



Closeout Presentation

Director's Independent Design and CD-2/3 Review of the Muon g-2 Project

June 17-19, 2014

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Executive Summary

The Muon g-2 Project (“the Project”) is being constructed at Fermilab to support an experimental measurement of the anomalous magnetic moment of the muon at an unprecedented level of precision. The experimental goal is a measurement uncertainty of 0.14 parts per million, or a factor of four beyond the world’s current best measurement by E821 at Brookhaven National Laboratory. This precision measurement offers one of the most sensitive tests of the Standard Model and a powerful potential window into new physics.

This Fermilab review comprised an Independent Design Review (IDR) and a readiness assessment for CD2/3. The Review Committee (the Committee) was specifically asked to assess whether the Project’s design, as documented in the Technical Design Report (TDR), can be characterized as a final, or near-final, design. The Committee was also asked to review the Project’s readiness for CD2/3, including an assessment of the adequacy of the technical development, cost, schedule, and associated documentation. The Project is scheduled for a CD-2/3 review by the Department of Energy over July 29-31, 2014.

The g-2 Collaboration is supported by forty institutions from nine countries and merges experimenters from E821 with new collaborators. The Collaboration capitalizes on the prior experience with the E821 experiment and utilizes significant hardware from that experiment, most notably the muon storage ring. As a result the understanding of the experimental requirements and characteristics of the primary hardware system is quite mature.

The Project consists of five WBS Level 2 systems one of which, E821 Equipment Transfer, is now nearly complete. The Project Management team, including the Project Office, Level 2 and Level 3 managers, and Cost Account Managers is in place. This team is strong and highly motivated, bringing to the Project a deep understanding of the detector, the accelerator, the experimental and technical challenges, and the physics goals. The Committee believes this team is capable of successfully executing the Project. The Deputy Project Manager, who is also serving as the ESH&Q coordinator, will be retiring later this year and will need to be replaced.

The Project relies on the completion of the Muon Campus, in particular the MC-1 building and upstream beam enclosure, and a set of associated Accelerator Improvement Projects (AIPs). The MC-1 building is now substantially complete and muon storage ring installation activities have been initiated.

The Project is utilizing funding and in-kind contributions from multiple sources including the Department of Energy, a DOE/Early Career Award, the NSF through a Major Research Instrumentation (MRI) grant, and international in-kind contributions from the United Kingdom and Italy. The non-DOE funding is devoted nearly entirely to construction of the detector, and represents approximately 90% of the detector cost.

Significant progress has been made since the Project received CD-1 in December 2013. The Project has established a cost estimate based on a resource loaded schedule (RLS) implemented in Primavera and documented through a complete set of bases of estimate (BOEs). The RLS is now integrated with COBRA and the Project has started exercising earned value management system (EVMS) tools in a preliminary manner. The proposed baseline total project cost (TPC) is \$46.4M with a completion date of 3rd quarter FY2017. The TPC incorporates contingency at 27% of base costs, corresponding to 37% on the estimate to complete. The contingency analysis incorporates both estimate uncertainties and risk-based contingency. The baseline completion date provides two years of float to the 3rd quarter FY2019 CD-4 date. The TPC and CD-4 parameters lie within the range established at CD-1 and the Committee believes they provide a firm basis for CD2.

A draft Project Execution Plan (PEP) exists including Project Key Performance Parameters (KPPs). This document needs to be finalized and signed in advance of CD-2. The Committee notes that the difference between the “Threshold” and “Objective” parameters represents a significant resource investment, which is included within the proposed Project baseline.

The Committee reviewed the technical design of the three major technical systems (Accelerator, Ring, Detector). It is the assessment of the Committee that the designs presented are likely to meet the Project’s technical, cost, and schedule goals. Most systems are in final to near-final design – the Project characterizes the overall design as 72% complete at the time of the DOE Review in July. Planning Packages incorporated into the CD-1 estimates have now been replaced with real estimates. Both the Accelerator and Ring systems have strong external dependencies which are well understood. The Committee believes the maturity of design is sufficient to proceed to CD-3.

The Committee believes the Project is ready to proceed to its CD-2/3 review following consideration of the recommendations contained in this report.

1.0 Introduction

A Director's Independent Design and CD-2/3 Review of the Muon g-2 Project was held on June 17-19, 2014 at the Fermi National Accelerator Laboratory. The objects of this review was to assess the level of maturity of the Project's design and to determine if the project meets the Critical Decision (CD) 2/3 (CD-2, Approval of Performance Baseline and CD-3, Approve to Start Construction) requirements as specified in DOE O 413.3B. To meet the design requirements for CD-2 the design has to be at the preliminary level or greater, and for CD-3 the design has to be at the level of final or near final design.

Additionally, the committee assessed the Project's progress on addressing the recommendations from the prior reviews; DOE CD-1 Review performed on September 17-18, 2013, Director's CD-1 Review performed on July 23-25, 2013, and the Director's Independent Conceptual Design Review conducted on June 5-7, 2013. The charge included a list of specific questions to be addressed as part of the review. The assessment of the Review Committee is documented in the body of this closeout presentation.

This closeout report is broken down into two basic sections. The first section provides the assessments of the project's design of technical deliverables and project management. Each area within this first section is generally organized by Findings, Comments and Recommendations. Findings are statements of fact that summarize noteworthy information presented during the review. The Comments are judgment statements about the facts presented during the review and are based on reviewers' experience and expertise. The comments are to be evaluated by the project team and actions taken as deemed appropriate. Recommendations are statements of actions that should be addressed by the project team. The second section of this presentation has the committee's answers to the review charge questions.

The Muon g-2 Project is to develop a response to the review recommendations and present it to the Laboratory Management and regularly report on the progress during the Project's Project Management Group Meetings (PMGs) and at the Performance Oversight Group (POG). The recommendations will be tracked to closure, in the iTrack system. Documented status of the project's resolution of the recommendations will need to be available for future reviews.

2.0 Technical

2.1 Accelerator

Primary Writers: Marion White

Contributors: Dave Capista and Bob Webber

Findings

- The accelerator WBS 476.2 includes the accelerator project management, target station, beamlines, and controls and instrumentation. The respective base costs are \$2.7M, \$1.6M, \$12.2M, and \$1.8M, for a total base cost of \$18.3M.
- Commissioning is not part of this project; it is an operations task.
- The accelerator portion of the muon g-2 Technical Design Report (TDR) is a detailed and comprehensive description of the project and its requirements.
- An approved, configuration-controlled, overall requirements document does not yet exist. We were told that current requirements are captured in the TDR, and that they plan to have a requirements document in two weeks.
- The muon campus program comprises several interconnected, inter-related AIP and GPP projects on which the scientific mission of g-2 depends: Beam transport AIP, Recycler RF AIP, Delivery Ring AIP, Cryogenics AIP, MC-1 building GPP, MC Infrastructure GPP, and the beamline enclosure GPP. The overall muon campus program was not the subject of this review. Project progress and coordination across these areas is being actively managed by interface milestones.
- There is a common installation coordinator for project and non-project components.
- Each of the presenters showed cost, schedule, and resource allocation in addition to technical information. The presenters demonstrated ownership, technical competence, and a high level of understanding of their sections of the WBS.
- Many of the required designs are well advanced or final at this time. Achieving the 100-Hz burst rate is the particular challenge in final design of the pulsed power supplies.
- The g-2 experiment has no stated requirement for measurement information on the incoming transverse and longitudinal beam parameters.
- The accelerator schedule is funding limited, and accelerator and beamline component installation work is concentrated at the end of the project.

- Most of the magnets needed for the beamlines are on hand already, repurposed from FNAL and BNL as value engineering. Six types, some of new or modified design, need to be built.
- The beamline layouts have been significantly improved and simplified since the June 2013 Independent Design Review.
- The design repetition rate to the experiment is 12 Hz. ANSYS simulations predict that a repetition rate greater than 15 Hz would cause unsafe overheating of the lithium lens.
- The design goal is transportation of a 40pi beam through beamlines and other specialized components. Many design instances were presented that specifically addressed and met this requirement.
- The D30 straight section reconfiguration work, funded by OPC, is underway.
- The baseline uses a newly-designed proportional wire chamber (PWC) as the profile monitor for the low-intensity M4/M5 beamlines. This design has not yet been tested with beam although there are plans to do so in the switchyard at the equivalent current but without the 100-ns bunch structure. The backup plan is to use proven segmented-wire ion chambers (SWICs).
- No budget is allocated for controls and instrumentation software. This software is to be developed off-project.
- There is a \$4.25M cost difference between the objective and threshold KPPs; \$3.5M of that is for installation of the M2/M3 and M4/M5 beamlines.
- The draft threshold accelerator KPP does not include beamline installation; however Level-1 Milestone 1.3 requires that M4/M5 beamlines be operational.
- Design of the beamline allows significant flexibility in tuning the incoming beam into the inflector.

Comments

- Since controls and instrumentation software will be developed off-project, appropriate interface milestones should be used to enable progress to be tracked.
- The project should ensure that the skillset granularity in assignment of technicians is adequate to avoid double-tasking personnel. Ideally, named resources should be used if at all possible. Doing so will help to enable more accurate effort scheduling, else if the schedule slips at all, there could be inadequate skilled personnel to accomplish some tasks.

- There is a dependency between progress on some of the AIPs and GPPs and the g-2 project; issues may not be evident soon enough if the milestones are not at a low enough level. Evaluate the adequacy of the interface milestones.
- Given the number of interrelated muon campus projects, it is challenging for reviewers to assess the probability of success of the g-2 scientific mission solely based on the performance of the narrowly-defined muon g-2 project.
- Power supplies need to be fully designed, constructed, and demonstrated. Until that work is complete some risk, presumably low, remains.
- Many items in the risk registry have been retired, enabling the associated contingency to be reduced; however, the number of new items being added to the registry appears small. The risk registry should be used as a living document, with new risks added as they are identified and retired as appropriate.
- Design maturity appears consistent with expectations for a project at the CD-2/3 stage.
- The exact timing and duration of shutdowns directly impact the project's ability to achieve the Objective KPPs. Shutdown details are presently unknown but are evidently somewhat negotiable.
- Accommodations to enable g-2 project work to proceed without requiring a shutdown should be considered, for example, by moving tunnel gates.
- Many of the accelerator installation tasks are occurring near the end of the project. This creates a risk of a delay in completion of Level-1 milestone 1.3.
- Consider a strategy for making the Level-1 milestones and Threshold KPPs more consistent.
- Understanding the beam parameters by measurements in the beamlines is valuable regardless of the currently-envisioned requirements from the experiment. Whether planned instrumentation is capable of making these measurements is not yet clear as the new Proportional Wire Chambers (PWC) are still in the development stage.
- The technical basis for the number and location of profile monitors in the beamlines was not presented. We encourage the project to verify that the quantity and placement of profile monitors will allow for lattice matching into the Delivery Ring and G-2 ring.
- We encourage testing of the new PWCs with beam as soon as possible.
- The accelerator subcommittee feels the project is ready for CD-2/3, subject to the recommendations below.

Recommendations

1. Before CD-2/3 add appropriate entries to the risk registry reflecting the scheduled late installation of g-2 accelerator components.
2. Before CD-2/3 verify that the number of low-level accelerator interface milestones is adequate to provide sufficient performance information before any real problems are able to develop in related AIP or GPP areas.
3. Create and have approved under configuration control an overall requirements document before the CD-2/3 review.
4. Demonstrate before the end of 2014, via beam simulations, the sensitivity of the beam in the g-2 ring to lattice mismatches in the upstream accelerator components. Make an entry to the risk registry reflecting a potential need to add or change instrumentation in the beamlines in the future.

2.2 Ring

Primary Writer: Lou Snyder

Contributors: Wuzheng Meng and Mike Tartaglia

2.2.1. Storage Ring (Magnet)

Findings

- The installation of the Storage Ring magnet yoke has started with two lower sectors being placed in position and partially aligned with a new metrology system at the time of this Review.
- The plan for Ring installation is very detailed and thorough. The completion of the assembly of the Storage Ring magnet is planned to be mid-FY15.
- The magnet coil cryostat assemblies will be transported into the MC-1 Hall in mid-July by the same company that transported them to FNAL from BNL. The contractor has presented the Job Hazard Analysis to FNAL Safety recently and is now responding to action items from that review.
- The alignment procedures and special tooling have been very well developed. For the yoke/pole installation the methods were tested on yokes and poles that were setup for this purpose. There is a plan to evaluate the alignment methods for the beam vacuum chambers by this September.
- The installation of the cryogenic system in MC-1 is currently in process. The helium transfer lines for coil supply and return are visible in the experimental hall, and assembly of the cryogenic system is ongoing in the cryogenic equipment room.
- The plan for grounding, electrical distribution, and quench protection is comprehensive and fully developed. The Quench protection system design will replace the E821 hardware with PLC-based hardware used for the DZero SC solenoid, and is a common solution for both the storage ring coils and the inflector.

Comments

- The design and plan for Storage Ring installation is proceeding well and is on schedule. The proposed schedule for completion of installation and powering the magnet by the end of March, 2015 is considered aggressive due to work required for cryogenic system completion. This work includes installation, test, and checkout of the following: main lead pot (and repair of existing ground fault), LN2 and LHe valve boxes, dewar and platform, 500-600 sensors, inflector lead pot (See 2.2.4 Inflector), and completion of the refrigerator and transfer lines.

- Coordination will likely get very complicated in FY15 and FY16 when all systems (especially those coupled to vacuum chambers) will come together, and many groups will simultaneously need to install, test and adjust their equipment.
- The risk that the Storage Ring will not achieve satisfactory operation seems low. During transport of the coil cryostat rings by Emmert there were no high acceleration levels that might cause failure (per Project Mechanical Engineer). Resistance measurement before and after the transport have not shown degradation. Any helium line and cryostat vacuum leaks can be resolved, but pose a cost and schedule risk.
- Cryogenic safety review and approval must be completed prior to starting the cryogenic operation and the time required to complete the safety review is an unknown, but often takes much longer than anticipated. Project should consider adding this concern to the Risk Registry.
- The documentation for ES&H seems to be complete with an ISM Plan and Hazard Analysis Plan. The technical presentations have mentioned ES&H topics in general. With the Project entering the construction phase, the inclusion of daily safety awareness, such as work planning, hazard analyses, check-off lists, and daily pre-job briefings becomes more important and should be presented at the CD-2/3 Review.
- A procedure for cooling down the SC coils has not yet been worked out. It would be helpful to know whether a controlled cool-down of the coils can be achieved to limit differential temperatures and stresses in the coils by mixing gas and liquid helium during the cool-down (this has been achieved in TD cryogenic systems in IB1 and at CHL).

Recommendations

5. Labor resources needed for multiple sub-systems have the potential to be oversubscribed. Show an overview of how concurrent installation and commissioning efforts are envisioned to take place, and how the resources are shared. This will help to alleviate concerns about meeting the Project schedule.
6. To avoid delays in the cool down schedule submit all required engineering notes to the cryogenic safety committee as early as possible.
7. Develop a procedure for cool-down that achieves the required differential temperatures between heat shields and coils.

2.2.2. Controls & Instrumentation

Findings

- A preliminary instrumentation and controls system design has been developed based on modern PLC-based hardware and software that will allow good

communication with the AD cryogenic distribution system and the g-2 experiment.

- Details of procedures for cryogenic controls for the Ring were not presented.

Comments

- The labor bar chart by fiscal year and labor category given in the presentation did not show FY15 values. Most of the cryogenic controls work must be completed by March, 2015 and constitutes more than \$500K in labor. The availability of labor to perform this work should be verified.

Recommendations

None

2.2.3. Beam Vacuum Chambers

Findings

- The Project will reuse and refurbish almost all components from BNL E821, including ten 'standard' chambers, the trolley drive chamber, and the inflector chamber. These chambers will be modified to change the position of the NMR probes mounted in the top and bottom surfaces. This machining will be done at BU. At this time two of the standard chambers will be modified to accept straw chambers.
- The methods to survey and align the chambers and internal components are currently being developed.

Comments

- The preparation of the chambers follows a complex schedule with the various stages of chamber modification, test, and assembly being shared by E989 collaborators: Cornell, BU, ANL, and BNL. A chamber sequencing plan and schedule has been developed to coordinate these efforts effectively.
- The survey and alignment of the chamber assemblies may be more difficult than planned due to the dependent positioning requirements of the quadrupoles, trolley rails, and collimators (i.e., adjusting one will change the other). There are also tighter tolerances for quadrupoles and collimators (+/-0.3mm).
- The estimate for installing the chambers in the magnet is 2 FTE'S - 120 hours (1.5 weeks). This seems low due to the interaction that will be required between metrology and mechanical technicians.
- Changes to the bar coding system for the trolley position may affect the assembly sequence. The bar coding is being investigated by the precision field team.

Recommendations

8. The procedures for alignment of the vacuum chambers and inner components are expected to be developed and tested on the Q1 chamber by September. It is suggested that this effort be completed as soon as reasonable to provide a higher level of confidence in the time estimate to complete chamber assembly.

2.2.4. Superconducting Inflector

Findings

- Present plan is to use BNL E821 SC inflector. The inflector lead pot will be rebuilt. A new power supply has been obtained, and the quench protection has been replaced by Dzero type protection.
- Present R&D funding for a new inflector stops by the end of FY14. Any further progress would require utilization of contingency funds. There have been two (2) new designs, both of them are still in early stage. Both of them will require SC shield to screen the residual fringe field, to achieve larger aperture and open-end windings.

Comments

- For developing SC shield, it is crucial that the SC sheet consists of enough Cu because the shield always works at the critical state and high RRR normal metal acting as a stabilizer is indispensable.

Recommendations

None

2.2.5. Quadrupoles and Collimators

Findings

- BNL has started to evaluate upgrades to the Q1 quadrupole design which will eliminate or reduce incoming beam losses. At the same time the trolley rail frame structure that supports the quadrupole electrodes will be upgraded to improve positioning tolerances. The changes to design will be implemented by FNAL to the other chambers.
- E989 collimators will be of similar configuration as E821, except that 5 full collimators will be used (E821 used 3 full and 8 half collimators). The collimator thickness will be determined by simulations

Comments

- The estimated level of effort to modify and to install/align the quadrupole system will be determined by the modifications implemented at BNL and by the alignment evaluation now being performed by the metrology group.

Recommendations

9. The evaluation of the prototype chamber/quadrupole assemblies should be performed as soon as possible to resolve uncertainties in the current schedule and costing.

2.2.6. Kicker

Findings

- A new kicker design will be provided by Cornell, including the electrodes and Blumlein pulse forming network (PFN). The existing kicker vacuum chamber will be reused. The total length of the electrode plates is 5.1m (3 x 1.7m), shorter than the E821 kicker plates due to the higher mid-plane B field.
- The kicker design is a major improvement over the existing one, although the Blumlein design is not final at this time. The Blumlein design provides an improved pulse shape with a resulting much improve capture efficiency.
- Final design of kicker plates and vacuum chamber modifications, power supply, and thyatron is now in progress.

Comments

- The manufacture of the electrode plates was not considered a risk item by the Project, since similar curved designs have been produced in the past. The macor trolley rail may be made from segmented metal if fabrication of the macor is problem.
- The design uncertainty is reflected in the cost estimates shown.

Recommendations

None

2.2.7. Precision Field

Findings

- The NMR Trolley used in BNL E821 will be used in the Project. This system was designed and manufactured by the University of Heidelberg. Peter Von Walter, retired from Heidelberg, helped in the re-commissioning of the system at Argonne.
- Argonne will improve the absolute calibration of the NMR probes by using an existing 20 ppb MRI magnet.
- Control of the experimental hall temperature to +/-1 degree C will lead directly to reduced errors in understanding of the precision field.

- Efforts to achieve higher precision magnetic field are comprehensive and thorough. These include careful attention to the passive and active shimming of the ring, using individual pole edge trims, improved pole face windings, etc. Major reductions in the error are expected by improving the NMR probe design and calibration, developing a second absolute calibration probe, upgrading electronics to capture FID waveforms, and improving knowledge of the NMR trolley position.

Comments

- We do not see any obstacles at this moment to achieve 70 ppb error level in measurement of the precision field parameter ω_p .
- Shimming the magnet to such precision after full disassembly and after a long distance transportation will be a difficult and tedious process. The present schedule showing that it will take about one year time (for field shimming) is tight.

Recommendations

None

2.3 Detectors

Primary Writers: Alan Hahn

Contributors: Harry Cheung and Brenna Flaughter

Findings

- The detector subsection consists of 5 funding sources and over 15 institutions. The project is doing an excellent job of coordinating the effort and capitalizing on the extensive expertise at these institutions.
- As currently defined there is a 12 month gap in the L2 and L3 milestones (June 2015 to June 2016). This gap is also present at L4 and L5 in many cases. In the detector section the gap in the L4 milestones is from August 2014 to April 2016.
- The group is aware of FNAL safety requirements and has already submitted many components to FNAL for initial checkout/recommendations that will be needed for eventual ORC approval.
- Decision to QA all Calorimeter Crystals vs. sampling has not yet been decided.
- The Calorimeter SiPM Bias Power Supply will be tested at SLAC test beam run with the Calorimeter modules. This will enable a decision on the particular bias supply chip.
- Backend electronics group has joined effort with CMS on the uTCA crates and AMC13. This has resulted in benefits to both g-2 and CMS.
- Straws will require cryo pumping stations to keep local vacuum at acceptable levels.
- Straw front-end electronics cooling is still being designed. Ambient cooling via the chamber gas proved inadequate.
- Straw module production is now in Liverpool, and with skilled labor.
- The behavior of the injected muon beam can impact the systematic errors in the ω_a measurement. The Tracker is built specifically to track the circulating muon beam centroid and width.
- Prototype DAQ performance, as tested with simulated signals and currently available hardware meets the performance needed for g-2 operations. The prototype DAQ will be used in the July 2014 calorimeter test beam run.
- INFN conducted an independent design review in May 2014 of the calorimeter calibration system. As a result of this review the Italian groups are funded to complete the final design phase. A successful demonstration of their system in the

SLAC beam test should result in INFN funding the construction/implementation phase. The calibration system could then be moved off-project. This is a high probability risk opportunity for the project (risk # 1104).

- Results of tests of a prototype laser calibration system showed which components still needed work. The systematic uncertainty for this test was dominated by the calibration source monitor systematic of 0.5% owing to the use of non-optimized electronics. Dedicated electronics has been designed and is to be tested at the SLAC beam tests. The light distribution system also contributed a systematic of 0.2%. The goal is a systematic of 0.1% for the calibration.

Comments

- The project presented interesting and detailed technical talks in the breakouts. These presentations could be improved by having a one slide summary of cost, funding source and significant (L4 and above) milestones at the beginning of each talk. Cost information could include the breakdowns in R&D, MIE, obligations, actuals, and have the totals separated into M&S and Labor. Many of the tasks are dominated by either M&S or Labor. Providing this information earlier in the presentations would avoid some confusion.
- In a combined CD2/3 review it is hard to strike the right balance of technical and cost/schedule information in the breakout presentations. Generally the presentations were weighted very heavily towards the technical information with little emphasis on the cost and schedule. Simplifying and focusing the technical parts of the presentations would allow more time for presentation of the cost and schedule. For example, when presenting data from prototype tests, include clear indication of the requirements on the same slide so that it is obvious if the prototype meets the requirement.
- The project needs more L2, L3 and L4 milestones in the 2015-2016 time frame. Adding more L4 milestones to the 20 month gap in the detector subsection would allow the Project manager to more closely monitor progress of the detector subsection and catch any problems early. This is particularly important because so much of the detector subsection is funded by external uncosted sources. Adding one L4 milestone per subsection every 2-3 months would give excellent feedback on progress to the project manager. Also consider adding a L2/L3 milestone every 1-2 months to fill the 12 month gap in the L2 /L3 milestones.
- The PIs of the MRI receive monthly cost reports from their accounting office and make periodic reports for NSF on the status of the technical progress and remaining funding. Providing this information on a monthly basis to the L2 manager, the CAM and the project would be a useful communication channel to establish and would keep all interested parties up-to-date on available funding. Monthly status reports from the other funding sources would also be useful. Requesting periodic (monthly) status from vendors on long procurements is also an established technique for keeping communication channels open and keeping track of progress.

- The detector subsection is distributed across a large number of institutions that are widely separated geographically. The project should develop a concise summary or narrative of the plans for where all the pieces come from, when they come together, including what is tested at each stage, finishing with installation at Fermilab. This could be done for the tracker and calorimeter separately to simplify the presentation.
- The project is hoping to begin commissioning in FY17 using operations (non-project) funds. Having some statement from FNAL management that they are prepared to support this plan would be helpful since it is not very far in the future.
- There are 6 CAMs in the detector subsection but only \$700k of DOE funding. This seems unnecessarily complicated. The project should consider consolidating the CAM responsibilities (and associated training) into fewer CAMs who manage multiple cost accounts.
- The project is making excellent progress with the design and prototyping of all the components. As the systems reach the final iteration the project should consider having expert design reviews before proceeding with the final production orders.
- A Requirements Document consolidating the Physics Requirement of g-2 to the individual subsystem requirements/specification is needed. This would allow a reviewer (or even a g-2 collaborator) to link requirements to specs –e.g. how does the tracker test beam performance match the physics requirements.
- As part of the quality control for the detector components, the team is testing all prototype components in a magnetic field to ensure the effect on the precision magnetic field is small, less than ~ 1 ppm. The maximum total effect from all the detector components should be less than 10ppm. This is an excellent plan and we encourage the team to work out a plan to repeat the tests for the production components prior to installation if possible.
- The ECAL calibration goal of 0.1% for the uncertainty in the knowledge of the gain is a challenging but necessary goal. It is achievable, e.g. as shown in CMS. The INFN collaborators have shown encouraging results for a prototype laser calibration system. The calibration source monitor electronics will be tested for the first time in the SLAC test beam. More work on the light distribution system (integrating sphere/beam-expander) and the calibration source monitor will likely be needed and having the full INFN team supported to do this will help ensure the performance needed can be achieved in a timely manner.
- The Detector critical path runs through the PbF crystal delivery, so monitoring the delivery is important. It is noted that only two milestones exist for this item: the order date and the final delivery. Perhaps partial delivery milestones might be appropriate, especially to provide links to further assembly tasks for these crystals.

- The design of the detector systems is well advanced, meets the science requirements and has been extensively tested with prototypes and simulations. Lessons learned from past test beam runs are already being applied to the current design. Future tests at SLAC in July 2014 will be an important system test of the nearly final designs of many of the systems. However the schedule appears tight to have some components ready, e.g. the WFD. We encourage the project to test as many of the final design components as possible in the SLAC beam test. For any components not ready for the SLAC July beam test, they should be tested in follow up beam tests, possibly earlier than the next planned beam tests which we understand to be in Spring 2015.
- The front-end waveform digitizer ADCs and FPGAs have been upgraded from the CDR versions to higher speed components (~1.6x faster) at no cost to the experiment, a ~\$300k savings to the experiment. The manufacturers (Texas Instruments and XILINX) are to be commended as are the g-2 members who have pursued these non-traditional ways (for HEP) to leverage the experiment's funding. It is noted that the enhanced performance of these components matches the narrower pulse widths of newer design SiPMs that will be used on the calorimeters.
- We believe the schedule shown by the Detector group is achievable. Resources are basically already in hand, and some major long lead-time components have already been ordered or will be ordered in the near future.
- During the drill down, it appeared that some cost numbers did not match the BOE supporting material, and there may be some typos, e.g. an activity with 17.7 postdoc hours. Also it seemed that some BOE backup information was old and updates were available. The schedule, cost book, and BOE information should be scrubbed to ensure consistent information. Also it would help the reviewers if the BOE supporting documentation explicitly showed how the numbers in the schedule were arrived at make it easy to verify consistent numbers. Having explanatory text only in the BOE spreadsheet comments column made verification difficult.
- A lot of documentation for the schedule, cost, and BOE was posted, and while appearing to contain all the needed information, we think the documentation could be improved. The posted flat PDF cost book file was not useful according to some subproject managers, they recommended we use only the Excel pivot table. Also some details like forward funding assumptions were not written down or known to some L3/CAM which confused the situation during drill down. Also the risk register PDF file should clearly state which risks are threats and which are opportunities, the text of some are confusing/contradicting – e.g. for the calibration system opportunity.
- Showing a complete detector organization chart down to L4 with persons responsible would have been useful to show the management structure.

- g-2 should demonstrate, via beam simulations, the sensitivity of the beam orbit in the Ring from lattice issues in the upstream Accelerator components. It is noted that the entire tracker is purposed to monitor this orbit, perhaps assuming the actual beam conditions will be similar to the previous experiment E821 at BNL.
- The maturity of the design for the detectors appeared much further ahead than indicated by the “CD-2/3 Readiness: Maturity of Design” slide presented by the g-2 Project Manager, less than 50% for all detector subsystems except DAQ which is 60% based on May actuals. The metric used did not seem to match our judgment of the design maturity. The Project needs to take credit for existing designs and subsystems from the original E821 experiment and all prototyping and testing that has been completed.
- No major risks remain and all systems are at the final design stage or have a clear path towards final design and procurement. The Detector Design is ready for CD2/3.

Recommendations

10. Prior to Baselineing, add L2, L3 and L4 milestones to the existing gaps during the 2014-2016 time frame.
11. The Cost and Schedule needs to be scrubbed to remove small inconsistencies. Update the BOE to make it easy to demonstrate how one arrives at the P6 value.
12. Consider consolidating the CAM responsibilities for the existing control accounts into 1 or 2 people.

3.0 Cost and Schedule

Primary Writer: Elmie Peoples-Evans

Contributors: Sherese Humphrey, Pam Utley and Richard Marcum

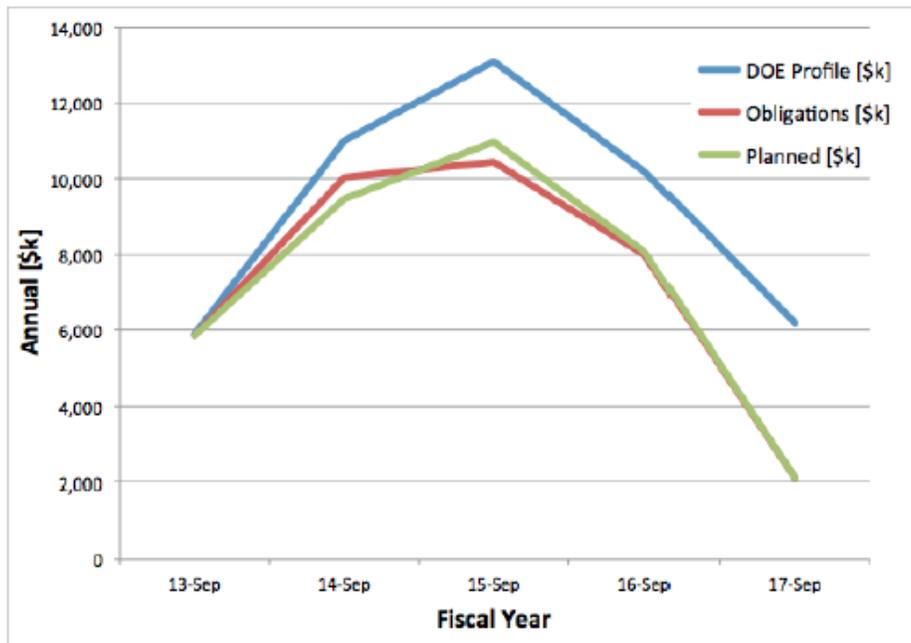
3.1 Cost

Findings

- The Muon G-2 Project’s proposed total project cost (TPC) is \$46.4M. This includes \$9.9M of contingency and \$36.5M of TEC. Half of the project’s TEC is associated with accelerator modifications. The project’s contingency is 27% of TPC and 37% of remaining cost to go.

The Project presented the BO vs BA curve which is provided below.

	13-Sep	14-Sep	15-Sep	16-Sep	17-Sep	Total
DOE Profile [\$k]	5,900	11,000	13,100	10,200	6,200	46,400
Obligations [\$k]	5,856	10,037	10,446	8,006	2,099	36,444
Planned [\$k]	5,856	9,469	10,963	8,086	2,101	36,475



- The Project presented a list of major procurements, of which, only one is considered a long lead (>9months) item. Many of the procurements are funded by NSF and other agencies.
- The project has 17 control account managers (CAMs) managing a total of 24 control

accounts, of which, two are complete. One CA is ~\$12M, and the other CAs range from \$1 to 2.5M on average. The average base costs (not including contingency) is about \$2.14M/CAM.

- The Project adjusted the measured performance to match actuals through April for most control accounts. Basically set $P=A$.
- A large fraction of the project's M&S cost is attributed to contract labor, and overall the project is approximately 50% labor driven.
- The Project Team is actively using Cobra to produce earned value related data, but no formal variance analysis has taken place.
- The project has performed Monte Carlo analysis on all project costs. The project's cost is within a 90% confidence level.
- The review team found some discrepancies in the cost data provided in the BOEs, P6, Cobra and/or the supporting documentation.
- Earned Value training is being provided to the CAMs on an ad-hoc basis during project meetings by the Project Manager.
- The Project has yet to clearly define and document their Estimate at Complete (EAC) process.

Comments

- The CAMs are to be commended on taking ownership of their costs, schedules and BOEs, regardless of the discrepancies uncovered during the drilldowns.
- The BOE Crosswalk prepared by the D30 Installation CAM was an excellent resource used during the drilldowns to explain how his cost estimate was prepared.
- The ratio of CAMs to control accounts seems excessive, given the average amount of base costs per CAM. An excessive number of CAMs has the potential to lead to complications in executing EVM on the project due to all the oversight that may be required.
- The cost and schedule review team was provided guidance on navigating the cost data in the BOEs and P6 after the drilldowns revealed some errors. The Project should consider presenting the BOE to P6 methodology up front in the presentations.
- Many of the discrepancies discovered during the drilldowns were attributed to modifications, such as setting $BCWP=ACWP$, performed by the PM. The CAMs

were unaware of these modifications and thus unable to speak to the cost estimate presented in the tools (P6 and Cobra) with confidence. These modifications also made it difficult for the review team to assess the Project's performance with respect to EVM.

- CAMs showed proficiency in statusing and use of the tools currently available to them. However, they have not demonstrated the ability to analyze variances.
- The Project's current method of EV training provided to the CAMs is not considered best practice, and there was a lack of knowledge with respect to EVM demonstrated by some CAMs.
- The Project team has been gradually implementing different steps of EVM, but has yet to process a full monthly cycle of EVM (including the qualitative analysis for all variances, monthly report, and freezing the baseline). The CD-2 Review expectation is that the project has performed a full monthly cycle or two before hand to ensure the project team has their EVM process ready for implementation.
- The Project in conjunction with the laboratory is currently reviewing standardization of the EAC process.

Recommendations

13. Include slides that discuss the methodology for the preparation of the basis of estimate documentation and how this was integrated into P6 and Cobra. This information should be understood by the entire project team in preparation of the CD-2/3 Review.
14. Provide formal EV training to all CAMs (regardless of home institution) and perform multiple practice drill downs prior to the CD-2/3 Review to ensure
 - 14.1 A basic understanding of EVM,
 - 14.2 Driver comfort during drilldowns, and
 - 14.3 Ease of documentation accessibility.
15. Determine and apply the Project's approach to performing EAC. This process needs to be defined and applied within six months post CD-2/3 Approval. The EAC process will enable the project to successfully monitor their estimates, especially if their goal is to recoup contingency for proposed enhancements.
16. Clean up all BOE, P6 and Cobra data to ensure the integrity and consistency of the data within each tool.
17. Process at least one full monthly cycle of EVM reporting and analysis to ensure the proper procedures and tools are in place. This will instill confidence in the CD-2/3 review team that the Project is ready to go from day one of ESAAB Approval.

3.2 Schedule

Findings

- The project's WBS is broken down at Level 2 into four major areas: accelerator, ring, equipment transfer and detector. Equipment transfer, WBS 476.5, has been completed.
- The project has developed a resource loaded schedule (RLS) in Primavera P6 that consists of 2,849 activities. 548 of these activities are constrained, 20 are missing predecessors and 178 are missing successors.
- The Project Team built in three months of schedule contingency within the discrete activities and two years of schedule float on the CD-4 date.
- The schedule milestone structure covers off project interfaces, scheduled shut-downs, fiscal year boundaries (for funding purposes) and completion of key activities.
- The project presented a critical path for Accelerator, Ring and the Detector L2 elements. The Accelerator critical path was manually derived using "dummy" activities.
- The CAMs have been reporting schedule performance against the schedule since October of 2013.

Comments

- The Accelerator team clearly understood their schedule and scope.
- Schedule is generally logically driven. However, there are several activities and milestones used to "adjust" the schedule that obscures the critical path using constraints and lags.
- The schedule log showed 548 activities of 2,849 have constraints, which calculates to 19% of the schedule. This seems excessive for a logically driven schedule.
- The interviewed CAMs could not speak to their critical path that was posted on the project web site from P6 (although Accelerator L2 Manager could speak to what she believed her critical path should be) due to the lack of understanding of the methodology used to arrive at the critical path.
- When CAMs were asked about lag in their schedules they had no idea why the lag was there, also when asked about the Earned Value Technique that they were using on their activities we got different answers such as: "it was chosen by the scheduler", "I don't know", and another said they used "steps" (but when we looked it was percent complete).

- The PM could not justify the stated assumption that the schedule reflects an 85% confidence level. The project has yet to perform Monte Carlo analysis on the schedule to determine the true float need to ensure 85% confidence in the schedule.
- During the drilldown a CAM stated that he updates the status on a monthly basis but doesn't receive any feedback afterward.

Recommendations

18. Perform general cleanup of the schedule logic (remove unnecessary constraints and open ended logic, provide explanations for all constraints, leads and lags, and remove dummy activities to show true critical path). The project can utilize the notes field in P6 to document the lead, lag and constraint explanations. The project team should address these issues before the CD-2/3 Review.
19. The review team recommends that the CAMs and the scheduler work closely together when updating all codes, lags, logic and structure of their schedule so that all parties are aware of all details in the schedule.
20. Update completed areas in the BOE, making these easily identified in future reviews to prevent choosing completed work for drill down demonstration.
21. CAMs need to practice performing horizontal and vertical drilldowns, with the assistance of the scheduler, within the schedule to demonstrate schedule integrity (logically linked).
22. Project controls needs to provide CAMs the end product of their monthly schedule status for validation.
23. The laboratory needs to finalize and release a CAM handbook as soon as possible.

4.0 ESH&Q

Primary Writer: Amber Kenney

Contributors: Jemila Adetunji

Findings

- The Project Management plenary talk highlights the integration and implementation of ESH&Q. The ESH&Q overview talk discusses ES&H and mentions the Quality Assurance Plan.
- Self-assessment activities are the responsibility of the L2 managers.
- Documents required for CD 2/3 are written and include the Quality Assurance Plan and the Hazard Analysis Report.
- Many subproject presentations include ESH and QA overviews.
- Most in-process activities which have Quality Controls in place have related documentation in DocDB, and there is a process to qualify vendors.
- L2 managers communicate weekly with collaborating institutions about quality related issues. Those institutions document their QC results in their own internal databases. This is also monitored by the PM and L2 managers.
- S/CI considerations are included in the QA Plan.
- A (Magnetic) Field Integration Coordinator role is being established to coordinate all installations near the magnetic field. He/she will verify that self-checks/QA activities are being done relative to the MC1 installations.
- Training is managed through the ITNA process. Employees' ITNAs are completed through line management, and the Project Manager completes ITNAs for visitors.
- MC1 JHA is required reading for all who work in the area. The Installation Coordinator posts hazards daily and meets daily to discuss activities and hazards.
- The removal and replacement of the dump in the target area is a new operation. The existing dump will be contained and stored on site indefinitely.
- Lessons learned activities seem to be engrained in the project activities as is stated in the QA plan.
- For example, the Installation Coordinator's visit to BNL prior to the ring removal, BNL ring installation procedure review, BNL personnel part of g-2 project team.

- Comments from CD1 Director's Review stated that the ARR and SAD should be added to the project milestones.
- Recommendations from last review were all completed.

Comments

- Breakout presentations should include references to QA- and ESH-related documentation.
- The g-2 document database contains some procedures, JHAs, etc. It would be helpful to have a few good/relevant examples of JHAs, procedures, reviews, meeting minutes, etc. on the DocDB reviewers' page.
- Weekly project meetings with project managers and collaborating institutions provide a good opportunity to assess quality requirements and objectives.
- The daily installation schedule at MC1 includes links to the JHAs and procedures. This is a best practice!
- The proposed position of (Magnetic) Field Integration Coordinator is a good idea and will help ensure quality objectives are met.
- Future activities should continue to consider lessons learned and specifically incorporate them into JHAs and procedures.
- Consider incorporating references to QAM 12020 to implement S/CI program.

Recommendations

24. Implementation of the QA Plan should be discussed in the ESH&Q talk. A draft slide has already been developed.
25. Ensure that all necessary ESH and QA/QC documents are controlled and on the g-2 (or other relevant) document database.
26. Add a breakout talk about the Accelerator installation activities.
 - 26.1 Include ESH and QA considerations in the all installation-related talks.

27. Add some information about the dump removal and its hazards to the Accelerator overview talk (or a breakout talk such as installation), and add hazards associated with the dump removal to the Hazard Analysis Report.
28. Clarify that ARR, SAD, etc. are off-project and included in the Transition to Operations Plan.

5.0 Management

Primary Writer: Ken Stanfield

Contributors: Marc Kaducak, Nancy Grossman and Ruben Carcagno

Findings

- The g-2 Project is led by Project Manager Chis Polly and Deputy Project Manager Wyatt Merritt. All Level 2 managers and Level 3 managers have been identified and are in place.
- The project organization parallels the WBS structure and therefore is aligned with project deliverables.
- The Level 2 Accelerator project cost estimate represents ~50% of the total project base cost. The L2 Accelerator manager is also Coordinator for the \$55M Muon Campus Program projects upon which the g-2 Project depends. This program is carried out by the Accelerator Division as AIP and GPP projects. There are a number of mechanisms in place, such as a PMG, the POG, and interface milestones, to assist in the coordination of the Muon Campus Program and the g-2 Project.
- Elements of a staffing plan, such as labor profiles over the life of the project, were presented. Much of the labor for the project is provided by Fermilab through its Divisions using a matrix approach.
- KPPs, both threshold and objective goals, have been defined. The project plan as represented in the base estimate is designed to achieve objective goals.
- The proposed DOE Total Project Cost is \$46.4M including a contingency of \$9.93M. This contingency allocation (37% on costs to go of \$26.48M) is based on a maturity of design approach estimated in a bottom up manner plus a top down component based on the analysis of risks.
- The cost estimate for the Project Management Office is \$3.77M.
- Early project completion is scheduled at the end of Q2FY17 with a CD-4 date of Q3FY19.
- The project management tools P6 and Cobra are in use to support project managers when making decisions.
- The project has twenty-five (25) Control Accounts with sixteen (16) Control Account Managers.
- The proposed baseline schedule requires the start of construction in FY14. Among the activities that should proceed are: D30 reconfiguration work, procurements for a number of subsystems (injection and precision field), and

- making purchases of new capital equipment, for example PLCs and vacuum pumps.
- The Project Manager is also fulfilling the Risk Manager role.
 - The Project team presented a Risk Management Plan describing the process for managing risks for the Project. A risk assessment has been completed and documented in the Project Risk Register. Both threats and opportunities have been addressed.
 - The Project presented a list of documentation deliverables required for CD-2. All documents are complete or in process except for the Requirements Document which will be developed and completed by the first week in July 2014.
 - Interface milestones for the deliverables from the Muon Campus AIPs and GPPs have been developed. The g-2 Project Manager monitors progress with Muon Campus monthly reports and PMG (Project Management Group) meetings.
 - There are 4 Muon Campus AIP Functional Requirements Specifications documents that are approved by stakeholders.
 - If all opportunities within the risk matrix were to occur, the schedule would be advanced by 3.5 months and if all risks within the risk matrix were to occur, there would be 9 months of delay in the early completion date.
 - The L3 Beamline WBS drives the critical path. That path has been stretched 3.5 months relative to the resource-leveled, technically driven schedule. There is roughly 10 months float between ring completion and the accelerator beamline completion.

Comments

- The Management team is a strong one having relevant experience with g-2 and with the accelerator systems that are needed for the project. This team is fully capable of delivering the project scope on schedule and within its budget.
- The organization structure is suitable for managing the project and is aligned with the WBS and therefore with project deliverables. All managers down through L3 are identified and in place. There is a need for succession planning.
- Fermilab management understands the advantages and risks of managing the Muon Campus Activities and is working to ensure success of the integrated program. They recognize the need to manage the interfaces and dependencies and have processes in place to do so.
- The proposed base cost estimate of \$36.47M seems complete, and reasonable. A 37% contingency (\$9.93M) on cost to go (\$26.48M) is based on estimation uncertainty (maturity of design) in a bottom-up approach plus a top down risk

based component. This contingency is considered to be adequate at this stage of the project. In addition, a list of scope options has been developed which could reduce cost by \$4.25M by decreasing scope or increase cost by \$2.094M by adding scope should the project have adverse or positive cost experience respectively. These scope options provide additional confidence in the cost estimate.

- The Project Management Office cost estimate of \$3.77M plus a 10% contingency is considered reasonable and complete.
- The project management tools P6 and Cobra are in use to support project managers when making decisions. The EVMS system is being exercised now; plans are to prepare monthly reports for May and June by the DOE CD-2/3 review.
- The number of Control Account Managers (CAMs) is large for a project of this size. Each CAM will require EVMS and CAM training and must keep up with evolving practices. Consider reducing the number of CAMs to improve efficiency of managing EVMS related activities.
- The resource loaded schedule has been prepared using the P6 tool. We were told that this schedule has 3.5 months of float relative to the early completion date of Q2FY17. The committee judges this schedule to be aggressive. The project has not yet developed its own quantitative view of the confidence level of the proposed base schedule. However, there is an additional 24 months of float in the schedule relative to the DOE CD-4 milestone date which we judge to be achievable with very high confidence.
- Scope should be increased only after primary risks have been retired and cost experience allows an adequate contingency to be maintained even after incorporating new scope.
- The proposed threshold and objective KPPs represent reasonable goals for the completion of the project. Threshold goals are associated with readiness for installation and Objective goals are associated with readiness for commissioning with beam.
- The risk register should explicitly include a risk for the impact of a possible ES&H incident.
- The overall project design maturity was presented at 55%, and is expected to reach 72% by the DOE CD-2/3 review. These assessments were based on the budget of hours for engineering work. The project should also assess the number of subcomponent design reviews that are needed as well as those that have been completed.

- The g-2 Project will be ready for CD-2 and CD-3 after recommendations from this review are addressed.

Recommendations

29. Prepare a more quantitative analysis of the likelihood of achieving the proposed baseline schedule and its early completion date.
30. Complete all required documents and obtain required signatures prior to the DOE CD-2/3 Review.

6.0 Charge Questions

6.1 Is the Project's design appropriately developed and documented in the Muon g-2 Technical Design Report (TDR)?

Accelerator WBS 476.2 – Yes, the Project's design is appropriately developed and documented in the Muon g-2 Technical Design Report.

Ring WBS 476.3 – Yes, the G-2 Ring Technical Design is very mature in all WBS elements, most are well into final design development, and the others have mature preliminary engineering designs. The design is well and clearly documented in the Technical Design Report.

Detectors WBS 476.4 – Yes, the detector design is appropriately developed and documented in the TDR.

Does the design satisfy the performance requirements to carry out the scientific mission?

Accelerator WBS 476.2 – The Muon g-2 Project designs laid out in the Technical Design Report appear to satisfy the performance requirements to carry out the scientific mission. The individual technical designs of the narrowly defined Muon g-2 Project as presented at this review satisfy the corresponding TDR requirements. We note that the scope of the Muon g-2 TDR is considerably larger than that of the narrowly defined Project and that overall success of the Muon g-2 scientific mission is dependent on multiple supporting AIP and GPP projects.

Ring WBS 476.3 – All of the designs build upon existing components, technologies, and experienced collaborators from E821. By refurbishing and making key component and system upgrades, sub-systems are predicted to achieve the required performance improvements that will meet the scientific goals of the Project.

Detectors WBS 476.4 – Yes, prototypes of many of the detector components were built and tested and demonstrated that the performance requirements are already met, or can meet the requirements with any final design changes.

Is the final design sufficiently mature such that the Project can initiate procurements and start construction?

Accelerator WBS 476.2 – Yes, the design status of the Muon g-2 Project is sufficiently mature to finalize designs, initiate procurements, and start construction. Some integral activities are already underway using OPC funding.

Ring WBS 476.3 – In most cases, construction and testing of new designs is under way; in others, at least prototype systems have been built to demonstrate the level of performance. Most of the designs are sufficiently mature to proceed with construction.

Detectors WBS 476.4 – Yes, the final design is sufficiently mature for many components to initiate procurements and start construction. In fact, NSF- MRI funds have already been used for long lead items such as the procurement of the calorimeter crystals and the expected procurement of the SiPMs, in the fall.

What outstanding design risks remain?

Accelerator WBS 476.2 – No significant outstanding design risks remain.

Ring WBS 476.3 – Some additional R&D is ongoing to advance the final design, but technical risks are generally low in these cases and risk mitigation strategies are clear. The greatest risks, related to performance of the SC coils and Inflector have been mitigated to the extent possible, and cannot be further addressed until systems are in place at MC-1 to determine whether any problems exist.

Detectors WBS 476.4 – The prototype version of the laser calibration source monitor electronics has not yet been tested, and the light distribution system performance is close but has yet to demonstrate the 0.1% required performance. These should be achievable but may require additional work and testing.

For those elements of the design that are not yet finalized, has the Project shown that there are no major risks or issues that impede a clear path to a final design?

Accelerator WBS 476.2 – Yes, the Project has shown credible paths with acceptable risks and mitigation plans to achieve final design for the few items not already at that stage.

Ring WBS 476.3 – No remaining major outstanding risks are believed to exist, or have been identified by reviewers.

Detectors WBS 476.4 – The project is on a clear path to a final design, the test beam planned for July at SLAC should allow all prototype detector subsystems to be tested, to demonstrate that the all performance requirements are met. For any components that need further work, there is sufficient time in the schedule to finalize and test them. The team, and especially the former E821 members, has enough experience so that any remaining issues should not be a problem.

6.2 Has the Project developed a resource-loaded schedule that includes the Project's full scope of work? Is the schedule realistic and achievable?

Yes, the project has a resource loaded schedule that includes the full scope of the project, along with key interface points to AIP/GPP projects that could impact the project's success. We believe the schedule is achievable based on the two years of float assigned to the CD-4 milestone. However, the review team believes the project should perform quantitative schedule analysis using the Laboratory's risk tool to ensure that the schedule contingency assumptions are valid.

6.3 Are the cost and schedule estimates complete and credible? Do they include adequate scope, cost and schedule contingency?

The project has developed a fully resource loaded schedule based on scope defined during this review. The schedule's integrity is fairly sound; however, there are areas that require further analysis to ensure the project's critical path(s) is clearly definable and owned by each CAM without unneeded manipulations. The project's basis of estimate documentation requires some fine tuning to minimize errors/omissions. The review team believes that two years of schedule contingency is more than adequate to achieve project objectives. However, the review team believes that the project should perform **quantitative** schedule analysis using the Laboratory's risk tool to ensure schedule contingency assumptions are valid.

6.4 Has the Project documented the Basis of Estimate (BOE) that supports the baseline cost and schedule presented?

Yes, however there are instances of inconsistencies between the BOE, P6, Cobra and supporting documentation. A strong effort should be made to clean this up for drilldown traces to alleviate any cause for concern with respect to the project cost estimate.

6.5 Is the scope of work clearly defined between what is funded by DOE or NSF, and is this reflected in the cost, schedule and risk assessment presented to the committee?

Yes, the funding from DOE, NSF and other sources is clearly defined and reflected in the cost, schedule, and risk assessment documentation as presented to the committee. The funding scope differentiation is also clearly defined in the scope documentation such as the WBS Dictionary.

6.6 Has the Project implemented Risk Management by identifying risks, performing a risk assessment (qualitative and quantitative) and developing mitigation plans?

Yes. The risk registry has been reviewed and updated since CD-1. 44 risks were realized or retired, 2 opportunities have been realized, and one risk added. Moving forward, risks will be revisited at monthly meetings.

6.7 Is CD-4 achievable with the Project's risks and within the DOE approved Total Project Cost?

Yes. There is 37% contingency on the costs remaining. This seems adequate especially given that the storage ring and pbar target design efforts are modifications to an existing system and people familiar with the initial operations of these systems are on the project.

6.8 Has the Project updated required project management documents per DOE Order 413.3B for CD-2/3 and per the Fermilab Project Management System?

Yes, the documents are in an appropriate state for this stage. All documents are either in process or complete. The PEP and PMP need to be finalized and a standalone controlled requirements document is being generated. All documents should be signed prior to the DOE CD-2/3 review.

6.9 Are the Project organization and staffing levels adequate to initiate construction and manage the work to achieve CD-4?

Yes, the project has identified the required staffing resources in the RLS, the sources of the labor resources have been identified and the current staffing level is tracking the plan.

6.10 Are ESH&Q aspects being properly addressed at this stage?

Yes. The CD 2/3 requirements, update QA Plan and Hazard Analysis Report and prepare Construction Project Safety & Health Plans, are completed. The QAP and HAR are final and need approval. Subcontractor safety and health plans are reviewed via the procurement process. See ESH&Q comments and recommendations for more.

6.11 Does the Project's process for monthly progress reporting satisfy DOE and Laboratory requirements?

Not at this time. The project has been ramping up an effort to fully implement EVMS and has been practicing the preparation of CPRs and providing status, but has yet to implement formal change control or variance analysis. CAMs will need to be trained and practice the entire EVMS process before fully satisfying DOE and Lab requirements. EVMS implementation will be a primary challenge area for the project in the near term.

6.12 Has the Project properly addressed the recommendations from the DOE CD-1 Review, the Director's CD-1 Review and the Independent Conceptual Design Review?

Yes. There were a total of 10 recommendations from the DOE CD-1 review, 26 recommendations from the Director's CD-1 review, and 8 recommendations from the Independent Conceptual Design Review. The review committee was shown response actions for each of the recommendations during the project management breakout sessions, including recent status updates from the initial response. The committee believes that the project has properly addressed the recommendations from previous reviews.

6.13 Is the Muon g-2 Project ready for a DOE CD-2/3 review in July?

Yes, following consideration of the recommendations contained in the body of this report, most notably those relating to:

- Schedule confidence level
- EVMS demonstration
- CAM structure, training, and deployment
- Requirements documentation
- Balance between technical/cost/schedule content of the presentations