The glue that binds us all: Latin America and the Electron-Ion Collider

III LASF4RI for HECAP Symposium: Update of the Strategic Plan

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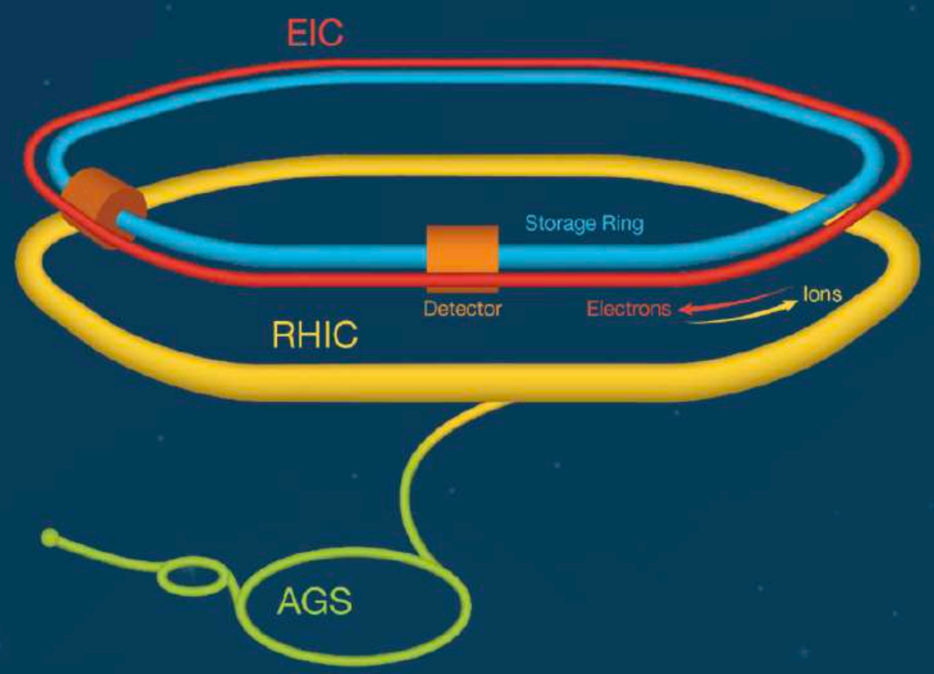
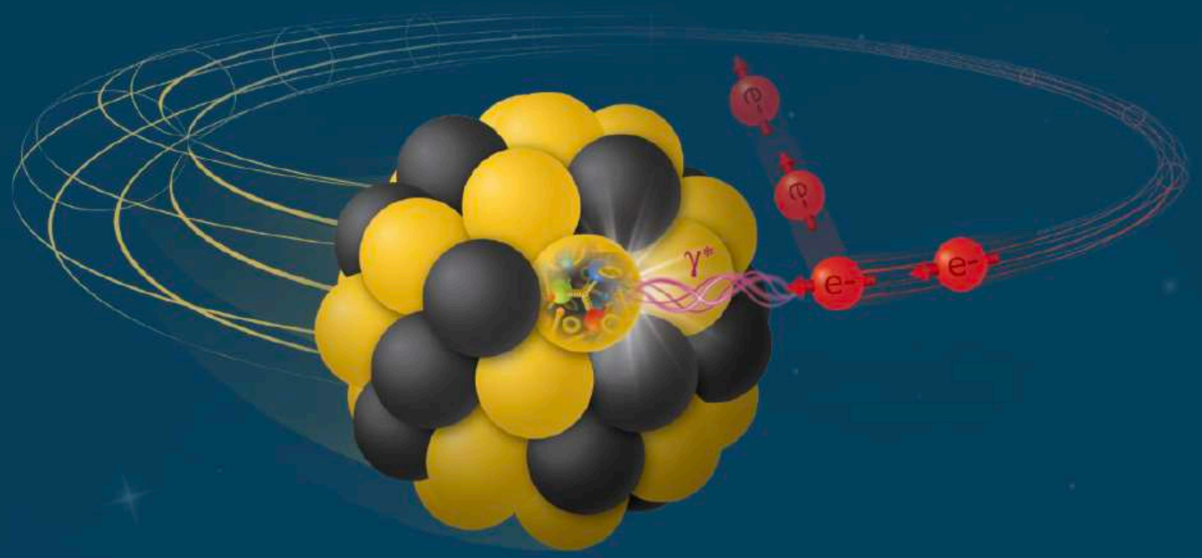
Why an Electron-Ion Collider ?

The Electron-Ion Collider (EIC) will be a 2.4-mile-circumference world-class particle collider, the first of its kind in the world. It will steer beams of high-energy polarized electrons into collisions with polarized protons and atomic nuclei to produce precision 3D snapshots of those particles' internal structure. Experiments at the EIC will help scientists unlock the secrets of the strongest force in nature and explore how tiny particles called quarks and gluons build up the mass, spin, and other properties of all visible matter.





Accelerator Physics

The Electron-Ion Collider (EIC) will make use of existing components of Brookhaven's Relativistic Heavy Ion Collider (RHIC), including its ion sources, pre-accelerator chain, and a superconducting magnet ion storage ring.

We'll add a new electron accelerator ring and electron storage ring inside the existing collider tunnel so that collisions can take place at points where the stored ion and electron beams cross.

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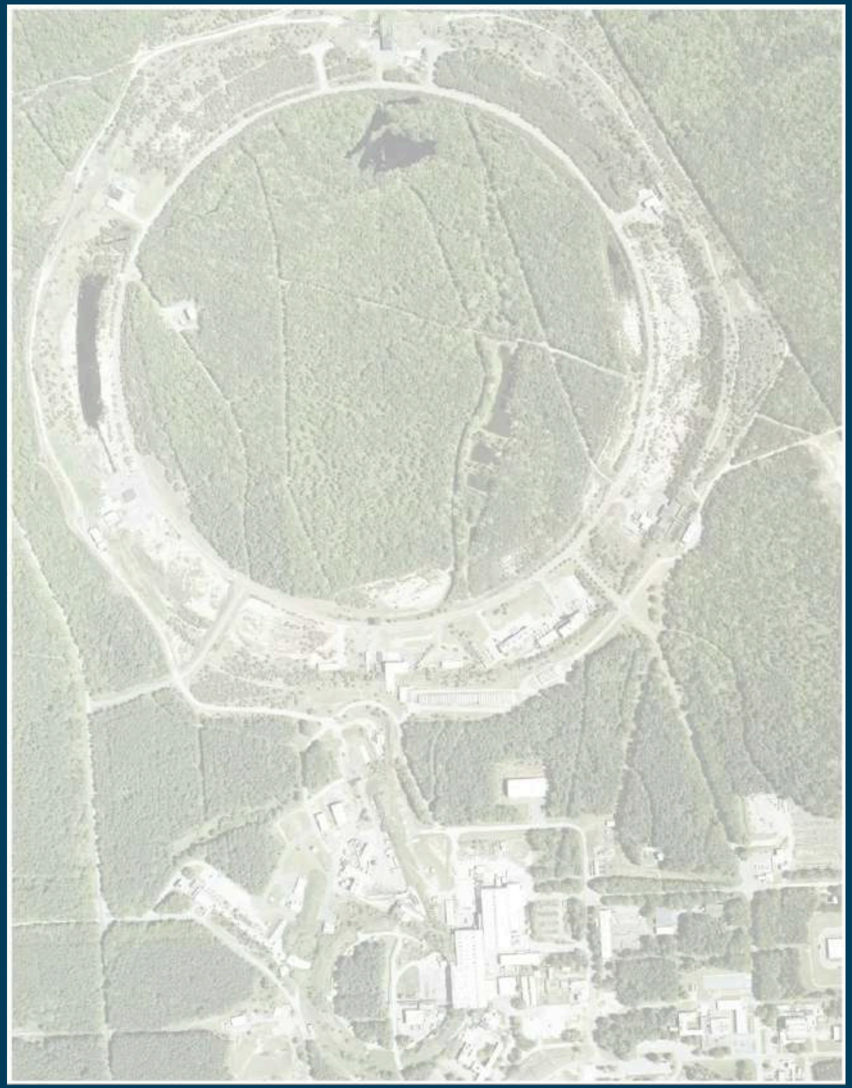

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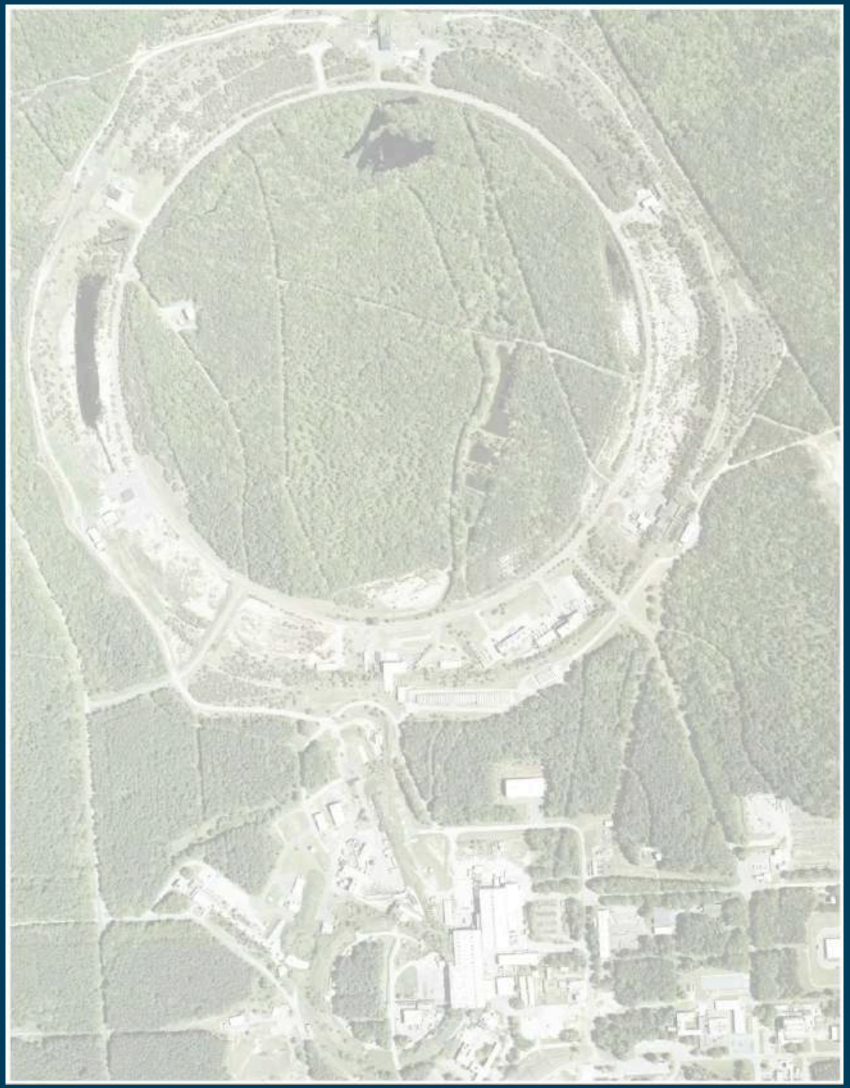
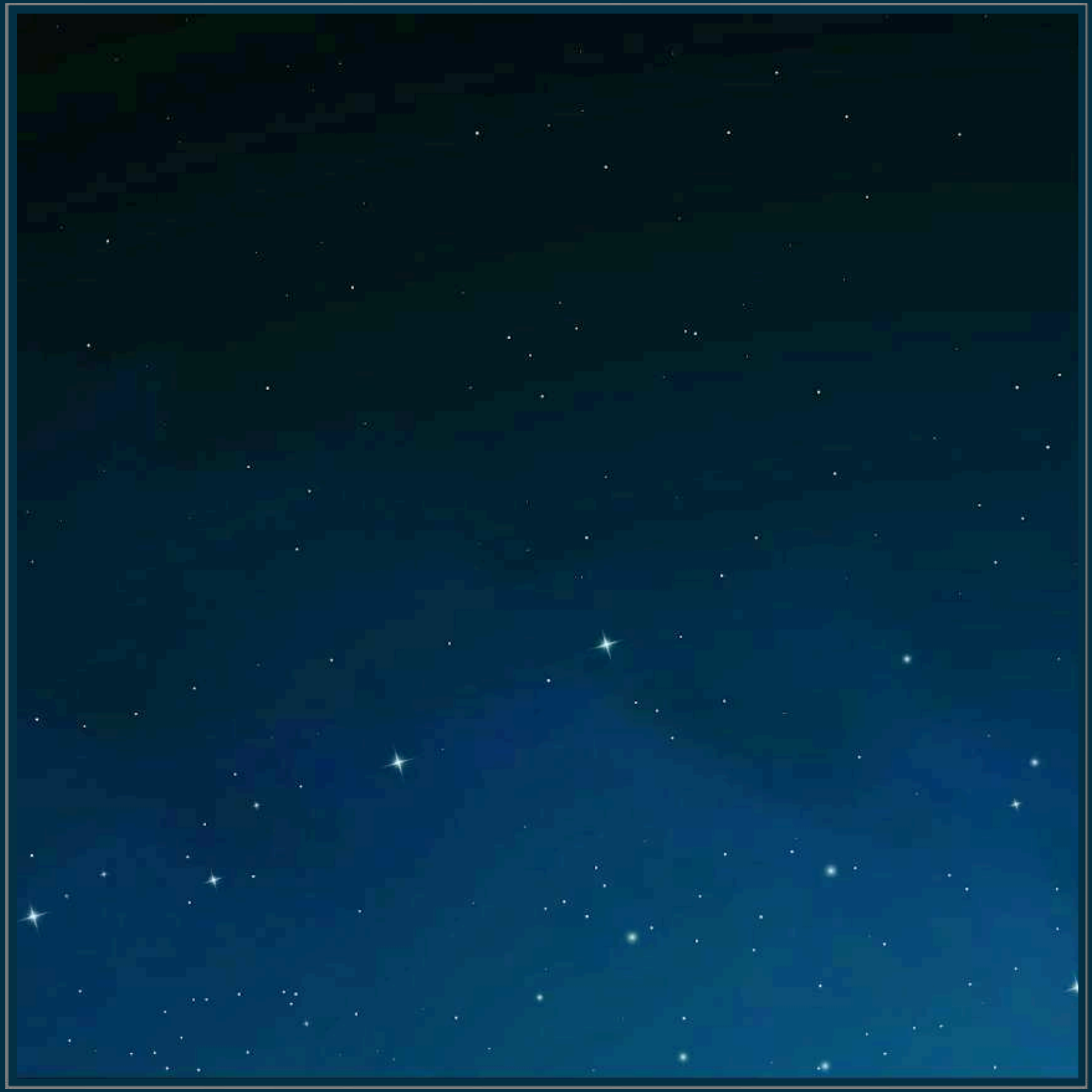


The Science at the EIC

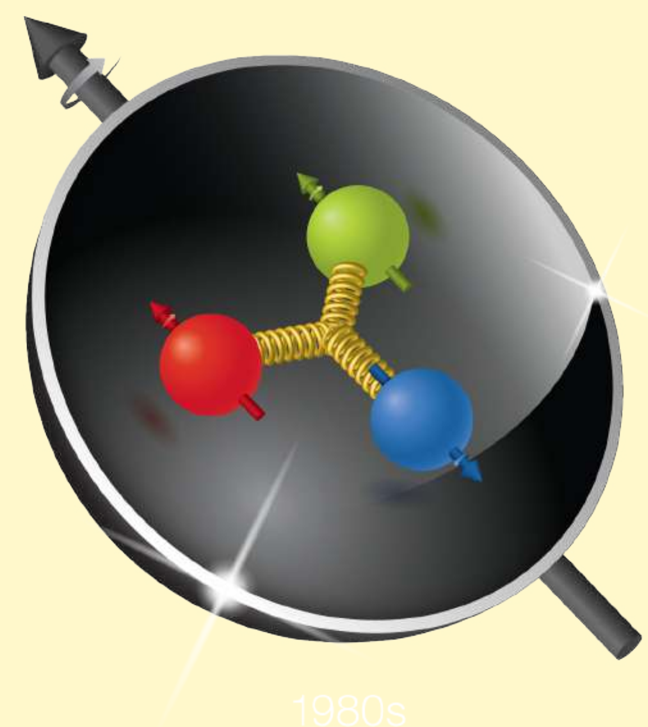


Courtesy of https://www.bnl.gov/eic

All of today's electronics and much of our economy depend on what scientists learned last century about atoms: the nucleus, its orbiting electrons, and the electromagnetic force. But there's a whole lot more going on inside the atomic nucleus and within its protons and neutrons.

The Electron-Ion Collider (EIC) will explore that inner microcosm. It will bring high-energy electrons into head-on collisions with high-energy protons or nuclei to reveal how the inner building blocks build up the properties and structure of all visible matter in the universe.

The origin of mass

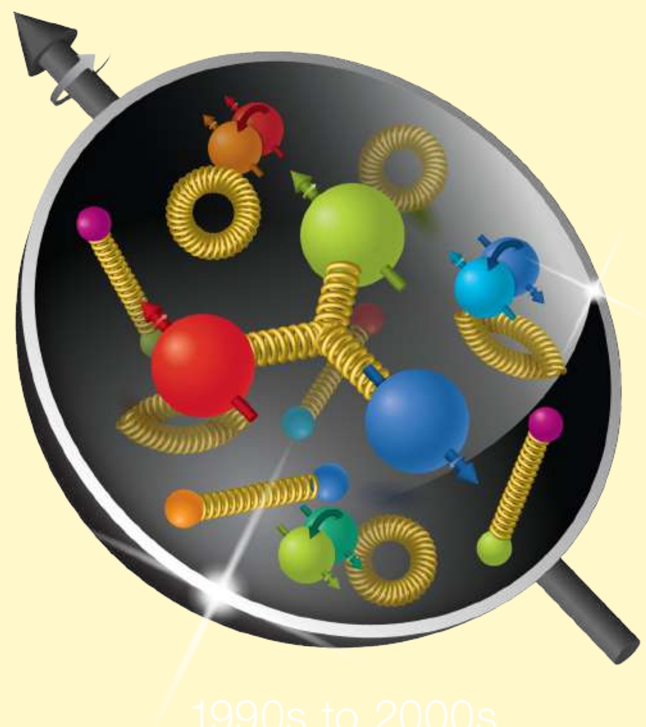


1970s to 1980s

The simplest view of a proton shows only three quarks held together by gluons.

Courtesy of https://www.bnl.gov/eic

The origin of mass



1990s to 2000s

Experiments have revealed that the internal structure of a proton can be much more complicated.

Courtesy of https://www.bnl.gov/eic

The origin of mass

Quarks have very little mass and gluons have none.

If you could weigh the mass of all the quarks and gluons outside of a proton, they'd account for only 1% of the total mass of the proton.

What creates the other 99%?

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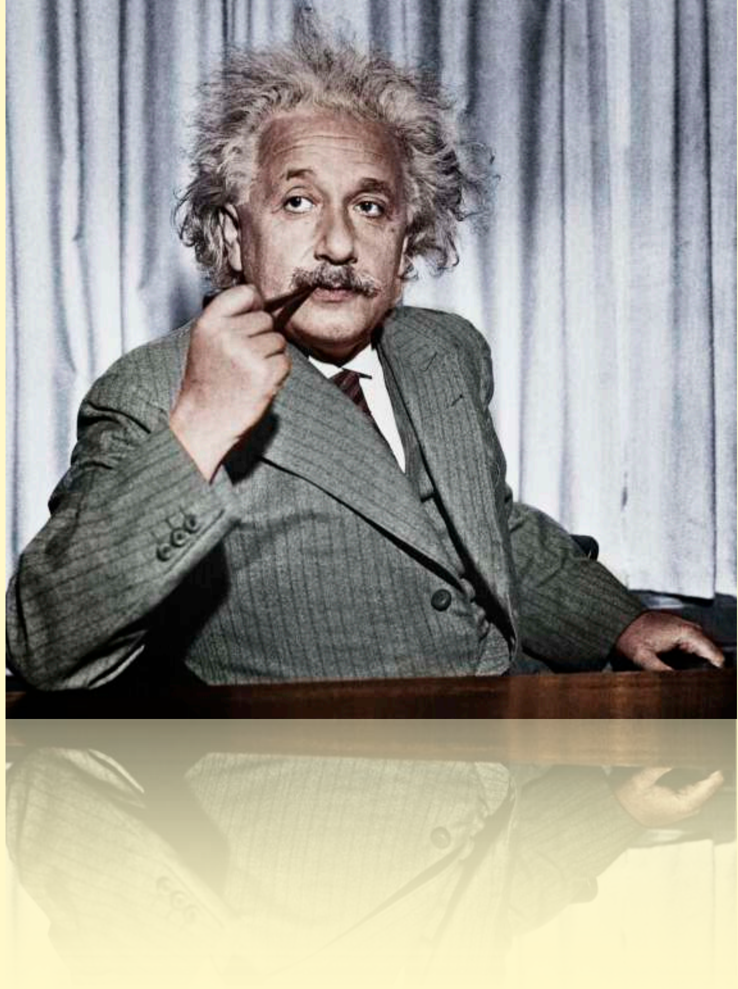
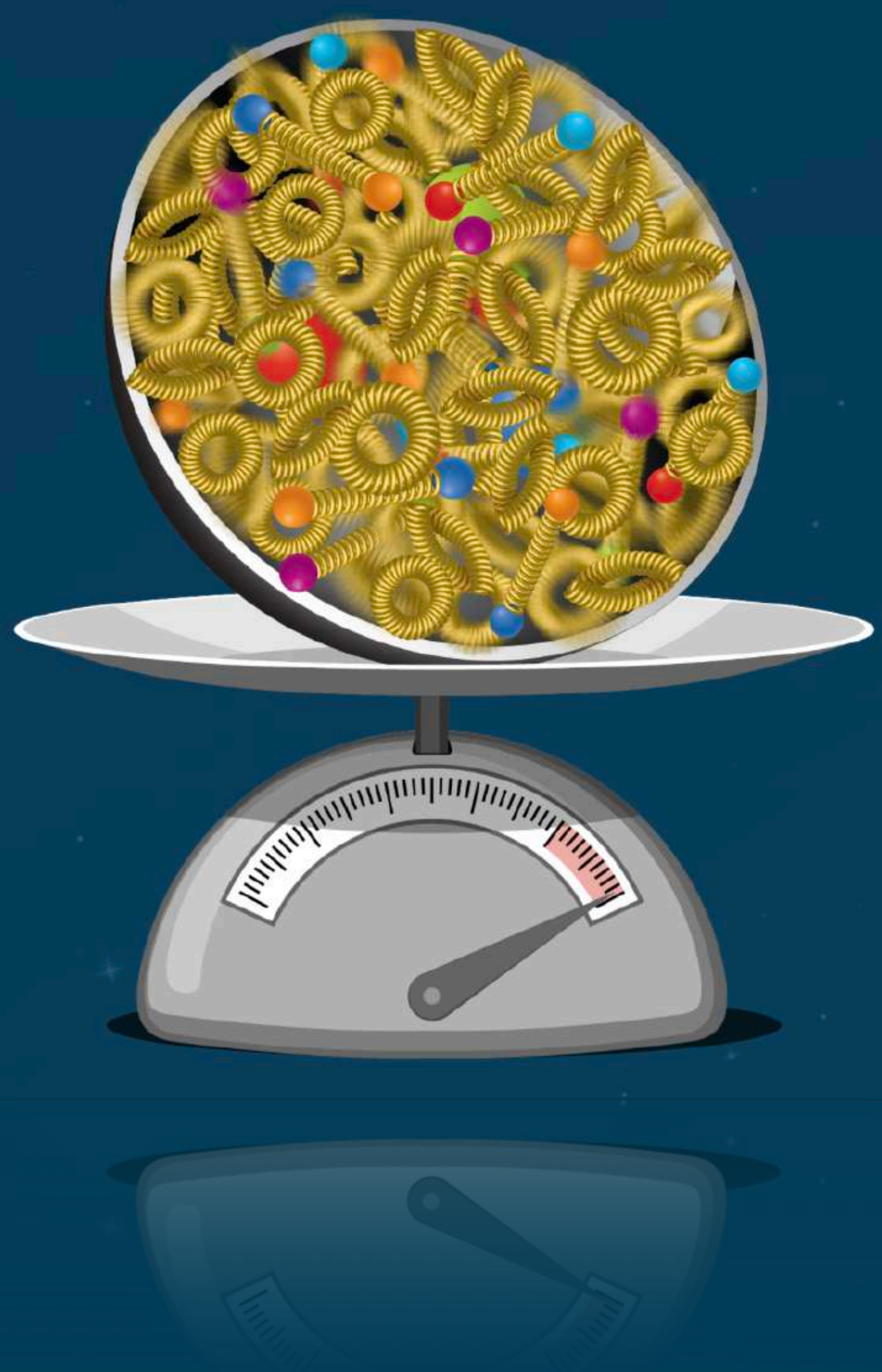
Remember Einstein?



$$E = mc^2$$

Theory of Relativity: "*Matter and energy are interchangeable, they are equivalent*"

The origin of mass



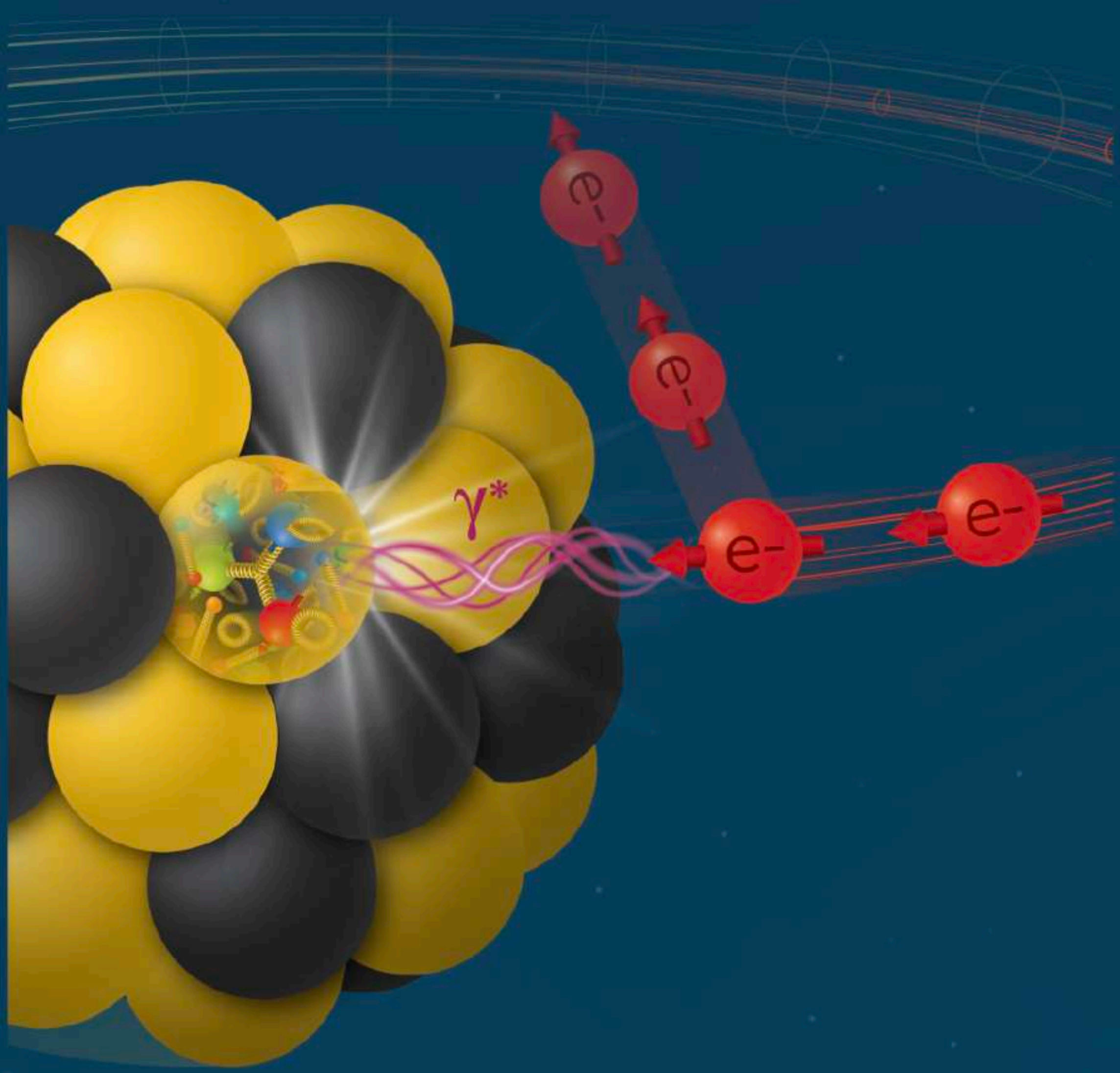
If gluons' interactions with quarks (and with one another) are sufficiently strong, they could generate the energy that gives mass to matter.

As Einstein's famous "energy = mass × the speed of light squared" equation ($E=mc^2$) tells us, energy and mass are interchangeable.

That means gluons, carriers of this strong-force energy, may play a bigger role in building the mass of visible matter than quarks.

Courtesy of https://www.bnl.gov/eic

The origin of mass: what EIC will tell us



The EIC will act like a combination MRI/CT scanner for the building blocks of atoms.

Electrons at the EIC will emit virtual light particles that scatter off quarks and gluons within a proton to produce the first ever 3D "freeze-frame" snapshots of the "sea" of quarks and "ocean" of gluons within these nuclear particles.

Understanding the structure and strong force interactions of the quarks and gluons will help us solve the mystery of how they generate the mass of all visible matter in the universe!

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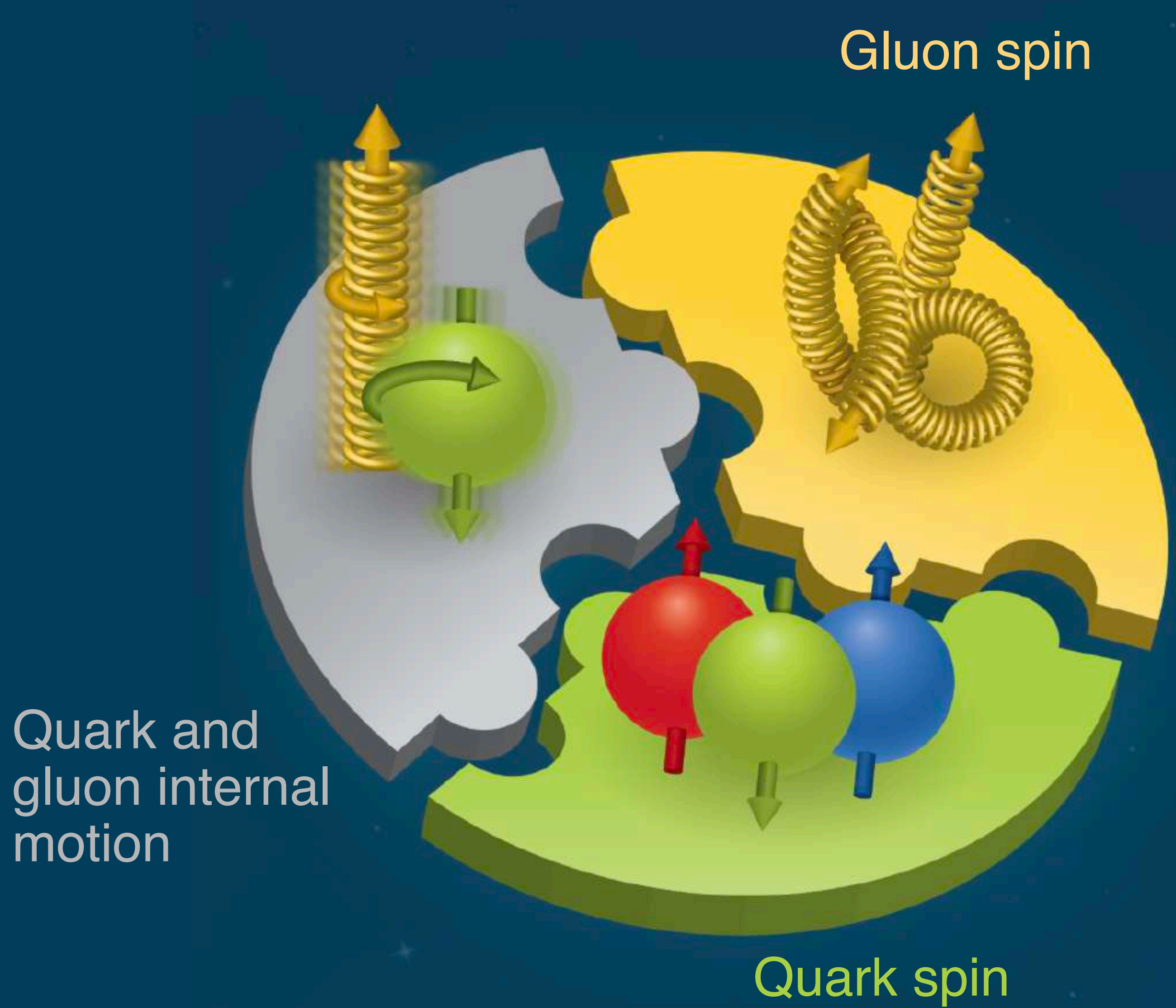
Solving the mystery of proton spin



The EIC will provide the data needed to solve the longstanding spin puzzle.

This state-of-the-art facility will be the world's first polarized electron-proton collider — meaning the spins of both colliding particles can be aligned in a controlled way.

It will make extremely precise, definitive measurements of the quark and gluon contributions to spin.

EIC scientists will also be able to measure the previously unknown piece: how these particles' orbital movements within the proton microcosm affect its overall spin.

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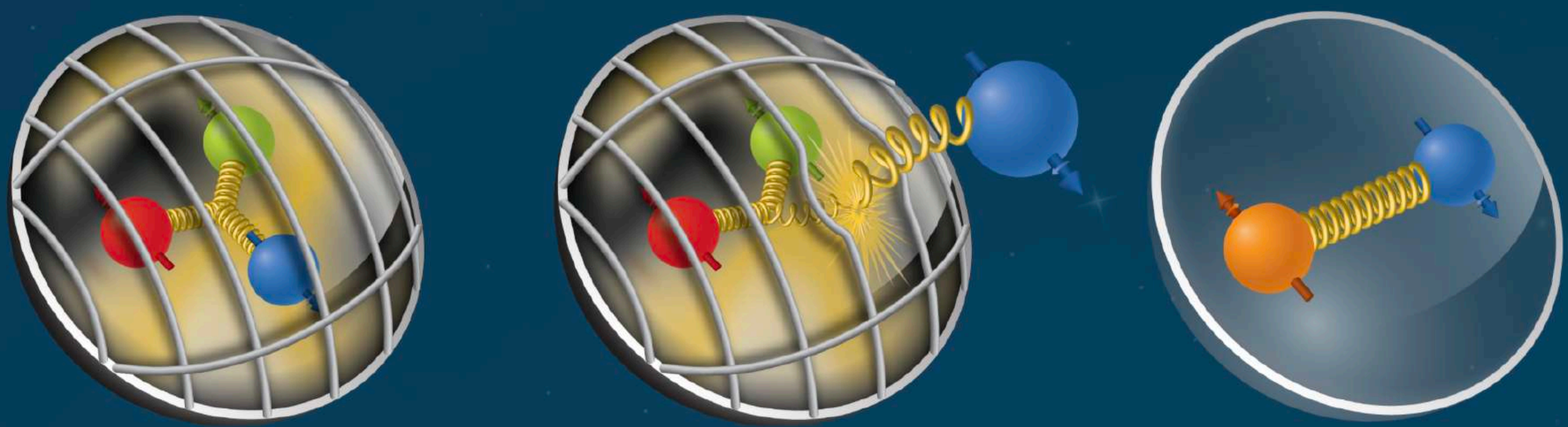
Confinement and nuclei: quantum vacuum

You might think of a vacuum as empty space, but the quantum vacuum inside a proton is teeming with energy. As Einstein's famous "energy = mass × the speed of light squared" equation ($E=mc^2$) tells us, energy can be transformed into matter. If a powerful particle collision kicks out an individual color-charged quark or gluon, it immediately pairs up with a new color-charged particle created out of that energy. The result: a new colorless composite particle. The dynamic details of how this happens are still a mystery!



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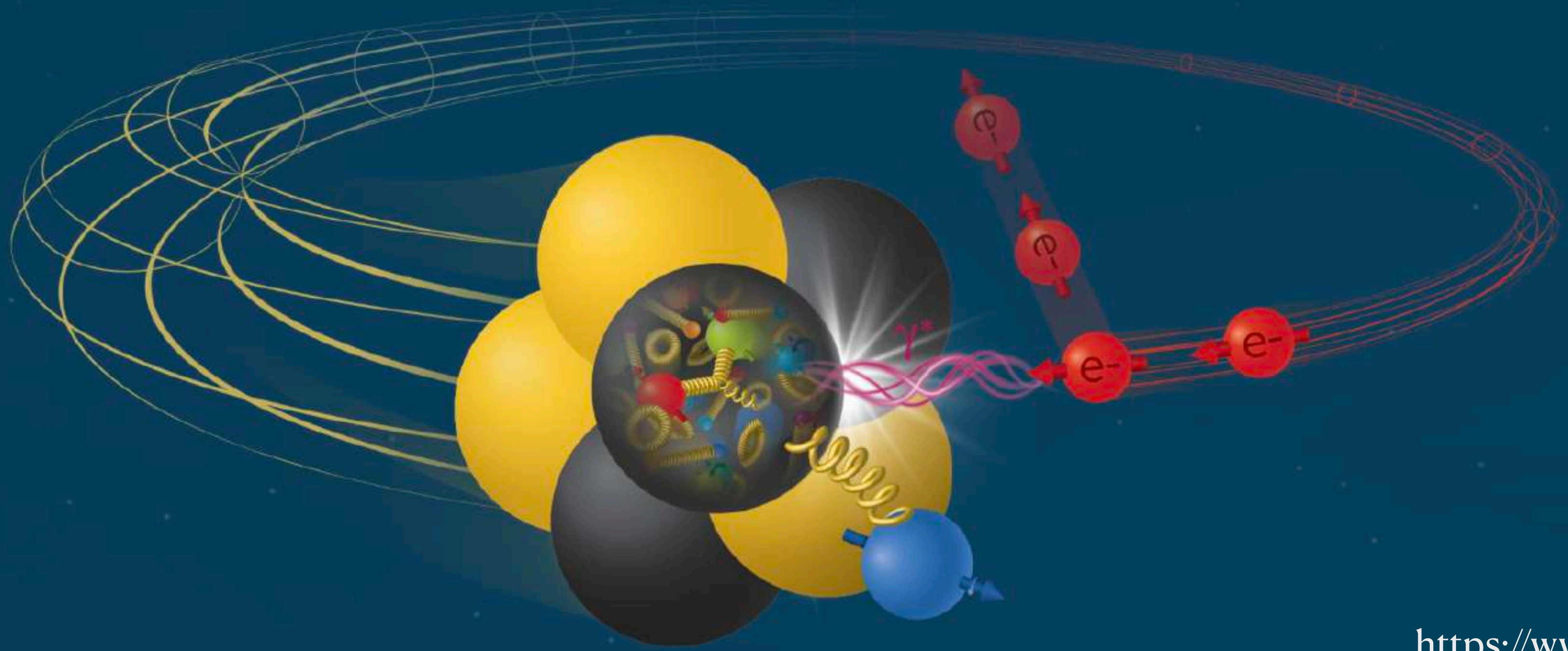
Confinement and nuclei: what EIC will tell us

The very energetic EIC collisions will be powerful enough to kick individual quarks and gluons out of protons or nuclei so scientists can study how these particles interact with the vacuum energy inside the proton. EIC scientists will also study how a proton's spin and how being in a nucleus (and the size of the nucleus) affect these interactions.



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Science and big data

Advances in data science will help scientists optimize the performance of the Electron-Ion Collider (EIC) and quickly turn measurements from billions of particle collisions into new insights and discoveries.

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Science and data

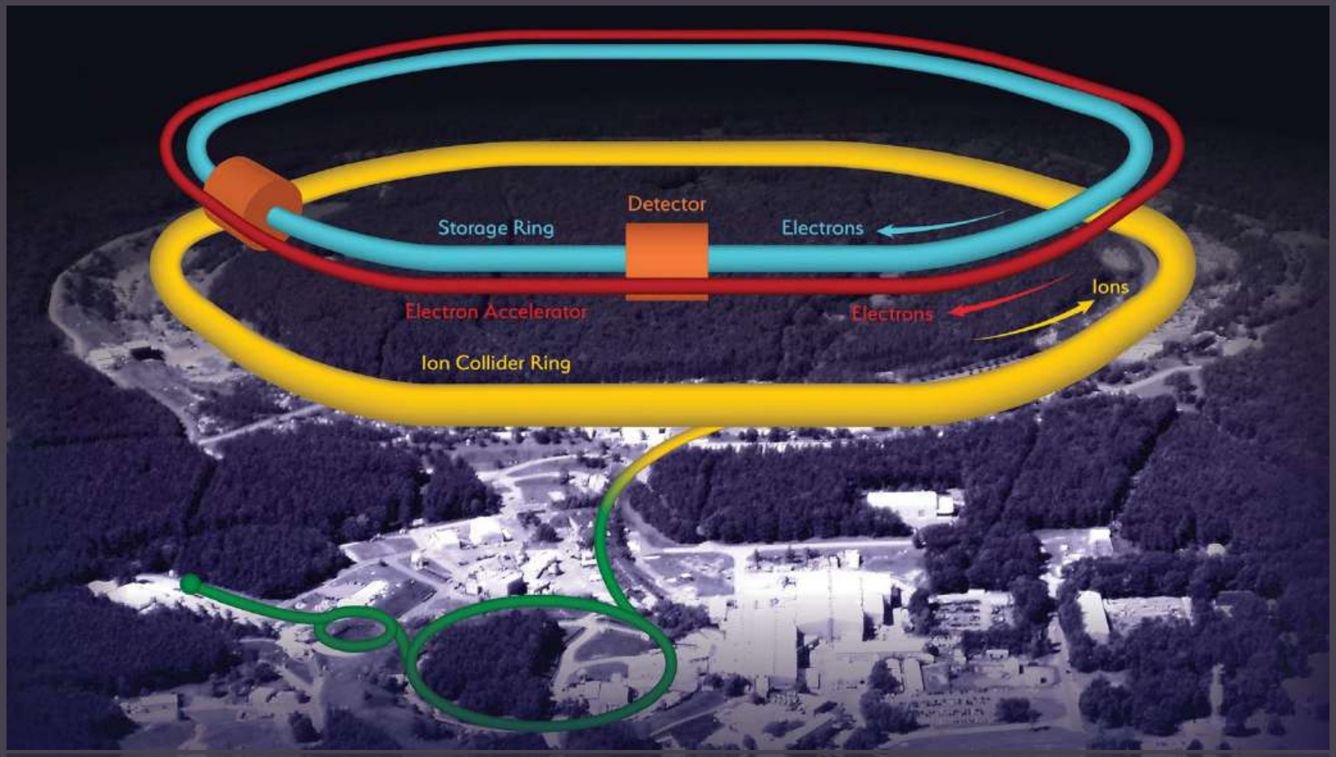
Scientists will record 1×10^{34} electron-ion collisions per square centimeter per second with polarized electrons and polarized ions !!

This vast amount of data will be sorted in real time before being shared with collaborators all over the world.

Funding

The ~$1.7-2.8 billion Electron-Ion Collider (EIC) will be funded primarily by the U.S. Department of Energy's Office of Science, with contributions from New York State and other science agencies in the U.S. and around the world.

Latin America and the EIC



The EIC worldwide

The EIC User Group (EICUG) consists of more than 1400 physicists from over 290 laboratories and universities from 38 countries around the world.

Latin America and the EIC

- Long tradition in hadron physics, quantum chromodynamics, nonperturbative methods in QFT and modeling in various universities and institutes, in particular in Argentina, Brazil, Chile and Mexico.

- Interest in theory and phenomenology related to contemporary hadron physics and experimental programs at Jefferson Lab, DESY, CERN (Alice, LHCb), BES III, Compass …

- Many collaborations of Latin-American groups or individual scientists with groups in Europe, USA, China, Japan …

- Perhaps less collaboration and interchange within Latin America, examples are São Paulo-Morelia & Mexico City, São Paulo & Colombia, São Paulo & Pelotas, Morelia-Sinaloa, Morelia-Unam …

- Many postdocs in this area work in Spain, Germany, Italy and USA.

Latin America and the EIC

- 46 physicists at 12 Latin American institutions are currently members of the Electron-Ion User Group (EICUG).
- A few participated actively in the elaboration of an EIC Yellow Report.
- Important issue: except for isolated groups in Chile and Mexico, hardly any experimental participation of Latin American physicists at labs mentioned before.
- Along with the HL-LHC and future high-energy accelerators (ILC, CEPC, FCC …), the EIC will be the most prominent accelerator facility dedicated to nuclear and particle physics in the world.
- Because of knowledge, technology and science transfer, Latin American participation is most desirable.

Physicists who signed White Paper

Mexico

Adnan Bashir (Universidad Michoacán)
Javier Cobos-Martínez (Universidad de Sonora)
Aurore Courtoy (Univ. Nacional Autónoma de México)
Martin Hentschinski (Univ. de las Américas Puebla)
Roger Hernández Pinto (Univ. Autónoma de Sinaloa)

Brazil

Arlene Cristina Aguilar (Univ. Estadual de Campinas)
Bruno El- Bennich (Univ. Federal de São Paulo)
Tobias Frederico (Instituto Tecnológico de Aeronáutica)
Victor Gonçalves (Universidade Federal de Pelotas)
Gastão Krein (Universidade Estadual Paulista)
Magno V. T. Machado (Univ. Federal do Rio Grande do Sul)
João Pacheco B. C. de Melo (Univ. Cidade de São Paulo)
Wayne de Paula (Instituto Tecnológico de Aeronáutica)

Colombia

Fernando Serna (Universidad de Sucre)

Argentina

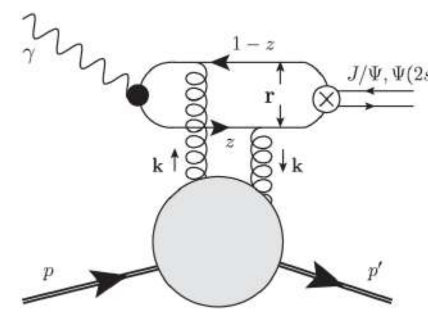
Daniel de Florian (Univ. Nacional de San Martín)
Rodolfo Sassot (Universidad de Buenos Aires)

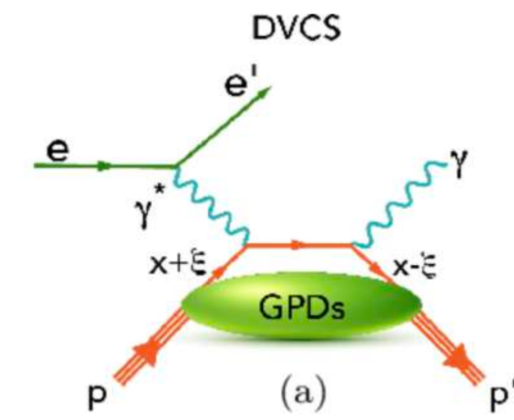
Outside Latin America

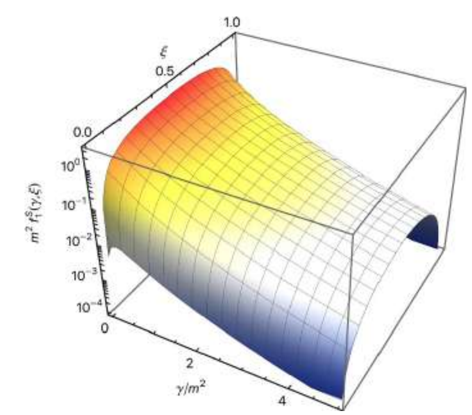
Luis Albino (Universidad Pablo de Olavide)
Leandro Cieri (Universitat de València)
Javier Mazzitelli (Paul Scherrer Institute)
Angel Miramontes (Universitat de València)
Khépani Raya (Universidad de Huelva)
Farid Salazar (University of Washington)
German Sborlini (Universidad de Salamanca)
Pia Zurita (Universidad Complutense de Madrid)

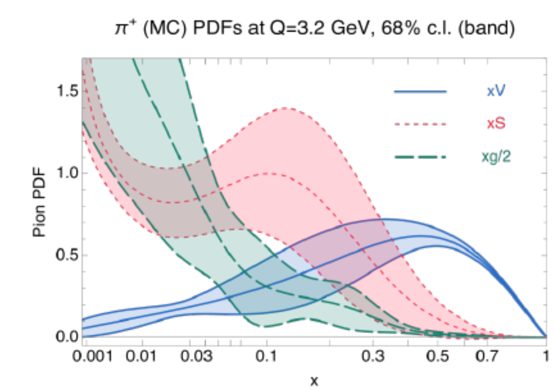
EIC related activities in Latin America

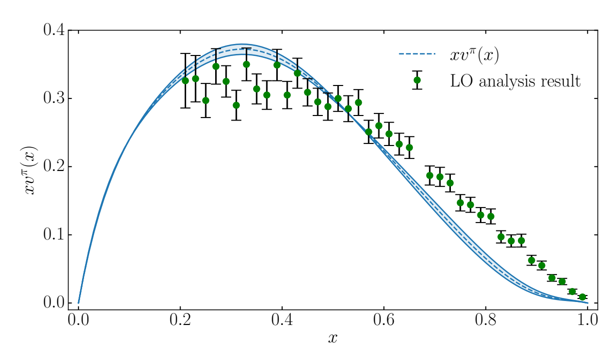
- Three-dimensional landscape of hadrons (PDF, TMD, GPD).
- Global QCD analyses, proton PDF fits.
- Elastic and time-like meson and proton form factors.
- Mass generation, trace anomaly, gluon content in protons.
- Gluon saturation, color glass condensate, small *x* physics.
- Vector-meson photo-production at high energies.
- Heavy mesons and quarkonia.
- Tetra- and Pentaquarks, exotic states, glueballs.
- Spin physics, high-precision pQCD.
- Computational physics, data analysis, machine learning.
- Entanglement entropy in inclusive and diffractive DIS.

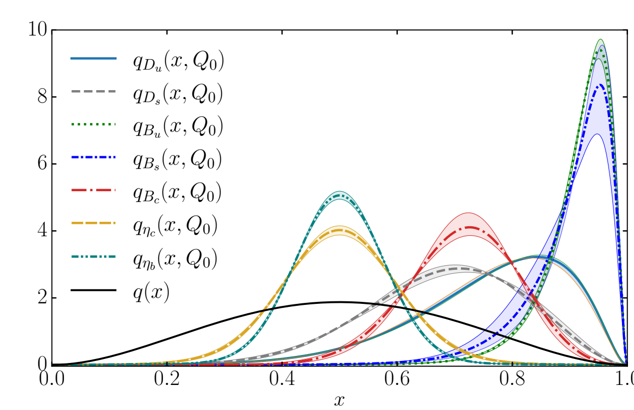












Building of a community

- Workshop series in Latin-America, for instance "Nonperturbative QCD" in Morelia (Mexico) and São Paulo (Brazil) with support by Conahcyt, CNPq, Capes and FAPESP.
- We organized "Physics Opportunities at an Electron-Ion Collider" (POETIC 2023) at the Principia Institute with support of ICTP-SAIFR, Brookhaven National Lab and Jefferson Lab.
- UNAM organized HADRON 2021 (online) and HADRON 2027 might be in São Paulo …
- "Light-Cone 2023: Hadrons and Symmetries" hosted by the Centro Brasileiro de Pesquisas Físicas (CBPF) in Rio de Janeiro.
- Several Latin American physicists have organized workshops at the Center for Frontiers in Nuclear Science, Stony Brook University.
- The QCD4EIC workshop was jointly organized by the Buenos Aires and Tübingen University groups: precision QCD.
- Lecturers at the "38th Annual Hampton University Graduate Studies" (HUGS) Summer School at Jefferson Lab.

EIC/U.S. support for Latin America

- The Inter-American Network of Networks of QCD challenges (I.ANN-QCD) has been very valuable to support visits of hadron physicists from Latin America at U.S. institutions.
- The EIC Theory Institute at Brookhaven National Laboratory has welcomed physicists from Colombia and Mexico (one-months stays).
- Jefferson Lab invited many physicists from Latin America for short- or long-term visits.
- The Center for Frontiers in Nuclear Physics (CFNS) funded QCD and EIC-related workshops of Latin-American organizers at Stony Brook (three workshops in 2024).
- Brookhaven National Lab and Jefferson Lab strongly supported and sponsored POETIC 2023 at the ICTP-SAIFR in São Paulo.

I·ANN Network of Networks QCD Inter-American

Center for Frontiers in Nuclear Science

Brookhaven National Laboratory

Jefferson Lab

Perspectives and projects

- Most scientific visits, student exchanges and postdoc positions within Latin America are based on individual or group grants.
- Push initiatives for collective applications for funding, following for instance the SPINT calls of FAPESP (agreements between two institutions), involving two or more universities and labs.
- Building a network of QCD groups, initially in Argentina, Mexico and Brazil, with a common and comprehensive proposal related to EIC physics.
- Submit common proposals jointly to FAPESP, CNPq, Conahcyt, Conicet.
- If successful, this would allow to finance workshops and EIC schools for graduate students (with support from BNL and Jlab) and finance PhD and Postdoc fellowships.
- Invite senior physicists from USA and Europe to give lecture series and for longer scientific visits to train students (groom them for experiments at EIC?)

Last not least …

- Abhay Deshpande, the EIC Scientific Director and Associate Laboratory Director at BNL visited São Paulo in 2023 and expressed strong interest in a more formal institutional agreement with State and Federal agencies.

- Elke-Caroline Aschenauer, EIC Co-Associate Director for Experimental Program, visited the the new Brazilian Synchrotron Light Source (SIRIUS @ LNLS) and made first contacts with accelerator scientists: interest in common detector projects.

Brookhaven National Laboratory

Timeline CD-1 to CD-4