Current Status of the US EIC Plan

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U.S. - based Electron-Ion Collider

- **Nuclear Science Advisory Committee (NSAC) 2007 Long-Range Plan:**

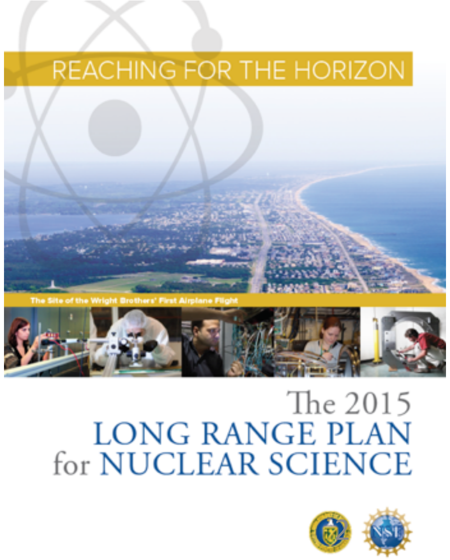
  "An Electron-Ion Collider (EIC) with polarized beams has been embraced by the U.S. nuclear science community as embodying the vision for reaching the next QCD frontier."

- **NSAC Facilities Subcommittee (2013):**

  "The Subcommittee ranks an EIC as Absolutely Central in its ability to contribute to world-leading science in the next decade."

- **NSAC 2015 Long-Range Plan:**

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

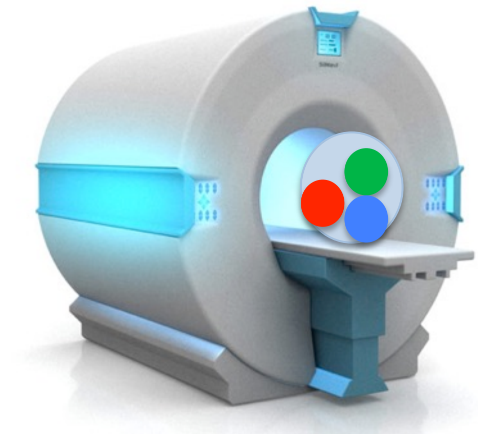


- **Review of National Academy of Sciences:**

  Committee report just released this week on July 24

The Electron-Ion Collider (EIC) – the Future!

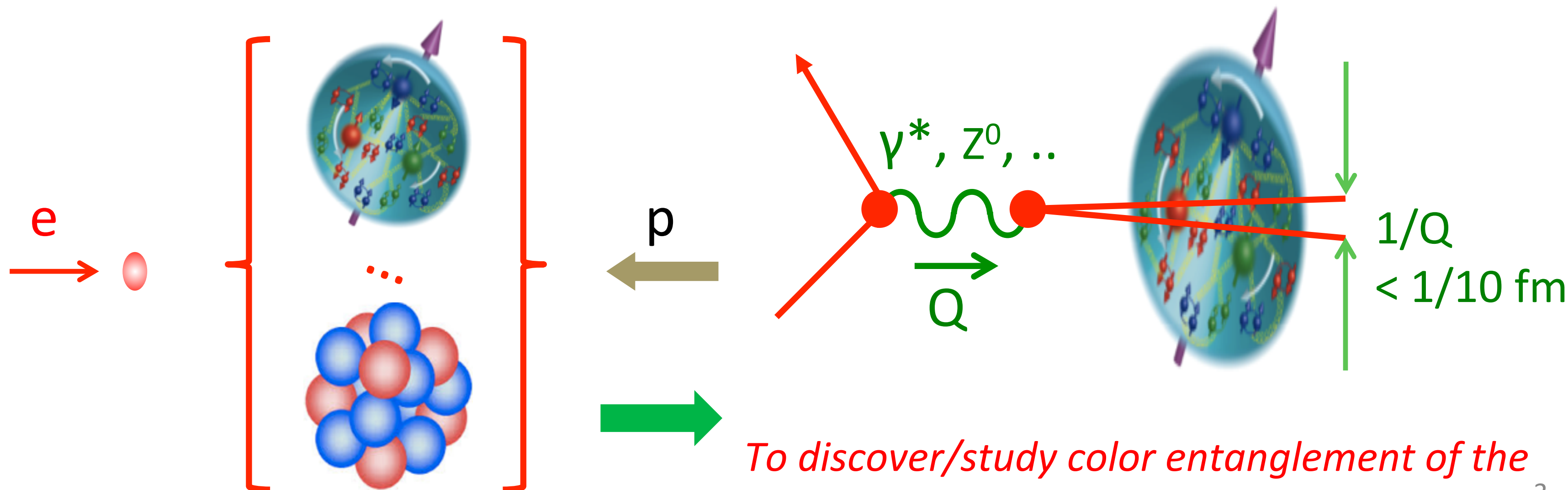
- **A sharpest "CT"** – **"imagine" quark/gluon structure** without breaking the hadron



  - "cat-scan" the nucleon and nuclei with a better than 1/10 fm resolution
  - "see" proton "radius" of quark/gluon density comparing with the radius of EM charge density

➡ *To discover color confining radius, hints on confining mechanism!*

- **A giant "Microscope"** – "see" quarks and gluons by breaking the hadron



➡ *To discover/study color entanglement of the non-linear dynamics of the glue!*

US EIC – Deliverables & Opportunities

Why existing facilities, even with upgrades,
cannot do the same?

✧ Emergence of hadrons

✧ Hadron properties:

mass, spin, …

✧ Hadron's 3D partonic structure:

confined motion, spatial distribution,

color correlation, fluctuation,

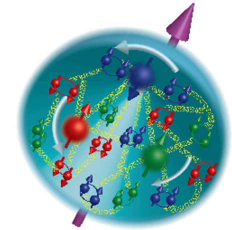
saturation, …

✧ Quantum correlation between

hadron properties and parton dynamics, …

…

Nucleon Spin Decomposition



Proton spin puzzle

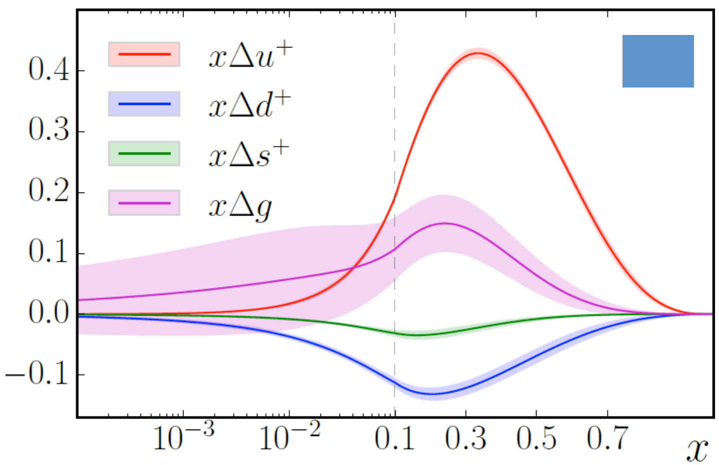
$$\Delta\Sigma = \Delta u + \Delta d + \Delta s \sim 0.3$$

Quark spin only contributes a small fraction to nucleon spin.

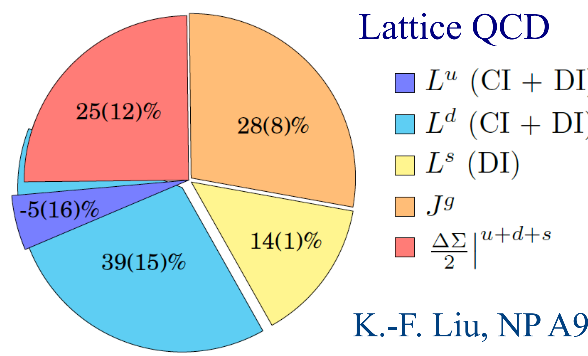
J. Ashman et al., PLB 206, 364 (1988); NP B328, 1 (1989).

Spin decomposition

$$J = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$



JAM Collaboration, PRD (2016).



K.-F. Liu, NP A928, 99 (2014).

Gluon spin: STAR and PHENIX (pp collisions)
Lattice: Yang *et al.* (χQCD Collaboration), PRL 118, 102001 (2017)

Access to $L_{q/g}$

It is necessary to have transverse information.

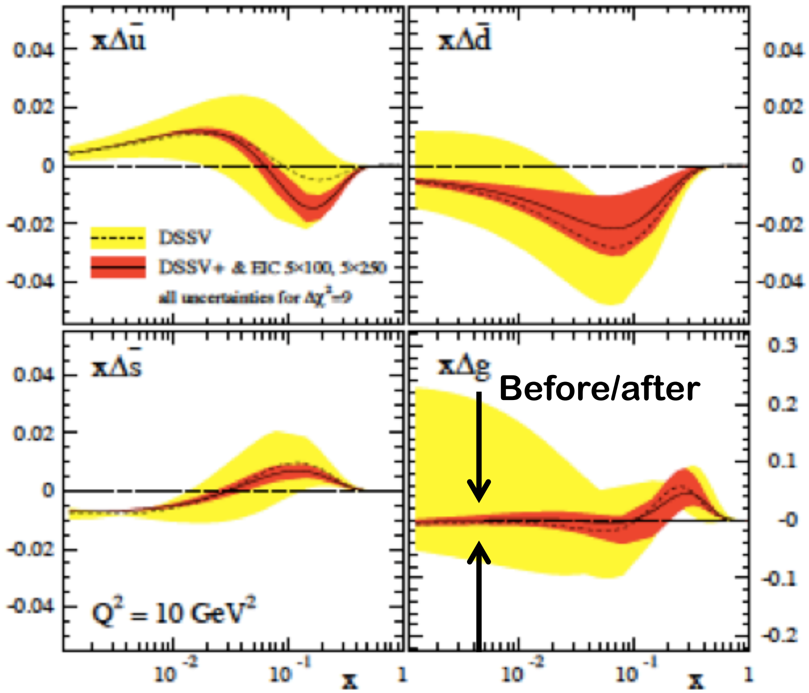
Coordinate space: GPDs
Momentum space: TMDs

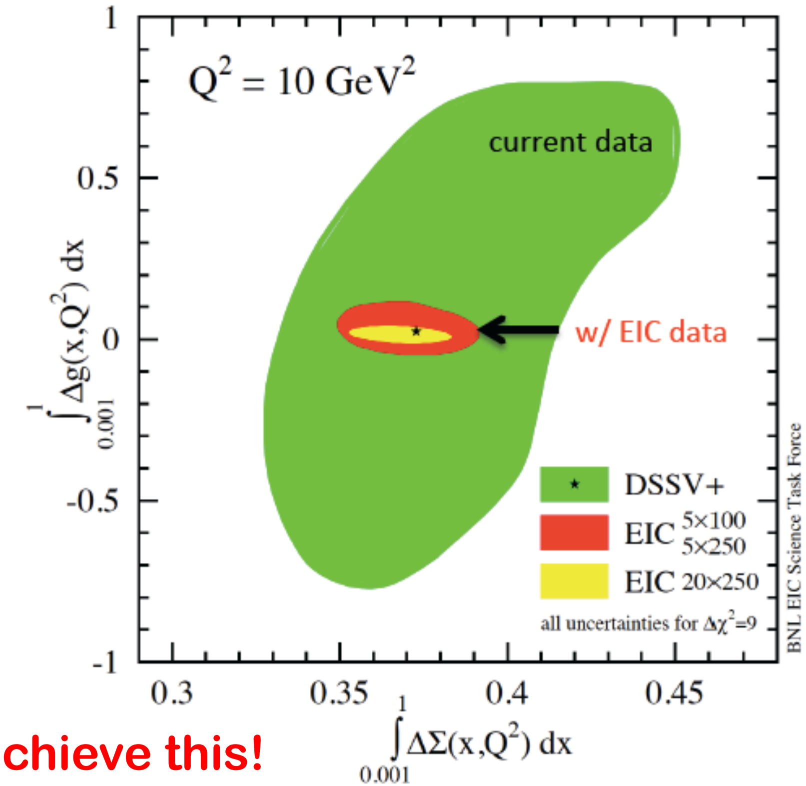
3D imaging of the nucleon.

The Proton Spin

- One-year of running at EIC:

Wider Q^2 and x range including low x at EIC!





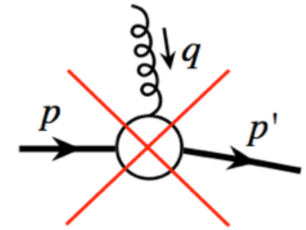
No other machine in the world can achieve this!

- Ultimate solution to the proton spin puzzle:
  - *Precision measurement of Δg(x) – extend to smaller x regime*
  - *Orbital angular momentum contribution – measurement of TMDs & GPDs!*

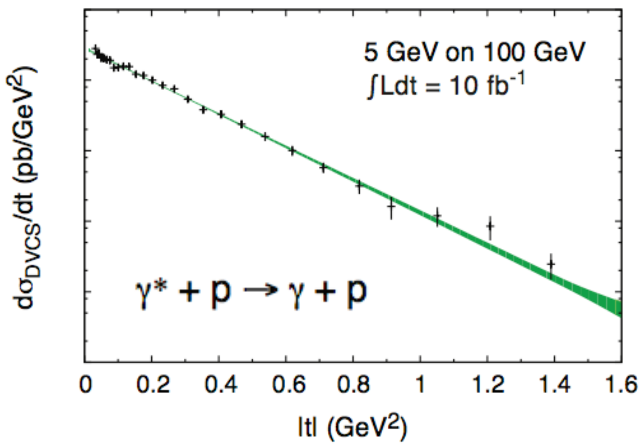
Spatial imaging of quarks & gluons

- No color elastic nucleon form factor!

  ➡ *Spatial distribution of quark/gluon densities – GPDs*



- DVCS at EIC:

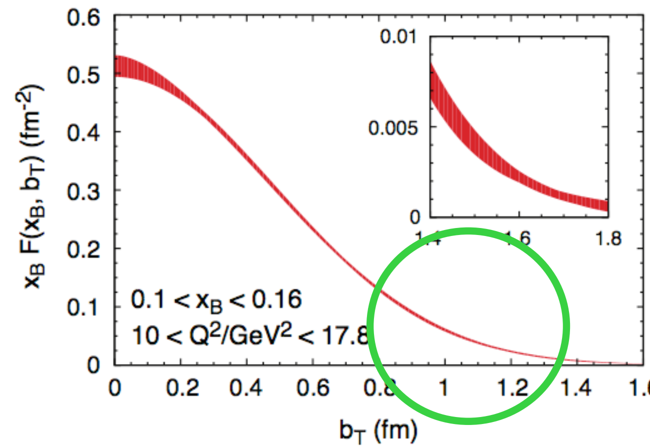


Factorization

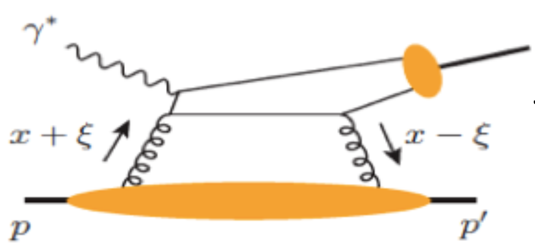
➡ GPDs ➡

F.T.

Proton radius of quarks (x)!



- "Seeing" the glue at EIC:

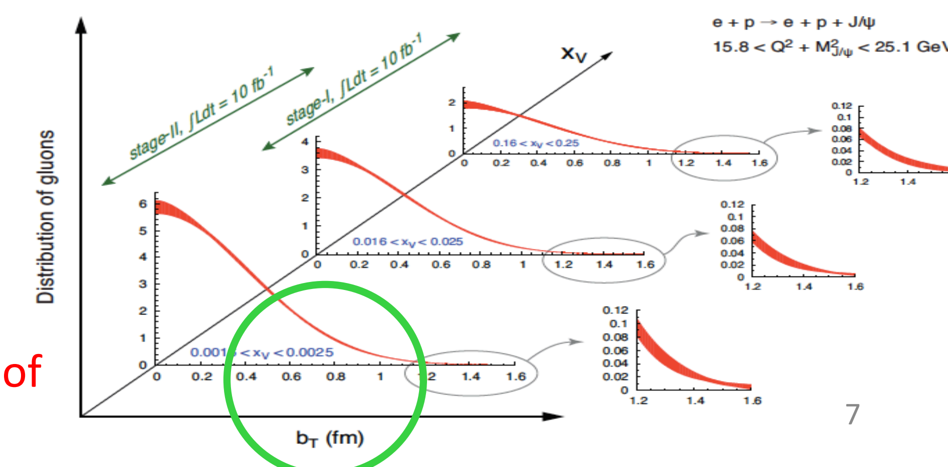


J/Ψ, Φ, …

t-dep

➡

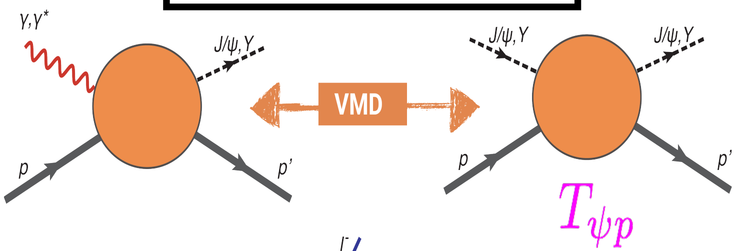
Proton radius of gluons (x)!

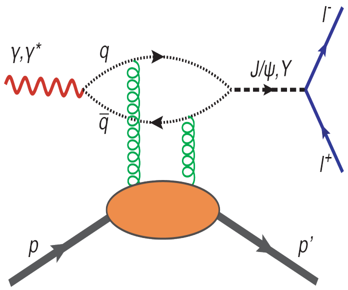


Only possible at EIC!

Charm @ SoLID and Beauty @ EIC

$$\gamma^* + N \rightarrow N + J/\psi$$





Heavy quark – dominated by twc

Proton Mass:

$$\langle P|T^\alpha_\alpha|P\rangle = 2P^\alpha P_\alpha = 2M_p^2$$

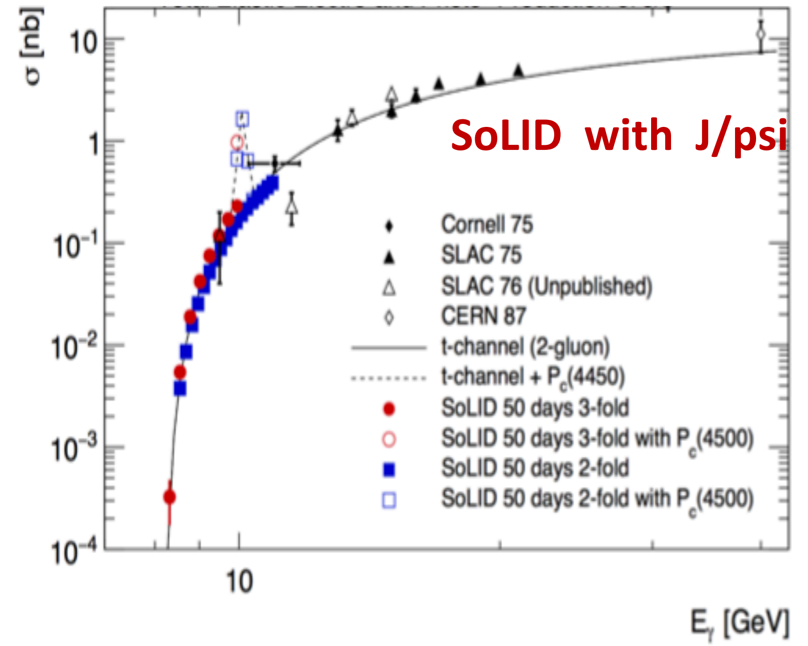
Covariant Decomposition of the Energy Momentum T

$$T^\alpha_\alpha = \frac{\tilde{\beta}(g)}{2g} F^{\mu\nu,a} F^a_{\mu\nu} + \sum_{q=u,d,s} m_q(1+\gamma_m)\bar{\psi}_q \psi_q$$

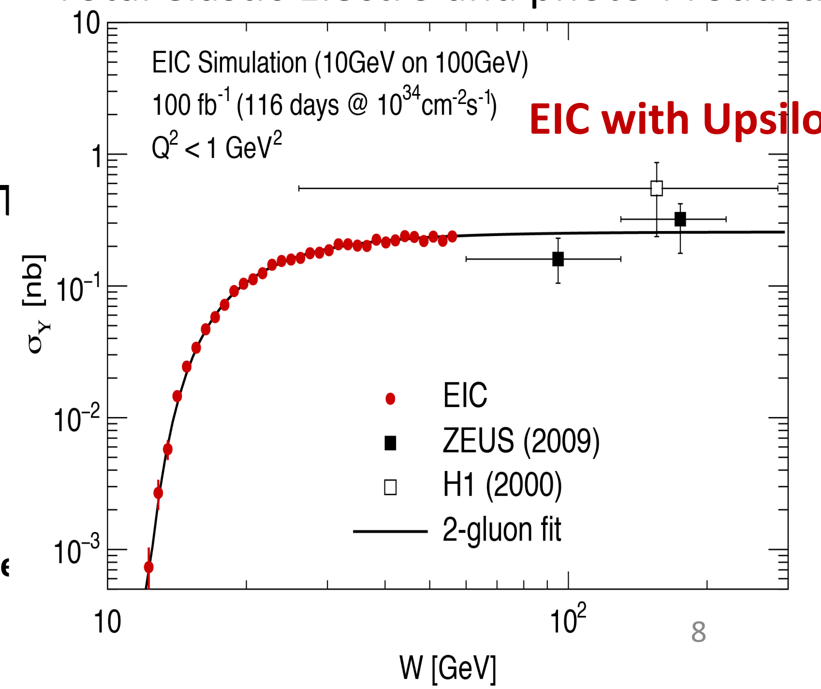
QCD trace anomaly — Light quark mass

Trace of EMT proportional to Quarkonium-proton scattering amplitude
$T_{\psi p}$ to be measured at JLab with J/psi at SoLID or Upsilon at EIC

Total elastic Electro and photo-Produc

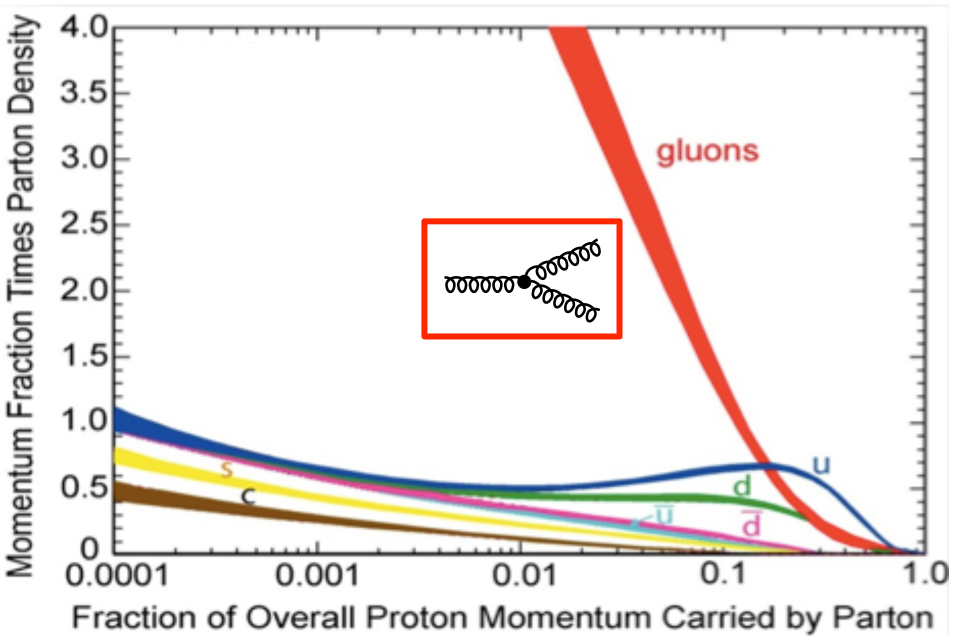


Total elastic Electro and photo-Producti



Gluon and the consequences of its interesting properties:

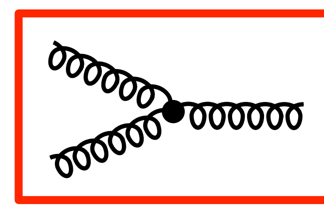
Gluons carry color charge ➔ Can interact with other gluons!



Apparent "indefinite rise" in gluon distribution in proton!

What could **limit this indefinite rise?** → saturation of soft gluon densities via gg→g recombination must be responsible.

recombination



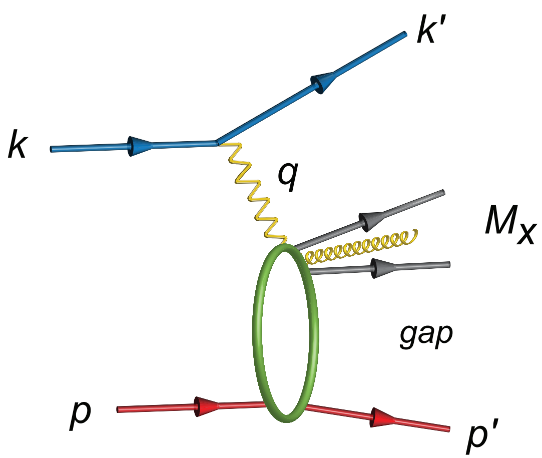
Where? No one has unambiguously seen this before!

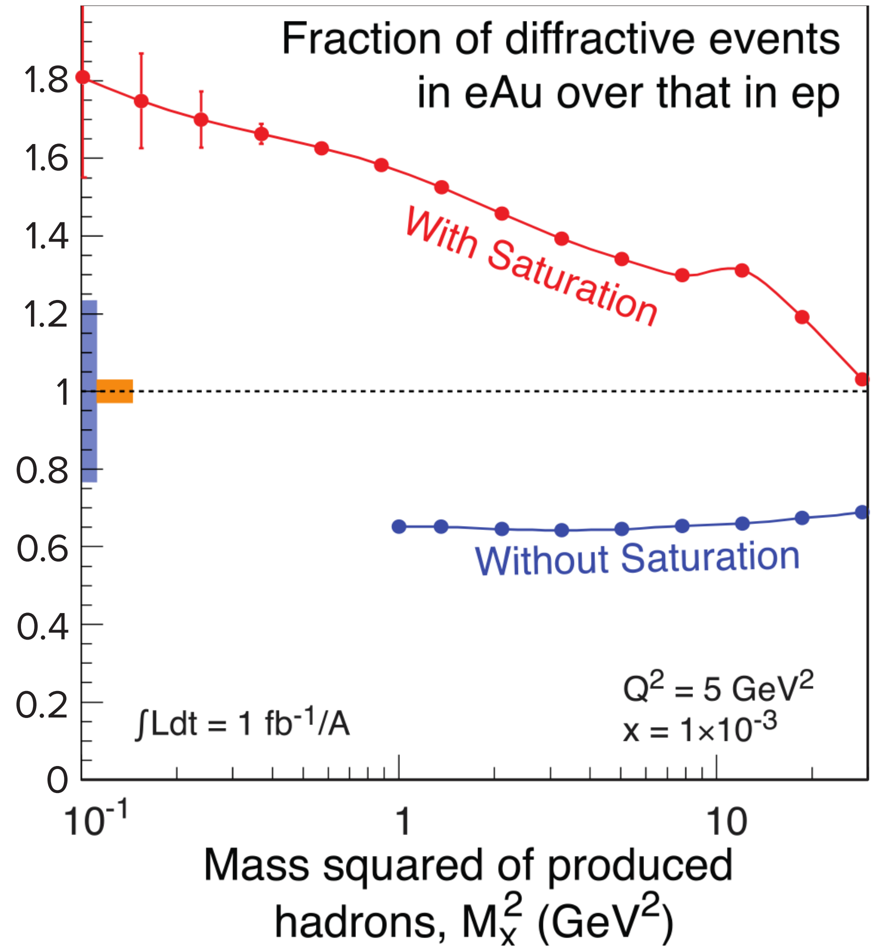
If true, effective theory of this →"Color Glass Condensate"

Saturation/CGC: What to measure?

Many ways to get to gluon distribution in nuclei, but diffraction most sensitive:

$$\sigma_{\rm diff} \propto [g(x,Q^2)]^2$$





At HERA

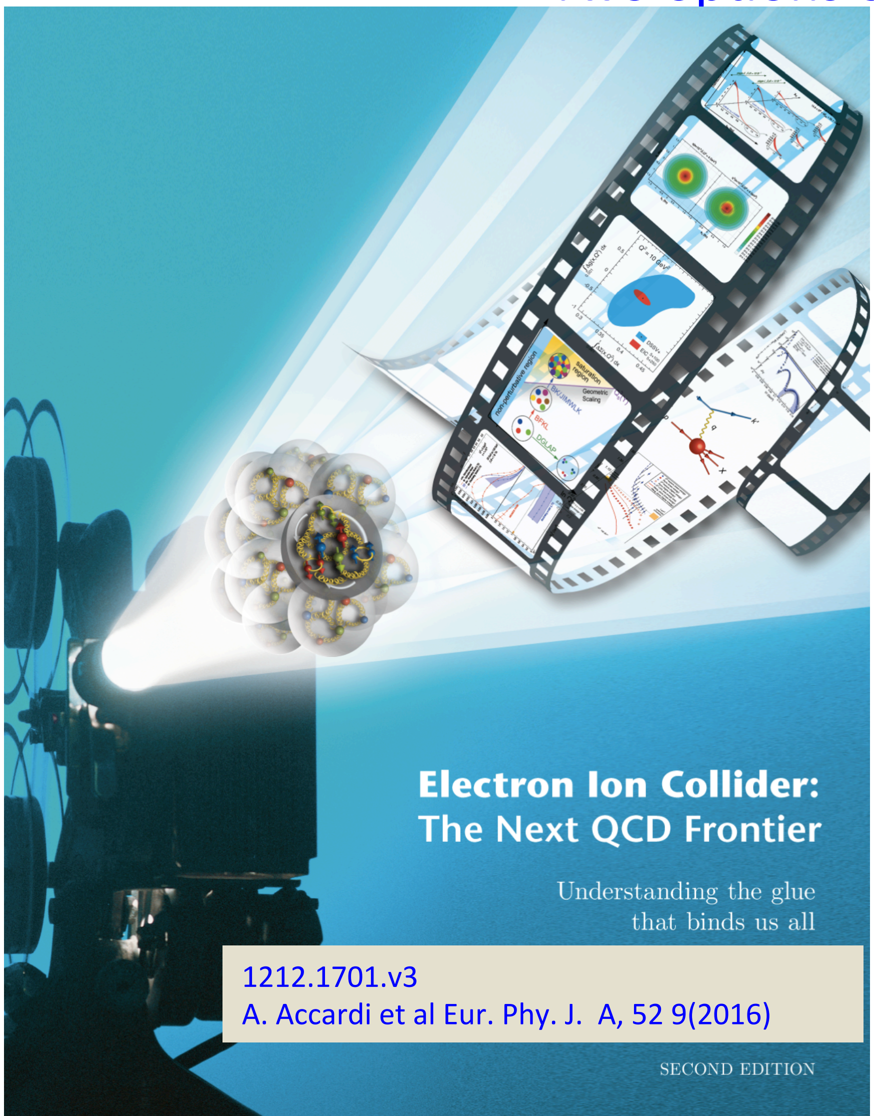
ep: 10-15% diffractive

At EIC eA, if Saturation/CGC

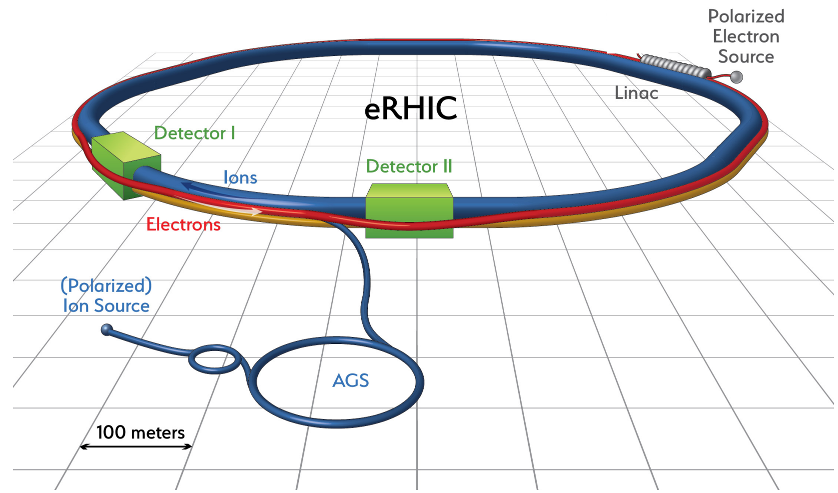
eA: 25-30% diffractive

The Electron Ion Collider

Two options of realization!

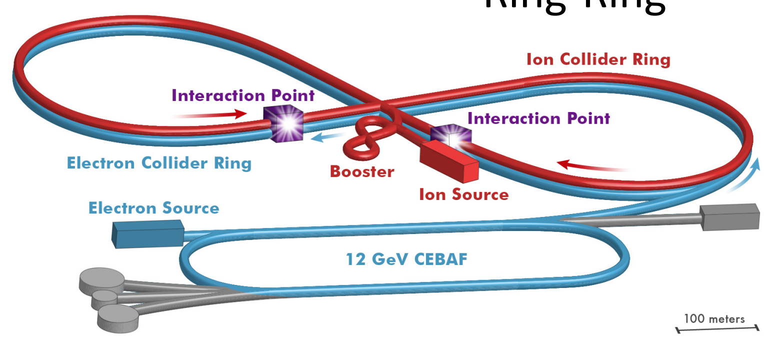


1212.1701.v3
A. Accardi et al Eur. Phy. J. A, 52 9(2016)

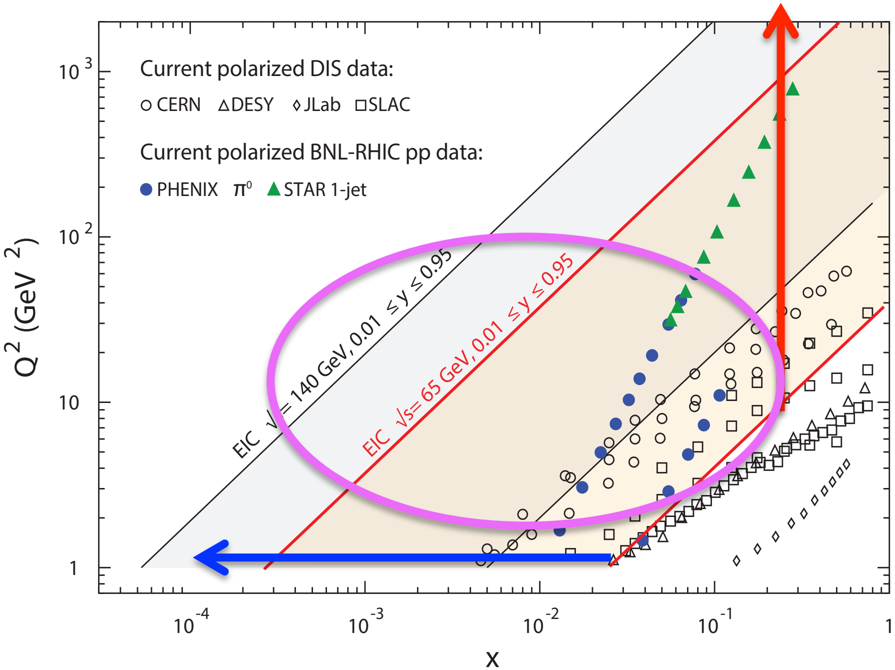


Not to scale

Ring-Ring



EIC: Kinematic reach & properties

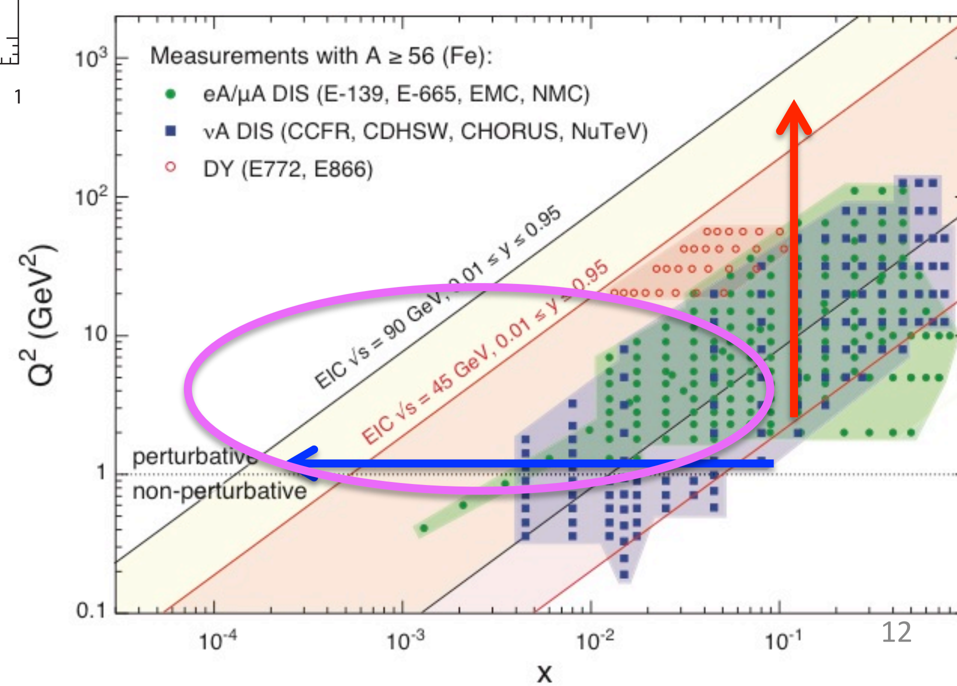


For e-N collisions at the EIC:

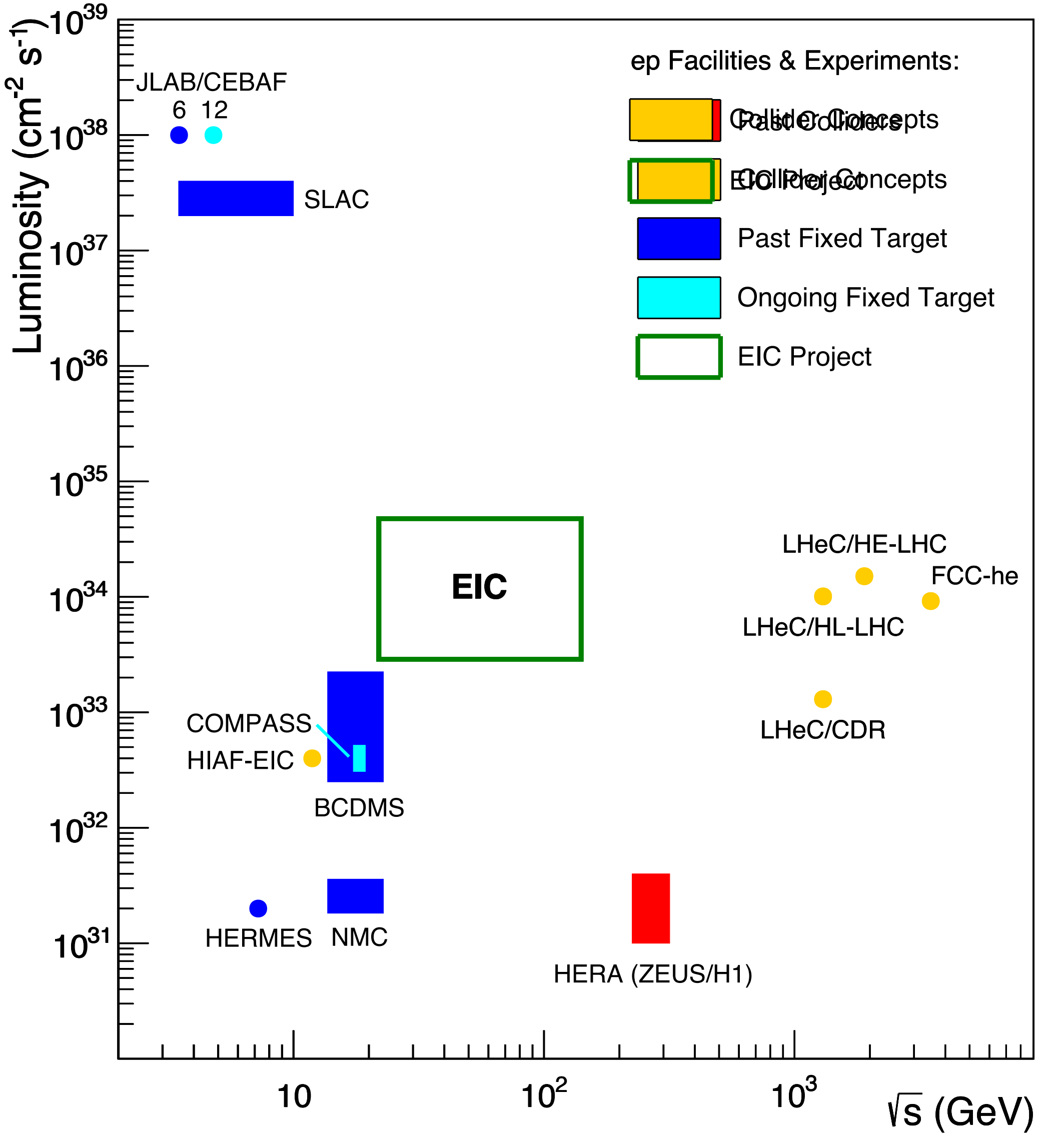
- ✓ **Polarized** beams: e, p, d/^{3}He
- ✓ Variable center of mass energy
- ✓ Wide Q^2 range → evolution
- ✓ Wide x range → spanning valence to low-x physics

For e-A collisions at the EIC:

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



Uniqueness of EIC among all DIS Facilities



All DIS facilities in the world.

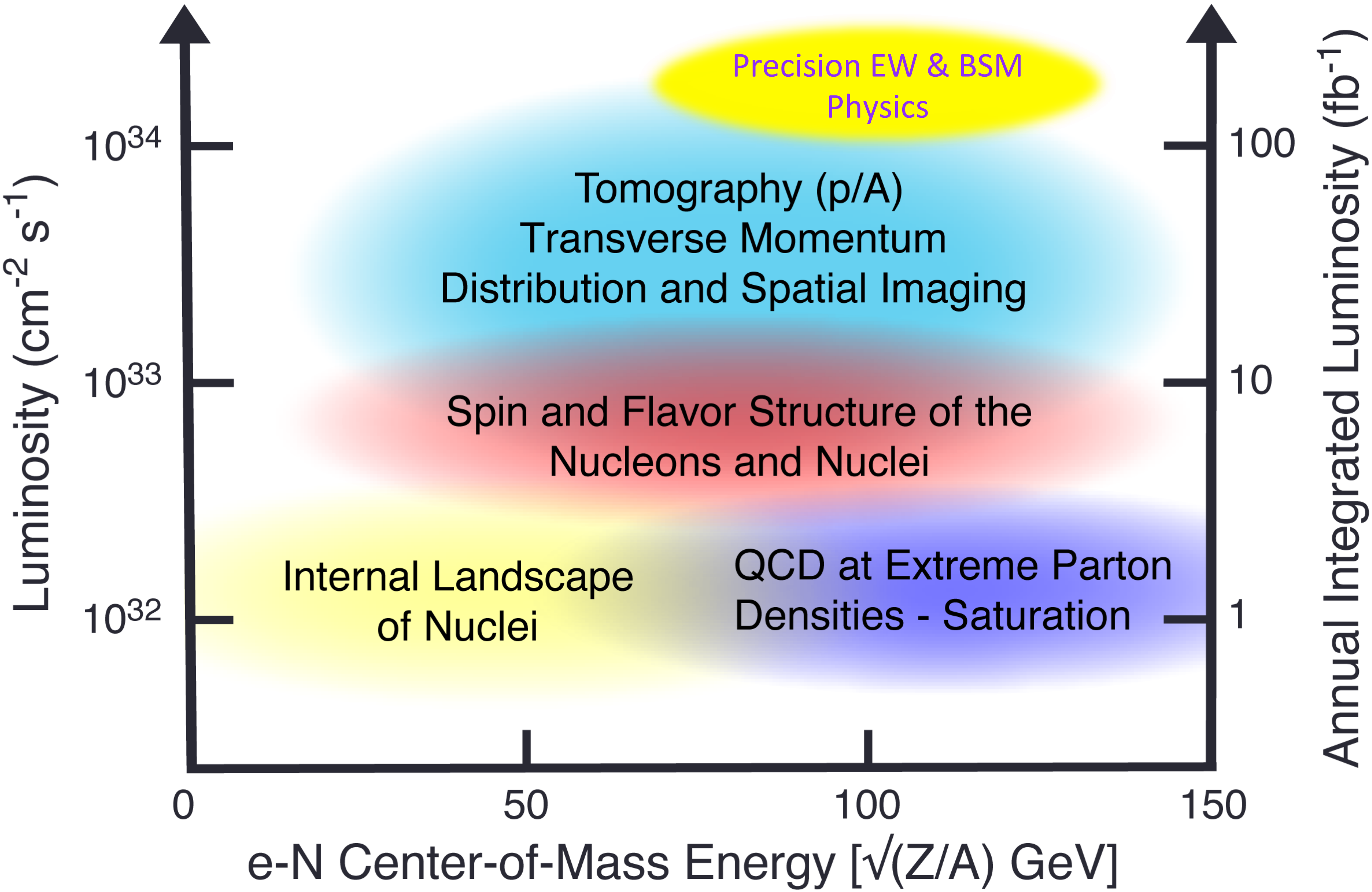
However,
if we ask for:

- high luminosity & wide reach in √s
- polarized lepton & hadron beams
- nuclear beams

EIC stands out as unique facility …

Need to include EicC

Summary: EIC Physics:
CM vs. Luminosity vs. Integrated luminosity



U.S. - based Electron-Ion Collider

- **Review of National Academy of Sciences following 2015 LRP:**

  Committee report just released this week on July 24

An Assessment of U.S.-Based Electron-Ion Collider Science

Committee on U.S.-Based Electron Ion Collider Science Assessment
Board on Physics and Astronomy
Division on Engineering and Physical Sciences
A Consensus Study Report of
The National Academies of Sciences • Engineering •Medicine

U.S. - based Electron-Ion Collider

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ERNST SICHTERMANN, Lawrence Berkeley National Laboratory
MICHAEL TURNER, NAS, University of Chicago

Committee met 4 times in person in 2017: February 1-2, DC; April 17-18, Irvine, CA; September 11-12, Woods Hole, MA; November 27-28, DC.

Statement of Task

The committee will assess the scientific justification for a U.S. domestic electron ion collider facility, taking into account current international plans and existing domestic facility infrastructure. In preparing its report, the committee will address the role that such a facility could play in the future of nuclear physics, considering the field broadly, but placing emphasis on its potential scientific impact on quantum chromodynamics.

In particular, the committee will address the following questions:

- *What is the merit and significance of the science that could be addressed by an electron ion collider facility and what is its importance in the overall context of research in nuclear physics and the physical sciences in general?*
- *What are the capabilities of other facilities, existing and planned, domestic and abroad, to address the science opportunities afforded by an electron ion collider? What unique scientific role could be played by a domestic electron ion collider facility that is complementary to existing and planned facilities at home and elsewhere?*
- *What are the benefits to U.S. leadership in nuclear physics if a domestic electron ion collider were constructed?*
- *What are the benefits to other fields of science and to society of establishing such a facility in the United States?*

Findings by The Committee on U.S.-Based Electron Ion Collider Science Assessment

- **Finding 1:** An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:
  - How does the mass of the nucleon arise?
  - How does the spin of the nucleon arise?
  - What are the emergent properties of dense systems of gluons?

citation: National Academies of Sciences, Engineering, and Medicine. 2018. *An Assessment of* 55 *U.S.-Based Electron-Ion Collider Science.* Washington, DC: The National Academies Press. 56 https://doi.org/10.17226/25171

Findings by The Committee on U.S.-Based Electron Ion Collider Science Assessment

- **Finding 2:** These three high-priority science questions can be answered by an EIC with highly polarized beams of electrons and ions, with sufficiently high luminosity and sufficient, and variable, center-of-mass energy.
- **Finding 3:** An EIC would be a unique facility in the world and would maintain U.S. leadership in nuclear physics.
- **Finding 4:** An EIC would maintain U.S. leadership in the accelerator science and technology of colliders and help to maintain scientific leadership more broadly.

Findings by The Committee on U.S.-Based Electron Ion Collider Science Assessment

- **Finding 5:** Taking advantage of existing accelerator infrastructure and accelerator expertise would make development of an EIC cost effective and would potentially reduce risk.
- **Finding 6:** The current accelerator R&D program supported by DOE is crucial to addressing outstanding design challenges.
- **Finding 7:** To realize fully the scientific opportunities an EIC would enable, a theory program will be required to predict and interpret the experimental results within the context of QCD, and furthermore, to glean the fundamental insights into QCD that an EIC can reveal.

Findings by The Committee on U.S.-Based Electron Ion Collider Science Assessment

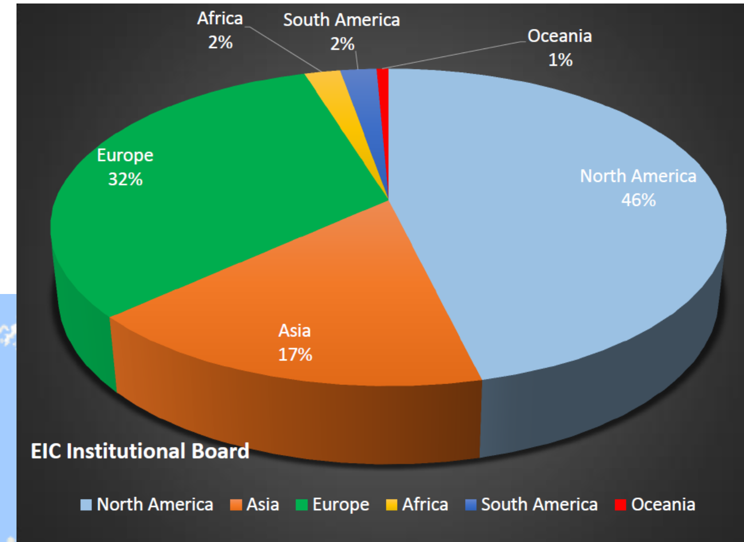
- **Finding 8:** The U.S. nuclear science community has been thorough and thoughtful in its planning for the future, taking into account both science priorities and budgetary realities. Its 2015 Long Range Plan identifies the construction of a high-luminosity polarized EIC as the highest priority for new facility construction following the completion of the Facility for Rare Isotope Beams (FRIB) at Michigan State University.
- **Finding 9:** The broader impacts of building an EIC in the United States are significant in related fields of science, including in particular the accelerator science and technology of colliders and workforce development.

The EIC Users Group: EICUG.ORG

(no students included as of yet)

800+ collaborators, 29 countries, 169 institutions... (July 2018)

Map of institution's locations



Path forward for the EIC

- DOE sponsored a science Review by National Academy of Science of EIC
  - Report released July 24, 2018

- Positive NAS review will trigger the DOE's CD process
  - CD0 (acceptance of the critical need for science by DOE)
  - EIC-Proposal's Technical & Cost review → site selection
  - CD1 requires site selection
  - **Major Construction funds ("CD3")**
    - Assuming 1.6% sustained increase over inflation of the next several years (Long Range Plan)
    - Consistent with the past 10 years of NP funding increases in the US

Summary and outlook

- US-EIC: the next and the ultimate QCD frontier endorsed by the NSAC 2015 Long Range Plan
- US based EIC positively endorsed by the NAS EIC assessment study – committee report just released this week
- Path forward – positive and stay tuned

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