Measurement of Lepton-Lepton Electroweak Reactions (MOLLER) Project

System Requirements Document for MOLLER Spectrometer (WBS 1.03) of the MOLLER EXPERIMENT

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1. CHANGE LOG

Revision No.	Pages Affected and Description	Effective Date
Revision 0	Initial Release	TBD

2. ACRONYM LIST

JLab	Thomas Jefferson National Accelerator Facility (Jefferson Lab)
MOLLER	Measurement of a Lepton-Lepton Electroweak Reaction
US	Upstream (referring to the upstream magnet, supports, power supplies, enclosure, etc.)
DS	Downstream (referring to the downstream magnet, supports, power supplies, enclosure, etc.)

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1 SCOPE

The MOLLER Spectrometer Systems Requirements Document (SRD) provides the technical performance requirements as pertains to the toroidal magnets, collimators, collars, lintels and beampipes for MOLLER. This document translates physics requirements into engineering requirements for the spectrometer.

1.1 DOCUMENT OVERVIEW

The remainder of Section 1 provides information about review and approval of this document as well as terminology used. Section 2 provides a high-level functional overview of the system. Section 3 provides the specific design requirements.

1.2 CONTROL AND REVISION

This document and any revisions to it shall be reviewed by the relevant MOLLER CAM, MOLLER Project Engineer and MOLLER Scientific Coordinator and approved by the MOLLER Project Manager.

1.3 TERMINOLOGY

The MOLLER experiment will operate in Hall A at Jefferson Lab. The hall is round with the beamline intersecting the center of the hall about 10 feet above the floor. The hall is usually configured with a pair of magnetic spectrometers (HRS) that rotate about a pivot at the center of the hall, where the target chamber is usually located. The Hall is shown in Figure 1 where the beamline can be seen entering the hall from the right side below the elevated utility platform, the target chamber can be seen at the center of the hall at the pivot, and the two HRS spectrometers can be seen, with HRS-left in the far forward direction and HRS-right about 60-degrees from the beam axis. The beam exits the hall into the beam dump on the left behind HRS-left in this image.

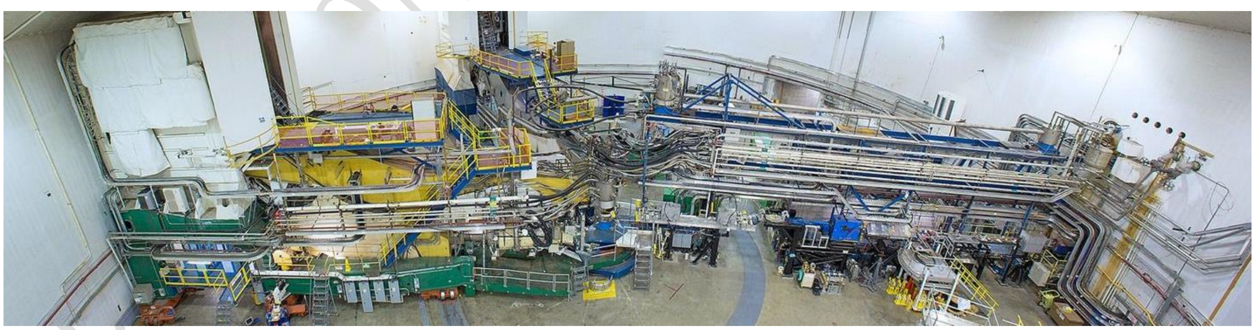


Figure 1: Jefferson Lab Hall A as recently configured. Beam comes from the right. The two spectrometer arms will be moved out of the way during MOLLER installation and running.

1.4 DEFINITION OF COORDINATE AXES

Within this document, the coordinate axes are defined with +z pointing downstream, +x to beam left and +y is vertically upward. The center of the coordinate axes is the center of the hall. The azimuthal angle, φ, is defined as equal to zero at the positive x axis and increasing going from the +x toward +y axis (clockwise, looking downstream).

1.5 INCOMPLETE AND TENTATIVE REQUIREMENTS

Within this document, the term "TBD" (to be determined) indicates that additional effort (analysis, trade-off studies, etc.) are required to define the particular requirement. The term "TBR" (to be revised) indicates that the value given is subject to change.

2 SYSTEM FUNCTION, CONFIGURATION AND INTERFACES

2.1 SYSTEM FUNCTION

The spectrometer systems provide the magnetic focusing, collimation and vacuum environment to separate and transport the signal, background and un-scattered beam to their respective destinations. The signal electrons are focused to ring 5 of the main detectors while the ep background is focused to ring 2. Radiative tails from these processes populate the remaining main detector rings. The un-scattered beam must be transported with minimal loss to the beam dump. Low energy electrons are bent outward and are a source of background that must be managed by stopping them in various types of absorbers which include collars, lintels, collimators and concrete shielding (shielding is in a separate WBS).

2.2 SYSTEM BASIC CONFIGURATION

The spectrometer system includes the vacuum pipes that extend from the vacuum window at the downstream end of the target chamber to the beam dump tunnel. All hardware in the beam dump tunnel remains as-is and the spectrometer vacuum pipe attaches to this; the vacuum is common. The two 7-fold toroidal magnets (upstream and downstream) provide the separation and focusing of the signal and background scattered electrons at the main detector plane. A series of collimators define the detector acceptance and sculpt the background charged particle and photon envelopes as they progress downstream. Sitting just upstream of the toroids are a movable blocker and sieve collimator used to study the spectrometer acceptance during dedicated counting mode (low current) runs.

2.3 SYSTEM INTERFACES

The Spectrometer system interfaces are captured in three Interface Control Documents (ICD):

- ICD0203-Target to Spectrometer
- ICD0304- Spectrometer to Integrating Detectors
- ICD0305- Spectrometer to Tracking Detectors
- ICD0306-Spectrometer to Infrastructure

Installation, including alignment accuracies required, are covered in the System Requirements Document (SRD) for WBS 1.08, *MOLLER-INSTALLATION-SRD.* This document defines the machining tolerances and the recommended corresponding relative positioning tolerances internal to the spectrometer system. The installation SRD should take precedence if there is a discrepancy in alignment tolerances.

3 DESIGN REQUIREMENTS

This section states general system requirements necessary to fulfill the system function statements. It also links to general constraints and requirements identified in the *MOLLER Functional Requirements* which are pertinent to the engineering of this system, where these are not included below.

3.1 MATERIALS

Materials inside the vacuum systems are documented in PMAG0000-0100-S0022.

	Item	Value	Comments
1	**Generally prohibited materials**	Steel (stainless, ferromagnetic), elastomers, glues, materials that can be activated with long half-life should be avoided where they receive doses that will activate them	The collaboration has a ferrous materials group and also does simulations on radiation dose to determine acceptable materials
2	**Generally allowed materials**	Copper, aluminum, epoxy and cyanate ester resins, carbon fiber, glass fiber, tungsten, brass, bronze, titanium, Inconel 625, glass/quartz, silicon-bronze, peroxide-cured EPDM O-ring seals that are suitable for use in low radiation areas (Viton is less radiation tolerant so it needs additional scrutiny)	PMAG0000-0100-S0022 - MOLLER Materials List (Inside Enclosure (selected materials within the enclosure)

3.2 MAGNETS

Reference should be made to '*PMAG0000-0100-A0007 MOLLER - Upstream and Downstream Coil Specification and Requirements*' for the engineering requirements for the upstream and downstream toroid coils and magnets.

Power supply specification is PMAG0000-0100-S0014.

	Item	Value	Comments
1	**Magnetic field temporal stability for the complete magnet.**	PS variation over a 24 hour period should be within ± 500 ppm at the nominal operating current The maximum variation of coil temperature from nominal should be no greater than ± 3°C over a 24 hour period	Only real concern is helicity correlated fluctuations. *[J. Mammei]*

<table>
<tr><td></td><td></td><td colspan="2">Should be able to operate at the same temperature for currents between 90% and 110% of the operating current

Ideally, using the operating current tap, the power supplies will provide 100 ppm stability (RMS over 24 hr) at the nominal operating current, but at a minimum must satisfy the stability values listed in Table 1 when operated with the nominal load values provided in Table 1.

Table 1: Nominal power supply operating characteristics.
<table>
<tr><th>Item</th><th>Power supply</th><th>Nominal Operating Current (DC Amps)</th><th>Output current stability better than (mA RMS 24 hours) at operating current</th><th>Normal Operating Voltage (DC volts, nominal)</th><th>L_{total} (milli-Henries)</th><th>R (ohms)</th></tr>
<tr><td>1</td><td>US torus</td><td>1075</td><td>500</td><td>77.5</td><td>0.631</td><td>0.059</td></tr>
<tr><td>2</td><td>DSTorus_1</td><td>2230</td><td>1000</td><td>40</td><td>0.153</td><td>0.015</td></tr>
<tr><td>3</td><td>DSTorus_2</td><td>2440</td><td>1000</td><td>42</td><td>0.246</td><td>0.013</td></tr>
<tr><td>4</td><td>DSTorus_3</td><td>3235</td><td>1500</td><td>57</td><td>0.348</td><td>0.013</td></tr>
<tr><td>5</td><td>DSTorus_4</td><td>3350</td><td>1500</td><td>224</td><td>3.051</td><td>0.056</td></tr>
</table>
Note: Load Characteristics Tolerance: Resistance 10% and Inductance 10%</td><td></td></tr>
<tr><td>2</td><td>Expected beam power deposition per coil for each magnet (with symmetric /asymmetric map at 70 µA)</td><td>UPSTREAM

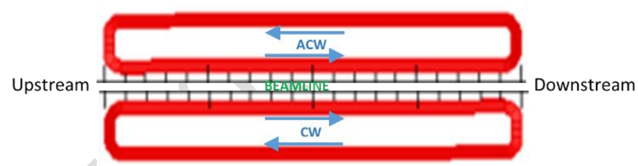
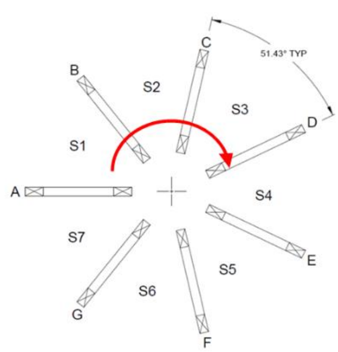
4 W / 4 W</td><td>DOWNSTREAM

SC1 = 1.5 W / 1.2 W

SC2 = 0.5 W / 2.3 W

SC3 = 0.7 W / 4.1 W

SC4 = 1.0 W / 4.6 W</td><td>7 total coils per magnet

Need to determine max power per coil in asymmetric case</td></tr>
<tr><td>3</td><td>Coil current direction (also refer to 'Magnetic field vector rotational direction')</td><td colspan="2">
</td><td>Only US torus shown here but applies equally to the DS torus</td></tr>
<tr><td>4</td><td>Magnetic field vector rotational direction (also refer to 'Coil current direction')</td><td colspan="2">CLOCKWISE (CW) - when looking downstream

</td><td>Applies to both US and DS torus magnets

Note: The azimuthal center of coil A in is magnet is at φ=0, which is the center of a closed sector.</td></tr>
</table>

3.3 MAGNET ENCLOSURES

	Item	Value		Comments
1	**Torus magnet environments**	**UPSTREAM** Nominal - 1 x 10^{-2} Torr No higher than 10^{-1} Torr	**DOWNSTREAM** Nominal - 1 x 10^{-2} Torr No higher than 10^{-1} Torr	Aim for leak rate of 1x10^{-8} mbar·l/s Vessel design must satisfy all JLab Pressure System requirements for vacuum vessels

3.4 COLLIMATORS / BLOCKERS / SHIELD ELEMENTS

	Item	Value	Comments
1	**Machining accuracy**	Collimator #1 = Outer ± 0.20 mm, Inner ± 0.10 mm Collimator #2 and #4 acceptance region machining = ± 0.10 mm of design Collimator 2 acceptance must be concentric to collimator 1 bore by ±0.50 mm Collimator #5 = ± 0.20 mm Collimators #6a/b = ± 0.20 mm Sieve = ± 0.10 mm Blocker =± 0.20 mm Lintels = ±0.50 mm* Collar #0 = inner diameter ±1 mm of nominal Collar #1 = inner diameter ±1.5 mm of nominal Collar 2 = inner diameter ±1.25 mm of nominal Side and underbelly plates = ± 0.50 mm 2-Bounce Shield = ± 0.50 mm	*Inner edges lead (not aluminum)
2	**Location accuracy of center of items listed in row one relative to one another (dr) (combo of dx, dy)**	± 1 mm	This is applicable at the center of the US face of most of the components, except for lintels, where we reference the center of the inner upstream edge

3	**Collimator/Collar/Blocker relative positioning accuracy** **(dz, dφ, dθ)**	± 3mm dz for all* dφ critical for collimators 2, 4, sieve dφ < 0.2° lintel ends of upstream inner radius edge within ±1 mm in radius of each other dφ not applicable for collimator 1, blocker, collars, 2-bounce shield, and collimators 5, 6a, and 6b and side and belly shields are relative to coils (see xy above) collimator 1+2 center of upstream and downstream ends within ± 0.5 mm radially (dθ ~ 0.1°) 2-bounce shield center of upstream and downstream ends within ±1 mm radially (dθ ~ 0.1°) sieve- z offset between opposite points on diameter ±1 mm (dθ ~ 0.1°) collars, blocker and collimator 4 - z offset between outer radius and nominal center ±1 mm (dθ ~ 0.2°)	dz is measured to the upstream face dφ is the rotation around the beam axis dθ refers to the out of parallel angle (relative to the other elements) ; defined by the allowed offset from the parallel over the length in z or radius * Sieve and blocker must have hard stops
4	**SAM Pipe Machining and Position Tolerances**	dr = 5 mm dz = 5 mm, dθ = 1.1°, dφ = 5°	This is for the pipe; not the SAMs themselves
5	**Cooling capacity should be able to handle the stated xpected power deposition (with symmetric / asymmetric map at 70 μA)**	Collimator #1 = 4.7 kW / 4.7 kW Collimator #2 = 950 W / 950 W Collimator #4 = 60 W / 60 W Coll #5 =1.5 W / 3.6 W (per piece, 14 total) Coll #6a = 1.1 W / 4.2 W (per piece, 14 total) Coll #6b = 1.0 W / 2.6 W (per piece, 14 total) Blocker = 1.4 kW Sieve = 19 W (at 1uA) Lintels = 7 W / 9 W 2-bounce Shield = 322 W /324 W (upstream 50 cm) US side plates 3 W / 3 W (per piece, 14 total) DS belly plates 0.6 W / 2.3 W (per piece)	Nominal – ideal operation with centered beam. Includes effect of 1mm offset beam

3.5 BEAM PIPE / WINDOWS / BELLOWS

	Item	Value	Comments
1	**Detector Window (relative to collimator openings)**	Detector Window - Aluminum with max thickness of 2 mm for main acceptance region (thinner preferred) Concentricity and thinned sections if any are centered to dr = ±3 mm (outer) and ±1 mm inner radius dφ* = ±1.5 mm at inner radius of thinned portion	* this means along the azimuthal direction
2	**Detector Window Maximum allowable variation in thickness**	+30/-0 % of nominal window thickness only locally at weld zones.	Welds should be located in closed sectors
3	**Beam pipe concentricity to beamline**	±3 mm (between scattering chamber and collar 0) ±1 mm at collar 0 Downstream of collar 0 to drift pipe ±2 mm	The downstream z location of the reduced diameter section of the upstream beampipe is a potential source of background. If possible, collar-0 should be closer to the downstream end of this section, and it should be flush welded.
4	**Drift Pipe**	US and DS ends centered on the beam to within ±3 mm DS end will be defined by center pipe of Detector Window	
5	**Bellows**	See bellows specification PMAG0000-0100-S0016 MOLLER Specifications of Bellows	Bellows are required to allow flange to flange alignment imperfections and temperature changes in the Hall. This then requires that each piece of the vacuum system have supports that can take all thrust loads.
6	**Gaskets of flanges**	Metal seals at bellows 1, 2 and 7, peroxide-cured EPDM2 O-rings at bellows 3, 4, and 5	

3.6 FIELD MEASUREMENT

	Item	Value	Comments
1	**Individual assembled magnets (US, DS 1-4)**	a) B_{ϕ} minimum between coils (number of locations **TBD**) b) Measurement of dipole moment in the bore (number of locations **TBD**) c) Stray field measurements (location of 5 Gauss line) d) Temporal field stability	Will be defined after the prototype coil built and studies (field and tracking) are completed with the prototype as built data

3.7 INSTRUMENTATION

	Item	Value	Comments
1	**Connection Wire insulation**	Either insulate bare wire with Kapton or wrap Kapton around already insulated wire or 'sandwich' already insulated wire between two strips of Kapton.	Potential vendor: https://www.allectra.com/
2	**Location of instrumentation**	Locate all instrumentation in low radiation areas – typically these will be at the outermost radii of the coils – i.e. where the leads and water connections exit.	

4 APPLICABLE DOCUMENTS

1. PMAG0000-0100-A0007 MOLLER - UPSTREAM AND DOWNSTREAM COIL SPECIFICATION AND REQUIREMENTS
2. PMAG0000-0100-A0009 MOLLER - Upstream and Downstream Coil Design Targets
3. ASME ode B31.3 for Process Piping
4. NEMA Standards for Electrical Control 1C1-1954, latest revision, 155 East 44th St., N.Y., N.Y., which shall constitute the minimum acceptable standards.
5. Institute of Electrical and Electronics Engineers (IEEE). All electrical equipment shall conform to the latest standards of the Institute of Electrical and Electronics Engineers (IEEE).
6. PMAG0000-0100-S0014 - Moller - Magnet Power Supply specification (Upstream and Downstream)
7. PMAG0000-0100-S0016 - MOLLER Specifications of Bellows
8. PMAG0000-0100-S0022 - MOLLER Materials List (Inside Enclosure)