Report of the Meeting of the 2nd Collider-Accelerator Department Machine Advisory Committee

Brookhaven National Laboratory, November 8-9 2004

Committee: Alexander Chao, SLAC; David McGinnis, FNAL; L. Merminga, JLAB, Ferdinand Willeke, DESY

Apologies: Oliver Boine-Frankenheim, GSI; Jean-Pierre Delahaye, CERN

Introduction

The Collider-Accelerator Machine Advisory Committee Meeting was held for the 2nd time on November 8-9 2004 in Brookhaven National Laboratory. The committee was charged to review the plans and preparation for a luminosity upgrade program for gold-gold collisions and polarized proton-proton collisions. The charge and the agenda of the meeting are attached at the end of this report.

The committee is quite impressed with the continuous progress in RHIC operation which has been achieved so far. The accelerator operates well above the original design. Polarized protons have been made available already. This is an excellent base for further progress. The committee would like to congratulate the accelerator team on these successes.

The meeting was very effective with well-prepared presentations and open exchange of information. The formal presentations were complemented by breakout session for clarification of some of the technical issues. The committee acknowledges the effort of the CAD-team.

The committee bases its assessments on the goals as presented during the meeting which may be summarized as:

- Increase of the Au-Au integrated luminosity by a factor of 2.5 by increasing the number of bunches from presently 45 to 112 in each ring.
- Increase of the proton beam polarization in RHIC from presently 45% to 70% and extend it to beam energies of 250GeV per beam.
- Increase of the proton-proton luminosity by a factor of 16 by increasing the number of bunches by a factor of two and by increasing the bunch intensity from $0.7 \cdot 10^{11}$ to $2 \cdot 10^{11}$ protons per bunch.

These goals are quite ambitious and represent a considerable challenge. They require careful study and well planned measures to be undertaken.

Heavy Ion Luminosity Operation

The committee learned that the luminosity for Gold-Gold collisions is limited in RHIC by various vacuum effects which do not allow increasing the total beam current above the levels achieved in the 2004 luminosity run. The ion intensity per bunch is exceeding already the design value by 10% and there are no immediate further plans to increase this parameter. The Committee agrees that the vacuum limitations are the only serious issues to be solved in order to obtain the desired increase in Au-Au luminosity. The high vacuum pressure observed at highest beam currents go along with intolerable background condition and poor luminosity lifetime.

The vacuum problems have been assessed by analyzing accelerator data and by performing dedicated experiments.

Evidence has been provided that the vacuum problem at injection energy can be explained by electron cloud instability. The committee agrees that the arguments which lead to this conclusion are quite compelling.

At luminosity operation, however where e-cloud appears to be a likely cause of strong vacuum pressure rise with high intensity, direct evidence for the presence of electron cloud instability (ECI) can not be demonstrated. Moreover, a number of other reasons such as compromises in the preparation of vacuum components are quite likely the cause of pressure instabilities which are observed occasionally. Nevertheless the committee believes the assumption that electron cloud is present at high energy as well is reasonable.

The committee endorses the approach to resolve the intensity limitation by improving the beam vacuum.

However, the fact that ECI can not be clearly identified as the cause is unsatisfactory. It appears to be highly desirable to provide direct evidence for ECI forming at high energy in order to assure that the optimum way to improve the vacuum is chosen and in order to make sure that the effort of adding solenoids around the beam pipe is justified.

The committee therefore recommends pursuing the quest of ECI in luminosity operation and attempting to clarify this issue. The committee can see possible way of

making further progress with this issue by measuring the coherent tune shift across the bunch train or additional effort to observe the electrons directly in the beam pipe.

The committee already learned on its last meeting **that stochastic cooling** is considered as a means to improve the luminosity lifetime and to suppress backgrounds due to loss of particle from the RF bucket. Meanwhile Schottky signals have been observed and transfer function measurements have been observed which indicate that stochastic bunched beam cooling in RHIC has a good chance to be successful. The plans for implementing stochastic cooling systems have been advanced and a layout of the cooling system is in the process of being implemented.

The committee endorses the plan for the installation of longitudinal kickers with half the required bandwidth already this year. This will provide a chance to demonstrate cooling and will provide the opportunity of gaining expertise and experience from which the further development of the full system will profit. This appears to be an effective way of proceeding in this challenging and exciting project.

The upper frequency of 8 GHz has very small design margin for a 2/3rd turn delay and stability at the desired cooling rates may become an issue. The committee therefore suggests investigating the possible benefit of a signal connection across the accelerator ring ("cutting a cord") which would provide more margins in the achievable cooling rates and in addition would open the possibility to increase the bandwidth to 16GHz, which might be feasible. This would result in a significant increase in the cooling rates of the system.

Vacuum and Technical Improvements

Plans to improve the RHIC vacuum in response to the experienced problems to achieve highest beam intensities have been presented to the committee which include

- In situ bake out of warm beam pipe sections
- NEG Coating of the warm beam pipe sections
- Better pumping of the cold beam pipe prior to cool down

As the committee believes that improved vacuum conditions will very likely be beneficial for high intensity operation of RHIC, the committee endorses the planned measures.

Moreover the committee encourages the vacuum support groups to start as soon as possible with the planning of the various actions. The detailed plan to work out should be flexible enough to take into account possible fall back positions or shift of emphasis in case new information becomes available during the upcoming RHIC luminosity running 2005.

The committee is somewhat concerned about the vacuum inside the cold part of the accelerator. The vacuum prior to cool down should be reduced to a level of at least 10^{-6} mbar or less to avoid saturation of the cold beam pipe surface and relatively high vacuum gas density during beam operation.

In order to study the impact of many layers of gas on the cold beam pipe, one sextant has been equipped with more pumps resulting in a significantly reduced gas pressure prior to cool down.

The committee endorses in particular plans to install additional turbo pumps around the accelerator in case that the improved sextant shows a better vacuum behaviour with respect to the rest of the ring. In case those additional pumps cannot be provided in time for the next shut down a staged cool down with concentration of the available pumping speed should be considered to be included in the shut down.

Pressure instabilities in the RHIC warm vacuum sections have been observed. They appear to coincide with recent vacuum installations where compromises between vacuum requirements and schedule constraints have been made.

The committee would like to encourage rigorous vacuum certifications.

Polarization

The committee is very pleased to see an impressive progress and success of the RHIC polarized proton program. These include application of an AC dipole in the AGS and a 5% Siberian snake to overcome the strongest intrinsic depolarizing resonances, the successful operation of the OPPIS polarized H^- source, the functioning of the RHIC Siberian snake and the spin rotators and last but not least the pC polarimeter. This success constitutes a solid base for the future performance enhancements.

The committee takes note of an ambitious upgrade plan with the goal to achieve 70% polarization in RHIC at a beam energy of 250GeV with a very high beam intensity of $2 \cdot 10^{11}$ protons per bunch in 112 bunches. To achieve this, a perfect polarization transmission efficiency of 100% in both AGS and RHIC acceleration is required under more demanding conditions. The simultaneous increase in polarization, beam intensity and beam energy represents a considerable challenge which requires careful analysis and planning.

Reviewing the plans of the polarization team to achieve these goals which are based on the installation of a superconducting 25% Siberian snake in the AGS and an improvement of the polarized ion source OPPIS, the committee can not recognize any principal problems with the planned upgrade. However, the committee would like to see a more clear estimate and identification of the necessary resources and study time.

As far as the **polarization in the AGS** is concerned, the committee expects that the addition of a superconducting Siberian snake, together with a combined optimal tuning with the existing warm snake, should help to cancel the depolarization resonances (3 weak intrinsic depolarising resonances at $24-Q_y$, $24+Q_y$, and $48-Q_y$, as well as the strong resonance at $36+Q_y$) which limited the performance in the previous run. The committee also believes that there is good chance to provide the necessary resonance free space in the working diagram to accommodate the tune spread of beams of intensities of up to $2 \cdot 10^{11}$. It is also expected that the AC dipoles will not be necessary anymore.
A challenging issue however is to operate the AGS with the vertical tune very close to the integer resonances, Q_y=8.96. The enhanced sensitivity to orbit error, dispersion error, distortion of the beam envelope function, as well as the presence of non-linear snake resonances will require considerable set-up and tuning time.

The committee suggests that the polarization team performs a simulation of ramping with orbit and beta errors and realistic orbit correction in order to assess the operational difficulties and as a base for the planning of the necessary machine study time. Particular attention should be paid to nonlinear depolarization resonances to avoid unpleasant surprises.
The committee supports the idea of using the planned luminosity run period with collisions of Cu ions parasitically to set up the AGS for high polarization and high intensity running. This however will require careful planning.

With regard to intensity dependent depolarization effects, the committee suggests that the polarization team should keep up the effort to provide more understanding of the issue. There are some obvious checks to perform such as comparison of the space charge enlarged tune footprint with the expected available resonance free space in the tune diagram. If space charge still turns out to be problem, the polarization team should design another way of operating the Siberian snake with higher strength.

The committee supports the idea of back-up plans for a second cold Siberian snake in case the problems in the AGS cannot be solved completely.

The achieved **polarization in RHIC** amounts to respectable 40% and 45% with a bunch intensity of $0.7 \cdot 10^{11}$ protons per bunch in 56 bunches and at a beam energy of 100GeV per beam in the two RHIC rings respectively. The proper functioning of the Siberian snakes and the spin rotators has been impressively demonstrated this way. The working point for RHIC has been optimized for simultaneous high polarization and accommodation of strong beam-beam forces.

The committee would like to note that this optimization is quite time consuming and need to be continued consequently. As beam-beam effect has to be observed in RHIC with the desired level of beam intensity, the committee is concerned about the depolarizing effect of the beam-beam interaction which might be of particular importance in the case of beam-beam emittance growth.

The committee would like to encourage the RHIC team to consider injection with both the Siberian snake and the rotator on in order to shorten the injection time, and hopefully increase the polarization transmission efficiency.

While the committee is quite confident about achieving high polarization at beam energies of 100GeV, to preserve polarization during acceleration to 250 GeV will be a new challenge. Confidence level is higher for 100 GeV/c (remove this sentence). Resonances get stronger with beam energy. The multitude of intrinsic and imperfection resonance to overcome will make it quite difficult obtaining 100% polarization transmission efficiency.

The committee believes that a condition of 250GeV polarization will be stringent orbit control resulting in RMS orbit deviations from the centre of the quadrupole magnets of less than 0.3 mm. Such an almost planar orbit will require careful realignment of the accelerator magnets and will require beam based alignment techniques.

The committee however would like to stress that beam based alignment is also very tedious and time consuming. The RHIC design team needs to develop and to test an appropriate algorithm.

The committee further believes that unfortunately harmonic orbit correction resonance by resonance is impractical. However, the committee would like to encourage the RHIC polarization team to make use of HERA experience where a very successful method of preserving high polarization without empirical retuning the bumps has been applied: Depolarization due to unavoidable orbit correction can be avoided if the orbit correction kicks are projected into the space of harmonic bumps and compensated with bumps of opposite sign.

The committee can see a considerable need for simulation studies and accelerator study time. The committee believes that good use of the time between now and 2008, when 250 GeV luminosity running is planned, needs to be made.

The committee would like to mention further optimization possibilities: The betatron tunes need to be fixed quite well during acceleration and low beta squeezing to stay within the limited window between depolarizing resonances.

There has been a good effort to search for a single working point which is optimum for both injection and luminosity operation. The committee would like to encourage the RHIC team to continue this effort as it believes there is more to be gained by this optimization. For example, it might be beneficial to attempt compensation of the strong persistent current driven 3rd integer resonances at RHIC injection in order to avoid depolarization during the change of the betatron tune from injection to luminosity values.

If betatron phase changes between the interaction points are employed to minimize the beam-beam effect, its effect on polarization must be studied in parallel.

The committee is pleased to take note of the good performance of the OPPIS polarized ion source. For the time being a polarization 80% has been achieved with beam intensities of $(3\text{-}5)\cdot 10^{11}$ H^- ions per pulse. The limitations are well understood. An improvement program based on a new solenoid magnet to be installed in 2005 is underway. This is expected to increase the polarization of the source to 85% at a beam intensity of $5\cdot 10^{11}$ H^- ions per pulse with a beam current stability of $\Delta I / I < 10^{-3}$ and a small momentum spread of $\Delta P/P < 1\%$. The committee is looking forward to hear the results from the source upgrade.

The committee takes notice that the pC and jet polarimeters both function well. The committee would like to congratulate the polarimeter team for the success with these devices which have been the subject of concern and uncertainty in the past.

The committee agrees that faster electronics is needed to measure polarization during the ramp. The committee endorses the efforts to resolve this issue.

The committee urges the polarimeter team to calibrate the polarimeters at 100 GeV/c. The uncertainty of this calibration has cast more uncertainties on the RHIC polarization effort more than necessarily, and should be resolved as soon as possible.

The committee is excited about the future option to perform spin "turn-by-turn" measurement of spin motion which allows detecting spin precession with an AC dipole magnet. This would be a fascinating diagnostics tool which allows further in-depth research of spin dynamics. The committee encourages the full pursuit of this exciting direction.

pp Luminosity

An ambitious upgrade of the proton-proton luminosity by a factor of 16 above design value is planned. This large factor is based on an increase of the bunch intensity from presently $0.7\cdot 10^{11}$ to $2\cdot 10^{11}$ protons per bunch and on an increase of the number of bunches from 56 to 112.

One limitation of the bunch intensity is given by the intensity dependent depolarization effects in the AGS which have been discussed above and are expected to be overcome by the planned measures in the AGS.

The remaining important constraints appear to be

- Beam-beam effect limiting the bunch intensity and
- Intensity dependent pressure rise in the cold beam pipe of the arcs.

Beam-beam experiments in RHIC with bunch intensities of $1.7 \cdot 10^{11}$ using the 2004 betatron tunes between the 5th and 4th integer resonance have revealed a considerable emittance growth in the order of 50% within 2 hours of operation. This would presumably lead to a drastic reduction of luminosity lifetime, achievable integrated luminosity and possibly deteriorate the background conditions.
The committee has been presented with several proposals to overcome these difficulties:

- Optimization of the working point
- Optimizing the betatron phase difference between the interaction points (IP)
- Minimizing the observed tune modulation

A thorough study of the working point by weak-strong beam-beam simulations including the lattice nonlinearities showed that a considerable increase of the dynamic aperture in collisions can be obtained by using the SPS working point between the 2nd and 3rd integer resonance. This tune is also quite favourable with respect to polarization, while other successful tunes, such as the HERA working point would not qualify for high polarization operation. The unfortunate disadvantage of the SPS working point is its closeness to the third integer resonance which is quite strong at injection due to the presence of persistent current sextupoles. The use of these tunes thus either requires to shift working points somewhere between injection and storage or to compensate for the strong 3rd integer resonances at injection.

The committee suggests pursuing both options in order to maximize the possibility to be able to operate at the most favourable working point in collisions.

The attempts to minimize the beam-beam effects by optimizing the betatron phases between the interaction points (IP) were apparently not very successful so far. The committee does not expect much benefit from this effort.

The low beta quadruple magnet triplet has been observed to perform low frequency oscillations in the order of 10Hz. These will translate into orbit oscillations and will

lead due to the non-linear beam-beam focusing to a low frequency tune modulation. Such modulation in presence of strong nonlinear forces is known to be potentially detrimental to the quality of beams.

The committee endorses plans to employ a closed orbit feedback to minimize the tune modulation due to orbit oscillation.

The committee acknowledges that the beam-beam effect is addressed quite thoroughly. However, the committee is nevertheless concerned, that the planned measures are not sufficient or that the planned measures will not address the beam-beam problems completely.

The committee therefore suggests to keep up to study the RHIC beam-beam effects by both simulation and accelerator study in a systematic fashion to make a serious attempt to clarify the remaining difficulties. A number of obvious studies could be performed: The effect of modulation should be clarified by weak strong beam-beam simulations and by accelerator experiments. The RHIC team should investigate the emittance growth versus beam intensity over a wider range and investigate the role of working points experimentally.

The committee believes that there is a good chance that the vacuum issues in conjunction with large proton beam intensity will be improved considerably by the improved pumping prior to cool down as discussed in the previous section. It will be however important to perform the improvement as soon as possible to verify this assumption.

The committee is somewhat more sceptical whether the beam-beam problems can be resolved completely by the planned measures. The committee further suggests considering fall back positions in case the beam intensity can not be brought to the desired level. A possibility might be the reduction of beta function at the interaction point. This will most likely increase luminosity somewhat and might even reduce the residual orbit induced tune modulation.

Collider – Accelerator Department Machine Advisory Committee
Nov 8-9, 2004 Meeting

Charge

The main goal for RHIC operation over the next four years is to reach enhanced luminosity and polarization performance as laid out in recent planning documents (see i.e. http://www.rhichome.bnl.gov/RHIC/Runs/RhicProjections.pdf). The main charge to the Committee consists of reviewing the development and commissioning plans. In particular please review, comment on, and offer recommendations as appropriate in the following areas:

- RHIC luminosity development for heavy ion operation: Are the limitations to the RHIC luminosity understood? Are the plans to overcome the present luminosity limitations well developed and properly focused? Are the commissioning plans realistic and developed in sufficient detail?
- RHIC luminosity development for polarized proton operation: Are the limitations to the
- RHIC luminosity understood? Are the plans to overcome the present luminosity limitations well developed and properly focused? Are the commissioning plans realistic and developed in sufficient detail?
- Polarization development in the AGS: Are the sources of beam depolarization in the AGS understood? Are the plans to reach full polarization (75%) at the nominal bunch intensity (2×10^{11} protons) at AGS extraction well developed and properly focused? Are the commissioning plans realistic and developed in sufficient detail?
- Polarized beam acceleration in RHIC to 250 GeV: Is there sufficient understanding of polarized proton acceleration in RHIC to 250 GeV to plan a successful commissioning effort? Are the plans to reach full polarization (70%) at 250 GeV in RHIC well developed and properly focused?

In additions, any comments or suggestions the committee might wish to make on other topics of the C-AD accelerator complex are very welcome.
It is requested that a concise report responsive to this charge be forwarded to the C-AD Chair Derek Lowenstein by December 15, 2004.

C-AD Machine Advisory Committee Meeting

November 8 - 9, 2004 Large Conference Room, Bldg. 911B

Presentations

Monday, November 8th

08:30	Executive Session	
09:00	Welcome	D. Lowenstein
09:15	Response to last MAC Recommendation	T. Roser
09:45	Setting the Scope: RHIC 4-year goals (HI & Polarized Protons)	W. Fischer
10:00	***Coffee Break - Small Conference Room***	

Heavy Ions

10:30	Update Stochastic Cooling	M. Brennan / M. Blaskiewicz
11:00	Vacuum Limitations	W. Fischer
11:20	Vacuum Upgrade Work	H. C. Hseuh
11:40	***reserve***	
12:30	***Lunch - Small Conference Room***	
13:00	Tour - AGS Cold Snake	

Polarized Protons

14:30	Polarized Proton Operations in AGS and RHIC	M. Bai
15:00	Polarized Source Upgrade	A. Zelenski
15:30	AGS Cold Snake Commissioning	W. MacKay
16:00	***Coffee Break - Small Conference Room***	
16:30	RHIC Polarization at 250 GeV Beam Energy	V. Ptitsyn
17:00	Polarimetry	H. Huang
17:30	pp Luminosity Development	R. Tomas

Tuesday, November 9th	
08:30	Executive Session / Discussion
10:30	Coffee Break - Small Conference Room
11:00	Executive Session / Discussion
13:00	Executive Session / Discussion
15:00	Closeout
16:00	Adjourn