THE RHIC FACILITY AND THE SBIR/STTR PROGRAM

ILAN BEN-ZVI
ASSOCIATE CHAIR / DIVISION HEAD
ACCELERATOR R&D DIVISION
COLLIDER-ACCELERATOR DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY

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RHIC and the SBIR/STTR Program

The RHIC complex comprises eight accelerators, including the twin 3.8 km superconducting collider rings.

The C-AD Department has about 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 the way we do accelerator R&D.

SBIR/STTR programs are highly encouraged and strongly supported by C-AD.

2012 RHIC Run (23.6 weeks of cryo ops) – most varied to date

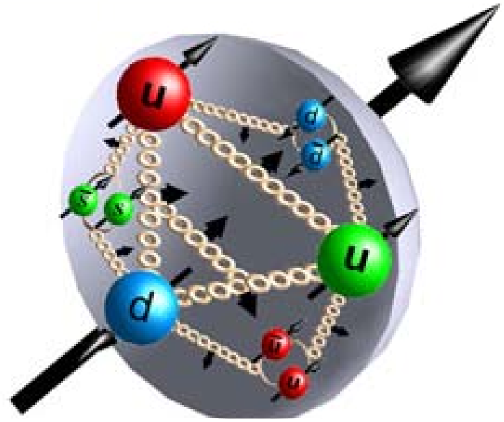
100 GeV polarized protons

new records for L_{peak} (1), L_{avg} (2), P (3)

255 GeV polarized protons

highest energy polarized proton beam (4)

new records for L_{peak} (5), L_{avg} (6), P (7)



96.4 GeV/nucleon uranium-uranium

heaviest element in collider (8), shape

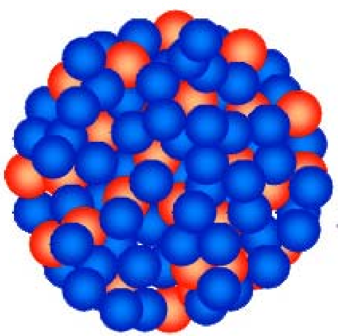
stochastic cooling: $L_{max} > L_0$ 1st time in hadron collider! (9)

all ions lost through burn-off 1st time in hadron collider! (10)

100 GeV/nucleon copper-gold

new species combination in collider (11)

highest ion charge/bunch (+8.5% rel. to Run-11) (12)



Uranium Nucleus

2.5 GeV/nucleon gold-gold collision test

lowest energy to date, 20% of nominal injection ($B\rho$) (13)

He-3 acceleration (unpolarized) in Booster and AGS

highest energy He-3 beam (14)

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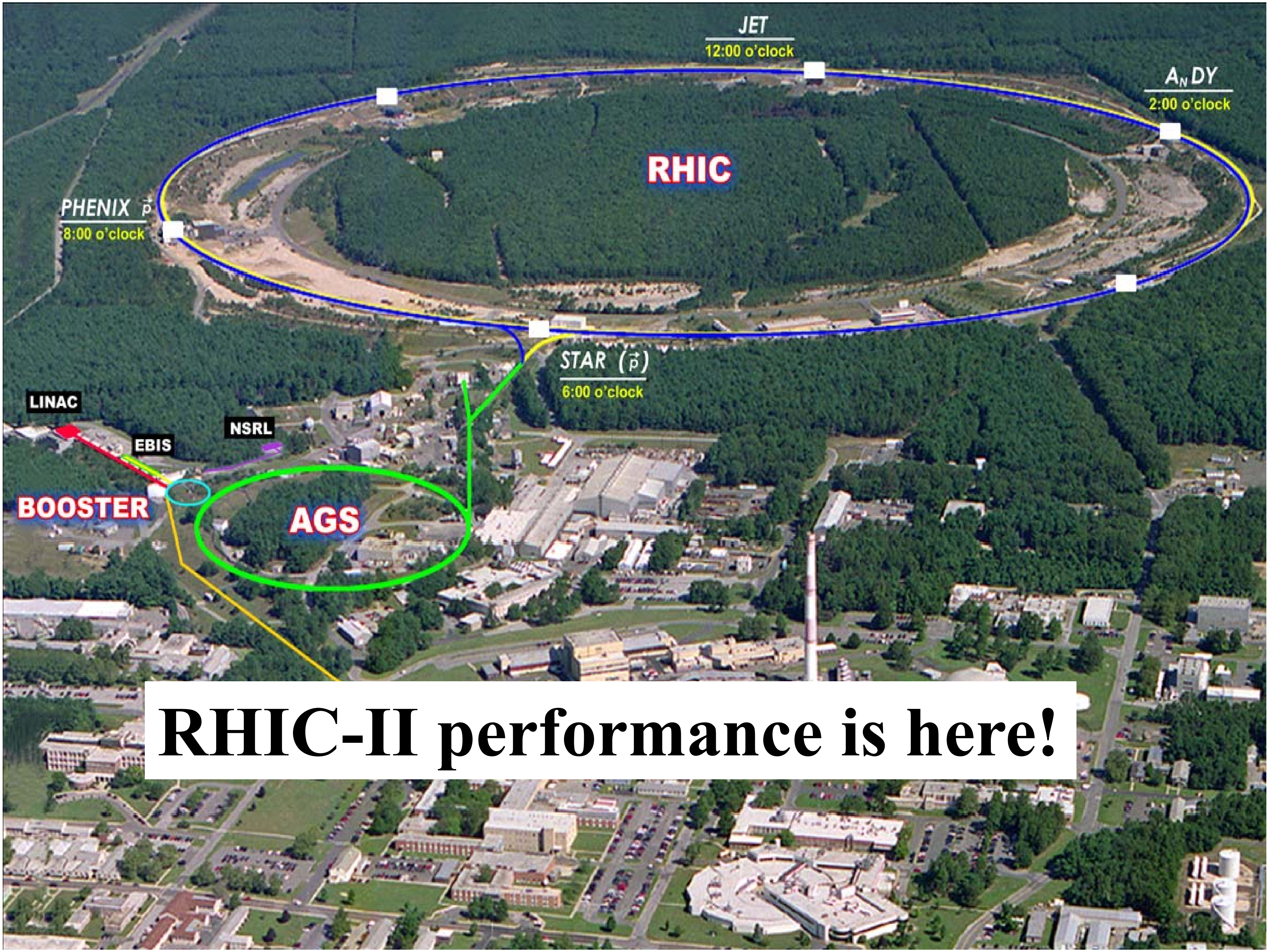
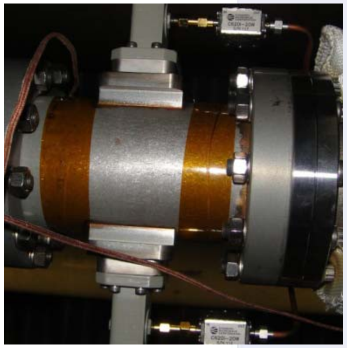


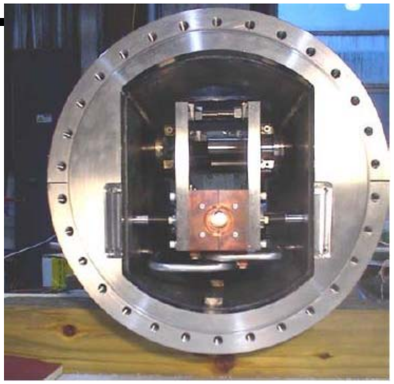
RHIC-II performance is here!

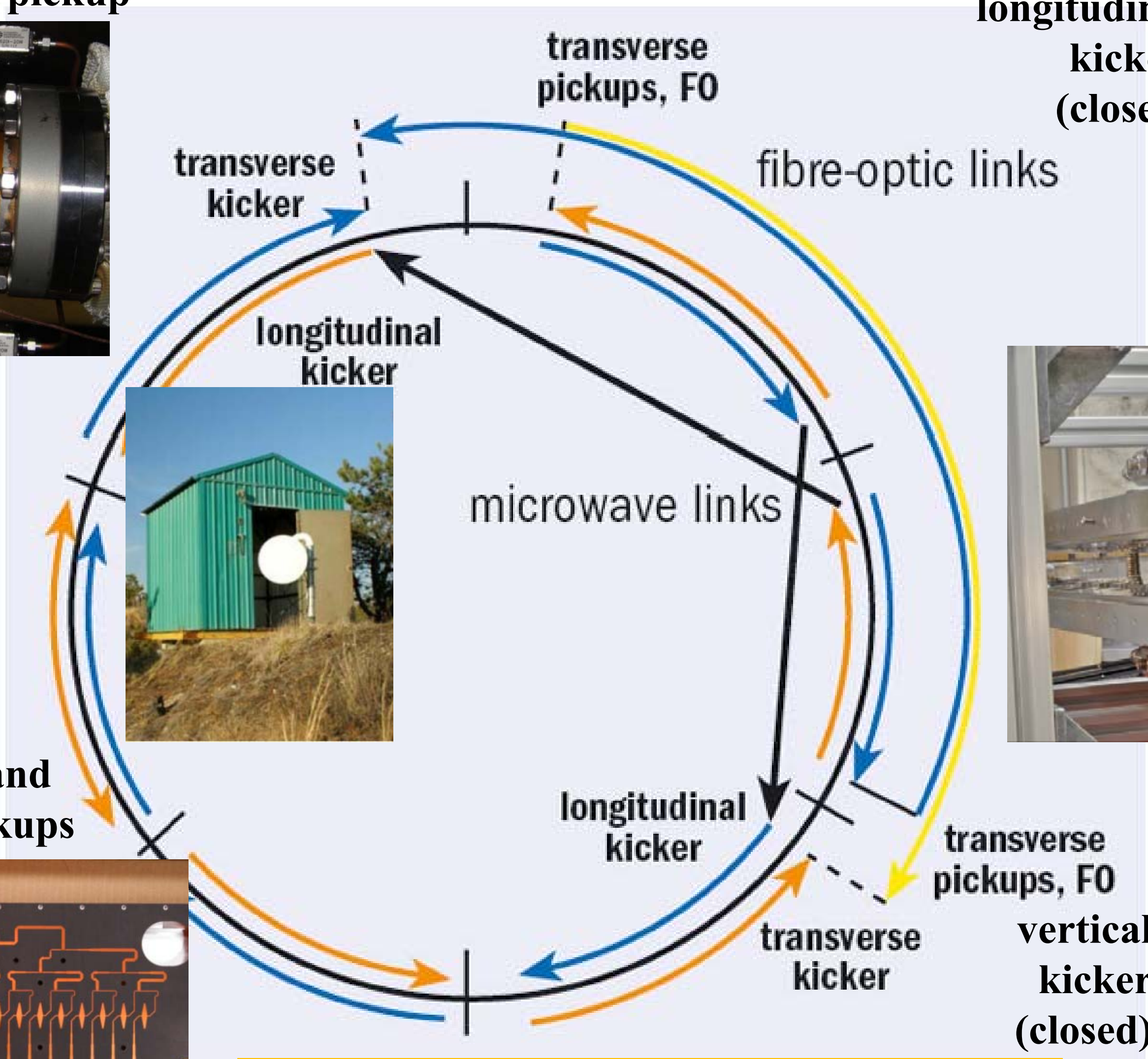
Now have full 3D stochastic cooling for heavy ions

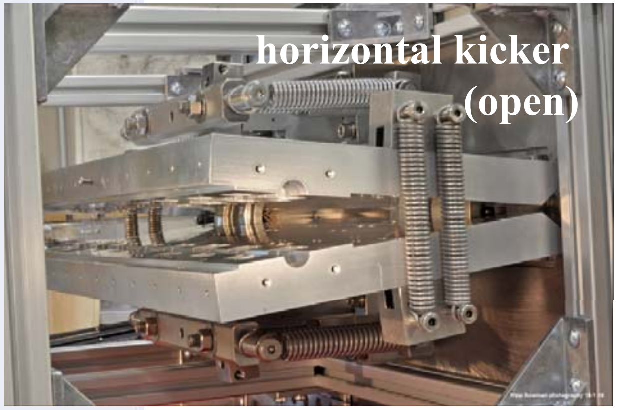
longitudinal pickup



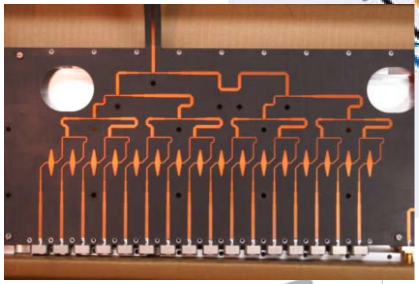
longitudinal kicker (closed)







horizontal and vertical pickups



vertical kicker (closed)

5-9 GHz, cooling times ~1 h

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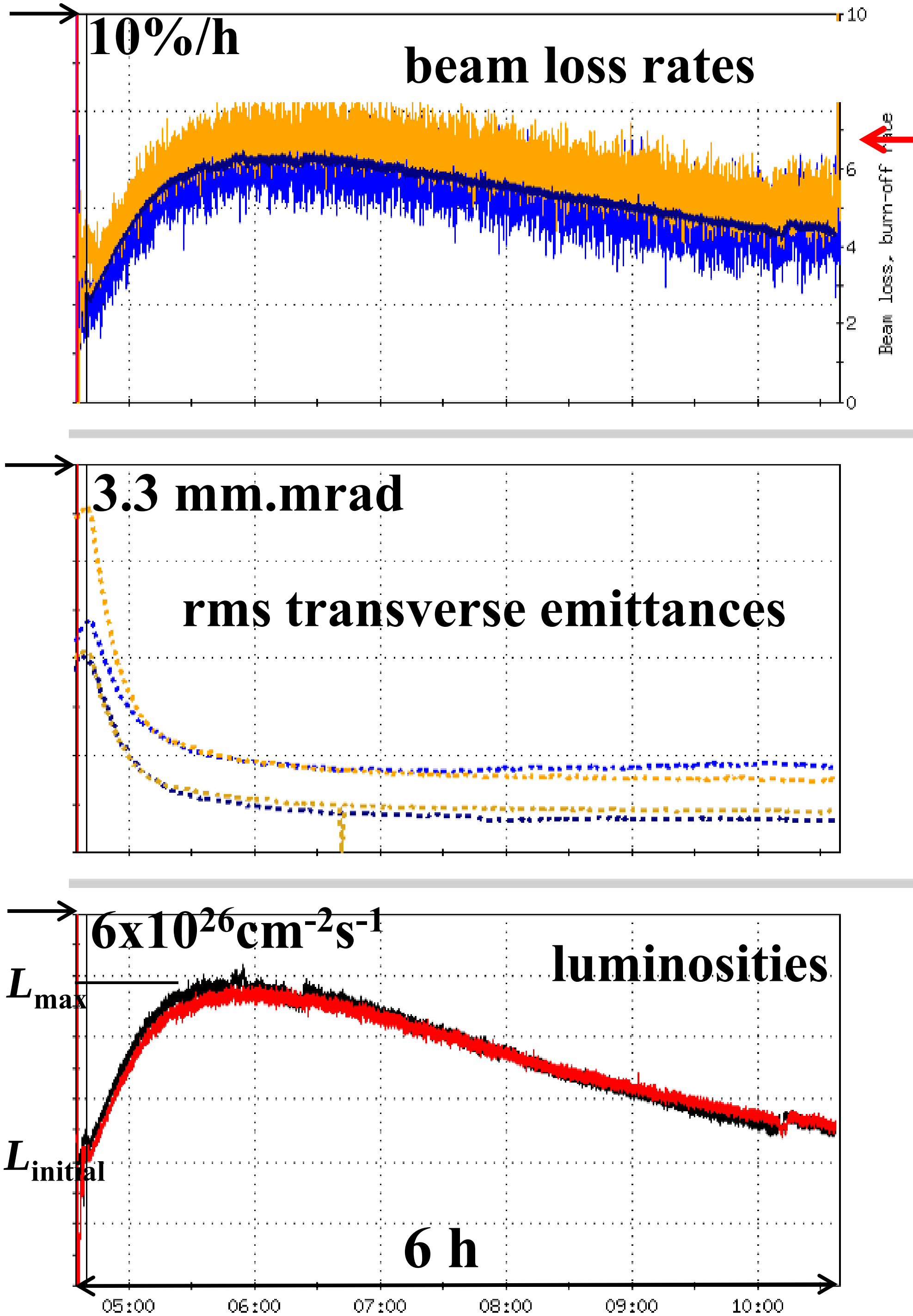
M. Brennan, M. Blaskiewicz, F. Severino, PRL 100 174803 (2008)

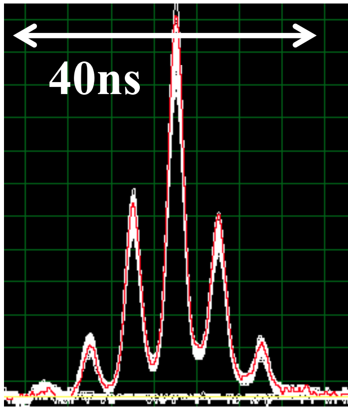


U-U store – new mode in 2012

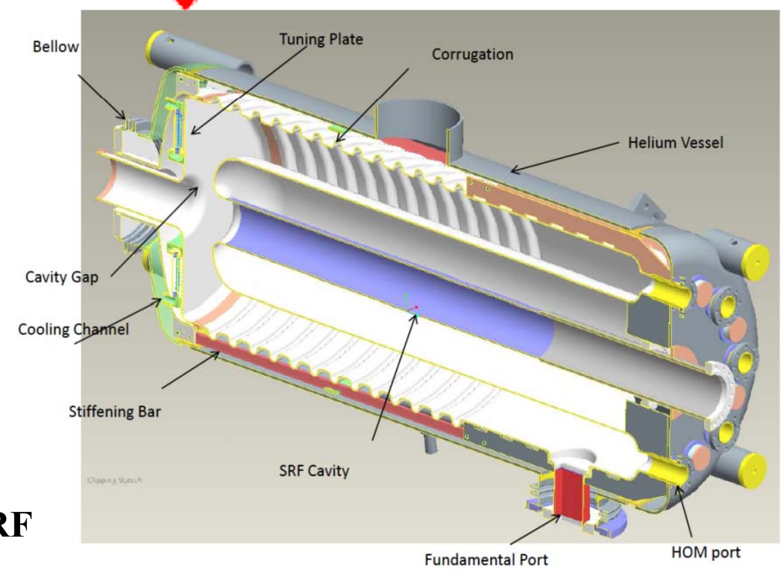
All beam loss though luminosity (burn-off)!

3D stochastic cooling leads to
new feature in hadron collider:
$L_{max} > L_{initial}$

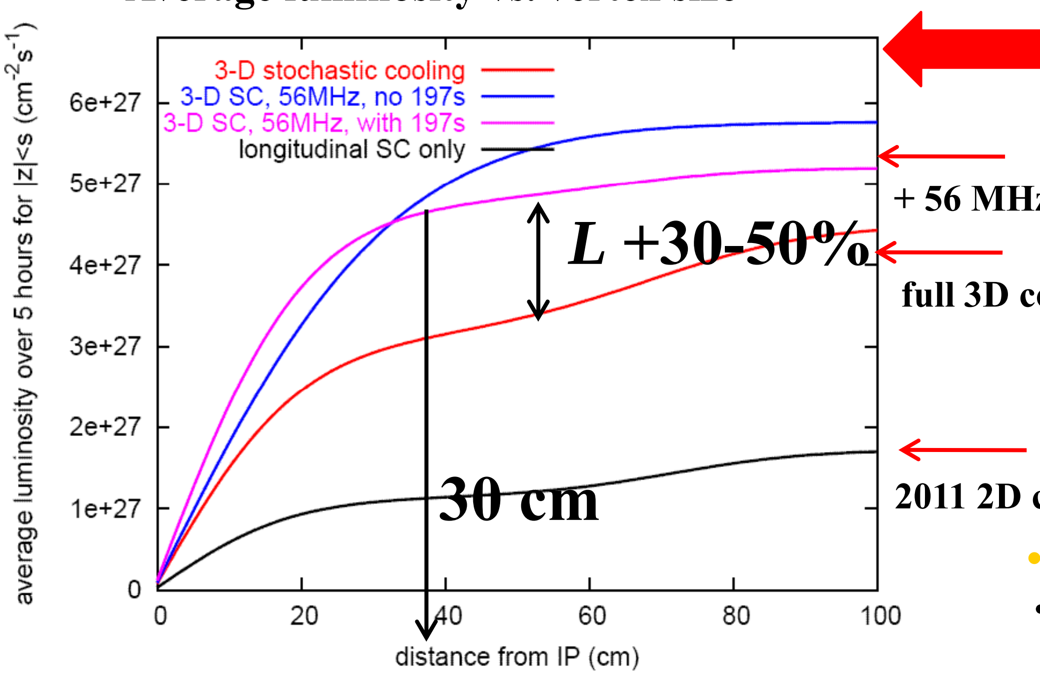
56 MHz SRF– Commissioning planned for 2014



Longitudinal profile at end of store
- **even with cooling ions migrate into neighboring buckets**
- **can be reduced with increased longitudinal focusing**



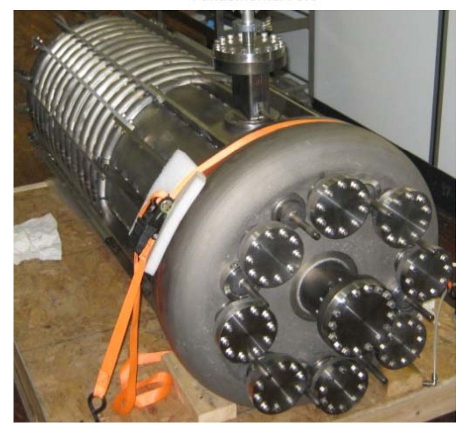
Average luminosity vs. vertex size



+ 56 MHz SRF

full 3D cooling

2011 2D cooling



- **λ/4 Nb resonator**
- **common to both beams**
- **beam driven**
- **56 MHz, 2 MV**

Built by Niowave

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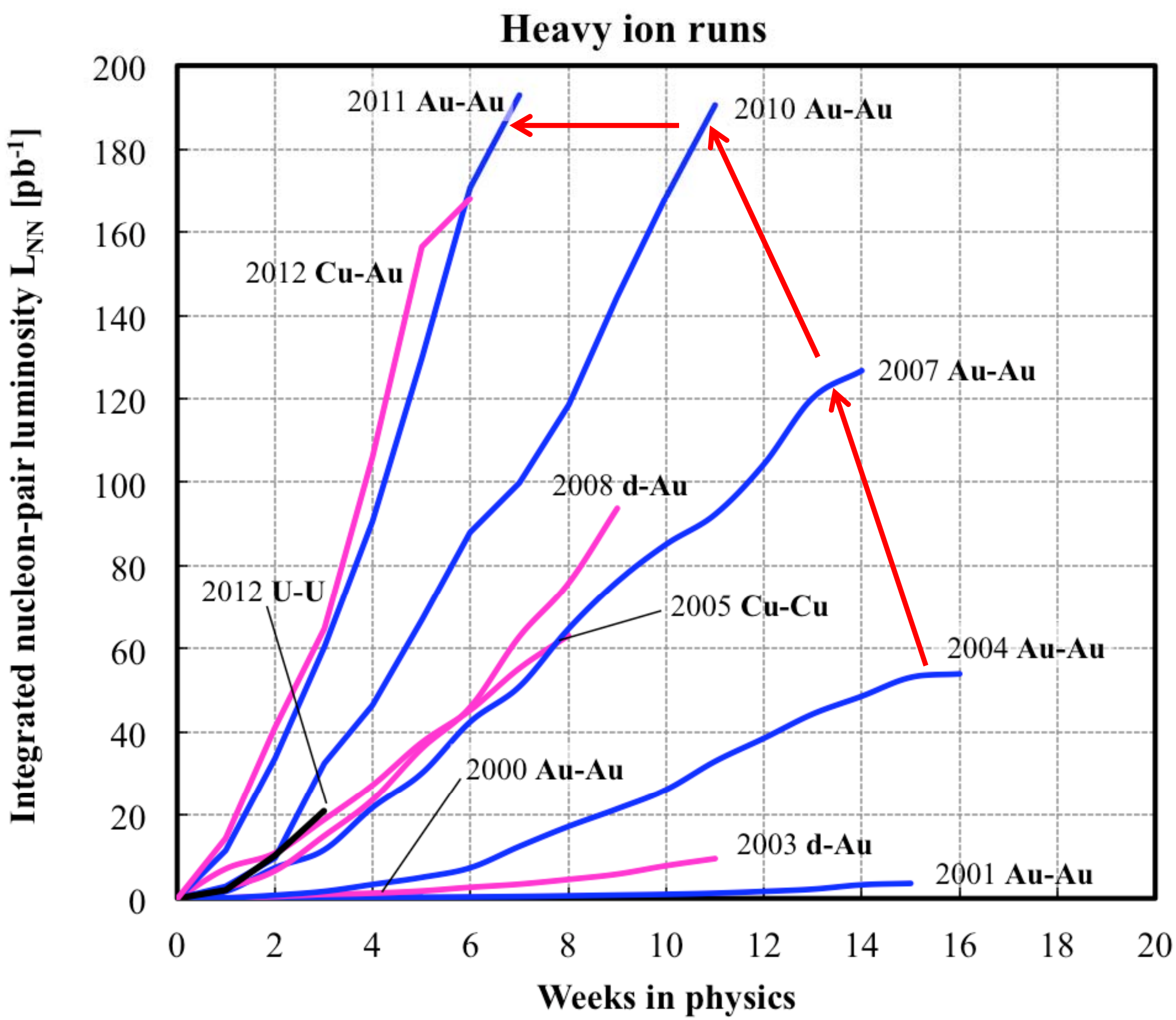
Calculation by M. Blaskiewicz

RHIC heavy ions – luminosity evolution to date



<L> = 15x design in 2011

About 2x increase in L_{int}/week each

- **Run-4 to Run-7**
- **Run-7 to Run10**
- **Run-10 to Run-11**

$L_{NN} = L\, N_1 N_2$ (= luminosity for beam of nucleons, not ions)

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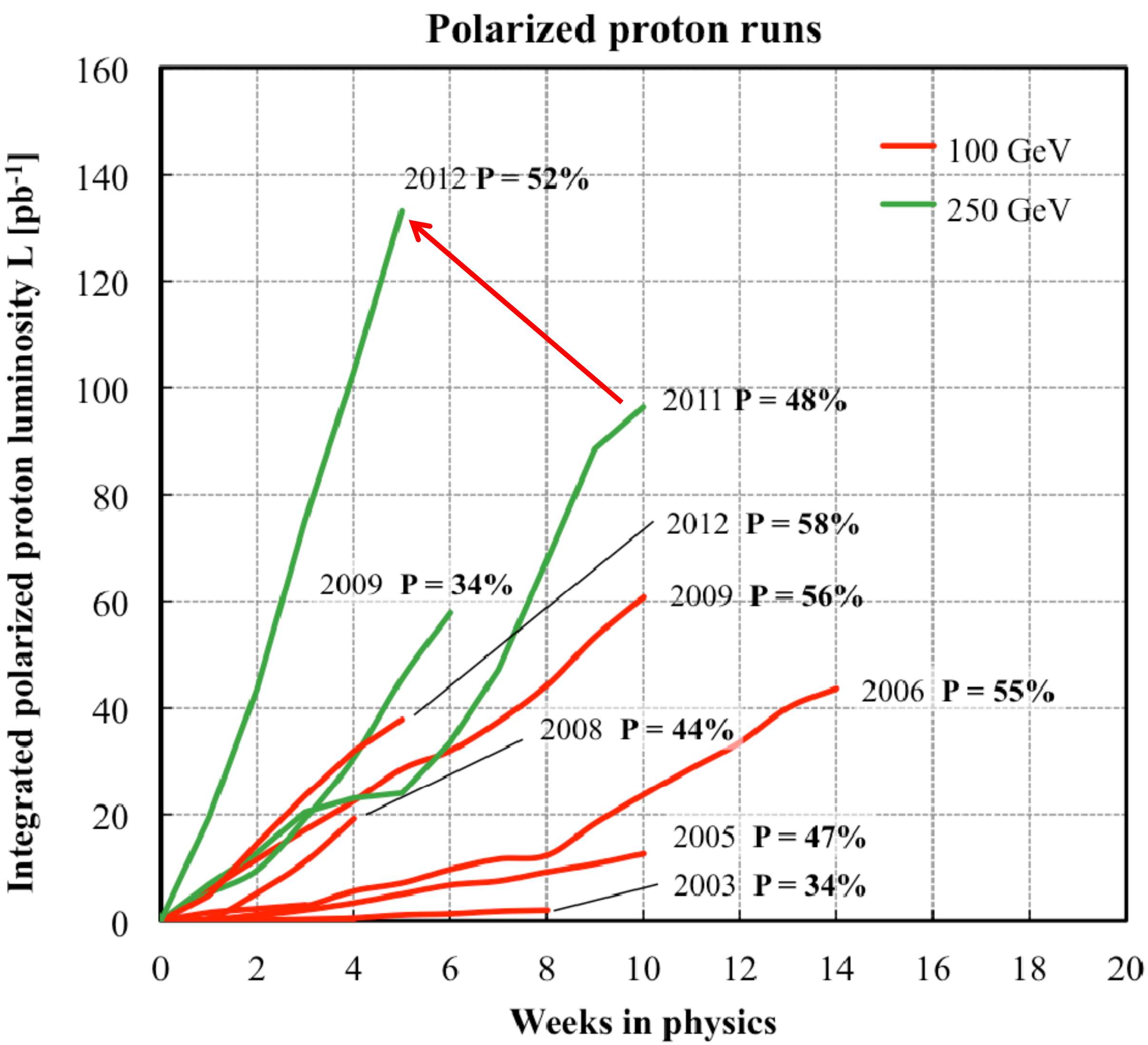
RHIC polarized protons – luminosity and polarization



At 255 GeV in 2012

$L_{avg} = 105 \times 10^{30} cm^{-2}s^{-1}$

$P_{avg} = 52\%$

L_{avg} +15% relative to 2011

P_{avg} +8% relative to 2011

$FOM = LP^2$

(single spin experiments)

$FOM = LP^4$

(double spin experiments)

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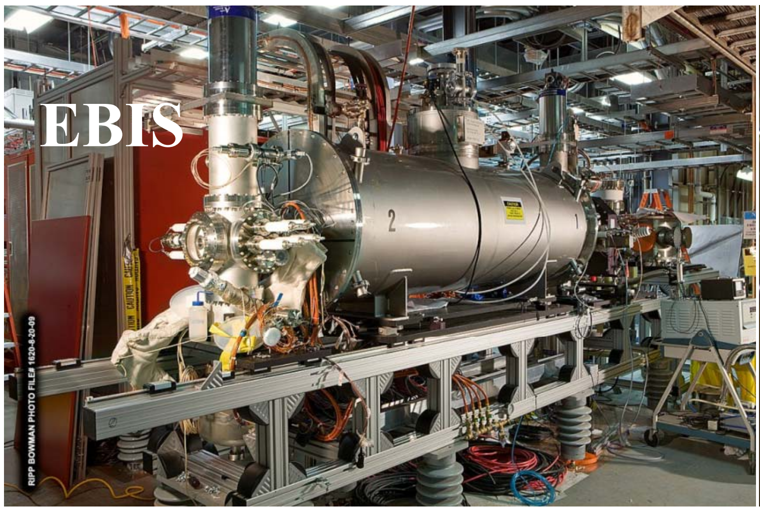
Electron Beam Ion Source (EBIS)

- Inject single charge ion from primary source (e.g. hollow cathode 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 in 2012 with

- **U^{39+} (not possible previously), Cu^{11+}, Au^{31+}**

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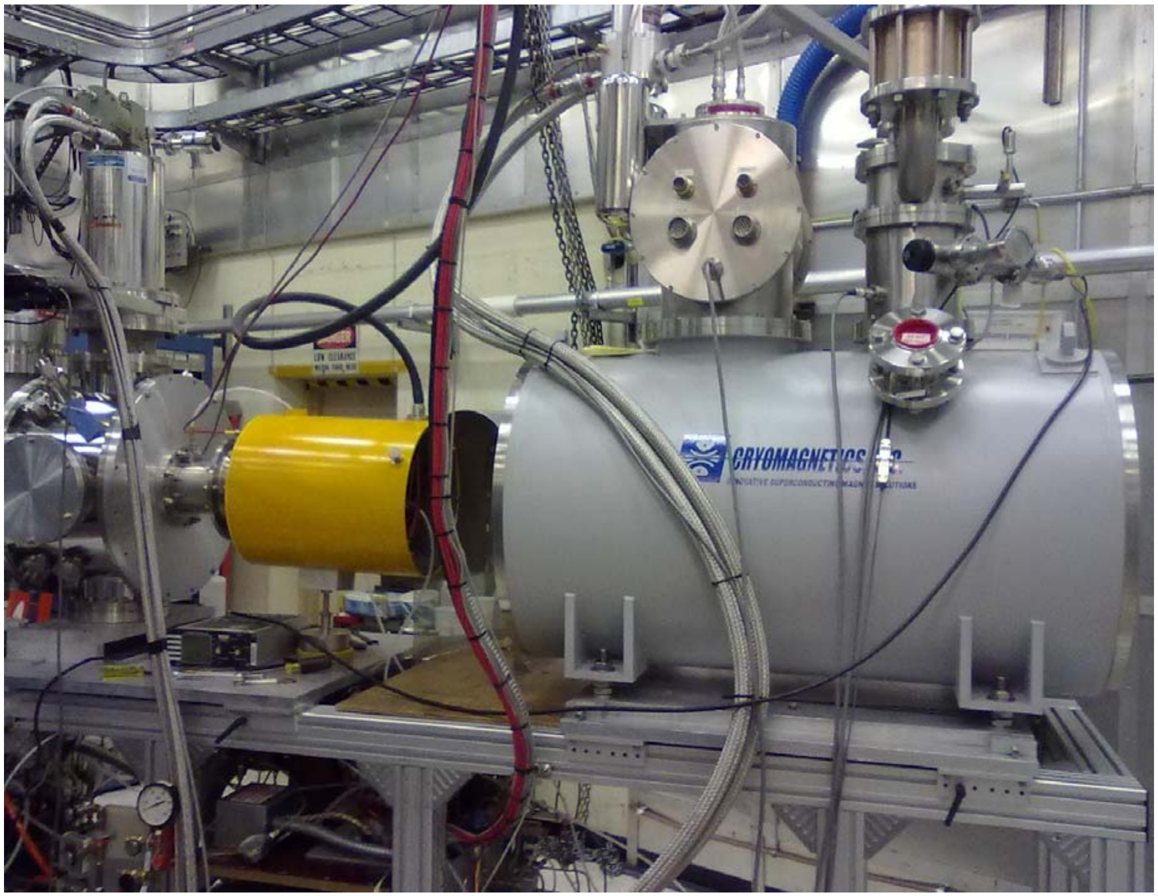
Optically Pumped Polarized H⁻ source (OPPIS) – A. Zelenski

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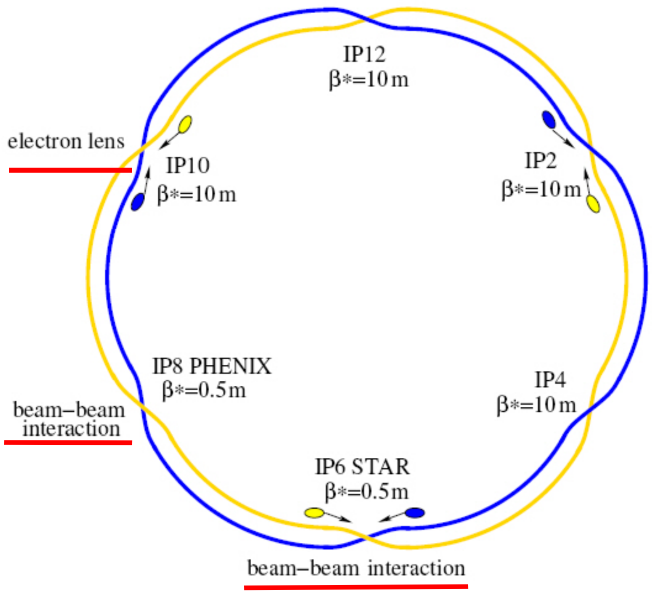
=> 10x intensity from Atomic Beam Source was accelerated through Linac

Electron lenses – partial head-on beam-beam compensation



Basic idea:

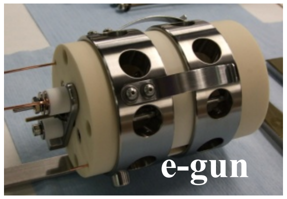
•2 beam-beam collisions with positively charged beam
•Add collision with a negatively charged beam – with matched intensity and same amplitude dependence

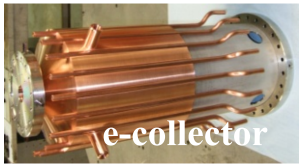
Compensation of nonlinear effects:

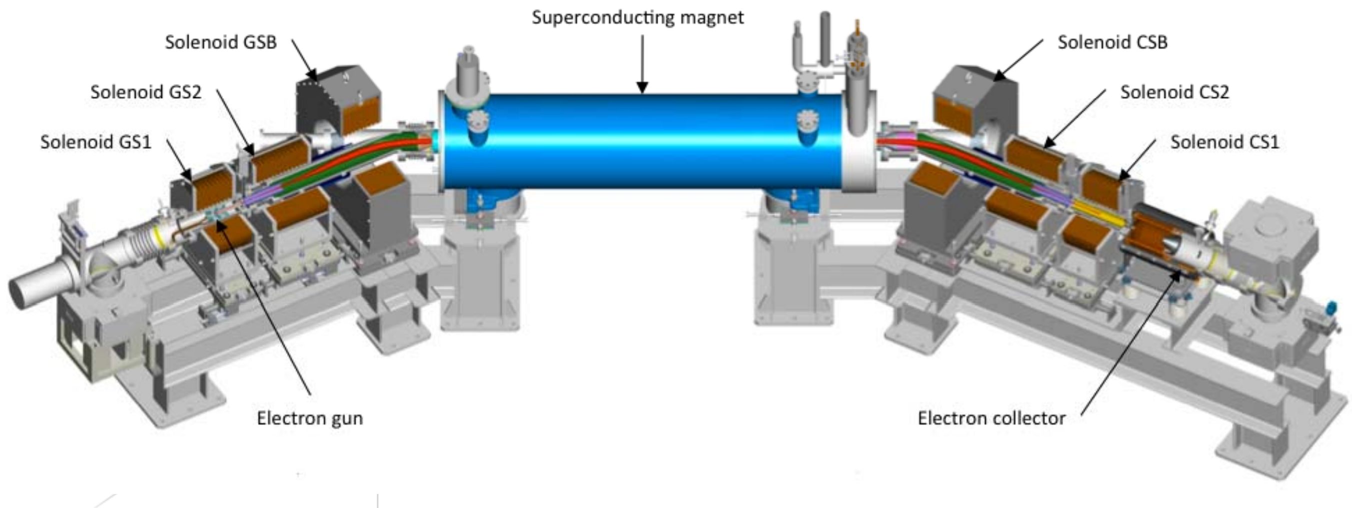
• e-beam current and shape
=> reduces tune spread
• $\Delta\psi_{x,y}$ = kπ between p-p and p-e collision
=> reduces resonance driving terms

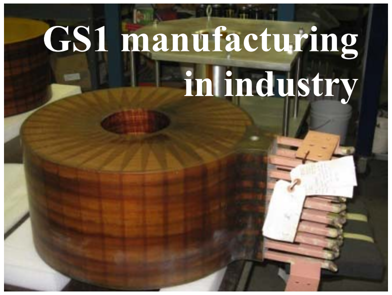
Installation in 2012

Expect up to 2x more luminosity



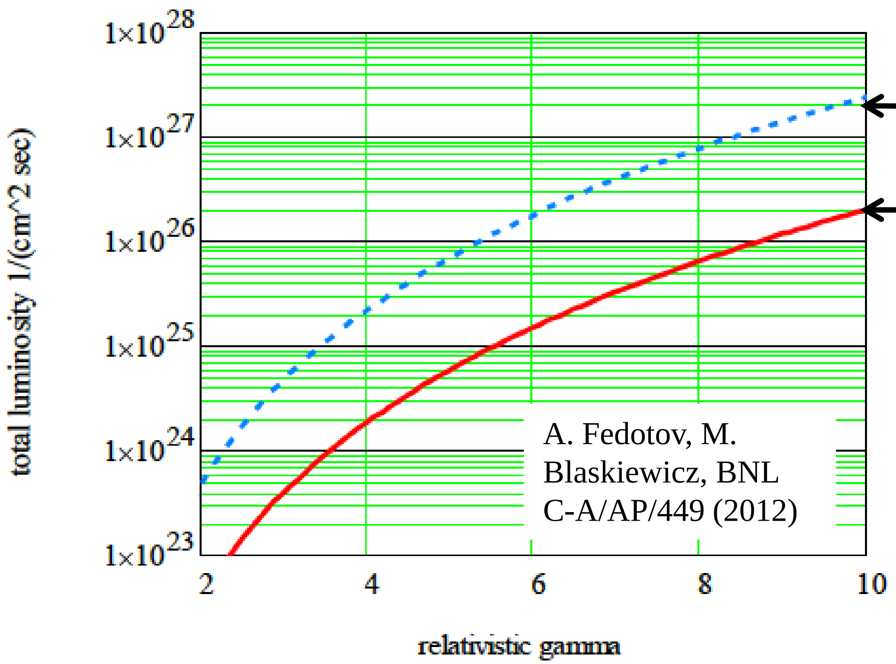






e-cooling for low energy RHIC operation

- Will likely use high brightness SRF electron gun for bunched beam electron cooling; up to ~10x L; ready after 2017
- Can use CeC setup for bunched e-cooling test

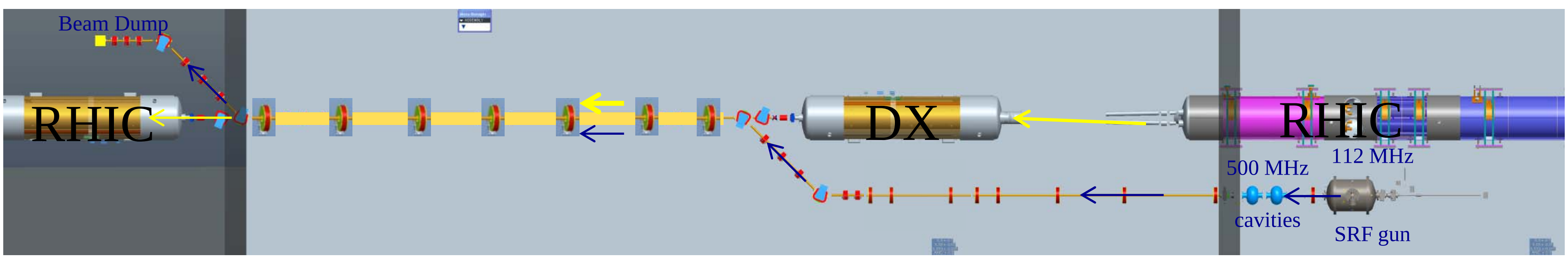


RHIC with cooling and long bunches (ΔQ_{sc} = 0.05, σ_s = 3m)

RHIC w/o cooling

Niowave's SBIR 112 MHz gun

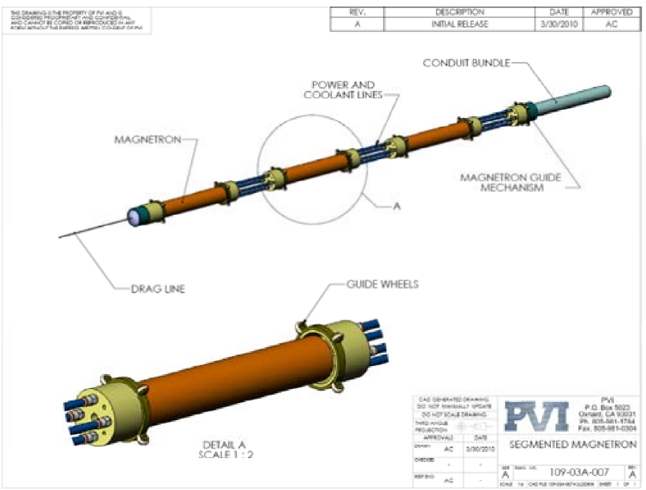
Bunched e-cooling test layout, same as CeC layout

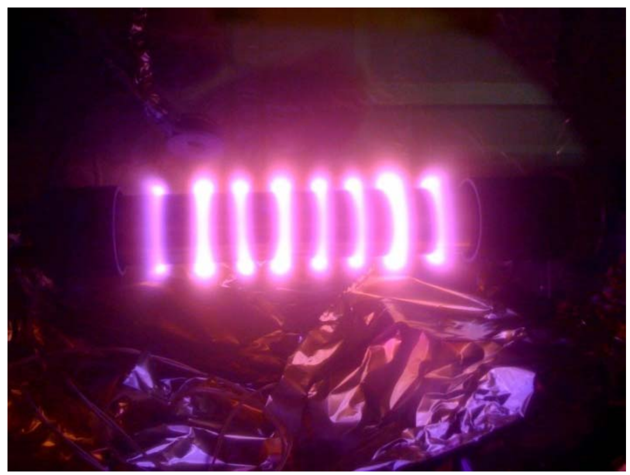


Upgrades for heavy ions and polarized protons – in situ-coating

- Electron clouds limit
  - Ion intensity (through instability at transition)
  - Proton emittance at injection, and intensity
- Warm parts are largely coated with NEG
- Cold arcs are SS, not coated => **Need in-situ coating for arcs**

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





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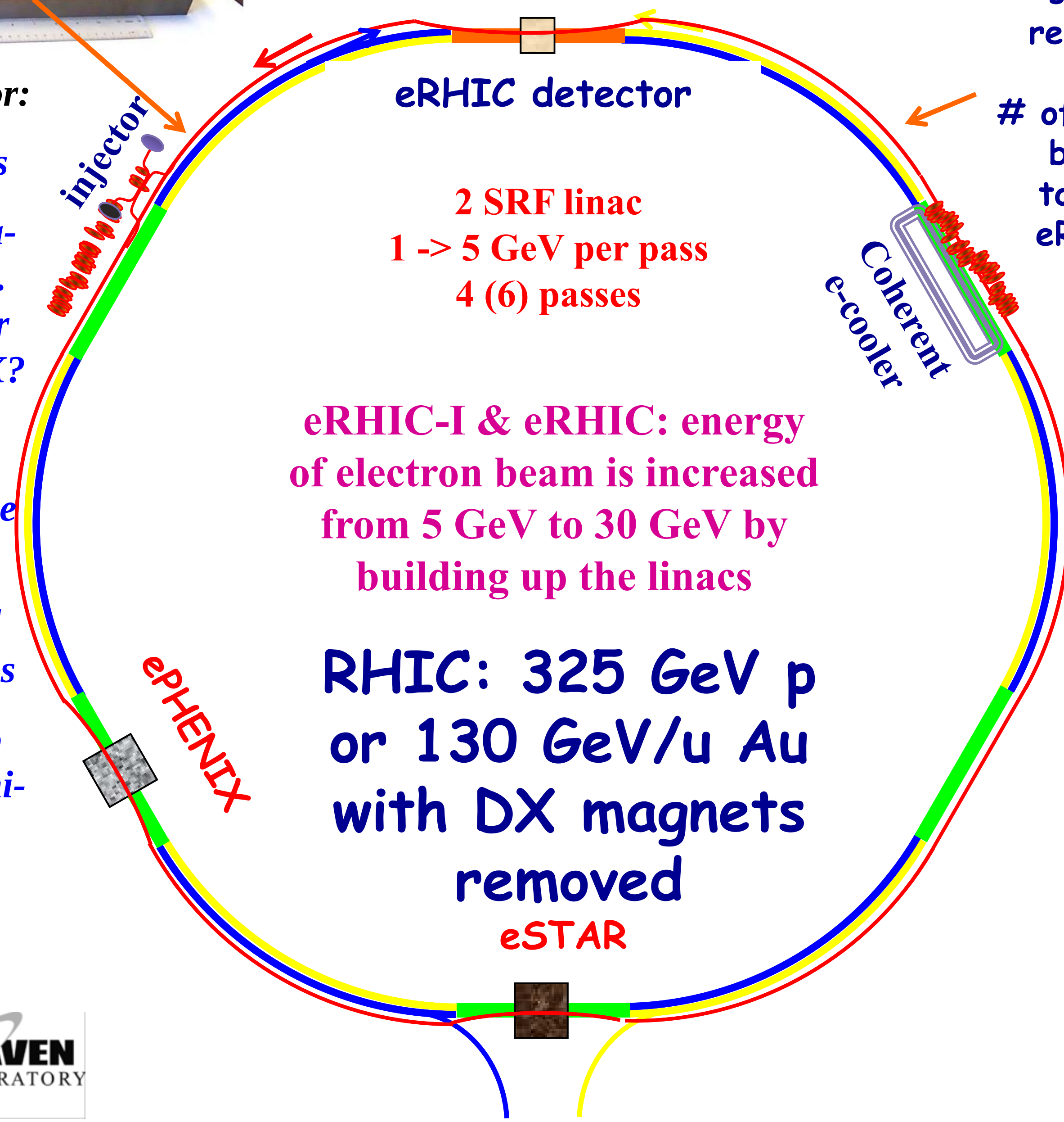
Need glow-discharge cleaning before Cu deposition
RF properties (at cryogenic temperatures) still to be determined

eRHIC Design

Design allows for:

- *multiple IP's*
- *reusing infra-structure + det. components for STAR, PHENIX?*
- *low cost*
- *easy up-grade*
- *minimal environmental impact concerns*
- *IR design to reach >10^{34} luminosity*

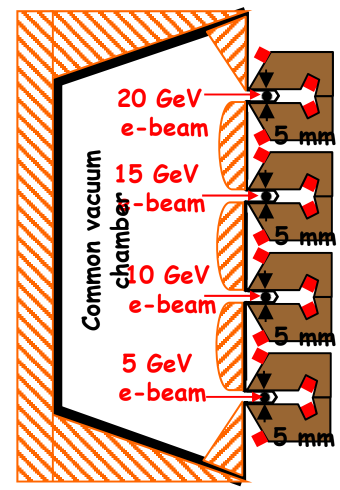


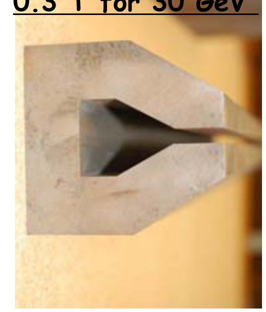
2 SRF linac
1 -> 5 GeV per pass
4 (6) passes

eRHIC-I & eRHIC: energy of electron beam is increased from 5 GeV to 30 GeV by building up the linacs

RHIC: 325 GeV p or 130 GeV/u Au with DX magnets removed

Vertically separated recirculating passes. # of passes will be chosen to optimize eRHIC cost





Gap 5 mm total
0.3 T for 30 GeV

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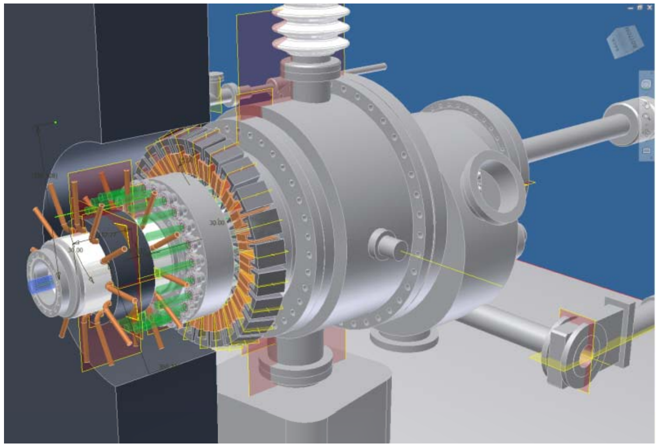
eRHIC R&D

- High current polarized electron gun.
- Polarized He^3 source.
- Coherent Electron Cooling.
- Beam-Beam simulations.
- SRF cavity development.
- High current ERL technology:
  - Non-destructive diagnostics
  - RF power and control
- Compact small-gap magnets.



Stony Brook U designed, AES built high-current cavity

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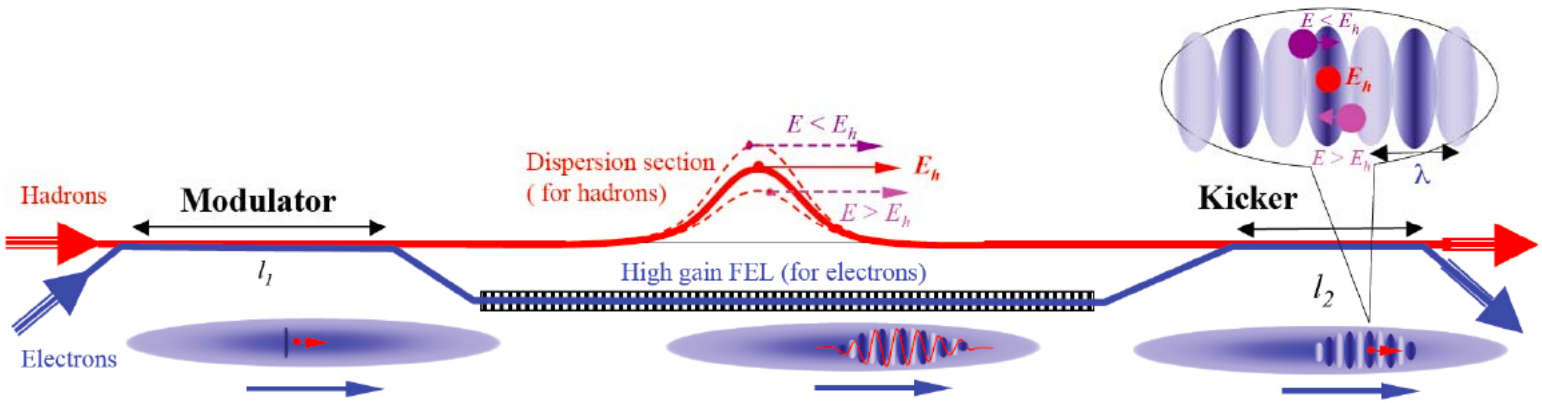
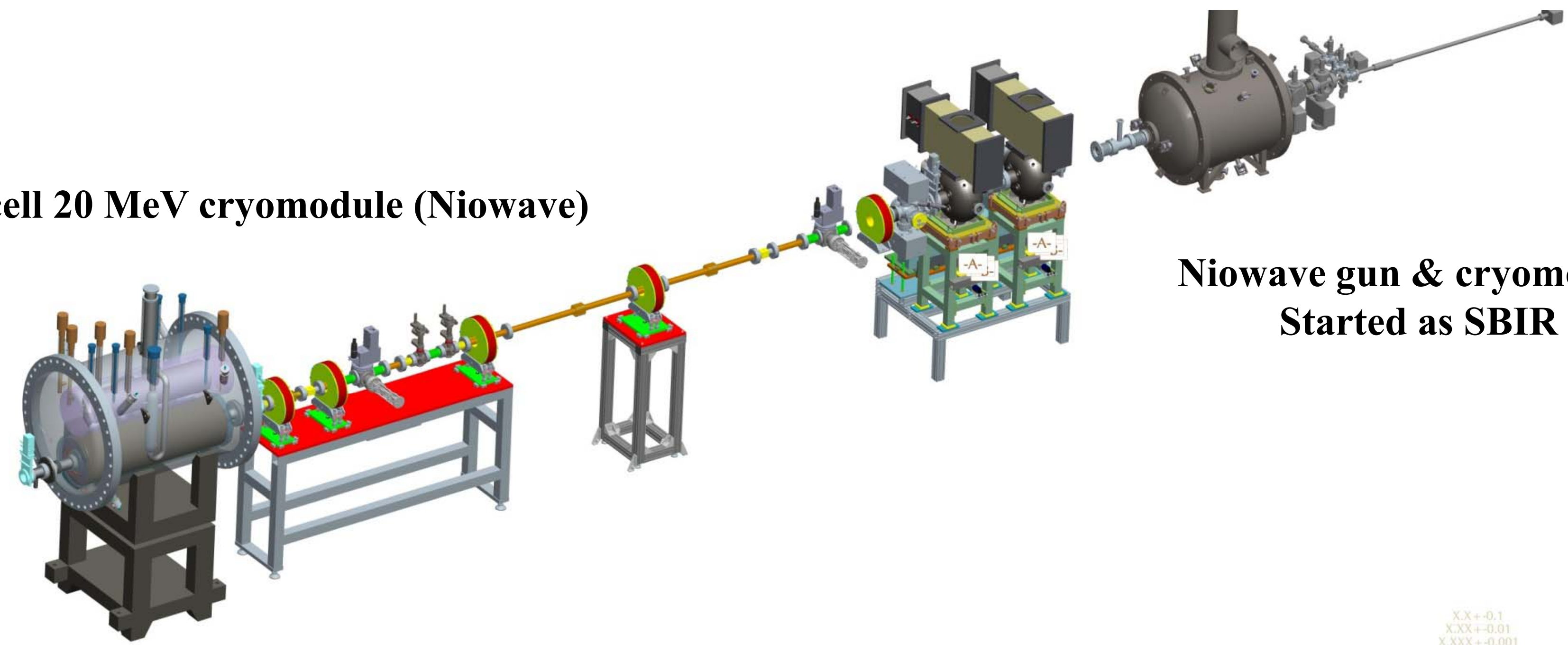
Coherent electron Cooling Proof-of-Principle experiment



5-cell 20 MeV cryomodule (Niowave)

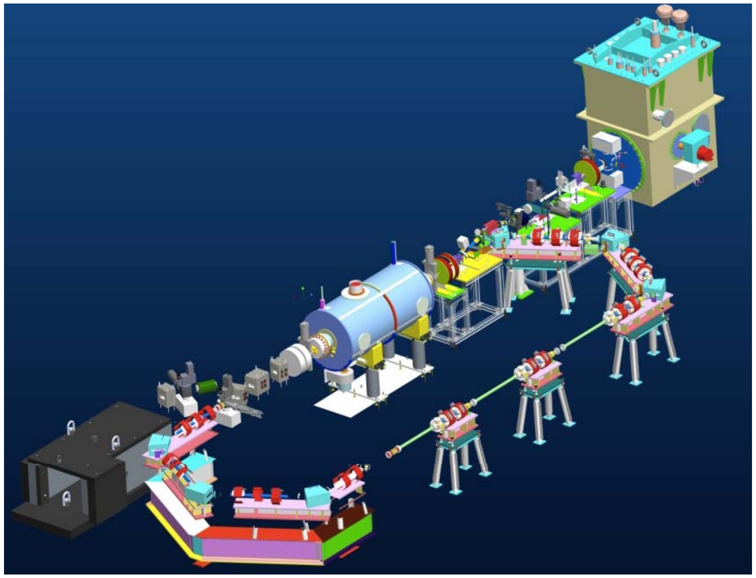


Niowave gun & cryomodule
Started as SBIR

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
  - Apply and evaluate high QE photocathodes
- 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



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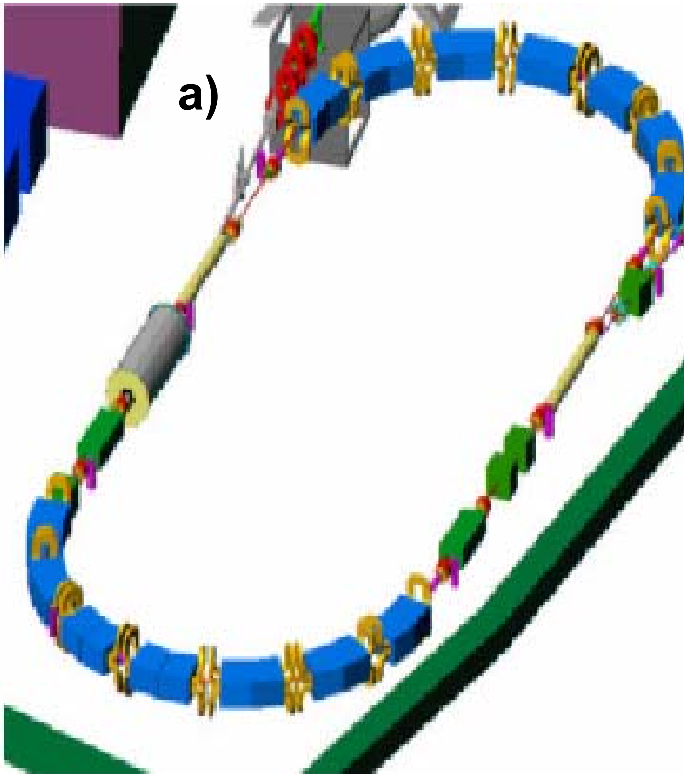
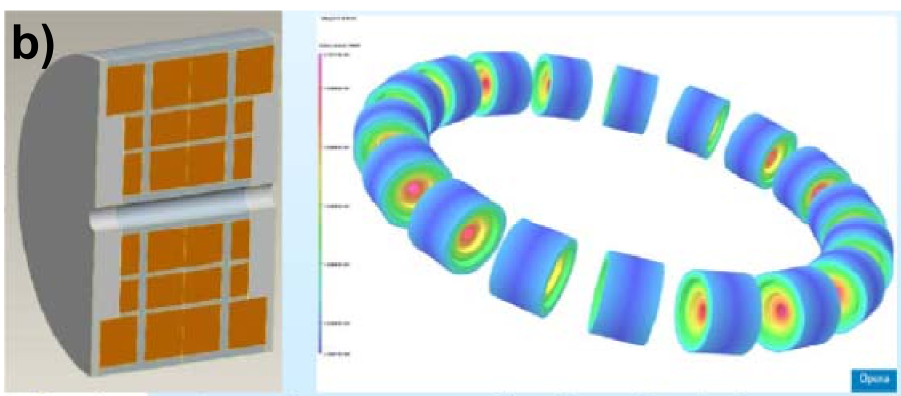
Recent Technological Impacts of BNL NP Research



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

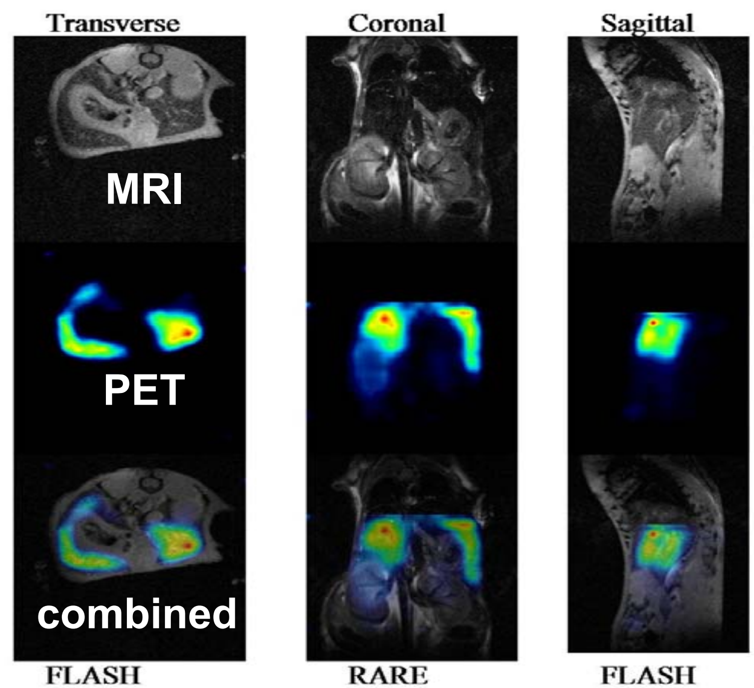
b) HTS magnet development expertise from BNL's work for NP accelerators critical in attracting ARPA-E grant for Superconducting Magnet Energy Storage (SMES)

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



Basic structure of a single SMES Unit

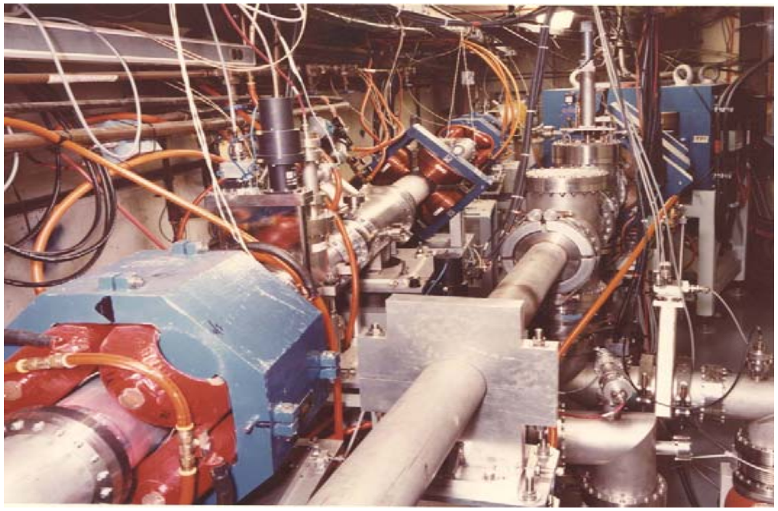
Number of units in a SMES system



Brookhaven LINAC Isotope Producer (BLIP)

The LINAC supplies protons to the Booster for nuclear physics. Excess pulses (~85-92%) are diverted to BLIP. Energy is incrementally variable from 66-202 MeV.

The BLIP beam line directs protons up to 115μA intensity to targets; parasitic operation with nuclear physics programs



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Medical Isotope Research and Production Program

Radionuclide R&D

- New/unique radionuclides
- Nuclear reactions, targetry research
- Processing chemistry, generator development

Radionuclide Production and Distribution

- Distribution of BLIP-produced isotopes
- Process development research: improve quality and speed, minimize waste and/or personnel exposure.

Radiopharmaceutical R&D (on a limited basis)

- Recombinant vehicles for targeting tumors with diagnostic/therapeutic isotopes
- Tin-117m chelates: imaging and treatment of bone metastases and of cardiovascular atherosclerotic disease
- Radiolabeled stem cells for non-invasive imaging

View of several processing hot cells

Examples of opportunities

Software and Data Management:

- Simulation software of beam cooling, photocathodes, SRF cavities
  - Examples: Tech-X VORPAL based simulations of electron cooling, coherent electron cooling, diamond amplified photocathodes, 3-D multipacting code
  - RHIC detectors produce many pewtabytes of data.

Electronics Design and Fabrication:

- RF power amplifiers
  - Example: Green Mountain Radio Research solid-state amps
- Reactive power tuners
  - Example: OmegaP development of high-power, fast reactive tuners
- Materials for reactive power tuners
  - Example: Euclid Techlabs development of Nonlinear Ferroelectric

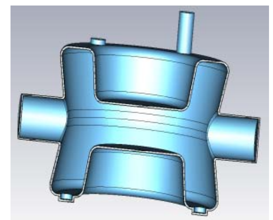
Examples of opportunities (continued)

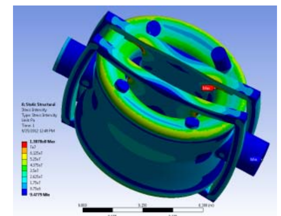
Accelerator Technology:

SRF cavity

Examples: Niowave development of 28 MHz fast tunable SRF cavity and crab cavities, AES development of 704 MHz cavity and gun

HOM damping





Cryomodule

Electron guns

Example: AES 1.3 GHz SRF gun, Niowave 112 MHz SRF gun

Photocathodes

Example: AES development of preparation chambers and load-locks

Example: Nanohmics surface modifications of photocathodes

Example: AES development of polarized SRF gun load-lock

Examples of opportunities (continued)

Accelerator Technology (continues)

Surface coating:

PVI's in-situ coating technology to reduce resistivity and secondary electron yield,

Specialty magnets:

HTS magnets for location with restricted power infrastructure

Instrumentation:

Non-destructive beam monitors

Nuclear Physics Isotope Science and Technology:

BLIP is a major producer of medical radioactive isotopes for medical and research applications. Development of raster scan beam is proposed.

Summary

The RHIC Complex is supporting the mission of the Office of Science in providing a thriving and highly successful service to the users' community and carrying out cutting edge accelerator R&D program.

The SBIR/STTR program is playing an important role in our 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 R&D needs of the RHIC complex and their capabilities and ideas.