

MUSE PROJECT MANAGEMENT

1. Description of the research objectives motivating the facility proposal
2. Comprehensive statement of the science requirements to be fulfilled by the proposed facility (to the extent possible identifying minimum essential as well as desirable quantitative requirements), which provide a basis for determining the scope of the associated infrastructure requirements;
3. Description of the Educational Outreach and Broader Societal Impacts associated with the purpose of the facility, including the scope of work, budget and schedule.
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1. Description of the research objectives motivating the facility proposal

The objective of this proposal is to measure cross sections for elastic scattering from the proton of electrons and negative muons, and positrons and positive muons, using the same apparatus. The cross sections will be used to compare electron to muon scattering, positive polarity to negative polarity scattering, and to extract the proton radius. The goal is for generally sub-percent level uncertainties, allowing the proton radius to be extracted with a combined systematic and statistical uncertainty of about 0.012 fm for both the muon and electron.

The proton charge radius can be determined by scattering charged leptons from protons, or by measuring the Lamb shift in hydrogen or muonic hydrogen. The radius determined from the scattering of electrons and Lamb shift in hydrogen are in good agreement, with values of 0.8791 ± 0.0079 fm and 0.8758 ± 0.0077 fm, respectively. The most precise measurement from muonic hydrogen of 0.84087 ± 0.00039 fm disagrees with the electron based measurements by about $7\alpha\mu\gamma\iota\sigma$. No accepted explanation has yet been found. This discrepancy, along with the muon g-2 discrepancy and the cosmic positron excess, gives hints of new physics. No measurement of the radius using muon scattering exists.

2. Comprehensive statement of the science requirements to be fulfilled by the proposed facility (to the extent possible identifying minimum essential as well as desirable quantitative requirements), which provide a basis for determining the scope of the associated infrastructure requirements;

In order to resolve the discrepancy, the facility must be able to measure the scattering of muons and electrons at the sub-percent level. In order to study possible two-photon exchange effects, measurements using scattering of both positive and negative muons, as well as positrons must be done. The critical elements are: hydrogen target, particle identification, good scattering angle determination, high tracking efficiency, and a data acquisition rate of about 2 kHz with dead-time of 15% or less.

These elements led to the following design elements:

- (1) A liquid hydrogen target to ensure adequate rate and low background (rather than CH₂ which requires a large background subtraction).
- (2) Particle ID: The beam is a mixture of electrons, muons, and pions. Particle ID can be achieved by a combination of timing relative to the accelerator RF and time of flight measurements. Cerenkov and scintillating fiber detectors provide the needed timing. The good time resolution of the Cerenkov detectors allows suppression of events from muons in the beam decaying into electrons (and undetected neutrinos). Scintillation detectors for the scattered particles are needed to cleanly identify scattered particles and trigger the data acquisition.
- (3) Scattering angle: The divergence of the beam is sufficiently large that tracking of the incident beam particles is needed to adequately determine the scattering angles. GEM detectors provide this measurement. The scintillating fiber tracking allows separation of multiple tracks by timing. The outgoing scattering angle is determined by a straw tube

chamber. The straw tubes have good resolution and the multiple layers provide high efficiency.

3. Description of the Educational Outreach and Broader Societal Impacts associated with the purpose of the facility, including the scope of work, budget and schedule.

The broader impact of this project is primarily in the training of students and young scientists, at the undergraduate, graduate, post-doctoral, and junior faculty levels. The institutions involved in this project have trained large numbers of students of each type, including from minority populations. The training they have received in the process of doing basic research has led to careers in a variety of areas, from medical physics to national security, in addition to continuing to work in fundamental physics research. The MUSE experiment will broaden the perspective of American students by having them work in an international collaboration at an international laboratory, which will prepare them effectively to become prominent global scientists of the next generation. With the broad interest in the proton radius puzzle, MUSE has the potential to be broadly inspirational beyond the current scientific community.

4. Description of the infrastructure necessary to obtain the research and education objectives

The infrastructure consists of the π M1 beam-line at PSI and the detector assembly described above. The PSI beam-line provides a mixed particle beam, with a momentum range of 100-500 MeV/c.

5. Work breakdown structure (WBS)

The MUSE project consists of several fairly self contained elements, which form the natural basis for the WBS. The WBS is shown in the table below. Each WBS, except for WBS 9 corresponds to a detector/subsystem needed for the detector. WBS 9 relates to the integration and testing of all elements at PSI.

WBS #	Title	Manager
1	Frames & Design	Gilman
2	Scintillating Fiber	Ron
3	Cerenkov	Gilman
4	Straw Chambers	Ron
5	Cryo-target	Briscoe
6	Electronics	Downie
7	Scintillators	Strauch
8	GEM	Kohl
9	Installation	Gilman

6. Work breakdown structure dictionary defining scope of WBS elements

See attached document.

7. Project budget, by WBS element

See attached document.

8. Description of the basis of estimate for budget components

Each WBS will have list of components and basis of estimate. A summary is attached.

9. Project risk analysis and description analysis methodology

We will base the risk analysis on techniques described in the PBMOK 3rd Edition.

10. Contingency budget and description of method for calculating contingency

We will be guided by the FNAL system as applied to MINERvA. See attached document. A significant part of the budget is related to purchase of components in Europe and travel to Europe, giving an uncertainty in currency exchange rate. For purposes of this project, we have assumed a first year exchange contingency of 10% and 15% for the subsequent years. Travel costs contingency is assumed at 10% for the first year, with an additional 5% per year to account for inflation. 10% contingency is also estimated for uncertainty on time needed for set-up and running the experiment.

11. Project schedule (and eventually a resource-loaded schedule)

See attached document.

12. Organizational structure

The overall guidance of the experiment is given by the spokespersons: R. Gilman (Rutgers), E. Downie (GWU), and G. Ron (Hebrew University). The construction project will be led by R. Ransome (Rutgers) and W. Briscoe (GWU). The WBS breakdown with WBS managers is given in the attached organizational chart.

13. Plans and commitments for interagency and international partnerships

The experiment will take place at the Paul Scherrer Institute, Villigen Switzerland. The laboratory's commitment will be the installation of the beam line and associated hardware/software, maintenance of the liquid hydrogen target, and providing the beam. A commitment letter is attached.

14. Acquisition plans, sub-awards and subcontracting strategy

Purchase of either off-the-shelf items or specialty components is detailed in the BOE documents associated with each WBS. There will be no subcontracting.

15. Project technical and financial status reporting, function of the PMCS, and description of financial and business controls

Financial reports will be submitted to the Project Manager. The technical status will be reported to and reviewed by the Spokespersons and Project Manager.

16. Project governance

The Project Manager and assistant Project Manager will govern the project, with full consultation of the spokespersons and WBS managers.

17. Configuration control plans

All changes in scope with cost variance greater than \$5000 or time to completion variance greater than 4 weeks must be submitted to Project Manager for review. Any change in scope with significant impact on the physics goals must be reviewed and approved by Project Manager and Spokespersons.

18. Contingency management

Contingency reserves will be determined through an analysis of the risks and contingency estimates of each WBS. The Project Manager will have the responsibility for allocation of reserves. Contingency of less than \$5000 will be at the discretion of each WBS manager. The Project Manager will consult with all WBS managers for any allocation request greater than \$25,000, but will have final say on all allocations.

19. Internal and institutional oversight plans, advisory committees, and plans for building and maintaining effective relationships with the broader research community that will eventually utilize the facility to conduct research

N/A.

20. Quality control and quality assurance plans

Each WBS will list quality control plan. See attached document for a summary of each WBS.

21. Environmental plans, permitting and assessment

N/A.

22. Safety and health issues

The project construction does not involve the use of exceptionally hazardous materials or work conditions. The construction will take place primarily at university laboratories. All university safety requirements will be met. The primary safety hazard is the cryogenic target.

23. Systems engineering requirements

These are described in items 24 and 25 below.

24. Systems integration, testing, acceptance, commissioning and operational readiness criteria

1. Detectors all connected to DAQ, read out, and decoded successfully, with

trigger functioning at level to read out detectors.

2. Various calibrations runs and performance confirmed, at least at low rates

- a) beam Cerenkov efficiency and timing
- b) SciFi efficiency and time resolution, and alignment wrt GEMs
- c) GEMs read out in ~ 0.15 ms time scale, tracking efficiently, 3 hit events show < 100 μ m resolution
- d) Veto efficiency confirmed (can offset and put it in beam)
- e) Beam Monitor efficiency and time resolution confirmed
- f) STT position, track finding, and efficiency calibrated by measurements with STT rotated to be in beam.
- g) Scintillator plane performance check - pulse heights and timing - by running beam through them.
- h) Trigger performance checked with combination of real data and random signals.
- i) DAQ readout rate ability can be checked with pseduodata (pulser signals) and monitoring readout on scope.

25. Plans for transitioning to operational status

Follows from 24.

26. Estimates of operational cost for the facility

Cost to this project will be travel funds. Cost of running the beam and detectors will be paid by PSI.