THE RHIC FACILITY AND THE SBIR/STTR PROGRAM

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COLLIDER-ACCELERATOR DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY

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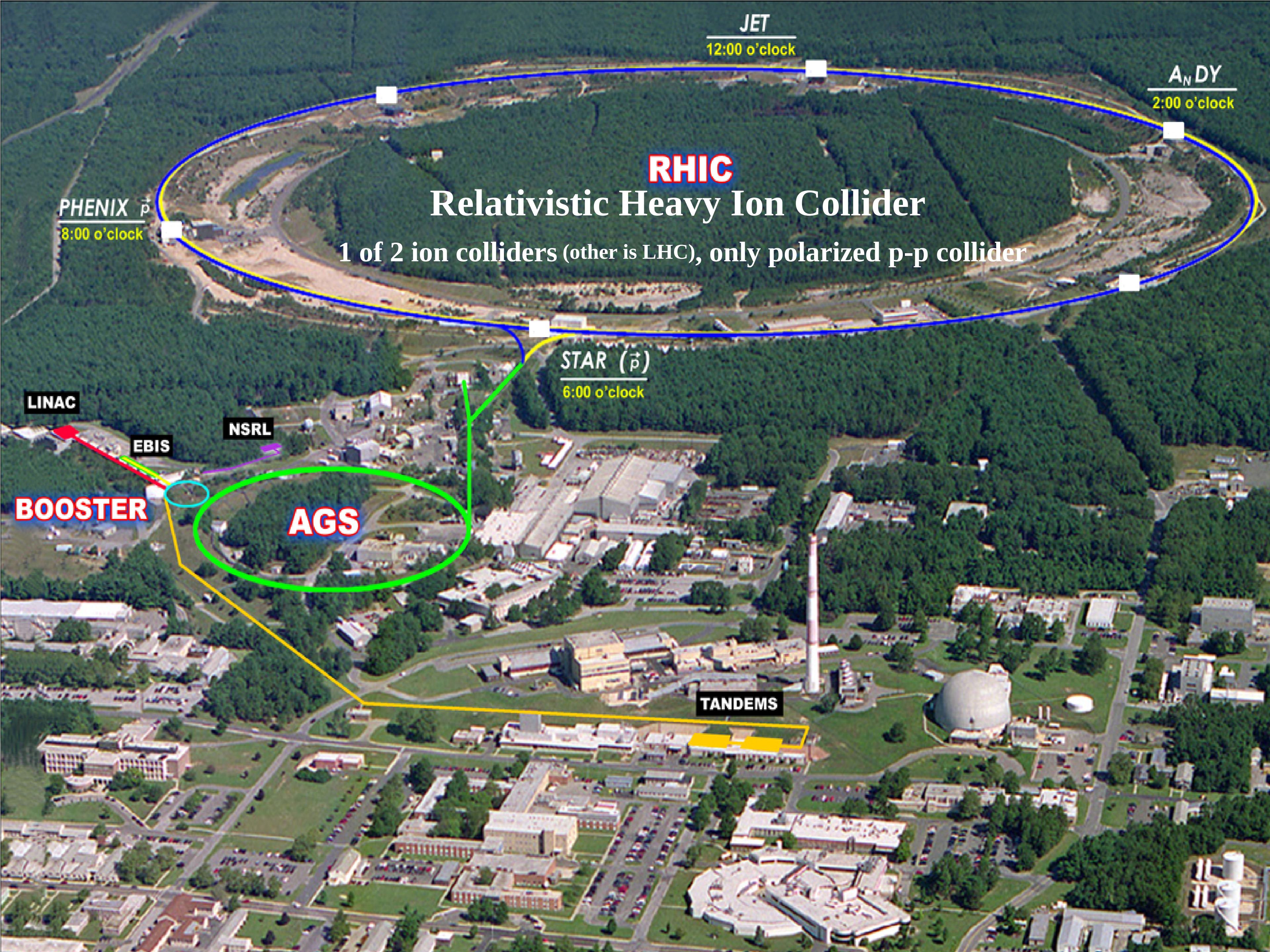
RHIC and the SBIR/STTR Program

- The RHIC complex comprises eight accelerators, including the twin 3.8 km superconducting collider rings.
- The C-AD Department has 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 the way we do accelerator R&D.
- SBIR/STTR programs are highly encouraged and strongly supported by C-AD. Talk to us!


JET
12:00 o'clock
$A_N DY$
2:00 o'clock
RHIC
Relativistic Heavy Ion Collider
1 of 2 ion colliders (other is LHC), only polarized p-p collider
PHENIX $\vec{p}$
8:00 o'clock
STAR ($\vec{p}$)
6:00 o'clock
LINAC
EBIS
NSRL
BOOSTER
AGS
TANDEMS

Preparation for Run-14

Stochastic cooling

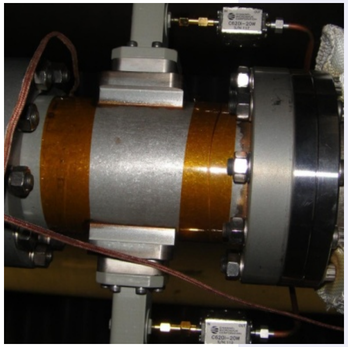
- First 100 GeV/nucleon Au-Au run with full 3D cooling
- New longitudinal pick-ups – better signals
- New longitudinal kickers – better mechanics, wave guides and vacuum performance (one kicker became stuck in Run-10)

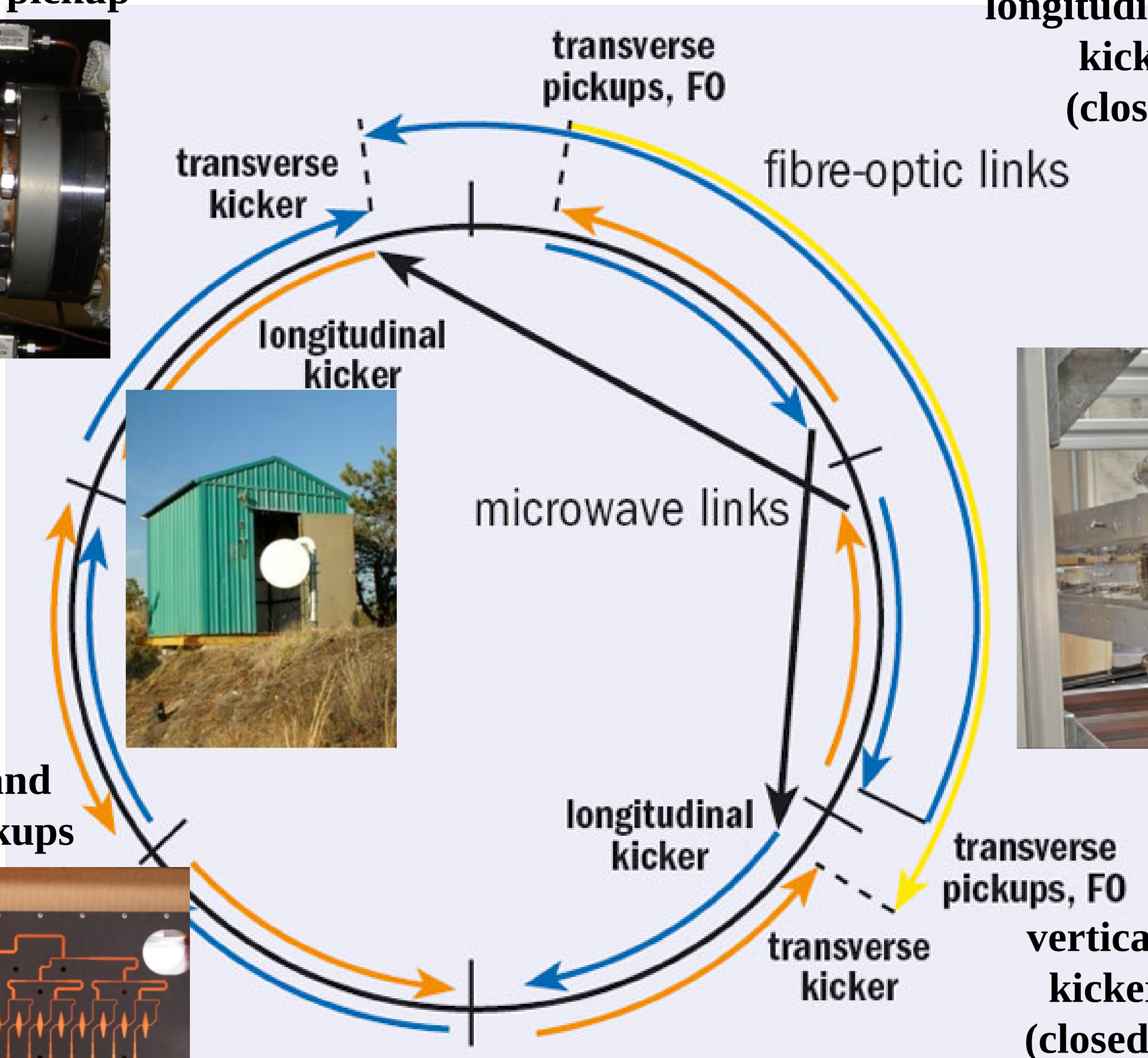
56 MHz SRF

- Plan installation and commissioning of 56 MHz cavity
- Schedule pressure due to vendor issues on HOM damper fabrication
- Due to commissioning will only have modest contribution to Run-14 total luminosity
- Expect 30-50% luminosity increase after full commissioning

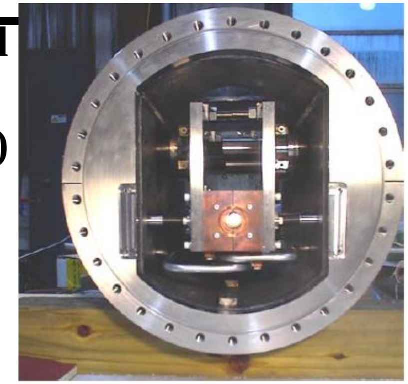
Now have full 3D stochastic cooling for heavy ions

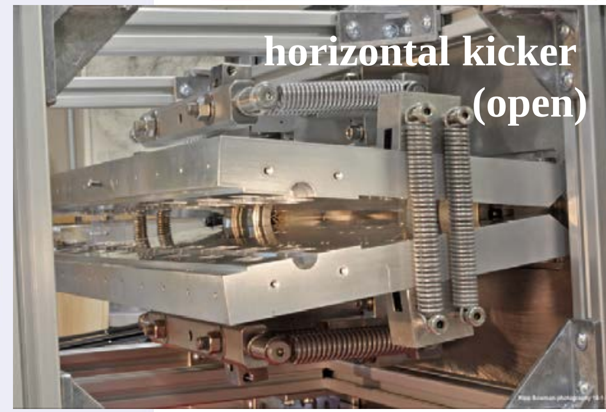
longitudinal pickup



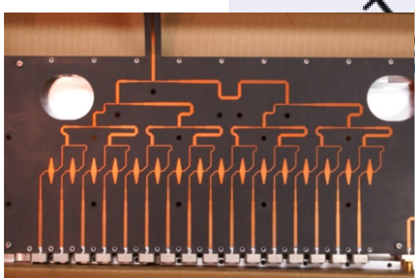


longitudinal kicker (closed)

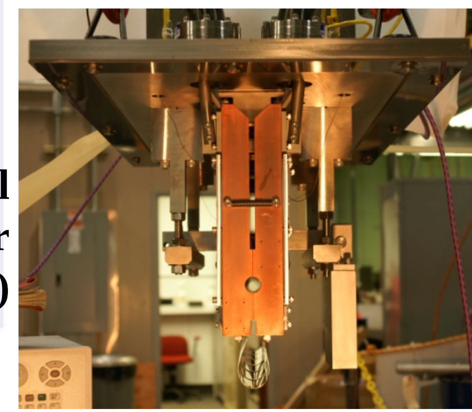




horizontal and vertical pickups



vertical kicker (closed)



5-9 GHz, cooling times ~1 h

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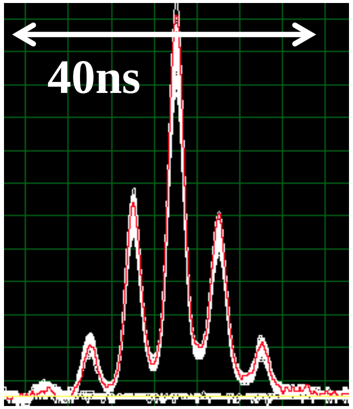
M. Brennan, M. Blaskiewicz, F. Severino, PRL 100 174803 (2008)

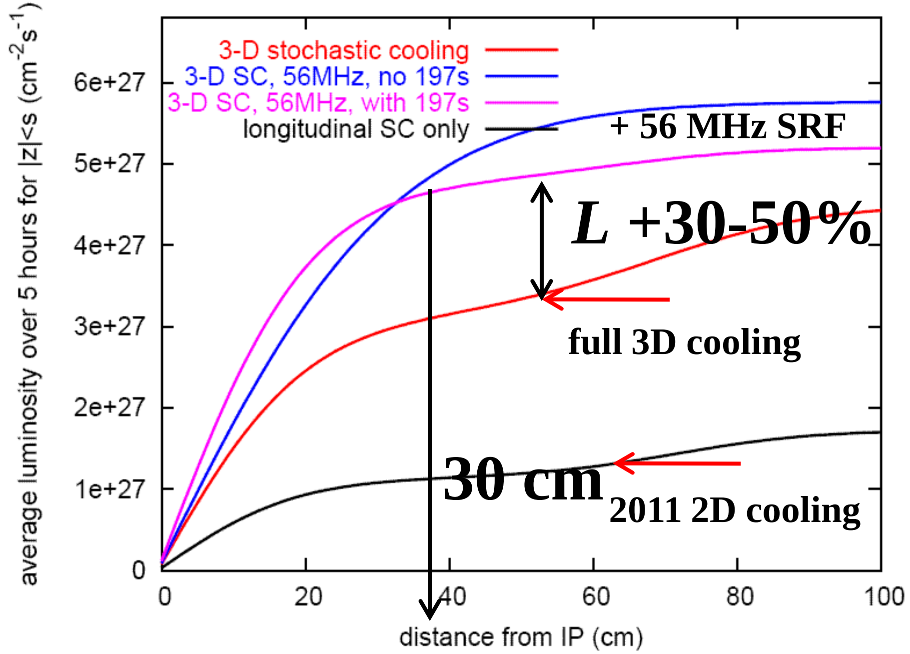
56 MHz SRF– Commissioning planned for 2014

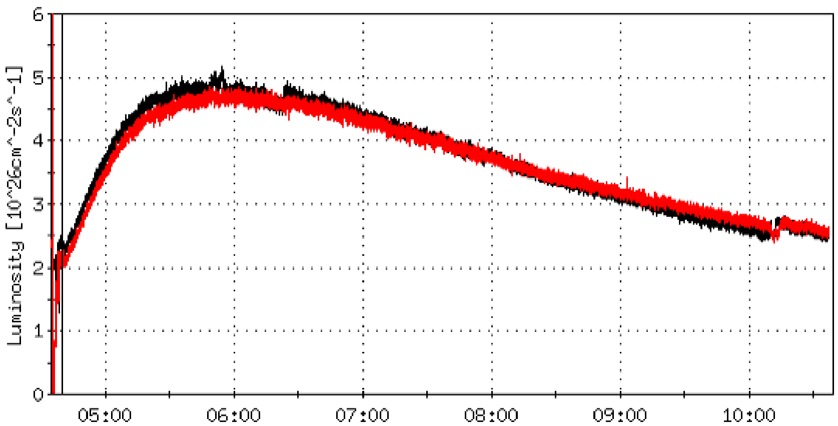
Longitudinal profile at end of store

- **even with cooling ions migrate into neighboring buckets**
- **can be reduced with increased longitudinal focusing**



Average luminosity vs. vertex size





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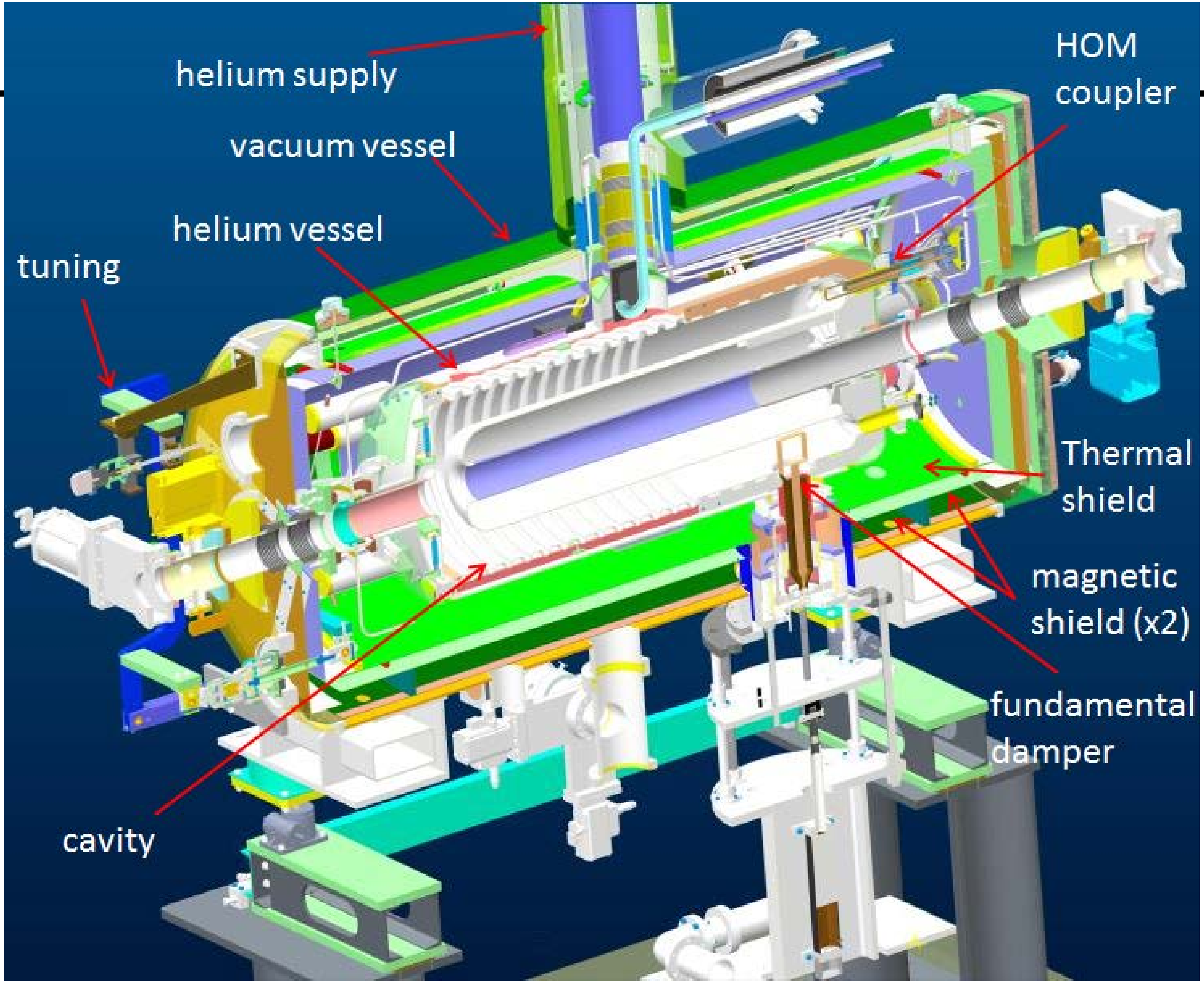
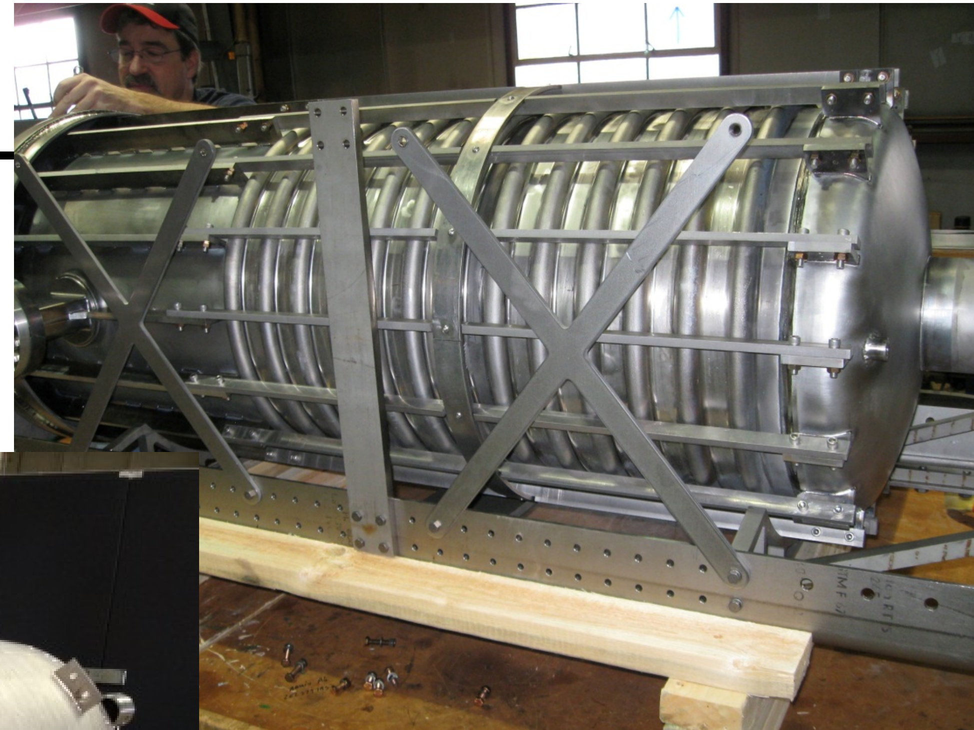
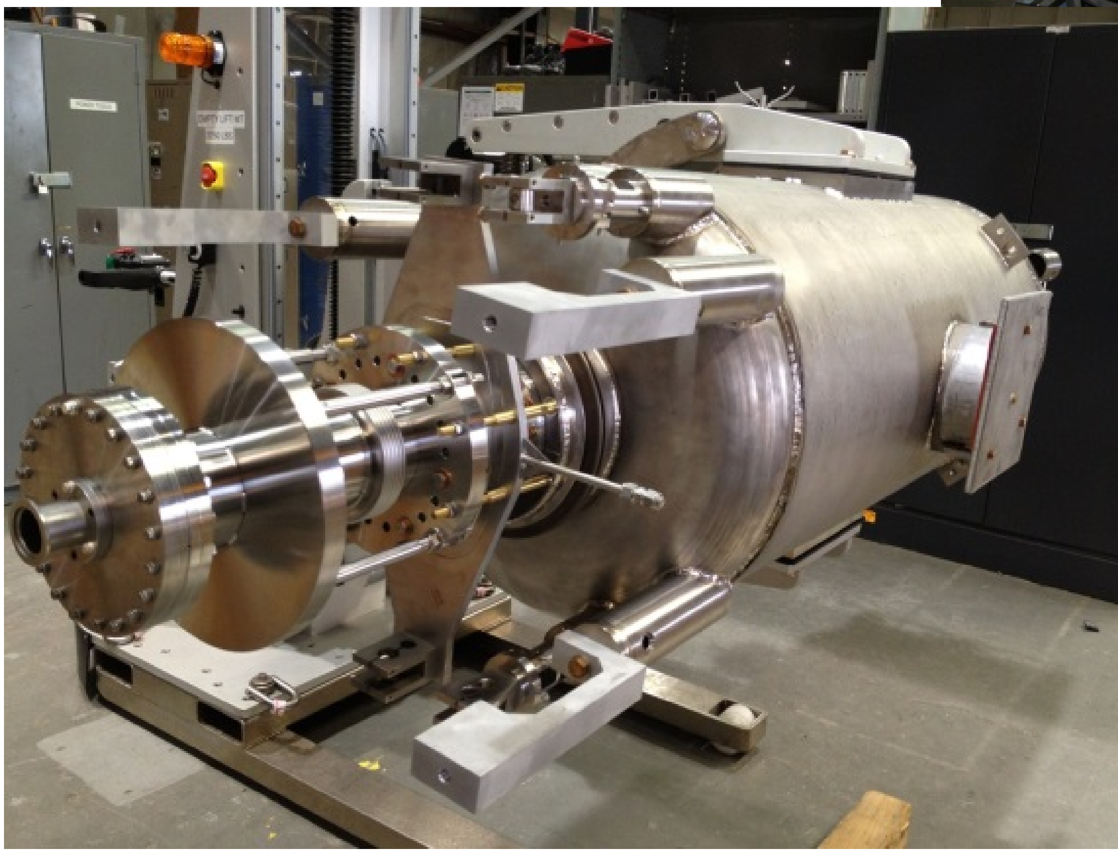
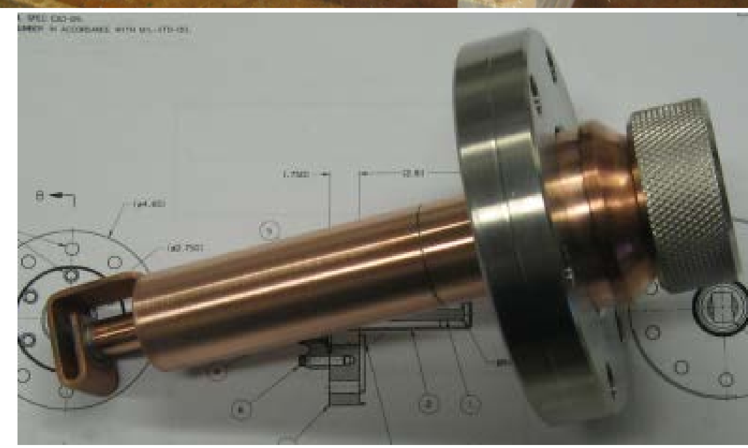
Calculation by M. Blaskiewicz


helium supply
vacuum vessel
helium vessel
tuning
HOM
coupler
Thermal
shield
magnetic
shield (x2)
fundamental
damper
cavity

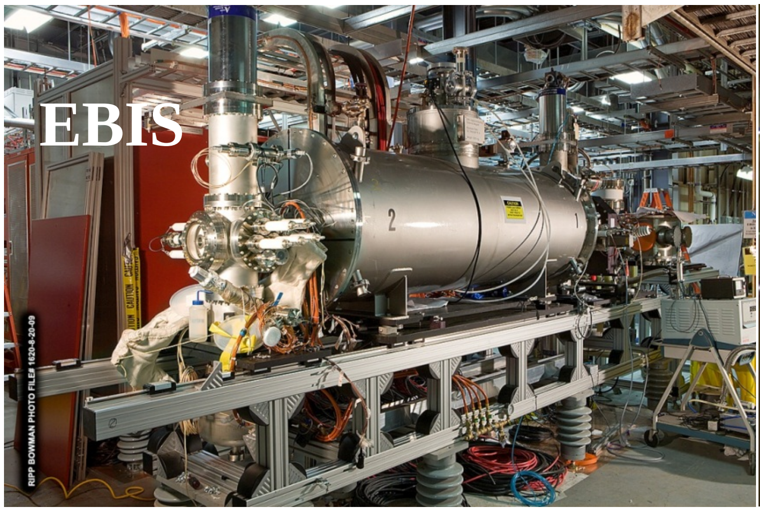






Electron Beam Ion Source (EBIS)

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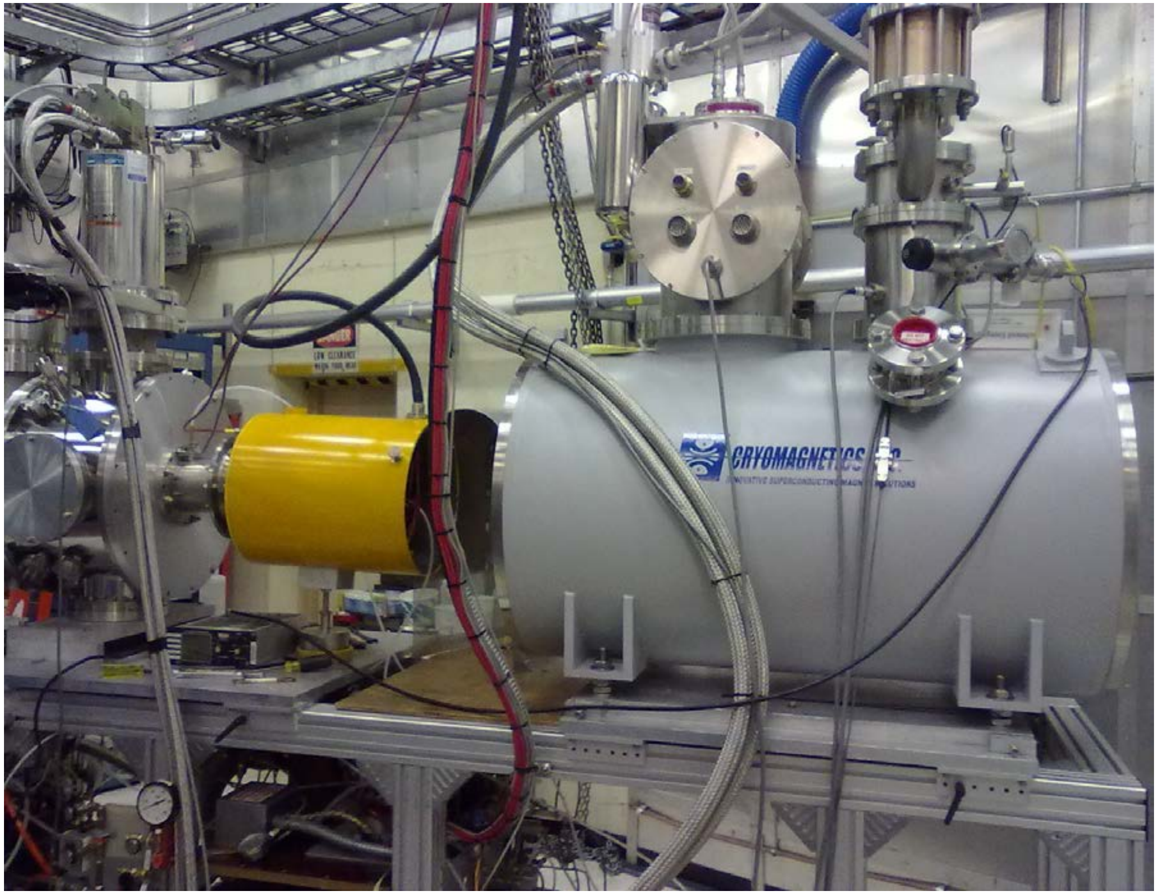
Optically Pumped Polarized H⁻ source (OPPIS) – A. Zelenski

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**

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

Electron lenses – partial head-on beam-beam compensation

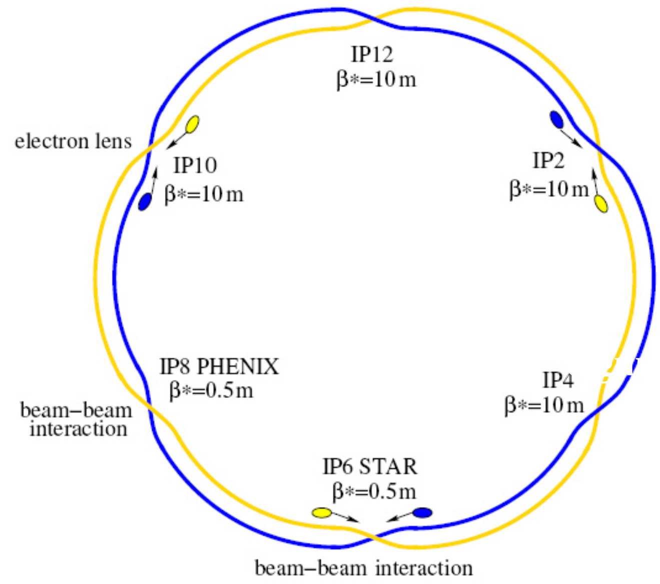
Basic idea:

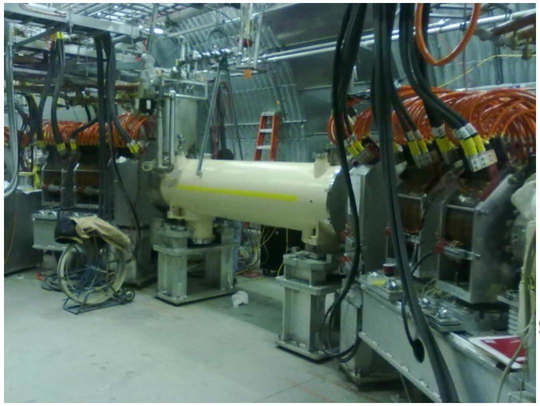
- 2 beam-beam collisions with positively charged beam
- Add collision with a negatively charged beam – with matched intensity and same amplitude dependence

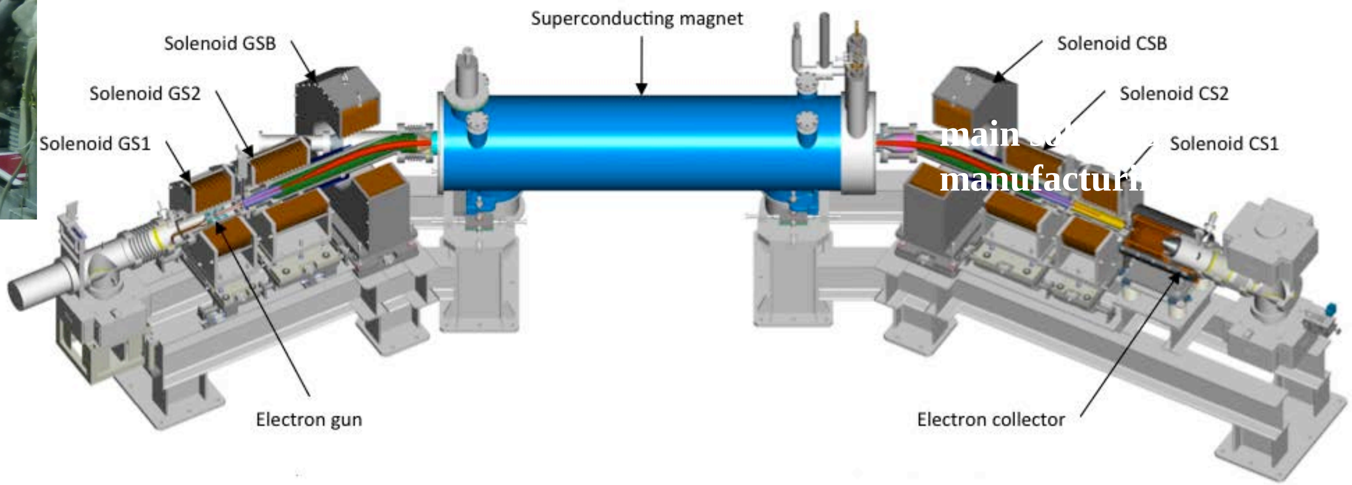
Compensation of nonlinear effects:

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

Expect up to 2x more luminosity







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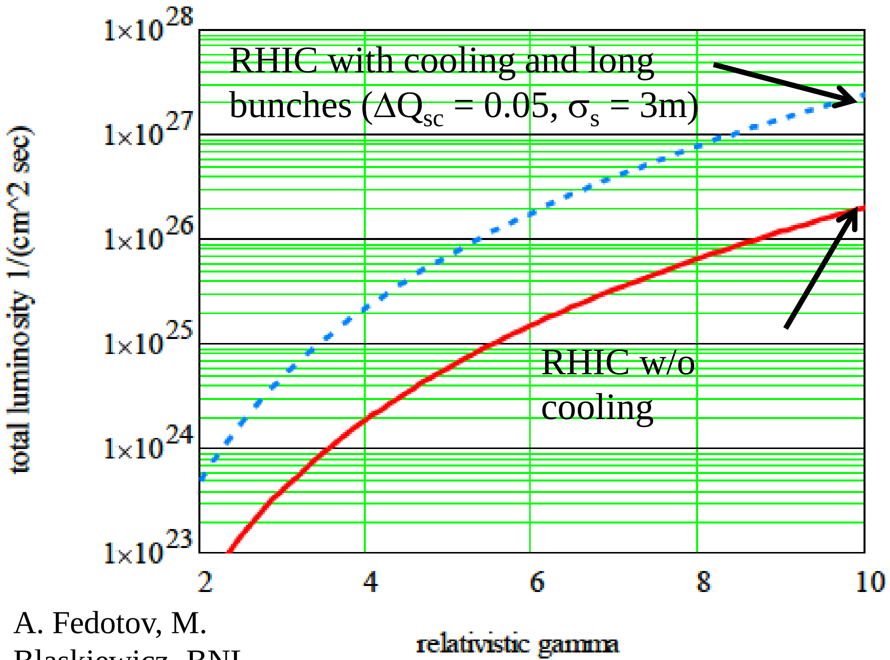
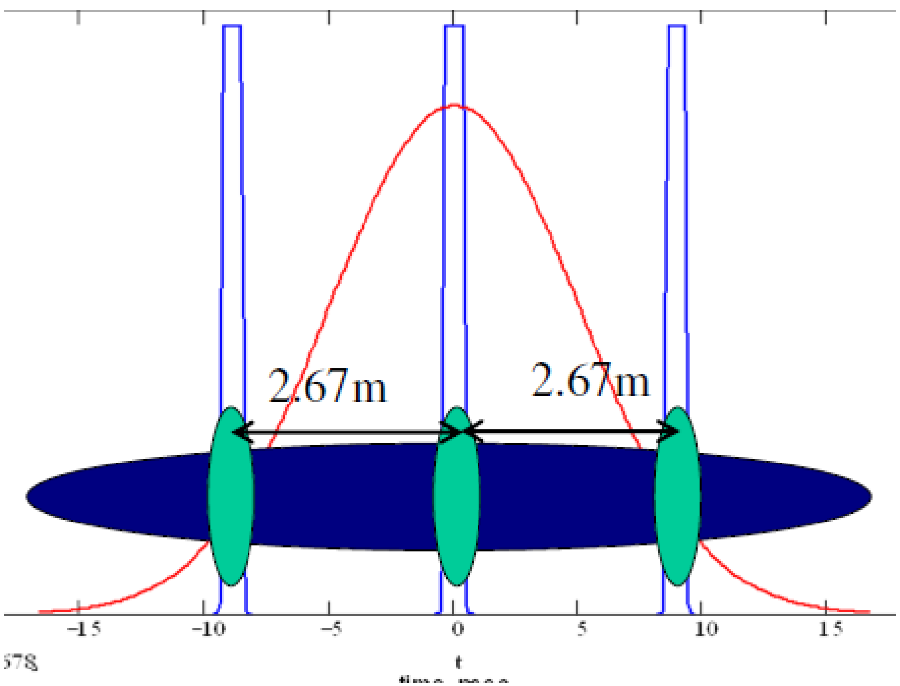
e-cooling for low energy RHIC operation

Will use high brightness SRF electron gun for bunched beam electron cooling; up to ~10x L; planned for run 2018-2019

Low-energy RHIC, yet high-energy electron cooling!



A. Fedotov, M. Blaskiewicz, BNL C-A/AP/449 (2012)



•Bunched beam electron cooling

A natural way for high-energy cooling (when RF acceleration becomes more practical)

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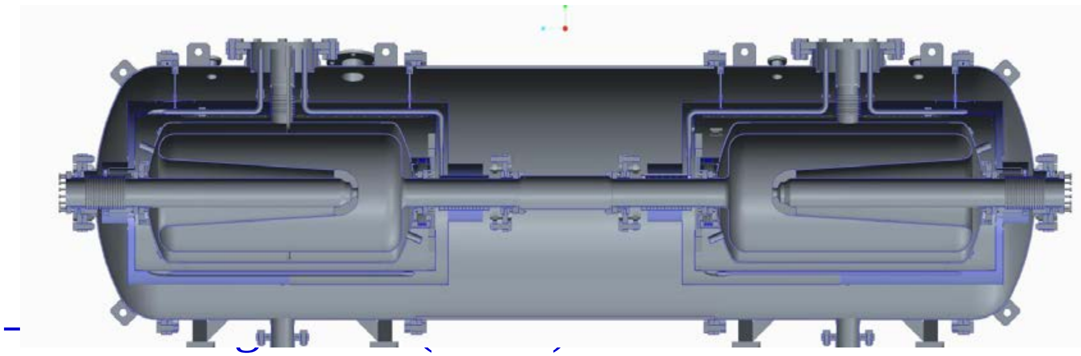
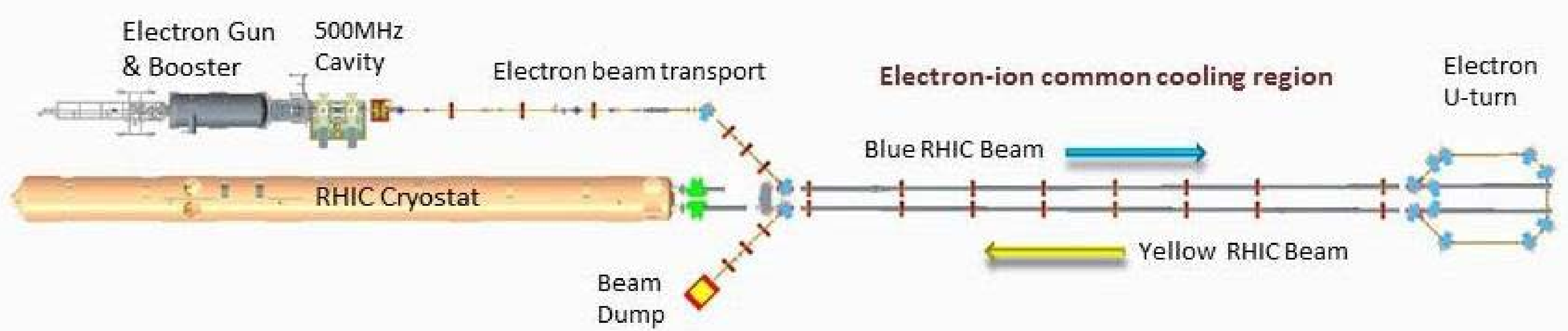
First electron cooling in a collider

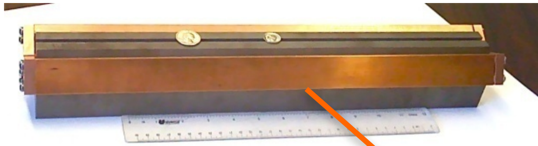
- Requires careful control of ion beam distribution under cooling to avoid over cooling of beam core.
- 84.5 MHz SRF gun, 2.5 MV.
- 2.5 MV booster 84.5 MHz
- 507 MHz NC energy correction
- Cooling sections in RHIC rings -



solenoids (200G) located every 2m. U-turn between cooling sections

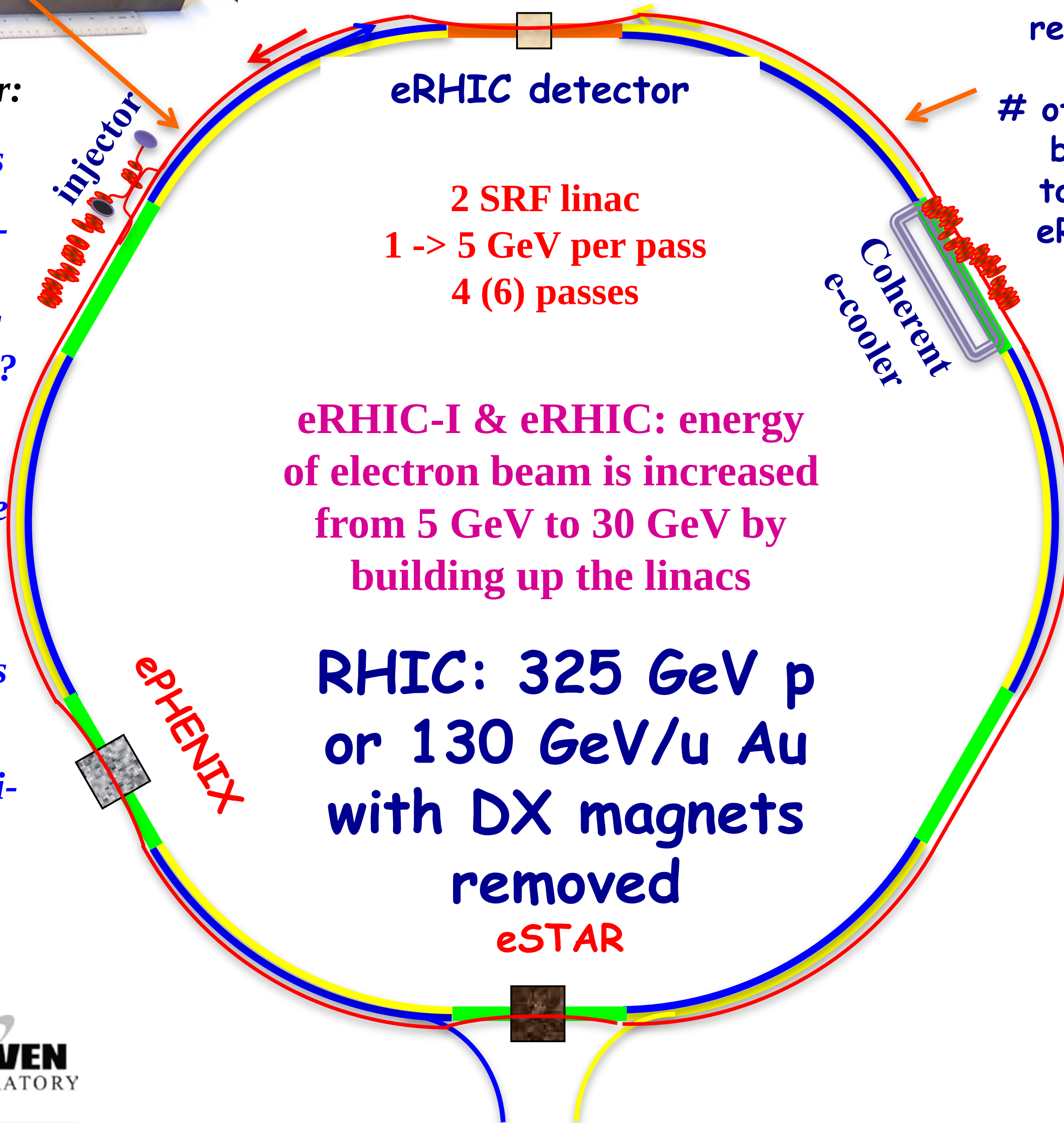


eRHIC Design



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_

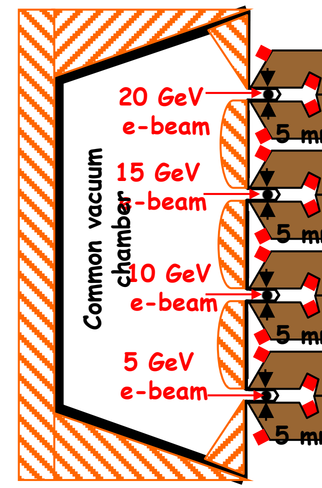


2 SRF linac
1 -> 5 GeV per pass
4 (6) passes

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

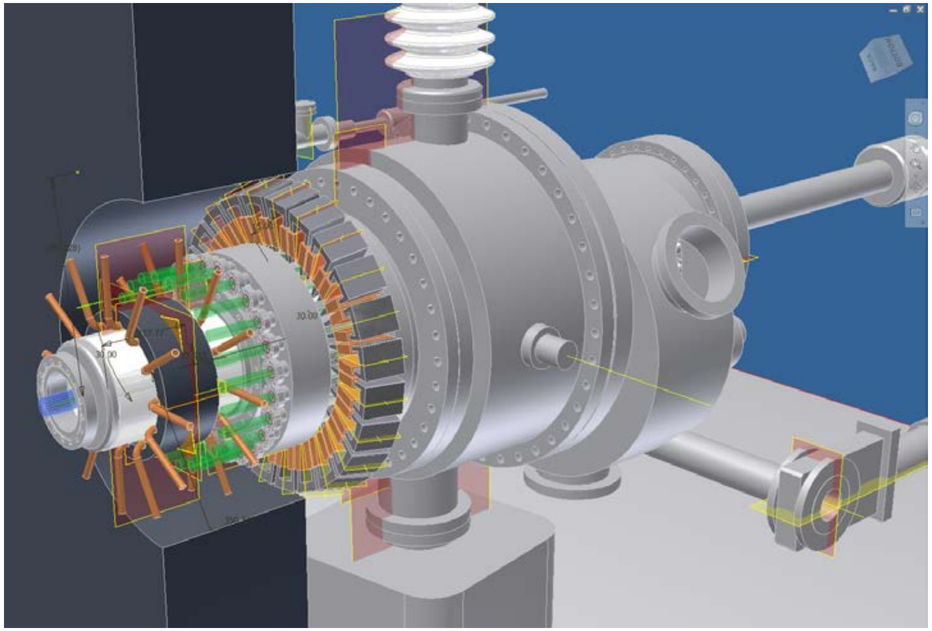
Vertically separated recirculating passes.
# of passes will be chosen to optimize eRHIC cost



Gap 5 mm total
0.3 T for 30 GeV

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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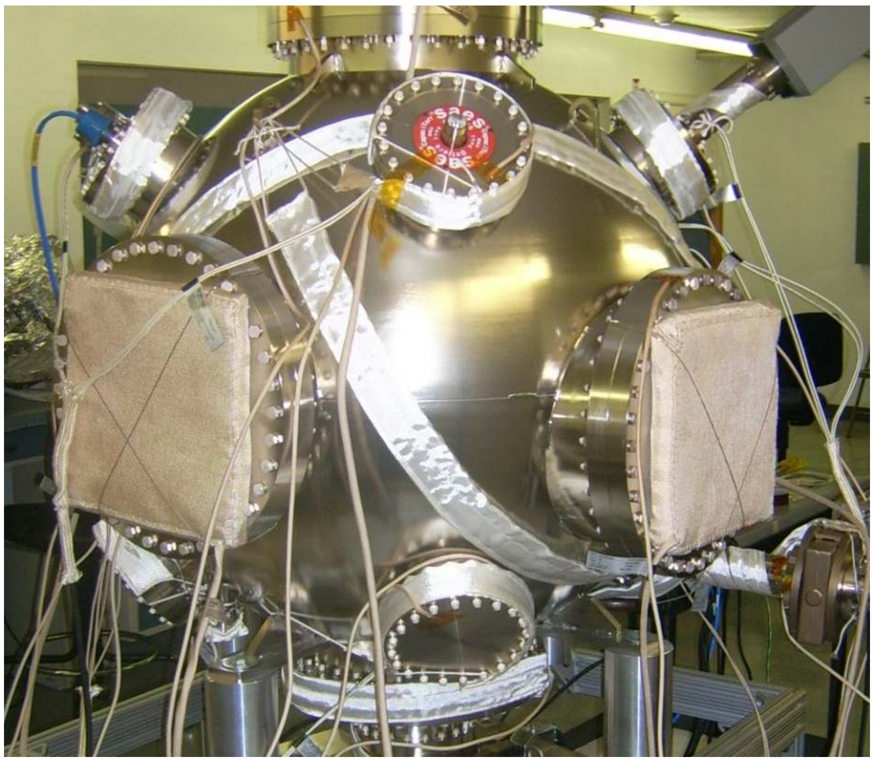
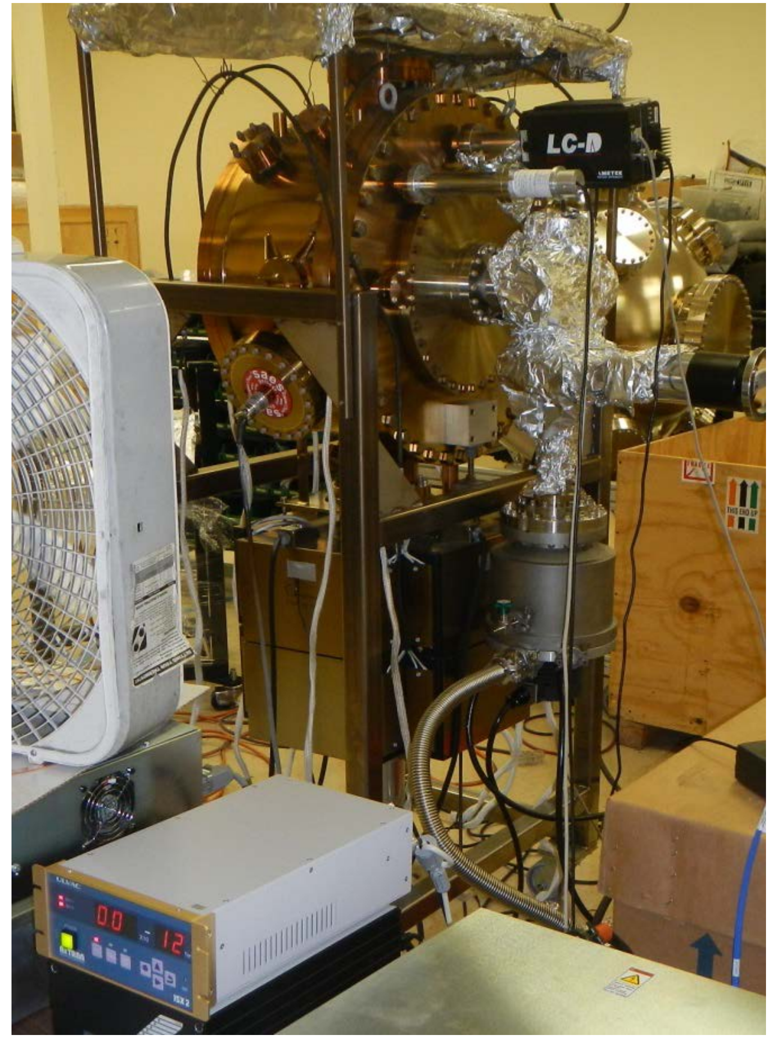
Funneling high-current polarized electron gun

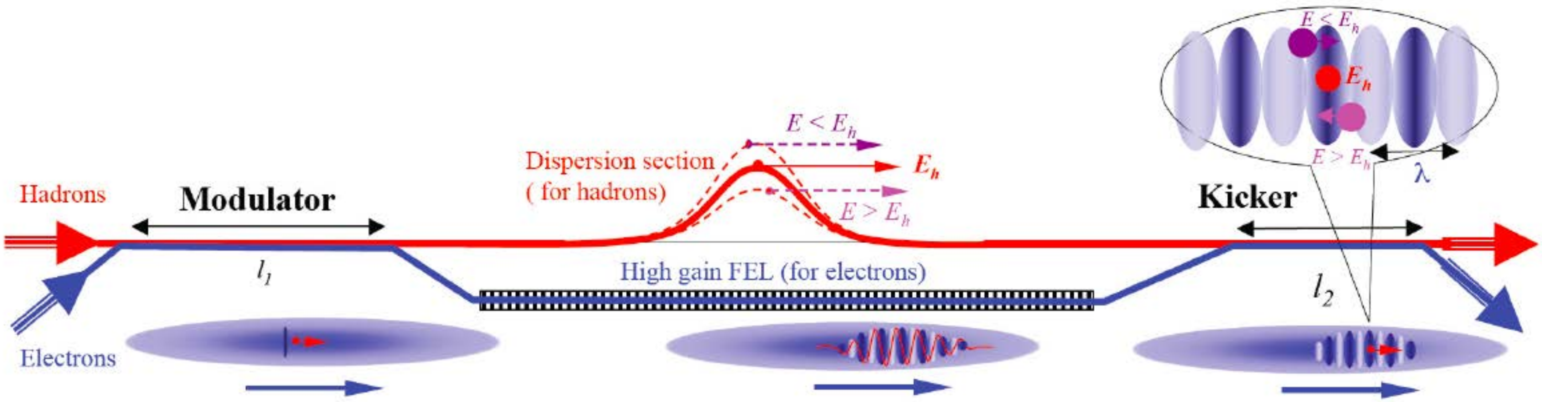
Recent measurements have confirmed that large vessels can be made to achieve low to mid 10^{-12} Torr vacuum levels





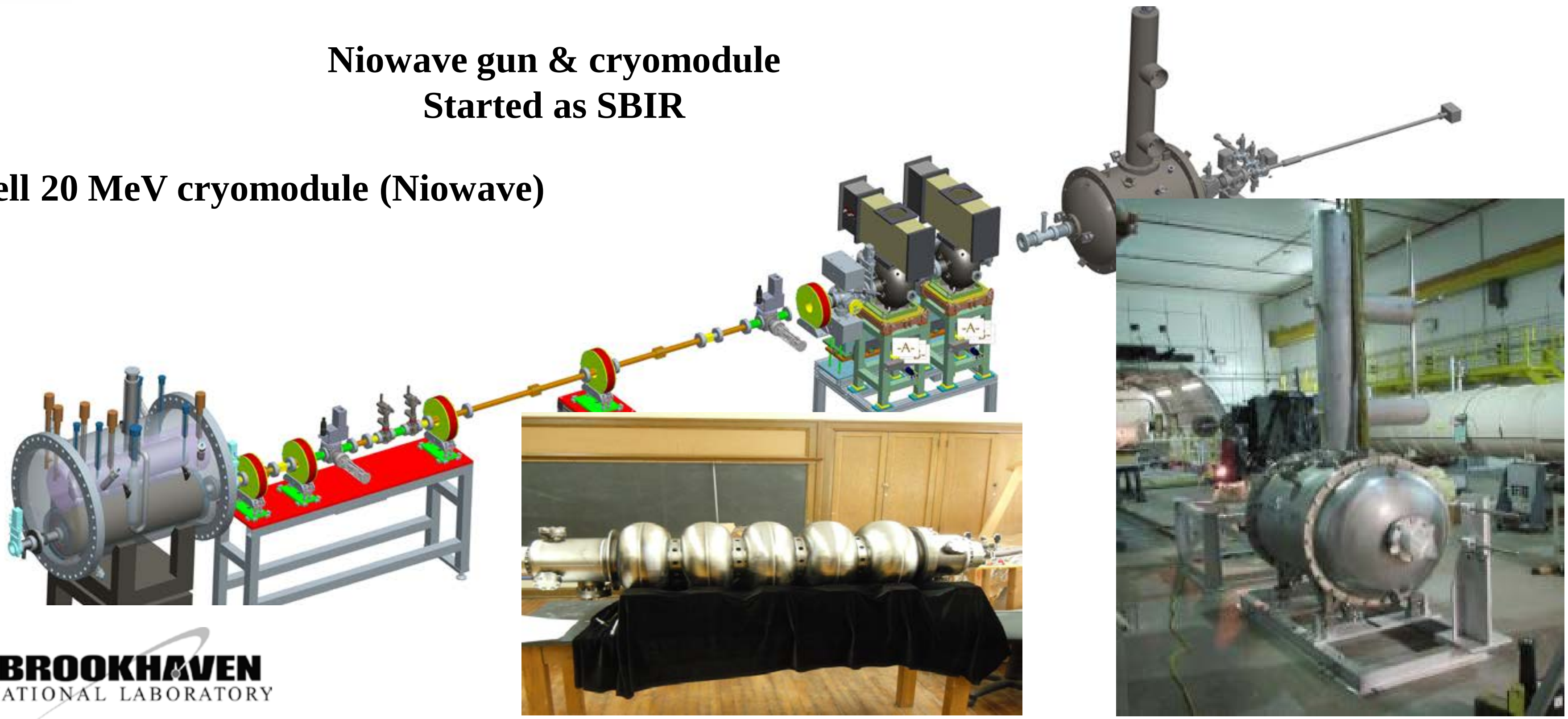
View of Gatling Gun Main vessel under XHV Vacuum

Coherent electron Cooling Proof-of-Principle experiment



Niowave gun & cryomodule
Started as SBIR

5-cell 20 MeV cryomodule (Niowave)



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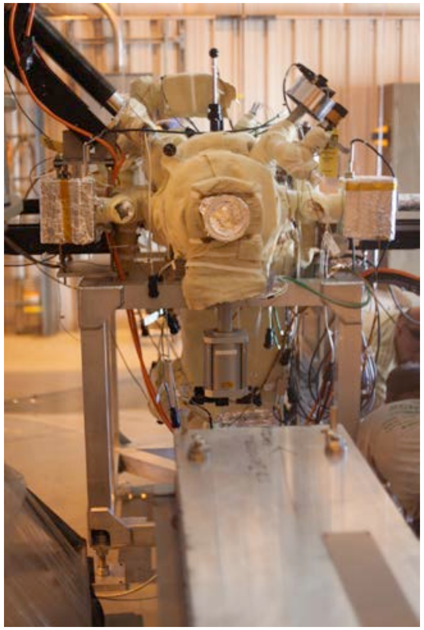
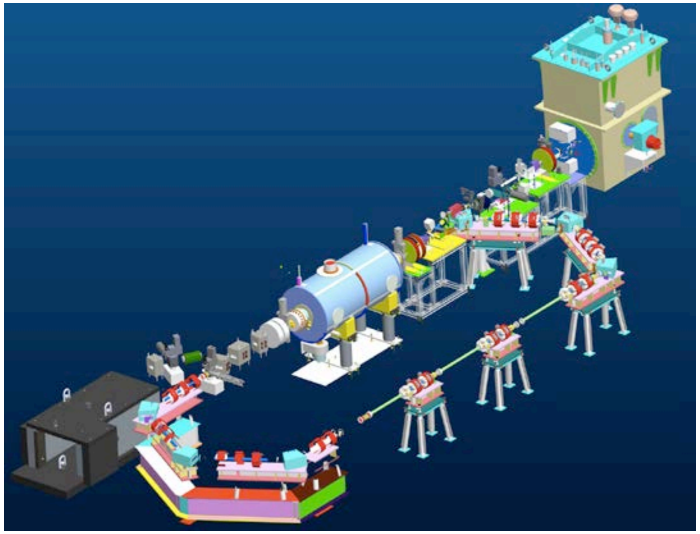
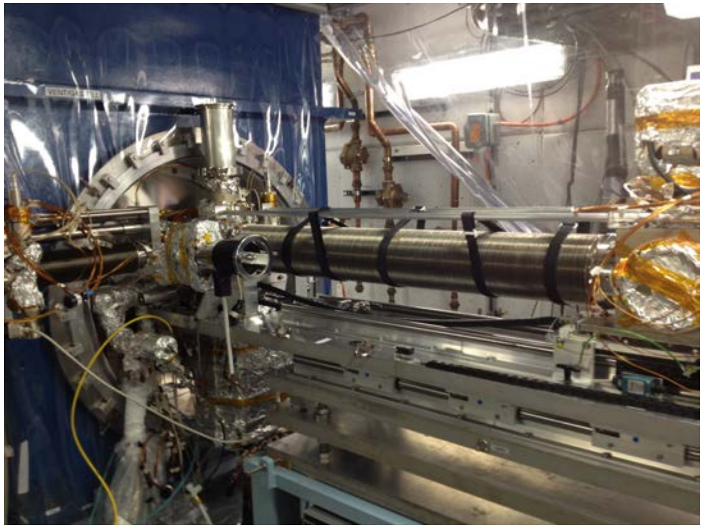
R&D on ERL

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
  - 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





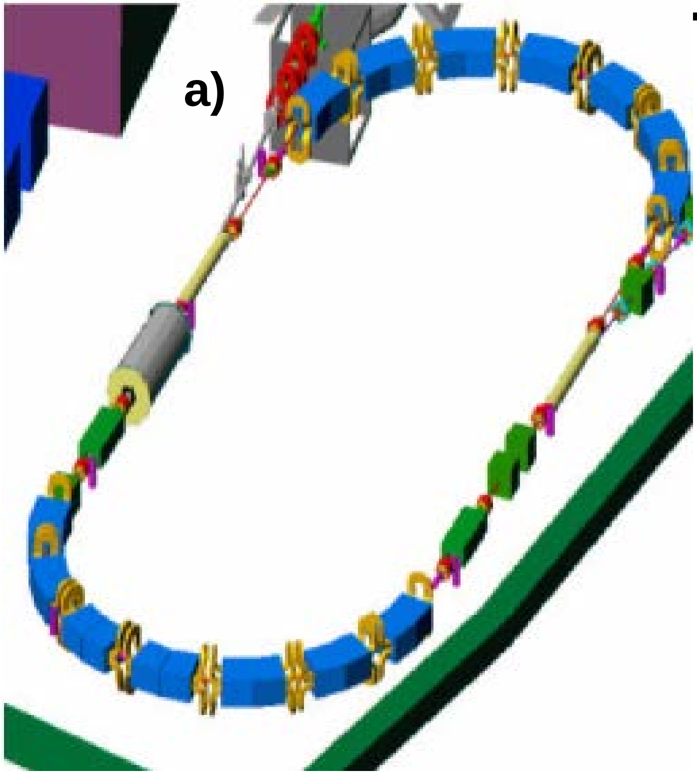


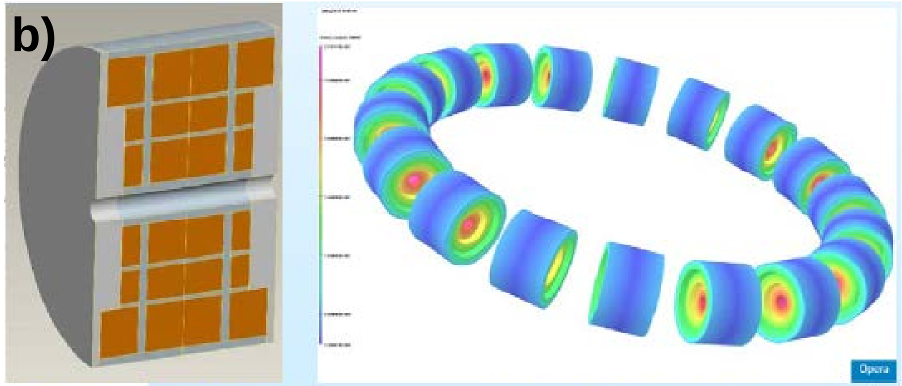
Recent Technological Impacts of BNL NP Research

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)*

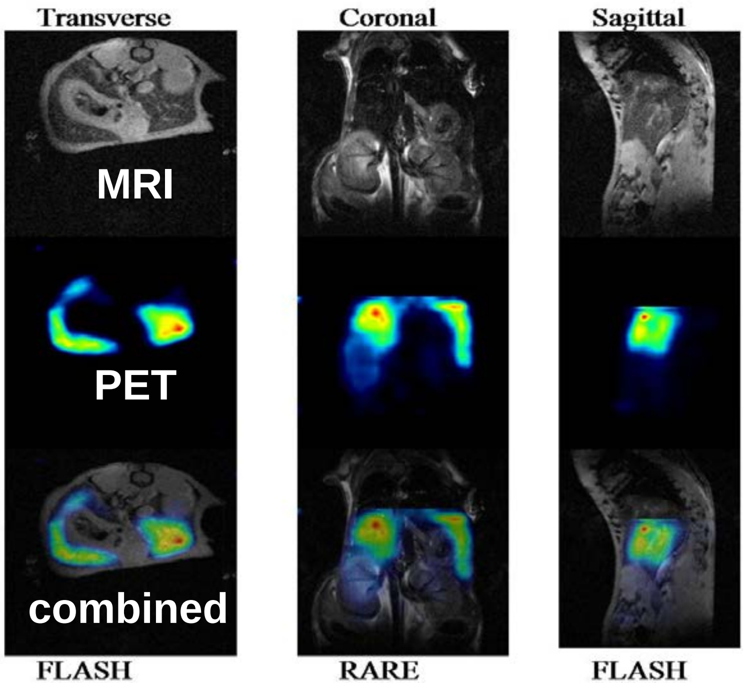
c) *First combined MRI-PET imaging (on mouse liver) done with ^{52}Fe nanoparticles developed by BNL's radioisotope group*





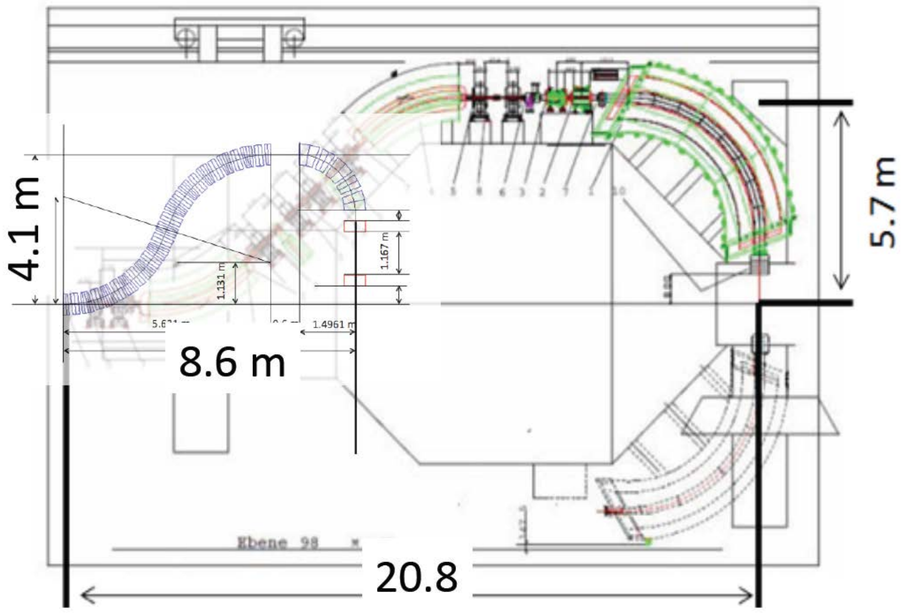
Basic structure of a single SMES Unit

Number of units in a SMES system



Non-Scaling Fixed Field Alternating Gradient

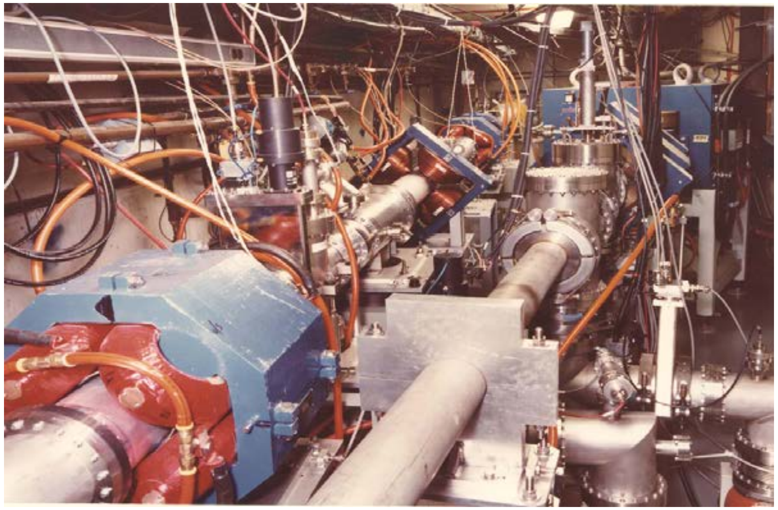
Using NP developed NS-FFAG to reducing the size and weight of a radio-therapy carbon gantry **(135 tons** to **2 tons)** (Dejan Trbojevic)



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



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

Electronics Design and Fabrication:

RF power amplifiers

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

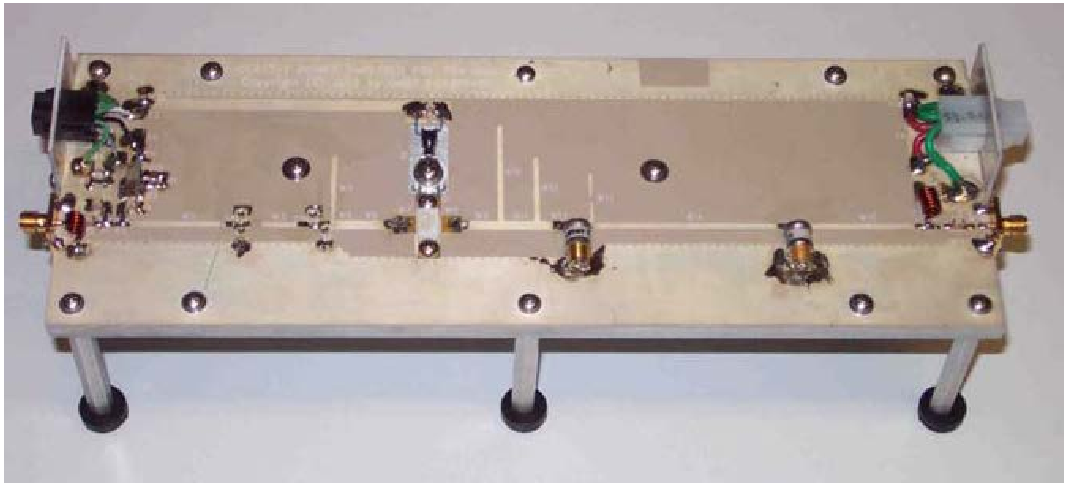
Need for 350-400 MHz

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



Examples of opportunities (continued)

Extreme High Vacuum (XHV) Valve

- High Quantum Efficiency Polarized Photo-cathode electron sources will require reliable XHV conditions on the order of 10^{-12} Torr vacuum range to maintain practical cathode life times.

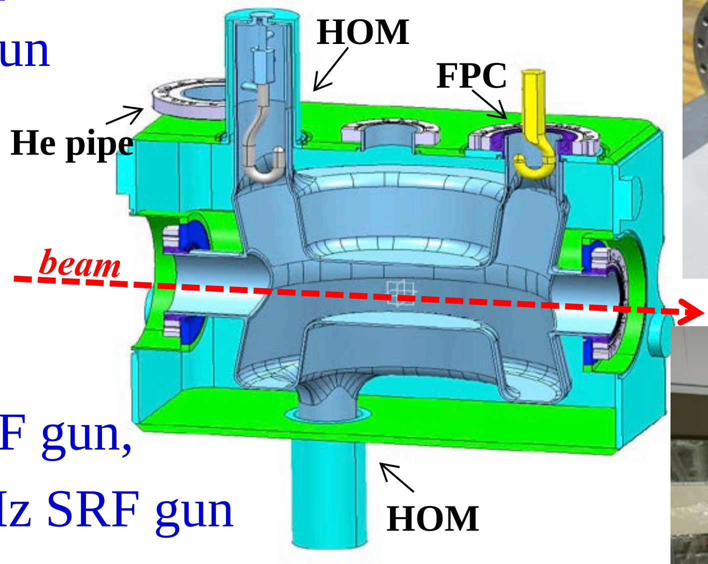
- When UHV all metal gate valves are actuated, bursts of gas emanate from the bellows and gate actuator mechanism in the valve bonnet into the bore of the Valve. This behavior is acceptable for most UHV applications but detrimental when it comes to XHV

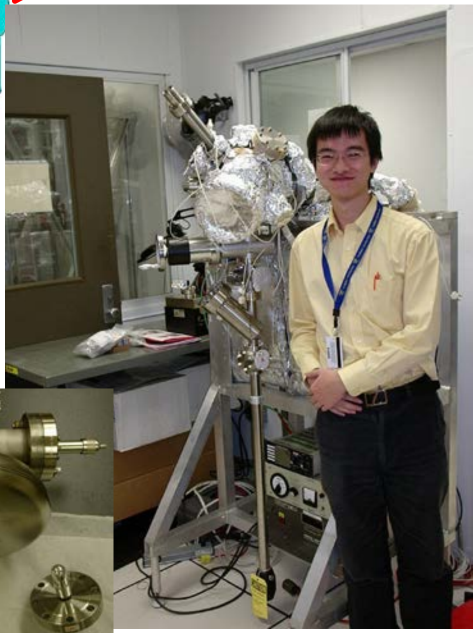
- There is a need for a bakeable XHV valve that maintains a constant internal pressure independent of opening and closure at vacuum levels down to the low 10^{-12} Torr vacuum range.

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 gun,
- Example: Niowave 112 MHz SRF gun
- Photocathodes
- Example: AES preparation chambers
- Example: AES polarized SRF gun load-lock





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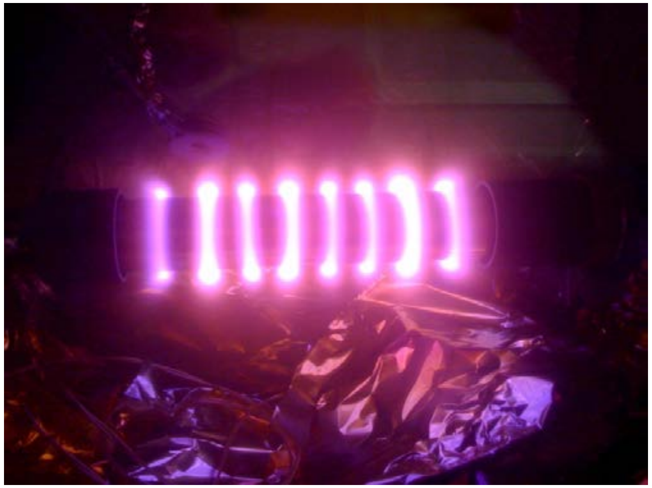
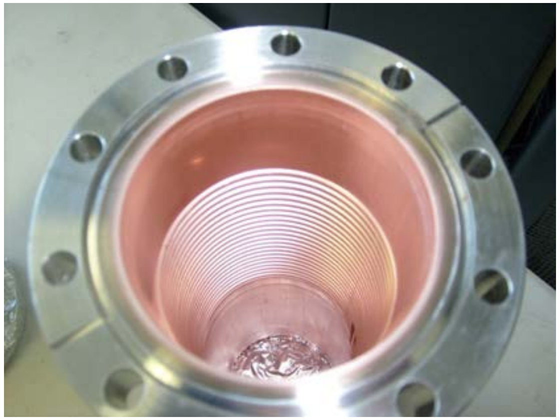
Examples of opportunities (continued)

- In-situ copper coating
- RHIC electron cloud limits: Ion intensity (through instability at transition), proton emittance at injection, and intensity
- Warm parts of RHIC are largely coated with NEG
- Cold arcs are SS, not coated => **Need in-situ coating for arcs**
- (Ady Hershcovitch)

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





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

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Examples of opportunities (continued)

Accelerator Technology (continues)

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.

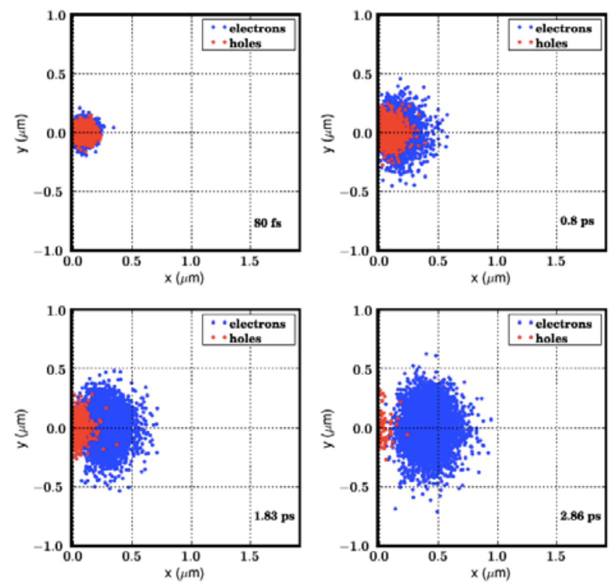
Software and Data Management:

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, …

RHIC detectors produce many pewtabytes of data.



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.