Oct 8th 2008

Summary of the mu2e Experiment Concept Review

On September 26th 2008 the laboratory conducted a review of the "mu2e" experiment concept review subject to the following charge:

Charge:

"In preparation of the upcoming proposal of the mu2e experiment to the PAC on November 3 – 5 and in preparation for CD-0, we are appointing a team of Fermilab scientists and engineers to help us with this process. In particular we would like you to review the draft proposal to the PAC on the physics case, the proton source and beamline concept and the detector design to make a better proposal, and help identify critical R&D areas, and provide your recommendations".

The review committee team and schedule are included in Appendix A. The short duration of this review precluded a deep investigation of the science, experiment or project. Nevertheless the committee endeavored to identify critical R&D areas that the collaboration should consider and address for favorable consideration by the Fermilab PAC. The committee considered the domains listed below, and developed a non-exhaustive list of R&D important to the design, costing, and eventual success of the experiment.

Domains Considered:

- The physics case and collaboration.
- The project
- The proton source, beam-line and target.
- The solenoid systems.
- The detector
- Relationship to Project-X

The Physics Case and Collaboration.

While the physics impact of observing muon to electron conversion would be dramatic, the utility of upper limits in constraining new physics models is less clear. The committee recommends that the collaboration enhance their efforts to describe how both an actual measurement and upper limits interact with other timely measurements, most notably at the LHC, to determine and constrain parameters of new physics models. This case will be particularly important in the early phase of the experiment which will likely be a program of ever-improving upper limits in pursuit of an eventual discovery.

By necessity the experiment is tuned for observation of muon-to-electron conversion which tightly constrains the breadth of an eventual research program. Operation with different stopping targets would add breadth to the program, but the experiment is highly optimized for an aluminum stopping target. As designed the experiment has no detector acceptance for decay electrons with momenta substantially less than the conversion momentum (about 100 MeV/c) which precludes, for example, a program to measure $\mu \rightarrow eee$ or precision measurement of the Michel decay parameters both of which are windows to new physics. A more straightforward step to a broader program would be enhanced instrumentation of the stopping target which might support an advanced research program of muonic x-rays.

It is clearly naïve to imagine that the research program can be broadened with simple extensions of the detector as designed. Nevertheless, the experiment will be operating at the world's most luminous source of muons through at least the next decade, and it is worth considering how this resource can be exploited to develop a broader program through running with special beam and detector configurations and/or the addition of instrumentation.

Achieving the proposed muon-to-electron conversion sensitivity will be daunting challenge. The collaboration will need to grow in expertise and number to develop and deliver this research program in a timely way.

The Project

The committee regards a slow start to be the greatest risk to the project and the eventual success of the experiment. The project requires several years of construction after the necessary R&D is complete. The committee concurs with the project's assessment that the solenoid magnet systems are and will be the critical path in the overall schedule. The committee recommends that the project and laboratory explore mechanisms to advance the magnet schedule, possibly through collaboration with international partners and/or mechanisms to forward-fund the R&D phase of these critical magnet systems.

The committee recommends that the laboratory work to quickly staff key positions in the project office.

Regarding costs, the project presented a single cost estimate and at this stage they should be working with a cost-range.

Regarding scope, the experimental technique requires close integration with the Fermilab accelerator complex. The project should work closely with the Fermilab accelerator division to determine what is the appropriate project scope, and where the project relies on development of the accelerator complex. One example of this interdependency is the upgrade of the Booster from 10 Hz (which is required by Nova) to reliable 15 Hz operation which is necessary for mu2e operations. This Booster upgrade is proposed to be outside the scope of the mu2e project. Another example is the discussion of a 100 MeV electron linac to serve as a calibration source which is not in the project scope and not part of the accelerator division infrastructure plan.

The Proton Source, Beam-line and Target.

R&D tasks and issues important to the timely start of construction and eventual success of the experiment:

The committee recommends that the collaboration and accelerator division embark on a quantitative analysis of the high current performance of the modified Debuncher/Accumulator (D/A) complex. The beam current required for the mu2e experiment is x300,000 higher than the beam current of present anti-proton operations. To date, space-charge effects have not been explicitly considered in the modeling of injection, RF manipulations, and extraction of beam from the modified complex. Modeling of these collective effects should be pursued in the near future.

The modified D/A complex operating at this relatively high beam power will require a fast loss-detection and beam abort system and an associated high power beam dump. The committee recommends that the project work with the accelerator division to develop, design, and cost this beam abort system.

The current physical location of the extinction channel is motivated by wetland considerations. The committee recommends that background rates induced by the extinction channel should likewise be a leading consideration in the physical location of the extinction channel.

There appears to be no provision for monitoring the muon production target or physical space to service the muon production target in the current design of the building. Successful operation of the target will require an appropriate space to work and instrumentation to monitor the status and performance of the production target. The committee recommends that the project and laboratory embark on this design work.

There does not appear to be a provision to trim the muon orbit as it traverses the transport solenoid and enters the detector solenoid. Some type of trim package will no doubt be necessary to deal with production tolerances in the solenoids. The committee recommends that the project embark on this design work.

An estimate of how thermal neutrons produced from the proton beam delivery system affects detector rates will be important to the design of the detector.

The level of losses associated with 15 Hz Booster operation and resonant extraction of beam from the modified D/A complex needs to be carefully estimated and a clear loss mitigation scheme needs to be developed.

A requirement should be established on the maximum variation in the number of protons and stopped muons per pulse. This will have implications on the design of the extraction system.

The removal of aperture restrictions (cooling tanks) and reconstitution of the modified D/A complex needs to be costed.

The Solenoid Systems.

R&D tasks and issues important to the timely start of construction and eventual success of the experiment:

The unfortunate loss of the surplus SSC superconducting cable asset risks further delay of the solenoid systems. The existing cable served as a constraint in the design as well as an asset. While it is no doubt true that improvement in SC cable over the past 15 years can lead to an improved design, there is now increased schedule risk associated with a new design based on a new conductor. The committee recommends that the project strive to develop strategies to involve vendors at the R&D stage, and to explore mechanisms to forward-fund this R&D.

The muon production solenoid has a strongly graded magnetic field designed to collect both the forward and backward muons produced from reverse proton beam. The graded field that reflects the forward muons back toward the transport channel results in an increase of 30-40% in the muon flux at the detector. The committee recommends that the project and collaboration explore the question: Does abandoning recovery of these forward muons substantially reduce the complexity and cost of the production solenoid system?

There is a rather stringent specification (5%) on the gradient of the production solenoid. It was not clear that this stringent requirement is necessary. The committee recommends that the project and collaboration explore the question: What are the cost and complexity implications of a less uniform field constructed from fewer than the nine nominal solenoids in the design now?

It is not clear from the designs presented how the injection of the proton beam into the production solenoid is controlled and trimmed. The beam enters at an oblique angle off the solenoid axis and must swim through the solenoid field and strike a small production target in the center of the production solenoid. It is likely that successful operation in this difficult geometry will require beam trimming capability.

In principle reverse targeting of the proton beam could be realized by injection on-axis into the transport solenoid immediately downstream of the first transport bend. This may simplify the production solenoid and the transport of the proton beam to the target.

The Detector

R&D tasks and issues important to the timely start of construction and eventual success of the experiment:

The committee recommends that the collaboration and project develop a comprehensive Monte Carlo simulation environment that can serve to address many design issues that remain, such as the detailed design of the straw-based tracker and the role of a calorimetry-based measurement of the electron energy. This simulation environment should be designed so that it is accessible and useable by the substantial expertise that exists in the collaboration today.

In developing the next generation of the simulation environment the collaboration should ensure that the framework can support the temporal development of a train of beam pulses so that the build-up and wrap-around effect of background processes can be correctly simulated.

The proposed $PbW0_4$ based calorimeter is technically quite challenging, comparable to the complexity of the tracker. Yet the requirements of the calorimeter are not clear. Discussion regarding the role of the calorimeter included a triggering capability, a fast timing reference, a downstream space-point for anchoring reconstruction of the decay electron helix, and the possibility of an independent measurement of the electron energy. Of all these possible requirements, crystal based calorimetry does uniquely serve as an independent measurement of the electron energy. The other possible requirements could be served by simpler, more robust detector and data acquisition technologies. The committee recommends that the project and collaboration work to refine the downstream electron tagging and/or calorimetry requirements of the experiment and identify technologies that can best serve these requirements.

The committee found the possibility of an independent measurement of the electron energy to be compelling, if an energy resolution at about the 1% scale or better can be achieved---a formidable challenge for 100 MeV electrons. The proposed $PbW0_4$ based calorimeter however has a resolution of 4-5% at best. An independent measurement of the electron energy would be particularly valuable in supporting a discovery claim just at the edge of experimental sensitivity where a handful of events, or less, would constitute a putative signal. With a paucity of events in this instance, the limited statistics near the signal region would confound a demonstration from the data that the non-guassian tails of the spectrometer momentum resolution function are well understood.

The committee recommends that the collaboration re-visit the design of the trigger and data acquisition system to take full advantage of high performance networking and computing technology that has become commercially available in the past few years.

Readily available commercial systems could substantially relax the requirement of a maximum trigger rate of 1 kHz, and may even support architectures where a hardware-based trigger is not necessary.

Relationship to Project-X

R&D tasks and issues important to the timely start of construction and eventual success of the experiment:

The collaboration discussed the mu2e research program in two phases, where phase-I is based on the modified D/A complex driven by the Booster and phase-II is driven by Project-X. From discussion it became clear that already handling the Booster power of 50 kW in the modified D/A complex will be a challenge, and that it is unlikely that this complex could accept the high Project-X beam power (at least 200 kW). Further the target, solenoid, and detector systems would all likely have to be next generation rather than a perturbation of phase-I systems. In recognition of this the committee recommends for clarity that the collaboration not refer to these two different eras as phases of the same experiment.

Appendix A.

Membership:

Name (Organization)	Name (Organization)
Rick Coleman (AD)	Rich Stanek (Directorate)
Keith Gollwitzer (AD)	Brendan Casey (PPD)
Sergei Nagaitsev (AD)	David Christian (PPD)
Vaia Papadimitriou (AD)	Doug Glenzinski (PPD)
Jim Amundson (CD)	Aseet Mukherjee (PPD)
Rob Kutschke (CD)	Vadim Rusu (PPD)
Paul Lebrun (CD)	Jim Kerby (TD)
Bob Tschirhart (CD) – Chair	Peter Limon (TD)

Schedule

Friday, September 26, 2008

Mu2e Review (Tentative Agenda) – Hornet's Nest on 8th Floor Crossover

08:00 Executive Session
08:30 Physics and Collaboration Overview –Bob Bernstein (30'+15')
09:15 Project Overview – Ron Ray (30'+15')
10:00 Proton source, beam extraction and targeting
—M. Syphers (20'+10')
10:30 Coffee Break (30')
11:00 Muon beam transport --Jim Miller (20'+10')
11:30 Solenoid designs and procurement – Mike Lamm (20'+10')
12:00 Detector – Craig Dukes (20'+10')
12:30 Working Lunch (60')
13:30 Review Team – Writing (75')
14:45 Closeout / Discussion (45')