

Measurement of Lepton-Lepton Electroweak Reactions (MOLLER) Project

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



Page intentionally left blank

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

| Mike Bevins, CAM (Acting), Spectrometer | Date |
|---|------|
| Juliette Mammei, MOLLER Physics Lead | Date |
| | |
| David Kashy, MOLLER Technical Lead | Date |
| | |
| Kent Paschke, MOLLER Scientific Coordinator | Date |
| Robin Wines, Moller Project Engineer | Date |
| Jim Fast, MOLLER Project Manager | Date |

1. Change Log

| Revision No. | Pages Affected and Description | Effective Date |
|--------------|--------------------------------|----------------|
| Revision 0 | Initial Release | TBD |
| | | |
| | | |
| | | 0,67 |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | ~ O' | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

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.)

Table of Contents

| 1. | Change Log | 4 |
|----|---|----|
| 2. | Acronym List | 5 |
| 1 | Scope | 7 |
| 1 | 1 Document Overview | 7 |
| 1 | .2 Control and Revision | 7 |
| 1 | 3 Terminology | 7 |
| 1 | .4 Definition of Coordinate axes | 7 |
| 1 | .5 Incomplete and Tentative Requirements | 8 |
| 2 | SYSTEM Function, Configuration and Interfaces | 8 |
| 2 | .1 System Function | 8 |
| 2 | .2 System Basic Configuration | 8 |
| 2 | 3.3 System Interfaces | 8 |
| 3 | Design Requirements | 9 |
| 3 | .1 MATERIALS | 9 |
| 3 | .2 MAGNETS | 9 |
| 3 | .3 MAGNET ENCLOSURES | 11 |
| 3 | .4 COLLIMATORS / BLOCKERS / Shield elements | 11 |
| 3 | 5.5 BEAM PIPE / WINDOWS / BELLOWS | 13 |
| 3 | .6 FIELD MEASUREMENT | 14 |
| 3 | .7 INSTRUMENTATION | 14 |
| 4 | APPLICABLE DOCUMENTS | 14 |

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, OUT-OF-ROUND AND ANGLES

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). Many items described within this document are cylindrical and meant to be centered on the beam center with their upstream and downstream faces parallel to the x-y plane. The out-of-plane angle, θ , refers to a rotation of a surface that is transverse to the beamline (parallel to the x-y plane) out of that plane (includes pitch and yaw).

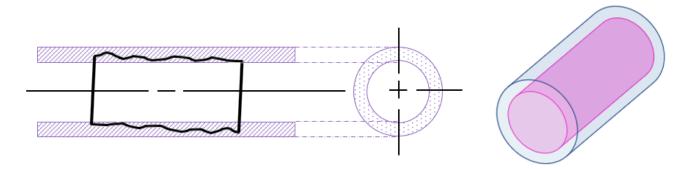


Figure 2: Cartoon of a cylinder that has a theta offset as well as being "wavy" on the sides of the cylinder. Out-of-round tolerances refer to the machining accuracy such that the cylinder fits within the inner and outer cylinders of radii $r \pm dr$ as shown. The theta tolerance is listed separately as $d\theta$.

Out-of-round tolerances listed in the tables below are defined in Fig. 2. These are in addition to and separate from the radial and angle tolerances.

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.

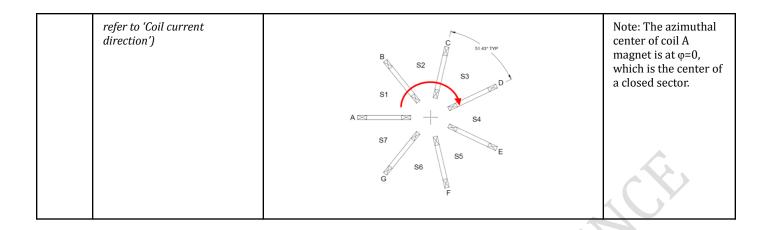
| | Item | Value | Comments |
|---|-----------------------------------|--|--|
| | | | |
| | Generally prohibited materials | | |
| 2 | Generally allowed materials | Copper, aluminum, epoxy and cyanate ester resins, carbon fiber, glass fiber, tungsten, brass, bronze, titanium, Inconel 625, | PMAG0000-0100-S0022 - 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 | Val | lue | Comments |
|---|---|--|---|---|
| 1 | Magnetic field temporal stability for the complete magnet. | stability (RMS over 24 hr) at the non must satisfy the stability values lister load values provided in Table 1. Table 1: Nominal power sulter litem Power Operating supply Operating supply Operating stability (mA RMS (DC Amps) 1 US torus 1075 2 DSTorus 1 2230 11 11 1230 11 1230 11 1230 11 1230 11 1230 11 1230 11 1230 11 1230 11 1230 1230 11 1230 1230 11 1230 1230 11 1230 1230 13 1230 13 1230 13 13 13 13 13 13 13 | temperature from nominal over a 24 hour period e same temperature for 19% of the operating current ap, the power supplies will provide 100 ppm ninal operating current, but at a minimum d in Table 1 when operated with the nominal apply operating characteristics. I current Voltage (milli- lower) (i) C volts, roomally (ii) (ii) (iii) | Only real concern is helicity correlated fluctuations. [J. Mammei] |
| 2 | Expected beam power deposition per coil for each magnet (with symmetric /asymmetric map at 70 µA) | UPSTREAM 4 W / 4 W | 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 | 7 total coils per magnet |
| 3 | Coil current direction (also refer to 'Magnetic field vector rotational direction') | Upstream BEAMU | Downstream | Only US torus shown here but applies equally to the DS torus |
| 4 | Magnetic field vector rotational direction (also | CLOCKWISE (CW) - wh | en looking downstream | Applies to both US and DS torus magnets |



3.3 MAGNET ENCLOSURES

| | Item | Val | lue | Comments |
|---|---------------------------|---|---|---|
| 1 | Torus magnet environments | UPSTREAM Nominal -1×10^{-2} Torr No higher than 10^{-1} Torr | DOWNSTREAM Nominal - 1×10^{-2} Torr No higher than 10^{-1} Torr | 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 | *Inner edges lead |
| | | Collimator #2 and #4 acceptance region machining = ± 0.10 mm of design | (not aluminum) |
| | | Collimator 2 acceptance must be concentric to collimator 1 bore by $\pm 0.50 \text{ mm}$ | |
| | | Collimator $#5 = \pm 0.20 \text{ mm}$ | |
| | | Collimators $\#6a/b = \pm 0.20 \text{ mm}$ | |
| | | Sieve = ± 0.10 mm | |
| | | Blocker =± 0.20 mm | |
| | | Lintels = $\pm 0.50 \text{ mm}^*$ | |
| | | 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 | |
| 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) | \pm 3mm dz for all (Sieve and blocker must have hard stops) $ d\varphi \ critical \ for \ collimators \ 2, \ 4, \ sieve \ d\varphi < 0.2^{\circ} $ lintel ends of upstream inner radius edge within ± 1 mm in radius of each other $ d\varphi \ 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 \(ends\) ends within \(\pm 0.5\) mm \(radially\) \((d\theta \sim 0.1^{\circ})\) | ** |
| 4 | Cooling capacity should be able to handle the stated expected 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 $dr = \pm 3 \text{ mm (outer) and } \pm 1 \text{ mm inner radius}$ $d\phi^* = \pm 1.5 \text{ mm at inner radius of thinned portion}$ | * 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. | Weld(s) 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. |
| 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 | SAM spool piece and stubs/flanges | ID of spool piece $out\text{-of round of spool piece} \pm 3 \text{ mm}$ $flanges:$ $positions of centers - dz = \pm 5 \text{ mm, } d\phi^* = \pm 2 \text{ mm}$ $orientation - d\phi, d\theta = 1^\circ$ $flanges should be less than 300 mm from nominal center of spool piece$ | The spool piece should be manufactured before the tubes (tubes are part of the detector SRD) * along azimuthal direction |
| 6 | Bellows | See bellows specification PMAG0000-0100-S0016 MOLLER Specifications of Bellows | |
| 7 | Gaskets of flanges | Metal seals at bellows 1, 2 and 7, peroxide-cured EPDM 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_g 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)