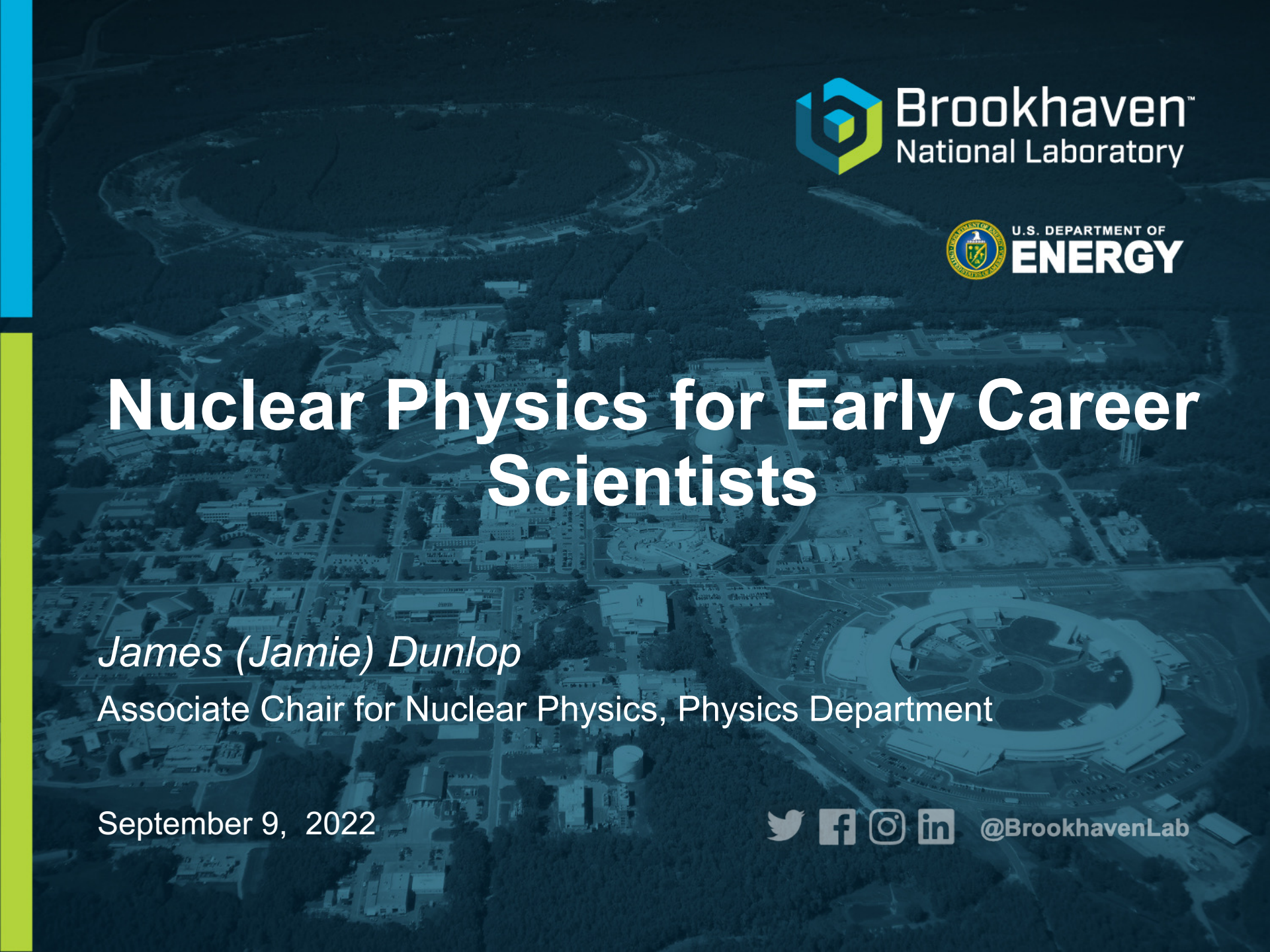


Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Nuclear Physics for Early Career Scientists

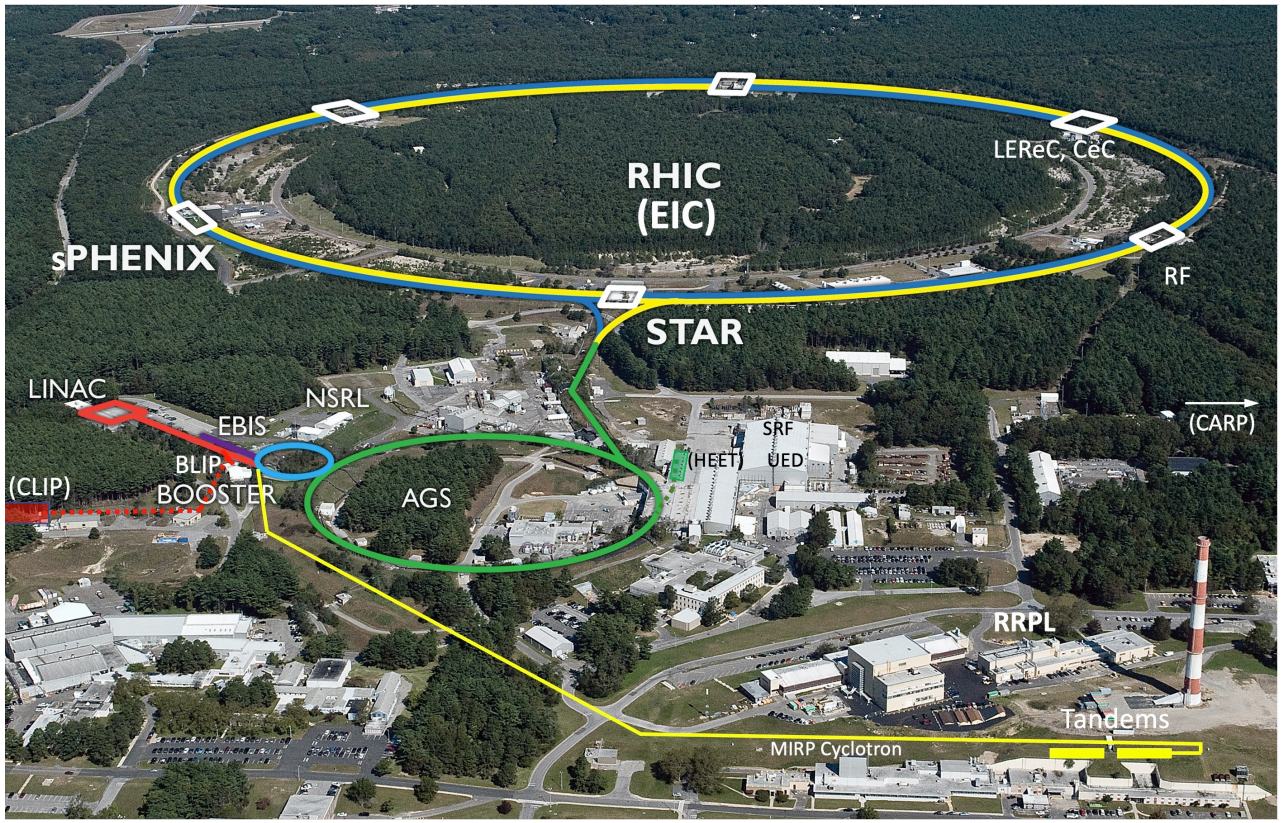
James (Jamie) Dunlop

Associate Chair for Nuclear Physics, Physics Department

September 9, 2022

@BrookhavenLab

Nuclear Physics at BNL

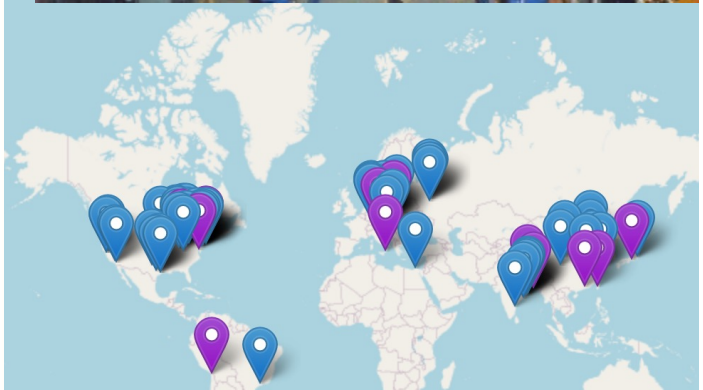


Our mission is to lead and support discovery-based, innovation-driven research at the frontiers of the subatomic world.

We are world-leading in nuclear physics research, building and operating accelerator-based user facilities that serve international scientific communities.

Serve International Scientific Communities

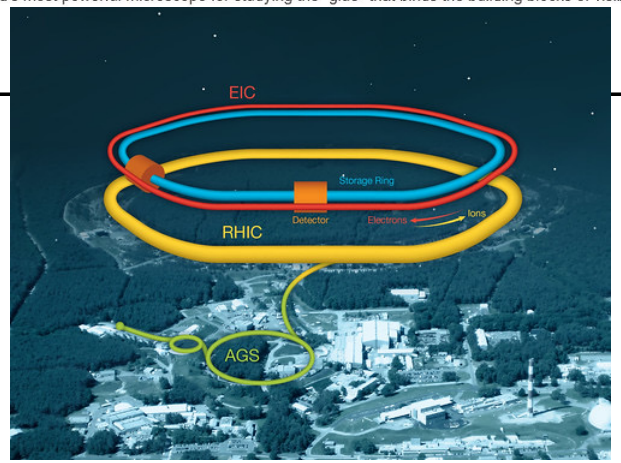
STAR

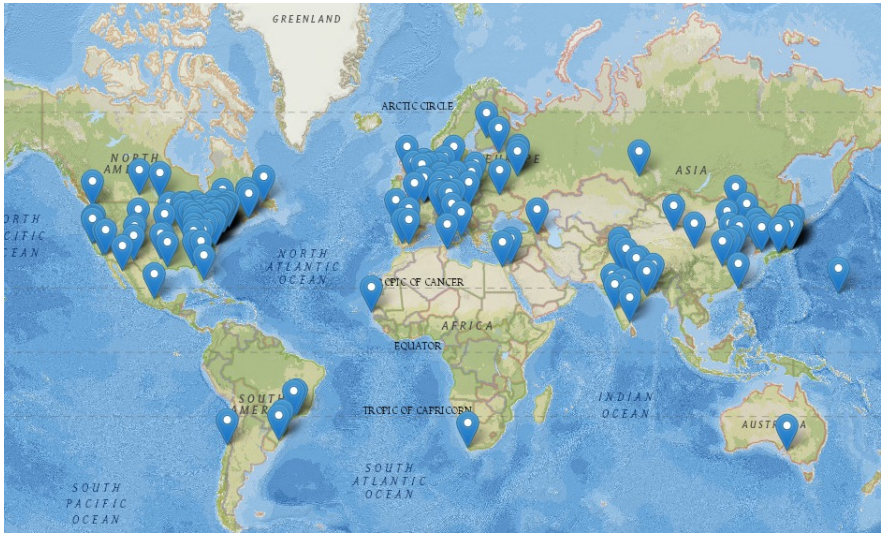


STAR: 72 Institutes
from 15 Countries,
736 Collaborators

Electron-Ion Collider User Group

The world's most powerful microscope for studying the "glue" that binds the building blocks of visible matter.

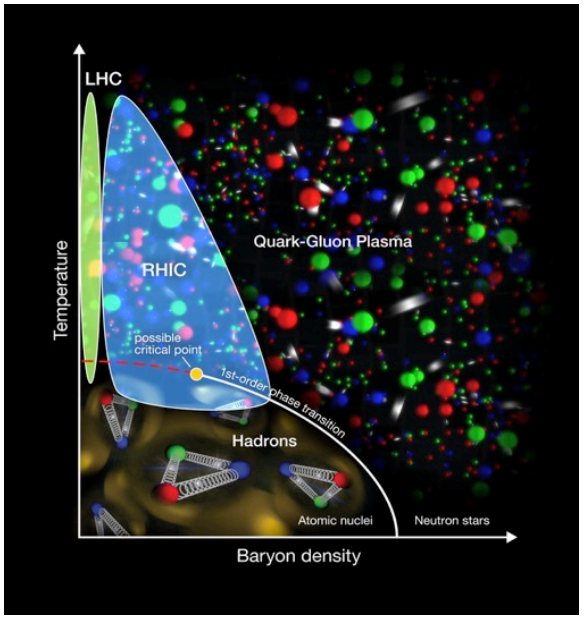


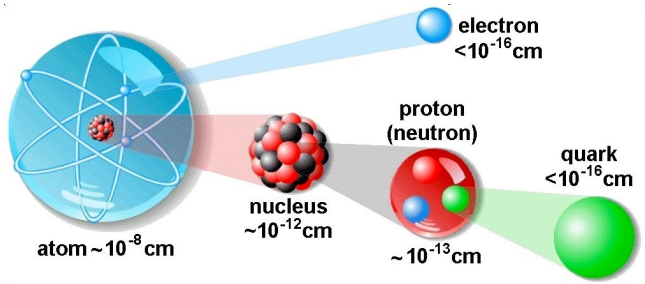


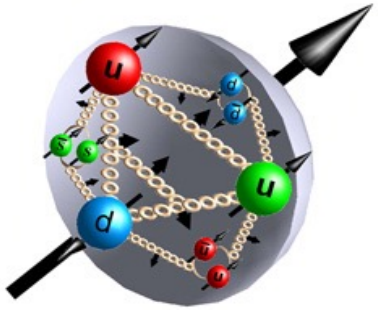
EIC Users Group: 267 Institutes
from 36 Countries,
1358 members

RHIC – 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 of spin polarized protons to explore the internal spin structure of protons.
  - Gluons carry part of proton spin







Brookhaven National Laboratory

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

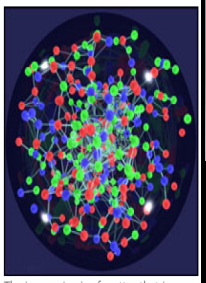
The Washington Post

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

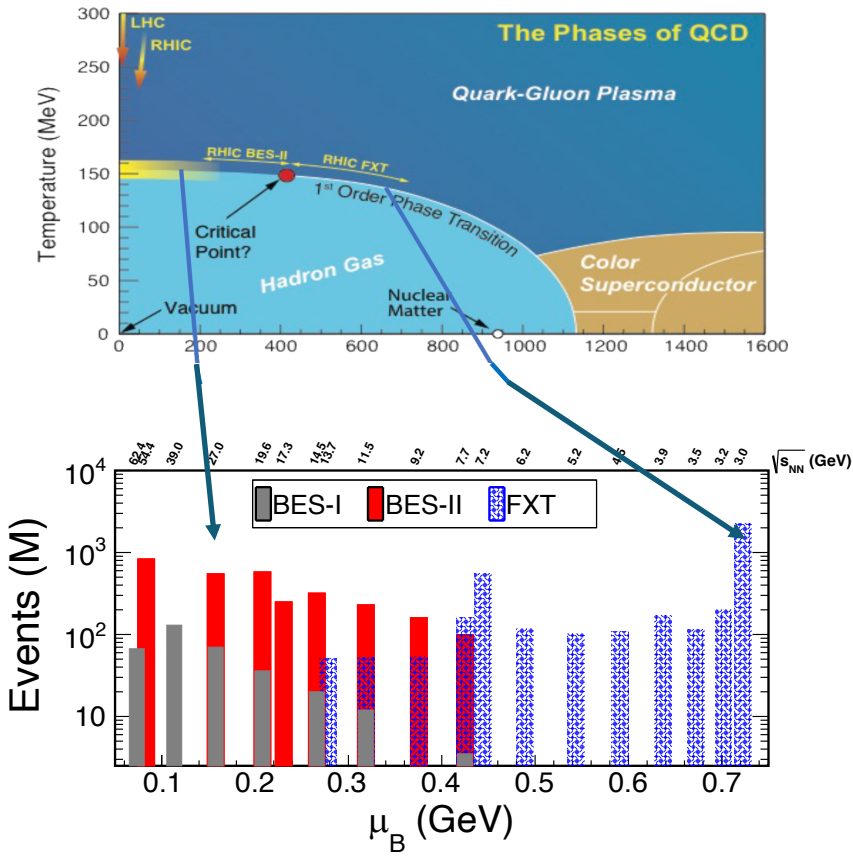
PHYSICISTS RE-CREATE THE LIQUID STUFF OF THE EARLIEST UNIVERSE

Brookhaven National Laboratory

RHIC in the 2015 Nuclear Science Advisory Committee 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.**"

LEReC = Low Energy RHIC electron Cooling
First-ever electron cooling with bunched beams
Test case for electron cooling at EIC



Beam Energy Scan

- What is the phase boundary of ordinary nuclear matter?
- Is there a critical point in the QCD phase diagram? If so, where?

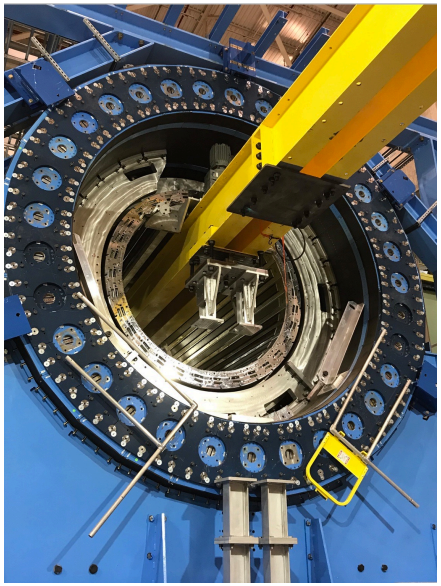
BES-2 Completed as of June 7, 2021!

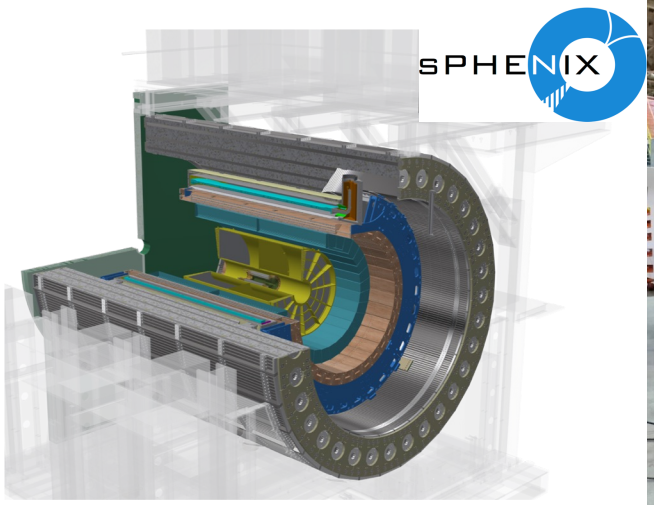
Brookhaven National Laboratory

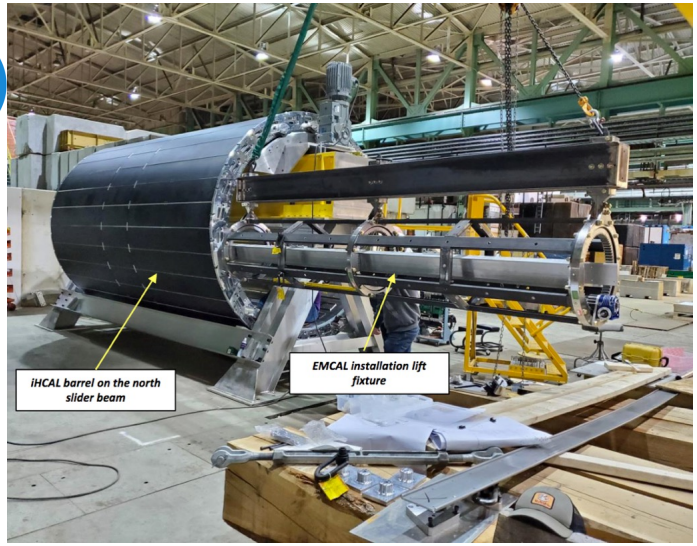
Completing the 2nd RHIC Goal in 2015 LRP

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 will fully utilize the enhanced (~50 times AuAu design) luminosity of RHIC together with STAR

sPHENIX moving into its home

Scientific Data and Computer Center

Smooth operation of computing for RHIC

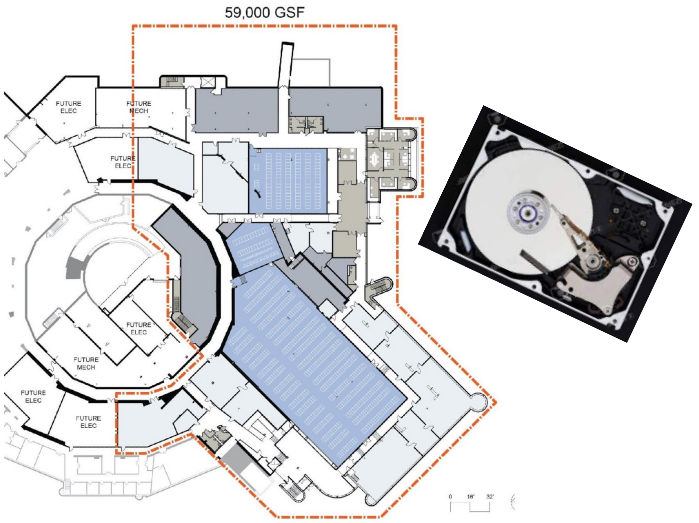
BIG Data: sPHENIX > 100 PB/year

Preparing for the Future

- sPHENIX computing model commissioning
- Installation of sPHENIX hardware
- Support for EIC detector proposals
- Coordinated effort with JLAB on EIC computing
- Engagement in BNL's AI/ML strategy and planning
- Model to support BNL's centralized computing being developed

New data center

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



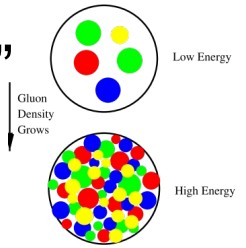
New data center - main hall

Brookhaven National Laboratory

Nuclear Theory

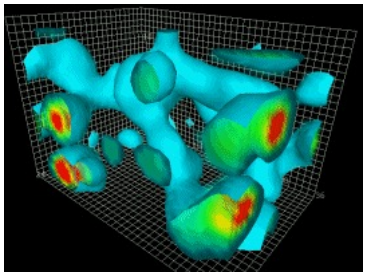
BNL Nuclear Theory group: flagship group with deep expertise

Saturation physics: coined the “Color Glass Condensate”



Condensed matter of the QCD form:

Topological properties and phase transitions



Spin structure of the proton and nuclei

Lattice QCD: fundaments and advances in computation

Major contributor to BNL’s Quantum Computing effort (C^2QA)

Early Career Awards

Lijuan Ruan (2013)

Mid-rapidity Di-lepton Measurements at RHIC with the Muon Telescope Detector at STAR

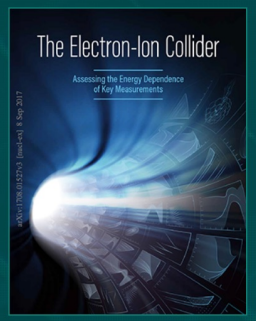
Bjorn Schenke (2014)

Development of a Comprehensive Description of High-Energy Nuclear Collisions at RHIC and LHC and Electron-Ion Collisions at a Future Electron-Ion-Collider

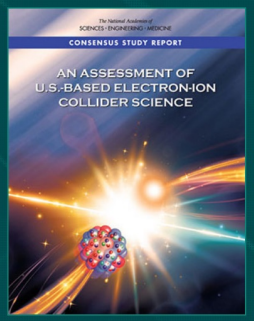
Electron Ion Collider

EIC Studies and Reports

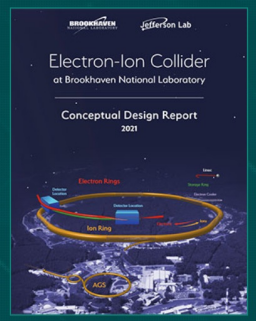
Electron-Ion Collider: The Next QCD Frontier (PDF)



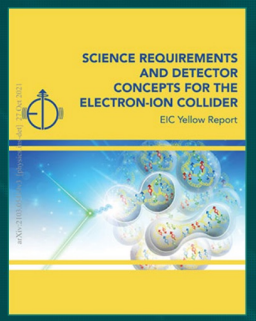
The Electron-Ion Collider: Assessing the Energy Dependence of Key Measurements (PDF)



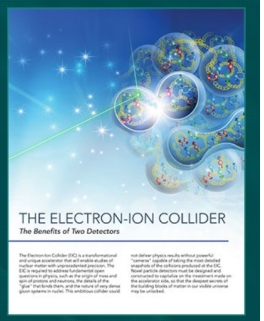
An Assessment of U.S.-Based Electron-Ion Collider Science



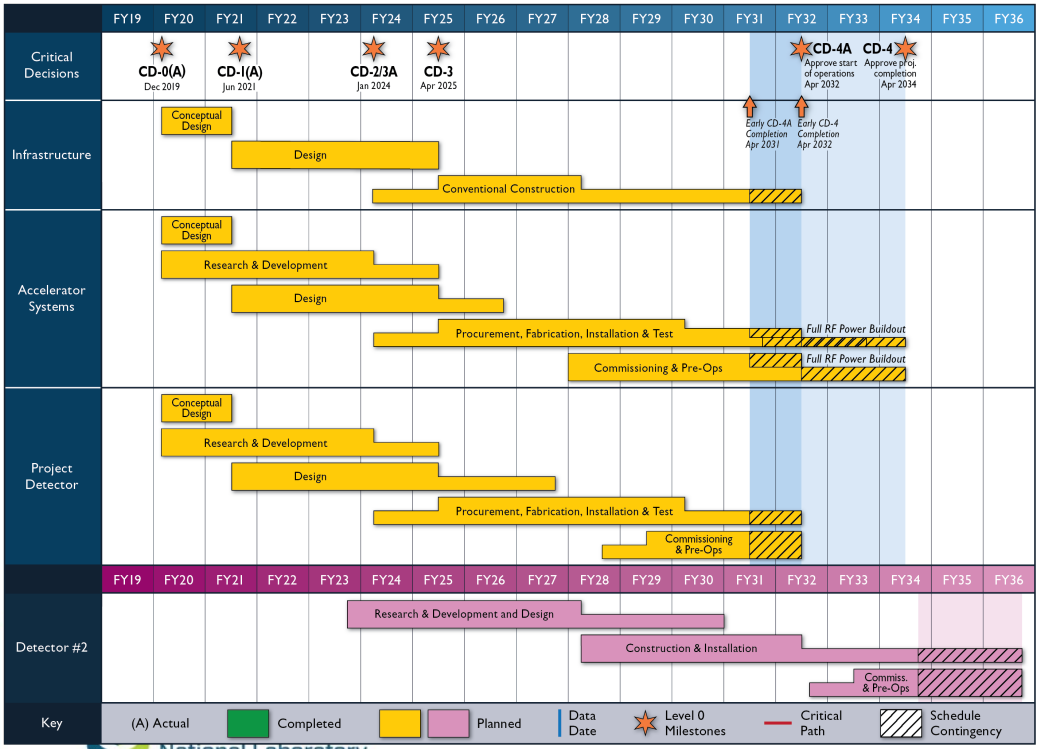
Conceptual Design Report for the Electron-Ion Collider (PDF, 170 Mb)



Science Requirements and Detector Concepts for the Electron-Ion Collider (PDF)



The Electron-Ion Collider: the Benefits of Two Detectors (PDF)



EIC is coming, soon

- Plan: RHIC datataking ends June 2025
- ePIC detector concept rapidly converging
  - CD-2/3A Jan 2024

Many opportunities to make your mark