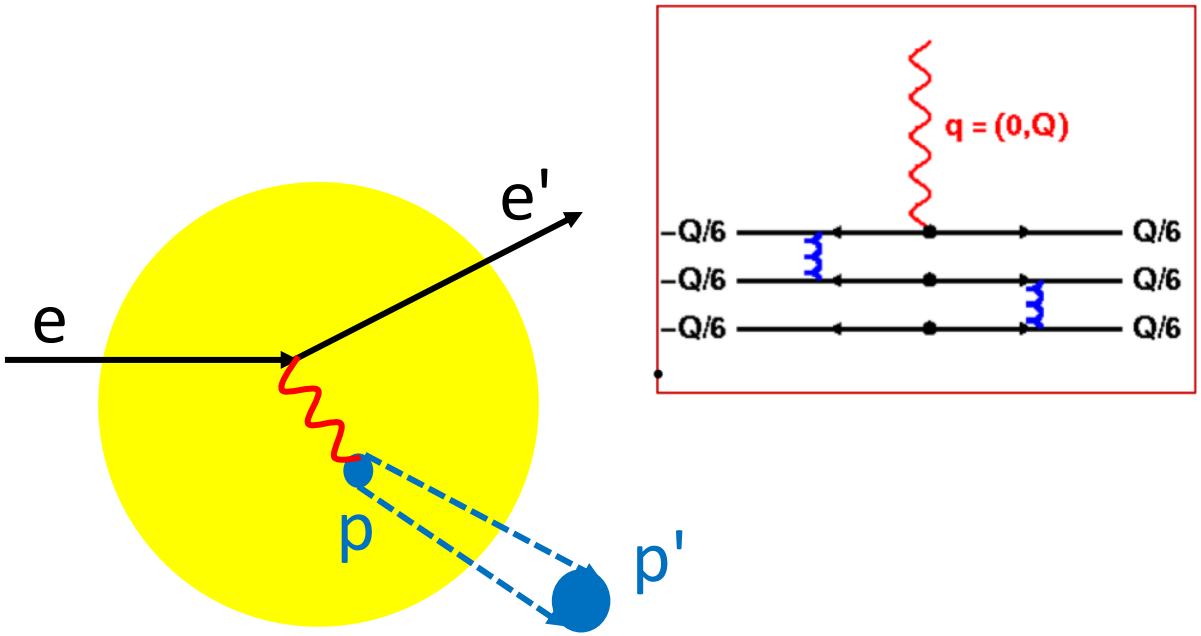
A review of the recent status of Color Transparency

Holly Szumila-Vance
Jefferson Lab

Correlations in Partonic and Hadronic Interactions

9 March 2022

Color transparency fundamental prediction of QCD

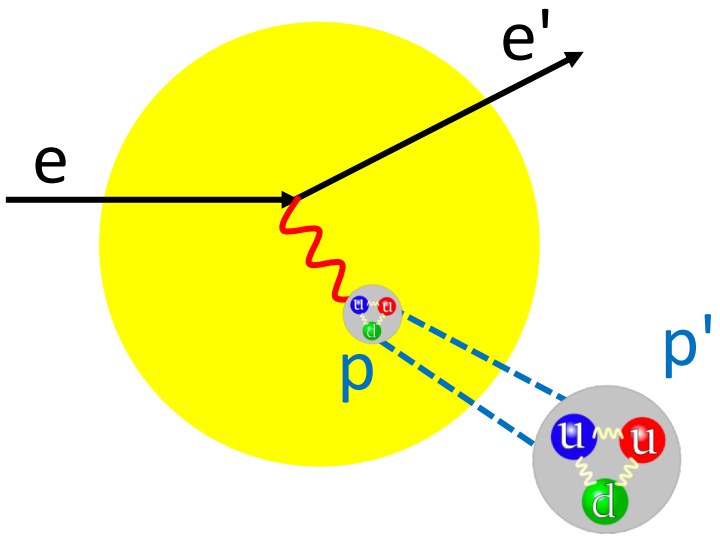


Introduced by Mueller and Brodsky, 1982

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

Color transparency fundamental prediction of QCD

Quantum mechanics:
Hadrons fluctuate to small transverse size (*squeezing*, transferred momentum)



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

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

Nuclear transparency

Probability knocked out proton in scattering to be deflected or absorbed.

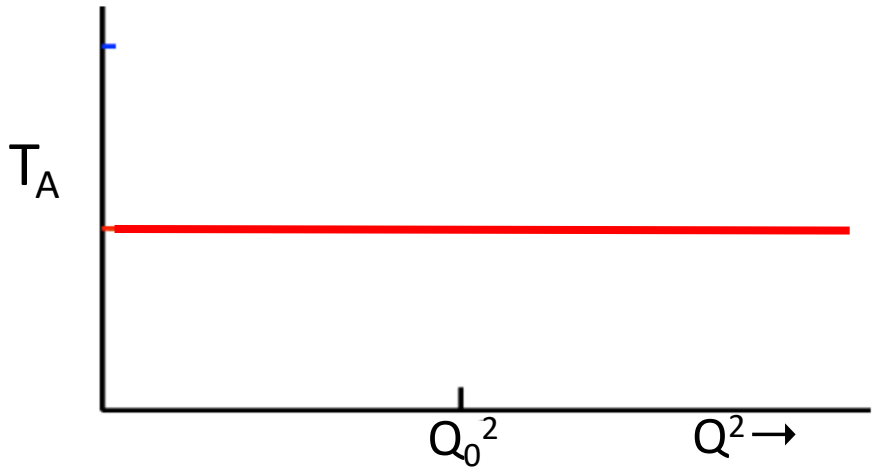
$$T_A = \frac{\sigma_A}{A\ \sigma_N}$$

(nuclear cross section)

(free nucleon cross section)

$$\sigma_A = \sigma_N\ A^{\alpha}$$

Traditional nuclear physics calculations predict energy independent transparency

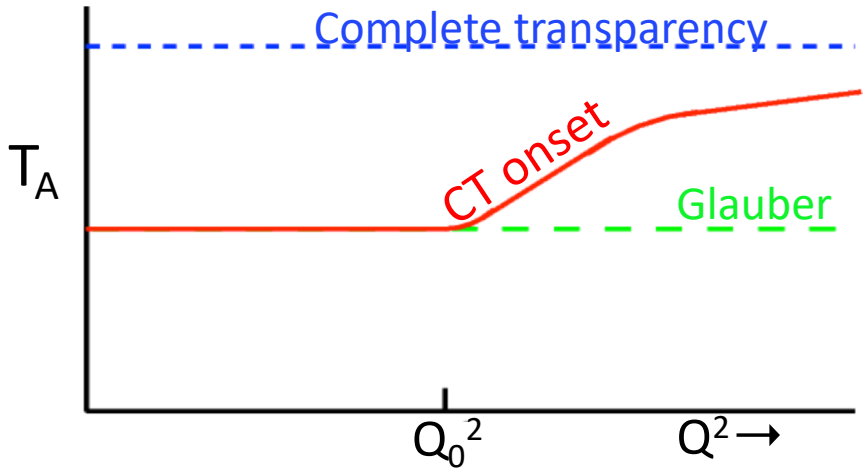


Transparency:

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

Color transparency fundamental prediction of QCD

- Not predicted by strongly interacting hadronic picture → arises in picture of quark-gluon interactions
- QCD: color field of singlet objects vanishes as size is reduced
- Signature is a rise in nuclear transparency, T_A, as a function of the momentum transfer, Q^2



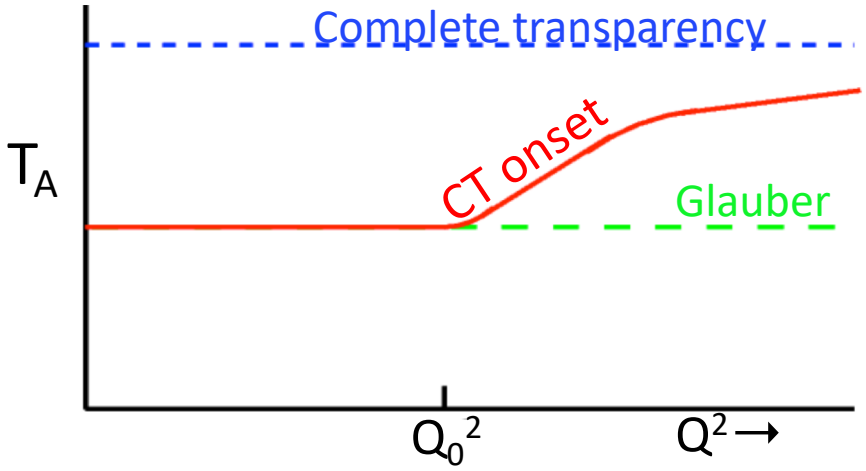
In this talk:

Onset of CT

CT at high energies

Onset of CT, experimental status

Next CT experiments



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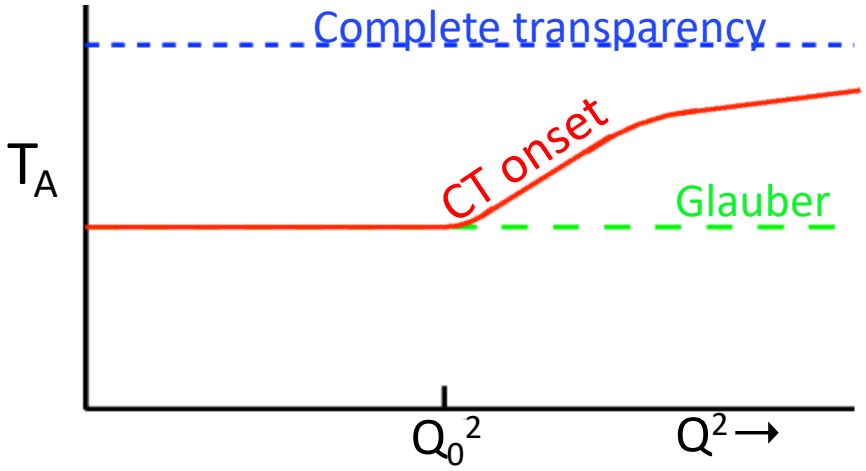
CT at high energies



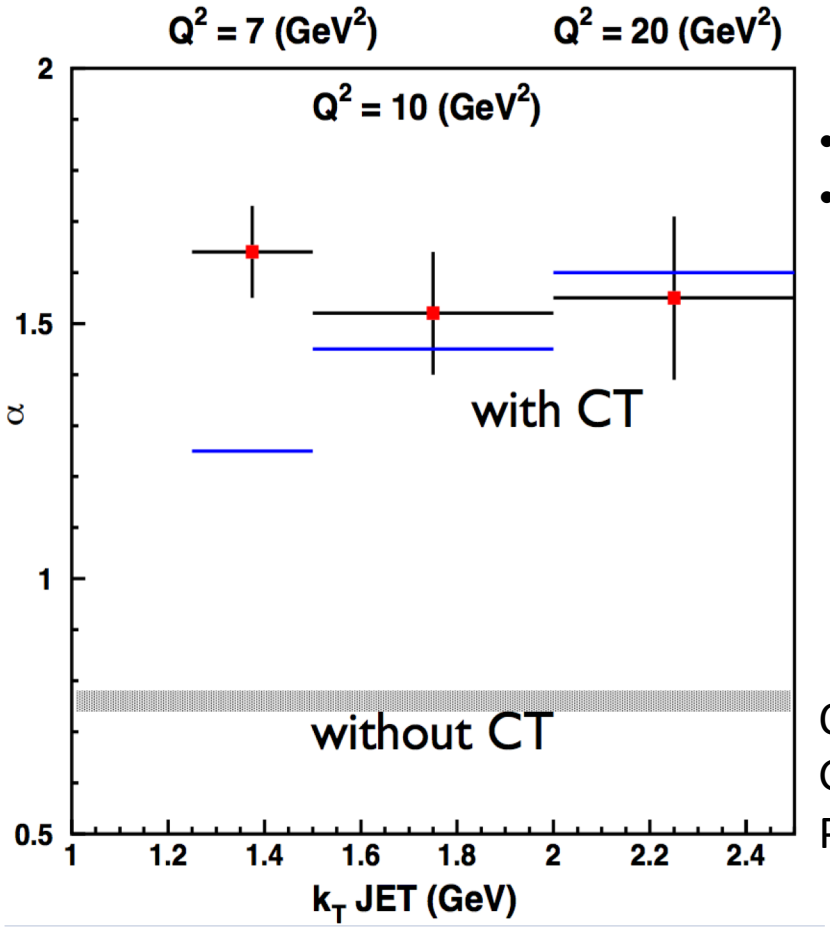
Onset of CT, experimental status

Next CT experiments

CT at high energies

Coherent diffractive dissociation of 500 GeV/c pions on C and Pt

π + A → 2 jets + A'



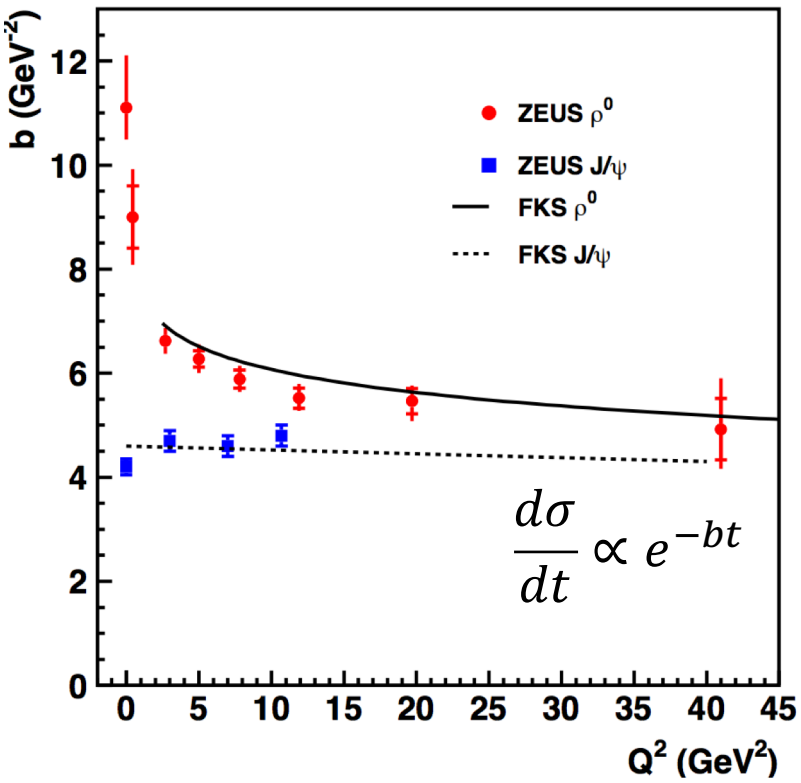
- Fit to $\sigma = \sigma_0 A^{\alpha}$
- Pion-nucleus total cross section, α=1.6

CT predictions by L. L. Frankfurt, G. A. Miller, and M. Strikman, Phys. Lett. B304, 1 (1993)

Aitala et al., PRL 86, 4773 (2001)

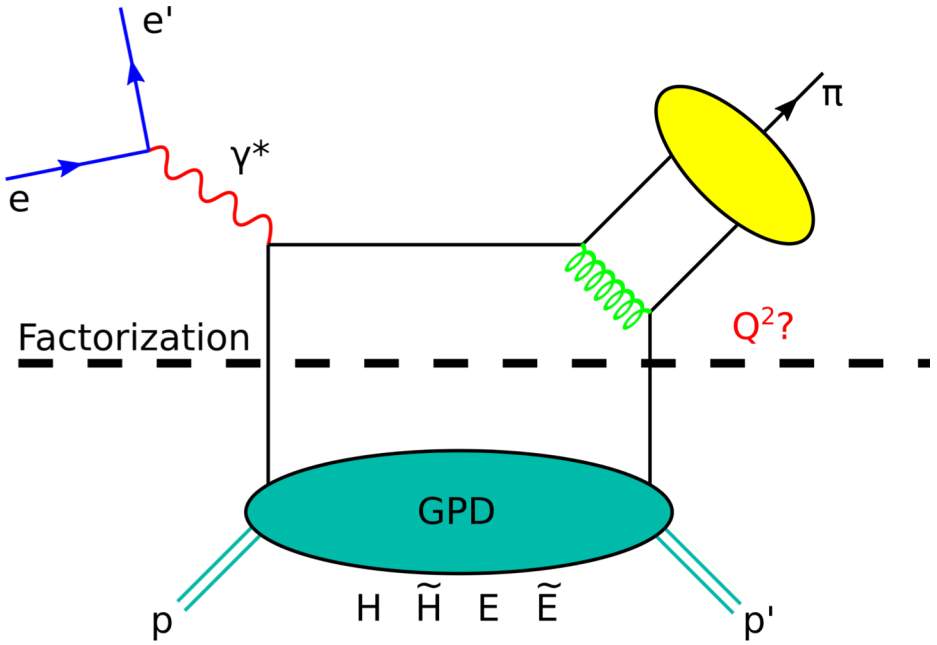
CT at high energies

Vector meson production at HERA



Convergence of t-slope at large Q^2 is seen to be related to presence of small configuration qq-bar

CT relates to factorization

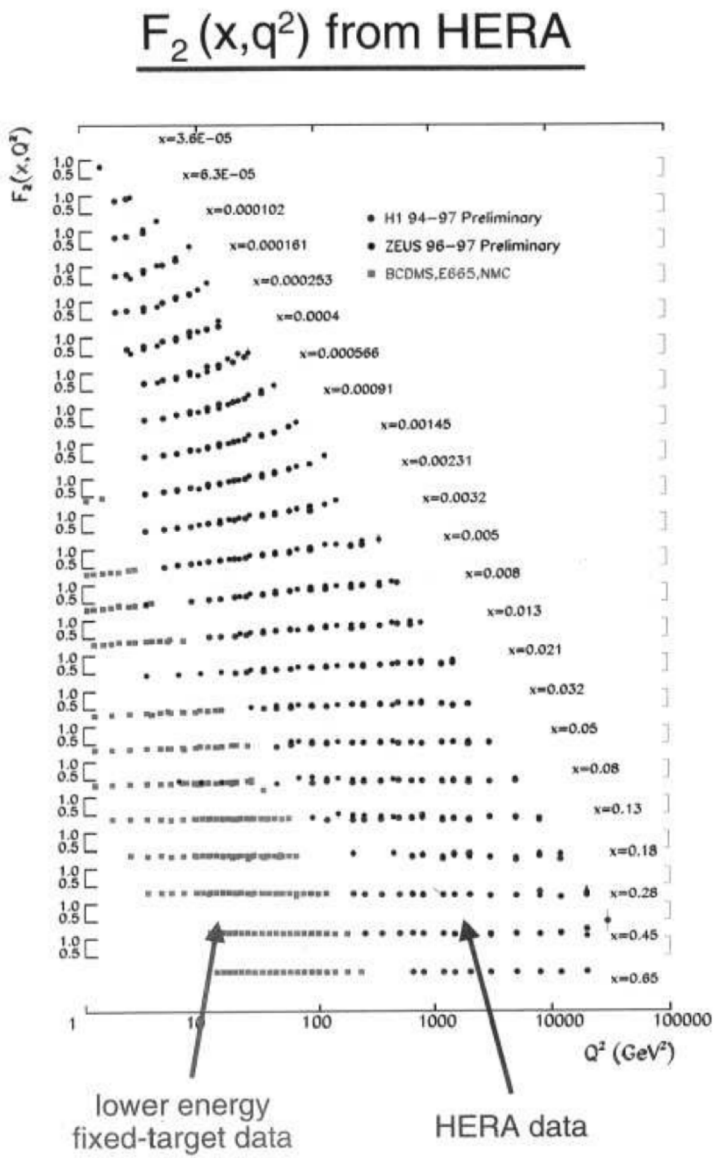


Color cancellation needed for **factorization**:

-> small objects

-> at high Q^2, small size object moves through nucleus

CT at high energies



DIS from heavy targets at high energies shows Bjorken scaling

evidence of no FSI ➞ CT?

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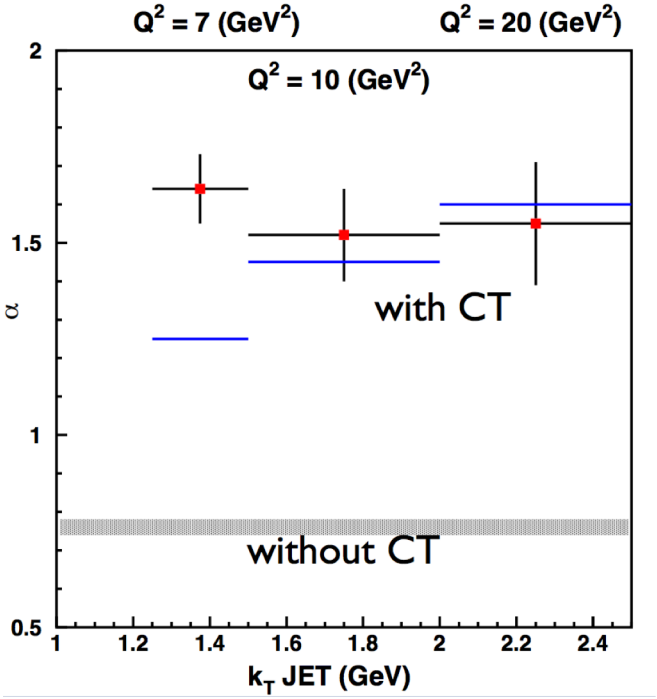
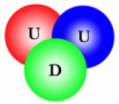


CT experiments

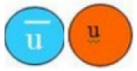
CT experiments

Baryon

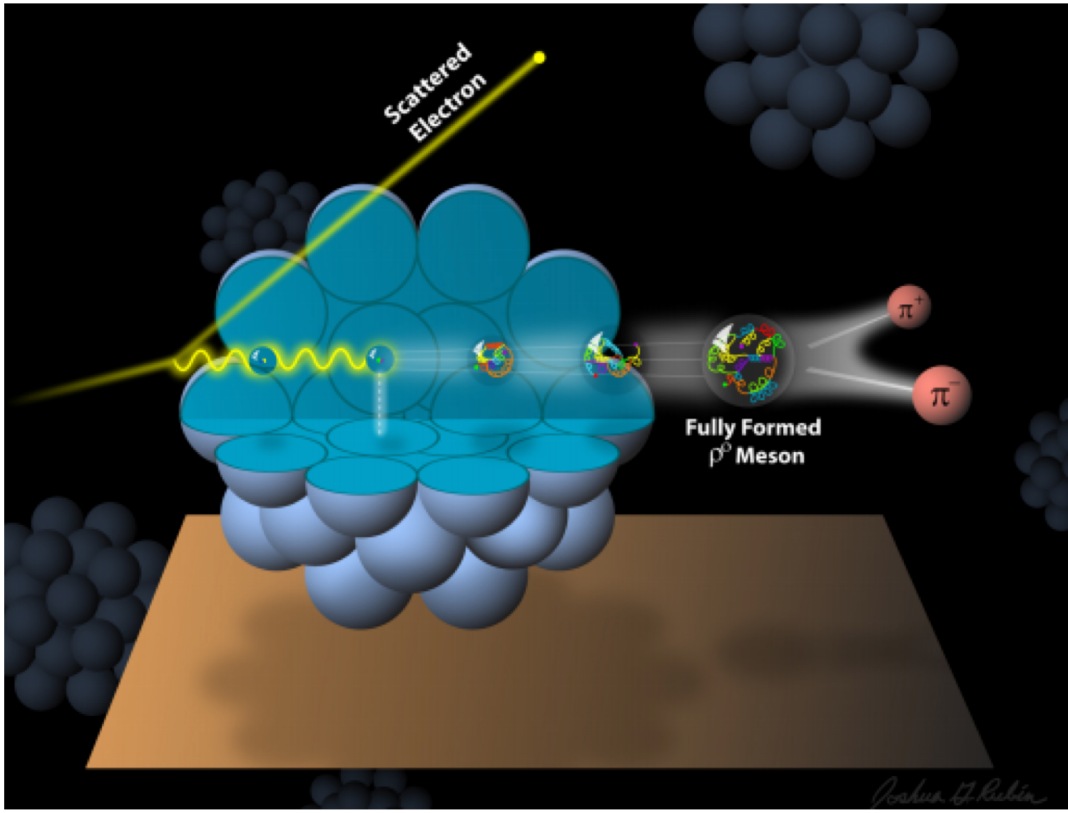


A(p,2p): BNL
A(e,e'p): SLAC, JLab

Meson



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



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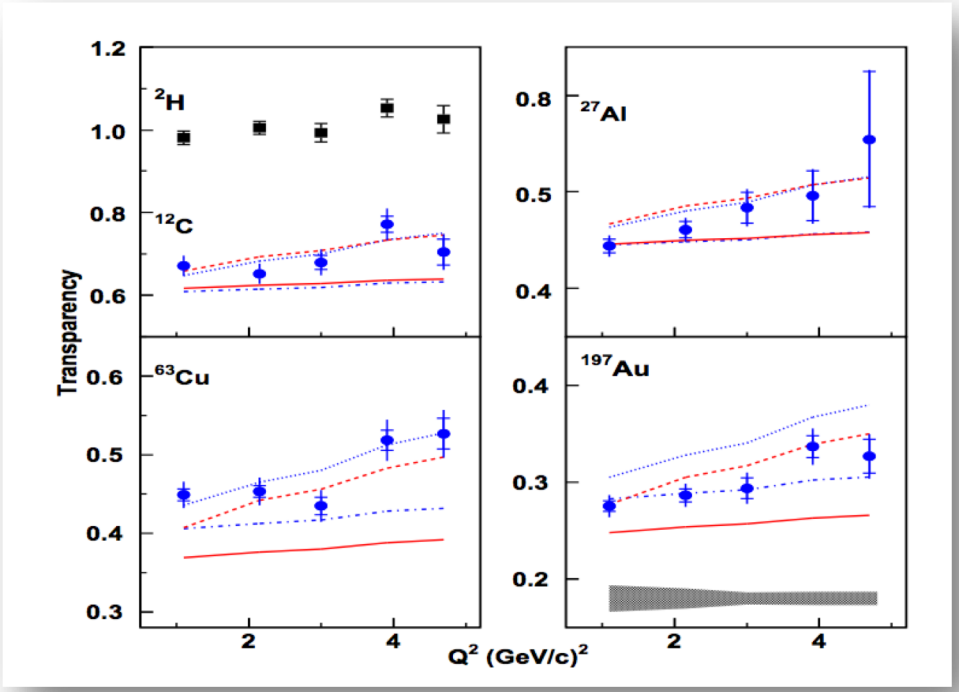
Previous Measurements: Mesons

Enhancements consistent with CT (increasing with Q^2 and A) observed

Hall C E01-107 pion electro-production

$A(e,e'\pi^+)$

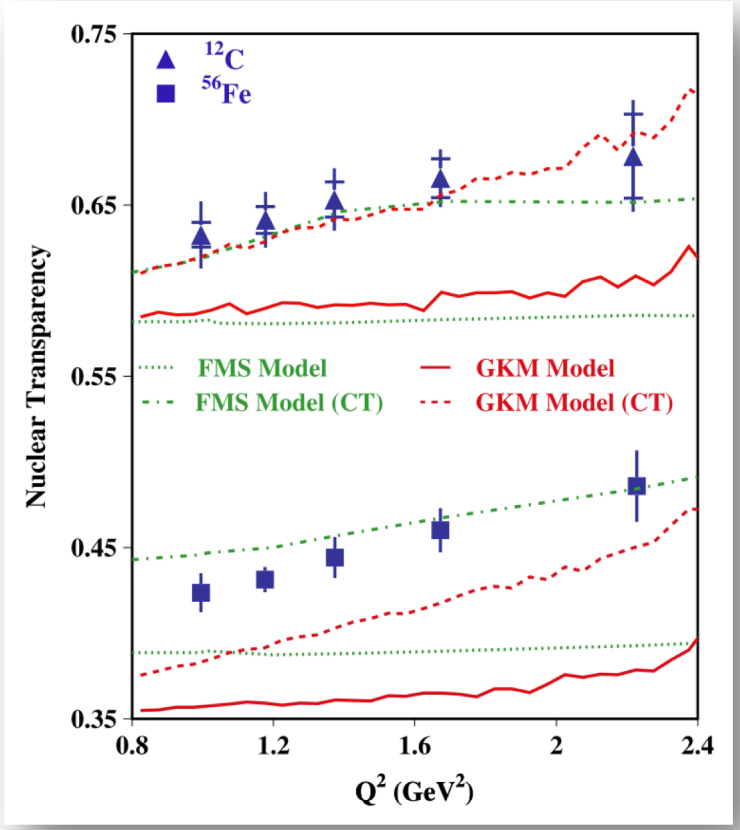


B.Clasie *et al.* PRL 99:242502 (2007)

X. Qian *et al.* PRC81:055209 (2010)

CLAS E02-110 rho electro-production

$A(e,e'\rho^0)$



L. El Fassi *et al.* PLB 712,326 (2012)

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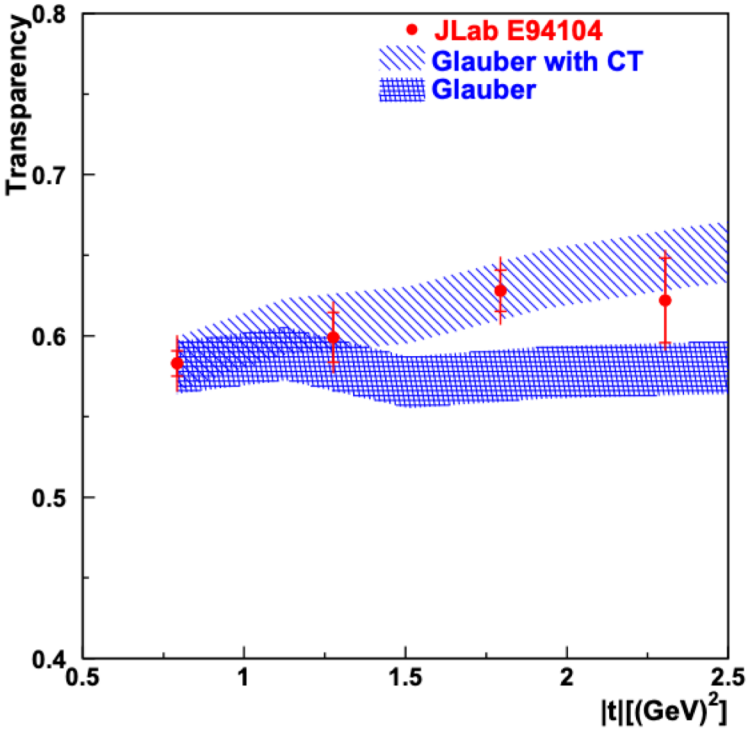
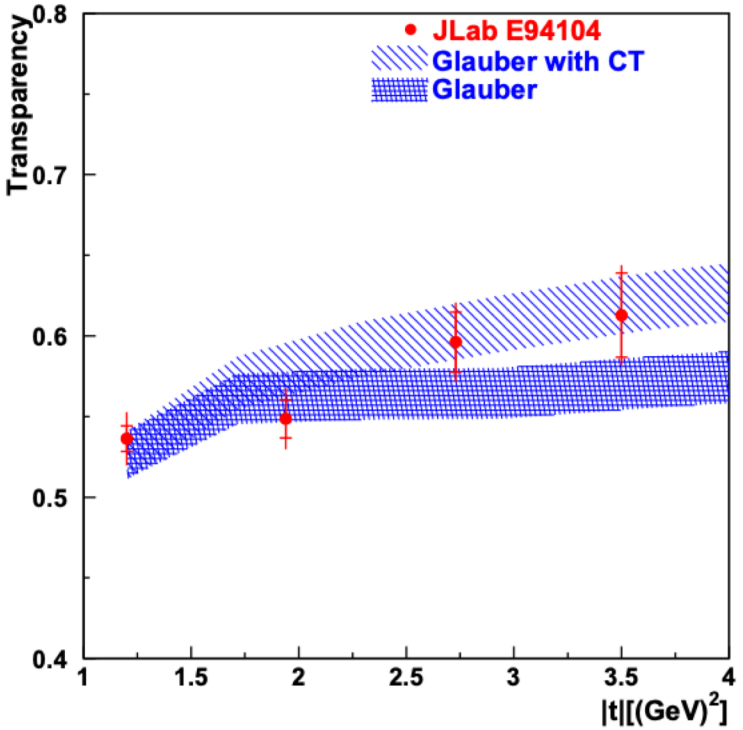
Previous Measurements: Testing pion photoproduction

$\gamma n \rightarrow \pi^- p$ in 4He in Hall A

70° c.m. scattering

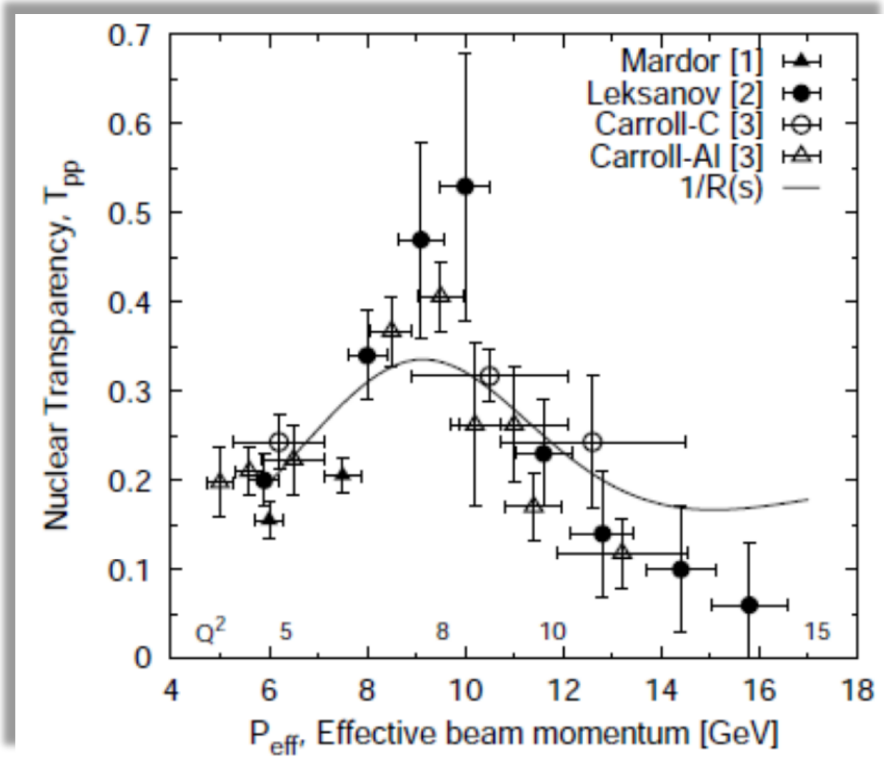


90° c.m. scattering



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

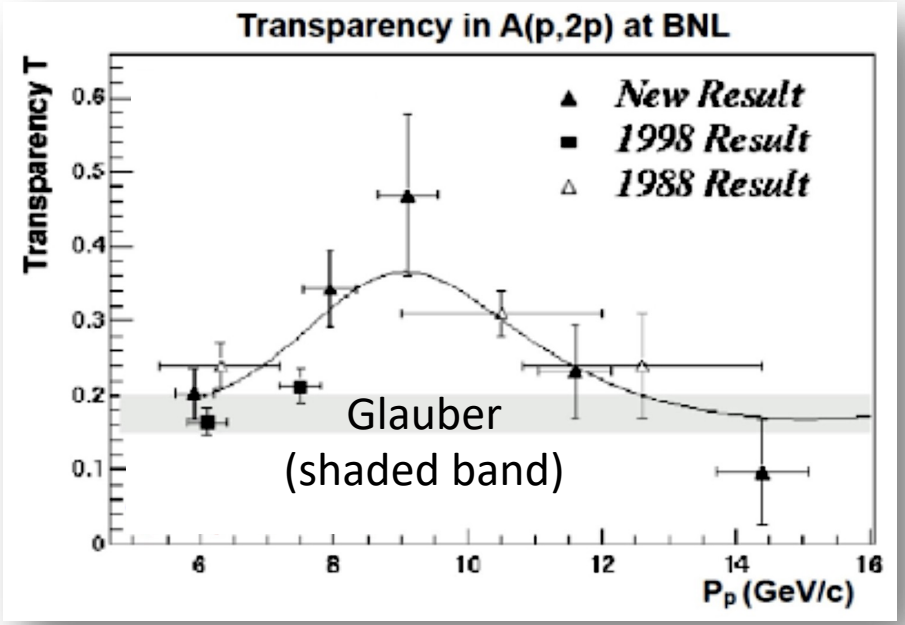
Previous Measurements: Baryons



A. Leksanov et al. PRL 87 (2001)
J. L. S. Aclander et al., PRC 70 (2004)

Transparency in A(p,2p) experiment at Brookhaven:

- observed enhancement in transparency
- inconsistent with CT only
- could be explained by including nuclear filtering or charm resonance



PRL 87, 212301 (2001)
PRL 81, 5085 (1998)
PRL 61, 1698 (1988)

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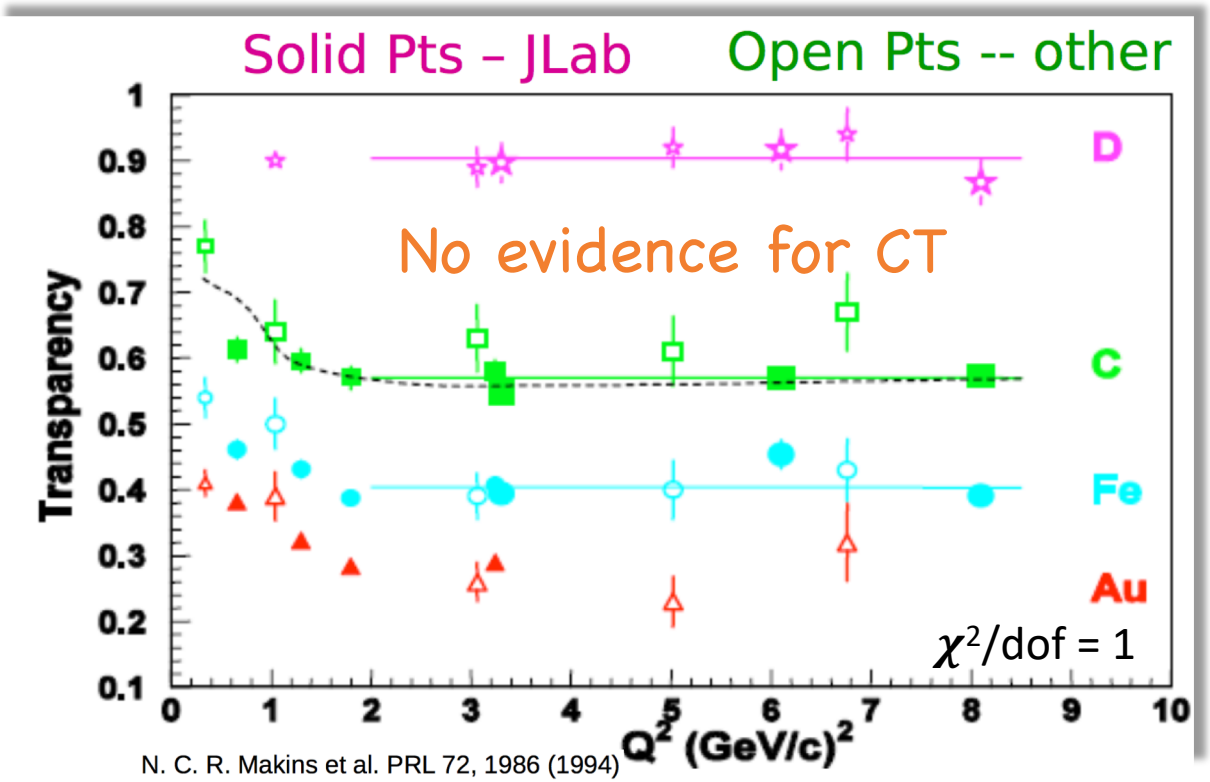
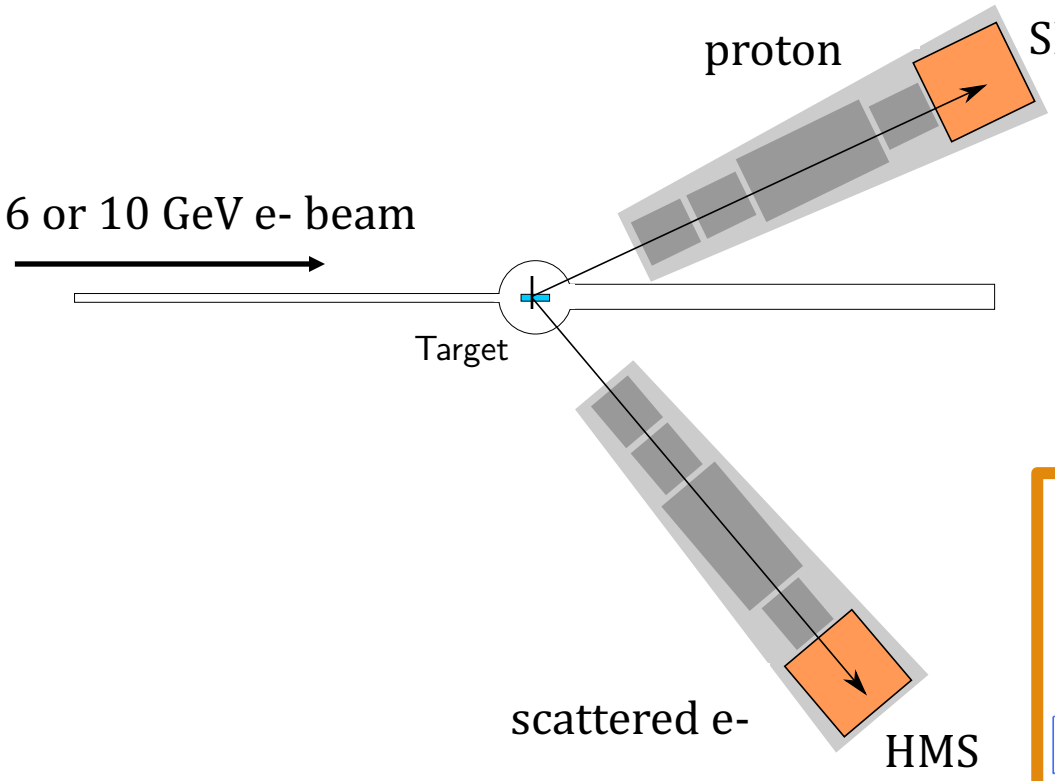
Previous Measurements: Baryons

A(e,e'p) results consistent with standard nuclear physics

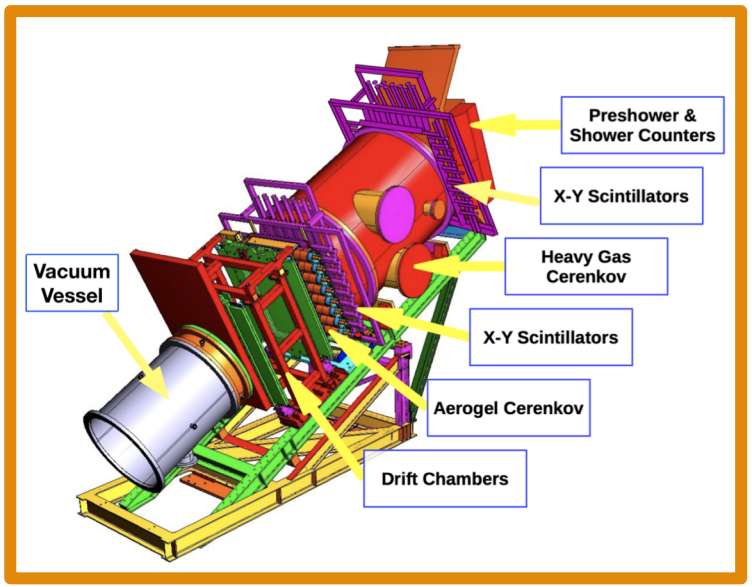


N. C. R. Makins et al. PRL 72, 1986 (1994)
G. Garino et al. PRC 45, 780 (1992)
D. Abbott et al. PRL 80, 5072 (1998)
K. Garrow et al. PRC 66, 044613 (2002)

CT in Hall C at Jefferson Lab



Probing higher momenta!



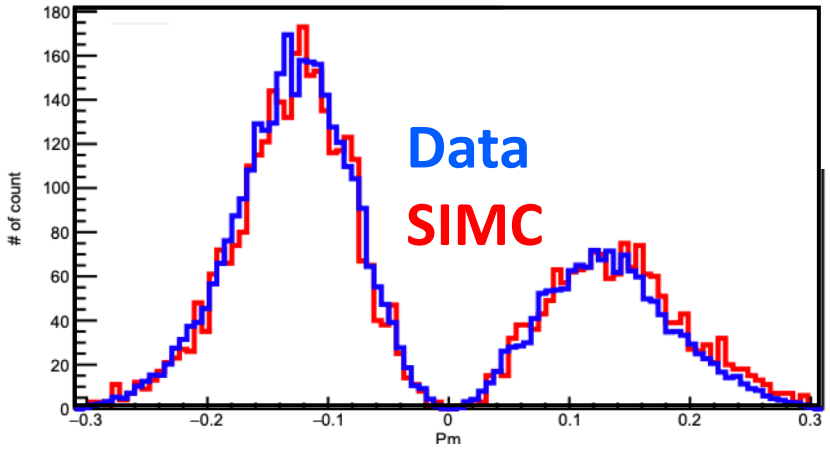
$$T(Q^2) = \frac{\int_V d^3p_m dE_m Y_{\rm exp}(E_m, \vec{p}_m)}{\int_V d^3p_m dE_m Y_{\rm PWIA}(E_m, \vec{p}_m)}$$

Jefferson Lab

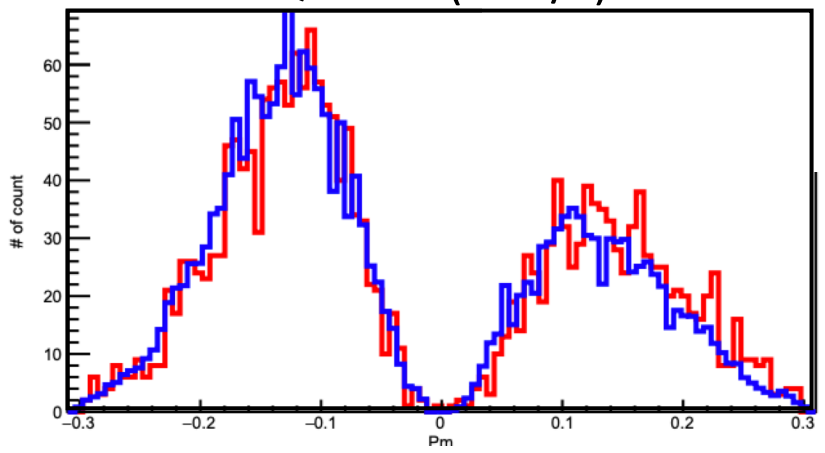
Carbon missing momentum

$$\frac{d^6\sigma}{dE_{e'}d\Omega_{e'}dE_{p'}d\Omega_{p'}} = E_{p'}|p_{p'}|\sigma_{ep}S(E_m,\vec{p}_m)$$

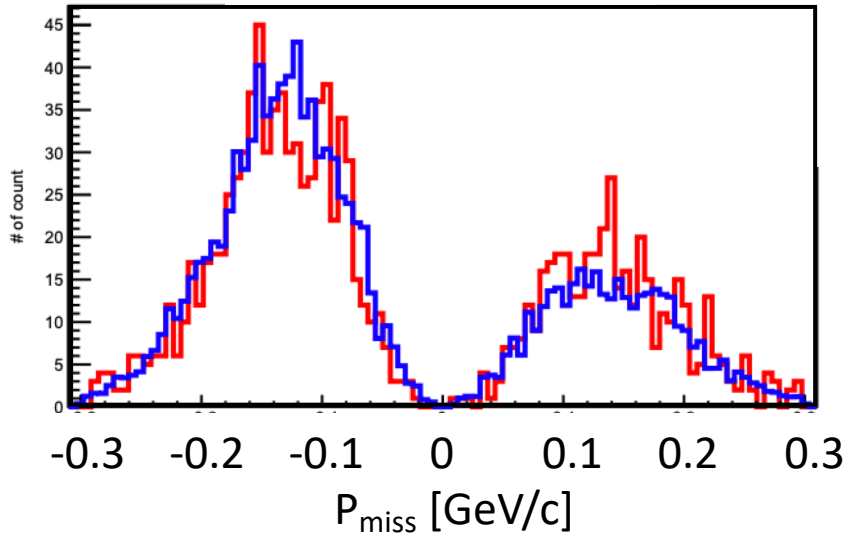
Q^2 = 8 (GeV/c)^2



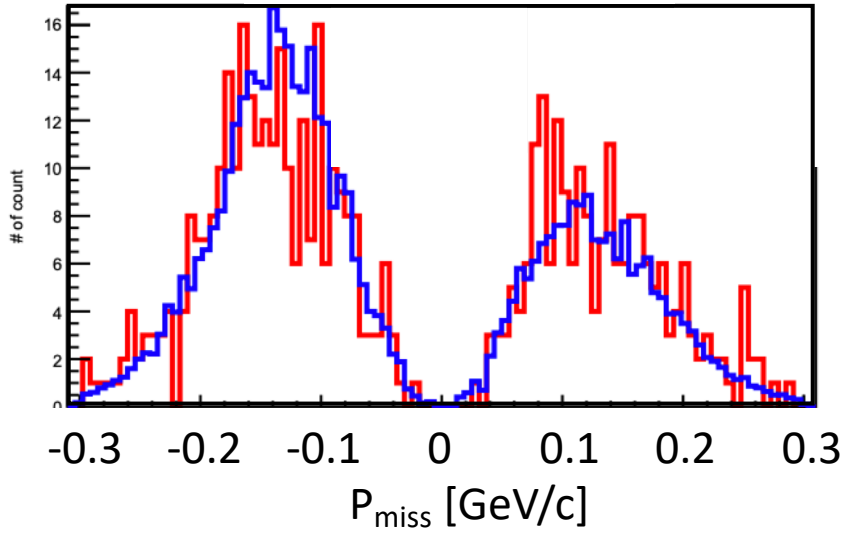
Q^2 = 9.4 (GeV/c)^2



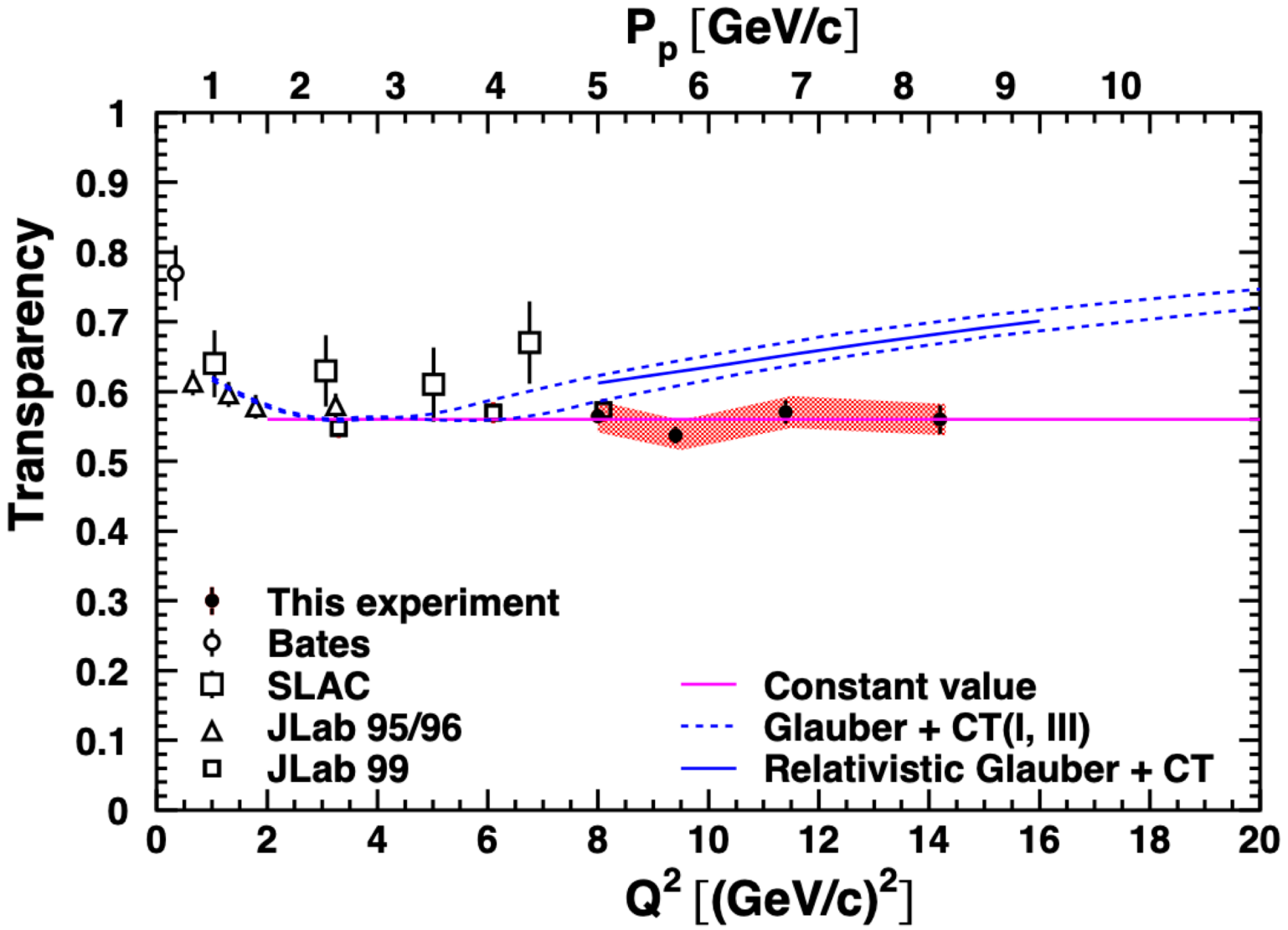
Q^2 = 11.4 (GeV/c)^2



Q^2 = 14.3 (GeV/c)^2



No observation of the onset of CT

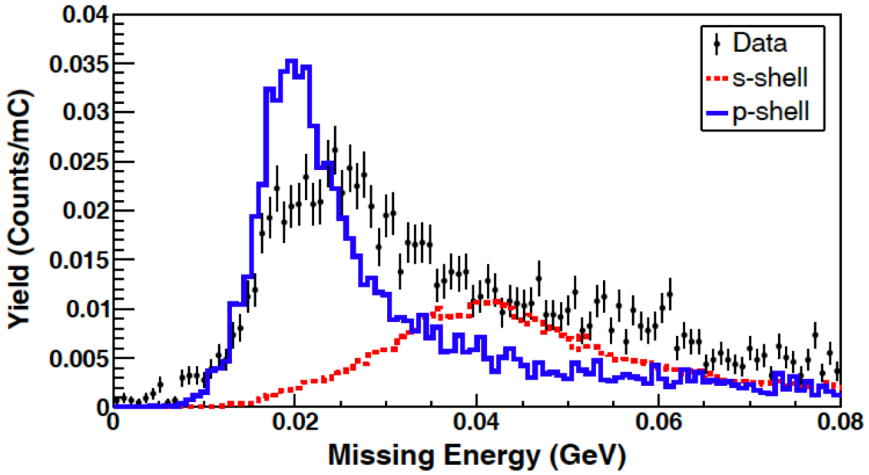


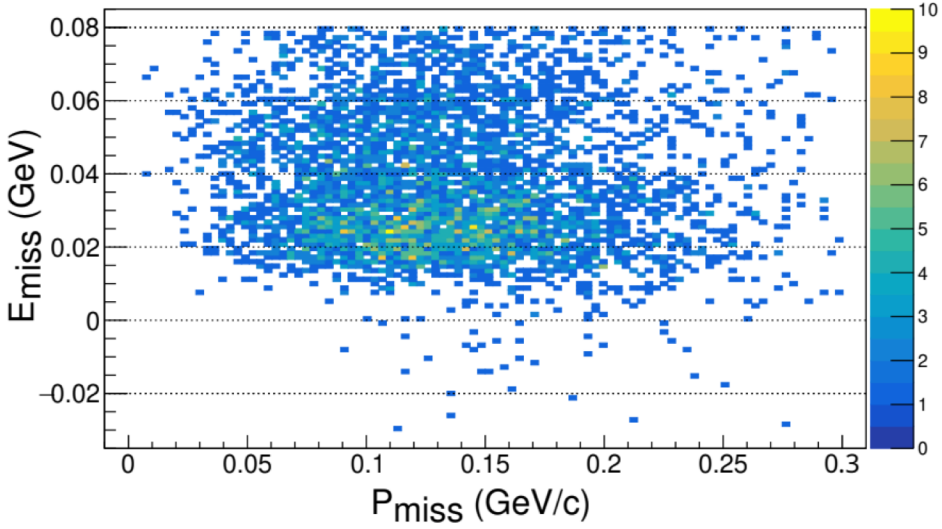
. Bhetuwal et al., PRL 126 082301 (2021)

Checking for shell dependent transparency

Predicted by L. Frankfurt, M. Strikman, and M. Zhalov, Nuclear Physics A, vol. 515, no. 4, 1990, pp. 599–608.

Hall C CT experiment, $Q^2 = 8\ GeV^2$





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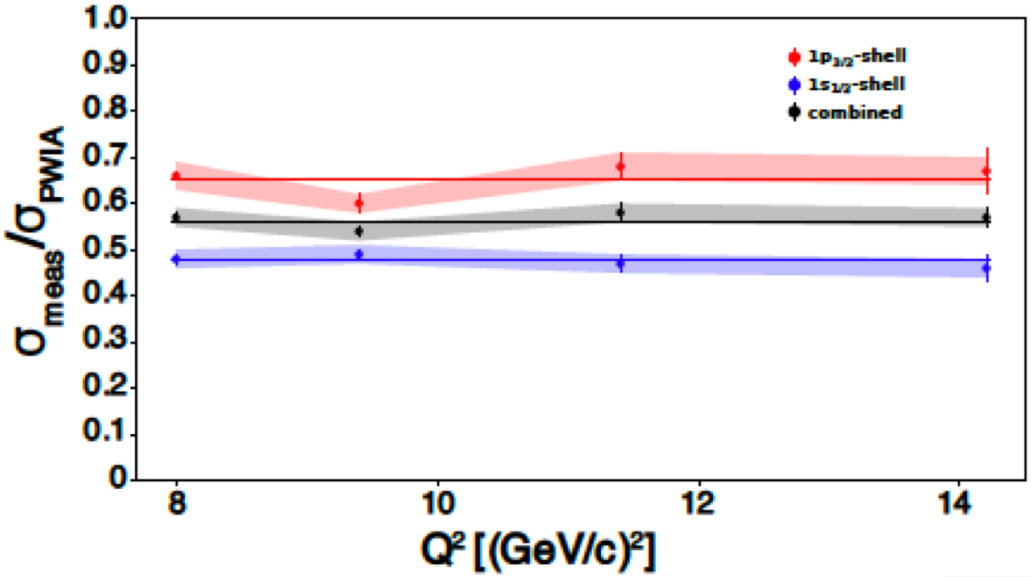
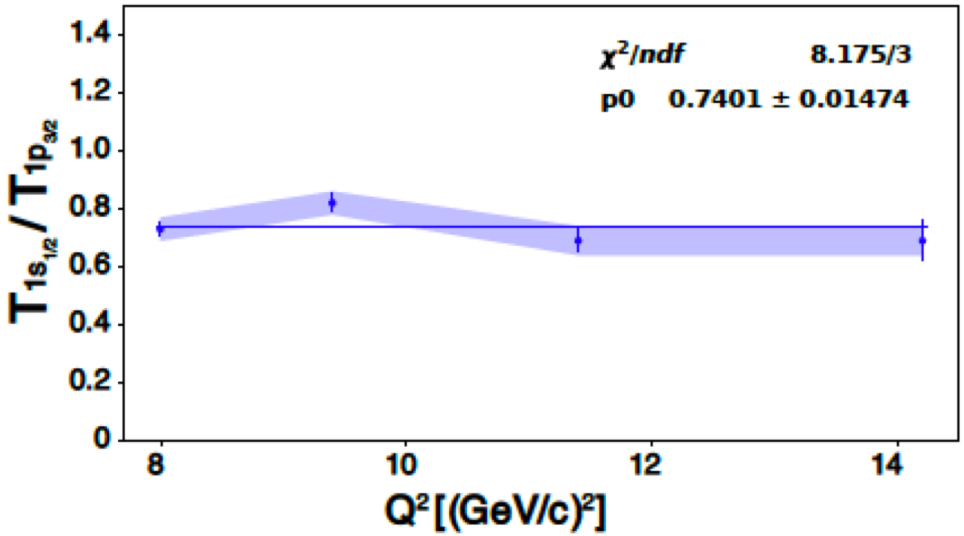
1s- and 1p- shell transparency

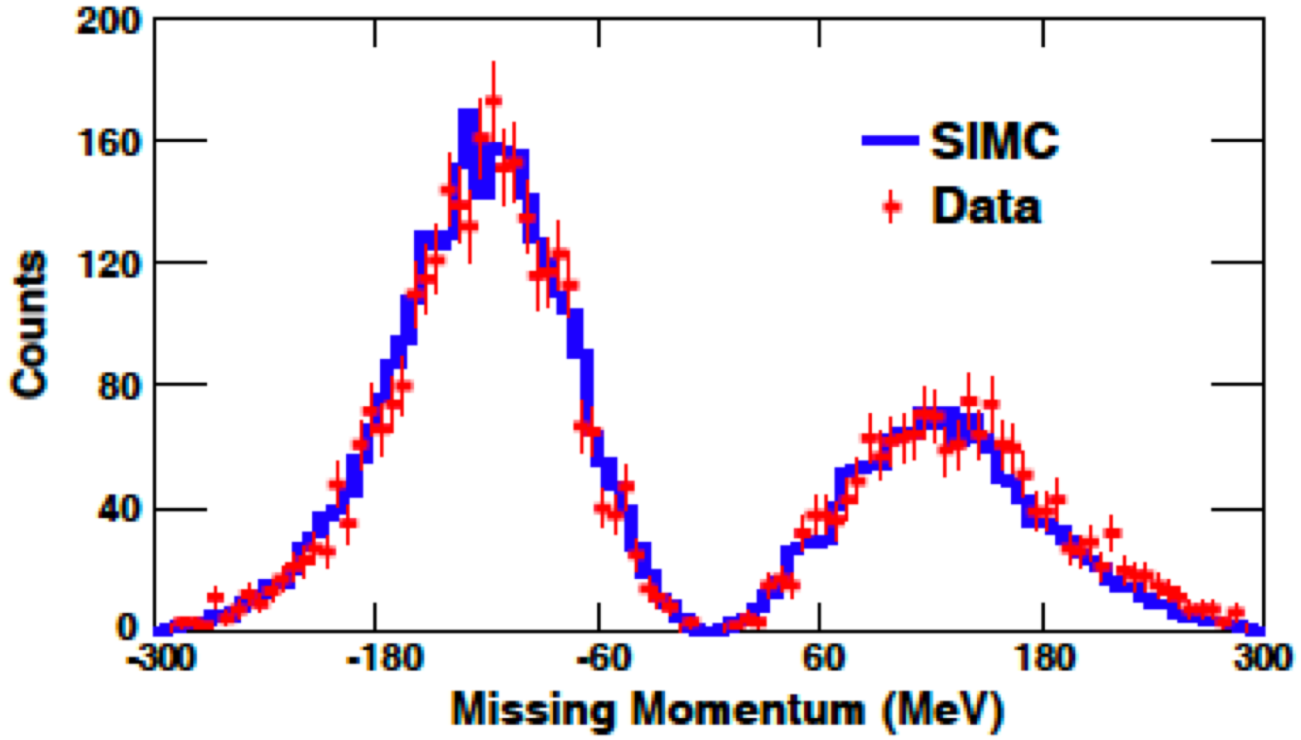


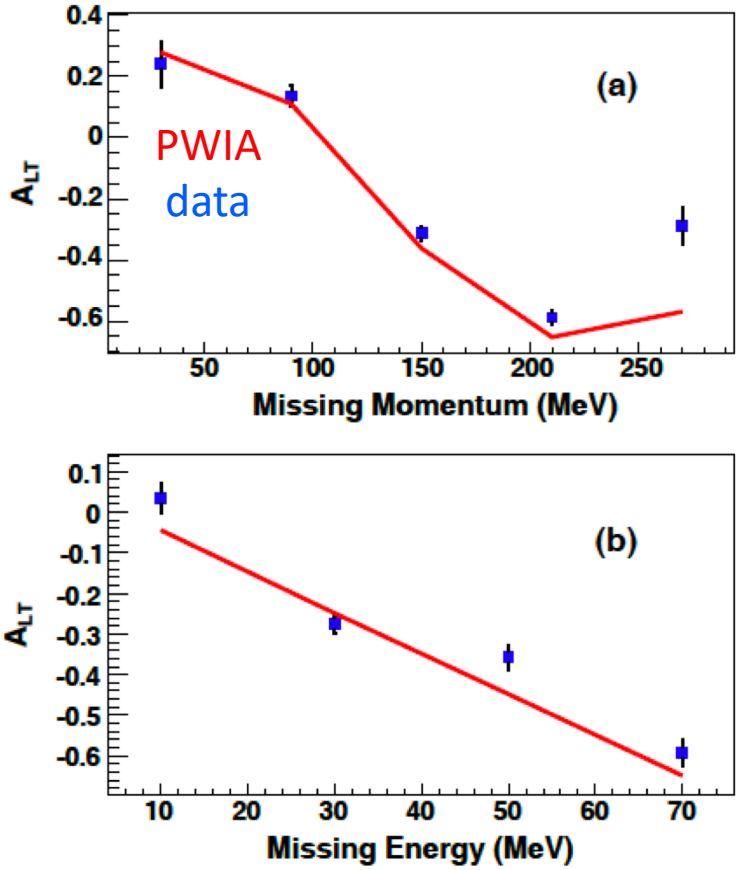


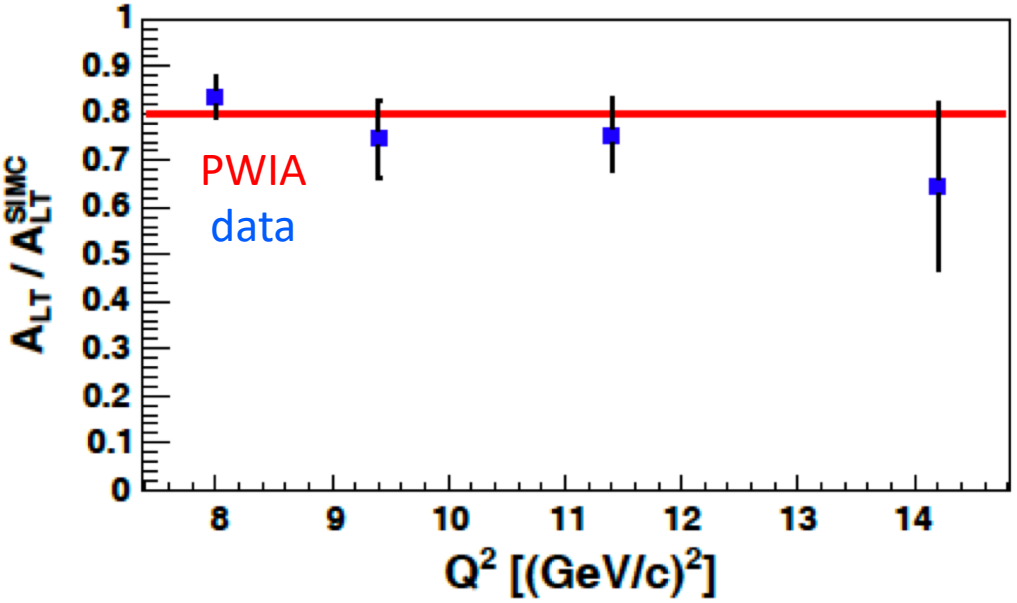
Preliminary – under collaboration review

Missing momentum asymmetry

$$A_{LT} \equiv \frac{N_+ - N_-}{N_+ + N_-}$$







Preliminary – under collaboration review

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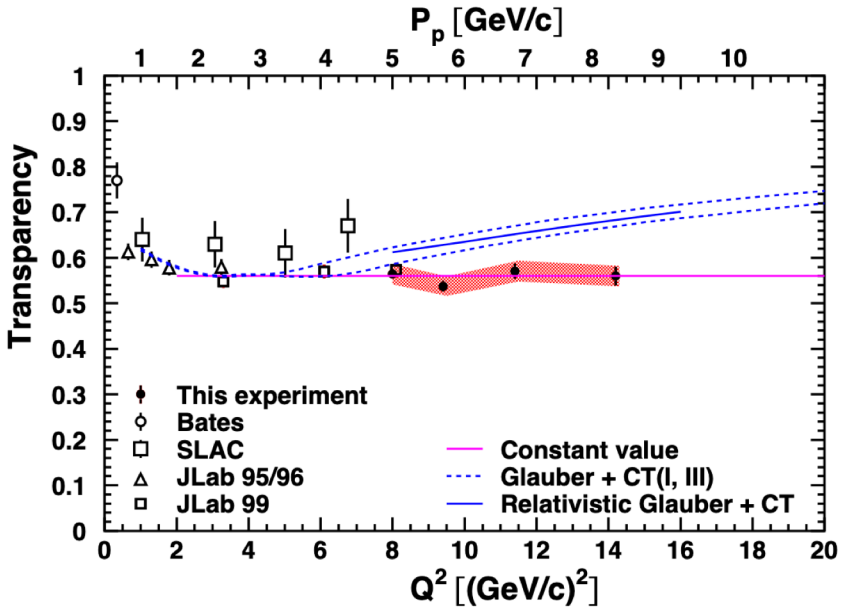
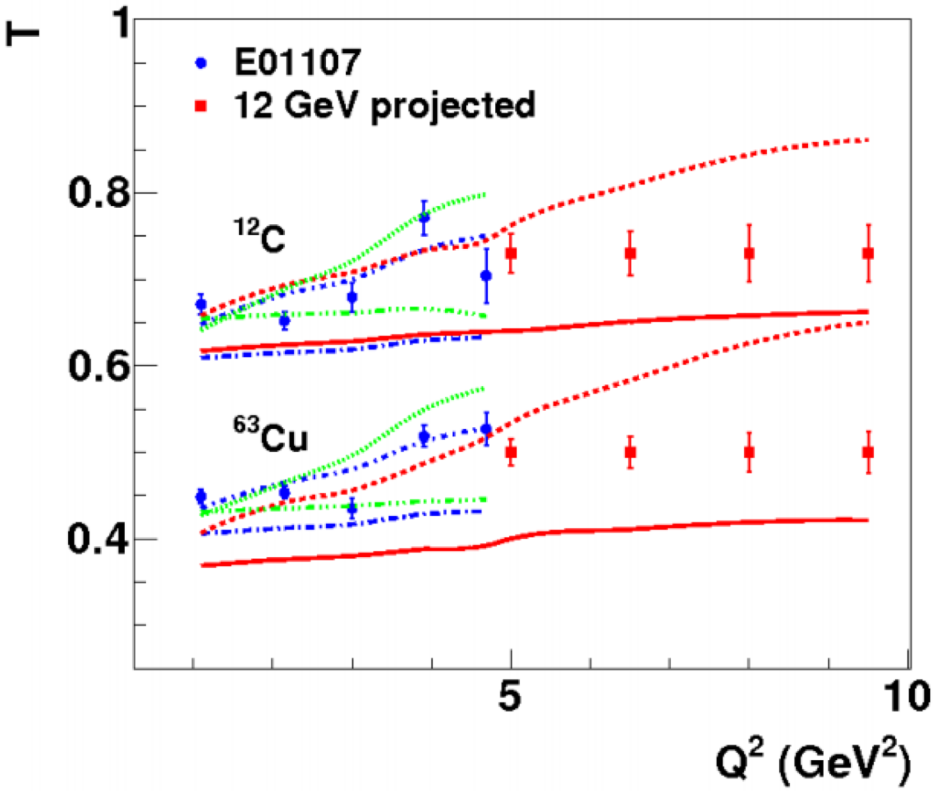
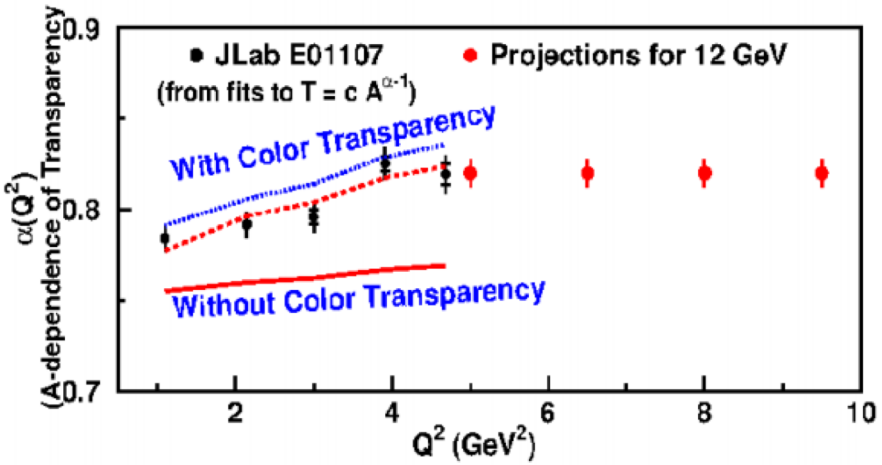


Jefferson Lab

Explore onset of CT in mesons

Measure the onset in pion electro-production over large momentum range in Hall C

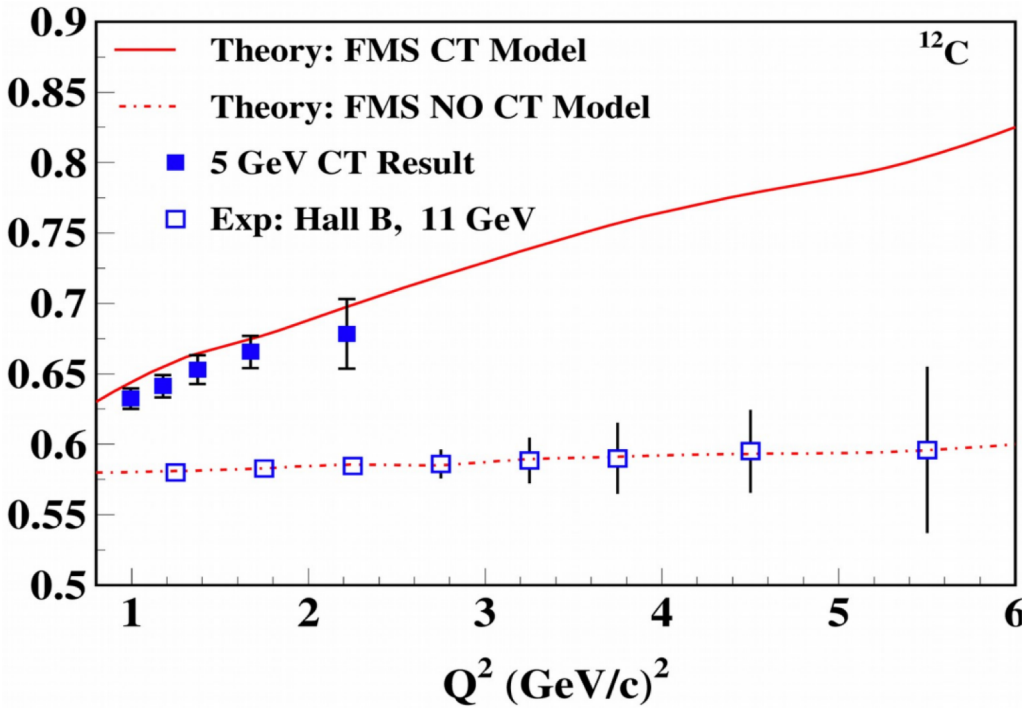




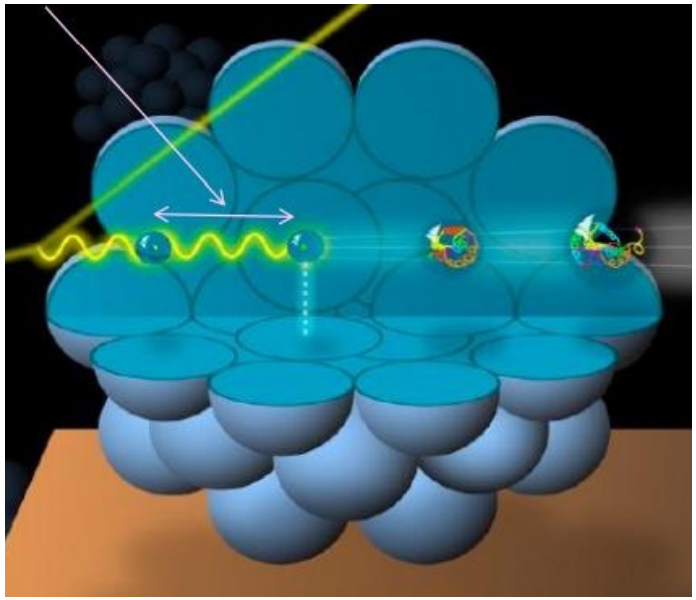
Jefferson Lab

Explore onset of CT in mesons

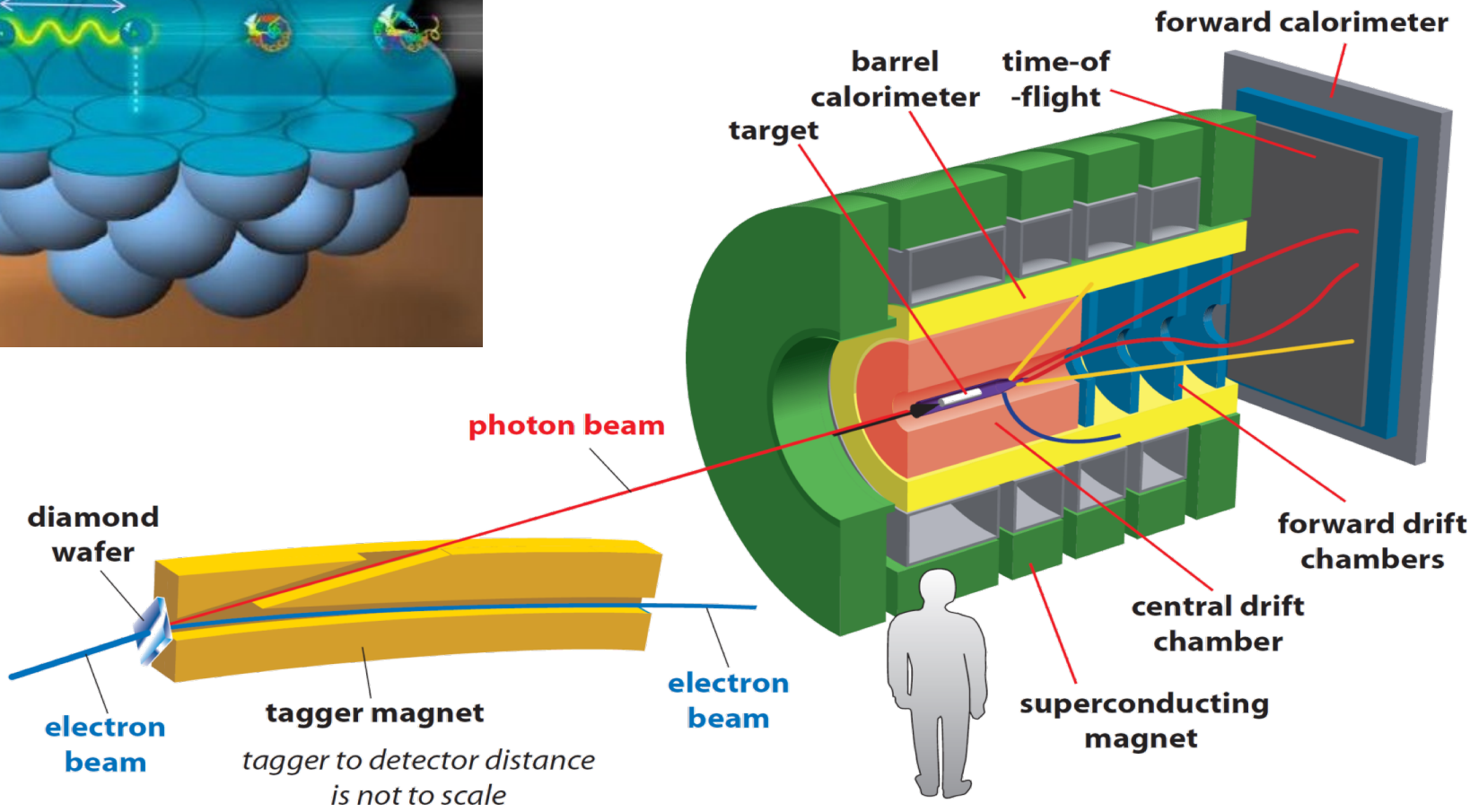
Rho transparency measurements will be extended to highest Q^2 in Hall B



CT in Hall D using photoproduction – ran in Nov/Dec 2021!



Targets: ^{2}H, ^{4}He, ^{12}C



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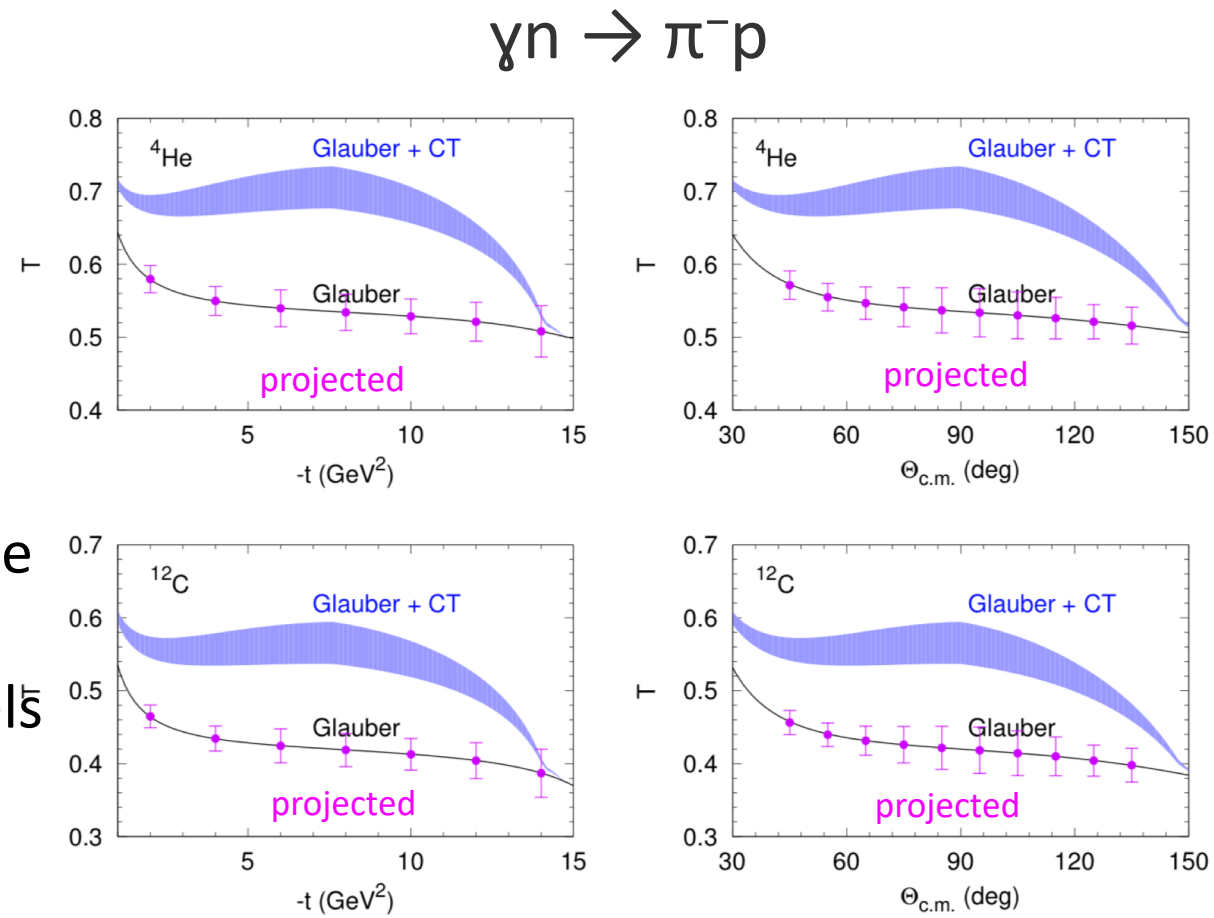
CT in Hall D using photoproduction - analysis underway!

- High photon energy (freezing)
- Extends t-range (3.5 to >10 !)
- Extended $\theta_{C.M}$ coverage
- Many reaction channels (mesons and baryons)
- Ratios taken from data



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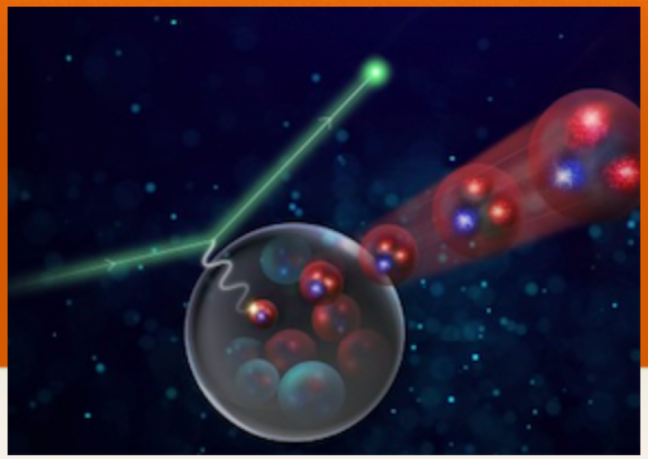
Highlight CT workshop from June 2021



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

7-8 June 2021
Online
US/Eastern timezone

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

Soon to appear!

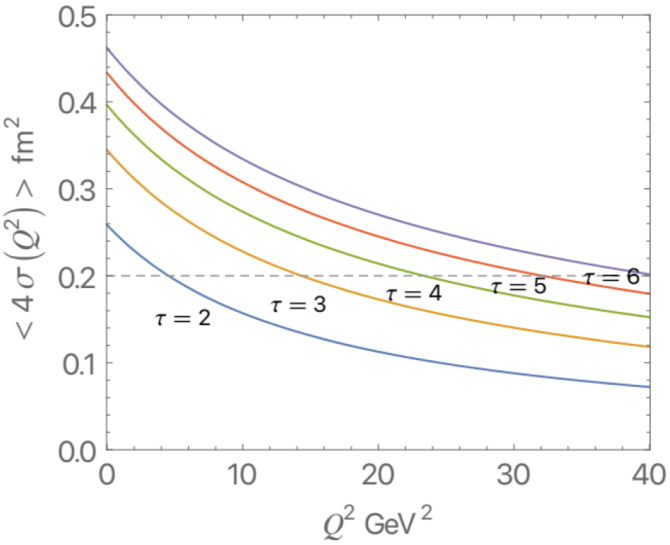
Special Issue "The Future of Color Transparency, Hadronization and Short-Range Nucleon-Nucleon Correlation Studies"

- Special Issue Editors
- Special Issue Information
- Keywords
- Published Papers

A special issue of *Physics* (ISSN 2624-8174). This special issue belongs to the section "High Energy Physics".

Deadline for manuscript submissions: **30 April 2022**.

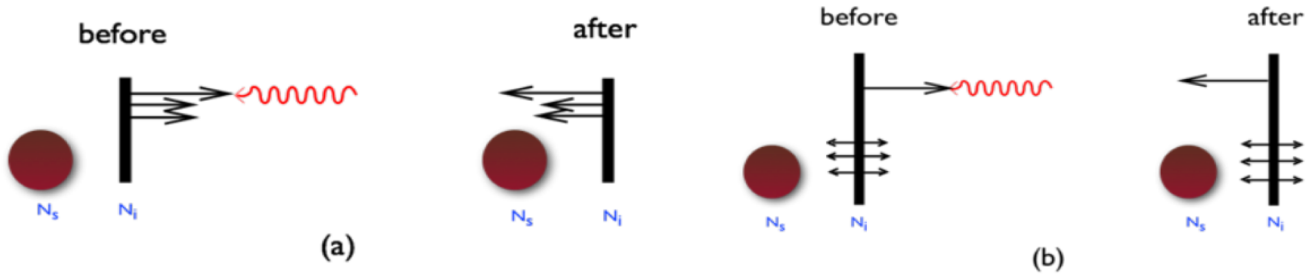
Theory response to recent lack of proton CT – not exhaustive!



Proton has 2-stage CT beginning at Q^2>14 GeV^2, and full onset at Q^2>22 GeV^2

Onset of color transparency in holographic light-front QCD, Brodsky & Teramond, https://arxiv.org/pdf/2202.13283.pdf

PLC not formed, Feynman Mechanism responsible for high momentum EM FF of proton



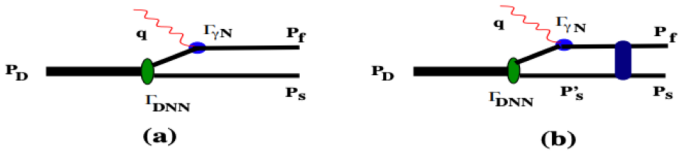
PLC

Feynman

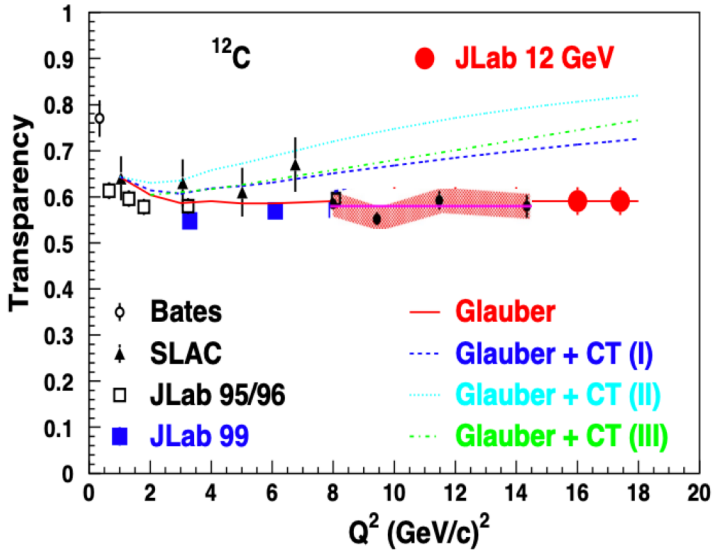
Color Transparency and the Proton Form Factor- Feynman Wins, Caplow-Munro & Miller, https://arxiv.org/pdf/2104.11168.pdf

Alternative places to look: deuterium!

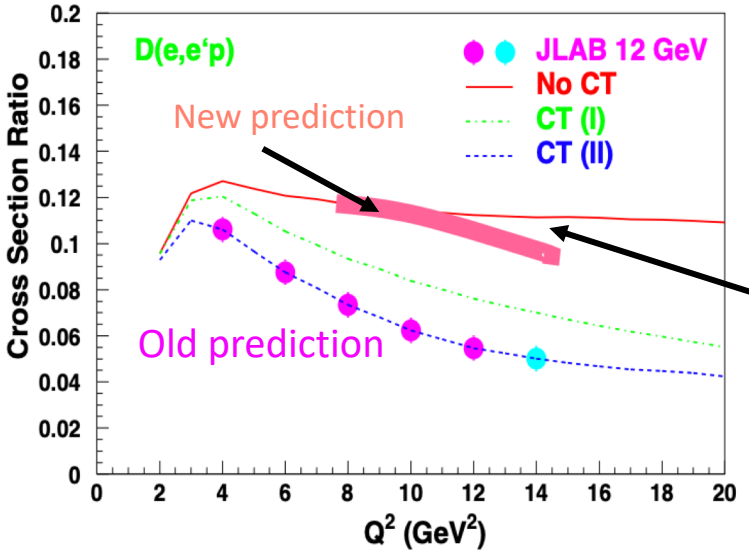
$e + d \rightarrow e' + p + n$ CT in Double Scattering



MS et al, Hadrons in the Nuclear Medium, J.Phys. G 2003



$$R = \frac{\sigma(p_r = 400 MeV/c)}{\sigma(p_r = 200 MeV/c)}$$



Look for CT here

$$\sigma_{tot}(l, Q^2) = \sigma_{tot} \left\{ \left[\left(\frac{l}{l_h} \right)^n + \frac{\langle r_t(Q^2)^2 \rangle}{\langle r_t^2 \rangle} \left(1 - \left(\frac{l}{l_h} \right)^n \right) \right] \Theta(l_h - l) + \Theta(l - l_h) \right\},$$

$$n = \frac{1}{2}$$

$$l_h = 2p_f / \Delta\, M^2 \qquad \Delta\, M^2 = 1.1\ GeV^2$$

Slide from Misak Sargsian

Jefferson Lab

Summary and outlook

- Recent Hall C measurement inspires new theory examination
- Recent measurement using photoproduction in Hall D, and new measurements on mesons in coming year
- Active and exciting field of research with lots of theory and experimental collaboration!

Special thanks to the Hall C Collaboration!

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