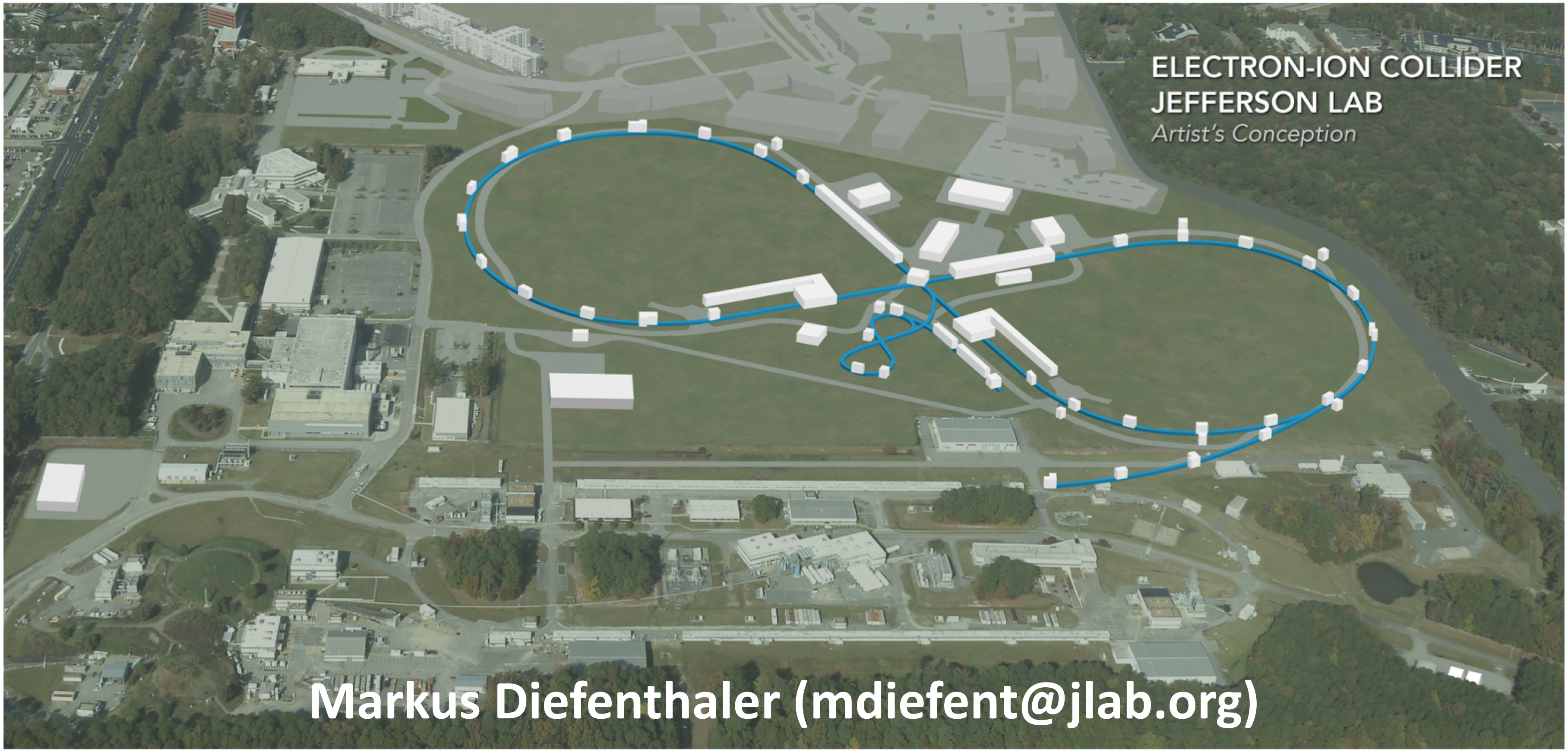
Realizing the Electron-Ion Collider at Jefferson Lab



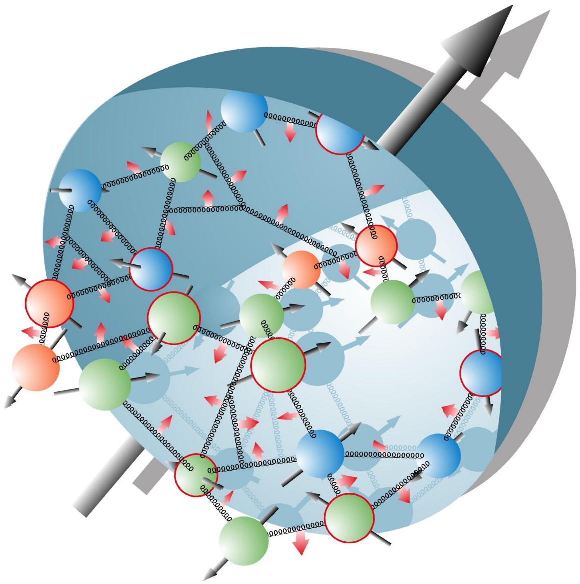
Markus Diefenthaler (mdiefent@jlab.org)

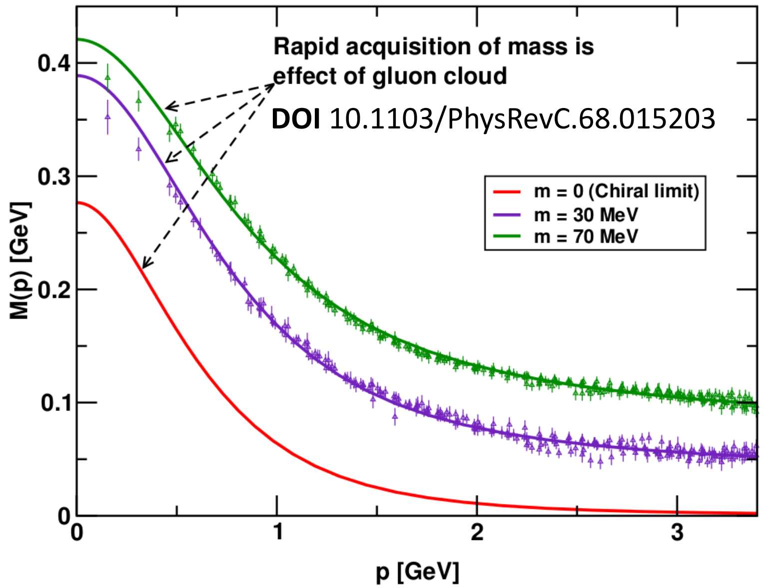
QCD Evolution 2018,
Santa Fe, New Mexico, May 20-24

The dynamical nature of nuclear matter

Nuclear Matter Interactions and structures are inextricably mixed up

Observed properties such as mass and spin emerge out of the complex system



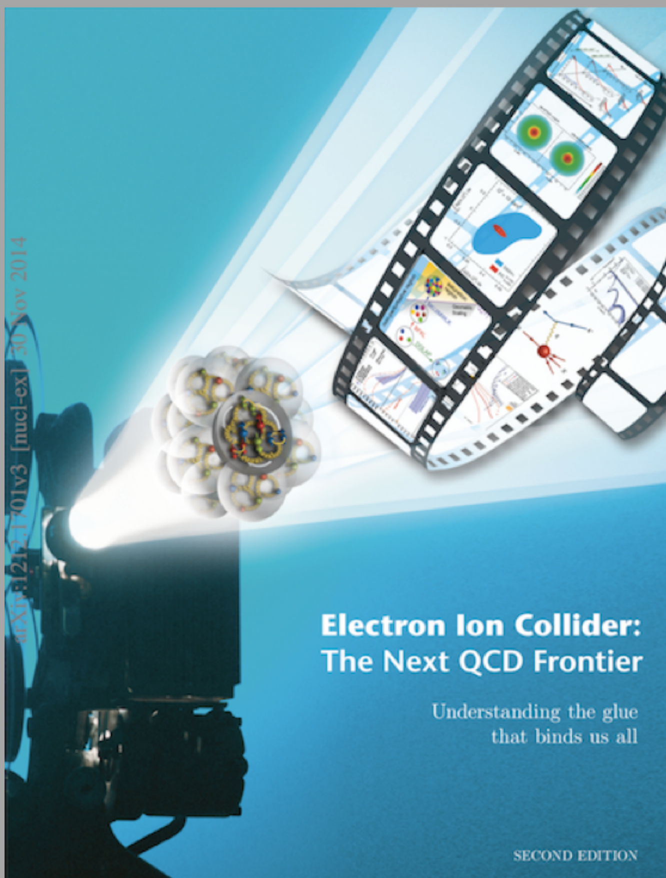


Ultimate goal Understand how matter at its most fundamental level is made

To reach goal precisely image quarks and gluons and their interactions

Why an Electron-Ion Collider?

EIC: The Next QCD Frontier

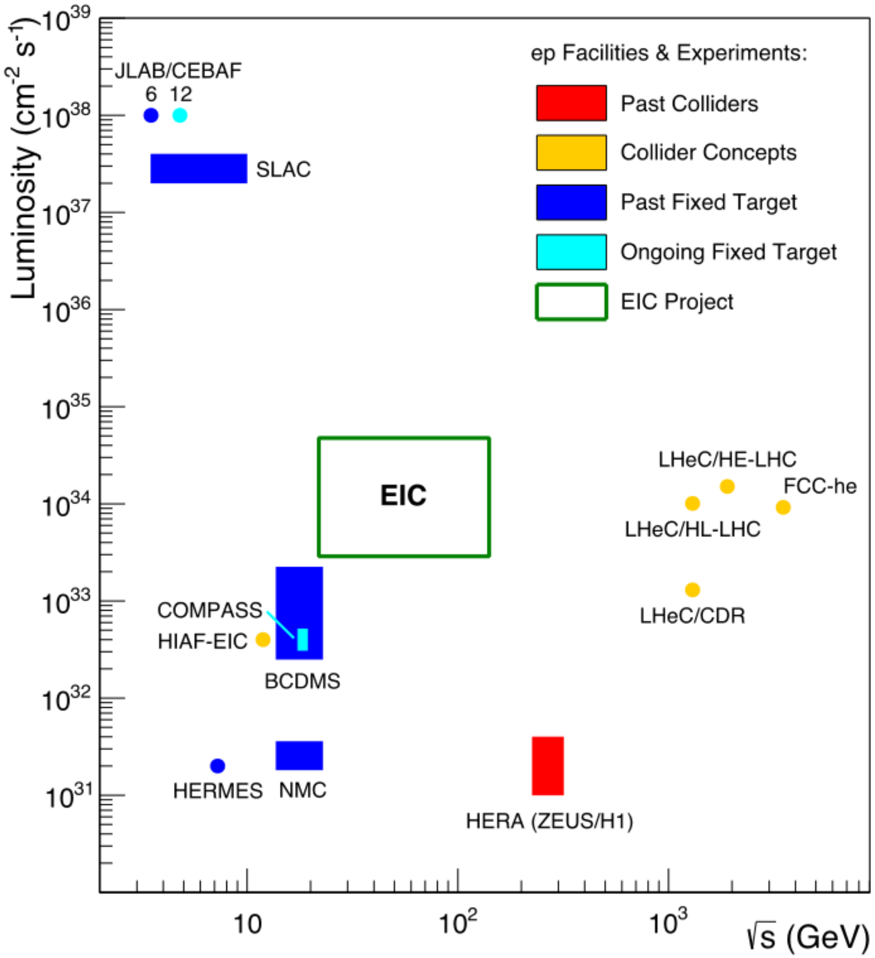


Eur.Phys.J. A52 (2016) no.9, 268

- **Right tool**:
  - to precisely **image quarks and gluons** and their interactions
  - to explore the new **QCD frontier of strong color fields in nuclei**
  - to to understand **how matter at its most fundamental level is made**.
- **Understanding of nuclear matter** is **transformational**,
  - perhaps in an even more dramatic way than how the understanding of the atomic and molecular structure of matter led to new frontiers, new sciences and new technologies.

The Electron-Ion Collider (EIC)

Frontier accelerator facility in the U.S.



World's first collider of:

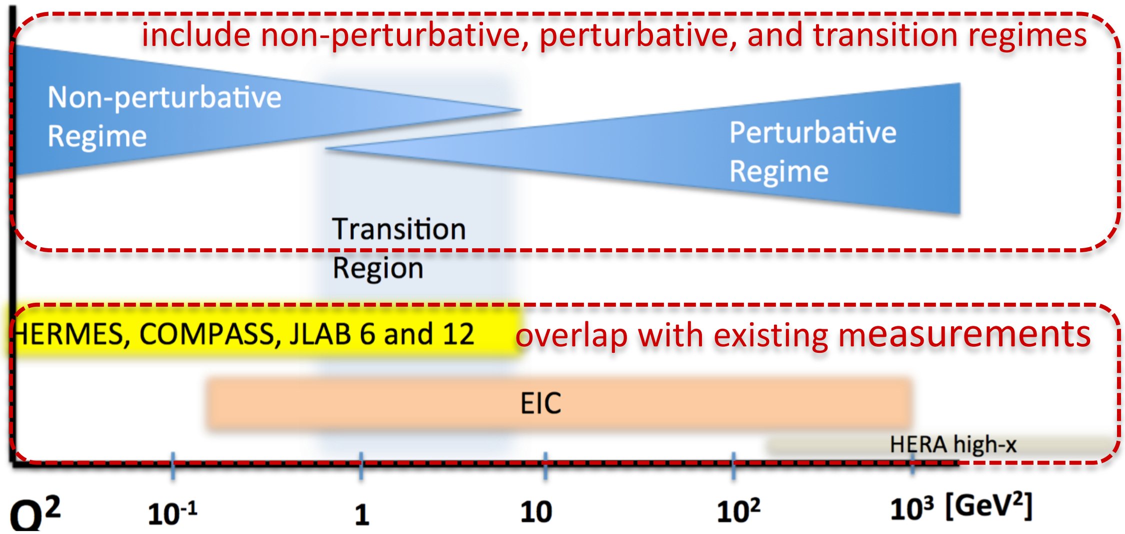
- polarized electrons and polarized protons/light ions
- electrons and nuclei

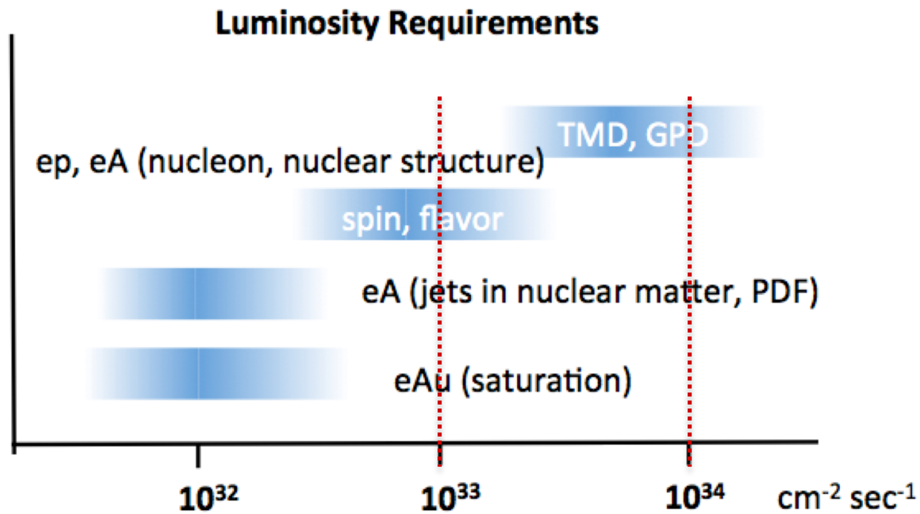
Versatile range of

- beam energies
- beam polarizations
- beam species

High luminosity

EIC: ideal facility for studying QCD





Various beam energy

broad Q^2 range for

- studying evolution to Q^2 of ~1000 GeV^2
- disentangling non-perturbative and perturbative regimes
- overlap with existing measurements

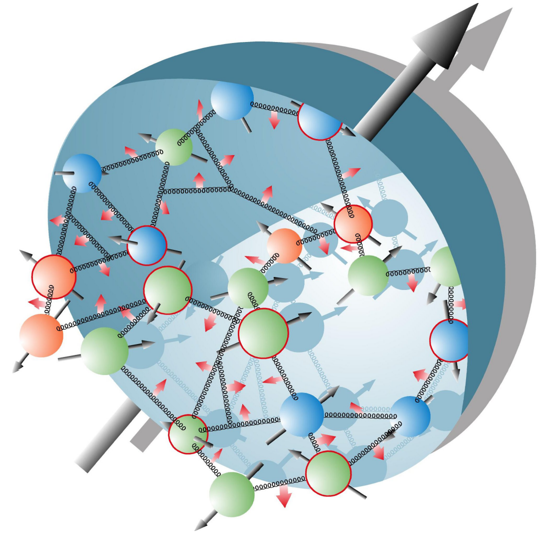
High luminosity

high precision

- for various measurements
- in various configurations
- **e-A** luminosity per nucleon same as **e-p**

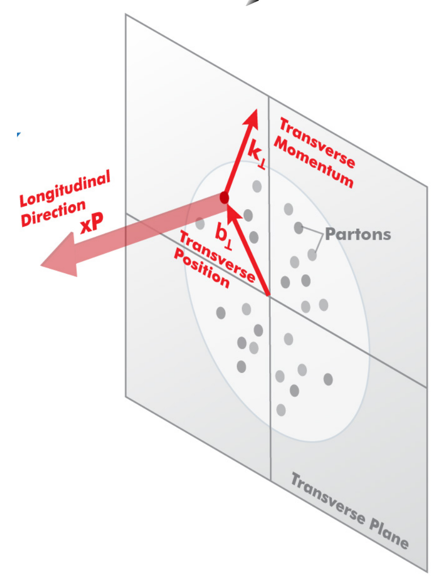
EIC: ideal facility for studying QCD

Polarization
Understanding hadron structure cannot be done without understanding spin:
- polarized **electrons (e)** and
- polarized **protons/light ions (p, d, ^{3}He)**



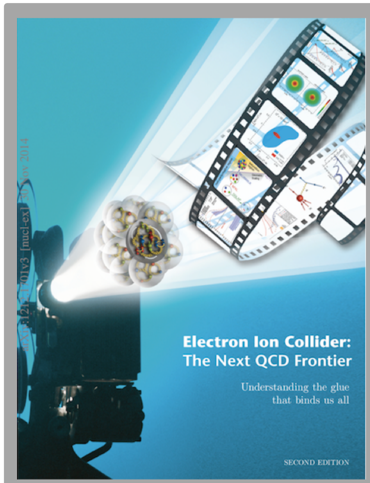
Longitudinal and transverse polarization of light ions

- 3D imaging in space and momentum
- spin-orbit correlations

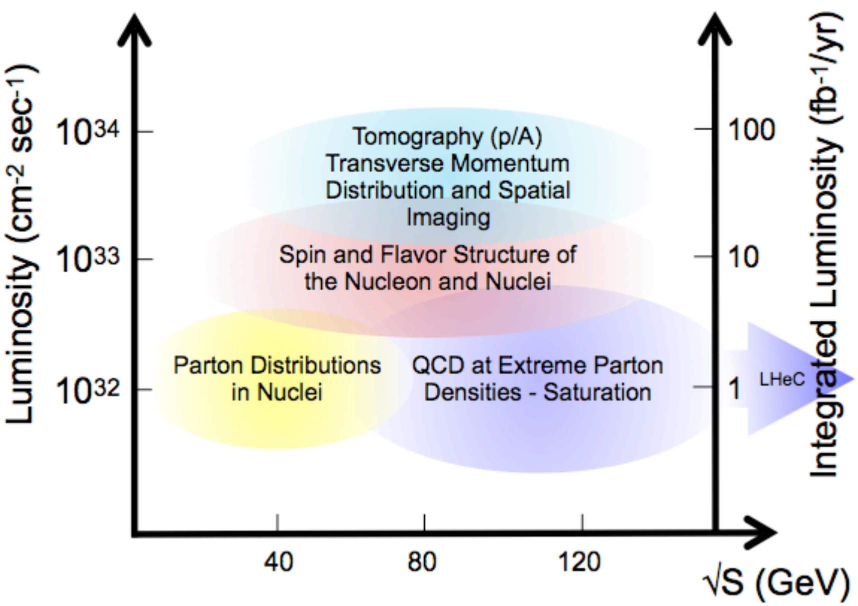


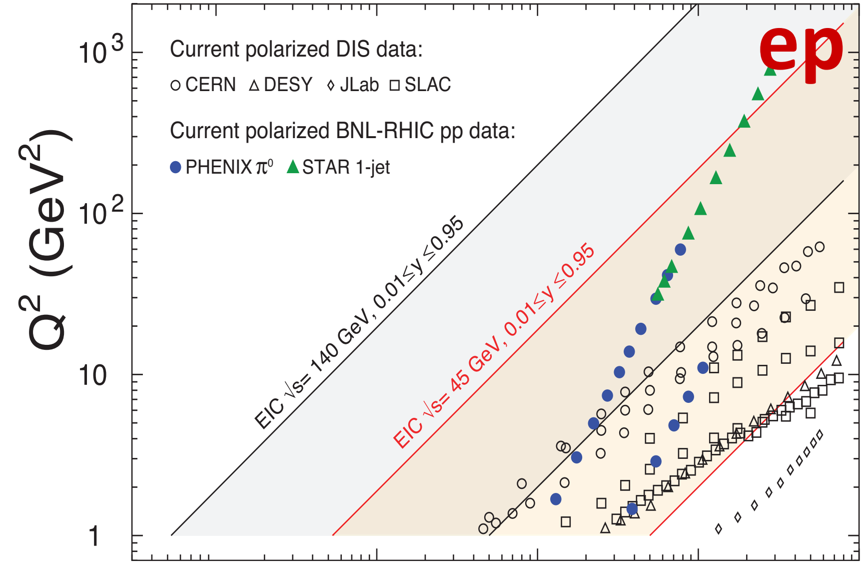
Wide range in nuclei (e-A)

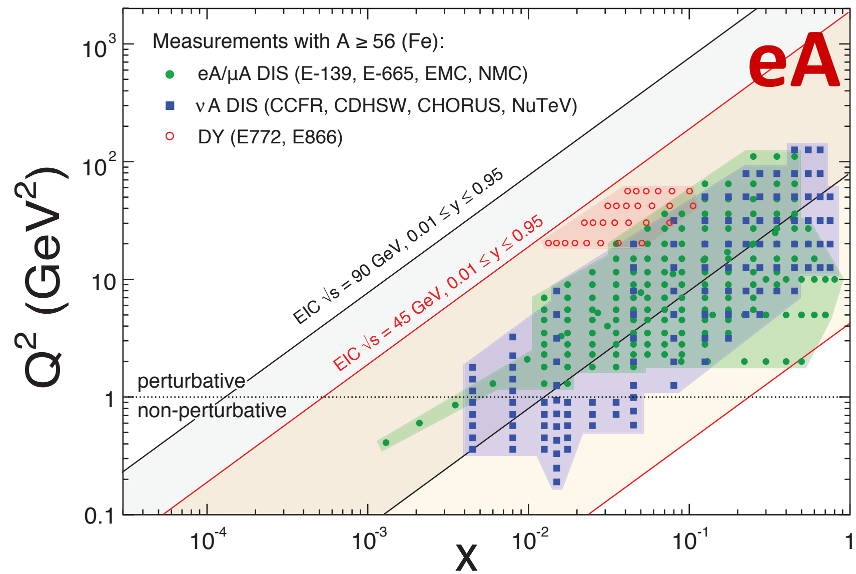
EIC: Science program



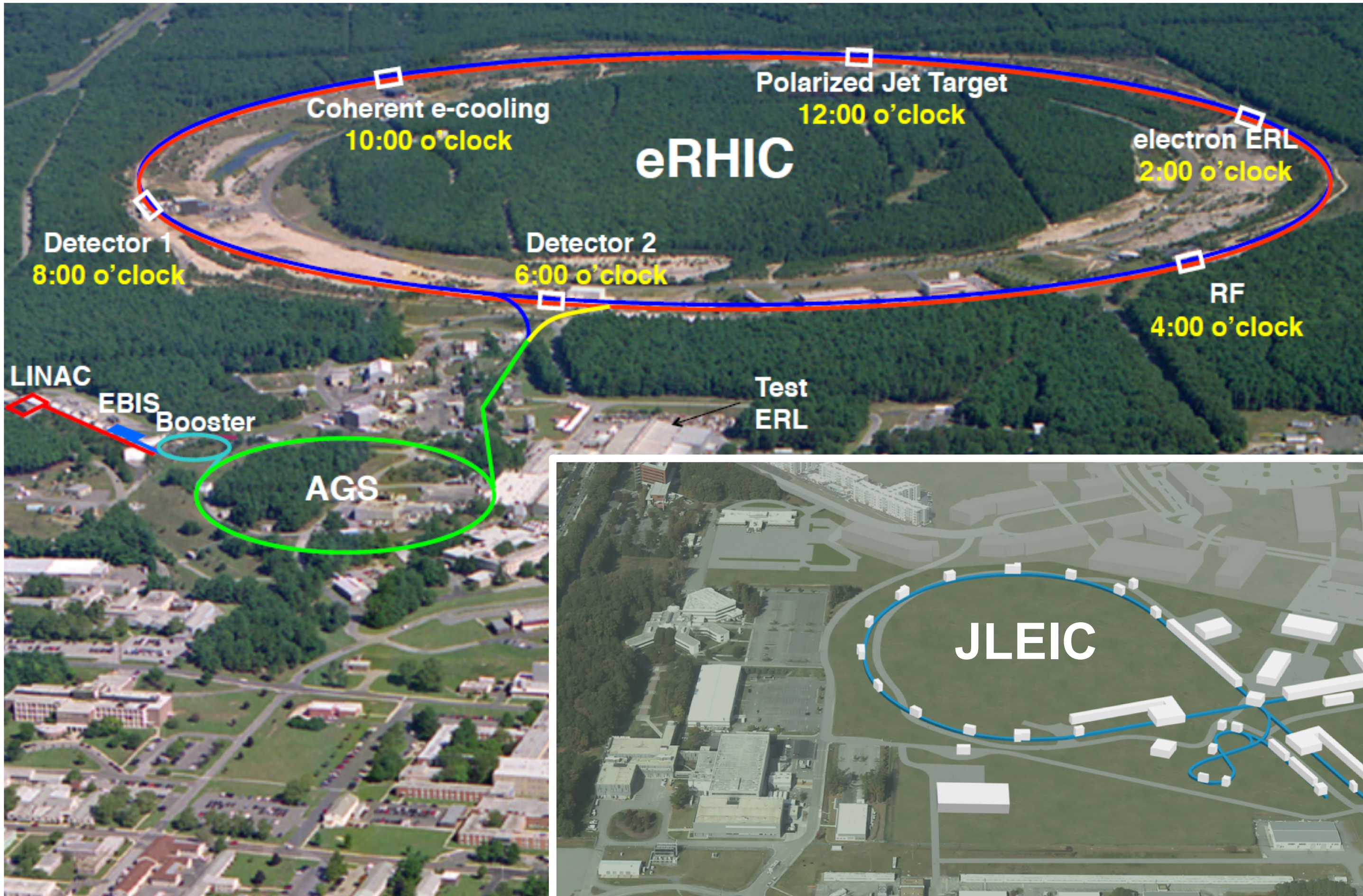
Study **structure** and **dynamics** of **nuclear matter** in **ep** and **eA collisions** with high luminosity and versatile range of beam energies, beam polarizations, and beam species.



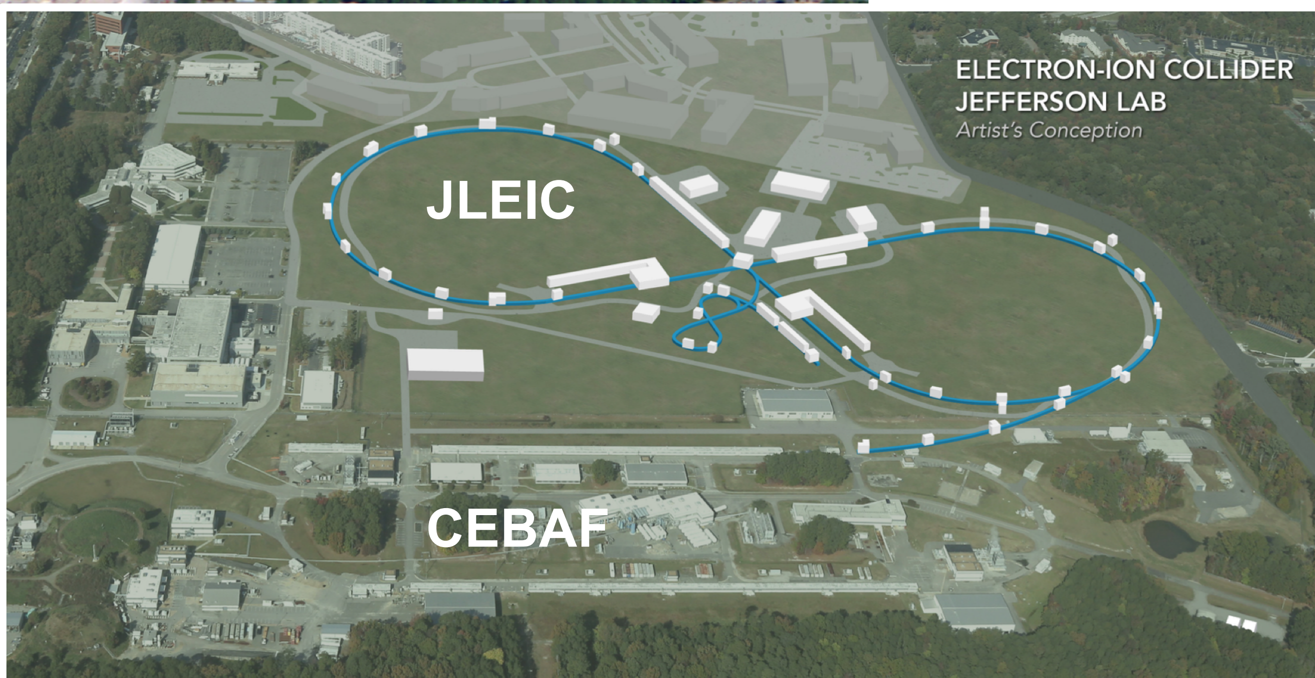




Realization of the science case



Brookhaven Lab
Long Island, NY

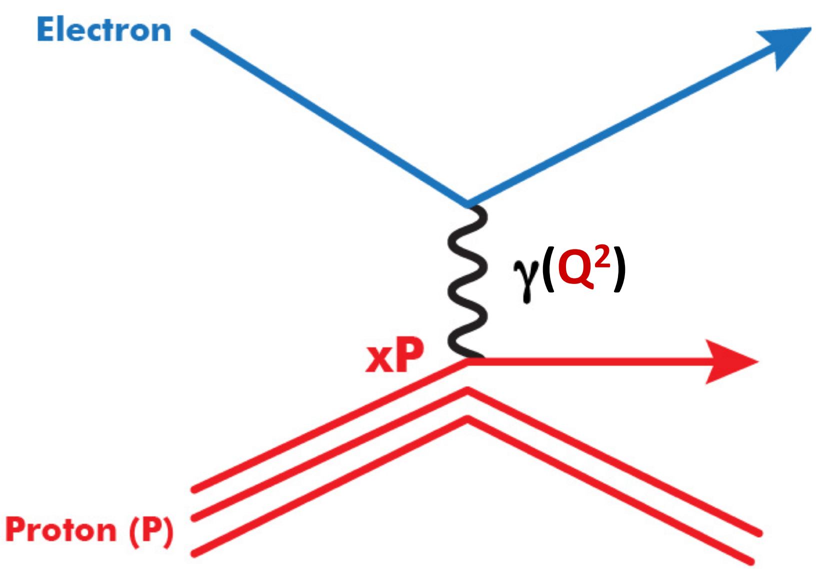


Jefferson Lab
Newport News, VA

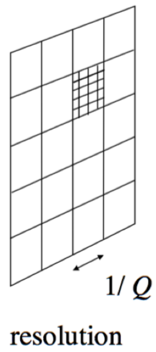
Section

Accelerator design: Designing the right probe

Electron-Proton Scattering

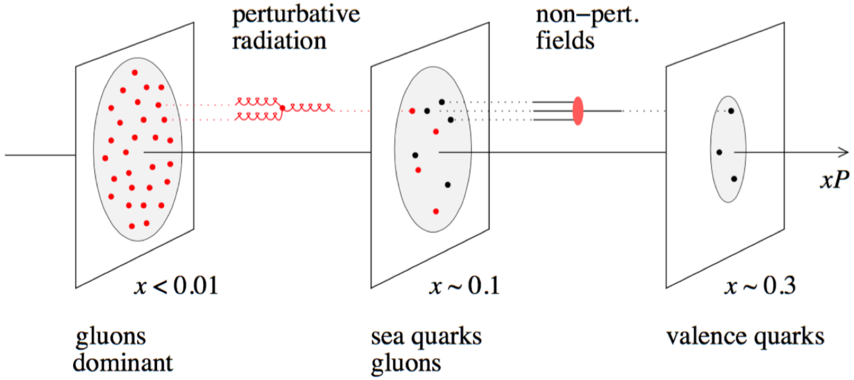


Ability to change Q^2 changes the resolution scale

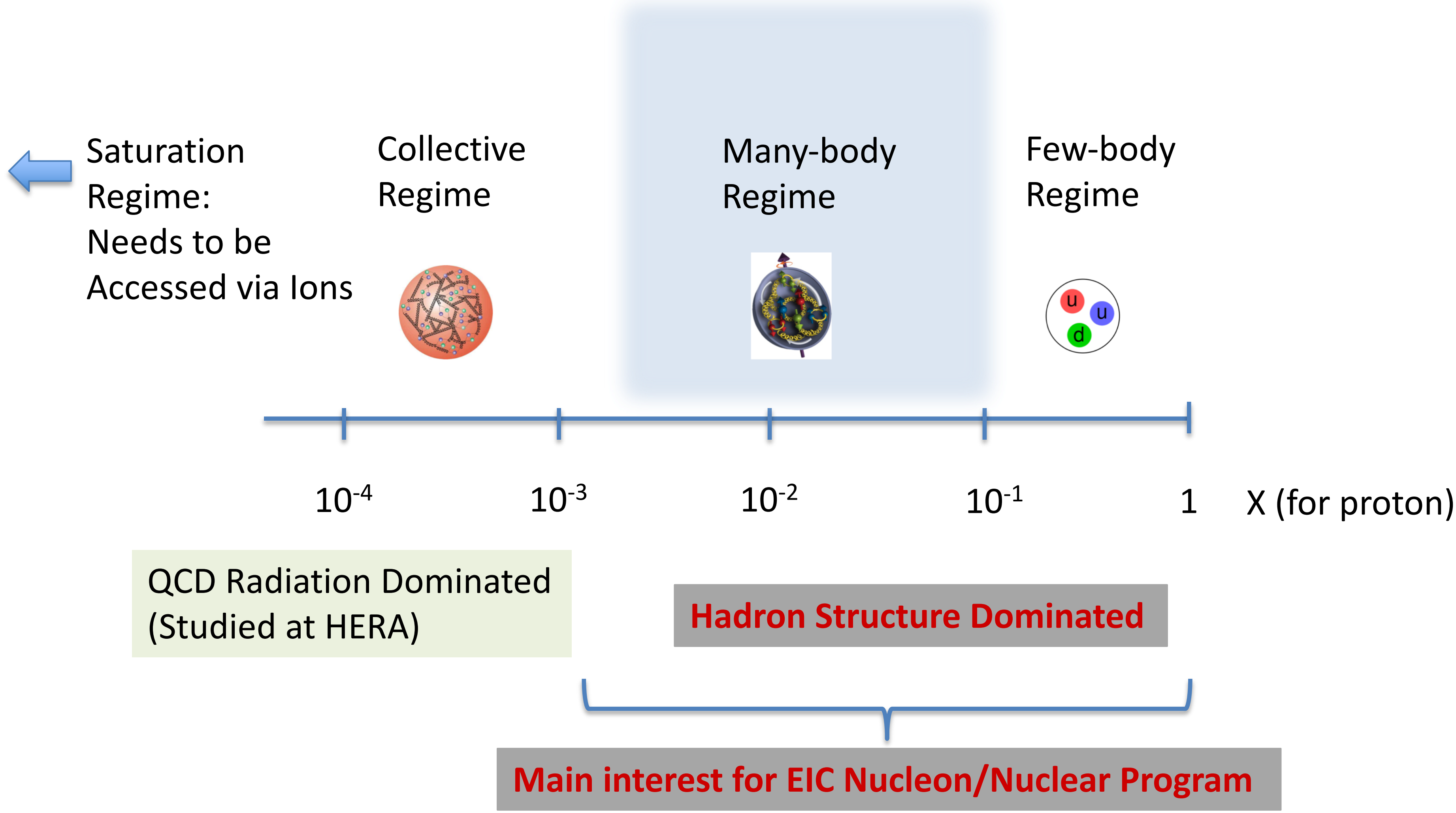


$Q^2 = 400\ GeV^2$
$\Rightarrow 1/Q = 0.01$ fm

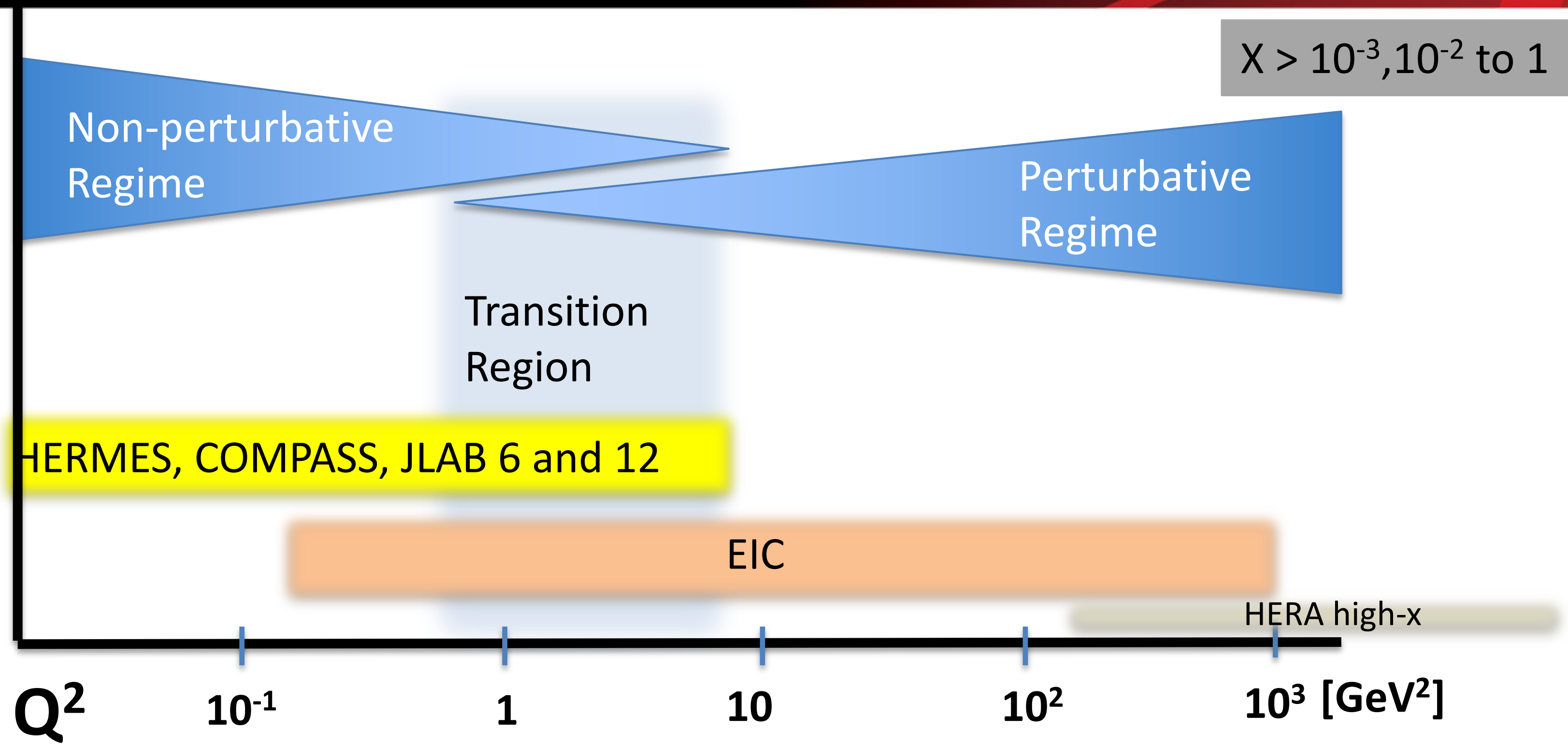
Ability to change x projects out different con-figurations where different dynamics dominate



Where EIC Needs to be in x (nucleon)



Where EIC needs to be in Q^2



- Include non-perturbative, perturbative and transition regimes
- Provide long evolution length and up to Q^2 of ~1000 GeV^2 (~.005 fm)
- Overlap with existing measurements

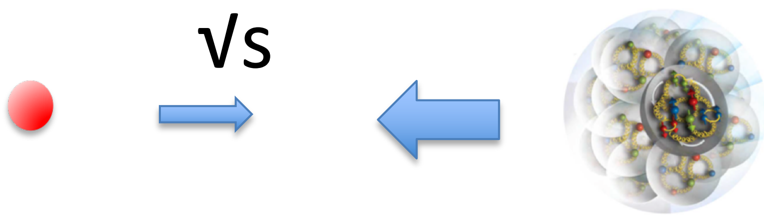
Disentangle Pert./Non-pert., Leading Twist/Higher Twist

Designing The Right Probe: $\sqrt{s}$

What are the right parameters for the collider for the EIC science program?

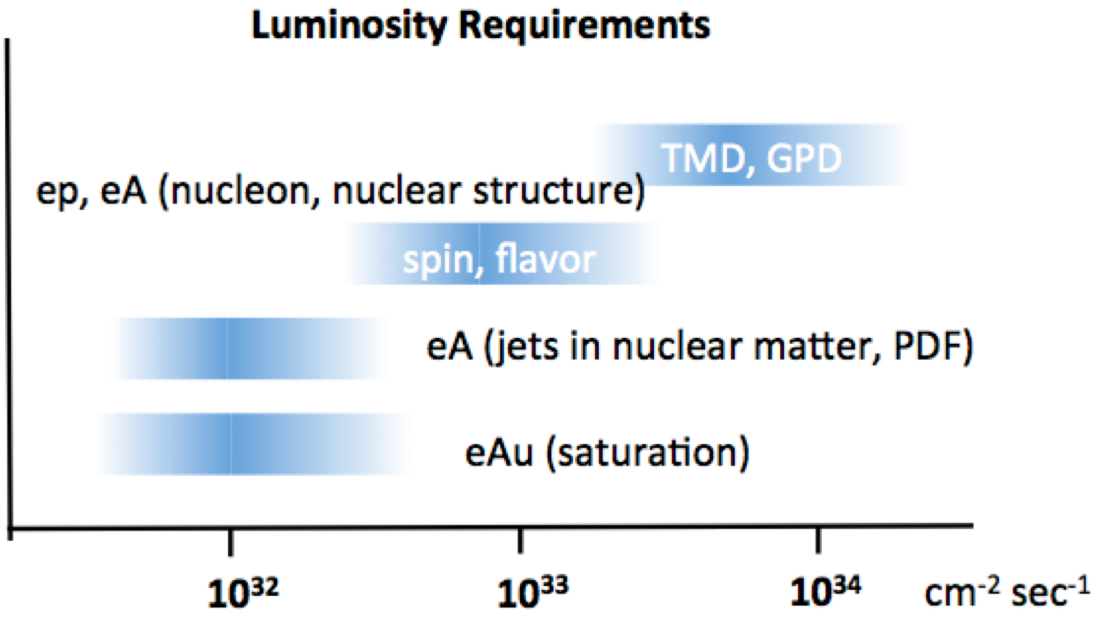
We know the x range: down to ~ 10^{-3-4}
We know the Q^2 range: up to ~1000 GeV^2

$Q^2=sxy$, $s=4E_eE_{hadron}$
→ energies we need.



order 10 GeV electron order 100 GeV/u ion

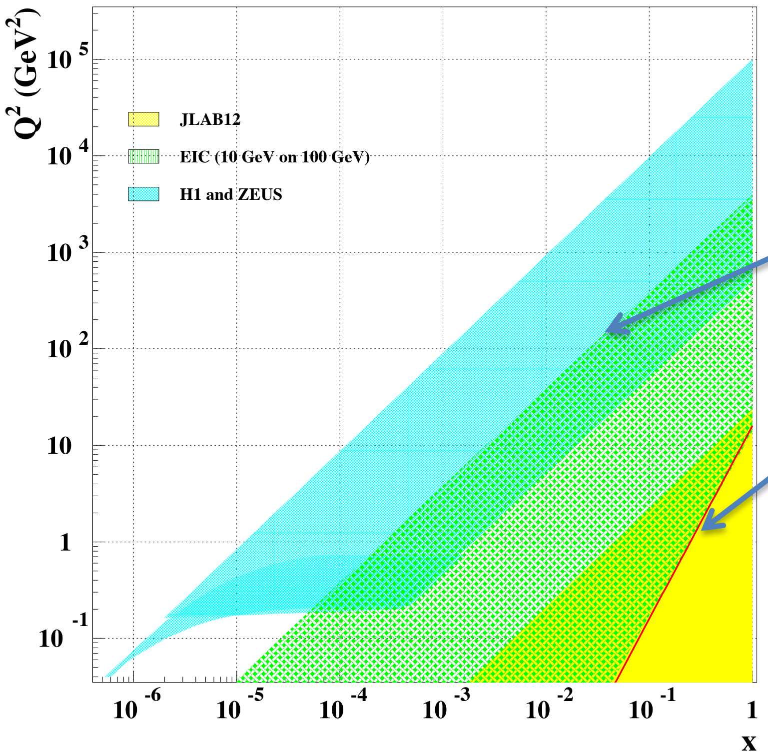
Luminosity needed for topics



Central mission of EIC (nuclear and nucleon structure) requires high luminosity.

We need to design a EIC physics program: including how and when to upgrade the machine

JLEIC parameters (nucleon)



Cross section decreases rapidly with higher X

This edge determined by √s:
√s = 65 GeV

This edge determined by proton beam energy:
E_{proton} < 100 GeV -> $E_{electron}$ = 10 GeV^2

Measure at x of 10^{-3} to 1, exclusive processes
Luminosity: x 10 to 100 that of HERA

Sets some of the basic parameters of the JLEIC design

JLEIC design strategy: High luminosity and polarization

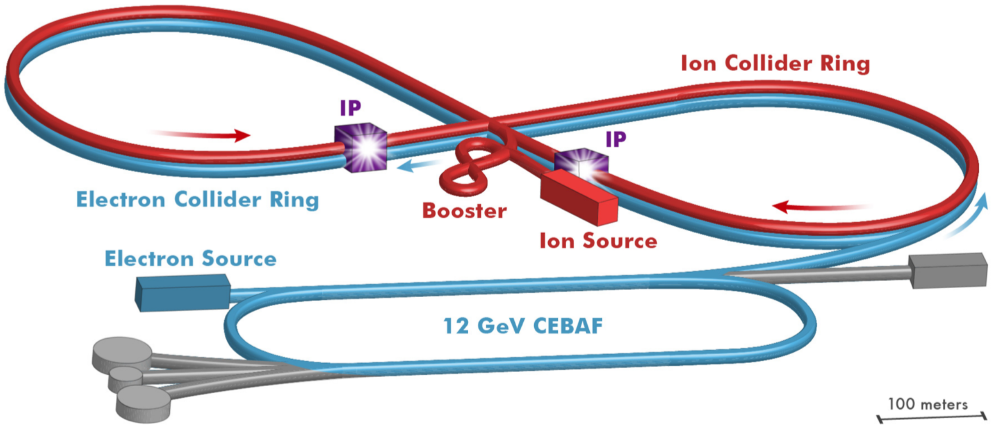
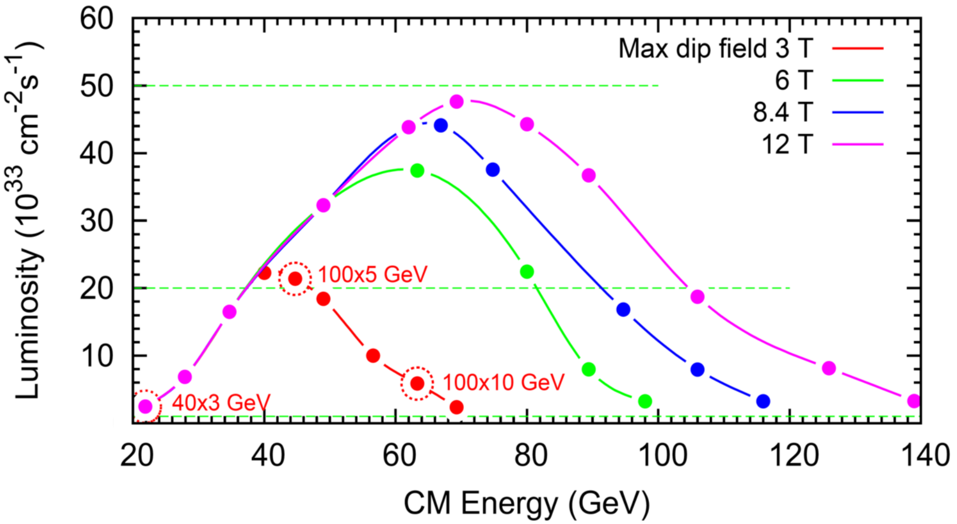


Figure-8 shaped ring-ring collider

- zero **spin tune** (net spin precession)
- energy-independent **spin tune**

- **polarization** easily preserved and manipulated:
    - by small solenoids
    - by other compact spin rotators



High luminosity

- high-rate collision of short bunches
    - with small emittance
    - with low charge
- **ion beam:** high-energy electron cooling (R&D)
- **electron beam:** synchrotron radiation damping

Technology choice determines initial and upgraded energy reach.

Requirement for high luminosity

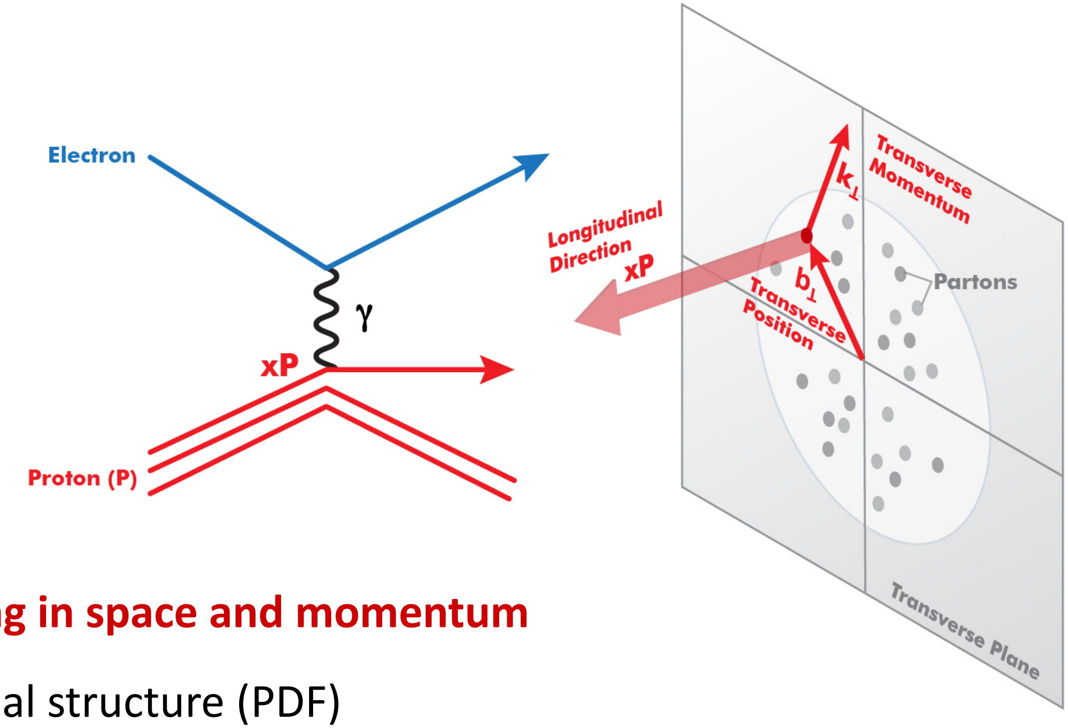
Beam species	Luminosity/ duration	CMS energies	Physics topics
ep polarized	100 /fb	20/40/65	TMD, GPD, High-x PDF, gluon, pi/K structure, EW, BSM
ed polarized	100 /fb	20/40/65	N-PDF, N-TMD, N-GPD, proton structure and nuclear binding
ePb	100 /fb	20/40/65	nPDF, nTMD, jets in QCD, saturation
eSn	100 /fb		
eC	100 /fb		

Section

Detector Design – General design considerations

Mapping position and motion of quarks and gluons

Study nuclear matter **beyond longitudinal description** makes the **requirements for IR and detector design different** from all previous colliders including HERA.

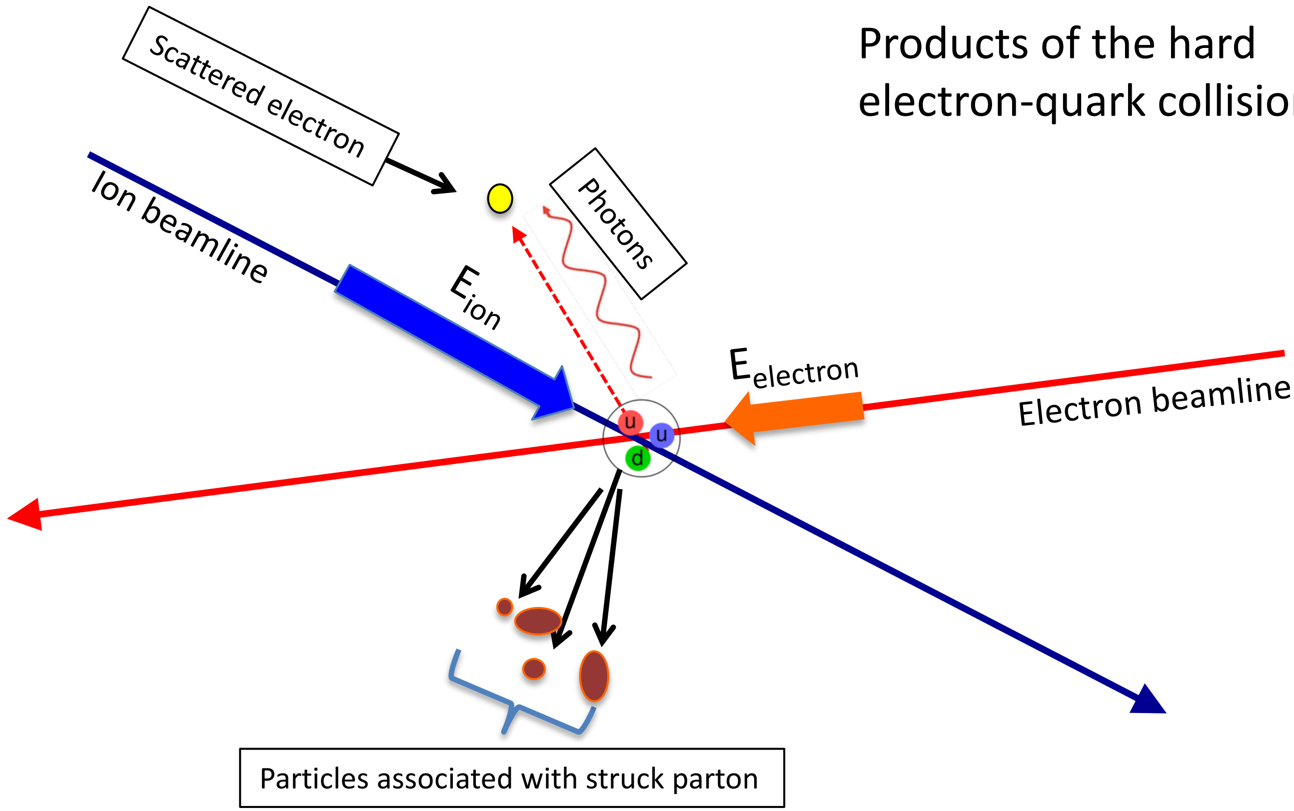


3D imaging in space and momentum

longitudinal structure (PDF)
+ transverse position Information (GPDs)
+ transverse momentum information (TMDs)

order of a few hundred MeV **measurement**

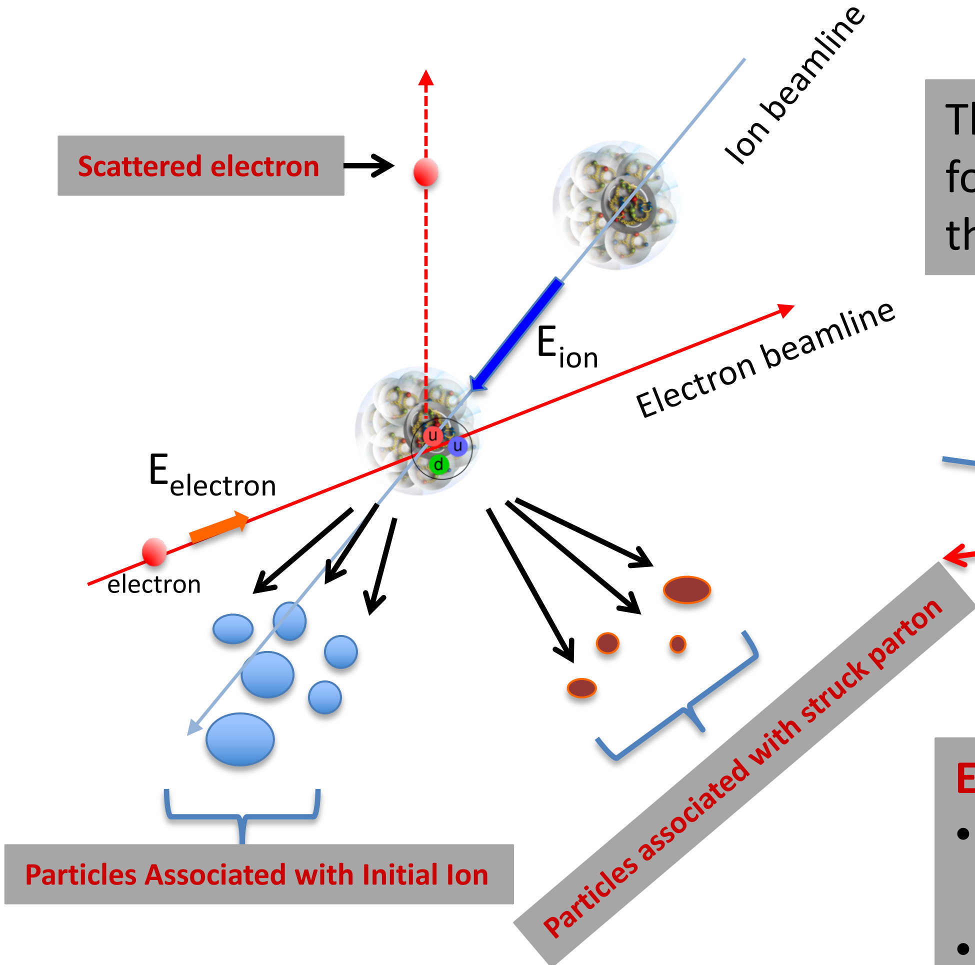
Particle Identification



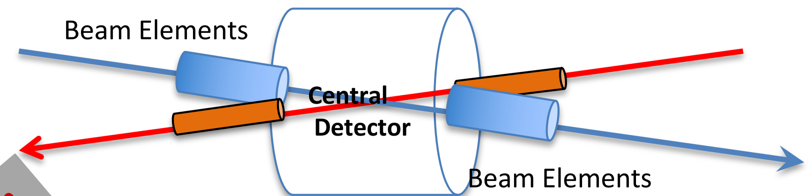
Products of the hard electron-quark collision

Transverse and flavor structure measurement of the nucleon and nuclei: The particles associated with struck parton must have its species identified and measured. **Particle ID much more important than at HERA** colliders.

Final-state particles



The aim is to get **~100% acceptance** for all final state particles, and measure them with good resolution.

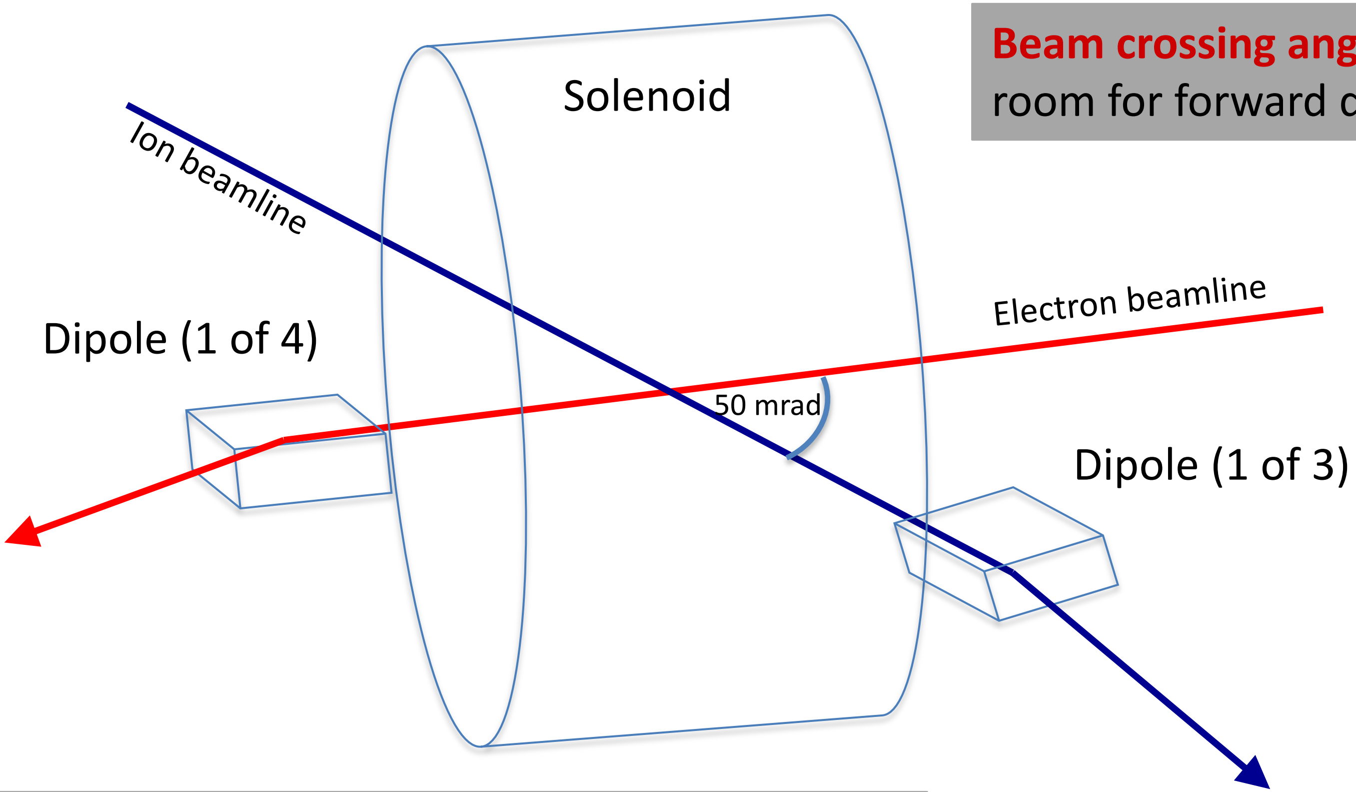


Experimental challenges:

- beam elements limit forward acceptance
- central Solenoid not effective for forward

Interaction region concept

NOT TO SCALE!

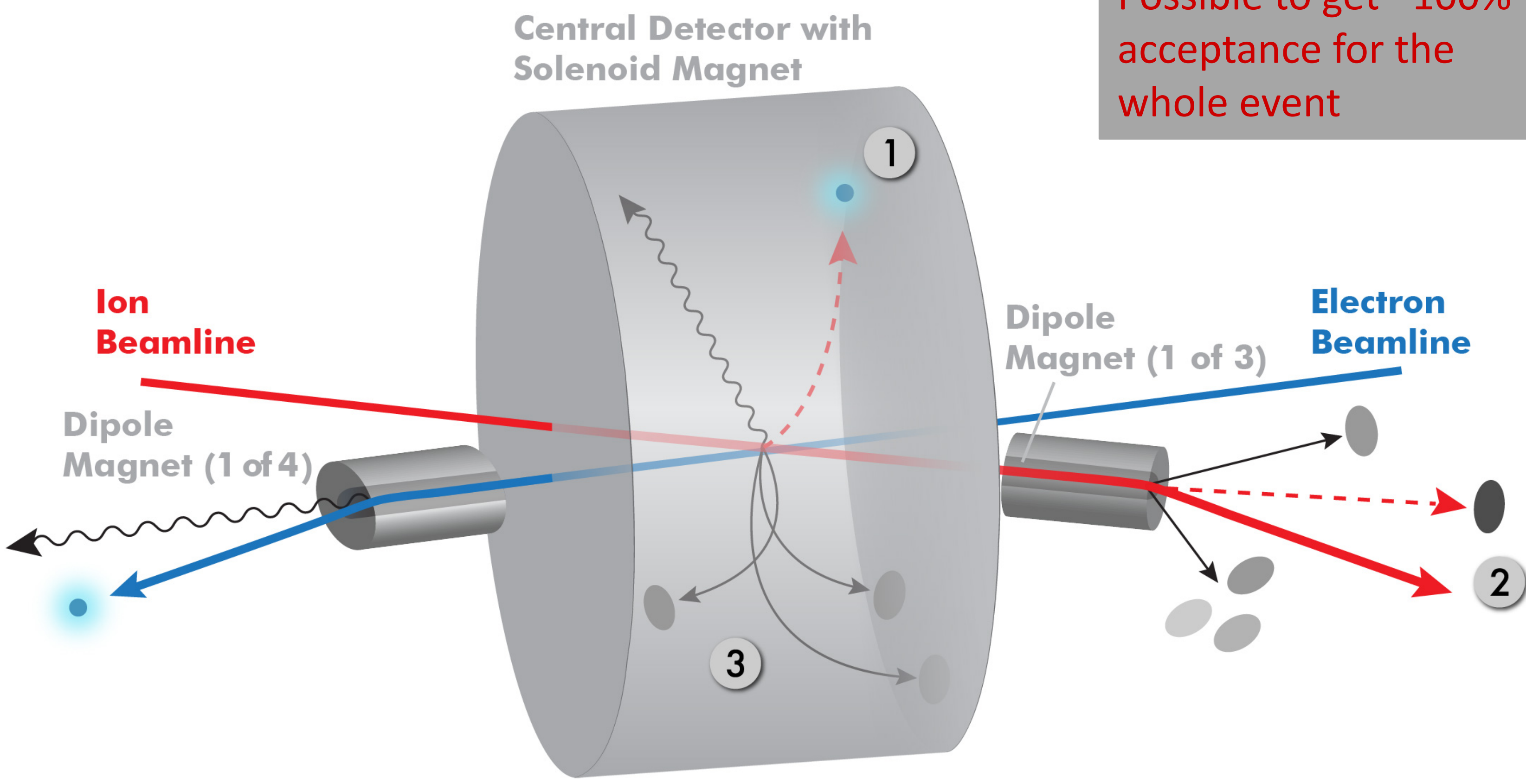


Beam crossing angle creates room for forward dipoles

Dipoles analyze the forward particles and create space for detectors in the forward direction

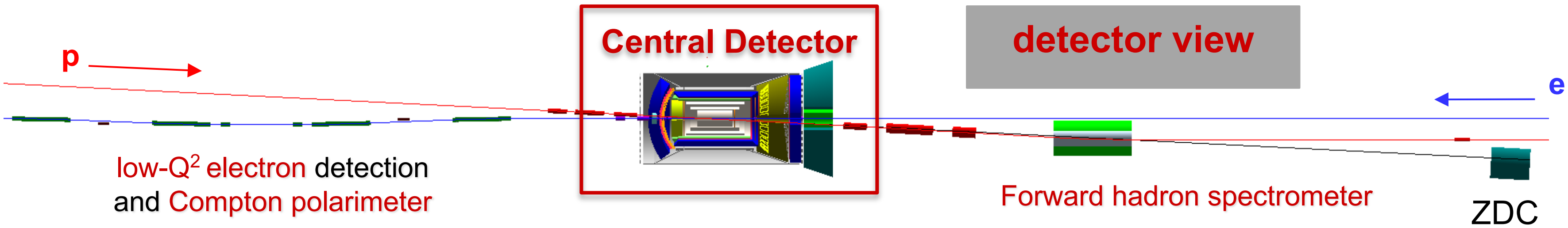
Interaction region concept

Possible to get ~100% acceptance for the whole event



Total acceptance detector (and IR)

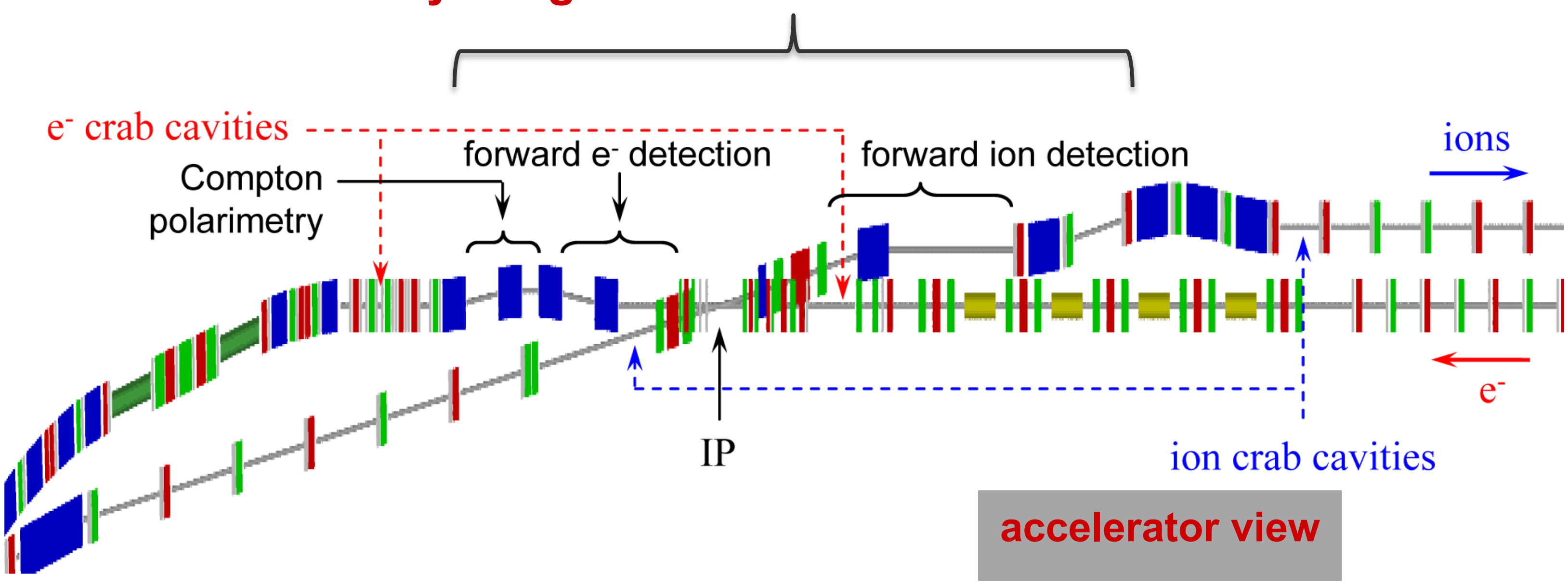
Detector and interaction region



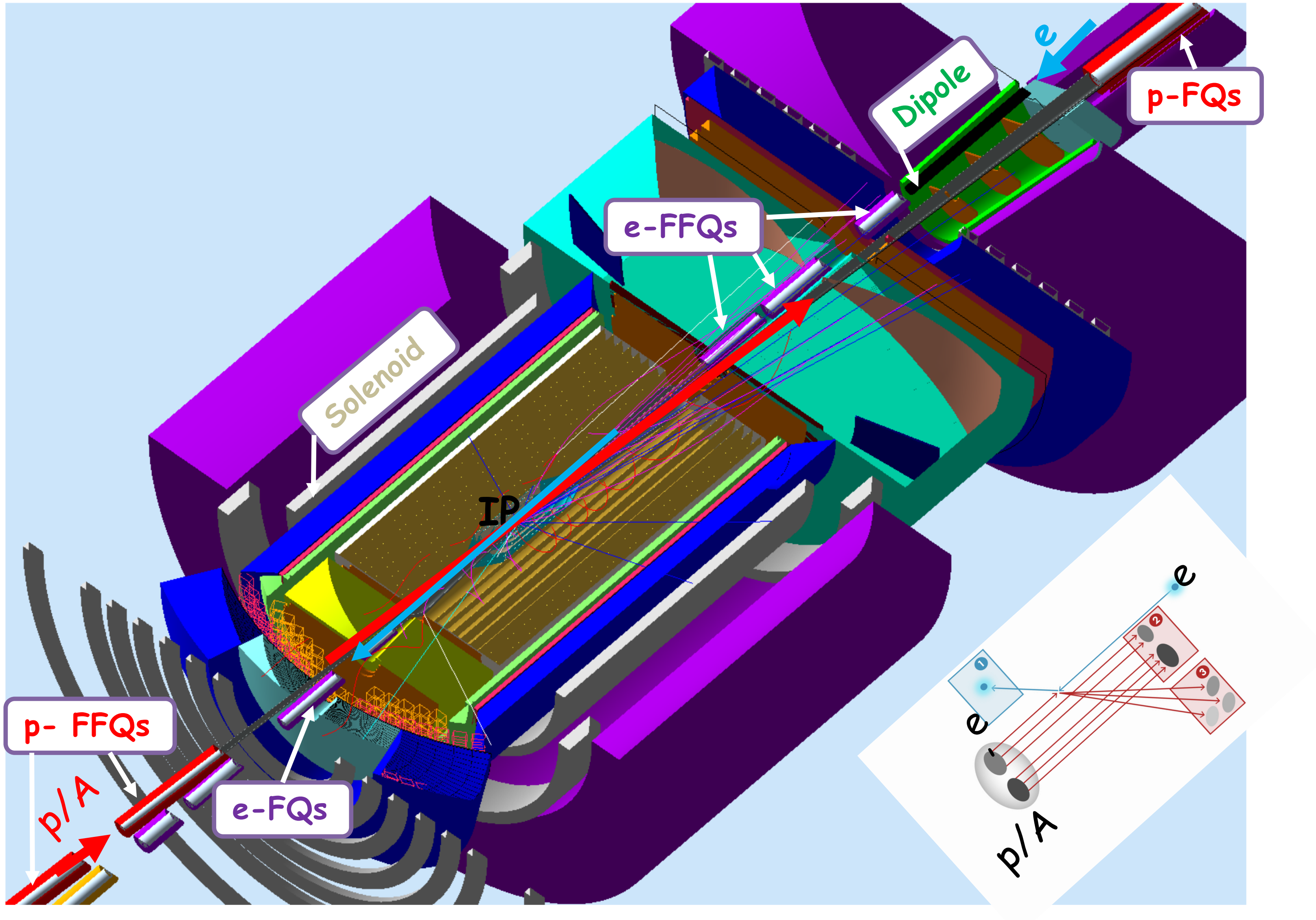
Extended detector: 80m

30m for multi-purpose chicane, 10m for central detector, 40m for the forward hadron spectrometer

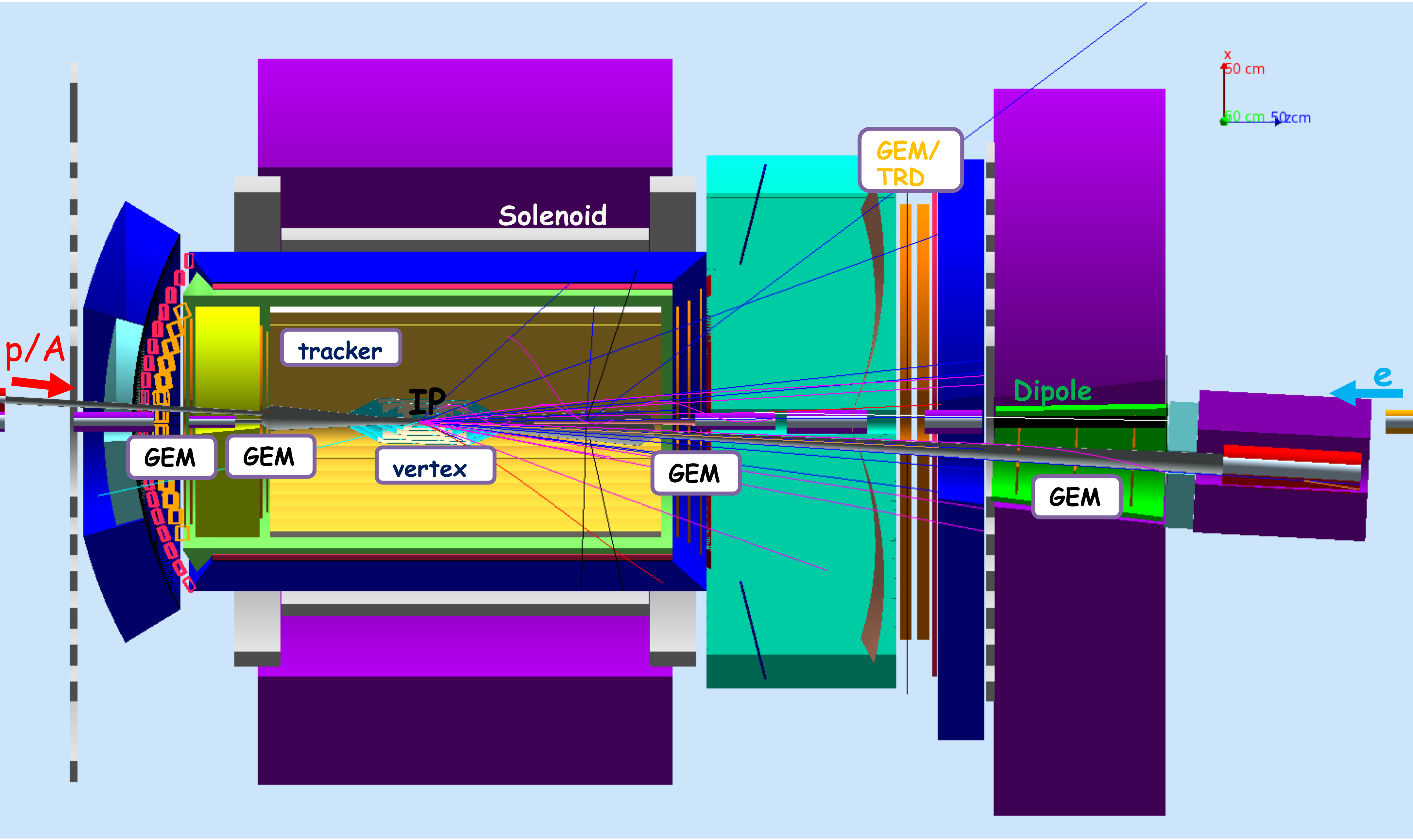
fully integrated with accelerator lattice



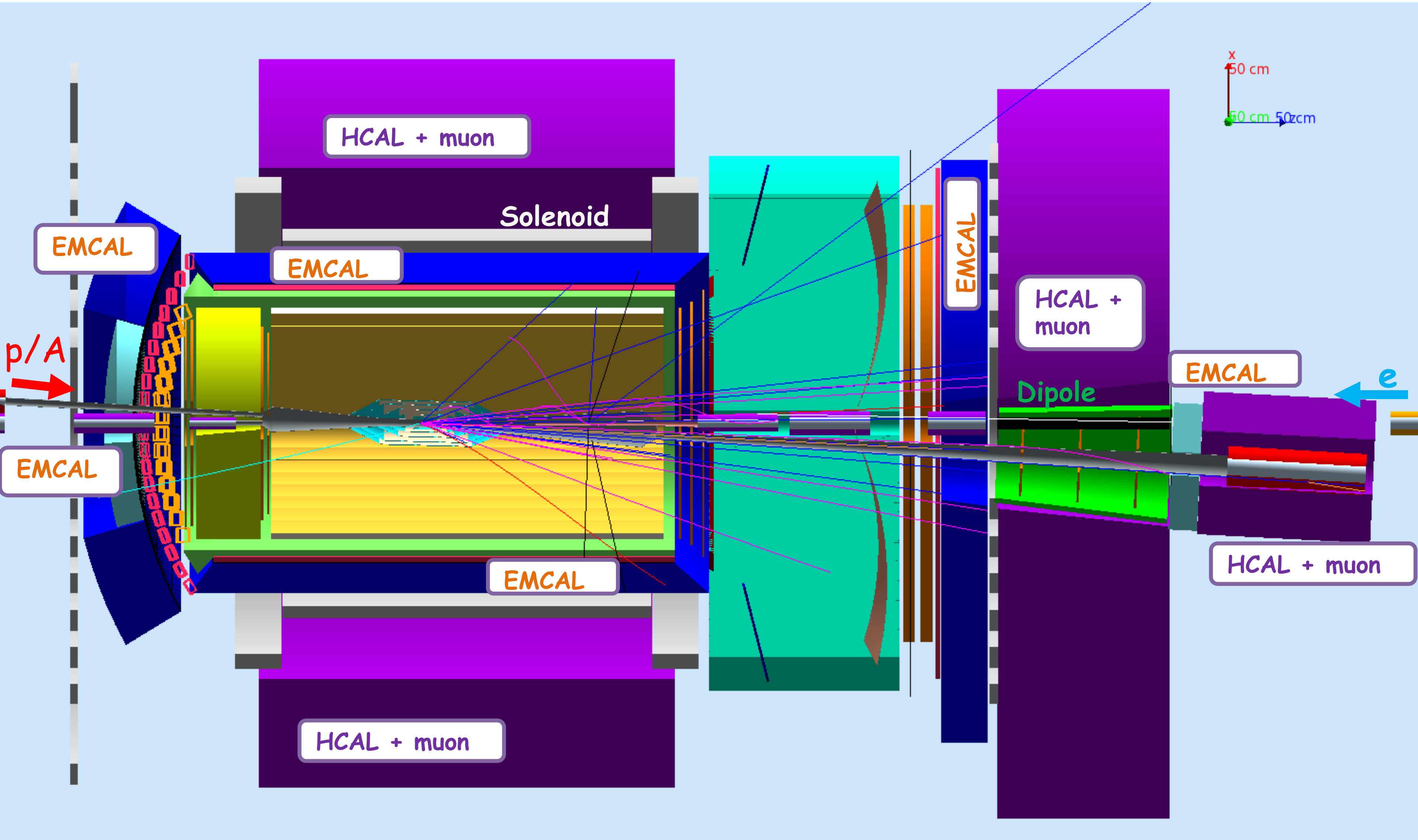
Central Detector



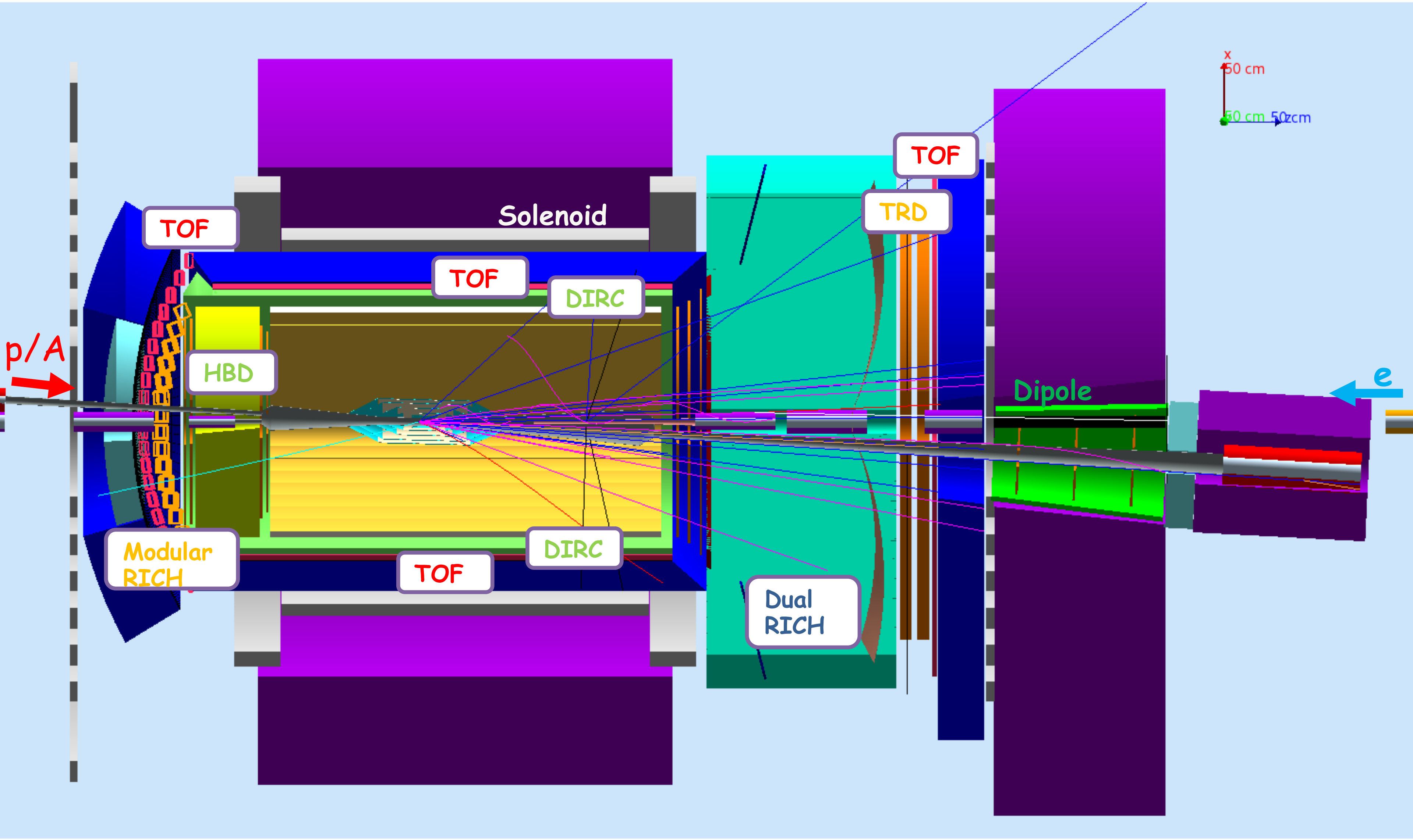
Central Detector: Tracking



Central Detector: Calorimetry



Central Detector: PID



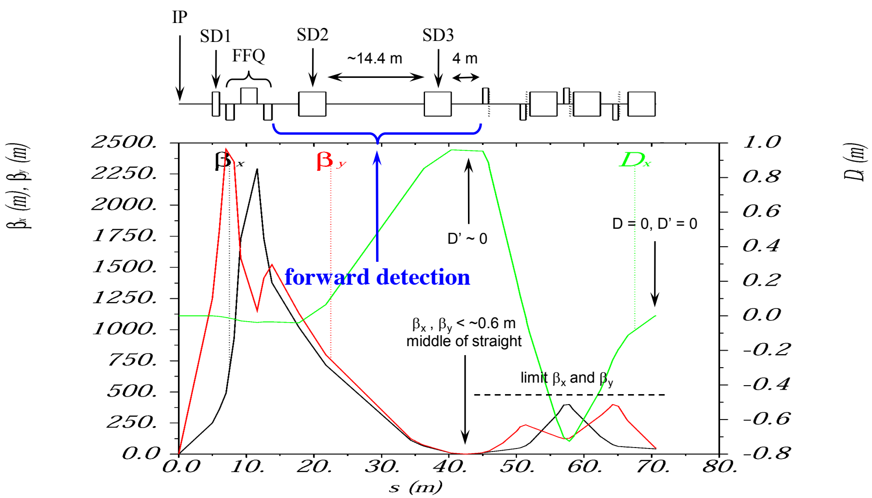
Far-forward ion detection

Neutron structure essential to understand non-perturbative nucleon structure.

Forward detection of p, n, A

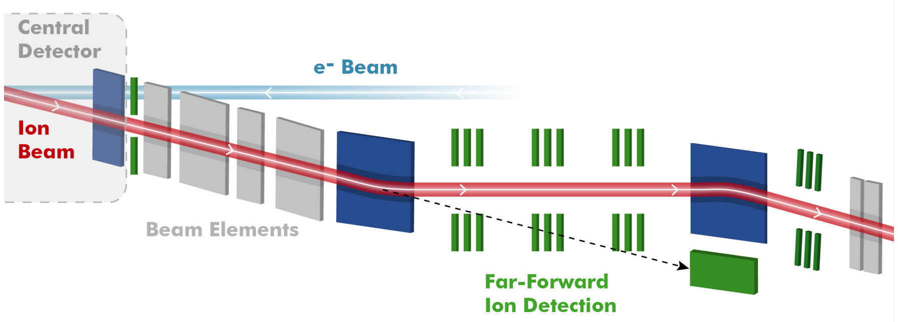
- diffractive and exclusive processes
- nuclear breakup and spectator tagging
- coherent nuclear scattering

Tagging essential for exclusivity!



Requirements

- good acceptance for recoil nucleons (rigidity close to beam)
- good acceptance for fragments (rigidity different than beam)

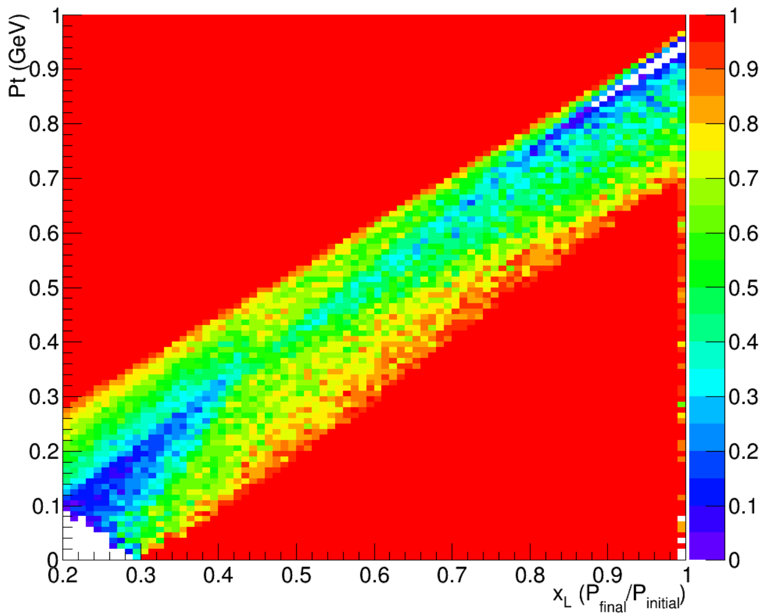


Instrumentation

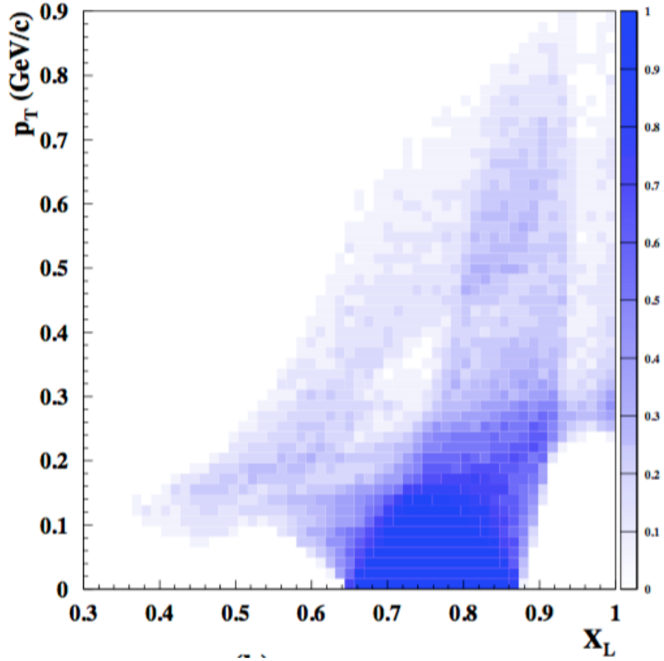
- **GEM detectors** decay products of, e.g., Λ', Σ (π, K)
- **Roman-pots** for (p)-tagging
- **Zero degree calorimeter** for (n)-tagging

Acceptance for p' in DDIS

JLEIC



ZEUS



Acceptance in diffractive peak (X_L>~.98)

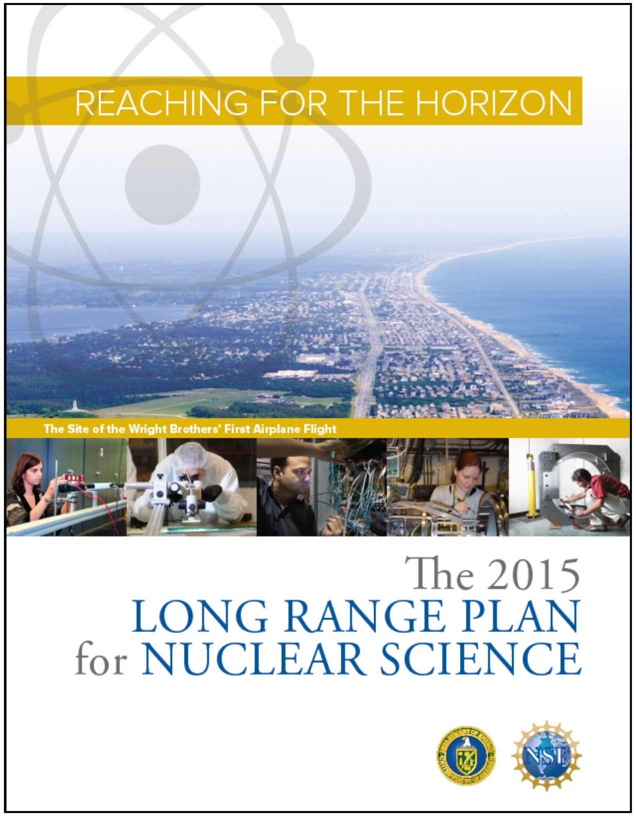
ZEUS: ~2%

JLEIC: ~100%

Section

Status of the EIC project

2015 Nuclear science long-range plan



1. **The highest priority in this 2015 Plan is to capitalize on the investments made.**
   - **12 GeV** – unfold quark & gluon structure of hadrons and nuclei
   - **FRIB** – understanding of nuclei and their role in the cosmos
   - **Fundamental Symmetries Initiative** – physics beyond the SM
   - **RHIC** – properties and phases of quark and gluon matter
2. We recommend the timely development and deployment of a U.S.-led ton-scale neutrinoless double beta decay experiment.
3. **We recommend a high-energy high-luminosity polarized Electron Ion Collider as the highest priority for new facility construction following the completion of FRIB.**
4. We recommend increasing investment in small and mid-scale projects and initiatives that enable forefront research at universities and laboratories.

NAS: EIC Science Assessment

THE NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE

next formal step on EIC science case (before CD0)

NAS committee

Ani Aprahamian, Co-Chair (University of Notre Dame)
Gordon Baym, Co-Chair (U. Illinois at Urbana-Champaign)
Christine Aidala (University of Michigan)
Richard Milner (MIT)
Ernst Sichtermann (LBNL)
Zein-Eddine Meziani (Temple University)
Thomas Schaefer (NC State University)
Michael Turner (University of Chicago)
Wick Haxton (University of California-Berkeley)
Kawtar Hafidi (Argonne)
Peter Braun-Munzinger (GSI)
Larry McLerran (University of Washington)
Haiyan Gao (Duke)
John Jowett (CERN)

Meetings in Feb., Apr., Sept. 2017
Report expected in summer of 2018

NAS charge

1 What is the **merit and significance of the science** that could be addressed by an EIC facility and what is its **importance in the overall context of research in nuclear physics** and the physical sciences in general?

2 What are the **capabilities of other facilities, existing and planned, domestic and abroad**, to address the science opportunities afforded by an EIC? What **unique scientific role** could be played by a domestic EIC that is complementary to existing and planned facilities at home and abroad?

3 What are the **benefits of US leadership** in nuclear physics if a domestic EIC were constructed?

4 What are the **benefits to other fields of science and to society** of establishing such a facility in the US?

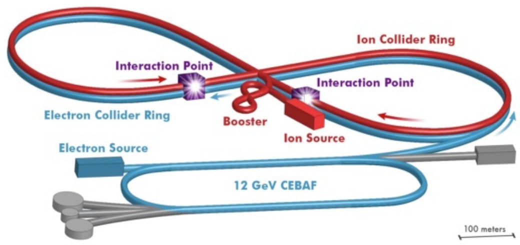
EIC Realization Imagined

- **Summer of 2018** NAS report on EIC science case
- **Late 2018** CD-0 (US Mission Need statement)
- **2019** critical EIC accelerator R&D questions could be answered
- **2019 - 2020** site selection
- **2020** EIC construction has to start **after FRIB completion**
- **2021 - 2023** construction starts
- **2025 – 2030** EIC completion

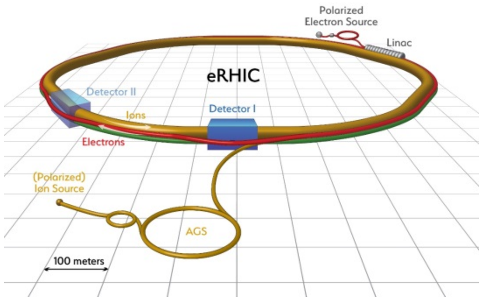
EIC^2@JLab

- advance and promote the science program at a future electron-ion collider facility: fellowships, seminars, summer school, workshops
- emphasis is on the close connection of EIC science to the current JLab 12 GeV science program

BNL and JLAB working together



Adapted from
F. Willeke (BNL)



Complementary expertise

JLab expertise:

- Polarized electron sources
- Superconducting RF development
- Superconducting RF production and industrialization
- Superconducting LINAC technology
- Energy-recovery LINACs
- Superconducting LINAC beam physics
- Acceleration and transport of polarized electron beams

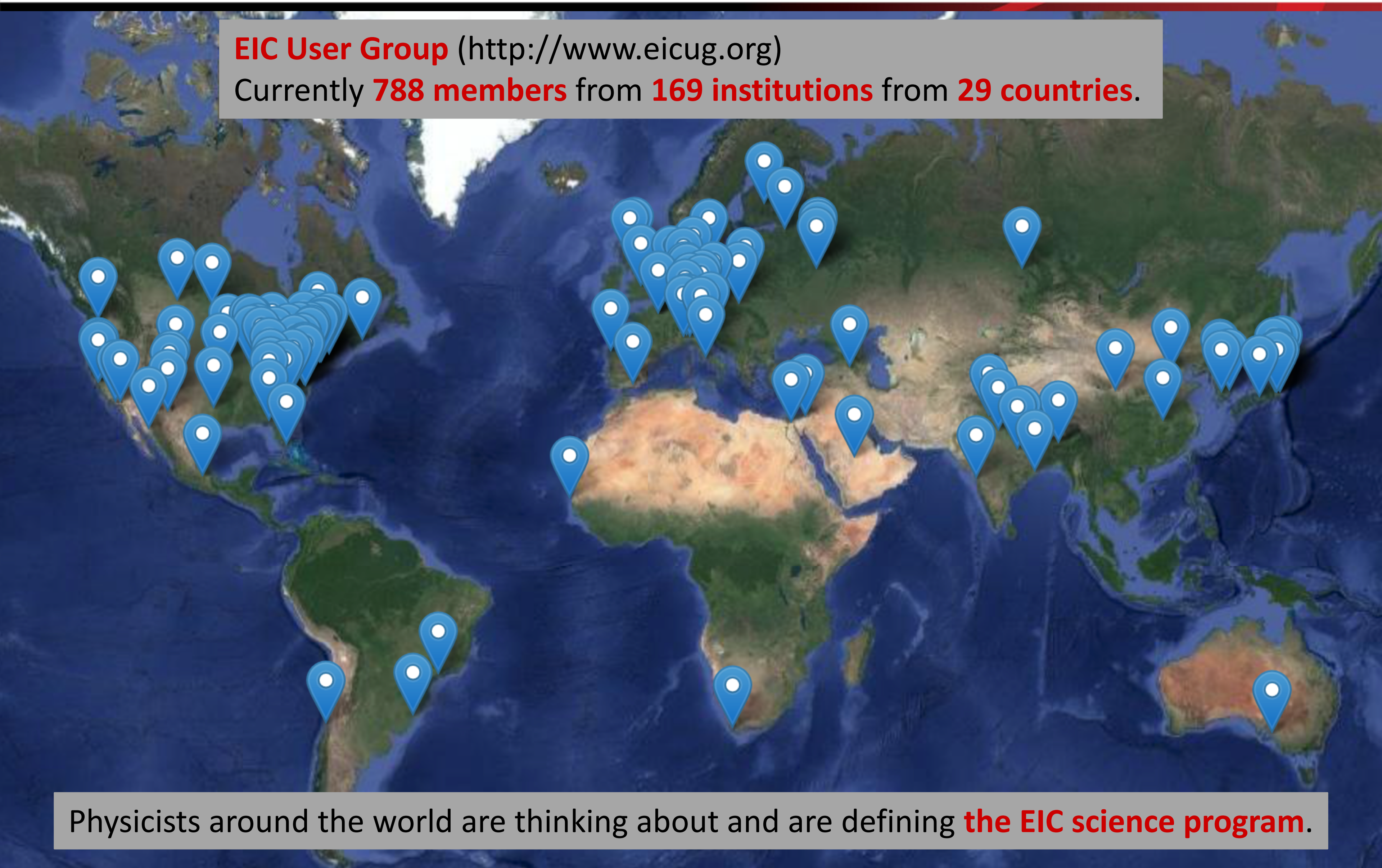
BNL expertise:

- Ion/proton beam sources
- Ion acceleration
- Ion spin preservation
- Hadron beam dynamics
- RF for hadron beams
- Hadron beam instrumentation
- Superconducting magnets
- Storage beam ring physics
- Electron cooling

Accelerator R&D going on with **strong cooperation between BNL and JLAB** under DOE NP guidance

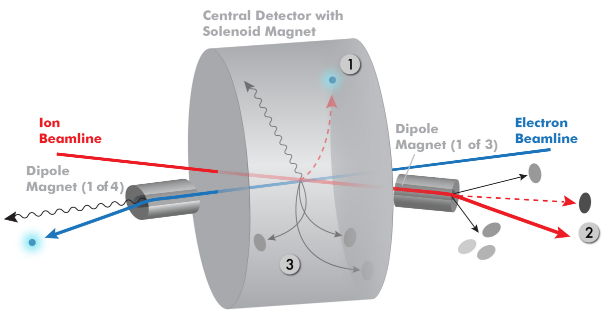
EIC User Group

EIC User Group (http://www.eicug.org)
Currently **788 members** from **169 institutions** from **29 countries**.



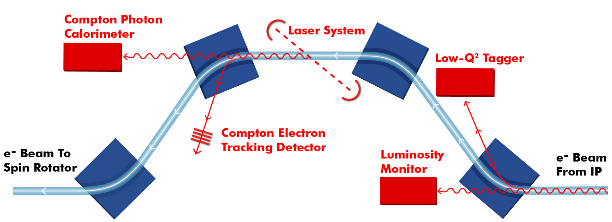
Physicists around the world are thinking about and are defining **the EIC science program**.

EICUG Working Groups



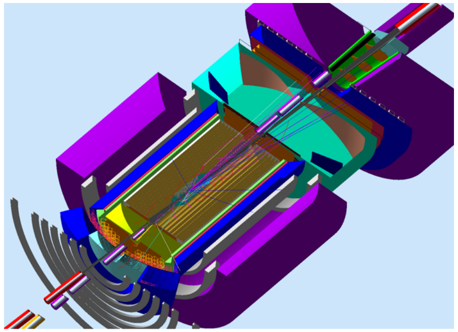
EICUG IR / Luminosity Working Group

- interface between accelerator / IR design and the physics requirements
- proper implementation of the physics program is properly, in particular for forward / backward detection
- **Conveners**
    - Accelerator / IR: C. Montag (BNL), V. Morozov (JLab)
    - Physics: C. Hyde (ODU), A, Kiselev (BNL)



EICUG Working Group on Polarimetry

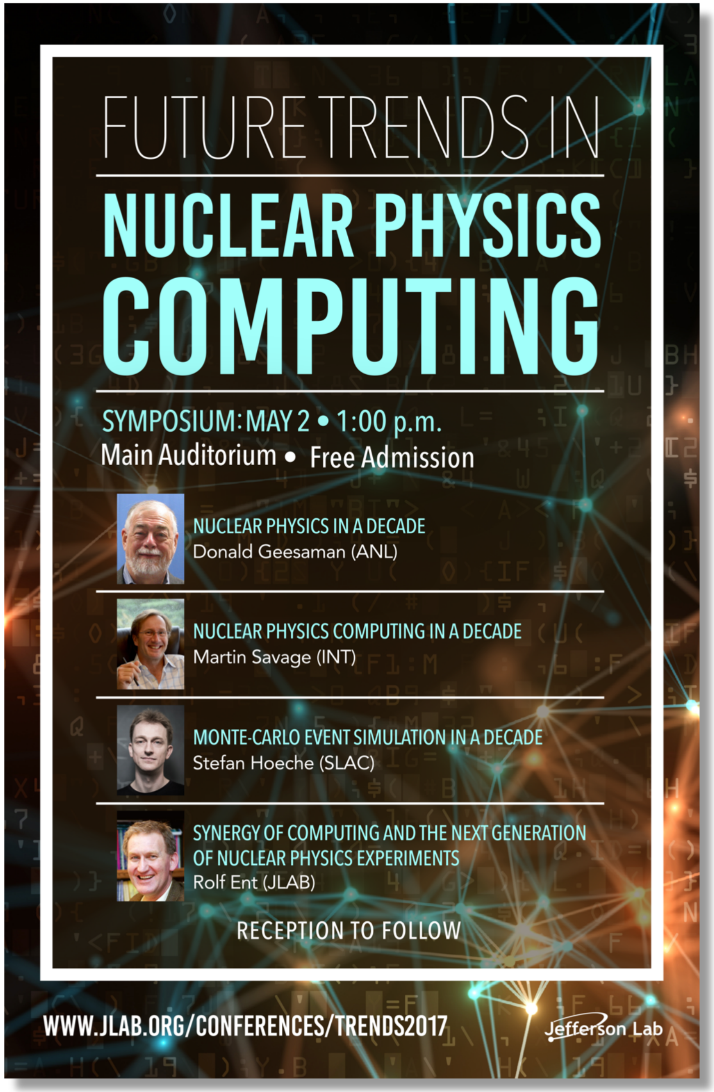
- plan / develop the optimal methods and techniques for measuring the electron and ion beam polarization with high precision
- **Conveners** E.-C. Aschenauer (BNL), D. Gaskell (JLab)



EICUG Software Working Group (announced soon)

- simulations of physics processes and detector response to enable quantitative assessment of measurement capabilities and their physics impact
- **Conveners** announced soon

The future research model in NP



Quotes from a workshop on “Future Trends in Nuclear Physics Computing”:

- **Don Geesaman (ANL)** *“It will be **joint progress of theory and experiment** that moves us forward, not in one side alone”*

- **Martin Savage (INT)** *“The next decade will be looked back upon as a **truly astonishing period in NP** and in our understanding of fundamental aspects of nature. This will be **made possible by advances in scientific computing** and in how the NP community organizes and collaborates, and how DOE and NSF supports this, to take full advantage of these advances.”*

Summary

EIC program Revolutionize the QCD understanding of nucleon and nuclear structure and associated dynamics. Explore new states of QCD.

- Outstanding questions raised both by the science at HERMES/COMPASS/JLab and RHIC/LHC, have naturally led to the science and design parameters of the EIC.
- EIC will enable us to embark on a **precision study of the nucleon and the nucleus at the scale of sea quarks and gluons**, over all of the kinematic range that are relevant.
- What we learn at JLab12 and later EIC, together with advances enabled by FRIB and LQCD studies, will open the door to **a transformation of Nuclear Science**.
- There exists **world wide interest** in collaborating on the EIC.
- Accelerator scientists at BNL and Jlab, in collaboration with many outside interested accelerator groups, can provide the intellectual and technical leadership to realize the EIC, a frontier accelerator facility.

The future of QCD-based nuclear science demands an EIC.

Thank you very much for attending my presentation!