Center for Frontiers in Nuclear Science

Why a second detector at the EIC?

Abhay Deshpande

EIC Workshop 1: Experimental Opportunities and Challenges Workshop

November 2, 2023

These are my personal thoughts, not “the opinion” of the EIC Project

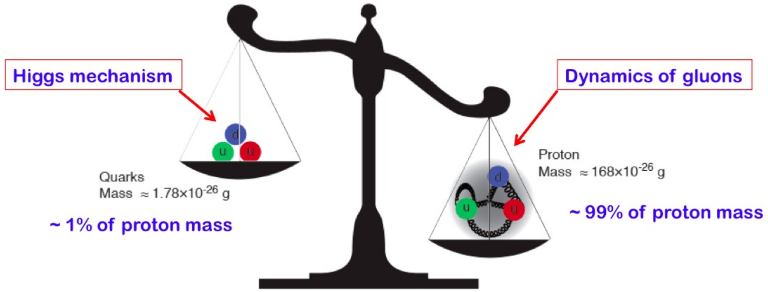
(although they should be ;-))

Background against which we will make this case…

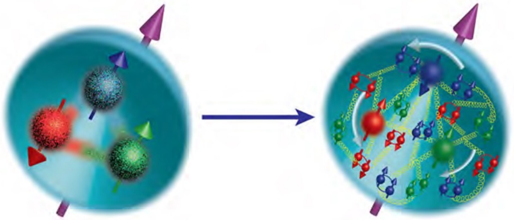
Where is EIC now and what physics is being pursued?

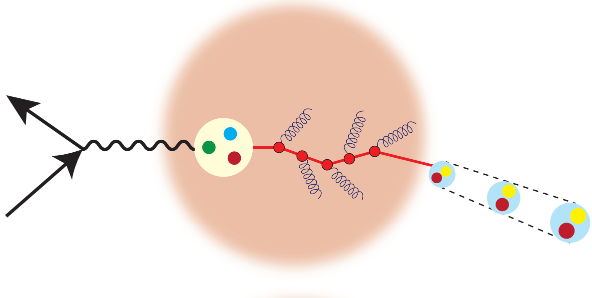
EIC Physics at-a-Glance

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

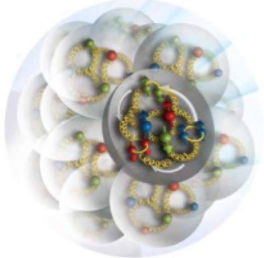


How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties (mass & spin) emerge from their interactions?



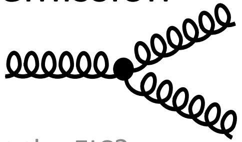


How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?



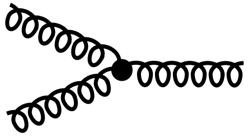
How does a dense nuclear environment affect the quark- and gluon- distributions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?

gluon emission

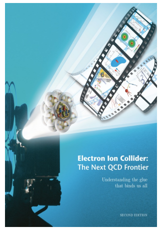


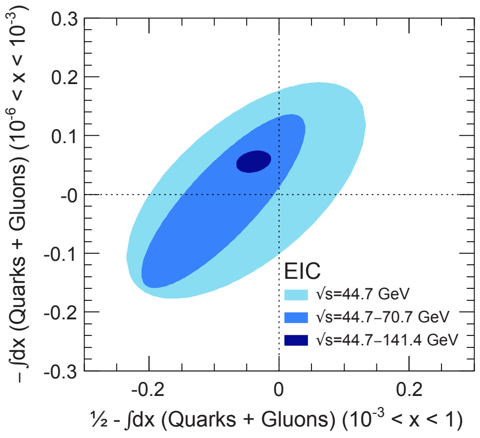
?
=

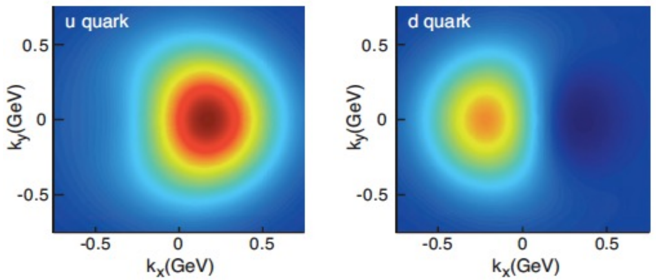
gluon recombination

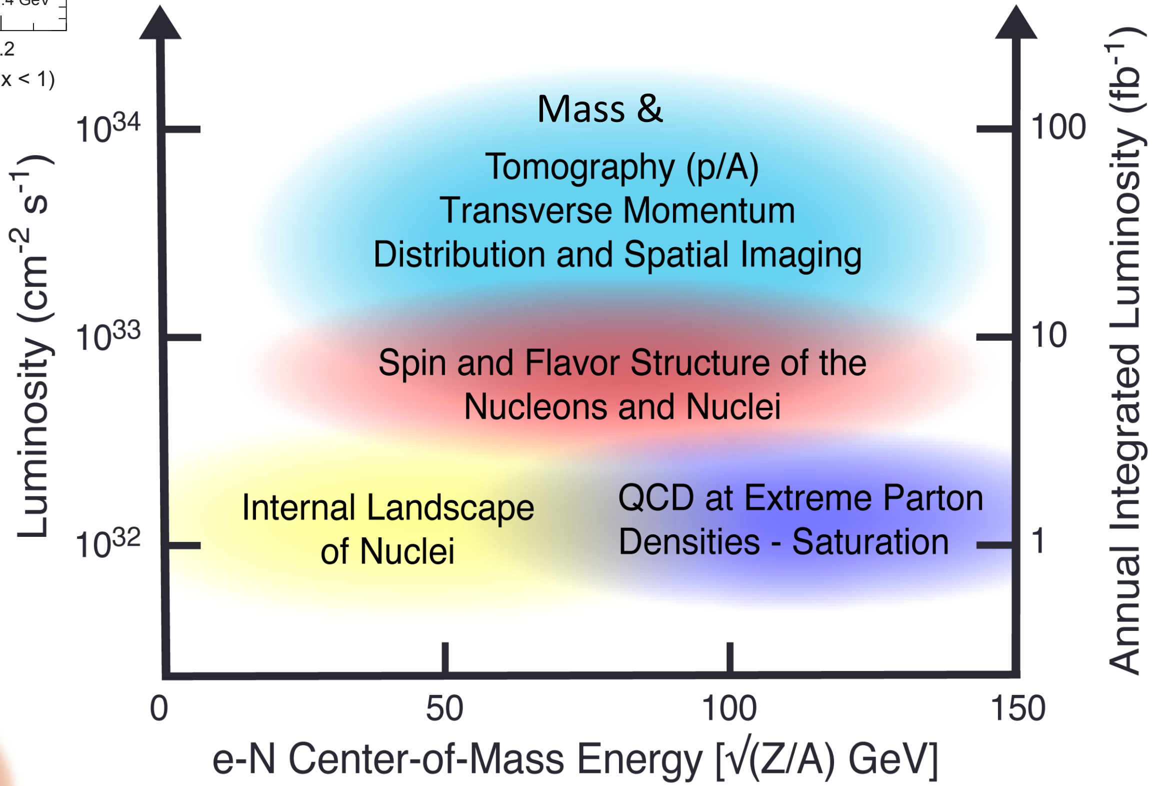


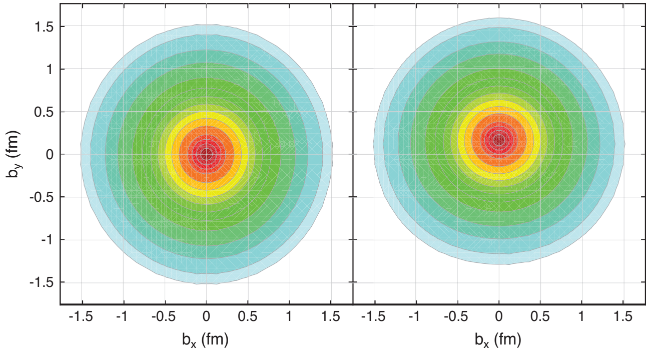
EIC science highlights

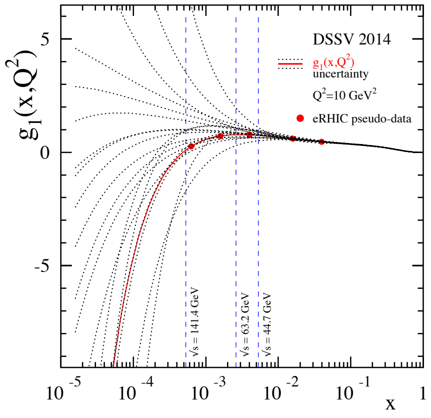


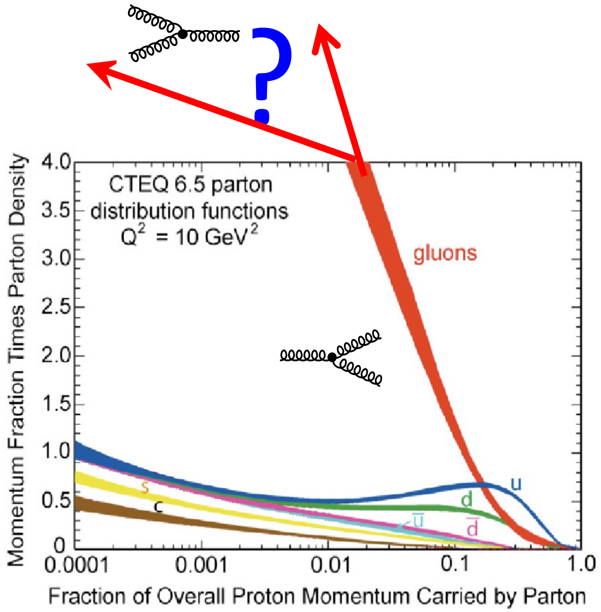


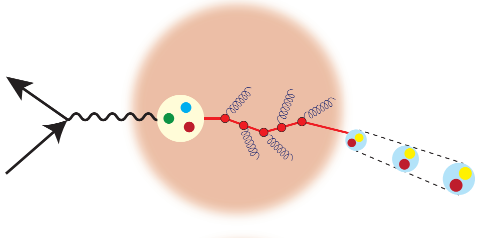




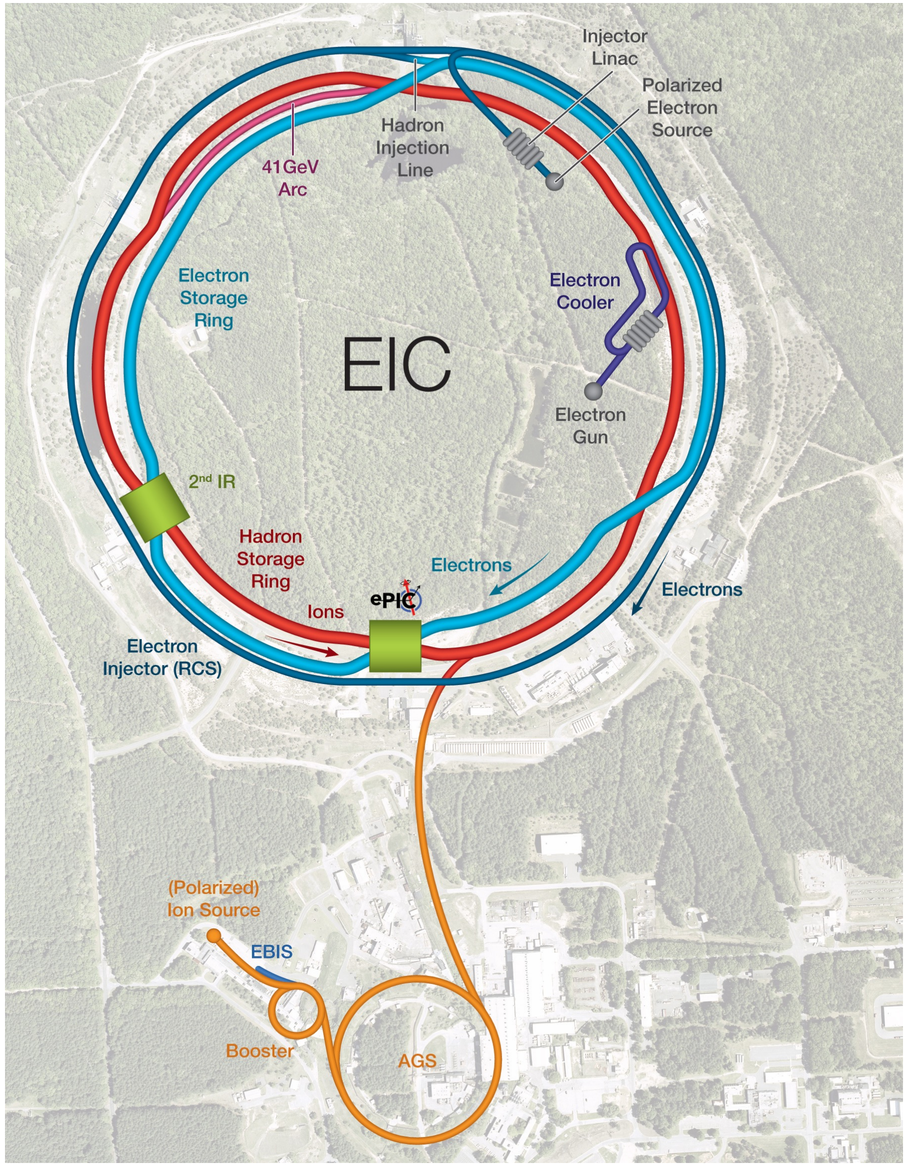




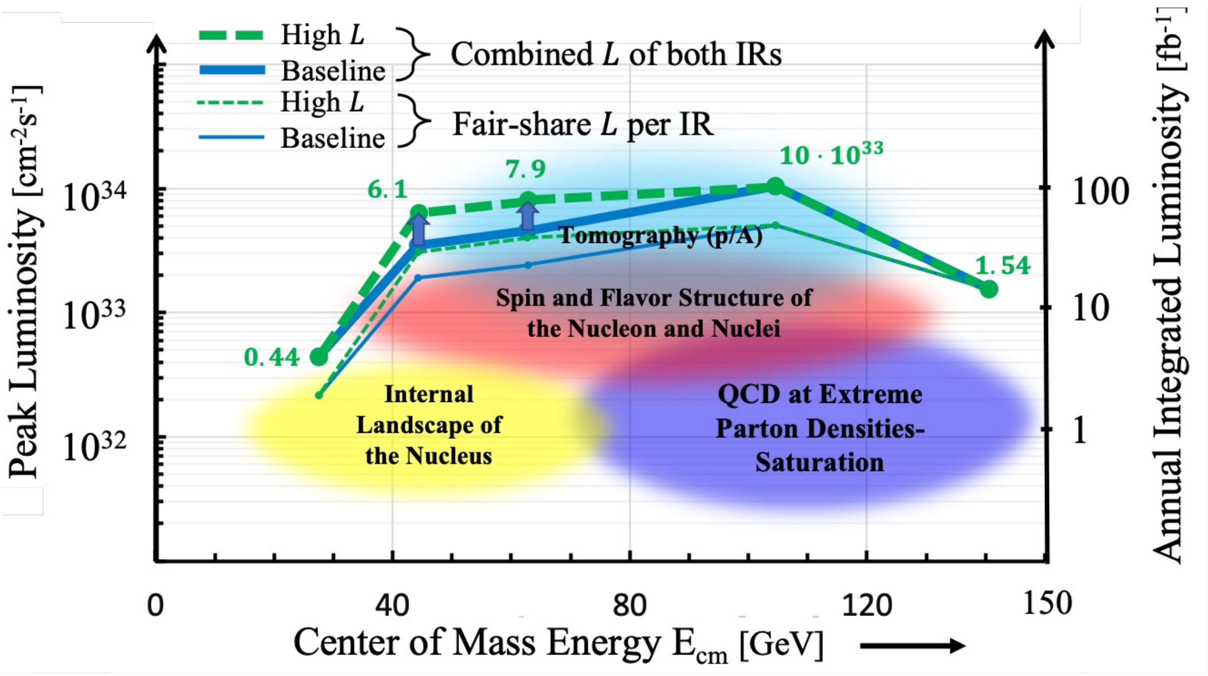




EIC Accelerator Design

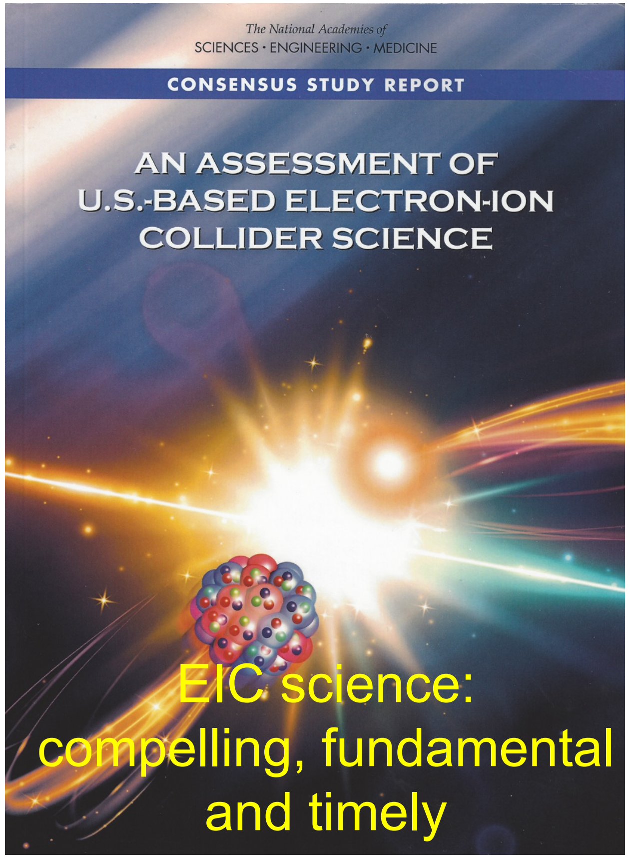


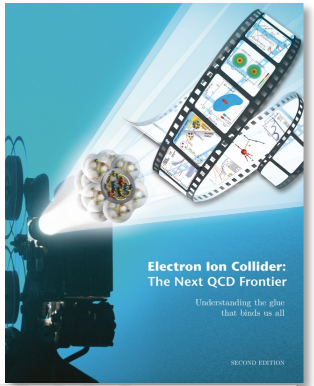
Center of Mass Energies:	20GeV - 140GeV
Luminosity:	10^{33} - 10^{34} $cm^{-2}s^{-1}$ / 10-100fb^{-1} / year
Highly Polarized Beams:	70%
Large Ion Species Range:	p to U
Number of Interaction Regions:	Up to 2!

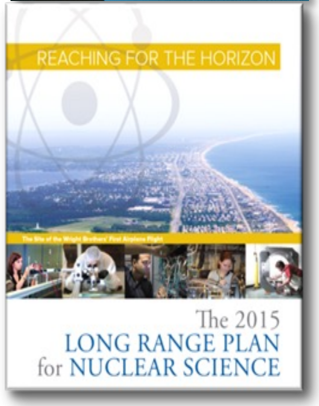


National Academy of Science, Engineering and Medicine

Assessment July 2018







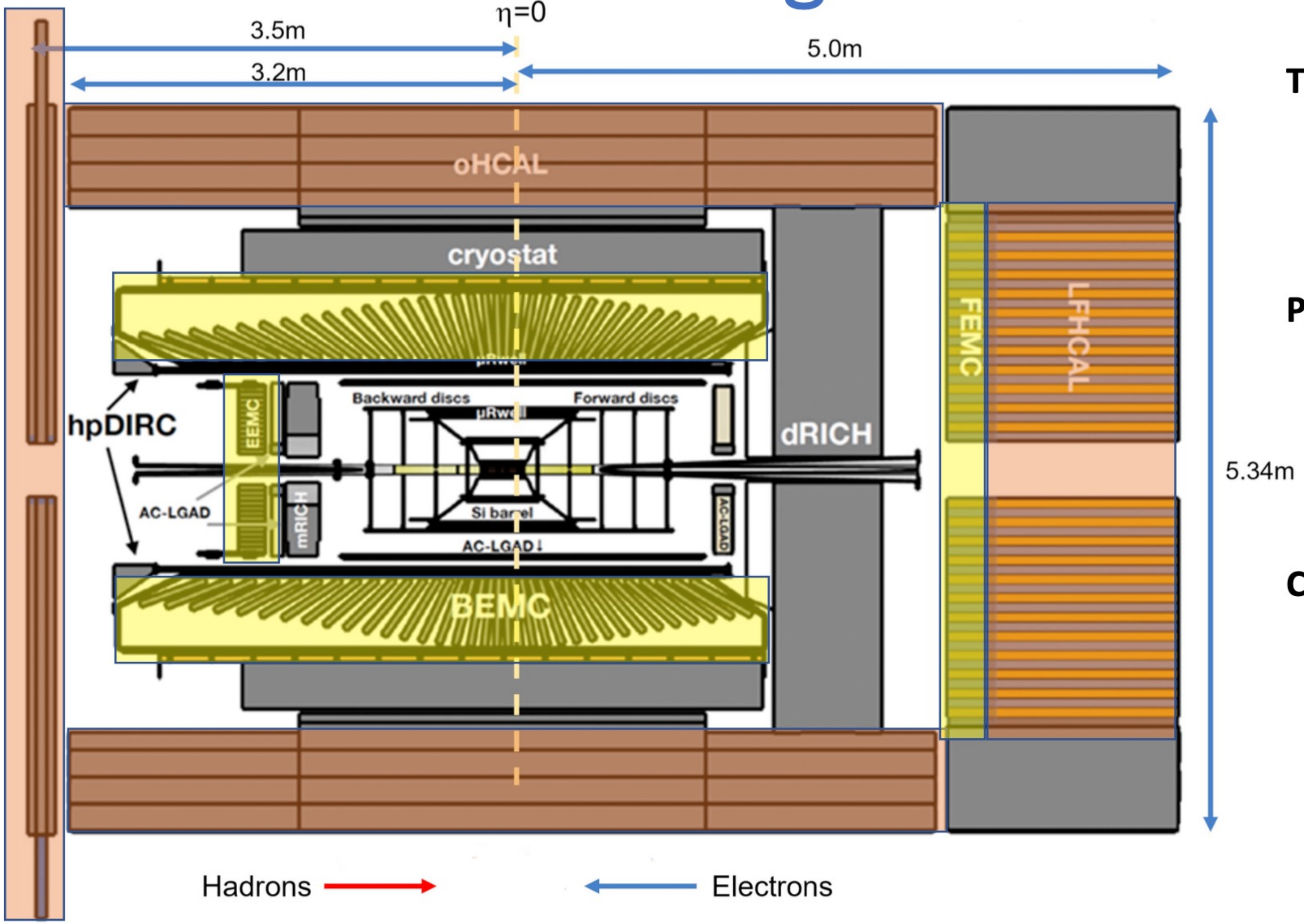
Physics of EIC

- 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

ePIC Detector Design



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)
- Backwards HCal (tail-catcher)

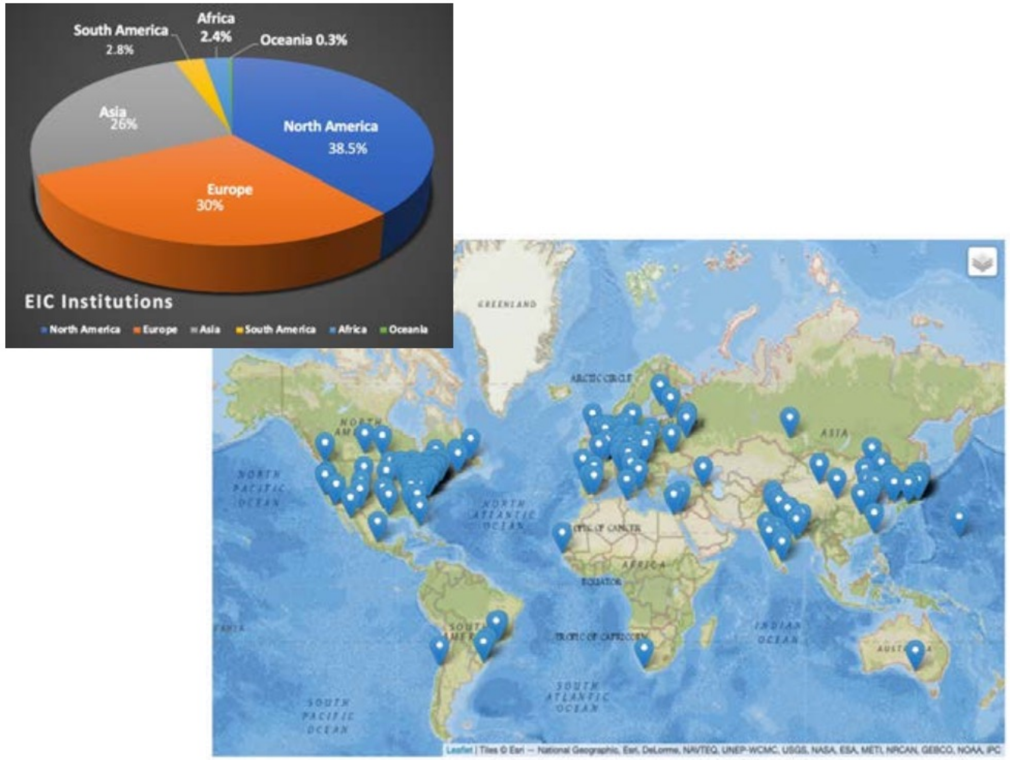
World-Wide Interest in EIC and ePIC

The EIC Users Group: EICUG.ORG

Formed 2016, Current Status

1430 collaborators, 38 countries, 291 institutions

(Experimentalists 897, Theory 362, Acc. Sci. 156)



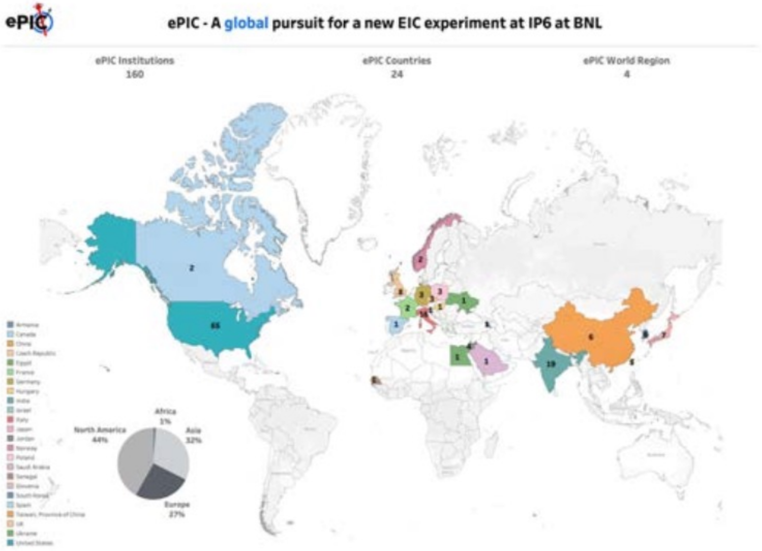
ePIC Collaboration Established December 2022

- Spokesperson: John Lajoie (Iowa State)

  Deputy – Spokesperson: Silvia Dalla Torre (INFN Trieste)

ePIC is now 171 institutions representing 24 countries with 500+ participants

15 new institutions joined since July 2023

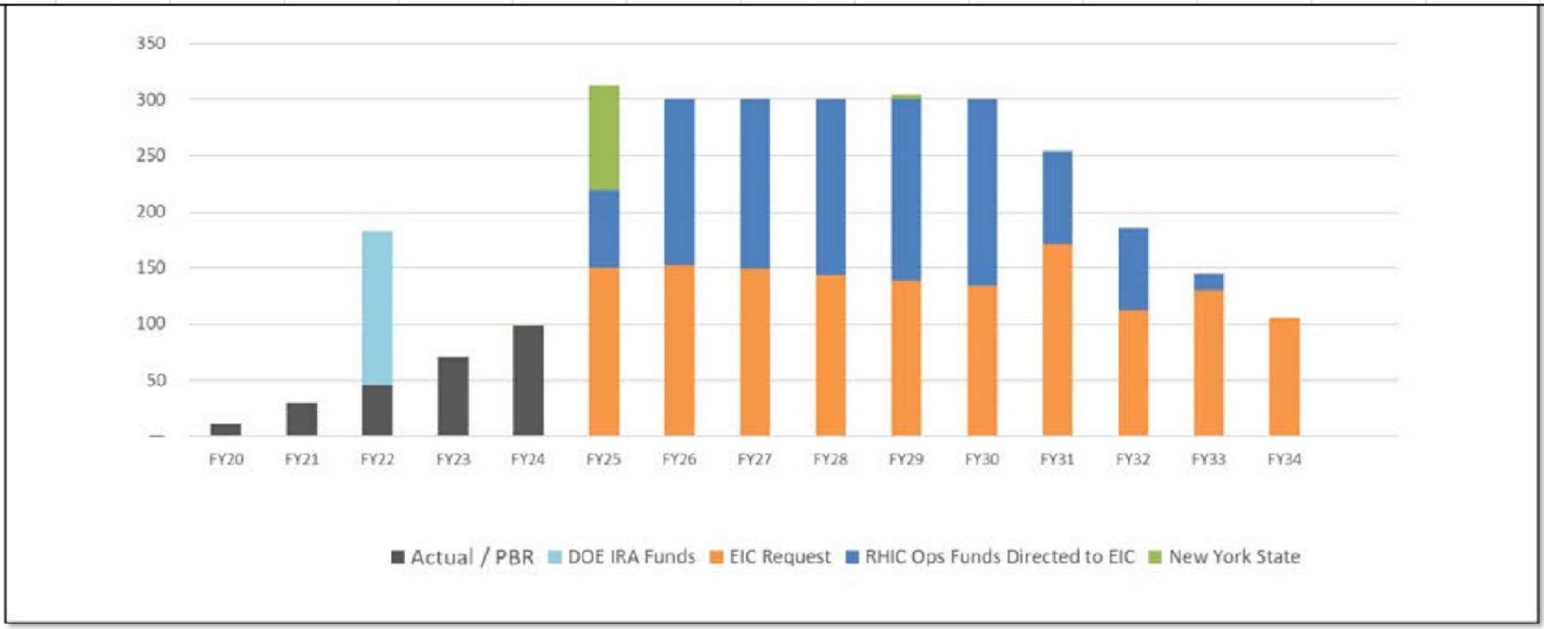


Details:

https://wiki.bnl.gov/EPIC/index.php?title=Main_Page

Reference DOE Funding Profile- V4

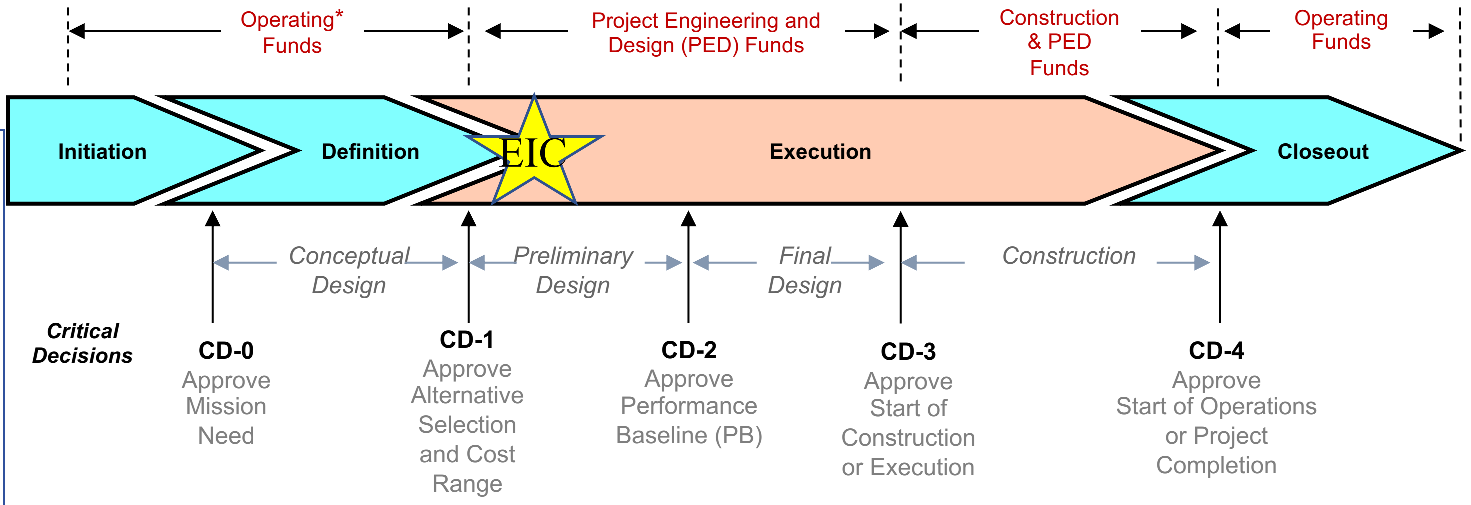
	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34
TEC	1	5	146	50	95	216	300	300	300	275	275	200	130	120	80
OPC	10	25	37	20	3	3	0	0	0	25	25	54	55	25	25
Total	11	30	183	70	98	219	300	300	300	300	300	254	185	145	105



Total EIC funding commitments through FY2024 is expected to be $492.5M

- DOE funding through FY2023, including $138M of IRA funding = $294M
- FY24 PBR = $98.5M
- Pending NYS commitment = $100M

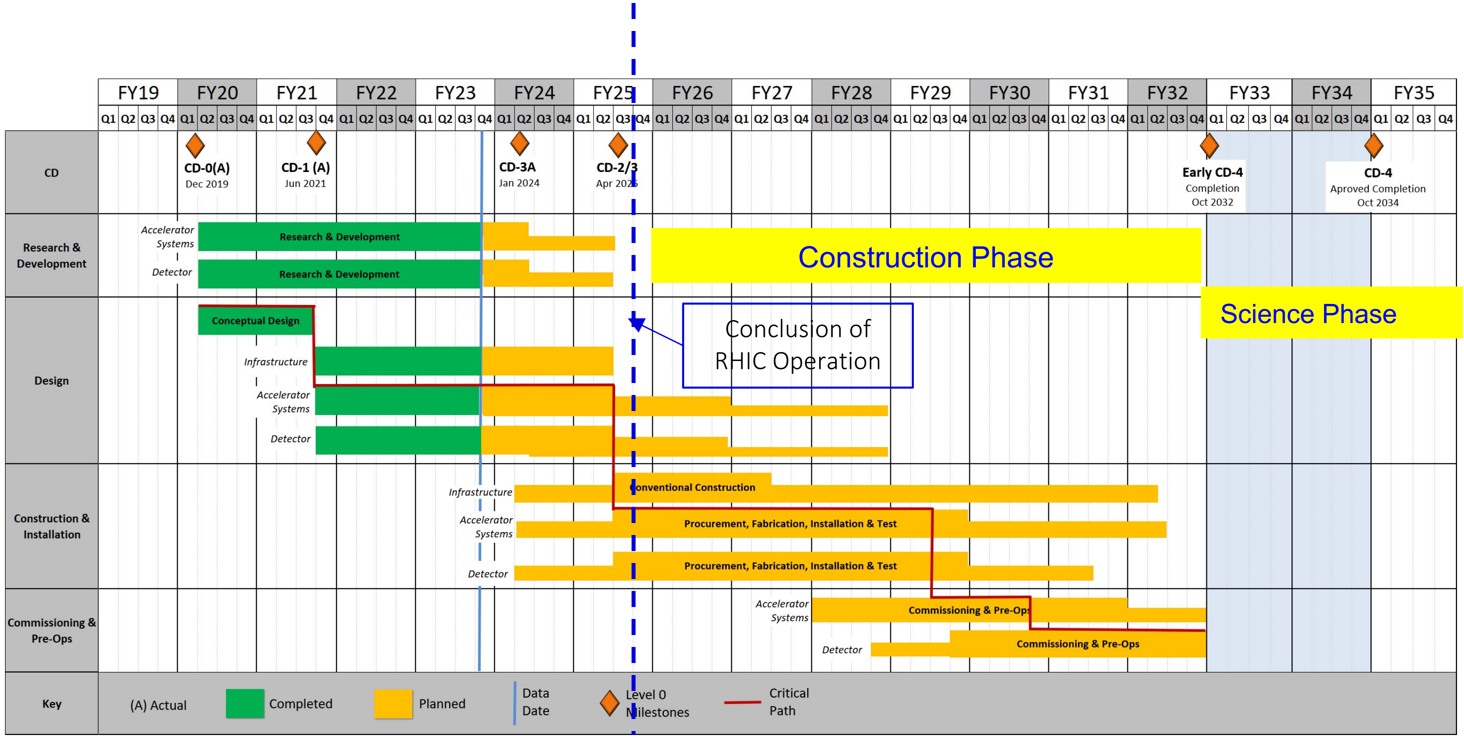
Timeline:



EIC Critical Decision Plan

CD-0/Site Selection	December 2019 ✓
CD-1	June 2021 ✓
CD-3A	**January 2024**
CD-2/3	**April 2025**
CD-4A	October 2032
CD-4	**October 2034**

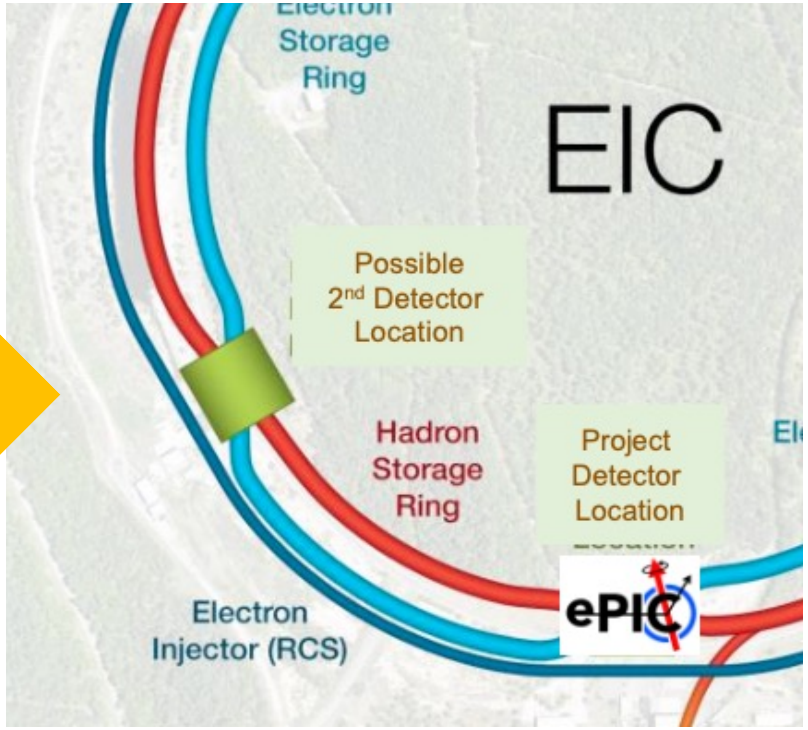
CD-3A: (review mid-November)
Define Baseline:
technologies, Scope, Cost & Schedule
Long Lead Procurement (LLP) items
Design Maturity: ~90%
Plan is tracked through EVMS
& Change control process
Start of construction for LLPs



While EIC project (machine and 1st detector) has to succeed…. We also need to sow the seeds for a 2nd detector

When it comes to detectors: 1 + 1 > 2

The 2nd detector



NSAC documents 2015: talk about possibly ~4 detectors

NAS Report 2018 : planning for up to 2 well-integrated detectors

EICUG 2018 – Present : desires 2 Detectors

EIC Project funds support: 1 Machine, 1 Interaction Region and 1 Detector

without negating the possibility of the 2nd IR/Detector

Cost? = cost of IR infrastructure + a new Detector

Two documents: Overlapping Arguments

EICUG SC produced a document

JLAB-PHY-23-3761

Motivation for Two Detectors at a Particle Physics Collider

Paul D. Grannis[*] and Hugh E. Montgomery[†]
(Dated: March 27, 2023)

It is generally accepted that it is preferable to build two general purpose detectors at any given collider facility. We reinforce this point by discussing a number of aspects and particular instances in which this has been important. The examples are taken mainly, but not exclusively, from experience at the Tevatron collider.

arXiv: 2303.08228v2 March 24, 20234

Case for two detectors being made from **Nuclear** and **Particle** Physics

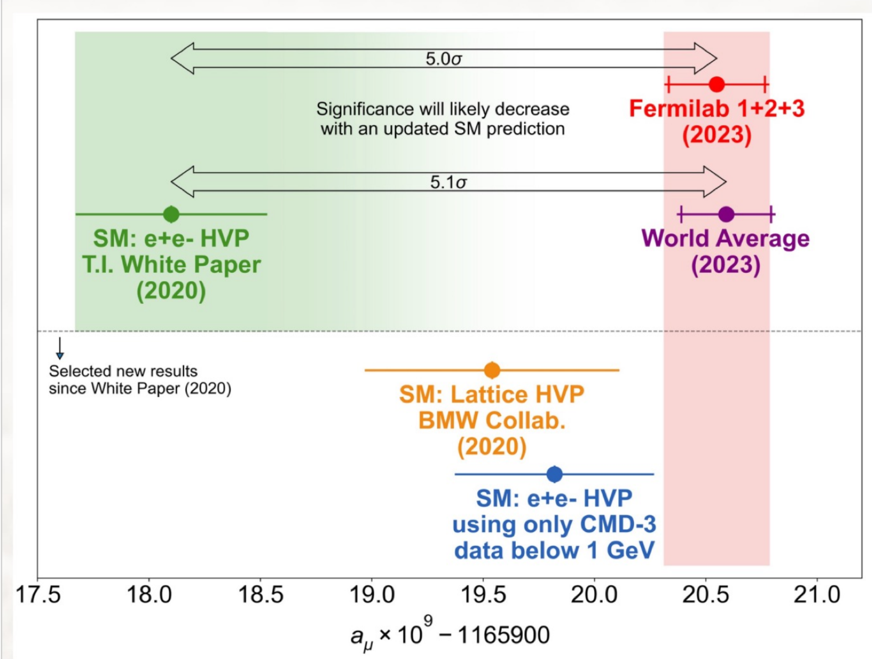
History: Discoveries established with **more than one** detectors in Nuclear Science

- Discovery of gluon : TASSO, JADE, Mark J, and PLUTO @ DESY
- H1 and ZEUS at Rise of F_2 and hence the gluon dominance at low-x
- BRAHMS, PHOBOS, PHENIX and STAR Discovery and establishing the existence of Quark Gluon Plasma
- Measurements at DESY and JLab eventually led to “parton imaging”

- EMC/CERN discovered and then SMC/CERN and EXXX/SLAC established nucleon spin crisis (low-x) & EMC discovered and then NMC/CERN & E865/FNAL established nuclear effects on nucleon PDFs (also low-x)

Tension: take-home message #1 g-2 (after 10/2023)

Systematic/statistical error ratios: lattice ≈2; R-ratio ≈4



Experimental result

- Recent result at Fermilab (2023)

$$a_\mu(\text{FNAL}) = 11\,659\,205.5(2.4) \cdot 10^{-10} \quad (0.20\,\text{ppm})$$

- Equivalent to: bathroom scale sensitive to weight of a single eyelash.

- Fully agrees with the BNL E821 measurement

$$a_\mu(\text{BNL}) = 11\,659\,209.1(6.3) \cdot 10^{-10} \quad (0.54\,\text{ppm})$$
$$a_\mu(\text{combined}) = 11\,659\,205.9(2.2) \cdot 10^{-10} \quad (0.19\,\text{ppm})$$

- Final target uncertainty (1.6)
- J-PARC experiment very different systematics but same accuracy (2027)

Muon g-2… example presented by Prof. Fodor

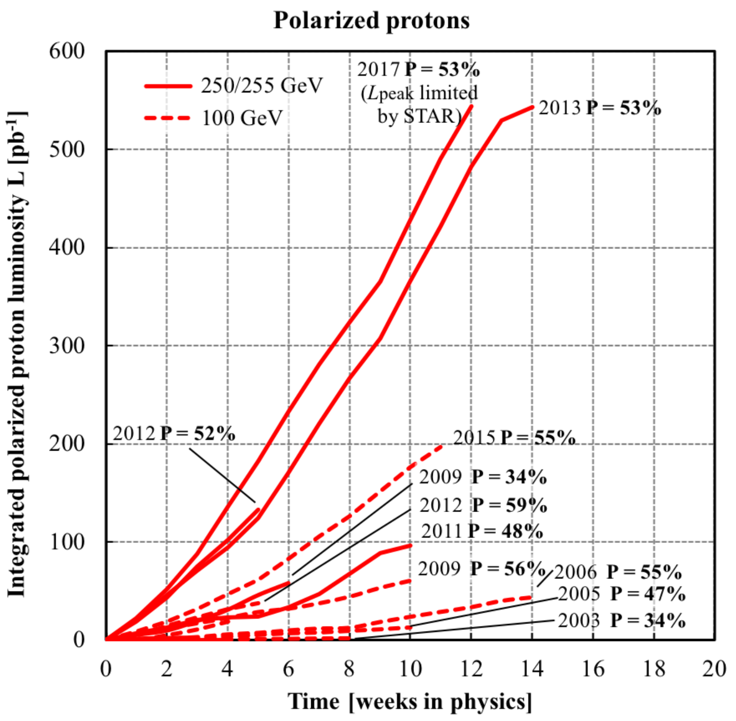
Two detectors (independent cross checks) build trust in novel discoveries and prevents historical mistakes

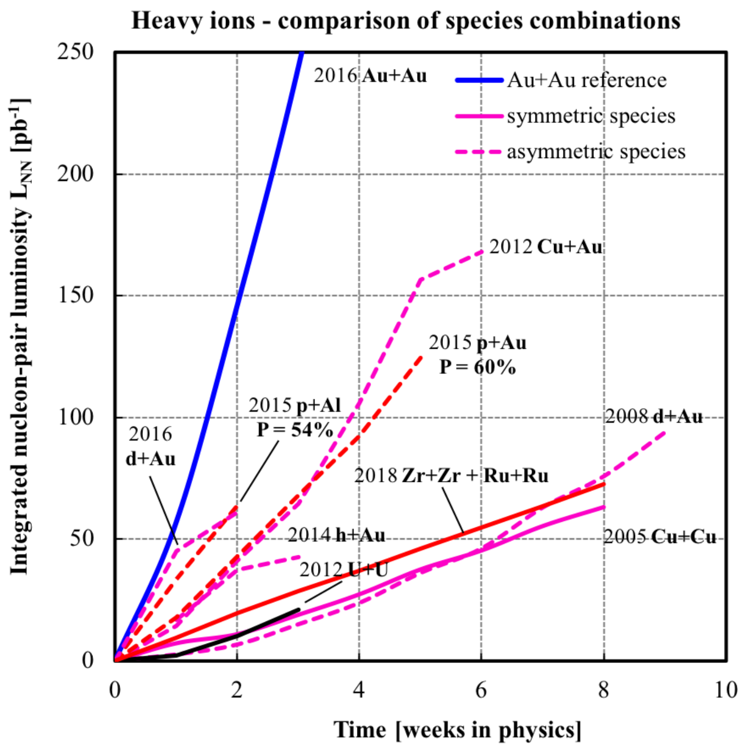
Building Trust

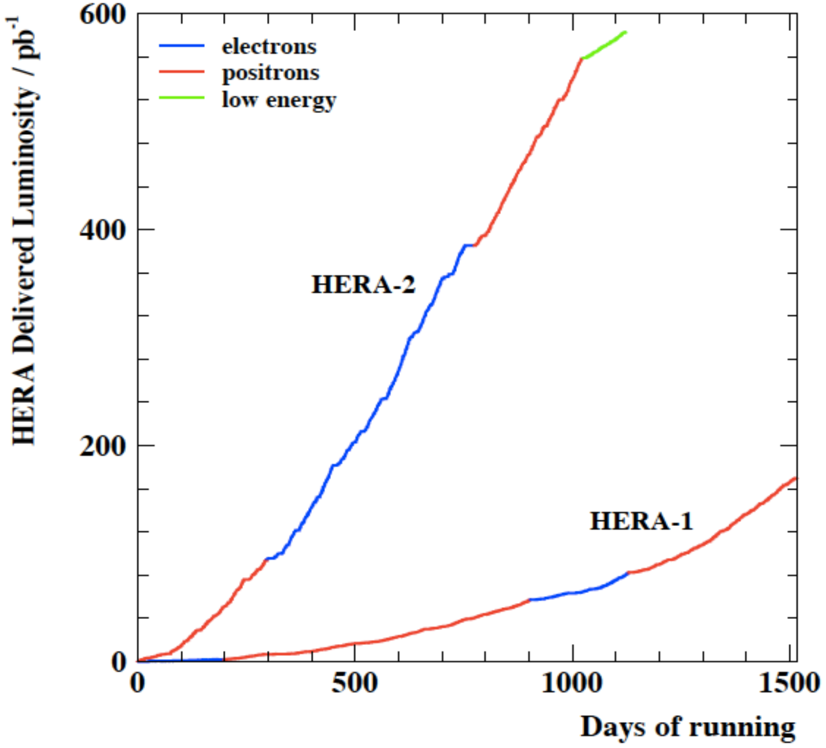
- Quark Gluon Plasma: RHIC Experiments
- Discovery of Top Quark D0/CDF
- Discovery of Higgs Boson: ATLAS and CMS
- Gravitational Waves: LIGO and VIRGO
- Neutrino oscillations

Mistakes or misinterpretations:

- Cold fusion
- 17 KeV neutrinos in Tritium
- Superluminal neutrinos
- Leptoquarks
- Pentaquarks from 2000's







Lessons from HERA and RHIC:

Start of the machine slow and deliberate

Development of polarization (with luminosity) takes time but early investments pay-off

Lesson from Tevatron:

D0 came 5 years later than CDF with no real difference in physics output

Lesson from C. Montag (day 1)

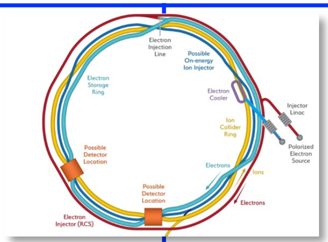
Luminosity Sharing with two IRs

- Both electrons and hadrons are at the beam-beam limit with one collision point – they would not “survive” a second IR
- To enable two collision points, both electron and hadron bunch intensity would have to be reduced by a factor two – resulting luminosity at each IR would be factor 4 smaller
- Instead, we modify the fill pattern such that half the bunches collide in IR6, while the other half collides in IR8
- As a result, total luminosity is preserved, and each detector gets half of the total

Opportunity for complementary detector designs for different IRs exists!

Complementarity for 1^{st}-IR & 2^{nd}-IR

	1^{st} IR (IP-6) ePIC	2^{nd} IR (IP-8)
Geometry:	tunnel and assembly hall are larger Tunnel: ⃠ 7m +/- 140m	tunnel and assembly hall are smaller Tunnel: ⃠ 6.3m to 60m then 5.3m
Crossing Angle:	25 mrad	35 mrad secondary focus
	different blind spots different forward detectors and acceptances	
Focusing:	Optimize Doublet focusing FDD vs. FDF → impact of far forward p_T acceptance	
Experiment:	1.7 Tesla or 2-3 (?) Tesla different subdetector technologies in all directions	



Potential Physics topics beyond EPIC detector's mandate?

Focus first on Physics beyond the EIC's core (CD0) science

Physics with nucleons and nuclear Fragments: e-A light and heavy nuclei

- Connecting to low energy nuclear physics (exotic nuclei): studying the shapes of nuclei and their internal substructure
- Set novel concepts of entanglement & entropy in DIS, as major goals
- Nuclear and proton fragmentation, hadronization and such phenomena
- Quark **Exotica**: 4,5,6 quark systems…? Much interest after recent **LHCb** led results.

Precision electroweak and BSM physics:

- Electroweak physics & searches beyond the SM: Parity, charge symmetry, lepton flavor violation
- LHC-EIC Synergies & complementarity: (**muon detectors** were of particular interest)

New Studies with proton or neutron target: (mostly overlapping?)

- 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 1000 times lumi of HERA (and polarization)

Vision for the 2nd detector: C²C

- Complementary (IR, detector technologies & design)
  - Continue to explore complementary ready and not-yet-ready technologies
  - Generic detector R&D program
- Complementary (physics)
  - A significant list of physics topics exists (some-exclusive to IR8 (2nd IR) and some-overlapping with ePIC/IR6)
  - Which of those can *develop into strong pillars of science for the 2nd detector?*
  - New physics developing around the world: we need to monitor constantly
- Complementary (people)
  - New non-US/outside groups who may bring new interests & funding in future
  - New US groups – other than those with significant responsibilities in ePIC
  - Impact of different perspectives that different collaborators bring to the same problem.
  - Complementary analyses strategies build confidence in conclusions

EIC Science from the perspective of High Energy Physicists

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

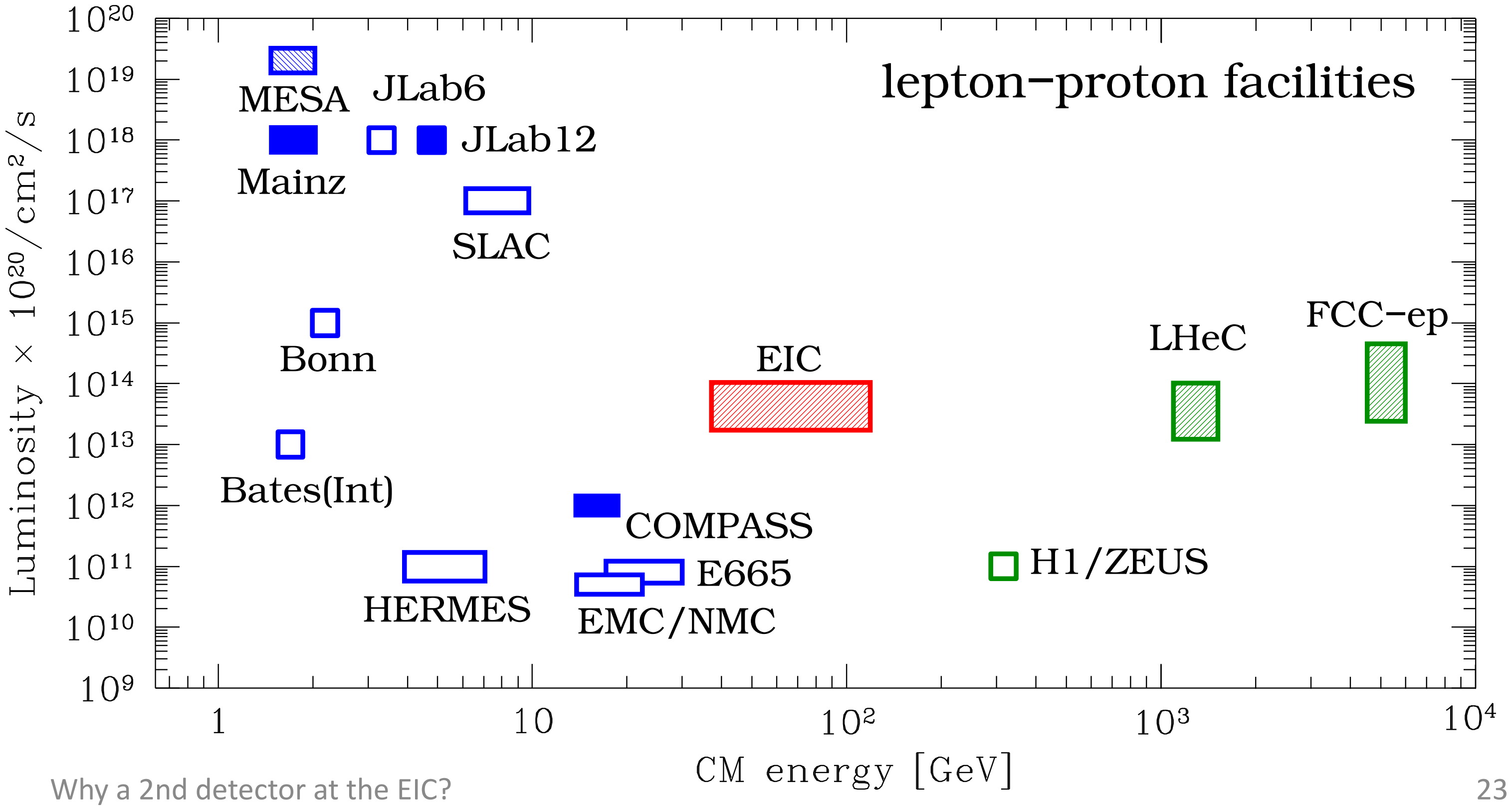
Snowmass 2021 White Paper:
Electron Ion Collider for High Energy Physics

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 (1-5D 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 technologies EIC & LHC:

Many EIC collaborators already part of RD51 (and family) at CERN & vice-versa.

- MAPS μVertex for primary/secondary vtx: barrel & end-caps (ALICE ITS3)
- Micro Pattern Gas Detectors: large rapidity, spatial resolution ~100 μm
- Electromagnetic Calorimetry for kinematic reconstruction, precise energy measurements e, γ; e/π & π^0/γ separation. Various technologies at various locations:
  - W/SciFi w/o PMT, PbWO4, SiGlass; AstroPix & Pb/SciFi
  - High resolution Crystal Cal for e-endcap
  - Barrel EMCal 6 layers AstroPix and Pb/SciFi
- Particle Identification – extremely important for most EIC physics
  - K/pi separation over a wide range 1-20 GeV/c
  - Hadron ID: hpDIRC in Barrel, forward EndCap: duel RICH, backward Endcap: modular RICH or pF RICH, also TOF for short lever arm : LGAD, LAPPD
- Streaming Readout

Path forward 2nd Detector:
Focused workshops and detector studies on new physics topics:

- ✓Look at **complementary detector technologies** (to ePIC) and attract groups that are experts in them to the EICUG
- ✓Focused discussions on **new physics topics** (not just listed in this talk but also beyond) to try to make a unique case complementary to ePIC/EIC White Paper
- ✓**Build community** – new groups/faces/resources needed to contribute and become part of new detector effort

Resources:

Generic detector R&D – supported by DOE administered from JLab

Center for Frontiers in Nuclear Science @ Stony Brook (& EIC – Theory Institute at BNL) and the EIC^2 at JLab

Message to Early Career Scientists: You can be leaders in all of this!

- EIC project's path is well understood. Its success is paramount. Your input and leadership will be paramount in EIC's success and EIC assure a great career for all of you!

- 2nd detector is essential for completing the Vision of EIC
  - C^2C : Complementary physics, technology and people
  - Series of workshops, outreach and critical evaluation
  - Reasonable to aim for physics starting in ~5 years after ePIC/1st detector

Thank you

Item 2:
Transition to operation:
Operations planning

Start with lowest possible luminosity to build confidence in the machine in order to avoid accidental damage to the detector components and the machine itself. As we go forward and we get some explicit guidance on luminosity rise from EIC/CAD – we should be able to make more concrete proposals for early running – energy, species and physics goals/outcomes.

Preliminary thoughts & estimates

Time on this slide starts at CD4

We should (hope to) see ~1 x $10^{32}cm^{-2}sec^{-1}$ in the 1st year (already twice the maximum reached at HERA), and reach ~10^{33} in ~2-3 years, and 10^{34} in ~5+ years at 10 x 250 GeV polarized proton operation.

18 GeV e beam will be experimented with before CD4 if RF is ready but not for "physics operation" until about 3-5 years into the program.

I expect polarization of electron and proton would be harder to achieve compared to e-A luminosity.

We would like to show fast physics results ➔

- e-A physics 10 x 100 GeV beams at the beginning with highest luminosity possible
- run at least two nuclei in the first two years
- ample time would be given to develop polarization and luminosity for e-p

Start EIC physics program hence *could* be:

Begin with electron-Nucleus/Ion Physics:

Intermediate/high energy operations with different nuclei leading to:

- Search for saturation from inclusive to sem-inclusive ➔ F_2^A, disappearance of jet
- Interactions in color with nuclear matter: with multiple nuclear sized targets; study of jet production and its interaction with nuclear matter, study jet internal structure, hadronization
- With luminosity increase: exclusive diffraction in e-A to establish saturation
- Comparison runs of e-p should be expected at moderate luminosity (not for polarization) but we should be ready to utilize what we get **for inclusive & start semi-inclusive spin physics**

Allow ample **time for luminosity and polarization development. In RHIC era, significant time of *p-p* was given to R&D.** This philosophy gave high returns later in the program.

Operational thoughts further….

10^{33} luminosity ➔ 20 fb^{-1}/year including 70% accelerator & detector efficiency

White paper and Yellow Report hence assumed those luminosities and hardly any measurement showed more luminosity in e-p-equivalent would be needed.

- It is hence my guess that physics with polarized beams will start happening after the 2nd year with.
- Transverse spin measurements needing only proton beam polarization should be easier to achieve than double longitudinal spin measurements with high e-polarization