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Summary of the RHIC Retreat 2005

F. Pilat, W. Fischer, P. Ingrassia, V. Ptitsyn, T. Roser, T. Satogata

Collider-Accelerator Department
Brookhaven National Laboratory
Upton, NY 11973

C-AD Note 212

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The RHIC Retreat 2005 took place on June 15-17 2005 in Shelter Island, one week before the end of Run-5 machine operations. The Retreat has been for years the primary forum to informally assess the past, discuss future performance, and to plan for the next run together with the physics experiments. Relevant C-AD personnel, representatives and liaisons from the experiments, and management, attended the Retreat. The overall agenda and copy of all Retreat presentations can be found at:
http://www.c-ad.bnl.gov/RHIC/retreat2005

Run-5 Cu-Cu and P-P have been a success. In the Cu-Cu run, an integrated luminosity of 15nb^{-1} – more than twice the goal for the run – has been delivered during the 8 weeks 200 GeV/n run (high-energy), and exceeding the maximum luminosity projections. Two experiments reached the goal for the run and two a considerable fraction. Machine set-up time was shortened to 2 ½ weeks from the projected 4, excluding time for major repairs. 520 nb^{-1} have been delivered during the 2 weeks of collisions at 62.4 GeV/n (low-energy). The data collected by the experiments in the low energy run far exceeded the experiment goal. The run was ended by one day of Cu collision at injection energy.
In the P-P run at $\sqrt{s}$ =200 GeV, a total of 12.6 pb^{-1} have been delivered to the experiments with an average polarization of respectively 49.5% in the blue ring and 44.5% in yellow. Polarization levels exceeded the projected numbers. All experiments achieved a considerable fraction of their data goal for the run. Moreover, during 3 days of development, acceleration of P-P with 30% polarization to 205 GeV beam energy was demonstrated, making RHIC the highest energy polarized beam to date.

The goal of this document is to present a selected list of issues that were discussed at the Retreat, and were recognized to be high priority for work during the shutdown and planning for the next Runs. This list can be used as an aid to work planning for the next run and as input to the RHIC PAC, planned for late summer 2005, together with the updated RHIC Collider Projections documents. Points addressed in the latter will not be repeated here.

The species and energies for Run-6 are not yet defined although all running scenarios discussed include a long P-P run at $\sqrt{s}$ = 200 GeV/n, and possibly at 62.4 GeV/n.

The rest of this document is an annotated list of issues and discussions from the Retreat, loosely organized around the structure of the Retreat sessions.

1. Integration of machine and experiments

The main goal of the session was to find ways to turn more delivered luminosity into recorded luminosity. The experiments were asked to provide input in the following areas:

(1) How can more delivered luminosity be turned into recorded luminosity?
(2) Dealing with more luminosity and polarization
(3) Maintenance, accelerator physics experiments and access
(4) Communication
(5) Store length
(6) Other issues

- For **PHOBOS** Run-5 was very likely the last run. Although a small experiment, PHOBOS had presented a number of challenges for the machine operation due to radiation and loss limits, frequent changes in the experimental magnet settings, and a long beryllium beam pipe in which electron clouds were formed with smaller beam intensities than in other locations.
- Both PHENIX and STAR noted that the **time from beam cogged into collisions to steered and collimated beam** is still critical and any improvement is welcome. It was noted by operations that the level of automation in establishing physics conditions deteriorated somewhat compared to last year, possibly a consequence of the higher bunch intensity used this year in operations, for both Cu and P-P. BRAHMS is not very sensitive to background and usually starts data taking before the two large experiments can turn on.
- **STAR** suffered from high **background** throughout the run. The early investigation of the background problems was slowed down because the background signals provided by the experiment were contaminated by a large component stemming from collisions. While the establishment of background signals must be the responsibility of the experiment, a larger degree of cooperation between the machine and experiment would have been useful in analyzing this problem. Background problems were the main cause that prevented turning more delivered luminosity into recorded one. The Experimental Facilities and Support Division is investigating possibilities to install shielding at STAR to block particles coming from the triplets into the detector. PHENIX expressed concerns that the STAR background problems will hold down the luminosity for all experiments in the next run. The liaison physicist pointed out that the STAR background signal was an unreliable input to optimize collimation, and may thus has contributed to the time needed to establish physics conditions. We need better simulations and understanding of the collimation process.
- A proposal was made to have **scheduled maintenance** only every 3 weeks. Only STAR insisted in maintaining a 2-week schedule, although there is no STAR subsystem that does specifically require bi-weekly maintenance. With maintenance every 3 weeks the Accelerator Physics Experiments would precede the Wednesday maintenance immediately, and would be on Tuesdays or Wednesdays in weeks without maintenance. Since the experiments currently use

Tuesdays for overlap shifts, this must be shifted to Thursday, and the RHIC access training from currently Monday to Wednesday.

- Generally the experiments prefer to have a strict separation between **machine development time** and physics time. However, statistics from operation that compare the latest run with previous runs indicate that a more flexible approach, in which machine development and setup time are interchangeable to some extent, can lead to an increased time in store.
- All parties agreed to maintain the **Monday scheduling meetin**g as it is.
- All experiments are satisfied with **stores of fixed length**, calculated from the luminosity lifetime and store-to-store time. The option to shorten or extend a store is maintained if all experiments agree.
- Finally the **role of the scheduling physicist** was discussed. Although there was no consensus between all participants, it was generally acknowledged that a scheduling physicist is needed when RHIC is not the only physics program running. While the RHIC Run Coordinator must concentrate on the technical progress, the scheduling physicist's task is to optimize the time allocation (for physics, accelerator physics experiments, access). In most cases this can be achieved by consensus between experiments and machine. In cases for which this is not possible, the C-AD and lab line management must be involved.

2. Operations

Machine Reliability and Uptime

- Machine availability averaged at ~80% (consistent with DoE metric)
- Fraction of time in physics for Run-5: 42% for Cu and 44% for P-P (Run-4 Au: 47%, Run-3 ~30% for d-Au and PP). Calendar time at store: Cu-HE: 53%, Cu-LE: 74%
- Total failure time in Run-5 was down from Run-4, distribution of failures is similar, turn-over in the “top 10 offenders” list with 5 new entries (operator errors, access control, AGS RF27, radiation interlock, water service)
- Identified necessity to get the list of maintenance items, from the Maintenance Coordinator, to the Scheduling Physicist prior to the Monday Scheduling meeting. Formalize a method to modify the list after the Scheduling meeting

Reliability Cu Run-5 HE vs. LE

- Factors affecting reliability – bunch intensity, beta squeeze and to a lesser extent energy.
- Integrated luminosity strategies: i) push bunch intensity, beta*, find the limit, and adjust number of bunches; ii) (more) conservative parameter approach – would require dedicated machine development time to make luminosity gains.
- STAR comments: no machine development at the start of the run; when doing MD – do it for 24 hours at a stretch, regarding PP operations, the goal this year

was physics, not to learn about performance limits – slow improvement was not appropriate – uptime was what was needed.

- PHENIX comments: base performance estimates for Run-6 on facts (past performance). Let experiments decide whether C-AD should take the time to push the performance envelope. Regarding P-P: the program was luminosity starved. Diagnose problems using a block of stores and dedicated time. The question was raised "who is driving?" – that is who is determining whether performance needs to be pursued or production running?
- T. Roser comments: a factor of 2 came incrementally by pushing bunch number and bunch intensity – get another factor of 2 when Brahms turns off – can only solve problems with statistics – need to run on the edge to see where there is a problem.

Orbit

- Observed vertical orbit variation with time (worst at IR8) with a 24 h periodicity. Problem was present in previous runs but not discovered. Model predicts that the source of the problem is likely at IR4. Daily orbit variations similar to RHIC were observed at Fermilab due to roll and tilt of low beta quads.
- Found momentum aperture dependence on dispersion function, which in turns depends on the closed orbit.
- Flat orbit requires ring re-alignment
- Orbit correction improvement planned for Run-6: dispersion correction, model prediction of tune and coupling shifts, improved Best Corrector method.

Input from the operations group

Applications

- Orbit display, trigger orbits in application – single application for both rings
- Ramp editor – read back of wfg, ramp reversion for individual stones needed
- Loss monitor – view thresholds as well as slow or accumulated losses
- Sequencer – improver cryptic error messages
- Polarimeter Analysis Tool – unreliable, need to integrate AGS polarimeter

Processes

- Sequencing and automation – want auto steering, auto collimation, and ramp orbit correction. When RF dampers remain in we get no alarms or indications.
- Collimator positions added to configuration control
- Application documentation and training – more to be done – involve operators in new application development
- PASS: slow responsiveness, mode selection.
- Injector Operation
- Scaler and multiplexer upgrades needed

Communications

- Operators experience and judgment not listened to enough
- Lack of clarity regarding machine setup and operating parameters.

- Schedules and goals – make clear
- Communications between operations and experiment control rooms

Working Conditions

- Maintain diagnostic equipment
- Replace chairs, soundproofing. Need dust and climate control. Housekeeping.

Injector operations

- Injection with multiple proton bunches in the AGS would save time, especially with 111 bunches per ring.
- Reduction of longitudinal emittance in the injectors to improve vertex cuts
- Constraint on Booster repetition period limited by power dissipated in transformers for the power supply.
- Found that changing repetition periods in Booster (2.5 to 5 sec) changed magnetic corrections for spin resonances.
- Careful accounting of spin up/down needed during NSRL proton pulse stealing
- Timing for HEBT dipole for 200 MeV polarimeter affected by pulse stealing
- Bending Magnet 2 and RFQ affected by NSRL use of P-P

Configuration Control

- Fill number and ramp number not sufficient to restore previous ramp
- Changing species should involve changing a set of parameters
- Configuration Control Contents = measured values not archived set points
- Make Configuration Control a database reference for other applications
- Do we make a Standard Operating REcord (STORE) document for RHIC?
- STORE could be a combination of ramp files, snapshot data and archives

Ramp Software

- Recode ramp editor in C++ or Java (presently in TCL)
- Re-write Sequencer (presently in TCL)
- Drive ramp from configuration control database – makes standard ramps feasible
- Save tunes and chromaticity in all step-stones
- Embed ramp save/restore/compare in RE
- Knobs would be useful for some applications, in particular BBA

Instrumentation

- No to get rid of existing instruments
- Improvements required: BPMs, emittance measurements for Hi and PP, CNI polarimeter
- New instruments wish-list: wire scanner for PP emittance, jet for 2d profiles, real time spectrum analyzer for instabilities, oscilloscope (20 GHz band- 40 GHz sampling) for stochastic cooling, 2 low frequency spectrum analyzers for BBQ

ZDC's

- Copy of ZDC electronics under CAD ownership proved more difficult than anticipated
- Agreement was reached to defer indefinitely this endeavor

BLAM

- BLAM is software and hardware based administrative tool to help the Operations Coordinator guard the Accelerator Safety Envelope and limit the dose rate on the RHIC berm to 5 mRem/hr.
- If BLAM fails then the OC must turn RHIC off – BLAM was a problem only when broken
- BLAM did not fail under real operating conditions – that is during dirty dumps
- However: hitting BLAM limits is getting easier. Copper put us out of the "comfort range". BLAM can be made less restrictive mainly by desensitizing the loss monitors.

3. Systems

BPM's

- The BPMs have reproducibility of 0.2 mm without the relays. This and fixed timing trigger will be implemented for all BPMs next run. Fixed trigger (formerly "dead-reckoning") timing seems stable over a timescale of weeks. The goal is to do fixed trigger timing for all BPMs
- Started the run without about 20 modules; at end of run have fully populated ring and about 30 spares. Move of BPM modules to alcoves was very successful in reducing radiation-induced failures.
- All cables will be labeled before summer shutdown disassembly.
- A capacitor change will fix trigger jitter in self-trigger mode.
- BPMs with a pushbutton system at the start of the next run.
- Broken feed-troughs and cryo cables will be opened and repaired during the summer shutdown.
- Proactive diagnostics of the system (top to bottom, including module and Sederta card failures, with alarms) are found necessary.
- The million-turn BPM system should be made more accessible and user-friendly.

Polarimetry / Polarimeters

- Improvements over last year: separated readouts for yellow and blue polarimeters, much improved DAQ speed
- The CNI polarimeter is still dominated by statistics, and polarization profile measurements require more systematic studies at start and end of the store.

- As serious problem of FY05 polarimetry was target production, many produced targets were too thick. We need a good supply of proper thin targets (4 microgram/cm^2 thick, 5 micrometer wide) for the RHIC polarimeter.
- Vacuum pressure increased by 100 with very slow decay, due to out-gassing of some vacuum parts. Ideas to improve this include a pump-down load locker chamber, and an IR heater to help bake-out.
- Analysis of absolute calibration is a long process; absolute calibration of polarization from Run-4 is not yet finalized. A manpower problem for polarimeter data analysis and run support has been reported and discussed.

Power Supplies

- Power supply robustness and run analysis continue to improve. A new automated trouble-shooting program was tested in Run-5and works well.
- Corrector PS reliability improved almost a factor 10 in the last 2 years of running. QLIs caused by main PS are also reduced by an order of magnitude compared to last year.
- Blue sector 12 Q6 shunt bus developed some resistance during the 205 GeV P-P test. Will modify a voltage tap to isolate this before fall.
- IR supply failures (more frequent in Run-5 than Run-4) and beam induced quenches top the failures list.
- Quench detectors may go on a separate network for the next year to isolate them from network problems.
- Individual 50A corrector leads will be instrumented but not hooked to interlocks for the next run. Individual interlocks are planned for the FY07 run.

RF systems

- Cavities are being physically shuffled and moved around the IR4 region to make room for scaffolding and improve accessibility and safety. This needs breaking vacuum in IR4.
- Mechanical tuners have scored over time, and motion is getting jerky. Work in progress on ferrite tuners (without moving parts), and on a new design for mechanical tuners.
- A new design for storage cavity windows from CERN that showed promise was tested. This design doesn't require Ti coating, and worked well to 500 kV but then multipactored.
- Ring-to-ring synchro during the ramp has to work for 110-bunch operation. For heavy ions this means it needs to stay locked during transition crossing. The best way may be to servo the dipole trim parameter to keep the radius constant.
- Unless we do major injector development, the beam will always longitudinally fill the storage RF buckets. Stochastic cooling may help. Mode dampers will not handle 110 bunches of $2xe^{11}$/bunch while ramping.

Controls

- File server upgrades were successful, though Linux Red Hat Enterprise WS has uptime problems, with crashes, servers hanging during reboots, and NFS auto-mount problems.
- Alcove radiation and other FEC failures are the dominant cause of Controls downtime, though Linux servers are coming up.
- The new radiation-resistant crates are working well, but the error correcting memory in WFGs is not.
- A complete history of all RHIC ADO settings is working well so far.
- There were significant loss-induced problems during low-energy runs, caused by ramp transmission of ~85-90% instead of desirable ~95+%

Cryogenics

- Cryo-driven downtime mostly due to component failures in the ring, with no clear standouts to attack for improvement.
- Helium losses match the best loss rate from last year run. There were no turbine failures this year after adding high-quality filters.
- Working to get obsolete electronics out of system, particularly UPS for power dip recovery and updated control system interface.
- Started Phase III efficiency upgrade, and are modifying cold box 5 in preparation for new turbine. Next year, cryo will operate without the cold re-circulators, which are potentially involved in 10Hz beam jitter.
- Summer shutdown will bring the entire ring to 80K.

Vacuum

- Huge amount of work to be done this shutdown, vacuum is on the critical path
- Four IPs, seven Q3-4 regions, and the entire cold bore will be affected.
- Adding another 150 m of NEG in six areas. It may be beneficial to condition the NEG at higher temperatures, but don't want to poison it.
- Cold bore pressure rise is mostly at Q4 ends and in the arcs. The AIP plan for cold bore upgrades is to pump on every cold bore through summer down to 10^{-3} Torr. Early ion pump cable runs are on the critical path, and should be done by August to start pumping.
- NEG validation: lower pressure in NEG-coated pipe areas have been observed, so NEG does help and works to lower pressure as expected.

PLL/Schottky

- A timer will be added to the PLL so it cannot be accidentally left on after a ramp and cause emittance growth.
- Dynamic range at transition will always be a problem for the existing 245 MHz system but good progress was made with coupling and eigen-tune measurements.
- The chromaticity measurement on the ramp with the PLL is automated, fairly routine, and gives believable results. Smaller modulation depth should be tried. Base-band systems, 3D and BBQ, seem to solve dynamic range issues at

transition for tune tracking but have problems with 60Hz lines. 60Hz is in particular a problem when ramping supplies turn on. Collaboration with LHC will likely provide four boards. There is a commitment to developing tune feedback with the base-band system for Run-6.

- For Schottky, LabView stability is a major issue that needs to be solved.
- HF Schottky can provide ramp data with sweeping LO (local oscillator)
- Chromaticity at store (highly nonlinear) and tune spread in beam-beam conditions require collaboration of physicists in the development of algorithms and analysis.

Jet Camera

- The optical jet camera got good signals in Run-5with a low-noise CCD camera borrowed from Tandem. The camera is radiation-sensitive.
- Some profiles showed both the yellow and the blue beam together.
- Japanese collaborators plan to develop another jet camera.

4. Machine Developments, Model, AP Experiments

- The majority of this year's **accelerator physics experiments** was still mainly related to RHIC operation ("class-1"), to study existing machine limits and problems, with the goal to increase short and medium term machine performance. Very few experiments were aimed at general accelerator physics and none purely of "class-2". AP experiments were regularly scheduled during the Cu and PP runs, with limited cancellations and re-scheduling. There was no discussed or perceived necessity of substantially modifying the APEX organization.
- **Stochastic cooling** has been under intensive development. The cause of a significant coherent pickup signal was tracked to the bunch shape. The electronics should be developed to cope with the coherent signal. Signal suppression from the feedback loop, necessary condition for cooling, was observed. The plan is to have a complete longitudinal stochastic cooling operational a few weeks into the heavy ion run.
- **111-bunch operation** requires special attention to the timing of the injection kicker and to the IR separation bump control on the ramp. Steady improvement of the vacuum limits over last runs together with planned upgrade of cold bore vacuum should allow to put up to 2e11 proton per bunch. Ion pressure rise limitations arise at the transition and re-bucketing. RF frequency lock for ions through the transition region is necessary. Beam experiments at the end of the PP run (attempt at ramping 111x1.5 e11 protons/bunch) highlights the necessity of limiting losses on the ramp via collimation on the ramp, in order to operate with significantly increased intensity.
- The skew modulation technique proved successful in **decoupling on the ramp**. The procedure is not completely operational yet, and the development of a new application is necessary and planned during the shutdown. The 245 MHz PLL system is vulnerable to strong coupling. More promising might be the "6-

parameters” technique that together with the development of the broadband PLL can make decoupling feedback on the ramp possible.

- **RHIC online and offline model** have been consolidated. The main priorities in the model development plan are: i) adding closed orbits and orbit based algorithms into the online model (calculation of tune/coupling shift caused by orbit correction, dispersion, twiss, spin resonances versus orbit) and ii) improving our understanding of machine optics (model prediction vs. measurements), that did not significantly improve during Run-5. Another area is exporting the RHIC online and offline modeling to the injectors, starting from the AGS.
- **Enhancement** of a fast transverse instability by electron clouds was observed at transition with bunch distance reduced to 108 ns (120 bunch pattern). A clear dependence of beam losses and beam emittance on the bunch position along the train was observed. Assuming that electron cloud formation cannot be prevented, mitigation techniques are not trivial (induction RF is under consideration). Fast feedback may be feasible using a kicker similar to the design of the RHIC stochastic cooler kickers.
- **Beam Based Alignment** has been under intense development during Run-5. BBA of IR triplet BPMs was successfully done in some interaction regions. Calibration drifts and recalibration still need to be studied. BBA of BPMs in gamma-t quad regions will require more statistics in next ion run, including the data with local bumps. BBA technique with 1Hz quad modulation, which is under development for electron cooling, aims to reach ~10μm accuracy. Presently, reproducibility of the measurements is at 40μm level with possible systematic causes of this limitation under the evaluation.
- **10Hz orbit feedback** is believed to reduce emittance blowup due to the combined effect of the orbit modulation and beam-beam, likely caused by the helium re-circulator spectrum. Beam-beam simulation showed that the 10 Hz orbit oscillations can cause emittance growth to 40 π in 2 hours for a beam-beam parameter of 0.005. This is in reasonable agreements with observed emittance growth in RHIC.
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5. Conclusions

Run-5 has been an overall successful year for RHIC operations.

Improvements in the following areas can significantly and directly improve machine performance and physics output:

- Development of 110 bunches with >1.5e11 pp/bunch (ring-2-ring synchro, control of losses and collimation on the ramp)
- Collimation (automation, better background signals available already at set-up time, STAR shielding)
- Narrowing the vertex distribution. That would require an aggressive program to reduce the longitudinal emittance in the injectors.
- Increasing of time at store from 53-54% to 60-% (through improved reliability of main offending systems, optimal choice of machine parameters, reduction of scheduled maintenance and machine development time)

- Polarimetry (targets, vacuum, increased support for running and analysis)
- Correction of orbit variations in RHIC (24 hr, 10 Hz, 60 Hz?)
- Understanding and improvement of momentum aperture in Yellow ring.

Work in the following areas can indirectly improve machine performance by easing operation:

- Improvement of machine understanding via online model
- Continued developments of ramp software, sequencer, and main MCR applications
- Continued use of AP experiments to develop new operational techniques