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U.S. DEPARTMENT of ENERGY

Introduction and Scientific Origins of the Electron Ion Collider

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Associate Laboratory Director
Nuclear and Particle Physics Directorate

June 3, 2026

@BrookhavenLab

Two Milestones Many People

February 6, 2026

The Relativistic Heavy Ion Collider (RHIC): A smashing success

- 25 years of world-class operations
- Groundbreaking discoveries – Quark Gluon Plasma, Gluon Spin
- Sustained scientific output over 25+ years

The Electron-Ion Collider (EIC): Why and Why Now?

- Transformational physics research
- Advanced accelerator, detector, and computing technologies
- AI from design to discovery

World leadership in nuclear & accelerator physics for decades

People behind the achievements: THANK YOU!

- Scientists, engineers, technicians, support staff
- From Brookhaven, other DOE Labs, across the U.S., around the world

Support from DOE, Congress, New York State

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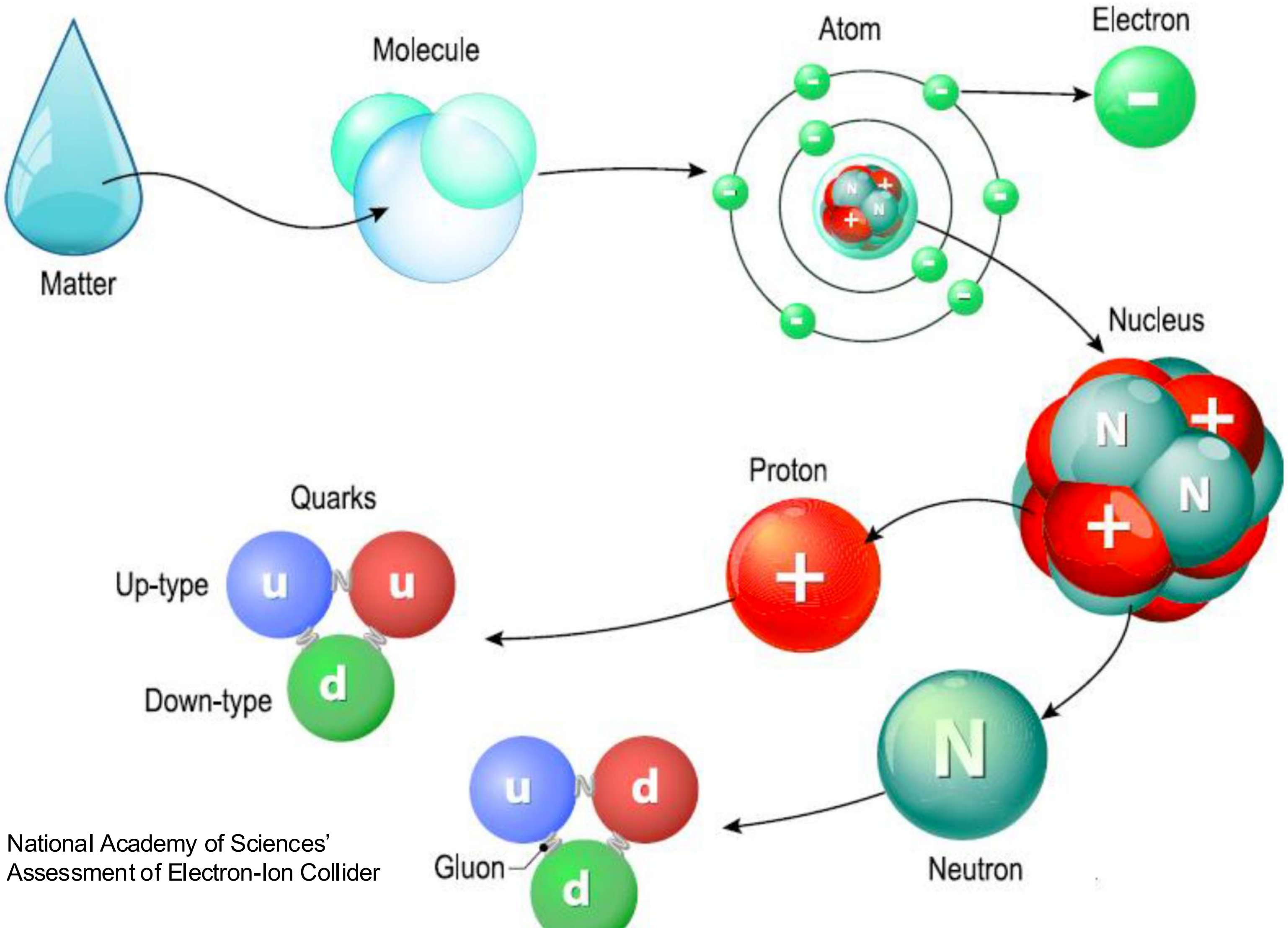
Breaking ground for RHIC in 1995

Attendees at the 2025 RHIC-AGS Users' Meeting

Humankind's Quest to Discover the Fundamental Structure of Matter

- What's inside?
- What are we made of?
- What's the "smallest?"
- What can't be broken down any further?



National Academy of Sciences' Assessment of Electron-Ion Collider

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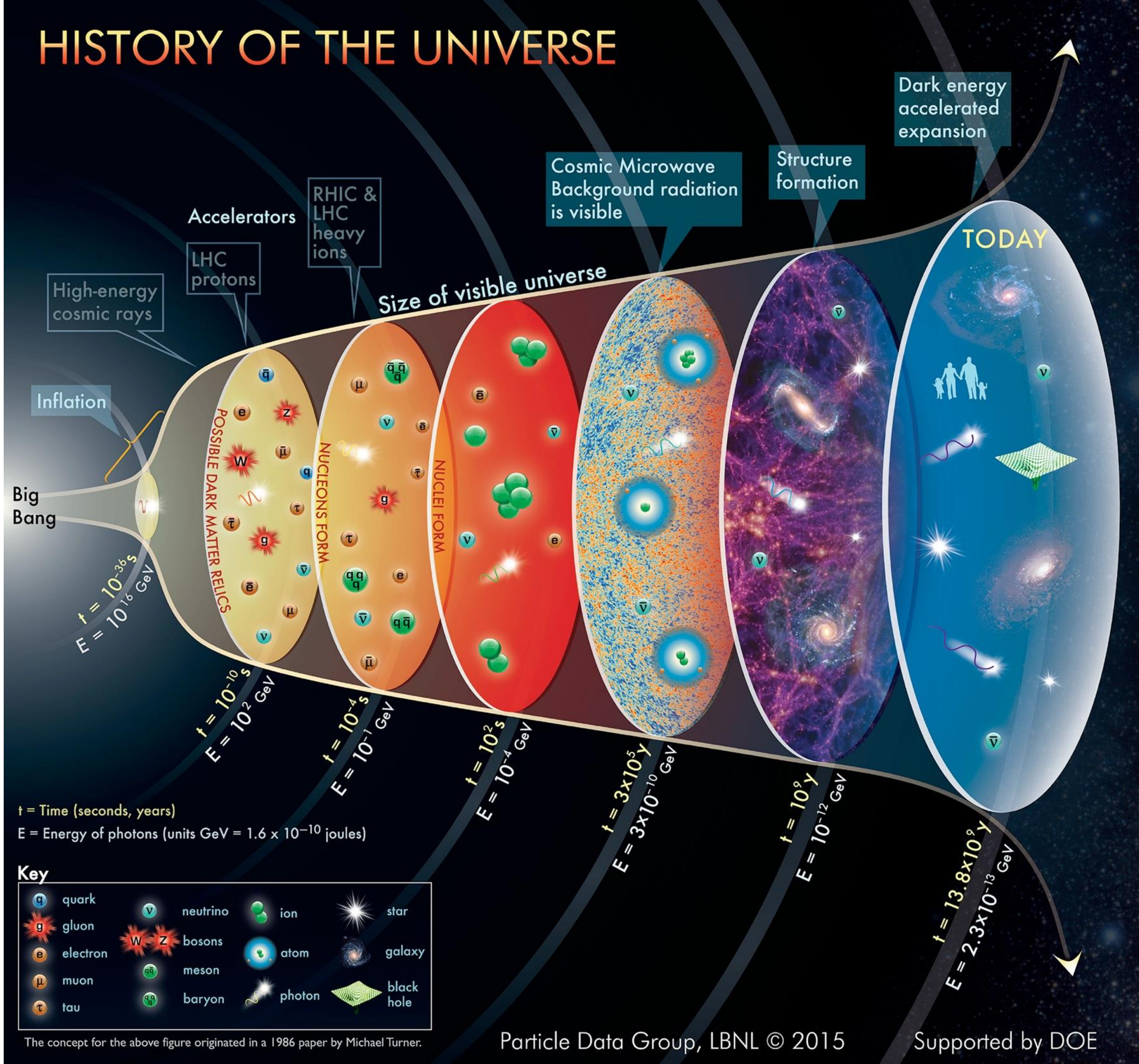
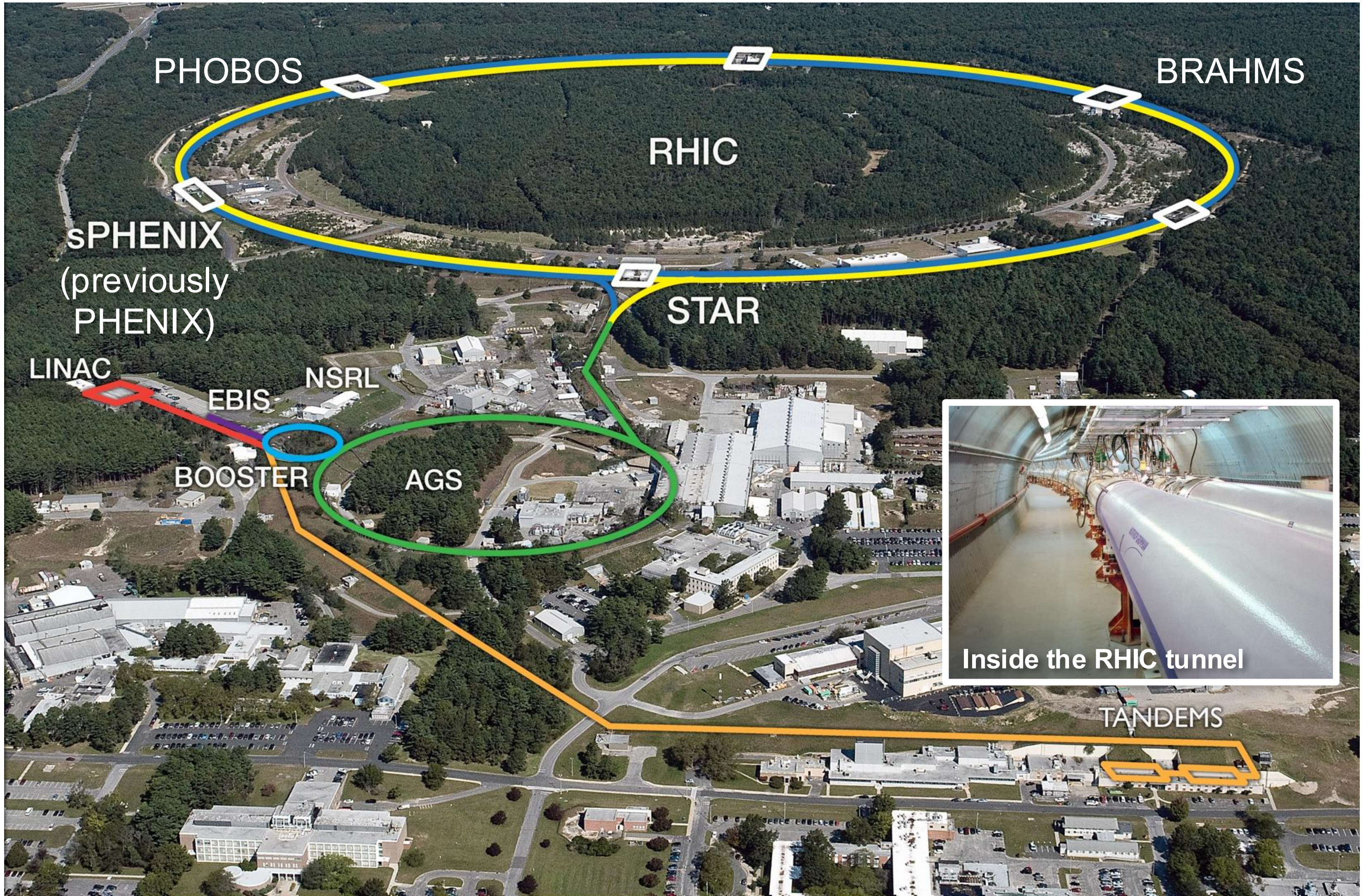
Quest for understanding the fundamental structures of matter is also a journey to the early Universe

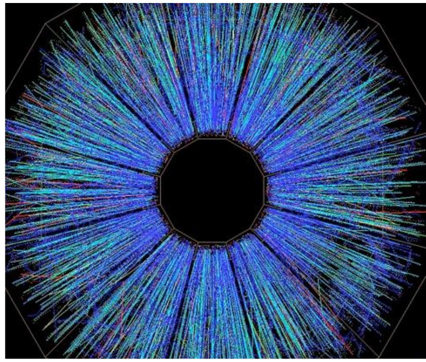
Journey to the Early Universe



The Relativistic Heavy Ion Collider (2000-2026)

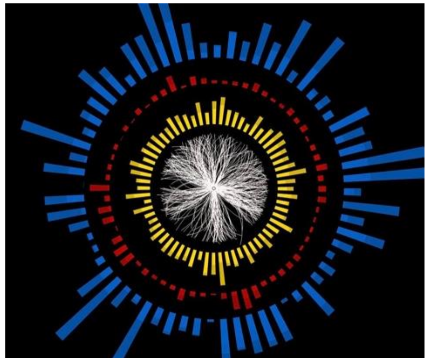
A machine built to explore fundamental matter at the dawn of time



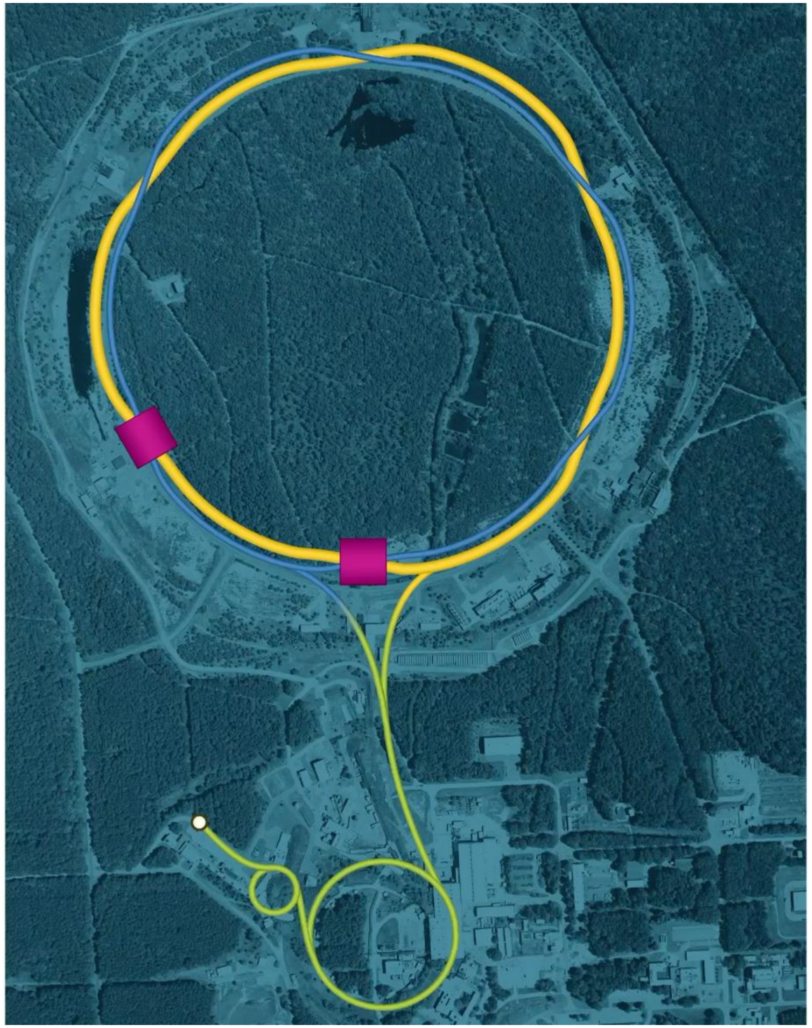


Collaborations, experiments

- PHOBOS: 2000 – 2005
- BRAHMS: 2000 – 2006
- PHENIX: 2000 – 2016
- STAR: 2000 – 2026
- sPHENIX: 2023 – 2026



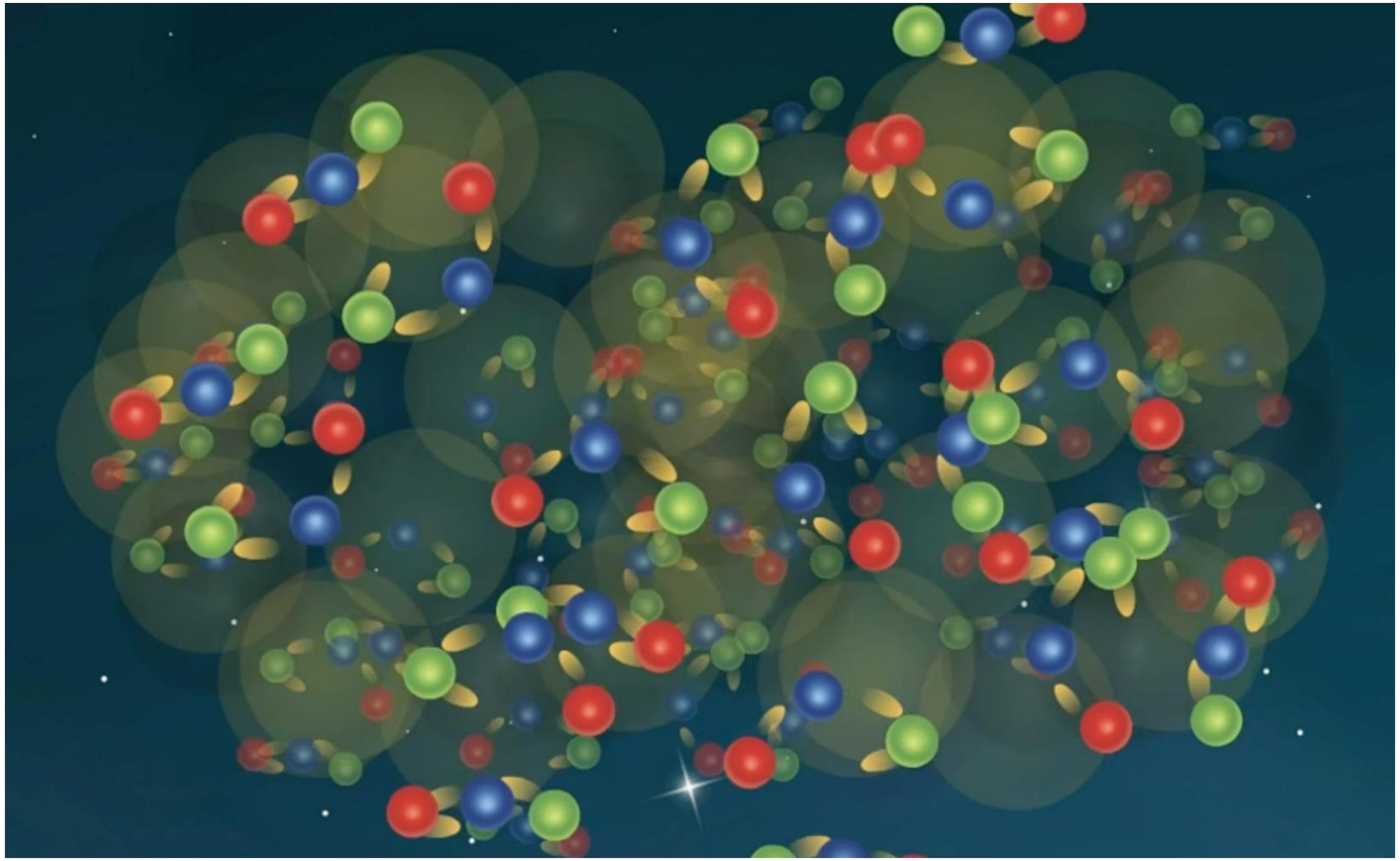
RHIC: The World’s Most Versatile Collider



- High-intensity, high-brightness ion and proton sources
- 49 different combinations of energy, ions, and collision configurations
  - 10 different ion species
  - 18 center-of-mass energies
- Innovative accelerator technologies
- Gold-gold collision rates 44 times higher than design
- Only polarized proton collider in the world

Discoveries at RHIC

Quark-Gluon Plasma: A ‘Perfect’ Fluid

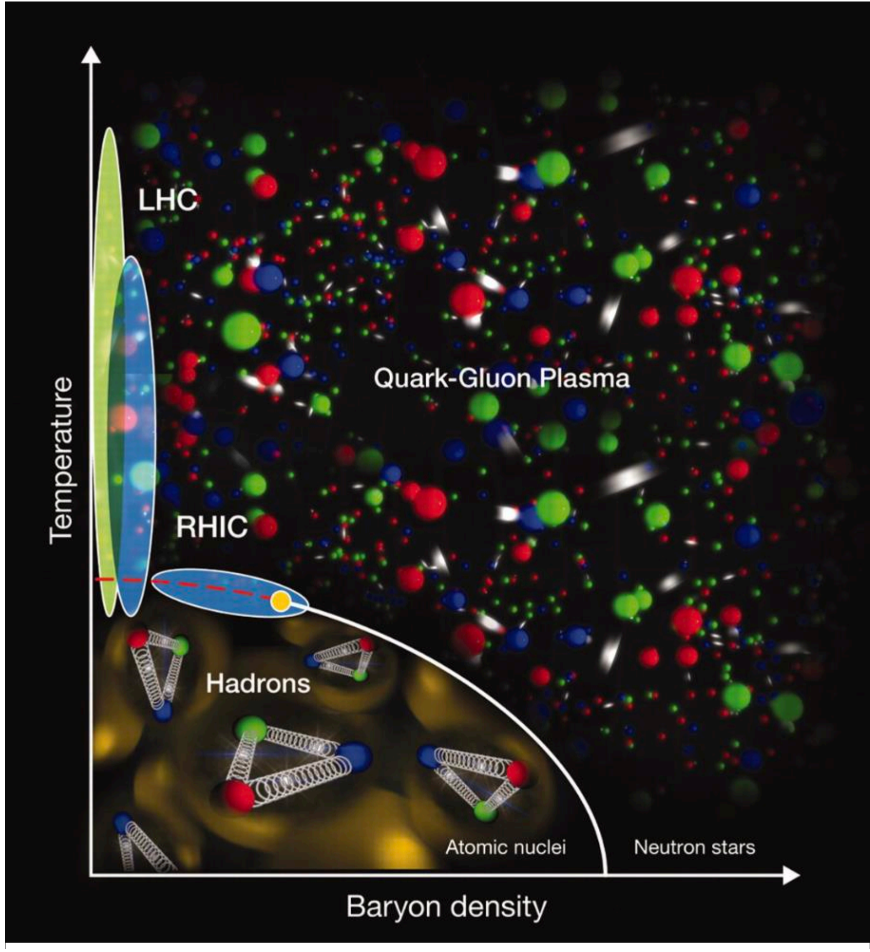


Discoveries at RHIC

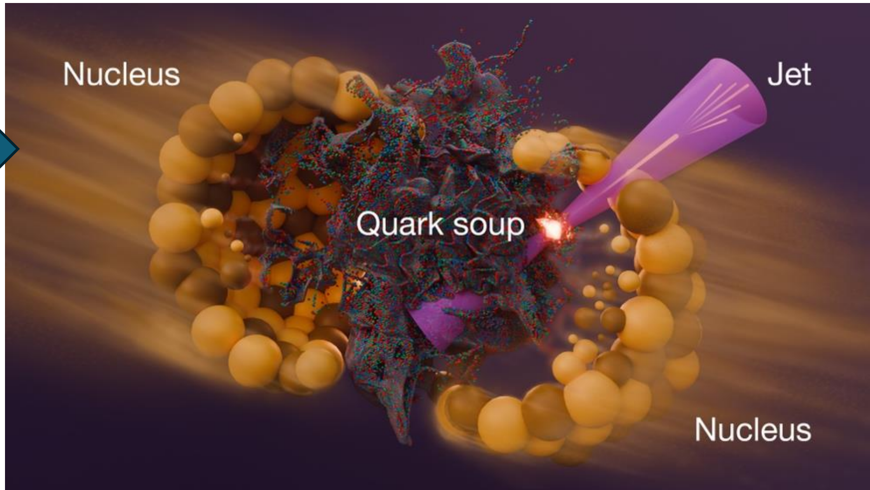
Quark-Gluon Plasma (QGP): A 'Perfect,' Ultra-Dense Fluid

RHIC re-created the quark-gluon plasma of the early universe.

- 4 trillion °C — **hottest matter** ever created at the time.
- Expected to be a gas, but it **flows like a liquid**.
- Extremely low viscosity — near the **quantum limit.**
- Unique transition from **gas to liquid upon heating!**



- Extreme density "quenches" energetic "jets" of particles.
- Surprising: QGP "droplets" discovered in collisions of small nuclei as well!



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Discoveries at RHIC

Gluons’ Contribution to Proton Spin

- Unique ability to accelerate/collide spin-aligned protons.
- Enabled studies of how quarks and gluons contribute to proton spin.
- Experiments elsewhere showed quarks only contribute about 30%.
- RHIC found that gluons also contribute to spin, about as much as the quarks
- Establishes the groundwork for understanding this important quantum property.

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Over 25 years: Trillions of Collisions, Extraordinary Impacts

- ~300 trillion collisions, in total
- ~450 petabytes of data (raw and derived)
- 3,500+ scientific collaborators from 36 countries (2000-present)
- 650+ scientific publications; 640+ Ph.D.s awarded
- ~220 newsworthy announcements (1991 to present)
- Papers and their impact (1700+ papers, 120,000+ citations)
  - PHENIX (2000-2016, 635 papers, 41.6k Citations),
  - STAR (2000-2026, 869 papers, 61.3k citations)
  - BRAHMS (2000-2006, 90 papers, 6.6k citations)
  - PHOBOS (2000-2006, 121 papers, 10.5k citations)
  - sPHENIX (2023-2026, 8 papers, 80 citations)

RHIC science graduates now in leadership positions at LHC, JLab and facilities in Europe and Asia

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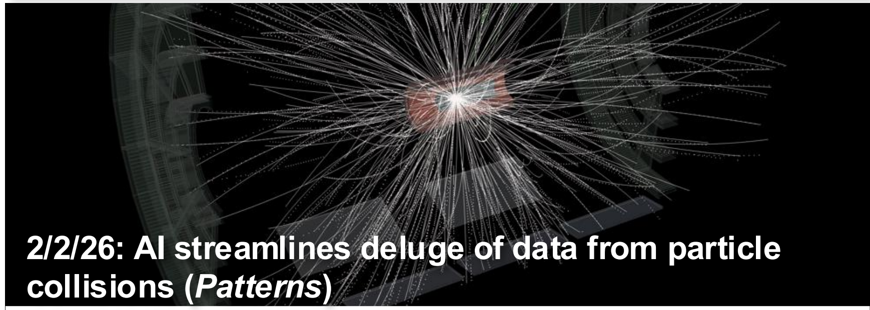
RHIC science now in textbooks!


RHIC operators in the main control room


Thesis and merit award honorees in 2025

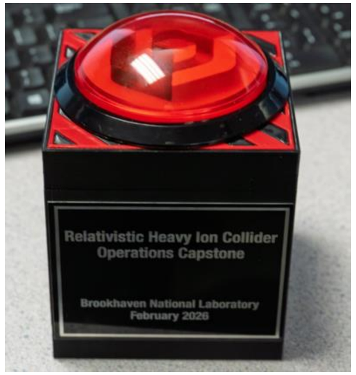

2/2/26: AI streamlines deluge of data from particle collisions (*Patterns*)

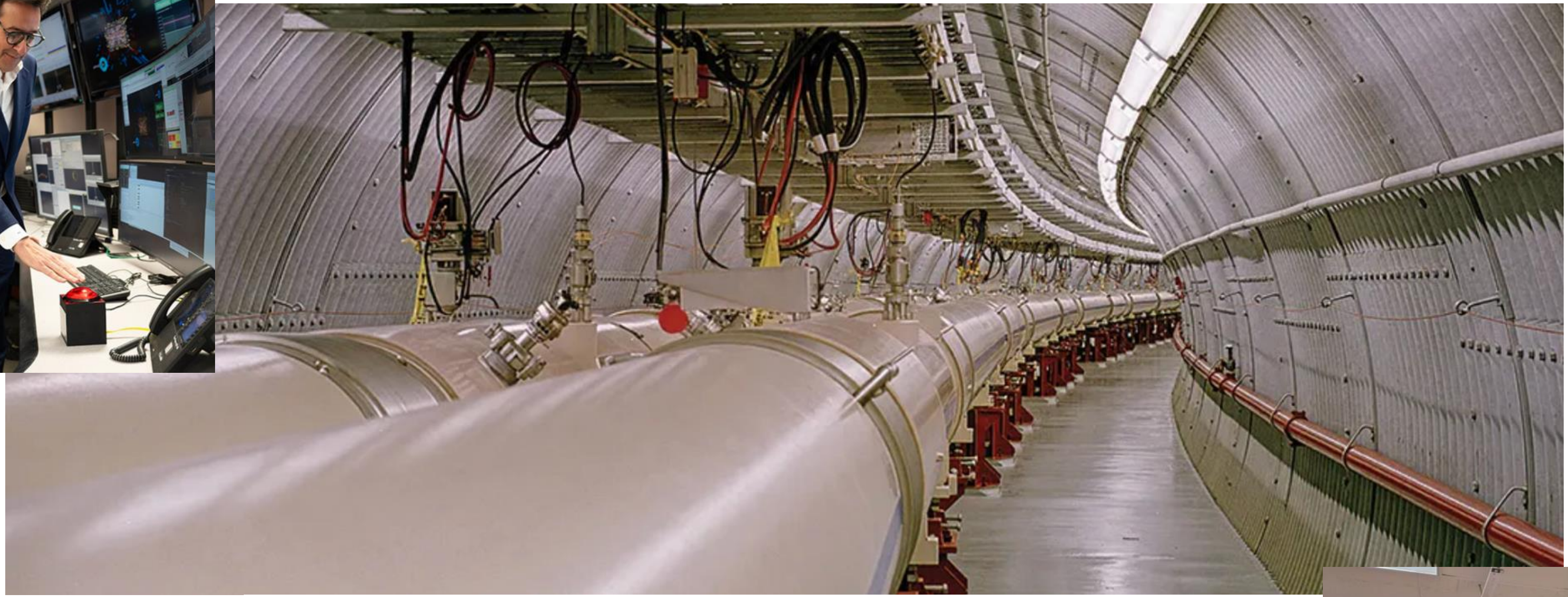

2/4/26: Scientists capture a glimpse into the quantum vacuum (*Nature*)

February 6, 2026

EIC CD3 B approval announced

The button that shut RHIC down





PHYSICS

The only U.S. particle collider shuts down – so a new one may rise

The Relativistic Heavy Ion Collider stops work after more than 25 years of mind-bending discoveries

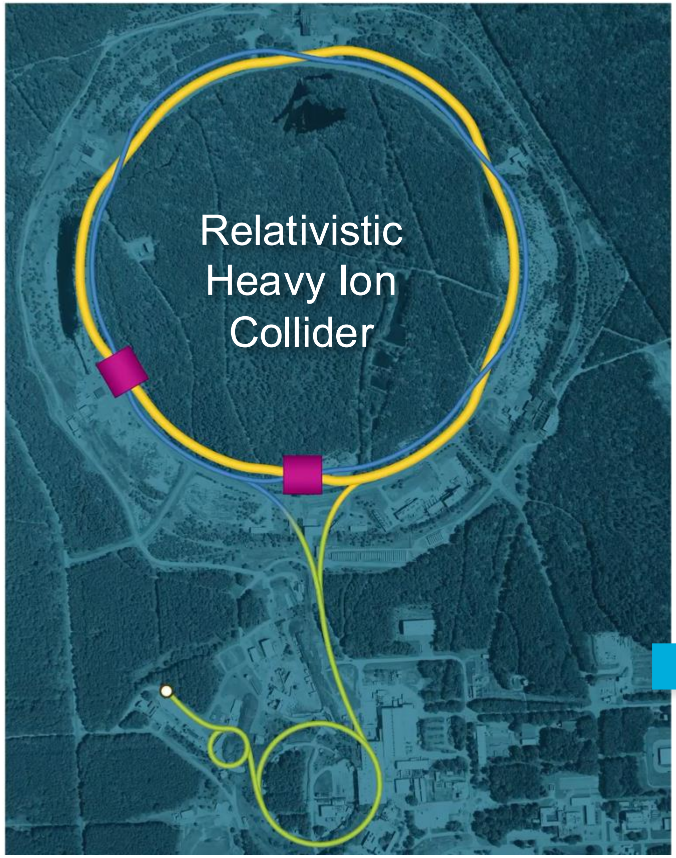
By Emily Conover

Feb 3, 2006:
Last weekly RHIC planning meeting started in 2000

sPHENIX

STAR

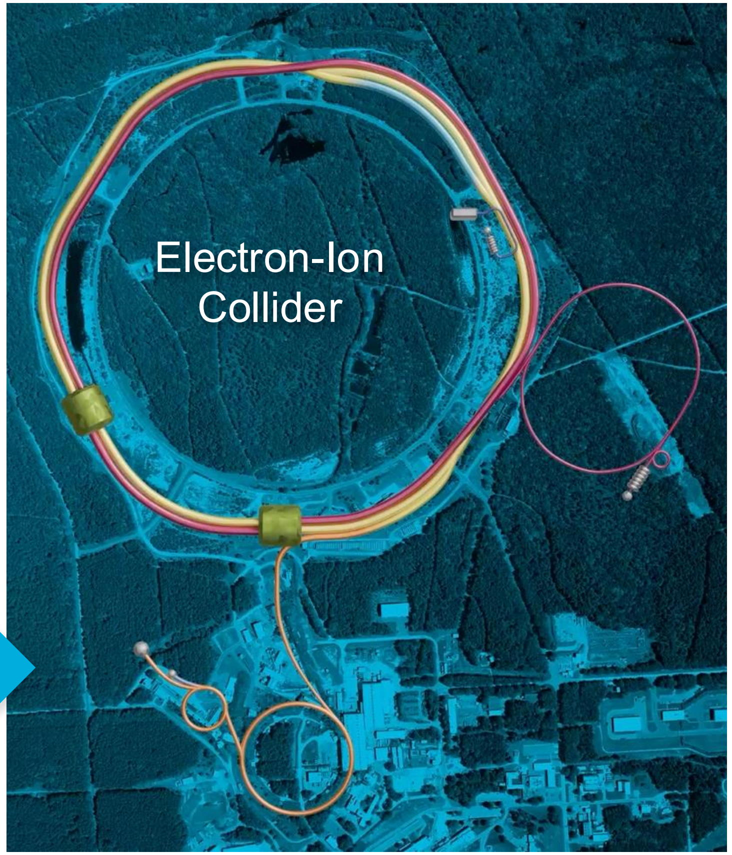
A New Era of Discovery: From RHIC to the Electron-Ion Collider (EIC)



Building on the ~$2 billion+ investment in RHIC:

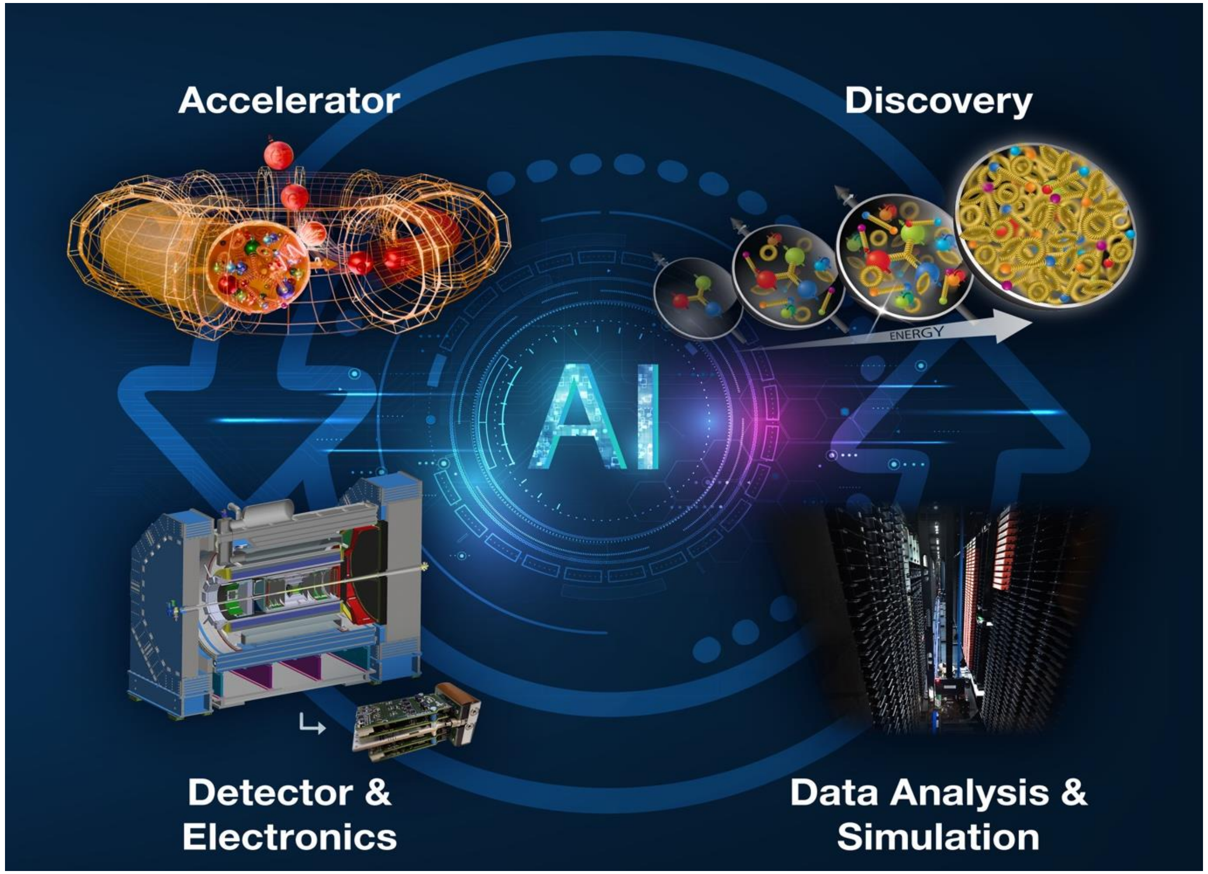
- Re-use existing tunnel
- Minimal modification to ion beam complex (yellow)
- New electron beam facility

Partnership between U.S. Department of Energy, Brookhaven Lab, Thomas Jefferson National Accelerator Facility, New York State, and collaborators around the world.



The Electron-Ion Collider

An AI End-to-End Facility



- First large-scale facility to leverage AI from the design and R&D phases to discovery.
- Accelerator, detector, and data analysis will all use — and push the evolution of — advanced AI techniques with potential impacts for other fields and facilities.

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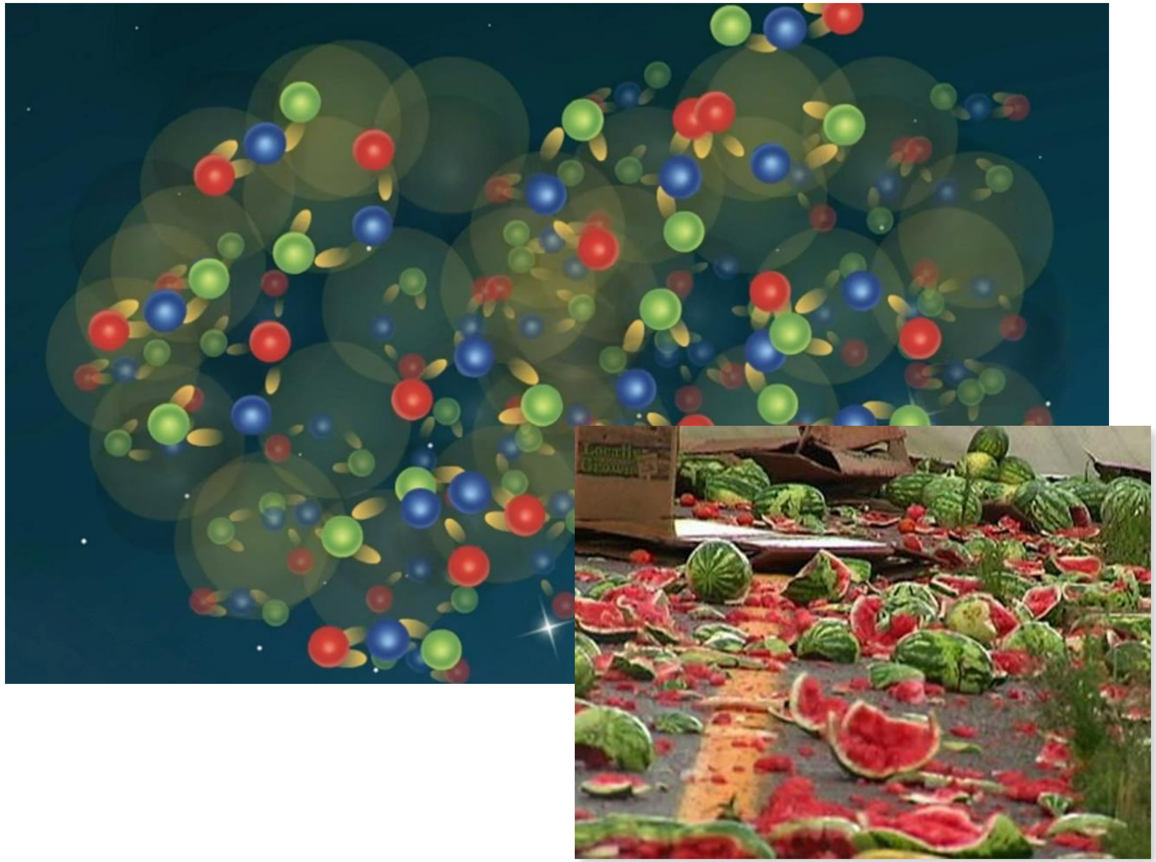
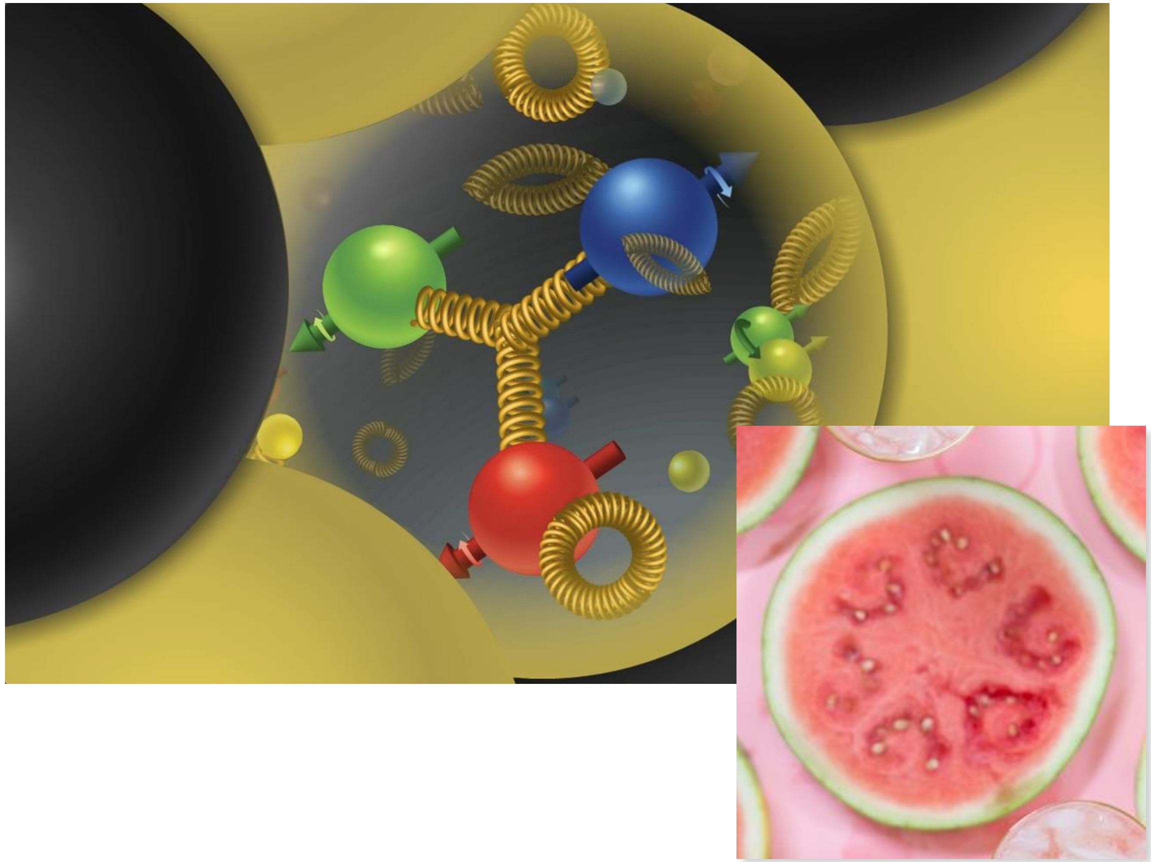
RHIC Smashed Ions, EIC Will ‘Slice’

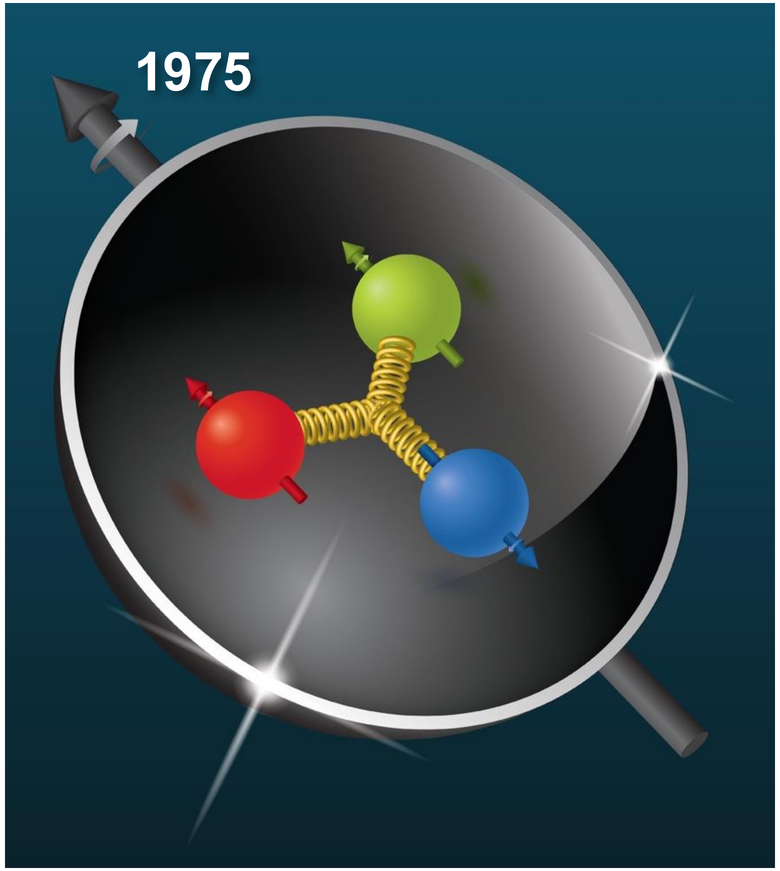
RHIC

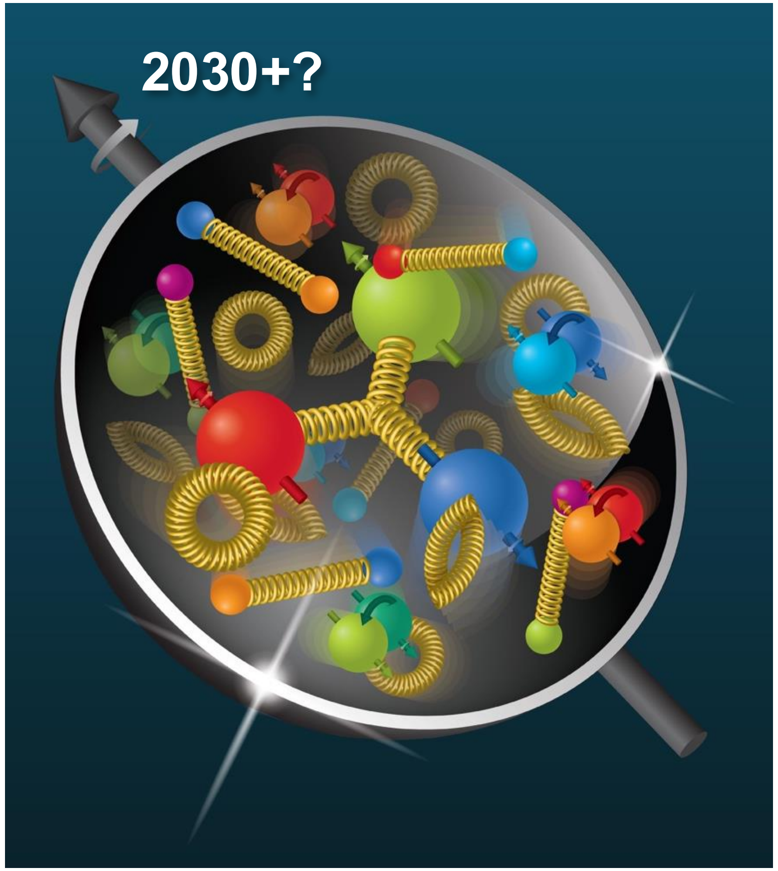


EIC



Revealing the Proton's Inner Structure





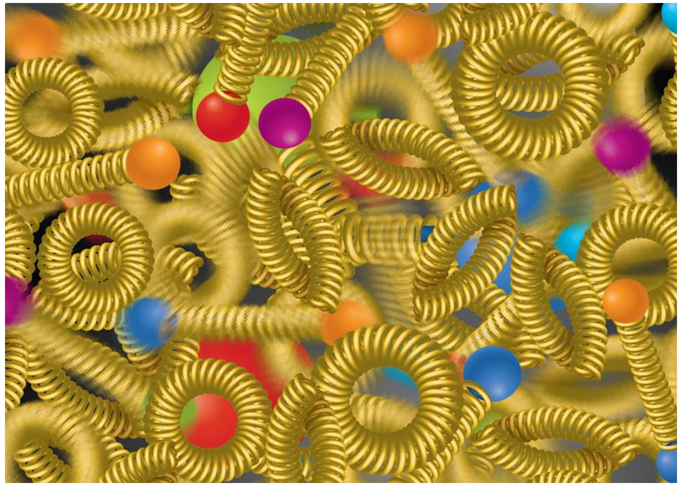
The Electron-Ion Collider

Answers to Nobel-Prize-Worthy Questions

How do nearly massless quarks and gluons generate the mass of all visible matter — everything we see in the universe today?

How is proton spin — a fundamental property used in medical imaging yet not fully understood — influenced by quarks and gluons?

What is the nature of the gluons that “glue” visible matter together, and how do they generate the strongest force in nature?



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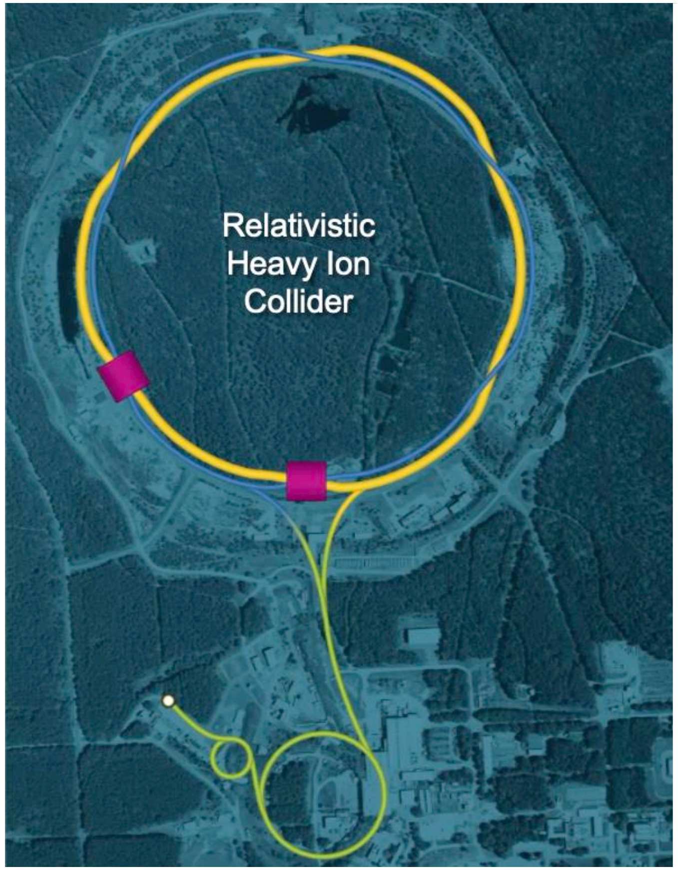
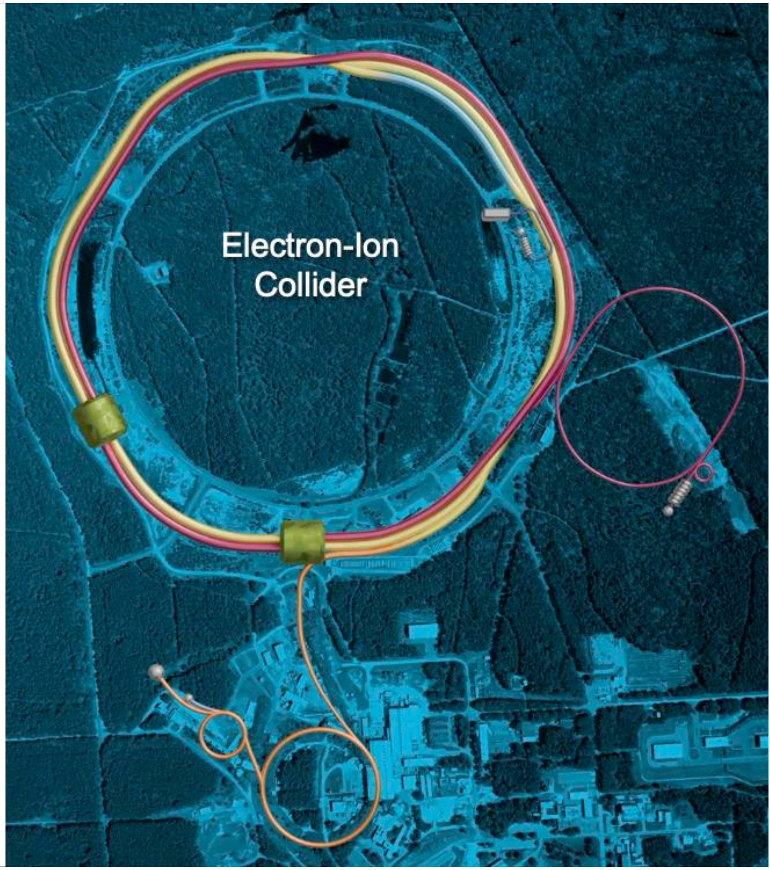
We are moving forward… NOW!



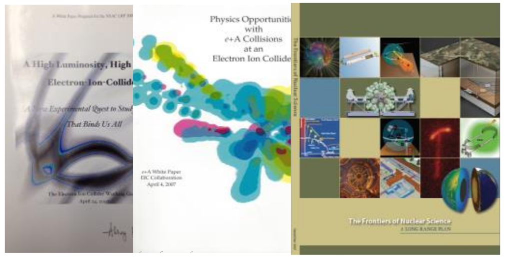


EIC: How did it come about?

Scientific and social history of the Electron Ion Collider

Center for Frontiers in Nuclear Science

Electron Ion Collider: ~~An Overview~~
From a dream to reality

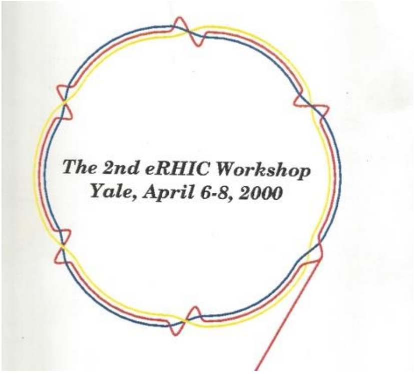


Ring-Ring
1st at BNL
Dec. 3-4, 1999

Ring-Ring Linac-Ring

Ring-Ring

Ring-Ring



eRHIC 1999-2000

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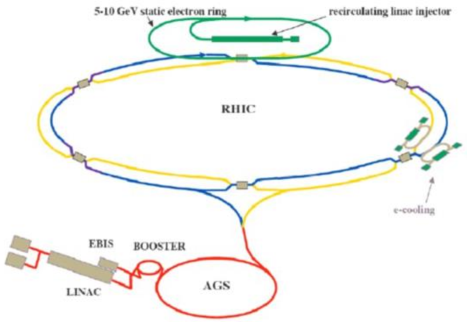
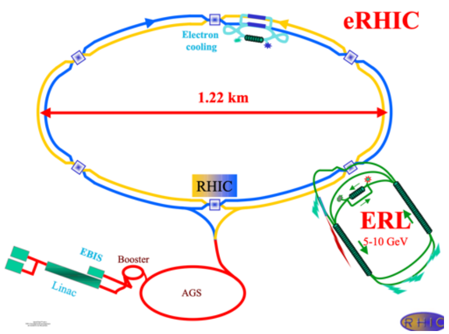
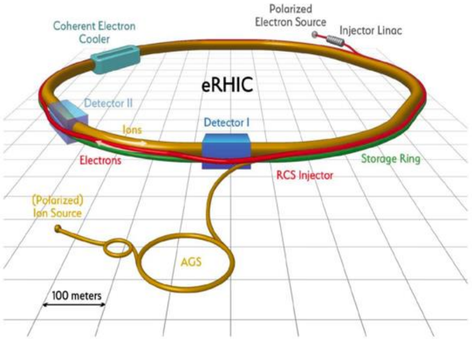
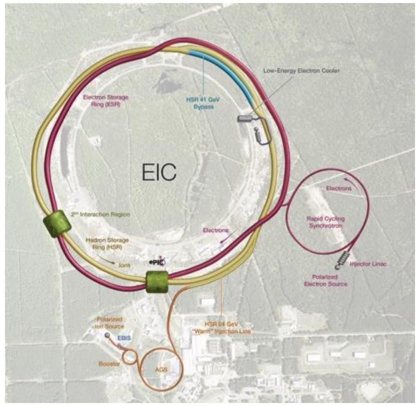




2008



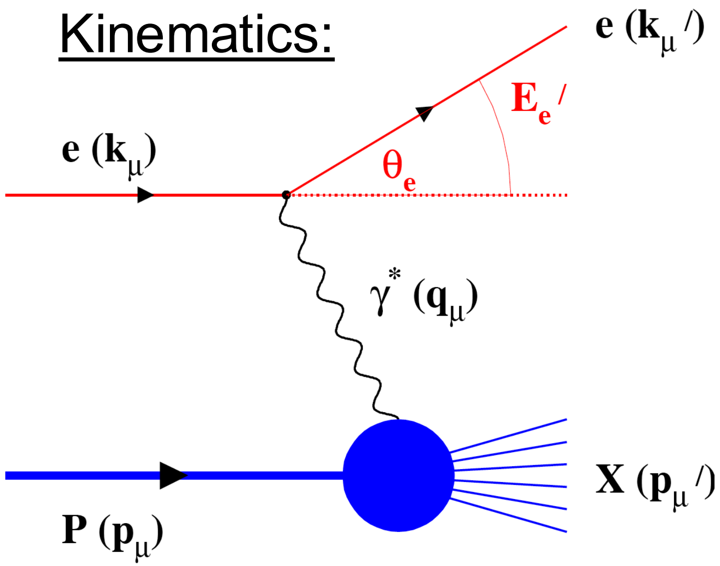
2016-2024



2025

Deep Inelastic Scattering: Precision and control

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

$$Q^2 = 2E_e E'_e(1 - \cos\Theta_{e'})$$

Measure of resolution power

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

$$s = 4\,E_t\,E_e \qquad x = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

Hadron :

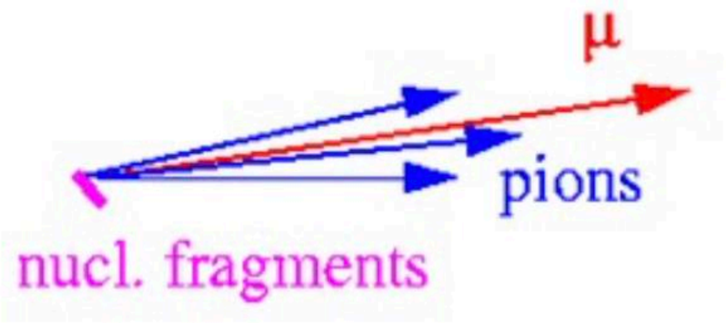
$$z = \frac{E_h}{\nu};\ p_t$$ with respect to γ

Inclusive events:
e+p/A → e'+X
detect only the scattered lepton in the detector

Semi-inclusive events:
e+p/A → e'+h(π,K,p,jet)+X
detect the scattered lepton in coincidence with identified hadrons/jets in the detector

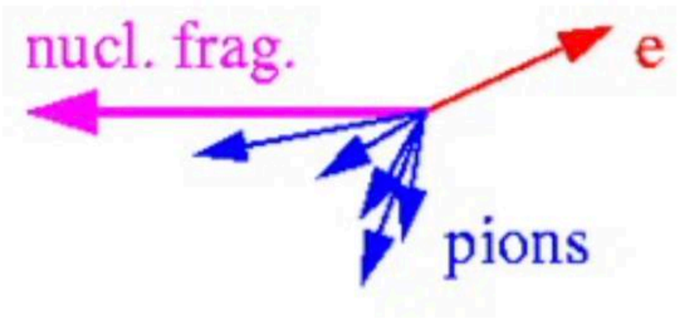
Motivations were simple and intuitive

Fixed target geometry



Separate of “target” fragment difficult

Collider Collision geometry



separate “beam-” and “target-” fragment possible

Collider vs. Fixed Target DIS

- Large Center of Mass Energy – access to low-x, high-Q^2
- HERA a grant success for QCD
  - Low-x gluon rise
  - Diffraction
  - Discovery of Deeply Virtual Compton Scattering

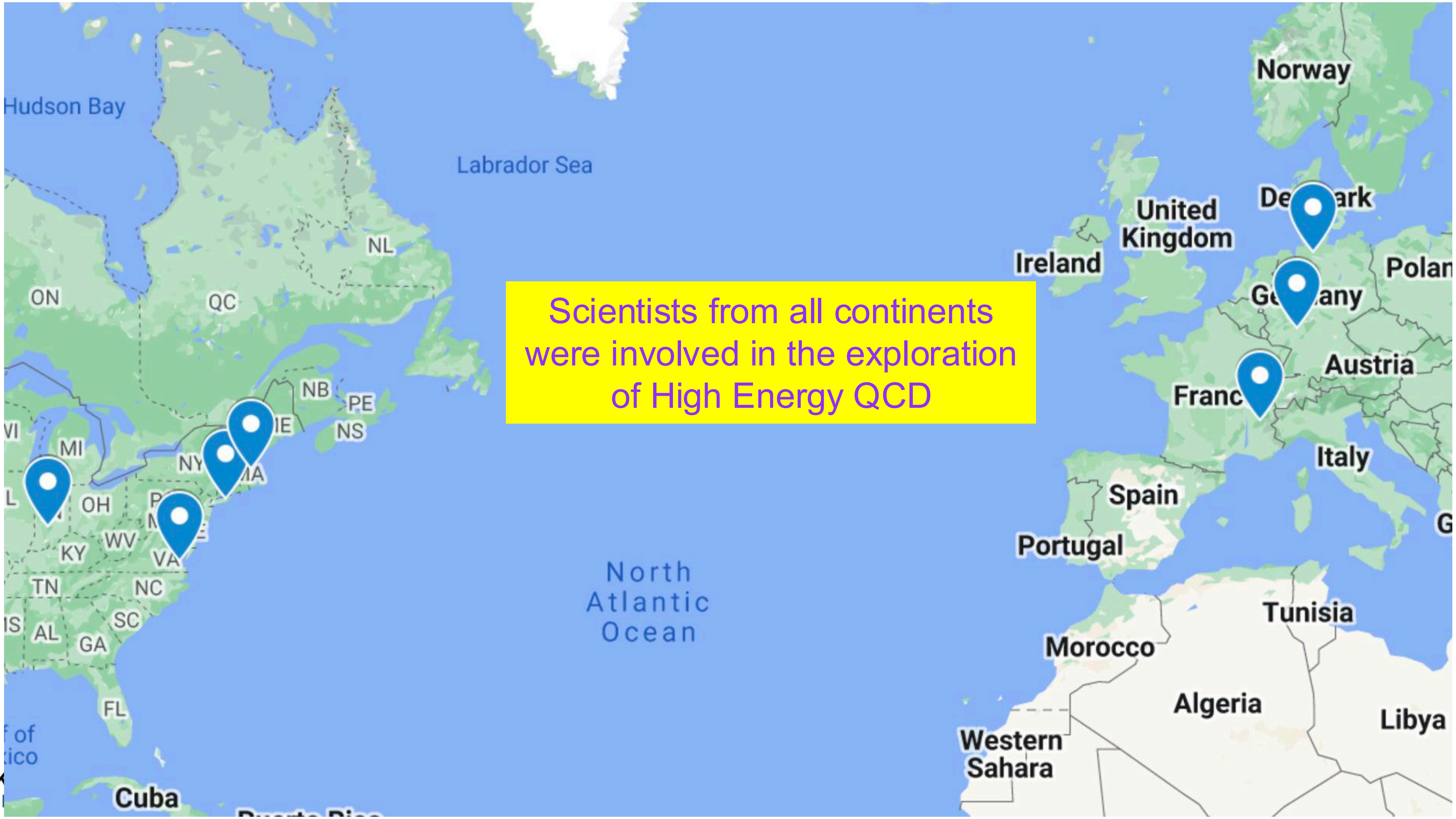
Proposals for double polarized e-p and e-A colliders emerged out of scientific discoveries at EMC at CERN and HERA at DESY

MIT Bates

eRHIC

IUCF

JLab



Scientists from all continents were involved in the exploration of High Energy QCD

DESY

GSI

Grenoble?

1995-2000:

HERA 30 GeV e x 800 GeV p ➔ Future HERA (1995-97) polarized e-p OR e-Nucleus ➔ Sqrt(s) ~ 300 GeV

Ed. A. De Roeck and R. Klannar, DESY (1996); De Roeck, Deshpande, Hughes and Arneodo, Biales,Krasny, T. Sloan, McLerran, Strikman, Venugopalan et al. (1996-1999)

Theory e-p support: Altarelli, Ball, Forte, Ridolfi, Blumlein, Gluck, Reya, Stratmann and Vogelsang

GSI European Nucleon Collider (ENC) 1997, ELFE (Saclay, DESY using TESLA & HERA and at CERN) Sqrt(s) ~ 30 GeV

Von-Harrach et al… GSI Report 97-04/07 (1997)

Indiana University + MIT Bates (EPIC 1999/2000) Sqrt(s) ~ 3-7 GeV

Bland, Londergan, Vigdor, Szczepaniak and Milner et al.

BNL eRHIC (December 1999 & April/June 2000) Sqrt (s) ~ 100 GeV (e-p)

Deshpande, Hughes, G. Garvey, McLerran, Venugopalan

EPIC (Indiana + MIT) + eRHIC (BNL) ➔ “Electron Ion Collider” at BNL (2000)

Deshpande, Milner, McLerran, Venugopalan, Vogelsang

Sqrt (s) ~ 30 – 100(upgradable to 140) GeV (e-p)

Strength in unity :
by using RHIC &
finding Physics
connections

Crossing the x-Q^2 Barrier in DIS: Low-x surprises!

- Elastic e-p scattering (SLAC, 1950s)
  Q2 ~ 1 GeV^2 → *Finite Size of proton*
- Inelastic e-p scattering (SLAC, 1960s)
  Q2 > 1 GeV^2 → *Parton structure of the proton*
- Inelastic m-p scattering off p/d at CERN (1980s)
  Q2 > 1 GeV^2 → *Unpolarized EMC effect*
- Inelastic e-p scattering at HERA/DESY (1990s)
  Q2 > 1 GeV^2 → *Unexpected rise of F_2, Study of pQCD and QCD through various physics processes, diffraction…*

Low x ↓

What NEXT?

APPRECIATION FOR LOW-X PHYSICS

(Could not find the talks from 2000
this is from 2002)

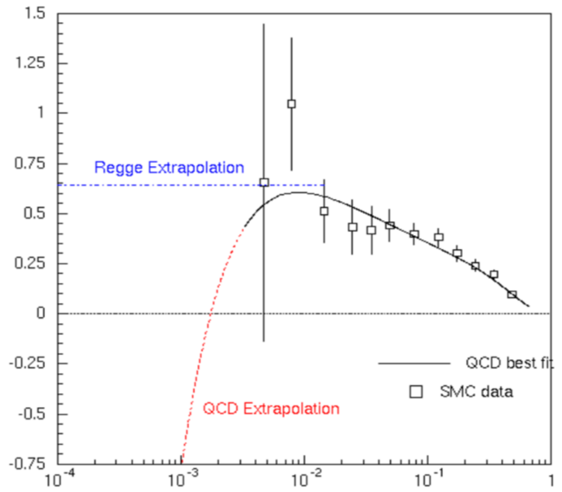
APPRECIATION FOR "SPIN" AS A TOOL

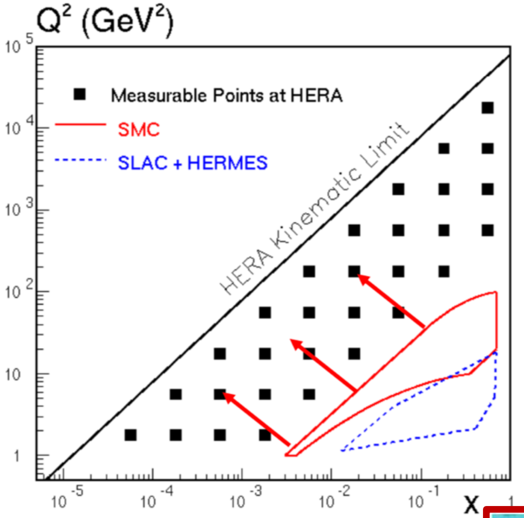
Physics with "Spin" full of Surprises!

- Stern & Gehrlach (1921): Space quantization associated with direction
- Goudschmidt & Ulhenbeck (1926): Atomic fine structure and electron spin magnetic moment
- Stern (1933): Proton anomalous magnetic moment $\mu_p / \mu_N = 2.79$
- Kusch (1947): Electron anomalous magnetic moment $\mu_e = 1.00119\mu_0$
- Prescott & Yale-SLAC Collaboration (1978): EW interference in polarized e-d DIS, parity non-conservation
- EMC (1989): Proton spin crisis/puzzle Low x!
- E704, AGS pp scattering, HERMES ep (1999):
  ???? Transverse spin asymmetries ???? →

Low x behavior of $g_1(p)$!

A. Deshpande & V. W. Hughes
~1995 SMC (internal) analysis meeting



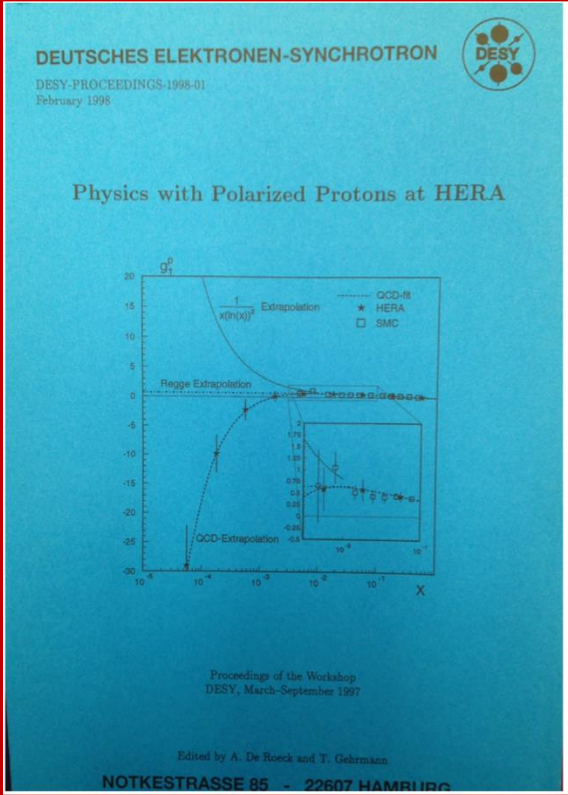


Regge : $g_1(x \to 0) \sim x^{-\alpha}; \quad 0 < \alpha < 0.5$

Clear need for
low x measurements!

Work done with Altarelli, Ball, Forte and Ridolfi

Ellis-Jaffe and Bjorken Sum Rule



Encouraged by
B. Wiik, R. Klanner (DESY),
&
A. Caldwell, F. Sciulli (Columbia)

The Yale group (A.D., V. Hughes & S. Dhawan) joined ZEUS and together with **A. De Roeck** & J. Feltesse (H1) and theorist **T. Gehrmann** ran the 1999 workshop on Physics with Polarized Proton Beams at HERA.

Accelerator Experts: D. Barber, G. Hoffstaedter & M. Vogt
External advisors: Mei Bai & Thomas Roser

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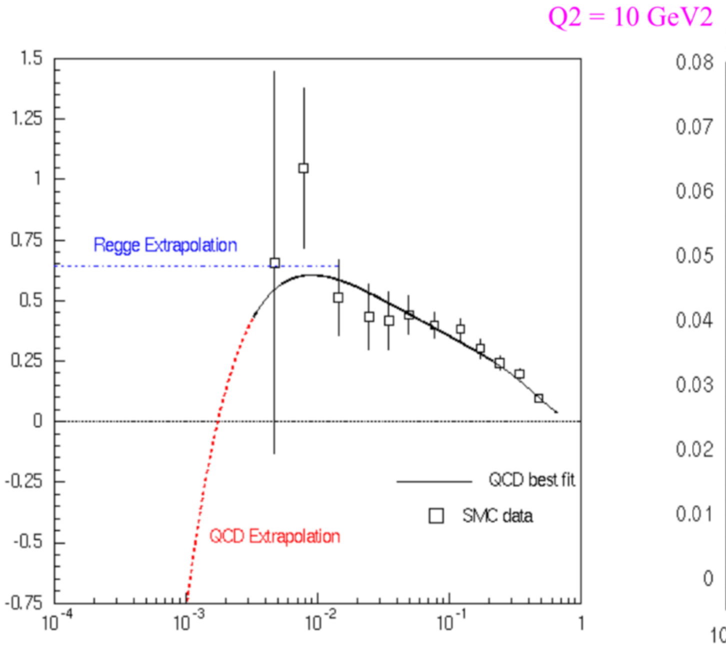
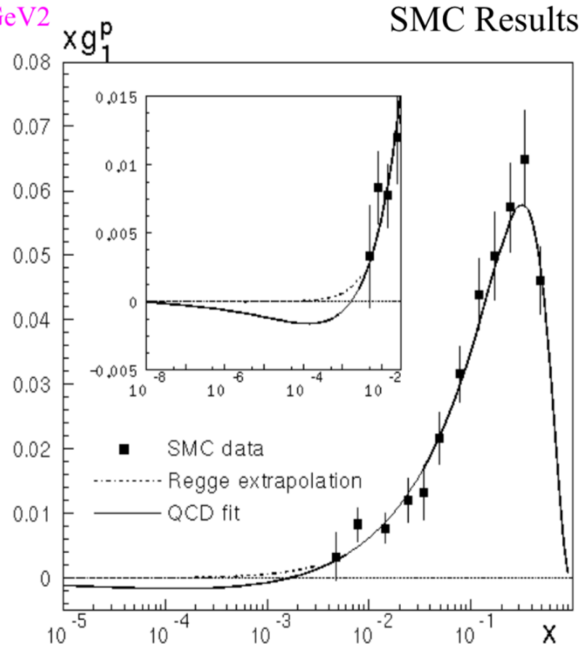
Lack of low x data… consequences





- **Regge extrapolation:**

$$\int_0^{0.003} g_1^p(x, Q_0^2)dx = 0.002 \pm 0.002$$

- **QCD fit extrapolation:**

$$\int_0^{0.003} g_1^p(x, Q_0^2)dx = -0.011 \pm 0.011$$

$$g_1(x \to 0) \propto x^{\alpha} \quad \text{as } 0 < \alpha < 0.5$$

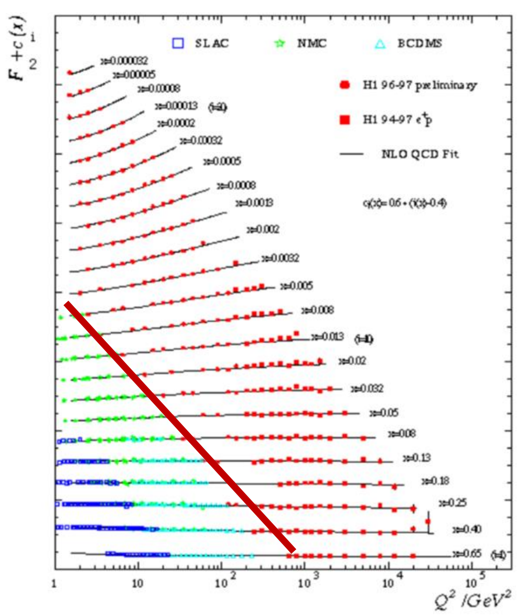
Regge/QCD

Seeds for a **polarized collider**

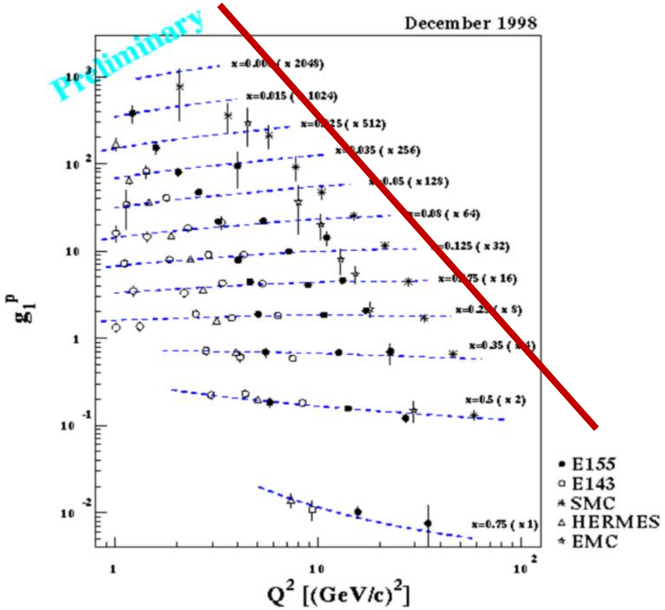
SMC PRD98 (112002) 1998

How far does polarized DIS have to go!

World data on F_1^p



World data on g_1^p



In these discussions mach focus on the low-x extrapolations of spin structure function leading to novel results for E-J and Bjorken Spin Sum Rule

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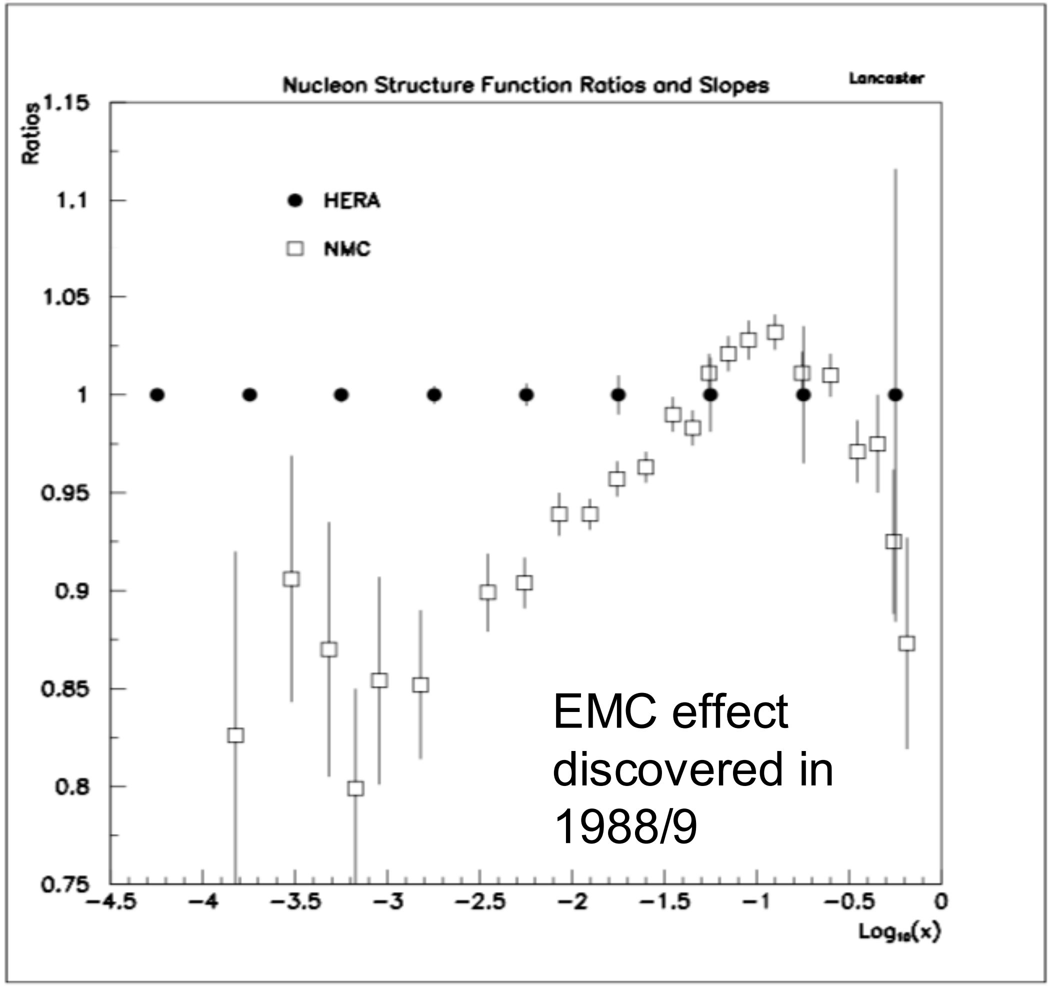
Nuclei are not just simple collection of protons and neutrons: quarks/gluon distribution in a proton in a nucleus is different than in a proton.

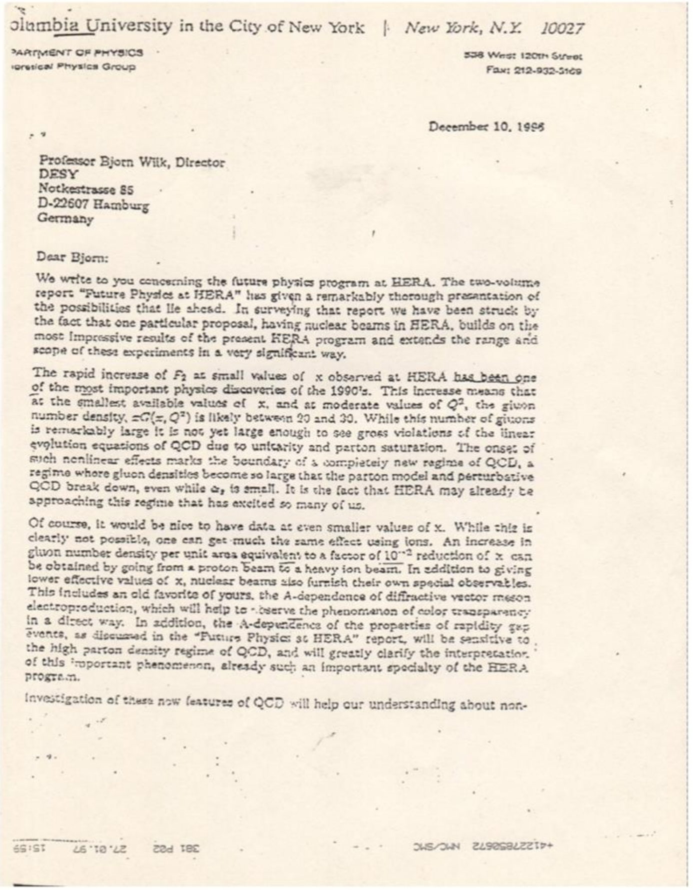


J.D. Bjorken Letter in support of e-A collisions

Strikman and McLerran

Letter to Director Wiik
From
Bjorken, McLerran and Mueller
Page 2 with their signatures could not be found

Courtesy: Mark Strikman



olumbia University in the City of New York | New York, N.Y. 10027

PARTMENT OF PHYSICS
oretical Physics Group

538 West 120th Street
Fax: 212-932-3169

December 10, 1996

Professor Bjorn Wiik, Director
DESY
Notkestrasse 85
D-22607 Hamburg
Germany

Dear Bjorn:

We write to you concerning the future physics program at HERA. The two-volume report "Future Physics at HERA" has given a remarkably thorough presentation of the possibilities that lie ahead. In surveying that report we have been struck by the fact that one particular proposal, having nuclear beams in HERA, builds on the most impressive results of the present HERA program and extends the range and scope of these experiments in a very significant way.

The rapid increase of F_2 at small values of x observed at HERA has been one of the most important physics discoveries of the 1990's. This increase means that at the smallest available values of x, and at moderate values of Q^2, the gluon number density, $xG(x,Q^2)$ is likely between 20 and 30. While this number of gluons is remarkably large it is not yet large enough to see gross violations of the linear evolution equations of QCD due to unitarity and parton saturation. The onset of such nonlinear effects marks the boundary of a completely new regime of QCD, a regime where gluon densities become so large that the parton model and perturbative QCD break down, even while α_s is small. It is the fact that HERA may already be approaching this regime that has excited so many of us.

Of course, it would be nice to have data at even smaller values of x. While this is clearly not possible, one can get much the same effect using ions. An increase in gluon number density per unit area equivalent to a factor of 10^{-2} reduction of x can be obtained by going from a proton beam to a heavy ion beam. In addition to giving lower effective values of x, nuclear beams also furnish their own special observables. This includes an old favorite of yours, the A-dependence of diffractive vector meson electroproduction, which will help to observe the phenomenon of color transparency in a direct way. In addition, the A-dependence of the properties of rapidity gap events, as discussed in the "Future Physics at HERA" report, will be sensitive to the high parton density regime of QCD, and will greatly clarify the interpretation of this important phenomenon, already such an important specialty of the HERA program.

Investigation of these new features of QCD will help our understanding about non-

We were very worried, but Vernon Hughes contacted Bj and asked if nucleon spin at low-x was interesting. Immediately Bj wrote a very enthusiastic letter supporting the case for polarized DIS at high energy.

Brookhaven National Laboratory

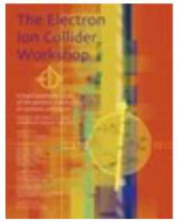
DESY had other things in mind – other than polarized protons at high energy & nuclei which were planned at RHIC

Although no one was initially talking about an electron beam until 1999/2000 some of us moved to BNL

In search of new possibilities, the High Energy DIS proponents shifted focus to the US

Brookhaven National Laboratory

eRHIC* = first introduced to BNL in 1999/2000



2002 EIC White Paper

Early discussions at BNL:

Deshpande, Hughes, McLerran, Venugopalan (with HERA legacy)

Supported strongly by:

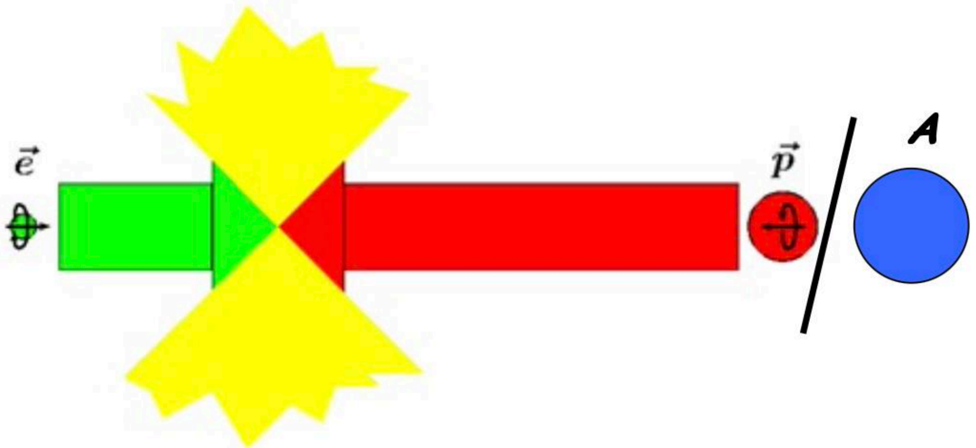
Gerry Garvey, Vernon Hughes, **Peter Paul**, Praveen Choudhury… and then all later BNL Directors of the Lab

After 2002 a broad group of people (see 2002 eRHIC White Paper, for Long Range Plan) joined the effort.

* Term coined by R. Venugopalan

Physics Case For Electron Ion Collider

Abhay Deshpande



AA Physics Capabilities of an EIC Detector

Mini-Workshop at BNL

September 19, 2002

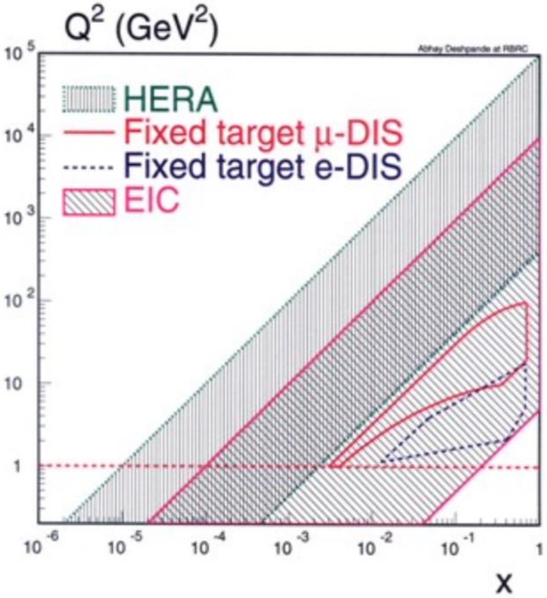
Riken BNL Research Center

BROOKHAVEN NATIONAL LABORATORY

managed by Brookhaven Science Associates for the U.S. Department of Energy

Brookhaven National Laboratory

The EIC w.r.t. Other Experimental Facilities



- New kinematic region to be explored
- EIC = eRHIC + EPIC

$E_e \approx 3-10 GeV, E_p \approx 30-250 GeV$

$\sqrt{s} \approx 20-100 GeV$

- Kinematic Reach for DIS:

  $Q^2 > 1 GeV^2, 10^{-4} < x < 0.7$

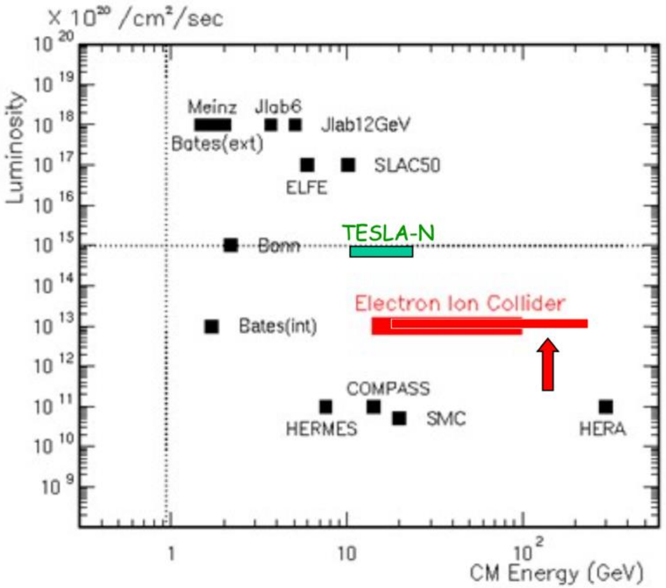
  $1 < Q^2 < 10^4$

- High Luminosity!

$L \sim (0.3-1.0)*10^{33} / sec/cm^2$

A modern version of this Plot in B. Surrow's talk

The EIC w.r.t. Other Facilities



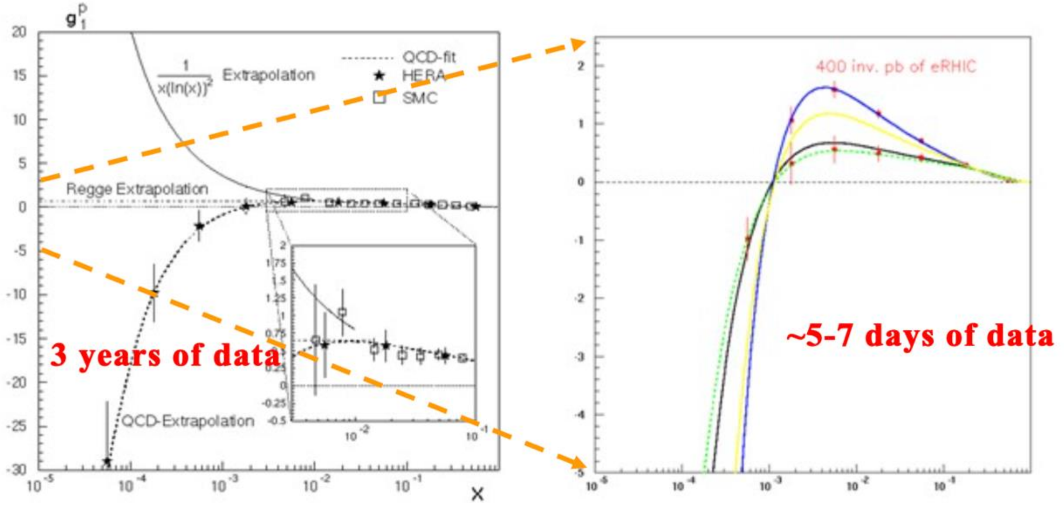
Large luminosity and high CM Energy makes EIC unique!

Variable CM energy, ion species and polarizability of hadron beams enhances its versatility!

Brookhaven National Laboratory

Spin Structure Function g_1 at low x

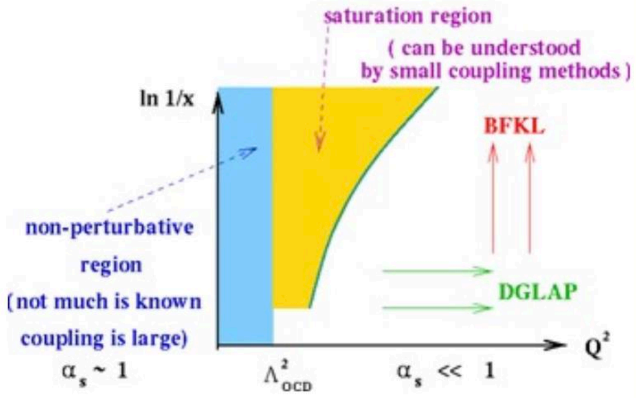
A. Deshpande, V. W. Hughes



Studies included statistical errors & detector smearing

No present/future approved experiment will do as well.

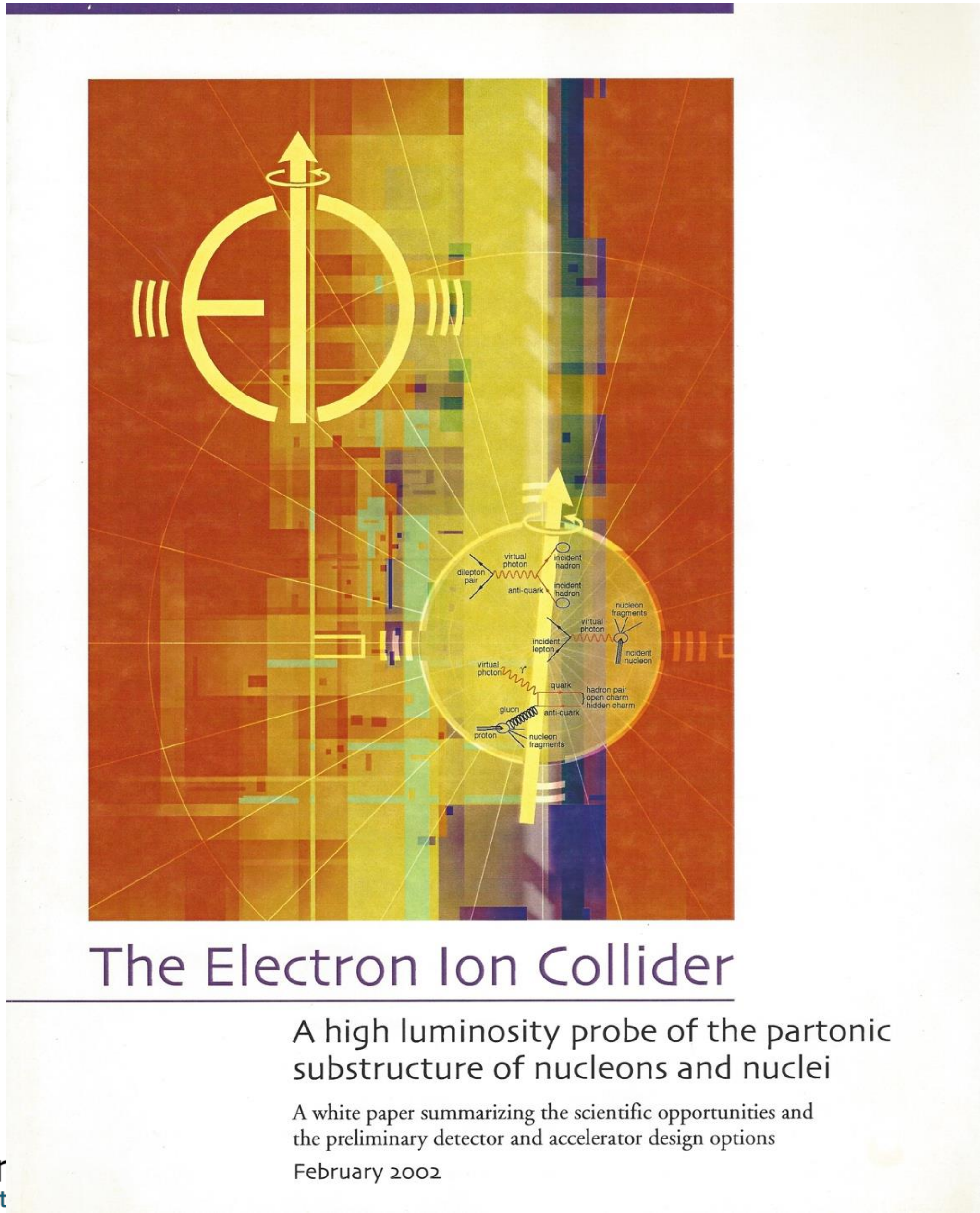
In Summary....



- As parton densities become too high, standard pQCD breaks down.
- Even though the coupling is weak, the physics may be non-perturbative due to high field strengths generated by large number of partons
- A novel state of matter?

To experimentally explore this novel state of matter an e-A collider with LARGE luminosity and HIGH energy beams is essential!

Recent history: Approval, evaluation and realization…

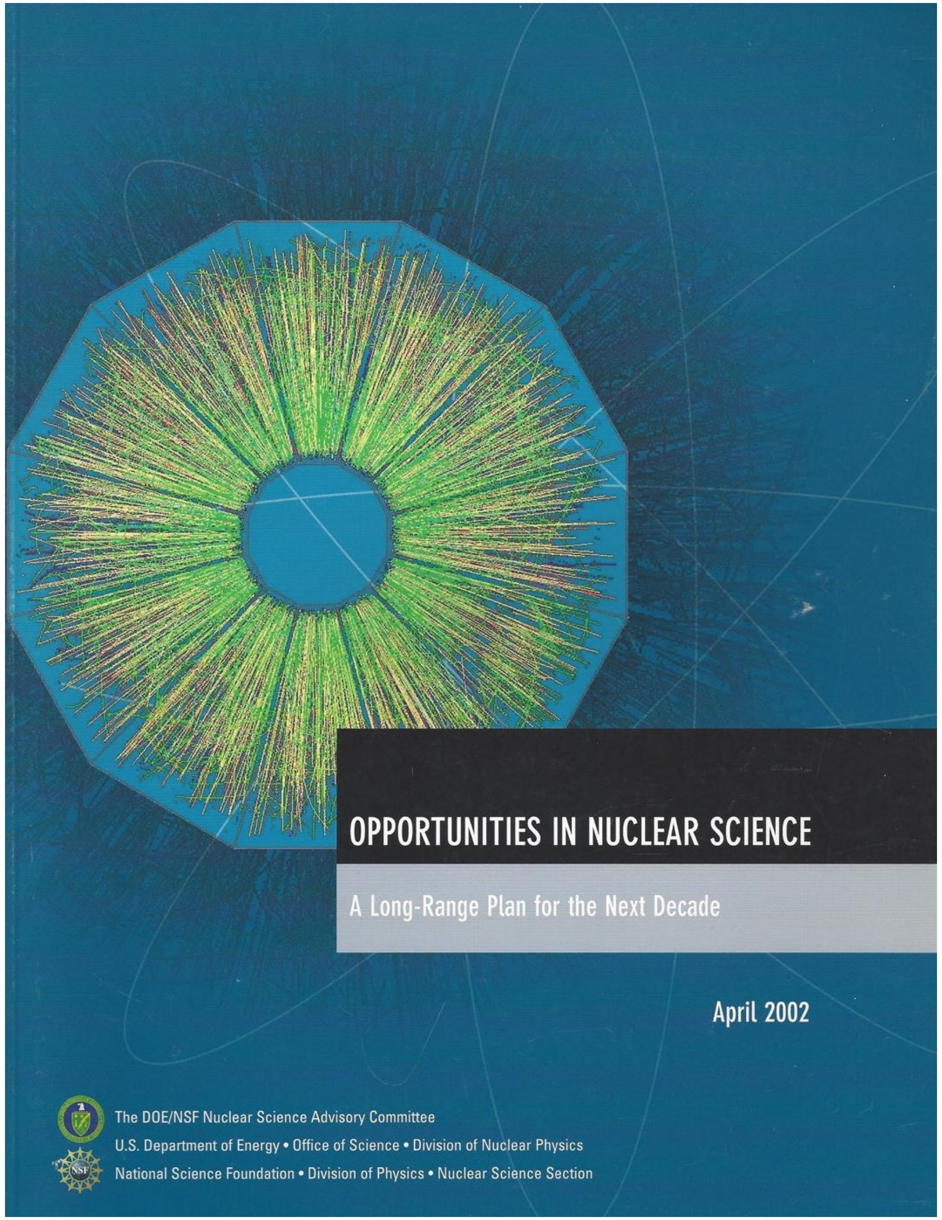


EIC White Paper for the 2002 Long-Range Plan

White Paper prepared/edited by:
A. Deshpande (RBRC), R. Milner (MIT) & R. Venugopalan (BNL)

Actively Supported by:
G. Garvey (Los Alamos) & Peter Paul (Acting Director BNL Dep. Director) & T. D. Lee (RBRC/Columbia)

Institutions:
BNL, Budker Institute, CERN, U. of Colorado (Boulder), FNAL, UIUC, Indiana U., JLab, LBNL, Los Alamos, MIT, INP Poland, U. of Paris VI, Penn State, Regensburg, RIKEN-BNL, Saclay, Triumf, Yale



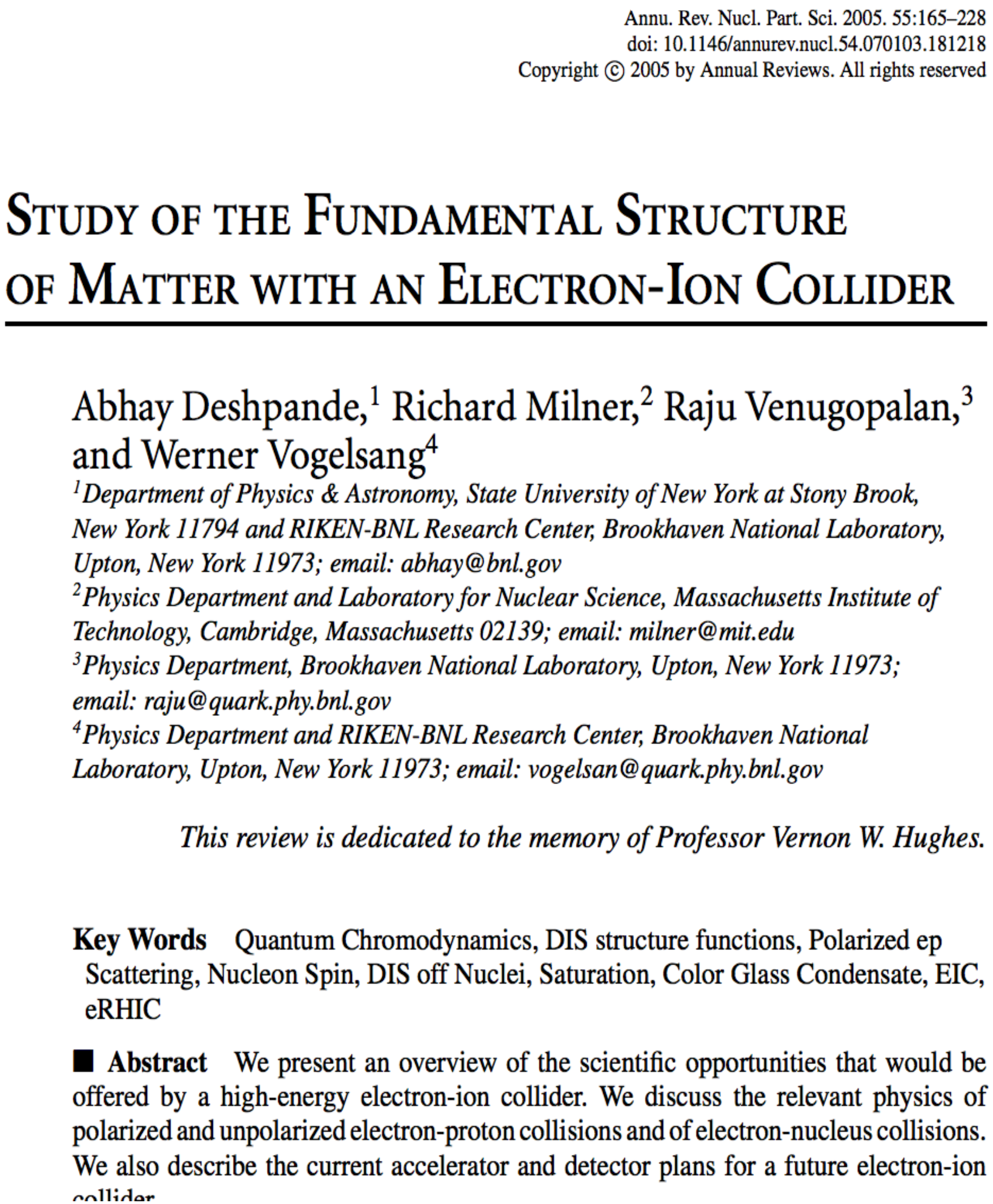
NSAC 2002 Long Range Plan

The Electron-Ion Collider is a new accelerator concept that has been proposed to extend our understanding of the structure of matter in terms of its quark and gluon constituents.
Two classes of machine design for the EIC have been considered: a ring-ring option where both electron and ion beams circulate in storage rings, and a ring-linac option where a linear electron beam incident on a stored ion beam.

There is a strong consensus among nuclear scientists to pursue R&D over the next three years to address a number of EIC design issues.In parallel, the scientific case for the EIC will be significantly refined.

Deshpande & Milner 2016 EICUG Trieste Meeting

First formal publication?


Annu. Rev. Nucl. Part. Sci. 2005. 55:165–228
doi: 10.1146/annurev.nucl.54.070103.181218

Study of the Fundamental Structure of Matter with an Electron-Ion Collider

Abhay Deshpande,[1] Richard Milner,[2] Raju Venugopalan,[3] and Werner Vogelsang[4]

[1]Department of Physics & Astronomy, State University of New York at Stony Brook, New York 11794 and RIKEN-BNL Research Center, Brookhaven National Laboratory, Upton, New York 11973; email: abhay@bnl.gov

[2]Physics Department and Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139; email: milner@mit.edu

[3]Physics Department, Brookhaven National Laboratory, Upton, New York 11973; email: raju@quark.phy.bnl.gov

[4]Physics Department and RIKEN-BNL Research Center, Brookhaven National Laboratory, Upton, New York 11973; email: vogelsan@quark.phy.bnl.gov

This review is dedicated to the memory of Professor Vernon W. Hughes.

Key Words Quantum Chromodynamics, DIS structure functions, Polarized ep Scattering, Nucleon Spin, DIS off Nuclei, Saturation, Color Glass Condensate, EIC, eRHIC

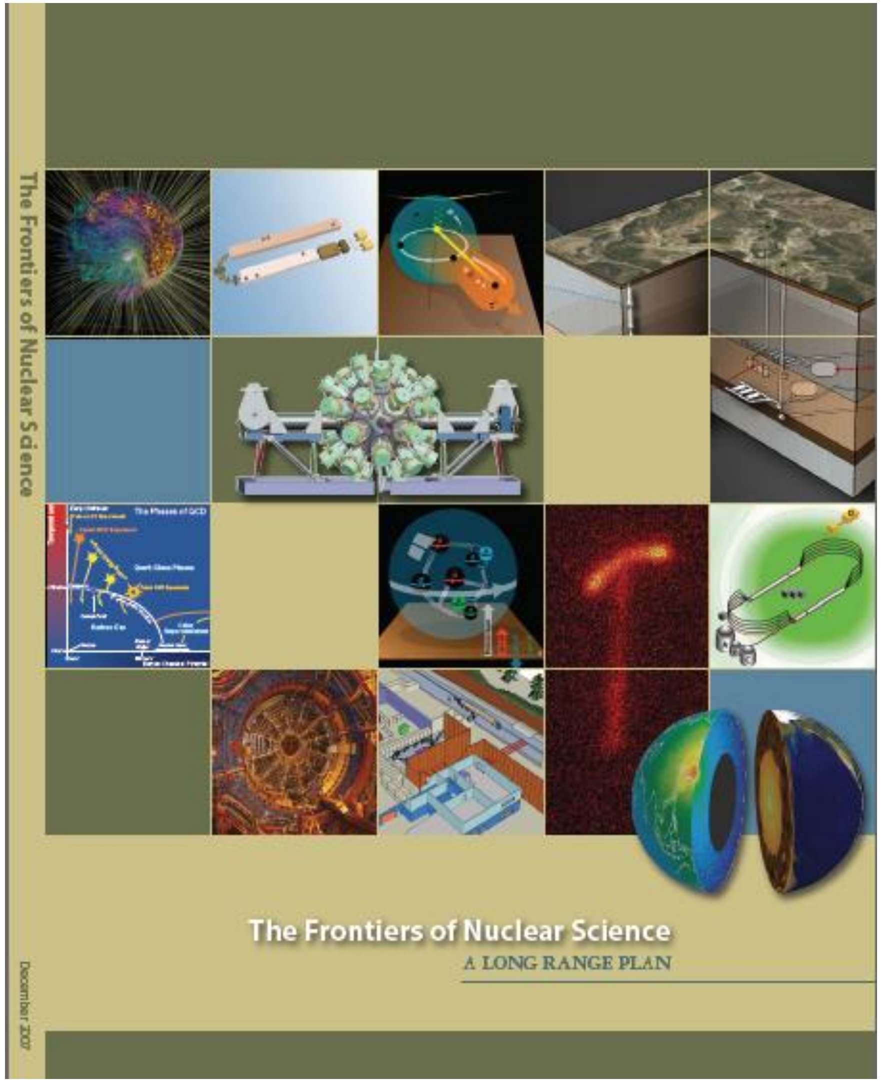
■ **Abstract** We present an overview of the scientific opportunities that would be offered by a high-energy electron-ion collider. We discuss the relevant physics of polarized and unpolarized electron-proton collisions and of electron-nucleus collisions. We also describe the current accelerator and detector plans for a future electron-ion collider

Brookhaven National Laboratory

NSAC 2007 Long Range Plan

"An **Electron-Ion Collider (EIC)** with polarized beams has been **embraced by the U.S. nuclear science community** as embodying the vision for **reaching the next QCD frontier**. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide and complementary to those planned for the next generation of accelerators in Europe and Asia. In support of this new direction:

We recommend the allocation of resources to develop accelerator and detector technology necessary to lay the foundation for a polarized Electron Ion Collider. The EIC would explore the new QCD frontier of strong color fields in nuclei and precisely image the gluons in the proton."



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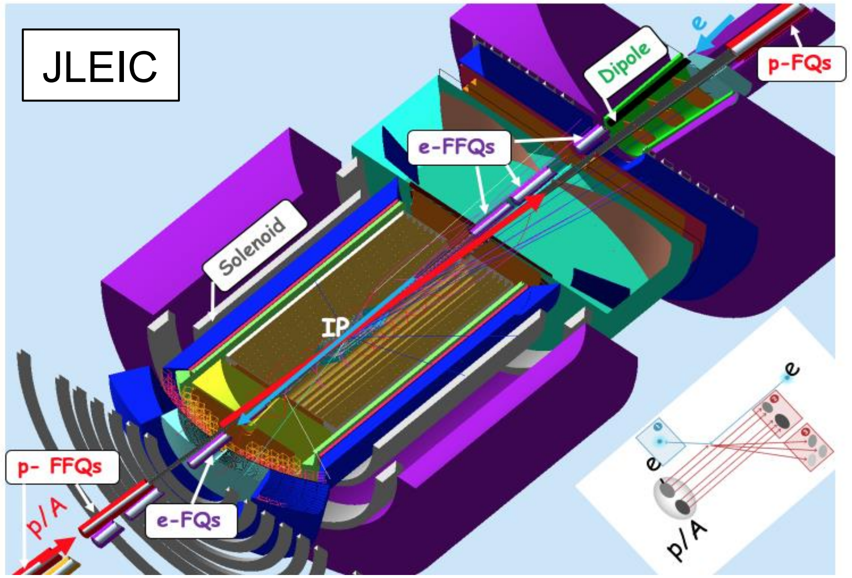
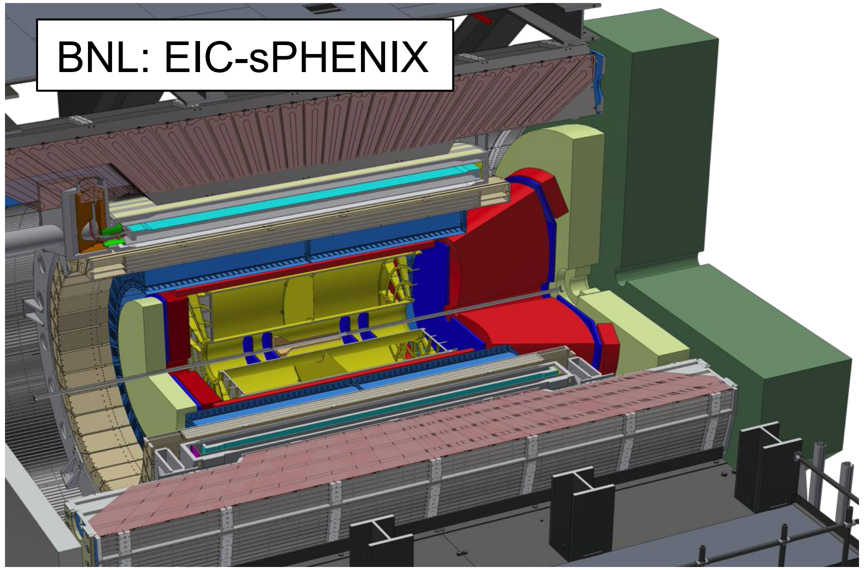
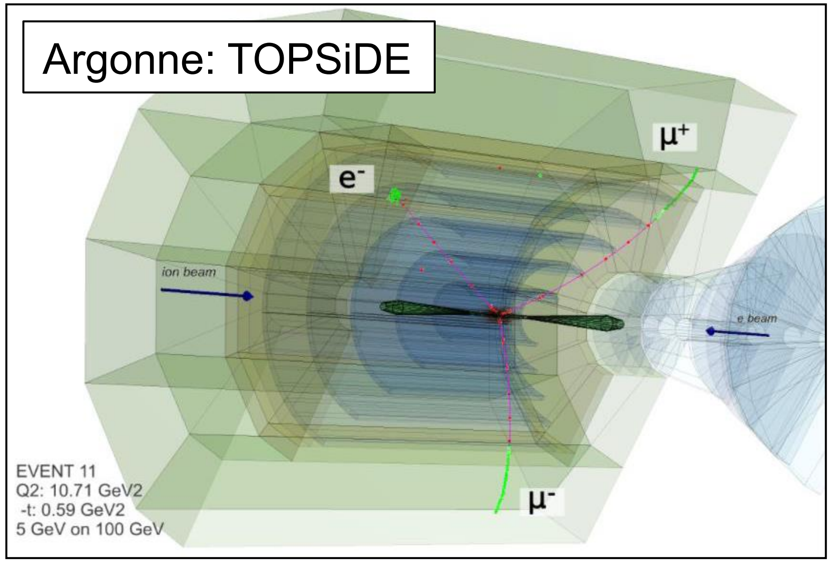
2010-2015 EIC detector concepts

But new are developing

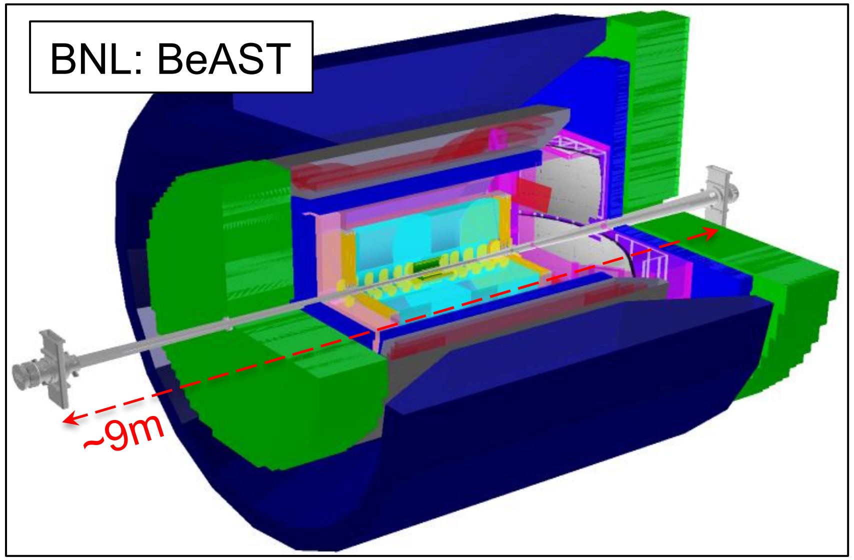
[Defining features]







Time OPtimized Silicon Detector for EIC



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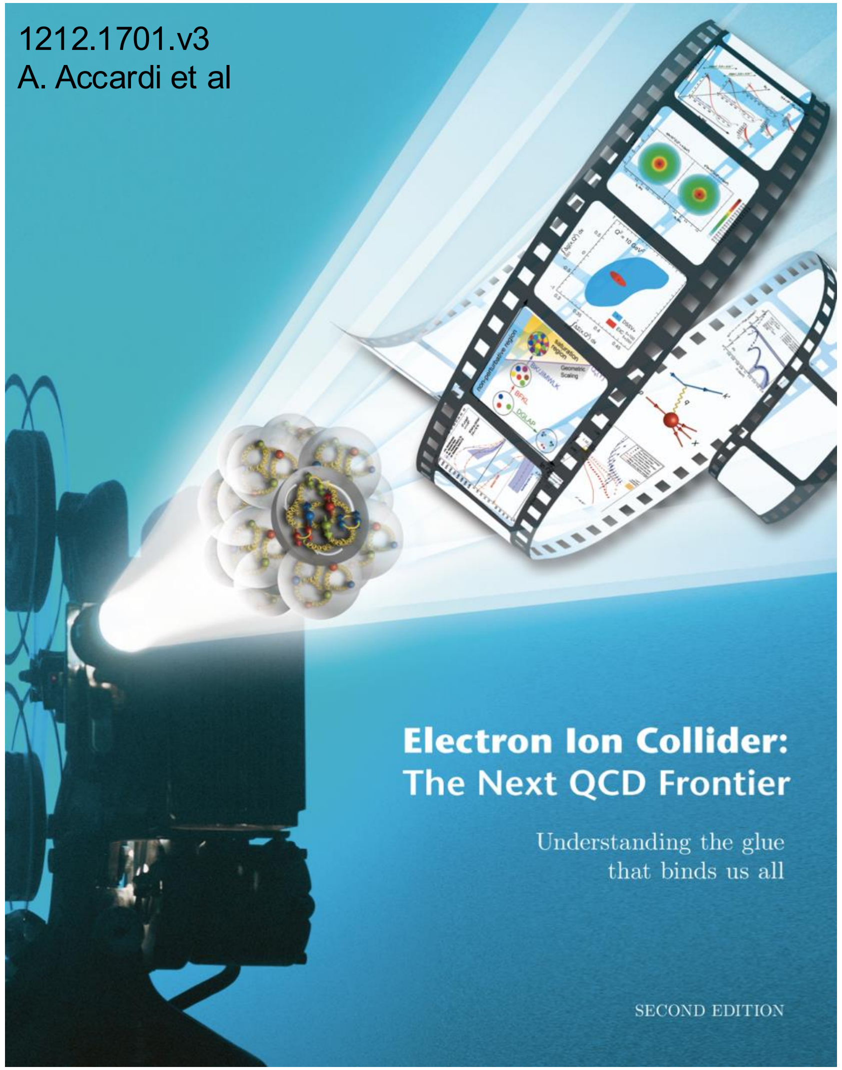


EIC White Paper for LRP 2015

arXiv: 1212.1701.v3, A. Accardi et al.

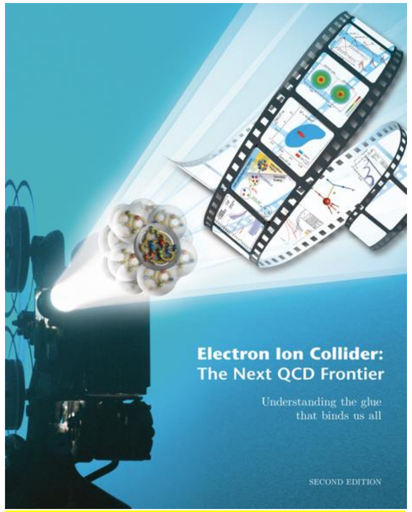
Editors: A. Deshpande (SBU), J. Qiu (Jlab) & Z-E Meziani (Temple)

Charged by R. McKeown (Jlab DD) & S. Vigdor (BNL ALD) in 2010

QCD Town Meeting of the Long-Range Plan held at Temple University (Meziani, Surrow et al hosted it)

Hot & Cold QCD Working Groups unanimously declared EIC to be the most desired future facility for US Nuclear Science – September 2014

The Electron Ion Collider
2018



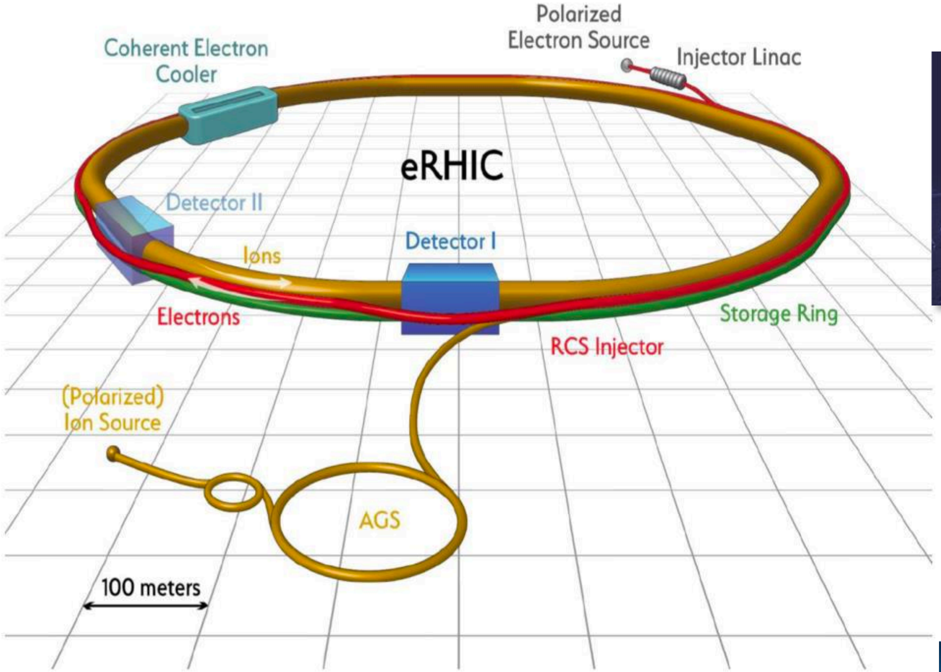
1212.1701.v3
A. Accardi et al
Eur. Phy. J. A, 52
9(2016)

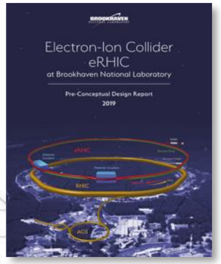
For e-N collisions at the EIC:
- ✓ Polarized beams: e, p, d/^{3}He
- ✓ e beam 5-10(20) GeV
- ✓ Luminosity L_{ep} ~ 10^{33-34} cm^{-2}sec^{-1}
  100-1000 times HERA
- ✓ 20-100 (140) GeV Variable CoM

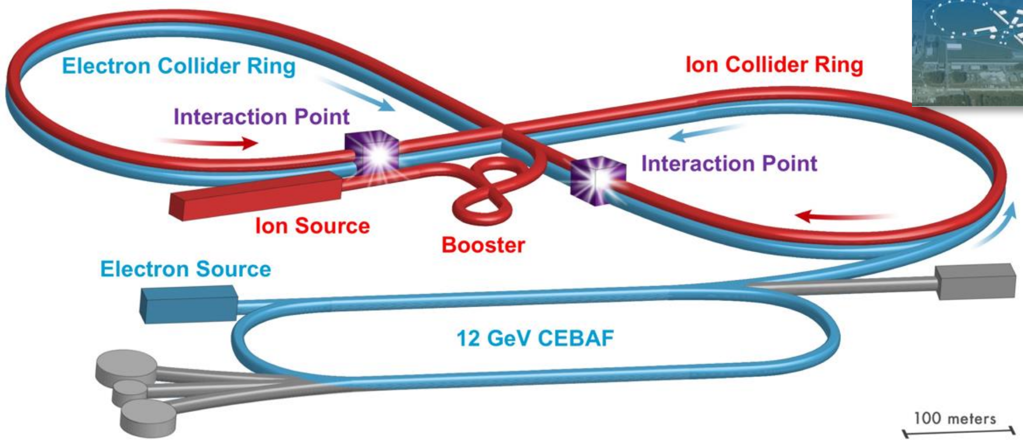
For e-A collisions at the EIC:
- ✓ **Wide range in nuclei**
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy

World's first
Polarized electron-proton/light ion
and electron-Nucleus collider

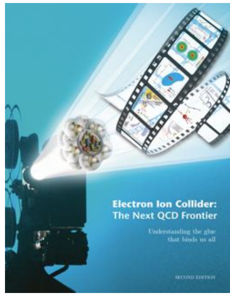
Both designs use DOE's significant investments in infrastructure





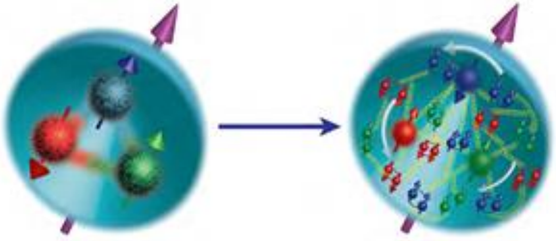


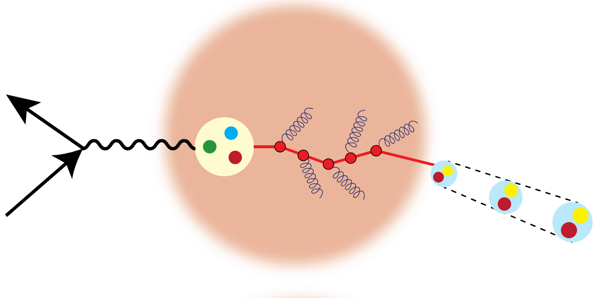
A new facility is needed to investigate, with precision, the dynamics of gluons & sea quarks and their role in the structure of visible matter



How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?

How do the nucleon properties emerge from them and their interactions?





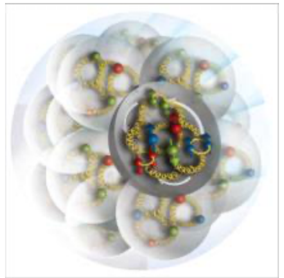
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

How do the confined hadronic states emerge from these quarks and gluons?

How do the quark-gluon interactions create nuclear binding?

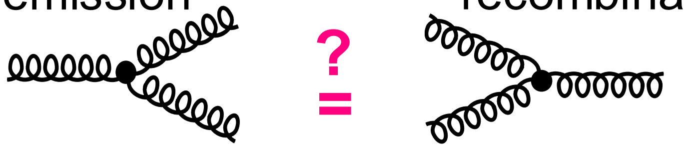
How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?



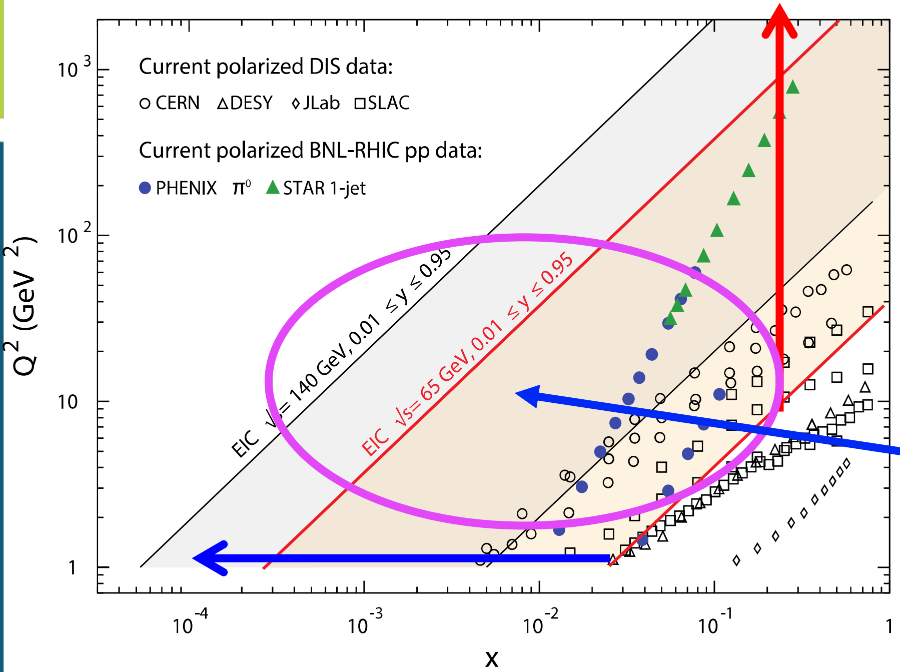
gluon emission

gluon recombination



Brookhaven National Laboratory

EIC: Kinematic reach & properties



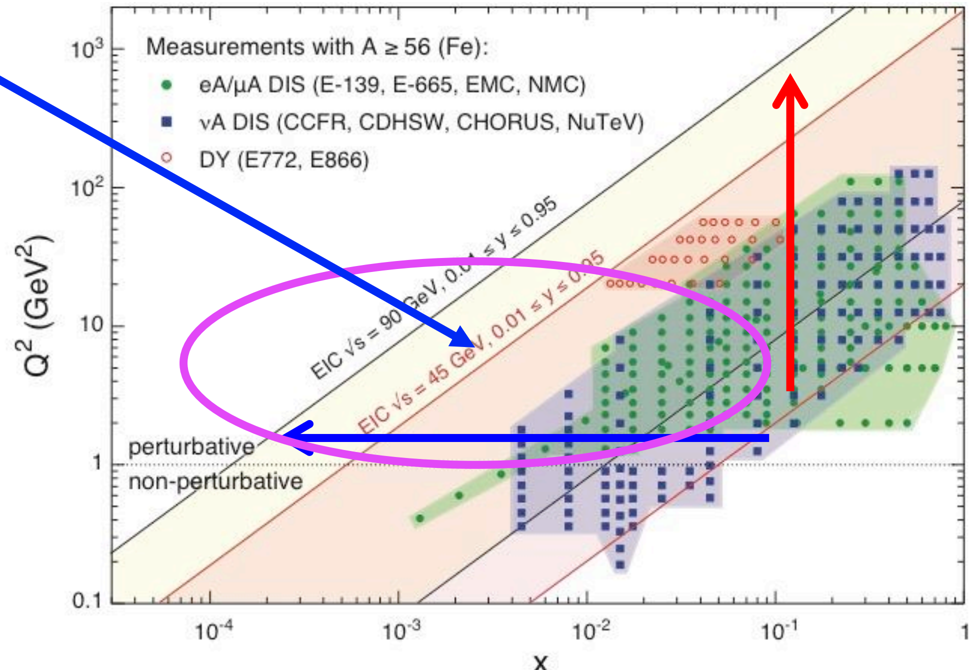
For e-N collisions at the EIC:

- ✓ **Polarized** beams: e, p, d/^{3}He
- ✓ Variable center of mass energy
- ✓ Wide Q^2 range → evolution
- ✓ Wide x range → spanning valence to low-x physics

A Q^2 and x evolution

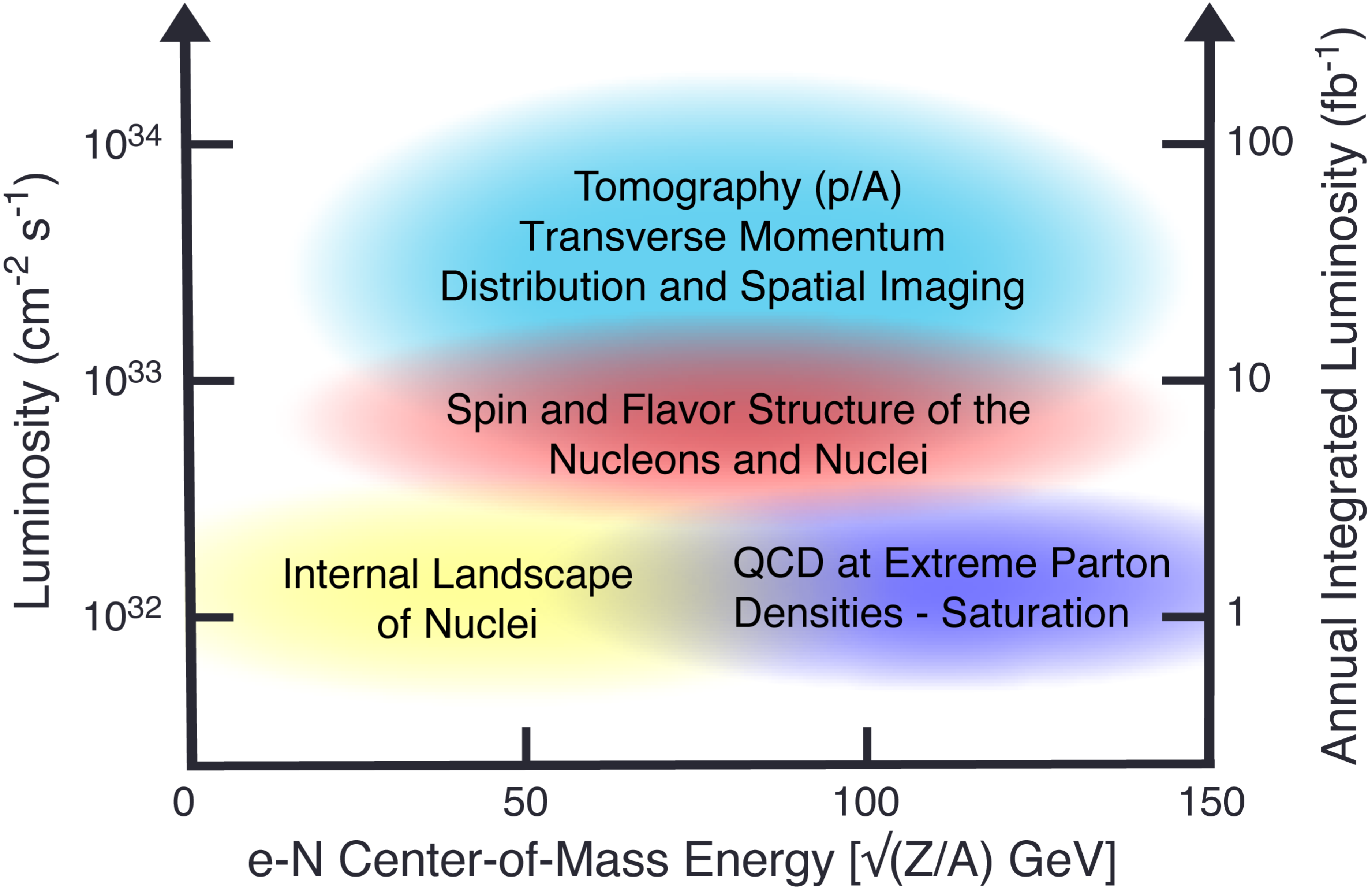
For e-A collisions at the EIC:

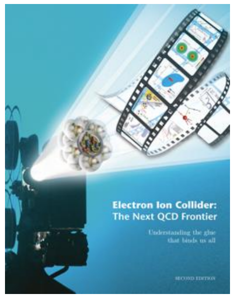
- ✓ **Wide range in nuclei**
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy
- ✓ Wide x range (evolution)
- ✓ Wide x region (reach high gluon densities)



Brookhaven National Laboratory

Summary: EIC Physics: CM vs. Luminosity vs. Integrated luminosity





Some Felt the Need to Invoke Higher Powers to Get the Recommendations Right

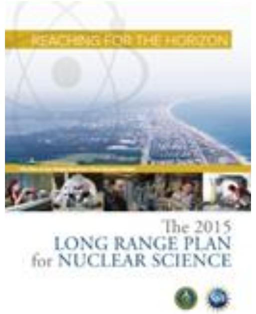
April 16, 2015
Kitty Hawk, NC
NSAC Long Range Plan
Resolution Meeting

Drafting of the EIC Recommendation

From L-to-R
Dave Hertzog,
Abhay Deshpande
(Face of) Naomi Makins

Picture & Title
By D. Geesaman
Chair, NSAC

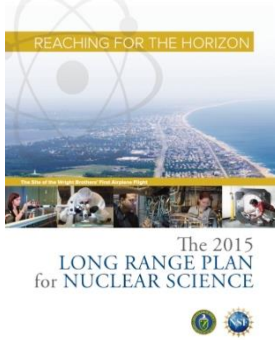
The EIC Recommendation



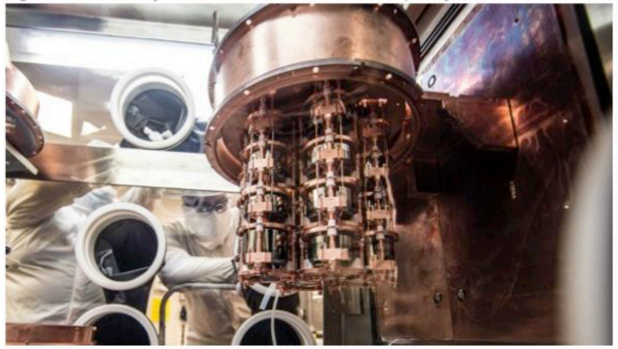
Gluons, the carriers of the strong force, bind the quarks together inside nucleons and nuclei and generate nearly all of the visible mass in the universe. Despite their importance, fundamental questions remain about the role of gluons in nucleons and nuclei. These questions can only be answered with a powerful new Electron ion Collider (EIC), providing unprecedented precision and versatility. The realization of this instrument is enabled by recent advances in accelerator technology.

We recommend a high-energy high luminosity polarized Electron Ion Collider as the highest priority for new facility construction after the completion of FRIB.

Precise imaging of gluons in nucleons and nuclei, origin of nucleon spin, explore new QCD frontier of ultra-dense gluon fields, with potential to discover a new form of gluonic matter predicted to be common to all nuclei…..



Breaking news and analysis from the world of science policy



MATTHEW KAPUST, SANFORD UNDERGROUND RESEARCH FACILITY

Researchers assemble a prototype detector for observing a rare form of radioactive decay known as neutrinoless double-beta decay. Physicists hope to scale up to a much larger, tonne-sized detector.

U.S. nuclear physicists push for new neutrino experiment

By Adrian Cho (/author/adrian-cho) | 15 October 2015 6:30 pm | 3 Comments (/physics/2015/10/u-s-nuclear-physicists-push-new-neutrino-experiment#disqus_thread)

The United States should seize the initiative and soon mount a massive experiment to search for a hypothesized type of nuclear decay that is possible only if an elusive, nearly massless particle called the neutrino is—weirdly—its own antiparticle. That's one of four recommendations in a new long-range plan developed by U.S. nuclear physicists (http://science.energy.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf)

APS NEWS

Nuclear Physicists Look to the Future

The 2015 Long Range Plan for Nuclear Science is unanimously approved

October 16, 2015 | Emily Conover

To prepare for the future, nuclear scientists have united behind a report outlining their priorities for research in the next decade. At a meeting of the Nuclear Science Advisory Committee (NSAC) on Thursday, members voted unanimously to approve the plan.

Photo: Michigan State University

These massive cyclotron components will be used at the Facility for Rare Isotope Beams being built at Michigan State University.

The 150-page plan makes four major recommendations for nuclear research: capitalize on recently completed and ongoing construction projects and upgrades to major facilities; develop a ton-scale, US-led neutrino-less double beta decay experiment that could indicate whether neutrinos are their own antiparticles; construct a high-luminosity electron ion collider; and increase funding for small- and mid-scale projects.

The committee hashed out the impact of varying funding scenarios on accomplishing these goals. These goals would be achievable with yearly budget increases of 1.6% beyond inflation, the report indicates. But even if funding increases only at the pace of inflation, nuclear physicists say they could still meet their main objectives, although the science reach would be more limited.

The plan also highlights two initiatives that would undergird their recommendations: one to support nuclear theory research, and one to support detector and accelerator R&D.

Finally, the committee emphasized the importance of training young scientists and students in nuclear science, and recommended boosting programs in that area, including the Research Experiences for Undergraduates (REU) program, the National Nuclear Physics Summer School, and fellowships for postdocs.

NSAC advises both the Department of Energy (DOE) and National Science Foundation (NSF) on basic research in the nuclear sciences. It has produced six long-term plans since 1979, with the previous plan in 2007. In April 2014, the agencies charged NSAC with creating a new report.

The current plan builds on the successes of the 2007 guidelines. An upgrade to Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab is nearly complete, and the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab received an upgrade as well. The Facility for Rare Isotope Beams (FRIB), at Michigan State University, is now under construction. The first recommendation of the report was to take full advantage of these upgraded and upcoming facilities.

Neutrinoless double beta decay experiments, the second recommendation in the report, search for a hypothetical type of radioactive decay in which two electrons are emitted without any accompanying antineutrinos. Discovery of such a process would indicate that the neutrino is its own antiparticle. Several current-generation experiments are preparing for the search, and hope to demonstrate technology that could be scaled up to a next-generation, ton-scale experiment of the type endorsed by the report, which would have a greater chance of detecting the elusive decay if it occurs.

The plan's third proposition — an electron ion collider — would be a high-energy, high-luminosity machine that collides a beam of polarized electrons with polarized protons and ions. Construction of the collider would begin following the completion of construction on FRIB, and could be operational beginning around the end of the 2020s. The collider would allow researchers to uncover the source of the neutron spin and reach the next frontier of quantum chromodynamics, systematically studying the properties of gluons.

The fourth recommendation, to increase funding for small- and mid-scale projects, follows a period with decreased investment in such efforts, as a result of intense focus on large undertakings like FRIB, said NSAC chair Donald Geesaman, a physicist at Argonne National Lab. Now, "we have to have projects at a number of scales," he said in a presentation at the meeting.

The plan passed easily, without any significant critique or questions from the committee or the audience, and the vote was unanimous, an indication of what Geesaman described as broad engagement from the nuclear physics community. Difficult decisions had already been worked out in the committee, said Geesaman, leading to "a lot of consensus" on the most important priorities. To produce the report, NSAC created a dedicated working group that held a series of town meetings and produced white papers. "The key thing, in my mind, is actually going through real budget scenarios," he added.

The plan was well received by DOE and NSF officials, as well. "I think it's an outstanding plan. I think it builds on the past and looks toward a very vigorous future," said Patricia Dehmer, acting director of DOE's Office of Science, in a presentation at the meeting. Fleming Crim, assistant director of NSF's Directorate of Mathematical and Physical Sciences, commended nuclear scientists for coming together to set goals. "Plans like this are successful when they really engage the community," he said.

Brookhaven National Laboratory in New York is a potential host for the Electron-Ion Collider.

NUCLEAR PHYSICS

Billion-dollar collider gets thumbs up

Proposed US electron–ion smasher wins endorsement from influential nuclear-science panel.

BY EDWIN CARTLIDGE

A machine that would allow scientists to peer deeper than ever before into the atomic nucleus is a big step closer to being built. A high-level panel of nuclear physicists is expected to endorse the proposed Electron-Ion Collider (EIC) in a report scheduled for publication by October. It is unclear how long construction would take.

The panel is the Nuclear Science Advisory Committee, or NSAC, which produces regular ten-year plans for the US Department of Energy (DOE) and the National Science Foundation. Its latest plan is still being finalized, but NSAC's long-range planning group "strongly recommended" construction of the EIC at a meeting last month, says NSAC member Abhay Deshpande, a nuclear physicist at Stony Brook University in New York. The EIC will almost certainly be formally endorsed in the NSAC report, he says. It must then be approved by the DOE, but most projects backed by the expert panel have come to fruition, he says.

The collider would allow unprecedented insights into how protons and neutrons are built up from quarks and the particles that act between them, known as gluons.

The current leading facilities for studying quark–gluon matter are the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory in Upton, New York, and the Large Hadron Collider at CERN, Europe's particle-physics laboratory near Geneva, Switzerland. These facilities smash protons and heavy ions together to recreate the energetic conditions of the early Universe, when quarks and gluons existed as a plasma rather than in atomic nuclei. The EIC would collide point-like electrons with either protons or heavy ions, generating collisions that have a similarly high energy but are more precise and so can be used to study subatomic particles in detail.

> ***"It is hard to see how to do this unless you get international buy-in."***

In particular, the EIC would be ideal for studying an exotic state of matter that is made up entirely of gluons. The machine should also solve a puzzle about the proton that has baffled physicists for nearly 30 years. The proton has a quantum-mechanical property called spin, but, strangely, the spins of its three constituent quarks add up to only about one-third of its own spin. The EIC would determine what makes up the difference: options include the spin of the proton's gluons, the angular momentum of its quarks or of the gluons from their orbital motion, or a mixture of all three.

"Until we have the EIC, there are huge areas of nuclear physics that we are not going to make progress in," says Donald Geesaman, a nuclear physicist at Argonne National Laboratory in Illinois, and the chair of NSAC.

The machine would not be built from scratch. One option is to add an electron-beam facility to RHIC — a plan that is estimated to cost about US$1 billion and would depend on some as-yet-unproven technologies. Another is to add an ion accelerator and new collider rings to the Continuous Electron Beam Accelerator Facility at the Thomas Jefferson National Accelerator Facility in Newport News, Virginia, which would cost about $1.5 billion.

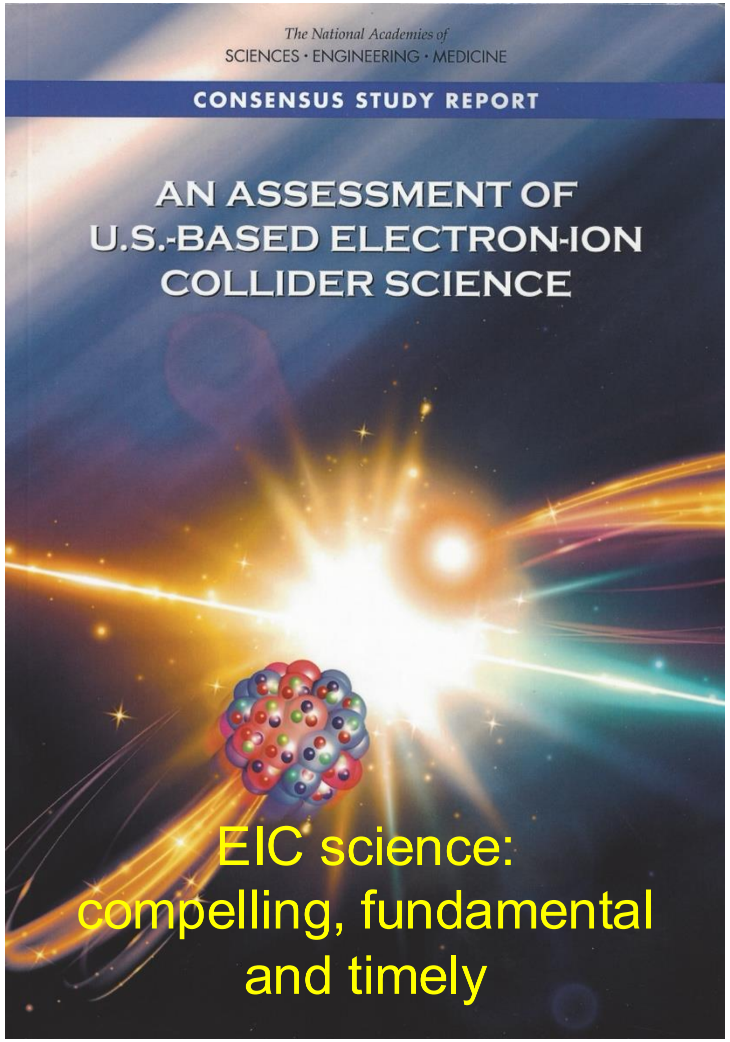
Deshpande hopes that the DOE will give the collider the thumbs up within a year of the NSAC plan's publication. Two or three more years would be needed to finalize the competing bids and choose one, meaning that construction could start in about 2020 and be completed five years later, he says.

Others say that this outlook is too rosy. The 2008 financial crisis led to a drop in science funding that forced NSAC to review its 2007 ten-year plan. A specially formed subcommittee concluded in 2013 that RHIC would have to shut down if funding for the DOE's Office of Nuclear Physics remained flat over the following five years. In fact, those funds have grown slightly, keeping RHIC in business, but the scare led to a more cautious approach this time around, says Geesaman. He points out that when the DOE and the National Science Foundation commissioned the ten-year plan, they specified that NSAC should consider what US physicists could achieve if funding remained flat, as well as how much support they would need to maintain a "world-leadership position".

Robert McKeown, deputy director for science at the Jefferson lab, thinks that limited funds might delay the start up of the EIC until at least 2030. And Michael Lubell, director of public affairs at the American Physical Society, questions whether it is feasible for the EIC to be built by the United States alone. He notes that the $1.5-billion Long-Baseline Neutrino Experiment became an international project after a slimmed-down $600-million version failed to pass scientific muster. "It is hard to see how to do this unless you get international buy-in," he says.

Deshpande thinks that the United States can go it alone. But he notes that collaborations at CERN and in China are also developing plans for electron–ion colliders and that the three groups are already exchanging ideas. ■

The National Academy of Sciences, Engineering and Medicine 2018



Consensus Study Report on the US based Electron Ion Collider

Summary:

The science questions that an EIC will answer *are central* to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today. In addition, the development of an EIC would *advance accelerator science and technology* in nuclear science; it would as well *benefit other fields of accelerator based science and society*, from medicine through materials science to elementary particle physics


SMC at CERN 1995/96
Low x behavior of g1(p)!
A. Deshpande & V. W. Hughes
~1995 SMC (internal) analysis meeting
Regge Extrapolation
Q² (GeV²)
Measurable Points at HERA
SMC
SLAC + HERMES
Kinematic Limit
DEUTSCHES ELEKTRONEN-SYNCHROTRON
DESY
Physics with Polarized Protons at HERA
saturation ?
enhancement
Fermi smearing
EMC
Columbia University in the City of New York
December 10, 1996
Professor Bjorn Wiik, Director
DESY
Notkestrasse 85
D-22607 Hamburg
Germany
Dear Bjorn:
en Letter
The National Academies of SCIENCES · ENGINEERING · MEDICINE
CONSENSUS STUDY REPORT
AN ASSESSMENT OF U.S.-BASED ELECTRON-ION COLLIDER SCIENCE
1999
BROOKHAVEN NATIONAL LABORATORY
Electron-Ion Collider
eRHIC
at Brookhaven National Laboratory
Pre-Conceptual Design Report
2019
eRHIC
RHIC
AGS
Linac
Storage Ring
Electron Cooler
Detector Location
Ions
SCIENCE REQUIREMENTS AND DETECTOR CONCEPTS FOR THE ELECTRON-ION COLLIDER
EIC Yellow Report
2021
THE HORIZON
2015
The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE
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January 9, 2020

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Department of Energy

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

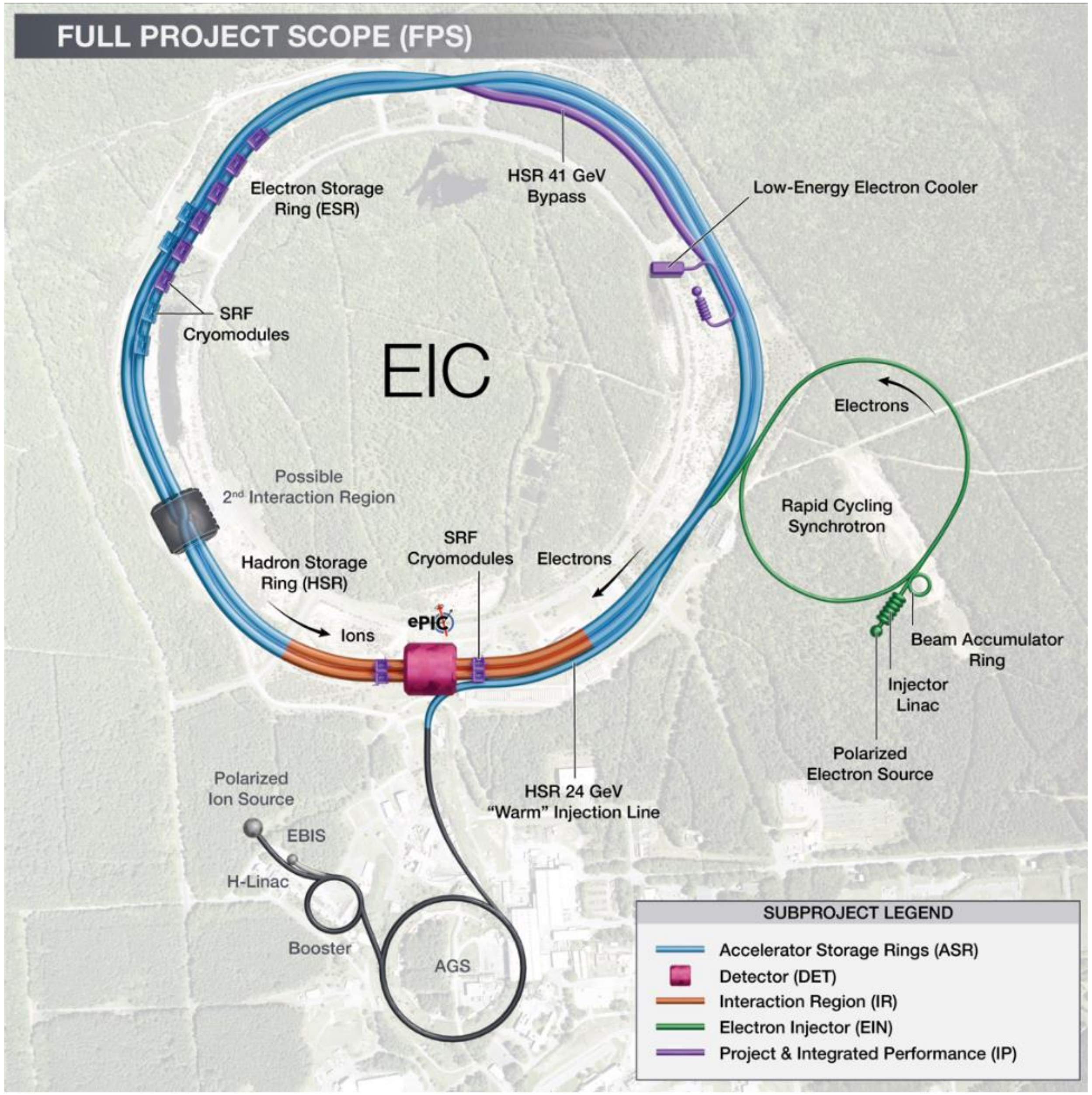
JANUARY 9, 2020

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

WASHINGTON, D.C. – Today, the **U.S. Department of Energy (DOE)** announced the selection of Brookhaven National Laboratory in Upton, NY, as the site for a planned major new nuclear physics research facility.

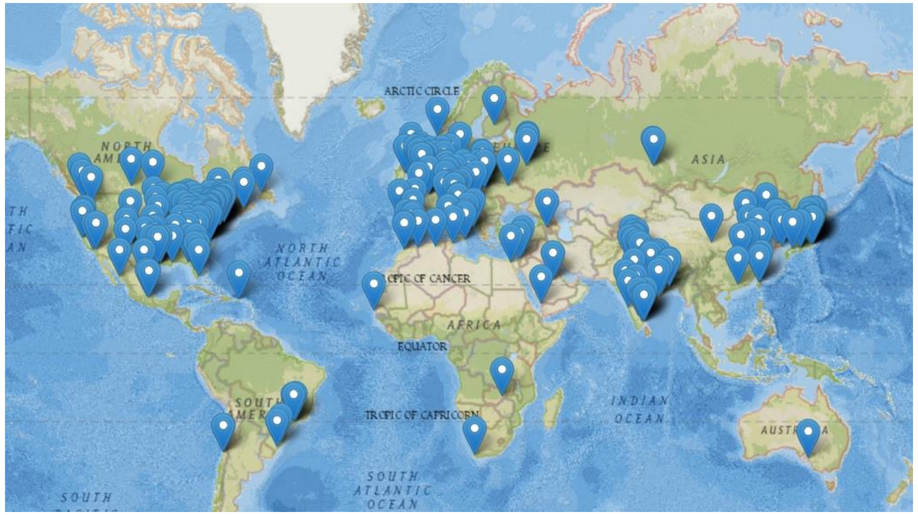
In the same also announced CD0 on December 19, 2019

2025/6



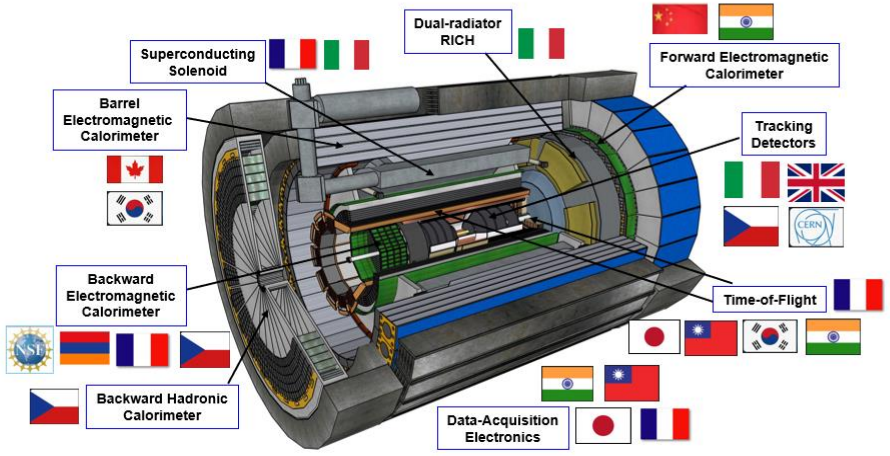
Brookhaven National Laboratory

Attracting Worldwide Attention, Collaborators



The EIC design and construction has many scientific and technical challenges, creating opportunities for worldwide collaborators to become part of this exciting endeavor.

- **EIC U.S. Partners** (performing work and/or providing materials)
  - Brookhaven and Jefferson Lab among eight, total, national laboratories
  - 22 universities
- **EIC Collaborators** (developing experiments, contributing expertise)
  - EIC User Group: 1,558 members and increasing
  - 907 institutions worldwide representing 41 countries
  - 80+ U.S. universities



Department of Energy Lab Partners

Brookhaven National Laboratory | Jefferson Lab | Argonne National Laboratory | Berkeley Lab (Lawrence Berkeley National Laboratory) | Fermilab | Oak Ridge National Laboratory | Los Alamos National Laboratory (Est. 1943) | SLAC National Accelerator Laboratory

EIC Why Now?

- The EIC is needed now because our understanding of QCD has reached the point where the biggest unanswered questions about the structure of matter are experimentally accessible, technically feasible, and strategically aligned with existing US infrastructure and scientific priorities.

- RHIC reached scientific maturity when the U.S. had an opportunity to repurpose the existing world-class collider complex. A uniquely qualified, irreplaceable workforce is available now.

- The National Academy of Sciences, Engineering and Medicine called the realization of such a facility “timely” - It preserves US collider and accelerator expertise and keeps the US in the forefront of innovation and global competitiveness.

- Over 1,500 scientists across more than 300 institutions are engaged and the US NP + HEP communities are initiating investigations to yield new discoveries, and drive innovation.

EIC is Underway

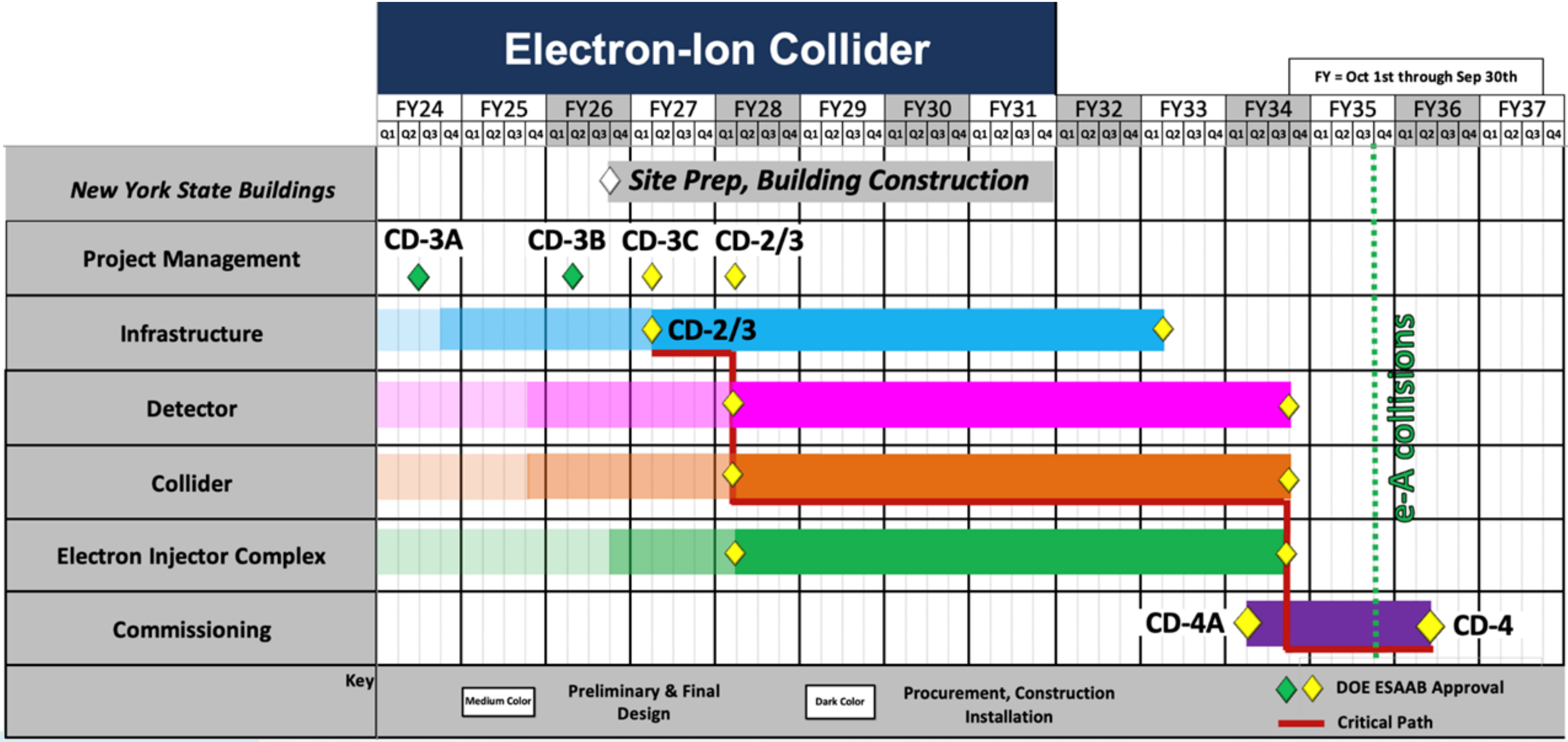
EIC will be a unique collider facility in the world and the only collider in the US

- EIC Science endorsed in US, UK, Europe, Canada, Japan, South Korea & India
- International collaboration engaged and preparing to deliver world—class science

Good understanding of the project scope, cost, and delivery plans

- Long lead procurements underway (CD3A, 3B) and prepared to start construction
- Installation of EIC magnets repurposed from RHIC underway
- In-kind contributions by international partners (accelerator $50M and detector $90M)

EIC Technically-Driven Schedule



EIC Time Line… (future)….

"Predictions are very difficult to make, especially when they are about the future….." - Albert E.

- Expected presentation & approval in next LRP (2006)
- R&D money for detector could start (2007)
- Construction of IR and Detector components (2008)
- 3 yrs for construction of IR & Detector (??) without interfering with the on going RHIC program
- First collisions (2011) ??

If you know how to get it done earlier…
-- I am listening….

Summary

Electron Ion Collider, a high-energy **high-luminosity polarized e-p, e-A collider**, will be built in this decade and operate in 2030’s.

- Will address the most profound unanswered questions in QCD
- The only new collider (and detector) to be built in the next 20-30 years

Up to two hermetic (full acceptance(?) and complementary) detectors under consideration: **EIC project has funds for 1 detector**.

- A truly international experimental collaboration (ePIC) formed
- A world-wide accelerator collaboration formed
- An aggressive timeline : first collisions by ~2034/5; physics start by ~2035/36
- High interest in having international partners both on detector and accelerator

For all early career scientists, graduate and undergraduate students: This machine is for you! Ample opportunity to contribute to machine, detector & physics of the EIC.


"New directions in science are launched by new tools much more often than by new concepts."
Freeman Dyson