
The EIC Science case: a report on the joint BNL/INT/JLab program

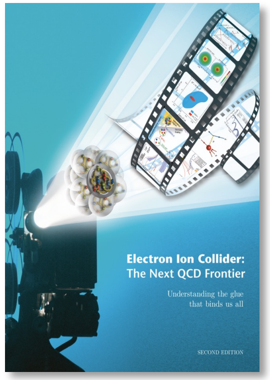
Gluons and the quark sea at high energies: distributions, polarization, tomography

Institute for Nuclear Theory • University of Washington, USA
September 13 to November 19, 2010

Editors:
D. Boer
Rijksuniversiteit Groningen, The Netherlands
M. Diehl
Deutsches Elektronen-Synchroton DESY, Germany
R. Milner
Massachusetts Institute of Technology, USA
R. Venugopalan
Brookhaven National Laboratory, USA
W. Vogelsang
Universität Tübingen, Germany

# Electron Ion Collider: Science, Status and Opportunities

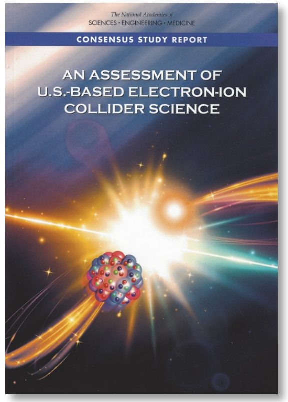
2012-15




2016


Physics of EIC

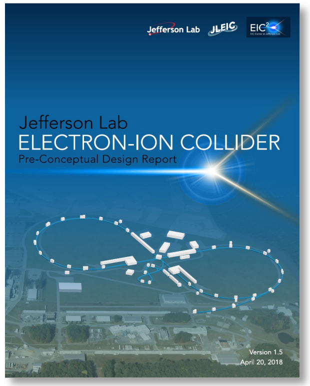
2018



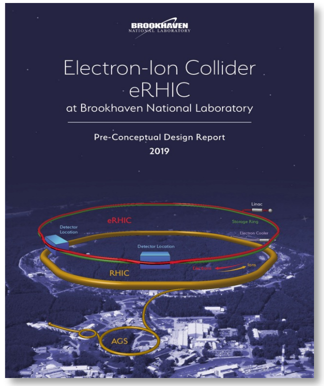

Evaluation

2019-present

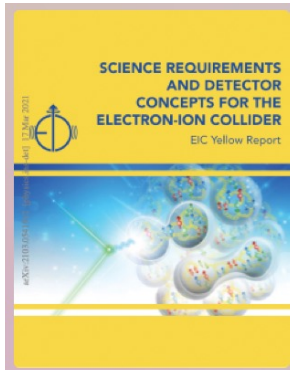
2019




machine




detector

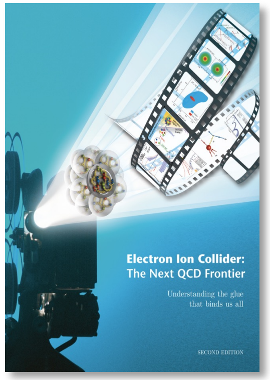



Realization


# Electron Ion Collider: Science, why, how and when

## Physics of EIC

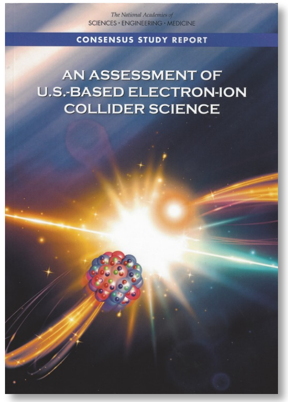
2012-15




2016

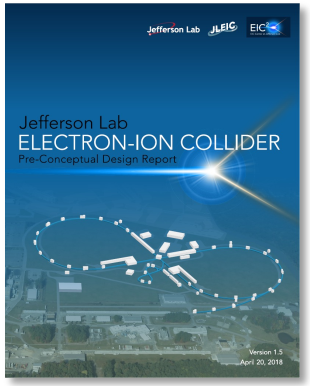

## Evaluation

2018



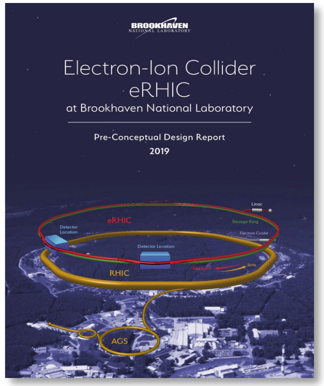

## 2019-present

2019

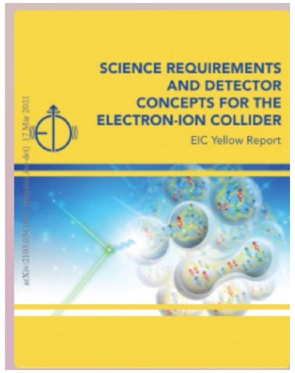



### Realization

machine




detector



# Outline of this talk

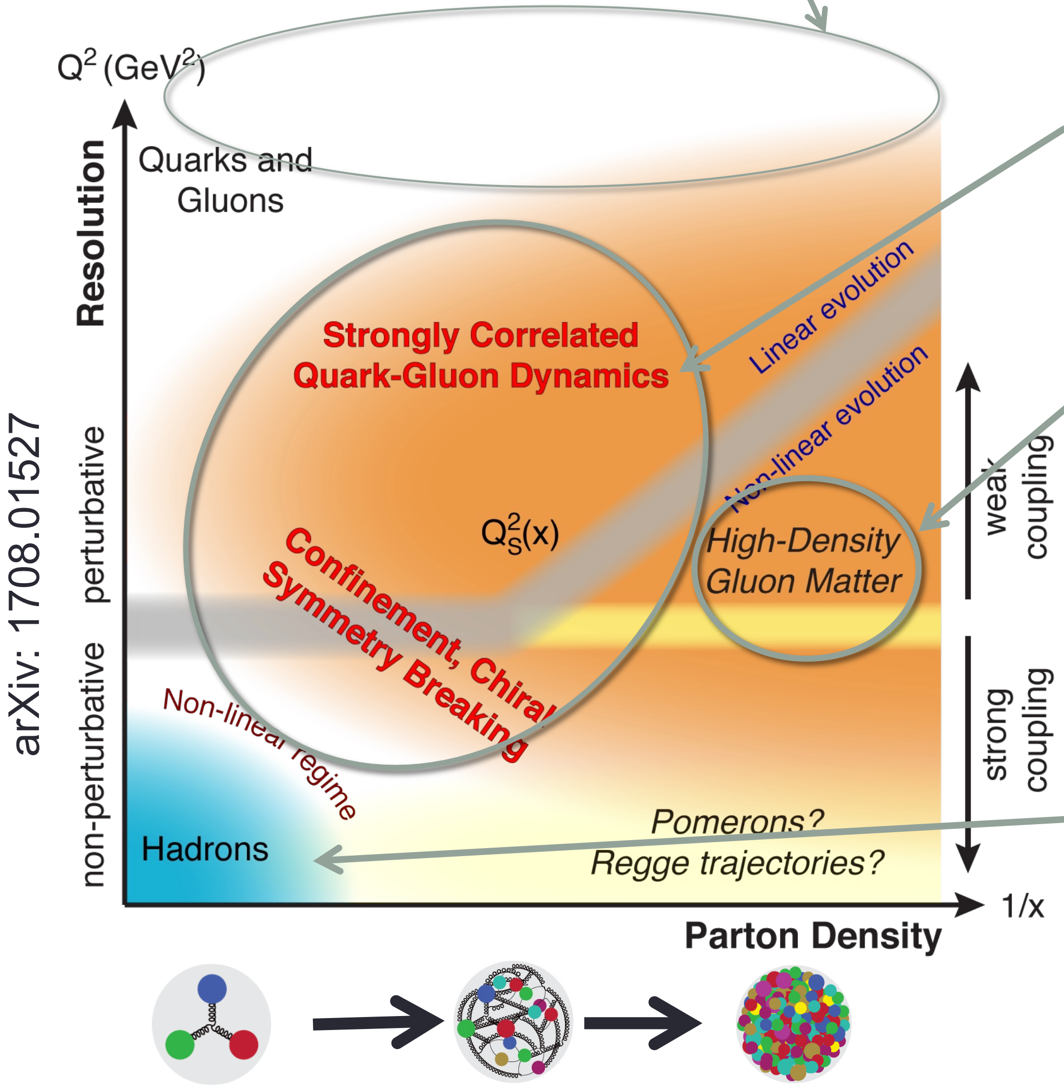
- A (high level) review of EIC science
  - Core physics of the EIC – This talk
  - Many talks in this meeting

- EIC project &  EIC users, their activities
  - EIC accelerator
  - Beyond the Core Physics of EIC
  - EIC Detector 1: “EPIC”
  - EIC Detector 2: ??

- EIC Outlook path to realization

# QCD Landscape to be explored by a new future facility

QCD at high resolution ($Q^2$) —weakly correlated quarks and gluons are well-described

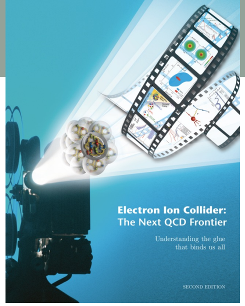



Systematically explore correlations in this region.

An exciting opportunity: Observation of a new regime in QCD of weakly coupled high-density matter

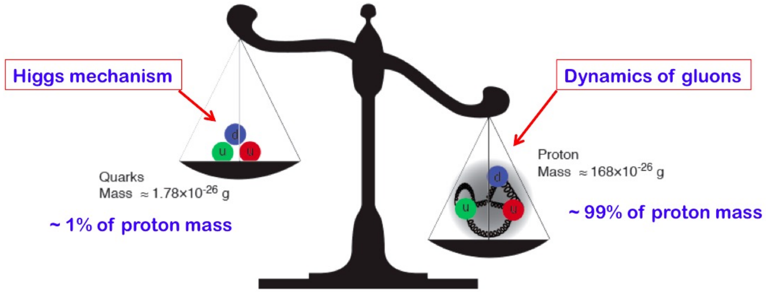
Strong QCD dynamics creates many-body correlations between quarks and gluons
→ hadron structure emerges

**Need Precision and Control**

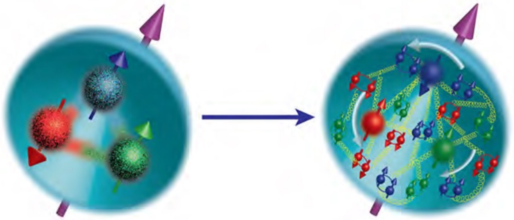


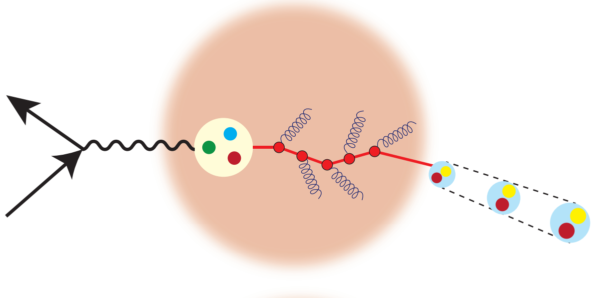

# EIC Physics at-a-Glance

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



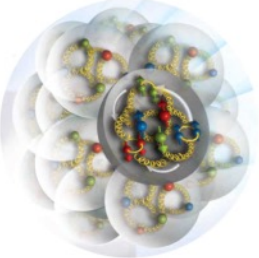

How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties (mass & spin) emerge from their interactions?

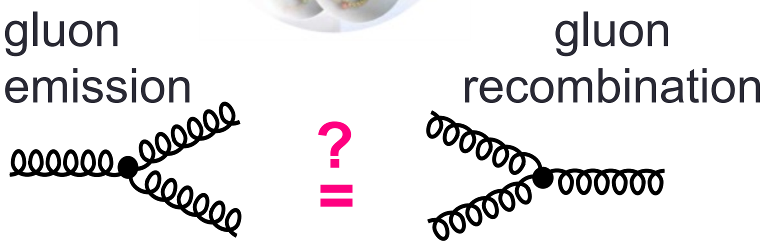




How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

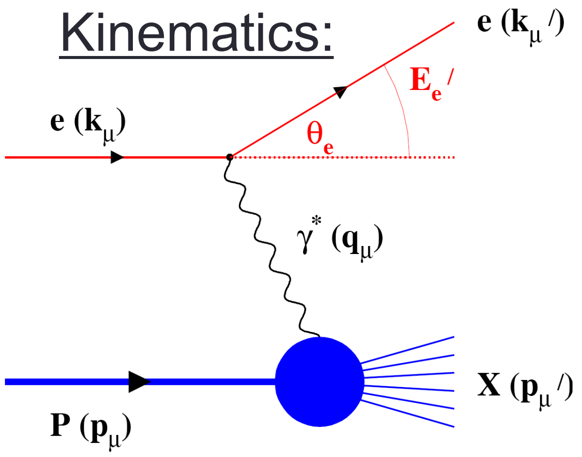
How does a dense nuclear environment affect the quark- and gluon- distributions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?





# 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 $\gamma^*$

$$s = 4E_h E_e$$

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

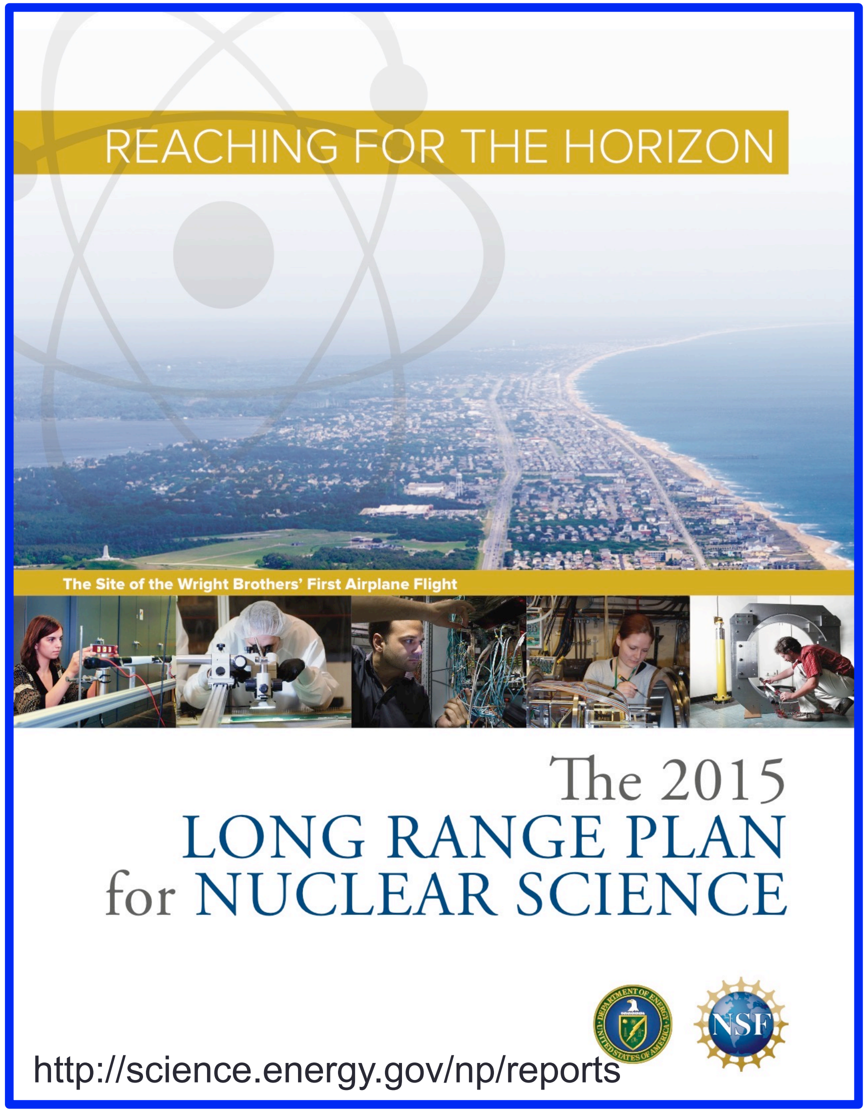
detect the scattered lepton in coincidence with identified hadrons/jets

**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.*

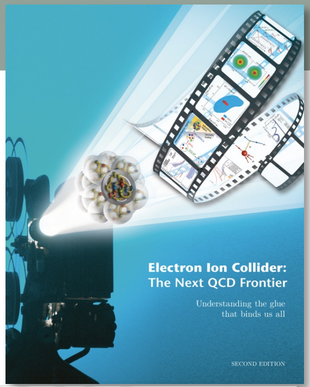
RECOMMENDATION:

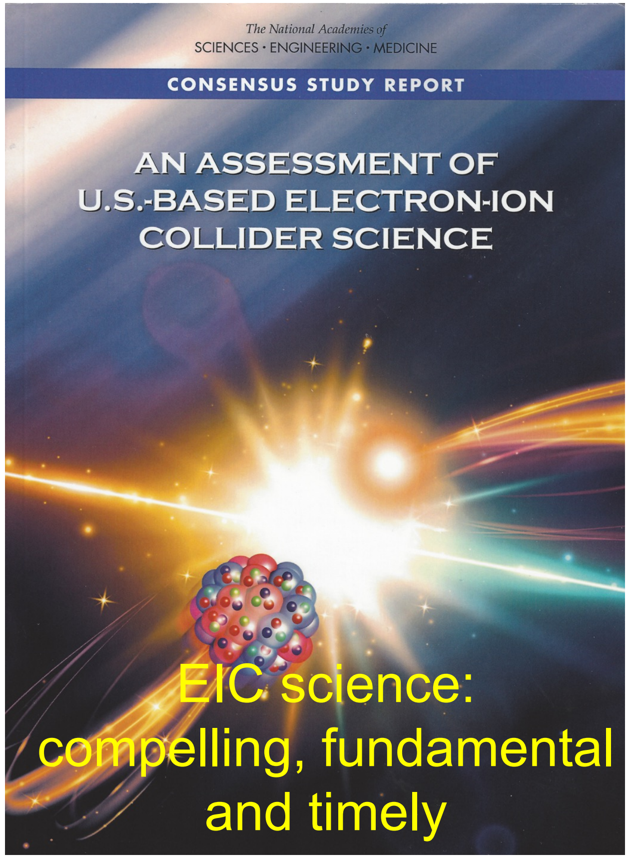
*We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.*

FRIB construction completed, operations began May 2022.

# National Academy of Science, Engineering and Medicine

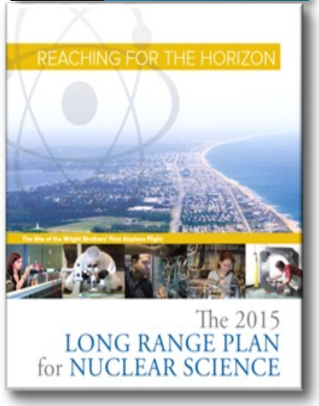
## Assessment July 2018




### Physics of EIC

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




### Machine Design Parameters:

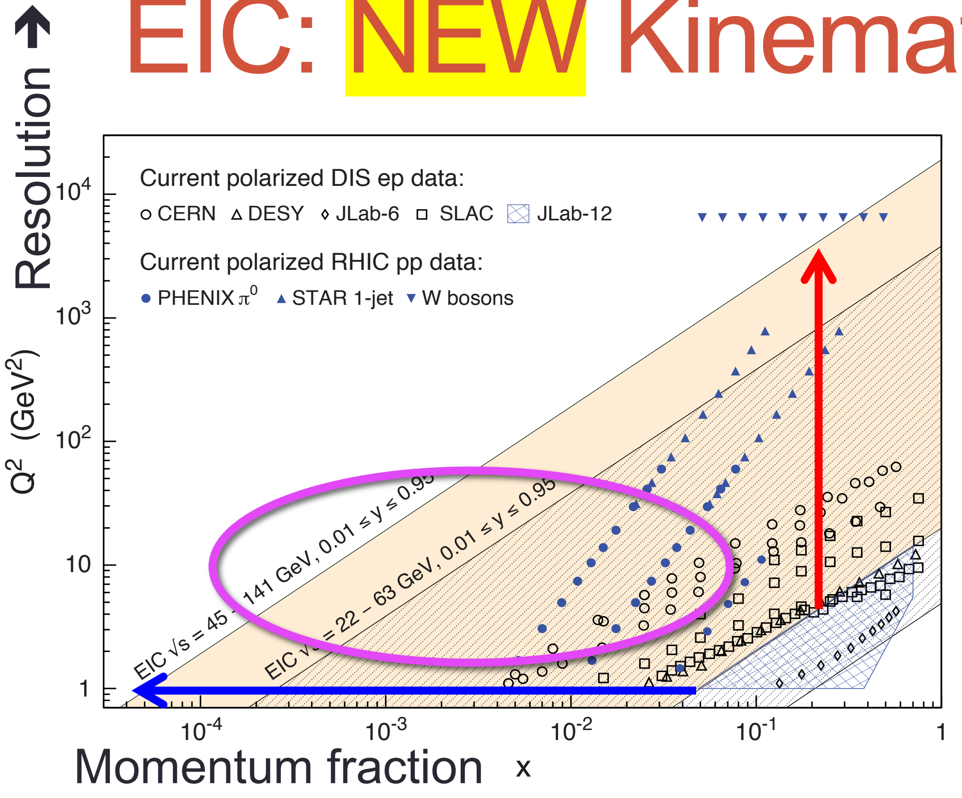
- High luminosity: up to $10^{33}$-$10^{34}$ $cm^{-2}sec^{-1}$
  - a factor ~100-1000 times HERA
- Broad range in center-of-mass energy: ~20-140 GeV
- Polarized beams e-, p, and light ion beams with flexible spin patterns/orientation
- Broad range in hadron species: protons…. Uranium
- Up to two detectors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

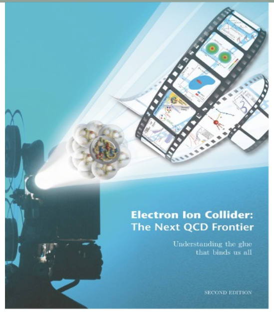
# EIC SCIENCE

Core science of the “DOE Mission Need”

➔ Has to be done to call the EIC project a success.

# EIC: NEW Kinematic reach & properties



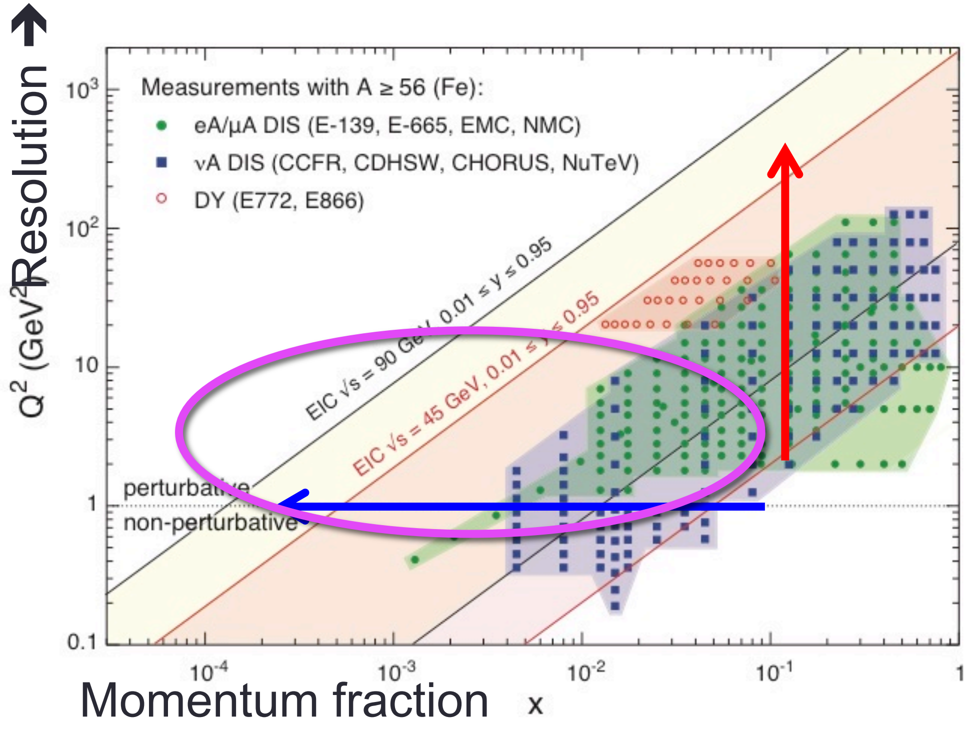




## For e-N collisions at the EIC:

- ✓ 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

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

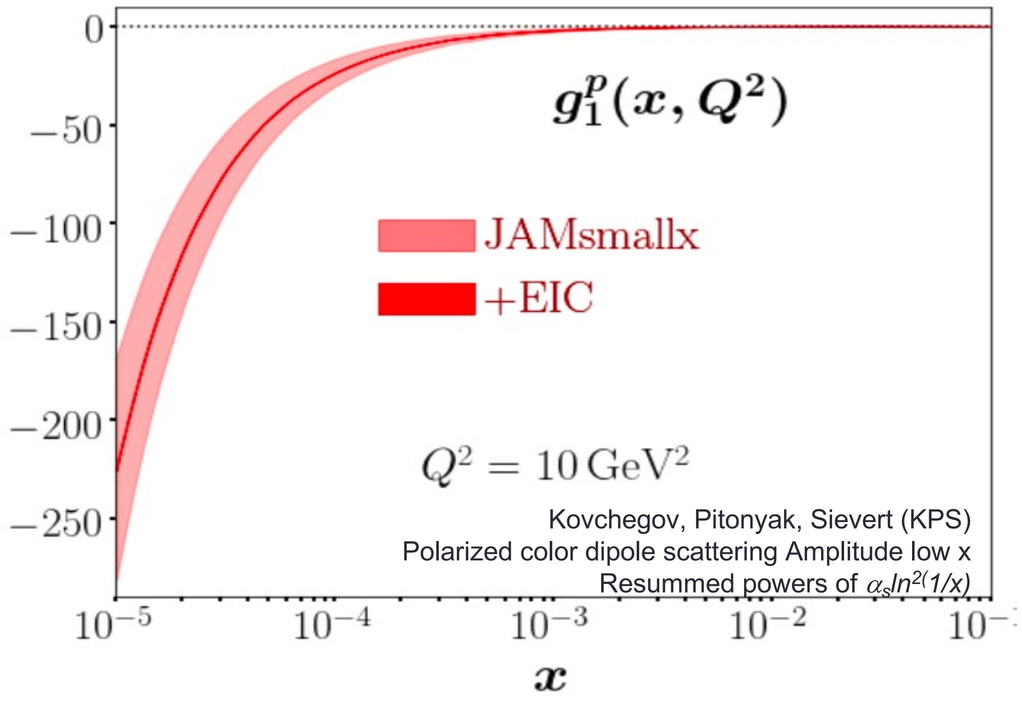
$\Delta\Sigma/2$ = Quark contribution to Proton Spin
$\Delta g$ = Gluon contribution to Proton Spin
$L_Q$ = Quark Orbital Ang. Mom
$L_G$ = Gluon Orbital Ang. Mom

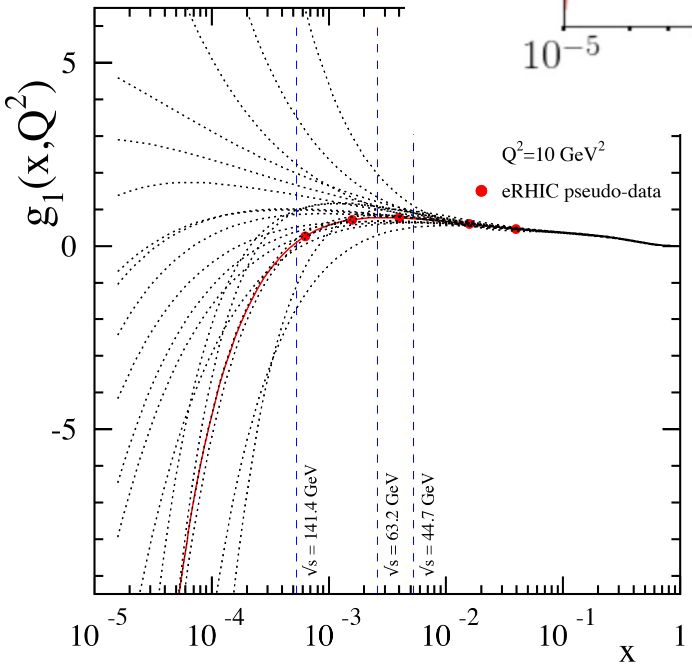
Spin structure function $g_1$ needs to be measured over a large/**wide range in x-Q²**

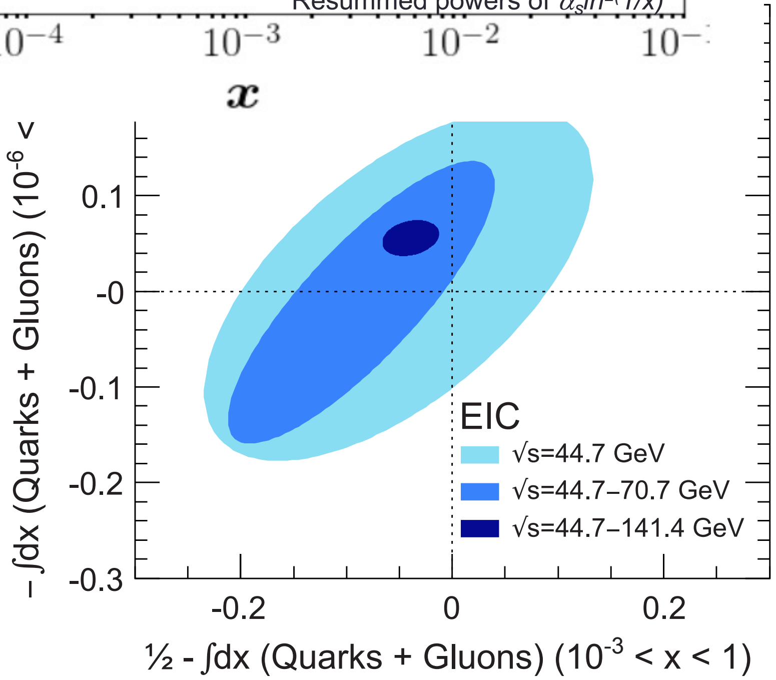
Precision in $\Delta\Sigma$ and $\Delta g$ ➔ A clear idea Of the magnitude of $L_Q+L_G$ = L

Lattice Calculations : comparison

SIDIS: strange and charm quark spin contributions



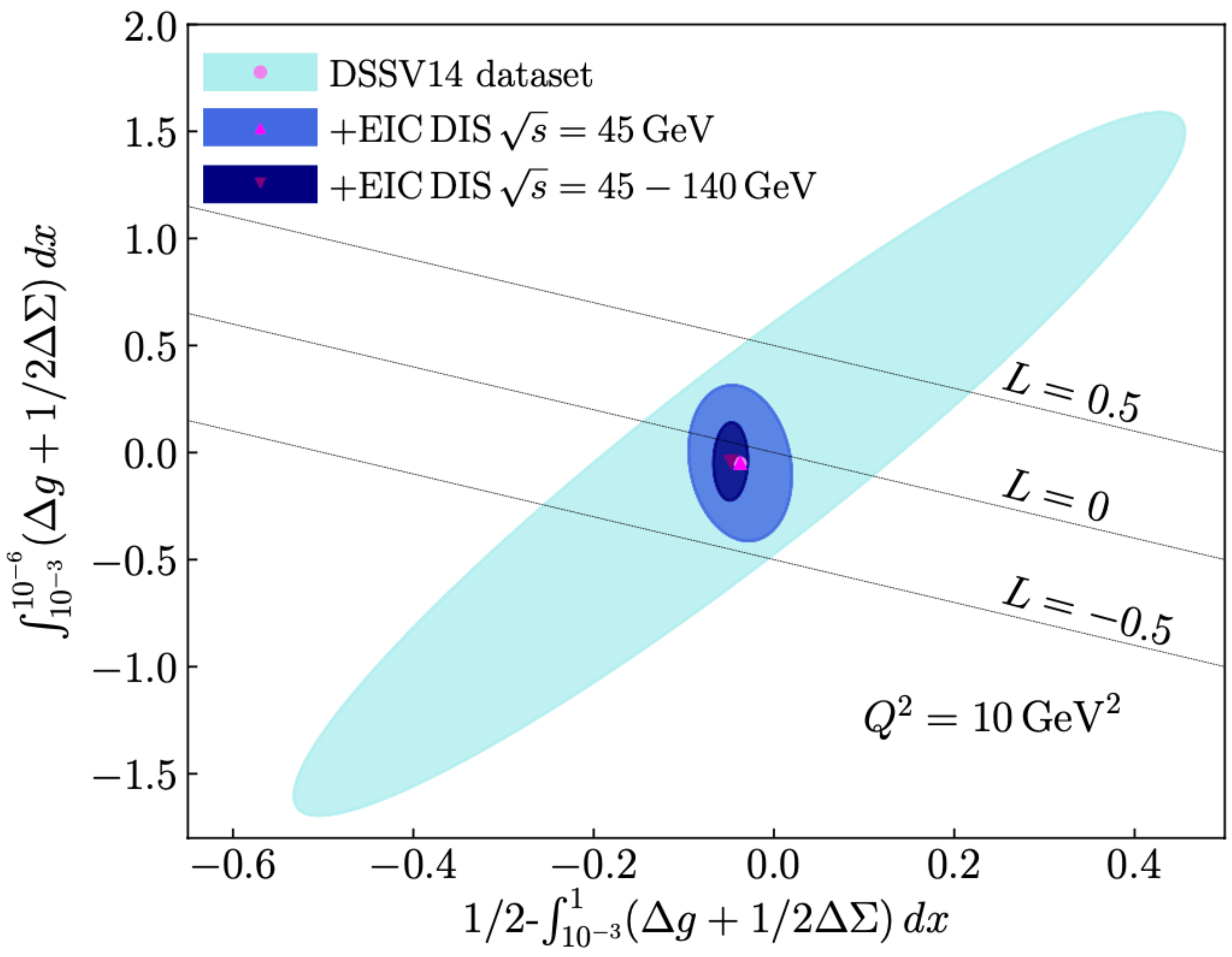



# Room left for orbital angular momentum (OAM)

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

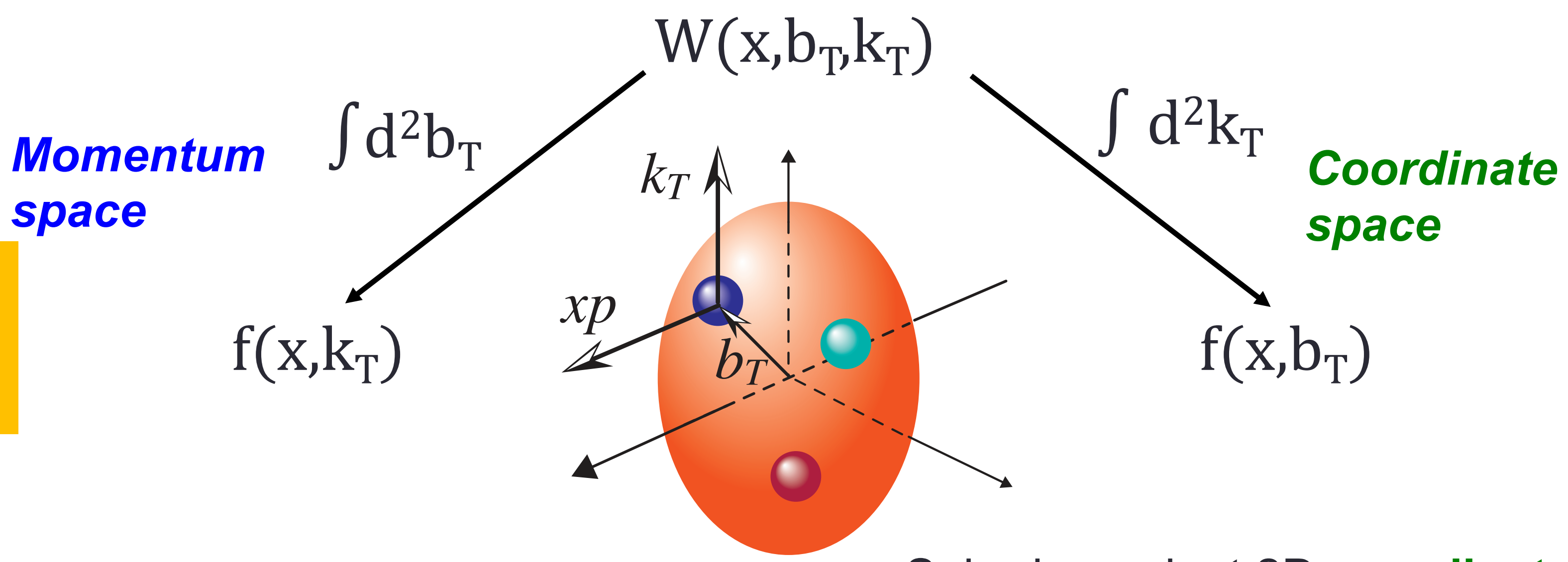
$$L = L_Q + L_G$$



# 2+1-Dimensional Imaging Quarks and Gluons

**Wigner** functions **$W(x,b_T,k_T)$**
offer unprecedented insight into confinement and chiral symmetry breaking.

Direct Comparison with lattice QCD




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

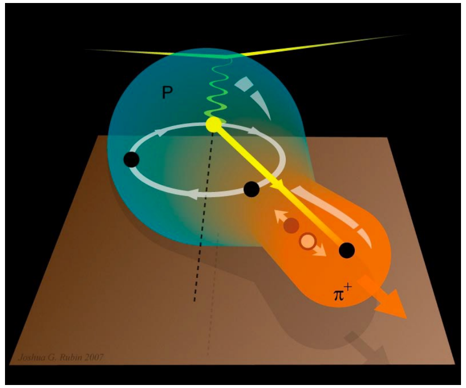
Spin-dependent 2D **coordinate space** (transverse) + 1D (longitudinal momentum) images from exclusive scattering (Deeply virtual Compton scattering and meson production)
→ **Generalized Parton Distributions**

momentum and position distributions → Orbital motion of quarks and gluons

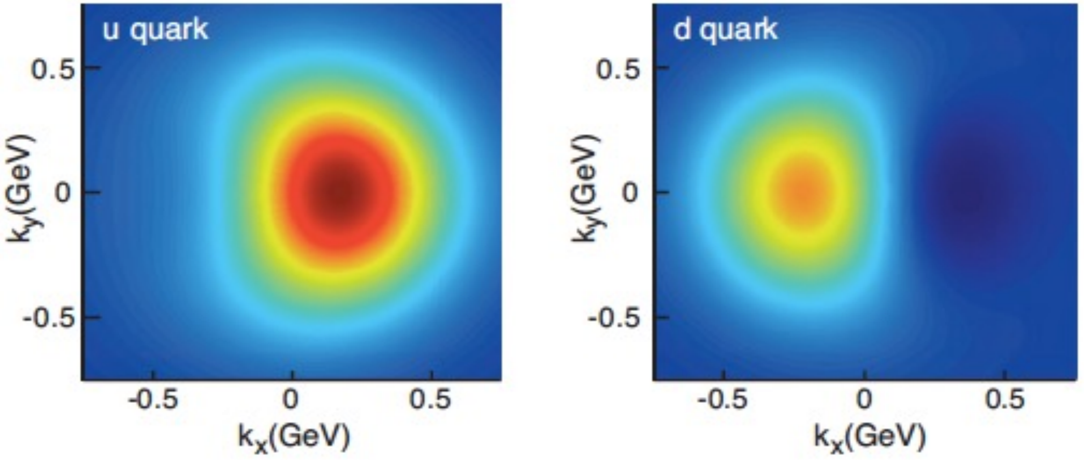
# 2+1 D partonic image of the proton with the EIC

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

**Transverse Momentum Distributions**

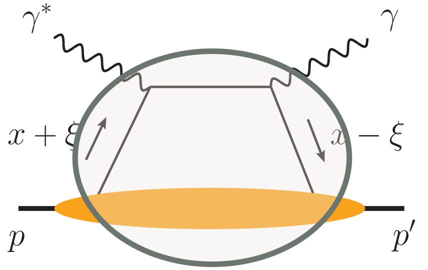


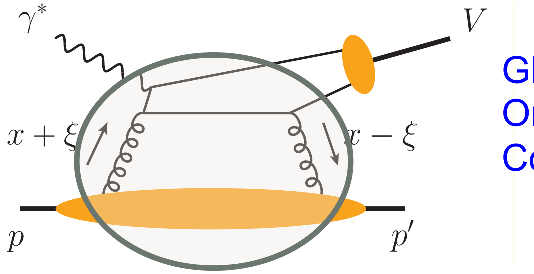

Quark's 2D momentum distribution




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

Quarks Motion



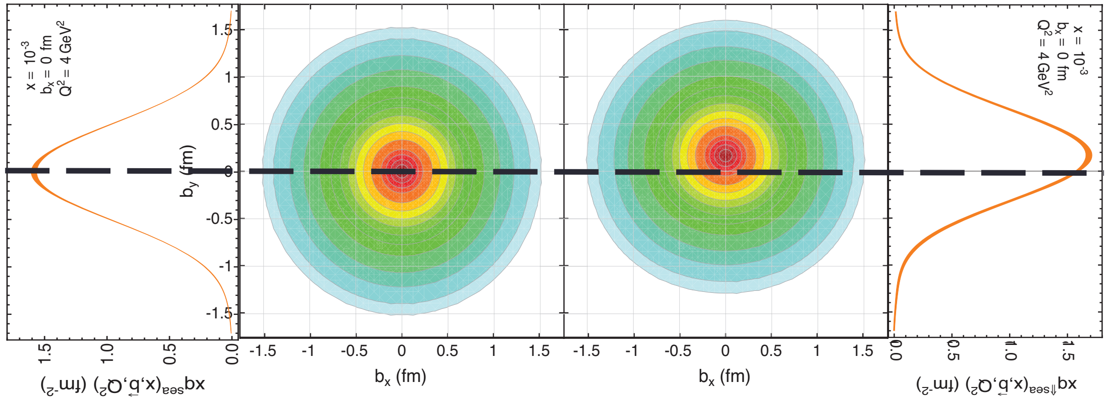




Gluons: Only @ Collider

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

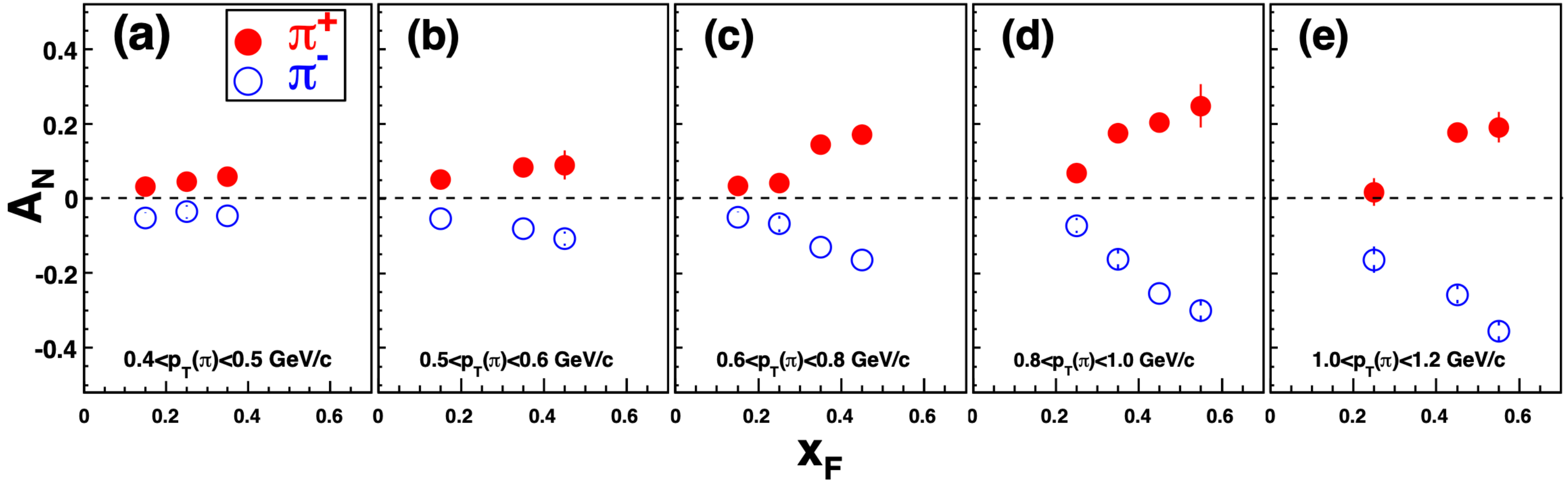
Fourier transform of momentum transferred=(p-p') → Spatial distribution

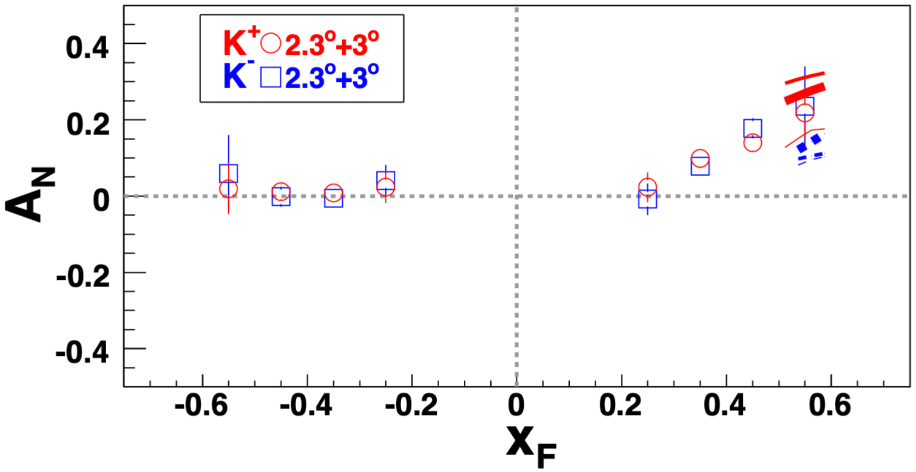
Sea quark's 2D position distribution
unpolarized polarized

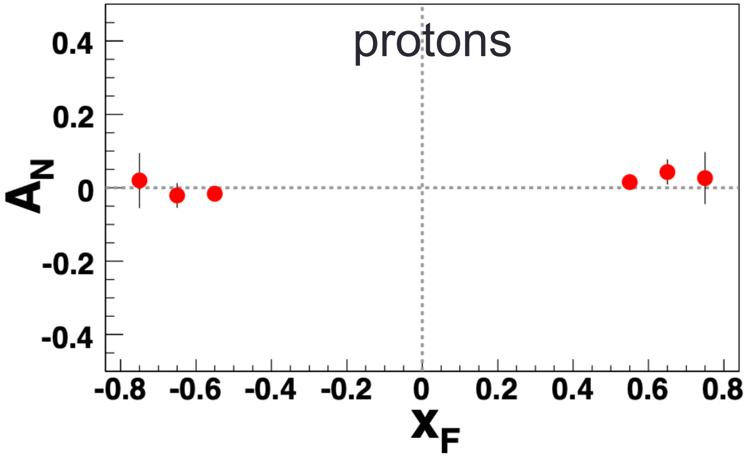


# RHIC $\pi^{+/-}$, $K^{+/-}$, proton asymmetries @ high $|\eta|$

arXiv:0801.1078v2 [nucl-ex] July 2008



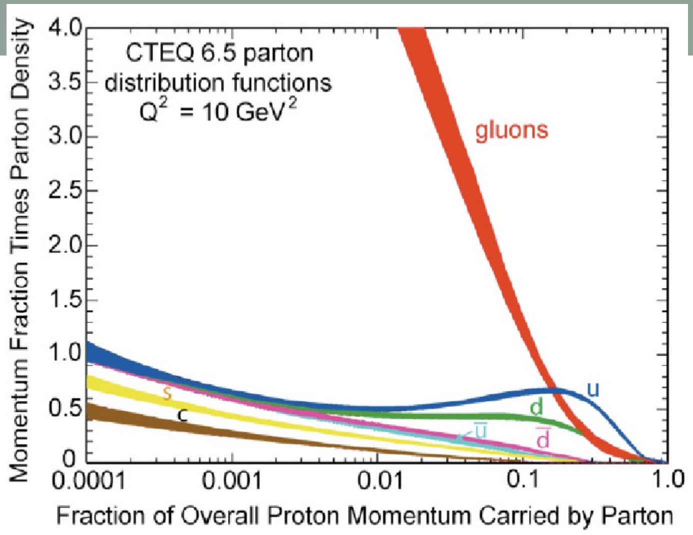




How do past RHIC measurements relate what might be seen at the EIC?

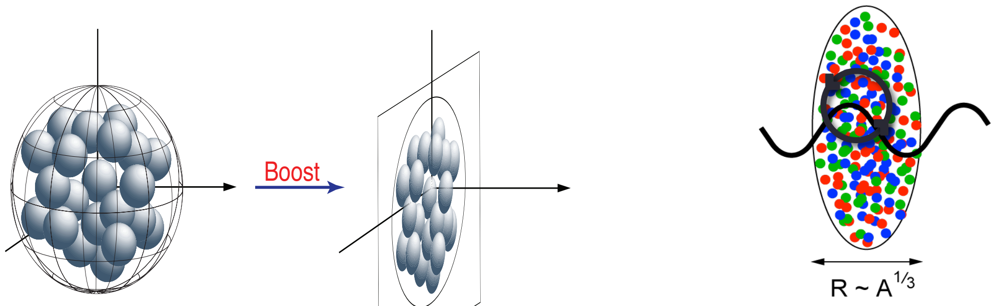
What would we learn about orbital angular momentum?

What would we learn about the 3D structure and dynamics of partons in the proton?



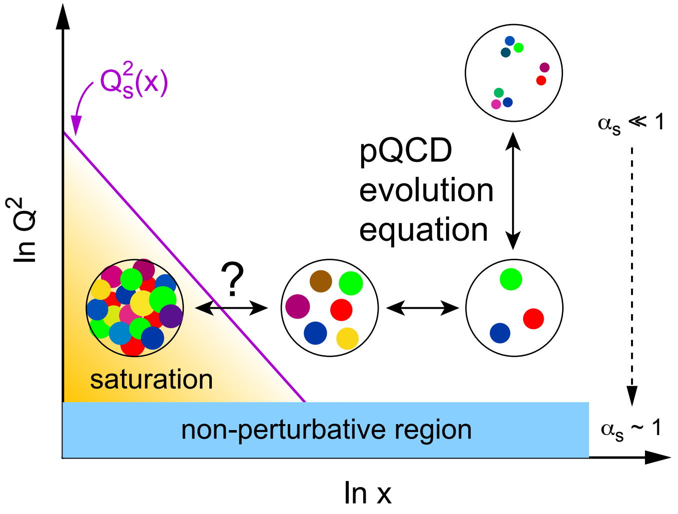

See a lot more in Anna Stasto's talk

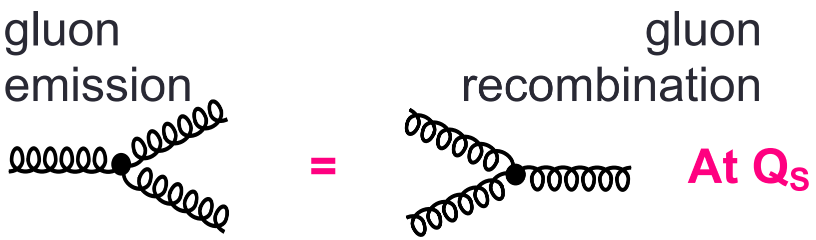
# Low x physics with nuclei



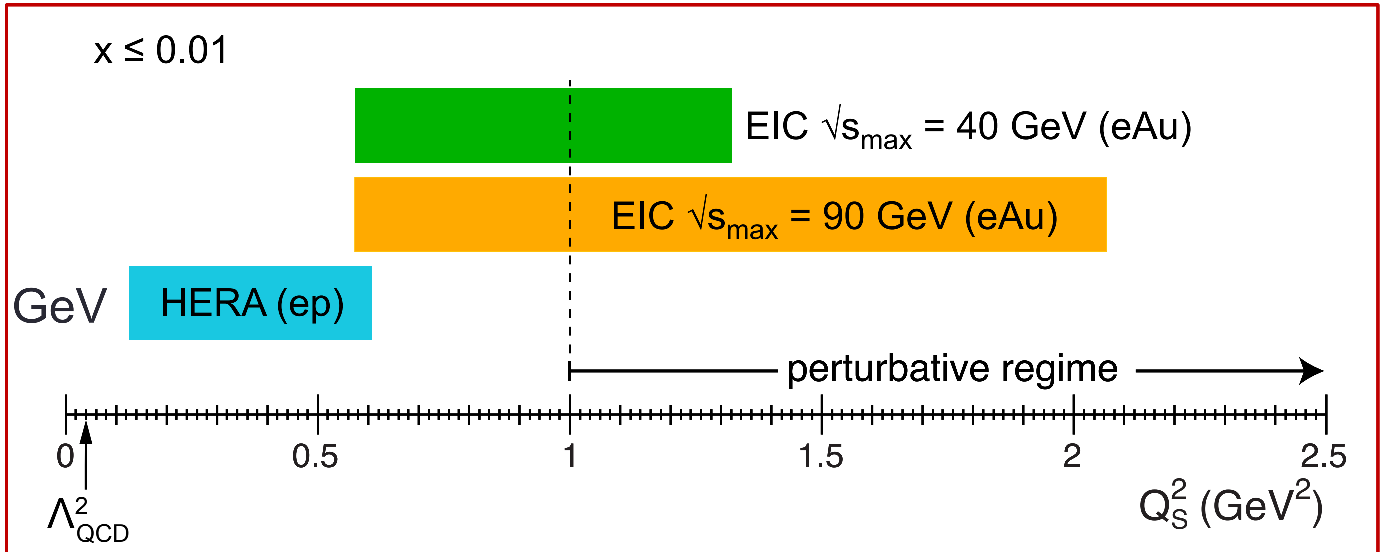

$$(Q_s^A)^2 \approx c Q_0^2 \left[\frac{A}{x}\right]^{1/3}$$

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



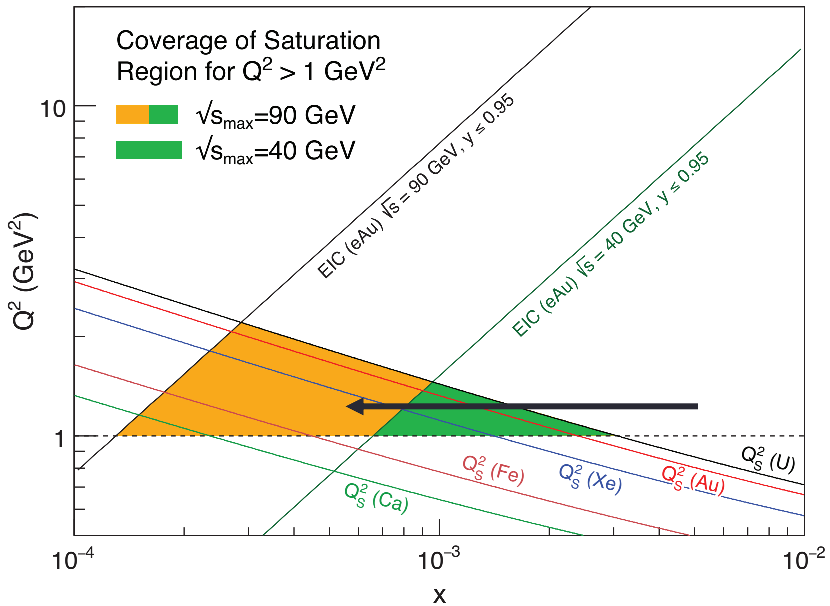

Accessible range of saturation scale $Q_s^{\ 2}$ at the EIC with e+A collisions. arXiv:1708.01527



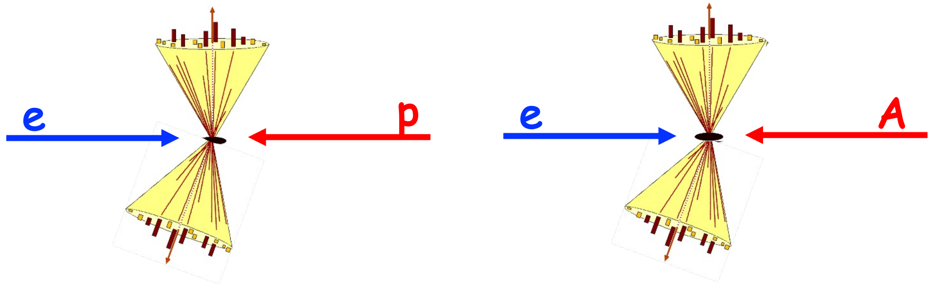
# Can EIC discover a new state of matter?

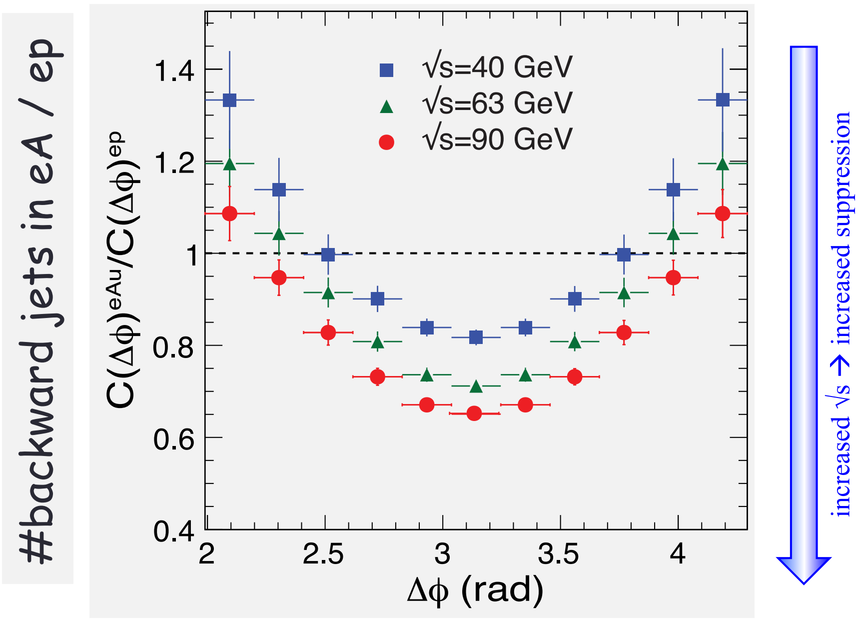
EIC provides an absolutely unique opportunity to have very high gluon densities
→ electron – lead collisions
combined with an unambiguous observable

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

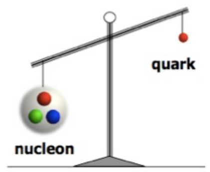



counting experiment of
Di-jets in ep and eA
Saturation:
Disappearance of backward jet in eA



# 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***

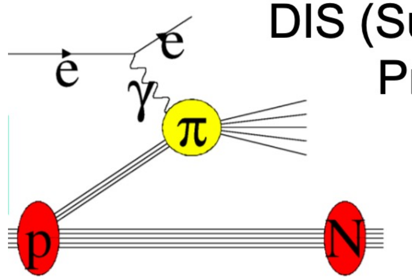
***Relativistic Motion*** | ***Chiral Symmetry Breaking*** | ***Quantum Fluctuations***

**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)

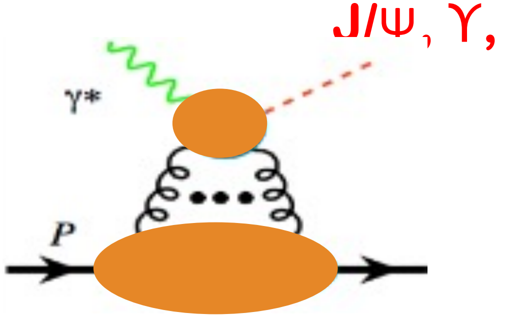
- Criticisms: not scale-invariant, decompositions: Lorentz invariant vs. rest frame
- Recent interest (workshops) planned: how to determine the different contributions
- **Lattice QCD providing estimates**

$E_q$ ~30% $E_g$ ~40% $\chi_{m_q}$ ~10% $T_g$ ~ 25%

**arXiv: 1710.09011**

**Trace anomaly:**
Upsilon production
near threshold:

SoLID@JLab & EIC



# EIC Yellow Report arXiv:2103.05419

For SoLID and EIC measurement of J/Psi and Y on the threshold allows to access the trace anomaly contribution.

SoLID and EIC are complementary in their region accessible.

Anomaly contribution as a ratio of proton mass in this model is assumed to be 25%. For EIC three different W ranges are considered.

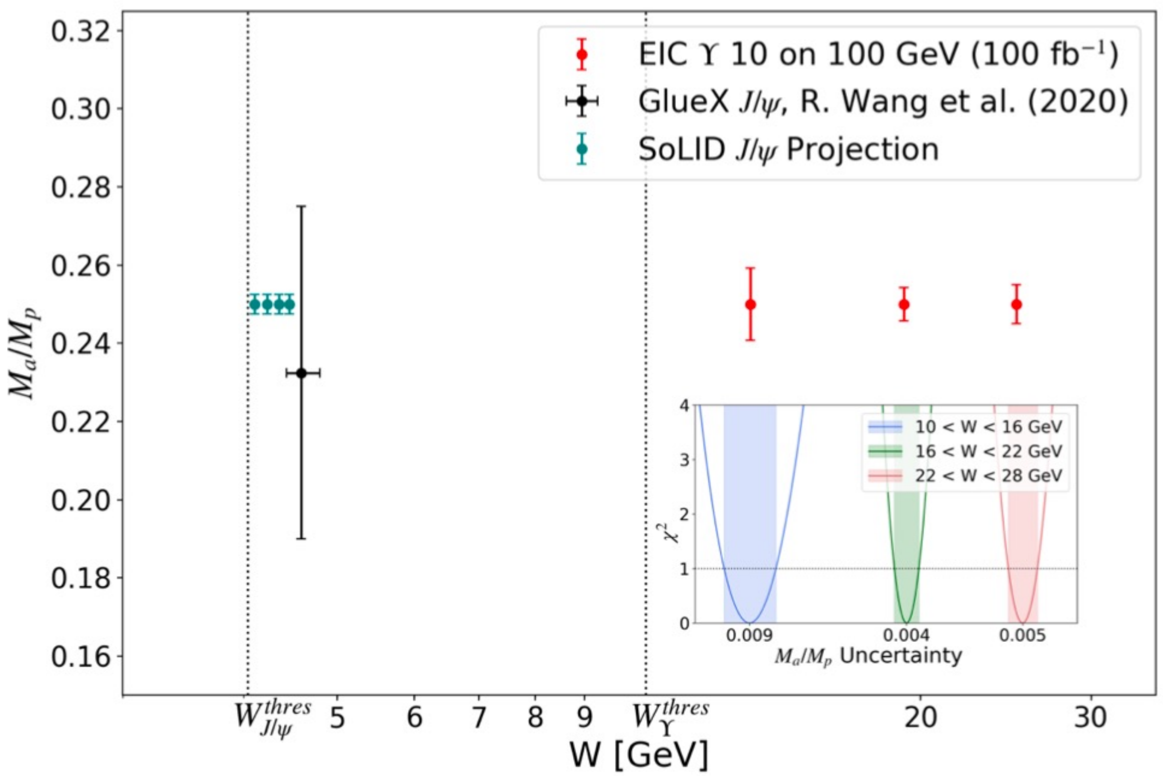
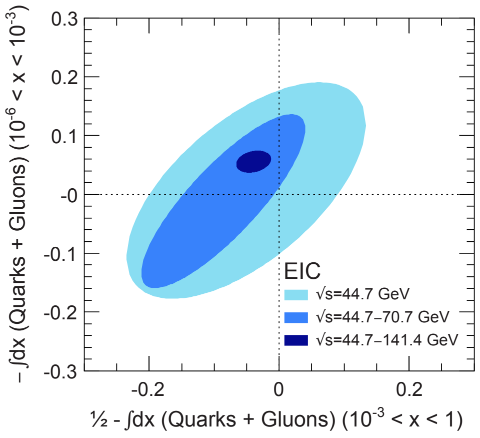
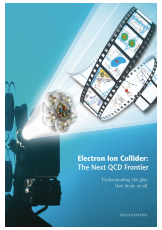
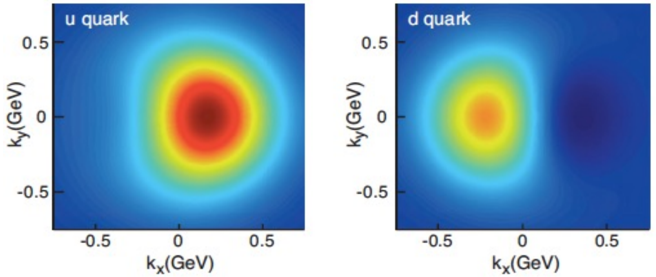


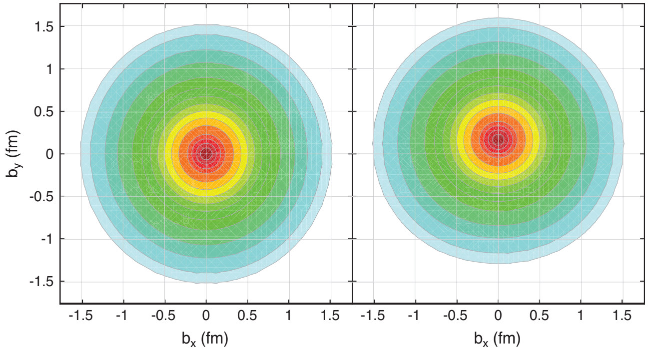

**Figure 7.26:** Projection of the trace anomaly contribution to the proton mass ($M_a/M_p$) with Υ photoproduction on the proton at the EIC in 10 × 100 GeV electron/proton beam-energy configuration. The insert panel illustrates the minimization used to determine the uncertainty for each data point. The black circles are the results from the analysis of the GlueX $J/\psi$ data [191], while the dark green circles correspond the JLab SoLID $J/\psi$ projections. The Υ projections were generated following the approach from Ref. [192] with the lAger Monte Carlo generator [193].

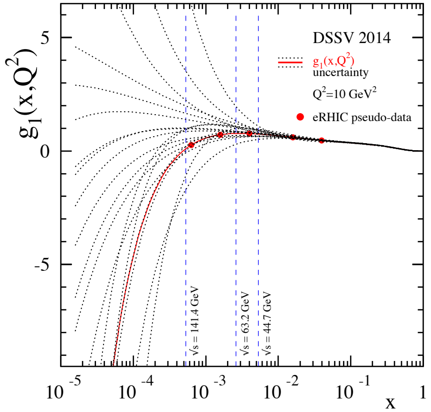


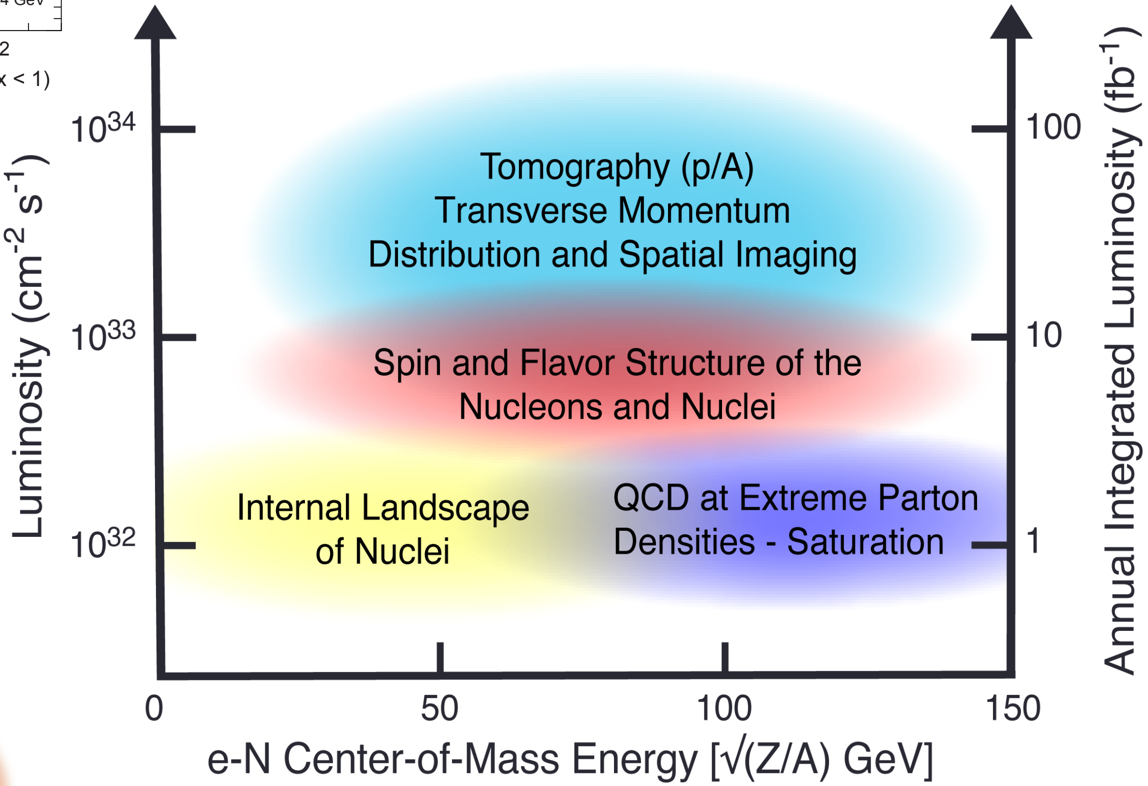



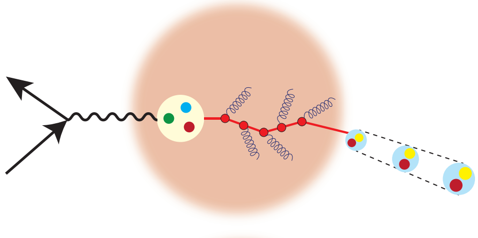

# EIC science highlights

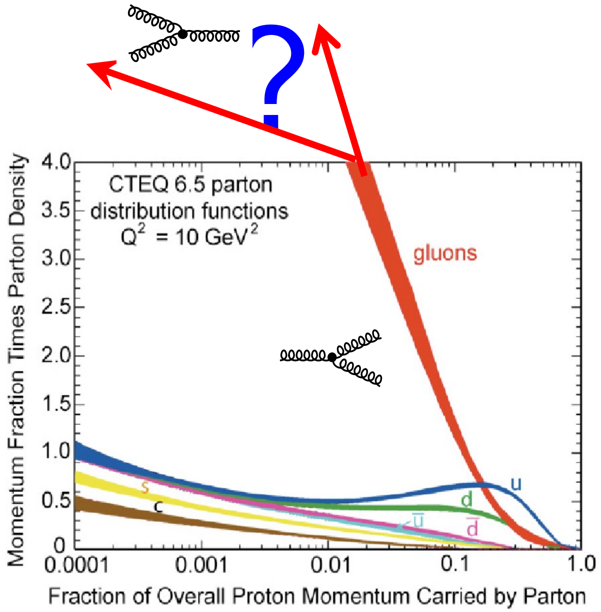




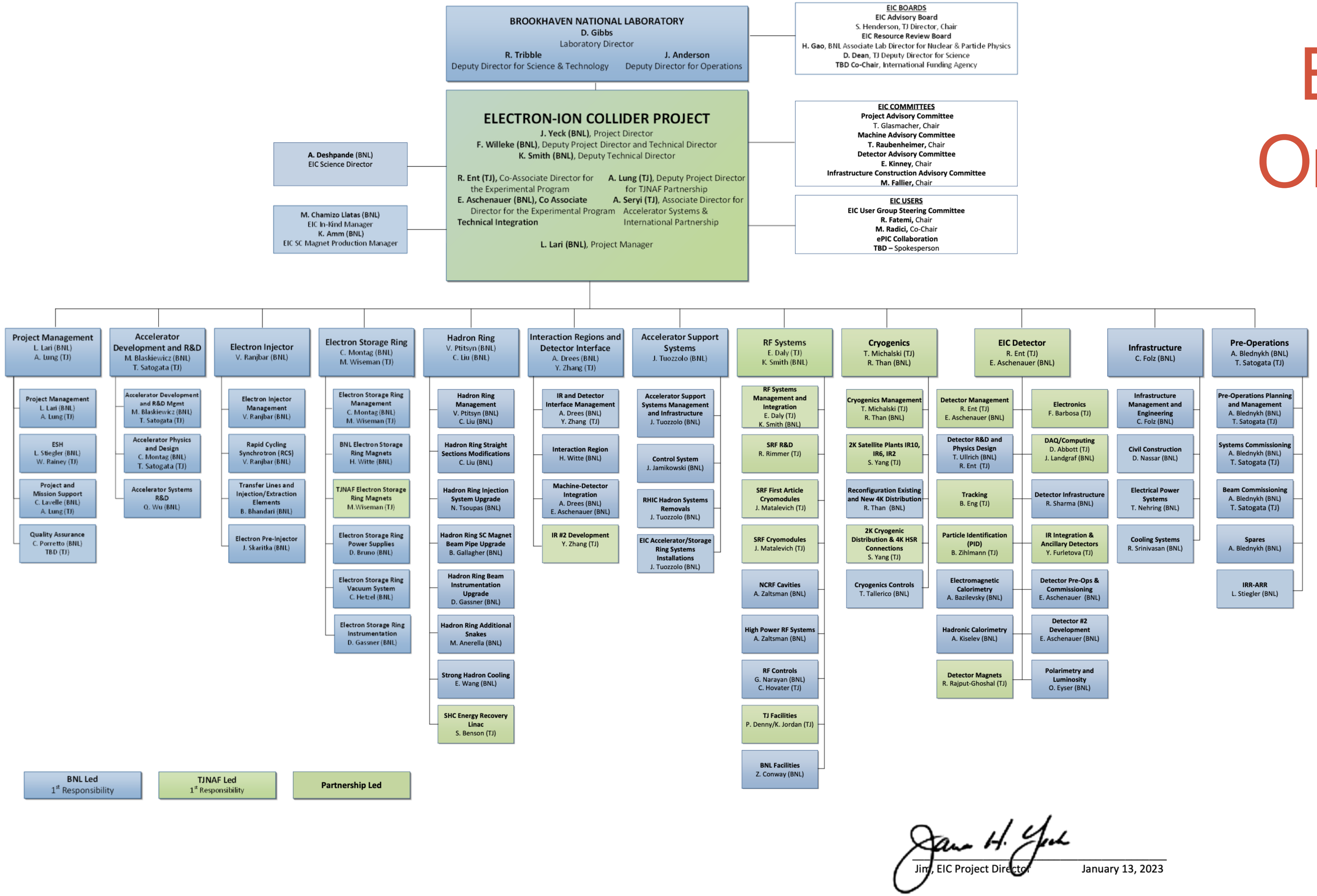
# THE EIC PROJECT

Partnership between BNL and Jefferson Lab

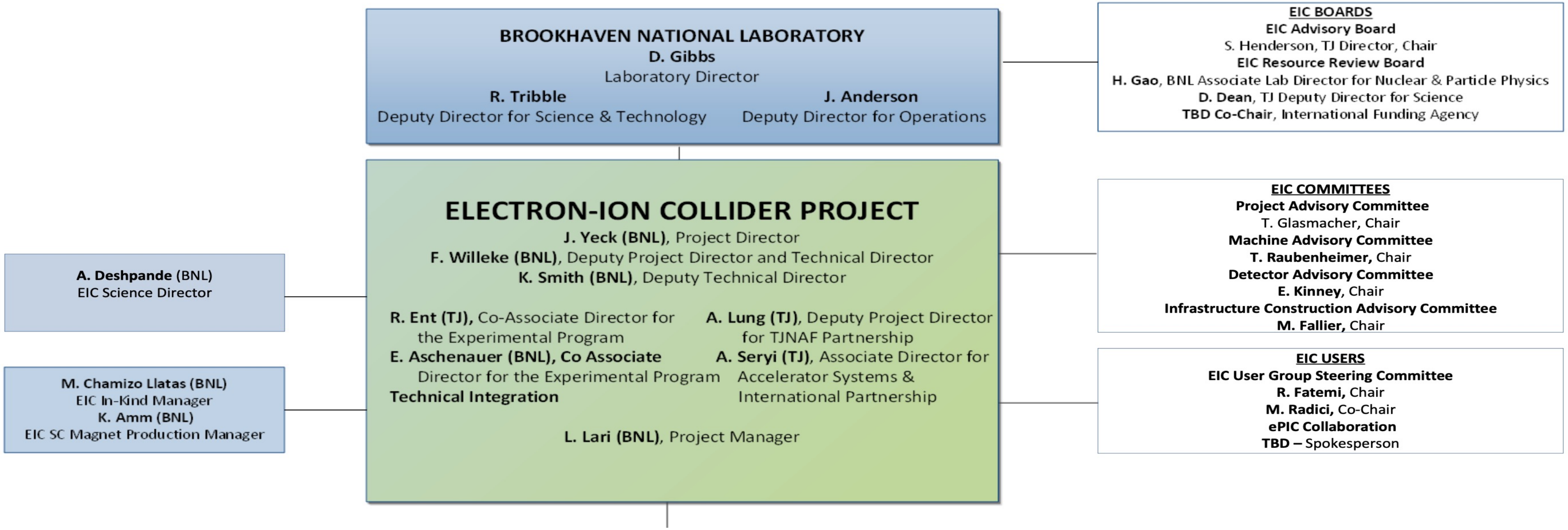
Includes: the accelerator complex, one IR, most of 1st detector

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

# EIC Project Organization

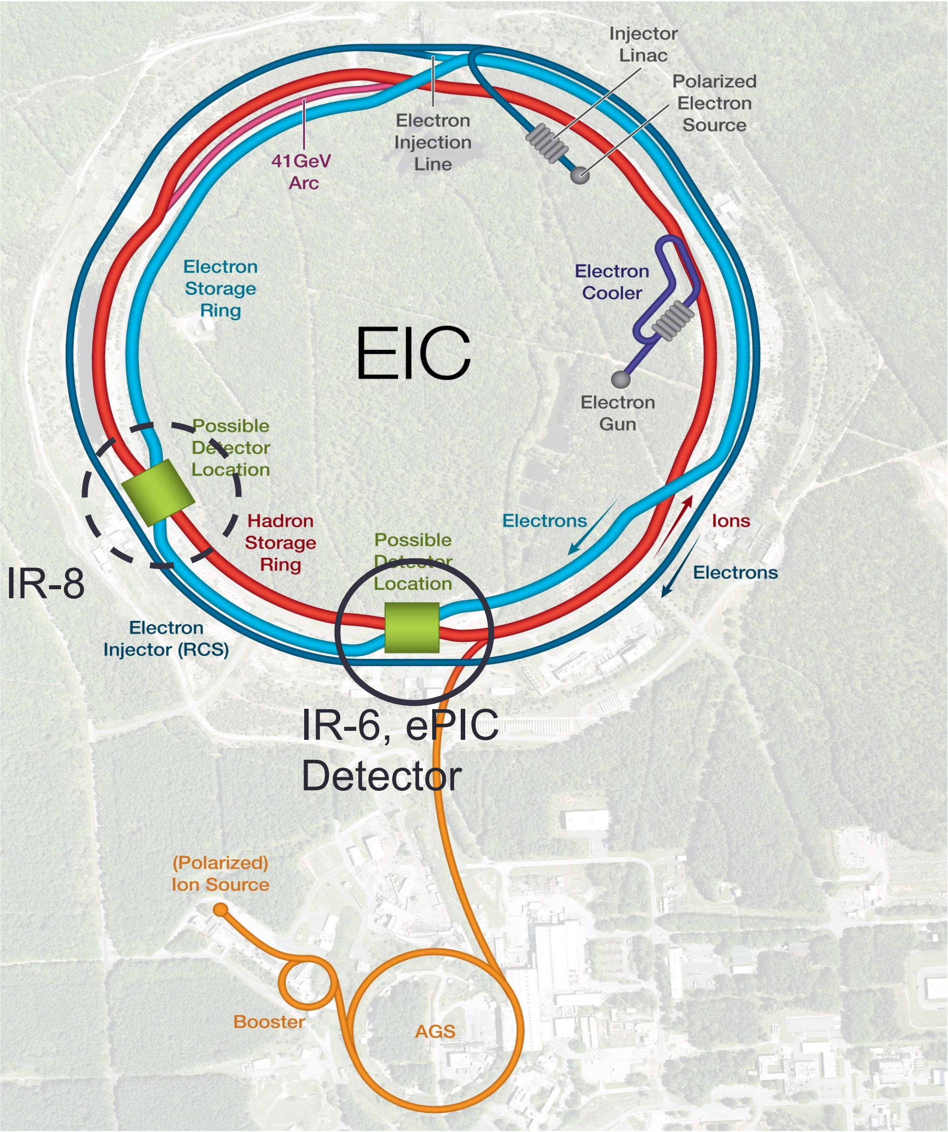


# EIC Project – BNL/JLab, Boards, Advisory Committees

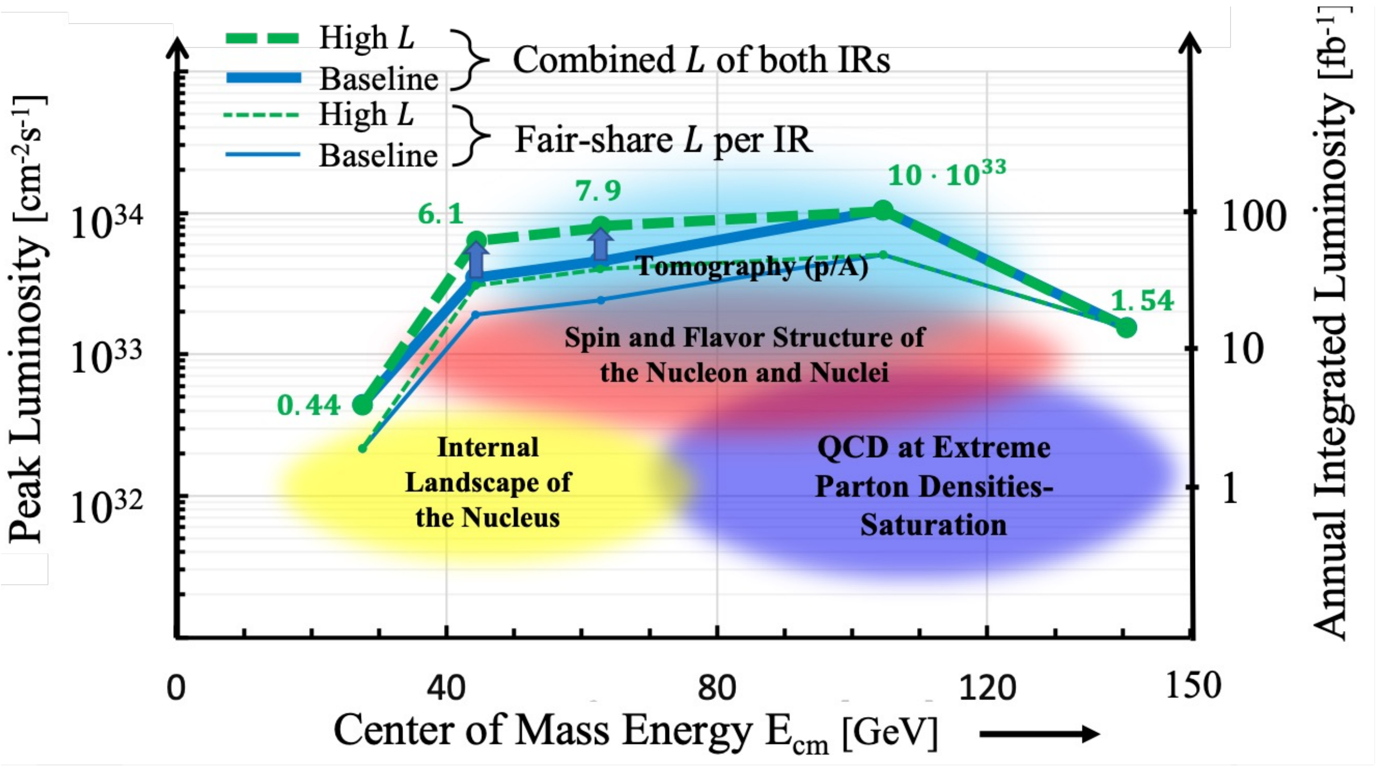



- DOE, together with BNL and JLab, envision an EIC facility that is "fully international in character."
- EIC Advisory Board provides oversight and advice on the construction of the facility, focusing on the accelerator (BNL, TJNAF, LBNL, ANL, TRIUMF, IN2P3, CEA, STFC, INFN).
- EIC Project Advisory Committee 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

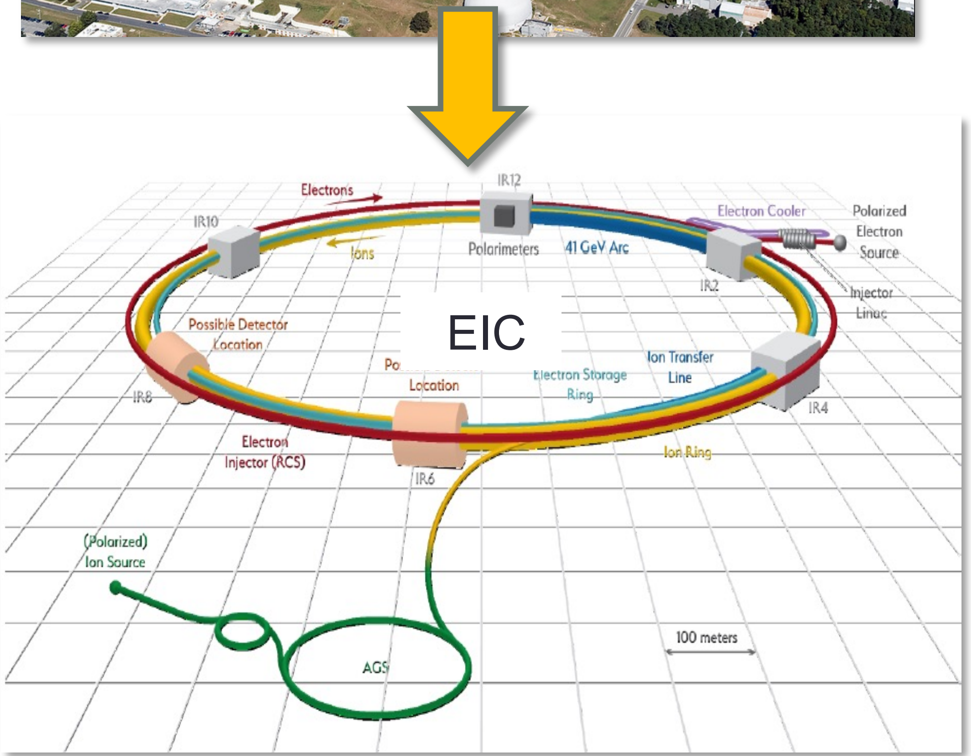



| | |
|---|---|
| Center of Mass Energies: | 20GeV - 140GeV |
| Luminosity: | $10^{33}$ - $10^{34}$ $cm^{-2}s^{-1}$ / 10-100$fb^{-1}$ / year |
| Highly Polarized Beams: | 70% |
| Large Ion Species Range: | p to U |
| Number of Interaction Regions: | Up to 2! |



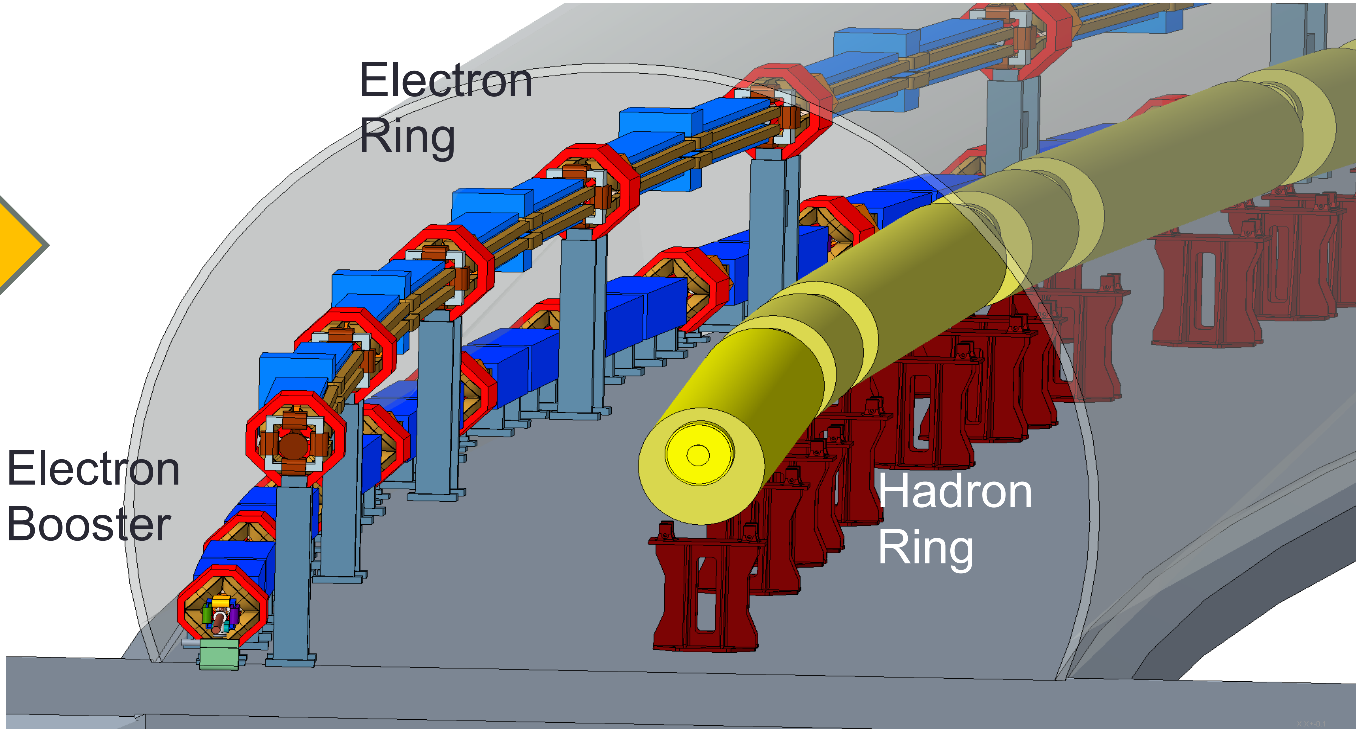
# EIC Accelerator Design Overview

- **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)



# RHIC to EIC

TYPICAL ARC SECTION RENDERING



# Towards high luminosity: optimizing a multidimensional parameter space

- Luminosity will always benefit from large beam currents
  ➔ maximize beam currents

- EIC luminosity benefits from reducing hadron emittance by "cooling" to maximize luminosity as normalized emittance from source is too large

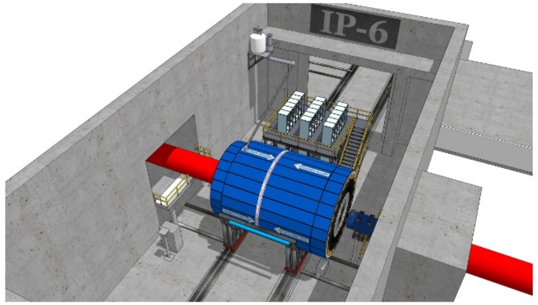
- Minimizing number of bunches (1060, still a large number) will
  - Reduce demand on beam cooling (since cooling is hard)
  - Is detector friendly because bunch spacing is relatively large (12 ns)
  - Results in smaller beam divergence at IP ➔ helps with $p_T$ acceptance

# EIC CDR Parameters for $E_{cm}$ and Luminosity

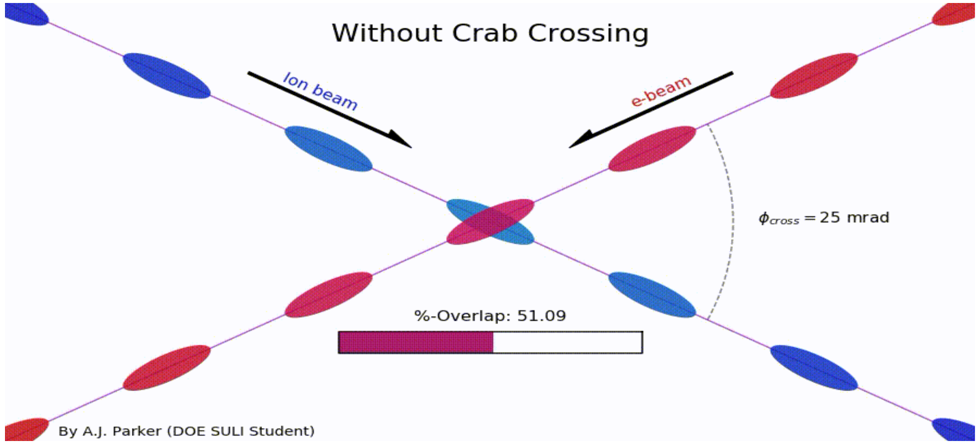
| | Electrons | Protons |
|---|---|---|
| Beam energies | 2.5 - 18 GeV | 41- 275 GeV |
| Center of mass energy range | $E_{cm}$ = 20-140 GeV | |

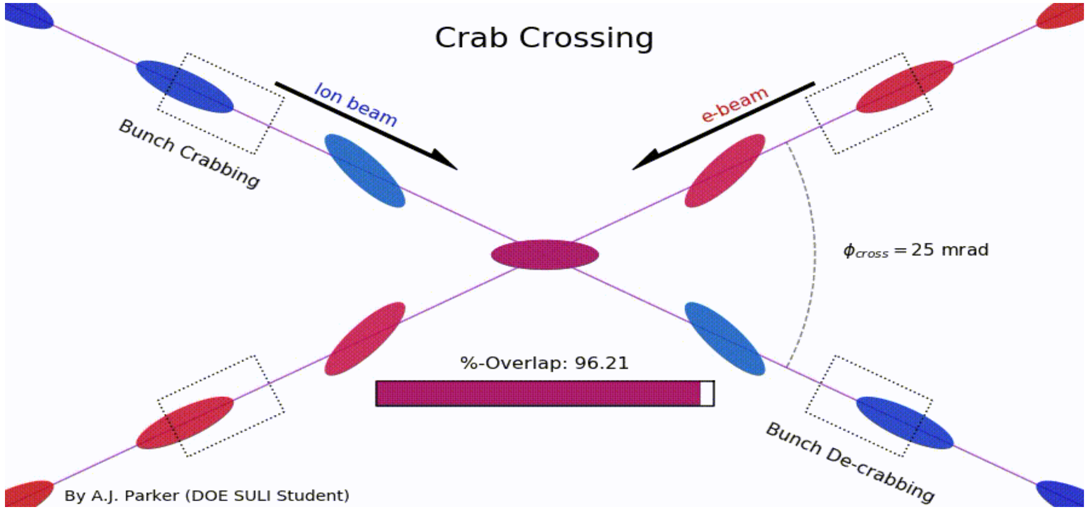
| | Electrons | Protons |
|---|---|---|
| Beam energies | 10 GeV | 275 GeV |
| Center of mass energy | $E_{cm}$ = 105 GeV | |
| number of bunches | nb =1160 | |
| crossing angle | 25 mrad | |
| Bunch Charge | $1.7 \cdot 10^{11}$e | $0.7 \cdot 10^{11}$e |
| Total beam current | 2.5 A | 1 A |
| Beam emittance, horizontal | 20 nm | 9.5 nm |
| Beam emittance, vertical | 1.2 nm | 1.5 nm |
| $\beta$- function at IP, horizontal | 43 cm | 90 cm |
| $\beta$- function at IP, vertical | 5 cm | 4 cm |
| Beam-beam tuneshift, horizontal | 0.073 | 0.014 |
| Beam-beam tuneshift, vertical | 0.1 | 0.007 |
| Luminosity at $E_{cm}$ = 105 Gev | $\mathbf{1 \cdot 10^{34} cm^{-2} s^{-1}}$ | |

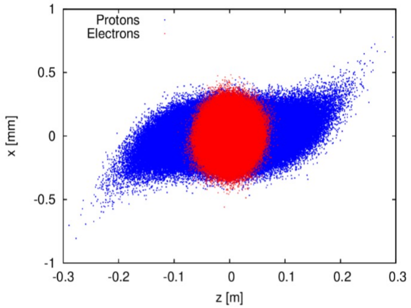
# Interaction Region




- 12 ns bunch spacing ➔ 25 mrad crossing angle
- Superconducting final focus magnets
- Spin rotators
- Large acceptance for forward scattered hadrons
- Need compensate crossing angle effects ➔ **Crab cavities**

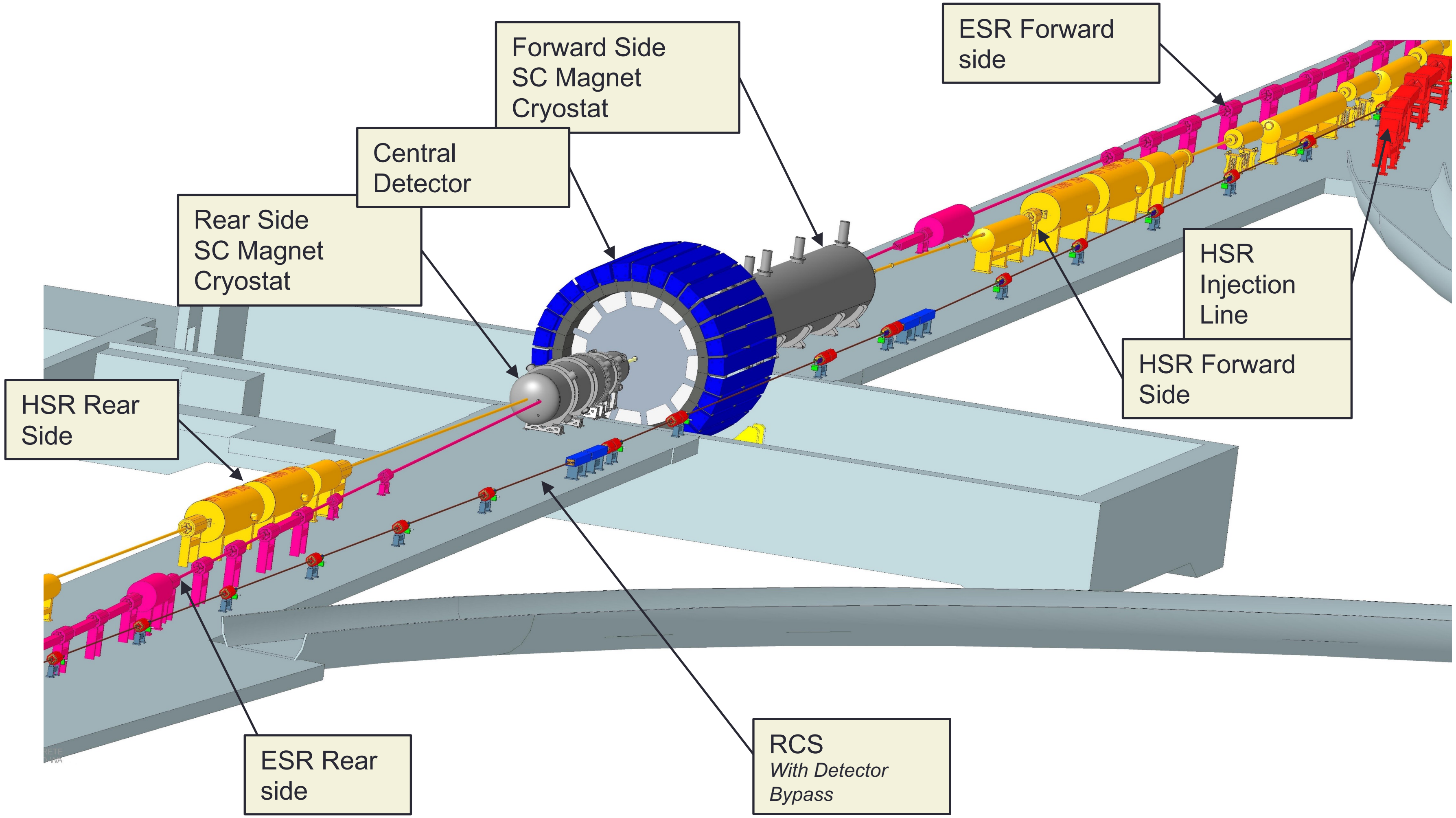



- Crabbing Complicates beam-beam interaction, source of hadron emittance blow-up
- Once hadron beam size is blown up, electron re-shrink and the blow-up accelerated
- Crab Phase noise: Fluctuating beam-beam offset causes rapid emittance growth many ➔ extremely small tolerances

# IR-6


ESR Forward side
Forward Side SC Magnet Cryostat
Central Detector
Rear Side SC Magnet Cryostat
HSR Injection Line
HSR Forward Side
HSR Rear Side
ESR Rear side
RCS
With Detector Bypass

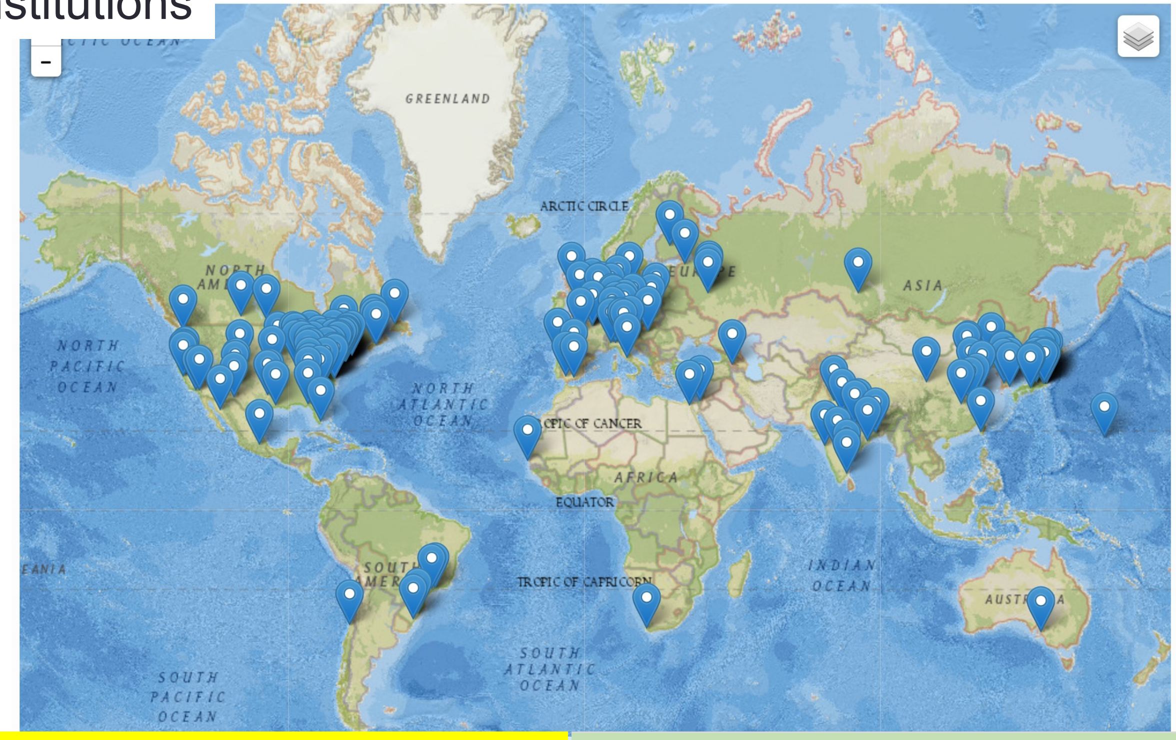
# EIC USERS, DETECTOR DESIGN & DETECTOR COLLABORATION

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

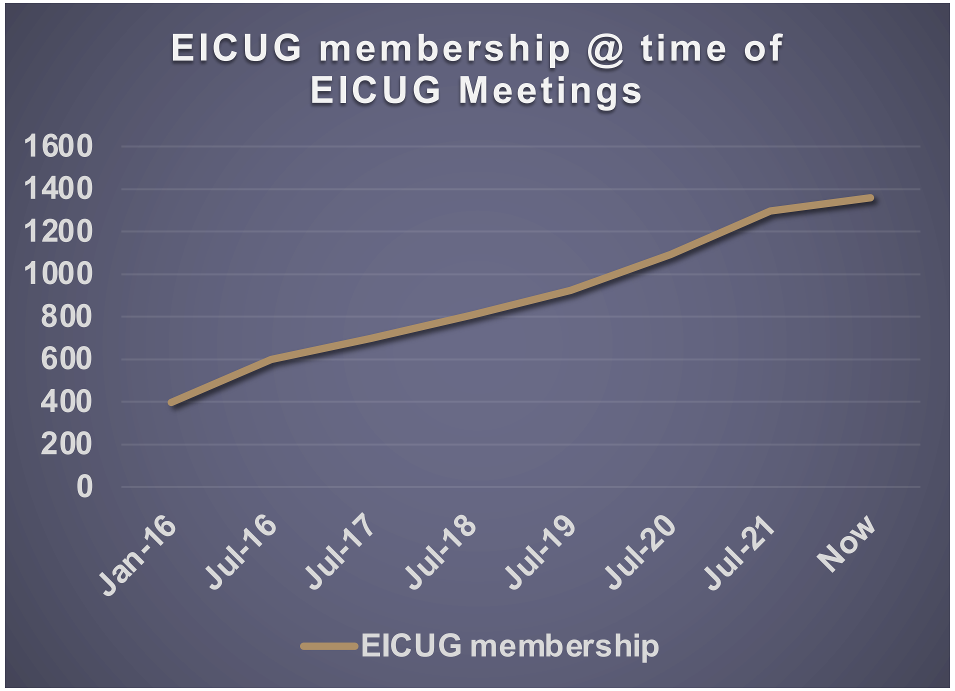
# The EIC User Group: [https://eicug.github.io/](https://eicug.github.io/)

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

Institutions

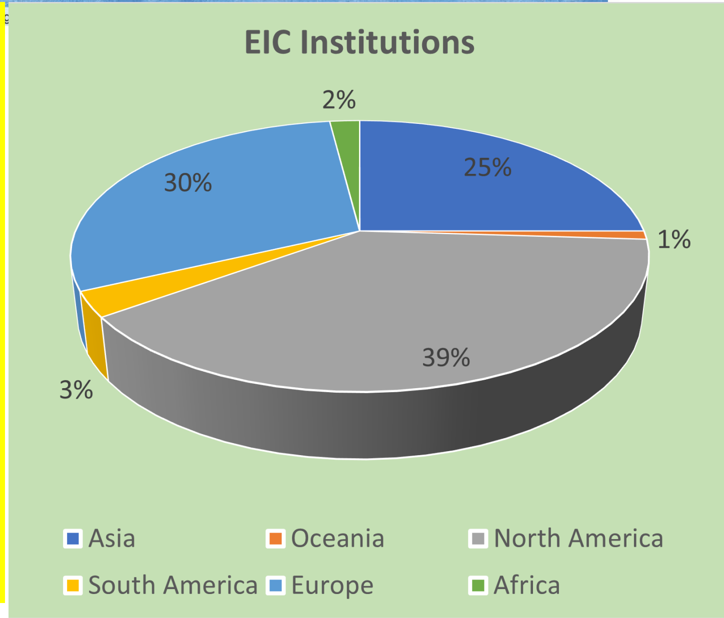



## International Participation Growing




**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 $\alpha_S$ : 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

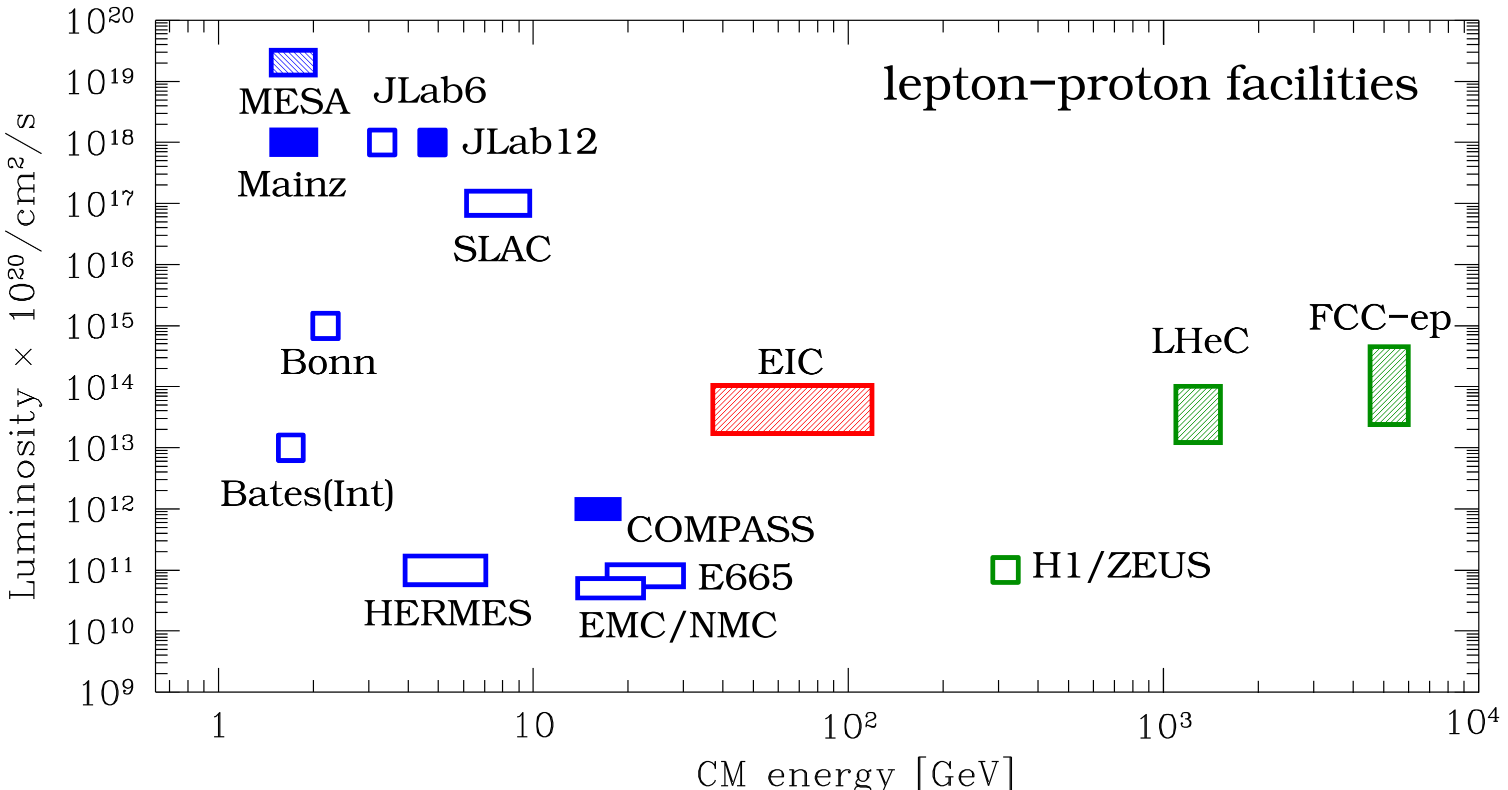
## Snowmass 2021 White Paper: Electron Ion Collider for High Energy Physics

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]

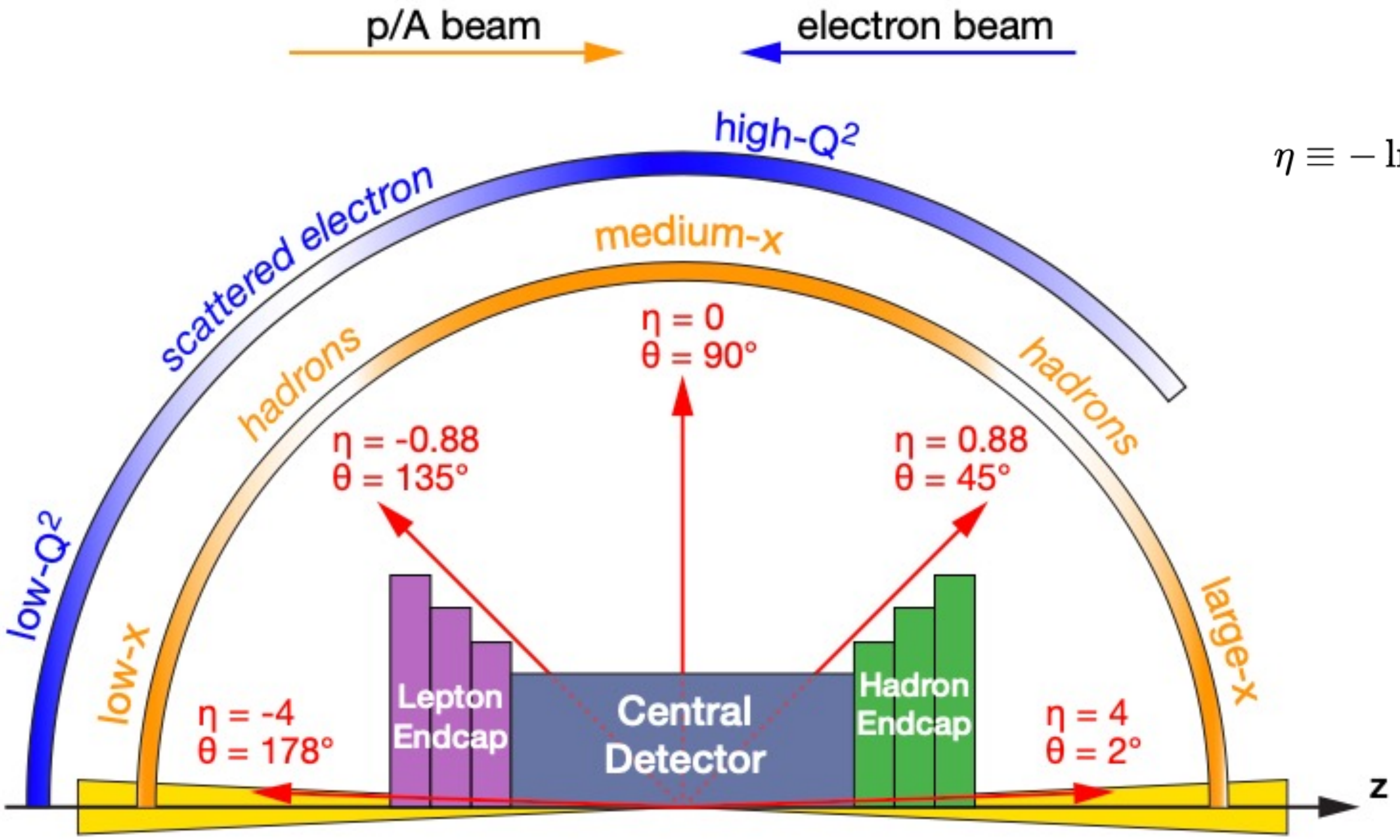
EIC’s versatility, resolving power and intensity (luminosity) open new windows of opportunity to address some of the crucial and fundamental scientific questions in particle physics. The paper summarizes the EIC physics from the perspective of the HEP community participating in Snowmass 2021

- 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

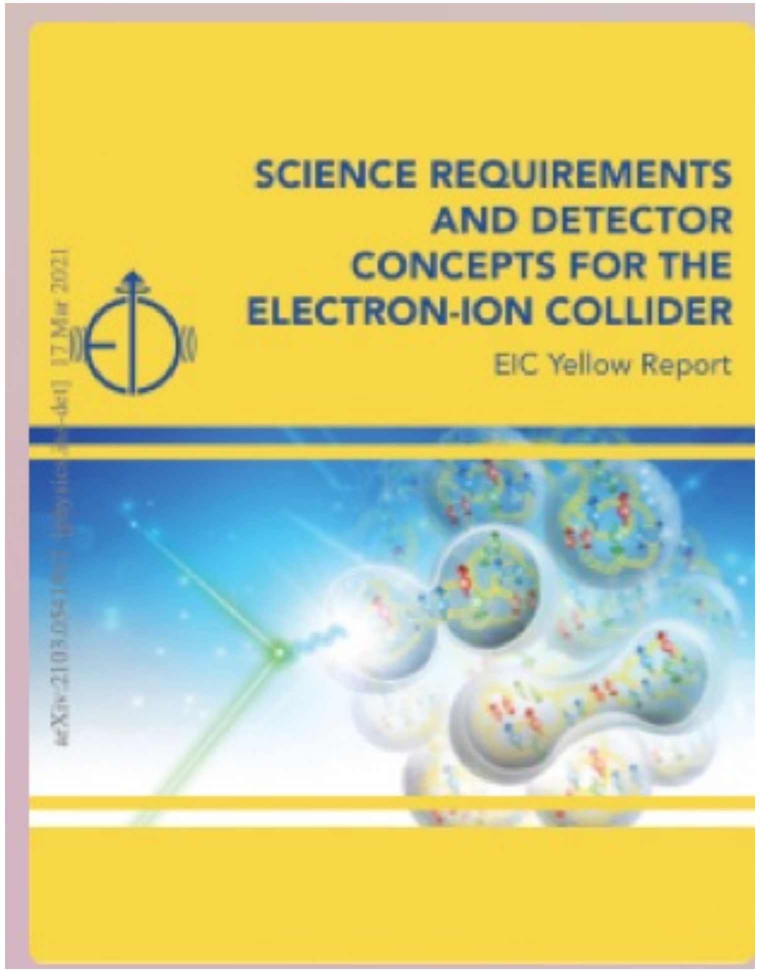


# Detector polar angle / pseudo-rapidity coverage



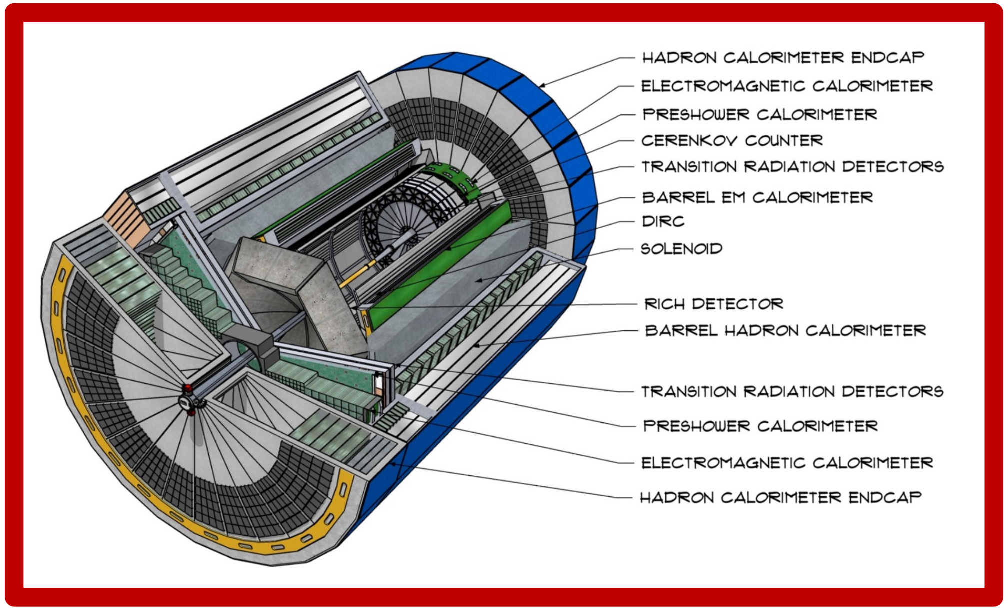

$$\eta \equiv -\ln\left[\tan\left(\frac{\theta}{2}\right)\right],$$

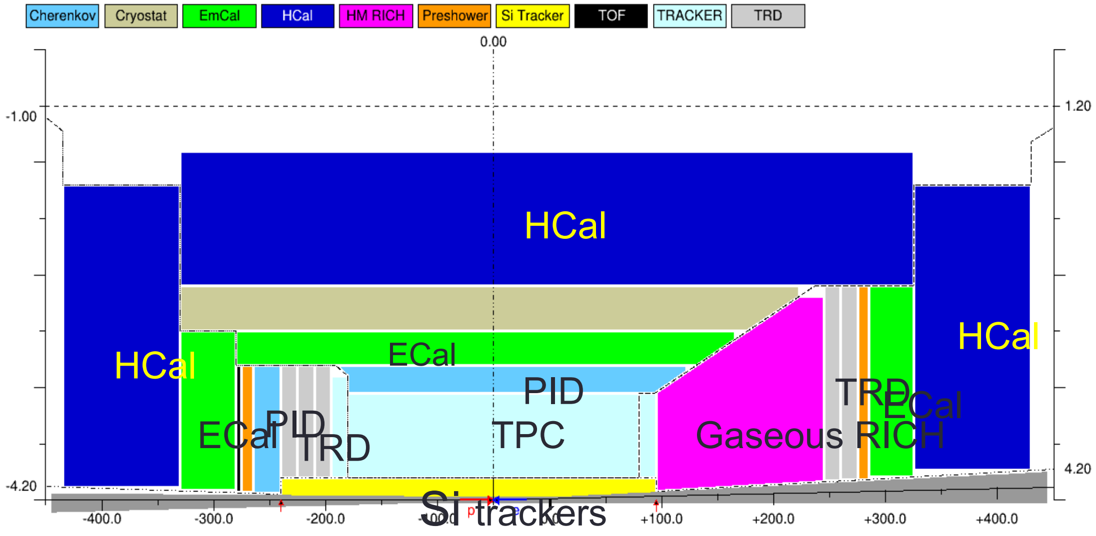
# EICUG led "reference" detector design 2019-2021 "Yellow Report"




902 pages
415 authors
151 institutions

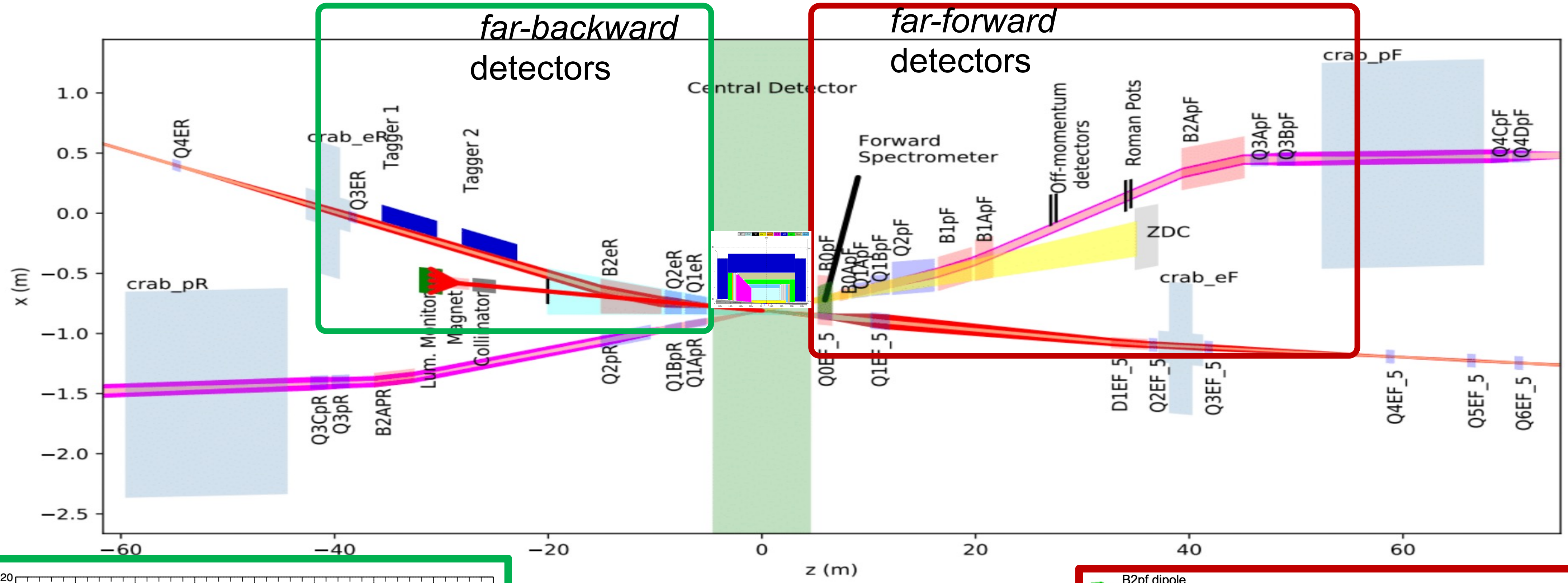
120 MB

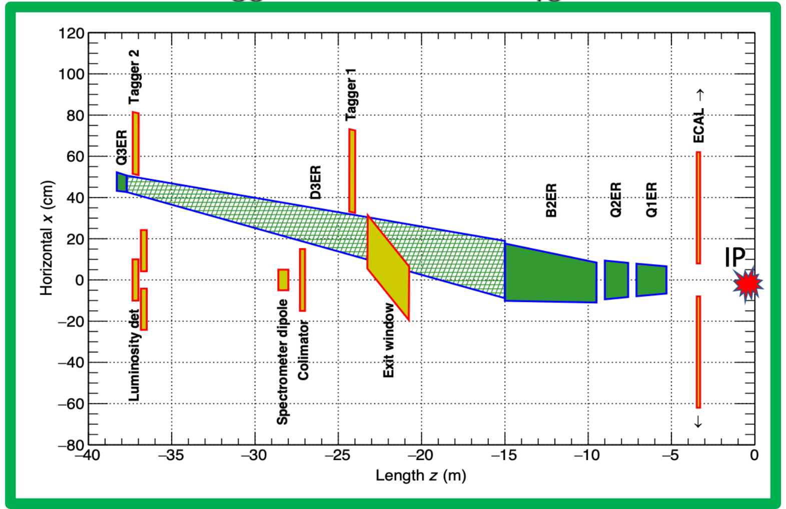


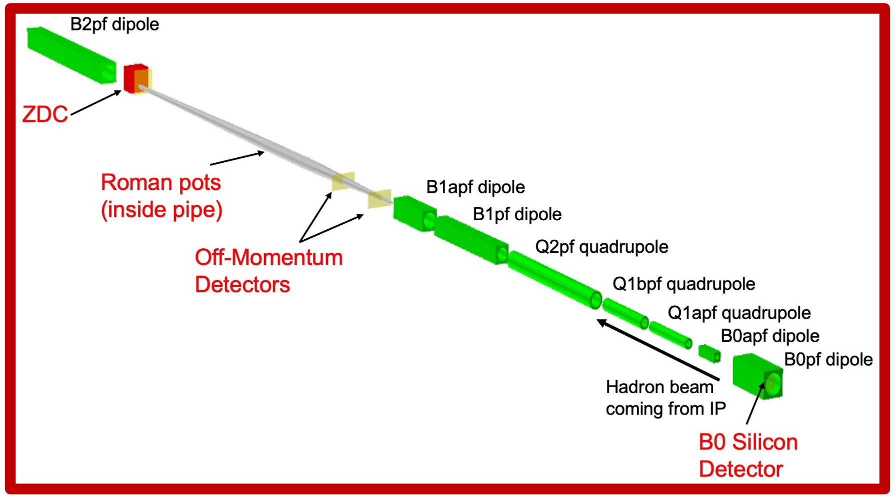

Nucl. Phys. A 1026 (2022) ; arXiv:2103.05419

# Reference Detector – Backward/Forward Detectors



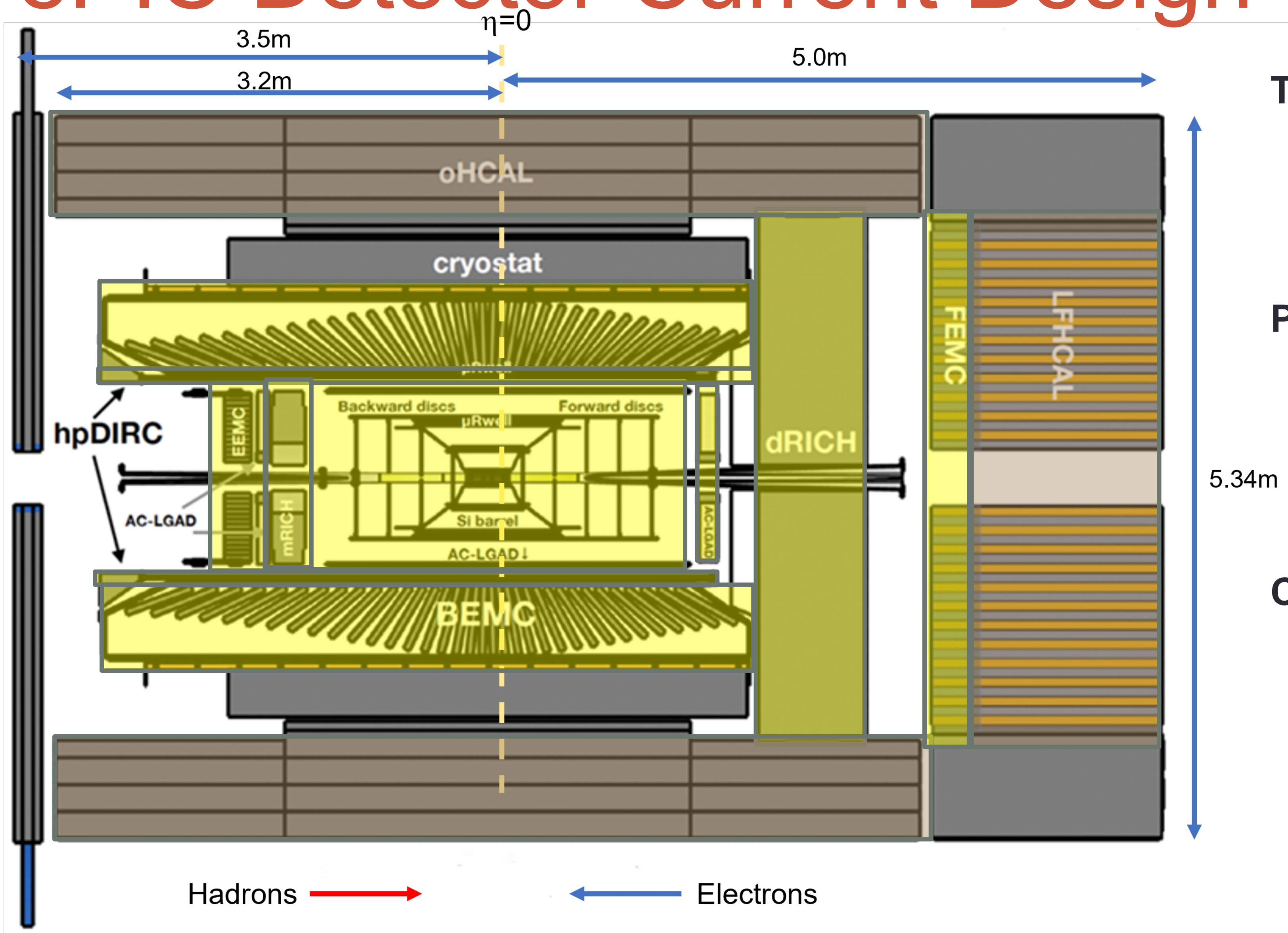




Extensive integration of forward and backward detector elements into the accelerator lattice



# ePIC Detector Current Design

Collaboration Setup
February 2023 : Elections
John Lejoie & Silvia Dalla Torre




**Tracking:**

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

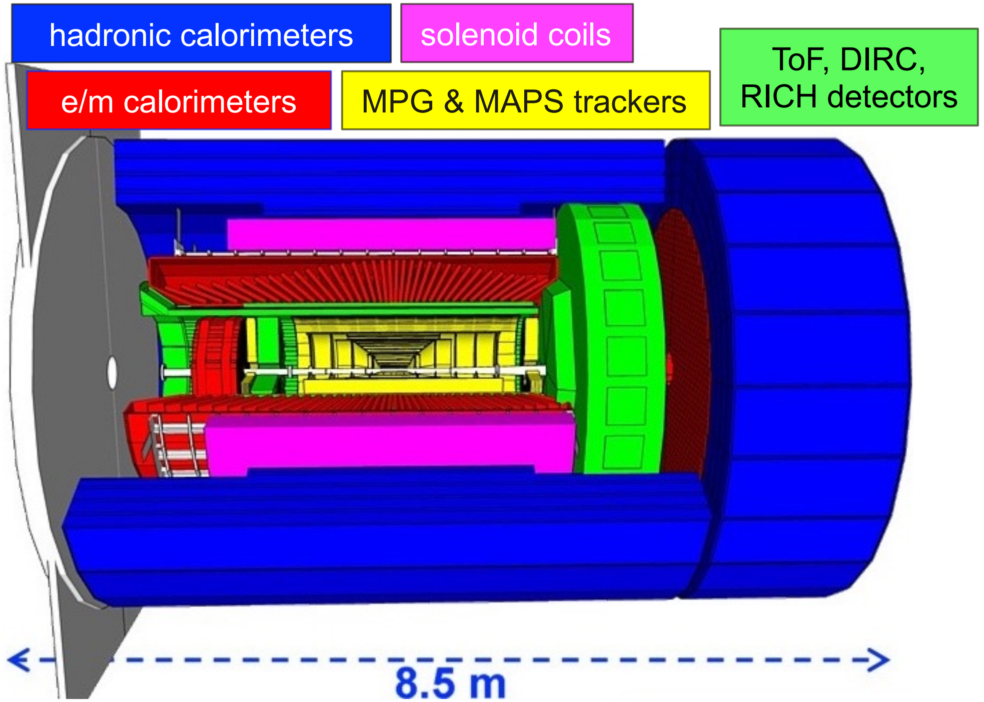
**PID:**

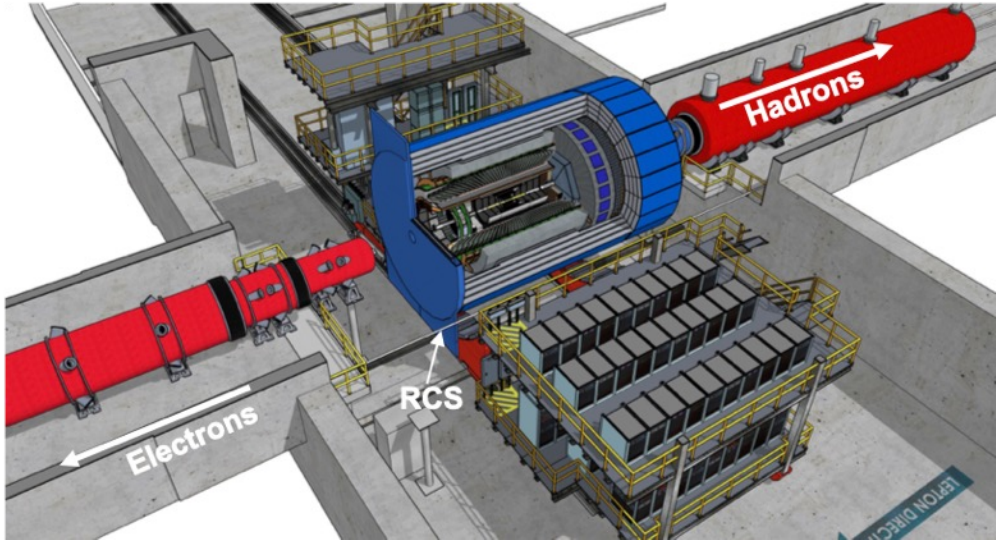
- hpDIRC
- mRICH/pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

**Calorimetry:**

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

From John Lajoie @ Epiphany 2023



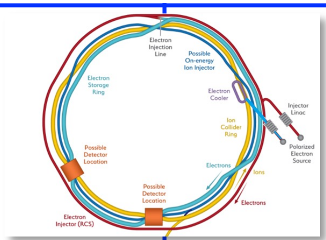

# EIC Management team working with the EICUG to realize "EPIC"

## Detector requirements:

- ❑ Large rapidity ($-4 < \eta < 4$) coverage; and far beyond
  - o 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
  - o small ($\mu$-vertex Silicon) and large radius (gas-based) tracking
- ❑ Electromagnetic and Hadronic Calorimetry
  - o equal coverage of tracking and EM-calorimetry
- ❑ High performance PID to separate e, $\pi$, K, p on track level
  - o good e/h separation critical for scattered electron ID
- ❑ Maximum scientific flexibility
  - o Streaming DAQ → integrating AI/ML
- ❑ Excellent control of systematics
  - o luminosity monitor, electron & hadron Polarimetry

# Complementarity for 1st-IR & 2nd-IR

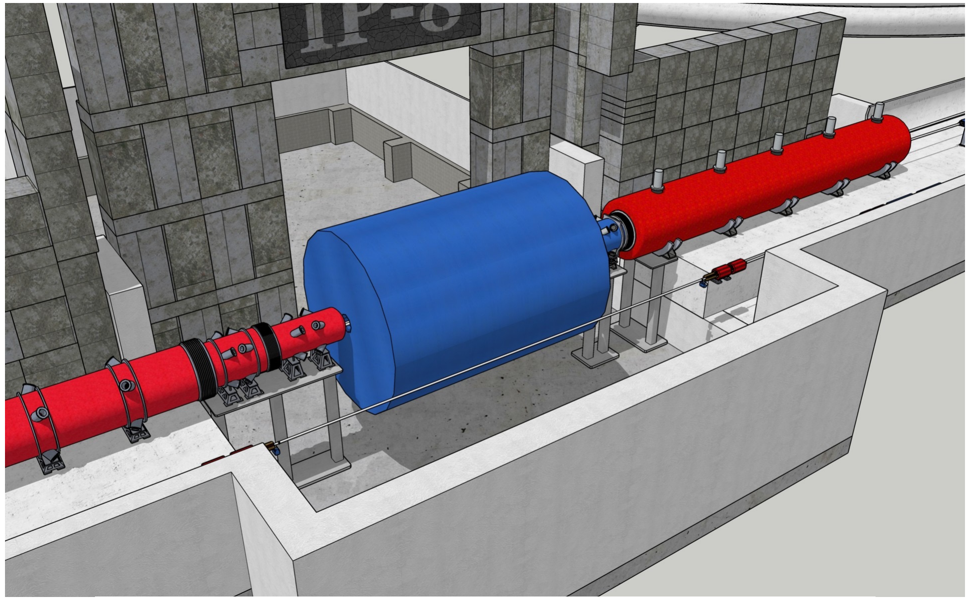
| | 1st IR (IP-6) | 2nd IR (IP-8) |
|---|---|---|
| Geometry: | ring inside to outside<br>tunnel and assembly hall are larger<br>Tunnel: ⦰ 7m +/- 140m | ring outside to inside<br>tunnel and assembly hall are smaller<br>Tunnel: ⦰ 6.3m to 60m then 5.3m |
| Crossing Angle: | 25 mrad | 35 mrad<br>secondary focus |
| | different blind spots<br>different forward detectors and acceptances<br>different acceptance of central detector | |
| Luminosity: | optimize Doublet focusing FDD vs. FDF<br>→ impact of far forward $p_T$ acceptance | |
| Experiment: | 1.7-2.0 Tesla or 3(?) Tesla<br>different subdetector technologies | |



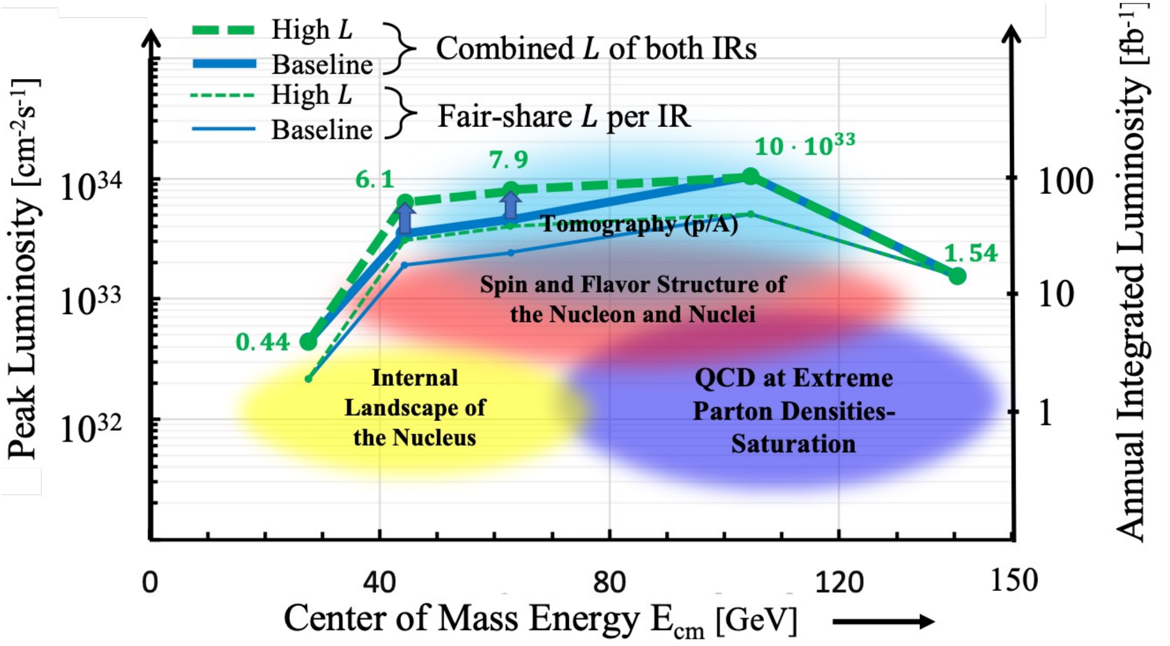
# EIC 2nd Detector and IR work

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

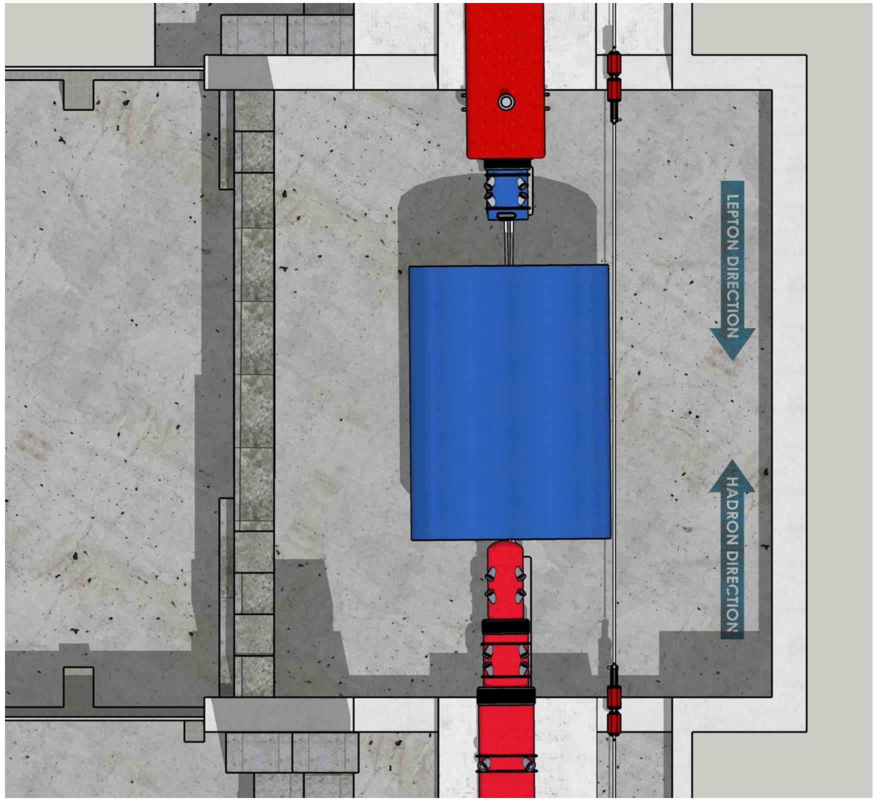
*Typical in ad-hoc meetings by E. Aschenauer, S. Berg, A. Drees, R. Ent, R. Gamage, A. Jentsch, V. Morozov, T. Satogata, W. Wittmer (now Y. Zhang)*



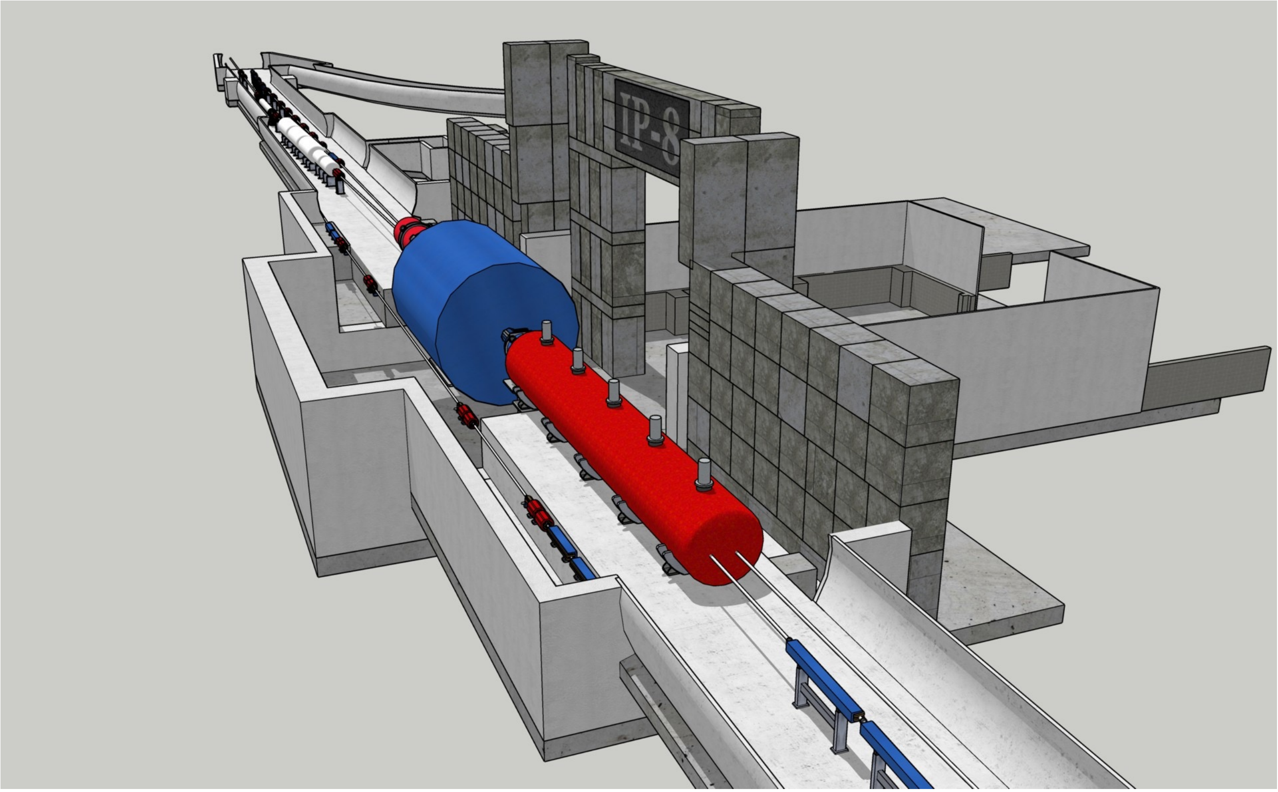

Detector = Blue cylinder of 838 cm



# EIC 2nd Detector and IR Work




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

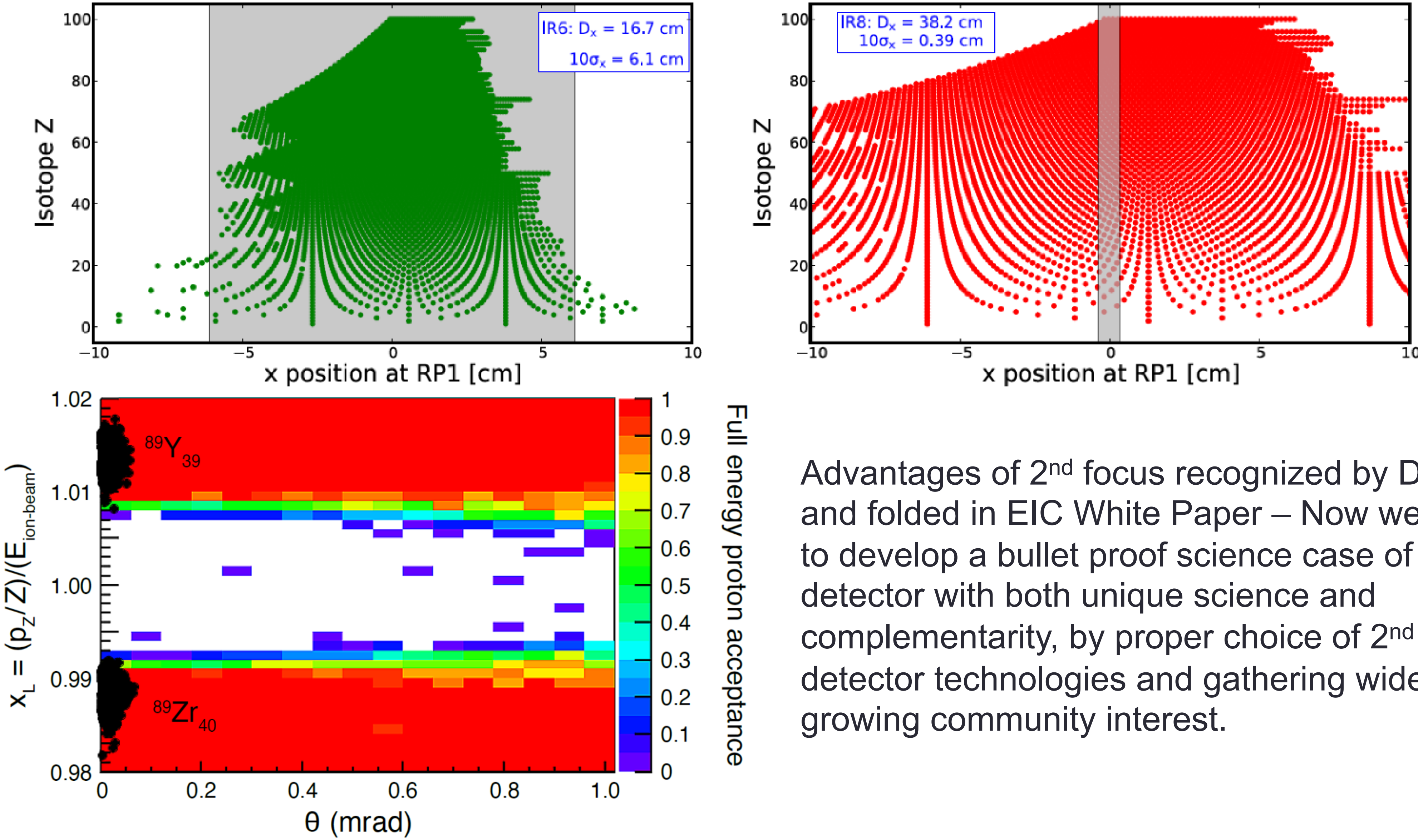



Can develop “handmade” beam pipe (or take the one Alex Jentsch did for his detector acceptance studies)

# 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)

See talk by Barak Schmookler Week 2




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.

# $2^{nd}$ IR and $2^{nd}$ Detector

- Not in the EIC project
- Challenging parameters of EIC require careful attention to the post $2^{nd}$ IR era.
- No design decisions now should negate the possibility of the second IR and detector

**Activities starting now: Led by EIC Users Group**

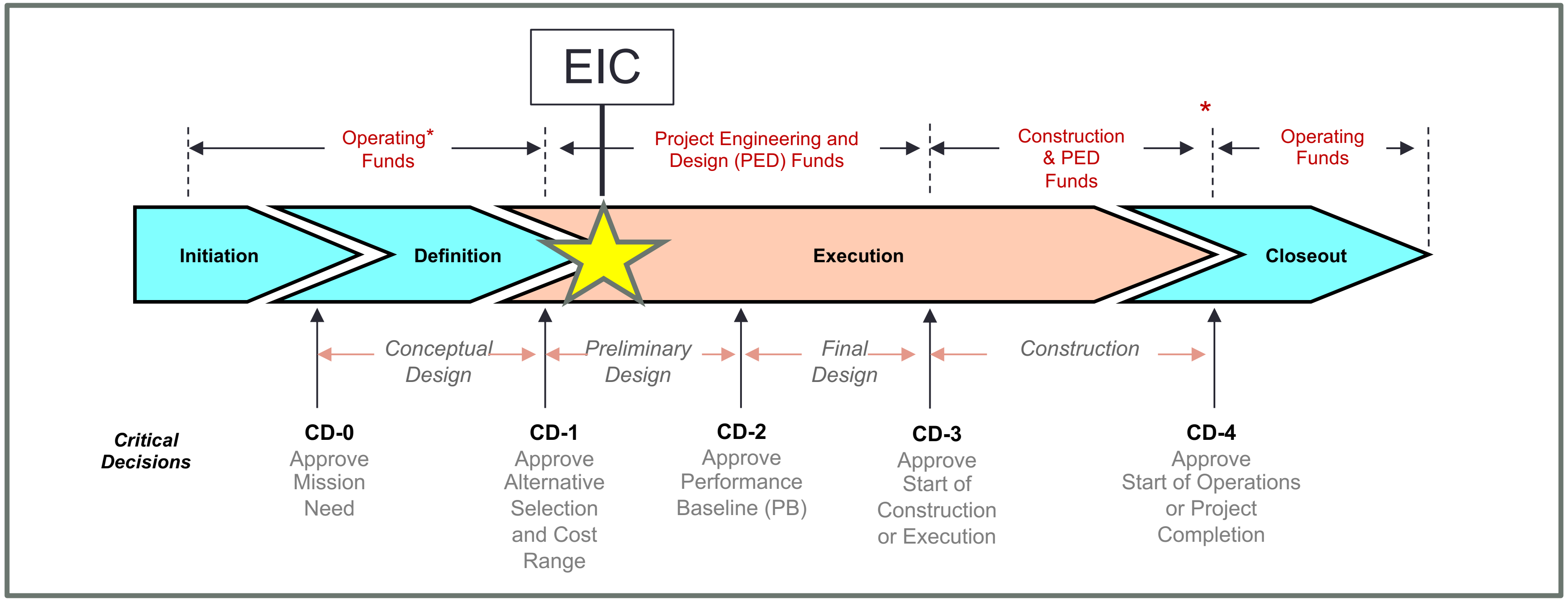
- What is a compelling physics case for the $2^{nd}$ IR?
- Balance between new physics and affirming important core physics (Detector 1)
- Complementary technologies ←→ generic detector R&D
- Need to get consensus amongst the EIC Users → acceptance in US NP community along with a buy-in from non-DOE sources (within and outside of the US)
- Proposals for a timeline and realization plans

# REALIZATION TIMELINE & OPPORTUNITIES

Mainly focused on EIC project: accelerator and 1st detector leading to the start of EIC science

2nd detector considerations peripheral to this section.

# DOE Project Phases



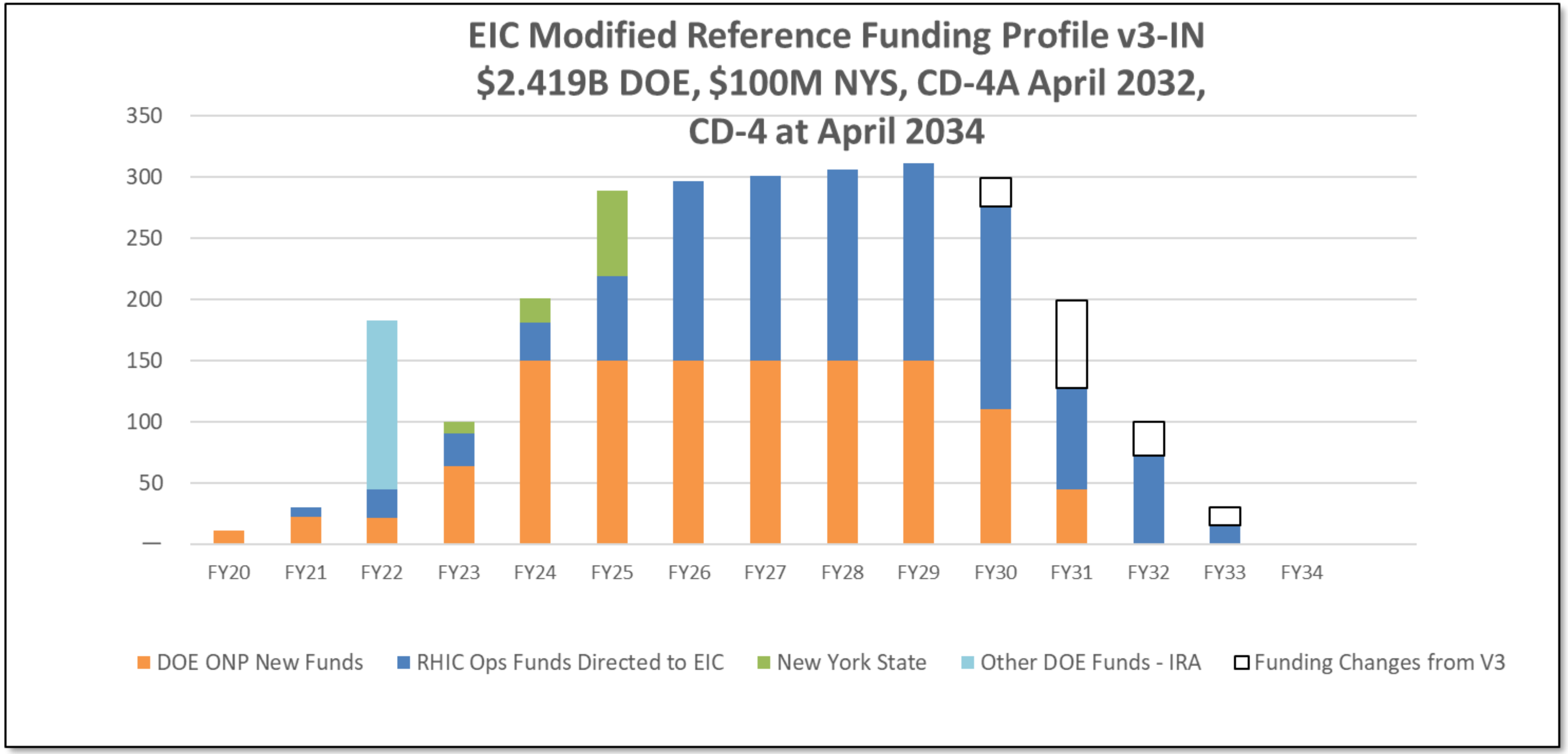

Formal Process of DOE Gateway Reviews

- 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.

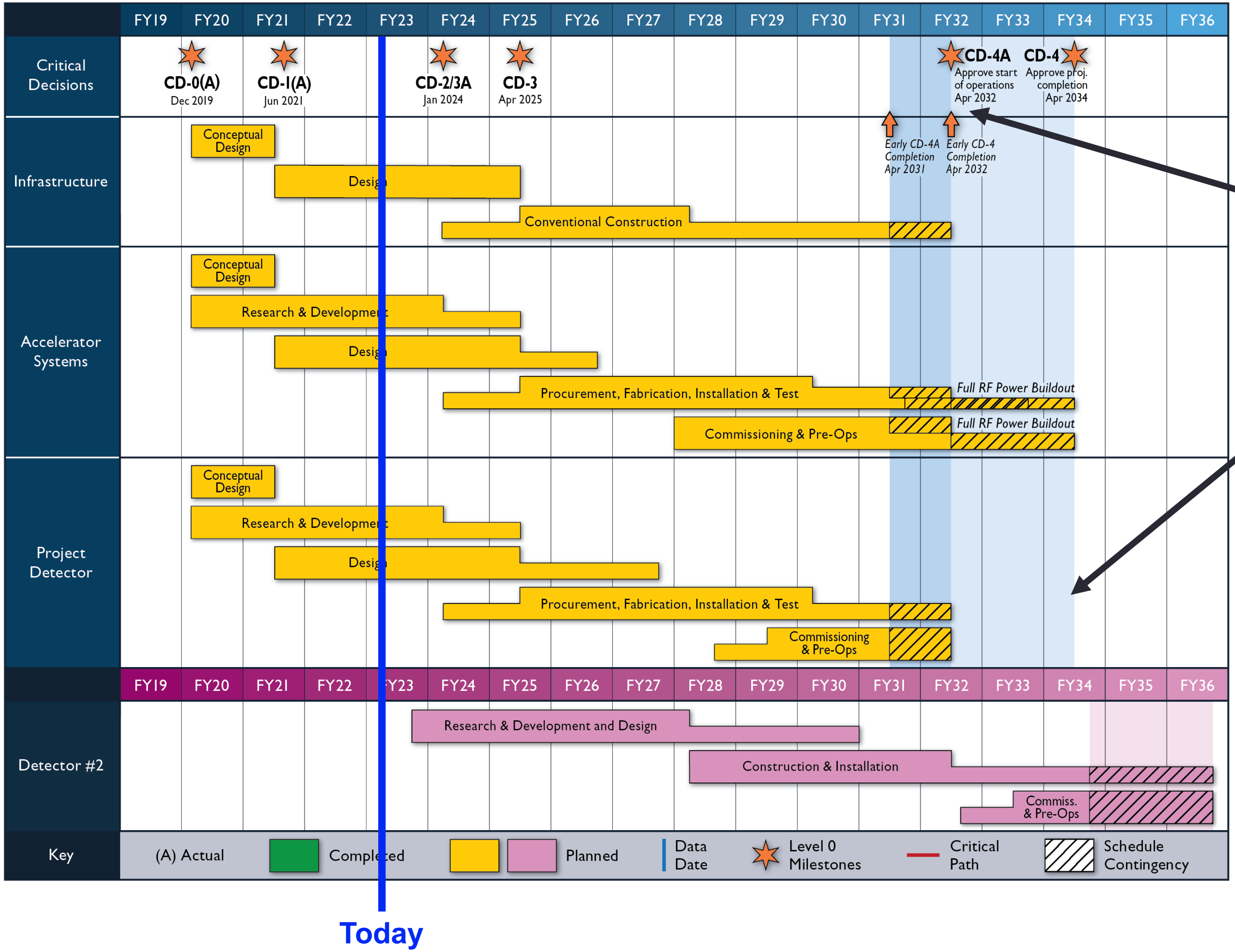
# EIC Project – Path to CD-2/3A and CD-3

- ✓ 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

# Polarized HERA and nuclei in HERA

DeRoeck, Deshpande, Hughes, McLerran, Strikman

1996-1999

# 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