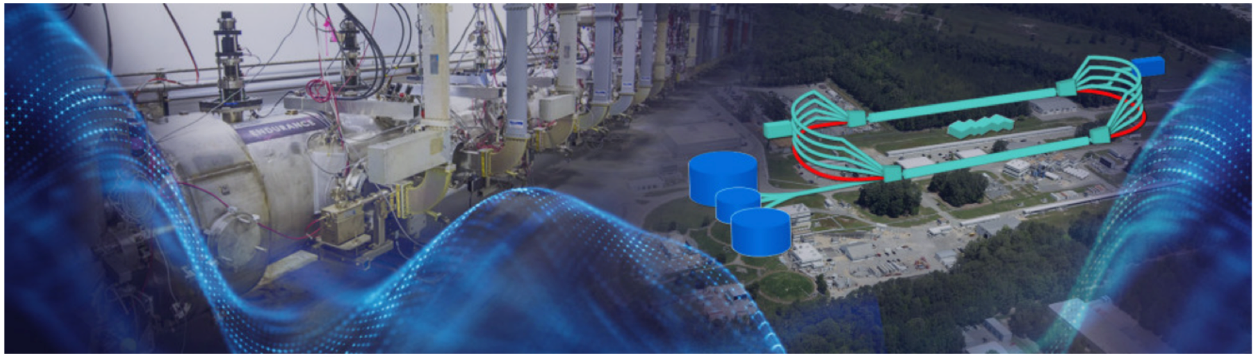
Color transparency studies at 22 GeV



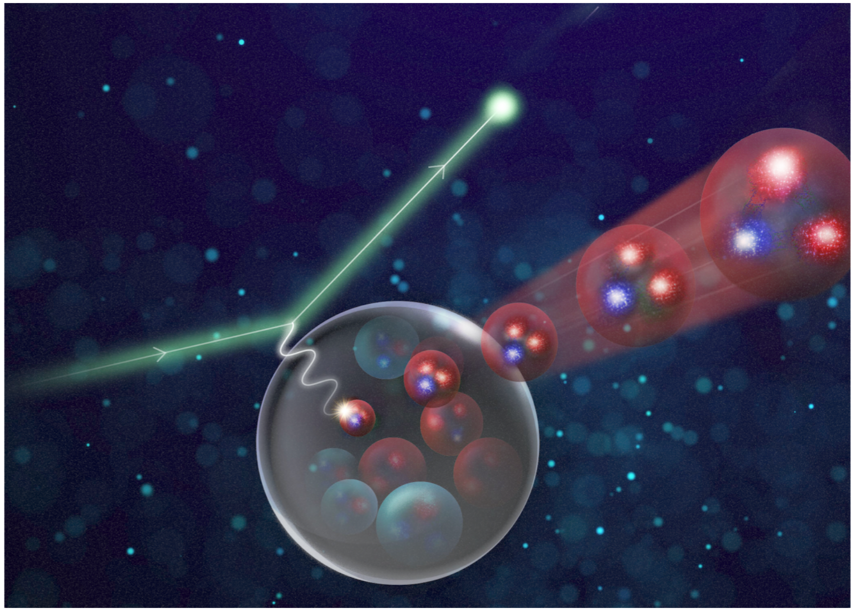
Holly Szumila-Vance
In collaboration with Dipangkar Dutta
Jefferson Lab
Science at the Luminosity Frontier: Jefferson Lab at 22 GeV Workshop
25 Jan 2023

Jefferson Lab

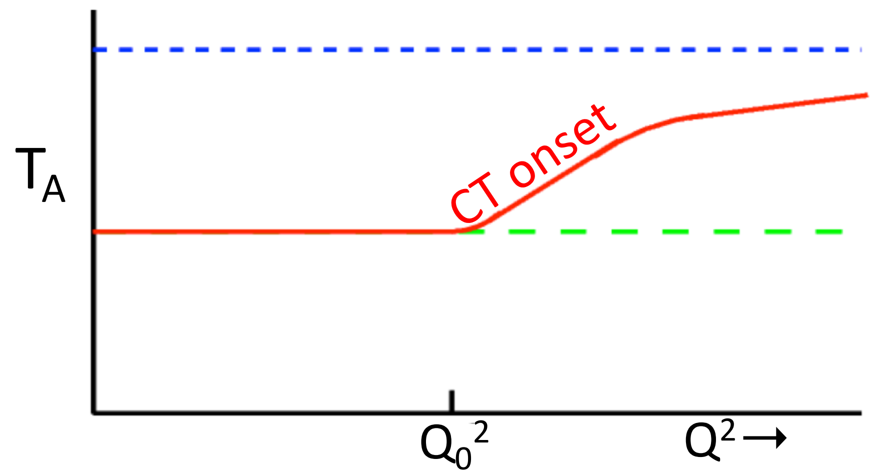
U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Color Transparency studies at Jlab probe the anticipated "onset regime"



$$T_A = \frac{\sigma_A}{A\,\sigma_N} \qquad \sigma_A = \sigma_N\, A^{\alpha}$$



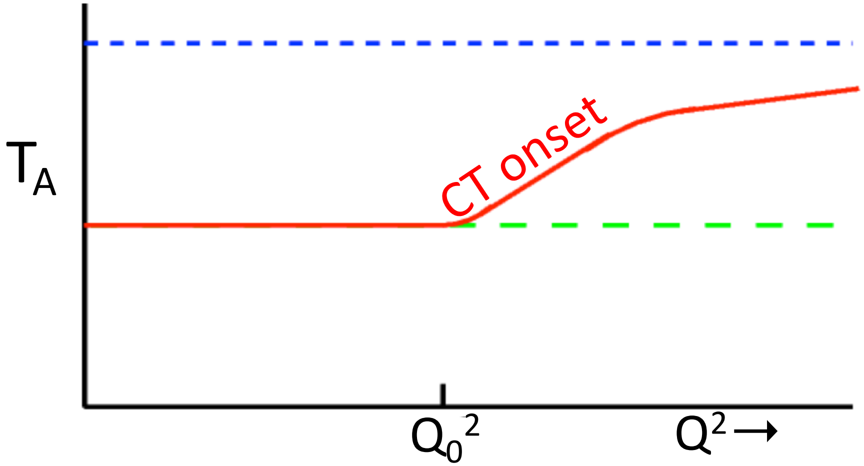
Introduced by Mueller and Brodsky, 1982

Vanishing of initial/final state interaction of hadrons with nuclear medium in exclusive processes at high momentum transfer

Color Transparency studies at Jlab probe the anticipated "onset regime"

- Hadron fluctuates to small transverse size (quantum mechanics)
- Maintains this small size as it propagates out of the nucleus (relativity)
- Experiences reduced attenuation in nucleus, color screened (strong force)

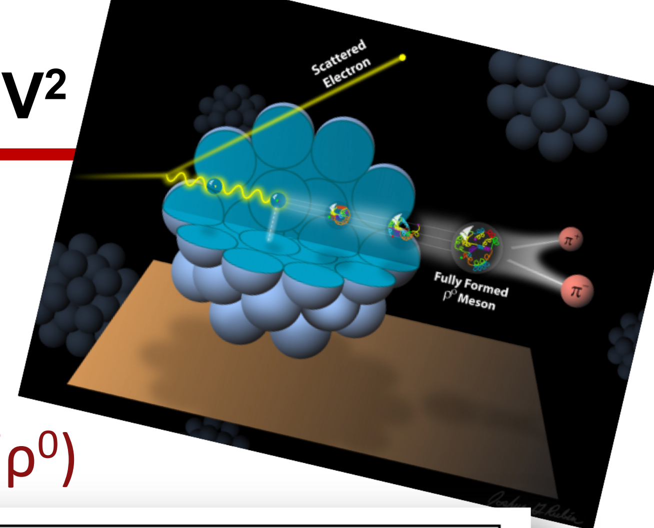
$$T_A = \frac{\sigma_A}{A\,\sigma_N} \qquad \sigma_A = \sigma_N\, A^{\alpha}$$



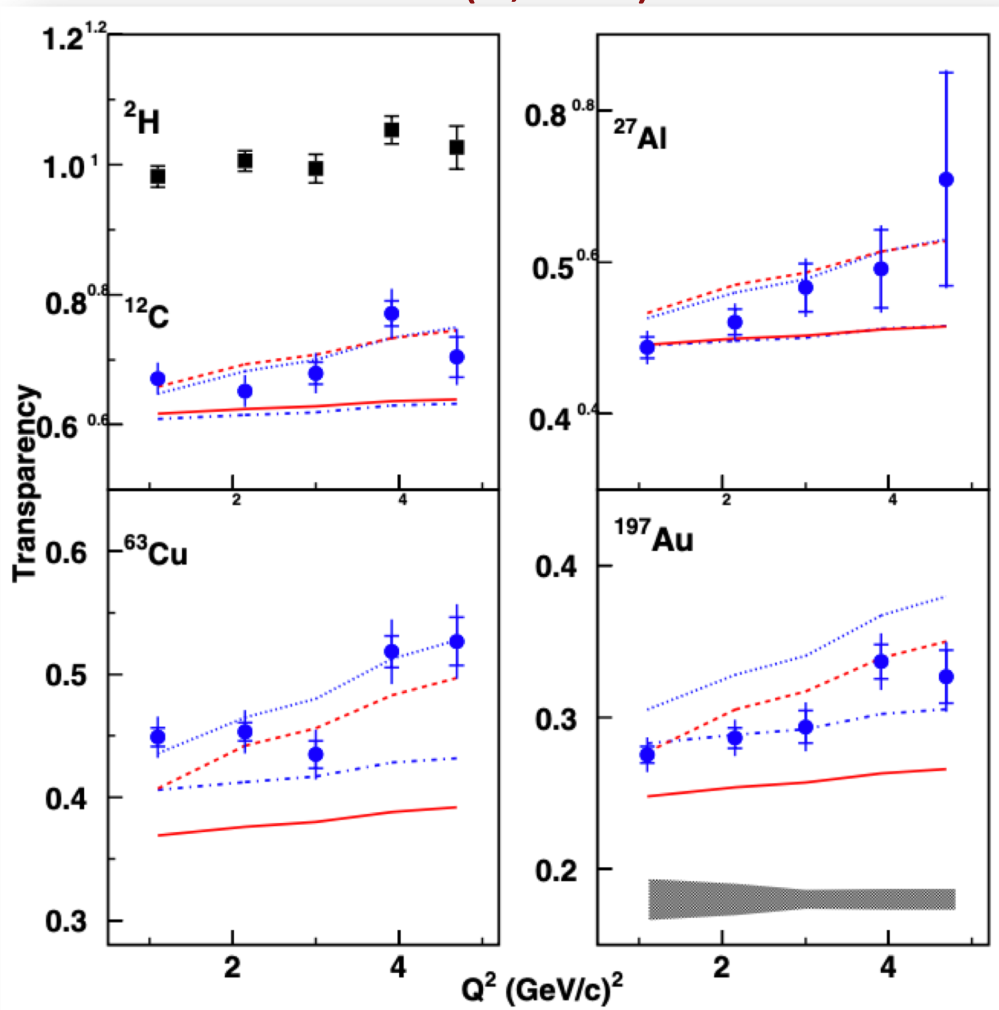
Traditional picture -> energy independent:

- NN cross section
- Glauber multiple scattering
- FSI and correlation effects

Onset of CT for mesons at Q^2 of few GeV^2

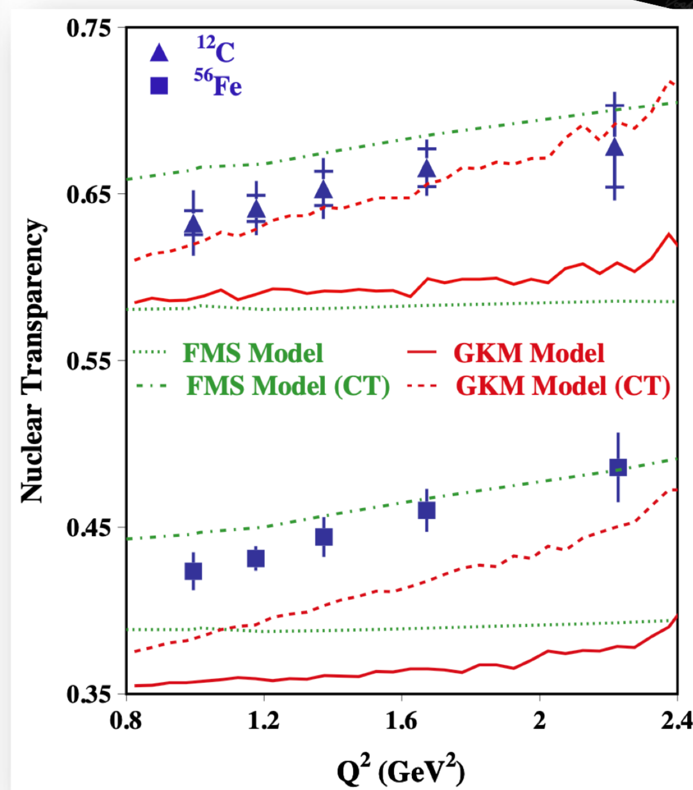


A(e,e'π^+)



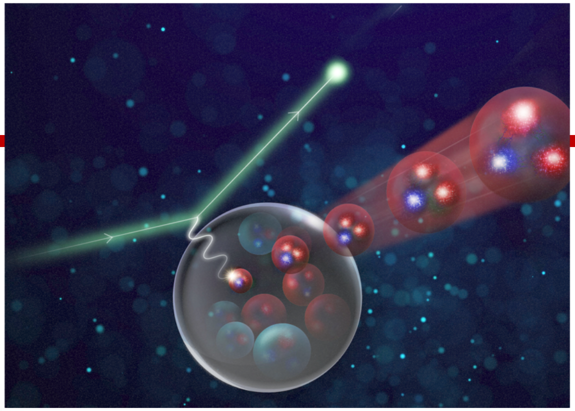
B. Clasie et al, PRL99:242502 (2007)
X. Qian et al, PRC81:055209 (2010)

A(e,e'ρ^0)

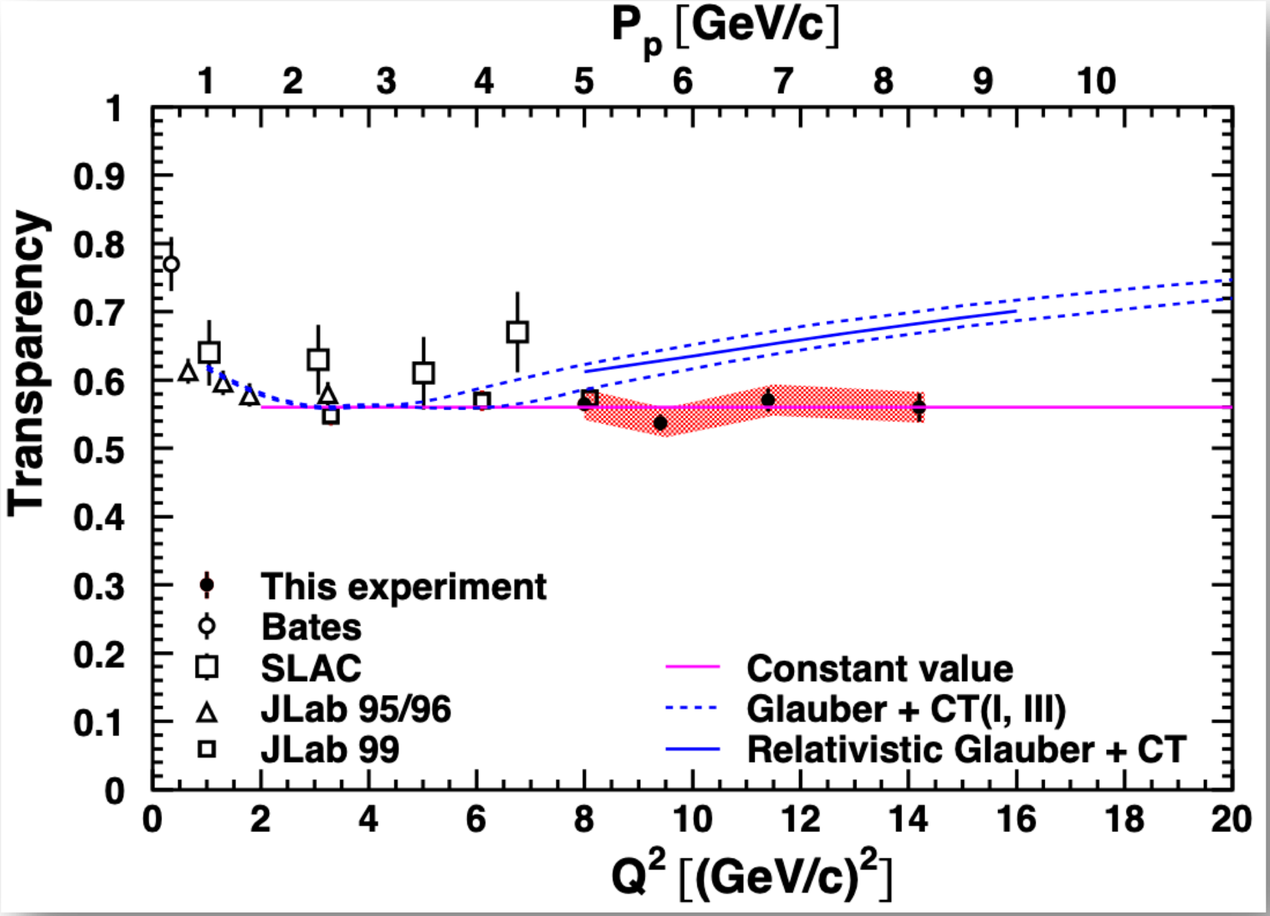


L. El Fassi et al, PLB 712,326 (2012)
L. El Fassi, Physics 4, no. 3 (2022)

An interesting picture has arisen…



A(e,e’p)



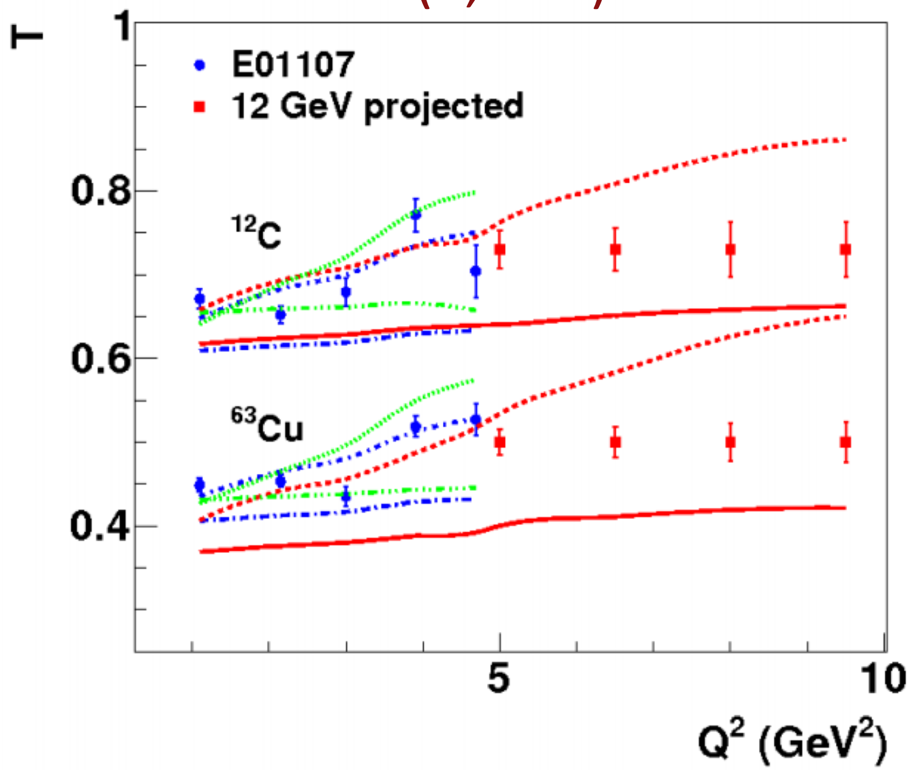
Onset not observed for protons at Q^2 = 14 GeV^2

Parallel kinematics: reduced FSIs, θ_{pq} = 0

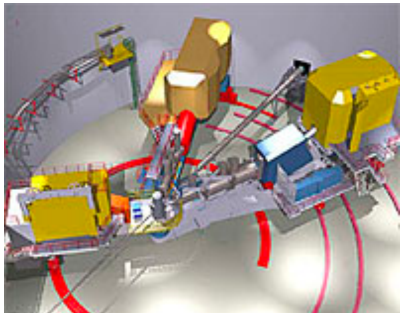
D. Bhetuwal et al, PRL126:082301 (2021)

Near-term experiments extend meson CT measurements

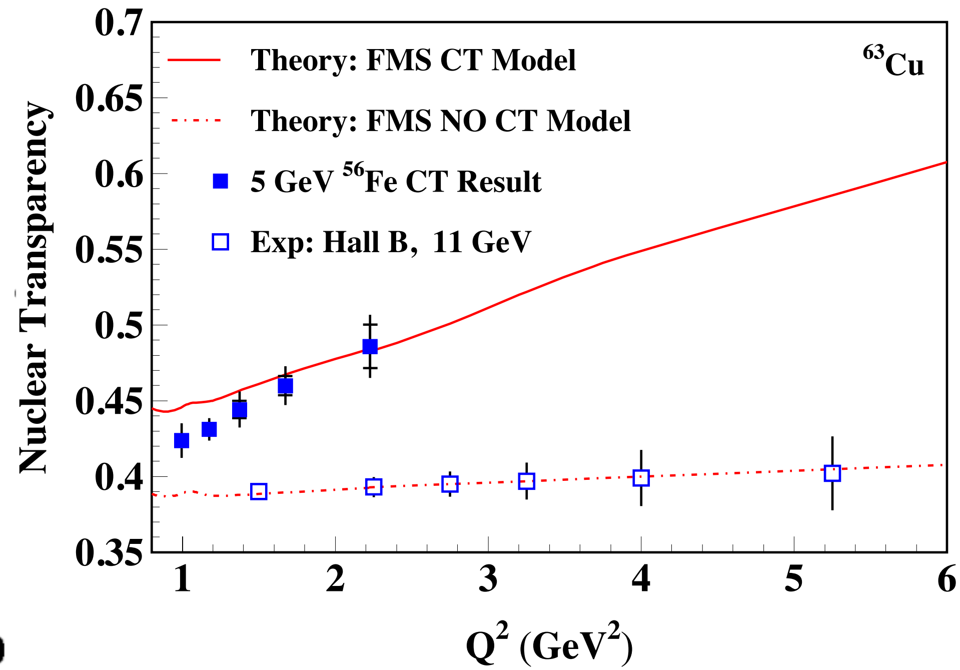
A(e,e'π^+)



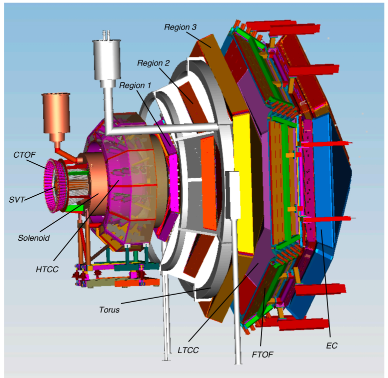
Will run late 2024 in Hall C



A(e,e'ρ^0)



CLAS12 RG-D scheduled for this year!

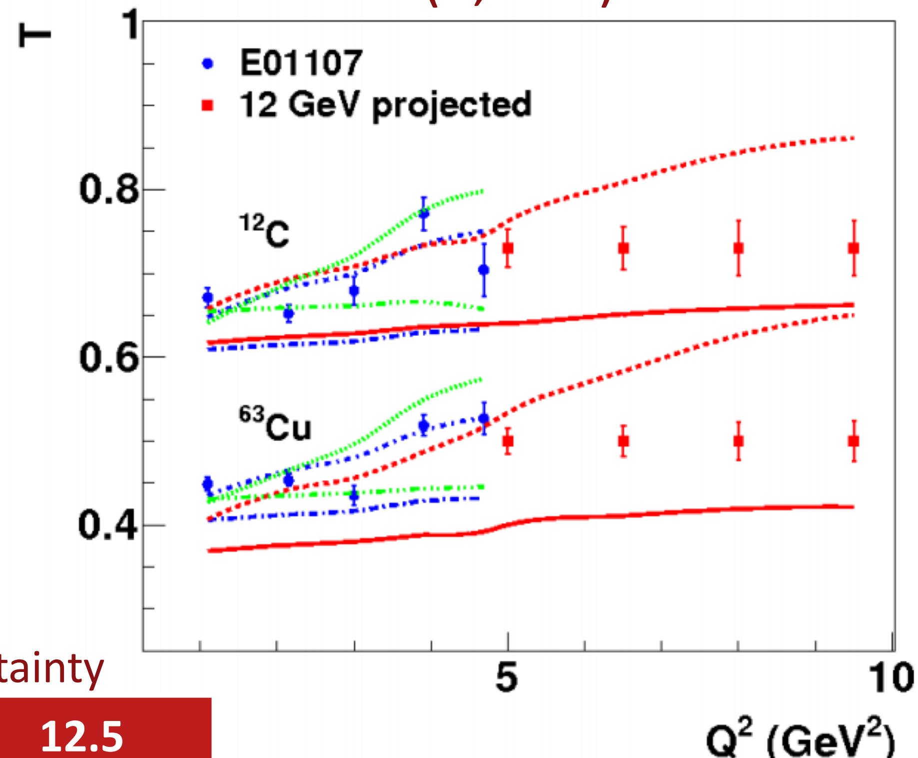


Same kinematics strategy….higher beam energy in Hall C

Increasing beam energy:

- E_b = 13.2 GeV or E_b = 17.6 GeV
- x4 rate increase from 13.2 -> 17.6 GeV
- Both E_b kinematics are limited to approx. max Q^2=12.5 GeV^2 to keep t<1 GeV^2 (reduced FSI)
- At 17.6 GeV, run HMS at high $P_{central}$

A(e,e'π^+)

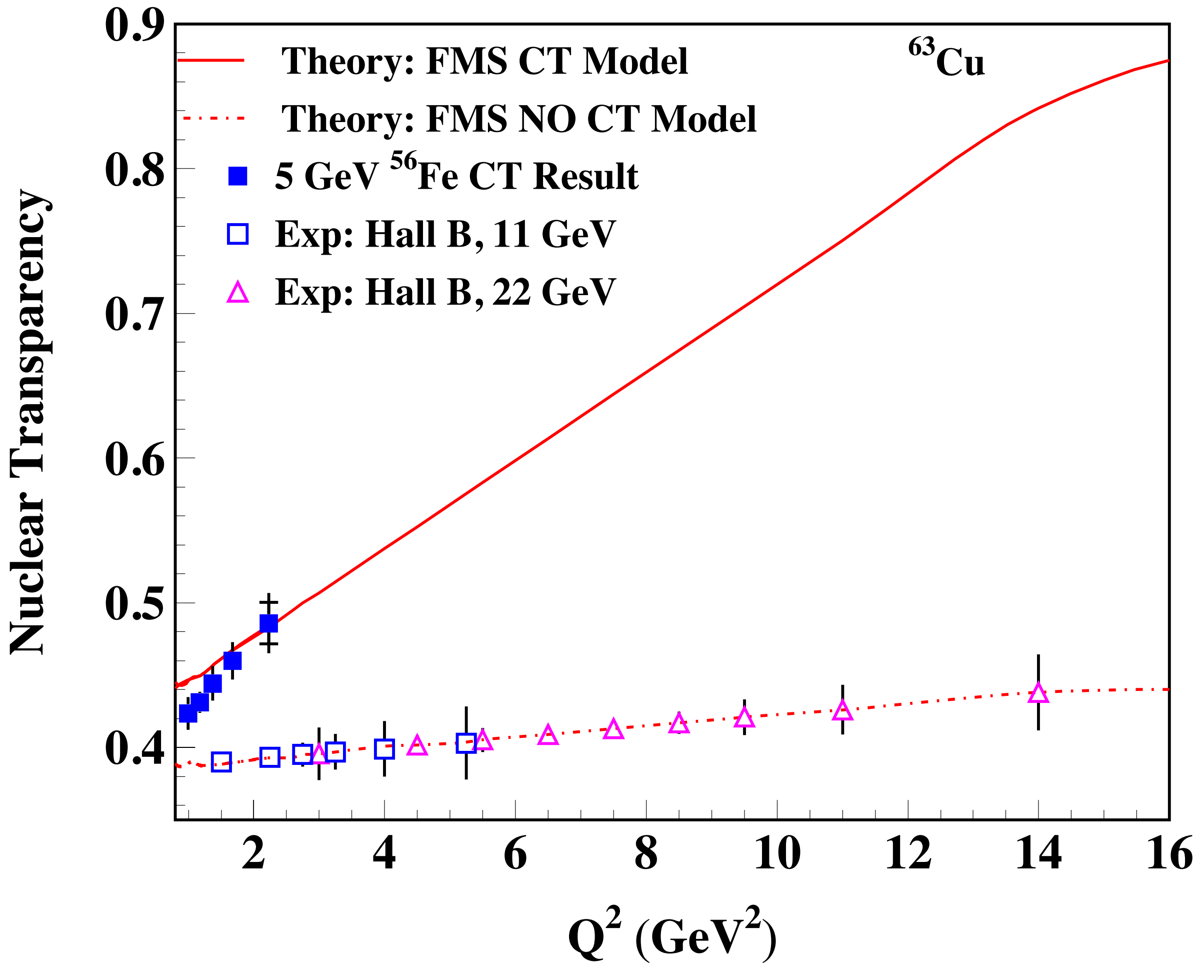


Beam hours on each target, 3% uncertainty

	9.5	11	12.5
H	1.5x2	7x2	13x2
D	1.5	7	13
C	2	9	16
Cu	7	37	66

200 hours beam on target:
E_b = 17.6 GeV
Q^2=9.5, 11, 12.5 GeV^2

22 GeV implications for the rho meson



Assumes same number of beam days at 11 and 22 GeV for comparison

Courtesy of L. El Fassi

Same kinematics strategy….higher beam energy in Hall C

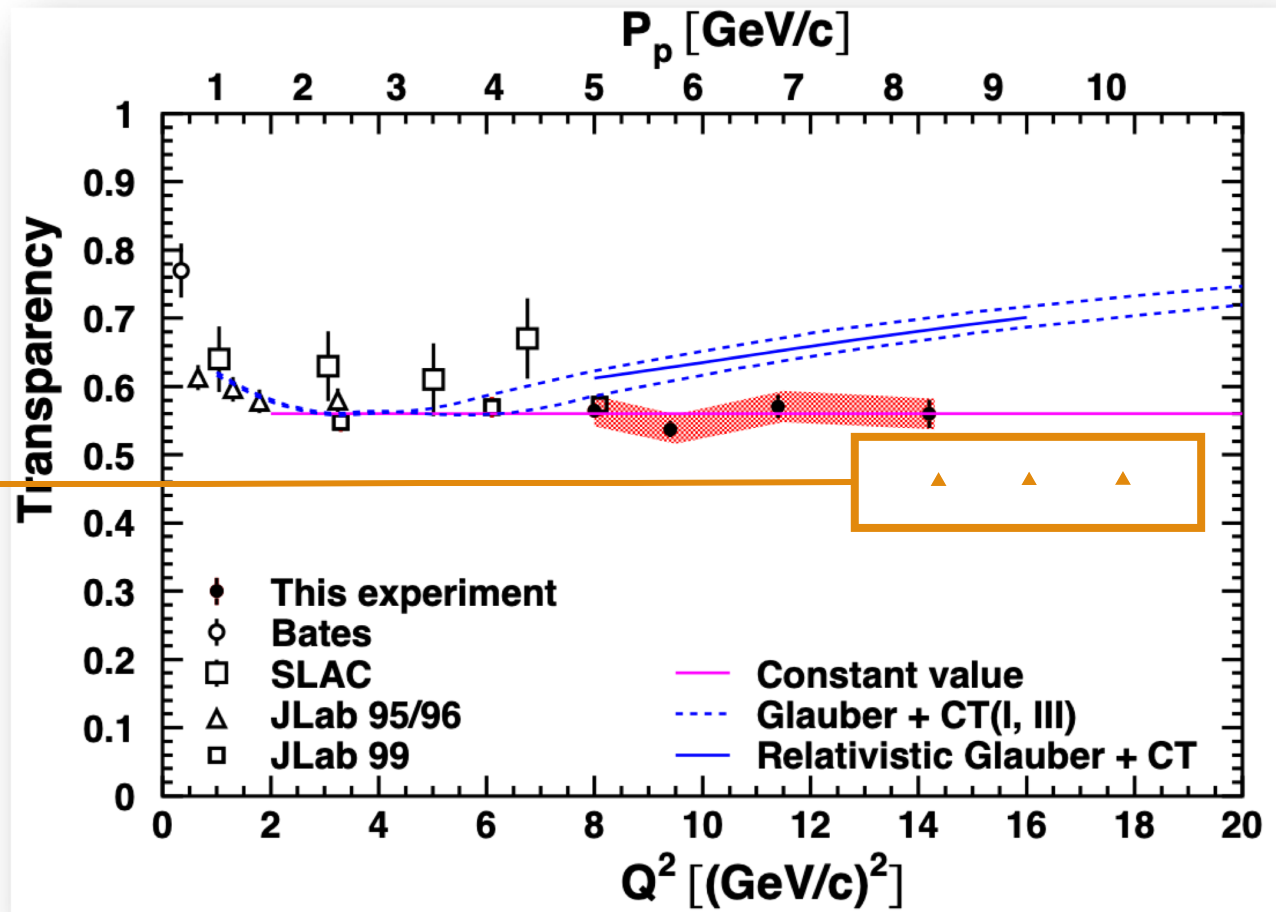
If we choose to climb in Q^2 (same strategy), we gain more in rates, limited by spectrometers

Increasing E_b =13 GeV: 14.2 GeV^2 gains x3 on rate

In <200 hrs beam on target, can get 2.2% stats on 14.2, 15.8, 17.4 GeV^2

Faster, not necessarily merits the E_b upgrade alone…. need to think about spectrometers!

A(e,e'p)



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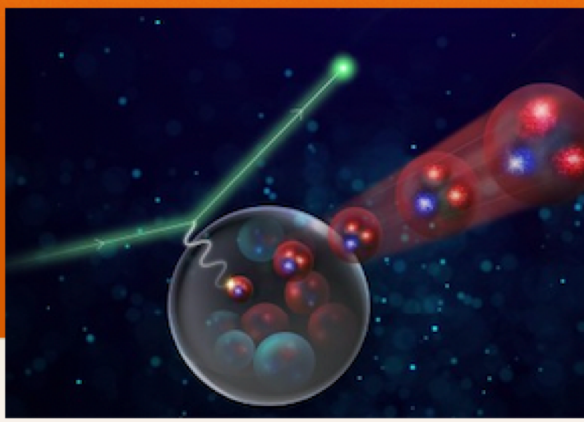
But what about the protons?!



The Future of Color Transparency and Hadronization Studies at Jefferson Lab and Beyond

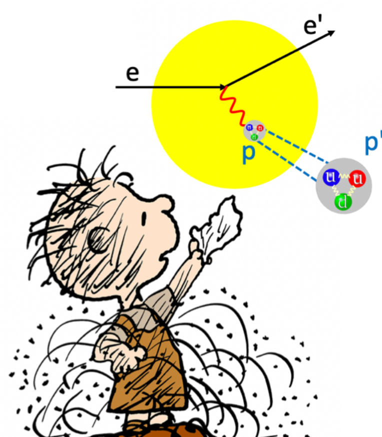
June 2021

101 participants, 22 talks, 6 discussion topics

https://indico.jlab.org/event/437

Key ideas emerged (implications for today's talk):

- Interpretations for the recent Hall C results
- Explore other experimental avenues

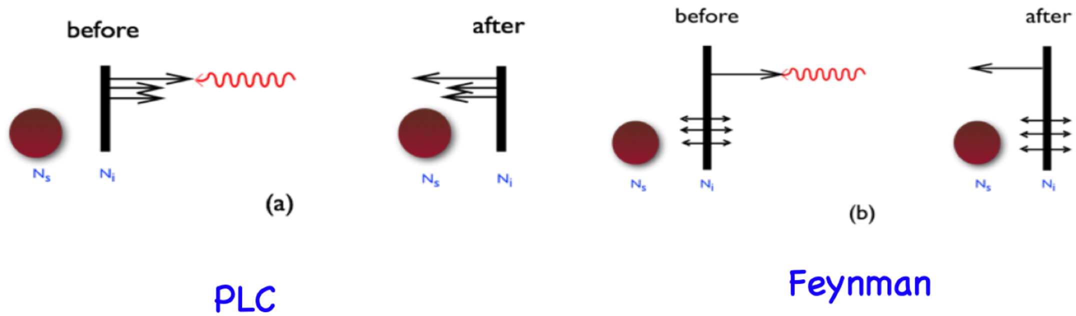


No observation of the onset of CT at Q^2<14 GeV^2/c^2

Explanations:

Illustration: M. Sargsian

- No PLC was formed
(Feynman Mechanism)

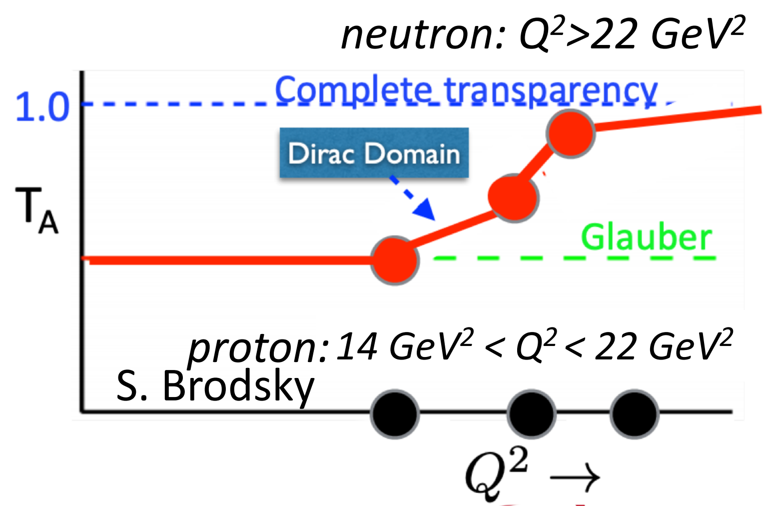


G. Miller, Physics 2022, 4(2), 590-596; https://doi.org/10.3390/physics4020039

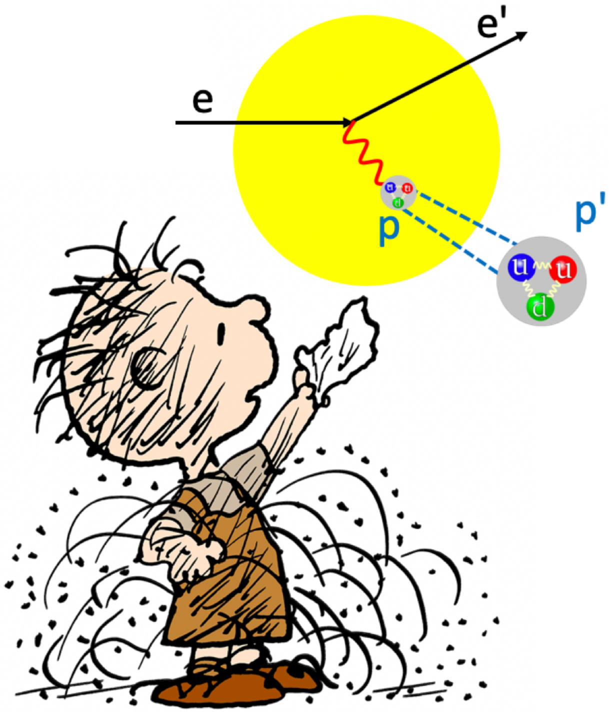
O. Caplow-Munro and G. Miller, PRC 104, L012201 (2021)

- Not high enough in Q^2
(Holographic light front QCD predictions)

S. Brodsky and G. de Téramond, Physics 2022, 4(2), 633-646; https://doi.org/10.3390/physics4020042



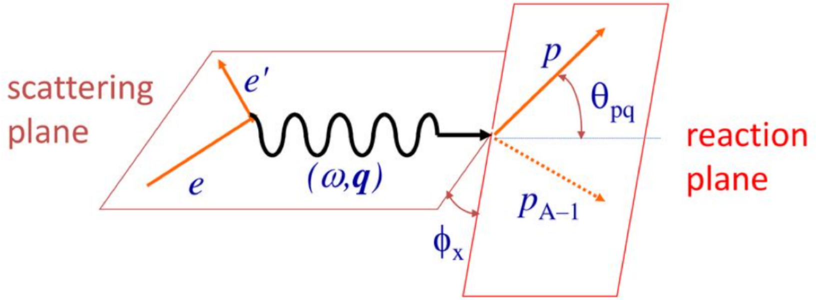
Embrace dirty kinematics!



Traditionally looked in regions with already reduced FSIs (parallel kinematics)

New approach to choose kinematics with large FSIs and compare with kinematics with low FSIs and map the Q^2 dependence

Parallel kinematics -> high rates, small FSI
proton initial momentum parallel to q-vector



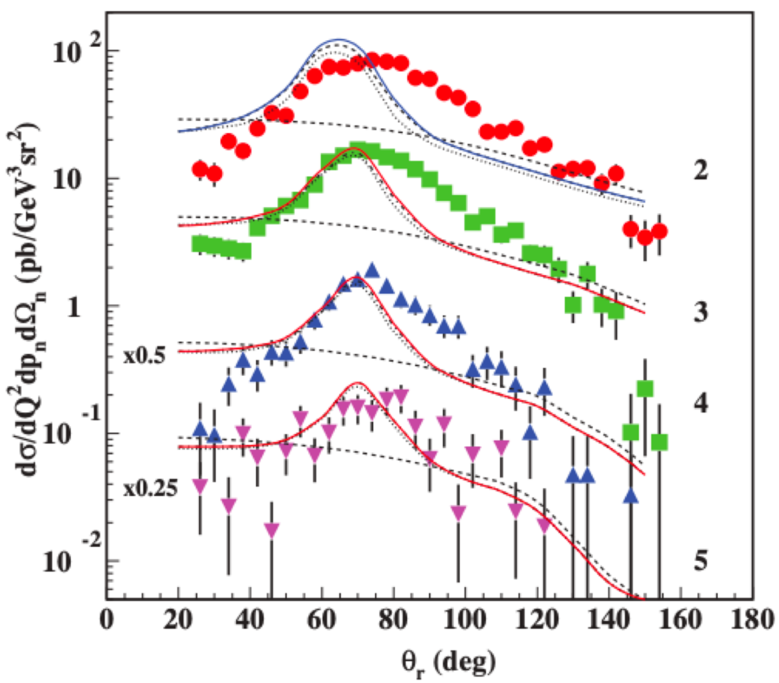
Deuterium and dirty kinematics

Deuteron has well known FSI contributions from double scattering

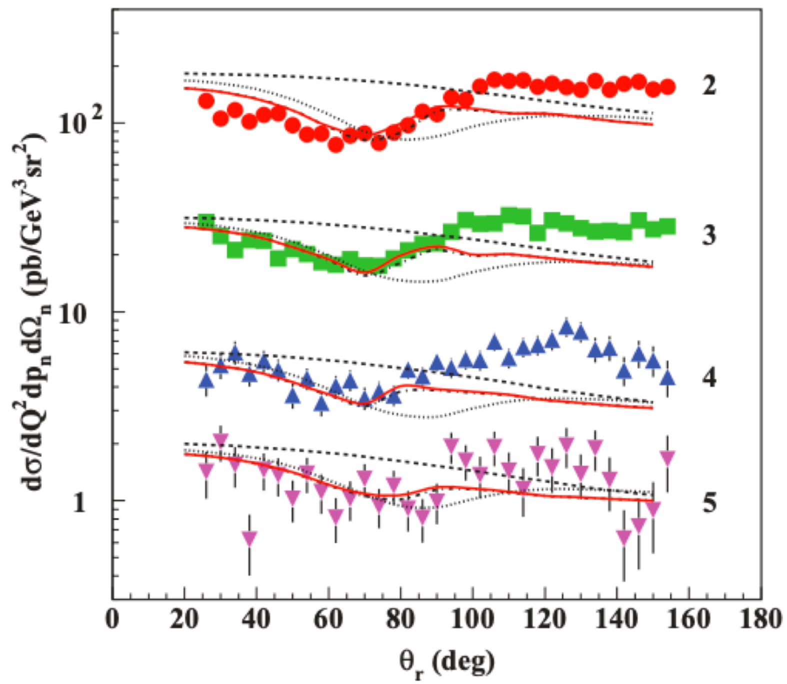
Double-scattering is the square of re-scattering amplitude of knocked out nucleon

Can construct the ratio, R = XS high FSI / XS low FSI – varied by P_r or angle

$400 < P_r < 600$ MeV



$200 < P_r < 300$ MeV



K. S. Egiyan et al., PRL 98:262502 (2007)

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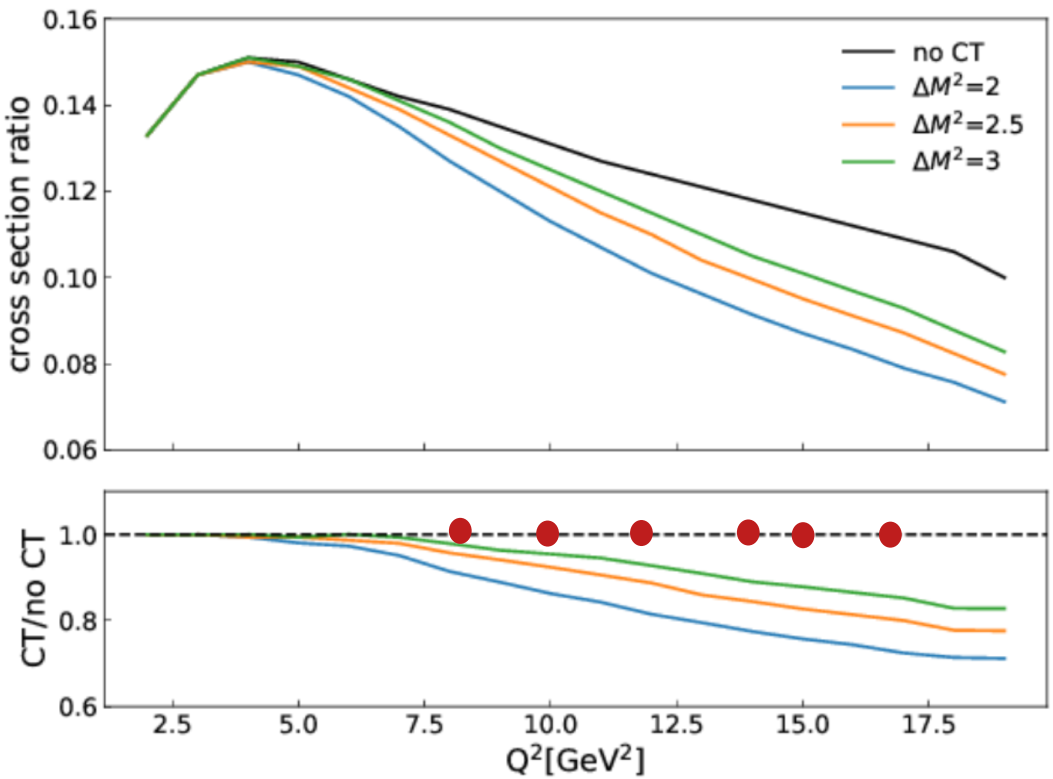
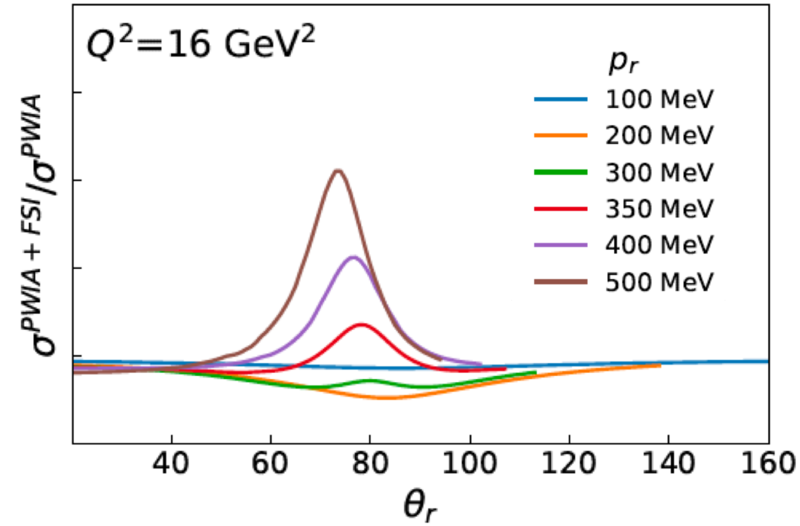
Deuterium and dirty kinematics

Kinematics limited by spectrometers

Well-described by GEA (more realistic at higher Q^2)

Data already at Q^2=3.5 an 4.5 GeV^2





LOI at PAC50 to measure at Q^2 = 8, 10, 12, 14, 15 GeV^2 with E_b=11 GeV, 3 months of beam on target at 3% stat uncertainty

Rates improve by x3 with increase to E_b=13 GeV but not much gain in Q^2 due to spectrometer limitations….could include point at 17 GeV^2 with 2 months beam on target

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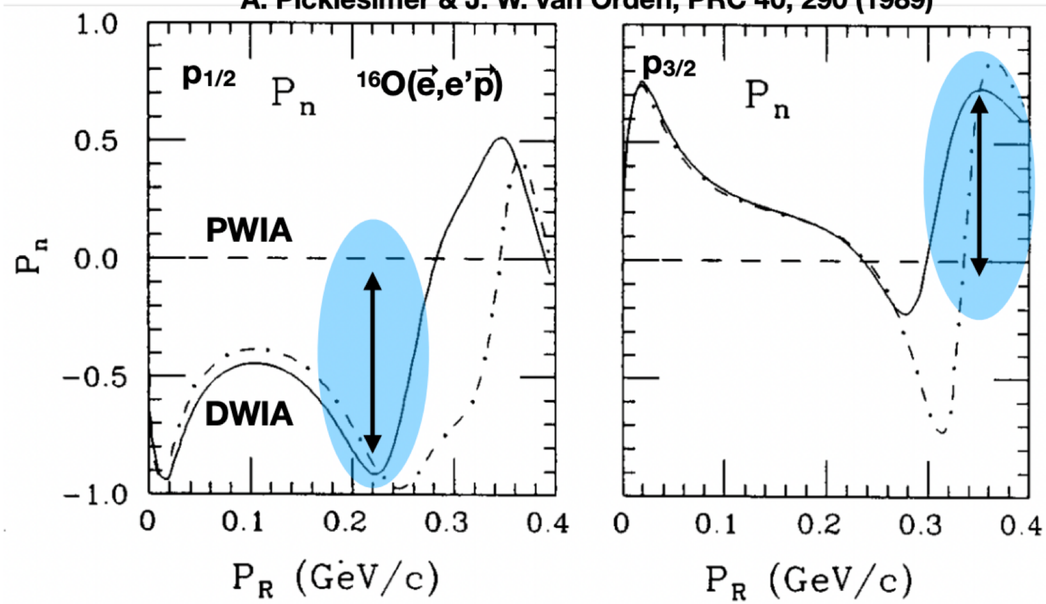
P_n (normal) component of recoil proton polarization in $A(\vec{e},e'\vec{p})$

P_n =0 in the absence of any nuclear medium effects (FSI filter)

A. Picklesimer & J. W. van Orden, PRC 40, 290 (1989)



In-plane kinematics: $\cos(\beta) = n\pi$

$$\frac{d^3\sigma}{d\omega d\Omega_e d\Omega_p} = \sigma_0[1 + P_n]$$

$$\sigma_0 = K[v_L R_L + v_T R_T + v_{TT} R_{TT} \cos 2\beta + v_{LT} R_{LT} \cos\beta]$$

$$P_n = \frac{K}{\sigma_0}[v_L R_L^n + v_T R_T^n + v_{TT} R_{TT}^n \cos 2\beta + v_{LT} R_{LT}^n \cos\beta]$$

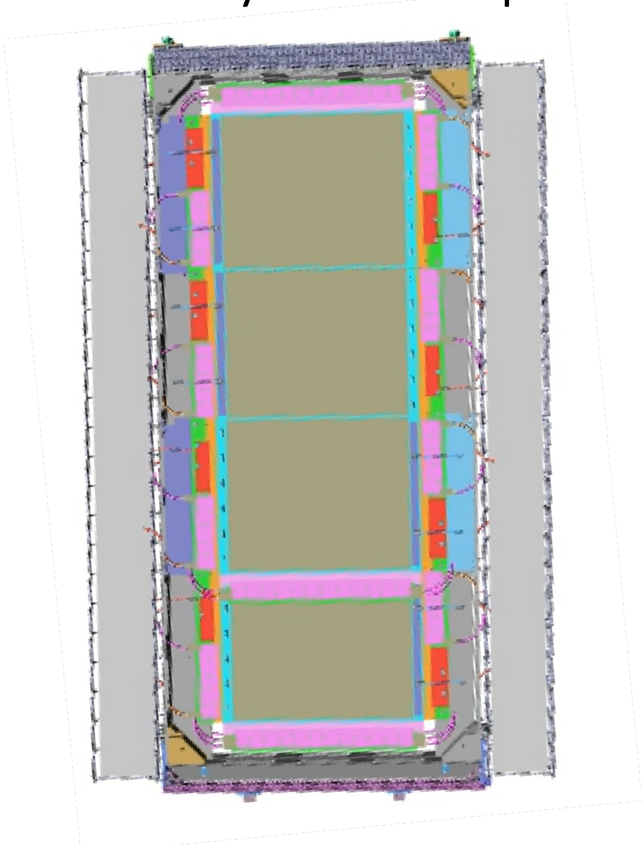
$$K = \frac{m|\vec{p}'|}{2(2\pi)^3}\left[\frac{d\sigma}{d\Omega_e}\right]_{Mott}$$

Dirty kinematics: large P_r

CT signature: $P_n \rightarrow 0$ with increasing Q^2

Pn (normal) component of polarization transfer

- Construct double focal plane polarimeter for SHMS to measure P_n for ^2H, ^{12}C, ^{63}Cu
- p(e,e'p) for self-calibration (analyzing power, A_c) and false asymmetry
- Already measured proton form factors



Statistical uncertainty:

$$\Delta P_n = \frac{\pi}{2}(N_0\epsilon)^{-1/2}$$

Where $\epsilon = A_c^2 f$

And f is the useful fraction of events in the FPP acceptance

Using ϵ=0.003 and 13 GeV beam,
scan Q^2 and targets:
2-10 GeV^2 (ΔP_n<0.1) = 200 hrs

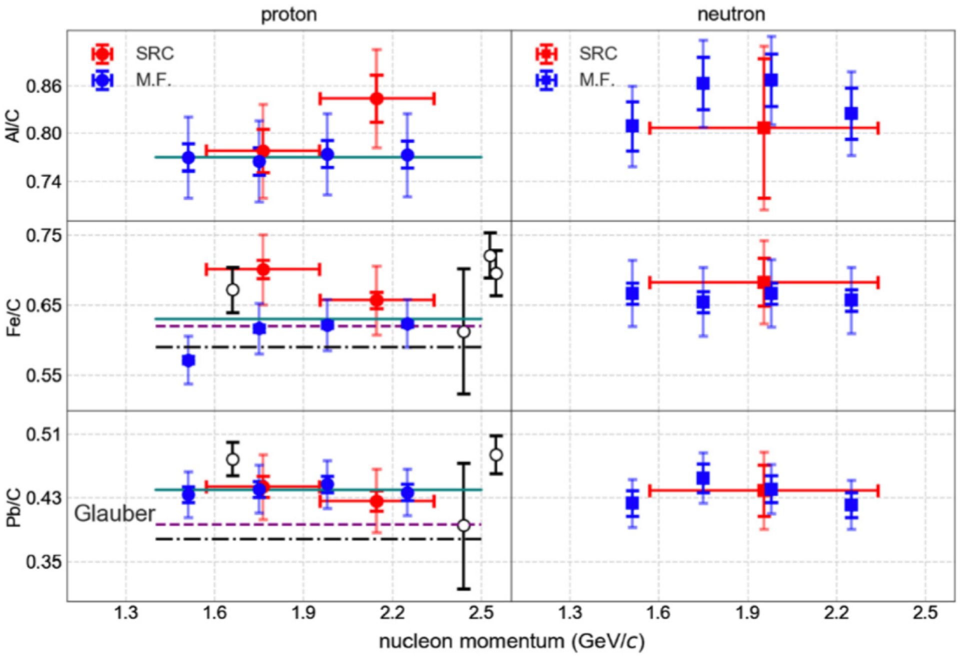
A. Saha et al., PR 91-006, Hall A proposal.
B. Anklin H. et al., The ELFE Project, Conference Proceedings, Vol. 44, p.223 (1993)

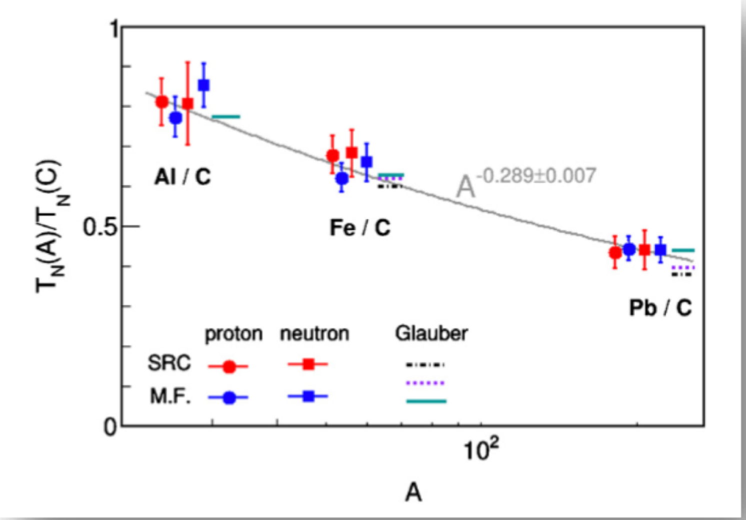
SRC breakup and target ratios

With E_b upgrade:

- Extend nucleon momentum and Q^2
- Explore A-dependence
- A(e,e'pN)/A(e,e'p)?
- Proton vs neutron T

A(e,e'p) A(e,e'n)





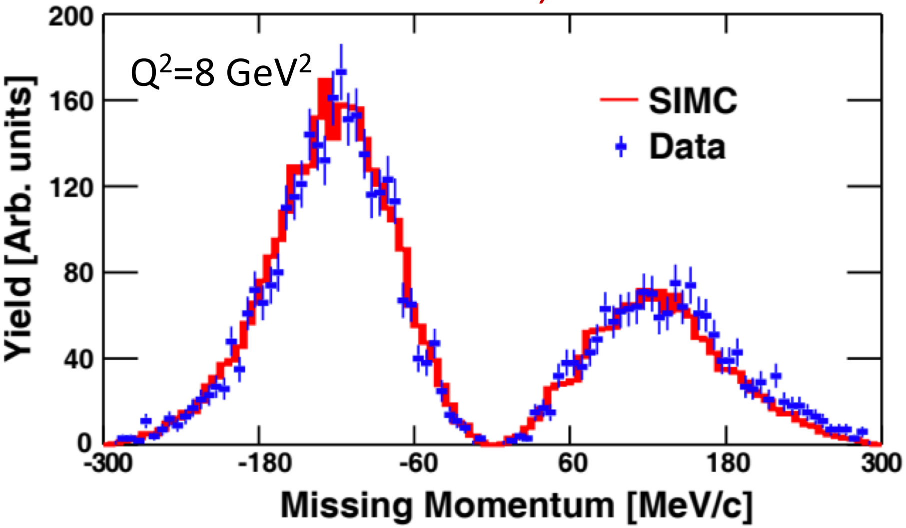
M. Duer et al., PLB 797:134792 (2019)
O. Hen et al, PLB 722:63 (2013)

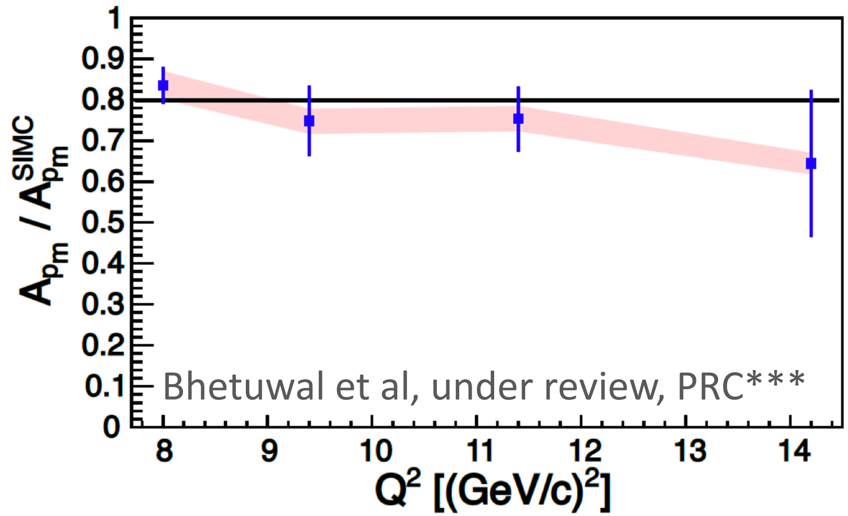
Left-right asymmetry in A(e,e'p) in perpendicular kinematics

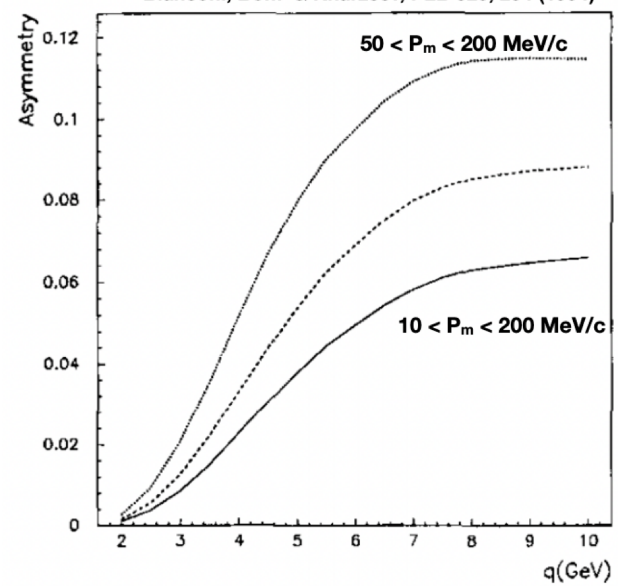
Bianconi, Boffi & Kharzeev, PLB 325, 294 (1994)

L-R Asymmetry is very sensitive to FSI at large P_{miss}, away from parallel kinematics ($|\theta_{pq}| > 0$)

L-R asymmetry in parallel kinematics, Hall C







Extend Q^2 coverage with upgraded E_b (limited by spectrometers)

***Under review with PRC, https://doi.org/10.48550/arXiv.2205.13495

Summary

- CT onset not observed in protons in parallel kinematics (small FSI). Higher beam energy can explore slightly higher Q^2.

- Observations in mesons consistent with CT. Higher beam energies access higher Q^2 with improved rates.

- Numerous avenues to explore onset of CT in proton with high FSIs and non-traditional kinematics – higher beam energy improves rates and could extend Q^2 access

- Hall C would further benefit from at least 1 spectrometer upgrade to access higher Q^2 kinematics