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U.S. DEPARTMENT OF ENERGY

21 years of RHIC – performance far beyond the design

Wolfram Fischer

14 October 2021

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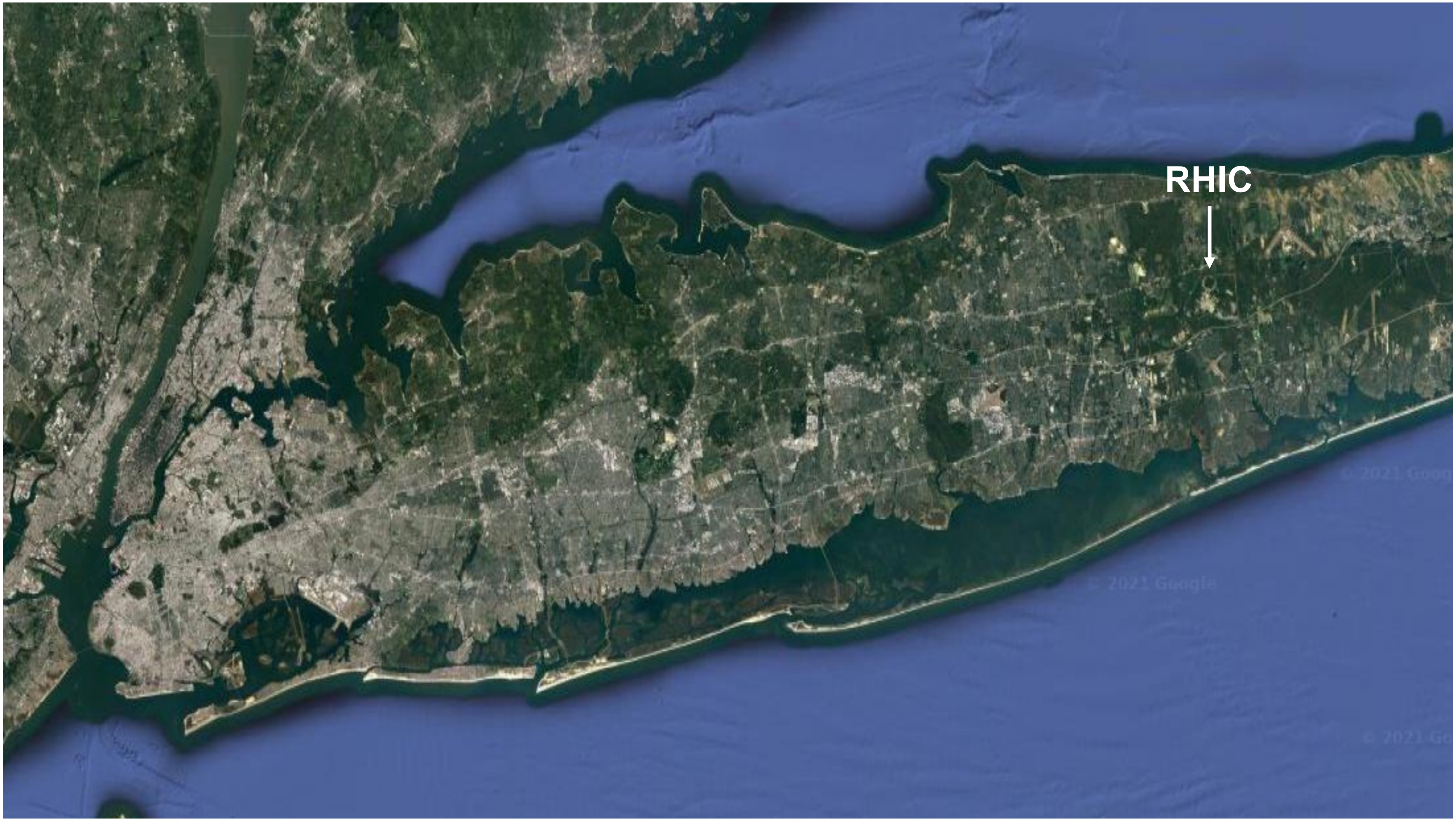
RHIC
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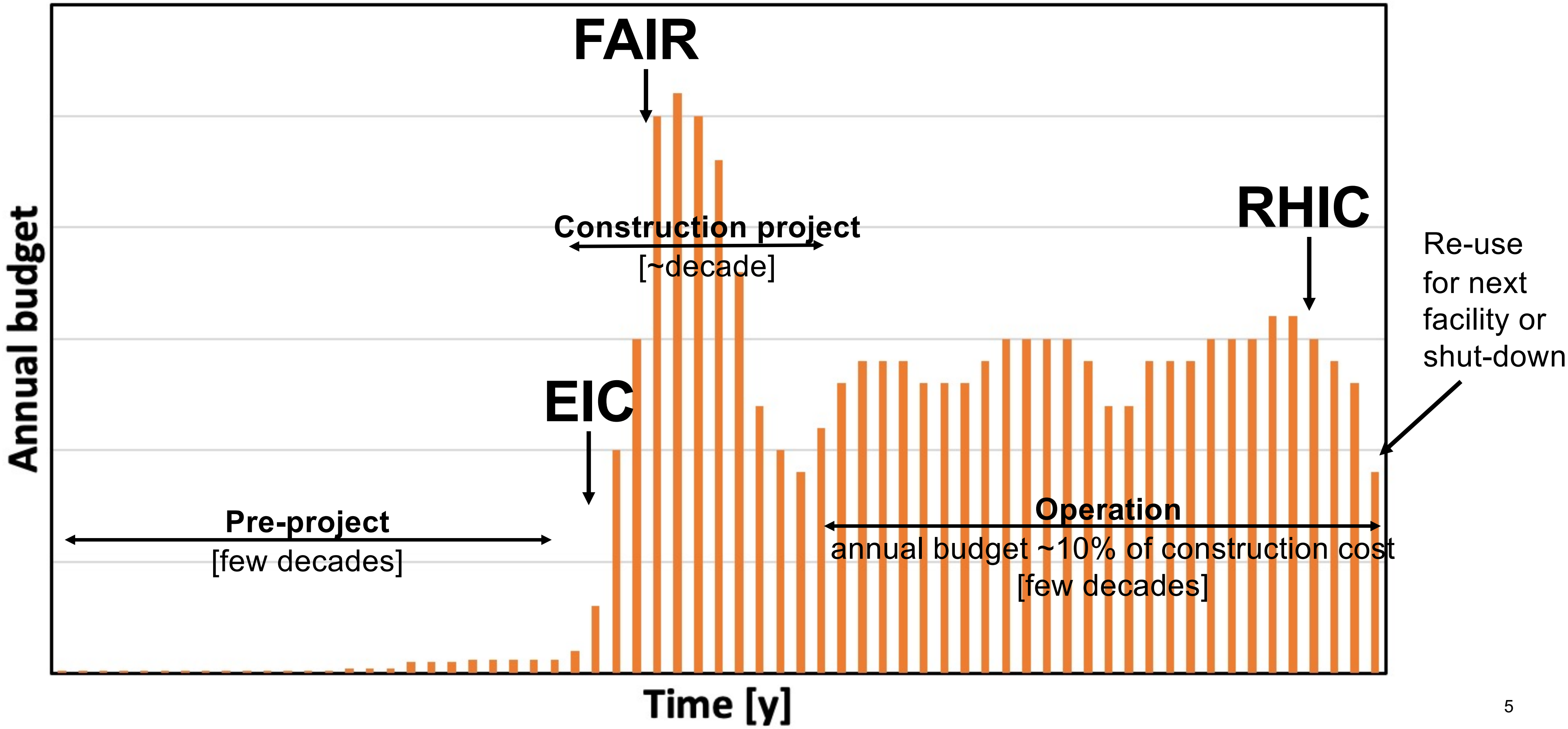
Abstract

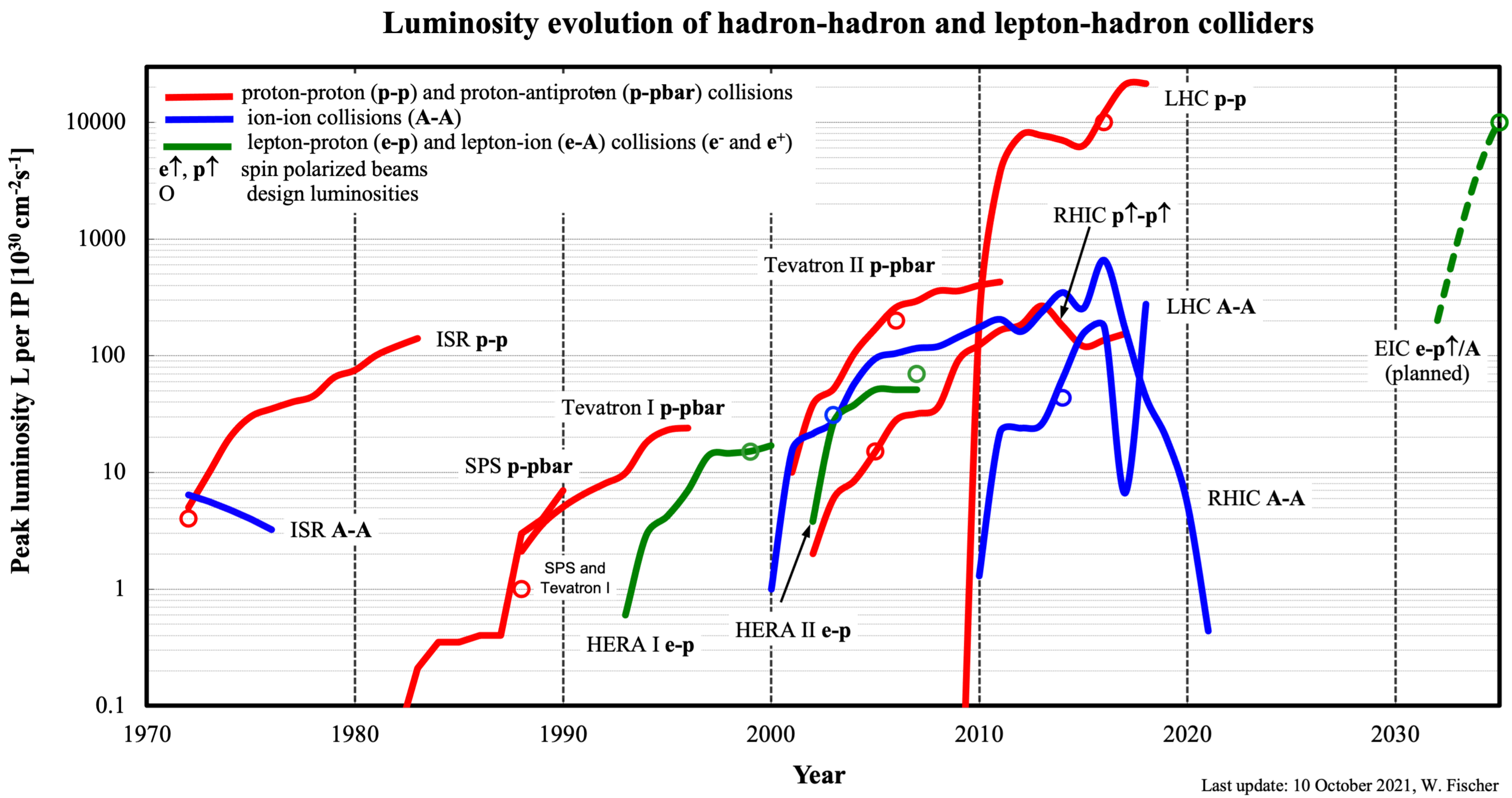
The BNL Relativistic Ion Collider (RHIC) started operation more than two decades ago with a program of high-energy ion collisions. A few years later a program with polarized proton collisions was added, and the following years the program expanded further and further with ever-increasing luminosity, polarization, species combinations and operational flexibility. The machine is now also preparing for use in the Electron-Ion Collider. We examine the path from the beginning to the present state, and outline the technical and other components and strategies to sustain a long and varied physics program.

Contents

- Before RHIC
- The RHIC design
  - Ions
  - Polarized protons
- Performance evolutions
  - Luminosity, polarization
  - Species and “exotic runs”
  - Remaining years
- What made 2.5 decades of operation possible

Life cycle of a large accelerator facility

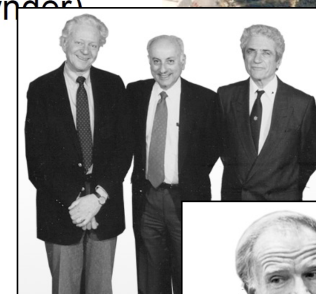


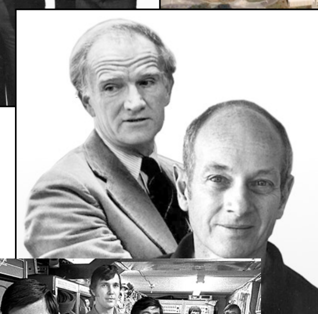

Luminosity evolution of hadron-hadron and lepton-hadron colliders
proton-proton (p-p) and proton-antiproton (p-pbar) collisions
ion-ion collisions (A-A)
lepton-proton (e-p) and lepton-ion (e-A) collisions (e- and e+)
e↑, p↑ spin polarized beams
O design luminosities
Peak luminosity L per IP [10^30 cm^-2 s^-1]
10000
1000
100
10
1
0.1
1970
1980
1990
2000
2010
2020
2030
Year
ISR p-p
ISR A-A
SPS p-pbar
SPS and Tevatron I
Tevatron I p-pbar
HERA I e-p
HERA II e-p
Tevatron II p-pbar
RHIC p↑-p↑
LHC p-p
LHC A-A
RHIC A-A
EIC e-p↑/A (planned)
Last update: 10 October 2021, W. Fischer

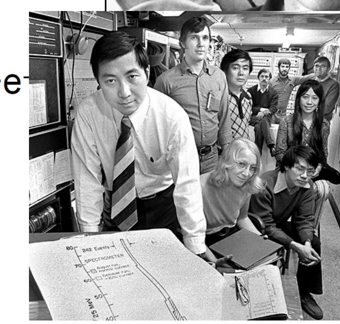
AGS Early History

the Discovery Phase

- **1952:** Strong focusing principle discovered (Courant, Livingston & Synder) making AGS possible
  - Transition problem---electron analog
- **1960:** AGS Commissioned, 33 GeV protons **1959**: CERN PS
- **1962: Discovery,** Muon neutrino discovered (Schwartz, Lederman & Steinberger, 1960 proposal) – **1988 Nobel Prize**
- **1963: Discovery,** CP violation discovered (AGS E181, 1963,$K_2^0 \rightarrow \pi^+ + \pi^-$ Experiment, Cronin & Fitch) – **1980 Nobel Prize**
- **1964: Discovery,** Ω^- (Samios, 80" Bubble Chamber)
- **1974: Discovery,** J(/ψ) Particle Discovered (AGS E598, 1972, $p+Be \rightarrow e^+ + e^- + X$ Experiment, Ting) – shared **1976 Nobel Prize** with Richter for same discovery at SLAC (ψ particle)
- **1974: Discovery,** Charmed Baryon discovered (Samios, 7' Bubble Chamber)

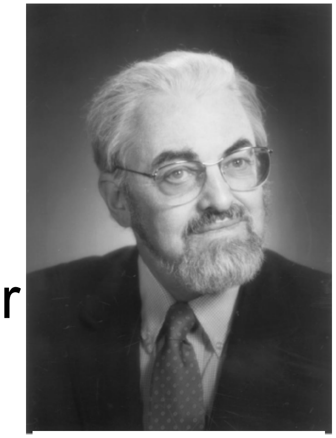






[Y.Y. Lee, "50 years of the BNL AGS", 14th Intl. Conf. on Accelerator and Beam Utilization, Gyeongju, Korea (2010).]

ISABELLE



Ernest Courant
1920-2020

- Early 1970 studies for 200+200 GeV proton-proton collider superconducting magnets
- 3.8 km circumference, 6 intersection, AGS as injector
- At the same time Fermilab started working on the Tevatron
- Only one working dipole prototype (Mark V) – sc cable issues
- Tunnel, office building, helium refrigerator built (still in use today)
- 1983 canceled in favor of SSC (itself canceled in 1993)
- BNL quickly build a heavy ion physics program with AGS

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[Ernest D. Courant, “Accelerators, colliders, and snakes”, Annu. Rev. Nucl. Sci. 2003. 53:1-37]

Relativistic Heavy Ion Collider

- 1984 began to think about heavy ion collider
- ~100 GeV/nucleon,
  dipoles ~3.5 T (5 T for ISABELLE)
- develop heavy ion beams in AGS,
  with heavy ion experiments
- 1991 construction begins
- 2000 first collisions

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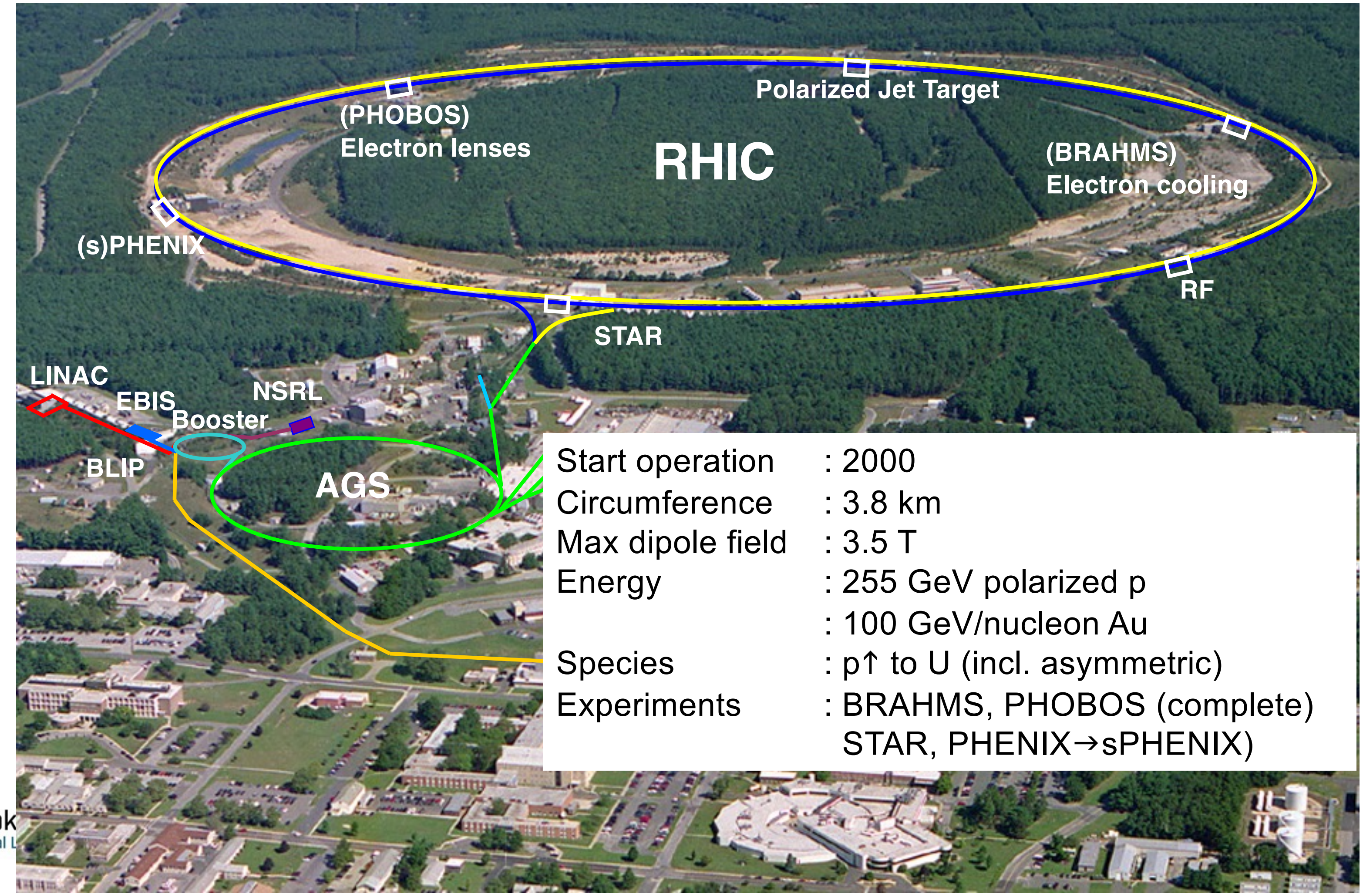
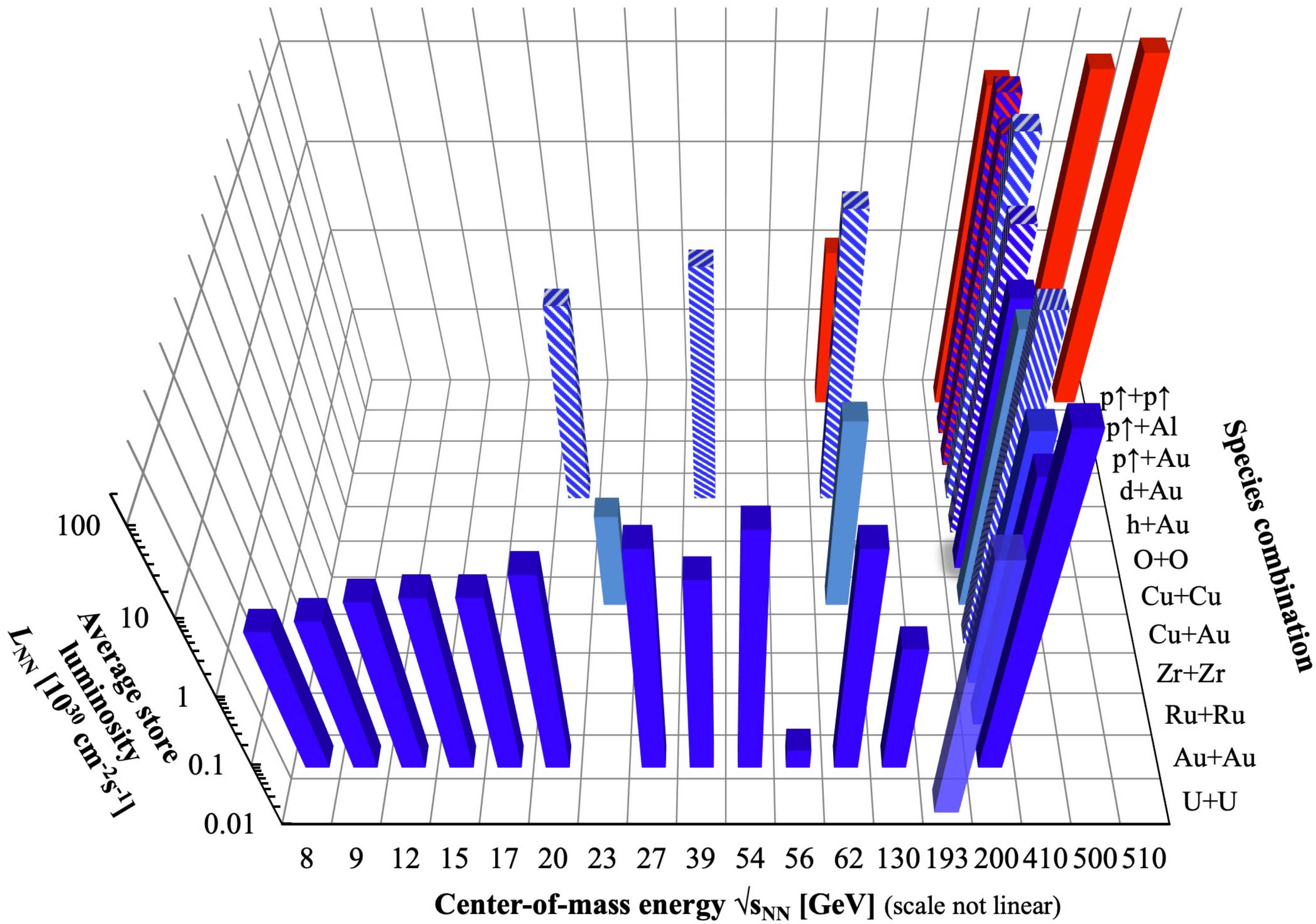
[Ernest D. Courant, “Accelerators, colliders, and snakes”, Annu. Rev. Nucl. Sci. 2003. 53:1-37]

Relativistic Heavy Ion Collider – main parameters



Start operation	: 2000
Circumference	: 3.8 km
Max dipole field	: 3.5 T
Energy	: 255 GeV polarized p
	: 100 GeV/nucleon Au
Species	: p↑ to U (incl. asymmetric)
Experiments	: BRAHMS, PHOBOS (complete) STAR, PHENIX→sPHENIX)

RHIC energies, species combinations and luminosities (Run-1 to 21)



RHIC Design Manual

July 1998

now $L_{avg} = 88 \times 10^{26}$ cm^{-2}s^{-1}

Luminosity. The collider is designed for a Au-Au luminosity of about 2×10^{26} cm^{-2} sec^{-1} at top energy, while maintaining the potential for future upgrades by an order of magnitude. Operation with the heaviest ions imposes the most demanding requirements on the collider design, and gold-on-gold is taken as the prototypical example. The luminosity is energy dependent and decreases in first approximation proporti[...] will be higher, with ~1×10^{31} cm^{-2} sec^{-1} for pp collisions.

now $L_{avg} = 15.4 \times 10^{31}$ cm^{-2}s^{-1} (with P_{avg} = 55%)

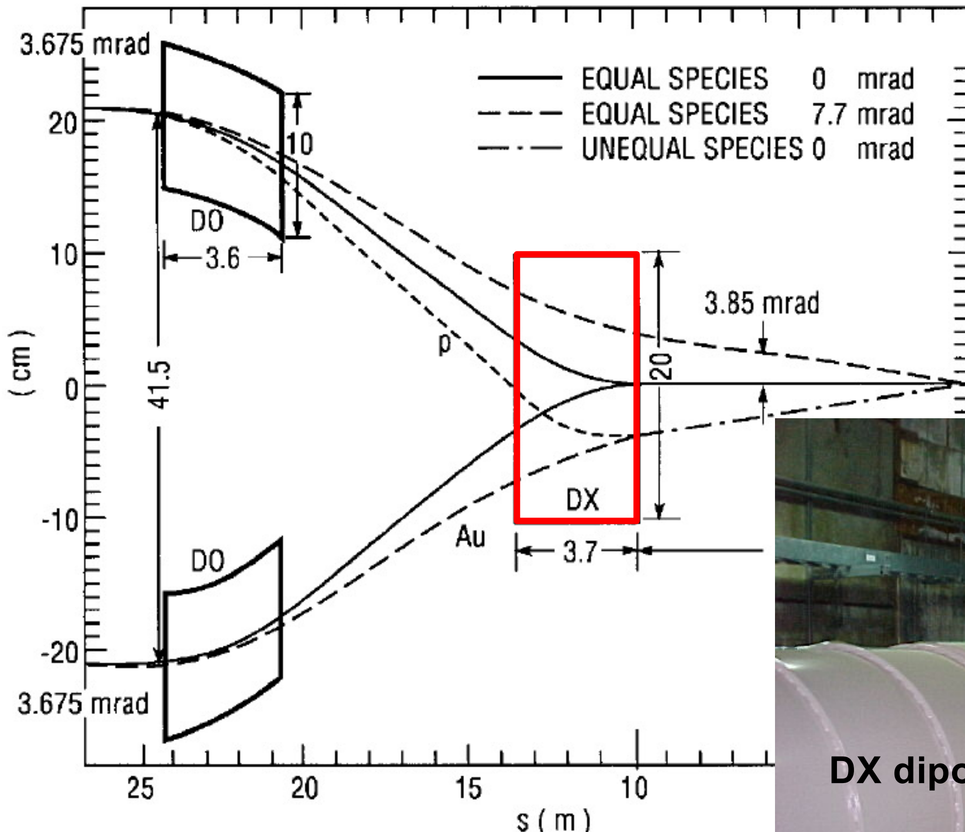
Range of ion masses. The expectations for interesting physics phenomena require a broad range of nuclei from the heaviest to the lightest, including protons. Asymmetric operation with heavy ions colliding on protons is considered to be crucial for the experimental program. The collider will allow collisions of beams of equal ion species from Au-Au all the way down to p-p. It will also allow operation of unequal species such as protons on gold ions.

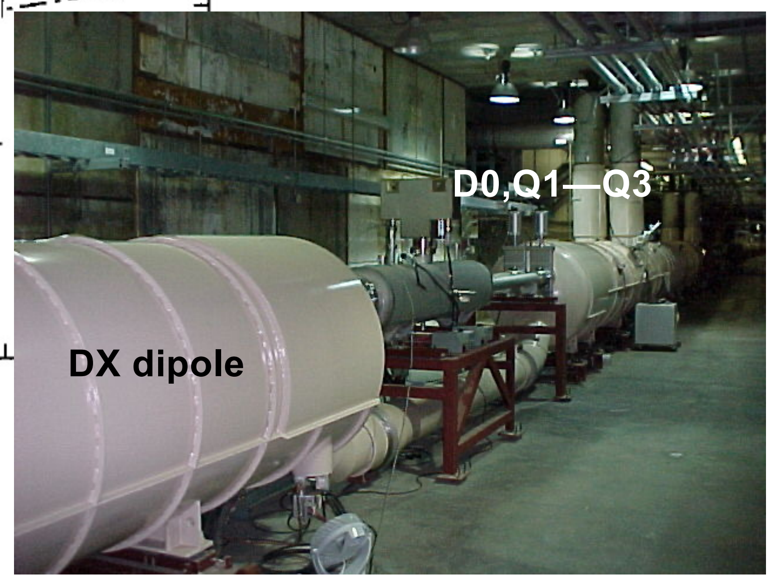
Uranium is a viable species and can be considered as a future upgrade. However, at the present, an adequate source for uranium does not exist at Brookhaven and further R&D will be needed to achieve this goal.

Intersection Regions. The existing tunnel and the magnet lattice configuration provides for six experimental areas where the circulating beams cross. Three of the experimental areas presently

RHIC Design Manual (July 1998)

IR design with beam splitting DX dipoles first





DX dipoles

- L_{mag} = 3.7 m, B_{max} = 4.3 T
- large aperture
  (18 cm coil ID)
- only magnets that need training
  (~5 for IR6/8 only)

Transition crossing – with sc magnets

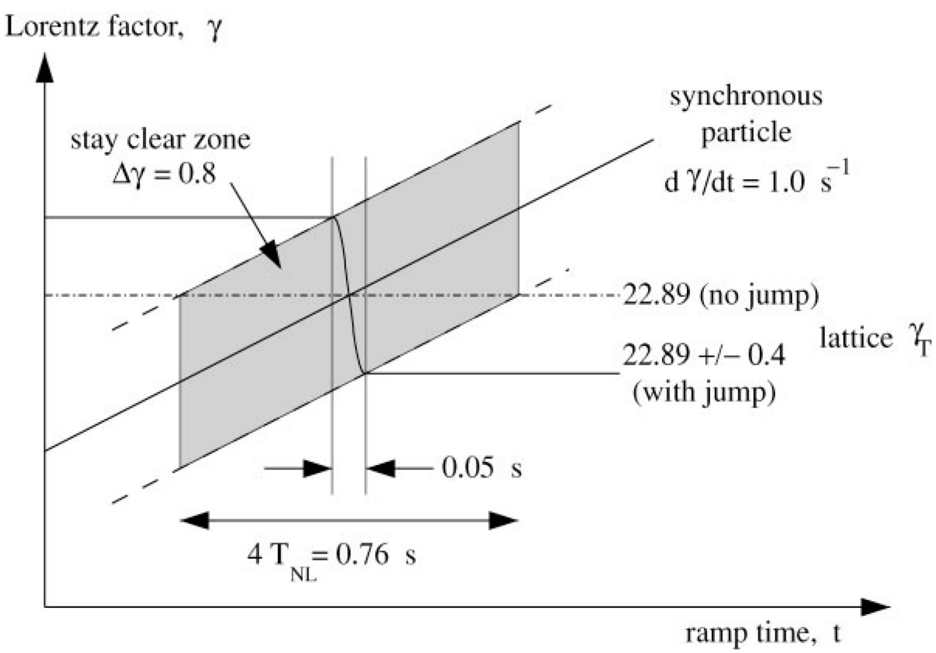


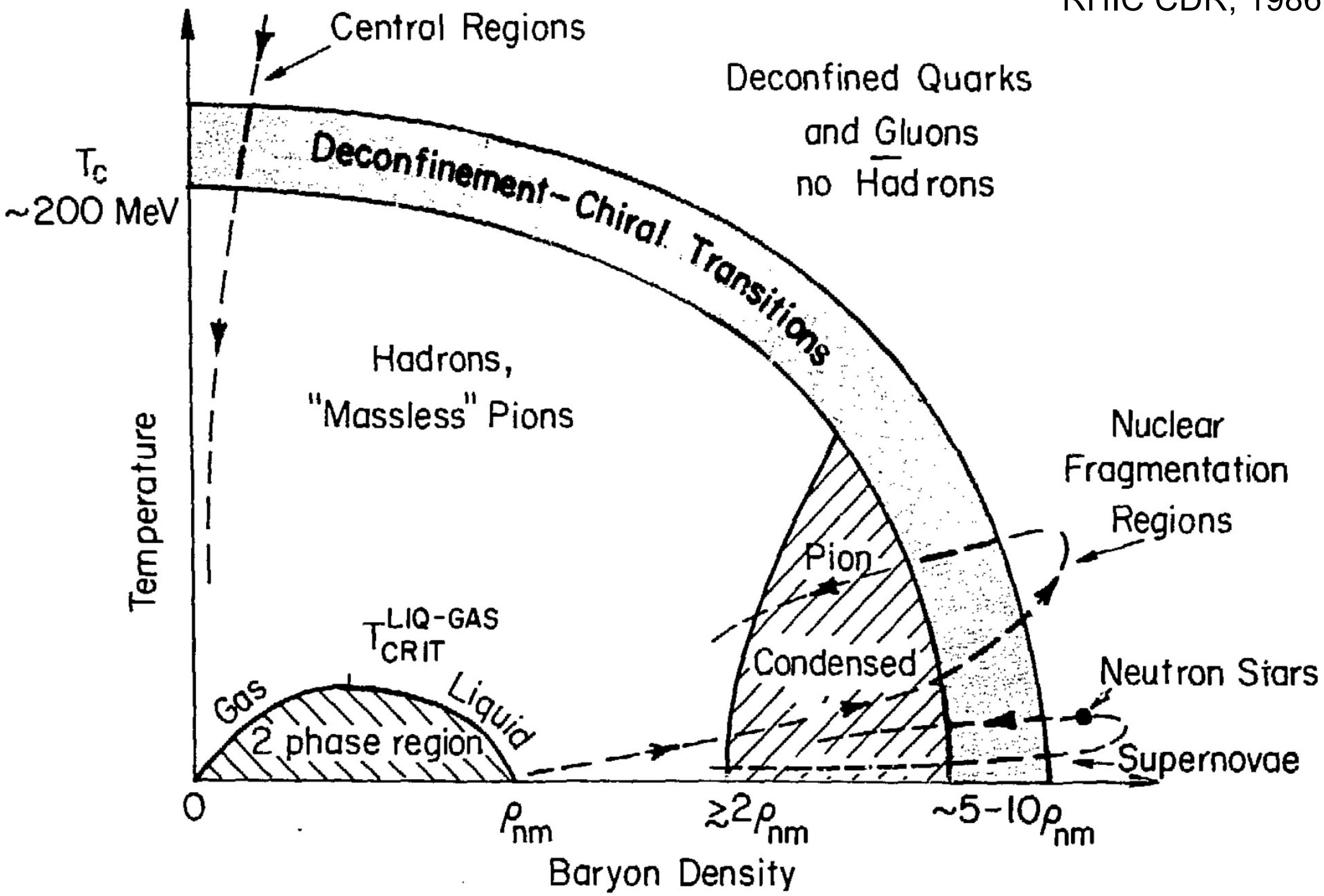
Figure 12 Schematic representation of the RHIC transition jump. Transition is crossed about 15 times faster with the jump than without.

Did limit intensity for some time

- Electron clouds
- Instabilities

[M. Harrison, S. Peggs, and T. Roser, "The RHIC accelerator", Annu. Rev. Nucl. Sci. 2002. 52:425-369

RHIC CDR, 1986



Houston

BROOKHAVEN BULLETIN

Vol. 54 - No. 21 June 16, 2000

BROOKHAVEN NATIONAL LABORATORY

RHIC Begins World's Highest Energy Heavy-Ion Collisions

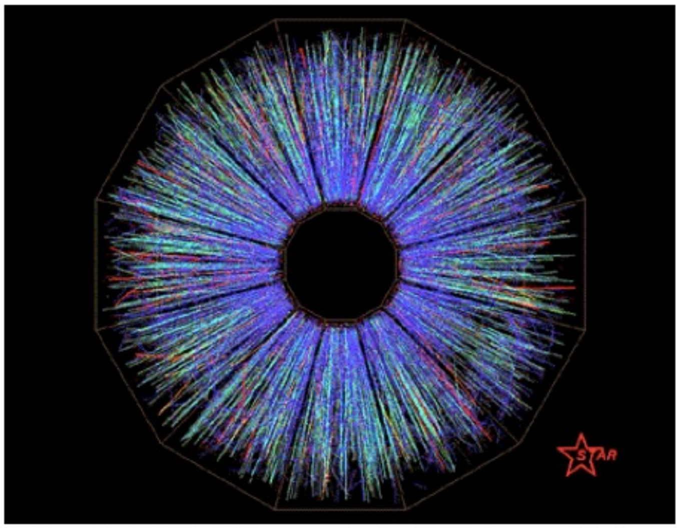
On the evening of Monday, June 12, operators in the main control room of the Relativistic Heavy Ion Collider (RHIC) watched control displays anxiously as the beams circulating in the collider's twin rings appeared to be colliding.

"The atmosphere was tense and very exciting," said Thomas Roser, head of the Accelerator Division and run coordinator for RHIC's first collision run. "We were operating at nearly 30 billion electron volts (GeV) per nucleon, our target energy for first collisions,

"We are crossing into a new frontier of scientific inquiry."

and we knew the beams were crossing at the collider's intersection points. But we couldn't say for sure that we'd had collisions until we got definitive, corroborative evidence from the detectors."

All four of RHIC's detectors — BRAHMS, PHENIX, PHOBOS and STAR — were poised and ready to take data as the accelerator physicists began to steer the beams into collision, necessarily one detector at a time.

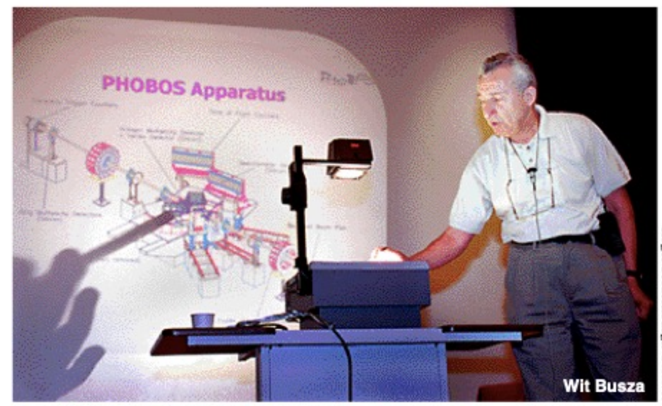


A view of a RHIC collision seen in the STAR detector. "We knew immediately that we'd seen a true, beam-on-beam collision because all the particle tracks clearly originated at the center of the beam tube and sprayed out in all directions," said John Harris of Yale University and head of the STAR team. The symmetric pattern of particle tracks contrasts dramatically with so-called background events the team had witnessed, where collisions between ions and gas particles in the beam tube produce tracks going in only one direction.

est and biggest particle a
studies in nuclear phy:
crossing into a new fror
tific inquiry," said Ener
Bill Richardson upon h
first collisions. "Scientist
the world will use this
swer some of the most ba
about the properties of m
evolution of our univers
The collider aims to
conditions of the early un
insights into the fundan
of matter — and exten
aries of scientific un
through the 21st century
Scientists will use d
during the collisions to
particles known as quar

The high tem tures and den should allow soup-like plas a state of mat believed to ha existed millions of a second after the

PHOBOS Collaboration Presents First Physics Results From RHIC



Roger Stoutenburgh

The first physics results from the initial collisions at BNL's Relativistic Heavy Ion Collider (RHIC) were presented by the PHOBOS collaboration to a full house at Berkner Hall on July 19.

collisions. At the higher energy, the collisions achieved an energy density 50 percent higher than that observed for lead-lead collisions at CERN, the European particle physics laboratory."

As Busza explained, data for the

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Configuration Manual Polarized Proton Collider, 2006

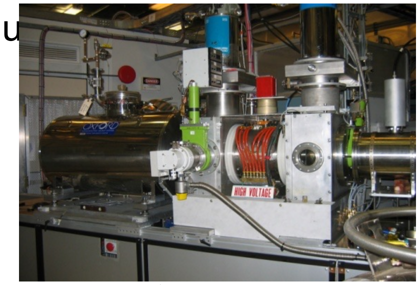
Parameter	
Peak c.m. energy	500 GeV
Initial luminosity	$2 \times 10^{32} \text{cm}^{-2}\text{sec}^{-1}$
Interactions per crossing (60 mb)	1
Protons per bunch	2×10^{11}
Bunches per ring	120
Normalized emittance (95%)	20 π mm mrad
β^*	1 m
Average polarization	70%
Stable Spin direction at Interaction Point	vert. or long.
RF voltage per turn	6 MV
RF harmonic number	2520
Long. emittance (95%)	0.3 eV sec
Beam Momentum Spread	2.6×10^{-4}
Beam-beam tune spread (per IR)	0.007

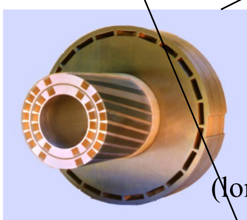
Table 1.1: RHIC Spin Accelerator Parameters.

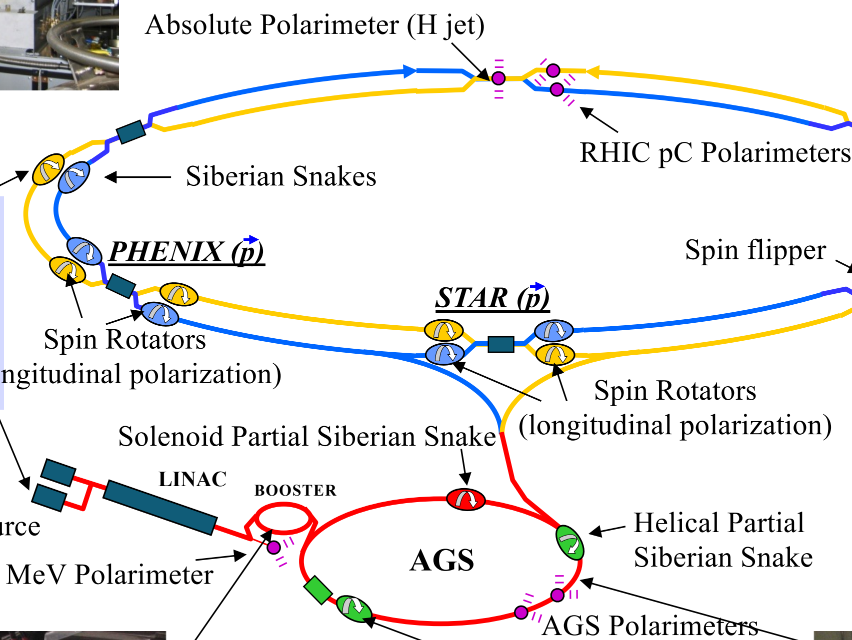
now $L_{avg} = 1.54 \times 10^{32}$ cm^{-2}s^{-1}

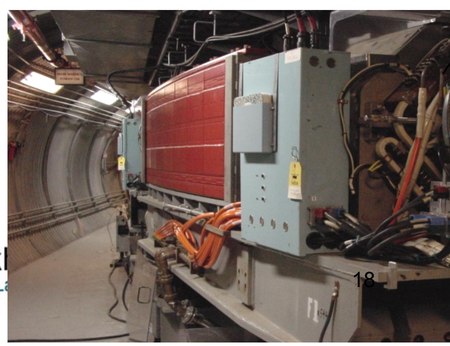
now P_{avg} = 55% (average over 3D distribution and time)

Special devices for polarized protons: source, polarimeters, snakes, rotator, flipper









RHIC performance evolutions

- Au+Au luminosity at 100 GeV/nucleon
- p↑+p↑ luminosity and polarization (100 and 255 GeV)
- Medium energy (Cu+Cu, O+O)
- Asymmetric collisions (p↑+Au, d+Au, h+Au, Cu+Au)
- U+U, Zr+Zr / Ru+Ru
- Au+Au luminosity at 3.85 to 9.8 GeV/nucleon
  (Beam Energy Scan, including a fixed target program)
- New detector for 2023 to 2025: sPHENIX

Curious fact: RHIC and LHC did not collide the same ion species (except p), oxygen also planned for LHC

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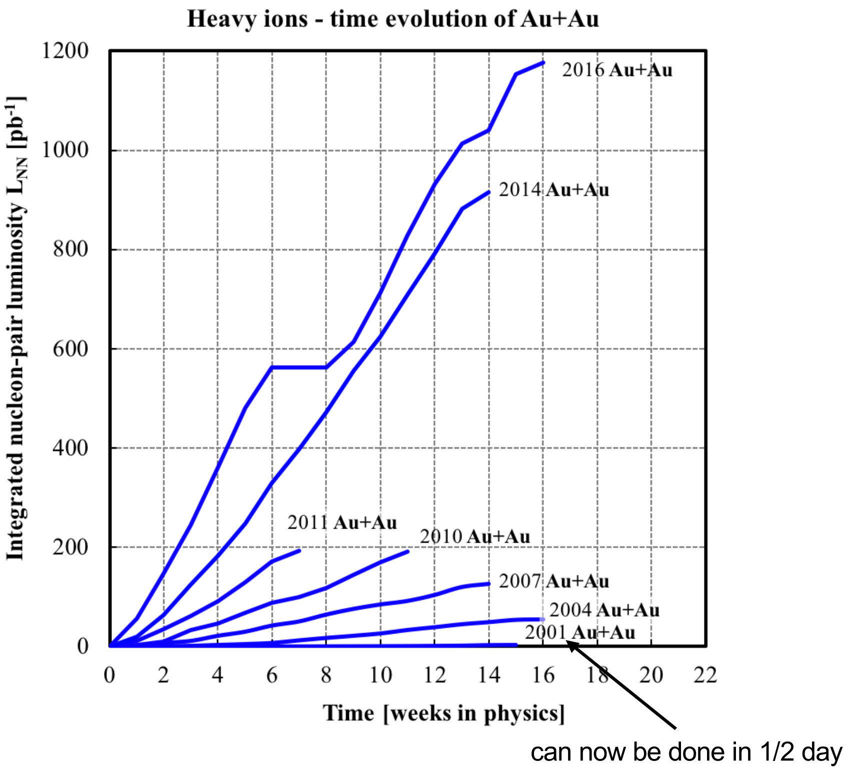
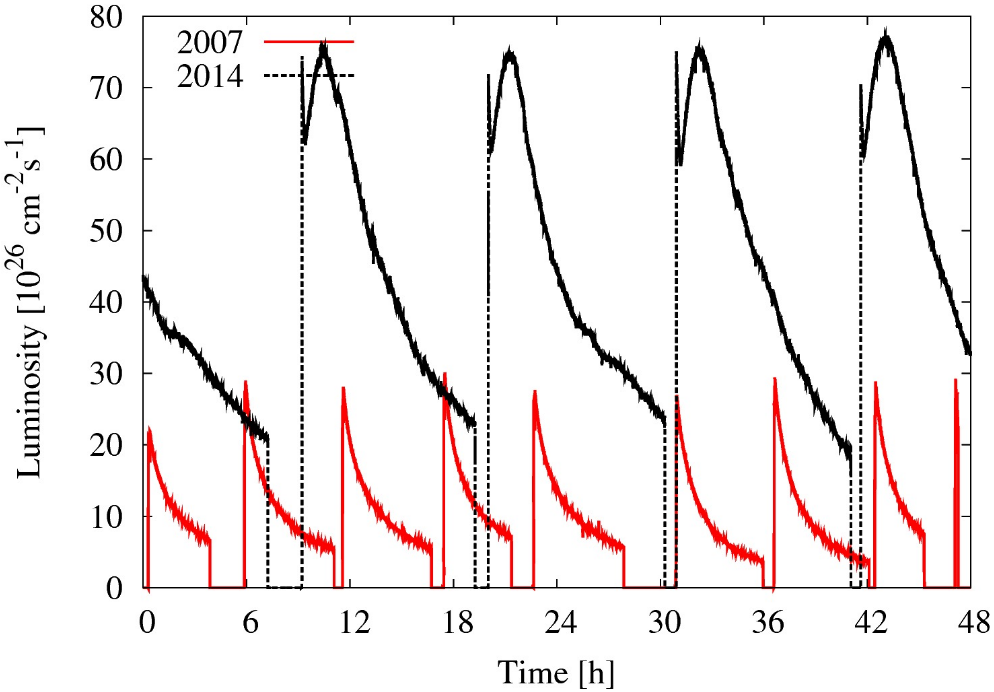


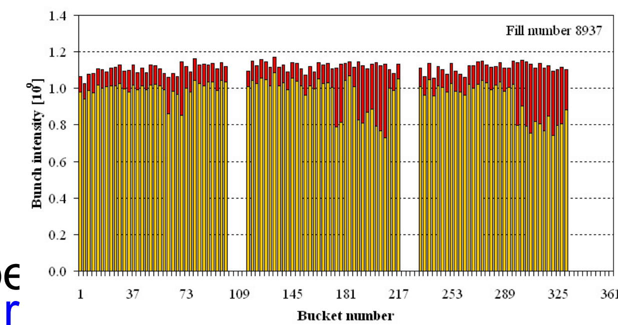


RHIC Au+Au / U+U operation at full energy

Performance limits – RHIC ions, high energy

$$L(t) = \frac{1}{4\pi} f_0 N \frac{N_b^2(t)}{\varepsilon(t)\beta^*(t)} h(\beta^*, \sigma_s, \theta)$$

- Bunch intensity N_b, limited by injectors
  EBIS, bunch merges in Booster and AGS
  transition instability
  aim for 2×10^9 in store ultimately



- Intrabeam scattering
  => stochastic cooling
  => 56 MHz SRF (stronger longitudinal focusing)

- Lattice with small β* and large off-momentum dynamic ape
  with hourglass factor ≈0.5 at end of store, need large β* r
  any lattice change must not result in additional beam losses
  (momentum spread with 56 MHz SRF will be increased)
  dynamic β* reduction after emittance decreased by cooling

Goal is to have burn-off as the dominant beam loss mechanism.

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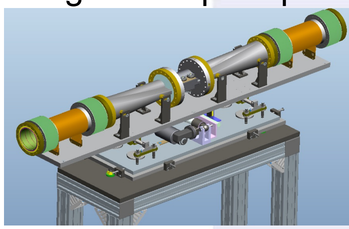
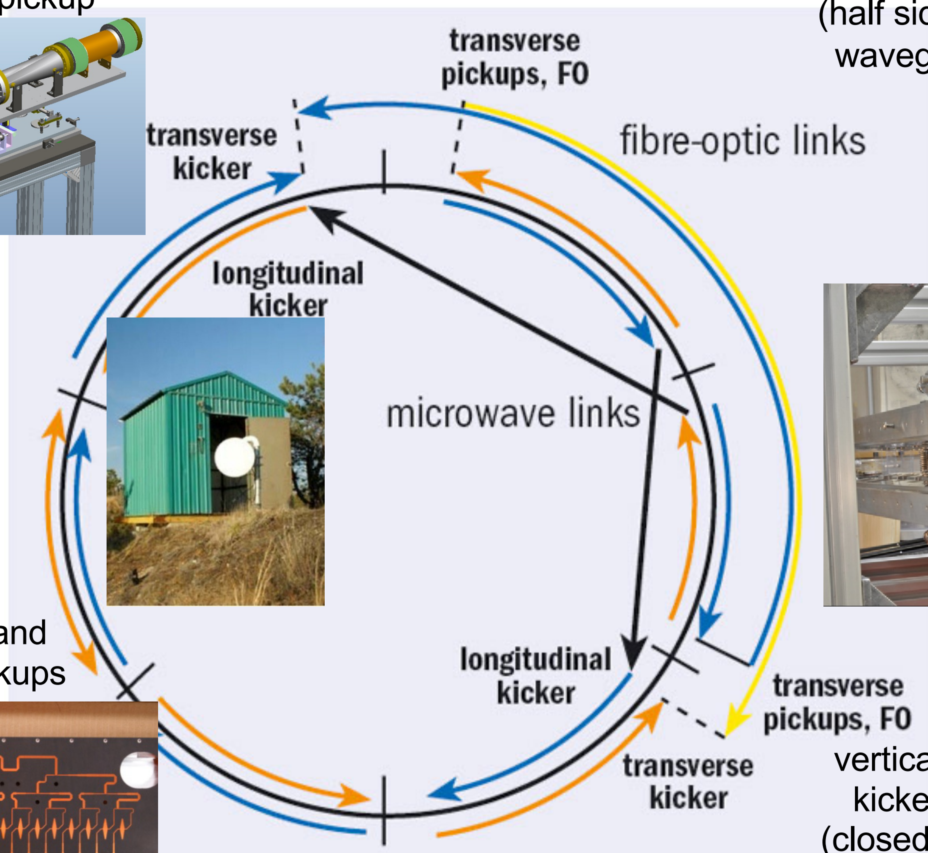
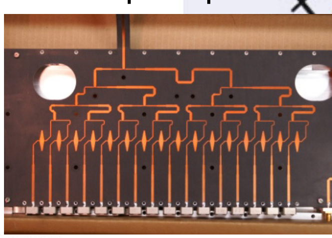
3D stochastic cooling for heavy ions

longitudinal pickup



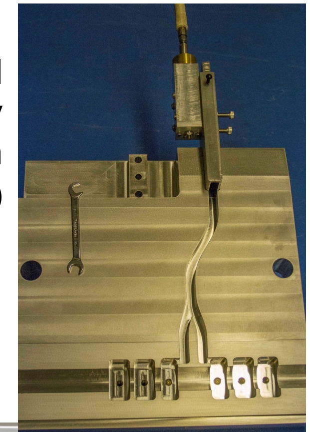


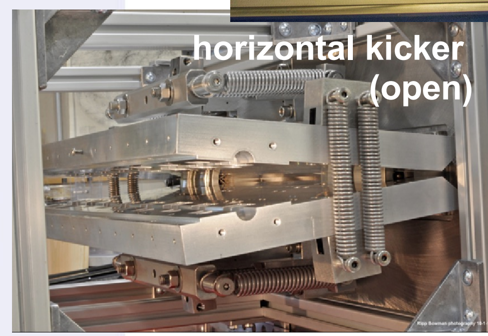
horizontal and vertical pickups



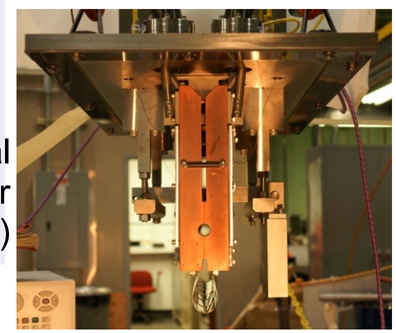
5-9 GHz, cooling times ~1 h

longitudinal kicker cavity (half side with waveguides)





vertical kicker (closed)



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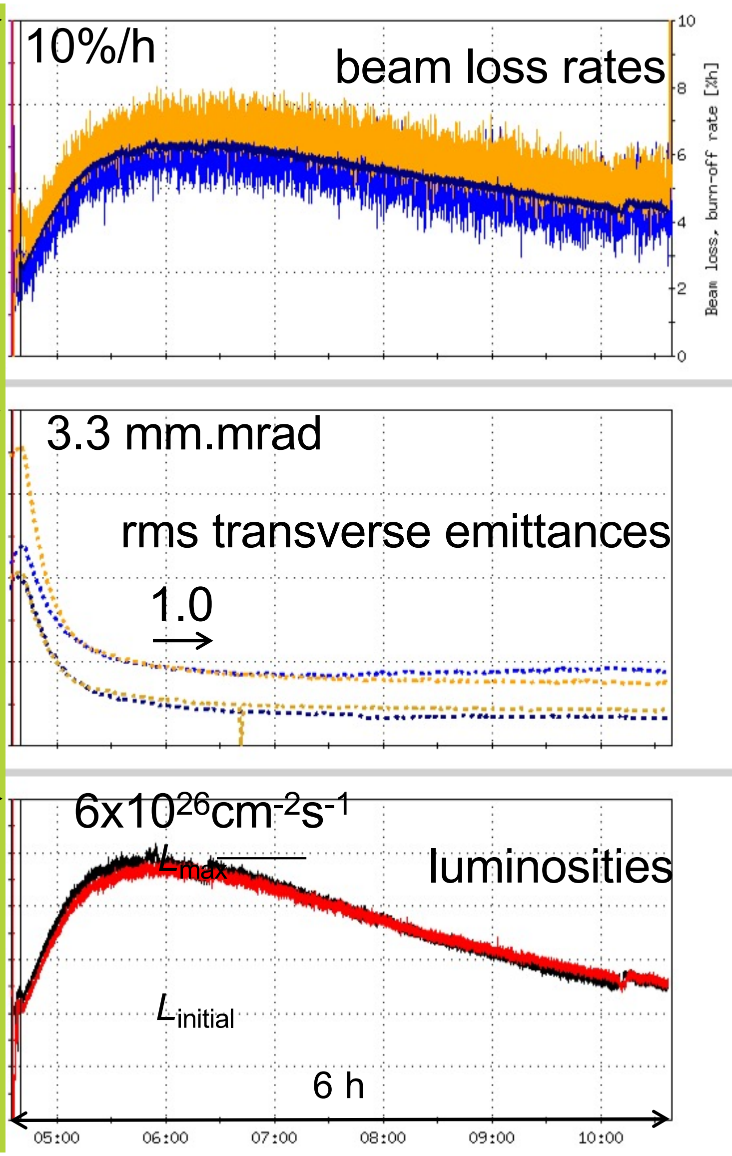
M. Brennan, M. Blaskiewicz, F. Severino, PRL **100** 174803 (2008); K. Mernick PRSTAB, PAC, EPAC



U-U store – new mode in 2012

(1) Lattice optimized for large off- momentum dynamic aperture, not for smallest β* (Y. Luo)

$$L \propto \frac{N_b^2}{\beta^*} H\left(\frac{\beta^*}{\sigma_s}\right)$$

(2) Minimum loss rates given by total U-U cross sections, 2 largest contributions from BFPP and EMD:

	Au-Au	U-U
BFPP	117 b	329 b
EMD	99 b	160 b

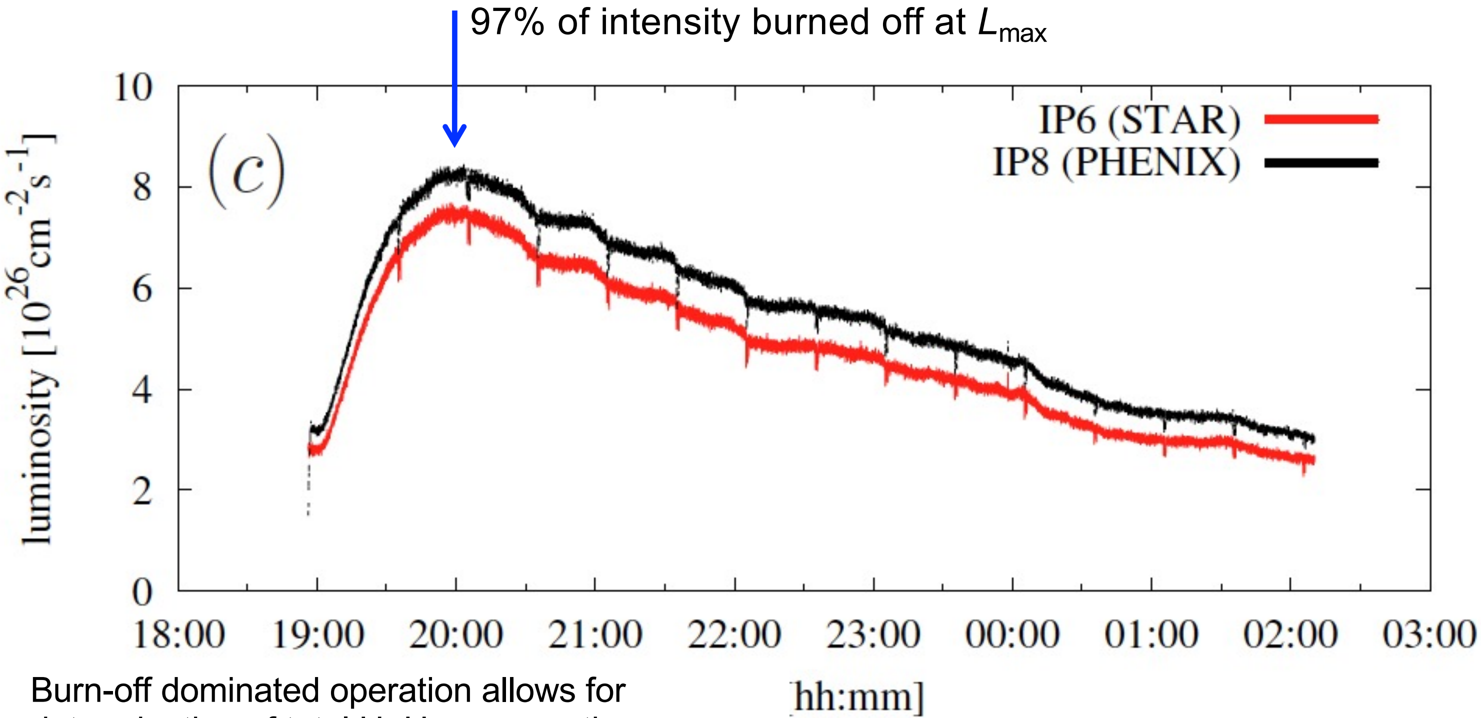
$\sigma_{BFPP} \propto Z^7$

Nearly all beam loss though luminosity (burn-off)!

3D stochastic cooling leads to new feature in hadron collider:

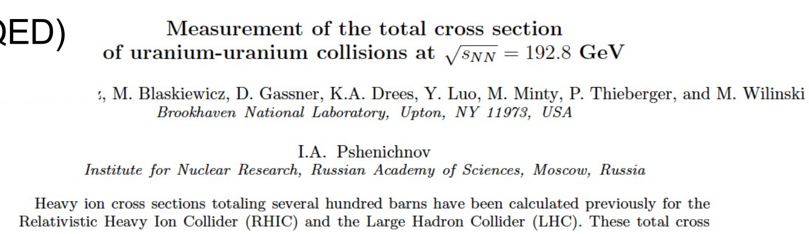
L_{max} > $L_{initial}$

Operation at burn-off limit in U+U



Burn-off dominated operation allows for determination of total U+U cross section – and comparison with calculation (mostly QED) (published in Phys. Rev. C) =>

$$\frac{dN_B(t)}{dt} = \frac{dN_Y(t)}{dt} = -\left[\mathcal{L}_6(t) + \mathcal{L}_8(t)\right]\sigma_{tot}$$



Measurement of the total cross section of uranium-uranium collisions at $\sqrt{s_{NN}} = 192.8$ GeV

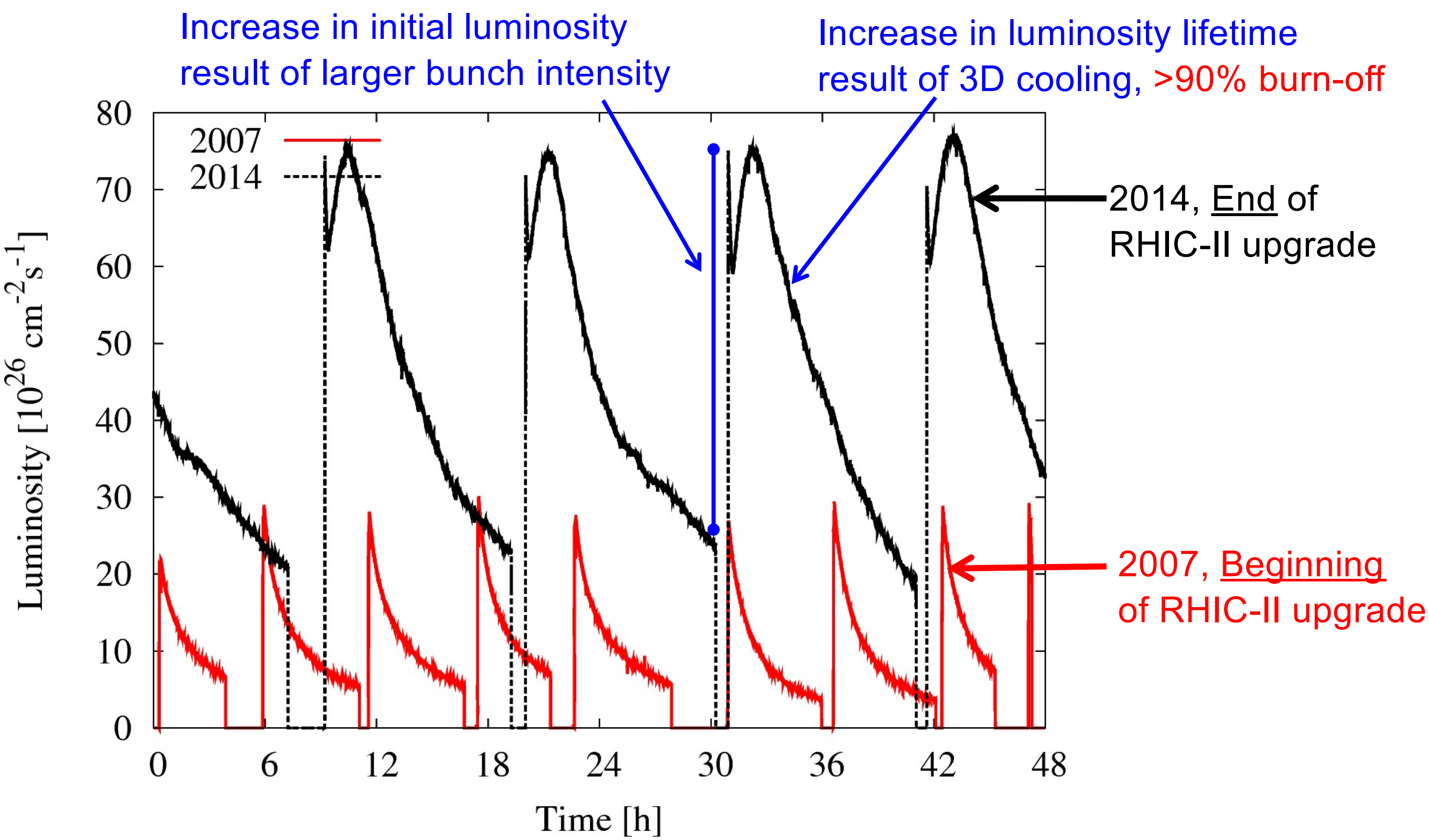
:, M. Blaskiewicz, D. Gassner, K.A. Drees, Y. Luo, M. Minty, P. Thieberger, and M. Wilinski
Brookhaven National Laboratory, Upton, NY 11973, USA

I.A. Pshenichnov
Institute for Nuclear Research, Russian Academy of Sciences, Moscow, Russia

Heavy ion cross sections totaling several hundred barns have been calculated previously for the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC). These total cross

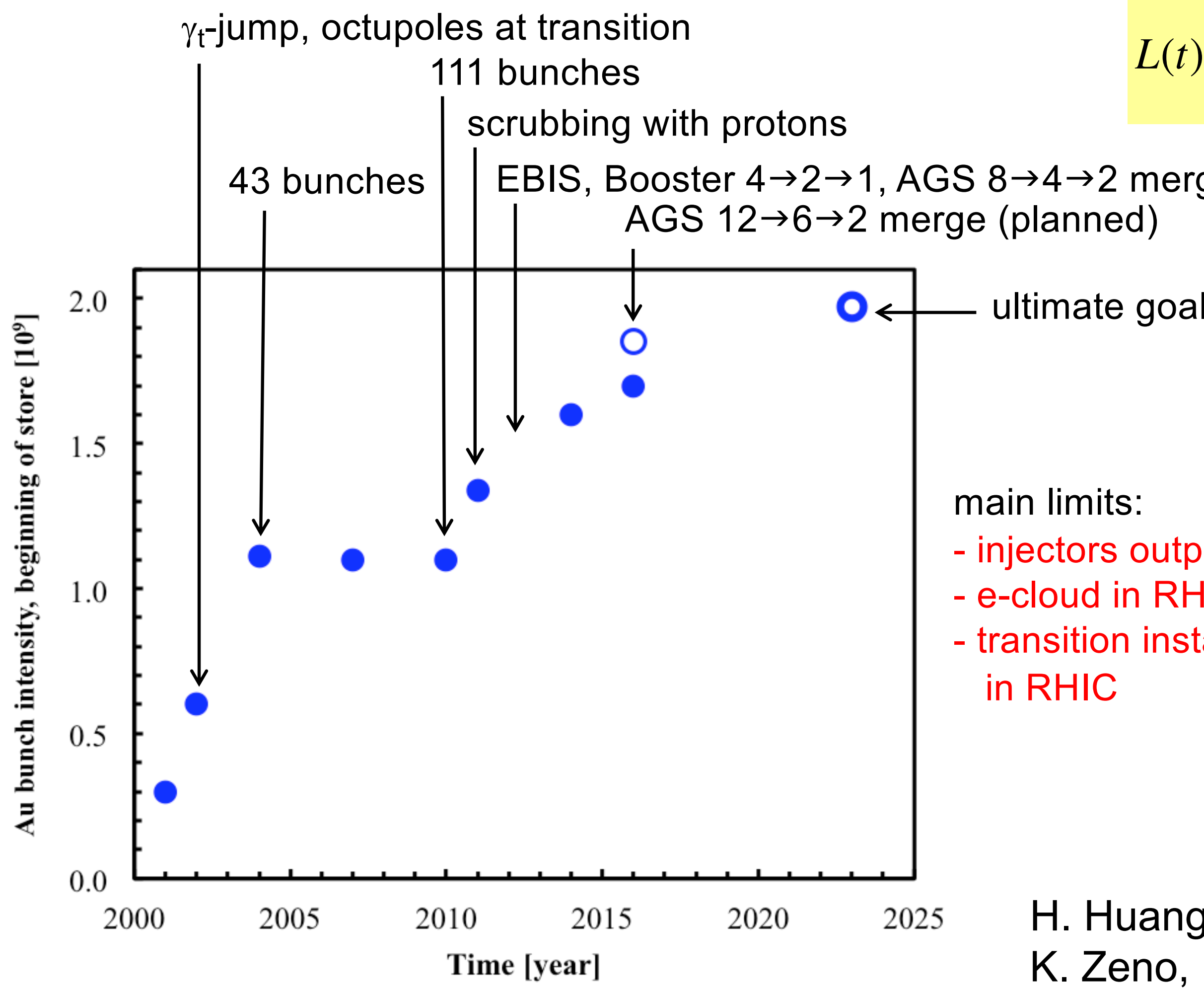
RHIC Run-14

Delivering RHIC-II luminosity



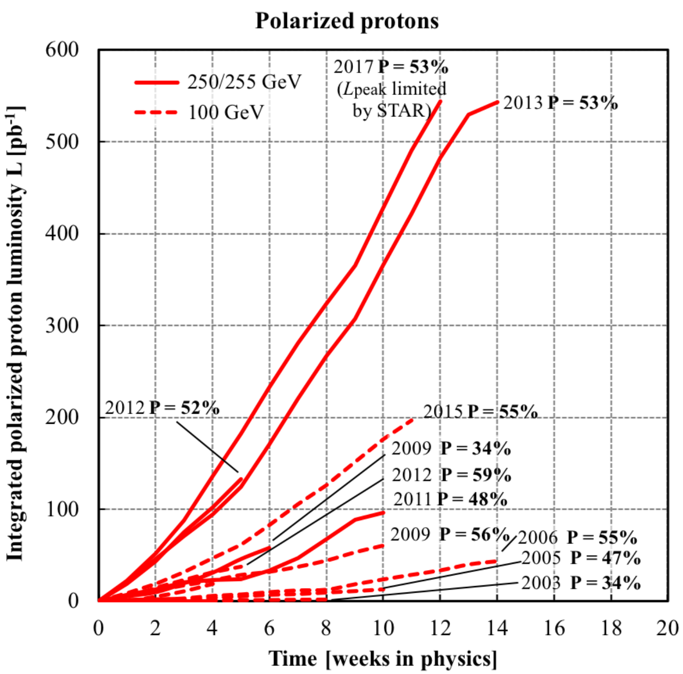
Au bunch intensity evolution

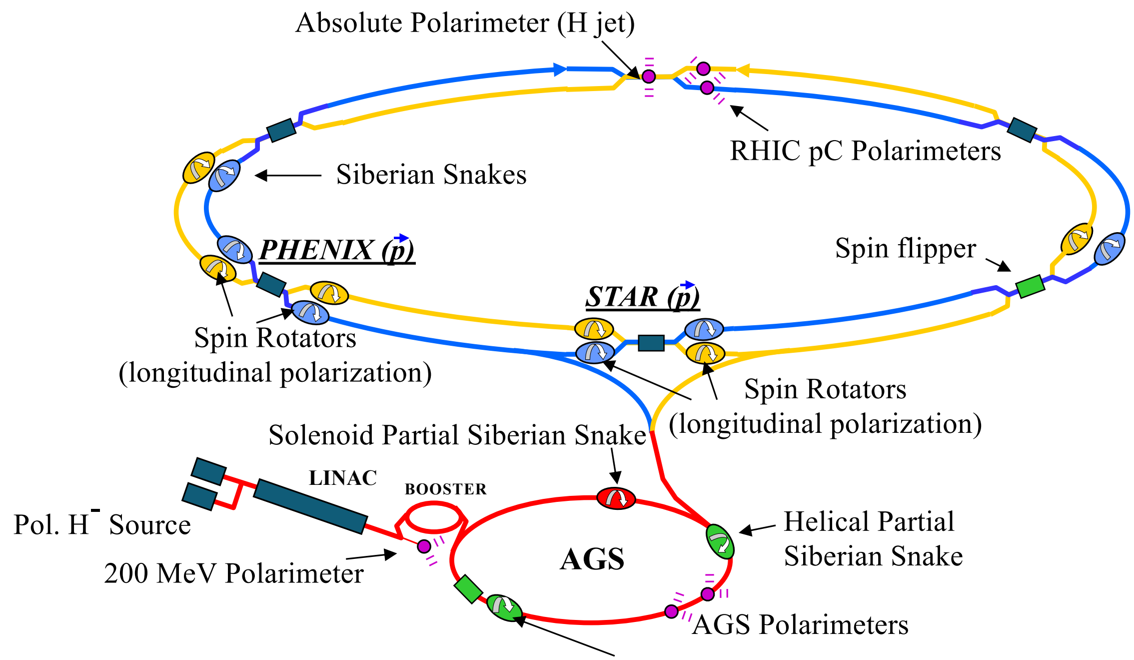
$$L(t) = \frac{1}{4\pi} f_0 N \frac{N_b^2(t)}{\varepsilon(t)\beta^*(t)} h(\beta^*, \sigma_s, \theta)$$



main limits:
- injectors output
- e-cloud in RHIC
- transition instability in RHIC

H. Huang, K. Gardner, K. Zeno, RF, et al.





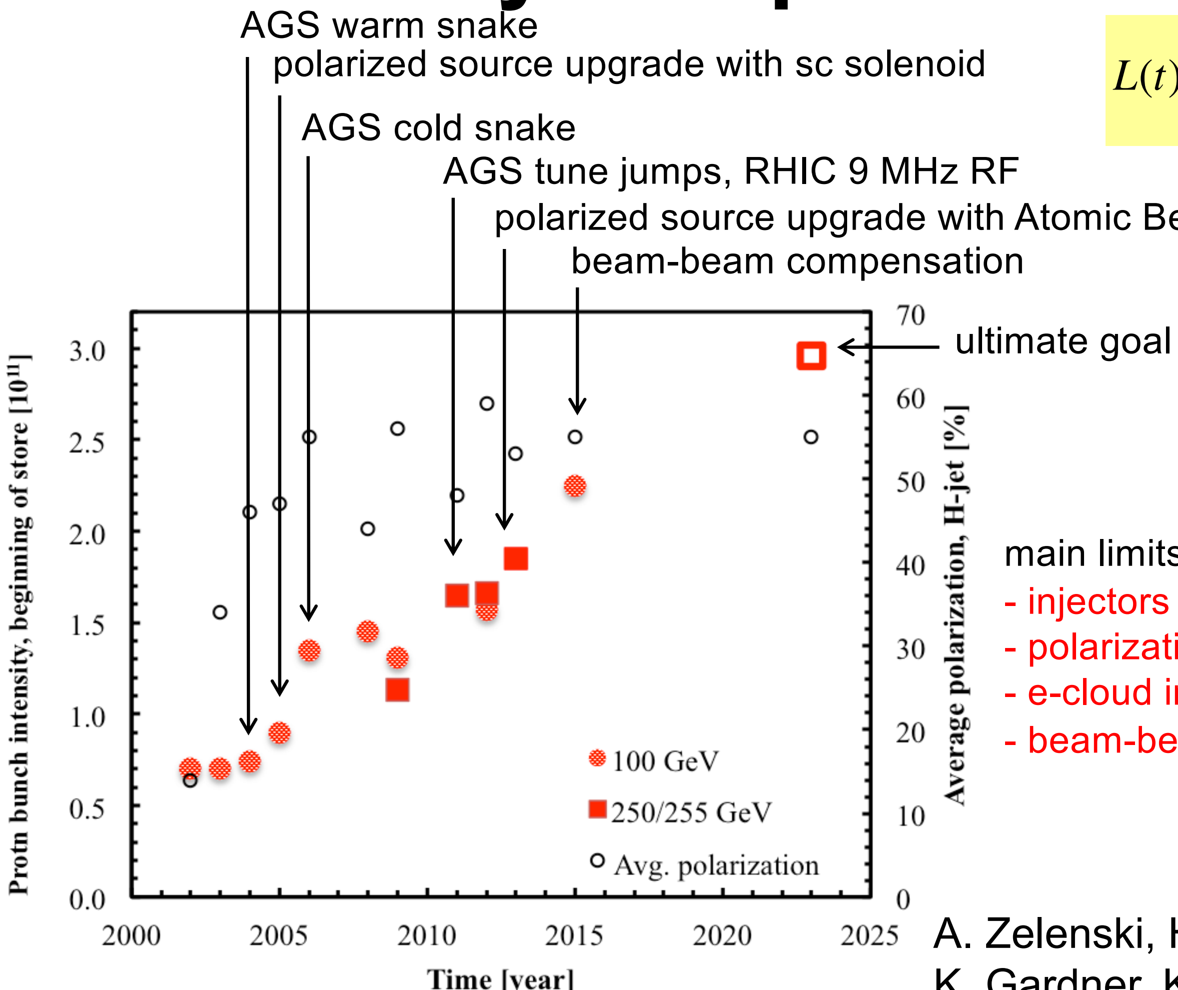
RHIC p↑+p↑ operation at 100 / 255 GeV

p bunch intensity and polarization

$$L(t) = \frac{1}{4\pi} f_0 N \frac{N_b^2(t)}{\varepsilon(t)\beta^*(t)} h(\beta^*, \sigma_s, \theta)$$

$FOM = LP^4 \sim N_b^2 P^4$

(double-spin experiments)



main limits:

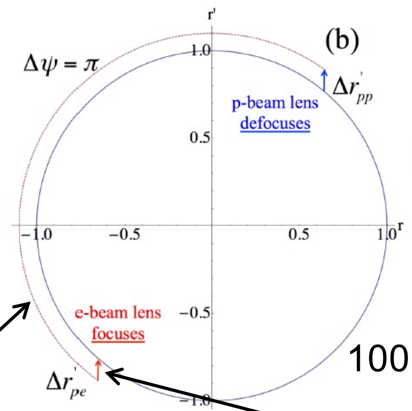
- injectors output
- polarization
- e-cloud in RHIC
- beam-beam in RHIC

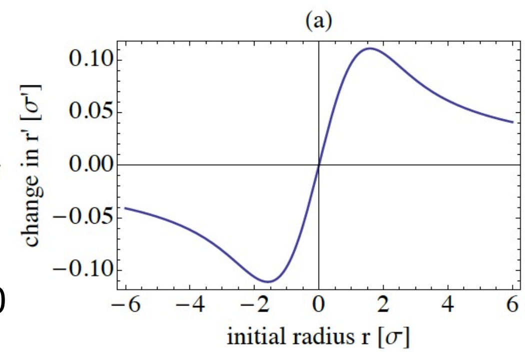
A. Zelenski, H. Huang, K. Gardner, K. Zeno, RF, et al.

Head-on beam-beam compensation

Principle

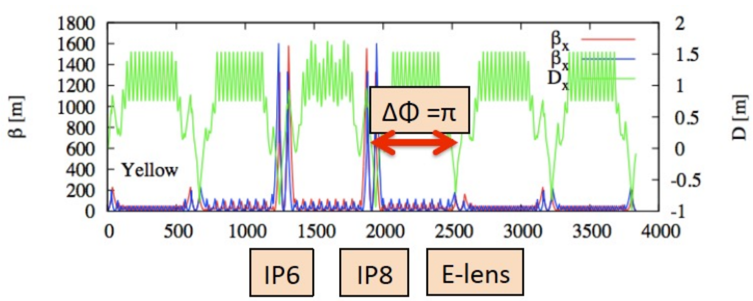
Correction in same turn, need to fulfill 2 conditions:

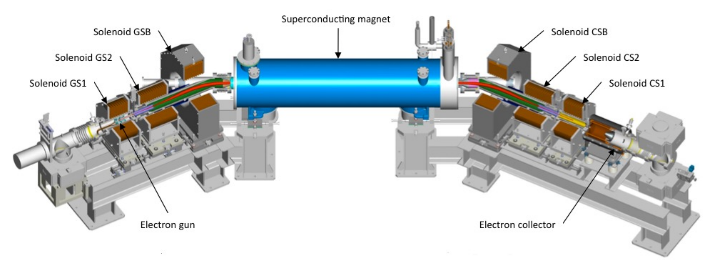




(1) $k\pi$ phase advance minimizes beam-beam resonance driving terms – implemented with ATS type lattice (Simon White)

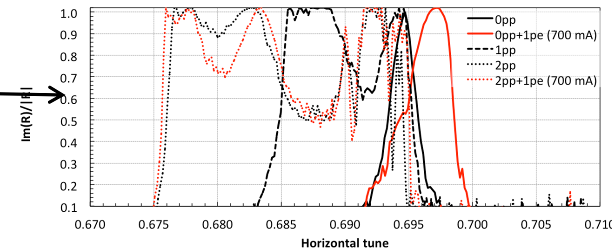
(2) Same amplitude correction kick as bb kick reduces beam-beam tune spread – implemented with electron lenses (not possible with magnets)



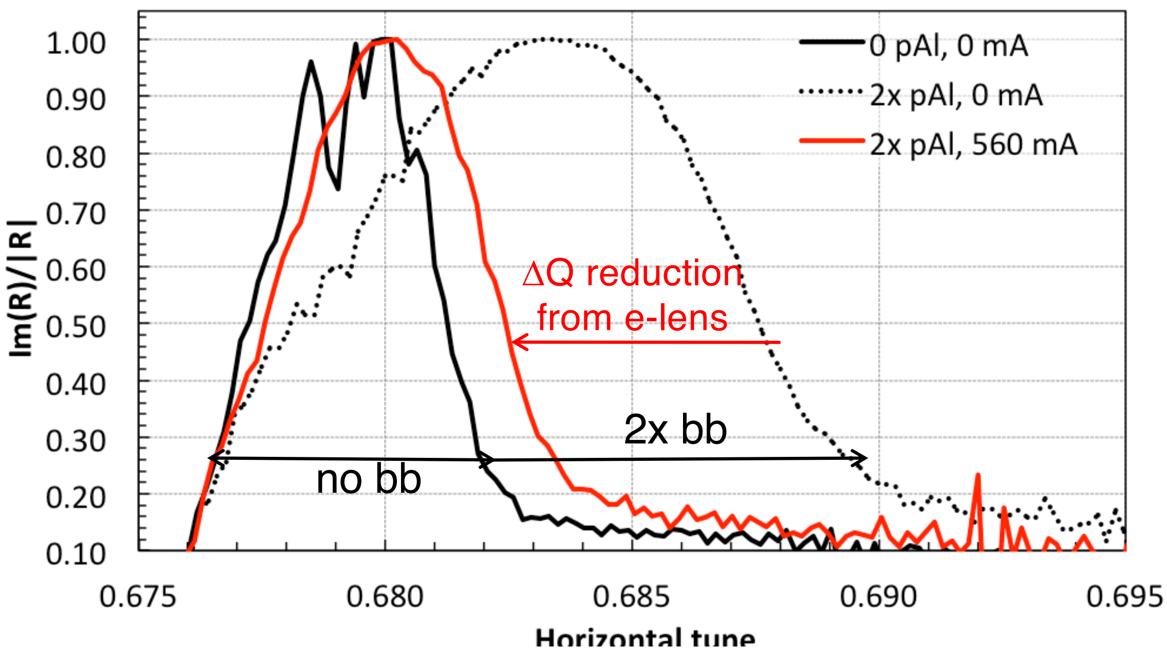


Head-on bb compensation Footprint compression

tune distribution could not be measured with BTF and p+p collisions due to coherent modes
(works in simulations – P. Görgen (TU Darmstadt) et al. NIM A 777, pp. 43-53 (2015))



tune distribution can be measured with BTF and p+Al collisions
proton beam: (Q_x,Q_y) = (.685,.695); Al beam: (Q_x,Q_y) = (.685,.695); ΔQ_x, ΔQ_y >> ξ => no coherent modes

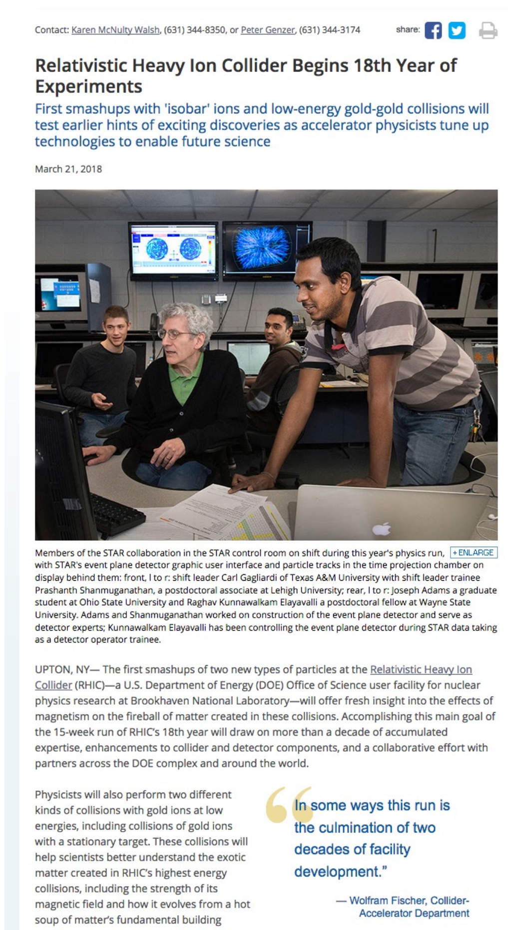


Can only reduced BB tune spread (black curve is limit)

Run-18 Zr+Zr/Ru+Ru – same A, different Z (CME)

Zr-96/Ru-96

Extraordinary help from DOE, ORNL, RIKEN
for source material and preparation



Contact: Karen McNulty Walsh, (631) 344-8350, or Peter Genzer, (631) 344-3174

share:

Relativistic Heavy Ion Collider Begins 18th Year of Experiments

First smashups with 'isobar' ions and low-energy gold-gold collisions will test earlier hints of exciting discoveries as accelerator physicists tune up technologies to enable future science

March 21, 2018

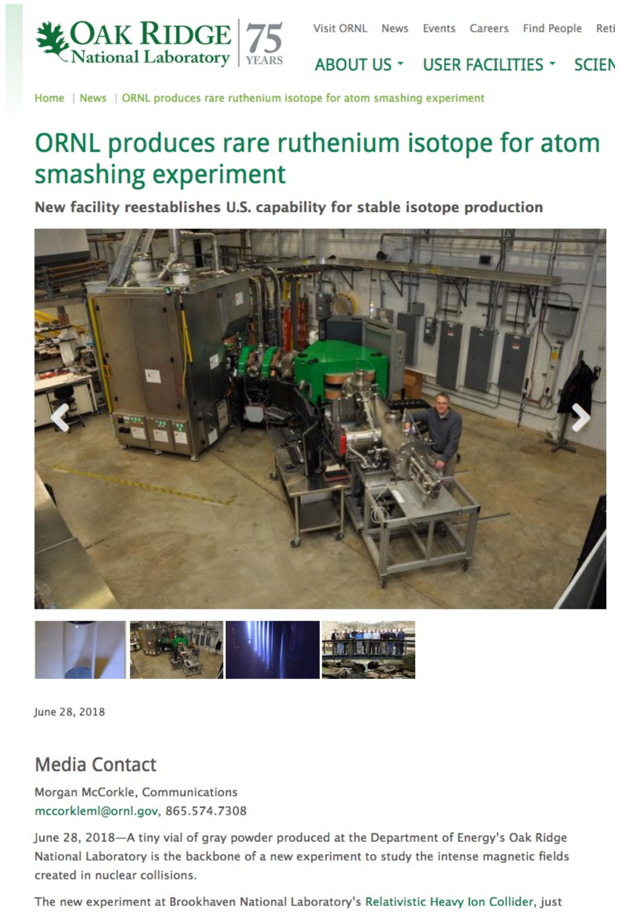
Members of the STAR collaboration in the STAR control room on shift during this year's physics run, with STAR's event plane detector graphic user interface and particle tracks in the time projection chamber on display behind them: front, l to r: shift leader Carl Gagliardi of Texas A&M University with shift leader trainee Prashanth Shanmuganathan, a postdoctoral associate at Lehigh University; rear, l to r: Joseph Adams a graduate student at Ohio State University and Raghav Kunnawalkam Elayavalli a postdoctoral fellow at Wayne State University. Adams and Shanmuganathan worked on construction of the event plane detector and serve as detector experts; Kunnawalkam Elayavalli has been controlling the event plane detector during STAR data taking as a detector operator trainee. + ENLARGE

UPTON, NY— The first smashups of two new types of particles at the Relativistic Heavy Ion Collider (RHIC)—a U.S. Department of Energy (DOE) Office of Science user facility for nuclear physics research at Brookhaven National Laboratory—will offer fresh insight into the effects of magnetism on the fireball of matter created in these collisions. Accomplishing this main goal of the 15-week run of RHIC's 18th year will draw on more than a decade of accumulated expertise, enhancements to collider and detector components, and a collaborative effort with partners across the DOE complex and around the world.

Physicists will also perform two different kinds of collisions with gold ions at low energies, including collisions of gold ions with a stationary target. These collisions will help scientists better understand the exotic matter created in RHIC's highest energy collisions, including the strength of its magnetic field and how it evolves from a hot soup of matter's fundamental building blocks (quarks and gluons) to the ordinary

"In some ways this run is the culmination of two decades of facility development."

— Wolfram Fischer, Collider-Accelerator Department



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ORNL produces rare ruthenium isotope for atom smashing experiment

New facility reestablishes U.S. capability for stable isotope production

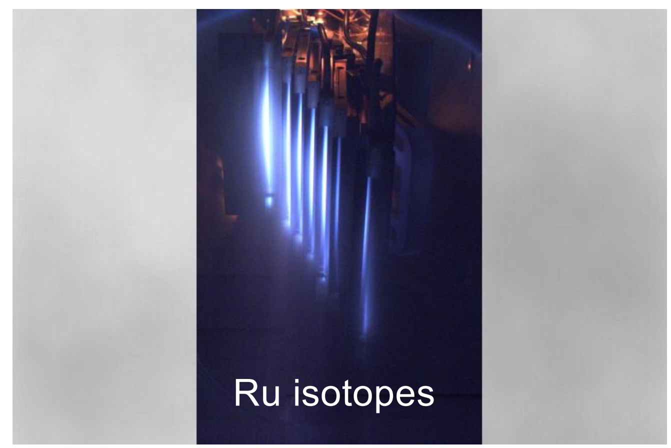
June 28, 2018

Media Contact

Morgan McCorkle, Communications
mccorkleml@ornl.gov, 865.574.7308

June 28, 2018—A tiny vial of gray powder produced at the Department of Energy's Oak Ridge National Laboratory is the backbone of a new experiment to study the intense magnetic fields created in nuclear collisions.

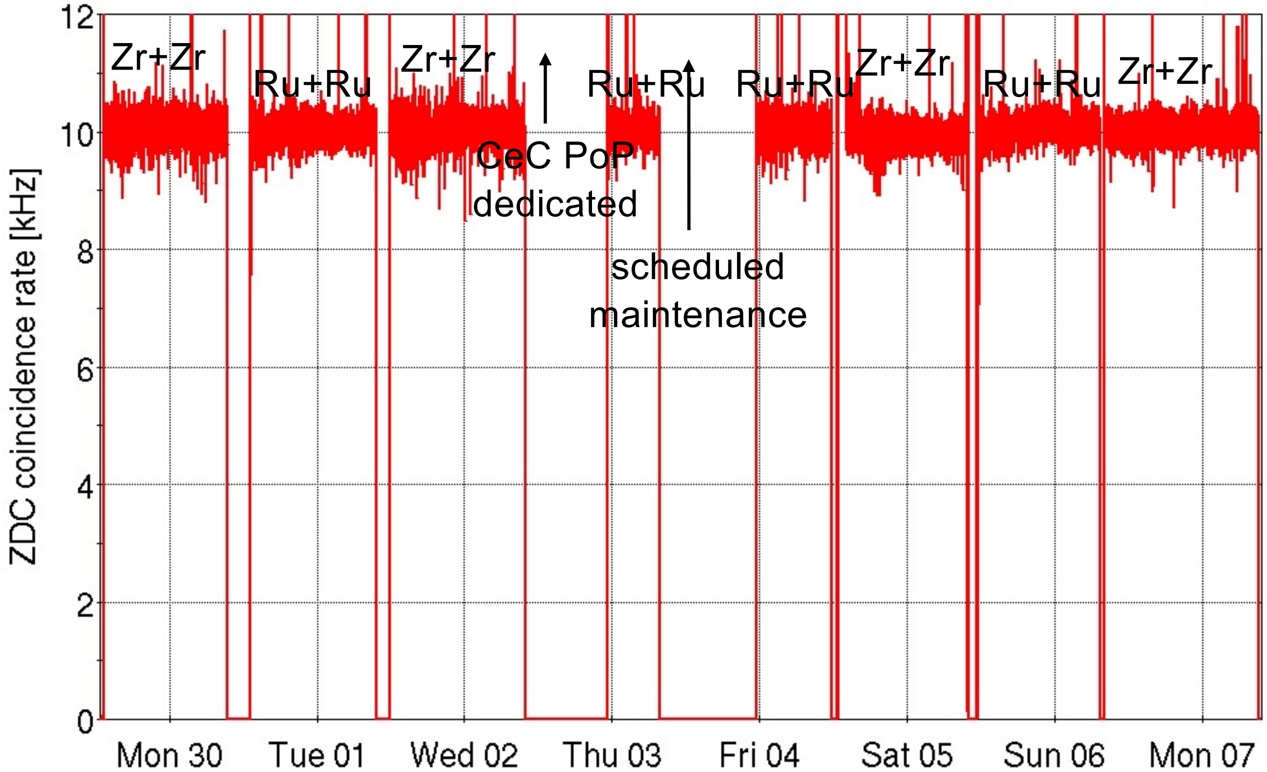
The new experiment at Brookhaven National Laboratory's Relativistic Heavy Ion Collider, just



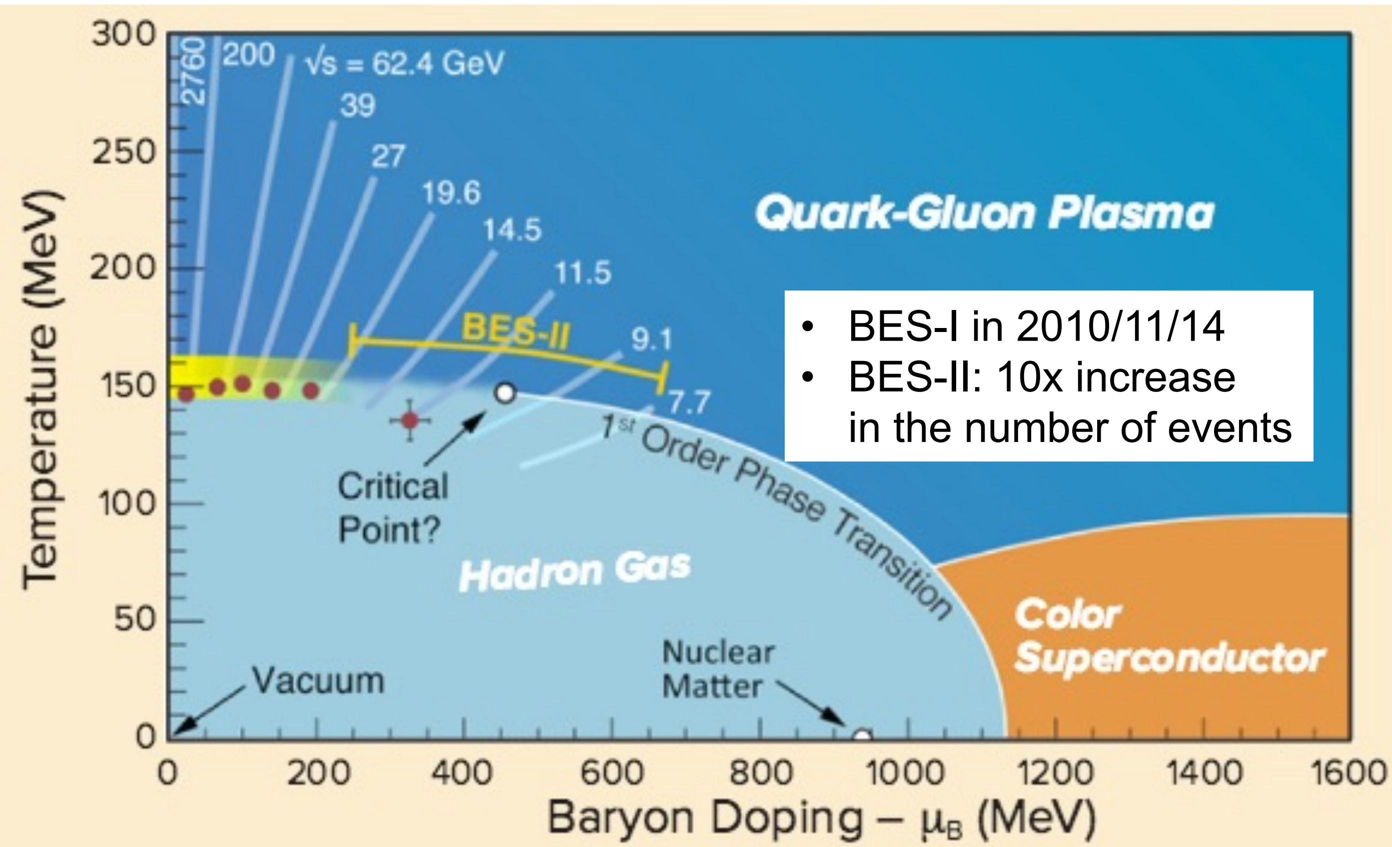
Run-18 Zr+Zr/Ru+Ru at 100 GeV/nucleon

Store-by-store species change and flat luminosity of 21.5×10^{26} $cm^{-2}s^{-1}$
20 h nominal store length (WEEK: 30-Apr-18 to 07-May-18)

Run Coordinator: Greg Marr
paper: IPAC 2019



Beam Energy Scan I and II (BES-I, II)



- BES-I in 2010/11/14
- BES-II: 10x increase in the number of events

[2015 NSAC Long Range Plan for Nuclear Science]

Au+Au collisions down to 3.85 GeV/n
(40% of CoM energy at nominal injection)

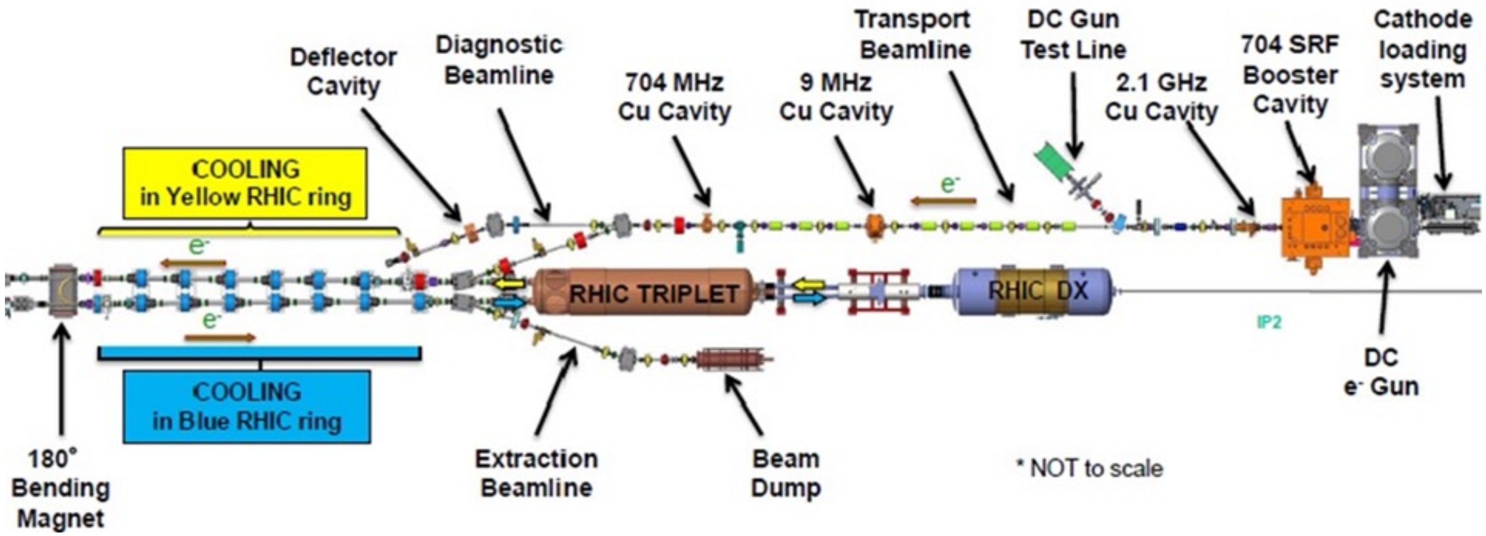
Luminosity really low

- Space charge
- Intrabeam scattering
- Magnetic field errors (also time dependent)
- Large beam with losses

BES-II goal of 4x luminosity over 3.85 – 9.8 GeV/n
(highest energy is nominal injection)

Designed cooler for 2 lowest energies

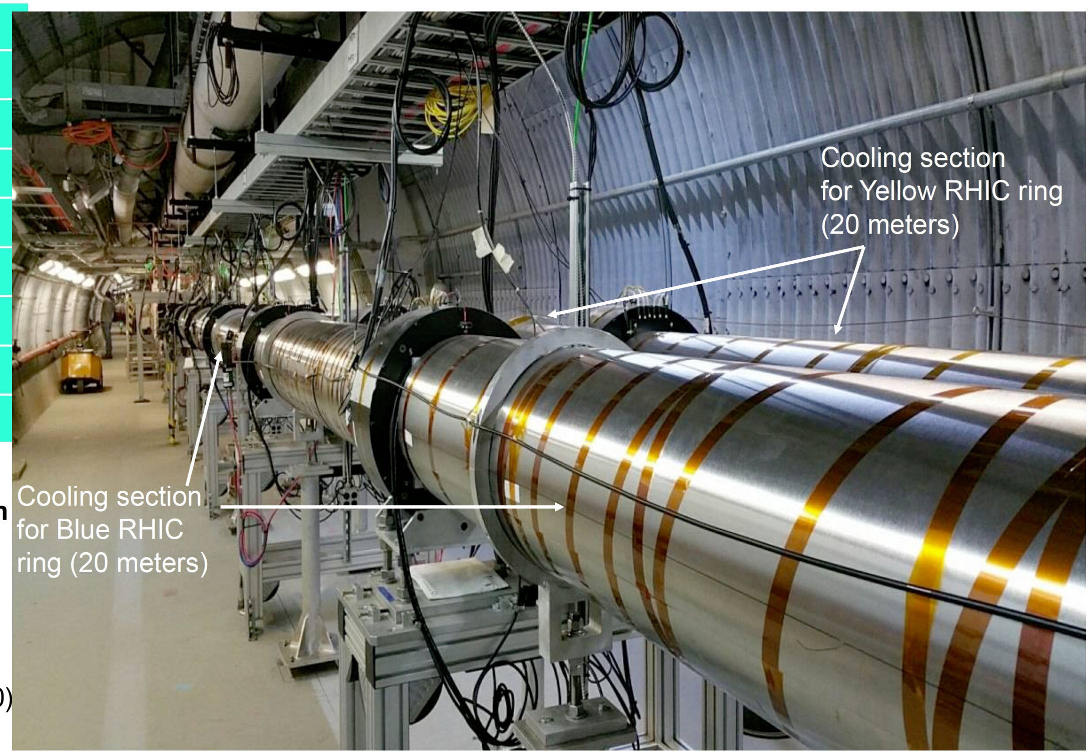
Distinctive features of Low-Energy RHIC electron Cooler (LEReC)



- LEReC is fully operational electron cooler which:
  - utilizes RF-accelerated electron bunches
  - uses non-magnetized electron beam (there is no magnetization at the cathode and there is no continuous solenoidal field in the cooling section)
- LEReC approach to cooling is directly scalable to high-energies (eg 41 GeV p in EIC)

LEReC operating parameters

Parameters used for RHIC operations		
Kinetic energy, MeV	1.6	2
Cooling section length, m	20	20
Electron bunch (704MHz) charge, pC	30-70	50-70
Bunches per macrobunch (9 MHz)	36	30-36
Charge in macrobunch, nC	1-2	1.5-2
RMS normalized emittance, um	< 2.5	< 2.5
Average current, mA	8-20	15-20
RMS energy spread	< 4e-4	< 4e-4
RMS angular spread	<150 urad	<150 urad

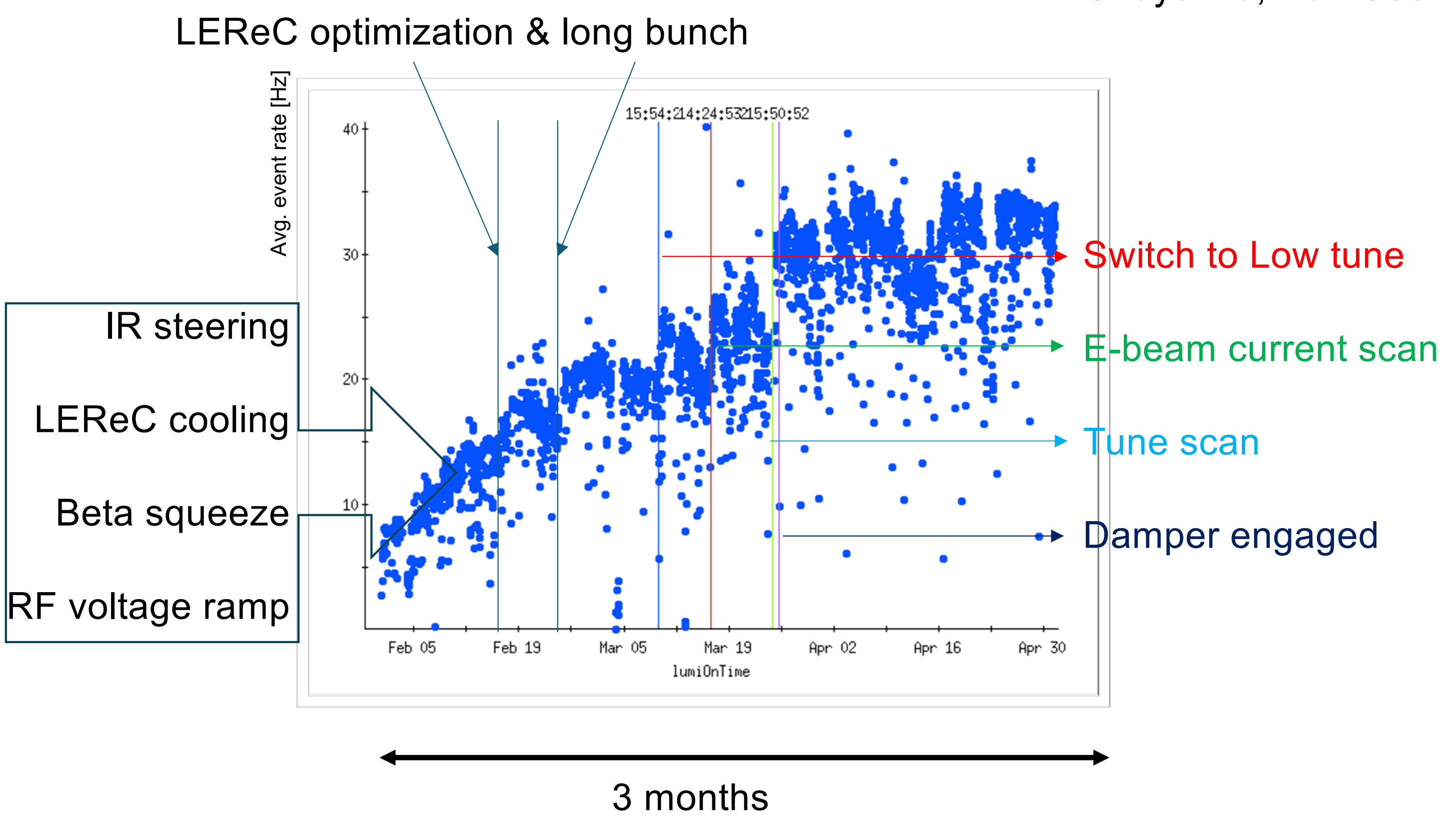


Papers:

- S. Seletskiy et al., **Accurate setting of electron energy for demonstration of first hadron beam cooling with RF-accelerated electron bunches,** *PRAB* 22, 111004 (2019).
- D. Kayran et al., **High-brightness electron beams for linac-based bunched beam electron cooling**, *PRAB* 23, 021003 (2020).
- A.V. Fedotov et al., **Experimental demonstration of hadron beam cooling using RF accelerated electron Bunches**, *PRL* 124, 084801 (2020)
- H. Zhao et al., **Cooling simulation and experimental benchmarking for an rf-based electron cooler**, PRAB 23, 074201 (2020).
- S. Seletskiy et al., **Obtaining transverse cooling with nonmagnetized electron beam**, PRAB 23, 110101 (2020).

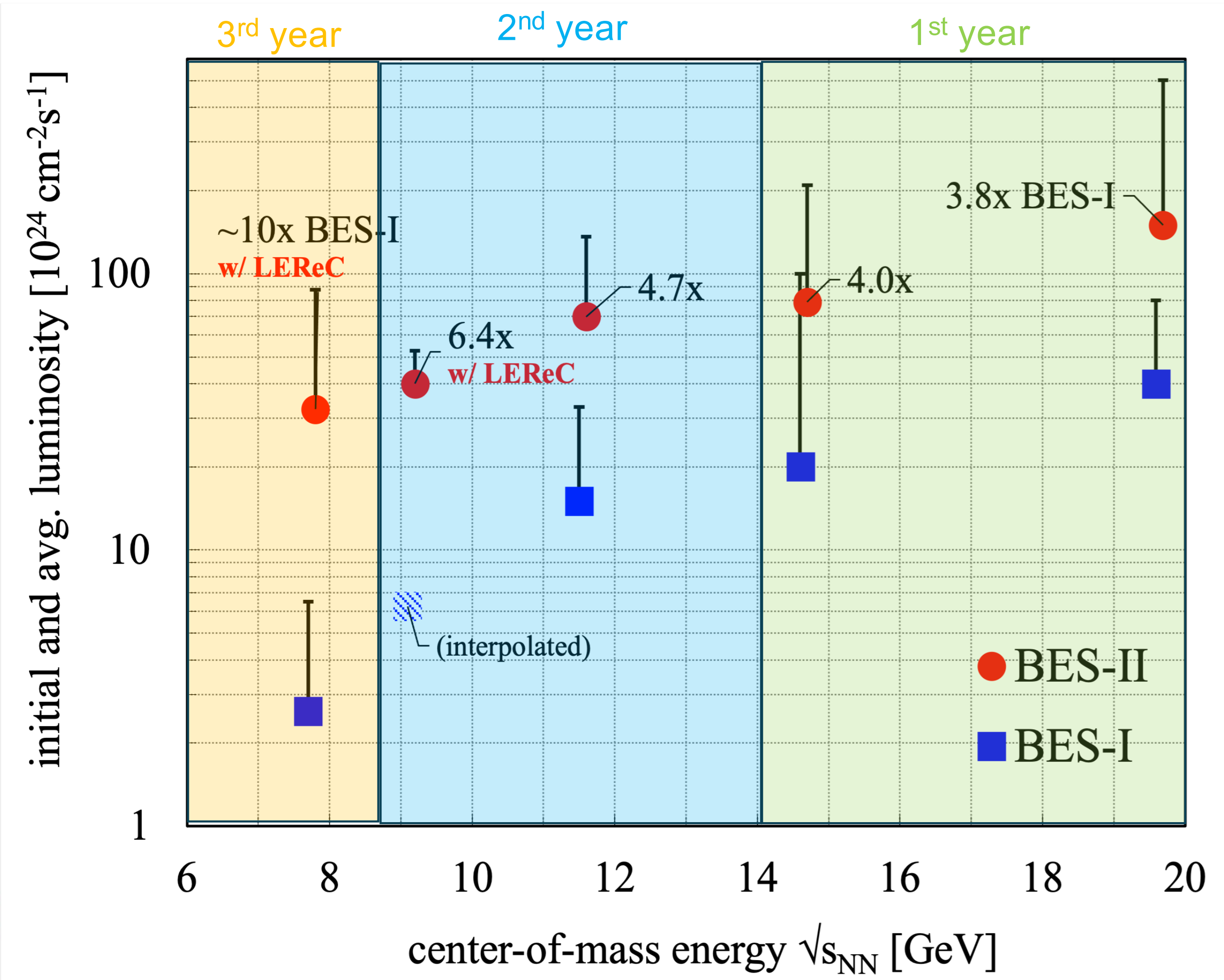
Many other optimizations beyond LEReC
Au+Au collision at 7.7 GeV (lowest and most difficult energy)

Chuyu Liu, Run Coordinator BES-II



BES-I vs BES-II luminosity

Run Coordinator: Chuyu Liu (Run-19 to 21)



Goal was

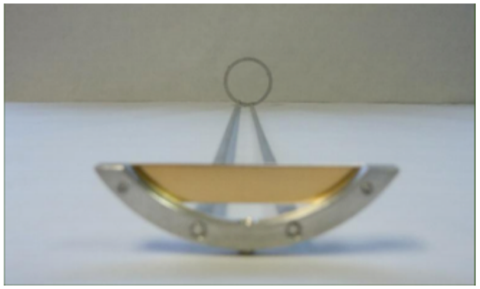
L_{avg} (BES-II) = 4x L_{avg} (BES-I)

Beam Energy Scan II scoreboard

Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Run Time	Number Events Requested (Recorded)	Date Collected
13.5	27	156	24 days	(560 M)	Run-18
9.8	19.6	206	36 days	400 M (582 M)	Run-19
7.3	14.6	262	60 days	300 M (324 M)	Run-19
5.75	11.5	316	54 days	230 M (235 M)	Run-20
4.59	9.2	373	102 days	160 M (162 M)[1]	Run-20+20b
31.2	7.7 (FXT)	420	0.5+1.1 days	100 M (50 M+112 M)	Run-19+20
19.5	6.2 (FXT)	487	1.4 days	100 M (118 M)	Run-20
13.5	5.2 (FXT)	541	1.0 day	100 M (103 M)	Run-20
9.8	4.5 (FXT)	589	0.9 days	100 M (108 M)	Run-20
7.3	3.9 (FXT)	633	1.1 days	100 M (117 M)	Run-20
5.75	3.5 (FXT)	666	0.9 days	100 M (116 M)	Run-20
4.59	3.2 (FXT)	699	2.0 days	100 M (200 M)	Run-19
3.85	3.0 (FXT)	721	4.6 days	100 M (259 M)	Run-18
3.85	7.7	420	11-20 weeks	100 M (101 M)	Run-21[2]

Colliding energies
(added 8.65 GeV/nucleon)

Fixed target energies



Fixed Au foil target in STAR
Direct vertical beam tail on foil

All BES-II event goals achieved or exceeded

Next year (FY 2022) – preparing for p↑+p↑ at 255 GeV

Run Coordinator: Vincent Schoefer

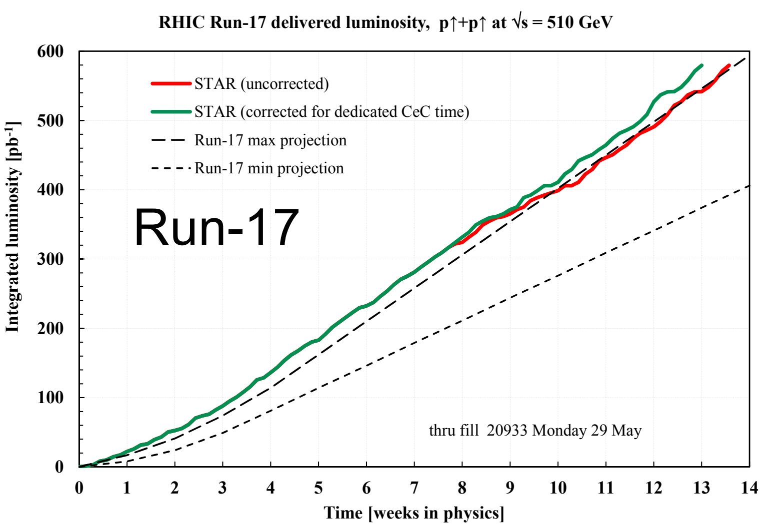
Challenging mode because of

- Short shut-down
- Polarization
- First use of abort kicker relays with large stored beam energy
- Very tight schedule

Table 1: Proposed Run-22 assuming 20 cryo-weeks, including an initial one week of cool-down and a two weeks set-up time.

$\sqrt{s}$ (GeV)	Species	Polarization	Run Time	Sampled Luminosity	Priority
510	*pp*	Transverse	16 weeks	400 pb^{-1}	1

+ 2 weeks CeC (=> Vladimir)



Last time p↑+p↑ at 255 GeV in Run-17:

- N_b = 2x10^{11}/bunch
- β^* = 1.5 -> 1.2 m (dynamic β-squeeze)
- L_{peak} = 154x10^{30} cm^{-2}s^{-1} (limited by STAR)
- L_{avg} = 127x10^{30} cm^{-2}s^{-1}
- L_{week} = 50 pb^{-1}
- P_{avg} = 55%

After Run-22 – completing the RHIC program with sPHENIX (new) and STAR

sPHENIX – new detector in IR8

- Run-23: Au+Au
- Run-24: p↑+p↑, p↑+Au
- Run-25: Au+Au

- All beams at 100 GeV/nucleon
- Ideally 28 cryo weeks each year, less with budget constraints

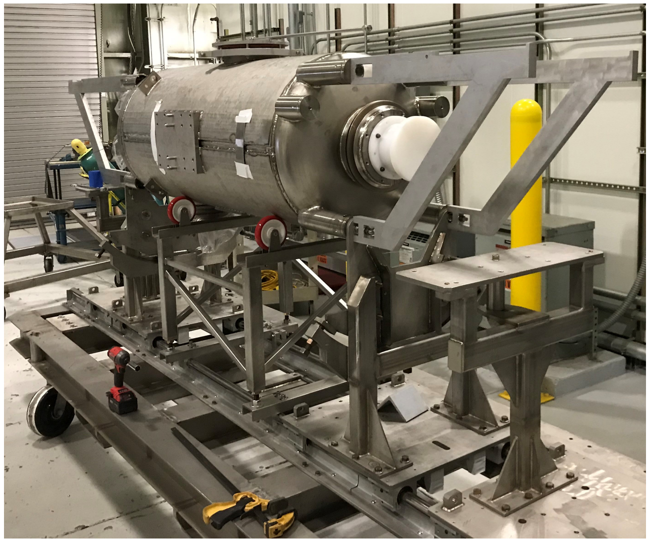
sPHENIX construction (30 Sep 2021)

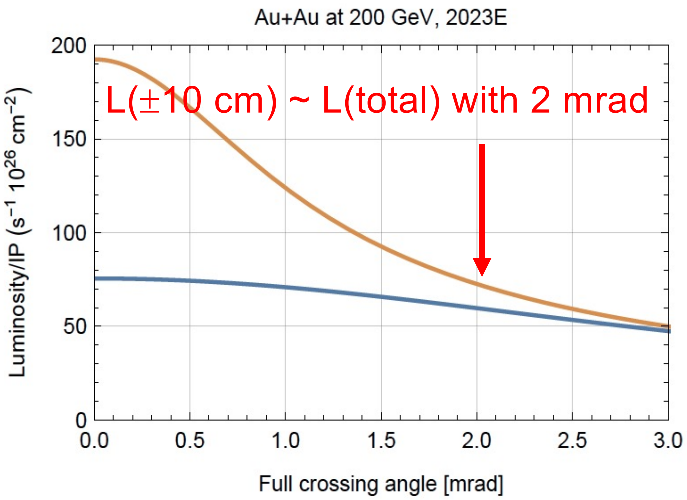
Brookhaven National Laboratory

Running with sPHENIX

To maximize useful luminosity:

- Operational use of 56 MHz SRF cavity
  (increased longitudinal focusing)
- 2 mrad crossing angle limits
  collisions only in small vertex cut ±10 mm
- Use of upgraded machine/experimental protection system (abort kicker relays
  + faster detection of anomalies)
- Also new ±150 A PS in IR8
  (larger operating margin for small β^*)





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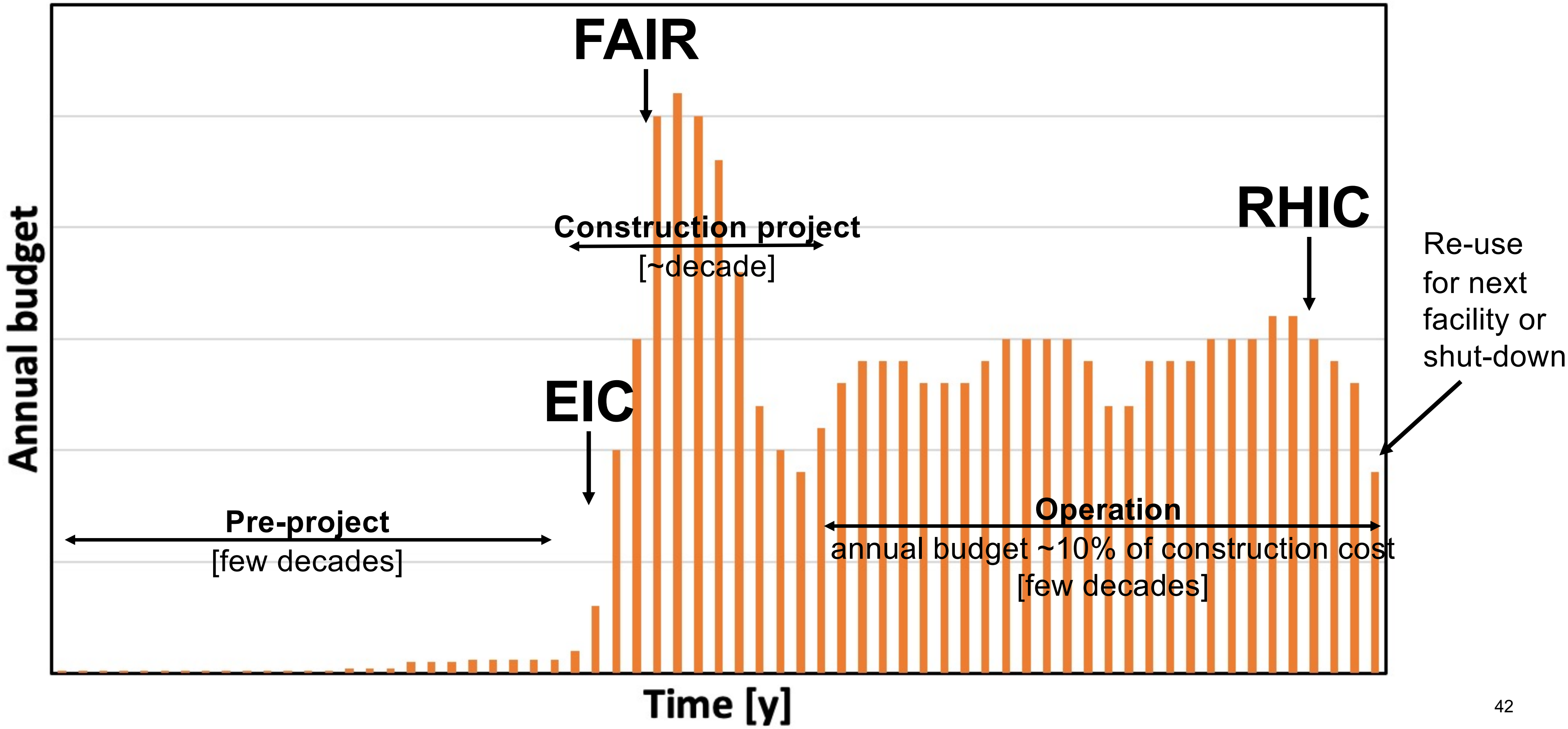
Life cycle of a large accelerator facility



EIC Overview

Ferdinand Willeke et al.

Design based on **existing RHIC Complex**
RHIC is well-maintained, operating at its peak

Hadron storage ring 40-275 GeV

based on RHIC, existing

- 1160 bunches, 1A beam current (3xRHIC)
- Bright vertical beam emittance 1.5 nm
- Strong cooling (coherent electron cooling)

Electron storage ring 2.5–18 GeV new ring in RHIC tunnel

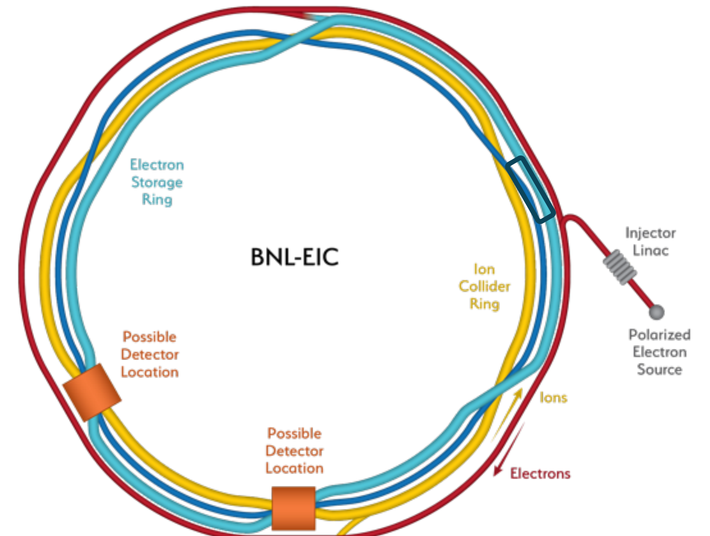
- 1160 bunches
- Large beam current, 2.5 A ➔ 9 MW S.R. power
- SRF cavities

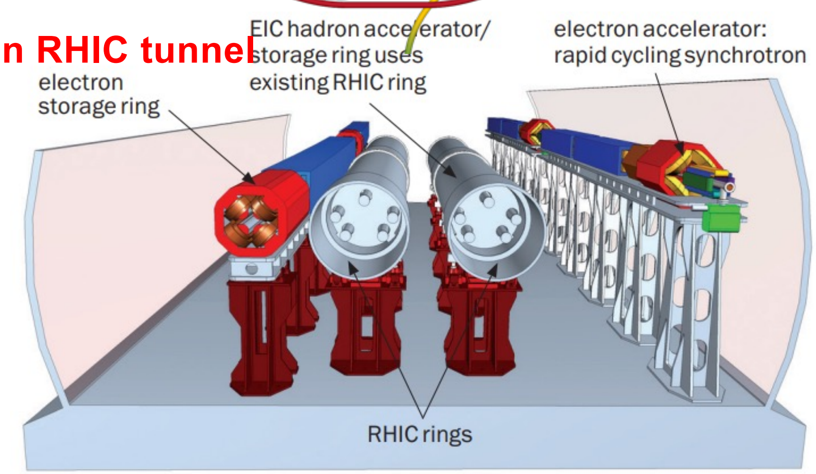
Electron rapid cycling synchrotron 0.4-18 GeV new ring in RHIC tunnel

- 2 x 28 nC bunches, 1 Hz cycle time
- Use spin transparency for high polarization

High luminosity interaction region(s) new

- $L = 10^{34}\ cm^{-2}s^{-1}$, Superconducting magnets
- 25 mrad crossing angle with crab cavities
- Spin rotators (longitudinal electron spin)
- Forward hadron instrumentation for tagging





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What made 2.5 decades possible?

- Facility remails priority of science community, science program evolved in new directions, detector upgrades
- Evolving experimenters interests could be met with evolving accelerator developments (*L*, *P*, flexibility)
- For example:
  - some unusual species (Ru-96/Zr-96)
    => required ORNL for Run-96 enrichment (with DOE support),
    existing BNL sources, help from RIKEN, stochastic cooling
  - Collisions below nominal injection energy
    => required construction of an electron cooler
- Strong funding agency commitment

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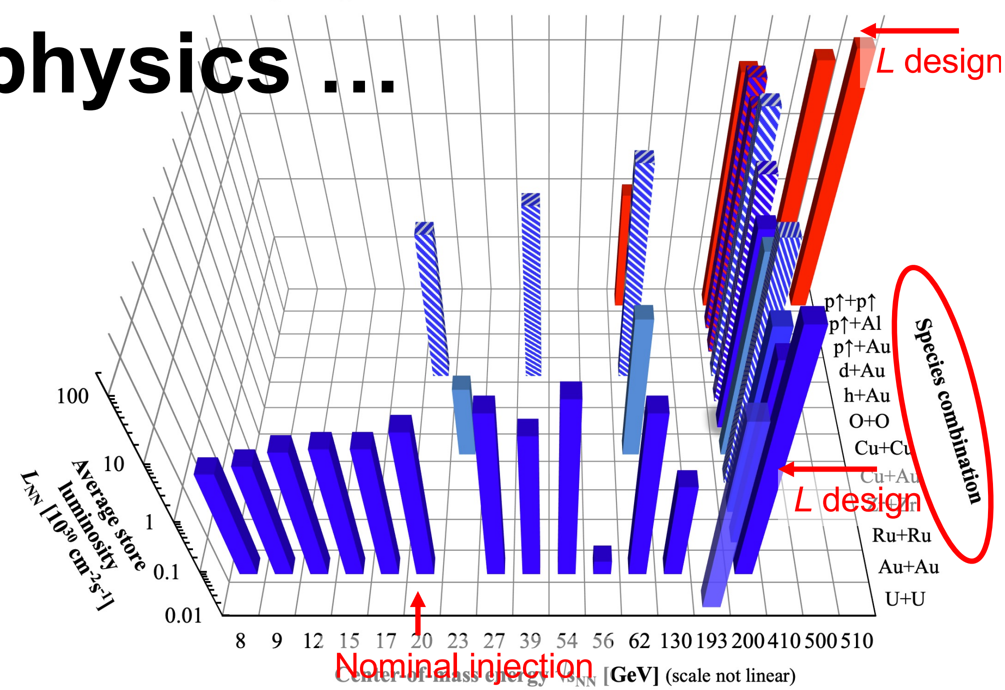
RHIC after 21 years of physics …

- Full energy Au+Au L_{avg} = 44x design
- Only p↑+p↑ collider, L_{avg} = 0.8x design, P ~ 55%, still challenging
- Many species and combinations, incl. asymmetric and low natural abundance
- Extended energy range below nominal injection
- 4 more years planned, 3 with a new detector

RHIC energies, species combinations and luminosities (Run-1 to 21)



- Strong and evolving science program + steady stakeholders support (users, lab, DOE)
- Developed technology for evolving program, eg operational stochastic (high energy) and electron cooling with RF accelerated e-beam (low energy)
- Most of RHIC complex will be re-used for the Electron-Ion Collider

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ACCELERATOR SEMINAR

Wolfram Fischer
BNL

Thursday, 14. Oktober 2021 at 4 pm

Online-Seminar via Zoom
(ID: 952 6046 8012 / PW: 102080)

21 years of RHIC – performance far beyond the design

The BNL Relativistic Ion Collider (RHIC) started operation more than two decades ago with a program of high-energy ion collisions. A few years later a program with polarized proton collisions was added, and the following years the program expanded further and further with ever-increasing luminosity, polarization, species combinations, energy range, and operational flexibility. The machine is now also preparing for use in the Electron-Ion Collider. We examine the path from the beginning to the present state, and outline the technical and other components and strategies to sustain a long and varied physics program.

GSI

Coordinator: Anja Seibel, Janet Schmidt
Secretary: Larissa Birli
https://indico.gsi.de/categoryDisplay.py?categId=359

FAIR

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