Addendum to
Memorandum of Understanding
between
Paul Scherrer Institute
and the
MUon Scattering Experiment (MUSE)

17 May 2017

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1. Introduction

This is an addendum to the memorandum of understanding (MOU) between the Paul Scherrer Institute (PSI) and the Muon Scattering Experiment (MUSE) Collaboration (hereinafter referred to as "Collaboration") to clarify and define their respective responsibilities towards performance of MUSE at the PSI PiM1 channel.

The changes are primarily related to new responsibilities for the cryogenic target and to the clarifications requested by the US National Science Foundation (NSF).

This addendum includes in full all sections of the MOU that are being modified, with added or modified text highlighted, with the exception that this introduction does not include and is not intended to replace the MOU introduction. Unmodified sections have been omitted from this addendum.

2. Personnel and Institutions

2.1. Collaboration Leadership

The organization of the Collaboration is described in the MUSE Collaboration Charter. The primary management responsibilities for the Collaboration are assigned to the Spokespersons and Project Manager, and for PSI to the PSI Liaison and Safety Manager. The Spokespersons are in charge of safety for the Collaboration. The persons currently holding these positions are listed in Table 1. The Spokespersons are in overall charge of the experiment, while the Project Manager is responsible for overseeing the construction project. The PSI Liaison is the primary contact at the laboratory, while the PSI Safety Manager is the primary contact for ensuring safety.

Table 1. Management positions and the persons currently holding those positions in the MUSE Collaboration.

Position	Person	Affiliation
Spokespersons	Evangeline Downie Guy Ron Steffen Strauch	The George Washington University Hebrew University of Jerusalem University of South Carolina
Project Manager	Ronald Gilman	Rutgers University
PSI Safety Manager	Konrad Deiters	PSI
PSI Liaison	Konrad Deiters	PSI

2.2. Updated Collaboration

In Table 2 we present the subset of the MUSE Collaboration membership that is involved in the construction project, organized by institution, along with their planned research time that will be spent on MUSE. We assume 40 hour work weeks, with faculty having 20 hours per week research time. Additional individuals will participate in running the experiment.

Table 2. Summary of personnel commitments to MUSE ordered by institution.

			Hours/week vs Year			
Institution	Individual	Position	2016	2017	2018	2019
Argonne						
	Paul Reimer	Faculty	6	12	12	12
	John Arrington	Faculty	2	4	6	6
	TBD	Post Doc	4	8	16	8
	Kevin Bailey	Technician	2	6		
	Tom O'Connor	Technician	6	10	6	
GW						
	Andrei Afanasev	Faculty	4	4	4	4
	William Briscoe	Faculty	8	12	12	12
	Evangeline Downie	Faculty	16	16	16	16
	Cristina Collicott	Post Doc	30	4	4	12
	Alexander Golossanov	Post Doc		40	40	40
	Ievgen Lavrukhin	Grad Student	40	40	40	40
Hampton						

	Michael Kohl (MK is 75% Hampton, 25% JLab.)	Faculty	4	6	8	10
	Anusha Liyanage	Post Doc	32	32	32	32
	(TBD)	Grad Student	40	40	40	40
Hebrew						
	Guy Ron	Faculty	10	10	10	10
	Dan Cohen	Grad Student	40	40	40	40
	Eran Gilad	Technician	20	20	20	20
U-M						
	Wolfgang Lorenzon	Faculty	10	10	10	10
	Richard Raymond	Faculty	20	20	20	10
	Priyashree Roy	Post Doc	40	40	40	40
	Noah Steinberg	Grad Student	40	40	40	40
Montgomery College						
	Arya Akmal	Faculty	5	12	12	12
	Nawal Benmouna	Faculty	2	4	6	6
	Ismael Coulibaly	Undergrad student		5	5	
	Ezhro Moaddab	Undergrad student		5	5	
Rutgers						
	Ron Gilman	Faculty	18	18	18	18
	Ron Ransome	Faculty	3	3	3	3

	Tigran Rostomyan	Post Doc	40	40	40	40
	Ethan Cline	Grad Student	40	40	40	40
	Wan Lin	Grad Student	5	5	20	20
	Ariella Atencion	Undergraduate	5	5	5	5
South Carolina						
	Ralf Gothe	Faculty	5	5	5	5
	Yordanka Ilieva	Faculty	2	2	5	5
	Steffen Strauch	Faculty	16	16	16	16
	new Post Doc	Post Doc	20	20	20	20
	Li Lin	Grad Student	40	40	40	40
	new Grad student	Grad Student			40	40
	Collin Gleason	Grad Student	4	4	4	
	Arjun Trivedi	Grad Student	4			
	Hao Jiang	Grad Student	4			
	Undergraduates (total for 8 students)	Undergraduate				
Tel Aviv						
	Eli Piasetzky	Faculty	5	6	6	6
	Jechiel Lichtenstadt	Faculty	2	3	3	3
	Erez Cohen	Grad Student	40	40	40	40
	Nikolay Pilip	Technician	20	20		
	Yair Shamai	Physicist	16	16		
Temple						

	Nikos Sparveris	Faculty	4	6	6	6
	Adam Blomberg	Grad Student	10			
	Hamza Atac	Grad Student	10	4		
	Huta Banjade	Grad Student		15	0	0
	Patrick Moran	Undergraduate	20			
	Postdoc				20	20

4. Collaboration Responsibilities

The general responsibilities of the Collaboration as well as the specific responsibilities of the individual institutions in terms of constructing and commissioning the spectrometer, data collection, analysis and decommissioning are outlined below. When providing experimental equipment, these responsibilities include appropriate support structures and alignment fixtures, unless otherwise specified. For the major tasks, these responsibilities are summarized in Table 3.

The schedule presented in Section 6 requires the Collaboration to be present at PSI for several test runs, equipment installation and commissioning, and extended periods of production data taking. The Collaboration typically will have 6 - 10 appropriate people present during these periods to carry out the research program, including at least one senior person to oversee activities and expert coverage for the technologies being tested, installed, and / or commissioned. Collaborators at PSI will follow PSI policies for visiting researchers.

4.1. General Responsibilities of All Institutions

4.1.1. All institutions will support the normal research operating expenses (such as physicists' salaries, project managers' salaries, travel expenses, miscellaneous supplies and administrative support) of their respective groups working on this experiment.

4.2. Argonne National Laboratory

4.2.1. Argonne National Laboratory's role in the experiment includes experiment mechanical design and integration, including coordination of the mechanical design to ensure detector compatibility both for installation and survey purposes.

4.2.2. Argonne will oversee the construction of the detector table and support frames.

4.2.3. Argonne will participate in the data collection and analysis.

4.3. University of Basel

2.2.1. Basel will participate in the design, procurement, setup, commissioning and operation of the experiment electronics and DAQ, including detector specific as well as general contributions.

2.2.2. Basel will participate in the data collection and analysis.

4.4. The George Washington University (GW)

4.4.1. GW has primary responsibility for the design, procurement, setup, commissioning and operation of the readout electronics. GW is in overall charge of the data acquisition system, but not responsible for detector specific software. This responsibility includes the provision of an order of 100 TB file server for archiving data and computers for DAQ and monitoring. Basel University, Montgomery College, and Rutgers University will participate in these activities.

4.4.2. GW is responsible for the overall integration of the physical components of the project. This includes, but is not limited to the match up of the different detection systems, including support frames and mounting relative to the detector table and target system. It also includes cable routing and support, and positioning of the read-out electronics. In general this includes most hardware associated with the project.

4.4.3. GW will participate in the data collection and analysis.

4.5. Hampton University

4.5.1. Hampton is responsible for the fabrication, installation, commissioning, operation and maintenance of the beam line GEM telescope. This responsibility includes the GEM data acquisition system including fronted readout electronics and software.

4.5.2. The GEM chambers are expected to use a chamber gas mix of Ar:CO_2 (70:30). PSI is responsible for the gas, gas supply system and controls, and safety issues.

4.5.3. Hampton is responsible for the development and maintenance of the GEM analysis code.

4.5.4. Hampton will participate in the data collection and analysis.

4.5.5. Hampton is responsible for the decommissioning of the GEM telescope, as outlined in Sec. 7.2.

4.6. Hebrew University of Jerusalem (HUJI)

4.6.1. HUJI has primary responsibility for the design, fabrication, installation, commissioning, operation and maintenance of the Straw Tube Tracker (STT) chambers. Temple University will participate in these activities.

4.6.2. The STT chambers are expected to use a chamber gas mix of Ar:CO_2 (90:10). HUJI is responsible for fabrication of a gas supply system and controls, consistent with PSI safety regulations. PSI is responsible for supplying the gas.

4.6.3. HUJI is responsible for the development and maintenance of the STT analysis code.

4.6.4. HUJI will participate in the data collection and analysis.

4.6.5. HUJI will participate in the decommissioning of the STT chambers as outlined in Sec. 7.2.

4.7. University of Michigan (U-M)

4.7.1. U-M is responsible for overseeing the design, fabrication, installation, commissioning, and operations and maintenance of the cryotarget.

4.7.2. U-M will produce the safety documentation and operating procedures required for safe operation of the cryogenic target.

4.7.3. U-M will test functionality of the cryogenic target at a PSI staging area using neon gas prior to testing the target with hydrogen.

4.7.4. Prior to obtaining final safety approval from PSI, testing or operation of the cryogenic target at PSI with hydrogen must be performed under the supervision of a target expert designated by PSI.

4.7.5. U-M will participate in the data collection and analysis.

4.7.6. U-M is responsible for the decommissioning of the cryotarget as outlined in Sec. 7.2, with the exception of the storage and disposal of any activated elements of the target system.

4.8. Montgomery College

4.8.1. Montgomery will participate in the procurement, setup, commissioning and operation of the readout electronics, and in the development of the data acquisition system hardware and software.

4.8.2. Montgomery will participate in the data collection and analysis.

4.8.3. Montgomery will participate in the decommissioning of the readout electronics, as outlined in Sec. 7.2.

4.9. Rutgers University

4.9.1. Rutgers will participate in the development of the trigger system, the beam line SiPM scintillator system, and the PSI on-site installation and setup of the experimental systems.

4.9.2. Rutgers will participate in the development and implementation of the DAQ system, and in the Monte Carlo simulation.

4.9.3. Rutgers is in charge of the beam Cerenkov system used for test measurements.

4.9.4. Rutgers will participate in the data collection and analysis.

4.9.5. Rutgers is responsible for the decommissioning of the beam Cerenkov, as outlined in Sec. 7.2.

4.10. University of South Carolina

4.10.1. South Carolina has primary responsibility for the design, fabrication, installation, commissioning, operation and maintenance of the fast scintillators, including the scattered particle scintillators, the veto scintillator, and the beam line monitor.

4.10.2. South Carolina is responsible for the development and maintenance of the analysis code for the scintillators.

4.10.3. South Carolina has primary responsibility for the development of the Geant4 Monte Carlo simulation of the experiment.

4.10.4. South Carolina will participate in the data collection and analysis.

4.10.5. South Carolina is responsible for the decommissioning of the fast scintillators, as outlined in Sec. 7.2.

4.11. Tel Aviv University

4.11.1. Tel Aviv has primary responsibility for the design, fabrication, installation, commissioning, operation and maintenance of the beam line SiPM scintillator system. Rutgers University will participate in this effort.

4.11.2. Tel Aviv is responsible for the development and maintenance of the analysis code for the beam line scintillators.

4.11.3. Tel Aviv will participate in the data collection and analysis.

4.11.4. Tel Aviv is responsible for the decommissioning of the beam line scintillators, as outlined in Sec. 7.2.

4.12. Temple University

4.12.1. Temple, working with HUJI, will participate in the design, fabrication, installation, commissioning, operation and maintenance of the STT system.

4.12.2. Temple will participate in the data collection and analysis.

4.12.3. Temple will participate in the decommissioning of the STT system, as outlined in Sec. 7.2.

Table 3. Summary, for each significant task in the MUSE project where the Collaboration has the lead, of the institution(s) with primary and secondary roles.

Task	Primary Institute	Secondary Institutes
Design		
Design	Argonne	
Beam line scintillators		
Hardware & software	Tel Aviv	Rutgers
GEMs		
Hardware & software	Hampton	
Cryotarget		
Hardware & software	U-M	PSI
STT		
Hardware & software	HUJI	Temple
Scintillators		
Hardware & software	South Carolina	
Electronics		
Hardware & software	GW	Montgomery, Basel
DAQ		
Software	GW	All hardware builders
Trigger	Rutgers	

Monte Carlo Simulation		
Software	South Carolina	Rutgers
Integration		
Hardware & Software	GW	All hardware builders

These tasks require the Collaboration to have sufficient personnel to construct hardware and software systems, and to run the experiments. Table 2 presented the personnel time commitments of the Collaboration to the experiment.

5. PSI Responsibilities

To successfully complete the proposed measurement, PSI is directly responsible for the tasks and equipment described in this section.

5.1. Beam

5.1.1. Provide primary proton beam as outlined in Sec. 4.2

5.1.2. Provide piM1 channel with appropriate instrumentation, cabling and electronics. This includes magnets and magnet controls, including Hall probes.

5.1.3. Provide appropriate radiation shielding, radiation safety interlocks and handle all aspects of radiation safety monitoring for the beam intensity delivered.

5.2. PiM1 Area

5.2.1. Prepare PiM1 area to house MUSE.

5.2.2. Provide, install and maintain utilities for experiment, including electrical power for equipment and low voltage and high voltage power supplies and gas for wire chambers.

5.2.3. Provide AC for temperature stabilization of equipment.

5.2.4. Provide slow controls readouts for experimental equipment, including voltages and temperatures. The integration into the DAQ will be provided by the Collaboration.

5.2.5. Provide some support for the cryogenic targets. This includes:

- Review of designs, especially with respect to satisfying safety requirements; share the responsibilities for the safety review with the collaboration.

- Assembly and testing of cryogenic target on site,
- Assistance with needed cryogenic target repair and maintenance.

5.2.6. Provide a FPGA based PLC target slow control system. This includes both hardware and software components. Design of the slow control system will be performed in collaboration with the MUSE cryotarget group.

5.2.7. Integrate the target slow control system into the MUSE LabVIEW slow control system.

5.2.8. Provide high purity (99.9%) hydrogen gas for use in cryogenic targets.

5.2.9. Provide a hydrogen exhaust system for safe disposal of hydrogen gas leaving the target vessel. This will be achieved either by the use of a balloon storage system, or by the direct release of the hydrogen gas into an exhaust from the PiM1 area. Systems of both types have been used at PSI.

5.2.10. Provide installation support for experimental equipment, including rigging for installation of spectrometer elements and for removal of spectrometer elements at the conclusion of the experiment.

5.2.11. Provide facilities for the Collaboration to use for SiPM-readout hodoscope fabrication.

5.2.12. Provide counting house and electronics areas with appropriate utilities installed, including computer networking, computers to control beam line equipment, and existing DAQ computers. (Additional monitoring and DAQ computers are the responsibility of the Collaboration.)

5.2.13. Provide 3 electronic equipment racks and 3 VME crates.

5.2.14. Provide equipment staging areas as needed for assembly of the spectrometer and for the removal of the spectrometer at the conclusion of the experiment.

5.2.15. PSI is responsible for supplying gas for the chambers and safety issues. For the GEM chambers PSI is responsible for the gas supply system and controls.

5.2.16. Provide office space and furniture for approximately six persons for the duration of the experiment and analysis during the beam time.

5.2.17. Provide an alignment survey of the spectrometer once installed. The experimenters will supply alignment marks on the detector elements in consultation with PSI.

5.3. Computing

5.3.1. Provide appropriate networking at PiM1 hall and counting house, including connections for collaboration laptops, a collaboration data storage archive, and transfers of data offsite to home institutions. Provide appropriate firewalls/bridges and other network security consistent with PSI policies.

5.3.2. Provide PSI accounts for collaborators. Primary analysis and Monte Carlo computing will be done on PC's provided by the Collaboration.

5.3.3. Provide about 16 TB of non-archival disk space for use of the Collaboration is data taking and analysis, until 6 months after data taking is complete.

5.3.4. Provide NIM crates and electronics from the supplies already in PiM1, and repairs as needed. Provide access to the oscilloscopes and other tools already in PiM1.

5.4. Environment, Safety and Health

5.4.1. PSI will provide radioactive sources from existing stocks, as appropriate.

5.4.2. PSI will conduct needed safety reviews, and provide appropriate training and personal dosimetry.

5.4.3. PSI will conduct two cryotarget safety reviews with scope and deadlines described in the MUSE Hydrogen Target Safety and Operating Procedures Report:

- The first safety review will be conducted after completion of the engineering design,
- The second safety review will be conducted after installation of the cryogenic target in the PiM1 hall and its integration into MUSE.

5.4.4. PSI must approve the MUSE Hydrogen Target Safety and Operating Procedures Report, which will include details of testing, before MUSE can operate the cryogenic target in the PiM1 area.

5.4.5. PSI will designate a target expert to oversee testing or operation of the cryogenic target at PSI with hydrogen prior to final safety approval from PSI.

6. Schedule

The Collaboration has an ongoing series of short test runs to prototype equipment, verify performance, and measure beam line parameters. The first significant long-term installation of MUSE will begin mid-2017, in preparation for a ``dress rehearsal'' run in November / December 2017. Production data taking is planned for two six-month periods in 2018 and 2019. This schedule is subject to the final budget and funding timeline, in addition to the awarding of beam time by PSI and the availability of the PiM1 area. It is understood that the PiM1 area might be rebuilt for another use after 2020.

8. Signatures

This memorandum shall enter into force after date of last signature. This memorandum was prepared in 8 (8) copies, one for each party.

Evangeline T. Downie — May 18th 2018
E. Downie – MUSE Spokesperson — Date

May 19, 2017
G. Ron – MUSE Co-spokesperson — Date

Steffen Strauch — May 18, 2017
S. Strauch – MUSE Co-spokesperson — Date

May 18, 2017
R. Gilman – MUSE Project Manager — Date

Paul E Reimer — 18 May 2017
P. Reimer– MUSE Asst. Project Manager — Date

17.5.17
C. Rüegg – Head of Division Neutrons and Muons, PSI — Date

17.5.17
K. Kirch – Head, Laboratory of Particle Physics, PSI — Date

17.5.17
K. Deiters – PSI Liaison, PiM1 safety warden — Date

Appendix A. Preliminary MUSE Hazard Analysis Checklist

Table 4. Preliminary MUSE hazard analysis checklist.

Category	Hazard	Notes
Cryogenics	Liquid H_2 target	About 300 ml LH_2.
Electrical Equipment	High voltage	Chambers and PMTs, shielded in normal operation.
Hazardous/ Toxic Materials	lead	Lead bricks are present near the beam line intermediate focus, in an area not accessible to the Collaboration.
Pressure Vessels	chamber gas bottles	Standard commercial gases, bottles chained to gas rack.
Flammable Gases	H_2	LH_2 target or gas supply.
Radioactive Sources	^{90}Sr	PSI source for temporary use in detector tests, continuously supervised, locked in source box when not in use.
Vacuum Vessels	Beam line vacuum system	Thin windows.
	Target vacuum chamber	Thin windows.
Target Materials	kapton, graphite, H_2	Non-hazardous.
Lasers	Alignment lasers	Low power, no special eye protection required.
Hazardous Chemicals		None.
Mechanical Structures	Lifting devices	Only operated by trained PSI personnel.

Category	Hazard	Notes
	Motion controllers	Channel jaws and collimators and cryotarget are remotely moved. No moving parts are in normally accessible places during operations, so lock-out/tag-out procedures are not needed.
	Tables and frames	Detector components are generally accessible from the floor, so elevated platforms and fall protection training are not needed.
Oxygen Deficiency Hazard	LH_2 conversion to gas, bottle venting	Due to the size of piM1 and it being an open area, the cryotarget and venting of chamber gases do not present an ODH hazard.
Radiation	Exposure to ionizing radiation	Collaboration is required to have training, wear dosimetry in PiM1, and follow PSI ALARA practices.