

Nuclear dynamics at JLab 22 GeV

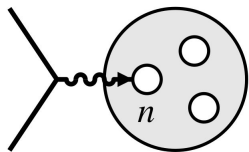
Wim Cosyn
Florida International University

Hall A/C Collaboration meeting
July 16, 2024

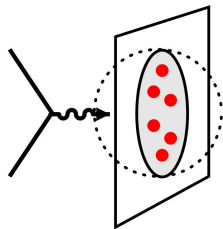
22 GeV white paper: 2306.09360
2024 LDRD proposal (PI C. Weiss)



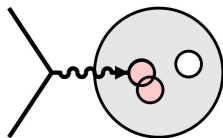
Nuclear ($A>1$) physics in high-energy scattering



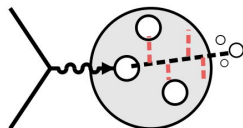
- Neutron structure
→ Flavor separation of distribution functions



- Imaging nuclear bound states
→ Nuclear GPDs

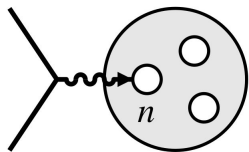


- Nuclear interactions
→ Medium modifications of partonic structure
→ QCD origin of nuclear core
→ Superfast quarks
→ Nuclear gluons

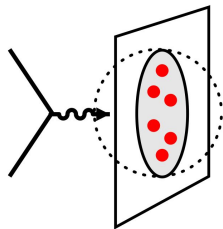


- Nuclear medium as filter
→ Hadronization
→ Color transparency
→ hN cross section

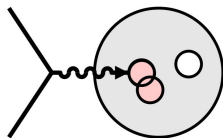
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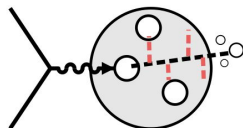
- Neutron structure ✗
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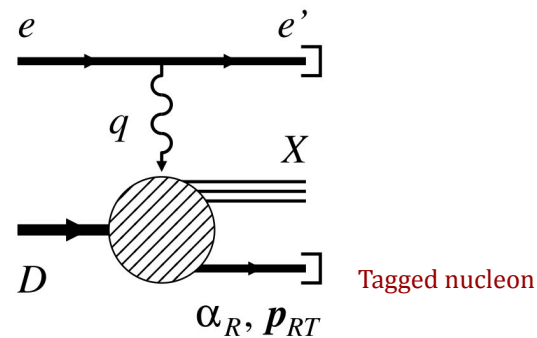
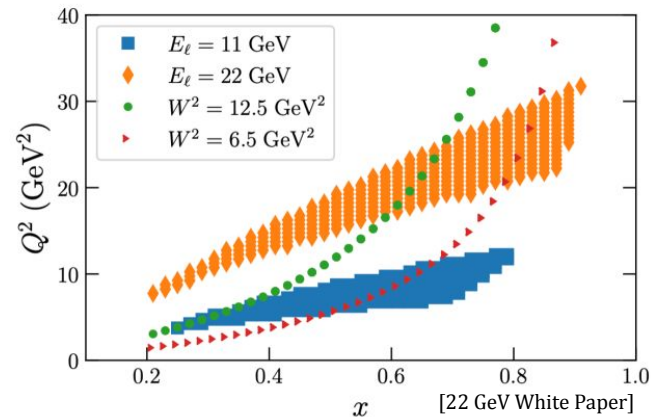
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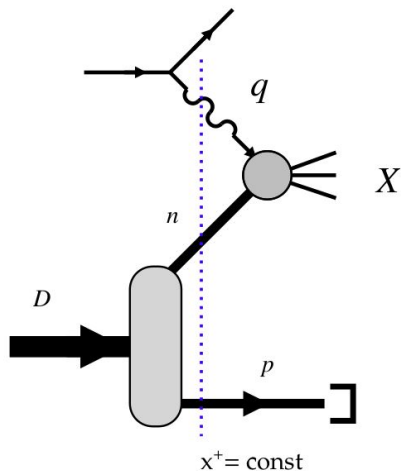
JLab 22 GeV with $A > 1$

- High luminosity
- Polarized electron, light nuclei
- High Q^2 , **intermediate** to high x
 - Both valence and sea quarks
 - Antishadowing region
- Nuclei
 - Inclusive or coherent reactions
 - **Average** over all nuclear configurations
 - “Tagging” (nuclear breakup)
 - **Select** certain (exceptional) nuclear configurations
 - **Final state interactions**
- High-energy nuclear scattering is interplay of
 - Low-energy nuclear structure
 - High-energy electron scattering



Theoretical framework

[Frankfurt, Strikman 80s+]

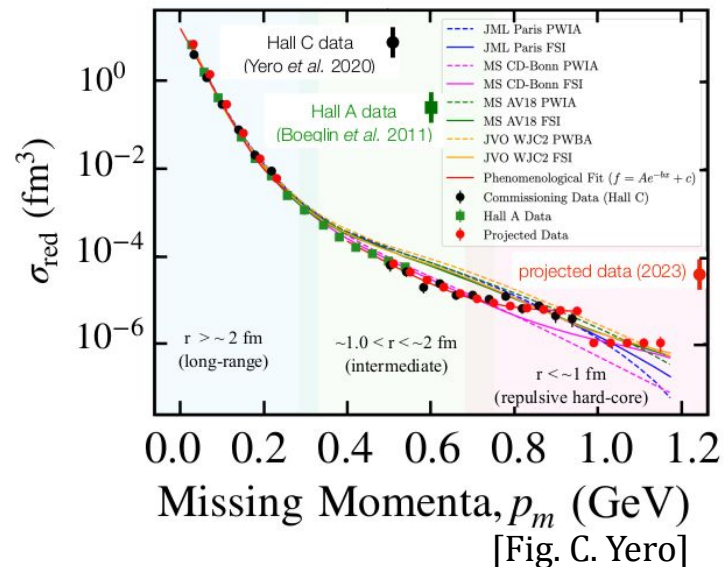


- Virtual photon probes nucleus at fixed lightfront time $x^+ = x^0 + x^3$
→ Fixes nuclear configuration during scattering
- Scales can be separated using methods of light-front quantization and QCD factorization
- Tools for high-energy scattering known from ep
- Nuclear input: light-front momentum densities, spectral functions, overlaps with specific final states in breakup/tagging reactions

→ Still low energy nuclear physics

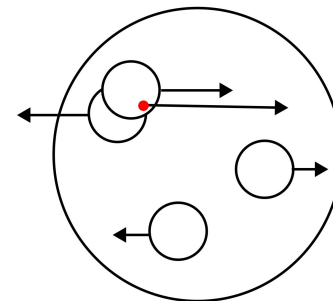
Quasi-elastic deuteron breakup: $e + d \rightarrow e' + p + n$

- Simplest nuclear system
 - Well understood, except...
 - **Core!** [parametrized in potentials / contact terms in EFT]
- Simplest exclusive reaction (well understood: FSI/meson exchange/charge exchange)
- Large Q^2 needed to reach internal momenta ~ 1 -1.5 GeV
- Beyond np component
 - $\Delta\Delta$ configurations (luminosity!)
 - Hidden color (6q state)
- Separation of S(L=0) and D(L=2) wave?
 - Unpolarized: $f_0^2 + f_2^2$
 - Tensor polarized: $\left(2f_0 + \frac{f_2}{\sqrt{2}}\right) \frac{f_2}{\sqrt{2}}$
- Studies of 3N short-range dynamics in ^3He breakup

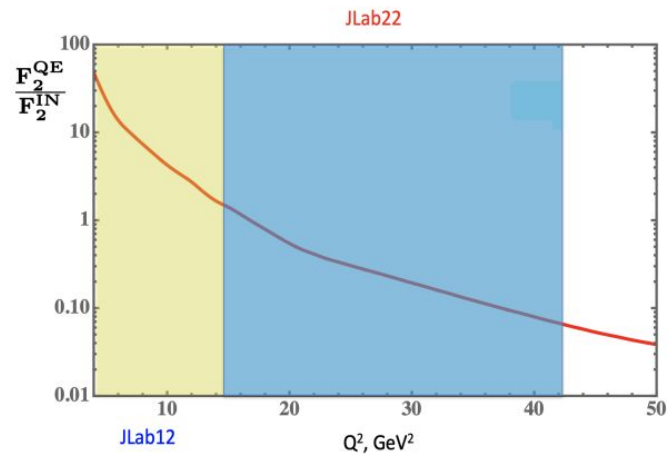
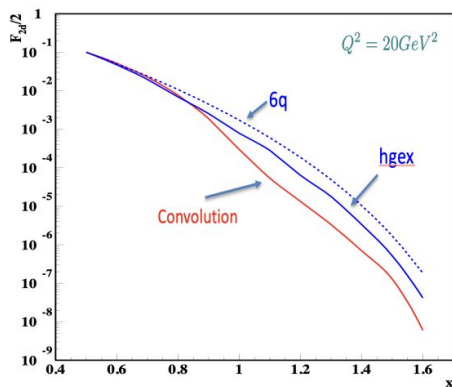


Superfast quarks

- In nuclei $0 < x < A \dots$ in DIS corresponds to momentum fractions
 → $1 < x$ is **superfast**



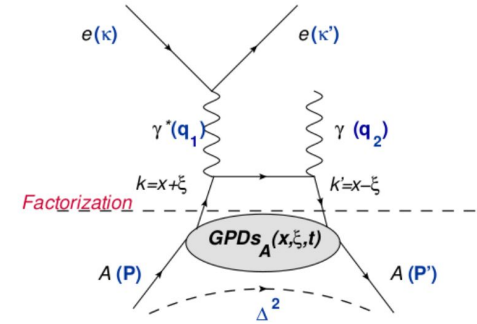
- In convolution model of partonic nuclear structure originates from nucleons in correlation (large p)
- Needs **large Q^2** to dominate over QE
 → Existing Jlab6 [Fomin, Arrington et al.]
- F_2 sensitive to core dynamics



[M. Sargsian]

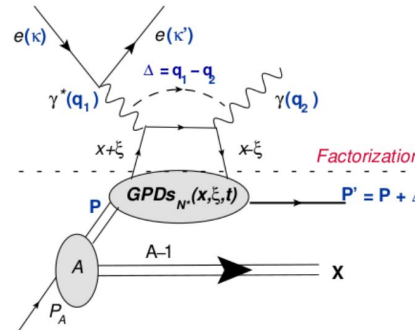
Deuteron DVCS

- Coherent
 - 3D imaging of nuclei
 - Clustering and spin-orbit phenomena
 - Tensor polarized deuteron sensitive to interactions

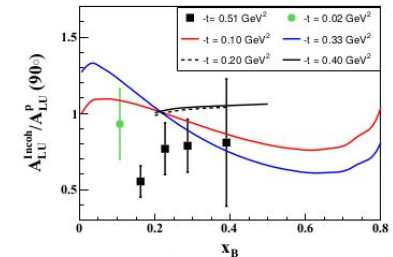


[Diagrams from S. Fucini]

- Incoherent
 - Medium modification of nucleon GPD
 - Bethe Heitler has imaginary part
 - FSI contribute



- Beam charge asymmetries with positrons

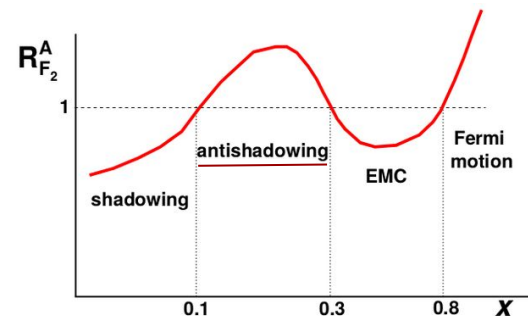


${}^4\text{He}$ DVCS

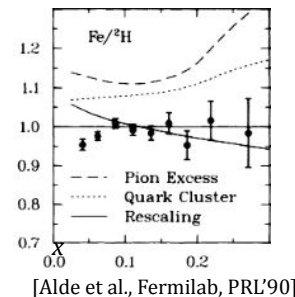
M. Hattawy et al. [GLAS PRL]

Anti-Shadowing

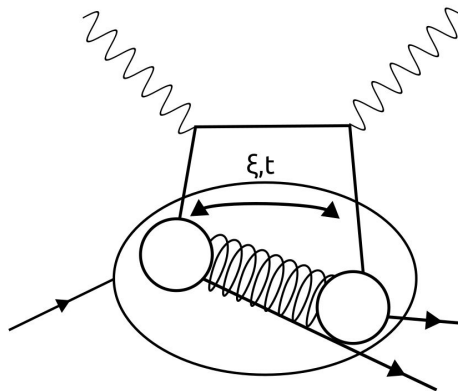
- Enhancement in inclusive nuclear ratio around $x \sim 0.1-0.2$
→ Valence + sea quarks



- No enhancement seen in dimuon production in pA (DY)
→ Rules out meson interactions

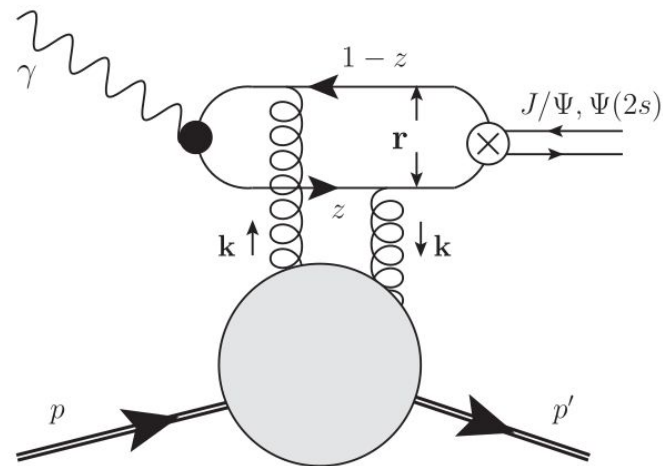


- More differential measurements can select specific nuclear configurations
→ Tagged deuteron DIS (spectator p)
→ Tagged deuteron DVCS (ξ, t)



J/ψ Production on $A = 2-4$

- Gluonic distribution of light nuclei
 - Fourier transf. of nuclear form factor (coherent scatt.)
 - Nuclear modifications: convolution of nucleon gluonic structure and **nuclear effects**
- LHC: ultraperipheral collision (small x)
EIC: $x < 0.2$
JLab 22: $x > 0.2$
- Incoherent scattering
 - J/ψ - nucleon cross section (fully formed in nucleus)



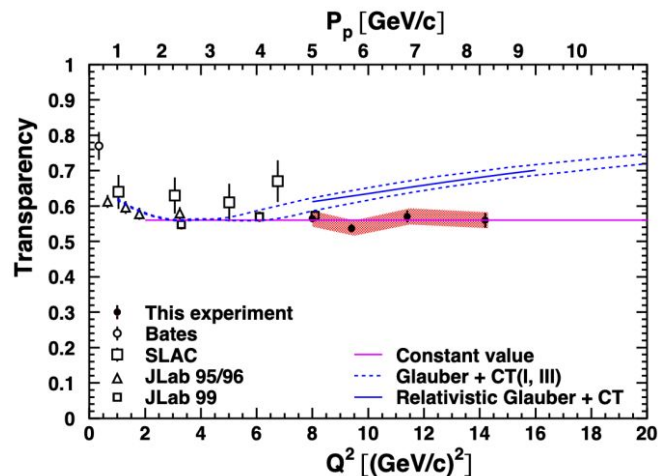
[Fig. from Hentschinski, Molina PRD'21]

Color transparency

- Disappearance of medium interactions for hadrons in small-sized configuration
 - Produced in high-energy exclusive reactions
 - Necessary condition for factorization in exclusive processes

- Jlab 6/12: forward kinematics
 - CT = Reduction of absorption (transparency)
 - Not observed for protons
 - Convincing hints for π, ρ

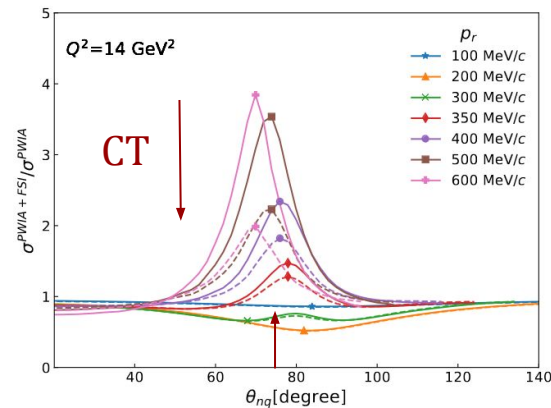
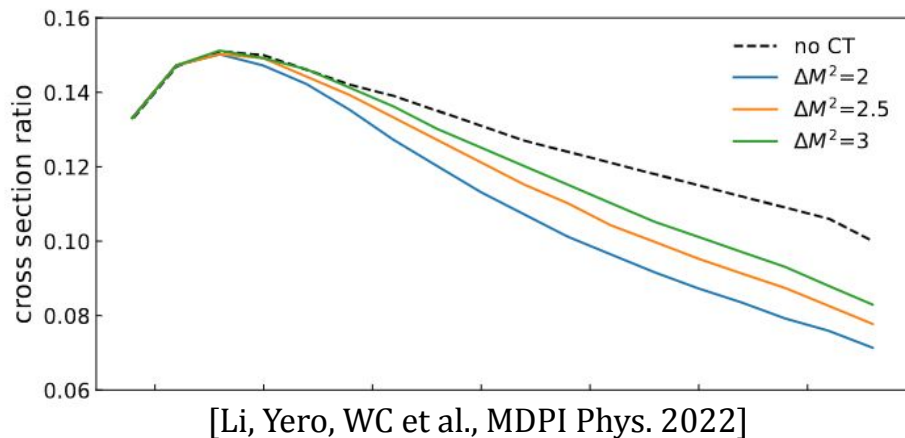
- JLab 22 can map out transition region



[Jlab Hall C, PRL (2021)]

Color Transparency in “dirty” kinematics

- Look for CT in kinematics with high FSI
 - QE deuteron breakup
 - Ratio $d\sigma(500 \text{ MeV})/d\sigma(200 \text{ MeV})$ **decreases** when CT is present



Conclusions: With 22 GeV

- Explore underexplored aspects of nuclear dynamics in QCD
 - Nuclear core
 - Antishadowing
- Image light nuclei in partonic degrees of freedom
 - Valence & sea quarks (GPDs)
 - Gluonic radius
- Breakup / tagging / exclusive enable differential studies of medium modification effects
- More that wasn't covered here...
- Needs dedicated efforts to extend theory frameworks, do simulations etc.
 - LDRD proposal