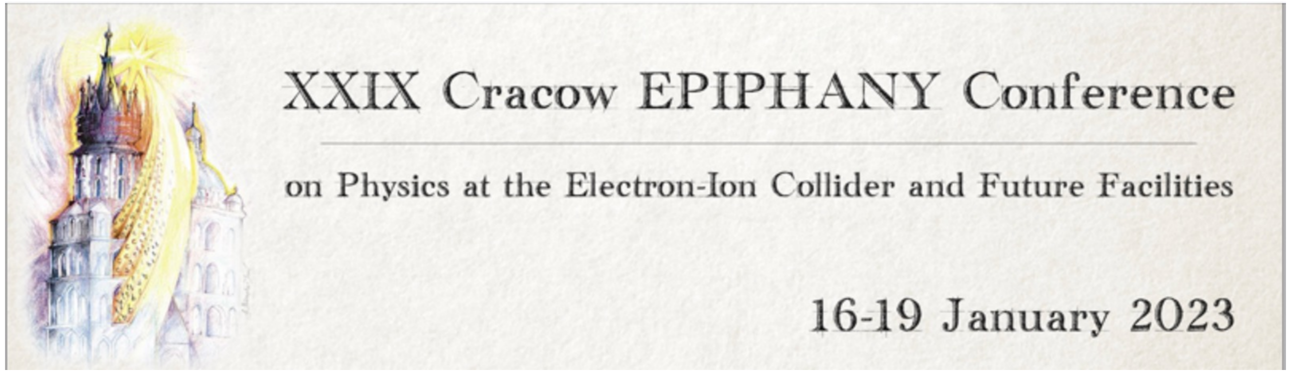
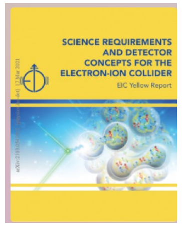
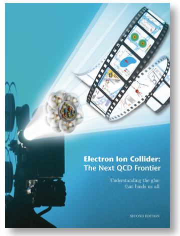
Center for Frontiers in Nuclear Science

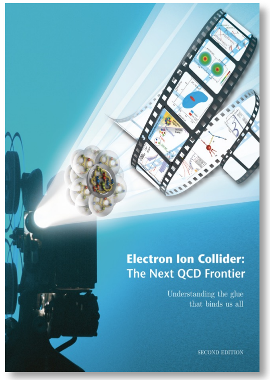






Electron Ion Collider: Science, Status and Opportunities

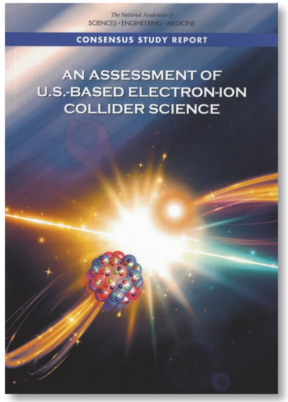
2015



2016

Physics of EIC

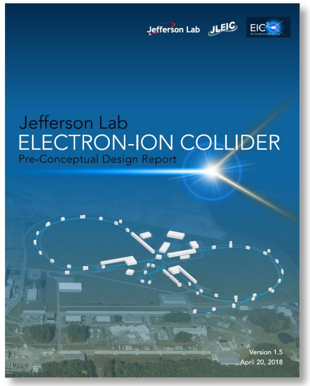
2018



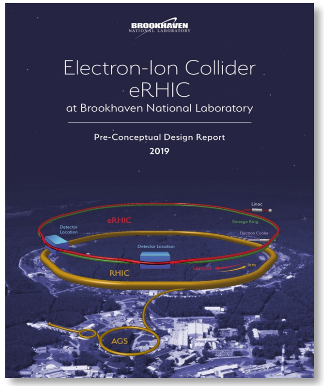
Evaluation

2019-present

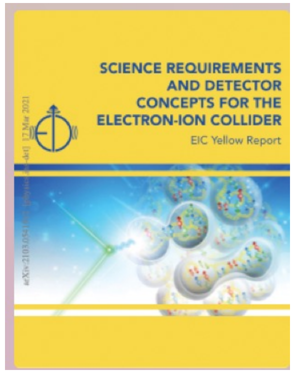
2019



machine



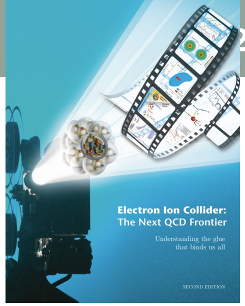
detector



Realization

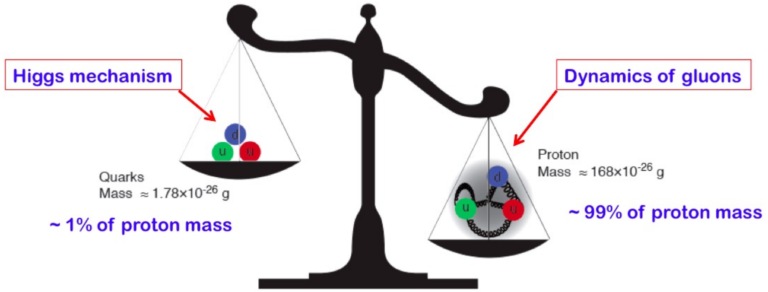
Outline of this talk

- A (high level) review of EIC science
  - Core physics of the EIC – This talk
  - Many talks in this meeting
- EIC project & EIC users, their activities
  - Beyond the Core Physics of EIC – This talk
  - EIC accelerator -- Ferdinand Willeke
  - EIC Detector 1: “EPIC” -- John Lajoie
- EIC Outlook path to realization

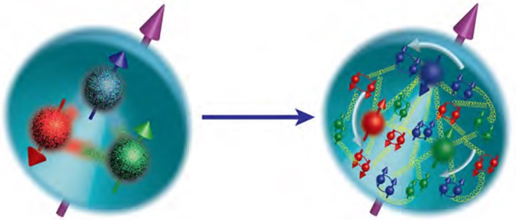


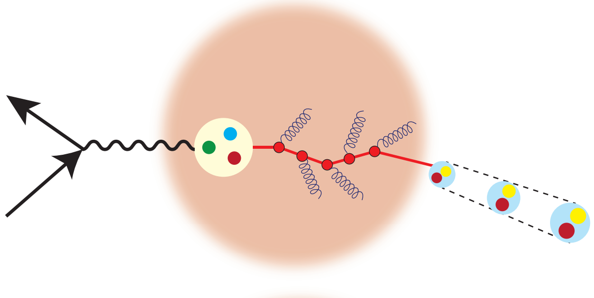
EIC Physics at-a-Glance

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

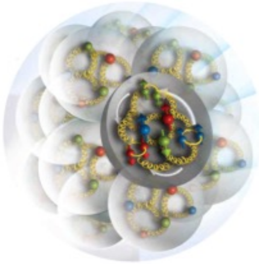


How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties (mass & spin) emerge from their interactions?

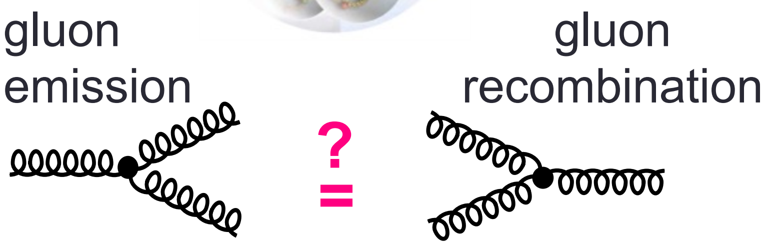




How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

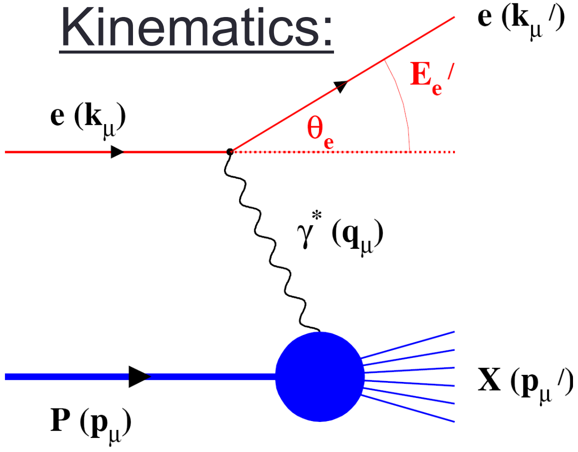


How does a dense nuclear environment affect the quark- and gluon- distributions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?



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

$$x = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

Hadron :

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

$$s = 4E_h E_e$$

High lumi & acceptance

Exclusive DIS

detect & identify *everything* e+p/A → e'+h(π,K,p,jet)+…

Semi-inclusive events:

e+p/A → e'+h(π,K,p,jet)+X

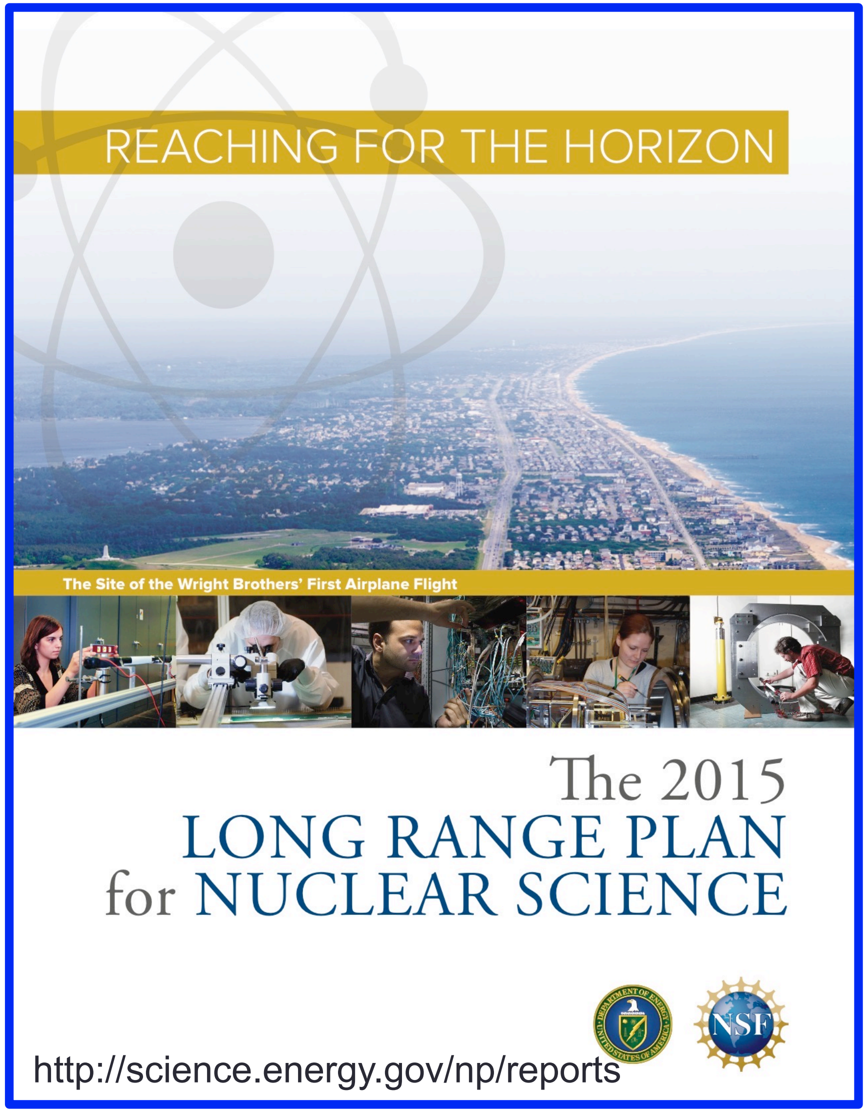
detect the scattered lepton in coincidence with identified hadrons/jets

Inclusive events:

e+p/A → e'+X

detect *only the scattered lepton* in the detector

Low lumi & acceptance



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.

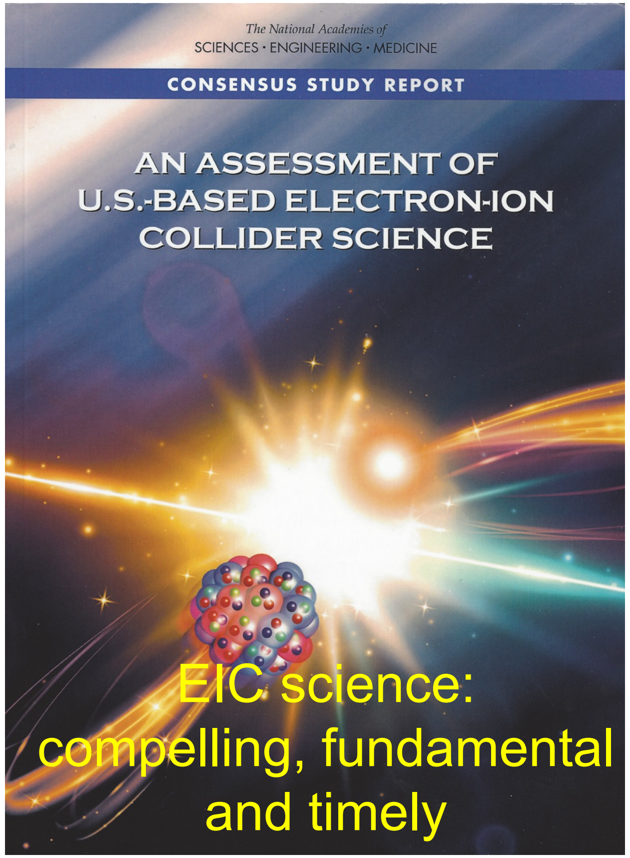
RECOMMENDATION:

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

FRIB construction completed, operations began May 2022.

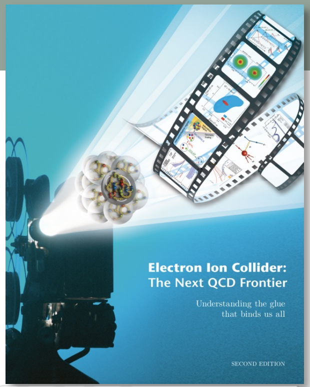
National Academy of Science, Engineering and Medicine

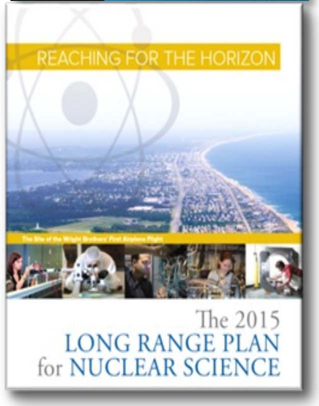
Assessment July 2018



Physics of EIC
- Emergence of Spin
- Emergence of Mass
- Physics of high-density gluon fields

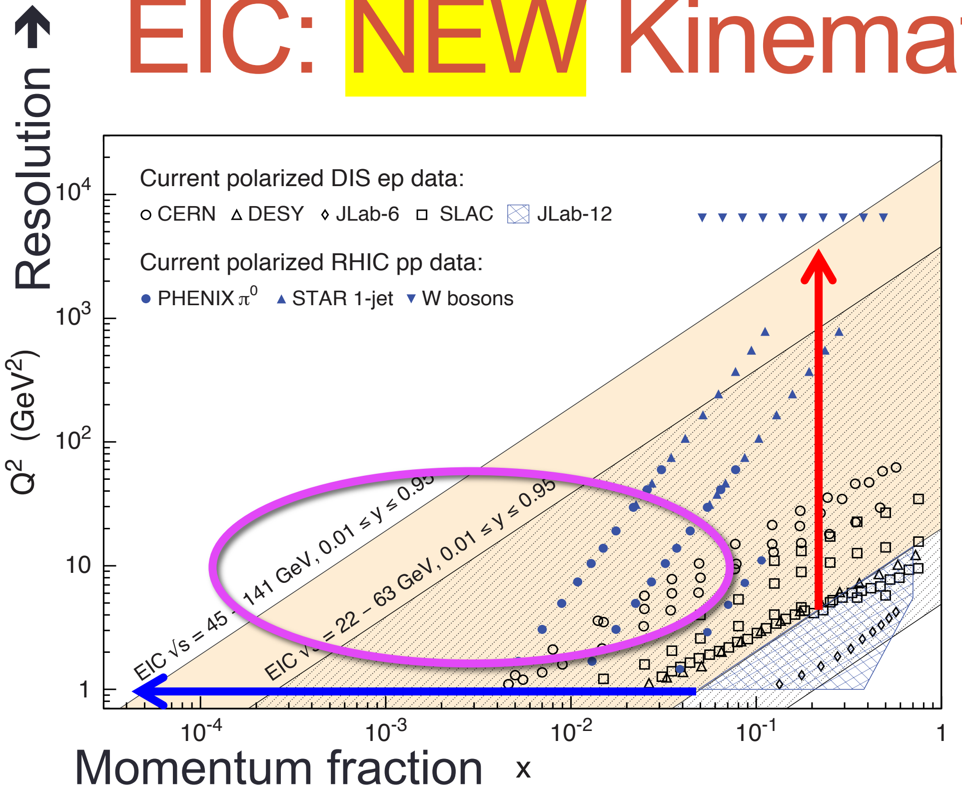
Machine Design Parameters:
- High luminosity: up to 10^{33}-10^{34} cm^{-2}sec^{-1}
  - a factor ~100-1000 times HERA
- Broad range in center-of-mass energy: ~20-140 GeV
- Polarized beams e-, p, and light ion beams with flexible spin patterns/orientation
- Broad range in hadron species: protons…. Uranium
- Up to two detectors well-integrated detector(s) into the machine lattice

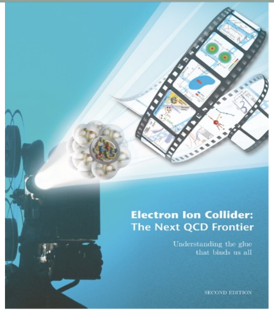




EIC SCIENCE

EIC: NEW Kinematic reach & properties



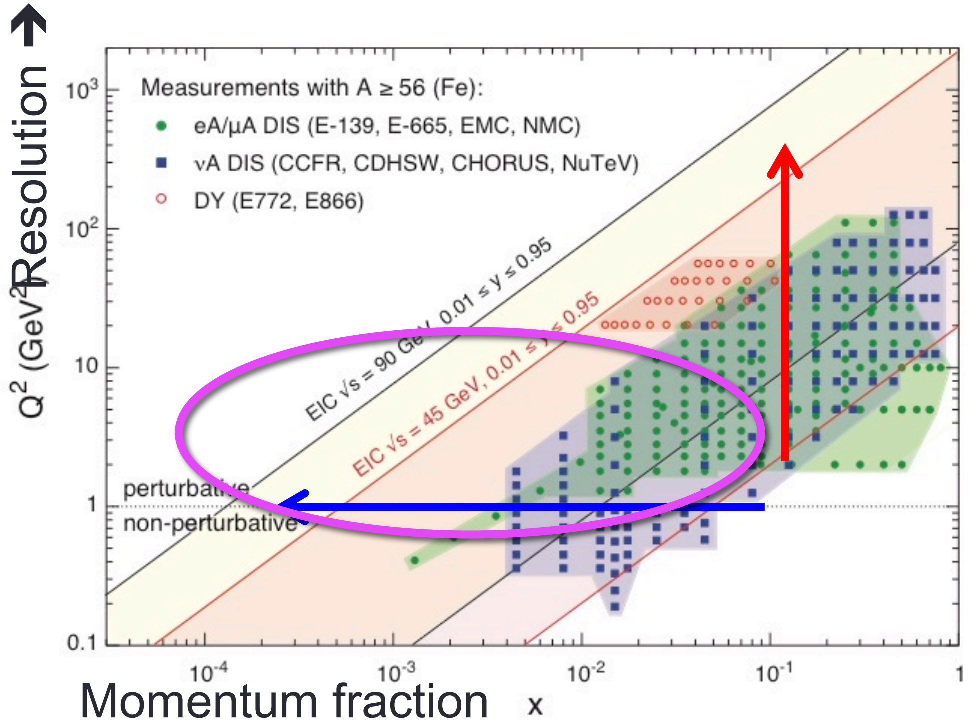


For e-N collisions at the EIC:

- ✓ 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

For e-A collisions at the EIC:

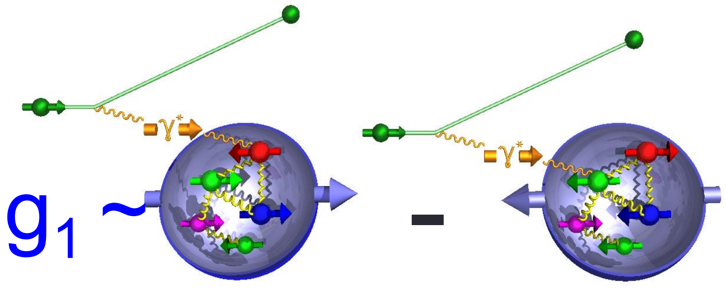
- ✓ Wide range in nuclei
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy
- ✓ Wide x range (evolution)
- ✓ Wide x region (reach high gluon densities)



Nucleon Spin: Precision with EIC

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

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

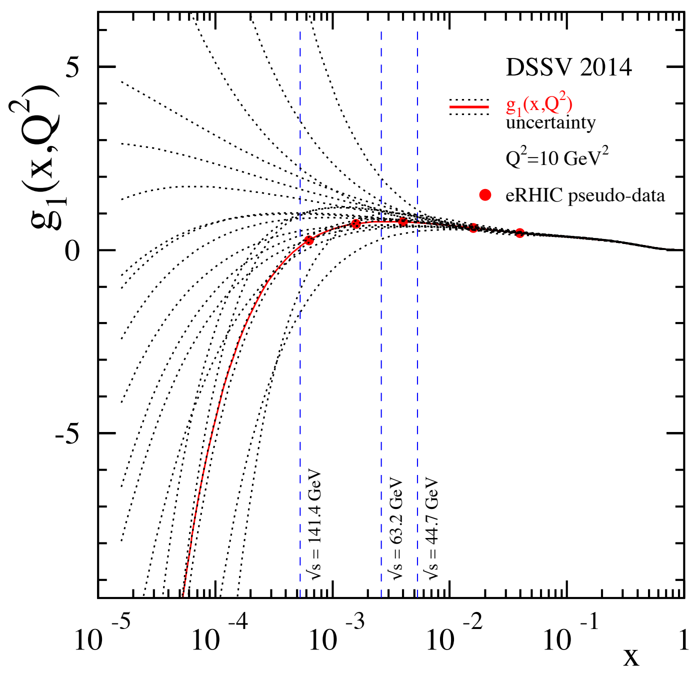


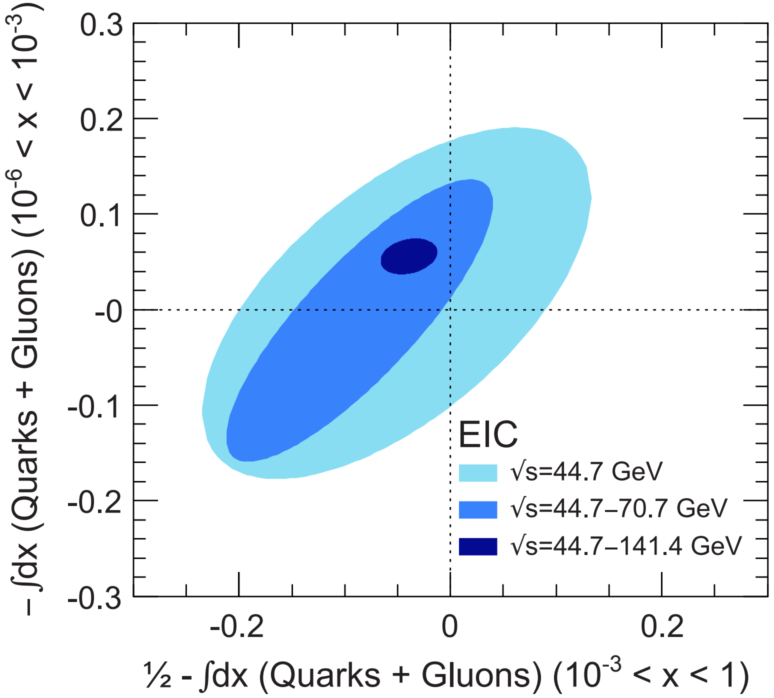
Spin structure function g_1 needs to be measured over a large/**wide range in x-Q²**

Precision in $\Delta\Sigma$ and Δg ➔ A clear idea Of the magnitude of L_Q+L_G = L

Lattice Calculations : comparison

SIDIS: strange and charm quark spin contributions





2+1-Dimensional Imaging Quarks and Gluons

Wigner functions **$W(x,b_T,k_T)$**

offer unprecedented insight into confinement and chiral symmetry breaking.

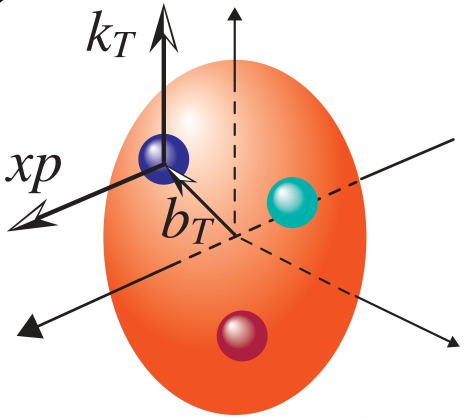
$W(x,b_T,k_T)$

$\int d^2b_T$ $\int d^2k_T$

Momentum space ***Coordinate space***

Direct Comparison with lattice QCD

$f(x,k_T)$



$f(x,b_T)$

Spin-dependent 3D **momentum space** images from semi-inclusive scattering
→ **Transverse Momentum Distribution**

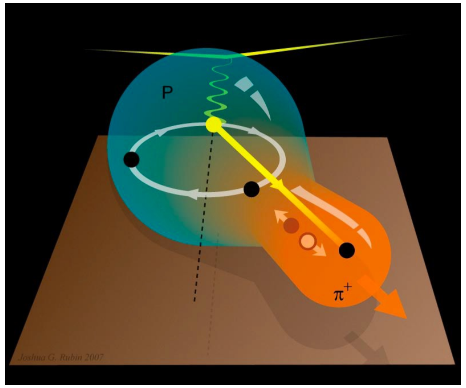
Spin-dependent 2D **coordinate space** (transverse) + 1D (longitudinal momentum) images from exclusive scattering (Deeply virtual Compton scattering and meson production)
→ **Generalized Parton Distributions**

momentum and position distributions → Orbital motion of quarks and gluons

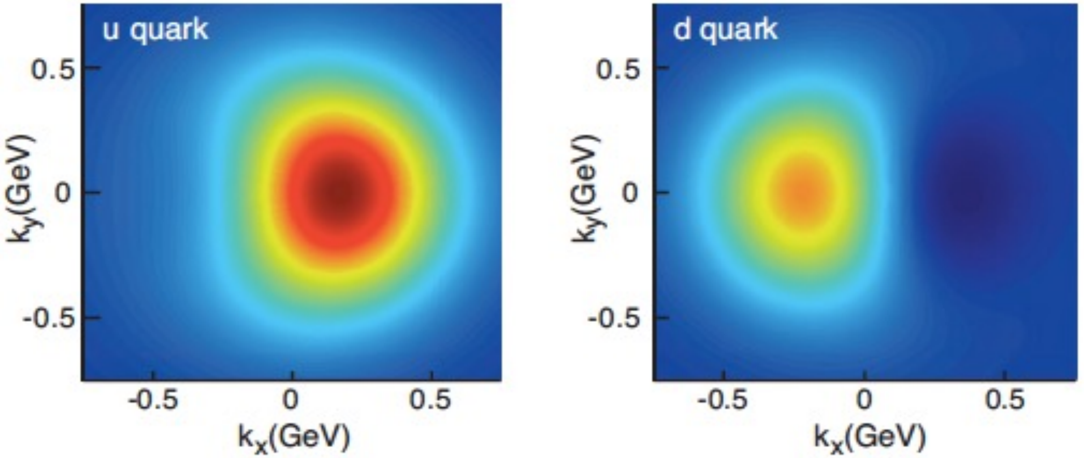
2+1 D partonic image of the proton with the EIC

Spin-dependent (2+1)D momentum space images from semi-inclusive scattering (SIDS)

Transverse Momentum Distributions



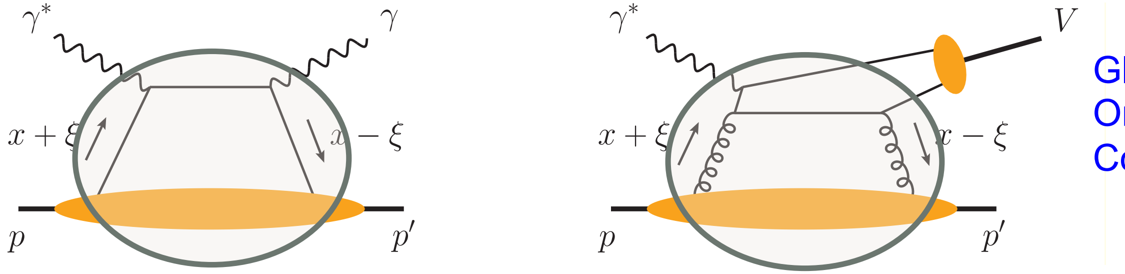
Quark's 2D momentum distribution



Spin-dependent 2D coordinate space (transverse) + 1D (longitudinal momentum) images from exclusive scattering

Transverse Position Distributions

Quarks Motion

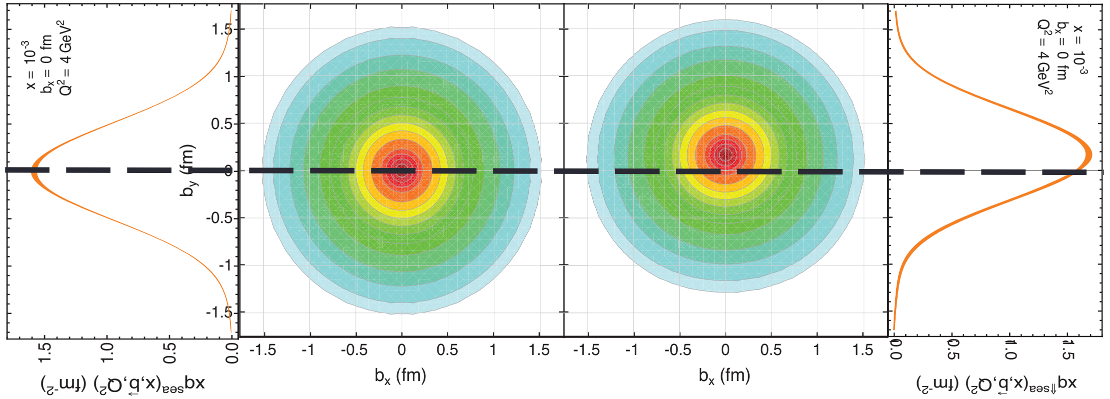


Gluons: Only @ Collider

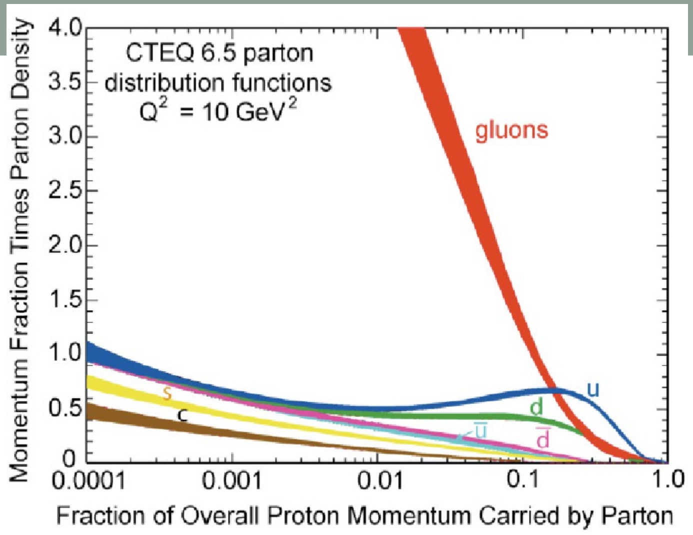
Deeply Virtual Compton Scattering
Measure all three final states
e + **p** → e'+ **p'**+ γ

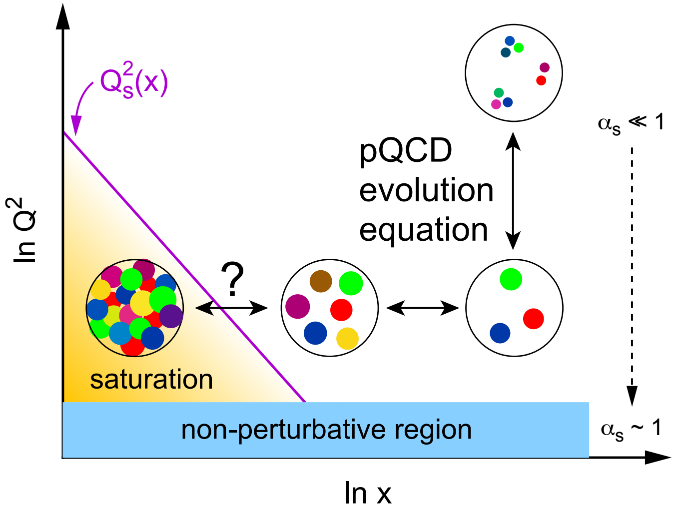
Fourier transform of momentum transferred=(p-p') → Spatial distribution

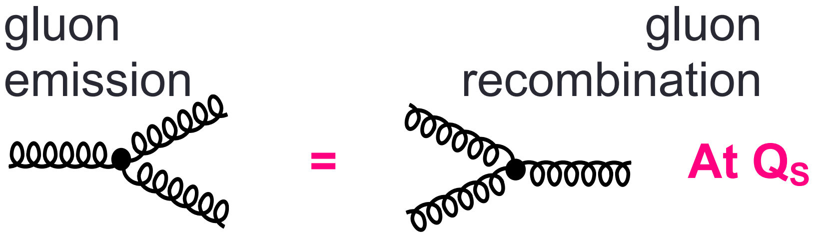
Sea quark's 2D position distribution
unpolarized polarized

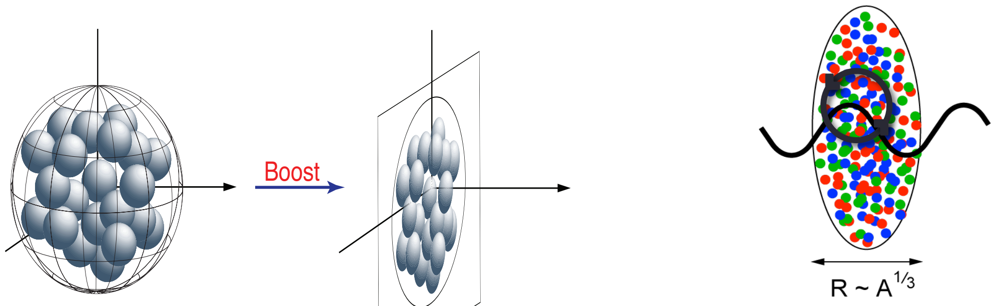


Low x physics with nuclei





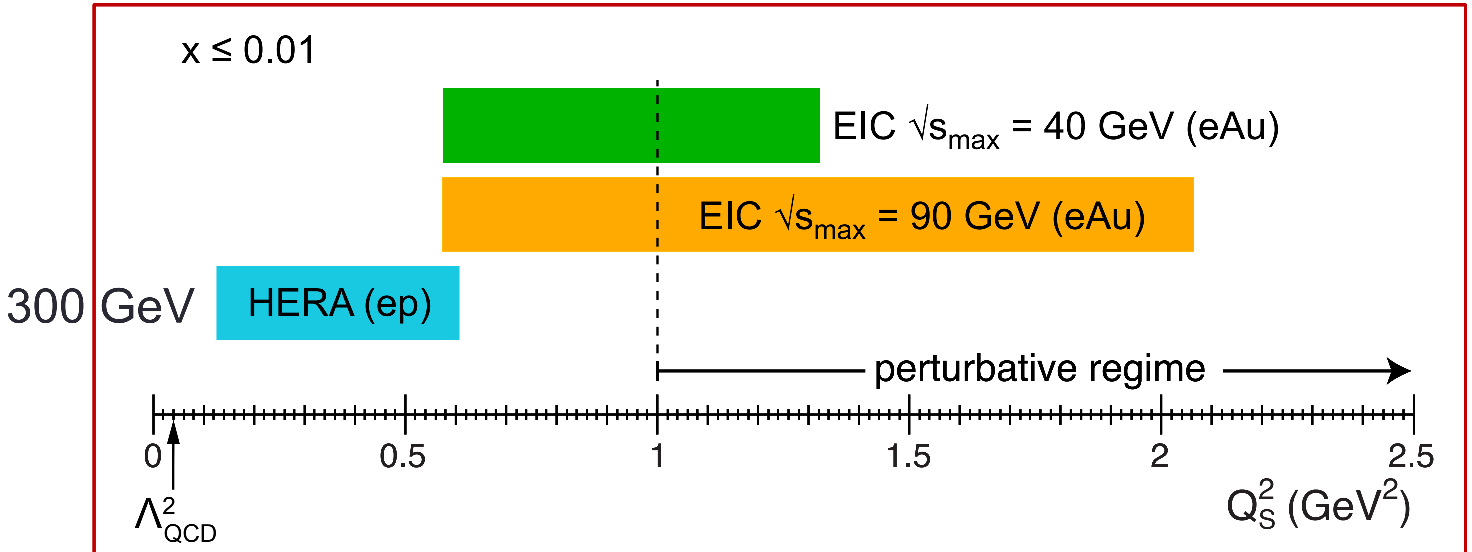




$$(Q_s^A)^2 \approx c Q_0^2 \left[\frac{A}{x}\right]^{1/3}$$

$L \sim (2m_N x)^{-1} > 2 R_A \sim A^{1/3}$

Accessible range of saturation scale $Q_s{}^2$ at the EIC with e+A collisions. arXiv:1708.01527



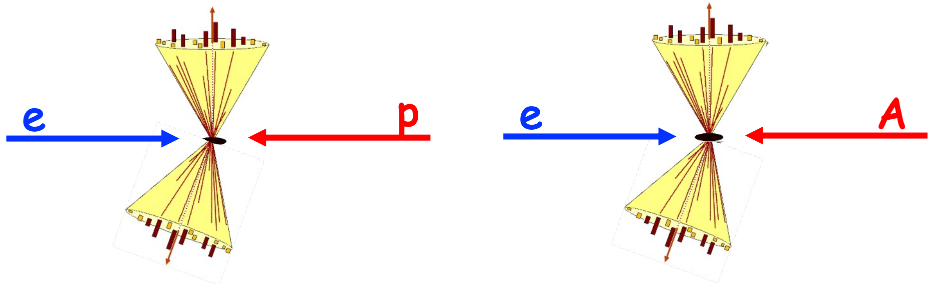
Can EIC discover a new state of matter?

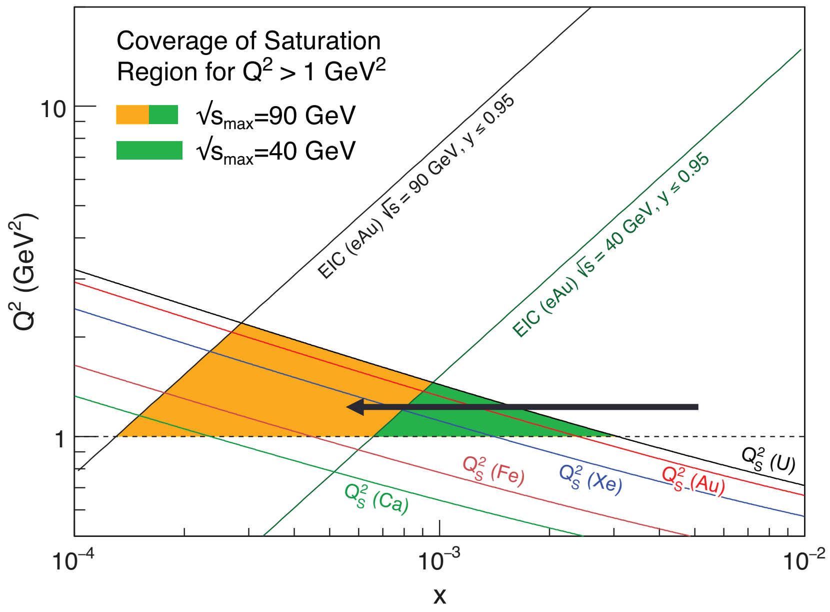
EIC provides an absolutely unique opportunity to have very high gluon densities
→ electron – lead collisions
combined with an unambiguous observable

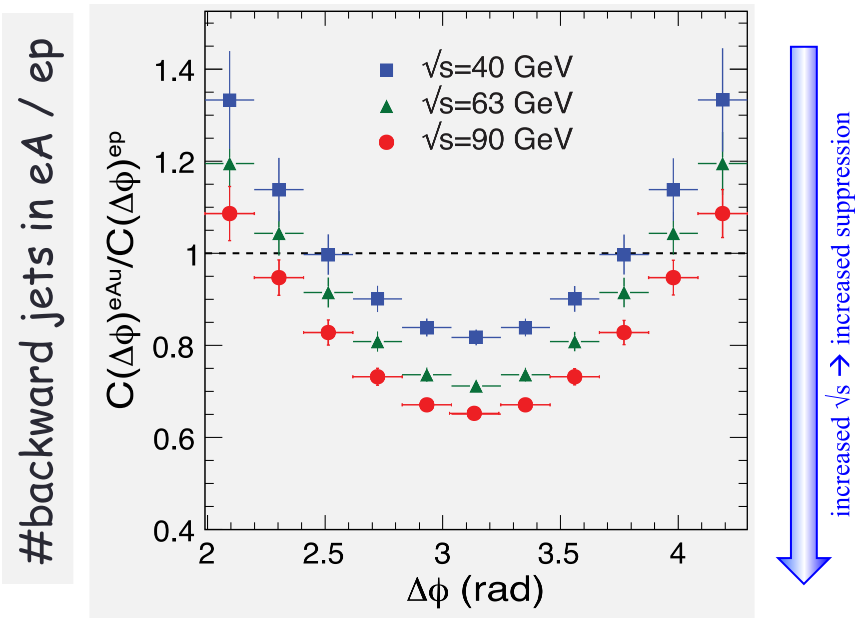
EIC will allow to unambiguously map the transition from a non-saturated to saturated regime

counting experiment of Di-jets in ep and eA

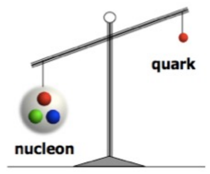
Saturation: Disappearance of backward jet in eA







Mass of the Nucleon (Pion & Kaon)



"The mass is the result of the equilibrium reached through dynamical processes." **X. Ji**

"… The vast majority of the nucleon's mass is due to quantum fluctuations of quark-antiquark pairs, the gluons, and the energy associated with quarks moving around at close to the speed of light. …"
-- The 2015 Long Range Plan for Nuclear Science

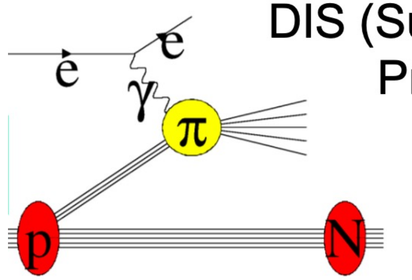
Relativistic Motion | ***Chiral Symmetry Breaking*** | ***Quantum Fluctuations***

X. Ji, PRL 74 1071 (1995)

$$M = E_q + E_g + \chi_{m_q} + T_g$$

Quark Energy | **Gluon Energy** | **Quark Mass** | **Trace Anomaly**

DIS (Sullivan Process)



(pion/Kaon) PDFs: P. C. Barry et al. PRL 127, 232001 (2021)

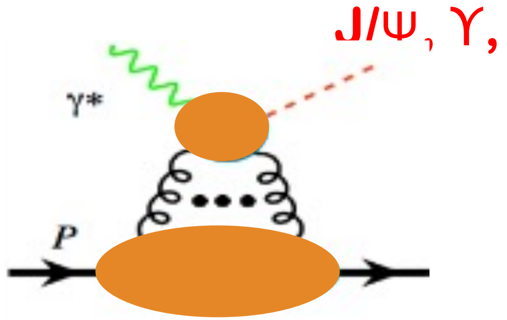
- Criticisms: not scale-invariant, decompositions: Lorentz invariant vs. rest frame
- Recent interest (workshops) planned: how to determine the different contributions
- **Lattice QCD providing estimates**

E_q ~30% E_g ~40% χ_{m_q} ~10% T_g ~ 25%

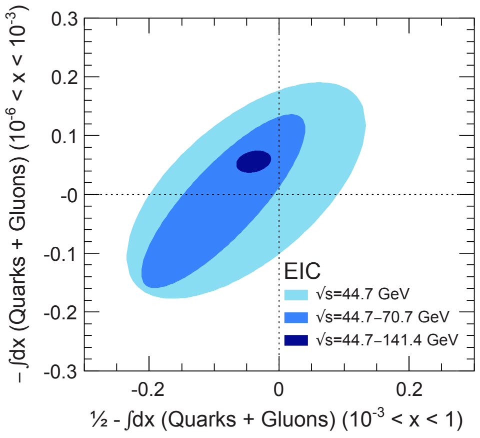
arXiv: 1710.09011

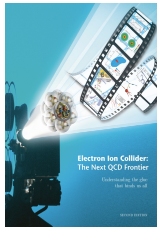
Trace anomaly:
Upsilon production
near threshold:

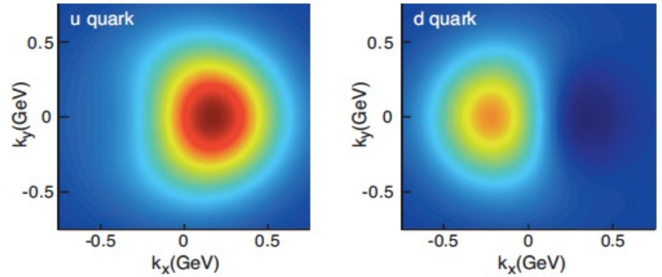
SoLID@JLab & EIC

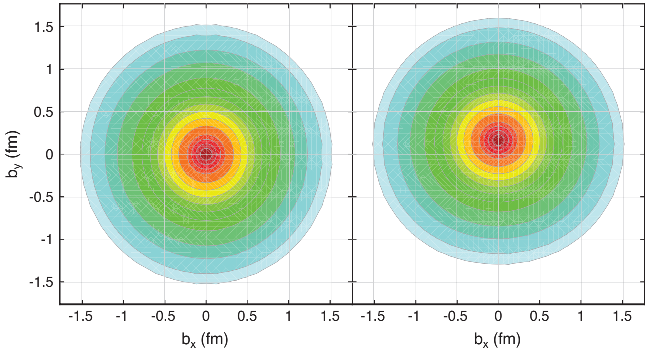


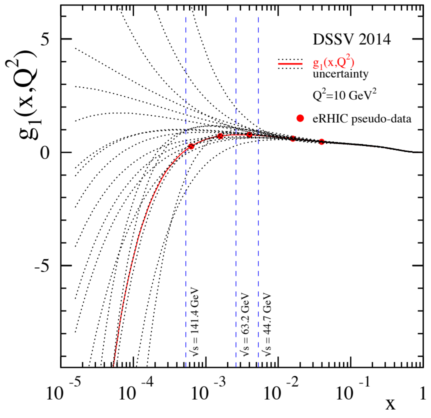
EIC science highlights

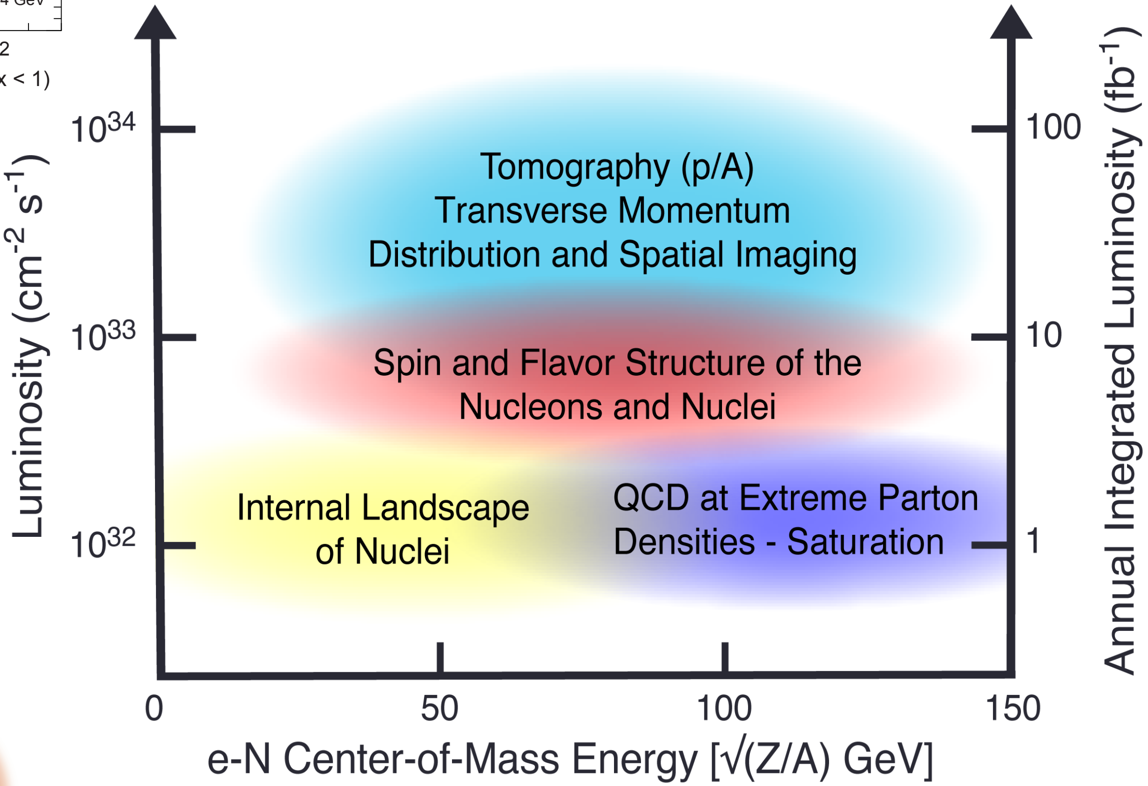


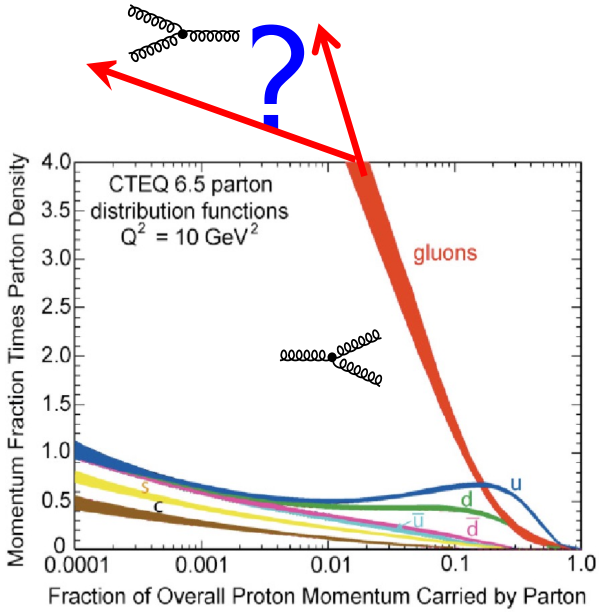


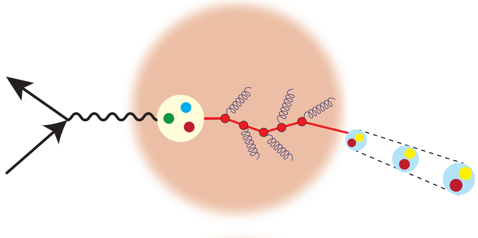












THE EIC PROJECT

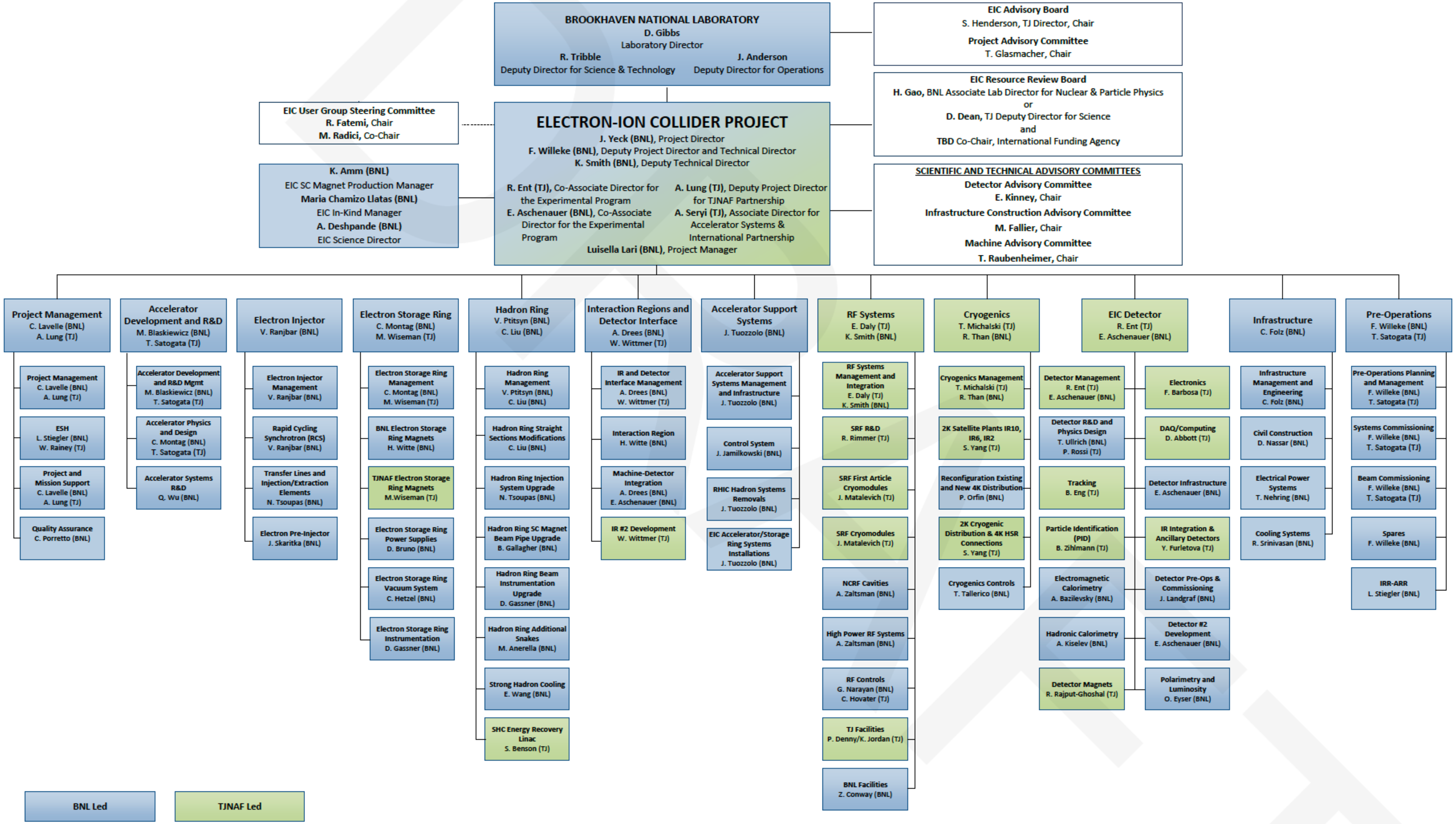
Partnership between BNL and Jefferson Lab

Includes, the accelerator, one IR, most of one detector

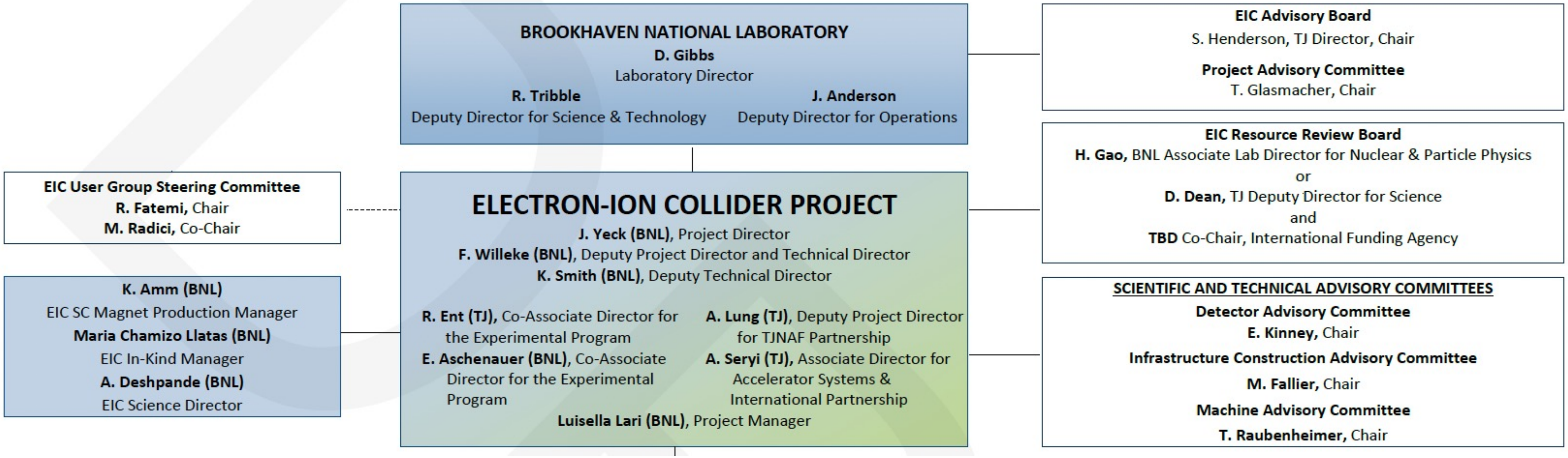
- Talks by Ferdinand Willeke & John Lajoie

Responsible for not-negating the 2nd IR – early studies of feasibility

EIC Project Organization

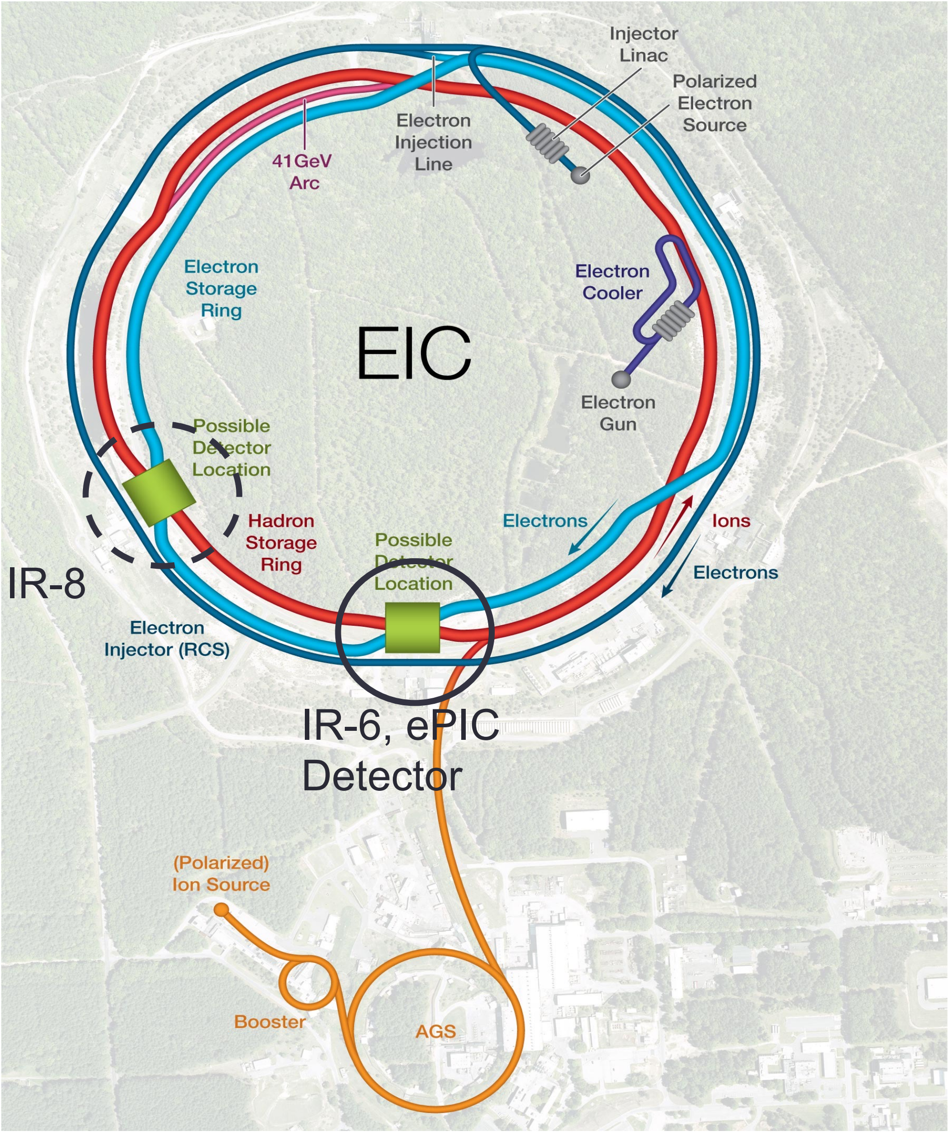


EIC Project – BNL/JLab, Boards, Advisory Committees

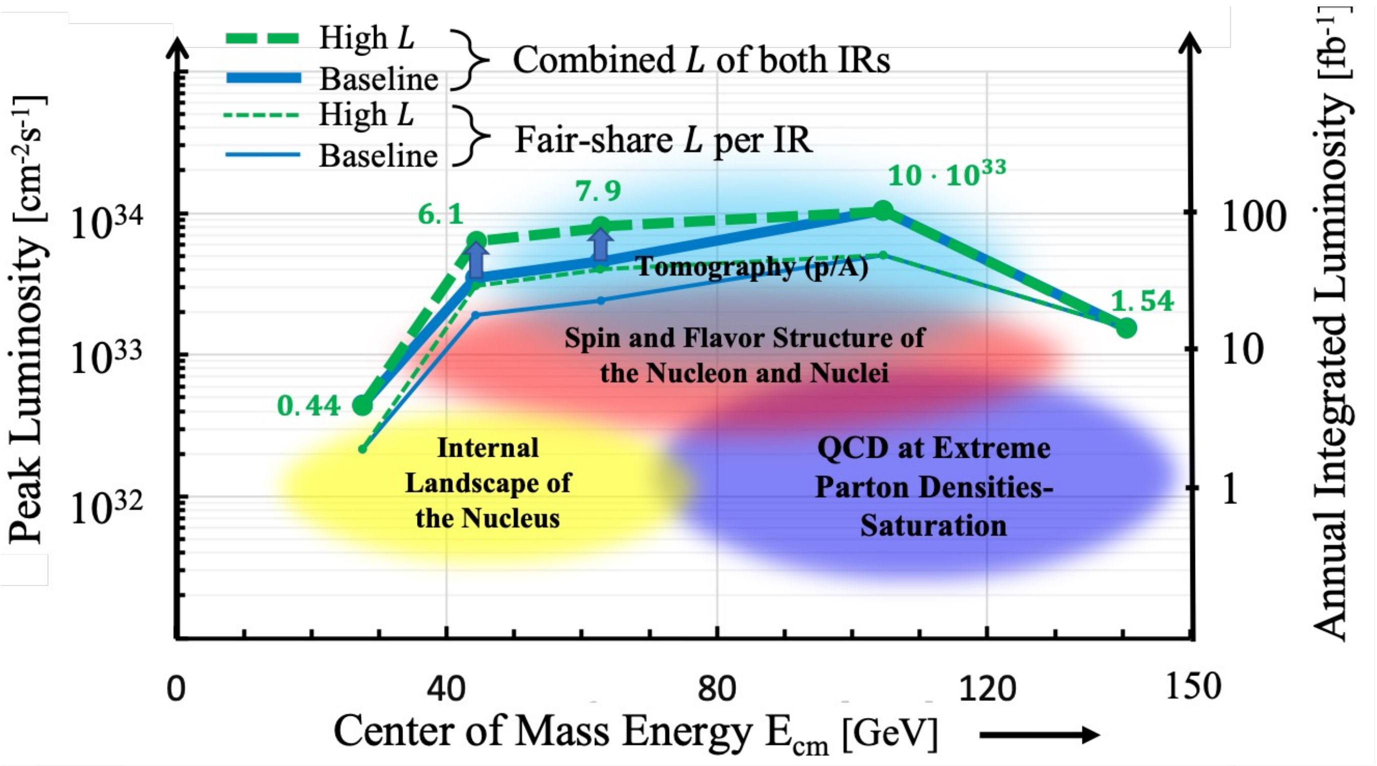


- DOE, together with BNL and JLab, envision an EIC facility that is “fully international in character.”
- EIC Advisory Board provides oversight and advice on the construction of the facility, focusing on the accelerator (BNL, TJNAF, LBNL, ANL, TRIUMF, IN2P3, CEA, STFC, INFN).
- EIC Project Advisory Committee provides advice on the successful delivery of the DOE Project (management, scope, schedule, cost, and performance).
- EIC Resource Review Board (RRB) to provide oversight of the experiments.

EIC Accelerator Design



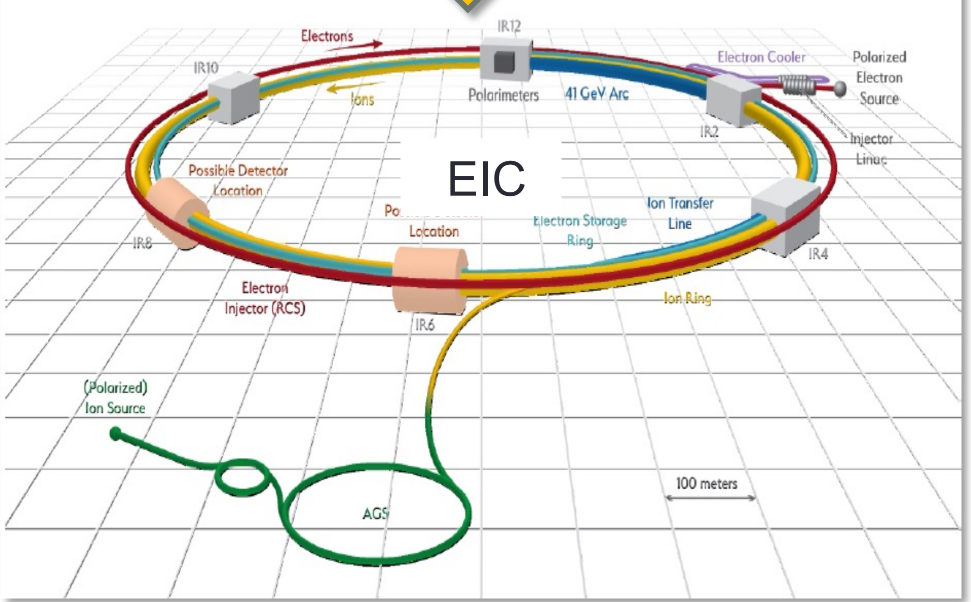
Center of Mass Energies:	20GeV - 140GeV
Luminosity:	10^{33} - 10^{34} $cm^{-2}s^{-1}$ / 10-100fb^{-1} / year
Highly Polarized Beams:	70%
Large Ion Species Range:	p to U
Number of Interaction Regions:	Up to 2!



EIC Accelerator Design Overview

- **Hadron storage ring (HSR): 41-275 GeV** (**based on RHIC**)
  - up to 1160 bunches, 1A beam current (3x RHIC)
  - bright vertical beam emittance (1.5 nm)
  - strong cooling (coherent electron cooling, ERL)
- **Electron storage ring (ESR): 2.5–18 GeV** (**new**)
  - up to 1160 polarized bunches
    - high polarization by continual reinjection from RCS
  - large beam current (2.5 A) ➔ 9 MW SR power
  - superconducting RF cavities
- **Rapid cycling synchrotron (RCS): 0.4-18 GeV** (**new**)
  - 2 bunches at 1 Hz; spin transparent due to high periodicity
- **High luminosity interaction region(s)** (**new**)
  - $L = 10^{34}\ cm^{-2}s^{-1}$
  - superconducting magnets
  - 25 mrad crossing angle with crab cavities
  - spin rotators (produce longitudinal spin at IP)

Ferdinand Willeke's talk



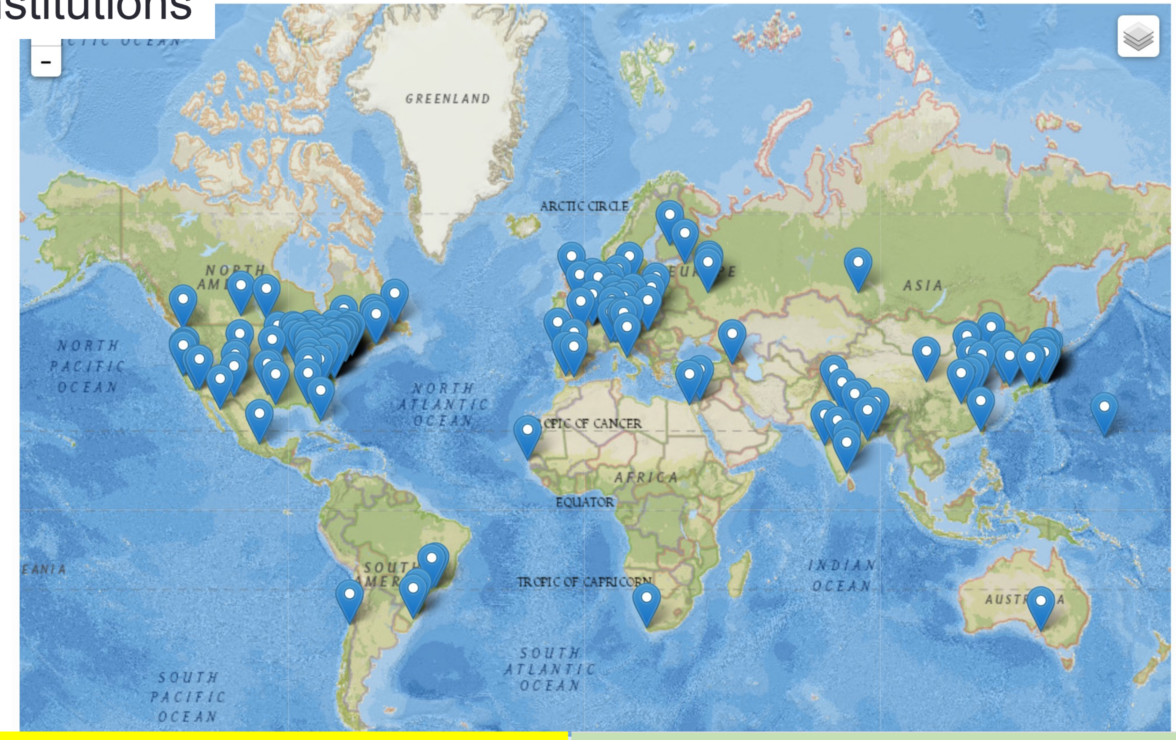
EIC USERS, DETECTOR DESIGN & DETECTOR COLLABORATION

For talk on the Detector: See (also) talk by John Lajoie

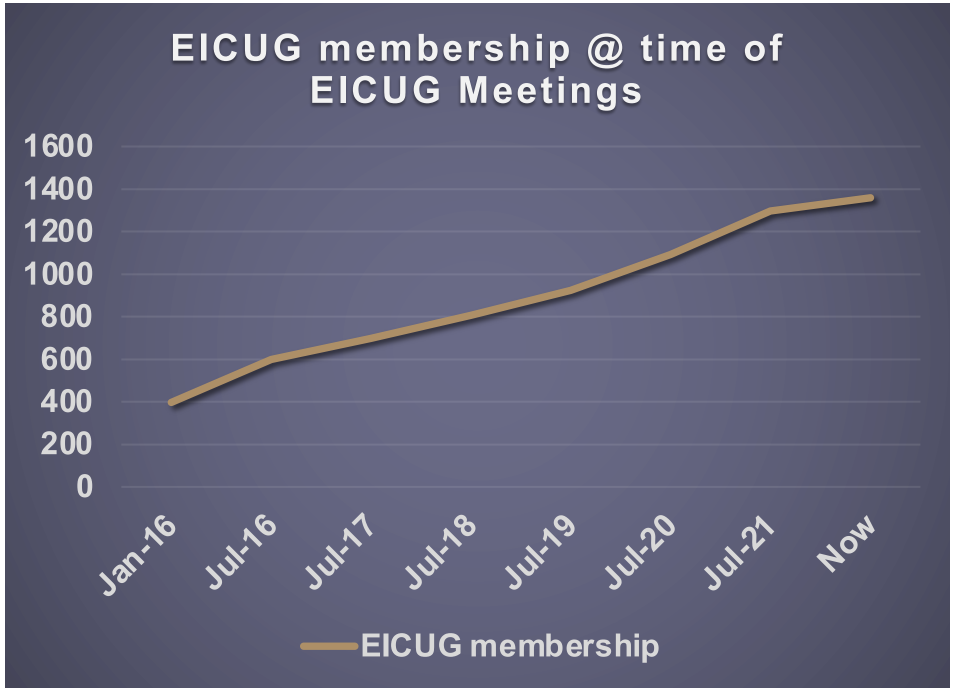
The EIC User Group: https://eicug.github.io/

Formed in 2016, Currently:
- **1369 collaborators,**
- **36 countries,**
- **267 institutions**

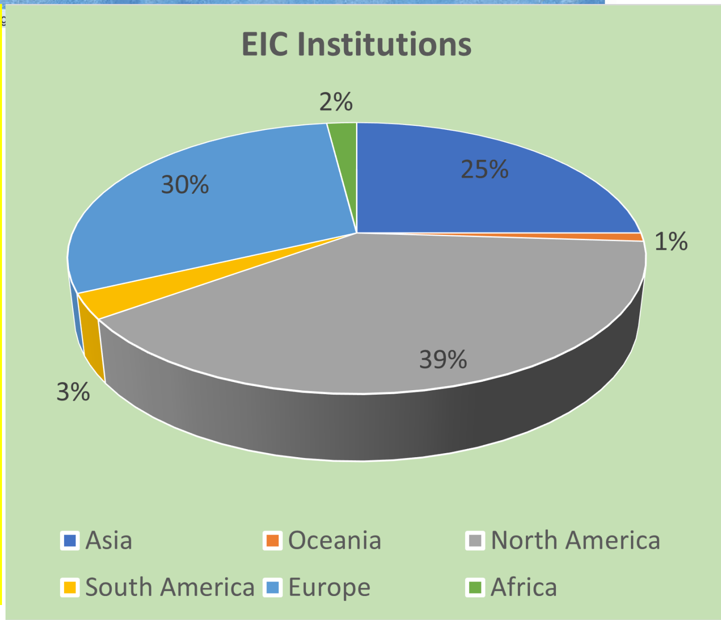
Institutions



International Participation Growing



Annual EICUG meeting
2016 UC Berkeley, CA
2016 Argonne, IL
2017 Trieste, Italy
2018 CUA, Washington, DC
2019 Paris, France
2020 Miami, FL
2021 VUU, VA & UCR, CA
2022 Stony Brook U, NY
2023 Warsaw, Poland



Perhaps other intersections with LQCD?

Physics @ the US EIC beyond the EIC's core science

Of HEP/LHC-HI interest to Snowmass 2021 (EF 05, 06, and 07 and possibly also EF 04)

New Studies with proton or neutron target:

- Impact of precision measurements of unpolarized PDFs at high x/Q^2, on LHC-Upgrade results(?)
- Precision calculation of α_S : higher order pQCD calculations, twist 3
- Heavy quark and quarkonia (c, b quarks) studies with **100-1000 times lumi of HERA and with polarization**
- Polarized light nuclei in the EIC

Physics with nucleons and nuclear targets:

- Quark Exotica: 4,5,6 quark systems…? Much interest after recent **LHCb** led results.
- Physic of and with jets with EIC as a precision QCD machine:
  - Jets as probe of nuclear matter & Internal structure of jets : novel new observables, energy variability
  - Entanglement, entropy, connections to fragmentation, hadronization and confinement

Precision electroweak and BSM physics:

- Electroweak physics & searches beyond the SM: Parity, charge symmetry, lepton flavor violation
- LHC-EIC Synergies & complementarity

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

EIC Science from the perspective of High Energy Physicists

arXiv:2203.13199v1 [hep-ph] 24 March 2022

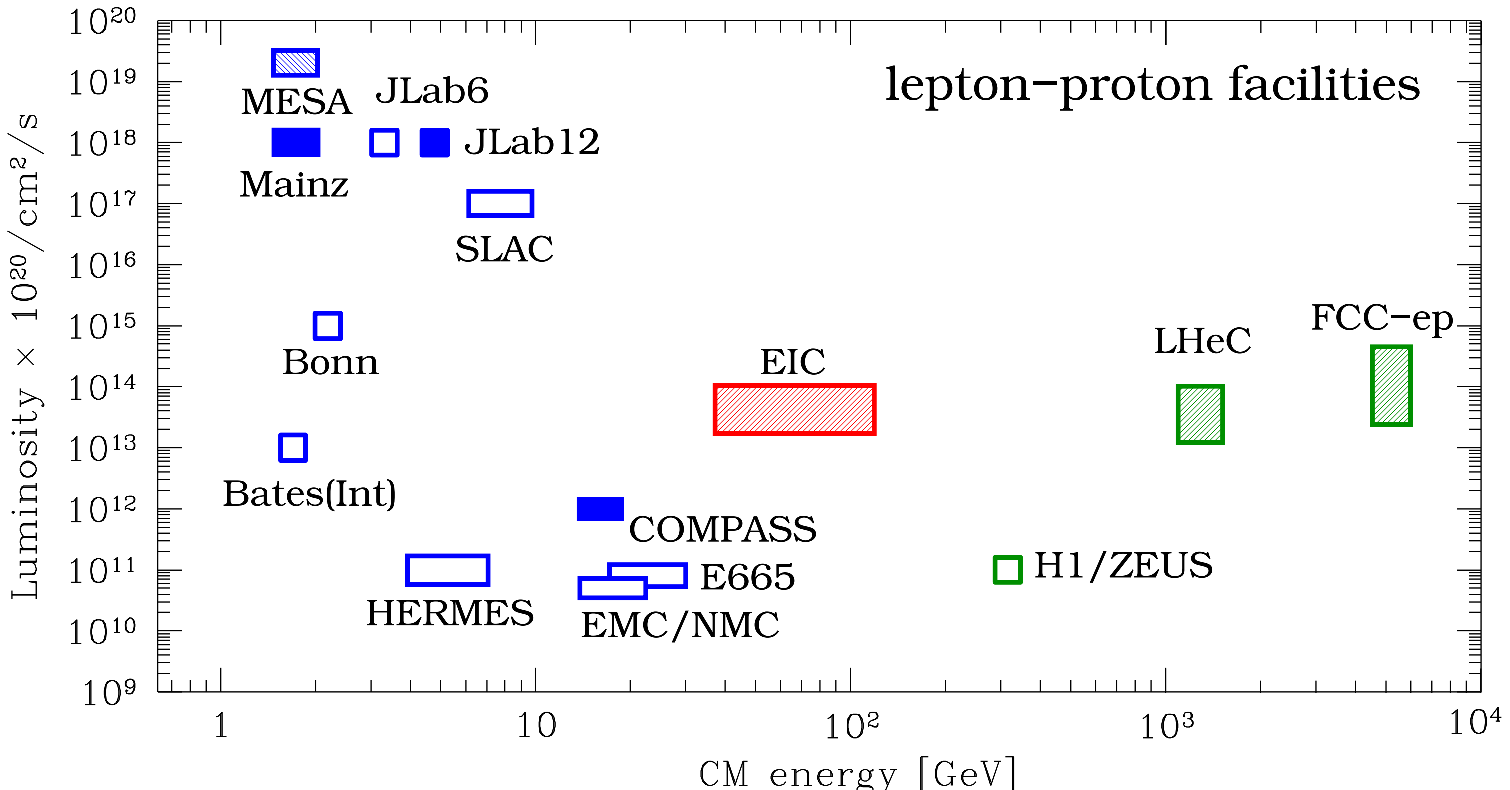
Snowmass 2021 White Paper: Electron Ion Collider for High Energy Physics

R. Abdul Khalek,[1] U. D'Alesio,[2,3] Miguel Arratia,[4,5,*] A. Bacchetta,[6] M. Battaglieri,[7,1] M. Begel,[8] M. Boglione,[9] R. Boughezal,[10] Renaud Boussarie,[11,*] G. Bozzi,[12,3] S. V. Chekanov,[10] F. G. Celiberto,[13,14,15] G. Chirilli,[16] T. Cridge,[17] R. Cruz-Torres,[18] R. Corliss,[19,20] C. Cotton,[21] H. Davoudiasl,[8] A. Deshpande,[8,19] Xin Dong,[18,*] A. Emmert,[21] S. Fazio,[8] S. Forte,[22] Yulia Furletova,[1,*] Ciprian Gal,[23,20,*] Claire Gwenlan,[24,*] V. Guzey,[25] L. A. Harland-Lang,[26] I. Helenius,[27,28] M. Hentschinski,[29] Timothy J. Hobbs,[30,31,*] S. Höche,[32] T.-J. Hou,[33] Y. Ji,[18] X. Jing,[34] M. Kelsey,[35,18] M. Klasen,[36] Zhong-Bo Kang,[37,38,20,*] Y. V. Kovchegov,[39] K.S. Kumar,[40] Tuomas Lappi,[27,28,*] K. Lee,[41,42] Yen-Jie Lee,[43,44,*] H.-T. Li,[45,46,47] X. Li,[48] H.-W. Lin,[49] H. Liu,[40] Z. L. Liu,[50] S. Liuti,[21] C. Lorcé,[51] E. Lunghi,[52] R. Marcarelli,[53] S. Magill,[54] Y. Makris,[55] S. Mantry,[56] W. Melnitchouk,[1] C. Mezrag,[57] S. Moch,[58] H. Moutarde,[57] Swagato Mukherjee,[8,†] F. Murgia,[3] B. Nachman,[59,60] P. M. Nadolsky,[61] J.D. Nam,[62] D. Neill,[63] E.T. Neill,[53] E. Nocera,[64] M. Nycz,[21] F. Olness,[61] F. Petriello,[46,47] D. Pitonyak,[65] S. Plätzer,[66] Stefan Prestel,[67,*] Alexei Prokudin,[68,1,*] J. Qiu,[1] M. Radici,[6] S. Radhakrishnan,[69,18] A. Sadofyev,[70] J. Rojo,[71,72] F. Ringer,[73,19] Farid Salazar,[37,38,74,75,*] N. Sato,[1] Björn Schenke,[8,*] Sören Schlichting,[76,*] P. Schweitzer,[77] S. J. Sekula,[78,*] D. Y. Shao,[79] N. Sherrill,[80] E. Sichtermann,[18] A. Signori,[6] K. Şimşek,[81] A. Simonelli,[9] P. Sznajder,[82] K. Tezgin,[83] R. S. Thorne,[17] A. Tricoli,[8] R. Venugopalan,[8] A. Vladimirov,[84] Alessandro Vicini,[22,*] Ivan Vitev,[85,*] D. Wiegand,[86] C.-P. Wong,[48] K. Xie,[87] M. Zaccheddu,[2,3] Y. Zhao,[88] J. Zhang,[89] X. Zheng,[21] and P. Zurita[84]

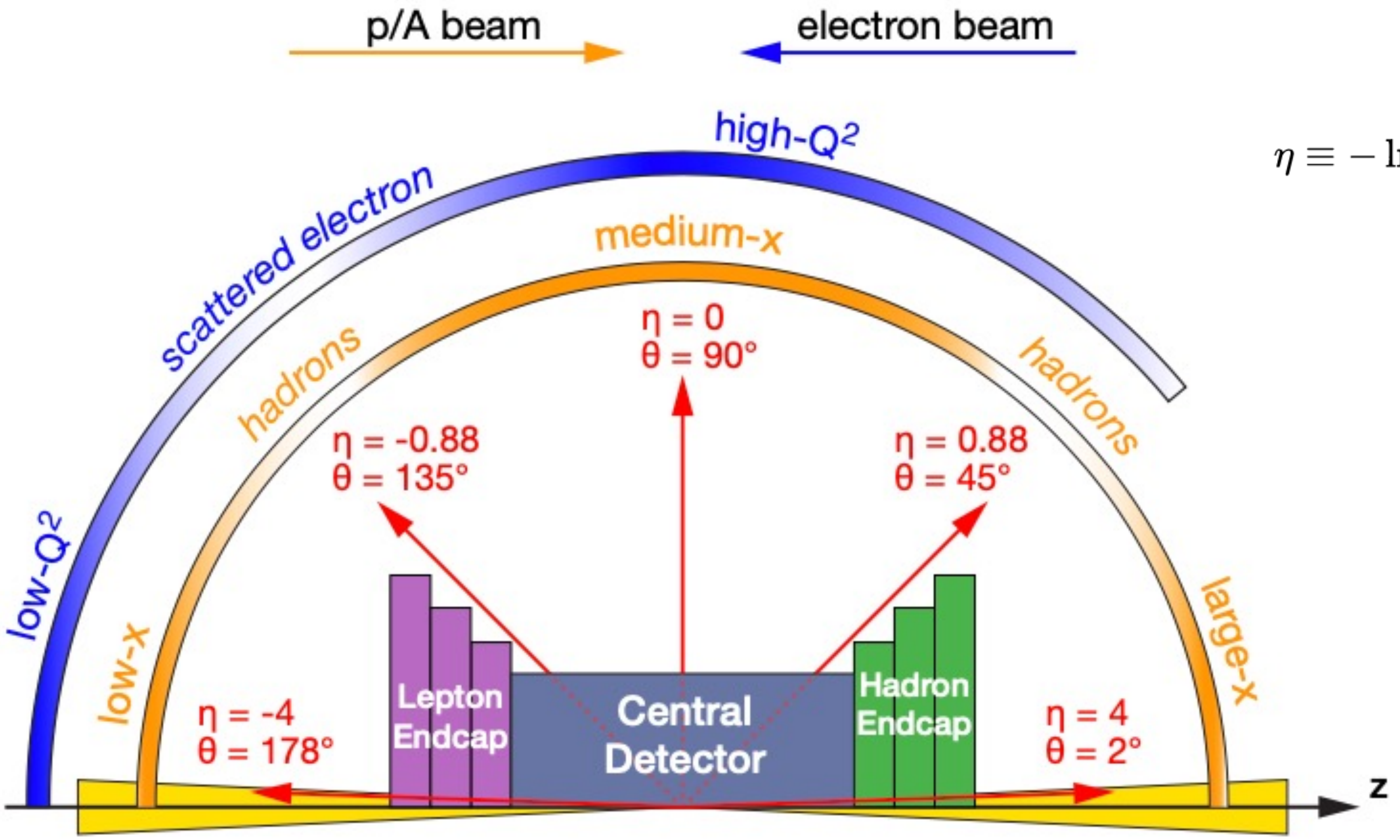
EIC's versatility, resolving power and intensity (luminosity) open new windows of opportunity to address some of the crucial and fundamental scientific questions in particle physics. The paper summarizes the EIC physics from the perspective of the HEP community participating in Snowmass 2021

- Beyond the Standard Model Physics at the EIC
- Tomography (1,3,5 d PDFs) of Hadrons and Nuclei at the EIC
- Jets at EIC
- Heavy Flavors at EIC
- Small-x Physics at the EIC

- High luminosity wide CM range
- Polarized e, p, and ion beams
- All nuclei

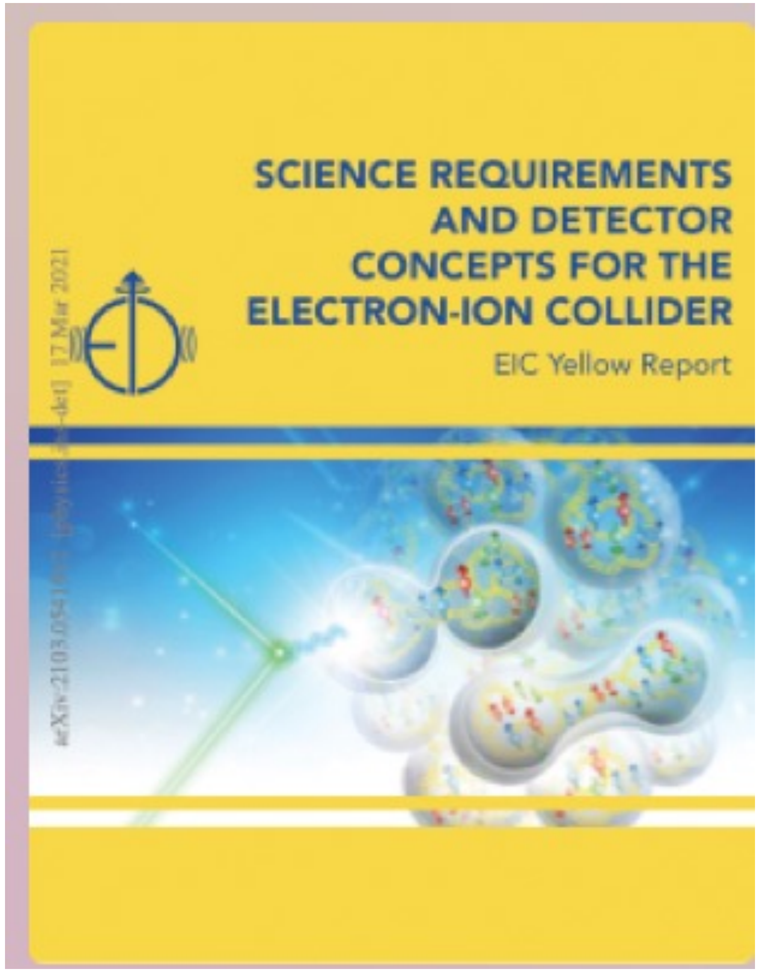


Detector polar angle / pseudo-rapidity coverage



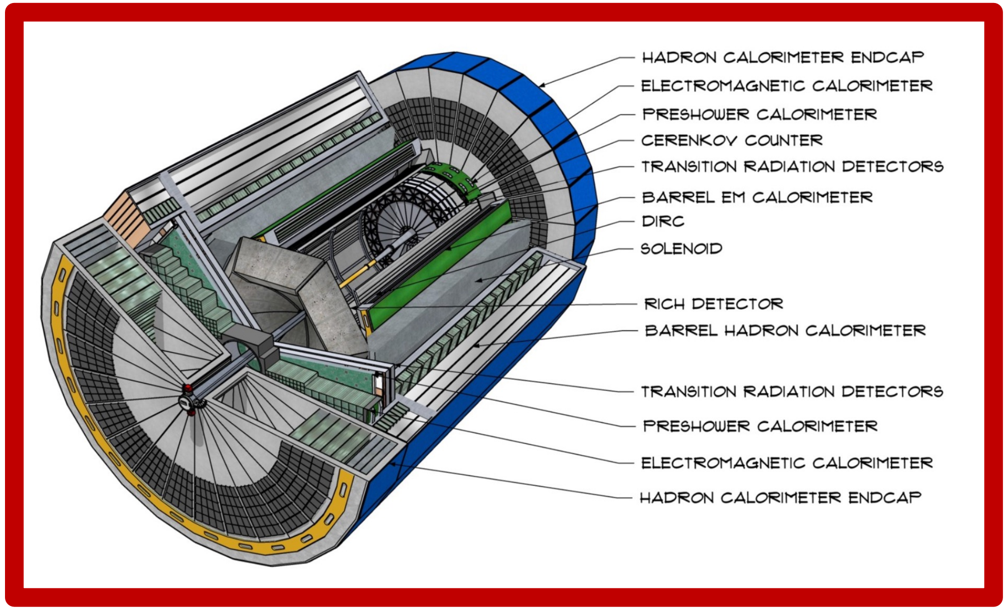
$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right],$$

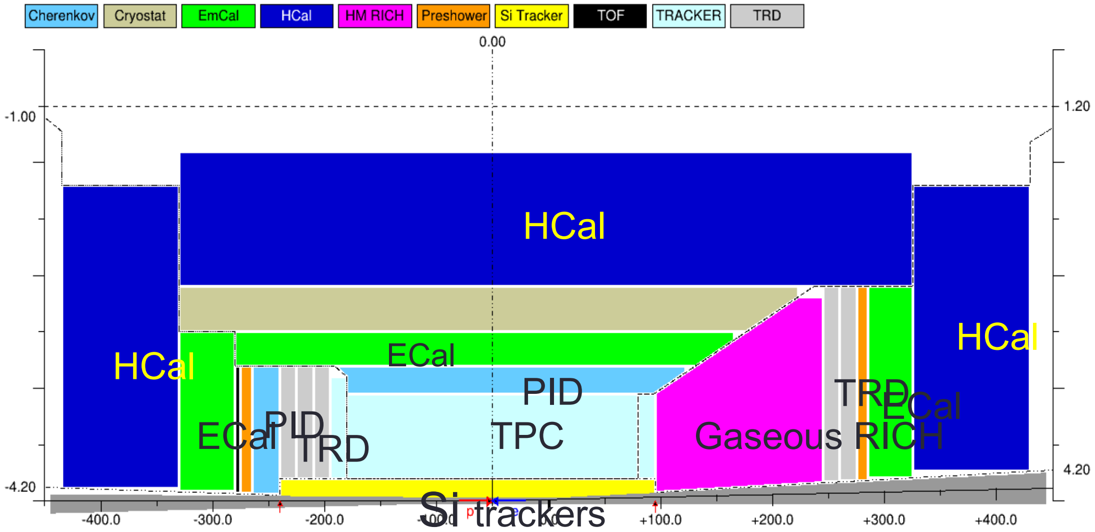
EICUG led “reference” detector design
2019-2021 “Yellow Report”



902 pages
415 authors
151 institutions

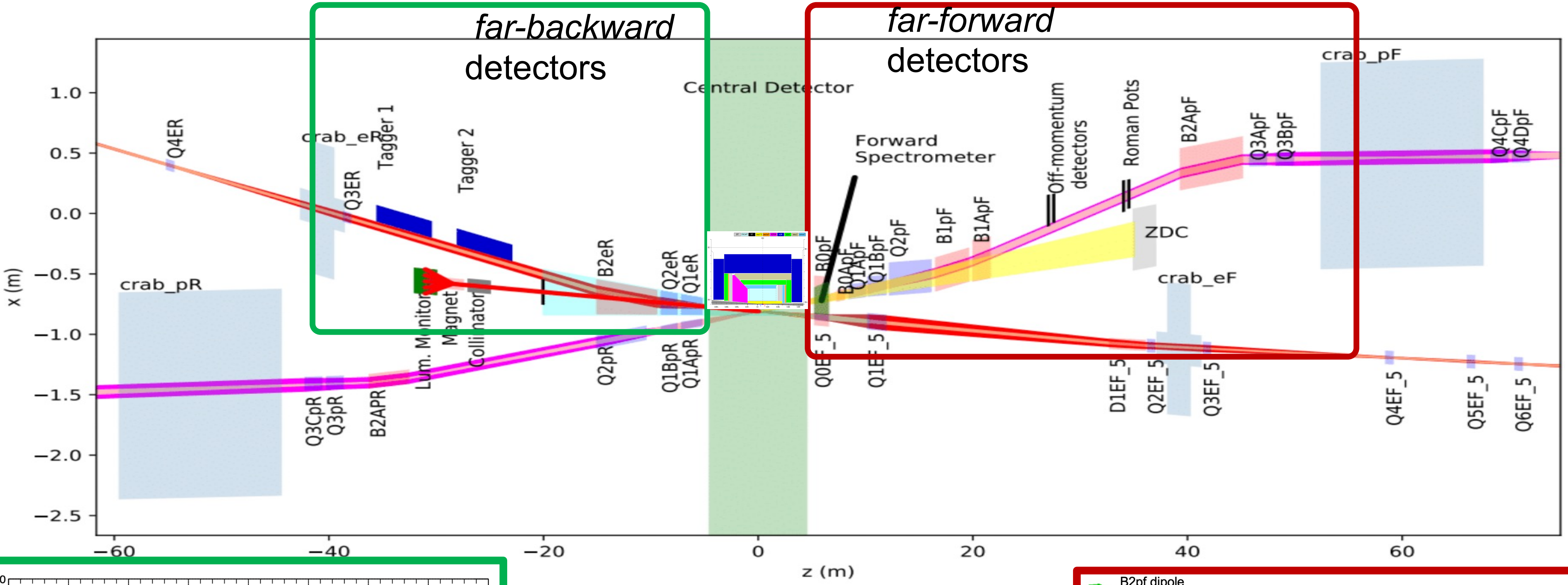
120 MB

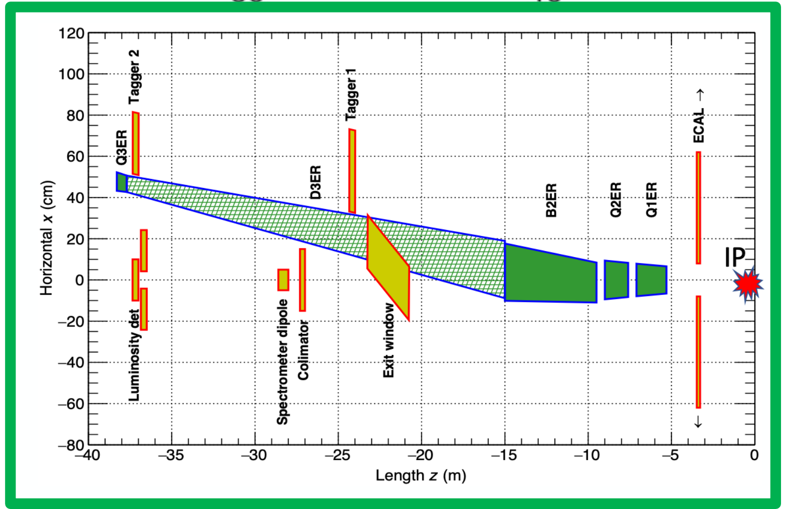




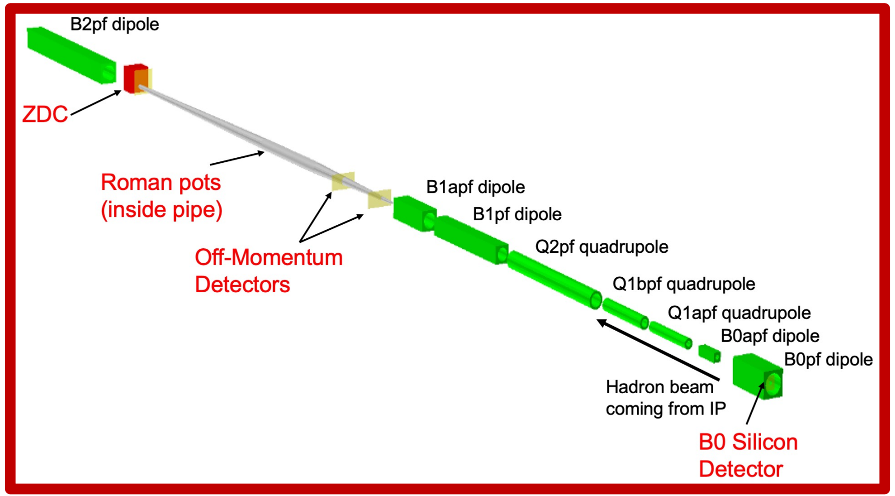
Nucl. Phys. A 1026 (2022) ; arXiv:2103.05419

Reference Detector – Backward/Forward Detectors



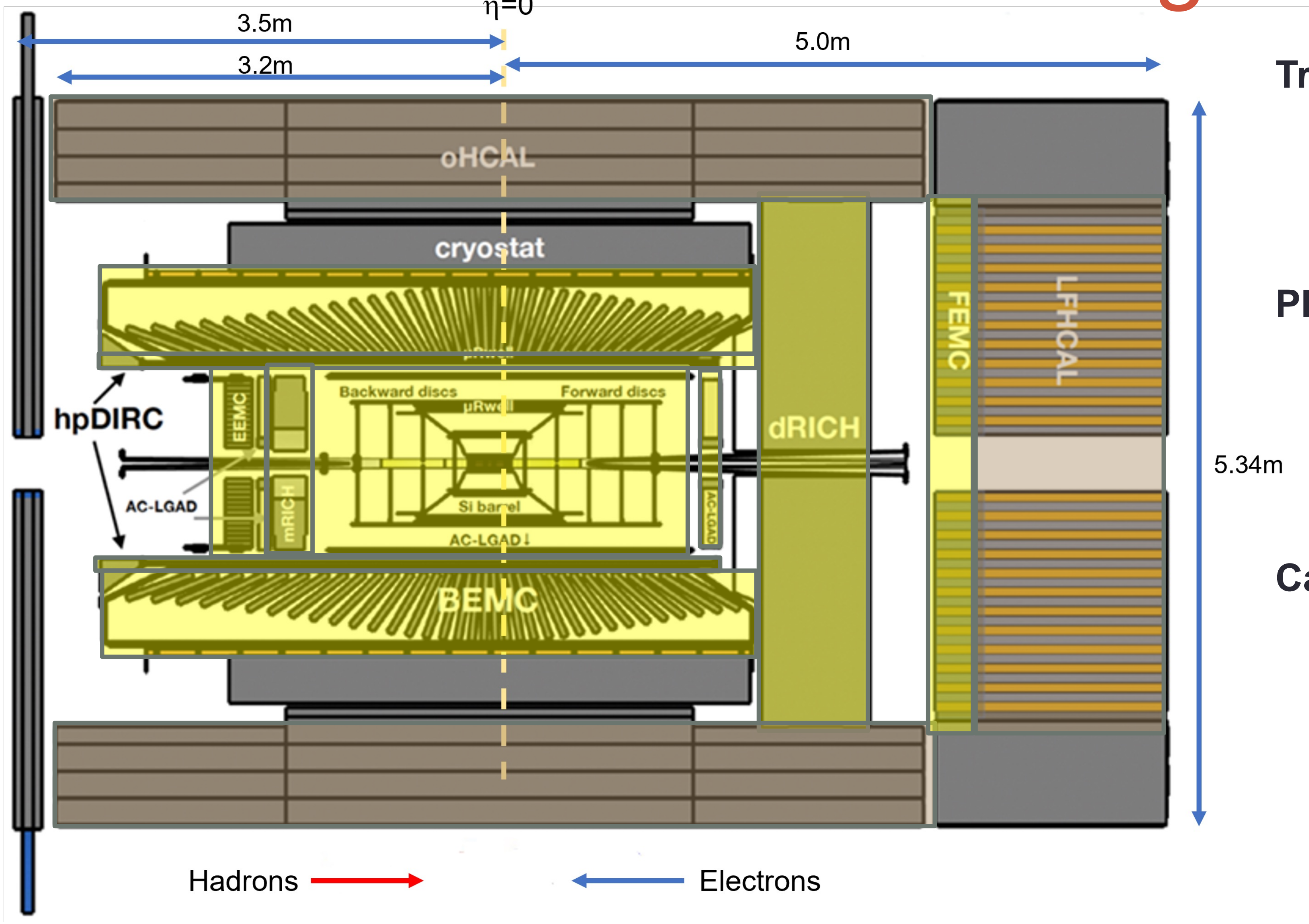


Extensive integration of forward and backward detector elements into the accelerator lattice



ePIC Detector Current Design

More in John Lajoie's talk



From John Lajoie

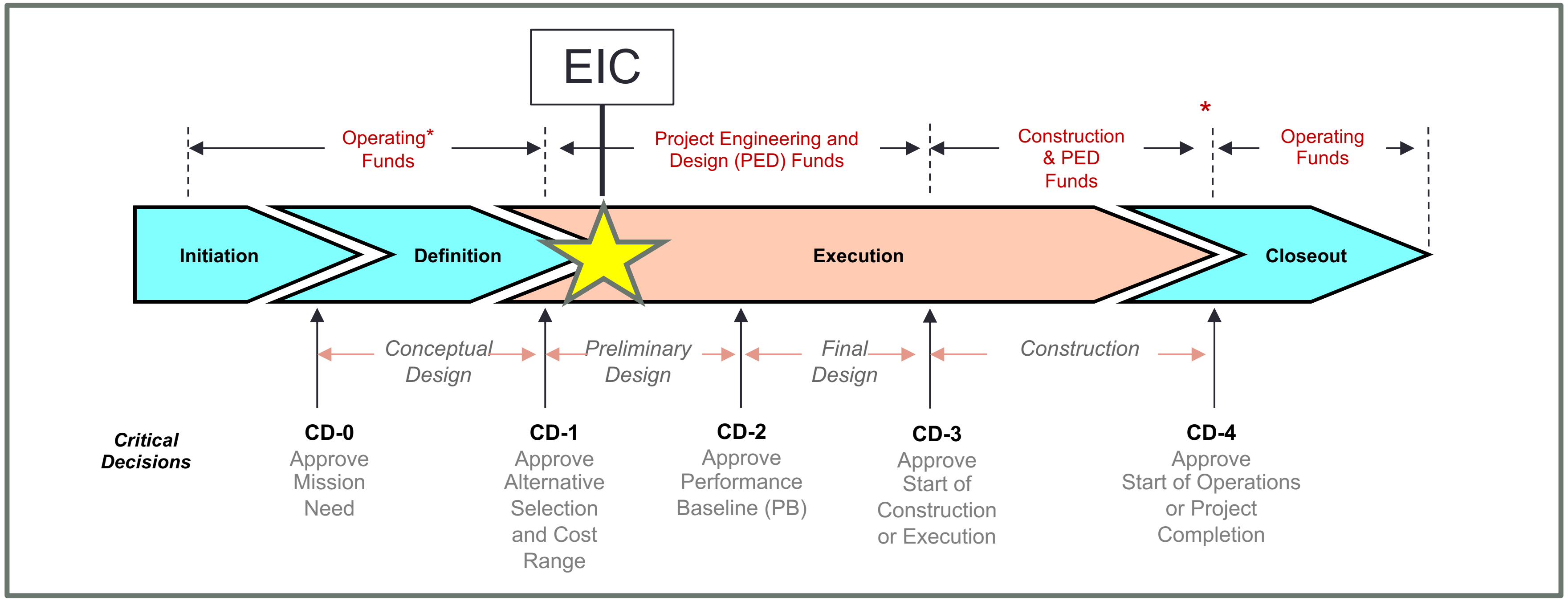
Tracking:
- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (µRWELL/µMegas)

PID:
- hpDIRC
- mRICH/pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry:
- SciGlass/Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)

REALIZATION TIMELINE & OPPORTUNITIES

DOE Project Phases



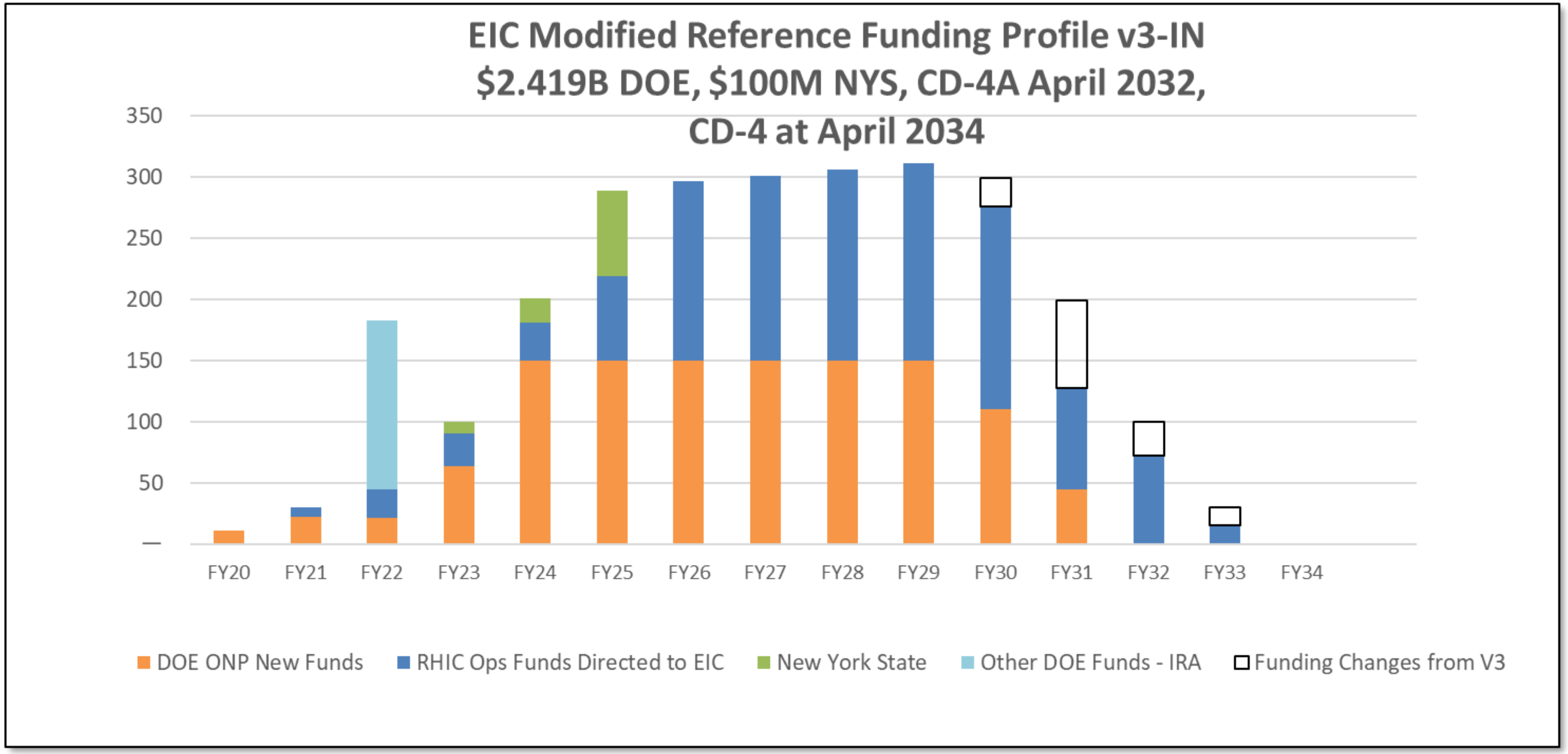
Formal Process of DOE Gateway Reviews

- CD-0, Mission Need ✓
- CD-1, Alternative Selection and Cost Range ✓

Partner and collaboration engagement needed to establish the baseline

- CD-2, Performance Baseline
- CD-3a, Long Lead Procurement

DOE Funding Plan



- **Inflation Reduction Act funding of $138.24M** is a game changer and mitigates risk of slower than optimum ramp of new funding to the $150M/year needed.
- Possibility of significant package of long lead procurement items (CD-3A) helping to mitigate risks including procurement, supply chain, inflation and schedule.

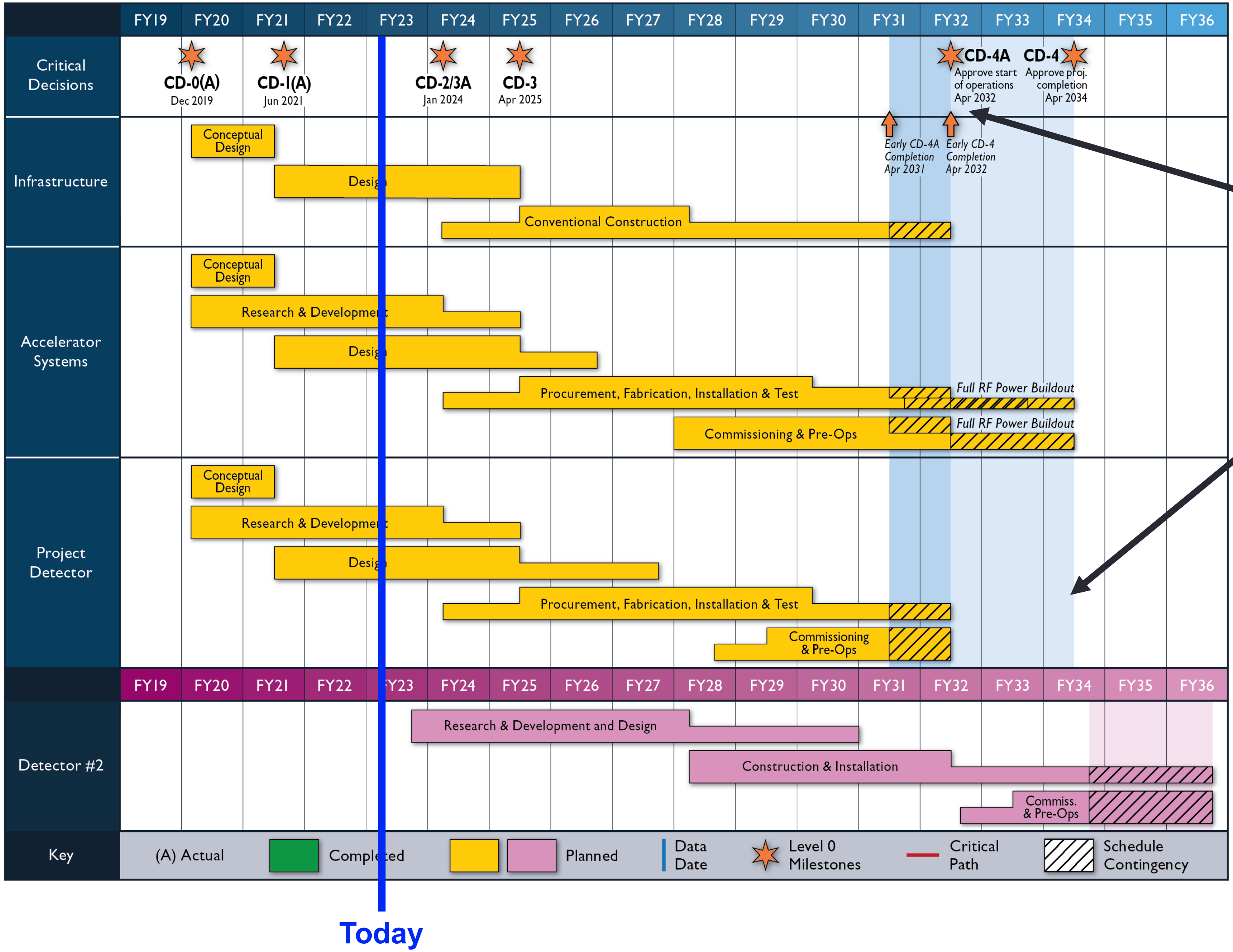
EIC Project – Path to CD-2/3A and CD-3

- ✓ DOE OPA Status Review (Remote) October 19-21, 2021(A)
- ✓ Funding Discussion at DOE ONP (In-Person) April 26, 2022 (A)
- ✓ FPD Status Update at BNL (Hybrid) June 28-30, 2022 (A)
- ✓ Cost and Schedule Scrutiny Meetings July - September 2022
- Project Detector Meetings 2022
  - *Technical Subsystem Reviews* *Feb. – Dec. 2022*
  - ✓ *Pre-Resource Review Board Kickoff Meeting* *October 2022*
- DOE OPA Status Review - Confirm CD-2/3A PlansJan. 31 – Feb. 2, 2023
- Preliminary Design and Director's Reviews June 2023
- DOE CD 2/3A OPA Review and ICR, requires pre-TDR October 2023
- DOE CD 2/3A ESAAB Approval January 2024

- DOE CD 3 OPA Review, requires TDR ~January 2025
- DOE CD 3 ESAAB Approval ~April 2025

OPA = Office of Project Assessment
FPD = Federal Project Director
ICR = Independent Cost Review
ESAAB = Energy Systems Acquisition Advisory Board
TDR = Technical Design Report

Overall Schedule



CD4A early finish, collisions begin for machine tuning
Detector 1 needs to be ready to give feedback.

CD4 Machine delivers for physics
Detector 1 should be fully functional to start physics

2nd Detector and IR

- Current assumption realization trailing ~ 5 years behind Detector-1
- focus on complementary IR/physics & technologies

EIC Partnerships

- EIC is planned to be an international project
  - Collaboration on EIC design and construction –mutually beneficial, advancing accelerator science and technology and providing a gateway to EIC science
- Contributions to the accelerator could include full range of accelerator design & hardware
  - Examples: IR magnet design and construction, luminosity monitoring, RF R&D and construction, normal conducting magnets, critical vacuum components, feedback systems, polarimetry, contributions to the 2^{nd} IR, beam-dynamics calculations, etc.
- Detector: International collaboration, with substantial contribution from partners
  - Detailed contributions to EPIC *now under discussions* with EIC management
  - High level contacts between US DOE and international funding agencies: welcome

International Boards

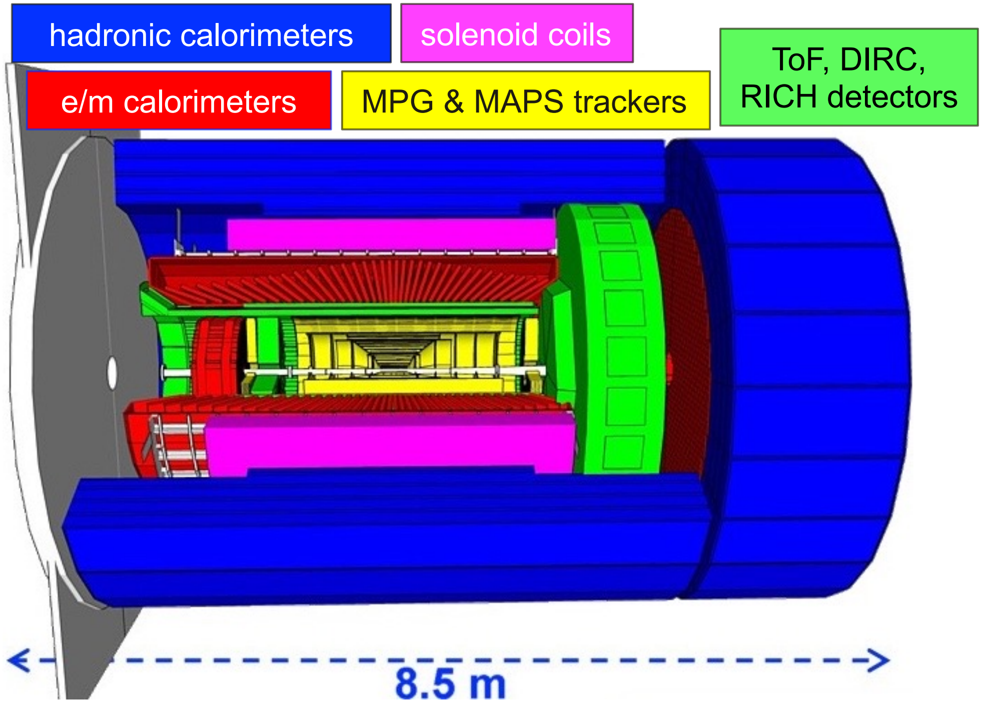
- EIC Advisory Board
  - Includes leaders of international and domestic partner institutions
  - BNL Director welcoming new members interested in contributing to the EIC accelerator facility
- Resource Review Board (RRB) for the EIC experiments
  - Similar to the LHC RRBs, includes funding agency reps
  - EIC RRB pre-planning meeting October 12-13, 2022
  - 1st EIC RRB meeting is April 3-4, 2023
  - ePIC collaboration is forming now

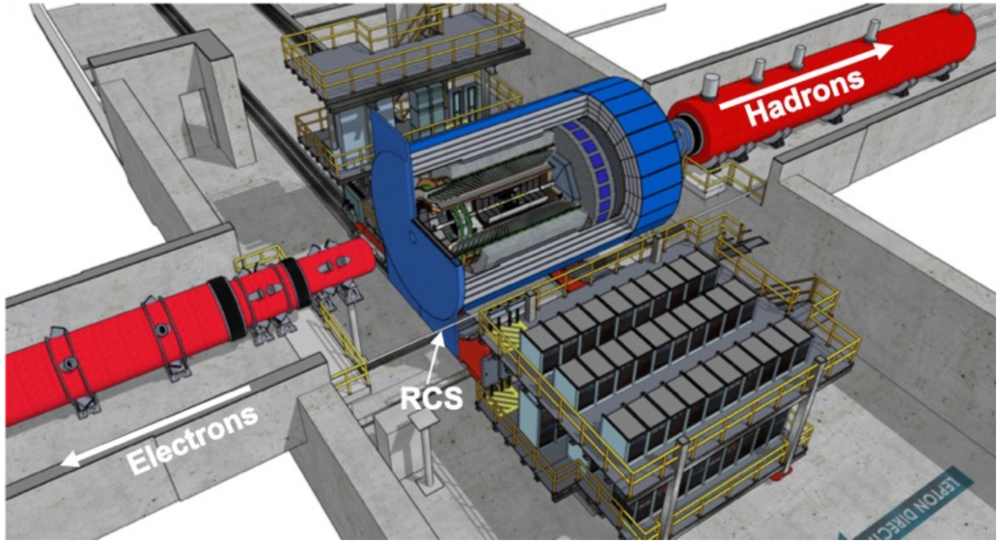

Low x behavior of $g_1(p)$
Regge Extrapolation
Polarized HERA and nuclei in HERA
DeRoeck, Deshpande, Hughes, McLerran, Strikman
1996-1999
The National Academies of SCIENCES · ENGINEERING · MEDICINE
CONSENSUS STUDY REPORT
AN ASSESSMENT OF U.S.-BASED ELECTRON-ION COLLIDER SCIENCE
BROOKHAVEN NATIONAL LABORATORY
Electron-Ion Collider eRHIC at Brookhaven National Laboratory
Pre-Conceptual Design Report
2019
eRHIC
RHIC
AGS
Detector Location
Storage Ring
Electron Cooler
Linac
SCIENCE REQUIREMENTS AND DETECTOR CONCEPTS FOR THE ELECTRON-ION COLLIDER
EIC Yellow Report
en Letter
THE HORIZON
2015
1999
The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE
e+A White Pap
EIC Collaborat
April 4, 2007
The Elect

Summary & Outlook

- Electron Ion Collider, a high-energy **high-luminosity polarized e-p, e-A collider**, funded by the DOE will be built in this decade and operate in 2030's.
  - Will address the most profound unanswered questions in QCD
- EIC – an international project both for accelerator & detector(s) : Time line: physics by ~2033
- Up to two hermetic (& complementary) detectors under consideration. EIC project has funds for 1 detector.
  - EPIC – first detector collaboration : project includes most of its funds (not all)
  - Second detector science justification process initiated now. Needs
    - Needs substantial funding from – yet unidentified -- non-DOE source(s)
- **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 a EIC.*


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





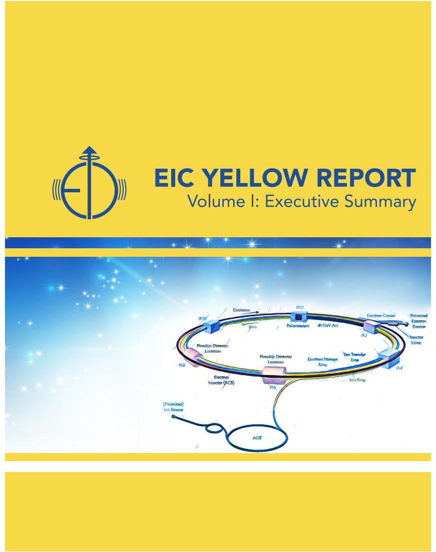
EIC Management team working with the EICUG to realize "EPIC"

Detector requirements:

- Large rapidity (-4 < η < 4) coverage; and far beyond
  - Large acceptance for diffraction, tagging, neutrons from nuclear breakup: critical for physics program
    → Integration into IR from the beginning critical
    Many ancillary detector along the beam lines: low-Q^2 tagger, Roman Pots, Zero-Degree Calorimeter, ….
- High precision low mass tracking
  - small (μ-vertex Silicon) and large radius (gas-based) tracking
- Electromagnetic and Hadronic Calorimetry
  - equal coverage of tracking and EM-calorimetry
- High performance PID to separate e, π, K, p on track level
  - good e/h separation critical for scattered electron ID
- Maximum scientific flexibility
  - Streaming DAQ → integrating AI/ML
- Excellent control of systematics
  - luminosity monitor, electron & hadron Polarimetry

Experimental program preparation

- Year-long EIC User Group driven EIC Yellow Report activity
  - Science Requirements and Detector Concepts for the EIC – Drives the requirements of EIC detectors
  - arXiv:2103.05419 & Nucl. Phys. A 1026 (2022) 122447 – 418 citations (12/06/22)



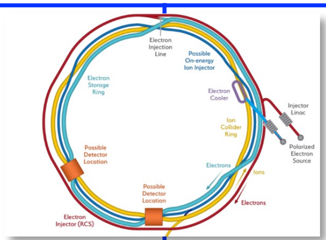
	BNL and TJNAF Jointly Leading Efforts Towards Experimental Program	
2020	Call for Expressions of Interest (EOI) https://www.bnl.gov/eic/EOI.php	May 2020
2020	EOI Responses Submitted	November 2020
2020	Assessment of EOI Responses	On-going[&]
2021	Call for Collaboration Proposals for Detectors https://www.bnl.gov/eic/CFC.php	March 2021
2021	BNL/TJNAF Proposal Evaluation Committee	Spring 2021
2021	Collaboration Proposals for Detectors Submitted	December 2021
2022	Decision on Project Detector – “ECCE”	March 2022
2022	Guide process to joint “Detector-1” Collaboration	Spring 2022
2022	EPIC Collaboration* Formed – 160 institutions	July 2022
2022	EIC Software Infrastructure Review	August 2022

[&]Remains ongoing until formal agreements are in place – it originally led to confirmation that in-kind level assumed for the EIC detector was in range.

*Merger of two large ATHENA and ECCE proposals

Complementarity for 1st-IR & 2nd-IR

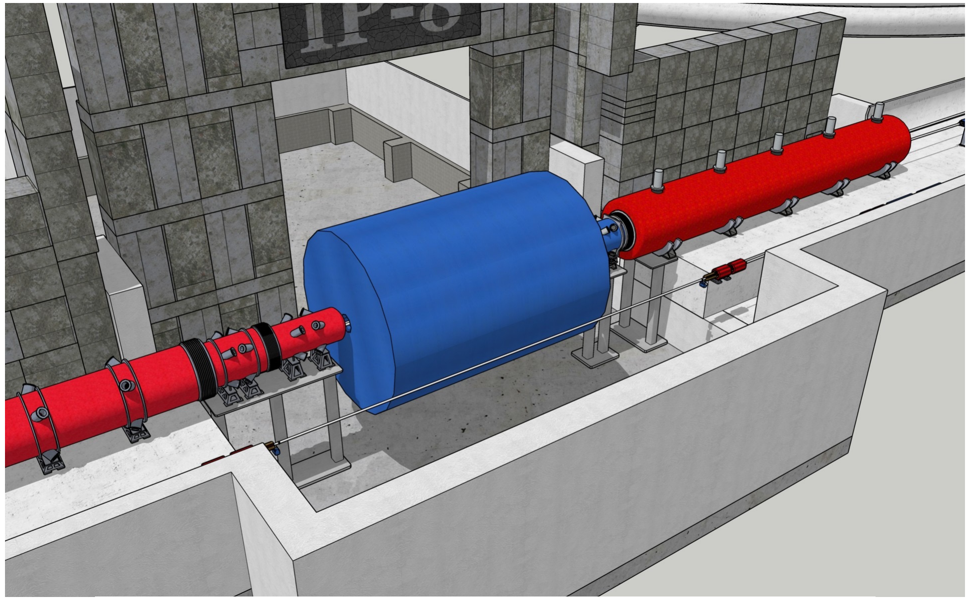
<table>
<tr><th></th><th>1st IR (IP-6)</th><th>2nd IR (IP-8)</th></tr>
<tr><td>Geometry:</td><td>ring inside to outside
tunnel and assembly hall are larger
Tunnel: ⃠ 7m +/- 140m</td><td>ring outside to inside
tunnel and assembly hall are smaller
Tunnel: ⃠ 6.3m to 60m then 5.3m</td></tr>
<tr><td>Crossing Angle:</td><td>25 mrad</td><td>35 mrad
secondary focus</td></tr>
<tr><td></td><td colspan="2">different blind spots
different forward detectors and acceptances
different acceptance of central detector</td></tr>
<tr><td>Luminosity:</td><td colspan="2">more luminosity at lower E_{CM}
optimize Doublet focusing FDD vs. FDF
→ impact of far forward p_T acceptance</td></tr>
<tr><td>Experiment:</td><td colspan="2">1.5 Tesla or 3 Tesla
different subdetector technologies</td></tr>
</table>



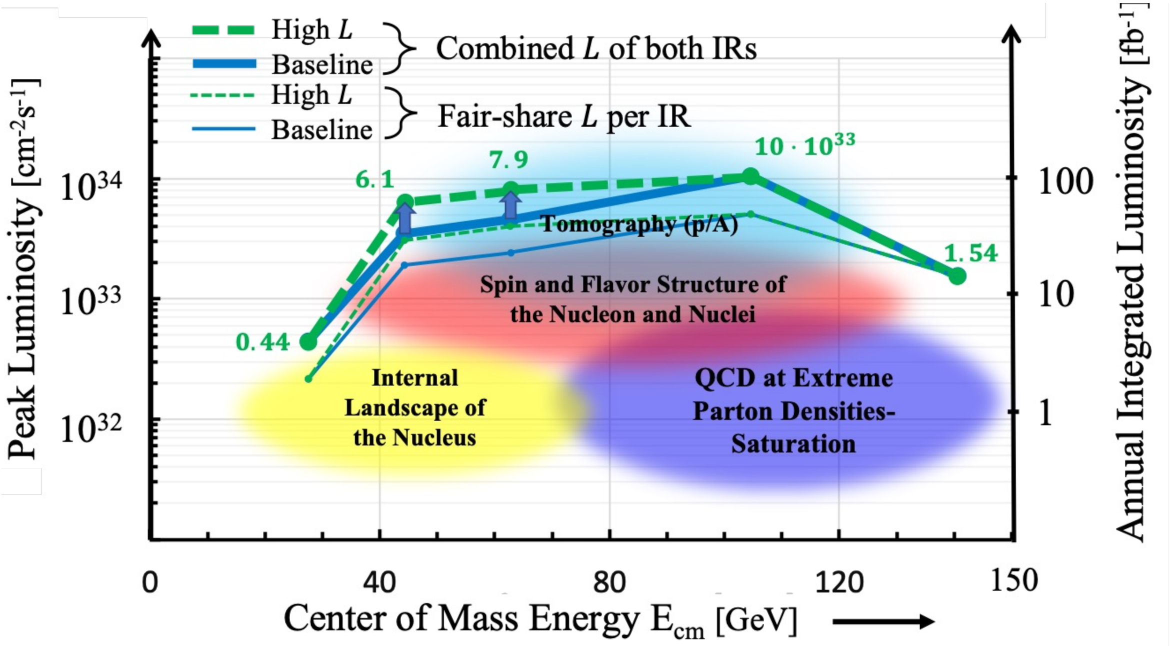
EIC 2nd Detector and IR work

- Scope: Ensure feasibility of two simultaneous IRs
    - Recall that the luminosity is (at best) shared
- Updates on IR layout and detector impacts – Randy Gamage and Alex Jentsch
- Updates on 3D CAD – Karim Hamdi
- Integration in SketchUp – Walt Akers
- (also instrumental to bring up need for generic detector R&D with DOE)

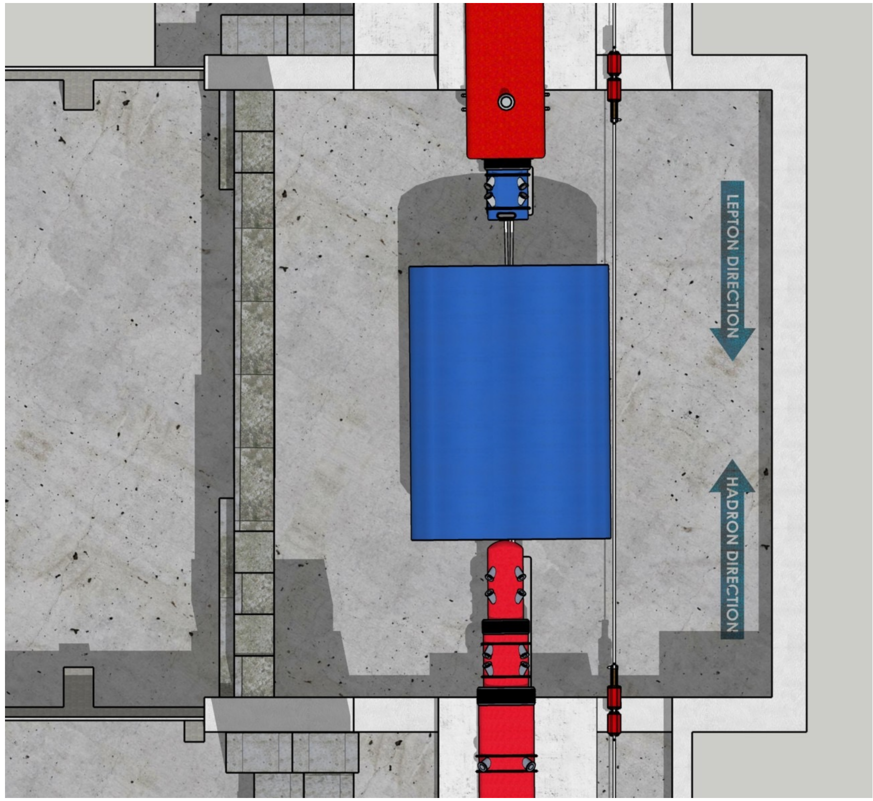
Typical in ad-hoc meetings by E. Aschenauer, S. Berg, A. Drees, R. Ent, R. Gamage, A. Jentsch, V. Morozov, T. Satogata, W. Wittmer (now Y. Zhang)



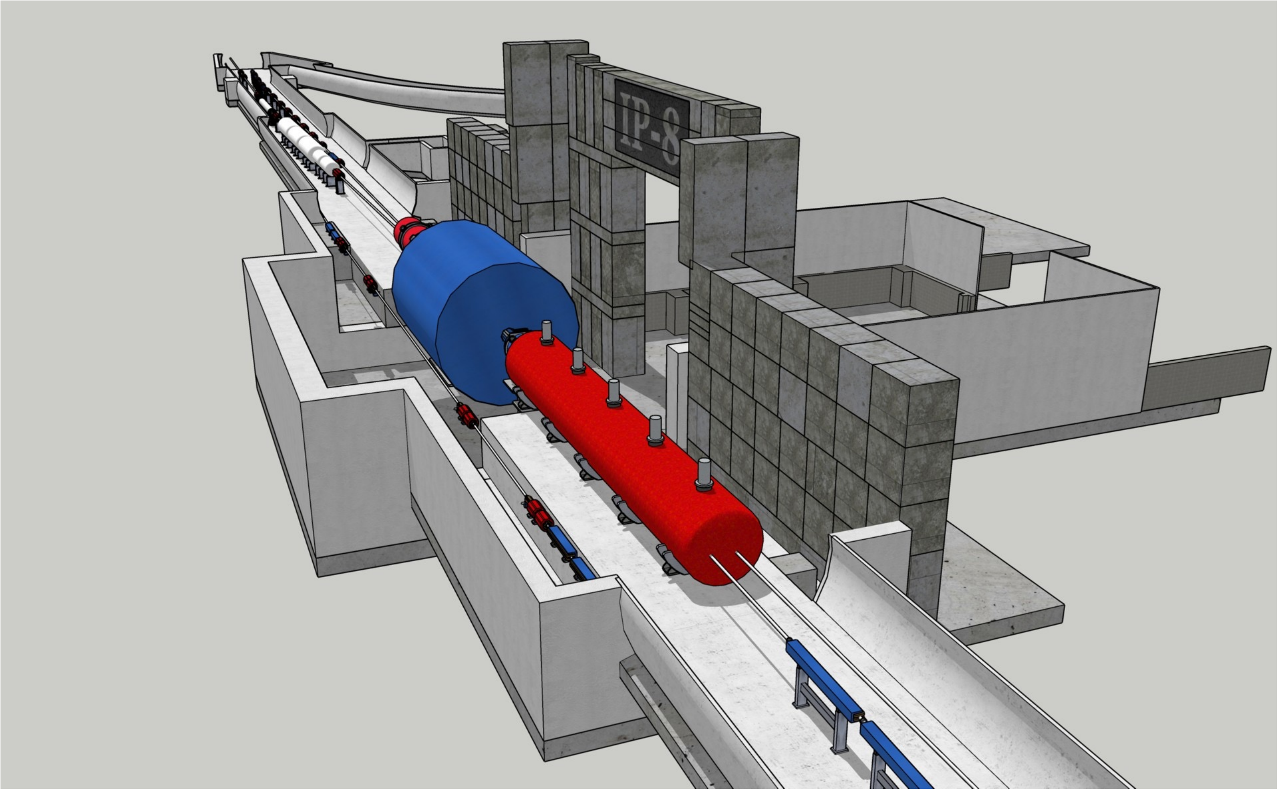
Detector = Blue cylinder of 838 cm



EIC 2nd Detector and IR Work



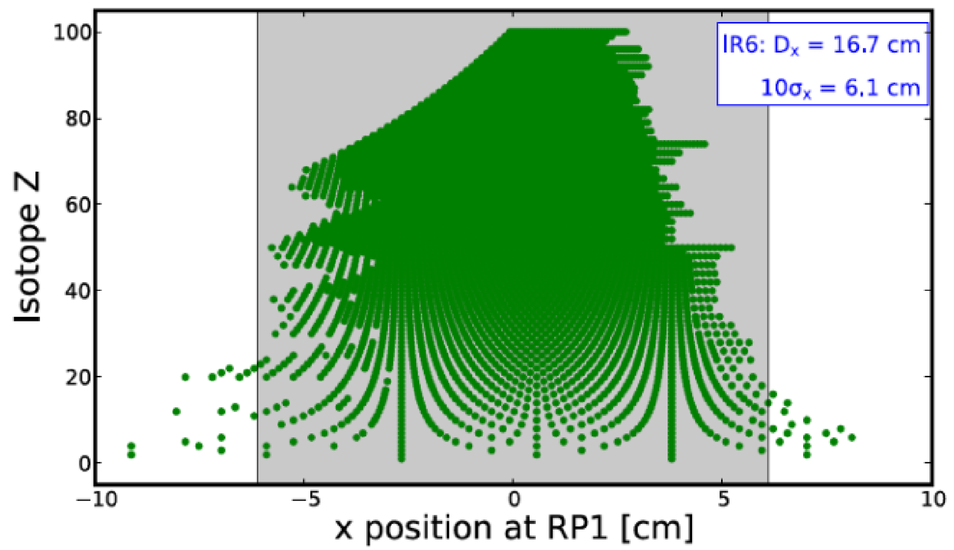
Detector = Blue cylinder of 838 cm
→ Does not fit through the door

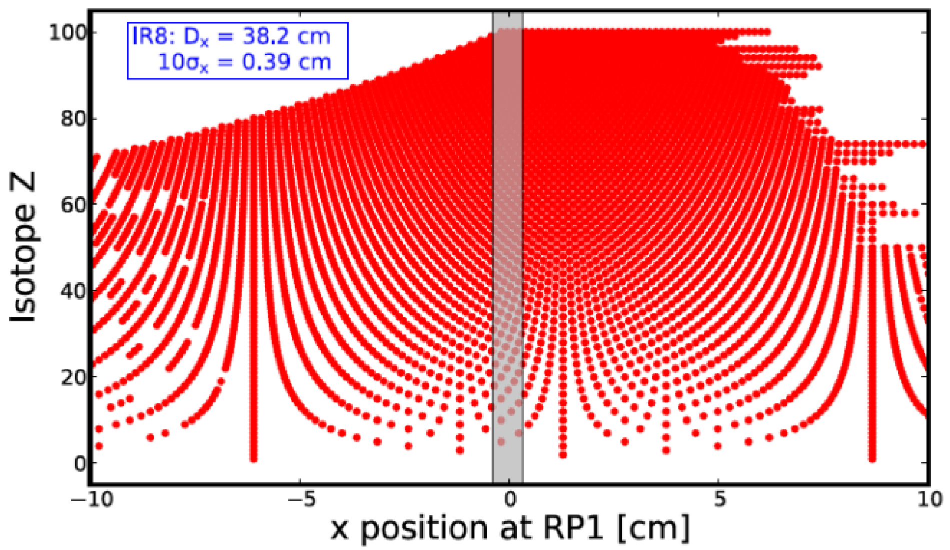


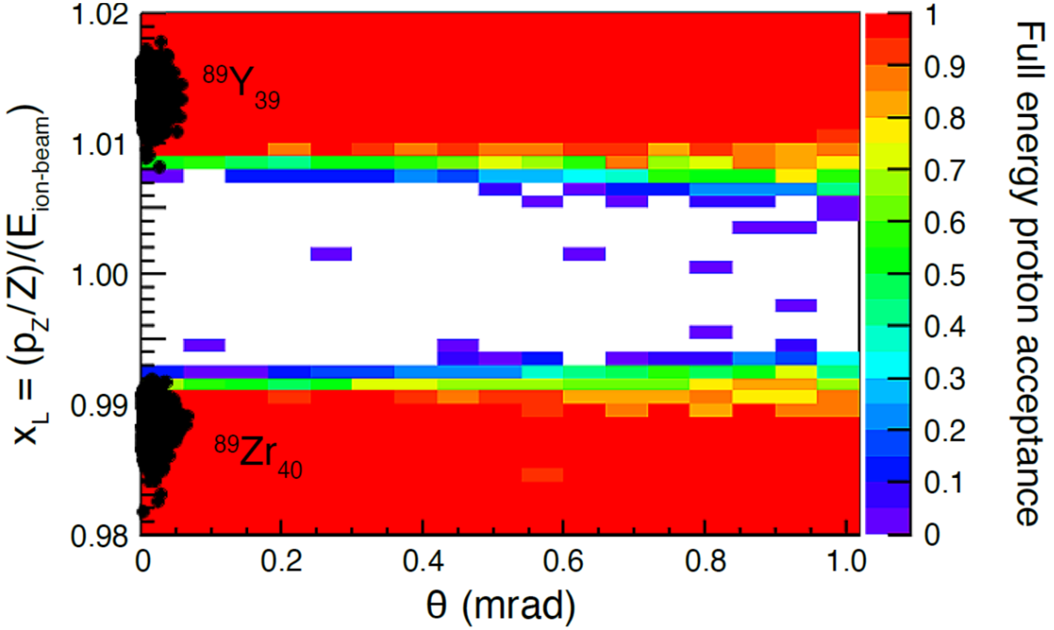
Can develop "handmade" beam pipe (or take the one Alex Jentsch did for his detector acceptance studies)

EIC 2nd Detector and IR – new EIC WP

(for US Nuclear Science Long Range Planning activity, driven by EICUG and accompanied by similar efforts for NuPECC long-range plan)







Advantages of 2nd focus recognized by DPAP and folded in EIC White Paper – Now we need to develop a bullet proof science case of a 2nd detector with both unique science and complementarity, by proper choice of 2nd EIC detector technologies and gathering wide and growing community interest.

Collaboration Topics with DOE Laboratories: Accelerator

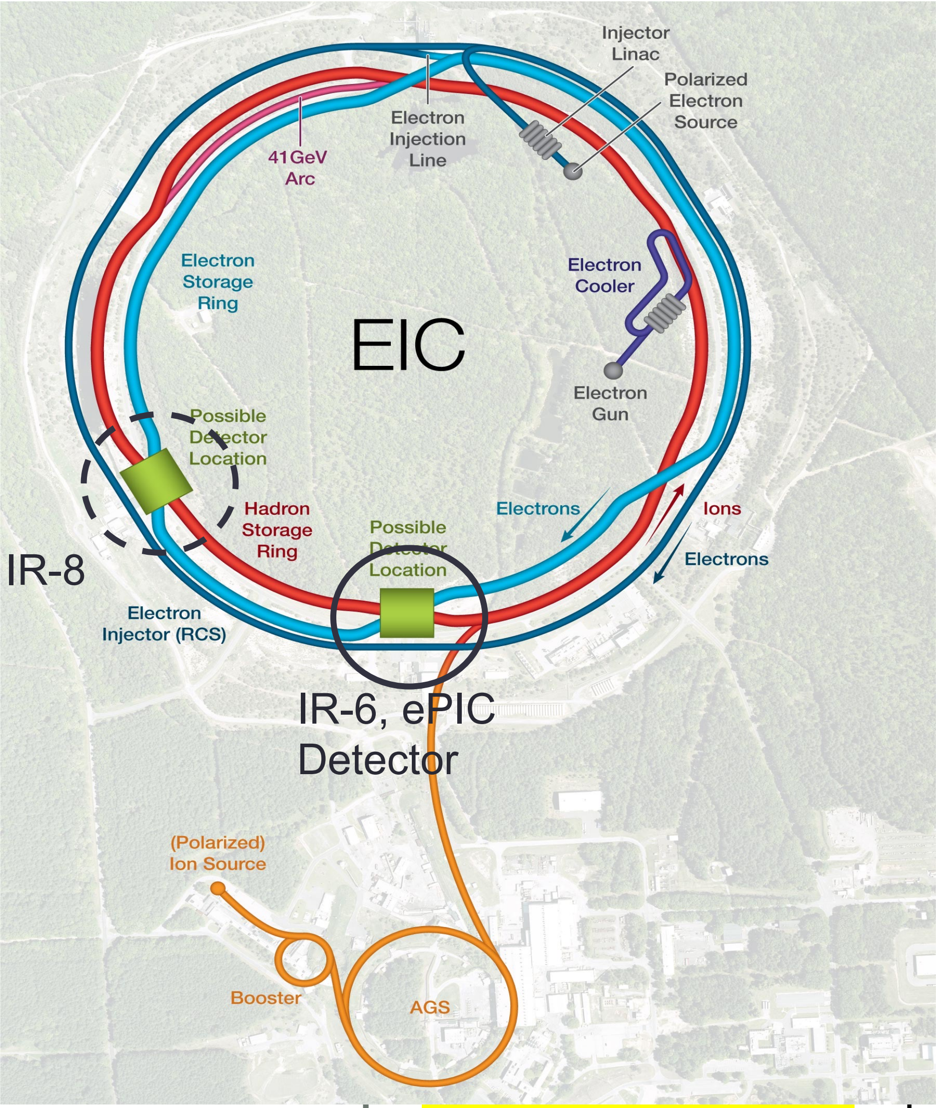
- **ANL**
  - RCS Quadrupole and sextupole preliminary engineering design, *status: in progress*
  - Prototype and first article cavity processing (TJ), *status: under discussion*
- **LBNL:**
  - Beam dynamics, *status: in progress*
  - Superconducting cable production, design (and possibly production) of superconducting dipole magnets, *status: agreement in principle, details to be worked out*
- **SLAC:**
  - Beam dynamics, IR design, *status: in progress*
- **FNAL**
  - Beam dynamics (ESR polarization), *status: in progress*
  - Design of collared s.c. IR magnet, *status: under discussion*
  - Design s.c. cavity (of 5-cell?), *status: preliminary discussion*
  - RCS dipoles & ESR quads design (TJ), *status: under discussion*
- **ORNL**
  - Polarization and Beam dynamics (TJ), *status: in progress*
  - EIC instrumentation, *status: under discussion*

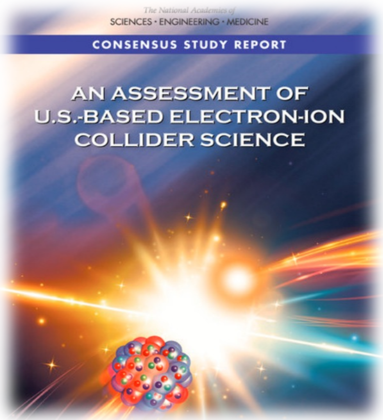
Collaboration Topics with International Partners: Accelerator

- **Italy / INFN:**
  - Beam screens for HSR, prototyping, design, manufacturing,

    status: agreement in principle; EIC L2&L3 ready to finalize the scope of work
- **Canada / TRIUMF:**
  - Crab cavity system, 394 MHz, design, prototype, manufacturing (TJ), *status: agreement in principle; EIC L2&L3 are ready to finalize the scope of work*
  - Pulsed devices, *status: agreement in principle, details to be worked out*
- **France / CEA Saclay:**
  - SC spin rotator solenoids, *status: under discussion*
- **France / IJCLAB:**
  - ERL diagnostics, *status: under discussion*
- **UK / CI, JAI, Daresbury Lab, …**
  - Crab cavity system phase stabilization, *status: under discussion*
  - ERL (TJ), *status: under discussion*
- **CERN:**
  - Joint work working groups on variety of FCCee-EIC topics, SRF, polarization, impedances, feedbacks, etc., *status: in progress*

EIC Scope





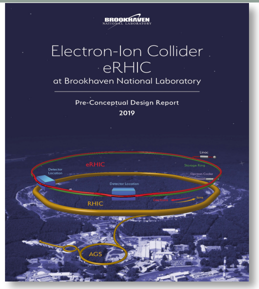
Project Design Goals

- High Luminosity: L= $10^{33} – 10^{34} cm^{-2} sec^{-1}$, 10 – 100 fb^{-1}/year
- Highly Polarized Beams: 70%
- Large Center of Mass Energy Range: E_{cm} = 29 – 140 GeV
- Large Ion Species Range: protons – Uranium
- Large Detector Acceptance and Good Background Conditions
- Accommodate a Second Interaction Region (IR) IR-8

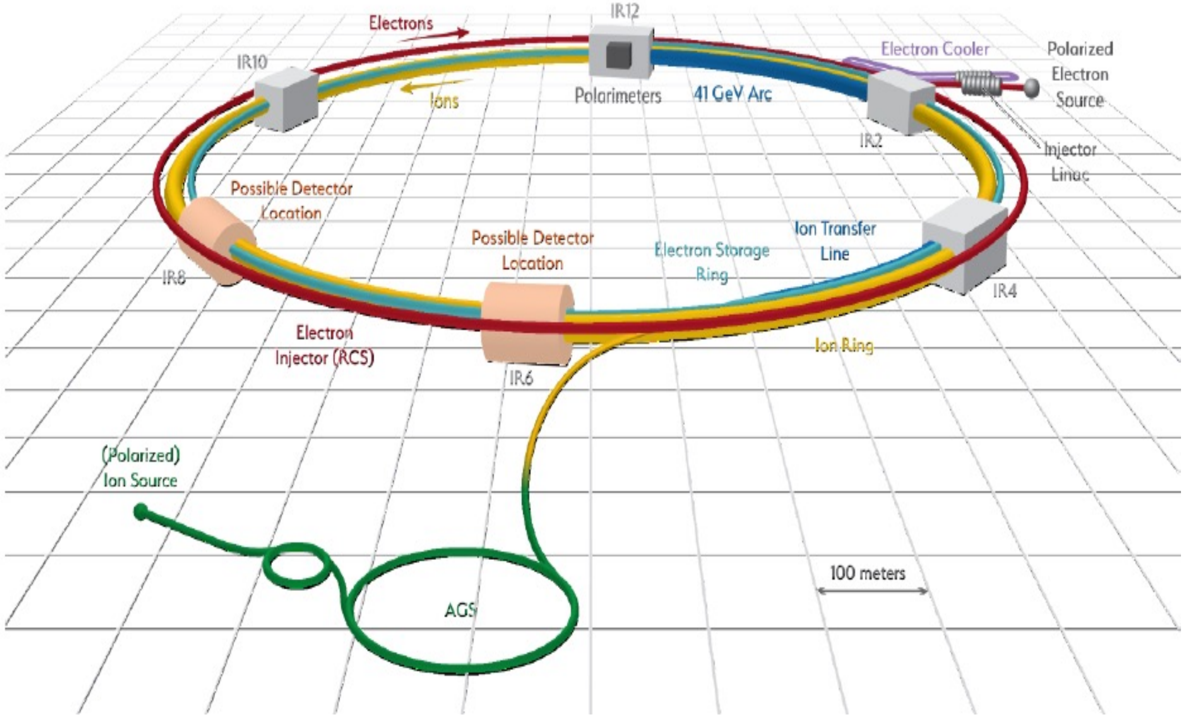
/A beam → ← e beam

p: 41 GeV, 100 to 275 GeV

e: 5 GeV to 18 GeV



The US Electron Ion Collider



- ❖ Electron storage ring with frequent injection of fresh polarized electron bunches
- ❖ Hadron storage ring with strong cooling or frequent injection of hadron bunches

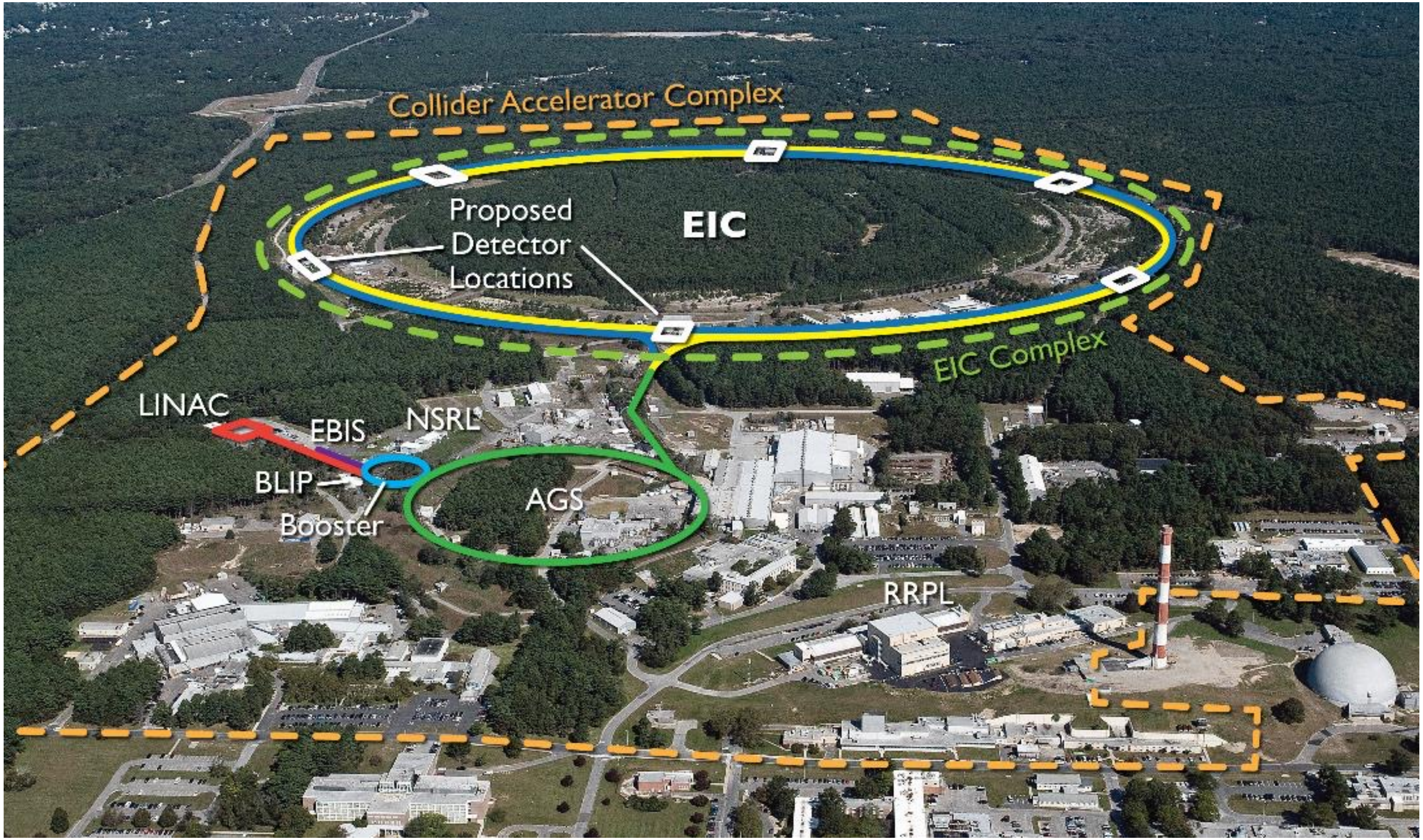
Hadrons up to 275 GeV

- ➢ Existing RHIC complex: Storage (Yellow), injectors (source, booster, AGS)
- ➢ Need few modifications
- ➢ RHIC beam parameters fairly close to those required for EIC@BNL

Electrons up to 18 GeV

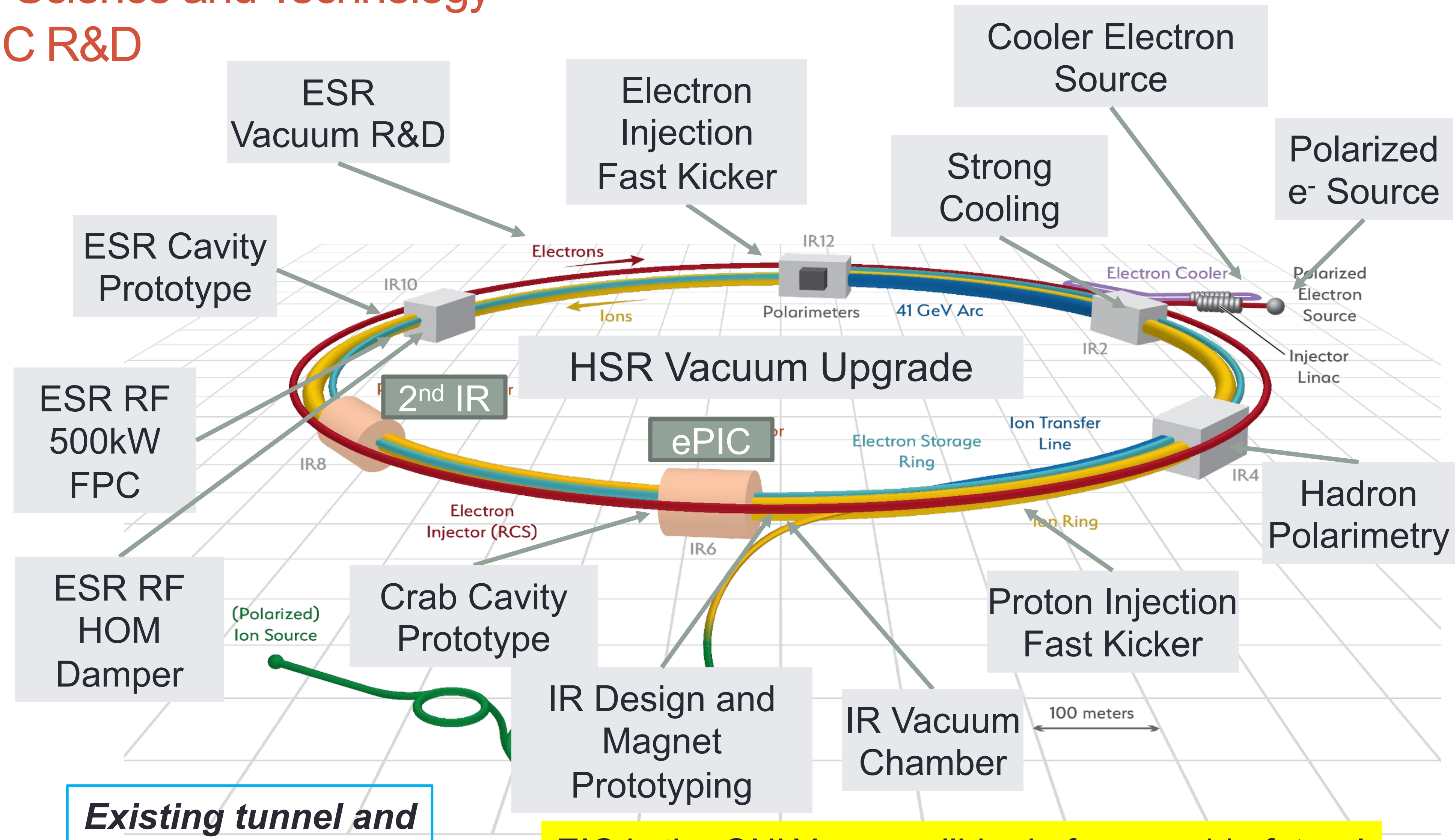
- ➢ Storage ring, provides the range sqrt(s) = 20-140 GeV. Beam current limited by RF power of 10 MW
- ➢ Electron beam with variable spin pattern (s) accelerated in on-energy, spin transparent injector (Rapid-Cycling-Synchrotron) with 1-2 Hz cycle frequency
- ➢ Polarized e-source and a 400 MeV s-band injector LINAC in the existing tunnel

Design optimized to reach 10^{34} $cm^{-2}sec^{-1}$



- EIC benefits from $B class investments at BNL and the highly successful RHIC program.
- RHIC will conclude operations in 2025. EIC installation will begin after RHIC ops concludes.

Accelerator Science and Technology – Ongoing EIC R&D



Existing tunnel and experiment halls

EIC is the ONLY new collider in foreseeable future!
Allows to remain at frontier of Accelerator S&T.

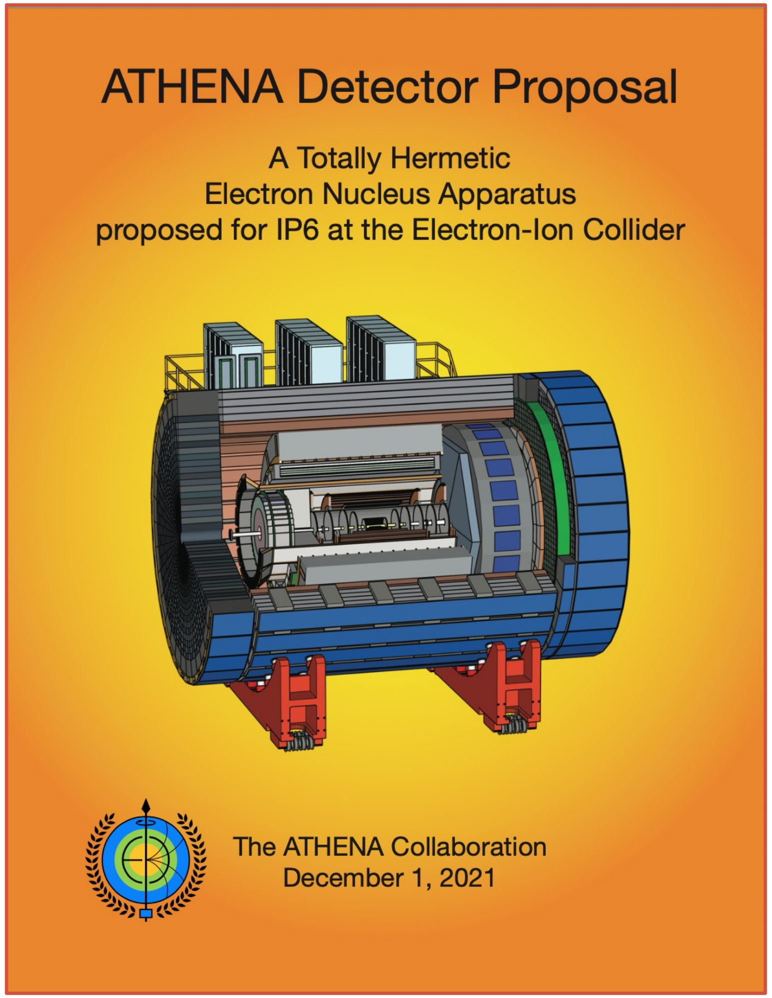
… and enable applications (isotopes, space radiation, water treatment, etc.)

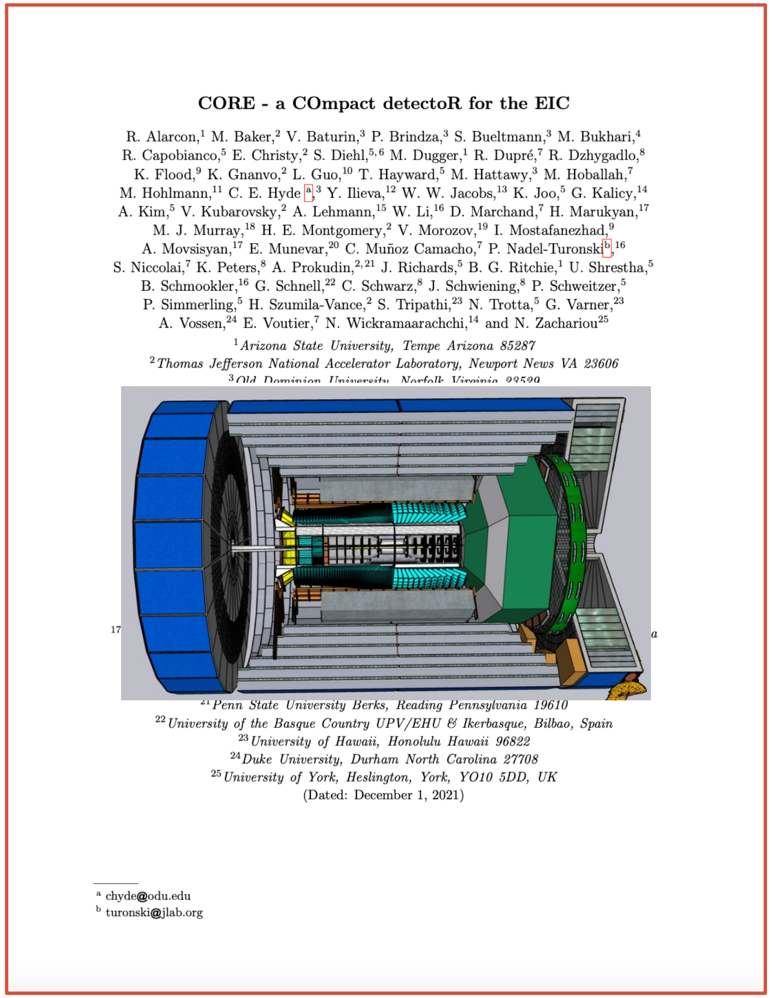
Summary

- DOE Inflation Reduction Act funding is a game changer – shift from progress constrained by availability of early DOE funding to technical progress determined by ability to advance the design, hiring, partnering, collaboration, and procurement – bringing on people!
- Priority is to secure DOE CD-2/3a in early 2024 and CD-3 before RHIC concludes operations in 2025.
  - CD-3a, Long Lead Procurement Approval, key factor in mitigating risk and determining overall project schedule and cost.
  - CD-2, Performance Baseline Approval, establishes Total Project Cost, schedule, performance, and annual funding profile.
- Excellent progress defining the EIC project detector, ePIC, and establishing the collaboration responsible for the experiment.
- Engage now in the world-wide effort to build a collider facility and detectors designed to meet EIC performance and science goals.

The three proposals: reviewed by an external panel

EIC Advisory Panel's recommendation on April 8, 2022





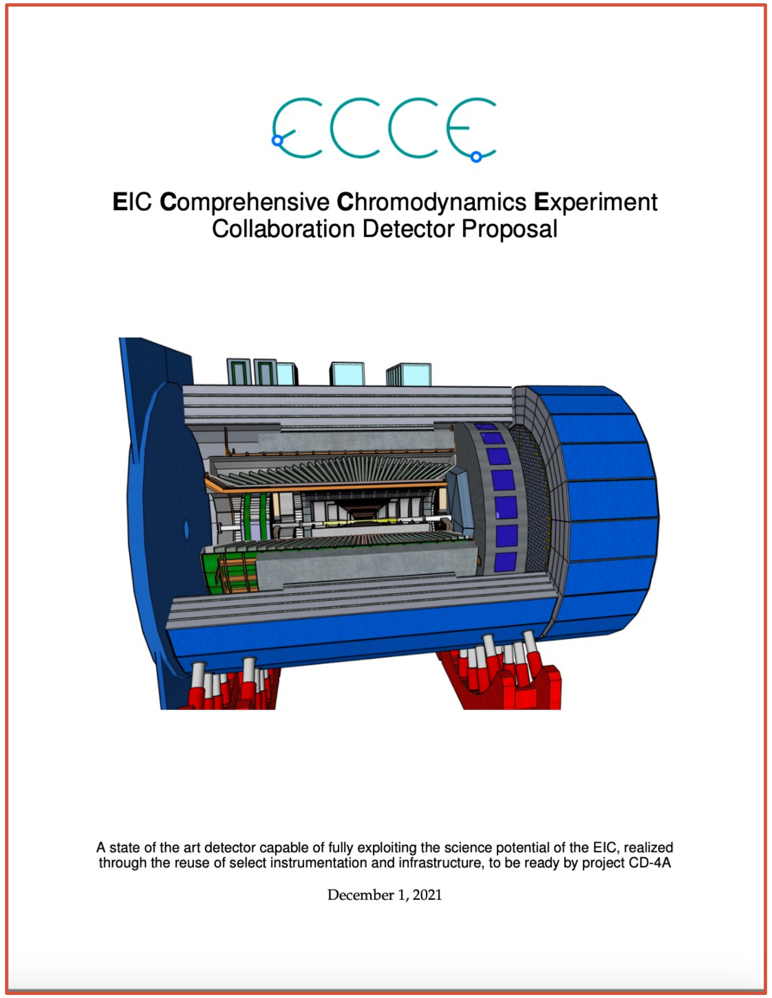
CORE - a COmpact detectoR for the EIC

R. Alarcon,[1] M. Baker,[2] V. Baturin,[3] P. Brindza,[3] S. Bueltmann,[3] M. Bukhari,[4] R. Capobianco,[5] E. Christy,[2] S. Diehl,[5,6] M. Dugger,[1] R. Dupré,[7] R. Dzhygadlo,[8] K. Flood,[9] K. Gnanvo,[2] L. Guo,[10] T. Hayward,[5] M. Hattawy,[3] M. Hoballah,[7] M. Hohlmann,[11] C. E. Hyde[a],[3] Y. Ilieva,[12] W. W. Jacobs,[13] K. Joo,[5] G. Kalicy,[14] A. Kim,[5] V. Kubarovsky,[2] A. Lehmann,[15] W. Li,[16] D. Marchand,[7] H. Marukyan,[17] M. J. Murray,[18] H. E. Montgomery,[2] V. Morozov,[19] I. Mostafanezhad,[9] A. Movsisyan,[17] E. Munevar,[20] C. Muñoz Camacho,[7] P. Nadel-Turonski[b],[16] S. Niccolai,[7] K. Peters,[8] A. Prokudin,[2,21] J. Richards,[5] B. G. Ritchie,[1] U. Shrestha,[5] B. Schmookler,[16] G. Schnell,[22] C. Schwarz,[8] J. Schwiening,[8] P. Schweitzer,[5] P. Simmerling,[5] H. Szumila-Vance,[2] S. Tripathi,[23] N. Trotta,[5] G. Varner,[23] A. Vossen,[24] E. Voutier,[7] N. Wickramaarachchi,[14] and N. Zachariou[25]

[1] *Arizona State University, Tempe Arizona 85287*
[2] *Thomas Jefferson National Accelerator Laboratory, Newport News VA 23606*
[3] *Old Dominion University, Norfolk Virginia 23529*

[21] *Penn State University Berks, Reading Pennsylvania 19610*
[22] *University of the Basque Country UPV/EHU & Ikerbasque, Bilbao, Spain*
[23] *University of Hawaii, Honolulu Hawaii 96822*
[24] *Duke University, Durham North Carolina 27708*
[25] *University of York, Heslington, York, YO10 5DD, UK*
(Dated: December 1, 2021)

[a] chyde@odu.edu
[b] turonski@jlab.org



Detector Proposal Advisory Panel ➔

All three proposals received high marks & concluded that both ATHENA and ECCE satisfied the requirements

Recommended ECCE as the “reference detector”: lower risk and cost

- ATHENA, ECCE – collaborator overlap – neither large enough to become Detector 1
- Strongly encouraged the proto-collaborations to merge and build the **Project Detector** starting from ECCE‘s reference design

As of July 2022: (ATHENA + ECCE) : Electron Proton Ion Collider (**EPIC**) Detector Collaboration formed ➔ working together to realize the EIC science

Enthusiastically supported the idea of a **second detector for the 2nd IR**