Brookhaven National Laboratory

Relativistic Heavy Ion Collider

Economic Impact Report

Discovery Science Fuels Economy, Technology, Education

RHIC Highlights

By the numbers...

$157 Million FY 2012 operating budget, supported **859** Brookhaven employees (scientists, engineers, and support staff) – more than 25 percent of employee population

$183.4 Million in economic output generated in New York State by RHIC and visiting researchers

1,000+ visiting researchers from the nation and around the world

1,469 full-time equivalent jobs (directly/indirectly) supported throughout New York State and Long Island, **$114.3 Million** in earnings

350+ students awarded Ph.Ds at RHIC to date, hundreds in pipeline

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Introduction

RHIC is really two accelerators in one — made of crisscrossing rings of superconducting magnets, enclosed in a tunnel 2.4 miles in circumference. In the two rings, beams of heavy ions are accelerated to nearly the speed of light in opposite directions, held in their orbits by powerful magnetic fields.

Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) is a particle accelerator commissioned in 2000 that supports an extensive program of research into the fundamental nature of matter. Financed by the U.S. Department of Energy with significant contributions from Japan and other nations, it is one of the world's most powerful accelerators, and is the only collider now operating in the U.S.

RHIC was the first machine in the world capable of colliding heavy ions – atoms of heavy elements such as gold that have had their outer cloud of electrons removed. RHIC uses ions of gold and other heavy elements because these nuclei are densely packed with particles (protons and neutrons). By colliding two beams of heavy ions traveling at nearly the speed of light (what physicists call relativistic speeds), scientists can recreate and study the hot, dense matter of the very early universe.

The extreme conditions created in RHIC's collisions "melt" the ions' protons and neutrons to briefly liberate those particles' constituents -- quarks and gluons. These are the particles that filled the infant universe as a so-called quark-gluon plasma before joining up to form the building blocks of everything we see in the universe today.

During the past twelve years, physicists working at RHIC have conducted cutting-edge research that has advanced our understanding of conditions that prevailed in the instant following the "Big Bang," including how matter is held together and details of its fundamental nature. RHIC is also the only accelerator capable of colliding spin-polarized protons to explore the source of proton spin, a property exploited in MRI scanners but still not fully understood.

This report assesses RHIC's economic impact. Part One analyzes RHIC's impact as a significant enterprise in its own right, focusing on its impact on the economy of Long Island and New York State. Part Two highlights a variety of ways in which RHIC is contributing to the discovery of new knowledge and the development of new technologies that can provide a foundation for future economic growth – on Long Island, in New York, and nationwide.

Part One: The Impact of RHIC as an Enterprise

In an economy that is increasingly built on science and technology, Brookhaven National Laboratory (BNL) is one of Long Island's – and New York State's – leading scientific enterprises; and RHIC accounts for a significant part of all activity at the Laboratory. With an operating budget of $157 million in FY 2012, RHIC supported more than 25 percent of the employee population, including scientists, engineers, and support staff across the Lab. This part of the report focuses on RHIC's impact as an enterprise – as an employer, a purchaser of goods and services, and as a source of investment in new facilities.

RHIC as an Employer

RHIC accounts for hundreds of high-quality jobs at Brookhaven National Laboratory. As Table 1 shows, 463 BNL employees are directly engaged in RHIC development and operations, and in research at RHIC.[1] They include scientists, other professionals, management and administrative personnel, and technical and support staff.

In addition to jobs directly associated with RHIC operations and research, a portion of all central administrative and support jobs and other centrally administered programs at BNL can also be attributed to RHIC. Based on RHIC's share of overall direct spending at the Laboratory, we estimate that 396 of these jobs can be allocated to RHIC. These jobs are also shown in Table 1.

Virtually all of the jobs cited in Table 1 are well-paid, full-time jobs. As Table 2 shows, average annual earnings per employee in the categories listed in Table 2 average $94,100, ranging from $74,660 for unionized support staff (of the 152 technical and support staff cited in Table 1, 112 are unionized) to $110,670 for scientists. The Laboratory also provides a full range of benefits, valued at about 35.8 percent of direct salaries and wages.

Wages and salaries paid in fiscal year 2011 to employees directly engaged in operations of and research at RHIC, as well as those allocated to RHIC, totaled $78.8 million. We estimate that approximately 96 percent of this total was paid to residents of Suffolk and Nassau counties, with the remainder paid to other residents of New York State. Spending on benefits provided to these employees totaled approximately $28.3 million.

Impact of Purchasing and Construction

Purchases of goods and services allocated to RHIC in fiscal year 2011 totaled $24.3 million. We estimate that payments to Long Island-based contractors and vendors accounted for 26 percent of this total –

Table 1: BNL employment associated with RHIC (direct allocated and total)

Job category	Direct jobs	Allocated jobs	Total RHIC jobs
Management and administrative	14	131	145
Scientists	78	37	115
Other professionals	172	76	248
Technical and support	199	152	351
Total	**463**	**396**	**859**

Table 2: Average earnings by job category, fiscal year 2011

Job category	Average annual salary
Scientists	$110,670
Other professionals	$99,570
Management and administrative	$89,800
Technical	$85,530
Unionized support staff	$74,660
Average, all groups	**$94,100**

1 Includes employees of the Laboratory's Collider and Accelerator Department, Physics Department, and the RIKEN-BNL Institute, a joint Japanese-U.S research center located at BNL

PHENIX is one of the two large detectors that helps physicists analyze the particle collisions at Brookhaven's Relativistic Heavy Ion Collider.

about $6.4 million. Major categories of local purchasing included electrical and electronic equipment, and a variety of professional and technical services.

Purchases for RHIC from companies elsewhere in New York State totaled more than $7.3 million – about 30 percent of all RHIC-related spending.

In addition to its payments to Long Island-based suppliers, we estimate that Brookhaven National Laboratory spent approximately $9.4 million on employee health benefits, which paid for the delivery of a variety of health services to BNL employees and their families. Because the Laboratory is self-insured, nearly all of this spending consisted of payment to Long Island health care providers.

During fiscal year 2011, BNL also invested $14.7 million in various upgrades to RHIC facilities, of which we estimate approximately $3.4 million was paid to Long Island contractors and suppliers.

Taking into account purchases of goods and services, spending on employee health care, and investments in facility upgrades, we estimate that RHIC-related payments to Long Island companies in fiscal year 2011 directly supported 87 full-time-equivalent jobs with these businesses.

Indirect and Induced Effects

RHIC's impact on the Long Island economy goes beyond the direct impact of the Laboratory's spending on payroll, purchasing, and construction; it also includes "indirect and induced" or "multiplier" effects. Long Island companies from which BNL buys goods and services use some of the money they earn from the Laboratory to buy goods and services from other local businesses; and those businesses in turn buy some of what they need from still other Long Island companies. Similarly, BNL employees associated with RHIC (and the employees of the Laboratory's Long Island-based suppliers) spend part of their take-home pay locally – for housing, utilities, food, child care, entertainment, and other household needs.

Using the IMPLAN input-output modeling system – a tool of economic analysis commonly used to conduct economic impact analyses – we estimate that in fiscal year 2011, BNL's spending on RHIC indirectly generated:

- 437 full-time-equivalent jobs on Long Island;
- $24.3 million in earnings; and
- $71.5 million in regional economic output.

Total Impact of RHIC Spending

Taking into account both direct and indirect and induced effects of RHIC-related spending in payroll, purchasing, and RHIC upgrades, we estimate as shown in Table 3 that in fiscal year 2011 RHIC directly and indirectly accounted for:

- 1,383 FTE jobs on Long Island;
- $109.2 million in earnings; and
- $168.0 million in regional economic output.

Impact of Visitor Spending

Each year, RHIC brings hundreds of visitors to Long Island from outside the region – most of them from outside New York State. They include:

- External users of RHIC, including faculty members and graduate students from universities throughout the U.S. and from other countries, and scientists from other research institutions. As of September 2012, there were approximately 1,000 external RHIC users;
- Participants in scientific meetings at BNL on work related to RHIC; and
- Representatives of companies doing RHIC-related business with the Laboratory.

We estimate that in fiscal year 2011, RHIC visitors spent more than $1.0 million on lodging, food, entertainment, and transportation while on Long Island. As shown in Table 4, visitor spending directly supported 21 FTE jobs on Long Island; and through the multiplier effect, 7 additional FTE jobs.

Adding It All Up: The Impact of BNL and Visitor Spending

Combining the impact of the Laboratory's spending on RHIC with the impact of spending by visitors, we estimate that in fiscal year 2011 RHIC directly and indirectly accounted for:

- 1,411 FTE jobs on Long Island;
- $110.4 million in earnings; and
- $171.2 million in regional economic output.

Because RHIC-related in-state spending for payroll, purchasing, RHIC upgrades, and spending by visitors are heavily concentrated on Long Island, the statewide impact of RHIC-related spending is only slightly larger than its impact on Long Island. We estimate that at the state level, RHIC-related BNL and visitor spending directly and indirectly generate:

- 1,469 FTE jobs in New York State (including Long Island);
- $114.3 million in earnings; and
- $183.4 million in statewide economic output.

Impact on State Revenues

In addition to its impact on the local economy, RHIC generates revenues for New York State government. The most significant of these are the income tax revenues derived from wages and salaries paid to RHIC-related BNL employees. We estimate that in fiscal year 2011, nearly $4 million in New York State income taxes were withheld from these employees' earnings.

Similarly, BNL's spending on purchases of goods and services, and household spending by BNL employees, also create jobs that generate state income taxes. We estimate that in 2012 this spending indirectly generated about $1.8 million in State income taxes.

Local governments also benefit from property taxes paid by BNL employees who live on Long Island. Employees also pay both State and local sales taxes.

Table 3: Direct, indirect/induced and total impact of BNL spending on RHIC, FY 2011 ($000's)

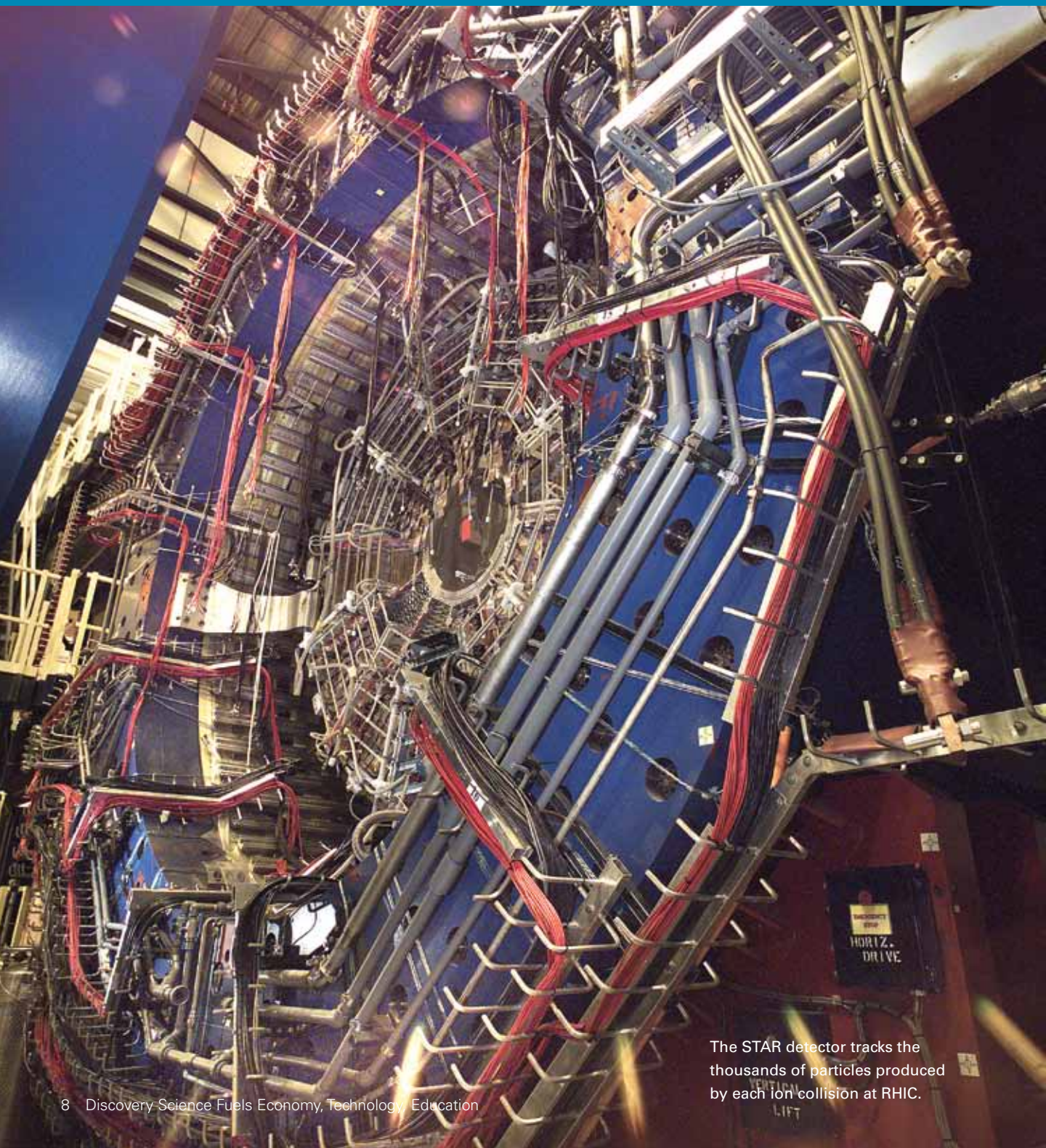
	Employment	Earnings	Output
Direct	946	$84,932	$96,583
Indirect and induced	437	24,299	71,453
Total	**1,383**	**$109,231**	**$168,036**

Table 4: Impact of visitor spending ($000s)

	Employment	Earnings	Output
Direct	21	$731.3	$1,881.5
Indirect and induced	7	448.7	1,277.4
Total	**28**	**$1,180.0**	**$3,158.9**

Part Two: Research, Education, and Innovation

As great as RHIC's impact as an enterprise may be, its contribution as a center of research, education, and innovation is in the long run likely to be even more significant.



The STAR detector tracks the thousands of particles produced by each ion collision at RHIC.

Research

For Long Island, New York, and the nation, RHIC is a uniquely valuable scientific resource. As noted previously, it is now the only particle collider operating in the U.S. – and it is one of the most powerful (and most versatile) colliders anywhere in the world.

Physicists have for twelve years been using RHIC to study quarks and gluons – the particles of which protons and neutrons are made, and the most basic components of visible matter. Using the collider to recreate the conditions thought to have existed in the instant immediately following the Big Bang, international collaborations of nuclear physicists have discovered that the "quark-gluon plasma" from which protons and neutrons emerged appears to have been a "perfect liquid" rather than a gas, as had been predicted. Through further experiments, these scientists are now working toward a better understanding of this quark-gluon soup and its transition to the matter we know today – and thus a better understanding of the nature of matter itself.

RHIC is also the world's only facility that can collide polarized protons – a capability essential to the study of proton spin, an area of physics research with important practical implications in areas such as medical imaging and nuclear medicine.

RHIC offers a wide range of beam energies and beam types that are available nowhere else in the world As a result, RHIC can support research that today cannot be conducted anywhere else – including at the Large Hadron Collider in Europe.

Both because of its versatility and because it is located at a multi-disciplinary, multi-function laboratory, RHIC has had an impact in areas of science well beyond nuclear physics, influencing work in string theory, cosmology, low-temperature physics, cancer treatment and other fields. Its impact is reflected in the fact that in its first decade, more than 350 refereed papers were published based on work done at RHIC – papers that subsequently earned more than 35,000 citations.

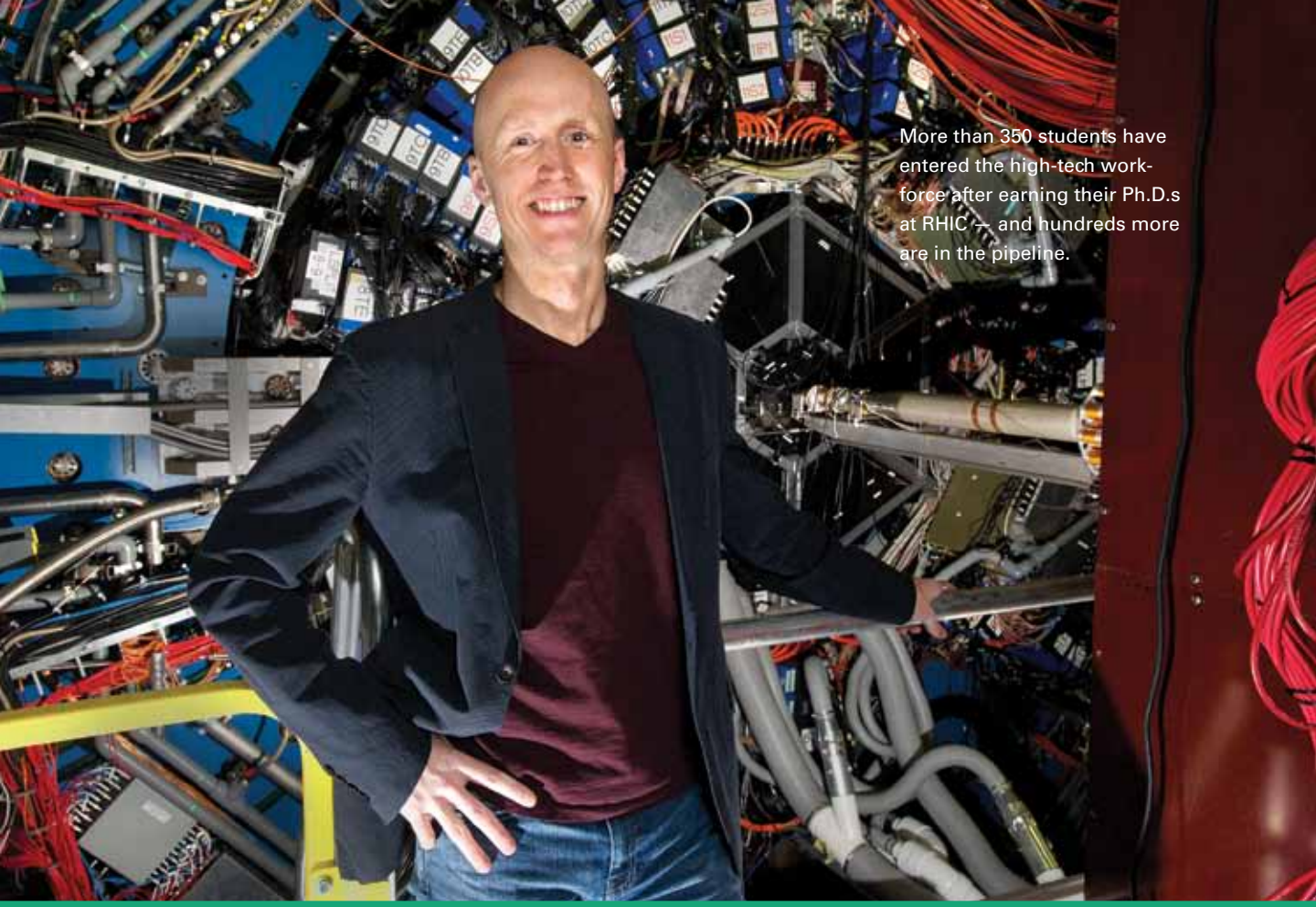
BNL's collaboration with NASA on another particle accelerator offers a notable example of RHIC's impact in fields beyond physics. Since 2003, researchers at BNL's NASA Space Radiation Laboratory have used heavy ions accelerated by RHIC's pre-injector chain of accelerators to explore the effects of space radiation. This research is helping to answer why the radiation to which humans are exposed in space causes more damage to DNA than other types of radiation (such as gamma rays and x-rays) that are more common on Earth – and why it is more difficult for DNA that has been damaged by such radiation to repair itself. Their work could lead to a better understanding of how space travelers could more effectively be protected against space radiation – and also a better understanding of how to deal with the effects of radiation on Earth. NASA located its Space Radiation Laboratory at BNL in part because the accelerators that "drive" RHIC make it the only facility in the U.S. capable of generating heavy ion beams at the high energy levels required for space radiation studies.

Just as it has helped the U.S. establish or maintain world leadership in several emerging areas of physics, RHIC has strengthened New York's position as a center of scientific research. It currently supports the work of dozens of scientists at BNL, and more than 1000 external users. Their work has made BNL (and by extension, New York) the hub of a worldwide network of leading researchers in physics and related disciplines, and in several areas of applied science and technology.

RHIC's currently active external users include 32 scientists from New York State – virtually all of them affiliated with New York colleges and universities. SUNY Stony Brook accounts for the largest number of New York State-based external users (19), followed by Columbia (11) and the University of Rochester (3). Each year, the research that these scientists conduct at RHIC enables them to bring millions of dollars in federal and other research funds to New York. RHIC thus contributes to the vitality of scientific research throughout the state – from Rochester to Stony Brook.

Education

RHIC is not only a research facility – it is an important resource for educating the next generation of scientists. From 2000 to 2010, more than 350



More than 350 students have entered the high-tech workforce after earning their Ph.D.s at RHIC — and hundreds more are in the pipeline.

"RHIC is not only a research facility - it is an important resource for educating the next generation of scientists."

Ph.D. degrees were awarded to scientists who had done their doctoral research at RHIC. RHIC alumni currently hold about 150 tenured or tenure-track positions at U.S. universities, or similar positions at national laboratories and other research centers. Other RHIC alumni are working in areas as diverse as developing new technologies for detecting explosives, development of medical imaging systems and finance.

RHIC's role in education is not limited to those who are working toward advanced degrees. Faculty members at New York colleges and universities also use RHIC as a resource for teaching undergraduates. As one has noted:

> *Many undergraduate students in the university have had first-hand experience with experimental research because of our involvement and activities in RHIC science.*

Scientists working in BNL's Physics and Collider-Accelerator Departments are also active in several programs aimed at strengthening science education in elementary and secondary schools in New York State – especially on Long Island. BNL's Science Learning Center, for example, offers a program through which middle school students can learn about accelerators and colliders, use RHIC to observe the behavior of atomic particles, and learn about the properties of superconducting materials.

Innovation and Economic Growth

As essential as it may be to the nation's future, even the best research does not by itself drive growth. Economic growth occurs only as new knowledge is translated into new technologies, and new products, processes, and services – and then

into new businesses and new jobs. During the past several years, scientists, engineers, and administrators at Brookhaven National Laboratory have become increasingly active in this process of moving new knowledge "from discovery to deployment." Below we highlight several notable examples of ways in which the human and intellectual capital that have developed around RHIC – and in some cases the facilities that support the collider – are contributing to the development of new technologies, and to practical solutions to some of New York's (and the nation's) most pressing problems.

Developing and producing medical isotopes

Building off the capabilities of facilities first developed to support RHIC, BNL has developed a facility called BLIP (the Brookhaven Linac Isotope Producer) that is one of just two accelerator facilities in the U.S. that develop and produce medical isotopes. Demand for these isotopes is strong. Demand for strontium 82, for example – an isotope that is widely used in heart scans – now exceeds the capacity of existing production facilities at Brookhaven and Los Alamos National Laboratory; and demand for others is trending the same way.

Closely associated with (but in the long run perhaps even more important than) the production capacity RHIC provides are BNL's strengths in medical isotope research and development. The Laboratory has been a center of R&D in this field for many years.

- BNL scientists developed a generator system used to produce Technetium-99m, an isotope that revolutionized nuclear medicine. It is now used in medical imaging for more than 10 million patients annually in the U.S. alone.

- BNL also developed the generator system for Strontium-82/Rubidium-82, now widely used for PET scans of the human heart.

- Ongoing BLIP R&D now includes developing production of new isotopes for cancer therapy (copper-67), PET imaging (yttrium-86) and combined PET/MRI imaging (iron-52 labeled nanoparticles).

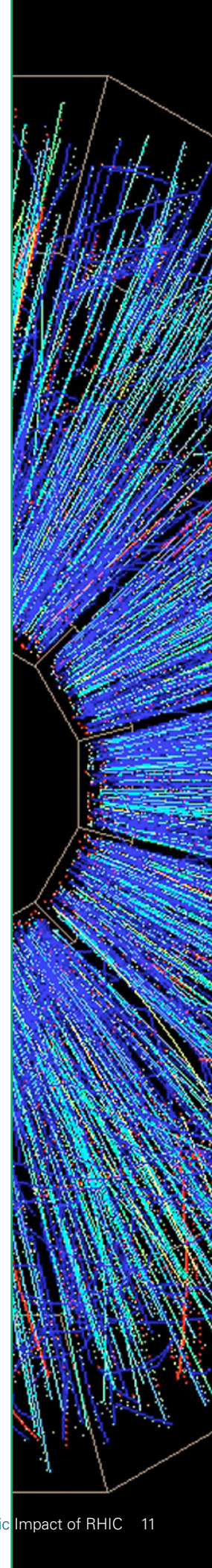
The next generation of particle therapy

In addition to the Laboratory's work on medical isotopes, the capabilities developed around RHIC have been instrumental in the development of a new type of particle therapy. This new technology involves use of a "rapidly-cycling medical synchrotron" to target tumors more precisely than is possible with the current generation of proton therapy technology. This not only provides much greater efficiency in attacking the targeted tumor (thus allowing treatment with lower doses of radiation); it also minimizes potential damage to the surrounding healthy tissue.

Under a co-operative research and development agreement (CRADA) with a Vancouver-based company called Best Particle Therapy, scientists and engineers at BNL are currently working on detailed engineering designs for the new machine, after which they would develop a working prototype.

Developing a new energy storage technology

RHIC relies on powerful superconducting magnets to generate the immense power and speed needed to accelerate and collide heavy particles; and in part because of the role these superconducting magnets play in RHIC, BNL is among the world's leading centers for research and development on the science and technology of superconductivity. In particular, BNL scientists are world-renowned for their expertise in designing magnets utilizing so-called high-temperature superconducting materials, which lose all their resistance when cooled by liquid nitrogen, rather than by the much more challenging and expensive liquid helium. Some of these specialized magnets have



A data tape storage system at Brookhaven's RHIC/ATLAS Computing Facility.

been built expressly for use in RHIC accelerator systems.

The magnetic fields generated by these magnets can hold enormous quantities of electrical energy. Moreover, because of their superconductivity they are highly efficient, with virtually no energy lost to resistance. These qualities mean that high-temperature superconducting magnets could provide the basis for a new generation of especially powerful, highly efficient energy storage devices. The Advanced Research Project Agency – Energy (ARPA-e, the federal agency charged with promoting the development of new energy technologies) and the U.S. Army are supporting research at BNL that is exploring the use of superconducting magnets for energy storage. This type of storage would significantly improve the prospects for integrating energy from renewable but intermittent sources, such as wind and solar, into the mix that currently feeds the nation's electric grid.

World-leading expertise in data mining

RHIC physicists have developed world-leading expertise in managing and processing extremely large volumes of data, a capability that could serve as a template for the design of more general data-mining approaches applicable to other data-intensive fields such as climate research, protein modeling, and even finance. In addition to providing all data storage and access for research at RHIC, Brookhaven's RHIC-ATLAS Computing Facility (RACF) serves as the top-level computing facility for all U.S. collaborators on the ATLAS experiment at Europe's Large Hadron Collider. When both RHIC and ATLAS are conducting research, data streams into the RACF at a rate of 4 to 5 gigabytes per second. Some 12,000 computational processing units (CPUs) sift through 1.3 petabytes of data per day, store up to 50 terabytes on tape, and distribute a fraction of the processed data to collaborators around the U.S. and overseas. Keeping such systems running smoothly 24 hours a day, seven days a week has made Brookhaven Lab a world leader in handling and mining "big data." This has the potential to become a lucrative industry in the future.

RHIC uses a system of intense radio waves to give the particle beam a little extra "kick" of energy to accelerate it each time it travels around the ring. This is called the radio frequency cavity system.

A new type of nuclear power

Physicists at BNL have studied the feasibility of developing a new type of nuclear power plant that would be fueled with thorium, rather than uranium. In this new model, a nuclear chain reaction would be initiated by using an accelerator system to irradiate the fuel.

An accelerator-driven, thorium-based reactor would offer several advantages: The chain reaction could be stopped simply by turning off the accelerator – almost literally by throwing a switch – and it would produce less nuclear waste than uranium-based reactors. Moreover, thorium is by itself much less hazardous than uranium or plutonium – and without a particle accelerator, cannot be used as nuclear fuel (for energy production or for developing weapons).

In the wake of the Fukushima disaster, work on the development of new nuclear technologies has slowed, both in the U.S. and elsewhere. In the long run, however, this new type of reactor, if proven feasible, has the potential to reduce significantly the environmental, safety, and security concerns associated with increased use of nuclear power.

Partnerships with New York companies

BNL's investments in RHIC, and in the research and technological development that RHIC make possible, also support the growth of technology-based companies in New York State.

- **Advanced Energy Systems** (AES), based in Medford, manufactures highly sophisticated components that are used in particle accelerators around the world. In 2010 the company opened a new facility – financed in part by an investment of $2 million from BNL – for production of superconducting radiofrequency cavities – complex devices made with superconducting materials that improve the performance of accelerators and colliders. AES, which was spun off from Northrop Grumman in 1998, currently employs 27 people.

- **Superpower, Inc.**, based in Schenectady, is working with BNL scientists and with ABB on the Laboratory's ARPA-e funded work on the development of superconducting magnetic energy storage systems. Founded in 2000, Superpower was acquired in 2012 by Furukawa Electric Company Ltd. The company currently employs 56 people.

As these examples show, RHIC is an important resource not just for scientific discovery, but also for technological innovations that could help drive the next round of economic growth, both in New York and elsewhere. The final section of the report briefly highlights why RHIC's impact could be even greater during the next decade than it is now.

Part Three: RHIC's Future Impact

In just twelve years, the U.S. government's investments in RHIC, along with those of other partners, have already yielded significant advances in physics and in applied science and technology, and have had a significant impact on Long Island's and New York State's economy as well. Over the course of the next decade, RHIC's impact on science and technology – and on Long Island's and New York's economy – could be even greater than it has been today.

From RHIC to eRHIC

From fiscal year 2013 through 2016, Brookhaven National Laboratory is planning to invest $15.9 million in upgrades to RHIC's existing facilities. Beyond these incremental upgrades, the next generation of research in particle physics will require an electron ion collider (EIC) — that is, an accelerator with the capacity to collide beams of heavy ions with beams of electrons, which is not currently possible at any of the world's physics research centers. BNL has proposed to develop this capacity by building a new electron accelerator ring within RHIC's existing tunnel structure.

BNL argues that this arrangement, dubbed eRHIC, offers the most cost-effective approach to developing an electron ion collider, because it would allow the new collider to make full use of RHIC's existing capabilities and can be accommodated within its existing structure. If ultimately approved and funded by the Department of Energy, development of eRHIC would require an investment of approximately $600 million at BNL, starting in 2020.

Development of eRHIC would open up new avenues for research into the fundamental nature and properties of matter, and help maintain U.S. leadership in this critically important area of science.

From Discovery to Deployment

During the past several years, BNL's heightened emphasis on combining scientific excellence with the translation of new knowledge into solutions to critical problems has begun to show results. Part Two of the report highlighted several examples of areas in which BNL's strengths in superconductivity, accelerator science and technology, and other disciplines are being used to develop new applications in health care and energy storage. The next ten years could see the further development and possibly the deployment of next-generation particle therapy technology, superconducting magnetic energy storage, and other technologies that have their roots at RHIC, including advances in national security and data-intensive computing.

During the next decade, leadership in the development of new technologies such as these – and taking advantage of the economic development opportunities that they will offer – will be essential to the continued growth of New York's, and the nation's, economy.

"During the next decade, leadership in the development of new technologies…will be essential to the continued growth of New York's, and the nation's, economy."

This report was prepared by Appleseed, a New York City-based economic development consulting firm that works with government, corporations, and nonprofit institutions to promote economic growth and opportunity.

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