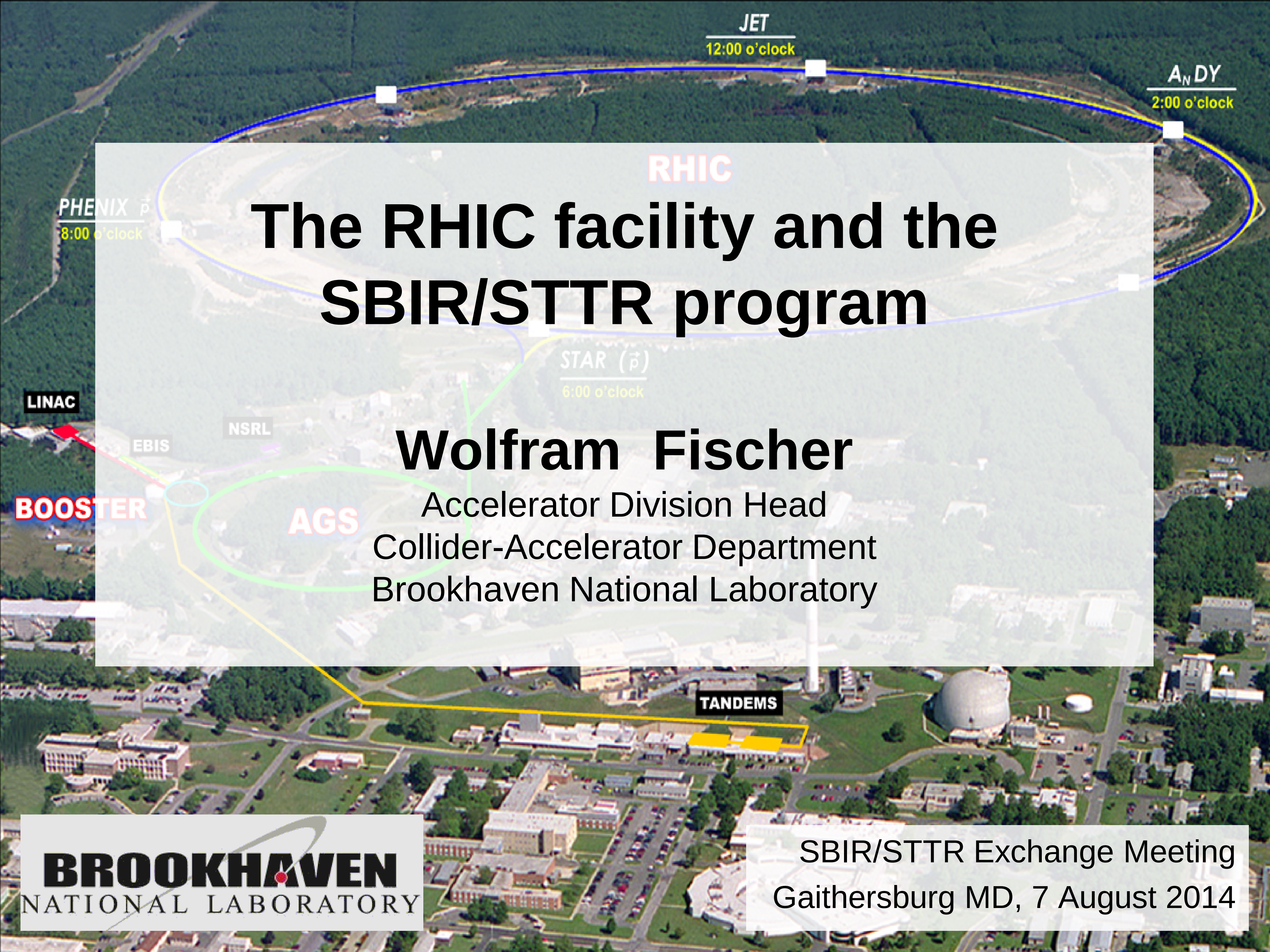
The RHIC facility and the SBIR/STTR program

Wolfram Fischer

Accelerator Division Head

Collider-Accelerator Department

Brookhaven National Laboratory



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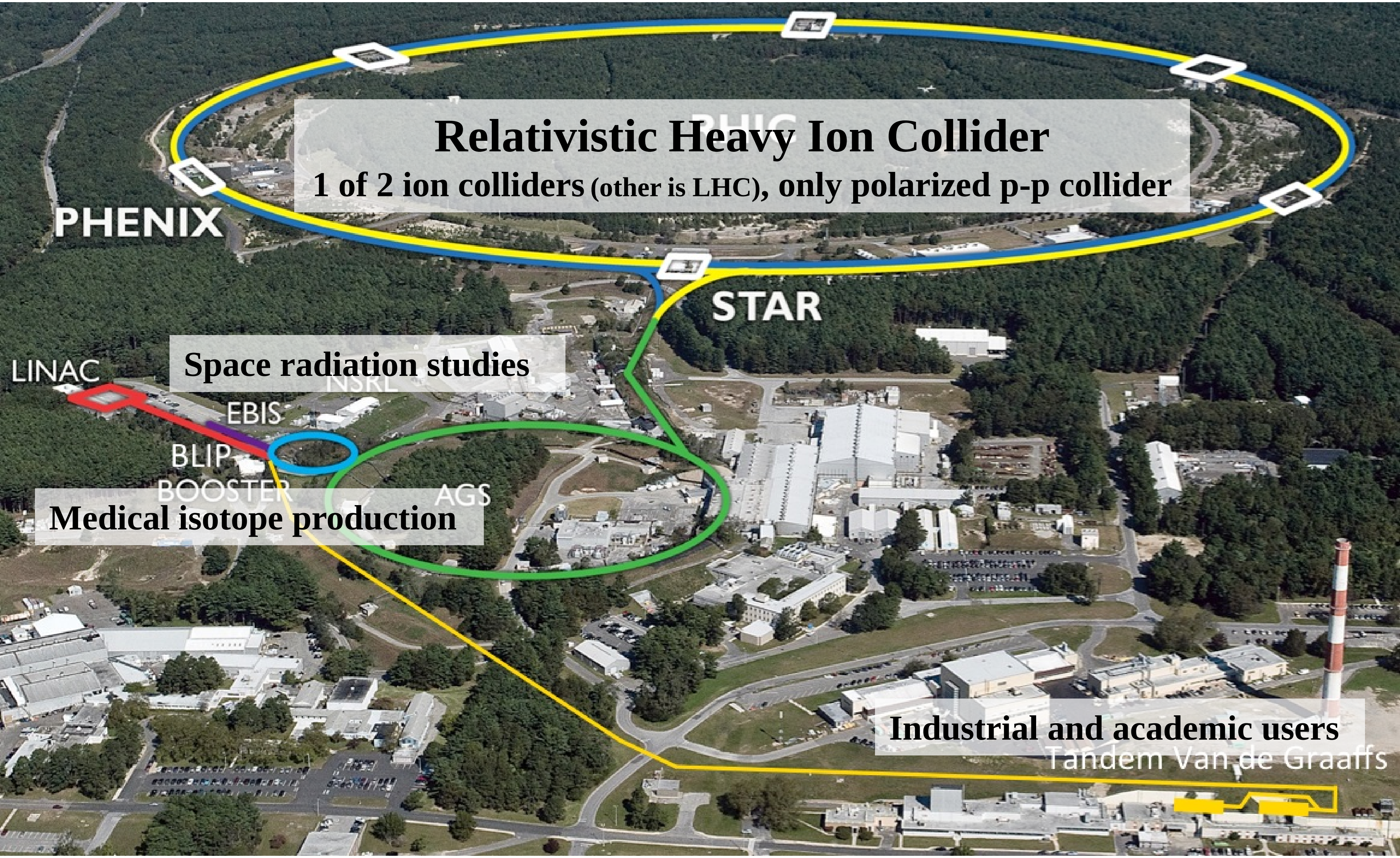
SBIR/STTR Exchange Meeting

Gaithersburg MD, 7 August 2014

Content

- BNL Hadron Complex
- Recent RHIC performance and planned upgrades
- Ongoing R&D

BNL hadron complex



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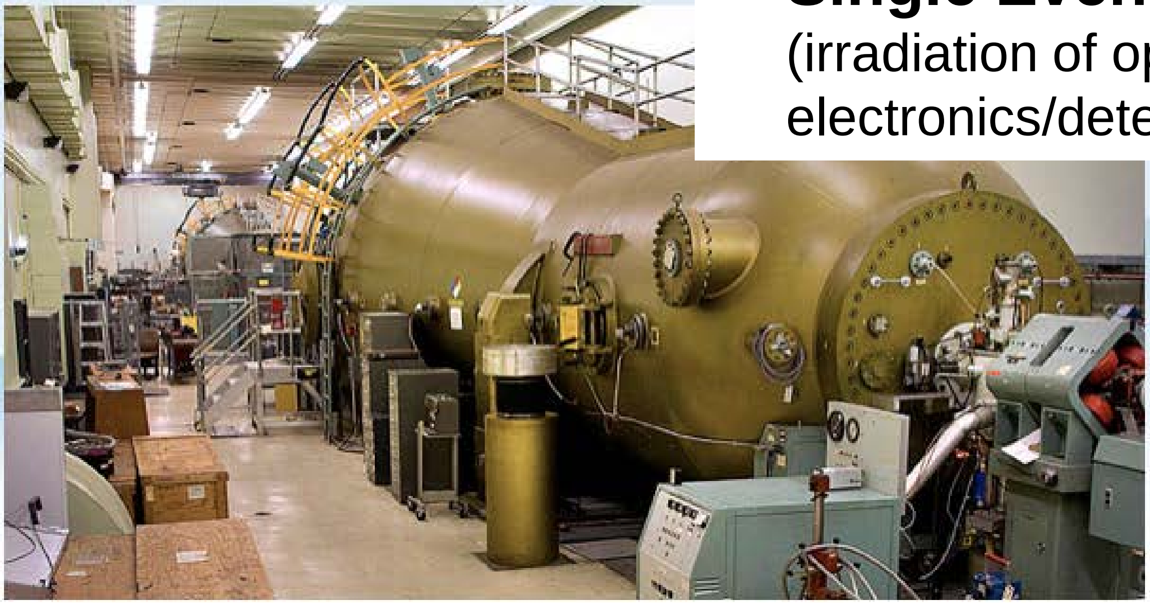
Tandem Van de Graaff

Tandem Home | Conduct Research at the Tandem | Capabiliti

- **30 MeV ion beams, p to Au**
  (hourly use rates)
- **Single Event Upset test facility**
  (irradiation of operating x-y movable electronics/detectors)



consists of two 15-megavolt electrostatic accelerators capable of delivering continuous, or high-intensity pulsed ion beams in a wide range of ion species at various energies to experimental chambers that are available to researchers on a full cost-recovery basis.

More »

Use the Tandem

Follow these simple steps to determine if the Tandem meets your experimental needs, reserve

Review Capabilities

Learn what ion species are available at the Tandem and at what LETs, maximum energies, and energy

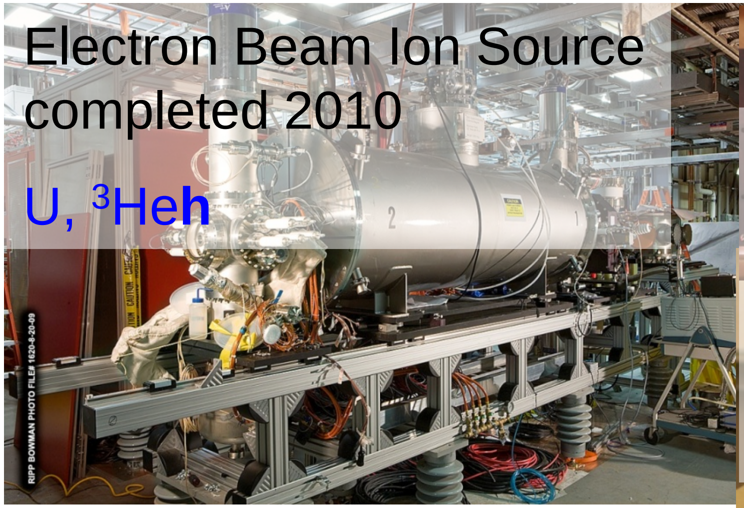
Check Schedule

Review the Tandem's run schedule and check the Single Event Upset facility for availability.

Contact Us

Do you have any questions or would you like to provide feedback to staff at the Tandem? Then use

Main upgrades for RHIC II performance

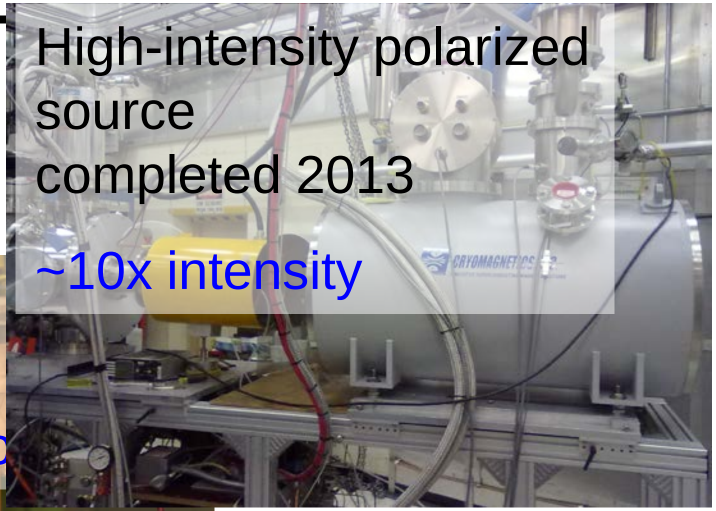


Electron Beam Ion Source
completed 2010

U, ^{3}He**h**

3-Dimensional Stochastic Cooling
completed 2012

~3x Au+Au lumino



High-intensity polarized source
completed 2013

~10x intensity

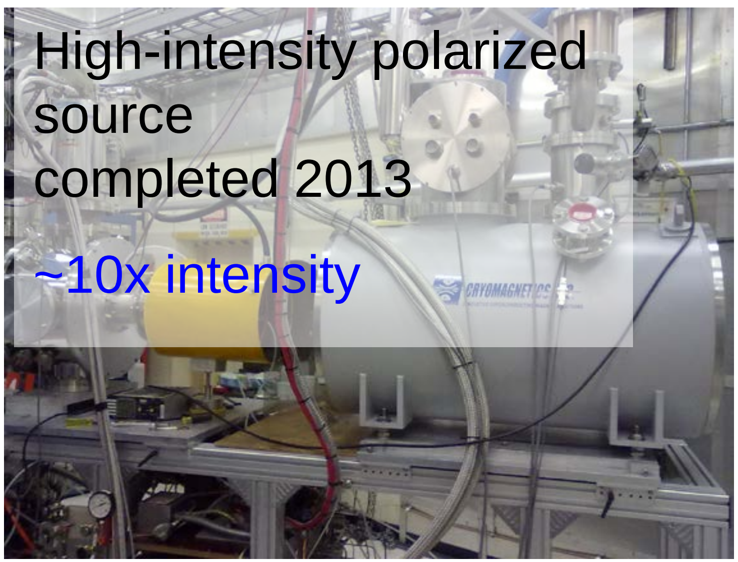
56 MHz Superconducting Radio Frequency
under commissioning 2014

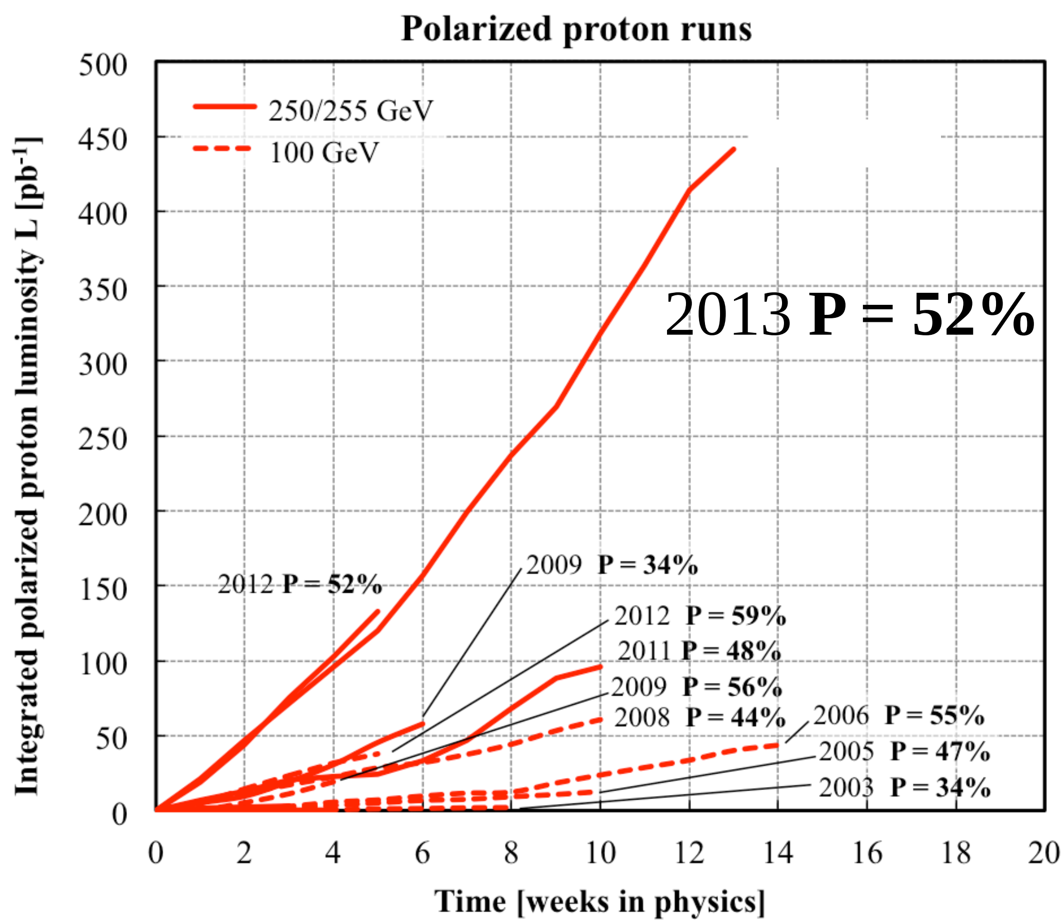
+30-50% Au+Au luminosity

Electron lenses
under commissioning 2014

~2x p**h**+p**h** luminosity

p+p luminosity from Run-13 exceeds all previous p+p runs combined





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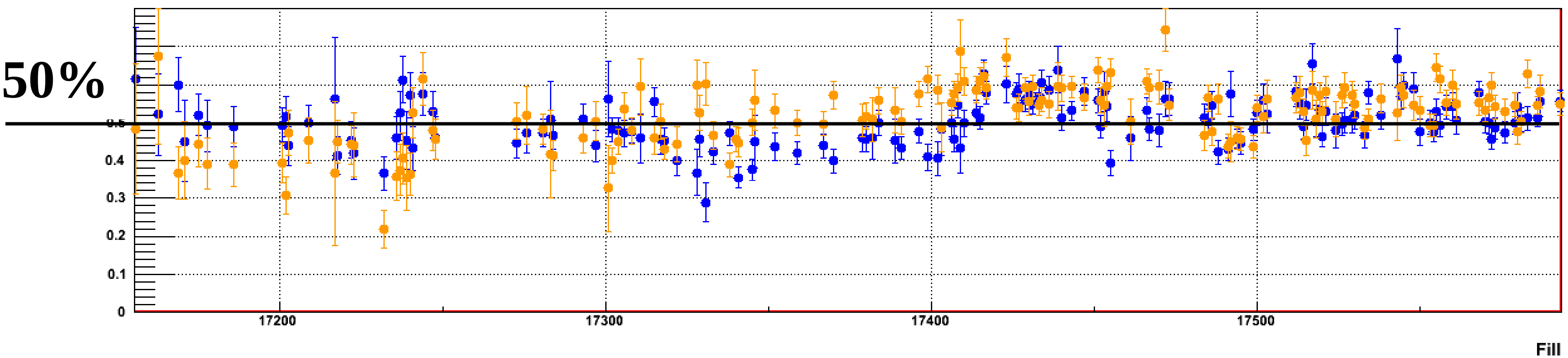
Run-13 polarization

FOM = LP² (single spin experiments)

FOM = LP⁴ (double spin experiments)

Transverse emittance reduction after optimization of AGS transition crossing



H-jet measured polarization
(average over intensity, time, 14 best stores)

	Run-12	Run-13
Blue	52.0%	57.0%
Yellow	58.2%	57.7%

- **H-jet measures intensity-averaged *P***
- ***LP*² and *LP*⁴ are luminosity-averaged**
- **Luminosity-averaged values are higher than intensity-averaged values**

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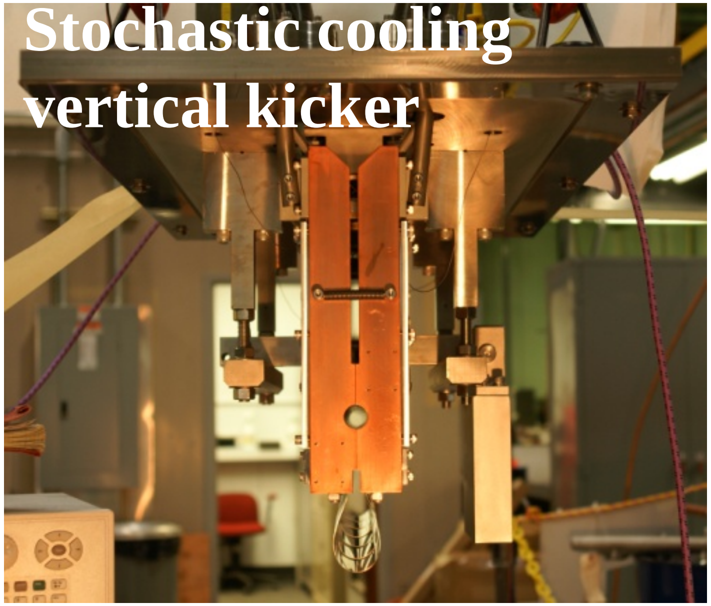
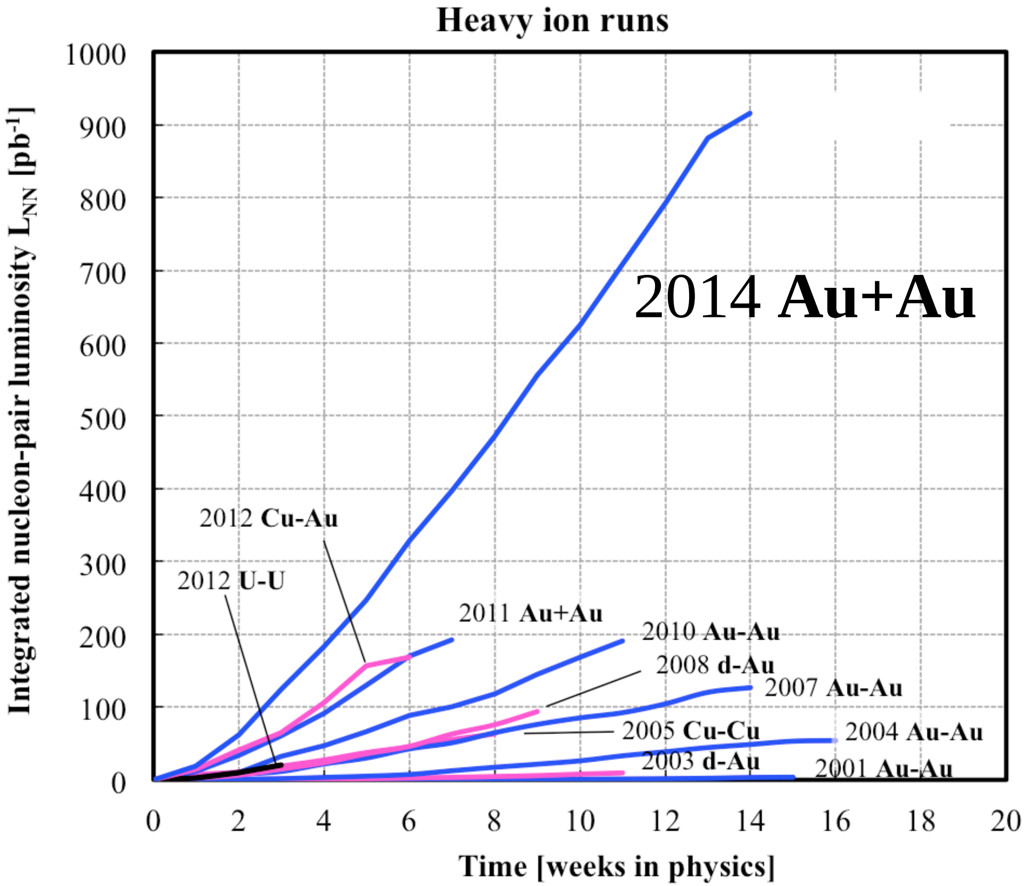
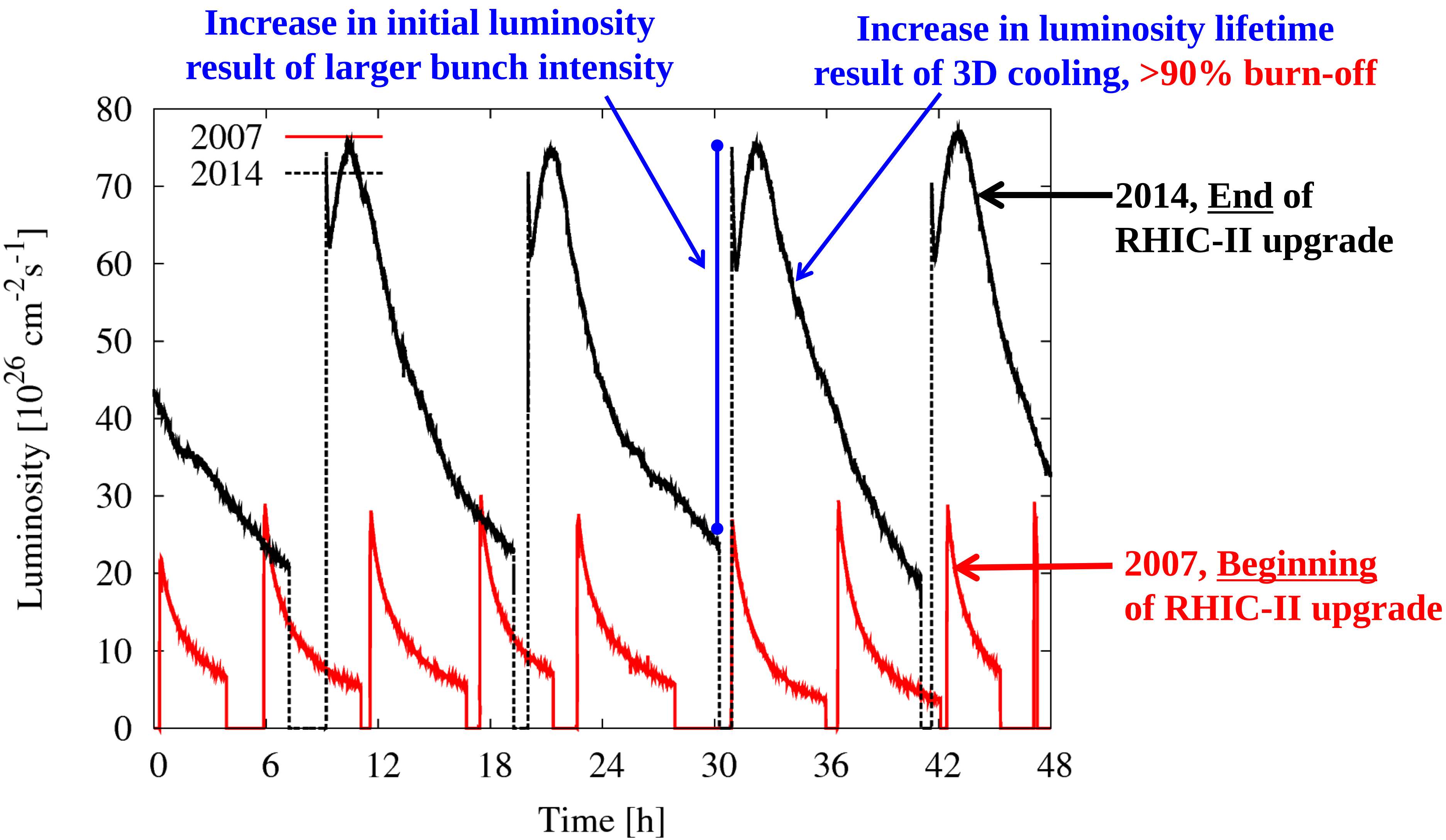
Au+Au luminosity from Run-14 exceeds all previous Au+Au runs combined



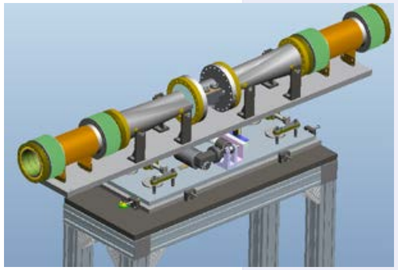


RHIC Run-14 Delivering RHIC-II luminosity

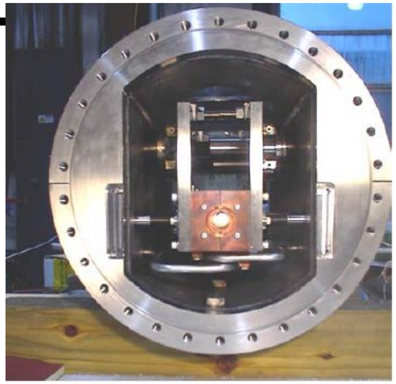


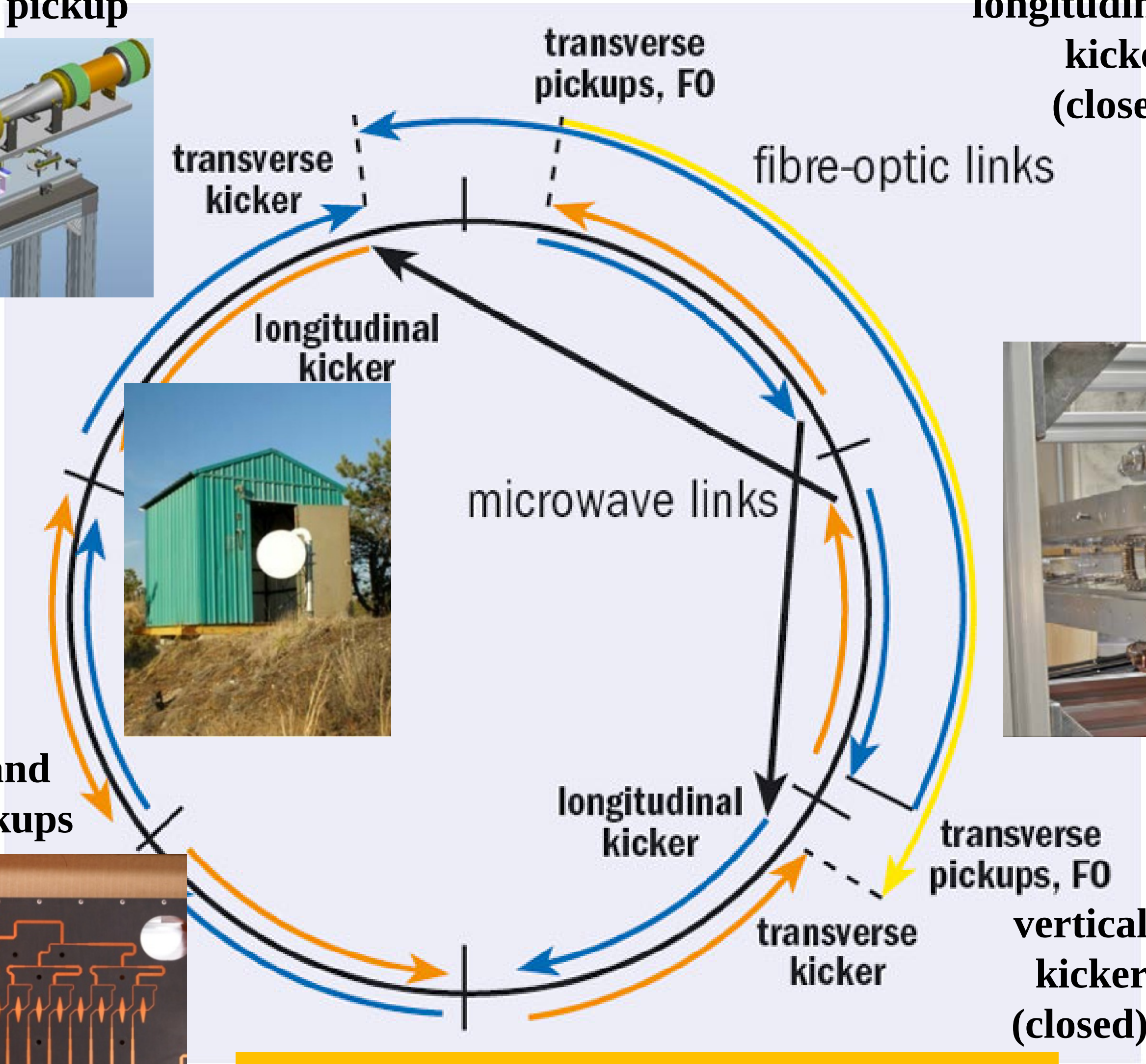
Now have full 3D stochastic cooling for heavy ions

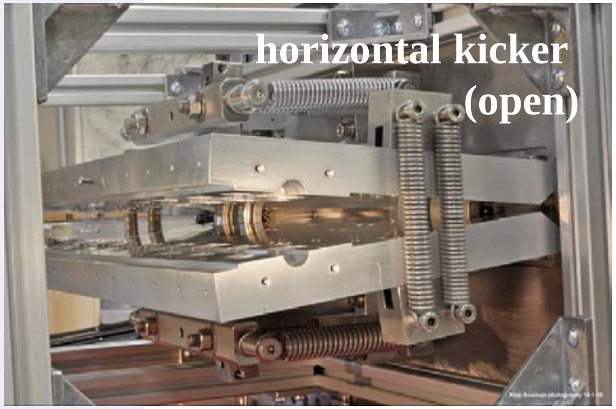
longitudinal pickup



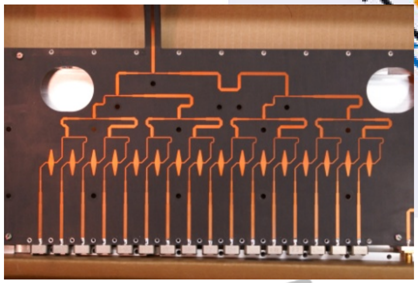
longitudinal kicker (closed)



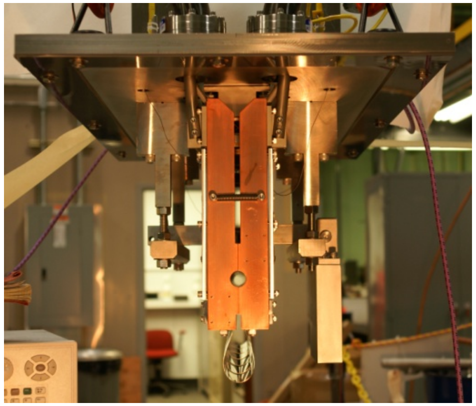




horizontal and vertical pickups



vertical kicker (closed)



5-9 GHz, cooling times ~1 h

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M. Brennan, M. Blaskiewicz, F. Severino, PRL 100 174803 (2008)

Heavy ions – high energy

2x L_{avg}, within 2 years

- 56 MHz SRF fully operational
- Laser Ion Source (LION) + EBIS for higher bunch intensity

Heavy ions – low energy

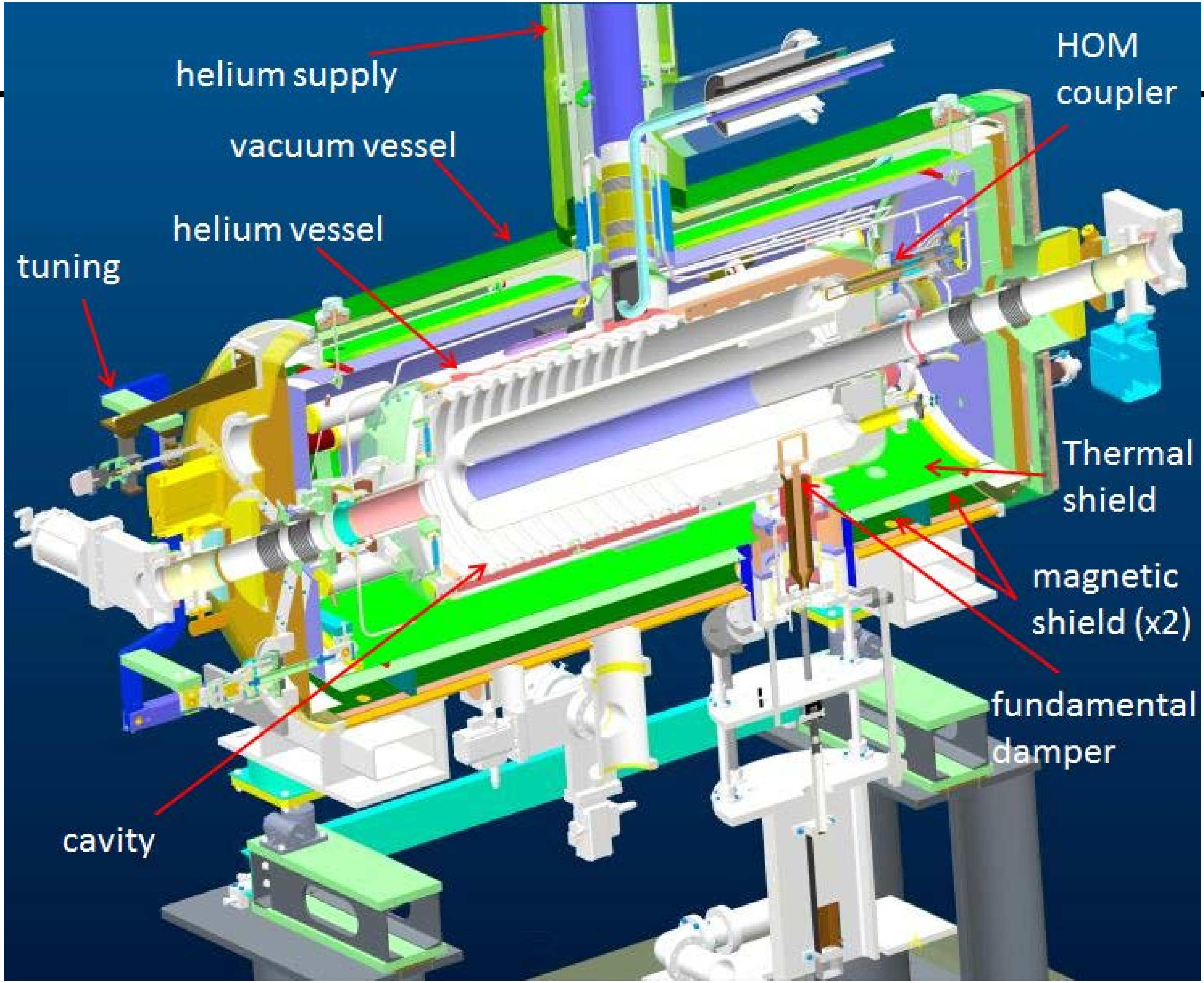
~3-10x L_{avg}, within 4 years

- Low-Energy electron cooling (AIP)

Polarized protons

2x L_{avg} 100 and 255 GeV, P+ (small), within 1-2 years

- New OPPIS for higher bunch intensity
- Electron lenses for head-on beam-beam compensation
- Also: polarized ^{3}He acceleration in AGS and possibly RHIC (>2 years)



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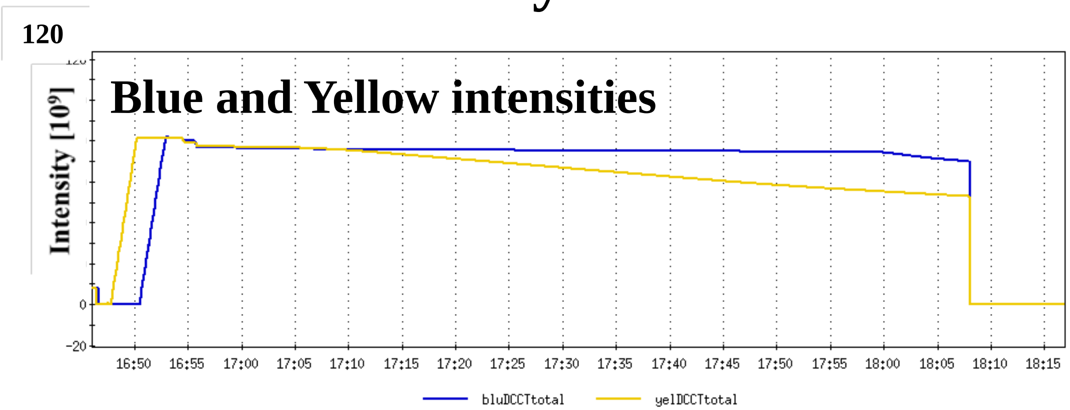
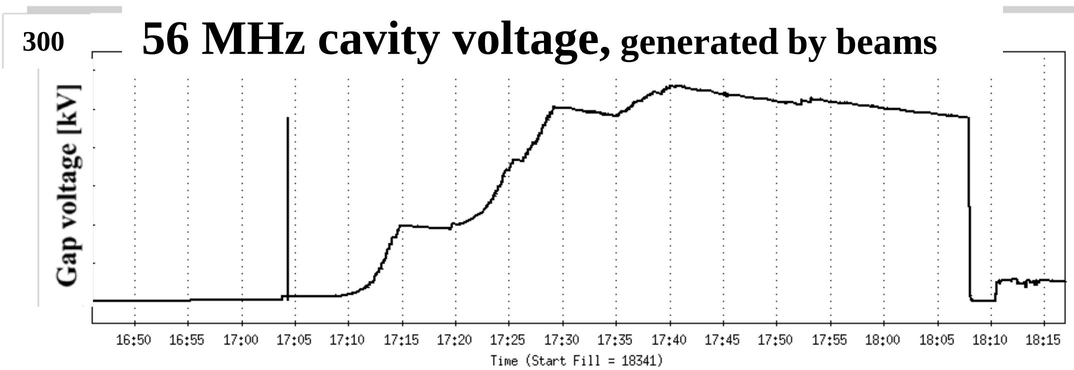
cavity built by Niowave

RHIC Run-14 56 MHz SRF commissioning

30-50% luminosity increase due to stronger longitudinal focusing



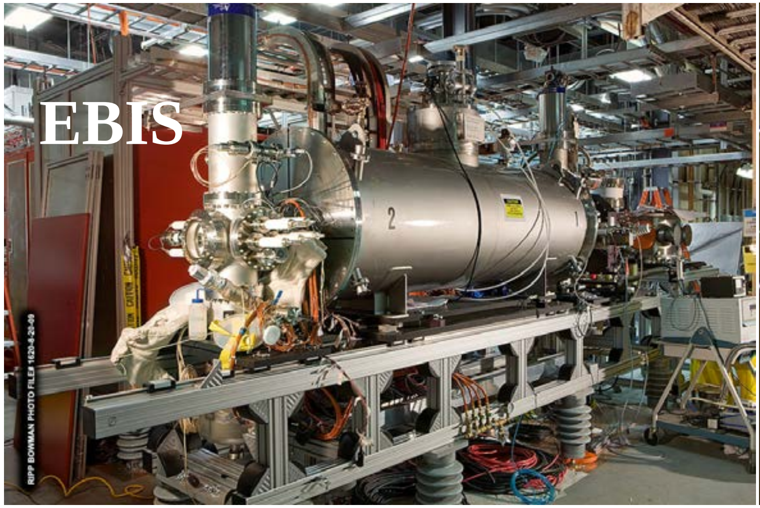


Demonstrated in Run-14 **(to date):**

- -Cavity operation with Au beams:
  no cavity quenches
  no Au beam instabilities
- -Voltage generation up to 300 kV (limited by HOM damper) – design of 2 MV
- -Cavity operation with up to 111 bunches

Electron Beam Ion Source (EBIS)

- Inject single charge ion from primary source (hollow cathode, laser ion source)
- 10 A electron beam creates desired charge state in trap (5 T sc solenoid)
- Source for high-charge state, high brightness ion beams
- Accelerated through RFQ and linac, injected into AGS Booster
- All ion species including noble gas, uranium and polarized ^{3}He



Operated for NASA Space Radiation Laboratory in 2011-12 with

•He^{+}, He^{2+}, Ne^{5+}, Ne^{8+}, Ar^{10+}, Kr^{18+}, Ti^{18+}, Fe^{20+}, Xe^{27+}, Ta^{33+}, Ta^{38+}

Operated for RHIC with

•$^{3}He^{2+}$ (unpolarized), Cu^{11+}, Au^{31+}, U^{39+} (not possible previously) – $^{27}Al^{13+}$ next year

SBIR: Simulations by Far-Tech (presentation by Jin-Soo Kim yesterday)

Laser Ion Source

M. Okamura, T. Kanesu et al.

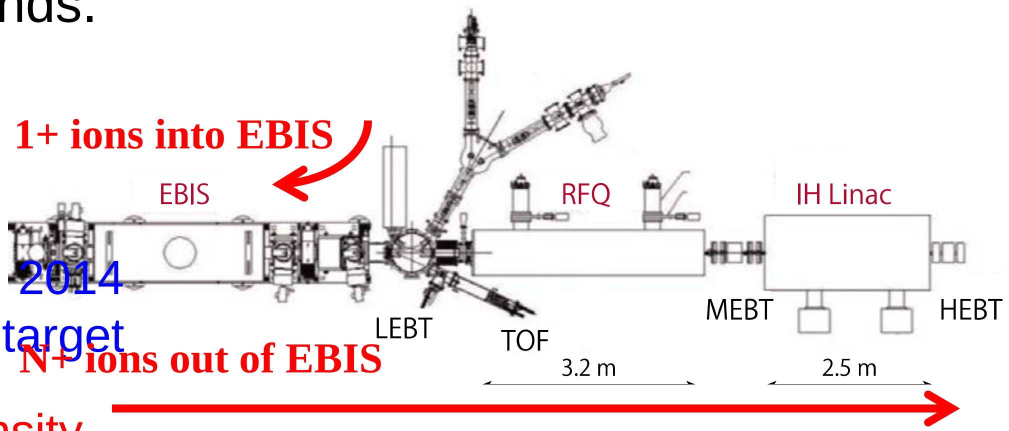
More than ten species can be provided.

Al, Ti, Cr, Mn, Fe, Cu, Ta, Au on test stand

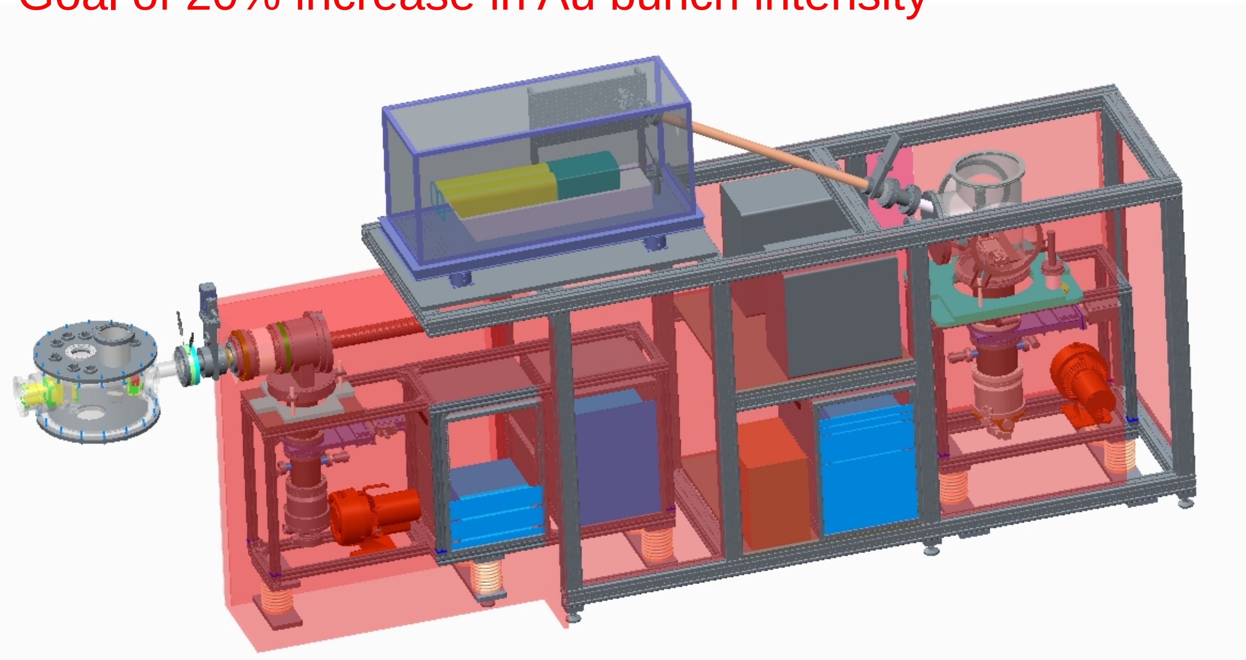
Switching species is in a few seconds.

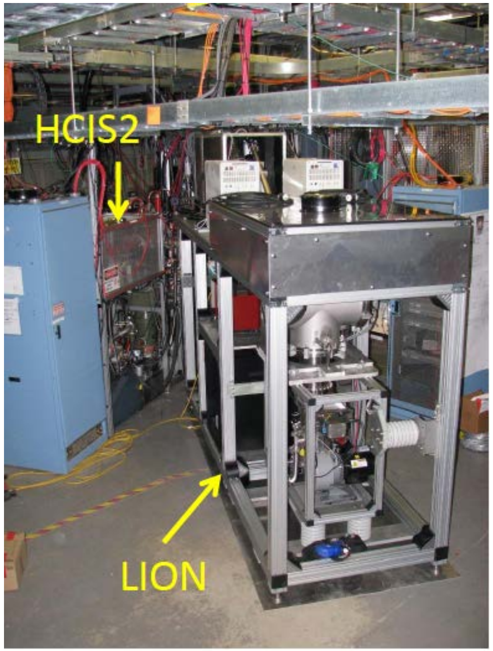
Status:

- Routine operation for NSRL in2014
- Delivered Au to RHIC (18381)
- Upgrade in summer 2014 for improved Au target

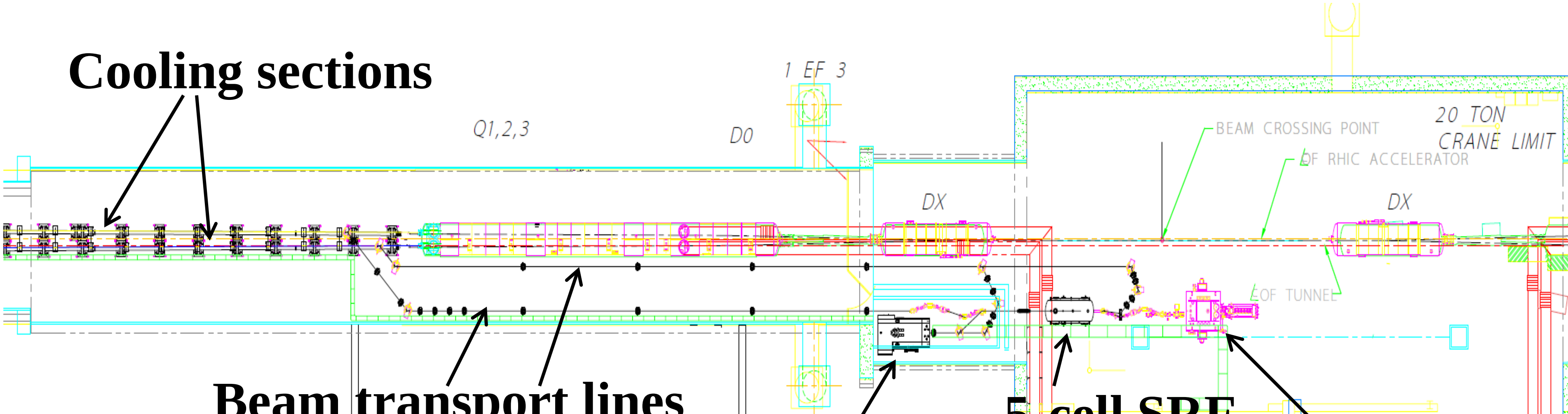


Goal of 20% increase in Au bunch intensity





Low-Energy RHIC electron Cooler (LEReC) at IP2



LEReC accelerator:

Gun (SRF or DC)

704 MHz SRF ½-cell + 5-cell cavity from R&D ERL (under commissioning)

- Needed beam parameters from the SRF gun need be demonstrated in the near future (2014-15)
-Add electron beam transport lines with magnets, warm RF cavities and two cooling sections with short solenoids

LEReC luminosity projection

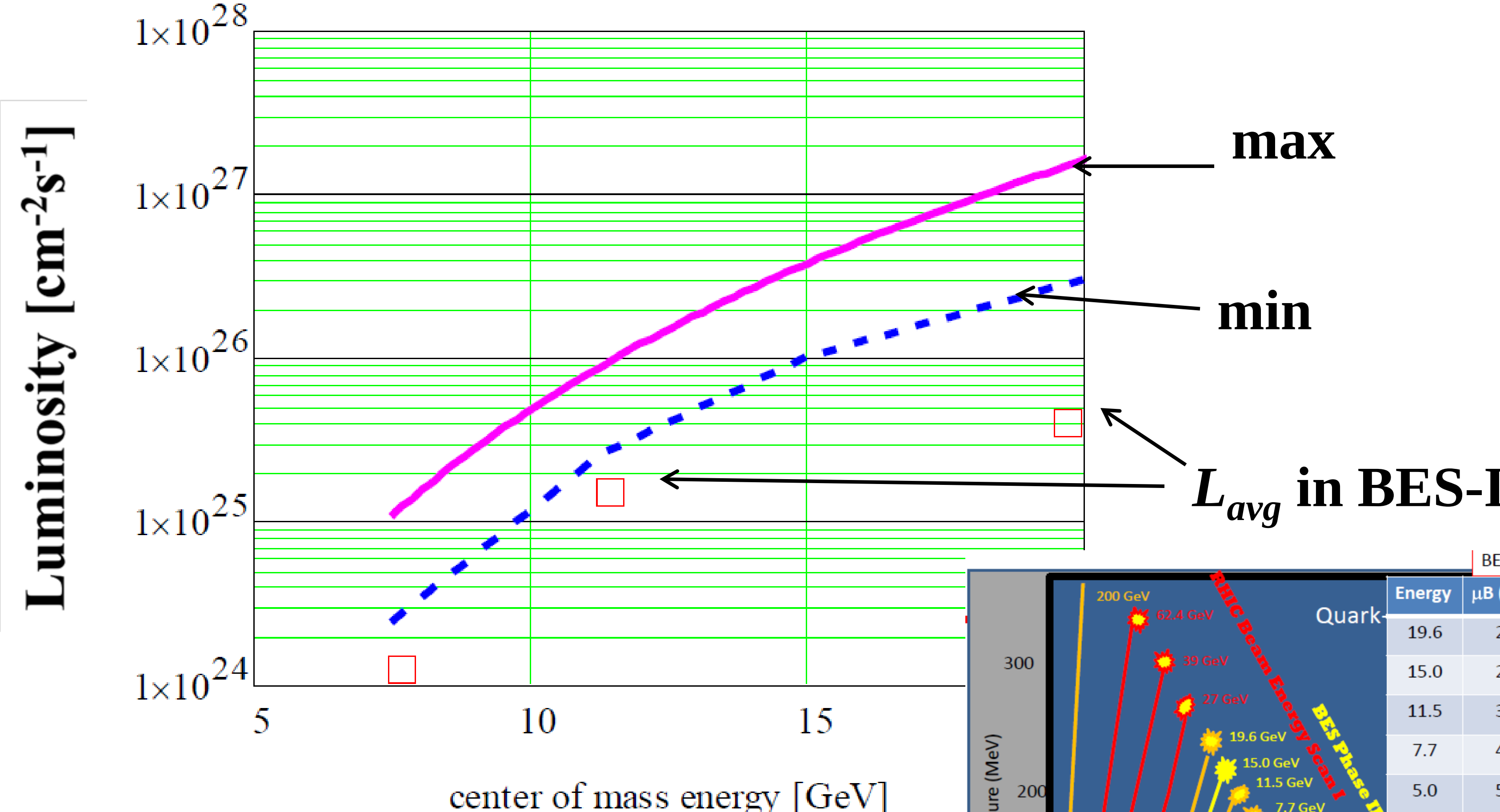
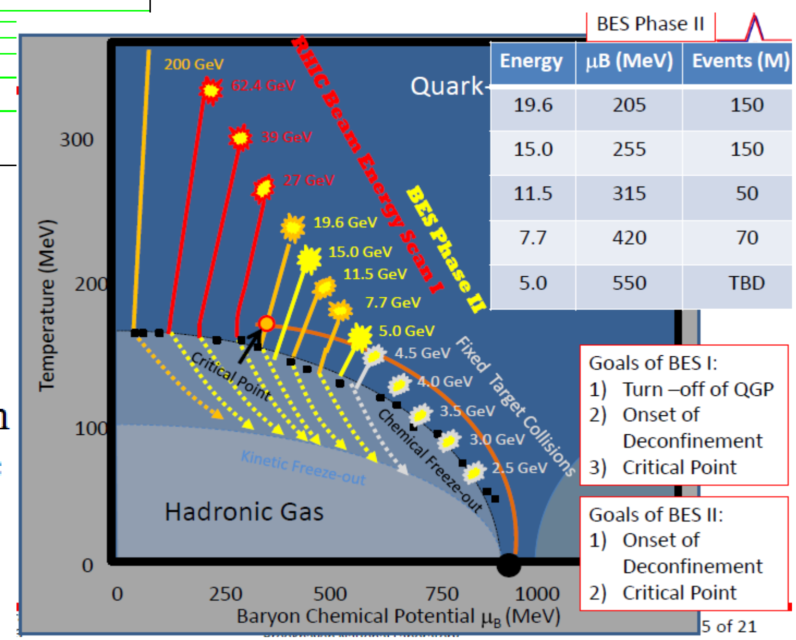


Figure 1. Projection of average store luminosity within +/-1m RHIC with electron cooling. Red squares: measured average line: minimum projection of improvement with cooling. projection of luminosity improvement with cooling.

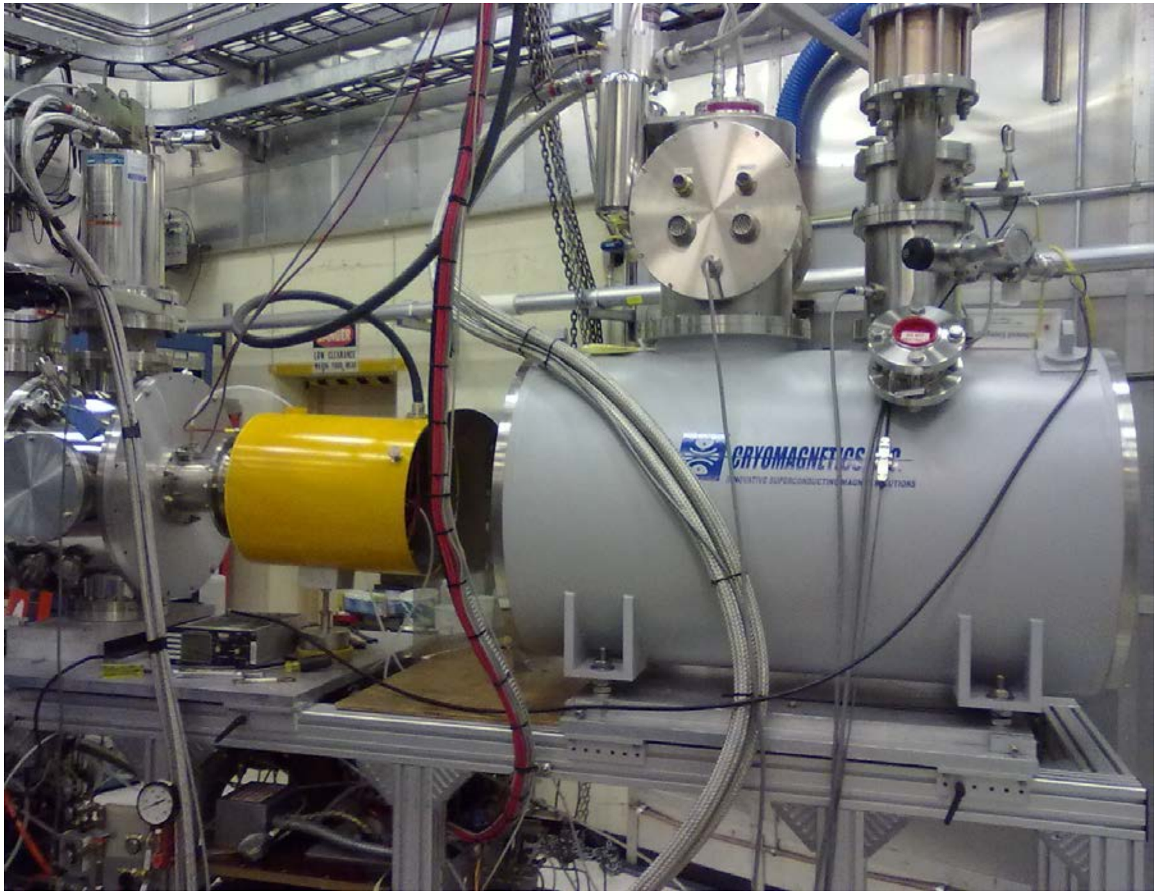


Energy	μB (MeV)	Events (M)
19.6	205	150
15.0	255	150
11.5	315	50
7.7	420	70
5.0	550	TBD

LEReC luminosity gain: 3x (low energy) to 10x (high energy)

Optically Pumped Polarized H⁻ source (OPPIS) – A. Zelenski

Upgraded OPPIS (2013)



Goals:

1. **H⁻ beam current increase to 10mA** (order of magnitude)
2. **Polarization to 85-90%** (~5% increase)

Upgrade components:

1. **Atomic hydrogen injector** (collaboration with BINP Novosibirsk)
2. **Superconducting solenoid** (3 T)
3. **Beam diagnostics and polarimetry**

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=> 10x intensity from Atomic Beam Source was accelerated through Linac

Electron lenses – partial head-on beam-beam compensation

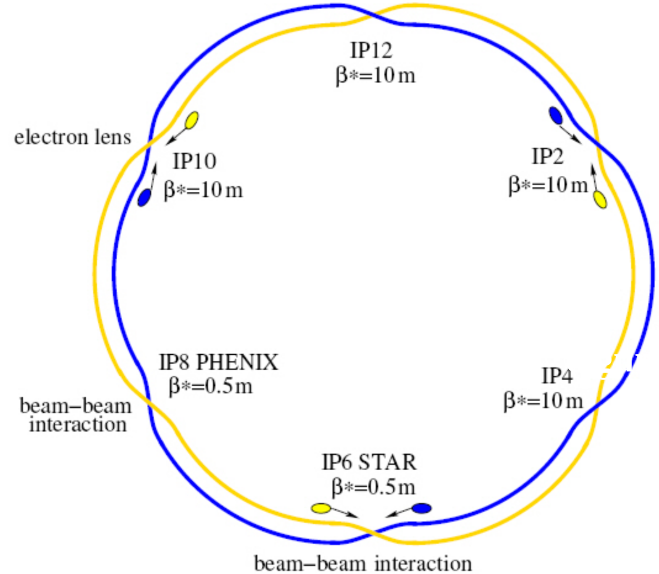
Basic idea:

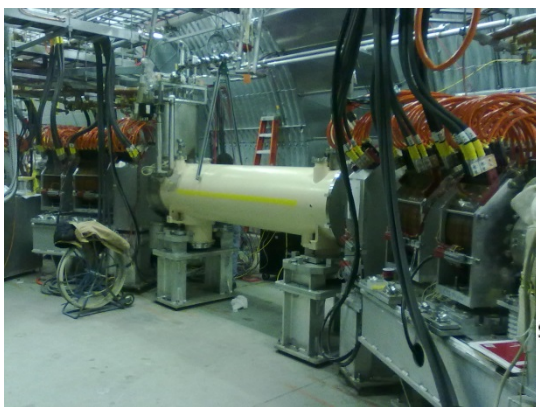
•2 beam-beam collisions with positively charged beam
•Add collision with a negatively charged beam – with matched intensity and same amplitude dependence

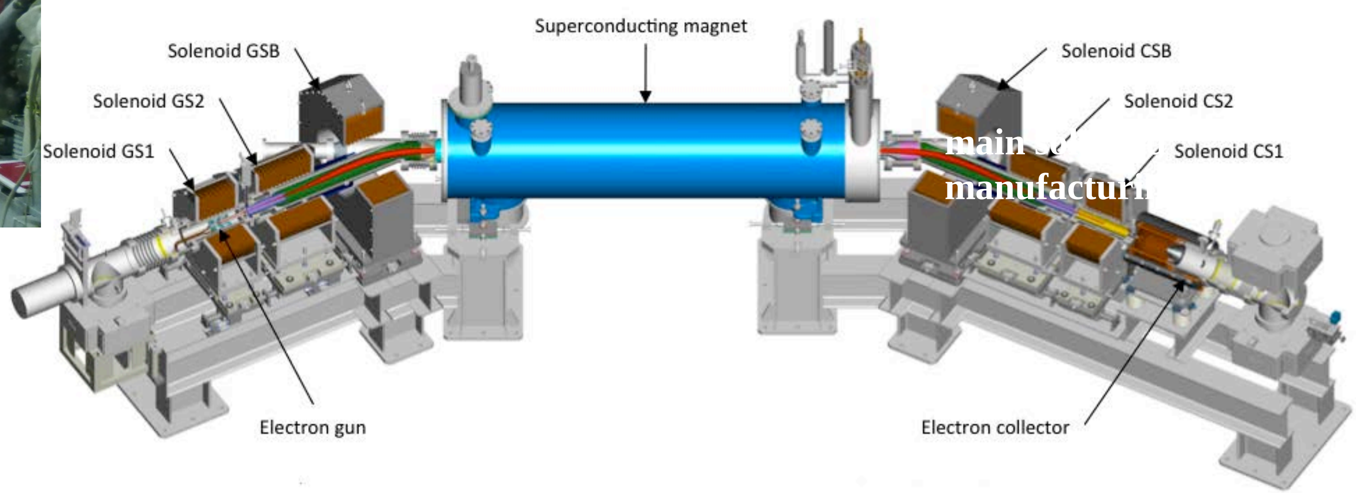
Compensation of nonlinear effects:

• e-beam current and shape
  => reduces tune spread
• $\Delta\psi_{x,y}$ = kp between p-p and p-e collision
  => reduces resonance driving terms

Expect up to 2x more luminosity







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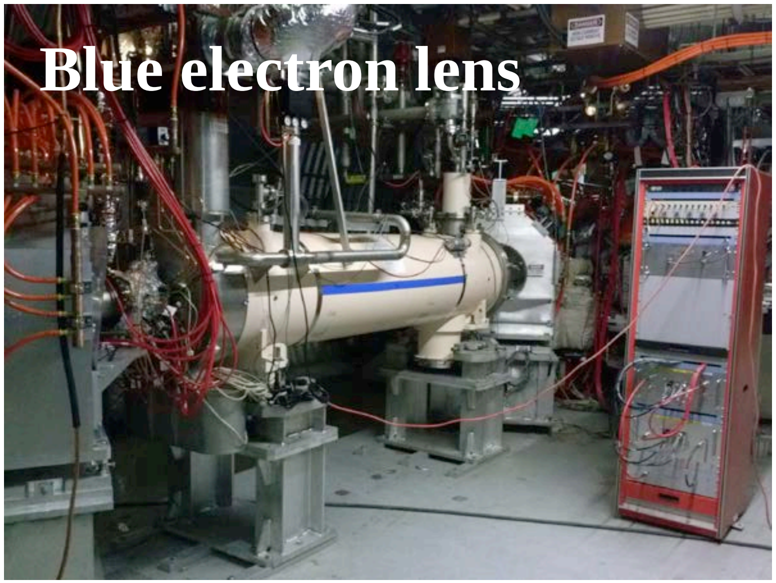
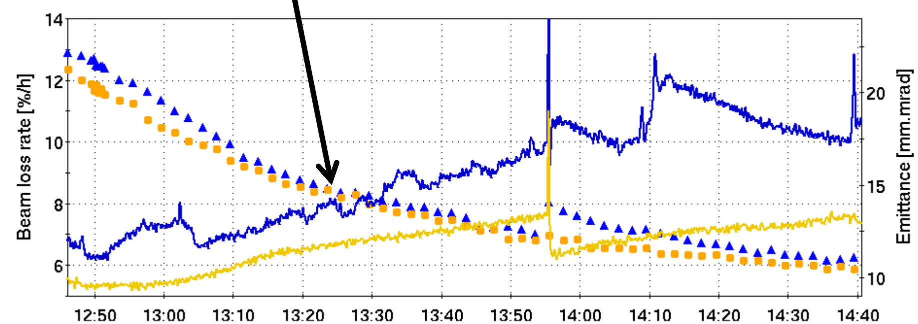
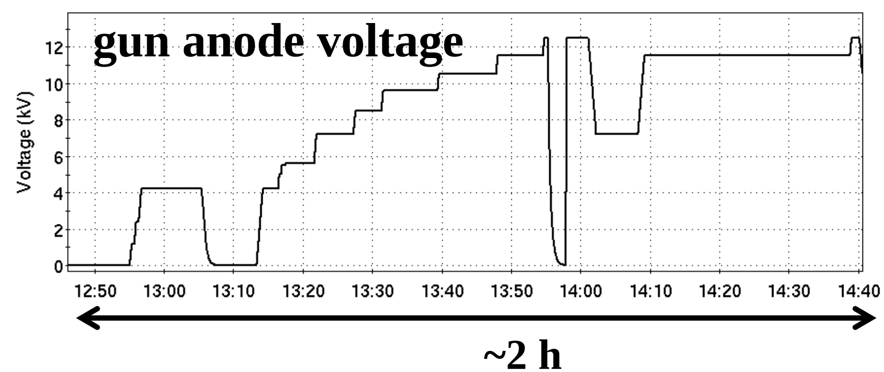
RHIC Run-14 Electron lenses commissioning with Au

For beam-beam compensation in polarized proton runs, goal of 2x luminosity increase



Blue emittance with e-lens cools as fast as Yellow emittance without e-lens





Demonstrated in Run-14 (to date):

- Magnetic structure, including field quality
- Electron beam current and shape
- Automatic alignment of Au and e-beam
- Effect on Au beam orbit and tunes
- No additional Au beam emittance growth with e-beam

First opportunity for beam-beam compensation in 2015

Research and Development Overview

- Isotopes at BLIP
- RHIC
- eRHIC

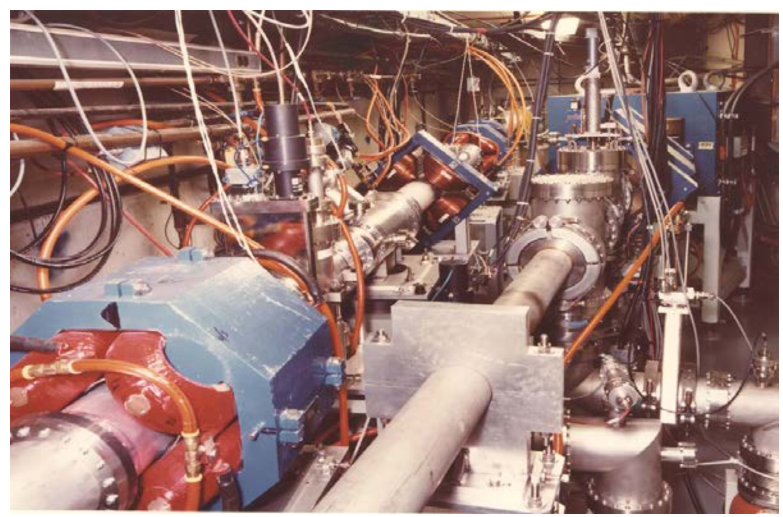
Brookhaven LINAC Isotope Producer (BLIP)

- LINAC supplies H^- (polarized protons) to the Booster for nuclear physics

- Most pulses (85-100%) go to BLIP. Energy is variable from 66-200 MeV

- Average current up 125 μA
- Upgrade to 140 μA under way
- Upgrade to 250 μA under study

- Record number of protons delivered to BLIP in 2014 (+13% compared to 2013)



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Medical Isotope Research and Production Program

View of several processing hot cells

Radionuclide R&D

- Nuclear reactions, targetry research
- Chemical process and generator development
  - Ac-225 for cancer therapy – ongoing, 11 test irradiations successful to date
  - Cu-67, for cancer therapy applications

Isotope Production and Distribution at BLIP

- Distribution for sale; process & target development to improve quality & yield.
- Sr-82/Rb-82 for human heart scans PET
- Ge-68 for calibration of PET devices, and for production of Ge-68/Ga-68 generators for PET imaging of cancer and other diseases
- Zn-65 tracer for metabolic or environmental studies

Training

- Support (space, equipment, faculty) for DOE funded NuclearChemistry Summer School, an undergraduate course in nuclear and radiochemistry

Radiation damage studies

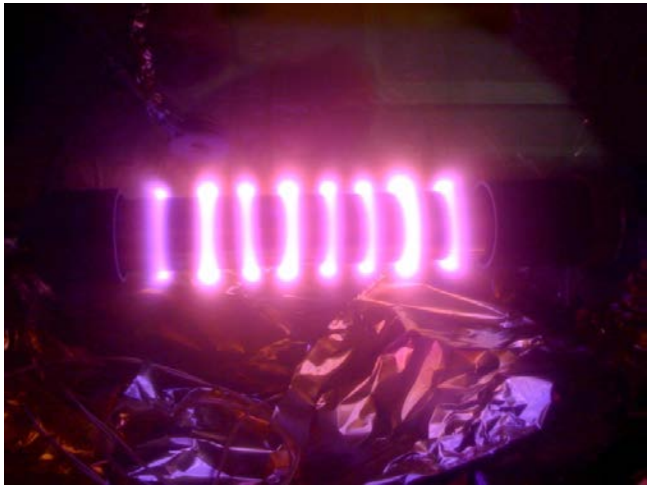
- Target and magnet materials for Fermi Lab & LHC
- Materials for Facility Rare Isotope Beams (FRIB),

Examples of opportunities

- RHIC cold arcs are stainless steel
  => **limit intensity** (ohmic heating, electron clouds)
- Warm parts of RHIC are largely coated with NEG
- Cold arcs need copper coating for high intensity, in-situ

A. Hershkovitch et al. IPAC14

R&D for magnetron mole (SBIR, PVI) – coating with good adhesion developed



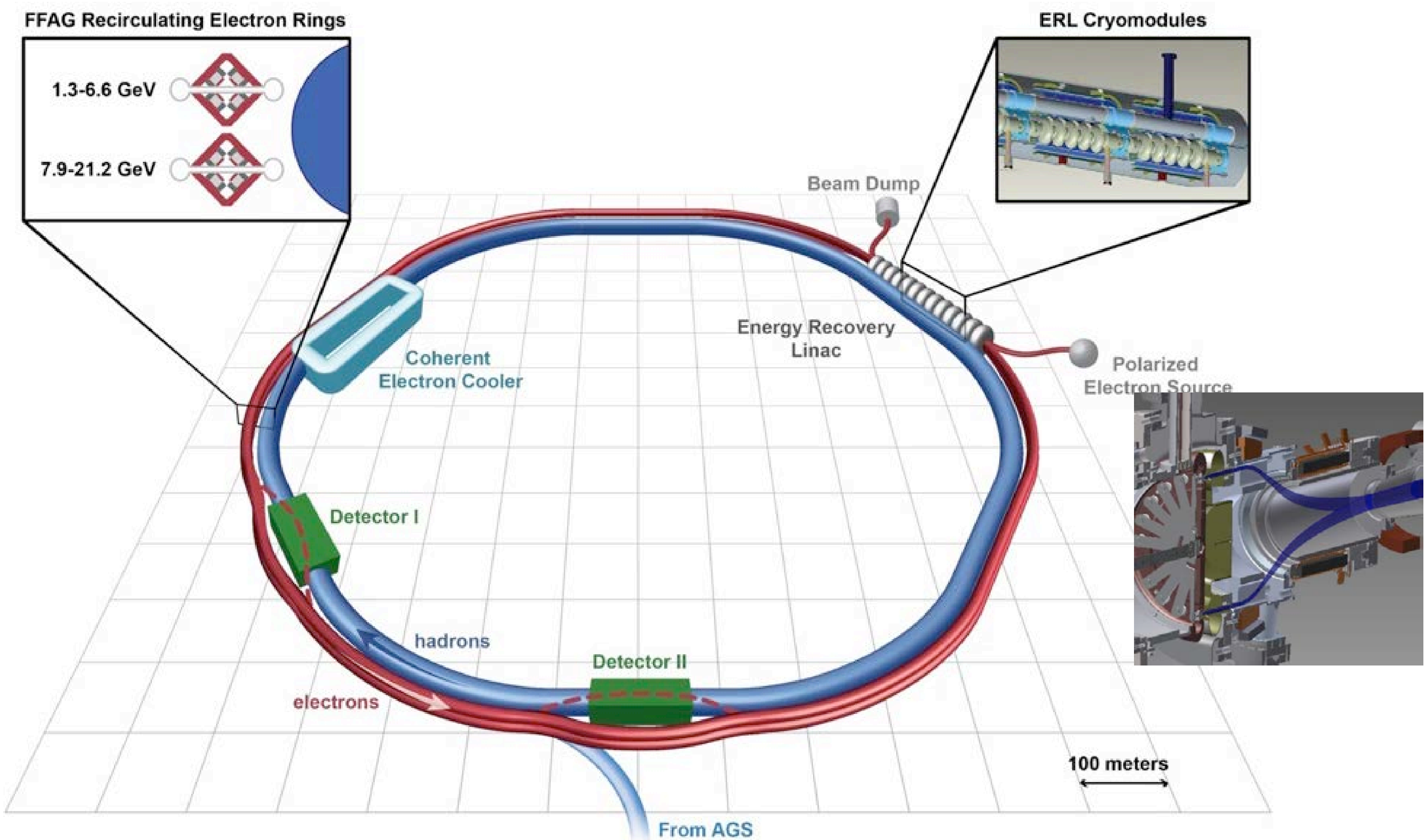
Need glow-discharge cleaning before Cu deposition, RF properties (at cryogenic temperatures) still to be determined

eRHIC design

Electron beam accelerated with Energy Recovery Linac (ERL) inside RHIC tunnel collides with existing 255 GeV polarized protons and 100 GeV/nucleon HI RHIC beams

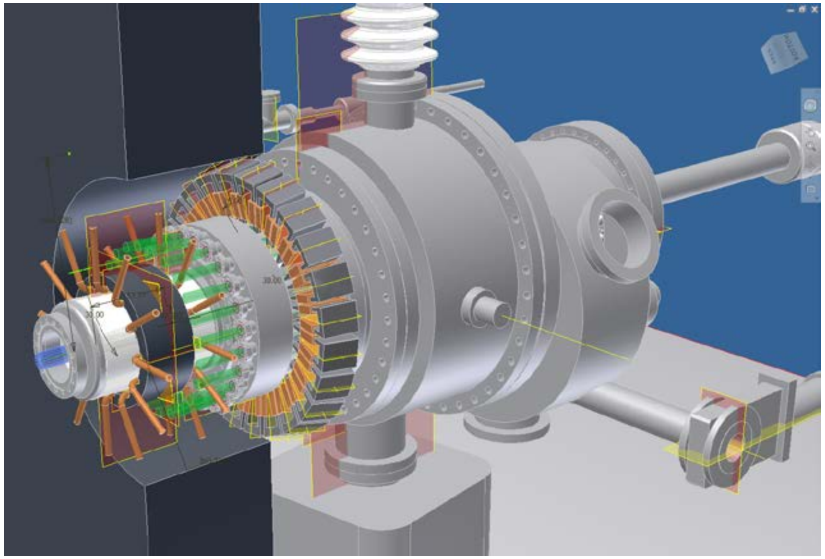
Single collision of each electron bunch allows for large beam disruption, giving high luminosity and full electron polarization transparency

ERL with 1.32 GeV SRF Linac and two FFAG recirculating allow for full luminosity ($> 10^{33}\ cm^{-2}\ s^{-1}$) up to 15.9 GeV and reduced luminosity up to 21.2 GeV



eRHIC R&D

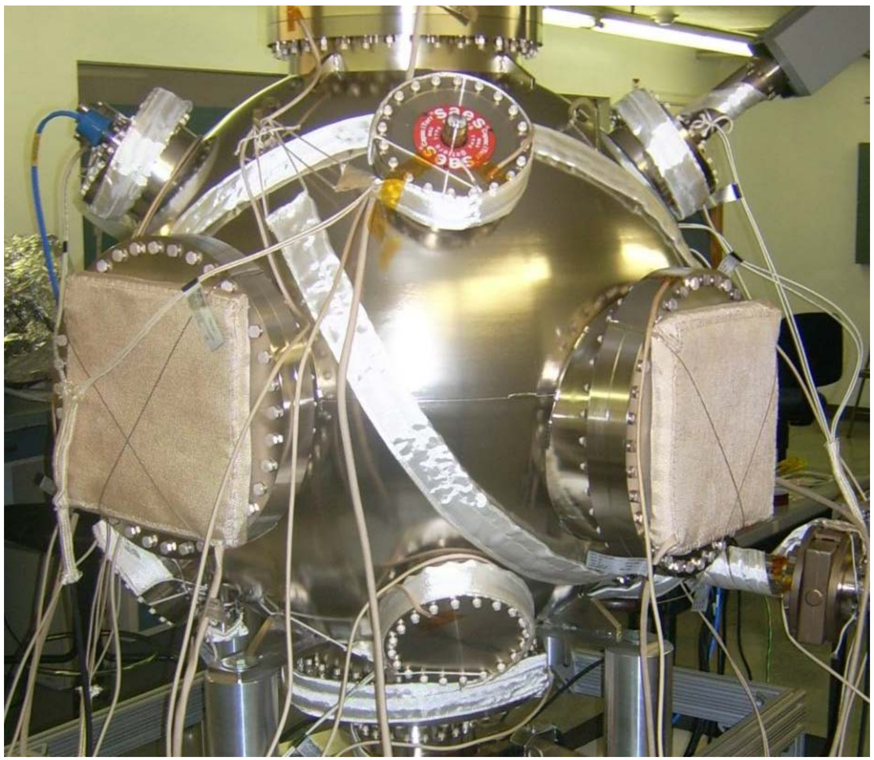
- High current polarized e-gun (SBIR SVT – presentation yesterday)
- Polarized ^{3}He source
- Coherent Electron Cooling
- Beam-Beam simulations
- SRF cavity development
- High current ERL technology
  - Non-destructive diagnostics
  - RF power and control
- FFAG accelerator
- Compact small-gap magnets with permanent magnets



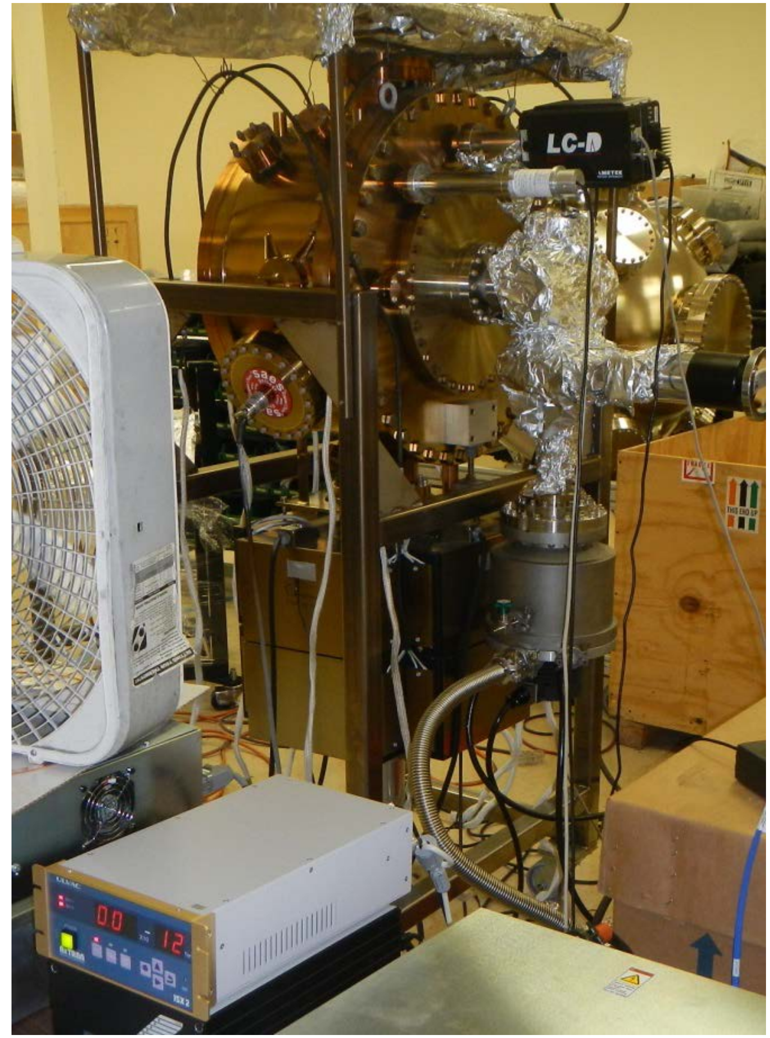
Stony Brook U designed, AES built high-current cavity

Funneling high-current polarized electron gun

Recent measurements have confirmed that large vessels can be made to achieve low to mid 10^{-12} Torr vacuum levels



Recently current extracted from gun



View of Gatling Gun Main vessel under XHV Vacuum

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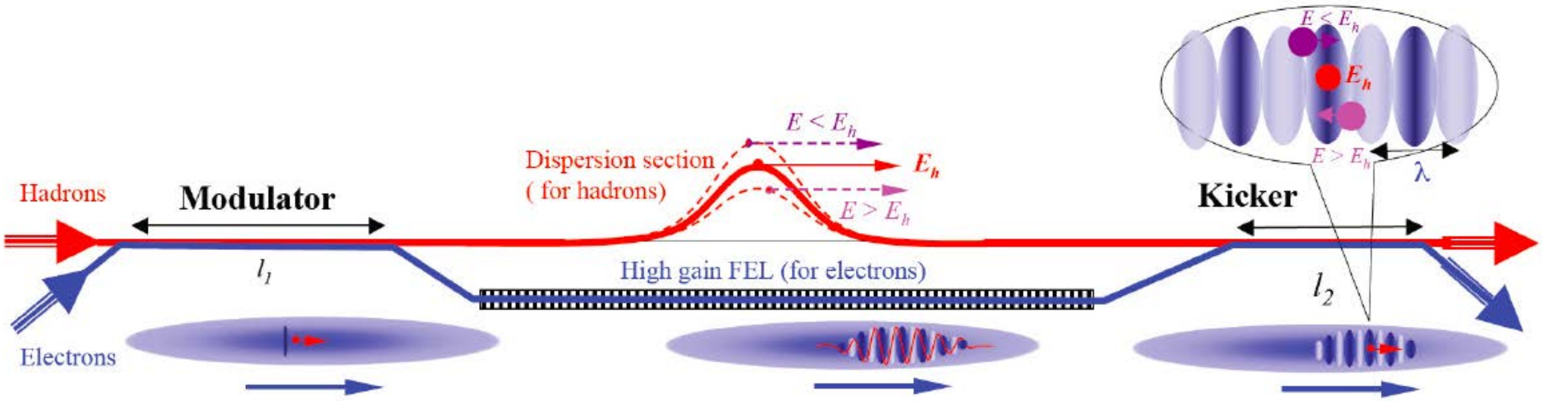
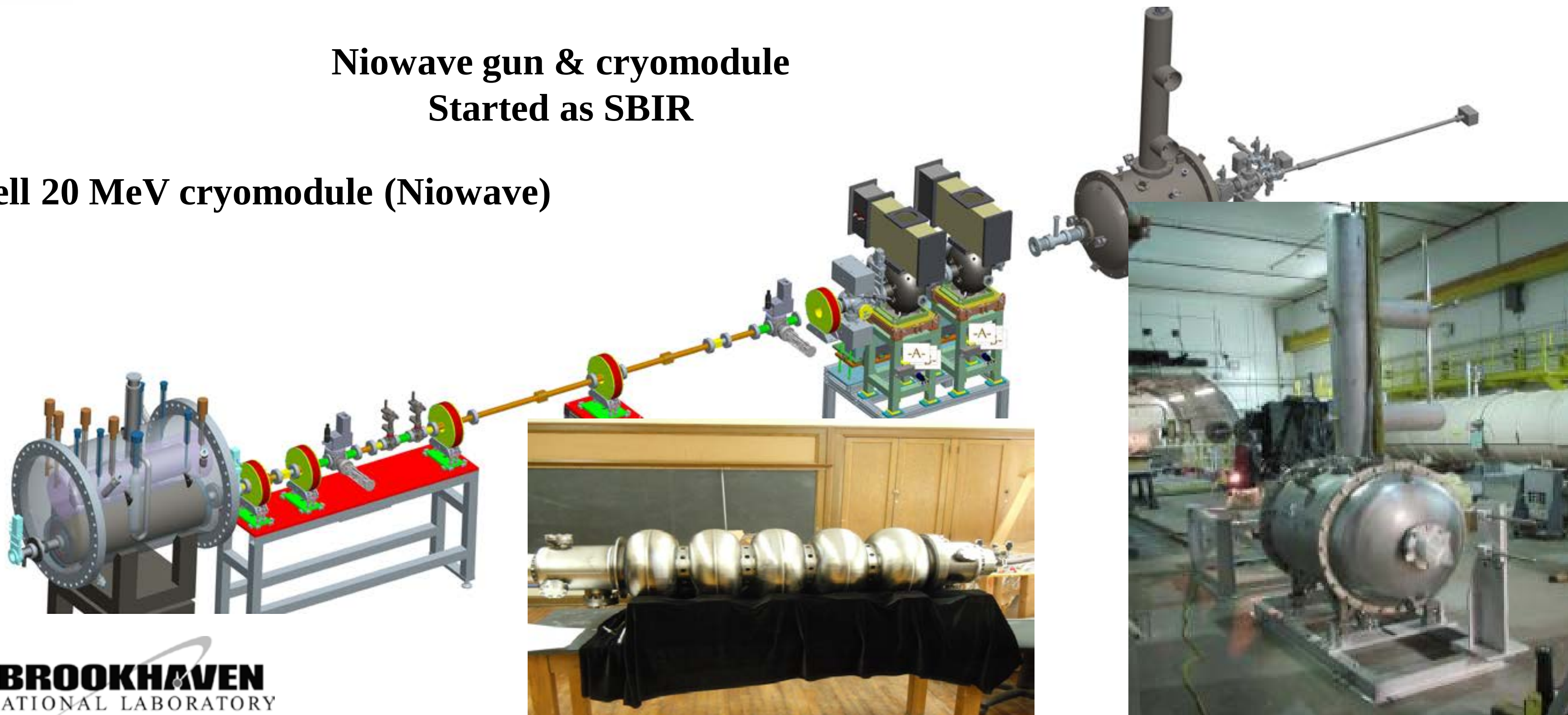
Coherent electron Cooling Proof-of-Principle experiment



Niowave gun & cryomodule
Started as SBIR

5-cell 20 MeV cryomodule (Niowave)



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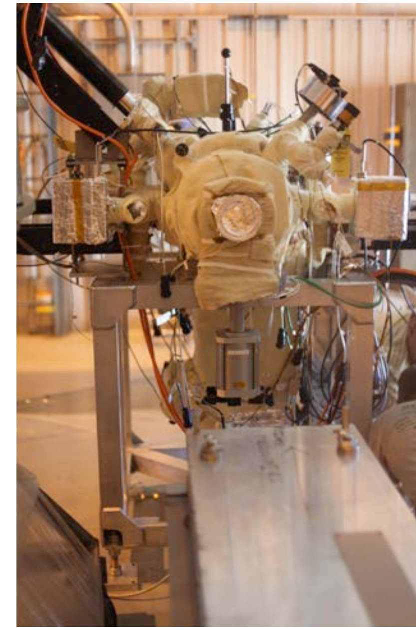
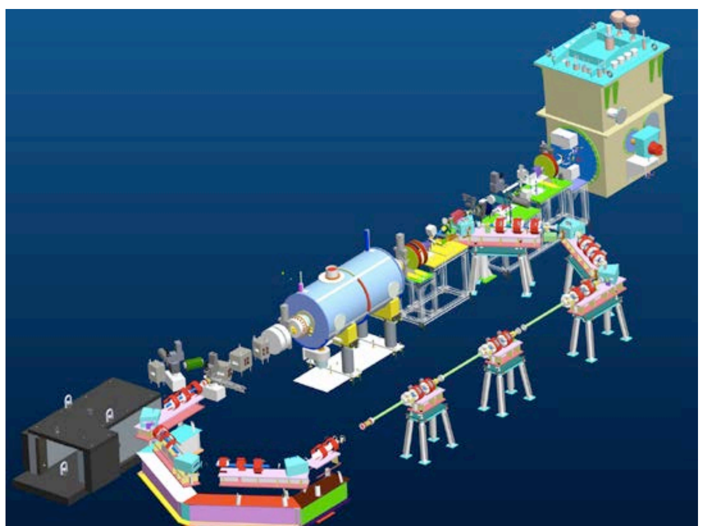
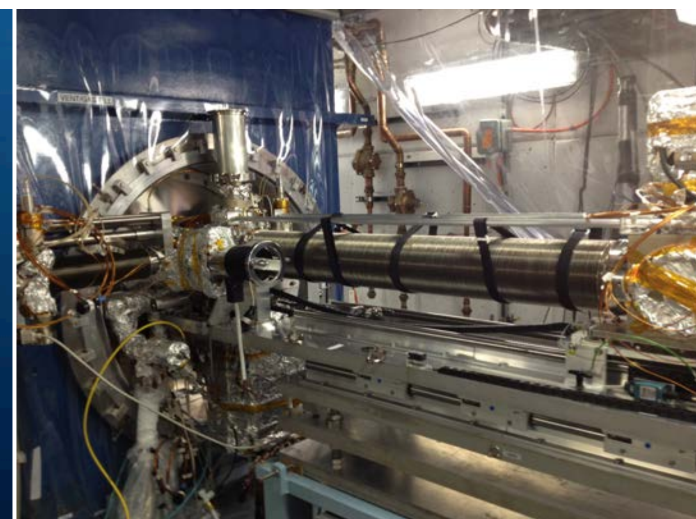
R&D on ERL



Test the key components of the 300 mA, 20 MeV SRF ERL (many AES components, including results of SBIRs)

- 703.75 MHz **SRF gun** test
- high current 5-cell **SRF ERL** with ferrite HOM absorbers
- test the beam current stability criteria for CW beam currents
- measure beam quality
- measure halo, radiations





Examples of opportunities

Extreme High Vacuum (XHV) Valve

- High Quantum Efficiency Polarized Photo-cathode electron sources will require reliable XHV conditions (~10^{-12} Torr) to maintain practical cathode life times
- When UHV all metal gate valves are actuated, bursts of gas emanate from the bellows and gate actuator mechanism in the valve bonnet into the bore of the Valve. This behavior is acceptable for most UHV applications but detrimental when it comes to XHV
- There is a need for a bakeable XHV valve that maintains a constant internal pressure independent of opening and closure at vacuum levels down to the low 10^{-12} Torr vacuum range

Examples of opportunities (continued)

Accelerator Technology:

SRF cavity

Examples: Niowave development of SRF crab cavities.

AES 704 MHz cavity and gun

HOM damping

Cryomodule

Crab cavities

Electron guns

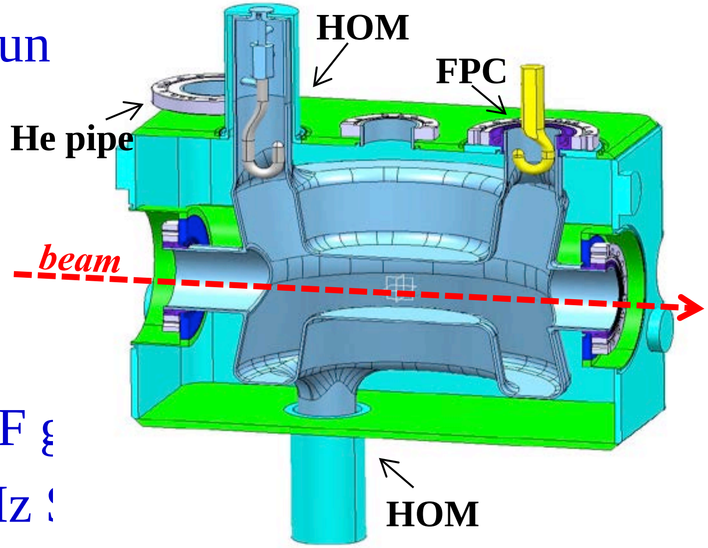
Example: AES 1.3 GHz SRF g

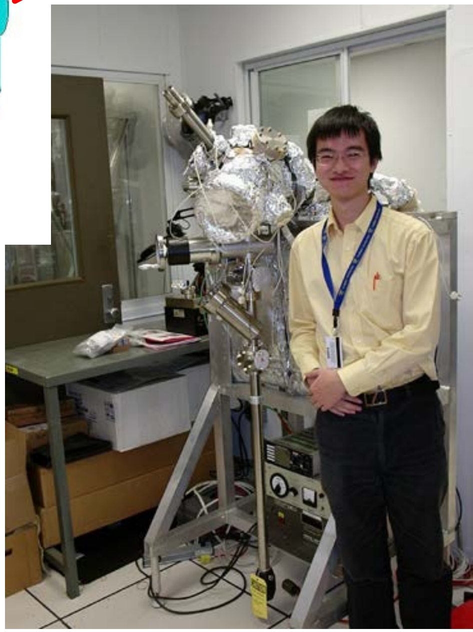
Example: Niowave 112 MHz S

Photocathodes

Example: AES preparation chambers

Example: AES polarized SRF gun load-lock





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Examples of opportunities (continued)

Instrumentation:

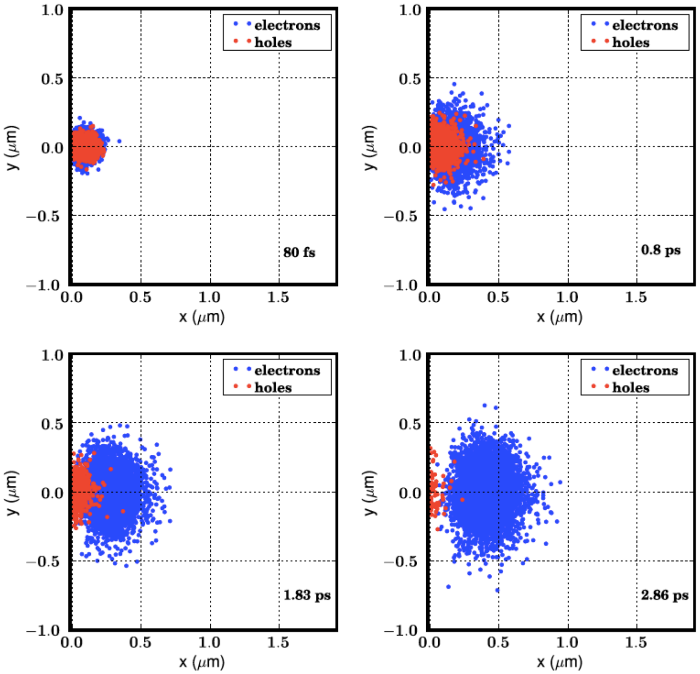
Non-destructive beam monitors

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

diamond amplified photocathodes, …



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Summary

The RHIC complex serves a wide user base (RHIC experiments, isotope production, space radiation studies), and is continually upgraded

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 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

RHIC and the SBIR/STTR Program

- The BNL hadron complex comprises eight accelerators for operation, including the 2 RHIC rings
- The C-AD Department has over 400 staff members which operate, maintain and upgrade the accelerator complex and do R&D on a variety of subjects
- We consider the SBIR/STTR program as an important element in upgrades and accelerator R&D
- SBIR/STTR programs are highly encouraged and strongly supported by C-AD. Talk to us!

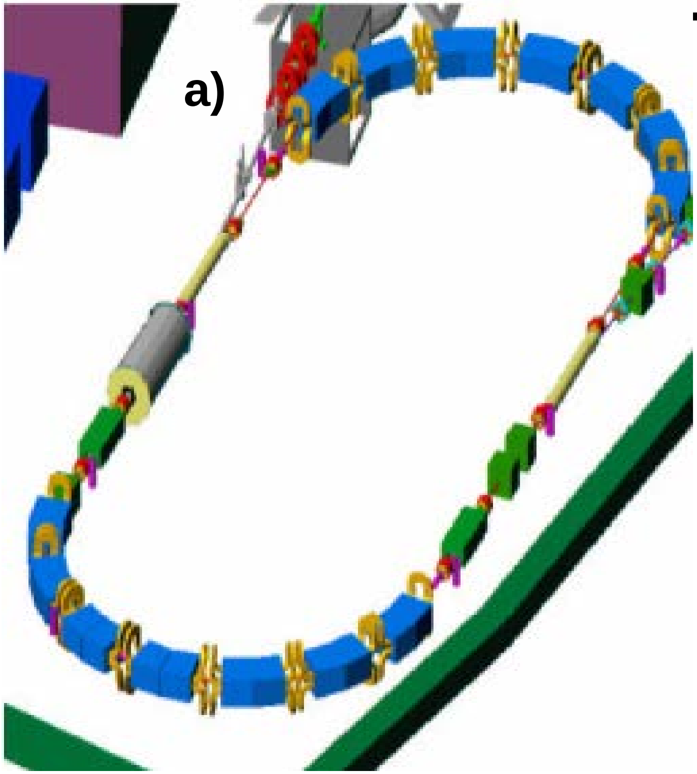
RHIC luminosity and polarization goals

parameter	unit	achieved		goals	
Au-Au operation		**2014**		**≥ 2016** 56 MHz SRF + LION	
energy	GeV/nucleon	100		100	
no colliding bunches	…	111		111	
bunch intensity	10^9	1.6		1.9	
avg. luminosity	10^{26} cm^{-2}s^{-1}	**50**		**100**	
p↑-p↑ operation		**2013**		**≥ 2015** **OPPIS** + e-lenses	
energy	GeV	100	255	100	255
no colliding bunches	…	107	111	– 111 –	
bunch intensity	10^{11}	1.6	1.85	2.0	2.5
avg. luminosity	10^{30} cm^{-2}s^{-1}	**33**	**160**	**60**	**300**
avg. polarization*	%	**59**	**52**	**65**	**60**

*Intensity and time-averaged polarization as measured by the H-jet. Luminosity-averaged polarizations, relevant in single-spin colliding beam experiments, are higher. For example, for intensity-averaged P = 48% and $R_x = R_y$ = 0.2 (250 GeV, 2011), the luminosity-averaged polarization is P = 52%.

Recent Technological Impacts of BNL NP Research

a)

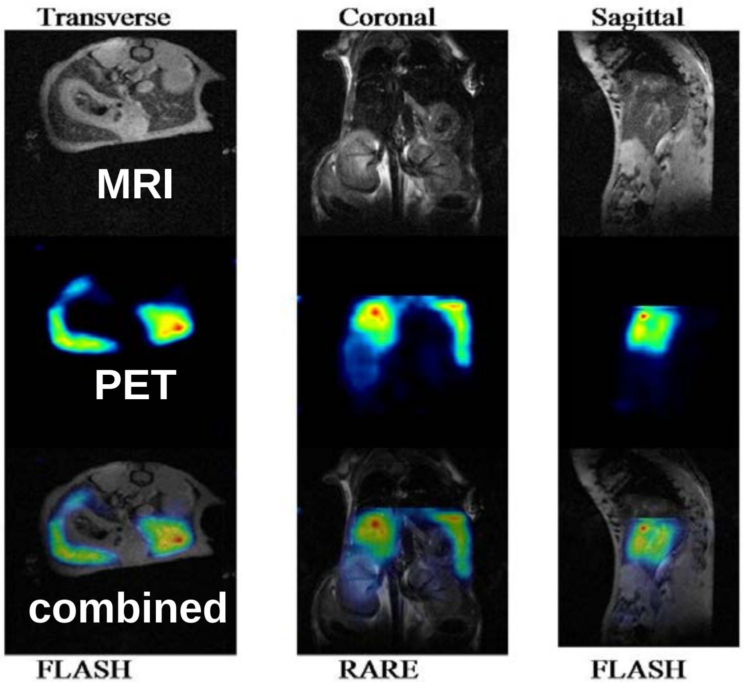


b)

a) CRADA to develop ion Rapid Cycling Medical Synchrotron (iRCMS) with BEST Medical

b) HTS magnet development expertise from BNL's work for NP accelerators critical in attracting ARPA-E grant for Superconducting Magnet Energy Storage (SMES)

c) First combined MRI-PET imaging (on mouse liver) done with ^{52}Fe nanoparticles developed by BNL's radioisotope group



Examples of opportunities

Electronics Design and Fabrication:

RF power amplifiers

Example: Green Mountain – GaN-FET class-F power amplifier.

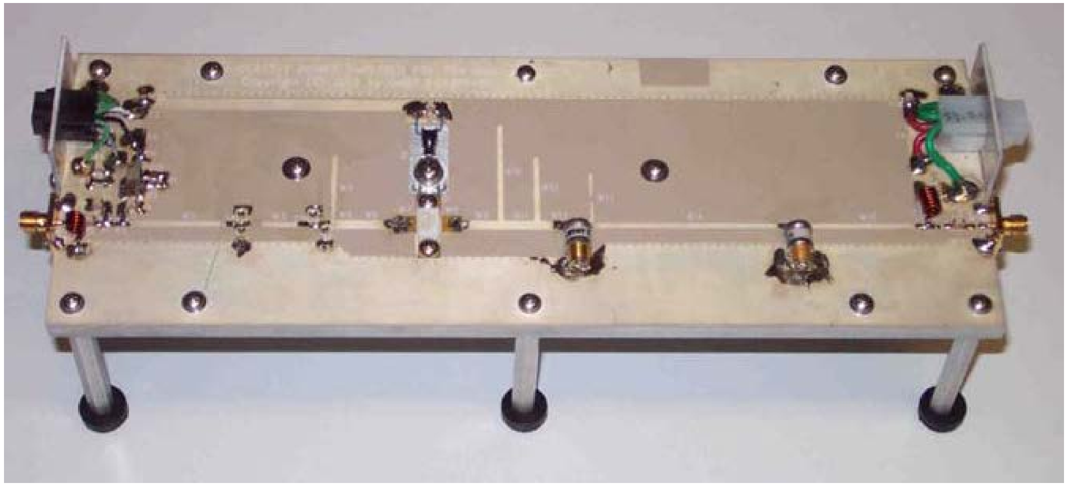
Need for 350-400 MHz

Reactive power tuners

Example: Omega-P development of high-power, fast reactive tuners

Materials for reactive power tuners

Example: Euclid Techlabs development of Nonlinear Ferroelectric



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Non-Scaling Fixed Field Alternating Gradient

Using NP developed NS-FFAG to reducing the size and weight of a radio-therapy carbon gantry (**135 tons** to **2 tons**) (Dejan Trbojevic)