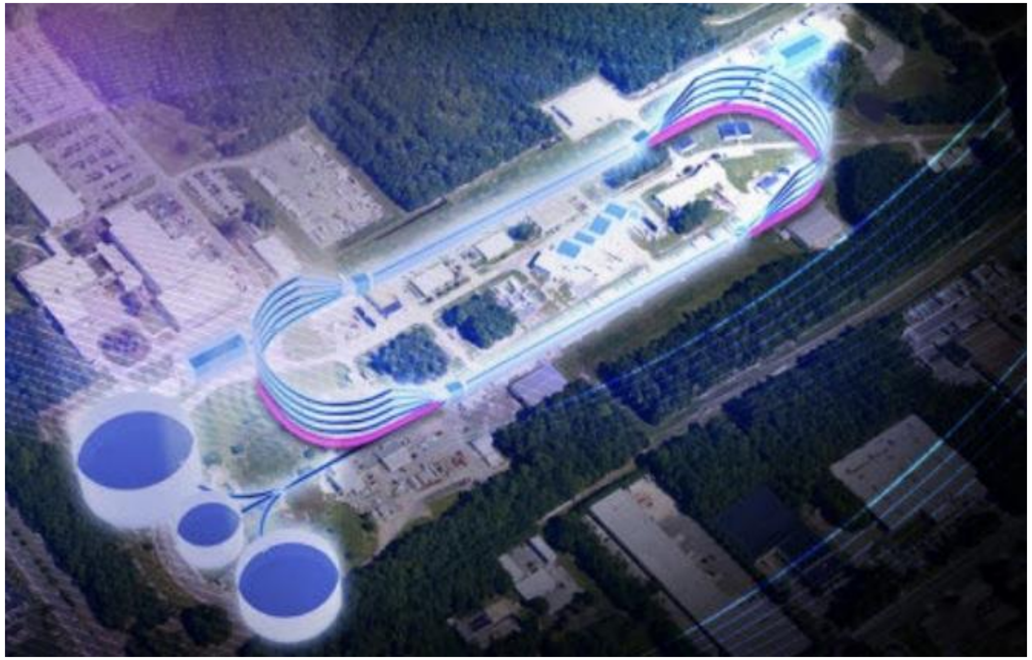
Color Transparency effects at 22 GeV

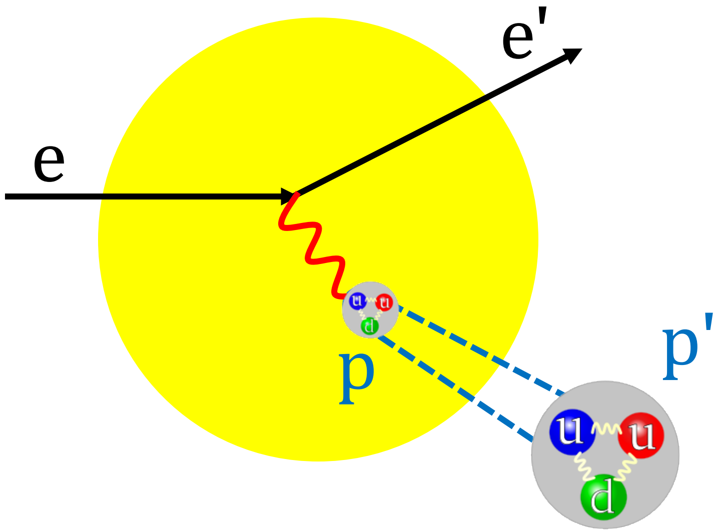


Science at the Luminosity Fronter: Jefferson Lab at 22 GeV
INFN Frascati-LNF
December 12, 2024

Holly Szumila-Vance (FIU)
Dipangkar Dutta (MSU)
Lamiaa El Fassi (MSU)

Color transparency is a fundamental prediction of pQCD

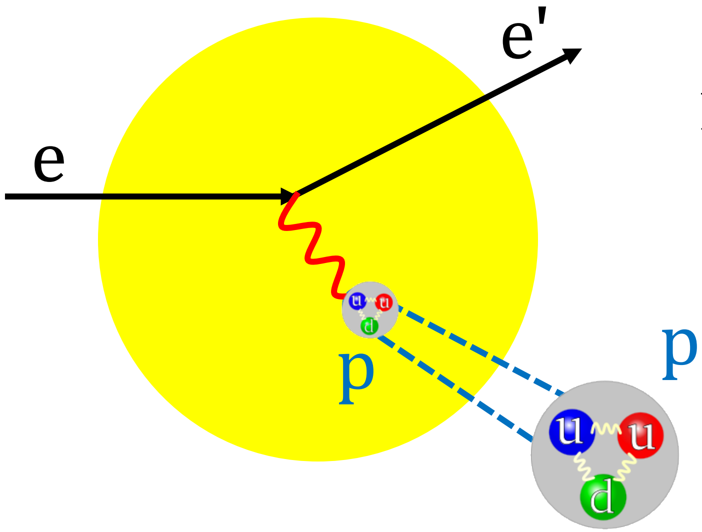
Introduced by
Mueller and Brodsky, 1982



Vanishing of final state interactions of hadrons with nuclear medium in exclusive processes at high momentum transfer

Color transparency is a fundamental prediction of pQCD

Quantum mechanics:
Shorter wavelength photons are absorbed on smaller-size hadrons (*squeezing*)



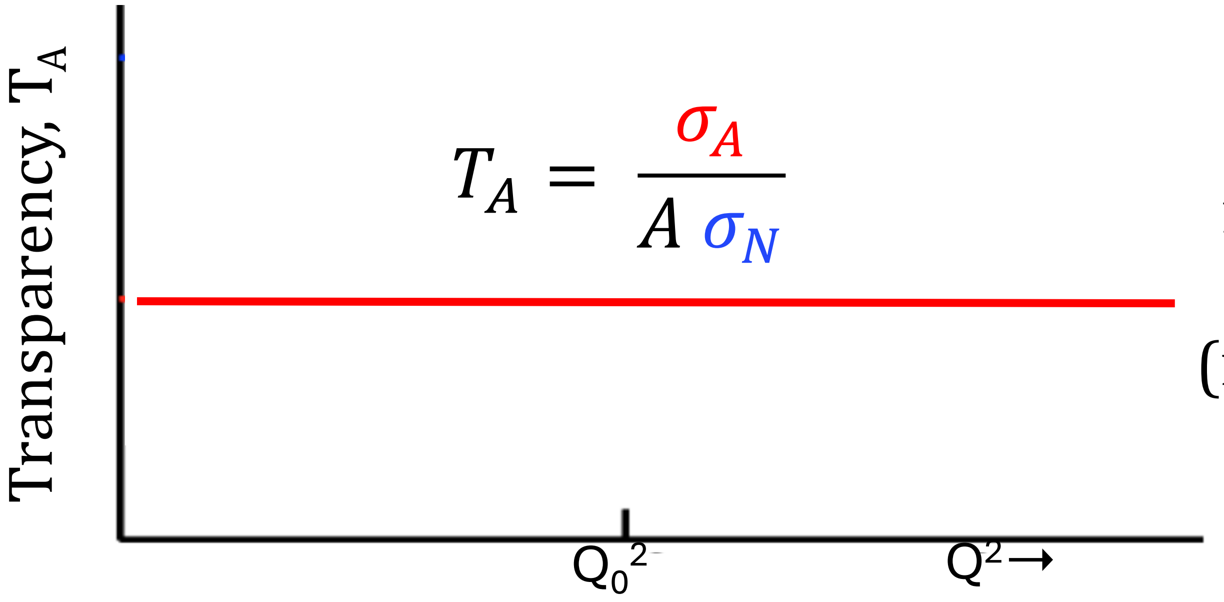
Relativity:
Maintains this small size as it propagates out of the nucleus (*freezing*)

$$\gamma t_l = \frac{E}{m} t_l$$

Strong force:
Experience reduced attenuation in the nucleus, color screened

$$\sigma_{PLC} \approx \sigma_{hN} \frac{b^2}{R_h^2}$$

Transparency is the probability that the struck hadron emerges from the nucleus without being deflected or absorbed



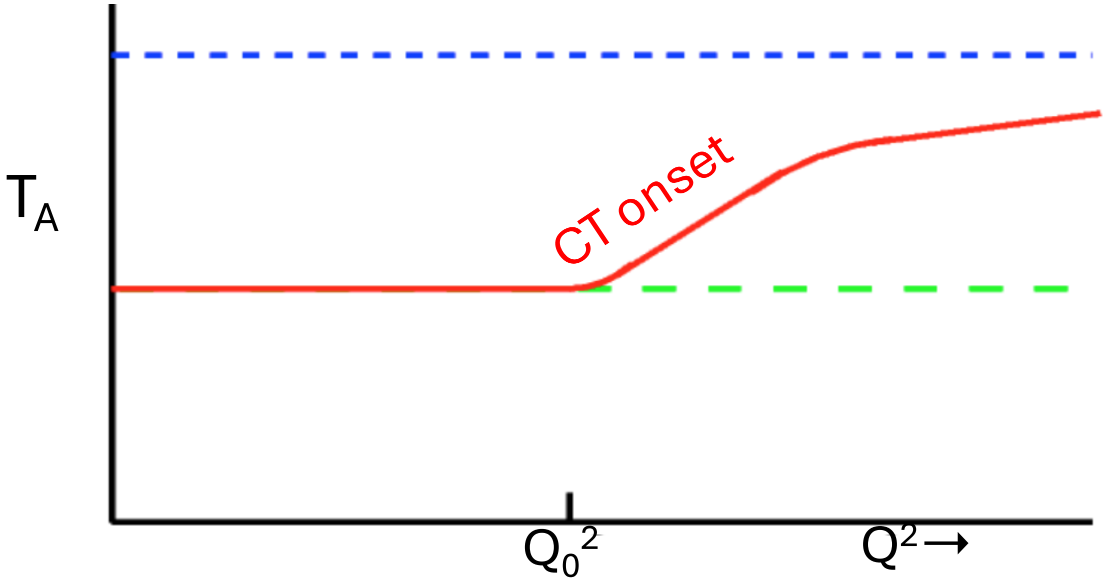
Transparency should be momentum independent

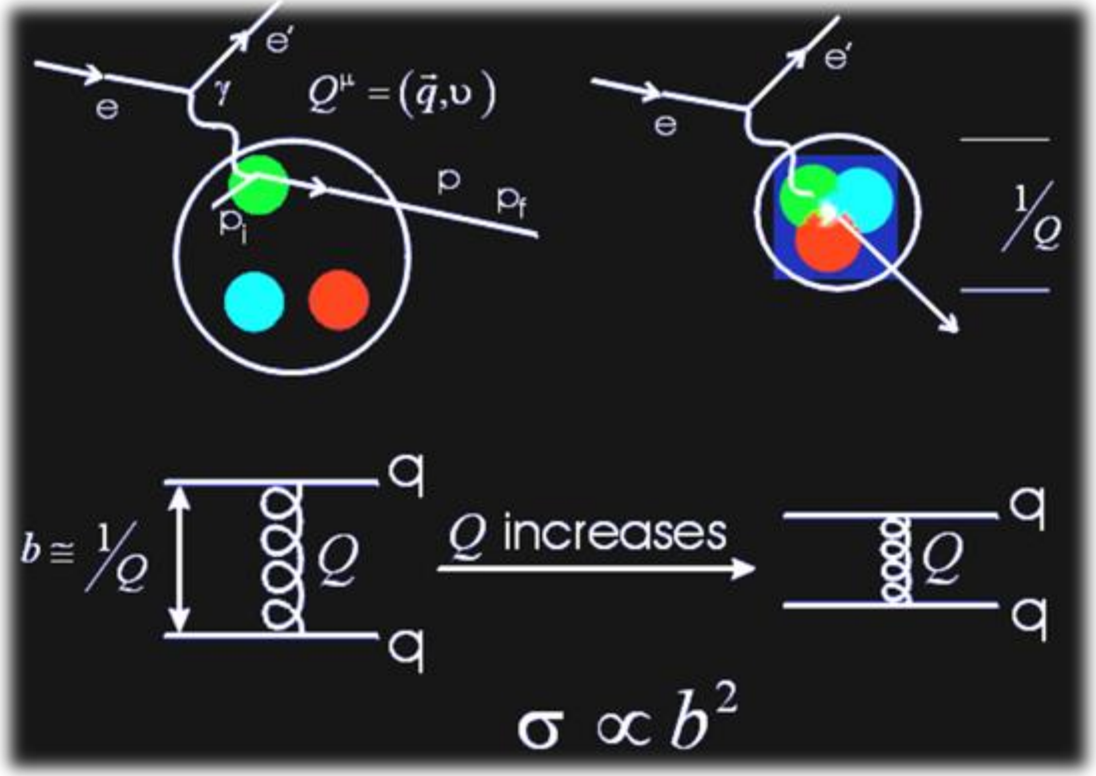
(in the strongly interacting hadronic picture)

- scattering cross section
- Glauber multiple scattering
- NN Correlations and Final State Interaction (FSI) effects

Onset of CT indicates the transition to quark-gluon degrees of freedom

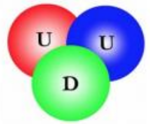
Onset of CT indicates where quark-gluon degrees of freedom become relevant





CT experiments

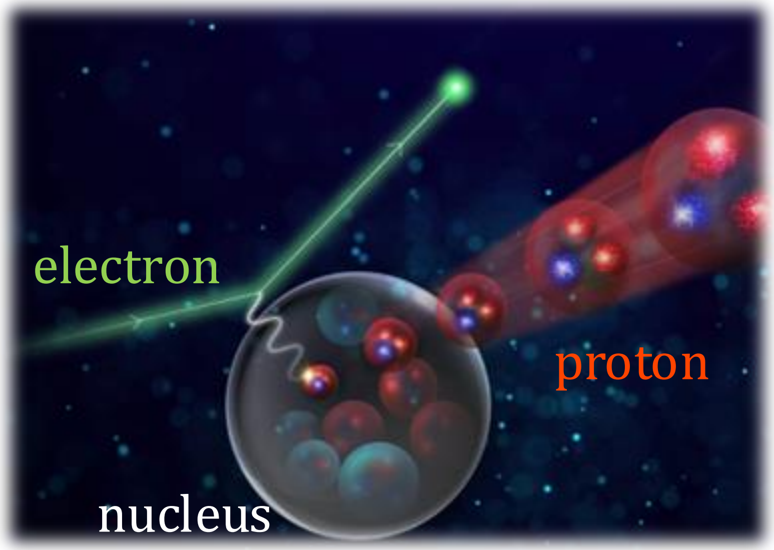
Baryon

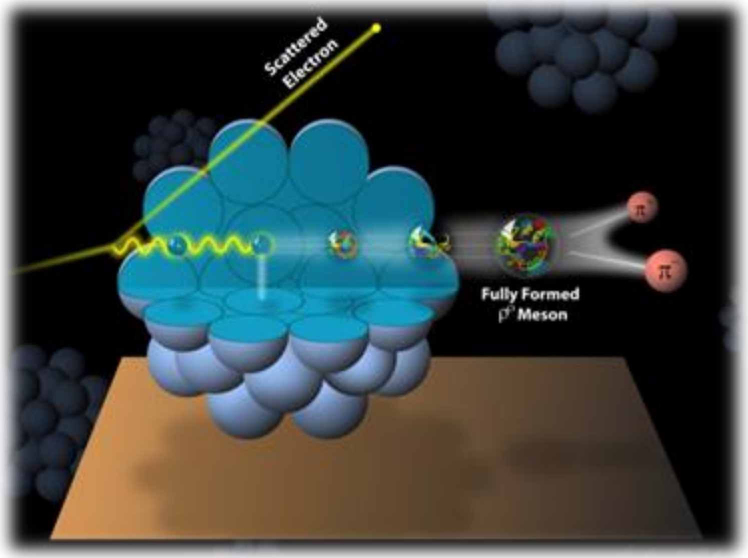


A(p,2p): BNL
A(e,e'p): SLAC, JLab

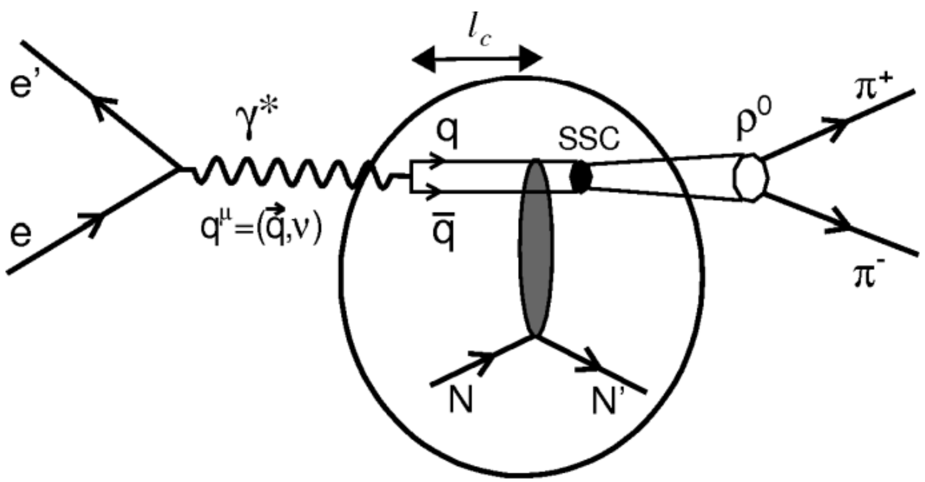
Meson

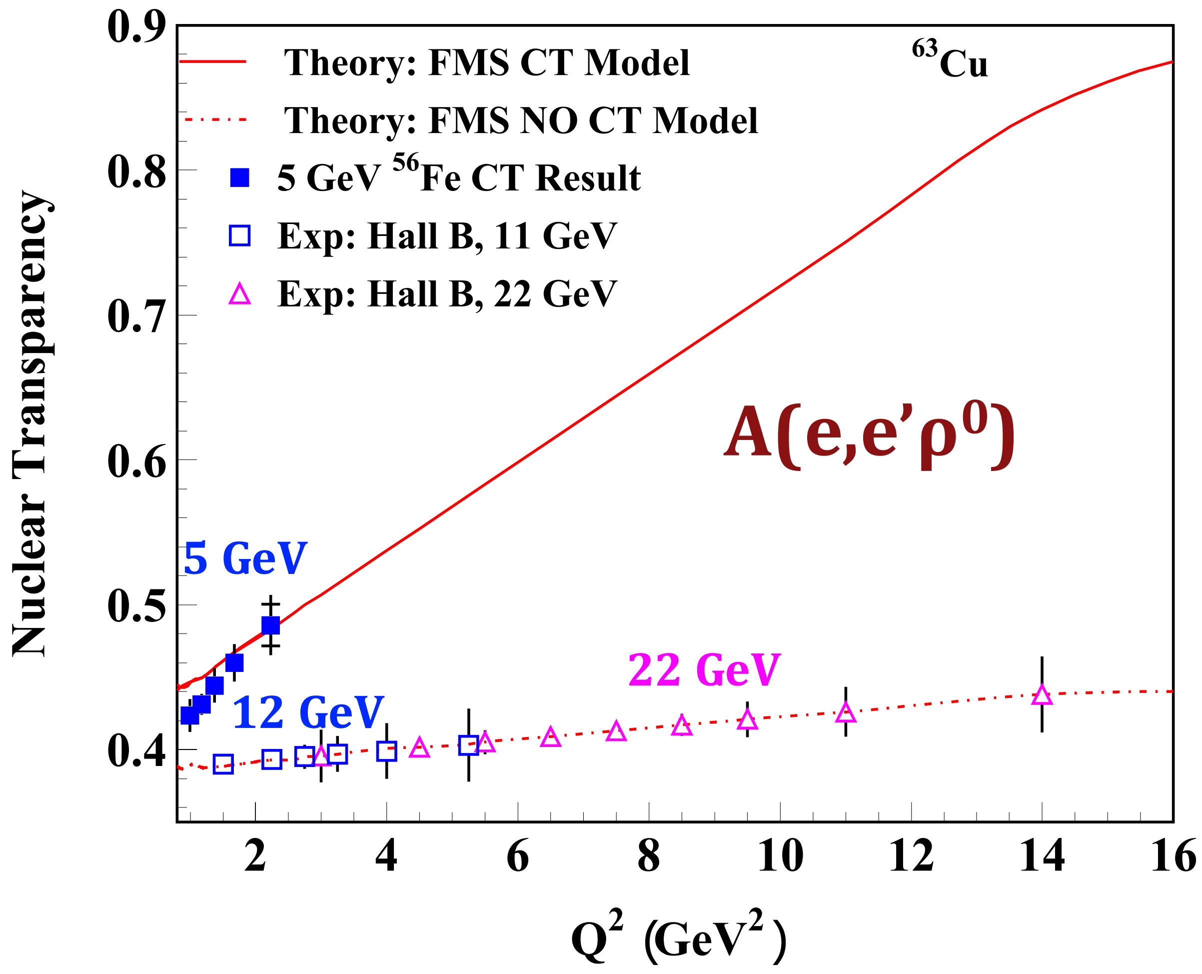
A(π,di-jet): FNAL
A(γ, π^- p): JLab
A(e, e'π^+): JLab
A(e, e'ρ^0): DESY & JLab





Extend measurements on ρ^0 in Hall B





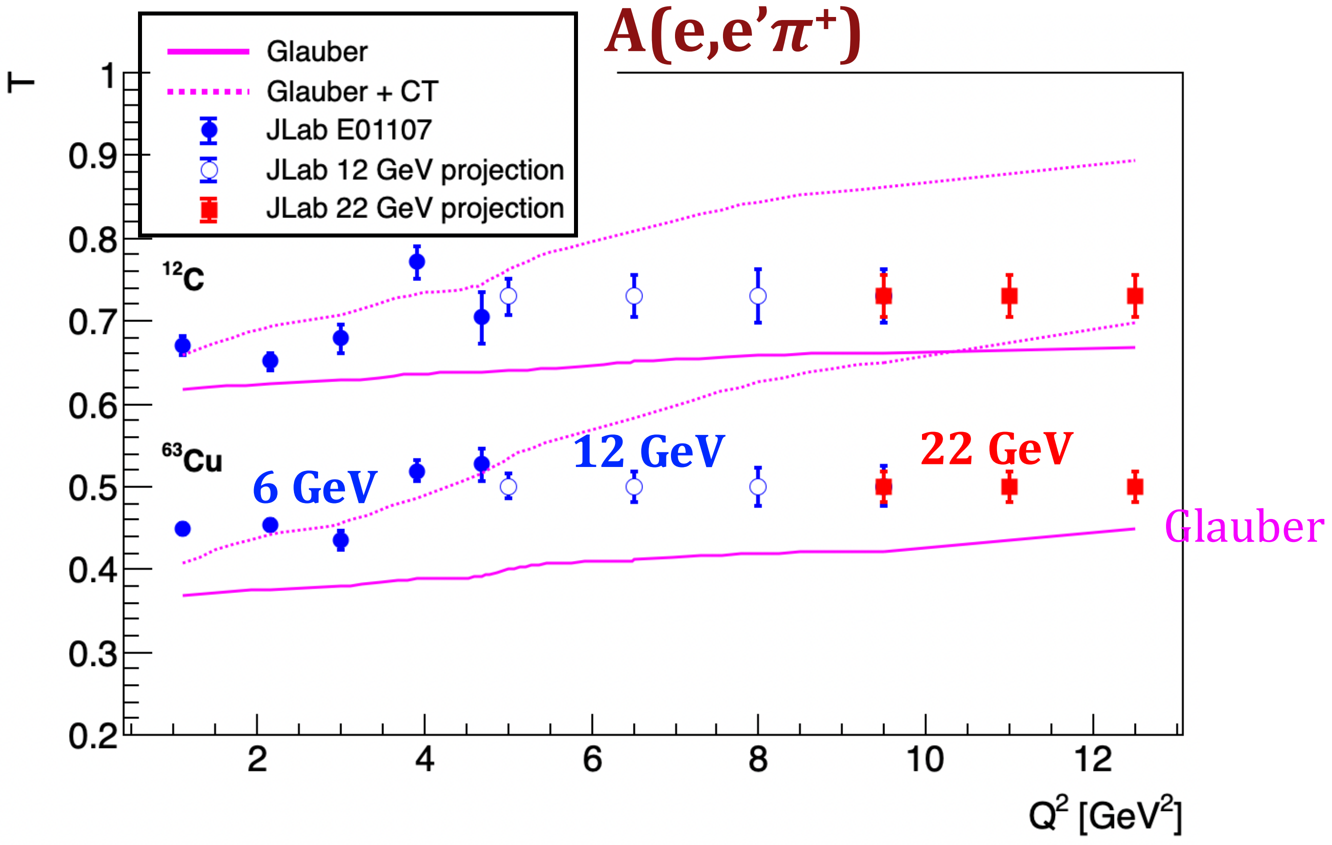
Assumes same number of beam days at 11 and 22 GeV for comparison

Extend measurements on π^+ in Hall C

- 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 $P_{central}$

200 beam hours total, E_b = 17.6 GeV
Beam hours on each target, 3% uncertainty

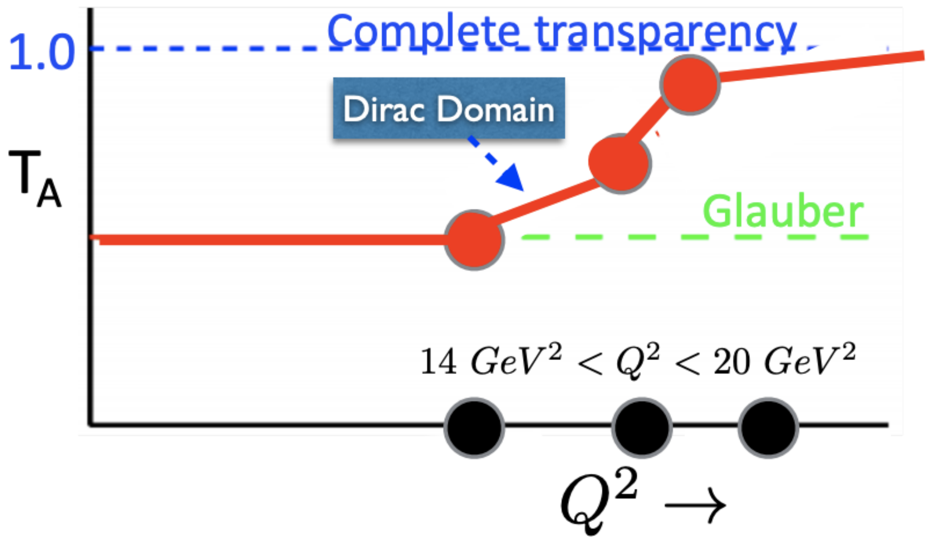
	9.5	11	12.5
H	1.5x2	7x2	13x2
D	1.5	7	13
C	2	9	16
Cu	7	37	66



~Could further confirm meson CT with J/ψ at 22 GeV~

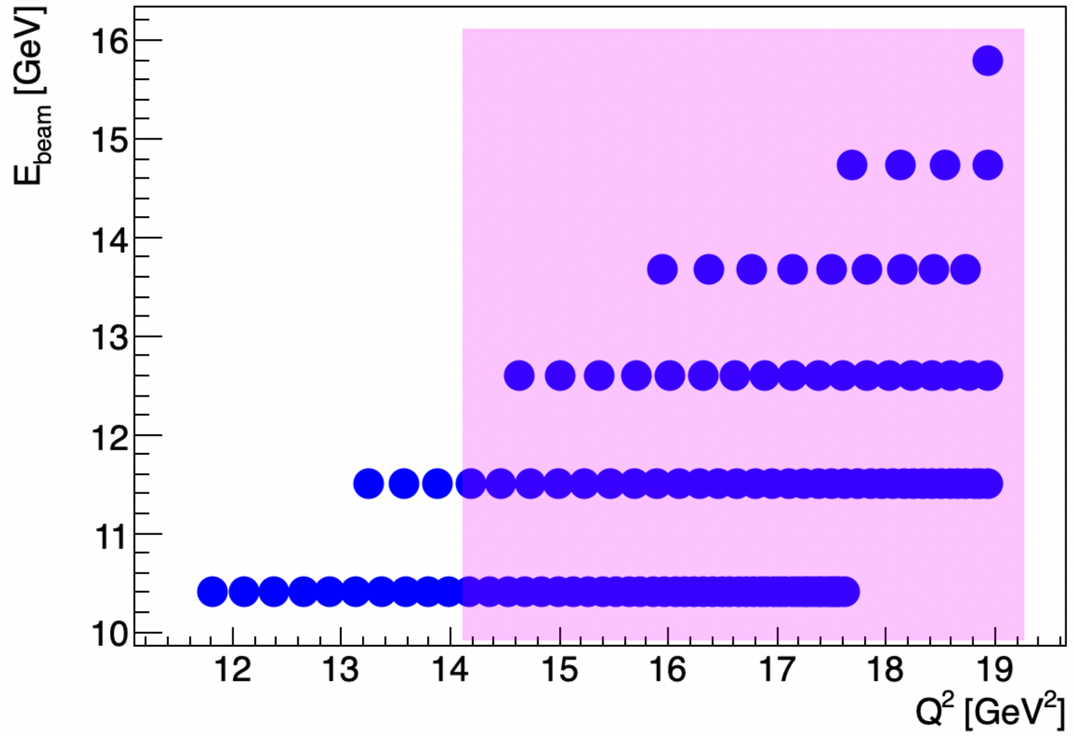
Extending the proton measurements in Hall C: Parallel kinematics, access higher Q^2

Previous attempt at 12 GeV did not observe CT in protons.
HLFQCD predicts we will see it at higher Q^2.



Brodsky and de Téramond, Physics 2022

Kinematics possible in current Hall C spectrometers



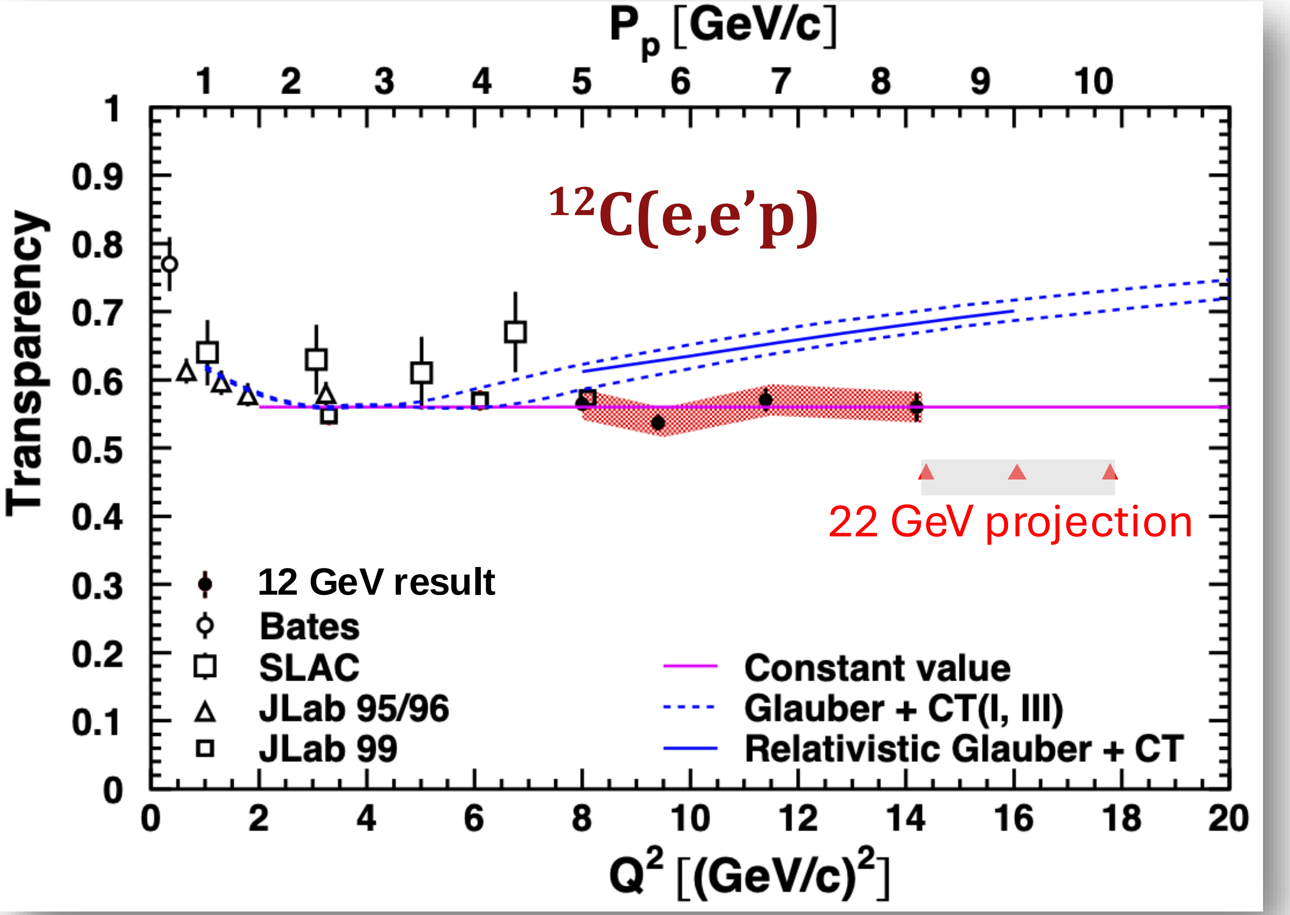
Region of interest at high Q^2

Extending the proton measurements in Hall C: Parallel kinematics, access higher Q^2

$\vec{p}||\vec{q}$

Increasing E_b =13 GeV:

- 14.2 GeV^2 gains x3 on rate compared to previous 10.6 GeV beam
- ~180 hrs beam on target, can get 2.2% stats on 14.2, 15.8, 17.4 GeV^2

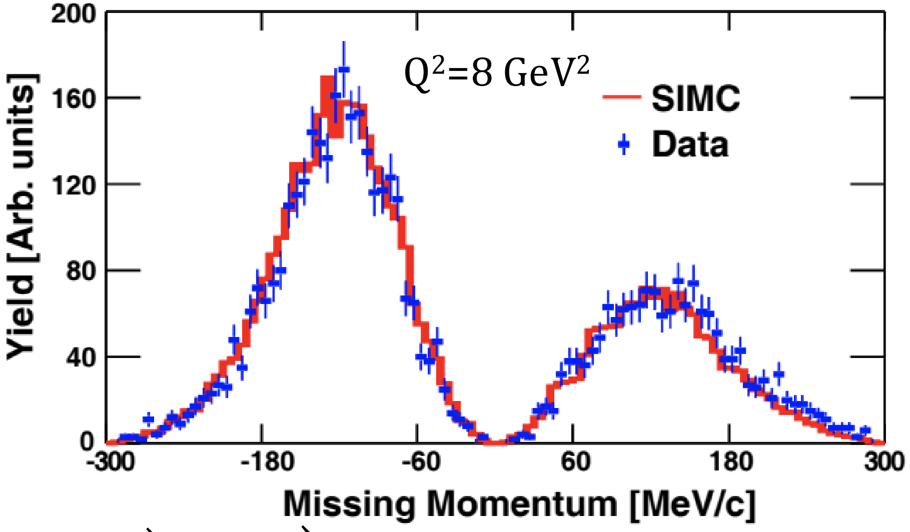


Left-right asymmetry in A(e,e'p) in perpendicular kinematics

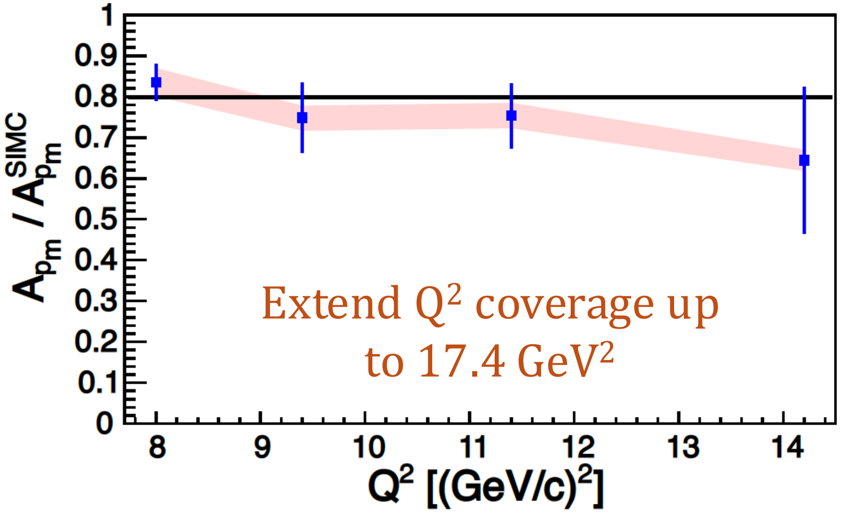
Bianconi, Boffi & Kharzeev, PLB 325, 294 (1994)

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

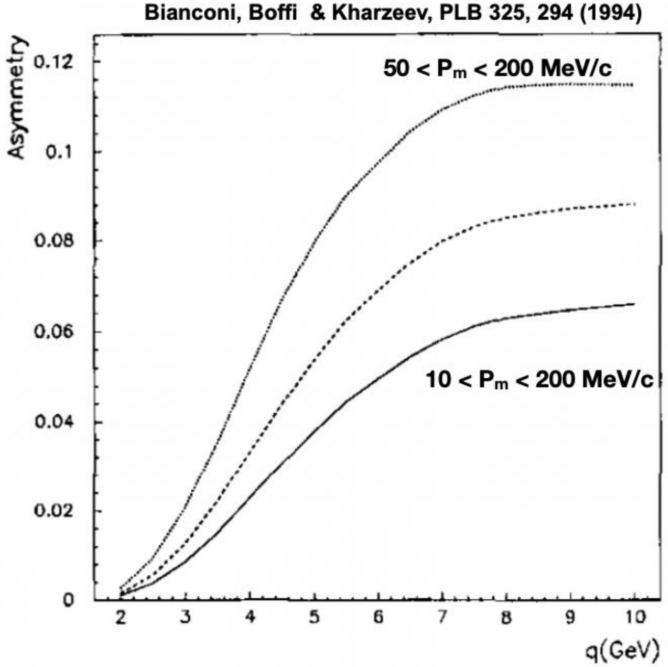
L-R asymmetry in parallel kinematics, Hall C



$\vec{p}_m \parallel \vec{q}$ $\vec{p}_m \parallel -\vec{q}$



$$A_{pm} = \frac{N_+ - N_-}{N_+ + N_-}$$



Jennings and Kopeliovich PRL 70 (1993)

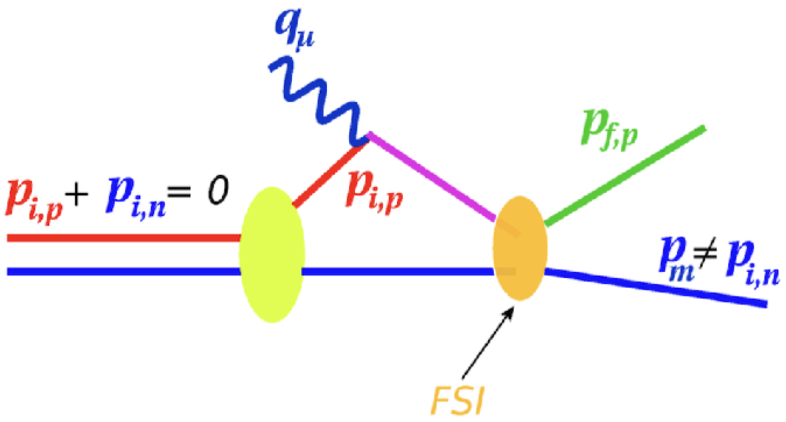
CT arising from Fermi motion predicted to occur when $\vec{p}_m \parallel -\vec{q}$

D. Bhetuwal, et al, Phys. Rev. C **108**, 025203 (2023)

Extending proton measurements in Hall C: New (high FSI) kinematics, access higher Q^2

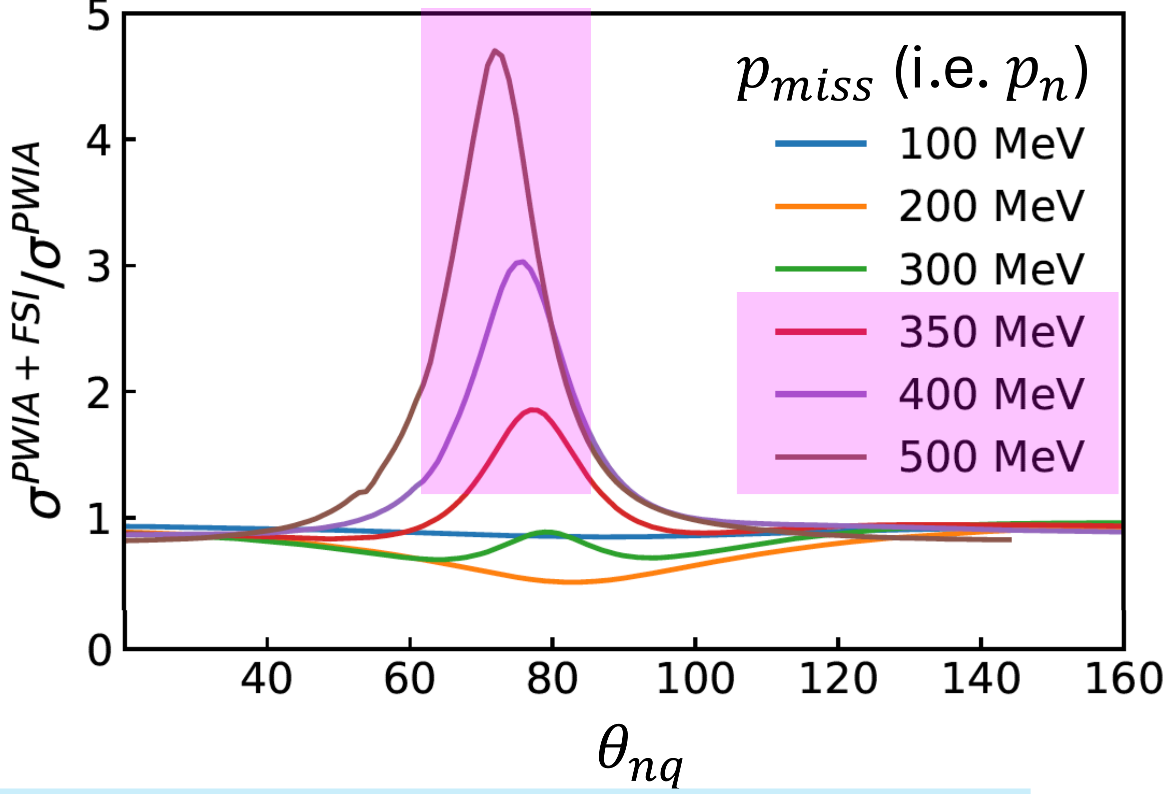
Deuterium is well-described through Generalized Eikonal Approximation (GEA)

Measure d(e,e'p)n



Final State Interactions (FSI)

High FSI from rescattering

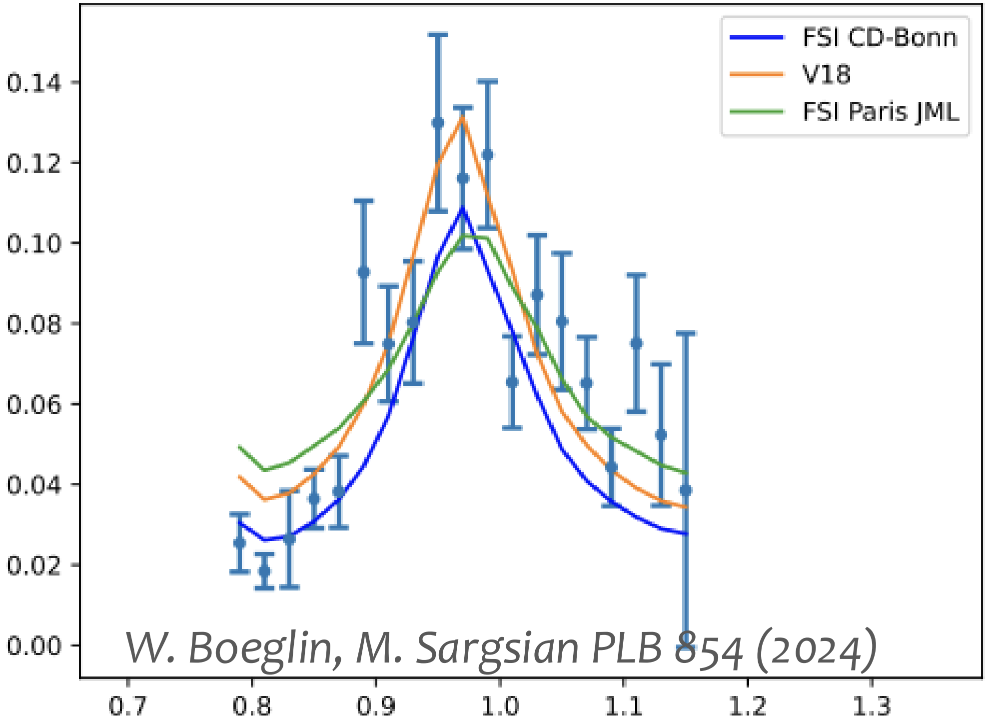


Larger spectator momentum →
smaller distances between the production and rescattering vertices

Extending proton measurements in Hall C: New (high FSI) kinematics, access higher Q^2

Measure protons from re-scattering, look for **decrease** with increasing Q^2

$Q^2 = 3.5\ (\mathrm{GeV/c})^2$

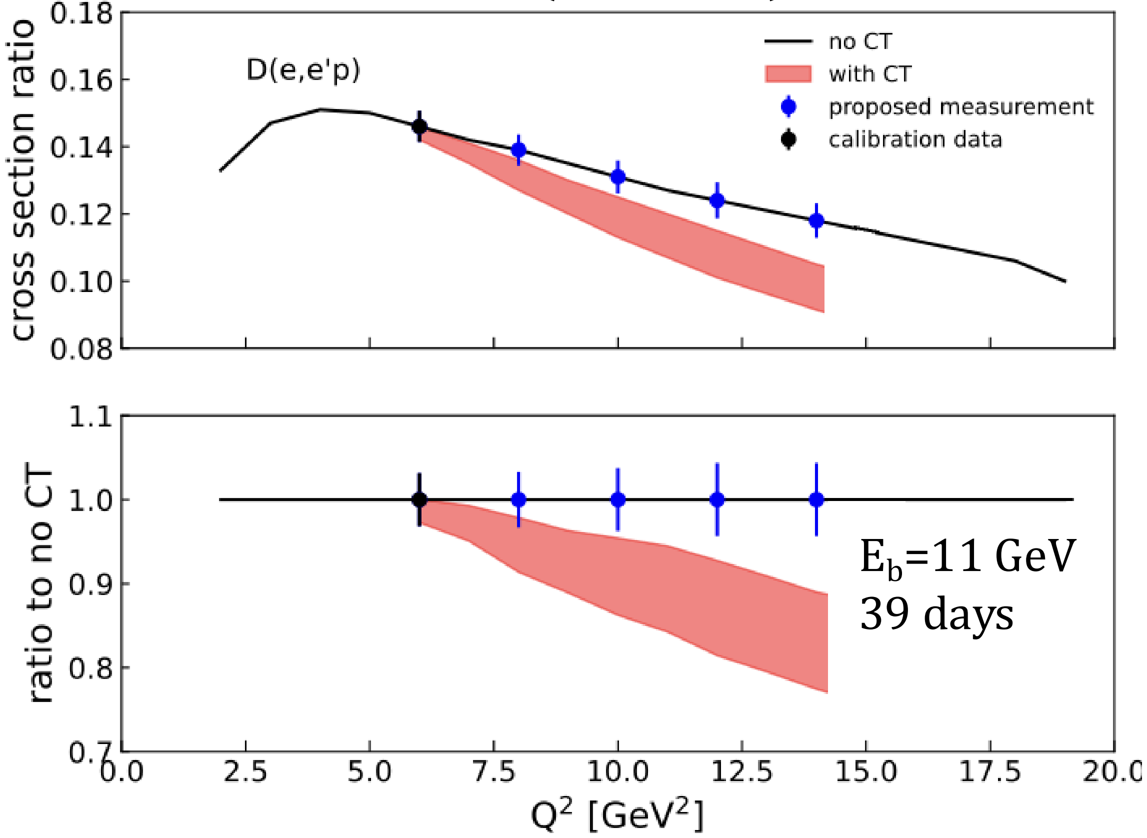


$$R = \frac{\sigma_{red}(p_m = 0.41\ GeV)}{\sigma_{red}(p_m = 0.21\ GeV)}$$

α

$$\alpha = (E_n - p_n cos\theta_{\gamma n})/m_n$$

$$\downarrow R = \frac{\sigma(high\ Pm)\downarrow}{\sigma(low\ Pm)\uparrow}$$



Approved 12 GeV experiment

Extending proton measurements in Hall C: New (high FSI) kinematics, access higher Q^2

With 13 GeV beam, approved experiment is ~14 days

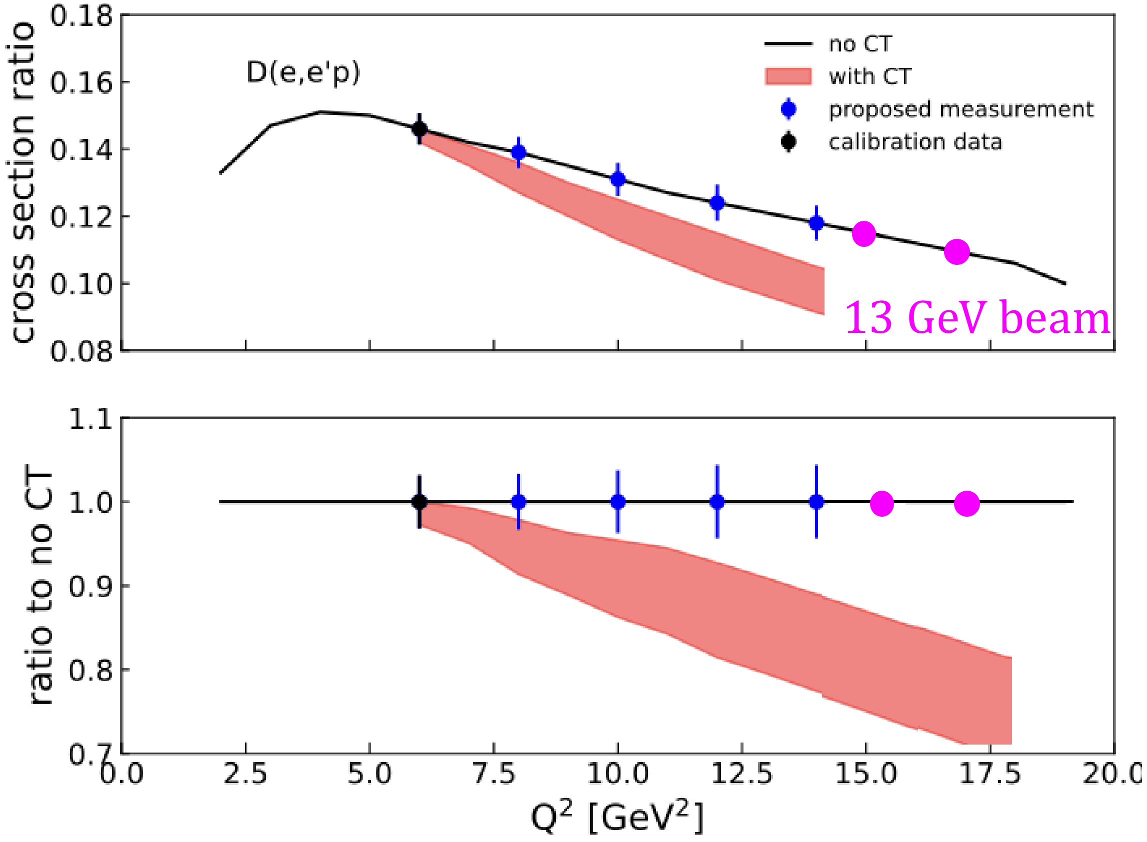
Farrar et al., PRL (1988)

Higher Q^2 important to increase sensitivity to larger ΔM^2

Larger ΔM^2 → $l_h = 2p_h/\Delta M^2$ shorter PLC lifetime → delays CT onset

Larger ΔM^2 consistent with lack of observation of weakly interacting quark-gluon plasma

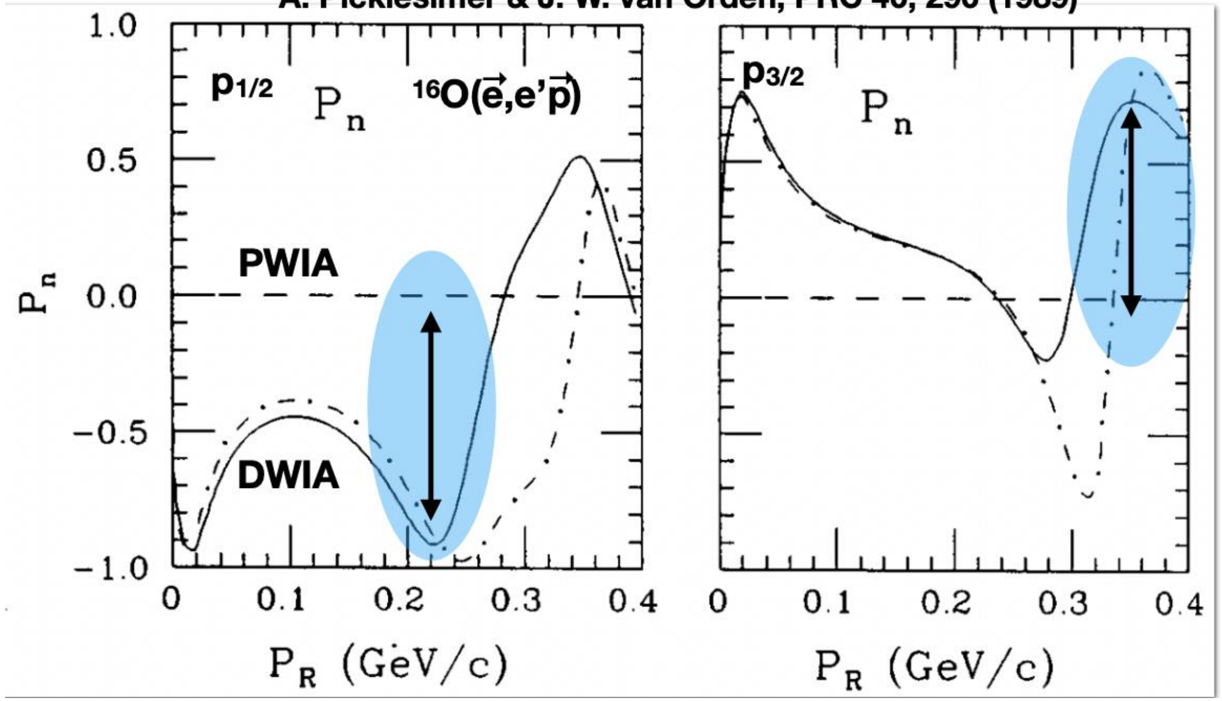
Add two new Q^2 points at 15 and 17 GeV^2 with 3% uncertainty (19 days and 2 months, respectively)



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)



Dirty kinematics: large P_r

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

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

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

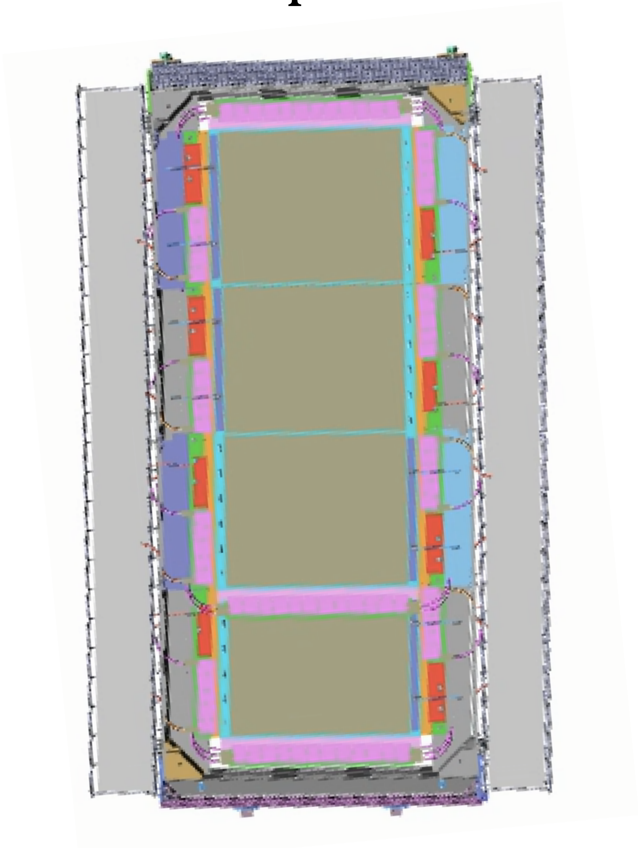
$$P_n = \frac{K}{\sigma_0}[v_L R_L^n + v_T R_T^n + v_{TT} R_{TT}^n \cos 2\beta + v_{LT} R_{LT}^n \cos\beta]$$

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

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

P_n (normal) component of polarization transfer

- Construct double focal plane polarimeter for SHMS to measure P_n for ^{2}H, ^{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

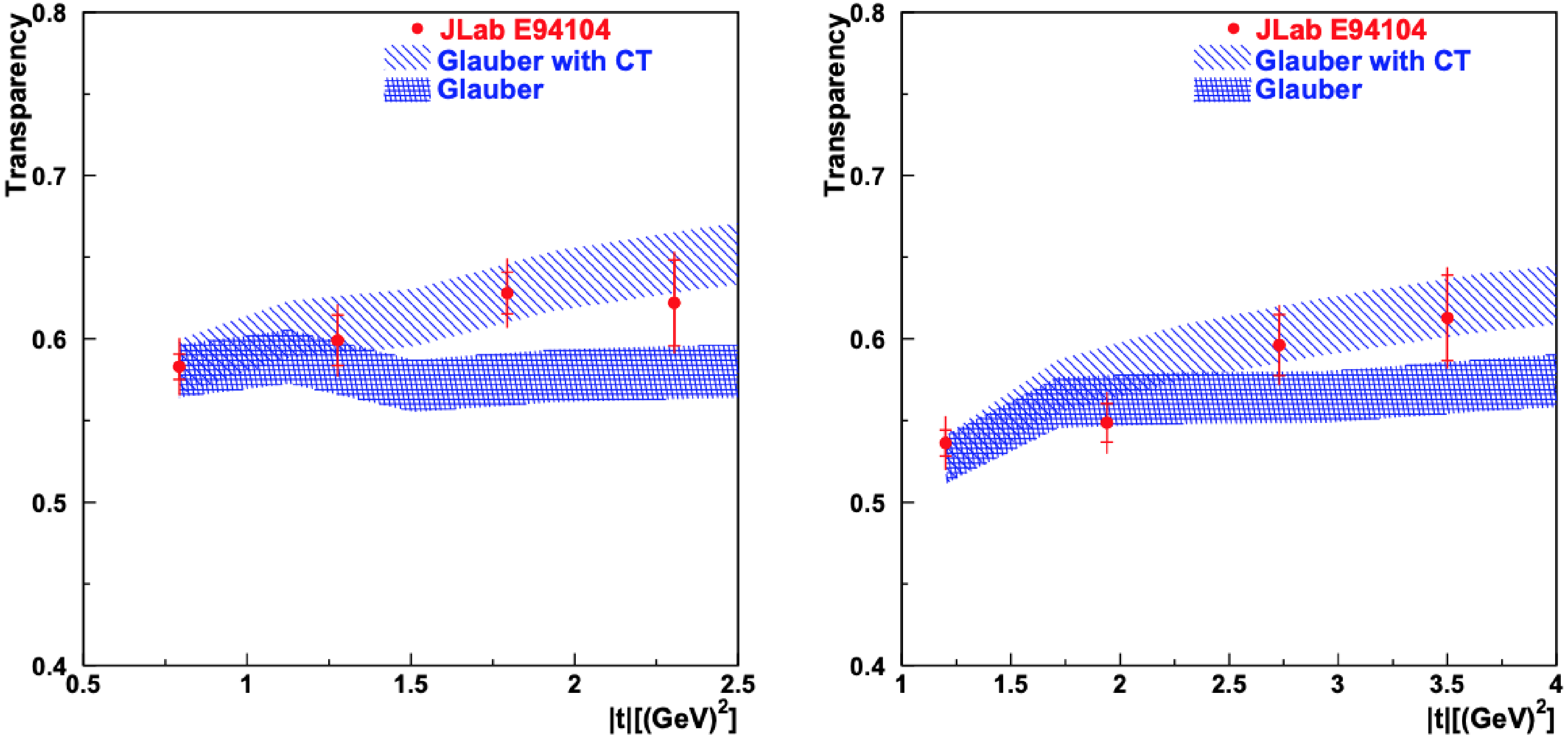
A. Saha et al., PR 91-006, Hall A proposal.
B. Anklin H. et al., The ELFE Project, Conference Proceedings, Vol. 44, p.223 (1993)

Reaction mechanism dependent? Photoproduction!

$\gamma n \to \pi^- p$ in ^{4}He in Hall A (6 GeV era)

70° c.m. scattering

90° c.m. scattering



Possible onset?

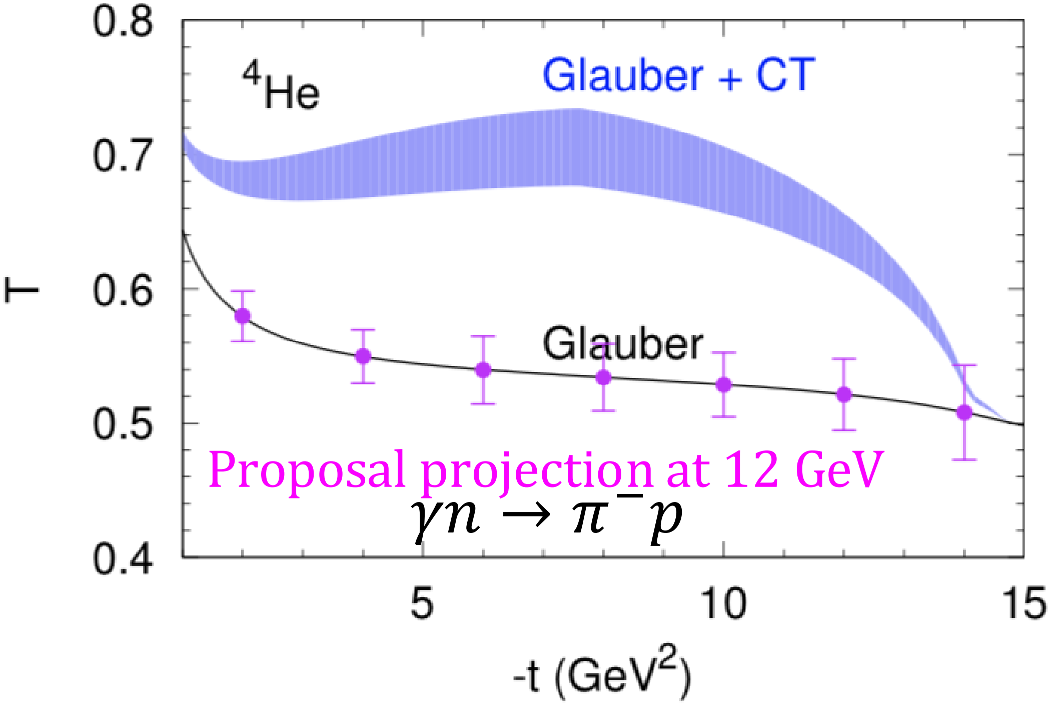
Important to reach high enough "freezing"!

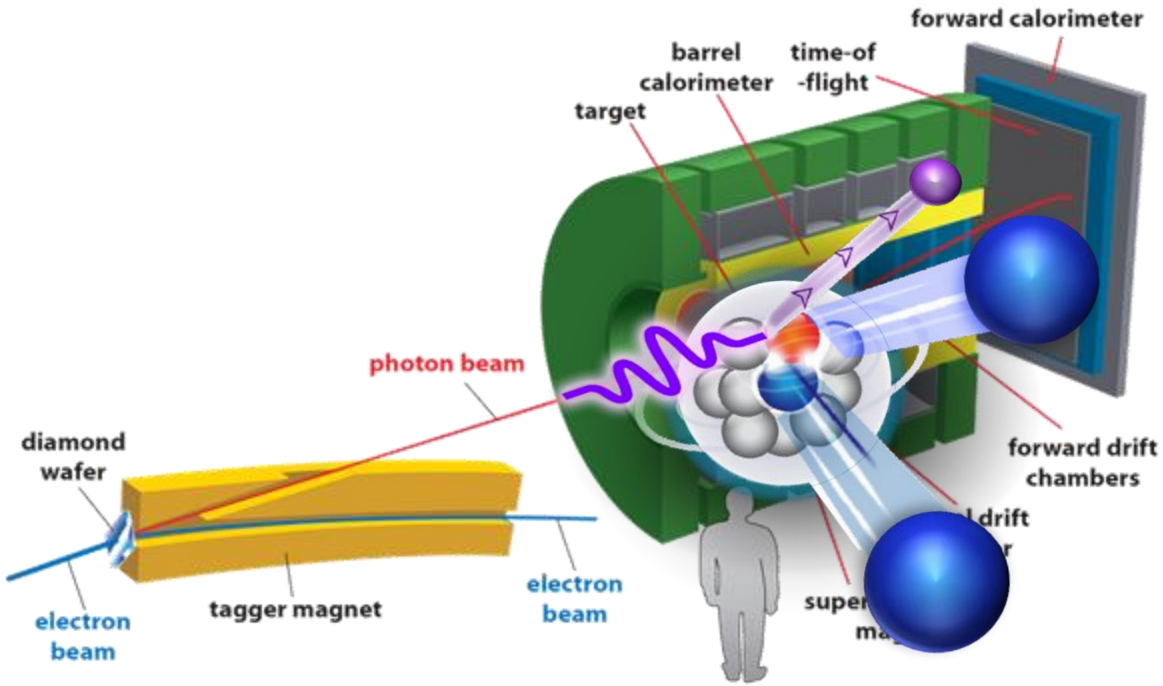
D. Dutta *et al*. PRC 68.021001 (2003)

Photoproduction in Hall D

Experiment ran in 2021 on ^{4}He, ^{12}C and deuterium

- Goal to study SRCs and test our assumptions
- Look for CT effects using photons





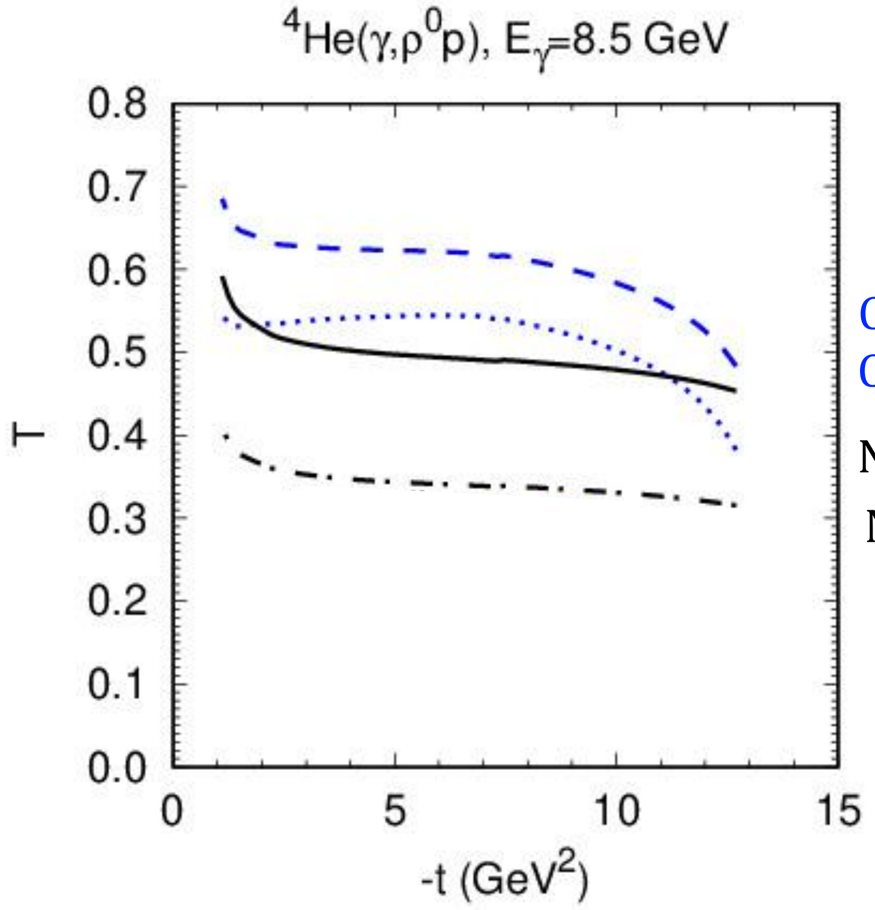
Photoproduction in Hall D at 22 GeV

$$\gamma p \rightarrow \rho^0 p$$

Increasing the photon energy:

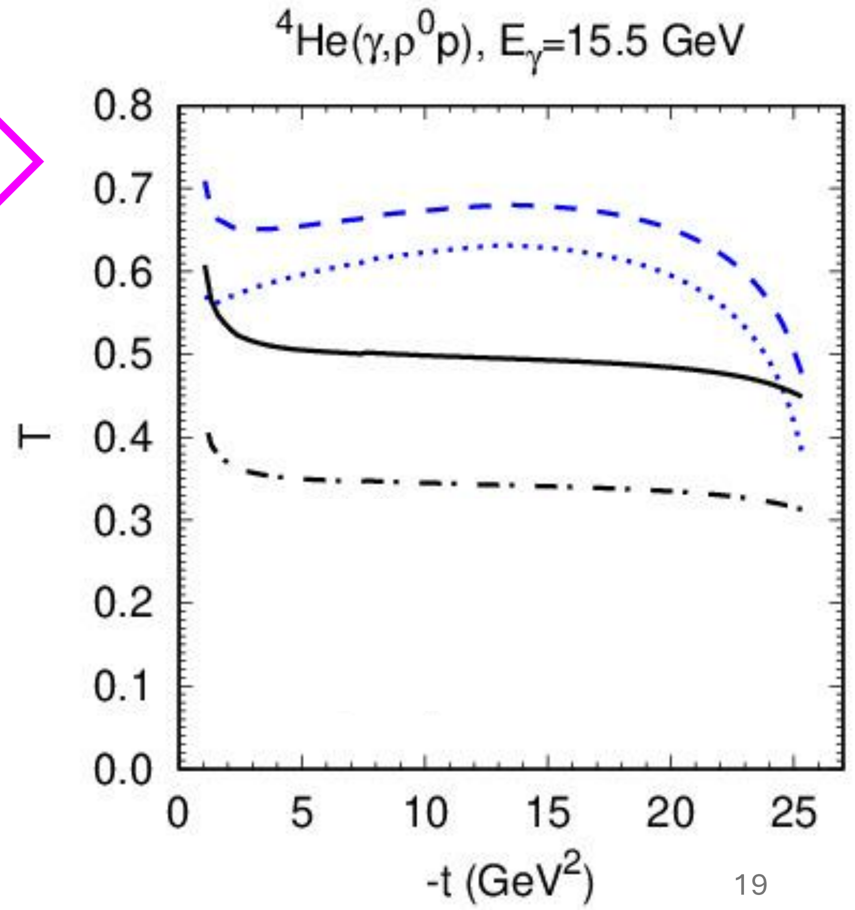
- extend the t-range
- Distinguish CT VM γ from Glauber

Assuming |t| and |u| >1 GeV^2



Increase photon energy

CT, point-like γ
CT, vector-meson γ
No CT, point-like γ
No CT, vector-meson γ



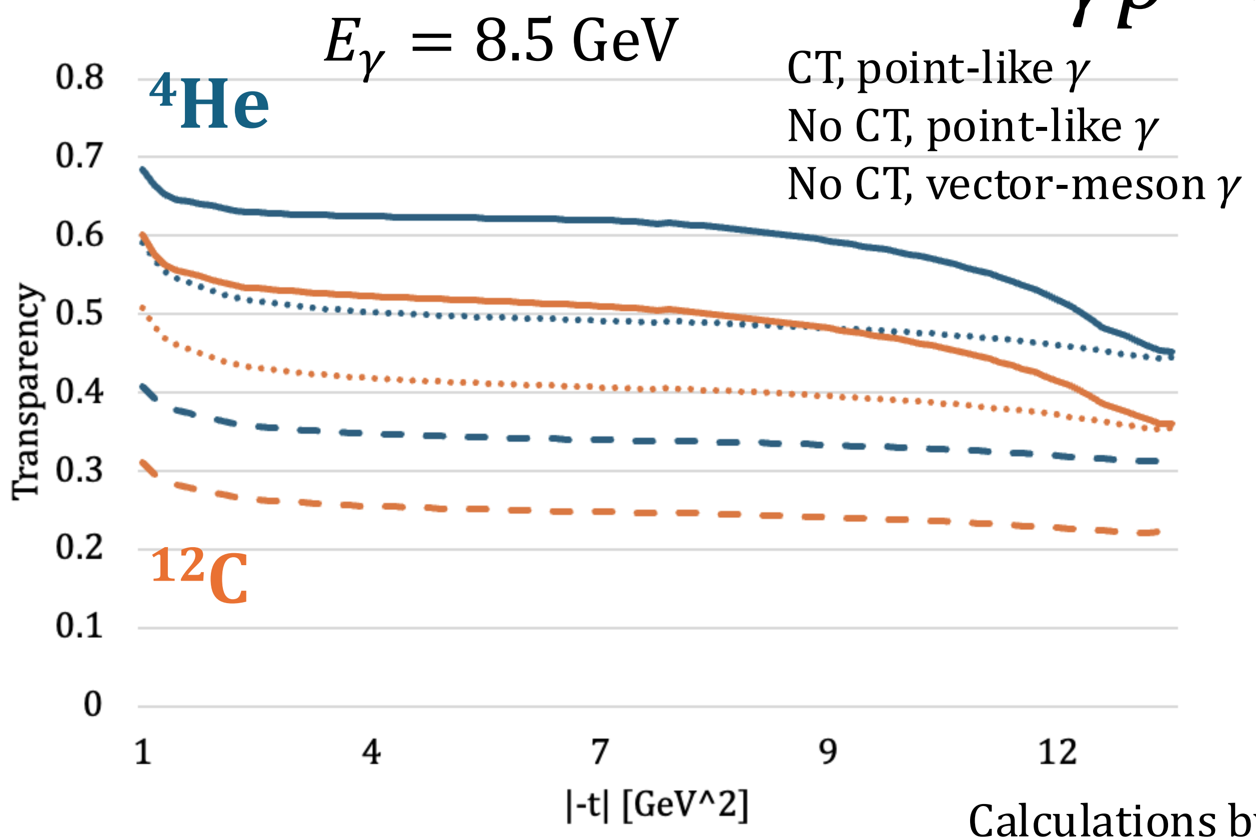
Calculations by A. Larionov

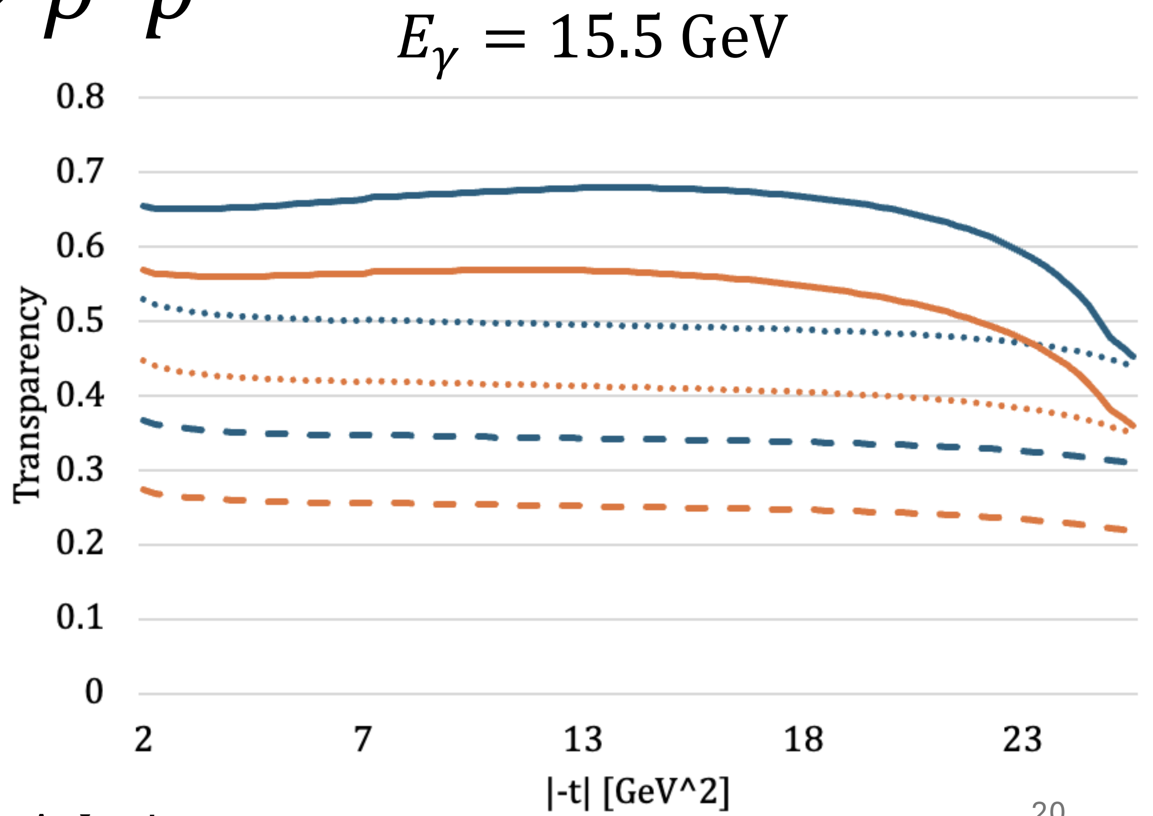
Photoproduction in Hall D at 22 GeV

Photon energy can be fine-tuned for reactions of interest:

- Polarization-optimization could enable better access transverse kinematics
- Rates
- Collimator
- Access J/ψ for confirmation of meson CT

$$\gamma p \rightarrow \rho^0 p$$





Calculations by A. Larionov

Summary

With a 22 GeV upgrade, we can:

- Extend $\rho^0$and π^+ meson measurements to higher Q^2
- Extend proton studies to higher Q^2 and shorter PLC lifetime with increased sensitivity
- Access higher “freezing” in photoproduction
- Access other kinematics with sensitive FSIs in proton recoil polarization transfer
- Explore J/ψ in electro- and photoproduction as confirmation of meson CT
- Explore high precision nuclear transparency measurements in general
- Consider neutron transparency studies

Thank you for your attention!