Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Report from Brookhaven National Laboratory

Haiyan Gao

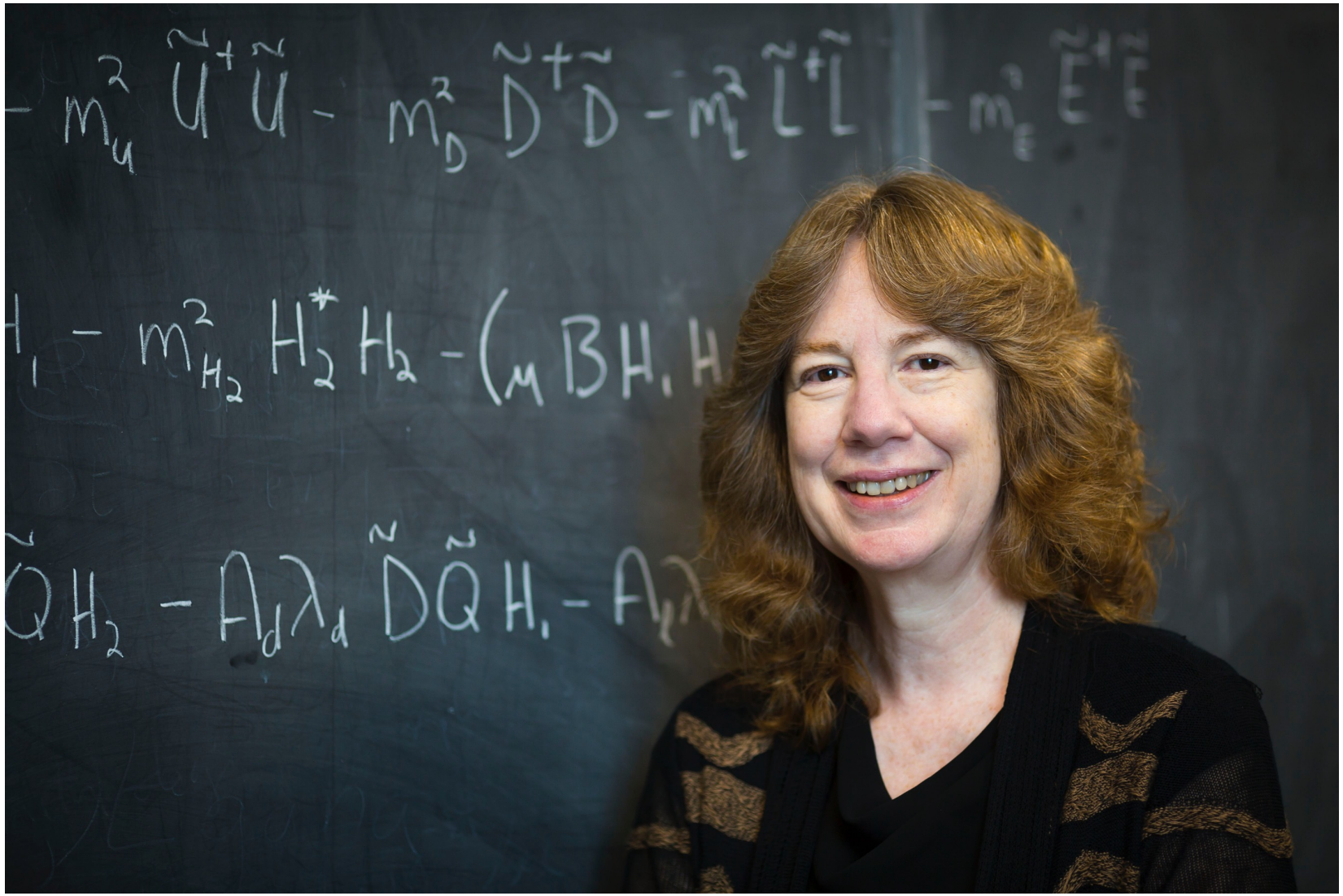
Nuclear and Particle Physics

April 12, 2023

GHP Business Meeting

@BrookhavenLab

JoAnne Hewett Named Director of Brookhaven National Laboratory



Brookhaven National Laboratory

Brookhaven Lab: A Multi-purpose DOE Office of Science Lab

Managed by Brookhaven Science Associates

- Partnership between Stony Brook University and Battelle Memorial Institute
- Core universities: Columbia, Cornell, Harvard, MIT, Princeton, Yale

People

- 2,800 staff, 130 joint faculty, 500 students (FY22)
- 166 summer interns remotely; 189 in person (FY22)
- ~4,400 guests/users, including remote (FY22)
- >30,000 (K-12) students and educators annually (pre-COVID)
- 7 Nobel Prizes; 21 Laureates

Budget

- FY22 costs: $704 million
- Strongly aligned to SC (86%) and to DOE (91%)
- DOE-NP is the largest program (user facility RHIC)

Regional Economic Impact

A Few of BNL's Employee Resource Groups

Brookhaven National Laboratory

Selected Recent DEIA Initiatives and Activities

- Brookhaven makes the Top 20 Government Employer List for 2023 in the 32nd Annual Equal Opportunity Magazine; BNL is a member of the APS Bridge Program (contacts: Noel Blackburn, David Jaffe, Lijuan Ruan)

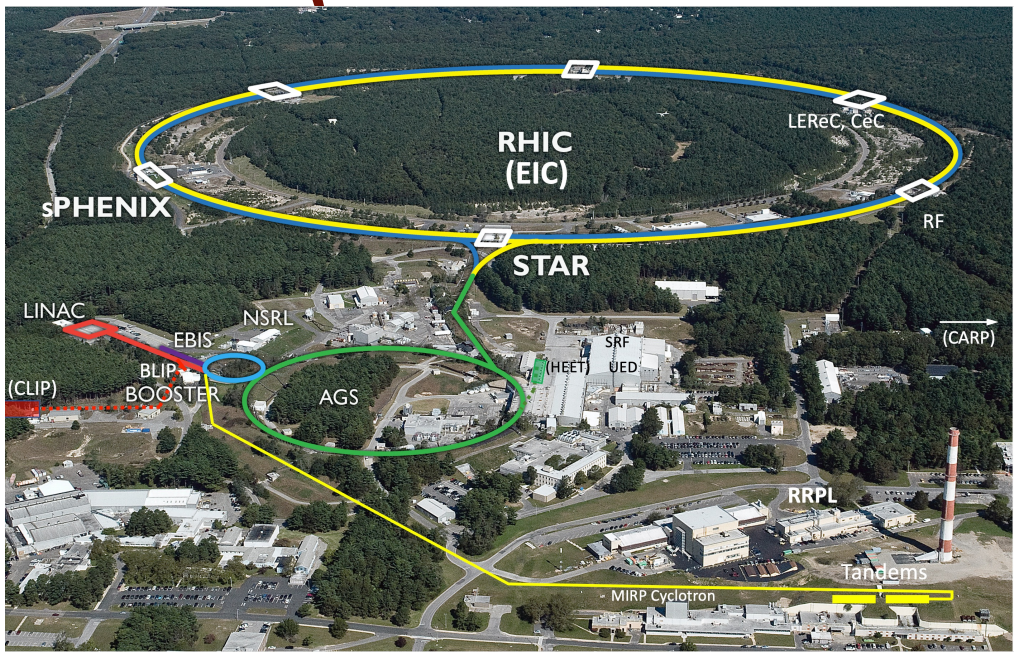
- The NPP DEI Council has been leading many initiatives and activities (e.g., Code of Conduct & Hiring Practice Recommendations (report shared broadly)

- Pipeline – Nuclear Physics traineeship & summer school programs
  - **Funded by the DOE-ONP NPT supported 8 URM students onsite summer 2022 (PI: Mickey Chiu)**
  - **NuSTEAM - Nuclear Science in Texas for the Enhancement and the Advancement of Minorities (9 students onsite 2022)**
  - **Held summer school in nuclear and radiochemistry onsite 2022**

- Collaborations with many MSIs on RENEW and FAIR proposals; summer workshop with MSIs funded by program development; BNL@NCA&T day April 19-20, 2023, Greensboro, NC

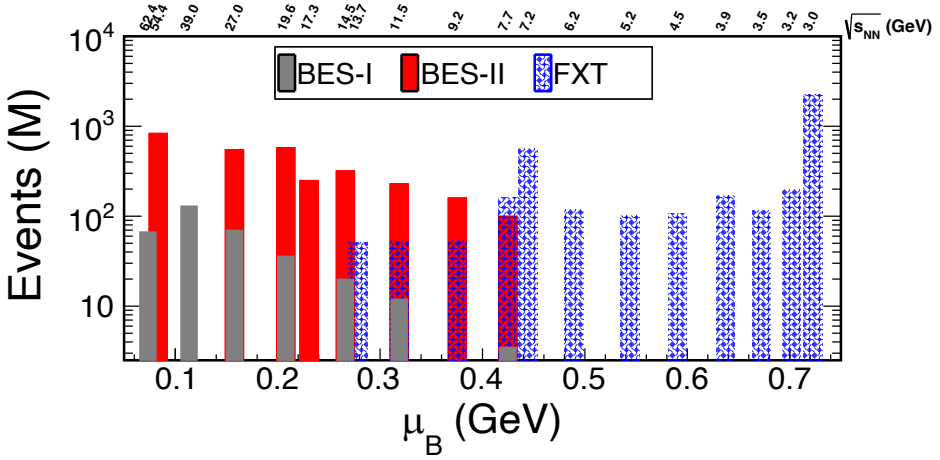
Complete RHIC Science Mission (2015 NSAC LRP)

"There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX.** (2) **Map the phase diagram of QCD with experiments planned at RHIC." (completed data taking in 2021)**



Run 2021: last, lowest (~40% of nominal injection energy), and most difficult colliding Au+Au BES-II energy –second year with low-energy electron cooler (LEReC)

Exceeded STAR data taking goals



Brookhaven National Laboratory

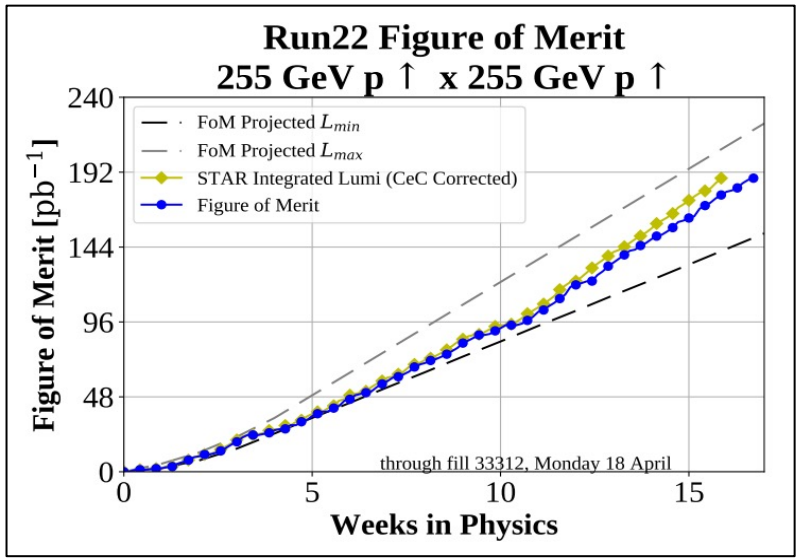
Major Science and Facility Accomplishments

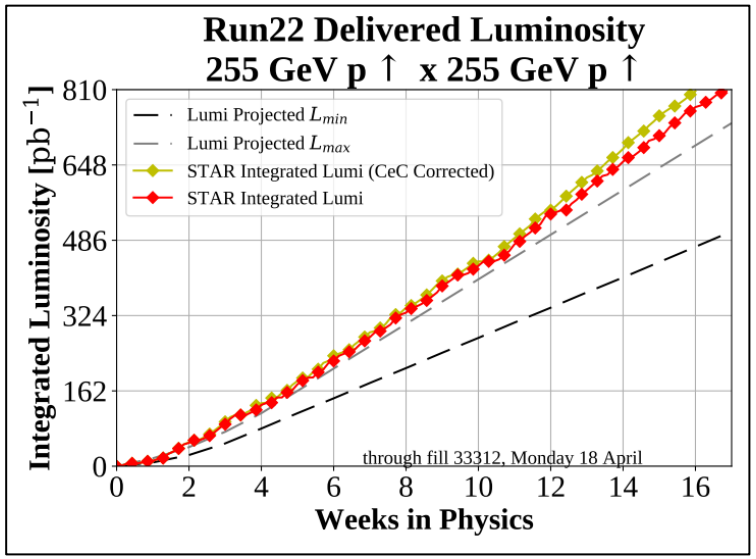
- Successful completion of RHIC Run 2022 despite many challenges and achieved STAR goals thanks to the two-week extension
- sPHENIX MIE achieved PD-4 approval – the first DOE SC laboratory delegated project completed on time and on budget despite COVID impact
- STAR forward upgrade detectors employed in Run 2022 successfully
- SDCC provides smooth computing for RHIC and moved into new building
- The STAR collaboration continues with excellent record of publishing high-impact papers
- The PHENIX collaboration continues with good publication record and important results including $\psi(2S)$ suppression in p+Al, and p+Au and low P_T direct photon production
- The Nuclear Theory Group has been highly productive in all aspects

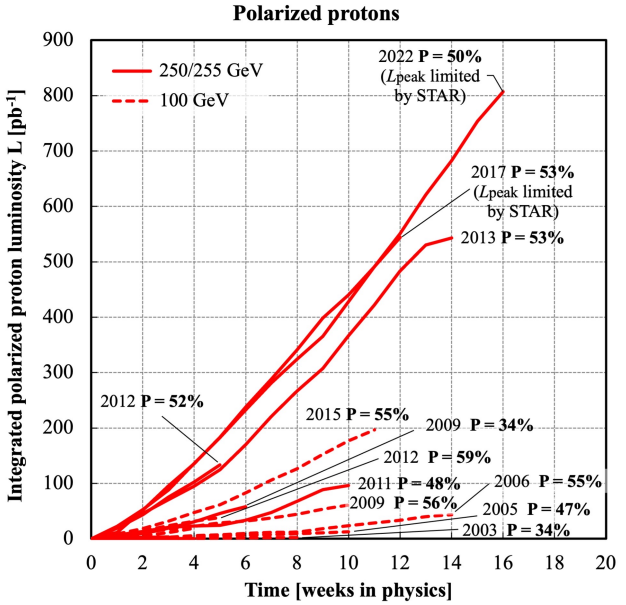
RHIC Run 2022

Goals Run Coordinator: Vincent Schoefer **2-week extension made a huge impact!**

- p↑+p↑ polarized proton collisions at full energy (~508 GeV c.o.m.) with new STAR forward detector upgrade
  - forward program: 107%, exceeding the goal
  - mid-rapidity: ~98%, achieving the goal
- Demonstration of Coherent electron Cooling (CeC-X)
  - demonstrated Plasma Cascade Amplification (PCA) with high gain, which is a prerequisite for cooling, however demonstration of coherent electron cooling was not achieved



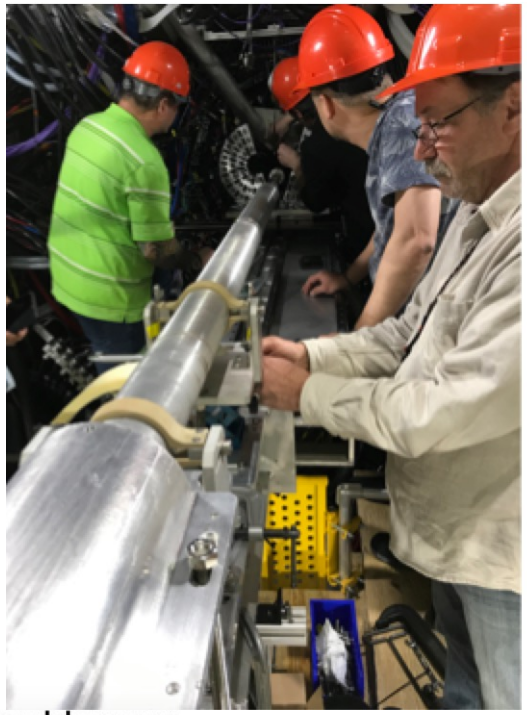




sPHENIX Highlights

- sPHENIX MIE PD-4 Approval achieved in December 2022
- sPHENIX ribbon cutting event attended by Drs. Berhe and Chan
- sPHENIX installation is nearly complete
- sPHENIX Internal Readiness Review April 5-7
- RHIC cooldown will start early May, 2023 for Run 2023

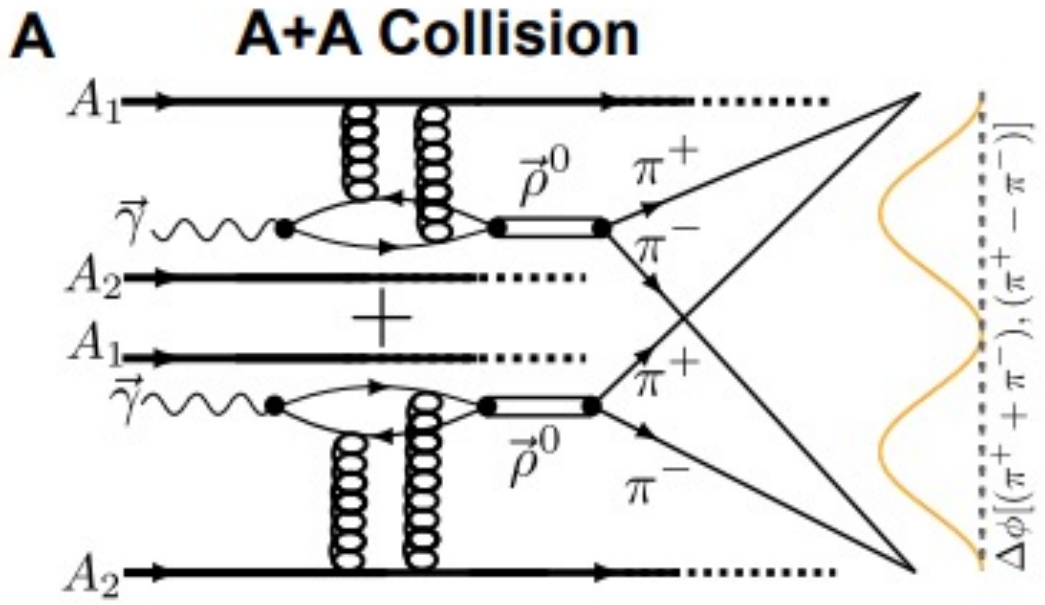
Byron Golden (C-AD, vacuum group)

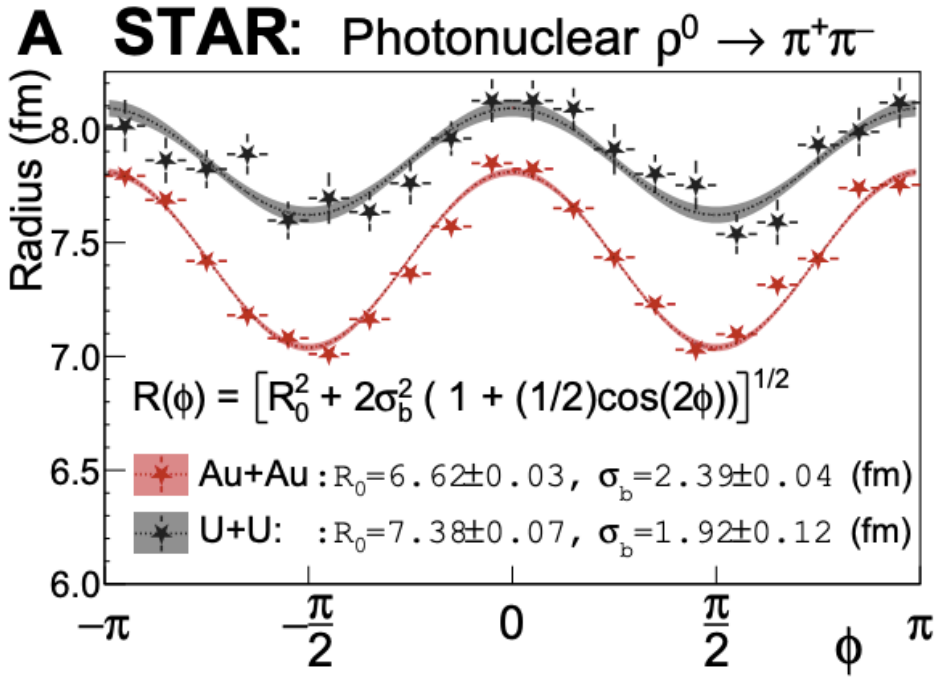


Drs. Berhe and Chan with the sPHENIX project team

Brookhaven National Laboratory

Tomography of Ultra-relativistic Nuclei with Gamma + A Collisions





Quantum interference enabled nuclear tomography:

- A novel approach to extract the strong-interaction nuclear radii, which were found to be larger than the nuclear charge radii

2204.01625, Science Advances 9 (2023) 3903

Global spin alignment of vector mesons

Λ-like (-10^{-5})

Electric field (10^{-5})

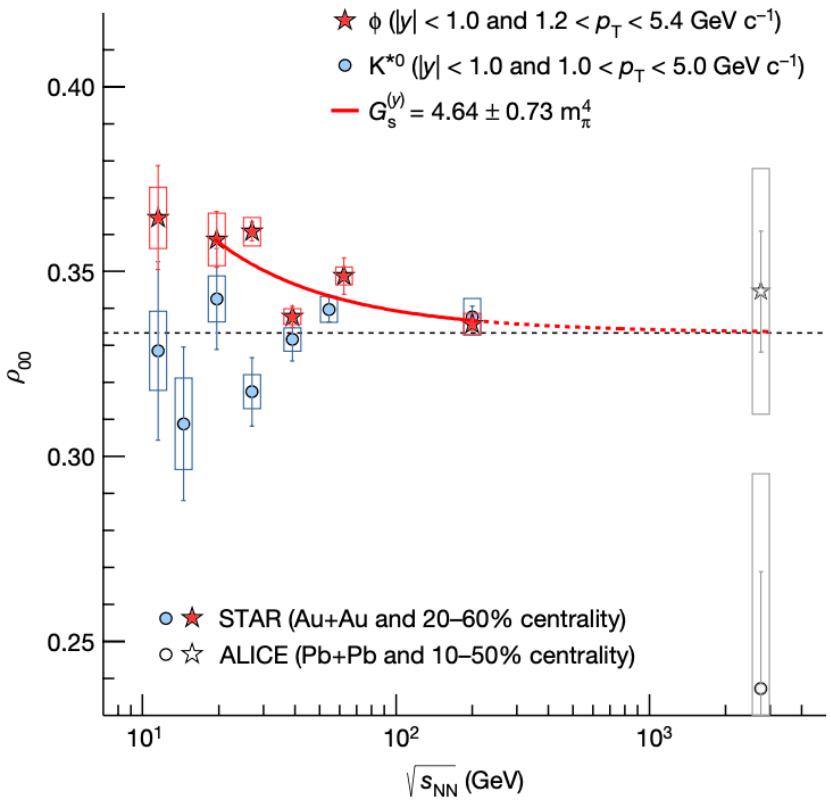
$$\rho_{00}(\phi) \approx \frac{1}{3} + c_\Lambda + c_\epsilon + c_E + c_\phi;$$

Vorticity tensor (-10^{-4})

Vector meson field

Surprising pattern observed:

ϕ–meson $\rho_{00} > 1/3$ by 7.4σ



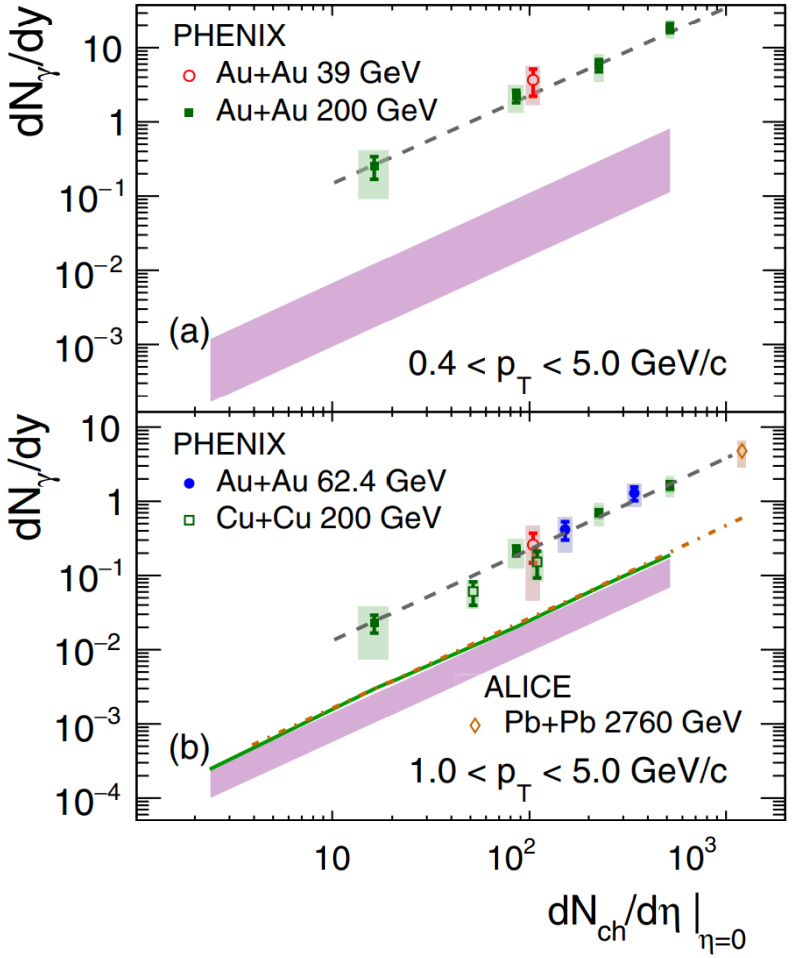
Possible explanation with a strong vector meson field;

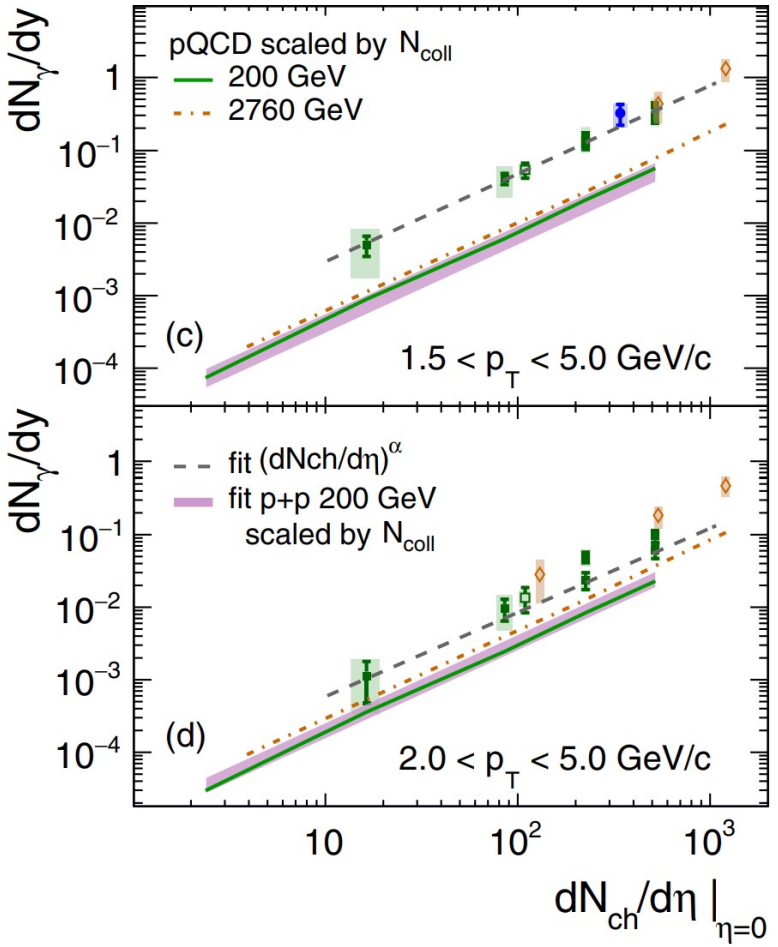
Provides a potential new avenue for understanding the strong interaction at work at the subnucleon level

2204.02302, Nature 614 (2023) 244

Brookhaven National Laboratory

Low pT direct photon at 39 and 62 GeV





arXiv:2203.12354 (2022),
PRC **107**, 024914 (2023)

- Systematic study of low p_T direct photon production at 39 and 62 GeV and comparison with higher collisions energy
- Photon yield scaled with $dN/d\eta$ for all systems
- PRC Editor's suggestion

Scientific Data and Computing Center and NP

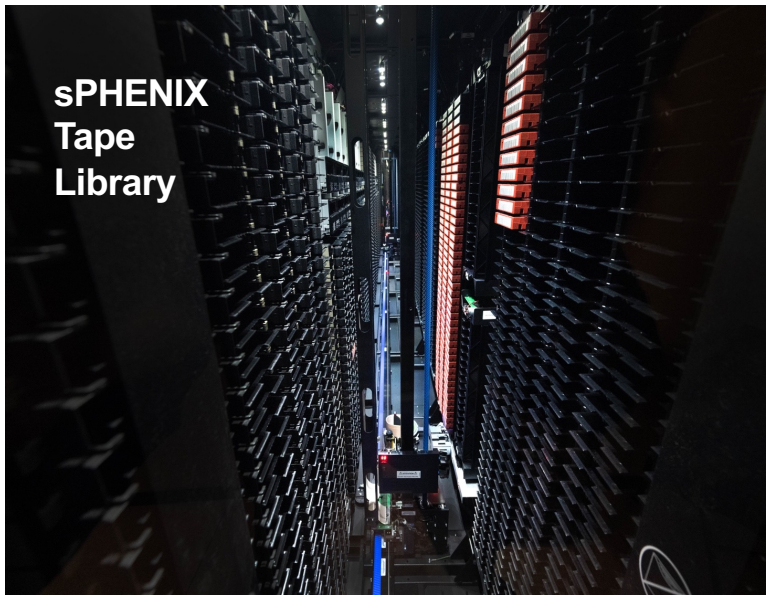
Smooth operation of computing for RHIC

New energy-efficient data center commissioned

- Beneficial occupancy since July 2021 (3 months Covid-19 related delay)
- New hardware deployed in the new data center

Preparing for the Future

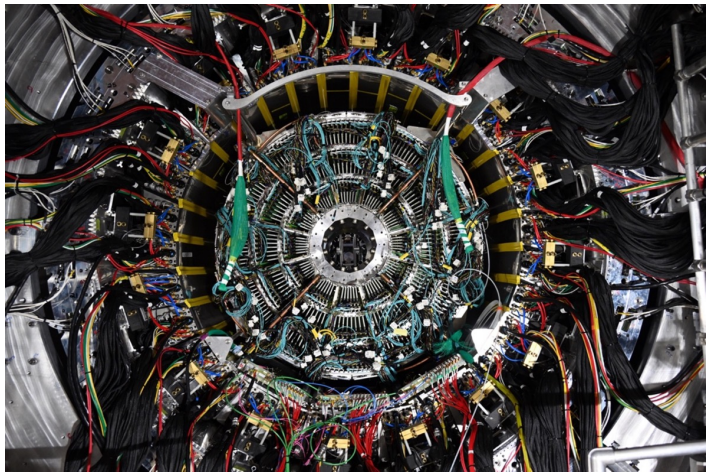
- Commissioning of sPHENIX computing model
- Installation of hardware for sPHENIX
- Support for RHIC data & knowledge preservation
- Support for EIC simulations studies
- Engagement in BNL's AI/ML strategy and planning
- Coordinated effort with JLAB on EIC computing

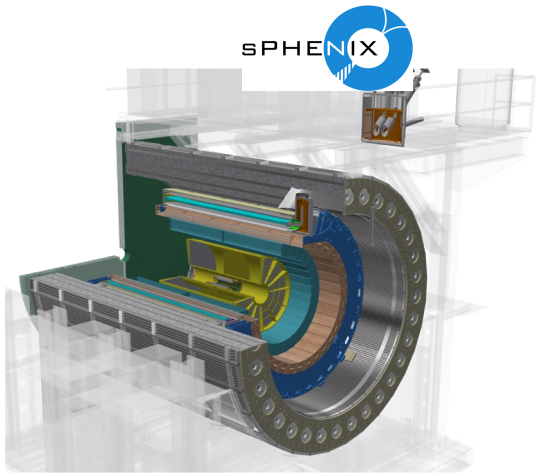


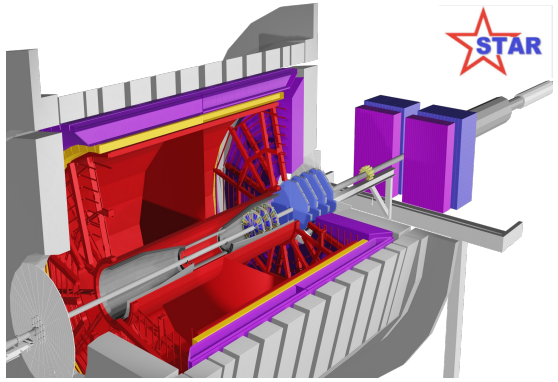
Completing the RHIC Mission with sPHENIX and STAR

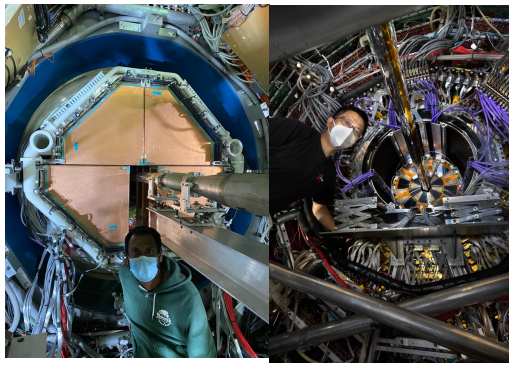
- sPHENIX will use energetic probes (jets, heavy quarks) to study quark-gluon plasma with unprecedented precision
  - How the structureless "perfect" fluid emerges from the underlying interactions of quarks and gluons at high temperature
- sPHENIX outer hadron calorimeter will be part of the EIC project detector
- Detector (sPHENIX and STAR) removal and repurpose for EIC

- STAR with forward upgraded detectors will understand the initial state of nucleon and nuclei from high to low x and the inner workings of QGP
- How are gluons and sea quarks distributed in space and momentum inside the nucleon?
- How does a dense nuclear environment affect quarks and gluons, their correlations, and their interactions and giving rise to non-linear effects?









Synergies with the EIC science and contribute to EIC workforce development

RHIC data taking scheduled for 2023–2025
sPHENIX upgrade and STAR with forward upgrade will fully utilize the enhanced (~50 times Au+Au design) luminosity of RHIC

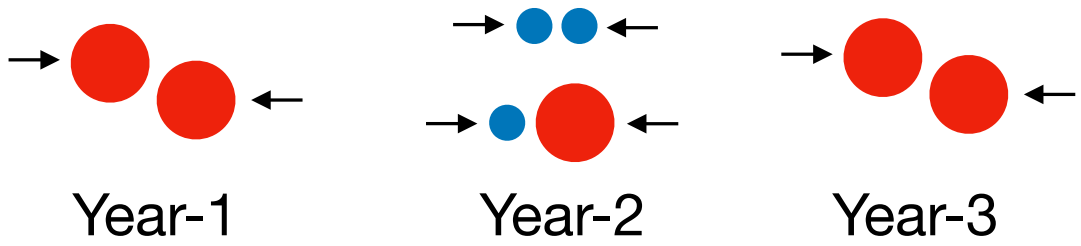
Brookhaven National Laboratory

Proposed run plan 2023-2025

Table 1: Summary of the sPHENIX Beam Use Proposal for years 2023–2025, as requested in the charge. The values correspond to 24 cryo-week scenarios, while those in parentheses correspond to 28 cryo-week scenarios. The 10%-*str* values correspond to the modest streaming readout upgrade of the tracking detectors. Full details are provided in Chapter 2.

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	45 (62) pb^{-1}
2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5 kHz] 0.01 pb^{-1} [10%-*str*]	0.11 pb^{-1}
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb^{-1}	21 (25) nb^{-1}

- Focus on core science mission of sPHENIX and RHIC
- Minimization of risk guides ramp-up, commissioning and running conditions
- Maximize science output for investment (in MIE, 1008 facility upgrades, RHIC ops, U.S. HI research programs)
- Note: requested collision species and luminosity unchanged compared to 2020 and 2021 Beam Use Proposals



The Electron-Ion Collider

2015 NSAC LRP

"We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB."

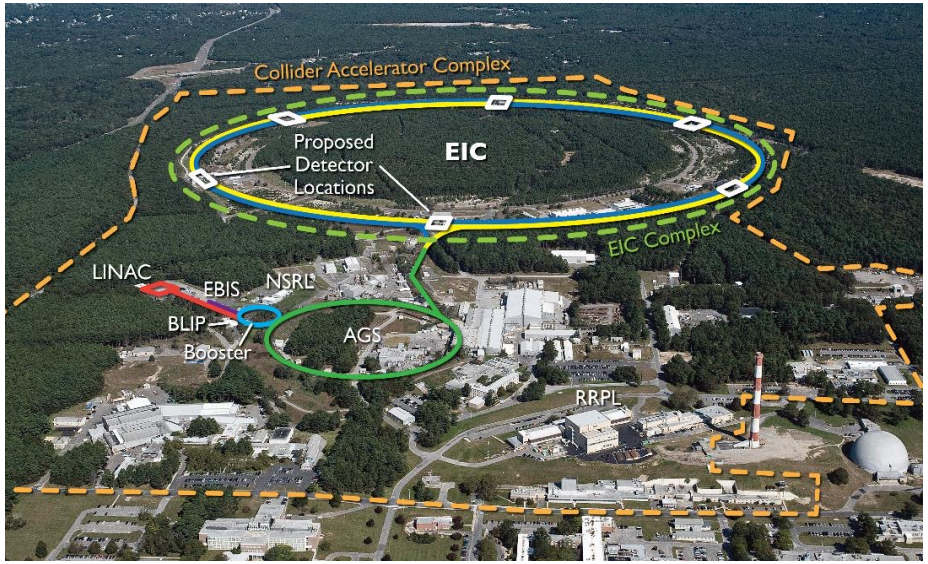
Project Design Goals

- High Luminosity: L= 10^{33}–10^{34}cm^{-2}sec^{-1}, 10–100 fb^{-1}/year
- Highly Polarized Beams: ~70%
- Large Center of Mass Energy Range: E_{cm} = 20–140 GeV
- Large Ion Species Range: protons – Uranium
- Large Detector Acceptance and Good Background Conditions
- Accommodate a Second Interaction Region (IR)

Conceptual design scope and expected performance meet or exceed NSAC Long Range Plan (2015) and the EIC White Paper requirements endorsed by NAS (2018)

An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:

- How does the **mass** of the nucleon arise?
- How does the **spin** of the nucleon arise?
- What are the emergent properties of dense systems of gluons?



Double Ring Design Based on Existing RHIC Facility

Major milestones: CD-0 December 2019; DOE EIC site (BNL) selection Jan 2020; CD-1 June 2021; EIC project detector selected in March 2022; ePIC collaboration formed in July 2022 & spokesperson (John Lajoie) and deputy spokesperson (Silvia Dalla Torre) elected Feb 2023; EIC Resource Review Board (RRB) meeting April 2023

Thank you for your attention!