Brookhaven National Laboratory

U.S. Department of ENERGY

From RHIC to EIC

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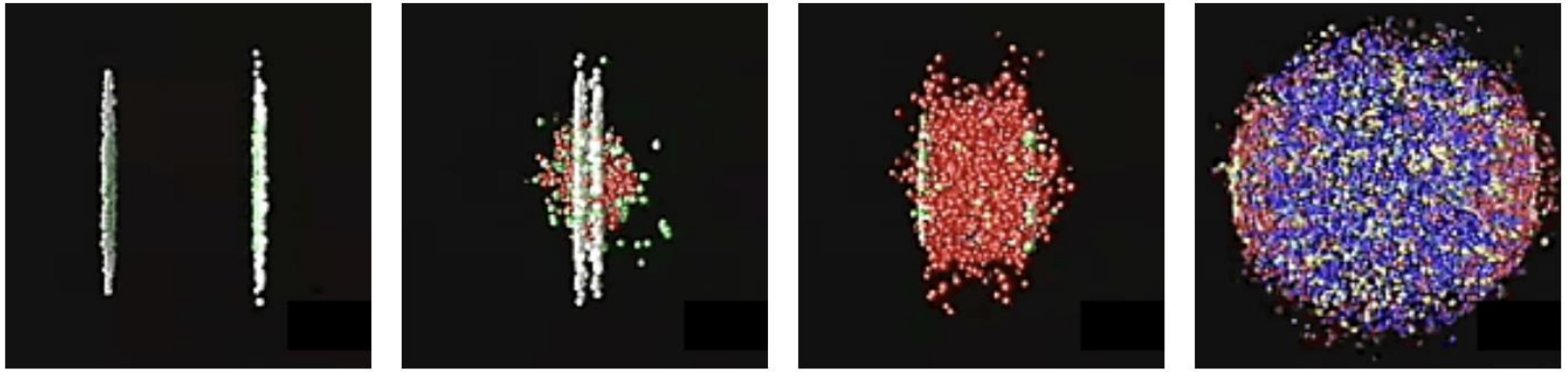
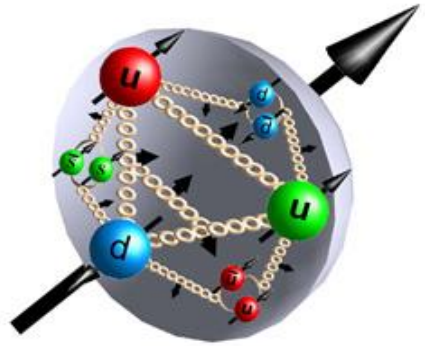
Research at the Relativistic Heavy Ion Collider

- Heavy ion collisions at RHIC
  - Discovered a new state of matter: **Quark Gluon Plasma**
  - Detailed studies with collision of different ion species



Hottest matter observed in the Universe

- Polarized proton collisions
  - Only collider in the world of spin polarized protons to explore the internal spin structure of protons.
  - How do protons get the property of “spin”? (used in MRI’s)
- The most advanced & versatile accelerator to date



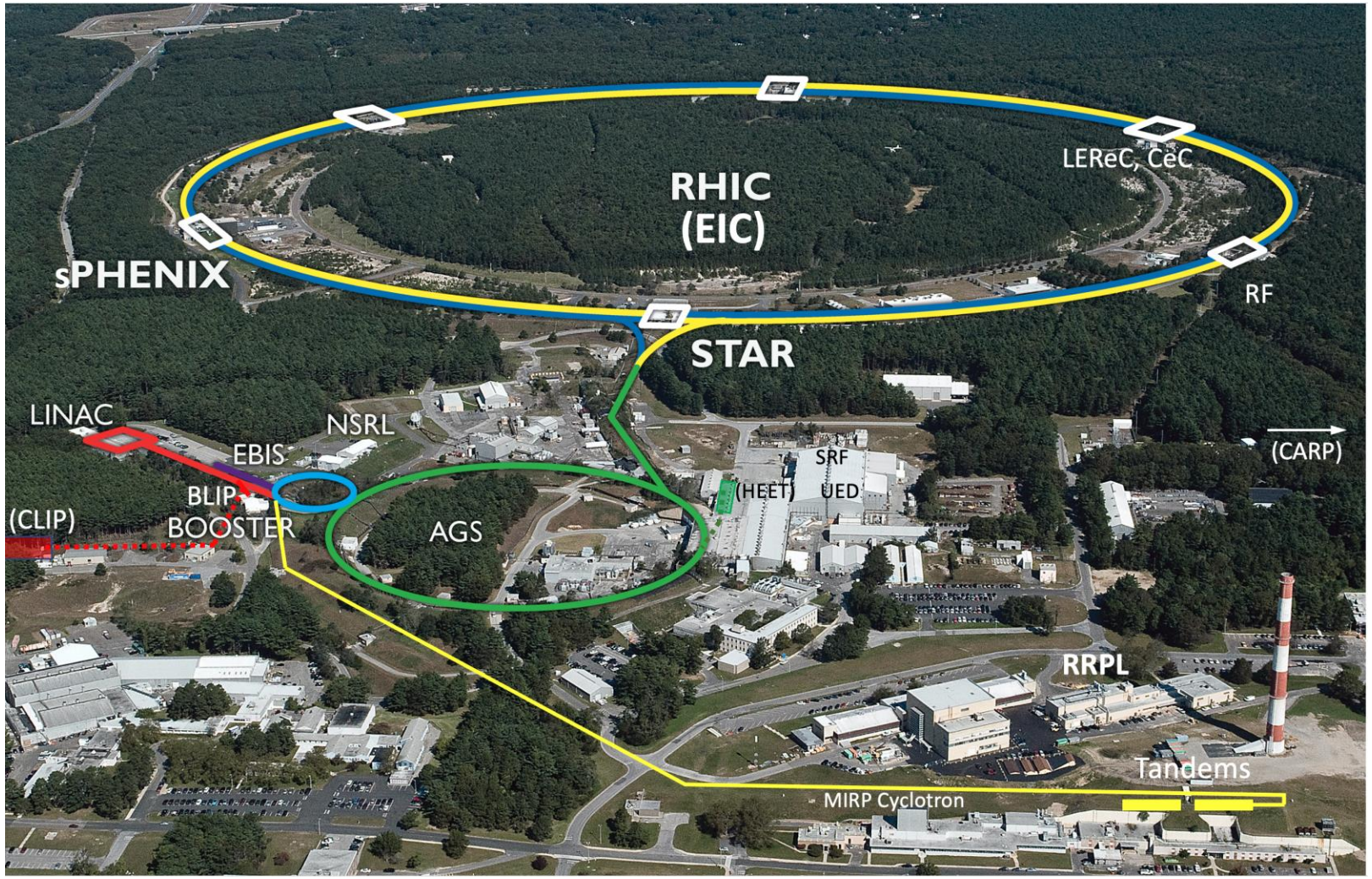
Relativistic Heavy Ion Collider (RHIC)

Basic scientific research woven with direct benefits to society

Uniquely flexible and only hadron collider in US for exploration of Quark Gluon Plasma and proton structure

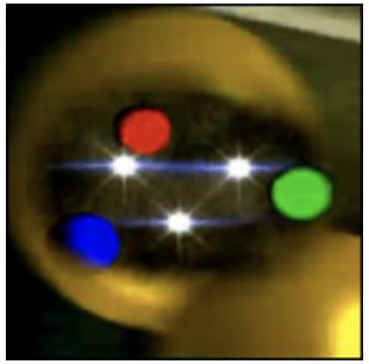
Injectors also used for application programs:

- **LINAC**: Brookhaven Linear Isotope Producer: (medical and other Isotope production)
- **Booster** NASA Space Radiation Lab for space radiation studies
- **Tandem** for industrial/academic users
- **R&D for future facilities and application** sources, beam cooling, polarized beams, …

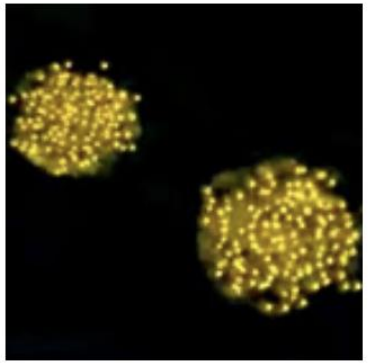


A New Area of Physics

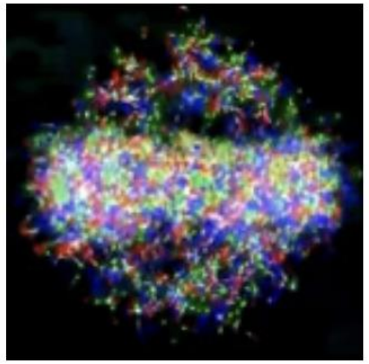
RHIC has created a new state of hot, dense matter out of the quarks and gluons that are the basic particles of atomic nuclei, but it is a state quite different and even more remarkable than had been predicted. Instead of behaving like a gas of free quarks and gluons, as was expected, the matter created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



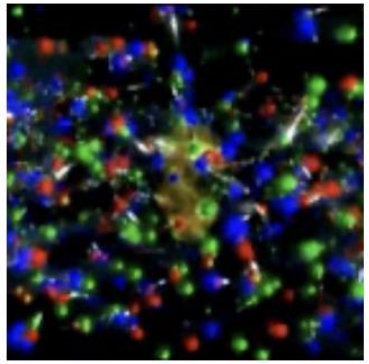
Gluons and quarks



Ions about to collide

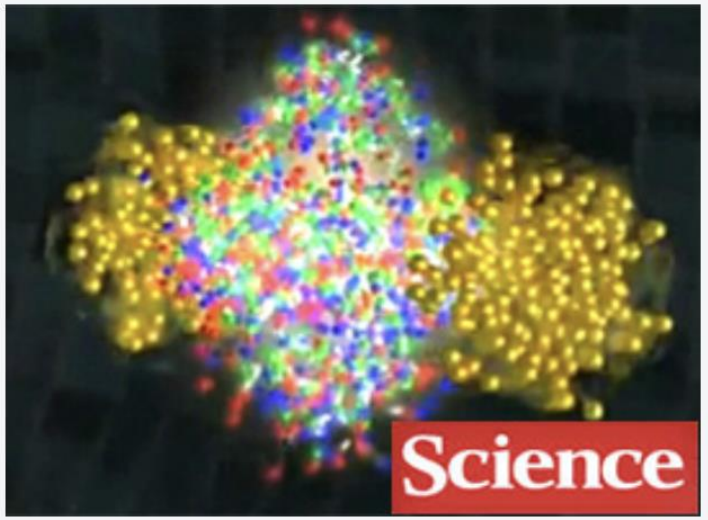


Just after collision



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.

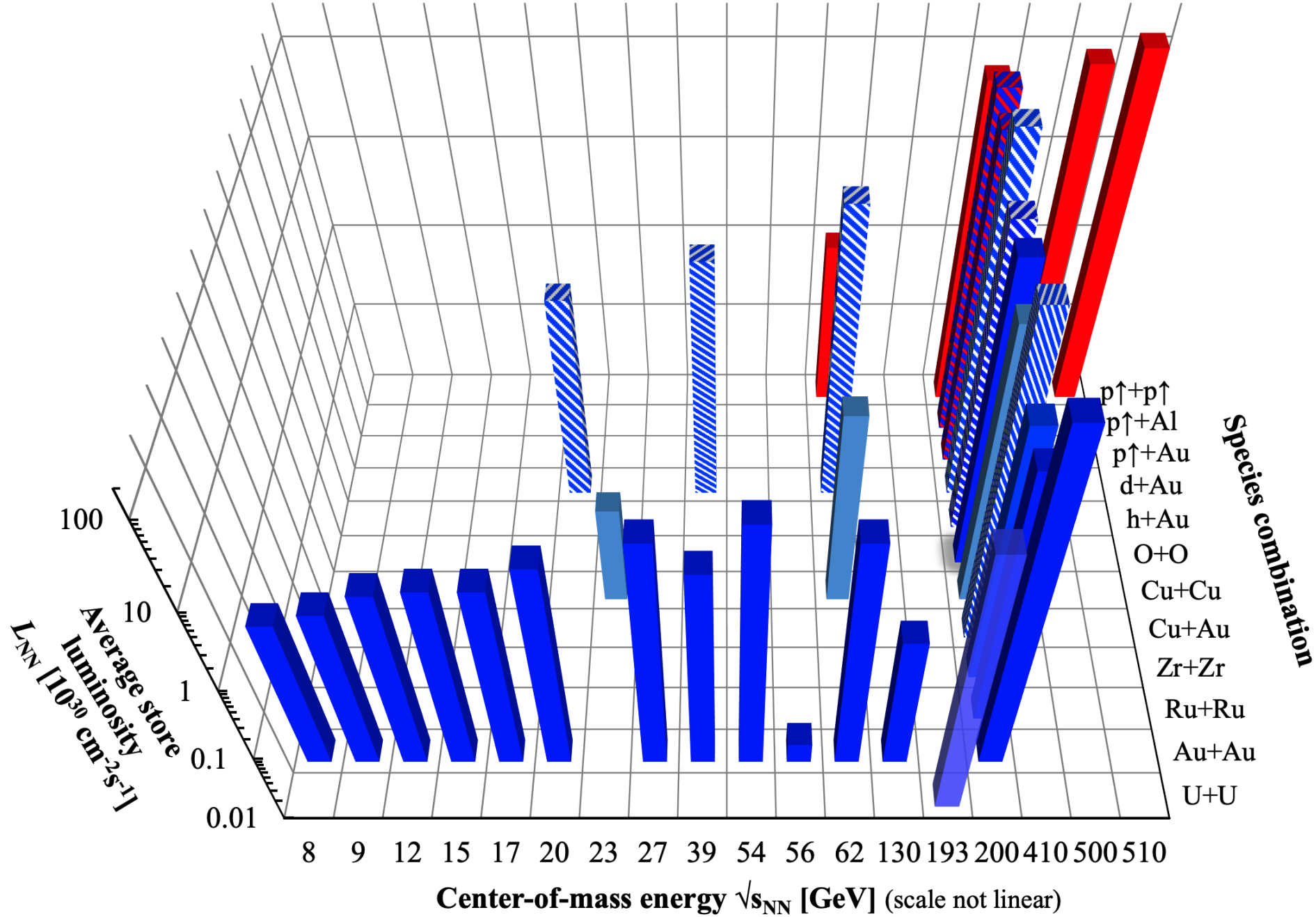
Abstract | Reprint | Full Text | BNL release

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

Recent highlights from RHIC

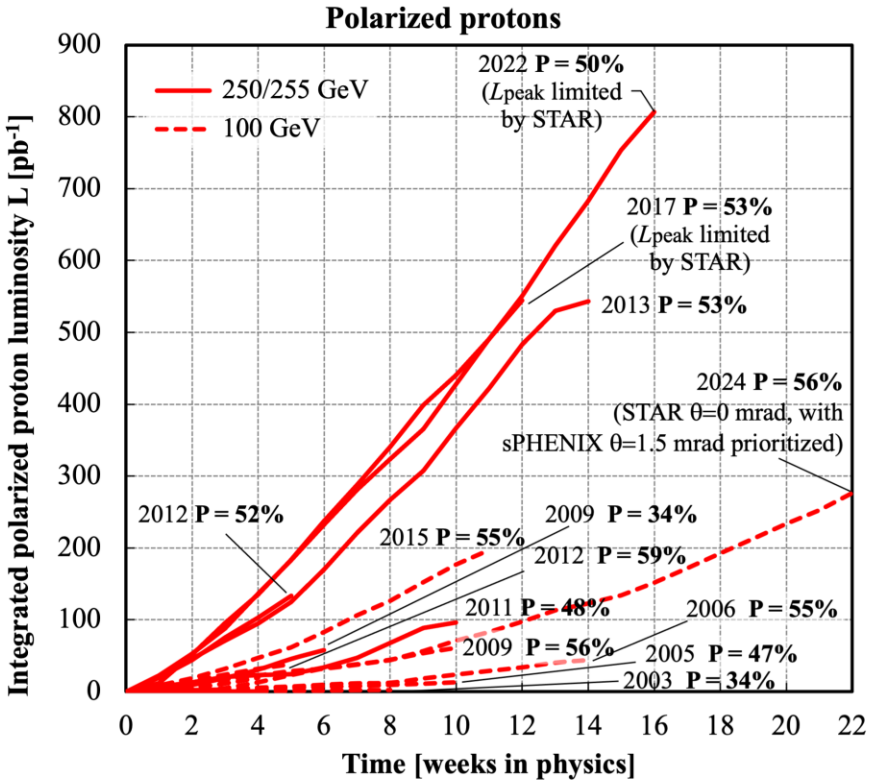
Brookhaven National Laboratory

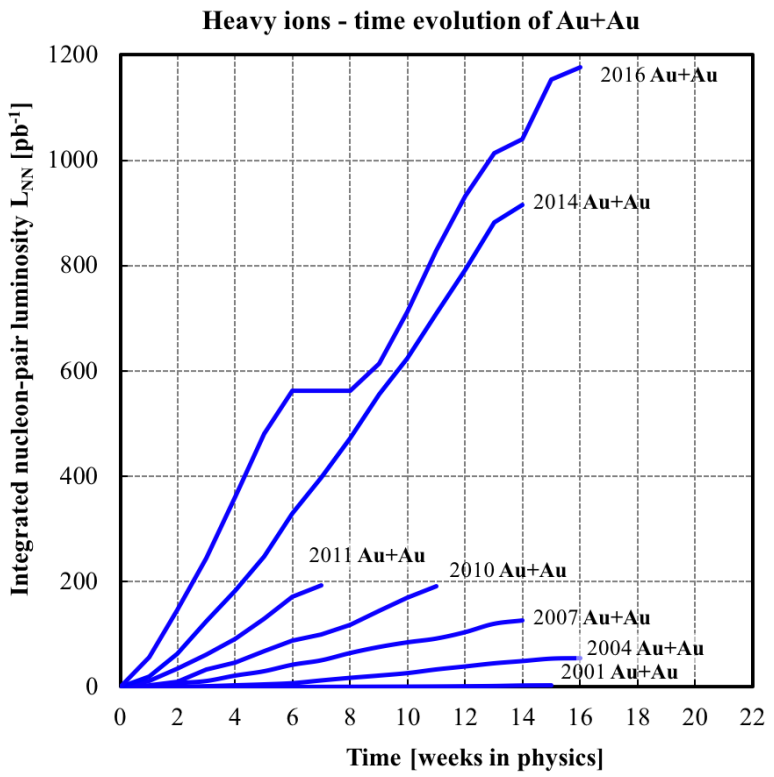
RHIC energies, species combinations and luminosities (Run-1 to 24)

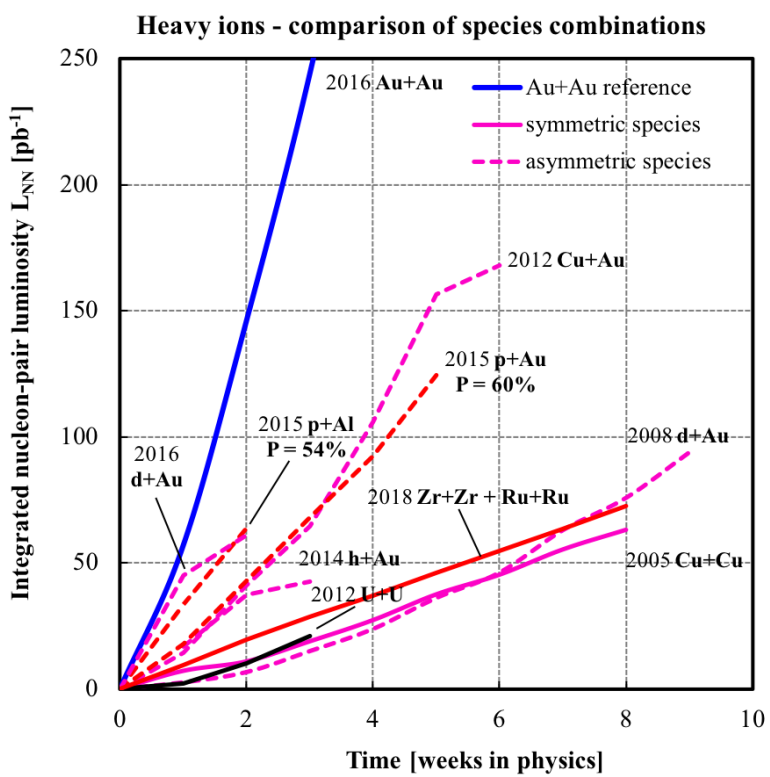


RHIC Integrated Luminosity

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





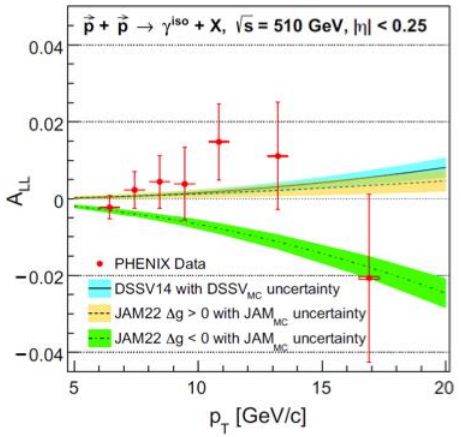


PHENIX Selected Science Highlights

Direct photon A_{LL}

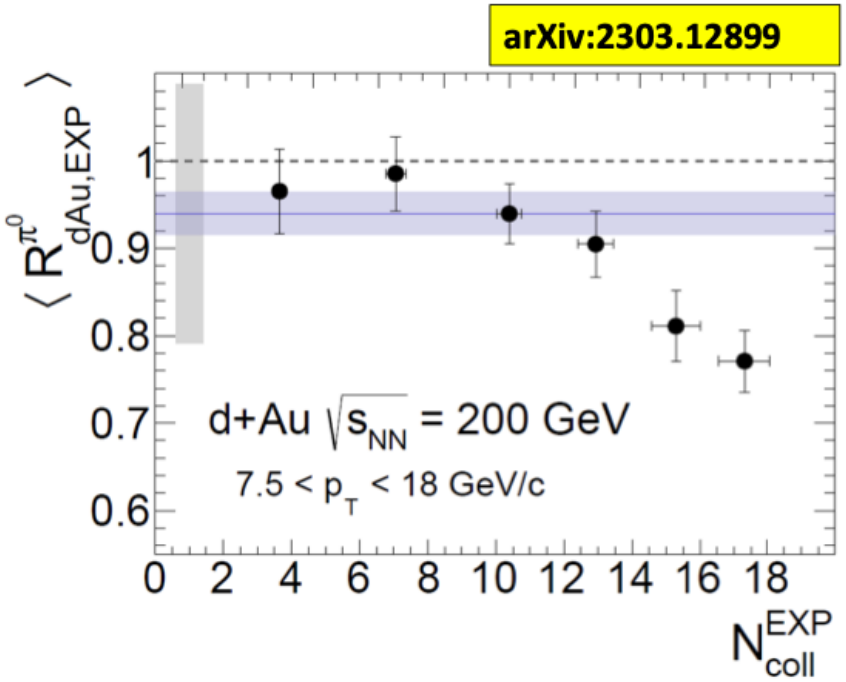
PHYSICAL REVIEW LETTERS **130,** 251901 (2023)

Measurement of Direct-Photon Cross Section and Double-Helicity Asymmetry at $\sqrt{s} = 510$ GeV in $\vec{p}+\vec{p}$ Collisions



One of the original motivations for RHIC SPIN program, (only) now established directly polarized gluon distribution is positive. Press releases at BNL and RIKEN and US DOE Science news (highlights)

π^0 and direct photons (γ) in d-Au
π^0 suppressed relative to γ
Evidence in most central collisions



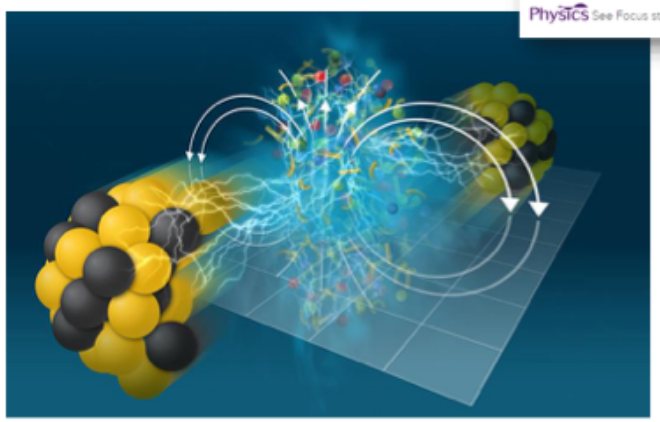
Recent Highlights from RHIC

Featured in Physics | Open Access

Observation of the Electromagnetic Field Effect via Charge-Dependent Directed Flow in Heavy-Ion Collisions at the Relativistic Heavy Ion Collider

M. I. Abdulhamid *et al.* (STAR Collaboration)
Phys. Rev. X **14**, 011028 – Published 23 February 2024

Physics See Focus story: Colossal Magnetic Field Detected in Nuclear Matter



- Results in central collisions can be explained by transported quark effect
- Results in peripheral collisions reveal the contributions from Faraday induction and Coulomb effect for the first time in heavy-ion collisions

PHYSICAL REVIEW LETTERS

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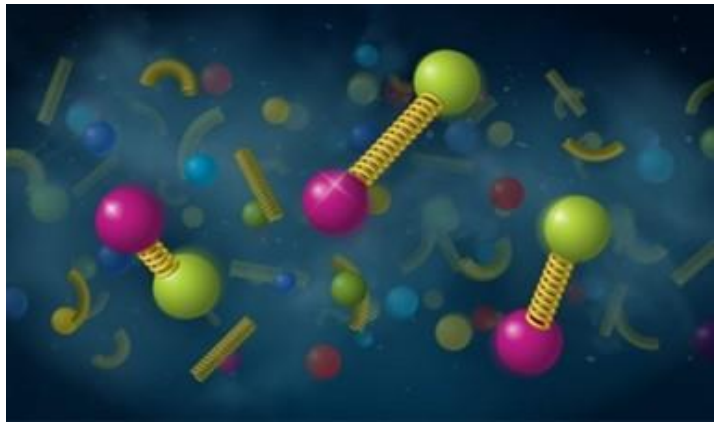
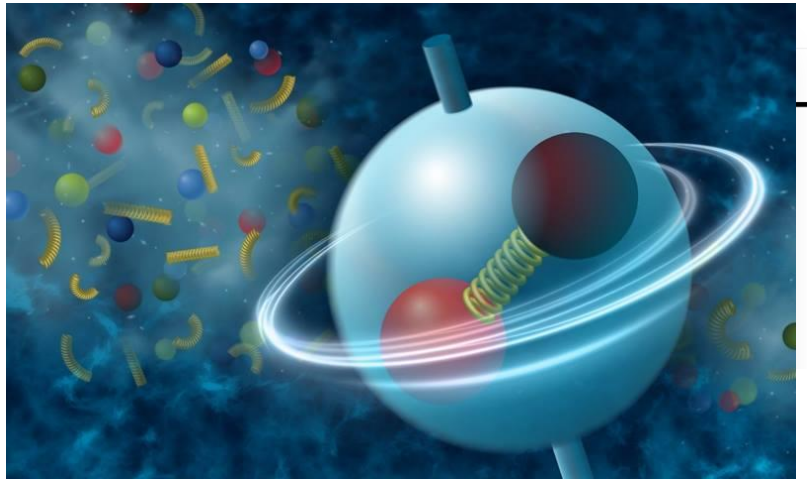
Measurement of Sequential Υ Suppression in $\mathrm{Au} + \mathrm{Au}$ Collisions at $\sqrt{s_{NN}} = 200$ GeV with the STAR Experiment

B. E. Aboona *et al.* (STAR Collaboration)
Phys. Rev. Lett. **130**, 112301 – Published 14 March 2023





nature

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Article | Published: 18 January 2023

Pattern of global spin alignment of φ and K^{*0} mesons in heavy-ion collisions

STAR Collaboration

Nature **614**, 244–248 (2023) | Cite this article

Also accessible as DOE Highlights

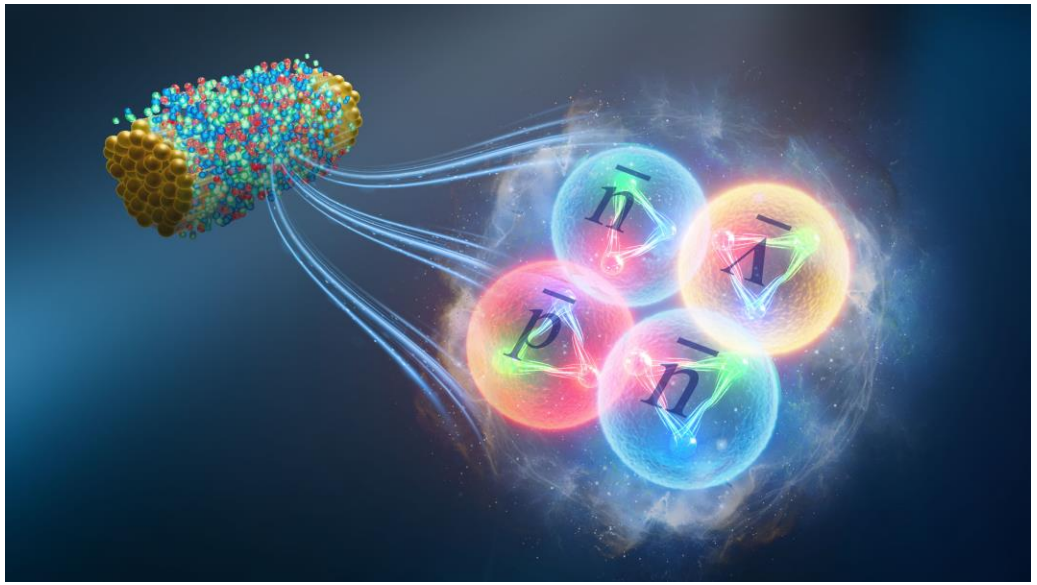
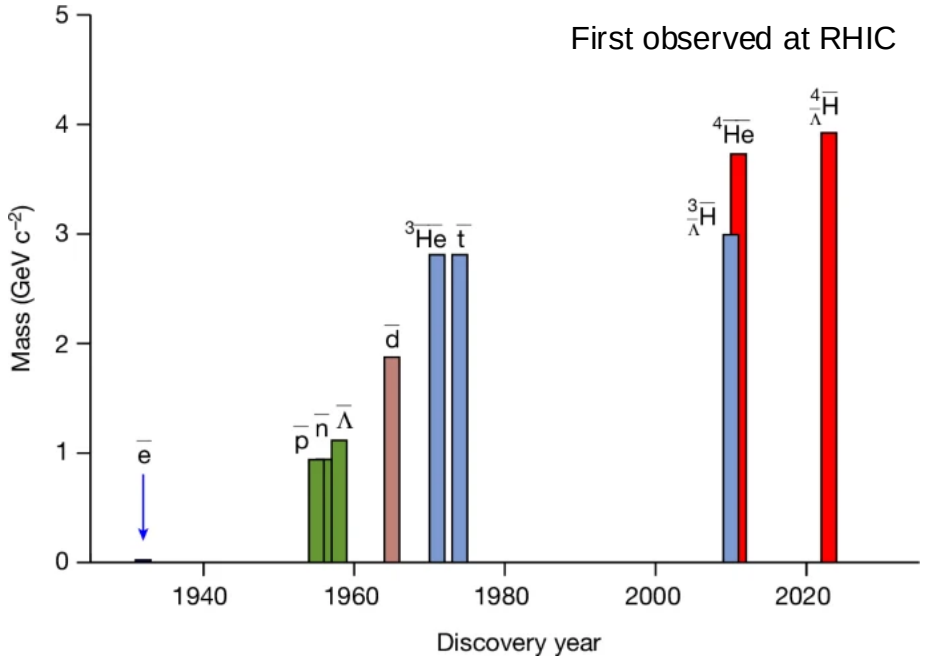


Fig. 1: Masses versus discovery years of selected antimatter particles.



nature

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Terminal

nature › articles › article

Article | Published: 21 August 2024

Observation of the antimatter hypernucleus $_{\bar{\Lambda}}{}^{4}\bar{\mathrm{H}}$

STAR Collaboration

Nature (2024) | Cite this article

Observation of the heaviest antimatter nucleus to date

Relativistic Heavy Ion Collider:

- Also serves as an antimatter creation machine
- 3 first observations to date

Enables fundamental tests of matter-antimatter symmetry by comparing properties such as lifetime

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

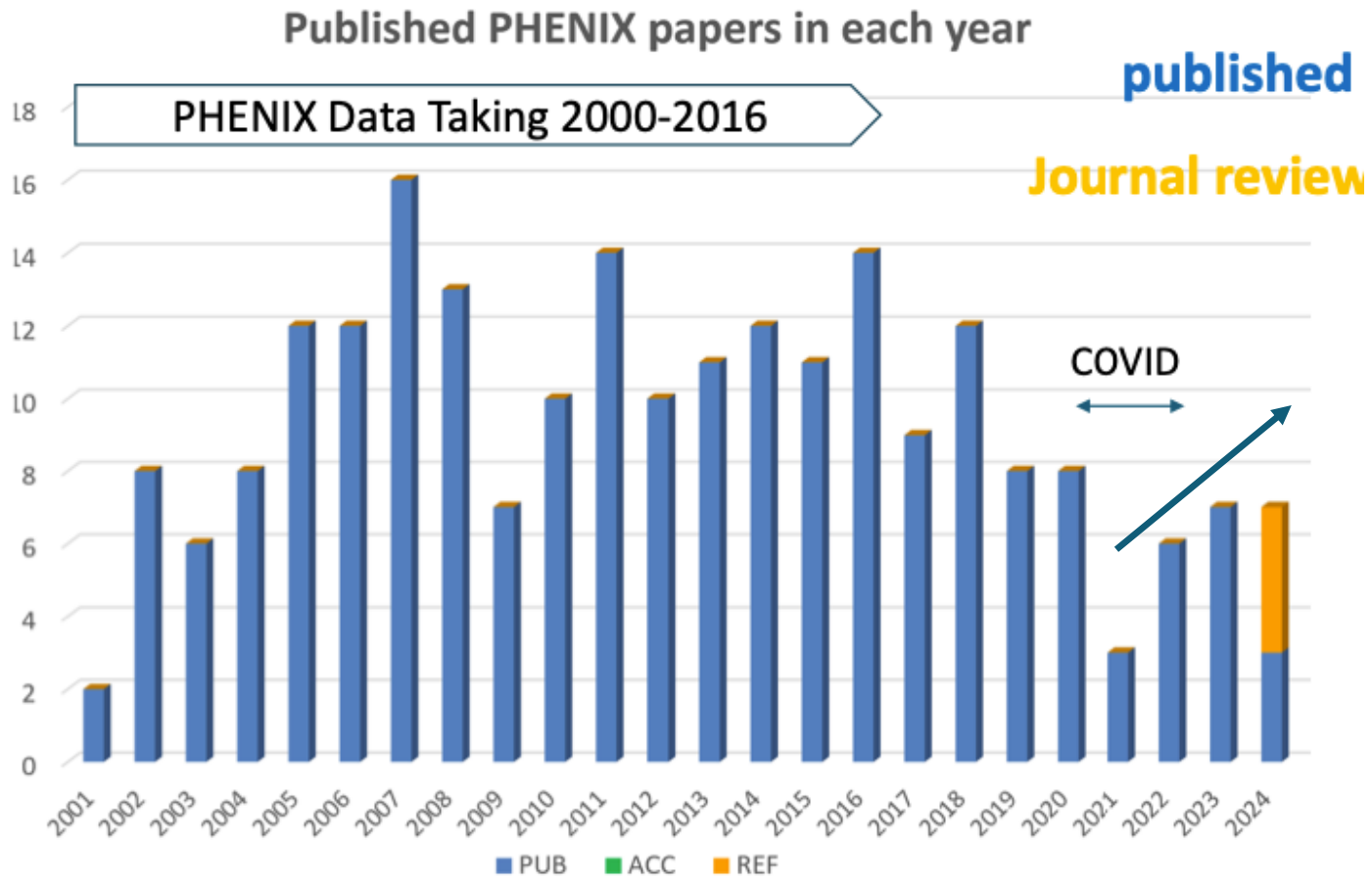
Jet quenching discovery: 1220 cites

PID hadron in AuAu: 1015 cites

Nature P paper: 304 citations

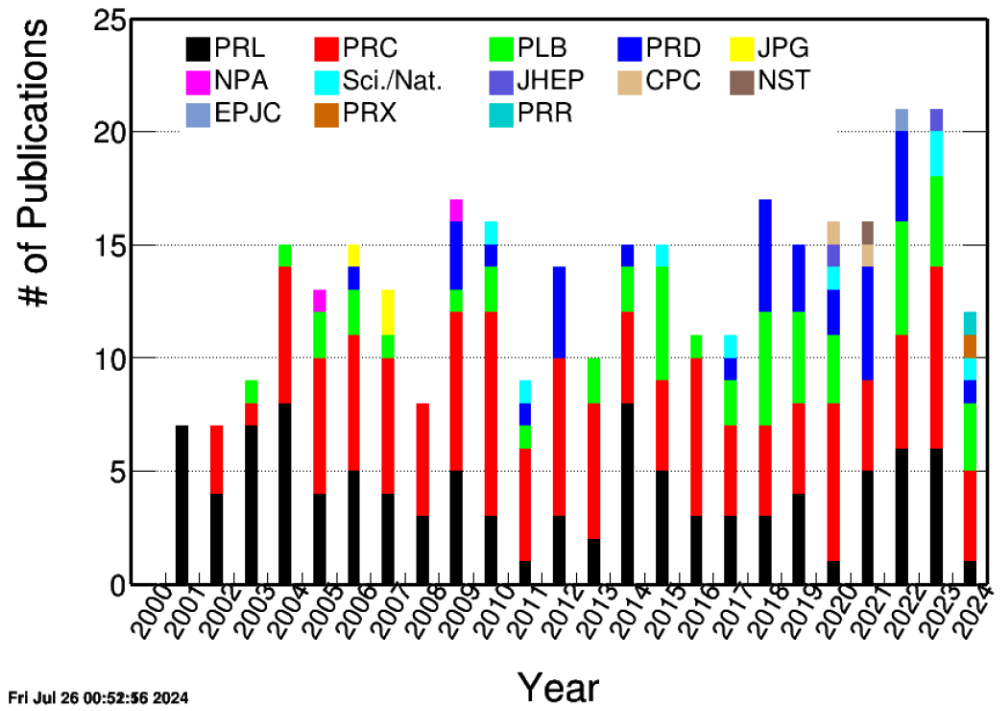
143 physics papers in topcite 50+

(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.

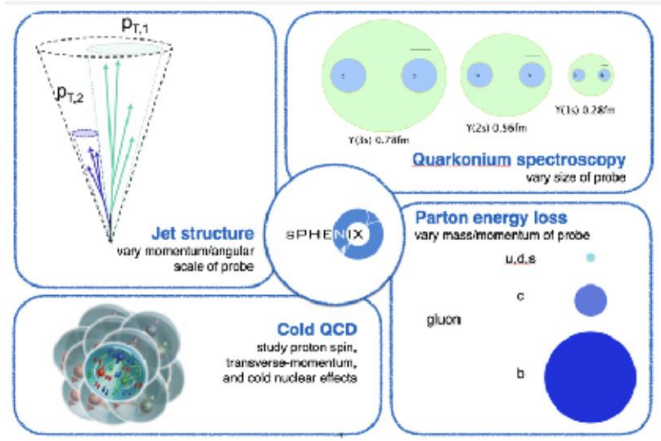
- **2023**: 21 published 6 PRL, 8 PRC, 4 PLB, 2 Sci/Nat, 1 JHEP
- **2024**: 12 published + accepted: 1 PRL, 4 PRC, 3 PLB, 1 PRD, 1 Nat, 1 PRX, 1 PRR

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

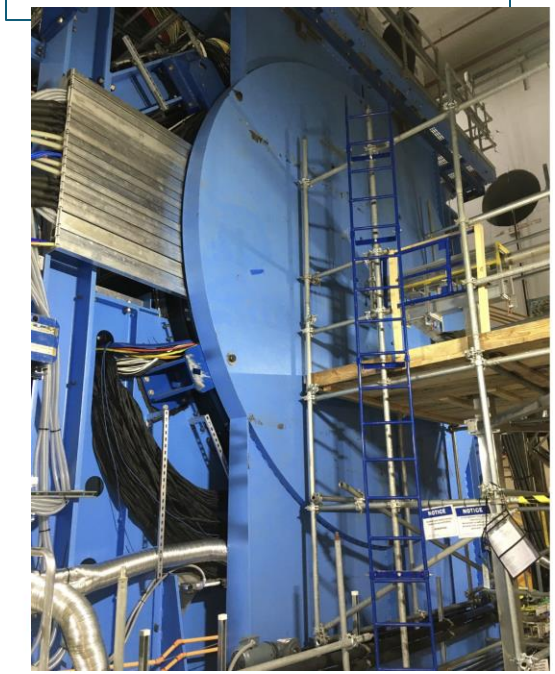
99% of STAR papers uploaded to HEPData, remaining 2 papers are newer and on track to be uploaded soon

Continued steady growth in citations

sPHENIX science, status and progress

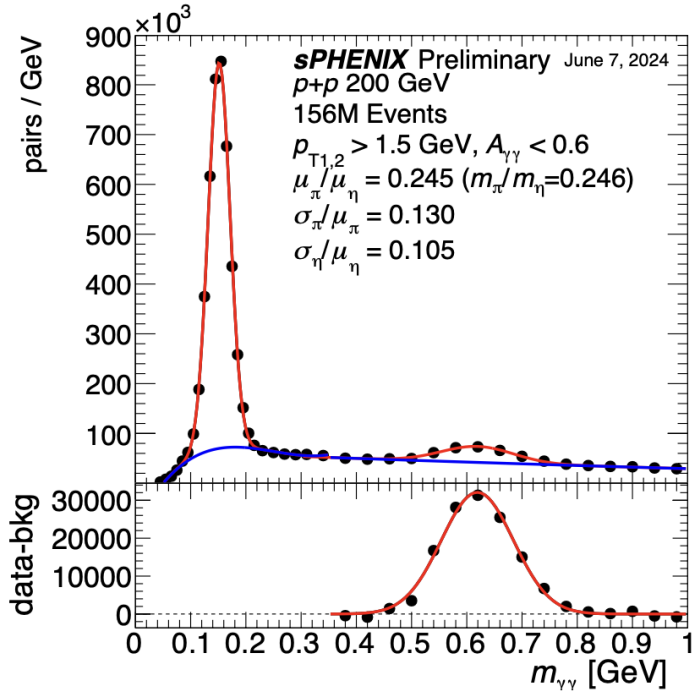


Detector completed in time for Run 23



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 & run cut short by DX magnet failure

- Limited luminosity |z| < 10 cm
- Time Projection Chamber unstable

Run 24:

- Late start of Run 24 requested
- Significant work MVTX, TPC
- Allowed 20 weeks of p-p and 5-weeks with Au-Au collisions

First physics results at QM2025

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 Operations mission

Run 25 and 26 in calendar year 2025

FY25: Run 25 (18) weeks of Au+Au at 200 GeV

FY26: Potential Run 26 ~12 weeks

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

Aim: 1) To accumulate 7 nb^{-1} integrated Au-Au data, 2) EIC (APEX ~3 weeks) and the if there is time**: 3**) p-p (? Weeks) 4) p-Au (~3-weeks) 5) O-O data 6) Space Radiation studies @ STAR (fixed tgt)

RHIC PAC meeting online planned June 17-18, 2025 to discuss the run status and give the best advice for the remaining RHIC operation

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,

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

All this be done with the EIC Project plan, despite uncertainties in annual funding…

From RHIC to EIC: Outlook

RHIC operations mission expected to complete in 2025

Transition to EIC will start immediately: Removal & Repurposing (both for accelerator complex, interaction region and experiments)

Let us work *together* try minimize the RHIC to EIC “transition” as short as possible