Electron-Ion Collider

Its Interest to the HI Community

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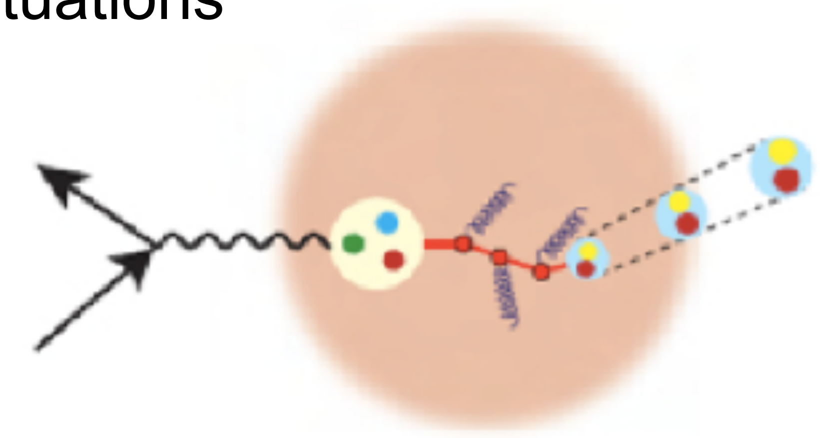
MSO Think Tank III

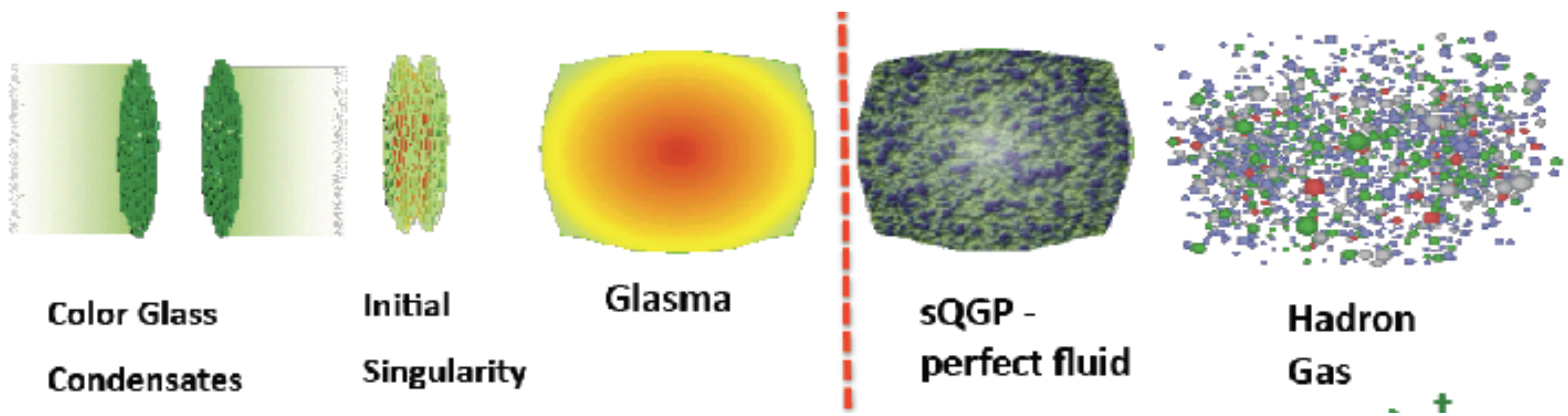
Loyola University - 13 February 2017

Why HI Physicists should care

- Intellectual Synergy
  - Dense Cold QCD Matter ⟺ Dense Hot QCD Matter
  - Quantum phase transitions ⟺ Phase transition
- Applications to Relativistic HI Collisions
  - Nuclear parton distribution functions
  - Initial conditions, transverse & longitudinal fluctuations
  - Transport in dense QCD matter
  - Dynamics of hadronization



QGP at RHIC/LHC



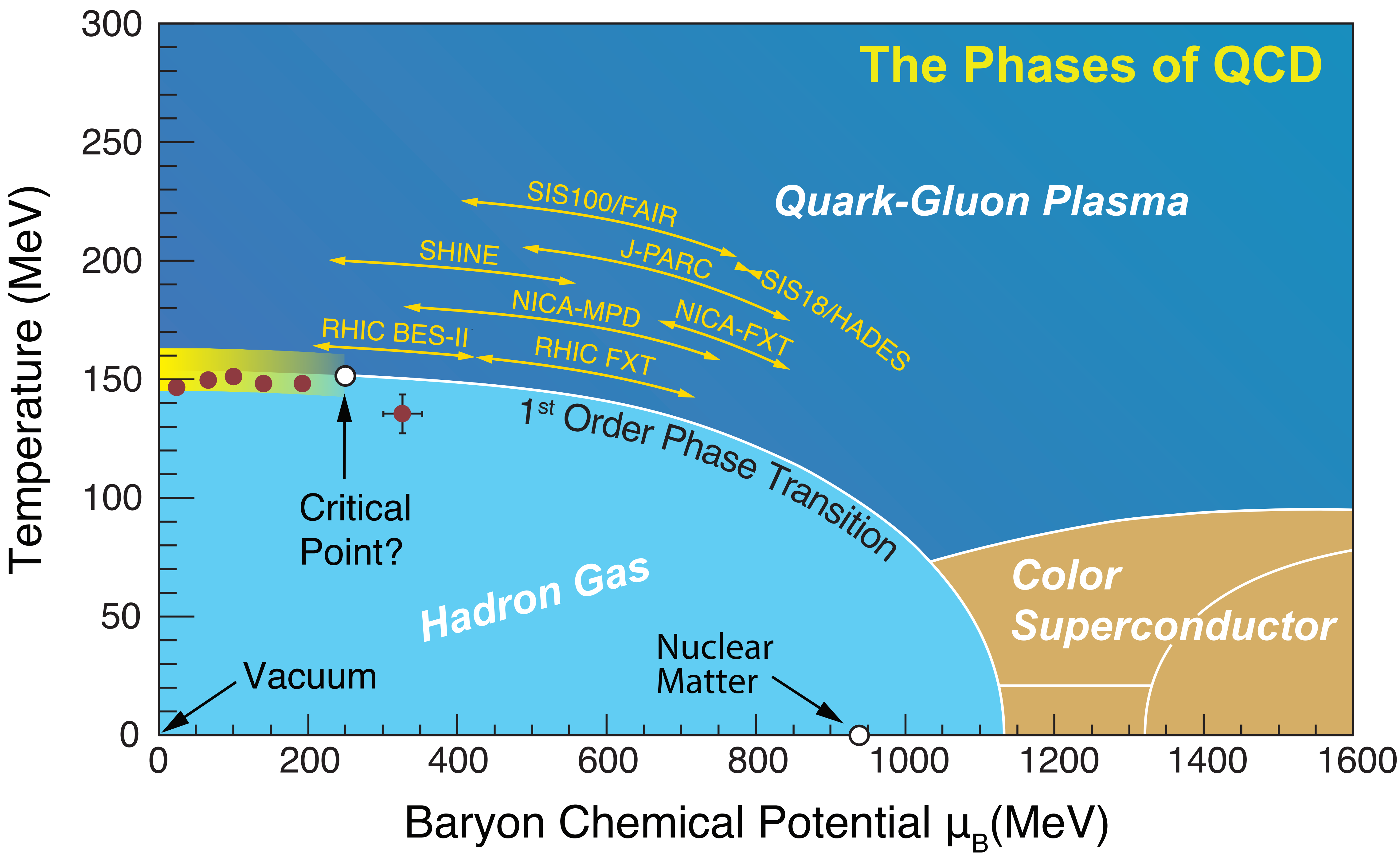
What HI Physicists can contribute

- Polarized p+p collisions:
  - Test QCD spin dynamics (e.g. sign change of Sivers function)

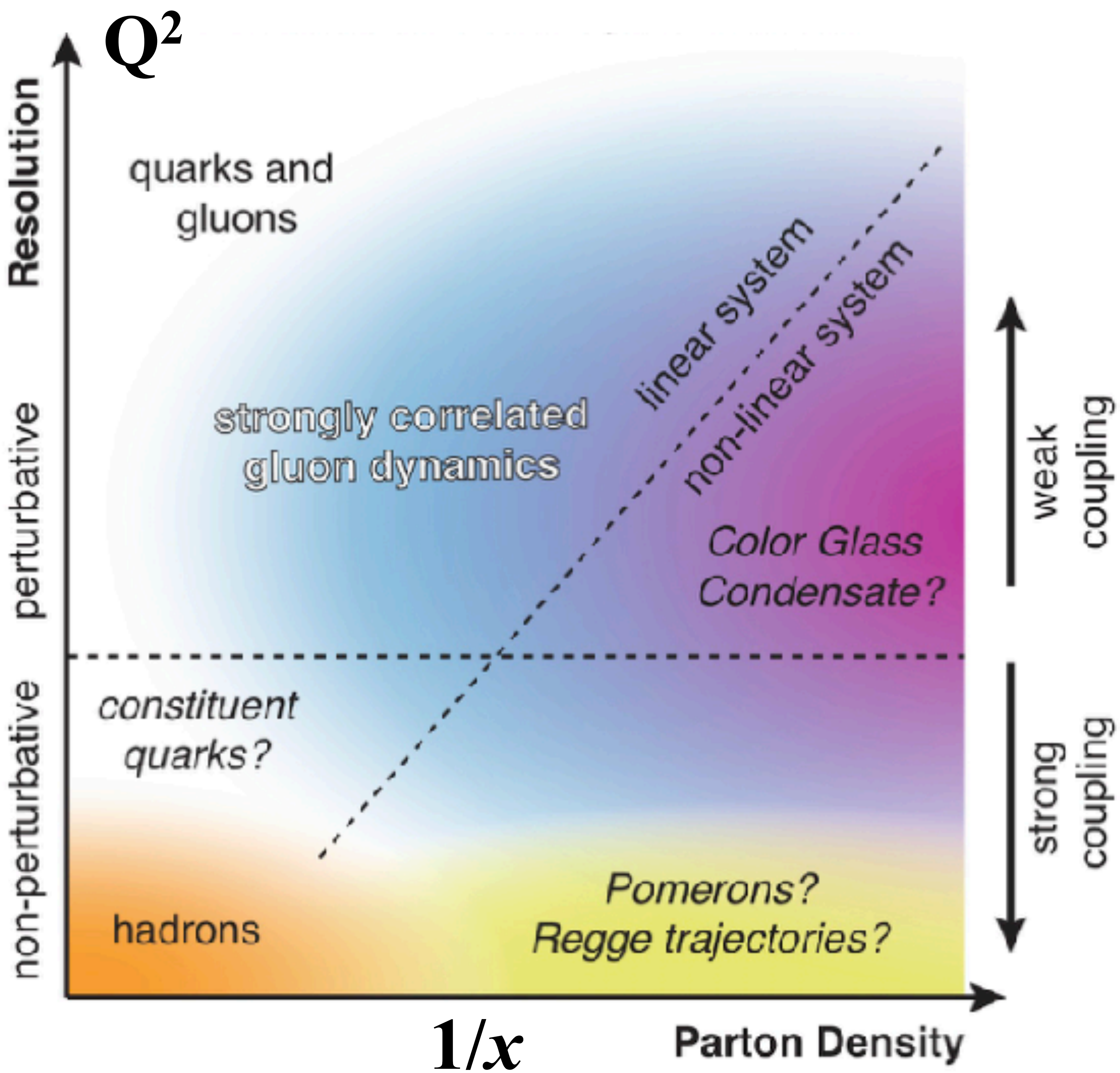
- p+A collisions:
  - Nuclear parton distributions and gluon saturation?
  - p+A and e+A are both needed to establish universality
  - What **must** be measured before RHIC shuts down?

- A+A collisions:
  - Ultra-peripheral collisions at RHIC and LHC have very intense quasi-real photon flux
  - Photon-gluon fusion reactions are sensitive to nuclear gluon PDF

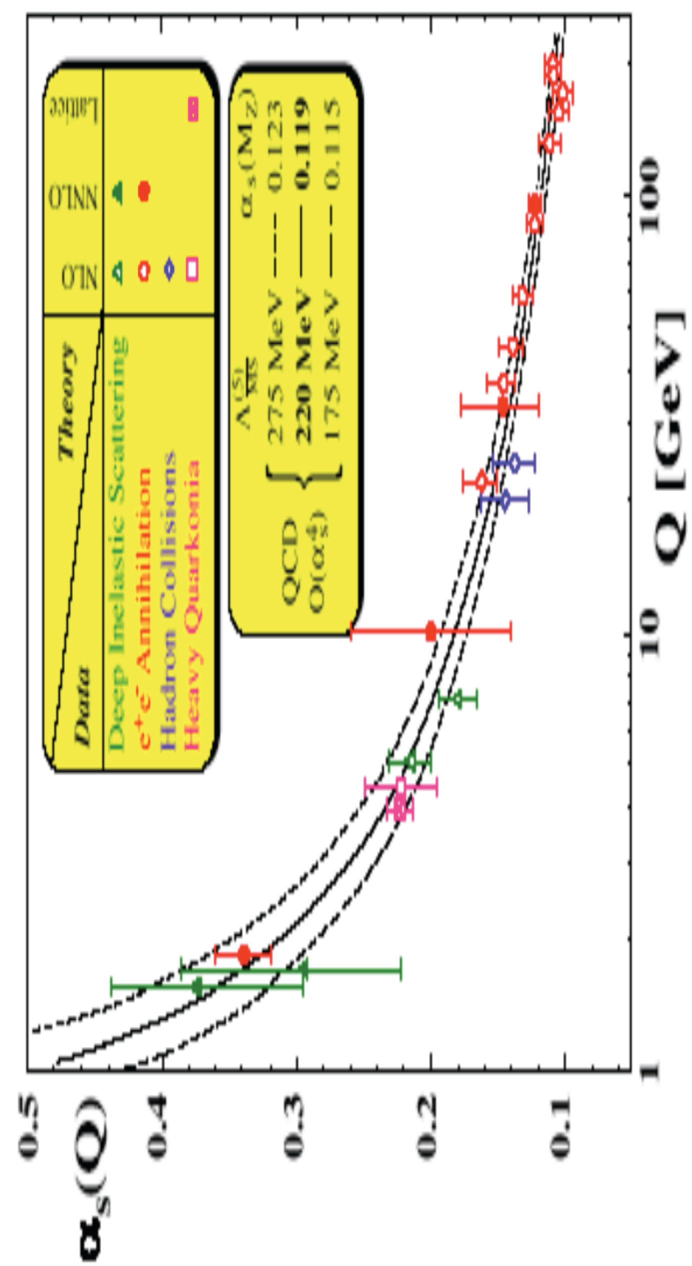
Hot QCD Landscape



Cold QCD Landscape



QCD running coupling



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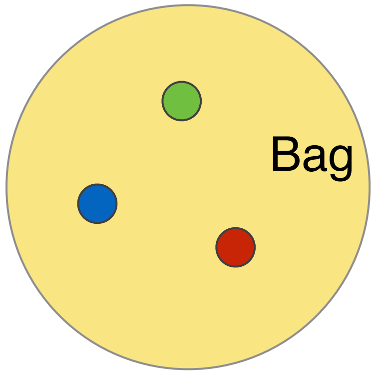
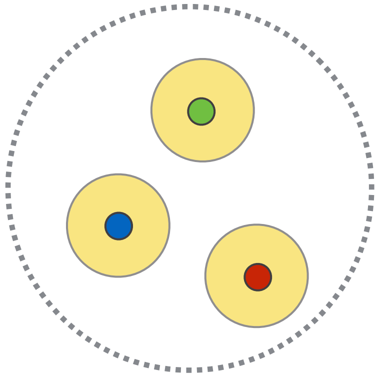
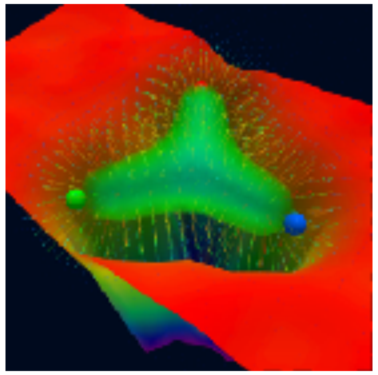
Where are the gluons?

- Bag model:
  - Field energy distribution is wider than the distribution of fast moving light quarks
- Constituent quark model:
  - Gluons and sea quarks “hide” inside massive quarks
  - Sea parton distribution similar to valence quark distribution
- Lattice gauge theory:
  - (with slow moving quarks)
  - gluons are more concentrated than quarks







Rest Frame

Boosted Nucleon

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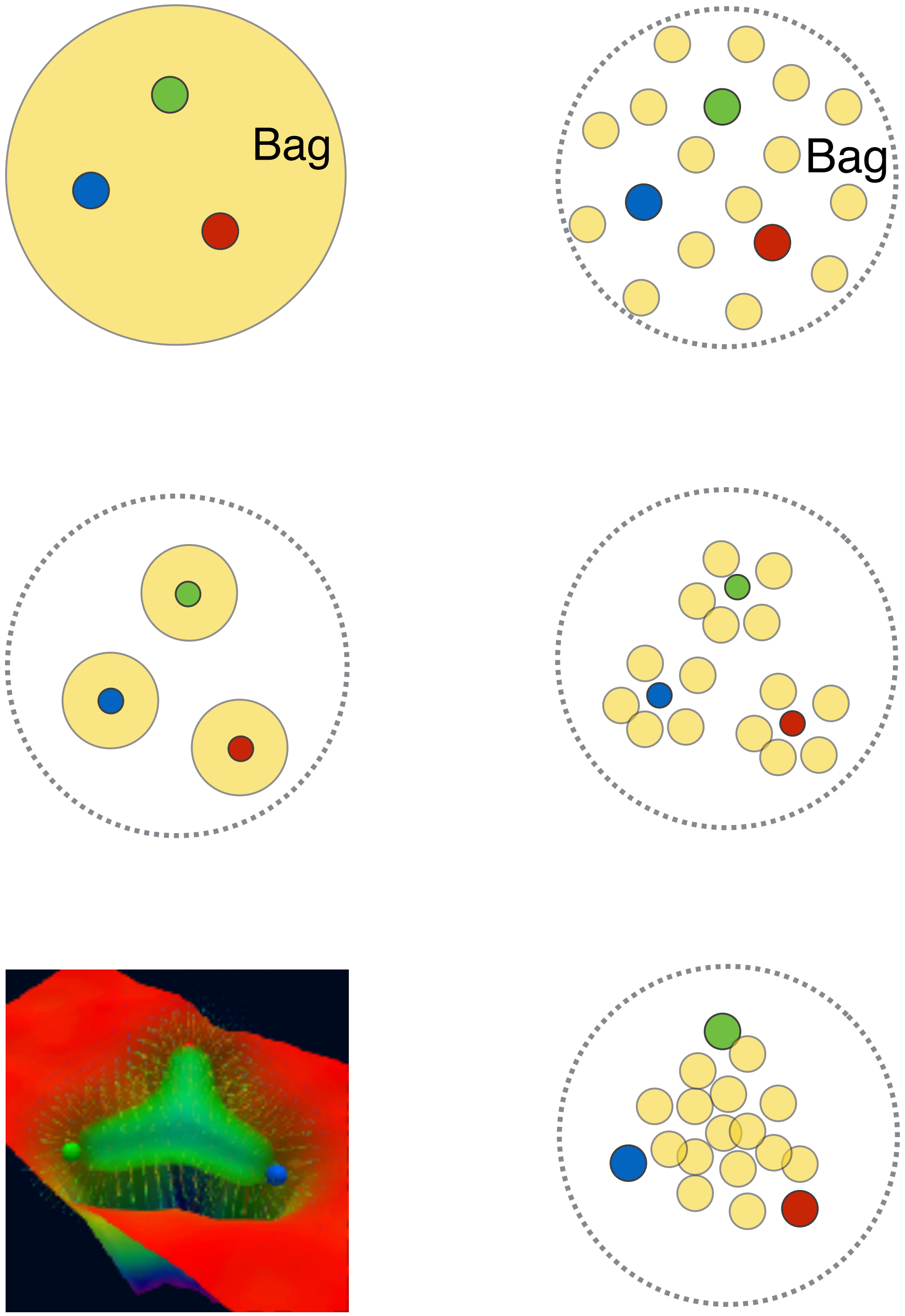


Rest Frame **Boosted Nucleon**

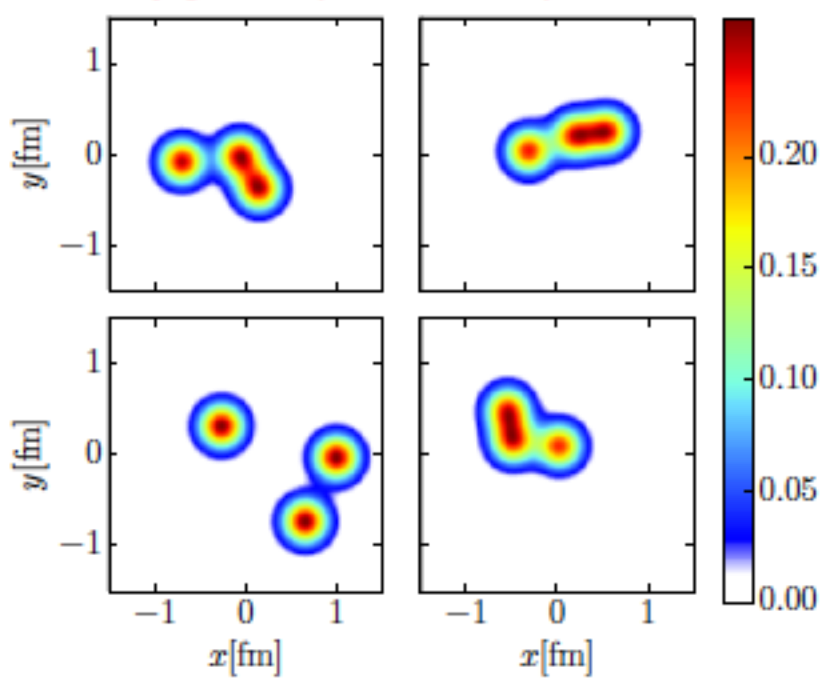
Lumpy proton v_2

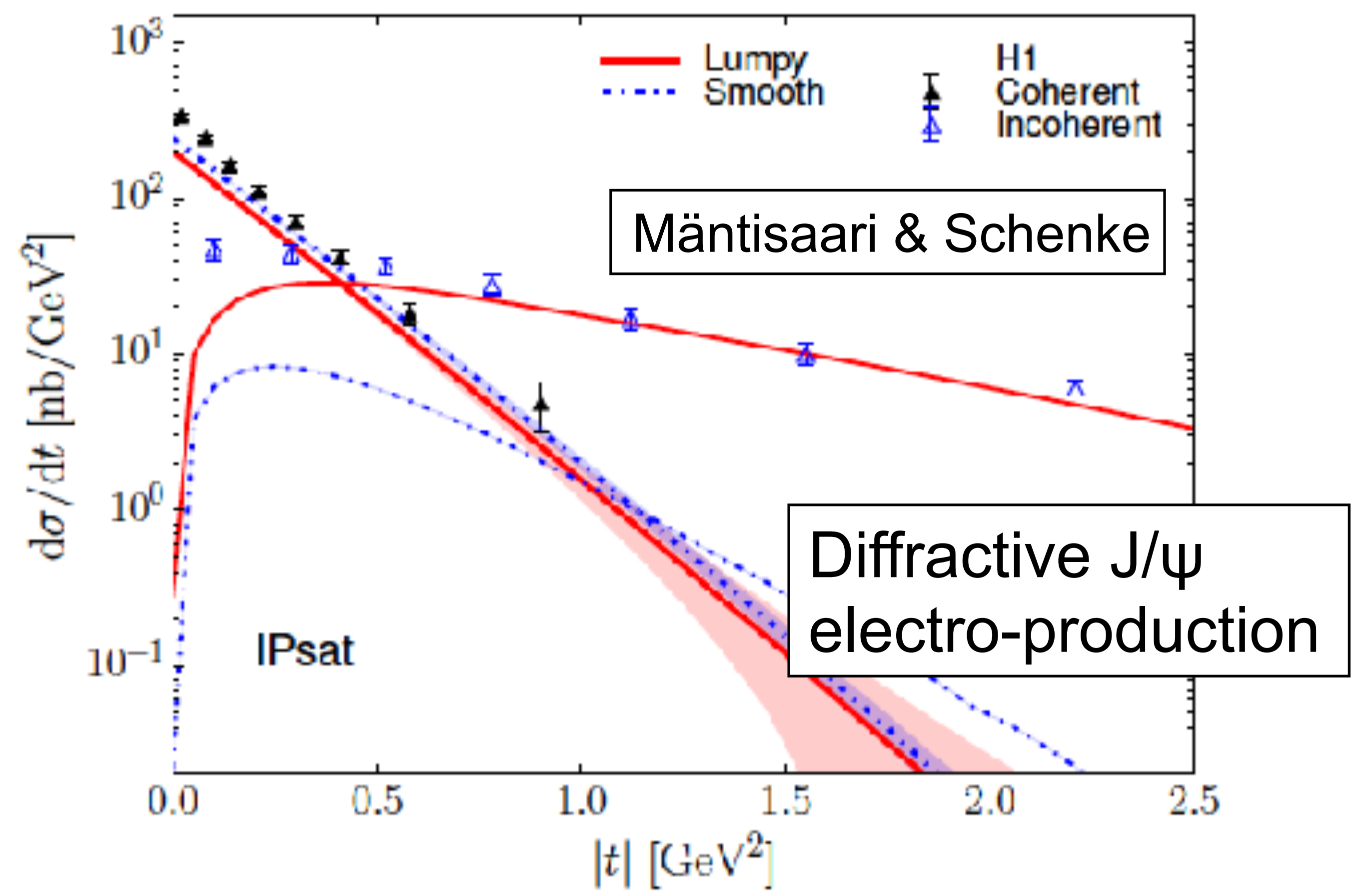
Proton: sum of gluon clouds around 3 valence quarks

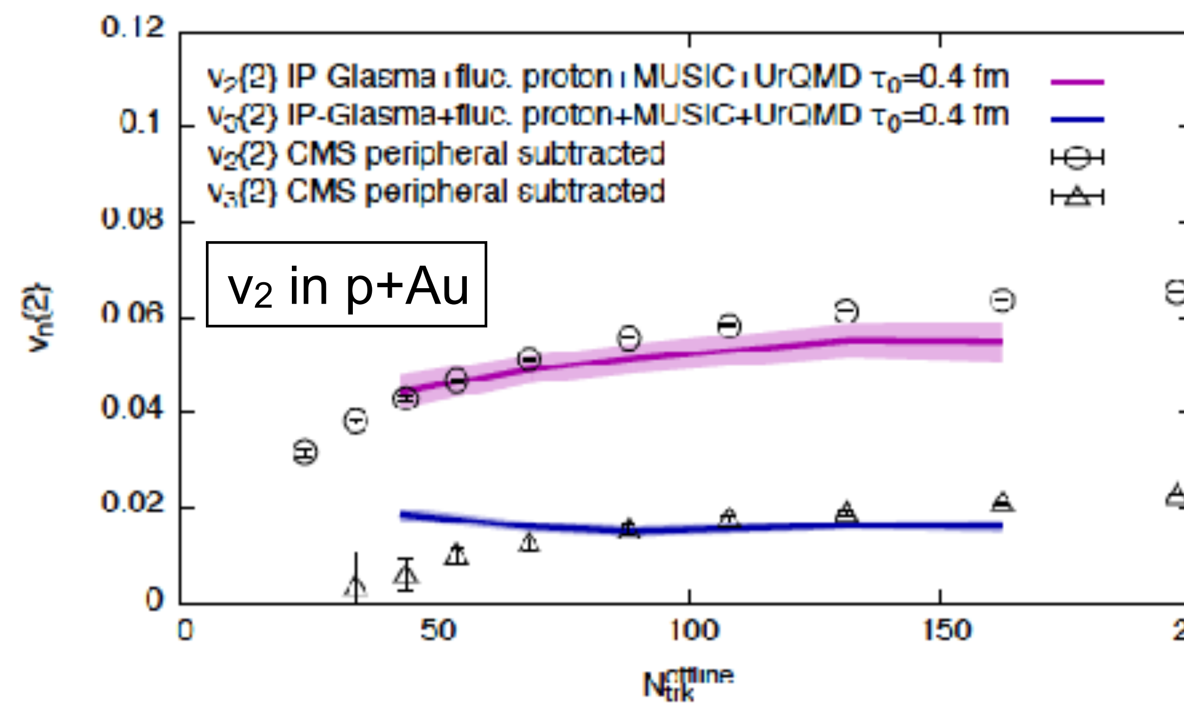
$$T_{\text{proton}}(b) = \sum_{i=1}^{3} T_q(b - b_i)$$

with $T_q(b) \sim e^{-b^2/(2B_q)}$

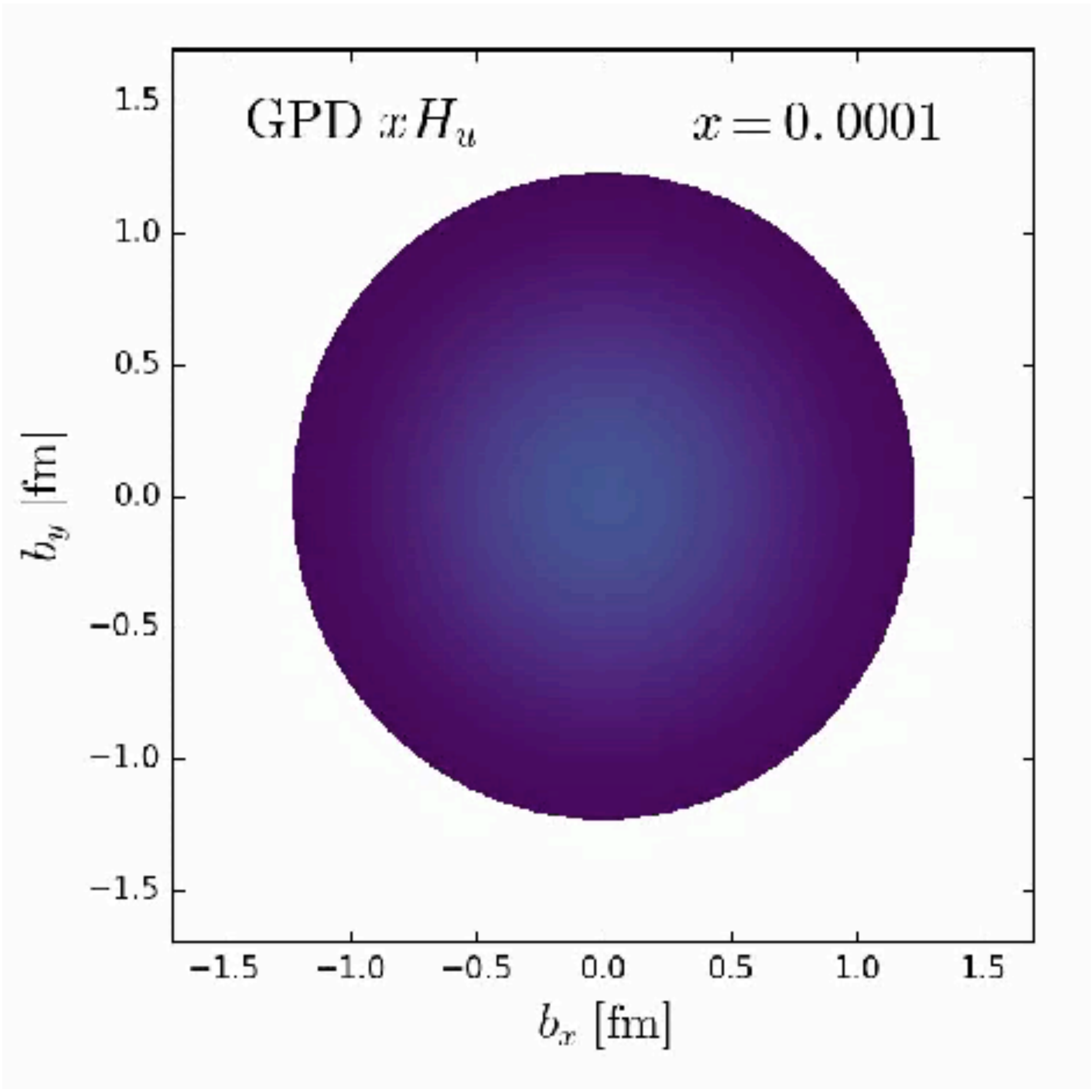
Lumpy: $B_{qc} = 3.3,\ B_q = 0.7$

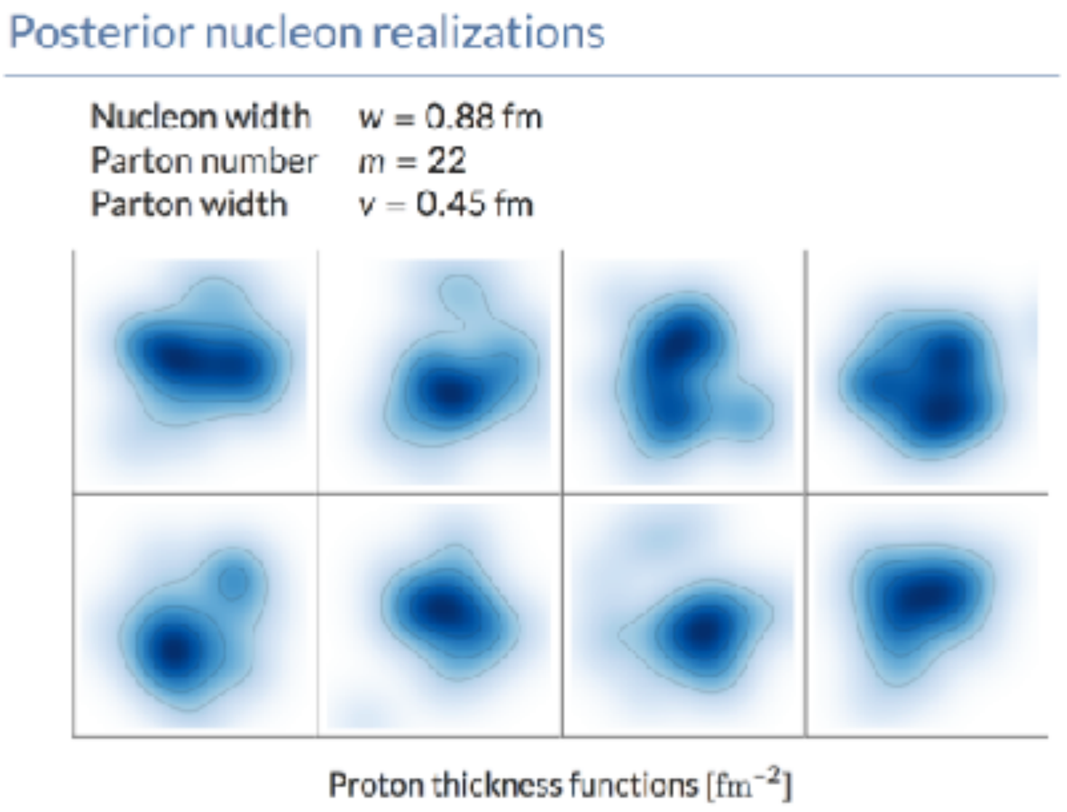






The evolving (in x) proton





EIC will provide exquisite images of the average partonic shape of the nucleon as function of x, but p+A collisions may provide more information about instantaneous shape (e.g. triangularity?)

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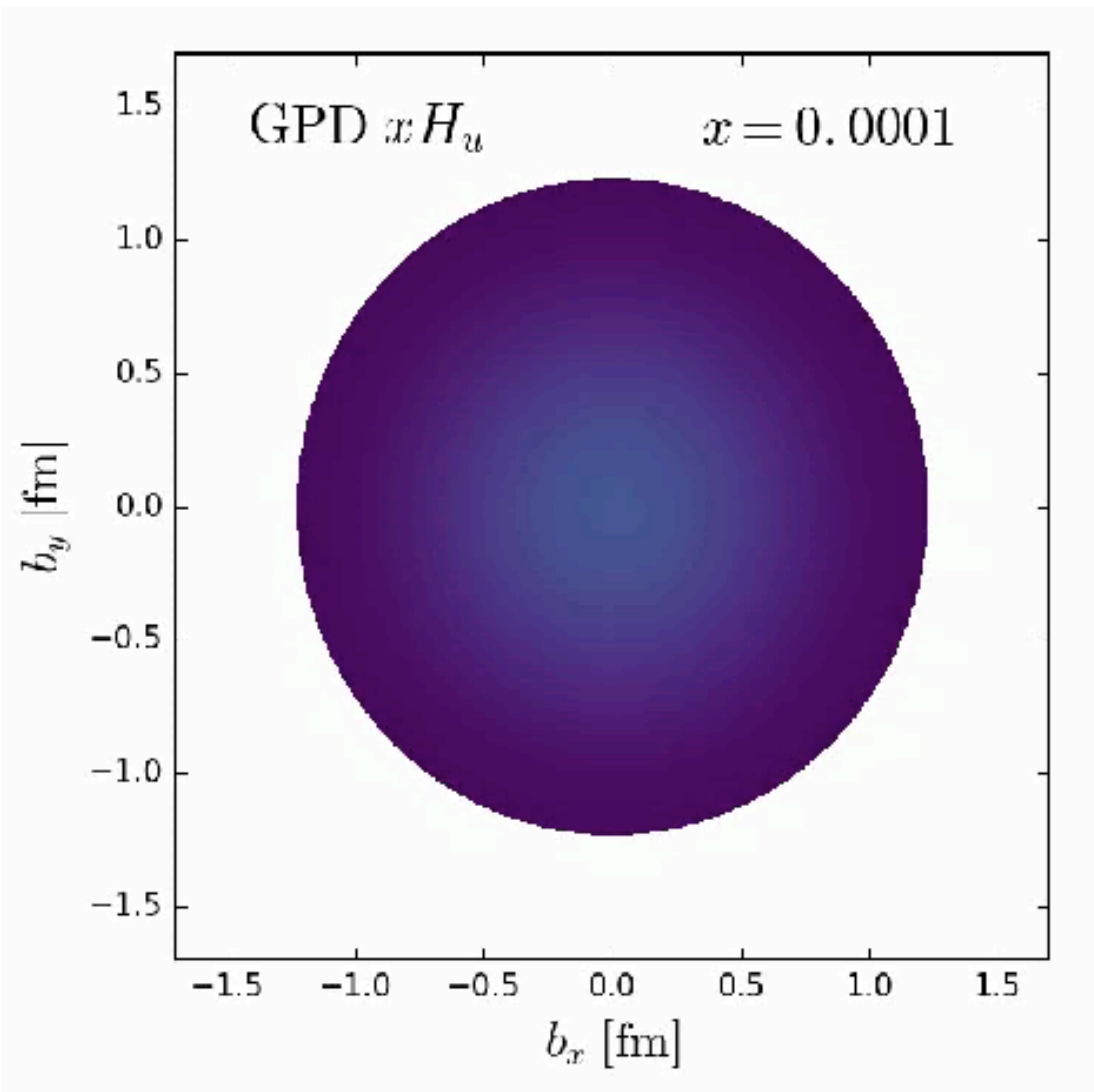

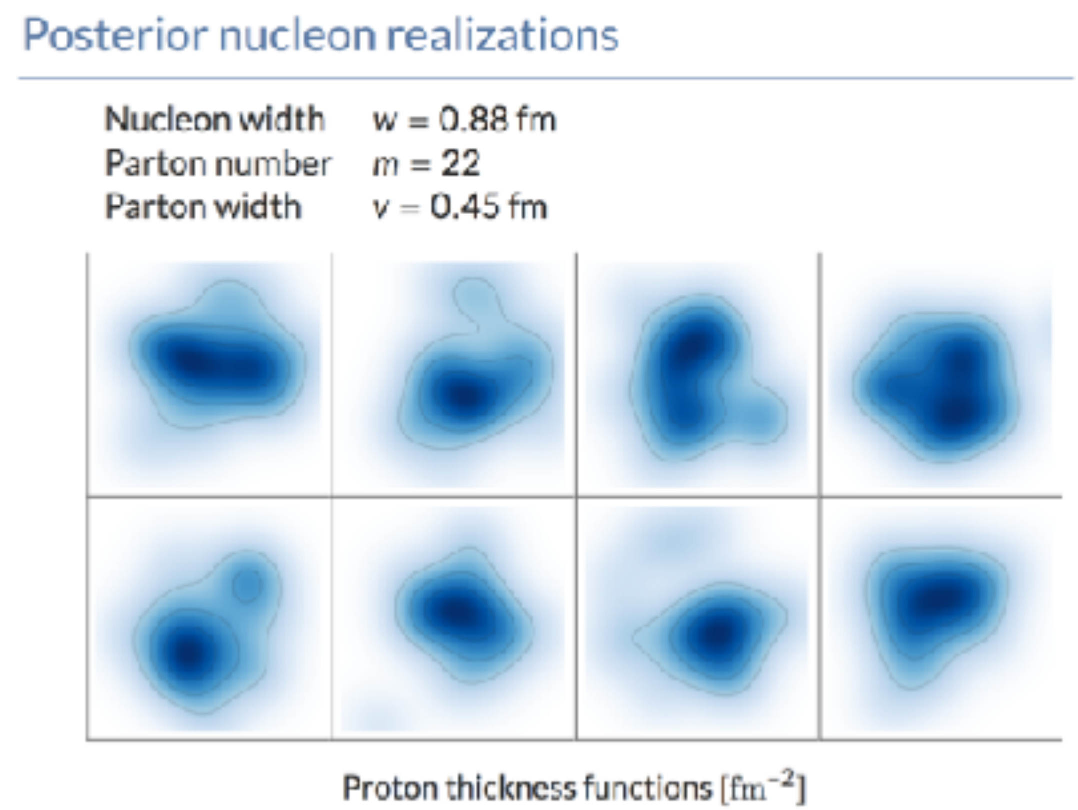

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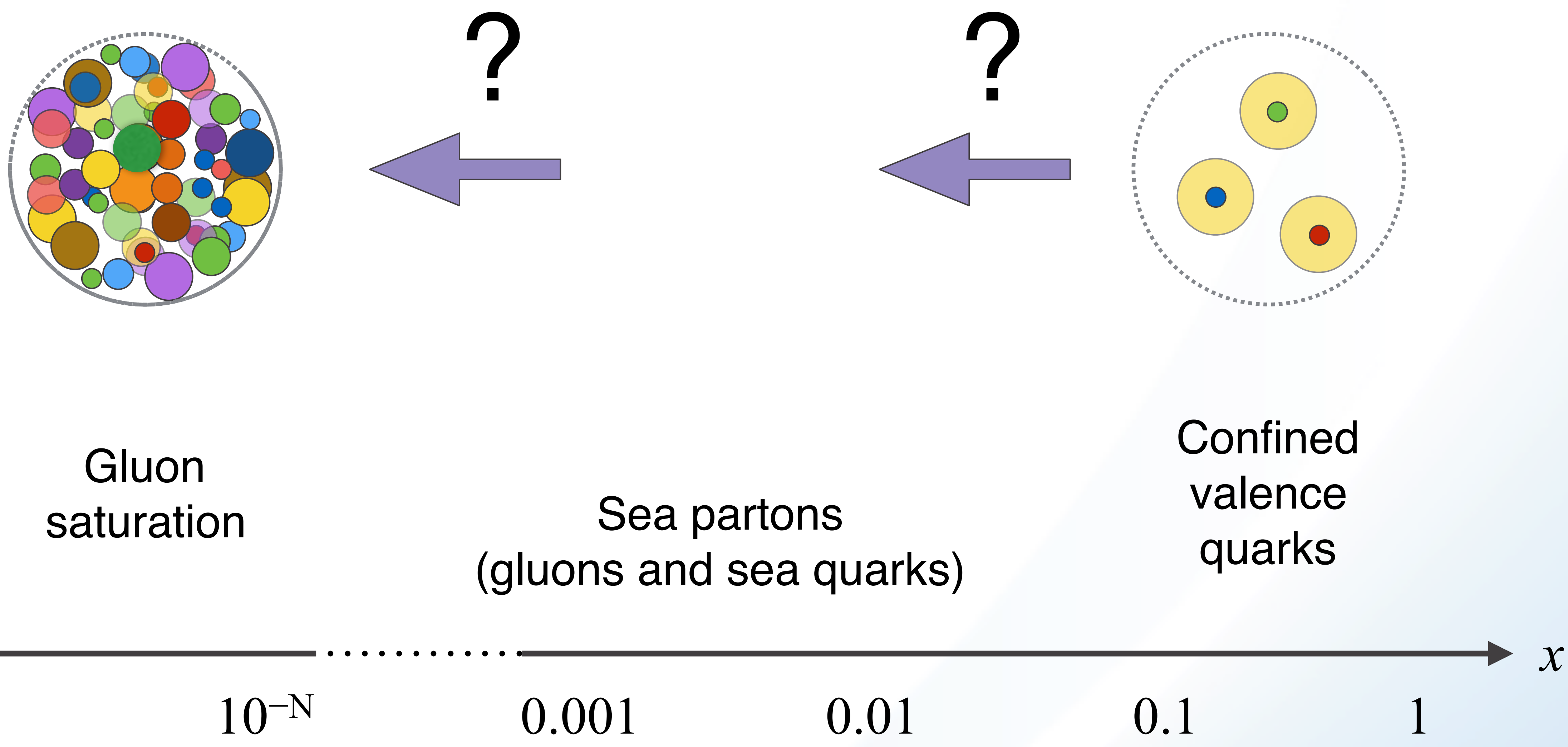
Partons at $Q^2 \sim$ few GeV^2

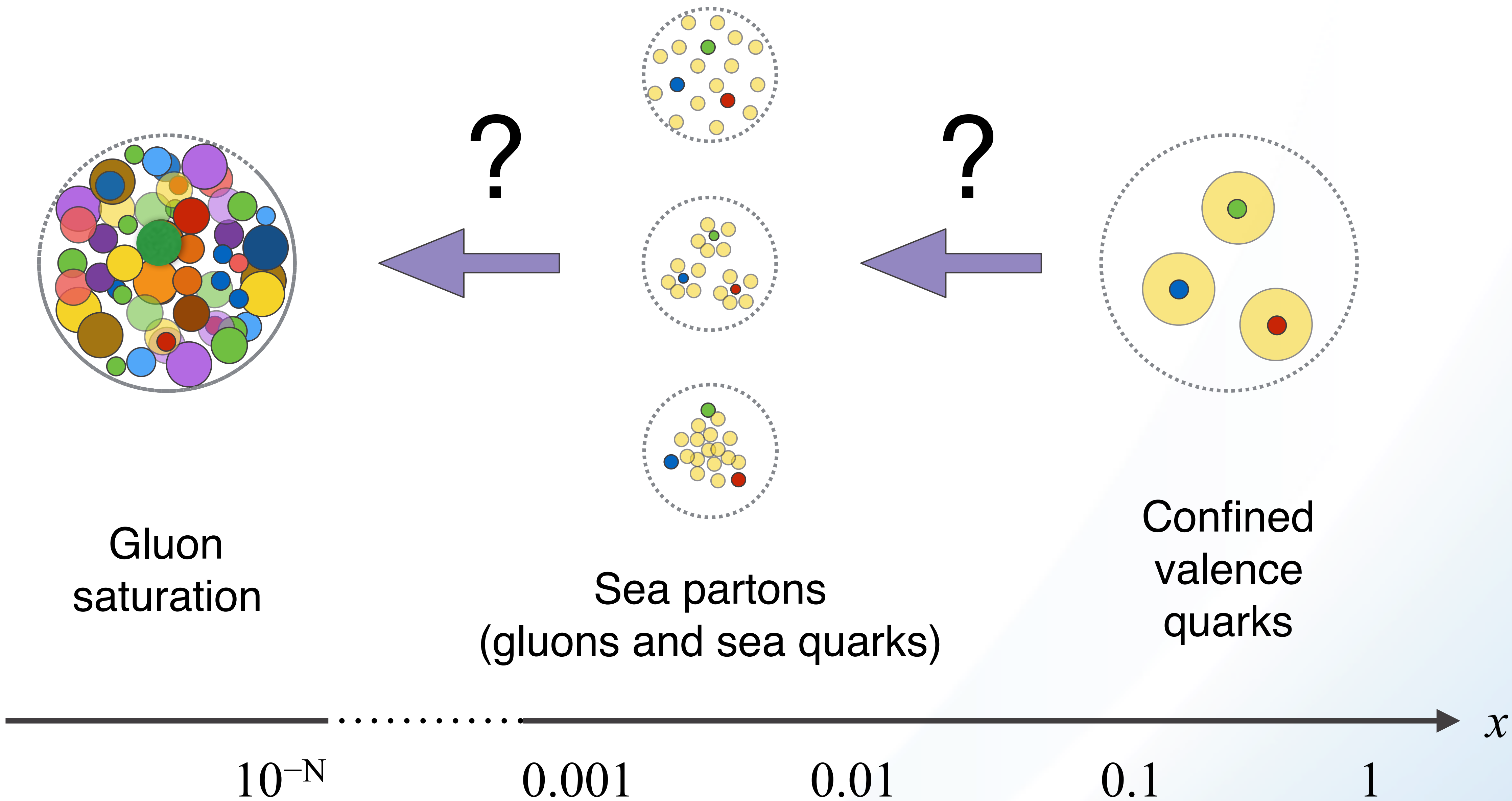


Theoretically under control at weak coupling

EIC domain
Weakly or strongly coupled?

JLab 12 GeV program will explore

Partons at Q^2 ~ few GeV^2



Theoretically under control at weak coupling

EIC domain
Weakly or strongly coupled?

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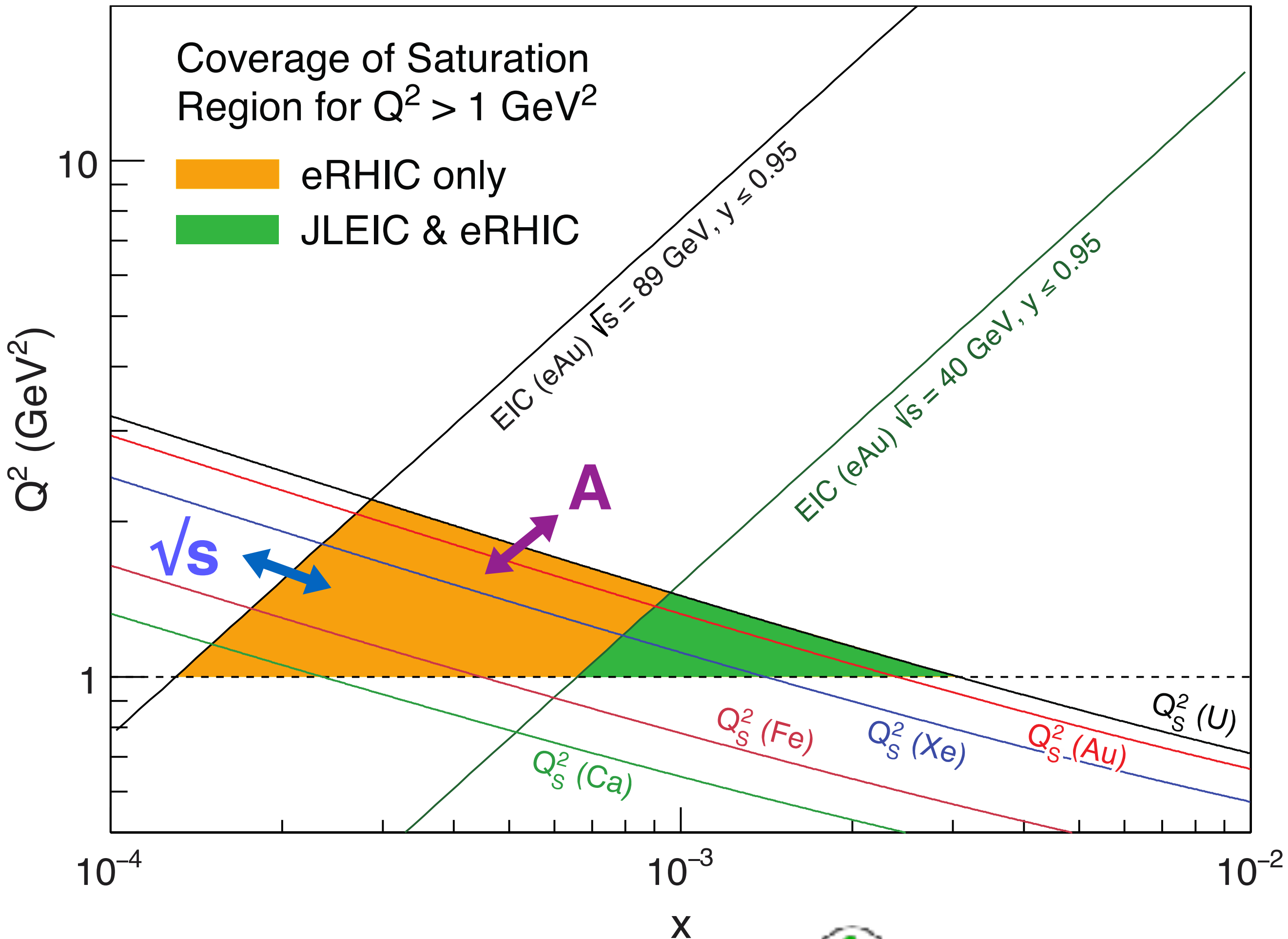
JIMWLK and beyond

- At T>0 temperature T adds a second scale to QCD:
  - At weak coupling $\alpha_s(T)$ thermal perturbation theory provides an effective description of the QGP
  - At strong coupling dual gravity models provide useful guidance; the dual gravity theory has a black brane and is approximately conformal if $T \gg \Lambda$
  - Effective theory at 4D boundary is hydrodynamics
- At high field strength (high gluon density) Q_s adds a second scale to QCD:
  - At weak coupling $\alpha_s(Q_s)$ JIMWLK provides an effective theory of the color glass condensate
  - What does the holographic space look like when $Q_s \gg \Lambda$?
  - What is the strong coupling analogue of CGC ?
  - Is the a strong coupling version of JIMWLK ?

Gluons at low x in Nuclei

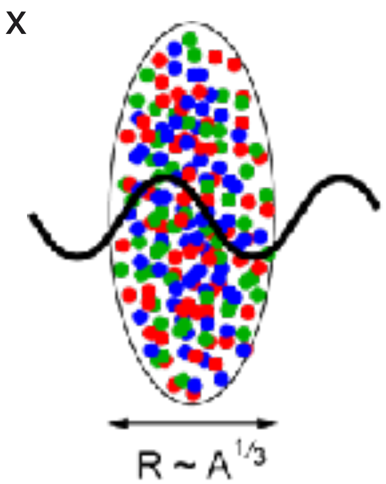


High CM energy required to study the evolution of Q_s with *x* and *A* and thus test models of gluon saturation

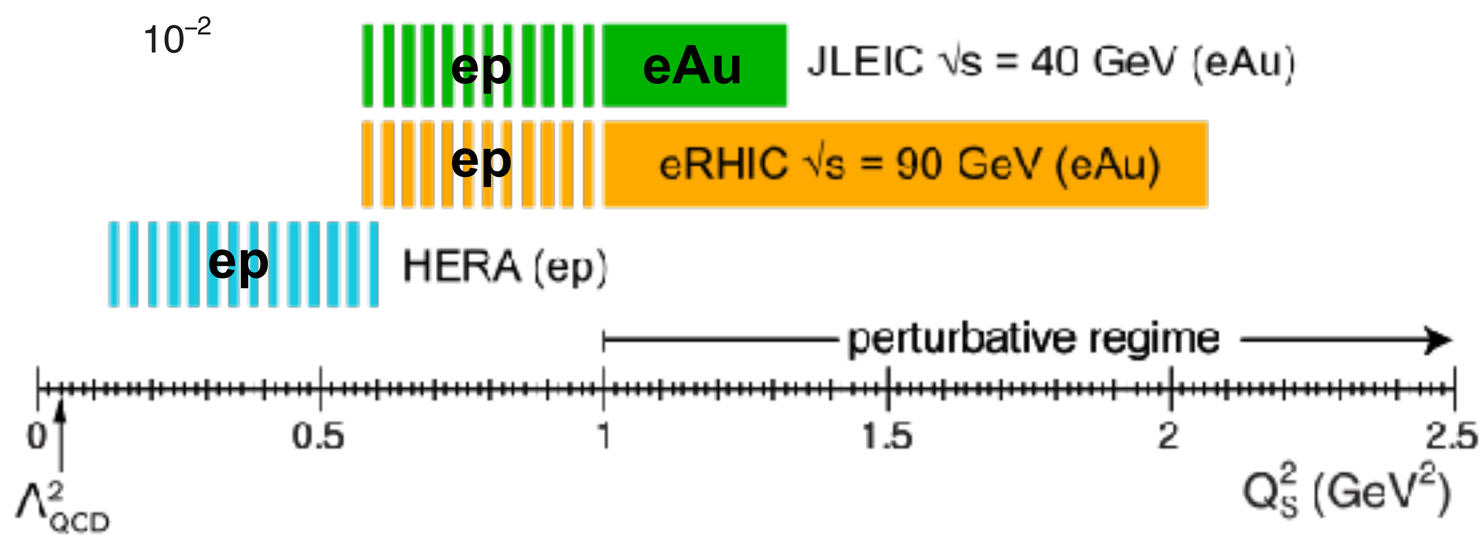
Nuclear “oomph” factor

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

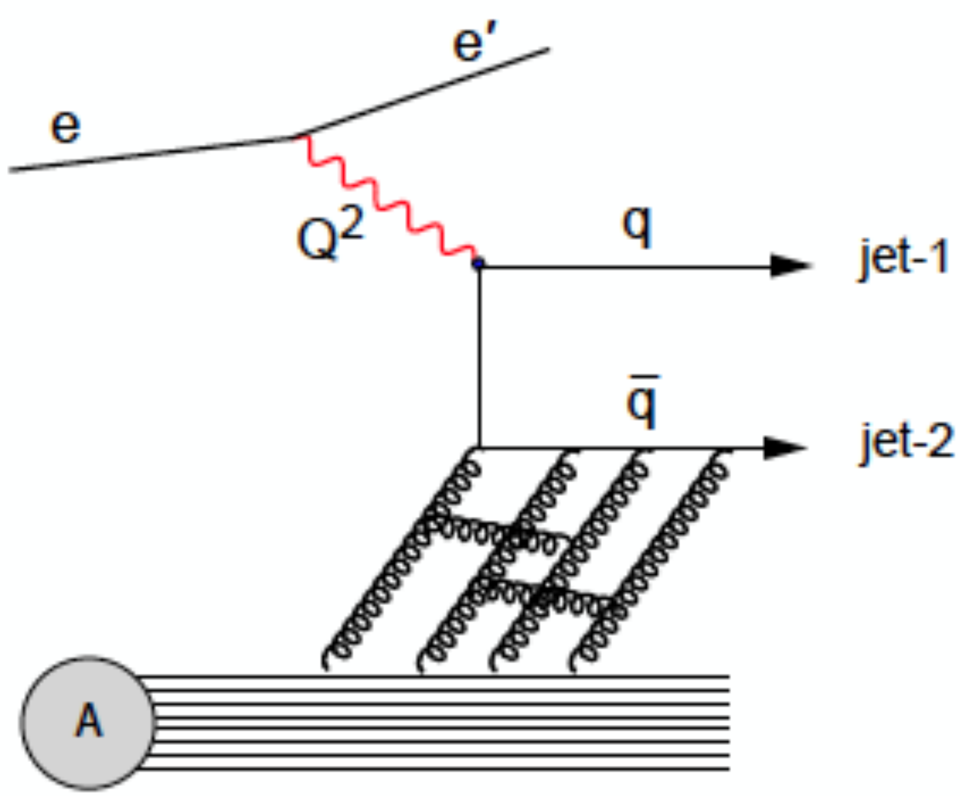
Low-x probe interacts coherently with all nucleons

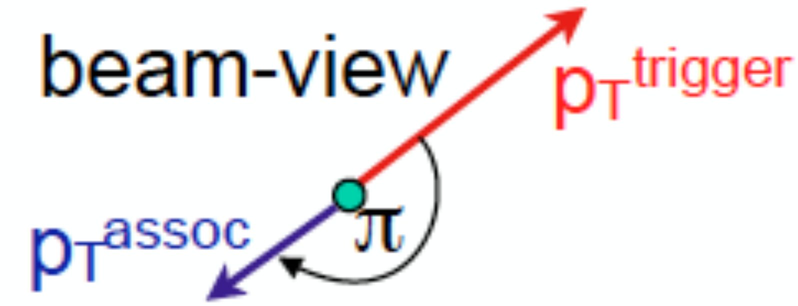


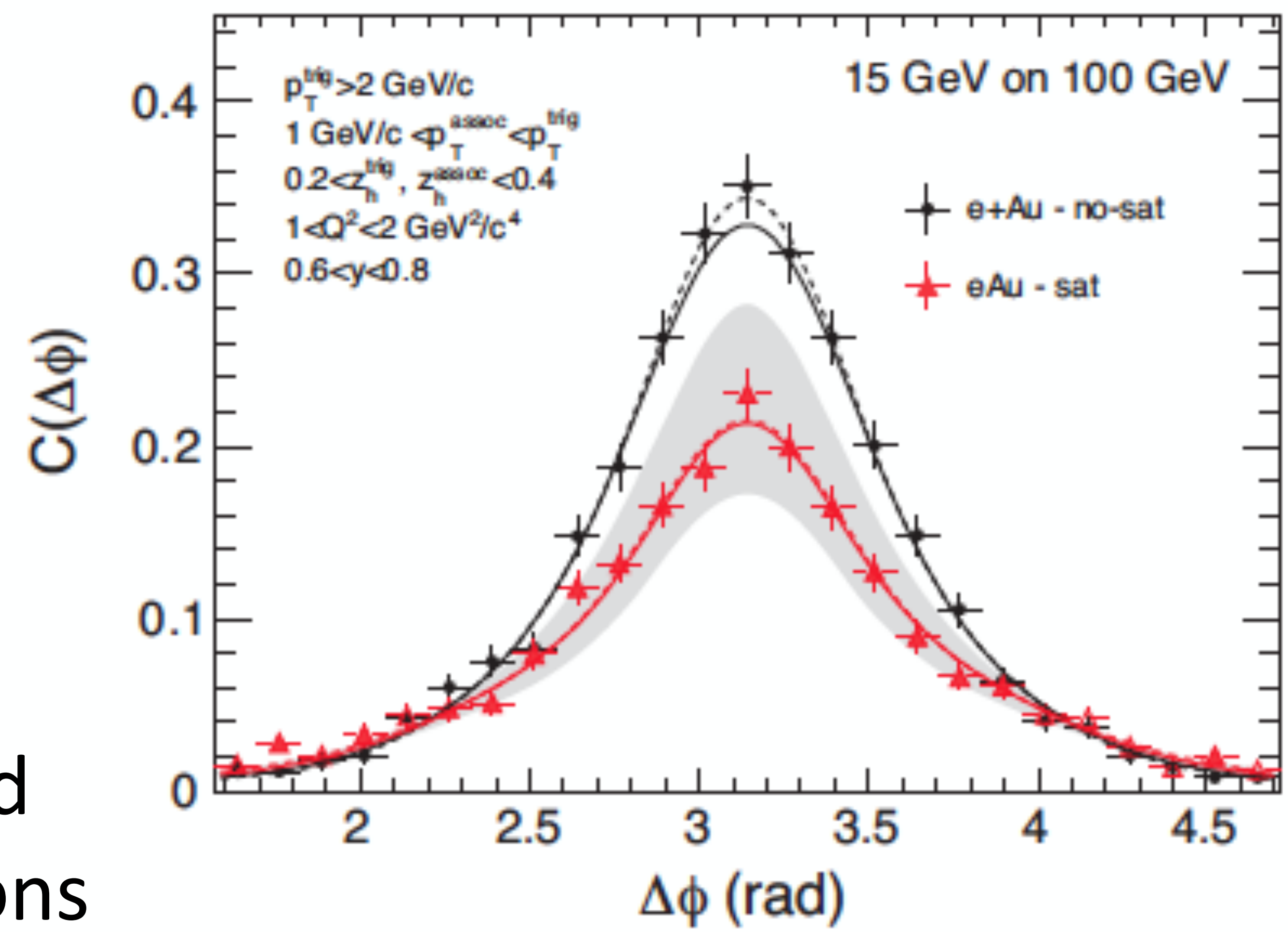
Saturation scale range (Q_s)



Gluon saturation



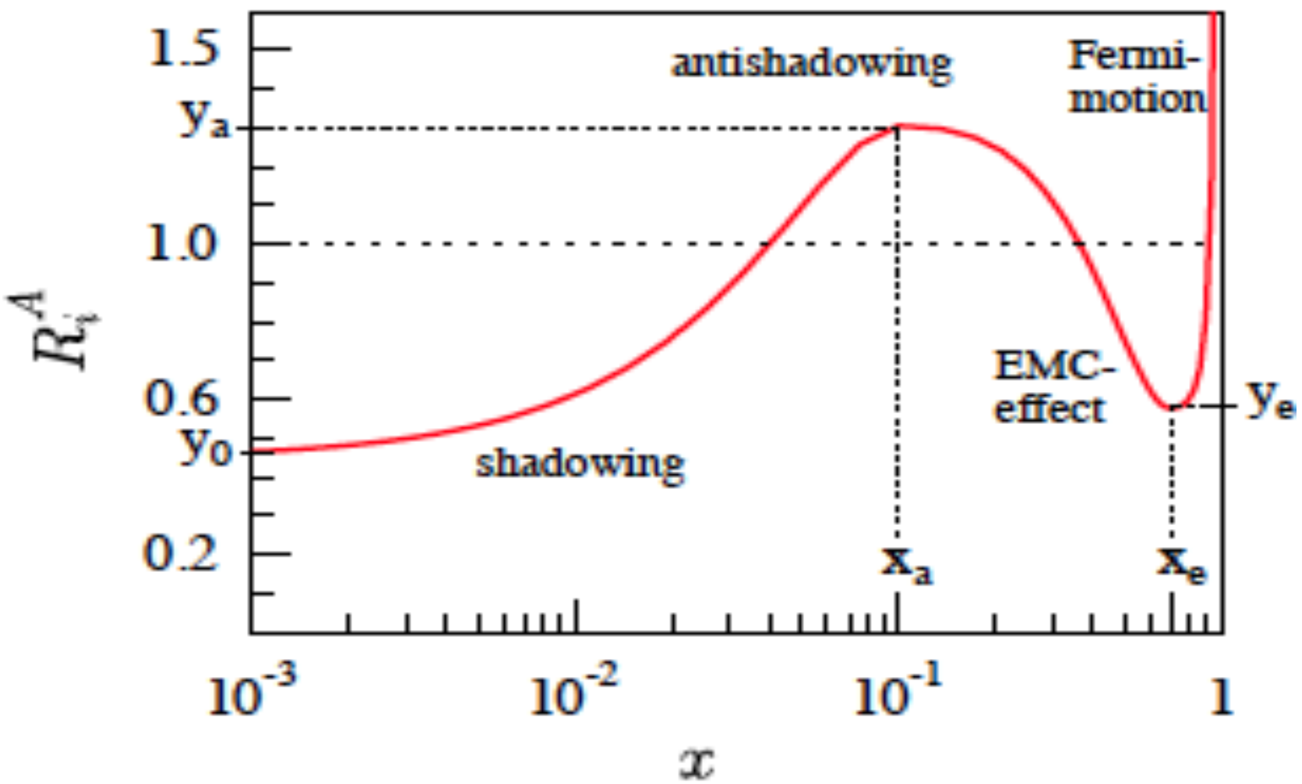


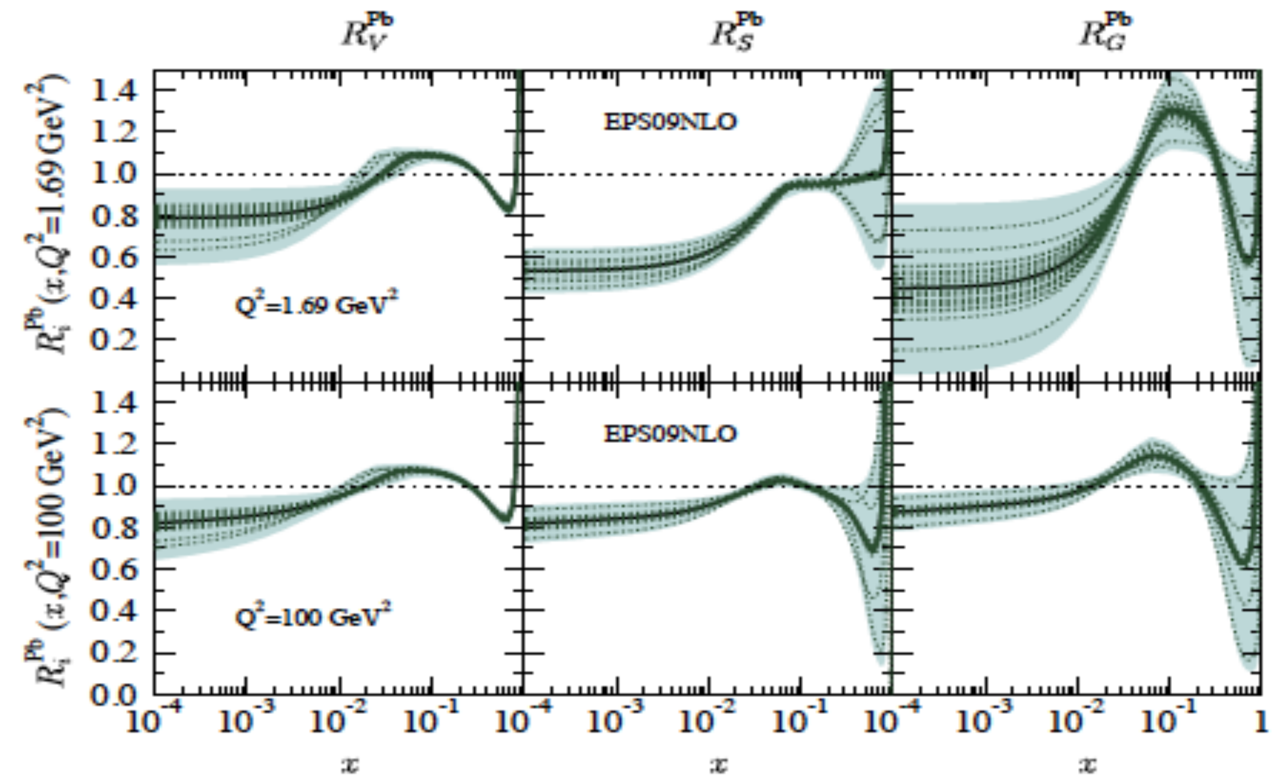


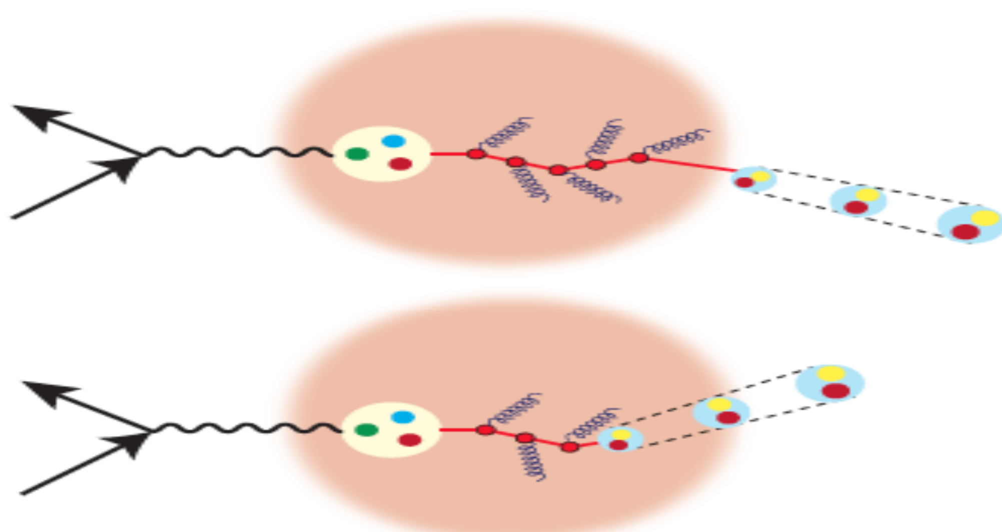
Di-hadron correlations are
very sensitive to the evolution and
dynamics of many body correlations

Zheng et al., PRD89 (2014) 074037

Nuclear gluon PDFs







The nucleus as a QCD laboratory :

Understand how quarks and gluons fragment and hadronize in and out of the medium

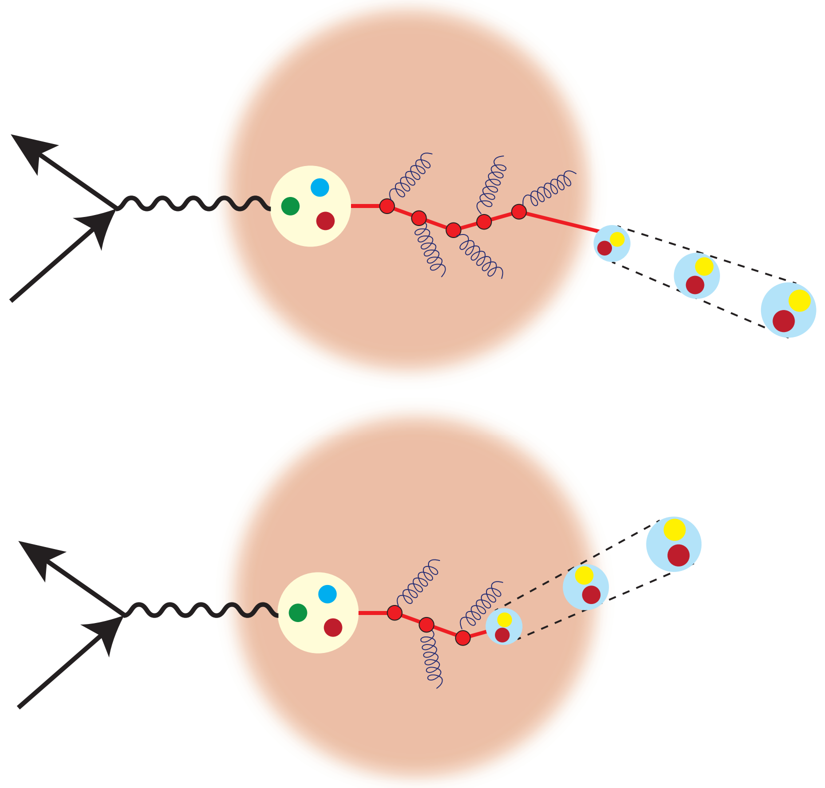
What is the quark-gluon nature of nuclear short-range correlations ?

Exploring hadron formation

Color propagation and neutralization

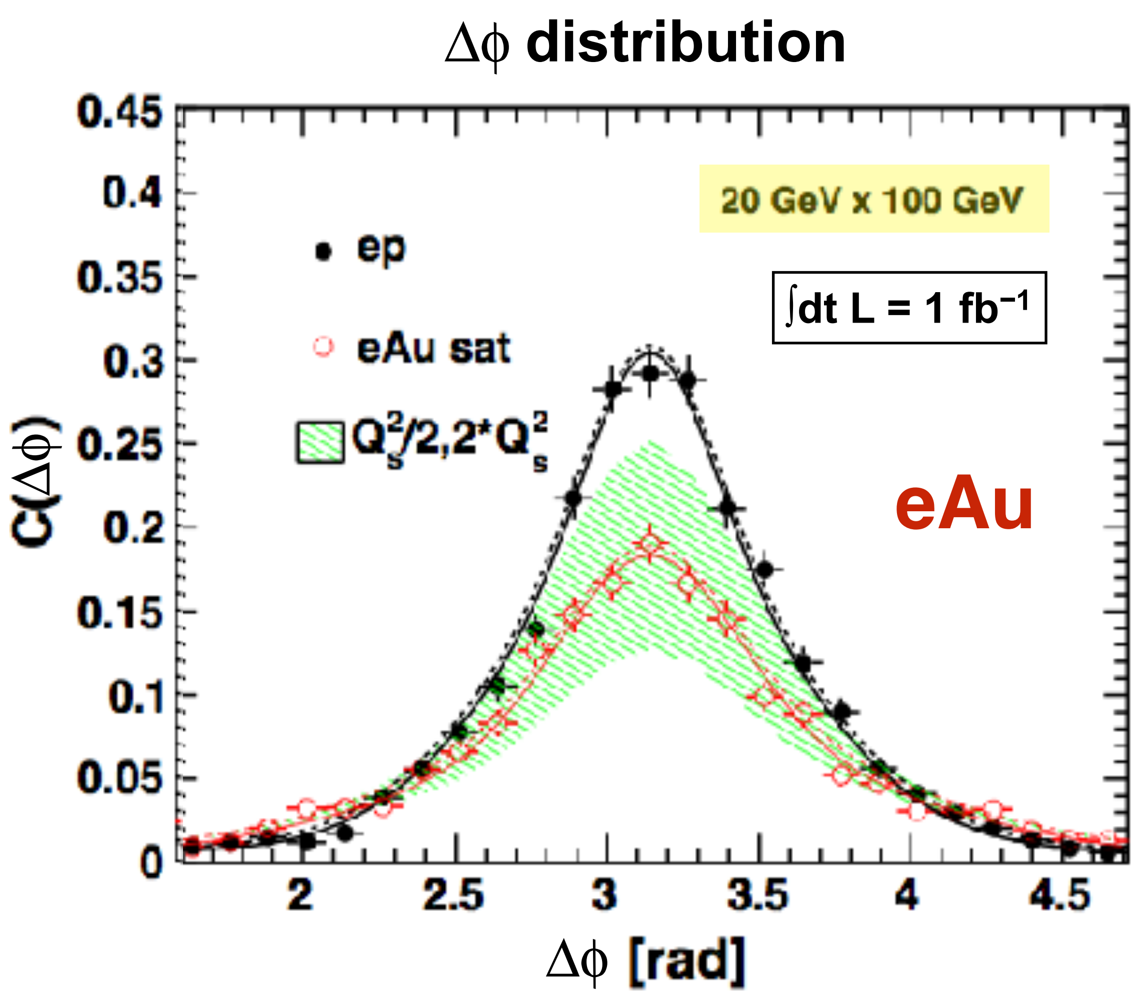
- Fundamental QCD Processes:
  - Partonic elastic scattering
  - Gluon bremsstrahlung in vacuum and in medium (E-loss)
  - Color neutralization
  - Hadron formation

dynamic confinement

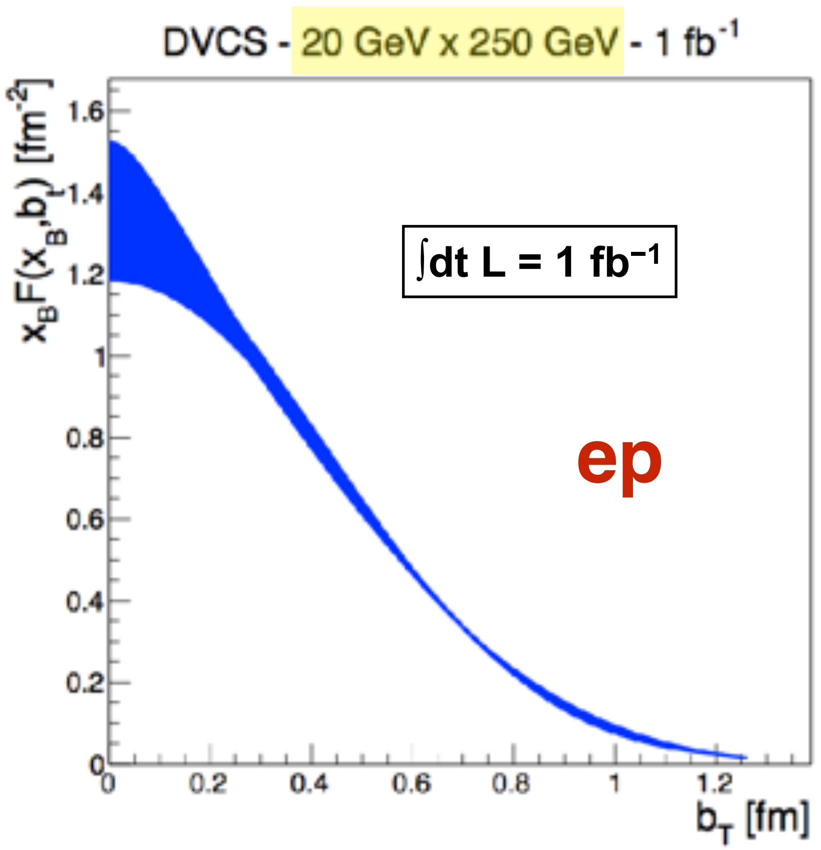


- **Nucleus as a space-time analyzer**
  - high Q^2 and ν ($\rightarrow$ large x):
    - Energy of struck quark (the probe) is known
    - No initial-state interactions
    - No color spectators (as in pA)
    - Hadronization in and out of medium can be varied (ν)

Day-1 measurements (Year 2)



Di-hadron angular correlation from γ* p → h h is a measure of gluon saturation: Correlation is suppressed when the virtual photon interactions with color field instead of a particle-like gluon. Large CM energy is essential for a clear signal.



Unpolarized transverse quark distribution $H(x,b_T)$ from deeply virtual Compton scattering.

Lumi & parton imaging (Year 4)

$\int dt\, L \approx 10\ \text{fb}^{-1} \Leftrightarrow$ 1 year running at $L \approx 10^{33}\ \text{cm}^{-2}\text{s}^{-1}$

Exclusive real photon production (DVCS) and exclusive J/ψ production cross sections are very small and luminosity hungry. Nevertheless, precision imaging of unpolarized quark and gluon distributions is possible with 10 fb^{-1} integrated luminosity (1 year running at $L \approx 10^{33}\ \text{cm}^{-2}\text{s}^{-1}$).