MUTAC Committee Report on the Muon Collaboration 2005 Review March 16-17, 2006, FNAL

Charge

1. Review and comment on the R&D progress achieved since the last MUTAC Review within the context of the 5-year plan developed in 2005.
2. Review and give advice on the R&D plans and corresponding budgets for FY06.
3. Assess and comment on progress toward the international MERIT experiment.
4. Assess and comment on the MUCOOL R&D program and progress toward the International MICE experiment.
5. Review and comment on Simulation Group plans including Neutrino Factory design optimization, FFAG acceleration system activities, Muon Collider studies, and participation in the International Scoping Study

Organization of this report:

We start with an Overview and Executive Summary section. Next we comment on the Physics Case for Neutrino Factories and Muon Colliders. The remainder of the report is then attempts to respond to the questions in the charge to the committee. For each element of the charge we list findings, comments, and recommendations from the committee. In the last section the committee evaluates the collaboration management. The membership of the MUTAC review committee is attached as Appendix 1. The agenda for the review and links to the presentations can be found at http://mice.iit.edu/mutac06/.

Overview and Executive Summary

The committee notes and congratulates the Neutrino Factory and Muon Collider Collaboration (NFMCC) on the steady and impressive technical progress in the past year. The physics case for Neutrino Factories and Muon Colliders remains strong. The technical goals established by the collaboration in FY05 were largely accomplished. Several new and exciting developments were reported at the meeting. These include the idea of muon re-bunching which re-aligns a neutrino factory with a possible subsequent muon collider and new muon cooling schemes which bring a muon collider closer to the realm of technical feasibility.

FY05 work included fabrication of MERIT Target magnet, development of MUCOOL test area (MTA) at Fermilab, and development and successful test of a 201 MHz NCRF cavity that reached its no-field design goal. The collaboration also obtained money for MICE and explored 6-D cooling performance. The 805 MHz R&D program was the exception. This program was delayed first by the removal of the RF power source from Lab G (klystron needed for the Tevatron collider program) and then by the move of equipment from Lab G to MTA. The 805 MHz work has now resumed but the net result was a two year delay. Another potential delay is developing in the 201 MHz program because the collaboration has not been funded to build a large SC coupling coil needed to test these cavities in a magnetic field. This delay could be avoided with an additional $1M of FY06 funding.

The NFMCC collaboration remains viable but diffuse. It consists of about 150 people with about 30 FTE equivalent of effort in the last year. Last year the collaboration prepared a 5 yr plan assuming flat-flat funding and developed strawman budgets. The focus is on funding MERIT and MUCOOL in FY05-07 which means that collaboration is behind 1–2 yrs with respect to MICE schedule. In general, the committee notes that technical progress by the NFMCC collaboration is limited by the available funding.
The committee recommends that the funding agencies make every effort to provide $1M to fund the coupling coil as soon as possible. In addition the agencies should work to provide at least a $400k/yr increase in annual funding to the NFMCC. Both last year's committee and this believe that funding levels substantially above the FY06 levels could be used effectively to advance the goals of NFMCC.

The committee notes the excellent use of SBIR funds to advance the R&D activities of the collaboration. In FY06 Muons Inc, funded by an SBIR, performed initial tests of a H_2 filled RF cavity with encouraging results.

<u>The Physics Case:</u>

There exist a number of convincing theoretical reasons for physics beyond the Standard Model (SM) which motivate a strong experimental program. The search for the Higgs particle, supersymmetry, or other extensions related to the deficits of the Higgs sector of the SM are particularly promising areas of exploration. Another unresolved issue in the Standard Model is the origin of generations (flavor) and the apparent, but not yet understood, regularities in the masses and mixings of quarks and leptons. Neutrino physics is likely to play an important role in understanding these issues and the discovery of neutrino masses is indeed the first solid evidence for physics beyond the Standard Model. The fact that large mixings among the neutrino generations came as a complete surprise demonstrates that neutrino experiments may lead us to other new and unexpected phenomenon. Neutrinos carry unique information which might help us to ultimately understand the origin of flavor and are likely to continue to play an important role in both astro-physics and cosmology.

Neutrino mass splittings (and therefore non-zero masses) were discovered in recent years by the observation of neutrino oscillations. A number of new experiments aim now at the determination of the absolute neutrino mass scale. The possible Majorana nature of neutrinos would imply that the minimally extended Standard Model violates lepton number. This allows for leptogenesis, perhaps the most natural candidate for the explanation of the observed baryon asymmetry of the universe.

Future neutrino experiments with beams and nuclear reactors are by far the best place for very precise neutrino oscillation measurements. The determination of generic three flavor oscillation effects and a measurement of the leptonic Dirac-like CP-phase are goals for this program. If the mixing angle ($\sin^2 2\theta_{13}$) is not too small, the combination of super-beam and reactor experiments may be able to discover leptonic CP-violation. For small $\sin^2 2\theta_{13}$, neutrino factories will be required to discover CP violation. For larger $\sin^2 2\theta_{13}$, experiments using neutrino factories can yield very precise measurements of the involved neutrino parameters.

Neutrinos often play a special role in scenarios beyond the Standard Model. Precision oscillation experiments may well be the place where completely new phenomena are first observed. One such example might be the discovery of sterile neutrinos. Similarly, the origin of generations (flavor) is not yet understood and it is easily conceivable that neutrinos are the place where flavor-surprises first show up in precision oscillation experiments. Precision measurements with neutrinos also provide interesting tests of many non-standard scenarios, like mass varying neutrinos, extra dimensions, etc.

There is no question that the physics case for further exploration of the neutrino sector is compelling. The issue for this collaboration is the role of a neutrino factory in this exploration. In describing the physics case for neutrino factories the Collaboration described under the conservative assumption of a three neutrino scenario various physics measurements that might only be possible with a neutrino factory. There remains considerable uncertainty in the scope of the physics that might be accessible only with a neutrino factory. This is because the value of the neutrino mixing angle ($\sin^2 2\theta_{13}$) is not yet known. In past years the collaboration has argued that a neutrino factory is needed for all conceivable measured values of this angle.

- For $0.04 < \sin^2 2\theta_{13} < 0.1$ a neutrino factory would be needed to measure δ, the parameter controlling CP violation, with any precision.
- For $0.01 < \sin^2 2\theta_{13} < 0.04$ a neutrino factory is probably needed to resolve the mass hierarchy (and to have any hope of measuring CP violation).
- For $\sin^2 2\theta_{13} < 0.01$ a neutrino factory needed to measure this angle or to set the best limits.
- Precision is in all cases very sensitive to new physics beyond the conventional three neutrino case

There is no question that measurements of these parameters constitute important contributions to beyond-standard-model physics, leptogenesis, and perhaps cosmological questions. Reactor experiments and existing or approved long baseline experiments will make measurements indicating the relative need for the neutrino factory by about 2012 to 2015. It is inappropriate for a committee focused on only one subtopic to make relative evaluations of the neutrino program vs. others. However, we do note that there is the potential that the Neutrino Factory and Muon Collider Collaboration efforts now may be required to enable significant physics opportunities in the future. Readiness to exploit these opportunities requires completion of a variety of proof-of-concept R&D tasks by the NFMCC.

Charge Point 1: Review and comment on the R&D progress achieved since the last MUTAC Review within the context of the 5-year plan developed in 2005.

<u>Findings:</u>
Significant hardware and design progress for MUCOOL, MERIT, and MICE were described in the presentations. The MICE and MERIT experiments are both about 1 yr from beam and large pieces of hardware are under construction. Work in FY05 included fabrication of the MERIT Target magnet, development of the MUCOOL test area (MTA) at Fermilab, and development and successful test of a 201 MHz NCRF cavity that reached its no-field design goal. The collaboration also obtained money for MICE and explored 6-D cooling performance. The 805 MHz R&D program was the exception. This program was delayed first by the removal of the RF power source from Lab G (klystron needed for the Tevatron collider program) and then by the move of equipment from Lab G to MTA. The move was also delayed by lack of availability of RF techs. In total this resulted in a two year delay. The 805 MHz work has now resumed.

<u>Comments:</u>
Last year the collaboration prepared a 5 yr plan assuming flat-flat funding and developed strawman budgets. The committee supports the collaborations decision to focus on funding MERIT and MUCOOL in FY05-07 but notes that this choice means that collaboration is behind 1-2 yrs with respect to MICE schedule. The committee notes that technical progress by the NFMCC collaboration and its ability to participate in MICE in a timely way is limited by the available funding.

Charge Point 2: Review and give advice on the R&D plans and corresponding budgets for FY06.

<u>Findings:</u>
The R&D plans for FY06 emphasize MERIT, MUCOOL, and MICE activities, while maintaining the university programs. The collaboration will provide components of the MERIT (Hg target) experiment at CERN. The principal remaining contributions of the NFMCC to MERIT are the simulation and fabrication of the Hg-jet system. For MUCOOL (muon cooling) the plans call for test of the 201 MHz high-gradient cavity (with magnetic field), and continued tests of the 805 MHz cavity with curved windows and buttons in the new MTA facility at Fermilab. For a complete test of the 201 MHz cavity, a 2.5 T superconducting coupling coil is required. Due to funding limitations, it will not be possible to procure this coil in FY06. The support for MICE provides funding for the spectrometer solenoids and tracking systems for Phase 1. Additional, smaller efforts are supported for the acceleration system (study of Q disease and beam dynamics simulations), for general design and simulation work (continued development of cost-optimized Neutrino Factory front-ends, and exploration of realistic Muon Collider

scenarios), and for support of the International Scoping Study (ISS).

NFMCC funding is flat-flat in FY06 remaining at about $ 3.6 M per year from DOE and DOE labs. The budget for FY06 includes $1.8M of DOE base program support ($0.9M at BNL, 0.6M at Fermilab and $0.3M at LBNL), $1.8M of DOE support through the NFMCC funding, and about $0.85M of support from the NSF (of which $0.75M is in the form of an MRI grant). Of the DOE funds, $280K is expected to go to muon cooling personnel staffing, $20K for absorber work, $45K for MTA operations, $620K to MICE, $640K to targetry, and the remainder ($195K) to general system studies. The NSF funds pay for tracker support (personnel), and superconductor for the spectrometers.

The collaboration plans to continue 201 and 805 MHz cavity R&D program in FY06. Both MICE and MERIT require substantial M&S funding in FY06. Constant funding for the overall effort has resulted in attrition in the design effort. Limited funds mean that the only contingency available to the collaboration is the schedule for completing tasks. FY06 goals are to maintain the University Program while making progress on key fabrication activities. Construction of the large solenoid (coupling coil) that surrounds the 201 MHz RF cavities cannot be funded with present FY06 budget.

Comments:
The Neutrino Factory and Muon Collider Collaboration (NFMCC) funding has been constrained for a number of years. Flat-flat funding has eroded the ability of the collaboration to carry out its program in an effective way. Funds have not been available for procurements of expensive items. Large cost items must often wait over fiscal year boundaries so that sufficient funding can be made available. In addition the collaboration's human resources have been suffered from attrition especially in the area of simulations. The MICE detector work is beginning to need students and postdocs to carry out detector implementation. However, funding is not available to pay them.

In the component fabrication area, we note that the testing of the 201-MHz normal-conducting RF cavity in its design magnetic-field configuration, a task of the MUCOOL program, is a critical test for the whole ionization cooling scheme as well as the heart of the international MICE experiment). In FY06 and for several years now, no funds have been available for procurement of the required solenoid—a coupling coil costing roughly $1M. The collaboration has sought supplemental funding from DOE and NSF in FY06 to remedy this problem. Subsequent to the review it was learned that DOE supplemental funds were not granted. The NSF request is pending.

In view of the critical need to test the RF cavity to full gradient in the presence of the full field, the committee strongly supports this request.

In terms of system tests, we note that the schedule of providing components for the MICE experiment is inconsistent with the desires of the MICE collaboration by at least one year, and quite possibly two years.

The MERIT experiment procurements, while nominally on track, have no contingency in either cost or schedule, putting the timely completion of this international experiment in some jeopardy.

Beyond the present international commitments to MICE and MERIT, there is a growing interest in FFAG rings that the NFMCC should be involved in. Though further design work and modeling of non-scaling FFAG's is necessary, there is growing interest in building an electron model of a non-scaling FFAG ring. The justification of such a model still needs to be made. However, even if this justification were complete, the resources within NFMCC are too limited for it to participate in a meaningful way in the development of the proposed EMMA experimental model of a non-scaling FFAG ring. As a result, the proposed experiment is effectively dominated by European colleagues, despite the NFMCC's role in proposing the use of the non-scaling FFAG concept for use in neutrino factories or Muon Collider. International interest in neutrino factories and investment in the associated R&D is rapidly growing. There is real risk that the creative ideas and significant efforts that the NFMCC have put in over the years may have to be completed without NFMCC involvement if some significant funding increment is not forthcoming. In particular, new ideas presented at this review point toward an exciting possible breakthrough in muon collider design. These new ideas make it possible to combine features of the neutrino factory with the initial stages of a muon collider. These ideas merit concerted study and development.

Recommendations:

1) The collaboration should give high priority to the test of the 201 MHz cavity with the field that can currently be applied using the existing superconducting coil at MTA.

2) We recommend the funding agencies make every effort to provide $1M to fund the coupling coil as soon as possible. In addition the agencies should work to provide at least a $400k/yr increase in annual funding to the NFMCC. We note that both last year's committee and this believe that funding levels substantially above the present levels could be used to advance the delivery of key components for MICE.

Charge Point 3: Assess and comment on progress toward the international MERIT experiment.

NFMCC collaborates on the MERIT experiment at CERN which is intended to demonstrate high power mercury jet target technology intended for use with neutrino superbeams or as a production target for a neutrino factory or a Muon Collider.

Findings:

Impressive progress has been made in preparing for the MERIT experiment. The 15 T superconducting solenoid is complete and is undergoing initial tests at MIT. The design of the Hg delivery system is complete and critical components such as the mercury syringe are in fabrication. The jet diagnostics are defined. MHD simulations of mercury jet flow in magnetic fields, which include proton beam interactions, cavitation, and bubble simulation, are impressive and represent good progress in theoretical understanding of the dynamics of the mercury jet target. The design of the MERIT cryogenic system is complete. Infrastructure work at CERN is well underway. Progress includes the installation of the power supply and some of the associated subsystems, completion of drawings of the experimental layout, and initiation of the safety review. Experiment planning is also underway. The beam request has been defined, discussions with accelerator staff are underway, and beam instrumentation is defined. The experiment remains on track for an April 2007 beam test.

Impressive progress has also been made in other areas of target R&D in the last year. Studies have included beam tests with solid targets, irradiation tests of solid target candidate materials, laser based shock studies, etc. Candidate solid target materials show intriguing annealing results, which have the potential to provide a path to higher power solid targets. The committee notes the excellent cooperation with the larger target development community both at SNS and elsewhere.

Comments:

The MERIT experiment has the necessary priority within the NFMCC, and is receiving sufficient funding to fulfill its obligations. The schedule for integration in September seems tight. Six months remain to complete procurement, fabrication, initial component testing, assembly and integration. There is a lot of hardware that must come together rather quickly. The secondary containment snout is not yet ordered and in a few months may threaten the schedule for integration testing.

The committee is pleased to hear the progress in negotiations with CERN regarding the MERIT run schedule. We continue to endorse the plan for a follow-up experimental run, separated by sufficient time to allow preliminary analysis to proceed.

The safety review process related to Hg handling, monitoring and activation may become a rather involved and lengthy one. This process should begin soon so that it doesn't interfere with the run schedule.

The role of the beam current and currents induced in the Hg jet itself, while expected to be small, has not yet been estimated.

Recommendations:

1) Pay close attention to the delivery of the Hg delivery system components to keep on-track with integration tests at MIT and installation at CERN.
2) Continue negotiations with CERN regarding run schedule with the goal of obtaining a commitment for a follow-up run.
3) Proceed rapidly with Hg-related safety reviews at CERN, sooner rather than later, to ensure timely readiness for the experimental run.
4) Continue to investigate mixed-waste issues related to shipping the apparatus back to Oak Ridge after the CERN exposure.

Charge Point 4: Assess and comment on the MUCOOL R&D program and progress toward the International MICE experiment.

MUCOOL R&D Program

Findings:

The committee was given a tour of the MTA area at Fermilab and found a well constructed test facility with initial installation of MUCOOL equipment in progress. Both 201 MHz and 805 MHz rf power sources are nearing completion. The collaboration still needs to install the beam line from the Fermilab linac and the cryo-plant. Installation of the cryogenics system competes with ILC work and currently has lower priority. For now they are using 500 L dewars for tests requiring liquid He.

The current LH_2 absorber is convection cooled. Its design limits heat dissipation to about 70 W, substantially below the ~ 1 kW needed for a 4 MW proton beam and both muon signs. The committee also heard about tests of encapsulated LiH that could serve as the required absorbers. In addition, SBIR-funded work on a high-pressure H_2-filled cavity (805 MHz) was described. The results are encouraging and may allow the cavity and absorber to be integrated.

The 'baseline' 201 MHz normal-conducting (NC) cavity development continued in FY05. The collaboration developed an electropolishing scheme at TJNL that resulted in a cavity that processed quickly to 16 MV/m (power limited) with 200 microsecond pulses. The group is to be commended for this impressive result. Work also continued on superconducting cavities, which at the time of previous review, was focused on building 201 MHz cavities made with sputtered Nb on copper. During the past year, higher frequency (500 MHz) cavities were built to lower development cost. Tests so far of magnetron-sputtered cavities from ACCEL and spun cavities made with HIP-bonded Nb/Cu were disappointing (steep Q drop with the sputtered cavities and blisters on the HIP-bonded Nb/Cu sheet after baking).

Comments:

While the NC 201 MHz cavity program is off to a good start, the first cavity has not been run with 1 ms pulses as required at MICE, it has yet to be equipped with Be windows, and it has shown signs of strong multipacting in low magnetic fields. It also has not been operated in a high magnetic field (several Tesla), which may reduce its sustainable gradient (a factor of two reduction was observed in 805 MHz cavities). There is general consensus that this is the most critical evaluation for these cavities. Unfortunately this test will not occur using the nominal solenoids for a few years. It was also noted that the expected stress level on the Be windows from average heating is high, with less than a factor of two safety margin. Finally, measuring dark currents from this cavity is important to verify that the MICE tracker will work with the resulting photon-induced backgrounds.

The 201 MHz SC cavity program is over and the 500 MHz program is scheduled to end in FY06 after several more cavities are tested, including ones sputtered with higher energy ion sources. The higher energy may solve the *Q* drop and peeling problems, and results from test strips made with these techniques look promising. Tests will also be done of cavities made with explosive-bonded Nb/Cu. They are expected to have the best chance of success. Cornell will apply for general SCRF cavity development funds to continue the Nb/Cu development in FY07.

The committee is encouraged by the recent 805 MHz cavity results at MTA in that they reproduce those obtained earlier at Lab G. The planned coating studies should produce interesting results.

Recommendations:

1) High priority should be given to testing the 201 MHz cavity with highest magnetic field available.

2) The committee is concerned about contracting the work to produce 8 additional NC 201 MHz cavities. The collaboration has benefited greatly from TJNL expertise, but TJNL has indicated that they cannot do this work in the future. The qualifications of alternative vendors must be carefully evaluated.

3) The absorber heating tests (up to 600 W) are ideally done with a high intensity beam. Since MICE will not have such a beam, it seems reasonable to do this at MTA. However, the cost for providing a high intensity proton beam is estimated to be about \$ 400 k (\$ 100 k from the Muon Collaboration). Given the tight NFMCC funding situation, the collaboration should investigate whether this measurement can be done elsewhere or if it is really necessary.

MICE:

Findings:

The Committee notes that new collaboration members have been added since last year and the collaboration is now up to 140 names. Phase I of MICE is approved and funded. An ISIS production target test is scheduled for July 06. The first tests with beam were scheduled for 1 April 07 at RAL (but subsequent to this review were postponed by ISIS until September 07) and hardware will soon be installed in the new beam line area. The U.K. portion of the collaboration will submit a Phase II proposal in the next few months. The necessary safety reviews are in progress, and importantly in this regard, the operational aspects involving the use of hydrogen have been addressed by RAL. The Collaboration would like to shorten the overall schedule by ~ 18 months if possible to demonstrate ionization cooling results by 2010. The necessary resources to accomplish this are not yet in place.

US MICE is responsible for Cerenkov counter, CKOV1, and the solenoid spectrometers for phase I. The phase II contributions are centered on the 201 MHz cavities and associated coupling coils. The tracker detector DAQ will be based on identical front-end electronics to the Tevatron Dzero detector and will include use of existing Dzero items, resulting in significant savings to MICE.

A build-to-spec bid package for the spectrometer solenoids is presently being prepared by LBNL and is projected to be released in May 2006.

Comments:
The Committee notes with satisfaction both the obvious signs of maturity in the MICE Collaboration and the significant technical progress made in many areas during the past 12 months. The overall collaboration resources appears well matched to the overall scope of the MICE proposal. However, the schedule for the solenoid procurement/installation/commissioning does not look consistent with the goal of having the equipment in place and operational by September 2007.

While the desire of the MICE management to shorten the overall schedule is laudable, the scope of the experiment should not be compromised to meet this goal. MUTAC believes the shorter schedule is feasible with modestly enhanced out-year funding.
The US role in the spectrometer DAQ will not be completely finalized until hardware and software decisions are made following testing at Frascati in July. US manpower to support additional scope in the DAQ system is not abundant and NFMCC should be careful to ensure that scope does not exceed resources.

Dark current in the RF cavities could give rise to background tracks in the spectrometer. At some point an estimate of acceptable dark current should be made to help determine the goals of the on-going R&D effort. The Committee notes that in order to minimize power supply costs the MICE experiment plans to run at only 8 MV/m rather than 16 MV/m envisaged for a cooling channel. MUTAC supports the MICE plan to operate a subset of the cavities at 16 MV/m for some portion of the experiment.

Recommendations:

1) The NFMCC should review the solenoid procurement and work to minimize the overall schedule.

Charge Point 5: Review and comment on Simulation Group plans including Neutrino Factory design optimization, FFAG acceleration system activities, Muon Collider studies, and participation in the International Scoping Study.

Physics Simulation

Comments:
Simulations of the physics potential of a neutrino factory and optimization studies are important. The ongoing physics and R&D studies have made significant progress. Several variations of neutrino factories have been identified which show excellent physics potential. However, the exchange of information between machine, detector and

physics simulations needs to be further improved such that the crucial R&D issues become more visible. The International Scoping Study (ISS) is a very effective way to carry out this work. Further work is needed to understand the R&D required for the machine and detectors as a whole. In addition, the feasibility and the performance of beta beams needs to be further studied to find how much it could compete with a neutrino factory. Currently beta beam studies are much less mature than neutrino factory studies.

Within the ISS, efforts are made to better link the detector design parameters to the studies of physics potential. It would be desirable to better identify cost gradients for various machine designs to allow better feedback with physics and detector planning and to optimize the over-all balance between machine and detectors.

The value of $\sin^2 2\theta_{13}$ is crucial for the optimal strategy for future oscillation experiments. Reactor experiments may determine if $\sin^2 2\theta_{13}$ is small or tiny by 2010. There is a chance that NOvA is not built or is constructed with reduced mass (~25 kt). The integrated neutrino flux required for a determination of the sign of Δm^2 (mass hierarchy) is large and, depending on the size of $\sin^2 2\theta_{13}$, may require a more intense source than currently exists at Fermilab (e.g., the Proton Driver). Similarly, the baseline from Fermilab to Soudan is not optimal. Given these uncertainties, it is possible that determination of the neutrino mass hierarchy may end up as a topic for a future neutrino factory and this possibility should be explored. Matter effect uncertainties for the largest possible values of $\sin^2 2\theta_{13}$ are non-negligible, and conventional beams may perform better than a neutrino factory unless the matter uncertainties are improved. This problem should also be investigated.

The overall roadmap depends on a number of physics unknowns, which makes planning difficult. The ISS aims at a time frame (approximately 2010) set by the anticipated ILC decision and the CERN planning process for a machine to follow the LHC. This schedule appears overly optimistic. A somewhat slower roadmap should be considered. In addition, it should be stressed that various interim branching points exist that may change the program substantially. Examples include a positive result from MiniBooNe confirming LSND, an observation of a large $\sin^2 2\theta_{13}$, new LHC results, measurement of LFV, etc.

Machine Design and Simulation: Neutrino Factory

Findings:

The NFMCC simulation group is heavily involved in a broad-range of studies and design optimizations, culminating in the International Scoping Study (ISS) for the neutrino factory. The ISS appears to be a valuable mechanism for focusing efforts and selecting amongst the various design choices on a worldwide scale. Arriving at a consensus on high-level neutrino factory parameters is an important goal of this endeavor.

The committee heard a presentation on the optimization of a Neutrino factory front end. It seems the present design is not far from the optimum. Although more study remains there are signs of convergence. Simulation of the muon acceleration technology is now more advanced, however detailed 6D simulation of a non-scaling FFAG revealed a problem, amplitude dependence of the tune.

Comments:
The committee was encouraged to learn that the collaboration is actively comparing different schemes. The Japanese plan of using an FFAG without cooling is less efficient by factor 5 to 10. It is not clear that adding a cooling system later to such a machine is a viable upgrade path due to the expense that would be involved. However, even without cooling such a scheme may be a path to a lower performance machine that could be pursued more quickly. FS IIa gives high performance with and without cooling. For this design it may be possible to start with a non-cooling design and add cooling later. The difference in efficiency between cooling and non-cooling is only a factor of 1.7; this difference is not as large as once envisioned. Since cooling needs extensive R&D, starting with a machine without cooling may be an attractive possibility. In the present design, if one reserves empty space for a linear cooling channel as an upgrade possibility, there is a performance penalty because muon decays in that region would be significant. During the meeting, the idea of using a "Guggenheim"-style cooling channel was proposed, so that the empty space in the initial stage is minimal. This is a very good idea that should be pursued further.

More detailed studies of linear non-scaling, isochronous non-scaling, and non-linear scaling FFAGs are needed. Once the FFAG scheme is chosen, the simulation group should proceed with full scale end-to-end simulations of the acceleration stage in order to evaluate the beam dynamics performance of the complete system.

The electron cloud buildup in the decay ring and its potential influence on the beam should be estimated. The large flux of high energy electrons will shower and ultimately produce a large number of low energy seed electrons within the beam pipe. Observed electron cloud instability growth rates at other machines can be as rapid as 100 turns, so the short storage time in the decay ring does not make it immune from electron cloud effects. Even small neutralization has been shown to influence beam dynamics and lead to instability in other machines.

Machine Design and Simulation: Muon Collider

Findings:
Good progress has been made recently in ideas for achieving muon collider emittances. A scheme now exists for a cooling system that could reach parameters needed for the muon collider. Central to this design are high-field 50–60 T solenoids, bunch merging, and the invention of 6D cooling in a "Guggenheim"-style cooling channel. The scenarios envisioned for a Muon Collider share a common front-end with the Neutrino Factory discussed above. The use of ILC SCRF technology is another interesting possibility.

Comments:
There has been significant conceptual progress in the past year. Much more study is needed, but the prospect of an eventual muon collider seems more real today than a year ago.

Collaboration Management

Findings:
The NFMCC is part of the worldwide effort in the development of next generation neutrino facilities and is playing a significant role in the ongoing ISS, MICE and MERIT collaborations. Both the ISS and MICE projects are fully international with members from the major HEP regions of the EU, Asia and the US. The ISS program as a precursor to a world design study is a significant step in evaluating the various different technical approaches under consideration.

The NFMCC currently involves 135 people with several standing committees guiding various aspects of the work. The management and structure of the NFMCC have been stable for several years. The NFMCC management has developed a multi-year R&D plan to address the highest priority topics related to demonstrating the ability to construct a Neutrino Factory. Funding is spread across several sources as well as the US base program and has been limited to constant dollars during the recent past. The NFMCC has worked effectively to derive technical benefit from the SBIR program and utilization of these resources continues to grow

Comments:
The steady tread towards the internationalization of many aspects of this work continues to be apparent. MUTAC continues to support this evolution, which permits more effective use of the limited global resources. The ISS activities, together with the MICE experiment, have required a close integration of the various regional programs. The NFMCC is to be commended for its role in facilitating this process. MUTAC suspects that, at some point in the not-too-distant future, better clarification of the international structure will be required.

The NFMCC is to be congratulated on its work with Muons, Inc. to bring additional resources to bear on various topics via the SBIR Program.

Recommendations**:**

Continue to work at the international level towards creating a unified management structure.

Appendix 1:

MUTAC Committee:

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