secondary cooling system to isolate the water due to concerns about radioactive contamination. There would be substantial savings to the project if the LCW could be used directly. A more detailed analysis of the radiation deposition in the water could show the dose is small enough for direct LCW use.
19. There was an assessment conducted by "Mason & Hanger" to review the need for fire protection associated with the Hydrogen gas line and H2 target. There was an action for HallA to add another hydrogen "sniffer" to the VESDA system, the details are yet to be ironed out.

Recommendations:

1. Consider creating a Procurement Readiness Review presentation/status for the CD-3A scope of work prior to the CD-3A review.
2. Lowering the input voltage to the power supply will increase the current requirement which will place requirements on the switchgear. These numbers need to be revisited and updated in the interface control documents (ICD-0306) before power supply and switch board acquisition.

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Agenda

Time	Subsystem	Presenter
8:30 - 9:00	Welcome Review Committee (Closed Session)	
9:00 - 9:40	Overview of Experiment and Requirements	Krishna Kumar
9:40 - 9:50	Program Overview	Jim Fast
9:50 - 10:00	Interface Control	Robin Wines
	TARGET PAGE HERE	
10:00 - 10:30	CFD analysis of the Cell	Silviu Covrig Dusa
10:30 -10:45	Break	
10:45 - 11:15	Target Engineering Overview and Status	Dave Meekins
11:15 - 12:15	Design Details	Dave Meekins
12:15 - 1:15	Lunch (Committee Lunch F224)	
1:15 - 1:45	Calculations	Dave Meekins
1:45 - 2:15	Safety and Quality Assurance	Dave Meekins
	INFRASTRUCTURE PAGE HERE	
2:15 - 2:30	Break	
2:30 - 3:15	Infrastructure Overview	Robin Wines
3:15 -3:45	Shielding Requirements	Ciprian Gal
3:45 - 4:15	Shielding Design and Engineering	Ryan Biraben
4:15 - 6:00	Review Committee (Closed Session)	

December 6th, 2022

Time	Subsystem	Presenter
8:00 - 8:30	Response to Homework	Target and Infrastructure Teams
	SPECTROMETER PAGE HERE	
8:30 - 8:45	Spectrometer Overview	Juliette Mammei
8:45 - 9:30	Spectrometer Engineering Overview and Downstream Torus System Details and Status	Dave Kashy
9:30 - 9:50	Upstream Toroid Design and Analysis	Ernie Ihloff
9:50 - 10:10	Upstream Collimator Design and Analysis	Jason Bessuille
10:10 - 10:30	Break	
10:30 - 10:50	Beam Pipes, Windows and Bellows	Eric Sun
10:50 - 11:10	Downstream Enclosure and Window Analysis	Sandesh Gopinath
11:10 - 11:25	Photon Scraper Analysis	Kris Cleveland
11:25 - 11:40	Magnet Assembly	Joe Lamont
11:40 - 12:10	Magnet Power Supply and I&C	Brian Eng
12:10 - 12:30	Wrap Up	James Fast
12:30 - 1:30	Lunch	
1:30 - 3:00	Review Committee (Closed Session)	
3:00 - 3:30	Response to Questions	
3:30 - 5:00	Review Committee (Closed Session)	
5:00 - 6:00	Closeout	

Additional findings

Maturity
DOE scope items underwent prelim design review Feb-June 2022
Technical Design Report draft released Nov 2022
CD-2/3 planned for Jan-Feb
Independent FDR required prior to CD-2/3
May require additional Independent FDR prior to CD-3A

Interfaces
Presently have 11 Interface Control Documents; these have been generated via Interface Control Matrix and have been reviewed/signed
Documents are maintained in Sharepoint

Target cell
CFD utilized to validate Qweak Target loop components (except the pump) meets the requirements.
Nominal simulations conditions:
  LH2 at inlet to the cell: 20K; 35 psia; 1.5kg/s (30g/s for flow process)
  75uA beam current with 4x4 mm2 raster 3300W (Raster is up to 5x5 mm^2 in operation)

Target loop
For off-normal conditions, a heat flux value of 50kW/m^2 was used to determine relief valve sizing for overpressure analysis. This is consistent with the most widely used reference value from the literature - W Lehmann and G Zahn (1978) give 3.8 W/cm^2 for heat flux to the uninsulated walls of a 4.5K cryostat
The high power heater maintains constant heat load into the target loop regardless of the beam power; this reduces the density variation during the 1-10s time scale after a beam trip
Heater control uses feedback from fluid temperature (sensor located in the fluid, at the cell entrance) and feed-forward using beam power
When beam is on, heater is expected to deliver ~100W to fluid - but it controls all the time to maintain the temperature at 20K
Pump, once primed, delivers stable pressure
At high heat flux locations the Hydrogen that turns into vapor is very localized and recondenses before bubbles form.
Beam rastering moves the beam parallel in the target.
H2 cooling by cold helium gas (Counterflow heat exchanger)
Primary relief back into Hydrogen storage, but secondary relief to stack

90% Design Definition
3D CAD model complete; 2D drawings near complete
Calculations complete to extent to conform confidence in design
Scattering Chamber; Stands; Upstream & Downstream Spectrometer; Supply/Return Piping; Gas Panel; …….

Target scale ~70 liters
Very similar to Qweak target
Chamber is forged 7075-T6 3.5” thick wall (potential for small cost reduction vs 2219 referenced in TDR)
Vacuum system repeat of existing system
Window into target chamber is Beryllium E-beam welded to 2219 Aluminum by sole vendor, Materion
Hydrogen line 1E-9 leak check all CF seals
He temp low enough to freeze H2 in HX
Space for Solid targets is there and travel is designed for
Reuse Qweak HX, lot’s of capacity
Alignment is done by locating the chamber. Use a portable CMM (Faroarm) to locate cell relative to the chamber.
Pump has been tested.
Large side seals and top flange seal are O-rings on the target vacuum chamber
Pressure relief calculations are extremely conservative, but designing to these does not create problems.
Experiment lifetime 3 years at 50% duty cycle

Scope of Work:
A statement of work for the full scope is complete.
Statements of work for individual procurements still need to be developed.

Infrastructure:
No access to hall when beam is on. Some things activate from operation. Should be OK outside target and spectrometer shielding. Radiation crew goes in and makes measurements.
Jib crane is 2t. Plan powered hoist. Perhaps with trolly drive, but jib rotation is not motorized.
Fixing the existing hall crane is planned, but not on MOLLER budget.
Worthwhile to consider tie off locations for elevated work
Lead filled aluminum rings may need more constraint

Pump:
The LH2 pump was used in Qweak. There were problems with the initial bearing. They were replaced with ceramic bearings.

Coils:

What are magnetic loads on coils? They are in the same range as the gravity loads. Magnetic loads and thermal loads have been analyzed.
Will the field be measured? Plans are under development… field measurement is hard.
Relying on mechanical placement and coil fabrication tolerance
What is used for feedback of position during alignment?
LCW Bldg 92 supplies 500 gpM, 2 MW of cooling. Need 1.5 MW
Is the water from Bldg 92 not good enough to use directly? There is a concern that the water going through the magnets may be activated, so the secondary loop is for isolation of that risk.
Protection of vacuum system if there is a water leak? There is a system that will shut down the vacuum pumps if the pressure get's to high.
How is the magnet system assembled?
Conductor by Luvata. Coil Fab by Everson Tesla.
Upstream chamber with all subsystems 16,000 lb. All instruments outside of vacuum to get out of radiation field
Water velocity 12 ft/sec (this is quite high), delta t = 30 C. Some existing magnets at JLab run as high as 15 ft/sec. Dave is not worried because lifetime of coils is 3 years.
Temperature integral measured by monitoring voltage across coil.
Current lead to and from the coil are a source of field distortion. A quick analysis of this was done and it was not thought to be a problem.

Collimators:
What are stresses in W due to thermal differentials. They are low.
CMM of collimators is part of fabrication contract

Beampipes:
Welds in Drift Pipe & Detector Pipe
*Are there protectors for the bellows during assembly? Use?

Spectrometer Enclosure:
Fabrication tolerances for these large aluminum weldments?
The place where the magnet links are connected to the base are over top of a tall aluminum rib bolted to the bottom of the base plate. This is separated from the location of the vacuum seal.
Loads from flattening out distortions in the lid are some distance from the magnet support points. The lid can be removed, the magnet readjusted, and the lid replaced.
O-ring loads not specifically addressed.
Is steel OK in linkages?
Earthquake Loads? Yes
Has vacuum test been done on prototype window? Not yet. Deflections can be measured during the test.
Single element carries large Z load.

Magnet Assembly:
Coil inspection; visual inspection, pressure test, survey (geometric map)
Coils installed with "beamaxis" vertical. Then rotate assembly.

Current carrying coil interconnects are brazed in place. Some water only connections will be soldered. Could consider memory metal connections (http://www.smartechnology.com/shapmem.htm) These are Ti-Ni alloy. Is Nickel allowed?
Coil ringing done at vendor.

Power Supplies:
100 ppm stability and 50 ppm accuracy are not really required. These are overstating what is actually required. Relaxing these requirements might reduce cost or increase vendor participation.
Are there frequencies of ripple in the PS that should be avoided so to stay away from possible interference with the physics?
95% efficiency is optimistic.

ESH
Commercially available stairs and platforms will be utilized for accessing the MOLLER beamline components.

ICD for UPstream Toroid Magnet in development?
>>> Interface for beamline bellows and foundation in development.

Questions:
1. Are the Be to 2219 E-beam welded windows part of CD3a? No. Is the plan to purchase many of these? Yes
2. The H2 pump is inside the target vacuum vessel. How reliable is this pump? What could go wrong with it? Bearings? Seals? Is there a spare? Spare parts?
3. Would the aluminum windows on the H2 chamber be OK if there were beam but no flow?
4. What is the schedule, cost, staffing of activities, experimental runs, downtimes, operations, etc….?
5. What scope is included in CD-3A?

Notes from Paul Powers
1. Consolidate drawings into a single file.
2. Develop electrical drawings (one-line) for power distributions.
3. Develop control drawings (P&ID).
4. Develop mechanical drawings.
5. Consolidate charts in 250+ page report and shoe on drawings.
6. For each piece of equipments show the following:
    a. Minimum circuit amps.
    b. Maximum overcurent protections.

    c. LCW flow data.
    d. Heat rejection to air.
7. Where does target bunker(?) and electronic bunker get power?
8. Are there any requirements for additional cooling (A/C, pumps, etc.)
9. Suggest on-site testing of power supplies to include op test at voltage extremes especially around -10% of nominal.