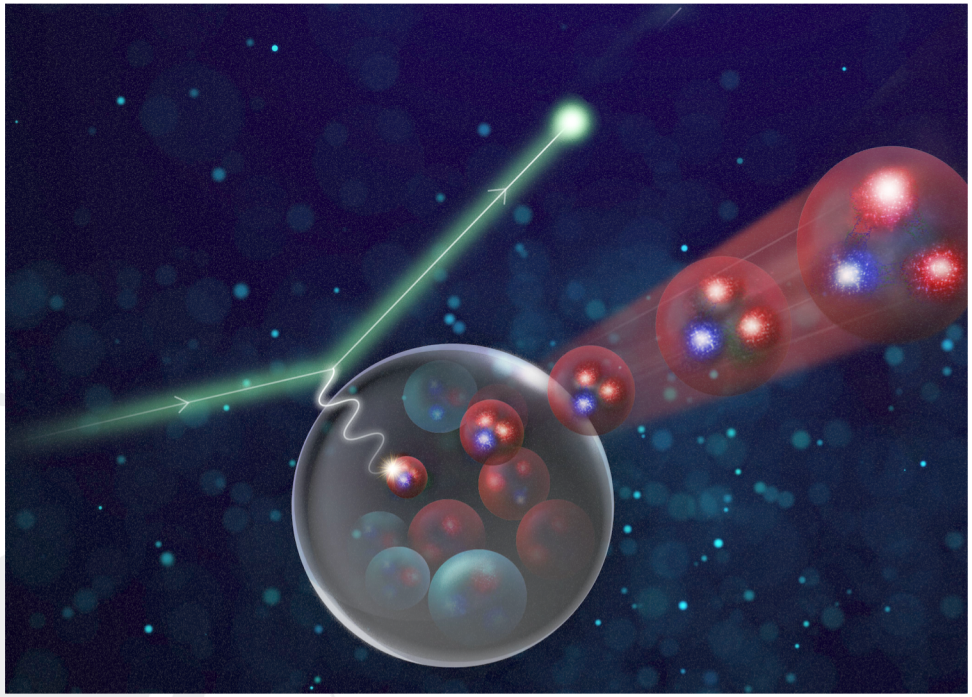
Color transparency in JLab experiments and different reaction mechanisms



Holly Szumila-Vance
Jefferson Lab

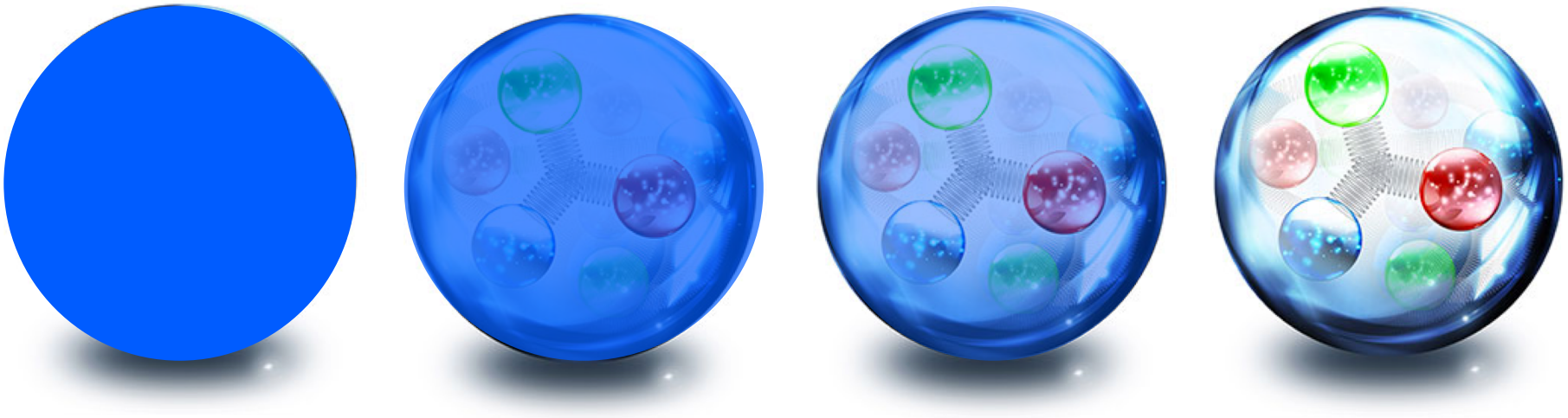
Workshop on The Future of Color Transparency and Hadronization Studies at Jefferson Lab and Beyond

7 June 2021

QCD describes the strong force in terms of quarks and gluons with color charge

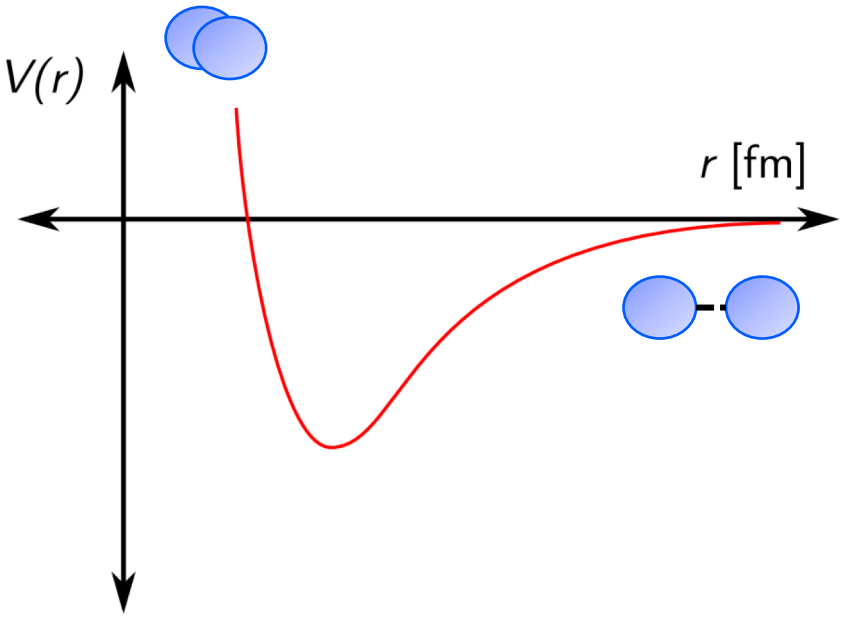
nucleons & nuclei

quarks & gluons



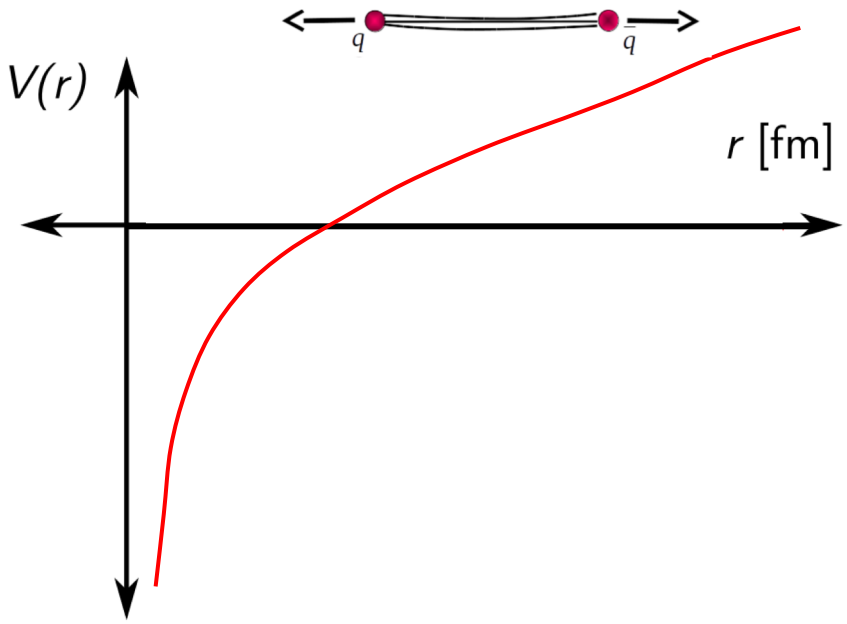
How do we describe nuclei in terms of quarks & gluons?

Potential between nucleons



nucleons & mesons

Potential between quarks

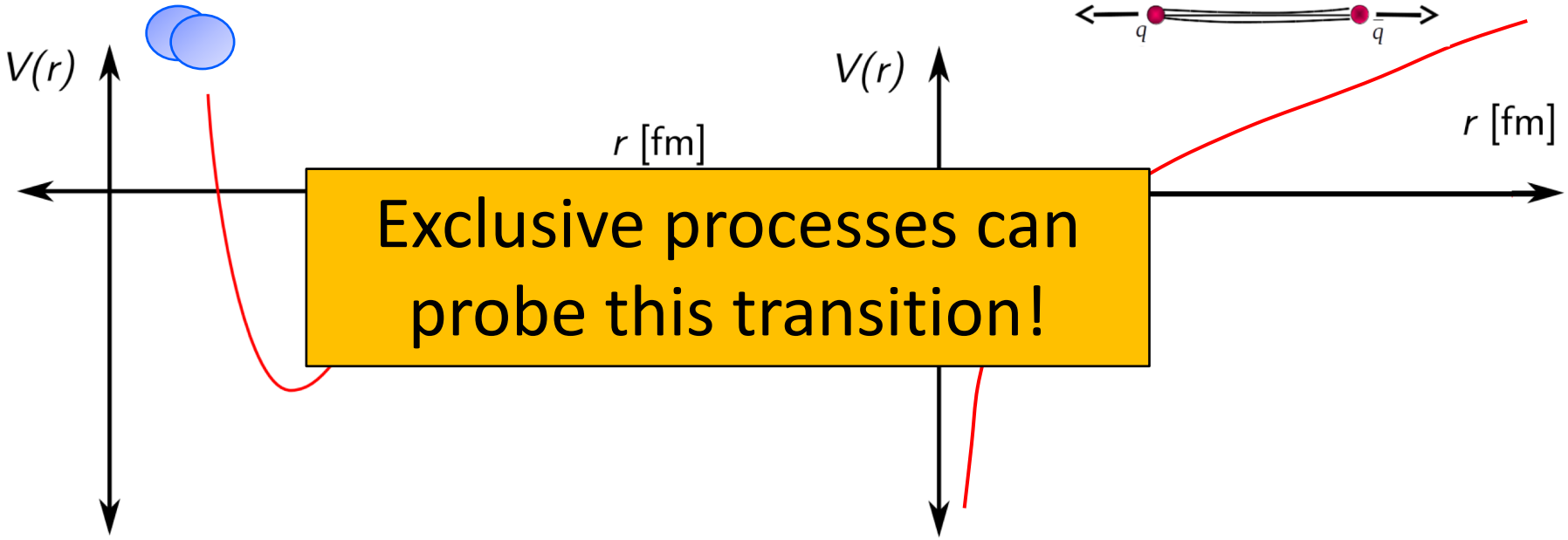


quarks & gluons

How do we describe nuclei in terms of quarks & gluons?

Potential between nucleons

Potential between quarks



Exclusive processes can probe this transition!

nucleons & mesons

quarks & gluons

In this talk:

Onset of CT

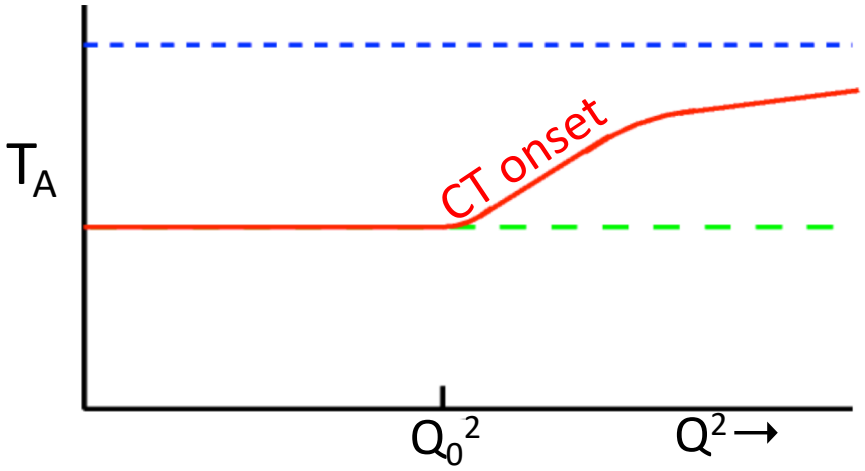
^{12}C(e,e'p) results from Hall C

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

Next photo- and electro-production experiments

In this talk:

Onset of CT



^{12}C(e,e'p) results from Hall C

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

Next photo- and electro-production experiments

Nuclear transparency

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

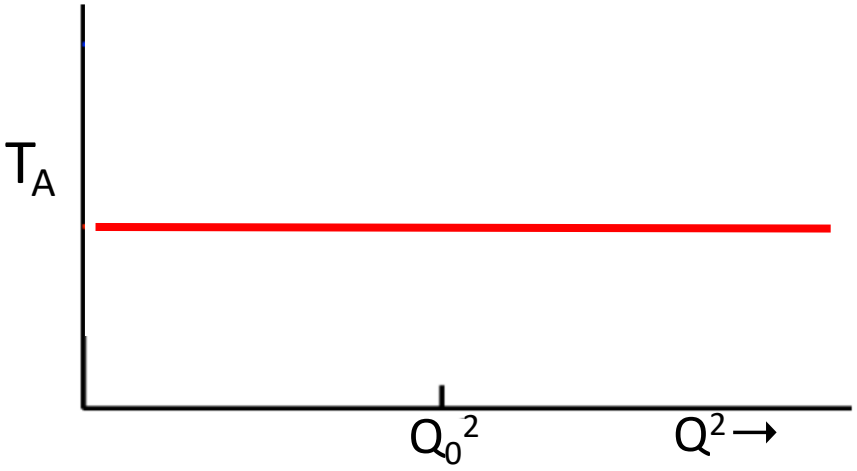
$$T_A = \frac{\sigma_A}{A\ \sigma_N}$$

(nuclear cross section)

(free nucleon cross section)

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

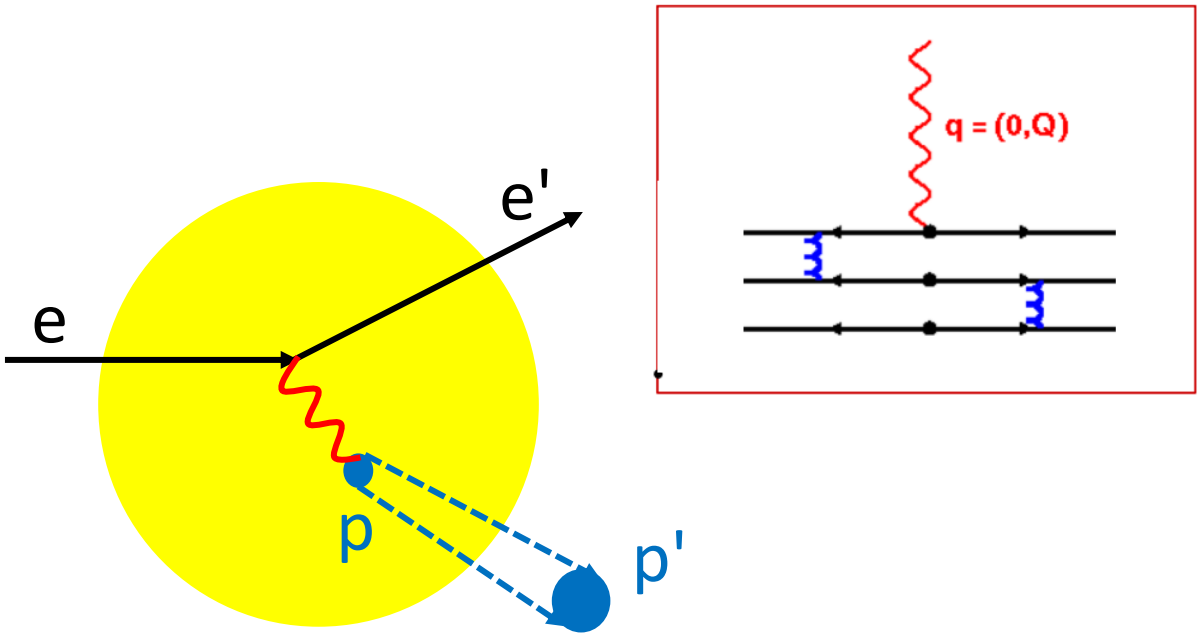
Traditional nuclear physics calculations predict energy independent transparency



Transparency:

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

Color transparency fundamental prediction of QCD

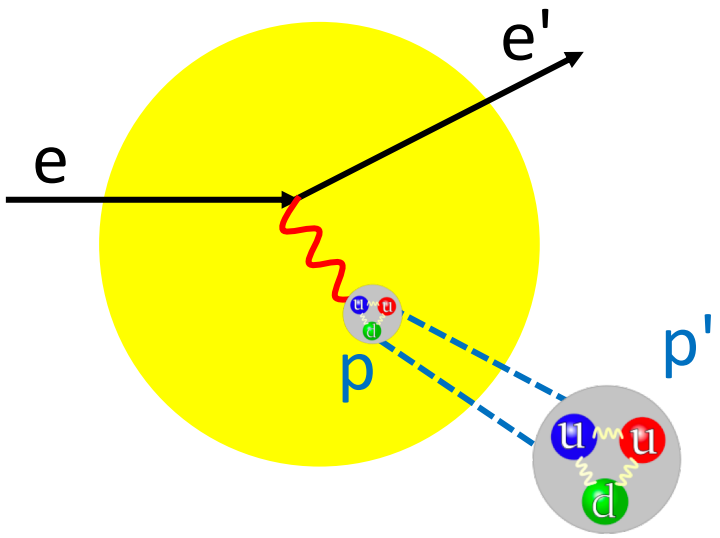


Introduced by Mueller and Brodsky, 1982

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)

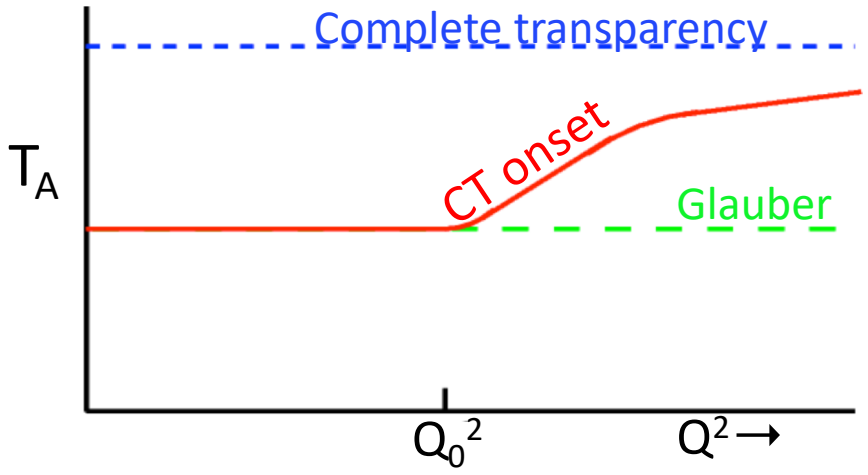


Relativity:
Maintains this small size as it propagates out of the nucleus (*freezing*, transferred energy)

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

Color transparency fundamental prediction of QCD

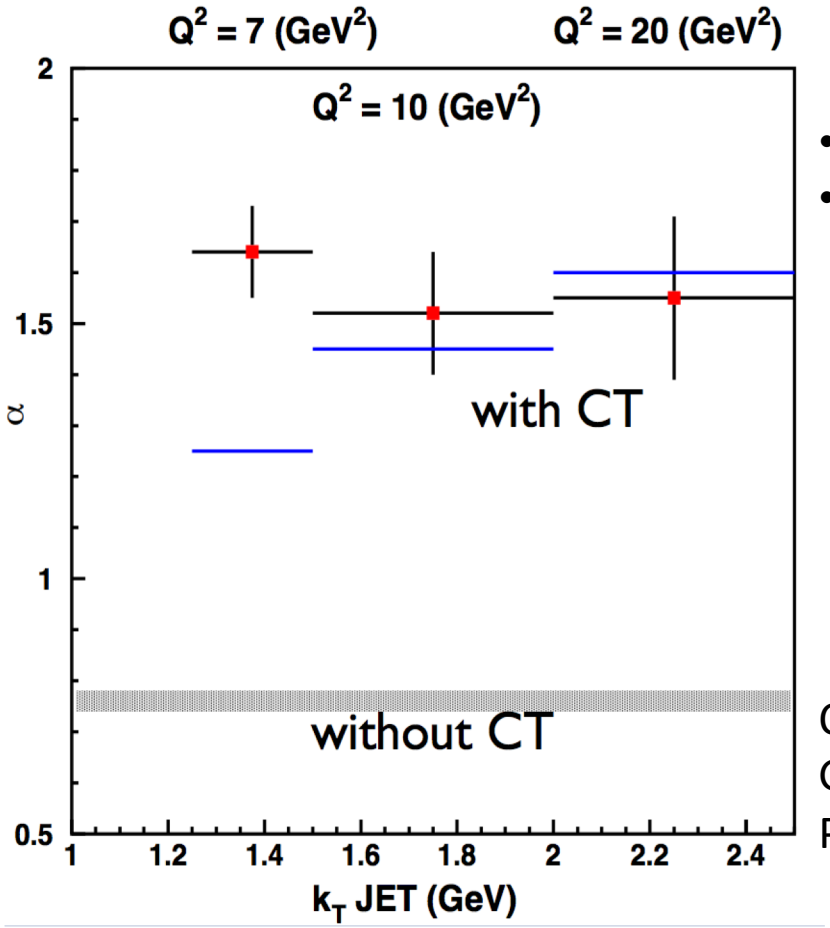
- Not predicted by strongly interacting hadronic picture → arises in picture of quark-gluon interactions
- QCD: color field of singlet objects vanishes as size is reduced
- Signature is a rise in nuclear transparency, T_A, as a function of the momentum transfer, Q^2



CT at high energies

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

π + A → 2 jets + A'



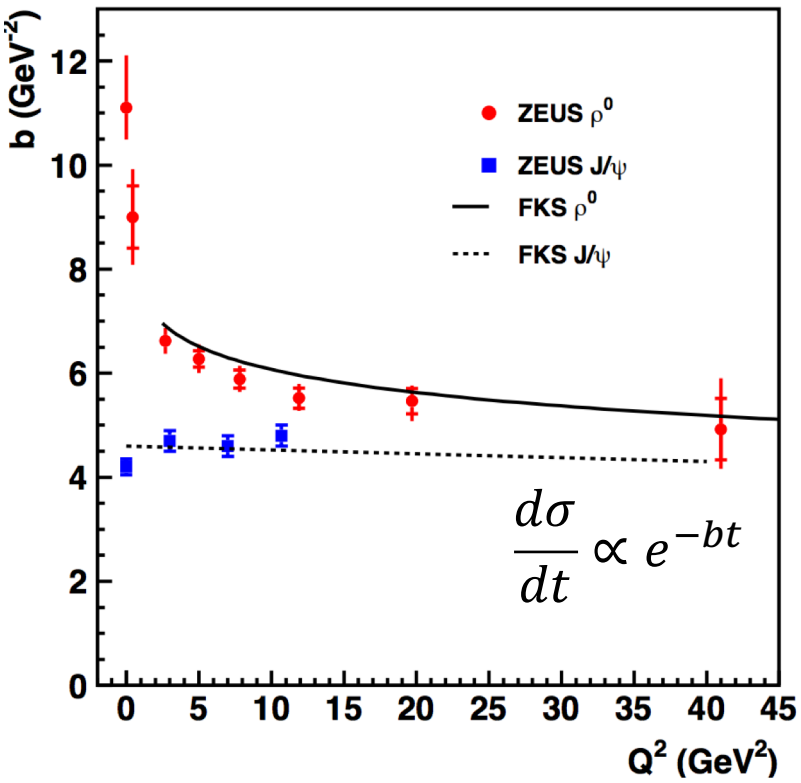
- Fit to $\sigma = \sigma_0 A^{\alpha}$
- Pion-nucleus total cross section, α=1.6

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

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

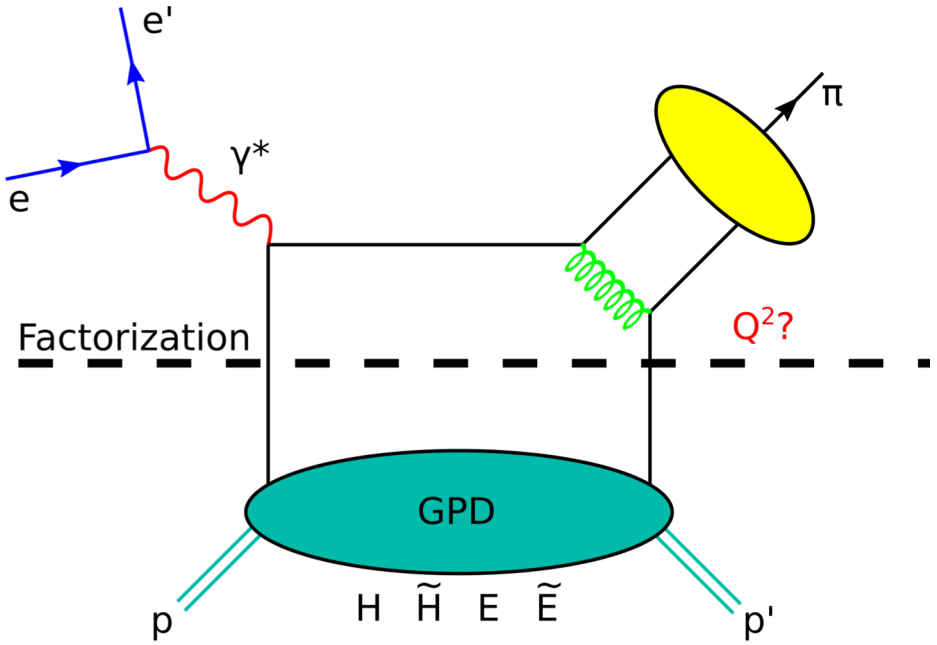
CT at high energies

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

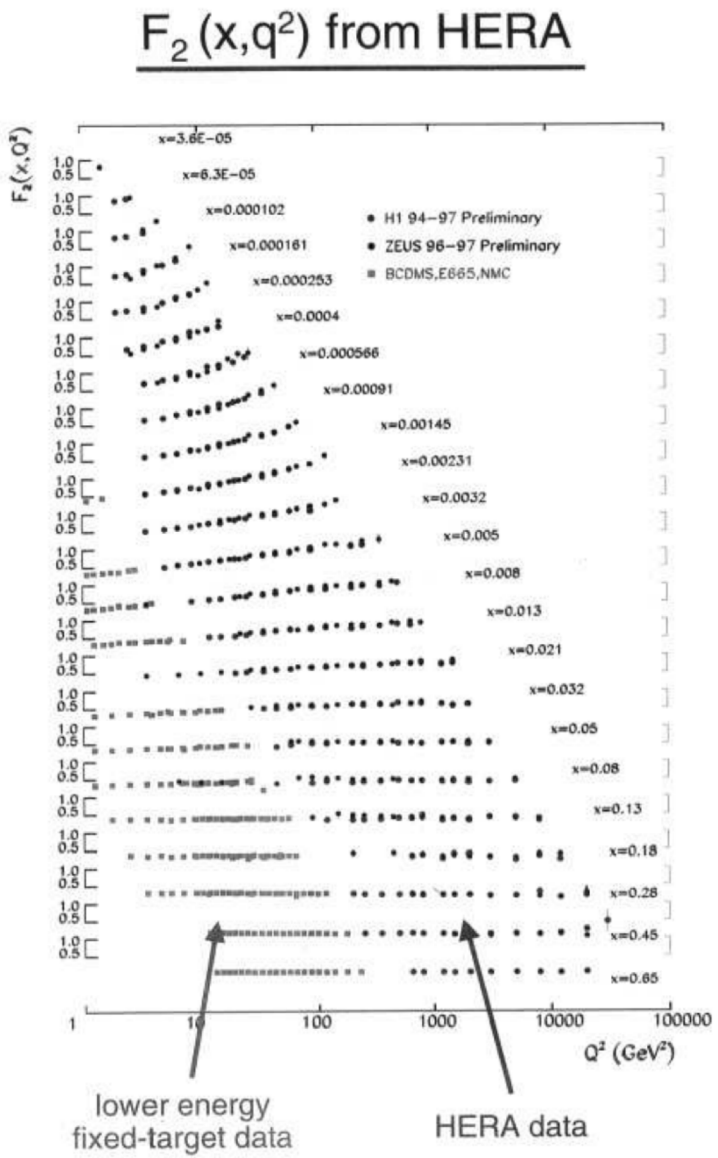


Color cancellation needed for **factorization**:

-> small objects

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

CT at high energies



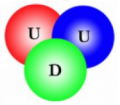
DIS from heavy targets at high energies shows Bjorken scaling

evidence of no FSI ➞ CT?

CT experiments

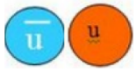
CT experiments

Baryon

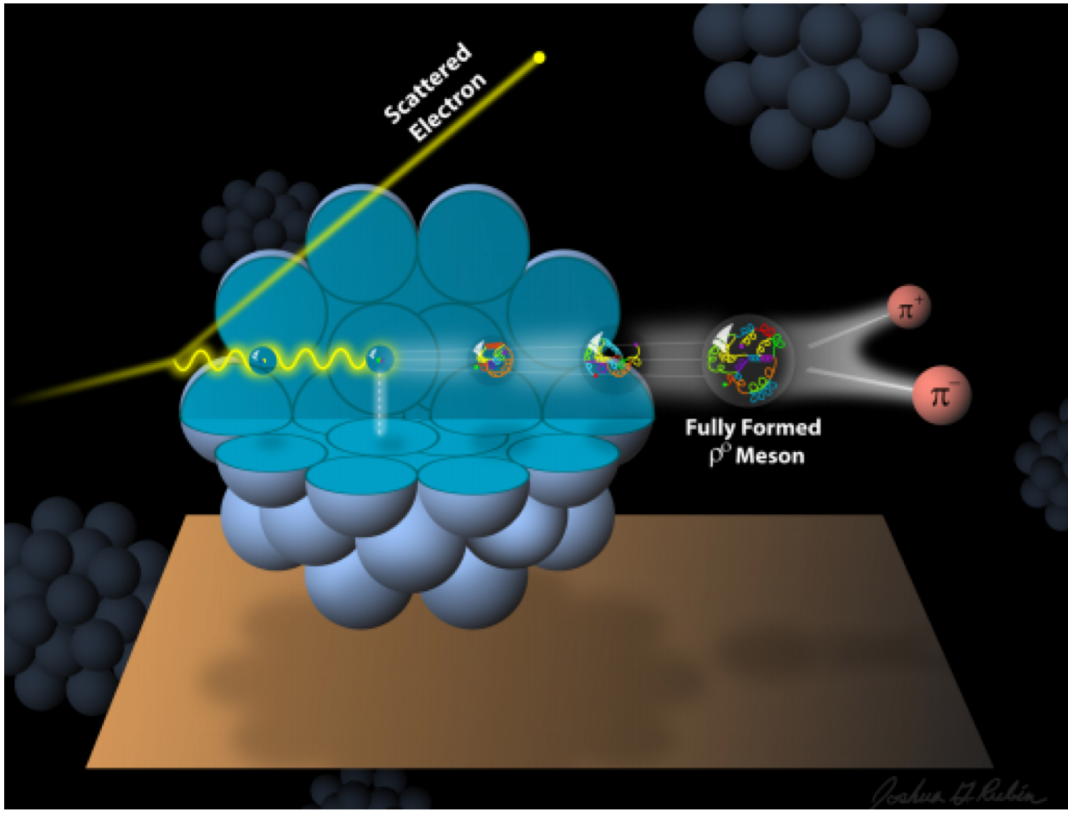


A(p,2p): BNL
A(e,e'p): SLAC, JLab

Meson



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

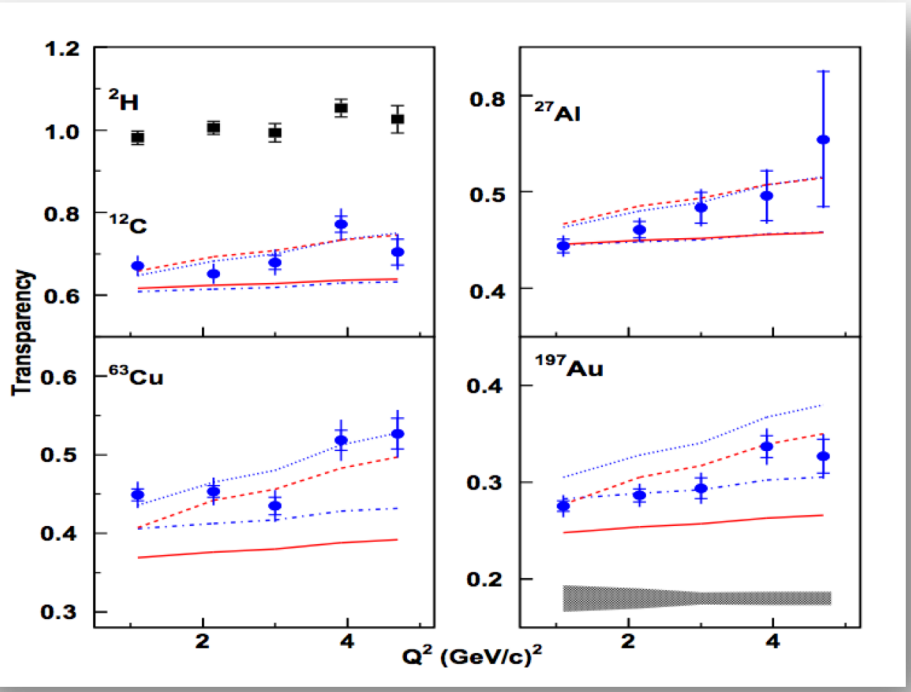


Previous Measurements: Mesons

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

Hall C E01-107 pion electro-production

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

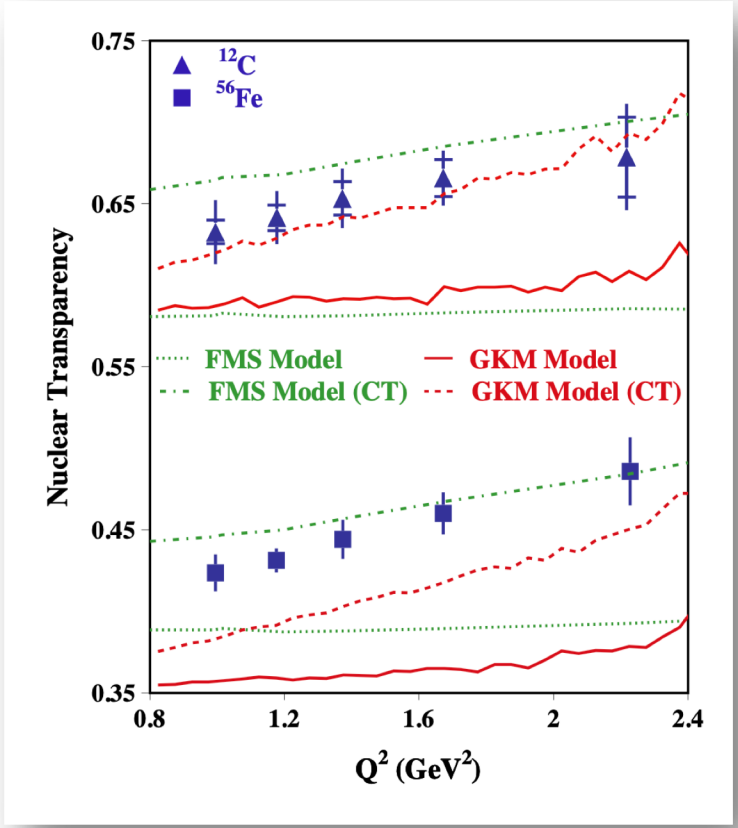


B.Clasie *et al.* PRL 99:242502 (2007)

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

CLAS E02-110 rho electro-production

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



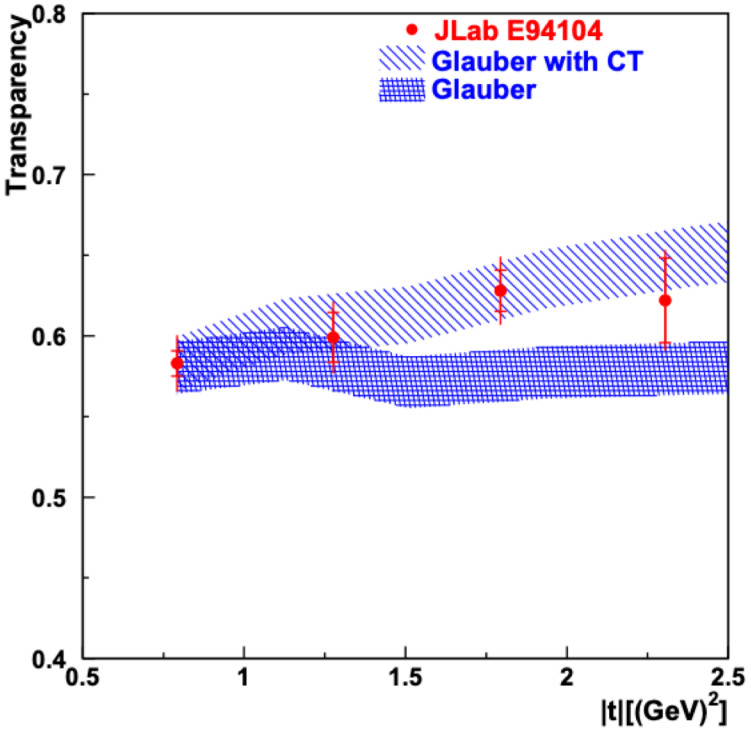
L. El Fassi *et al.* PLB 712,326 (2012)

Jefferson Lab

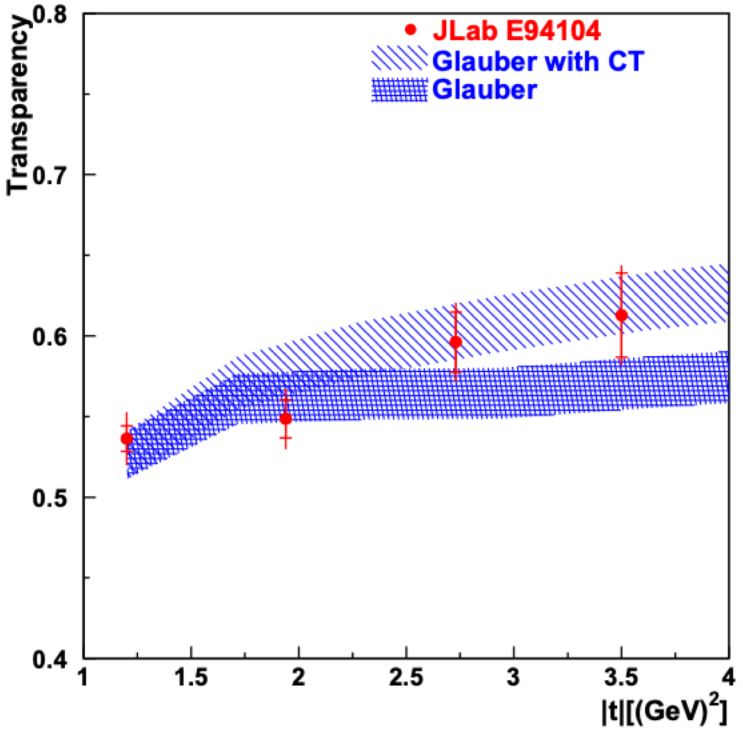
Previous Measurements: Testing pion photoproduction

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

70° c.m. scattering

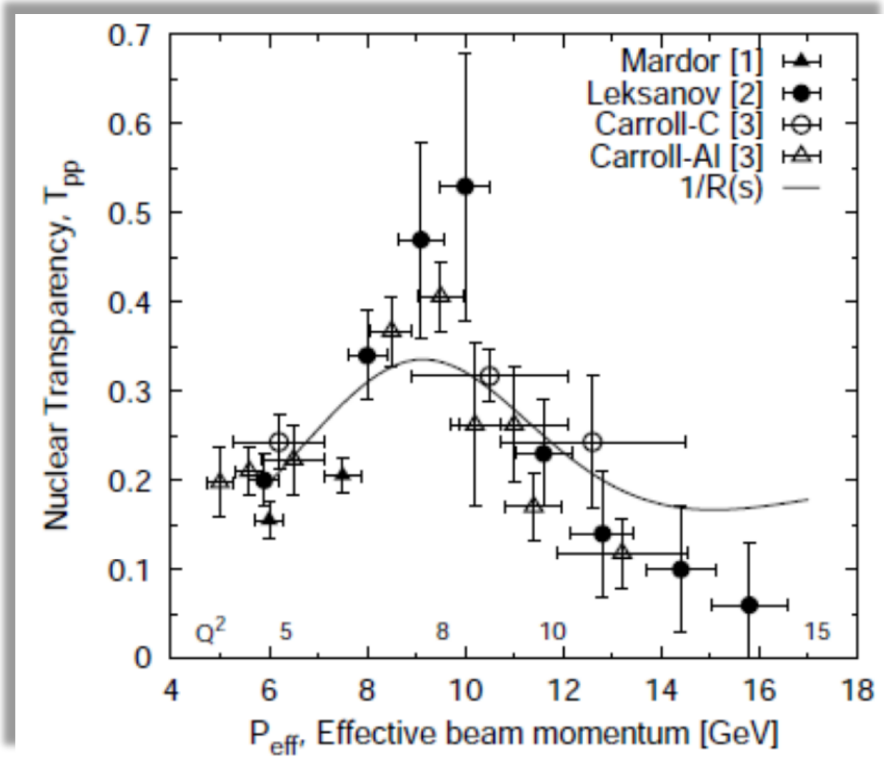


90° c.m. scattering



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

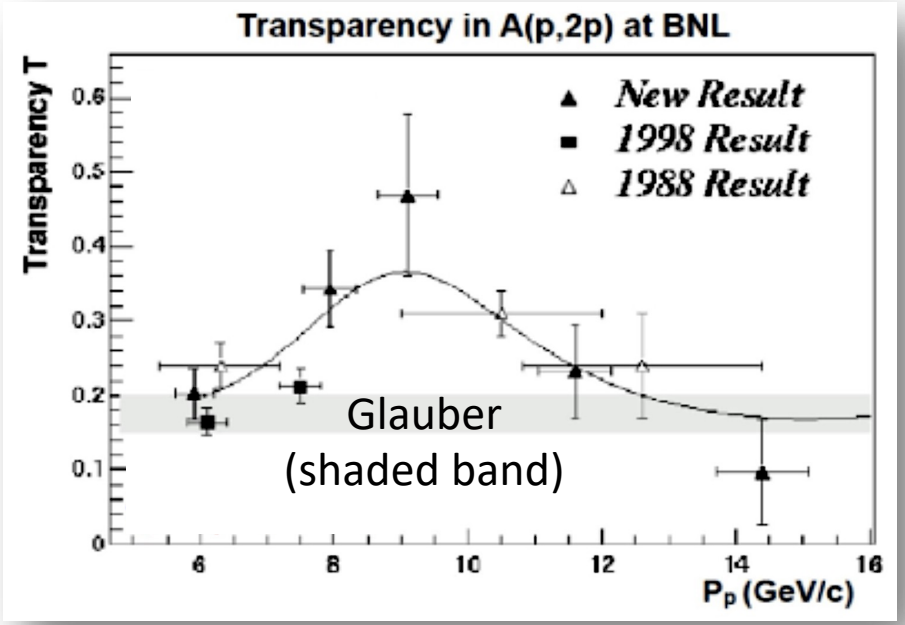
Previous Measurements: Baryons



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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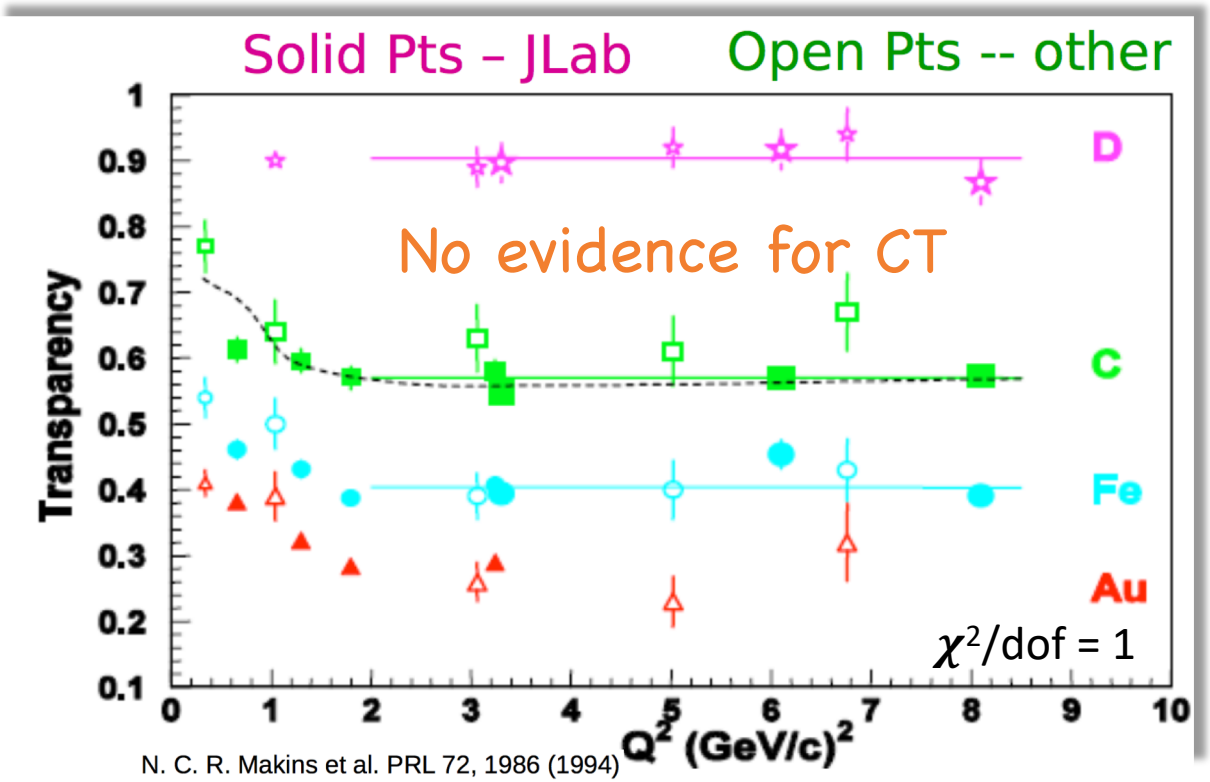
Previous Measurements: Baryons

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)

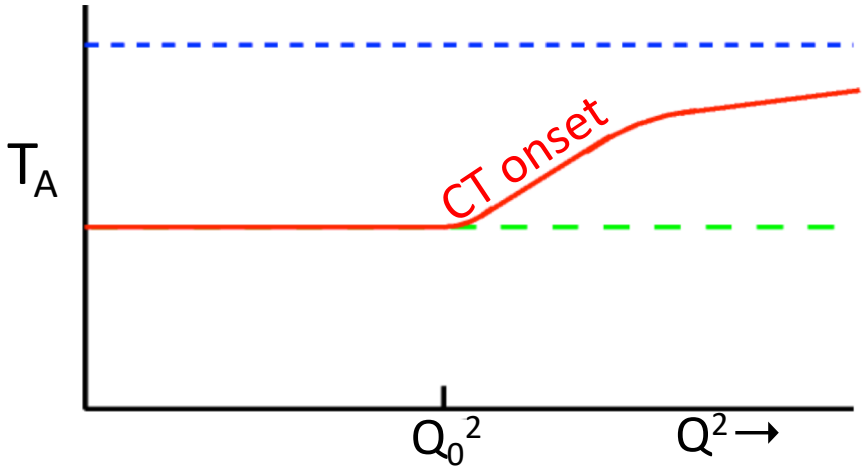
In this talk:

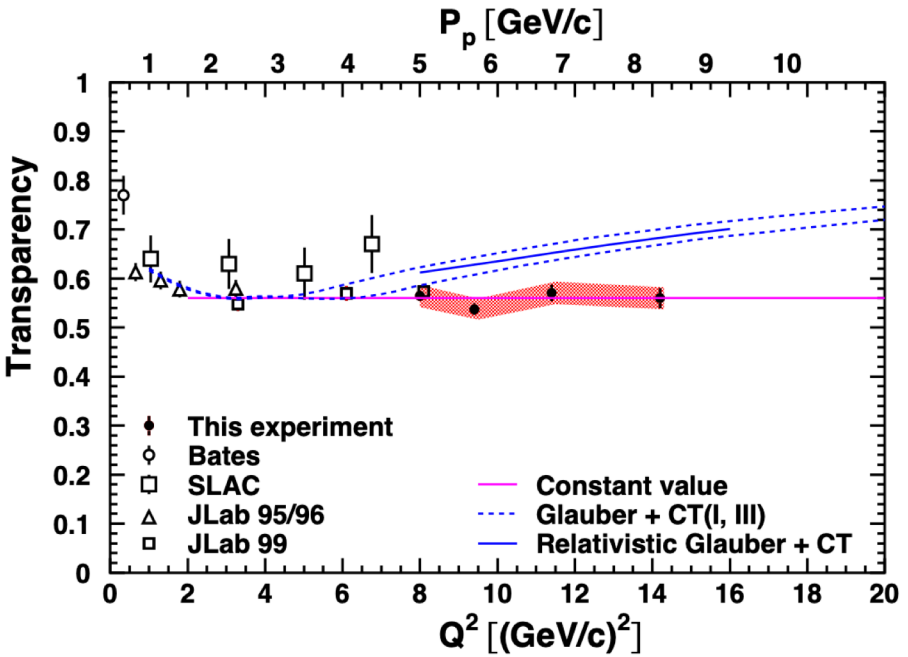
Onset of CT

^{12}C(e,e'p) results from Hall C

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

Next photo- and electro-production experiments





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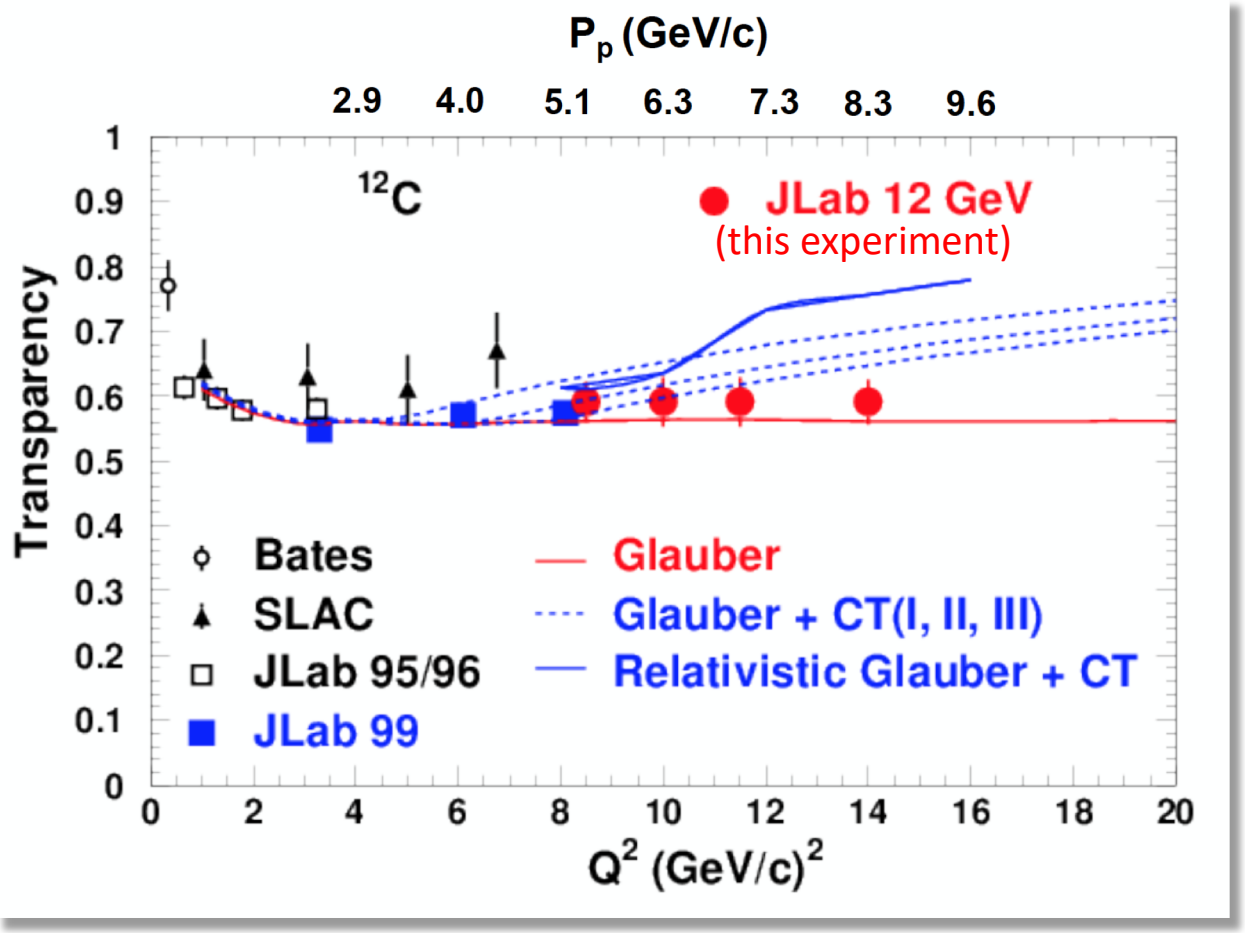
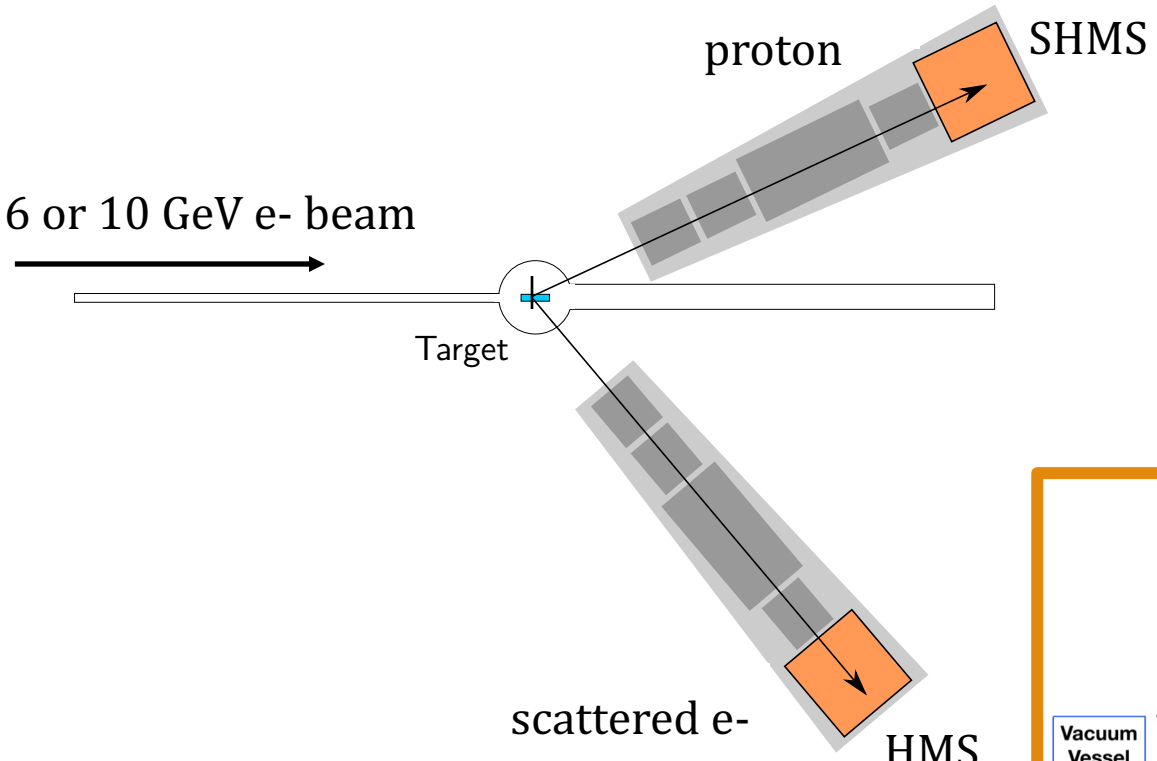
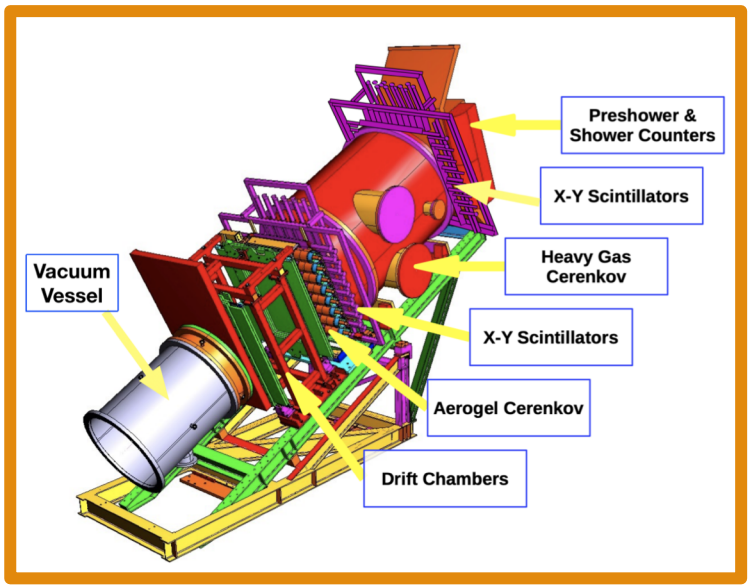
A(e,e'p) can reach higher proton momenta in 12 GeV upgrade



Jefferson Lab

CT in Hall C at Jefferson Lab





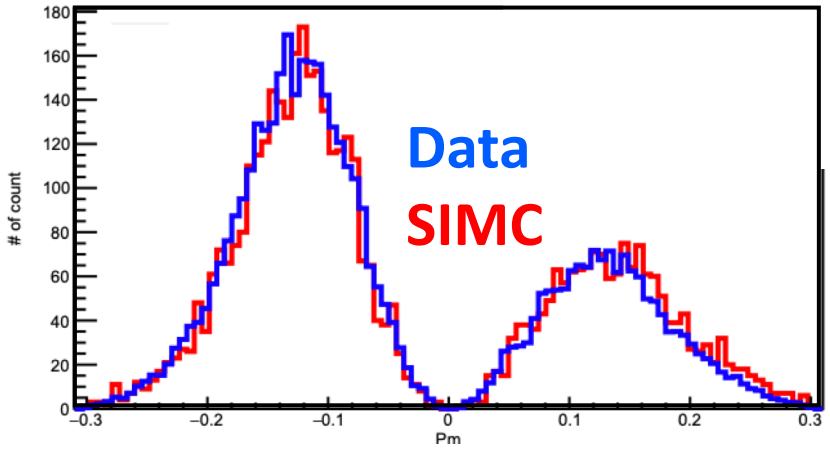
$$T(Q^2) = \frac{\int_V d^3p_m dE_m Y_{\rm exp}(E_m, \vec{p}_m)}{\int_V d^3p_m dE_m Y_{\rm PWIA}(E_m, \vec{p}_m)}$$

Jefferson Lab

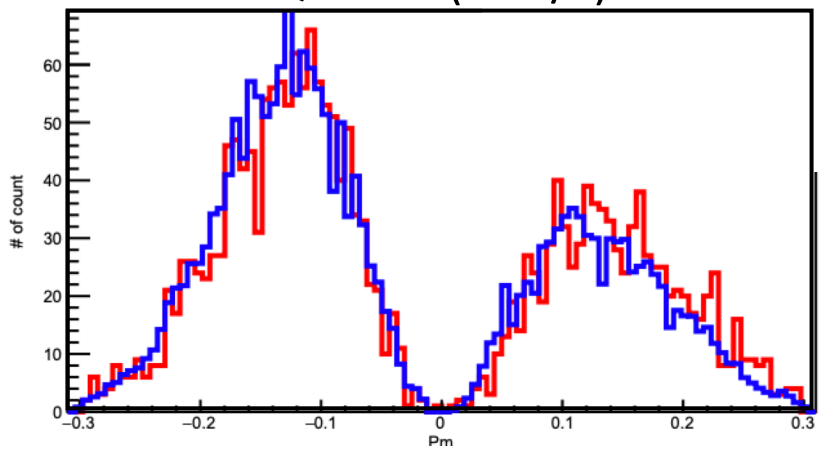
Carbon missing momentum

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

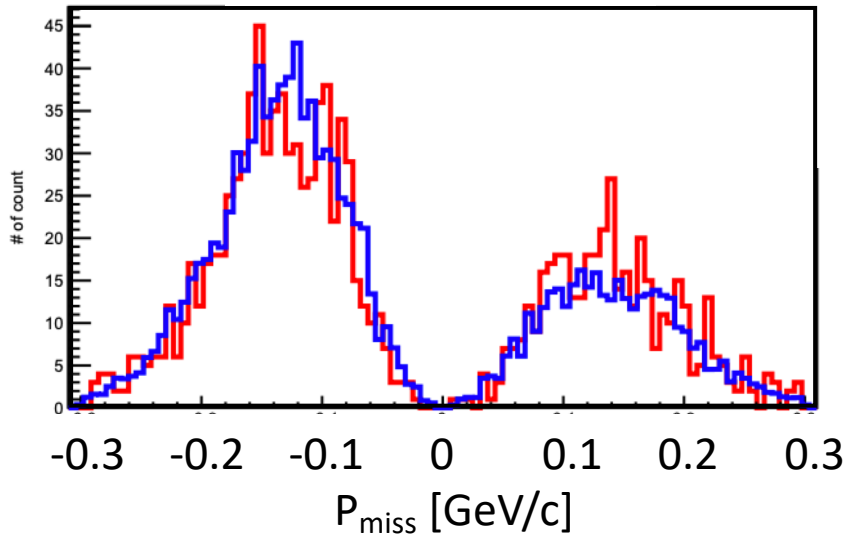
Q^2 = 8 (GeV/c)^2



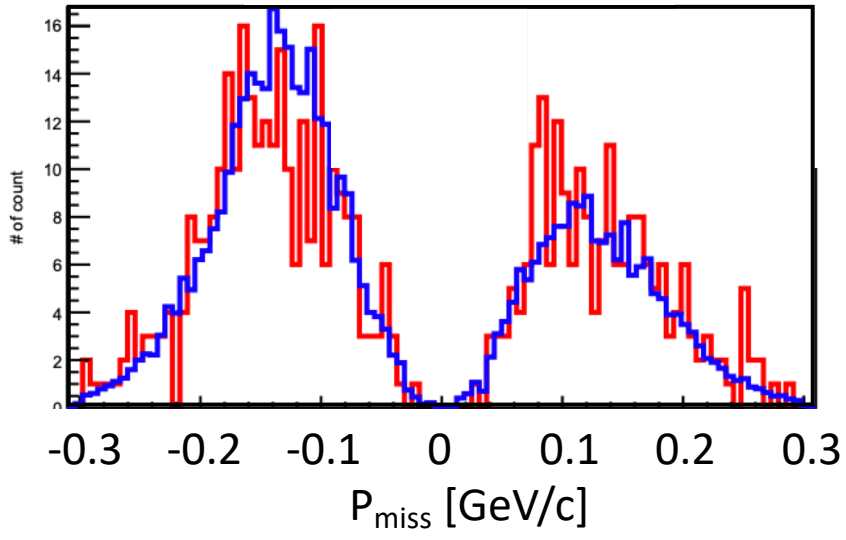
Q^2 = 9.4 (GeV/c)^2



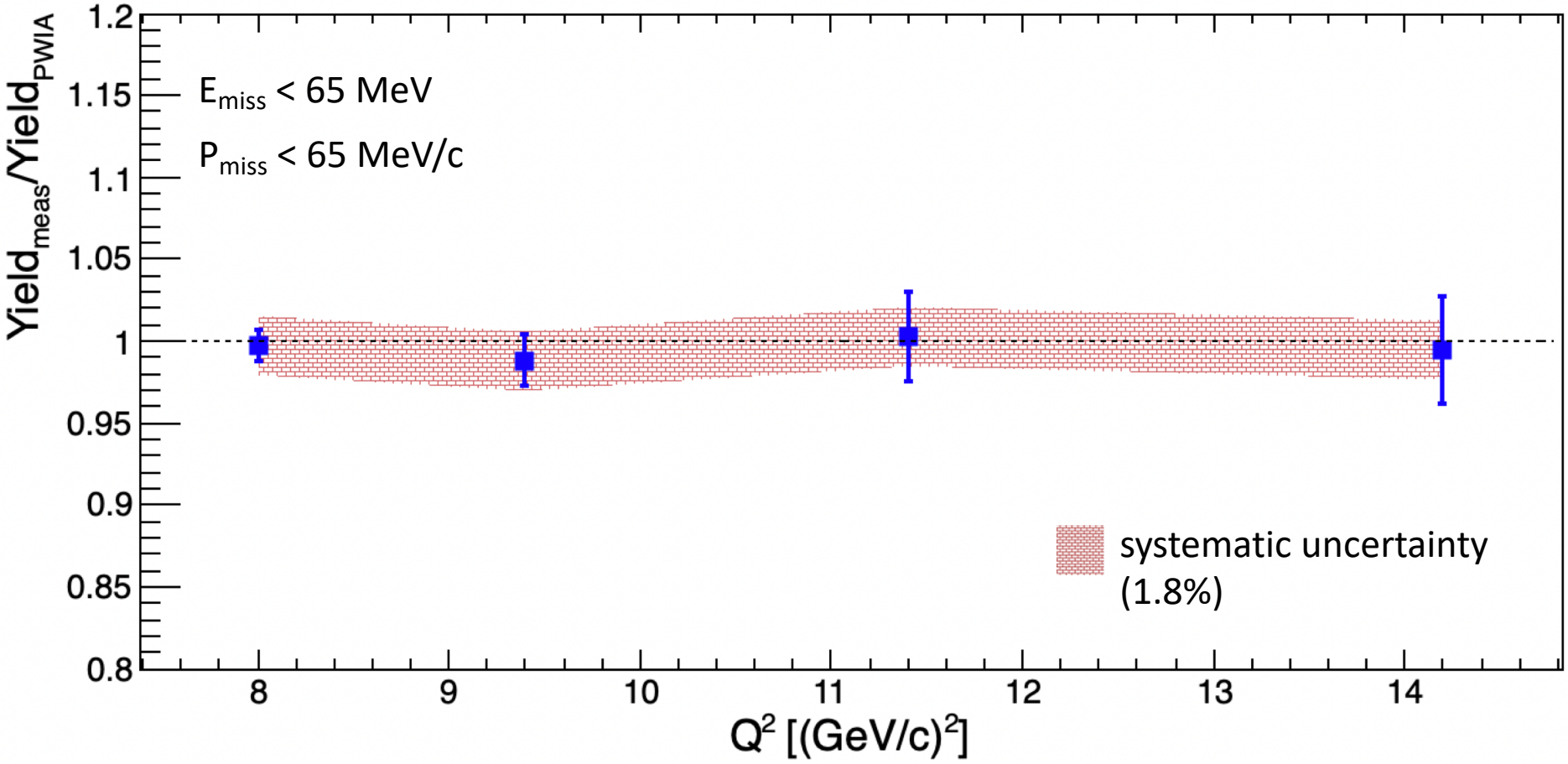
Q^2 = 11.4 (GeV/c)^2



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



Hydrogen yield



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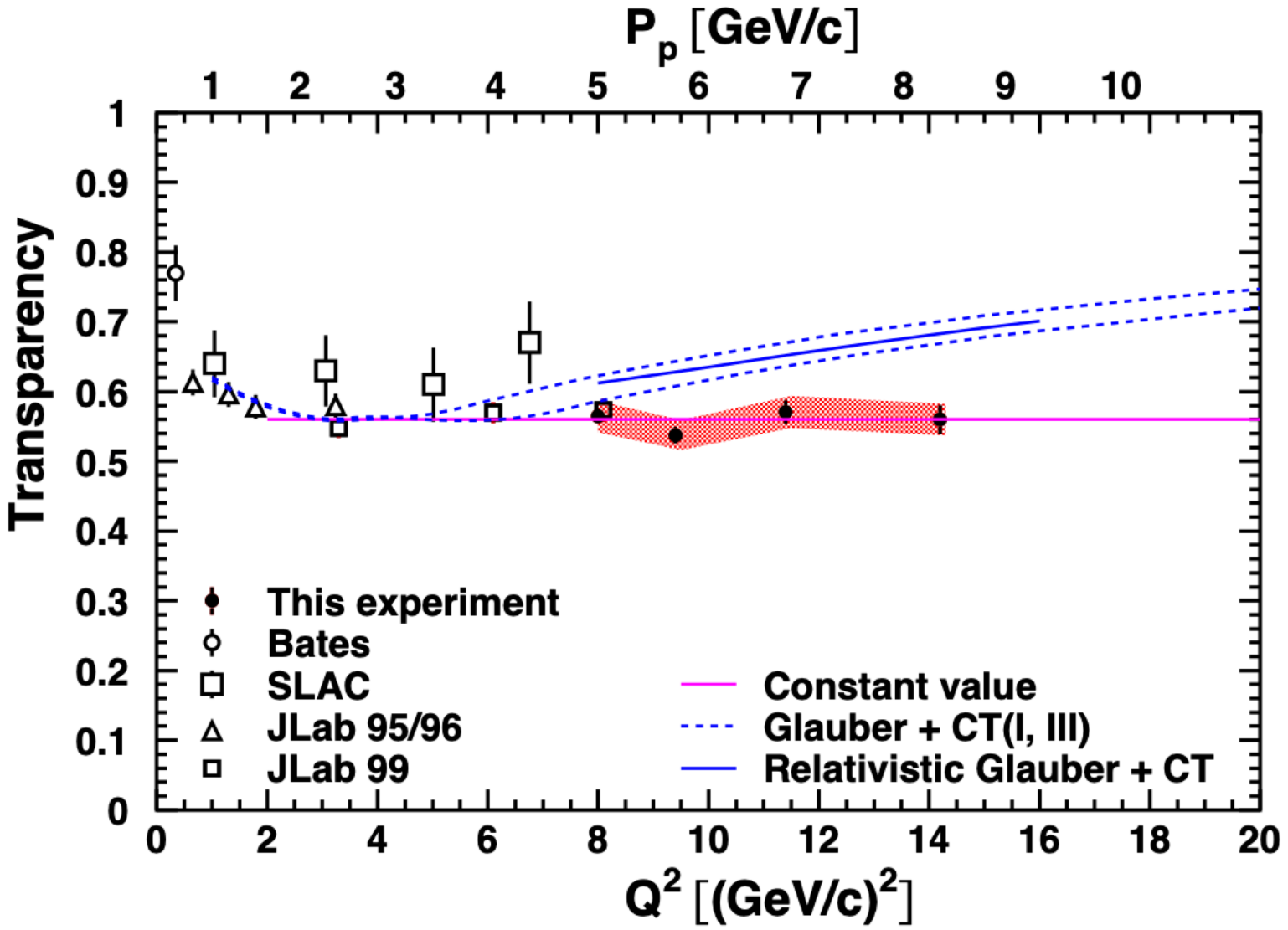
Systematic uncertainty

Source	Q^2 dependent uncertainty (%)
Spectrometer acceptance	2.6
Event selection	1.4
Tracking efficiency	0.5
Radiative corrections	1.0
Live time & Det. efficiency	0.5
Source	**Normalization uncertainty (%)**
Elastic *ep* cross section	1.8
Target thickness	0.5
Beam charge	1.0
Proton absorption	1.2
Total	4.0

No observation of the onset of CT



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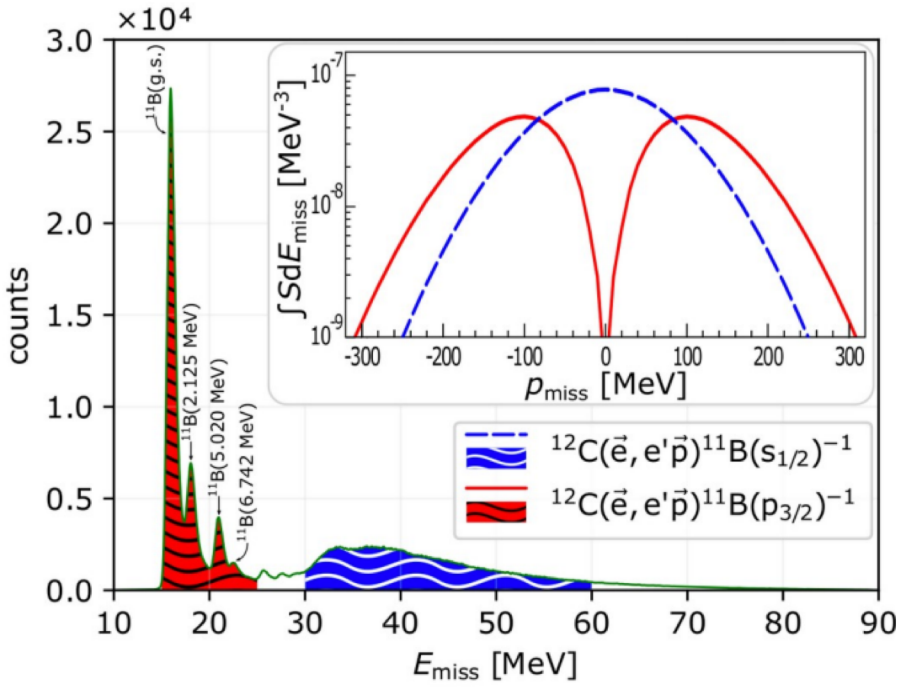
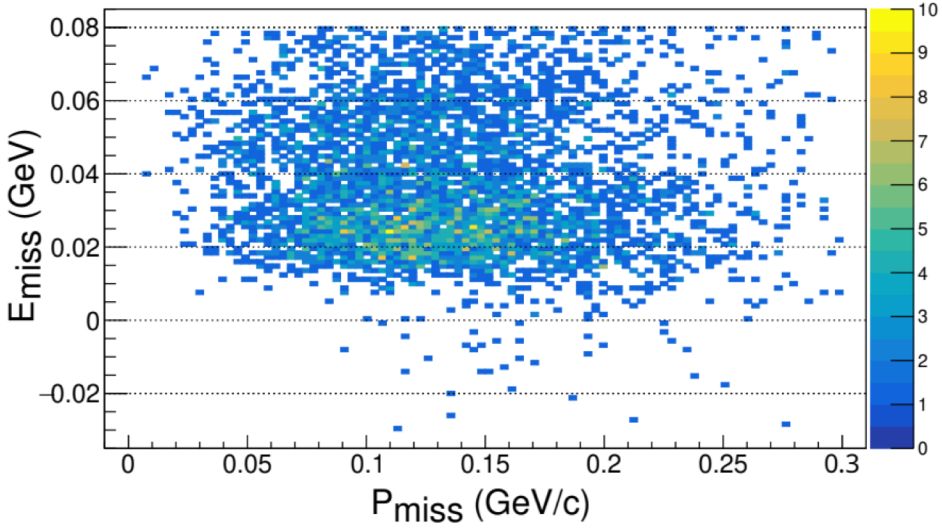
Checking for shell dependent transparency

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



D. Izraeli et al.,PLB, vol. 781, Jun 2018, p. 95–98

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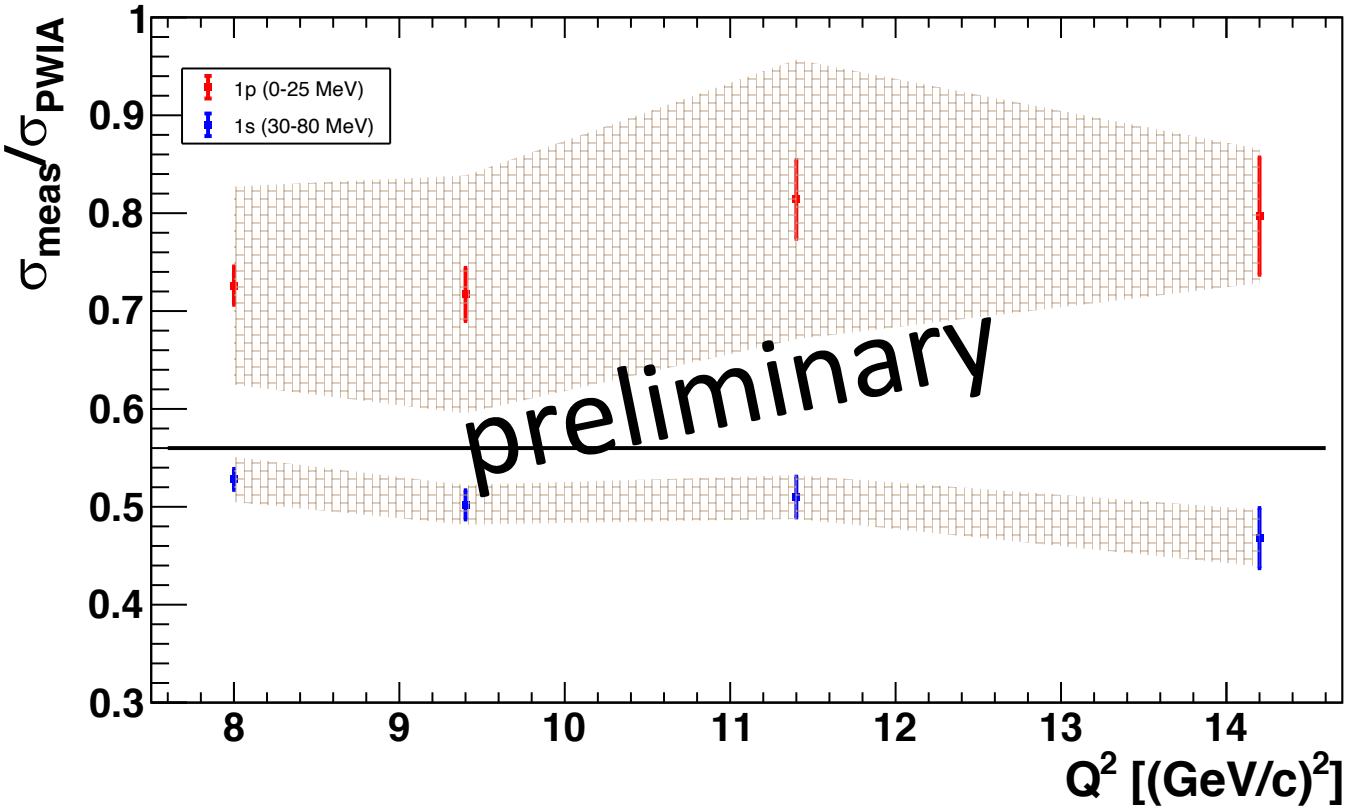
1s- and 1p- shell transparency

Courtesy of D. Bhetuwal



Seems to be an apparent issue with the cut dependence

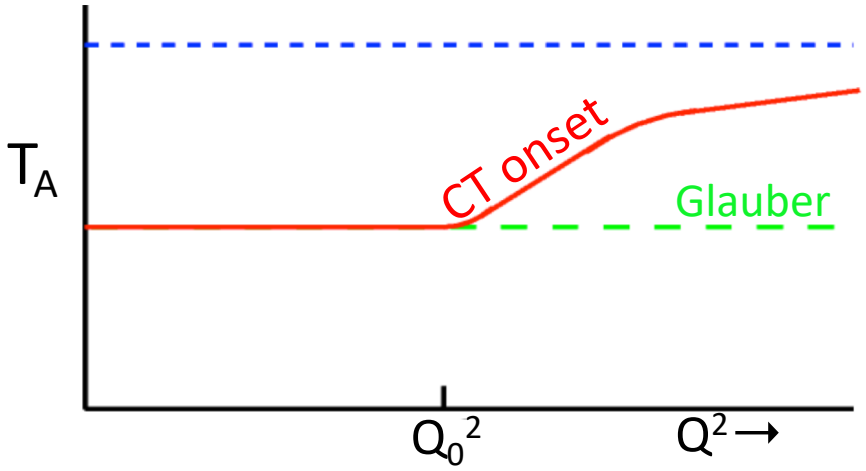
In this talk:

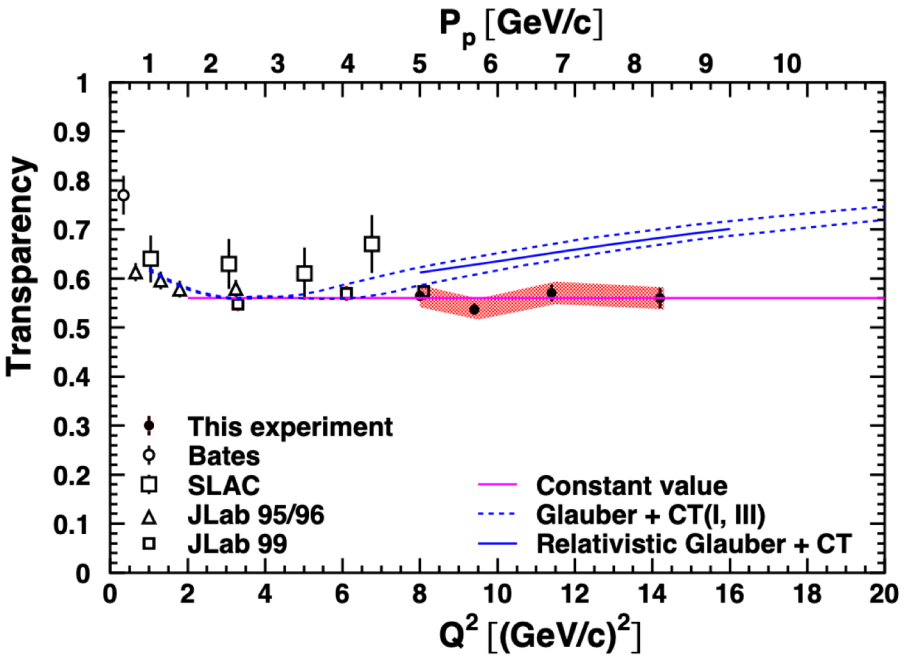
Onset of CT

^{12}C(e,e'p) results from Hall C

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

Next photo- and electro-production experiments

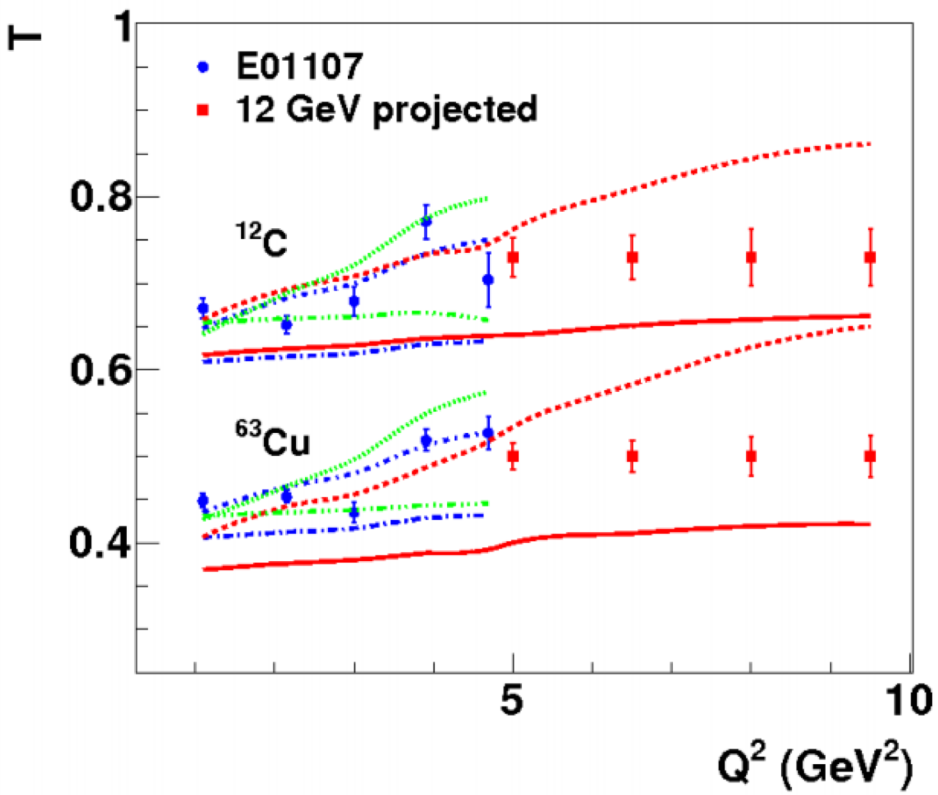


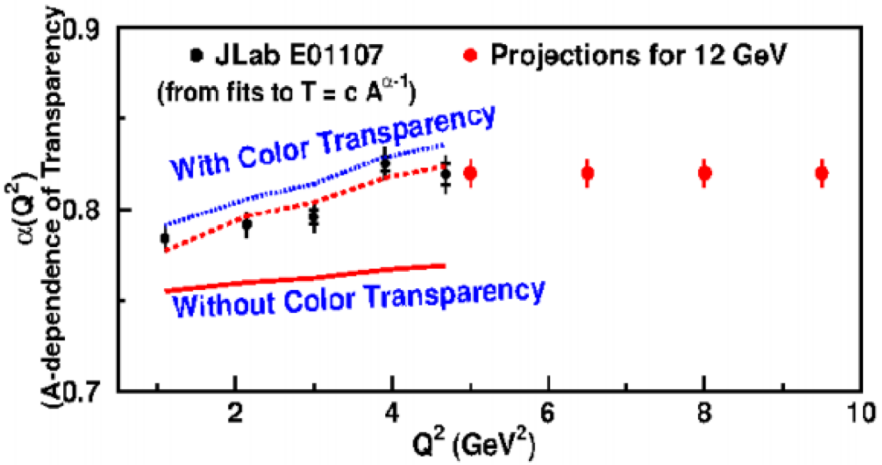


Jefferson Lab

Explore onset of CT in mesons

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

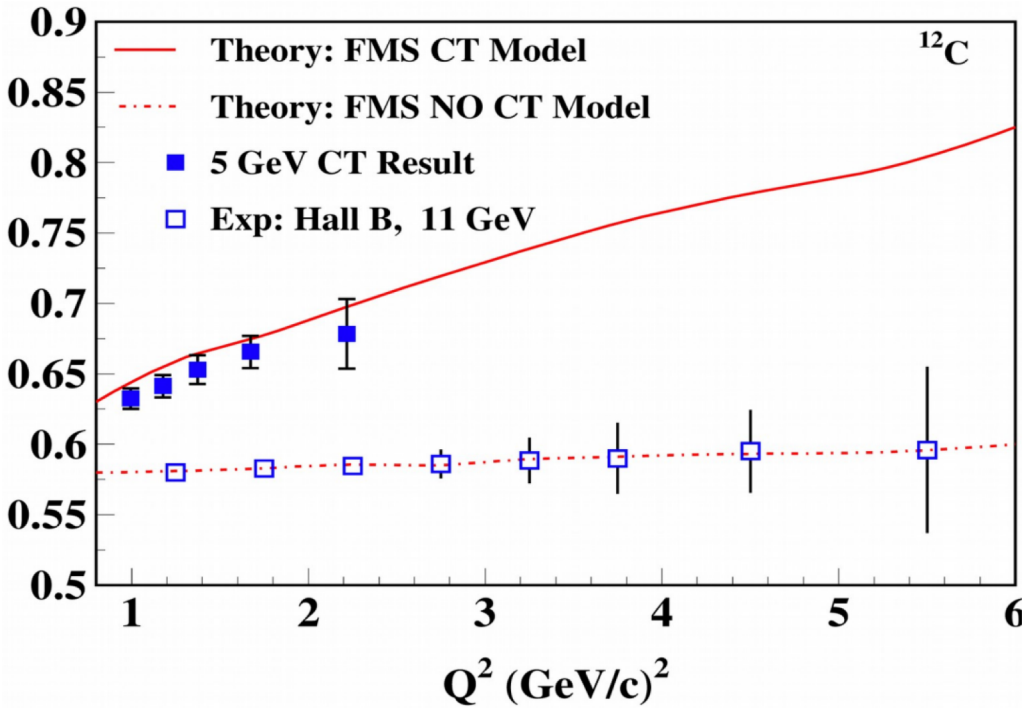




Jefferson Lab

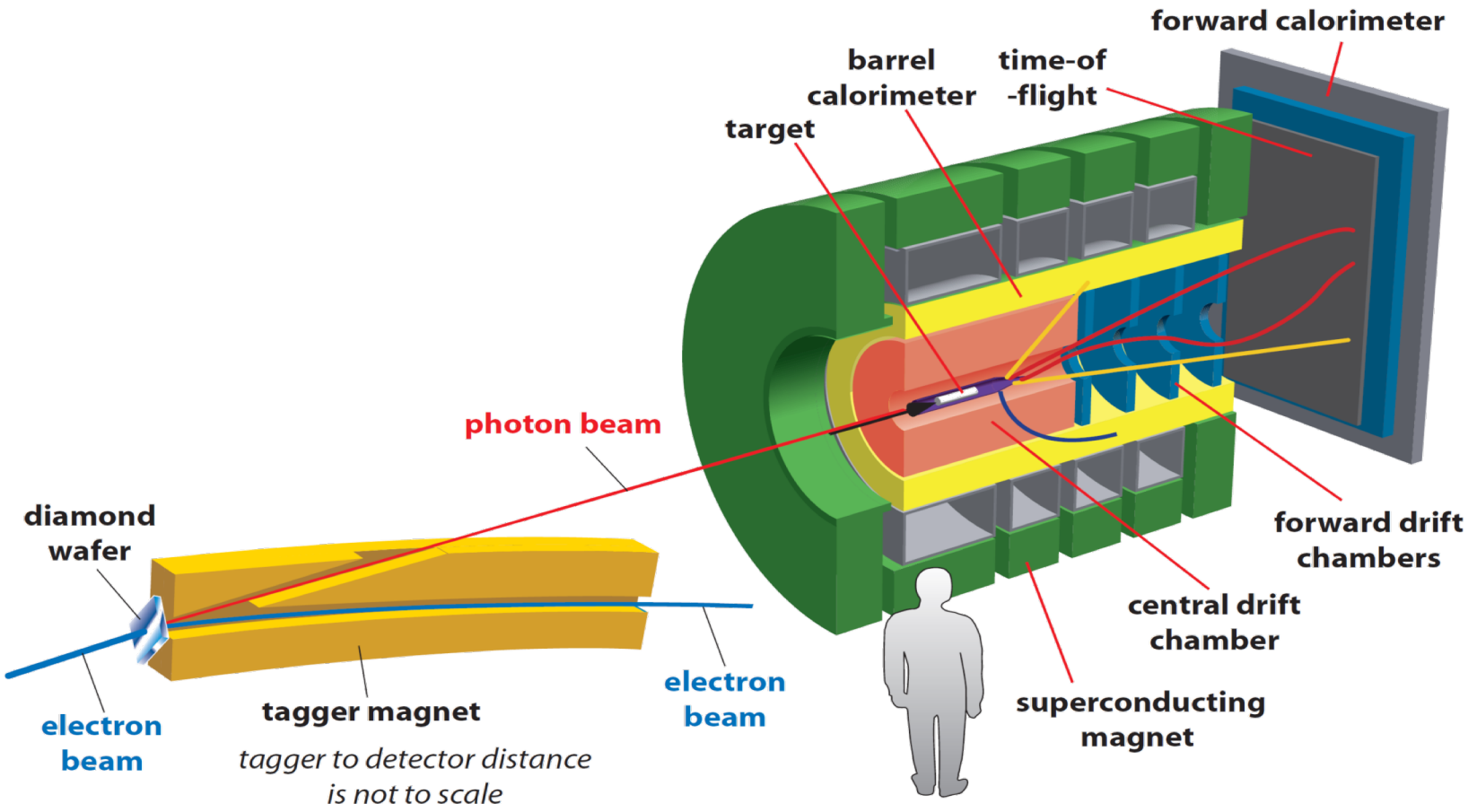
Explore onset of CT in mesons

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



CT in Hall D using photoproduction running Fall 2021!

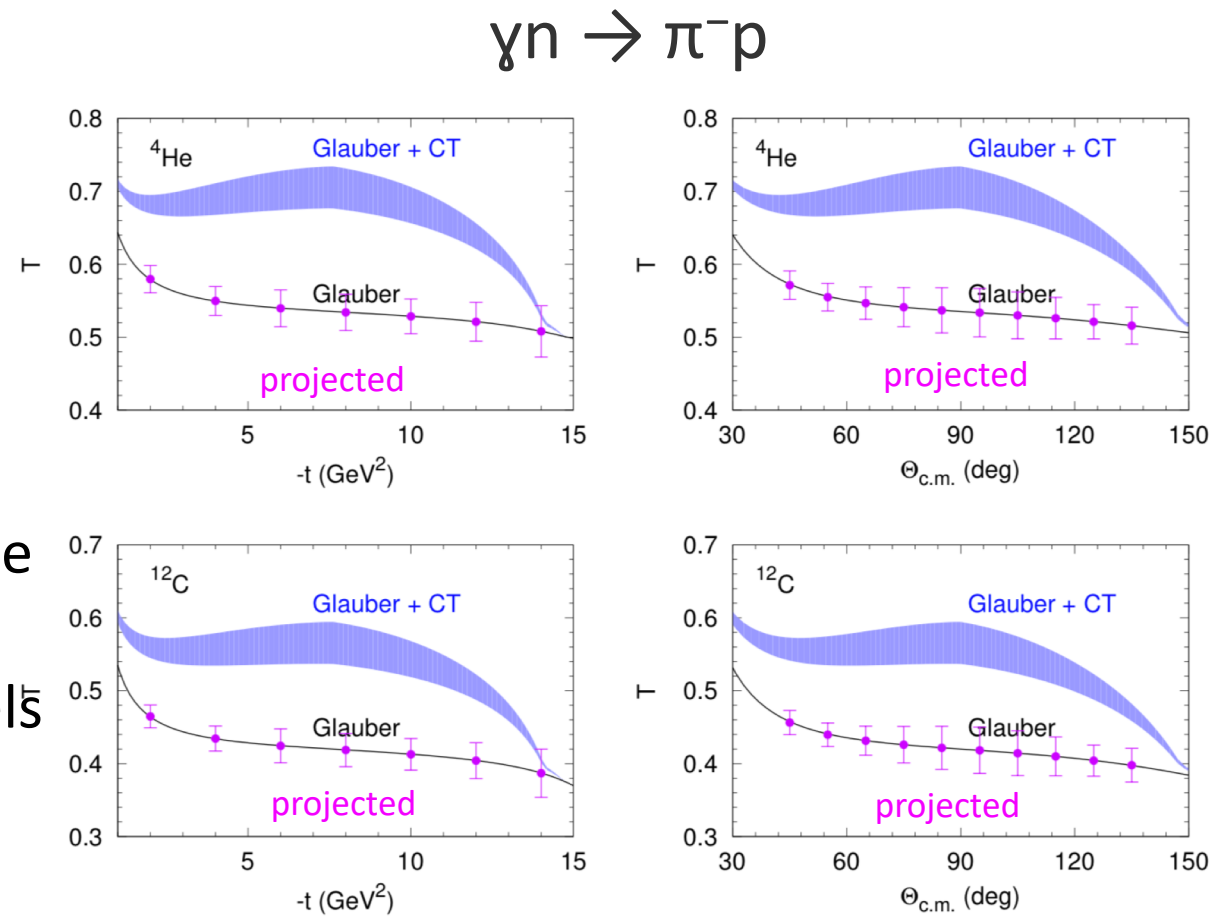
Targets: ^{2}H, ^{4}He, ^{12}C, ^{63}Cu



Jefferson Lab

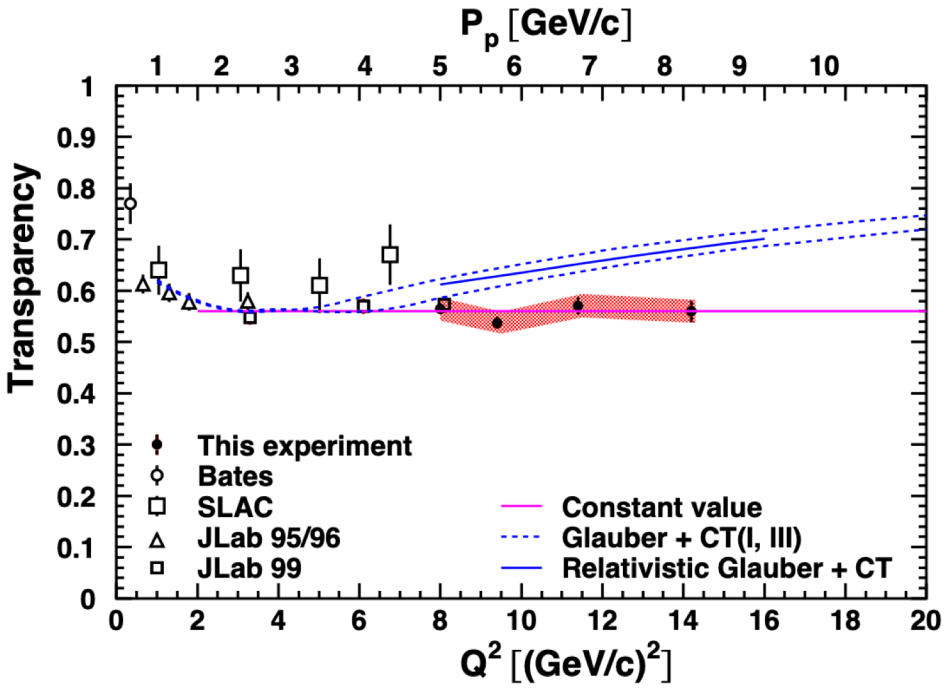
CT in Hall D using photoproduction

- 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



Jefferson Lab

Summary and outlook



Recent measurement will lead to new understanding!

- Caplow-Munro, Miller 2104.11168 (previous talk)
- Two-stage CT, Brodsky & Teramond (next talk)

Next stage experiments will measure CT effects with different reaction mechanisms and precision