

# The RHIC facility and the SBIR/STTR program

- Overview of facility
- Major new accelerator technologies
- R&D programs
- NP SBIR/STTR synergies and opportunities

Michiko Minty

SBIR/STTR Exchange Meeting  
Gaithersburg, MD  
9-10 August, 2016

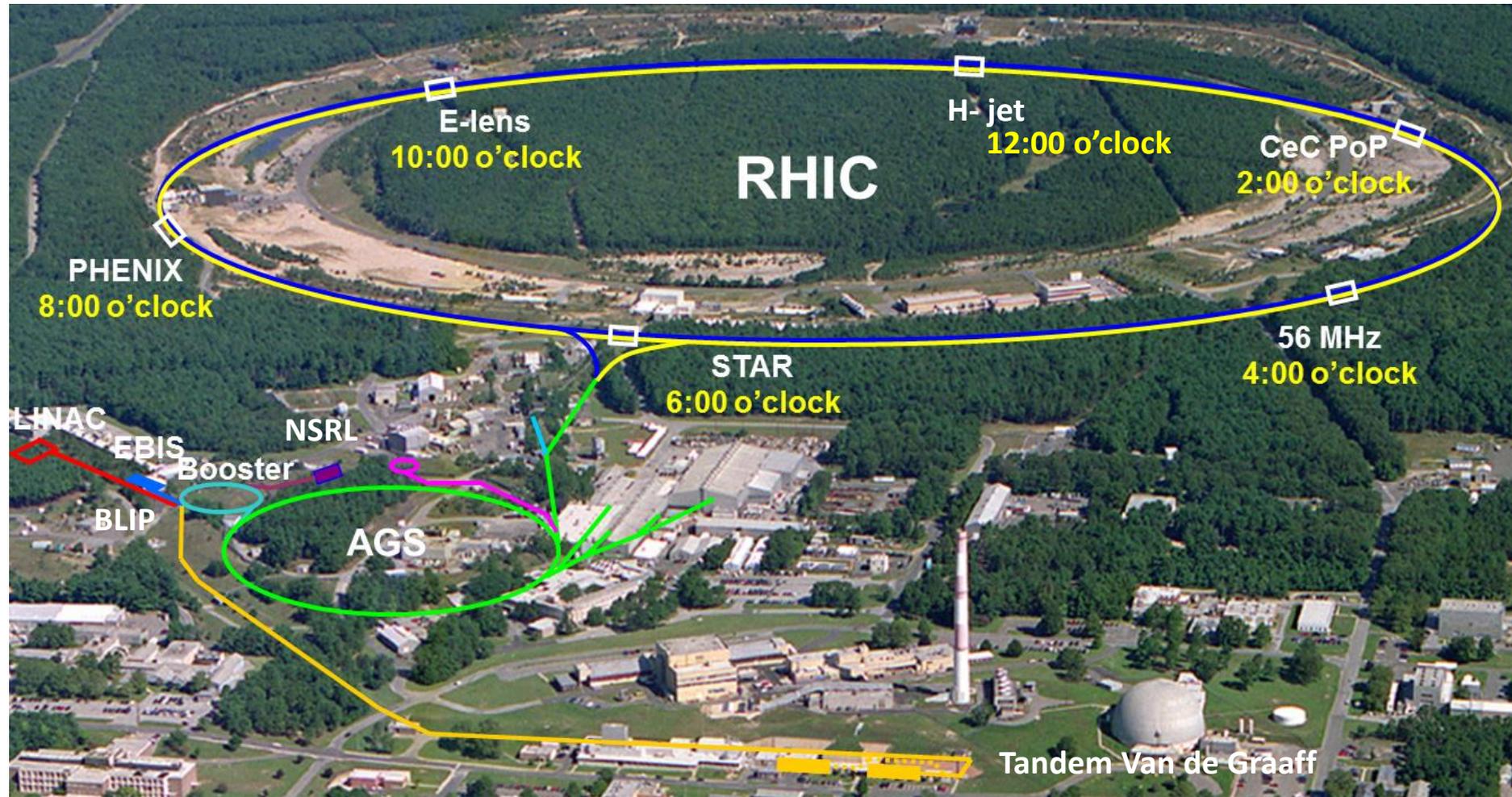
**BROOKHAVEN**  
NATIONAL LABORATORY  
*a passion for discovery*

Office of  
Science  
U.S. DEPARTMENT OF ENERGY



- **Overview of facility**
- Major new accelerator technologies
- R&D programs
- NP SBIR/STTR synergies and opportunities
- Summary

# Overview of the BNL hadron complex



Brookhaven National Laboratory (BNL)

Relativistic Heavy Ion Collider (RHIC)

NASA Space Radiation Laboratory (NSRL)

Linac Isotope Production (BLIP) / Medical Isotope Research and Production Program

Tandem van de Graaff accelerators

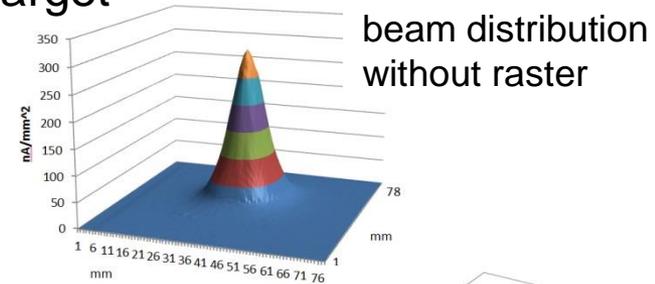
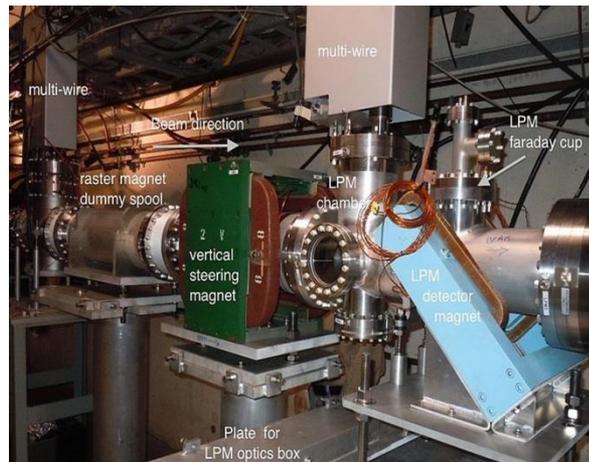
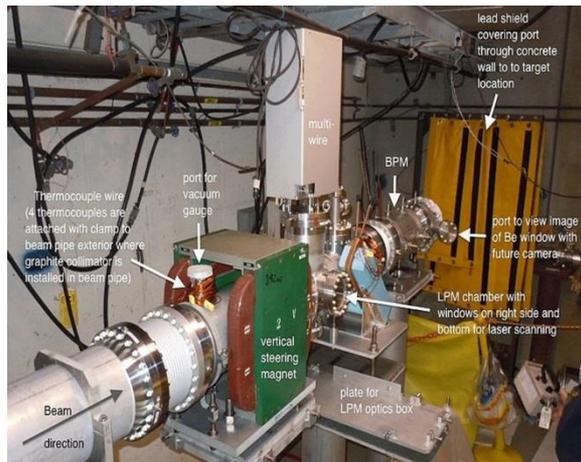
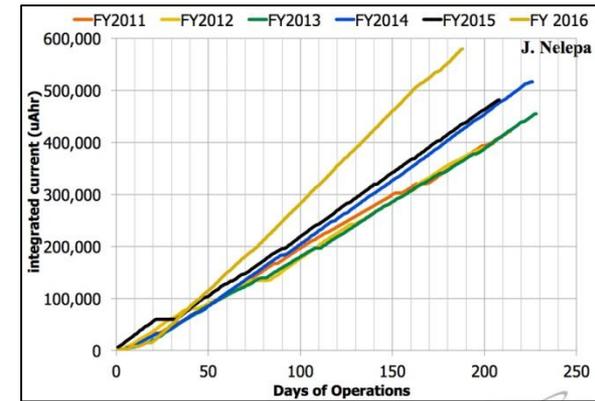
# BNL LINAC Isotope Producer (BLIP)

Medical isotope research and production program:

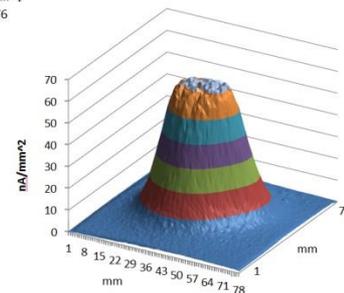
- Preparation of certain commercially unavailable radioisotopes to distribute to the nuclear medicine community
- perform research to develop new radioisotopes for nuclear medicine investigators

Operates generally parasitically to RHIC

- Higher isotope yields afforded by Linac intensity phase-1 upgrade (2016) which enabled average current increase from 125 to 140  $\mu\text{A}$
- BLIP raster upgrade (2016) to reduce peak power on target



beam distribution with raster



See also C. Cutler's User Facility presentation 10 August, 2016

# BNL NASA Space Radiation Laboratory



## Offers:

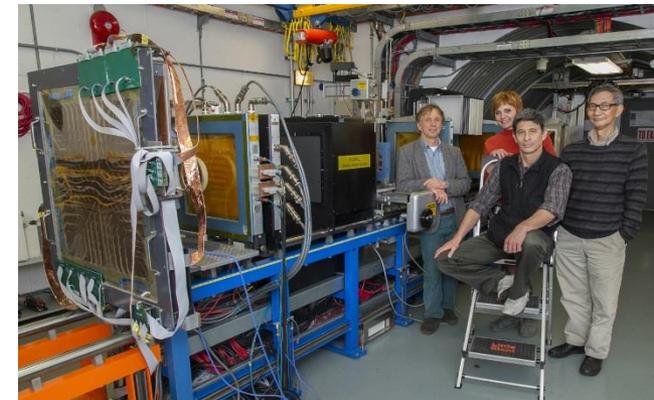
- Beams of all ions from protons to Uranium
- Energy range of 50 MeV to 1000 MeV (ion species dependent)
- A 400 square foot shielded target hall connected to a 4560 sq. foot support building with five laboratories for biological and materials experiments, specimen and control rooms
- User support from BNL's Biosciences and Collider-Accelerator Departments

## Applications include:

Radiobiology studies with beams simulating the cosmic rays found in space.

Industrial material studies on suitability of new materials for space suits and spacecraft shielding.

Space radiation risk and countermeasure development



# BNL Tandem Van de Graaff Accelerator Facility

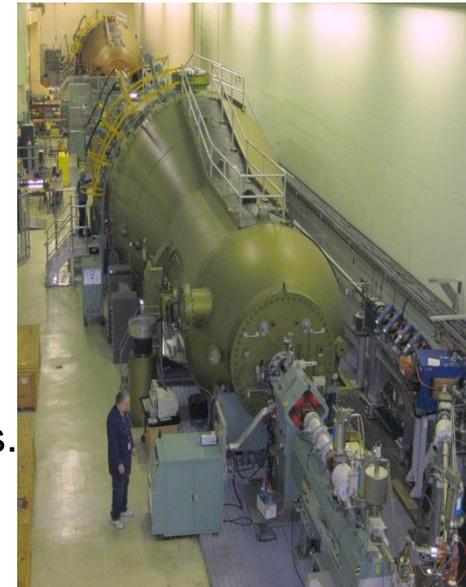
## Offers:

- A wide variety of light and heavy ions for industrial and space applications.
- Precisely known and continuously variable energies from a maximum of 28 MeV for protons to 400 MeV for gold ions.
- Accurate dosimetry and user friendly operation based on cost reimbursement.



## Applications include:

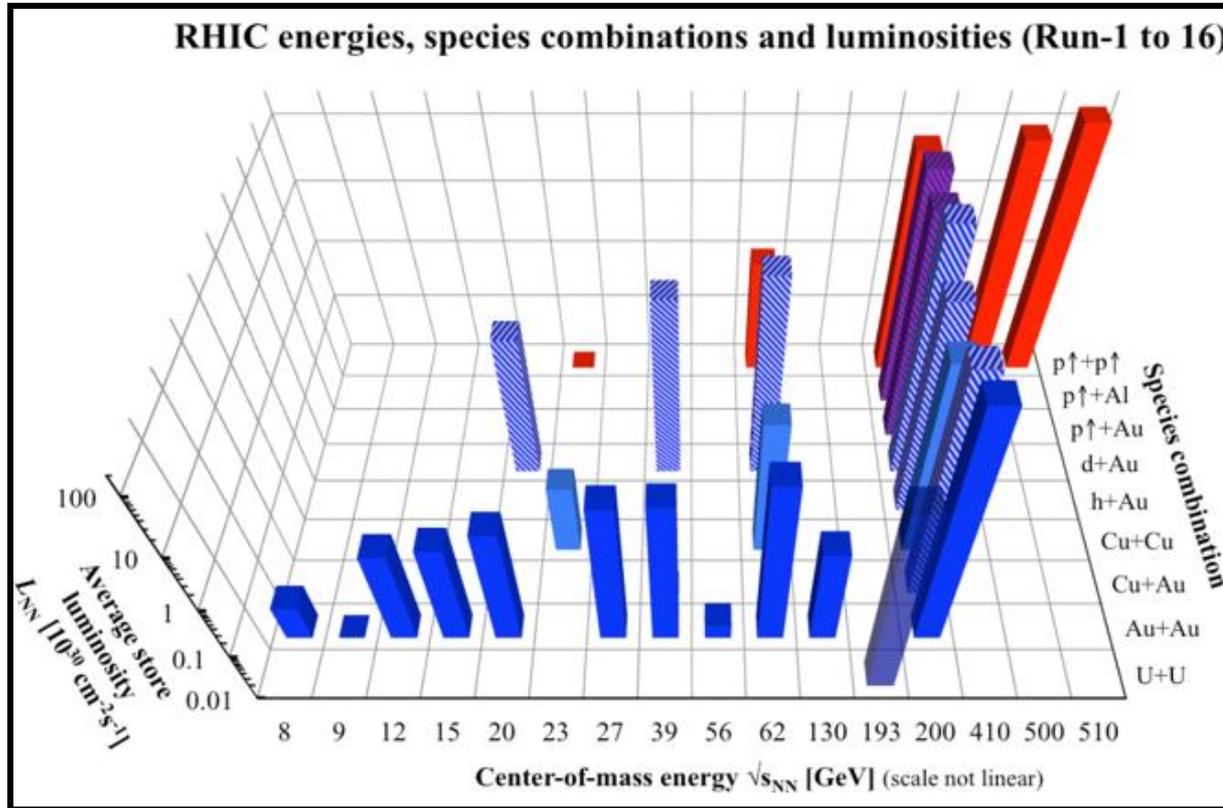
- Single event upset testing of micro-electronic devices.
- Calibrations of instruments for space applications.
- Radiation damage studies.
- Fabrication of track-etched filter materials.
- High energy ion implantations for new semiconductor material developments.
- Enhancement of high TC superconductor properties through ion irradiation.
- Cell radiobiology investigations at low energies and high stopping powers.



# RHIC history and future

- RHIC commissioning era (2000 to 2002)  
first full energy (100 GeV/n) heavy ion runs, first 100 GeV polarized proton run
- RHIC-I era (2003 to 2013)  
first full energy (250 GeV) polarized proton runs  
**new technology:** stochastic cooling proof-of-principle (2007)  
**new technology:** high intensity electron beam ion source, EBIS (>2010)
- RHIC-II era (2014 to 2016)  
**new technology:** 3D stochastic cooling (>2014)  
**new technology:** electron lenses for head-on beam-beam compensation (>2015)  
**new technology:** 56 MHz superconducting cavity used in operations (>2016)
- RHIC future  
**new technology:** low energy electron cooling (2017-2020)  
physics operations with detector upgrade, sPHENIX (>2022)
- plus ongoing R&D for future electron-ion collider, eRHIC

# RHIC - the champion of versatility



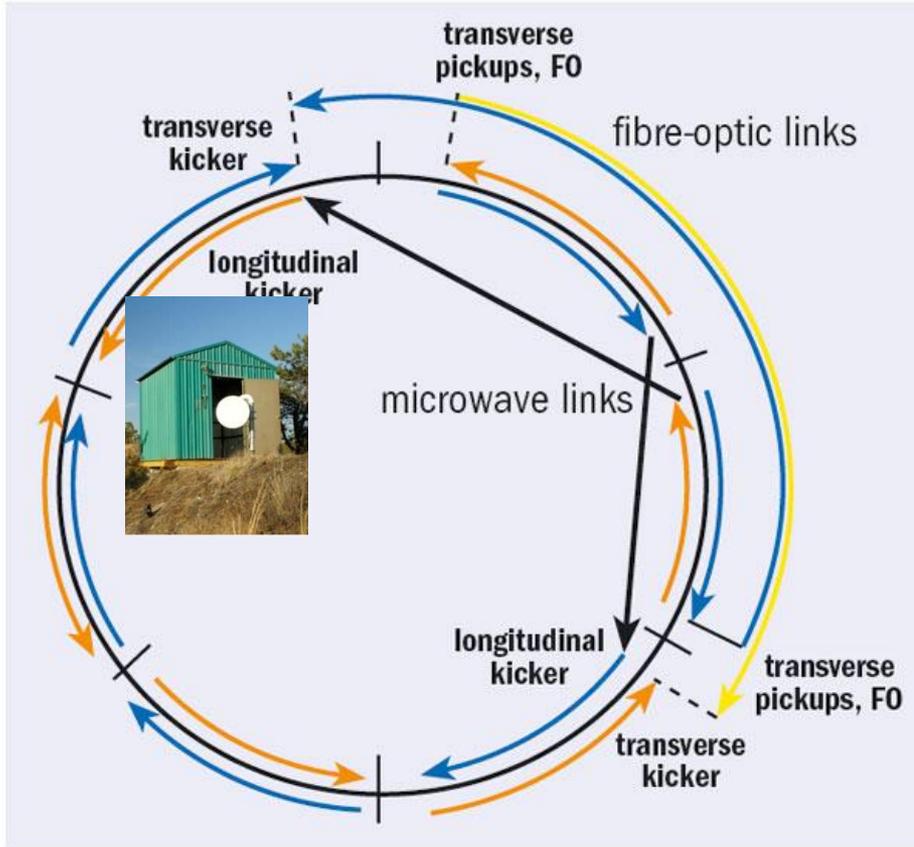
Mission (Collider-Accelerator Department):

- develop, improve and operate the suite of particle / heavy ion accelerators used to carry out the program of accelerator-based experiments
- support the experimental program including design, construction and operation of the beam transports to the experiments plus support of detector and research needs of the experiments
- design and construct new accelerator facilities in support of the BNL and national missions

- Overview of facility
- **Major new accelerator technologies**
  - stochastic cooling
  - electron lenses
  - superconducting cavities
  - bunched beam electron cooling
- R&D programs
- NP SBIR/STTR synergies and opportunities
- Summary

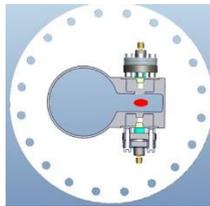
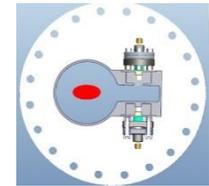
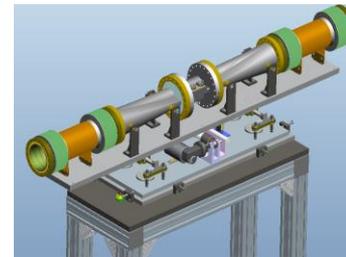
# Accelerator Technology: 3D stochastic cooling for heavy ions

Motivation: counteract intrabeam scattering (IBS) and cool beam distributions for higher luminosity

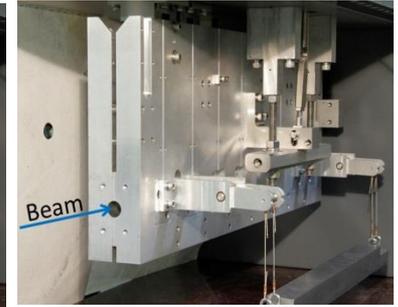
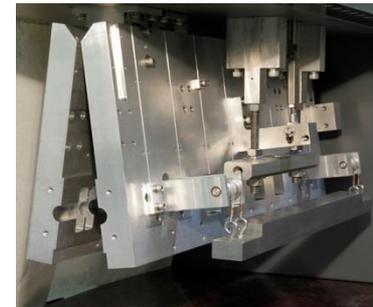


3 GHz bandwidth, cooling times  $\sim 1$  h

pickups

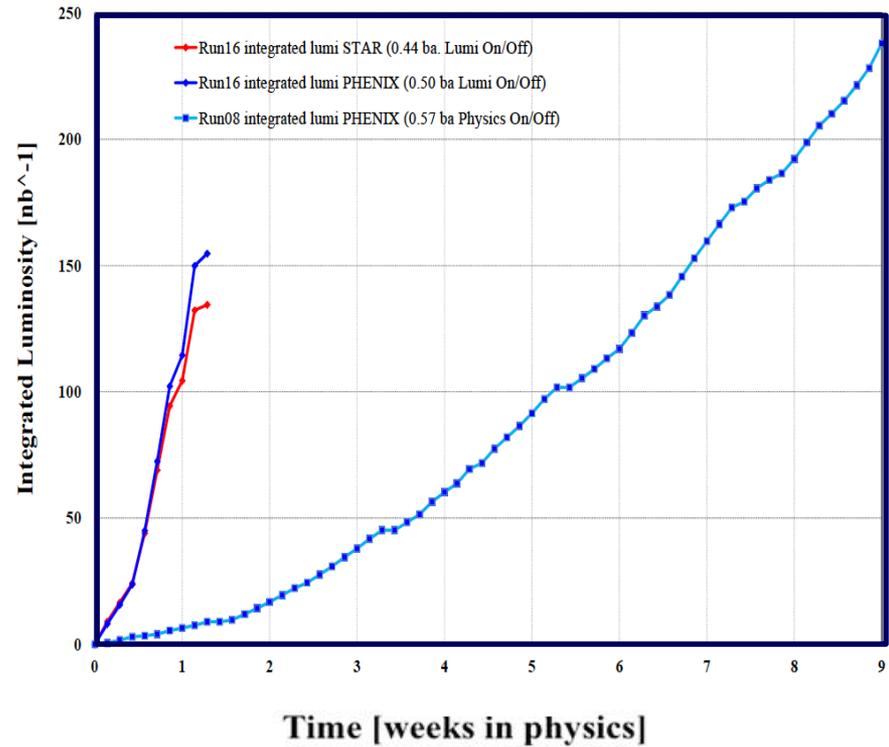
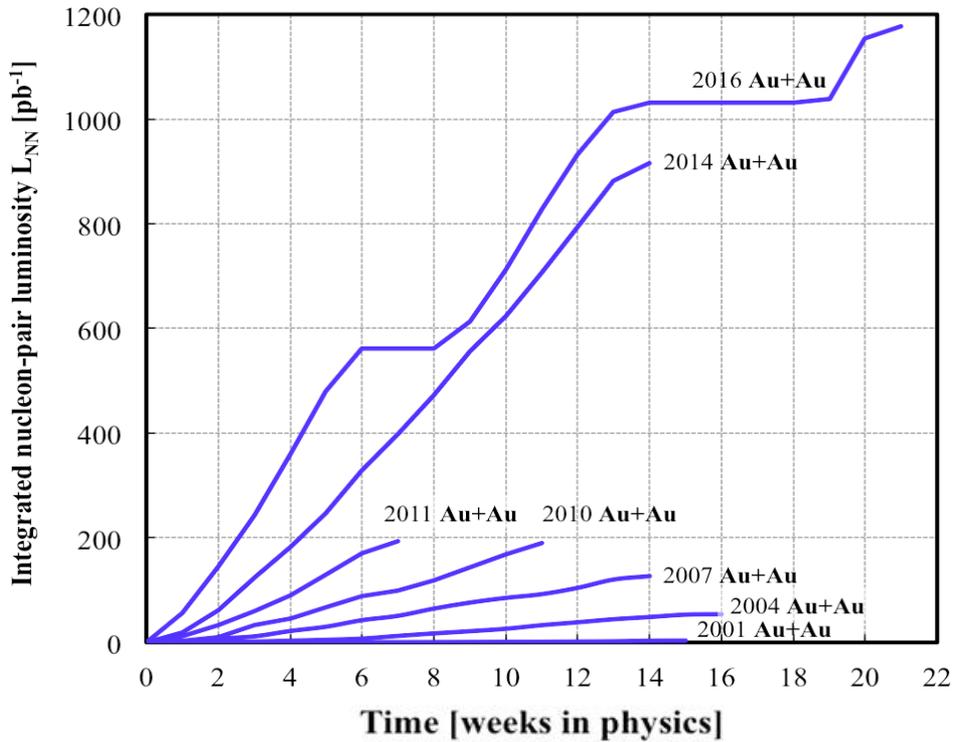


kickers



# Run-16 Au+Au at 100 GeV/nucleon

# Run-16 d+Au at 100, 31.2, 9.8, 19.5 GeV/nucleon



more collisions in 10 min than in the entire 5-week commissioning run in 2001

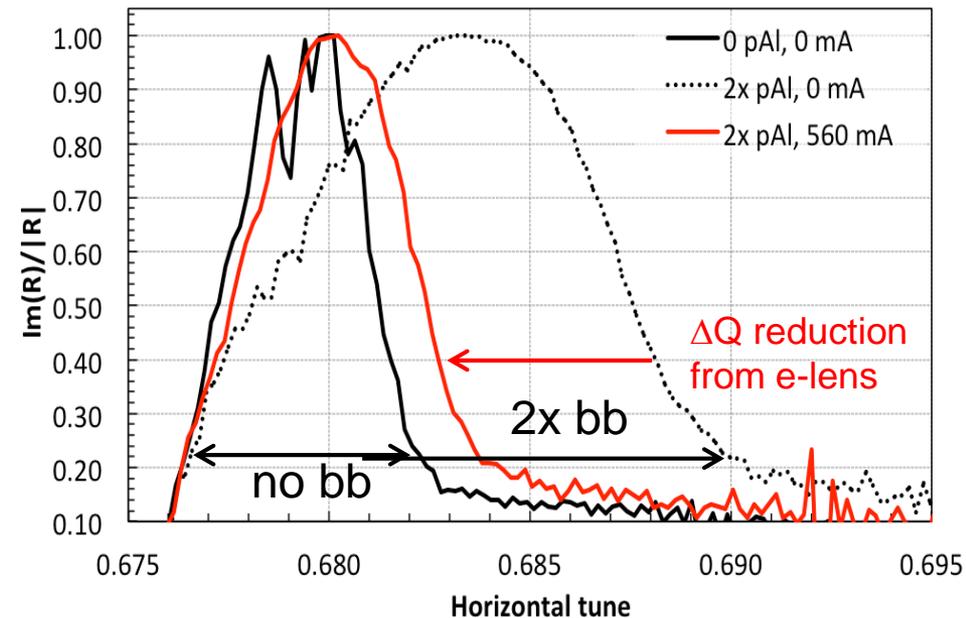
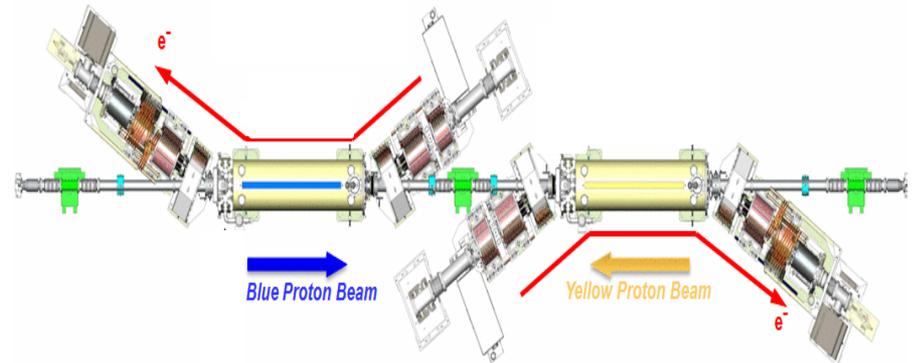
d+Au collision of ~1 week each at 4 different energies + 1 week return to Au+Au demonstrating unparalleled collider flexibility

# Accelerator Technology: electron lenses for head-on beam-beam compensation



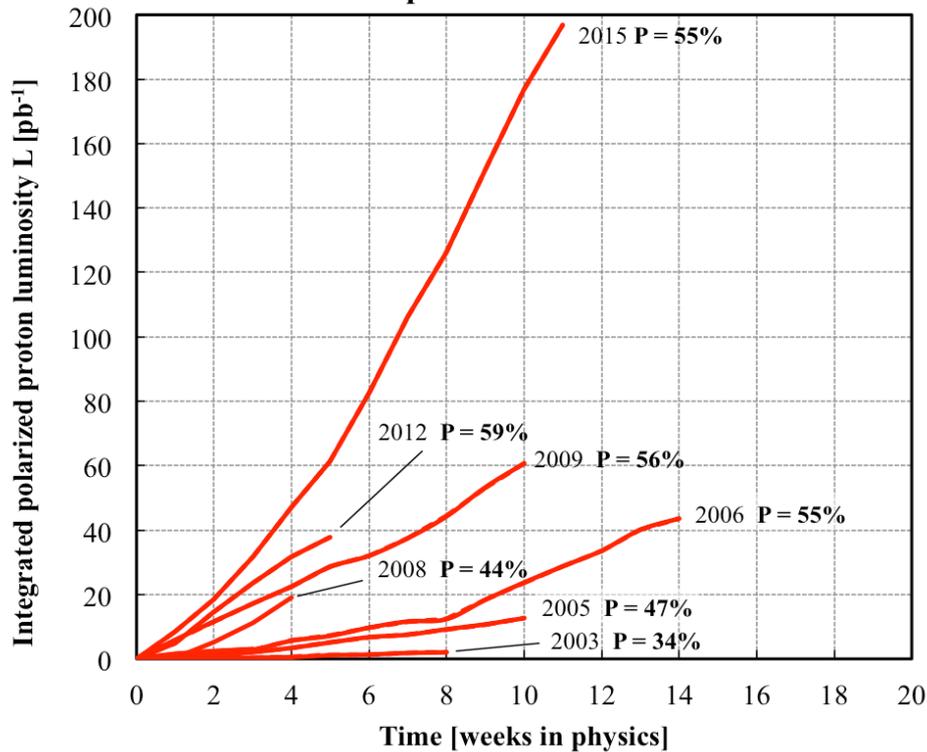
Polarized proton collision luminosity is limited by the defocusing forces of one beam on the other during collisions ("beam-beam interaction").

The electron lens provides an equal and opposite focusing force to "undo" the effect of the primary beam-beam interaction.

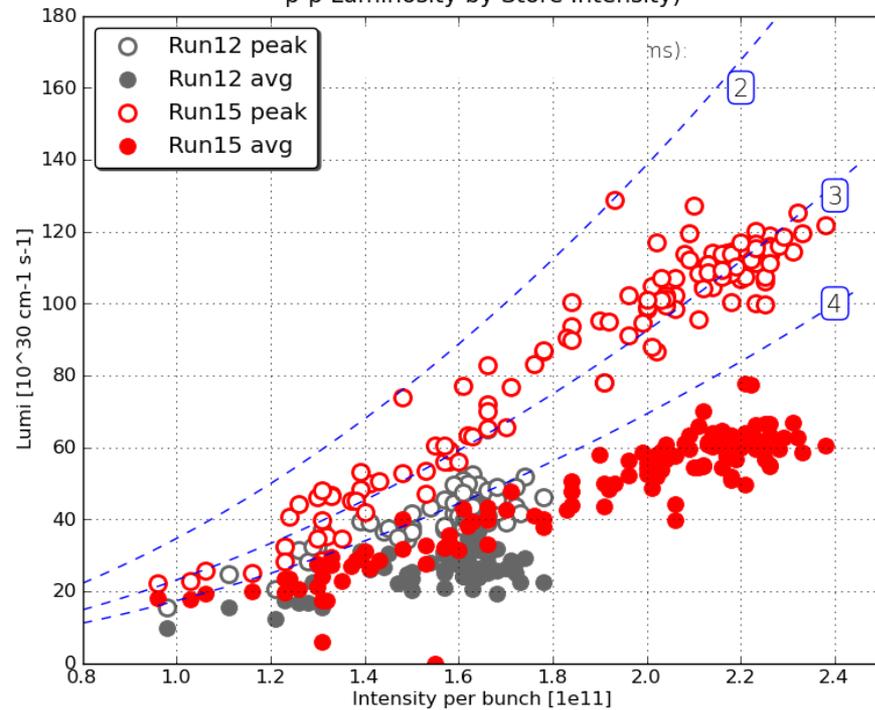


# Run-15 100 GeV p+p with electron lenses

### Polarized proton runs $\sqrt{s} = 200$ GeV



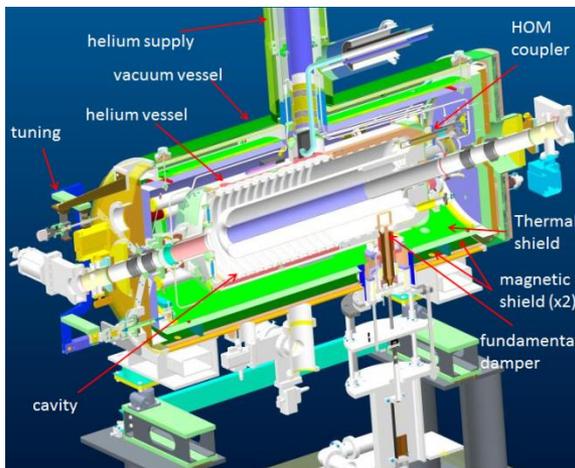
### p-p Luminosity by Store Intensity)



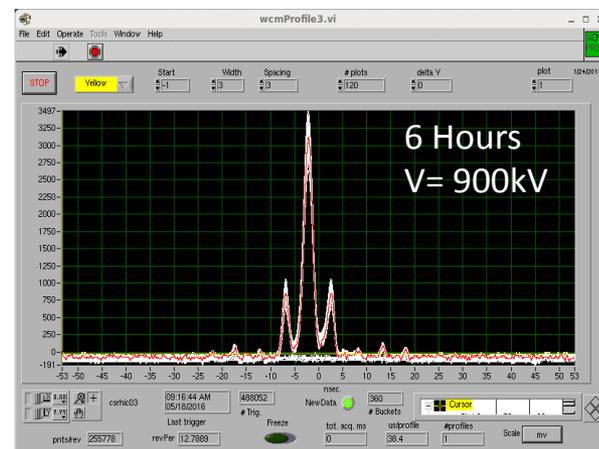
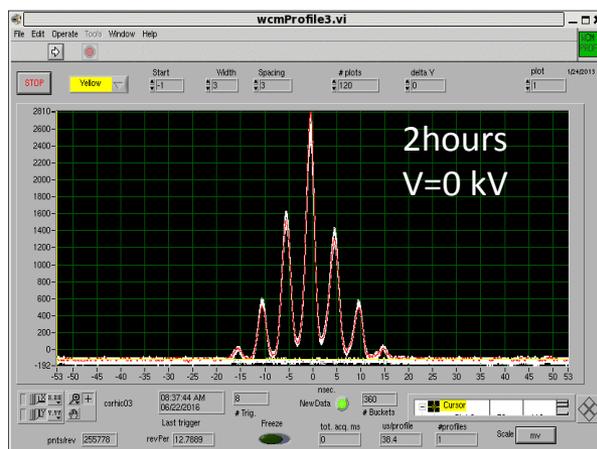
Run-15 integrated luminosity at  $\sqrt{s} = 200$  GeV exceeds sum of all previous runs

# Accelerator Technology: 56 MHz superconducting RF cavity

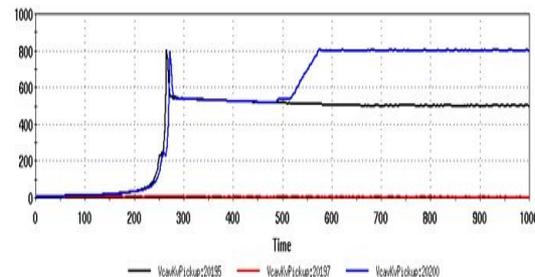
Run-16: Au-Au 100 GeV



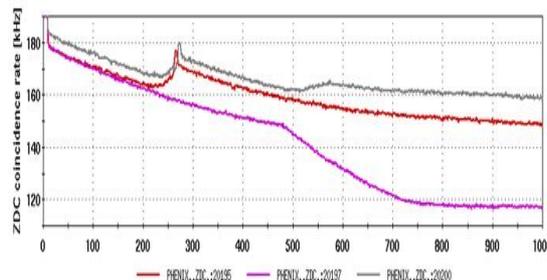
Designed by BNL, built by NioWave



56 MHz cavity  
voltage (kV)

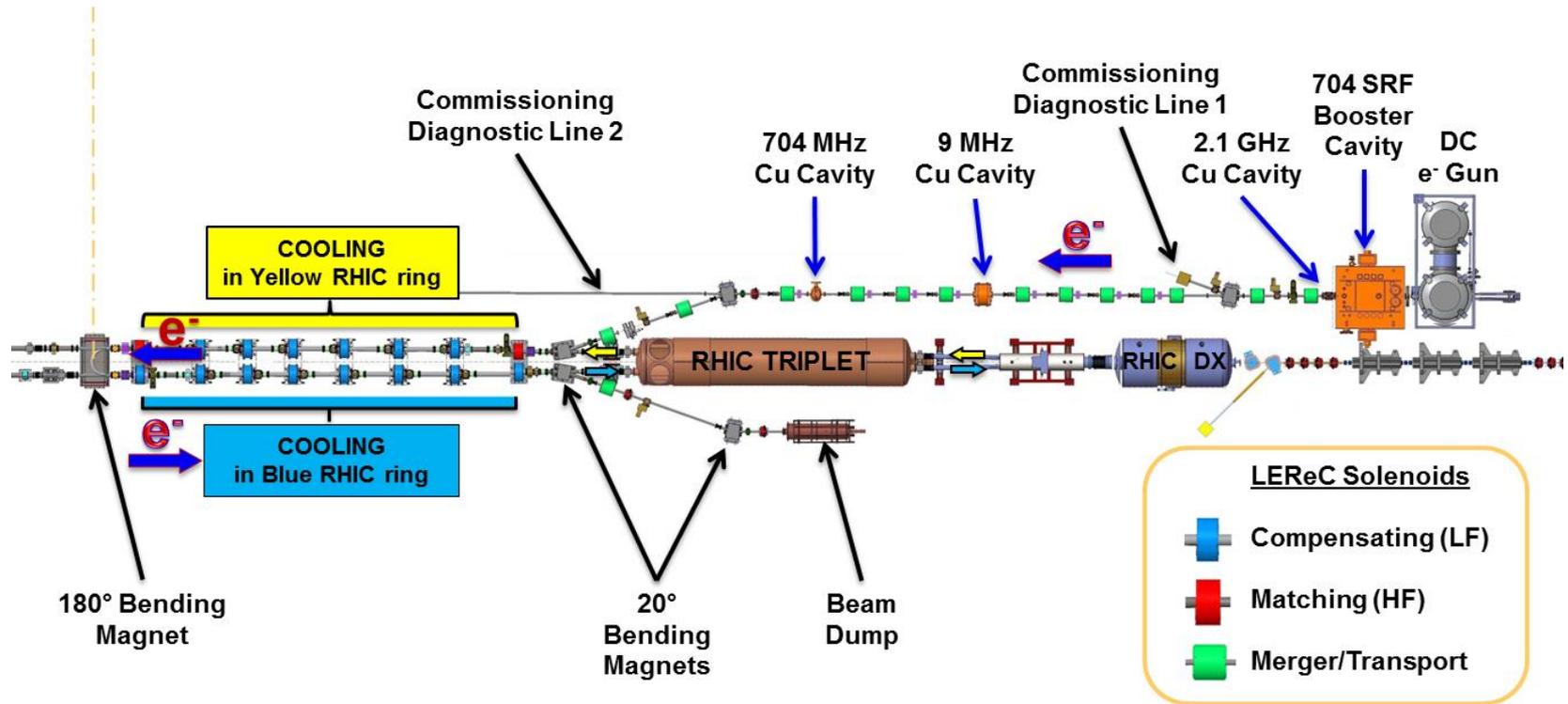


PHENIX ZDC



(15-20)% increase  
in PHENIX narrow  
vertex luminosity

# Accelerator Technology: Low Energy RHIC electron Cooling



Energies  $E$  : 1.6, 2.0 (2.65) MeV

Avg. current  $I_{\text{avg}}$  : 27 mA

Momentum  $dp/p$  :  $5 \times 10^{-4}$

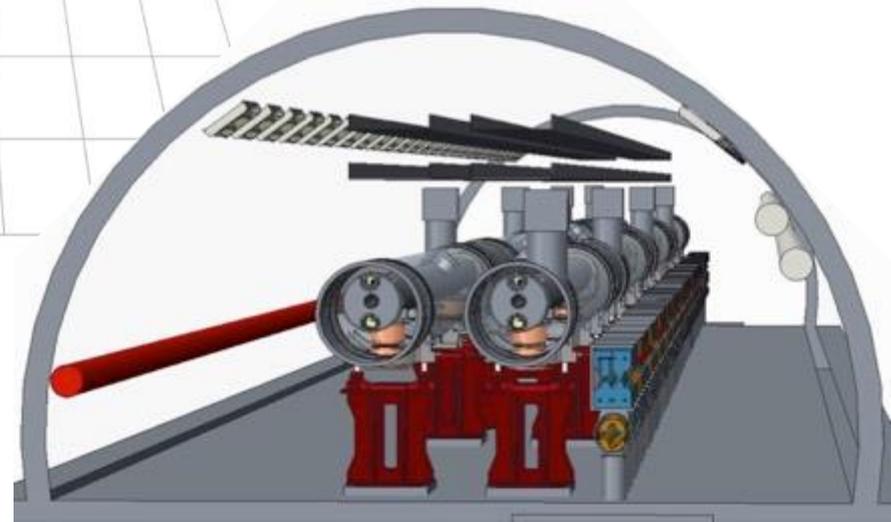
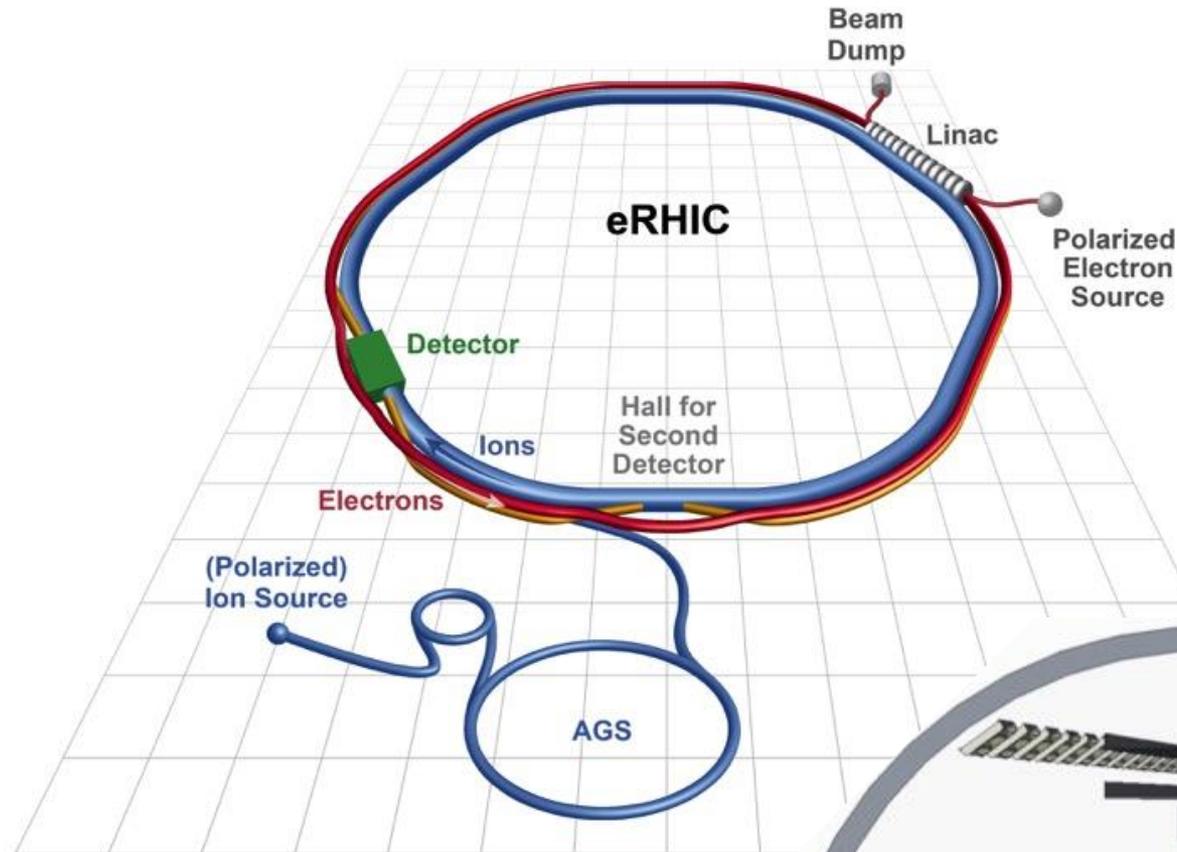
Luminosity gain : 4×

**1<sup>st</sup> bunched beam electron cooler**  
planned operation in 2019/2020

- Overview of facility
- Major new accelerator technologies
- **R&D programs**
  - eRHIC
    - High-current, CW, polarized electron gun
    - Superconducting rf
  - C-Beta
    - Coherent electron cooling
- NP SBIR/STTR synergies and opportunities
- Summary

# R&D: eRHIC (ultimate design)

Highly advanced and energy efficient accelerator



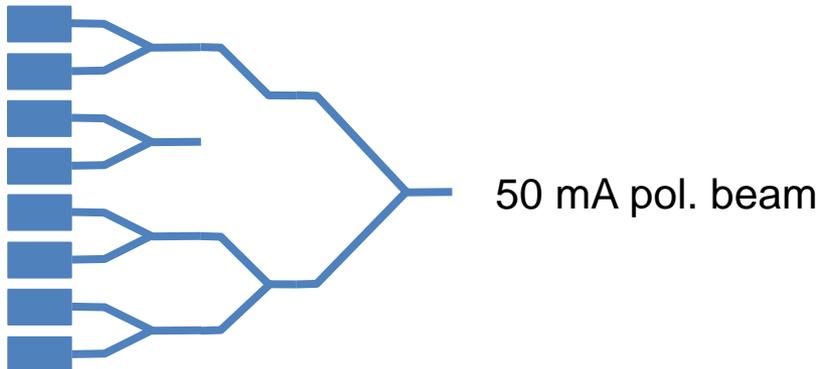
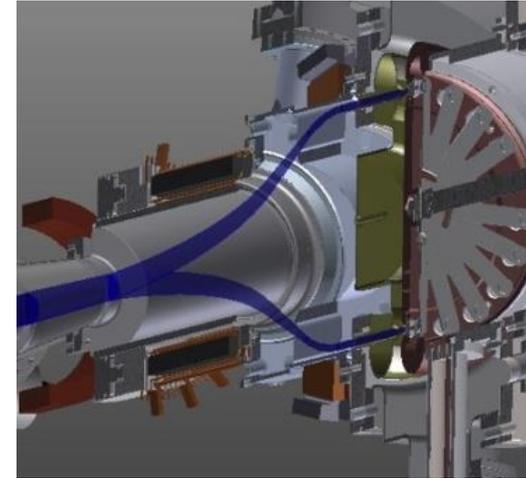
- Peak luminosity:  $2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- ERL and permanent magnet arcs greatly reduce electric power consumption to about 15 MW!

# Initial eRHIC design

- Minimize cost and technical risk:
  - The initial configuration of eRHIC will have a center-of-mass energy reach (18 GeV electrons on 275 GeV protons or 140 GeV CM energy) and detector acceptance to cover the whole EIC science case.
  - The initial luminosity will be  $10^{32-33} \text{ cm}^{-2} \text{ s}^{-1}$  and will later be increased through incremental upgrades, as was done for RHIC and other colliders.
- Two designs are being developed:
  - **Low risk ERL-Ring:** Expected to have lower cost, especially if cost reduction R&D is successful
  - **Low risk Ring-Ring:** Based on mainly existing technology. Cost is expected to be higher than the ERL-Ring design.
- Both designs can be upgraded to the ultimate eRHIC ERL-Ring design for modest cost.
  - A CEBAF-like recirculating linac used as full energy injector for the Ring-Ring design can easily be converted to an ERL.

# R&D: High-current CW polarized electron gun

- Gatling gun principle: multiple guns/cathodes with same charge lifetime
  - Requires fast switching between guns/cathodes
- Gatling Gun test-stand at SBU:
  - Tests with beam from two cathodes started
- Low risk backup to single high current gun: Fast switching between eight 6.25 mA guns



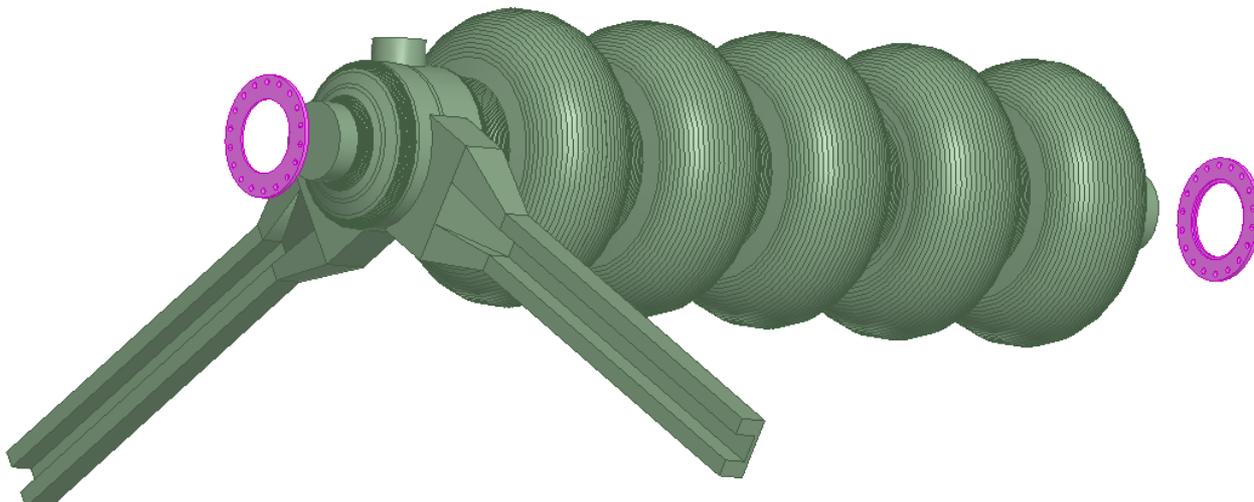
8 separate  
6.25 mA guns



Gatling Gun @ SBU

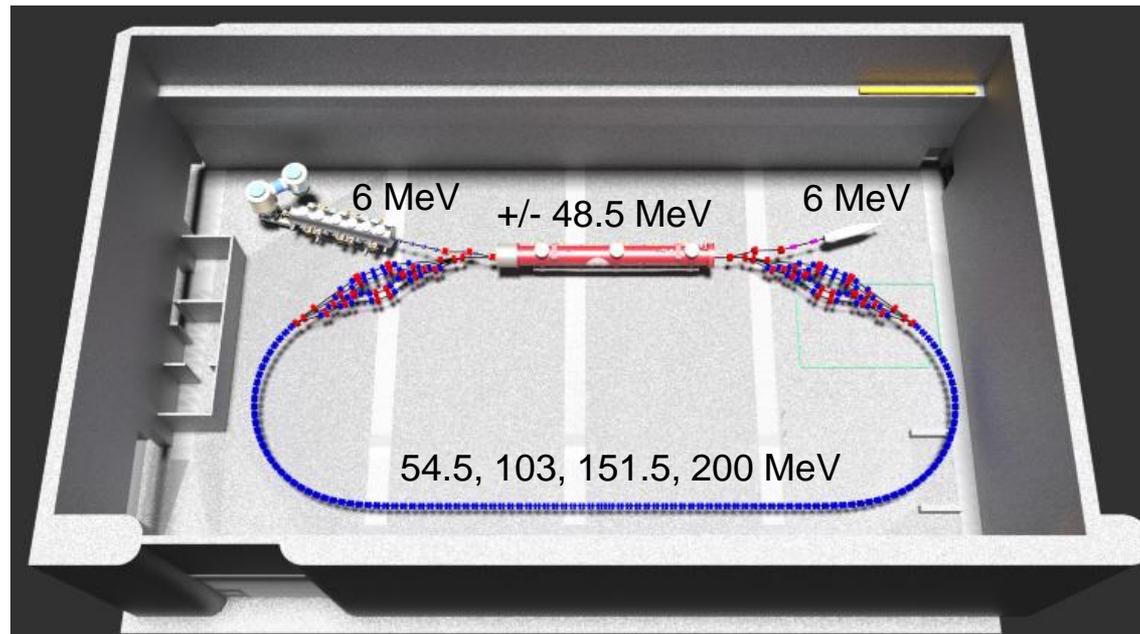
# R&D: 650 MHz Linac cavity with HOM damping

- 650 MHz frequency of main linac accelerating cavities is benefitting from the SRF development program for the Fermilab PIP II project.
- 6 passes each of accelerating and decelerating 50 mA beam results in 600 mA total beam current in the Linac.
- This is similar to circulating beam in storage rings at KEKB and Cornell with  $\sim 10$  kW of HOM power absorbed using Ferrite or SiC beam-line dampers
- Develop waveguide dampers for more compact construction.

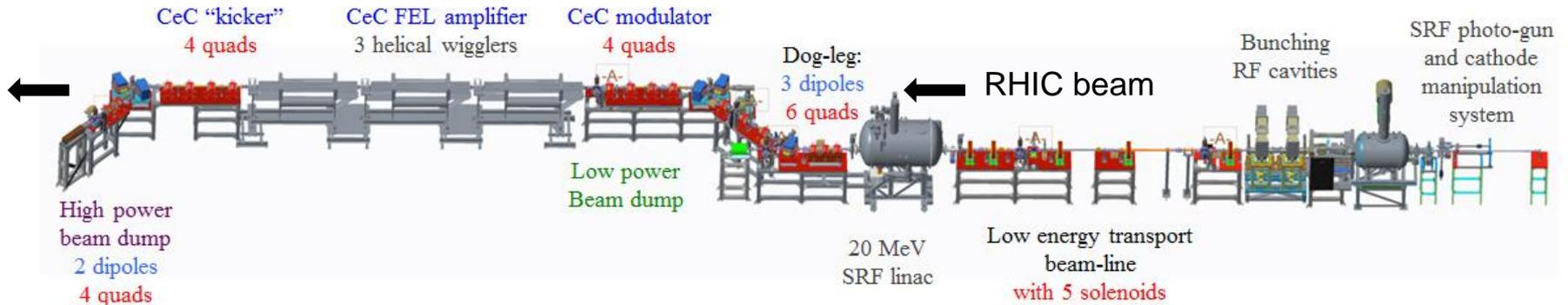


# R&D: C-Beta (Cornell/BNL ERL Test Accelerator)– an eRHIC prototype

- Uses existing low-emittance, high-current injector and CW SRF Linac
- ERL with single four-pass recirculation arc with x4 momentum range
- Permanent magnets used for recirculation arc
- Adiabatic transitions from curved to straight sections
- Test of spreader/combiner beam lines
- High current can be used to test HOM damping by replacing Linac with eRHIC Linac cryostat



# R&D: Coherent electron Cooling demonstration experiment



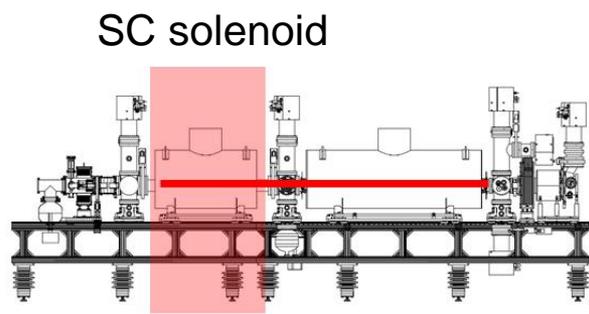
- DOE NP R&D project aiming for demonstration of CeC technique
- First beam from SRF gun (3 nC/bunch, 1.7 MeV) on 6/24/2016, world record
- 20 MeV SRF linac and helical wigglers for FEL amplifier are installed, 8 MeV beam transported to beam dump
- Proof-of-principle demonstration with 40 GeV/n Au beam scheduled during RHIC Run 17
- Micro-bunching test planned with same set-up



- Overview of facility
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# Particle beam sources (including polarized beams)

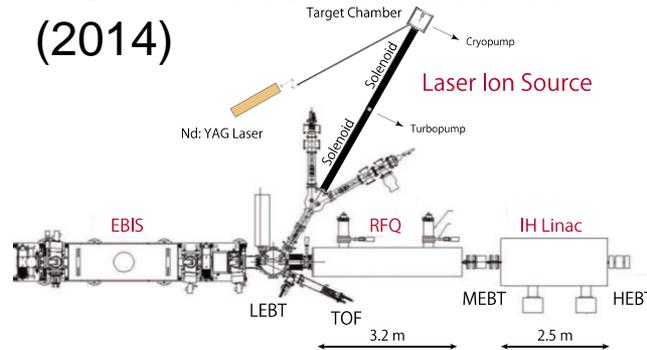
EBIS trap length extension



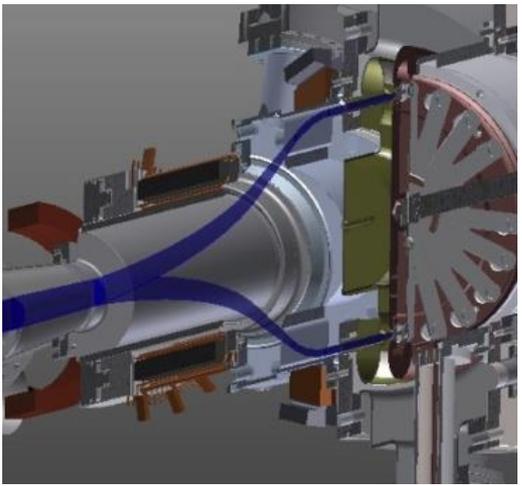
Optically Pumped Polarized H- Source (2013)



LION – Laser Ion Source (2014)



Gatling gun for eRHIC



All aspects pertaining to beam brightness including

- photocathode development
- laser development
- gun cavity development
- technologies for XHV
- chamber coatings
- simulations
- diagnostics

Examples: AES 704 MHz cavity and gun, 1.3 GHz SRF gun, preparation chambers and polarized SRF gun load-lock, Niowave 112 MHz SRF gun

# Superconducting RF cavity development

All aspects including

- Gun cavity developments
- Gun load-lock systems
- Crab cavity developments
- HOM damping designs
- RF power coupler designs
- Cavity materials and material processing methods
- Cavity cleaning techniques
- Cavity coating techniques and associated diagnostics
- Peripheral components (e.g. windows, seals, ceramics)
- Rf power sources

Example: Niowave development of SRF crab cavities

# High current ERL technology

- RF power and control
- High time resolution beam position monitors
- Nondestructive beam profile monitors

# FFAG accelerators including compact small-gap chambers with permanent magnets

All aspects pertaining to magnet developments including design, simulation and prototyping. Potential application in proton Gantries for cancer therapy.

# Software and data management

Simulation software of beam cooling, photocathodes, SRF cavities.

Examples: Tech-X VORPAL based simulations of electron cooling, coherent electron cooling, 3-D multipacting code

# Summary: The RHIC facility and the SBIR/STTR program

- The RHIC complex serves a wide user base (RHIC experiments, isotope production, industrial and space applications) and is continually upgraded
- eRHIC R&D is necessary for cost reduction and performance upgrade, current focus is on the electron source, cavity development with full HOM damping, the CeC proof-of-principle test at RHIC, and the high intensity ERL with multi-pass FFAG (C-Beta)
- The SBIR/STTR program serves an important role in accelerator upgrades and the R&D program
- Small business companies are encouraged to get in touch with the speaker or others at C-AD to find a match between the upgrade and R&D needs of the RHIC complex and their capabilities and ideas

### The RHIC facility and the SBIR/STTR program

- Overview of facility
- Major new accelerator technologies
- R&D programs
- NP SBIR/STTR synergies and opportunities

Mission: Enhance SBIR/STTR program leading to high-impact research  
 2014-2016

### Overview of facility

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### Overview of the BNL hadron complex

Brookhaven National Laboratory (BNL)  
 National Science Foundation (NSF)  
 NASA Space Radiation Laboratory (NSRL)  
 Linac-based Neutron Spallation Neutron Source and Production Program  
 Tandem Van de Graaff Accelerator

### BNL LINAC Isotope Producer (BLIP)

Medical isotope research and production program

- Preparation of beam components (accelerator technologies) to contribute to the nuclear medicine community
- Partners: research to develop new radioisotopes for nuclear medicine investigations
- Operates generally parallel to RHIC
- Higher isotope yields afforded by Linac intensity profile upgrade (2016) which increased average current increase from 125 to 140  $\mu\text{A}$
- BLIP reactor upgrade (2016) to reduce peak power of beam

### NSRL

The mission and program at NSRL and its associated facilities is to support the effort of the primary administration interaction.

### BNL Tandem Van de Graaff Accelerator Facility

- A wide array of light-ion heavy ion and nuclear and nuclear astrophysics
- Produce most of the continuous-wave ion beams from a mechanical drive for the production of the ion beams
- Accurate delivery and low energy operation based on size compensation

Acceleration modes:  
 Single beam continuous-wave of intermediate energies  
 Continuous-wave of intermediate energies  
 Pulsed beam operation  
 Production of radioactive ion beams  
 High energy ion beams for nuclear astrophysics investigations  
 Enhancement of Superconducting properties through ion beams  
 Developmental investigations in ion beams and light scattering

### RHIC history and future

- RHIC commissioning era (2000 to 2002)
- RHIC Era (2003 to 2013)
- RHIC Era (2014 to 2016)
- RHIC Era (2017 to 2020)
- RHIC Future

plus ongoing R&D for future electron-ion collider, eRHIC

### RHIC - the champion of versatility

- Identify, improve and optimize the suite of particle (heavy ion) accelerators used to carry out the program of accelerator-based experiments
- Support the user-driven program through design, construction and operation of the particle accelerators and the experiments that support the research needs of the experiments
- Design and construct new accelerator facilities in support of the BNL and national missions

- Overview of facility
- Major new accelerator technologies
- stochastic cooling
- electron lenses
- superconducting cavities
- bunched beam electron cooling
- R&D programs
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### Accelerator Technology: 3D stochastic cooling for heavy ions

3-D stochastic cooling system for heavy ions

### Run-16 d+Au at 100 GeV/nucleon

Run-16 d+Au at 100, 31.2, 9.8, 19.5 GeV/nucleon

### Accelerator Technology: electron lenses for head-on beam-beam compensation

The electron lens provides an axial and azimuthal focusing force to "cool" the effect of the primary beam-beam interaction.

### Run-15 100 GeV p+p with electron lenses

Run-15 100 GeV p+p with electron lenses

### Accelerator Technology: 56 MHz superconducting RF cavity

Run-16-10 Au-Au 100 GeV

### Accelerator Technology: Low Energy RHIC electron Cooling

Run-16-10 Au-Au 100 GeV

- Overview of facility
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- eRHIC
- High-current, CW, polarized electron gun
- Superconducting rf
- C-Beta
- Coherent electron cooling
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### R&D: eRHIC (ultimate design)

Highly advanced and energy efficient accelerator

### Initial eRHIC design

- Minimize cost and technical risk
- Two designs are being developed
- Both designs can be upgraded to the ultimate eRHIC ERL Ring design for modest cost

### R&D: High-current CW polarized electron gun

High-current CW polarized electron gun

### R&D: 650 MHz Linac cavity with HOM damping

650 MHz Linac cavity with HOM damping

### R&D: C-Beta (Cornell/BNL ERL Test Accelerator)—an eRHIC prototype

C-Beta (Cornell/BNL ERL Test Accelerator)—an eRHIC prototype

### R&D: Coherent electron Cooling demonstration experiment

Coherent electron Cooling demonstration experiment

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### Particle beam sources (including polarized beams)

Particle beam sources (including polarized beams)

### Superconducting RF cavity development

All aspects including:

- Coupler development
- Gun lock systems
- Coupler lock systems
- RF power source design
- RF power source design
- Cable, insulator and thermal processing methods
- Cable cooling techniques
- Cable cooling techniques and associated diagnostics
- Performance components (e.g. windows, seals, ceramics)
- RF power source

Example: Nonlinear development of SRF cryo-cavities

### High current ERL technology

- RF power and control
- High time resolution beam monitors
- Non-destructive beam profile monitors

### FFAG accelerators including compact small-gap chambers with permanent magnets

An exciting possibility is hybrid accelerators including design, simulation and prototyping, suitable application in proton therapy for cancer therapy.

### Software and data management

Simulated software for beam cooling, simulation, SRF cavities, etc.

Examples: Top-X-VISOR, based simulations of electron cooling, coherent electron cooling, 3-D modelling tool

### Summary: The RHIC facility and the SBIR/STTR program

- The RHIC complex serves a wide user base (RHIC experiments, astroparticle production, space radiation studies) and is continually upgraded
- eRHIC R&D is necessary for cost reduction and performance upgrade current SRFs in the electron source, cavity development, with full HOM damping, the CAC production/operation, test at RHIC, and the high intensity ERL with multi-pass FFAG (C-Beta)
- The SBIR/STTR program is playing an important role in accelerator upgrades and the R&D program
- Small business companies are encouraged to get in touch with the support of BNL at C&C to find a host institution, the corporate and R&D needs of the RHIC complex and their capabilities and assets

User benefits take 35 minutes each, including presentation and Q&A. For these lists, please allow 5-10 minutes for Q&A. (~15-20 min each)

- Overview of facility (6)
- Major new accelerator technologies (6)
- R&D programs (6)
- NP SBIR/STTR synergies and opportunities (3)
- Summary (1)

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User facility talks: 35 minutes each, including presentation and Q/A.  
For these talks, please allow 8-10 minutes for Q&A. (~ 25 minute talk)

- Overview of facility (6)
- Major new accelerator technologies (6)
- R&D programs (6)
- NP SBIR/STTR synergies and opportunities (3)
- Summary (1)

For your presentation, the emphasis will be on Accelerator Technology, however please consider including SBIR activities BNL may have in other topics that are supported by NP.