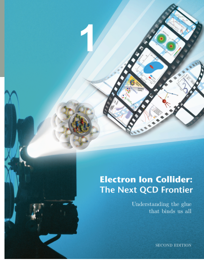
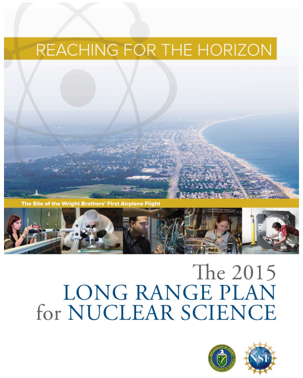


Electron Ion Collider: The next QCD frontier

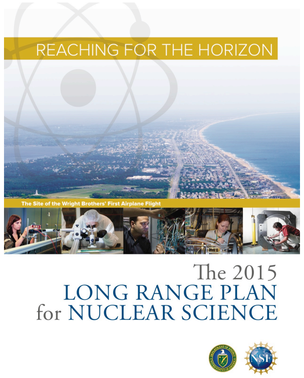
Understanding the Glue that Binds Us All

Why the EIC? ➔ "Gluon Imaging"
To understand the role of gluons in binding quarks & gluons into Nucleons and Nuclei



RECOMMENDATION:

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



Stony Brook University
Abhay Deshpande
BROOKHAVEN NATIONAL LABORATORY

QCD: The Holy Grail of Quantum Field Theories

- QCD : “nearly perfect” theory that explains nature’s strong interactions, is a fundamental quantum theory of quarks and gluon fields
- QCD is rich with symmetries

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(1) (2) (3)

(1) Gauge "color" symmetry : unbroken but confined
(2) Global "chiral" flavor symmetry: exact for massless quarks
(3) Baryon number and axial charge (massless quarks) conservation
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- Chiral, Axial, Scale & P&T symmetries broken by quantum effects: Most of the visible matter in the Universe emerges as a result

- Inherent in QCD are the deepest aspects of relativistic quantum field theories: (confinement, asymptotic freedom, anomalies, spontaneous breaking of chiral symmetry) ➔ all depend on non-linear dynamics in QCD

Non-linear Structure of QCD: Fundamental Consequences

- Quark (Color) confinement:
  - Consequence of nonlinear gluon self-interactions
  - Unique property of the strong interaction

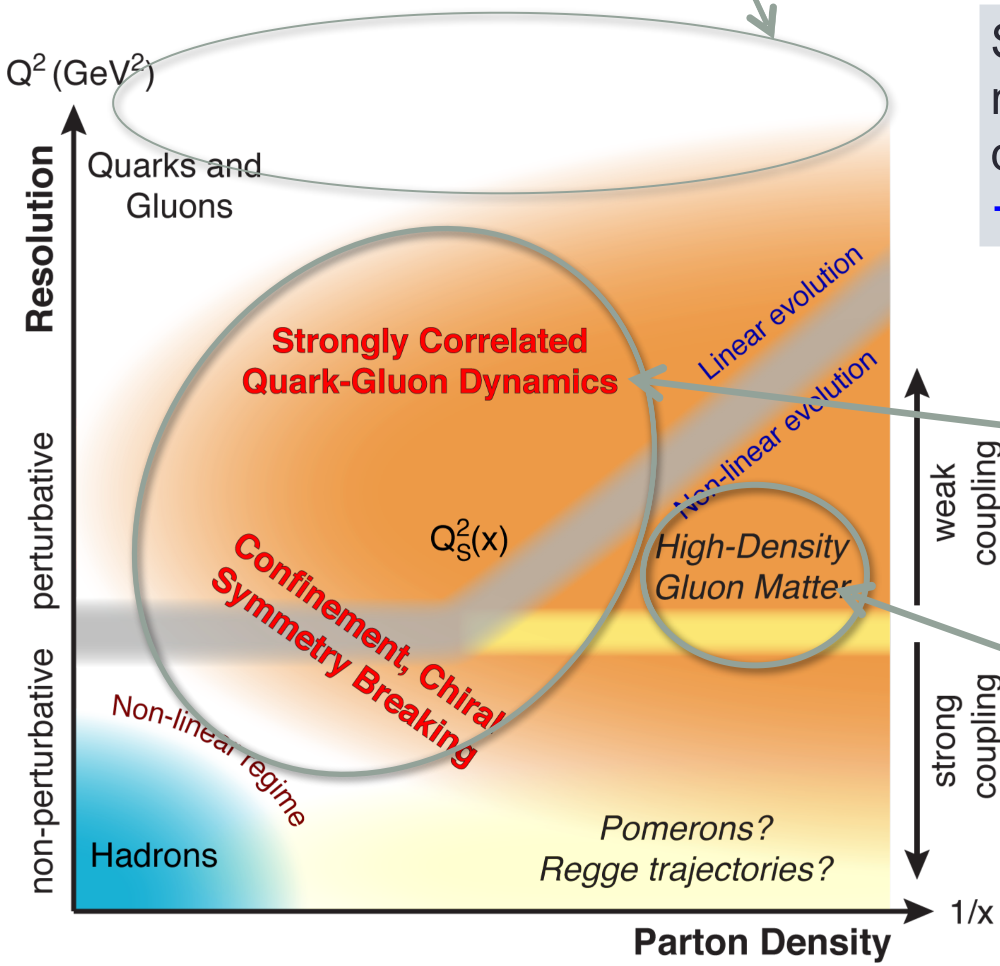
- Strong Quark-Gluon Interactions:
  - Confined motion of quarks and gluons – Transverse Momentum Dependent Parton Distributions (TMDs)
  - Confined spatial correlations of quark and gluon distributions – Generalized Parton Distributions (GPDs)

- Ultra-dense color (gluon) fields:
  - Is there a universal many-body structure due to ultra-dense color fields at the core of **all** hadrons and nuclei?

All expected to be under the "femtoscope" called the EIC

QCD Landscape to be explored by EIC

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



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

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

Emergent Dynamics in QCD

Without gluons,* *there would be no nucleons,

no atomic nuclei… no visible world!

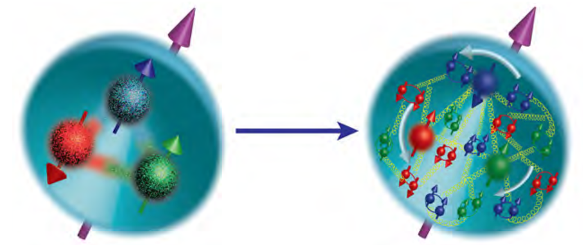
- Massless gluons & almost massless quarks, *through their interactions,* generate most of the mass of the nucleons
- Gluons carry ~50% of the proton's momentum, a significant fraction of the nucleon's spin, and are essential for the dynamics of confined partons
- Properties of hadrons are emergent phenomena resulting not only from the equation of motion but are also inextricably tied to the properties of the QCD vacuum. Striking examples besides confinement are spontaneous symmetry breaking and anomalies
- The nucleon-nucleon forces emerge from quark-gluon interactions: how this happens remains a mystery

Experimental insight and guidance crucial for complete understanding of *how* hadrons & nuclei emerge from quarks and gluons

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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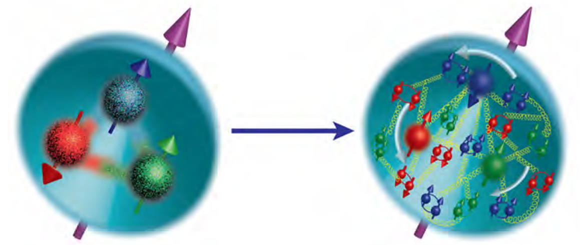

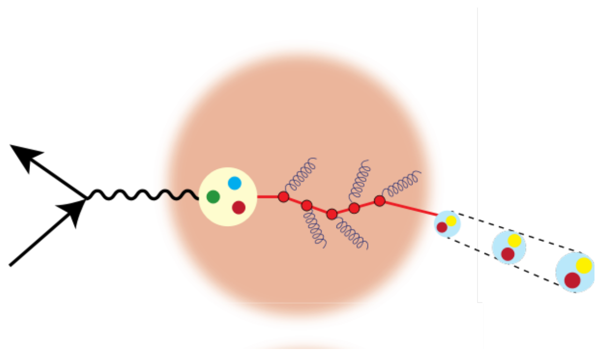

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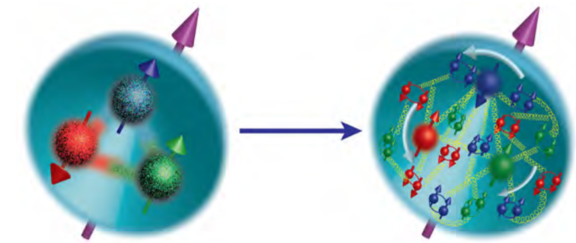

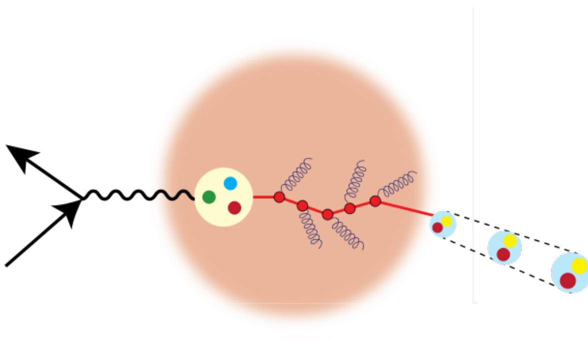

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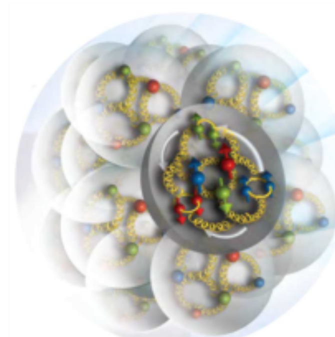
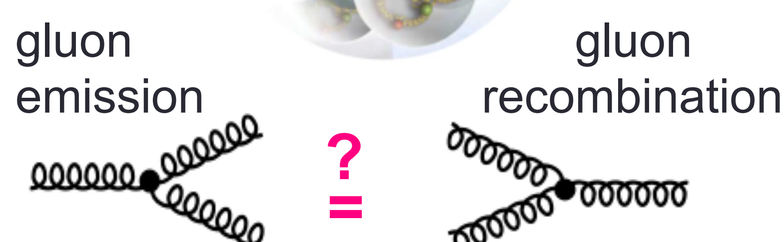


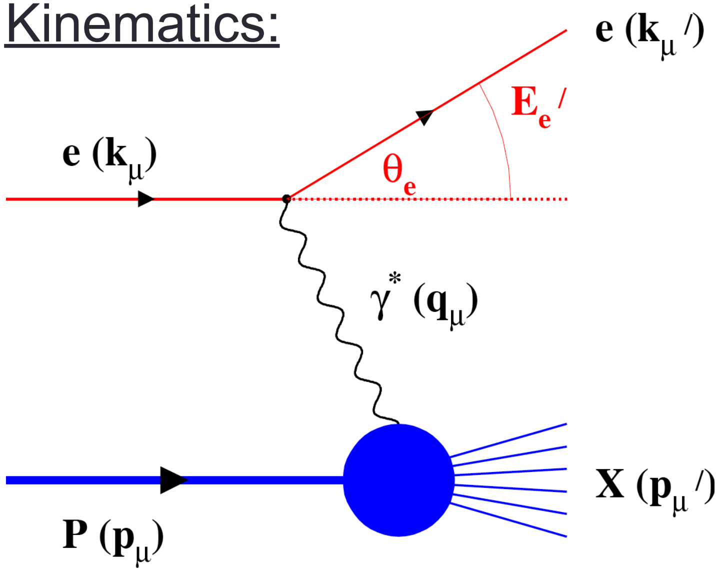
How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

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?



Deep Inelastic Scattering brings Precision

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 :

$$z = \frac{E_h}{\nu};\ p_t \text{ with respect to } \gamma$$

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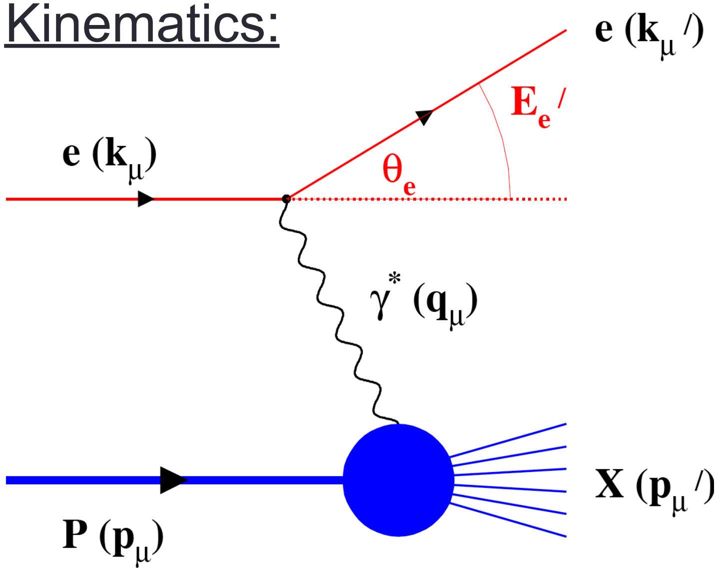

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Inclusive measurements:

e+p/A → e'+X

Detect only the scattered lepton in the detector

Semi-inclusive measurements:

e+p/A → e'+h(π,K,p,jet)+X

Detect the scattered lepton in coincidence with identified hadrons/jets

Exclusive measurements:

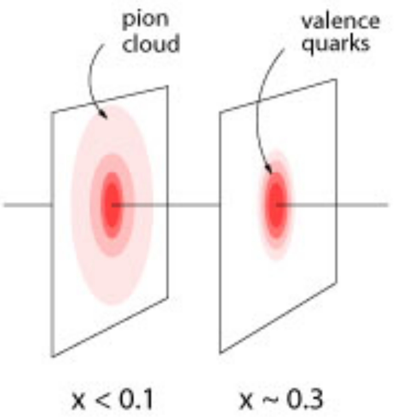
e+p/A → e'+h(π,K,p,jet)+p'/A'

Detect scattered lepton, identify produced hadrons/jets and measure target remnants

What does a proton look like with increasing energy?

One of several possible scenarios: a pion cloud model

A parton core in the proton gets increasingly surrounded by a meson cloud with decreasing x
→ large impact on gluon and sea-quark observables



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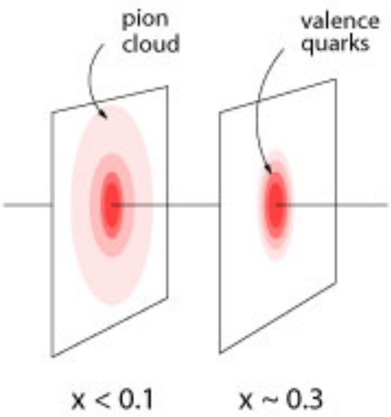

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What do we expect to see:

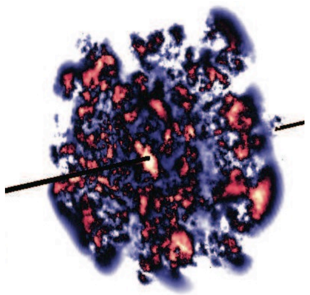
- ❑ $q\bar{q}$ pairs (sea quarks) generated at small(ish)-x are predicted to be unpolarized
- ❑ gluons generated from sea quarks are unpolarized

→ needed:

- ➢ high precision measurement of flavor separated polarized quark and gluon distributions as functions of x
- ➢ high precision spatial imaging: Gluon radius ~ sea-quark radius ?

What happens in the gluon dominated small-x regime?

- ➢ possible scenario: lumpy glue



EIC needs to and will explore the dynamical spatial structure of hadrons

Gluon and the consequences of its interesting properties:

Gluons carry color charge ➔ Can interact with other gluons!

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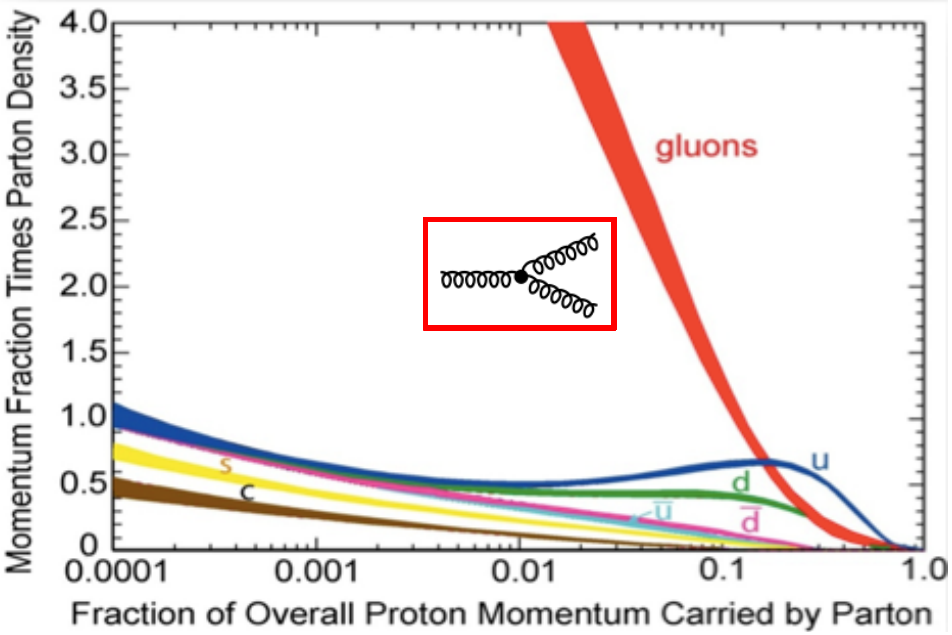

Apparent "indefinite rise" in gluon distribution in proton!

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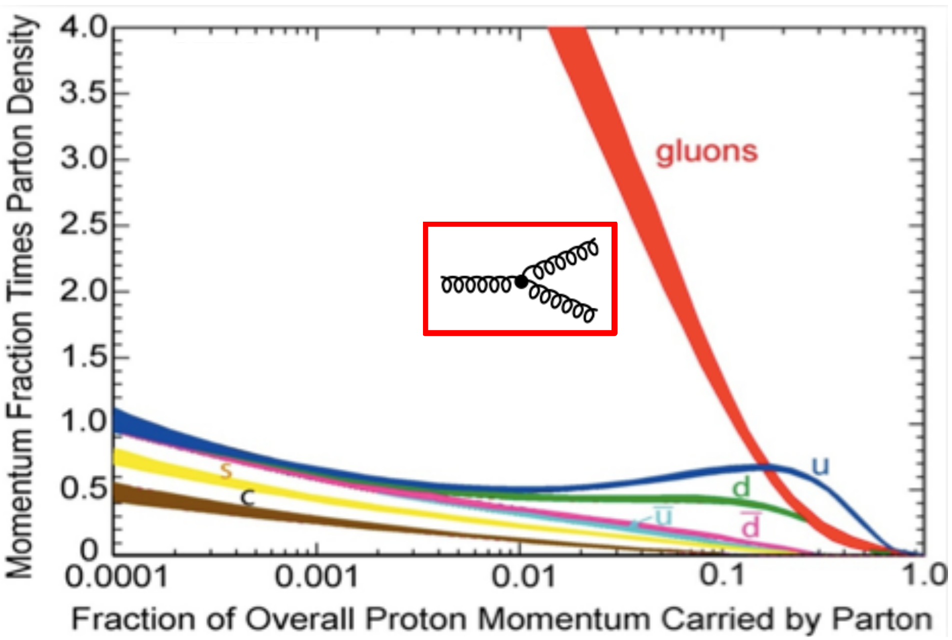

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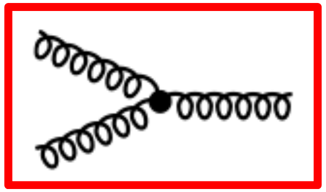
What could **limit this indefinite rise?** → saturation of soft gluon densities via gg→g recombination must be responsible.

recombination

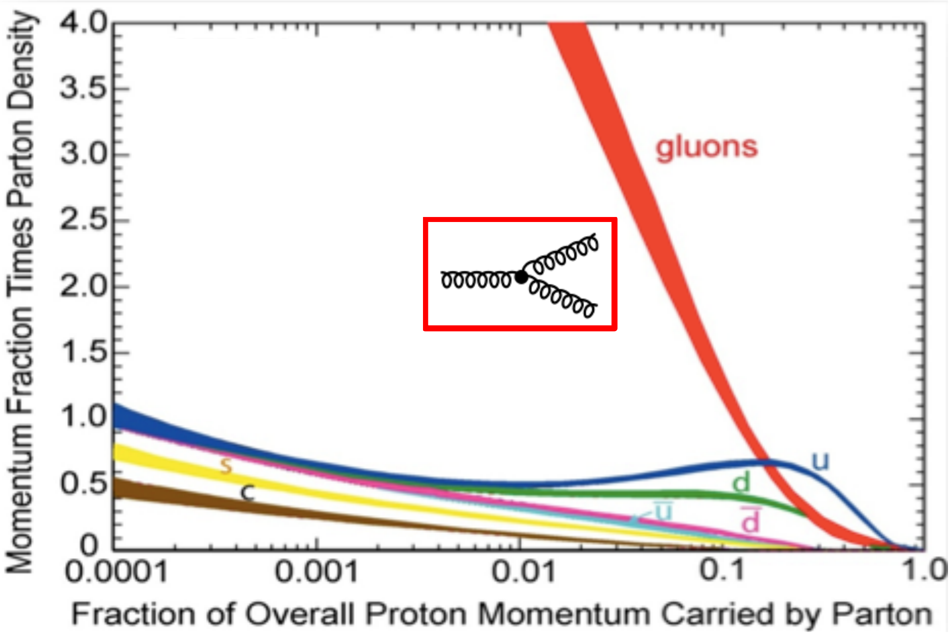


Gluon and the consequences of its interesting properties:

QCD Terra-incognita!

High Potential for Discovery

Gluons carry color charge → Can interact with other gluons!



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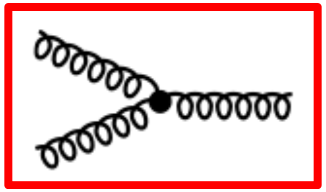


Where? No one has unambiguously seen this before!

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

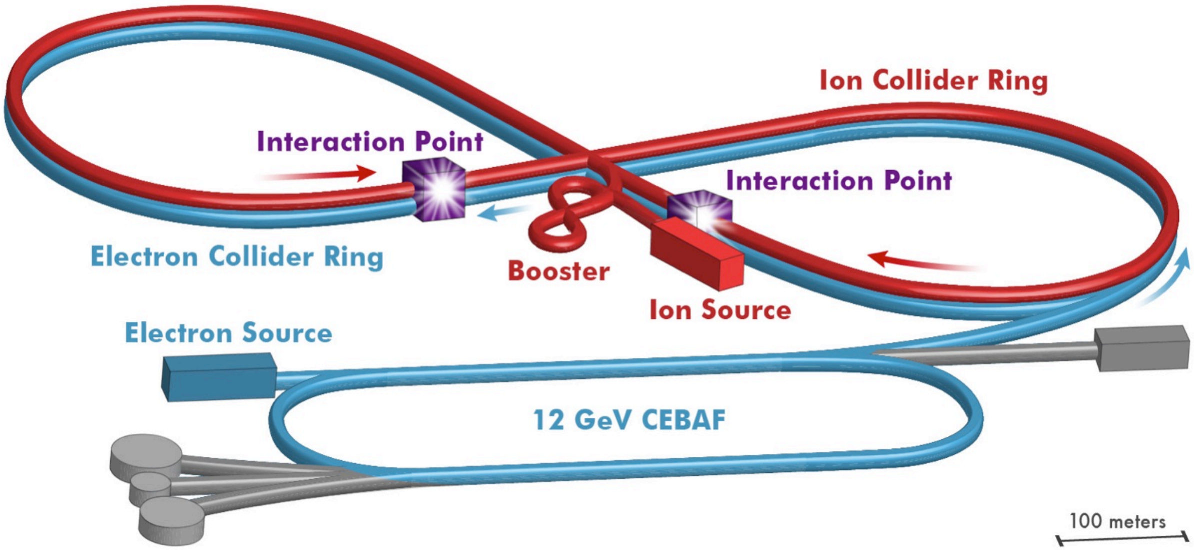
The Electron Ion Collider

Two proposals being pursued in the US

-- eRHIC at Brookhaven National Laboratory

-- JLEIC at Jefferson National Laboratory

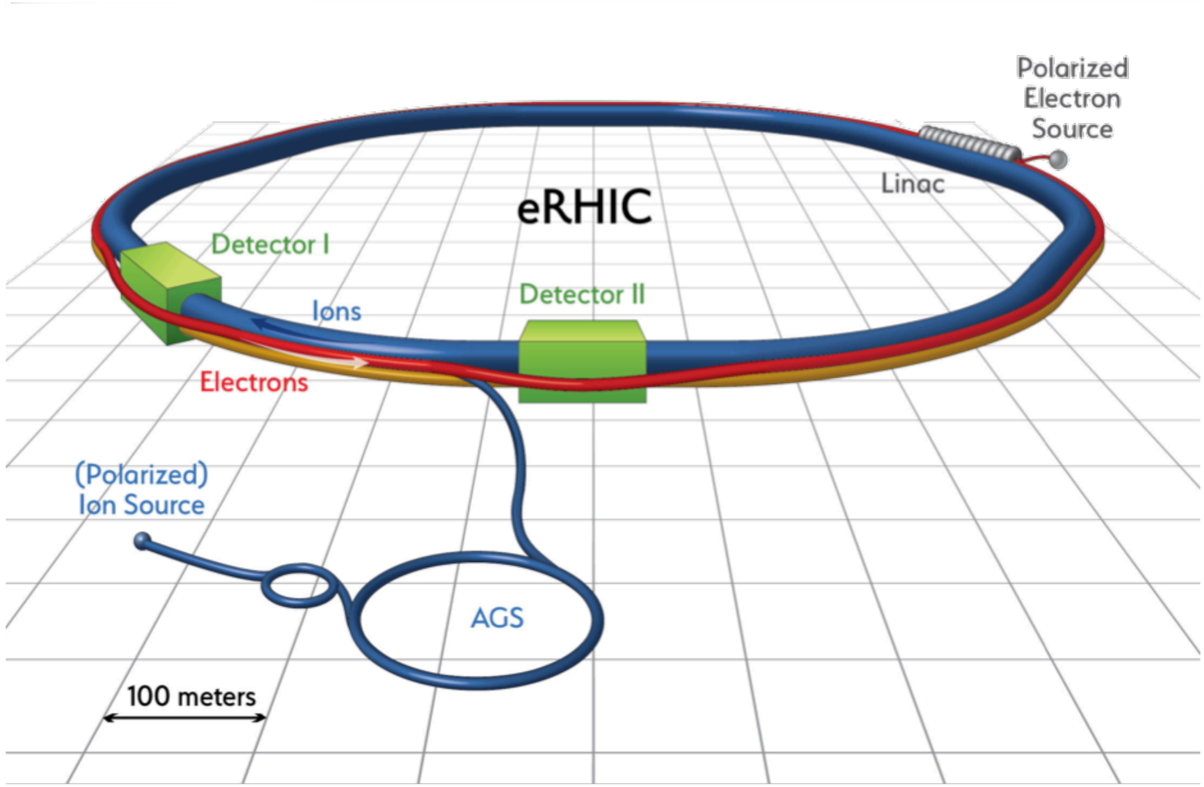
JLEIC at Jefferson Laboratory (Newport News, VA)



- Use existing CEBAF for polarized electron injector
- Figure 8 Layout: Optimized for high ion beam polarization → polarized deuterons
- Energy Range: √s : 20 to 65 - 140 GeV (magnet technology choice)
- Fully integrated detector/IR
- JLEIC achieves initial high luminosity, with technology choice determining initial and upgraded energy reach

eRHIC at BNL

Upton, NY



- Use existing RHIC
  - Up to 275 GeV protons
  - Existing: tunnel, detector halls & hadron injector complex
- Add 18 GeV electron accelerator in the same tunnel
  - Use either high intensity Electron Storage Ring or Energy Recovery Linac
- Achieve high luminosity, high energy e-p/A collisions with full acceptance detector
- Luminosity staging possible and may be required

The Electron Ion Collider

For e-N collisions at the EIC:

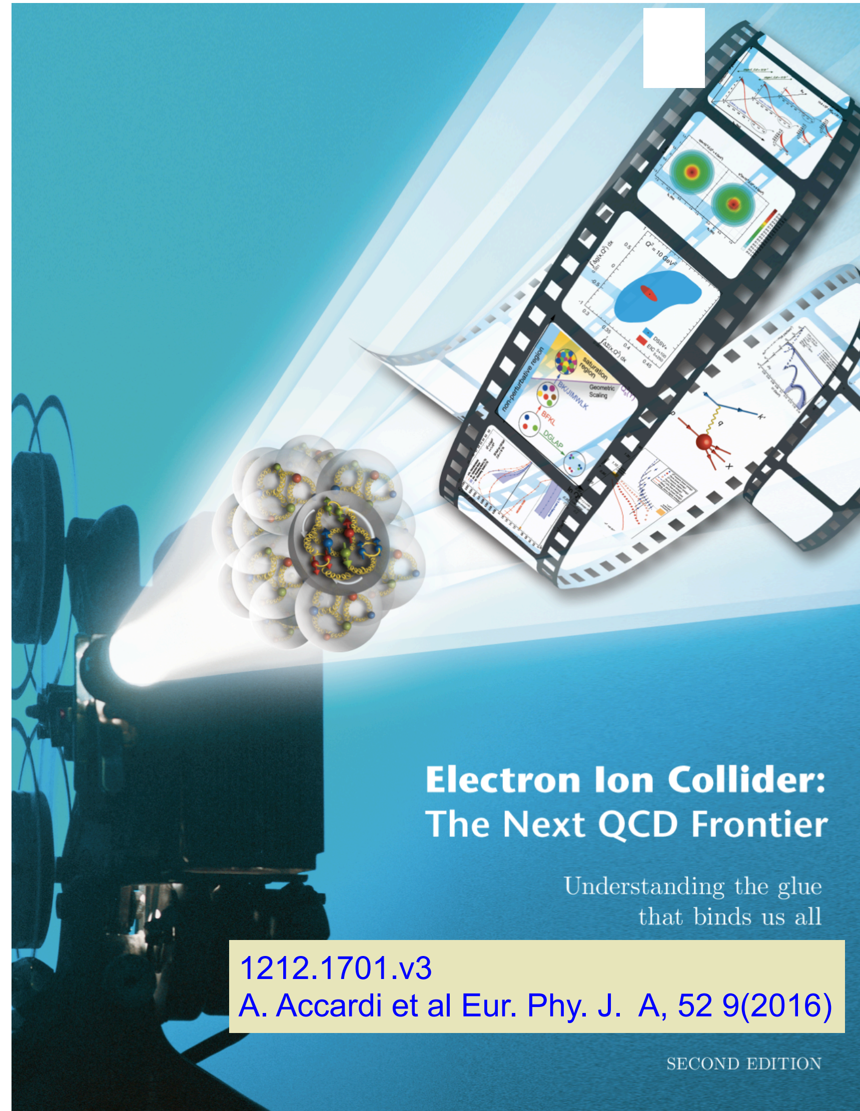
- ✓ Polarized beams: e, p, d/^{3}He
- ✓ e beam 5-10(20) GeV
- ✓ Luminosity L_{ep} ~ 10^{33-34} $cm^{-2}sec^{-1}$
  100-1000 times HERA
- ✓ 20-100 (140) GeV Variable CoM

For e-A collisions at the EIC:

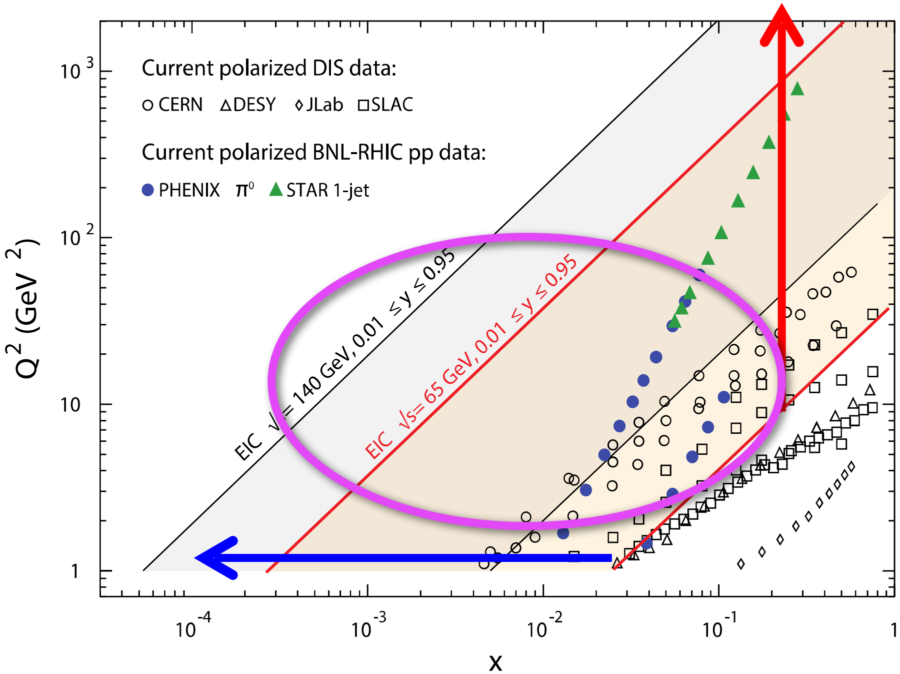
- ✓ **Wide range in nuclei**
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy

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

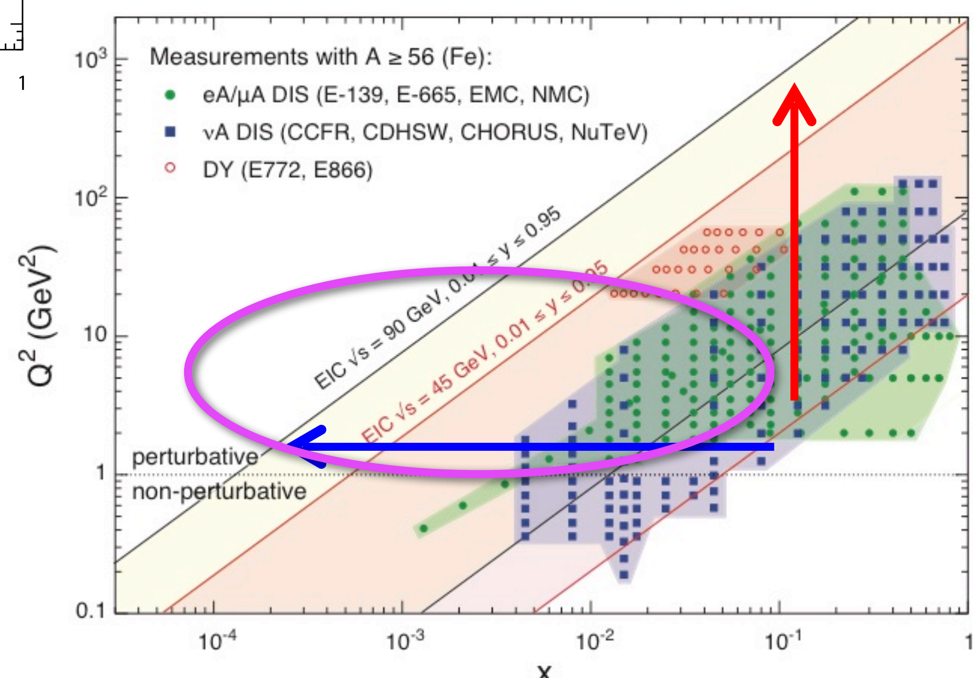


For e-N collisions at the EIC:

- ✓ **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

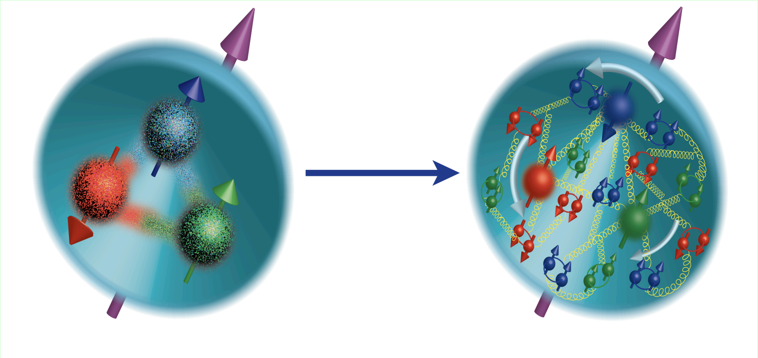
For e-A collisions at the EIC:

- ✓ **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)



The world's first polarized electron-proton collider

Polarized proton as a laboratory for QCD



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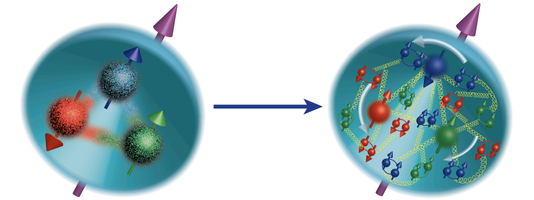


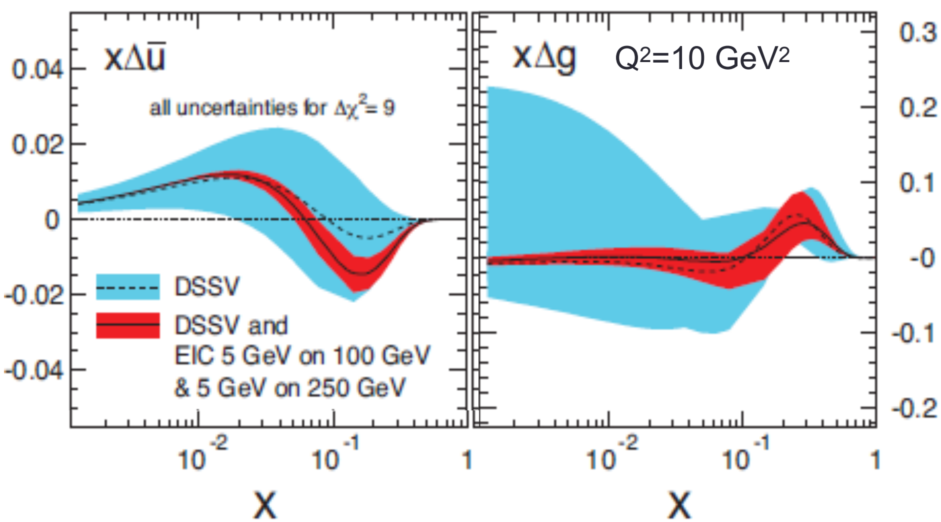
Understanding Nucleon Spin

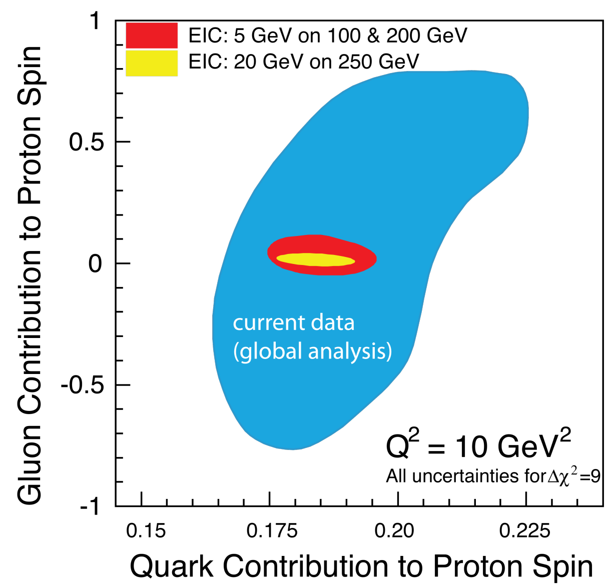
"Helicity sum rule"

$$\frac{1}{2}\hbar = \frac{1}{2}\Delta\Sigma + \Delta G + \sum_q L_q^z + L_g^z$$

- $\frac{1}{2}\Delta\Sigma$: quark contribution
- ΔG: gluon contribution
- $\sum_q L_q^z + L_g^z$: orbital angular momentum

EIC projected measurements:
precise determination of polarized PDFs of quark sea and gluons ➔ precision ΔG and $\Delta\Sigma$
→ A clear idea of the magnitude of $\sum L_q + L_g$





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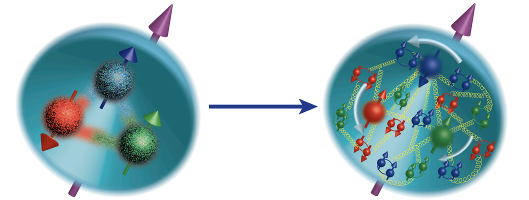

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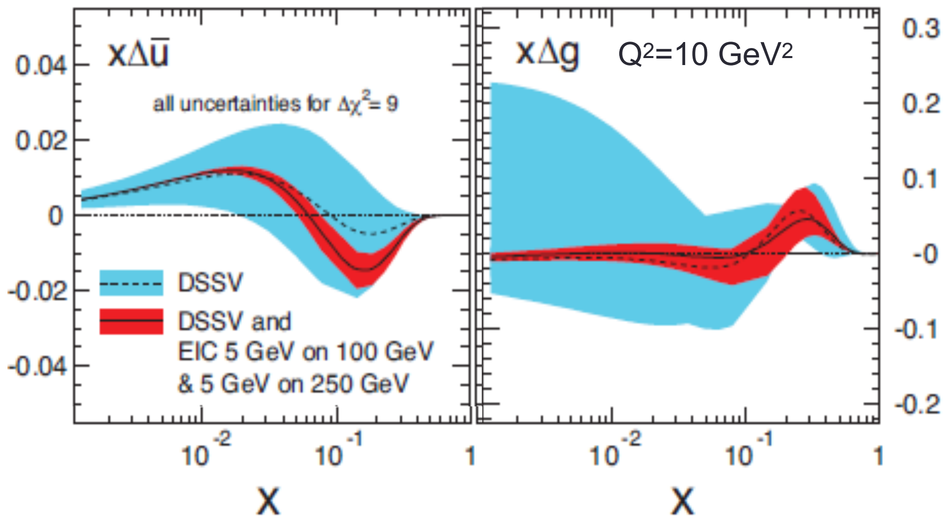
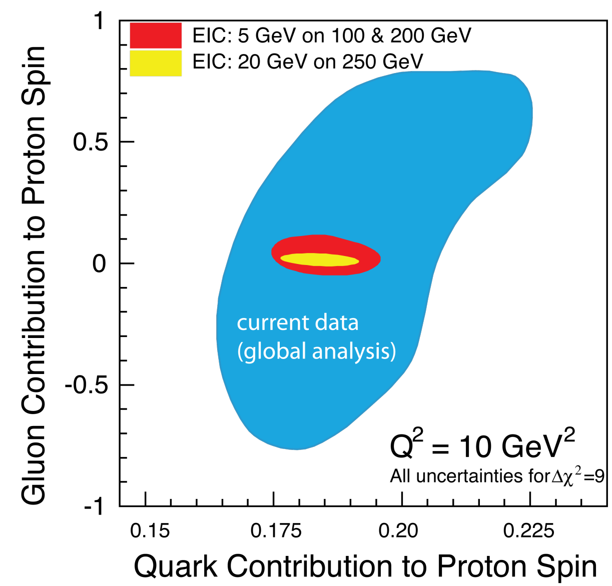
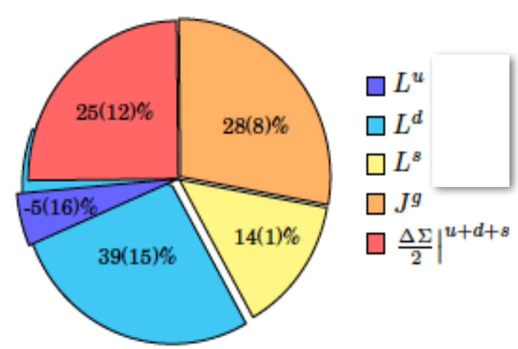




Spin and Lattice: Recent Activities

- **Gluon's spin contribution on Lattice: S_G = 0.5(0.1)**
  Yi-Bo Yang et al. PRL **118**, 102001 (2017)
- **J_q calculated on Lattice QCD:**
  [illegible]QCD Collaboration, PRD91, 014505, 2015

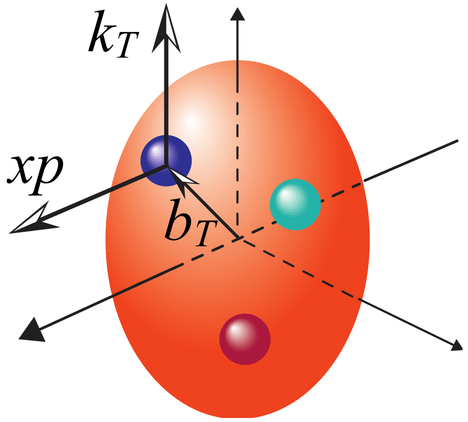


3-Dimensional Imaging Quarks and Gluons

Wigner functions $W(x,b_T,k_T)$

offer unprecedented insight into confinement and chiral symmetry breaking.

$$W(x,b_T,k_T)$$



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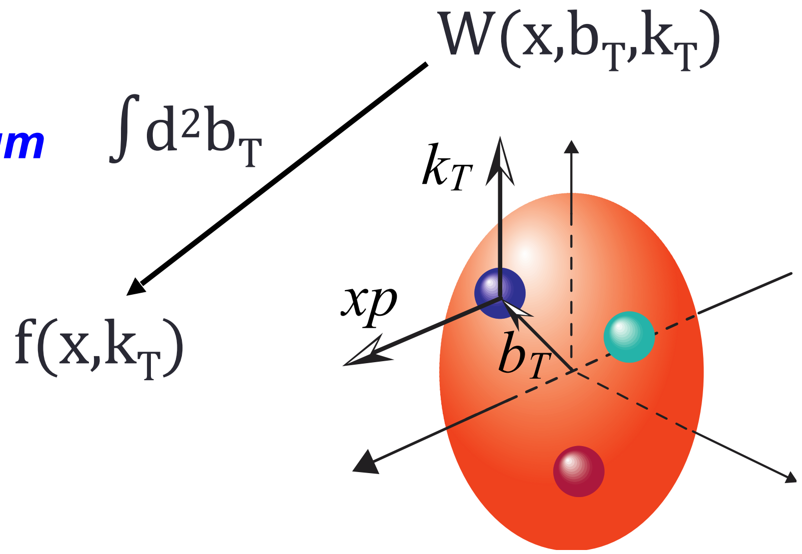
Momentum space



Spin-dependent 3D momentum space images from semi-inclusive scattering → **TMDs**

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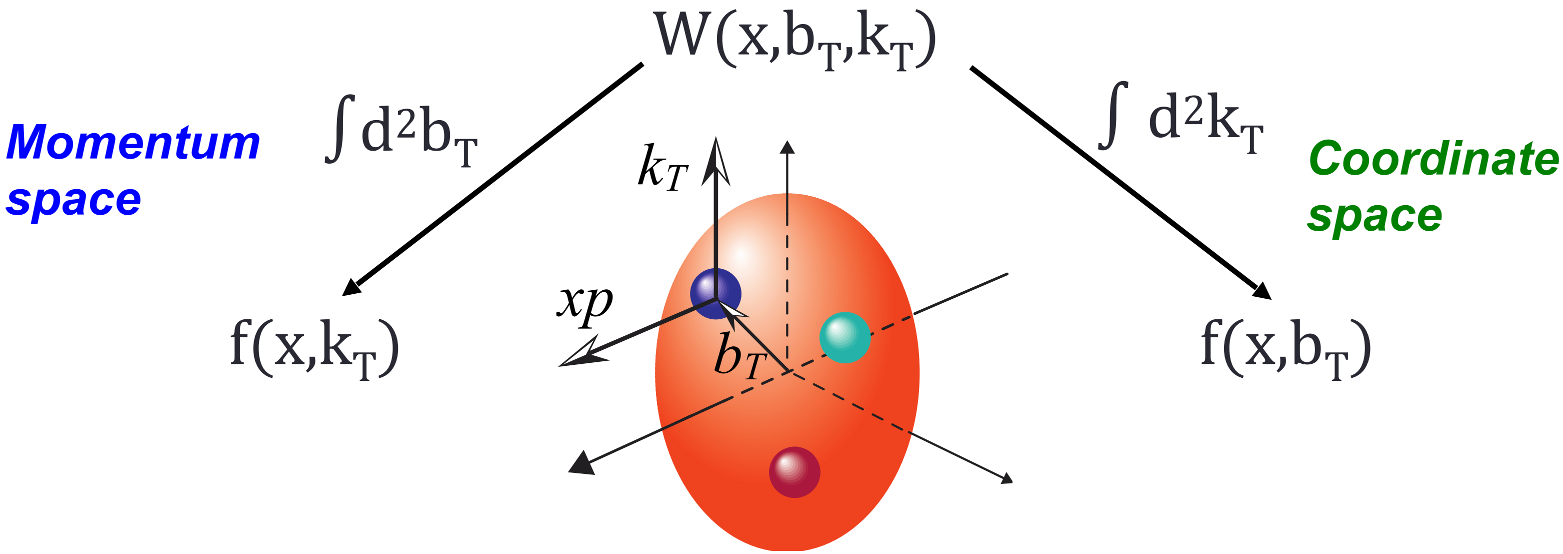

Spin-dependent 3D momentum space images from semi-inclusive scattering
→ **TMDs**

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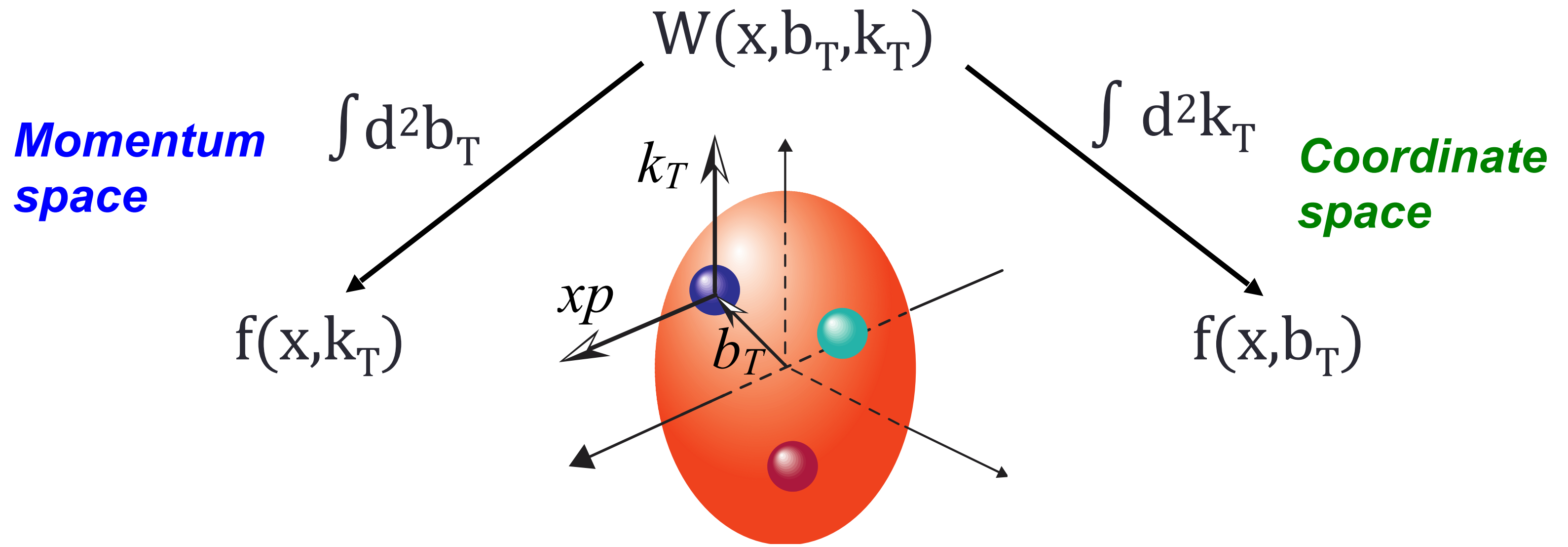

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Position and momentum → Orbital motion of quarks and gluons

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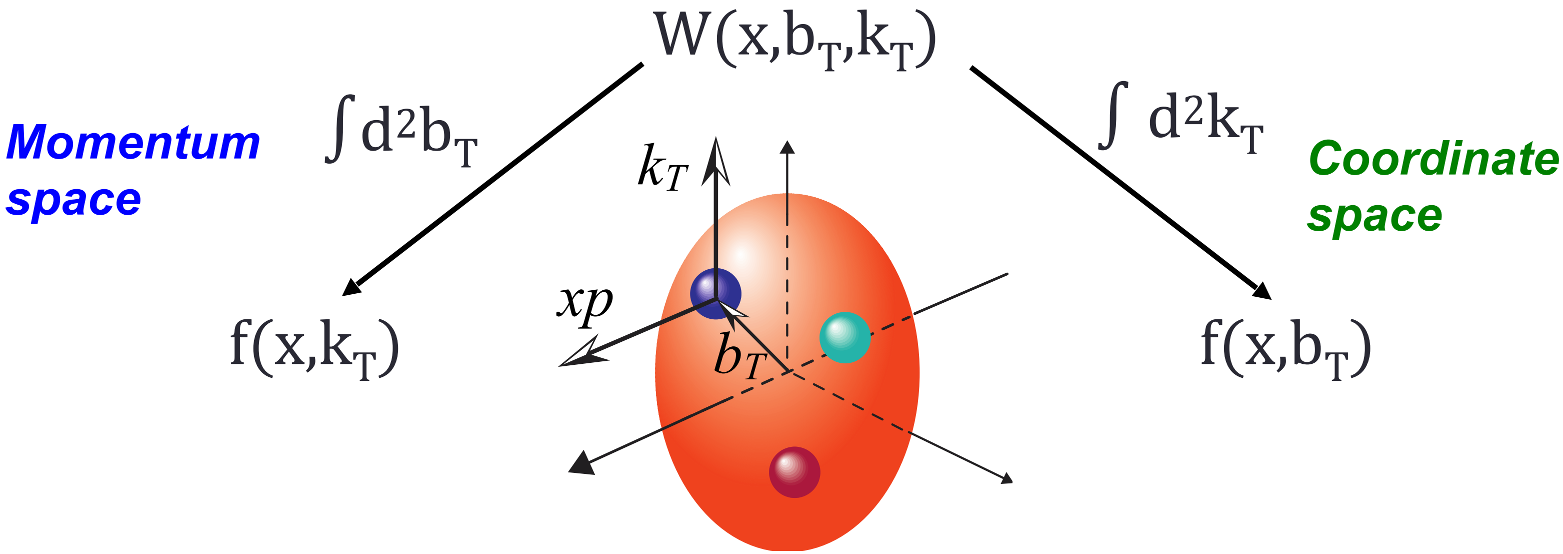

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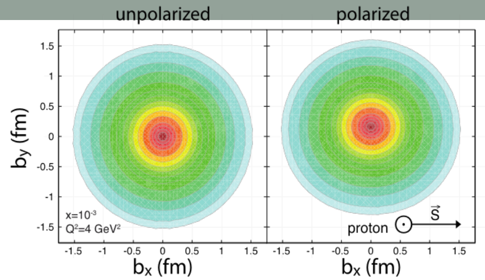
Position and momentum → Orbital motion of quarks and gluons

Recent theoretical work indicates possible direct access to gluon Wigner function through diffractive di-jet measurements at an EIC

Hatta, Xiao, Yuan, PRL 116, 022301 (2016)

Spatial Imaging of quarks & gluons

Generalized Parton Distributions



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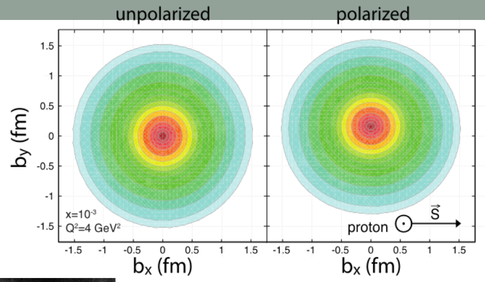
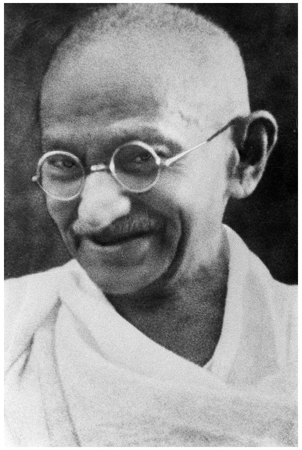
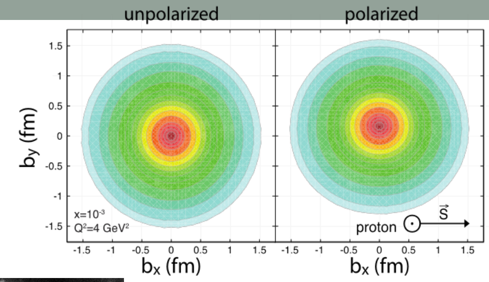


Historically, investigations of nucleon structure and dynamics involved breaking the nucleon…. (exploration of internal structure!)

To get to the **orbital motion** of quarks and gluons we need **non-violent collisions**





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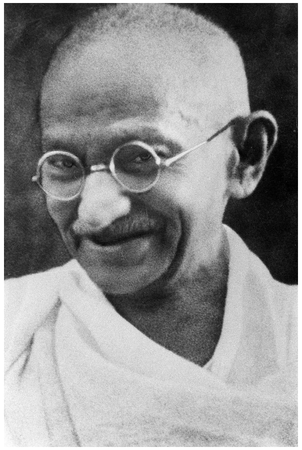

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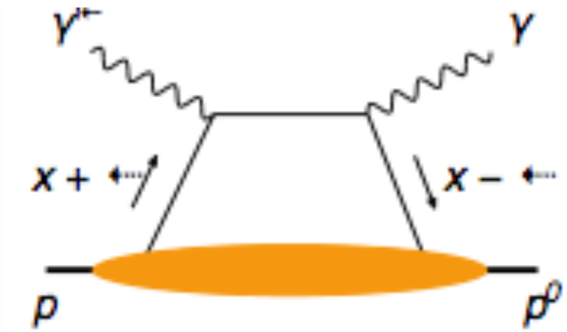
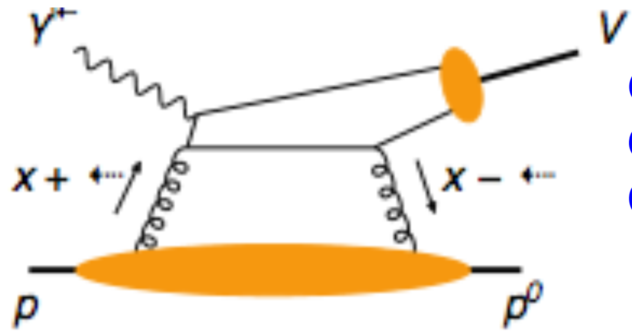
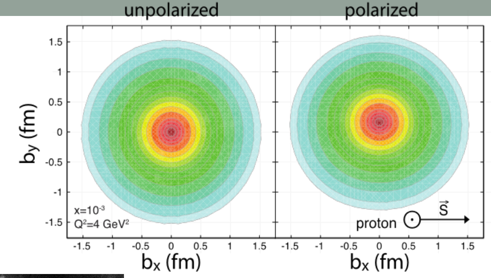




Gluons: Only @ Collider

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

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



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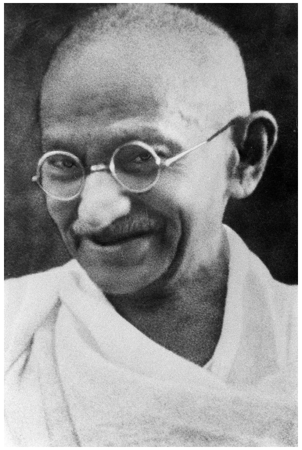

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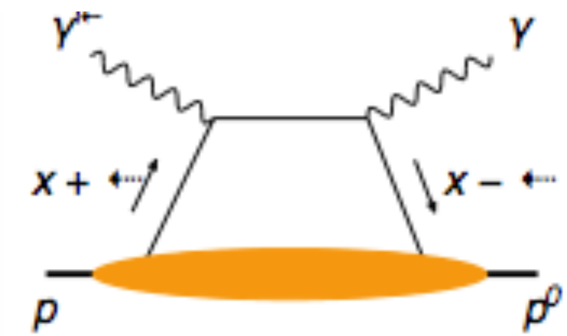

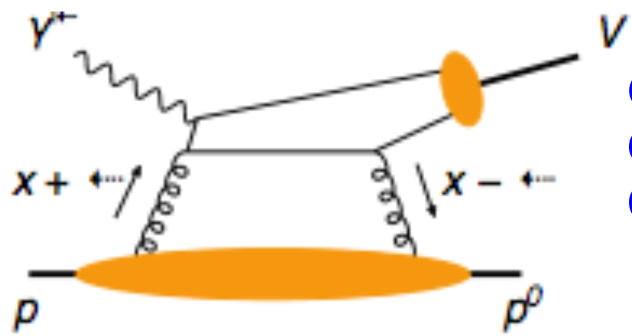

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Fourier transform of momentum transferred=(p-p') → Spatial distribution

Exclusive measurements → measure "everything"

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

Spin-dependent 3D momentum space images from semi-inclusive scattering

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

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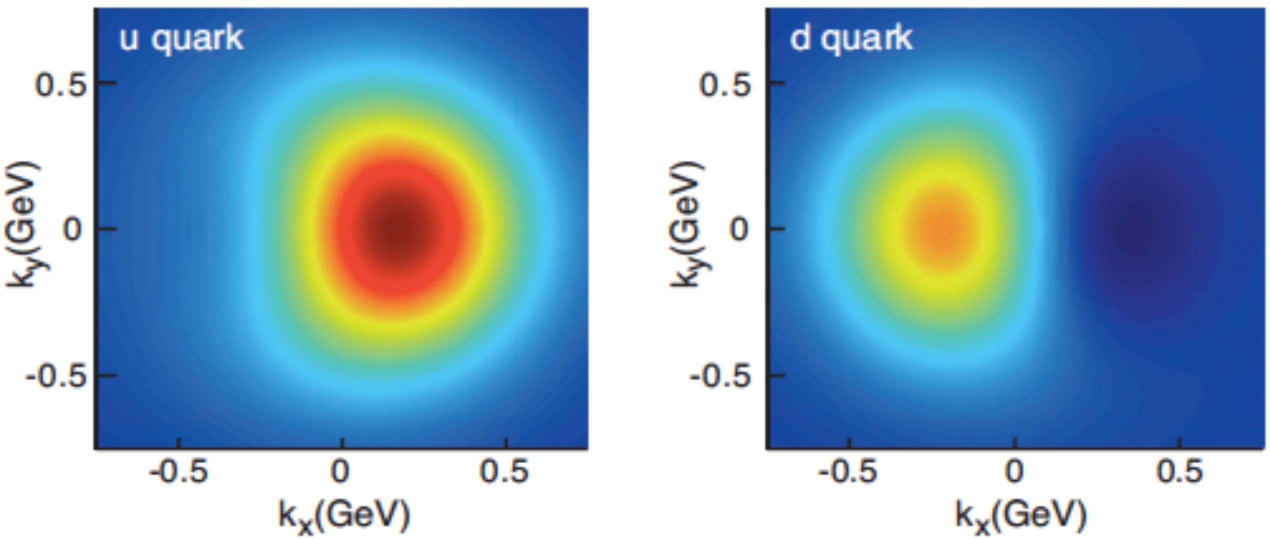

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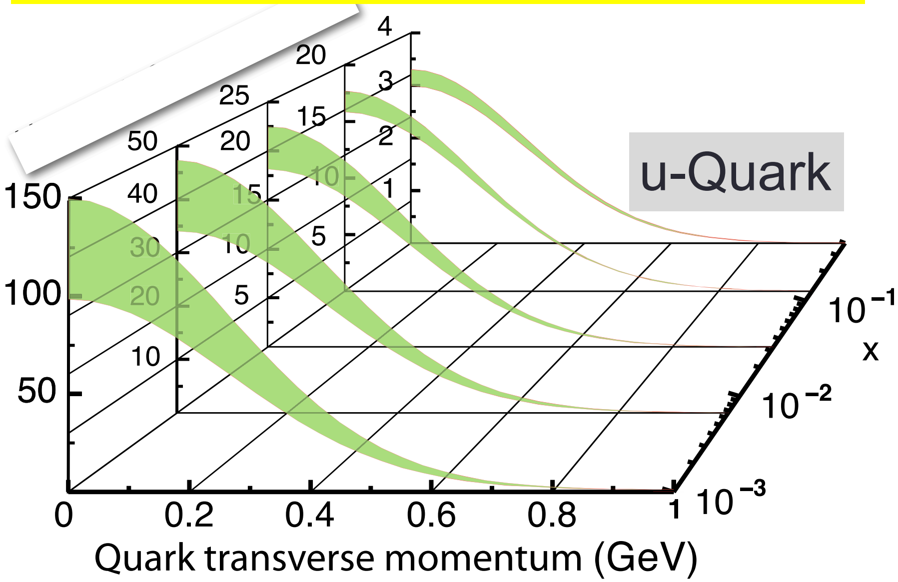

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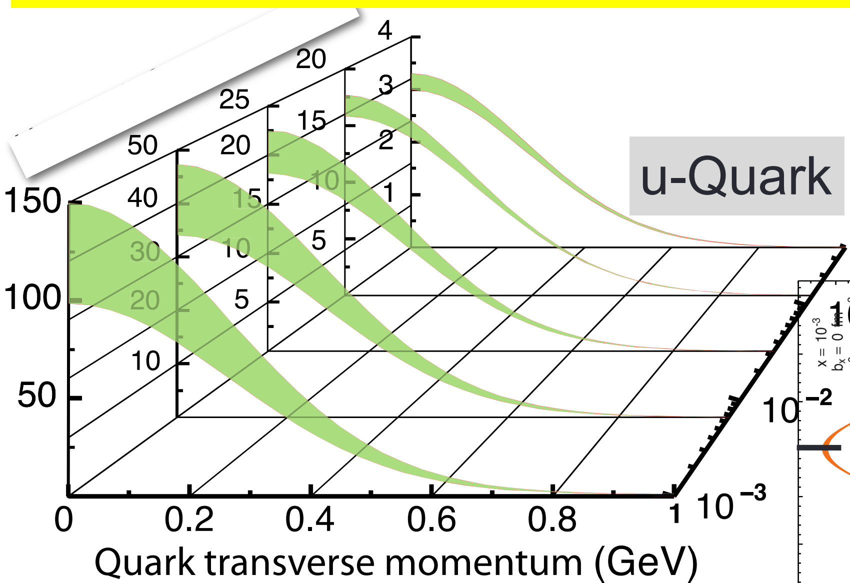

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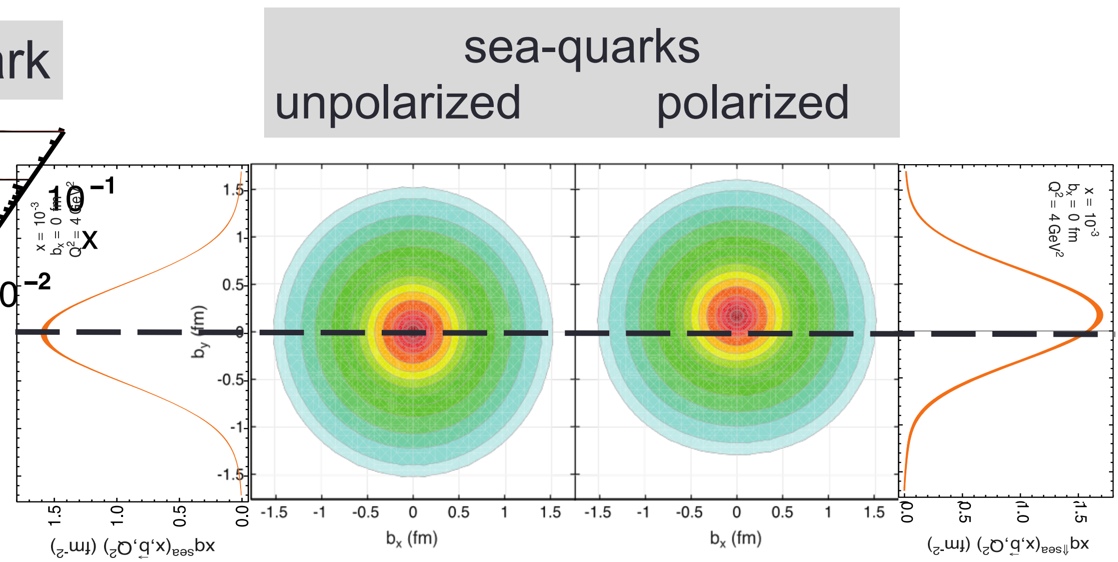

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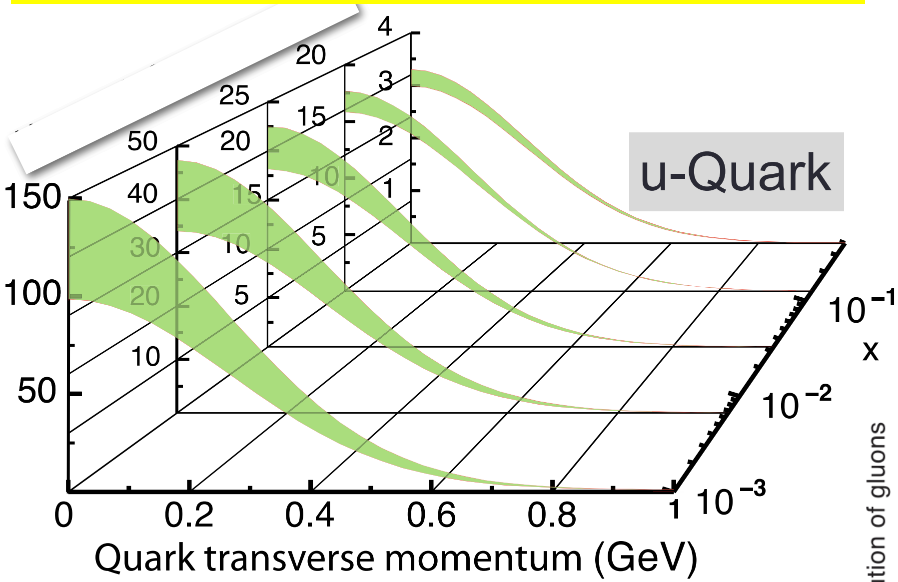

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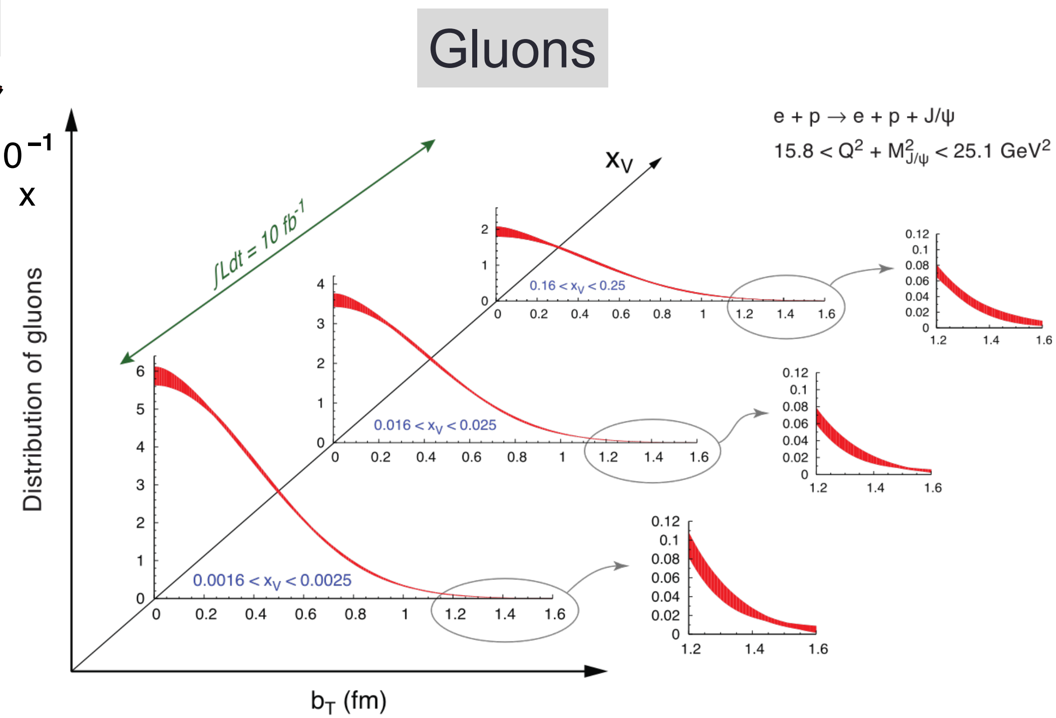
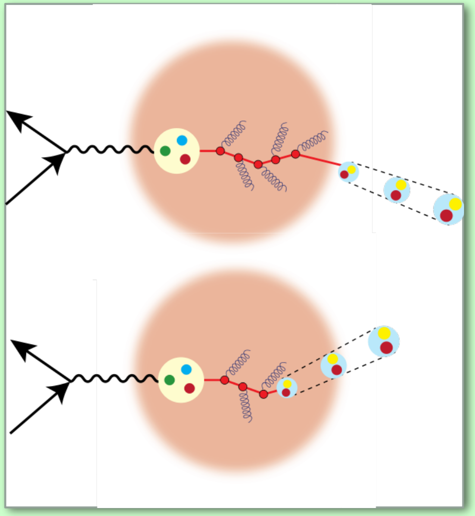
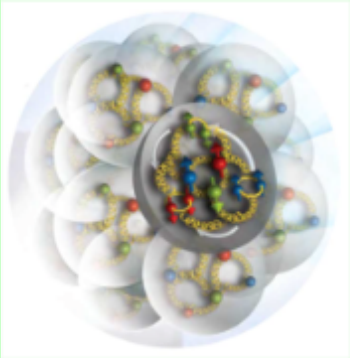
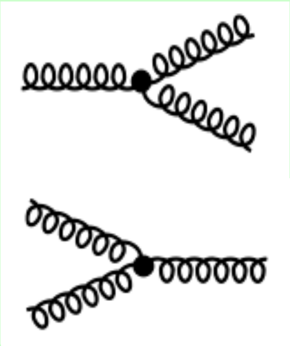


The world's first electron-nucleus collider

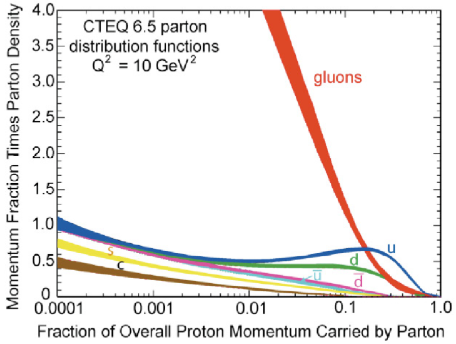
The Nucleus as a laboratory for QCD



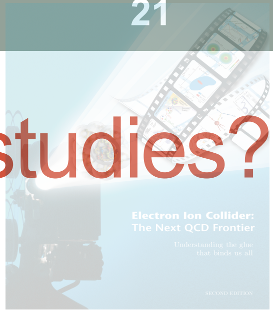




- How do color-charged quarks and gluons, and colorless jets, *interact with a nuclear medium*?
- How *do the confined hadronic states emerge* from these quarks and gluons?
- How does the quark-gluon interaction *create nuclear binding*?



What do we learn from low-x studies?



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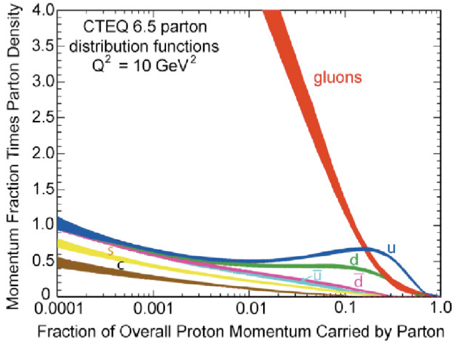

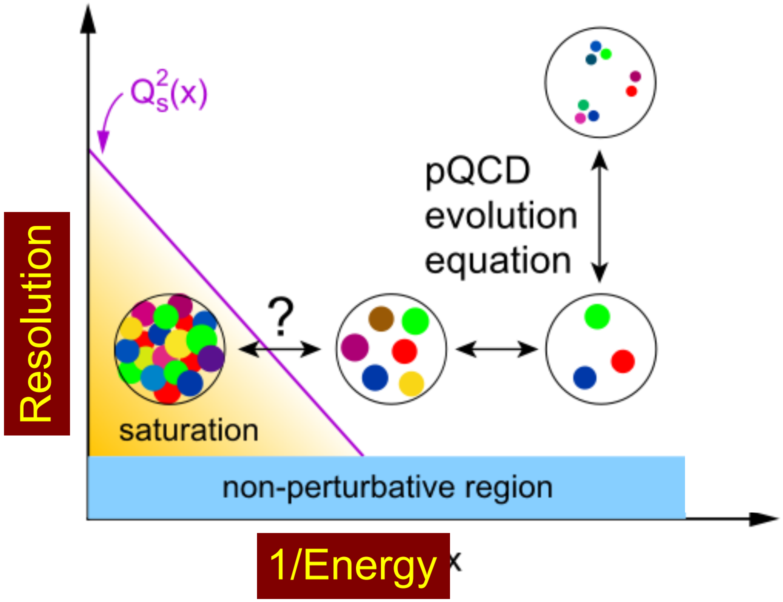

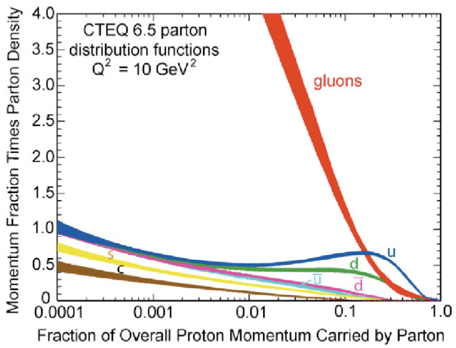

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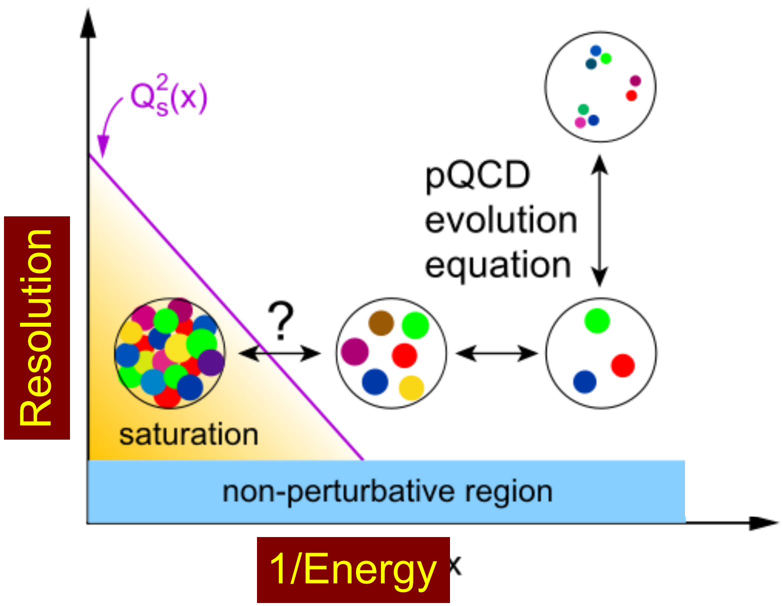
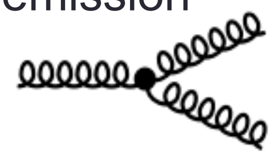


What tames the low-x rise?

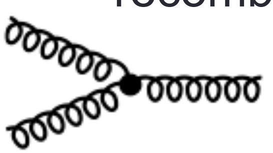
- New evolution eqn.s @ low x & moderate Q^2
- Saturation Scale $Q_S(x)$ where gluon emission and recombination comparable

gluon emission

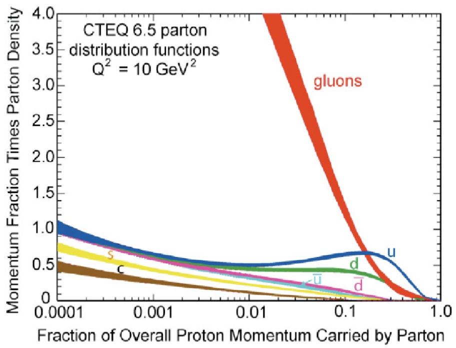


=

gluon recombination



At Q_S



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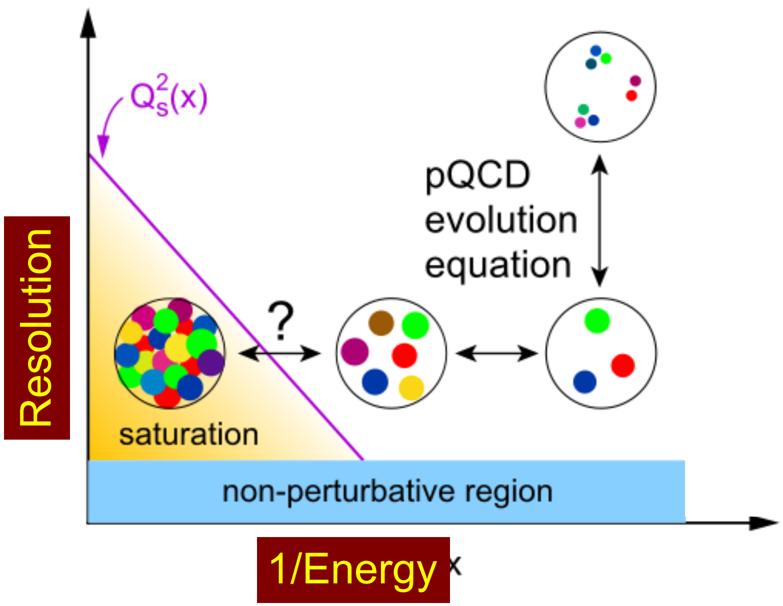

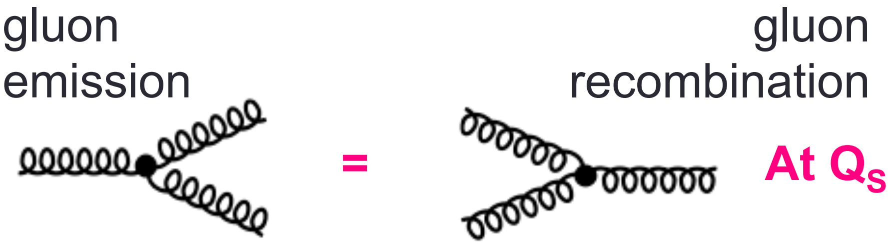

First observation of gluon recombination effects in nuclei:
→leading to a *collective* gluonic system!
First observation of g-g recombination in *different* nuclei
→ **Is this a universal property?**
→ **Is the Color Glass Condensate the correct effective theory?**

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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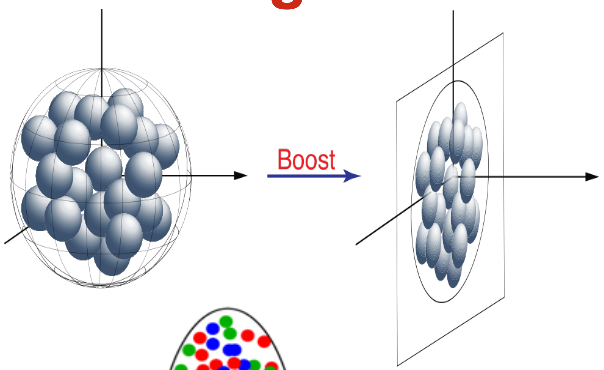

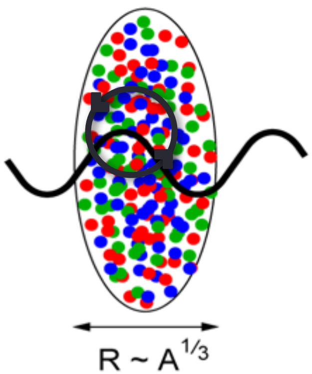

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$L \sim (2m_N x)^{-1} > 2\,R_A \sim A^{1/3}$

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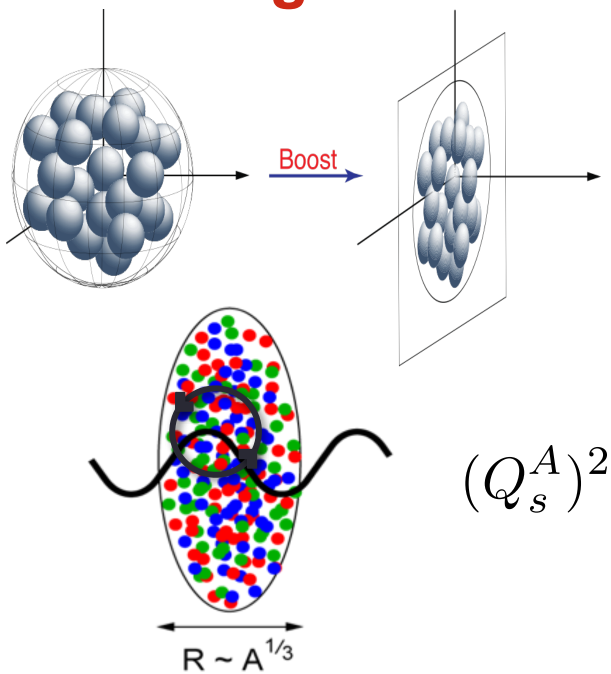

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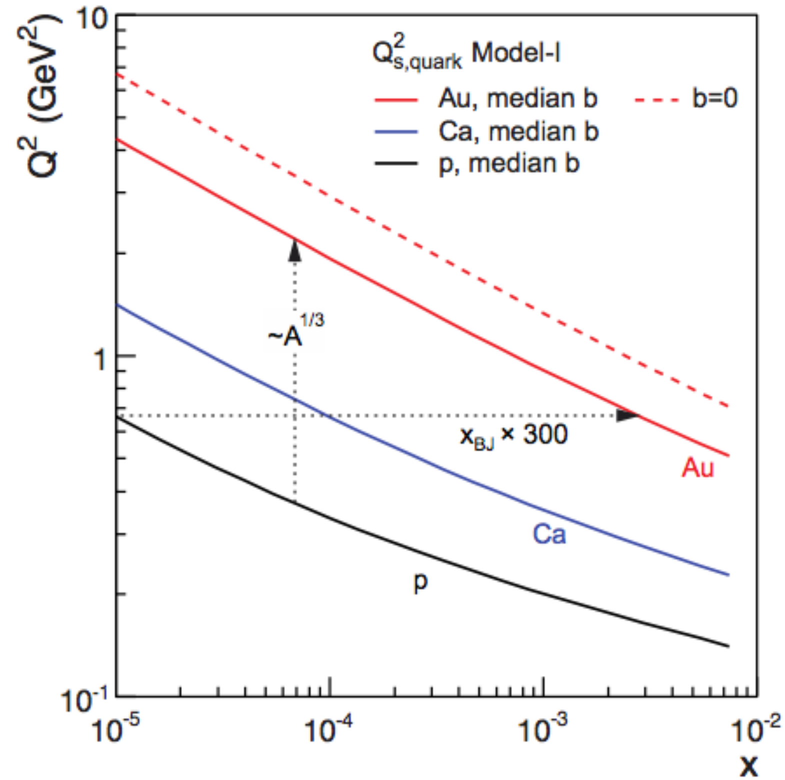
Kovchegov et al.



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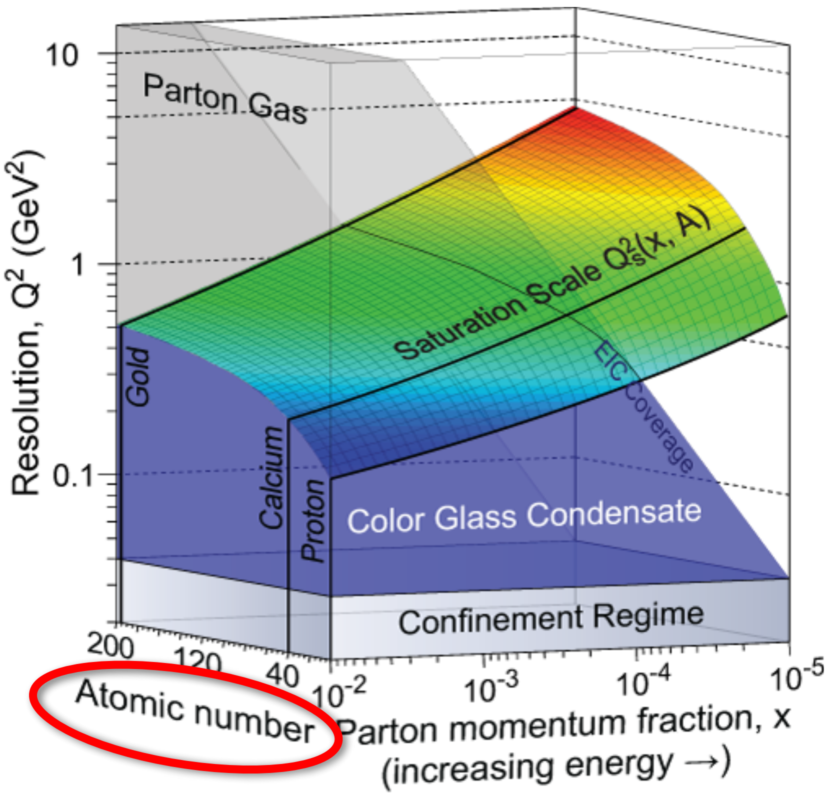

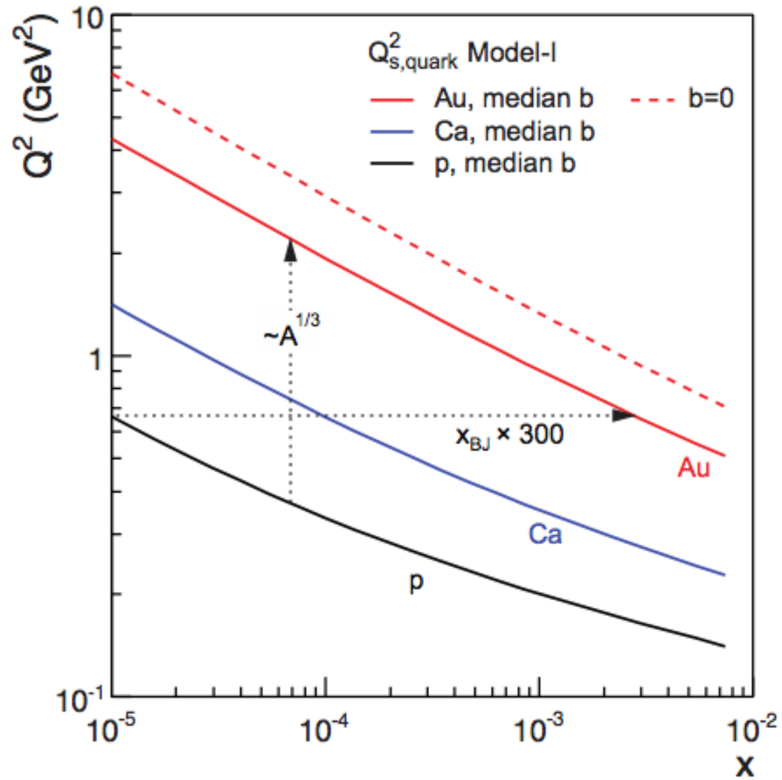

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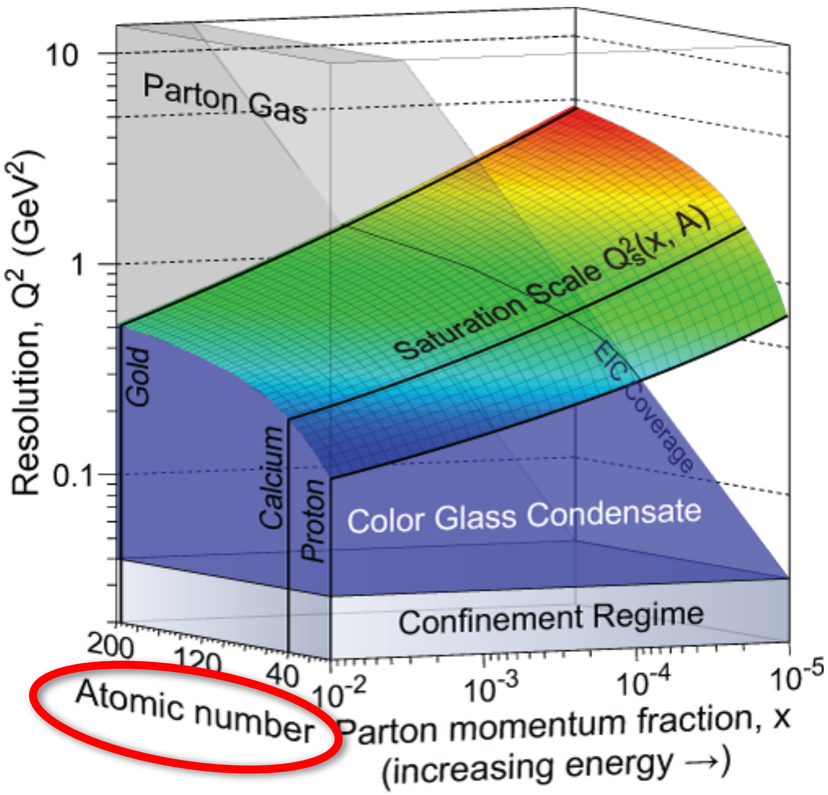
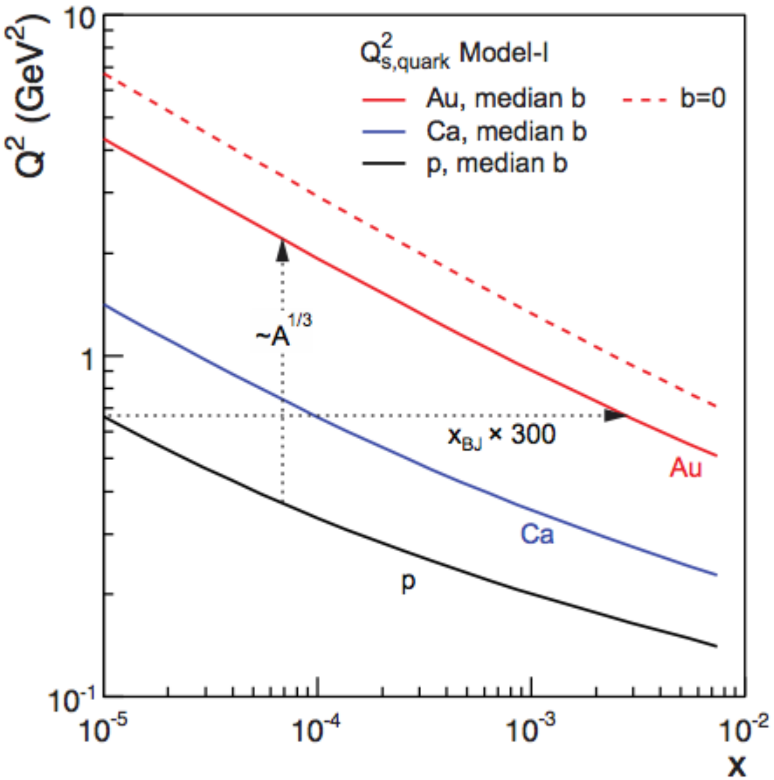




Enhancement of Q_S with A:

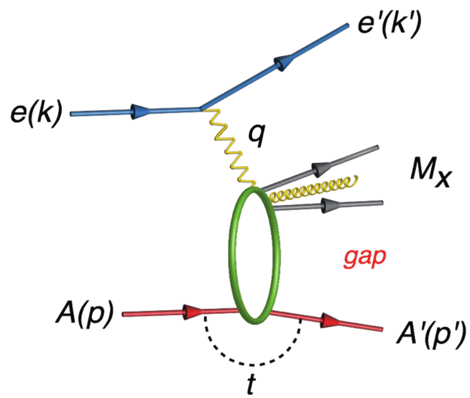
Saturation regime reached at significantly lower energy (read: "cost") in nuclei

Diffraction for the 21st Century

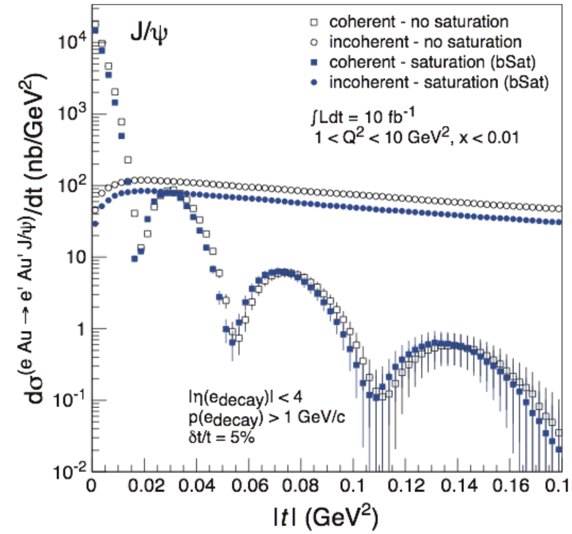
Diffraction cross-sections have strong discovery potential:

High sensitivity to gluon density in linear regime: $\sigma \sim [g(x,Q^2)]^2$

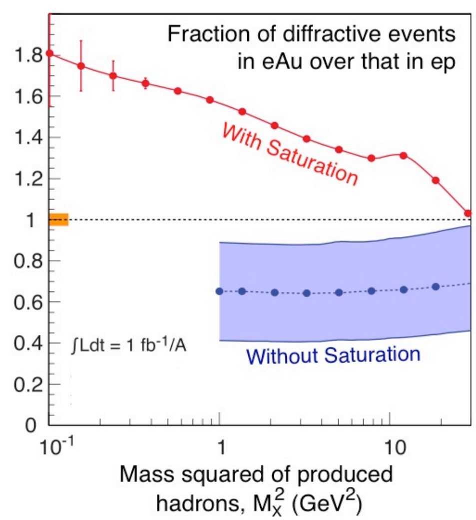
Dramatic changes in cross-sections with onset of non-linear strong color fields



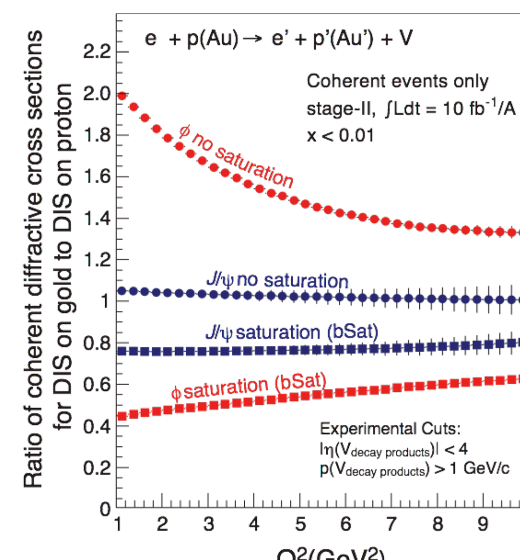
Extracting the gluon distribution $\rho(b_T)$ of nuclei via Fourier transformation of $d\sigma/dt$ in diffractive J/ψ production



Probing gluon saturation through measuring $\sigma_{diff}/\sigma_{tot}$



Probing Q^2 dependence of gluon saturation in diffractive vector meson production

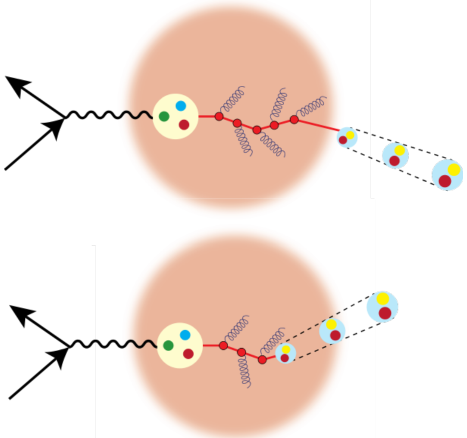


Emergence of Hadrons from Partons

Nucleus as a Femtometer sized filter

Unprecedented ν, the virtual photon energy range @ EIC : *precision & control*

$$\nu = \frac{Q^2}{2mx}$$



Control of ν by selecting kinematics;
Also under control the nuclear size.

Colored quark emerges as color neutral hadron ➔ What is nature telling us about confinement?

Need the collider energy of EIC and its control on parton kinematics

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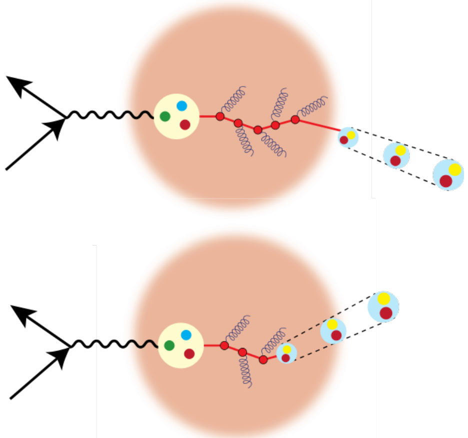

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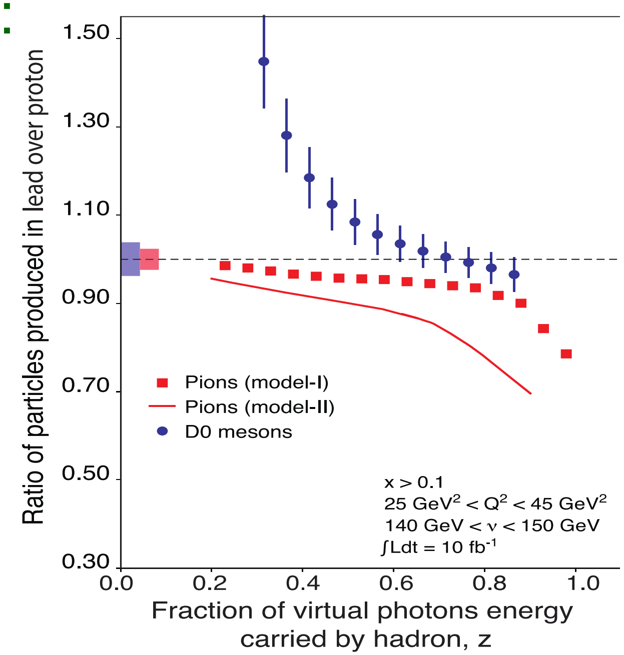
Energy loss by light vs. heavy quarks:



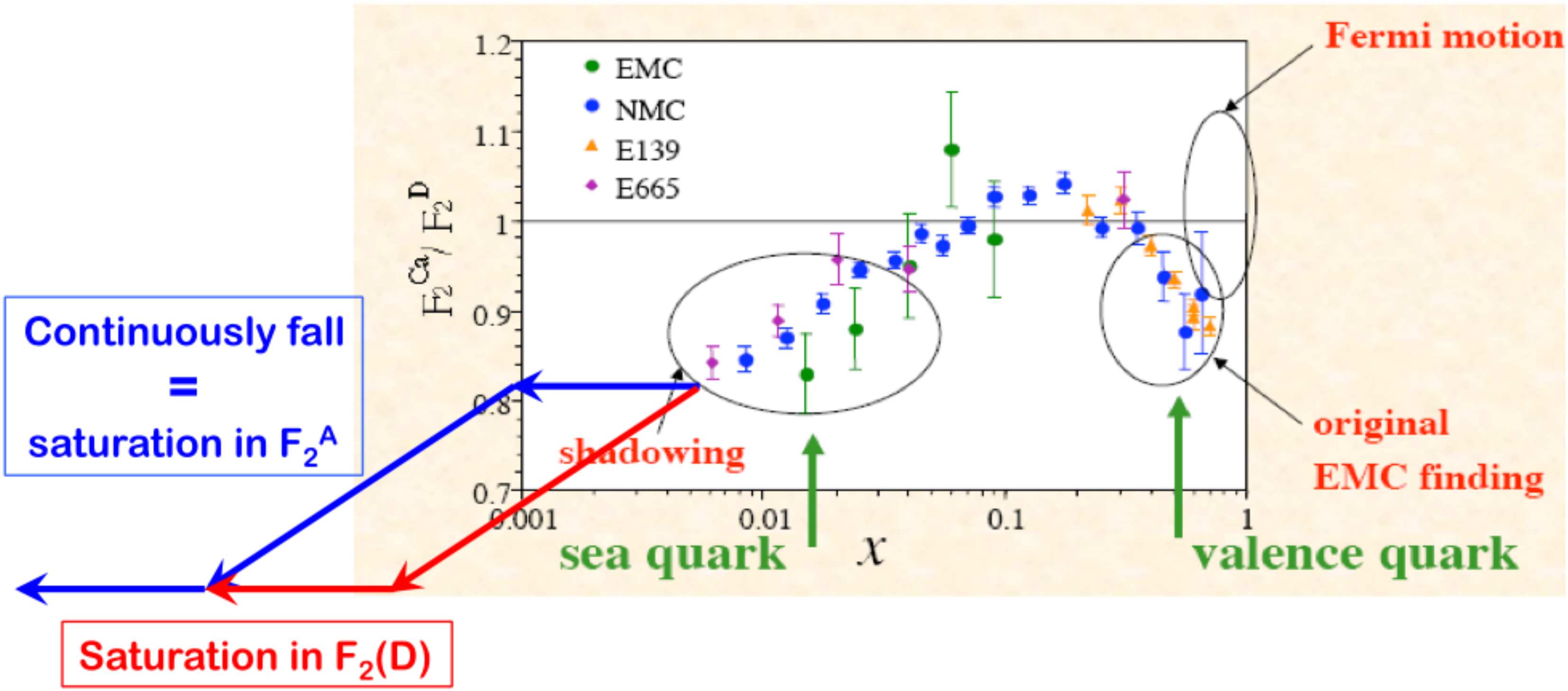
Identify π vs. D^0 **(charm)** mesons in e-A collisions: Understand energy loss of light vs. heavy quarks traversing the cold nuclear matter:

Connect to energy loss in Hot QCD

Need the collider energy of EIC and its control on parton kinematics

An easy measurement (early program)

- ❑ **Ratio of F_2: EMC effect, Shadowing and Saturation:**



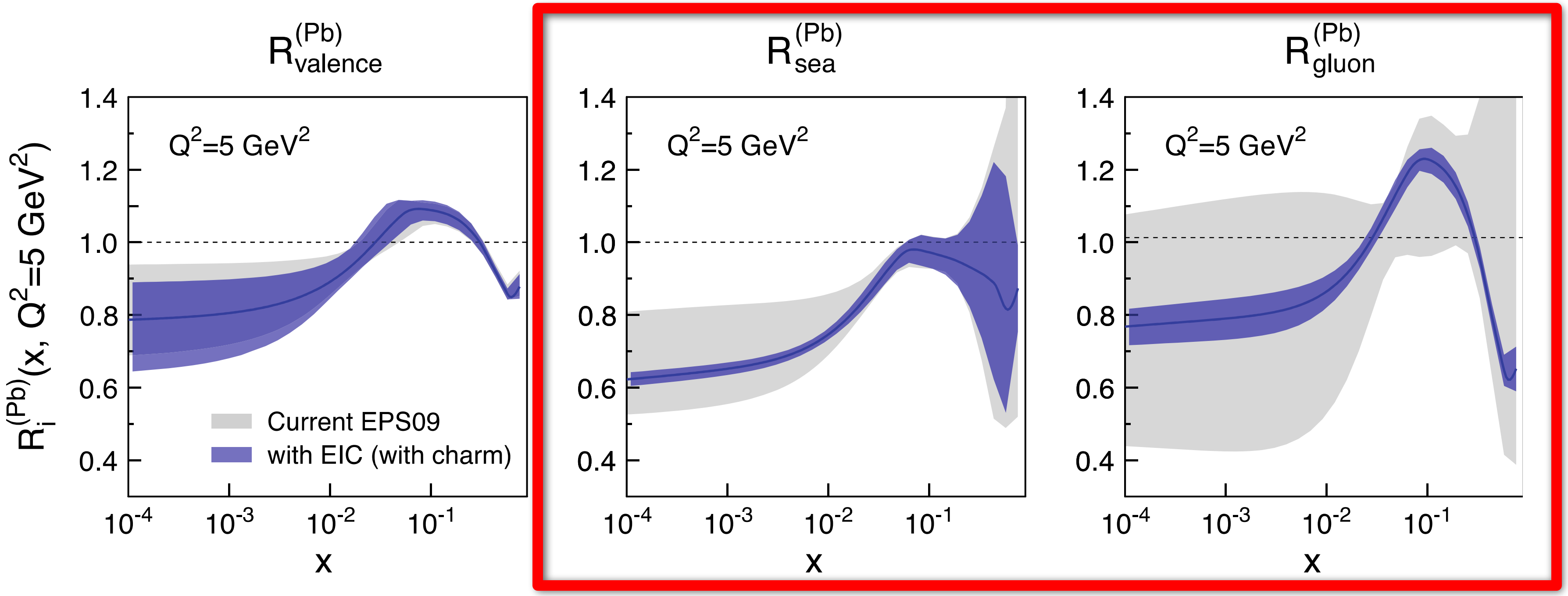
- ❑ **Questions:**

Will the suppression/shadowing continue fall as x decreases?

Could nucleus behaves as a large proton at small-x?

Range of color correlation – could impact the center of neutron stars!

EIC: impact on the knowledge of nPDFs



Ratio of Parton Distribution Functions of Pb over Proton:

- Without EIC, large uncertainties in **nuclear sea quarks and gluons**
- With EIC significantly reduces uncertainties

- Impossible for current and future pA data at RHIC & LHC data to achieve

REALIZATION….

Support for Accelerator R&D

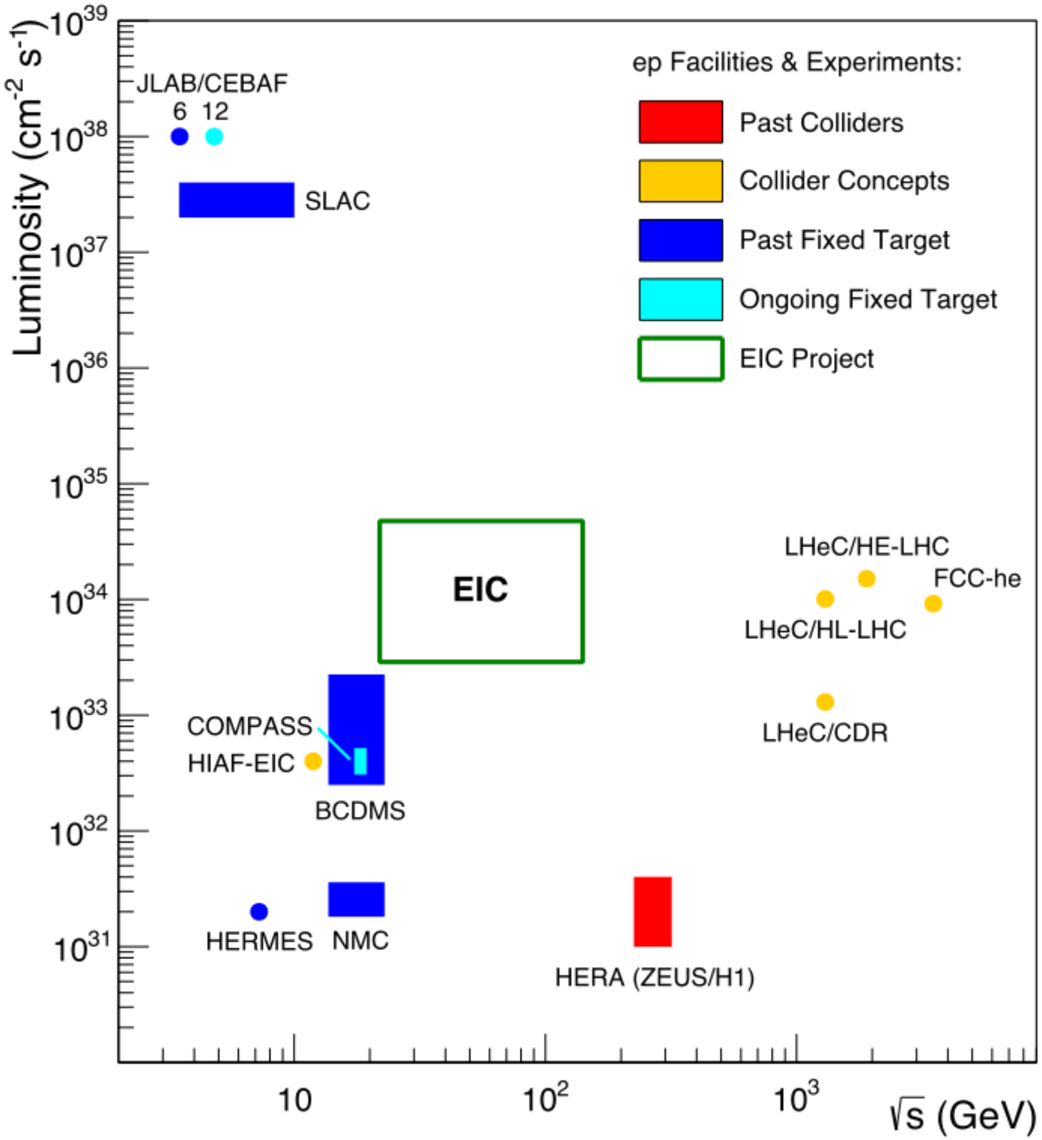
User group formation ➔ leading to future collaborations

Early experimental design concepts

Support for detector pre-conception design R&D

The National Academy of Science (NAS- NRC) Review

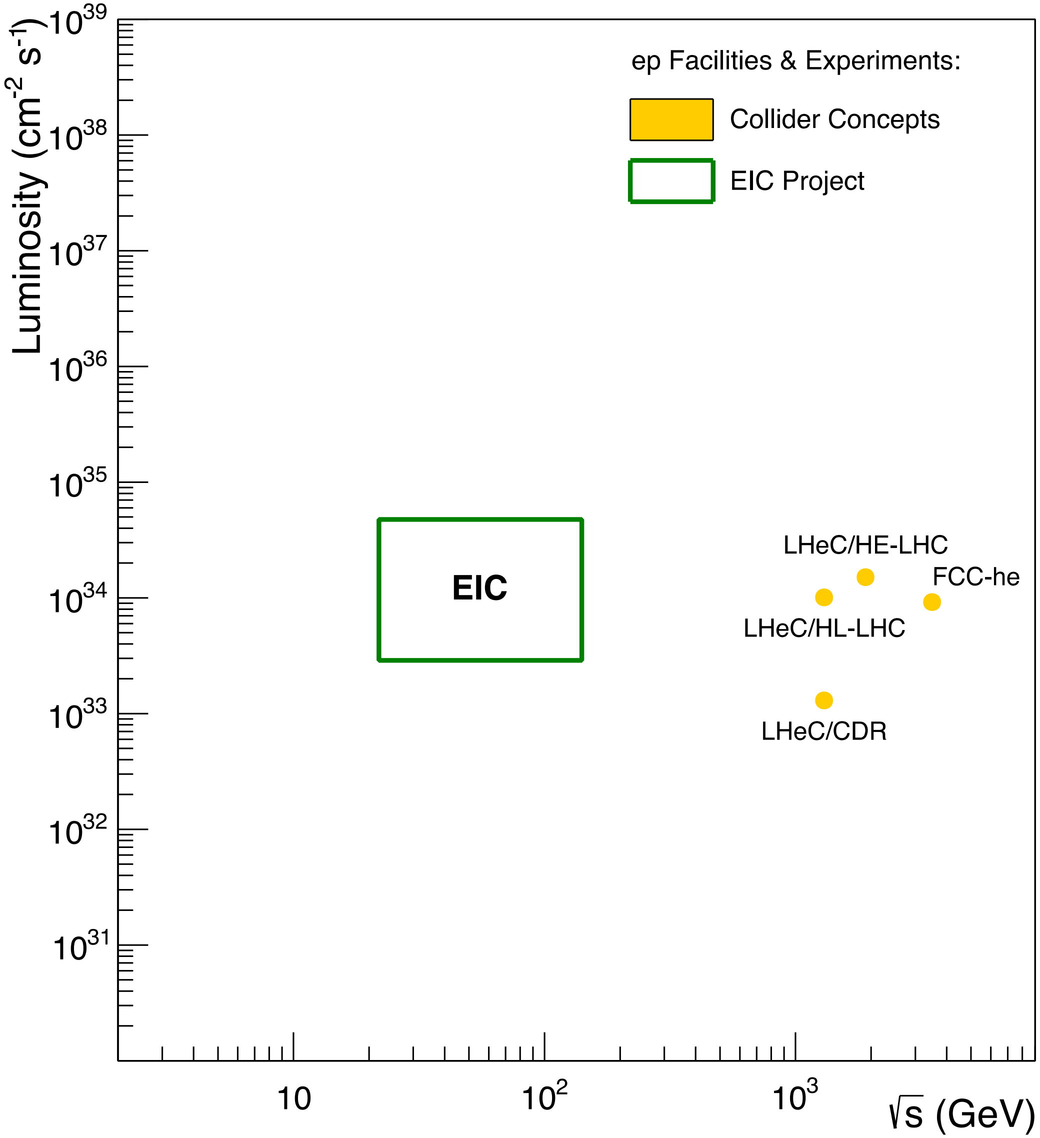
Uniqueness of EIC among all DIS Facilities



All DIS facilities in the world.

However,
if we ask for:

Uniqueness of EIC among all DIS Facilities



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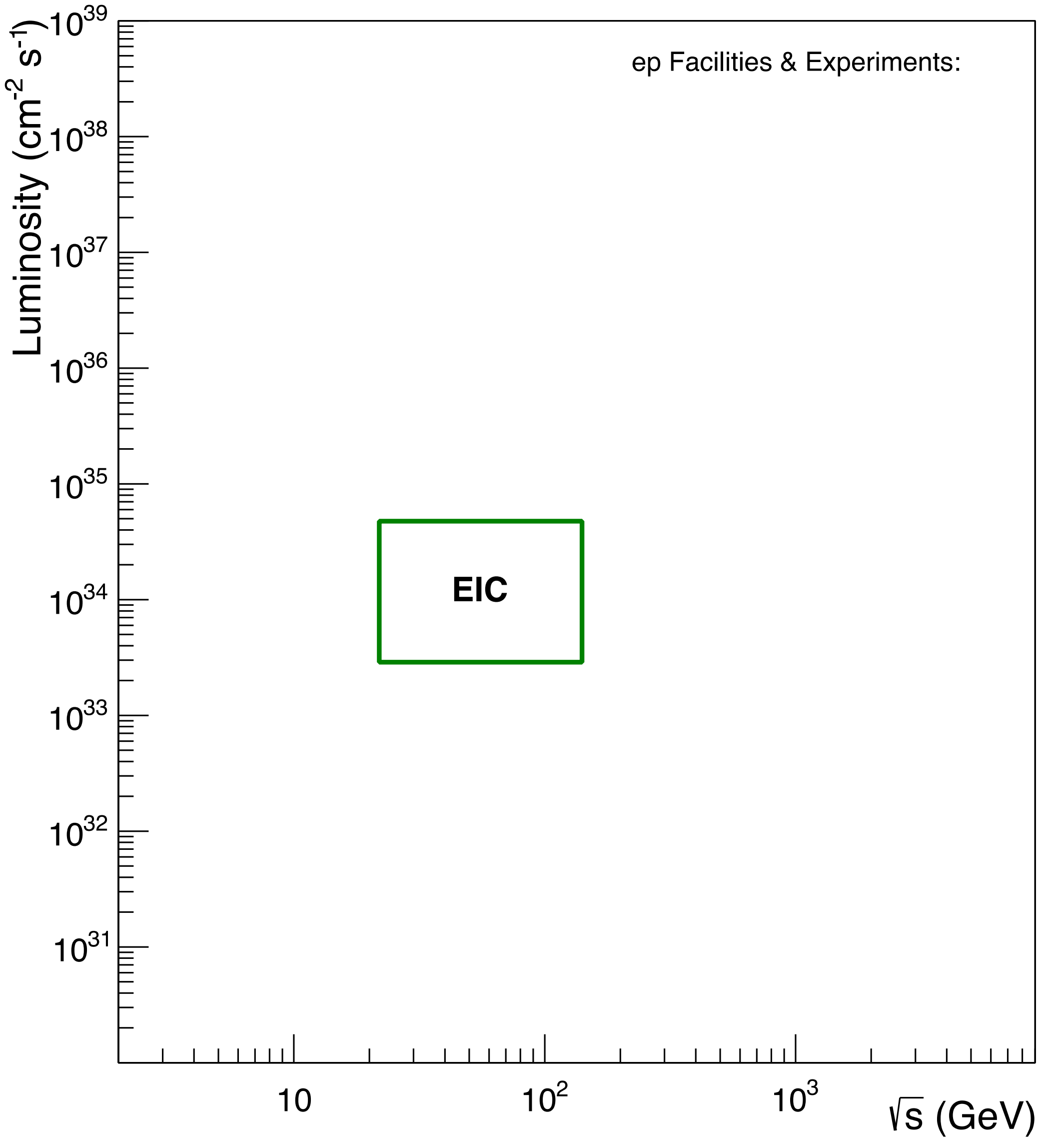


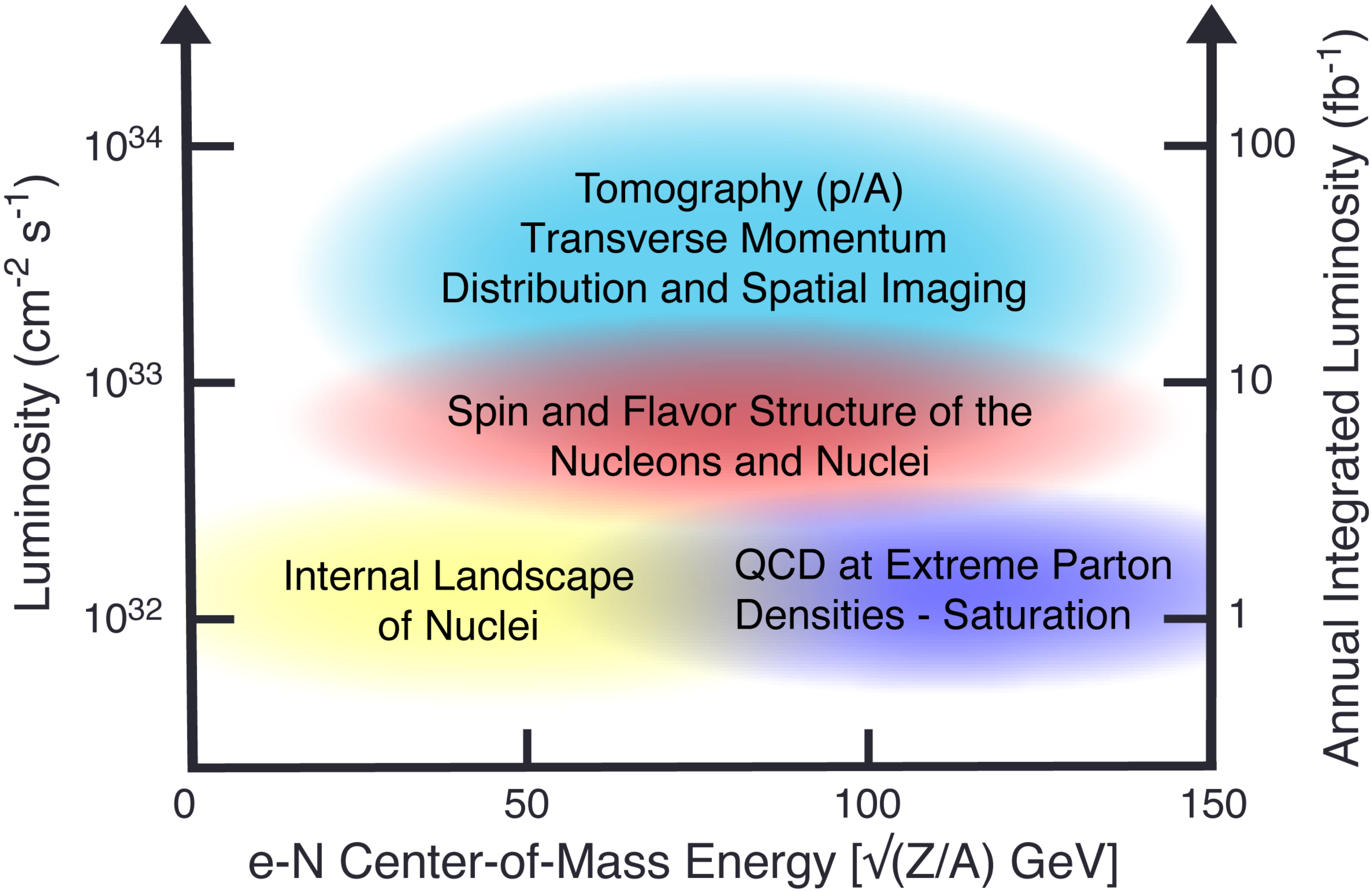
All DIS facilities in the world.

However,
if we ask for:

- high luminosity & wide reach in $\sqrt{s}$
- polarized lepton & hadron beams
- nuclear beams

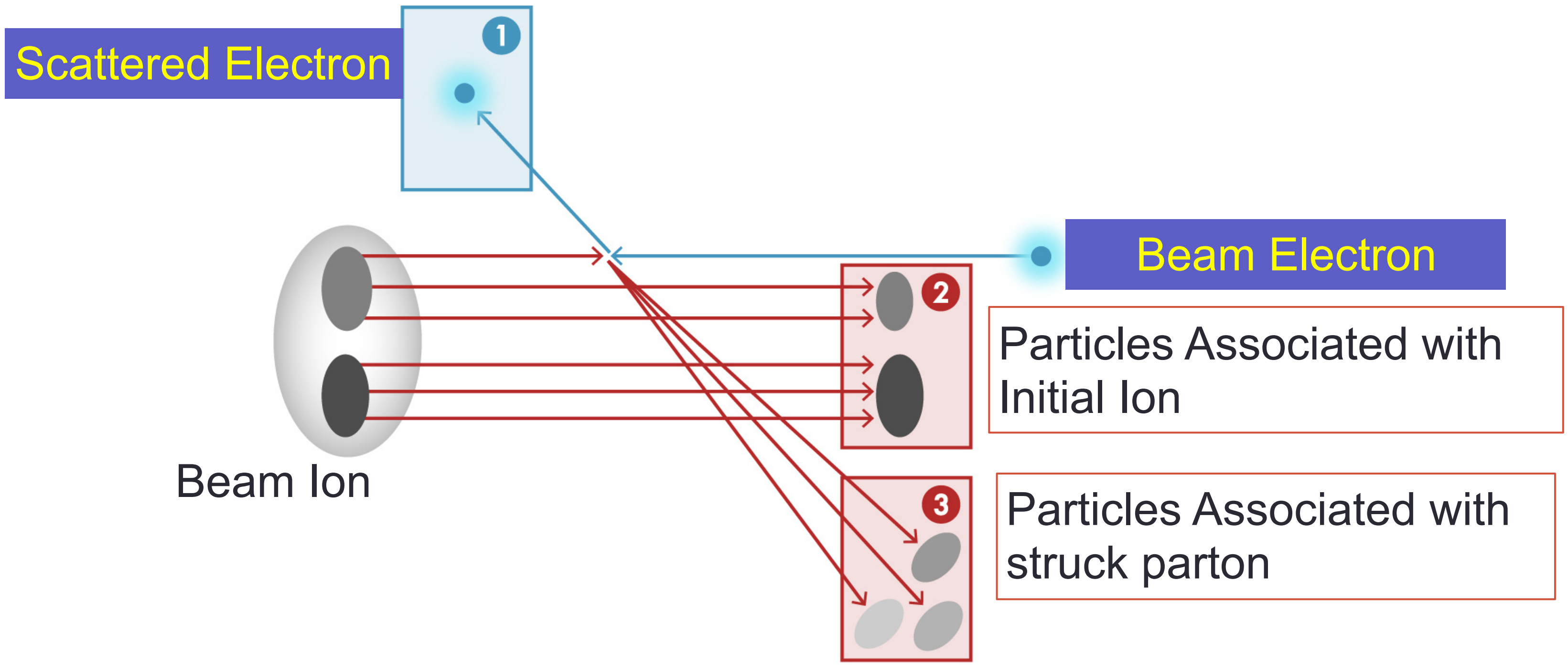
EIC stands out as unique facility …

Uniqueness of EIC among all DIS Facilities



Total Acceptance Detector

"Statistics" = Luminosity × Acceptance



EIC Physics demands ~100% acceptance for all final state particles (1,2, and 3)

2 is particularly challenging: 100% acceptance not usual concern at colliders. Higher the Ion Beam energy, more difficult to achieve.

R. Yoshida

EIC forward detection requirements

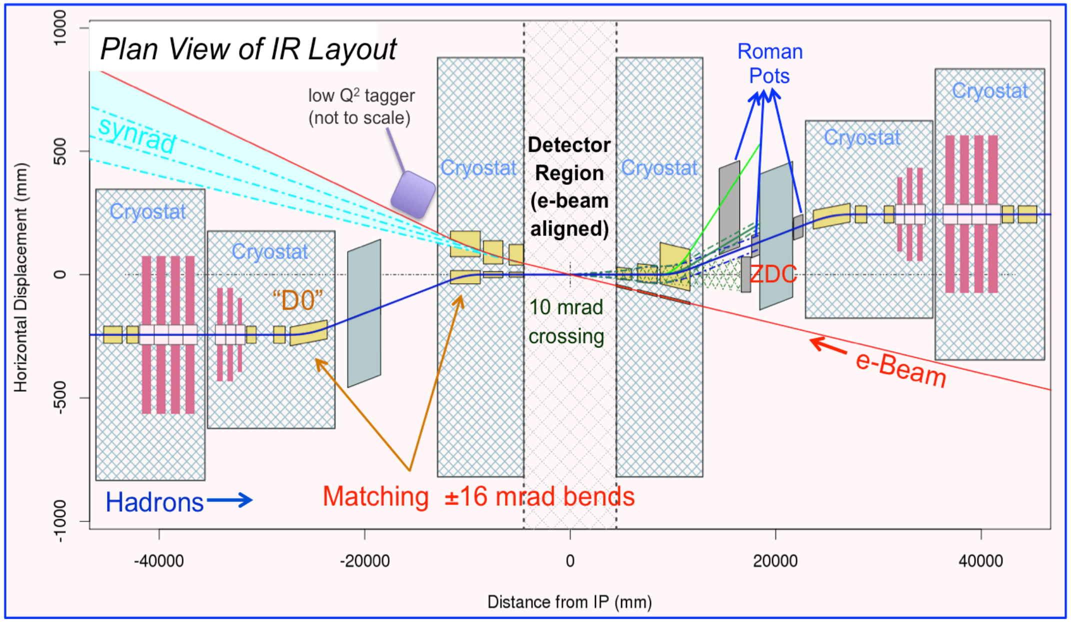
- Good acceptance for recoil nucleons (rigidity close to beam)
  - **Diffractive processes on nucleon, coherent nuclear reactions**
  - Small beam size at detection point (to get close to the beam)
  - Large dispersion (to separate scattered particles from the beam)

- Good acceptance for fragments (rigidity different than beam)
  - **Tagging in light and heavy nuclei, nuclear diffraction**
  - Large magnet apertures (low gradients)
  - Detection at several points along a long, aperture-free drift region

- Good momentum- and angular resolution
  - **Free neutron structure through spectator tagging, imaging**
  - Both in roman pots and fixed detectors

IR Designed: to maximize forward acceptance

eRHIC IR Design (evolving)



For example:
HERA saw typically 2-5% of forward acceptance for diffractive events

EIC designs aim at 90%+

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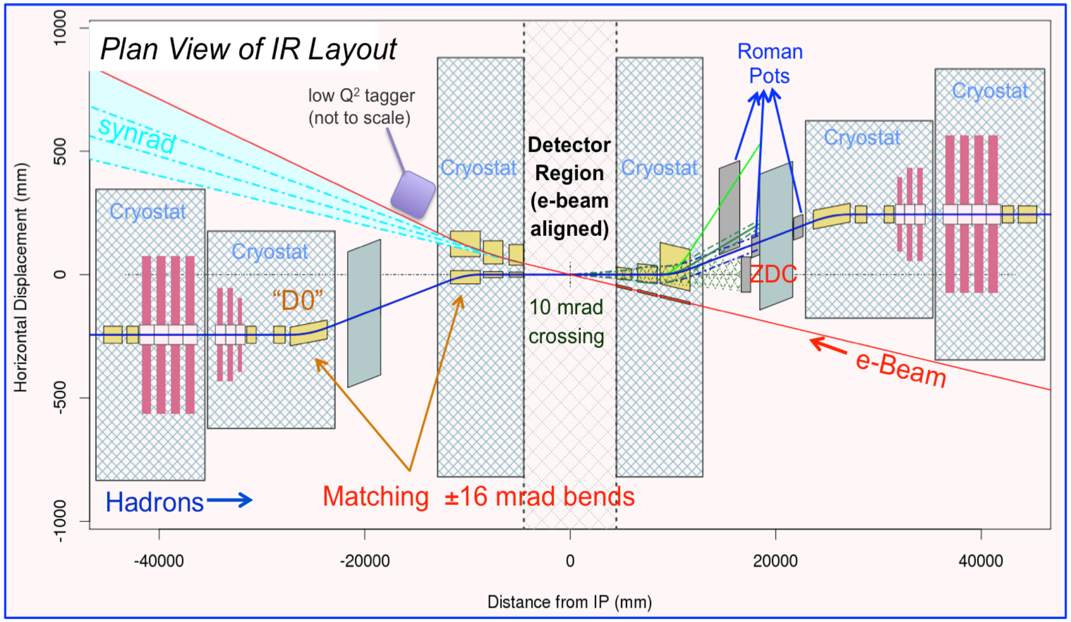

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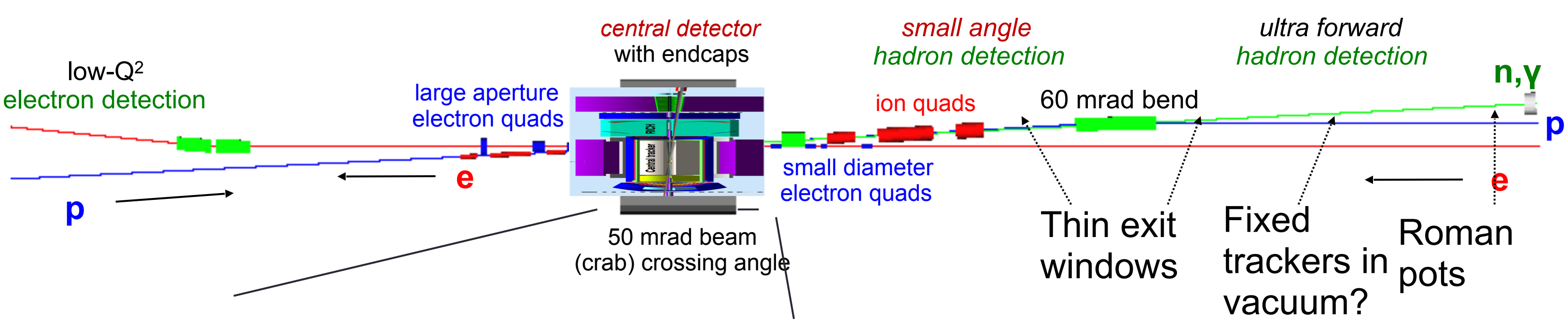
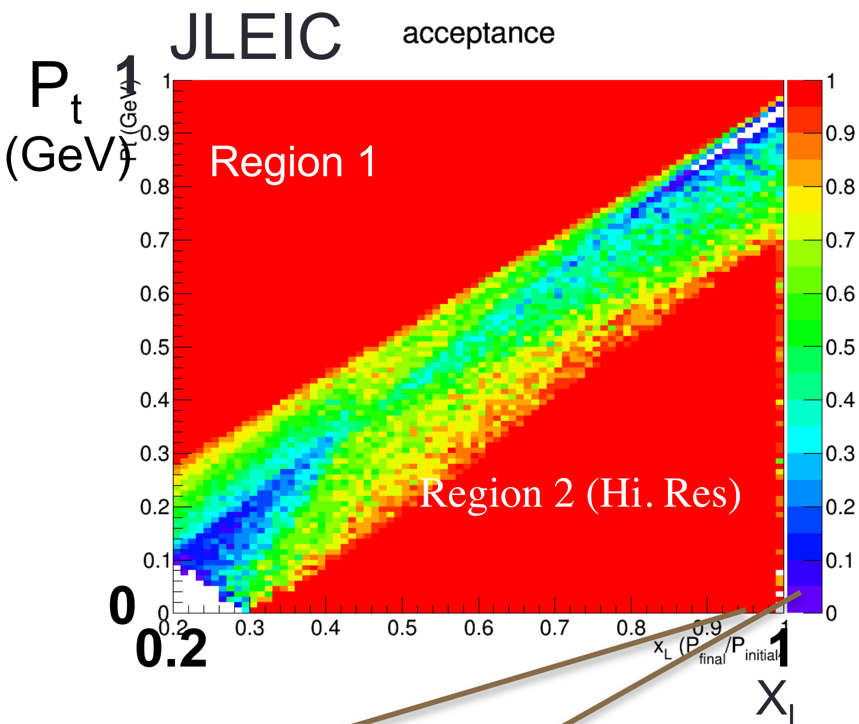
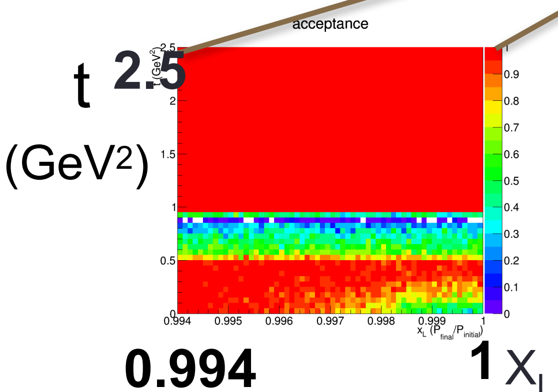
JLEIC IR Design



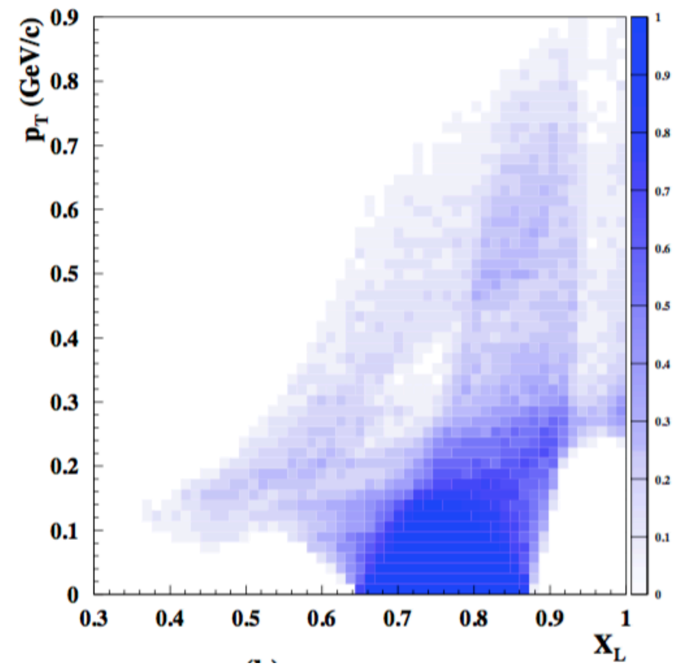
Rik Yoshida
Zhiwen Zhao

Acceptance : p' in Diffractive DIS





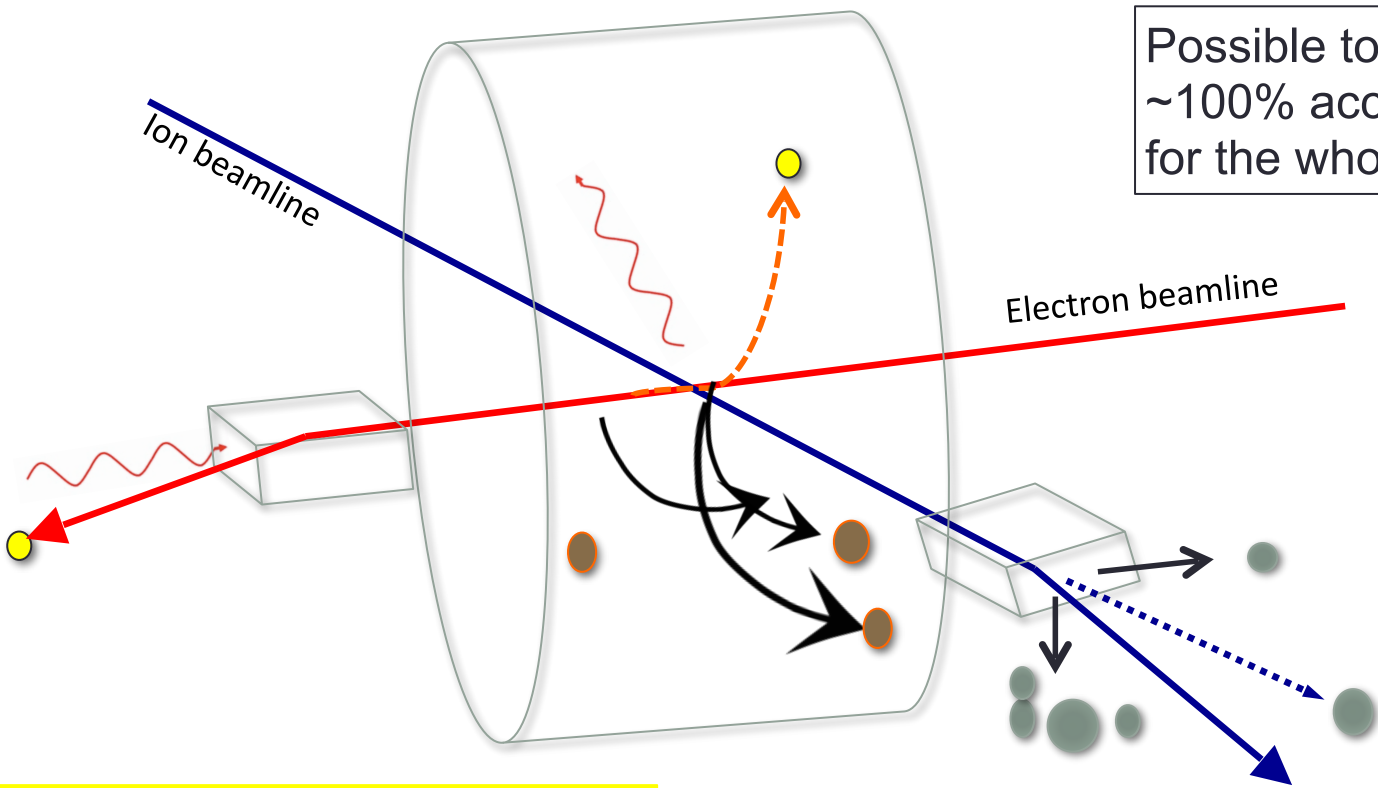
ZEUS
Leading Proton Spectrometer



Acceptance in diffractive peak (X_L>~.98)
ZEUS: ~2%
(JL)EIC: ~100%

Detector integration with the Interaction Region accelerator components:

Possible to get ~100% acceptance for the whole event



Total acceptance detector (and IR)

Crossing angles:
eRHIC: 10-22 mrad
JLEIC : 40-50 mrad

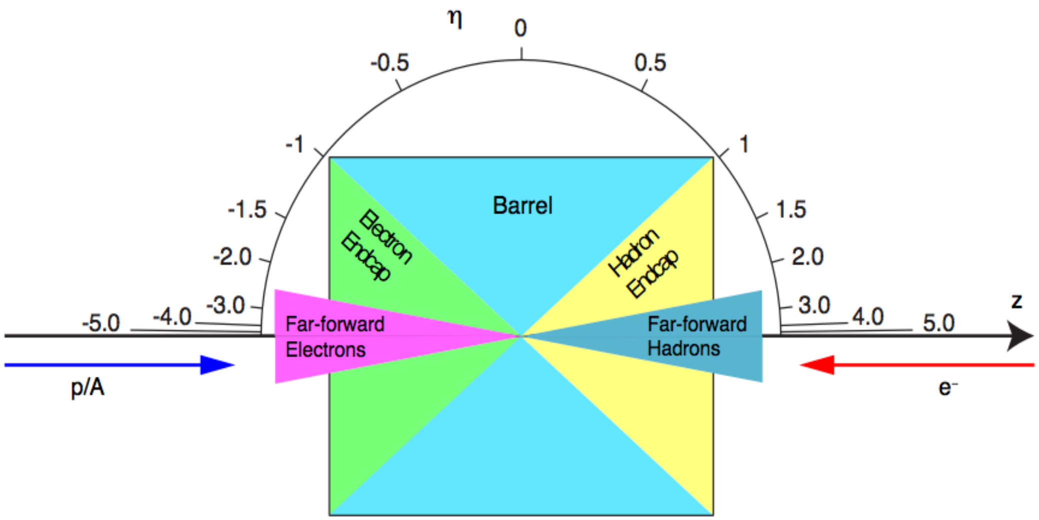
Figure Courtsey: Rik Yoshida

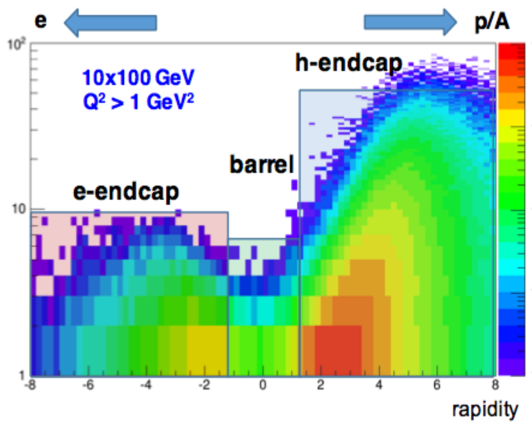
EIC Detector Concepts

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

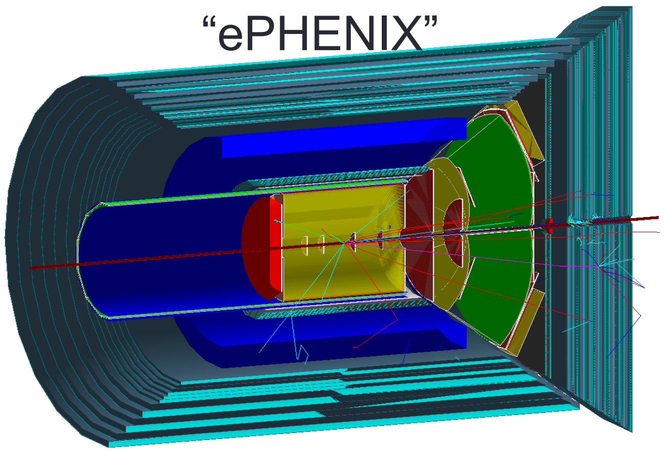


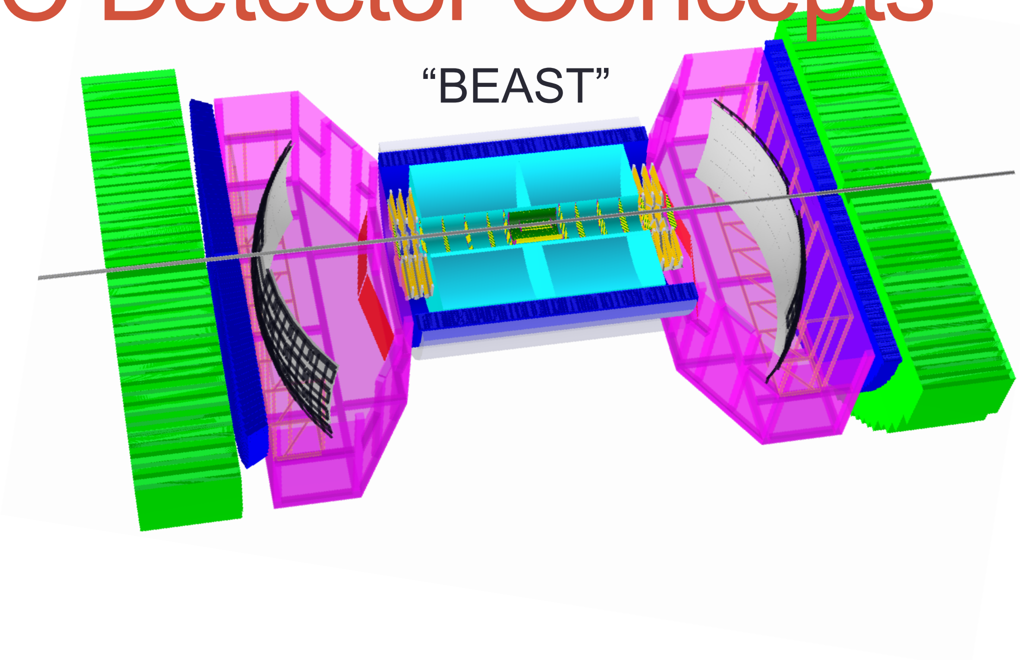


Courtesey of Thomas Ullrich

EIC Detector Concepts

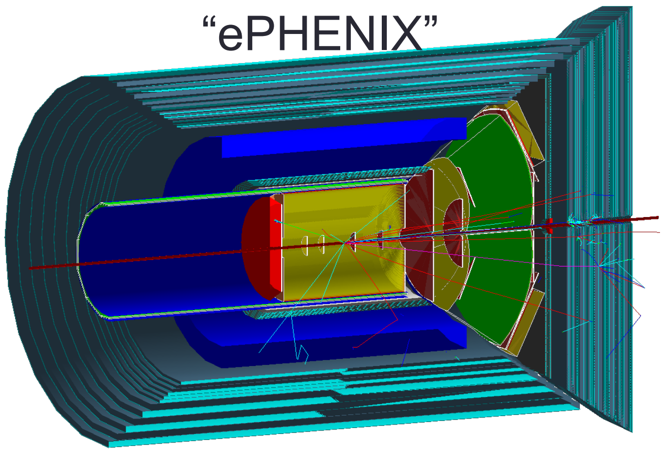
EIC Detector Concepts



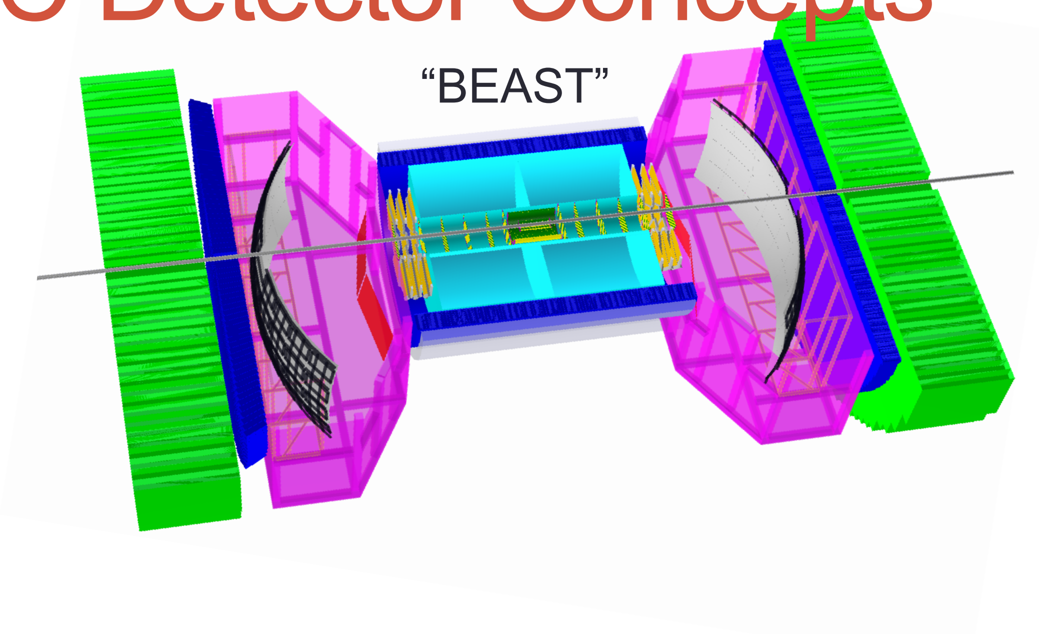


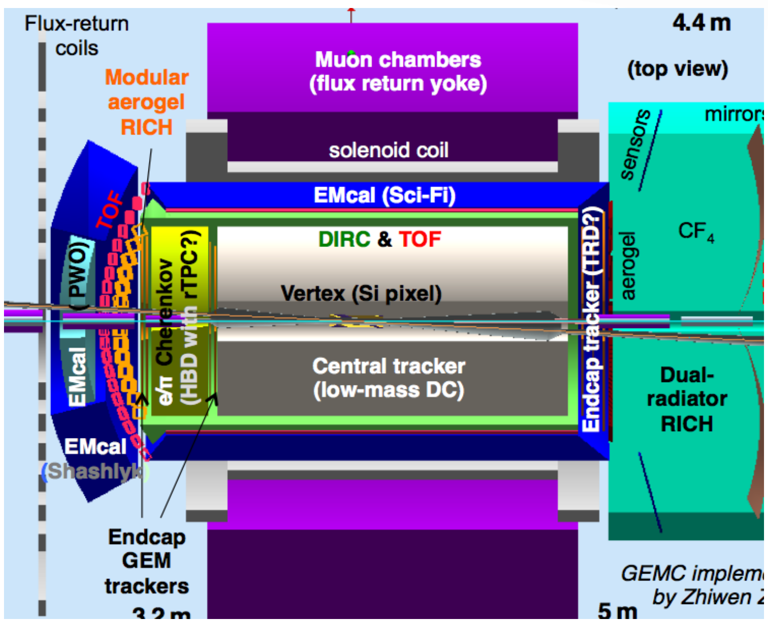
EIC Detector Concepts

"ePHENIX"



"BEAST"





JLEIC

EIC Detector Concepts

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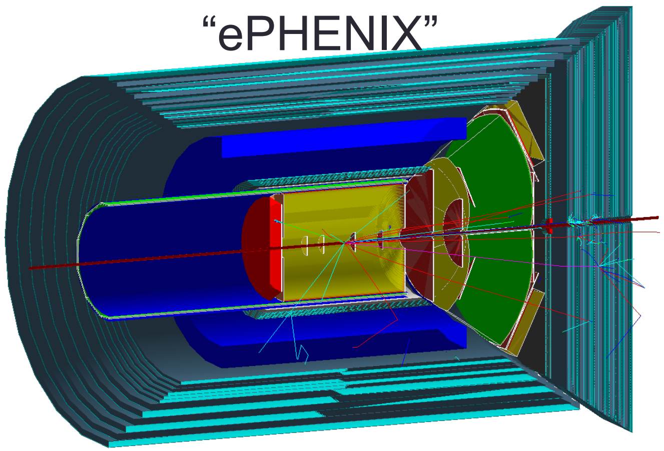

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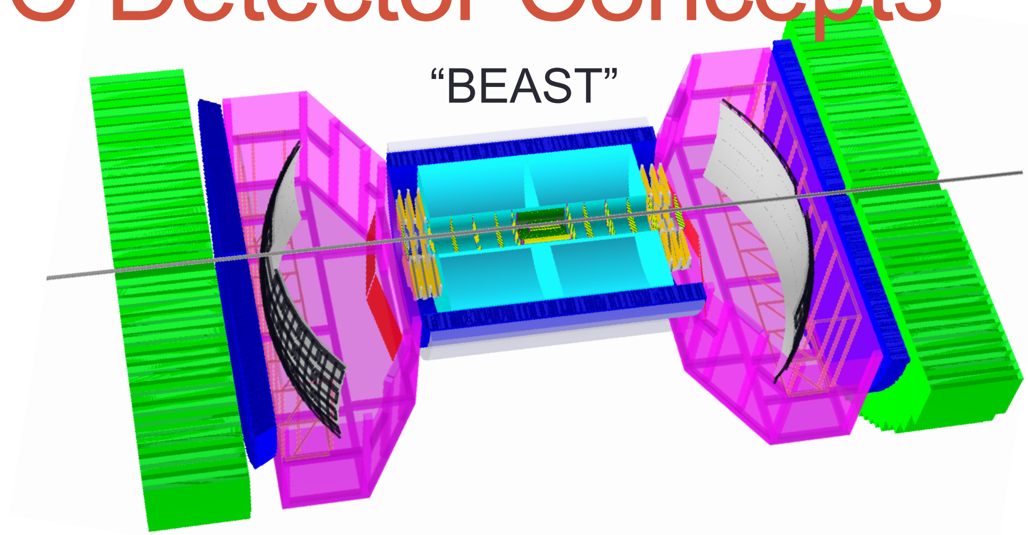
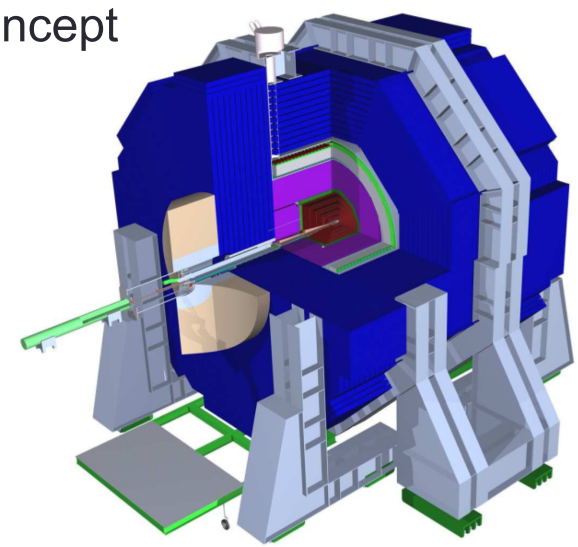
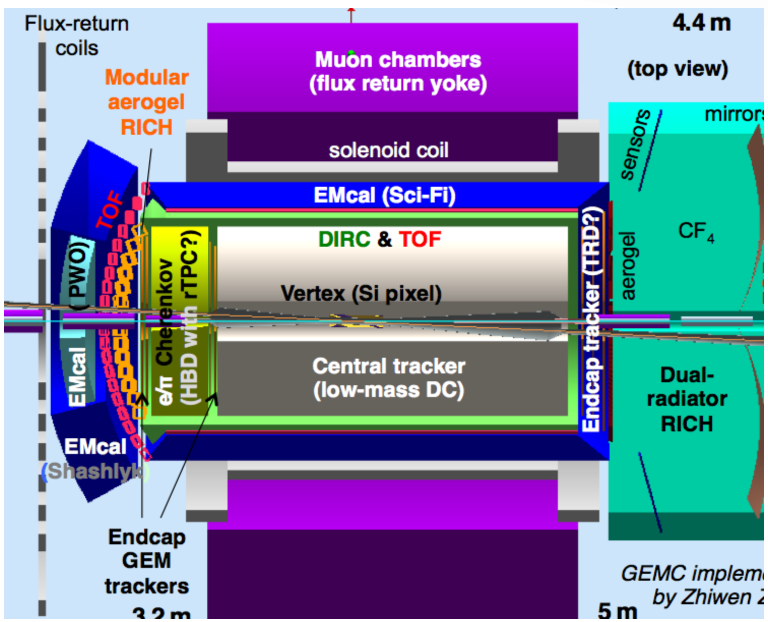


ANL’s: “SiEIC Detector” Si-tracker & Precision calorimetry: particle flow detecor concept

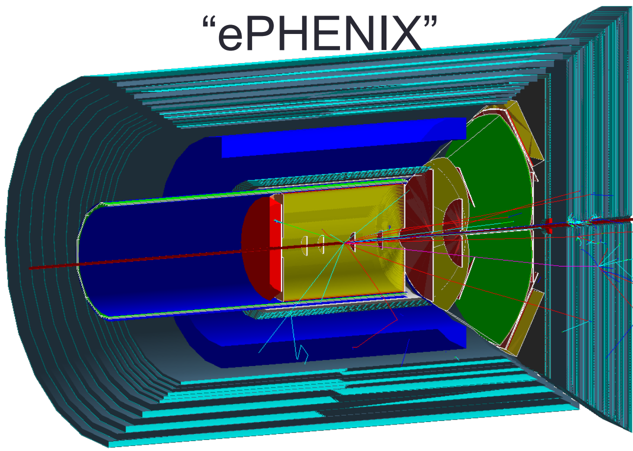




JLEIC

EIC Detector Concepts

“ePHENIX”



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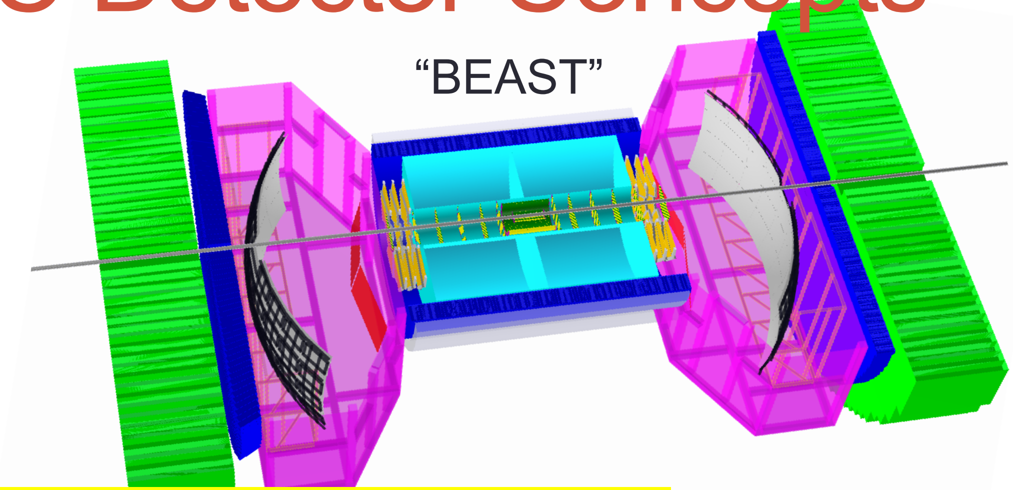
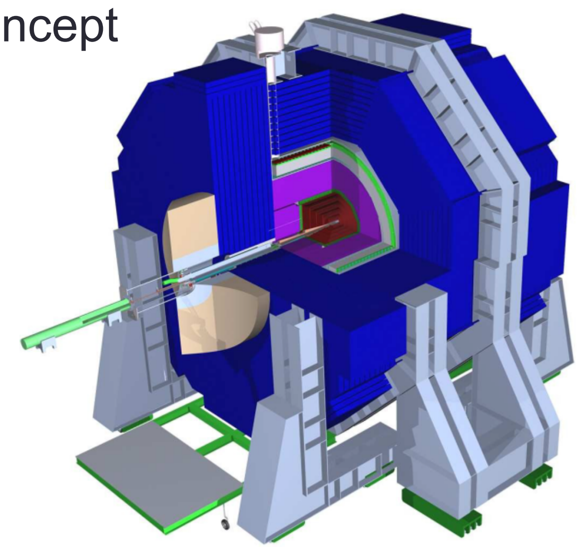
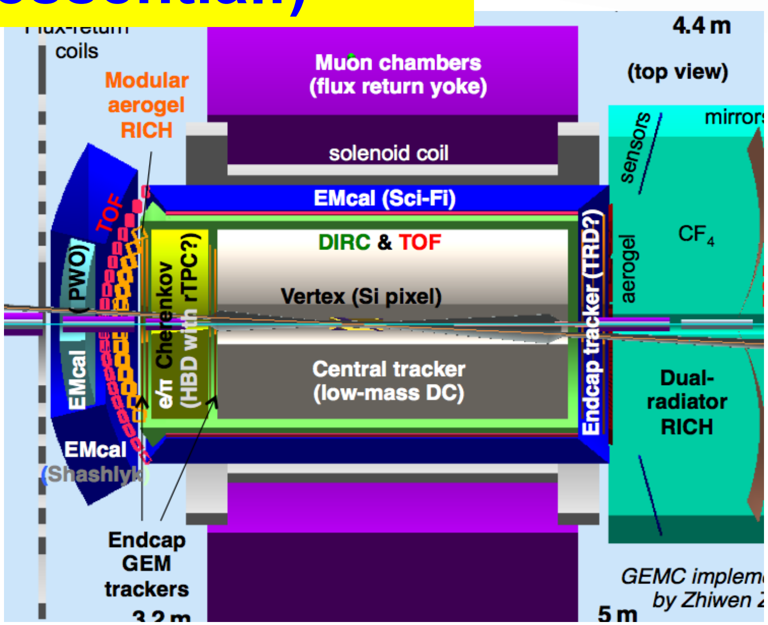


Other ideas from the Users Group are welcome! (essential!)

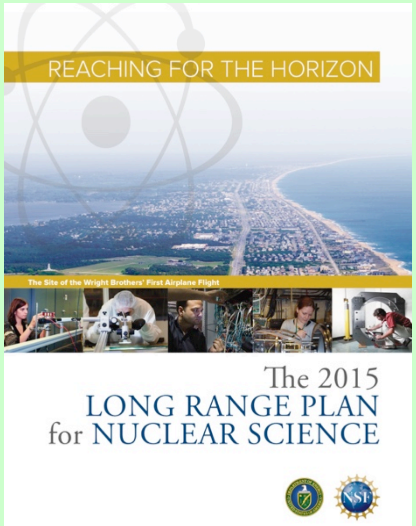
ANL’s: “SiEIC De
Precision calorimetry: particle flow detecor concept



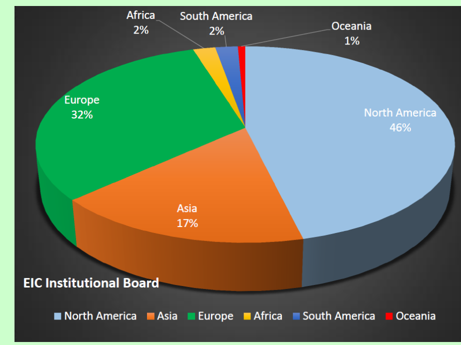


JLEIC

EIC Users Group



"….This facility can lead to the convergence of the present world-leading QCD programs at CEBAF and RHIC in a single facility….."



EIC Users Group: 707 people, 162 institutes 29 Countries

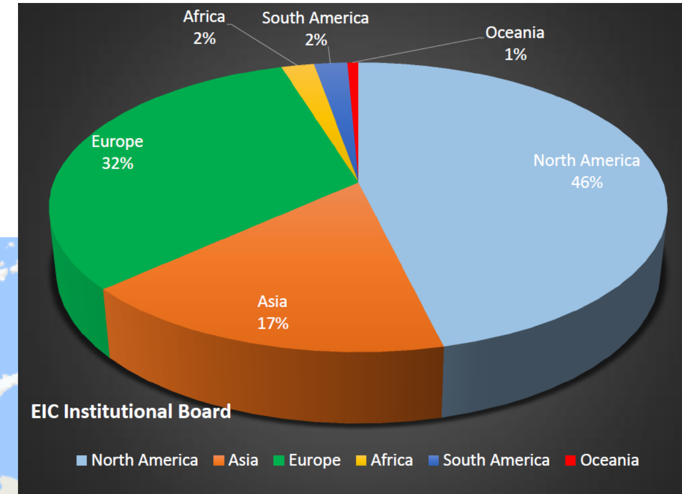
- Established, enthusiastic and active: Approx. 32% users are European, 17% are from Japan, China, India, South Korea, Australia.
- New physics ideas initiated with new influx of people….

The EIC Users Group: EICUG.ORG

(no students included as of yet)

707 collaborators, 29 countries, 161 institutions… (September, 2017)

Map of institution's locations



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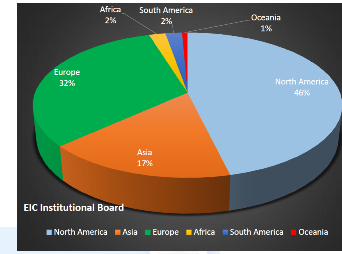


Map of institution's locations

1st EIC Users Meeting at Stony Brook, June 2014:
→ http://skipper.physics.sunysb.edu/~eicug/meeting1/SBU.html

2nd EIC UG Meeting at University of Berkeley, January 6-9, 2016
http://skipper.physics.sunysb.edu/~eicug/meeting2/UCB2016.html

3rd EIC UG Argonne National Laboratory July 7-10, 2016
http://eic2016.phy.anl.gov

4th EIC UG meeting: July 18-22, 2017 Trieste, Italy
https://agenda.infn.it/conferenceDisplay.py?confId=13037

5th EICUG MEETING: Catholic American University, July 2018

New Users → New Physics → Lots of activities

- Jet studies at the EIC:
  - Systematic investigations of general issues in jet-finding at an EIC
  - Understanding of "micro-jets" – jets with only few hadrons
  - Understanding the jet structure modifications in nuclei vs. protons
  - Energy loss in cold QCD matter (Nuclei) vs. hot QCD matter at RHIC and LHC
- Precision measurements of the "initial state" for collisions leading to the QGP being studied at RHIC and LHC
- Precision PDF measurements in proton, neutron & photons at the EIC:
  - Study the free neutron PDFs through tagging and on-shell extrapolation
  - Study the gluon PDFs at large Bjorken x through evolution and open-charm production
  - Study of gluons TMDs
  - Study the potential impact on Higgs studies in the High-Luminosity LHC era
  - Study the impact of TMDs @ EIC on W-production at the LHC
  - Polarized and unpolarized photon PDFs
- Measurements of PDFs in pions and kaons through the Sullivan process
  - Theoretical studies of the equivalence of near-off-shell and on-shell pions and kaons
  - Study the extraction of, and expected differences of, quark and gluon PDFs in pions, kaons and nucleons, and the relation to their physical masses
- Nucleon structure with electroweak probes, and precision BSM physics (i.e. $\sin^2\Theta_W$)
- Heavy quark & quarkonia production with 100-1000 times HERA luminosity
- In view of new discoveries of multi-quark XYZ states: what could EIC contribute?

New Users → New Physics → Lots of activities

- M…
- …relation to their physica…
- …n electroweak probe…
- …onia production with…
- in view of new discoveries of multi-quark…

New Users → New Physics → Lots of activities

Programs related to EIC

Highly Active EIC Community has evolved

Detector R&D

An active Generic Detector R&D Program for EIC underway (supported by DOE administered by BNL, T. Ullrich):

- An external committee of 8 peple reviews all proposals
- ~140 physicists, 31 institutes (5 Labs, 22 Universities, 9 Non-US Institutions) 15+ detector consortia exploring novel technologies for tracking, particle ID, calorimetry
- → *Weekly meetings, workshops and test beam activities already underway*
- → *https://wiki.bnl.gov/conferences/index.php/EIC_R%25D*
- → *MUCH TO BE DONE… despite many successes….*

Currently the program receives ~$1.3M annually.

Recently requested an **increase to two-three times this amount in near future**, mainly dictated by **doubling of proposals in 2017/18** and potential growth of the **active Users Group**.

Opportunity for non-US Sources to make an impact!

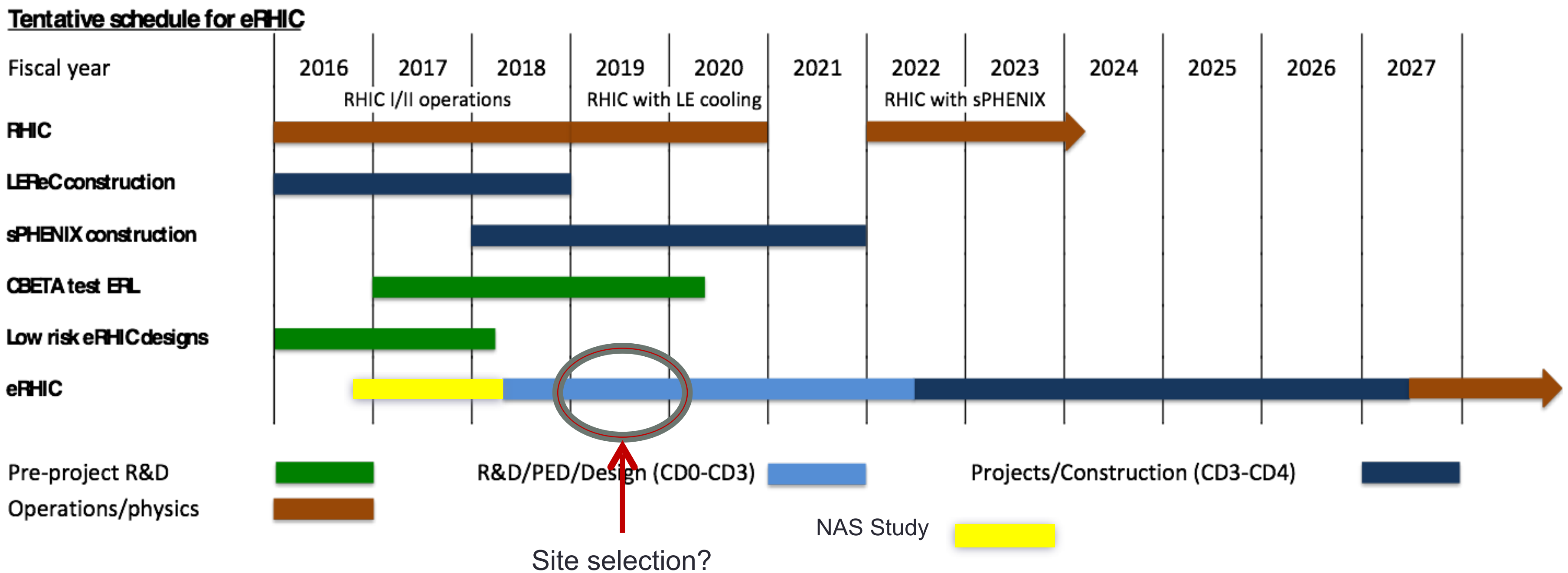
Path forward for the EIC:

- Science Review by National Academy of Science (& Engineering & Arts) (National Research Council)
  - Committee being formed now, expect report by Early 2018
- Positive NAS review will trigger the DOE's CD process
  - CD0 (acceptance of the critical need for science by DOE) FY19
  - EIC-Proposal's Technical & Cost review → FY20 (site selection)
  - CD2 requires site selection
  - **Major Construction funds ("CD3") by 2022/23"**
    - 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

EIC / eRHIC Schedule

JLEIC readiness schedule
not too different

- Design of baseline Ring-Ring option with recirculating electron Linac based on existing technology is in progress; cost saving alternatives are being investigated
- We intend to complete a full pre-CDR and conduct a technical and cost review in 2018
- R&D into cost reducing and/or luminosity enhancing technologies continues
- Major R&D projects: C-BETA high-current multi-pass ERL demonstrator; coherent electron cooling (CeC) experiment; high-intensity polarized electron sources



Courtesy B. Mueller, ALD @ BNL

Summary:

The EIC (with its precision and control) will profoundly impact our understanding of **the many body structure of nucleons and nuclei in terms of sea quarks & gluons** → ***The bridge between sea quark/gluons to Nuclei***

The EIC will enable **IMAGES** of **yet unexplored regions of phase spaces in QCD** with its high luminosity/energy, nuclei & beam polarization

→ ***High potential for discovery***

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World wide interest and opportunity in collaborating on the EIC

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Accelerator scientists at RHIC, Jlab in collaboration with **many outside accelerator experts** will provide the **intellectual and technical leadership to realize the EIC** -- *a frontier accelerator facility.*

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Future QCD studies, particularly for Gluons, demands an Electron Ion Collider

NSAC agrees and we are moving forward!

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→

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W

The scientists at HEGZ have special expertise in measurements in the *very forward region*:

→ Could make a very decisive contribution to the project IR/Detector Design

Accelerator scientists at RHIC, Jlab in collaboration with **<u>many outside accelerator experts</u>** will provide the **intellectual and technical leadership to realize the EIC --** *a frontier accelerator facility.*

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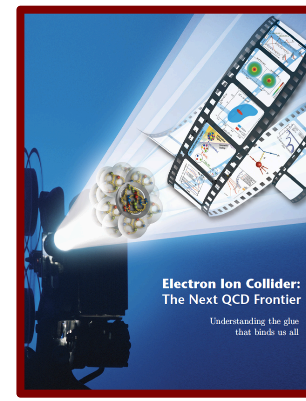
THANK YOU

Thanks to many of my EIC Collaborators and Enthusiasts who led many of the studies presented in this talk
See: arXiv:1108.1713, D. Boer et al.

Without the EIC White Paper Writing Group the EIC White Paper would not have existed.
Special thanks to Dr. Jianwei Qiu and Prof. Zein-Eddine Meziani, my Co-Editors for the EIC White Paper
See: arXiv:1212.1701.v3 , A. Accardi et al.
Eur. Phy. J. A 52, 9 (2016)



The eRHIC and JLEIC machine design teams

Also gratefully acknowledge recent input from: M. Diefenthaler, R. Ent, R. Milner and R. Yoshida

Assumption: "Modest Growth" → 1.6% growth/year above constant effort

The 2015 Long Range Plan for Nuclear Science

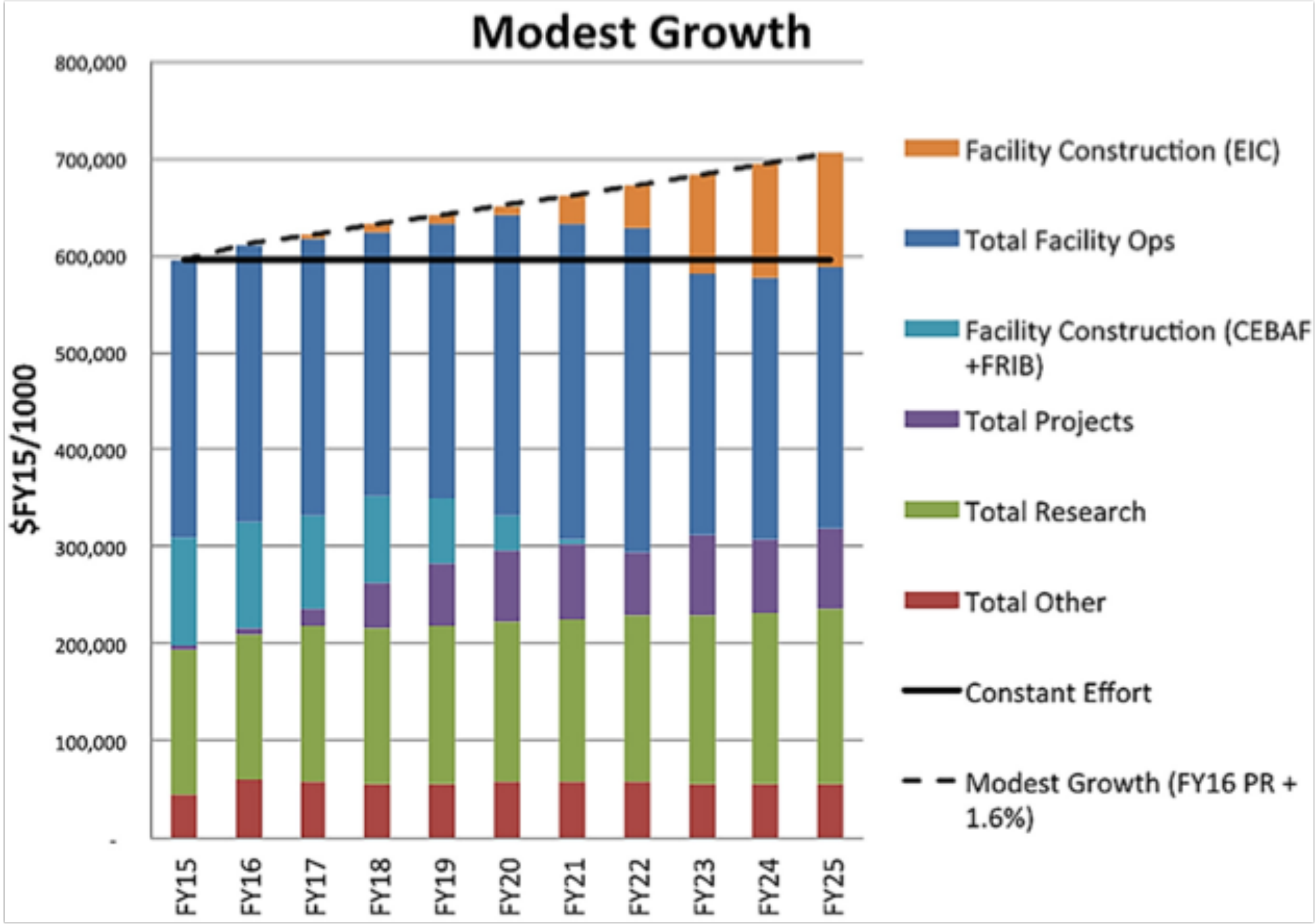


Figure 10.4: *DOE budget in FY 2015 dollars for the Modest Growth scenario.*

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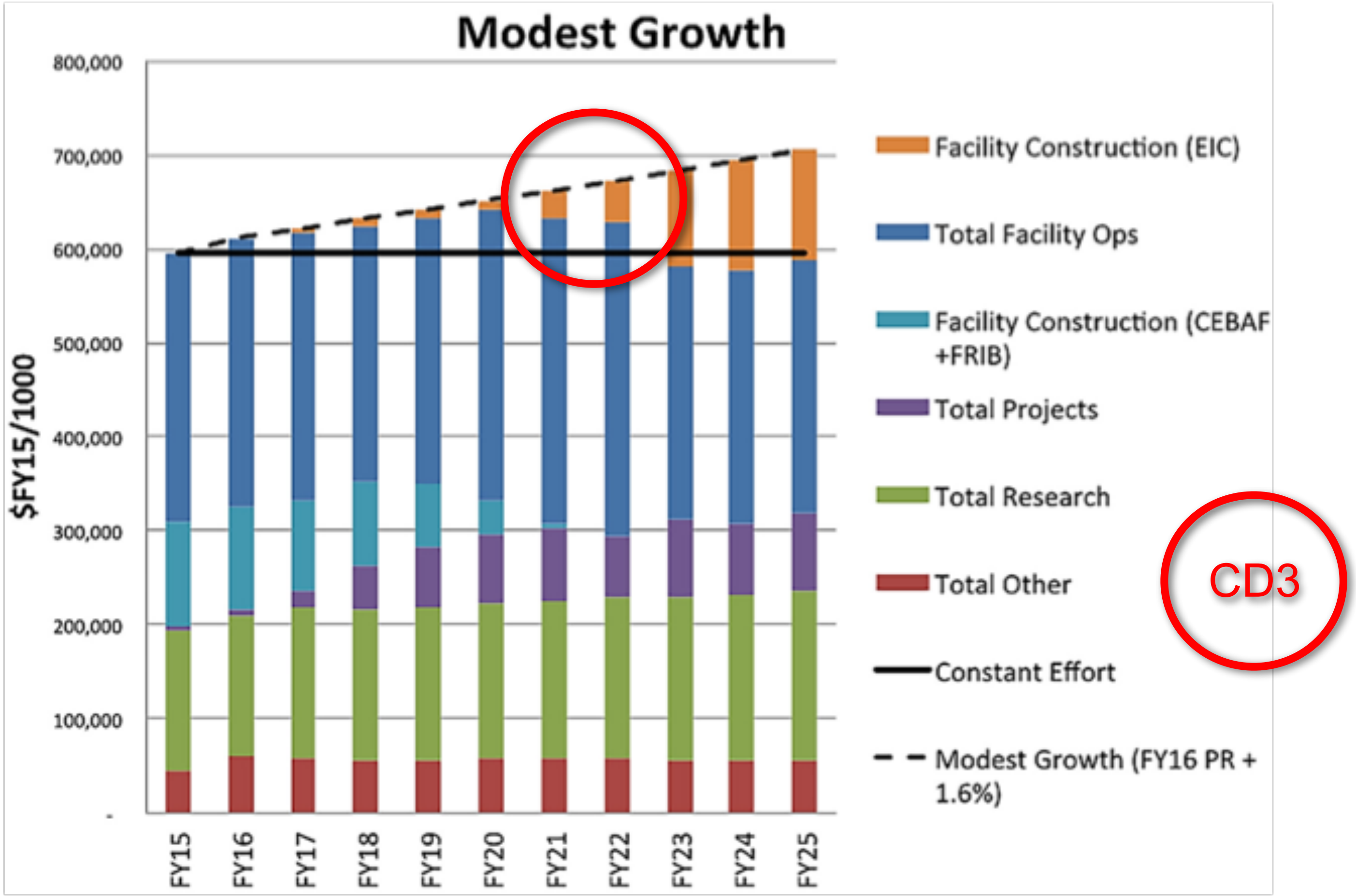

Figure 10.4: DOE budget in FY 2015 dollars for the Modest Growth scenario.

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.*