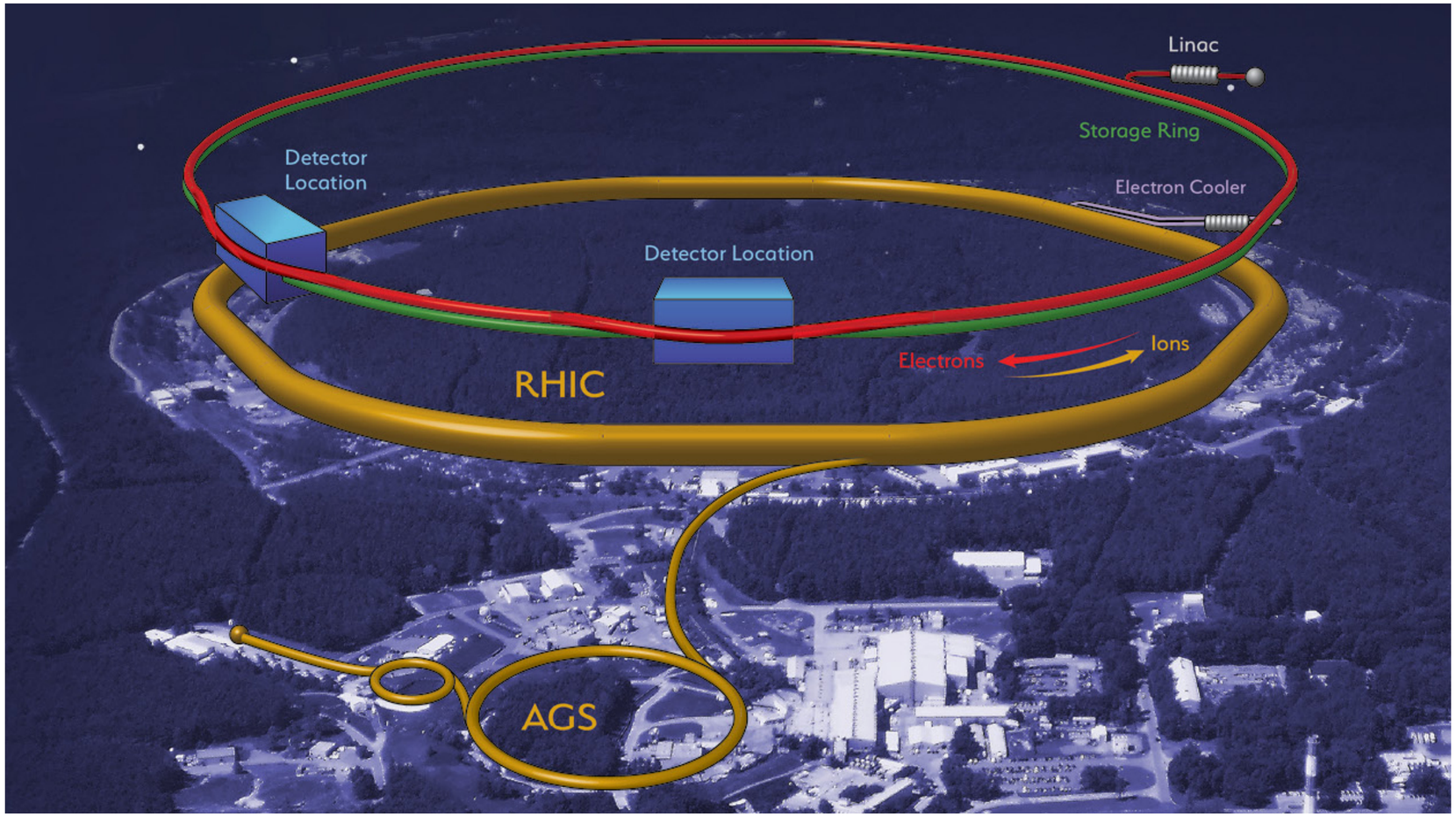
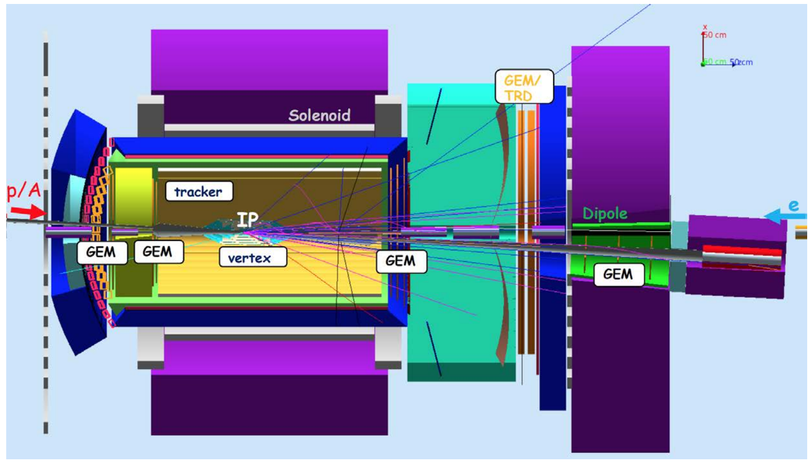
The Electron-Ion Collider

Opportunities in Instrumentation





Thomas Ullrich (BNL/Yale)
Yale Day of Instrumentation
January 24, 2020

January 9, 2020

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🚨BREAKING: DOE Selects @BrookhavenLab to Host Major New Nuclear Physics Facility

"This facility will deepen our understanding of nature and is expected to be the source of insights ultimately leading to new technology and innovation." -@SecBrouillette

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U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020

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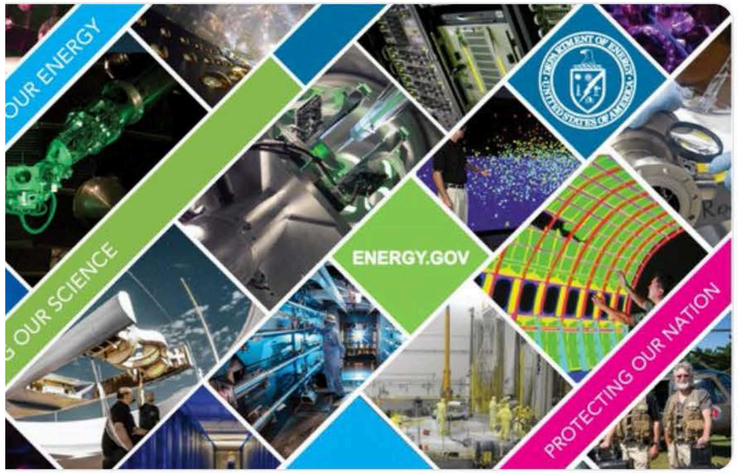

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Science

If all goes as physicists hope, the Relativistic Heavy Ion Collider (ring above) at Brookhaven National Laboratory will be converted into the Electron-Ion Collider. GETTY IMAGES

Department of Energy picks New York over Virginia for site of new particle collider

By **Adrian Cho** | Jan. 9, 2020 , 12:00 PM

Nuclear physicists' next dream machine will be built at Brookhaven National Laboratory in Upton, New York, officials with the Department of Energy (DOE) announced today. The Electron-Ion Collider (EIC) will smash a high-energy beam of electrons into one of protons to probe the mysterious innards of the proton. The machine will cost between $1.6 billion and $2.6 billion and should be up and running by 2030, said Paul Dabbar, DOE's undersecretary for science, in a telephone press briefing.

"It will be the first brand-new greenfield collider built in the country in decades," Dabbar said. "The U.S. has been at the front end in nuclear physics since the end of the Second World War and this machine will enable the U.S. to stay at the front end for decades to come."

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Ion-collider project to cost up to $2.6B and may generate 1,000 jobs

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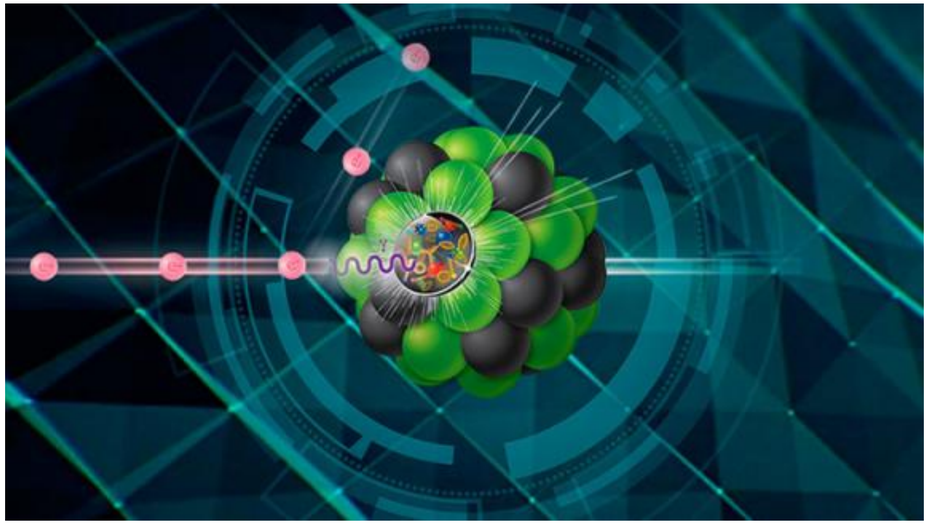
Department of Energy Selects Site for Electron-Ion Collider

10 January 2020 - Brookhaven National Laboratory

New facility to be located at Brookhaven Lab will allow scientists from across the nation and around the globe to peer inside protons and atomic nuclei to reveal secrets of the strongest force in nature



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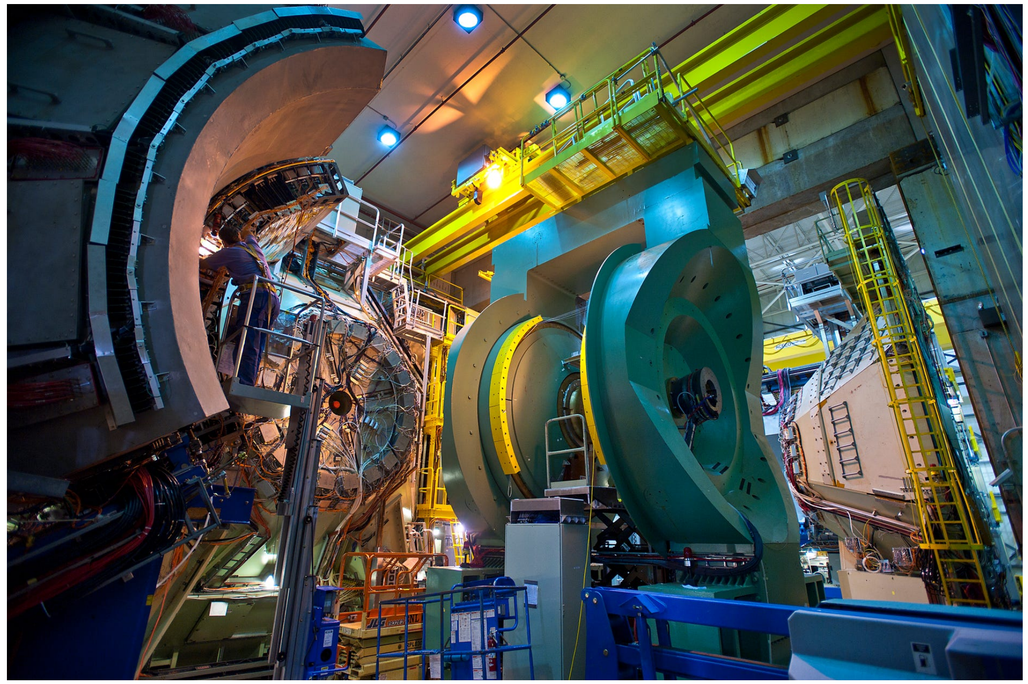
The US is building its first new particle collider in decades on Long Island. Stephen Hawking called the technology a 'time machine.'

Aria Bendix Jan 11, 2020, 8:56 AM



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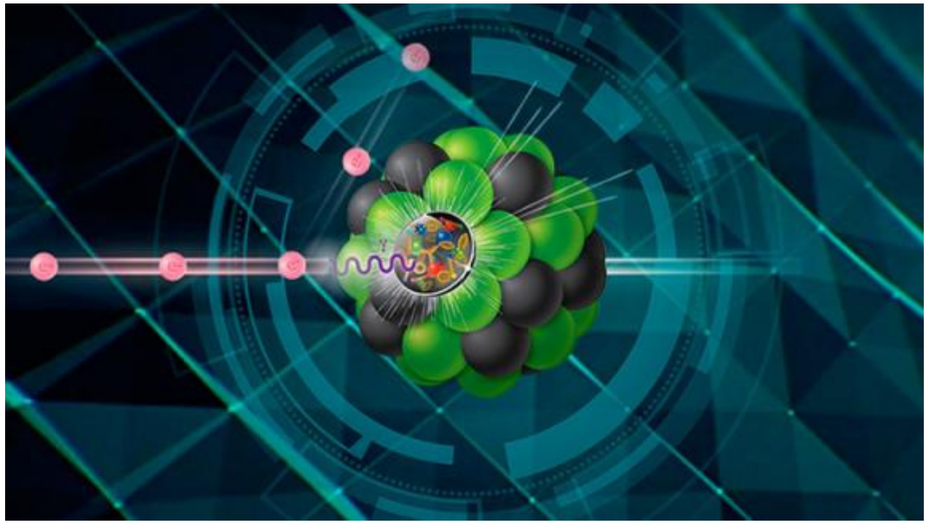

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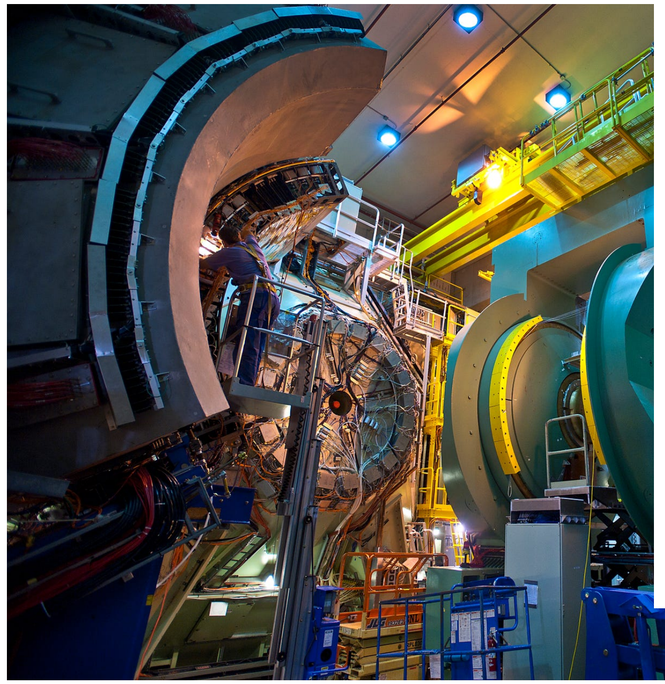

The Relativistic Heavy Ion Collider at the Brookhaven National Laboratory. Brookhaven National Laboratory

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Brookhaven to host Electron-Ion Collider

14 January 2020

The US Department of Energy has selected a plan whereby accelerator infrastructure at the Relativistic Heavy-Ion Collider at Brookhaven National Laboratory (pictured) will be reconfigured to boast a new electron storage ring in addition to existing infrastructure for the acceleration of heavy ions. Credit: BNL

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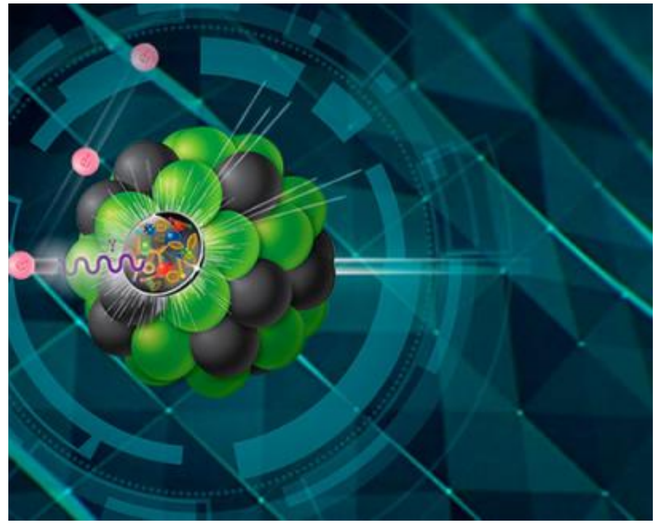

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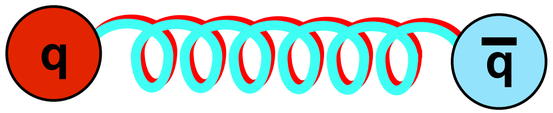
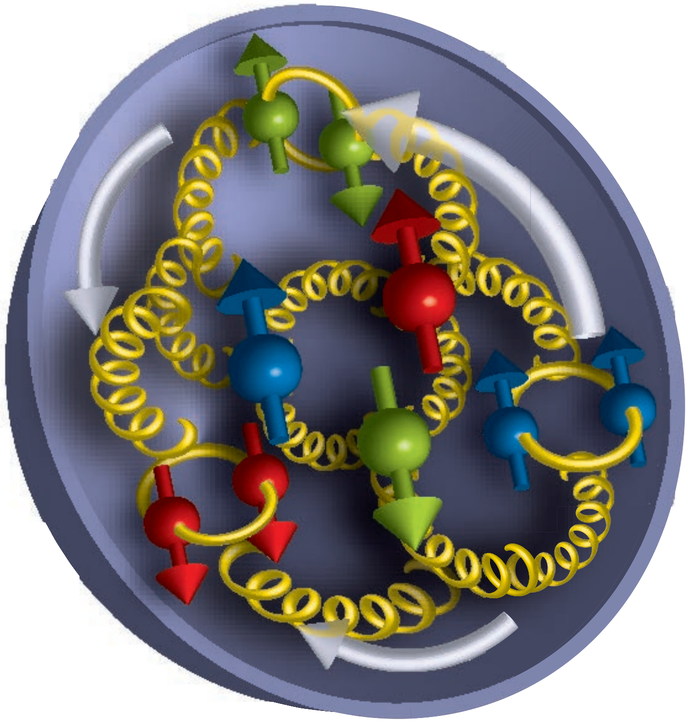
The Glue that Binds Us All

Quarks are the fundamental building blocks of nucleons (protons and neutrons) and thus of all visible matter.

What holds them together are gluons the exchange particles of the color fields

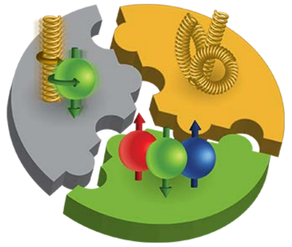


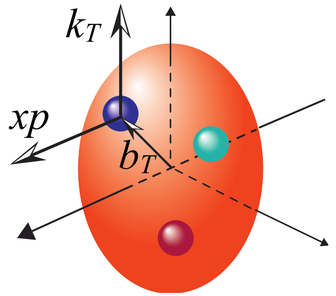


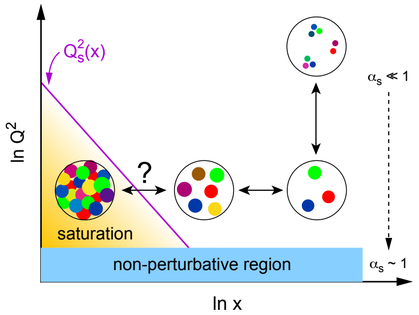
As we learned in the 90s, the closer we look (with more powerful instruments) the more we realized that nucleons consist almost entirely of gluons

The Big Questions

- All visible matter is an *emergent* consequence of quark-gluon dynamics & gluon self-interaction
- Despite their fundamental importance, little is known about gluons and their dynamics
- How do the nucleon properties emerge from quarks and gluons and their interactions?
  - Spin, mass?
  - Distribution of quarks and gluons in momentum and coordinate space?
- How do particles emerge from these quarks and gluons?
- What happens to the exploding gluon density at higher energies? Does it saturate, giving rise to a realm of gluonic matter with universal properties?

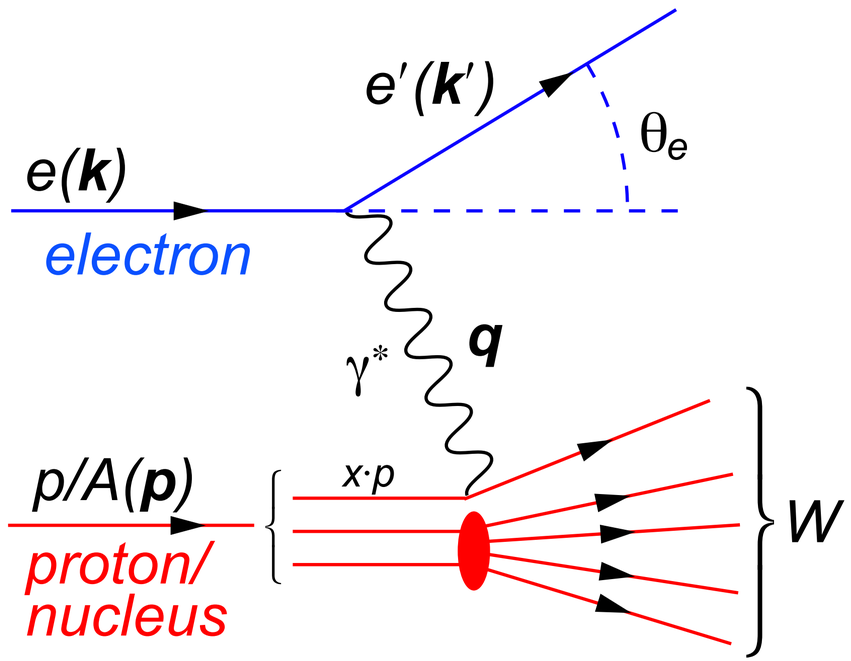






How to Answer these Questions?

Deep inelastic Scattering

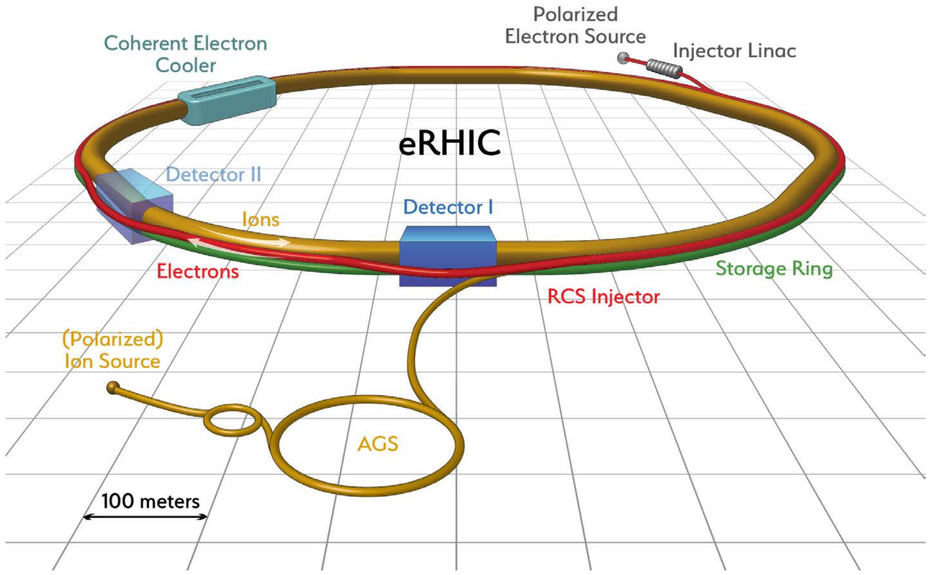


- Electrons scatter off the proton/ion and kick-out their building blocks, the quarks
- Quarks hadronize into particles
- From measuring the scattered electrons and the debris of the collision we can learn about the inner working and dynamics in the target (proton or nuclei) and ultimately about quarks and gluons

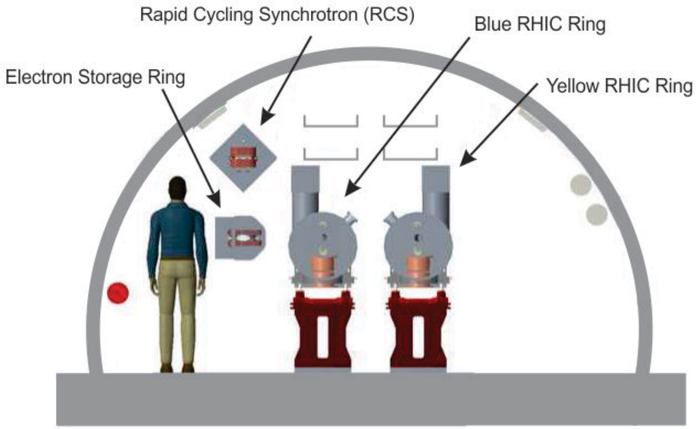
Electron-Ion Collider is high-resolution giant electron microscope (≤ 0.01 fm) to understand hadronic and nuclear matter and their properties

The Electron-Ion Collider (EIC)

- Particle Collider (Accelerator)
  - One ring accelerates and stores electrons
  - Another ring accelerates and hadrons
    - protons
    - ions from D, He, up to Au and Pb
- Beams collide at 2 Interaction Points



- Variable energy $\sqrt{s}$ = 20 - 140 GeV
- High intensity/luminosity (100-1000 times that of previous ep collider)
- Unique at EIC: polarized electrons and protons

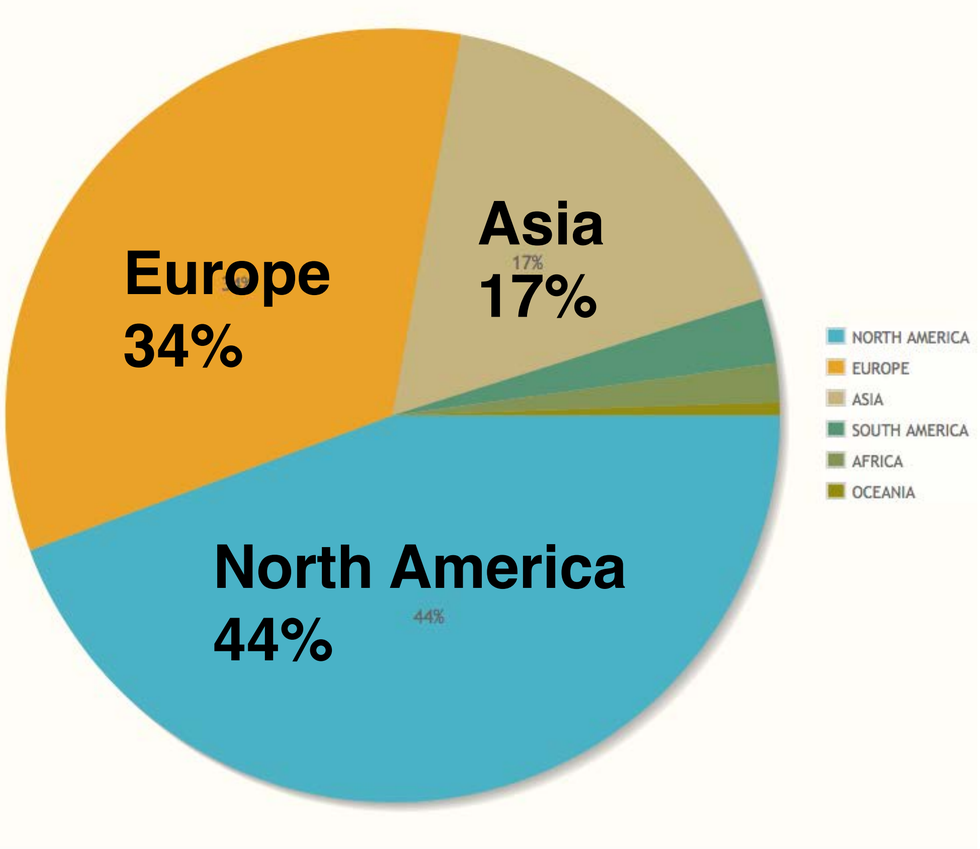


Originally proposed to be constructed in the US at either Jefferson Lab or Brookhaven Lab

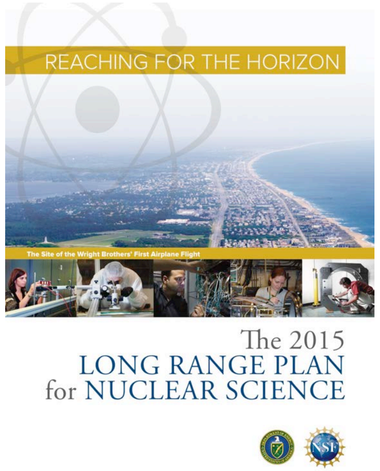
The Community Behind the EIC

The EIC User Group: http://eicug.org

- 995 members, 205 institutions, 30 countries
- Elected Steering Committee, Workshops, User Meetings, Working Groups



Status of US Based EIC?

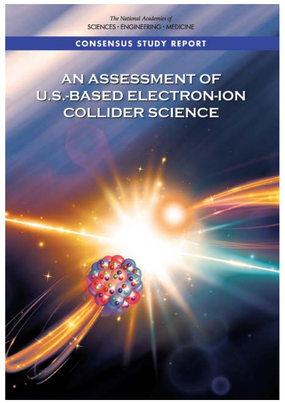


2015: US Nuclear Physics Long Range Plan:

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

2018: National Academy EIC Review

"The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely."



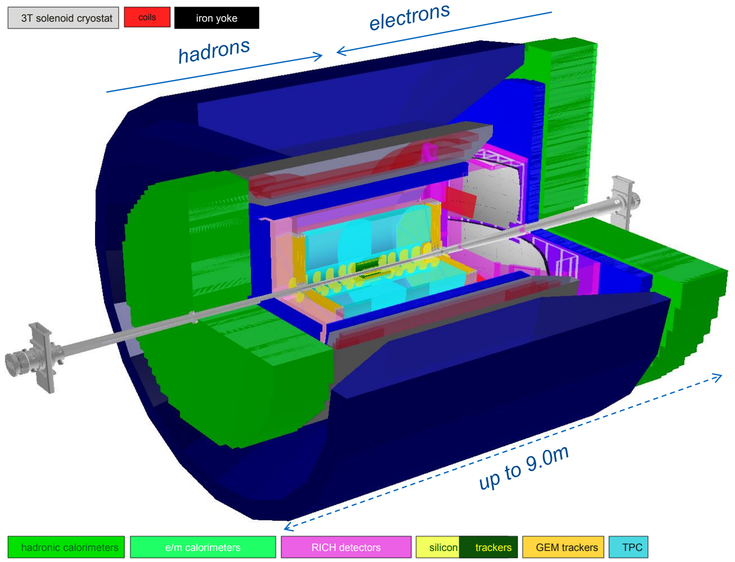
January 2020: DoE (US Department of Energy)

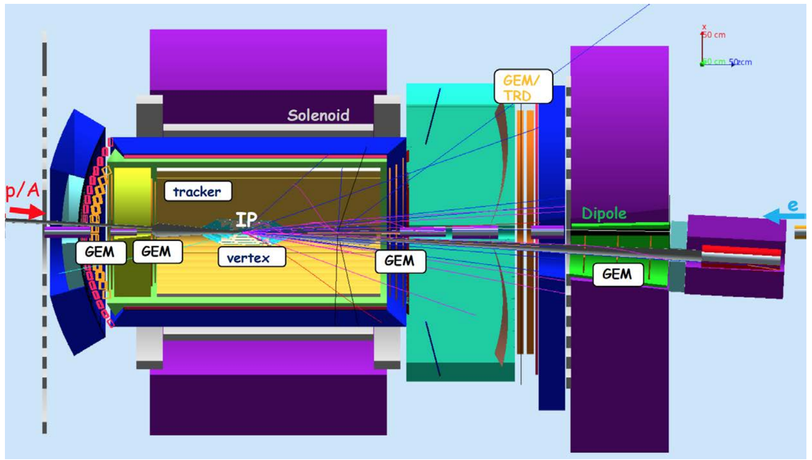
After science, cost, and host review DoE gives EIC CD-0 (Mission Need) and selects BNL as the site ending a decade long competition between JLab and BNL

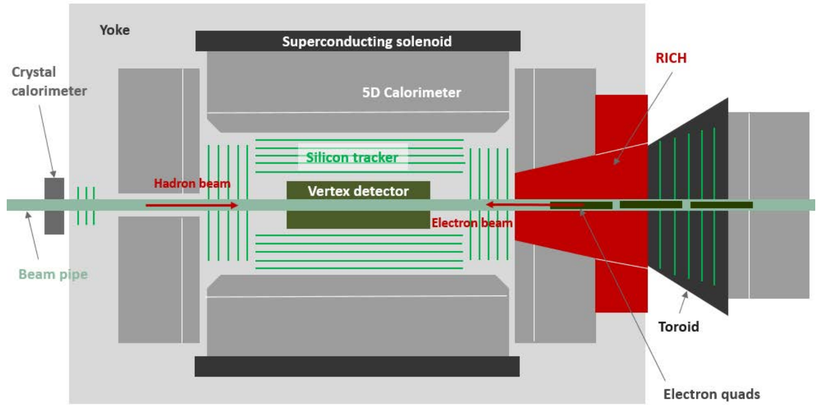
Cost estimate: ~$2B, Start of operations ~ FY30

Detectors

- Community desires 2 general-purpose detectors
- Estimated cost ~$300M/detector requiring strong international participation to contribute to the cost
- Rough first concepts exist but user community is working on refined designs in a large effort that just started





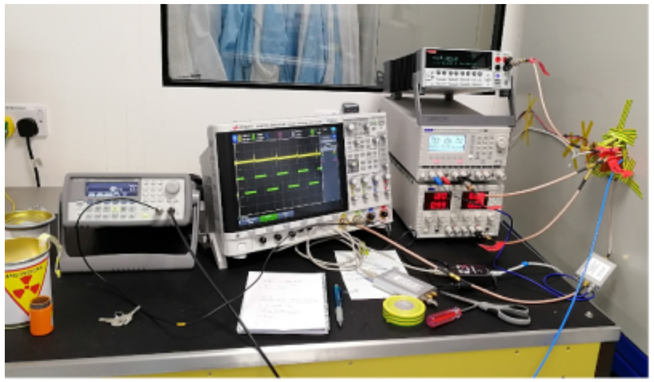


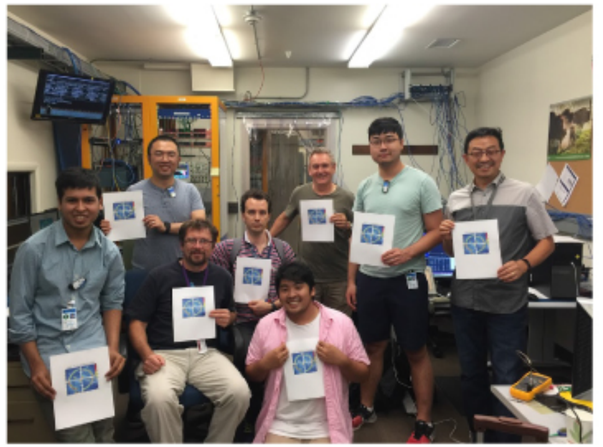
EIC General-Purpose Detectors

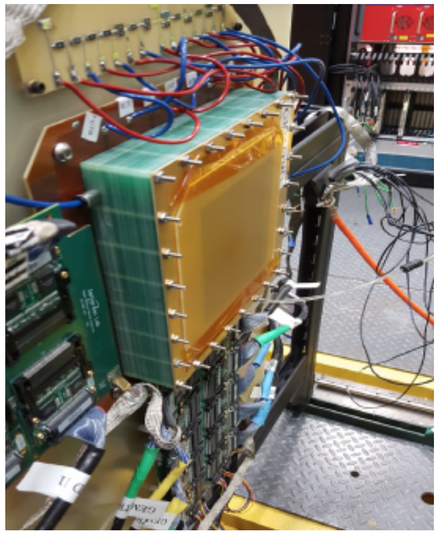
- EIC detectors are unique and challenging to realize
  - Hermitic (~4π coverage)
    - no collider detector was ever built with that coverage
  - Precision
    - high resolution in momentum/energy of particles
- Big challenge: Particle identification
  - Needed in unprecedented wide range from 0.25 GeV to 50 GeV
    - requires various cutting edge technologies
- ~20 subsystems/detector will be needed
- Expect typical size of ~500 member/collaboration
  - Universities, national labs, international contributions
  - Focus now is on conceptual design and R&D

EIC Detector R&D Program

- Started 2011 BNL, open to international participation
- Typical 10-11 projects supported per FY (funding ~$1M/year)
- 187 participants from 46 institutions (13 non-US) among them Yale, MIT, CalTech, Duke, UCLA, UCB, UCONN, SBU, …
- Engagement of undergraduate and grad students
  - Various student awards and prizes coming out of the program

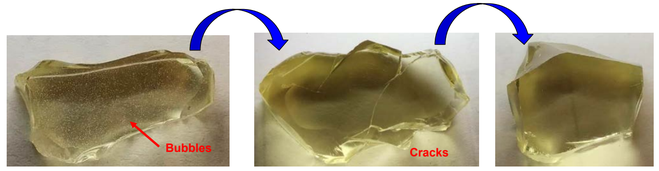






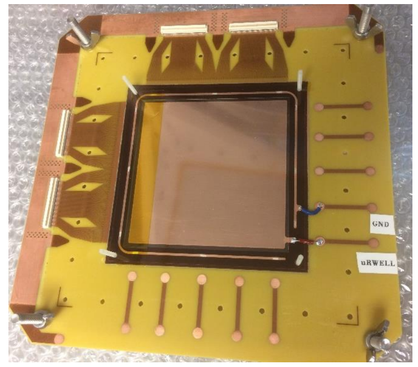
URL: https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

Pushing Technology Frontier (Examples)



- Calorimetry (Energy Measurement)
  - Crystals and scintillating glasses (vitreous materials)
  - Light Sensors in high magnetic fields
- Particle Identification
  - Novel Ring Imaging Cherenkov detectors
  - Light conversion through novel photocathode using hydrogenated diamond film
  - Large-Area Picosecond PhotoDetector (LAPPD)
- Tracking (Momentum Measurement)
  - Micro-Pattern Gas Detectors: MicroMegas (MM), Gas electron multiplier (GEM), μ-RWELL detectors
- Silicon Sensors (Vertex Tracking)
  - Fully depleted ultra-thin pixel sensors (DMAPS)
  - Extremely low mass cylindrical sensors with “bent” silicon

μRWELL with 2D X-Y readout



Opportunities for Yale (I)

- EIC detectors are *massive* instrumentation effort
- Huge opportunities for
  - students
  - technology and instrumentation development

  on almost all aspects of a complex detector
- Students
  - EIC is huge opportunity to work on various cutting edge technologies
  - If RHIC is a guide: ~550 PhD one 20 years, many with instrumentation elements
- Technology
  - Contribute to/propose/lead state-of-the-art construction projects
    - Opportunity to adapt technologies and gain experience for future projects
    - Develop new solutions (R&D) and build them
    - Apply and refine existing expertise

Opportunities for Yale (II)

- Wright Lab is perfect place offering excellent infrastructure to participate in detector building effort
  - Facilities: lab space, workshops
  - People: expertise, skills
- Group of Caines/Harris committed to EIC
  - Expertise in micro-pattern gas detector technologies
  - Level of instrumentation personnel would need to be maintained/strengthened
- Growing interest from other groups (e.g. Baker) in Physics Department
- BNL has also a lot to give back in terms of expertise, engineers and technicians opening opportunities for students and researchers (BNL is 30 miles away)

Mutual Benefit:

- A closer collaboration between BNL and Yale would be beneficial for both. Much overlap besides the EIC: e.g. STAR, ATLAS, DUNE groups on both sides

Take Away Message

- Electron-Ion Collider is new collider/accelerator to be constructed at BNL
- Expect 2 detectors to be constructed
  - design and R&D underway
- Huge opportunities for contributions from storm institutions
  - for students
  - for technology and instrumentation development
- Collaboration to build detectors will form in the next 1.5 years
  - Now is a good time to engage as leaders