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U.S. DEPARTMENT of ENERGY

EIC Science and Status

Abhay Deshpande
Associate Laboratory Director for Nuclear and Particle Physics

May 26, 2025

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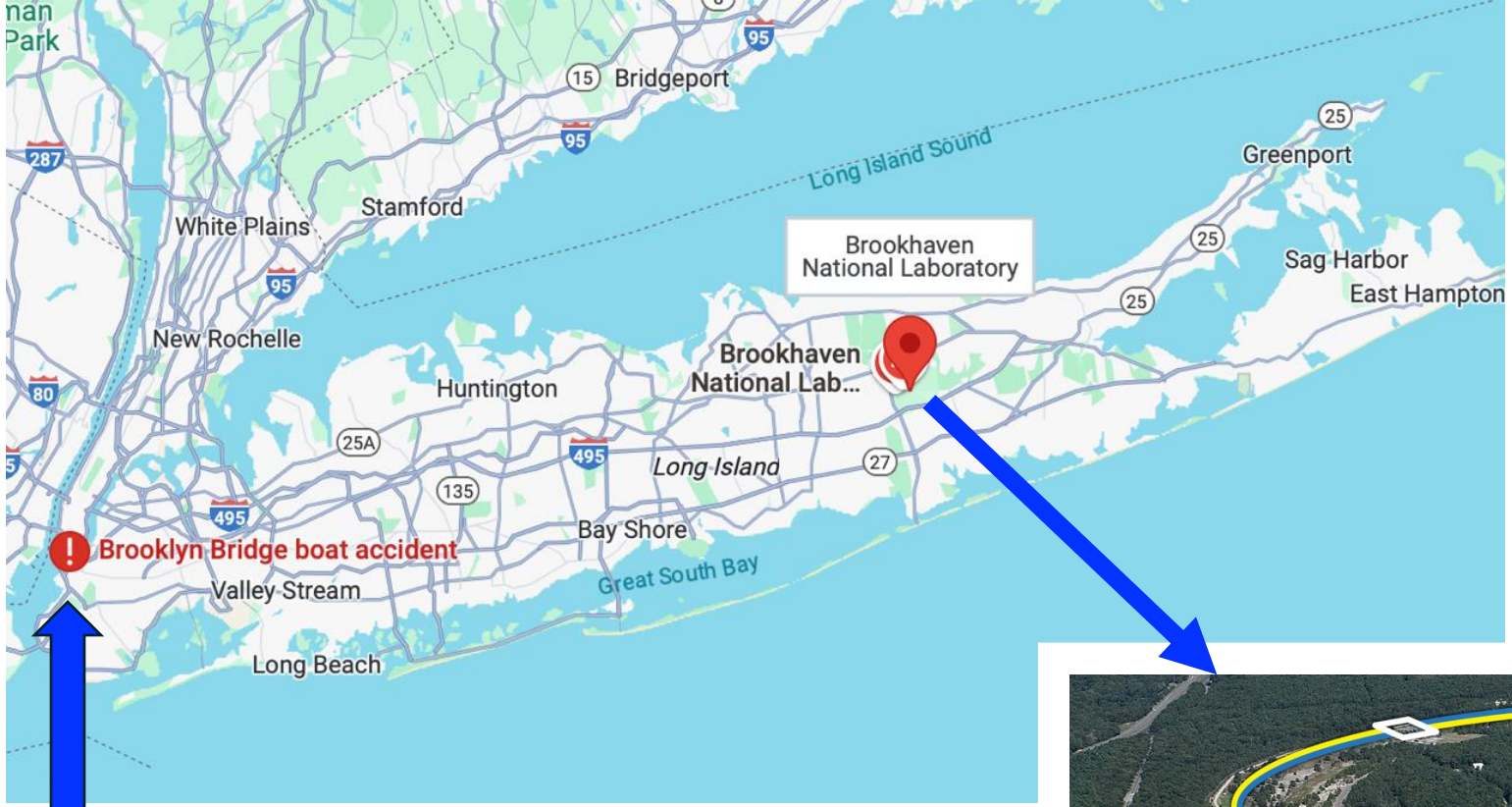
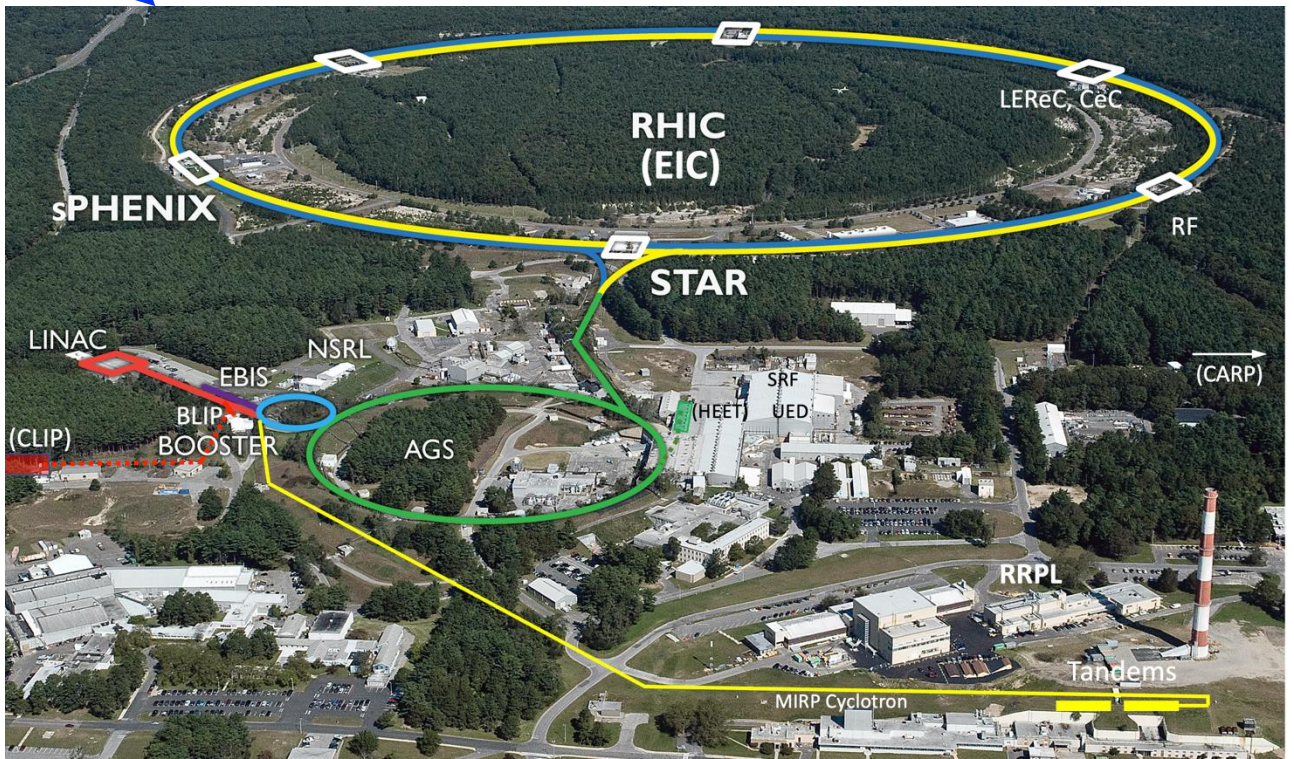


New York City



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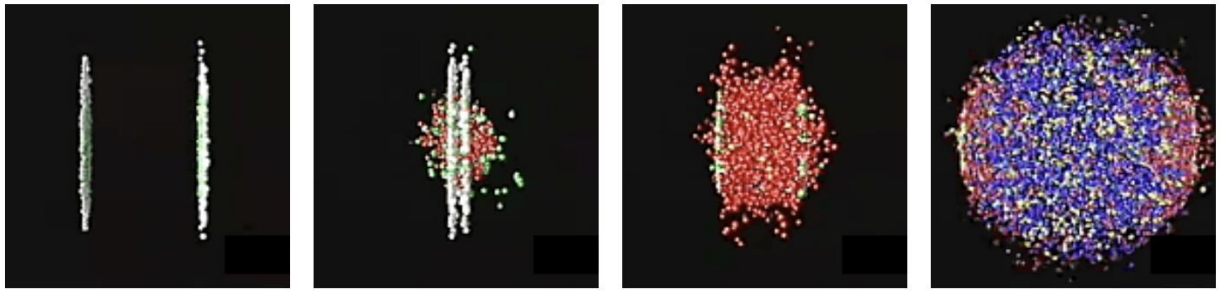
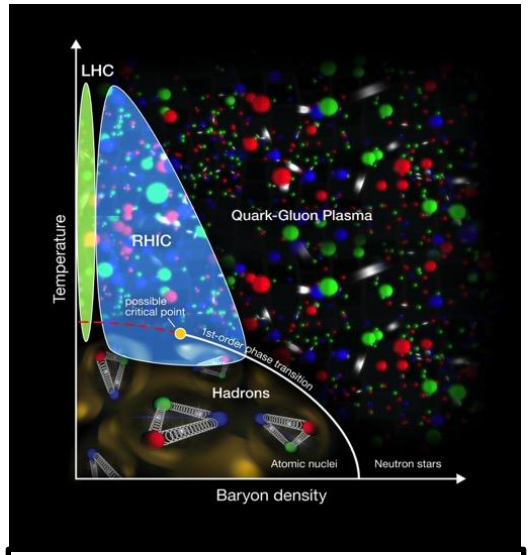
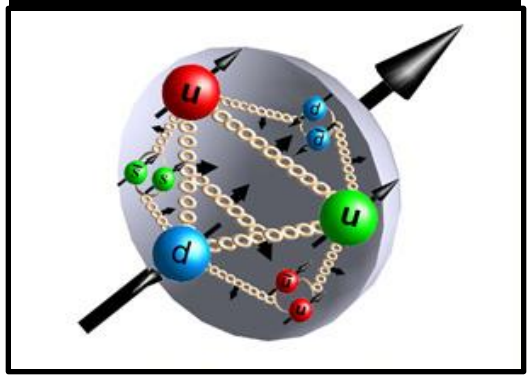
The Relativistic Heavy Ion Collider

- Heavy ion collisions at RHIC
  - Discovered a new state of matter: **Quark Gluon Plasma**
  - Detailed studies with collision of different ion species







- Polarized proton collisions
  - Only collider in the world of spin polarized protons to explore the internal spin structure of protons.
  - How do protons get the property of “spin”?
- The most versatile accelerator (and arguably, the most complex accelerator) to date

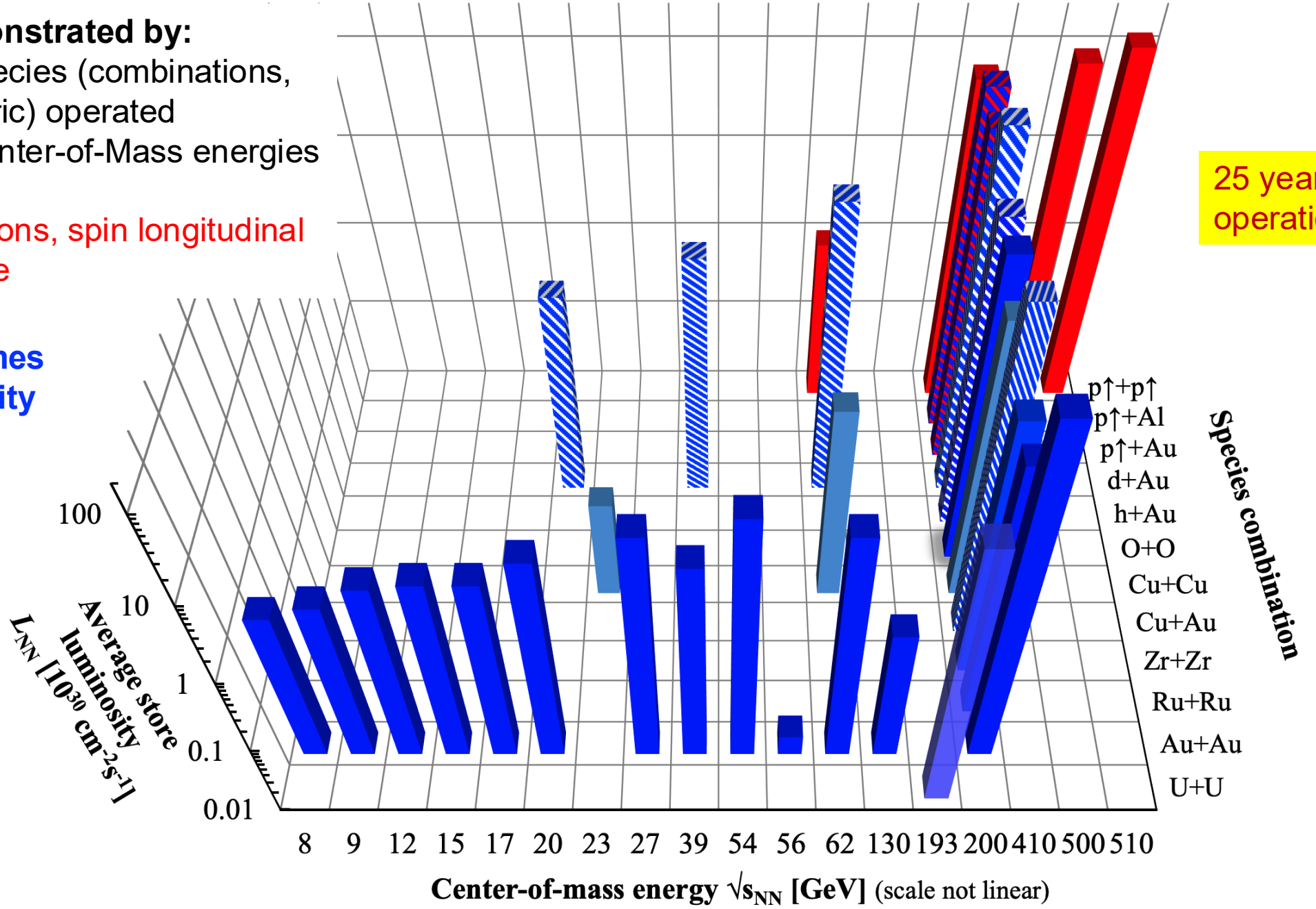
RHIC energies, species combinations and luminosities (Run-1 to 24)

Versatility demonstrated by:

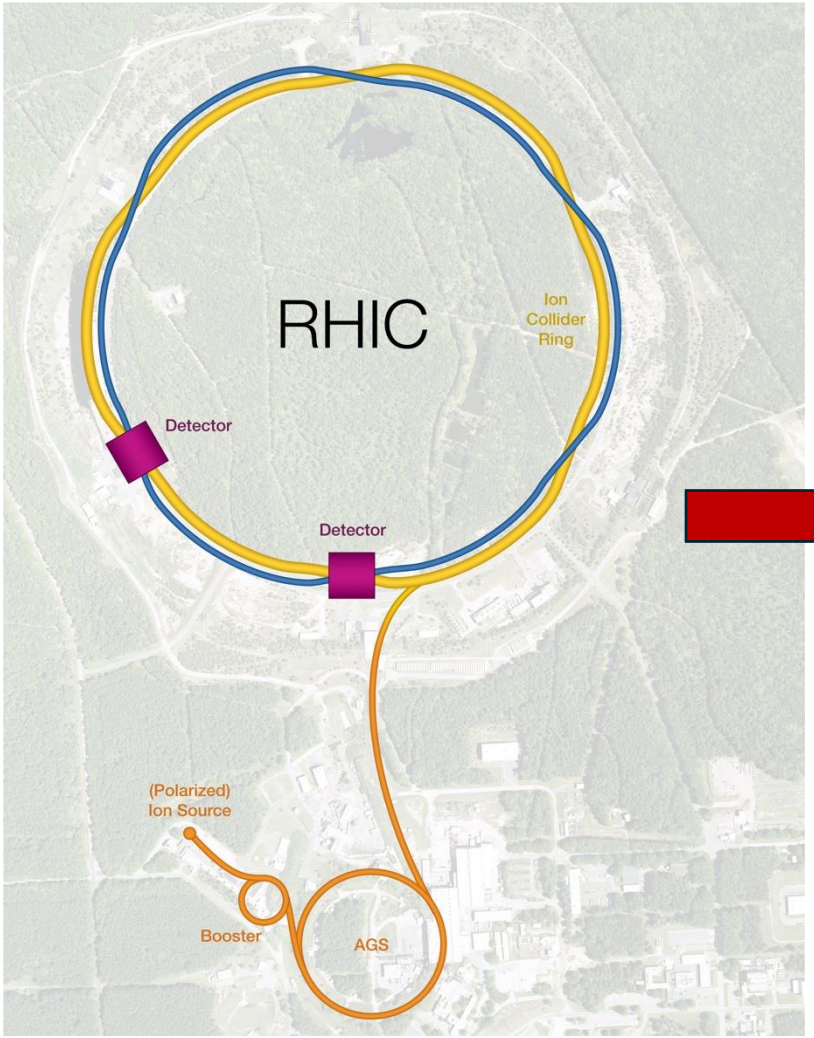
- Number of species (combinations, and asymmetric) operated
- Number of Center-of-Mass energies operated
- Polarized protons, spin longitudinal and transverse

Delivered 50 times design luminosity

25 years of operation



Transition from RHIC to Electron Ion Collider (EIC) in 2026

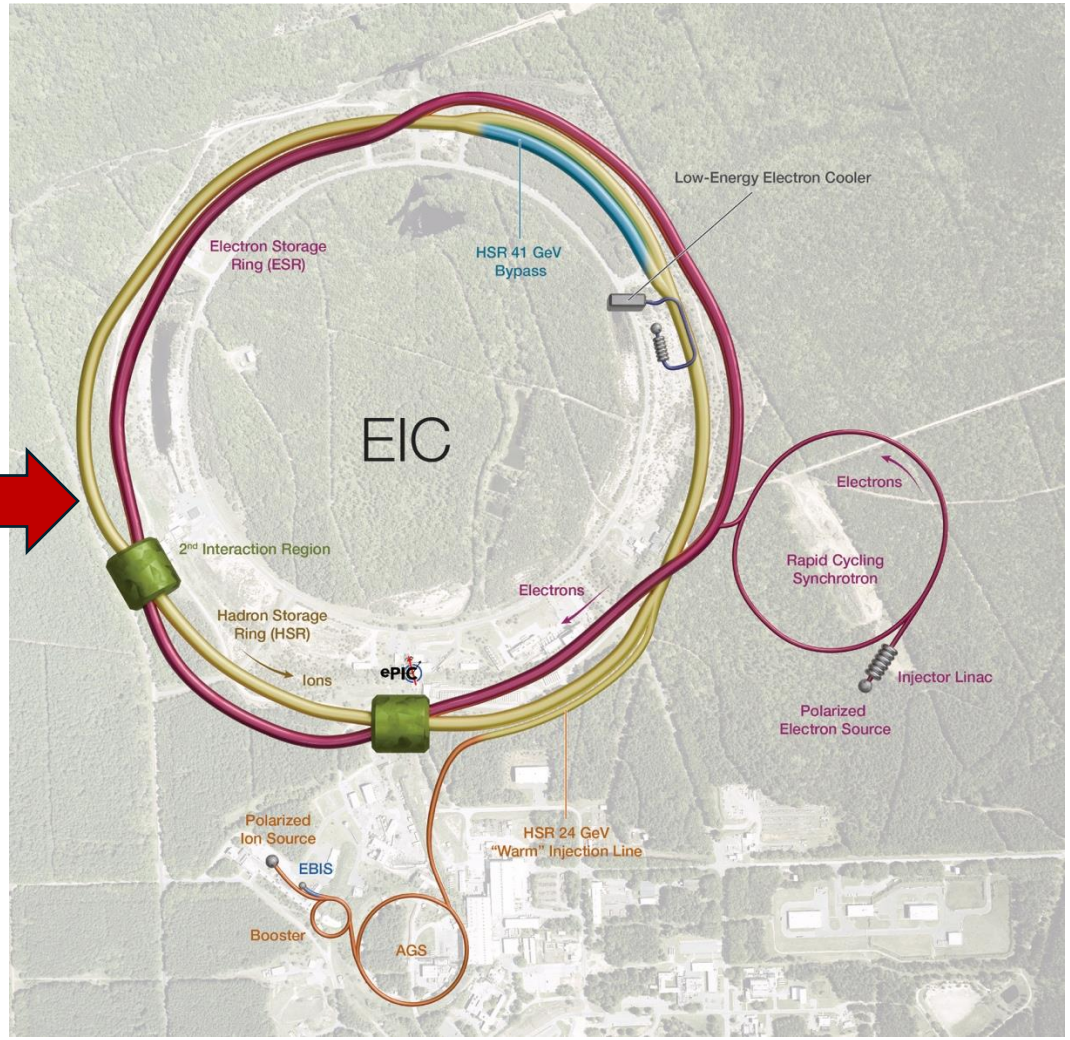


Re-Use the existing tunnel

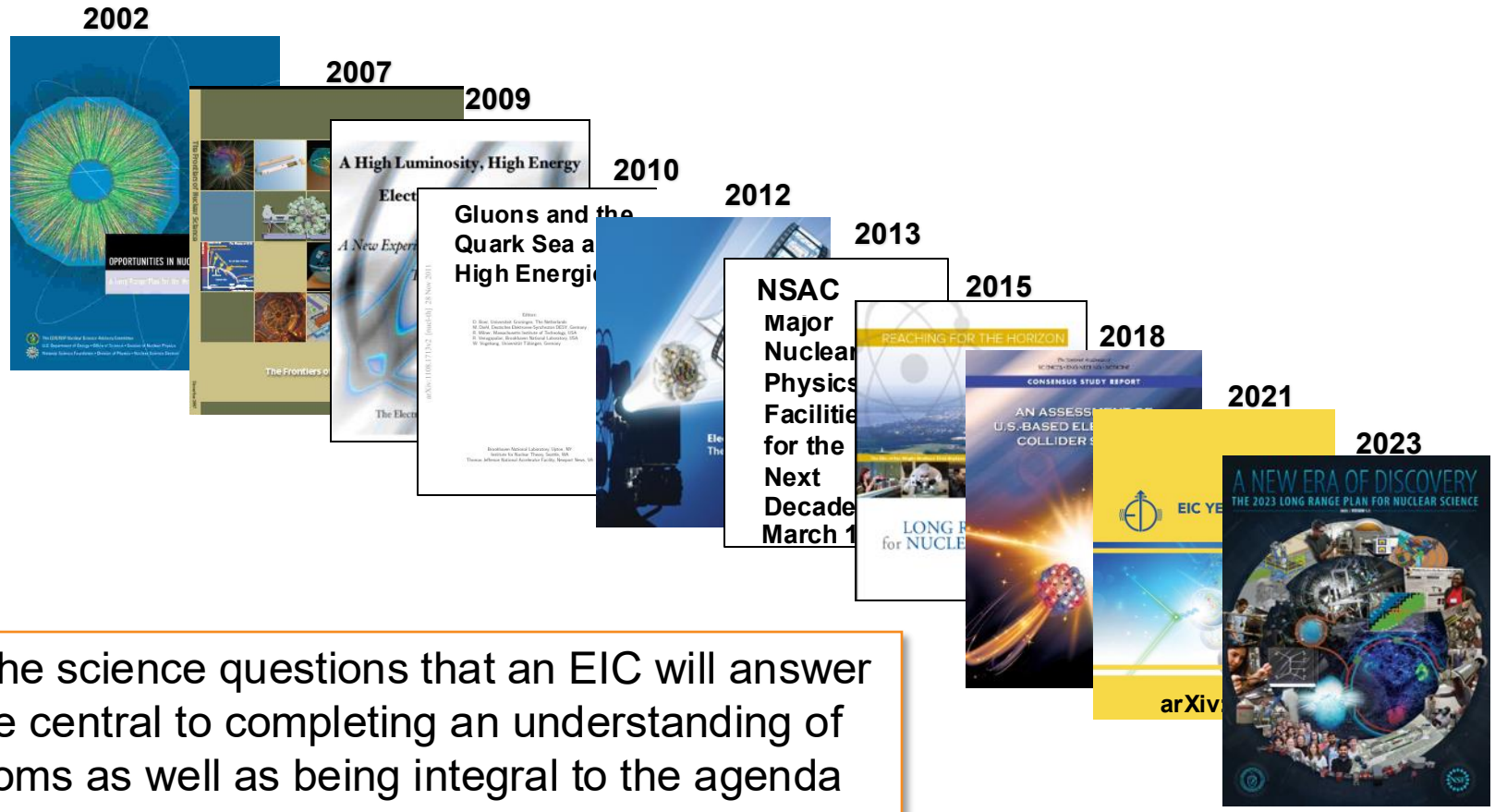
Minimal modification to the hadron beam complex (yellow)

New electron beam facility

Build on the ~$2B investment



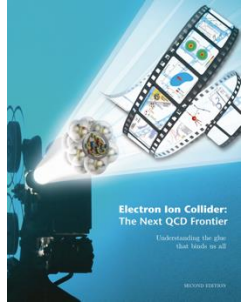
EIC Scientific Case Built Over Decades



"We recommend the expeditious completion of the EIC as the highest priority for facility construction." (2023)

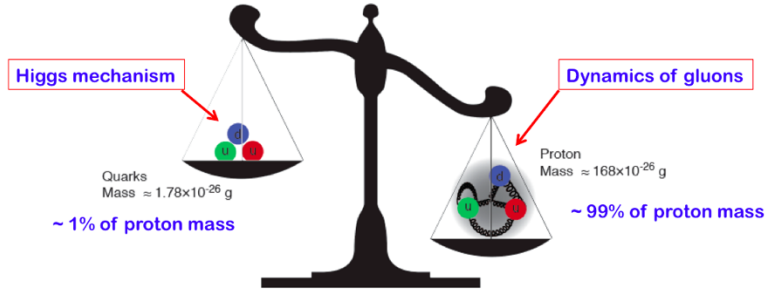
"The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today." (2018)

EIC will be the only operating particle collider in the U.S. and the only large collider to be built in the world in the next 20-30 years.

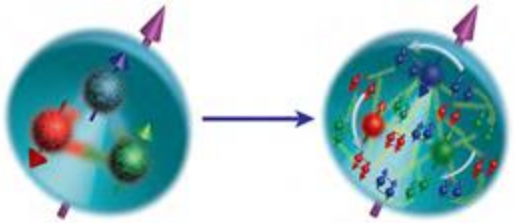


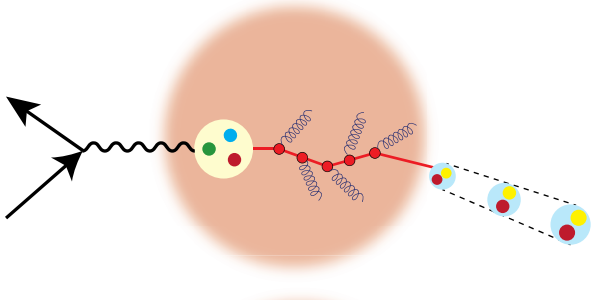
EIC Physics at-a-Glance

Eur. Phys. J. A 52 (2016) 9, 268 arXiv:1212.1701 (nucl-ex)



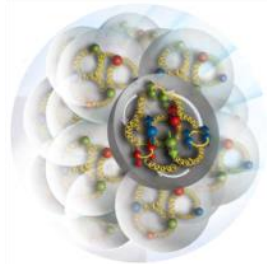
How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties (mass & spin) emerge from their interactions?

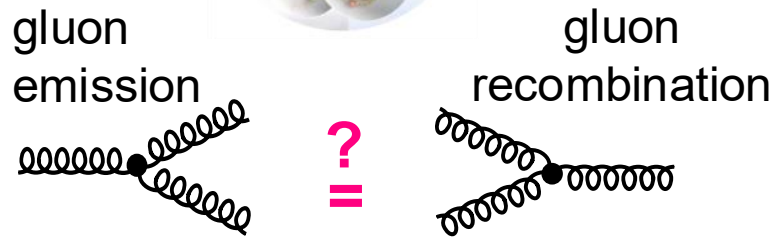




How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

How does a dense nuclear environment affect the quark- and gluon- distributions? 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?





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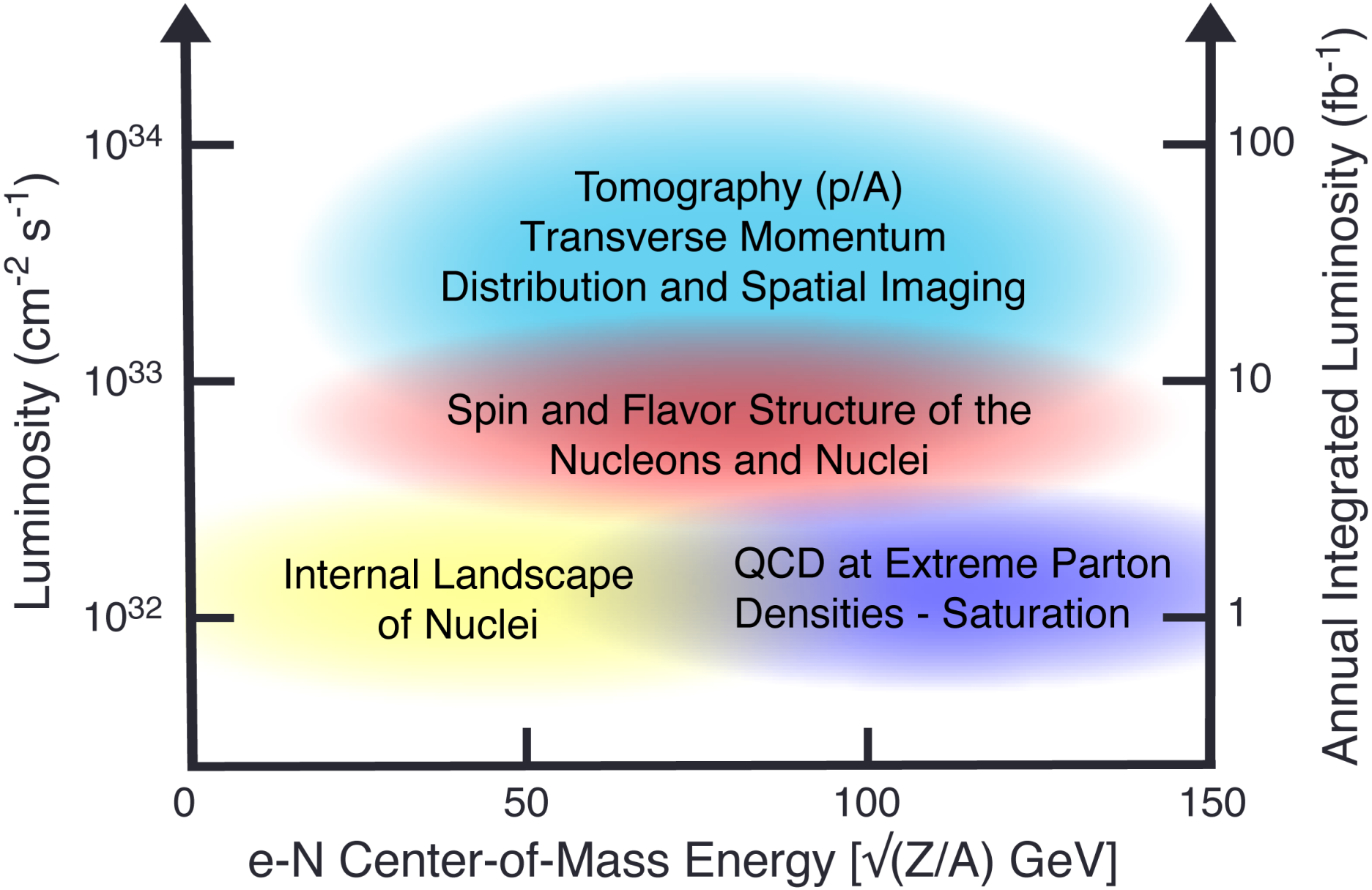
Summary: EIC Physics: CM vs. Luminosity vs. Integrated luminosity



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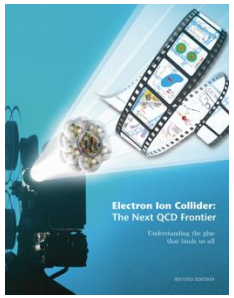
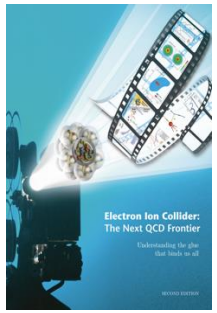
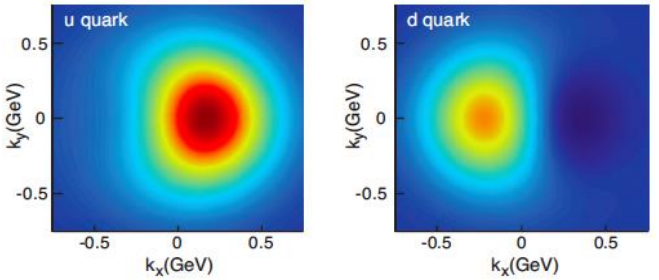
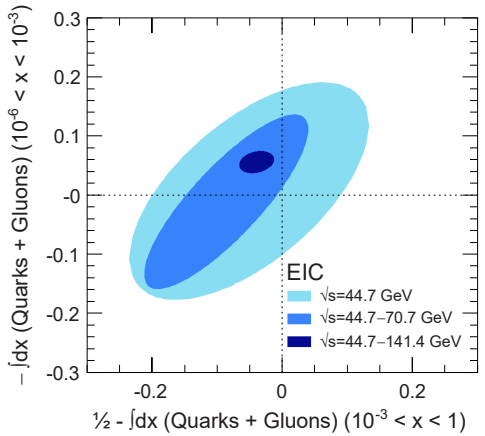


EIC White Paper selected highlights

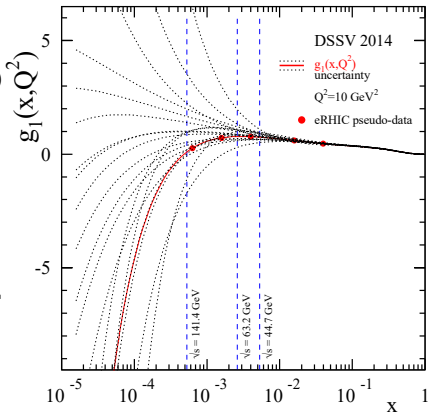


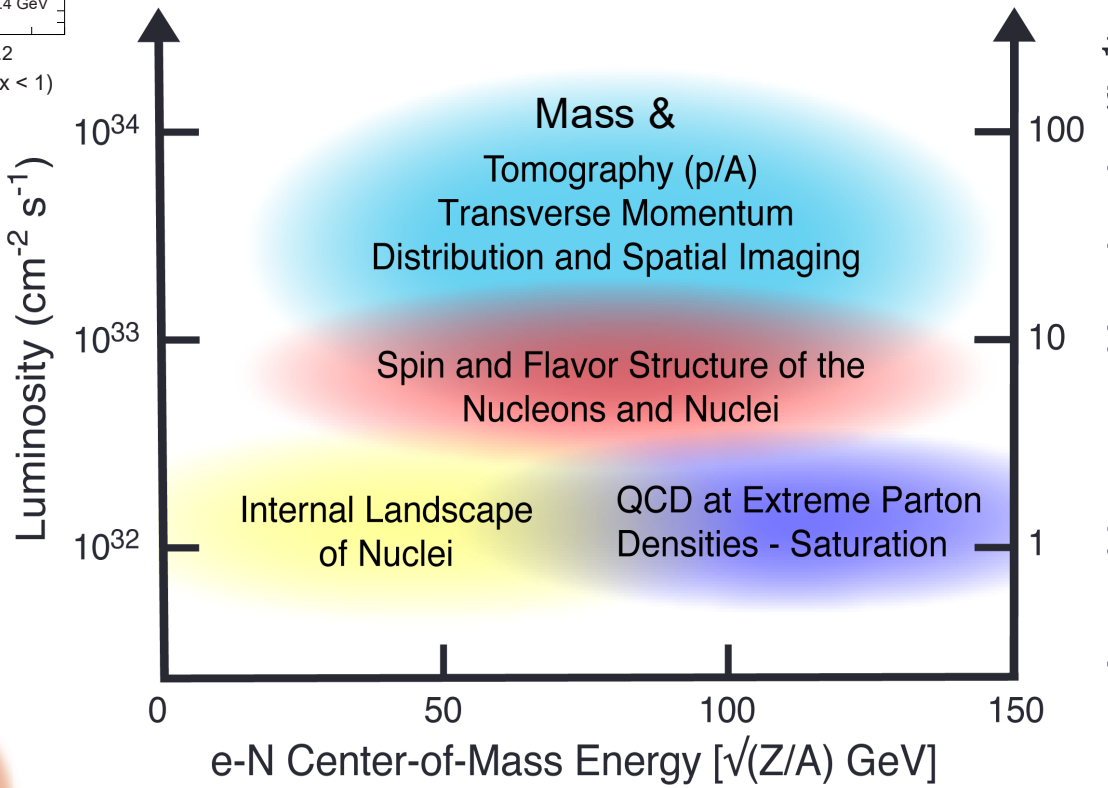
A. Accardi et al.
https://doi.org/10.48550/arXiv.1212.1701
A. Deshpande, Z. Meziani & J. Qiu Editors

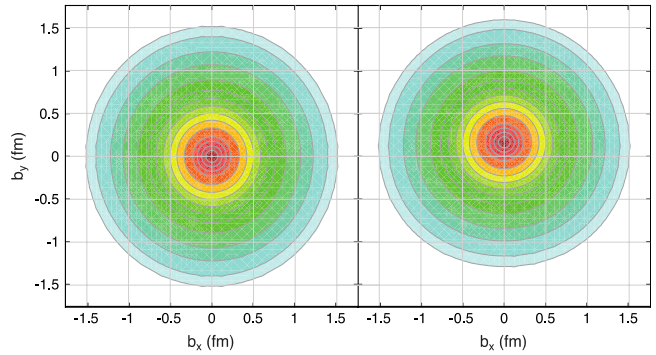


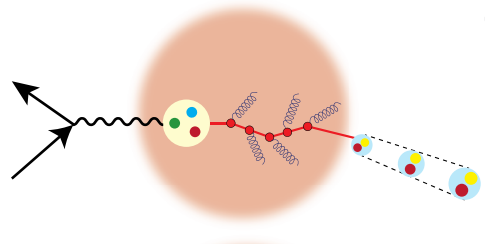


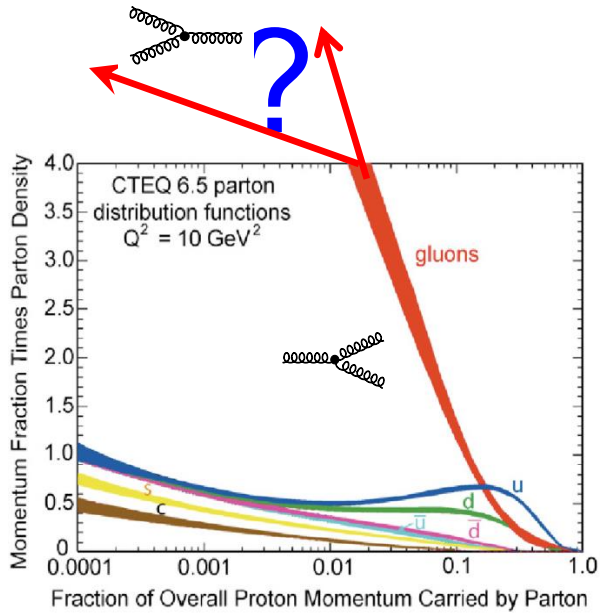
Longitudinal Spin contribution from quark and gluons



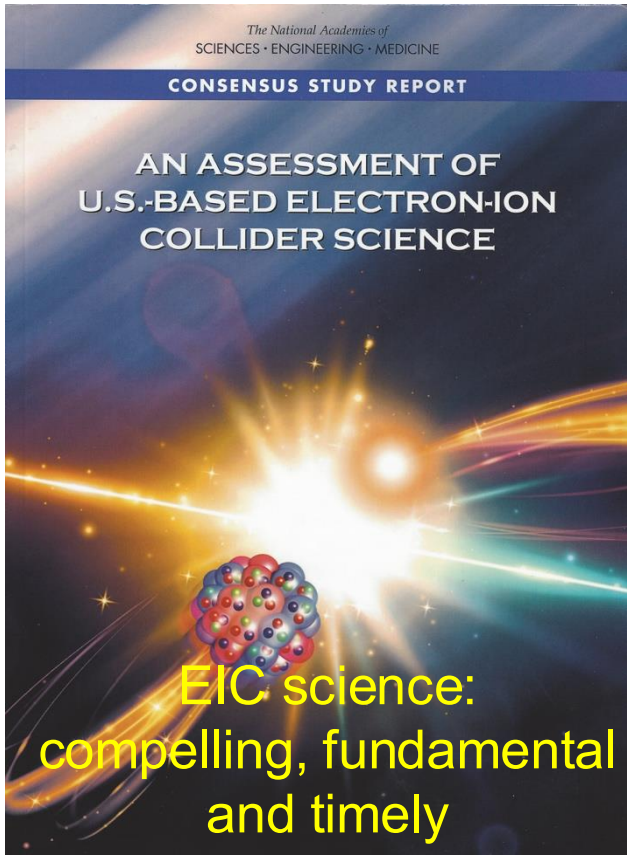








National Academy's Assessment, July 2018
Electron Ion Collider

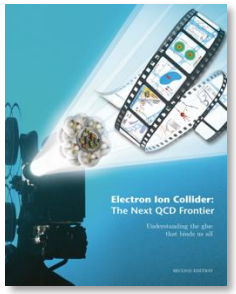


Electron Ion Collider Science:

Origin of nucleon spin & 3D imaging of partons

Understanding the origin of mass of the visible universe

Intense gluon fields ➔ novel gluonic matter?



Machine Design Parameters:

High luminosity: up to 10^{33}-10^{34} $cm^{-2}sec^{-1}$

- a factor ~100-1000 times HERA

Broad range in center-of-mass energy: ~20-100 GeV upgradable to 140 GeV

Polarized beams e-, p, and light ion beams with flexible spin patterns/orientation

Broad range in hadron species: protons…. Uranium

Up to two detectors well-integrated detector(s) into the machine lattice

First operational facility & detector using AI and ML

Optimization of machine operations & Detector design & data acquisition (triggerless data collections)

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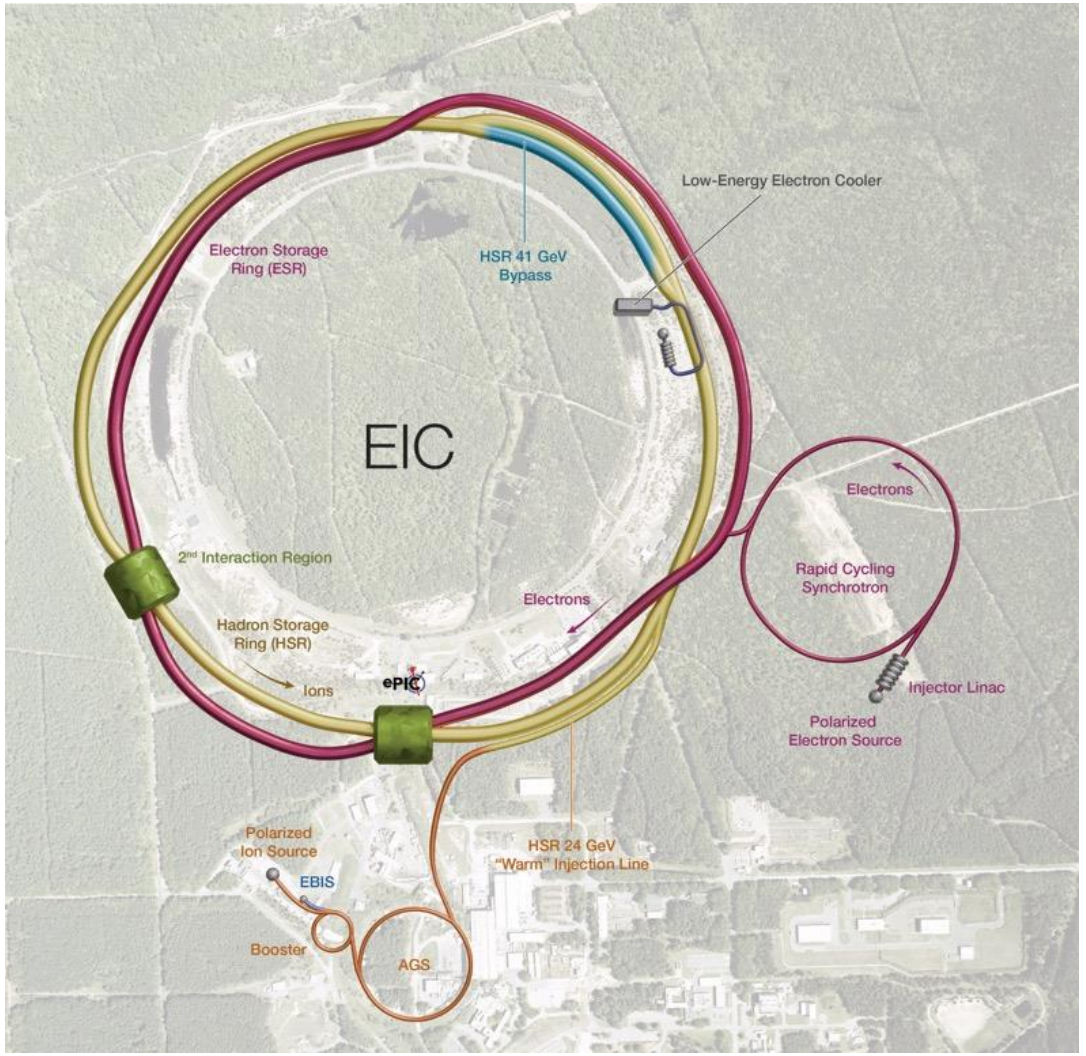
EIC Concept and Machine Parameters

Accelerator Status:

- ✓ Polarized ion/proton source
- ✓ Ion injection and initial acceleration systems:
  - Linac (200 MeV)
  - Booster (1.5 GeV)
  - AGS (25 GeV)
- UPGRADE Hadron Storage Ring (40-275 GeV)
- NEW Electron Pre-Injector (3 GeV SRF linac)
- NEW Electron Rapid Cycling Synchrotron (5-10 GeV – top energy)
- NEW Electron Storage Ring (5 GeV – 18 GeV)
- NEW Interaction Region(s)
- NEW Hadron Injection Cooling System



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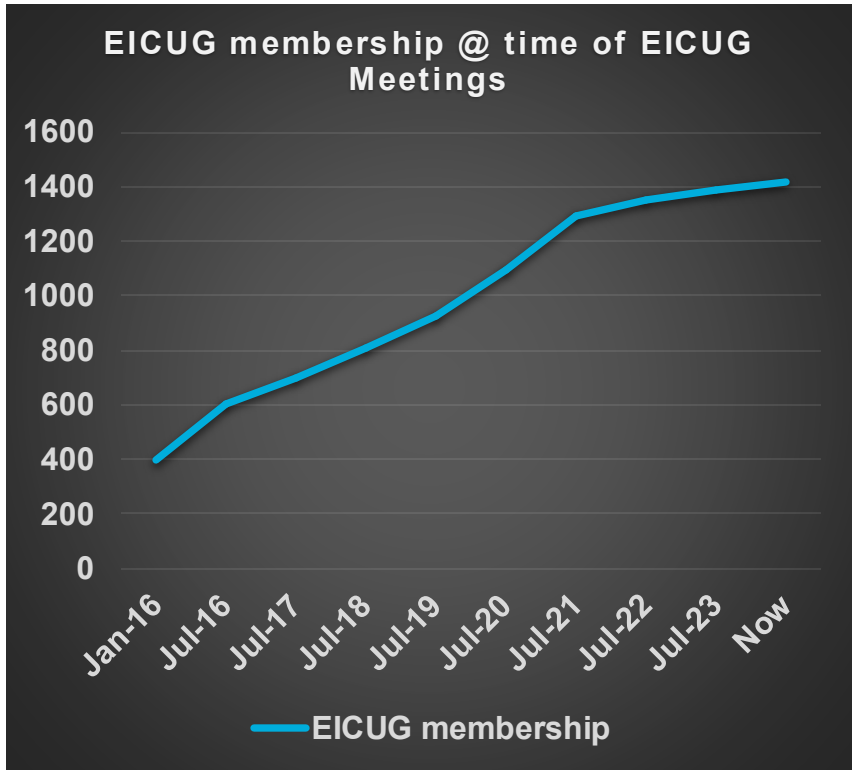
Worldwide Interest in EIC

The EIC User Group:
https://eicug.github.io/

Formed 2016 – (with 700 enthusiasts)

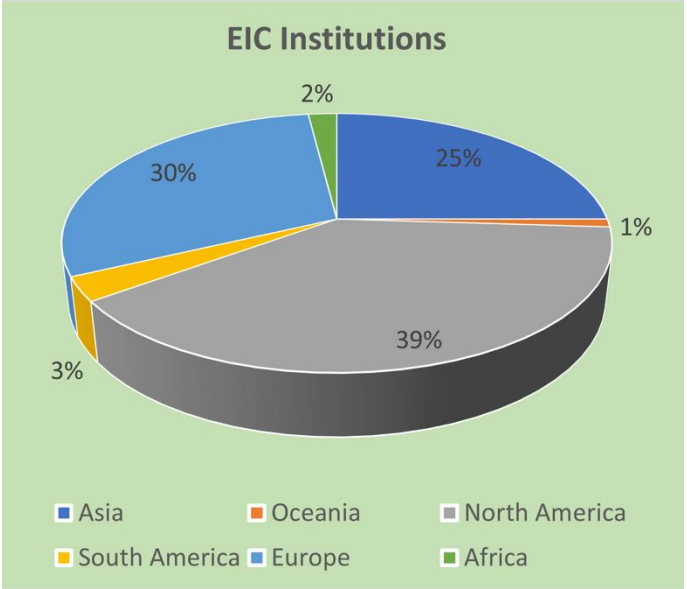
- **1500+ collaborators,**
- **40+ countries,**
- **300+ institutions**

Strong International Participation.



Annual EICUG meeting

2016 UC Berkeley, CA
2016 Argonne, IL
2017 Trieste, Italy
2018 CUA, Washington, DC
2019 Paris, France
2020 FIU, Miami, FL
2021 VUU, VA & UCR, CA
2022 Stony Brook U, NY
2023 Warsaw, Poland
2024 Lehigh U, PA
2025 Jefferson Lab, VA, USA



Physics @ the EIC: Connections to High Energy Physics & Beyond

Of HEP/LHC-HI interest to Snowmass 2021 (EF 05, 06, and 07 and possibly also EF 04)
LHC – EIC Synergies workshops in Europe

Could be topics for thrusts for 2nd detector (beyond ePIC)?

Novel precision QCD Studies with proton & (light & heavy) nuclear targets:

Precise measurements of unpolarized PDFs at high x/Q^2, impact on LHC-Upgrade results (BSM)

- Precision calculation of a_S : higher order & twist-3 pQCD calculations;

Heavy quark and quarkonia studies with 100-1000 times luminocity of HERA and with polarization

- Quark Exotica: 4,5,6 quark systems…? Much interest after recent Belle, LHCb led results.

Physic with jets with EIC as a precision QCD machine: ➔ Jets as probe of nuclear matter

- Internal structure of jets in e-p collisions, momentum, energy correlators ➔ Entanglement, entropy, connections to fragmentation, hadronization and to confinement

Polarized light nuclei in the EIC

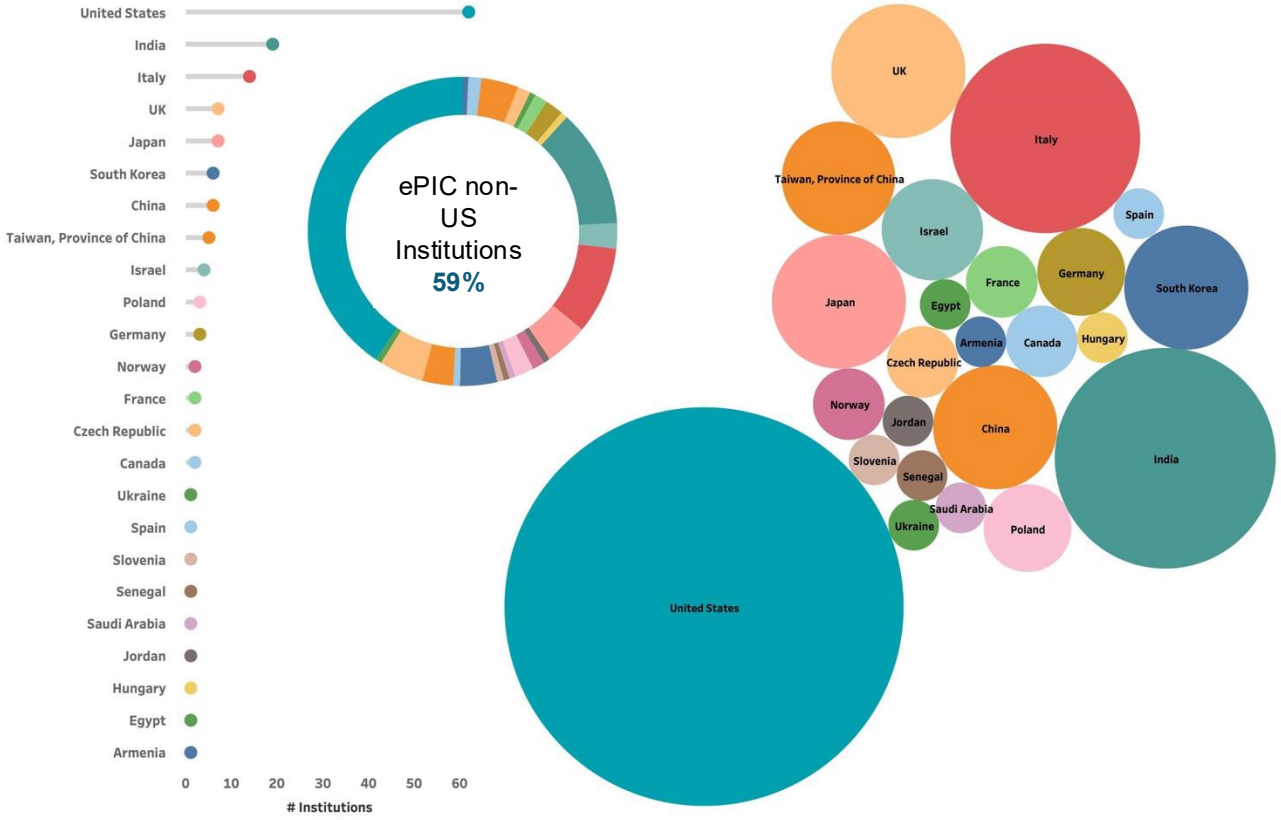
Study of universality in QCD: e-p/A vs. p-A, d-A, A-A at RHIC and LHC

Precision electroweak and BSM physics:

Electroweak physics & searches beyond the SM: Parity, charge symmetry, lepton flavor violation

LHC-EIC Synergies & complementarity

The ePIC Collaboration



ePIC formed 2022.

ePIC is now 190+ institutions

Representing 40+ countries

900+ participants

A global pursuit for a new experiment at the EIC!

ePIC Spokesperson:
John Lajoie (ORNL)

ePIC Deputy Spokesperson
Silvia Dalla Torre (INFN Trieste)

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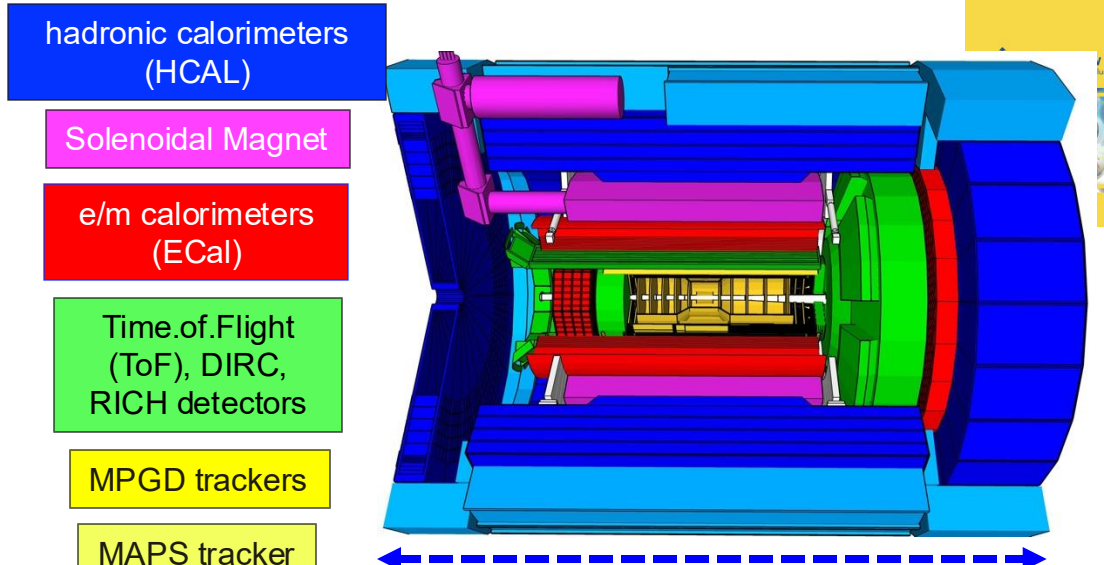
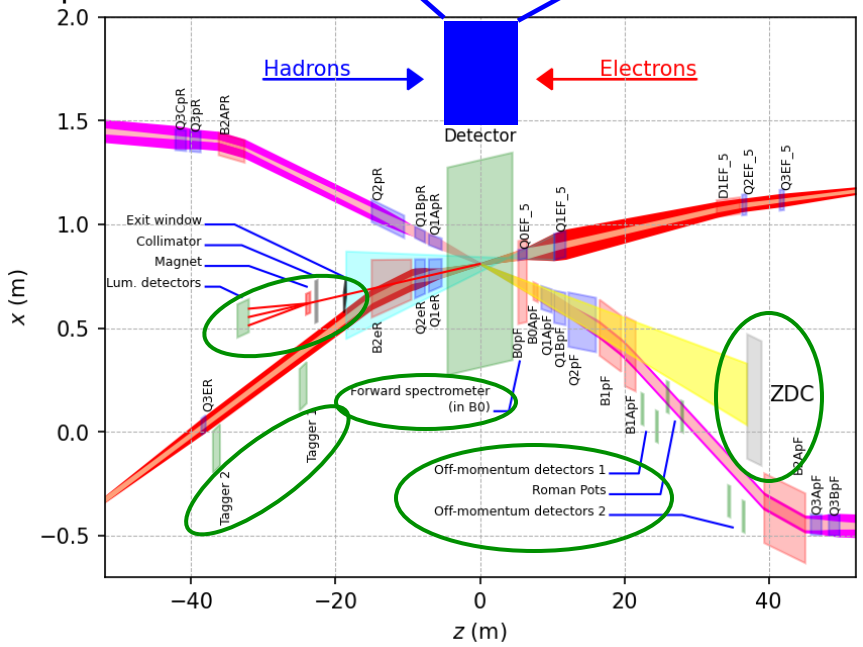
The ePIC Detector

- Asymmetric beam energies
  - requires an asymmetric detector with electron and hadron endcap
  - tracking, particle identification, EM calorimetry and hadronic calorimetry functionality in all directions
  - very compact Detector, **Integration** will be key
- Imaging science program with protons and nuclei
  - requires specialized detectors integrated in the IR over 80 m
- Momentum resolution for EIC science requires a large bore 2T magnet
- Highest scientific flexibility
  - requires Streaming Readout electronics model





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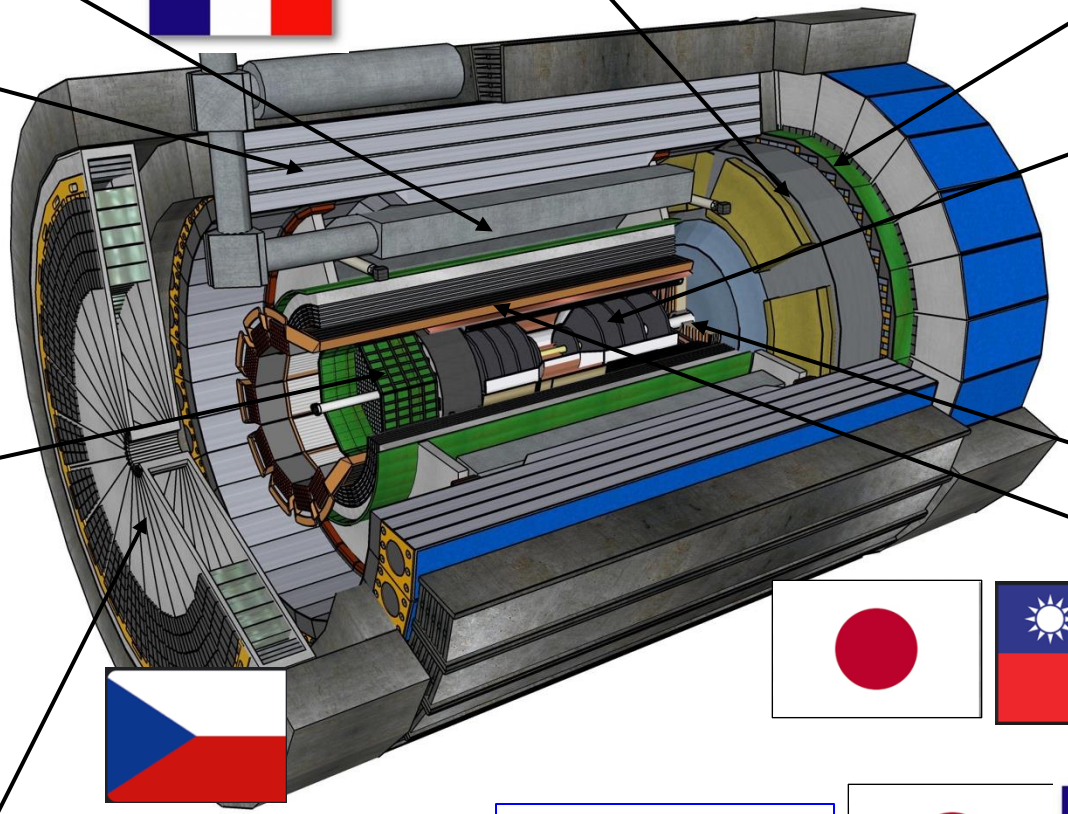
Central Detector Non-DOE Interest & In-Kind



Superconducting Solenoid

Dual-radiator RICH

Forward Electromagnetic Calorimeter

Barrel Electromagnetic Calorimeter

Tracking Detectors

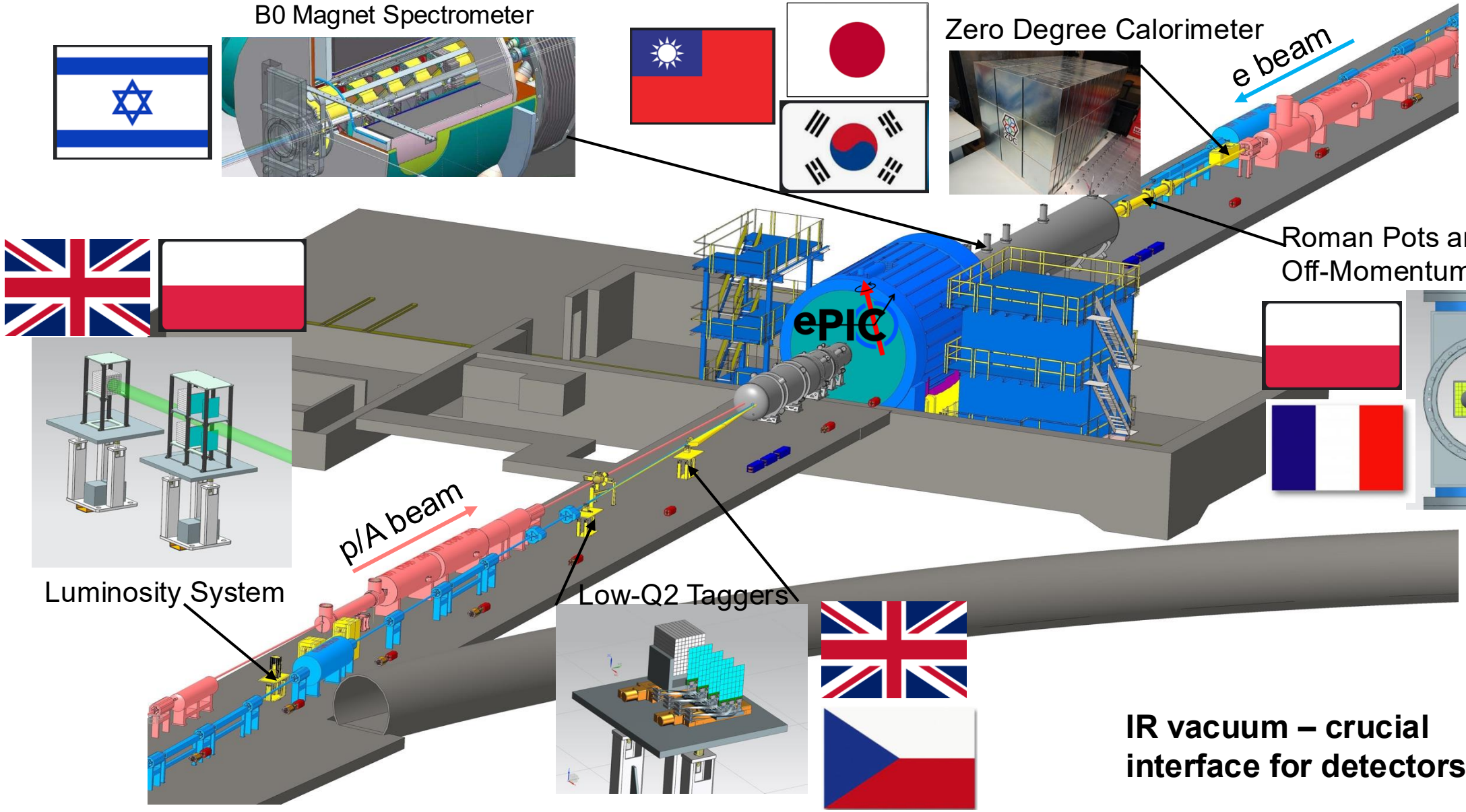
Backward Electromagnetic Calorimeter

Time-of-Flight

Backward Hadronic Calorimeter

Data-Acquisition Electronics

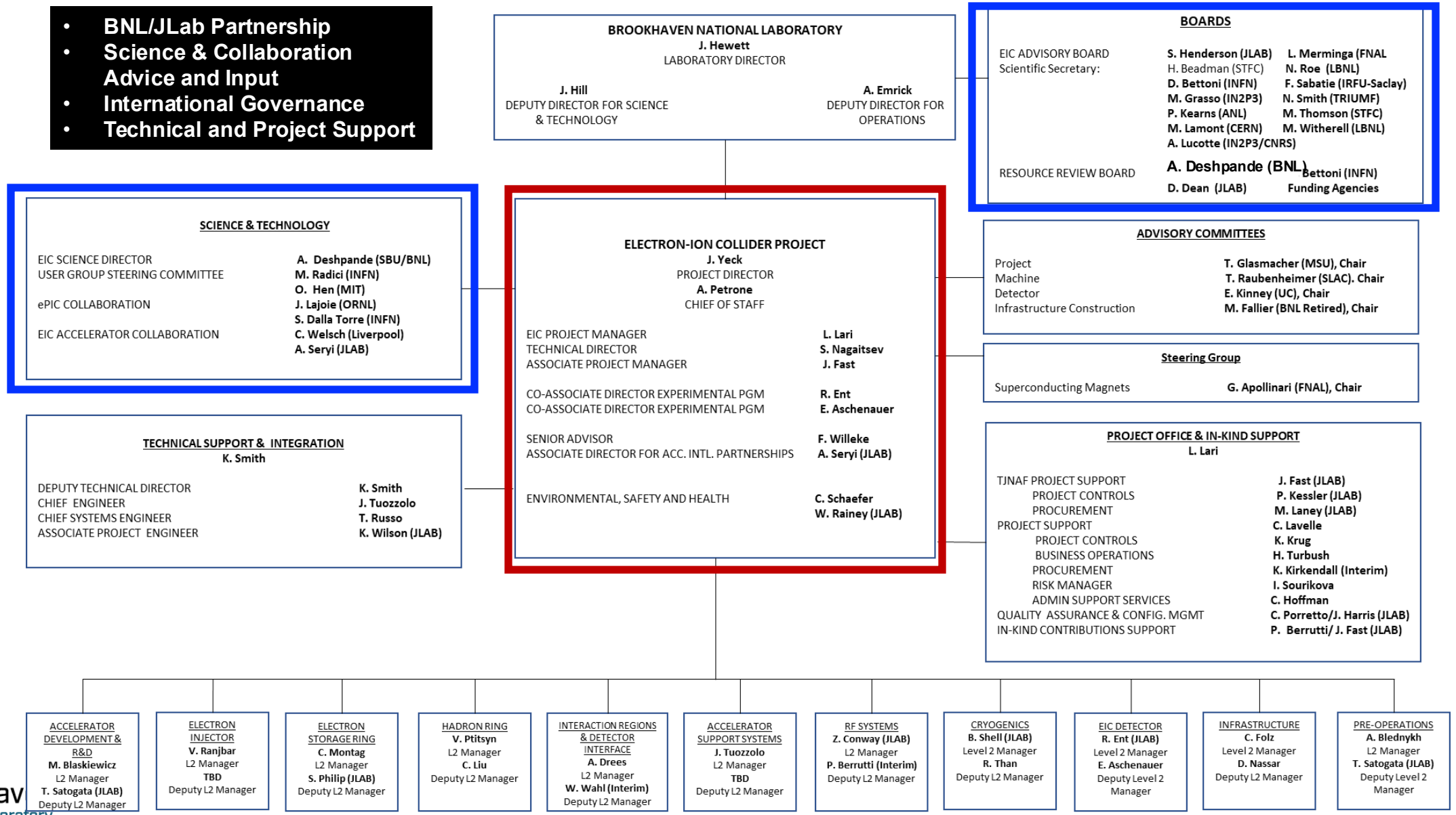
Far-Forward/Far-Backward Detectors Non-DOE Interest & In-kind



IR vacuum – crucial interface for detectors

Project Organization

- BNL/JLab Partnership
- Science & Collaboration Advice and Input
- International Governance
- Technical and Project Support



A very fast pace of the project

Major Project Milestones

- CD-3A LLP approved at ~$90M and initial contracts awarded! Examples:
  - Accelerator superconducting strand, $163K
  - Detector EMCal and HCal fibers, $2.3M
  - Infrastructure electrical substations, $11.2M
- CD-3B Final Design Reviews (FDRs) complete, one FDR repeated
- Requirements/interfaces for CD-3B items complete
- Project is benefiting from lessons learned on CD-3A.

Reviews, Board, and Advisory Committees

- More than 20 design reviews
- 6 Advisory Committee Meetings
- 5 Advisory Board and two Resource Review Board Meetings
- 5 Reviews of “Off-Project” Scope
- Interaction Region Superconducting Magnet Steering Group established
- Annual Director’s Review in October
- DOE CD-3B/Status Review in January

Accelerator

- New Technical Director in January
- Received and assessed Advanced Photon Source magnets at BNL and JLab
- Optimized design and scope to mitigate risk
- Electron injector modifications eliminate many risks and meet the Mission Need.
- International EIC Accelerator Collaboration established

Detector

- R&D nearly complete
- ePIC Detector technical baseline defined
- Preliminary Design Report in preparation
- Plans are developing for the EIC Science Program

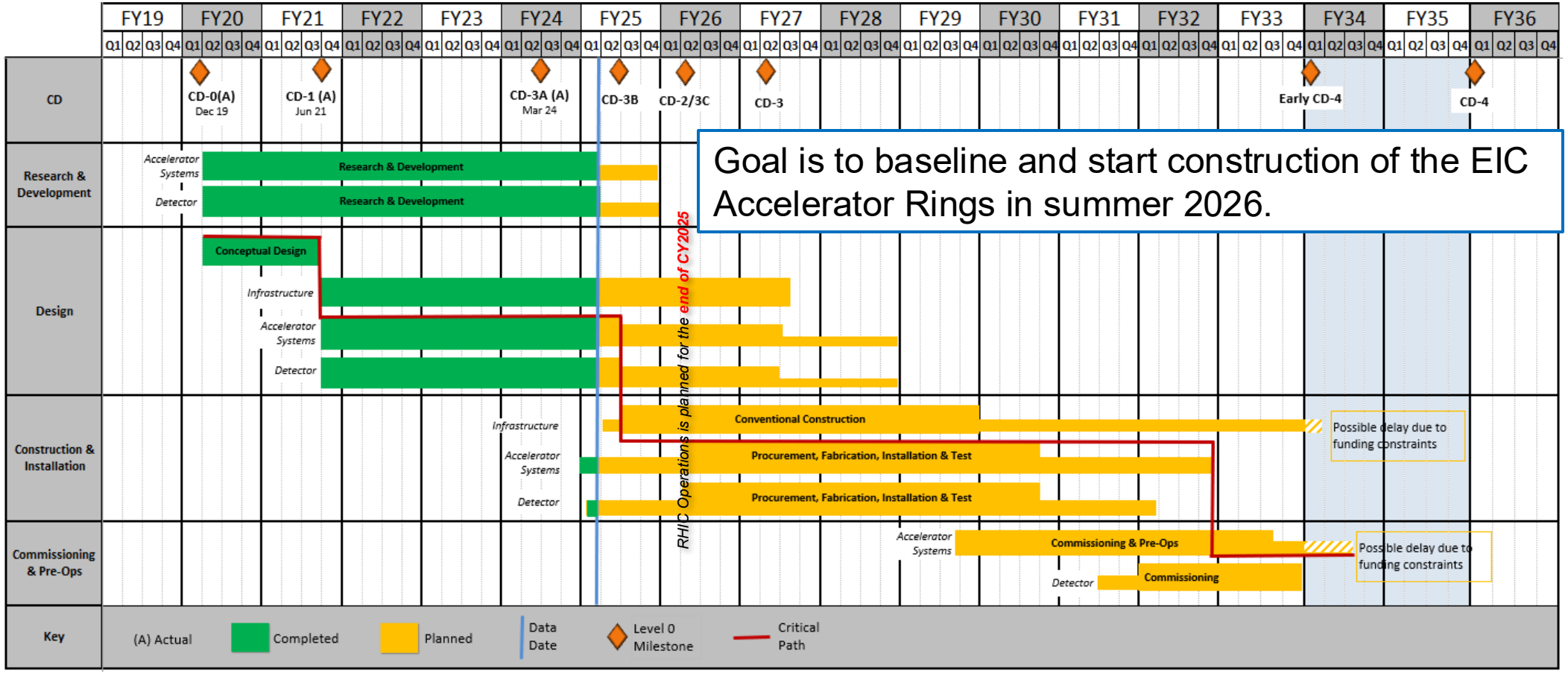
Infrastructure

- $100M New York State Grant for EIC buildings in February
- 30% Detailed Design submission received in August
- 60% Detailed Design submission received in December

Significant Progress in 2024, Started Awarding Contracts for Long Lead Items.

EIC Reference Schedule

EIC project is moving from R&D and design into the construction phase in 2026



Strong Support from Partners & Collaborators

- **New York State** committed **$100M** toward construction of EIC buildings and infrastructure.
- **EIC Accelerator Collaboration** kicked off at the International Particle Accelerator Conference with over 150 participants expressing interest in contributing to the global EIC effort.
- **UK** announced £58 million (**$75M**) for the EIC.

- **EIC Resource Review Board** Meetings in Rome in May 2024 and at BNL in Oct. 2024**.** Strong participation from **Canada, Czech Republic, France, India, Israel, Italy, Japan, Poland, South Korea, United Kingdom,** and **Taiwan.** Next meeting to be held in Prague in June 2025.

In-kind contributions are planned for the Detector (~30%) and the Accelerator (5%).

Summary & Outlook

Electron Ion Collider, a high-energy **high-luminosity polarized e-p, e-A collider**, will be start construction in this decade and operate in 2030's & 2040's.

- Will address the most profound unanswered questions in QCD
- Truly international in character: ~60% international participants, ~30% in-kind detector contributions, ~5% in-kind accelerator contributions

Up-to two hermetic detectors possible, although **funds for only ONE detector now**

- ePIC: An international detector collaboration formed and operating
- A second detector may realize a few years later

A world-wide EIC accelerator collaboration formed ➔ to tackle challenging problems

First collisions by ~2034; physics start by ~2035/36

EIC An Exciting opportunity for scientists and particularly early career scientists working in theoretical, experimental and accelerator physics & engineering

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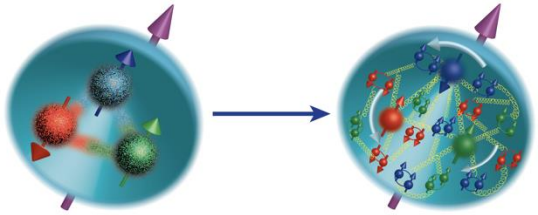
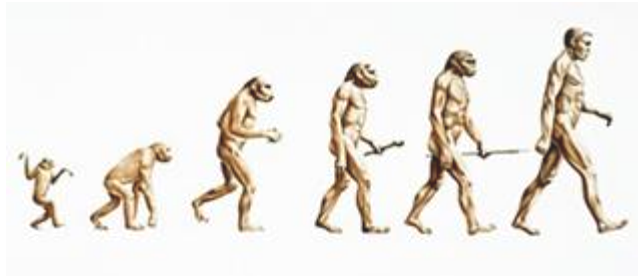


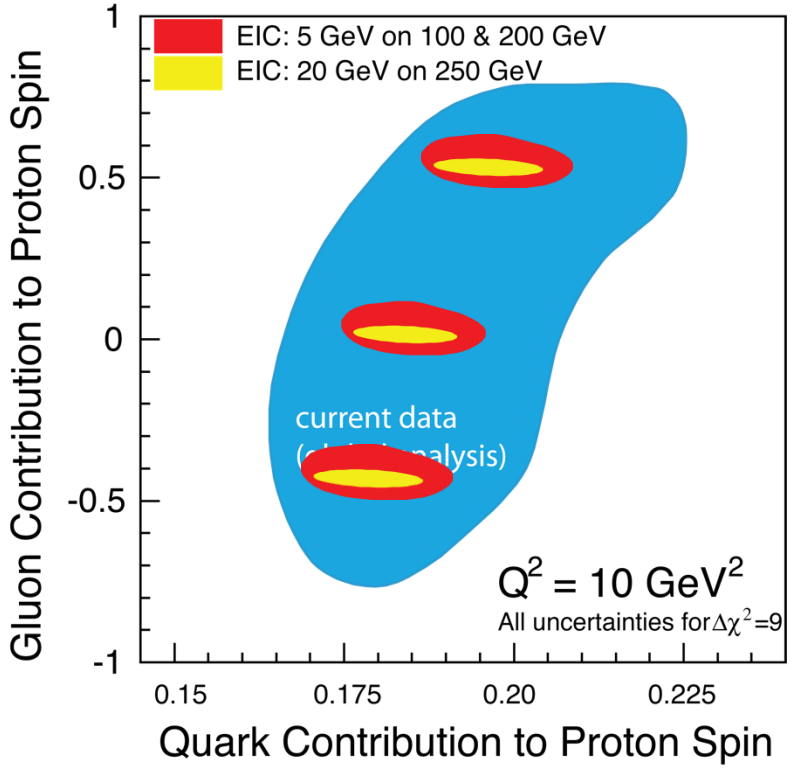
Understanding of Nucleon Spin

$$\frac{1}{2} = \left[\frac{1}{2}\Delta\Sigma + L_Q\right] + \left[\Delta g + L_G\right]$$

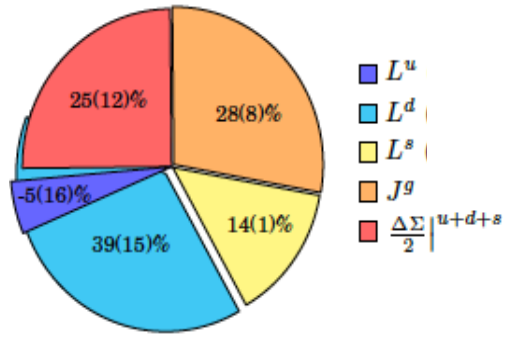
$\Delta\Sigma/2$ = Quark contribution to Proton Spin
L_Q = Quark Orbital Ang. Mom
Δg = Gluon contribution to Proton Spin
L_G = Gluon Orbital Ang. Mom

Precision in DS and Dg ➔ A clear idea
Of the magnitude of L_Q+L_G



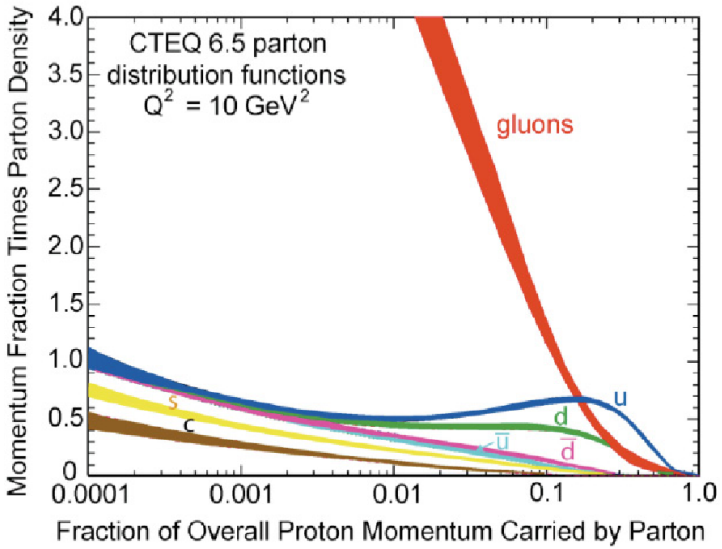


Spin in Lattice QCD: Ab initio Calculations



- **Gluon's spin contribution on Lattice: S_G = 0.5(0.1):** Yi-Bo Yang et al. PRL **118**, 102001 (2017)
- **J_q calculated on Lattice QCD:** χQCD Collaboration, PRD91, 014505, 2015

Brookhaven National Laboratory

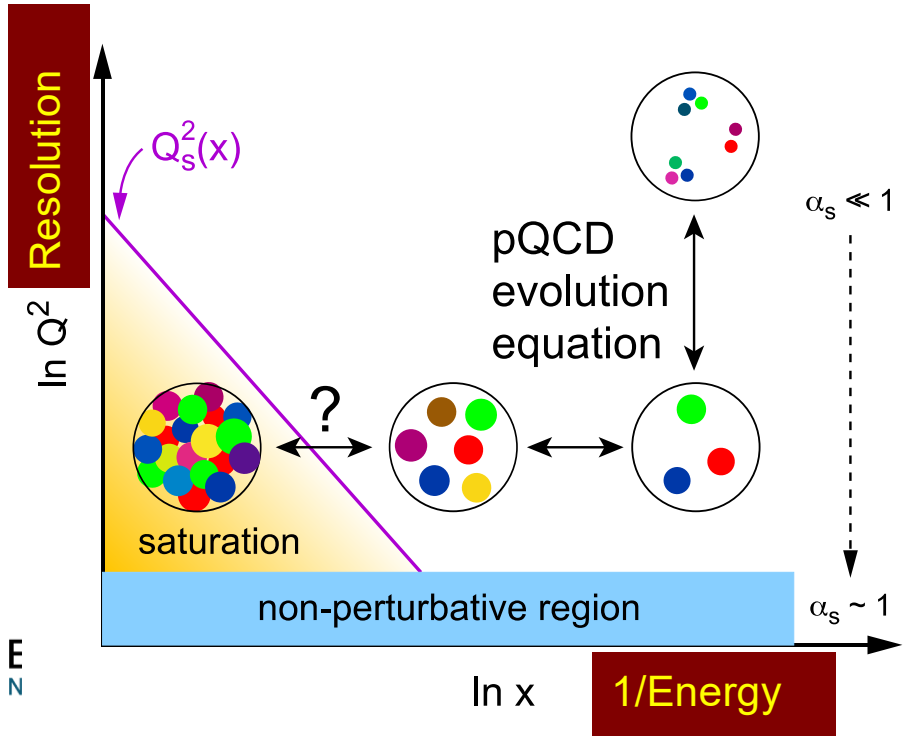


What do we learn from low-x studies?

What tames the low-x rise?

- New evolution eqn.s @ low x & moderate Q^2
- Saturation Scale $Q_S(x)$ where gluon emission and recombination comparable

gluon emission = gluon recombination **At Q_S**



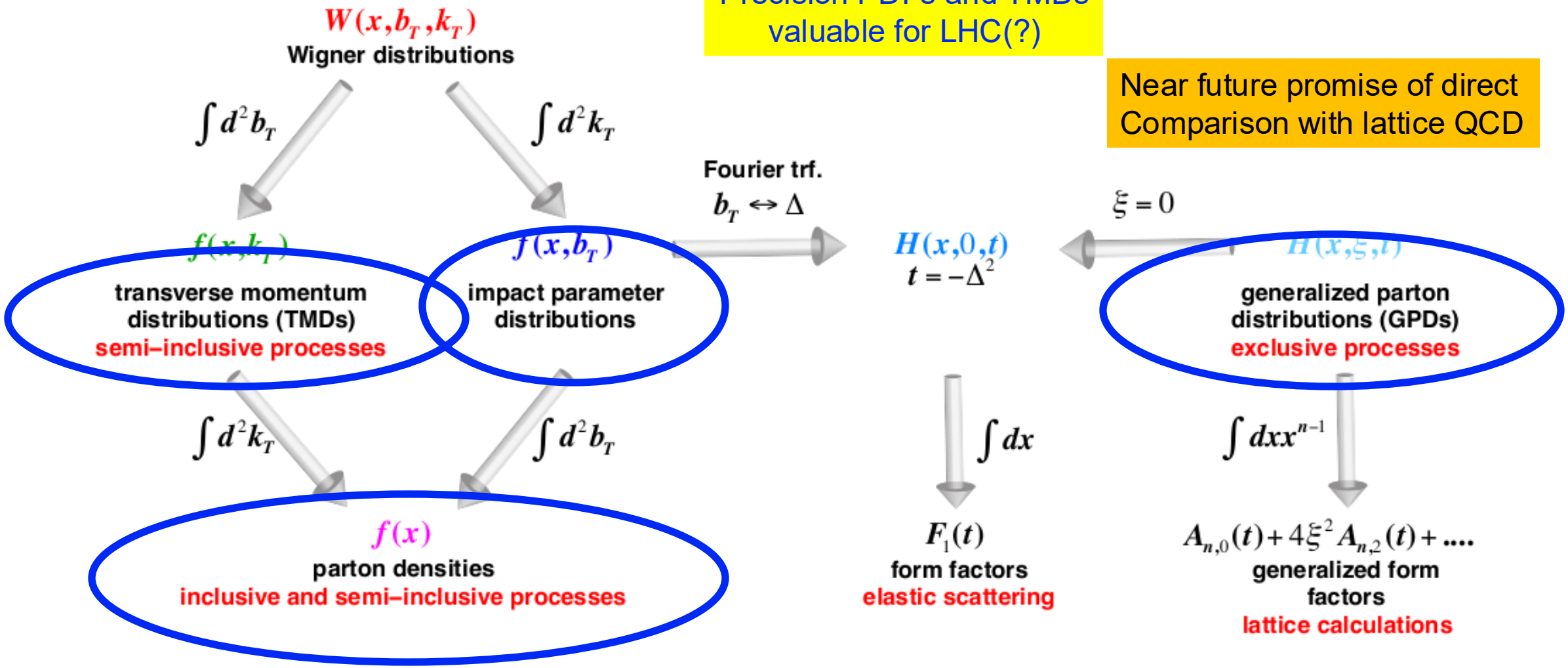
Novel and fundamental!

First observation of gluon recombination effects in nuclei:
➔leading to a *collective* gluonic system!
→ Is the Color Glass Condensate the correct effective theory?
➔ Is this a universal property?

2+1D Imaging of hadrons: beyond precision PDFs

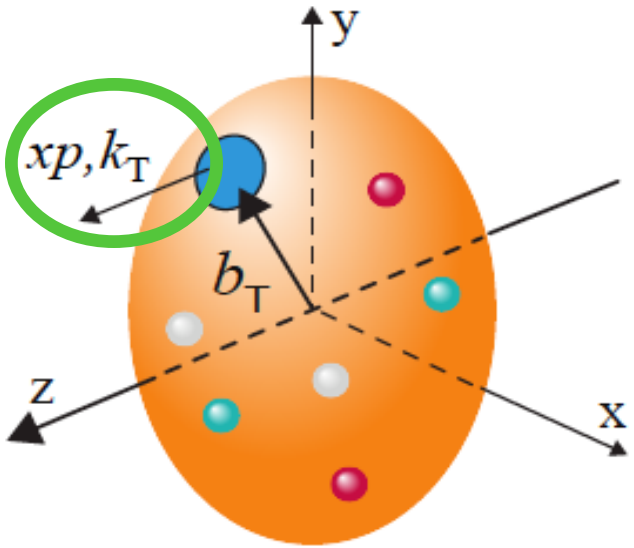
Precision PDFs and TMDs valuable for LHC(?)

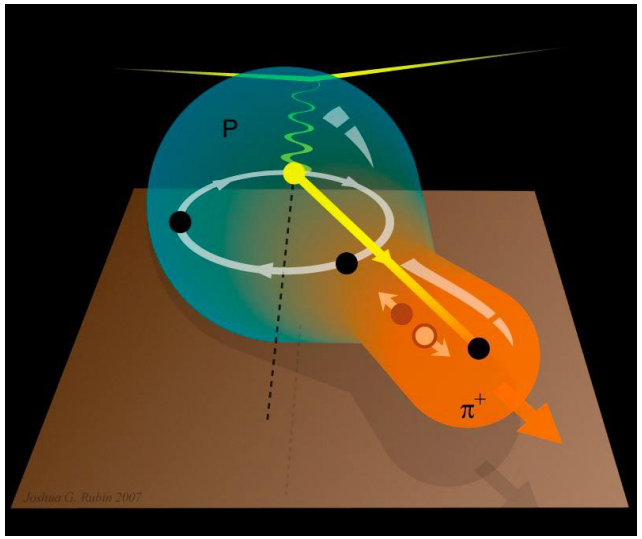
Near future promise of direct Comparison with lattice QCD

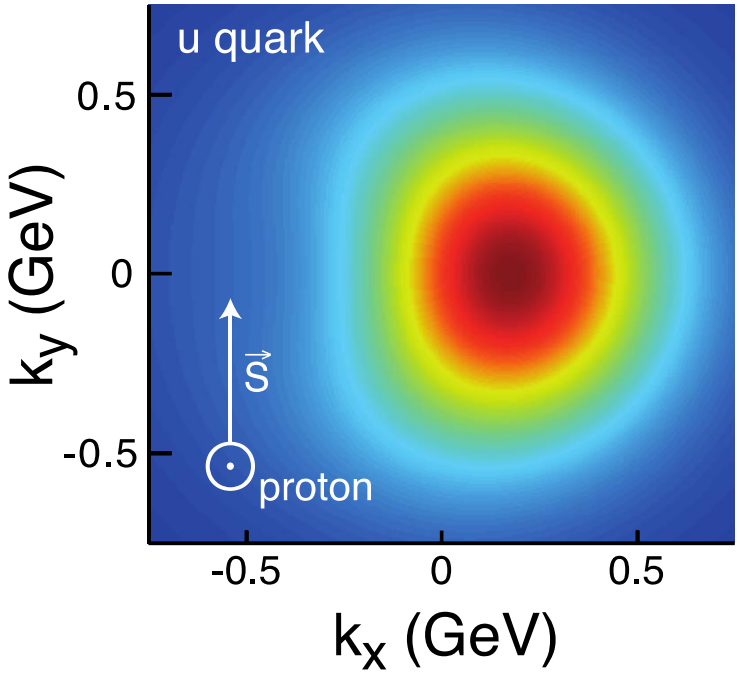


Measurement of Transverse Momentum Distribution

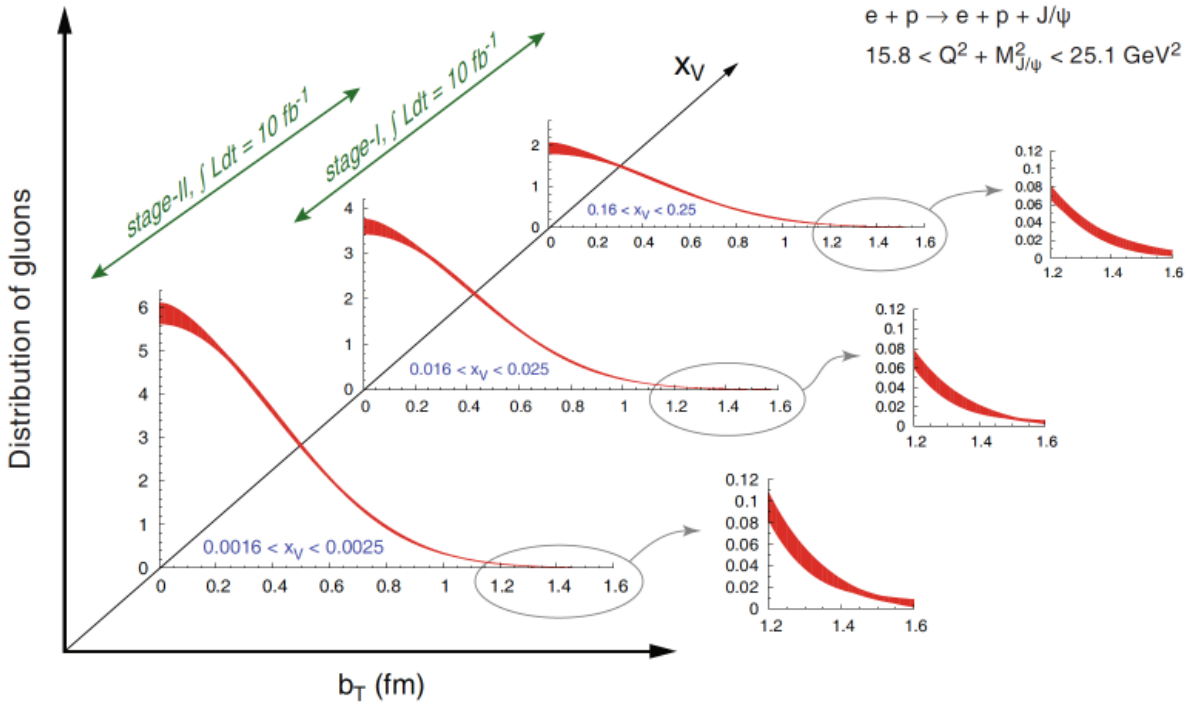
Semi-Inclusive Deep Inelastic Scattering

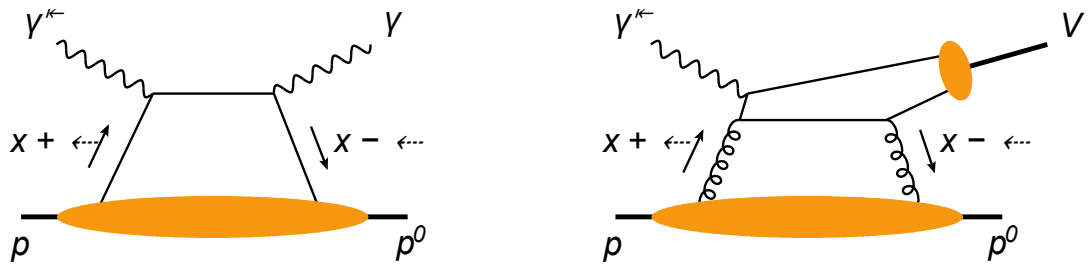






Spatial distribution of quarks and gluons: GPDs via DVCS & DVVM



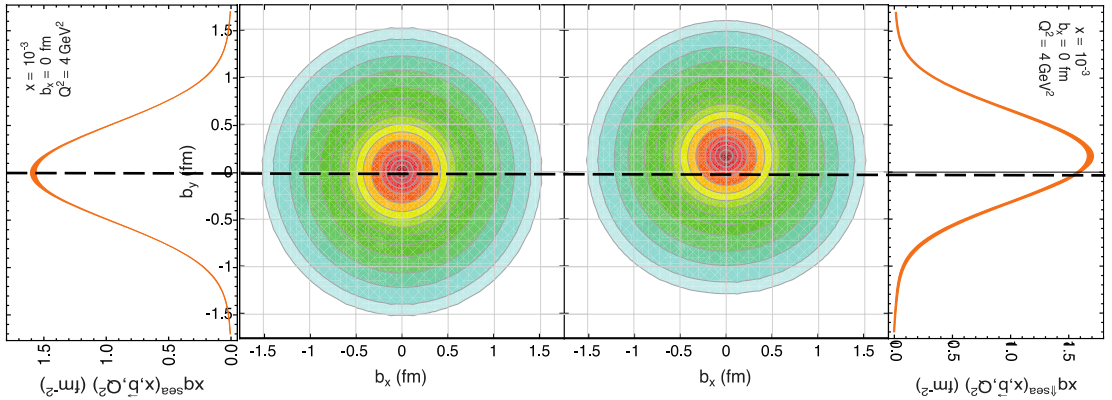


Fourier transform of momentum transferred = |t| = p-p' → Spatial distribution

Transverse Position Distributions

sea-quarks

unpolarized polarized



Lattice QCD calculations and EIC measurements will reinforce each other in QCD phase spaces of overlap and complement each other in QCD phases spaces are difficult to each by either.

Phase I and Phase II proposals

Change in baseline (independent of phasing) since Nov 2023 DOE review:

- Add injection cooler for hadrons; replace a 400-MeV NC commercial linac with a 3-GeV SRF (1.3 GHz) linac as injector to the RCS;

Phase I:

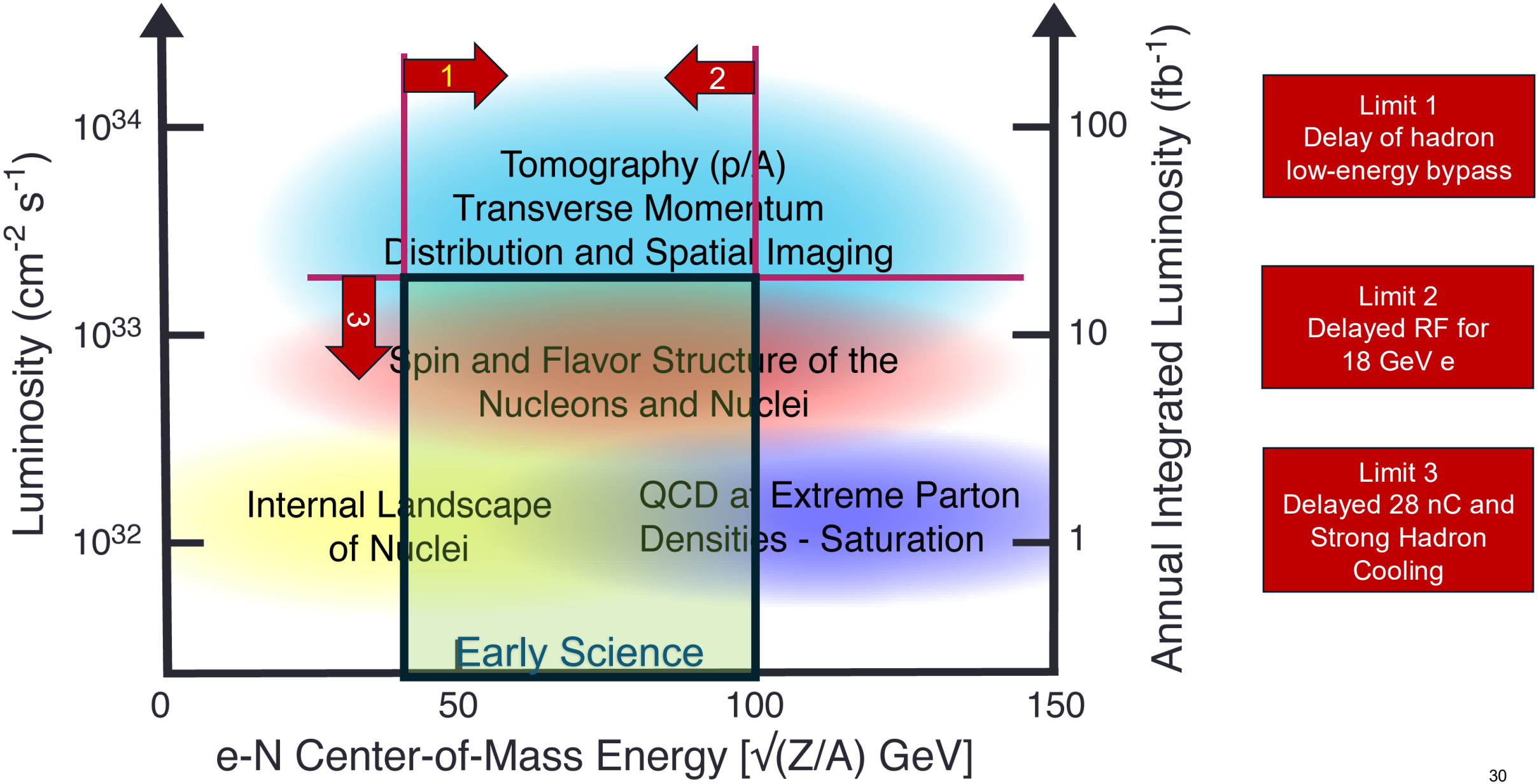
- HSR: no Strong Hadron Cooling, add precooler, no 41-GeV bypass
- ESR: 5-10 GeV, 7 nC max (means fewer rf cavities and amps); maybe no crabs (may require lower proton bunch intensities)
- RCS: operates with a 7-nC (single bunch), 3 –> 5 or 10 GeV, ramps at 1 Hz

Phase II:

- HSR: add SHC, add 41-GeV bypass
- ESR: add rf cavities and power to operate at 28 nC and 18 GeV; add crabs
- RCS: upgraded to 28 nC and 3 -> 18 GeV ramps (at 1 Hz);

EIC Early Science Program Reach:

All components of the NAS Report Science will start



Limit 1
Delay of hadron low-energy bypass

Limit 2
Delayed RF for 18 GeV e

Limit 3
Delayed 28 nC and Strong Hadron Cooling