The Electron-Ion Collider

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University of Glasgow

UK Nuclear Physics Community Meeting,
University of Warwick,
5th January 2017

Electron-Ion Collider

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

For e-N collisions at the EIC:

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

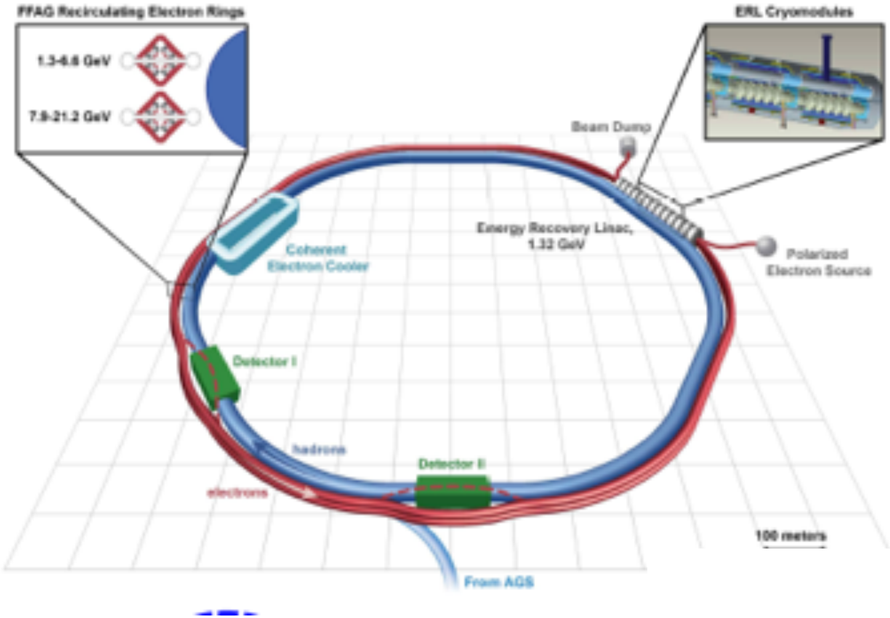
For e-A collisions at the EIC:

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

Two proposals for realisation of the science case:
JLEIC at Jefferson Lab, eRHIC at Brookhaven National Lab.

Design in flux: physics case evolving, machine and detector design developing.

The two EIC designs

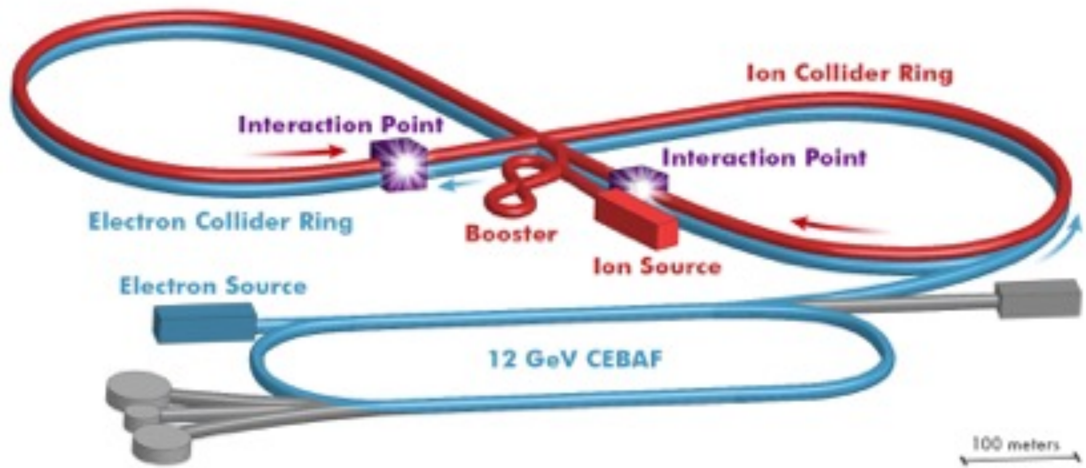


eRHIC at Brookhaven National Lab

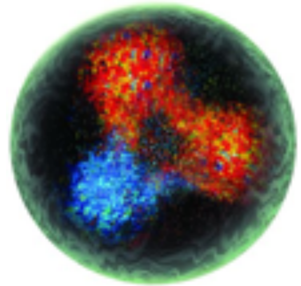
arXiv:1409.1633

JLEIC at Jefferson Lab

arXiv:1504.07961

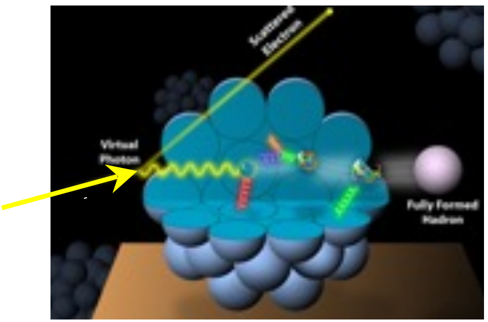


How do hadrons and nuclei emerge from quarks and gluons? What is the nature of confinement?



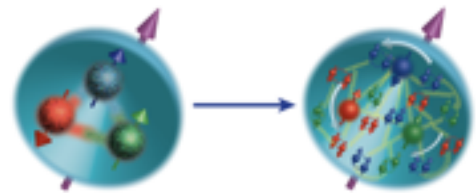
Courtesy of CNRS

What is the quark-gluon origin of the nuclear force?



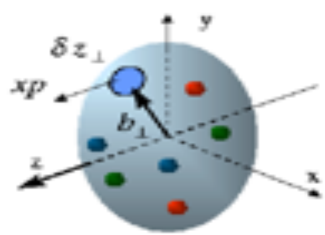
Courtesy of E. Aschenauer

Some questions for the EIC



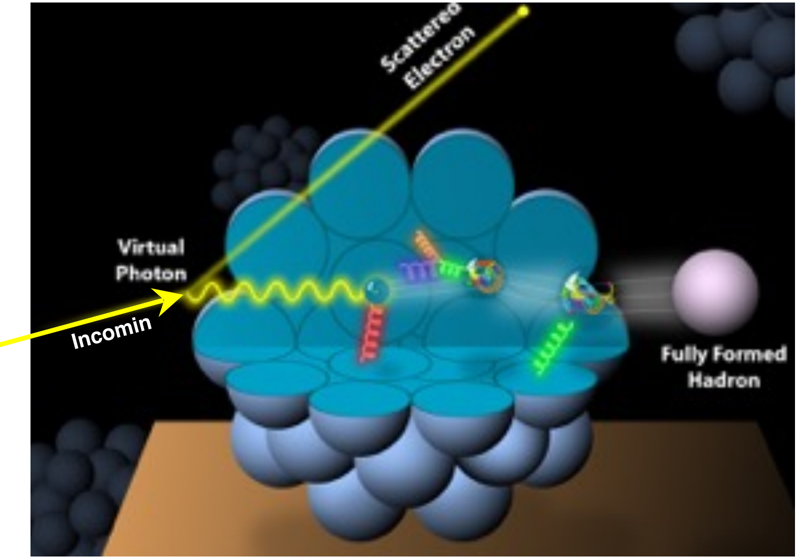
What is the full composition of nucleon spin? How much do sea quarks and glue contribute?

How does colour charge propagate through nuclear matter? Are there differences for light and heavy quarks?



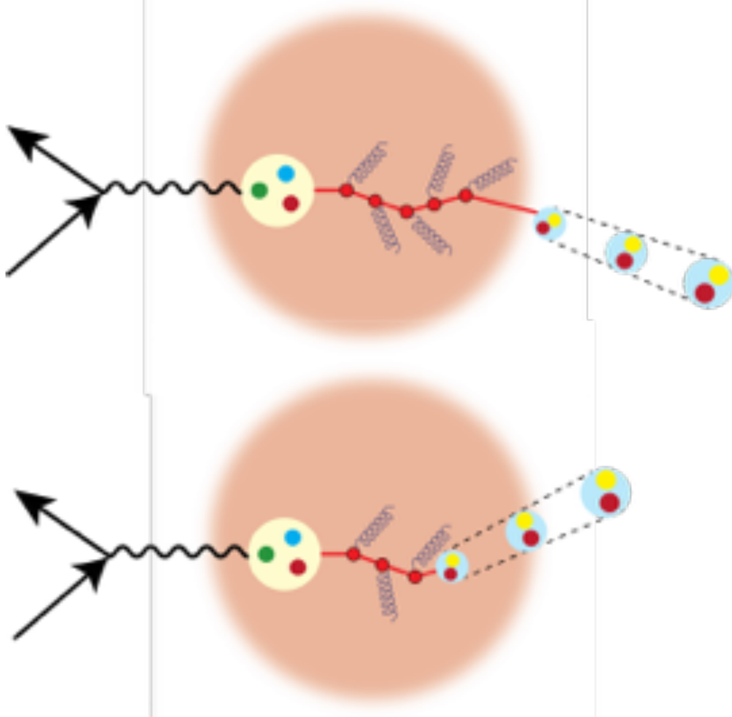
What is the origin of nucleon mass and what is the role of glue in it?

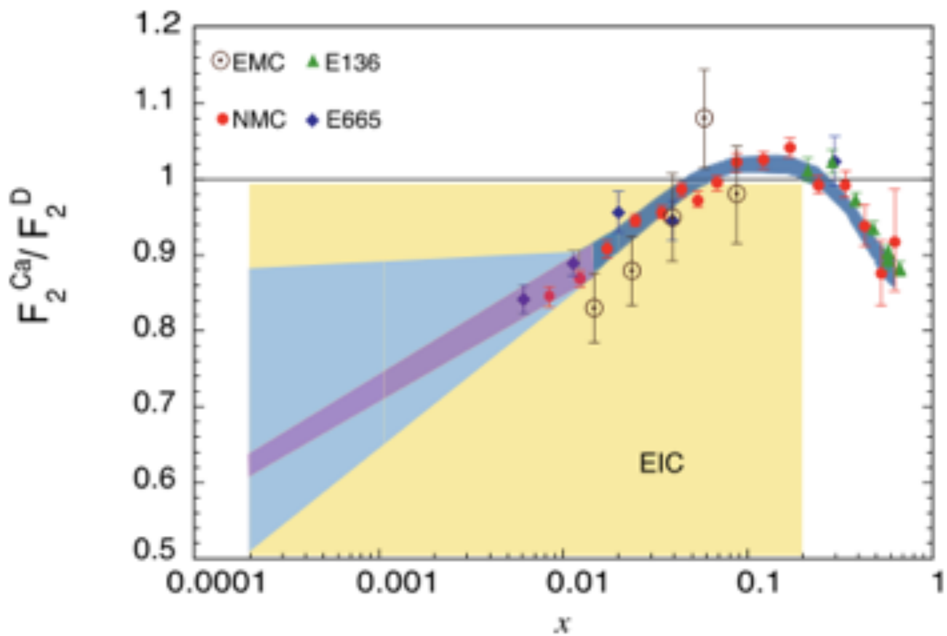
Hadronisation



Courtesy of E. Aschenauer

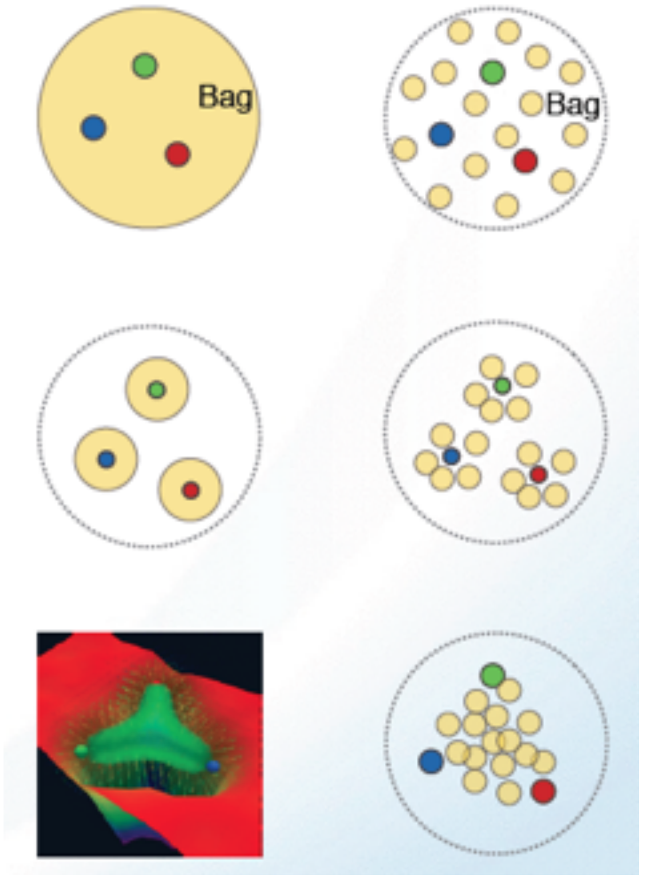
- How does the nuclear environment affect the quark-gluon distributions and their interactions inside nuclei?
- How does matter respond to a fast moving colour charge?
- Are there differences for light and heavy quarks?





Interpretations of the nucleon

What do spatial distributions tell us?



Courtesy of A. Deshpande

Bag Model: Gluon field distribution is wider than the fast moving quarks.

Gluon radius > Charge Radius

Constituent Quark Model: Gluons and sea quarks hide inside massive quarks.

Gluon radius ~ Charge Radius

Lattice Gauge theory (with slow moving quarks), gluons more concentrated inside the quarks:

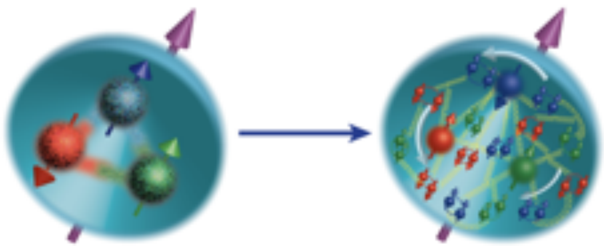
Gluon radius < Charge Radius

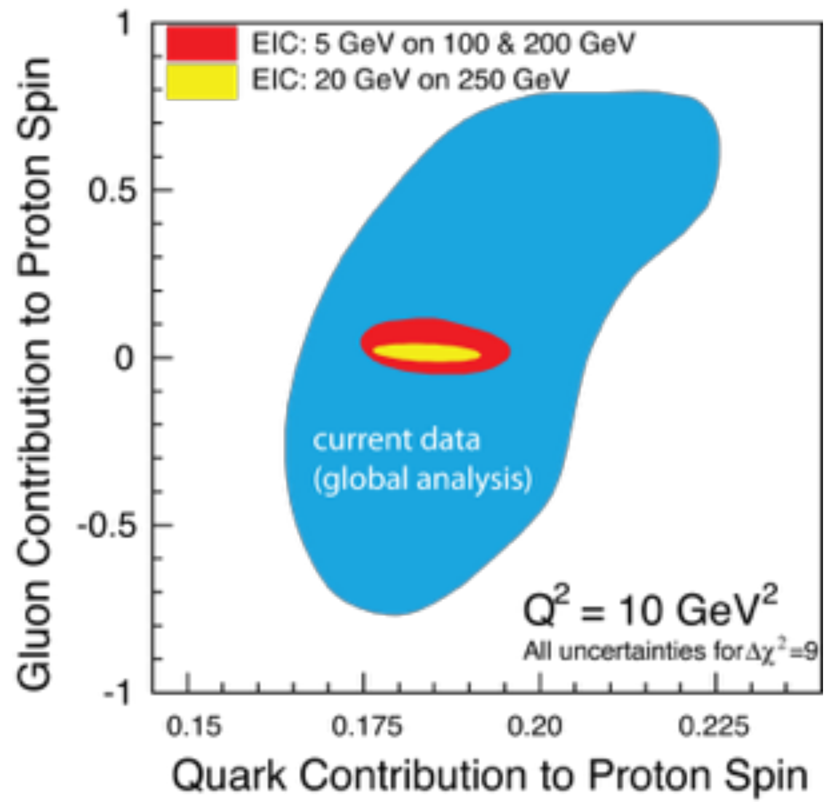
Need transverse images of the quarks and gluons in confinement: form factors

The puzzle of nucleon spin

- Gluons carry a sizeable fraction of nucleon momentum and give rise to transverse momentum of quarks. What is their contribution to nucleon spin? How do sea quarks contribute?

$$J_q = \frac{1}{2}\Delta\Sigma + L_q + J_g$$





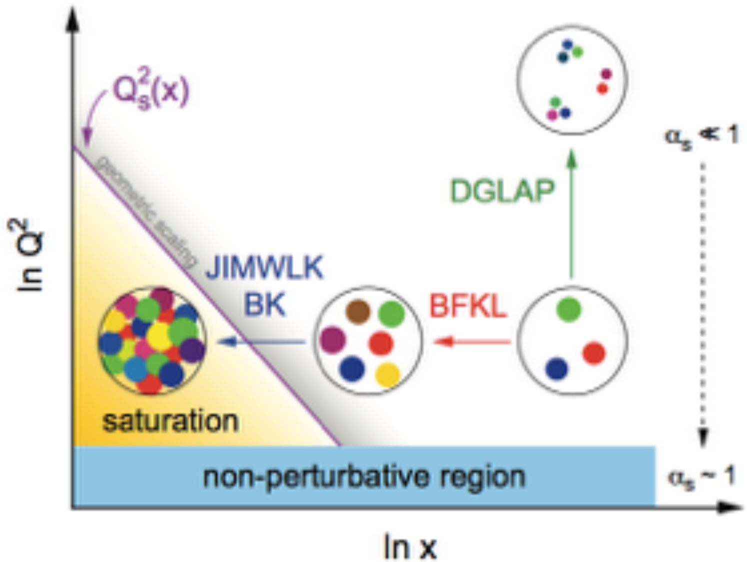
- 3D imaging of the hadrons across the widest range of scales.

Saturation of gluon density

- Runaway growth of glue at low-x:

“…A small color charge in isolation builds up a big color thundercloud….”

F. Wilczek, in “Origin of Mass”
Nobel Prize, 2004



But somewhere it must saturate…

rate of  = rate of 

Possible effective theory for the saturated phase:
Colour Glass Condensate.

2012 EIC White Paper: *Eur. Phy. J. A 52, 9 (2016)*

Physics case has already evolved far beyond it!

EIC timeline (tentative...)

- **2007 Nuclear Physics Long Range Plan**: *"The EIC is embodying the vision of reaching the next QCD frontier"*
- **2012 EIC White Paper**, *Eur. Phy. J. A 52, 9 (2016)*
- **2015 Nuclear Physics Long Range Plan**:*"high-energy, high-luminosity polarised EIC as the highest priority for new facility construction following completion of FRIB"*
- **2016 EIC Users Group acquires formal charter, representatives are elected to the board. Bi-annual meetings in the US. First European meeting of EICUG to be held in Trieste, Italy, July 2017.**
- **2017 National Academies of Science, Engineering and Medicine review of the science case. *First meeting Jan 2017, expect report towards end of the year.***
- **Assuming favourable report, *CD0 stage ~ 2018.***
- ***Construction: ~ 2025?***

Current UK interest

UNIVERSITY of GLASGOW

THE UNIVERSITY OF EDINBURGH

THE UNIVERSITY of LIVERPOOL

The Cockcroft Institute of Accelerator Science and Technology

UNIVERSITY OF BIRMINGHAM

Science & Technology Facilities Council Daresbury Laboratory

Plus some tentative interest from other groups…

“Precision Central Silicon Tracking & Vertexing for the EIC”

Peter Jones, Laura Gonella, Paul Newman, Phil Allport, …

Funded!

UNIVERSITY OF BIRMINGHAM

Proposal to the EIC detector advisory committee in June 2016, for EIC generic detector R&D.

Successful collaboration of nuclear, particle and instrumentation groups, synergies with existing R&D projects.

UNIVERSITY of GLASGOW

THE UNIVERSITY OF EDINBURGH

Physics case: nucleon structure, exotic nuclei.

Detector R&D: polarimetry, photon tagging and DIRC expertise. PID development.

Science & Technology Facilities Council Daresbury Laboratory

The Cockcroft Institute of Accelerator Science and Technology

Accelerator opportunities: pure design, experimental prep and execution, technical R&D.

Strong, existing connections to both JLab and BNL accelerator groups. A list of possible projects identified, some directly synergic with UK-FEL R&D.

First UK EIC meeting

Workshop on Physics & Engineering Opportunities at the Electron-Ion Collider 2016

Home | Programme | Venue | Registration | Accommodation | Travel | Dinner and Whisky Tasting | Entertainment

13 – 14 October 2016, Ross Priory on Loch Lomond, Scotland

https://ukeicworkshop2016.wordpress.com

First UK EIC meeting

https://ukeicworkshop2016.wordpress.com

Summary

- Electron-Ion Collider is a becoming the highest priority for US nuclear physics.

- The EIC Community spans the Americas, Europe, Asia and Australia.

  http://www.eicug.org

- The US EIC leadership is ***extremely positive*** about UK, and other European, involvement, *e.g.*:
  - Funding has been granted to the Birmingham project on tracking R&D.
  - Talks about concrete accelerator projects are underway with both JLab and BNL.
  - Work on the physics case is ongoing in a number of UK institutions, in collaboration with international colleagues.

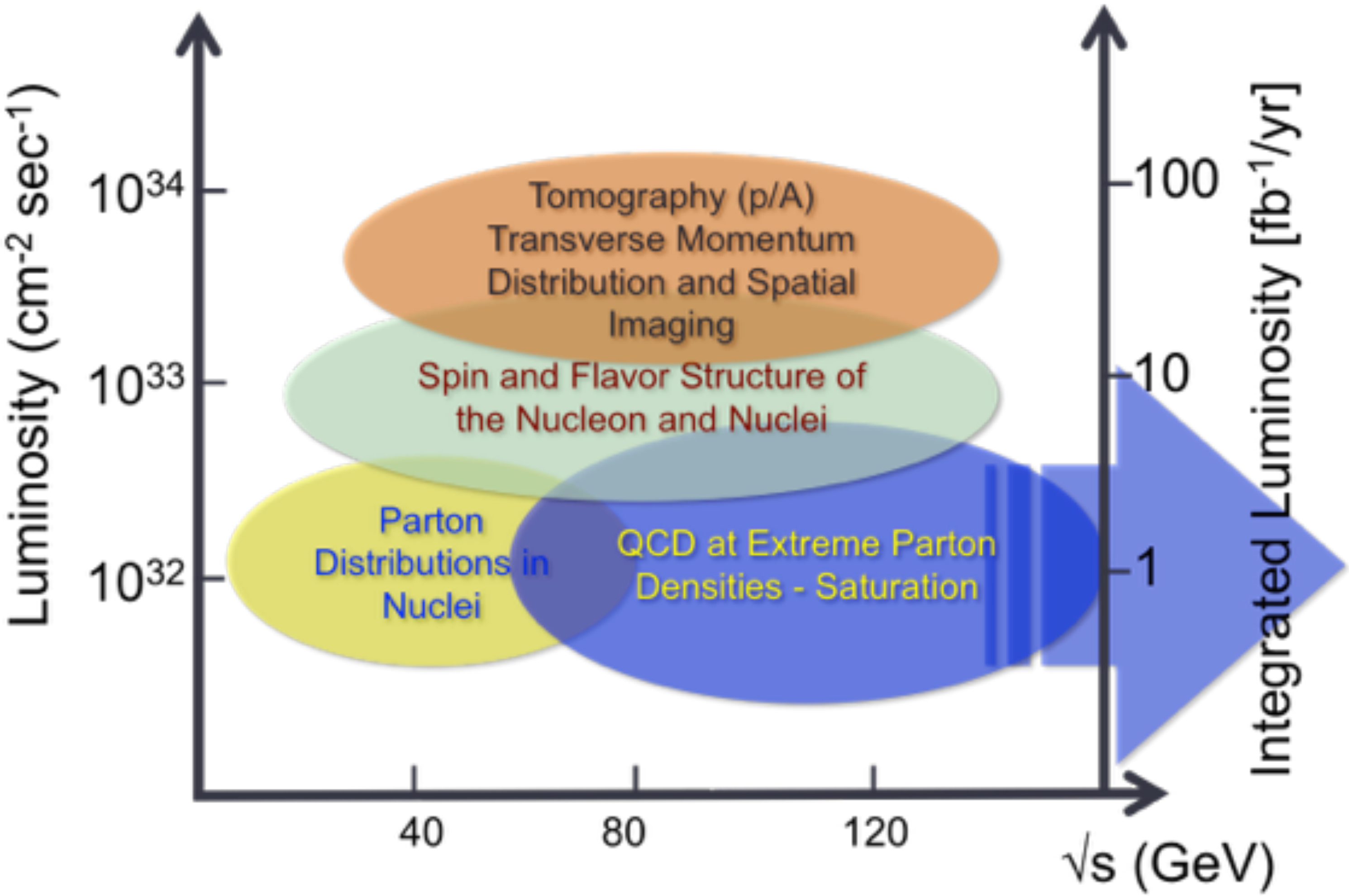
- Scope for contribution on all fronts, ***much overlap with existing projects.***

- UK involvement needs to be co-ordinated with the US timeline and within the UK.

→ UK EIC forum, perhaps meeting bi-annually?

Thank you

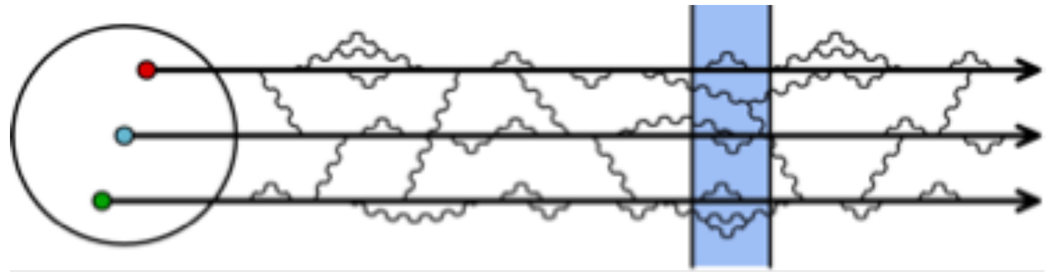
What will the EIC be able to do?



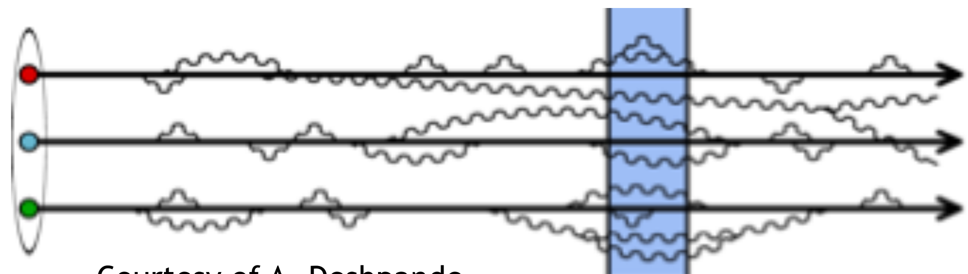
year =10^7 sec

Runaway glue

* Nucleon probed at low Q^2, high x.



* Nucleon probed at large Q^2, low x.

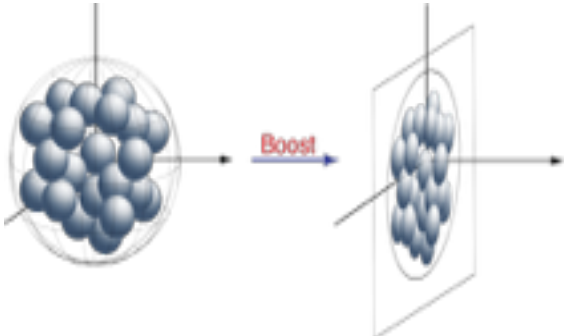


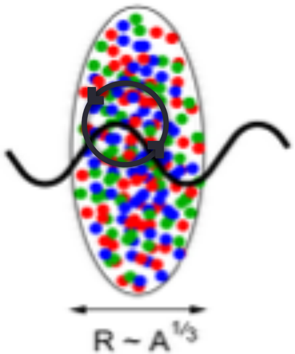
Courtesy of A. Deshpande

* Gluons are charged under colour: can generate (and absorb) other gluons.

* Nucleon probed at high energies, time dilation of strong interaction processes: gluons appear to live longer, emitting more and more gluons. Runaway growth! Runaway growth?

Can we reach saturation at EIC?

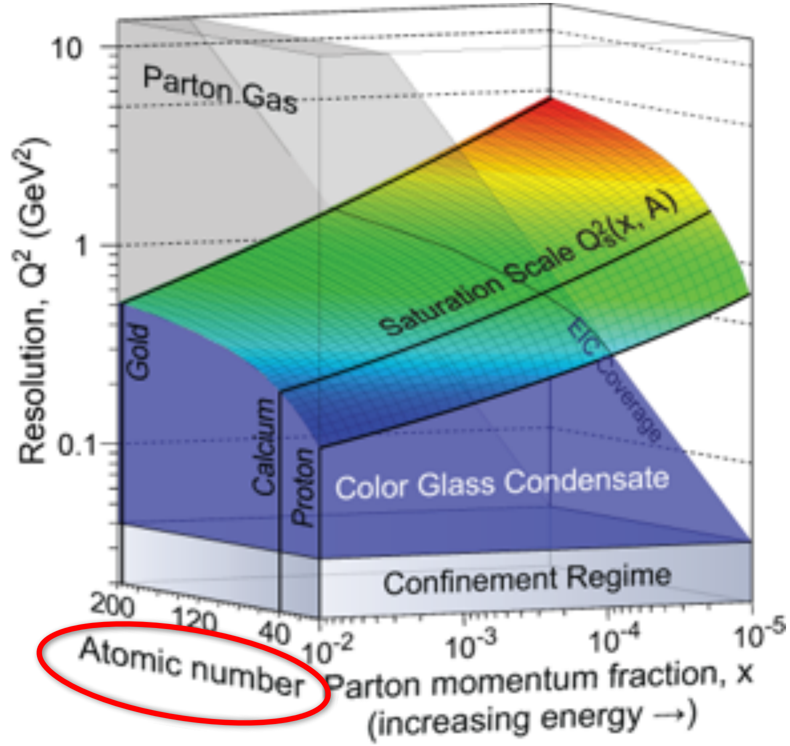




$L \sim (2m_N x)^{-1} > 2\,R_A \sim A^{1/3}$

$$(Q_s^A)^2 \approx cQ_0^2 \left[\frac{A}{x}\right]^{1/3}$$

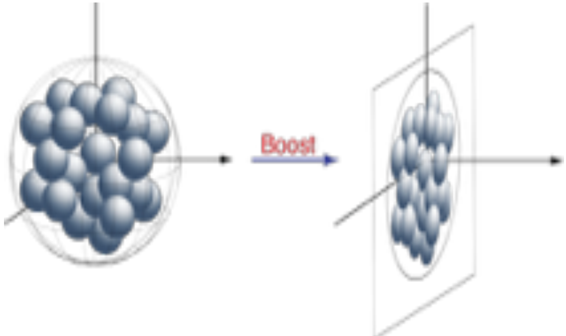
saturation scale

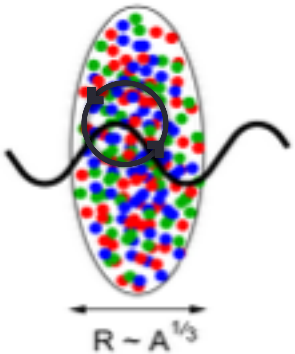


Saturation regime would be accessible at much lower energy in e-A collisions than e-p. You do not need a TeV collider!

Courtesy of A. Deshpande

Can we reach saturation at EIC?





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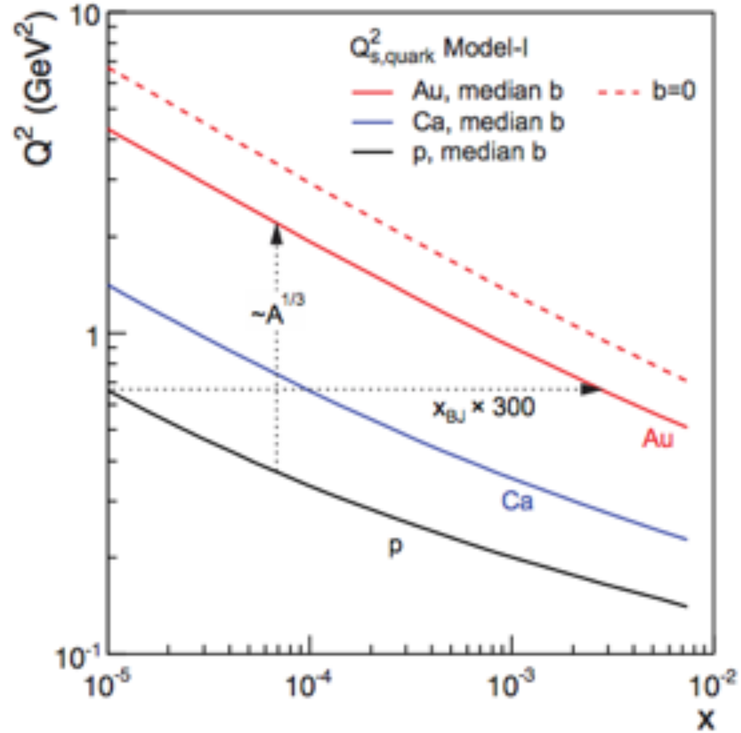


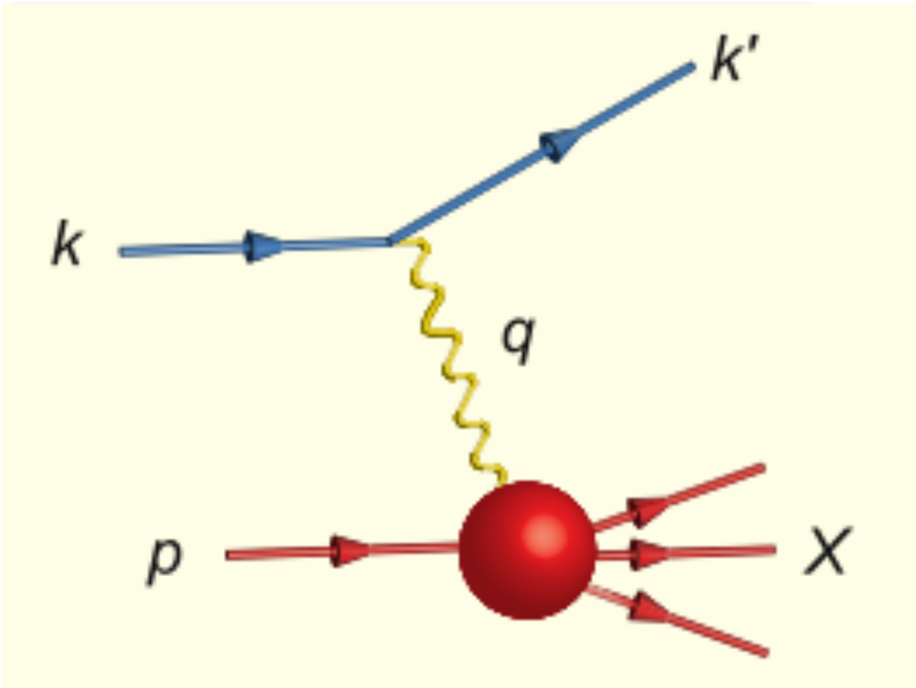
Saturation regime would be accessible at much lower energy in e-A collisions than e-p. You do not need a TeV collider!

Courtesy of A. Deshpande

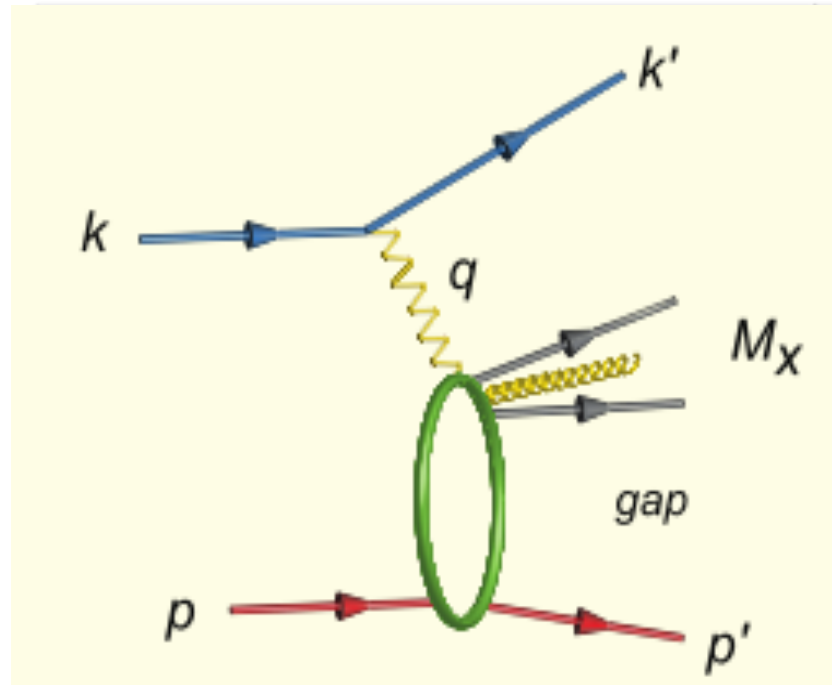
A sign of gluon saturation

A powerful signature is diffractive cross-sections:

Deep Inelastic Scattering



Diffractive Scattering



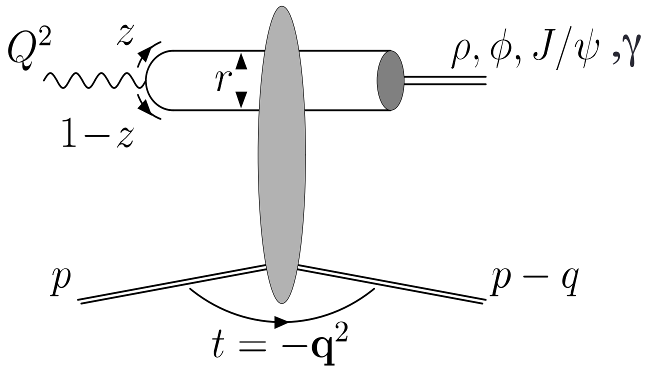
$$\sigma_{\text{diff}} \propto [g(x, Q^2)]^2$$

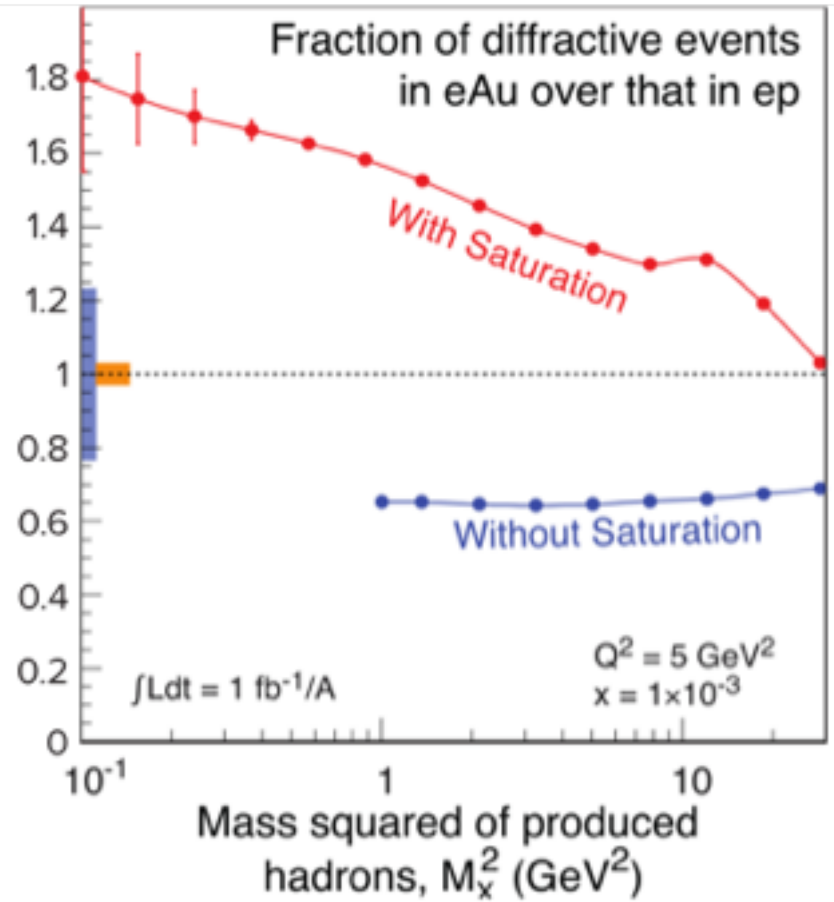
Saw ~10% diffractive events at HERA.

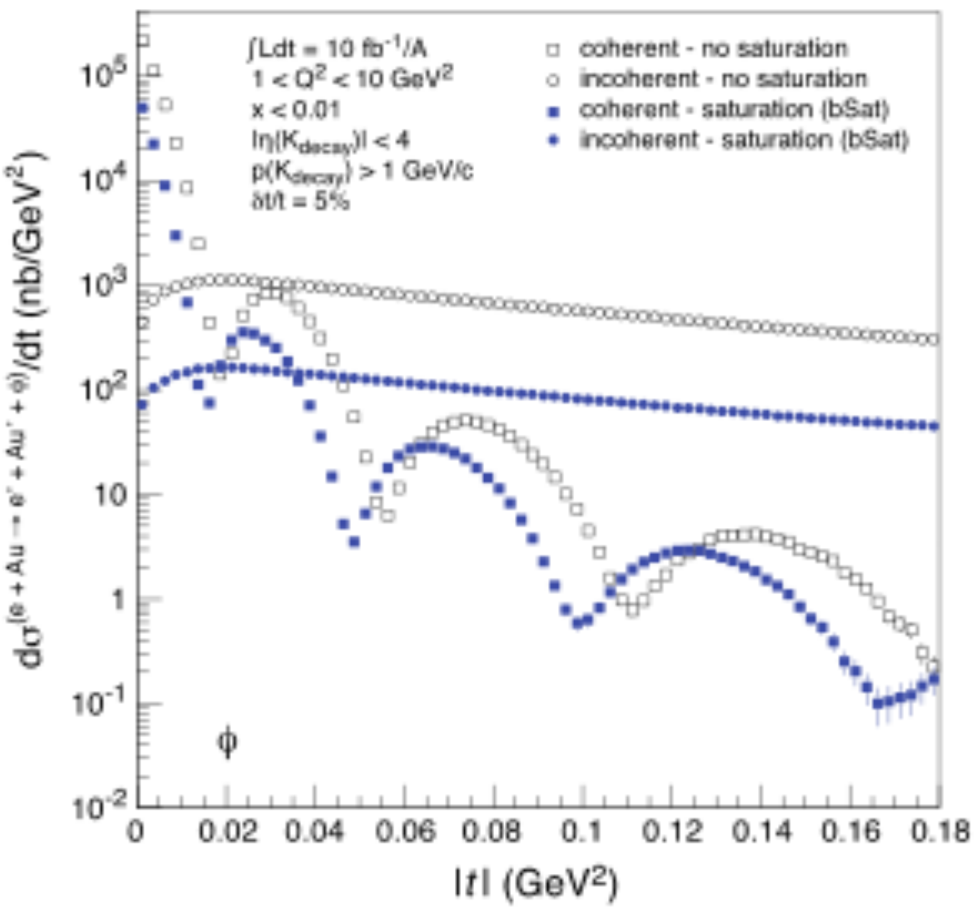
Courtesy of A. Deshpande

Gluon saturation

Modified transverse gluon distributions?





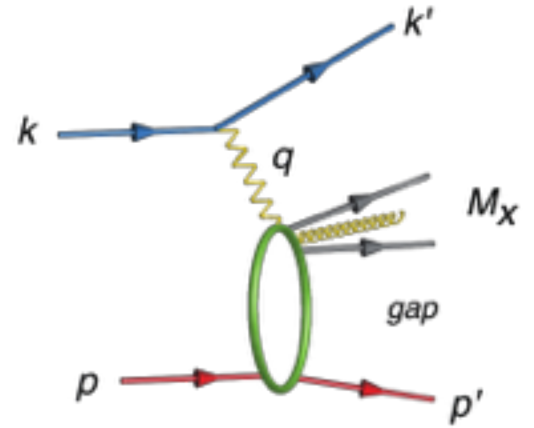


Courtesy of A. Deshpande

Saturation/CGC: What to measure?

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

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

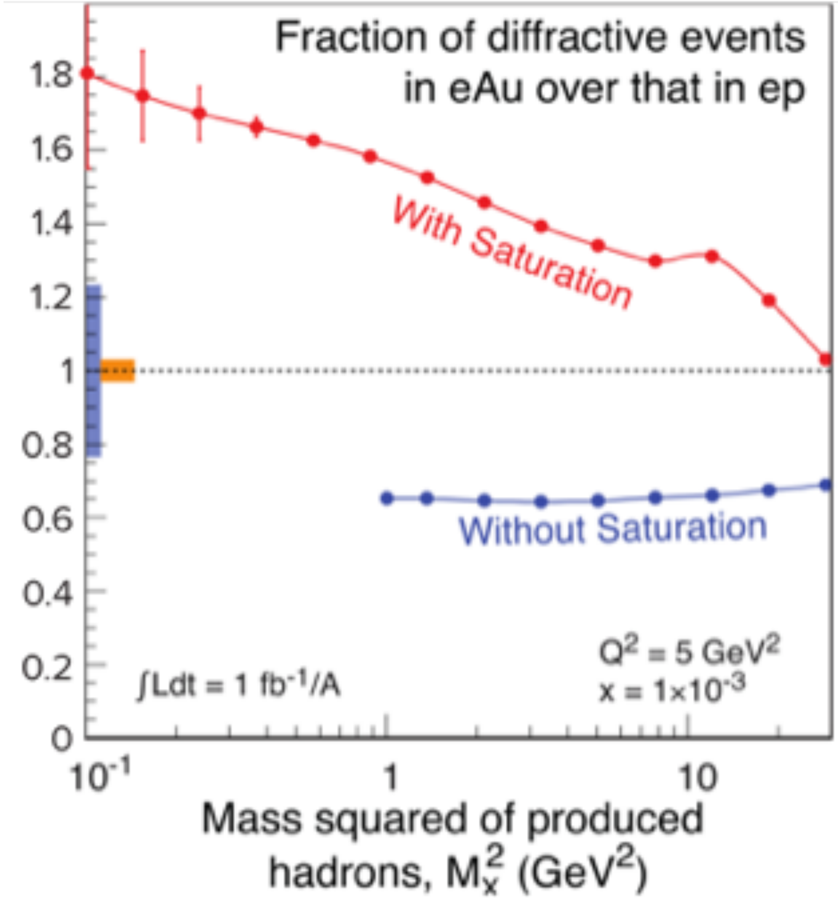


At HERA

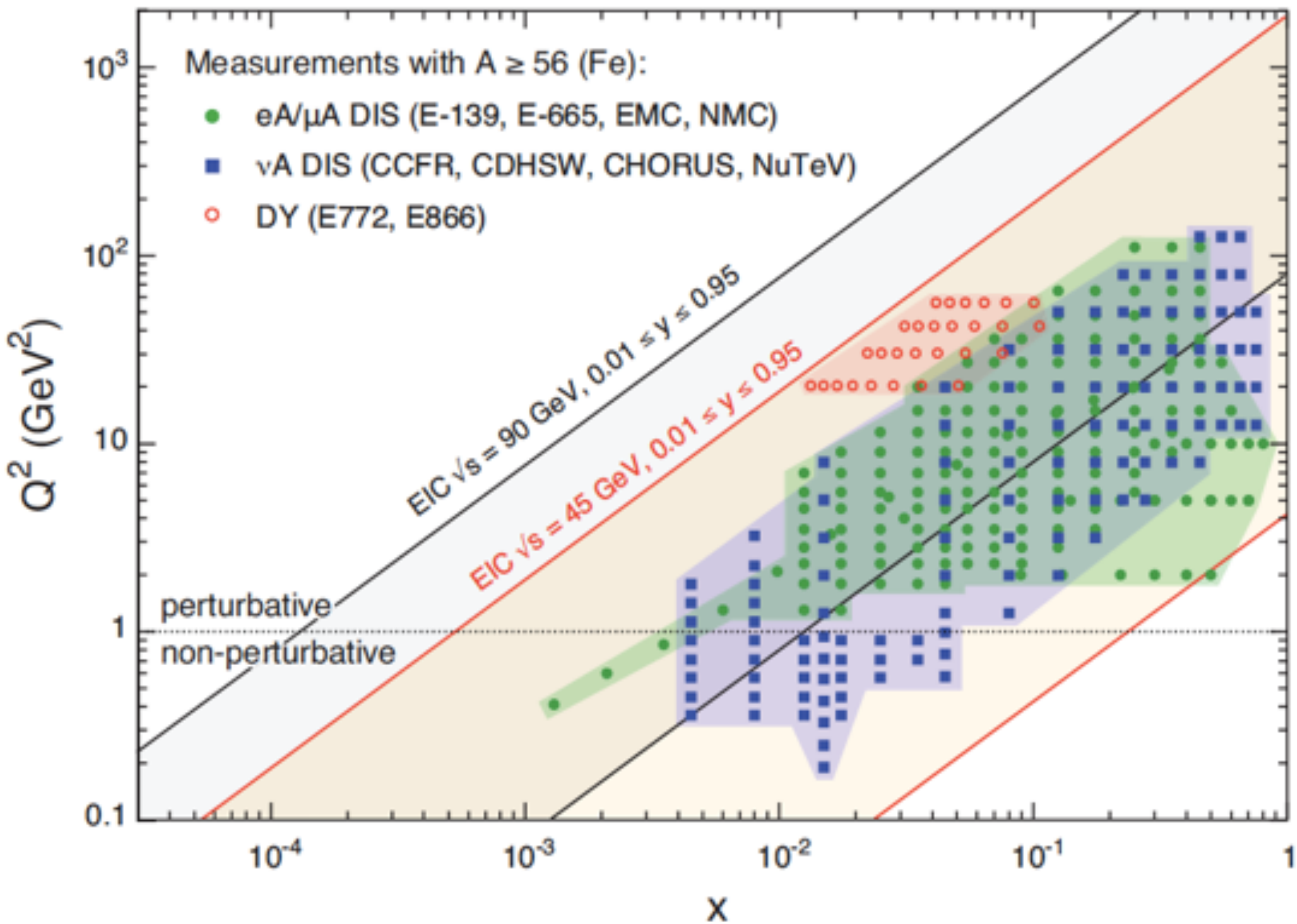
ep: 10-15% diffractive

At EIC eA, if Saturation/CGC

eA: 25-30% diffractive



EIC Reach: electron / heavy-ion

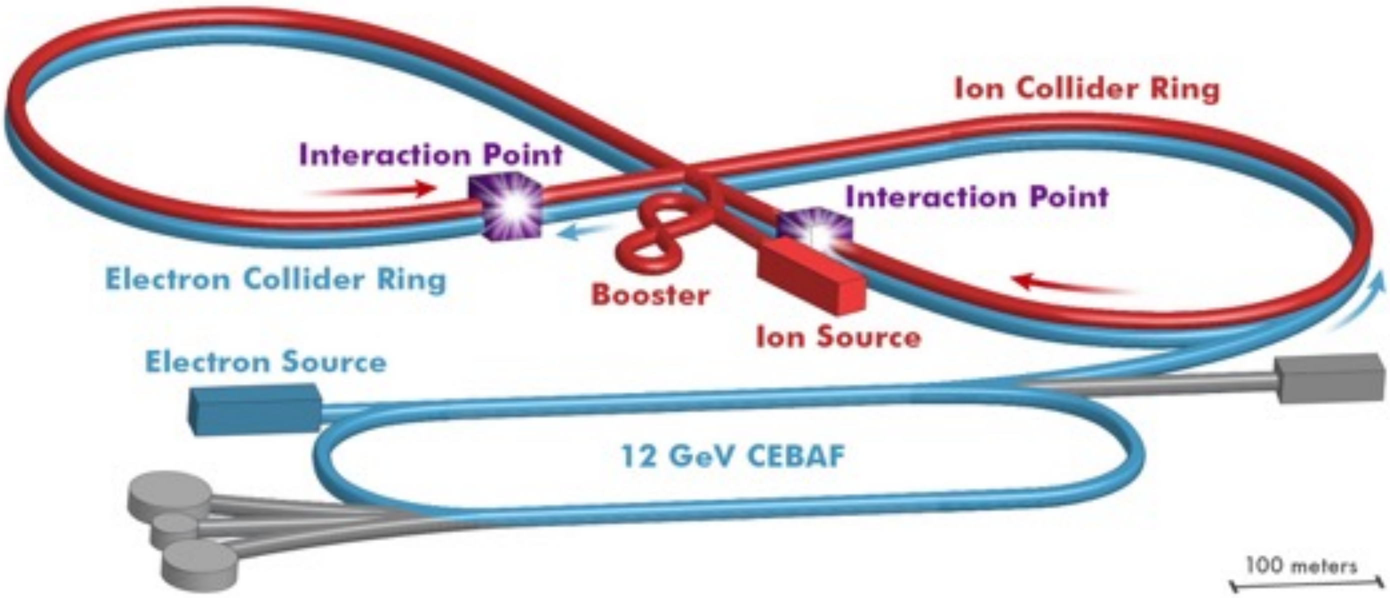


EIC White Paper, arXiv:1212.1701v3 [nucl-ex]

What do we want from the machine?

- Parton imaging in 3D: high luminosity, 10^{33-34} cm^{-2} s^{-1} and above.
- Wide coverage of phase space from low to high x and up to high Q^2: variable centre of mass energy.
- Spin structure: high polarisation of electrons (0.8) and light nuclei (0.7).
- Studies of hadronisation, search for saturation at high gluon densities: a wide range of ion species up to the heaviest elements (p -> U).
- Flavour tagging: large acceptance detectors with good PID capabilities.

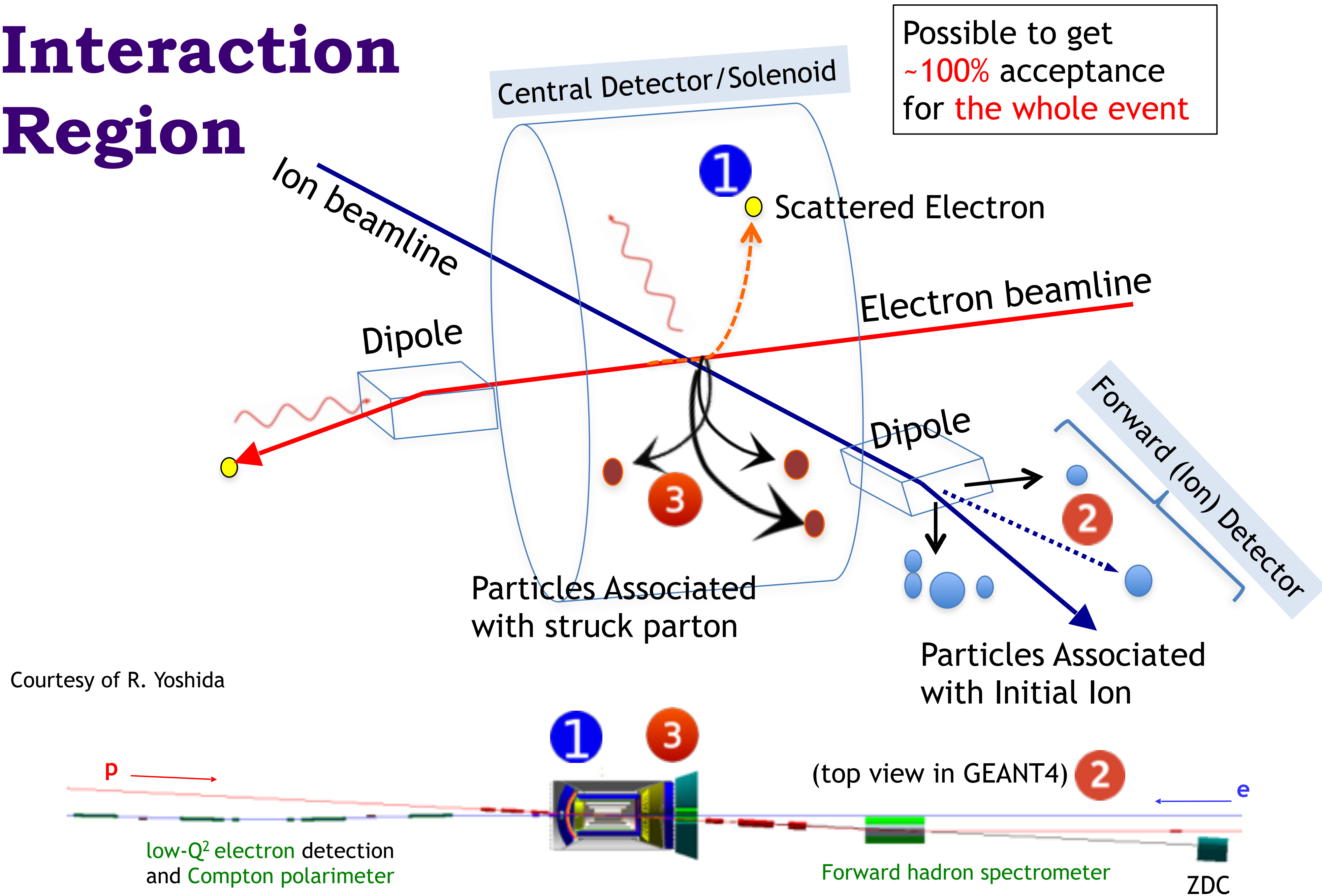
JLEIC



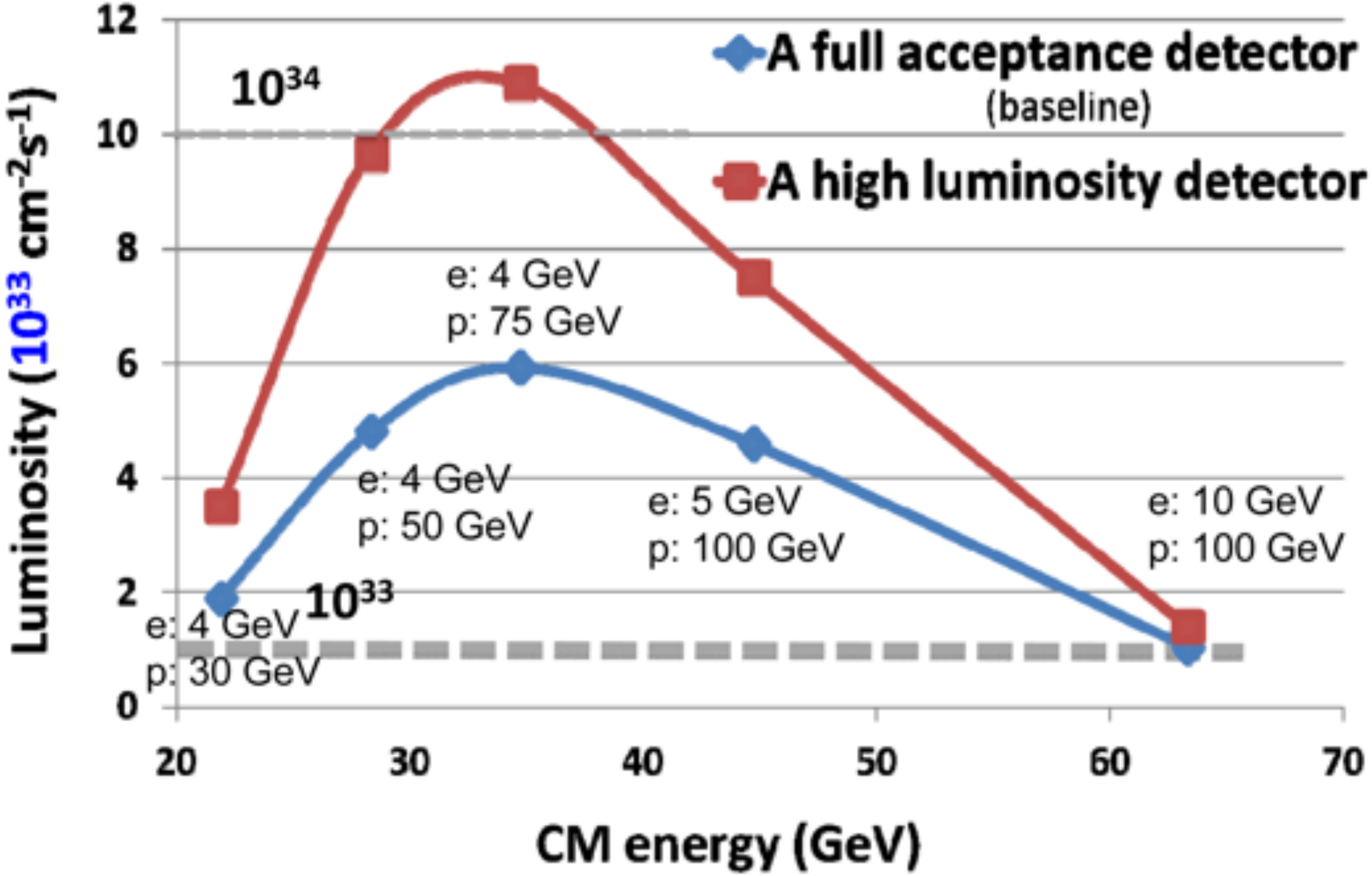
- High luminosity reached through small beam size (small emittance through cooling and low bunch charge with high repetition).

- High polarisation through figure-of-8 design (net spin precession is zero, spin controlled with small magnets)

Interaction Region

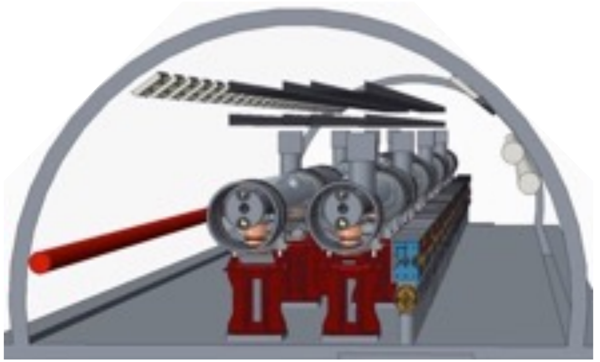


The JLEIC options

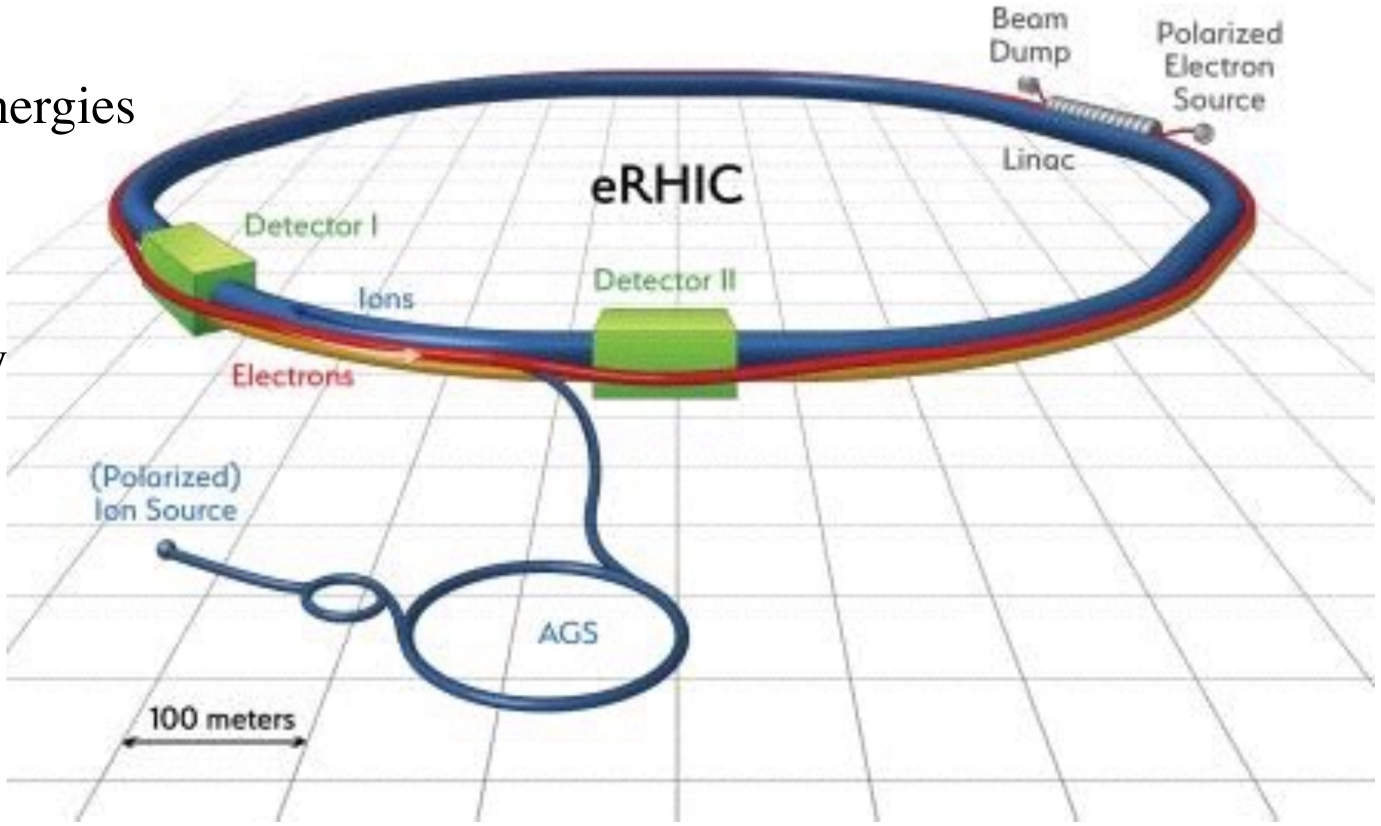


Courtesy of F. Pilat

eRHIC



- Exploit current 275 GeV proton collider by adding 18 GeV electron accelerator in the same tunnel.
- High luminosity requires novel technologies of coherent electron cooling.
- 20 - 140 GeV CoM energies
- Two designs under consideration for electrons: ERL (energy recovery LINAC) and high intensity electron storage ring.



The EIC Users Group

656 Users, 137 Institutes, 27 Countries

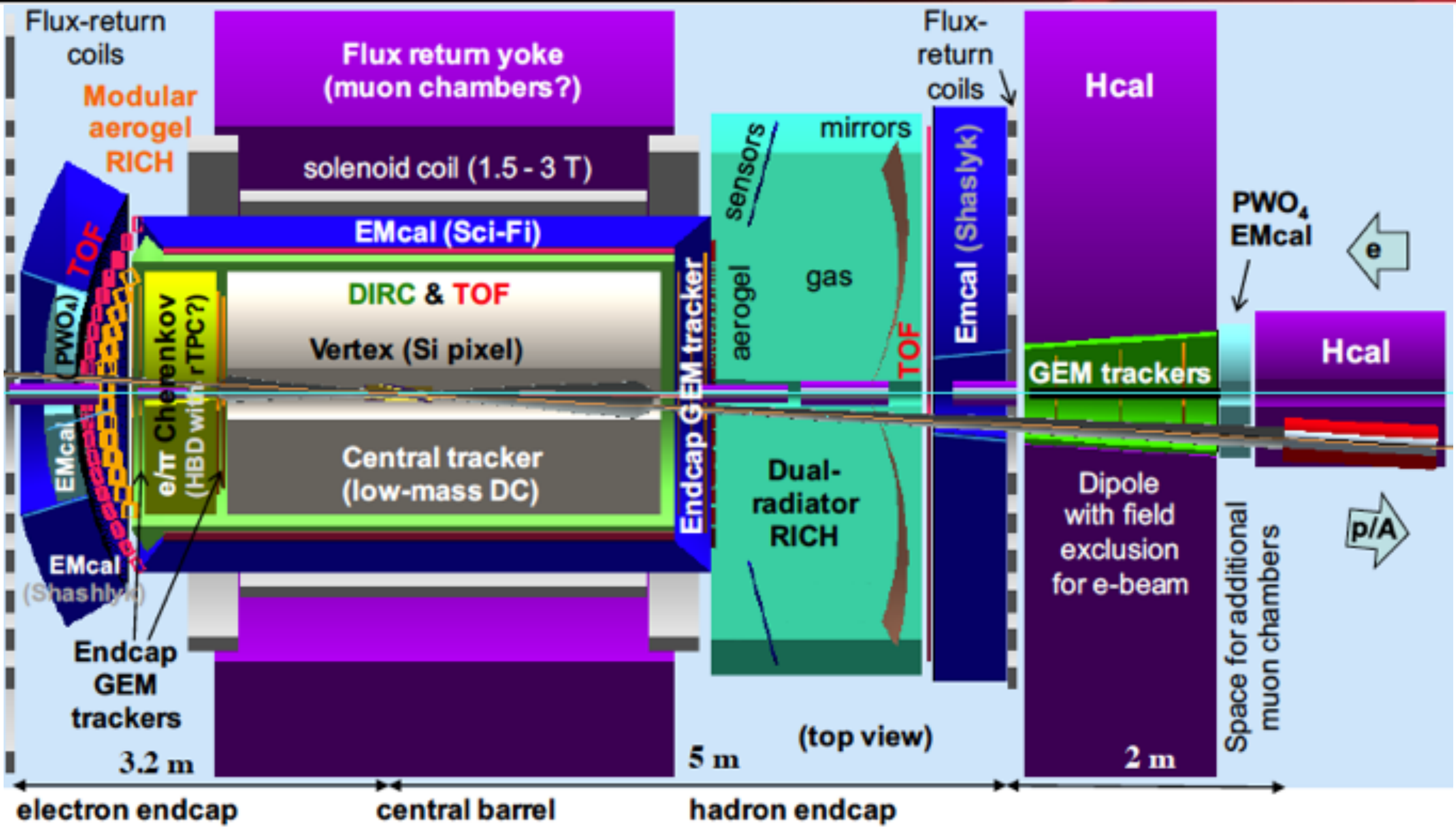
355 experimentalists, 111 theorists, 141 accelerator-physicists, 43 unknowns

Courtesy of A. Deshpande

The EIC Users Group Meeting

Next EICUG meetings: JLab (winter 2016-17),
Trieste, Italy (June/ July 2017).

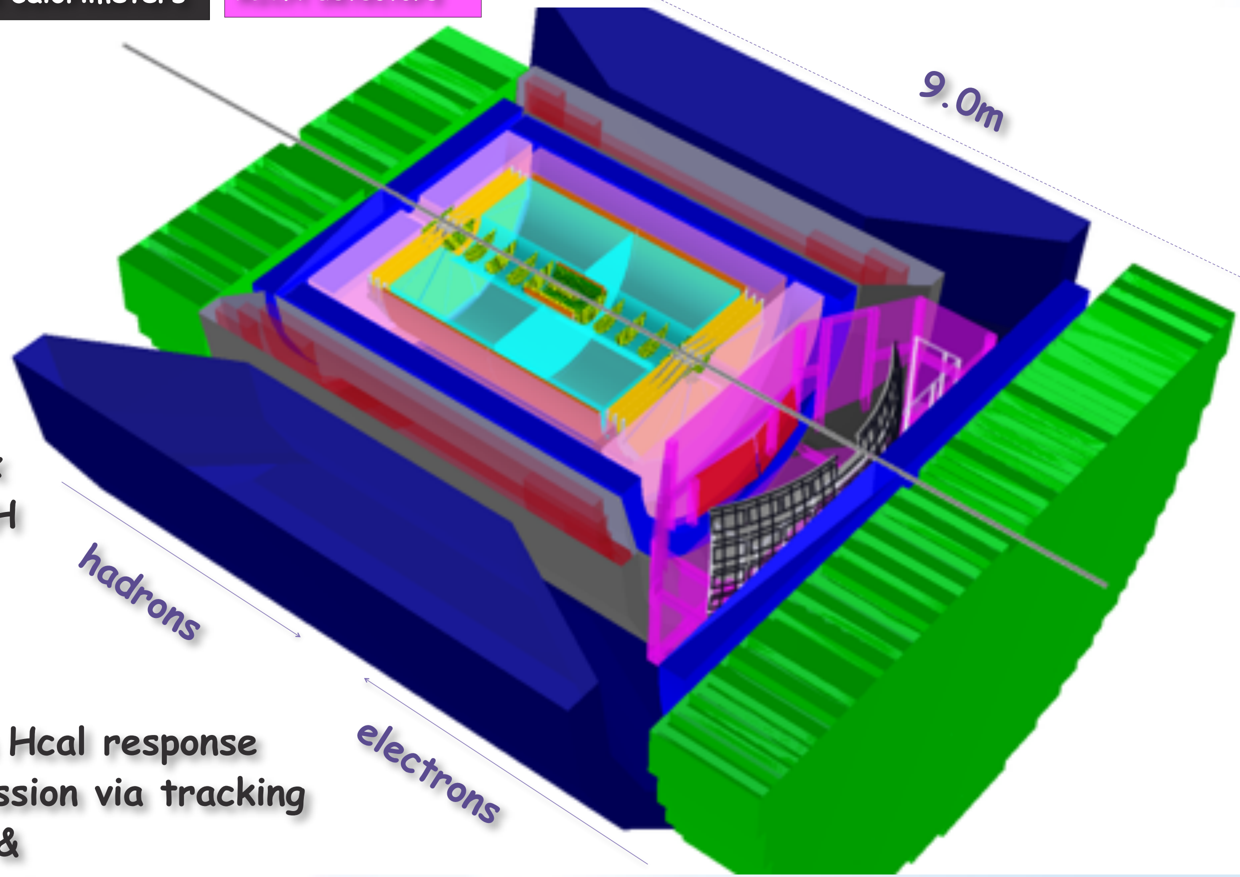
Current JLEIC Concept



BeAST DETECTOR LAYOUT

$-3.5<\eta<3.5$: Tracking & e/m Calorimetry (hermetic coverage)

hadronic calorimeters | e/m calorimeters | RICH detectors



silicon trackers | TPC | GEM trackers | 3T solenoid coils

MAPS: CMOS Monolithic Active Pixel Sensors

Hadron PID:

$-1<\eta<1$: proximity focusing RICH + TPC: dE/dx

$1<|\eta|<3$: Dual-radiator RICH

Lepton-ID:

$-3<\eta<3$: e/p

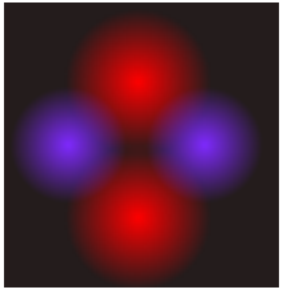
$1<|\eta|<3$: in addition Hcal response & γ suppression via tracking

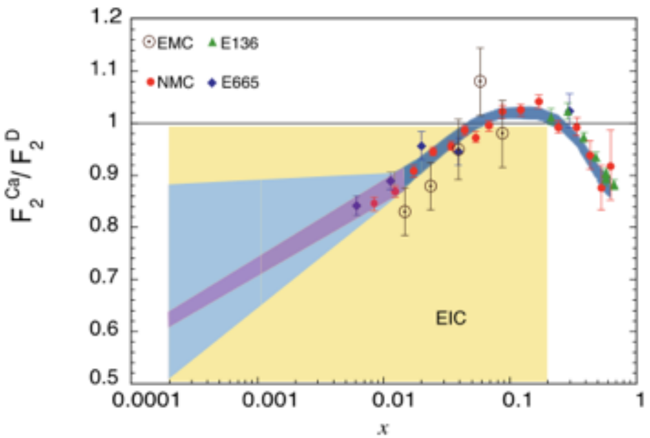
$|\eta|>3$: ECal+Hcal response & γ suppression via tracking

$-4<\eta<4$: Tracking (TPC+GEM+MAPS)

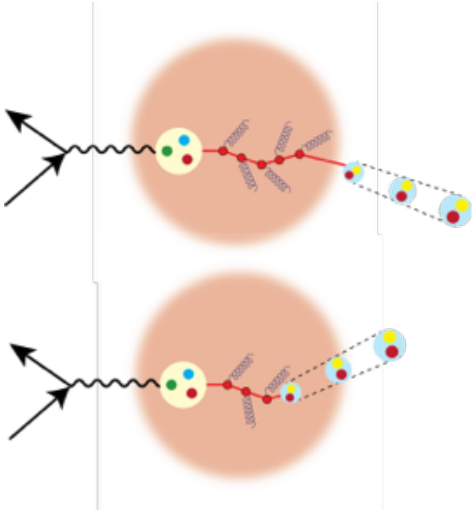
Puzzles and challenges….

How do gluons and sea quarks contribute to the nucleon-nucleon force?



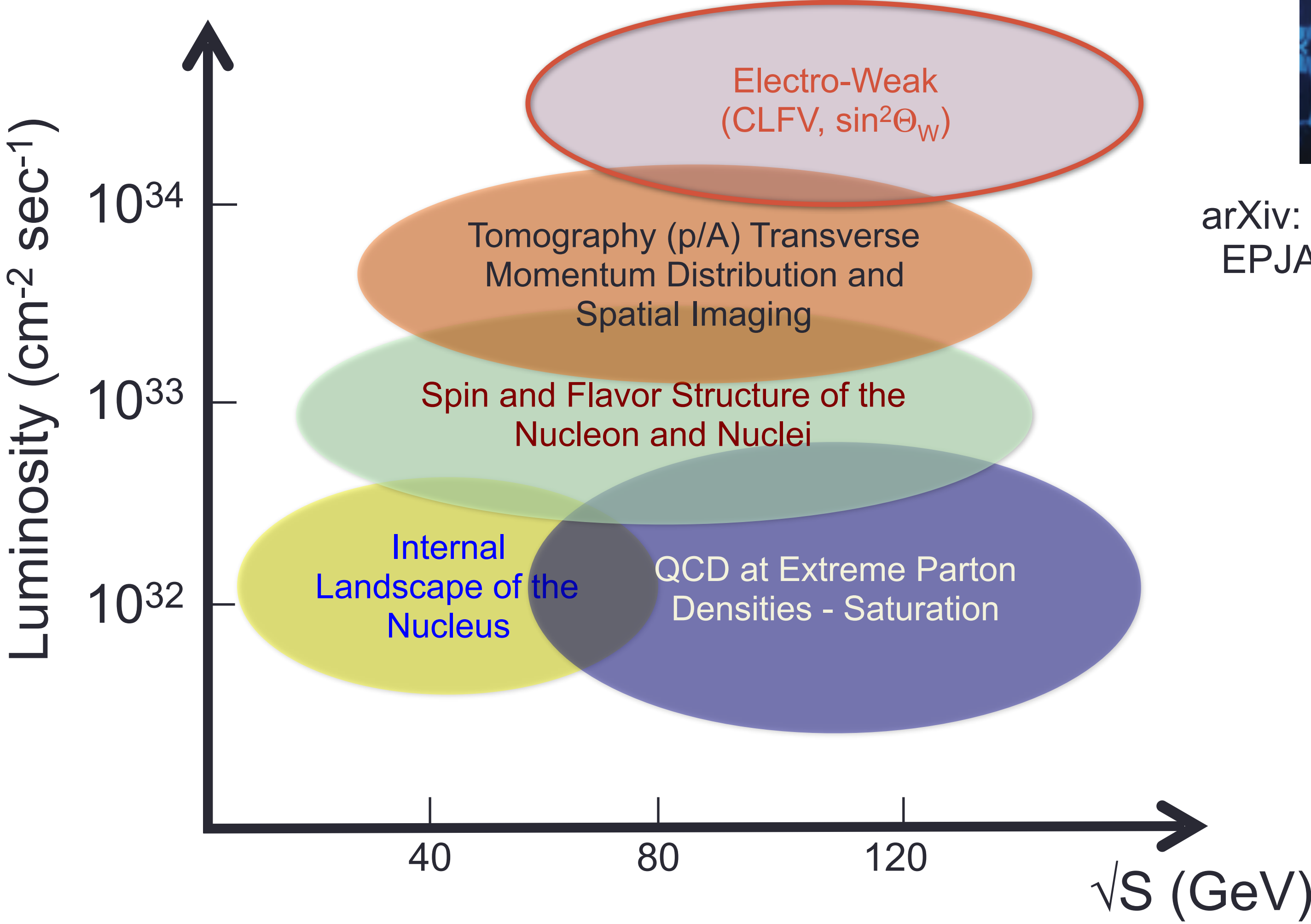


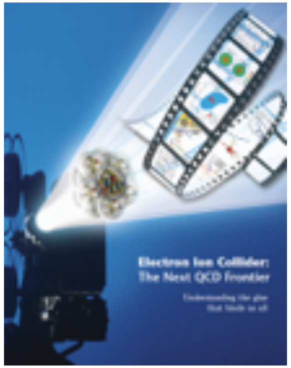
How does the nuclear environment affect the distributions of quarks and gluons and their interactions inside nuclei?



How does nuclear matter respond to fast moving color charge passing through it? (hadronization…. confinment?)

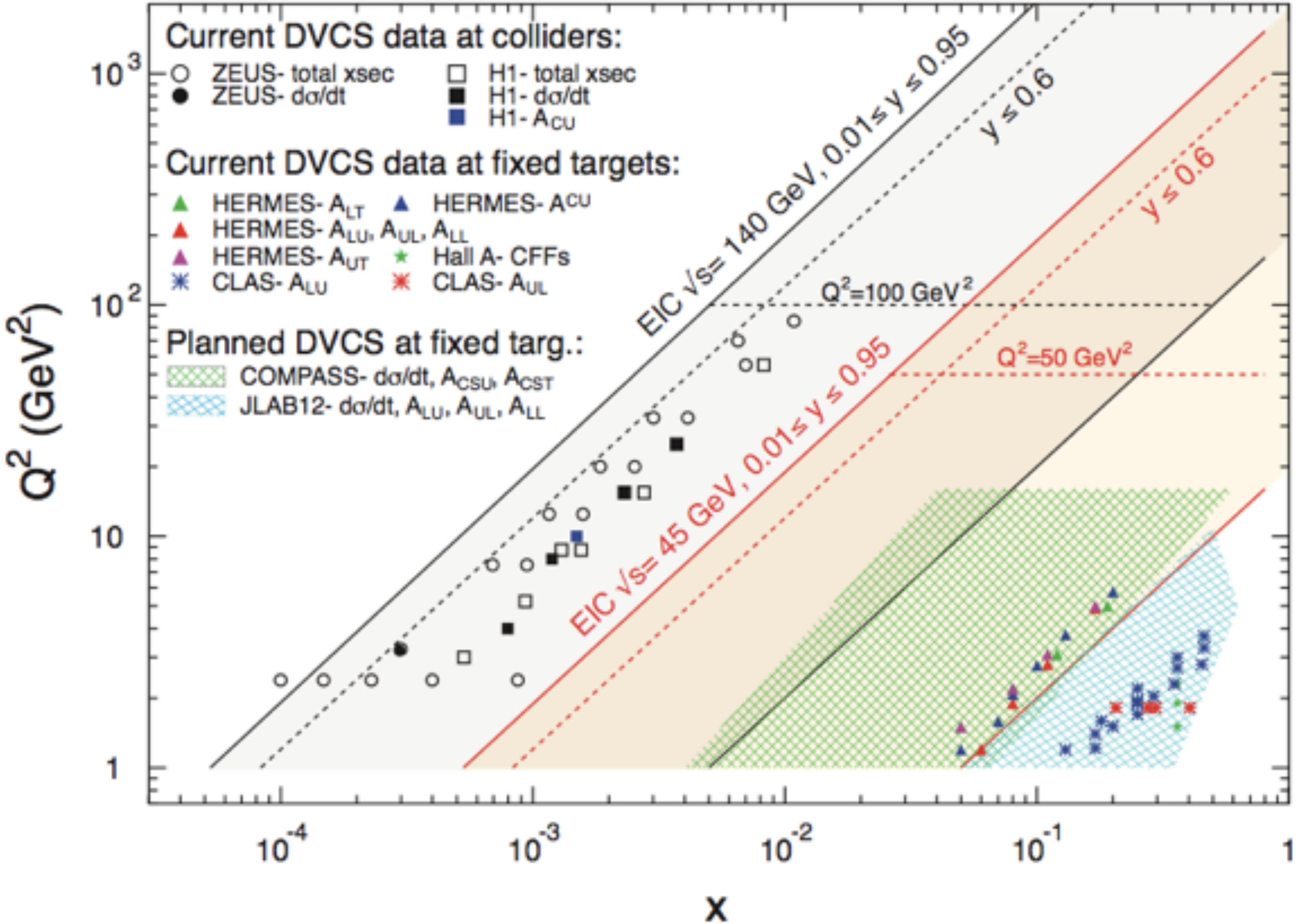
Physics vs. Luminosity & Energy





arXiv: 1212.1701.v3
EPJA 52, 9 (2016)

Phase-space of DVCS measurements



EIC White Paper, arXiv:1212.1701v3 [nucl-ex]

GPD opportunities at the EIC: I

DVCS

- Nucleon tomography at low x: sea quarks and gluons. Gluon distributions accessible via a log dependence of GPDs on Q^2.
- Access phase of the Compton amplitude through beam-charge asymmetry (using electron and positron beams) or Rosenbluth separation of cross-sections at different electron energies.

TCS

- Asymmetries carry similar information to beam-charge asymmetry in DVCS, without need for positron beams.

DVMP

- Flavour-separation of contributions from q and $\bar{q}$ and from gluons.
- J/Ψ production direct access to gluon GPDs.
- Vector meson production allows separation of cross-sections for longitudinal, σ_L, and transverse, σ_T, photon polarisation.
- $\pi^+\pi^-$ production is sensitive to differences in q and $\bar{q}$ distributions.

GPD opportunities at the EIC: II

DDVCS

* Direct access to x-dependence of GPDs.

Measurements on other hadrons

* Could potentially measure DVCS/DVMP off the virtual pion.

* Light nuclei (He, deuteron) allow measurements off the neutron: flavour separation of GPDs.

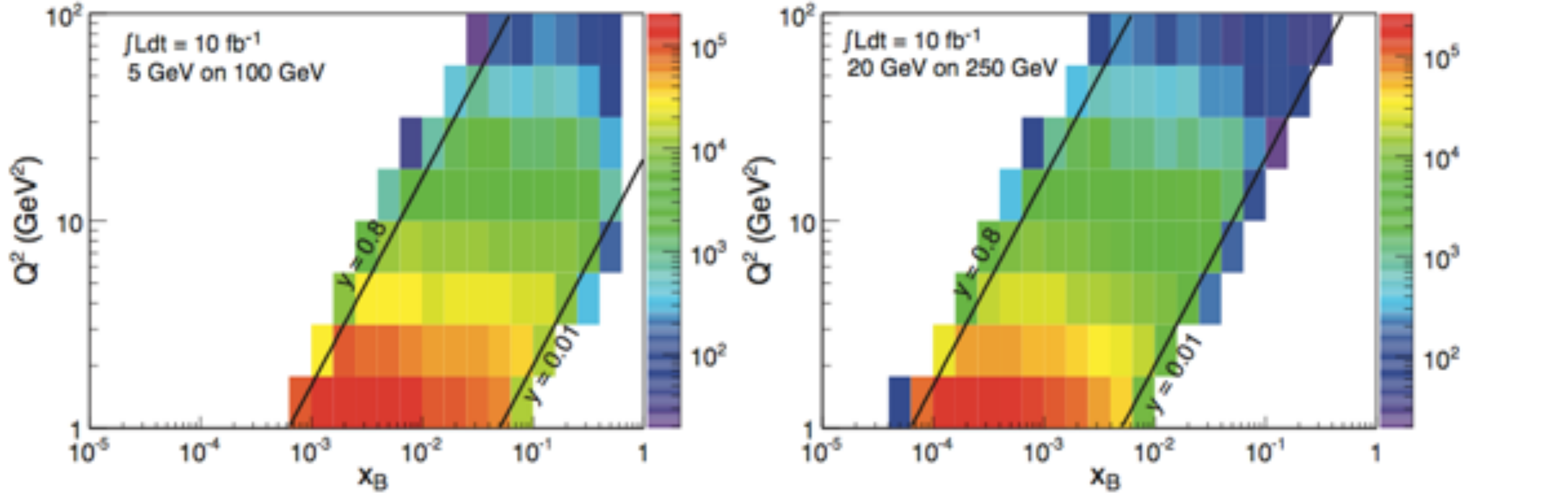
* Nuclear DVCS /DVMP: tomography of the nucleus, parton saturation.

* Scattering and J/Ψ-production off nuclei with multi-nucleon knockout: short-range correlations, contribution of glue.

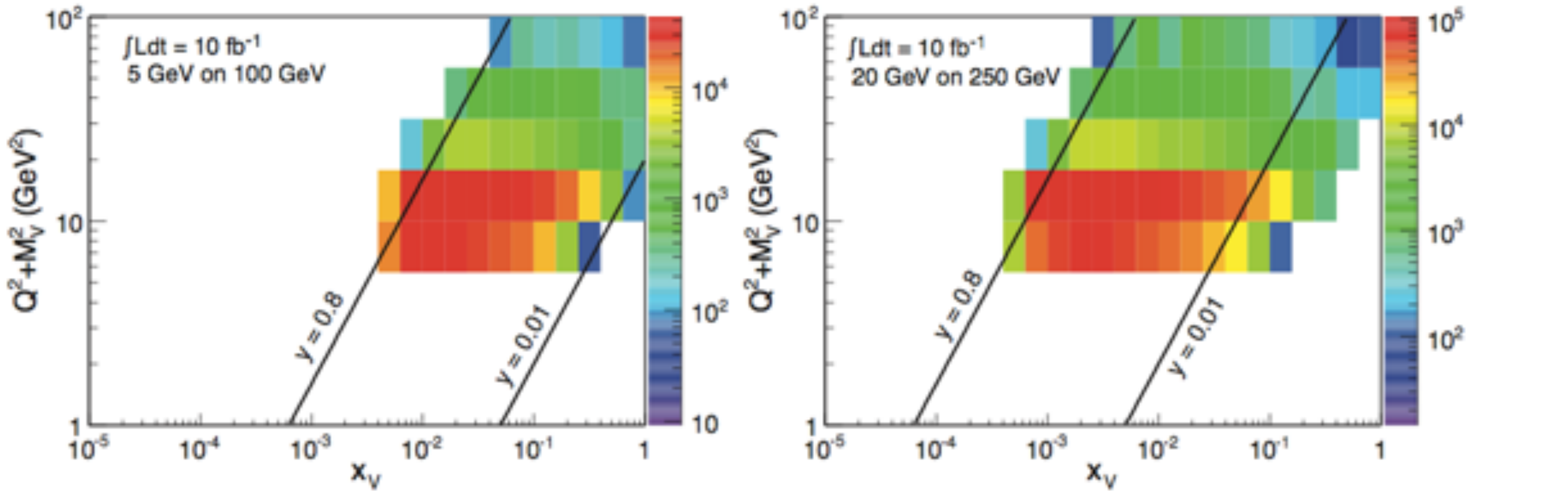
Wide range of Q^2 in the valence region will complement valence measurements: can observe scaling violations.

The estimated EIC reach

Simulations of expected distributions for DVCS



Simulations of expected distributions for J/Ψ production



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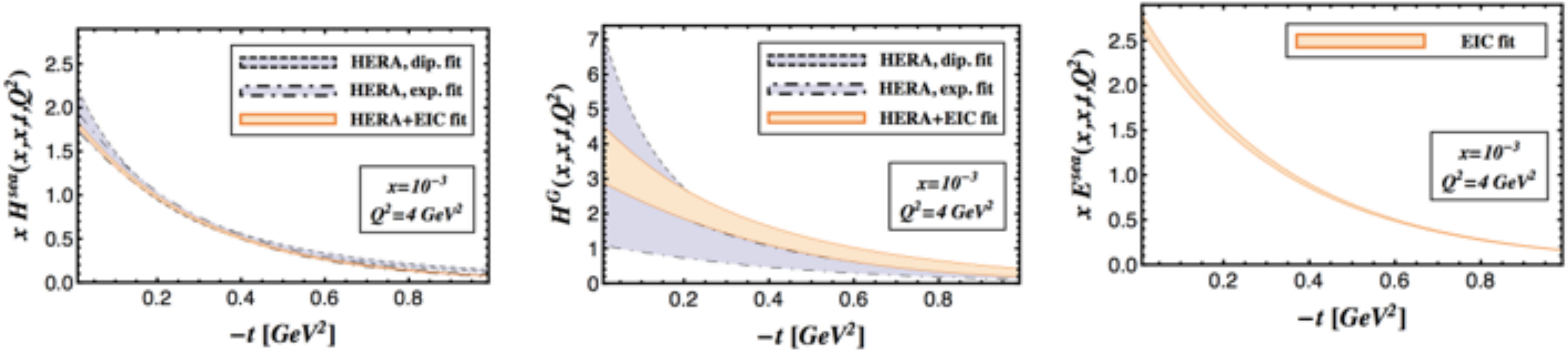
What can we expect from the EIC?

- Cross-sections and beam-charge asymmetries measured at H1 and ZEUS (HERA).

- Sensitivity expected from inclusion of EIC data with HERA measurements:

$E_e E_p$ = 20 x 250 GeV^2

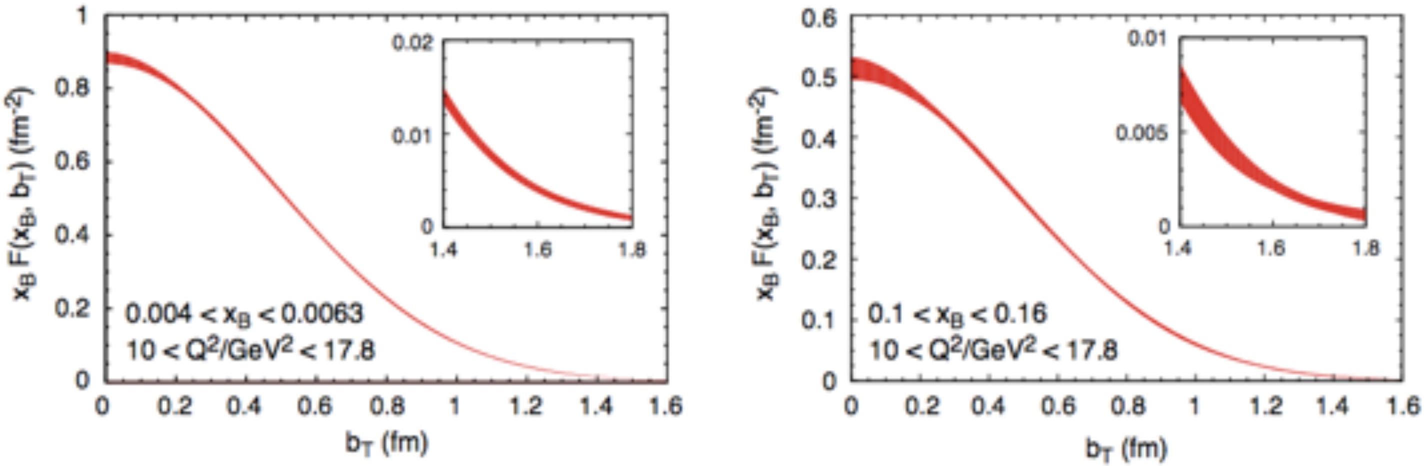


Least-squares fit with dipole and exponential ansatz from HERA collider data with and without EIC simulated pseudo-data (unpolarised cross-sections and transverse target spin asymmetry produced with AFKM12 model) fitted with the exponential ansatz.

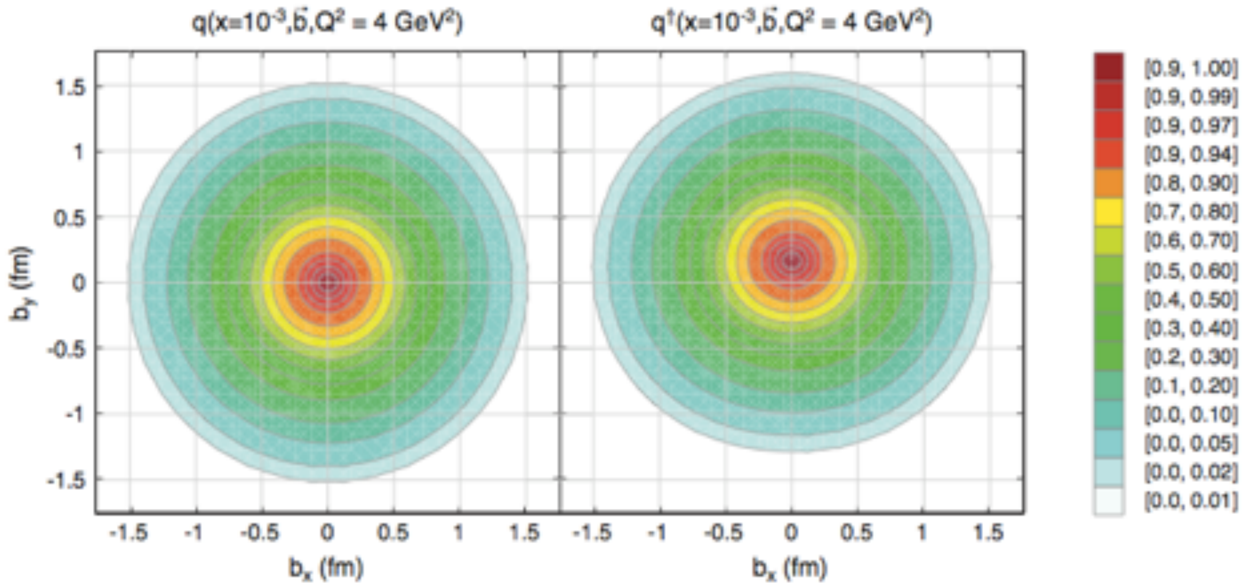
E.C. Aschenauer *et al*, ***JHEP* 1309** (2013) 093

Sea quarks at the EIC

Simulations of transverse spatial quark distributions from DVCS cross-sections.



Simulated density of sea quarks in transverse plane from DVCS cross-sections and spin-asymmetries.



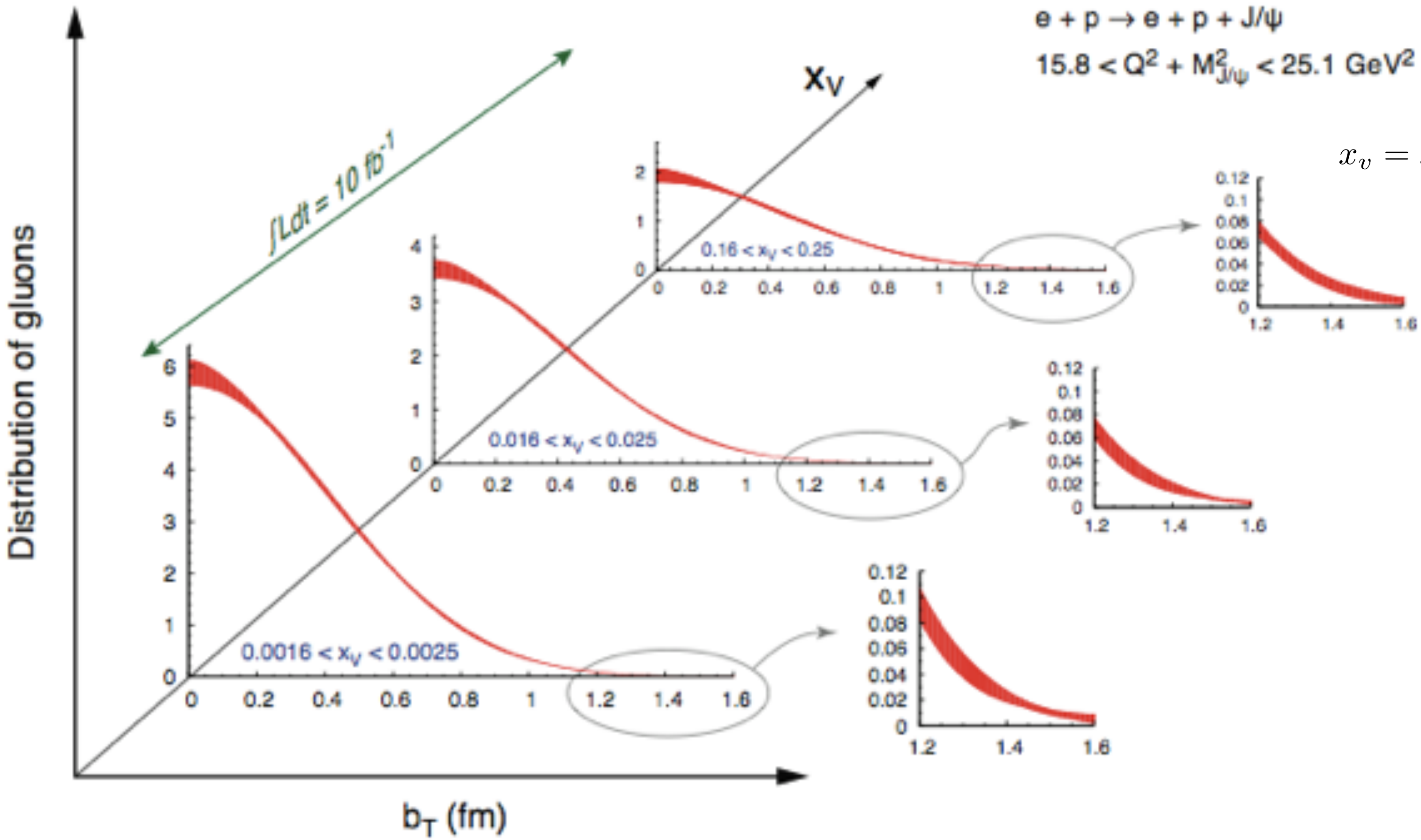
unpolarised proton

proton transversely polarised along x

EIC White Paper
arXiv:1212.1701v3 [nucl-ex]

Gluons at the EIC

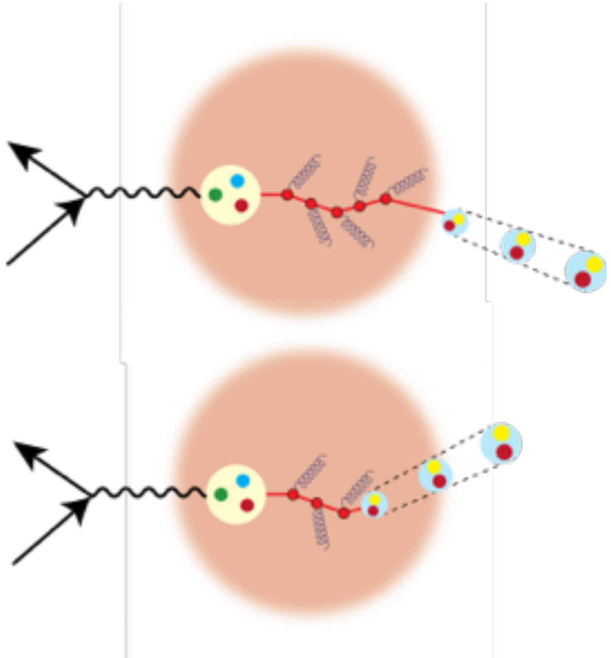
Simulations of transverse spatial gluon distributions from J/Ψ production at different gluon momenta x_v.

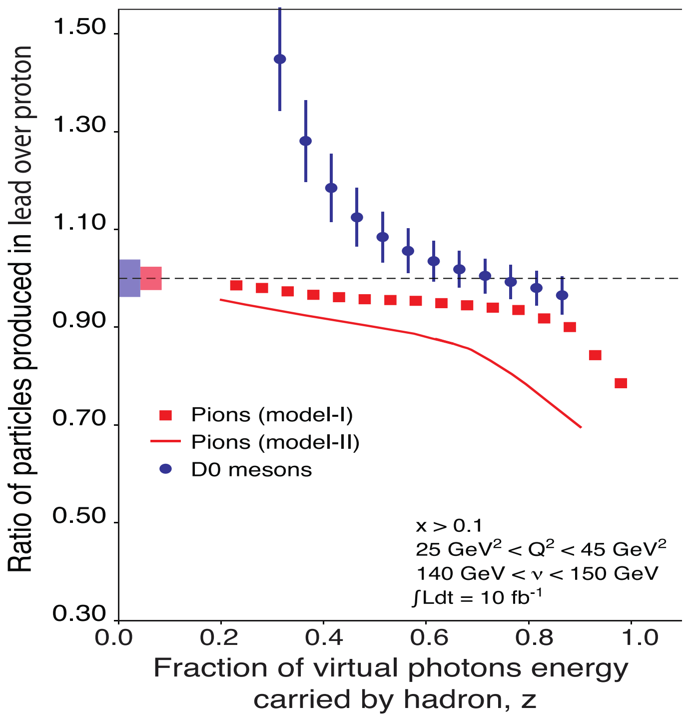


$$x_v = x_B(1 + M^2_{J/\Psi}/Q^2)$$

EIC White Paper, arXiv:1212.1701v3 [nucl-ex]

Jets, Hadronization





ν = E-E' = 100-200 GeV to keep jet within nucleus

√s = 32-45 GeV for y=0.1 (keeping jet in the central region of the detector)