From RHIC to EIC

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@BrookhavenLab

Overview

The Relativistic Heavy Ion Collider (RHIC) at first 24 years

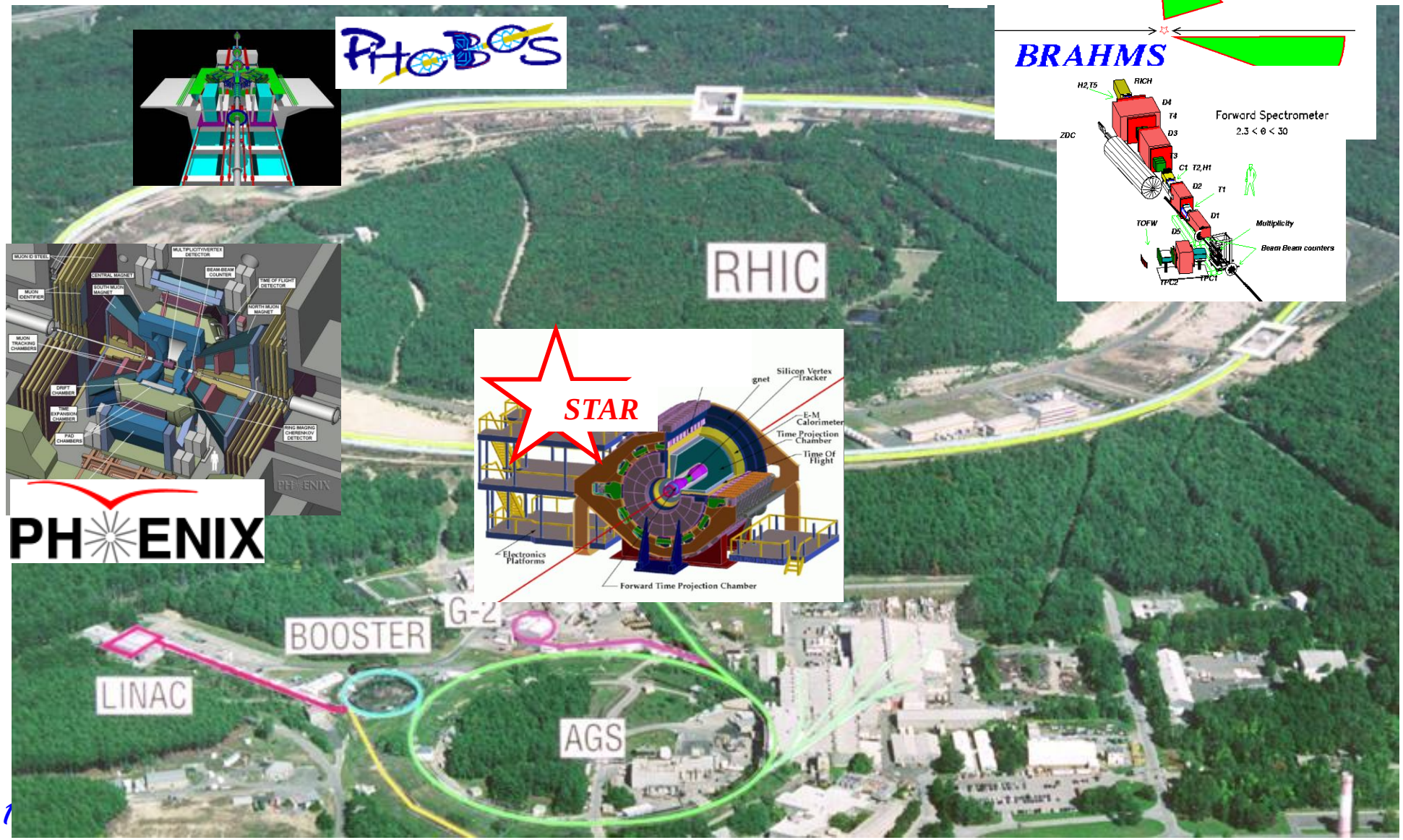
The 25th – last – year of RHIC and what's next for RHIC?

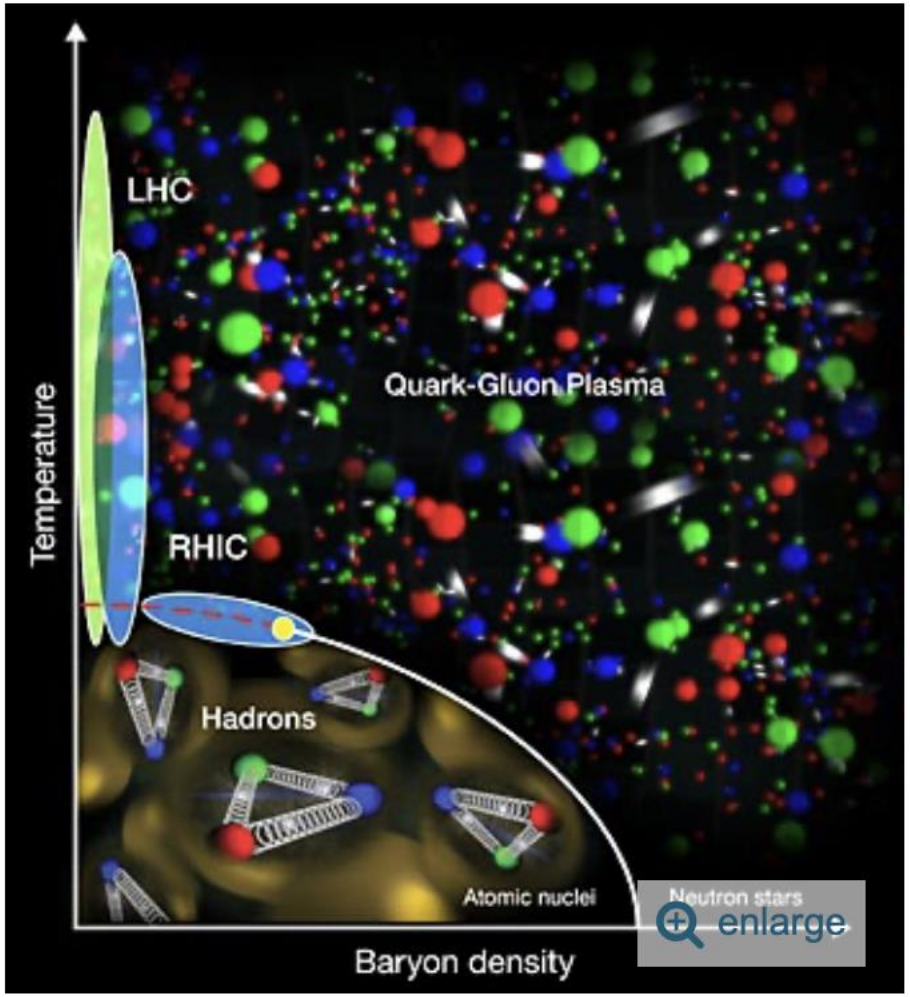
Electron Ion Collier (EIC) the next (ultimate(!)) QCD frontier

Early physics, early start through subprojects (details in Rolf's presentation)

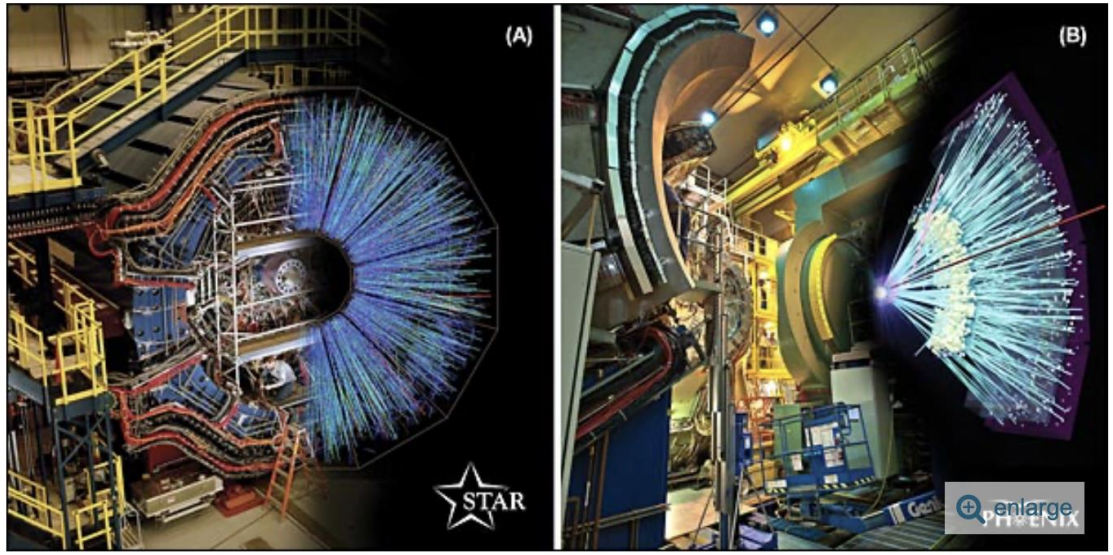
Between RHIC and EIC

Science and elements of transition, various dependencies and tasks

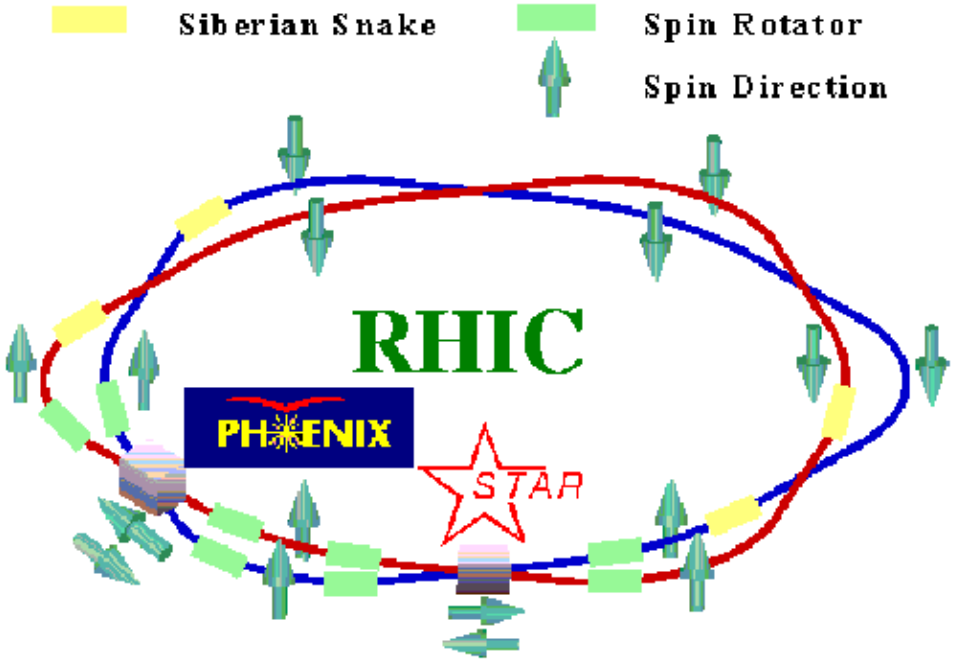

PHOBOS
BRAHMS
RICH
H2,T5
D4
T4
D3
ZDC
C1
T2,H1
D2
T1
D1
TOFW
D5
Multiplicity
Beam Beam counters
TPC2
TPC1
Forward Spectrometer
2.3 < θ < 30
PHENIX
MUON ID STEEL
MULTIPLICITY/VERTEX DETECTOR
CENTRAL MAGNET
BEAM-BEAM COUNTER
TIME OF FLIGHT DETECTOR
MUON IDENTIFIER
SOUTH MUON MAGNET
NORTH MUON MAGNET
MUON TRACKING CHAMBERS
DRIFT CHAMBER
TIME EXPANSION CHAMBER
PAD CHAMBERS
RING IMAGING CHERENKOV DETECTOR
STAR
Silicon Vertex Tracker
E-M Calorimeter
Time Projection Chamber
Time Of Flight
Electronics Platforms
Forward Time Projection Chamber
RHIC
G-2
BOOSTER
LINAC
AGS



The nuclear phase diagram: RHIC sits in the energy "sweet spot" for exploring the transition between ordinary matter made of hadrons and the early universe matter known as quark-gluon plasma.



RHIC's two large experiments, STAR and PHENIX, have multiple detector components and complex electronics for tracking and identifying the particles that fly out after ions collide at nearly the speed of light.



Origin of proton spin

- Gluon's contributions
- Anti-Quark contribution

Brookhaven National Laboratory

RHIC
1st Collisions
Monday, June 12, 2000

physicsworld

Topics Latest

particles and interactions

PARTICLES AND INTERACTIONS | RESEARCH UPDATE

RHIC makes its debut

14 Jun 2000

The first collisions have been detected at the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory in the US. The STAR detector recorded the first collisions at 9pm local time on Monday, while the PHOBOS detector recorded its first events early on Tuesday. The first physics results from RHIC are expected at the beginning of next year.

EurekAlert! | AAAS

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NEWS RELEASE 12-JUN-2000

Relativistic heavy ion collider (RHIC) begins smashing atoms

Peer-Reviewed Publication

DOE/BROOKHAVEN NATIONAL LABORATORY

Experiments will yield insights into the structure of matter and how the universe evolved

UPTON, NY -- Scientists at the U.S. Department of Energy's Brookhaven National Laboratory have begun detecting head-on collisions between gold nuclei in the Relativistic Heavy Ion Collider (RHIC), the world's newest and biggest particle accelerator for studies in nuclear physics. While the beams have been in collision mode since the weekend of June 10, the first spectacular images of particles streaming from a collision point -- the definitive evidence the scientists were waiting for -- were produced by the STAR detector last night at 9 p.m. High-energy collisions were also seen by the PHOBOS detector early this morning.

"We are crossing into a new frontier of scientific inquiry," said Energy Secretary Bill Richardson. "Scientists from around the world will use this facility to answer some of the most basic questions about the properties of matter and the evolution of our universe."

More on this News Release

Relativistic heavy ion collider (RHIC) begins smashing atoms

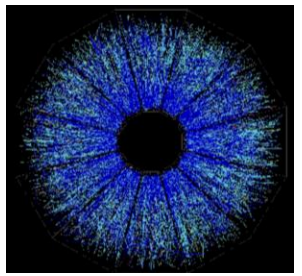
DOE/BROOKHAVEN NATIONAL LABORATORY

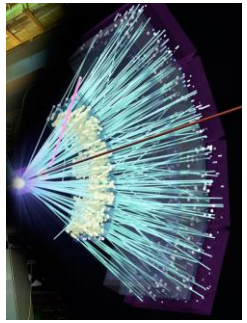
FUNDER

U.S. Department of Energy

KEYWORDS

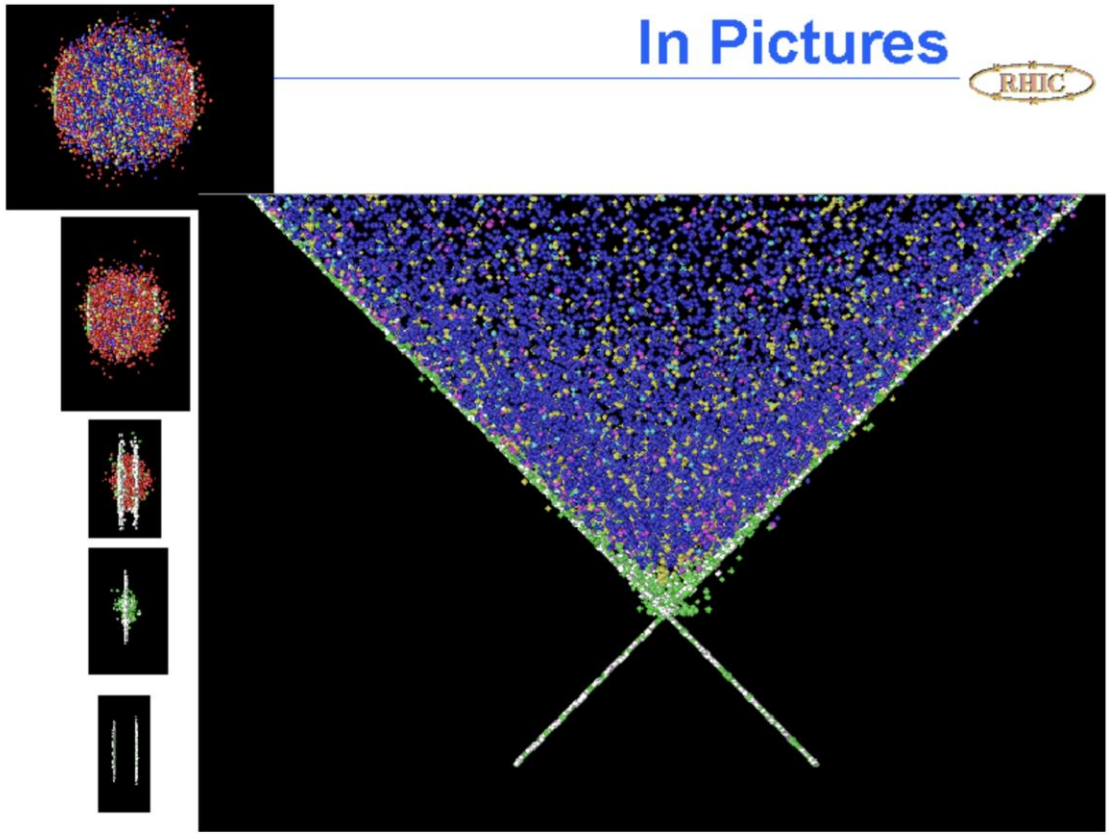
INDUSTRIAL SCIENCE THERMAL ENERGY IONS





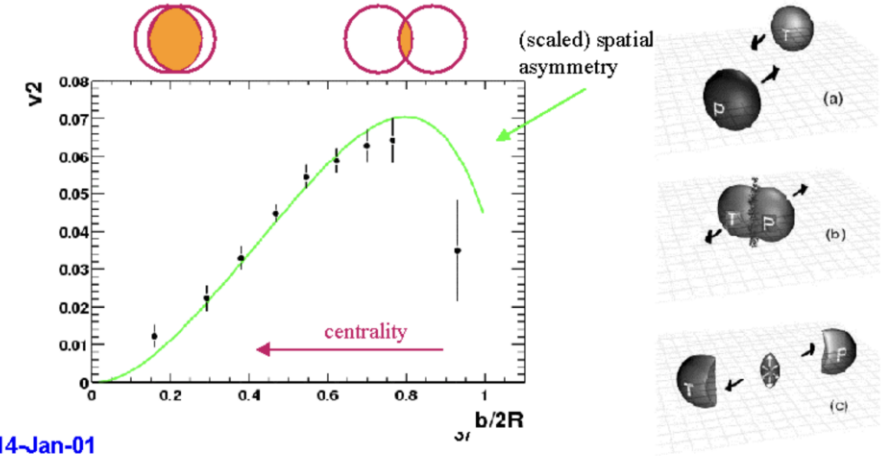
RHIC 1ST Results
QM 2001 at Stony Brook
January 2021

In Pictures



STAR results on Elliptic Flow

- First results on "elliptic flow at RHIC"
  - nucl-ex/0009011
  - Differential measure of response to initial geometry

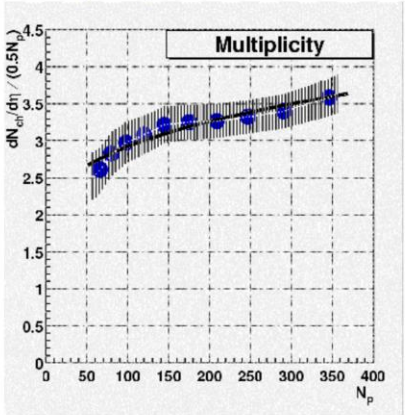


14-Jan-01

PHENIX Results

(See nucl-ex/0012008)

- Multiplicity grows significantly faster than N-participants
- Growth consistent with a term that goes as N-collisions (as expected from hard scattering)

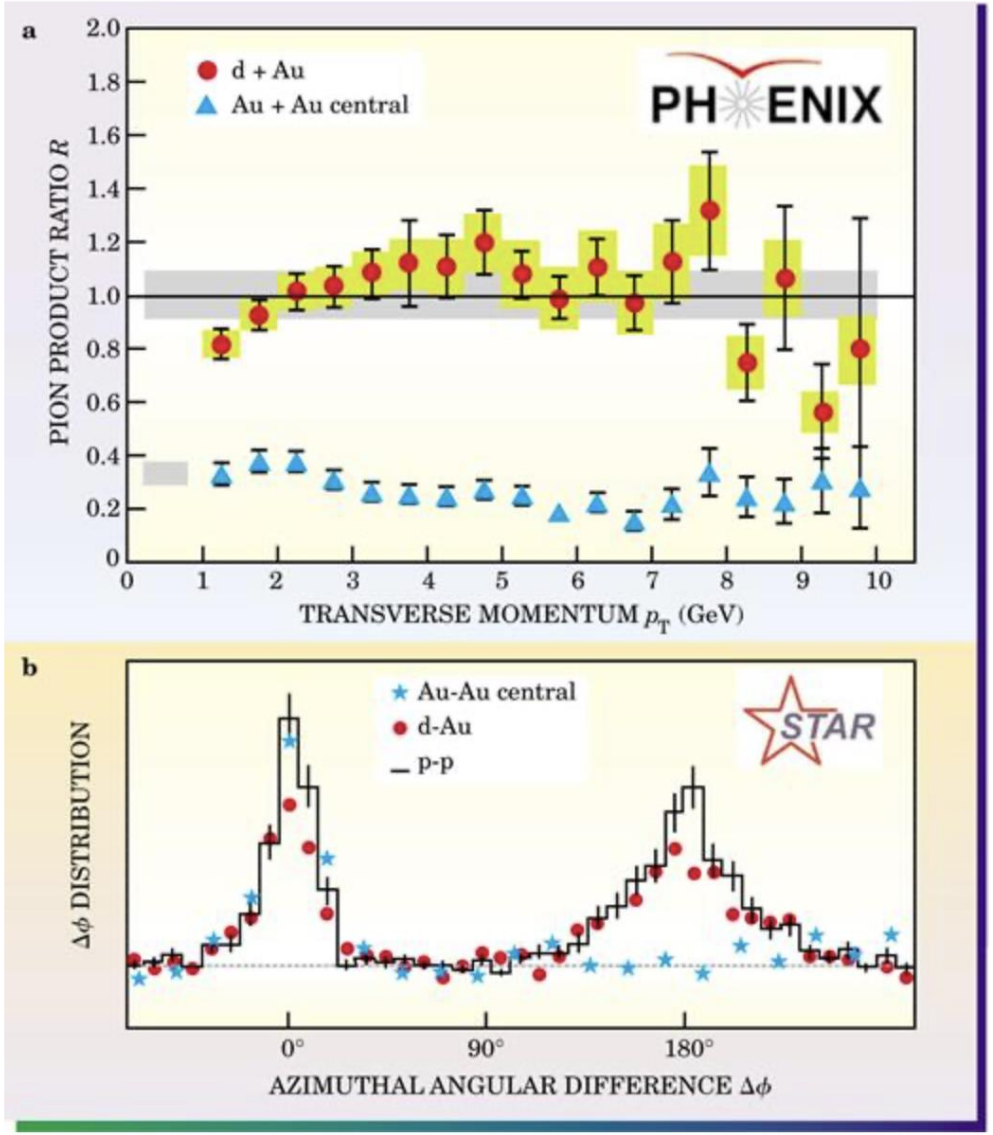


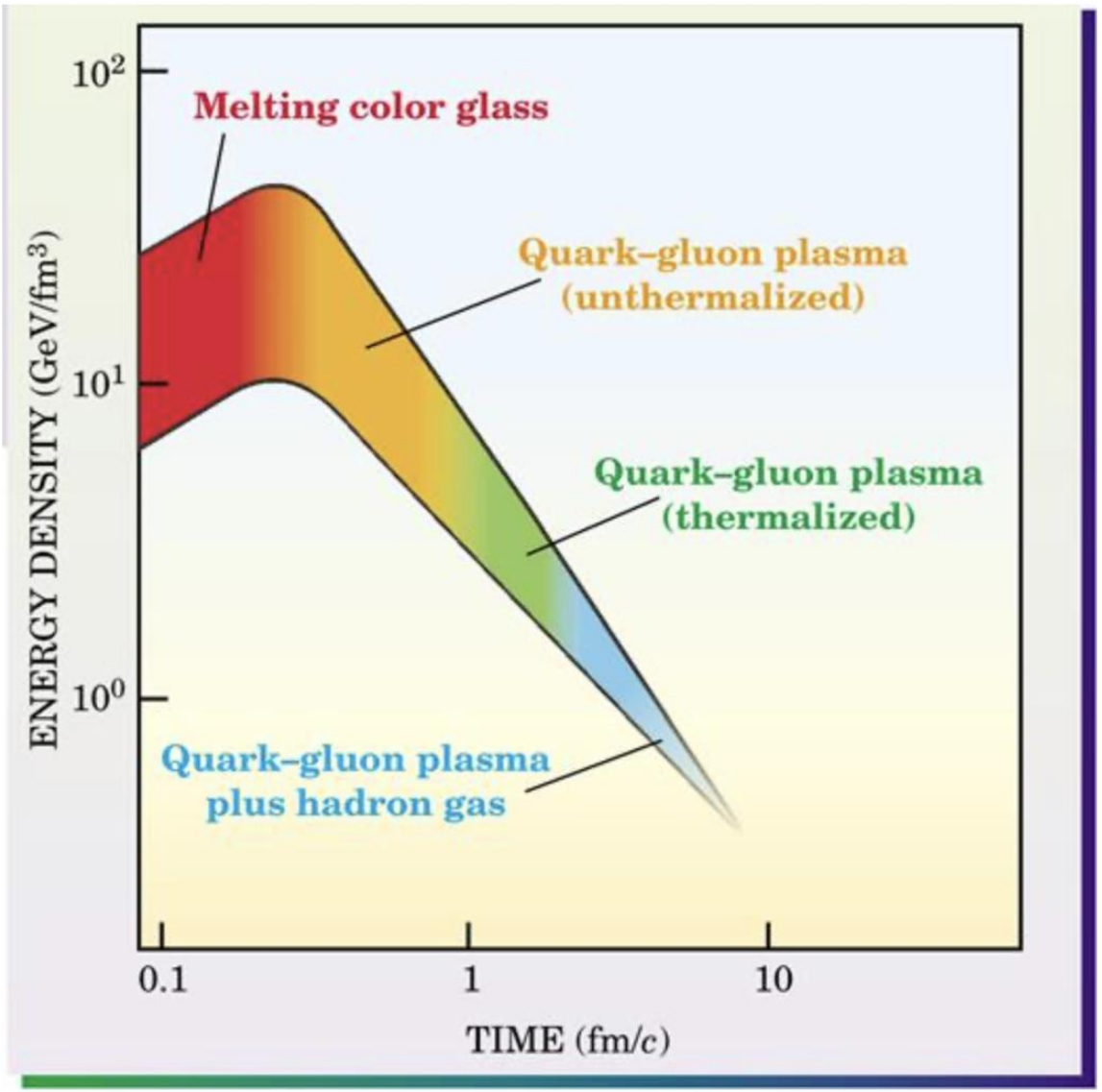
$$dN/d\eta\big|_{\eta=0} = A \times N_{part} + B \times N_{coll}$$

$$A = 0.88 \pm 0.28$$

$$B = 0.34 \mp 0.12$$

Initial State of Nuclear Collisions:
Color Glass Condensate : At the future EIC

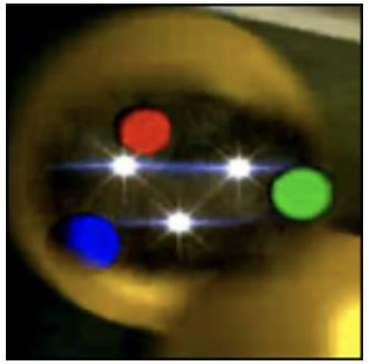




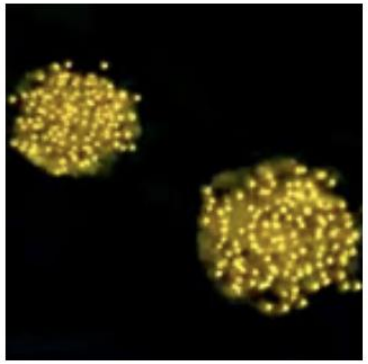
Ludlam and McLerran
Physics Today **56** (10), 48–54 (2003)

A New Area of Physics

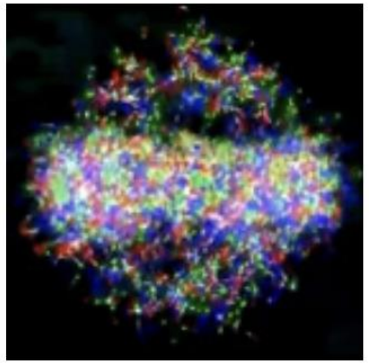
RHIC has created a new state of hot, dense matter out of the quarks and gluons that are the basic particles of atomic nuclei, but it is a state quite different and even more remarkable than had been predicted. Instead of behaving like a gas of free quarks and gluons, as was expected, the matter created in RHIC's heavy ion collisions is more like a liquid.



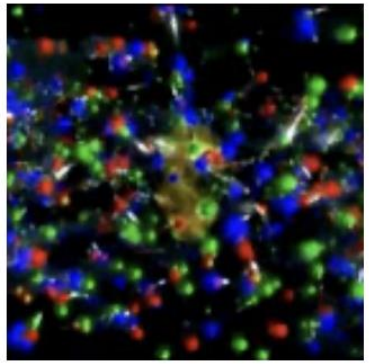
Gluons and quarks



Ions about to collide

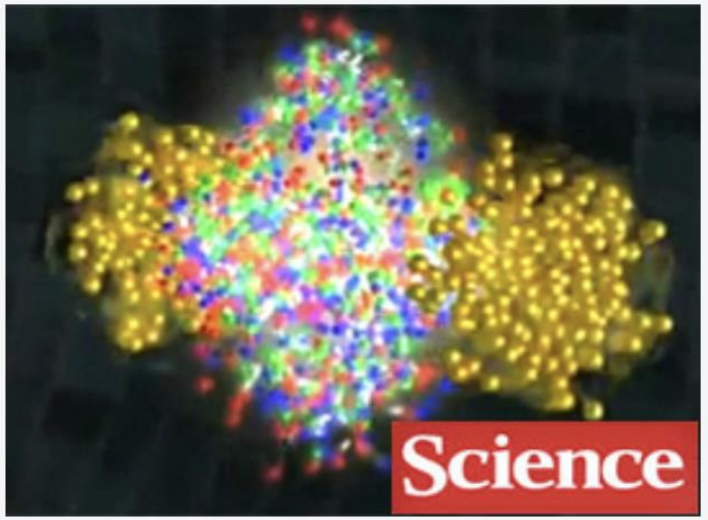


Just after collision



The "perfect" liquid

Hot Nuclear Matter



A review article in the journal *Science* describes groundbreaking discoveries that have emerged from RHIC, synergies with the heavy-ion program at the Large Hadron Collider, and the compelling questions that will drive this research forward on both sides of the Atlantic.

Abstract | Reprint | Full Text | BNL release

RHIC has operated phenomenally well and continues to be super-productive

Recent highlights from RHIC

Brookhaven National Laboratory

Accelerator Complex & Applications Facilities

There are three current IP facilities:

Brookhaven Linac Isotope Producer (BLIP),
Located in 931

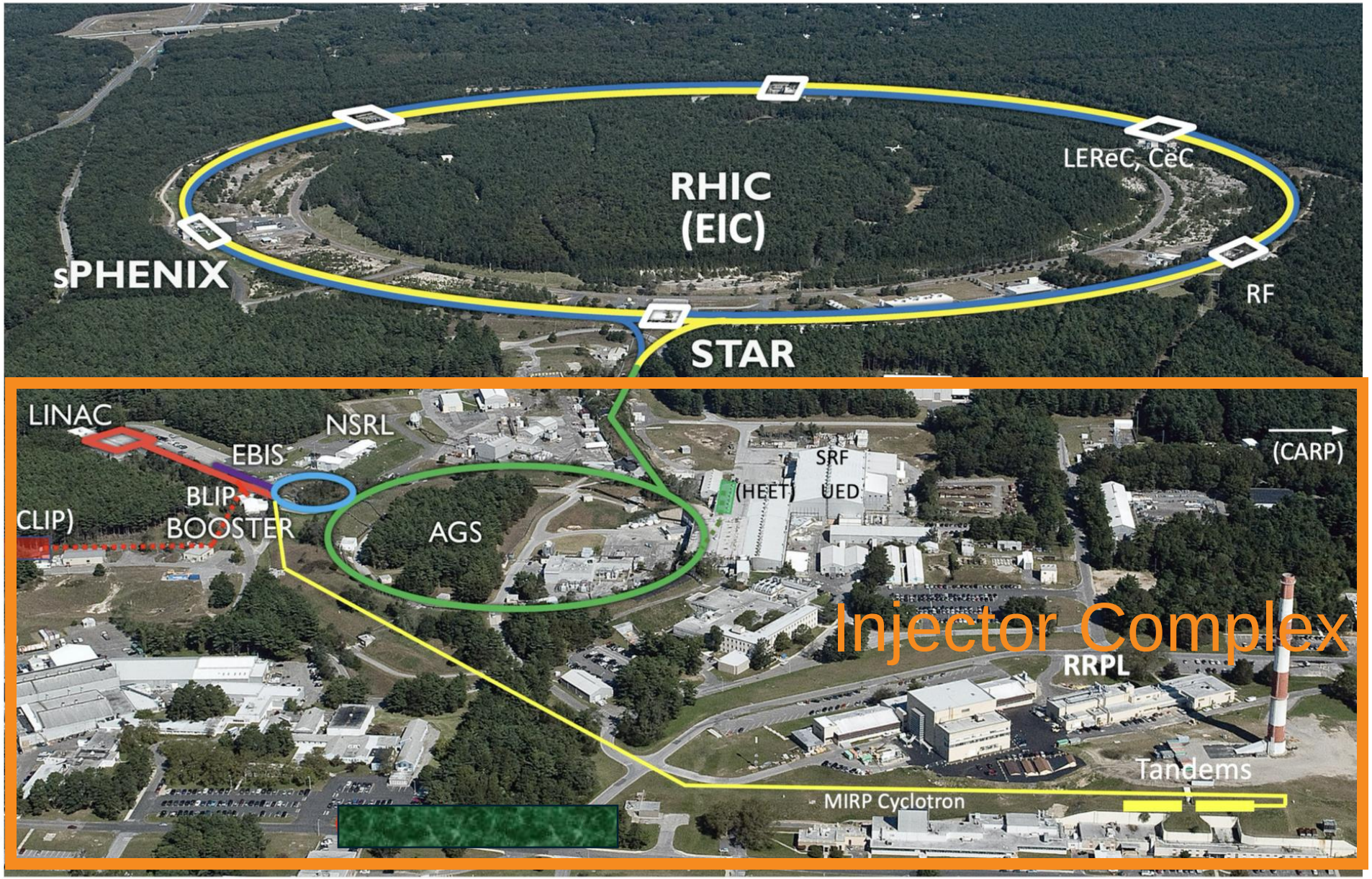
Radionuclide Research and Production Laboratory (RRPL),
Located in 801 housing the Research laboratories and hot cells

The MIRP Cyclotron,
Located in 901

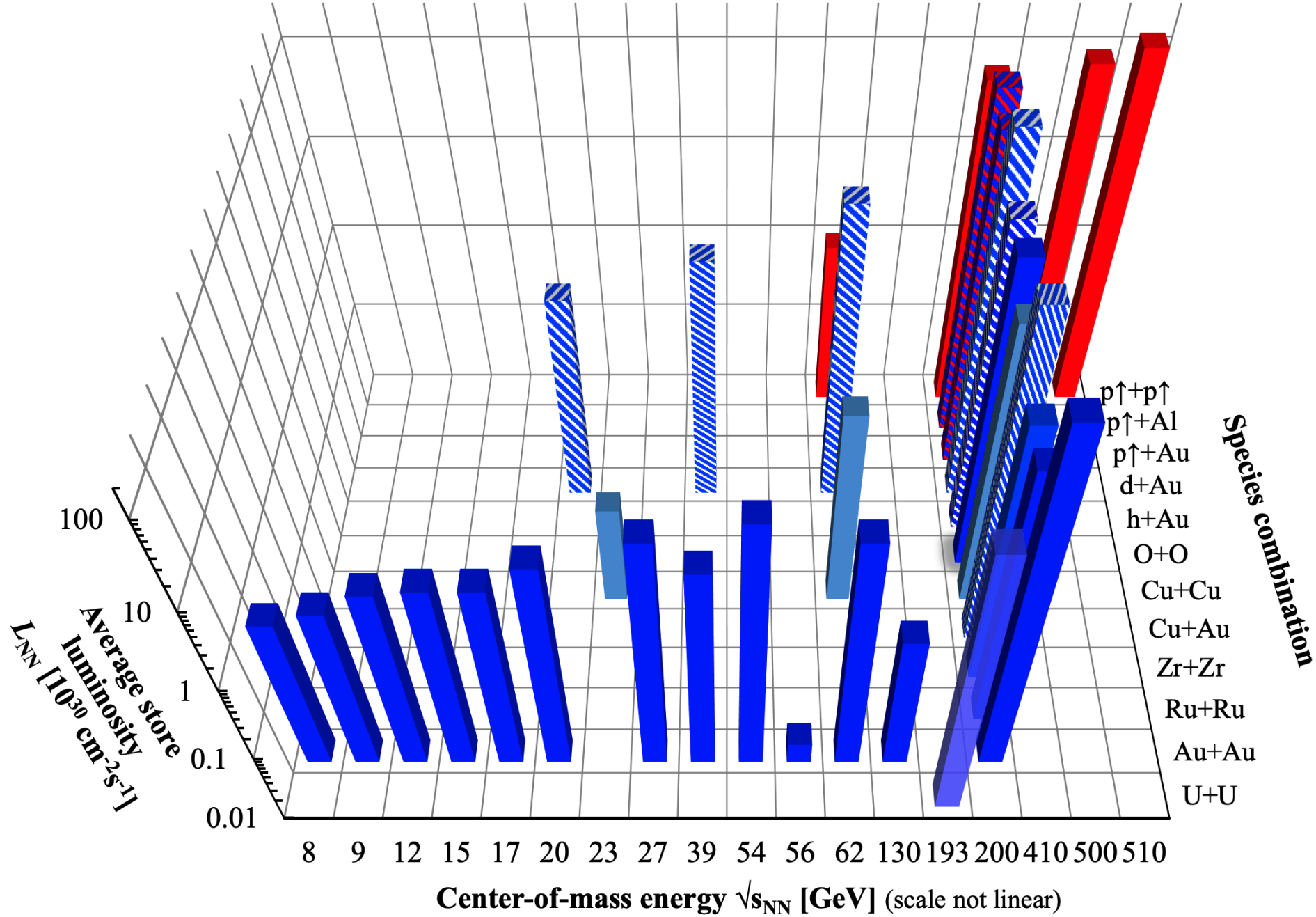
Three proposed facilities:
Clinical Alpha Radionuclide Producer (CARP),
Located in building 870

Medium Energy Cyclotron,
Located in new building

Clinical Linac Isotope Producer (CLIP)

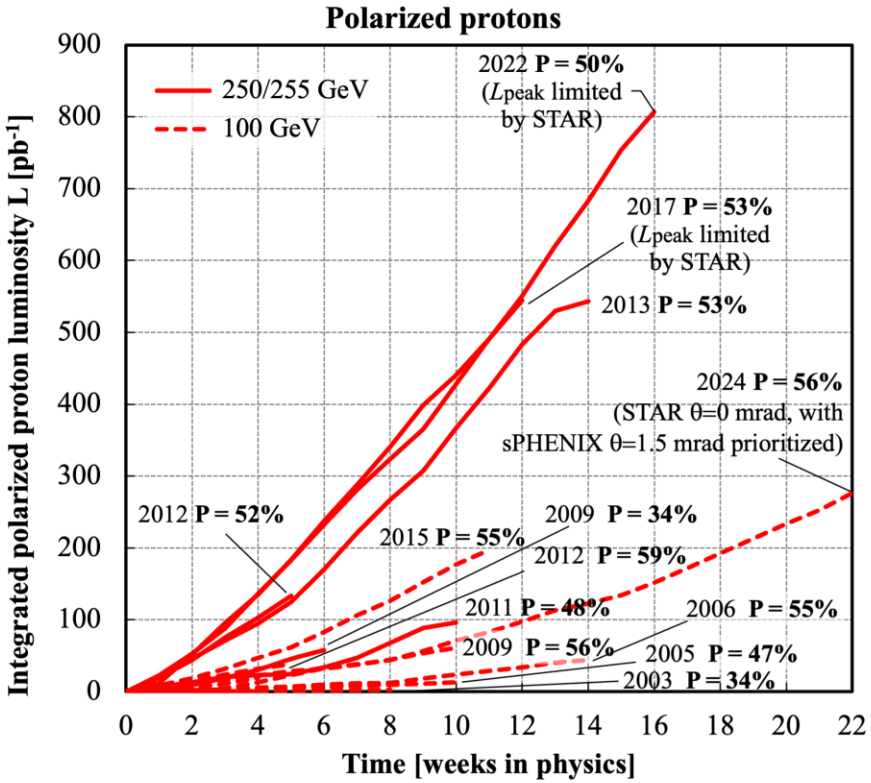


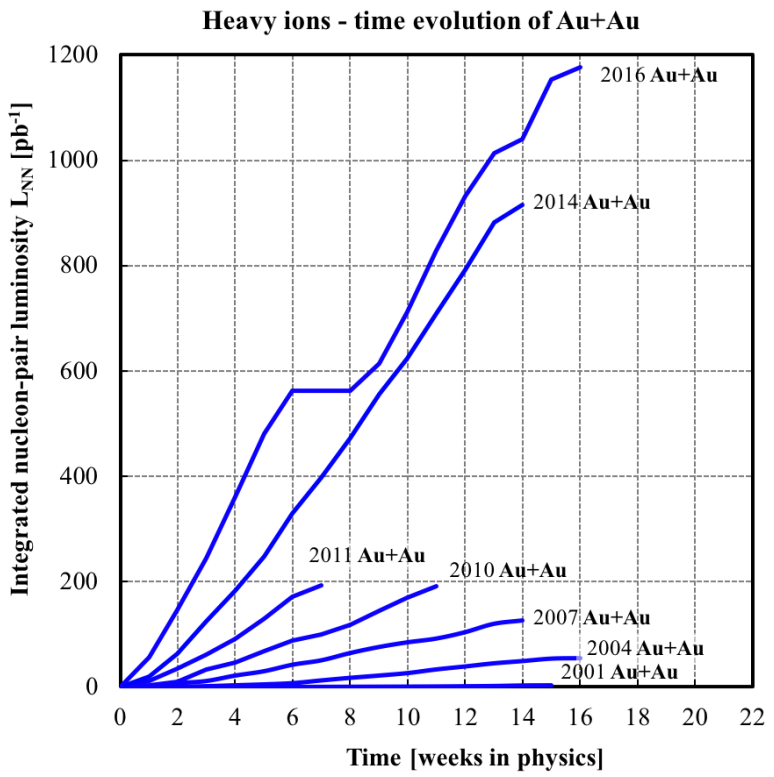
RHIC energies, species combinations and luminosities (Run-1 to 24)

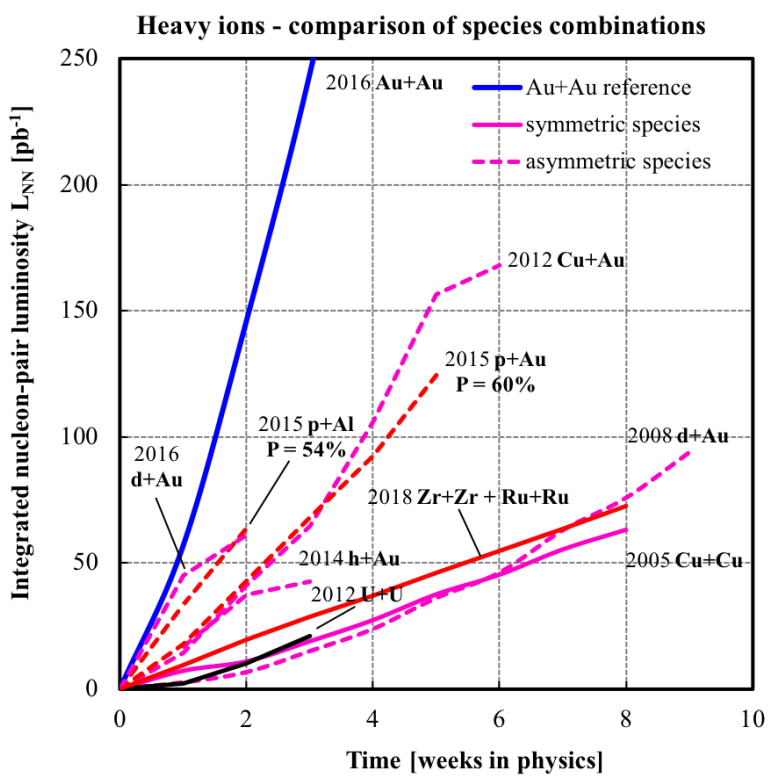


RHIC Integrated Luminosity

- Dramatic increase of RHIC performance as a result of ongoing accelerator R&D, accelerator improvements, and replacement of obsolete technology







PHENIX Publications Summary

- **222 physics papers published**
  - Phys. Rev. Lett. 76
  - Phys. Rev. C 93
  - Phys. Rev. D 47
  - Nature Physics 1
  - Phys. Letter B 4
  - Nucl. Phys. A 1
- **Total citation: ~35000**
- Topcite 1000+ 3
  - 500-1000 7
  - 250-500 22
  - 100-250 66
  - 50-100 45

PHENIX White Paper: 3650 cites

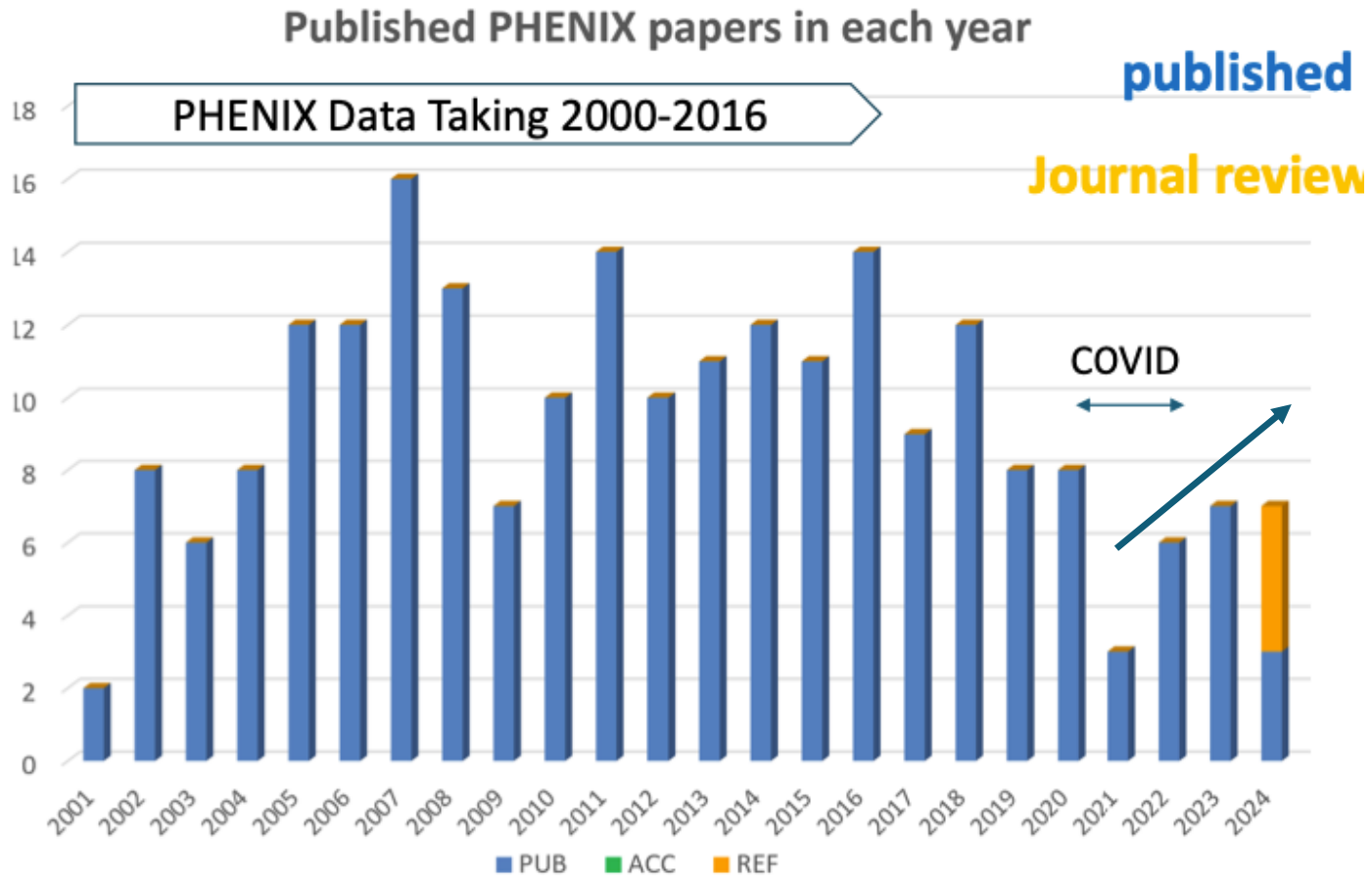
Jet quenching discovery: 1220 cites

PID hadron in AuAu: 1015 cites

Nature P paper: 304 citations

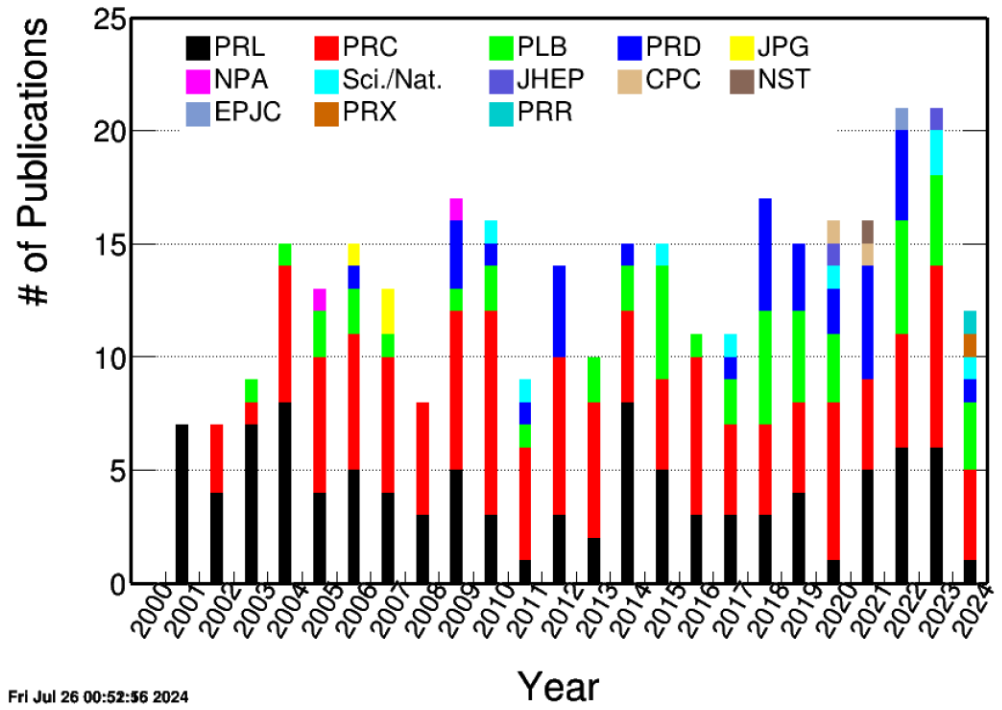
143 physics papers in topcite 50+

(165 if proceedings and detector papers are included)



Data taking ended in 2016, but analyses & publications continue

STAR Publication Summary



Continued strong publication and presentation record across all Physics Working Groups

Observation of Antihyperhydrogen-4 at RHIC, accepted for publication in Nature

Observation of the electromagnetic field effect via charge-dependent directed flow in heavy-ion collisions at the Relativistic Heavy Ion Collider, the first PRX paper in heavy ion physics.

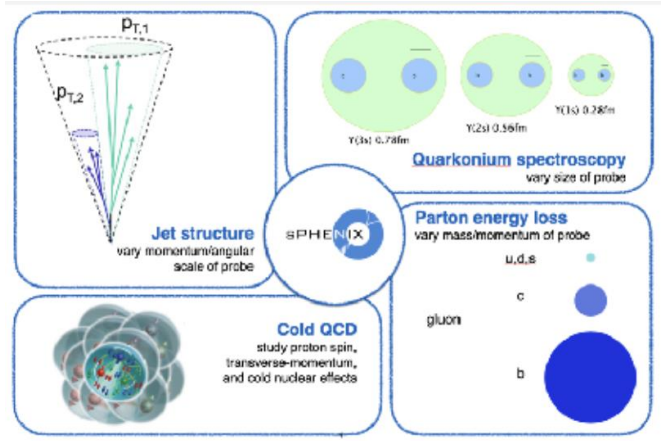
- **2023**: 21 published 6 PRL, 8 PRC, 4 PLB, 2 Sci/Nat, 1 JHEP
- **2024**: 12 published + accepted: 1 PRL, 4 PRC, 3 PLB, 1 PRD, 1 Nat, 1 PRX, 1 PRR

Journal review: 13; Collaboration review: 3; Active GPCs: 30

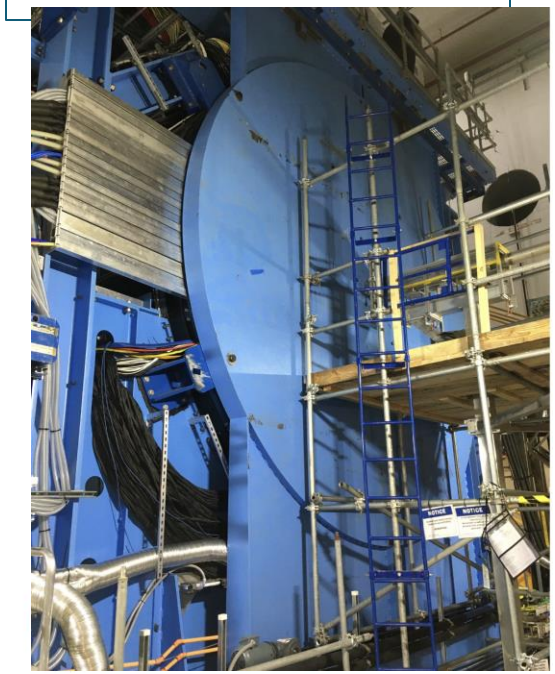
99% of STAR papers uploaded to HEPData, remaining 2 papers are newer and on track to be uploaded soon

Continued steady growth in citations

sPHENIX science, status and progress

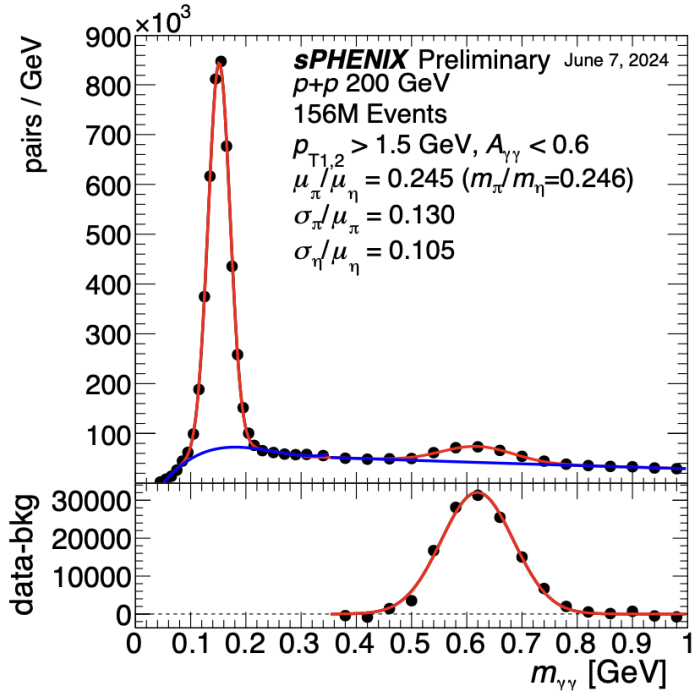


Detector completed in time for Run 23



The last remaining component of "**finishing the RHIC mission**" : **2023 LRP** Plan:

Commissioning & Au-Au run 2023
Operation with polarized (p-p) 2024
Operation with Au-Au 2025



π^0 and η invariant mass distributions
• 0.01% of collected data

Run 23: Commissioning cut short by DX magnet failure – run cut short, additionally:

- Limited luminosity |z| < 10 cm
- Beam background prevented MVTX operation
- Time Projection Chamber unstable

Run 24:

- Late start of Run 24 requested
- Significant work done on MVTX, TPC
- Isobutane, a flammable gas needed as a quencher. TPC has worked well since 8/19
- Allows 5-weeks with p-p collisions

A 3-week Au-Au run is planned as an ultimate test for full sPHENIX Au-Au operation

Despite a lot of difficulties now the detector is ready: Three out of four physics thrusts **expected to yield impactful results**

Anticipating a large Au-Au data set in (FY25+FY26) in CY2025

Data analyses easily until 2035

Priority and Run 25 & 26 Plan (PAC)

Complete RHIC mission successfully and timely

Run 24

18+2weeks of p+p and 6* weeks Au+Au

Run 25/26

FY25 (20-2) weeks of Au+Au at 200 GeV:

FY26: Potential Run 26 ~12 weeks

Dates: March 24-June 30 and Sep 1-December 22, 2025

End-Game: 1) To accumulate 7 nb^{-1} integrated Au-Au data, 2) EIC (APEX 3 weeks) and the if there is time**: 3**) p-Au (~3-weeks) 4) O-O data 5) Space Radiation studies @ STAR (fixed tgt)

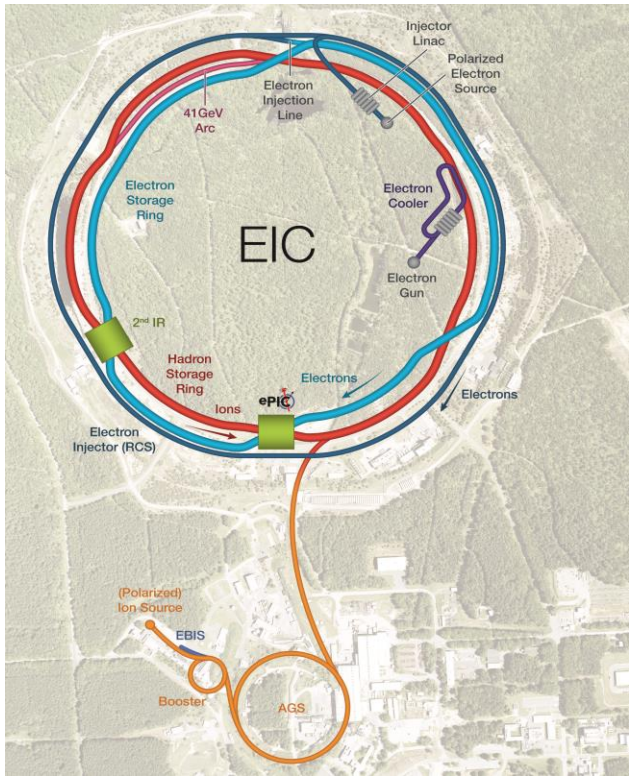
PAC meeting online planned June 17-18, to 2025 get the best advice for FY25/26 operation

RHIC operations slated end in ~December 2025

Transition to Electron Collider begins with “Removal and Repurposing”

Brookhaven National Laboratory

EIC 2023 → 2025



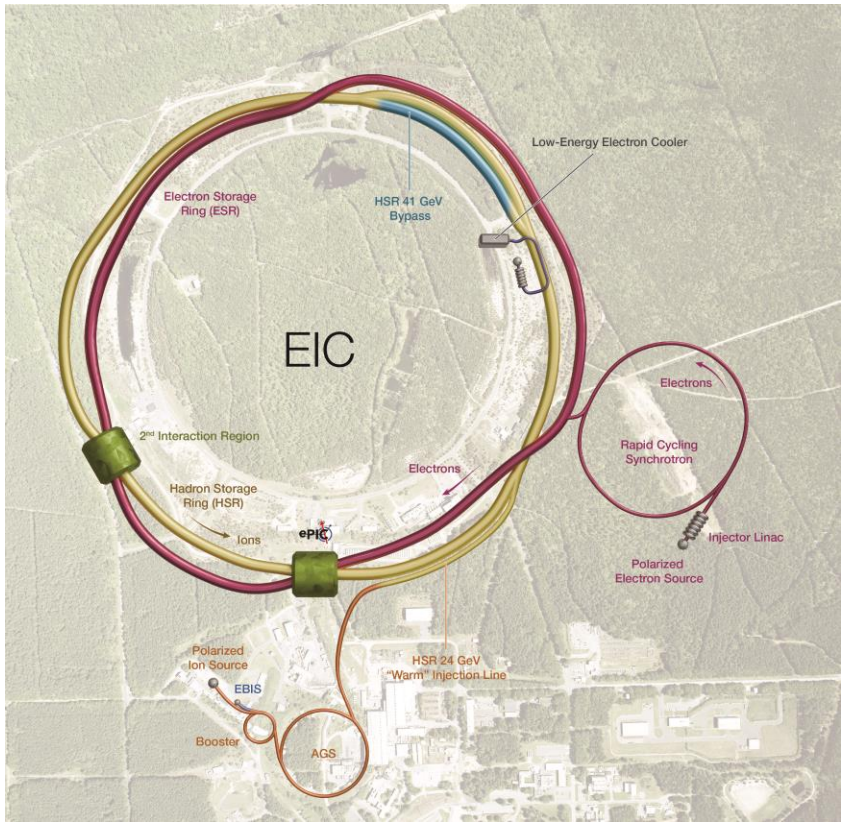
Reuse the entire Yellow RHIC ring, delay the 41-GeV bypass (a Blue RHIC arc)

Implement a new room-temperature HSR injection line

Drop SHC, add LEC

Move RCS out of the collider tunnel

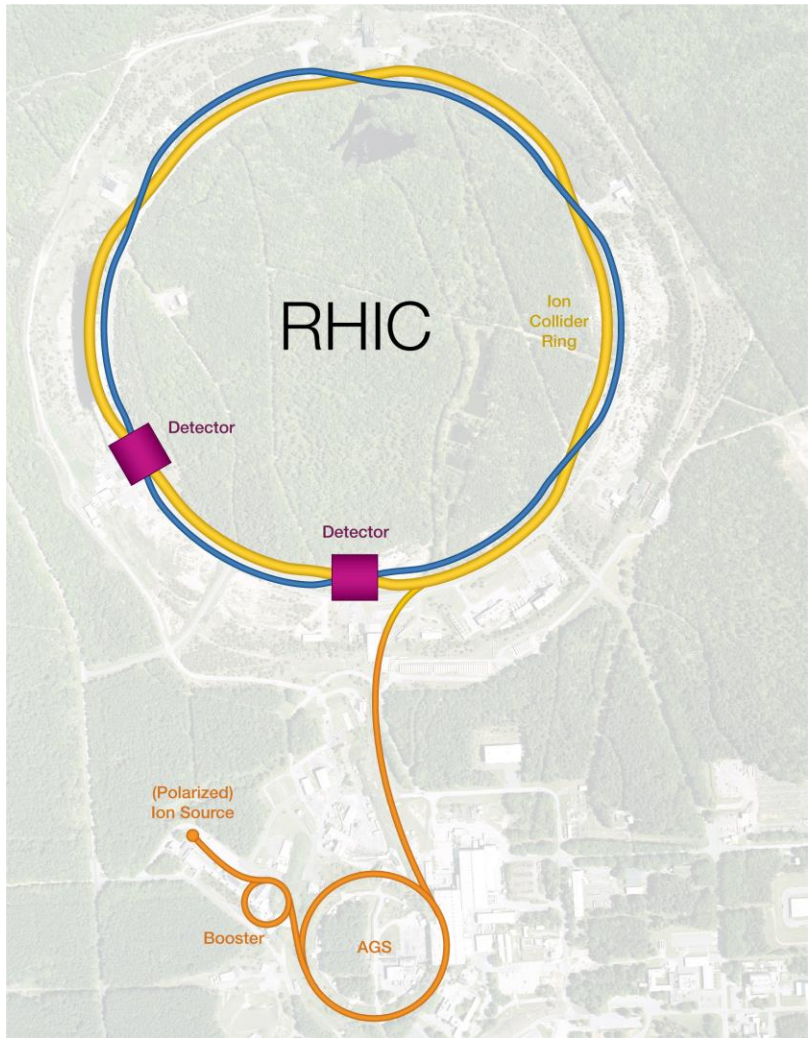
Delay the 28 nC/bunch and the 18 GeV capability implementation (ESR and RCS)



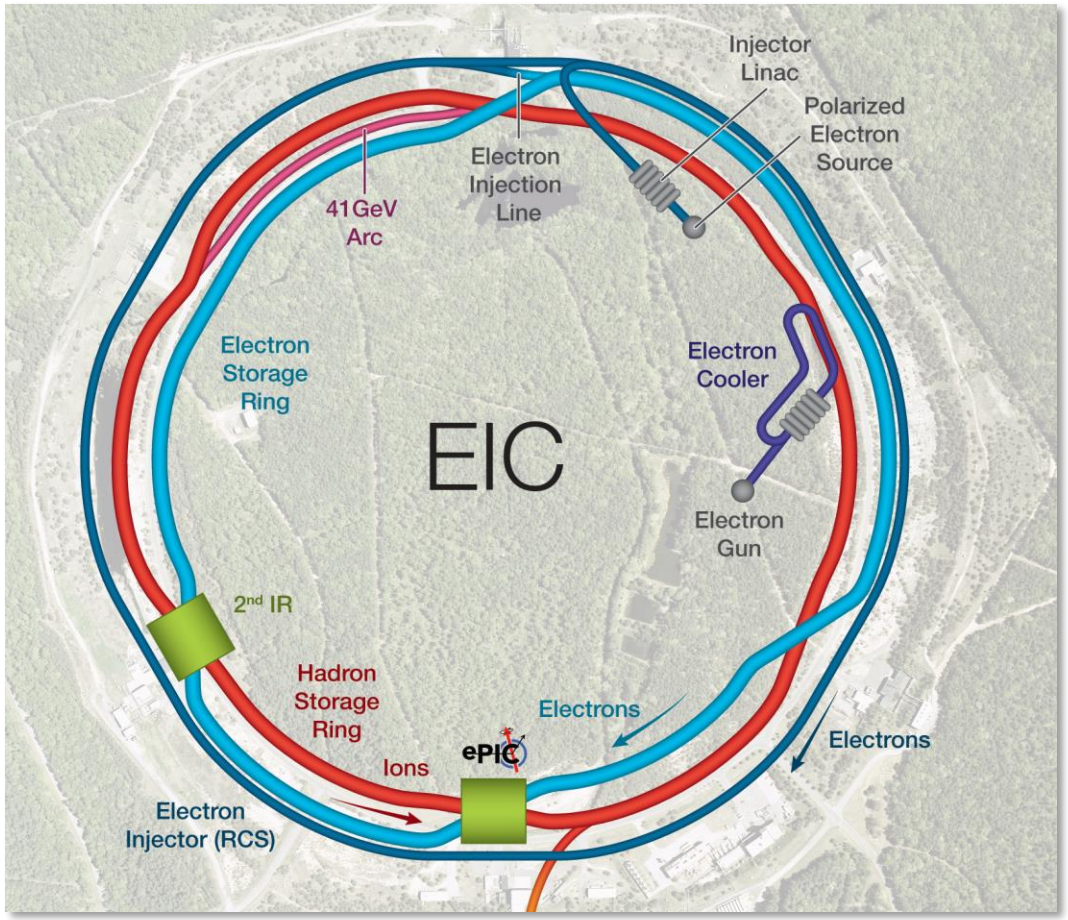
These design decisions motivated by resolving design uncertainties, challenges and risks to EIC performance, safety, and future operation and maintenance.

There is no change to the performance parameters and intend to keep the cost the same.

RHIC Tunnel Reuse

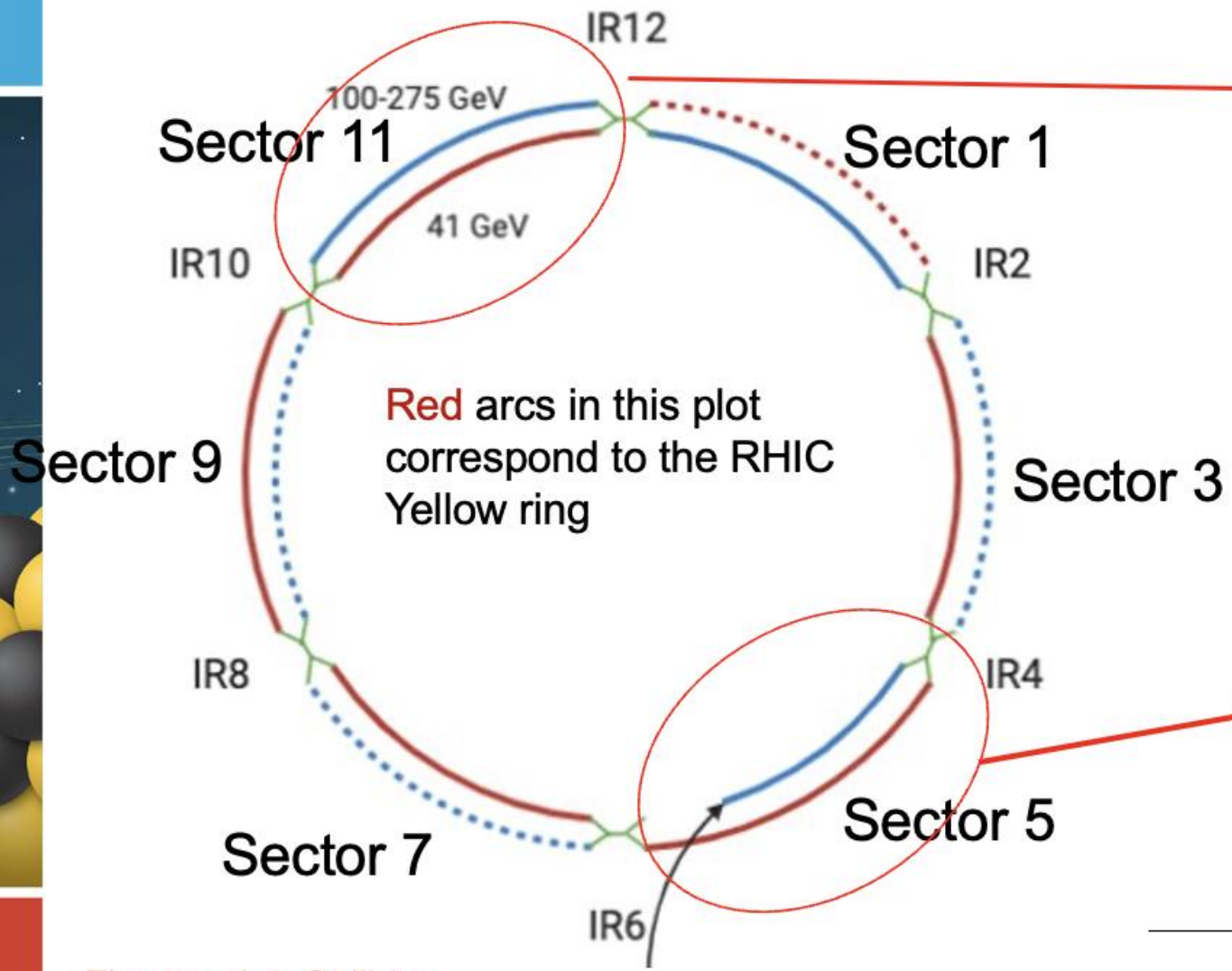


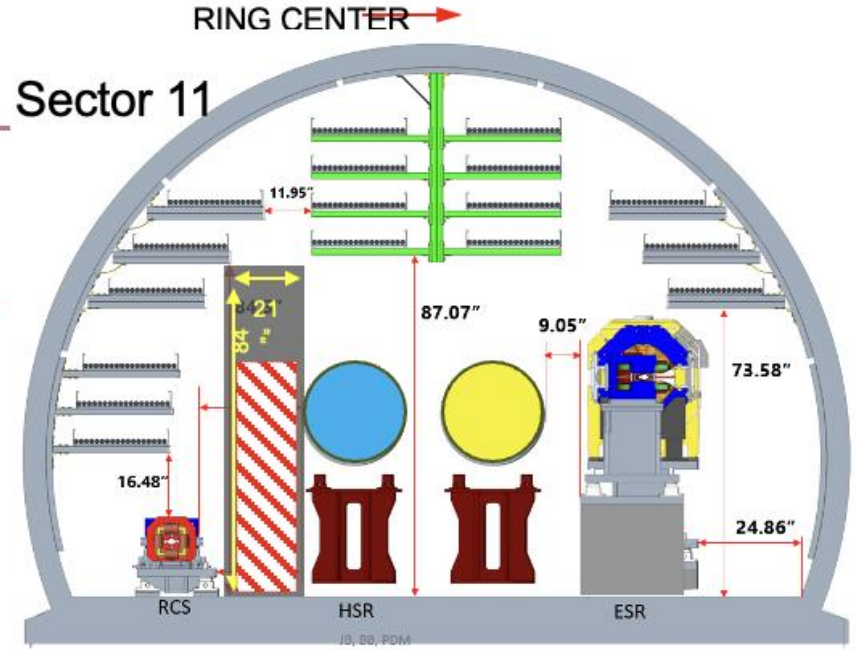
CDR concept (2021)

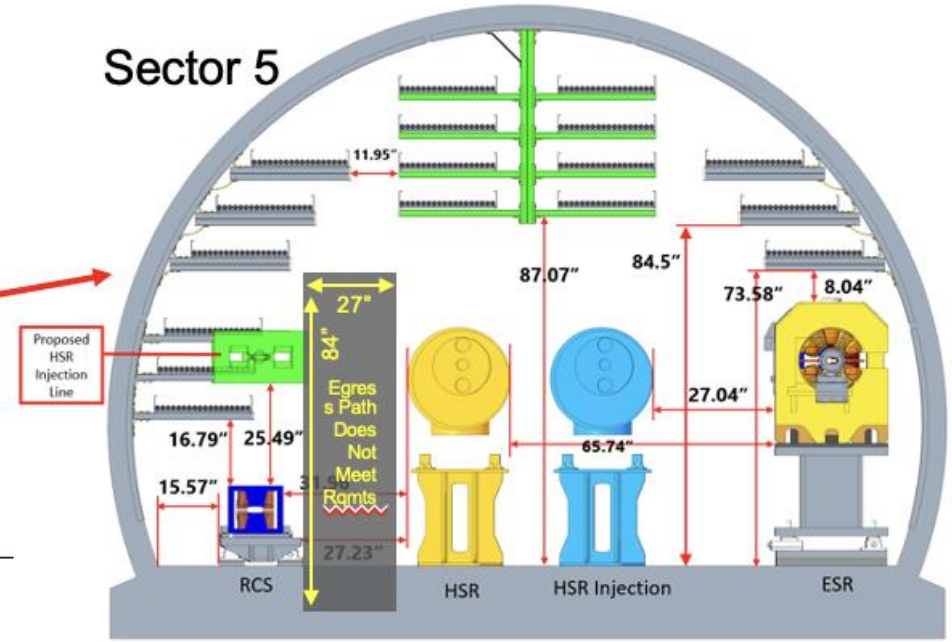


Tunnel Layout Optimization

2024: challenges identified with the CDR layout

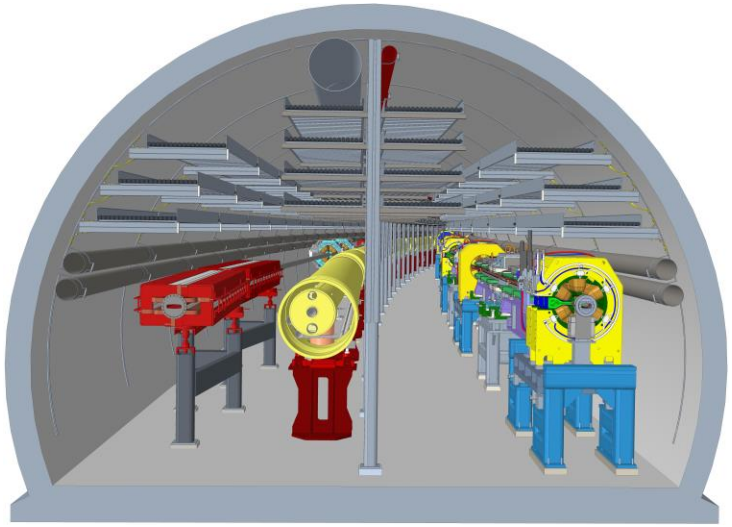




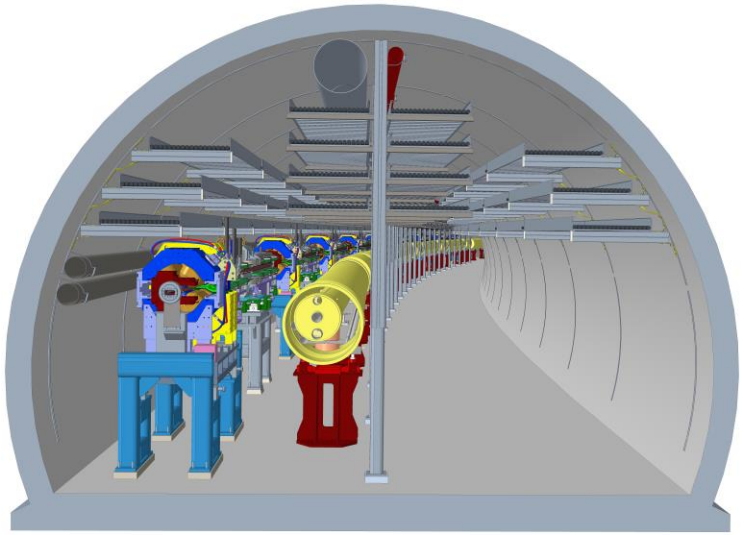


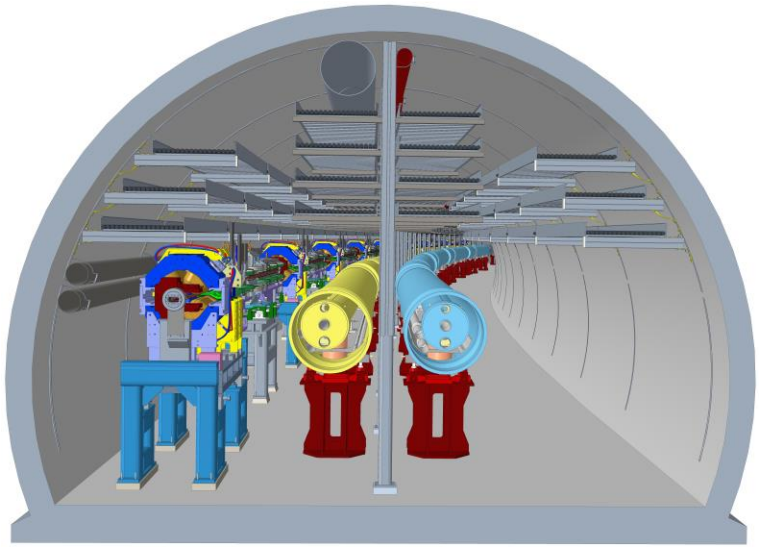
Sectors 1 and 5 now

Sector 5 with a new HSR injection line



Sector 1 without and with the 41-GeV bypass line





RHIC to EIC transition

NPP and EIC ALD's and the directorate working closely

After successful completion of RHIC operations mission change from RHIC operations mode to EIC Construction.

During the transition years: 8-10 years, NPP (C-AD and Physics staff have various responsibilities)

- Help finish RHIC data analyses
- Archive all data (PHENIX, STAR and sPHENIX) for 20+ years
- Staff transition from C-AD/Physics to EIC directorate to realize the EIC and ePIC – in partnership with JLab
- RHIC/EIC Injector complex (source, LINAC, booster, AGS and many RHIC related hardware in that complex) needs to be maintained and kept ready for EIC
- Allow NASA Space Radiation Lab & Isotope Program to continue

All this be done with EIC project plan, despite the annual funding…

Proposal for EIC Science Program in the First Years

Year - 1

Start with Phase 1 EIC
New Capability:
Commission electron polarization in parallel
Run:
10 GeV electrons on 115 GeV/u heavy ion beams (Ru or Cu)
Physics:
Add your preferred science topic

Year - 2

Phase 1 EIC
+ electron polarization
New Capability:
Commission proton polarization in parallel
Run:
10 GeV polarized electrons on 130 GeV/u Deuterium
Physics:
Add your preferred science topic

Run:
Last weeks 10 GeV electrons and 130 GeV polarized protons
Physics:
Add your preferred science topic

Year - 3

Phase 1 EIC
+ electron polarization
+ proton polarization
New Capability:
Commission running with hadron spin rotators
Run:
10 GeV polarized electrons on 130 GeV transverse polarized protons
Physics:
Add your preferred science topic

Run:
Last weeks switch to longitudinal proton polarization
Physics:
Add your preferred science topic

Year - 4

Phase 1 EIC
+ electron polarization
+ proton polarization
+ operation of hadron spin rotators
New Capability:
Commission hadron accelerator to operate with not centered orbits
Run:
10 GeV polarized electrons on 100 GeV Au
Physics:
Add your preferred science topic

Run:
10 GeV electrons on 250 GeV transverse and longitudinal polarized protons
Physics:
Add your preferred science topic

Year - 5

Phase 1 EIC
+ electron polarization
+ proton polarization
+ operation of hadron spin rotators
+ operation of hadron beams with not centered orbits
Run:
10 GeV polarized electrons on 100 GeV Au
Physics:
Add your preferred science topic

Run:
10 GeV electrons on 166 GeV transverse and longitudinal polarized He-3
Physics:
Add your preferred science topic

Time to install additional ESR RF and HSR PS to reach design Current and max. Energies

A proposal for the start of the EIC science program

The ePIC collaboration will fine-tune and adopt the physics

ogram in the First Years

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s with not

Year - 7

Phase 1 EIC
+ electron polarization
+ proton polarization
+ operation of hadron spin rotators
+ operation of hadron beams with not centered orbits
+ operation of ESR & HSR at max. energy and beam currents
New Capability:
Operate HSR with 41 GeV bypass
Run:
5 GeV polarized electrons on 41 GeV transverse polarized proton beams
Physics:
Add your preferred science topic

Physics:
Add your preferred science topic

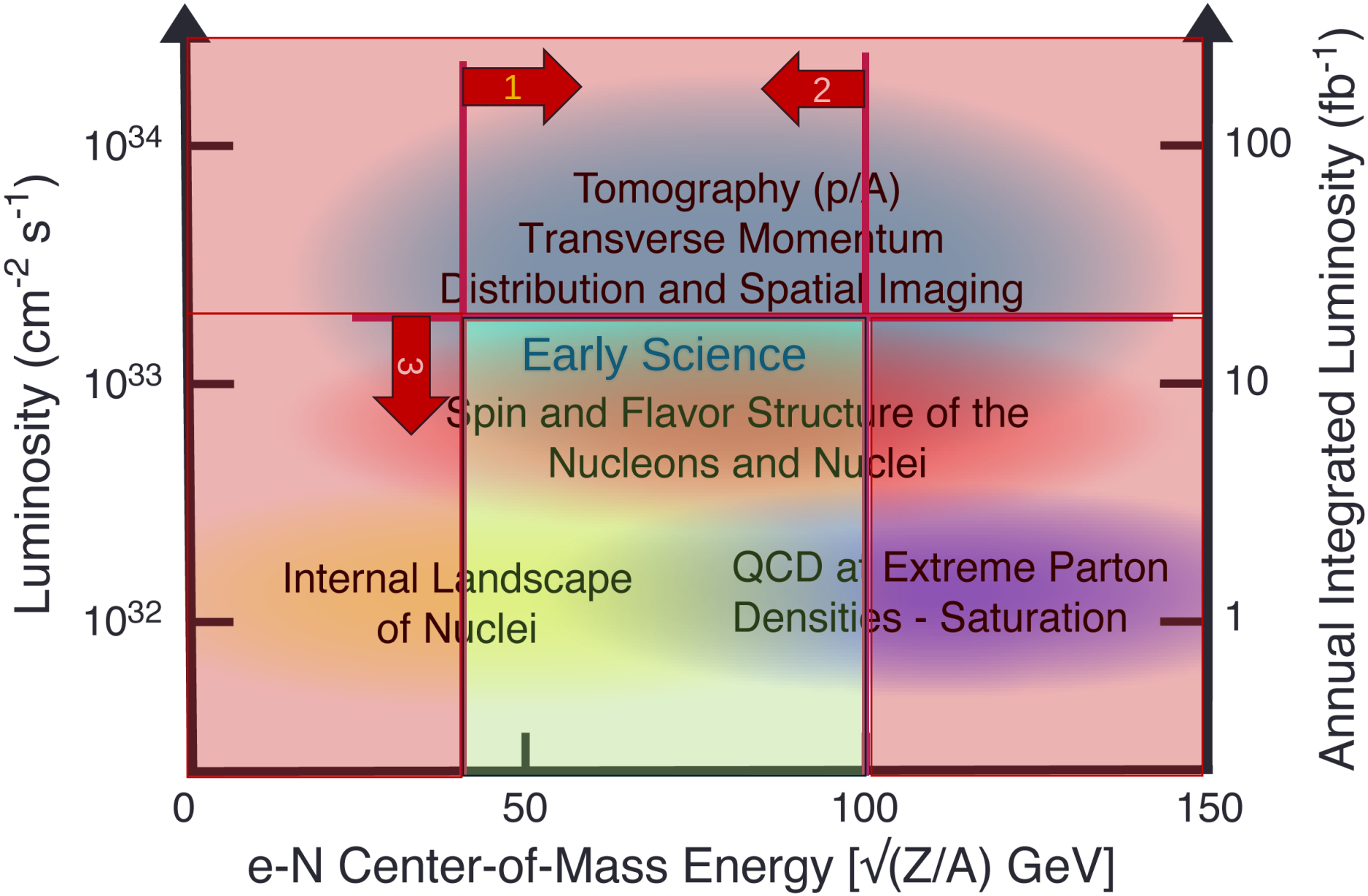
Run:
10 GeV electrons on 166 GeV transverse and longitudinal polarized He-3
Physics:
Add your preferred science topic

New Capability:
Commission ESR & HSR at max. energy and beam currents
Run:
18 GeV polarized electrons on 275 GeV/u polarized (longitudinal & transverse) proton beams
Physics:
Add your preferred science topic

Brookhaven National Laboratory

EIC Early Science Program

All components of the NAS Report Science start in phased Approach



Reasons for limits

Limit 1
Delay of hadron low-energy bypass

Limit 2
Delayed RF for 18 GeV e

Limit 3
Delayed 28 nC and SHC

Physics between RHIC & EIC data taking

Often referred to as the “dark period” – I disagree

A large number of papers will be produced by the RHIC collaborations

Recent lessons from HERA (HERA operation ended in 2006) both H1 and ZEUS archived data well. New (theory) ideas developed since 2006 have been tested and explored using H1 and ZEUS data and hence 2-5 publications a year have started emerging. Expect the same for RHIC in the next 10 and then again when EIC data are available.

Last but not the least: Ample data with polarization and DIS with nuclei will be acquired at JLab12. Ample opportunity for RHIC (& LHC) and Jlab users to collaborate on such novel cross correlating topics

From RHIC to EIC: Outlook

A hectic time but an exciting time as we move towards the EIC

The phase 1 EIC – impactful early results, will prepare us for the ultimate machine and its physics

Lot of work of transition, construction and commissioning

Let us try to keep the “transition” period as short as possible but also recognize that this is also the time of large QCD data sets to be analyzed both at RHIC and JLab