Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

# Brookhaven's Physics Program

JoAnne Hewett
IoP Meeting
April 11, 2024

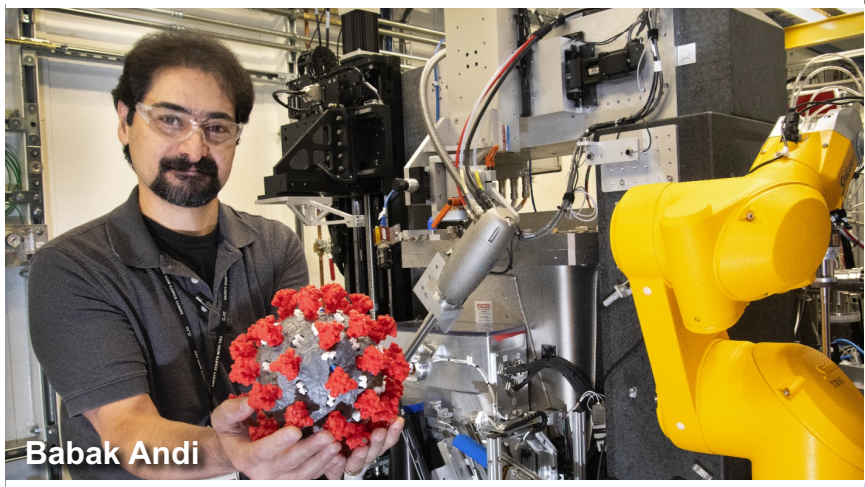
@BrookhavenLab

# Brookhaven National Laboratory

## A Multipurpose DOE Office of Science Lab

- Managed for the U.S Department of Energy (DOE) by Brookhaven Science Associates. BSA is a partnership between Stony Brook University and Battelle Memorial Institute.
- Vision: To accelerate pathways to scientific discovery and technological innovation that transforms the world.
  - Pull together large teams from labs, industry, universities
  - Builds, operates large facilities
- People
  - 2,900 staff
  - 140 joint faculty
  - 500 students
  - 4,400 facility users and guests
  - Pre-COVID: 30,000+ students and educators (K–12) annually
- Budget: $800 million
- Regional economic impact
  - Supports over 4,700 jobs in New York State
  - Strong relationship with New York State: $400M invested by NYS since 2013
  - New Long Island Railroad station bordering campus
  - Developing strategy for carbon-free operations by 2040


Jasmine Hatcher-Lamarre


Babak Andi


Jantana Keereetaweep

# Research @ Brookhaven has led to fundamental discoveries

## A history of discovery (Nobel Prizes)

- 1957 Physics: Lee (Columbia) and Yang (BNL) for parity violation
- 1976 Physics: Ting (MIT) for discovery of the J/Psi particle
- 1980 Physics: Cronin and Fitch (Princeton) for CP Violation
- 1988 Physics: Lederman, Schwartz, Steinberger (Columbia) for discovery of the muon-neutrino

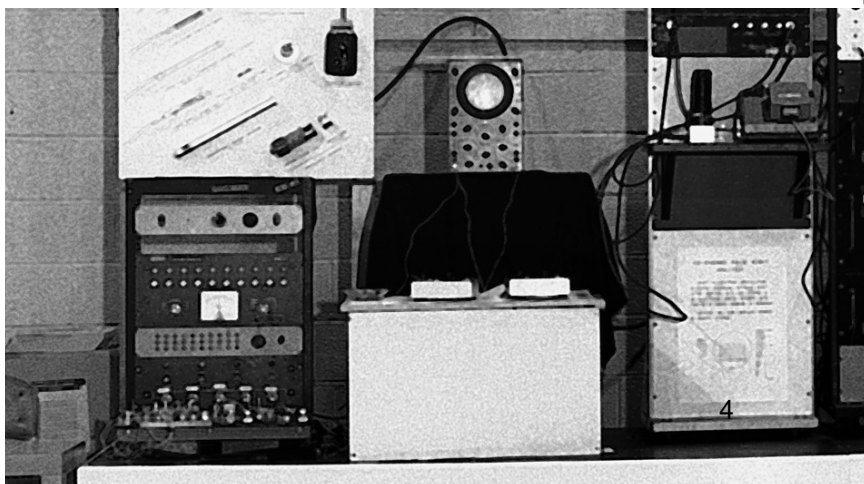
- 2002 Physics: Davis (BNL) for detection of solar neutrino deficit

- 2003 Chemistry: MacKinnon (BNL) explained how proteins generate nerve impulses

- 2009 Chemistry: Ramakrishnan and Steitz (BNL, Cambridge, Yale) for structure and function of the ribosome

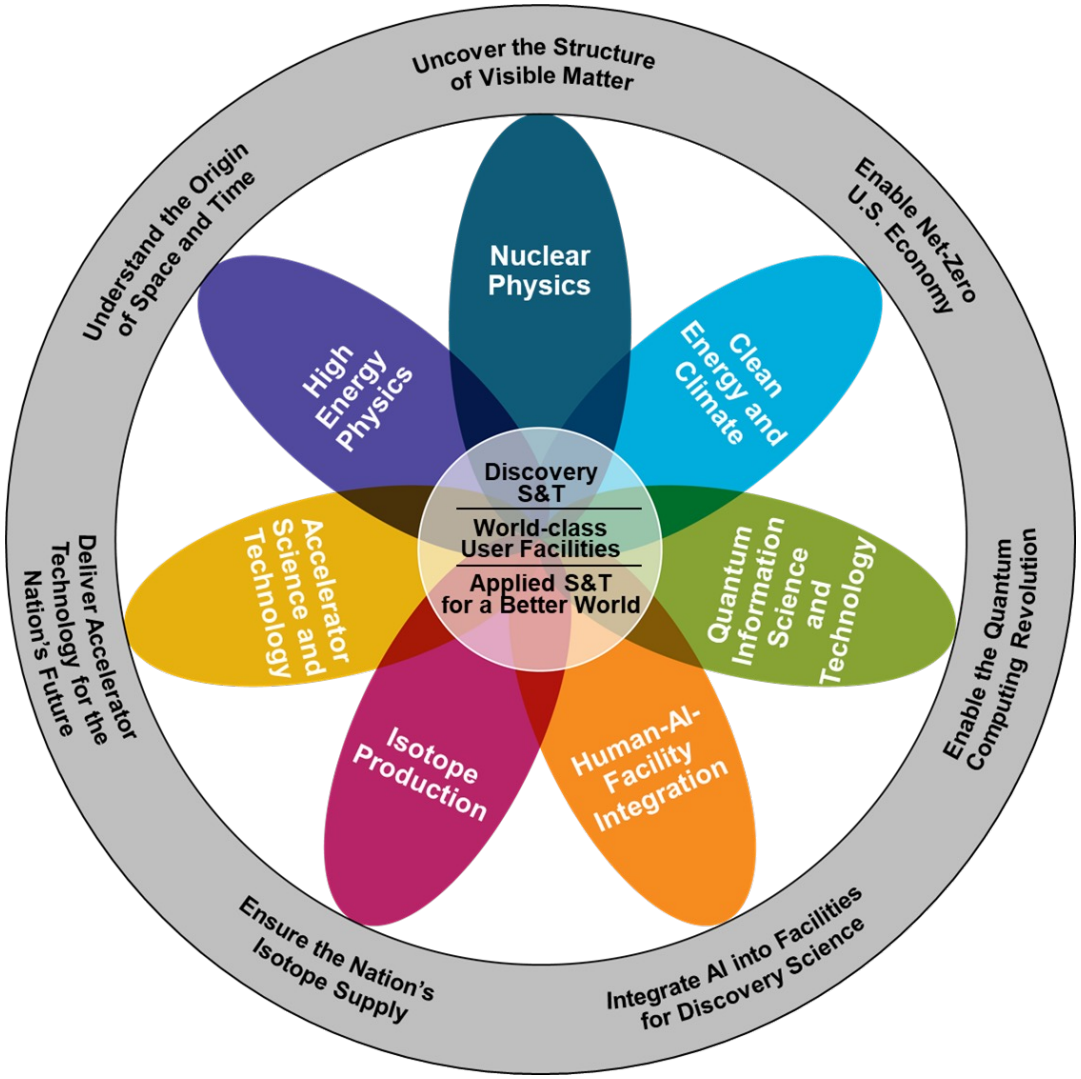
# Billion-Dollar Impacts

- T7 virus genome for biomedical research, diagnostics, and treatment. More than 35 years after being patented, was used to scale up production of Pfizer-BioNTech and Moderna's COVID-19 vaccines (2023 Nobel Prize in Medicine)
- Patented Maglev
- Cleaner-combusting oil burners, saving consumers approximately $25 billion in fuel costs and avoiding 160 megatons of carbon dioxide emissions
- Synthesized human insulin to treat diabetes
- Technetium-99m, most widely used radioisotope for imaging diseased organs
- Developed L-dopa, gold standard for treating Parkinson's disease
- "Tennis for Two" in 1958: the world's first video game



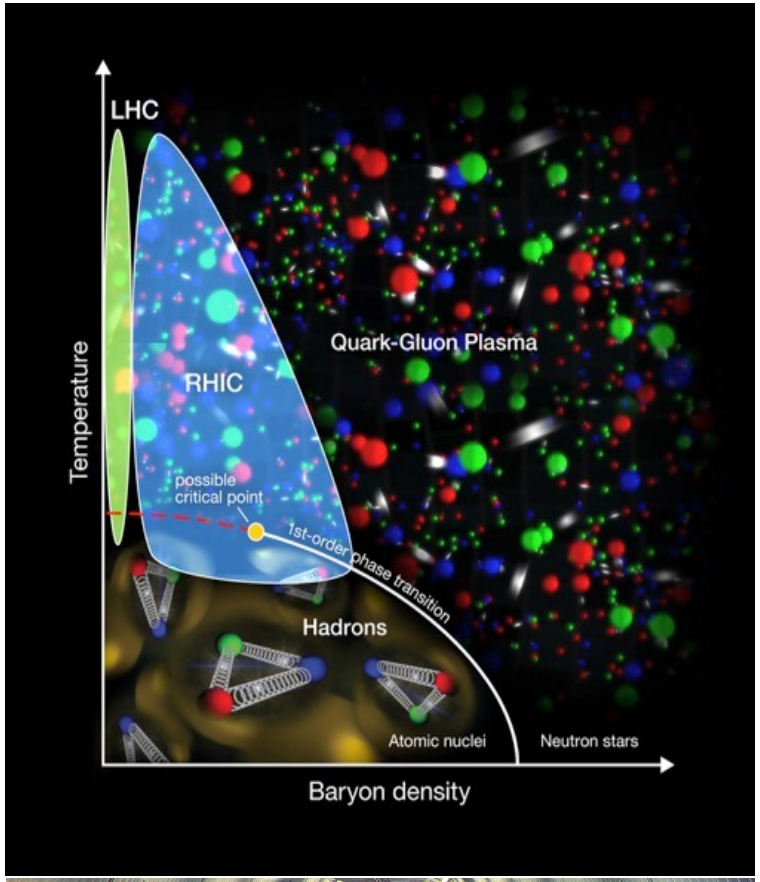
# Science Initiatives

1. **Discovery science enabled by accelerators**
   - Origin of mass and spin at the Electron Ion Collider
   - Fundamental science enabled by NSLS-II and its upgrade
   - Understanding the origin of space and time
   - Isotopes for Research
2. **Emerging innovation science and technology**
   - The quantum revolution
   - Energy efficient materials and supporting CHIPS
   - AI for autonomous facilities
3. **Protecting our Planet**
   - Carbon-Free Energy
   - Cloud in a box
   - Protecting the bio-economy



# Relativistic Heavy Ion Collider – a Unique Research Tool

- Heavy ion collisions
  - Explore new state of matter: Quark Gluon Plasma
  - Highest collision rates and collide many different ion species
- Polarized proton collisions
  - Only collider worldwide with spin polarized protons to explore the internal spin structure of protons
- Only operating collider in the U.S.

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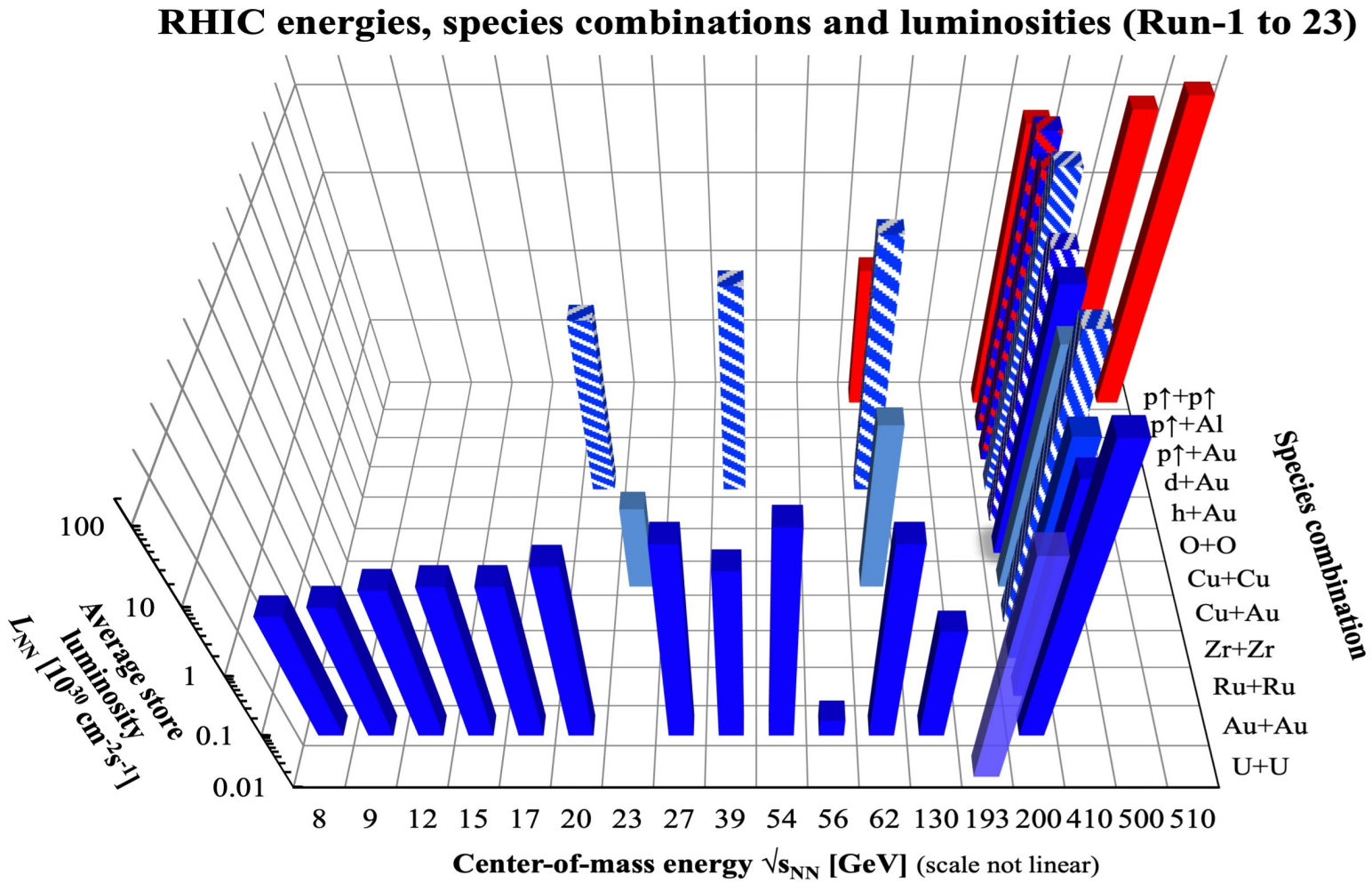
# 23 years of RHIC Performance: A versatile collider!




- 2024 Run starts Monday! Plan for 25 cryo-weeks
- 2025 run is expected to be RHIC's last

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# Quark-gluon plasma as “perfect liquid” discovered at RHIC

25

## *The News of the QGP Hit the Streets*

**Universe May Have Begun as Liquid, Not Gas**

Associated Press
Tuesday, April 19, 2005; Page A05

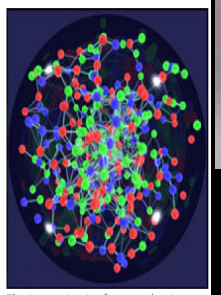
The Washington Post

New results from a particle collider suggest that the universe behaved like a liquid in its earliest moments, not the fiery gas that was thought to have pervaded the first microseconds of existence.

**Early Universe was 'liquid-like'**

Physicists say they have created a new state of hot, dense matter by crashing together the nuclei of gold atoms.

BBC NEWS



The impression is of matter that is more strongly interacting than predicted

The high-energy collisions prised open the nuclei to reveal their most basic particles, known as quarks and gluons.

The researchers, at the US Brookhaven National Laboratory, say these particles were seen to behave as an almost perfect "liquid".

The work is expected to help scientists explain the conditions that existed just milliseconds after the Big Bang.

**Early Universe was a liquid**

Quark-gluon blob surprises particle physicists.

by Mark Peplow
news@nature.com

nature

The Universe consisted of a perfect liquid in its first moments, according to results from an atom-smashing experiment.

Scientists at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory on Long Island, New York, have spent five years searching for the quark-gluon plasma that is thought to have filled our Universe in the first microseconds of its existence. Most of them are now convinced they have found it. But, strangely, it seems to be a liquid rather than the expected hot gas.

DISCOVER

Science, Technology, and The Future

THE BIG BANG MACHINE
A Long Island Particle Smasher Re-creates The Moment Of Creation


An atom smasher on Long Island re-creates the particle soup that gave rise to the universe

**"Here is where the action takes place. This is** where we effectively try to turn the clock back 14 billion years. Right above your head, about 13½ feet in the air."

Looking up, I try to imagine the events Tim Hallman is describing—atoms of gold colliding at 99.99 percent the speed of light; temperatures instantly soaring to 1 trillion degrees, 150,000 times hotter than the core of the sun. Then I try to picture a minuscule five-dimensional black hole, which, depending on your point of view, may or may not have formed at that same spot over my head. It's all a little much for an imagination that sometimes struggles with the plot of *Battlestar Galactica*.

SCIENTIFIC AMERICAN

Bringing DNA Computers to Life

MAY 2006
WWW.SCIAM.COM

Quark Soup

PHYSICISTS RE-CREATE THE LIQUID STUFF OF THE EARLIEST UNIVERSE

John Harris (Yale) 20th Anniversary of RHIC BNL-Online, June 12, 2020

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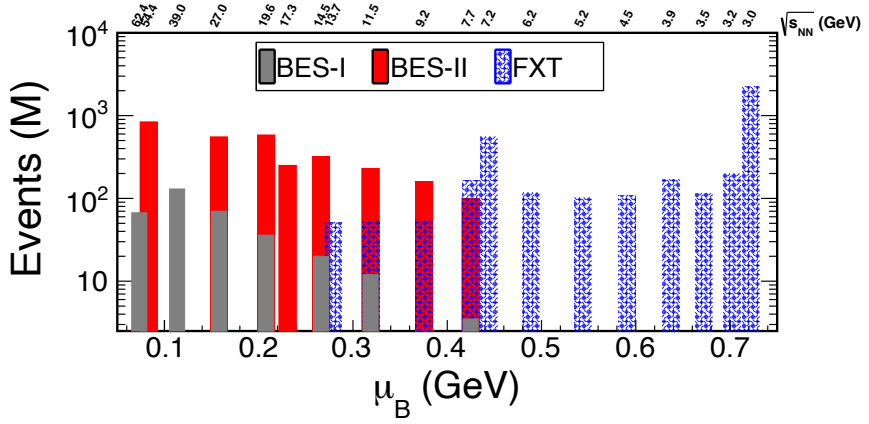
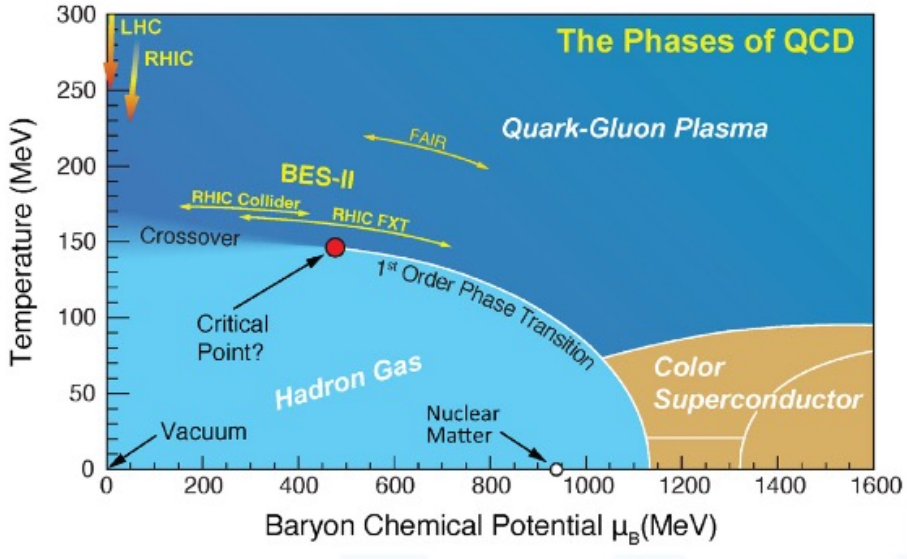
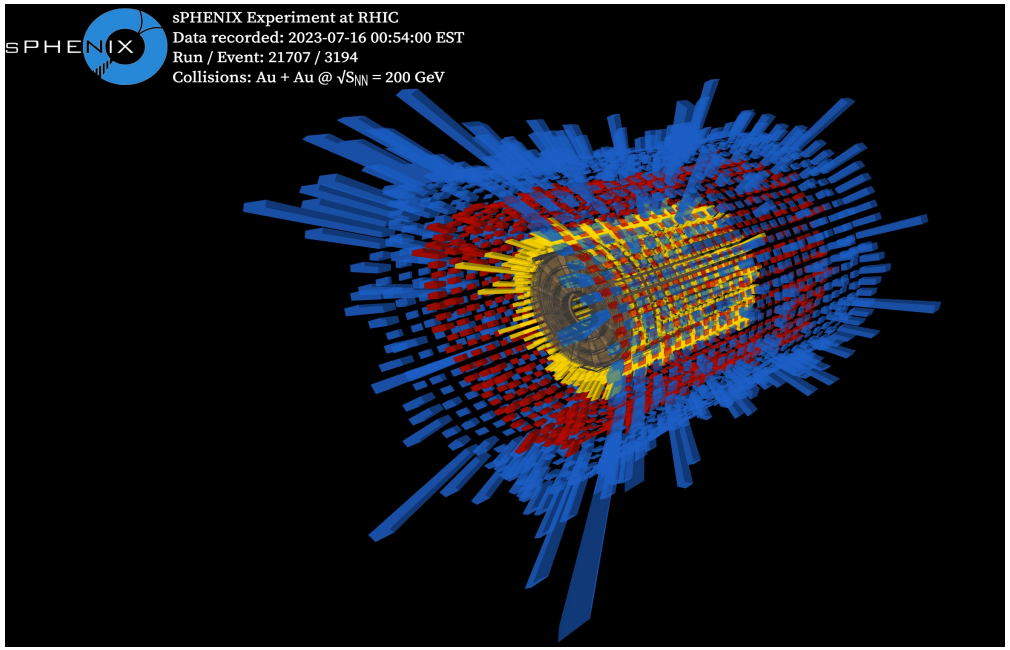
# Recent Accomplishments

STAR completed Beam Energy Scan (BES) data collection



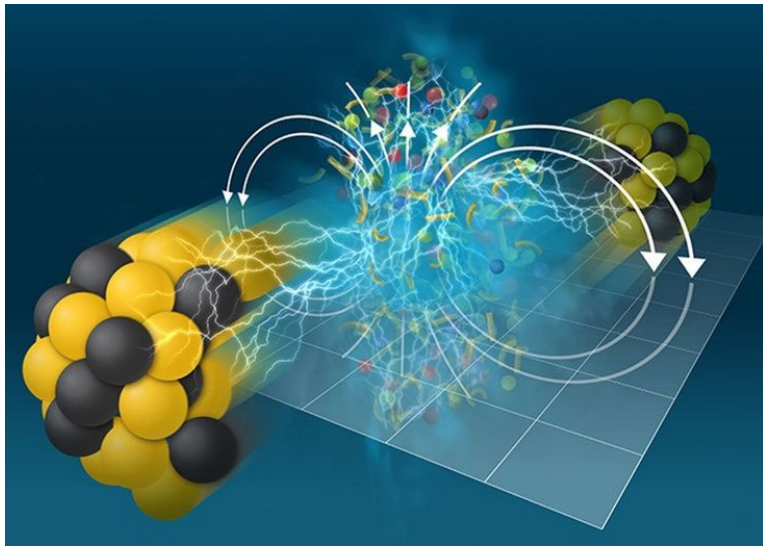



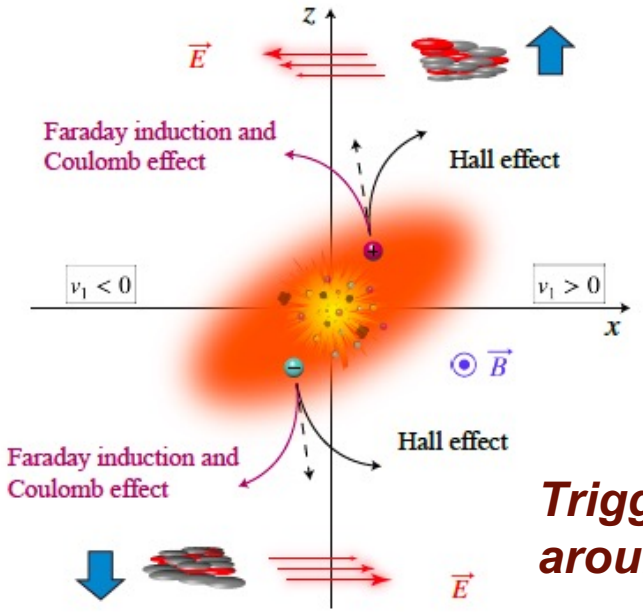

Completed sPHENIX detector construction and installation, sPHENIX commissioning with RHIC beams started in Run 2023



# Colossal Magnetic Field Detected in Nuclear Matter

STAR, arXiv: 2304.03430, PRX 14, 011028 (2024)

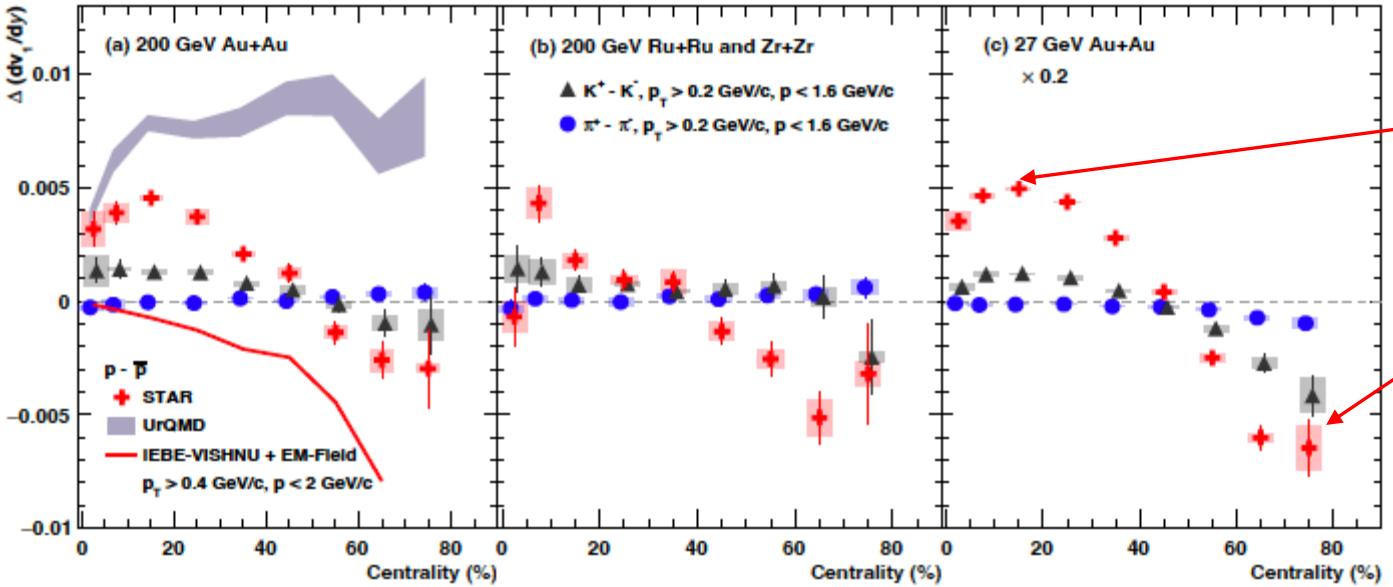





Transported-quark effect:
positive charge-dependent $v_1$ slope

Faraday + Coulomb:
negative charge-dependent $v_1$ slope

***Triggered international media interest around the world!***



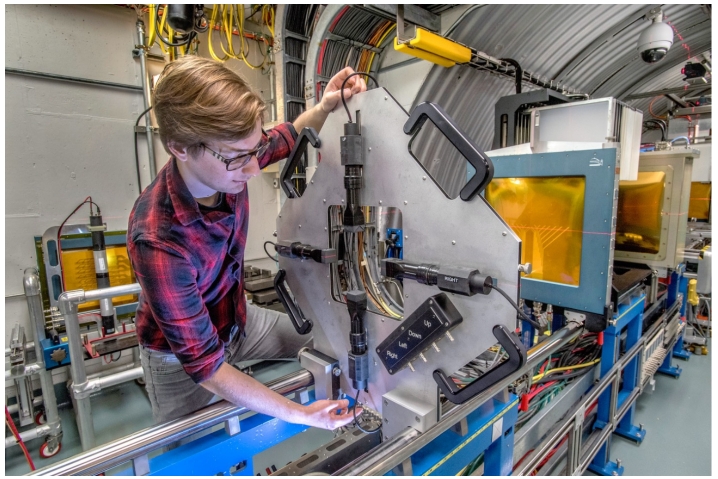

Results in central collisions can be explained by transported quark effect.

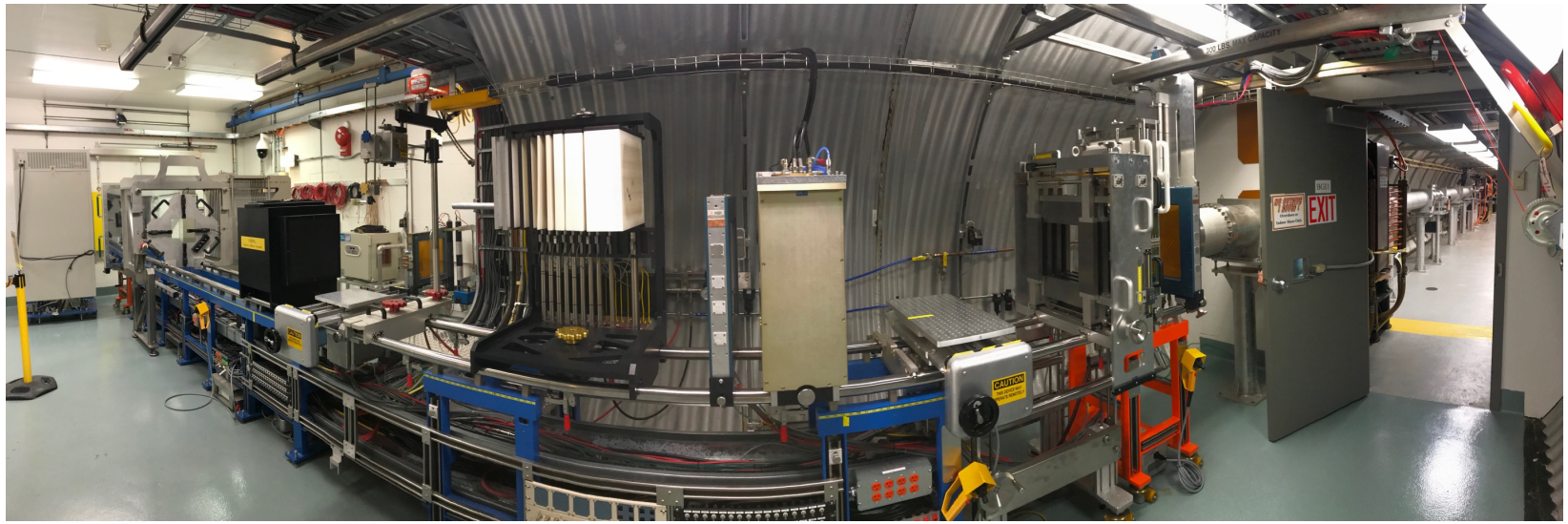
Results in peripheral collisions reveal the contributions from the Faraday induction and Coulomb effect for the first time in heavy-ion collisions.

# NASA Space Radiation Laboratory (NSRL)

- Started in 2003, simulates galactic radiation for human space flight
  - Heavy ion beams from AGS Booster
  - Electron Beam Ion Source (EBIS) provides all necessary ion beams
  - New laser ion source for EBIS allows for rapid species switching to simulate energy and species spectrum of deep space radiation field

- Additional uses of NSRL
  - Radiation effects studies (rapidly growing demand for satellite electronics testing)
  - R&D of ion beam cancer treatment
  - Agreement with NASA in place for non-NASA users ("non-designated user facility")



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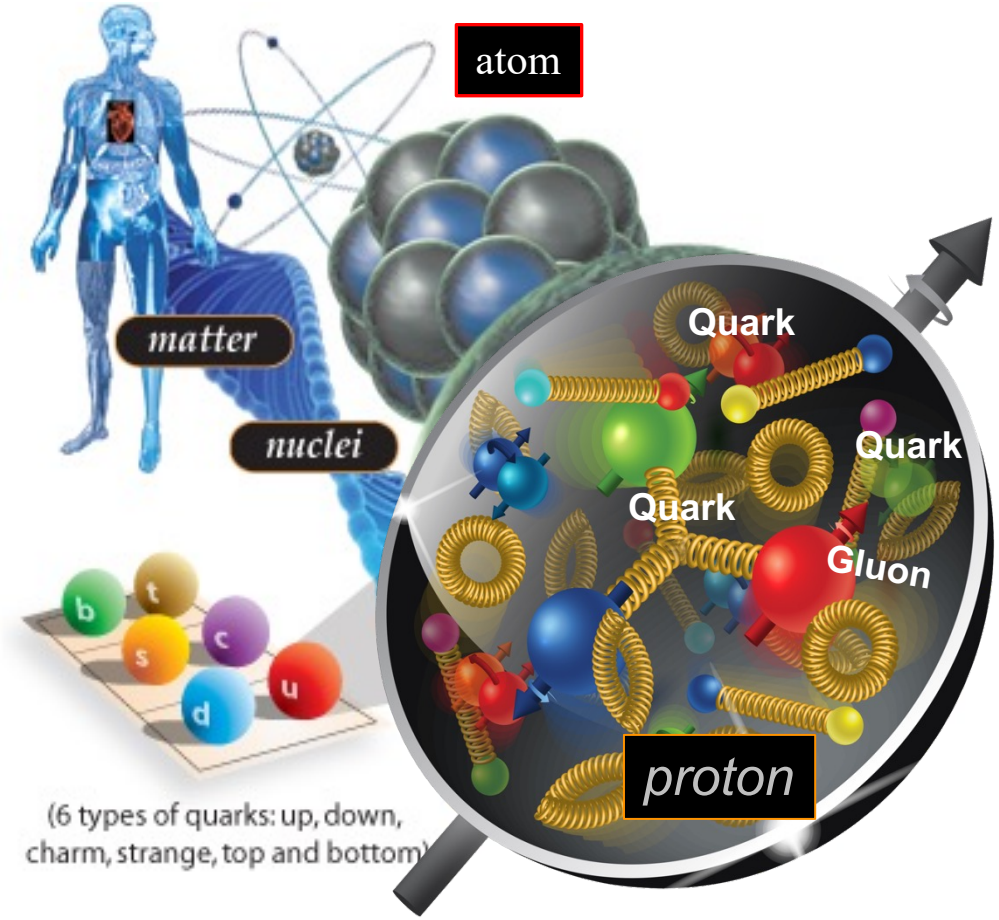
# Electron-Ion Collider is the Future for Brookhaven

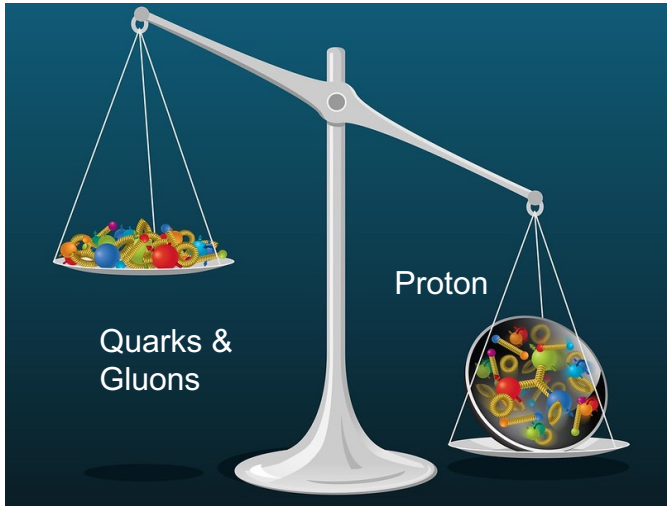


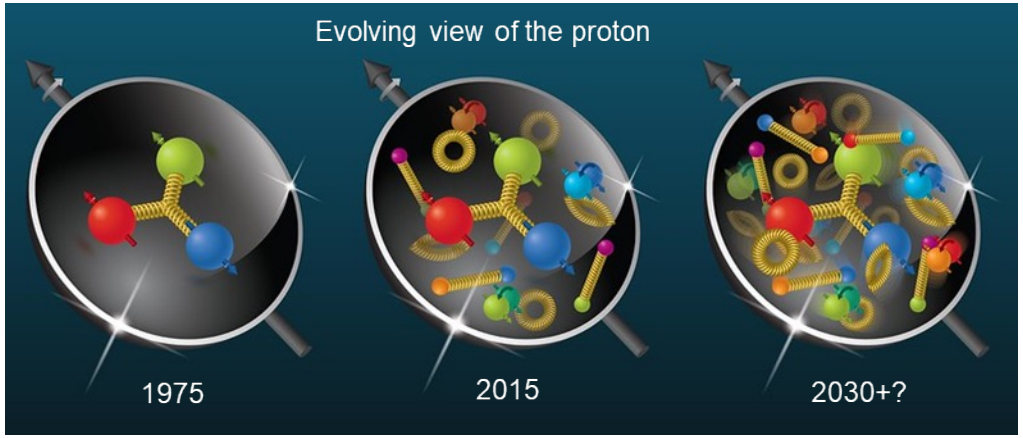

- The electronics revolution and today's technologies were driven by discoveries about electrons in the last century.
- EIC will peer *inside* atomic nuclei and individual protons to study the smallest building blocks of visible matter and the strongest force in nature.
- What we learn at the EIC will inspire the technologies of tomorrow.
- Partnership between DOE, NYS, BNL, and Jefferson Lab

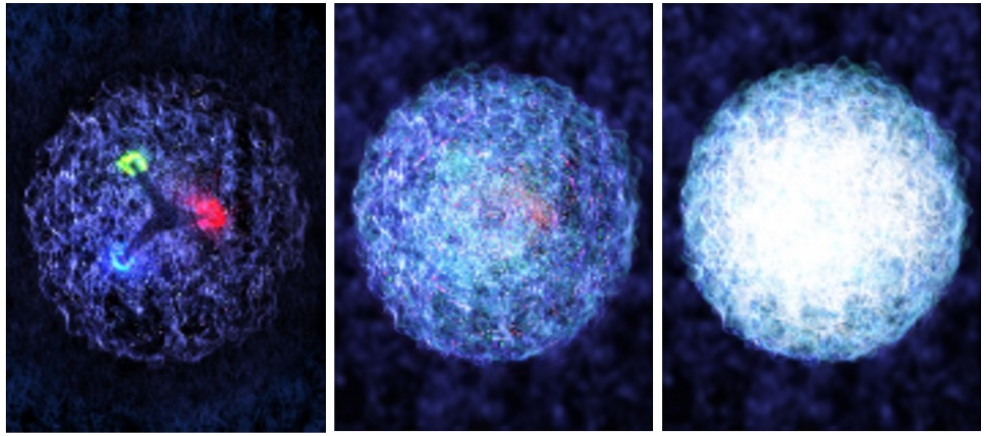
# EIC Science Goals

## EIC will answer these compelling questions:

- What is the origin of visible mass?
- What holds visible matter together, how?
- How do quarks and gluons contribute to the proton's spin?
- What is the nature of the "glue" that binds visible matter?
- Do gluons saturation the proton?
- What is the nature of pdf's at low-x?



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NATIONAL ACADEMY OF SCIENCES

# National Academy of Sciences Assessment (2018):

- EIC is **timely** and the science it will achieve is **unique** and **world leading** and will ensure **global U.S. leadership** in nuclear science, accelerator science, and the technology of colliders.
- EIC's questions regarding the building blocks of matter are **fundamental** and **compelling**; EIC is **essential** to answering these questions; EIC will have implications for particle physics and astrophysics and other fields.
- EIC innovations will **benefit** all accelerator-based sciences.

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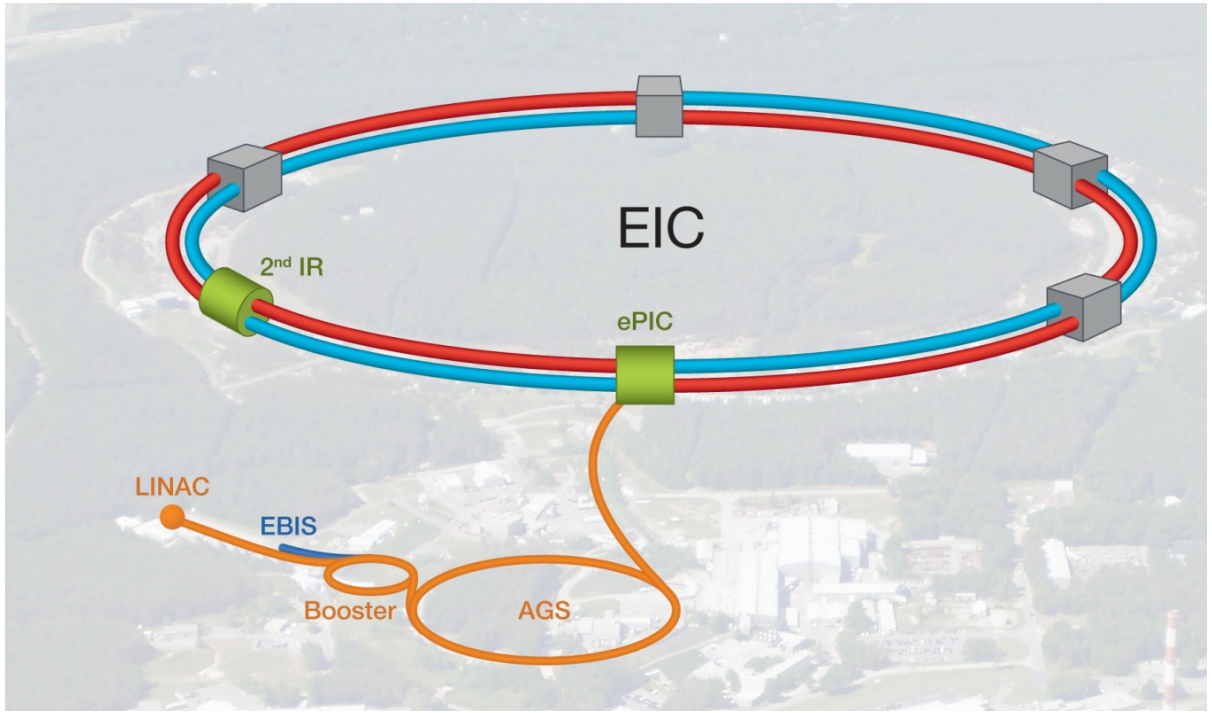
# U.S. Nuclear Science Advisory Committee
# 2023 Long Range Plan for Nuclear Science

"The Electron–Ion Collider (EIC), to be built in the United States, will elucidate the origin of visible matter in the universe and significantly advance accelerator technology as the first new particle collider to be constructed since the LHC."


**"We recommend the expeditious completion of the EIC as the highest priority for facility construction."**

# EIC Machine in the RHIC Tunnel

- Rapid Cycling Synchrotron (RCS) for electrons and Electron Storage Ring (SR) fit easily into the existing RHIC tunnel
- Polarized electron and proton and light-ion beams
- Two existing detector halls available for interaction regions and detectors
- Repurpose RHIC infrastructure and operations funding

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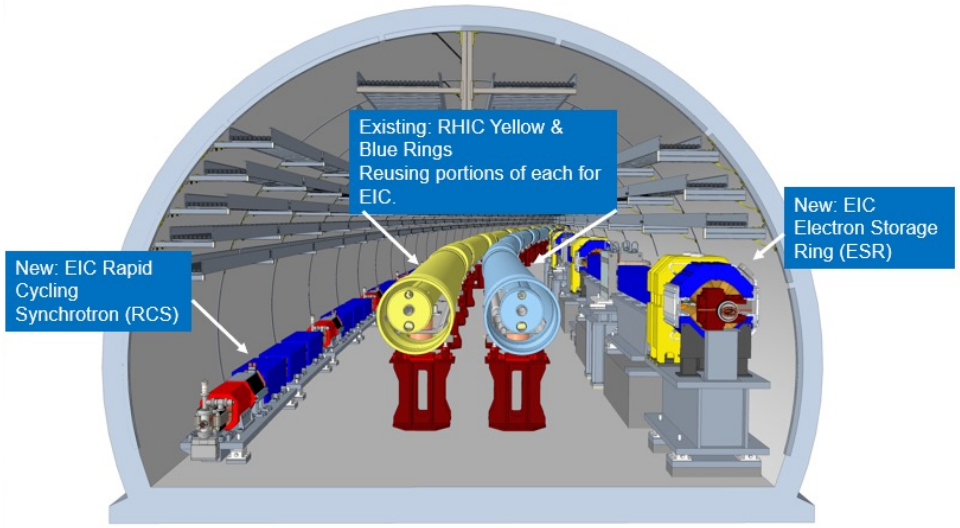
# Electron-Ion Collider Project Snapshot

| TPC | Project Leader | Last CD Achieved |
|---|---|---|
| $1.7B - $2.8B | Jim Yeck, EIC Project Director | CD-3A |

- CD-1 Approved Cost Range = $1.7-2.8B
- Current TPC Point Estimate = $2.78B
- Target Critical Decision Milestones Proposed Approval dates
  - Q2FY2024 CD-3A ($100M long-lead procurements)
  - FY2025-2026 CD-2/3
  - FY2034-35 CD-4 (early)




EIC Machine in the RHIC Tunnel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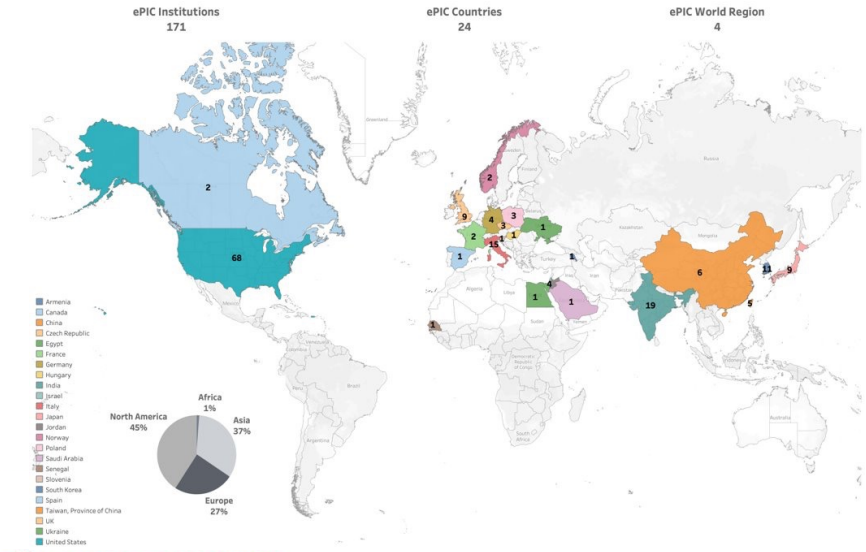
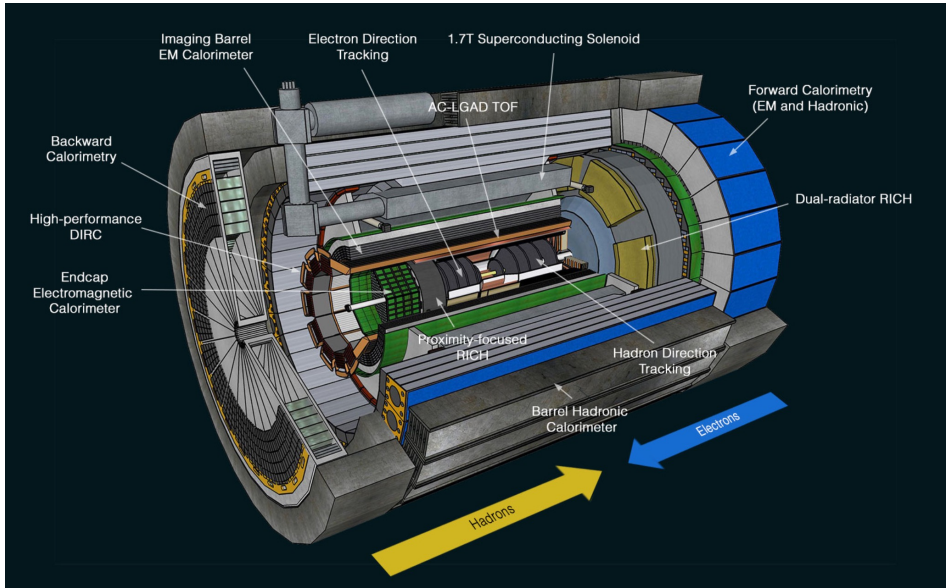
## Collaboration formed in 2022

- Current:  ~600 members, 24 countries, 171 institutions
- 13 new institutions since July 2023
- Leadership:
  - John Lajoie (ORNL) Spokesperson,
  - Silvia Dalla Torre (INFN Trieste) Deputy-Spokesperson




## 25 Detector subsystems

- Asymmetric beams and energies requires asymmetric detector with electron and hadron endcaps
- Tracking, PID, EM and hadronic calorimetry in all directions, covering equal rapidity areas (-4<η<4), high-precision polarimetry
- Momentum resolution dictates 2T large bore magnet
- Streaming electronic readout
- AI integrated from the start



# ePIC Baseline Technologies

Radius/Distance from IP

**Vertex detector** → Identify primary and secondary vertices,
Low material budget: 0.05% $X/X_0$ per layer;
High spatial resolution: 10 mm pitch CMOS Monolithic Active Pixel Sensor

**Central tracker** → Measure charged track momenta
MAPS – tracking layers in combination with micro pattern gas detectors
MPGD: m-RWell or MicroMegas

world's first

**electron and hadron endcap tracker** → Measure charged track momenta
MAPS – disks in combination with micro pattern gas detector disks

world's first

**Particle Identification** → pion, kaon, proton separation on track level
RICH detectors (modular and dual radiator RICH, DIRC) & Time-of-Flight
high resolution timing detectors (LAPPS, LGAD) 10 – 30 ps
novel photon sensors for RICHs: LAPPD & SiPMs

world's first

**Electromagnetic calorimeter** → Measure photons (E, angle), identify electrons
$PbWO_4$ Crystals (backward) with SiPM readout,
W/SciFi Spacal (forward), Barrel: Pb/SciFi+imaging part using ASTROPIX

world's first

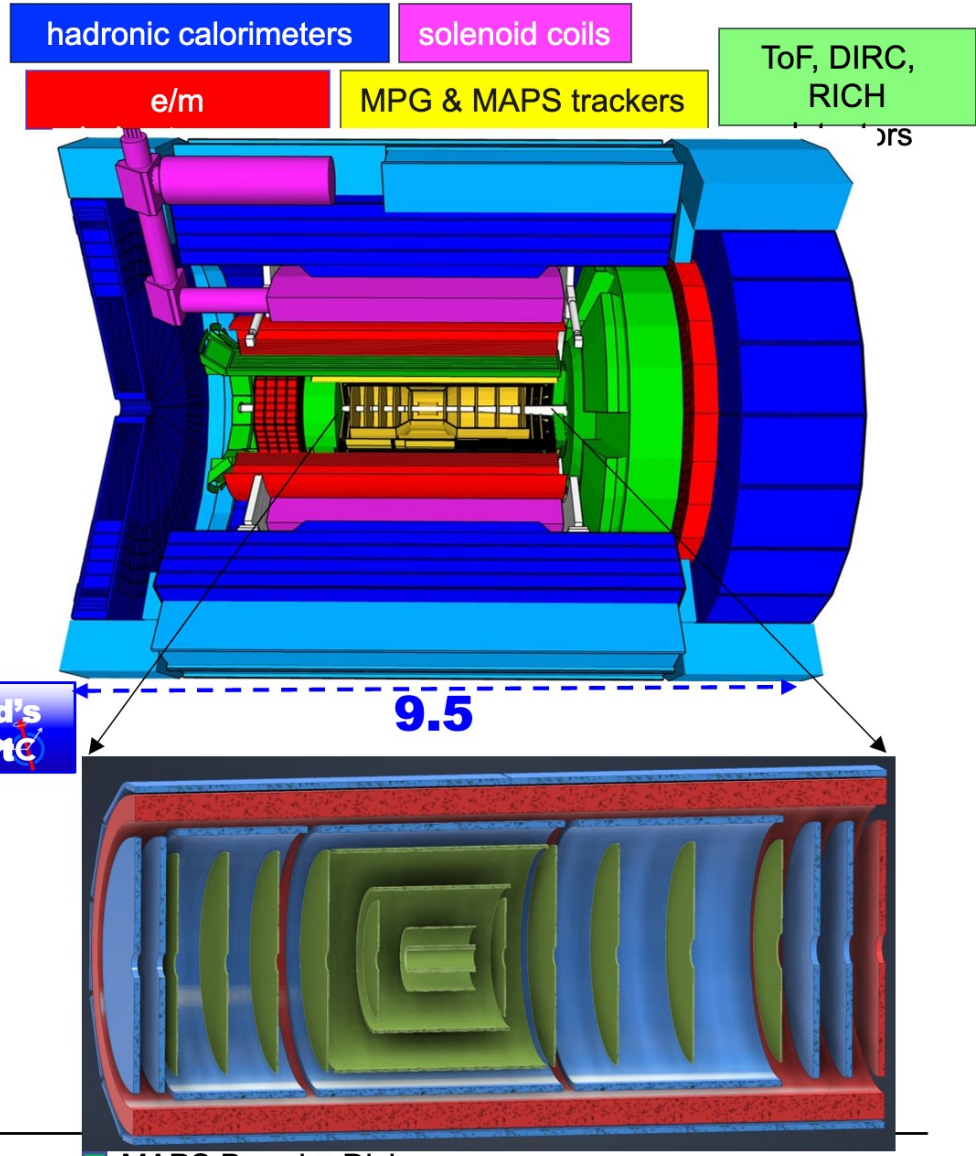
**Hadron calorimeter** → Measure charged hadrons, neutrons and $K_L^0$
challenge achieve ~50%/√E + 10% for low E hadrons (<E> ~ 20 GeV)
Steel/Sc sandwich sandwich with longitudinal segmentation & SiPM readout

world's first

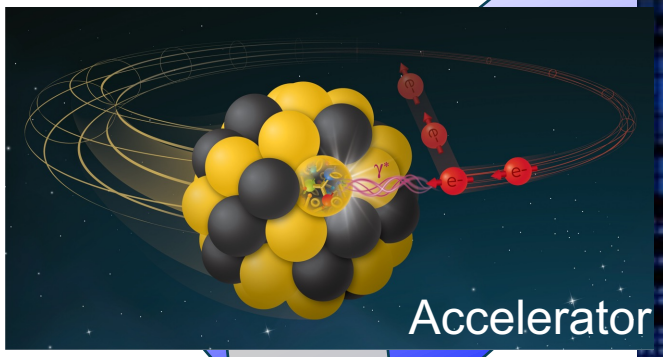
**DAQ & Readout Electronics:** trigger-less / streaming DAQ
Integrate AI into DAQ → cognizant Detector

**Very forward and backward detectors** → scattered particles under very small angles
AC-LGAD tracking layers in lepton and hadron beam direction
Zero – degree high resolution electromagnetic and hadronic calorimeter

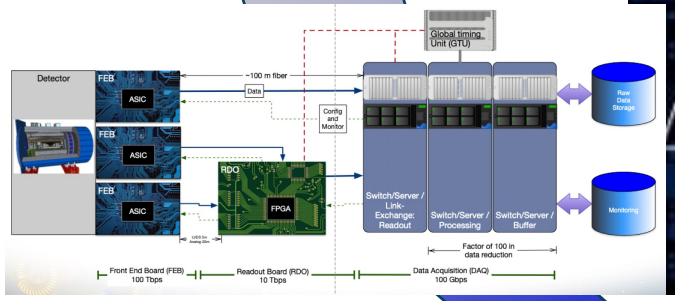
**Polarimetry**
Lepton: integrated transverse and longitudinal Compton polarimeter
Hadron: absolute and relative hadron polarimetry in the CNI region



# EIC end to end AI facility








Detector & Electronics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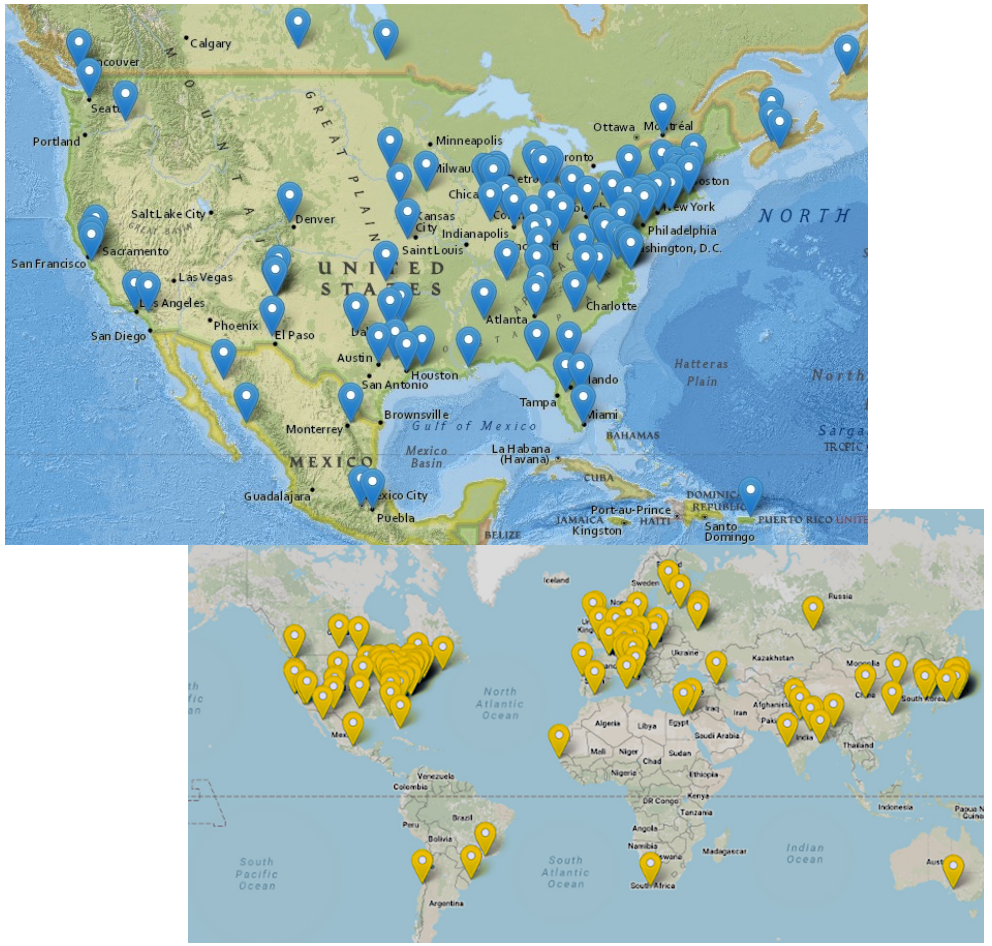
# Vibrant National & International Community

- Nine national labs and 99 U.S. universities and institutions, as well as 139 international partners, will participate in the EIC.
- The EIC scientist community has been growing rapidly—more than 1,400 scientists from more than 290 institutions in 38 countries around the world.
  - Electron-Ion Collider Group
  - EIC Theory Group
  - Center for Frontiers in Nuclear Science
  - EIC2@JLab

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# International Commitments & Interest

£ 58M Commitment

J. Hill (BNL), R. Patel (UKRI)

Signed Statements of Interest from CEA and CNRS

CNRS + BNL + DOE

A-I Etienvre (CEA), A. Berhe DOE

## Outlook

Mark Thomson Summary slide

**Overall, the STFC is in decent position**

- As always, there are many highlights
  - I was delighted that we secured approval of EIC funding
  - More generally, we are on track to deliver our Strategic Delivery Plan objectives

BNL is delighted with the UK EIC funding!

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# $100M from New York State ‘Empire State Development’

## Record funding from NYS for a scientific project!

- Partnership between NYS and DOE
- Signing ceremony April 9, 2024
- First installment already in hand
- Will support civil construction of EIC support buildings and roads
- Will create local jobs



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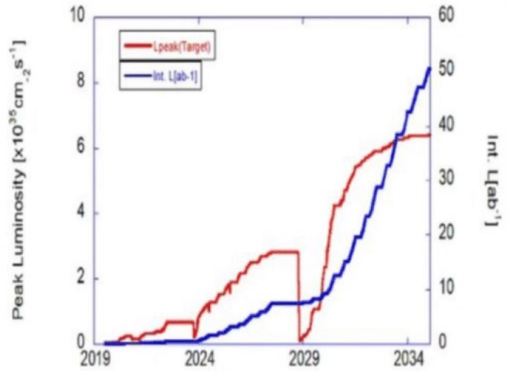
# Strong Ongoing BNL Program Enables HEP Science

- **ATLAS experiment at CERN**
  - Lead laboratory for US ATLAS
- **Neutrino Program at Fermilab**
  - Proto-DUNE detector with BNL-developed components
  - Studying properties of neutrinos at short-baseline
- **Belle II experiment at KEK**
  - Lead laboratory for US Belle II
- **Rubin Observatory**
  - Commissioning the experiment in Chile
- **Lu-SEE Night**
  - 21-cm cosmology from the dark-side of the moon
- **Theory, Detectors and Accelerators R&D**
  - Major contributions to the field

ATLAS muon system at CERN

SuperKEKB Luminosity

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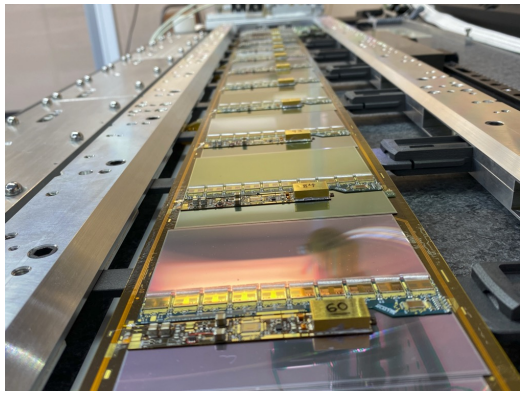
# Developing Future of BNL HEP Program

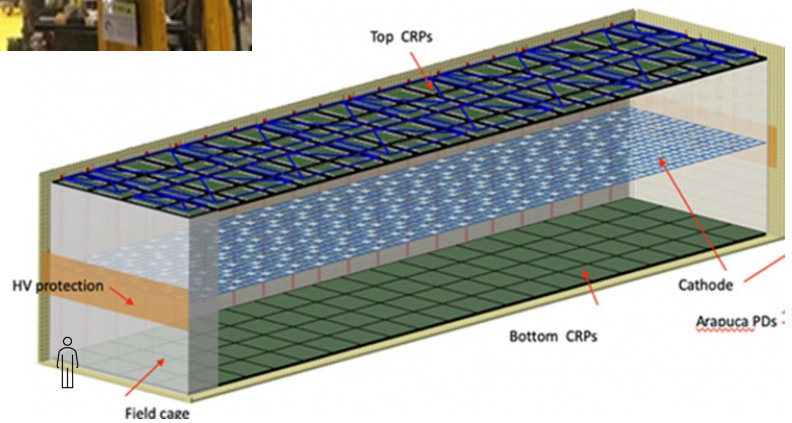
- **Energy Frontier**
  - Hosting project for $300M HL-LHC ATLAS upgrade
  - Building magnets for the HL-LHC
  - Developing HL-LHC computing and software
- **Intensity Frontier**
  - Contributing to DUNE experiment
    - Leading DUNE far detector Module 2 activities
  - Preparing Belle II detector for Run II
- **Cosmic Frontier**
  - Getting ready to analyze Rubin Observatory data
  - Lead-lab LuSEE-Night mission
- **Leading Technologies Developments for Particle Physics**
  - Computing and software
  - Detectors and electronics
  - Accelerator R&D including superconducting magnets

**HL-LHC magnet testing at BNL**

**ATLAS silicon assembly at BNL**



**DUNE Module 2 design**

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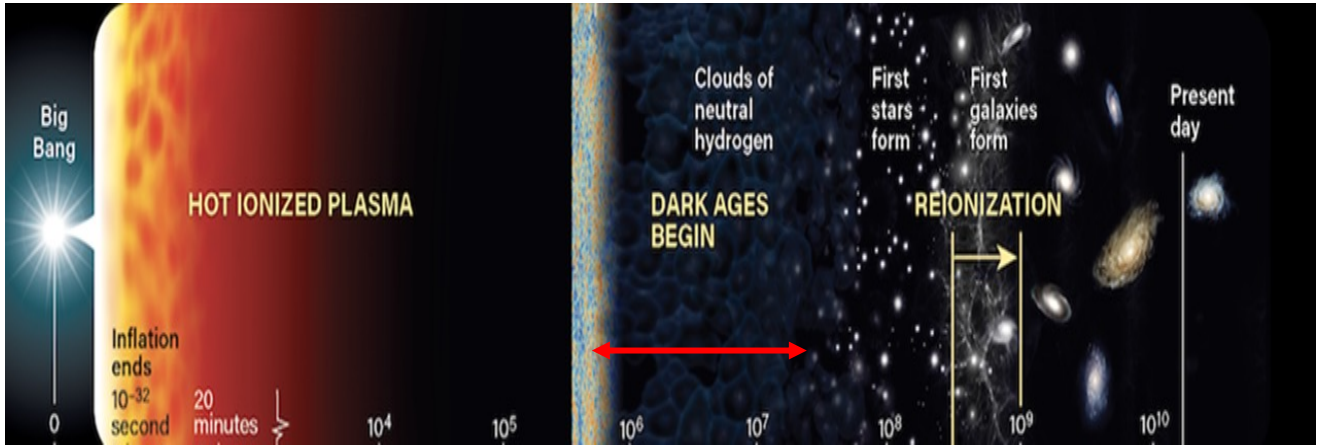
# Cosmic Frontier:  LuSEE-Night Mission

BNL leads joint DOE-NASA LuSEE-Night program

- Stage-1 21-cm cosmology experiment
- Radio antenna on NASA satellite
- Will operate on the dark side of the moon (!)
- Low-noise environment

**LuSEE-Night on the moon**

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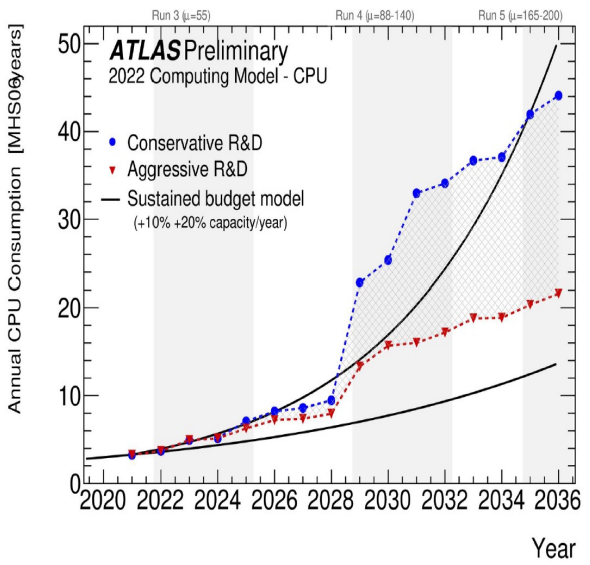
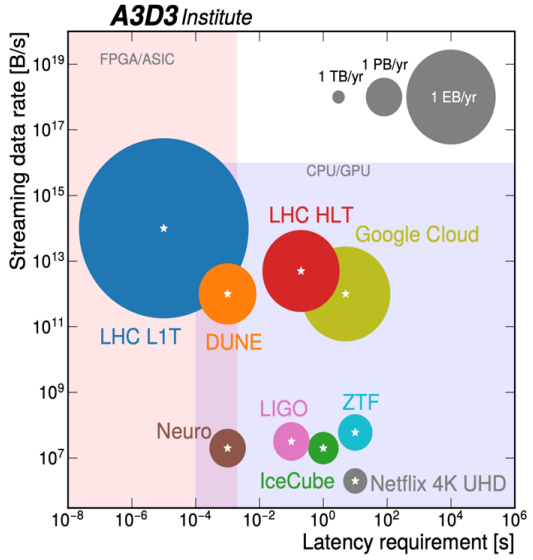
# Computing at Brookhaven

- Particle and Nuclear physics leads in the complexity and amount of the data collected and analyzed
- Computing requirements of HL-LHC/EIC are substantial
  - Solving them will advance computing frontier
- Synergies with other fields and industry
- Repurposed first generation light-source for new Scientific and Data Computation Center
  - Computing facility for ATLAS, Belle-II, NSLS-II, RHIC

## Computing challenges of LHC and DUNE




## New BNL computing facility

# Diversity, Equity, Inclusion and Accessibility

- Inclusive environment and diverse workforce are crucial for the field and for BNL to successfully pursue our mission
- Staff deeply committed to DEI improvements
- Brookhaven makes the Top 20 Government Employer List for 2023 in the 32nd Annual Equal Opportunity Magazine

**Top 20 Government Employers**

1. National Aeronautics and Space Administration (NASA)
2. Federal Aviation Administration (FAA)
3. National Security Agency (NSA)
4. U.S. Environmental Protection Agency (EPA)
5. U.S. Nuclear Regulatory Commission (NRC)
6. Air Force Civilian Service (AFCS)
7. U.S. Naval Research Lab (NRL)
8. U.S. Department of State (DOS)
9. Central Intelligence Agency (CIA)
10. Transportation Security Administration (TSA)
11. U.S. Secret Service (USSS)
12. Brookhaven National Laboratory
13. The Air Force Research Lab (AFRL)
14. U.S. Department of Commerce (DOC)
15. Oak Ridge National Laboratory (ORNL)
16. Military Sealift Command (MSC)
17. Los Alamos National Laboratory (LANL)
18. U.S. Army Corps of Engineers (USACE)
19. National Geospatial-Intelligence Agency (NGA)
20. Sandia National Laboratories

READERS' CHOICE 2022 TOP 20 GOVERNMENT EMPLOYERS STEM WORKFORCE DIVERSITY

Readers were asked to list the top STEM-focused government agencies for which they'd most like to work or which they believe would provide a positive working environment for members of minority groups and diverse cultures. Here are the results.

Brookhaven National Laboratory

# Brookhaven is Poised for Progress

## The EIC will be a world-leading discovery machine

- The only collider scheduled to be designed and built globally in the next one to two decades
- Crucial project to develop and maintain accelerator science workforce
- RHIC is a science producing machine!
- 23 continuous years of operation with 2 more years planned before shut-down
- Particle physics program is strong with major involvement in each of the Energy, Intensity, and Cosmic frontiers

Brookhaven National Laboratory