The Electron-Ion Collider (EIC)

A New Accelerator Facility for Subatomic Physics

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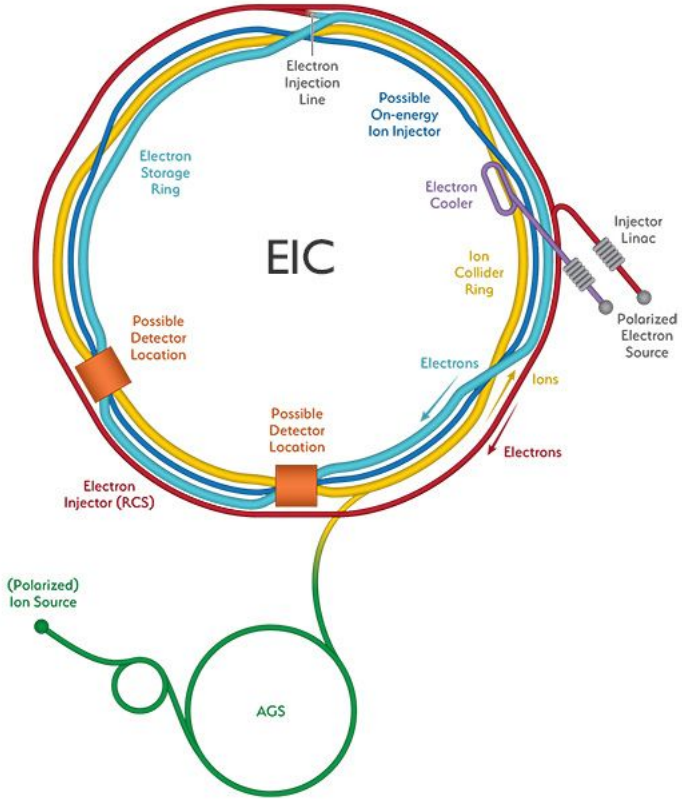
for the EIC Canada Collaboration (eic-canada.org)

With material by Michael Gericke, Dave Hornidge, Garth Huber, Juliette Mammei, Zisis Papandreou. Supported in part by NSERC.

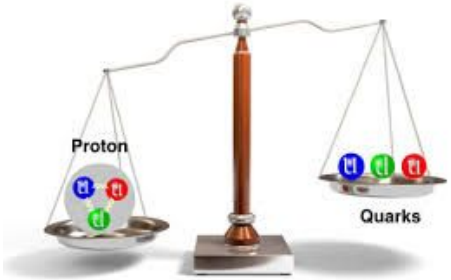
What is the Electron Ion Collider?

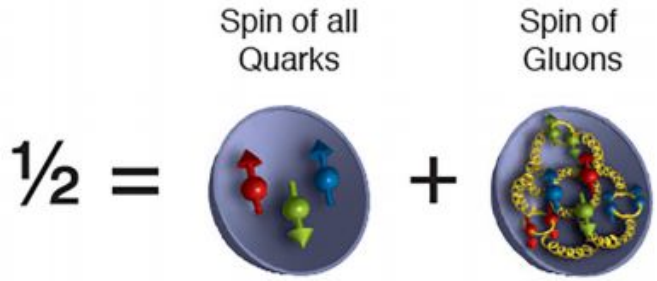
- **First major collider** to be built in North America in the 21st century
  - **Polarized electrons**, 10-20 GeV
  - **Polarized light ions** (p, d, ^{3}He) and unpolarized nuclei→U, 50-250 GeV
  - Center of mass energy of 20-140 GeV
  - **High luminosity** $\mathcal{L}$ of 10^{34} cm^{-2} s^{-1}
- International facility with estimated cost of US$1.6B to US$2.6B
- Large community of 1000+ users at 220+ institutions in 30+ countries
- Project driven by US Department of Energy (which runs national labs)

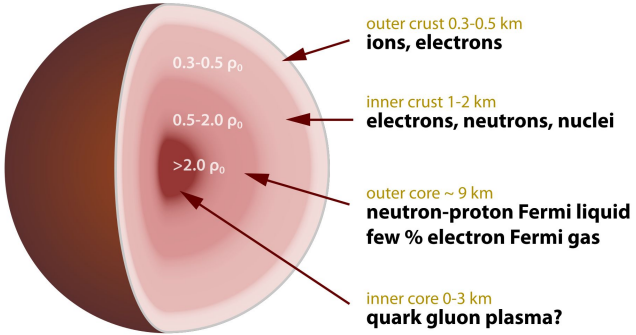


The EIC Will Answer Three Big Questions

- How does the **mass of the nucleon** arise?
  - While the Higgs mechanism can explain all of the mass of the electron, it accounts for only a small part of the mass of the nucleon
- How does the **spin of the nucleon** arise?
  - Three spin ½ quarks, bound by gluons, each with angular momentum, form a spin ½ proton.
- What are the **emergent properties** of dense systems of gluons?
  - How does nuclear matter behave at extremely high densities found in astrophysical systems?

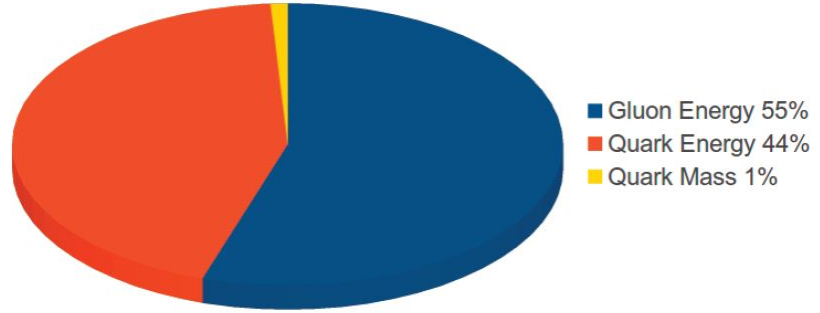


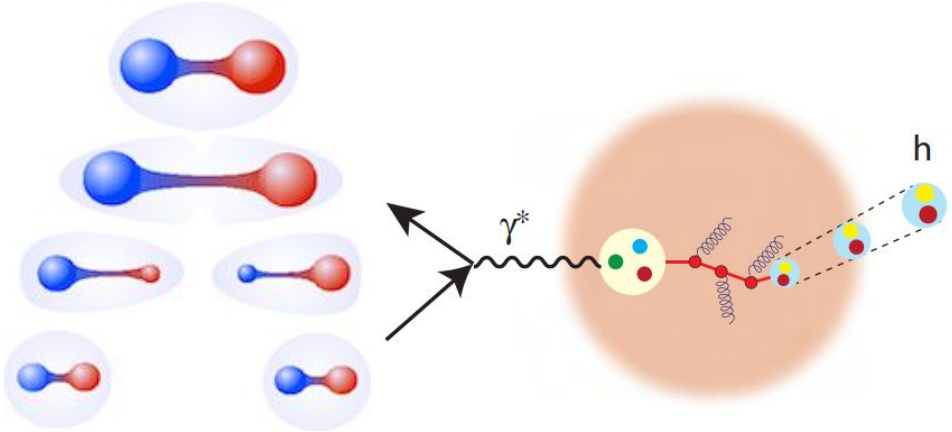




How does the mass of the nucleon arise?

- Vast majority of the nucleon's mass is due to quark-antiquark pairs, the gluons, and the energy of quarks moving at the speed of light.
- Confinement allows only colorless combinations of quarks. Struck quarks "hadronize" into these colorless states. The details of hadronization (including screening and nuclear medium effects) tell us about the components of mass.

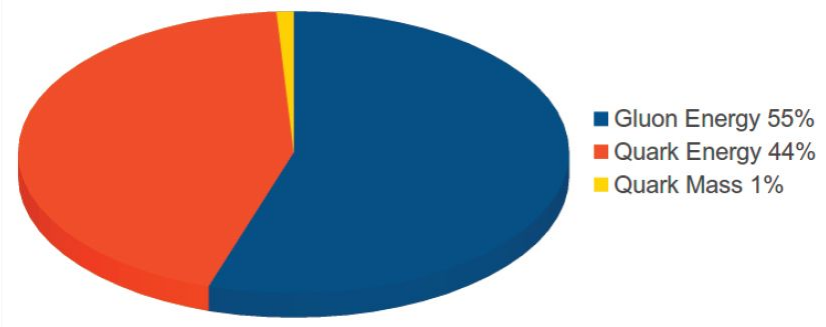


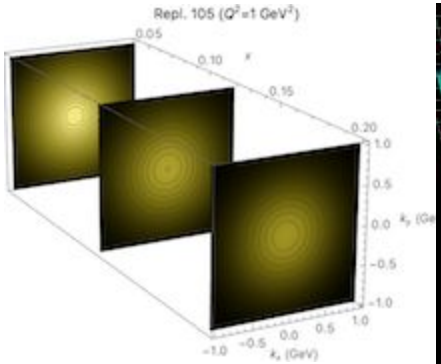


Confinement Hadronization

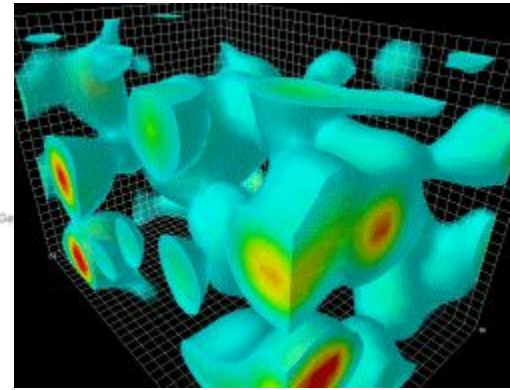
How does the mass of the nucleon arise?

- EIC will allow “proton tomography” in the multiple dimensions of x, Q^2, and impact parameter, allowing for spatial and momentum 3D maps (*i.e.* TMDs, GPDs).
- This will allow us to pinpoint the different contributions coming from quarks, gluons, and quark-antiquark pairs.



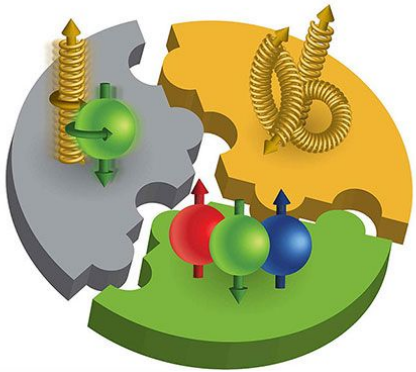


Proton Tomography

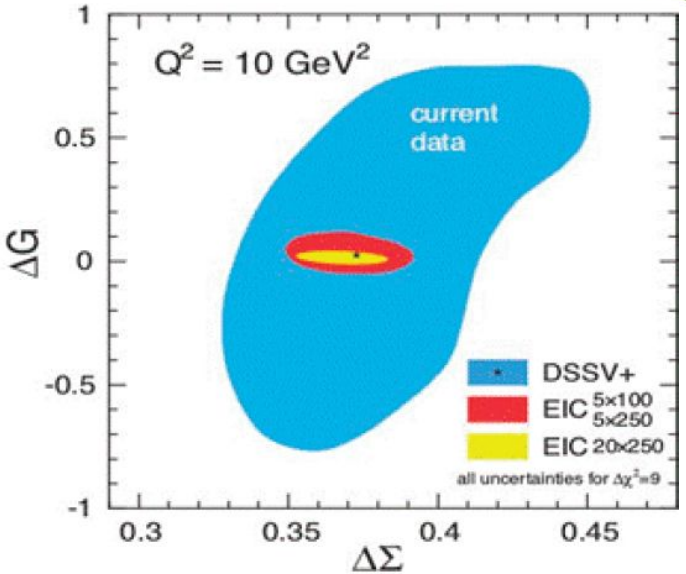


Vacuum gluon fluctuations

How does the spin of the nucleon arise?

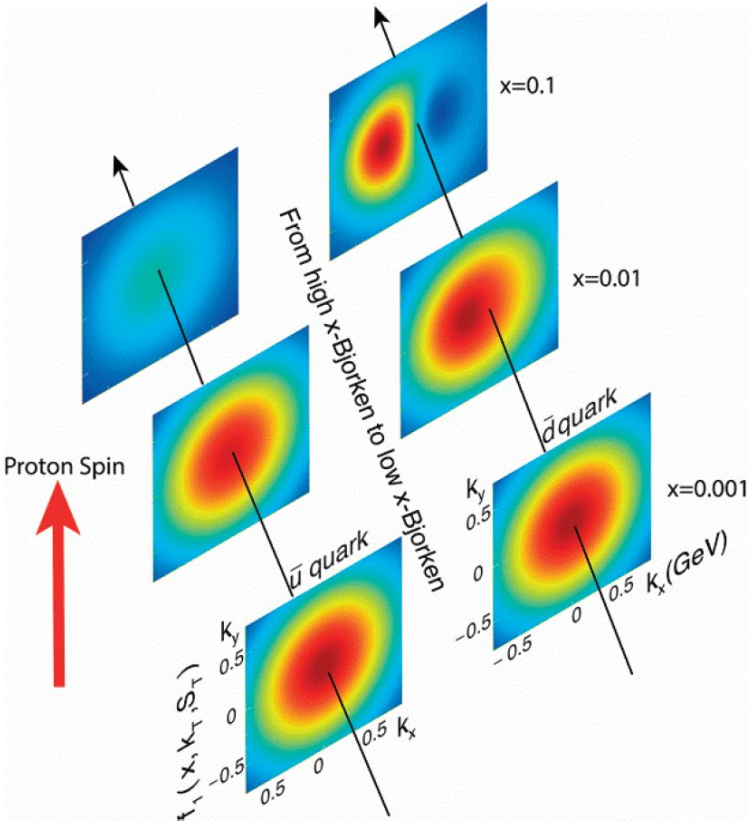


- Polarized electrons colliding with polarized hadrons: **a world's first!**
- The EIC will be able to separate the spin contribution from quark spin, gluon spin, and from quark and gluon angular momentum.
- Spin ½ = $\Delta\Sigma + \Delta G + L_q + L_g$
  - $\Delta\Sigma$ = quark spin contribution
  - ΔG = gluon spin contribution
  - $L_q + L_g$ = angular momentum contributions



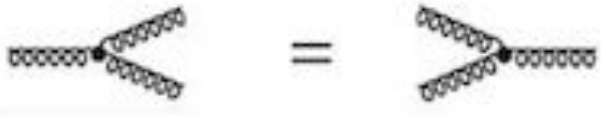
How does the spin of the nucleon arise?

- Adds unique spin degrees of freedom to “proton tomography”
- Example: the asymmetry in the d-bar transverse momentum profile for various x and Q^2 for transversely polarized protons allows us to extract how much of the proton’s spin is carried by the quark angular momentum.

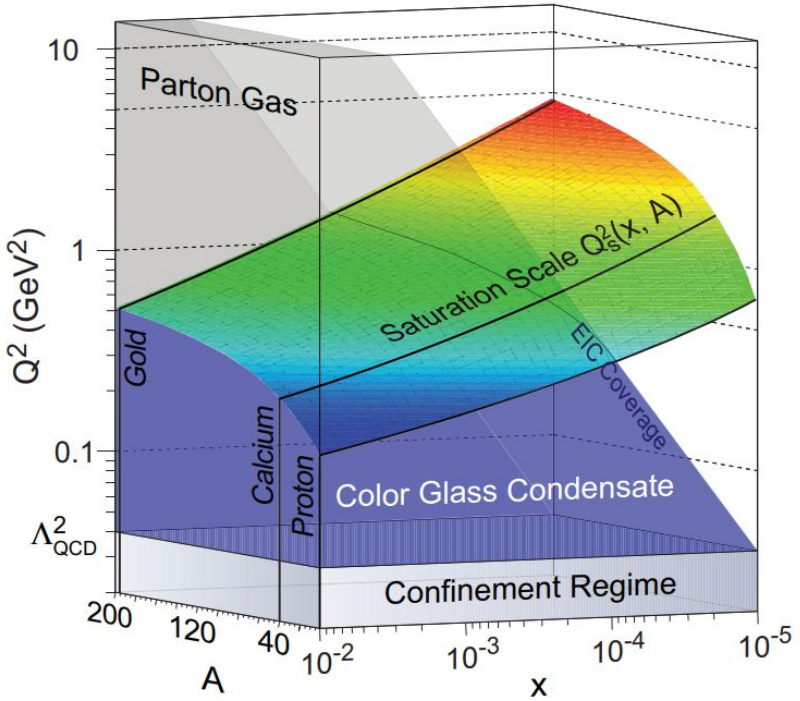


What emerges from dense gluon systems?

- Gluons in QCD are the only gauge bosons with a self-coupling: they can split and recombine.



- At the saturation densities, splitting and recombination are in balance.
- But even at lower densities of the proton, there are quark/gluon correlations.

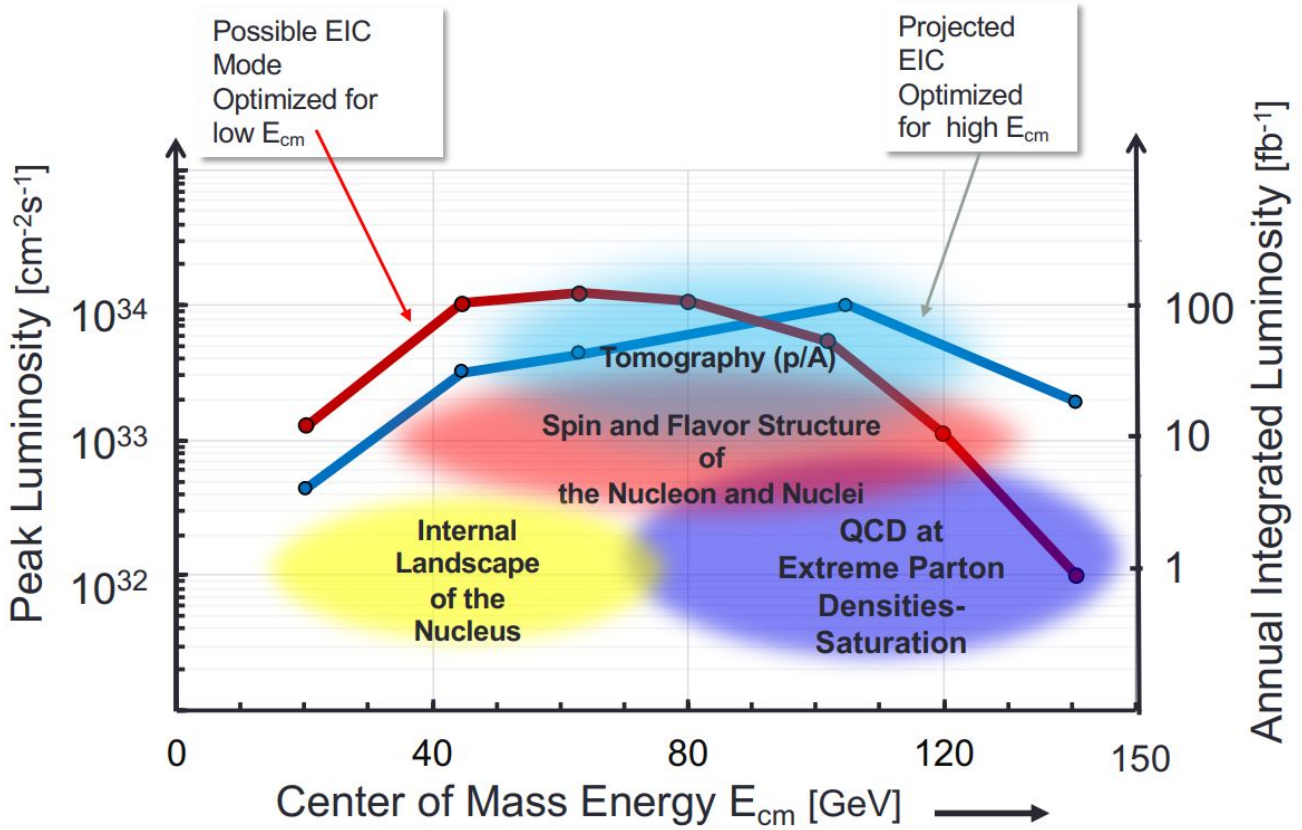


The EIC Luminosity Landscape

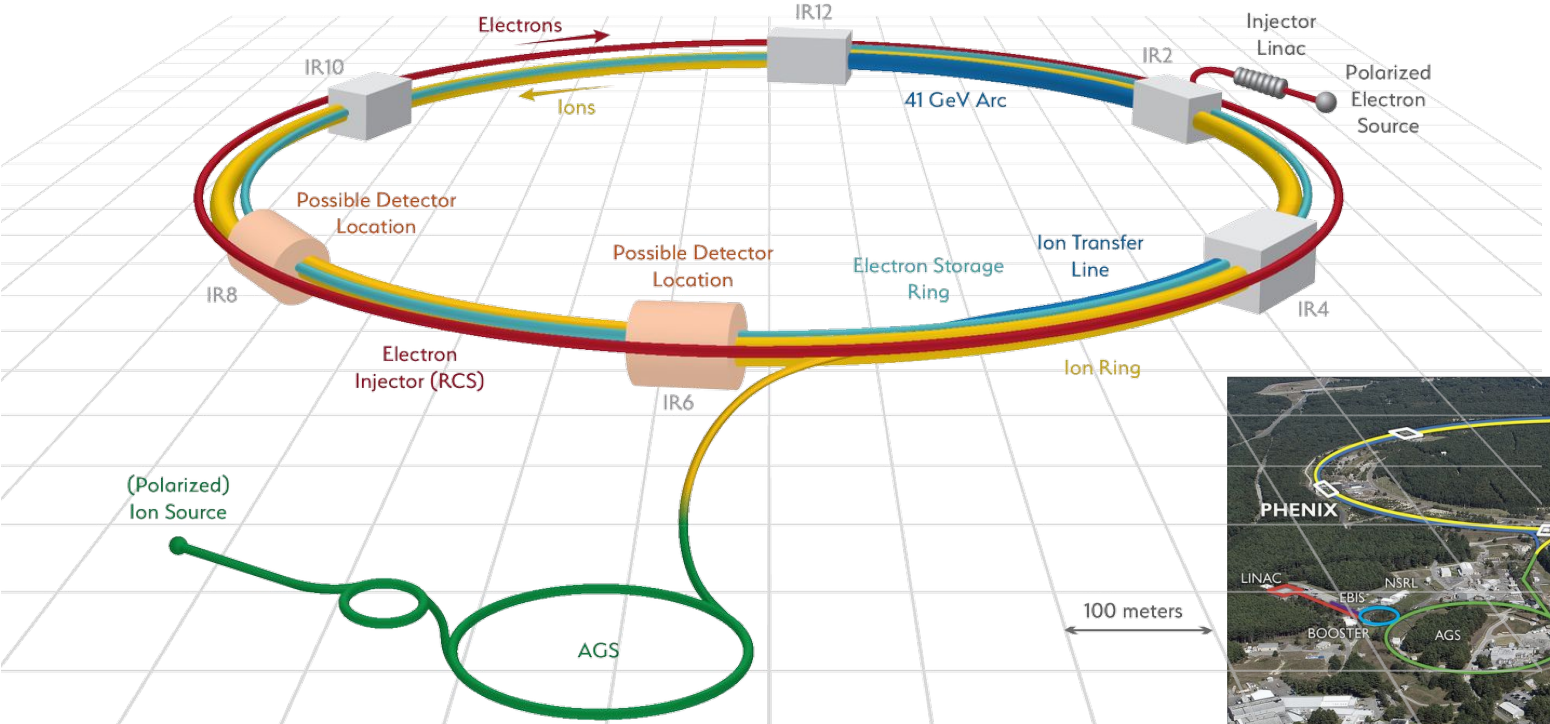
Low and high energy collisions probe different physics.

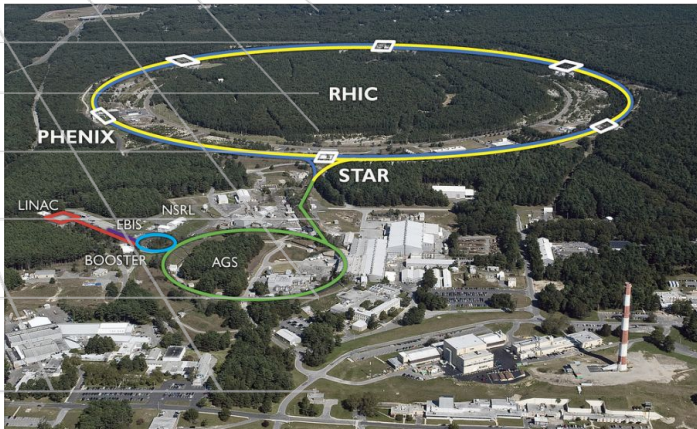
Proton tomography observables in multiple kinematic and spin dimensions require high luminosity.

Yellow Report process for considered decision on mutual optimization.



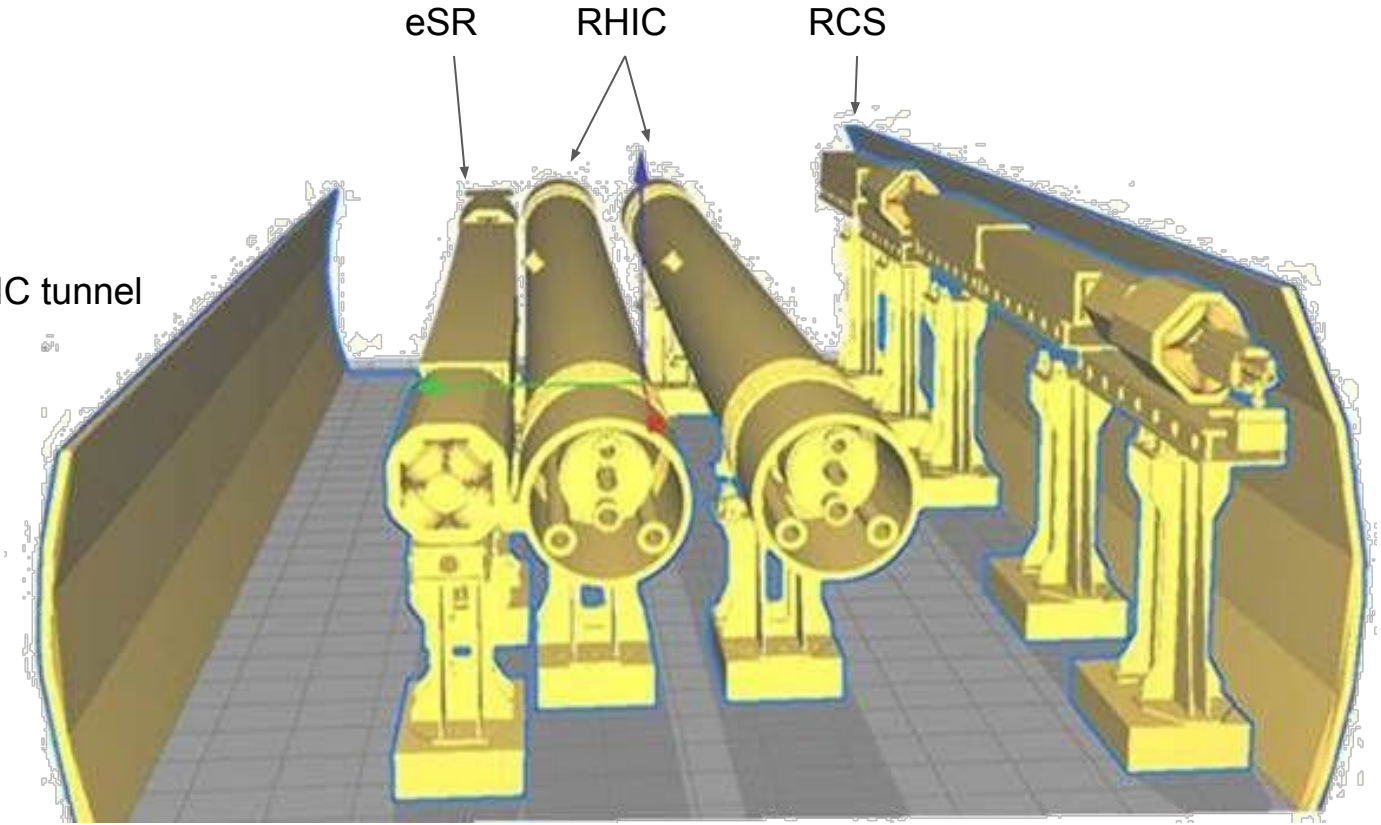
EIC Design Leverages Existing RHIC Facility





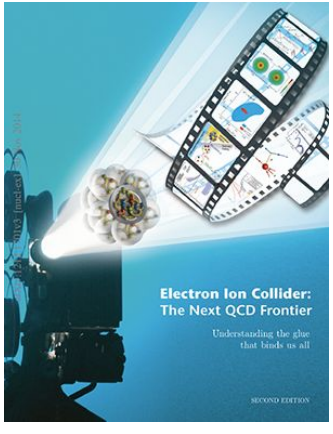
EIC Design Leverages Existing RHIC Facility

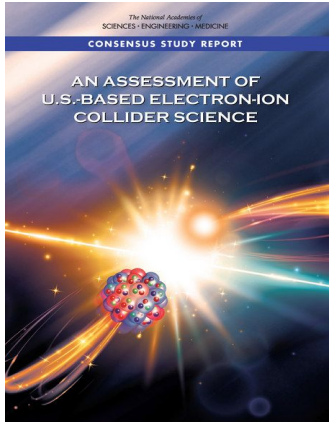
Existing RHIC tunnel

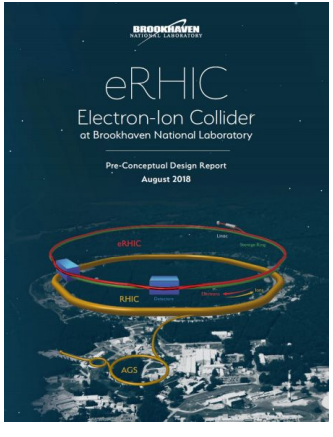


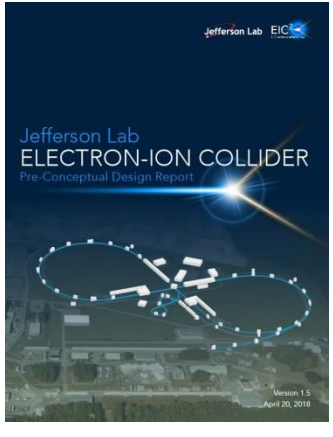
Milestones in the Electron Ion Collider Development

- **2012**: Community White Paper
- **2018**: Nat. Acad. of Sci., Eng., and Med., *An Assessment of U.S.-Based Electron-Ion Collider Science.*
- **2018**: Two pre-conceptual design reports
  - eRHIC at Brookhaven National Lab
  - JLEIC at Jefferson Lab
- **2019**: U.S. Dept. of Energy Critical Decision 0 (CD-0, approval of mission need, project start)
- **2020**: Site selection of Brookhaven National Lab
- **2020**: Yellow Reports to advance the state and detail of physics studies and detector concepts
- The project is moving fast: **first beam by 2029!**





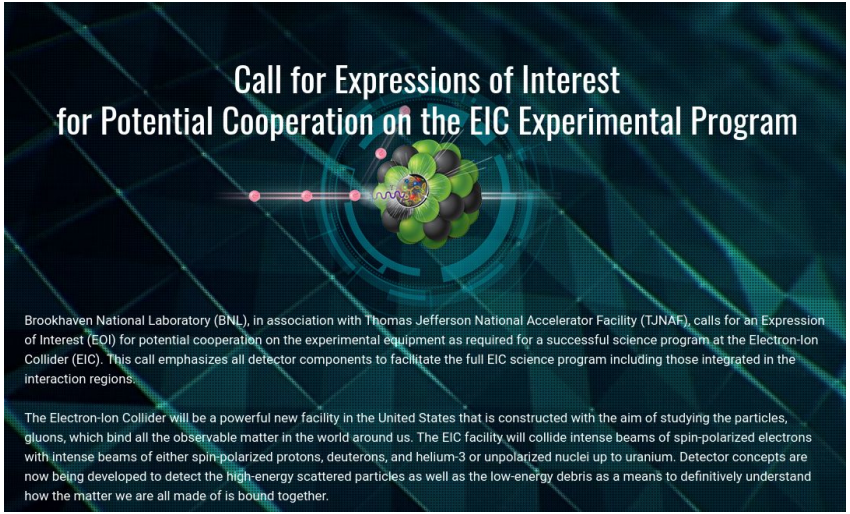




Call for Expressions of Interest by BNL/JLab

- Opportunities for countries, geographical regions, or general consortia to submit their interest for potential EIC equipment cooperation.
- From full material purchases or cost reductions to for contributed labor.

“The EOI will give the EIC Project guidance on current interest for participating in the EIC experimental program, including an initial understanding of the full scope of the experimental equipment that might be available for the expedient start of science operations at the time of EIC project completion.”



Deadline: November 1, 2020

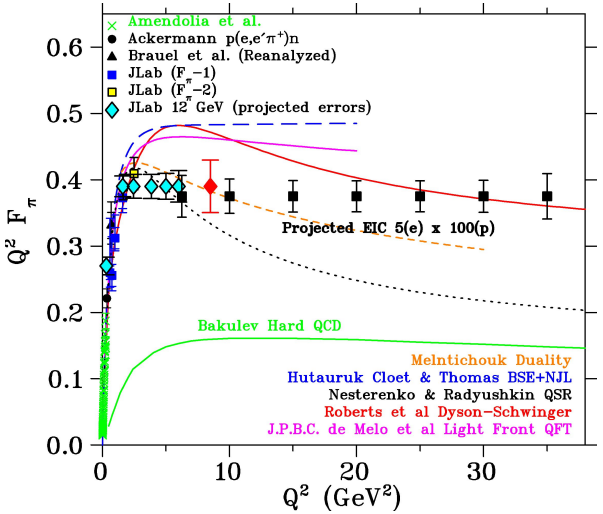
Submission by the EIC Canada Collaboration for development of hardware component.

EIC Canada Collaboration

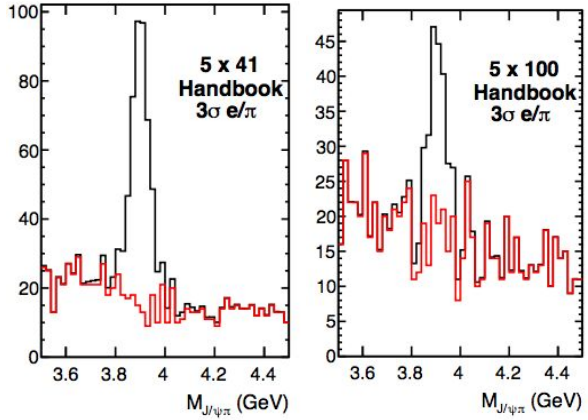
- Coordinating the Canadian participation in the Electron Ion Collider
- Chartered in 2020 after the CD-0 decision and site selection
- Current initiatives:
  - Engagement with the SAP **long range planning process**
  - Submission of unified SAP **project grants** (targeted for Fall 2020)
  - Interfacing with partner organizations:
    - nationally (NSERC, CFI, TRIUMF)
    - internationally (EIC UG, BNL, JLab)
  - Submission of **Expression of Interest** for Potential Cooperation to BNL / JLab
- Current membership:
  - PIs at U. Regina, U. Manitoba, Mt. Allison U.
  - Associate memberships targeted at PIs who want to ramp up their involvement
- More details at eic-canada.org

Canadian Contributions: U. Regina

- Pion form factors as probe of emergent mass generation in hadrons
  - Precision at high momentum transfers
- Light and heavy quark spectroscopy
  - Hadron Spectroscopy has components in: Semi-inclusive, Heavy Flavor and Exclusive.
  - Explore underlying degrees of freedom in Charmonium states
  - Explore Bottomonium Exotic Sector
- Detector development:
  - EIC Calorimetry Working group is collecting information about calorimetry technologies and simulations studies; examine physics-driven requirements to ECAL and HCAL calorimetry.

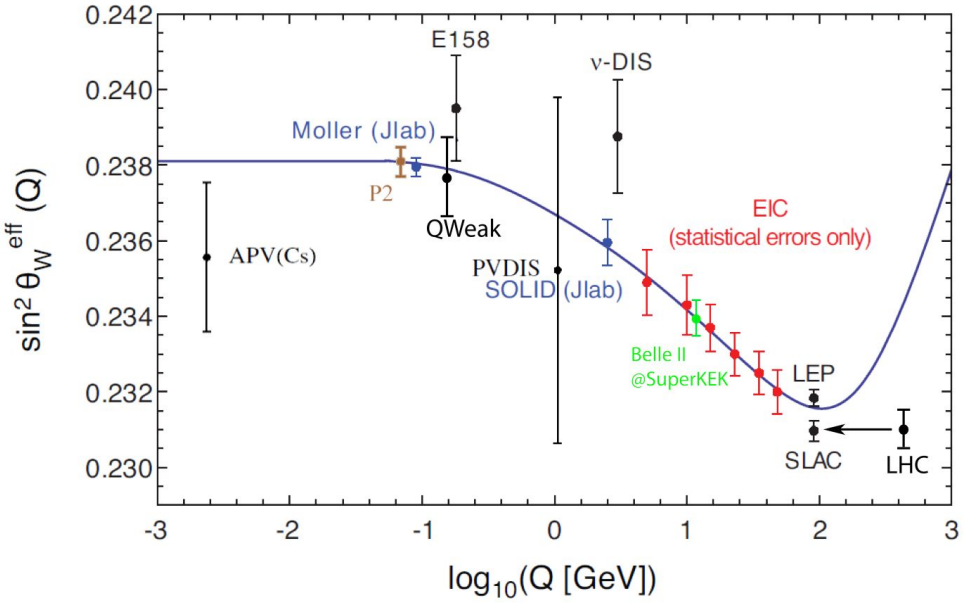


M(Z → J/ψ π)



Canadian Contributions: U. Manitoba

- Exploiting parity-violation in weak interaction to access observables:
  - Strangeness in nucleon (fixed target)
  - Precision searches for new physics
- CC and NC program of precision $\sin^2\theta_W$ measurements at the EIC span unexplored region between low energy and Z-pole (LHC)
- Detector development:
  - Electron beam polarimetry
  - Inclusive electron detection (calorimetry)
- Software development (EIC SWG)



Ref: YX Zhao, Eur.Phys.J.A (2017) 53:55

Projected Involvement by Canadian University PIs

- EIC logically follows extensive physics programs at Jefferson Lab, Brookhaven National Lab, and connects to other existing Canadian programs
- Anticipate major detector construction effort by EIC Canada Collaboration (calorimetry, polarimetry)
- EIC Expression of Interest submission Fall 2020
- NSERC SAP project grant proposal Fall 2020
- A community similar in size to the Belle II collaboration is feasible
  - PI FTEs: growth to **~10 PIs** by start of operations in 2029
  - HQP: growth to **~20 HQP** by start of operations 2029
  - More detailed projections in EIC SAP LRP brief (at eic-canada.org)
- Funding resources:
  - **CFI: $1.5M to $6M** infrastructure on 2025-2028 timescale
  - **NSERC: Grow to $550k/year** by start of operations 2029

Connections Between EIC and TRIUMF Programs

- Key **accelerator expertise** at TRIUMF that enable the EIC physics program
  - SRF, e.g. **crab cavities** for HL-LHC: enable reaching the **highest luminosity** with the EIC
  - **Spin/beam dynamics** calculations: enable **highest polarization** even at high luminosity
  - Magnet technologies
- Key **detector technology expertise** at TRIUMF under consideration for EIC
  - **Large TPC detectors**: building on RHIC STAR detector, synergy with ISAC detectors
  - **Ultra-thin silicon tracking detectors**: TIGRESS-Silicon Tracker ARray (TI-STAR), EIC MAPS detectors
  - **Photon-based detectors**: EIC particle ID with Cerenkov or TOF, could use LaBr4 as ISAC
  - **Hybrid silicon detector technology**: low gain avalanche diode on CMOS electronics for radiation hard tracking, high gain avalanche diode for UV photon detection
- Significant opportunity to align TRIUMF efforts with EIC physics program

Thanks to Oliver Kester, Bob Laxdal, Fabrice Retière for discussions and insights.

Connections Between EIC and TRIUMF Programs

Next steps

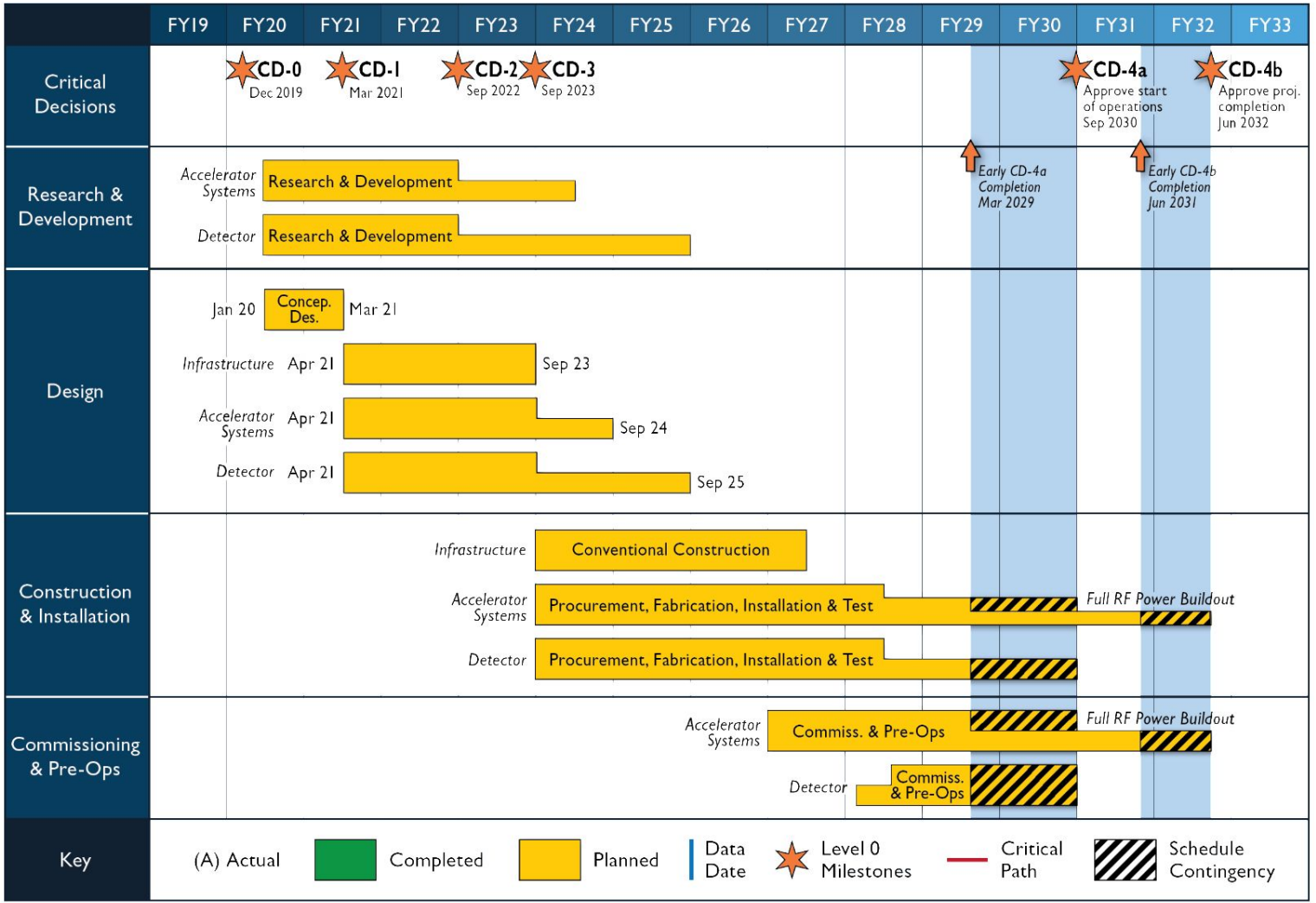
- Fall 2020: International Collaboration on Accelerator Construction Workshop
  - Possible contributions to IR magnet design and construction, luminosity monitoring, RF R&D and construction, subset of normal conducting magnets, critical vacuum components, feedback systems, polarimetry, contributions to a second IR, beam dynamics calculations,...
- Fall 2020: Interest in setting up meeting between the EIC Project Team and TRIUMF leadership, both on accelerator physics and detector development
- From HERA to EIC: TRIUMF was intimately involved in the physics program of HERMES. EIC Canada would want to include TRIUMF’s scientific expertise in addition to its technical expertise.

EIC in the Vision for Canadian Subatomic Physics

- The Electron Ion Collider will **uniquely address three profound questions** about nucleons and how they are assembled to form the nuclei of atom
  - How does the mass of the nucleon arise?
  - How does the spin of the nucleon arise?
  - What are the emergent properties of dense systems of gluons?
- The Electron Ion Collider will enable **ground-breaking discoveries** across a multidisciplinary subatomic physics research portfolio.
  - Canadian involvement will **enhance the global recognition** of Canada's contributions to discovery research.
- The Electron Ion Collider will lead to **major international collaboration** in research, technology, and innovation
  - Canadian subatomic physics community is uniquely positioned to contribute to a more **competitive Canada in discovery and innovation**.

Thank you

Schedule

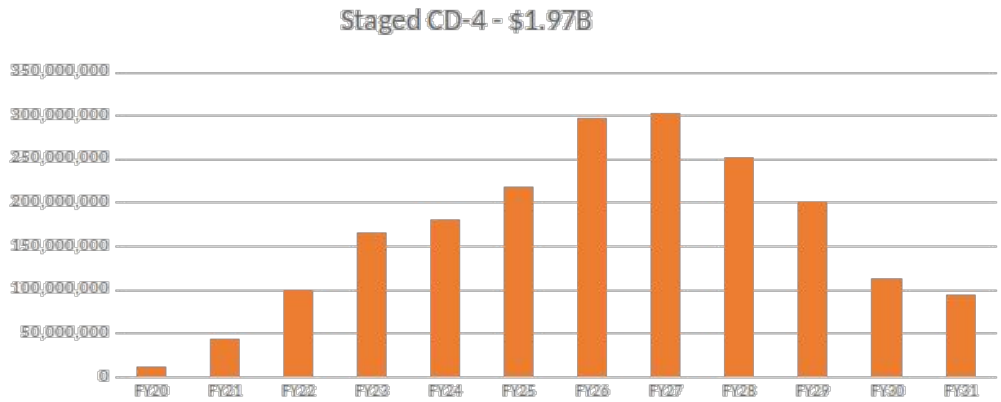


Ref: EIC UG, July 15, 2020

Reference Schedule and Funding Profile

Critical Decisions:

- CD-1: March 2021
- CD-2: September 2022
- CD-3: September 2023
- CD-4a: September 2030
- CD-4b: June 2032

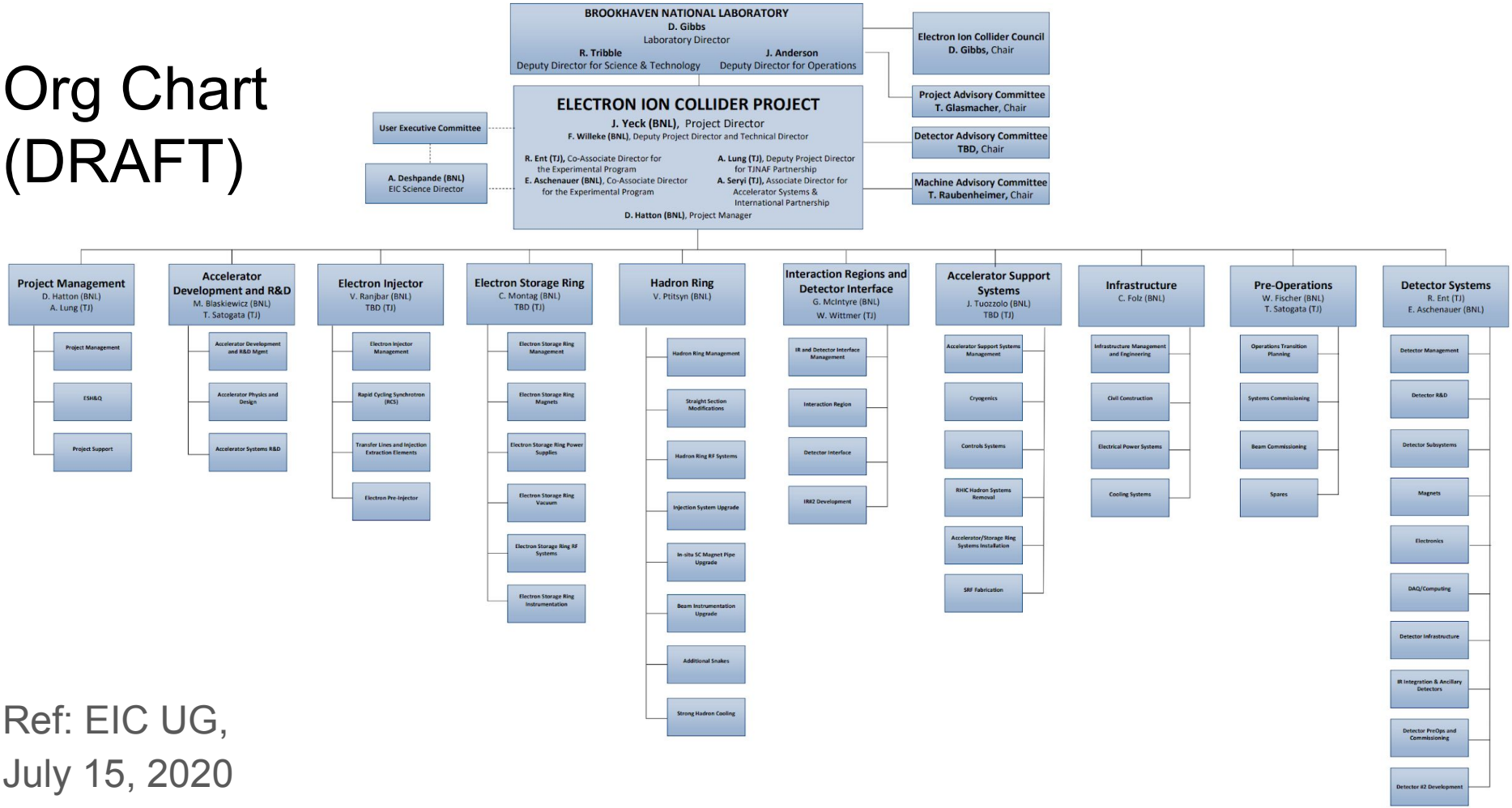


Staged Luminosity:

- Operations Start CD-4a
- Full RF Power Installed by CD-4b

Ref: EIC UG, July 15, 2020

Org Chart (DRAFT)



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