AAC Closeout Report

Fermilab Accelerator Advisory Committee Meeting

February 3-4, 2009

AAC Committee

- **Members present**

  K. Harkay (acting chair), I. Ben-Zvi, G. Geschonke, R. Garoby, S. Henderson, K-J. Kim, K. Oide, T. Raubenheimer, J. Rosenzweig (day 2), H. Weise

- **Absent**

  S. Chattopadhyay, H. Padamsee

- **Outline/tasks**

  Overview: K. Harkay (lead), K. Oide

  PX Linac/SRF: H. Weise (lead), G. Geschonke

  PX Rings/other: S. Henderson (lead), T. Raubenheimer, R. Garoby

  6-D cooling: K.-J. Kim (lead), K. Oide, J. Rosenzweig

  MANX vs. mu2e/MC: I. B-Z. (lead), R. Garoby, G. Geschonke

Overall comments

- **The committee commends FNAL Associate Director Steve Holmes and FNAL staff for much progress since May AAC in developing the ICD and updated RD&D plan for Project X.**
- **FNAL is preparing for PX CD-0, anticipated in 2009**
  - **Project planning appears to be progressing well**
  - **Focus on mission need and specification of high-level goals is good approach**
  - **Investigation of alternative configurations is good**
- **It is acknowledged that many of the committee's prior recommendations have been addressed for PX.**

Overall comments (cont)

- The committee was also asked to comment on the MANX proposal, a muon 6-D cooling experimental demo sited at RAL
  - FNAL has been asked to participate
  - Committee asked to address MANX technical feasibility, schedule, and relationship to mu2e upgrade and muon 5-year plan
- Additional talks requested by the committee include: design criteria for alternative PX configurations, NML beam structure, HINS milestones through 2011, beam dynamics calculations plan, stabilization of low-beta linac, MANX demo total cost estimate.
- The hard work by FNAL staff and collaborators in preparing the material presented is much appreciated.

Overall comments relating to charge

- Observations and recommendations relating to the charge are summarized on the following slides
- More details in presentations by Task Leaders

MANX proposal

- 6-D ionization cooling in a helical solenoid version of a helical cooling channel a novel idea and very encouraging if it can provide a factor of 2 in a compact configuration
- For this application, more homework is needed; we encourage a more detailed simulation effort on the scale of one year to better understand the technology
- We endorse the approach in the Muon 5-yr plan. However, given the momentum generated by the MANX effort, we encourage the collaboration to examine all cooling schemes and start developing plans for demonstration experiments for the post-MICE phase.
- We encourage further study of the impact of HCC on the mu2e upgrade, estimated to be ca. 2020.

Muon 6-D Cooling Development

Does MANX proposal provide validation of 6-D ionization cooling, based on requirements for a Muon Collider? What is optimum mix of simulations and experimental demonstration required?

- **Observations/Recommendations**
  - **The 6D cooling experiment may be done in an alternative configuration of the magnetic field. The HCC should be compared with other schemes in terms of performance and tolerances.**
  - **Time insufficient to absorb the theory in detail, but idea is novel and encouraged**

Muon 6-D Cooling Develop. (cont)

Does MANX proposal provide a validation of a mu2e upgrade experiment based on a collection scheme that reduces “flash” deadtime and the use of the ionization-cooling energy-absorber to range out hadronic backgrounds? What is optimum mix of simulations and experimental demonstration required?

Can the MANX approach to a mu2e upgrade impact the outlook for Project X?

- **Comments/Recommendations**
  - **The mu2e timeframe allows more detailed simulations to fully understand impact of HCC on mu2e upgrade. Based on the presentations alone, the committee was unable to make a specific recommendation.**

Muon 6-D Cooling Develop. (cont)

What are the primary technical risks within the MANX proposal and are they appropriately mitigated through the development period?

- **Comments/Recommendations**
  - **Details to be addressed in next talk**

Do the MANX resource requirements appear reasonably estimated?

- **Comments/Recommendations**
  - **The estimate for the HCC magnet construction is $10M. The information presented was insufficient for evaluation.**

Muon 6-D Cooling Develop. (cont)

Given the anticipated timelines within the Muon five year proposal and the mu2e development plan, what is appropriate schedule for implementation of MANX?

- **Comments/Recommendations**
  - **Given the momentum generated by the MANX effort, we encourage the collaboration to examine all cooling schemes and start developing plans for demonstration experiments for the post-MICE phase.**

Project X ICD and R&D Plan

Does the ICD describe a configuration that is likely to meet the proposed mission objectives?

- **Observations**
  - Focus on mission needs is commendable
  - Mission needs are, in priority order: long baseline neutrino oscillation (2 MW proton source at 60-120 GeV), muon-to-electron conversion (150 kW at 8 GeV), compatibility with future upgrade to 2-4 MW at 8 GeV.
  - Project X linac beam parameters has been redefined in ICD to address mission, i.e., decoupled from ILC, as appropriate
  - Revised baseline configurations v 1.1 (60 GeV MI and 160 kW mu2e or 120 GeV MI and 225 kW mu2e) addresses greater compatibility with mu2e

ICD configuration (cont)

- **Observations (cont)**
  - **Alternative config. studies have been initiated for future PX power upgrades that are compatible with muon collider beam requirements.**

- **Recommendations**
  - **The ACD schemes, especially the one with a synchrotron, needs further evaluation of the performance and the cost. FNAL recognizes that beam power is limited in this case. Further ADC studies are encouraged.**
  - **Compare costs of Recycler rf upgrade with adding H- injection region to MI**

Project X ICD and R&D Plan (cont)

What are the primary technical risks associated with the ICD? Are these risks recognized and addressed effectively in the RD&D plan?

- **Observations**
  - **Project X is a Fermilab-led national collaboration Fermilab needs to prioritize R&D program and should require important to have clear reporting and management of critical R&D. Collaboration organization and responsibilities was not clear**
    - **1.3 GHz beta=1 cavity systems are relatively well established and national collaboration exists**
    - **1.3 GHz beta=0.8 cavities needs design effort. Collaboration is underway with Indian institutions; FNAL should maintain strong involvement. Need design study to optimization energy at transition from beta=0.8 to beta=1.**
    - **R&D program for TSR cavities was not discussed**

PX primary technical risks (cont)

- **Observations (cont)**
  - **Concern that the slow progress of HINS and dropping of SSR2 will leave gaps in the injector R&D program**
  - **Project X relies on a new linac system and reuse of the existing Fermilab ring infrastructure**
  - **Design of the new linac systems has lots of flexibility while PX team will need to design around limitations of the ring systems.**

PX primary technical risks (cont)

- **Observations (cont)**
  - Important to establish performance limits of the rings using experiments and simulations as soon as possible. Increase effort on beam dynamics and design studies for rings.
  - More beam-dynamical studies are encouraged to estimate the space charge tune shift and beam loss in the rings, electron-cloud effects, and requirements on beam diagnostics.
  - Establish stronger collaboration to test beam instrumentation at SNS (coordinate with maintenance periods)

PX primary technical risks (cont)

- **Recommendations**
  - HOM dampers needs careful attention and proposal to eliminate them should be approached with caution
  - RF input couplers need considerable work
  - Electron cloud expected to be an important effect according to simulations – experimental program is appropriate. Bunch-by-bunch tune shift diagnostic may be useful, widely used and should be at least as sensitive as microwave transmission measurement. Better understanding of appropriate modeling input parameters is essential for accurate prediction for PX parameters.
  - Once Linac/Booster are replaced by PX linac, choice of rf frequency for RR/MI could be reexamined and optimized for things like cost and electron cloud mitigation (EC accumulation is sensitive to bunch spacing).

Project X ICD and R&D Plan (cont)

- **Is the RD&D plan appropriately integrated with the ILC, SRF, HINS, and Muon programs?**

- **Observations**
  - **Hardware and infrastructure development plans for both SCRF and HINS should be better aligned with Project X goals. Project X will be a large undertaking and will need focused resources.**
  - **Present progress of SCRF and HINS programs are aggressive and much progress has been made, although progress appears slower than desired.**
  - **Focus on more limited HINS program well aligned with PX program. Concern is that low energy (30 MeV) removes opportunity for important study of beam halo generation.**

RD&D integration (cont)

- **Observations (cont)**
  - ILC cryomodule type 4 adopted for PX beta=1 linac. The linac lattice and cryomodule design should be modeled and optimized.
  - PX cavity and CM development represents a path forward for U.S. industrialization. Better statistics needed!
  - ILC SRF program exceeds cavity/cryomodule test requirements for PX

RD&D integration (cont)

- **Observations (cont)**
  - **Clarify role of electron beam R&D within the lab. What are motivating applications? How does the RD&D plan address them?**
  - **Beam tests in NML can be relevant for evaluating HOM damper issue for PX if electron gun can produce PX bunch structure. HOM tests can potentially be studies elsewhere as well, e.g., at SNS.**
  - **Integration with Muon program not evaluated at this time**

Summary

- FNAL has made good progress in a mission-based configuration design and technical specifications for PX.
- Alternate configuration studies should continue, including cost and performance analyses.
- RD&D plan addresses many technical issues. However, greater beam dynamics and system design optimization modeling should be emphasized in several areas. Plan for hardware and infrastructure integration with ILC SRF, HINS is needed. Integration with NML should be defined.
- We encourage more work on HCC and evaluate its role with respect to muon programs in more detail.
- Committee thanks the FNAL directorate for its hospitality during this review.

MANX and Mu2e

Ilan Ben-Zvi

Roland Garoby

Gunther Geschonke

James Rosenzweig

Findings

- We heard excellent presentations delivered with passion. It is a great experience.
- NFMCC and MCTF are strong, international and productive activities.
- The collaborations are pursuing a broad, well managed R&D plan, including design, simulations and component testing.
- The physics potential of NF and MC are compelling.

Findings

- Mu2e physics potential is very impressive.
- A design is in place based on the cancelled MECO. A large investment exists in that.
- The benefits to Mu2e from Project X is enormous. MANX adds even more reach, we were informed of 2 orders of magnitude.

Findings

- The NFMCC and MCTF's five year plan calls for
  - MC feasibility study in 2013.
  - NF RDR by 2012.
  - Hardware development is needed to inform MC DFS and NF RDR
    - Cooling down-selection, complete MICE.
    - Other work: RF, magnets, absorbers, target.
    - Cooling channel components and plans.
    - Biggest challenge: High RF gradient in strong magnetic fields.

Findings

- **The HCC concept:**
  - it is a very valuable new idea that can be applied in numerous parts of a Muon Collider, as well as in physics experiments (e.g. Mu2e).
  - it is however impossible in the time frame of an AAC meeting to appreciate all implications and the limitations.

Findings

- The Helical cooling channel, of which MANX is a demonstration, one possibility to achieve the required muon cooling. The theoretical studies need to be complemented by experiments. If this is successful, it would be a great step forward towards the feasibility demonstration of a muon collider.
- Issues:
  - magnetic channel
  - RF system. For the MC, this is 1.5 GV system, which has to work under adverse conditions.
  - both need major R&D effort

Findings

- MICE expected to be done 2013. And, based on past progress, is expected to slip.
- Select baseline 6D channel in year 3. After selection, build and bench test cooling channel section.
- The MC collaboration plan is that 6D cooling experiment should start only at year 5, after the bench test, end to end simulations and planning of 6D demo experiment, that is after year 5.
- This is limited by developing confidence, making decisions and limited manpower.

Findings

- Cost of MANX:
  - $8M + 23 FTE for matched MANX, $5.5M + 18 FTE for off-axis MANX.
- Mu2e schedule and when does it need MANX working?
  - Fastest time for Mu2e is by 2016.
  - Need for HCC channel upgrade – 2020

Observations

- It would be good to get MANX development as soon as possible, if resources can be found.
- The whole muon program is resource limited, but the SBIR program is used well to move ahead and outside the main program.
- SBIRs do not apply well for cryogenics, which is a large expense.

Observations

- The MANX experiment does not fit in the 5-year plan. It cannot be started before MICE is done, that is 2013 or later.
- If successfully executed, the MANX proposal can provide a partial validation of 6-D ionization cooling, based on requirements for a Muon Collider. There is a much more significant cooling needed in parametric cooling and reverse emittance exchange.
- An optimum mix of simulations and experimental demonstration to provide validation would include execution of MICE followed by a 6-D cooling scheme with full simulations. We did not hear about PIC and REMEX.

Observations

- The primary technical risk within the MANX proposal is the high magnetic field with unusual configuration. In particular, the return field of the magnet has to be accommodated.
- It is appropriately mitigated through the development program, which includes the construction of high field magnets..

Observations

- Given the anticipated timelines within the Muon five year proposal and the mu2e development plan, the appropriate place and schedule for implementation of MANX:
  - Assuming MANX is not displaced by a new scheme
  - Place is RAL
  - starting about 2013 for installation (MICE ends?)
  - Equipment should be prepared ahead of time subject to previous remarks about resources.

Observations

- Do the MANX resource requirements appear reasonably estimated? We have no basis for making this evaluation.
- "Mu2e might be the only stepping stone between Neutrino physics and muon collider, if NF disappears". This would be a good application.
- In applying MANX to Mu2e, we are talking about an upgrade of an experiment which has not even started. However, the benefit for the experiment could be large. There were many decision points on the road.

Observations

- Simulation of the cooling process is very important. It seems, that the programs still need to be significantly improved to include many more physical effects.
- MANX after MICE: It is a possibility, but much more homework needs to be done, results and lessons learned from Mice should be taken into account before one can decide if MANX is the right thing to do

Recommendations

- There is need to start thinking what will be a follow up to MICE.
- Provide resources for MANX from FNAL in equipment, limited personnel. Possibly, when the design is well developed, provide the magnets.
- MANX should pay attention to the return field path of the magnet and its effect on the field and environment.
- If possible, use wedges, not liquid helium since LHe is not appropriate for the NF/MC application due to the huge heat load.
- Consider an approach to use SBIR/STTR funding for the TOF detectors.

Recommendations

- A more detailed cost and schedule of MANX should be prepared, providing the basis for the estimate and outlined expected funding sources.
- The muon collider as a long term goal needs a compelling physics argument to motivate it, both as an international priority, and at a project level. Fermilab should produce an optimized experimental design with clear luminosity requirements for producing this compelling physics.
- The MANX collaboration should identify results from MICE are needed to proceed with a follow-on like MANX, and estimate the likely impact the MANX schedule.
- The collaboration should evaluate whether it should build the on-axis MANX. Clear advantages to the off axis.

6D HCC

KJK, KO, JR

FNAL AAC, Feb. 2009

6D HCC : Observation

- Observation
  - An innovative addition to ionization cooling scheme, provoking excellent hardware development
  - Based on HS (helical solenoid), a combined function magnet producing solenoidal field and helical dipole & helical quadrupole field
  - Additional ideas, such as extreme cooling making use of parametric resonance.
  - Strong transverse focusing and continuous emittance exchange are advantages
  - A test experiment, MANX, was proposed to test a factor of two, 6D cooling in a 10 m channel following MICE
  - The initiative comes from an SBIR program
  - MANX is not in the 5-year plan of NF and MC collaboration

6D HCC: Recommendations

- As other cooling schemes were not presented, this Committee is not able to make a comparative evaluation of different cooling approaches
- We endorse the 5 year plan of NFMCC and MCTF to decide on proceeding with experiments after MICE, to take advantage of HCC and other schemes
- We recommend the impact of HCC on Mu2e plan within one year
- There are more work on theory-simulation level, which could be an excellent PhD topic
  - Optics, end-to-end simulation, tolerances, injection/extraction issue,..

General comments to the SRF talks

THE questions….

- What are the primary technical risks associated with the RD&D program?
- Is the RD&D plan appropriately integrated in the ILC, SRF, HINS programs?

Hans Weise & Günther Geschonke – AAC 2/2009

ILC/SRF and Project X

- The ILC/SRF program's mission is to contribute to the ILC machine design. The detailed plan for the SRF infrastructure development was reviewed in the past. This infrastructure and the gained expertise in SRF technology at Fermilab will be available not only for the ILC/SRF program but also for Project X.
- The actual assumption is that Project X is to be constructed from 2013 to 2017.

Cavities

- U.S. vendors still need ‘further education’. Even if some first cavities have reached a for the Project X quite acceptable performance, more cavities are to be produced in order to establish the cavity production. This is not a too large Project X risk since European vendors could be seen as a backup. Project X might profit from the ordering of 800 XFEL cavities.
- The Project X cavity will be different from the ILC and different from the XFEL cavity. All changes especially in the end groups require a series of tests. The time needed from the final test of a prototype cavity to the ordering of 300 cavities should not be underestimated.
- The first series cavities have to be available in 2014, i.e. the CFT is in less than 3 years.

Cavity and module testing

- Fermilab has established the successful operation of vertical and horizontal testing. The test rate and duration is acceptable for the ILC/SRF R&D program; it can be compared with similar activities at KEK and DESY.
- Nevertheless, Project X is a different order of magnitude. SRF infrastructure development was reported. The planned layout should be compared with the actually planned and ordered XFEL infrastructure at Saclay, Orsay, and DESY. Project X requires 38 + 8 CMs of 8 cavities each, i.e. almost 400 cavs or 50% of the XFEL project's cavities.
- The test of completely assembled accelerator modules requires a lot of attention. So far no CM test was carried out at Fermilab. The necessary changes in the CM design need a larger number of tests of prototype modules. The final test rate for the modules is clearly an issue. A comparison with the work done and planned for the XFEL might be useful to align the activities.

Cryostats

- The work on the type-IV CM is an excellent basis for the future Project X CMs. If there is the wish to establish CM production at U.S. companies, it's high time to integrate prototype production in the project plan. The qualification of a new company, the production of at least one prototype, the assembly and test of such an Project X cryomodule requires approx. 2 years after the final specification. The first type-IV CM is scheduled for 2011, the 2nd for 2012, i.e. the first Project X CM could be available in 2014 (see cavities).
- To which extend U.S. regulations require similar if not additional 'destructive' tests as carried out with the TESLA like module at DESY last year? Which module has to be used? The final Project X type CM?

Cavity string and module assembly

- There was and still is quite convincing 3.9 GHz assembly work. The final acid test will be the module test after arrival at DESY.
- Very important steps in the FNAL SRF program is the cold test of the 'assembly kit' and the complete string and module assembly of CM2 using the at FNAL existing cavities; both scheduled for FY09. The critical issue will be field emission at the design gradient.
- The now existing infrastructure at FNAL is well matched with the ILC/SRF program. Upgrade wrt. Project X should be further discussed, plans should be compared with e.g. Saclay.

Details

ILC R&D and SRF infrastructure

- The work towards the GDE SRF goals are important and should not too much be compromised by Project X prototyping.
- Is the assumed capacity of 1 CM/month sufficient for Project X? To which extent can assembly problems be covered? Do the components arrive just-in-time?
- Does the plan assume the integration of industrial partners for the assembly? (there is a lot behind this questions… assembly done in a reproducible way or 38 ‘individual’ modules assembled by ‘researchers’?)

Details

Project X / ILC Alignment:

- The choice of 25 MV/m seems to be reasonable. If higher gradients are available in 5 years then Project X can profit in terms of higher availability, i.e. ‘spares’ are included in the original design / number of components
- The cryomodule assembly facility (CAF) will be an installation comparable to the XFEL triggered Saclay infrastructure; what is the Japanese O(50)-CM project?

US: Cavity R&D:

- More U.S. cavities needed a.s.a.p.
- Statistics on U.S. cavities is still extremely poor….
- Reproducibility in surface treatment is a must, i.e. continue the closed-loop work!!!

Details

ß=0.81 cavities

- In principle just compressed but… number of cells, HOM couplers (?), main couplers
- Requires full R**D**&D program
- Has quite some impact on cryostat design so it might become time critical

Details

SRF materials:

- Impressive work has been reported but… a prediction of the cavity performance based on the optical inspection is not yet possible and might need quite some more R&D
- R&D to improve gradient and yield is more than important not only for the ILC R&D but also for all srf projects
- Further studies of the e beam welds and the heat affected zone are extremely important; the goal should be to understand the differences between different vendors
- According to most of the SRF experts we deal with a welding 'problem' and not with a material problem
- Laser melting / healing is great and could become a repair method for some clearly identified defects in some few cavities, i.e. it could be used to rescue some individuals; what a project really needs is the result of the first vertical test…yield; temperature mapping and other sophisticated / nice diagnostics can only be used during the R&D phase

Details

CM2 – the next accelerator module at FNAL:

- Which of the cavities were tested horizontally and what is the field emission level?

RF Unit Test Facility at NML:

- Good progress but keep the schedule since its already tight for Project X

Details

Infrastructure needed for Project X and ILC – technology Transfer to Industry

- A yield of 80% at 25 MV/m in 2014+ seems to be pessimistic; discuss the acceptable gradient spread and a specified minimum gradient
- Why final 20 micron etching in the lab and not in industry?
- 180 vertical tests for 125 cavities at 80% yield???
- What is the rational for horizontal cavity testing? Others than field emission, i.e. a check of the assembly procedure? Are you sure that the power coupler assembly is more risky than the module assembly?

Details

Vertical Cavity Test Facility – upgrade plans:

- Is there anything where 'copy and paste' can reduce costs? The XFEL-AMTF cryostat inserts and transportation frames are ready for production….

Project X Linac RD&D plan:

- Breakdown of primary elements looks reasonable
- Technical strategy as well

Need for HOM couplers:

- Go through the exercise but…. Suggestion: better solve technical problems than loose flexibility in beam time structure / HOM couplers cannot be added later on

Details

RF couplers:

- Average power dissipation is THE issue; another might be to identify the RF coupler team developing the necessary Project X coupler; there are some good starting points…

Klystrons / modulators:

- The long pulse up to 2.5 ms might be an issue… the TESLA MBK was characterized as somewhere between a pulsed and a cw klystron; is 2.5 ms / 10 Hz now quasi cw?

325 MHz Linac:

- The scope is clear, the 325 MHz part of THE linac with its source is an essential ingredient to the Project X; resources should be allocated by the Project X management team as far as the specs. are driven by Project X

Project X: Rings/Everything Else

Tor Raubenheimer, Roland Garoby, Stuart Henderson

Beam Dynamics

- It is critical for Project X that the performance of the Main Injector and Recycler rings be understood at relevant intensities
- There are many open questions in regards to beam dynamics . These include maximum allowable space-charge tune-shift, allowable phase-space painting amplitudes, KV-painting schemes, estimates of conventional instability thresholds, estimates of electron-cloud effects and mitigation, performance of collimation systems, etc.

- - ***We urge a dedicated, vigorous effort of beam dynamics evaluation for the Recycler and Main Injectors as an urgent task. This effort should include both an experimental effort to benchmark existing simulation codes and a strong beam dynamics effort to make predictions for the new operating regimes.***
- ***- We recommend the development of a beam-studies program aimed at exploring, to the extent possible, parameters more typical of those to be encountered in Project X.***

Beam Dynamics, cont'd

- Once Linac/Booster operations cease, the choice of RF frequency in the Main Injector is no longer constrained. This opportunity should be used to optimize the overall performance of the facility, for example, with respect to electron-cloud effects which strongly depend upon the time structure of the beam and especially upon the distance between bunches.
- ***- We recommend reconsidering the choice of RF frequency in the MI and RR based on beam dynamics.***

- With every-other pulse in the linac having a different intensity, there may be other dynamic effects that could influence the beam quality. With the same linac peak current, space-charge in the linac dynamics is identical pulse-to-pulse. The low-level RF system response will be different every other pulse, which can readily be incorporated into the design. There may be other effects worth considering.
- Exceedingly small beam loss can be tolerated in the transfer lines. The AAC takes note and finds adequate the work planned to meet that goal and allow for hands-on maintenance.

Cryogenic Systems

- The choice of cryogenic segmentation in the superconducting linac is a critical one with far-reaching operational implications. The risk associated with limited segmentation is that the thermal cycling of a large segment may result in cold-leaks. On the other hand, full segmentation is expensive.
- At one extreme, SNS requires warming up individual cryomodules (which is possible due to the parallel feed system), at a rate of a few per year to gain access to components in the insulating vacuum space. At another extreme, the FLASH accelerating sections are treated as a single continuous cryomodule, which is rarely cycled.
- ***- An assessment of world-wide experience in this area is essential in order to make an informed decision.***

Control Systems

- Controls have to smoothly evolve from their present status to first fulfill the needs of Nova and later support the upgraded accelerator complex.
- Project X will be a large accelerator and care should be taken in the choice of the control system architecture and technology to ensure the desired performance and the ability of external users to collaborate.
- The plans to test new control system ideas at NML and HINS should be supported. The Committee is satisfied with the foreseen plans for the control system.

Beam Instrumentation

- The existence and placement of beam instrumentation must be derived from the beam dynamics simulations and requirements for machine tune-up.
- One cannot overstate the importance of establishing a high-quality beam for injection into a high-power linac. Beam instrumentation must be incorporated into the front-end design to ensure that the capabilities for transverse and longitudinal matching are provided, and that emittances and emittance growth and halo can not only be measured, but used to refine set-points in order to minimize halo and beam loss.

- ***- We recommend an approach to beam instrumentation deployment that is based on beam dynamics evaluation and accelerator tune-up requirements. Perform a beam dynamics evaluation to establish the optimum layout for BPMS, BLMs, profile monitors, emittance measurement etc, keeping in mind the routine tune-up activities that are required at any high intensity linac (trajectory correction, RF setpoint determination, transverse and longitudinal matching).***
- ***- Instrumentation developed for Project X will require in-beam tests to validate performance. The project should pursue possibilities for beam tests at other institutions, SNS for example, if they cannot be obtained locally.***

Alternatives

- The committee agrees with the approach taken for the study of alternatives, in particular the consideration of a rapid-cycling synchrotron.
- As a way to reduce the risk associated with accumulating in the recycler, we suggest exploring the benefits of accumulating in the Main Injector for the neutrino program and perhaps accumulating for mu2e in another machine.