The US Electron Ion Collider Project

- What is the Electron Ion Collider?
- What physics is motivating it?

    MPI in nucleons and nuclei:

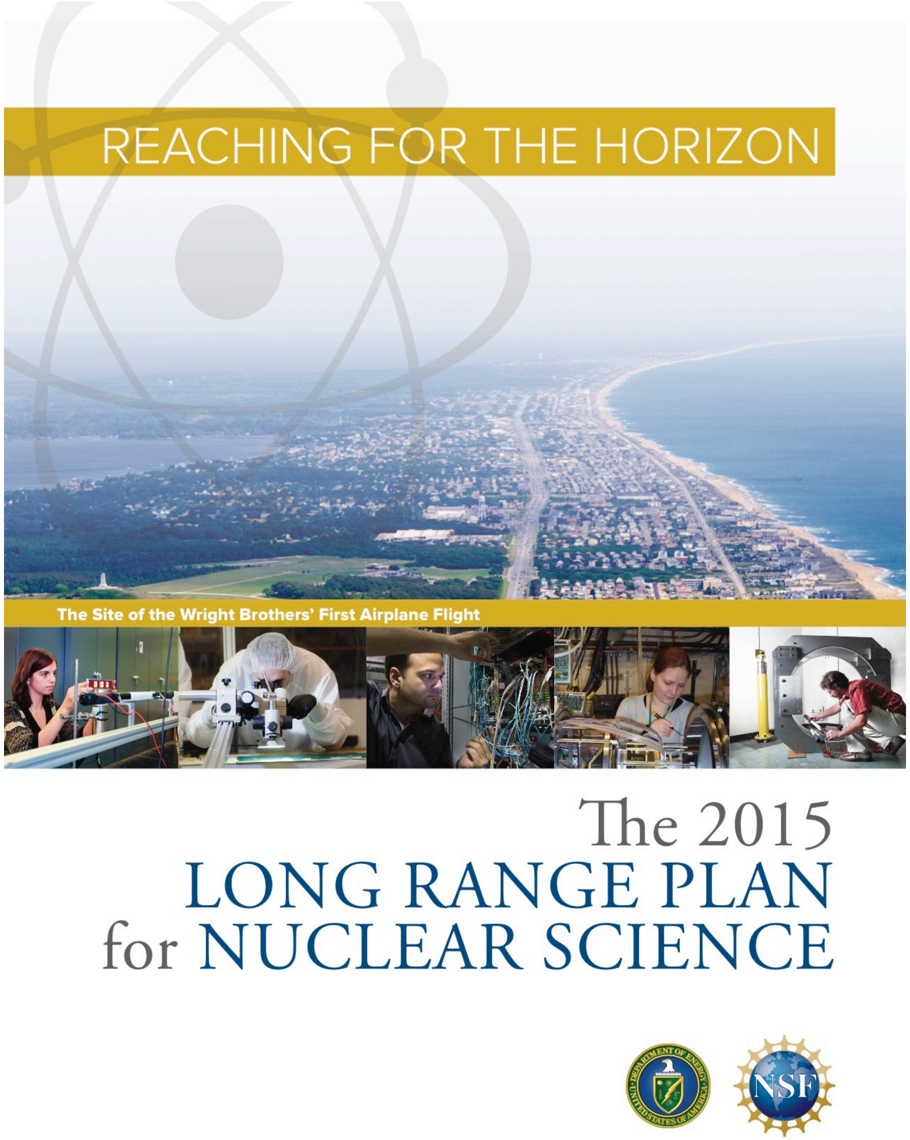
    Precision study of role of Gluons in QCD

- What is the status? Connections to MPI's

Stony Brook University

Abhay Deshpande

BROOKHAVEN NATIONAL LABORATORY



http://science.energy.gov/np/reports

RECOMMENDATION:

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

Initiatives:

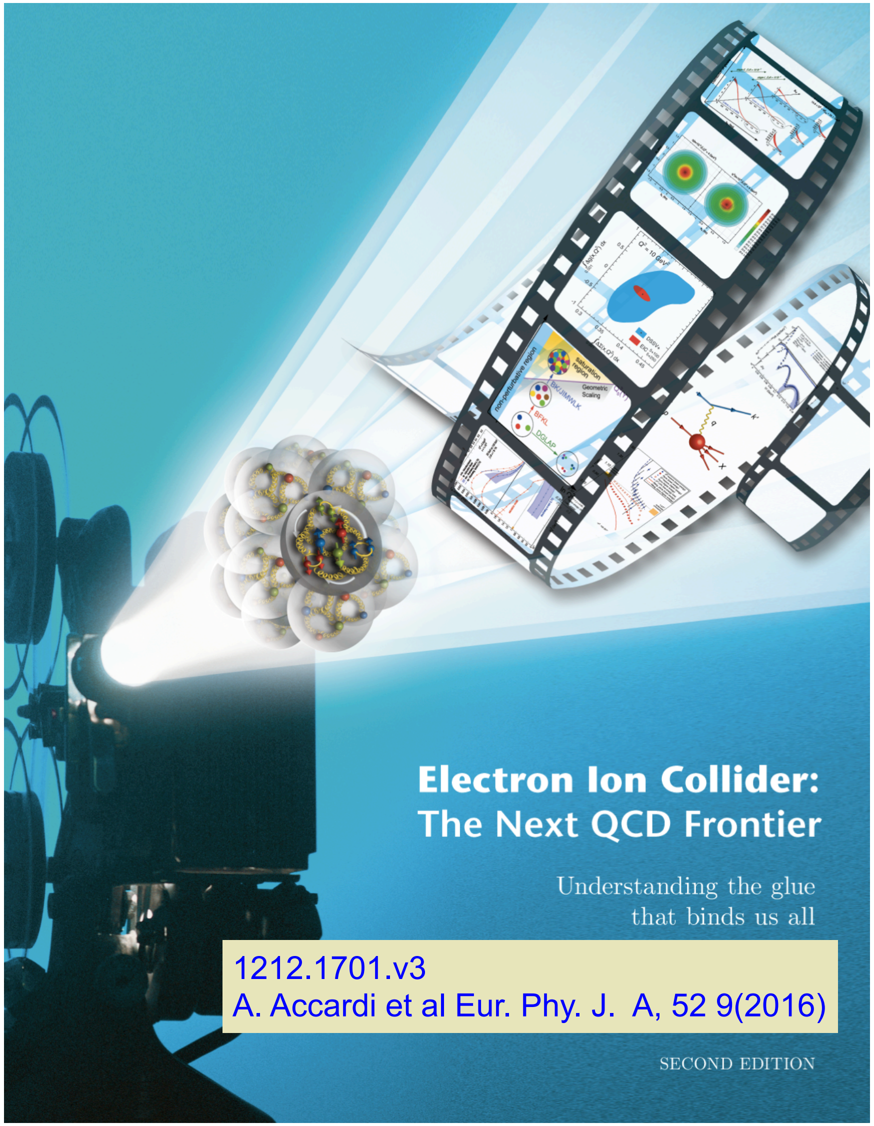
Theory
Detector & Accelerator R&D

NEW Money for EIC Accelerator R&D already assigned \$7m/yr

Detector R&D money ~1.3M/yr
Significant increase anticipated

The Electron Ion Collider

Two options of realization!



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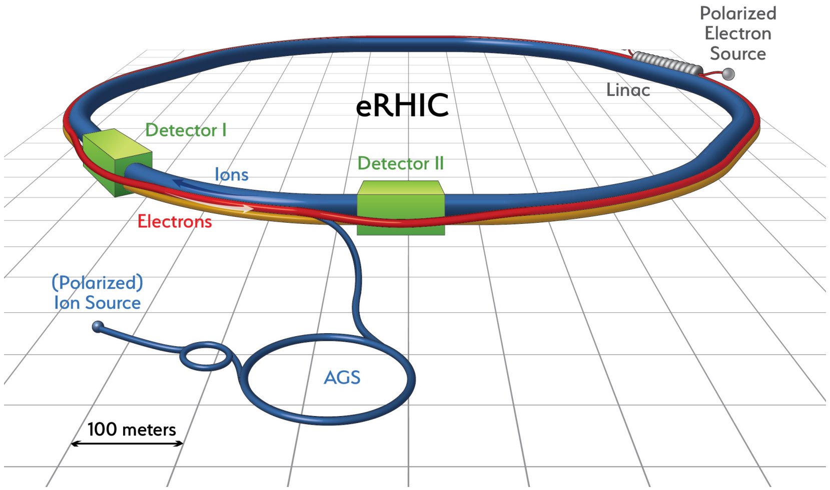
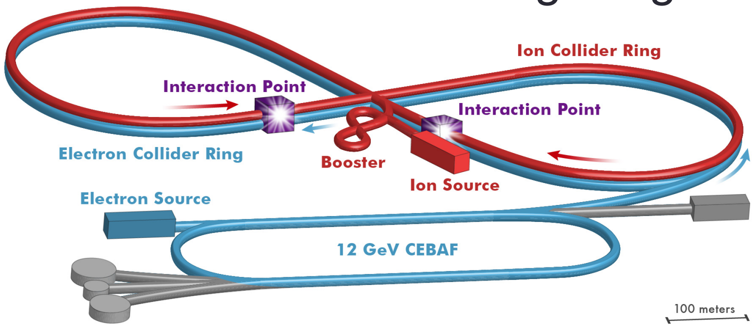


Not to scale

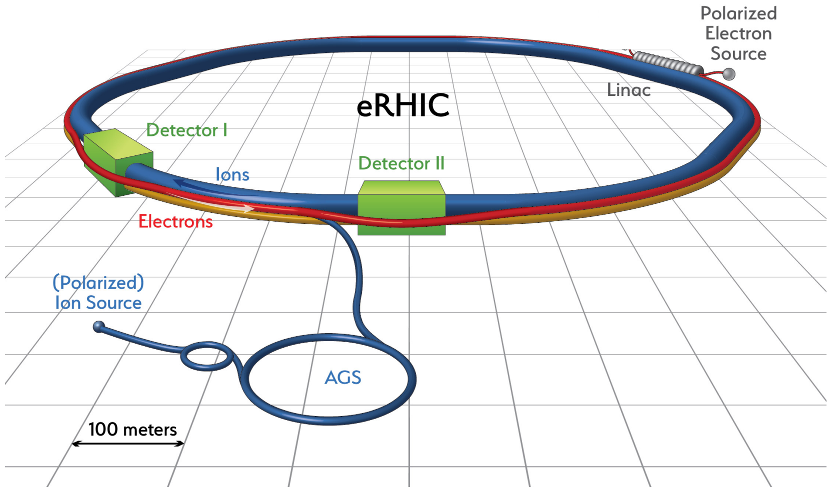
Ring-Ring



The Electron Ion Collider

Two options of realization!

For e-N collisions at the EIC:
- ✓ Polarized beams: e, p, d/^{3}He
- ✓ e beam 5-10(20) GeV
- ✓ Luminosity L_{ep} ~ 10^{33-34} cm^{-2}sec^{-1}
  100-1000 times HERA
- ✓ 20-100 (140) GeV Variable CoM



For e-A collisions at the EIC:
- ✓ **Wide range in nuclei**
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy

Not to scale

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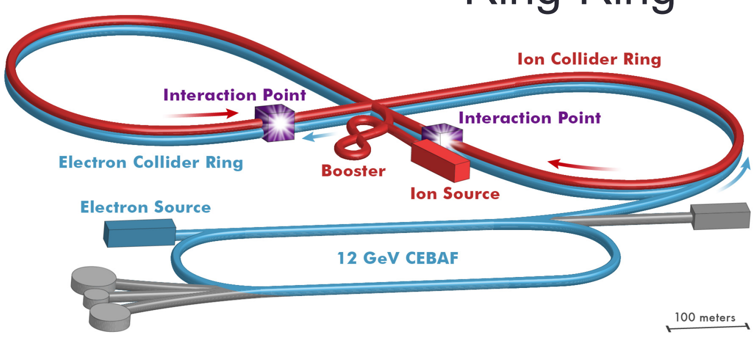
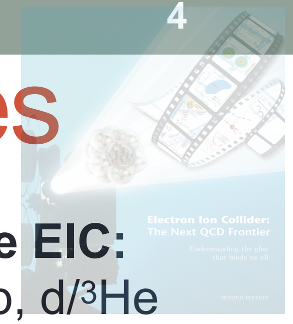
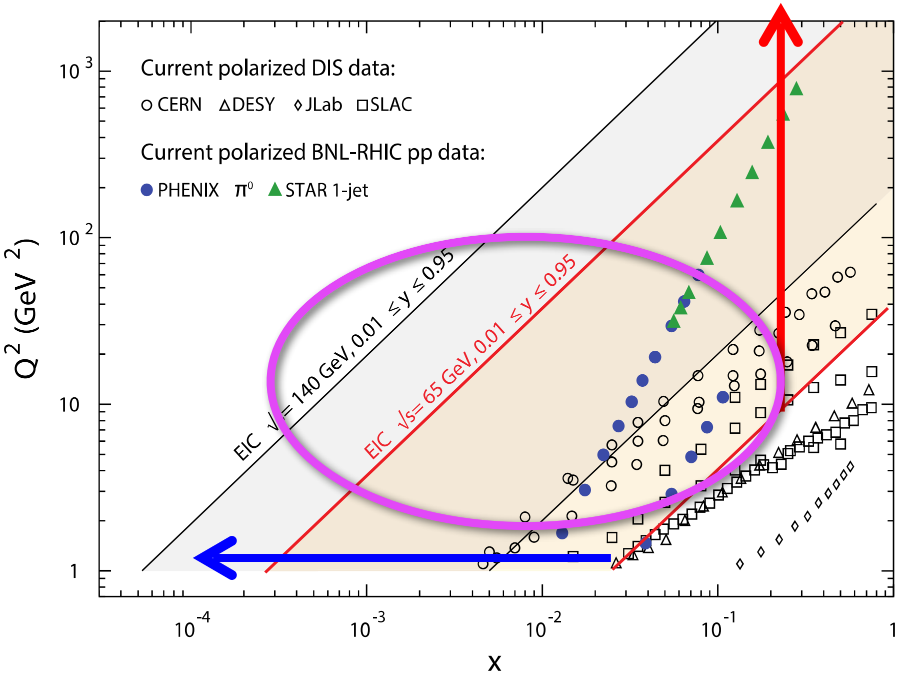


World's first
Polarized electron-proton/light ion
and electron-Nucleus collider

Both designs use DOE's significant investments in infrastructure

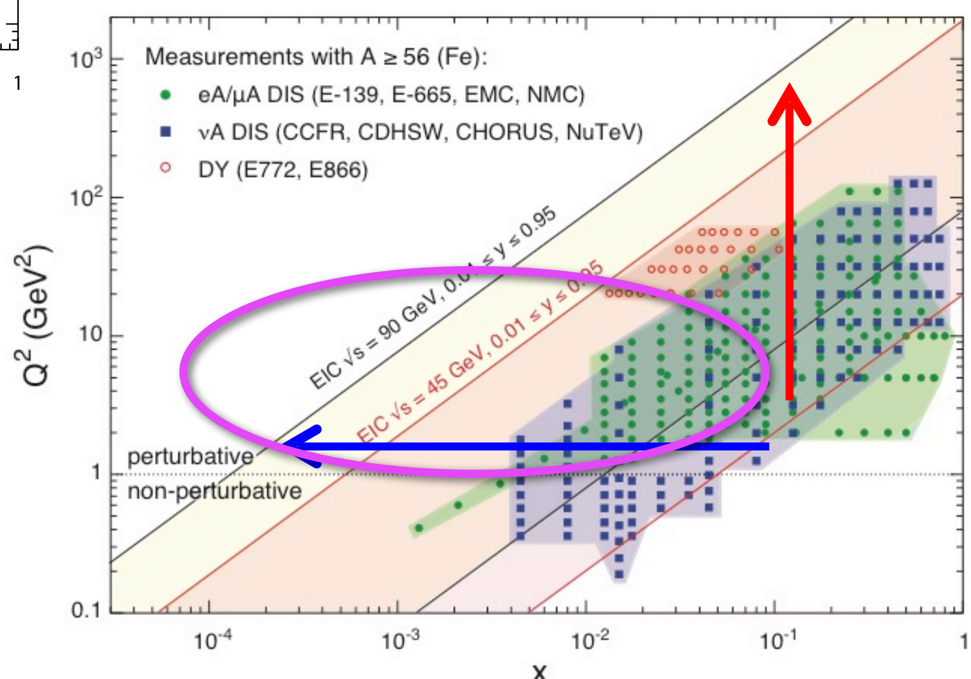
EIC: Kinematic reach & properties





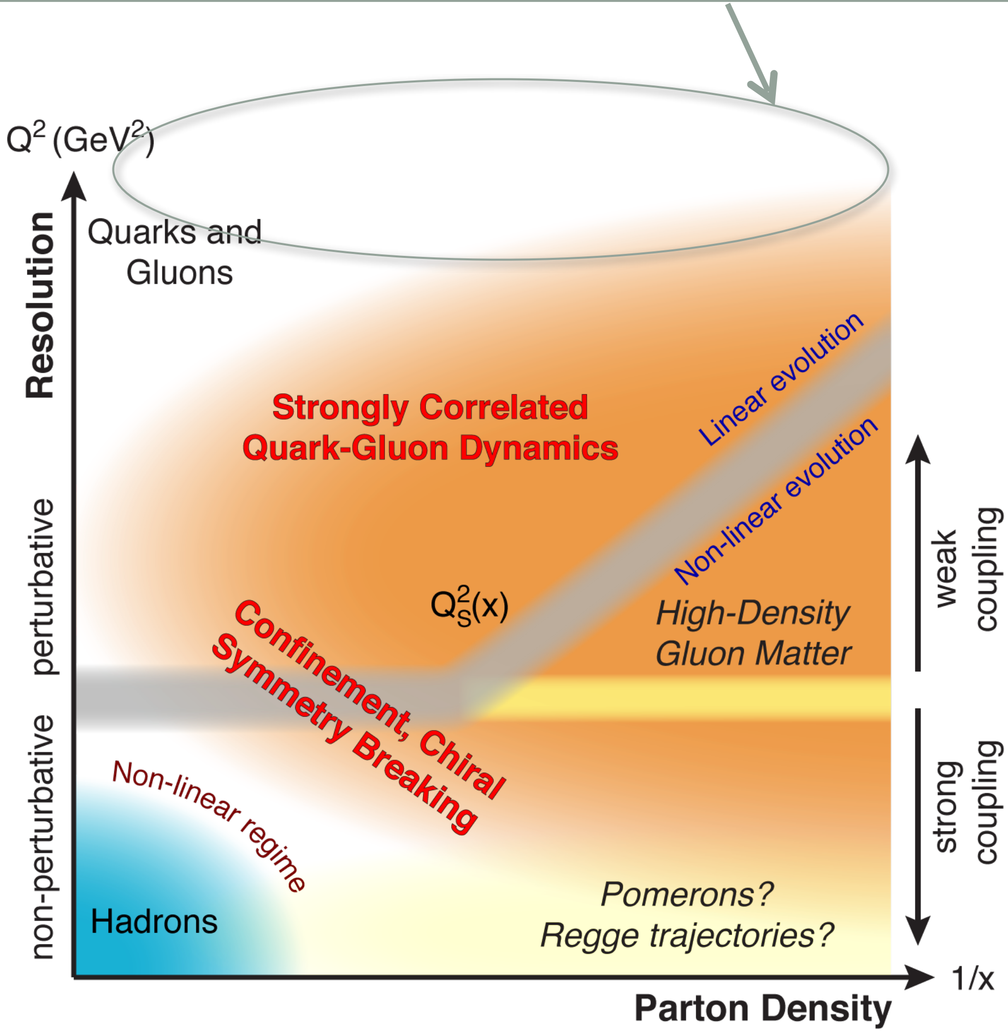
For e-N collisions at the EIC:
- ✓ **Polarized** beams: e, p, d/^{3}He
- ✓ Variable center of mass energy
- ✓ Wide Q^2 range → evolution
- ✓ Wide x range → spanning valence to low-x physics

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)



QCD Landscape to be explored by EIC

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



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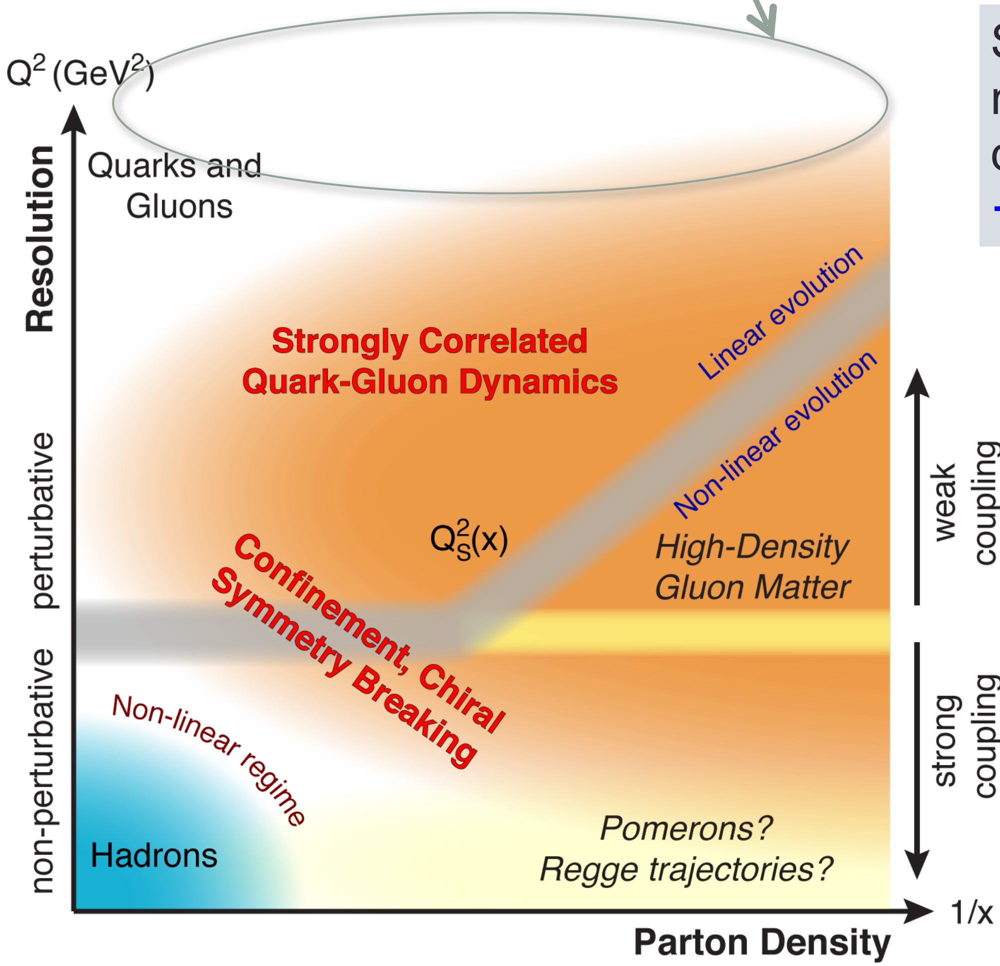

Strong QCD dynamics creates many-body correlations between quarks and gluons
→ hadron structure emerges

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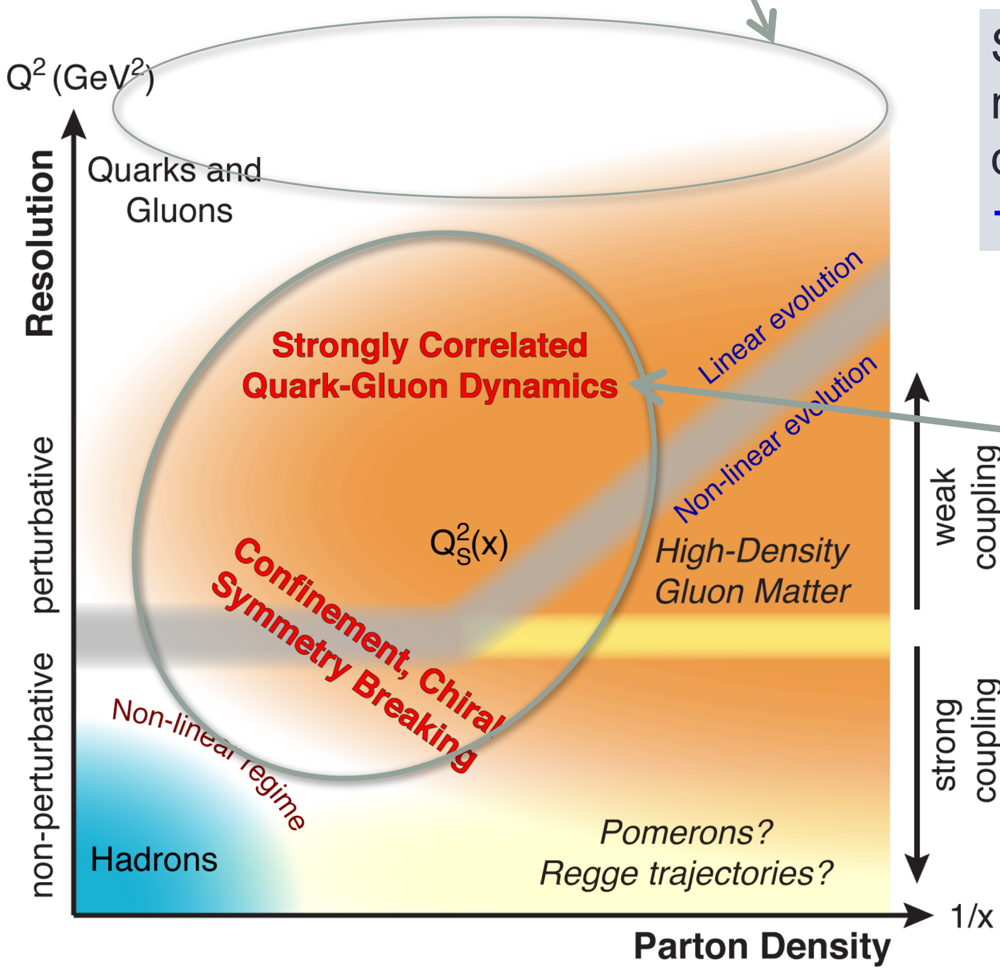

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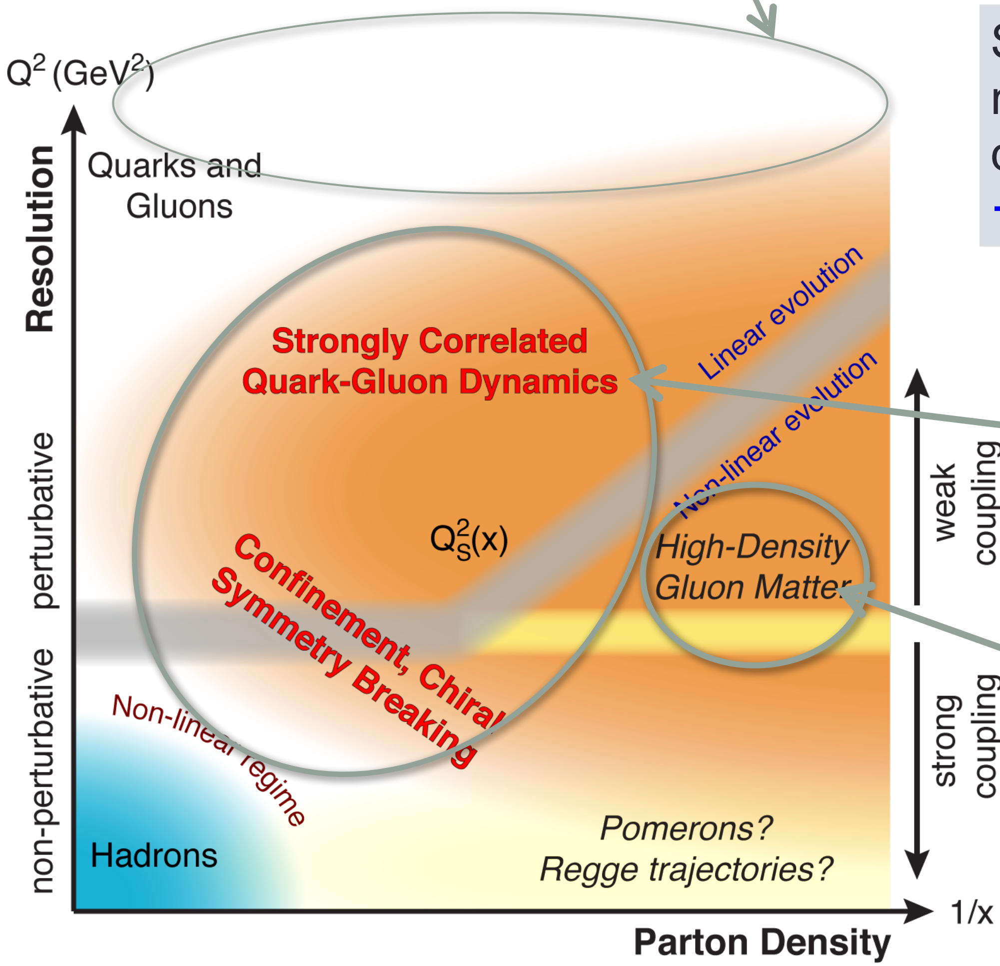
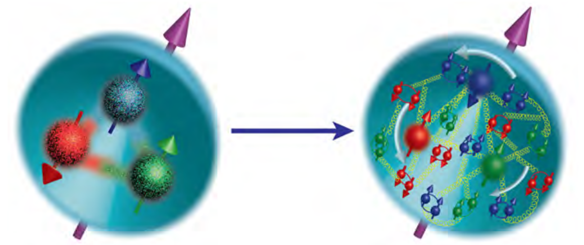


EIC will systematically explore correlations in this region.

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

A new facility is needed to investigate, with precision, the dynamics of gluons & sea quarks and their role in the structure of visible matter



How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?

How do the nucleon properties emerge from them and their interactions?

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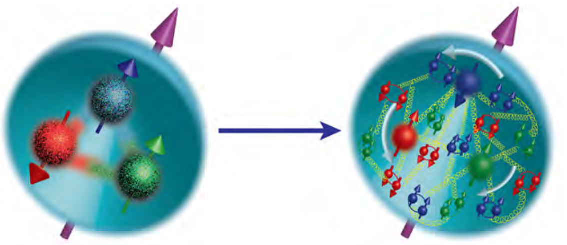

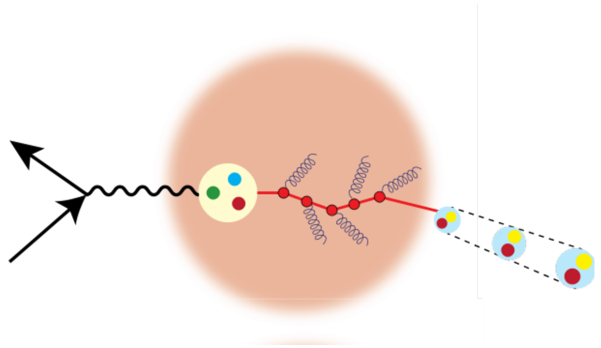

How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

How do the confined hadronic states emerge from these quarks and gluons?

How do the quark-gluon interactions create nuclear binding?

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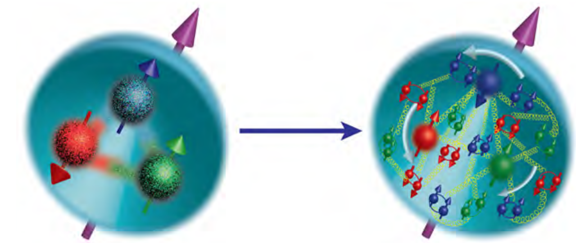

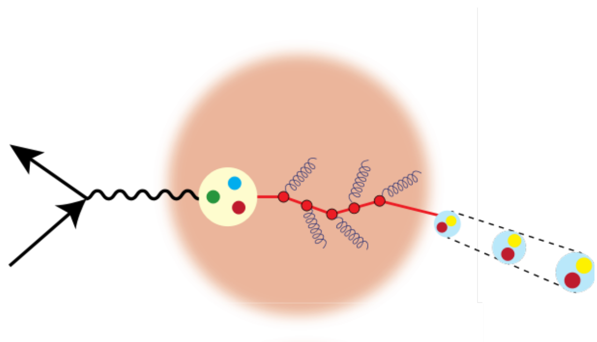

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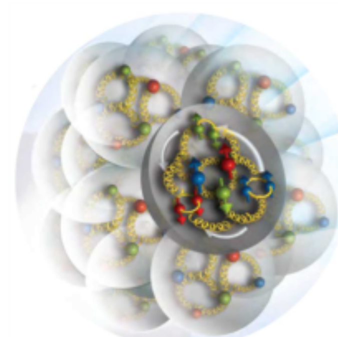
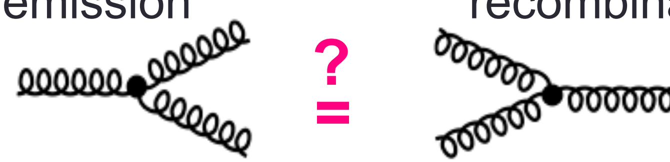


How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

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

gluon emission

gluon recombination

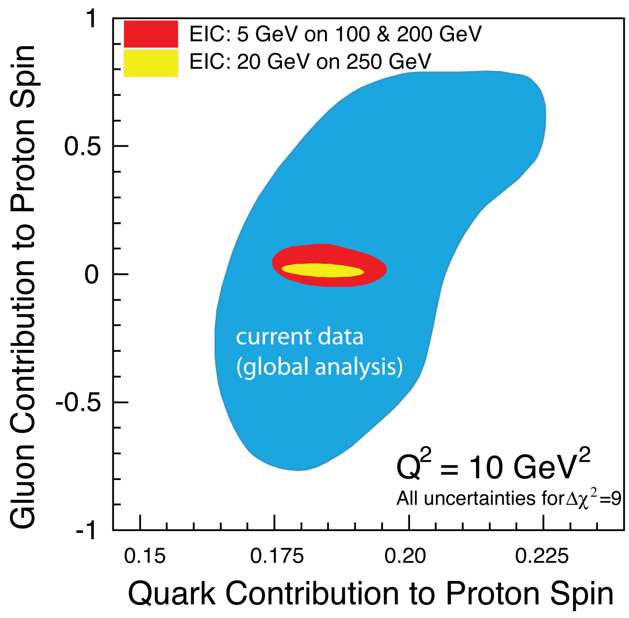


Nucleon's Spin:

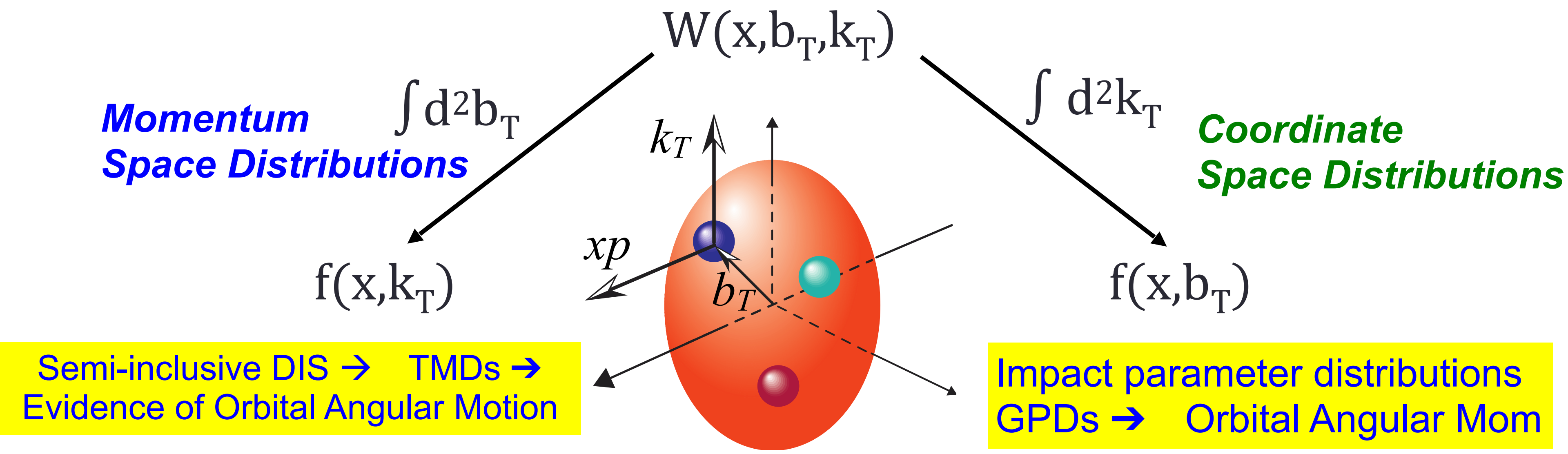
results from multi-partonic interactions

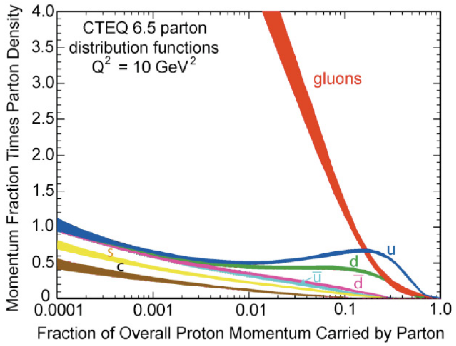
"Helicity sum rule"

$$\frac{1}{2}\hbar = \underbrace{\frac{1}{2}\Delta\Sigma}_{\text{quark contribution}} + \underbrace{\Delta G}_{\text{gluon contribution}} + \sum_q \underbrace{L_q^z + L_g^z}_{\text{orbital angular momentum}}$$

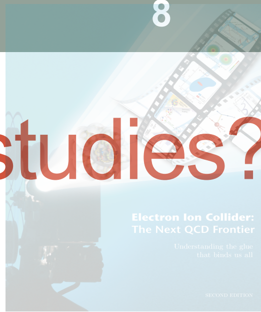


3D imaging of quarks and gluons in a nucleon: Wigner Functions





What do we learn from low-x studies?



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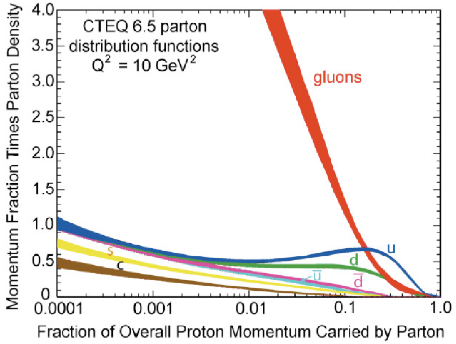

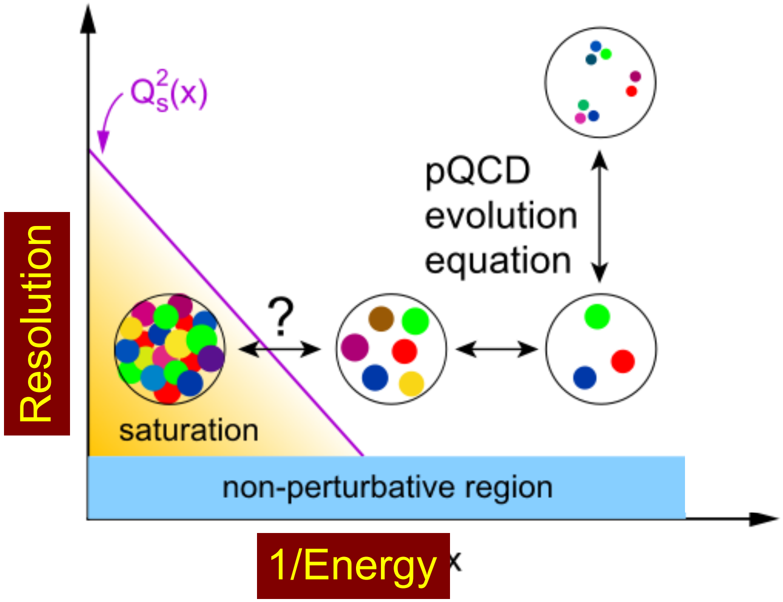

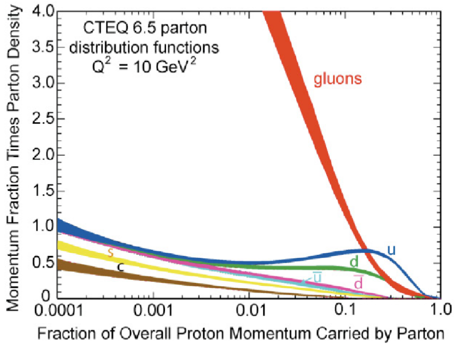

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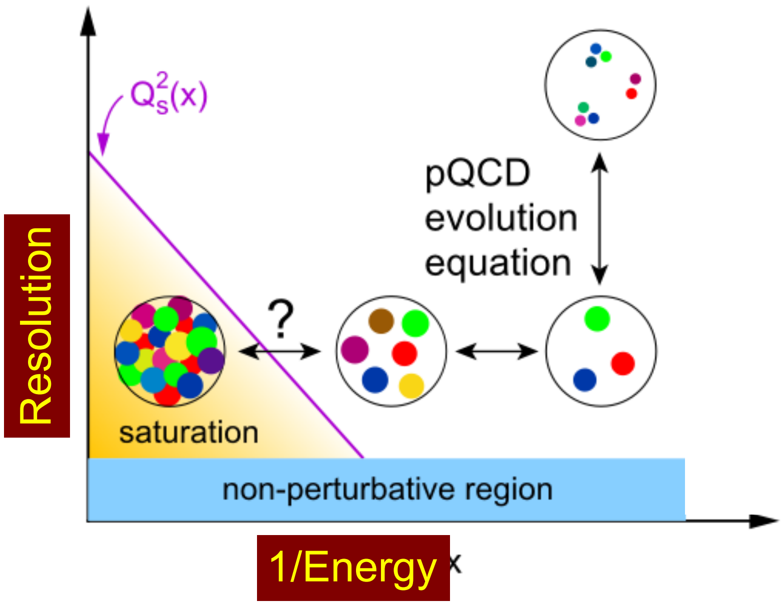
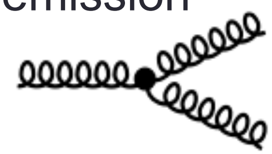


What tames the low-x rise?

- New evolution eqn.s @ low x & moderate Q^2
- Saturation Scale $Q_S(x)$ where gluon emission and recombination comparable

gluon emission



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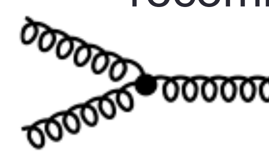
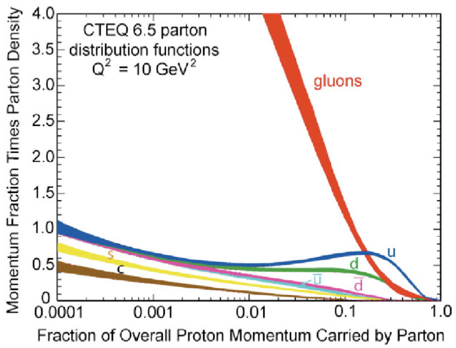
gluon recombination



At Q_S



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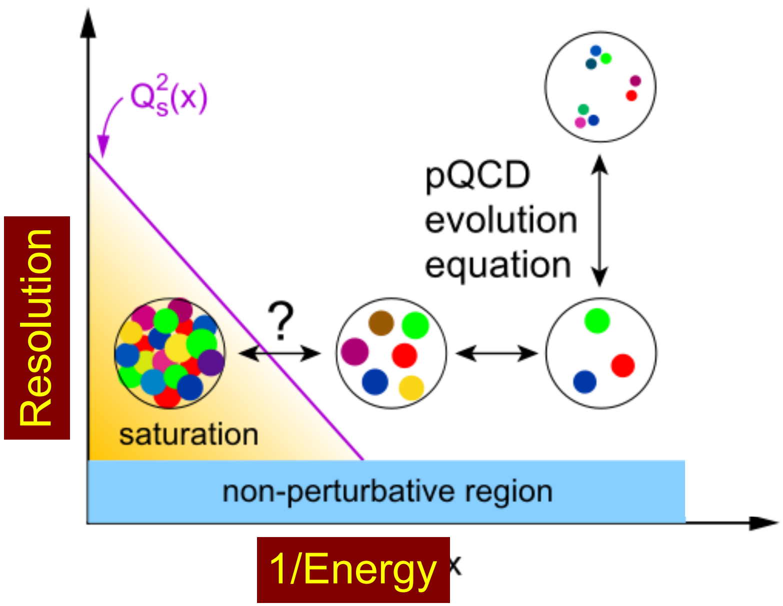

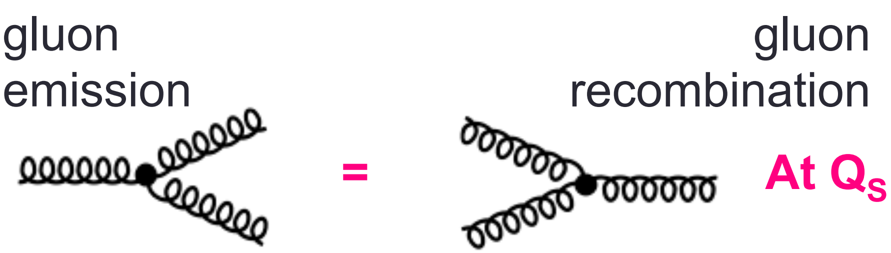

First unambiguous observation of gluon recombination effects in nuclei:
→leading to a *collective* gluonic system!
First observation of g-g recombination in *different* nuclei
→ **Is this a universal property?**
→ **Is the Color Glass Condensate the correct effective theory?**

How to explore/study this new phase of matter?

(multi-TeV) e-p collider OR **a (multi-10s GeV) e-A collider**

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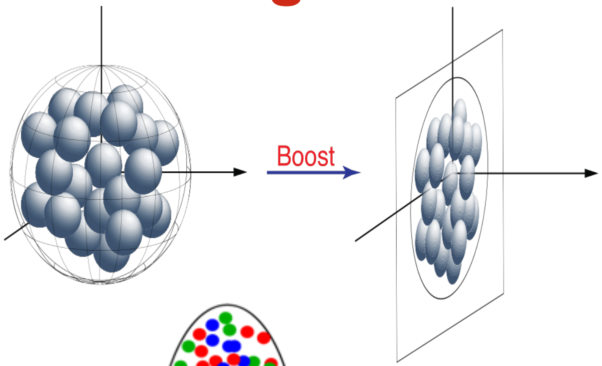
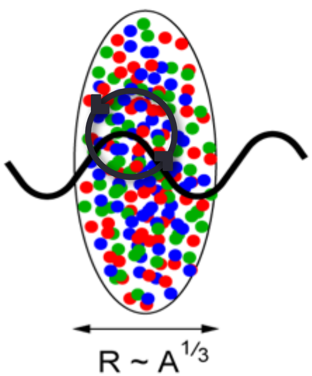
Advantage of nucleus →





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

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

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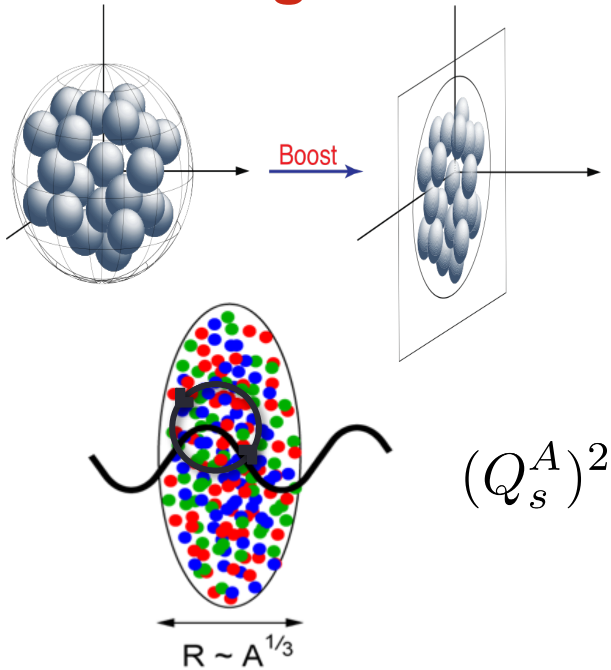

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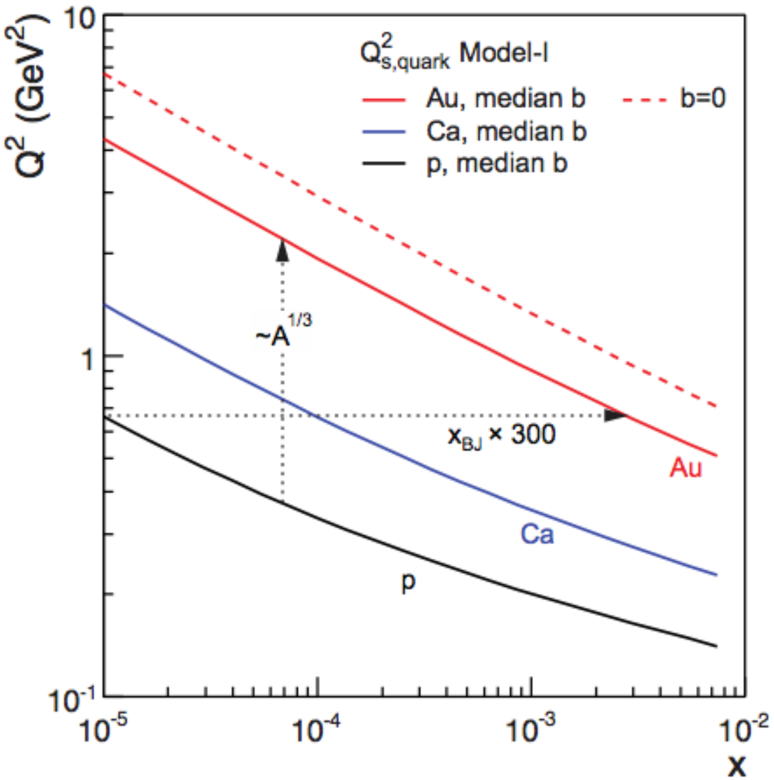

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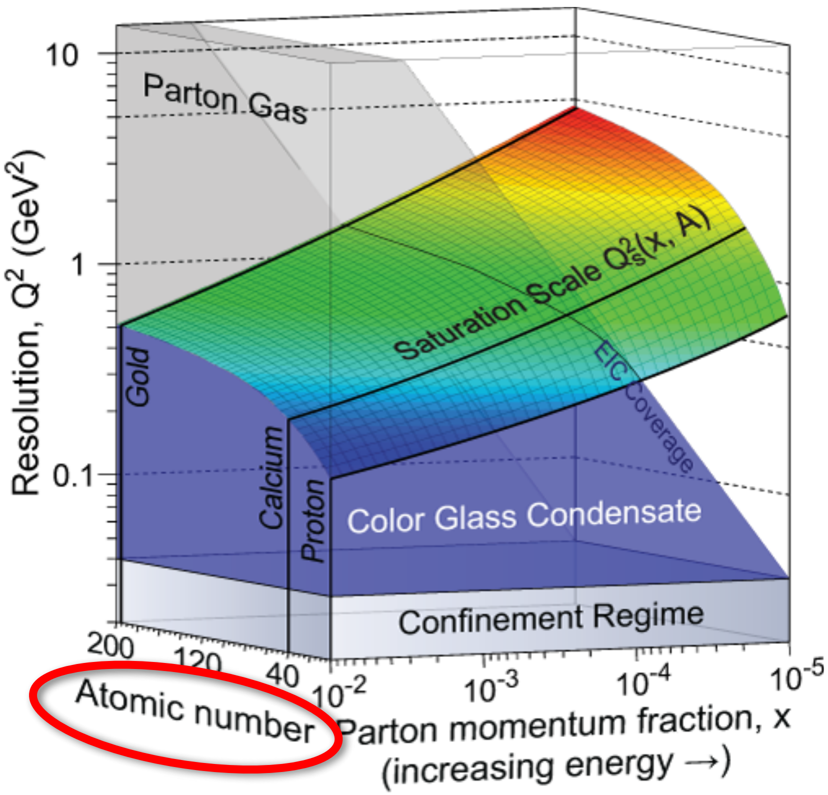

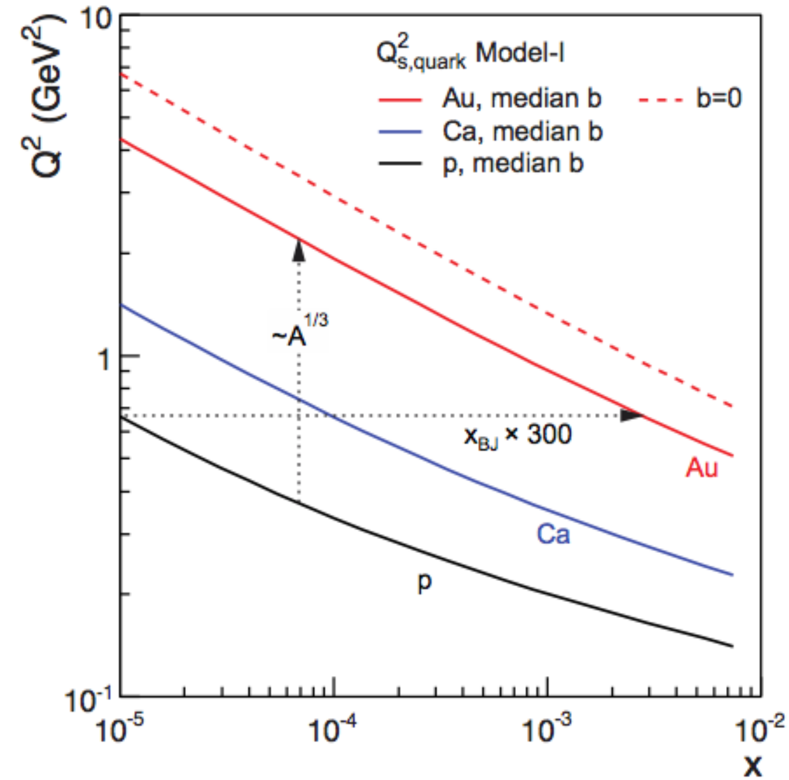

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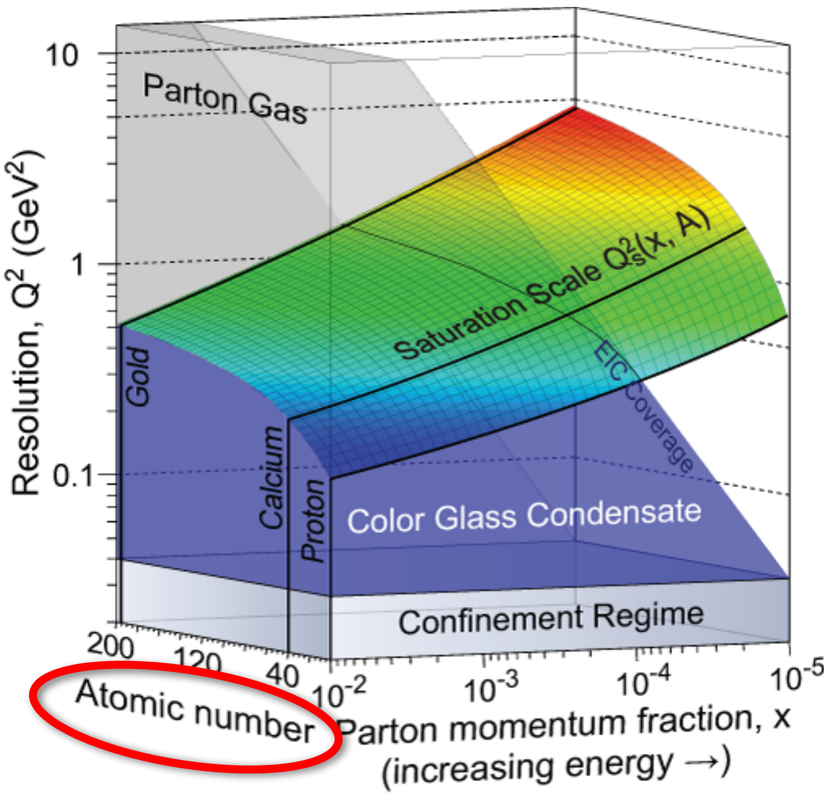

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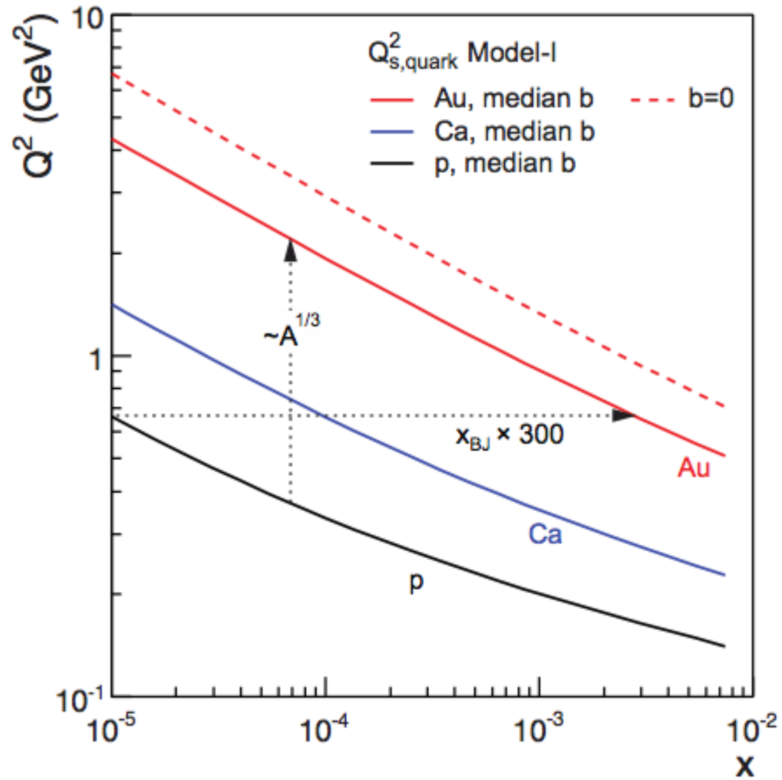
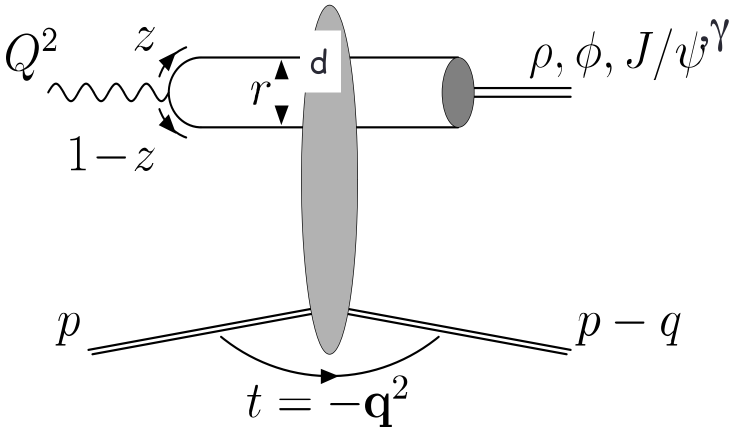


Enhancement of Q_S with A:

Saturation regime reached at significantly lower energy (read: "cost") in nuclei

Transverse imaging of the gluons nuclei

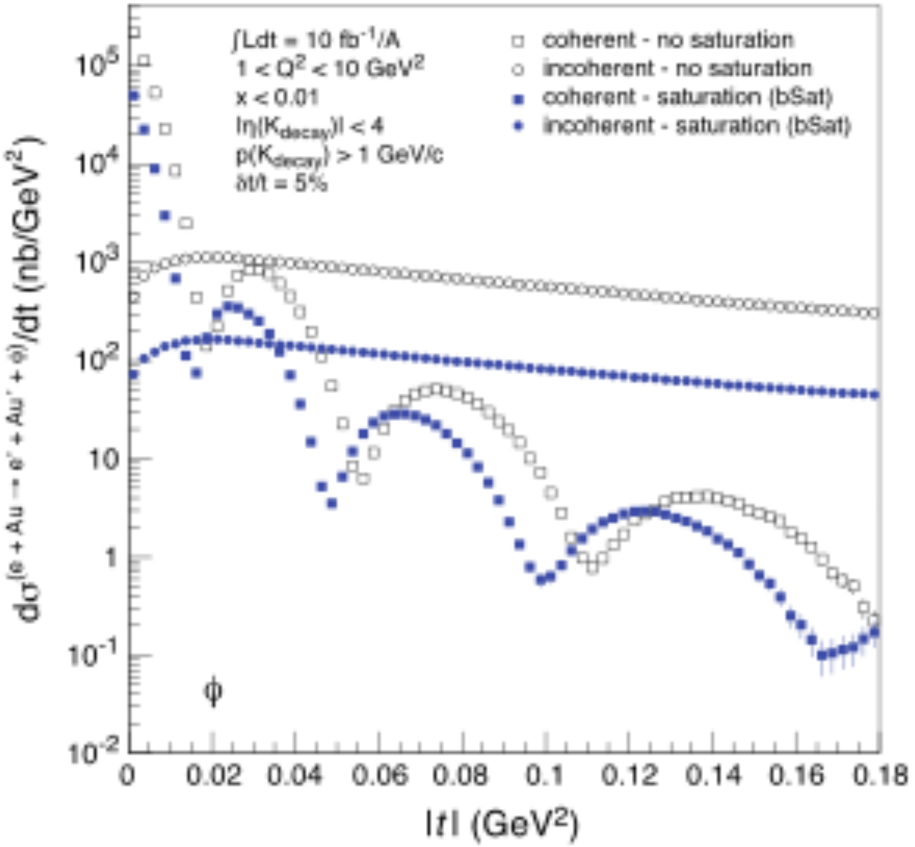


➔Does low x dynamics (Saturation) modify the transverse gluon distribution?

Experimental challenges being Studied.

Diffractive vector meson production in **e-Au**

Diff. MC: "Sartre"



Simulation study by Toll & Ullrich

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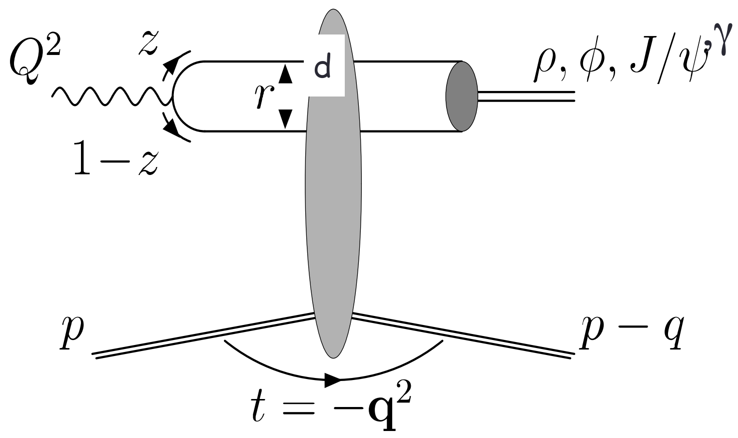

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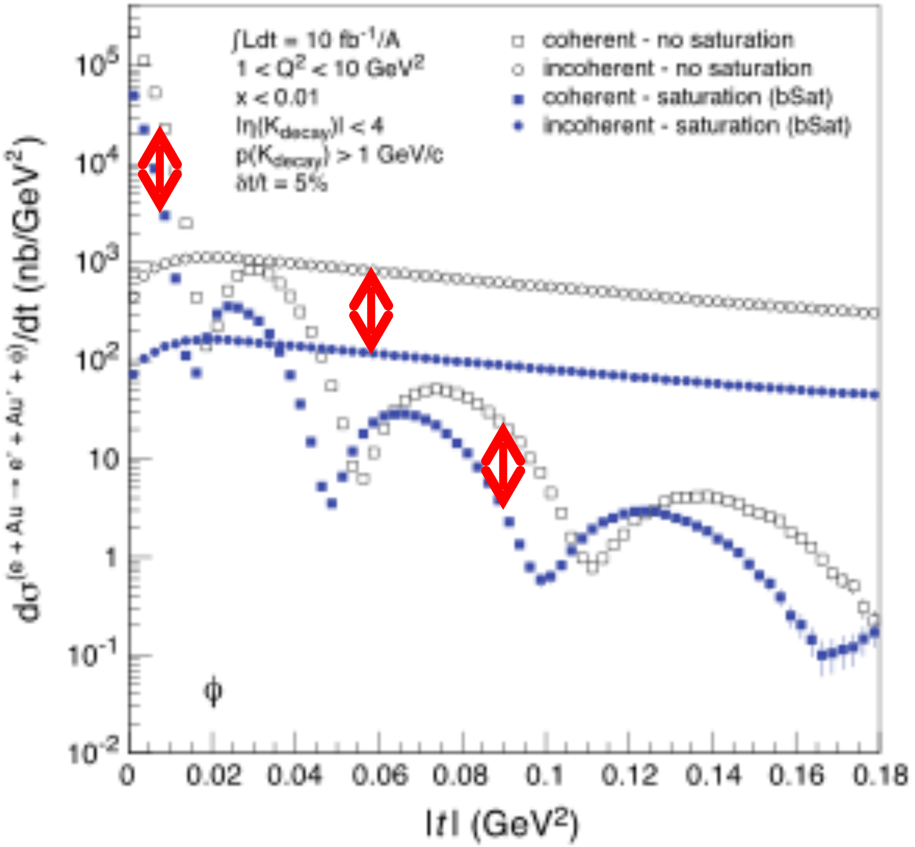

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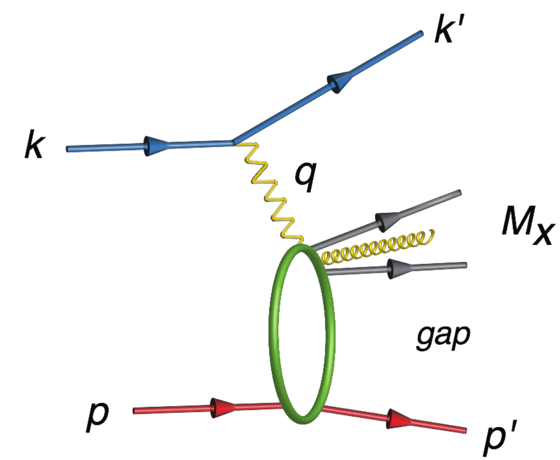
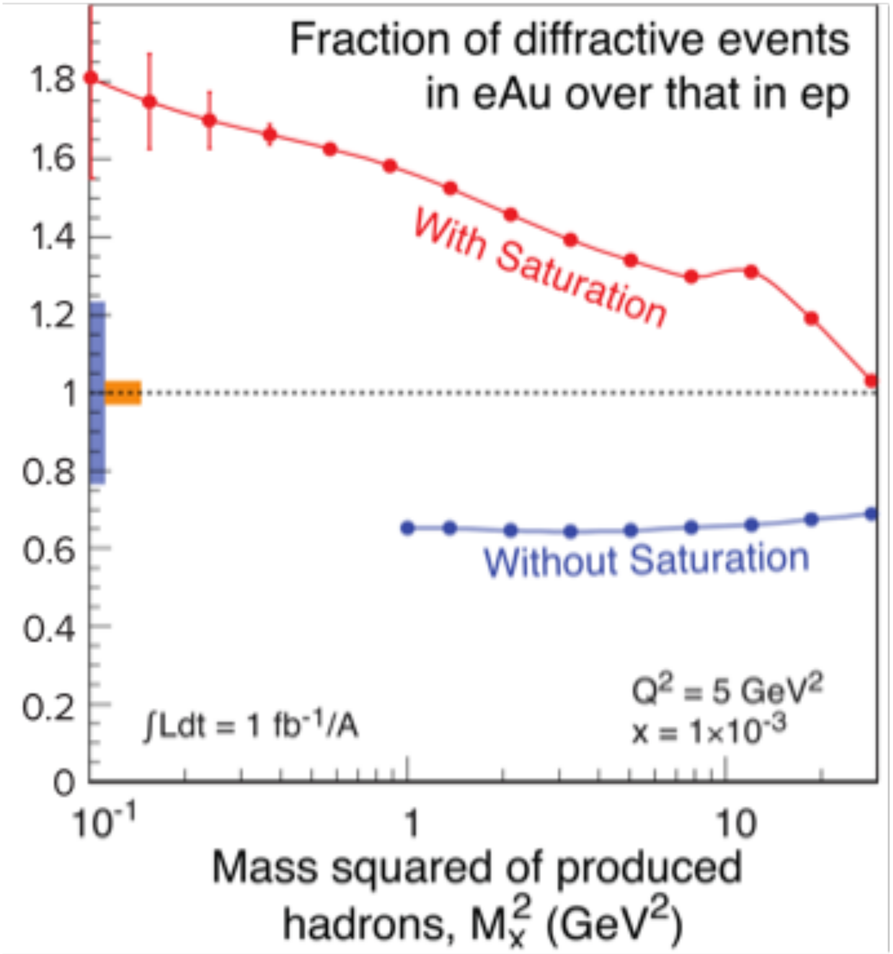
Experimental challenges being Studied.

Saturation/CGC: What to measure?

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

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





At HERA

ep: 10-15% diffractive

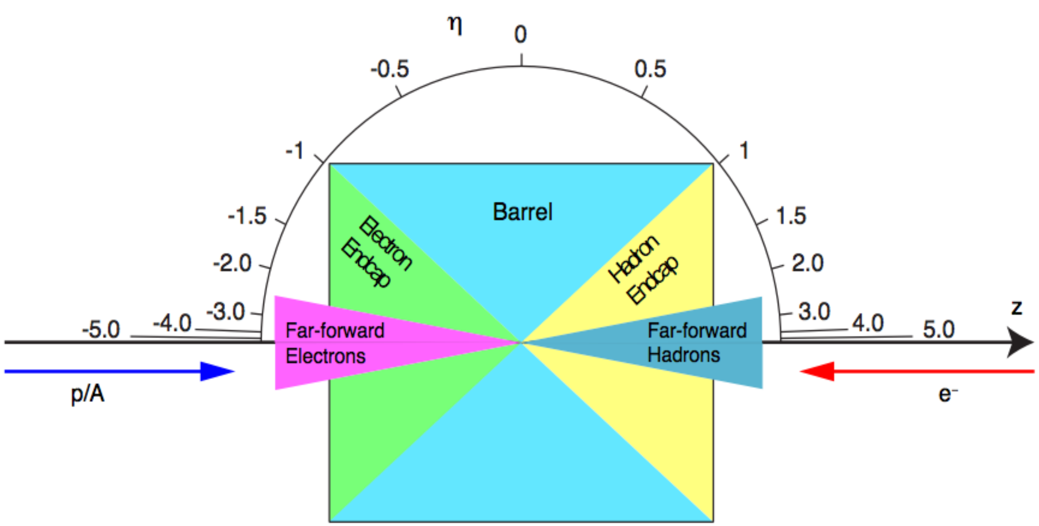
At EIC eA, if Saturation/CGC

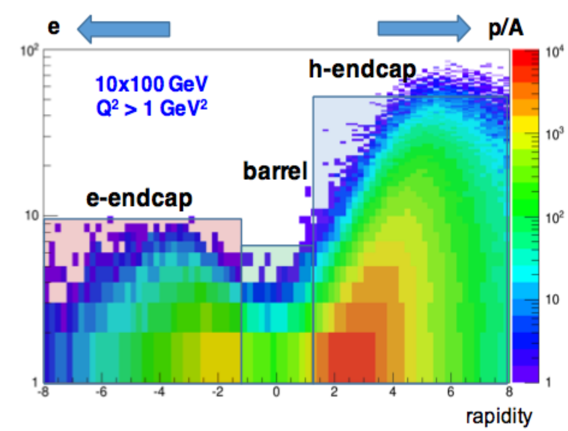
eA: 25-30% diffractive

Requirement are mostly site-independent with some slight differences in the forward region (IR integration)

In Short:

- Hermetic detector, low mass inner tracking, good PID (e and π/K/p) in wide range, calorimetry
- Moderate radiation hardness requirements, low pile-up, low multiplicity

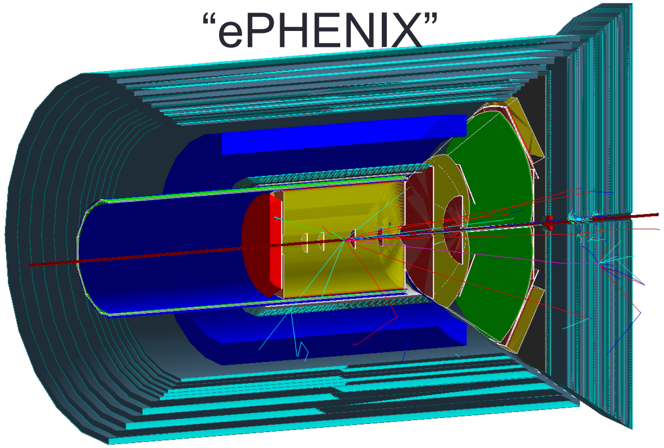




Curtesey of Thomas Ullrich

EIC Detector Concepts

EIC Detector Concepts



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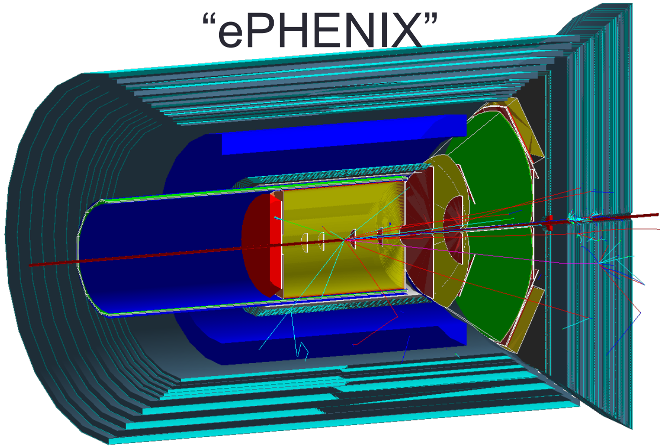
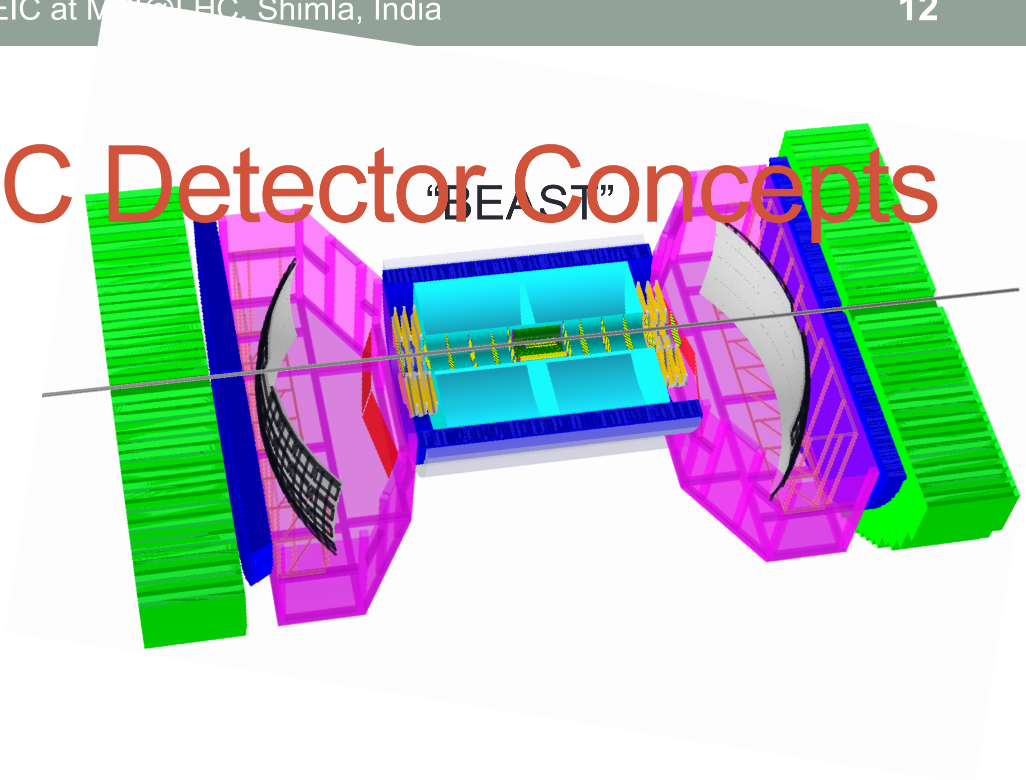
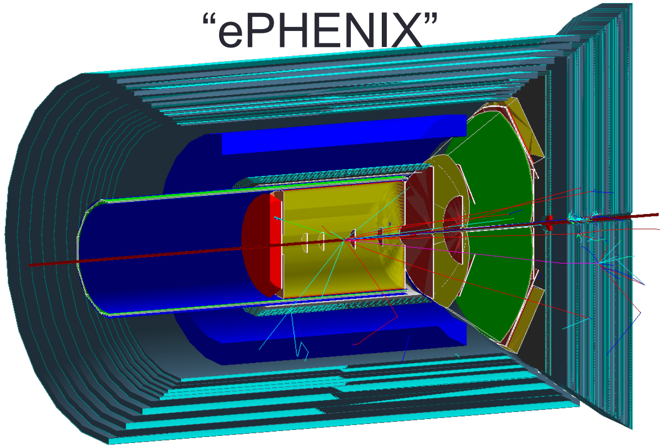


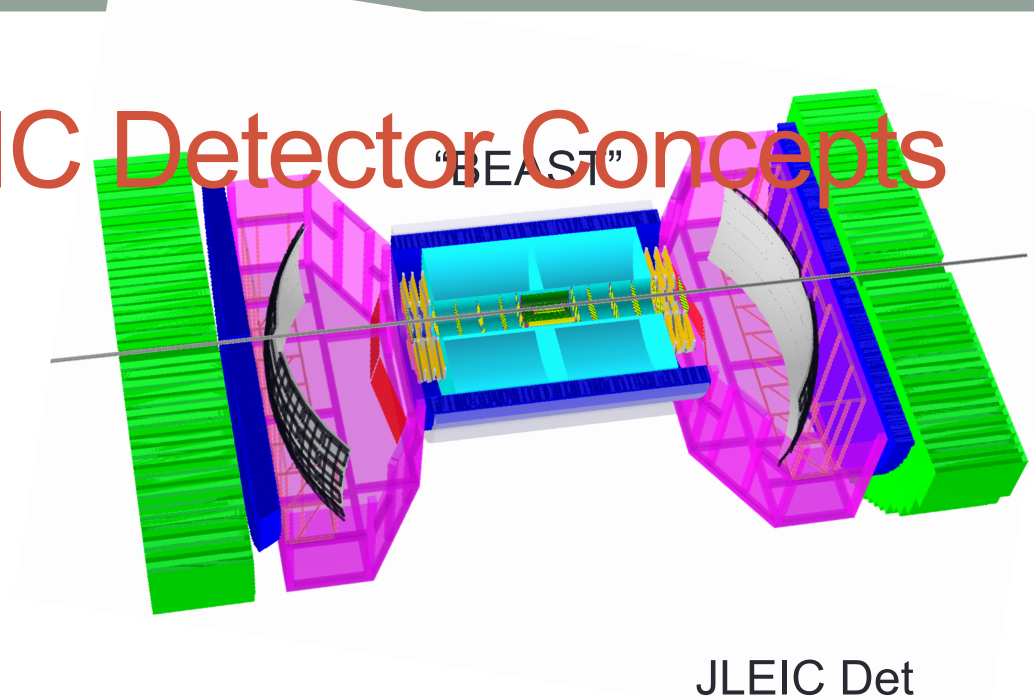


EIC Detector Concepts

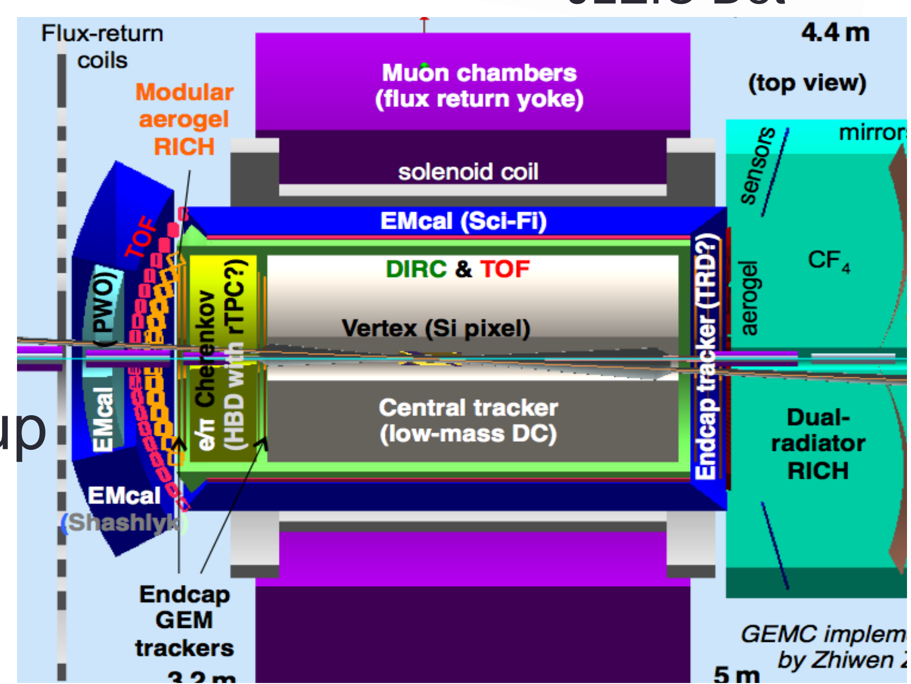
“ePHENIX”



“BEAST”



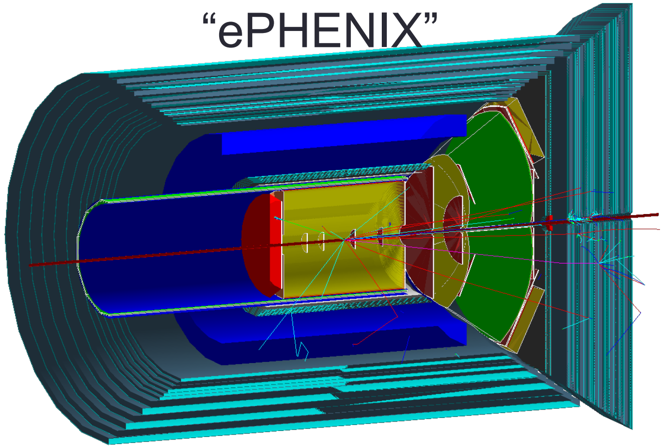
JLEIC Det



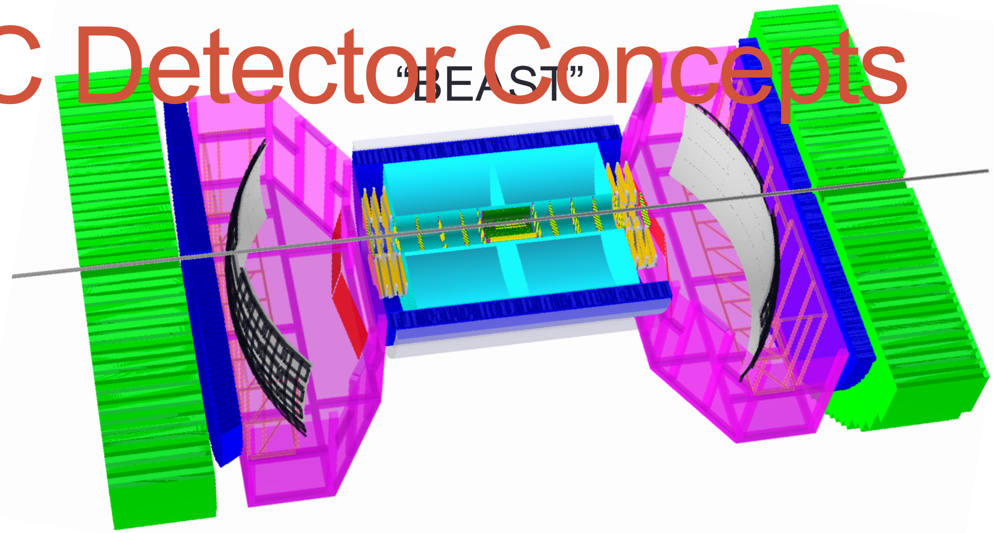
Other ideas from the Users Group are welcome! (essential!)

EIC Detector Concepts

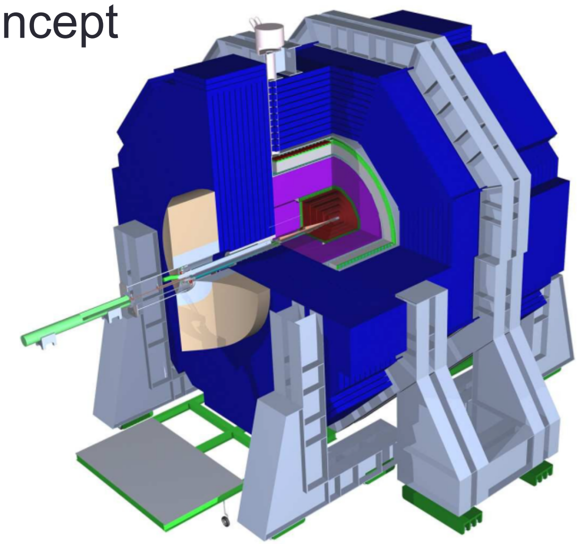
"ePHENIX"



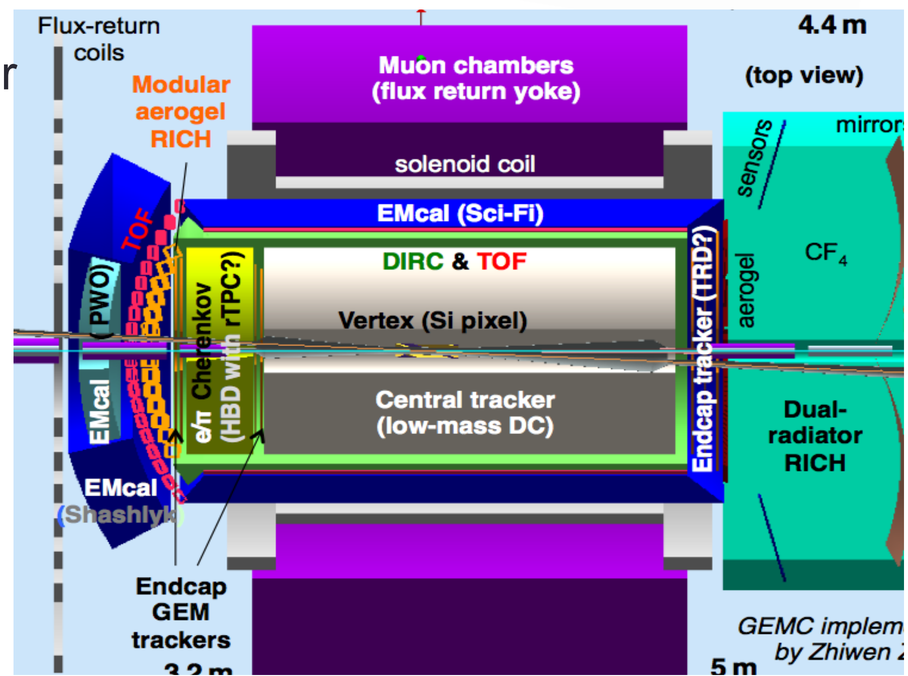
"BEAST"



ANL's: "SiEIC Detector" Si-tracker & Precision calorimetry: particle flow detecor concept



JLEIC Det



EIC Status:


Greenland
Iceland
Sweden
Russia
Ukraine
Kazakhstan
South Korea
Iraq
Iran
Algeria
Libya
Egypt
Saudi Arabia
India
Thailand
Mali
Niger
Chad
Sudan
Nigeria
Ethiopia
Kenya
DR Congo
Tanzania
Angola
Namibia
Madagascar
South Africa
Indonesia
Papua New Guinea
New Zealand
Venezuela
Colombia
Brazil
Peru
Bolivia
Argentina
North Atlantic Ocean
South Atlantic Ocean
Indian Ocean
South Pacific Ocean

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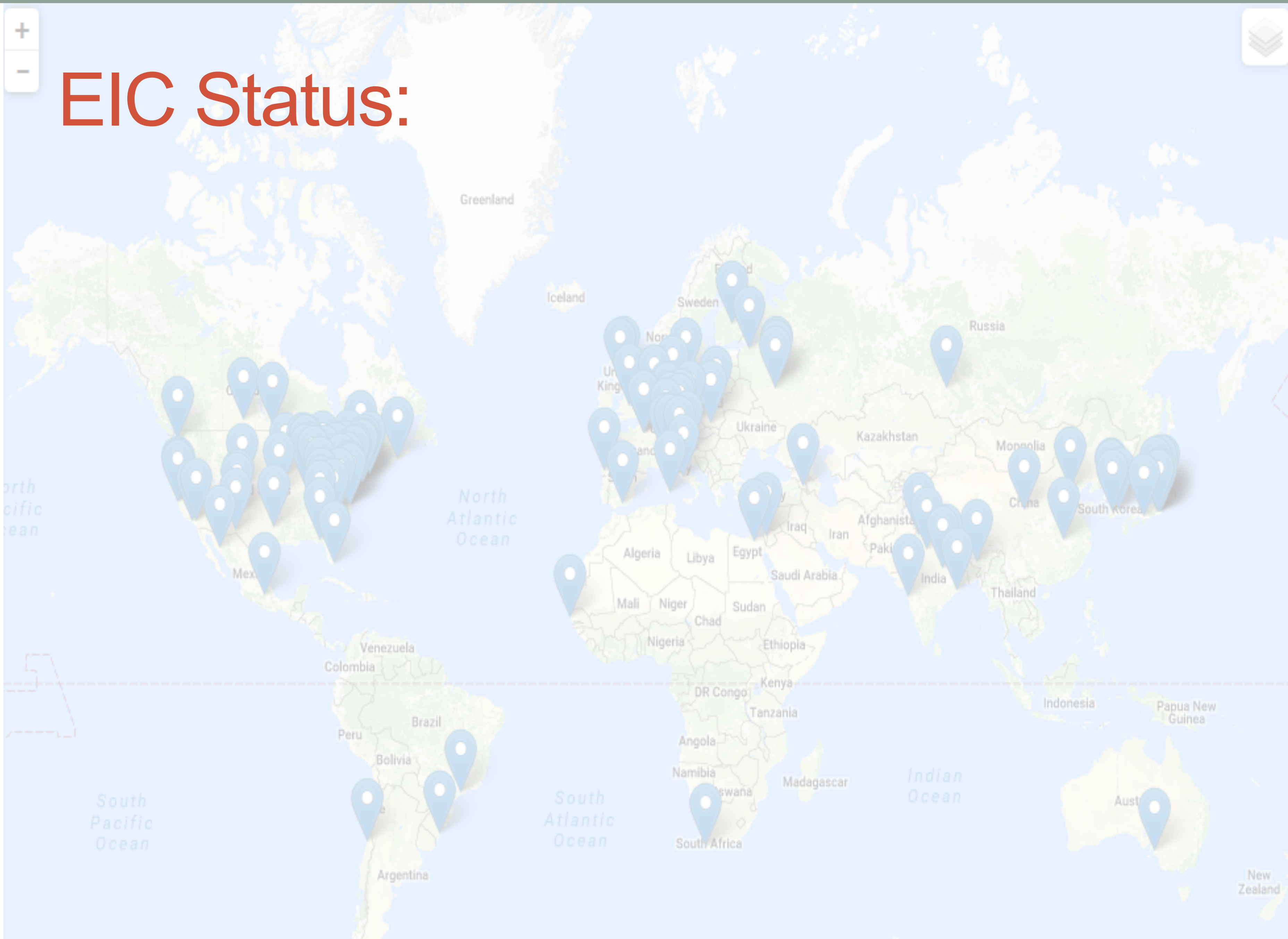
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Mali
Niger
Sudan
Chad
Nigeria
Ethiopia
Venezuela
Colombia
Kenya
DR Congo
Tanzania
Indonesia
Papua New Guinea
Brazil
Peru
Bolivia
Angola
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Madagascar
Indian Ocean
South Pacific Ocean
South Atlantic Ocean
South Africa
Argentina
New Zealand

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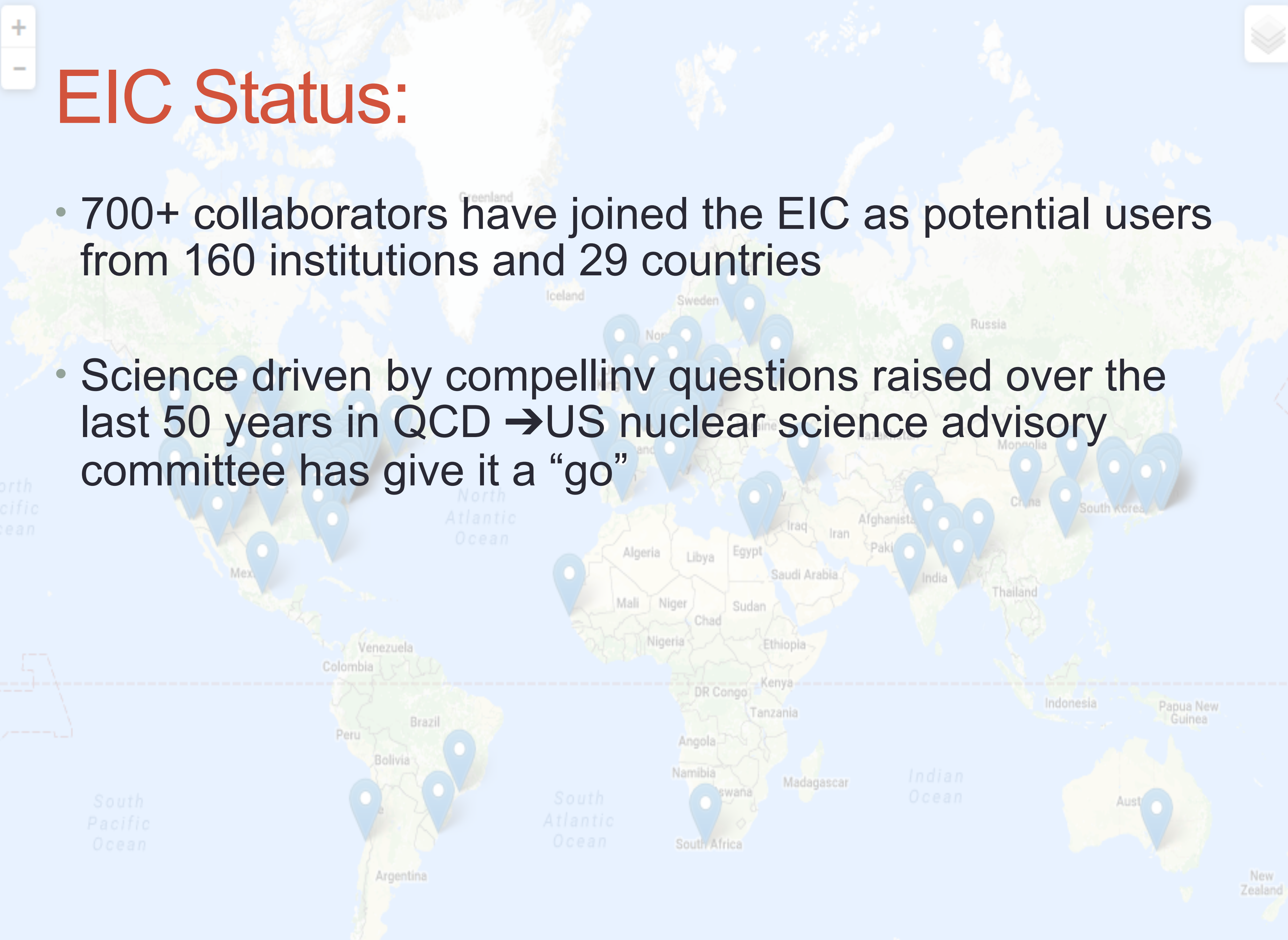

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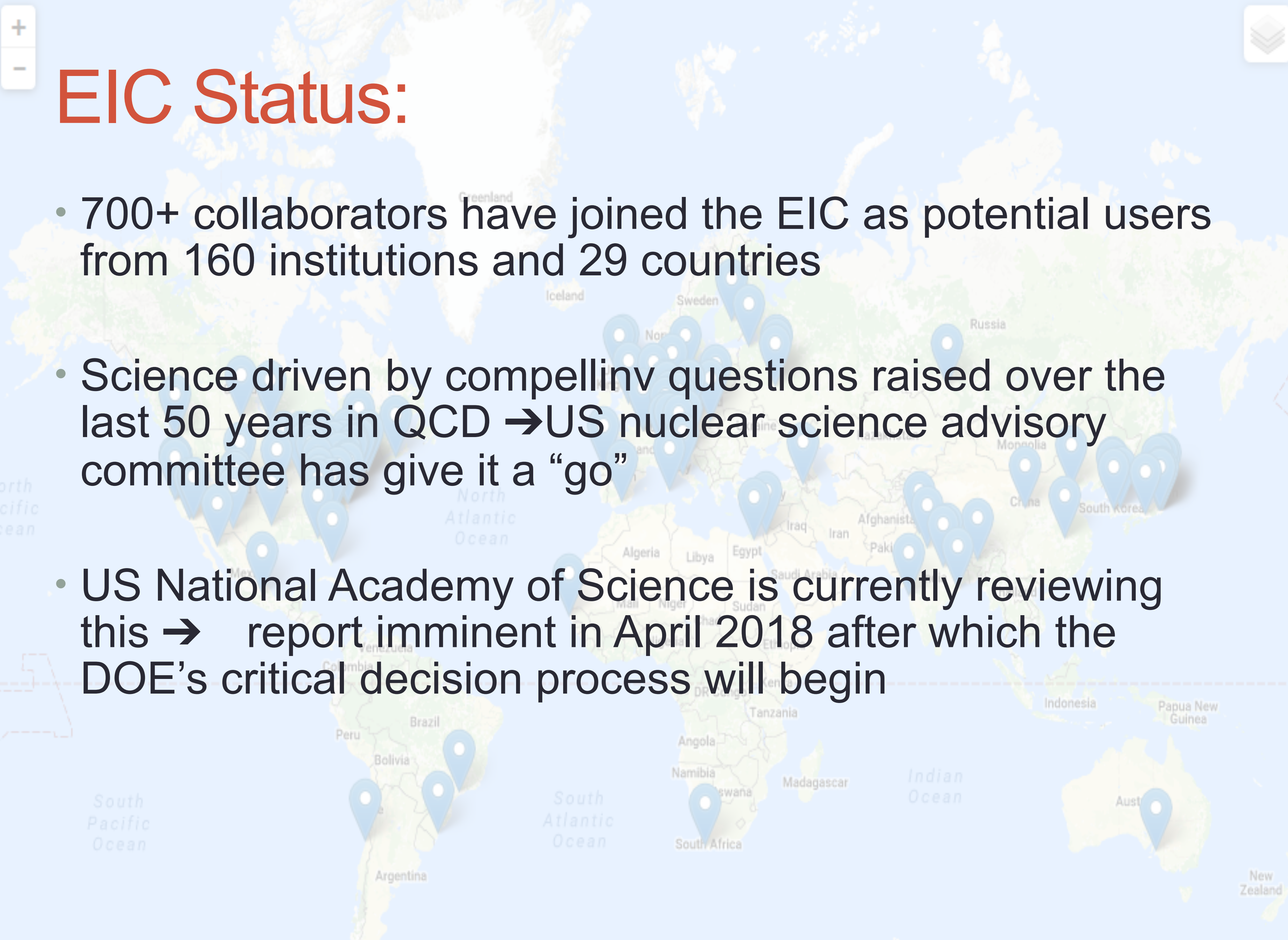

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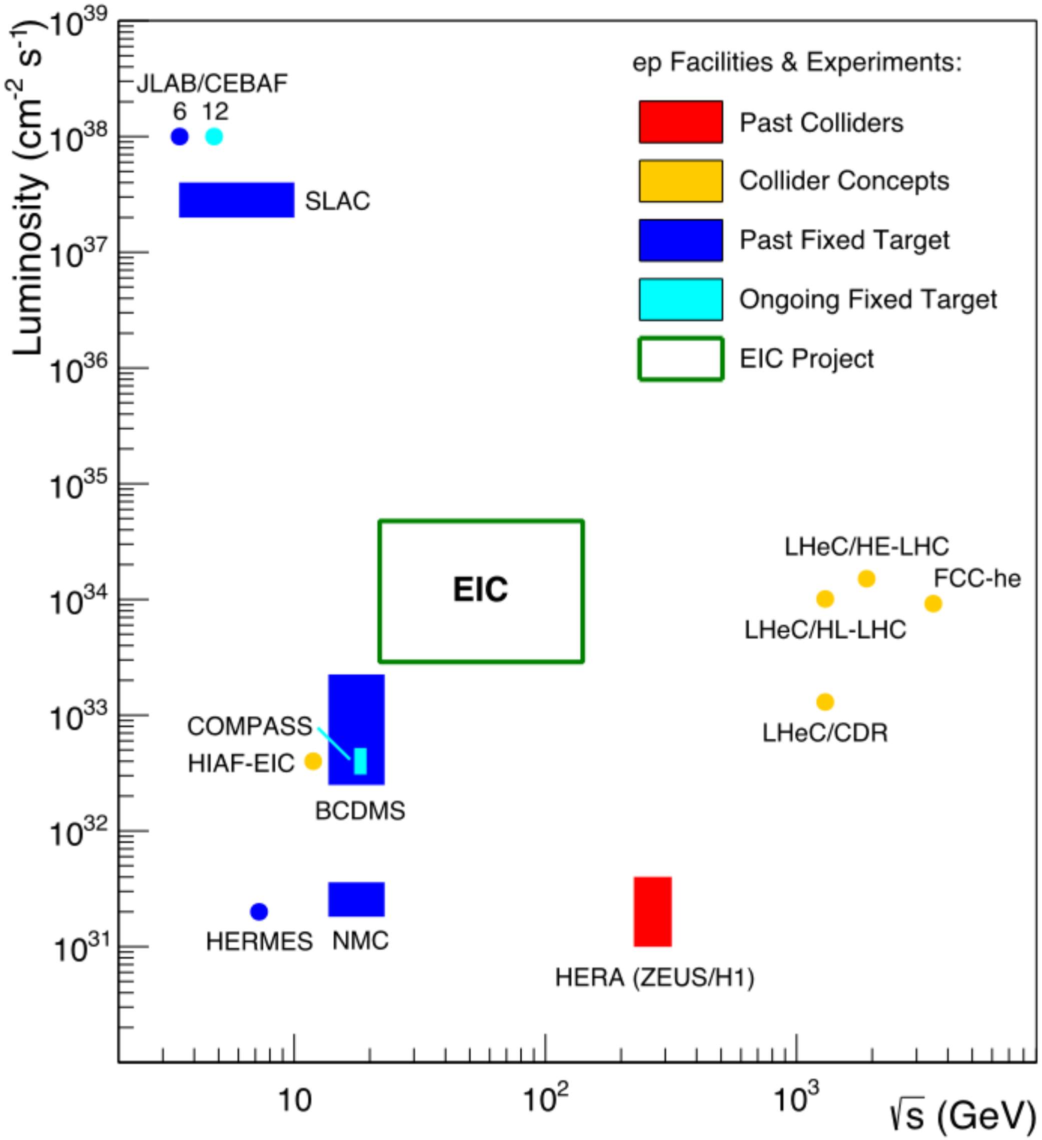
- Expect first collisions by ~2027 ➔ We are looking for good ideas and further strengthening of the science case

Thank you.

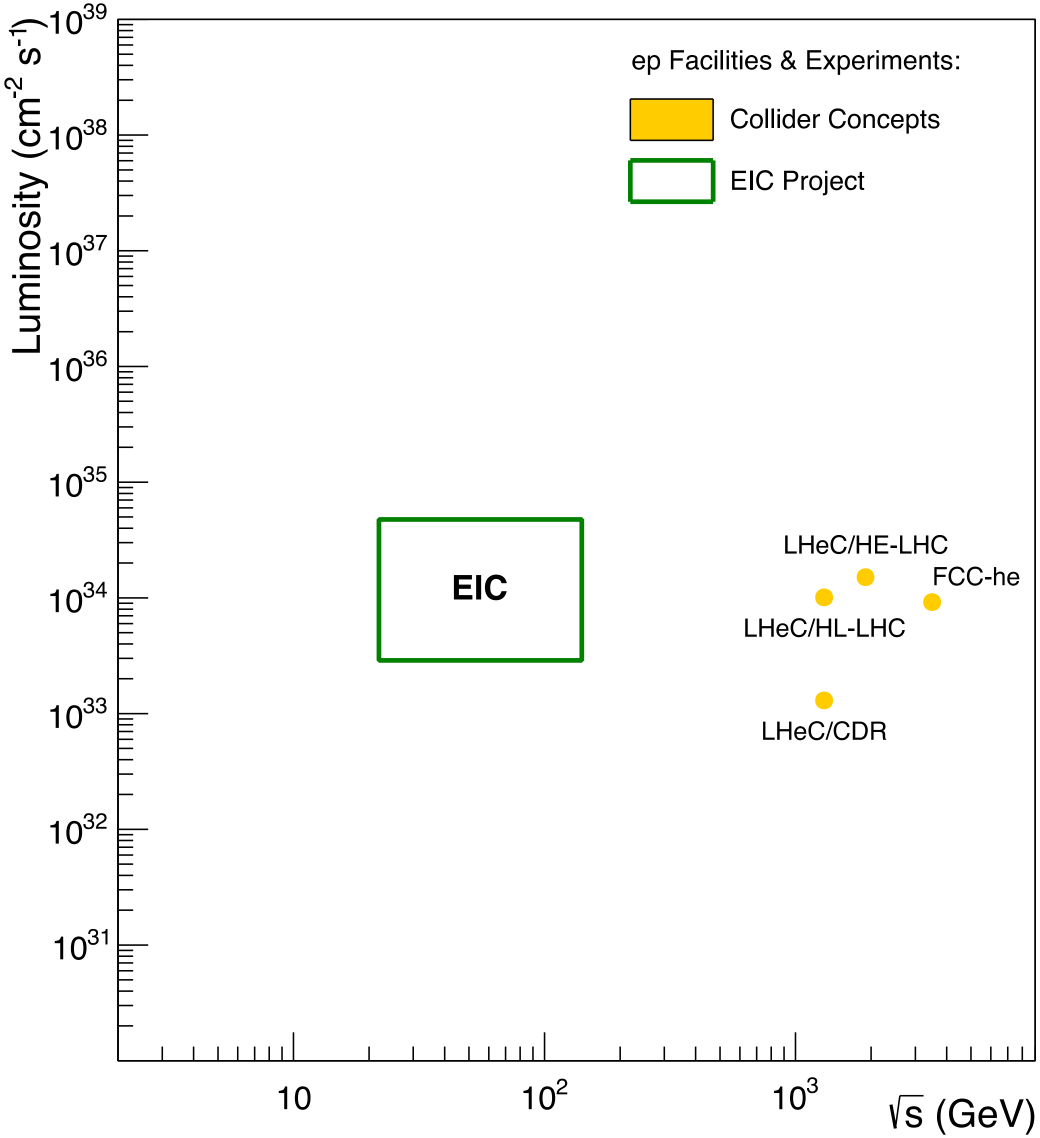
Uniqueness of EIC among all DIS Facilities



All DIS facilities in the world.

However,
if we ask for:

Uniqueness of EIC among all DIS Facilities



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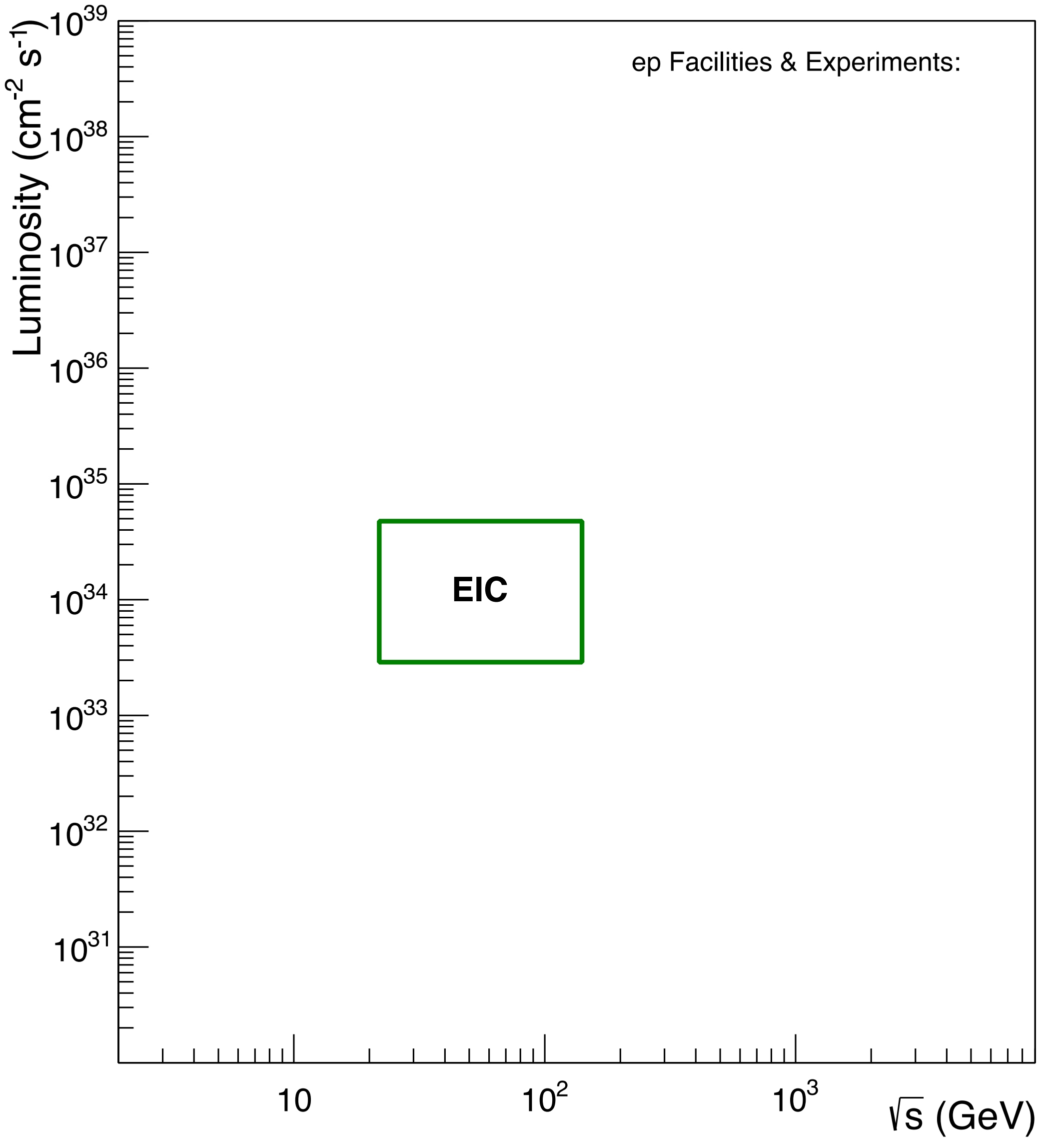
Uniqueness of EIC among all DIS Facilities



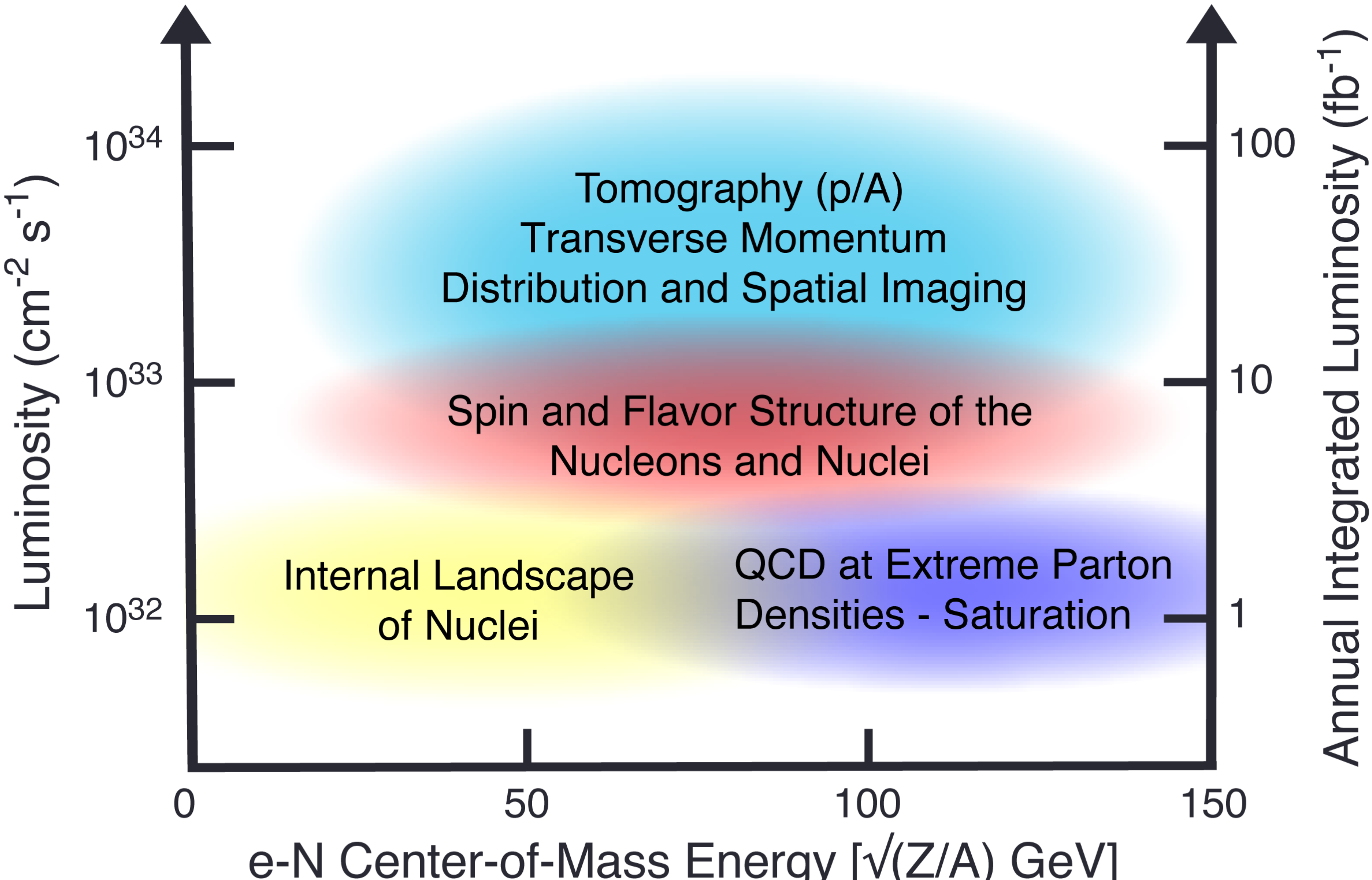
All DIS facilities in the world.

However,
if we ask for:

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

EIC stands out as unique facility …

Uniqueness of EIC among all DIS Facilities



Connections to other areas of physics

- Explorations of the stringy dynamics of hadrons led to the string theory of Gravity. A weakly coupled regime of 10-d gravity is conjectured to be dual to strongly coupled 4-d QCD-like theory. *Further profound connections may emerge from deeper investigations of the QCD landscape.*
- The dynamics *of strongly coupled cold atom gases and QCD (non-Abelian gauge fields but also strong nuclear fields) show strikingly common features*. Cold atom scientists are actively engaged in engineering cold atoms simulators of gauge field mechanism.
- Strong connections have emerged between studies of strongly correlated condensed matter systems and QCD: *topological effects arising from chiral anomaly*
- Strong field QED explores the breakdown of the QED vacuum and its nonlinear optical response in e^+e^- pair creation. *Reaching this regime is a major goal in developing high powered lasers.*