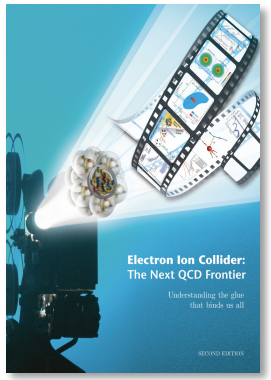
Electron Ion Collider
The Next QCD Frontier

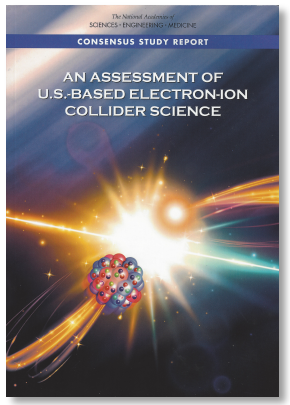
2015



2016

Physics of EIC

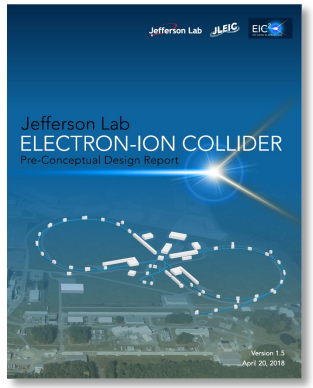
2018

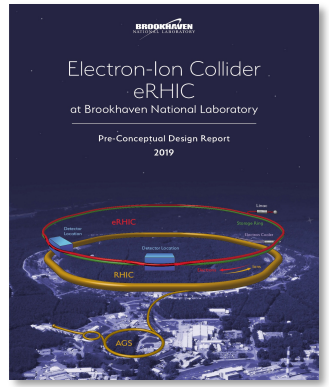


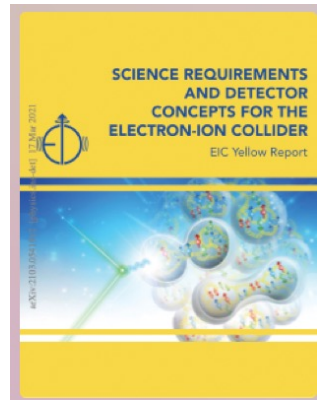
Evaluation

2019-present

2019







Realization

EIC moving forward….

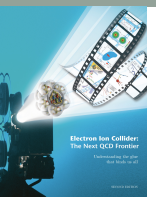
- DOE announced: January 9, 2020
  - CD0 December 19, 2019
  - Site of EIC: Brookhaven National Laboratory
- BNL and JLab realize EIC as partners
  - A formal EIC project is now setup at BNL
  - BNL+Jlab management & scientists
- CD1 June 28, 2021
- Detector Proposals in December 1, 2021
- CD2 Approval 3rd Quarter FY2023
- CD3 1st Quarter FY2024 (start construction)
- EIC CD4A Early Finish 4thQ FY (2030→2031)
  - Start of collisions
- EIC CD4 ~ 4thQ FY(2031→2033)
  - Start of Physics

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

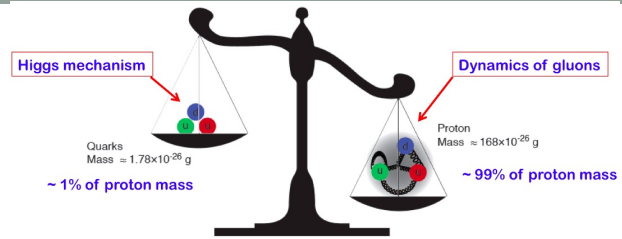
WASHINGTON, D.C. – Today, the **U.S. Department of Energy (DOE)** announced the selection of Brookhaven National Laboratory in Upton, NY, as the site for a planned major new nuclear physics research facility.

EIC Science: a very short overview

- Experiment: EIC high luminosity measurements; systematic uncertainties limited
- Theory: is theory ready for EIC? (N^XLO, summation, underlying assumptions of factorizability and such issues), and reliable lattice/continuation QCD methods

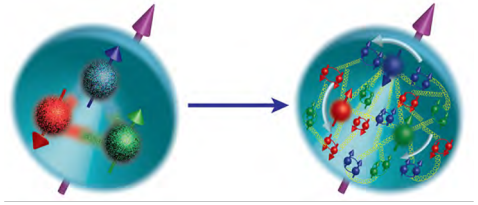


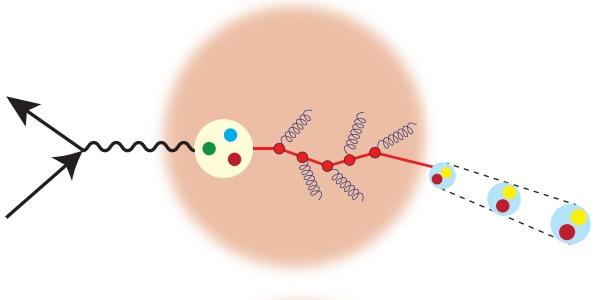
EIC Physics at-a-Glance



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?





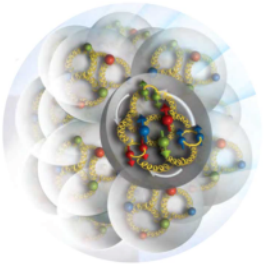
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

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 quarks and gluons, their correlations, and their interactions?

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

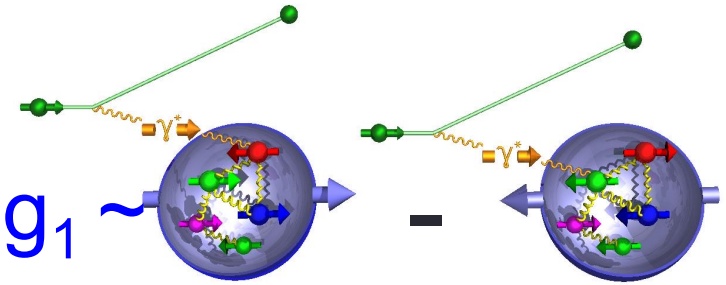


gluon emission ? = gluon recombination

Nucleon Spin: Precision with EIC

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

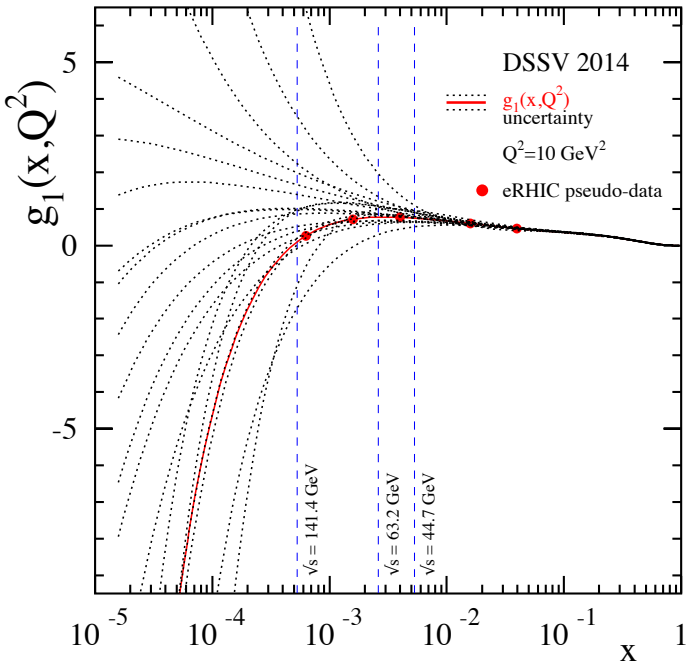
$\Delta\Sigma/2$ = Quark contribution to Proton Spin
Δg = Gluon contribution to Proton Spin
L_Q = Quark Orbital Ang. Mom
L_G = Gluon Orbital Ang. Mom

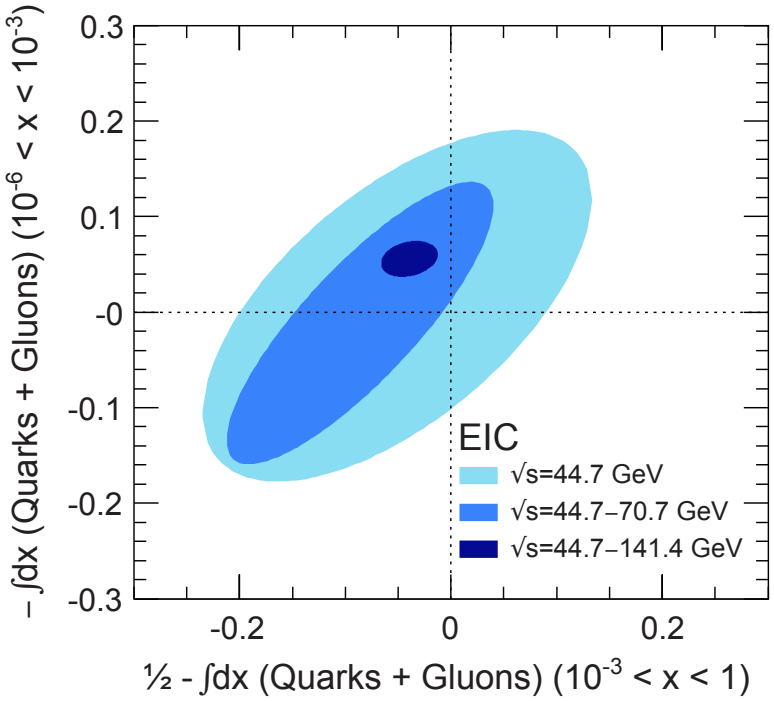


Spin structure function g_1 needs to be measured over a large range in x-Q^2

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

SIDIS: strange and charm quark spin contributions

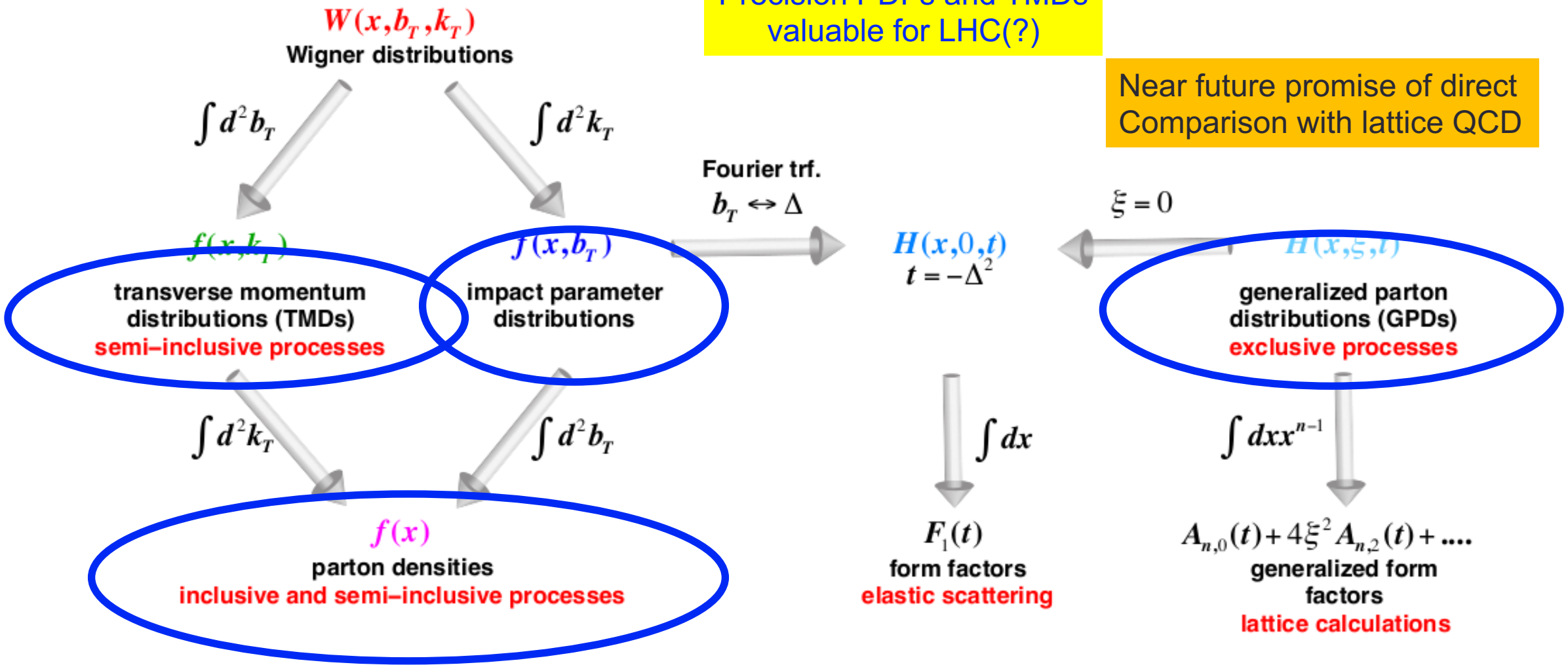




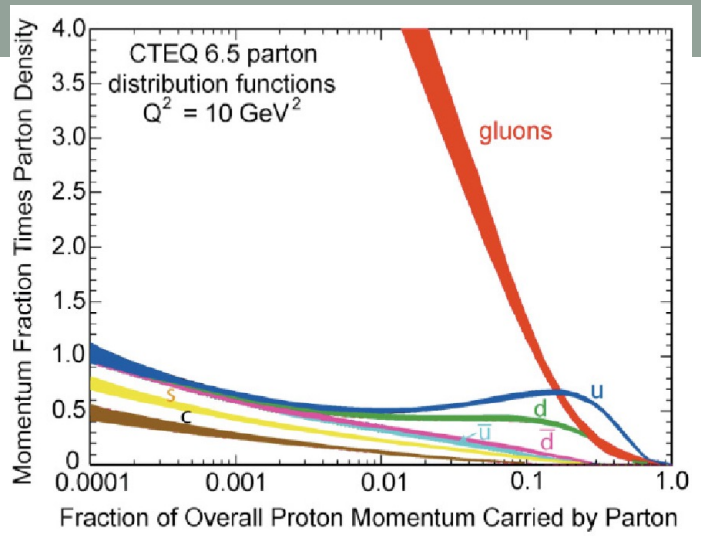
2+1D Imaging of hadrons: beyond precision PDFs

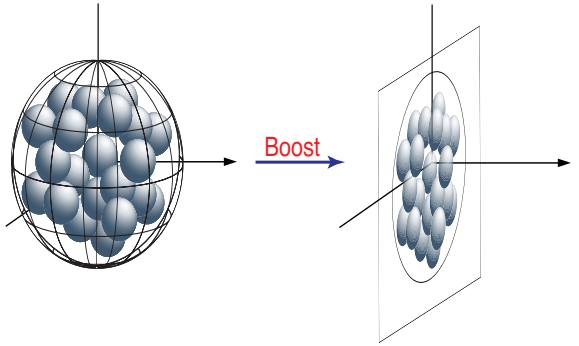
Precision PDFs and TMDs valuable for LHC(?)

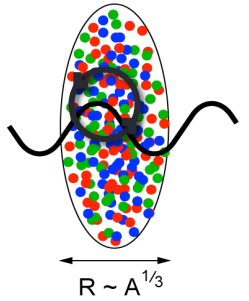
Near future promise of direct Comparison with lattice QCD



Low x physics with nuclei

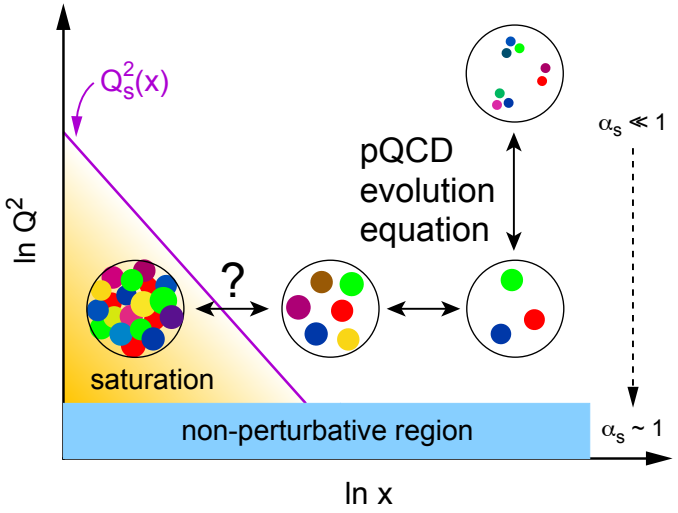






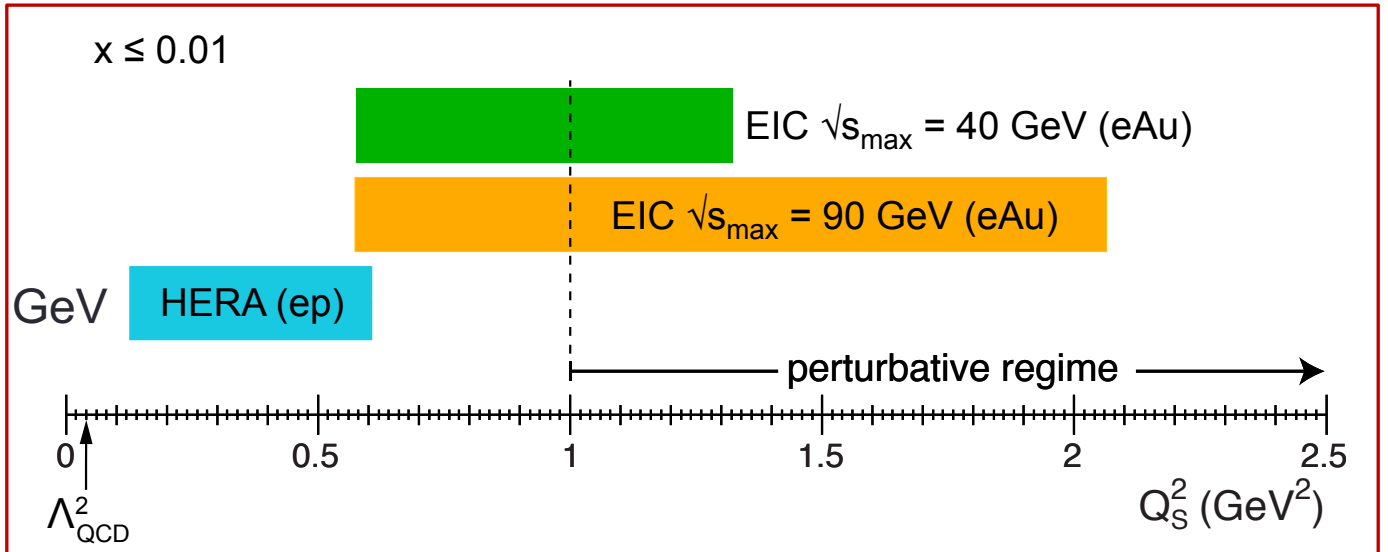
$$(Q_s^A)^2 \approx cQ_0^2 \left[\frac{A}{x}\right]^{1/3}$$

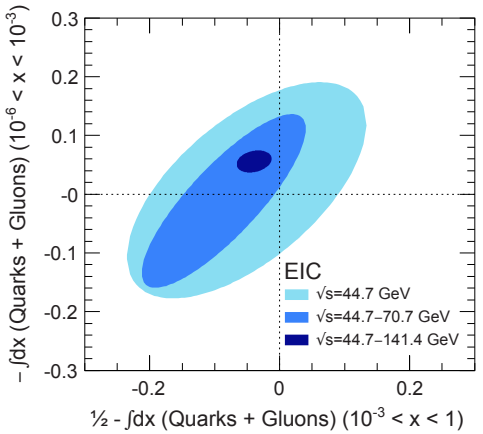
$L \sim (2m_N x)^{-1} > 2\ R_A \sim A^{1/3}$

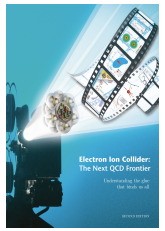


gluon emission = gluon recombination **At Q_S**

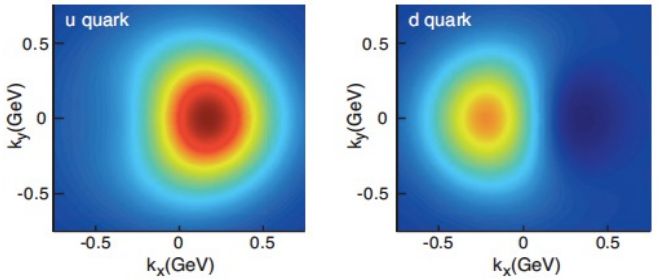
Accessible range of saturation scale Q_s^2 at the EIC with e+A collisions. arXiv:1708.01527

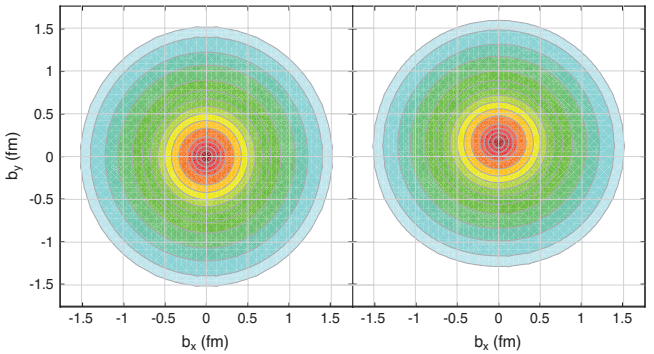


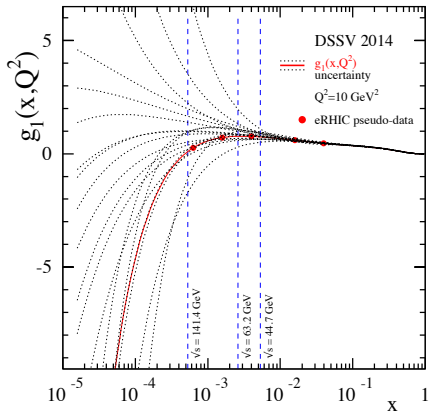


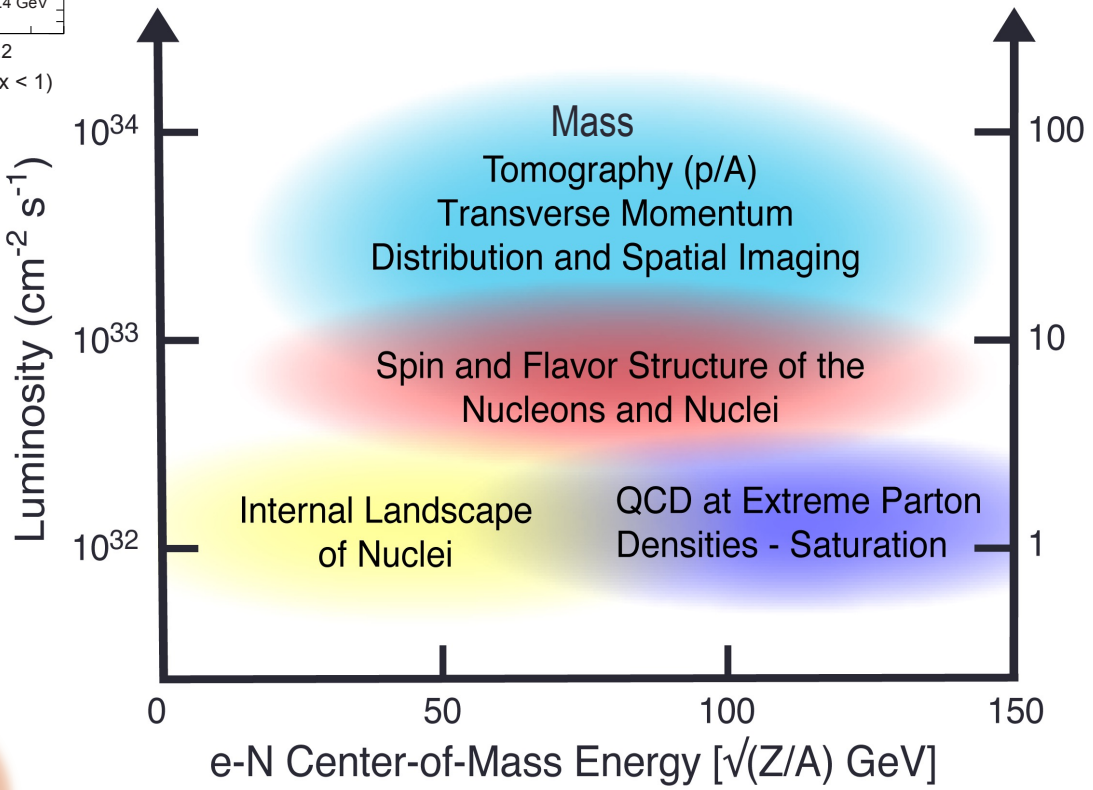


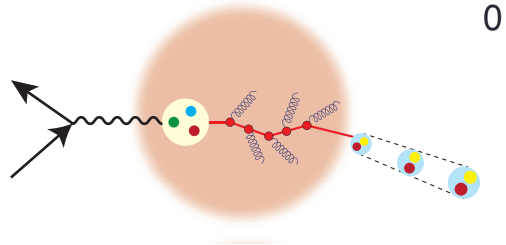
EIC science highlights

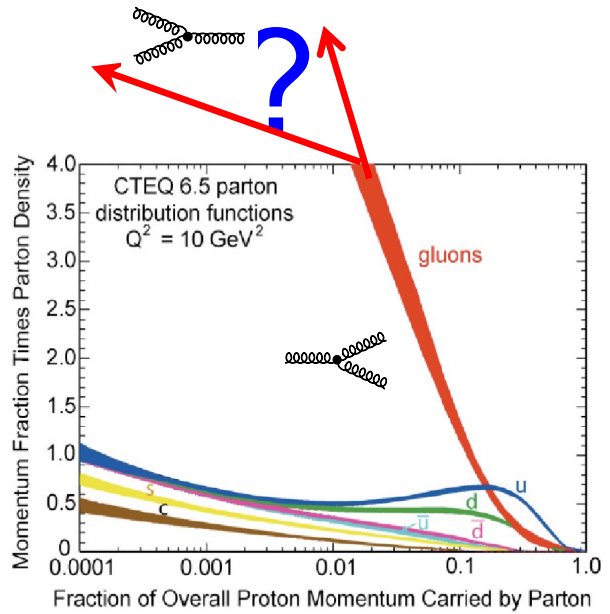




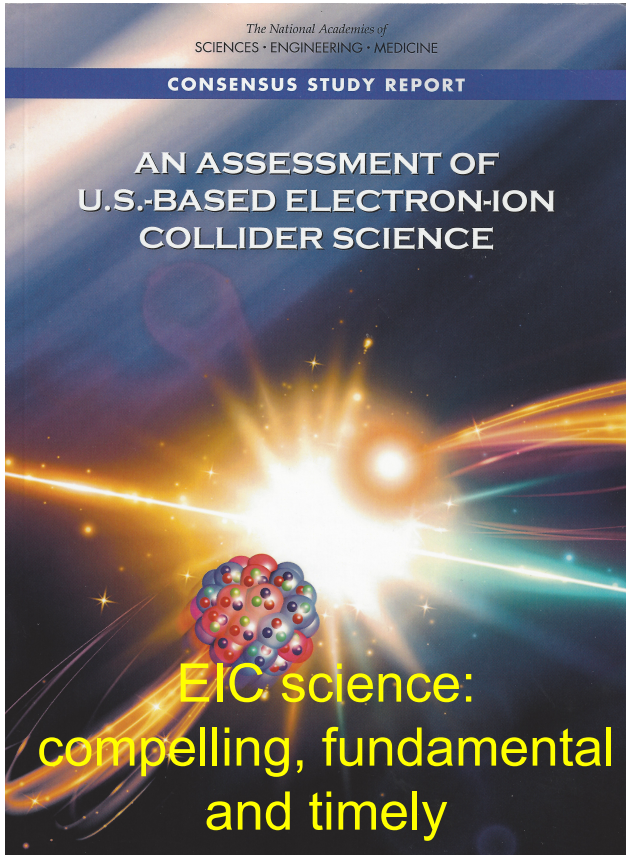


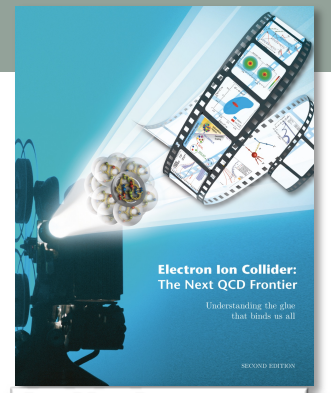


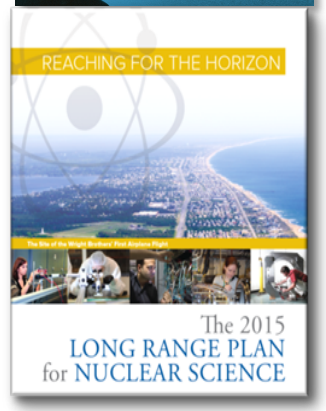




National Academy's Assessment







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: ~20-100 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

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:

- Heavy quark and quarkonia (c, b quarks) studies with 100-1000 time
- Feasibility to study kaon and pion structure
- Impact of precision measurements of unpolarized PDFs at high x/Q^2, on L
- What role would TMDs in e-p play in W-Production at LHC? Gluon TMDs
- Does polarization of play a role (in all or many of these?)

Physics with nucleons and nuclear targets:

- Quark Exotica: 4,5,6 quark systems…? Much interest after recent LHCb l
- Physic of and with jets with EIC as a precision QCD machine:
  - Internal structure of jets : novel new observables, energy variability, po
  - Entanglement, entropy, connections to fragmentation, hadronization ar
  - Studies with jets: Jet propagation in nuclei… energy loss in cold QCD
- Connection to p-A, d-A, A-A at RHIC and LHC
- Polarized light nuclei in the EIC

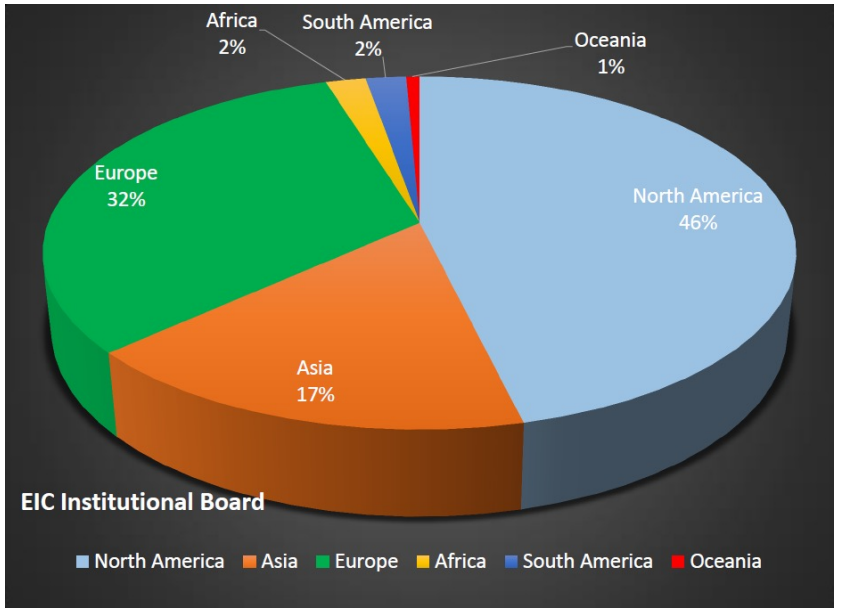
Precision electroweak and BSM physics:

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

Any physics topic requiring high luminosity, with polarized beams, broad range in nuclear size.

A lot of room for adding new topics.

The EIC Users Group: EICUG.ORG



Formally established in 2016, now we have:
~1300 Ph.D. Members from 34 countries, 254 institutions
New members welcome

New:
Center for Frontiers in Nuclear Science (at Stony Brook/BNL)
EIC² at Jefferson Laboratory

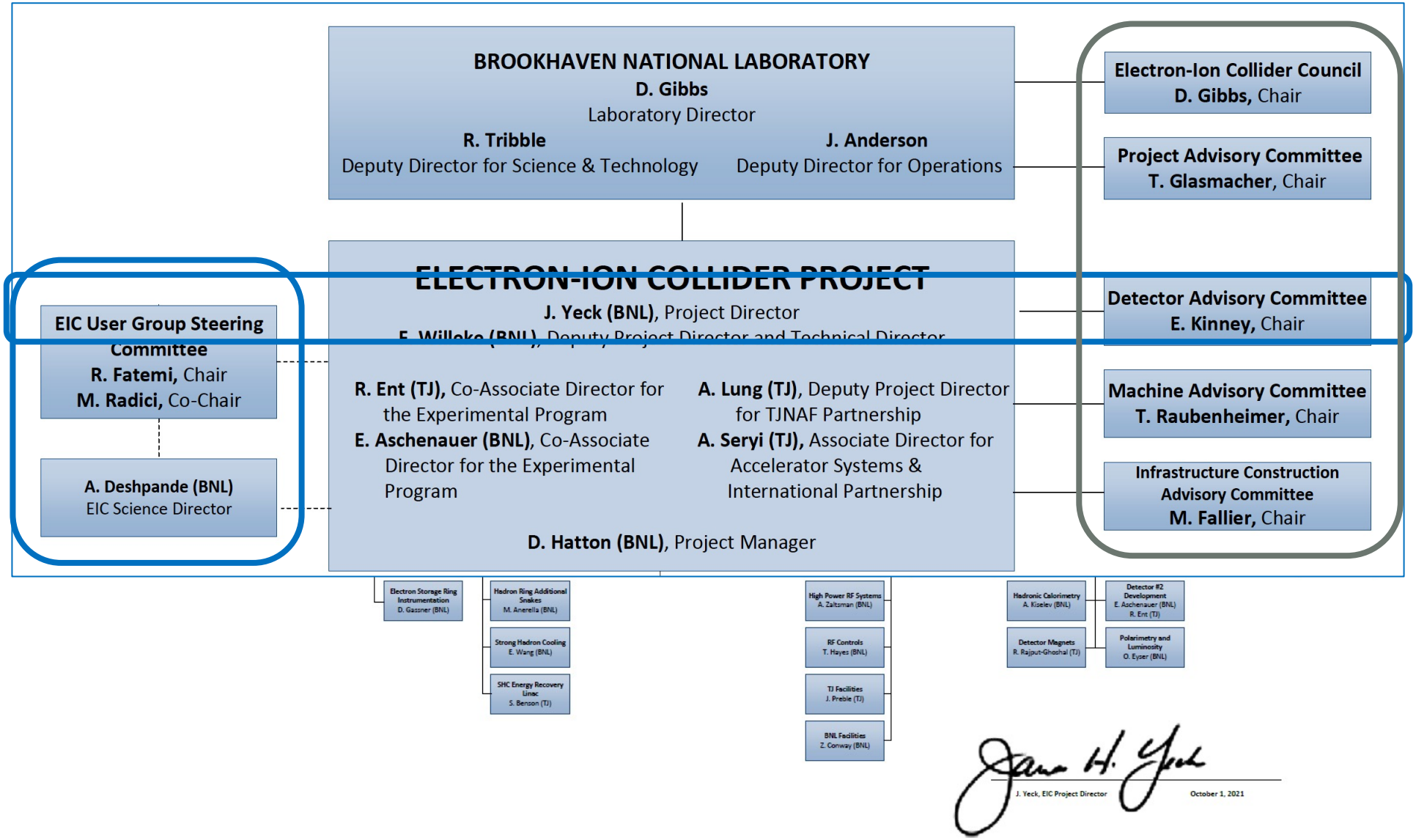
EICUG Structures in place and active:
EIC UG Steering Committee, Institutional Board, Speaker's Committee, Election & Nominations Committee

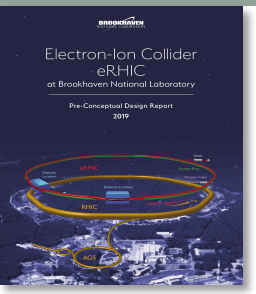
Year long workshops: Yellow Reports for detector design

Annual meetings: Stony Brook (2014), Berkeley (2015), **ANL (2016), Trieste (2017), CAU (2018), Paris (2019), FIU (2020), Remote (2021), Warsaw (2022)**

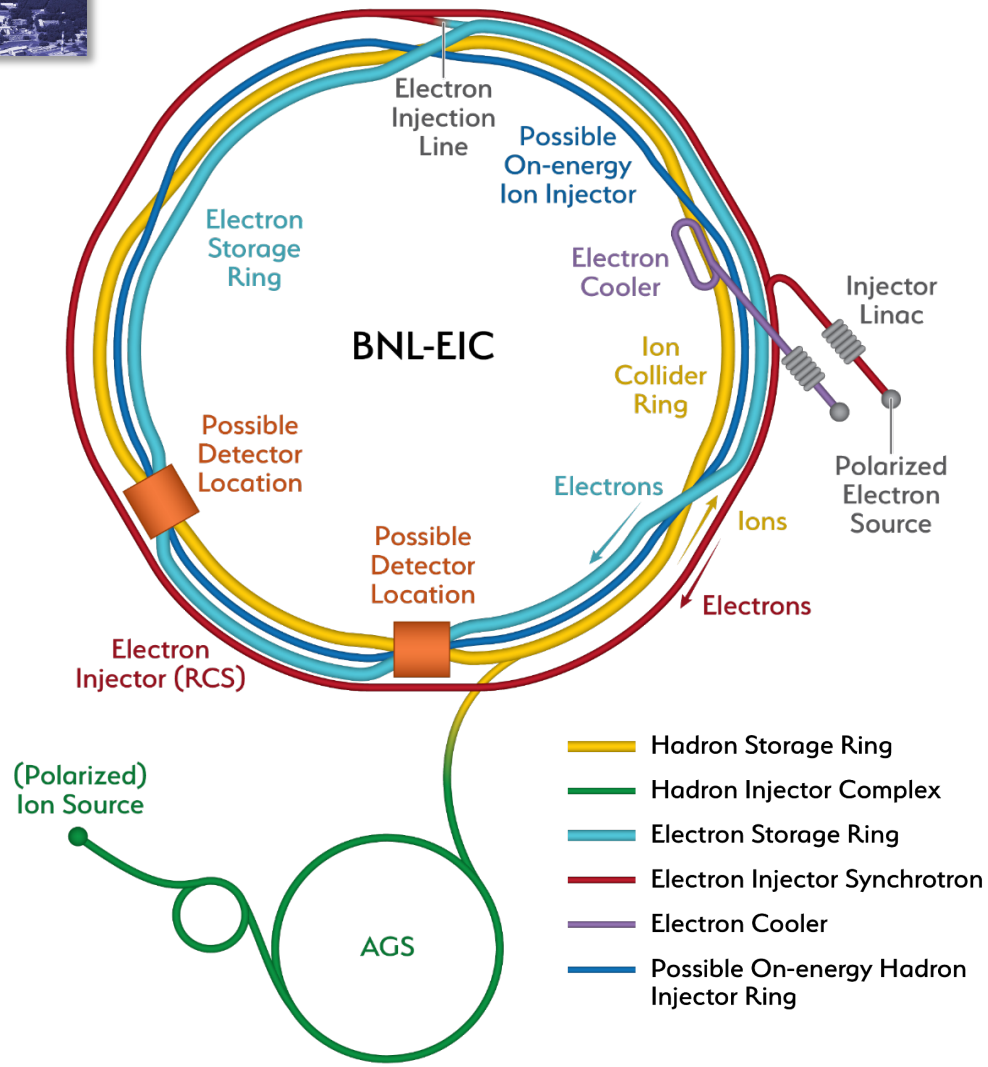
EIC Project & Path Towards Realization

EIC Project Organization

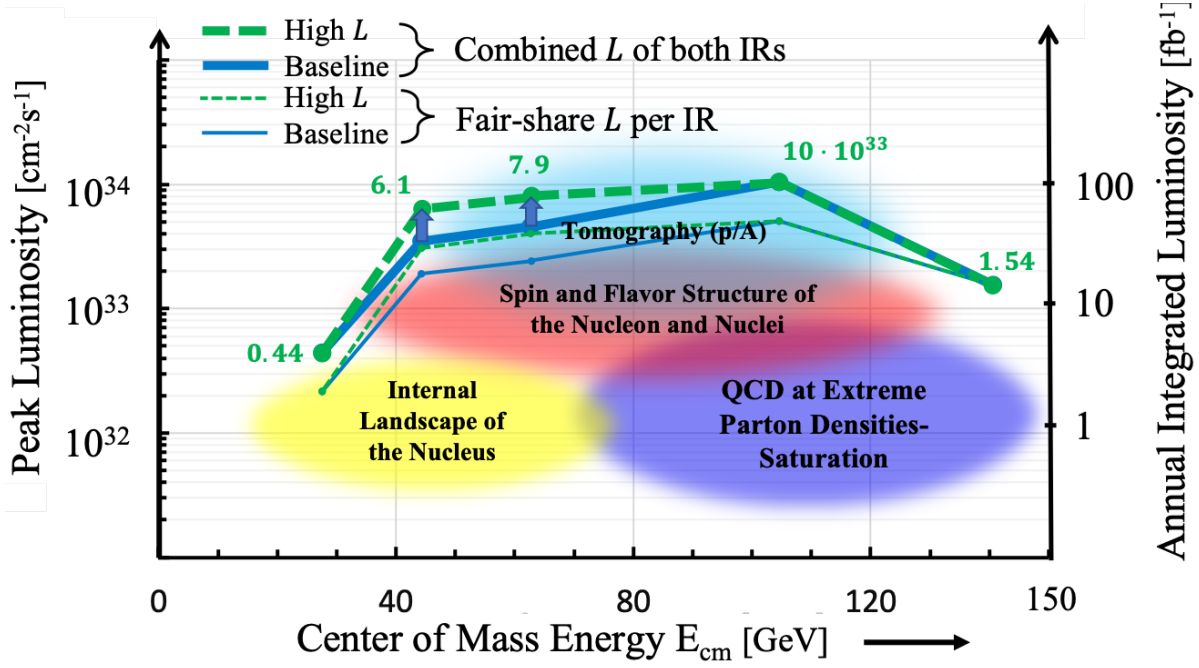




EIC Accelerator Design

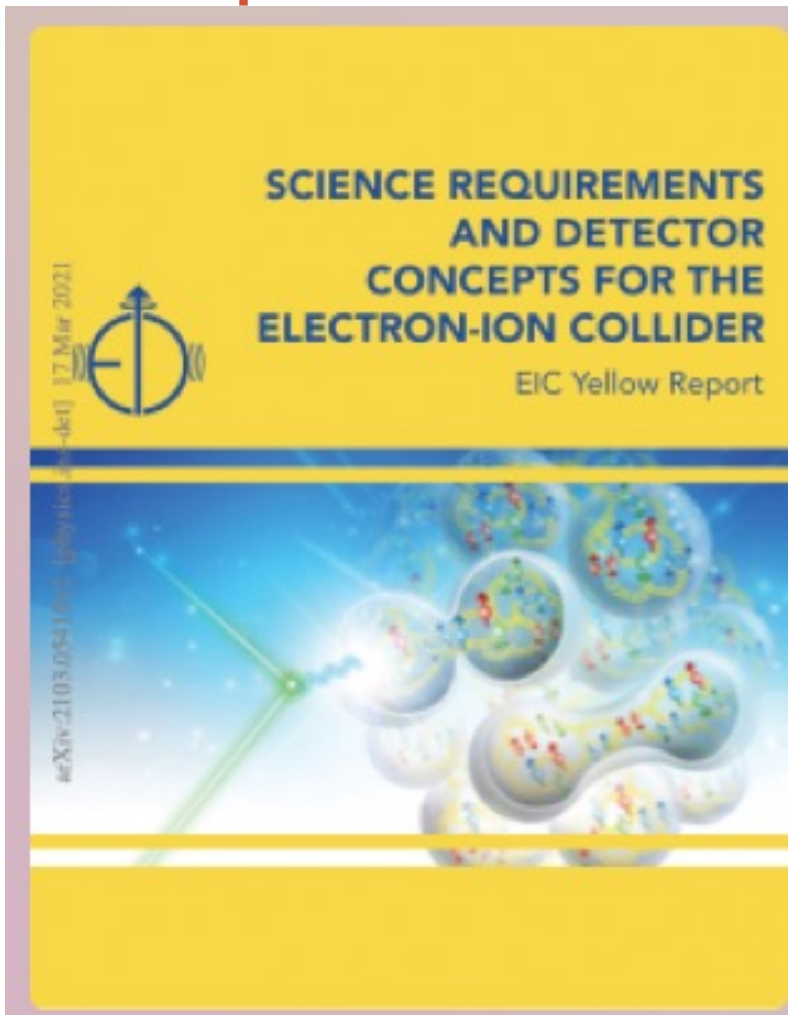


Center of Mass Energies:	20GeV - 140GeV
Luminosity:	10^{33} - 10^{34} $cm^{-2}s^{-1}$ / 10-100fb^{-1} / year
Highly Polarized Beams:	70%
Large Ion Species Range:	p to U
Number of Interaction Regions:	Up to 2!



December 2019 – March 2021
EICUG Yellow Report

- Led by EICUG Steering Committee, a UG-wide effort towards a detailed detector design
- Meetings from December 2019 Boston followed by 4 more meetings in 2020 all remote: Philadelphia, Pavia, Miami, Washington DC, Berkeley



902 pages
415 authors
151 institutions

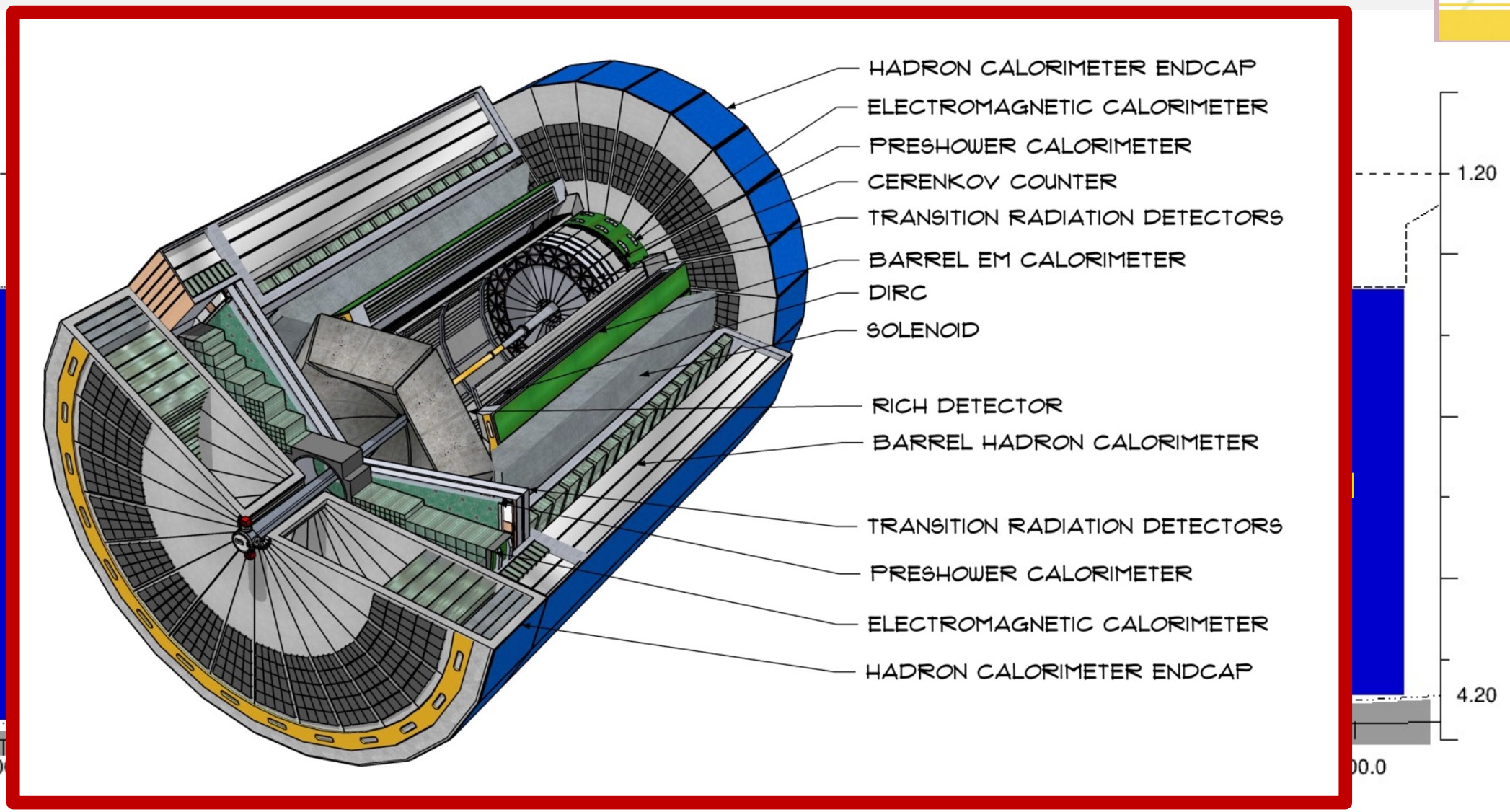
120 MB

R. Abdul Khalek et al.

arXiv:2103.05419v2

Concept DETECTOR

This detector concept was included in the EIC CDR prepared for the CD1 Review

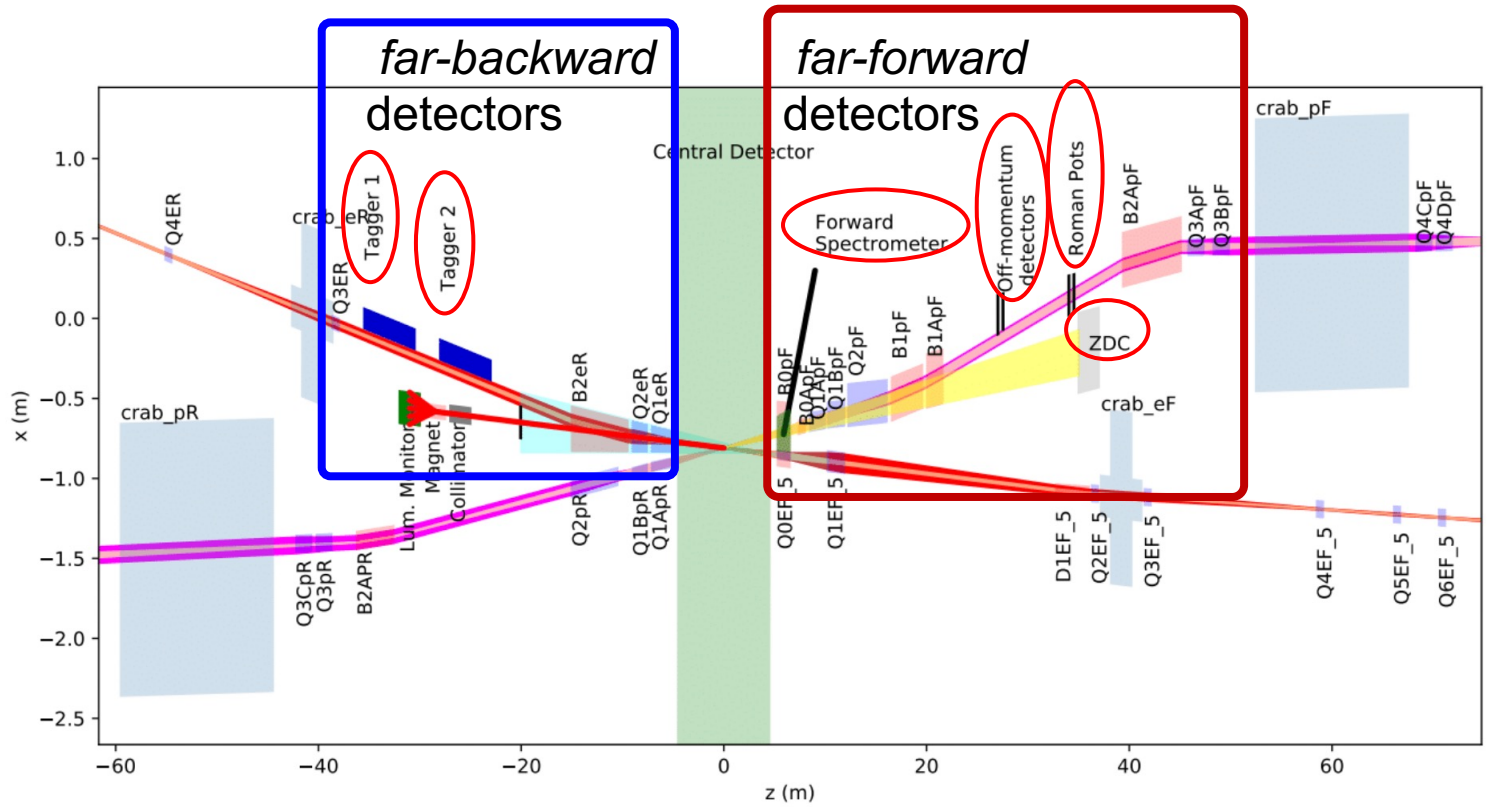


Reference Detector – Backward/Forward Detectors

Highly Integrated detector system: ~75m
1. Central detector: ~10m
2. Backward electron detection: ~35m
3. Forward hadron spectrometer: ~40m

Lesson learned from HERA – ensure low-Q^2 coverage

Various stage detector to capture forward-going protons and neutrons, and also decay products (Δ, Λ).



Ent

Summary of the call for detector proposals

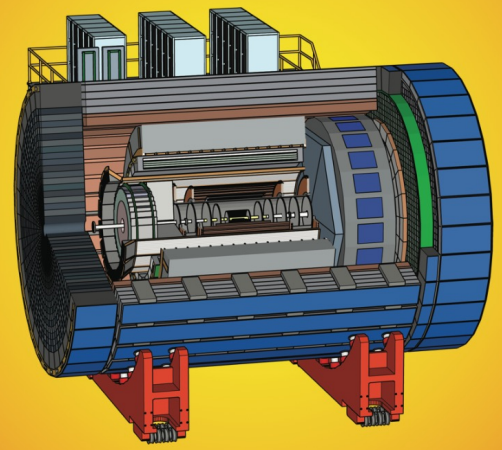
- Detector 1 (D1) : within the scope of the EIC project
  - Will cover most but not all acquisitions
  - Must satisfy EIC "mission need" ➔ Physics of EIC White Paper "blessed" by the NAS
  - Design should be compatible with accelerator & interaction region layout in CDR
  - Completion mandatory by **CD4A** -- @ beginning accelerator operation
- Detector 2 (D2): not within the scope of the EIC project
  - How to realize it are being explored
  - Focus on **specific topic within EIC WP** or (and) **science beyond** the EICWP & NAS
  - IR should be consistent with machine design in CDR, but modified IR design possible
  - Detector should be ready by **CD4 – about 2-5(?) years later**

Siting location of D1 and D2 between IP6 and IP8 is left open, with the caveat that the EIC project has so far assumed D1 will go to IP6

The three proposals

ATHENA Detector Proposal

A Totally Hermetic
Electron Nucleus Apparatus
proposed for IP6 at the Electron-Ion Collider

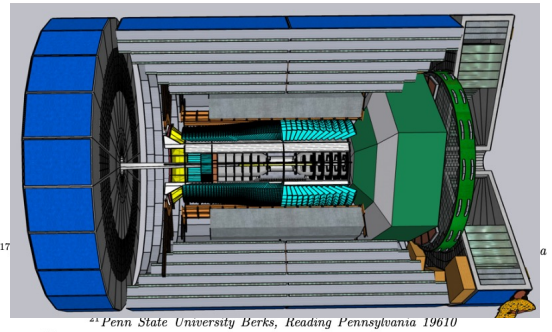


The ATHENA Collaboration
December 1, 2021

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)

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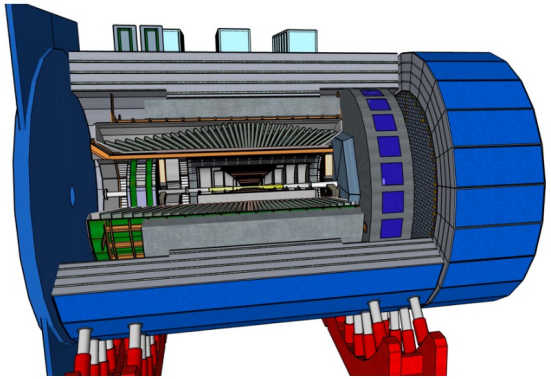
[b] turonski@jlab.org

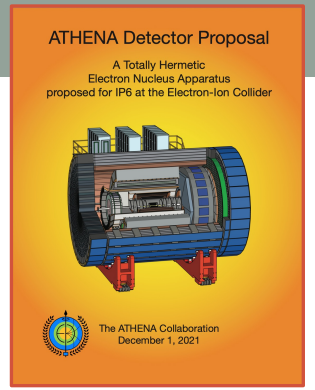
ECCE

EIC Comprehensive Chromodynamics Experiment
Collaboration Detector Proposal



A state of the art detector capable of fully exploiting the science potential of the EIC, realized through the reuse of select instrumentation and infrastructure, to be ready by project CD-4A

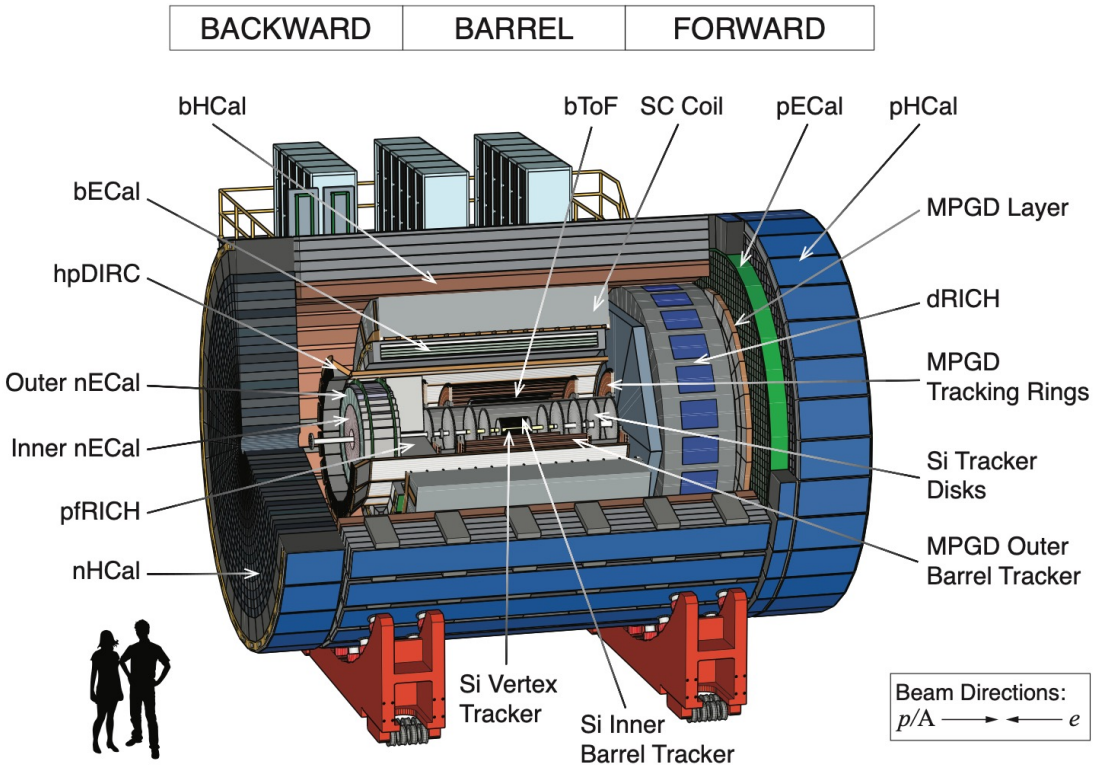
December 1, 2021

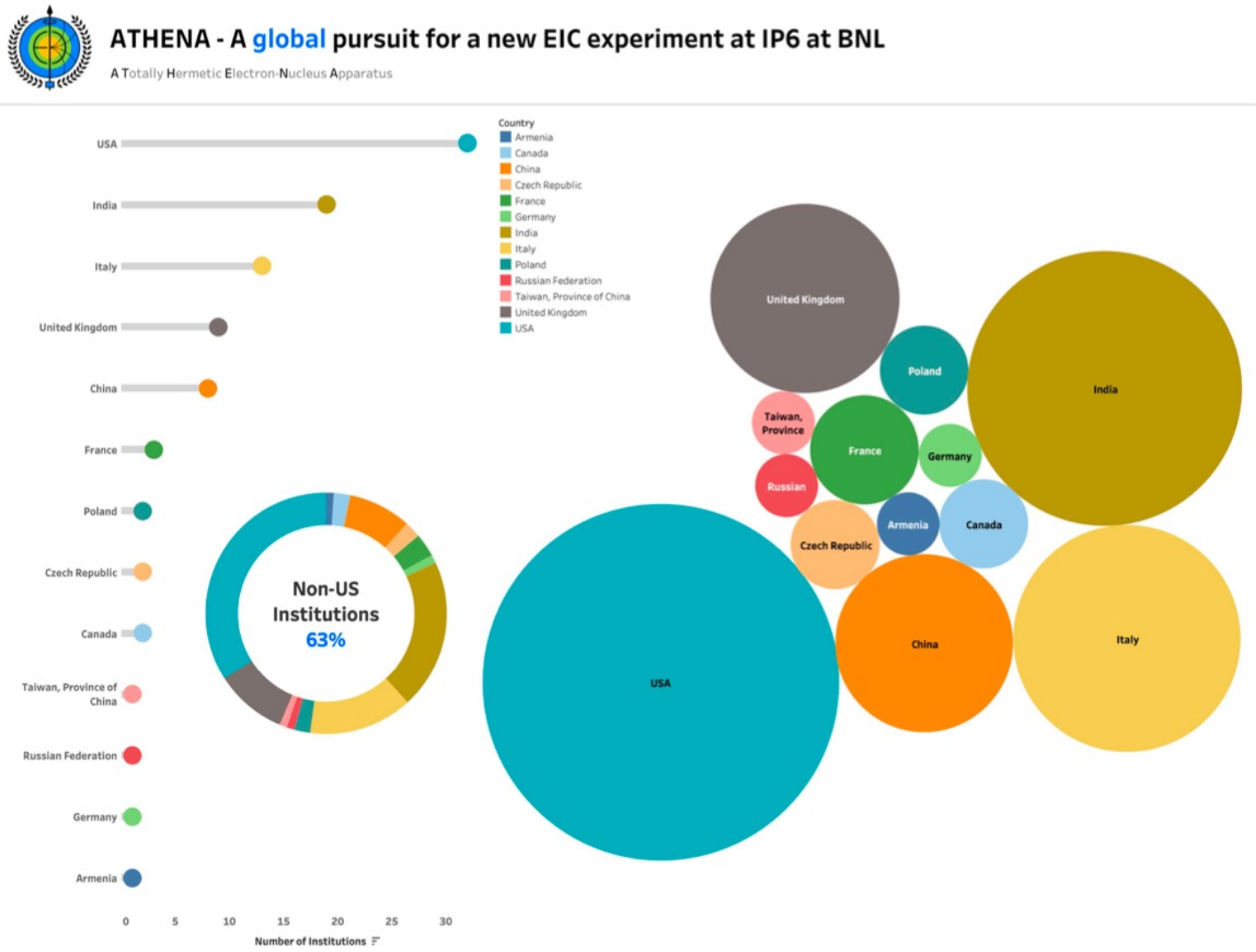


ATHENA

https://athena-eic.org

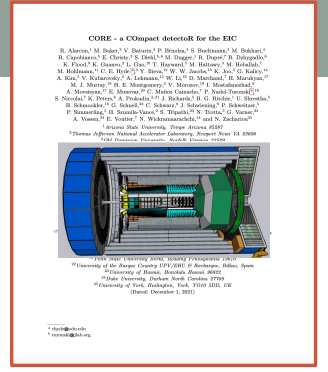
90+ institutions





ATHENA

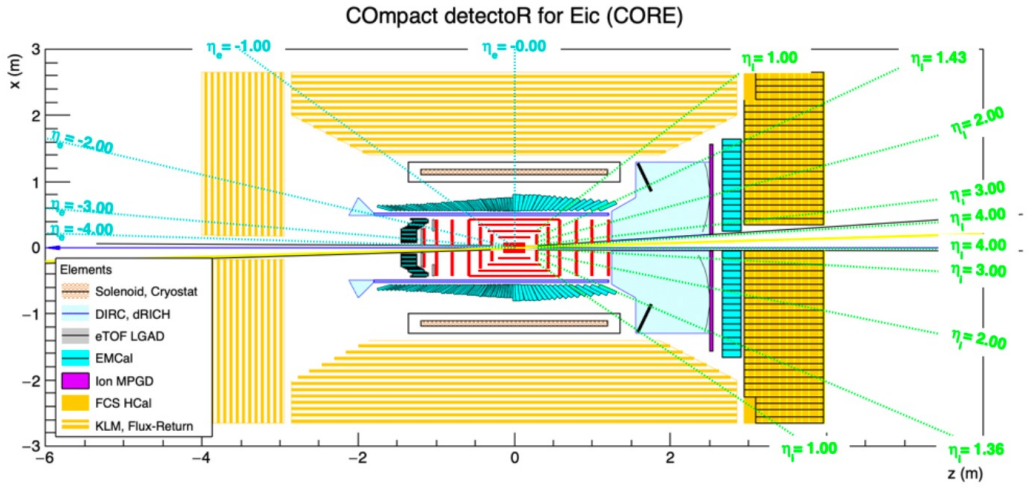
A Totally Hermetic Electron-Nucleus Apparatus


CORE - a COmpact detectoR for the EIC

CORE

https://eic.joab.org/core

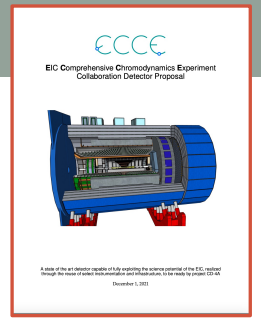
25+ institutions



CORE
COmpact detectoR for EIC

- CORE is a hermetic general-purpose detector for EIC physics outlined in the Yellow Report & EIC White Paper
- COMPACT size has advantages including reduced cost, accommodates closer strong focusing IR magnets to allow high luminosity

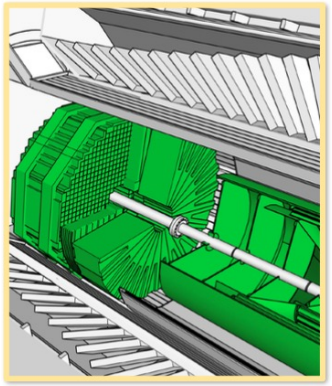
- New 3T magnet, 2.5m long, 1.1m inner radius
- Central all Si tracker, (+ MPGD/GEM in h-endcap)
- Particle ID: AC-LGAD (e-endcap), DIRC Barrel, dRHIC, (h-endcap)
- EMCalorimetry: $PbWO_4$ (barrel and endcap) W-shashlyk (barrel and h-endcap)
- HCal: some new and some from STAR + KLM



ECCE

https://www.ecce-eic.org

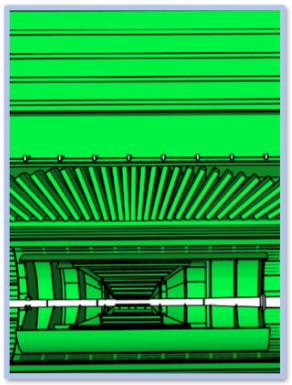
90+ institutions



Backward Endcap

Tracking:
- ITS3 MAPS Si discs (x4)
- AC-LGAD

PID:
- mRICH
- AC-LGAD TOF
- $PbWO_4$ EM Calorimeter (EEMC)



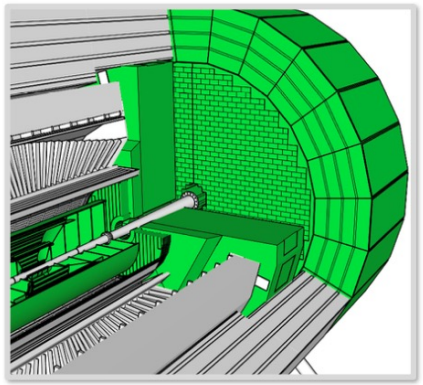
Barrel

Tracking:
- ITS3 MAPS Si (vertex x3; sagitta x2)
- µRWell outer layer (x2)
- AC-LGAD (before hpDIRC)
- µRWell (after hpDIRC)

h-PID:
- AC-LGAD TOF
- hpDIRC

Electron ID:
- SciGlass EM Cal (BEMC)

Hadron calorimetry:
- Outer Fe/Sc Calorimeter (oHCAL)
- Instrumented frame (iHCAL)



Forward Endcap

Tracking:
- ITS3 MAPS Si discs (x5)
- AC-LGAD

PID:
- dRICH
- AC-LGAD TOF

Calorimetry:
- Pb/ScFi shashlik (FEMC)
- Longitudinally separated hadronic calorimeter (LHFCAL)

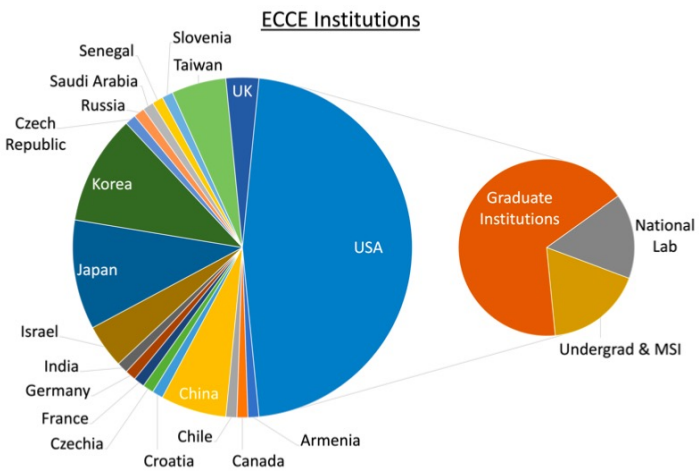
Magnet: 1.5T existing solenoid s-conducting magnet BaBar/sPHENIX

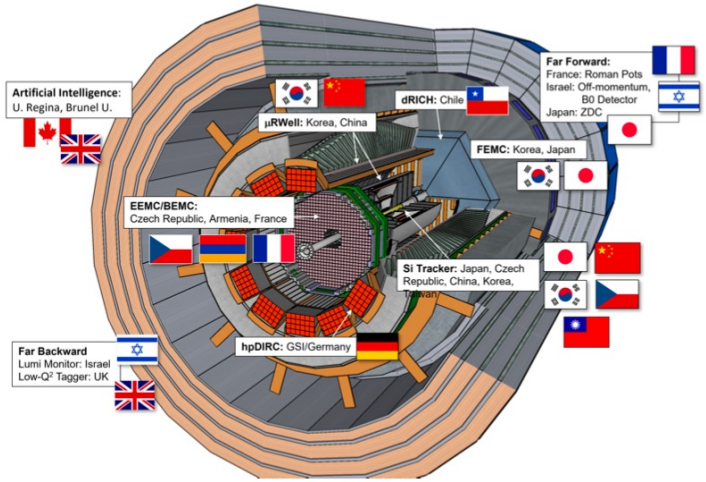
Tracking: Barrel mRWELL, end-caps: Si tracker

Particle ID: barrel hpDIRC, h- dRICH, e-mRICH, AC-LGAD ToF

EMCalorimetry: barrel: projective SiGl, f-endcap: PbSci Shashlik, e-endcap: $PbWO_4$

HCalorimetry: forward Steel-scintillator, Central barrel: Steel



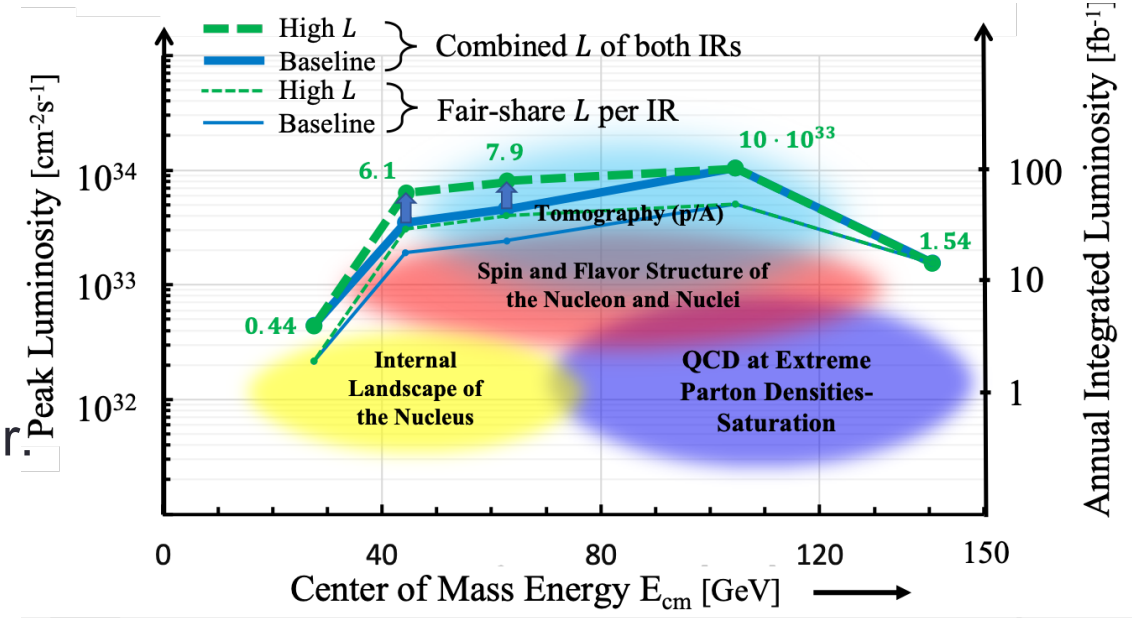


ECCE

EIC Comprehensive Chromodynamics Experiment

A White Paper on: Physics with Low CM & High Luminosity
A dedicated detector at IP8?

- Aim: to produce a White Paper to highlight the science at the EIC with a **high-luminosity at low-CM energy Interaction Region.**
  - DES, SIDIS, Jets, HF, Spectroscopy, various researches with light nuclei
  - Contact: Volker Burkert, Latifa Elouadrhiri, AD, X. Ji
- Conditions from the Call for proposal for the 2nd detector.
  - D2/IR2 complementary to D1/IR1, physics focus beyond EIC WP, and possibly modified IR2 design (compatible with IR1 and machine operations)
- Series of Center for Frontiers In Nuclear Science Workshops: 1st @ CFNS, 2nd @ ANL-CFNS, 3rd APCTP-CFNS, 4th CNF-CFNS (DC) in Spring 2022.



Recent machine development and studies
Possible to get high luminosity by only adjusting magnetic polarities of near-IR magnets

Timeline for Proposal Evaluation

December 1, 2021 Proposals submitted: ATHENA, ECCE, CORE expected

Proposals distributed to Advisory Panel and DAC members

December 13-15, 2021 First public Advisory Panel meeting (3 days, Virtual)

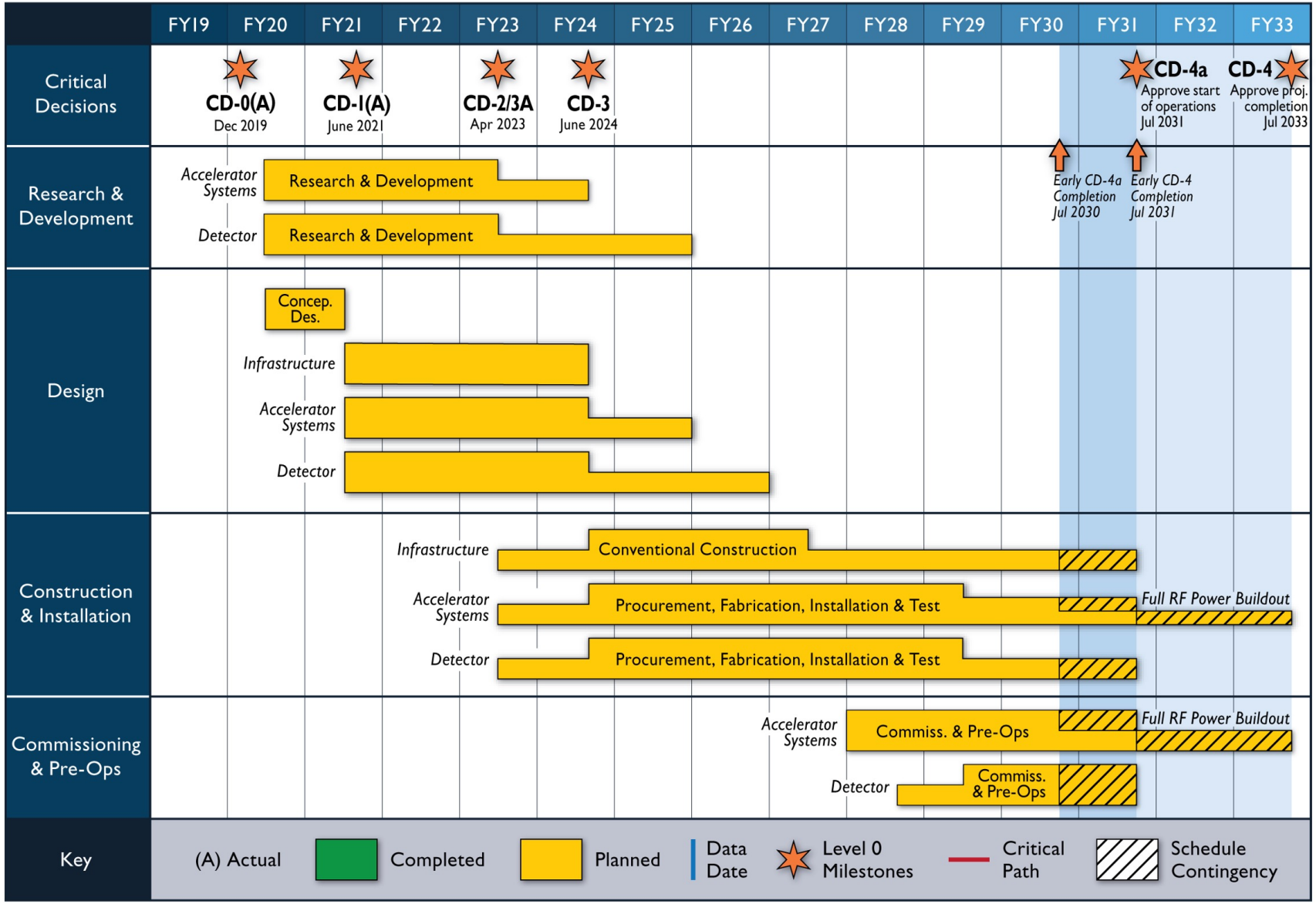
- Presentations from proto-collaborations
- Panel discussion of DAC input (written report)
- Panel develops homework questions for collaborations to address at January meeting

January 19-21, 2022 Second 3-day public Advisory Panel meeting

- Responses to homework and further input from DAC
- Panel begins Report writing

March 1, 2022 Panel Report & Recommendations submitted

Reference Schedule



J. Yeck, EICUG Meeting

Summary: Challenging but EXCITING times ahead

EIC Science : enthusiastically supported by NAS & 1300+ (growing) users, 254 institutions and 34 countries from 6 continents

EIC Project is moving forward with great speed within the DOE at BNL working closely with JLab

- International partners are significant component of the success:

EIC Detector: unique in its demanding: IR integration: Designs being developed and finalized

- Three detector proposals submitted in response to the Call for Proposals – Decision by March 2022

Precision anticipated from the EIC will push theory on multiple fronts: LO, NLO, NNLO and resummation, lattice/continuum QCD methods, aspects of universality, explicit proofs of factorization will become essential components for physics in 2030's. (no long room for "hand-waving" arguments)

An exciting symbiotic program between experiment and theory could emerge on many fronts: Mass, spin of hadrons, mesons… nuclei…

Thank you.