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Summary of the RHIC Retreat 2006

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Brookhaven National Laboratory

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C-AD Note 249

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1. Introduction

The RHIC Retreat 2006 took place on July 10-12 2006 in Port Jefferson, about 2 weeks after the end of the RHIC Run-6 with polarized protons. The goal of the Retreat is traditionally to optimally plan the upcoming run in the light of the results from the previous one, by providing a snapshot of the present understanding of the machine and a forum for free and frank discussion.. This year's Retreat extended the range of planning to the next 2-3 years, the timescale for the enhanced RHIC goals for luminosity, polarization and machine availability.
In Section 2 we summarize the results from Run-6 for RHIC and the injectors and discuss the present objectives of the RHIC program and performance. Sections 3-6 are summaries of the Retreat sessions focused on performance with heavy ion and polarized protons, respectively, machine availability and machine developments. We provide also, where relevant, a progress report of post Retreat activities, hopefully useful in the preparation for the upcoming run.

The overall agenda and copy of all Retreat presentations can be found at:
http://www.c-ad.bnl.gov/RHIC/retreat2006

2. Status and objectives for the RHIC program, performance, operations

The long term planning for the RHIC program, experiments and machine identifies at the moment 2 phases:

- Phase 1, years 2007-2011: improvement of machine performance with yearly running, upgrade of the 2 physics detectors STAR and Phenix, and development for e-cooling proceeding in parallel and driven by a technical schedule

- Phase 2, Years > 2011: RHIC luminosity upgrade with e-cooling operational, development of a "QCD laboratory" with the further added capability of eRHIC.

The main challenges to accomplish the long-term plan are to establish a physics case when LHC heavy ions will be operating, coordinating with JLAB, obtaining funding with other competing projects, other than the primary technical challenge of building, commissioning and operating RHIC with a high energy electron cooler.
For Phase 1, the main challenge is to achieve the RHIC enhanced goals for luminosity, polarization and time at store in physics production, on a time scale of 2-3 years:

Au-Au $\mathbf{L}_{store\ avg}$ = 8 x $10^{26}cm^{-2}s^{-1}$ at 100 GeV/n
p-p $\mathbf{L}_{store\ avg}$ = 150 x $10^{30}cm^{-2}s^{-1}$ at 250 GeV
$\mathbf{P}_{store\ avg}$ = 70%
60% of calendar time in store = 100h/week

The luminosity performance can be achieved with the following parameters:

Parameter	Unit	**Achieved**	**Enhanced**
<u>Au-Au operation</u>			
Energy	GeV/n	100	100
No of bunches	…	45	111
Bunch intensity	10^9	1.1	1.0
Average L	$\mathbf{10^{26}cm^{-2}s^{-1}}$	**5**	**8**
p- - p- operation			
Energy	GeV	100	250
No of bunches	…	111	111
Bunch intensity	10^{11}	1.4	2.0
Average L	$\mathbf{10^{30}cm^{-2}s^{-1}}$	**20**	**150**
Polarization P	**%**	**65**	**70**

It should be possible in Run-7 Au-Au to increase the average luminosity by a factor 1.6 to 8 x $10^{26}cm^{-2}s^{-1}$, while for Run-7 PP a reasonable goal is to double the average luminosity to 40 x $10^{30}cm^{-2}s^{-1}$. 60% time at store is a possible goal for Run-7 Au-Au but unrealistic for now for PP, given the emphasis on luminosity increase.

Run-6: Injectors performance

Run-6 has been a successful one for RHIC and the injectors, despite the initial budget uncertainties that challenged the run preparation. The following table illustrates the rate of progress in the injectors performance as a source of polarized beams:

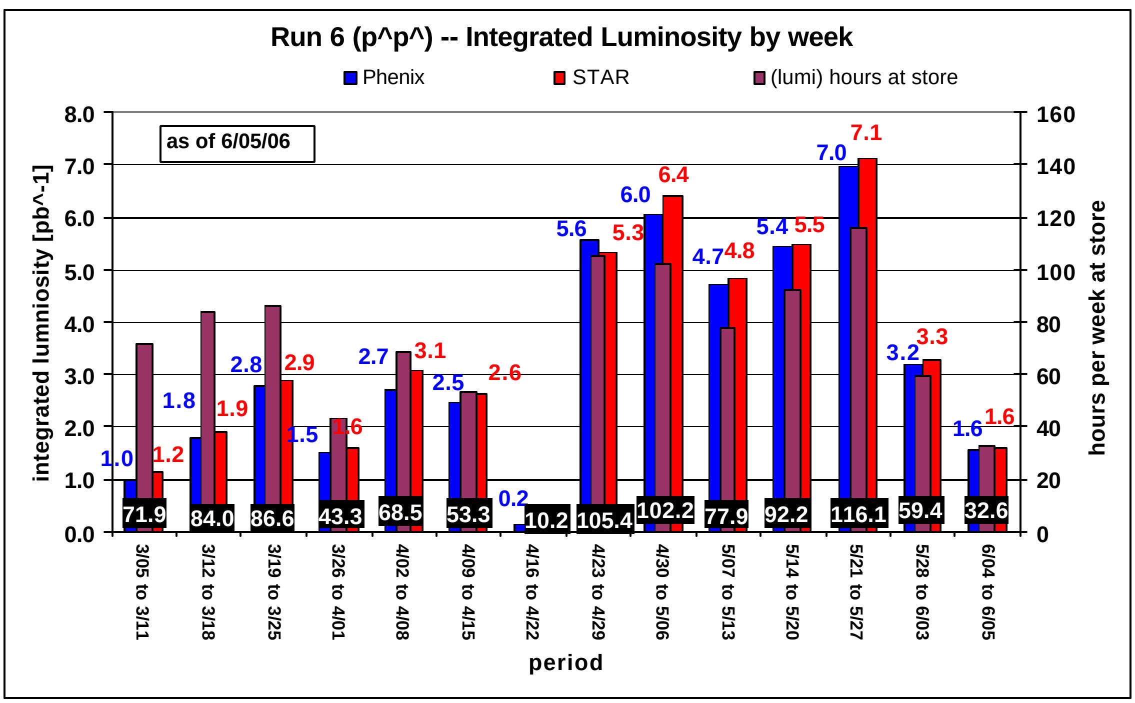
Year	2002	2003	2004	2005	2006
Intensity [10^{11}]	0.7	0.7	0.7	1.0	1.5
Polarization	30%	40%	50%	50%	65%
Main development	Slow ramp rate	Normal ramp rate	New warm snake	Booster scraping	Cold snake

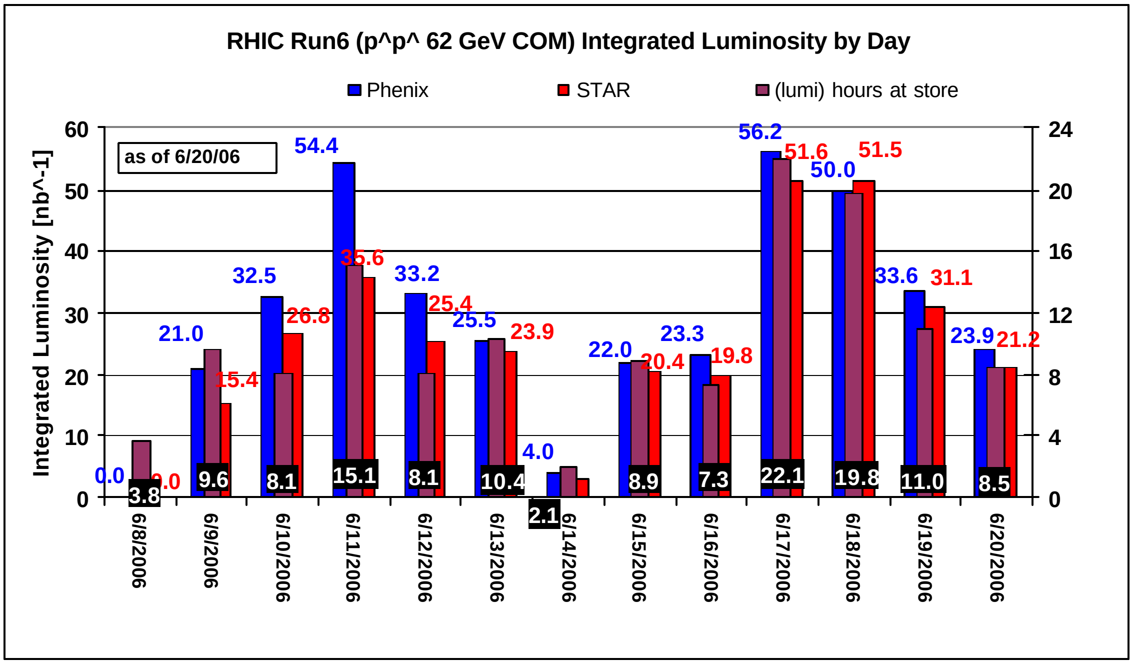
The highlights of Run-6 performance for the injectors are the fo llowing:

- The 65% polarization at the intensity of 1.5×10^{11} was achieved with two partial snakes in the AGS.
- The snake setup that yielded the best polarization is the 10% cold snake with a 5.9% warm snake.
- The four added compensation quadrupoles for the warm snake worked very well. The lattice is now easier to handle.
- The intensity dependence is very benign with this setup.
- There is polarization loss of 5% due to each of vertical and horizontal resonances. The injection and extraction mismatch is about 1%. We expect 73% polarization with 82% input. There is still a relative 10% polarization loss unexplained

Run-6: RHIC performance

The following figures summarize RHIC performance in Run-6 for the 100 GeV run and the 31.2 GeV run. The integrated luminosity evolution was in the range predicted by the Run-6 projections. One week of complete operations shutdown was caused by the accident that caused one of star trim magnet switches to blow up.





The RHIC set-up with polarized protons was done in record time and the coupling and tune feedback has been used successfully for ramp development for the first time.

The main factors contributing to the increase in PP luminosity in Run-6 vs. Run-5 are:

- Reducing the emittance from the injectors.
- Increasing the number of bunches from 54 to 111
- Separating the Blue and Yellow working points.
- Improving the synchro loop and tightening the longitudinal phase on the ramp.
- Switching Blue and Yellow working points.
- Increasing bunch intensity from $1e^{11}$ to $1.5\text{-}1.6e^{11}$ for the injected bunches

The main factors limiting the machine performance are:

- Store lifetime: Q_X=2/3 resonance, beam-beam effects, large momentum spread
- Transverse emittance: small longitudinal emittance and higher beam intensity (enhanced electron cloud effect), apparent emittance increase on the ramp
- Deterioration of ramp transmission with the beam intensity
- Beam oscillations with parasitic frequencies 10Hz, 60Hz from the cryo and power supply systems

Time at store was lower than in Run-5 and Run-6. Causes and plans to revert this trend were the motivation for a dedicated session at the Retreat and are discussed in Section 5.

Polarized protons at 250 GeV

Run-6 was concluded with 6 days dedicated to test the acceleration of polarized protons to 250 GeV. The main accomplishments:

- Accelerated successfully both beams to250 GeV, with both beams beyond 200 GeV during the first ramp attempted
- Used tune and decoupling feedback to attack the strong coupling about half way between 200 GeV and 250GeV
- Injected beam on tunes below 0.7
- Measured polarization in Blue at 250 GeV, and studied dependence on tunes at store and on energy on the ramp.

Other planned activities could not be accomplished, for lack of enough machine time:

- Analysis of the polarization transmission efficiency in Yellow
- A systematic study of polarization along the energy ramp as function of orbit distortion and beam tunes at depolarization resonances beyond 100 GeV
- Collision set-up to measure luminosity at 250 GeV
- Study of polarization lifetime as a function of tunes at store

Many factor contributed to the limited time available for development. On the machine side, strong coupling on the last part of the ramp delayed set-up, while set-up of the yellow ring was hampered by problems with yellow trim power supplies and the RF ring-to-ring synchro. Many systems failure and 44 hours of bad weather contributed significantly to reduced machine availability during the 250 GeV development.

Scheduling

Once again it was pointed out at the Retreat that the decision on the running mode for the next run comes too late for optimum planning of machine operation and developments. Ideally we should know the next running mode at the beginning of the summer shutdown.

Concerning scheduling during the run the following issues were raised and discussed:

- The scheduling physicist this year “owned” the schedule – to the satisfaction of all parties involved
- The distribution of run related meeting is good. The 8:30am and 4pm daily meeting should be kept short and focused.
- The experiments should present a detailed plan for detector upgrades at the beginning of the run to optimize scheduling of maintenance periods and scheduled accesses
- “Last minute changes” to machine configuration should be avoided, especially before a weekend
- APEX could benefit from planning the end-of-run activities earlier in the run to allow easier program evaluation
- Additional requests from the experiments include timely communication of Vernier scans data to all experiments, and read-only access to machine elogs.

3 Luminosity and preparation for heavy ion collisions

The session focused on the pros and cons of two possible run strategies for the next HI operation. Only 2 experiments will run, β^* will be kept at 5 m everywhere but IR6 and

IR8 at store. We will use the low tune settings (around 0.225). The strategies considered are:

- Run RHIC with β^* = 0.85 m (β^* = 1.0 m in Run-4), and 111 bunches (43 bunches in Run-4). From past experience, the main intensity limitations come from instabilities during transition crossing. We expect however that with this parameters, reliability and time in store can be high ("*factory mode*"), and that we can achieve a two to threefold increase in the integrated luminosity over Run-4. In addition, stochastic cooling in the Yellow ring will become operational.
- Run RHIC with a more demanding configuration ("*fully loaded*"). In addition to the changes above, the bunch intensity could be doubled by a bunch merge in the Booster, and the transverse IBS growth rates in RHIC could be reduced with a lattice with higher phase advance. For both these additional changes considerable resources would be needed, in possible competition with other planned improvements.

The table below summarizes the advantages and risks of the proposed changes in the "factory mode".

Different from Run-4	Advantage	Risk
Low dispersion lattice β^* (100 GeV) = 0.85, 0.85, 5,5,5,5	Lattice close to run4 15% gain in β^*	Losses and backgrounds in the triplet (collimation)
Stochastic cooling in yellow	Improved bunched lifetime in yellow Lower momentum spread	May require cooling before re-bucketing
Number of bunches (45 to 111)	Proportional increase in luminosity	Enhancement of transition crossing instabilities due to electron clouds Gap cleaning Collimation
AGS RF improvements	Lower longitudinal emittance Avoid low dp/p instability Avoid baby bunches	New hardware (phase detector) New concept of bunch merge in AGS
Tune-feedback	Shortens set-up time	Expert activity
Decoupling on the ramp	Shortens set-up time	Expert activity
Beginning of store automation	Improves time at store	N/A
Optimal injector tuning	Bunch current increase from 1.1 109 to 1.3 109	Transition crossing Pressure rises

The following developments were studied and presented in detail:

- **Injector Setup and Performance with Au and d**
  With the standard injector configuration we can reach at AGS extraction:
    - Intensity of 1.3 10^{11} d and 1.3 10^{9} Au ions/bunch
    - 0.27 eV/s (Au) and 0.72 eV/s (d) longitudinal emittance
    - < 9 mm.mrad (Au) and 12-25 mm.mrad (d) normalized transverse emittance
- **Injectors with Au: Bunch merges in Booster and AGS**
  Several possible Booster and AGS RF upgrades were discussed. The proposed upgrades are in general independent from each other.
    - Booster bunch merge (for illustration see below): costly in terms of man power and hardware changes, risky in terms of success and the effect of a doubled bunch intensity (transition crossing, gap cleaning, instabilities etc.). During the retreat it was recommended to not implement it for the upcoming. Decision was taken not to do it for now.
    - Replace the AGS debunch-rebunch procedure with a 24? 4 AGS bunch merge. This can and will be done.
    - Reduce AtR shot-to-shot jitter (1 ns): effort of about 1 man/week; needs high frequency phase detection. This should be implemented.
- **Can we start Run7 with an IBS suppression lattice?**
    - Results from testing, simulations and predictions with a lattice with 92 deg. phase advance (instead of 82) were presented.
        - Given the limited experience and existing data (31 GeV only) the results were not yet conclusive.
        - Simulation predicts an emittance reduction of about 10% in both planes over 1 hour (assuming h=360, and no debunching)
        - Assuming 0.5 h of store set-up and 1 h between stores the luminosity gain per store could be up to 30%.
    - Starting the run with this lattice would increase the setup time considerably by (estimated) 1-2 weeks. The implementation also requires a significant simulation effort that competes with simulations needed for the polarized proton luminosity improvements. More simulations after the retreat showed that:
        - With the storage cavities and h=2250 the potential gain is reduced to at most 10%.
        - Therefore it was decided to NOT to begin setup with a modified lattice. This effort, however, will be continued as an Accelerator Physics Experiment.
- **Stochastic Cooling**
  Cooling has been demonstrated with a p micro-bunch ($1x10^{9}$)
    - Stochastic Cooling will be available in the yellow ring only, which will improve yellow bunched lifetime (and therefore luminosity some). It will help the yellow gap cleaner. There are some issues:
        - Yellow RF cavity voltages are constrained

        - We will loose time at the beginning of the store if pre-cooling before re-bucketing proves necessary (approx. 20 min.)
    - We will be working on stochastic cooling for the blue ring (testing mode) in the background
        - Since blue is not cooled the net-effect of stochastic cooling on luminosity is relatively small (improvement < 10%).
- **Vacuum Performance and Run-7**
  We expect the dynamic pressure rise from EC to be manageable for Au operation. However, electron clouds during transition crossing could lower the instability threshold and limit the bunch intensity. The worst cases in the warm bore are expected to be up to 10^{-7} Torr, while in the cold bore up to 10^{-8} Torr (measured at the warm gauges). About 50 m of NEG coated beam pipes will be installed during the shutdown, bringing the total to approximately 480 m.
- **Transition Crossing**
  Transition crossing with higher bunch intensity (from better pre-injector tuning) and total intensity is expected to be the 'bottle neck' for the Run-7 operation with Au-Au.
  Chromaticity has to change from -2 to +2 units around transition and the suggestion is to double the step-size in the ramp editor to compensate for a discrepancy between the modeled and measured chromaticity of about a factor 2. This increment should be kept constant. Monitoring of transition crossing is mandatory for the upcoming run. We are in the process of installing a transition crossing monitor (TCM) that basically consists of a fast sampling scope (GHz) with a large memory to sample all bunches of 1 complete turn every 10^{th} -15^{th} turn in a time window of 100-200 ms around transition. The TCM will use existing dual plane button BPMs (one per ring). In addition, Pete Cameron's 3D detectors can be used to monitor of instabilities. Software to analyze the data and display the results will be available by the beginning of the run.

4. Luminosity and polarization for proton collisions

The goal of the polarized protons run in FY07 is to double the luminosity to 40×10^{30}cm^{-2} sec^{-1} while at least maintaining the polarization at the 65 percent level. To achieve this luminosity goal, intensities of 2 10^{11} protons per bunch are required, which is a factor 1.5 higher than what has been achieved in Run-6.
Since the AGS polarization has been demonstrated to be largely independent of intensity, preserving the polarization does not seem to be an issue.
The increased bunch intensity results in a larger beam-beam parameter, and this will most likely be the luminosity performance limitation. During Run-6 it was already apparent that the RHIC luminosity is limited by the beam-beam effect, making the working point search very delicate.
To accommodate the increased beam-beam parameter, two approaches are currently being pursued. The more conservative approach aims at providing additional tune space around the current RHIC working point (0.68/0.69) by compensating the Q_x=2/3 resonance and reducing the tune spread from nonlinear chromaticity.

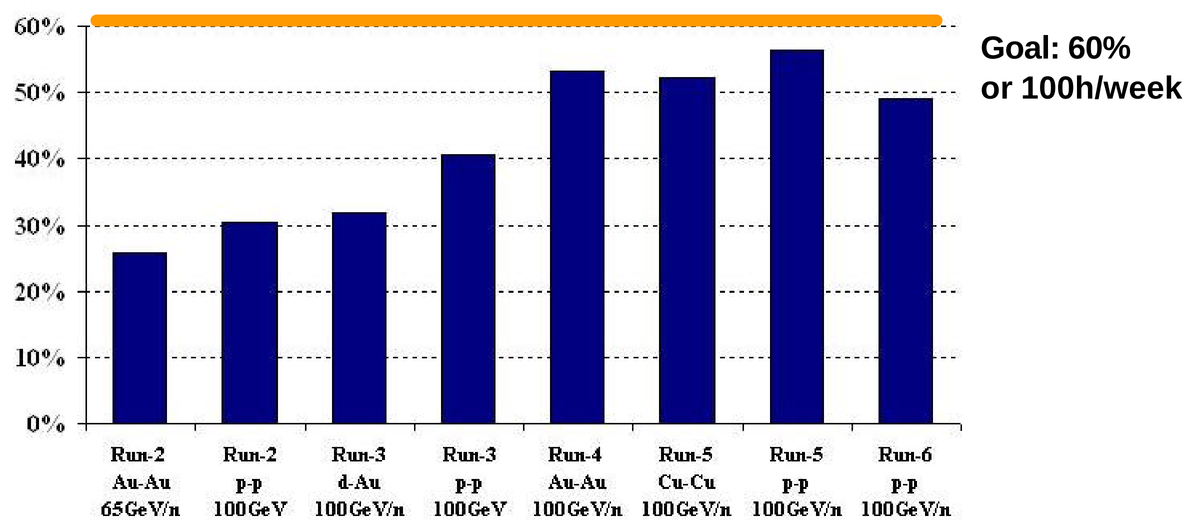
The alternative, more ambitious approach is to move the working point close to the integer resonance (0.92/0.93), where the spacing between resonances is largest. While such a working point is preferred from the polarization point of view, it is not known yet whether RHIC can be actually operated at these tunes. Tracking is required to study these issues.

Both approaches are expected to benefit from beam-based alignment, which may become an operational tool, and the 10 Hz IR orbit feedback. The latter will be made operational in its current configuration during this summer shutdown, with improvements such as new BPM electronics or new DSP boards to be made during the run.

To improve polarization in the AGS, it is planned to move the horizontal tune closer to an integer, which is expected to reduce the effect of a horizontal depolarizing resonance.

5 Machine availability and system reliability

The motivation for a full session on machine availability is that we have a goal of 60% time at store (commensurate to similar high energy colliders such as Hera and Tevatron) and that time at store for Run-6 decreased, as seen in the following picture. The session goals are to analyze the reasons determining time at store and find ways to increase it.



The breakdown for operations time is roughly the following:

Physics running	~50%
Injection, ramping, tuning	~20%
Development	~ 5%
APEX	~ 5%
Maintenance, access	~ 5%
Systems failure	~15%

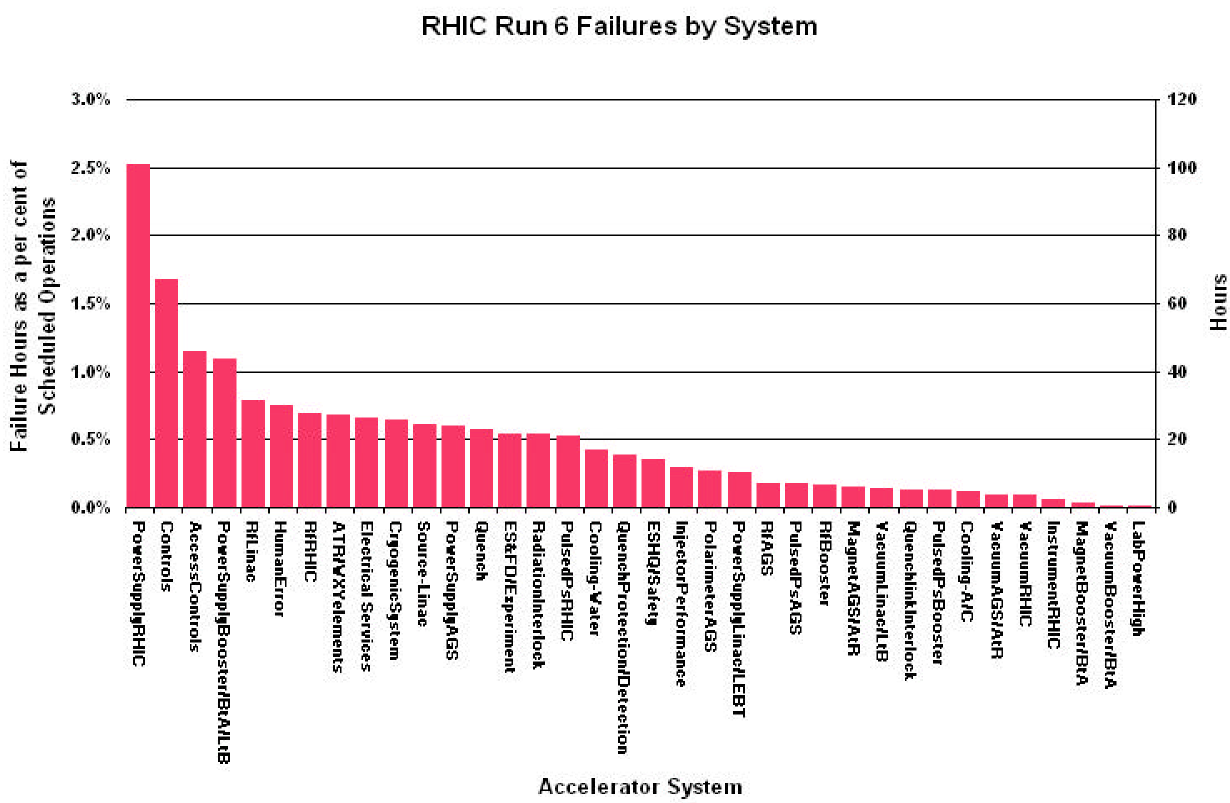
The factors typically affecting the time at store (TAS) are:

- System reliability (unscheduled failure time)

- Recovery from system failure
- Recovery after maintenance and accesses
- Machine tuning procedures
- Legacy systems (injectors), design choices (ex: no AC in service building)
- Other factors: power outages, weather, accidents
- Machine running mode and parameters (ex: the Cu low energy Run-5 reached 75% time at store by running a conservative set of parameters to minimize set-up time and increase store reproducibility)
- Human performance

Factor affecting TAS were analyzed and discussed by the presenters will be summarized here. That allowed formulating a plan to increase TAS for the next 2-3 years, starting from Run-7.

A comparative analysis of operations data from Run-4, Run-5 and Run-6 confirmed the fact that Run-6 inverted the positive trend on TAS, even when the 1-week of operations shutdown is subtracted. Despite longer stores, TAS was lower given the longer time between stores. At the Retreat it was suggested to bin the system failure time strictly by system (ignoring finer subdivision, blue vs. yellow PS for instance). The resulting distribution of system failure is the following:



Improving operations and minimizing time between stores

- Improvements needed on the ramp speed
- Best turn around time < 2.75 hr
- Top 3 Problems according to Operators: PASS, RHICInjection, Collimation
- Improvement maintained on the "RHIC Checklist" in the Operations Wiki
- Additional Data to track: End of store (cause), Store to Store (what goes on), Injection
- It is a priority to train operations better in performing collimation and Vernier scans. This is a request coming fro m both operations and the experiments.

Quality Maintenance

- Scheduling is now more structured and Web based.
- Important that maintenance starts on time and keeps to the scheduled (no last minute jobs unless really critical)
- Maintenance Coordinator drives people (includes MCR operators) during the maintenance – and this includes LOTO and sweeps. Clear hand over of systems and machine to MCR and OC.
- System testing is part of a maintenance job and is responsibility of the system groups.
- Typical problems:
  - Not enough staff for long day
  - Late starts
  - Unrealistic schedule – checkout only possible late in the day
  - Equipment failure during recovery

Total quality management

- Management concepts as total quality management can be used to assess the efficiency of operations. This is based on selecting competitive priorities for your 'company' (i.e. CAD) in the categories of cost, quality, time and flexibility.
- Six Sigma is a problem solving methodology that helps in TQM
- A practical application in our case can be finding ways of tracking downtime using Online Analytical Processing. We have existing operation analysis tools (i.e. OpsJournal, operations charts and spreadsheets, trouble reports, elogs, etc.) but they are not easy to search and cross-reference. The proposal is to organize the system for easy Web access and manipulation, for fast and 'online' reliability data analysis.

Controls Software

A detailed analysis of controls software failure and comparison with previous run shows that the main cause of downtime in Run-6 has been the controls servers. Without the UPS and raid failures, the overall data for Run-6 would have been slightly better than Run-5.
A strategy to reduce downtime from controls software includes:

- Communicate with operations re releases.
- Test well before release.
- Design with errors & unusual conditions in mind.

- Pay attention to vulnerabilities, not just failure history.
- Provide redundancy for critical components.

Controls Hardware

The main challenge for the injector's controls hardware is legacy systems in need of update. For RHIC the main challenge is radiations in alcoves, problem being the Ethernet switches and radiation upsets. The possible strategy here is:

- If future is low radiation environment then will switch memory to ferro-magnetic ram.
- If future is high radiation environment then will remove chassis (MADC & WFG) from the alcoves.

Access Controls

The improvements planned to increase the reliability of the access control system are the following:

- Change the incorrect terminations for the RHIC loop connections, and securing of all wiring during the 2006 shutdown

On a longer timescale:

- Replacement of the high traffic chain-link gates with stable hollow metal doors (~25 high-traffic gates in total. Evaluation of a prototype is in progress)
- Replacement of mechanical switches with magnetic ones
- Replacement of electric strikes with electromagnetic locks

Power Supplies

The evolution of failure time for the RHIC PS system is summarized in the following table:

Average RHIC PS Failure Hours/Week

	fy01-fy02	fy03	fy04	fy05	fy06
Avg Fail Hrs/wk	18.28	4.36	3.29	2.4	4

- It is important to notice that without the last 3 weeks of running this year, the average failure hours/week would have been 2 instead of 4. This confirms that the dominant factor for PS failures at RHIC is the environment, and AC in the service buildings is the first priority.
- The main QLI faults is going down from run to run. Run-6 is comparable with Run-5.
- Snake quenches are dominated by controls and power failures.
- A complete and thorough analysis of each fault mode in Run-6 has been performed.
- A complete list of summer shutdown jobs and expected improvements is in progress. A large effort is necessary in particular for the 300A IR PS to check the current sharing of FET's and to perform a detailed check-out procedure

Electrical Services

- Maintenance is important. If a switch requires maintenance, then it needs to be done.

- Regular monthly maintenance required for the AGS Motor-Generator (Siemens)
- Power Dips
    - Internal and External
    - Can't do anything about external ones
    - Internal ones can be dealt with by maintenance
- STAR Power supply – fixed
- DOE requirements as a result of the ARC flash
    - Active ground fault detection
    - Monitor Voltage Transients
    - Replace GE Spectra Series switches
    - Update on line diagrams
- Regular Preventative Maintenance Schedule Required
- Replace AGS MMPS transformer for P bank (single point of failure)

Linac

Up time ~95%

- Tubes (7835) fail due to beam load (38 mA, 400 micro sec pulse, 6.67 Hz) BLIP operation. All linac reliability issues are associated to BLIP operations, not RHIC.
- Linac RF appeared on top 10 list because this was the longest PP run for RHIC
- Linac personnel wish to have study time at the end of linac running for system development

RF

The discussion of the RF system focused on:

- Improvements to the systems for Run-6
- Status and R&D on acceleration cavity tuners
- R&D work for the storage cavity window R&D
- LLRF modifications and upgrade both for the AGS and RHIC systems
- Maintenance: it is necessary that enough time be allocated for RF work during scheduled system maintenance, with careful scheduling taking into account end effects (access time, LOTO, etc.). The priorities for RF repairs have to be clearly communicated by the RF group.

Vacuum

- The vacuum systems for both the injectors and RHIC are high-reliability, low failure systems
- Issues and failure modes for BLIP/Linac, Booster, AGS and RHIC have been carefully analyzed with possible solutions.
- Work on the RHIC beam shutter failures planned during the shutdown should reduce failure time
- An analysis of Run-5 data unveiled an interesting and statistically significant difference in the vacuum system failure between day (low) and owl (high). That suggests that additional regular system checking at night may be necessary.

Cryogenics

No report for the cryogenic system was presented.

Instrumentation

- Several improvements have been accomplished for Run-6 (the RHIC BPM upgrade, the commissioning of the luminescence monitor, HF instrumentation), problems solved (BLIP interlocks), and steady elimination of legacy systems. Many improvements are planned for Run-7.
- The BPM upgrade improved the overall system performance. The unsolved problem about the electronic calibration of BPM needs work before Run-7 if beam based alignment data and correction is to be meaningful.
- IPM: the system modifications were a mixed bag (Gated grids were added in '04 to extend the MCP lifetime but the pulsing grids also perturbed the beam and the electronics; the Blue Vertical IPM was modified with improved shielding but there is debate as to the efficacy of this shielding). A 5^{th} unit is being assembled as a spare for study outside of the RHIC tunnel.
- BBQ performed well but needs to made operational (see Section 6), PLL is being decommissioned
- Shottky systems are also discussed in Section 6

Increasing time at store

On the basis of Retreat information, discussion and follow-up, this is the present strategy to reach the goal for 60% time at store (TAS):

- Run the machine consistently with the TAS goal (i.e. choice to run Au-Au in "factory mode").
- Continue optimizing machine tuning and operations procedures, increase automation.
- Continue optimizing the scheduled maintenance process, recover and turn-over to operation
- Improve reliability of individual systems with the higher downtime (i.e. AC in service buildings for RHIC PS, metal gates for Access Controls, Servers and UPS for Controls, etc.)
- Create a WEB based, fast, online reliability analysis tools.
- Operations integration (MCR, Cryo, CAS, and Siemens operators in a common central control room).
- Work on human error issue, through improved training of personnel responsible for operations, operations support, and systems.

The time frame is 2 to 3 years. The effectiveness will be continuously monitored and Run-7 Au-Au is an important test.

6 Developments, model and AP Experiments

The Session was dedicated to the results of beam experiments, the status of RHIC/AGS modeling and related issues that emerged during the run like beam emittance growth and developments such as the tune and coupling feedback system. Discussion near the session end also focused on the requirements for an expert RHIC ramp design tool.

The discussion of the APEX program and policies in Run-6 generated the following conclusions:

- Scheduled time and effective beam time for APEX have been rather constant over the last 3 RHIC runs
- The weekly scheduling of APEX is close to optimal, but we should explore and exploit the "end of store" time for AP experiments, so that the dedicated, weekly time could be shorter
- The planning of "end of Run" APEX activities should be done earlier for optimal scheduling and minimum impact on the physics program
- The evaluation system of AP experiments needs to be revisited (AEAC Committee) and more information should be communicated after the Committee sessions to AP experiments spokespersons and teams.

Given the time constraints, discussion of APEX experiments results focused on four beam experiments on linear optics, e-cloud, long-range beam-beam and tune ripple. The measured beta functions using AC dipoles in both Blue and Yellow at injection and at store were presented. All the data show an average beta wave of about 10% ~ 20 % in the arcs. These data are consistent between injection and store optics, which suggest that triplet gradient errors may not be as severe as previously expected. Additional information comes from this year's year measurement of RHIC orbit response matrices (ORM) in both Blue and Yellow at injection and store. A preliminary analysis of Yellow ORM data suggests the gradient errors are of the order of 10% and mainly originate from the IR magnets. The full analysis of the ORM data should also provide measured beta functions, detailed gradient errors, BPM gain errors as well as corrector calibration errors. The capability of measuring gradient errors should make the correction of linear optics a reality.

Even though the long-range beam-beam is essentially negligible for our current RHIC operation, it will be a concern for eRHIC when the number of bunches exceeds 120 bunches per ring. It is also an important concern for the LHC and RHIC provides a good opportunity to test the technique of wire compensation. This experiment confirmed that the effect of long-range beam-beam can be amplified to the measurable level by tuning on the octupoles at store. A plan of installing two wire compensators in the RHIC ring during the 2006 summer shutdown is in progress.

The installation of NEG coated pipes during the 2004 and 2005 summer shutdowns basically eliminated the dynamics pressure rise due to electron multi-pacting and consequently removed the limit on the total beam intensity in Run-6. A dedicated beam experiment on the correlation between beam emittance growth and electron cloud induced pressure rise seems to confirm results from Run-5. For Run-7, an additional 50m NEG coated pipes will be installed in yellow and should help to further reduce the emittance growth due to electron cloud.

During Run-6 a lot of effort focused on emittance control. In addition to the traditional IPM, multiple tools were developed during the run for measuring beam emittance including the flags in the AtR line, RHIC CNI polarimeters, and Schottky detectors. However, so far the comparison of beam emittance measured at store by IPM, RHIC CNI polarimeters and Schottky with the emittance derived from the luminosity shows a very poor agreement. Another unsolved mystery is linear growth of beam emittance by the IPM during the energy ramp. It was also observed and studied the effect of bunch length on beam emittance. Recommended action items for Run-7:

- Calibrate emittance measurement and establish a reliable system for production emittance monitoring and control
- Continue and complete the effort on automatic emittance measurements in AtR

Currently, the RHIC ramp design is a one-person enterprise and involves a lot of scripts and considerable hand editing. These procedures not only are very time consuming but also increase the risk of mistakes. Hence, it is very important to develop a more sophisticated tool for RHIC ramp design.

The tune and coupling feedback using BBQ has been demonstrated its potential and capability during Run-6. It is now an expert system. The system ought to be made operational to fully exploit it potential. Chromaticity feedback is an interesting and advanced development, but not critical for RHIC, where the chromaticity limitations are around transition. However it is critical for the BBQ performance, in absence of compensation of the main PS harmonics.

Status and plans for Schottky systems have been summarized. During Run-6, the HF Schottky has not been modified, development on the LF Schottky has started and the TW Schottky (traveling wave) shows promise for bunch-by-bunch measurements but it is in even an earlier phase of development. The weak link at the moment for LF Schottky is LabView, but good results have been obtained with the LF Schottky earlier in the PP run, with lower intensity. Results were less reliable with higher intensity. An experiment dedicated to measure tune ripple with the Schottky determined that the best way at the moment to measure tune ripple might be BBQ. Plans are in place to make the LF Schottky operational for Run-7. One of the objectives is to develop a common software analysis tool for all Schottky systems.

Progress has been done in bringing the AGS and RHIC models to common environment. Based on a priority from RHIC Retreat 2005, a library (called OrbitCalc) is being developed to enable the RHIC online model to calculate tune changes due to orbit corrections, and enable server-based routine orbit correction during ramping and at store. This remains a priority for development this year and a library is expected to be ready for RHIC Run-7. An offline MADX AGS model is also under development, including the AGS strong snake. Several studies have accumulated data to benchmark this AGS model with AGS measurements. Currently, the AGS MADX model can make a good orbit prediction at AGS extraction but the difference between modeled and measured tunes is still a few times 0.01.