MUTAC Committee Report on the Muon Collaboration 2005 Review April 25, 26 2005, LBNL

Charge

1. Review and comment on the R&D progress achieved since the last MUTAC review.
2. Review and give advice on the R&D plans and corresponding budgets for FY05.
3. Assess and comment on plans for the CERN Targetry experiment.
4. Assess and comment on plans for the MICE experiment.
5. Review and comment on the Simulation Group plans, including Neutrino Factory design optimization, FFAG acceleration systems activities, and Muon Collider studies.
6. Review and give advice on the Muon Collaboration 5-year plan.

Executive Summary

The first part of this report discusses and comments on the work performed by the Collaboration. The charge is explicitly addressed in the final section.

The main areas of activity of the Muon Collaboration (MC) are:

- MUCOOL and its evolution toward participation in the MICE experiment
- Targetry and the experiment at CERN
- Work on the evolution of the design and layout of neutrino factory guided by course cost optimization models and simulation studies.

The Muon Collaboration team has done a serious job at adapting its goals to reduced resources. The activities pursued today are clearly focused on the most important subjects determining the feasibility of a neutrino factory, relying on - and contributing to – the MICE experiment at RAL (UK) and the NTOF11 experiment at CERN. *Reducing further the available resources in the coming years would endanger these international collaborations and considerably delay the possibility to build a neutrino factory anywhere in the world.*

There is the potential that the Muon Collaboration efforts would enable significant physics opportunities. Readiness to exploit these opportunities requires completion of a variety of proof of concept R&D tasks. MC is focused to carry out these tasks.

MUTAC heard during this meeting that there is the possibility of reduction or elimination of BNL resources (Base lab support) and possibly the BNL fraction of DOE-MC funding. We note; that muon accelerators (factories or colliders) are one of the very few HEP future accelerator ideas on the horizon, that R&D to develop these ideas and provide proof of principle takes years of consistent effort and support, that major collaborative efforts and international commitments must have consistent support. The MC is supported by three major labs (BNL, FNAL and LBNL). The withdrawal of one puts the whole collaboration at risk, and any movement in that direction must not be considered unilaterally.

We find the 5-year R&D funding "base line plan" plausible but extremely tight. In this (possibly pessimistic) scenario additional funds (~1M$) will have to be found from proposals not yet approved or other sources. The implementation schedule of the warm RF cavity systems and solenoids (MUCOOL and MICE) is far from ideal, especially for such a high-risk and important system that needs proof of principle.

The "incremental plan" (additional $400K/y) is much more workable and less risky. We recommend that DOE provide at least this level of support in order that both experiments (Targetry and MICE) can be carried out efficiently and design studies continue.

The US Muon Collaboration is playing a leadership role in the CERN target and is providing the spokesmen for this effort. MUTAC finds the target experiment to be in good shape provided the BNL group remains a part of the Muon Collaboration. In the absence of the BNL group it was less clear that sufficient leadership expertise and resources exist to perform the experiment at outlined.

MUTAC notes that NSF will no longer be supporting Cornell Muon SRF activities or University Consortium Muon activities (as far as we know). We consider this an unfortunate sign of the times. The 200MHz SRF R&D, though not as critical a priority to the feasibility of neutrino factories as Targetry and MICE is still significant and the understanding and control of Q slope a fundamental issue.

The MC has been exemplary in its drawing in of collaborators from a wide diversity of universities and engaging HE physicists in the muon acceleration futuristic concepts. It is truly unfortunate if these field-broadening activities (University Consortium) can no longer be supported.

Achieving the desired high gradient performance in the 200 MHz warm cavities operating in a solenoid field is critical for the muon-cooling program. It represents the biggest technical risk to the MICE experiment. The schedule for development and test of these cavities is too stretched out under present planning. Additional funds if obtained should be directed toward this activity.

The Committee notes with satisfaction the evident progress with regard to MICE during the past year and the approval of Phase 1 by RAL. MUTAC is pleased that MICE will become the highest priority MC activity after the target experiment is complete. In light of the anticipated flat budgetary situation MUTAC cautions the Muon Collaboration to be careful to contain any scope creep in the US contributions. US contributions are most highly leveraged when based on the MUCOOL development program rather than more generic contributions such as the recent responsibility for spectrometer solenoids. We suggest every attempt should be made to offload the cost obligation of the solenoids so as to be able to direct these funds toward warm

RF cavity- solenoid development.

We ask that a neutrino factory baseline parameter list and description be prepared prior to the next MUTAC review.

Comparison of neutrino factory scenarios with and without cooling (as proposed in Japan) is yet to be carried out. This study should have high priority.

I **The Physics Case**

The Muon Collaboration described the "standard model" and the measurements that might only be possible with a ν factory. The scope of the physics that is accessible only with a ν factory depends on the value of $\sin^2 2\theta_3$. The collaboration argues that a neutrino factory is needed for all conceivable measured values of this angle.

- For $0.04 < \sin^2 2\theta_3 < 0.1$ a Neutrino Factory would be needed to measure δ the parameter controlling CP violation, with any precision.
- For $0.01 < \sin^2 2\theta_3 < 0.04$ a Neutrino Factory is probably needed to resolve the mass hierarchy (and to have any hope of measuring CP violation).
- For $\sin^2 2\theta_3 < 0.01$ a Neutrino Factory needed to measure this angle or to set the best limits.

There is little 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 base line experiments will make measurements indicating the relative need for the νfactory by about 2012 to 2015.
At this time of severe funding shortfalls for physics, it is inappropriate for a committee focused on only one subtopic to make relative evaluations, but there is indeed the potential that the Muon Collaboration efforts would enable significant physics opportunities. Readiness to exploit these opportunities by 2012 to 2015 requires completion of a variety of proof of concept R&D tasks by the Muon Collaboration.

II Resources & Funding

Though not part of the formal charge to this committee, the committee learned about possible reduction of staff at BNL working in the Muon Collaboration, and the potential that DOE-MC and DOE-BNL Base funds might be diverted to other BNL activities.

The MC is a national collaboration spearheaded by BNL, FNAL, and LBNL. It has been the major creative force in the development of the neutrino factory concepts and evolution toward more realizable designs. The collaboration has aligned and integrated its self effectively with international partners both in Europe and Japan. The outcome of this international corporation has been the launching of two experiments critical to understanding the feasibility of two fundamental aspects of the NF: ionization cooling and Hg jet targets. The Muon Collider Ionization Experiment (MICE) is planned to demonstrate the cooling principal in an integrated systems test with prototype cooling cells of absorber, solenoids and cavities. The other experiment, the target experiment, planned at CERN is to observe the interaction of an Hg jet target with beam within a solenoid containment field. This is necessary to demonstrate the feasibility of the Hg jet as a high intensity target. A termination of participation of one Lab is likely to have substantial ripple effects within the collaboration. Significant leadership and commitment would be lost and in the longer run could lead to collapse of the collaboration. Because of this important interconnection any major impact to the program at one lab must be considered in the larger context than just the perspective and priorities of that lab. The collaboration is already struggling with dwindling resources. Projections indicate a stretch out of MICE by a year or two is quite likely. The impact of a BNL withdrawal could result in a ~1/3 reduction of funding raising the question of whether the other labs would continue.

The community as a whole has the responsibility to realize that R&D for future accelerators is not a short-term investment and consistency of purpose is necessary. There is grave risk that progress and hardware development accomplished so far will be lost or not come to completion and experimental test if the program is stressed further by the withdrawal of BNL or any substantial reduction in funding or resources. It is important that resources be assured that these experimental commitments can be carried out.

Both MC funds and Base funds (or personnel resources) must be stable for the MC to be able to manage and participate in international cooperation directed toward establishing the plausibility of the concepts of a neutrino factory or a muon collider.

The number of future accelerator concepts directed toward support of HEP programs is very small, and the challenges difficult. Those ideas that exist and show promise need to be nurtured over a duration of time measured in years and decades. In times of tight budgets it is extremely important that support be consistent and its base predictable even if sparse, so that plans and development programs can survive and progress year to year even if much slower than technically possible.

III The areas of activity of the Muon Collaboration:

A. MUCOOL
a. MTA
b. Liquid Hydrogen absorber
c. 200 MHz cavity and cavity window development and Normal cavity R&D
B. SRF 200MHz development
C. Targetry (discussed under Charge 3)
a. CERN Target Experiment (NTOF11)
D. MICE (Discussed under Charge 4)
E. Neutrino Storage Ring and Muon Collider design efforts (discussed under Charge 5)
a. Theory, Simulations,
b. Design Studies and FFAG model
c. Muons, INC (discussed under Charge 5)

III.A. MUCOOL

Over the last year

Installation of technical components for absorber and cavity testing is almost complete in the Muon Test Area (MTA) at the end of the linac at FNAL. However RF testing has had a hiatus for more than a year after the termination of testing in Lab G and the installation and outfitting at MTA. This has been very disruptive to tests of rf breakdown at 800MHz. Meanwhile the fabrication of the 200MHz cavity and windows has proceeded well at LBNL. First experiments with convection cooled absorber from Japan have taken place at MTA and have reached ~23W power handling capability. Further experiments of RF breakdown limits in high pressure Hydrogen are underway again.

Plans in FY05

RF cavity testing will begin in MTA in the summer. These tests include a continuation of the 800MHz program interrupted over a year ago. RF window tests and pillbox cavity test of different materials and coatings are proposed. The recently fabricated 200MHz cavity will undergo initial tests. The second phase of the KEK convection cooled absorber test will start in the fall. Low intensity400MeV beam commissioning to the MTA area will start at the end of the year. Absorber thin window development has become very refined, and will continue. A Tevatron refrigerator will be installed for operation at 5K and 14K. It is planned that RF and absorber tests will not be carried out at the same time.

About $500K of DOE-MC funds (M&S) is allocated toward MUCOOL activities in FY05. Both RF and absorber testing are important core activities for MUCOOL, MC and eventually toward MICE.

Further Discussion, Findings Comments and Recommendations

Liquid Hydrogen Absorber, and Absorber window-

The collaboration appears to be making progress as it investigates forced flow and convection cooled LH2 absorbers for the muon-cooling channel. A preliminary design of a forced flow absorber exists. A convection-cooled absorber was built at KEK and tested at MTA at Fermilab. The group made first measurements of the cooling power of the LH2 absorber and measured the temperature distribution in the vessel. Additional tests at higher power are planned with improved techniques and instrumentation. Tests of absorbers also were done at KEK. An interesting improvement in these tests is the use of a cryocooler to simplify the cryogenic system. RAL is investigating the use of LiH absorbers. The LH2 absorbers will eventually have to handle KW level heat loads from the beam so tests of their performance at high power is of considerable interest and we look forward to results at the next meetings. Considerable progress was reported on thin window design and testing for the elements of the cooling channel. Practical designs seem to be in hand.

200MHz Cavity and Cavity Window - Normal Conducting Cavity Program-

The Muon Collaboration described progress on development of high power 201 and 805 MHz cavities for the muon-cooling channel. An 805 MHz pill-box cavity is nearing completion and will be used to study materials, coatings, and various B field configurations. Considerable progress on the design of a 201 MHz cavity has taken place. Although there have been some fabrication delays, a 201 MHz cavity will be shipped to MTA at Fermilab in about a month. The committee looks forward to hearing the results of the MTA tests. The collaboration has been successful in fabricating large curved Be windows vs. pre-tensioned flat windows.

The cavity designers need to complete pulsed and average rf heating calculations to assess their effects on cavity detuning and their potential for damaging the windows during long pulse (1 msec) operation. Thermal performance of the Be window under the full length MICE pulse should be investigated. In the presentations, the peak temperatures were estimated to be 86 C under Neutrino Factory conditions of 4.5 MW peak power, 16.5MV/m, 125 microsec pulse and 15Hz repetition rate. The planned pulse length for MICE is much longer. So even though the gradient and peak power are limited to 8MV/m and ~1MW it may be wise to calculate the transient heating of the window and possible detuning.

Normal Conducting Cavity Program

Normal conducting cavities are used in the cooling channels proposed for neutrino factories to accommodate the strong solenoidal fields (multi-Tesla) required for beam focusing. A 201 MHz copper cavity has been designed for this purpose, and a first prototype with curved Beryllium windows is almost complete (eight will eventually be built for the MICE experiment). The prototype will be delivered to FNAL for high power tests in May, 2005. Tests so far with 805 MHZ cavities have shown degradation in the maximum sustainable acceleration field with increasing solenoidal magnetic field, so testing the 201 MHz cavity in a solenoidal field is important. To improve the cavity performance, different surface coating materials will be tried - they will be tested initially on a small section of the cavity windows, which are demountable Also, a 3D atomic probe microscope will be used to learn about the copper surface characteristics under high field.

Achieving the desired high gradient performance (> 8 MV/m with acceptable dark currents) in the 201 MHz cavities is critical for the muon-cooling program. It represents the biggest technical risk to the MICE experiment. Little (if any) comparable cavity operational experience exists as thermal constraints typically limit such cavities to lower gradients. However, the FNAL experience with the 805 MHz cavities in Lab G and the 805 MHz pi-mode SW cavities in the proton linac provide a reasonable base for comparison, especially as the gradient was pushed to the limit in each case. For pulse lengths of 20-40 microseconds, surface fields of about 40 MV/m were achieved in these cavities in the absence of a magnetic field (the surface field in the Lab G cavities, as with the 201 MHz cavities, roughly equals the acceleration gradient). Scaling this gradient to the 201 MHz case using empirically observed dependences on frequency (1/2 power) and pulse width (-1/6 power), yields ~20 MV/m for operation at MTA (20-30 microseconds pulse width at the top the rise time curve) and ~10 MV/m for operation in MICE with 1 msec pulses. In the Lab G tests, operating the cavities in a 3T magnetic field reduced the sustainable gradient by 60%: if this occurs in the 201 MHz cavities as well, then the gradients may be limited to ~ 8 MV/m in MTA and to 4 MV/m in MICE with 1 msec pulses. Also, the 201 MHz cavities have 16 times the surface area as the 805 cavities, and there are up to 8 of them in MICE, so consistent, high quality vacuum surfaces will need to be achieved.

Although these are only estimates, they do suggest a serious downside potential for the cavity performance. The Muon Collaboration clearly acknowledges the importance of the near term program at MTA to evaluate a single 201 MHz cavity. However, by recently taking on the responsibility to build the two spectrometer solenoids ($2M total cost), they have compromised the cavity development program. In both five-year plans that were presented, they would not acquire a coupler coil before 2009 when it would be needed for installation in MICE, and would only test one cavity in the interim. They state the desire to acquire the coupler earlier (the 'most critical need [for the cooling program] is for a coupling coil for 201 MHz tests') yet give the first spectrometer solenoid higher near-term priority ('priorities in FY05–07 are the CERN Targetry experiment and the first MICE spectrometer solenoid'). *If they could off-load the $1200K cost of the first solenoid, the funds could be used to build the $970K coupling coil earlier and another 201 MHz cavity (~$250K) to improve the fabrication methods and provide some contingency (the current plan has a several year cavity production hiatus, which is very inefficient).* Also, they might consider what cooling information could be derived from running MICE initially without the spectrometer solenoids (i.e., with a well momentum collimated beam, just measuring the position and angle of the muons before and after the absorbers and cavities may be sufficient to demonstrate cooling).

Other comments on the program:

Using surface coatings is unlikely to improve cavity performance, as they tend to burn off at rf breakdown sites.

The collaboration reported on initial attempts to use Local Electrode Atom Probe (LEAP) Tomography to explore surface contamination, microstructure, and breakdown mechanisms. The committee encourages the continued exploration of this interesting new tool for surface studies. The use of a 3D atom probe microscope to analyze the surface characteristics under high field is a novel approach of high interest for the RF community in general and extends beyond the scope of the Muon Collaboration.

The cavity group is to be commended for managing an efficient inter-laboratory collaboration to build and test cavities.

III. B. SRF Development at Cornell Superconducting Cavity Program

<u>Over the last year</u>

Previous to last year a 200MHz Nb sputtered Cu cavity had been tested and best results showed a strong Q slope and a maximum Eacc of 11MV/m with Q0 of 7e8.
Measurements of surface resistance were also carried out with an external applied magnetic field. The resistance at low RF gradient was unaffected up to 1200 Oe consistent with HC1.

Further testing of 200MHz Nb sputtered Cu cavities has been on hold awaiting a successful resputtering of the cavity at CERN.

The emphasis of the test program has shifted toward 500MHz cavities sputtered at ACCEL. The first cavity has only gone to ~4.5MV/m with strong field emission. The second achieved better results (10MV/m limited by rf and a Q of 5e8 at 4.2K. This test provided date on the change of Rs with gradient that agrees with earlier data in this frequency range but not with that obtained at 200 MHz

Characterization of deposited Nb surfaces analysis using Auger, SIMS, and Atomic Force Microscope techniques has been initiated.

<u>Plans in FY05</u>

Tests of the recoated 200MHz cavity should take place this summer. Measurements of the effect of external field on surface resistance will be extended to regions of higher RF gradient.

NSF funding for Muon SRF R&D contract will terminate in 9/05. Cornell plans to continue the effort on developing sputtered coated cavities past this time with their 500MHz program. It is planned to build (by spinning) and test cavities from explosively or isostaticly bonded Nb/Cu material. Research on various methods of applying Nb to single cell 500MHz cavities will continue.

The committee agrees with the Cornell group that using the remaining NSF funds toward measuring the 200MHz cavity once more, and then continuing with 500MHz cavity studies is most reasonable. This may lead to further understanding of the Q slope and surface properties of Nb applied to Cu by various methods. But in switching to 500MHz, other issues more important at 200MHz such as cavity frequency shift from pulsed operation should not be forgotten.

As it is very likely that Nb/Cu sandwich material will provide the necessary gradient performance for muon acceleration, proof of performance of Nb sputtered cavities does not have the imperative that cooling and targetry do.

Further Discussion, Findings Comments and Recommendations

Superconducting cavities would be used to accelerate the muons after cooling in a neutrino factory because high gradient and efficiency can achieved in large aperture cavities (201 MHz is current design frequency). However, demonstrating operation of such cavities at the proposed gradients (15-17 MV/m) is not as critical as that for the normal conducting cavities. Such gradients will likely be achieved based on past experience at somewhat higher frequencies (superconducting cavity performance at these gradient levels is fairly frequency independent). However, the task is made more difficult by the need to use Niobium 'coated' cavities since ones made of pure Niobium would be cost prohibitive for in neutrino factory. For this program, a 201 MHz copper cavity was built at CERN and Niobium sputtered there using the techniques learned from the LEP cavity program.

To date, the maximum gradient achieved in tests of this cavity at Cornell is ~ 11 MV/m with a Q below 10^9. The measured decrease of Q with gradient is much worse than usually observed in Nb sputtered devices. This is probably caused by the material properties of the Nb film. The cavity will be recoated using an improved geometry for the Nb deposition, which should improve performance based on what has been learned from surface analyses of the sputtered surfaces. Moreover, other coating techniques are being investigated like explosion bonding, ECR coating and cathodic arc deposition. For economical reasons, these tests are being done with 500 MHz cavities. Another group has achieved good performance with a 1.3 GHz cavity spun or hydroformed from explosive bonded Nb-Cu sheet.

The diagnosis of the difficulties encountered with the 201 MHz cavity is convincing. Investigating in detail the Nb surface behavior and building reduced size 500 MHz cavities is a reasonable approach. It is unfortunate that the 201 MHz cavity program will end this September. At least the sputter coating program will continue, which is important for the neutrino factory program.

IV. Response to the Charge 1-6

1. Review and comment on the R&D progress achieved since the last MUTAC review.

Excellent progress has been made in the areas of 200MHz cavity and cavity window fabrication, absorber testing, and preparation of the MTA area. Absorber window work continues to be state of the art.

Limited progress has been made in the area of SRF as the program is shifting from 200MHz to 500MHz and surface preparation R&D and analysis.
It has been unfortunate that the warm cavity development has been interrupted for so long.

2. ***Review and give advice on the R&D plans and corresponding budgets for FY05.***

Given the schedule for the target experiment, there appears to be little option or flexibility in the budget allocation for FY05.

We note again this year, the critical importance of the 200MHz warm cavity w magnetic field R&D. The priority of this activity relative to other areas does not appear sufficient and the schedule over 5 years far from desirable. Additional funds if they become available should be concentrated on the warm 200MHz program.
The switching of focus of the SRF program to 500MHz is appropriate.

3. ***Assess and comment on plans for the CERN Targetry experiment.***

Over the past year

CERN has given approval for the Mercury Target Experiment (NTOF 11). The experiment is scheduled for 2007. The 15T pulsed solenoid magnet is nearing completion. Both the coils and cryostat are under fabrication.

Plans in FY05

Test of the N2 cooled solenoid to 15T is planed for fall of 05 at MIT. The cryo valve box will also be tested in the fall. Integration of the solenoid and jet is scheduled for summer 06.

A substantial fraction of the DOE-MC funds will be dedicated to preparing the targetry during FY05-07 at about $600-700K/y. The total investment is ~$2M. This budget priority is necessary if the experiment is to proceed as scheduled.

Further Discussion, Findings Comments and Recommendations

The Muon Collaboration described simulation of high power solid and liquid mercury targets as well as the plans for a target experiment at CERN. Solid targets seem to be limited to about 1 MW or so, band saw targets made of materials with low thermal expansion coefficients may allow the power to be increased above this level. Higher power targets (up to 4 MW) may require liquid mercury targets. A CERN experiment is planned that uses a jet of liquid mercury in a 15-20 T solenoid magnet as the target. The jet is inclined to improve acceptance of low energy particle produced a wide angle WRT the beam axis. The group has modeled beam-induced cavitations in the jet and the hydrodynamic deformation of the 25 m/s mercury stream as it enters the magnetic field. Simulation indicates the jet will break up due to bubble formation with the mercury expanding at velocities of 20 m/s at the planned energy deposition of ~100 J/gm (up to 180J/g with 2.8 x 10^{13} p per pulse at 24 GeV) in the CERN test. The target is designed for a pulse rate up to 50 Hz this means about 20 ms is available for the jet to stabilize before the next pulse arrives.

In the past, experiments of the mercury jet in a magnetic field without beam and with beam but without a magnetic field have been carried out with promising results. Simulations of the process have gotten more powerful as well. Even so the whole dynamic situation is extremely complex and deserves a realistic test to assure that the jet and whole jet system behavior with high power beams will be as desired.

The behavior of the liquid mercury in the 20 T field both before and after it is struck with beam is far from clear. Even without beam, the behavior of the outgoing mercury stream as it strikes the back of the vessel in the 20 T field and makes its way back to the reservoir has not been modeled. Similarly, the transverse breakup of the mercury jet when hit with beam in a 20 T field also needs to be modeled. Are the outgoing mercury drops charged? Do they move transversely to the vessel walls or are they confined to move axially by the field? There are numerous other practical issues to allow operation and repair of what will become a very radioactive system. The planned experiment will address a variety of such questions and seems likely to discover other interesting "phenomenon". It will also serve to validate the modeling programs being used.

The target experiment was recently given final approval by CERN and is scheduled to run in April of 2007. The experiment is to be located in the NTOF11 beam line which is a good location in terms of the logistics in mounting the experiment. CERN/RAL will be responsible for the cryogenics and the power supplies, with the US delivering the diagnostics, the mercury jet, and the 15T magnet. The beam line is essentially unchanged. The equipment seems to be on schedule and a test of the magnet and the jet will take place in 2006 at MIT. The US Muon Collaboration is playing a leadership role in this experiment following the BNL beam tests with the jet and is providing the spokesmen for this effort.

MUTAC finds the target experiment to be in relatively good shape provided the BNL group remains a part of the Muon Collaboration. In the absence of the BNL group it was less clear that sufficient labor and resources exist to perform the experiment at outlined. MUTAC does consider the two-week planned CERN run to be short. It leaves little time to resolve any problems that may be encountered. We suggest that the collaboration explore the possibility of splitting the run into two with this end in mind. The very nature of the experiment poses potential safety issues. MUTAC suggests that the spokesmen contact CERN to determine to necessity for and the nature of any safety and operational readiness reviews.

4. Assess and comment on plans for the MICE experiment.

The concept of ionization cooling is central to the technical design of both Muon Colliders and Neutrino Factories. An experimental demonstration of cooling technology as represented by MICE is thus a major step to establishing overall technical viability. Given the novel nature of the cooling hardware an integrated system test such as this will be vital in advancing the designs to a second generation level. Conceived as a highly precise single particle 'tracking' experiment it has a goal of verifying fractional emittance changes down to the 0.1% level. The basic concept has remained unchanged for the past few years but is much more technically mature now. Issues include the operation of RF cavities in high magnetic fields, hydrogen safety, and precision tracking in the presence of RF noise and dark currents. The complete experimental set-up consists of the beam line, tracking spectrometers front and back, three Li-H absorber modules separated by two 4-cell 200 MHz RF cavities. The experiment is proposed in a phased scenario of six steps to be completed in the 2007/9 time frame. The Muon Ionization Cooling Experiment (MICE) is planned for an external beam from ISIS at RAL. The MICE experiment is scheduled in two phases and six steps. Phase 1 includes Steps 1, 2 and part of 3 and provides for preparation of the beam line, the upstream unit of particle ID, trackers and matching coils and part of the down stream unit. Phase 1 with the upstream ID/tracker is scheduled for operation by the end of 07. Phase 2 combines the upstream and downstream identification to check for consistency between them, then in steps 4, 5, 6 tests one absorber unit, 1/2 cooling cell with RF cavities-coupling coil, and two absorbers, and finally two 1/2 cooling cells with three absorber units. The goal is to show 10% cooling and requires 20MV of RF with a baseline gradient of 8MV/m. The tentative schedule through step 6 presented by Blondel is to have demonstrated cooling with precise measurements is 2009. As stated earlier in this report, this date is inconsistent with the MC 5 year funding scenario presented in this review. The proposed schedule (2009) assumes additional substantial funding from Japan, CH, and IT. The US hardware deliverables are based on the MUCOOL activities and include RF and absorber hardware in addition to spectrometer solenoids and a Cerenkov detector. In addition to hardware the US is also contributing to the MICE simulations using the ICOOL code. The required US funding support for MICE hardware is estimated at $5-6M over the next 5 years, and to date the DOE has committed $300K/year over the next three years, and the NSF has allocated $100K/yr over a similar time frame. An additional $2M has been requested from the NSF for direct support of MICE under an MRI proposal. With renewed interest in a future neutrino program in Europe the MICE collaboration has grown to encompass 7 countries (and CERN), 40 institutes, and 140 collaborators and is currently the main international collaborative effort in the area of Neutrino factories. The experimental hardware is under development in many locations and progress appears to be consistent with the overall schedule.

The Committee notes with satisfaction the evident progress with regard to MICE during the past year. The hardware design has progressed significantly and component integration is evident at the engineering level of detail. The highlight was the agreement with RAL (and the UK funding authorities) which authorized 'phase 1' approval for MICE and released £9.7M to that end. Phase 1 approval covers the beam line, the incoming particle spectrometer and possibly some components of the outgoing spectrometer. The last MUTAC report encouraged the US Muon Collaboration to consider a significant role in the MICE collaboration and MUTAC welcomes the success during the past 12 months in moving towards this goal. The US Project Manager who indicated that MICE would become the highest priority element of the program once the target experiment was completed affirmed this. MUTAC endorses the overall high priority given to MICE in the 5 year R&D program.

While the fiscal support for MICE phase 1 would appear to be in place, the anticipated funds available to the Muon Collaboration is not consistent with the desired schedule of the US scope for the complete experiment. Additional ‘common funds’ from the MICE collaboration or further NSF support would be required. The stated approach to deal with this funding shortfall should additional support not be forthcoming, is to slip the phase 2 schedule by ~12 months. MUTAC supports the approach of schedule slippage rather than scope reduction to deal with flat funding scenarios.

In light of the anticipated flat budgetary situation MUTAC cautions the Muon Collaboration to be careful to contain any scope creep in the US contributions. US contributions are most highly leveraged when based on the MUCOOL development program rather than more generic contributions. The recent decision for the US to adopt the spectrometer solenoids may be highly desirable from an overall MICE perspective but seems to MUTAC to represent a hardware element that does not rely on any specific US expertise.

5. Review and comment on the Simulation Group plans, including Neutrino Factory design optimization, FFAG acceleration systems activities, and Muon Collider studies.

The APS study, (Study IIa) Neutrino Factory and Beta Beam Experiments and Development (BNL 72369-2004, FNAL TM 2259, LBNL 55478) was completed in Nov 2004. This study, based on Study II, gives an overview summary of the present or recent thinking of the integrated NF design and possible design parameter changes to reduce cost. The main innovations integrated into the study were: bunching the beam before phase rotation and employing 200 MHZ RF systems instead of induction linacs, reducing the cooling requirements by choosing larger acceptance for acceleration, and going to a Dogbone RLA for 0.2 to 5 GeV followed by two “Non Scaling” FFAGs for 5-20 GeV acceleration. In this new scheme both signs of muons can be accelerated. Study IIa can be looked upon as the integrated summary of ideas this committee has heard developed in past MUTAC reviews.

The study also considered the use of LiH instead of liquid hydrogen, possibly a considerable safety advantage.

The new layout was roughly estimated by scaling from Study II to cost ~60% of that earlier Study with major savings in rotation, cooling, and acceleration.

<u>Plans in FY05</u>

Design work is and will be continuing with continued refinements for Study IIb and scoping studies for the World Design Study (Study 3). There are plans to try to incorporate aspects of Japanese and European designs.

Tabletop ring coolers- Studies on small rings will continue with optimization of ring and beam parameters, the use of gas filled rings, realistic fields, and investigation of injection and extraction issues.

Electron FFAG Model- Ideas of non-scaling FFAG acceleration rings are being developed. MC members have largely developed these ideas, but as MC cannot take on new hardware initiatives (within the projected 5 year funding plan), these ideas have been picked up by others. A group in the UK is now considering building an electron model in order to test the principle.

Muon collider- There is no complete, self-consistent, front-end muon collider design. There are plans for collider system design using ring coolers. Design issues include injection and extraction, the high thermal load of absorbers in ring coolers, lithium lens cooling and coalescence of bunch trains. Resources for these studies are limited.

New and interesting ideas are emerging in the area of 6D ionization cooling. Two of these involve the combination of high-density gas within bending wedge or helical magnet channels (solenoid and helical dipole) instead of separated density and bending/focusing schemes. Two such ideas are the Inverse Cyclotron and the Helical Channel.

The group of people working with Muons, Inc. has many innovative ideas that are being considered more thoroughly through SBIR/STTR opportunities. These include:

- Gaseous H_2 in rf cavities
- The 6D Helical cooling channel
- Parametric resonance ionization cooling
- Reverse emittance exchange
- Rf capture and Phase rotation with Gaseous H_2 RF

Further Discussion, Findings Comments and Recommendations

The simulation and theory effort is performed by a strong group of creative accelerator designers and modelers at several laboratories. Having completed Study IIa, the group is now focused on further refinement and exploration of new ideas. Study IIa incorporates major changes from Study II that have improved performance by a factor of 2 and reduced estimated costs by as much as 40%. Major improvements in Study IIa include i) a new adiabatic RF bunching and phase rotation scheme which eliminates the induction linacs, ii) a new linac front end with larger acceptance and iii) a simplified cooler design. Further refinement of the Study IIa configuration is underway (this is termed Study IIb), including exploration of a gas-filled cooling channel. Further creative ideas for ring based coolers are being explored and are showing good progress.

The acceleration System in Study IIa represents a substantial change from Study II with the replacement of the 20 GeV Recirculating Linac with a smaller dogbone RLA and two FFAG rings.

The relatively small change in the design of the neutrino factory might suggest the maturity of the design. In the past the rate of change of the acceleration section design exceeded the time it takes to fully evaluate one design from the beam dynamics standpoint. It is now a good opportunity to perform more detailed studies with one definite design. We therefore recommend that a single acceleration system design be “frozen” in order to evaluate beam dynamics issues and the full end-to-end performance of this important piece of the accelerator complex, with the goal of estimating the emittance growth and transmission to the linac output. This evaluation should include full 6D tracking, lattice non-linearities, full description of RF fields and transit-time effects, as well as tolerances on matching from the cooler section, transverse and longitudinal setpoint errors and so on. In addition, consideration of collective effects in the FFAG rings is warranted.

We ask that MC determine when an overall baseline design including coherent end-to-end support simulations can be available. We do not know at this time whether the World Study will fulfill this function or not. Nevertheless, we hope that the World Design Study will bring about substantial progress towards the real design of the neutrino factory.

In the report of the last MUTAC meeting we suggested a priority asignment for future study, in which the comparison with the non-cooling scenario had the first priority, the neutrino factory the second and the muon collider the third. The progress in the last year seems to be opposite. The committee was disappointed that the theory and simulations group had not yet seriously compared neutrino factory designs without cooling channels with their present design. We still would like to hear about the comparison of the two different scenarios of the neutrino factory, including the physics output, timeline, and the cost.

We heard about many new or improved ideas on muon-cooling, related in particular to the muon-collider, including HCC (Helical Cooling Channel), PIC (Parametric-resonance Ionization Cooling), gas absorber (to replace wedge absorber), table-top dipole ring cooler, etc. These are very exciting and should be pursued further. On the other hand, the progress on the neutrino factory design since the last meeting seems to be relatively slow compared with the rapid progress in the past from Study I to II and from II to IIa.

New members found it hard to assess the work accomplished and planned because of the lack of an overall picture of the present baseline configuration for the neutrino factory and an outline of the muon collider. Though the NF is described in the APS Study IIa it still would be helpful to have a short up to date baseline description.

The committee understanding and the assessment of the work accomplished would be simplified and certainly more accurate if the main parameters of the baseline solution and its main components were made available to the MUTAC members in a condensed and easily consultable parameter list.

Since for much of the machine the muon beam is large transversely and longitudinally, and is not yet ultra-relativistic, non-linear effects are critical and need to be fully incorporated into the simulations. In particular the treatment of the full radial dependence of RF fields and the defocusing radial RF fields need careful treatment in the simulations, as well as, obviously, time-dependent or transit-time effects. These types of effects are particularly important for large amplitude particles, as is expected in the cooling section and in the MICE experiment.

Accelerating fields terminated on curved windows in the 201 MHz RF cavity cells have a small radial electric field component. This RF defocusing (or focusing) term should be considered in simulations, particularly for muon beams at low energy, such as in the MICE experiment. To achieve the target emittance resolution goal for MICE, such effects may be important to include.

A new optimization algorithm for the phase rotation section was presented. This appears to be an efficient method. Obviously more studies are needed in order to draw realistic conclusions. The ultimate figure of merit needs to incorporate the full particle distribution, maximizing the flux into some acceptance. We understand that this work is heading in that direction. It would be extremely useful to work toward goal of 6D tracking of a realistic distribution through this section.

LiH absorbers have been mentioned as a possibility for a couple of years now. We encourage an analysis of the practicality of this direction as compared to the Hydrogen absorbers.

This time there was no presentation on the design of the storage ring. The ring is far from conventional and can be quite challenging. We would like to hear about design progresses in the next meeting.

Problems with funding in the BNL physics groups threaten the viability of the Muon Group, with the potential for grave consequences in the theory and simulation effort of the collaboration. The committee is very concerned about the impact of this on the Neutrino Factory studies, the CERN target experiment, and the development and maintenance of the ICOOL code. The committee notes that support of the simulation code "ICOOL" is limited to one person. It is important to have more than one individual with in depth understanding of the code. Plans should be made ASAP for the handoff of the ICOOL code to the larger collaboration.

6. Review and give advice on the Muon Collaboration 5-year plan.

The MCOG management has asked MC to prepare a 5-year R&D plan and indicate the corresponding funding needs. MCOG wants evidence that there is a plan and the wherewithal to follow it. A realistic plan should assume "flat-flat" funding. An optimistic plan could perhaps double the direct funding.

The funding situation and proposed plan is somewhat confusing and difficult to sort out. There are a number of uncertainties as the outcome of some funding requests is not yet known.

Past and present funding sources include:

- DOE to the MC collaboration (used primarily for hardware and M&S). DOE has approved that \$300k/y of these funds can be directed toward MICE starting in FY05 for 3 years.
- DOE Lab support of staff ("Base" funds coming from the Labs, BNL, FNAL, LBNL)
- NSF funds including SRF & University administrated by Cornell- This is now ended though ~1M\$ is still available in FY05 for SRF work at Cornell.
- NSF funds for MICE administrated by IIT – NSF is providing \$100K/yr for 3 years starting in 05
- ICAR funds- ended. In the past this provided ~9FTE's of support
- DOE SBIR/STTR funds (Muons, Inc) Funds for individual specific proposals awarded yearly.

The first two items contain the major part of the funding and over the years 2000-2005 have dropped from a total of $8M in FY00 to $3.6M in FY05. The funds are split about half and half between DOE-MC and Lab Base. In FY05 DOE-MC is $1.7M. Lab Base of $1.9M consists of BNL ($1.0M), FNAL ($0.6M), LBNL ($0.3M).

Two proposals have been submitted to NSF and await determination.

- NSF MRI $2M over 2 years for MICE: for one spectrometer solenoid, and US portion of tracker detector (Kaplan)
- NSF University Consortium $3.5M over 3 years for muon cooling R&D and MICE (Hanson)

The funding assumption presented by Zisman had a "baseline" model of $3.6M (as in FY05) and an "incremental" model of $4.0M projected for the DOE-MC and Lab Base yearly funding through FY10. Additionally, $0.625M ($0.175M) is assumed to come from NSF for the baseline model (incremental model).

The DOE-MC assumed funds of $1.7M/y for 6 years (M&S hardware) are distributed in the strawman over four activities: Targetry, System Studies, MUCOOL, and MICE. After assigning funding to targetry, which is front loaded, and system studies ($2.3M, and $1.4M over the 6 years) the remaining $6.55 $M (FY05-10) or $5.76M (FY06-10) can be compared with the needs of Mice and MUCOOL.

The current scope of US Mice obligations is:

Original scope

- Cooling cell components- 200MHz, RF LH2 absorbers, windows
- Cooling cell concepts, beam line simulations, software
- Cerenkov counter, readout and fibers for tracker
- Oversight

Additional recent responsibilities-

- Spectrometer solenoids,
- RF power

The estimated cost of hardware (M&S) needed for the MUCOOL coupling coil (CC) and MICE through step 5 (test of a cooling channel cell) is $5555K. An additional $1460K is needed for step 6, the 2nd half cooling channel cell in order to test a full cell. (The MUCOOL coupling coil is estimated at $970K.) Other MUCOOL activities are estimated to be $1165K. Thus in the FY06-10 time period $4595K strawman DOE funds are available for the CC and Mice in this model, whereas $5555K is needed. It is proposed that the additional funds ($960K) may be made up by a combination of NSF support and International contributions yet to be worked out. If this does not happen then further stretch-out is planned to create these funds.

In the incremental strawman DOE-MC funds of $2.1M/year are assumed along with small NSF funds ($175K for the tracker). No relief from international collaborators is assumed. With this scenario ~$900K is available for contingency or to proceed to fund MICE step 6 earlier.

Observations:

The MICE schedule presented by Blondel indicated the desire to be at step 5 in 2008 and step 6 in 2009. The baseline scenario does not make step 5 till 2010 and step 6 by 2012. The incremental scenario would reach step 6 one year earlier. As stated during the review, time stretch out is being used to accumulate the necessary funding.

It was mentioned during the review that the overall cost of MICE is $25-35M. It is important to know the scope of this estimate, how much of it has been agreed to? And how much still needs to find collaborators and support?

It is clear that the R&D plans that go with the assumed funding profiles are far from ideal, and in fact put one of the most important R&D activities at great risk. Accepting of responsibility for the spectrometer solenoids, though it may have helped get MICE approved has further exacerbated the risk and delay in schedule of building and testing the coupling coil and 200MHz cavities critical to the whole muon cooling concept. Already last year finding for the targetry had pushed cavity/coil testing back.

In the present scenarios the coupling coil is not completed until 09 (08) in the baseline (incremental) plans.

The funding R&D plans presented appear extremely tight though not impossible. The baseline plan clearly puts important R&D at risk.

Recommendations

International support should be aggressively sought for the construction of the MICE spectrometer solenoids. Support should be sought from other communities (neutrino superbeam proponents) with vested interest in high power targetry.

Further support from DOE, NSF at the level of $500K/year through the fabrication phase of MICE would substantially reduce the stress on the collaboration, risk and schedule to accomplish the cooling experiment. We note that DOE did increase FY04 funding by $400K and FY05 funding by $300K over the level it was at the time of last years review.

Further major commitments should not be entered into by the MC (or only with great caution) until the development plan for the 200MHz RF testing with representative magnetic fields is established in a timely way.

We note that the MC would like to have a major role in the development of an electron non-scaling FFAG model as the collaboration members have generated many of the ideas.

However at this time they are not taking on as a group any of this development.

MUTAC Committee:

Chris Adolphson	star@slac.stanford.edu
M Breidenbach	mib@slac.stanford.edu
H Edwards, Chair	hedwards@fnal.gov
R Geroby	roland.garoby@cern.ch
M Harrison	harrison@bnl.gov
S Henderson	shenderson@ornl.gov
R Kephart	kephart@fnal.gov
Lindner (excused)	lindner@ph.tum.de
K Yokoya	kaoru.yokoya@kek.gov