# Nuclear Effects Overview

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# High Density Nuclear Physics

## - Nuclear Potential

Nuclear Hamiltonian

$$H = -\sum_i \frac{\nabla_i^2}{2m} + \sum_{i<j} V_{ij}^{2N} + \sum_{i<j<k} V_{i,j,k}^{3N} + \ldots$$

$$H\Psi_A(r_1, \ldots, r_A) = E\Psi_A(r_1, \ldots, r_A)$$

$$V^{2N} = V_{EM}^{2N} + V_\pi^{2N} + V_R^{2N}$$

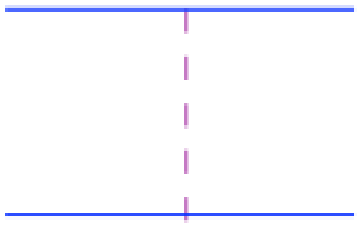
$$V_R^{2N} = V^c + V^{l2}L^2 + V^t S_{12} + V^{ls} L \cdot S + v^{ls2}(L \cdot S)^2$$

$$V^i = V_{int,R} + V_{core}$$

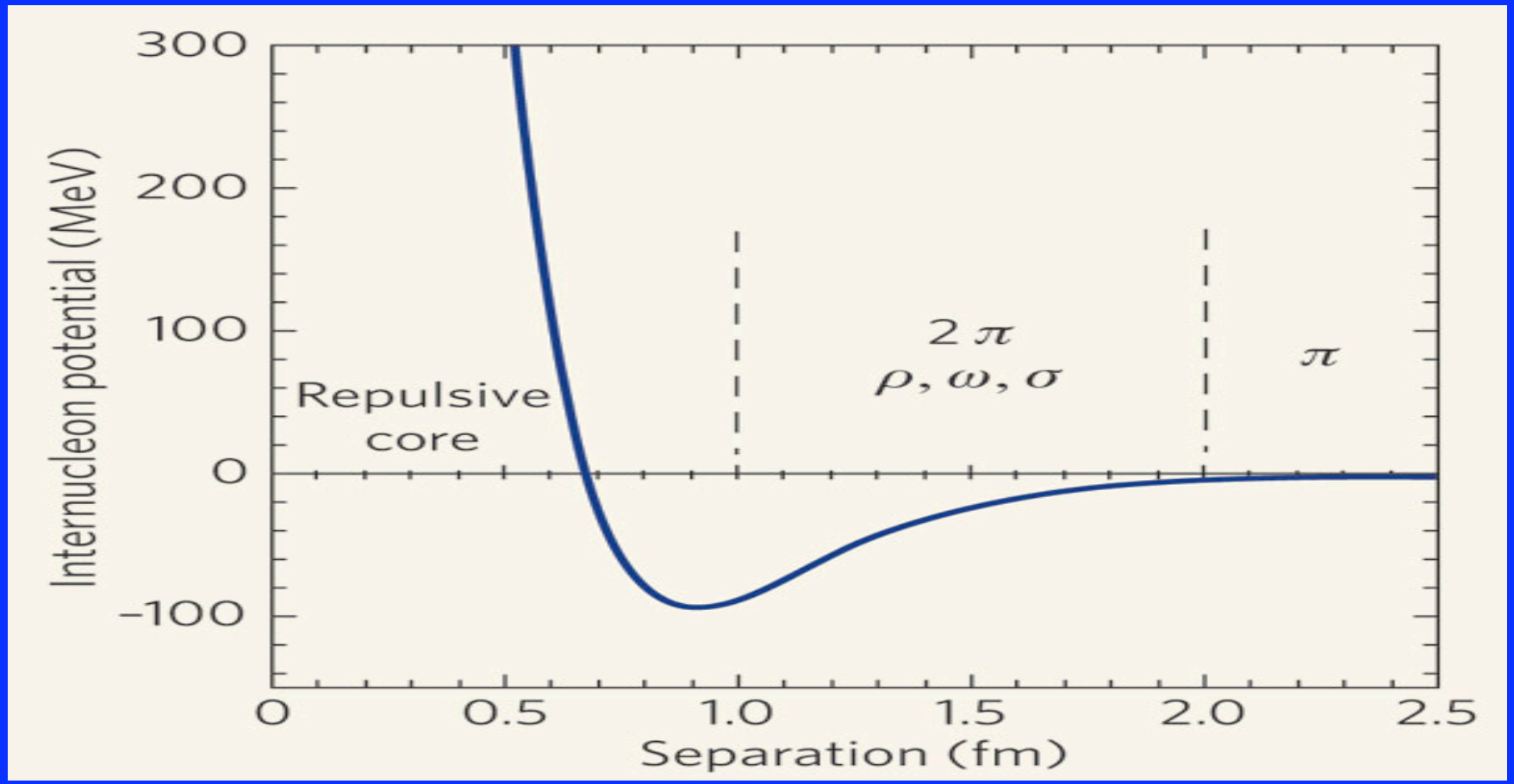
$$V_{core} = \left[1 + e^{\frac{r-r_0}{a}}\right]^{-1}$$

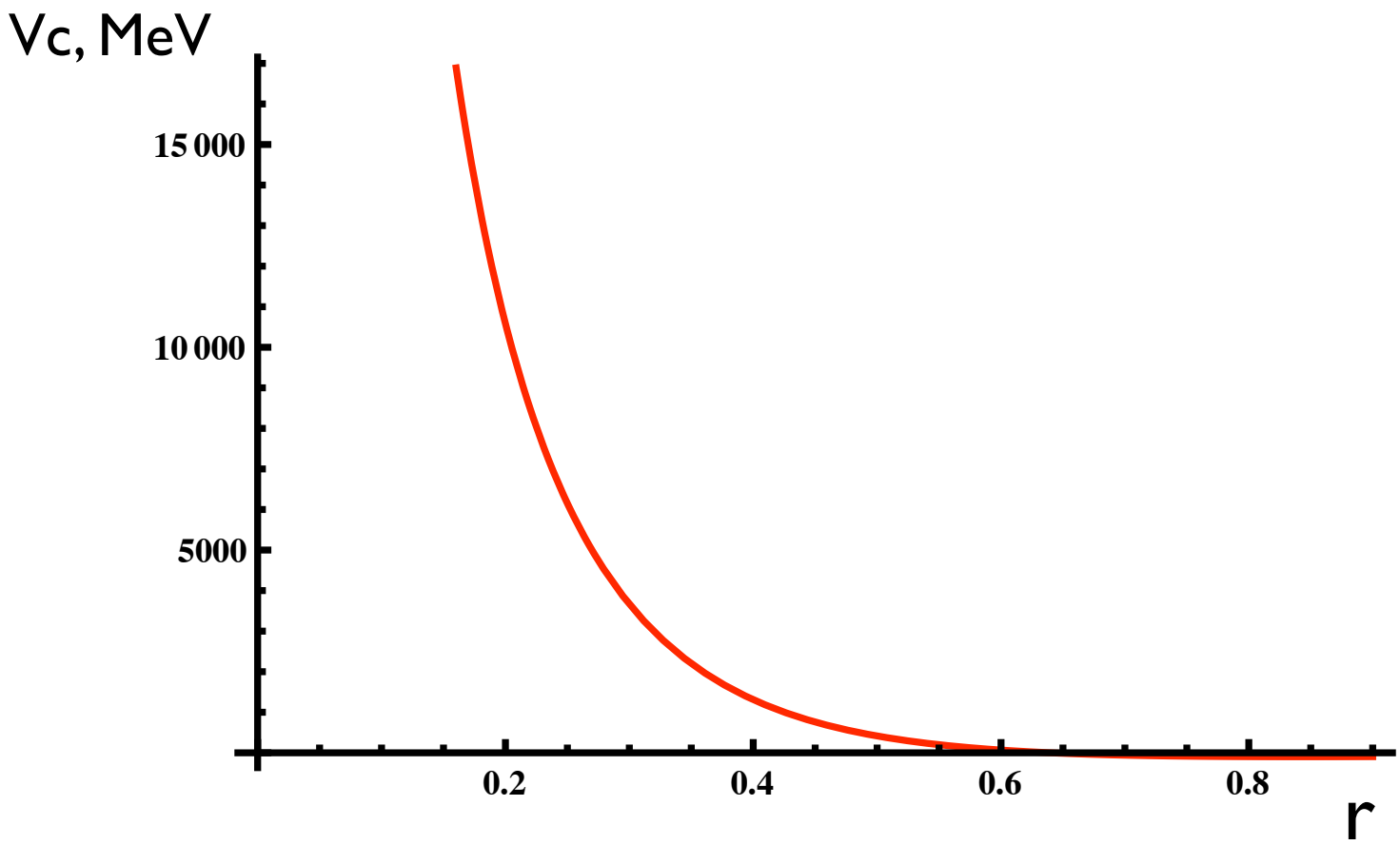
60's

# -Phenomenological OBE models 1947-



$\sigma, \quad \pi, \quad \rho, \quad \omega, \ldots$




Vc, MeV
15 000
10 000
5000
0.2
0.4
0.6
0.8
r

# High Energy Nuclear Physics and QCD

## FIU, Miami, February 3-6, 2010

- About the Meeting
- Participants
- Program
- Photos
- Registration
- Accommodation
- Contact


Jefferson Science Associates, LLC

Jefferson Lab

# NUCLEAR EIC (ENDEAVORS IN COLOR)

Hierarchy: Processes/ Physics

## 1. Inclusive

### 1.1 Physics: Superfast Quarks

Kinematics: Large Q^2 and x \sim 1.
Probe the superfast quarks in nuclei. It will allow the investigation of quark-clusters and quark-correlations in nuclei.
((Q^2 dependence at very large x is sensitive to higher twist, breakdown of DGLAP evolution at high x. Q^2 dependence in D/p ratio at large x yields information on integral of pdf at larger x values))

Key issues: kinematic coverage, accounting for low cross section at large x. This will also require high luminosity, sufficient resolution and acceptance for small scattering angles.

### 1.2 Physics: Nuclear Modification - EMC effect

Kinematics: x = 0.1-0.9 for antishadowing/EMC regions, smaller for shadowing
- Measure the Q^2 evolution in the nuclear medium: Measurement of the EMC effect in the extended Q^2 range will allow study of the evolution of parton distribution in the nuclear medium
- Isospin Dependence of the nuclear medium modification (EMC & antishadowing region)
- Gluon shadowing through F_L
- Physics of antishadowing

Key issue: kinematic coverage, accounting for low cross section at large x. Large radiative corrections at low x values; is explicit detection of radiated photons required? A reliable way to provide precise, relative normalization for different nuclei will be extremely important. May need variable energies to make good measurements of Q^2 dependence over wide x range.

## 2. Semi-Inclusive

### 2.1 Probing Higher-order Nucleonic Correlations in Nuclei

Considering e + A --> e' + NF + NB1 + NB2 + X:

Measuring two fast backward nucleons and momentum fraction larger than one for A>3 nuclei.

Advantage of EIC is that one can simultaneously measure target and current fragmentations

### 2.2 Probing Hidden-Color Component of Nuclei:

Considering e+ A --> e' + FF+ FB + X:

Measuring the yield of fast backward resonances such as \Delta  on can probe
the hidden color component in 6q configurations

Measuring resonances  with  strangeness or charm as a function of internal momentum of the nucleus will allow us to probe the effects of chiral-simmetry
restoration and strangeness/charm content of nucleon wave function.

### 2.3 Nuclear Medium Modification

- Considering e + A --> e' + pi/K + N + X will allow us to measure the flavor dependence of nuclear modification effects.  Measuring extra nucleon in specially chosen kinematics will allow control of the initial state.
- The same reaction at x\approx 0.1 will allow the study of the origin of nuclear enhancement.
- Considering e + A --> e' + J/Psi + N + X
For nuclear modification of gluonic field controlling the local density from where the J/Psi is produced.
- Spectator tagging: e + D --> e’ + N_s + X
Examine nucleon structure as function of nucleon virtuality.  Spectator proton tagging for ‘effective free neutron’ target, spectator neutron tagging for ‘effective free proton’ measurement to verify that the low momentum spectator reproduces free nucleon, high momentum spectators to study nucleons at high virtuality.
- Nuclear incoherent DVCS: medium modifications of quark GPDs

### 2.4 Color Transparency

- Considering e + A --> e' + B + X

Most challenging to observe the color transparency for baryons.
In addition to \bar q q case, QCD allows also color neutrality.
Interesting to observe A dependence for B=nucleon, strange, charmed baryons.

- Considering e + A --> e' + M + X

where M is a meson and X=A(coherent), noncoherent.

- coherent productions of two pions with a pion (2q) in the t-channel
  first establish CT, then interpret in terms of target GPD's

- considering reaction \gamma + N --> pi + B + pi (baryon color transparency)
  (Strikman Kumano)

## 3. Exclusive

### 3.1 Hard Photodisintegration

- Considering reactions e/gamma + A --> e' + B1 + B2 + (A-2)'

where B = N, Strange, Charmed baryons produced at large center of mass angles of B1 B2 system.

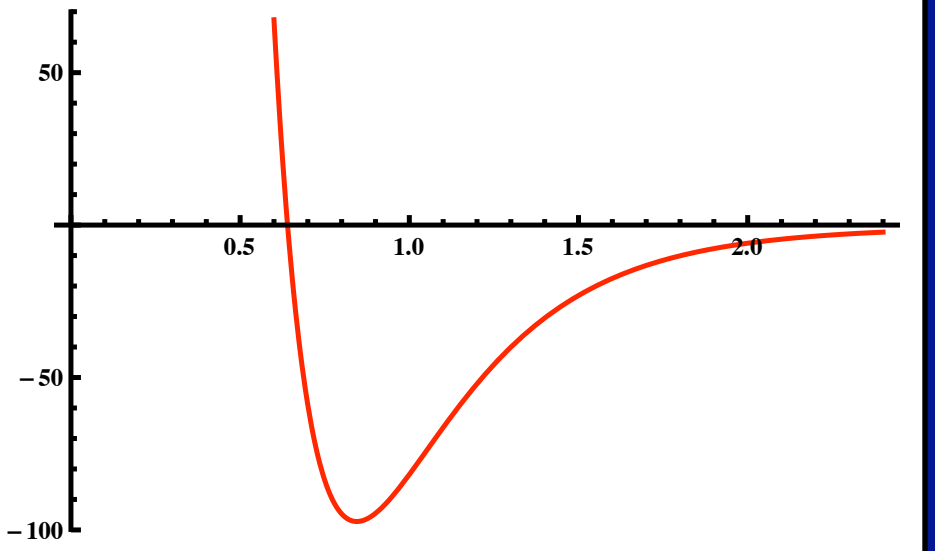
These studies will allow not only to probe the mechanism of hard break-up but also the dynamics of hard NN scattering such as the role of the charm threshold predicted to be important in hard NN scattering.

# Two Aspects of Nuclear Modification

Learning about hadronic structure

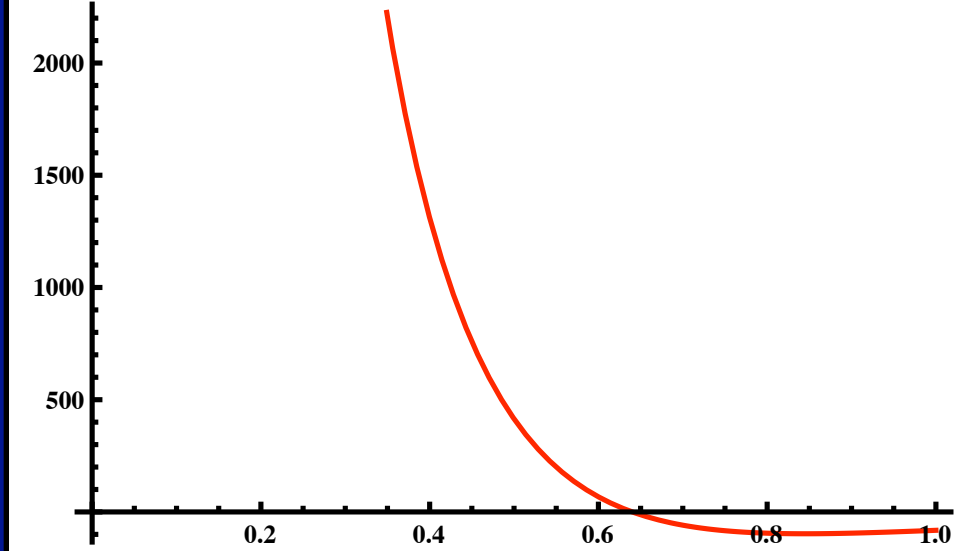
Learning about the nuclear structure

# Two Aspects of Nuclear Modification




Attraction

JLAB12, EIC

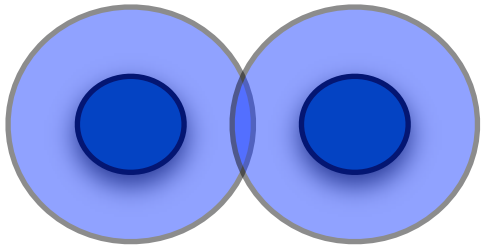



Repulsion/Core

EIC

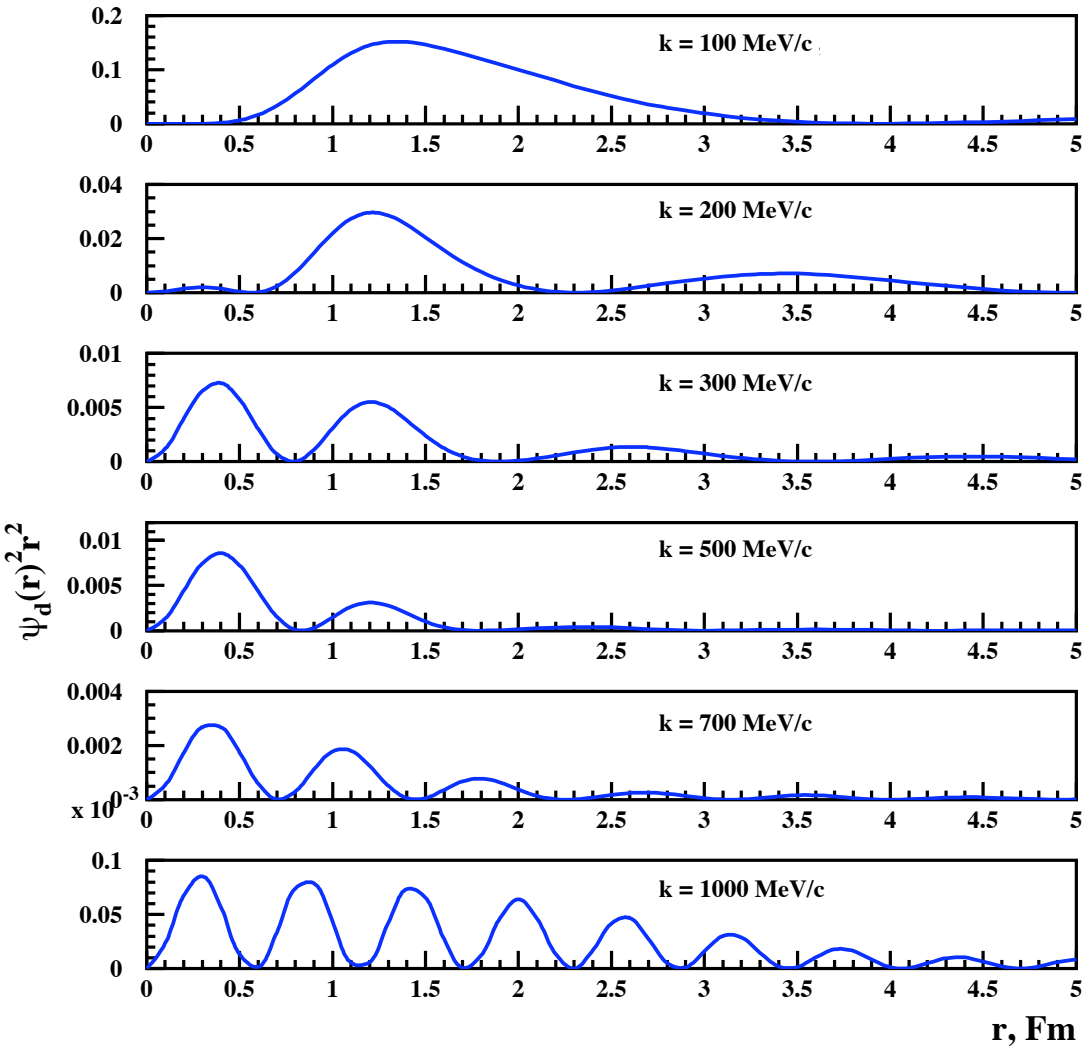
# How to get nucleons close together

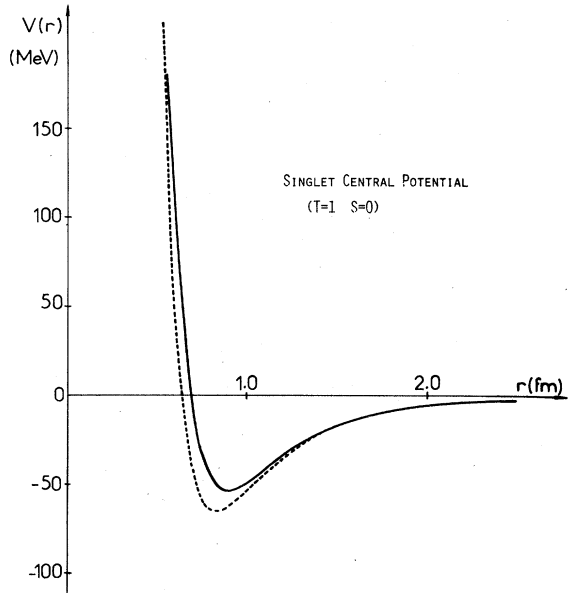
## Probing at large relative momenta



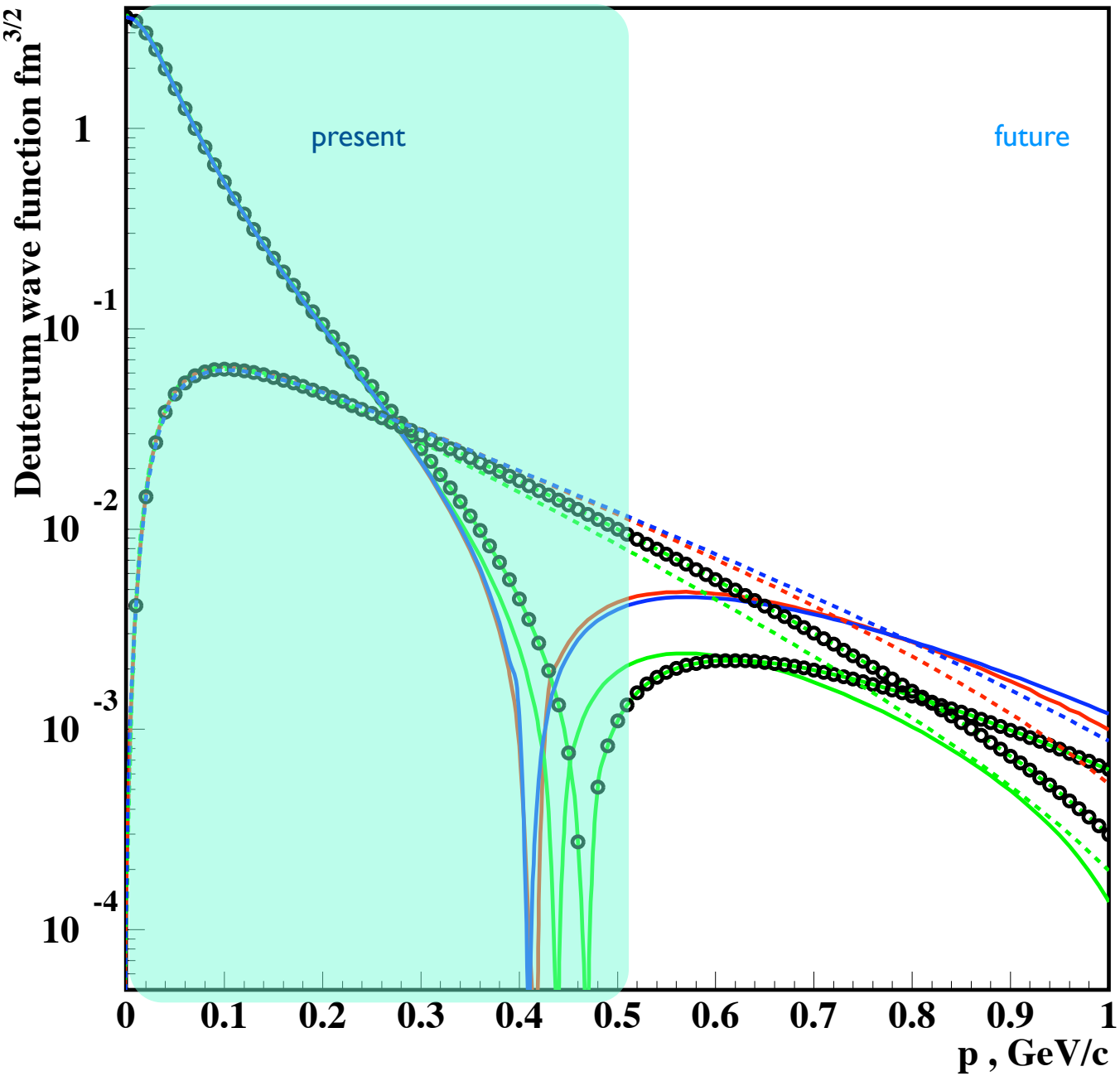
$$r \sim \frac{1}{k}$$

$$\psi(r,k) \sim \int \Theta(k-p)\psi(p)e^{-ipr}d^3p$$



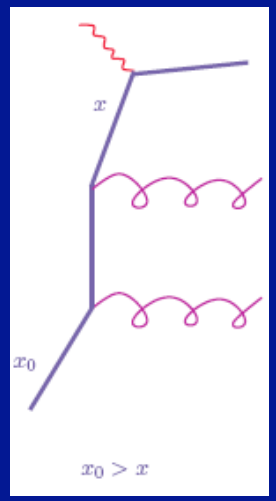
# Deuteron

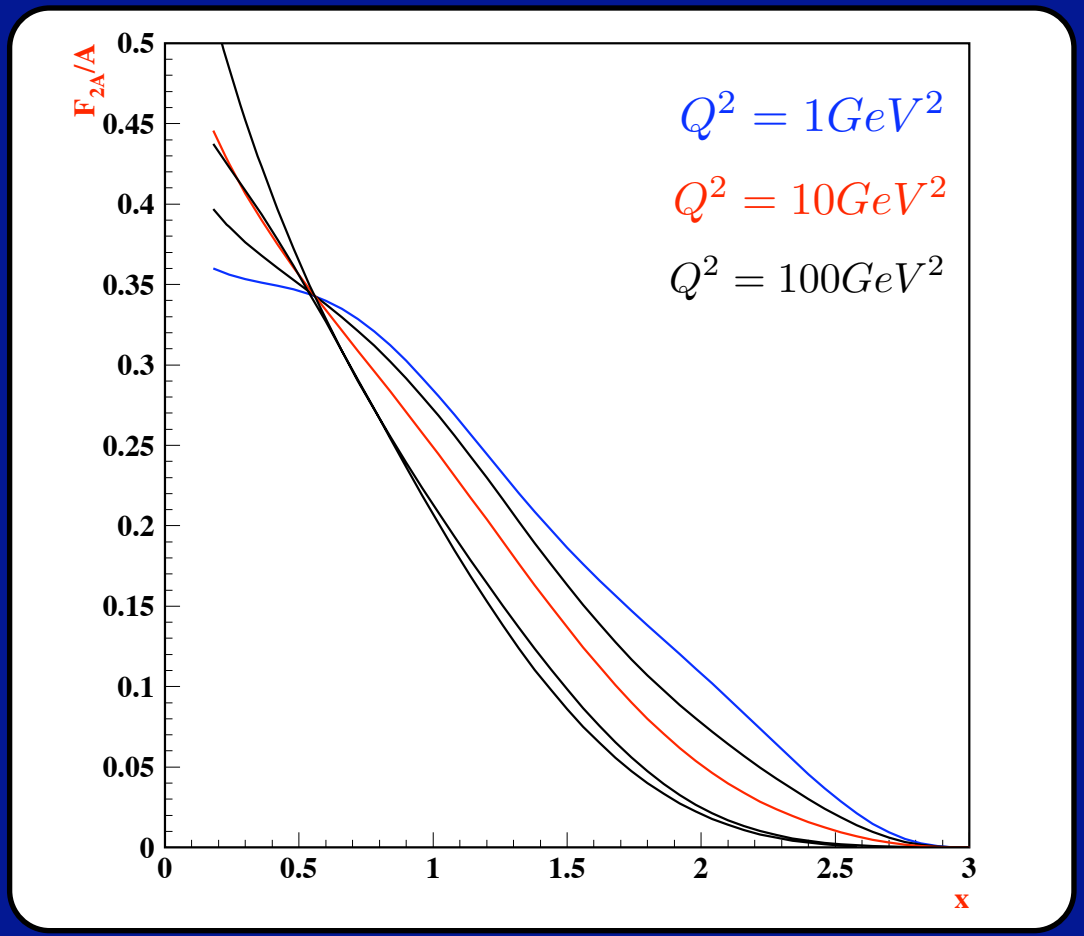

Deuterum wave function fm^3/2
1
10^-1
10^-2
10^-3
10^-4
present
future
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
p , GeV/c

# Inclusive (e,e'): Nuclear Medium Modification : EMC Effect

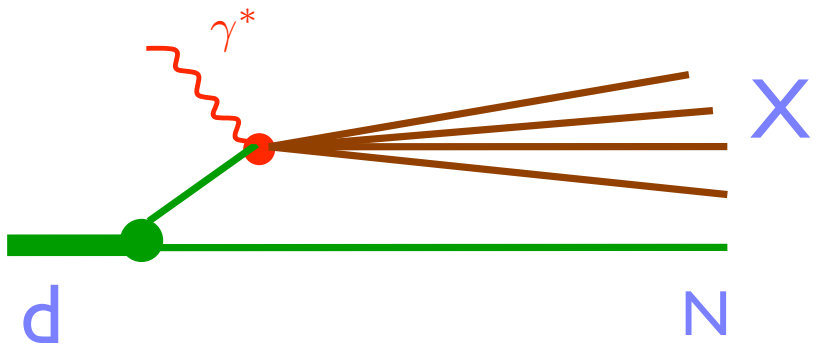
**Ways of probing large internal momenta**

- using condition $\alpha > x$
- parton evolution



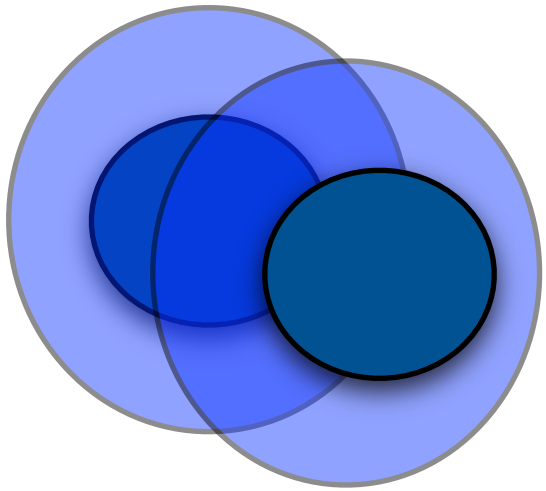



# Convolution Model




$$F_{2d} = \int_x^2 \rho_d^N(\alpha, p_t) F_{2N}(\tfrac{x}{\alpha}, Q^2) \frac{d^2\alpha}{\alpha} d^2 p_t$$

$$F_{2N} \rightarrow F_{2N}^{mod}$$



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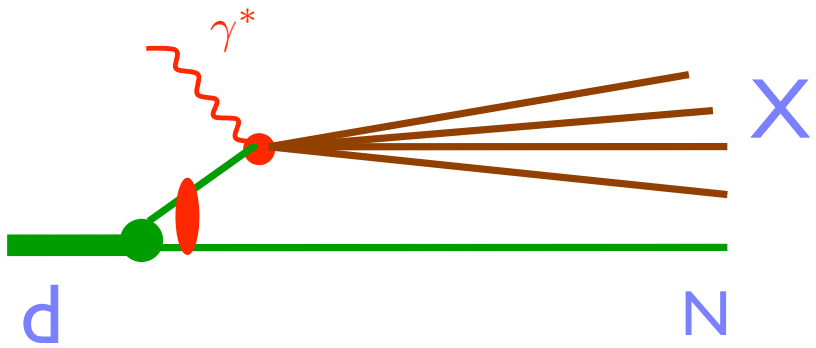


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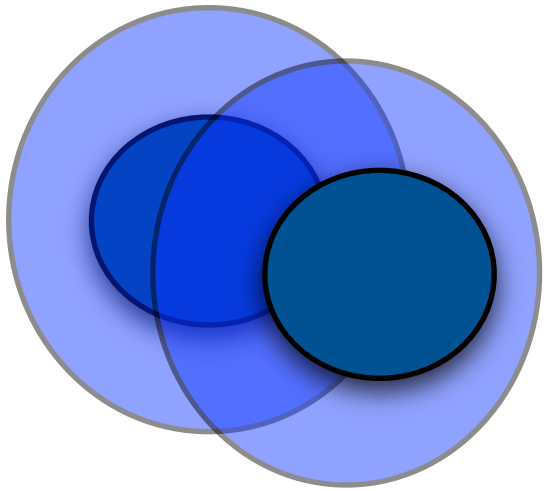
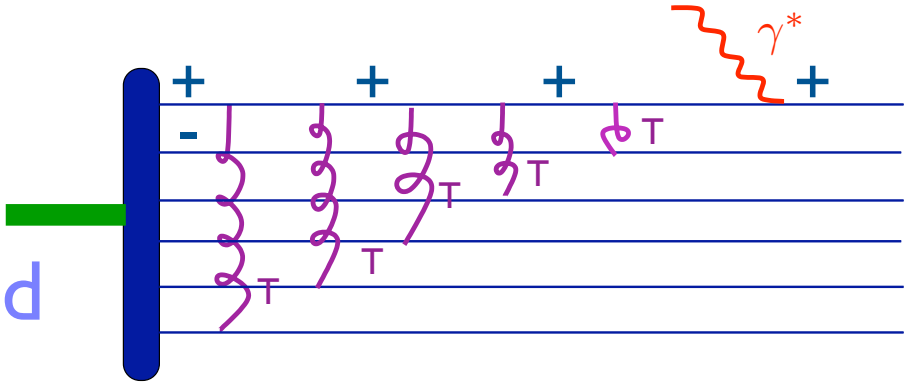


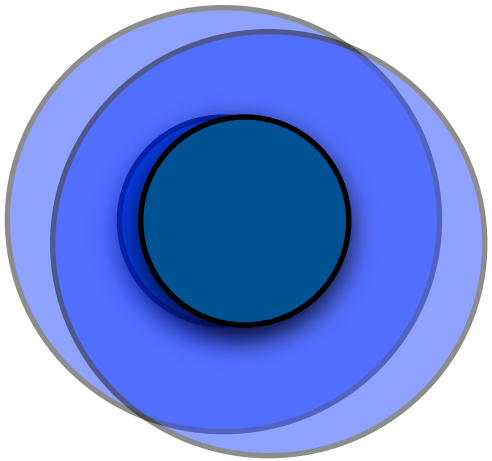
# Quark-Cluster - 6q - Model




$$F_2 \sim (1-x)^{2N-3+2|\Delta\lambda|}$$

Gunion, Nason, Blankenbecler, PRD 1984

$$F_{2D} = F_{2,(6q)} \sim (1-\frac{x}{2})^{10}$$



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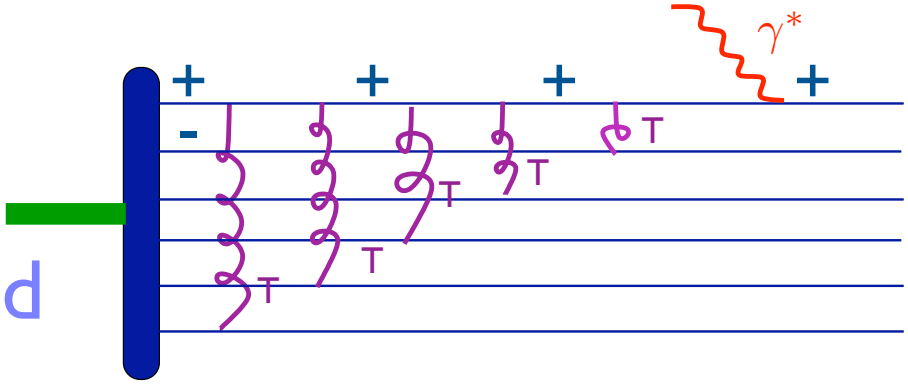


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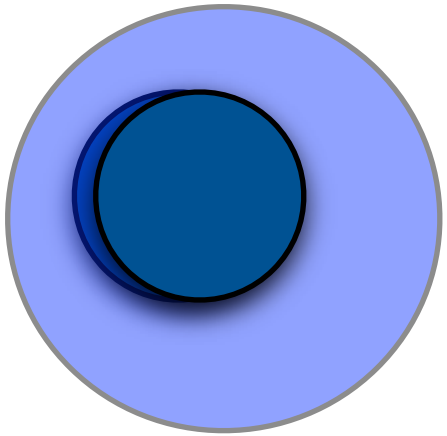

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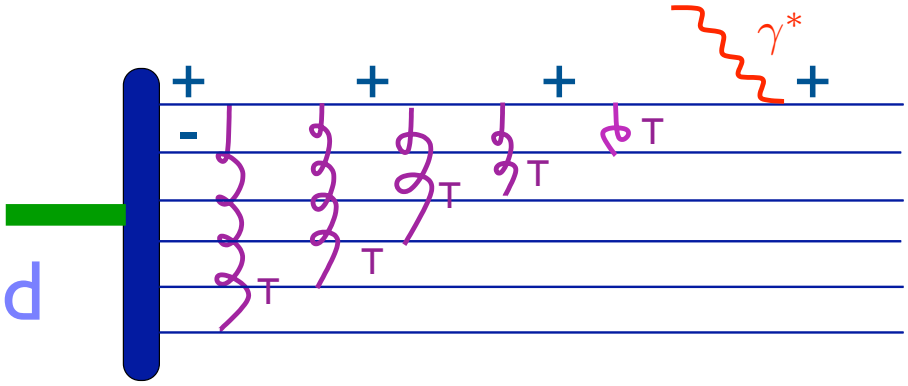


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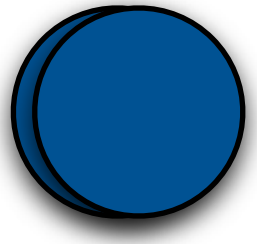


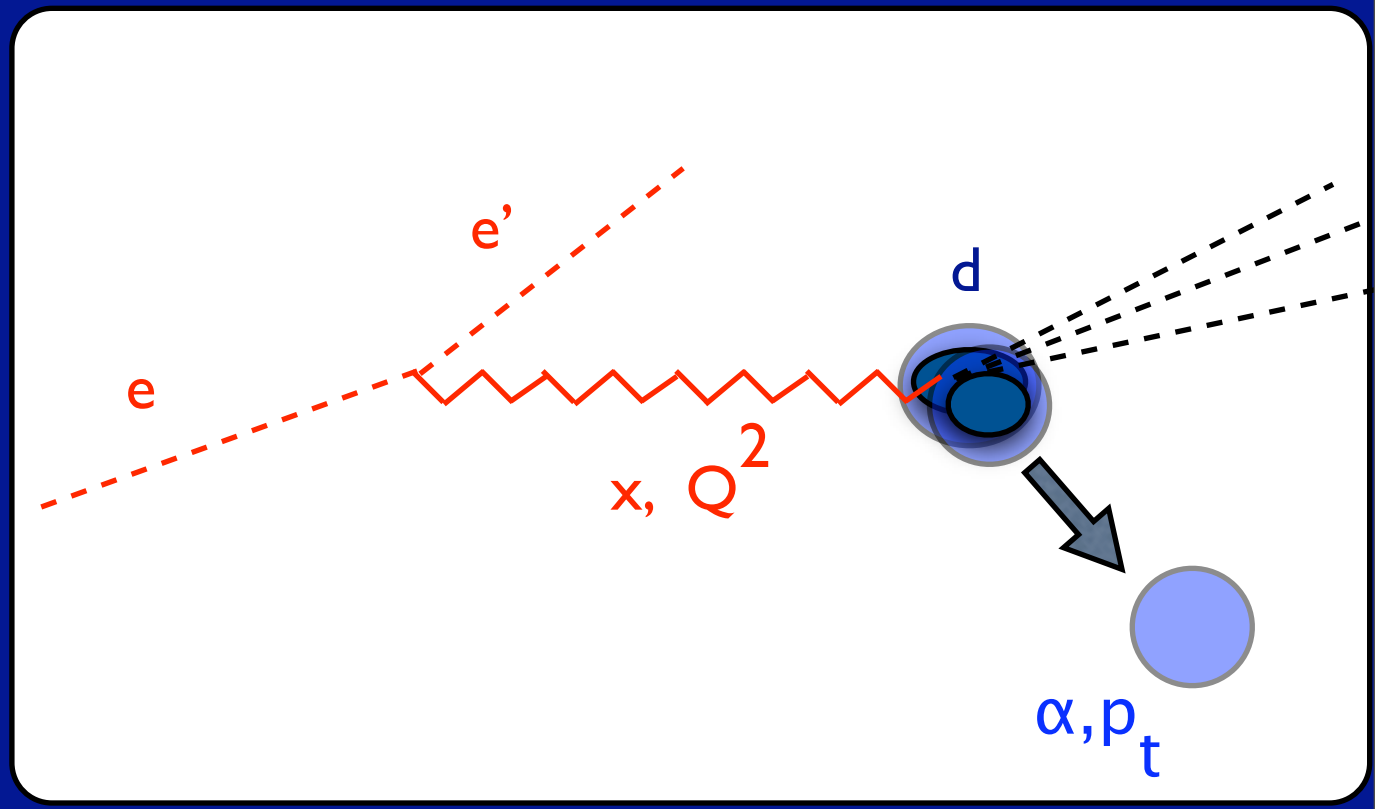
# Semi-Inclusive (e,e'N): Nuclear Medium Modification

**Ways of probing large internal momenta**

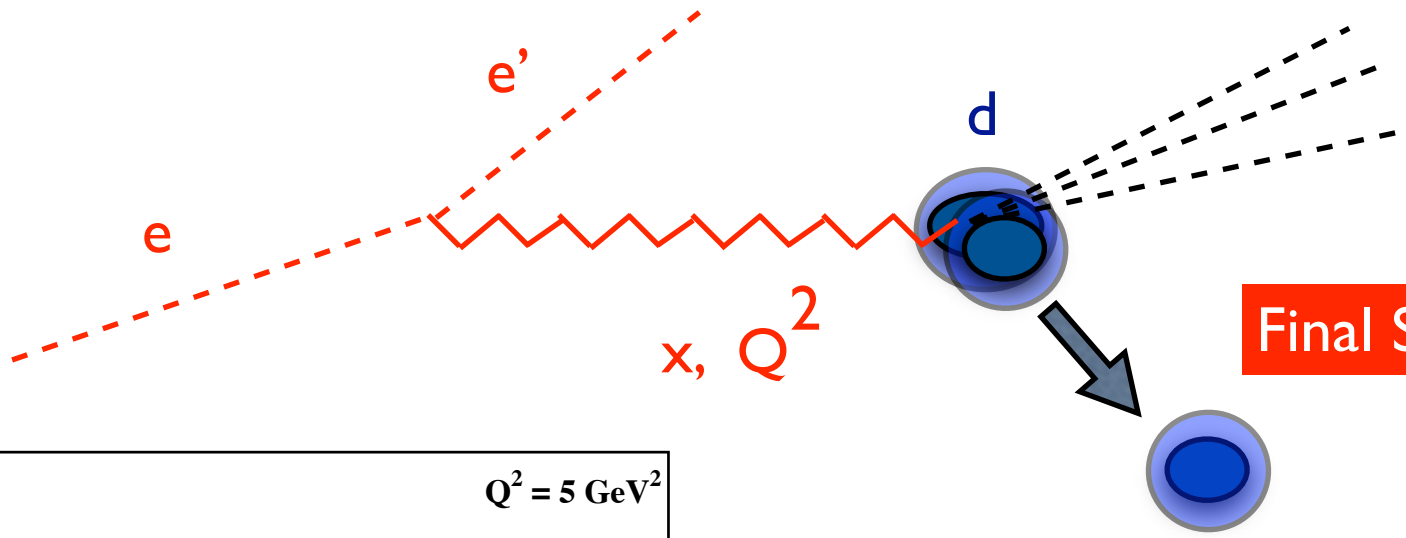
☑ using conditions: N is spectator and $p_N$ is large

$e + A \rightarrow e' + p_N + X$

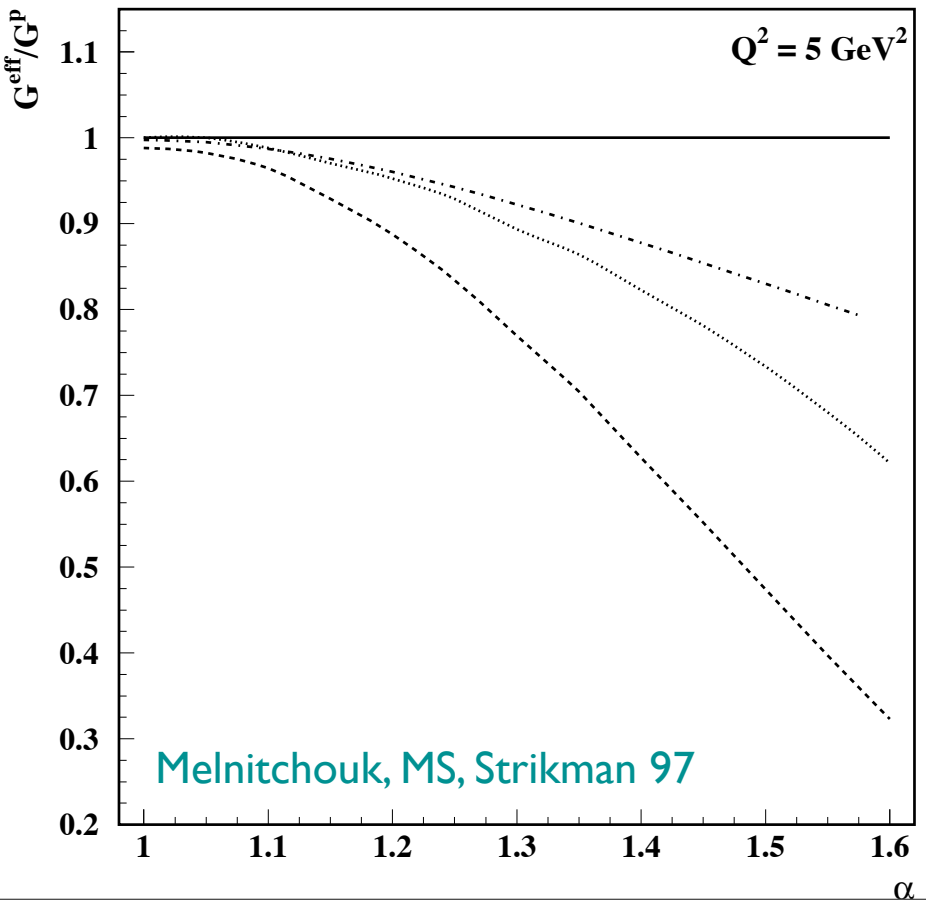
EMC
Shadowing
Structure Functions



# Modification of quark distributions in nuclei (EMC effect)




Final State Interaction




$\alpha, p_t$

controls the virtuality of bound nucleon in the Deuteron

JLAB Experiments, deeps, BONUS

# Semi-Inclusive (e,e'N): New Reactions

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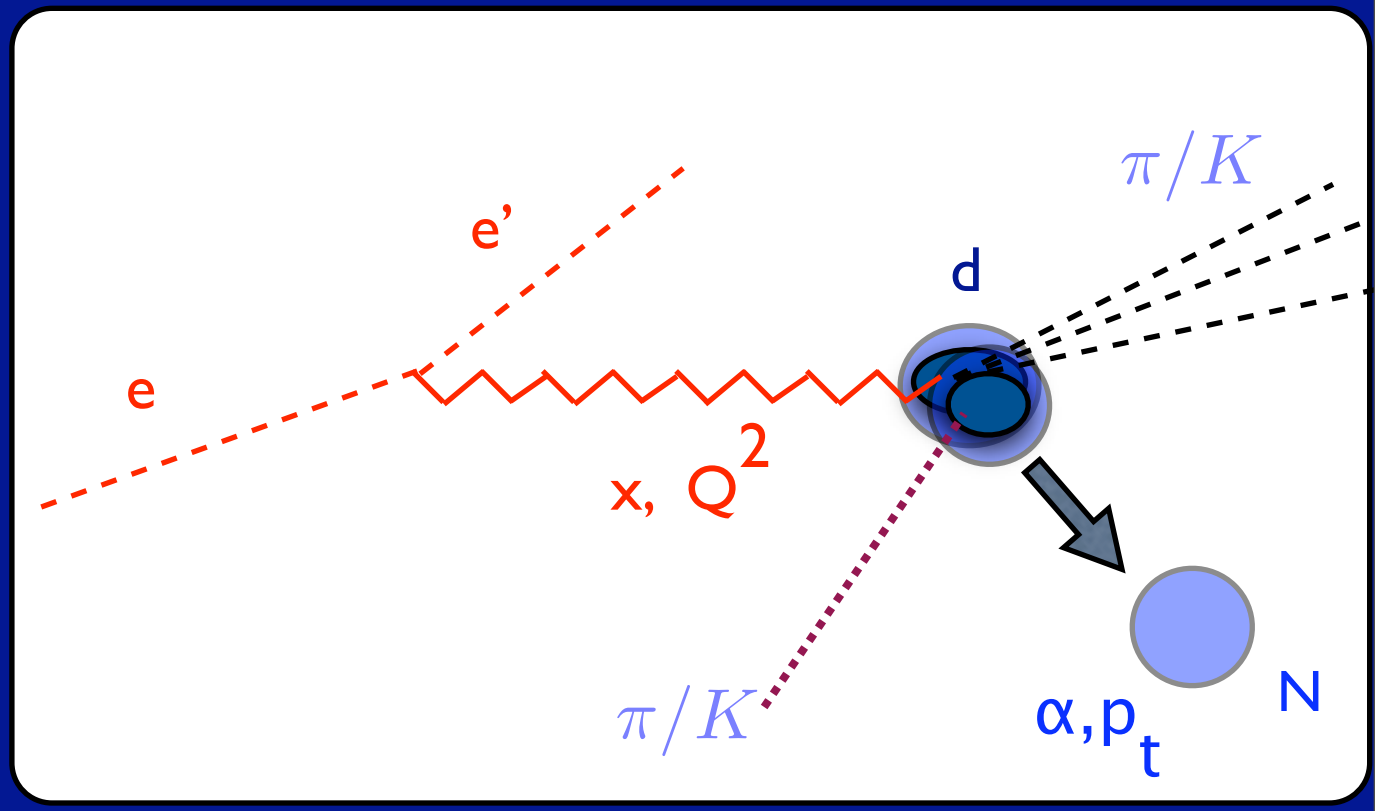
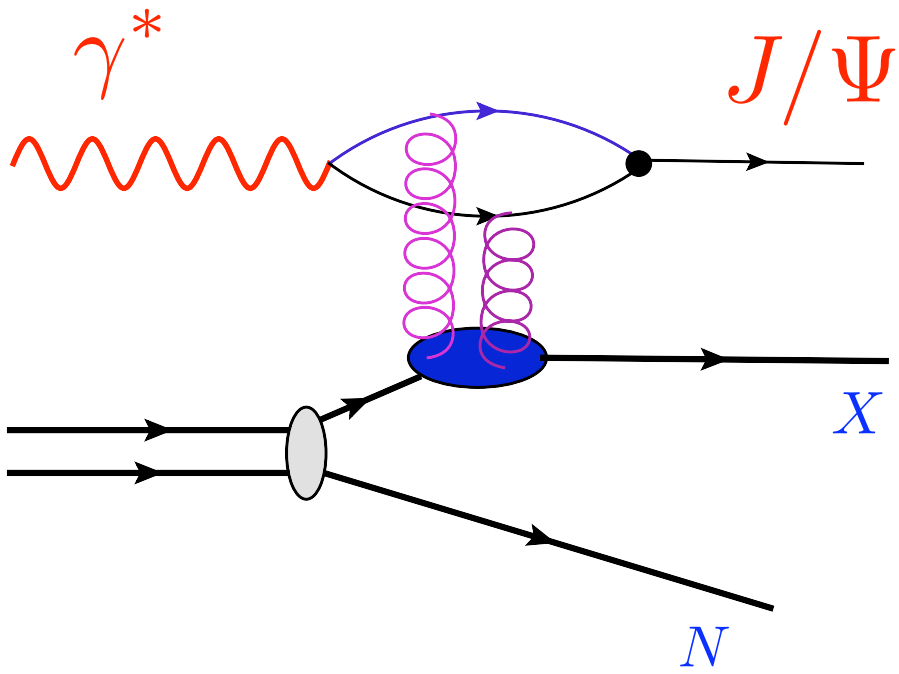
will allow us to measure the flavor dependence of nuclear modification effects. Measuring extra nucleon in specially chosen kinematics will allow control of the initial state.

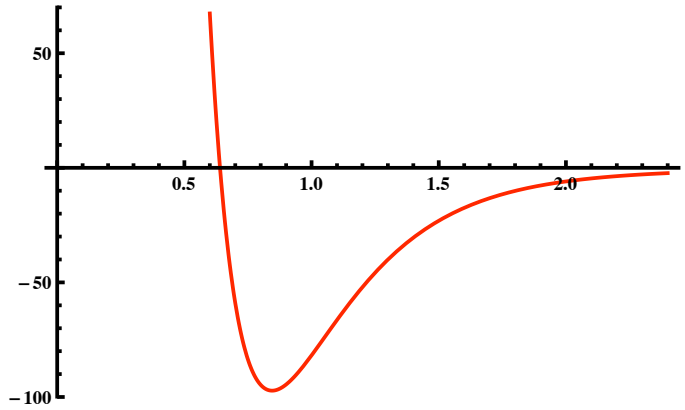


# New Reactions (e,e'J/Psi ):

☑ Considering $\gamma^* + d \to J/\Psi + p + n \quad \gamma^* + d \to J/\Psi + d'$

will probe the nuclear modification of gluonic field controlling the local density from where the J/Psi is produced.



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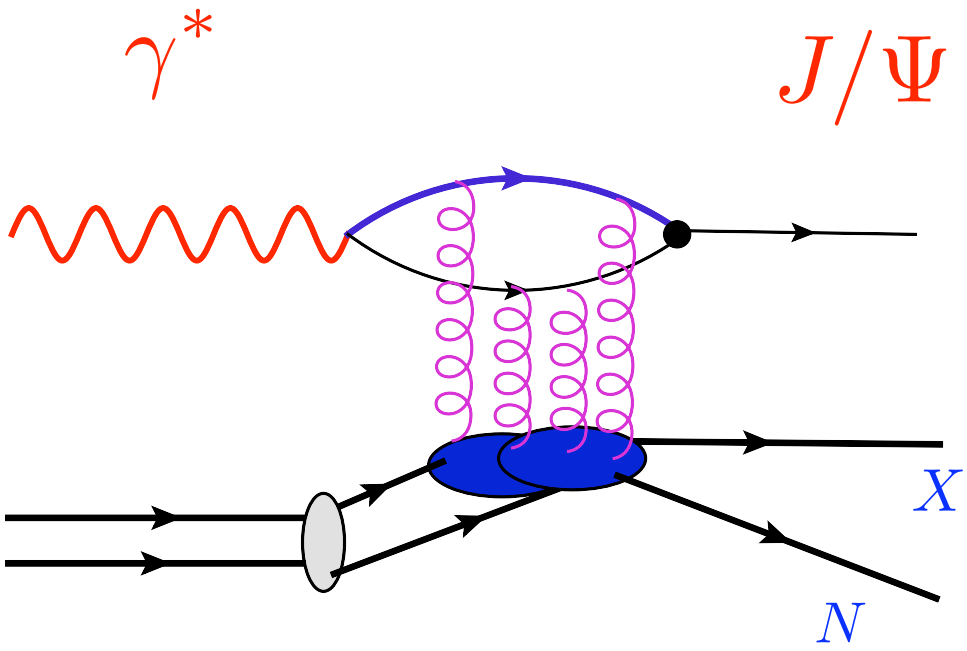
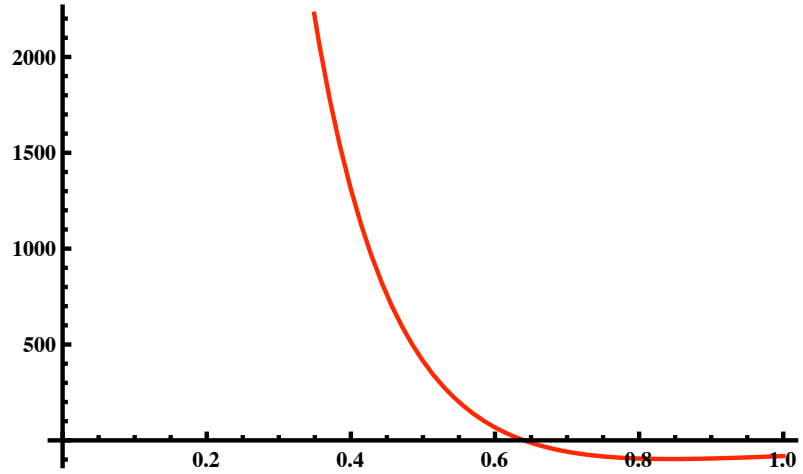
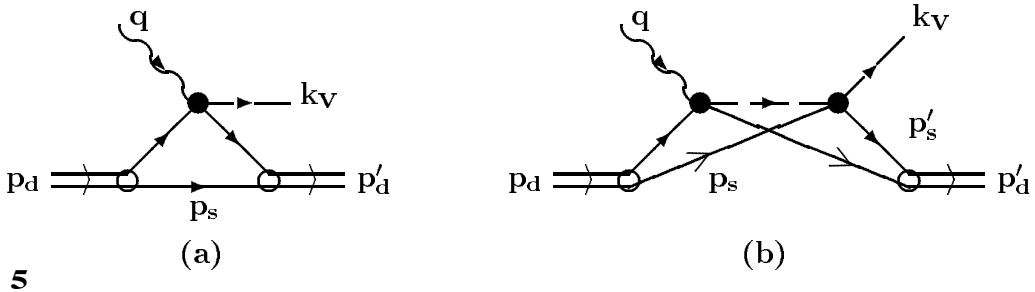
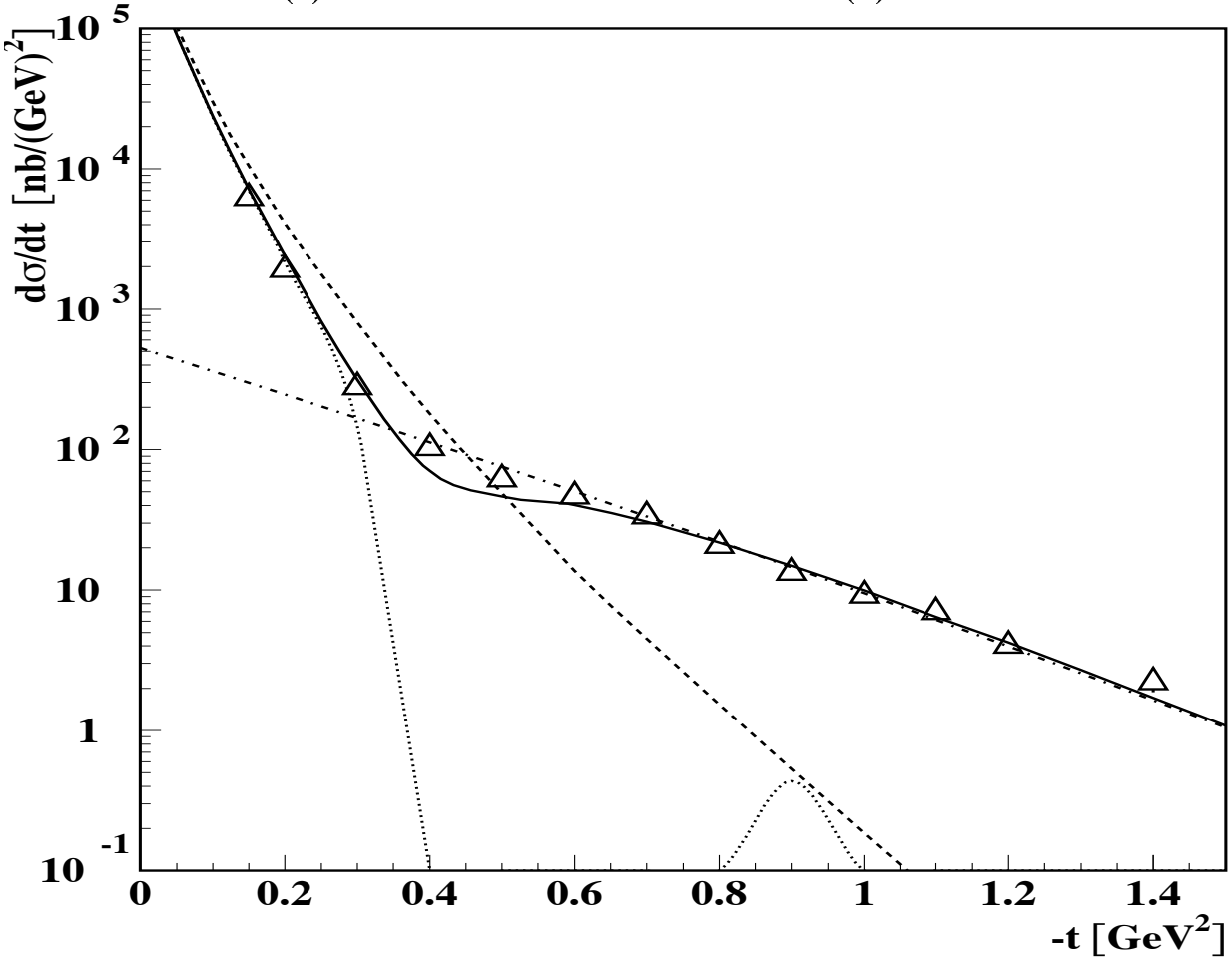


# Coherent Nuclear Processes

Considering $\gamma^* + A \rightarrow V + A'$



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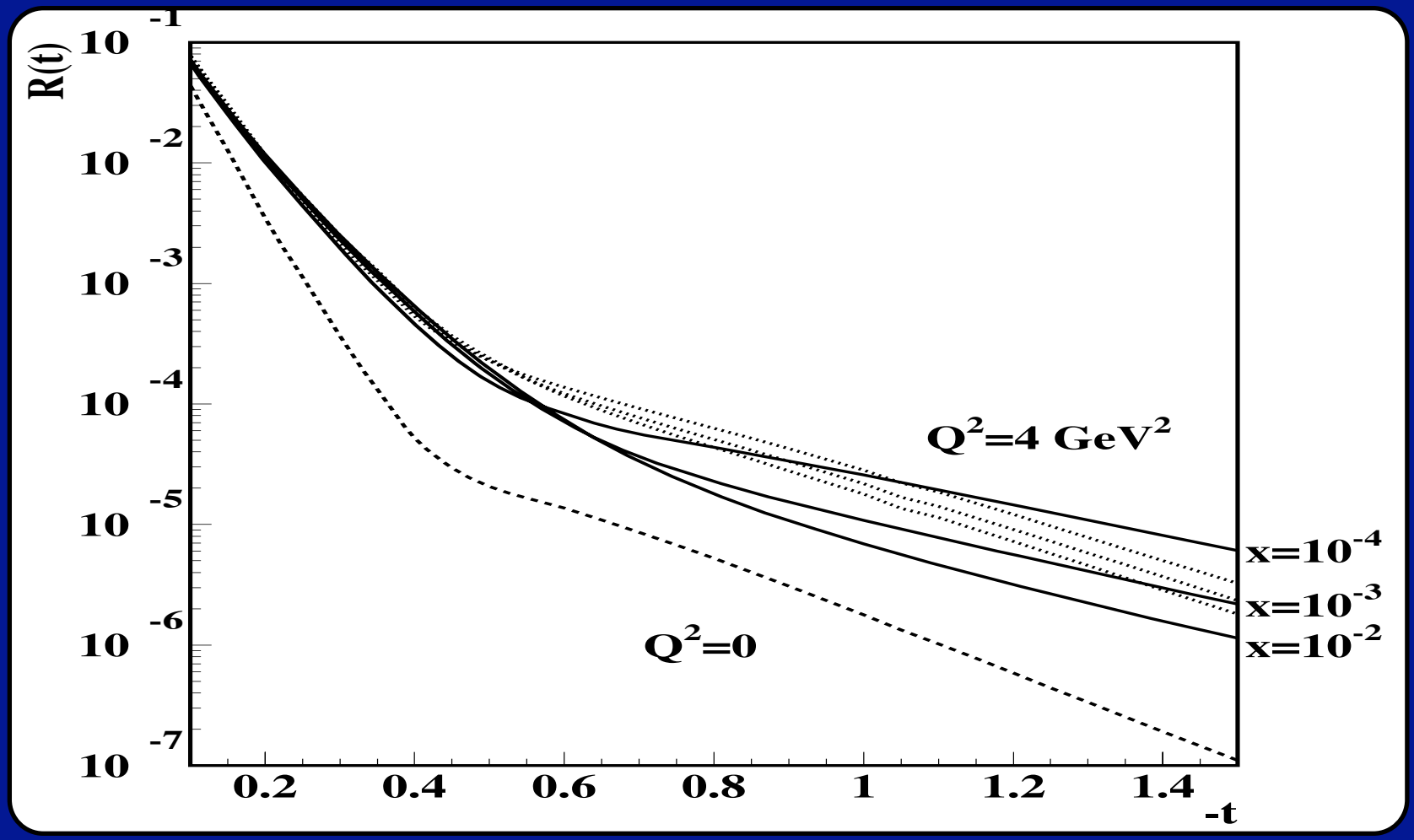

# Conclusions

- ☑ EIC may probe Nuclear Effects Relevant of the Nuclear Core
- ☑ There are set of processes unique to EIC
- ☑ Some successes depend on 12 GeV results