Report of the C-AD Machine Advisory Committee Meeting 23-25 March 2009

1. Executive Summary

The C-AD Advisory Committee was presented with material concerning four central topics of RHIC developments which fall under the following headings: stochastic cooling, R&D on ERLs, on RHIC electron-lens, and on eRHIC / MEeIC. The committee was impressed by the path laid out for the future of RHIC. Stochastic cooling together with the 56MHz RF system increases the luminosity in the short term, the electron lens and possibly coherent electron cooling may subsequently further improve performance in the mid term, and long term options for extending RHIC's physics reach by electron collisions are being worked out. The committee appreciates that it has been presented with a balanced plan of systematic RHIC improvements from the immediate to the long range future.

A significant increase of luminosity for gold on gold collisions can doubtlessly be expected from the additional cooling systems under preparation. The committee encourages building these systems with high priority to benefit in the next ion run. The cooling system with its present frequency window together with the new 56MHz SRF cavity promises significant additional luminosity increase which should be brought about as fast as possible.

Because many of the mid and long term options for RHIC depend on Energy Recovery Linac (ERL) technology, C-AD has invested in an ERL test for some time. This foresight is to be commented. The ERL test setup has made progress on several fronts, and the critical path item for commissioning is the SRF gun cryostat. We encourage speeding up its completion to before the 2010 RHIC shutdown. The envisioned ERLs for electron-ion collisions rely on multi turn energy recovery, currently 3 and 5 turns are being discussed, and it seems therefore recommendable to install a second recovery loop in the test ERL. The high current operation of the ERL either requires a dedicated laser, or the diamond amplifier. Because of the potential benefit of the diamond amplifier to several high current projects, we encourage increasing the emphasis on this project.

R&D efforts on electron-lens compensation of beam-beam effects are encouraged and the proposal for an operational demonstration is strongly supported. Because past attempts in implementing beam-beam compensation schemes with electron beams, e.g. at the FNAL, have not resulted in the expected gains, we urge developing a better understanding of the underlying processes by analyzing past observations at the Tevatron.

The committee was pleased to learn about an effort to provide medium energy electron-ion collisions with the MEeIC before high energy collisions can be provided at an eRHIC facility. MEeIC is a much smaller scale accelerator and an effort is made to optimally use existing tunnel boundary conditions for an optimal ERL installation. Naturally many topics still have to be analyzed, but the approach is very promising and shows again that C-AD has laid out a systematic path for RHIC's future.

2. RHIC developments

2.1. Stochastic Cooling

2.1.1. Findings

The efforts to continue the installation of additional stochastic cooling system were presented. The luminosity increase by installation of a longitudinal cooling system in one ring has already been demonstrated. Beginning of this year a vertical cooling system was installed in the yellow ring, but could not be tested so far. New filter systems for the transverse cooling system have been developed. It is foreseen to perform a first test of the vertical system with a low intensity proton bunch during the current run.

The installation of a horizontal cooling system in both rings and a longitudinal and vertical cooling system in the blue ring are in preparation. New pickup and kicker modules with an expected improvement of performance have been designed, but it took time to find a manufacturer.

2.1.2. Comments

As there is some technical risk for the new kicker design, the manufacturing of a prototype should be finished with high priority. After successful testing the new hardware should be installed as soon as possible. A further increase of luminosity for gold on gold collisions can doubtlessly be expected from the additional cooling systems. These systems should be built with highest priority to benefit in the next ion run.

The cooling system with its present frequency window together with the new 56MHz SRF cavity promises a luminosity increase by approximately a factor of 2. This is a significant increase which should be brought about as fast as possible.

There are future luminosity increases to be expected from increasing the frequency window by the 9-12GHz band, and the eRHIC and MEeIC assume the resulting faster cooling rates for electron-ion collisions. We therefore encourage further analysis of the advantages of this extended cooling system and to start an engineering design.

2.1.3. Recommendations

- Analyze the critical path items of the stochastic cooling system for the present frequency band to make it available as soon as possible.
- Start detailed engineering design of the 9-12GHz stochastic cooling system.
- Look into the newest microwave design tools for designing required pickups and RF hardware.
- Analyze crosstalk between pickups for the new cooling system to make sure the bandwidth can be achieved.

2.2. 56MHz cavity

2.2.1. Findings

A 56 MHz superconducting RF cavity of re-entrant resonator of ¼-wave design has been developed to increase the capture into one 197MHz bucket, to decrease the bunch lengthening, and thereby to increase the luminosity of RHIC. The cavity will be excited mainly by the beam loaded current. Substantial progress on the design has been achieved, electromagnetic measurements of a copper prototype have been

accomplished, and a thorough review of the design has recently been performed. Even though the luminosity potential is significant, it is planned initially not to have a spare cavity.

2.2.2. Comments

Because a luminosity increase of approximately a factor of 2 is achievable, it seems reasonable to have a spare once it has been shown that this system benefits RHIC. Because of the long lead time for the full cryomodule, it seems important to plan out when the development of a spare should be started.

2.2.3. Recommendations

- It will be important to have a plan and scheme to deal with “off-normal” conditions in the cavity, and determine cavity conditions and diagnostic signals requiring beam abort. A clear plan will be needed before the cavity may be integrated into the RHIC rings.
- There is concern about the HOM damping of a few isolated HOMs. A plan for damping these HOMs should be developed as soon as possible, if they have not been taken care of already.
- Check in more detail the transverse modes for the 56MHz cavity. Ensure that excitations of the transverse HOMs by the displaced beams will be properly handled and do not damage the beam.

3. ERL R&D

3.1. Status and commissioning plans

3.1.1. Findings

The MAC has been presented a convincing review of the ERL status and commissioning plans. It fully endorses the major goals of the R&D ERL project to develop Energy Recovery towards high charge (5nc/bunch) and high current (500mA) well above the current state of the art (nc/bunch and a few mA) and to provide a test bed for future RHIC facilities specially the high current ERL envisaged for eRHIC. The R&D ERL also provides an facility to develop and test high energy electron cooling and possibly demonstrate the proof of principle of the novel approach of Coherent Electron Cooling. For this, the ERL installation has to be transported to a RHIC IR. If this is done by 2012, this may be beneficial to RHIC performance.

3.1.2. Comments

Even if the parameters of the test have been initially derived for high energy electron cooling, the committee is convinced that the adopted scheme is the most pragmatic and the fastest approach to address all major issues related to DOE applications by taking advantage of the RF gun funded by the Navy. Indeed, an RF gun specially designed for DOE application with higher beam energy is not necessary for the R&D test, even though it would provide somewhat better performances which could be useful for the final application.

The committee appreciates the staged approach starting with the G5 straight pass from RF gun to the 5 cells SC accelerating structure allowing high charge generation studies by October 2010 and the completion of the first recirculation loop with high degrees of flexibility for high charge energy recovery studies by 2011. The committee

is looking forward to the G5 performances based on a commercial laser which will be delivered soon and will allow high charge studies (5nC/bunch) at a limited repetition rate of 10 MHz. Such a repetition rate is more than sufficient at the early stage of the facility for high charge studies but will limit the intensity to about 50mA or somewhat higher thanks to a factor 3 margin in laser energy. But it will not allow intensities of several hundreds of mA required for envisaged high intensity studies. The development of a high repetition rate laser is therefore planned. We consider the high current test important, because eRHIC and MEeIC have very high currents in the cavities. The high repetition rate laser development should therefore be planned out and proceed with suitable speed.
The committee is also concerned by the heavy HOM excitation induced in the SC accelerating structures at high current of several Amps due to the multiple passes in MEeIC or eRHIC operation. The first recirculation loop will allow HOM excitation and BBU studies at the Amp level. eRHIC and MEeIC rely on multiple return paths and therefore, the construction of a second recirculation loop for the test ERL is very recommendable. It would also allow a beam current close to the one foreseen in operation of eRHIC.

3.1.3. Recommendation

- Launch development of laser with high repetition rate (700MHz) for high current studies
- Consider installation of second loop of recirculation as soon as possible to test HOM excitation during operation of the energy recovery linac.
- Plan for maximum use of the ERL test facility, including its use for coherent electron cooling in the RHIC tunnel.

3.2. Gun and Accelerating Cavity

3.2.1. Findings

The ERL cryomodule that had been presented to the C-AD MAC in its design and construction phase has been delivered and is currently being connected to the RF and cryogenic system. An exciting commissioning phase will follow and is planned to continue for approximately one year. The cavity and many of the cryomodule components were produced in industry and the string was assembled in JLAB. The vessel was then completed at BNL. The first cool down happened just 3 weeks ago, the static loss was satisfactory, 1.8K could be reached, and the tuning range of the stepping motor and the Piezos were as expected. This module satisfies the pressure vessel code, which has become significantly more difficult to satisfy. And this SRF linac module is probably the first that is certified to satisfy that code. This added design constraint has several consequences, e.g. a restricted tuning range. The low level RF (LLRF) electronics has been tested for the 50kW transmitter system to be used for this linac.
The SRF gun that is to feed this ERL cavity is still under construction. The construction plan that was presented called for completion by late fall 2010.

3.2.2. Comments

SRF gun technology has been developed and tested for a very long time, mostly in Germany and the US. With high current CW linacs on the horizon, this technology is increasing in importance and there is much international interest in the success of the system that BNL is developing.

While a high level schedule for completion of the SRF gun has been presented, it did not become clear if there is a single item that defines the critical path and that could be approached faster to speed up the completion date. However, this high level schedule did indicate that the summer shutdown of RHIC and the associated manpower needs are responsible for a slowdown of the project during the summer months of 2010. It has been indicated that a critical analysis of the schedule may show options to complete the gun before that shutdown, i.e. in May 2010. This schedule would fit well to the planned completion of the linac's cold commissioning.

3.2.3. Recommendations

- Analyze risks involved in using a high Tc superconductor for the solenoid. If this technology has more risks than a low temperature superconducting magnet, we recommend the lower risk solution.
- Try to speed up the SRF gun completion to before the 2010 RHIC shutdown. This may include collaboration with other laboratories for critical items and tests.
- Work together with the RHIC control group early on.
- Work on a more detailed commissioning plan.

3.3. Laser and photo cathode

3.3.1. Findings

The MAC has been presented a comprehensive review of the status and commissioning plans of lasers and photo-cathodes. The committee is pleased to see that the high charge scheme (5nC/bunch) is based on a pretty robust scheme with well defined components:

- K2CsSb photo-cathodes with high quantum efficiency of up to 10% at 355 nm and mounted on stainless steel substrate for which great fabrication and operation experience has been developed and is available in the laboratory.
- Industrial laser with certified performances although with non standard 10 MHz repetition rate soon to be delivered.
- A very good behavior of the photocathode has been demonstrated with nearly no degradation by ion back bombardment over 24 hours in a cathode test setup.

3.3.2. Comments

Good lifetime of at least one week has to be achieved to allow reasonable operation with limited changes of photo-cathodes.

No plans have been presented towards high intensity beam generation of several hundred of mA which imply a laser with a different technology and high repetition rate of several hundreds of MHz if the same kind of photo-cathodes is used. An alternative approach would consist in diamond amplified cathode, a very attractive technology developed at BNL. Such a novel scheme has already demonstrated excellent potential with pulsed operation; however it has not yet been demonstrated in a photo-injector. By multiplying the laser induced electron emission of the photo-cathode, the required energy per pulse of the high repetition rate laser could be minimized. This technology cannot easily be tested in existing RF guns, because the RF frequency is limited by the fabrication technique of diamond with small thickness (presently, for a 700MHz system, about 100 microns). With the international interest in high current CW beams, the diamond amplifier could have a high impact and should be more vigorously pursued.

3.3.3. Recommendation

- Launch tests of diamond amplified cathodes in a photo-injector with frequency in the 700 MHz range, if available.
- Develop techniques of diamond fabrication with small thickness (a few tens of microns) in order to extend the application of the diamond amplified cathode technology to photo-injectors with L or S band frequency.

4. RHIC electron-lens R&D

4.1.1. Findings

The electron lens is meant to cancel the beam-beam force in the interaction region by that of an electron distribution located at another position from the collision point with n*2pi betatron phase advance (or n*pi for symmetric distributions) and assuming a linear transfer channel between the two interactions. Nonlinear lattice elements between the interactions break the nonlinear cancellation. The committee shares the assessment of the C-AD accelerator team that electron lenses can, at least in principle, increase significantly the performance reach of a circular collider. A demonstration of a partial compensation of the beam-beam force and the resulting beam-beam tune shift would not only open the door for higher performance levels in RHIC, but would be an achievement of general interest for any circular collider project and the accelerator community as a whole.

However, past attempts in implementing beam-beam compensation schemes with electron beams have not resulted in the expected performance gain. For example, recent experiments with electron lenses in the Tevatron collider have led to some performance improvements (e.g. abort gap cleaning and lifetime improvements for Packman bunches) but these improvements were not delivered in the originally planned operation mode. The improvements in the Tevatron were obtained in areas that were not part of the initial electron lens operation plan (e.g. abort gap cleaning) and have not yet been fully understood (e.g. the lifetime improvement of Packman bunches could not be reproduced with tune shifts generated with lattice quadrupole magnets).

Numerical simulations can play an important role in defining the operation tolerances of an electron lens and understanding the underlying processes. In particular, the numerical simulation studies can be used for analyzing in detail the dependence of the simulated lifetimes on various effects. For example, it could analyze the lifetime's dependence on beam distributions, on variations of the non-linear fields, and the coherent strong-strong beam-beam effect.

Numerical simulation in toy models that allow a faster simulation time can provide faster response times for parameter scans in the early preparation stage of the simulation campaigns.

4.1.2. Comments

R&D efforts on electron lens compensation schemes are encouraged and a proposal for an operational demonstration is strongly supported.

Reviewing operational experience from the Tevatron and developing a better understanding of the underlying processes by analyzing the Tevatron observations will

help specifying the requirements for an electron lens for the RHIC collider. Preparing already in the design phase of the electron lens a detailed commissioning plan and testing program can assure an in-time development and installation of the required diagnostic tools.

The committee is not convinced that the presented approach for the numerical simulations is fully developed and well specified. It was proposed to use different simulation tools for the RHIC electron lens studies than are currently used at FNAL for the Tevatron analysis. The committee is not yet convinced that the proposed detailed element-by-element tracking can provide additional information when comparing it the potentially faster Lifetrack code used at FNAL. The committee encourages C-AD to support their proposal first by bench marking the code with the current RHIC operation experience (lifetime simulation and a demonstration that the proposed simulation method can reproduce the observed beam lifetimes in RHIC without introducing additional empirical effects such as damping and noise excitations). It was not clear to the committee which of the tracking results can and will in the end be used for judging the electron lens performance in the simulations.

Several optics and lattice optimizations for RHIC are still outstanding, e.g. optimizing the phase advance between the IPs for a minimization of the off-momentum beta-beat. Therefore, the committee encourages including these optimization options into the numerical study of electron lens compensation. Similarly, benchmarking lifetime studies against RHIC data has to include known imperfections, e.g. 10Hz vibrations of the triplet magnets and orbit drifts.

Apart from the above comments, the committee felt that the computer requirements were well specified and that adequate resources for the simulations had been identified.

The proposal of using a small model ring with radiation damping as a test bed for fast parameter studies of the electron lens performance seems to be a reasonable first approach for the numerical studies. However, the committee felt that these studies could also be performed on the existing RHIC lattice by introducing artificial damping and excitation.

4.1.3. Recommendations

- The committee encourages C-AD to support their electron lens R&D efforts with a close follow-up of the Tevatron experience.
- Prepare a detailed commissioning plan and testing program already in the design phase of the electron lens.
- The committee supports the suggested massive simulation effort, but recommends to first establishing a clear simulation strategy and performance evaluation.
- Consider solutions to outstanding optics and lattice optimizations in the tracking studies.
- The simulation studies should include an evaluation of strong-strong beam-beam effects, including coherent motion.
- Add bunch length effects to the beam-beam and electron lens simulations.

5. eRHIC and MEeIC R&D

5.1. Layout and optics

5.1.1. Findings

Since the previous MAC meeting, BNL researchers have considered various plans to “stage” the eRHIC collider, i.e. develop a lower energy ERL-based collider that could directly address interesting physics and provide a “stepping stone” to the full collider.

Two linac lattices with constant gradient quads and scaled gradient quads are designed. HOM Impedance of RF cavities have been estimated. The BBU threshold is higher than 200mA for the base line lattice and it is increased to 1A for the scaled lattice.

A design of isochronous arcs and an IR lattice based for the ERL was presented. The committee was impressed with the completeness, competence, and simplicity of the lattice choices made in the MEeIC arc designs. It is highly proper that the synchrotron radiation aspects of the IR design have been considered and incorporated early in the design process.

Energy loss and energy spread caused by cavities, synchrotron radiation and resistive wall were estimated and are compensated by additional cavities and matching section. Single bunch effects due to short range wakes are being studied. Roughness wakes and a detailed impedance budget have not been included.

In the collision, electrons experience a large disruption due to the proton and ion beams. The disruption, which is related to oscillations of electrons in the proton bunch, entails a wake force for the proton beam, resulting in head-tail instability. Simulations show that the head-tail instability can be cured by chromaticity. The chromaticity effect should be checked by an analytical estimate. The proton beam experiences tune shift from the electron beam. The tune shift is very small 1.5e-3 for the main design. The tune shift is enhanced by factor 4 due to the disruption and depends on bunch length. Jitter of the electron beam may induce proton emittance growth, an analysis of which has not been presented.

5.1.2. Comments

It is important that the nuclear physics community be fully on board with and understand the staging plan, and be willing to support strongly the physics goals of the MEeIC, ideally even independently of the follow-on machine. It is very difficult for the committee to evaluate the strength of this support. For example the minimal reasonable electron energy did not become clear. After all, only a compelling physics case will eventually sell any machine.

Some form of beam cooling will be needed to realize either MeEIC or eRHIC. Coherent electron cooling seems to have the potential for providing this cooling. It was noted in the talks that the emittance growth in the electron beam bunches from the beam-beam collisions needs to be more thoroughly studied. Because of its potential importance in defining the allowable electron beam disruption and collision luminosity, good quantitative understanding of this and related beam-beam interactions should be further pursued.

Major progress in the “zeroth” order designs of many of the elements of the MEeIC were exhibited to the committee. More detailed work built on these results will lead to more detailed designs. It is appropriate, and will help to organize the deeper effort, when the design summary paper is completed on the planned May 2009 time scale.

The design presented assumed an average "real estate" accelerating gradient around 10MV/m, and there is not much margin for fitting the MEeIC in the space allotted. Continuous beam loss is a primary limitation of ERLs and is made more difficult by the requirement of high average current in the ERL designs being suggested at BNL. Quantifying beam loss, either through estimates or detailed measurements will be important for completing a credible MEEIC design.

While an FFAG type recirculator may have advantages, it was not clear to the committee whether such a system is possible given the current state of knowledge about the design.

5.1.3. Recommendations

- The minimal electron energy needed for compelling physics in the MEeIC, either 2 or 4GeV, should be determined.
- More sophisticated simulations and estimates of the cooling efficiency should be performed, as should early experimental tests of the technique.
- A FFAG type recirculator design, if possible, would reduce the number of components. C-AD is encouraged to explore the advantages and feasibility of such a design.
- Given the completeness of some of the beam optics designs, an appropriate next step is to start performing sensitivity analysis.
- The committee recommends that detailed design of the cryo-module be accomplished soon in order to verify that the required real estate gradient is achievable.
- It is recommended that a thorough study of beam loss and machine protection be undertaken for the MEeIC design, including IBS and Touschek scattering.
- Design the beam-beam compensation or matching section and include it in electron-beam dynamics simulations.
- Establish beam-beam simulations for the lifetime of ions and protons in MEeIC, including the pinch effect of the ERL’s electron beam.
- Analyze tolerances for electron beam stability to limit hadron emittance growth.
- The cost study for the MEeIC should be completed in a timely manner.
- The MEeIC design review document should undergo appropriate technical review when available.

5.2. Polarized gun

5.2.1. Finding

Today’s electron ion collider designs require unprecedented polarized electron beam currents. Providing these currents is a major R&D project. While multi-cathode guns have been suggested, the polarized electron source effort currently concentrates on developing a single cathode gun. However, an advanced arrangement, e.g. a “gattling gun”, would be required to obtain polarized currents at the 50mA level with reasonable

cathode lifetime by “sharing” and combining the current emitted from many cathodes. The problem of reproducing many cathodes and integrating them into the gattling gun arrangement was not discussed in a deep way. More detailed designs will be needed to evaluate the efficacy of this approach.

5.2.2. Comment

Although the gattling gun arrangement may allow high average current to be accumulated, it was not clear to the committee that this idea is greatly superior to the demonstrated expedient of just moving the laser spot on the cathode.
Load locks have been developed other laboratories.

5.2.3. Recommendations

- BNL and MIT should take advantage of prior experience with load lock gun designs.

6. Committee Members

Machine Advisory Committee
Georg Hoffstaetter, Chair, Cornell
Oliver Bruning, CERN
Alex Chao, SLAC (excused)
Jean-Pierre Delahaye, CERN
Geoff Krafft, Jefferson Lab
David McGinnis, FNAL
Kazuhito Ohmi, KEK
Markus Steck, GSI

7. Agenda

March 23 - 25, 2009
Large Conference Room, Bldg. 911B

Monday, March 23

08:30 Executive Session
09:00 Welcome ..... D. Lowenstein
09:05 Status and update RHIC stochastic cooling ..... M. Brennan (30 min)
09:45 Status and update RHIC 56 MHz cavity ..... I. Ben-Zvi (30 min)

10:30 Coffee Break - Small Conference Room

11:00 Test ERL status and commissioning plans..... D. Kayran (30 min)
11:40 Gun and linac cryo-module status & comm. plans . A. Burrill (30 min)

12:20 Lunch - Small Conference Room

13:20 Tour of test ERL

14:20 Photocathode status and commissioning plans ..... T. Rao (30 min)

15:00 Coffee Break - Small Conference Room

RHIC Electron Lens R&D

15:30 Introduction head-on beam-beam compensation .. W. Fischer (10 min)
15:45 Code adaptation and computing resources..... G. Robert-Demolaize (10 min)
16:00 Simulations for RHIC ..... Y. Luo (40 min)
17:00 Electron lens with electron beams ..... C. Montag (20 min)

17:30 Executive Session /
Requests for additional presentations

19:00 Dinner (Committee members and presenters)

Tuesday, March 24

08:30 Executive Session / Discussion

Design of a Medium Energy electron-Ion Collider (MEeIC)

09:00 MEeIC in the context of eRHIC ..... V. Litvinenko (20 min)
09:30 Layout and main parameters of MEeIC..... V. Ptitsyn (20 min)

10:00 Coffee Break - Small Conference Room

10:30 Polarized source..... E. Tsentalovich (20 min)
11:00 Beam dynamics issues in MEeIC..... E. Pozdeyev (20 min)
11:30 Lattice and IRs of MEeIC ..... D. Trbojevic (20 min)

12:00 Lunch - Small Conference Room

13:00 Additional requested presentations
14:00 Executive session and report writing

Wednesday, March 25

08:30 Executive session and report writing

10:30 Coffee Break - Small Conference Room

12:00 Lunch - Small Conference Room

13:00 Closeout