Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

RHIC Runs 2023-2025 and Beyond

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May 24, 2022

RHIC Retreat

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COVID, Safety, DEI

- **More than two years since the beginning of COVID-19 global pandemic**
  - Collectively we overcome many challenges and accomplished a lot
  - Unfortunately, COVID is not over yet and continue to challenges, e.g., health, supply chain issues impact on operations, projects, etc.
  - The new norm of “normal operations with telework”

- **Safety is a core value and a priority**
  - Many safety events including several electrical events last fall
  - Department, directorate, and laboratory wide actions taken
  - Safety culture, work planning and control, human performance improvement – DeepDive Survey results in April 2022
  - Improvements and thank you all for your effort

- **Diversity, Equity and Inclusion is a core value**
  - NPP leadership development
  - DEI council: hiring practice committee, Code of Conduct committee, many activities
  - DeepDive survey results – all hands meeting June 6th
  - Guidance on DEI goals by Lab’s DEI Office and individual engagement

RHIC in the 2015 NSAC Long Range Plan

"There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC:

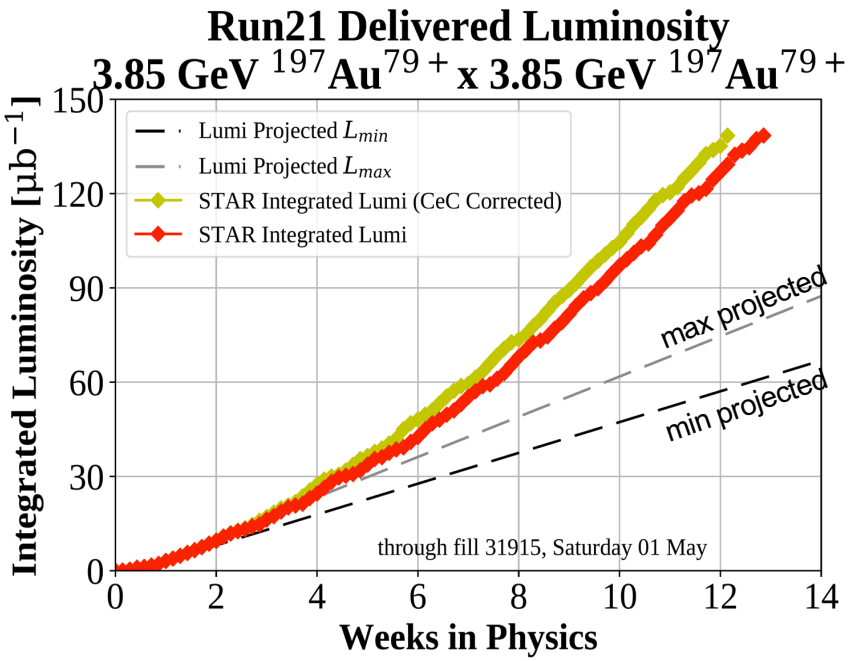
(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX.

(2) Map the phase diagram of QCD with experiments planned at RHIC."

RHIC 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, PI: Alexei Fedotov)

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



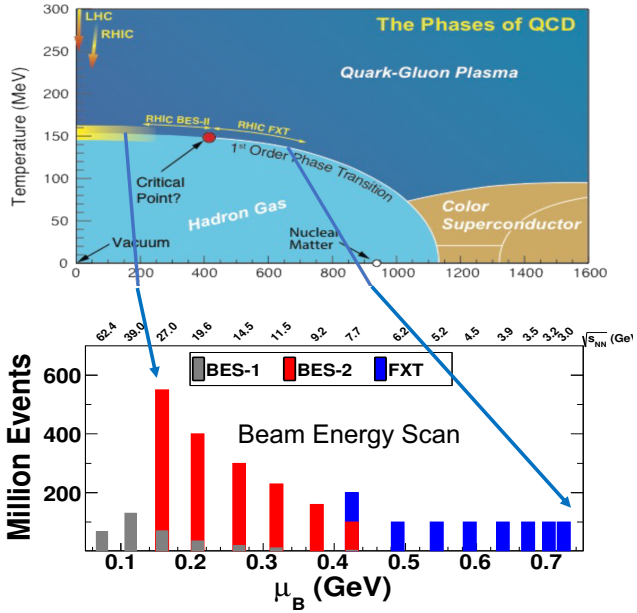


Table 2: Proposed Run-21 assuming 24-28 cryo-weeks, including an initial one week of cool-down, one week for CeC, a one week set-up time for each collider energy and 0.5 days for each FXT energy.

Single-Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	Run Time	Species	Events (MinBias)	Priority
3.85	7.7	11-20 weeks	Au+Au	100 M	✓
3.85	3 (FXT)	3 days	Au+Au	300 M	✓
44.5	9.2 (FXT)	0.5 days	Au+Au	50 M	✓
70	11.5 (FXT)	0.5 days	Au+Au	50 M	✓
100	13.7 (FXT)	0.5 days	Au+Au	50 M	✓ ✓
100	200	1 week	O+O	400 M 200 M (central)	✓
8.35	17.1	2.5 weeks	Au+Au	250 M	✓
3.85	3 (FXT)	3 weeks	Au+Au	1.7M	✓
100	200	8 days	d+Au	200M	4

(additional mode on short notice)

+ 2 dedicated weeks for the Coherent electron Cooling Proof-of-Principle experiment (CeC X)

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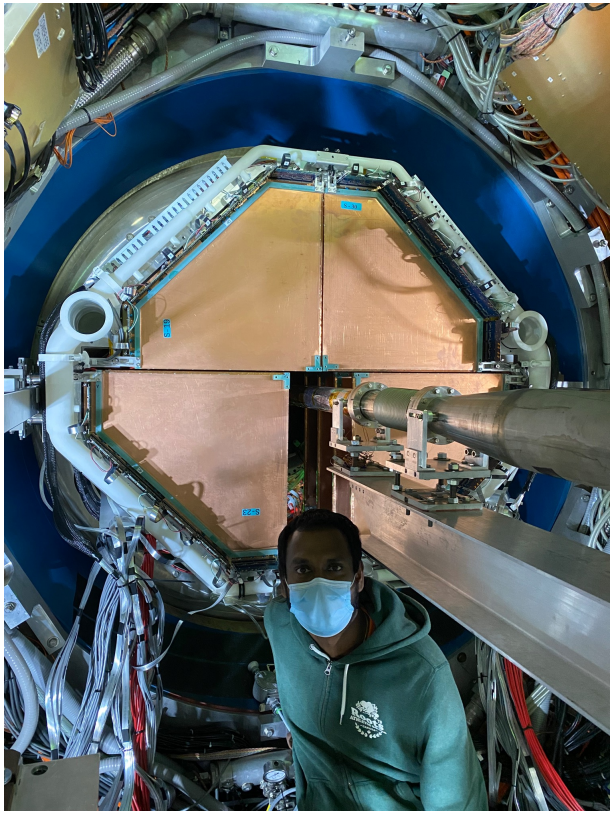
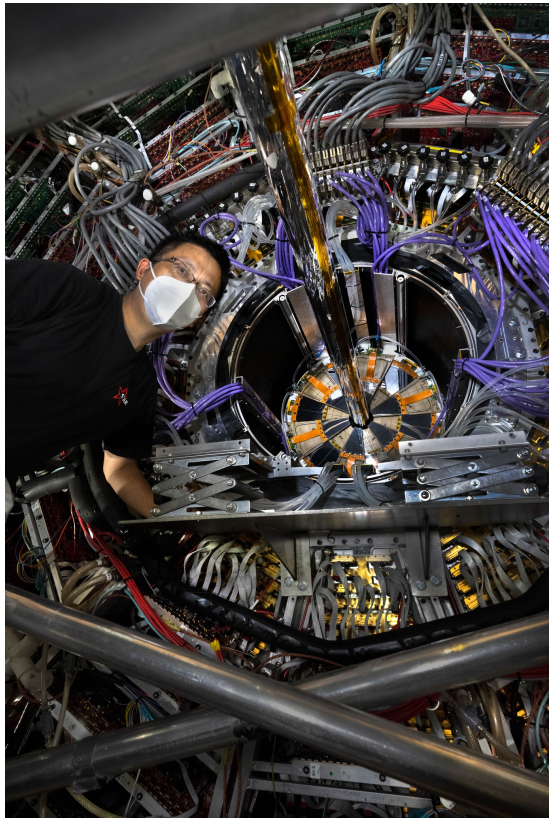
PAC 2021 Recommendation for Run 2022

- "The PAC strongly endorses the STAR Run 22 BUR. C-AD is strongly encouraged to optimize RHIC operations to fulfill the goals of both CeC X and STAR"

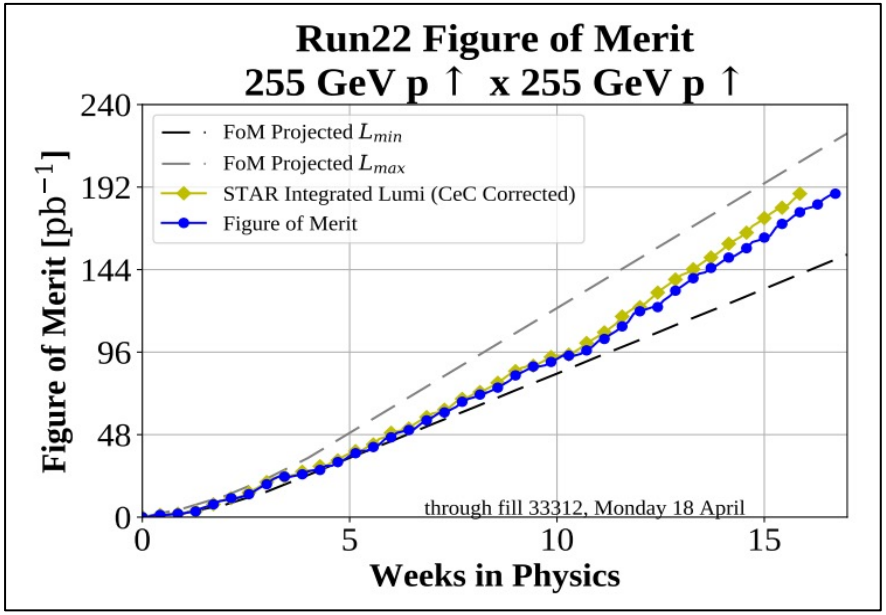


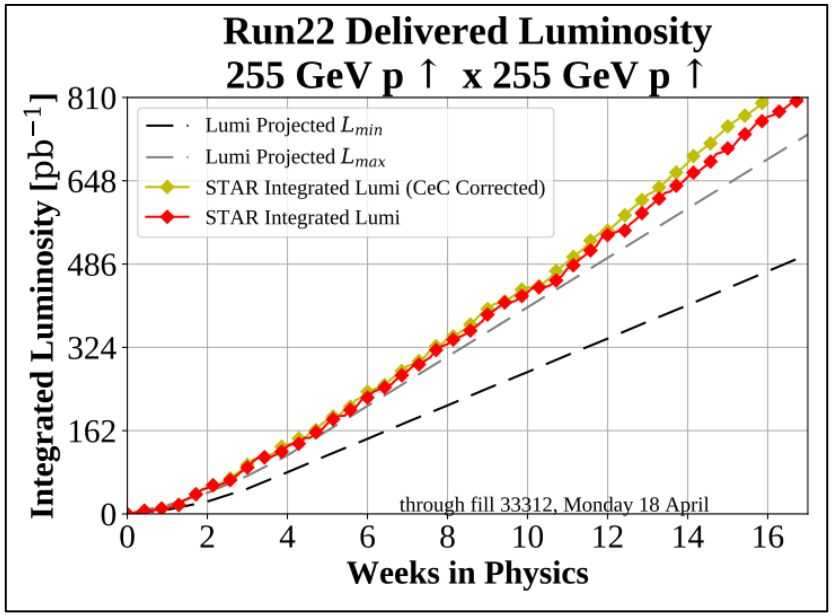


RHIC Run 2022

Goals Run Coordinator: Vincent Schoefer 2-week extension

- p↑+p↑ polarized proton collisions at full energy (~508 GeV c.o.m.) with new STAR forward detector upgrade (forward program: 107%, mid-rapidity: ~98%)
  - sampled integrated luminosity, L : 400 pb^{-1}
  - sampled integrated figure of merit, LP^2: 120 pb^{-1} with P = 55%
- demonstration of Coherent electron Cooling (CeC-X)





CeC-X demonstrated Plasma Cascade Amplification (PCA) with high gain

PHENIX publications

206 papers published. (75 PRL, 1 Nature physics)

3 papers published in 2021 ; 4 papers in journal review. 3 of these 4 published in January and February 2022

206 physics papers published

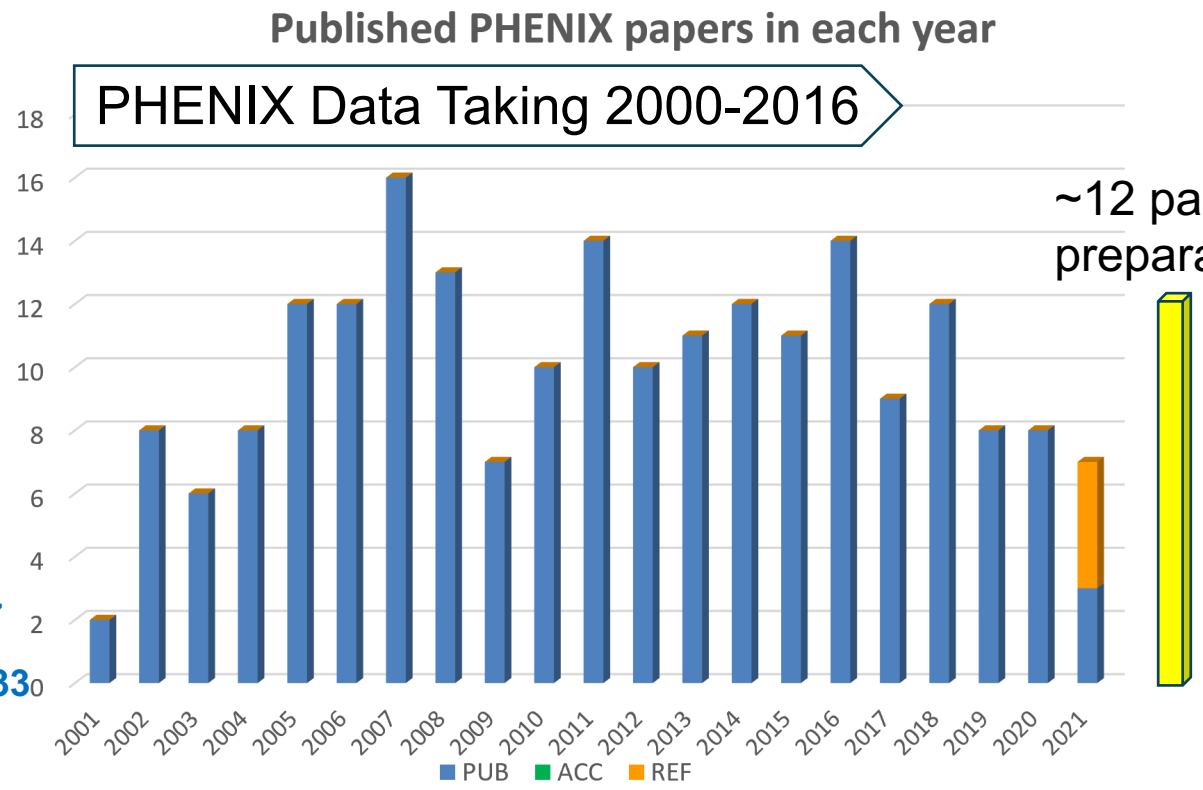
Phys. Rev. Lett.	75
Phys. Rev. C	83
Phys. Rev. D	42
Nature Physics	1
Phys. Letter B	4
Nucl. Phys. A	1
Topcite 1000+	2
500-1000	8
250-500	20
100-250	57
50-100	44

PHENIX White Paper: 3157

Jet quenching discovery: 1133

Nature P paper: 175

131 physics papers in topcite 50+



~12 papers in preparation.

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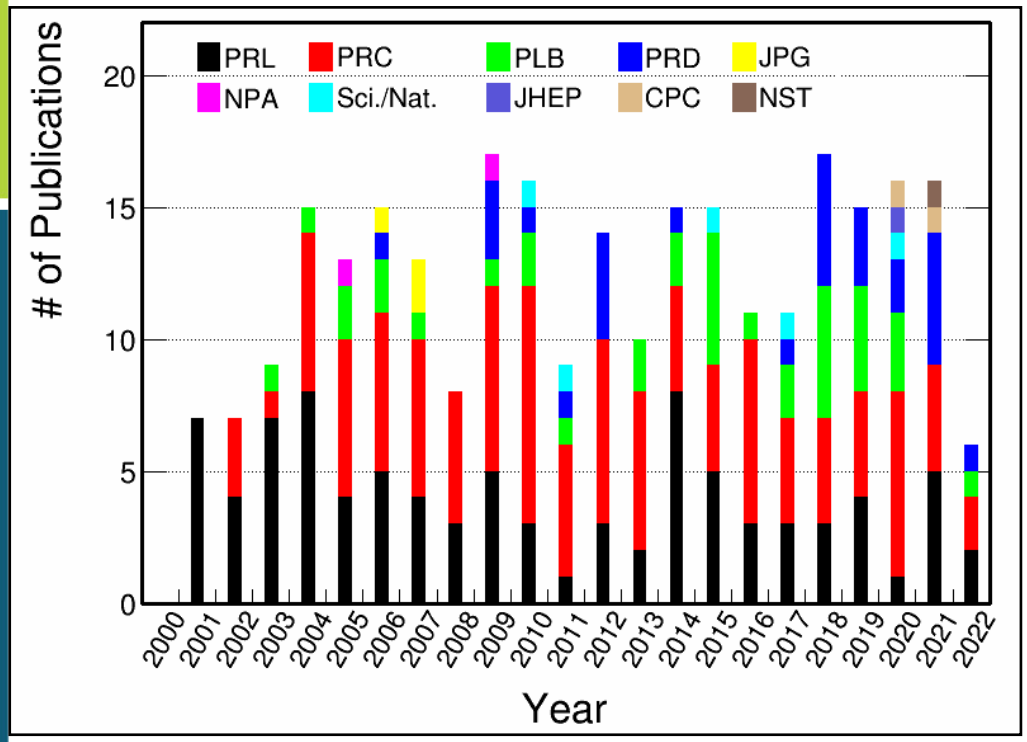
STAR publications



Continued strong publication and presentation record across all Physics Working Groups

Measurement of e^+e^- Momentum and Angular Distributions from Linearly Polarized Photon Collisions, Altmetric Attention Score 493, #45 out of all the 33431 papers published in PRL as of February 3, 2022

- **2021**: 16 published — 5 PRL, 4 PRC, 5 PRD, 1 CPC, 1 NST
- **2022**: 6 published + accepted — 2 PRL, 2 PRC, 1 PLB, 1 PRD

Journal review: 12; Collaboration review: 7; Active GPCs: 36

98.5% of STAR papers uploaded to HEPData, remaining 4 papers are newer and on track to be uploaded soon

Continued steady growth in citations

Feb 2022 budget briefing

RHIC Run Scenarios 2022-25

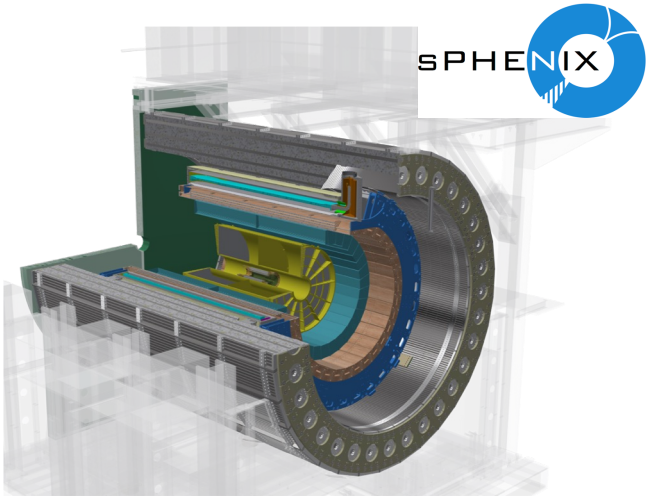
(Feb 2022 budget briefing)

Year	Budget Scenario 1	Budget Scenario 2
2022	22 cryo-weeks with fSTAR $p^{\uparrow}+p^{\uparrow}$ at 510 GeV	22 cryo-weeks with fSTAR $p^{\uparrow}+p^{\uparrow}$ at 510 GeV (20 weeks) ✓
2023	24 cryo-weeks with sPHENIX and STAR Au+Au at 200 GeV	28 cryo-weeks with sPHENIX and STAR Au+Au at 200 GeV
2024	24 cryo-weeks with sPHENIX and STAR $p^{\uparrow}+p^{\uparrow}$ and $p^{\uparrow}$+Au at 200 GeV	28 cryo-weeks with sPHENIX and STAR $p^{\uparrow}+p^{\uparrow}$ and $p^{\uparrow}$+Au at 200 GeV
2025	24 cryo-weeks with sPHENIX and STAR Au+Au at 200 GeV	28 cryo-weeks with sPHENIX and STAR Au+Au at 200 GeV

Completing the RHIC Science Mission

sPHENIX: **Study QCD phenomena discovered at RHIC** on different scales with unprecedented precision – How does the structureless "perfect fluid" emerge from the underlying asymptotically free gauge theory?

- Extend RHIC kinematic reach and capabilities for direct comparison with the LHC
- Focus on hard probes (jets and heavy flavor)



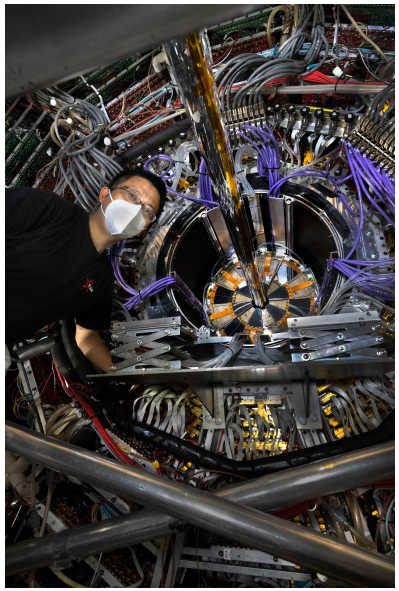
RHIC data taking scheduled for 2023–2025

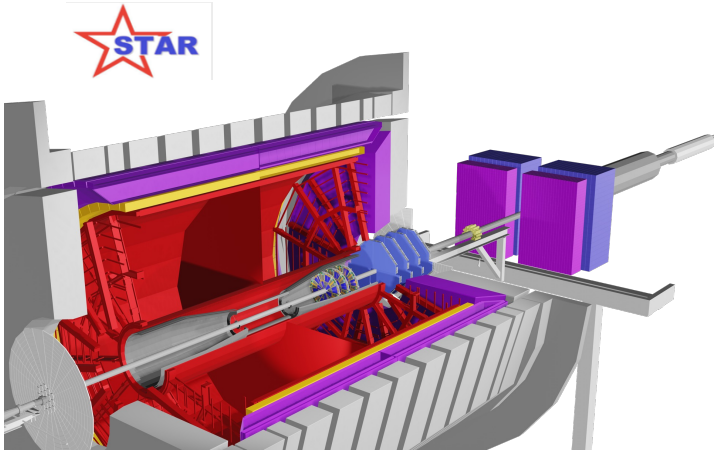
sPHENIX upgrade and STAR will fully utilize the enhanced (~50 times AuAu design) luminosity of RHIC

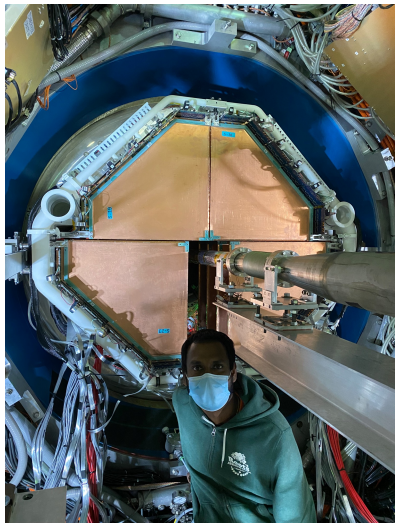
Completing the RHIC Science Mission

STAR Mission: **Understand the initial state for nucleons and nuclei** from high to low x and the inner workings of the 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?

- pp/pA – validity and limits of factorization and universality, important to EIC
- A+A – broad physics programs focusing on soft, hard and electromagnetic probes







PAC 2021 Recommendations

- Run 23-25: The top overall priority in planning for these three runs is to commission the sPHENIX detector and to achieve its scientific program
  - The PAC strongly supports focusing in Run 23 on sPHENIX commissioning using 200 GeV Au+Au collisions. This is the highest priority and must come first. This should be followed by continued running of 200 GeV Au+Au collisions to begin the sPHENIX scientific program.
  - The highest priority for Run 24 is a pp run of sufficient duration to provide the reference data needed to achieve the science goals, including the precision goals, that motivate the sPHENIX program.
  - Completion of the proposed 200 GeV Au+Au data set is the highest priority for Run 25

- Run 23-25: …..we commend the STAR collaboration for having developed a complementary science program that takes advantage of new STAR detector capabilities (detector elements developed for the BES program; the forward upgrades developed for Run 22) that will add further scientific impact during these run years.

PAC highlighted the critical importance of 28-week for each of the Run 2023 to Run 2025

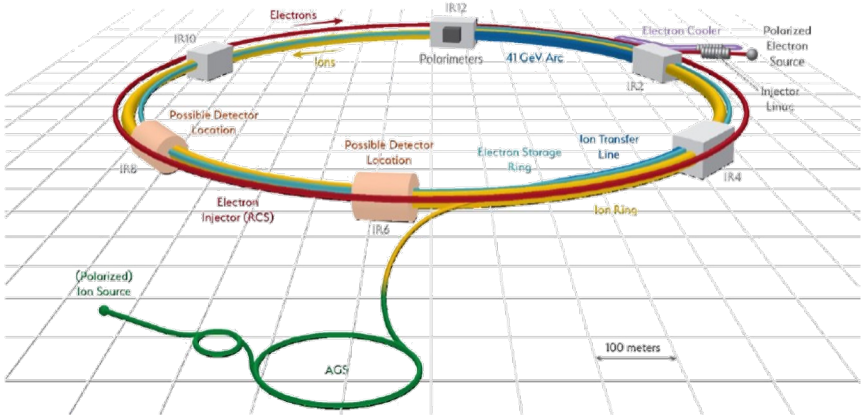
PAC 2022 is next week!

The Electron-Ion Collider

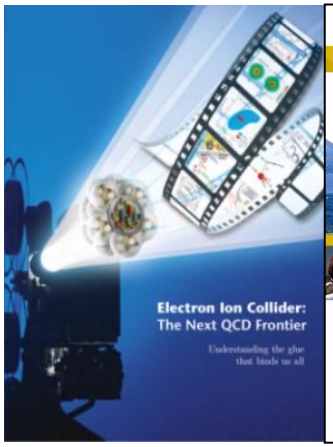
Project Design Goals

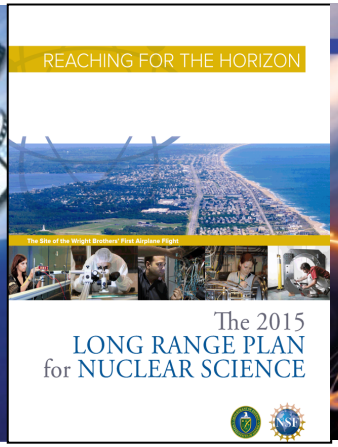
- High Luminosity: L= 10^{33}–10^{34}cm^{-2}sec^{-1}, 10–100 fb^{-1}/year
- Highly Polarized Beams: ~70%
- Large Center of Mass Energy Range: E_{cm} = 20–140 GeV
- Large Ion Species Range: protons – Uranium
- Large Detector Acceptance and Good Background Conditions
- Accommodate a Second Interaction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

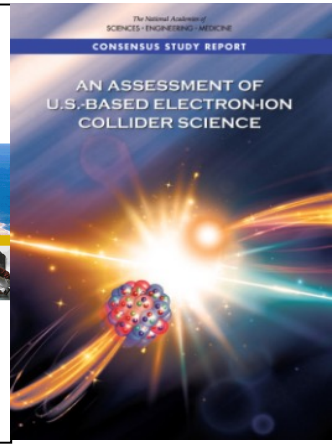
Conceptual design scope and expected performance meet or exceed NSAC Long Range Plan (2015) and the EIC White Paper requirements endorsed by NAS (2018)



Double Ring Design Based on Existing RHIC Facility







Major milestones: CD-0 December 2019; DOE EIC site (BNL) selection on Jan 9, 2020; CD-1 June 2021; EIC project detector reference design selected in March 2022

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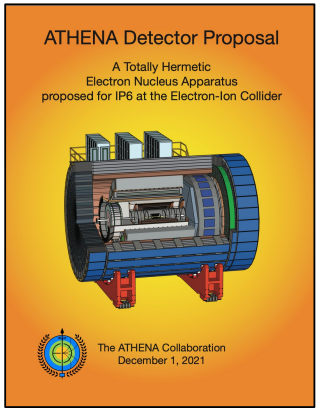
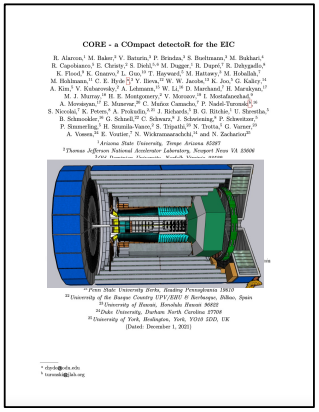
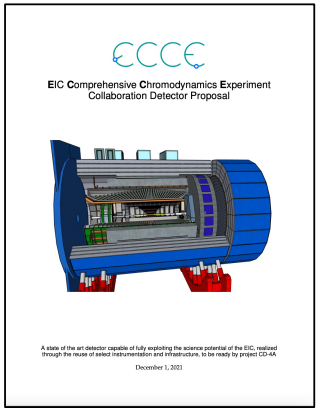
EIC Detector Proposal Advisory Panel (DPAP) Recommendations







- "The panel unanimously recommends ECCE as Detector 1. The proto-collaboration is urged to openly accept additional collaborators and quickly consolidate its design so that the Project Detector can advance to CD2/3a in a timely way."

- "The panel supports the case for a second EIC detector, however, given the current funding and available resources, the committee finds that a decision on Detector 2 should be delayed until the resources and schedule for the Project detector (Detector 1) are more fully realized."

A key point from DPAP

"*In order to ensure that the EIC has a maximally optimal Detector 1, the proto-collaboration for a concept selected for Detector 1 must be open to: (1) integrating new collaborators in a manner that enables them to make contributions that impact the capabilities and success of the experiment in significant ways, including some new collaborating individuals and groups into positions of responsibility and leadership; and (2) integrating new experimental concepts and technologies that improve physics capabilities without introducing inappropriate risk.*"

EIC project detector, Detector 1 collaboration is being formed

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Summary

- Despite of COVID + many challenges encountered, Run 2022 was a success story with STAR achieving its physics goals, especially for its forward upgrade physics
- sPHENIX upgrade has been progressing well, though many challenges ahead
- Run plans for 2023-2025 developed for sPHENIX and STAR
  - 28 cryo-week each year essential for sPHENIX physics
- We have exciting work ahead to complete the RHIC science mission
- Major progress has been made with the EIC project in the last year
  - CD-1 approval in June 2021
  - EIC project detector reference design was selected in March 2022
  - Next major milestone for the EIC: CD2/3a
- NPP and EIC are working together to ensure a smooth transition from RHIC to EIC

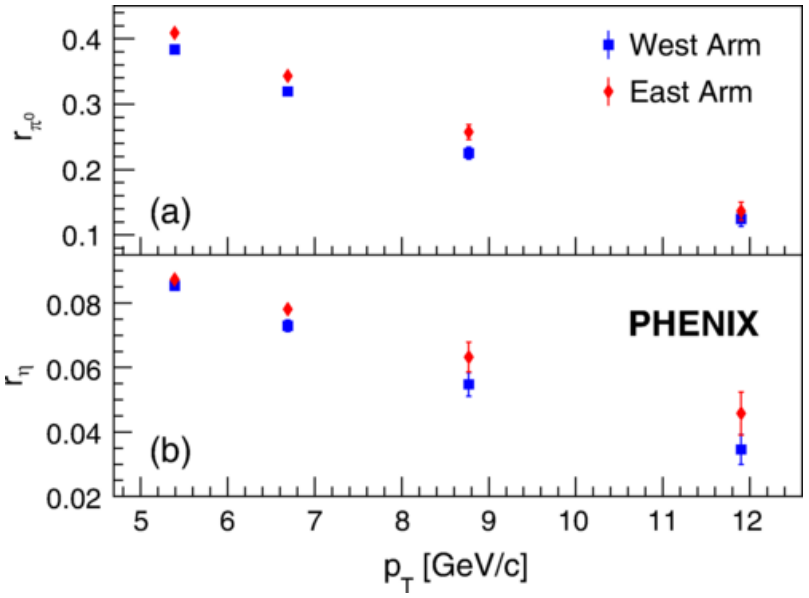
Spin highlights from direct photons

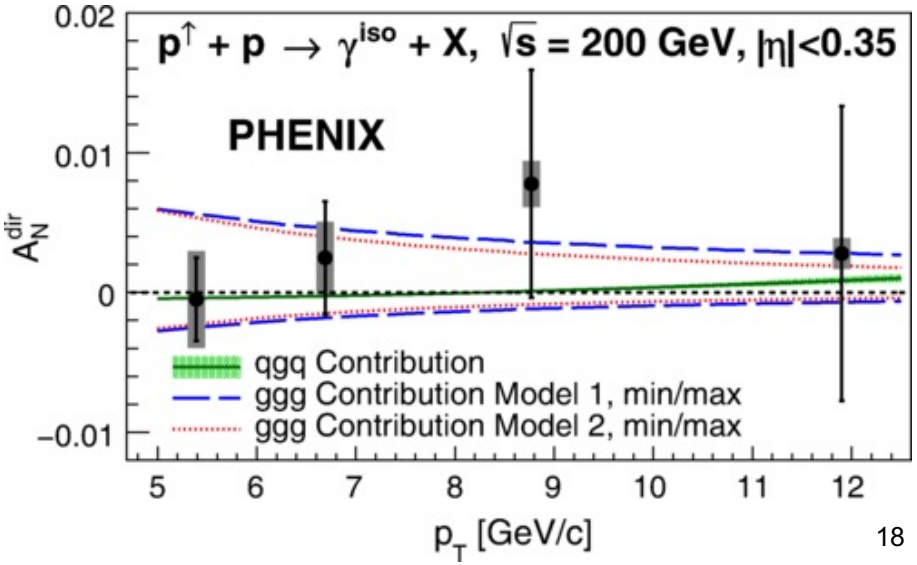
PHENIX

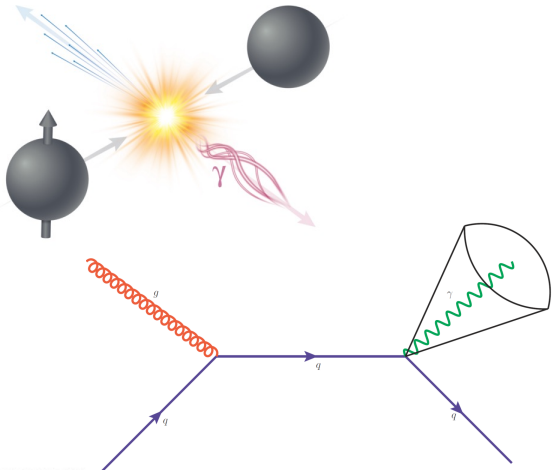
PRL 127, 162001 (2021)

First direct photon A_N extracted at RHIC

- Mostly sensitive to initial state effects (no fragmentation) → quark-gluon and gluon-gluon correlation functions
- Great potential to constrain gluon-gluon correlation function as well







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Discoveries of Breit-Wheeler process and vacuum birefringence

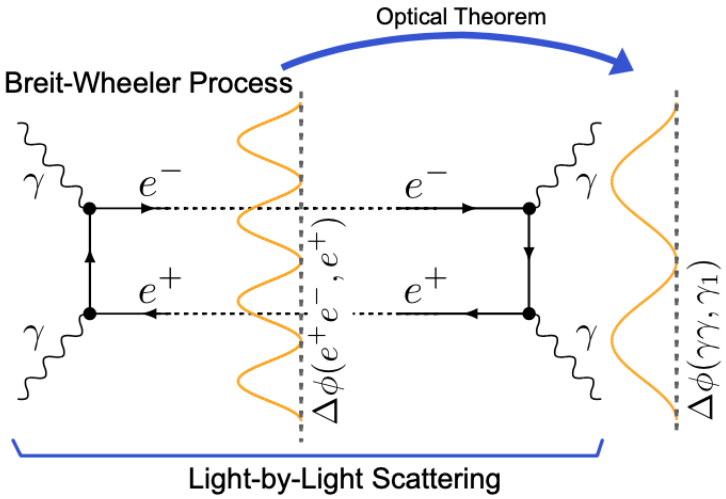
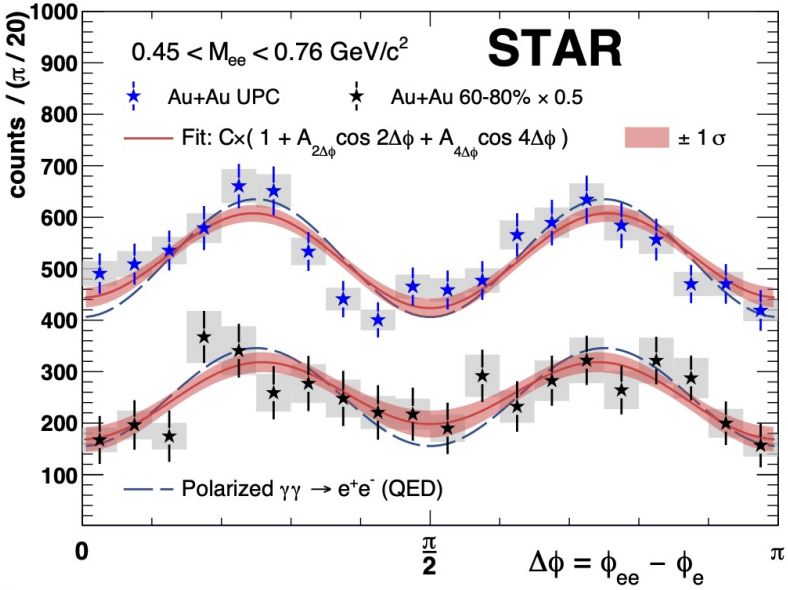
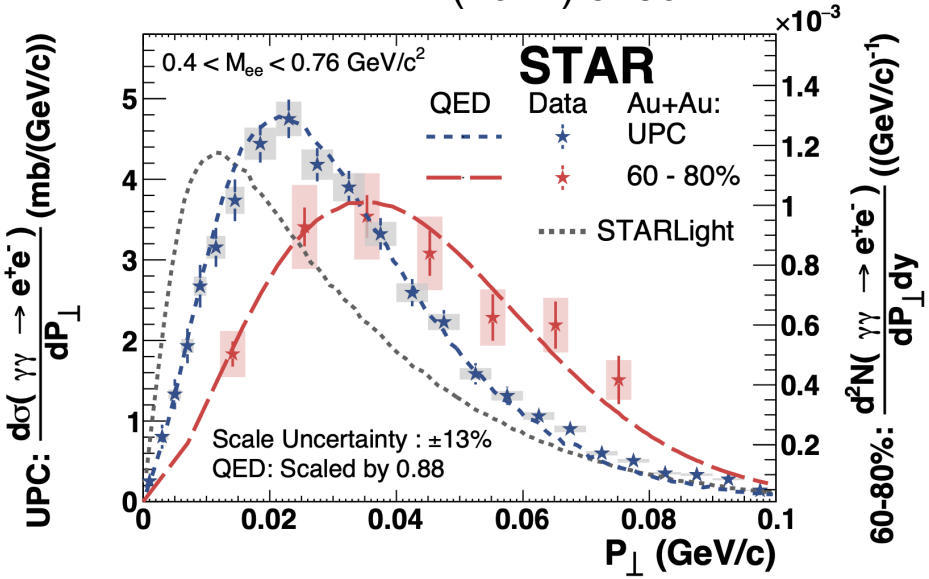


FIG. 1. A Feynman diagram for the exclusive Breit-Wheeler process and the related Light-by-Light scattering process illustrating the unique angular distribution predicted for each process due to the initial photon polarization.



PRL127 (2021) 52302



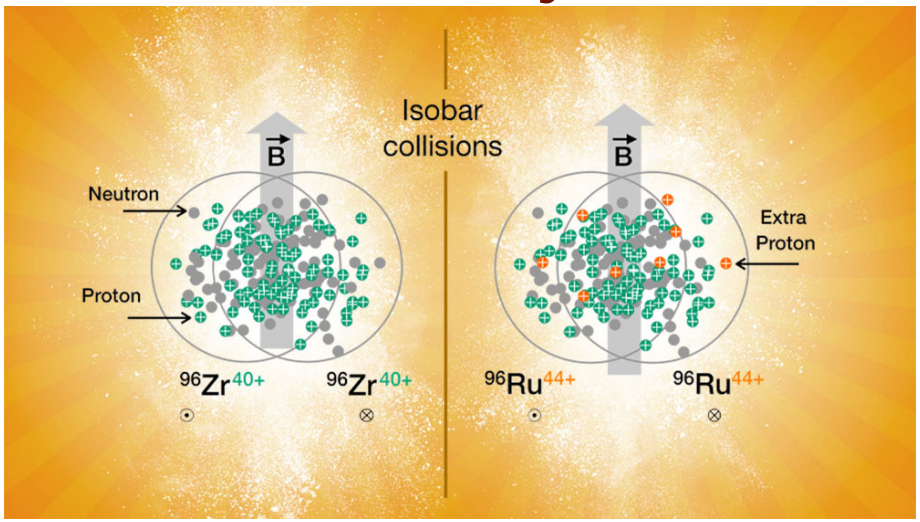
Observation of Breit-Wheeler process with all possible kinematic distributions (yields, M_{ee}, p_T, angle)

Dielectron p_T spectrum: broadened from large to small impact parameters

Observation of vacuum birefringence: 6.7σ in Ultra-peripheral collisions

Collisions of Light Produce Matter/Antimatter from Pure Energy:
https://www.bnl.gov/newsroom/news.php?a=119023
https://science.osti.gov/np/Highlights/2022/NP-2022-01-a

Isobar blind analysis: search for Chiral Magnetic Effect

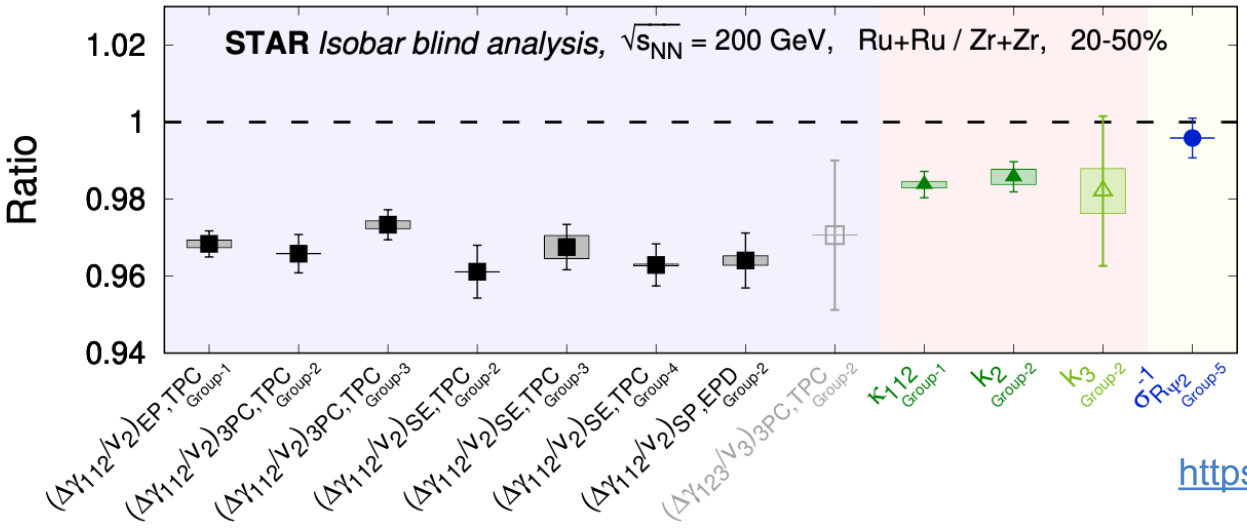


Phys. Rev. C 105 (2022) 014901

Isobar idea: change signal while keeping background fixed

Blind analyses of CME studies of Run-18 isobar data carried out by the STAR collaboration

https://www.bnl.gov/newsroom/news.php?a=119062



Pre-defined CME signatures:
All ratios > 1
Not seen

A precision down to 0.4% is achieved

RBRC workshop on "Physics Opportunities from the RHIC Isobar Run"

https://www.bnl.gov/porir2022/index.php

No CME signature that satisfies the pre-defined criteria observed
The observed multiplicity difference between the isobars requires future CME analyses to better understand the baselines in order to best utilize the precision demonstrated in this analysis