Technical Design Review of the Mu2e Beamline, Controls, and Instrumentation

Summary:
The Mu2e project received CD2 in March 2015 (along with 3b for long lead procurements) and anticipates complete CD3 for the remaining aspects of the project in 2016. As part of the CD3 requirements, the project is conducting a series of external independent design reviews for each major subsystem. This review, concentrating on the beamline (transporting protons from the Delivery Ring to the target), beam instrumentation, and controls is a part of that series.

The committee commends the project team on having accomplished a significant and impressive amount of work, which was clearly presented in an informative, relevant, and detailed manner. While there are small things yet to clean up, the committee feels that the beamline, controls, and instrumentation areas of the accelerator WBS are prepared to proceed to CD3.

Answers to Charge Questions:

1. Is the technical design of the Mu2e beamline, controls and instrumentation technically sound? Have all the principal issues been appropriately evaluated, simulated, and calculated? Are all of these issues properly addressed in the design?

Yes, the technical design is sound. As requirements were not directly addressed during the presentations, it is difficult to judge if all principal issues have been evaluated, simulated, or calculated. Issues presented during the presentations have been properly addressed.

2. What are the technical risks of the design? Have all of the technical risks been accounted for? Have these risks been properly evaluated and have mitigation plans in place?

The committee feels that few significant technical risks remain. The risk register identifies few technical risks associated with the Accelerator and no technical risks associated with the Beam lines/Controls/Instrumentation. The risks that have been identified appear to have appropriate mitigation strategies in place.

3. Is the technical design of the Mu2e beam lines, controls and instrumentation on track to satisfy the requirements for a DOE CD3 review in early CY 2016?

Yes.

The review committee presented Findings, Comments, and Recommendations to the project in 4 separate topical areas (Optics & Lattice, Controls & Instrumentation, Technical Components, Risk & Management), with the following definitions:

- Findings: Statements of fact about what was heard; the reviewer wants to emphasize something to the reader; this may provide the basis for a follow-on comment and / or recommendation
- Comments: Opinion / judgment based on the reviewers experience, background, or expertise. Comments do NOT REQUIRE a specific response.
- Recommendations: Opinions / judgments where the reviewer expects the Project Team will provide a specific response as to the disposition of the recommendation to upper management.

A total of seven recommendations result from this review.

Committee:

Herman Cease, Paul Derwent (chair), Giulio Stancari, Alexander Valishev, Robert Webber, Al Zeller

Optics & Lattice

A. Valishev, G. Stancari

Findings:

The requirements and constraints for the design of beam optics of Mu2e beam transfer line were presented clearly. The presentations addressed extraction from the Delivery Ring, transport through the M4 beam line (including the diagnostic branch), and focusing of the beam on to the production target. The necessary reconfiguration of the extraction section in the Delivery Ring and the analysis of extracted beam orbit were shown. The baseline lattice of M4 beam line satisfies the design constraints. Error analysis was performed for off-energy particles and element misalignments. The lattice of the final focus region provides the specification of the aperture and movable components. The layout of the instrumentation elements was reported.

Comments:

The committee appreciates the clarity and thorough analysis of the material presented in the Technical Design Report and in the review presentations.

The design of beam line optics is critically affected by the interplay with other systems, in particular, the extinction system and the position and angle scan at the target. The ability to cover the range of ±0.8° in angle scans is challenging in terms of requirements on aperture and magnet field quality. The beam line design team is interacting with the group in charge of muon production simulations to consider ways to loosen the requested angle range. The committee encourages further effort in this direction.

The extinction system is a critical component of the project and will be reviewed separately. However, it does have implications on the beam line optics tolerances and commissioning strategy. We encourage a careful comparison of the specifications of the extinction system (once they become available) with a comprehensive error analysis.

A concise presentation of a commissioning plan addressing the optics challenges and low beam intensity would be beneficial as part of future reviews.

Recommendations:

1) Perform error analysis of the beam line optics including the full set of imperfections: magnet tilts, field calibrations and if practical, higher order field effects in the Delivery Ring extraction and final focus sections.

2) Do a beginning-to-end integrated calculation, including the effect of Production Solenoid on the optics of the final focus and beam transport.

Controls & Instrumentation

R. Webber, P. Derwent

Findings:

Controls –

The controls systems required for Mu2e will utilize, almost entirely, re-purposed equipment that has a long operational history in other Fermilab applications. Some designs are quite dated, but sufficient spares are available to support an acceptable operational lifetime. Should problems arise, newer designs for most systems are readily available at Fermilab, e.g., an Ethernet based abort concentrator hardware.

The choice to re-use existing systems of older design was based on minimizing cost.

Extensions of the required controls network infrastructure are based on proven, existing designs.

The Mu2e beamline project places no new demands on either the high level layers of the control system or on the central services that system now provides.

Instrumentation –

The beam instrumentation suite to be delivered by this project includes a DC beam current monitor and a Schottky tune monitor in the Delivery Ring and ion chamber intensity monitors, ion chamber beam loss monitors, and multiwire profile monitors in the M4 beam line.

Presentations on each instrumentation system were clearly delivered by the respective technical specialists.

Instrumentation systems will almost entirely use either existing equipment or equipment based on existing designs that have been proven in similar Fermilab applications.

The primary risk described for the beam instrumentation is uncertainty about the effects of strong 'leakage' magnetic fields from the production solenoid on nearby wire monitors and actuators.

A concern was voiced that the new design for vacuum windows to be used on the ion chamber anti-vacuum boxes has yet to be tested.

Comments:

The Controls and Instrumentation upgrades build upon and make extensive use of existing hardware and designs. As such, the technical designs are proven and the remaining questions are in implementation.

The project has applied Lessons Learned from the work already done for g-2.

Controls –

The controls systems required for the Mu2e beam lines are well understood and the deliverables are based on existing equipment in most instances and on existing and proven designs otherwise.

For controls hardware in the Delivery Ring, the project will continue to use legacy CAMAC hardware and software. Vacuum controls will continue to use the legacy CIA crates, backplanes, and cards. This choice passes operational risk and responsibility to the laboratory.

The controls system designs presented for the Mu2e beam lines are appropriate and sound, low risk, and well on track for CD3 review in 2016.

Instrumentation –

The selected designs for the beam instrumentation are sound and appropriate for the project's needs.

The decision to use repurposed equipment for nearly all instrumentation systems is technically and financially sound. This equipment has a proven performance record in similar applications and has an available support and maintenance infrastructure at Fermilab.

The concern over the as-yet unproven vacuum window design is appropriate, but not a major issue for meeting project technical or schedule demands. The expectation is that a prototype will be ready for testing within a few weeks. There is adequate float in the Mu2e schedule should problems be discovered and the g-2 project needs a solution for this same design much sooner than Mu2e. The risk associated with deleterious effects on instrumentation of the production solenoid magnetic field is appropriately recognized and the need to resolve the concern is understood.

The principal issues related to beam instrumentation appear to be adequately understood and addressed.

The instrumentation system designs presented for the Mu2e beam lines project are appropriate and sound, low risk, and well on track for CD3 review in 2016.

The suitability of the beam instrumentation designs for Mu2e would be more easily reviewable if a listing of minimum quantitative requirements (e.g. for beam measurements) were included at the start of presentations. It would be informative and beneficial for the review committee if these requirements were described within the context of planned commissioning steps and operational beam modes.

The scope covers instrumentation required solely for Mu2e. Project success does depend on other instrumentation upgrades being carried out in the other

Muon Campus projects. As the L3 manager is common throughout the projects, communication should not be a problem.

Recommendations:

3) Pursue a location and test the remaining questions about the performance of the profile monitors in the fringe field of the production solenoid.

Technical Components

A. Zeller, H. Cease

Findings:

The majority of magnets already exist (62 quads and 15 dipoles) and will be repurposed to the project. Six other quadrupole magnets exist but will need to be refurbished. Three magnets will need to be built.

Because of symmetric optics designs, some quadrupoles can be run in series from single power supplies.

Significant quantities of vacuum, beam stands, diagnostic and controls equipment also exist and will be reused.

Since the beam line is a single pass device, they have identified that magnet field uniformity requirements are less strict than a ring.

The diagnostic absorber, rated for 170 W, is in place. The diagnostic absorber can take full-power beam pulses if the rate is less than 1 every 10 to 30 seconds.
The beam line is 245 m long and designed for 8.9 GeV protons. The beam line has an extinction section that eliminates unwanted particles between pulses. There are 6 horizontal dipoles that bend a total of 41 degrees. There are 2 vertical dipoles that run from the same power supply. Vacuum requirements are 5x 10^{-8} Torr.

Motorized magnet mounts are required for moving 4 dipoles up to 3” to allow scans. Movement of the 4 magnets is anticipated to be 5 times per year.

Comments:

Reusing existing components and designs significantly reduces technical, schedule and cost risks, but does open up the possibility that improvements in equipment discovered in the g-2 project will not be implemented because of capital costs. This will effectively transfer those costs to operations. Such cost shifts should be considered and realized that funding agencies will not look favorably if immediately after CD4 a large request shows up to correct these problems. These cost risks have been agreed to by the project and the laboratory.

A similar "free kitten" effect is also possible: Using more of the existing equipment than is really required and not optimizing as would be the case, resulting in operational inefficiencies.

Using an existing SDC dipole instead of a new construction MDC for the diagnostic line switching dipole is worthwhile exploring further.

Thirty existing beam loss monitors are planned to be used. There doesn't seem to be an adequate justification for this number, but more that they just happen to be available so we'll use them.

Vacuum components and magnet motion stands within the final focus region should be developed and tested in an equivalent solenoidal field as soon as reasonably possible.

The new vacuum window design seems to alleviate problems with failure due to cycling and stress induced by bolts.

Developing a more detailed installation plan prior to the CD3 review would be beneficial.

Power supply requirements seem well developed and existing supplies fulfill most of the requirements.

Continue work on reducing the ±0.8° requirements for target scans, as this will alleviate some problems with bellows and other components.

The beamline LCW system includes the cooling water for the heat and radiation shield in the production solenoid. Initial calculations indicate that this cooling water will not be activated so it is tied to the rest of the LCW system. This choice does reduce complexity and cost by bypassing a RAW system. It introduces operational risk if the water does become activated.

The major remaining design activities in the beamline are in the final focus section. The angle scan requirement at the target requires significant flexibility in this section in the vacuum design. There are 6 specialized beam pipe transitions identified which require additional engineering design. These may introduce cost and schedule risk as the transitions are complicated but all are technically feasible.

Recommendations:

4) Recheck the radiation transport calculations to ensure the final focus elements do not require radiation resistant coils.

5) Verify that activation of the LCW flowing through the HRS will not introduce radioactive contamination issues when that water is mixed with the general LCW system. In particular, if the LCW is also used to cool the SCR power supplies that are not in the tunnel.
6) Prepare a justification for the vacuum requirements that can be presented at the CD3 review.

Risk & Management

A. Zeller, P. Derwent

Findings:

Several risks, although not all risks identified in the TDR, were presented.
A project organization chart was presented that located the external beam line project within the overall Mu2e project.
The budget for the accelerator systems was given as $50.2M.
An overall and beam line specific schedule were shown. CD2 was achieved in March 2015. CD3c is scheduled for summer 2016. Installation of the beam line is scheduled to begin in FY17. This date is set by budgetary, not technical, considerations.

Coordination of Mu2e Project, AIP, and GPP portions of the required beam line are under a single person.
Mu2e and g-2 have a change control system in place.

The project risk register contains seven identified risks and two identified opportunities in the Accelerator WBS. Within the scope of this review, there are only two risks (Accel-200 and Accel-201) and they are considered Very Low technical risks. The two opportunities are still being pursued. There is one retired risk (Accel-026) mitigated via the plan to use AutoTune in the beamline and one risk (Accel-014) transferred to operations.

Comments:

The risks remaining in the beamline and controls section of the accelerator WBS fall more on the cost and schedule side rather than technical performance.

Starting installation earlier would be beneficial and should be explored to see if it fits within the funding constraints.

Having g-2 running during installation of the M4 beam line will present some complications to the schedule; however, it appears the project has a plan in place to deal with it. Careful attention to ensuring a radiological incident can never happen is very important as the consequences are significant even in the absence of any injury.

Mu2e stands to benefit from the earlier installation and operation of g-2, as questions regarding installation estimates, magnet performance, and others will be addressed by the earlier project.

There were technical risks discussed in the presentations that are not present in the risk register (e.g., the vacuum windows for the ion chamber). It would be advisable to gather all these loose threads in a coherent fashion before the CD3 review.

It would be beneficial to future committees to have a presentation on how the technical requirements flow from the science requirements and how the components then meet or exceed the requirements.

Recommendations:

7) Retain in the risk register all risks identified in the Technical Design Report or address as retired. This ensures that none of them slip through the cracks.

Charge:

The Mu2e project has recently received CD2/3b approval from the DOE (March 2015). The project is in the process of completing the final design and preparations for a CD3c DOE review in early CY2016. External peer reviews of key technical elements of the project are a part of this process. Beam line design, controls and instrumentation are essential parts of the beam delivery to the experiment. The Mu2e project management would like the committee to review and comment on the current technical design. In particular, the committee is asked to address the following questions:

1. Is the technical design of the Mu2e beamline, controls and instrumentation technically sound? Have all the principal issues been appropriately evaluated, simulated, and calculated? Are all of these issues properly addressed in the design?
2. What are the technical risks of the design? Have all of the technical risks been accounted for? Have these risks been properly evaluated and have mitigation plans in place?
3. Is the technical design of the Mu2e beam lines, controls and instrumentation on track to satisfy the requirements for a DOE CD3 review in early CY 2016.

The review is scheduled for October 6-7, 2015 with presentations and discussions during the first day; additional questions from the committee in the morning of the second day and executive session in the afternoon of the second day. The committee is requested to submit a report containing its answers to the charge questions and its recommendations to the Mu2e Accelerator project manager within two weeks after the conclusion of the review.