

RHIC Mid-Term Strategic Plan: 2006-2011
Interim Report to PAC
10/26/05; rev. 11/2/05
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Note: This is an interim report to the PAC, providing a snapshot of the Working Group's findings and initial conclusions. It is not a draft of a final report. That will come in mid-December, and will incorporate feedback from the PAC.

The aim of the mid-term strategy is to map out an achievable, aggressive program of detector upgrades and facility utilization that will maximize the scientific impact of the RHIC program in the years 2009 and beyond, when RHIC will start to compete with the LHC heavy ion program. This Mid-Term Plan is being developed specifically in response to two recommendations of the July 2005 DOE Science and Technology Review of RHIC:

- Develop a mid-term strategic plan which includes the implementation of necessary detector upgrades in the context of scientific priorities, expected machine performance, and the expected turn-on of the Large Hadron Collider (LHC). This plan should be cognizant of the DOE needs for formulating federal budgets and requirements for project management. The plan should be submitted to DOE by January 2006.
- Update the RCF five-year plan to consistently reflect the needs of a five-year run plan in the context of projected detector upgrades and accelerator performance. This plan should be complete and submitted to DOE by January 2006. This report may be combined with the mid-term strategic plan provided the RCF plan is a prominent component.

To be specific with regard to the first charge, we take the “mid-term” period to be the years 2006-2011. In addressing this strategy, we have kept in mind the long range planning for RHIC. In this regard, under favorable budget circumstances, the mid-term phase leads directly into operation of the collider at high luminosity with e-cooling, so the strategy should be consistent with achieving high-luminosity configurations of STAR and PHENIX, as well as providing computing resources via the RHIC Computing Facility (RCF) to deal with the corresponding increases in data volume and analysis requirements of the experiments. Thus, this Mid-Term Strategy will serve to illuminate the technically driven schedule and scope of RHIC II.

The mid-term strategic plan is being developed by a working group established by Sam Aronson early in September. The group is broadly representative of the two major experiments, including both the heavy ion and spin interests. It includes the leadership of RCF and the accelerator team responsible for machine development and upgrades in the C-A department. The planning group includes two members of the BNL theory group, and two leaders of the BRAHMS and PHOBOS collaborations who provide their own perspective on the future program at RHIC and its relation to the LHC heavy ion program.

In addition, the working group has included the computing leaders for PHENIX and STAR in its discussions of the RCF planning. The membership of the planning group is listed in Table 1.

T. Ludlam, convenor
S. Aronson, *ex officio*

PHENIX: A. Drees, E. O'Brien, W. Zajc, A. Deshpande
STAR: R. Majka, T. Hallman, B. Surrow
C-AD: P. Pile, W. Fischer, T. Roser
RCF: B. Gibbard, T. Throwe
Theory: D. Kharzeev, W. Vogelsang
RHIC Spin: G. Bunce
At Large: M. Baker, F. Videbaek
Consultants on Exp. Computing: J. Lauret, D. Morrison

Table 1: Working Group Membership

The working group has had four meetings to date, on Sept. 28, Oct. 5, Oct. 12, and Oct. 20. We have heard formal presentations from the PHENIX and STAR collaborations on their detector upgrade plans. We have also had presentations from the Collider-Accelerator group on machine development and performance expectations, and from RCF on the current status and mid-term planning for the computing facility. These presentations are posted on the working group web site:
www.rhic.bnl.gov/midterm/

Based on the group's findings and discussions so far, the elements of a strategic plan are emerging. More work needs to be done to knit these elements into a coherent plan that reflects the physics vision of the RHIC community and integrates a program of machine operation, detector upgrades, and a supporting evolution of RCF that can realistically be submitted to DOE as a basis for program planning over the next several years. We briefly outline here the elements of this plan.

Physics goals for the mid-term:

Spectacular early results raise important questions about new state of matter. The mid-term strategy outlined here calls for a balance of beam-on running time with investment in accelerator and detector upgrades necessary for crucial measurements of this new form of dense matter, and a full realization of the RHIC spin capability.

Heavy Ion measurements:

Detector and facility upgrades to address these measurements are shown in italics. The upgrades are discussed below.

- Electron-pair mass spectrum (DOE performance milestone for 2010)
Hadron Blind Detector for Dalitz pair rejection
- Open charm measurements in AA
High resolution vertex detection
- Charmonium spectroscopy (DOE performance milestone for 2010)
High luminosity; precision vertex; improved particle ID
- Jet Tomography
High luminosity; High-rate DAQ; improved particle ID
- Monojets in d-Au (DOE performance milestone for 2012)
Particle detection at forward rapidity

Spin measurements:

- Complete initial $\Delta G/G$ measurement (DOE performance milestone for 2008)
No upgrades needed
- Transversity measurement
Forward particle measurement
- W measurements at 500 GeV (DOE performance milestone for 2013)
Forward trigger in PHENIX and tracking in STAR

Collider upgrades and development: 2006-2011

The Collider group continues to enhance the machine performance through developments as part of the ongoing operations. At present, the achieved Au-Au luminosity is about twice the design value. Over the next few running periods the ion-ion luminosity, averaged over a store, is expected to increase by another factor of ~ 2 , reaching an average per store (Au-Au collisions) of $8 \times 10^{26} \text{ cm}^{-2} \text{ sec}^{-1}$.

The p-p luminosity, while it exceeds the design luminosity for RHIC, is less than the target value for carrying out the RHIC spin program. The polarization has increased steadily to a value, in run 5, of $\sim 50\%$. Over the next several years the luminosity is expected to increase by a factor of 6 over the presently achieved value, reaching $6 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$ at 100+100 GeV and $1.5 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$ at 250+250 GeV. These values assume collisions in 2 IRs. The polarization is expected to reach the design value of 70% by 2008.

The DOE construction start of EBIS will begin in FY 2007. The NASA supported part of the project began in late FY 2005. EBIS is a linac-based ion source and pre-injector that will replace the Tandems, providing more efficient, lower-cost operation. It is expected to be commissioned in 2009, and will make high-luminosity uranium beams, as well as polarized ^3He available for experiments.

R&D is underway on electron cooling of the full-energy ion beams in RHIC. By eliminating beam blow-up due to intra-beam scattering, this will provide an increase in Au-Au luminosity by a factor of ~ 10 , and is the basis for the RHIC II upgrade. A demonstration Energy Recovering Linac is being built, with funds from both DOE and the U.S. Navy. Development of SC cavities and high-brightness electron gun is underway. Codes to simulate beam blow-up and cooling are being benchmarked. It is

expected that a “proof of principle” for e-cooling in RHIC will be established and peer-reviewed during FY 2006. From a technical stand-point, a project to implement e-cooling for RHIC II will be ready for CD-0 determination by DOE in FY2006, leading to a construction start (CD-3) in 2009, and implementation ~2013.

PHENIX and STAR Upgrades

Each of the experiments has a planned suite of upgrades to address the physics topics described above. We give a brief listing here, noting the status of each. We have divided them into “short term” and “mid-term” upgrades. The short term upgrades are projects that either already underway, or expected to proceed in FY 2006. The mid-term upgrades are projects that are far enough along in the planning/development/proposal stage that they could be implemented as DOE construction projects and completed during the time window of this strategic plan.

In discussing these projects in the context of the strategic plan, we have considered the resources required to implement them, including manpower; the costs and expected funding sources; the R&D requirements, including R&D costs; the incremental operations costs and computing resources once the upgrade becomes operational; and the timing of these upgrades with respect to possible physics operations scenarios for the facility. Thus, for example, the planning for the next high-statistics Au-Au run is coupled to the availability of detector upgrades to allow direct observation of open charm. These considerations are the subject of the “integrated plan” for upgrades that we discuss below.

Short Term Upgrades:

PHENIX Hadron Blind Detector (HBD):

A proximity focused Cherenkov detector using CsI coated GEM detectors to detect soft electrons from Dalitz decays, reducing by orders of magnitude the combinatorial background for the low-mass spectrum of electron pairs. The project is being led by the Weizmann Institute. The DOE cost is \$1.1M, funded from RHIC operations capital (\$0.5M of this was provided in FY 04-05) \$0.25M has been provided by NSF. A full size prototype is installed for an engineering run in Run 6. The detector should be operational for Run 7.

PHENIX Muon Trigger:

A Resistive Plate Chamber array for each of the Muon Arms, providing an efficient trigger on leptonic W decays. This is essential for the PHENIX W measurements in the 500 GeV spin program. This project is funded by the NSF, at a cost of ~\$2M, and is led by the UIUC group. Construction is scheduled to begin in FY 2007, with completion in 2009.

STAR Time of Flight (TOF):

A fast, fine-grain barrel array of Multi-gap resistive plate chambers (MRPC) that will surround the STAR TPC. This is a line-item (MIE) project with a DOE cost of \$4.7M. It is funded for a start in FY 2006, with completion in 2009. The MRPC modules will be fabricated in China.

STAR Forward Meson Spectrometer (FMS):

A Pb glass array of ~1400 existing blocks, covering the η range from 1-4. Will provide neutral pion measurements in the range $x = .001 - .1$ in Au-Au and d-Au collisions. Funded from RHIC operations capital, at a cost of \$600K. Expected to be fully operational in FY 2007.

STAR DAQ1000:

Replaces the front-end electronics of the STAR TPC with a fully pipelined system using the readout chip designed for the ALICE TPC. This will increase the readout rate from its present 100Hz to 1000 HZ, increasing live time for triggered events by a factor of 2, allowing very large untriggered samples, and efficient triggering on rare events with, e.g., the STAR EM calorimeter. Funded from RHIC operations capital at a cost of \$1.8M (of which \$0.3M was funded in FY 05), it should be implemented by FY 2008.

Mid-Term Upgrades

PHENIX Si Barrel Vertex Detector:

A 3-layer silicon detector using pixels and strips to provide tracking with sufficient accuracy to detect displaced vertices of charm and beauty decays. This is a joint U.S. and Japanese effort. The U.S. component is proposed as an MIE project with a DOE cost of \$4.7M. It has been reviewed, and a management plan accepted by DOE. It is expected to be funded for a construction start in FY 2007, with completion in 2009.

PHENIX Si Forward Vertex Trackers:

Two “end-cap” silicon trackers that will increase the rapidity coverage of the Si barrel, extending displaced-vertex coverage to include the acceptance of the Muon Arms. The proposed DOE cost would be ~\$4.5M. There is not yet a formal proposal for this project.

PHENIX Nose Cone Calorimeter (NCC):

A project to instrument the pole pieces of the PHENIX axial field magnet with a compact, dense sampling calorimeter using tungsten plates interleaved with silicon readout. These will provide forward photon and jet coverage for the PHENIX heavy ion and spin measurements. The NCC is being developed by a collaboration of U.S., Japanese, Russian, and Czech institutions. A full technical design is not yet prepared. The estimated DOE cost is \$4M.

STAR Heavy Flavor Tracker (HFT):

A silicon pixel inner tracking device with vertex point-back accuracy $<50 \mu\text{m}$, consisting of two layers of CMOS active pixel sensors, 10^8 pixels, thin, 2 cm radius beam pipe, with detector thickness $\sim 50\mu\text{m}$ per layer. This is an on-going development effort, with expectation that a project to construct a functioning

detector for STAR could be undertaken in 2-3 years. The cost would be in the range \$5-10M.

STAR Inner/Forward Tracking (integrated tracker)

A silicon barrel consisting of 3 layers of Si strip detectors, replacing the present SVT, surrounding the HFT, and utilizing the existing SSD Si strip layer, provides a track pointing device for the HFT, connecting TPC tracks to the high precision inner layers, compatible with DAQ 1000. Forward tracking consists of 4 Si strip discs just forward of the Si barrel, and a GEM layer on the front face of the Forward EM Calorimeter. The forward tracking components provide precision tracking in the range $1 < \eta < 2$, giving charge sign discrimination for W decays. The estimated cost is ~\$10M.

In Table 2 we summarize the estimated costs and schedules for these upgrades. Only the DOE costs are shown. Here, the estimates for the short-term upgrades are well-established. For the mid-term upgrades we have provided the current best estimates. The schedules shown for the mid-term upgrades include the time required for review of technical designs and management plans by BNL and DOE in advance of the budget preparation cycle for the proposed construction start. (Thus, for example, proposed project starts in FY 2008 must be reviewed by mid-FY 2006).

Table 2.
Detector upgrade cost profiles (DOE costs): R&D and Construction
The cost profile for EBIS is also shown

		FY 2006		FY 2007		FY 2008		FY 2009		FY 2010		FY 2011	
		R&D	Constr.	R&D	Constr.	R&D	Constr.	R&D	Constr.	R&D	Constr.	R&D	Constr.
STAR	FMS		0.6										
	DAQ1000		0.9		0.6								
	TOF		2.4		2.4								
	HFT	0.5		1.0		1.0	0.3		2.5		2.5		
	Int. Trk.	0.2		0.2		0.5			3.6		4.2		0.7
STAR tot.		0.7	3.9	1.2	3.0	1.5	0.3	-	6.1	-	6.7	-	0.7
PHENIX	HBD	0.1	0.5										
	VTXb	0.4			2.3		2.3						
	VTXe	0.2		0.3		2.0		2.0		0.5			
	NCC	0.1		0.2		0.5	2.0		1.5		0.5		
	DAQ	0.1		0.2		0.2		0.2		0.2		0.2	
PHENIX tot.		0.9	0.5	0.6	2.3	0.7	6.3	0.2	3.5	0.2	1.0	0.2	-
Detectors		1.6	4.4	1.8	5.3	2.2	6.6	0.2	9.6	0.2	7.7	0.2	0.7
EBIS			2.1		7.5		4.5						

The total annual R&D and equipment fabrication costs for detectors in FY 2005 and 2006 is about \$6M per year. In Table 2 one sees that this annual investment would rise to an average level of about \$7-8M per year for the period 2007 – 2010 in order to implement these upgrades.

The working group is in the process of estimating the incremental annual operating costs for the RHIC facility as these upgrades come on-line. At present we have only a very rough estimate, based on rules of thumb, indicating that the operations costs would increase by approximately \$1-2M per year for the detectors. This is approximately balanced by the reduced operating costs of the accelerator complex when EBIS comes on line.

RHIC Computing Facility

Note: A detailed response to the DOE call for a 5-year plan is being developed, based on the overall mid-term strategic plan. This will be incorporated in the final report. We give a brief overview here for the interim report.

The RCF concept of a scalable architecture for CPU, disk, and mass storage, with annual replacement of ~1/4 of the installed hardware, has been successful in supporting the early runs at RHIC. Working with the experimental groups, RCF has developed algorithms to estimate the required capacities for CPU, disk, and mass storage for anticipated RHIC running scenarios. These algorithms, based primarily on the expected amount of raw data collected, allow for flexible planning and cost estimating based on multi-year beam use plans.

CPU has historically been the primary driver of RCF equipment costs. To date, the predictability of Moore's Law has been excellent for increasing CPU capacity through annual purchase of new hardware. New Dual Core Processor technology promises a significant price/performance enhancement. Growth in data volume and data recording rates has outpaced early expectations, hence RCF is moving toward cheaper (more commodity-like) solutions for mass storage.

In general, we do not foresee a significant change in the RCF architecture through the mid-term period. Nor do we see a significant increase in the annual cost of RCF operation during this period. However, a detailed study of the impact on data volume of the proposed detector upgrades is being carried out. The final report of this planning study will include an estimate of the incremental need for computing support, and the effect on RCF plans and equipment costs. It is worth noting that both PHENIX and STAR have made use of computing resources outside of RCF for data simulation and processing. In particular, this year, PHENIX utilized high-speed network connection to process the Run 5 p-p data at its computing center in Japan.

A very serious issue for RCF relates to physical infrastructure. The scale of computing has grown to the point where the physical hardware has outgrown the available floor space and associated power and cooling capacity. By the spring of 2007 additional floor space, with accompanying power, air conditioning, fire detection/suppression, etc. will have to be provided. This problem is being studied at the Laboratory level. While it is not expected that the cost of providing this infrastructure will be passed to the RHIC budget, there may be increased annual operating costs as a result.

An Integrated Strategic Plan

Based on the findings discussed above, the working group believes that the mid-term accelerator and detector upgrades could proceed over the coming 5-6 years while carrying out a physics operations program of 20-30 weeks each year. This could be accomplished with annual operating costs at a level of constant effort relative to FY 2005 funding, except for an increase in capital equipment funding of \$1-2M/yr in the period FY 2007-FY 2010, and non-DOE funding, as noted in the discussion of detector upgrades. In Figure 1 we show a time-line in which we have assumed a straw-man beam-use program that is consistent with (if not exactly congruent with) the recent Beam Use Proposals from PHENIX and STAR, and is also consistent with the present C-A Dept. projections for beam performance over this period.

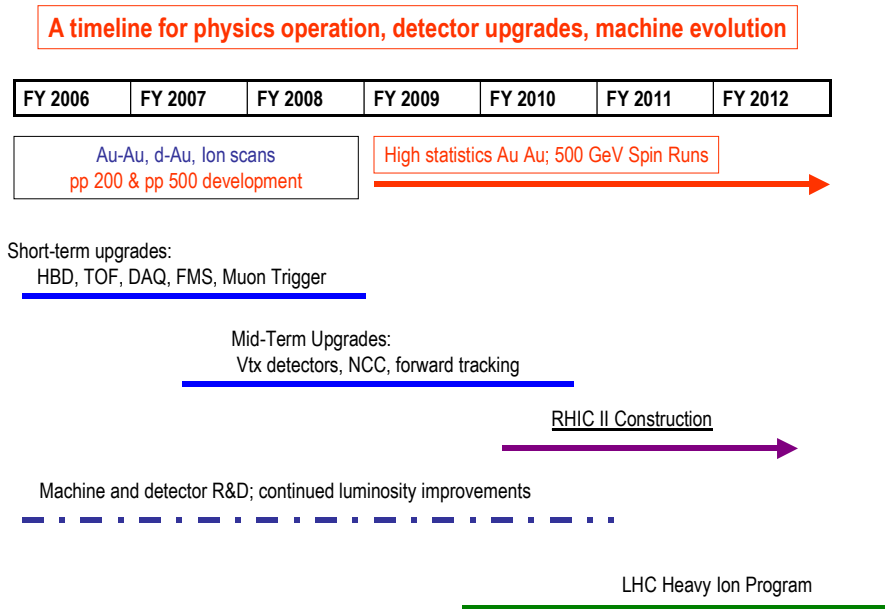


Figure 1
A Mid-Term timeline for physics operation and upgrades

A key element of this timeline is the readiness for high-statistics Au-Au runs from 2009 onward. This corresponds to the time when we expect the first results to emerge from the LHC heavy ion program. An important part of the strategy, reflected in the funding plan of Table 2, is to complete a complement of detector upgrades to enable measurements of open charm (and beauty), charmonium spectroscopy, and jet tomography in a high-statistics Au-Au run starting no later than 2009. Also in the mid-term time period, the forward tracking and calorimetry upgrades should enable the measurement of W^\pm production in 500 GeV p-p collisions.

We have noted that the development of e-cooling is proceeding at a pace that should allow the initiation of a construction project to implement full-energy cooling of the RHIC beams, producing the RHIC II luminosity gains, with a construction start (CD-3) in 2009. With the completion of the detector upgrades listed in Table 2, both STAR and PHENIX will be fully capable of exploiting the RHIC II luminosity to carry on with the physics program described at the beginning of this report, and in the findings of the RHIC II Science working groups.

Therefore, an important consequence of the mid-term strategy described here is the possibility to re-visit the planned scope of the RHIC II Project, which had previously been envisioned to include significant funding for detector upgrades. With the implementation of this mid-term plan, a RHIC II Project can be more narrowly defined, strictly as a luminosity upgrade for the machine. At correspondingly lower cost, this major upgrade in machine performance could become operational at the end of the mid-term period, with two large detectors well equipped for RHIC II physics. The graphic in Figure 2 illustrates this plan in detail, showing the timeline for machine and detector upgrades along with the evolution of machine capability over the mid-term period, and the corresponding readiness to begin the key physics measurements.

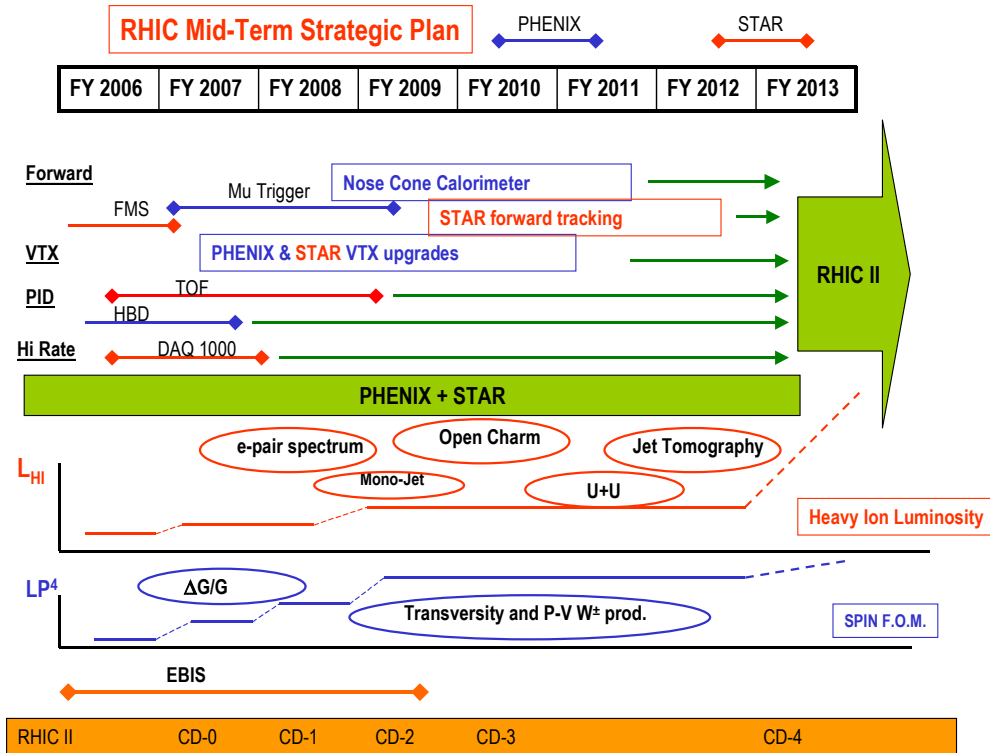


Figure 2
Graphic illustration of the Mid-Term Plan