RHIC and its SBIR/STTR opportunities

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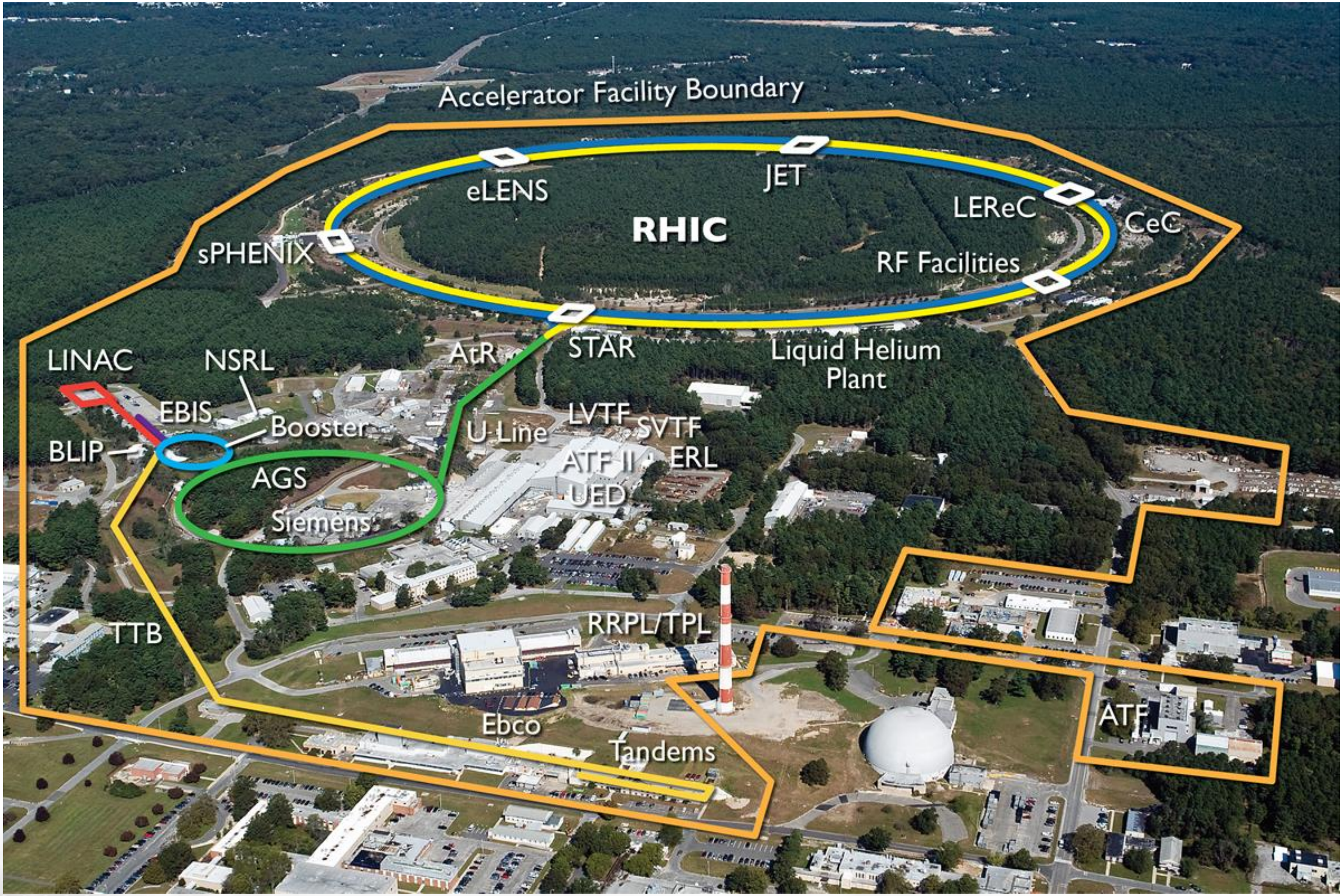
DOE-NP SBIR/STTR Exchange Meeting

Georgetown MD, 7-8 August 2018

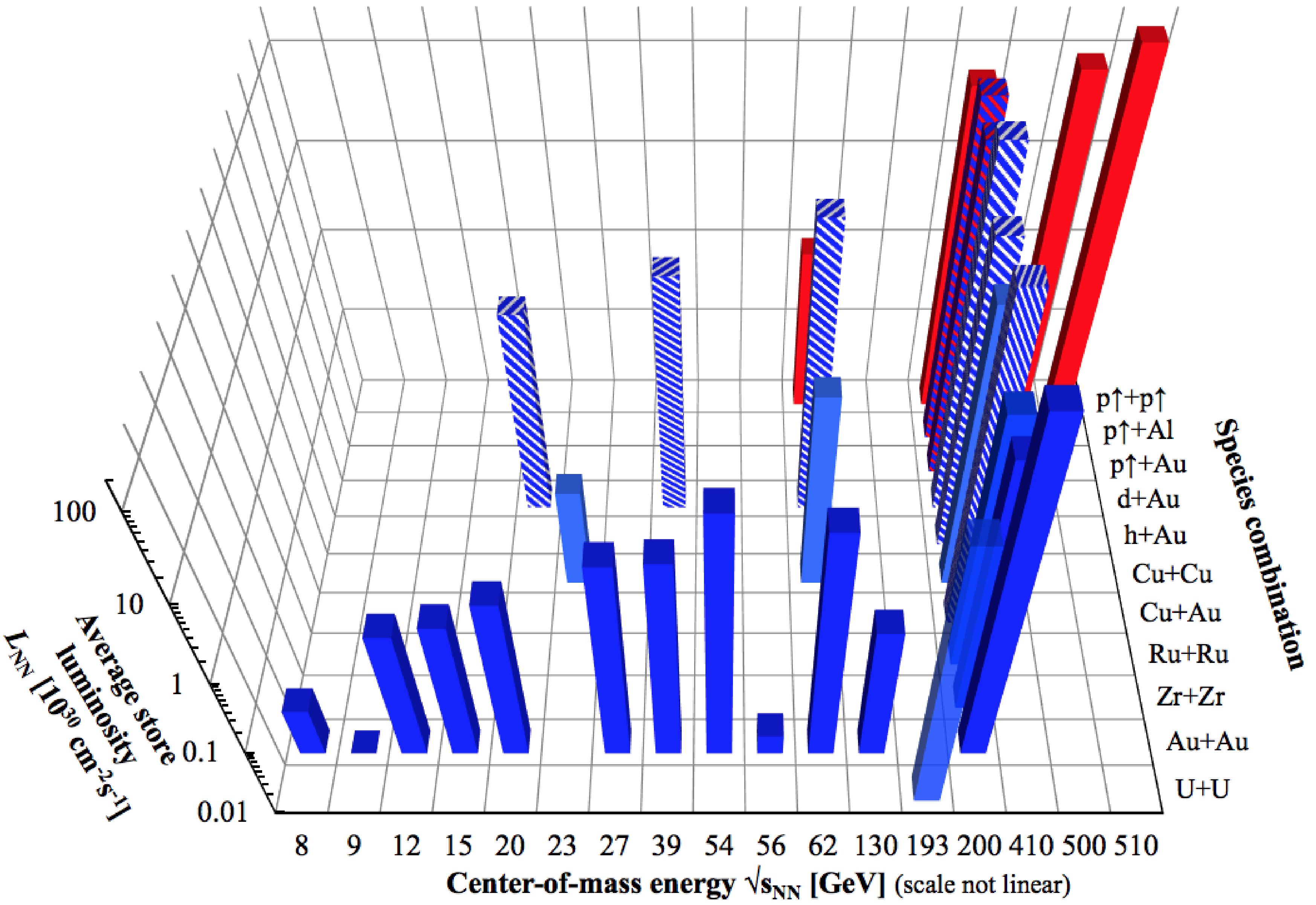
Contents

- RHIC hadron complex
- Recent developments of hadron complex
- Near future of RHIC
- Upgrade RHIC to eRHIC
- SBIR/STTR opportunities

Hadron complex


Accelerator Facility Boundary
eLENS
JET
RHIC
LEReC
CeC
sPHENIX
RF Facilities
LINAC
NSRL
AtR
STAR
Liquid Helium Plant
EBIS
Booster
LVTF
SVTF
U-Line
BLIP
ATF II
ERL
AGS
UED
Siemens
TTB
RRPL/TPL
ATF
Ebco
Tandems

RHIC energies, species combinations and luminosities (Run-1 to 18)



Tandem

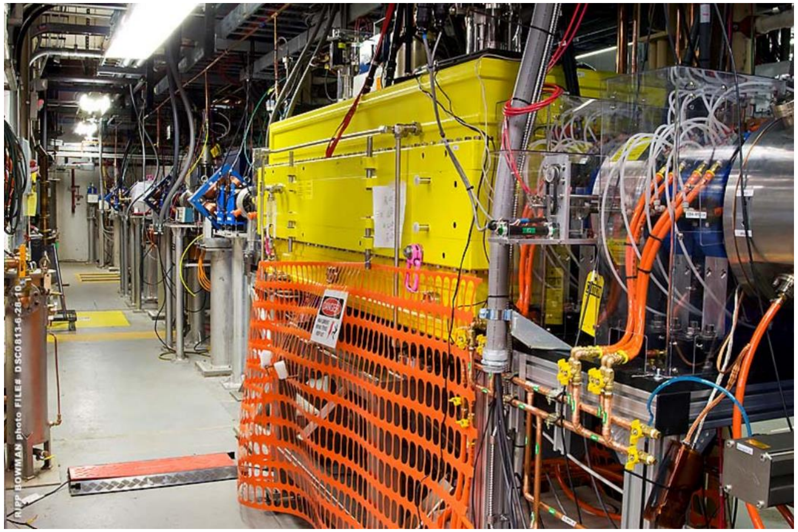
The Tandem Van de Graaff Facility consists of two 15-megavolt electrostatic accelerators capable of delivering continuous, or high-intensity pulsed ion beams in a wide range of ion species at various energies, operated since 1970. Energy: (Q+1)*15/A MeV/nucleon.

Main present applications:

- Track-etched film irradiations for filter fabrication.
- Micro-chip and solar cell testing for space applications.
- Detector calibrations of satellite instruments.
- Radiobiology at low energies and high stopping powers
- Work for the Non Proliferation and National Security Department.
- High TC superconductor enhancement through ion irradiation.
- Ion implantation in SiC wafers.
- Testing of possible spacecraft radiation-shielding approaches.
- Simulations of solar wind impact on lunar rock samples.

Offer proton and ion beams for testing and calibration, economic and flexible schedule.

Electron Beam Ion Source

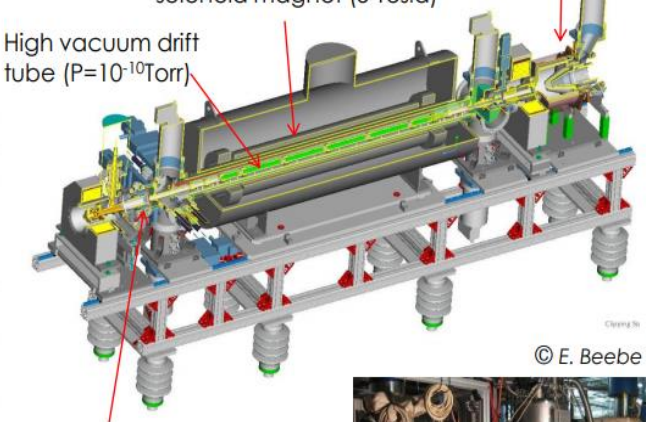


Provided Uranium, gold, copper, and He-3 and more for RHIC program, and a lot more for NSRL (NASA Space Radiation Laboratory) since 2012. Energy: ~2 MeV/nucleon.

The 15 Species provided by EBIS up to date to different experiments:

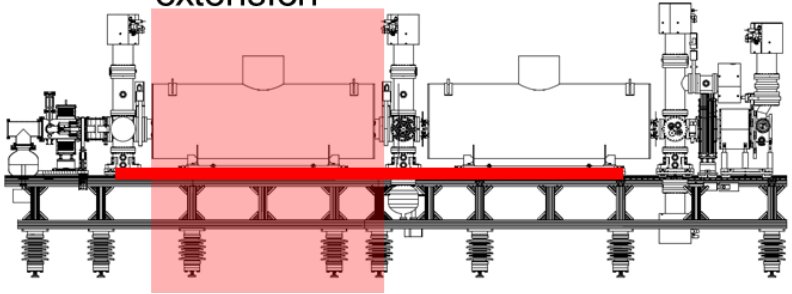
He-3	2+	AGS
He-4	1+, 2+	NSRL
C	5+	NSRL
O	6+	NSRL
Ne	5+	NSRL
Si	11+	NSRL
Ar	11+	NRSL
Ti	18+	NSRL
Fe	20+	NSRL
Cu	11+	RHIC
Kr	18+	NSRL
Xe	27+	NSRL
Ta	38+	NSRL
Au	32+	RHIC & NSRL
U	39+	RHIC

EBIS is a "charge breeder" of the injected 1+ ions



© E. Beebe ICIS2013

Hollow cathode ion source



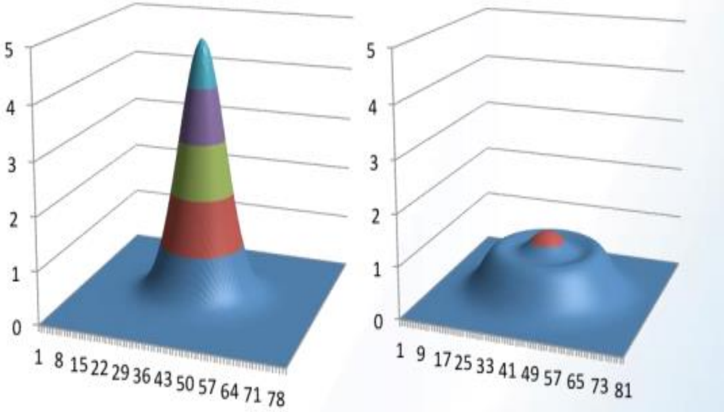
Upgrade: Extended EBIS

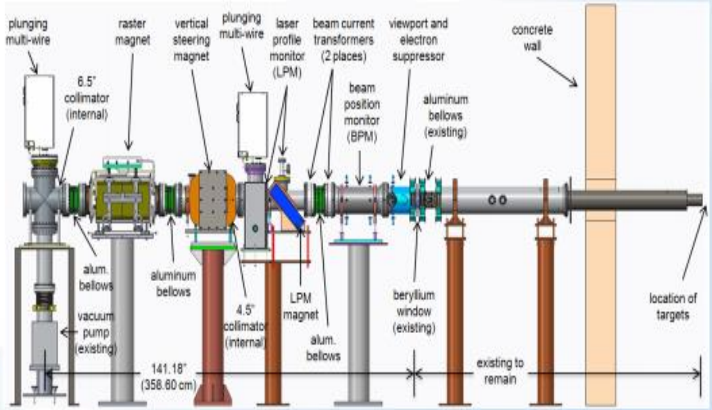
Add 2nd superconducting solenoid to increase intensity by ~40% for Run-20.

Medical Isotope Research & Production (MIRP)

- MIRP Program Missions:
  - Produce and/or distribute radioactive isotopes that are in short supply, including valuable byproducts, surplus materials and related isotope services.
  - Conduct R&D on new and improved isotope production and processing techniques which can make available new isotopes for research and applications. Currently working on fast production of Ac-225, a new cancer-treatment agent.
- BLIP beam raster system resulted in reduction in localized target heating.
- Linac intensity upgrade
  - Phase 1 (completed) Changes pulse shape to effectively increase current from 125 µA to 140 µA (reached 160 µA)
  - Phase 2 (proposed) Increases current to 250 µA by increasing pulse length, and vacuum upgrade

Isotope
Be-7
Mg-28
Fe-52
Fe-55
Ni-63
Zn-65
Cu-67
Ge-68
As-73
Sr-82
Rb-83
Y-86
Y-88
Tc-95m
Tc-96

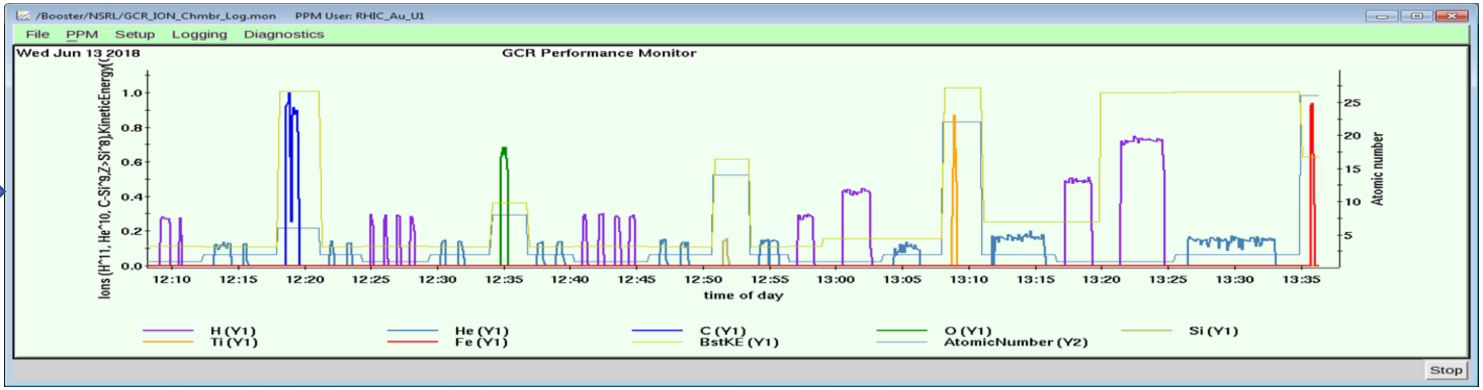




See also C. Cutler's presentation:
https://science.energy.gov/~/media/np/pdf/sbir%20sttr/SBIR_STTR_2016/Day2/Cutler_SBIR_STTR_Presentation_080516.pdf

NASA Space Radiation Laboratory

- Brookhaven’s Booster accelerator, which produces all species of ions within a range of energies, similar to those of cosmic particles found in space.
- NSRL operates 1,000–1,200 hours per year in three running cycles — typically early spring, early summer and autumn periods.
- The number of NSRL facility users has steadily increased each year since the facility’s inception. Users from NASA, national laboratories, and more than 50 institutes and universities in the U.S., Europe, and Japan tested medical, biological, and physical samples using the ion beam line at NSRL.

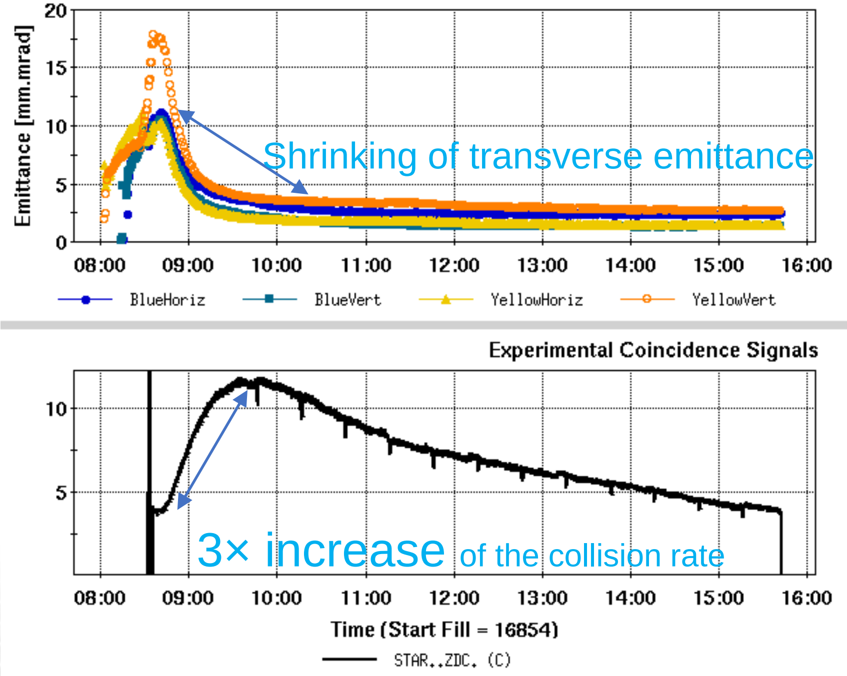


33 different species/energy ion beams in 1.3 hrs, switch time is ONLY 1.5 mins!

Recent developments

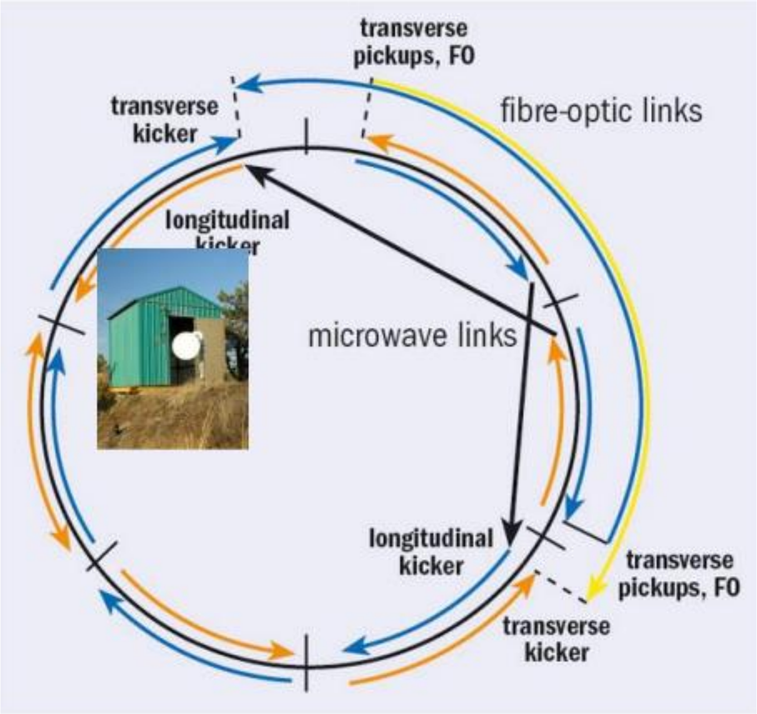
3D Stochastic cooling

- IBS (intra-beam scattering) dilute the beam emittances in all dimensions, Stochastic cooling reduces the emittances, which improves the luminosity.



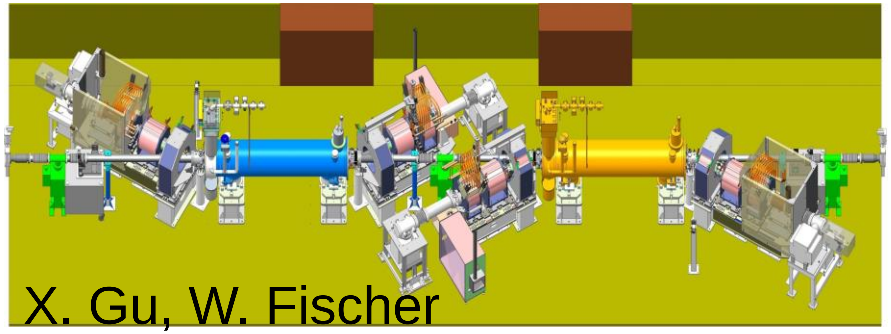
Shrinking of transverse emittance

3× increase of the collision rate

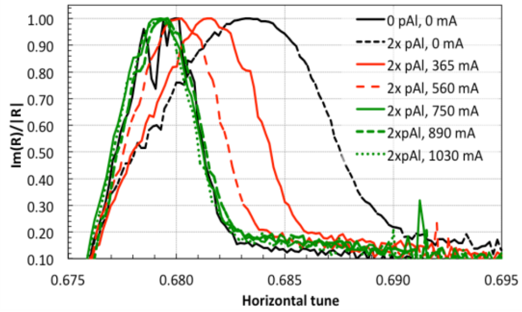


Electron lens--Head-on beam-beam compensation

First time demonstration of beam-beam compensation for proton, in operation since 2015 pp run.

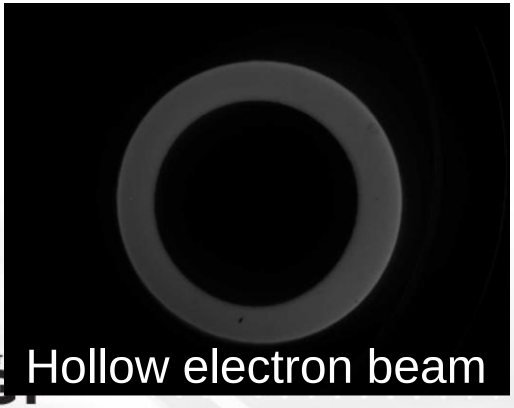


X. Gu, W. Fischer

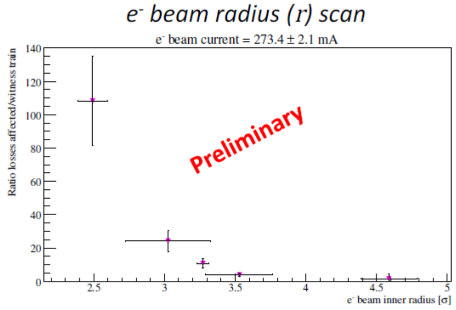


Reducing tune spread with e-lens

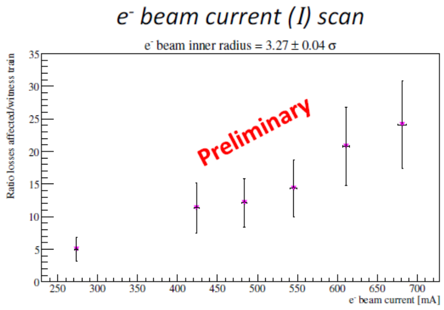
Potential applications: Hollow lens assisted collimation, space charge compensation.



Hollow electron beam



e^- beam radius (r) scan

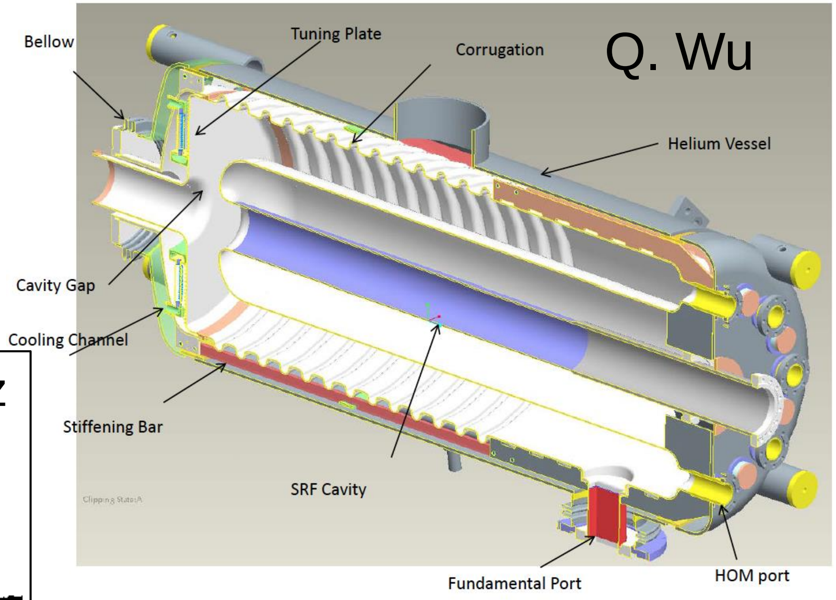


e^- beam current (I) scan

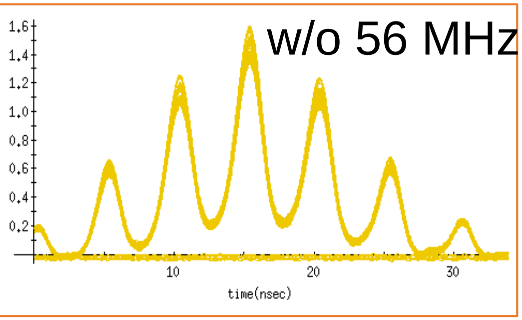
In agreement with expectations: $\theta \approx {}^{I}/_{r}$

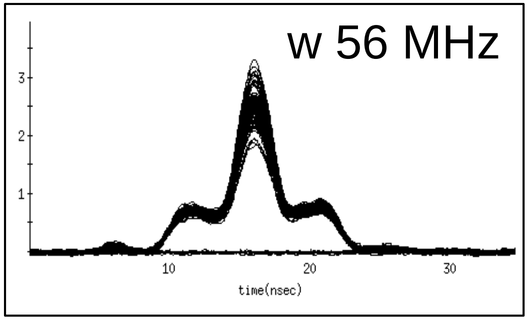
56 MHz SRF for heavy ions

Longitudinal profile at end of store
- even with cooling ions migrate into neighboring buckets
- can be reduced with increased longitudinal focusing provided by 56 MHz



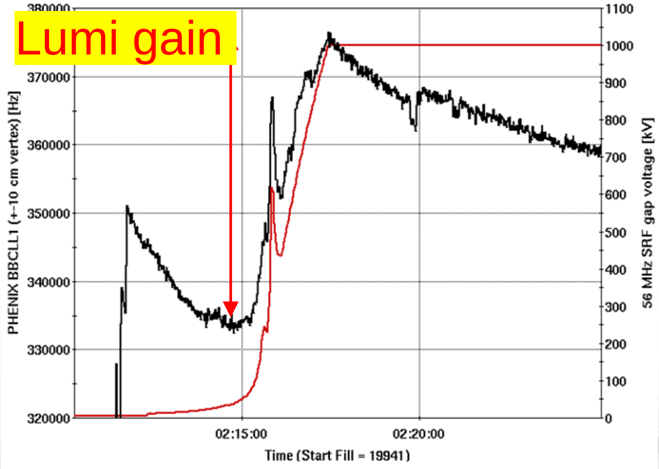
Q. Wu





- l/4 Ni resonator
- common to both beams
- beam driven
- 56 MHz, 2 MV

- There was an instant luminosity gain of 11% due to 56 MHz cavity.
- The instant gain of the PHENIX 10 cm vertex is around 15% due to 56 MHz cavity.

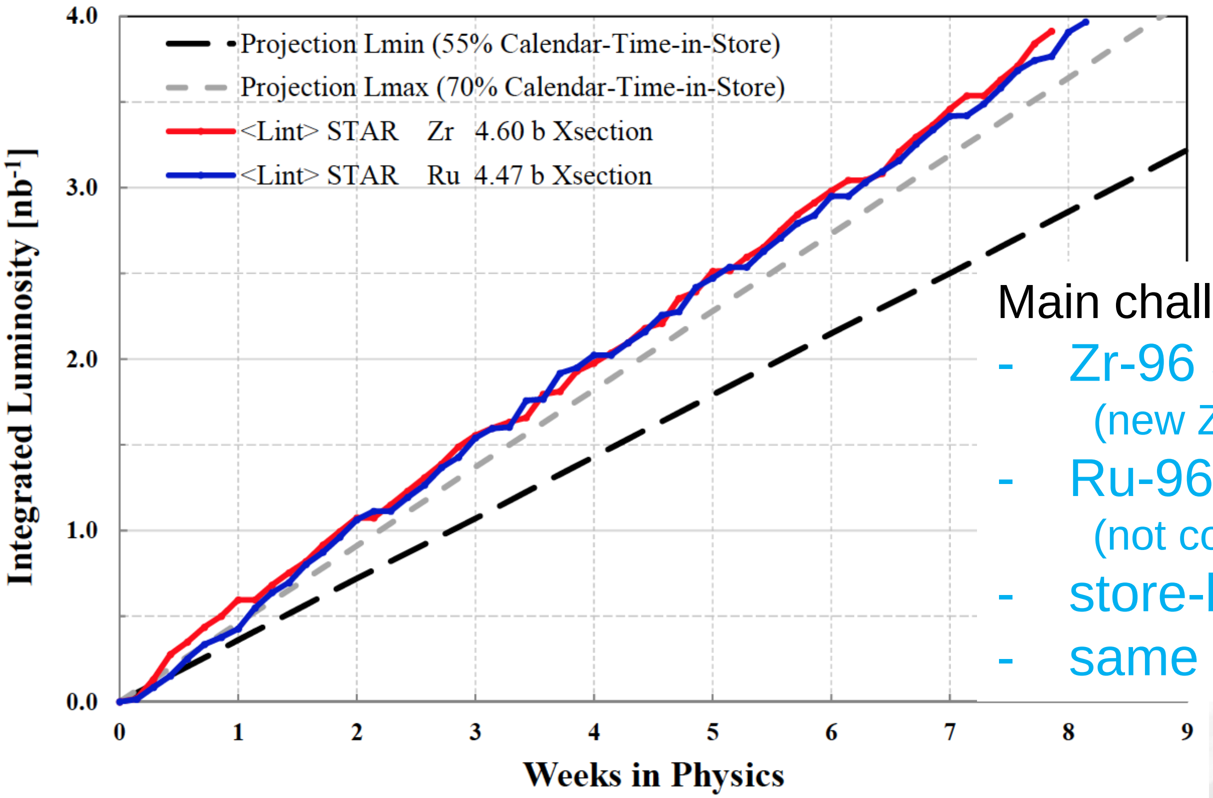


Run-18 Zr+Zr/Ru+Ru operation

Run Coordinator: Greg Marr

STAR *Lumi* flat at 21.5×10^{26} $cm^{-2}s^{-1}$

Outstanding performance of Zr-96 (EBIS)/Ru-96 (Tandem) sources, injectors, RHIC feedbacks, and stochastic cooling



Main challenges

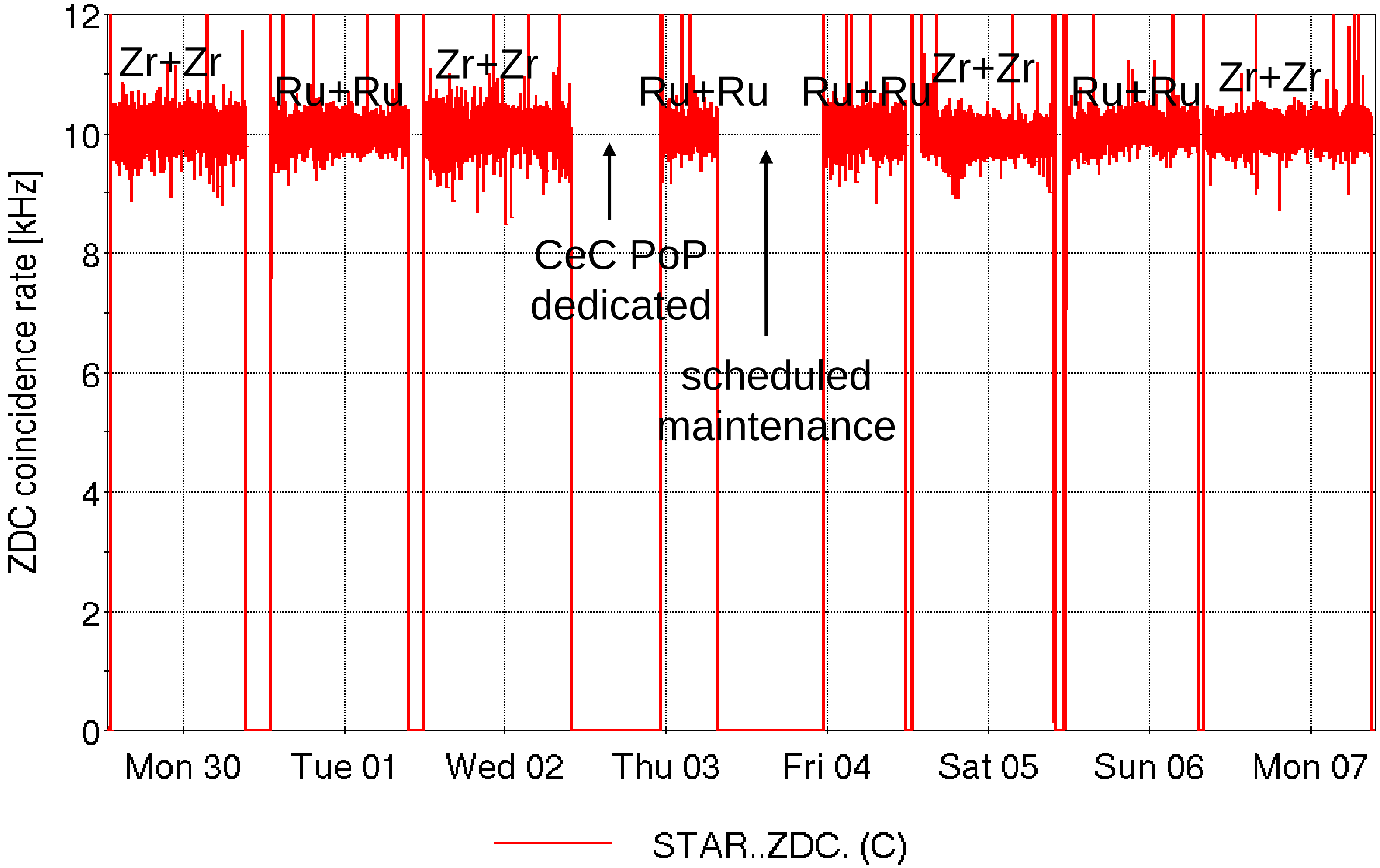
- Zr-96 3% natural abundance
  (new ZrO_2 LION target, RIKEN help)
- Ru-96 6% natural abundance
  (not commercially available, ORNL help)
- store-by-store switch Zr/Ru
- same store conditions Zr/Ru

BROOKHAVEN
NATIONAL LABORATORY

Run-18 Zr+Zr/Ru+Ru operation

Run Coordinator: Greg Marr

Flat STAR luminosity of 21.5×10^{26} cm^{-2}s^{-1} (WEEK: 30-Apr-18 to 07-May-18)



Wolfram Fischer, https://indico.bnl.gov/event/4770/contributions/22396/

Near future of RHIC

Near-term plans of RHIC

- Beam Energy Scan phase II from 2019~2021, with LEReC (Low Energy RHIC electron Cooling) commissioning in 2019, operation in 2020.

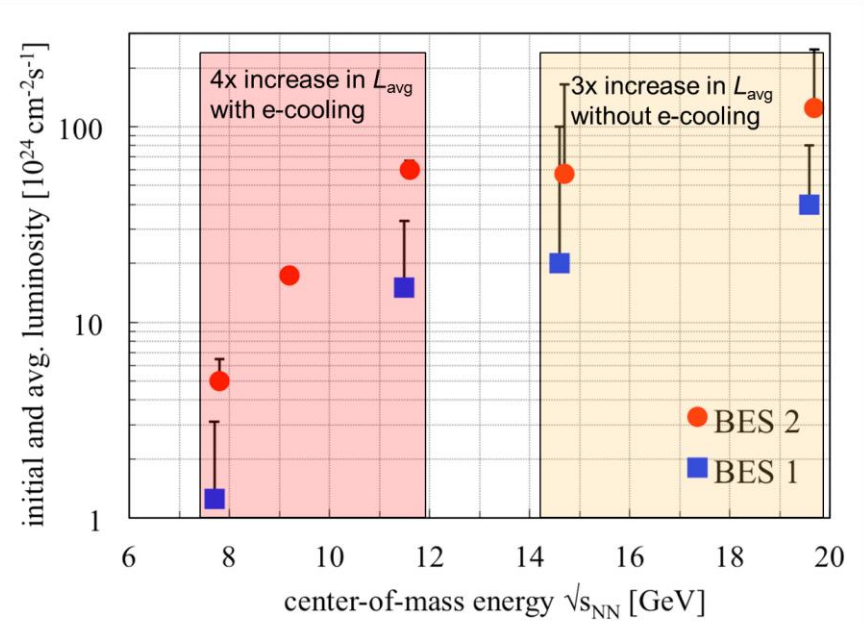
- Operation with sPHENIX detector from 2023~2026, with e-lens for proton, 3D stochastic cooling and 56 MHz cavity for Au beam.

- Meanwhile, work on eRHIC design and R&D.

Beam Energy Scan Phase II

To search for phase transition point, RHIC will operate in energy range 3.85~10 GeV. Luminosity goal of phase II is 3-4 times higher than that of phase I. The challenges are:

- Intra-beam scattering
  solution: Low Energy RHIC electron cooling
- Space charge
  solution: 9 MHz instead of 28 MHz cavity
- Lattice nonlinearity contributed by persistent current
  solution: degaussing magnet cycle
- Beam-beam interaction
  solution: near integer working point

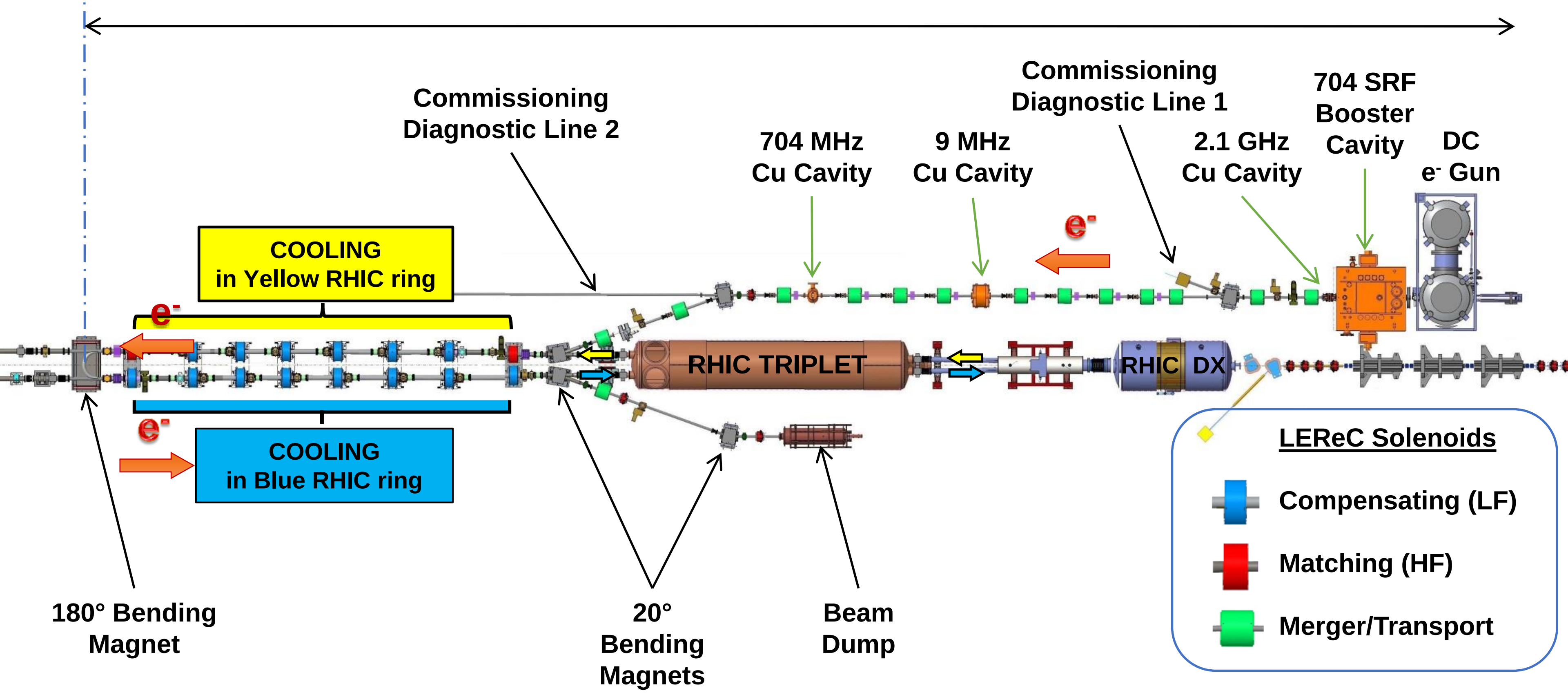


Low Energy RHIC electron Cooling

A. Fedotov

64 m to IP2

(not to scale)



Commissioning Diagnostic Line 2

704 MHz Cu Cavity

9 MHz Cu Cavity

Commissioning Diagnostic Line 1

2.1 GHz Cu Cavity

704 SRF Booster Cavity

DC e$^-$ Gun

COOLING in Yellow RHIC ring

COOLING in Blue RHIC ring

RHIC TRIPLET

RHIC DX

180° Bending Magnet

20° Bending Magnets

Beam Dump

LEReC Solenoids

- 🟦 **Compensating (LF)**
- 🟥 **Matching (HF)**
- 🟩 **Merger/Transport**

Challenges: high power laser, stable electron gun, beam loading, SRF cavities, extremely small dp/p (5E-4), beam measurements…

1st bunched beam electron cooler

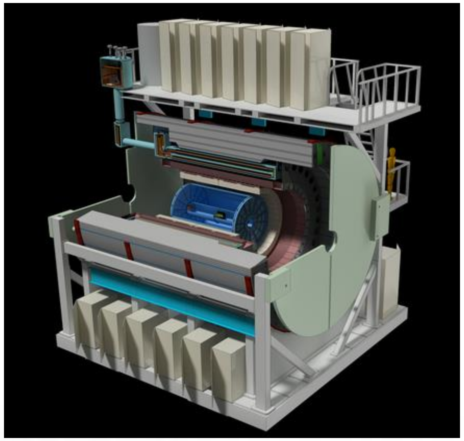
sPHENIX

<u>sPHENIX is a major upgrade to the PHENIX detector</u>. It is a large-acceptance, high-rate detector for Heavy Ion physics that repurposes >$20M in existing PHENIX equipment, infrastructure and support facilities.

The detector is optimized to measure jet and heavy quark physics by incorporating a Tracker, full EM and Hadronic calorimeter coverage at $|\eta| < 1.1$, and a 1.4 T solenoidal magnetic field.

Schedule

CD-0 received Sept 2016
Early completion Dec 2021
CD-4 Dec 2022 (proposed to DOE-ONP)



A schematic of the sPHENIX experiment

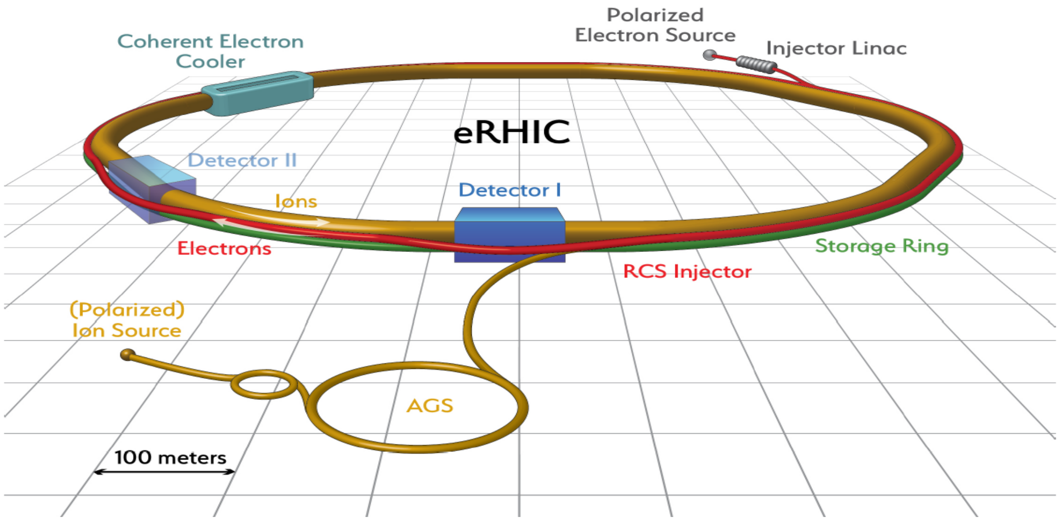
The solenoid magnet that will form the core of the sPHENIX detector

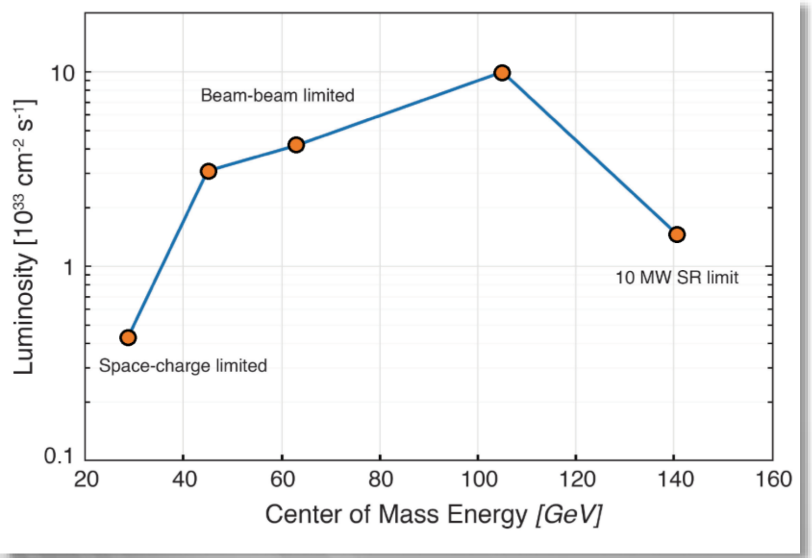
3D stochastic cooling, e-lens and 56 MHz cavity essential for sPHENIX operation

Edward O’Brien, https://indico.bnl.gov/event/4244/

Upgrade RHIC to eRHIC

eRHIC Design Concept





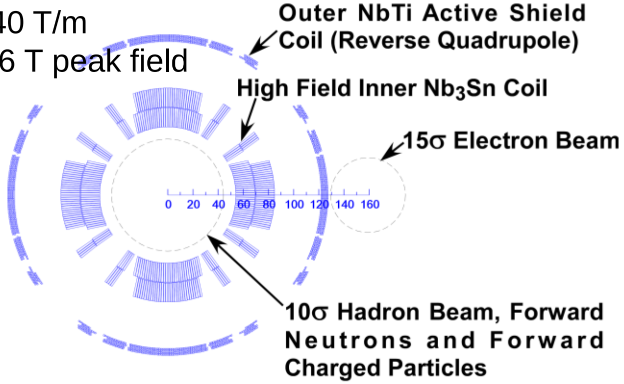
- Design goal: **$L= 10^{34}cm^{-2}s^{-1}$**
- eRHIC takes full advantage of existing RHIC complex, entirely re-using injection chain and one of RHIC rings.
- Electron storage ring and the electron injector (400 MeV linac and RCS) are added inside the existing RHIC tunnel.
- Wide coverage in Center-of-Mass energy: 29-140 GeV

  E_p: 41-275 GeV, E_e : 5-18 GeV
- Polarized beams (e, p, ^{3}He, d) with variable spin patterns
- Luminosity limitation factors on based of experience from previous colliders
- Hadron cooling is required to reach *$L= 10^{34}cm^{-2}s^{-1}$;*
  Without cooling the peak luminosity reaches 4.4 $10^{33}cm^{-2}s^{-1}$

IR magnets

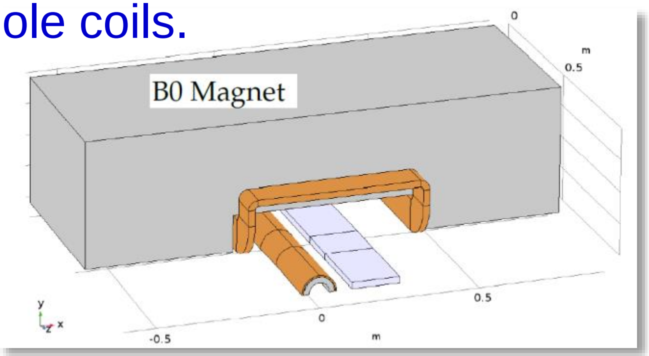
Variety of novel approaches is used for IR magnets

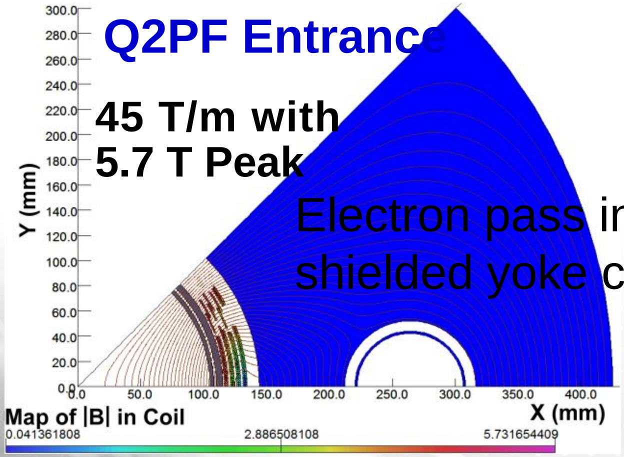
Q1PF
140 T/m
8.6 T peak field



Funded **BNL/Jlab R&D effort**: designing, building and testing a short prototype based on existing Nb_3Sn coils (from LARP work) actively shielded by new NbTi coil.

Hadron spectrometer magnet with detector elements inside. Superconducting coils. For electrons: dipole cancelling coil and quadrupole coils.

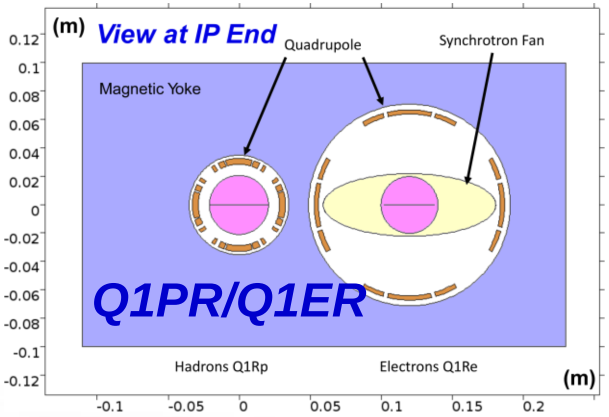




Q2PF Entrance

45 T/m with
5.7 T Peak

Electron pass in shielded yoke cutout



Concept for a Direct Wind tapered coil design for Q1PR that has a nearly constant gradient along its entire length

Hadron machine upgrade

Proton parameters	**Achieved at RHIC**	**eRHIC nominal**
Beam current, mA	330	1000
Bunch frequency, MHz	9.4	112.6
Peak current, A	12	24

In-situ copper coating of existing stainless steel beam pipe to reduce cryo-load from resistive heating.

Magnetron mole for coating long narrow tubes has been designed and built. Presently: equipment testing and preparing for coated surface measurements

Electron cloud

- Beam scrubbing is an efficient tool based on LHC experience
- But additional remedies may be needed to reduce SEY. Under evaluation:
  - aC coating (using the tooling developed for Cu-coating)
  - Laser-engineered grooving
- e-cloud simulation studies are on-going (PyEcloud, CSEC)

Required hardware upgrades:

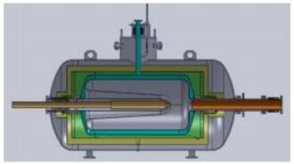
- New injection kickers (<12 ns rise time)
- RF system upgrade to incorporate bunch splitting and bunch compression

Coherent electron Cooling Proof of Principle

CeC (Coherent Electron Cooling) is a potential fast cooling method crucial for eRHIC high luminosity. Major components are:

- Multialkali photocathode
- High power laser
- High bunch charge with SC electron gun (3nC)
- Superconducting technology
- Helical wiggler magnets
- Beam detection along entire beam line

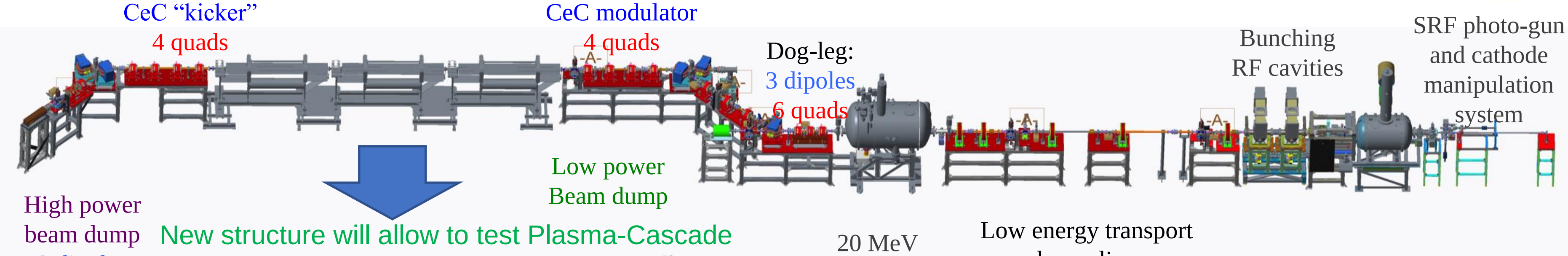
Observed “heating” of the hadron beam with the electron beam but were unable to obtain imprint of the hadrons on to the electron beam (giving increase in the FEL power). Presently investigating this result and possible causes.



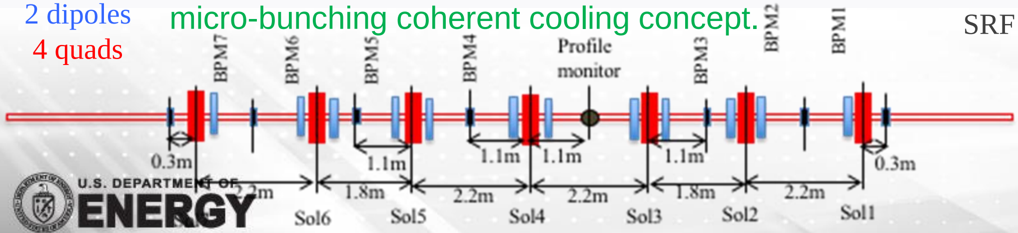
112 MHz SC electron gun

5-cell 704 MHz SC Cavity

Common section with RHIC



New structure will allow to test Plasma-Cascade micro-bunching coherent cooling concept.

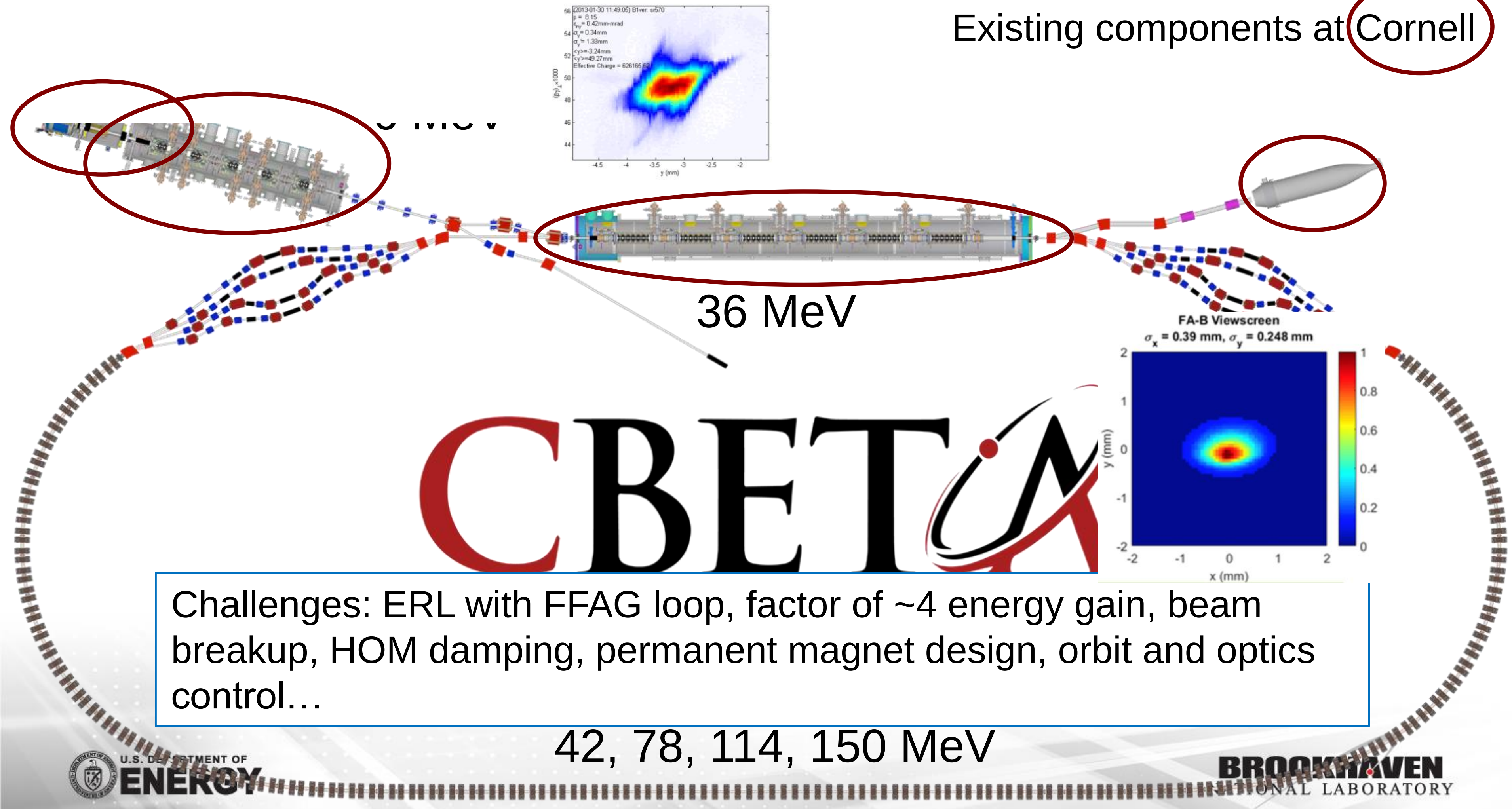


V. Litvinenko, I. Pinayev

https://arxiv.org/abs/1802.08677

CBETA—Cornell BNL ERL Test Accelerator

- A multi-turn ERL with FFAG return loops to demonstrate electron beam parameters for Strong Hadron Cooling, for example 100 mA, 150 MeV.



Existing components at Cornell

Challenges: ERL with FFAG loop, factor of ~4 energy gain, beam breakup, HOM damping, permanent magnet design, orbit and optics control…

eRHIC R&D Program is underway

- Strong Hadron Cooling
  - Theoretical and simulation studies of advanced techniques (micro-bunched cooling; staged plasma-amplification)
  - Coherent electron Cooling experimental Proof-of-Principle test at RHIC
  - High-current multi-pass ERL using FFAG recirculation passes (CBETA facility at Cornell)
- In-situ coating of RHIC beam pipe (with copper and amorphous carbon)
- High charge polarized electron gun prototype
- Crab-cavities: prototypes and study of related beam dynamics
- e-p beam-beam effect simulation studies
- Polarized He3 production and acceleration
- High-current polarized electron source (large cathode or based on merging scheme) (for ERL-Ring)

eRHIC SRF R&D for SBIR

- Design of high current SRF cavity with well-damped HOM capabilities.
- Design of the high power, broadband and compact HOM damper.
  - Power: more than 10 kW HOM power has to deliver outside the cryomodule.
  - Broadband: up to 10s GHz, as the bunch length is as short as 3 mm.
  - Compact: to fit cavities in limited space.
- High power adjustable fundamental power coupler.
  - To accommodate various operation scenarios
  - Reliability and cost-effective.
- Cavity control.
  - Minimization of micro-phonics
  - Reduction of transient beam loading and its impact.
  - Beam stability control (beam-cavity interaction, feedback)
- High power RF source.
  - Reliable and cost-effective high power RF sources

Potential SBIR R&D

- Crab cavity prototype for RHIC.
- Prototype IR magnets, super-ferric spectrometer, tapered coil magnet.
- Superfast kicker with rise time < 9 ns.
- Developing absolute polarimeter & spin rotator for He-3.
- High power laser for 50 mA highly polarized electron gun.
- Fast, non-invasive beam diagnostics for electron and ion beams.
- Longitudinal damper for coupled bunch instabilities in electron ring.
- Feedback to control fast ion instability in electron ring.
- Narrowband damper to control ion beam coupled bunch instabilities at injection.

Summary

- RHIC complex provides many species of ions with wide energy range for nuclear physics program, isotope production, industrial and academic research programs.
- Recent developments, intensity upgrade, stochastic cooling, e-lens, 56 MHz, CeC-PoP experiment, LEReC project, enhanced the performance of RHIC complex, and better positioned the CA department for future projects.
- R&D are crucial to upgrade RHIC to eRHIC. R&D which need expanding collaborations have been identified in this presentation.
- The SBIR/STTR program serves an important role in accelerator upgrades and the R&D program at RHIC.
- 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.