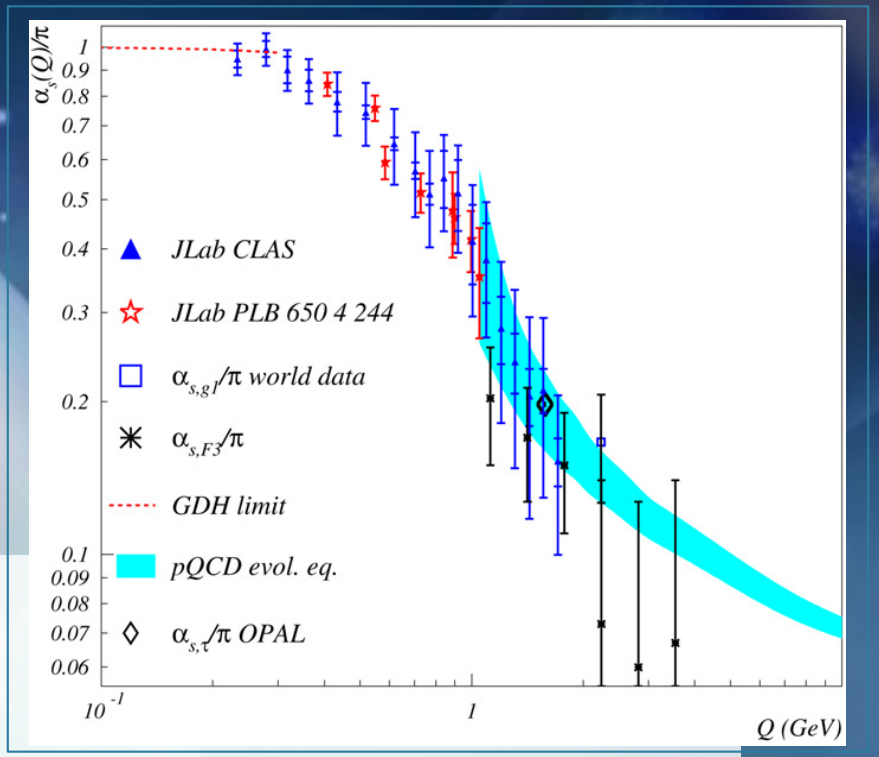
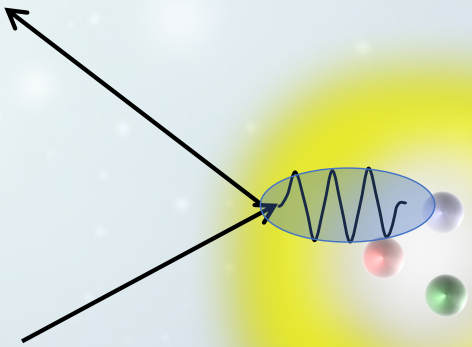
Why a high energy EIC to investigate low energy nuclear binding?

II. High energy probe travels through nucleus at speed of light, interacting at equal light-cone time x^+
   - Hard scattering scale results in perturbative dynamics:
     - LargeQ^2, and/or large p_T
     - Direct probe of quark-gluon structure of nuclear dynamics
   - Reconstruction of full nuclear final state constrains the initial state *via* principle of "Quantum Post-Selection"

The Tools of Deep Inelastic Scattering

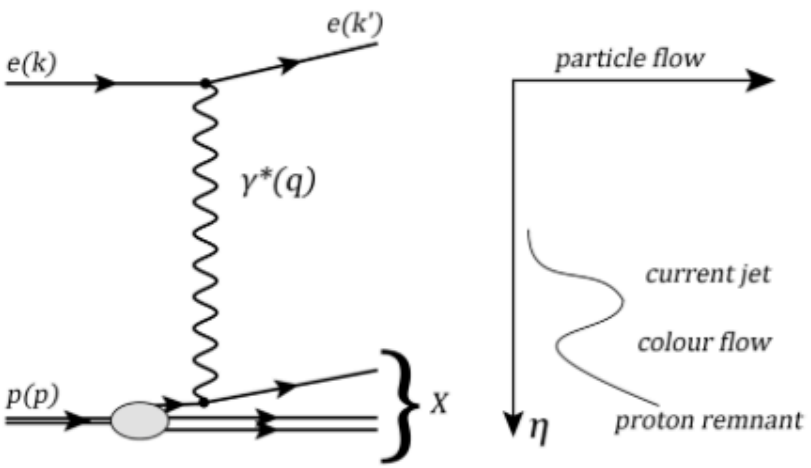


- $\frac{\alpha_S(Q^2)}{\pi} = \frac{4}{(11-2N_f/3} \ln \frac{Q^2}{\Lambda^2} \ldots$
- *Basic Variables: Q^2, x_{Bj}*
  - $\alpha_S(Q^2)/\pi < 0.5$ *for* $Q^2 > 1$ *GeV*^{2}
  - *Transverse spatial resolution* $\delta b \sim \hbar c/[Q^2]^{1/2}$
  - Longitudinal coherence length of virtual photon $\lambda \approx 1/(2Mx_{Bj})$
    - $x < 0.1 \leftrightarrow \lambda \geq 1$ fm



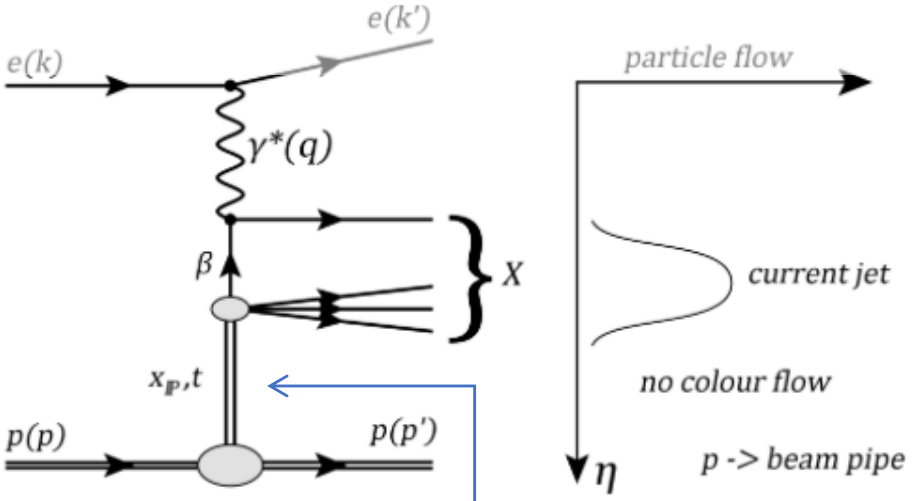
Final States: DIS & Diffractive DIS

Deep Inelastic Scattering (DIS)



Diffractive Scattering (DDIS)

- ~10% of HERA DIS events



Rapidity Gap: $\Delta\eta \geq 2$

Proton Remnant:

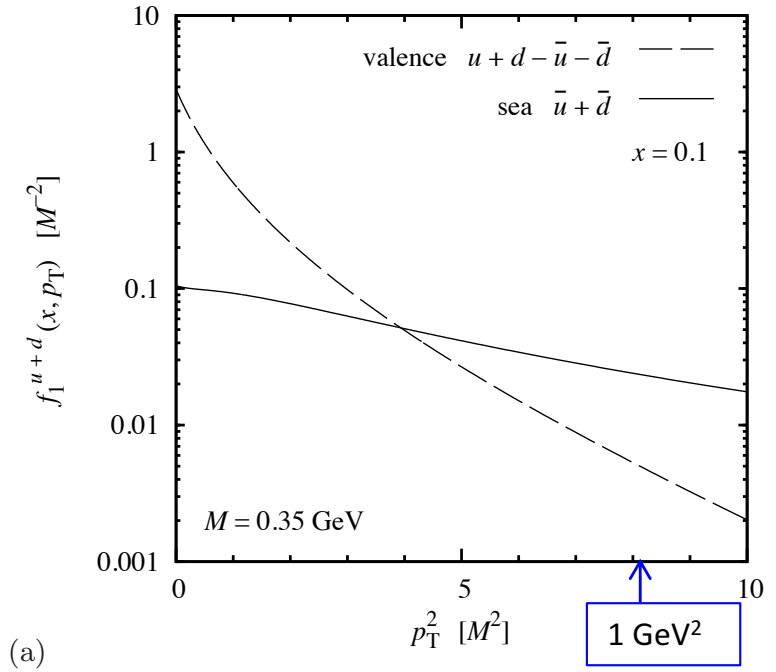
- Di-quark/ tetra-quark color triplet
- Color octet

Correlations between Current & Target fragments

- Chiral Symmetry Breaking: Parton-parton correlations at $p_T \sim \Lambda\chi \sim 1$ GeV.

- Coincident hadrons in target and current fragments, with correlated & spin-dependent p_T.

- Multiparton interactions in LHC pp collisions do not scale as average density



P. Schweitzer, Ch. Weiss, M. Strikman, JHEP **1301** (2013) 163

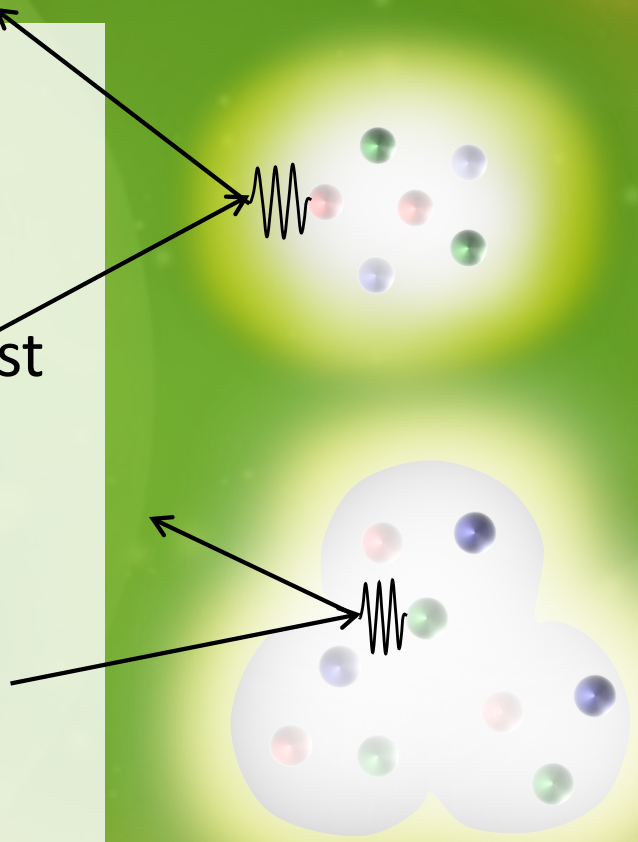
- Identify ion beam fragments over broad range of p_T

DIS and Many Body Nuclear Dynamics

- DIS at different x, Q^2 ranges probes particular configurations in the nucleus
- Forward tagging of spectator/recoil nucleons... to observe the dynamics of the active configurations.
- Illustrative Examples:
  - x>1 — Forbidden on free nucleon. Coherent NN, NNN interaction with large momentum sharing ➔6-quark bag states?
  - 0.2< x < 0.7 — Nuclear Binding, Short Range Correlations
  - x ≈ 0.1 — Anti-shadowing (enhancement): Hard Core of NN Force
  - x < 0.1 — Coherent Diffraction ➔ Shadowing: Coherence length ~ typical NN separation
  - $x \lll 0.1,\ Q^2 \geq 1\ \mathrm{GeV}^2$ — Coherence ➞Saturation Transition

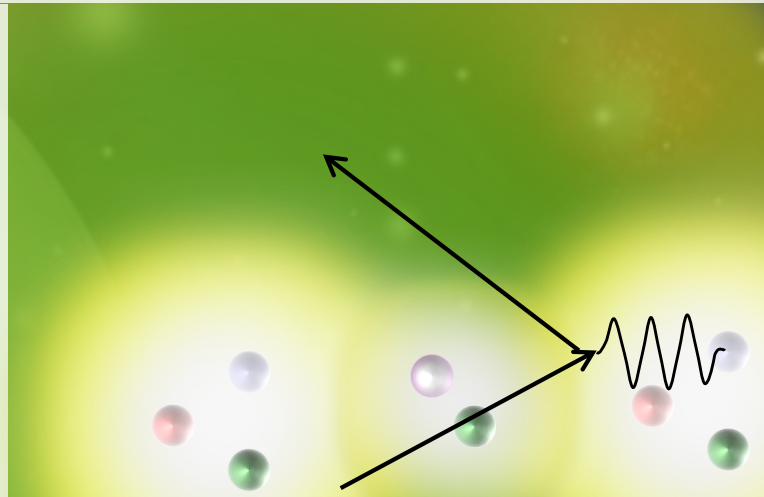
Nuclear Dynamics Probed by DIS: I

- Kinematic bound: $x_{Bj} < A$
- $x_{Bj} > 1$
  - Parton momentum fraction generated by interaction of at least two nucleons
  - [Color Octet]^2 states ?
- $x_{Bj} > 2$
  - Probe three body forces.

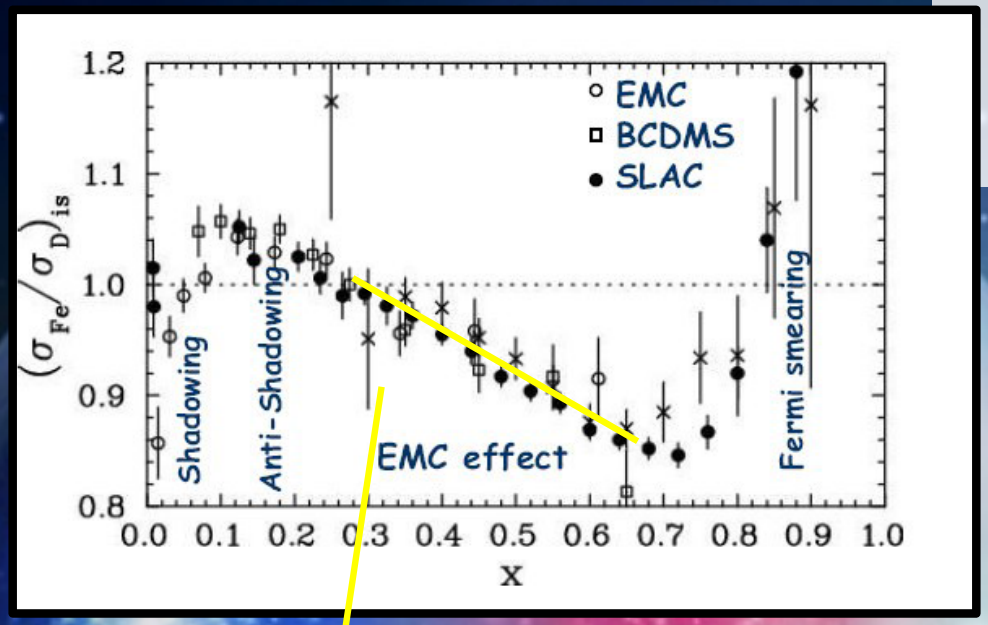


Nuclear Dynamics Probed by DIS: II

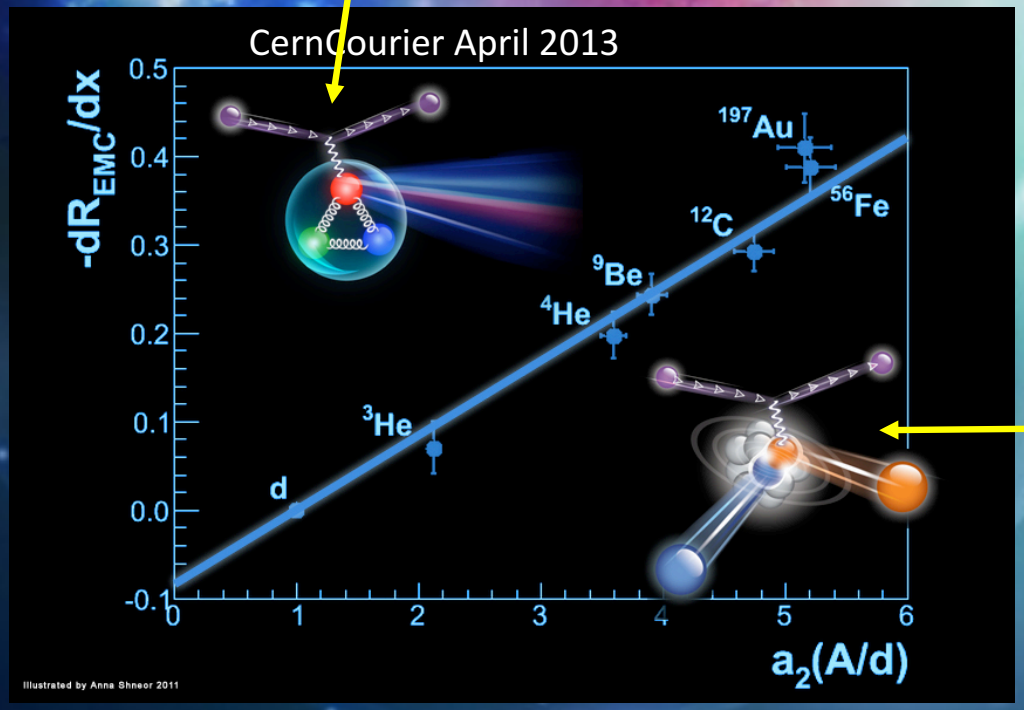
- $0.2 < x_{Bj} < 0.8$
  EMC Effect
- Quark-Gluon structure of nuclear binding at scale $1/(2x_B M) \leq 0.5$ fm
  - Incoherent over quarks in different nucleons or exchanged mesons
  - e.g. QMC model, NN-interactions generate strong σ-field, which modifies average q-structure of nucleon

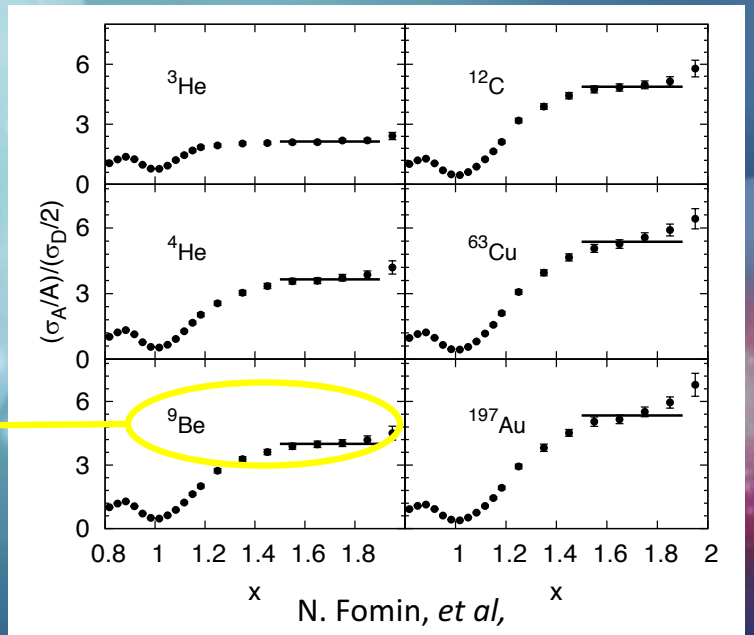


The EMC Effect



- Quark-gluon imprint of Nuclear Binding
- NN Correlations
  - Average density of ^{9}Be is low. Local density is high





N. Fomin, *et al,*

FIG. 2: Per-nucleon cross section ratios vs x at θ_e=18°.

Nuclear Final State at EIC

- Naive spectator kinematics:

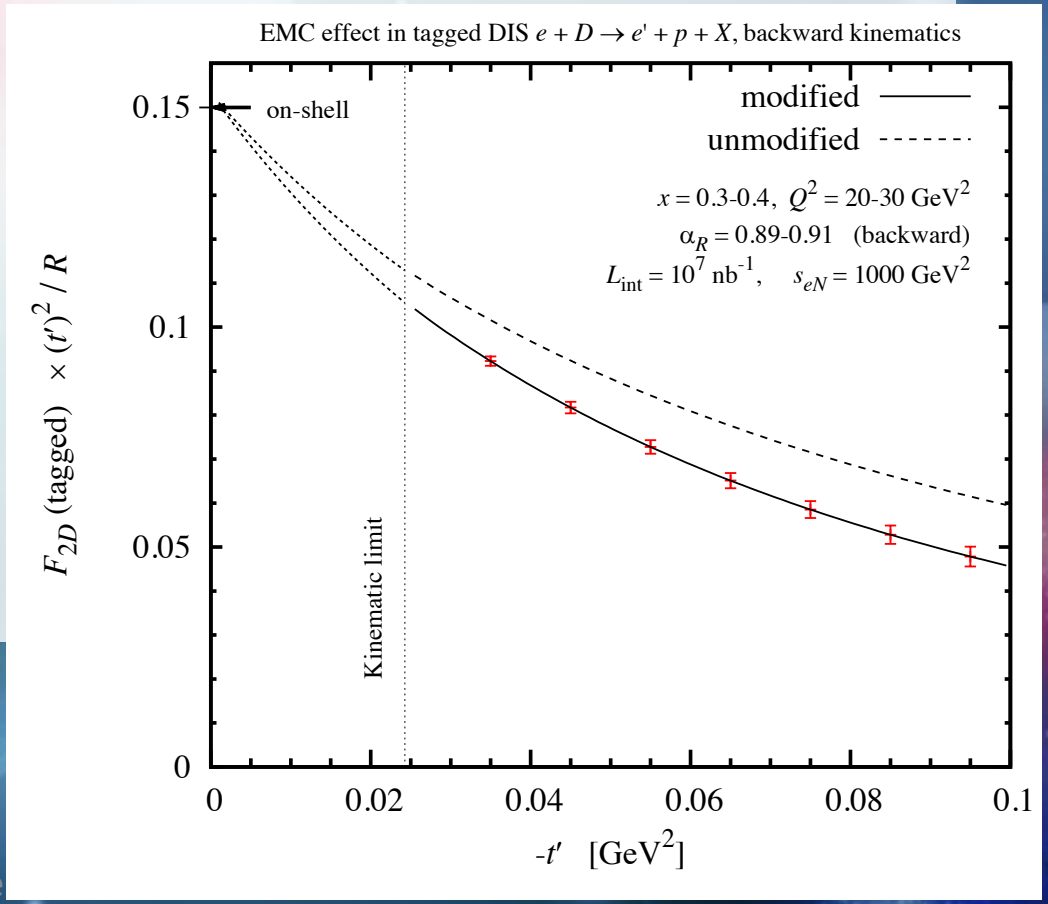
$$p_i^\mu = \left[\frac{\alpha_i}{A} P_A^+, \mathbf{p}_{i,T}, p_i^-\right]$$

$$\sum_{i=1}^{A} \alpha_i = A \qquad \sum_{i=1}^{A} \mathbf{p}_{i,T} = 0$$

- Fermi gas: $|\alpha_i - 1| \lesssim p_F/M \approx 0.25$ $\qquad \mathbf{p}_{i,T} \leq p_F$
- In a heavy nucleus of momentum $Z \bullet$*(100 GeV/c),* spectator neutrons, protons have laboratory momenta p ~ (100 GeV/c)Z/A
  $(p_{||}, p_T) \approx [\alpha_i(40\ \text{GeV/c}),\ \mathbf{p}_{i,T}]$
  - Forward Tagging!

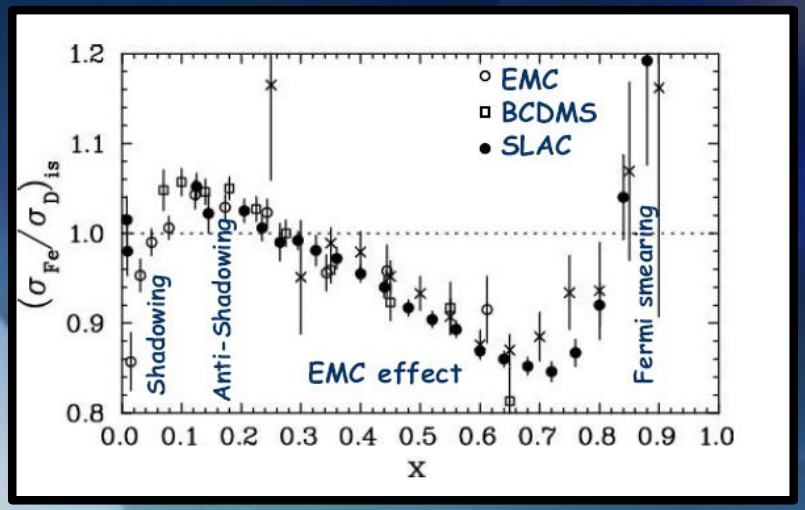
DIS on the Deuteron: Spectator Tagging

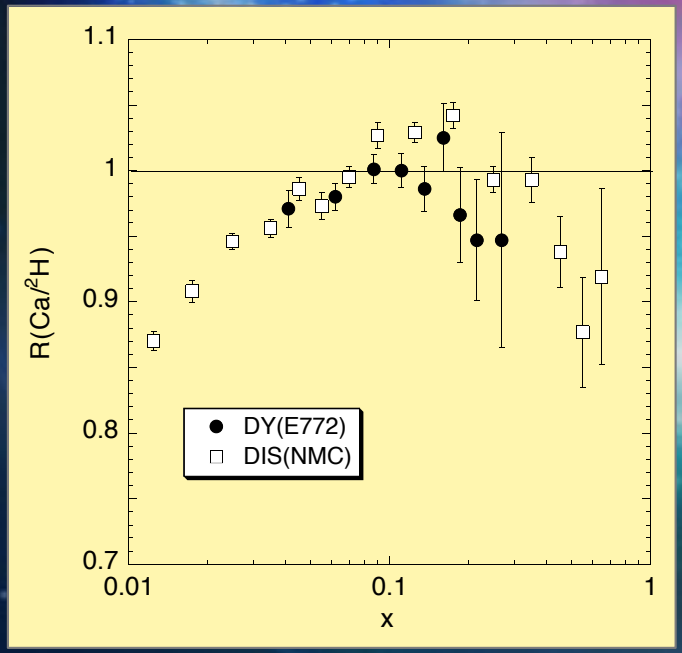
- $\alpha_p \approx 1$ = A•(spectator lightcone momentum fraction), $\mathbf{p}_{p,T} \approx 0$
  - Spectator proton at ≈0° and ≈50 GeV/c
  - On-shell extrapolation of DIS on neutron
- Calibrate with ZDC tagging of spectator neutron
  - DIS on nearly on-shell proton
- EMC effect from highly off-shell nucleons
  - $|1-\alpha_P| > 0.2$
  - EMC effect in Deuterium!



EMC Effect*: x=0.1 Anti-Shadowing

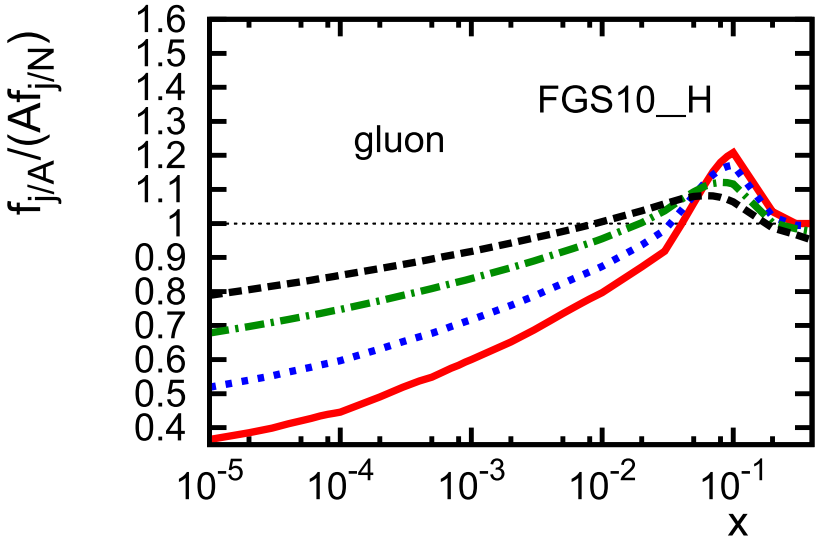
- Anti-shadowing is not anti-quarks! FermiLab Drell-Yan E722





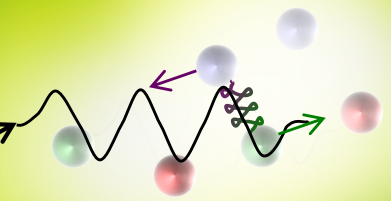
Anti-shadowing is glue

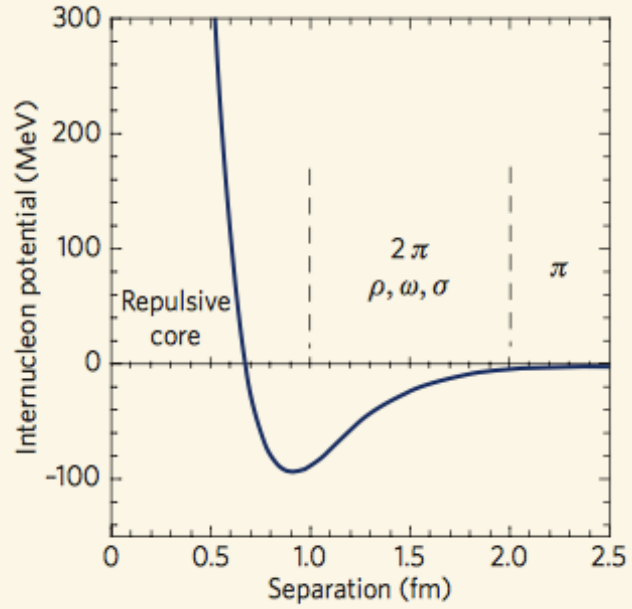
L. Frankfurt et al. / Physics Reports 512 (2012) 255–393



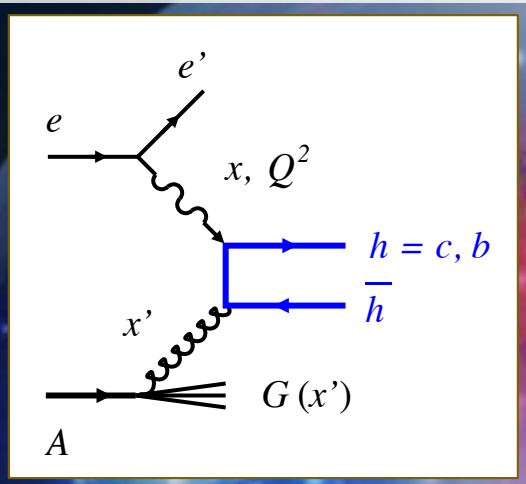
Nuclear Dynamics Probed by DIS: III

- $x_{Bj} \approx 0.1$: "Anti-Shadowing"
  - $q(x) + \bar{q}(x)$ enhanced (DIS)
  - No $\bar{q}(x)$ enhancement in Drell-Yan $(p + p \rightarrow \mu^+ + \mu^- + X)$.
  - Short distance NN-interaction from *q-q-g* exchange?
  - Look for predicted gluon anti-shadowing (enhancement in nuclei)
    - JLab LDRD program on open-charm in nuclear DIS
      - $\gamma^* + g \rightarrow c + \bar{c}$
    - Resolve separated vertex of D-meson decays to tag charm quark events





Tagging Photon-Gluon Fusion *via* Open Charm Production

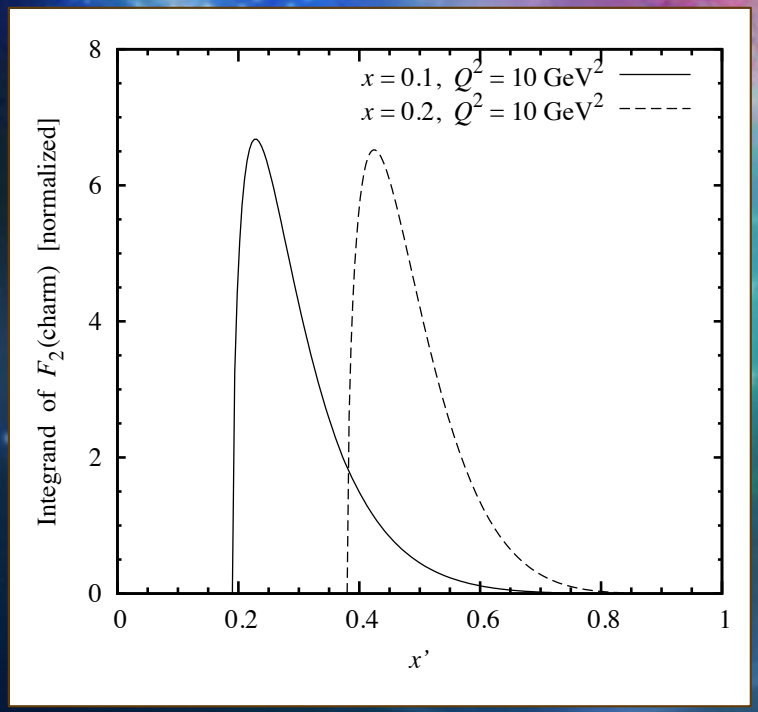


$$F_2^h(x,Q^2) \;=\; \int_{ax}^{1} \frac{dx'}{x'}\, x'G(x')\; \hat{F}_g^h(x/x',\, Q^2,\, m_h^2,\, \mu^2)$$

coefficient function

$$a \;=\; 1+\frac{4m_h^2}{Q^2}$$

sets limit of x' integral



$x_{glue}G(x_{glue})$ support localized near $x_{glue} \geq x_{Bj}[1+4m_h^2/Q^2]$.