Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Collider-Accelerator Department Programs

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Deputy ALD for Accelerators NPP, C-AD Chair

24 August 2023

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C-AD mission

… develop, improve and operate the suite of particle / heavy ion accelerators used to carry out the program of accelerator-based experiments at BNL;

… to 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;

… to design and construct new accelerator facilities in support of the BNL and national missions. Department supports an international user community of over 1,500 scientists.

… perform all these functions in an environmentally responsible and safe manner under a rigorous conduct of operations approach.

Collider-Accelerator Department facilities

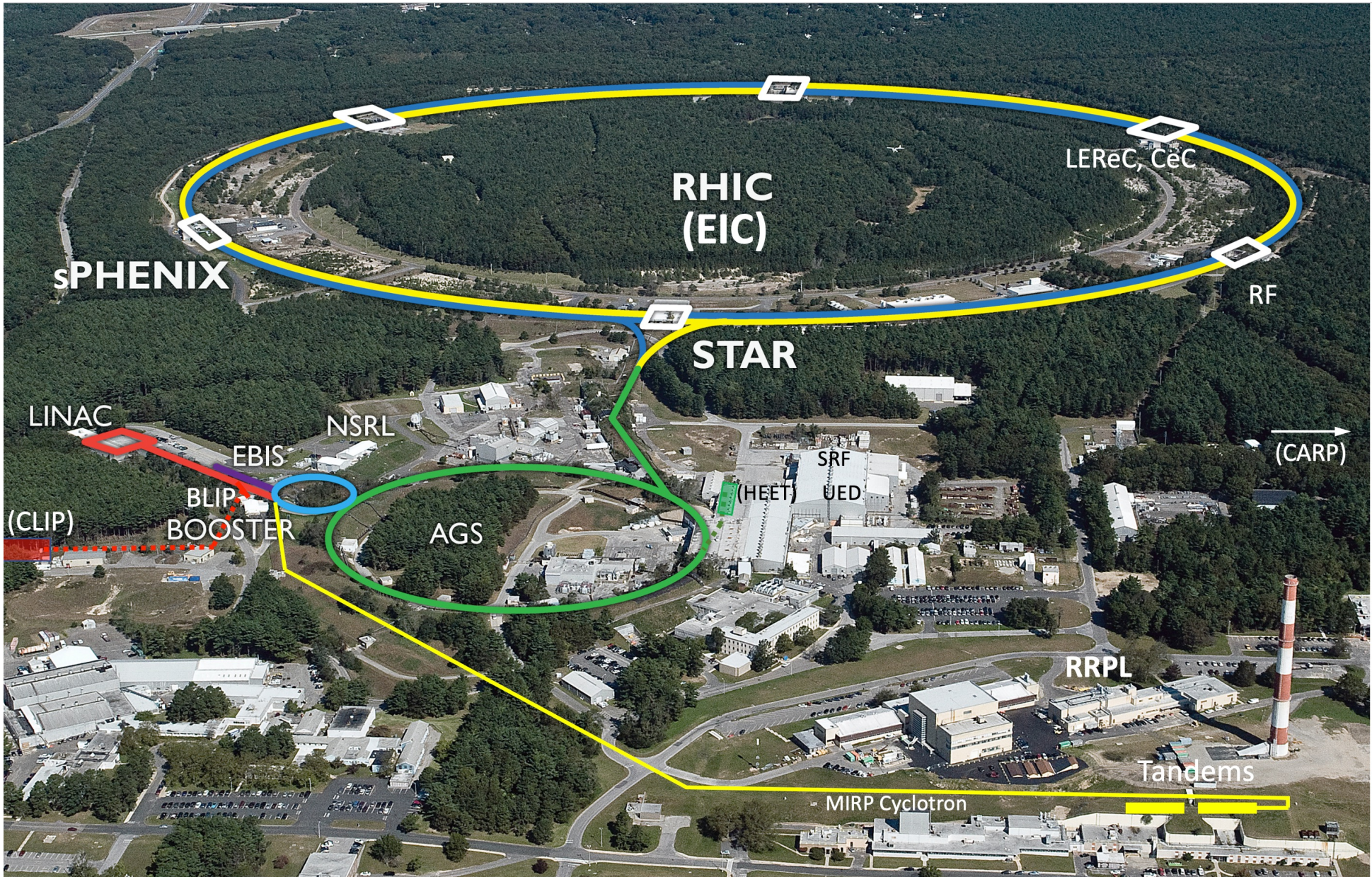
Uniquely flexible and only hadron collider in US for exploration of QCD phase diagram and proton spin

Injectors also used for application programs:

- Linac/BLIP for isotope production
- Booster/NSRL for space radiation studies
- Tandem for industrial/academic users

R&D for future facilities and application

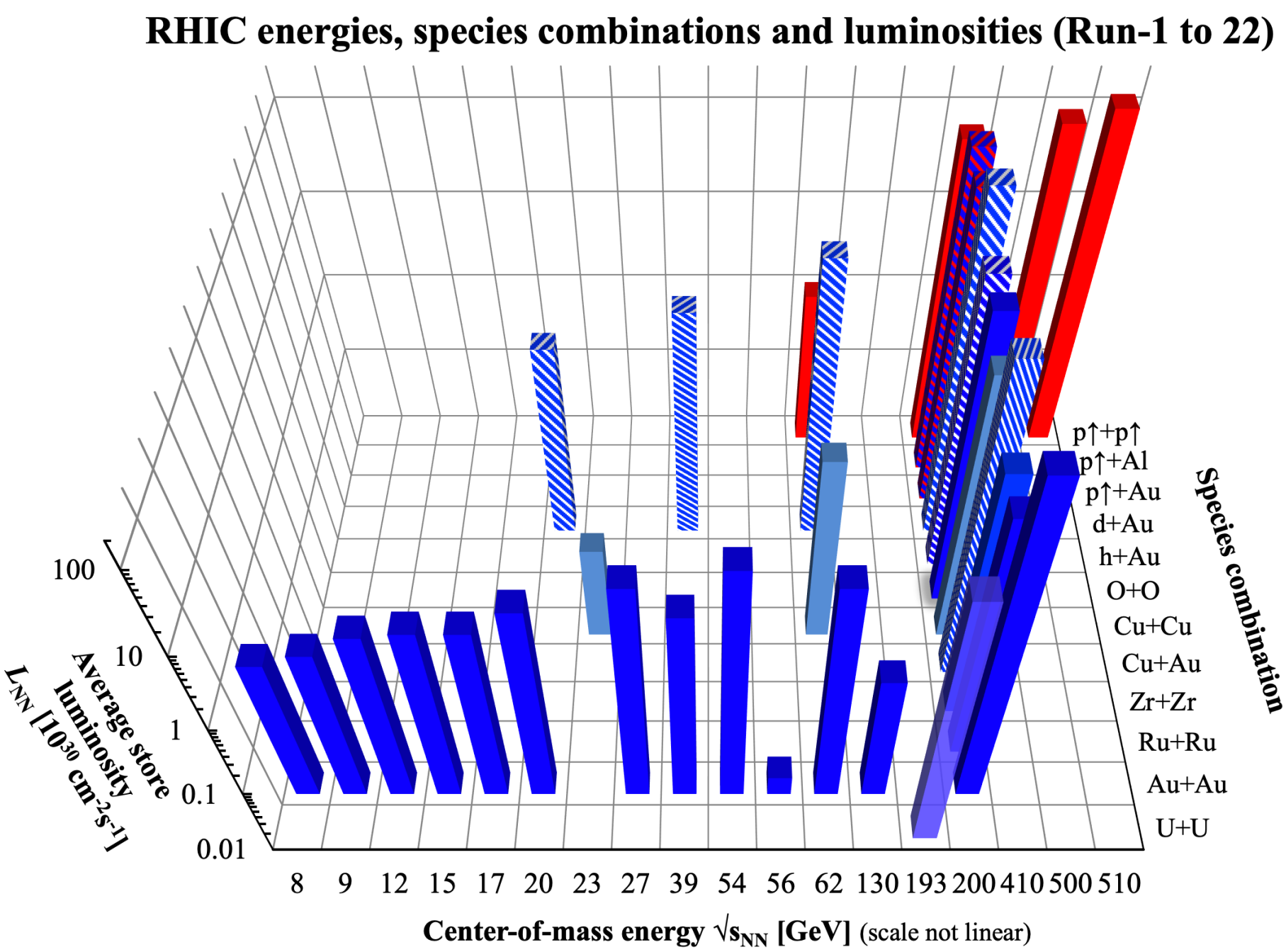
sources, cooling, pol. beams, …



C-AD programs

- RHIC – completing the science mission
- EIC project support – matrixed staff, scope
- Isotope production – MIRP => IP Department
- Space radiation studies – NSRL and Tandems
- Industrial applications – Tandems
- R&D

RHIC



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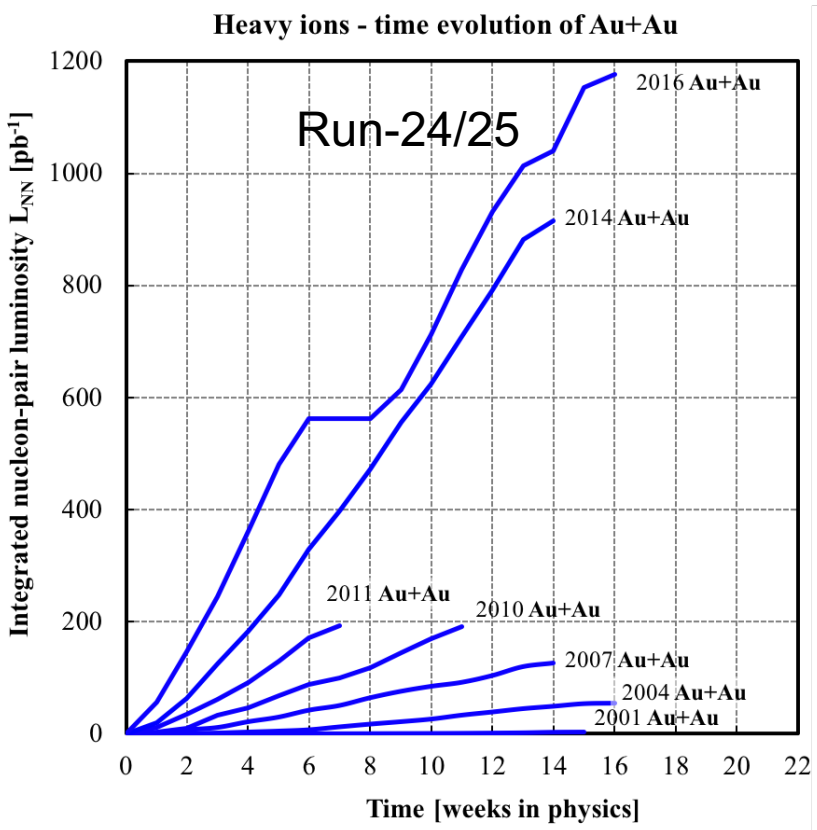
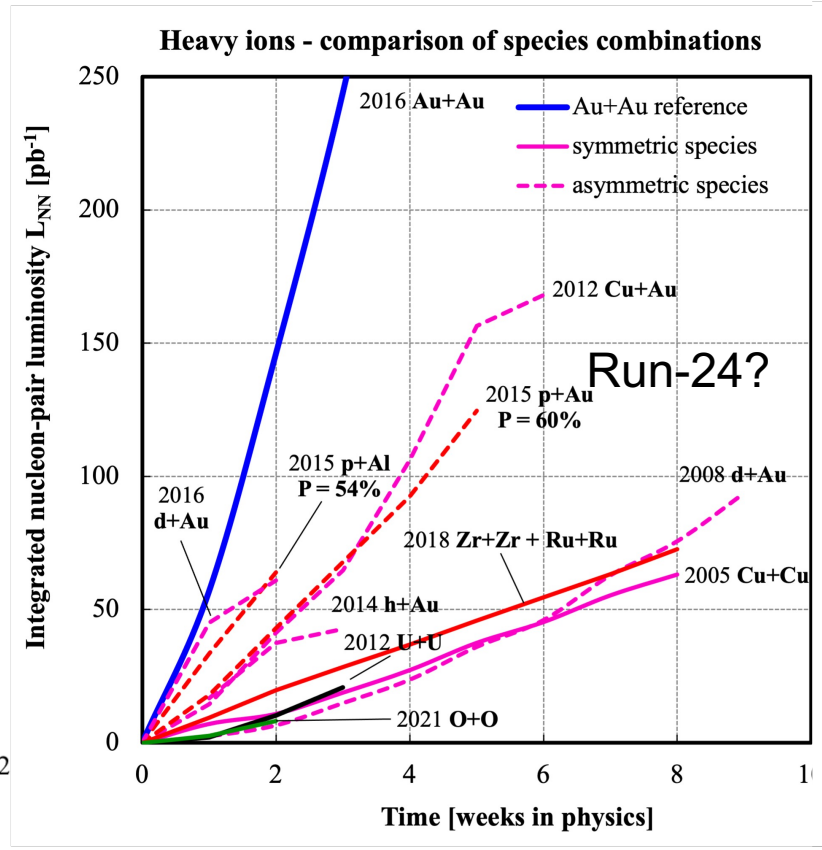
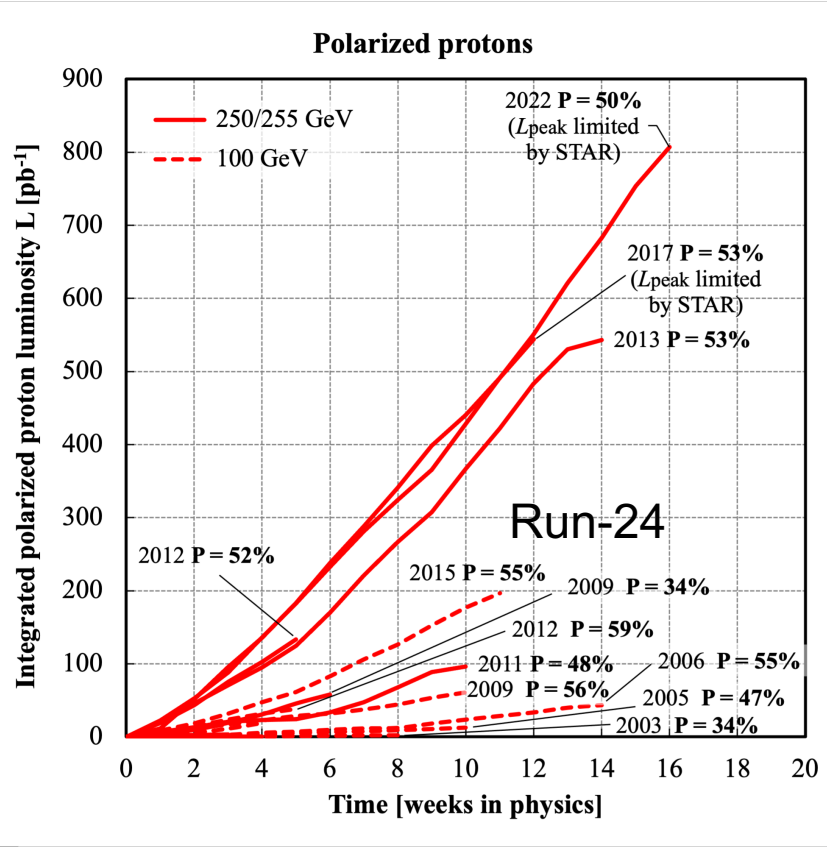
RHIC – completing the science mission with sPHENIX and STAR in FY2024 and FY2025







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C-AD and the Electron-Ion Collider

C-AD supports the EIC through

- Transfer of staff
- Matrixed staff
- EIC scope in C-AD
  - eg pre-cooler and ring cooler design
  - eg R&R (Removal and Repurposing)

EIC Design Overview

F. Willeke, EIC Technical Review, 23 Aug 2023

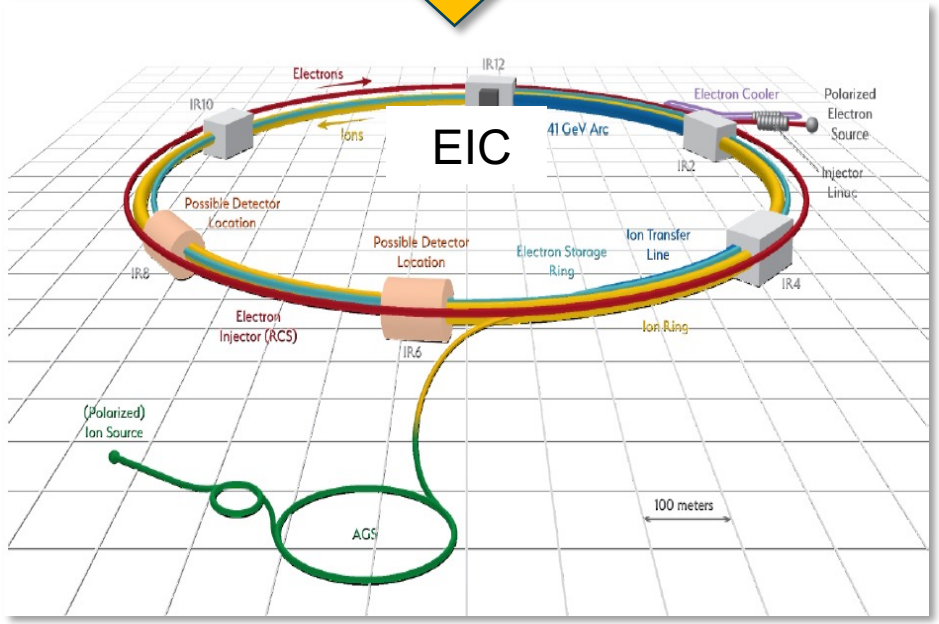
Design based on **existing RHIC Complex**
RHIC is well maintained, operating at its peak
RHIC accelerator chain will provide EIC Hadrons
EIC constructed in Collaboration with **Jefferson Lab**

Hadron storage Ring (RHIC Rings) 40-275 GeV
- Superconducting magnets (existing)
- 1160 bunches, 1A beam current (3x RHIC)
- bright vertical beam emittance 1.5 nm
- strong cooling (coherent electron cooling)

Electron Storage Ring 2.5–18 GeV
- large beam current, 2.5 A ➔ 9 MW S.R. power
- S.C. RF cavities
- Need to inject polarized bunches

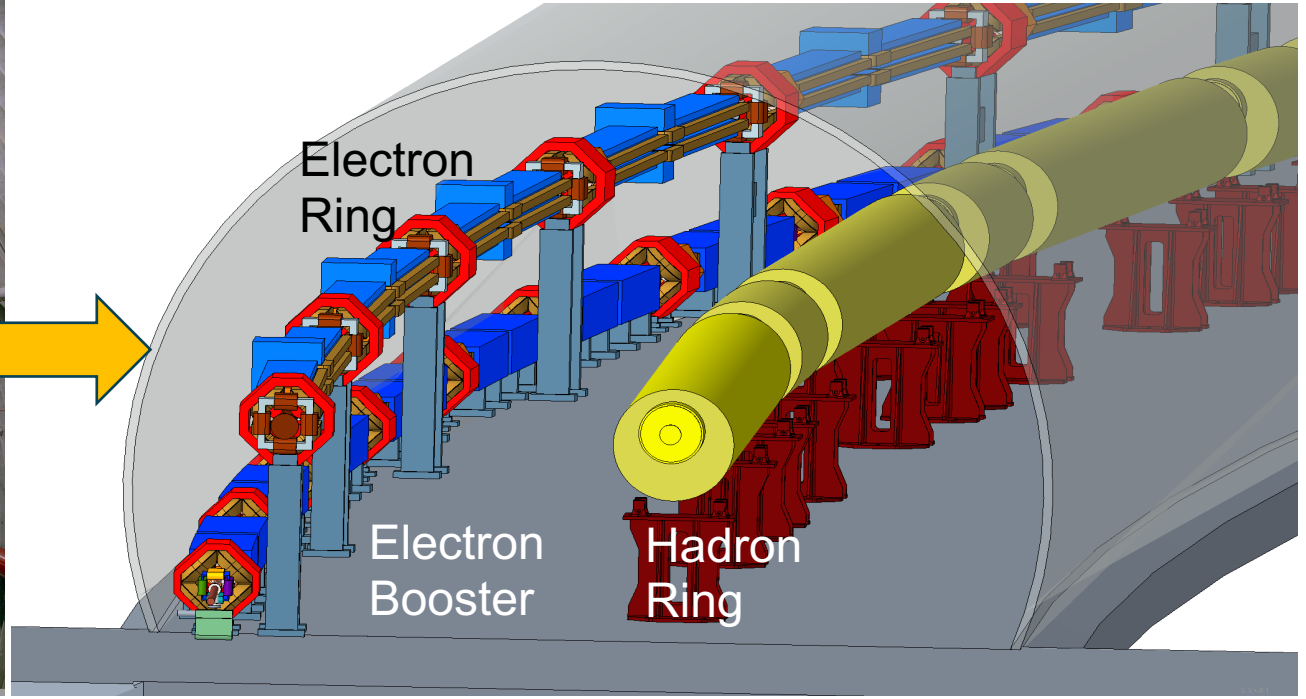
Electron rapid cycling synchrotron (0.4- 18) GeV
- 1-2 Hz
- Spin transparent due to high periodicity

High luminosity Interaction Region(s)
- Luminosity = $10^{34}cm^{-2}s^{-1}$
- Superconducting magnets
- 25 mrad crossing angle with crab cavities
- Spin Rotators (longitudinal spin)
- Forward hadron instrumentation



RHIC to EIC

TYPICAL ARC SECTION RENDERING



Isotope Production

- Medical Isotope Research and Production (MIRP) in C-A Department, becomes Isotope Research and Production Department (IP) on 1 October 2023
  - IP fastest growing program in DOE
  - target processing presently under accelerator order, will move to nuclear order (more stringent requirements)
- C-AD will continue to deliver beam, support IP, develop new capabilities for isotope production
  - Linac intensity upgrade
  - CLIP = Center for Linac Isotope Production
- more details on Isotope Research and Production in talk by Cathy Cutler

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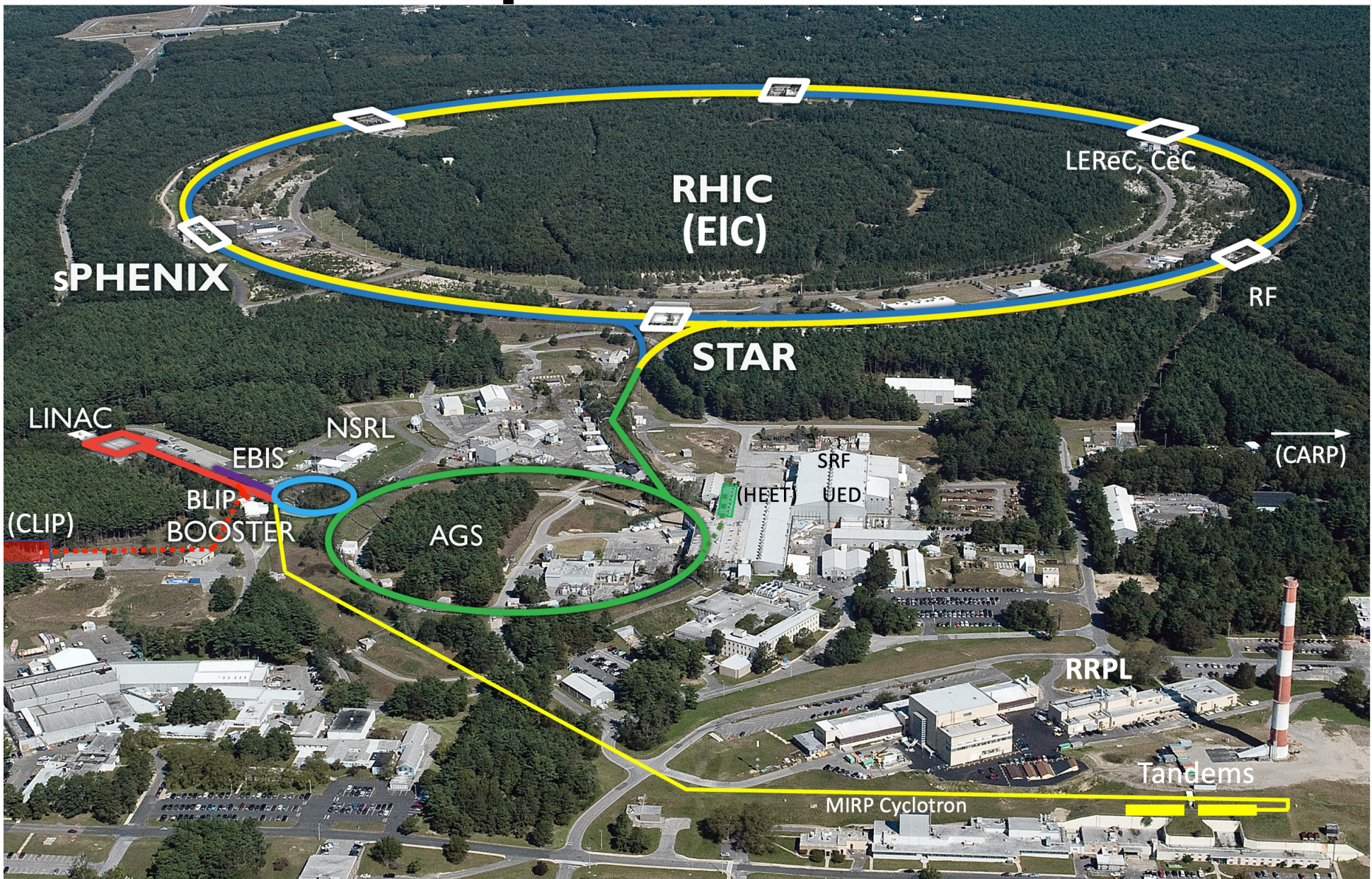
R&D for future facilities and application

sources, cooling, pol. beams, …



Space Radiation Studies

- NASA Space Radiation Laboratory (NSRL)
  - NASA research program is biology focused to support Human space flight
  - additional use for space radiation electronics testing
- Space radiation electronics testing at Tandems
- Proposal for dedicate space radiation test facility off AGS
  HEET = High-Energy Effects Test facility
  (high energy in electronics testing >100 MeV/nucleon)

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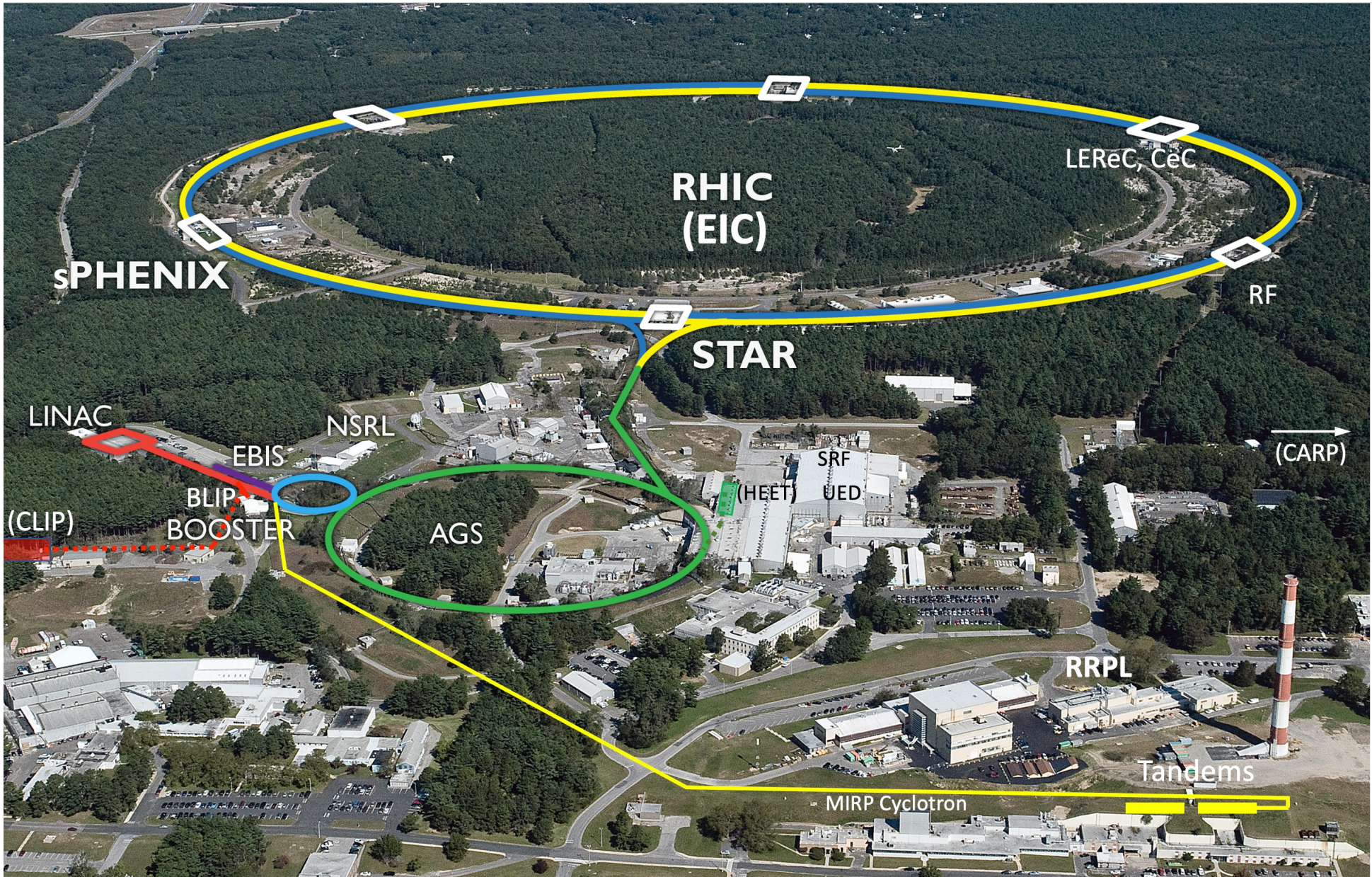
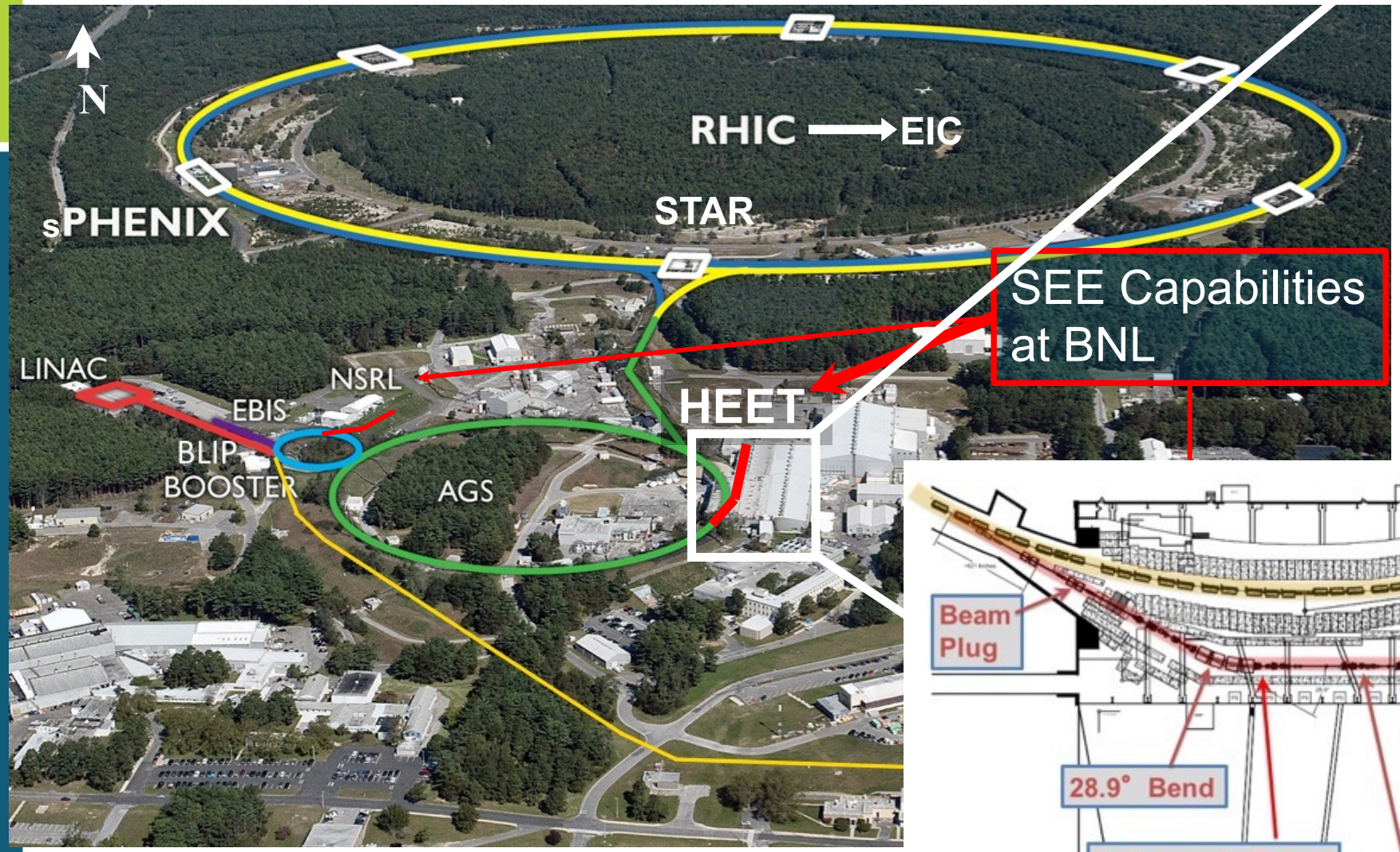
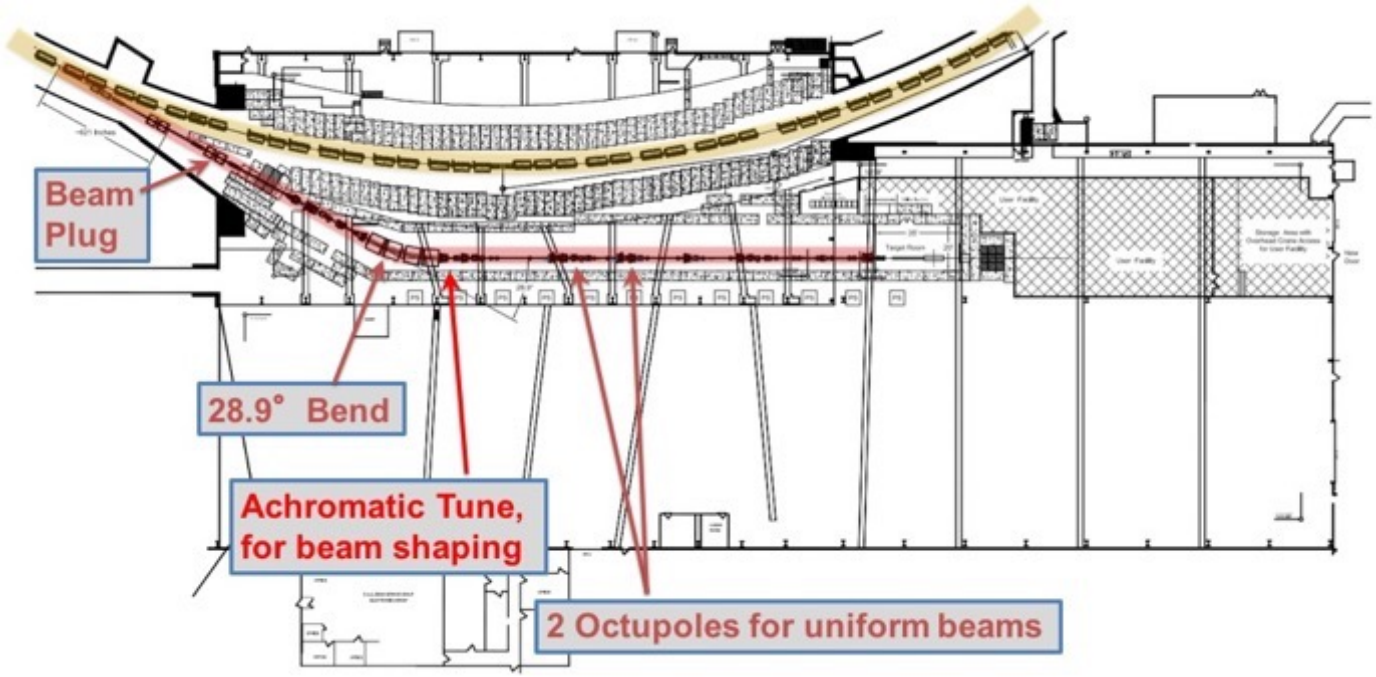


NASA Space Radiation Laboratory (NSRL)

- Started in 2003, simulates galactic radiation for human space flight
  - Heavy ion beams from AGS Booster
  - Electron Beam Ion Source (EBIS) provides all necessary ion beams
  - Laser ion source for EBIS allows for rapid species switching to simulate energy and species spectrum of deep space radiation field
- Additional uses of NSRL
  - **Radiation effects studies (rapidly growing demand for satellite electronics testing)**
  - Agreement with NASA in place for non-NASA users (“non-designated user facility”)

HEET proposal
Kevin Brown et al





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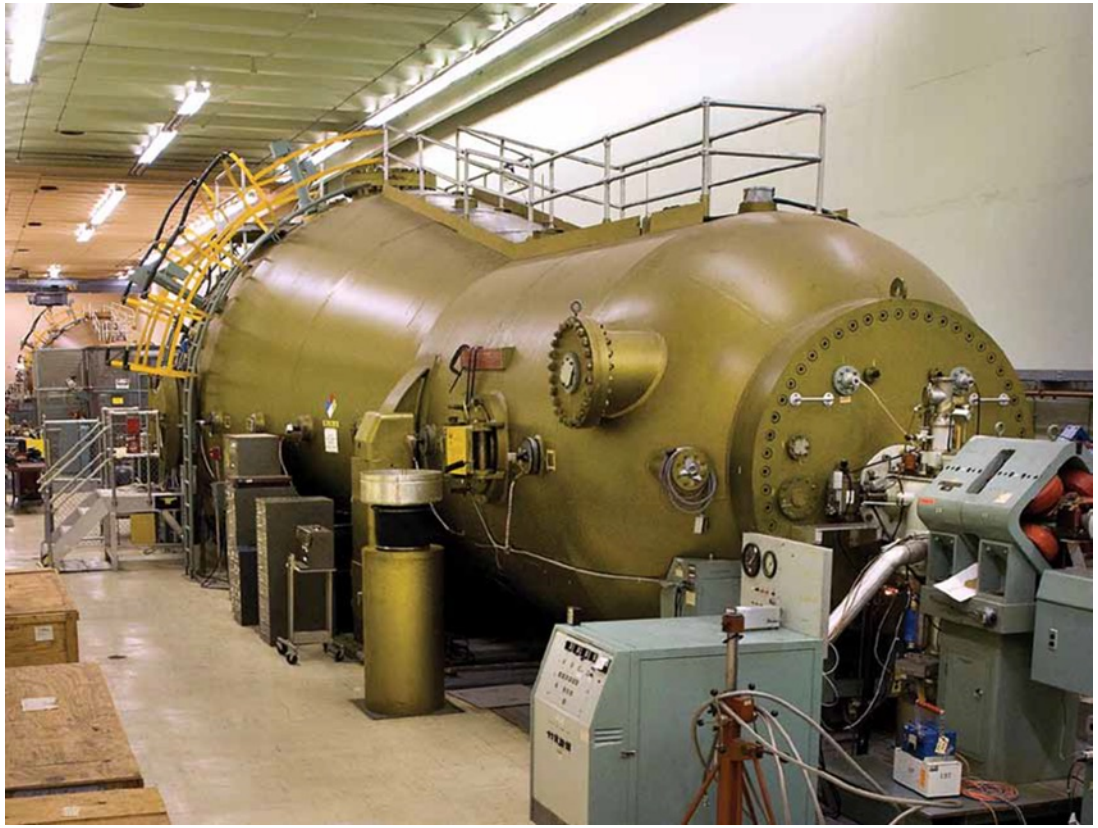
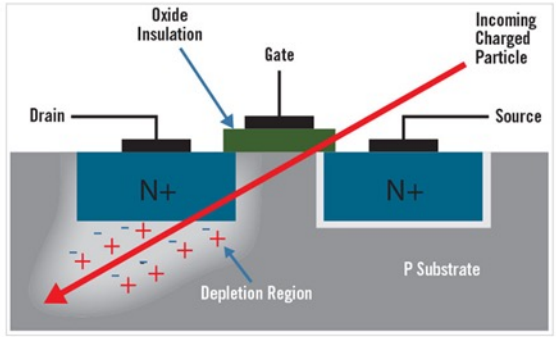
Industrial applications - Tandem Van de Graaff



- Completed 1970 for nuclear physics studies
- RHIC pre-injector until 2011
- Now ”non-designated user facility”
- 2 electrostatic accelerators
- 32 MV (=2x16 MV) voltage
- >40 ion species p to Au
- 80 feet long
- Diameter varies from 12’ - 18’
- 11,250 ft^3
- Insulating gas approx. 45% SF_6, 45% N_2, 5% CO_2, 5% O_2
- Nominal operating pressure 150 psig

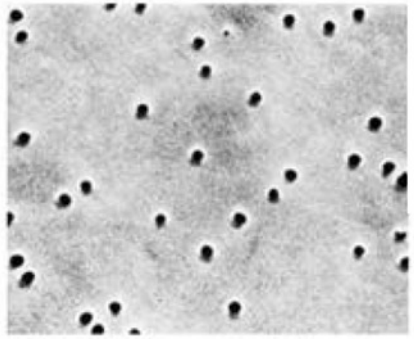
Applications of User Program

Space Radiation Effects



Single Event Upset. Image courtesy of COTS Journal Online.

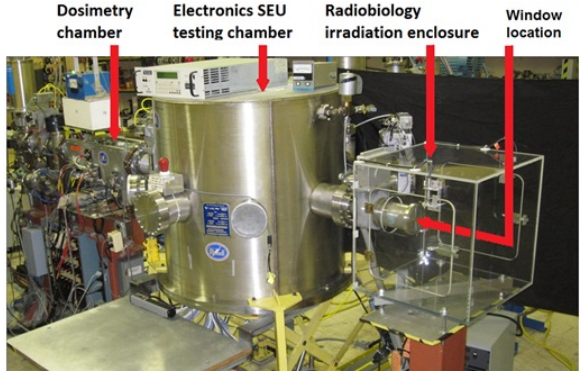
Micro-pore Filter Production



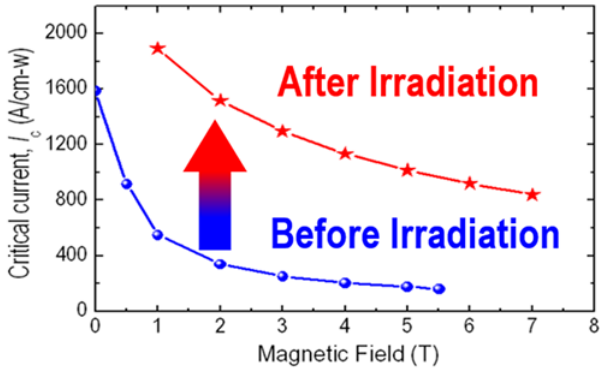
Typical Applications

- General filtration
- Removal of red blood cells from plasma
- Flow control of reagents through assay
- Precise filtration and prefiltration

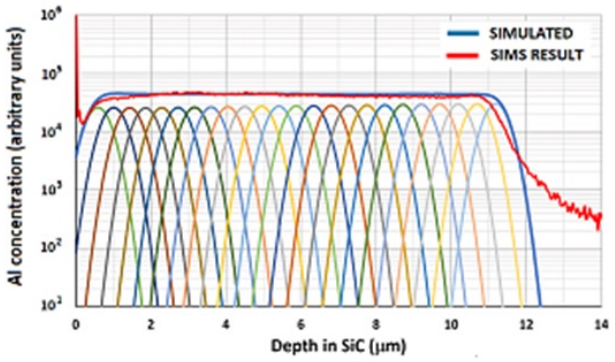
Radiation effects on cells



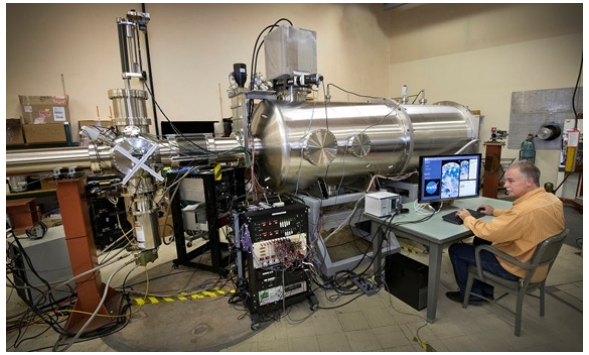
Superconductor enhancement



Silicon Carbide Implantation



Active Spacecraft Shielding



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Accelerator R&D at C-AD

Improvement of RHIC performance

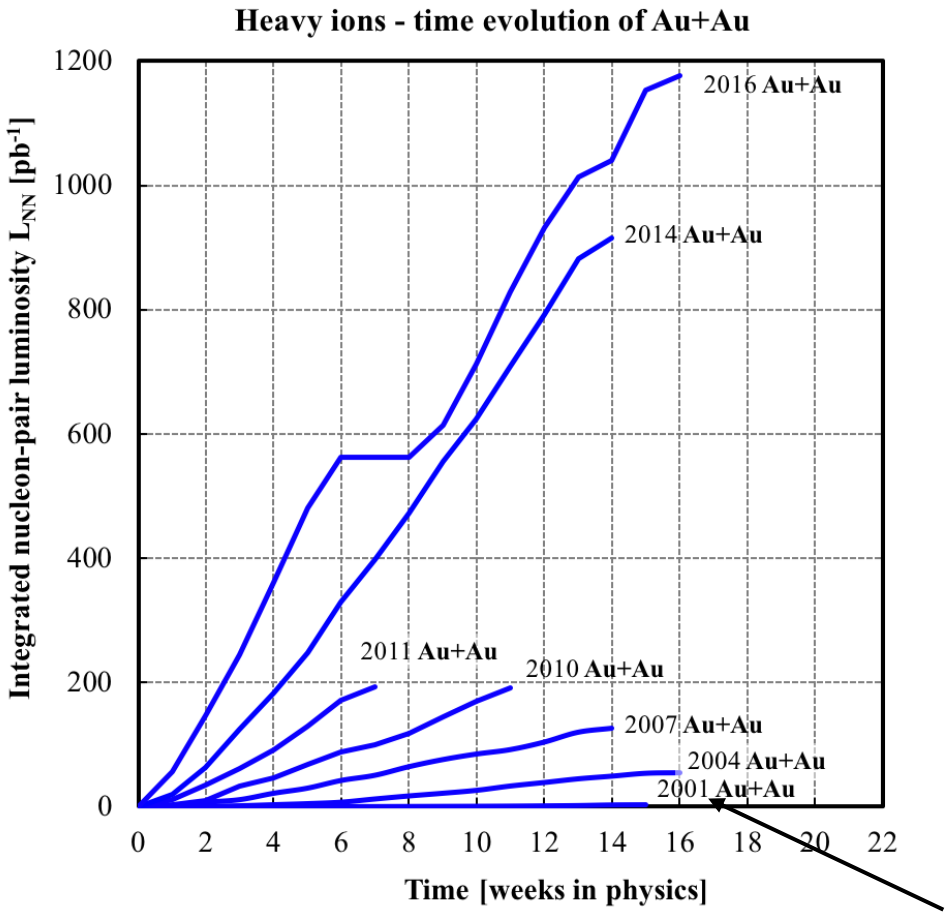
- Improved polarized proton acceleration in AGS and RHIC (~10% increase)
- Maximize useful luminosity for sPHENIX in small (±10 cm) vertex region (2023 – 2025)

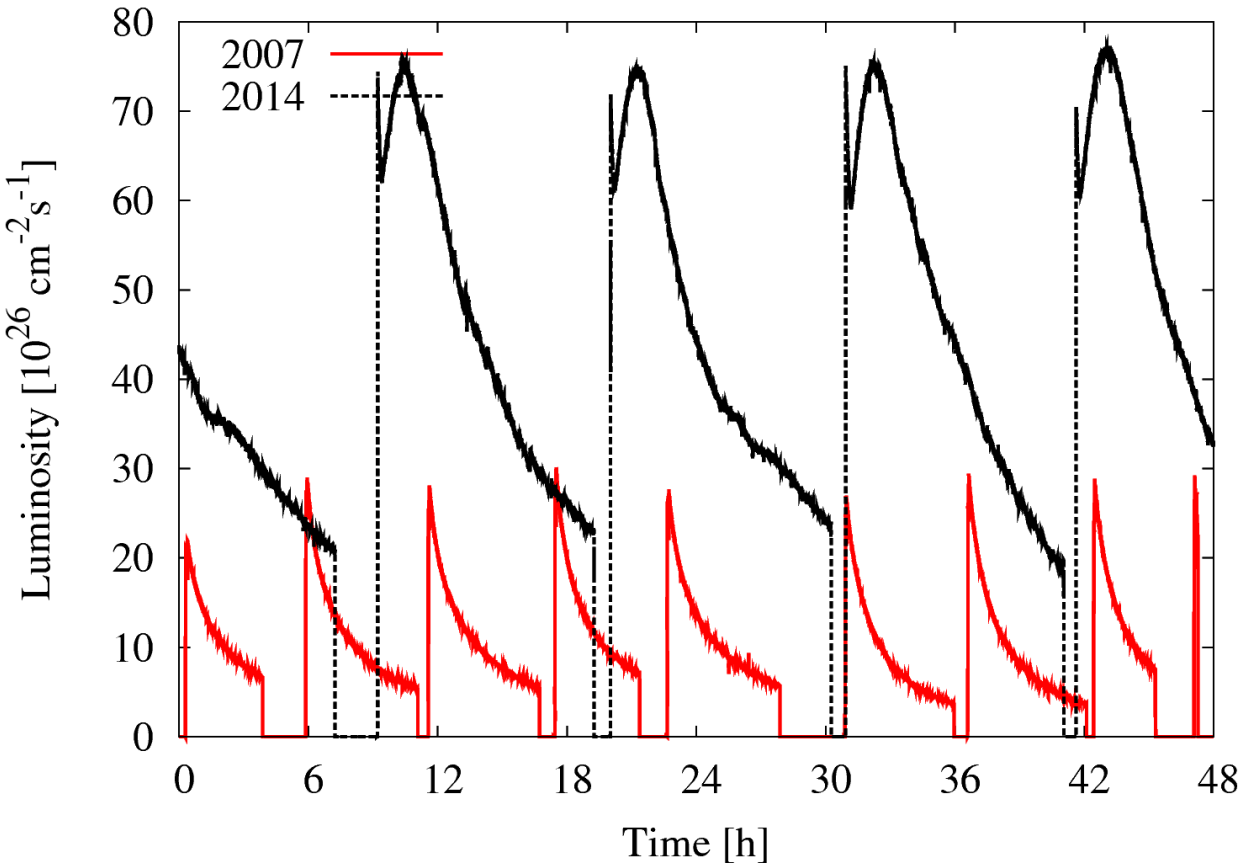
Transformational accelerator technologies in support of future NP facilities, including EIC

- Strong hadron cooling: CeC demonstration
- Polarized He-3 production, acceleration and polarimetry
- Development of high intensity high brightness electron source for strong hadron cooling
  - High intensity, high brightness SRF e gun development (NP Accelerator R&D FOA, contributing)
  - High intensity CW e gun, based on LEReC gun
- Photocathodes (ECA)
- Ion source developments
- Permanent magnet applications (LDRD)

Future possibilities:

- Polarized positron source for EIC and CEBAF
- High intensity ERL development (single pass CBETA) for strong hadron cooling
- FFA applications in CEBAF energy upgrade



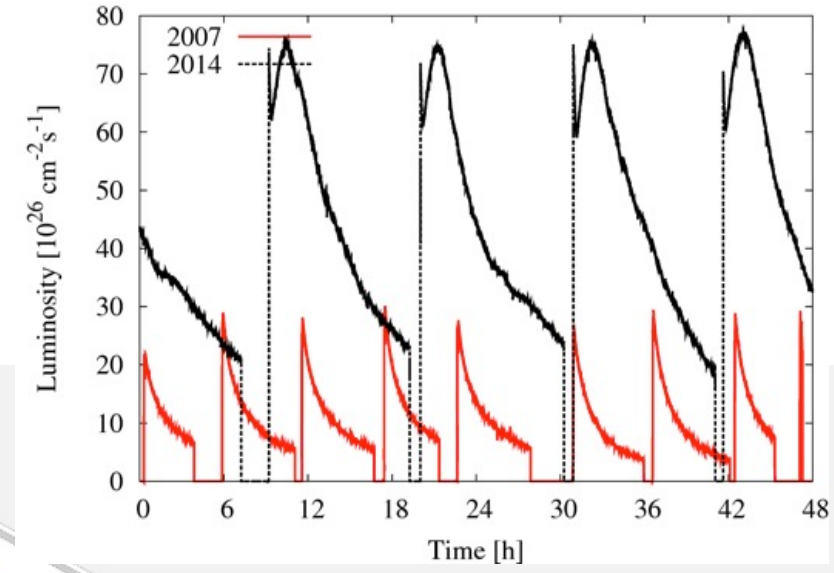


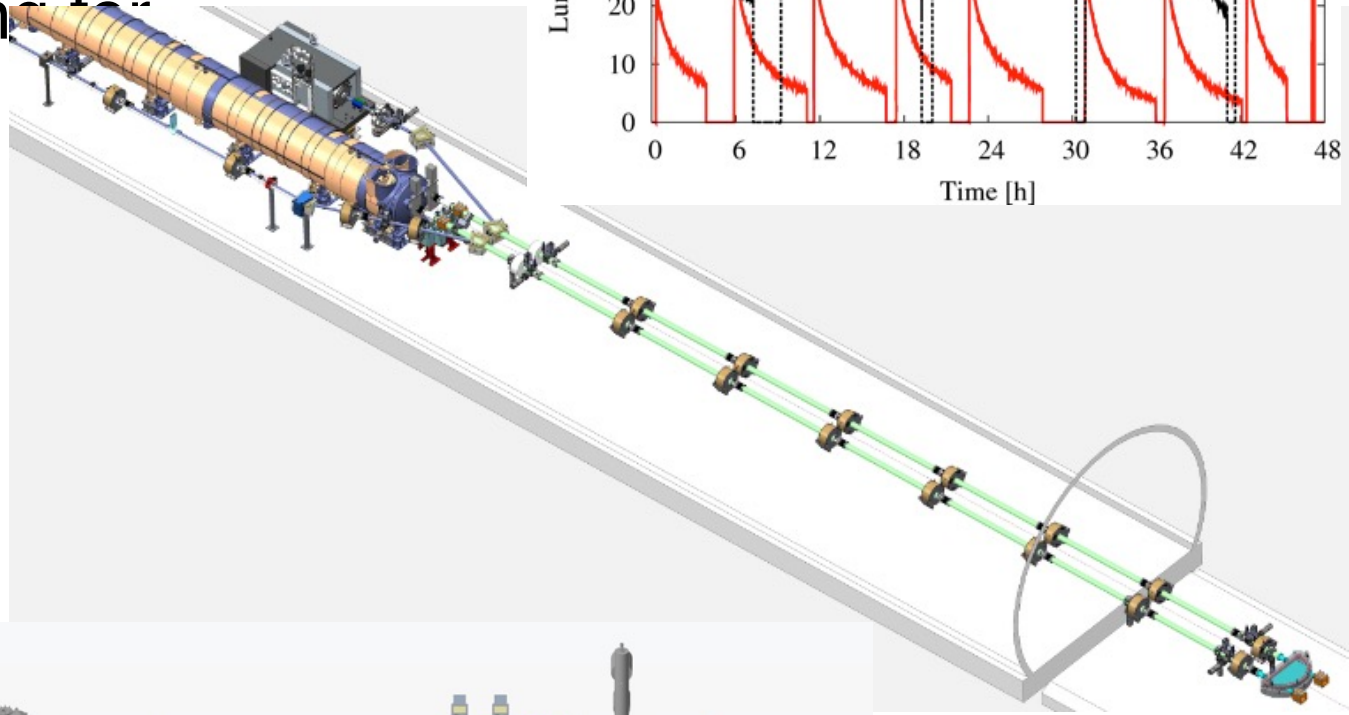
can now be done in 1/2 day (200x faster)

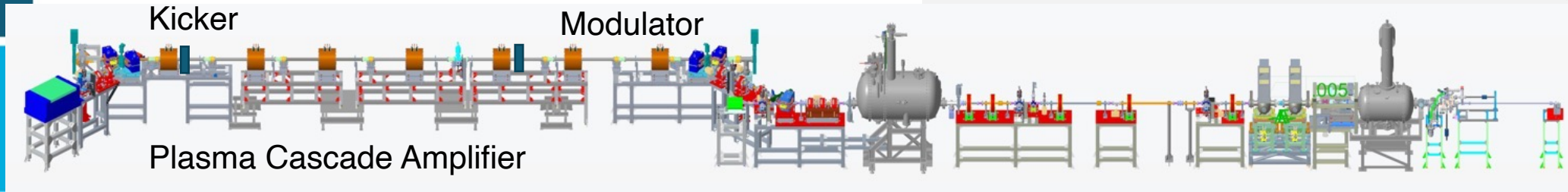
RHIC Au+Au operation at full energy

Beam cooling at RHIC

- First high energy, bunched beam stochastic cooling gives record heavy ion collision rates (10 GHz microwave technology)
- First bunched beam electron cooling for luminosity upgrade of “low” energy heavy ion collisions
- Experimental demonstration of Coherent electron Cooling, (stochastic cooling with a 30 THz bandwidth)







Ion Sources at BNL

BNL Magnetron H^- source

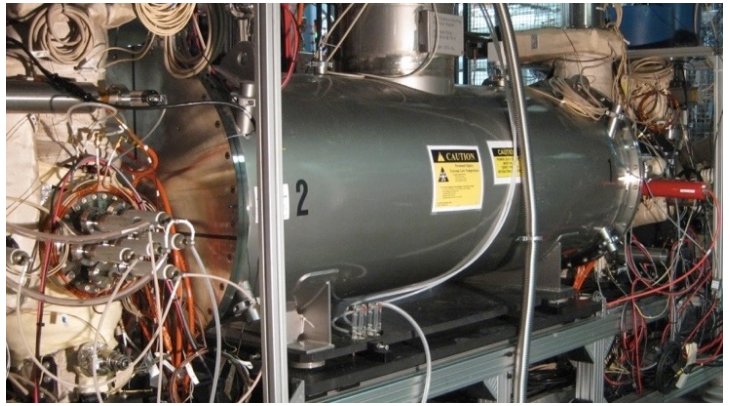
- Hydrogen plasma interacts with Cs-Mo surface
- Highest H^- peak current (100 mA)

BNL Optically Pumped Polarized Ion Source (OPPIS)

- Polarized electrons from optically pumped Rubidium are used to generate polarized H^- ions
- Highest intensity (1 mA) polarized (83%) H^- source

BNL Electron Beam Ion Source (EBIS)

- Intense electron beam inside high-field solenoid is used to stepwise ionize heavy ions. Reaches Au^{32+} after about 40 ms.
- Highest intensity EBIS, polarized He-3



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High intensity electron sources

Active photocathode development

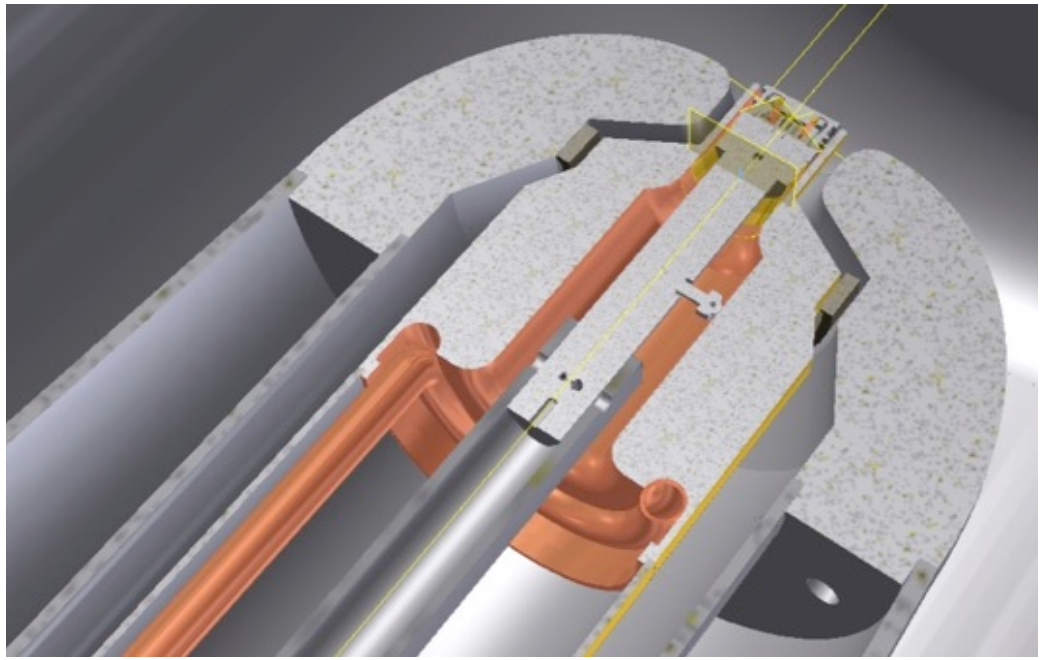
- Bi-alkali antimonide cathodes with QE up to 9%

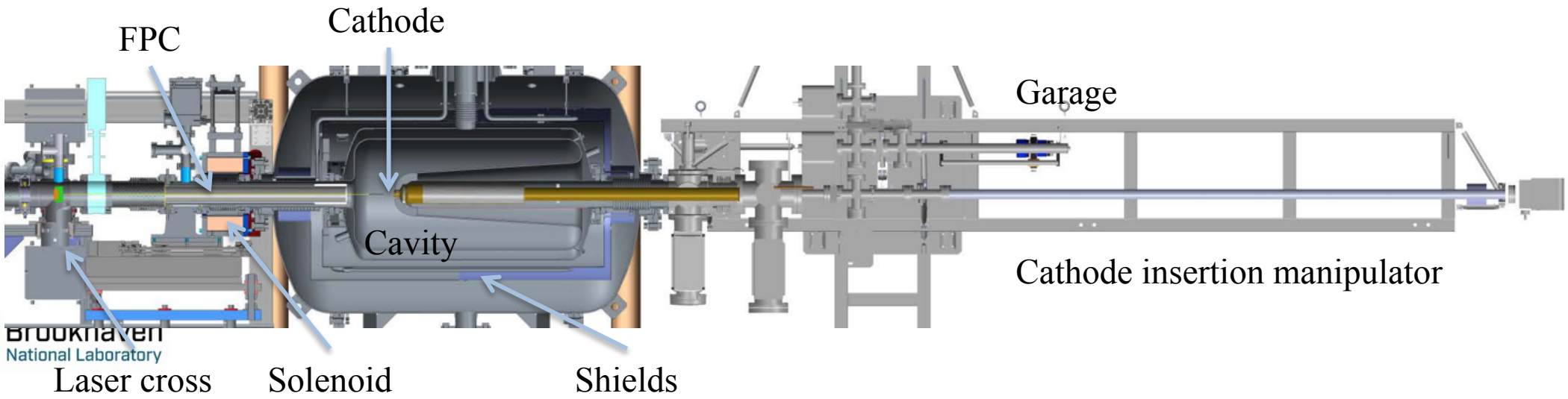
DC photo-electron gun for LEReC

- Built by Cornell and installed at RHIC IR2
- 400 kV operation
- 30 mA CW current demonstrated, plan for higher

SRF photo-electron gun for CeC

- High brightness: 1.56 MeV, 0.5 nC and 0.3 um
- High bunch charge: up to 10 nC
- CW operation at 80 kHz with little QE drop
- High current operation limited by FPC





Early Career Award 2021
Mengjia Gaowei

“Cathode R&D for high-intensity electron source in support of EIC”

Objectives:

- Improve quantum efficiency with reproducible single crystal photocathode material
- Upgrade the cathode growth chamber with offline characterization capabilities by incorporating a reflection high energy electron diffraction (RHEED) system
- Develop the capability to transfer cathodes between the initial growth chamber, the materials diagnostic tools and the chamber for high current damage analysis and emittance measurement
- Test the traditionally grown and single crystal cathodes at high emission current ~ 100 mA
- Evaluate various protective mechanisms including 2-D material encapsulation and nanostructure enhancement, for high current performance

Electron-Ion Collider

Ferdinand Willeke et al.

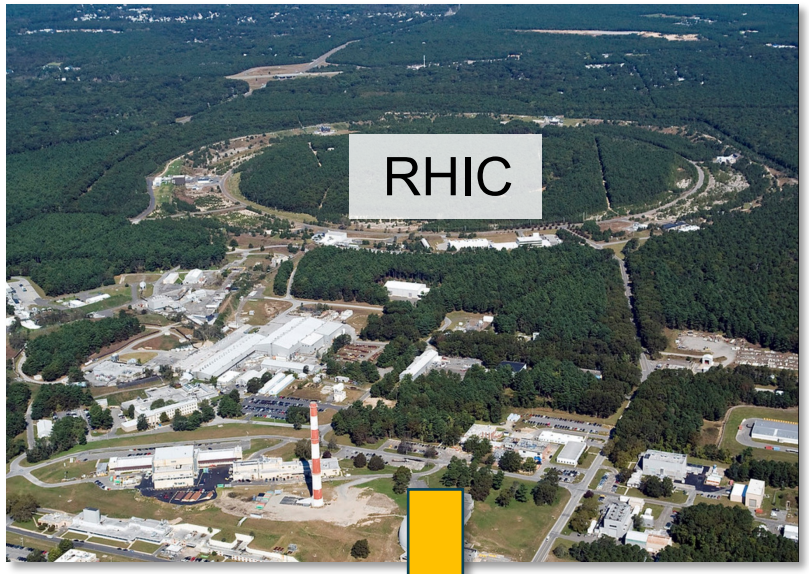
BNL-JLab partnership with national and international contribution sited at BNL - uses RHIC hadron complex
CD-1 June 2021 (Conceptual Design complete, cost range), operation 2032 (planned)

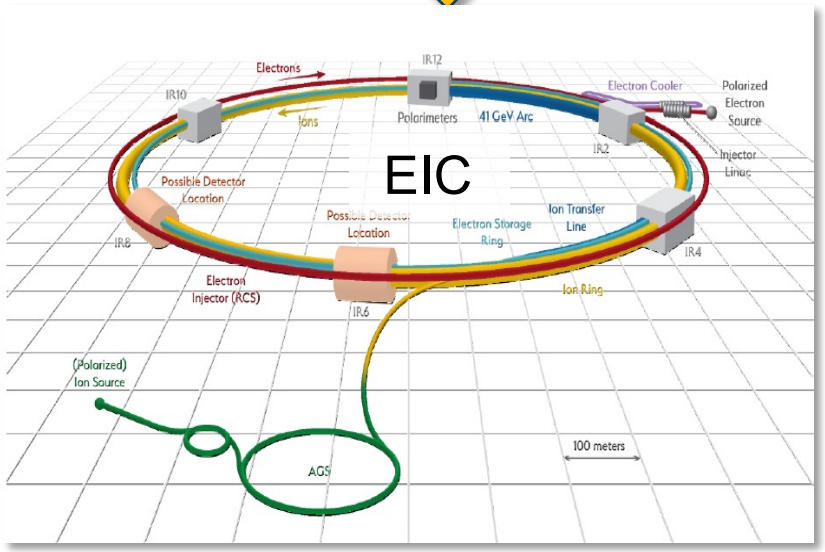
Hadron storage Ring (RHIC Rings) 40-275 GeV (existing)
- 1160 bunches, 1A beam current (3x RHIC)
- small vertical beam emittance 1.5 nm
- strong cooling (coherent electron cooling)

Electron storage ring 2.5–18 GeV (new)
- many bunches, large beam current, 2.5 A ➔ 9 MW S.R. power
- SC RF cavities
- Full energy injection of polarized bunches

Electron rapid cycling synchrotron 0.4–(new)
- 1-2 Hz
- Spin transparent due to high periodicity

High luminosity interaction region(s) (new)
- L = 10^{34} $cm^{-2}s^{-1}$
- Superconducting magnets
- 25 mrad full crossing angle with crab cavities
- Spin rotators (longitudinal spin)
- Forward hadron instrumentation





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