Office of Project Assessment
CD-2/3 Review Report on the

Muon g–2 Project

at Fermi National Accelerator Laboratory

June 2015

EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) review of the Muon g–2 project was conducted on June 25-26, 2015 at the Fermi National Accelerator Laboratory (FNAL). The review was conducted by the Office of Project Assessment (OPA), and chaired by Kurt Fisher, OPA, at the request of Michael Procario, Director, Facilities Division for High Energy Physics. The purpose of the review was to determine the project's readiness to proceed in requesting approval of Critical Decision (CD) 2/3, Approve Performance Baseline and Start of Construction. This review was a follow-up to a previous DOE/SC review conducted on July 29-31, 2014, that resulted in a number of recommendations requiring time to implement.

The Committee determined that the Muon g–2 project team made significant progress since the July 2014 DOE/SC review. At that review, the Committee noted that the most significant risk to the project is cool-down of the relocated storage ring and a strategic decision to baseline the project after cool-down. At the time of this review, the ring had been cooled down and was powered up to approximately 3000 A (of the 5200 A requirement).

Technical

The Committee noted that the detailed design of the accelerator systems is nearly complete for all subsystems. It was also determined that careful consideration of the booster timeline in the era of NuMI Off-Axis Neutrino Appearance Experiment (NOνA) operations has revealed that the proposed scheme of injecting four batches of four pulses in the g–2 ring is not possible. The project has responded by modifying the pulsed magnets providing flexibility to provide options for both g–2 and NOνA proton needs. The pulsed magnets and power supplies (including extraction kicker) remain a concern for the Committee. The design change to 8 pulses at 100 Hz makes the designs even more challenging than they were previously. It was also determined that the schedule for the completion of the magnet/PS is very late and close to the early finish date.

In the area of Storage Ring/Technical Integration, the Committee judged that the project team is addressing the most significant issue with powering-up the magnet. This is a major accomplishment and the project is very close to the goal of demonstrating successful operation of the magnet.

The Committee judged that a new, upgraded inflector may be a significant improvement as it could reduce the number of Protons on Target (POT) needed for Muon g–2. There is about $300K allocated to continue the study. Additional engineering design and planning of the new inflector is required to inform a decision to proceed based on a solid schedule and cost estimate.

The Committee identified that the Tracker design has been refined since the July 2014 review and that a mature design has resulted. It was noted that the cooling problem for the very front-end electronics, which, in order to be as close to the end of the straw tube wires has been placed inside the vacuum vessel, has been cleverly solved to minimize/eliminate the possibility of a water leak into vacuum. Also, the number of types of straw-tube modules has been reduced from three to one. This will simplify construction and maintenance during operations.

Cost and Schedule

The Committee identified that the proposed Total Project Cost (TPC) has remained constant at $46.4 million and the CD-4, Approve Project Completion date remained at third quarter FY 2019. As of May 2015, the project is 51% complete with $7.23 million of cost contingency (37% Baseline at Completion to go) and 24 months of schedule contingency (100% to go). There is a projected cost estimate uncertainty of $5.5 million on remaining work and a risk cost impact of $2.1 million at a 90% confidence level. A bottom-up Estimate to Complete and schedule review was performed in May 2015.

Management

The Committee commended the project team for the successful installation, cool-down, and initial testing of the storage ring magnet. Also noteworthy, is that FNAL is making good progress on the Muon Campus Program and has completed much of the work supporting the g–2 project. It was suggested that, to facilitate the efficient and timely on-budget completion of the experiment, FNAL management should continue its careful oversight and prioritization of the labor pool. Competing demands with other ongoing projects underscore this need.

The Committee recommended that the project team, in conjunction with FNAL, should develop a path forward for an improved inflector in the context of the overall proton economics plan for the Laboratory. They should consider integrating complimentary expertise external to the project in the formulation of this plan. In order to focus on delivering the baselined experiment, serious consideration should be given to pursuing the inflector as a future upgrade.

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1. INTRODUCTION

One of the more persistent hints of new physics has been the deviation between the measured muon anomalous magnetic moment, (g−2)/2, and its Standard Model expectation, where both are currently determined to a precision of 0.5 parts per million. This fundamental measurement has been pursued for decades with increasing precision. The discrepancy of several standard deviations that, if true, could be caused by the quantum effects of virtual particles too massive to be produced and detected directly has been interpreted to point toward several attractive candidates for Standard Model extensions such as supersymmetry, extra dimensions, or a dark matter candidate. Because a precision measurement of g–2 is sensitive to virtual particles, it offers a strategic opportunity to probe areas of TeV-scale physics beyond the reach of the Large Hadron Collider (LHC). Should the LHC discover new physics that would confirm the g–2 discrepancy, then precise determination of g–2 is expected to provide direct measurements of the coupling constants of the new particles responsible for the discrepancy, fundamental parameters of the underlying theory, and a window on the underlying symmetries of the new physics. For many possible cases, it is expected that these parameters will not be measured with adequate precision at the LHC alone.

The experimental technique involves measuring the precession frequency of the muon spin vector in a well-understood magnetic field; in this case the spin vector will be reconstructed from the angular distribution of muon-decay electrons in a storage ring and the precession of the spin vector in the storage ring's magnetic field will be tracked over time. The prior g–2 experiment at Brookhaven National Laboratory (BNL Experiment E821) ended with a successful, statistics-limited measurement of g–2 and is one of the most heavily cited High Energy Physics (HEP) experiments, with more than 2,000 citations.

The Muon g-2 project at Fermi National Accelerator Laboratory (FNAL) will fabricate a new experiment that seeks to improve the measurement of the muon anomalous magnet moment. The project will repurpose the storage ring from the prior BNL experiment and provide upgraded injection and detectors in order to utilize the high intensity proton beam at FNAL to produce the needed secondary beam of muons. CD-1 was approved on December 19, 2013, with a Total Project Cost range of $43.0 to $50.1 million. Transfer of the BNL storage ring to FNAL occurred in FY 2013. New instrumentation for the storage ring will be provided, in part, by in-kind contributions from non-DOE sources including the National Science Foundation (NSF). By virtue of having run the original apparatus for five years, the required technology and physics principles have been tested and demonstrated. Additionally, much of the expertise involved with the initial construction of the experiment is still available and remains involved, along with a number of new collaborators for the new Muon g–2 experiment at FNAL (FNAL Experiment E-989).

The Particle Physics Project Prioritization Panel (P5) subpanel of the High Energy Physics Advisory Panel recommended completing the Muon g–2 experiment as an immediate target of opportunity for searching new physics and identifying future directions for the field.

This review was conducted to assess readiness for Critical Decision (CD) 2, Approve Performance Baseline; and CD-3, Approve Start of Construction, now that the Muon g–2 project at FNAL is conducting critical operational testing of the repurposed superconducting ring magnet, reinstalled at FNAL with its new cryogenics and DC power systems.

2. TECHNICAL SYSTEMS EVALUATIONS

2.1 Accelerator

The Committee was pleased to see the progress that the g–2 project made since the initial July 2014 DOE/SC CD-2/3 review. In particular, the project received $2.8 million of early accelerator implementation Major Item of Equipment (MIE) funds in January allowing critical construction work to proceed. The project followed through on previous Committee recommendations.

2.1.1 Findings

The detailed design of the Accelerator Systems (WBS 476.2) is nearly complete for all subsystems. Most components are already being procured. Some design work of conventional accelerator components such as vacuum system and magnet stands will be completed by the end of FY 2015.

Interface milestones of various Accelerator Improvement Projects (AIP) and General Plant Projects (GPP) projects related to the Muon Campus are being implemented on schedule and create basis for the successful completion of the Accelerator Systems.

Careful consideration of the booster timeline in the era of NuMI Off-Axis Neutrino Appearance Experiment (NOνA) operations has revealed that the proposed scheme of injecting four batches of four pulses in the g–2 ring is not possible. The project has responded by modifying the pulsed magnets so that they can support 100Hz batch mode of up to 8 pulses, providing flexibility to provide options for both g–2 and NOνA proton needs.

Target and Beamlines

Following the July 2014 recommendations, the project team organized the technical and beam physics review of the beamline and injection into the storage ring. Two simulation codes have been developed to track muons from the injection beamline up to the first 20 revolutions in the storage ring. Optimal beam parameters, at the interface point of the beamline, were defined to provide highest efficiency of the muon beam injection into the storage erring. The beamline optics and beam instrumentation were designed to provide good accuracy of the beam centering and Twiss parameters at the injection plane to match the acceptance of the storage ring. There is sufficient flexibility in beam optics setting to cover possible parameter space including the beam injection into the storage ring with future new inflector.

There is technical risk in timely commissioning of the pulsed magnets and kicker once the repetition rate is 30 times higher than it was for antiproton operation. In February 2015, there was an internal technical review, which developed a series of practical steps toward procurement and fabrication of the kicker power supply.

Controls and Instrumentation

Secondary emission monitors (SEM) were successfully tested with the beam down to intensities of approximately $5x10^7$ per bunch.

Proportional Wire Chambers (PWC) and ion chambers are retractable using recycled bayonet cans. PWC was tested with the beam containing approximately 5,000 particles/bunch.

Beam loss monitors were successfully tested.

2.1.2 Comments

The project received $2.8 million of early accelerator implementation MIE funds in January allowing critical construction work to proceed. This has contributed to mitigating risk, and keeping critical systems making progress.

In all cases, the Committee was presented with the interfaces between the g–2 project and the muon campus Accelerator Improvement Project/General Plant Project (AIP/GPP). These AIP and GPP projects appear to be well managed by the Muon Campus Project Coordinator.

In addressing the loss of the ability to deliver four batches of four bunches (noted in 2.1.1 Findings), the Committee judged that the project provided the flexibility needed to address programmatic priority balancing.

The design of the accelerator systems is nearly complete. The Accelerator Systems (WBS 476.2) are entirely ready for CD-2/3.

The Committee was pleased to see technical design reviews being done. However, in some cases documentation for these does not exist. The Committee encouraged the project to formally capture design review results.

The current basis of estimate for the Accelerator appears to be appropriate for CD-2/3. As of this review, the Committee did not see any high-risk items or activities threatening the costs in the Accelerator areas. Managing the costs over the next year or so, where matrixed levels of effort/support and M&S are planned, will be important. Currently the majority of the systems are under budget.

An area of minor concern is the procurement cycle time.

Schedule dates have slipped since the July 2014 review. This was accommodated by the project as part of a baseline change request (BCR004), which was due to the previous delay in CD-2/3. The Committee judged that the schedule for the early finish date was challenging, particularly the pulsed magnet power supplies. However, the early finish date is followed by two years of schedule contingency prior to CD-4, which is achievable.

In the review presentations it would have been clearer to see both working schedule and official DOE schedule dates and scheduled contingency.

Forecast effort levels for the combined accelerator activities, from FY 2015 to FY 2017 appear to be marginal based on the work planned, and should be closely monitored.

Target and Beamlines

The project team should be commended for the timely response to the Committee's recommendation on beamline technical and beam physics review. The primary goal of this review was clarification of the beam parameters in the transition from the beamline to the storage ring.

The beamline interface control document is now in place; it is a good start, the Committee would like to see more detail, namely beam position and angle could be captured along with tuning ranges and error bars. (The Committee believed this information exists.)

There is a concern about the delivery and testing of the power supply for the extraction kicker in the Delivery Ring. After the recent modification of the schedule, the delivery of the kicker power supply was extended by a year. This results to only two months schedule contingency relative to March 2017 project completion date. There is a potential that the kicker power supply may end up on critical path. The Committee had a similar concern for the pulsed magnet systems in the target area.

The Committee was pleased to see that an additional pulsed power engineer is being hired to work on the pulsed magnet power supplies.

Controls and Instrumentation

Per the Committee's comments at July 2014 review, the project team conservatively decided to use more sensitive PWCs instead of 8 SEMs in two most downstream M3-line locations and in the Delivery Ring.

The electron beam welding of the Ti window to "anti-vacuum" aluminum chamber may not be trivial due to the difference in material properties. Earlier testing is recommended.

2.1.3 Recommendations

1. Regularly evaluate and take advantage of any opportunity to move up the completion of the pulsed magnet power supplies, including the extraction kicker, and test them in 100 Hz burst mode. Report on progress at independent project reviews.

2. Proceed to CD-2/3.

2.2 Storage Ring and Technical Integration

2.2.1 Findings

The Storage Ring System (WBS 3) is 53% complete, with an Estimate to Complete (ETC) of $5,746K for the work remaining. An uncertainty of 35% (about $2 million) is attached to the ETC. Installation of the magnet is nearly complete. The Magnet (WBS 3.2) is 95% complete.

Detailed procedures for cool-down and powering were developed, as recommended during the July 2014 DOE/SC review, and a dedicated magnet operations review conducted in March 2015. Powering-up of the magnet has begun. At the time of this review, more than half of the value necessary for 3.1 GeV muon energy (5200 A) was reached.

Rough shimming of the magnet is planned to be a nine-month activity, which needs to be completed before installation of the vacuum system. The whole task has been broken down into 15 steps with value assigned to each but no time frame. This is an on-project activity.

A significant amount of tracking simulations and studies have been done in order to assess the injection efficiency and optimize various parameters. This work has influenced actions like the construction of new, stronger kickers.

An interface document defining the beam parameters at the treaty point between injection line and the ring has been written. Beam parameters are given for an inflector gradient from 0 to a value determined from a detailed field map to cover the uncertainty in the effective gradient and a possible new inflector with lower gradient.

The Q1 quadrupole is being enlarged to avoid the incoming muon beam passing through the electrode material. Work on a new, improved inflector is ongoing although a decision point regarding actual implementation has not been reached, and it is presently not part of the proposed project baseline.

Transition to operation was not discussed at this review. Preparations for an Accelerator Readiness Review (ARR) were outlined at a high level and the necessary ingredients identified. The ARR itself will be off-project.

2.2.2 Comments

The Committee considered the responses to the July 2014 review, by the project team, to be adequate. An external review on the injection system was held; tracking studies have been accomplished to significant detail, and a magnet cool-down and power-up plan was being executed at the time of the review.

The design is sufficiently mature to proceed. Magnet power-up is proceeding and, so far, has not encountered significant problems.

The Committee did not see any outstanding issues that would preempt CD-2/3 approval. With the powering-up of the magnet, the project team is addressing the most significant issue preventing CD-2/3 approval in the previous CD-2/3 review. This is a major accomplishment and brings the project very close to the goal of demonstrating successful operation of the magnet.

Due to the complexities of operating the superconducting magnet in relation to cryogenics, high current supply and quench protection, magnet powering is being performed in steps. Results at each step should be carefully analyzed, and the sub-systems optimized based on the results.

Additional testing should follow to further characterize the system performance, in accordance with the recommendations from the magnet operations review, and to demonstrate operation at full current over an extended period of time.

The rough shimming of the magnet presents a schedule risk as it has to be substantially complete before installation of the vacuum chamber. The Committee suggested allocating time spans for the identified subtasks in the project schedule so earned value can be taken against them and schedule slippage be identified early.

The injection-ring Interface Control Documents (ICD) reduces the risk of a mismatch between these two systems. The Committee suggested adding steering requirements and tolerances to this document and keeping it up-to-date as the design evolves.

At this time, it appears that the tracking studies done to optimize various aspects of the injection system are not fully consistent with each other. The project team is encouraged to address this issue in order to ensure that the results obtained, like the improvement from enlarging the Q1 magnet and the possible improvement from the new inflector design, are in fact applicable to the present baseline design.

A new, upgraded inflector may be a significant improvement as it could reduce the number of Protons on Target needed for Muon g–2. About $300K were allocated in a recent Baseline Change Request (BCR) to continue the study of a new inflector. Conceptual design and materials R&D activities in this area were presented. Continued and focused engineering design of the new inflector is required to inform a decision to proceed based on a solid schedule and cost estimate. Even if this will be done as an upgrade, the sooner the new device can be installed the greater the benefit will be.

2.2.3 Recommendation

3. Proceed to CD-2/3, after successful magnet powering to full current.

2.3 Detectors

2.3.1 Findings and Comments

The Detector Team has responded satisfactorily to the two recommendations of the July 2014 DOE/SC review. The first dealt with the Tracker whose beam test was scheduled to occur in January. The recommendation was that, following completion of the analysis of the data acquired in that beam test, a review should be held at which the full suite of performance parameters would be presented to the review committee (which was to include external experts as members of the Committee).

The beam test was delayed due to a combination of the test beam schedule and Tracker readiness. At the time of this review, the beam test has been in progress for a few weeks. The pre-production prototype is being used in the test beam. Experience with the apparatus is being fed back into the design. It is expected that additional changes will be minor. The data appears

to be promising. The Tracker review has been scheduled for September, which should allow sufficient time for completion of a full analysis to extract quantities suggested in the July 2014 DOE/SC review report.

The second recommendation was that all lead difluoride ($PbF_{2)}$ crystals and Silicon Photomultiplier (SiPM) be fully characterized, rather than a subsample of each. The Calorimeter team, which has received half of the crystals at the time of this review, is characterizing all of them, and will characterize all of the SiPMs as they are delivered by the vendor during the next couple of months.

Comments in the detector section of the July 2014 report have been considered by the experimenters, taken to heart, and incorporated into design and implementation where deemed appropriate. The Committee commended this careful consideration of the July 2014 review report.

The detailed design of the detector is sufficiently mature that the project can continue, as planned, with the procurement and fabrication work. Sufficient review has occurred to this point.

The Tracker design has been refined since the July 2014 review. A mature design has resulted.

The cooling problem for the very front-end electronics, which, in order to be as close to the end of the straw tube wires has been placed inside the vacuum vessel, has been cleverly solved to minimize/eliminate the possibility of a water leak into vacuum.

Minor tweaks to dimensions have already been incorporated into the tracker design based on test beam experience.

The number of types of straw-tube modules has been reduced from three to one. This will simplify construction and maintenance during operations: there is only one set of tooling, and the number of spares is limited. The number of modules in each of the three tracker stations has been reduced from nine to eight in order to mechanically accommodate this design change. Overall, the performance of the tracker is improved, because the straws are closer to the beam, though there is a small cost in low momentum performance.

The downside of the reduction in the number of modules in each station has been that the vacuum chamber design required modification. These modifications are now undergoing finite element analysis. The cost of changes due to vacuum chamber modifications will be borne by the detector.

The gas mixture has been changed from Ar : CO_2 to Ar : Ethane. This leads to an improvement in resolution and provides more headroom in meeting the requirements. (The calorimeter had, at the time of the July 2014 review, already developed headroom with respect to the requirements.) A side benefit of the gas composition change is that leaks from the straws to vacuum are reduced due to the larger size of the ethane molecule.

The tracker has treated the current test beam as a system test, incorporating final versions of support systems wherever possible.

The Tracker beam test program has, as in the case of the Calorimeter program, proven to have had team building benefits.

The Committee commended the efforts of the Tracker team. The changes, which have been incorporated in the design since the July 2014 review, all go in the right direction.

More than half of the Calorimeter crystals have been received (funded by the NSF Major Research Instrumentation Grant). Completion of delivery is likely to be a month delayed relative to expectations.

Construction of the laser calibration system has been taken on by the Istituto Nazionale di Fisica Nucleare (INFN)-funded institutions.

The front-end electronics system has been simplified. The system includes wave form digitizers (WFD) developed for the calorimeter, as well as inherited electronics. The inherited electronics proved to be inappropriate. The detector team determined that the WFD could fill the additional front-end needs. Board counts were increased. The order for key components (field programmable gate arrays) was placed at a favorable price.

The Committee commended the progress in acquisition of calorimeter components and welcomes the in-kind contribution of the INFN-funded institutions, as well as the simplification in the front-end electronics system.

The Detector Level 2, 3, and 4 Managers are all successfully exercising the Earned Value Management System (EVMS) using tools developed by the project financial/schedule analysts. The reporting takes place on a monthly basis; the monthly report includes contributions from all non-DOE funded Level 3 and Level 4 managers.

Funding appears to be available with sufficient contingency to complete the project. Additional attention should be paid to the possibility that the MRI funds might be exhausted.

There is precious little schedule contingency (approximately 2.5 months) between completion of the detector and availability of beam. The detector team must be vigilant, recognize and respond quickly when schedule slippage occurs, and look for ways to advance the schedule.

The decision making process involved in the front-end electronics simplification should be considered with an eye toward lessons learned that might streamline the decision process in any similar situations that might arise in the future.

Any opportunities to advance the schedule of a full system test should be seized.

The likelihood of meeting the goals of the project is enhanced by the experiment's cohesiveness.

There are no outstanding issues that need to be addressed before CD-2/3.

2.3.2 Recommendation

4. Proceed to CD-2/3.

3. COST and SCHEDULE

3.1 Findings

PROJECT STATUS as of May 2015 Pre-CD 2 Baseline		
Project Type	MIE	
CD-1	Planned:	Actual: 12/19/2013
CD-2	Planned: 4QFY15	Actual: TBD
CD-3	Planned: 4QFY15	Actual: TBD
CD-4	Planned: 3QFY19	Actual: TBD
TPC Percent Complete	Planned: ~51%	Actual: ~51%
TPC Cost to Date	$19.80M	
TPC Committed to Date	$20.71M	
TPC	$46.4M	
TEC	$27.449M	
Contingency Cost (w/ Mgmt. Reserve)	$7.23M	37% to go
Contingency Schedule on CD-4	24 months	100% to go
CPI Cumulative	N/A	
SPI Cumulative	N/A	

The proposed Total Project Cost (TPC) has remained constant at $46.4 million and the CD-4 date has remained third quarter FY 2019. The project is 51% complete as of May 2015 with $7.23 million of cost contingency (37% Baseline at Completion to go) and 24 months of schedule contingency (100% to go). There is a projected cost estimate uncertainty of $5.5 million on remaining work and a risk cost impact of $2.1 million at a 90% confidence level. The proposed contingency level decreased $2.84 million since the July 2014 DOE/SC review mainly due to additional effort needed to prepare the ring for testing. The schedule is mostly unchanged, and the critical path remains through completing the accelerator work, but the detector and ring work are near the critical path and have little schedule contingency. Delays in the storage ring cold test and detector work have brought these activities closer to the critical path. A bottom-up Estimate to Complete (ETC) and schedule review was performed in May 2015. A practice Baseline Change Request (BCR #19) was processed to reflect the ETC and schedule review results.

The project has been employed an Earned Value Management System (EVMS) for 13 months and has processed 19 practice BCRs. An EVMS assessment was also conducted on the project in May 2015, and only minor issues were found. The project has been providing monthly reports to DOE since November 2014, and the reported monthly ETC will be calculated using manual input from control account managers (CAMs). Currently the Risk Management Board holds a general project meeting weekly, and risk management is on the agenda of this meeting as the Project Manager deems required. Also the project manager holds weekly group CAM meetings, but critical path and schedule analysis are not a topic during these meetings.

3.2 Comments

There were no prior Cost and Schedule recommendations from the July 2014 review, and the Committee was pleased to see that the project has tracked and appropriately addressed all prior cost and schedule comments. Cost and schedule contingency appear appropriate at this stage in the project, and the project appears to be embracing EVMS and using it as a management tool to help successfully complete the project. The project EVMS also appears to be functioning properly, and the project team and laboratory should be commended for their efforts in this area. Also the two comments made from the EVMS assessment conducted in May 2015 were properly addressed.

The Committee found that the project plans to have the CAMs forecast ETC and remaining work on a monthly basis. This monthly forecast will be used to develop the ETC on the monthly report. This is considered a best practice and will allow the project to better manage potential issues as they happen.

It was noted that the project was considering continuing certain cost variances created during the EVMS pre-baseline practice period, and incorporating these variances into the newly established performance measurement baseline after CD-2 approval. However, the Committee judged the project should consider eliminating the variances and resetting the cost and schedule performance index (Cost and Schedule Performance Indices) to 1.0 when establishing the baseline at CD-2. It is considered standard practice to start CD-2 EVMS reporting at a CPI and SPI of 1.0.

The project should also consider implementing a dedicated and routine monthly Risk Management Board meeting, and updating the Risk Management Plan accordingly if implemented. To better manage overall schedule, the project should also consider discussing at least monthly during the group CAM meetings, the topic of critical path and schedule analysis when talking about potential issues on the project.

3.3 Recommendation

5. Proceed to CD-2/3.

4. PROJECT MANAGEMENT

4.1 Findings

The Muon g–2 project is approaching 50% complete at this time. The project design is 93% complete.

The Chief Project Officer is accountable for the project portfolio in concert with successful operation of the scientific program. The Project Management Group/Performance Oversight Group is meeting monthly.

FNAL is continuing program and project management improvements and is building on previous successes. FNAL has demonstrated a commitment to providing the necessary technical personnel to support the Muon g–2 project.

The Storage Ring Magnet work is now included as a part of the Threshold Key Performance Parameters (KPP); Detector KPPs have been added as recommended by the July 2014 review; Objective KPPs have been built into the proposed CD-2/3 baseline.

The g–2 project team adapted some U.S. ITER project controls tools for change management and risk.

The project processed 20 BCRs within in the last year with a $2.5 million total value. The project has been under configuration control for almost one year at the time of this review.

Project to-go costs are largely associated with the construction of beamlines. Accelerator systems are the project critical path.

The Storage Ring Magnet has been turned over to operations; magnet shimming is ongoing.

The Muon g–2 project is anticipating carrying over $4 million funding into FY 2016.

The project costs and schedule were updated in May 2015 and will be proposed as the new baseline at CD-2/3.

The project team is developing a beamline construction strategy. When accelerator work is 50% complete, the project will evaluate remaining cost contingency for possible release to support beamline construction.

The project has identified Kicker Magnet technical expertise as a project risk and is actively trying to address this critical manpower need. The extraction kicker schedule is within two months of the project Critical Path.

The project has an active Value Engineering process yielding positive results throughout.

Detectors will be ready approximately 2.5 months before accelerator is ready to deliver the beam.

4.2 Comments

The project is to be commended for the successful installation, cool-down, and initial testing of the storage ring magnet.

The project made significant progress since the July 2014 review in finalizing the management team, formalizing roles and responsibilities within the project team, and implementing project management systems.

FNAL is making good progress on the Muon Campus Program and has completed much of the work supporting the g–2 project.

The current manpower and resource allocations appear appropriate; however, the project should remain diligent in its planning and in ensuring that expertise is available and that FNAL management is aware of its anticipated needs and requirements.

The Interface Control Document should include additional detail, especially milestones and handoff times. Ideally, these would be between all divisions and the project, all Level 2 subsystems, all U.S. collaborating institutions, and perhaps all foreign institutes.

The project should continue to develop and expand the Operations Plan including details on "phasing" of the different components (magnet/detector).

The project should continue to formalize agreements (Memoranda of Understanding, Statements of Work, or some other appropriate mechanism) with the collaborating institutions.

A few procurements are showing some initial, but recoverable, delays; the project leadership should ensure that the procurement processes (requirements/durations) are well understood by all relevant members of the project team and the laboratory.

The project has successfully mitigated early "high" risks; however, the project should formalize the Risk Management Meeting with the CAMs and ensure that the CAMs are fully engaged and that risks are identified and addressed in a timely manner.

Detectors will be ready approximately 2.5 months before accelerator is ready to deliver the beam, leaving little room for delays relative to the accelerator schedule. The project should continue to manage the overall critical path to help ensure unforeseen delays do not impact project delivery.

In order to facilitate the efficient and timely on-budget completion of the experiment, Laboratory Management should continue its careful oversight and prioritization of the FNAL labor pool. Continued competing demands with other ongoing projects underscore the importance of this management function.

The contingency needs for non-DOE funded deliverables should be revisited.

Complete and have signed all prerequisite CD-2/3 documentation.

The project, in conjunction with the laboratory, should develop a path forward for an improved inflector in the context of the overall proton economics plan for the laboratory. They should consider integrating complimentary expertise external to the project in the formulation of this plan. In order to focus on efficiently delivering the baselined experiment, serious consideration should be given to pursuing the inflector as a future upgrade.

4.3 Recommendations

6. Proceed to CD-2/3, after achieving storage ring magnet operating parameters.

7. The project should prepare for a DOE mini-review in four months' time.

Appendix A Charge Memo

Department of Energy
Washington, DC 20585

APR 3 2015

MEMORANDUM FOR STEPHEN MEADOR
DIRECTOR, OFFICE OF PROJECT ASSESSMENT

FROM: MICHAEL PROCARIO
DIRECTOR OF FACILITIES
FOR HIGH ENERGY PHYSICS

SUBJECT: REQUEST TO CONDUCT AN INDEPENDENT PROJECT REVIEW OF THE MUON g-2 PROJECT

I request that you conduct an Independent Project Review of the Muon g-2 Project at Fermilab on June 25-26, 2015. The purpose of this review is to evaluate the project's readiness for Critical Decision CD-2 which will approve of the proposed Performance Baseline for technical scope, cost and schedule, as well as the project's readiness for Critical Decision CD-3 which will approve the continuation of all procurement and fabrication to completion.

This will be a follow-up to the previous DOE review held July 29-31, 2014, that resulted in a number of recommendations that required time to implement. The purpose of the review is to evaluate the progress in resolving the recommendations from the previous review. In particular:

1. Have the Project and the Laboratory responded satisfactorily to the recommendations of the previous DOE review?
2. Is the detailed design sufficiently mature and appropriately reviewed so that the project can continue, as planned, with the procurement and fabrication work?
3. Has the superconducting magnet system for the experiment been tested with positive results?
4. Are there any outstanding issues that need to be addressed?

Dr. Theodore Lavine is the program manager for the Muon g-2 Project in this office and will serve as the DOE Office of High Energy Physics contact person for the review.

We appreciate your assistance in this matter. As you know, these reviews play an important role in our program. I look forward to receiving your Committee's report.

cc: M. Weis, FSO
P. Carolan, FSO
P. Philp, FSO
P. Dehmer, SC-2
J. Siegrist, SC-25
G. Crawford, SC-25
T. Lavine, SC-25
J. Kogut, SC-25
K. Fisher, SC-28
M. Lindgren, FNAL
P. McBride, FNAL
C. Polly, FNAL

Appendix B Review Committee

Department of Energy / Office of Science (CD-2/3) Review of the
Muon g-2 Project
June 25-26, 2015

Kurt Fisher, DOE/SC, Chairperson

SC1
Accelerator

* Rod Gerig, retired ANL
Peter Ostroumov, ANL
Geoff Pile, ANL

SC2
Storage Ring

* Uli Wienands, SLAC

SC3
Technical Integration

* GianLuca Sabbi, LBNL
Bruce Strauss, DOE/SC

SC4
Detectors

* Bill Wisniewski, SLAC

SC5
Cost and Schedule

* Jerry Kao, DOE/SC
Ron Lutha, DOE/ASO

SC6
Project Management

* Jon Kotcher, BNL
Dan Green, FNAL Emeritus
Ethan Merrill, DOE/SC

Observers

Mike Procario, DOE/SC
Ted Lavine, DOE/SC
John Kogut, DOE/SC
Alan Stone, DOE/SC
Pepin Carolan, DOE/FSO
Paul Philp, DOE/FSO

LEGEND

SC Subcommittee
* Chairperson

Count: 13 (excluding observers)

Appendix C Review Agenda

Department of Energy/Office of Science Review of the
Muon g-2 Project at Fermilab
June 25-26, 2015

AGENDA

Thursday, June 25, 2015—Comitium (WH2SE)

8:00 am	Executive Session .....K. Fisher
8:30 am	Welcome/Laboratory Role and Project Support – **One West** ..... M. Lindgren
8:45 am	Project Overview ..... C. Polly
	• Response to DOE Review Recommendations
9:30 am	Break – Outside One West
9:45 am	WBS Level 2 Summaries..... H. Nguyen, M. Convery, B. Casey
11:00 am	MC-1 Tour – Buses out Front
12:00 pm	Working Lunch – 2nd Floor Crossover
12:50 pm	Photo for Reviewers - Atrium
1:00 pm	**Subcommittee Breakout Sessions**
	• Session 1 Ring— Black Hole (WH2NW)
	• Session 2 Accelerator— Snake Pit (WH2NE)
	• Session 3 Detectors— One West (WH1W)
	• Session 4 Management— Comitium (WH2SE)
3:00 pm	Executive Session – Comitium (Break available outside of Comitium)
5:00 pm	Adjourn

Friday, June 26, 2015 – Comitium (WH2SE)

8:00 am	Answers to Questions ..... C. Polly
9:00 am	Writing Session.....Review Committee
10:00 am	Dry Run Closeout .....K. Fisher
11:00 am	Committee Reconvene with Project Management (if needed)
12:00 pm	Working Lunch
1:00 pm	Closeout – One West
2:00 pm	Adjourn

Appendix D Muon g–2 Cost Table

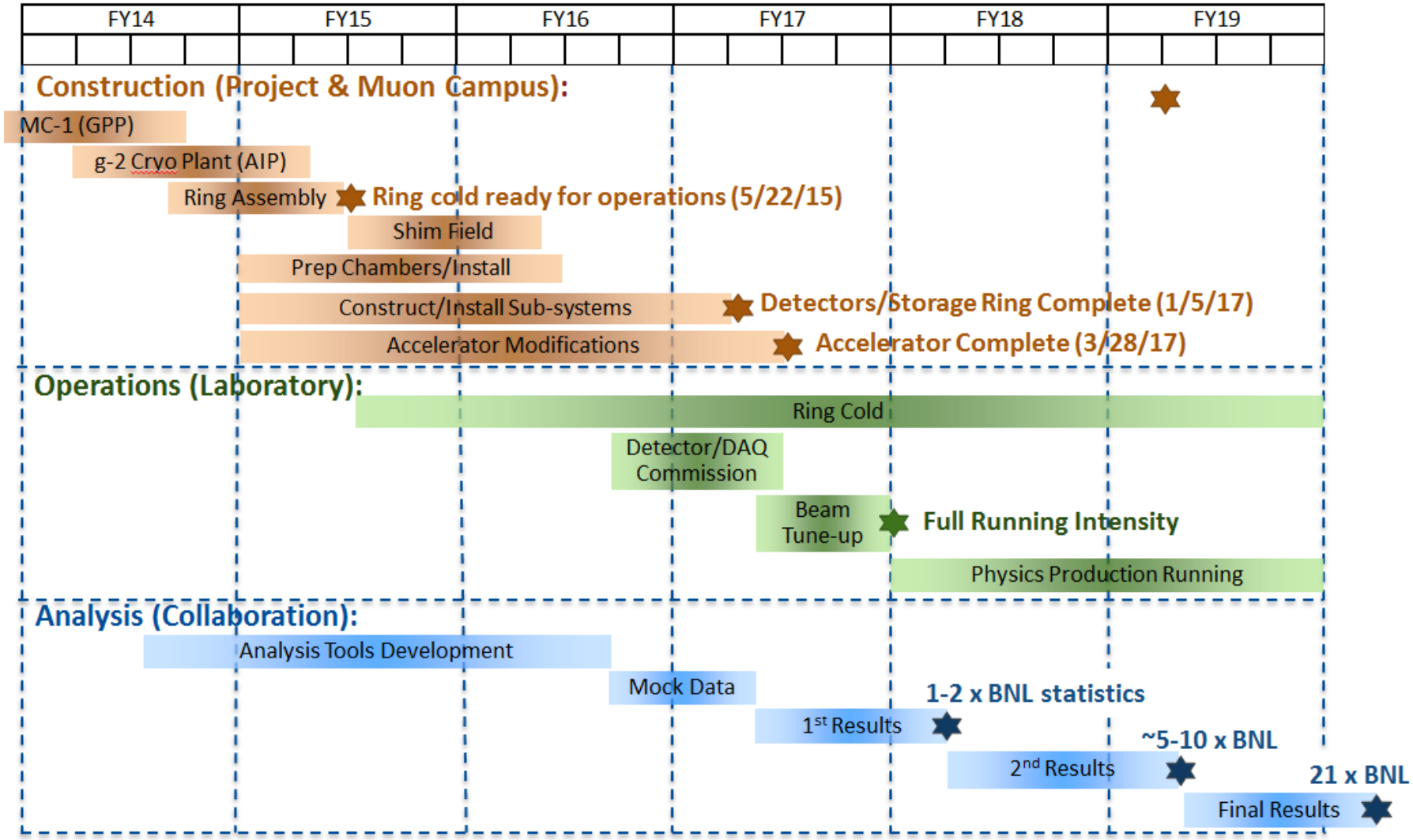
WBS Element	Item	DOE OPC	DOE TEC	DOE TPC
1.1	Project Management	2.6	1.5	4.1
1.2	Accelerator	4.9	12.9	17.8
1.3	Ring	4.4	7.8	12.3
1.4	Detectors*	0.1	0.4	0.5
1.5	BNL Equipment Transfer	4.2	0.0	4.2
	Subtotal of above	16.2	22.6	38.84
	Cumulative Cost Variance (May 2015)			0.33
	Remaining DOE Contingency			7.23
	DOE Total			**46.40**
	Cost of Work Remaining at CD-2			19.37
	% Contingency on Work Remaining			37%

* WBS 1.4 Detectors is mostly funded by NSF and in-kind university contributions.

Appendix D Muon g–2 Funding Table

	FY 2012	**FY 2013**	**FY 2014**	**FY 2015**	**FY 2016**	**FY 2017**	**Total**
OPC-Other	0.601	2.742	3.20				**6.543**
OPC-Design		3.108	5.20	4.1			**12.408**
TEC-MIE			2.00	9.0	10.20	6.249	**27.449**
Total	**0.601**	**5.850**	**10.40**	**13.10**	**10.20**	**6.249**	**46.400**

Appendix E Muon g–2 Schedule Chart



Appendix F Muon g–2 Management Chart