Overview of the future programs at JLAB and EIC

Jianwei Qiu

Theory Center, Jefferson Lab

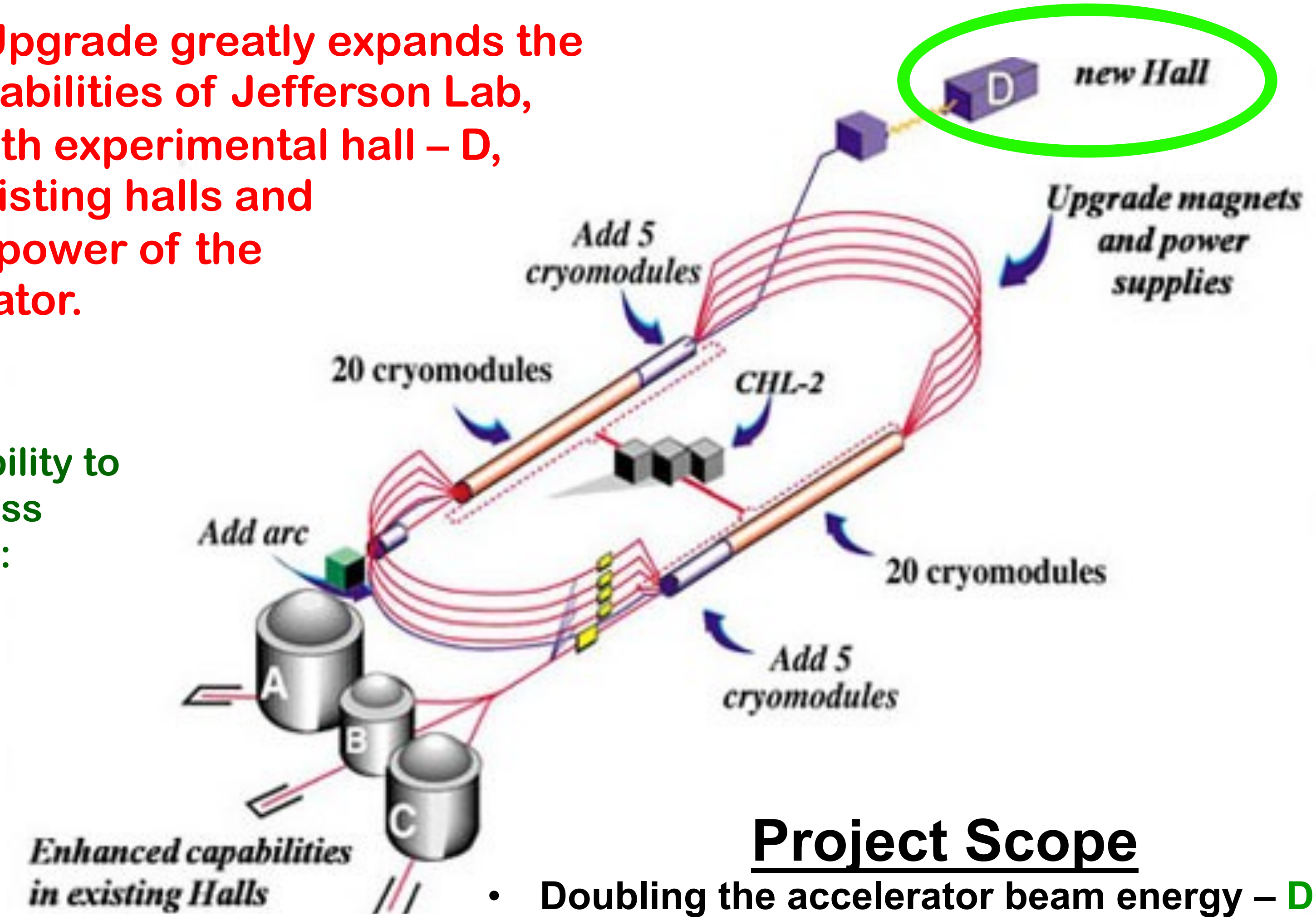
Theory Center

Jefferson Lab
EXPLORING THE NATURE OF MATTER

Jefferson Lab 12 GeV Upgrade Project

The 12 GeV Upgrade greatly expands the research capabilities of Jefferson Lab, adding a fourth experimental hall – D, upgrading existing halls and doubling the power of the lab's accelerator.

Maintain capability to delier lower pass beam energies: 2.2, 4.4, 6.6, …

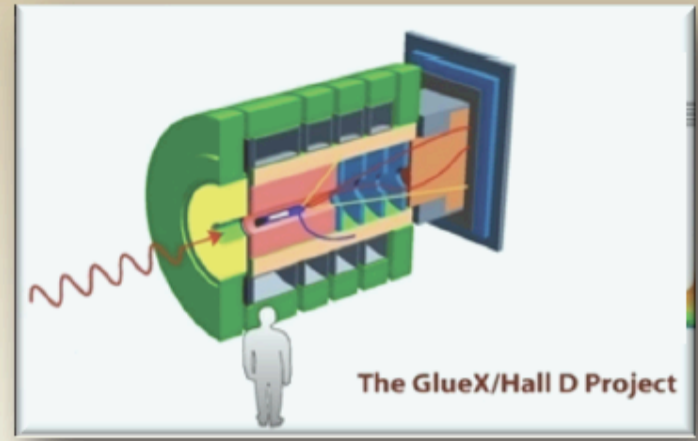


Project Scope

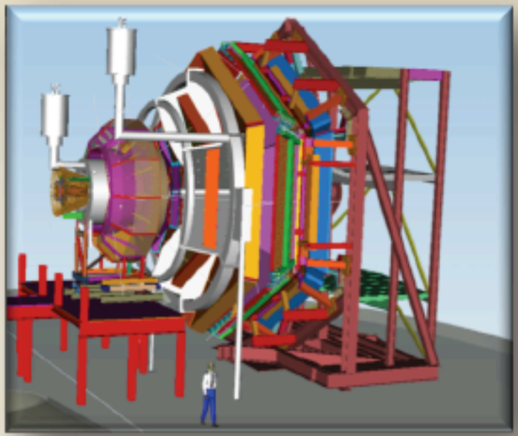
- Doubling the accelerator beam energy – DONE
- New experimental Hall D and beam line – DONE
- Civil construction including utilities – DONE
- Upgrades to Experimental Halls B & C – ~99%
  - Halls B & C Detectors – DONE

TPC = $338M
99% complete!

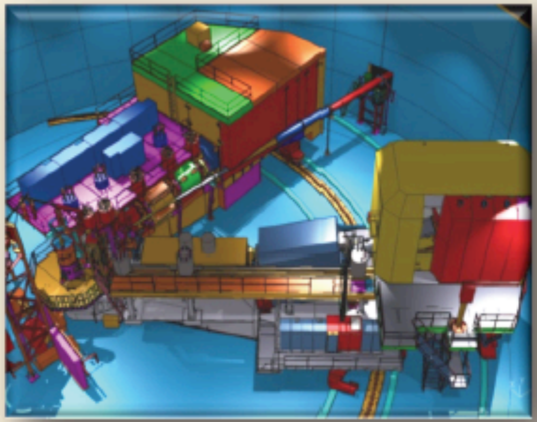
JLab 12 GeV Scientific Capabilities



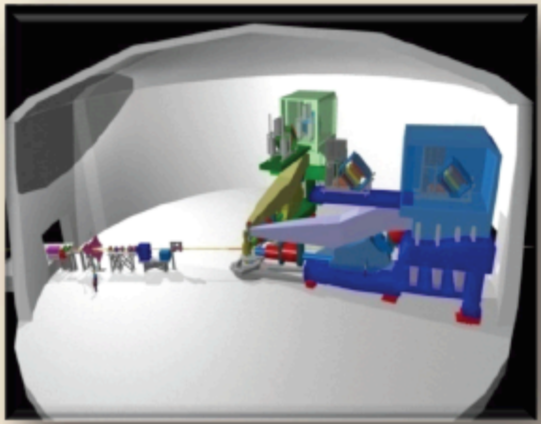
Hall D – exploring origin of confinement by studying exotic mesons



Hall B – understanding nucleon structure via generalized parton distributions



Hall C – precision determination of valence quark properties in nucleons and nuclei



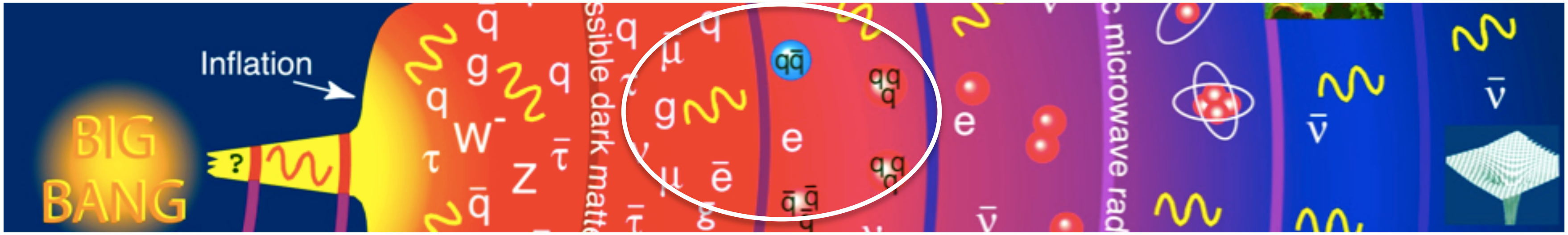
Hall A – form factors, future new experiments (e.g., SoLID and MOLLER)

Outline of the rest of my talk

- ❑ The next QCD frontier – the “big” questions, …
- ❑ JLAB12 and the Electron-Ion Collider (EIC)
- ❑ How JLAB12/EIC could answer the “big” questions?
- ❑ Path forward to the EIC era – unique role of JLAB12
- ❑ Summary

The next QCD frontier

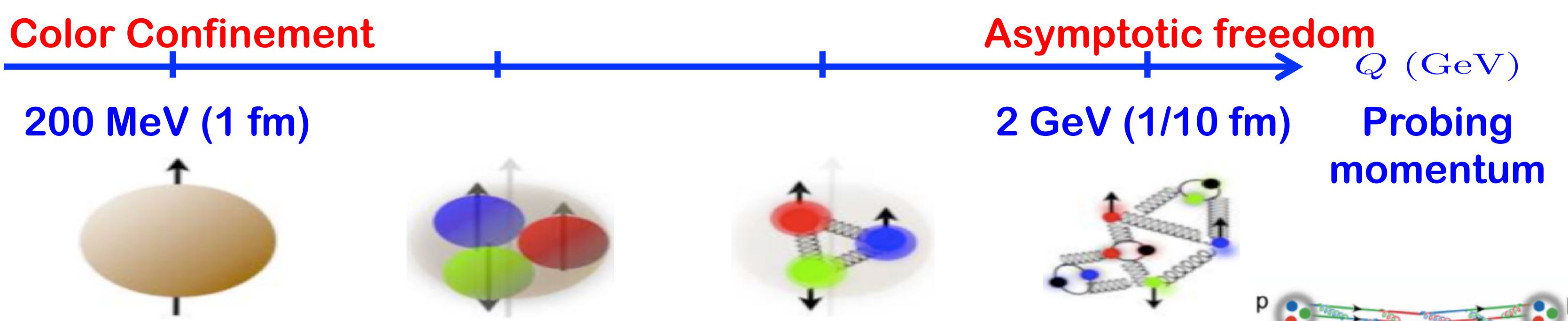
- ❑ What is the role of QCD in the evolution of the universe?



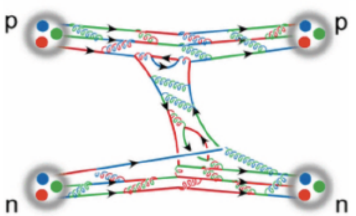
- ❑ How hadrons are emerged from quarks and gluons?
- ❑ How does QCD make up the properties of hadrons?

  Their mass, spin, magnetic moment, …

- ❑ What is the QCD landscape of nucleon and nuclei?



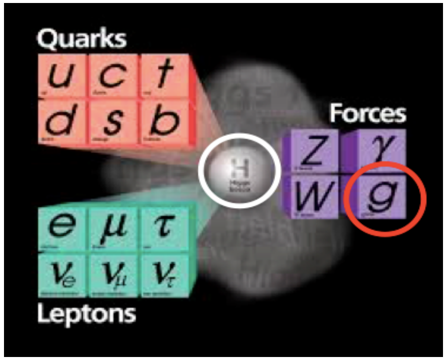
- ❑ How do the nuclear force arise from QCD?

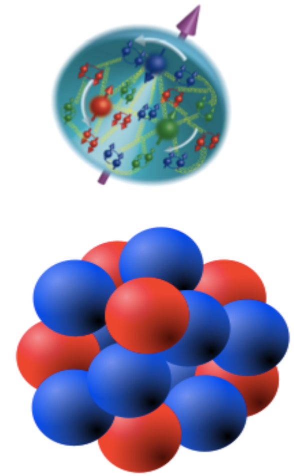


- ❑ …   ***Have to understand the role of glue!***

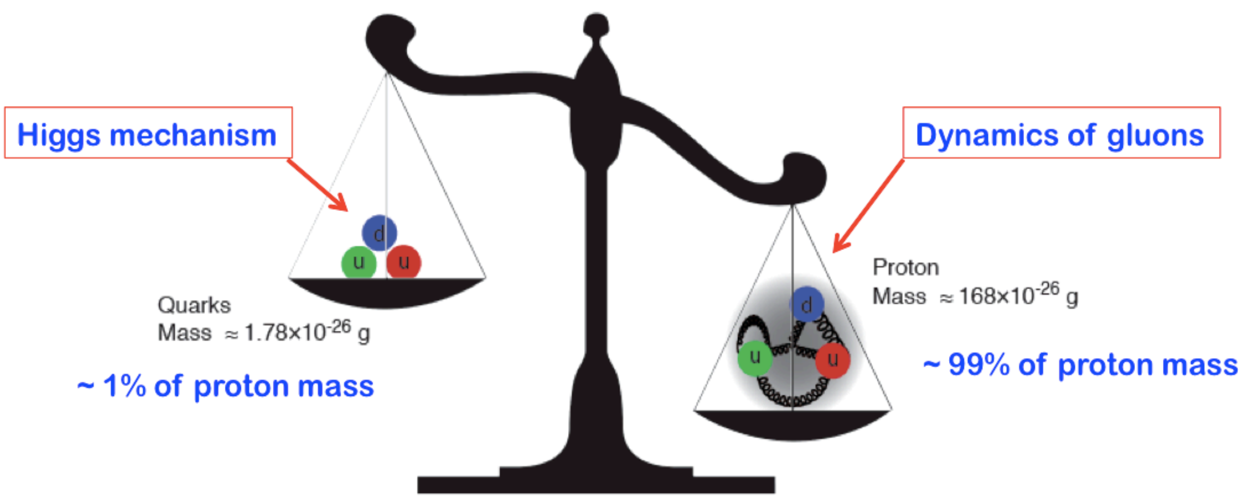
The next QCD frontier

- Understanding the glue – the Next QCD Frontier!

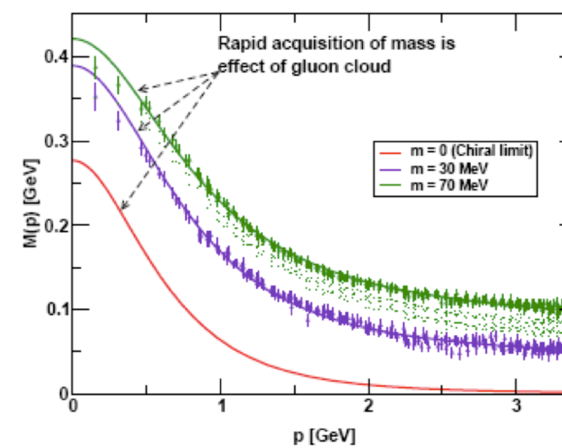




- Gluons are weird particles!
  - ✧ Massless, yet, responsible for nearly all visible mass



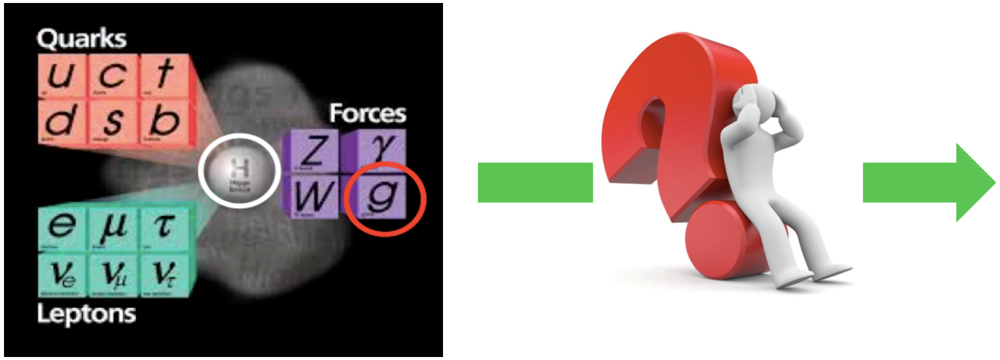
"Mass without mass!"

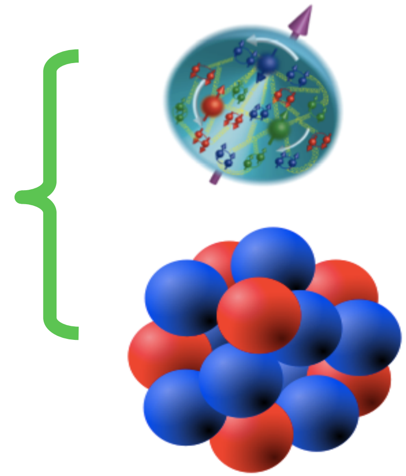


Bhagwat & Tandy/Roberts et al

The next QCD frontier

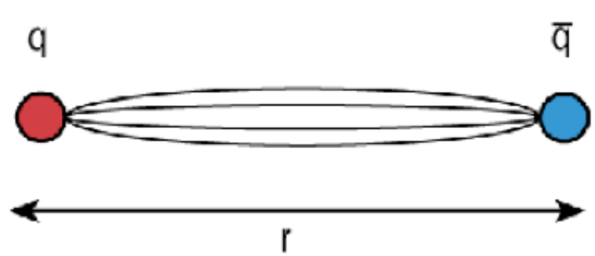
- Understanding the glue that binds us all – the Next QCD Frontier!



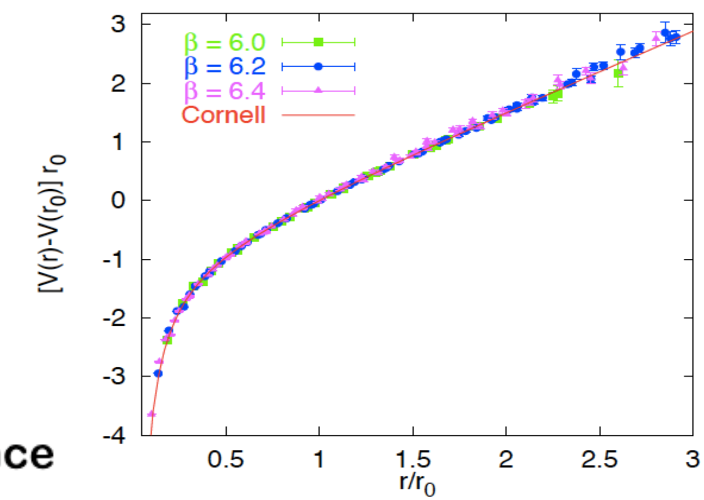


- Gluons are weird particles!
  - ✧ Massless, yet, responsible for nearly all visible mass
  - ✧ Carry color charge, responsible for color confinement and strong force

Force between a heavy quark pair

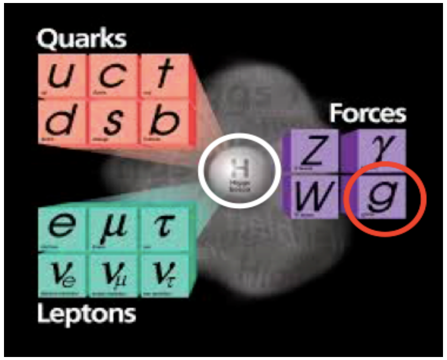


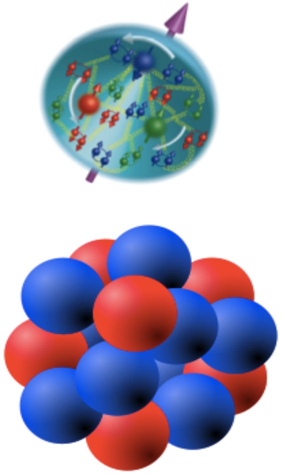
Heavy quarks experience a force of ~16 tons at ~1 Fermi (10^{-15} m) distance



The next QCD frontier

- Understanding the glue that binds us all – the Next QCD Frontier!

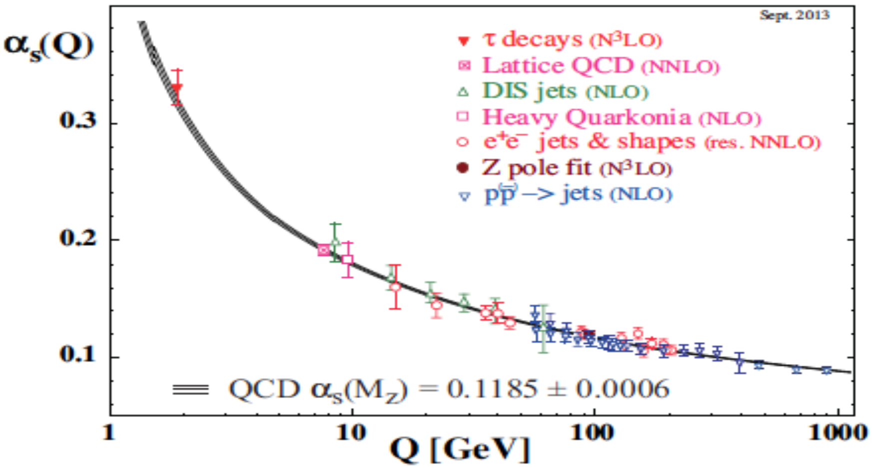




- Gluons are weird particles!
  - ✧ Massless, yet, responsible for nearly all visible mass
  - ✧ Carry color charge, responsible for color confinement and strong force

    but, also for asymptotic freedom

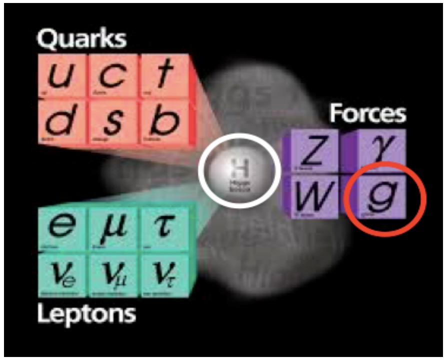
Nobel Prize, 2004

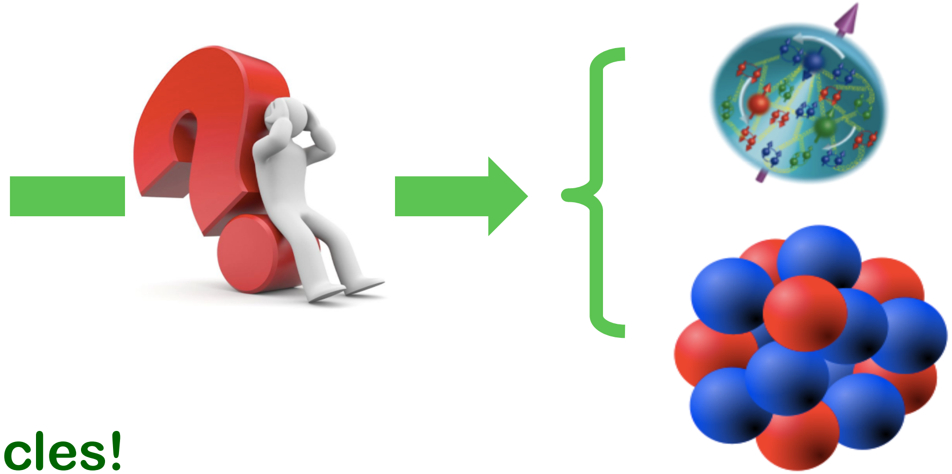


→ QCD perturbation theory

The next QCD frontier

- ❑ **Understanding the glue that binds us all – the Next QCD Frontier!**

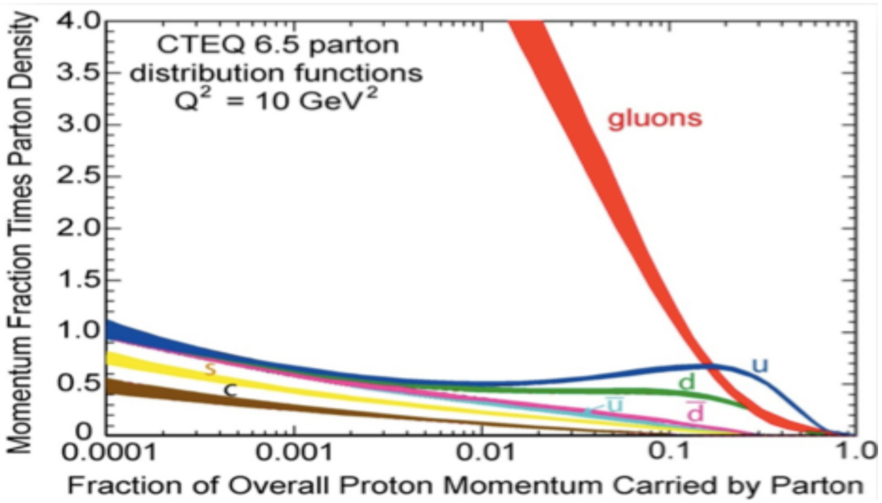




- ❑ **Gluons are weird particles!**
  - ✧ **Massless, yet, responsible for nearly all visible mass**
  - ✧ **Carry color charge, responsible for color confinement and strong force**

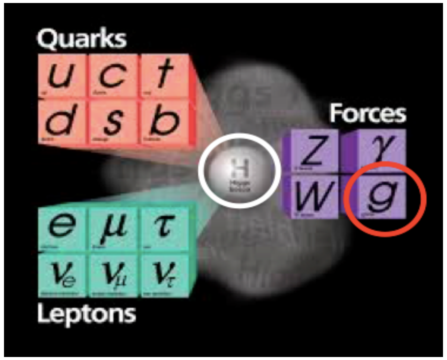
    but, also for asymptotic freedom,

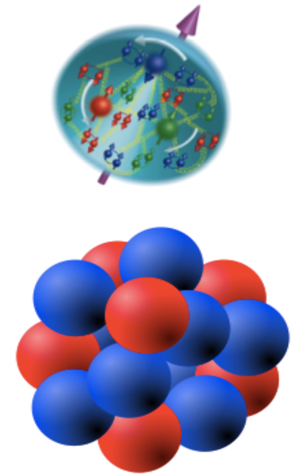
    as well as the abundance of glue



The next QCD frontier

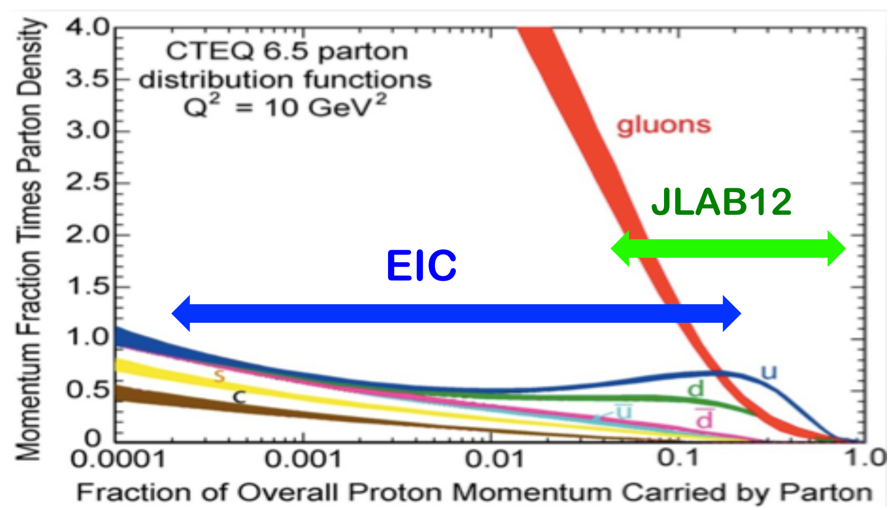
- ❑ Understanding the glue that binds us all – the Next QCD Frontier!





- ❑ Gluons are weird particles!
  - ✧ Massless, yet, responsible for nearly all visible mass
  - ✧ Carry color charge, responsible for color confinement and strong force but, also for asymptotic freedom, as well as the abundance of glue

Without gluons, there would be NO nucleons, NO atomic nuclei… NO visible world!



Unprecedented Intellectual Challenge!

- **Facts:**
  - ✧ We measure/detect leptons and hadrons
  - ✧ No modern detector has been able to see quarks and gluons in isolation!
- **The challenge:**

  How to probe the quark-gluon dynamics, quantify the hadron structure, study the emergence of hadrons, …, if we cannot see quarks and gluons?

- **Answer to the challenge:**

  Theory advances:

  QCD factorization – matching the quarks/gluons to hadrons with controllable approximations!

  Experimental breakthroughs:

  Energy, luminosity and measurement – Unprecedented resolution, event rates, and precision probes, especially EM probes, …

  Quarks – *Need the probe to "see" their existence, …*

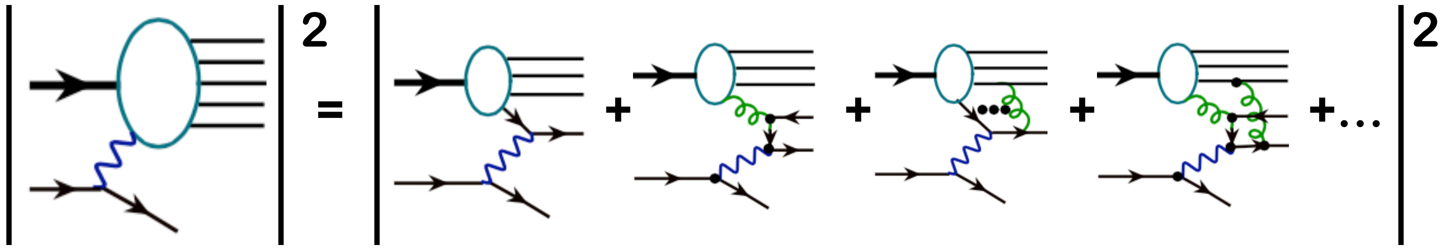
  Gluons – *Varying the probe's resolution to "see" their effect, …*

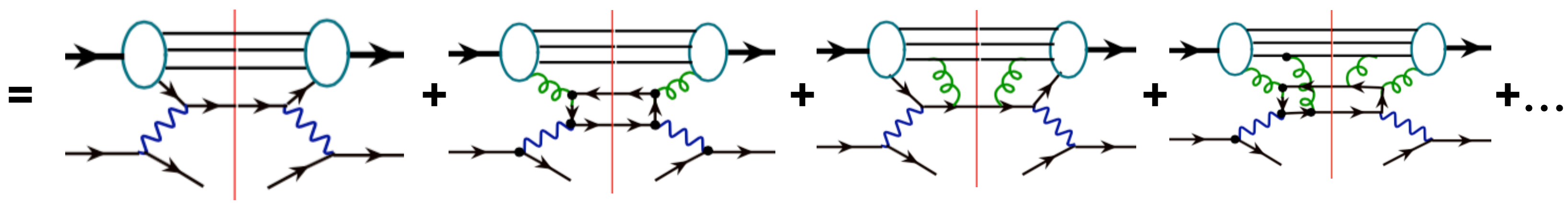
  Jets – *Footprints of energetic quarks and gluons*

QCD factorization is an approximation

- **Cross section with identified hadron(s) is NON-Perturbative!**

$$\sigma_{\rm DIS}(x,Q^2) =$$





$$= c_q \otimes q(x,Q^2) + c_g \otimes g(x,Q^2) + c_{qg} \otimes T_{qg}(\{x\},Q^2) + c_{gg} \otimes T_{gg}(\{x\},Q^2)$$

$$+\mathcal{O}\left(\langle k_T^n\rangle/Q^n, \langle F^{2n}\rangle/Q^n\right) + \ldots$$

Probe

structure

Leading power
Linear contribution
DGLAP regime
...

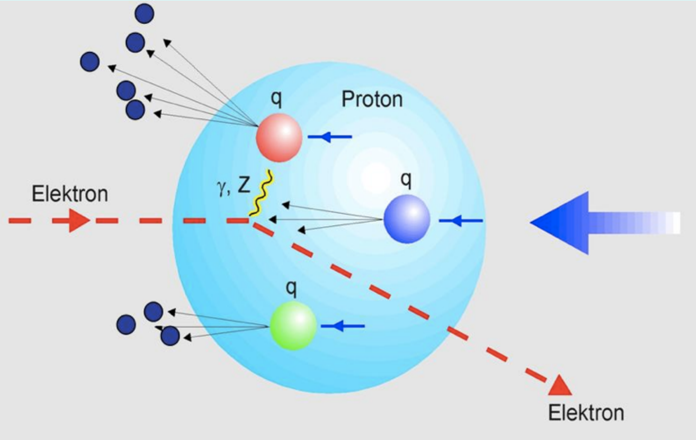
Power corrections
Non-Linear contribution
Multi-parton correlations

$$\approx c_q \otimes q(x,Q^2) + c_g \otimes g(x,Q^2) + \mathcal{O}\left(\frac{\langle k_T^2\rangle}{Q^2}, \frac{\langle F^2\rangle}{Q^2}, ..\right)$$

Approximation – Leading power/twist factorization!

Non-perturbative physics neglected or in input PDFs!

How to “see” and quantify the hadron structure?



- **EM probe:** **Not a camera!**

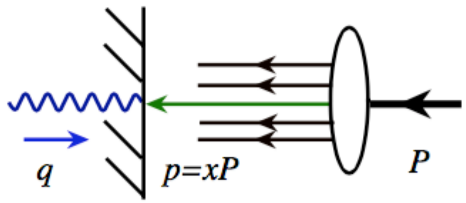
  Collision by photon exchange
  with a large momentum transfer: Q

  e.g. Photon momentum: $q^2 = -Q^2$ in DIS

- **Resolution:**

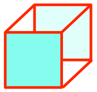
  $1/Q \sim 1/10$ fermi $= 10^{-14}$ cm $= 2$ GeV^{-1}

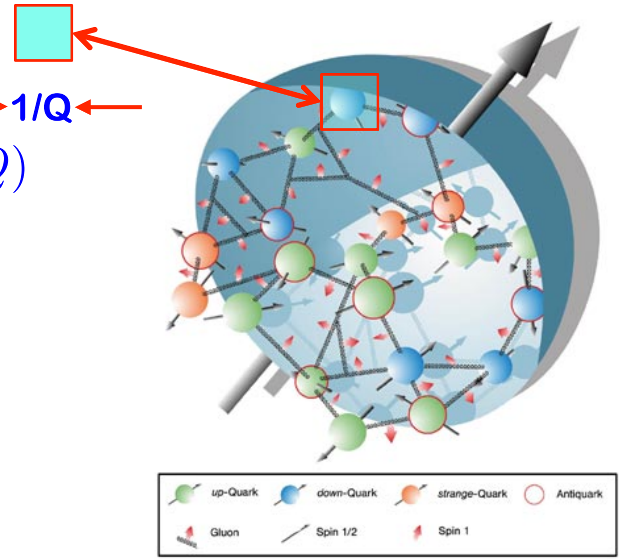
  Breit frame (Brick-Wall frame) in DIS:



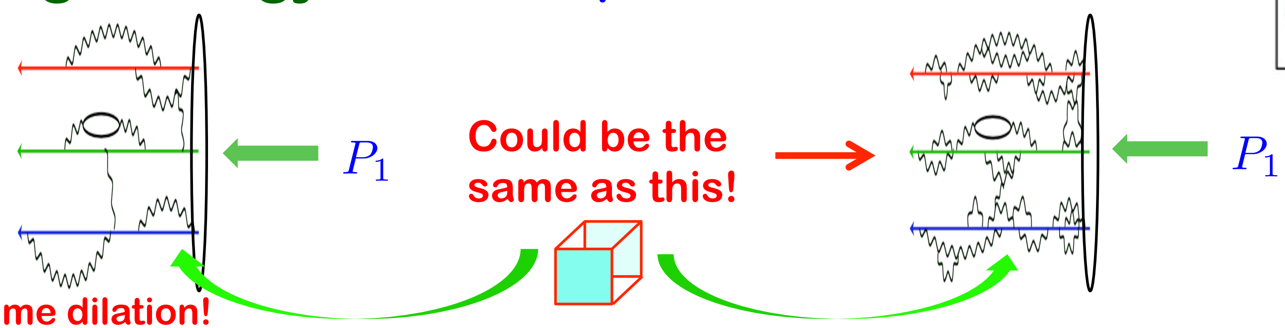
$$q = (q_0, q_\perp, q_z) = (0, 0_\perp, -Q)$$
$$p = (Q/2, 0_\perp, Q/2)$$
$$x_B = x = Q/(2P_z) \propto 1/P_z$$

Resolution in Breit frame:



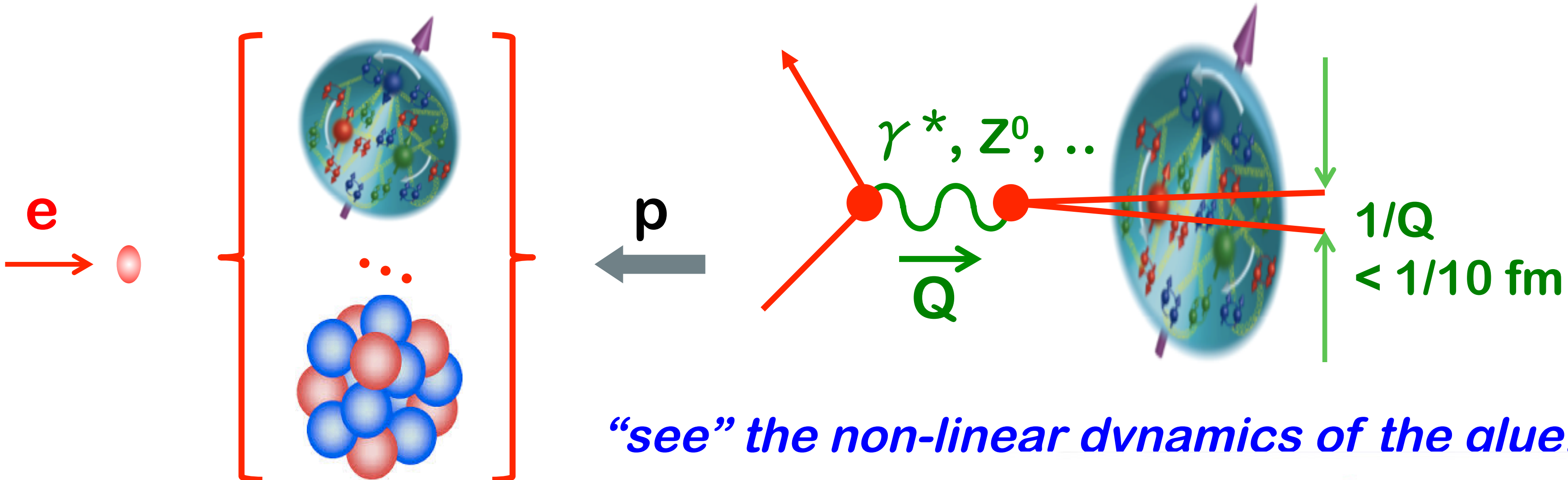


- **High energy:** **boosted partonic structure**



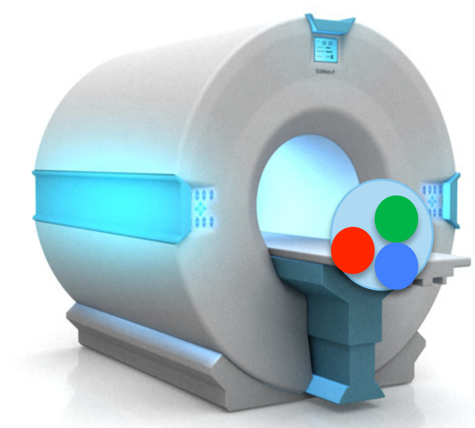
JLAB12 & the Electron-Ion Collider (EIC)

- A giant "Microscope":
  - "see" quarks/gluons and their dynamics by breaking the hadron



"see" the non-linear dynamics of the glue!

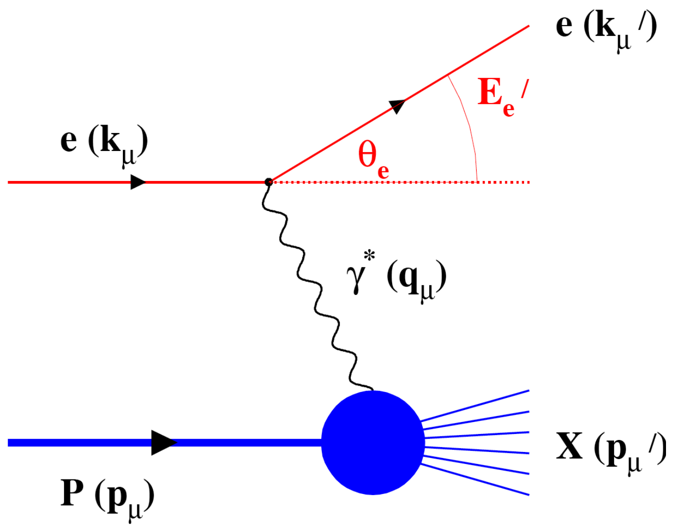
- A sharpest "CT":
  - "imagine" the quark/gluon structure without breaking the hadron
  - "cat-scan" the nucleon and nuclei with better than 1/10 fm resolution
  - "see" the proton "radius" of quark/gluon density
  - "explore" the range of color force



JLAB – Valence region
EIC – Sea & gluons

Many complementary probes at one facility

- High energy and luminosity Lepton-hadron facility:



Q^2 → Measure of resolution

y → Measure of inelasticity

x → Measure of momentum fraction of the struck quark in a proton

$Q^2 = S\ x\ y$

Inclusive events: e+p/A → e'+X

Detect only the scattered lepton in the detector

Semi-Inclusive events: e+p/A → e'+h(π,K,p,jet)+X

Detect the scattered lepton in coincidence with identified hadrons/jets

Exclusive events: e+p/A → e'+ p'/A'+ h(π,K,p,jet)

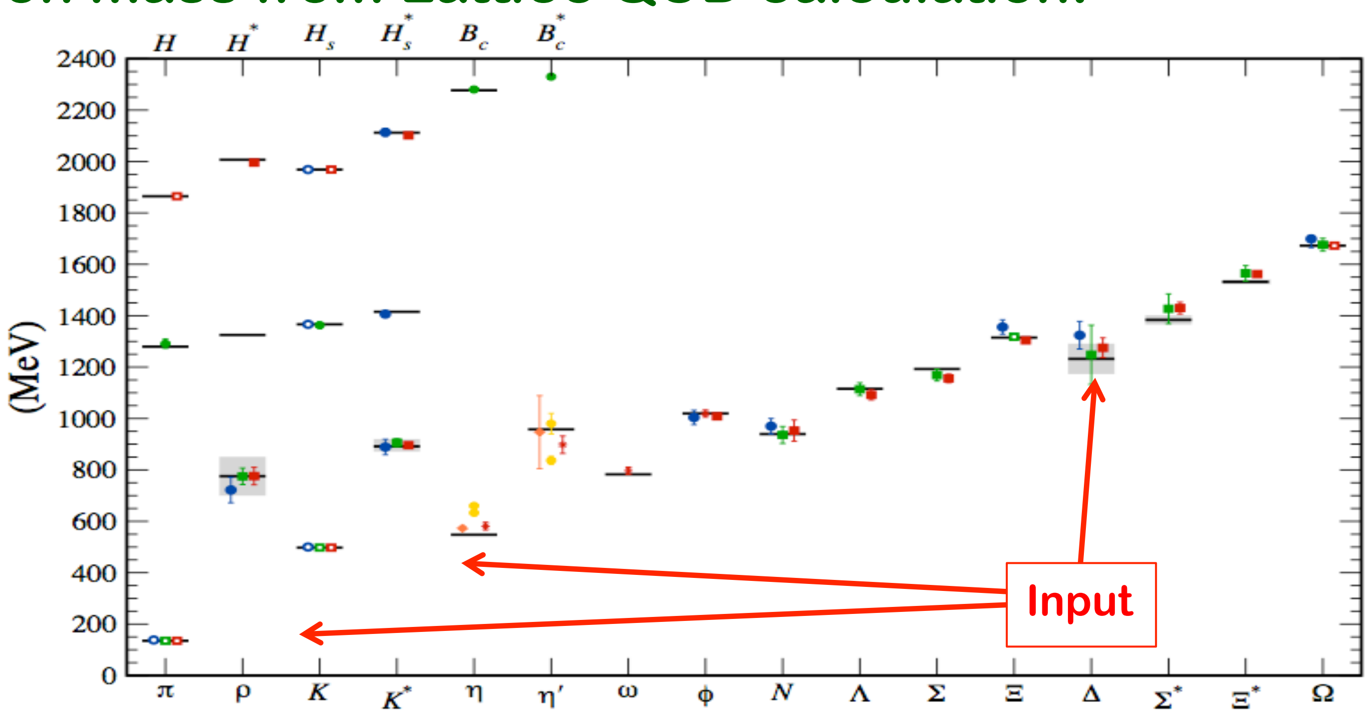
Detect every things including scattered proton/nucleus (or its fragments)

How to answer the "big" questions?

- **How does QCD generate the nucleon mass?**

"… The vast majority of the nucleon's mass is due to quantum fluctuations of quark-antiquark pairs, the gluons, and the energy associated with quarks moving around at close to the speed of light. …" *The 2015 Long Range Plan for Nuclear Science*

- **Hadron mass from Lattice QCD calculation:**



How does QCD generate this? The role of quarks vs that of gluons?

If we do not understand proton mass, we do not understand QCD

How to answer the “big” questions?

❑ **Three-pronged approach to explore the origin of hadron mass**

- ✧ **Lattice QCD**
- ✧ **Mass decomposition – roles of the constituents**
- ✧ **Model calculation – approximated analytical approach**

https://phys.cst.temple.edu/meziani/proton-mass-workshop-2016/

How to answer the "big" questions?

- ❑ **Three-pronged approach to explore the origin of hadron mass**
  - ✧ **Lattice QCD**
  - ✧ **Mass decomposition – roles of the constituents**
  - ✧ **Model calculation – approximated analytical approach**

http://www.ectstar.eu/node/2218

How to answer the "big" questions?

- **How does QCD generate the nucleon mass?**

  "… The vast majority of the nucleon's mass is due to quantum fluctuations of quark-antiquark pairs, the gluons, and the energy associated with quarks moving around at close to the speed of light. …" *The 2015 Long Range Plan for Nuclear Science*

- **Role of quarks and gluons?**

  ✧ QCD energy-momentum tensor:

$$T^{\mu\nu} = \frac{1}{2}\overline{\psi} i \overleftrightarrow{D}^{(\mu}\gamma^{\nu)}\psi + \frac{1}{4}g^{\mu\nu}F^2 - F^{\mu\alpha}F^{\nu}{}_{\alpha}$$

  ✧ Trace of the QCD energy-momentum tensor:

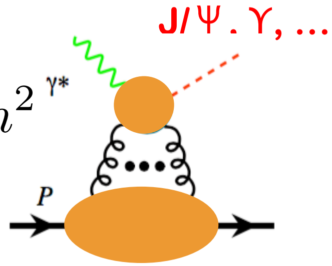
$$T^{\alpha}_{\ \alpha} = \underbrace{\frac{\beta(g)}{2g}F^{\mu\nu,a}F^{a}_{\mu\nu}}_{\text{QCD trace anomaly}} + \sum_{q=u,d,s} m_q(1+\gamma_m)\overline{\psi}_q\psi_q$$

$$\beta(g) = -(11 - 2n_f/3)\,g^3/(4\pi)^2 + \ldots$$

  ✧ Mass, trace anomaly, chiral symmetry break, and …

$$\langle p|\,T^{\mu\nu}\,|p\rangle \propto p^{\mu}p^{\nu} \;\Rightarrow\; \langle p|\,T^{\mu\nu}\,|p\rangle(g_{\mu\nu}) \propto p^{\mu}p^{\nu}(g_{\mu\nu}) = m^2$$

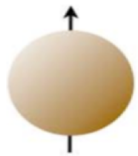
$$m^2 \propto \langle p|T^{\alpha}{}_{\alpha}\,|p\rangle \;\Rightarrow\; \frac{\beta(g)}{2g}\,\langle p|F^2|p\rangle$$



➡ Heavy quarkonium production near the threshold, from JLab12 to EIC

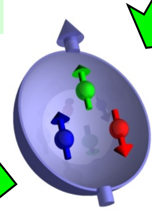
How to answer the "big" questions?

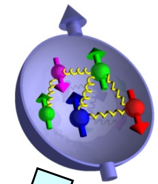
❑ **How does QCD generate the nucleon's spin?**

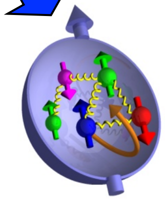


Proton Spin

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + (L_q + L_g) = \sum \langle P, S | \hat{J}_f^z(\mu) | P, S \rangle$$







Quark helicity
Best known

$$\frac{1}{2}\int dx \left(\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}\right)$$
$$\sim 30\%$$

Spin "puzzle"

Gluon helicity
Start to know

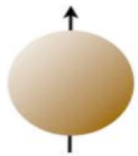
$$\Delta G = \int dx \Delta g(x)$$
$$\sim 20\% (\text{with RHIC data})$$

Orbital Angular Momentum of quarks and gluons
Little known

If we do not understand proton spin, we do not understand QCD

How to answer the “big” questions?

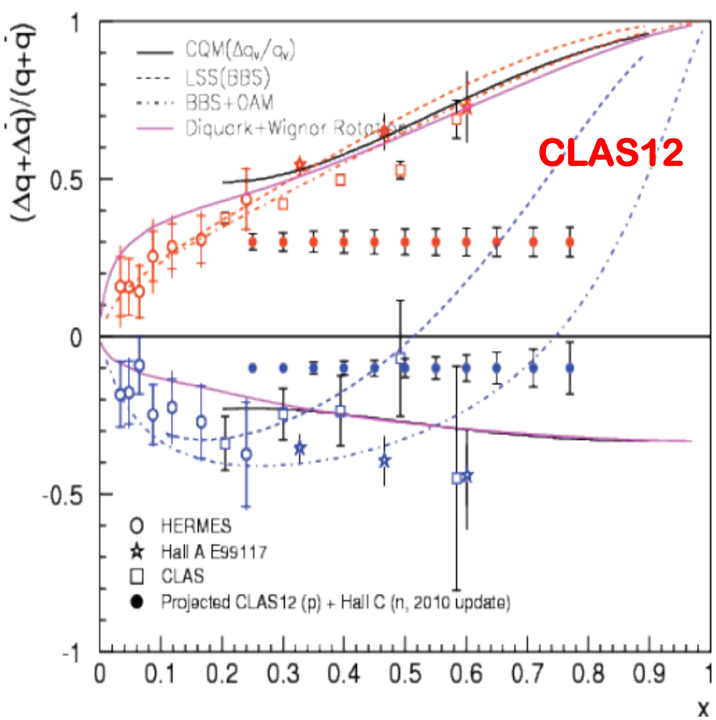
- ❑ **How does QCD generate the nucleon’s spin?**

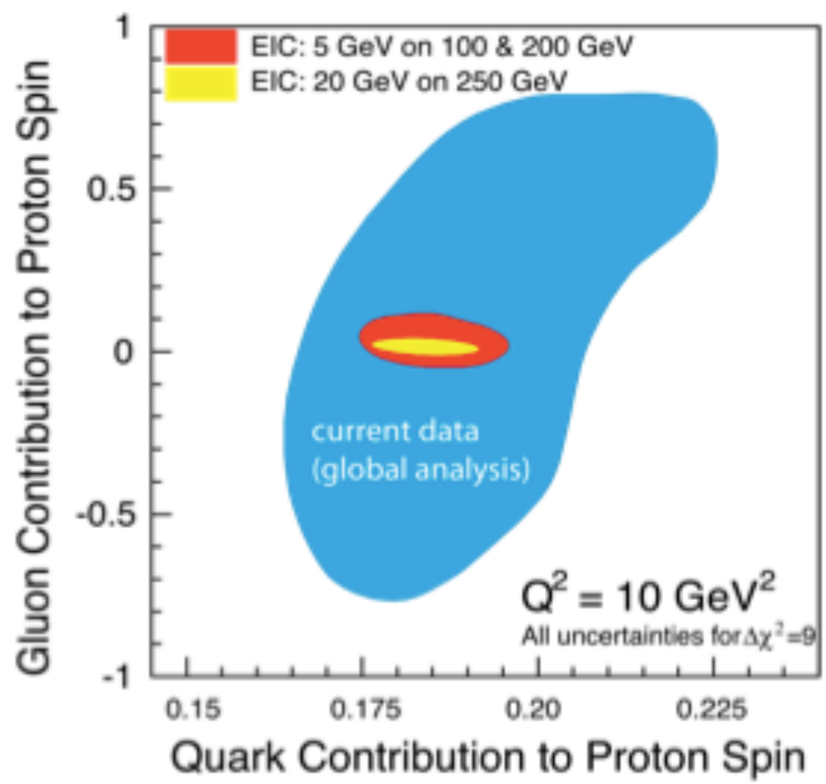


$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + (L_q + L_g)$$

Proton Spin

- ❑ **What can JLab12 and EIC do?**

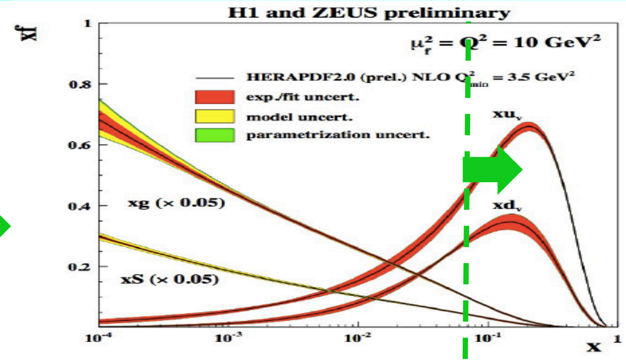




Plus many more JLab12 experiments – flavor

New role of the lattice calculations

Lattice QCD



X-dep distributions

- **New ideas – from quasi-PDFs (lattice calculable) to PDFs:**
  - High P_z effective field theory approach:

$$\tilde{q}(x,\mu^2,P_z) = \int_x^1 \frac{dy}{y} Z\left(\frac{x}{y},\frac{\mu}{P_z}\right) q(y,\mu^2) + \mathcal{O}\left(\frac{\Lambda^2}{P_z^2},\frac{M^2}{P_z^2}\right)$$

Ji, et al., arXiv:1305.1539, 1404.6680

  - QCD collinear factorization approach:

$$\tilde{q}(x,\mu^2,P_z) = \sum_f \int_0^1 \frac{dy}{y} \mathcal{C}_f\left(\frac{x}{y},\frac{\mu^2}{\bar{\mu}^2},P_z\right) f(y,\bar{\mu}^2) + \mathcal{O}\left(\frac{1}{\mu^2}\right)$$

Non-perturbative lattice UV renormalization:
Effective mass renormalization, Gradient flow, …

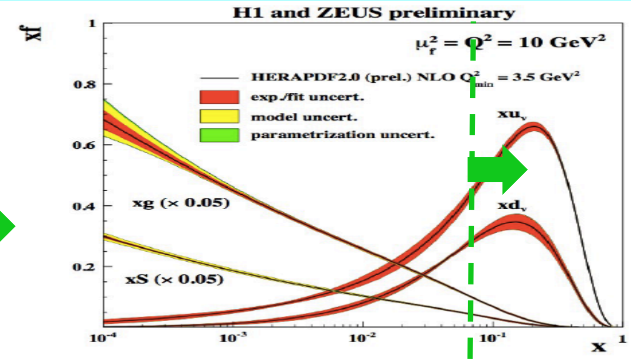
Ma and Qiu, arXiv:1404.6860, 1412.2688
Ishikawa, Ma, Qiu, Yoshida, 1609.02018
Monohan, Orginos, 1612.01584
…

- **The TMD Collaboration + on-going effort around the world!**

Plus the intense JLab and world-wide theory effort!

New role of the lattice calculations

Lattice QCD



X-dep distributions

- **New ideas – from quasi-PDFs (lattice calculable) to PDFs:**
  - High P_z effective field theory approach:

$$\tilde{q}(x,\mu^2,P_z) = \int_x^1 \frac{dy}{y} Z\left(\frac{x}{y},\frac{\mu}{P_z}\right) q(y,\mu^2) + \mathcal{O}\left(\frac{\Lambda^2}{P_z^2},\frac{M^2}{P_z^2}\right)$$

Ji, et al., arXiv:1305.1539, 1404.6680

  - QCD collinear factorization approach:

$$\tilde{q}(x,\mu^2,P_z) = \sum_f \int_0^1 \frac{dy}{y} \mathcal{C}_f\left(\frac{x}{y},\frac{\mu^2}{\bar{\mu}^2},P_z\right) f(y,\bar{\mu}^2) + \mathcal{O}\left(\frac{1}{\mu^2}\right)$$

Ma and Qiu, arXiv:1404.6860, 1412.2688
Ishikawa, Ma, Qiu, Yoshida, 1609.02018
Monohan, Orginos, 1612.01584
…

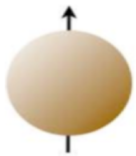
Non-perturbative lattice UV renormalization:
Effective mass renormalization, Gradient flow, …

- **Tremendous potentials!**

PDFs of proton, neutron, pion, …; TMDs, GPDs, …; JLab12 expts

How to answer the "big" questions?

- ❑ **How does QCD generate the nucleon's spin?**



Proton Spin

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

To understand the proton spin,
fully, we need to understand
the confined motion of
quarks and gluons in QCD

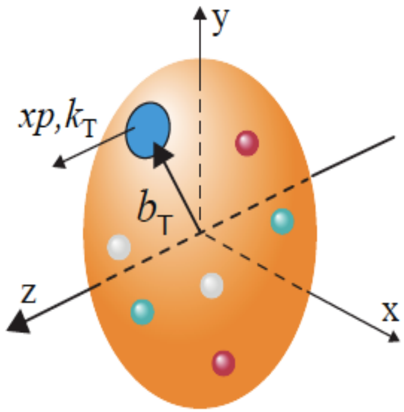
➡ **TMDs, GTMDs, …**

Need "probes"
for two-scale observables!

Two-momentum-scale observables

❑ Cross sections with two-momentum scales observed:

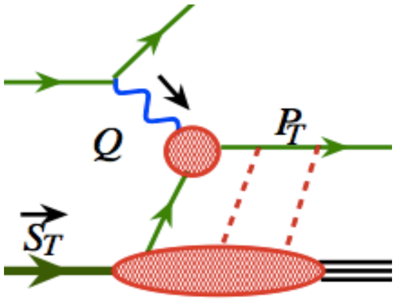
$$Q_1 \gg Q_2 \sim 1/R \sim \Lambda_{\rm QCD}$$



✧ Hard scale: Q_1 localizes the probe
to see the quark or gluon d.o.f.

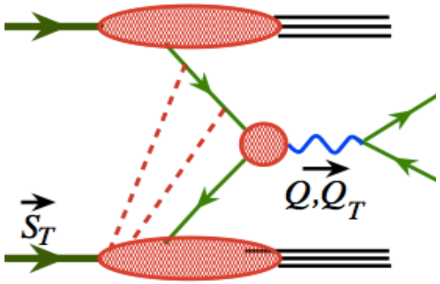
✧ "Soft" scale: Q_2 could be more sensitive to
hadron structure, e.g., confined motion

❑ Two-scale observables with the hadron broken:



SIDIS: $Q \gg P_T$

+



DY: $Q \gg P_T$

+ Two-jet momentum imbalance in SIDIS, …

➡

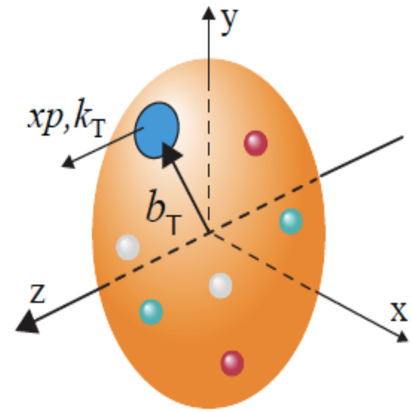
✧ Natural observables with TWO very different scales

✧ TMD factorization: partons' confined motion is encoded into TMDs

Two-momentum-scale observables

❑ Cross sections with two-momentum scales observed:

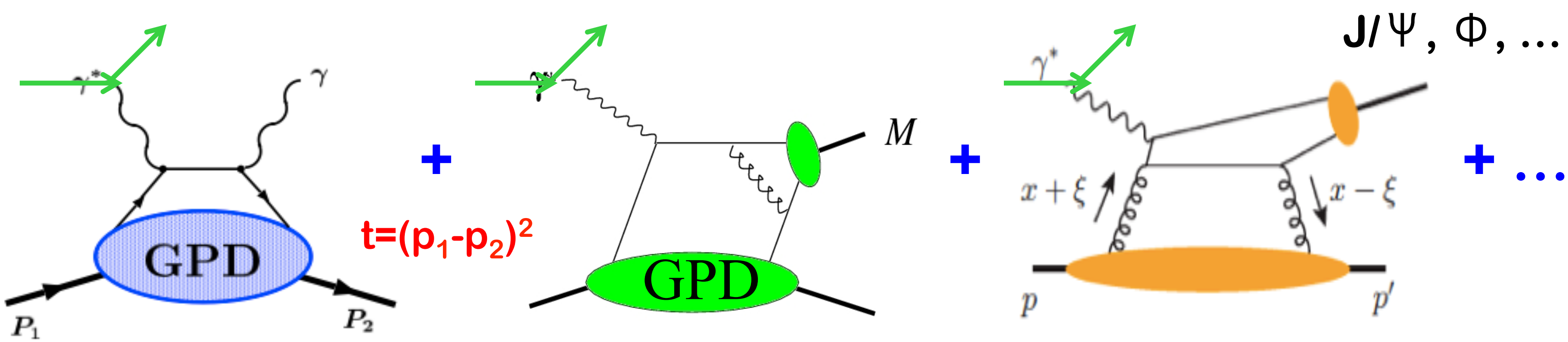
$$Q_1 \gg Q_2 \sim 1/R \sim \Lambda_{\rm QCD}$$



✧ Hard scale: Q_1 localizes the probe to see the quark or gluon d.o.f.

✧ "Soft" scale: Q_2 could be more sensitive to hadron structure, e.g., confined motion

❑ Two-scale observables with the hadron unbroken:



DVCS: $Q^2 >> |t|$ DVEM: $Q^2 >> |t|$ EHMP: $Q^2 >> |t|$

✧ Natural observables with TWO very different scales

✧ GPDs: Fourier Transform of t-dependence gives spatial b_T-dependence

How to answer the "big" questions?

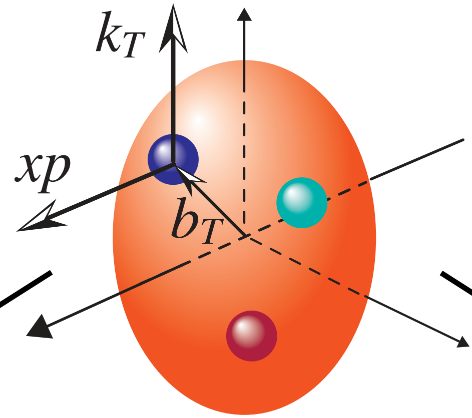
❑ 3D boosted partonic structure:

Momentum Space

TMDs

Confined motion

$\int d^2b_T$



$\int d^2k_T$

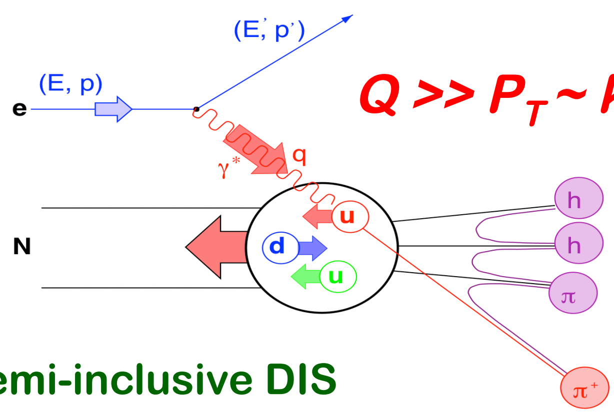
Coordinate Space

GPDs

Spatial distribution

$f(x,k_T)$ **Two-scales observables** $f(x,b_T)$

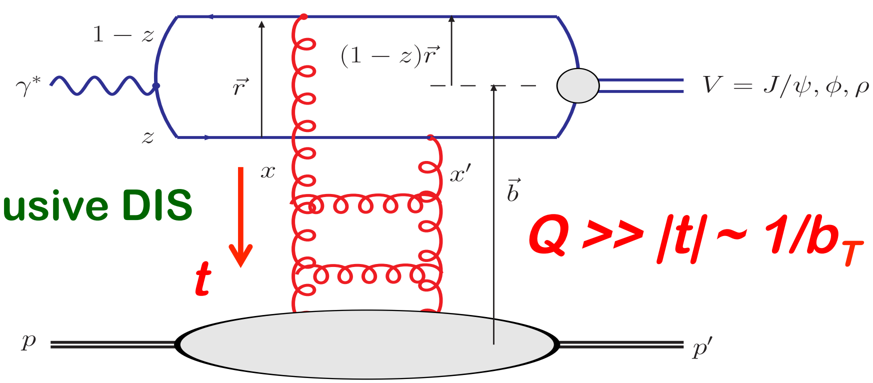
3D momentum space images



$Q >> P_T \sim k_T$

Semi-inclusive DIS

2+1D coordinate space images



Exclusive DIS

t

$Q >> |t| \sim 1/b_T$

JLab12 – valence quarks, EIC – sea quarks and gluons

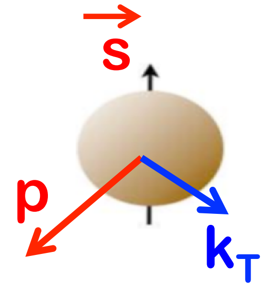
TMDs: confined motion, its spin correlation

❑ Power of spin – many more correlations:

Nucleon Polarization	Quark Polarization: Un-Polarized (U)	Quark Polarization: Longitudinally Polarized (L)	Quark Polarization: Transversely Polarized (T)
U	$f_1 =$		$h_1^{\perp} =$ − Boer-Mulders
L		$g_{1L} =$ − Helicity	$h_{1L}^{\perp} =$ −
T	$f_{1T}^{\perp} =$ − Sivers	$g_{1T}^{\perp} =$ −	$h_1 =$ − Transversity $h_{1T}^{\perp} =$ −

Nucleon Spin — Quark Spin

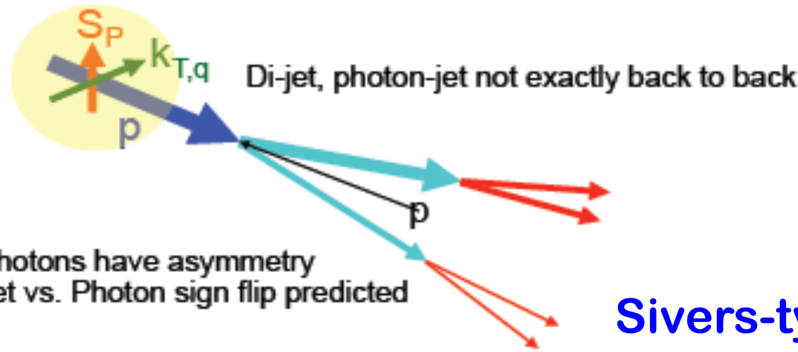
Similar for gluons



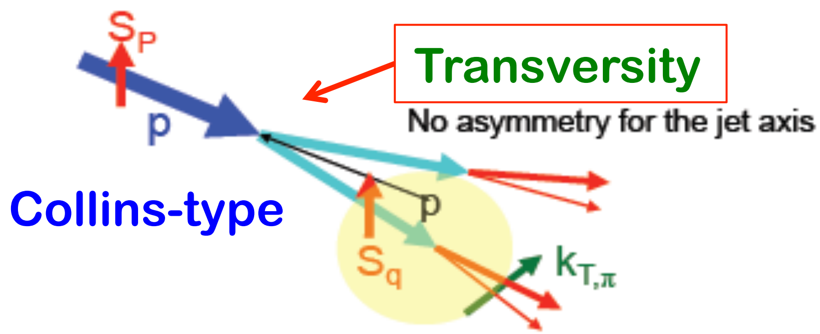
Require two Physical scales

More than one TMD contribute to the same observable!

❑ A_N – single hadron production:



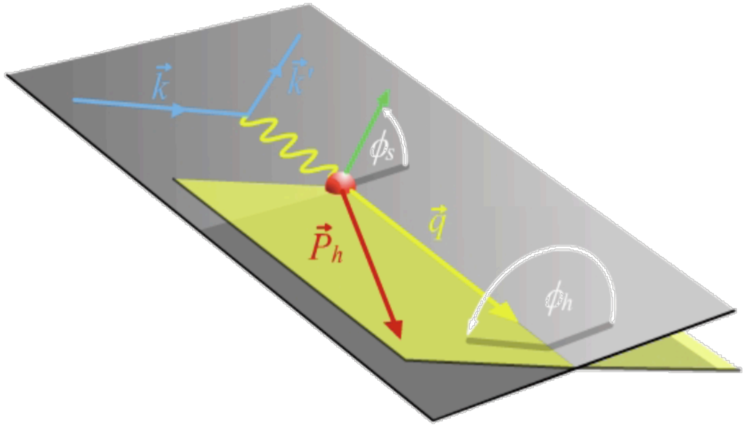
Sivers-type



SIDIS is the best for probing TMDs

- **Naturally, two scales & two planes:**

$$A_{UT}(\varphi_h^l,\varphi_S^l)=\frac{1}{P}\frac{N^{\uparrow}-N^{\downarrow}}{N^{\uparrow}+N^{\downarrow}}$$
$$=A_{UT}^{Collins}\sin(\phi_h+\phi_S)+A_{UT}^{Sivers}\sin(\phi_h-\phi_S)$$
$$+A_{UT}^{Pretzelosity}\sin(3\phi_h-\phi_S)$$



- **Separation of TMDs:**

$$A_{UT}^{Collins}\propto\left\langle\sin(\phi_h+\phi_S)\right\rangle_{UT}\propto h_1\otimes H_1^{\perp}$$
$$A_{UT}^{Sivers}\propto\left\langle\sin(\phi_h-\phi_S)\right\rangle_{UT}\propto f_{1T}^{\perp}\otimes D_1$$
$$A_{UT}^{Pretzelosity}\propto\left\langle\sin(3\phi_h-\phi_S)\right\rangle_{UT}\propto h_{1T}^{\perp}\otimes H_1^{\perp}$$

Collins frag. Func. from e^+e^- collisions

Hard, if not impossible, to separate TMDs in hadronic collisions

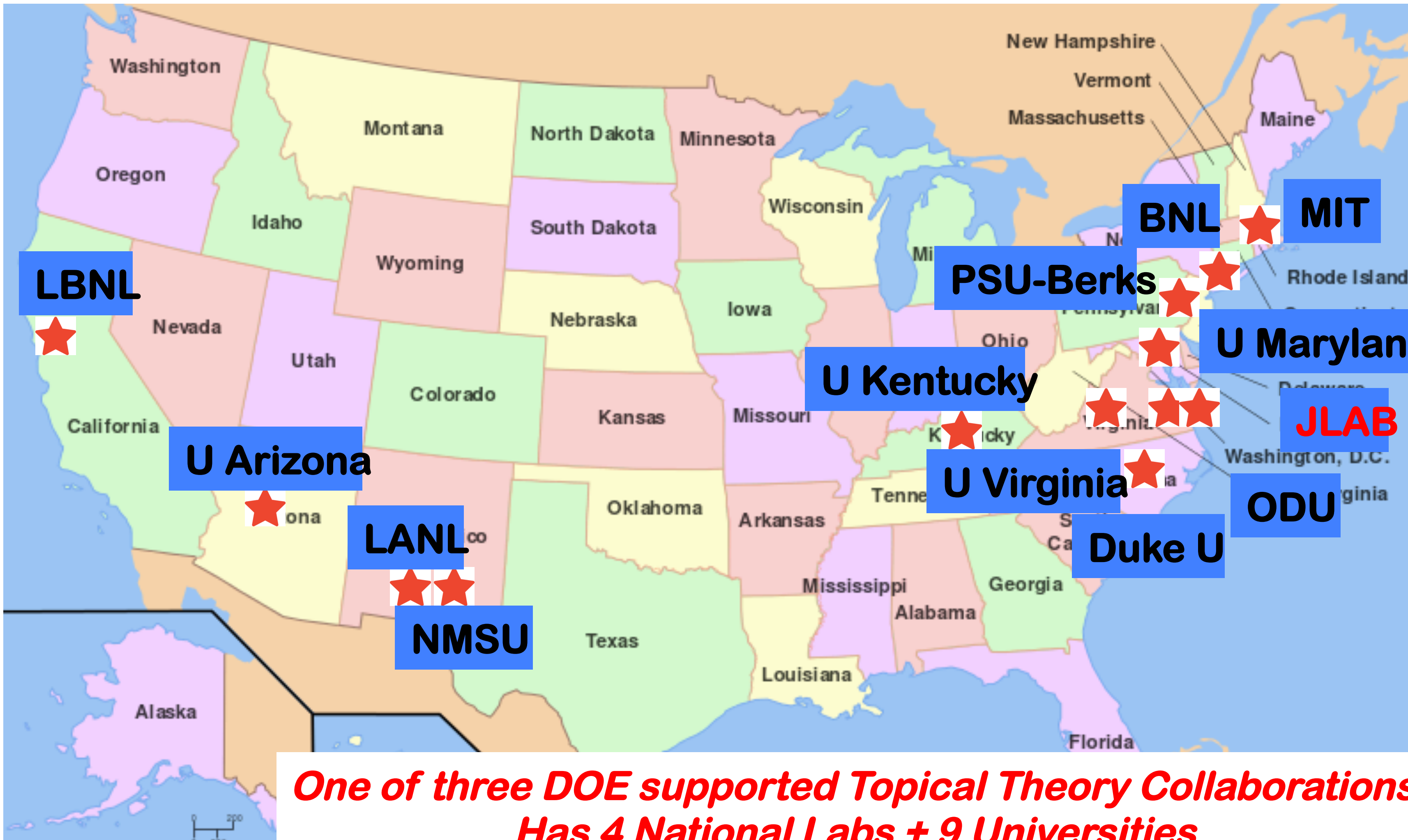
Using a combination of different observables (not the same observable): jet, identified hadron, photon, …

TMD Topical Theory Collaboration

Coordinated Theoretical Approach to Transverse Momentum Dependent Hadron Structure in QCD (TMD Collaboration)

Co-spokespersons: W. Detmold, J.W. Qiu

TMD Collaboration



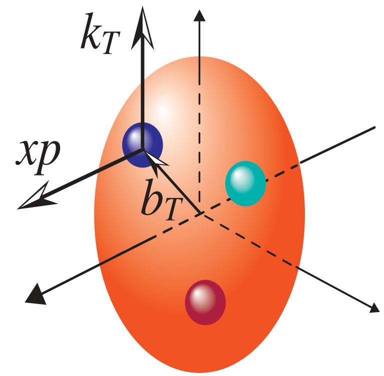
One of three DOE supported Topical Theory Collaborations
Has 4 National Labs + 9 Universities

TMD Topical Theory Collaboration

TMD Collaboration

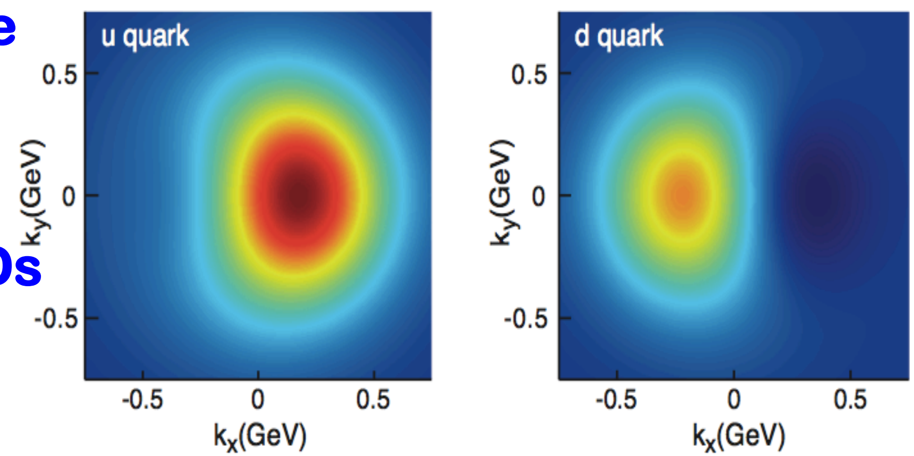
❑ Objectives/Deliverables – 3D Confined Motion:

Unique three pronged scientific effort: (1) theory, (2) phenomenology and (3) lattice QCD, to explore 3D hadron structure – 3D confined motion!



Sivers function

- ✧ **Matching x-section to parton motion**
  – QCD factorization
- ✧ **Parton motion vs. probing scale**
  – QCD quantum evolution
  – RHIC Run17 – W program
- ✧ **Lattice QCD calculation of TMDs**
  – QCD 1st principle prediction?
- ✧ **Fast software to extract TMDs**
  – Service to community
- ✧ **JLab12 data, …**

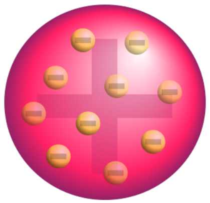


Density distribution of an unpolarized quark in a proton moving in z direction and polarized in y-direction

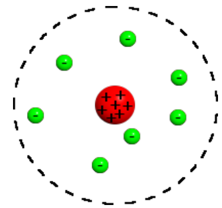
Why 3D nucleon structure?

❑ Rutherford's experiment – atomic structure (100 years ago):

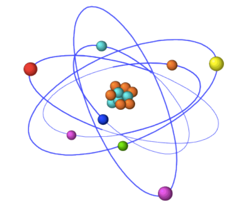
Atom:



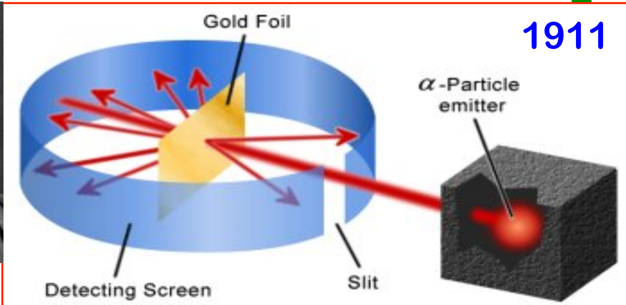
J.J. Thomson's
plum-pudding model



Rutherford's
planetary model



Modern model
Quantum orbitals



Discovery of nucleus
A localized
charge/force center
A vast
"open" space

Discovery of
Quantum Mechanics,
and
the Quantum World!

❑ Completely changed our "view" of the visible world:

✧ Mass by "tiny" nuclei – *less than 1 trillionth in volume of an atom*

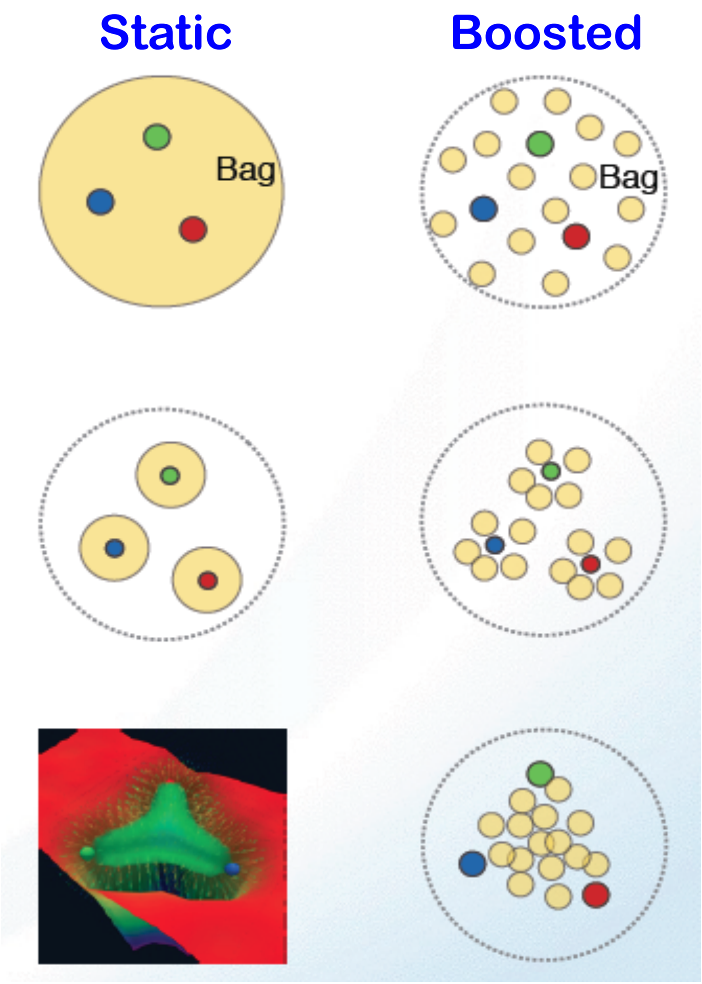
✧ Motion by quantum probability – *the quantum world!*

❑ 3D nucleon/nuclear structure:

✧ Distribution and motion of quarks and gluons – confining mechanism?

Why 3D nucleon structure?

- Spatial distributions of quarks and gluons:



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

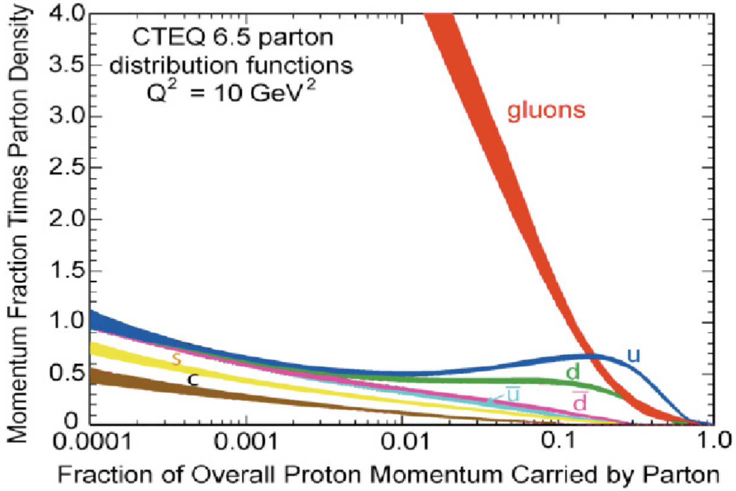
Lattice Gauge theory (with slow moving quarks):
Gluons more concentrated inside the quarks
Gluon radius < Charge Radius

3D Confined Motion (TMDs) + Spatial Distribution (GPDs)

Relation between charge radius, quark radius (x), and gluon radius (x)?

How to answer the "big" questions?

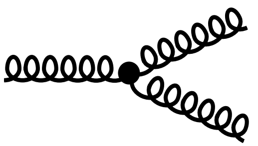
- ❑ **Run away gluon density at small x?**



What causes the low-x rise?

gluon radiation

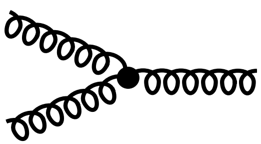
– non-linear gluon interaction



What tames the low-x rise?

gluon recombination

– non-linear gluon interaction



- ❑ **QCD vs. QED:**

QCD – gluon in a proton:

$$Q^2 \frac{d}{dQ^2} xG(x, Q^2) \approx \frac{\alpha_s N_c}{\pi} \int_x^1 \frac{dx'}{x'} x' G(x', Q^2)$$

QED – photon in a positronium:

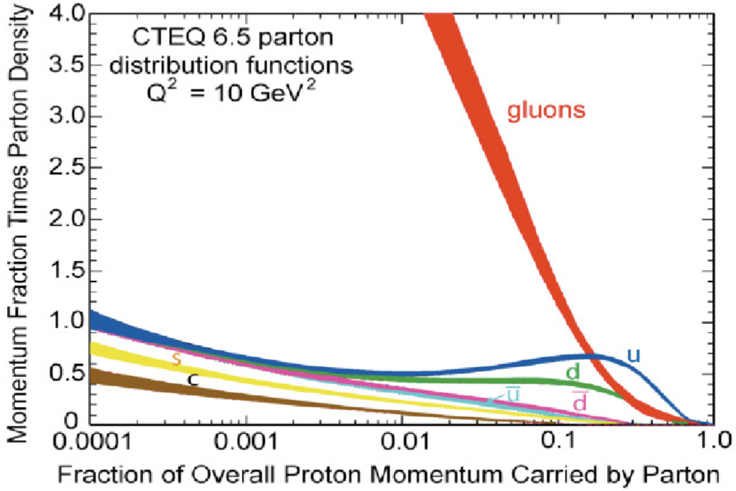
$$Q^2 \frac{d}{dQ^2} x\phi_\gamma(x, Q^2) \approx \frac{\alpha_{em}}{\pi} \left[-\frac{2}{3} x\phi_\gamma(x, Q^2) + \int_x^1 \frac{dx'}{x'} x' [\phi_{e^+}(x', Q^2) + \phi_{e^-}(x', Q^2)] \right]$$

✧ At very small-x, proton is "black", positronium is still transparent!

✧ Recombination of large numbers of glue could lead to saturation phenomena

How to answer the "big" questions?

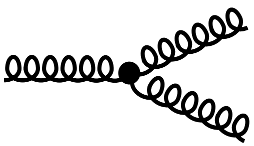
❑ **Run away gluon density at small x?**



What causes the low-x rise?

gluon radiation

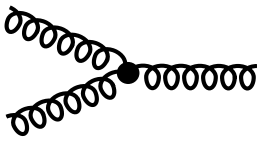
– non-linear gluon interaction



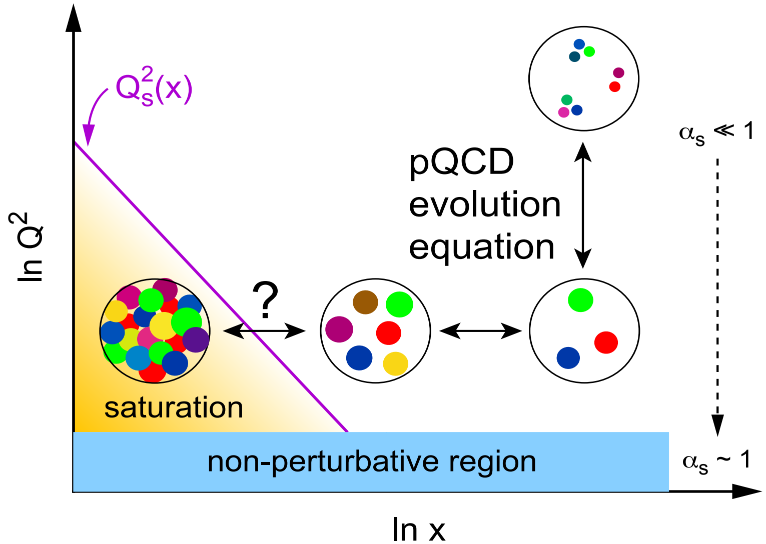
What tames the low-x rise?

gluon recombination

– non-linear gluon interaction

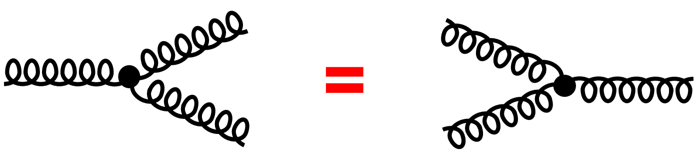


❑ **Particle vs. wave feature:**



Gluon saturation – Color Glass Condensate

Radiation = Recombination



at Q_s

Leading to a collective gluonic system?

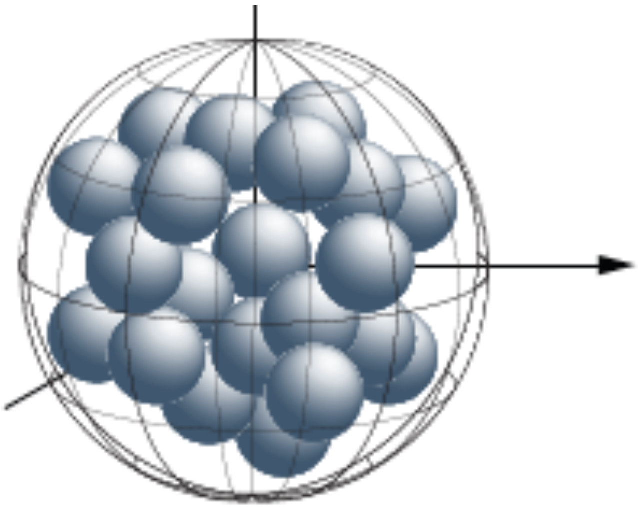
with a universal property of QCD?

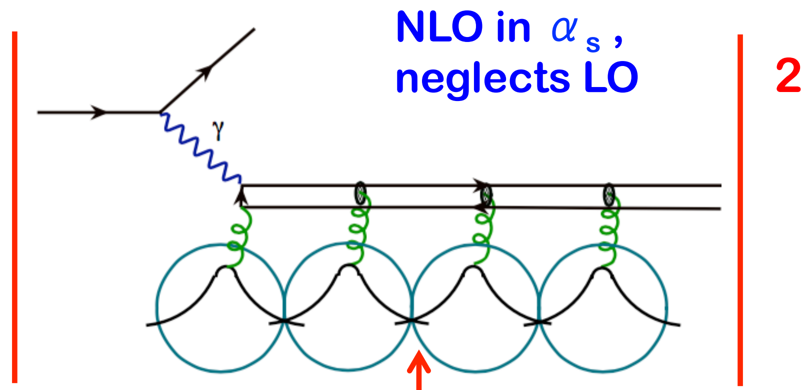
new effective theory QCD – CGC?

Expectation: $x=10^{-5}$ in a proton at $Q^2=5$ GeV^2

DIS on a large nucleus

- If we only see quarks and gluons, …





Could there be overlap of color between nucleons?

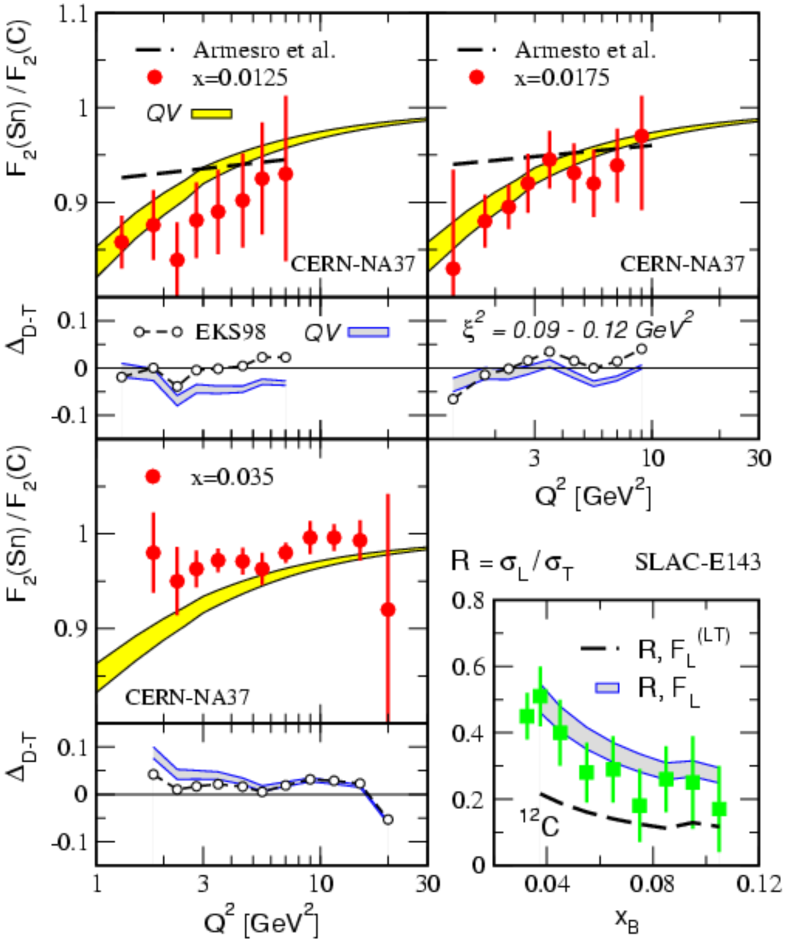
✧ If color is localized inside the nucleon, using a large nucleus does not change gluon dynamics inside nucleon
  - *no advantage for seeing the gluon saturation,*
  - *but, provides an opportunity to study QCD multiple scattering*

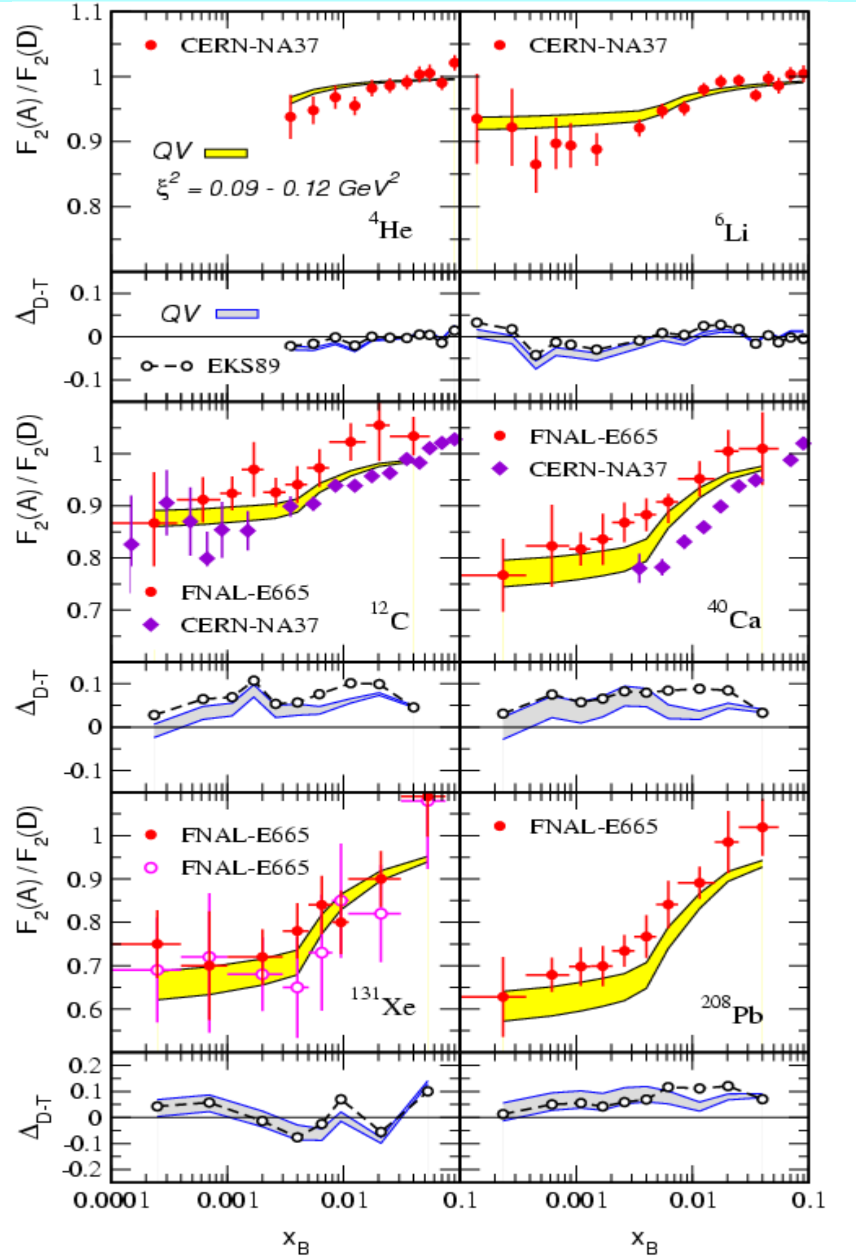
✧ If color leaks outside of the nucleon inside a large nucleus, color interaction between nucleons modifies the nuclear landscape
  - *large nucleus could have an advantage for discovering the universal properties of the gluon saturation "earlier"*

DIS on a large nucleus

- **If the color is localized inside nucleon, …** Qiu, Vitev, PRL2004

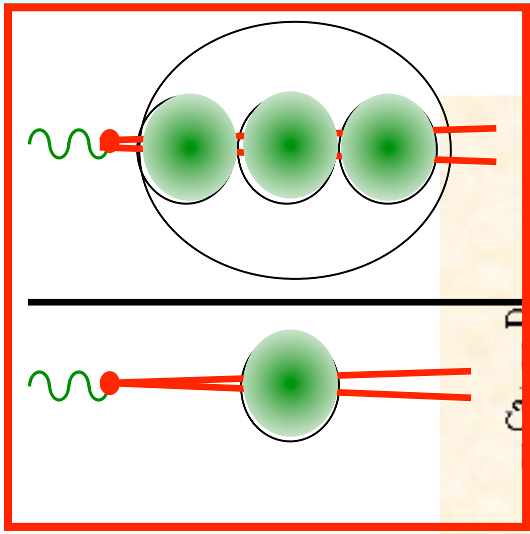
$\xi^2 = 0.09 - 0.12\ \mathrm{GeV}^2$

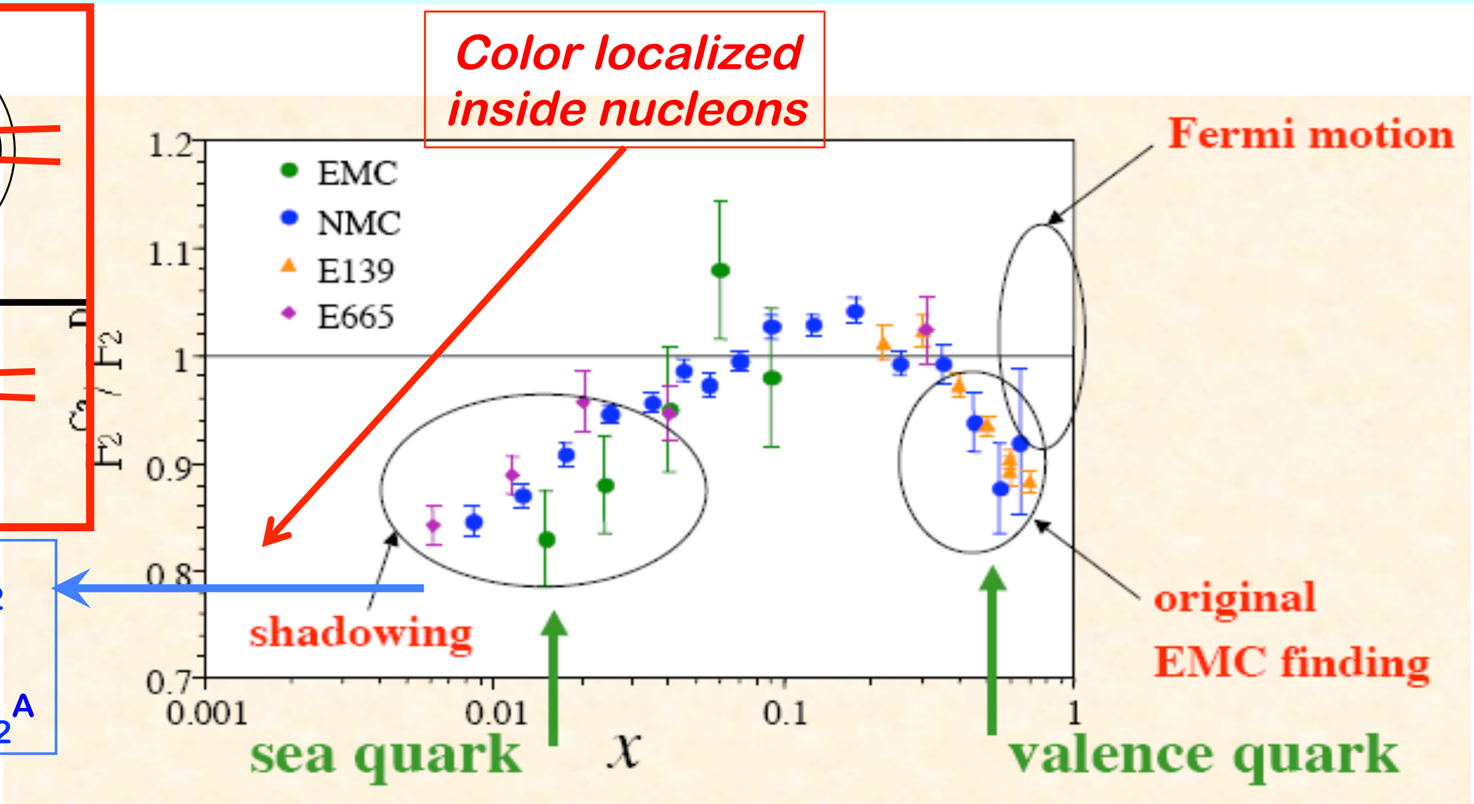




One number for all x_B, Q, and A dependence !

Ratio of F_2: Shadowing vs. Saturation





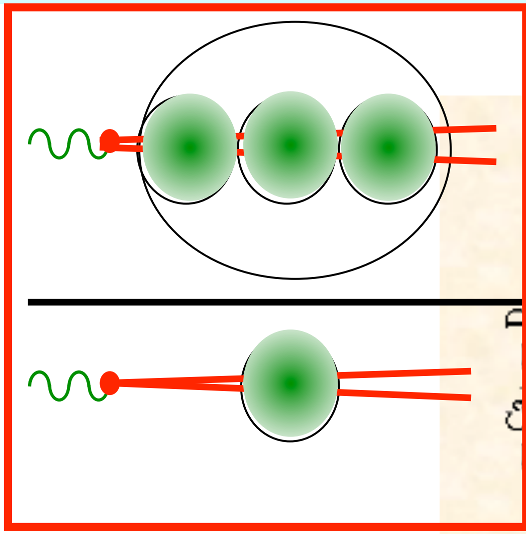
Saturation in RF_2
=
No saturation in F_2^A

Collision effects

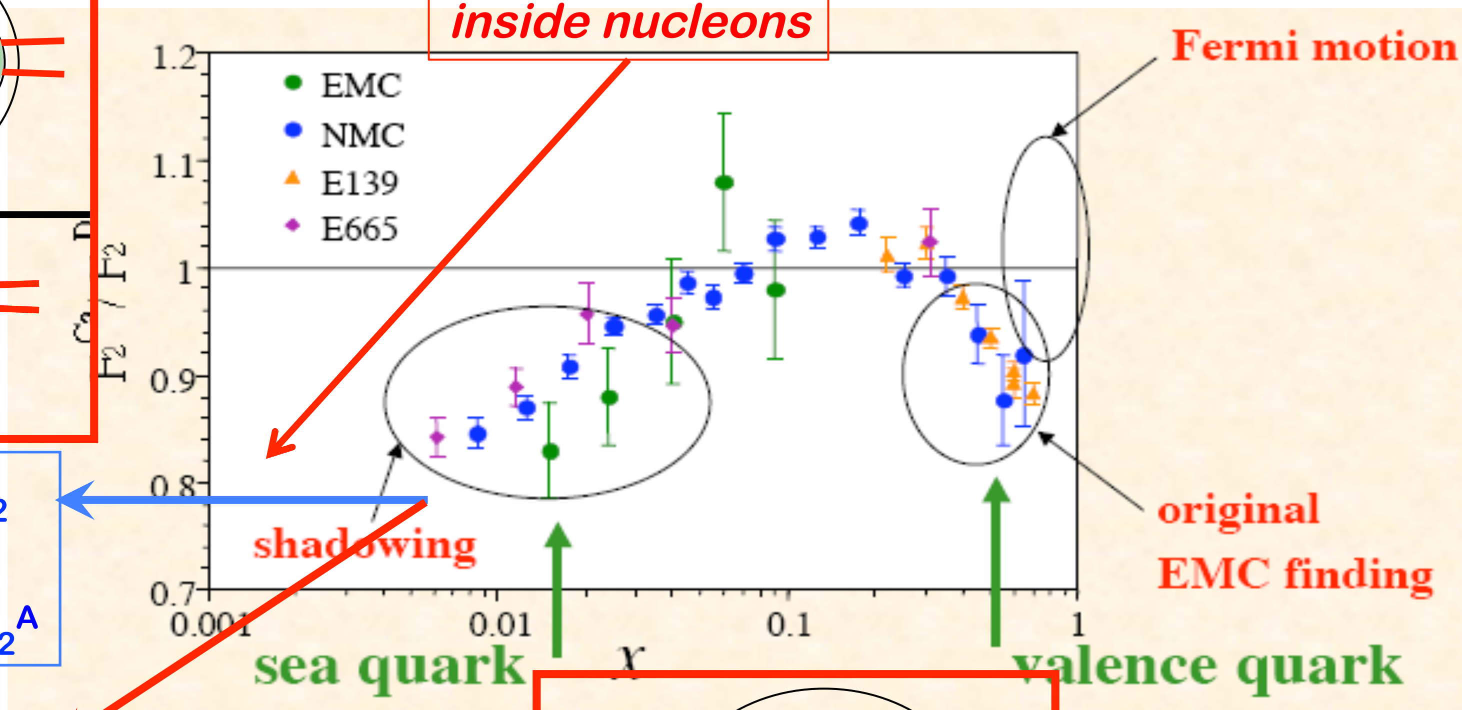
- ❑ **A simple question:**

  Will the suppression/shadowing continue to fall as x decreases?

Ratio of F_2: Shadowing vs. Saturation



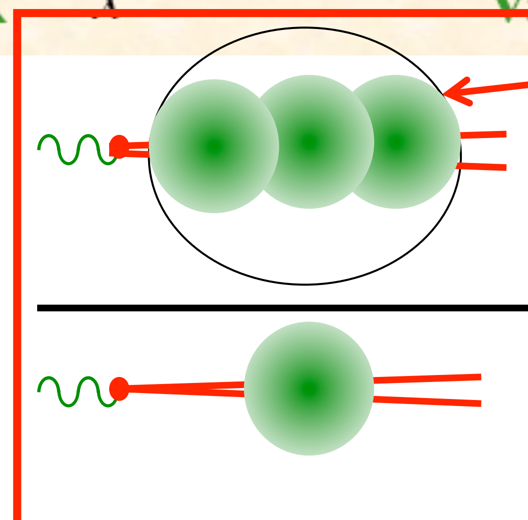
Color localized inside nucleons



Saturation in RF_2
=
No saturation in F_2^A

Collision effects

Saturation in nucleon



Color leaks outside nucleons Soft gluon radius is larger

- **A simple question:**

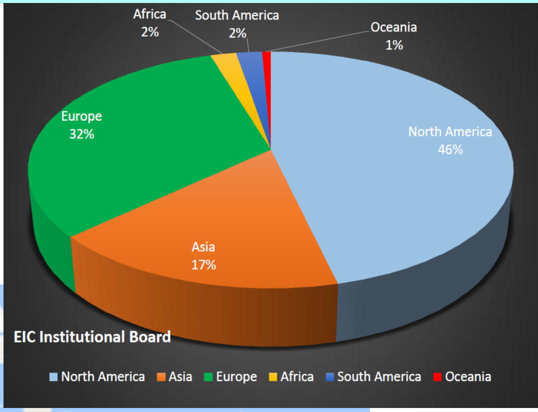
  Will the suppression/shadowing continue to fall as x decreases?

The EIC Users Group: *EICUG.ORG*

(no students included as of yet)

670 collaborators, 28 countries, 150 institutions... (December, 2016)

Map of institution's locations



The EIC Users Meeting at Stony Brook, June 2014:

→ *http://skipper.physics.sunysb.edu/~eicug/meeting1/SBU.html*

The EIC UG Meeting at University of Berkeley, January 6-9, 2016

http://skipper.physics.sunysb.edu/~eicug/meeting2/UCB2016.html

Recent EICUG Argonne National Laboratory July 7-10, 2016

http://eic2016.phy.anl.gov

Remote/Internet: meeting: March 16th : For NAS Review preparation

Next meeting:

July 18-22, 2017 Trieste, Italy

- **Registration opening by April 30**

EICUG MEETING – July 18-22
TRIESTE

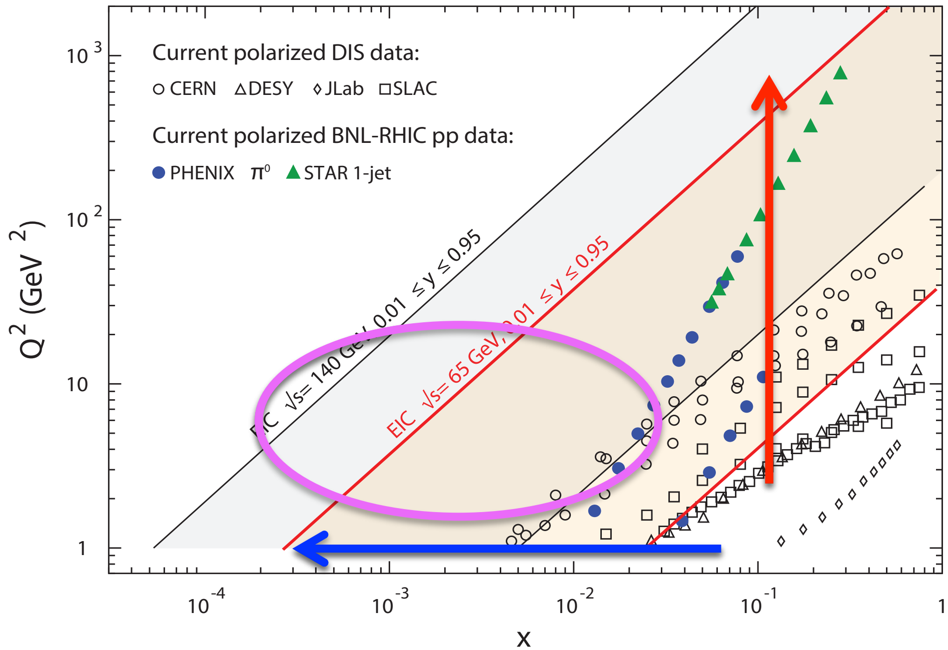
eicug2017.ts.infn.it

Summary

- EIC is a ultimate QCD machine:
  1) to discover and explore the quark/gluon structure and properties of hadrons and nuclei,
  2) to search for hints and clues of color confinement, and
  3) to measure the color fluctuation and color neutralization
- JLAB/EIC are tomographic machines for nucleons and nuclei with a resolution better than 1/10 fm
- EIC designs explore the polarization and intensity frontier, as well as the frontier of new accelerator/detector technology
- JLAB12 is a prerequisite of the full EIC program, in addition to its own rich physics program
- EIC@US is sitting at a sweet spot for rich QCD dynamics – capable of taking us to the next QCD frontier

Thanks!

US 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 from valence to low-x physics
- ✓ 100-1K times of HERA Luminosity

For e-A collisions at the EIC:

- ✓ Wide range in nuclei
- ✓ Variable center of mass energy
- ✓ Wide Q^2 range (evolution)
- ✓ Wide x region (high gluon densities)

EIC explores the "sea" and the "glue", the "valence" with a huge level arm