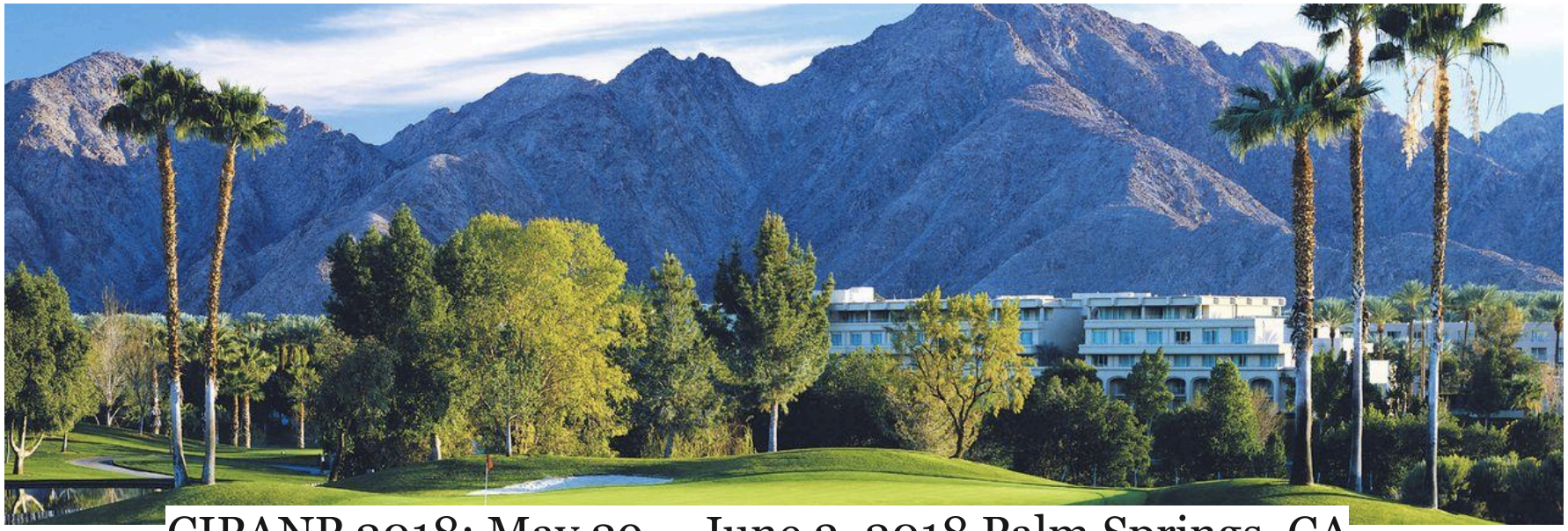
The Search for the onset of
Color Transparency

MISSISSIPPI STATE UNIVERSITY

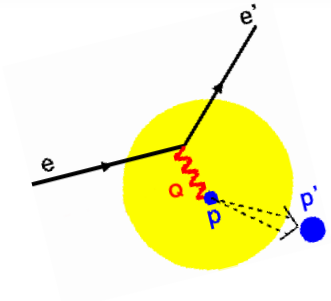
Dipangkar Dutta

Mississippi State University

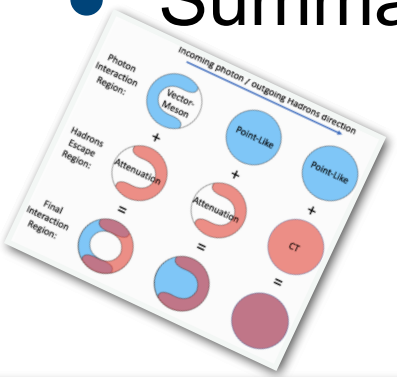


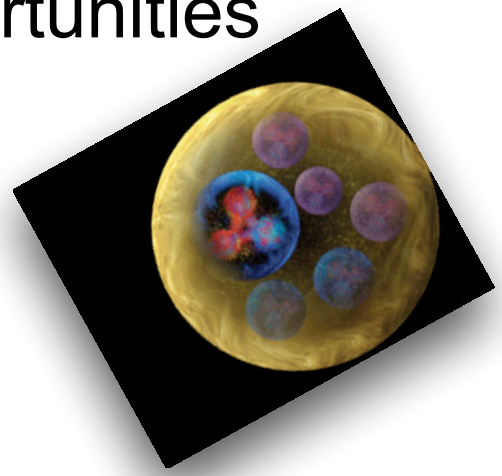
CIPANP 2018: May 29 – June 3, 2018 Palm Springs, CA

Outline



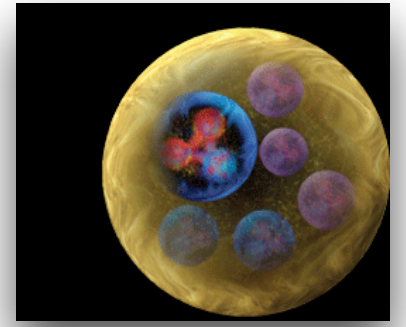
- Nuclear Transparency and Hadron Propagation
- Color Transparency & Small size configurations
- CT and soft-hard factorization/GPDs
- Experimental Status and New Opportunities
- Summary





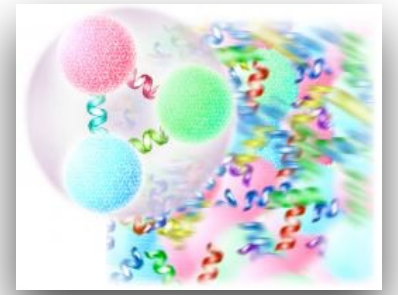
Hadron Propagation through nuclear matter is a key element of the nuclear many body problem.

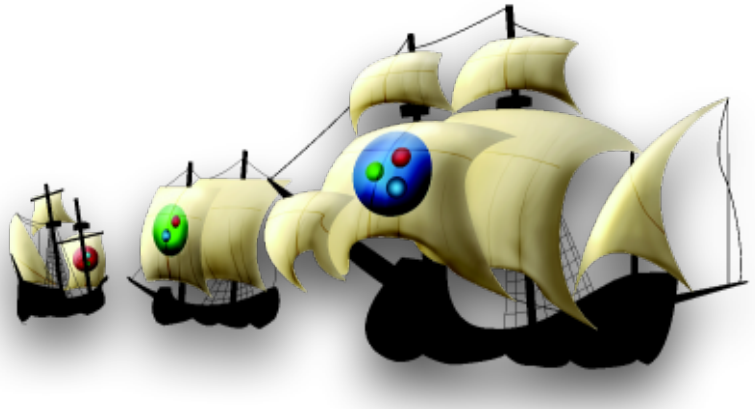
Needed for interpretation of experiments involving hadrons in the nuclear matter and searches for QCD in nuclei.



An active area of interest.

N. C. R. Makins et al. PRL 72, 1986 (1994) (cited 155 times);
K. Garrow et al. PRC 66, 044613 (2002) (cited 93 times);
B. Clasie et al. PRL (2007) (cited 61 times)
L. El-Fassi et al. PLB 712, 326 (2012) (cited 19 times)
D D, K. Hafidi and M. Strikman, Prog. in Nucl. & Part. Phy., 69, 1 (2013) (cited 15 times)





At high energies it is dominated by **reduction of flux**, which is quantified by **Nuclear Transparency**.

Nuclear Transparency is the ratio of cross-sections for exclusive processes from nuclei to nucleons.

$$T = \frac{\sigma_N}{A\sigma_0}$$

σ_0= free (nucleon) cross-section

σ_N parameterized as = $\sigma_0 A^{\alpha}$

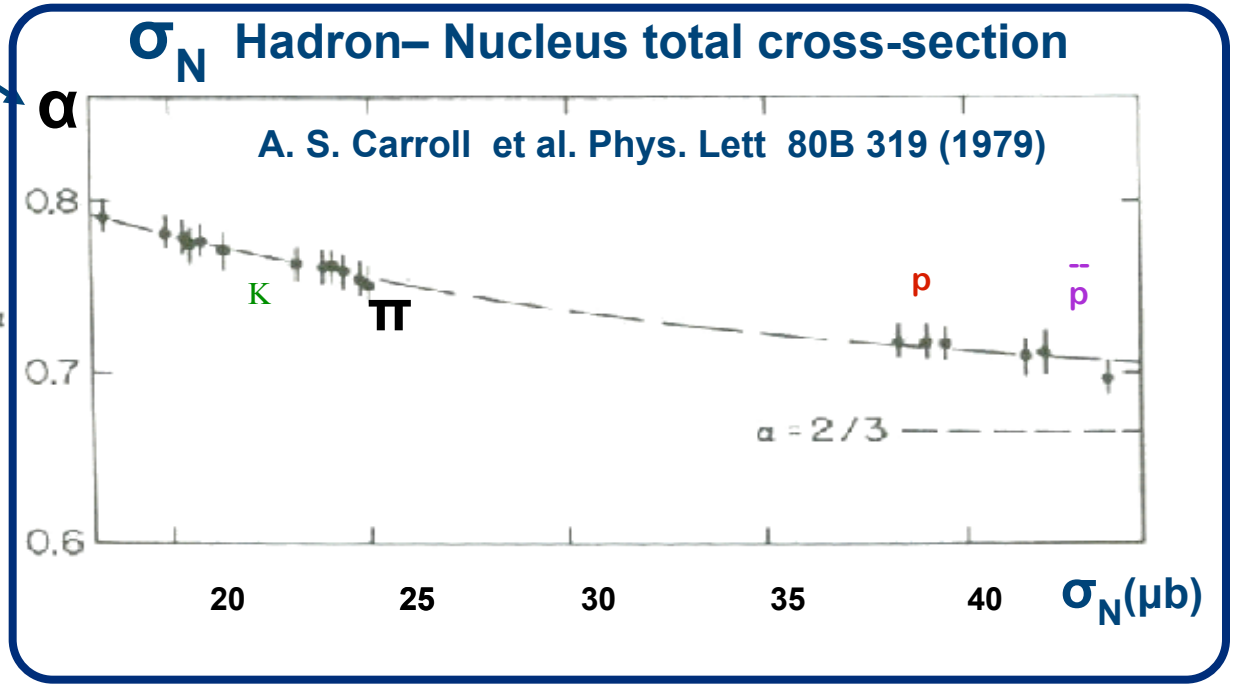
Fit to $\sigma(A) = \sigma_0 A^{\alpha}$

α = 0.72 - 0.78,

for π, K, p

Hadron momentum 60, 200, 250 GeV/c

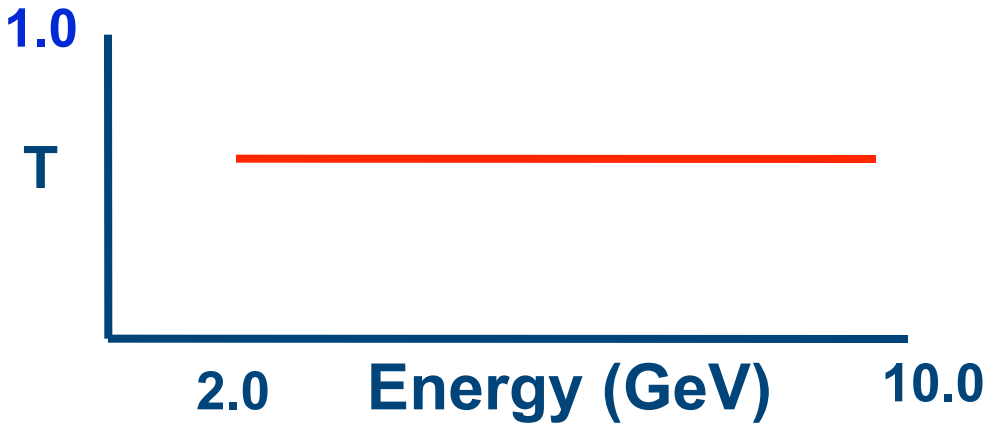
$$T = A^{\alpha-1}$$



α < 1 interpreted as due to the strong interaction nature of the probe

Nuclear Transparency is expected to be energy independent.

Traditional NP calculations



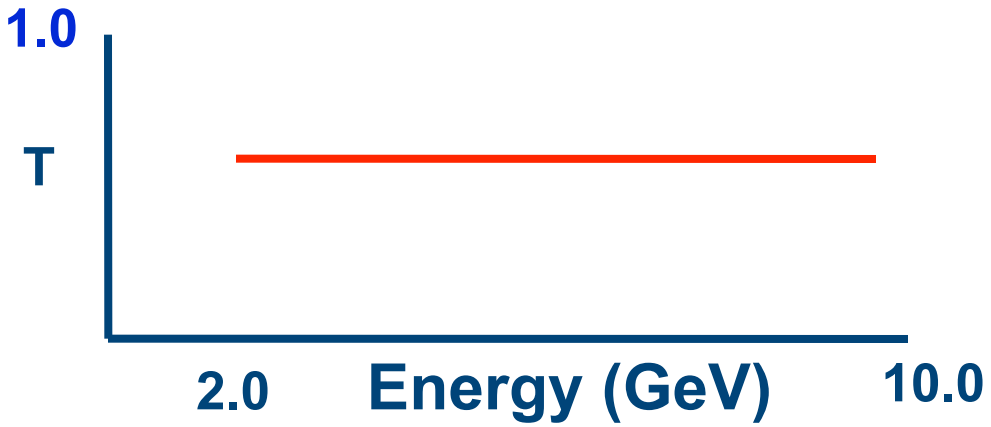
Ingredients

- σ_{hN} h-N cross-section
- Glauber multiple scattering approximation
- Correlations & FSI effects.

For light nuclei very precise calculations of are possible.

Nuclear Transparency is expected to be energy independent.

Traditional NP calculations



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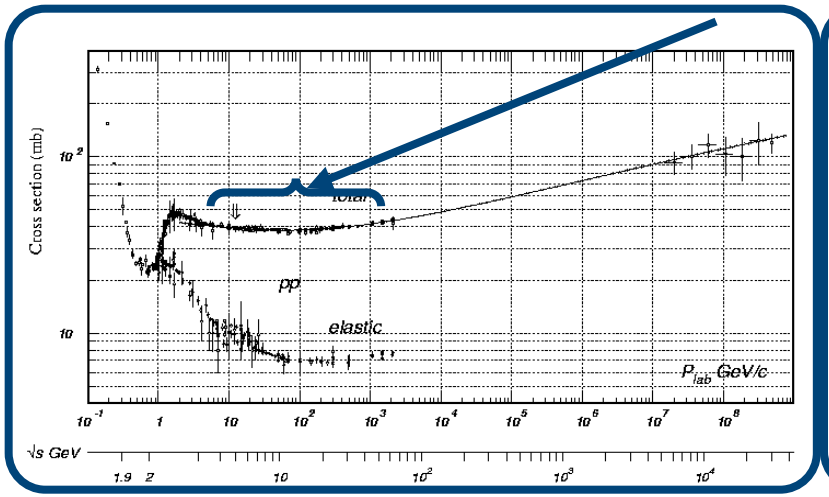
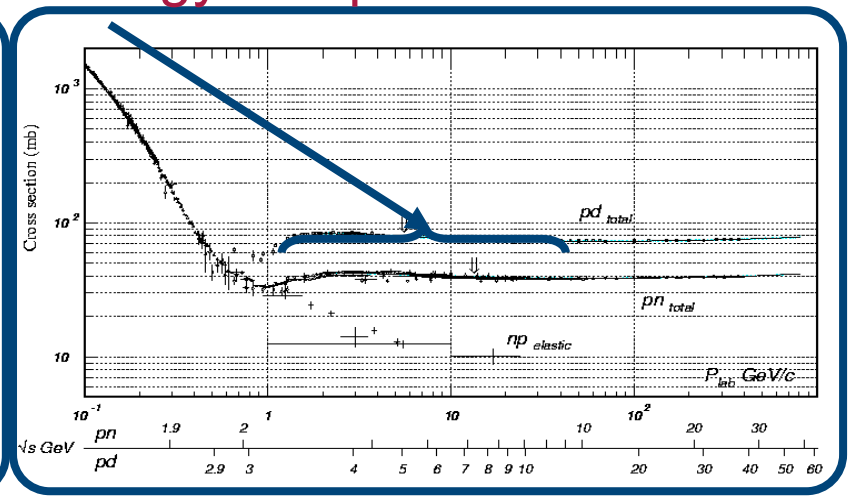
N-N cross-section is energy independent



pp scatt. cross-section



pn scatt. cross-section

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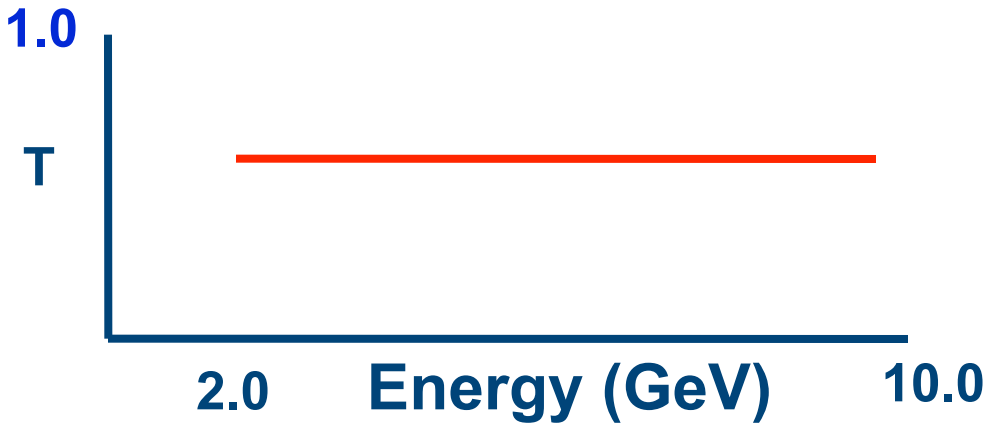

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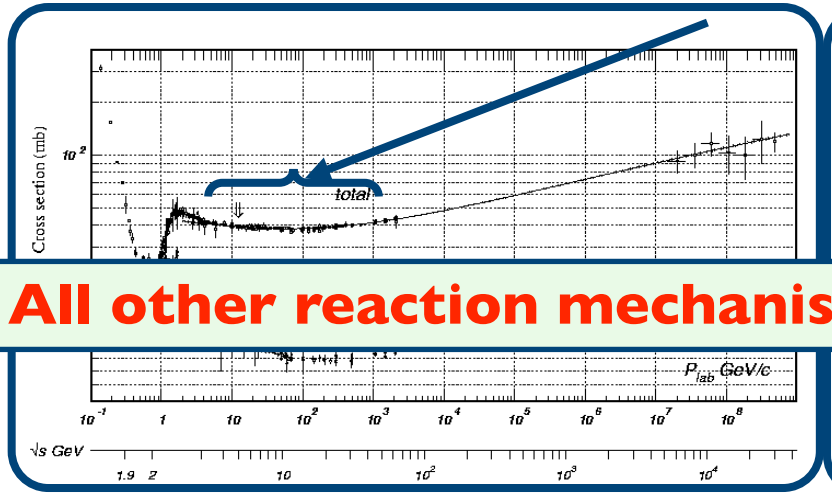
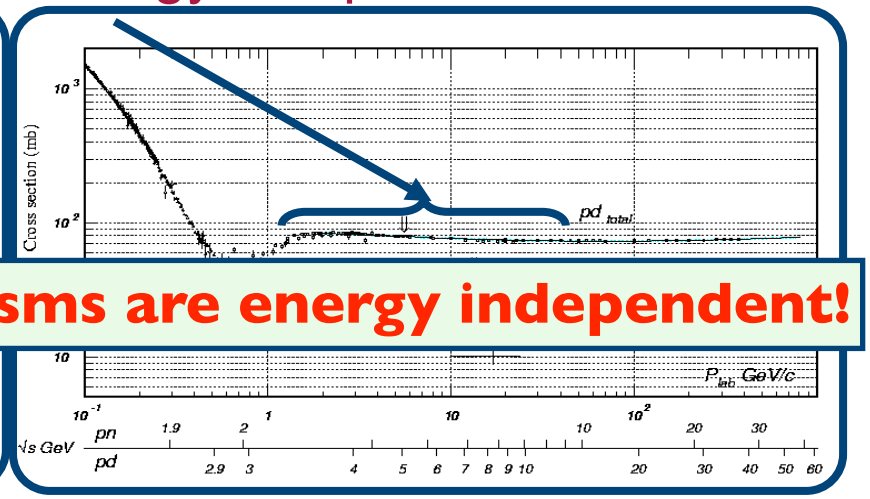


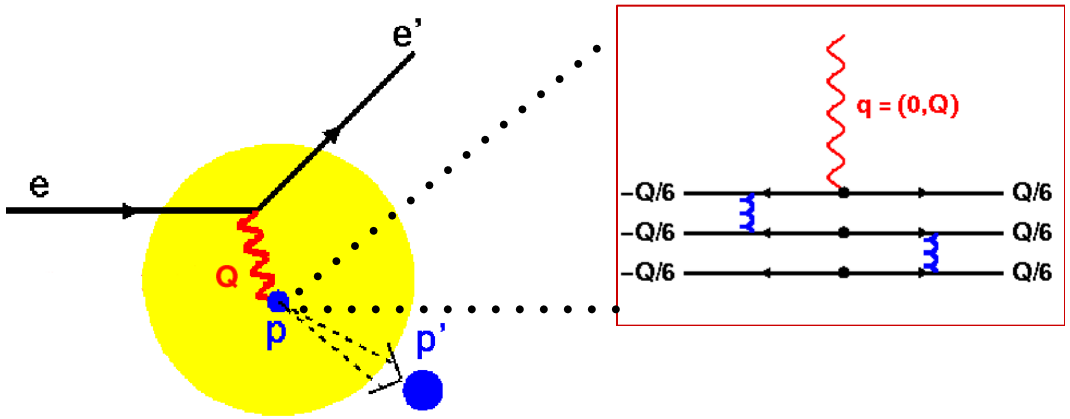
pp scatt. cross-section



pn scatt. cross-section

All other reaction mechanisms are energy independent!

Color Transparency is the result of “squeezing and freezing”.



At high momentum transfers, scattering takes place via selection of amplitudes characterized by small transverse size (PLC) - “squeezing”

The compact size is maintained while traversing the nuclear medium - “freezing”.

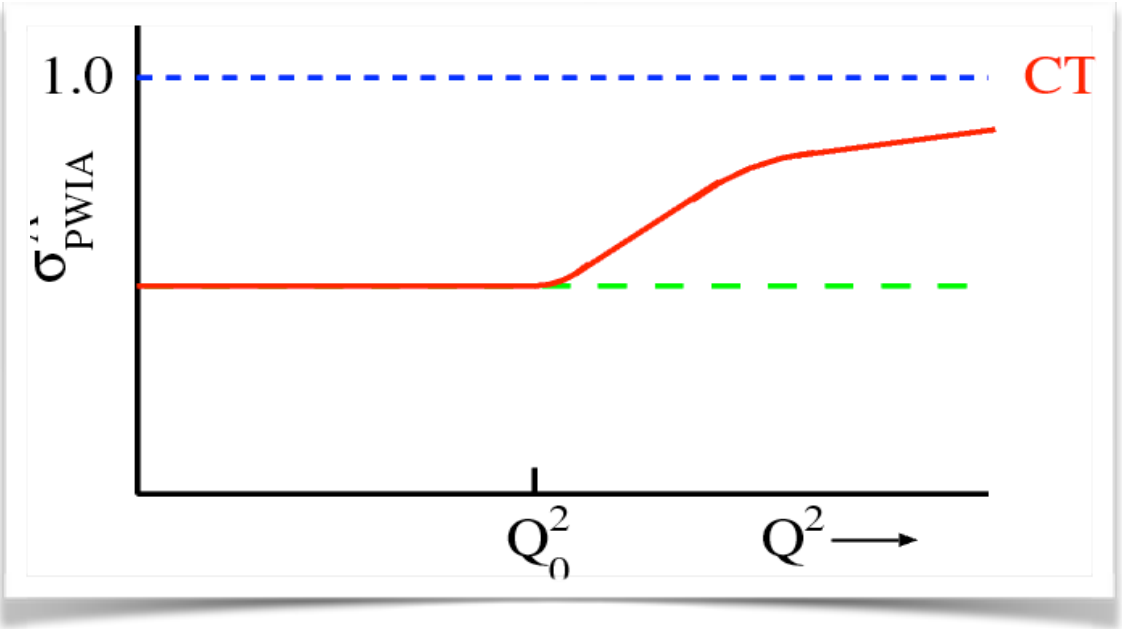
The PLC is ‘color screened’ - it passes undisturbed through the nuclear medium.

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

Color Transparency is a color coherence property of QCD.

CT leads to vanishing of the hadron-nucleon interaction for hadrons produced at high momentum transfers

CT is unexpected in a strongly interacting hadronic picture. But it is natural in a quark-gluon framework.



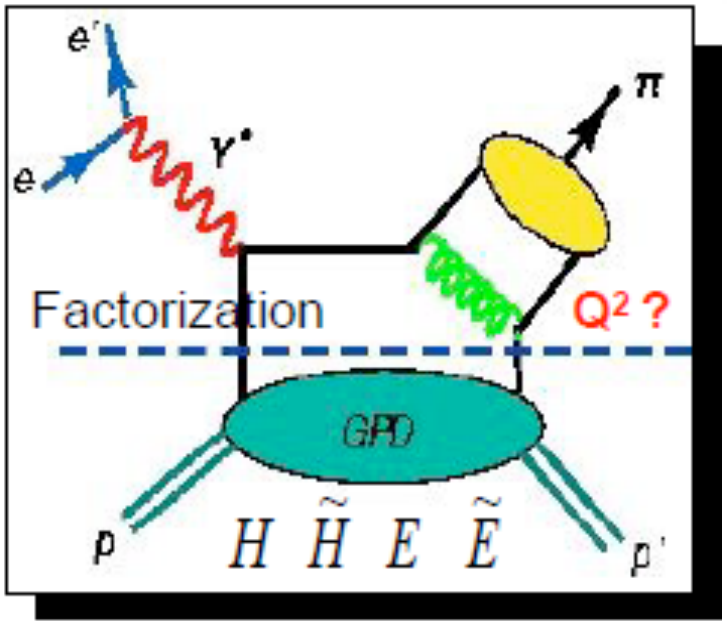
CT is well established at high energies (DIS data cannot be described without assuming CT).

The onset of CT is of primary interest.

Onset of CT would be a signature of the onset of QCD degrees of freedom in nuclei

For a recent review see: **D.D., K. Hafidi and M. Strikman, Prog. in Part. & Nucl. Phy., 69, 1 (2013).**

CT is also connected to the new framework of GPDs developed in the last two decades.



The new framework, assumes the dominance of the handbag mechanism.

-factorizes into a hard interaction with a single quark and a soft part parametrized as GPDs.

Factorization theorems have been derived for deep-exclusive processes and are essential to access GPDs

- small size configurations (SSC/PLC) needed for factorization
- It is still uncertain at what Q^2 value reaches the factorization regime

The onset of CT is a necessary (but not sufficient) conditions for factorization.

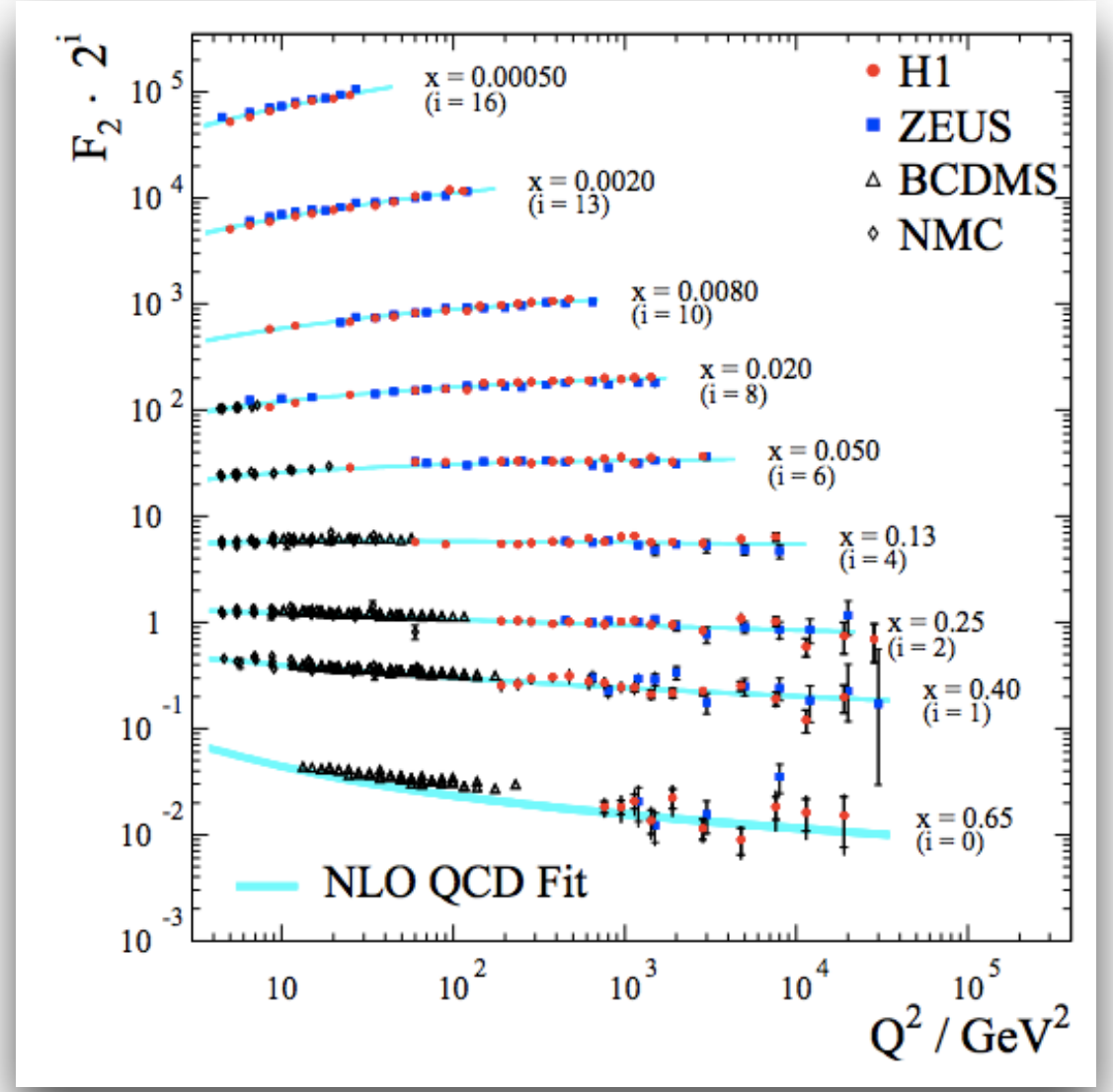
-Strikman, Frankfurt, Miller and Sargsian

Suppression of interaction is essential to account for Bjorken scaling in DIS at small x

Reduced interaction at high energies due to “squeezing and freezing”(i.e. due to CT) is assumed in calculations of structure functions.

L. Frankfurt and M. Strikman, Phys Rep. 160, 235 (1988).

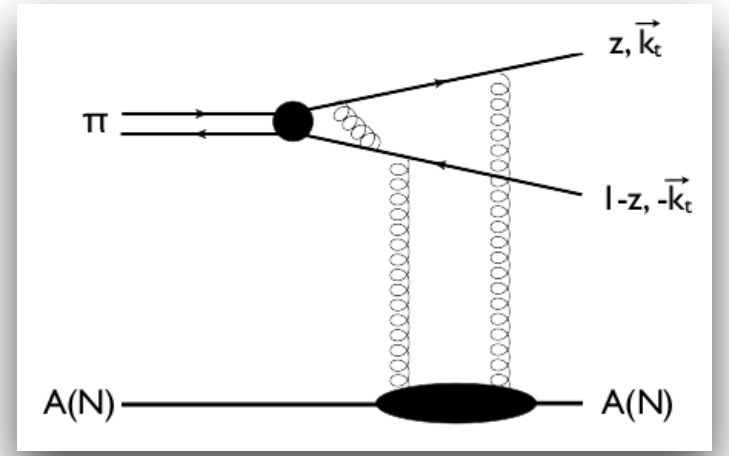
CT is implied by the successful description of DIS.



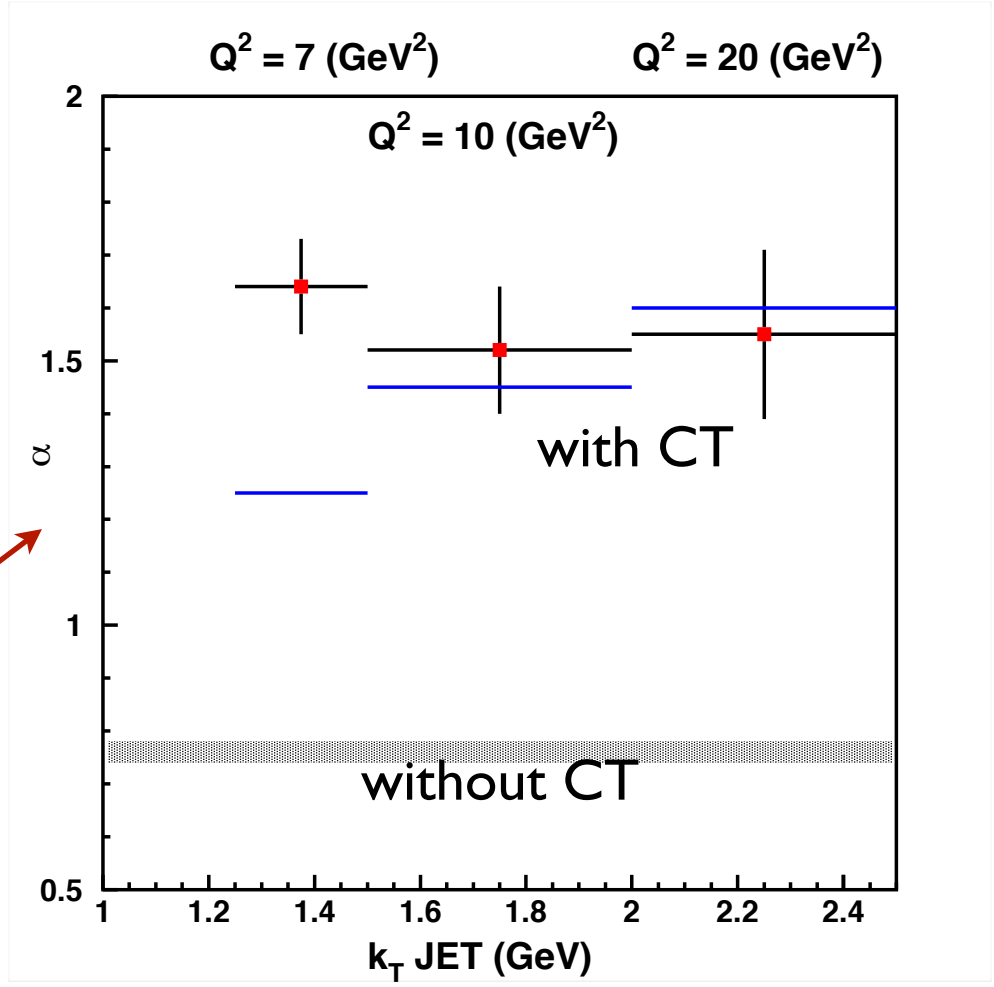
CT is well established at high energies.

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

$\pi + A \rightarrow (2\ \text{jets}) + A'$



diffractive dissociation cross-section fit to: $\sigma_0 A^{\alpha}$



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

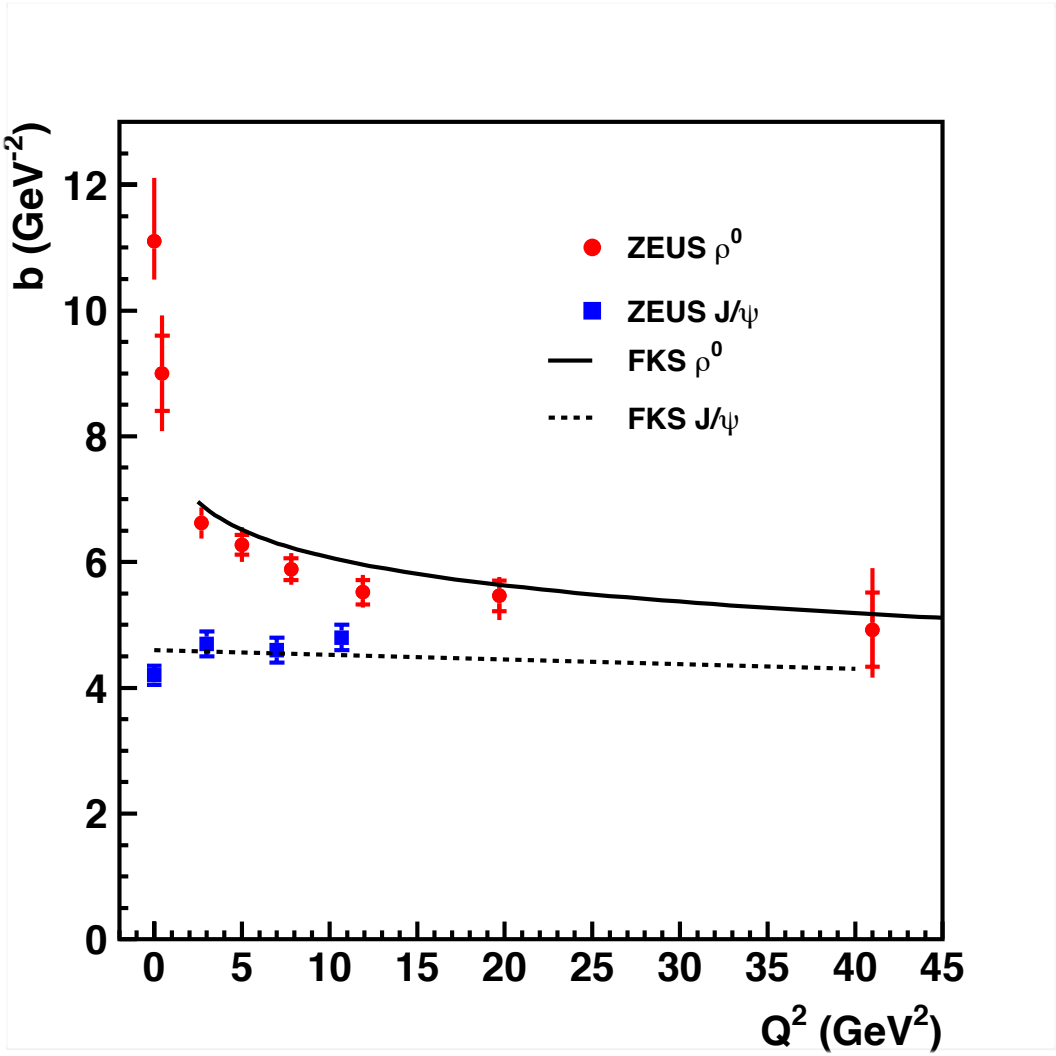
CT is well established at high energies.

Vector Meson production at large Q^2 at HERA

$$d\sigma/dt \propto e^{-bt}$$

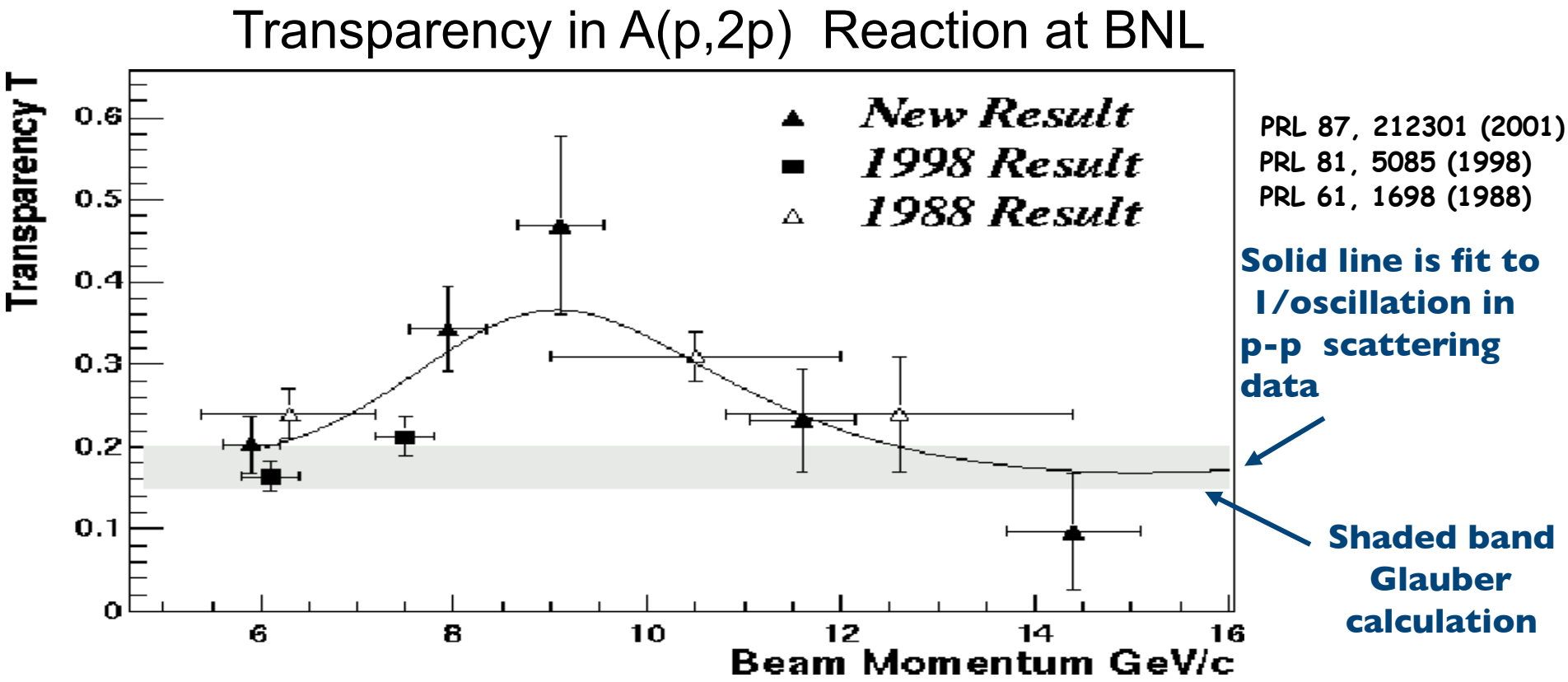
$$b = \frac{d}{dt}\ln\left(\frac{d\,\sigma^{el}_{hp}}{dt}\right) = \frac{1}{3}\left(R_h^2 + R_p^2\right)$$

Convergence of the t-slope of ρ and J/ψ electroproduction at large Q^2 predicted by the presence of small size qq-bar state



Evidence for CT at intermediate energies is a mixed bag.

First direct search for the onset of CT

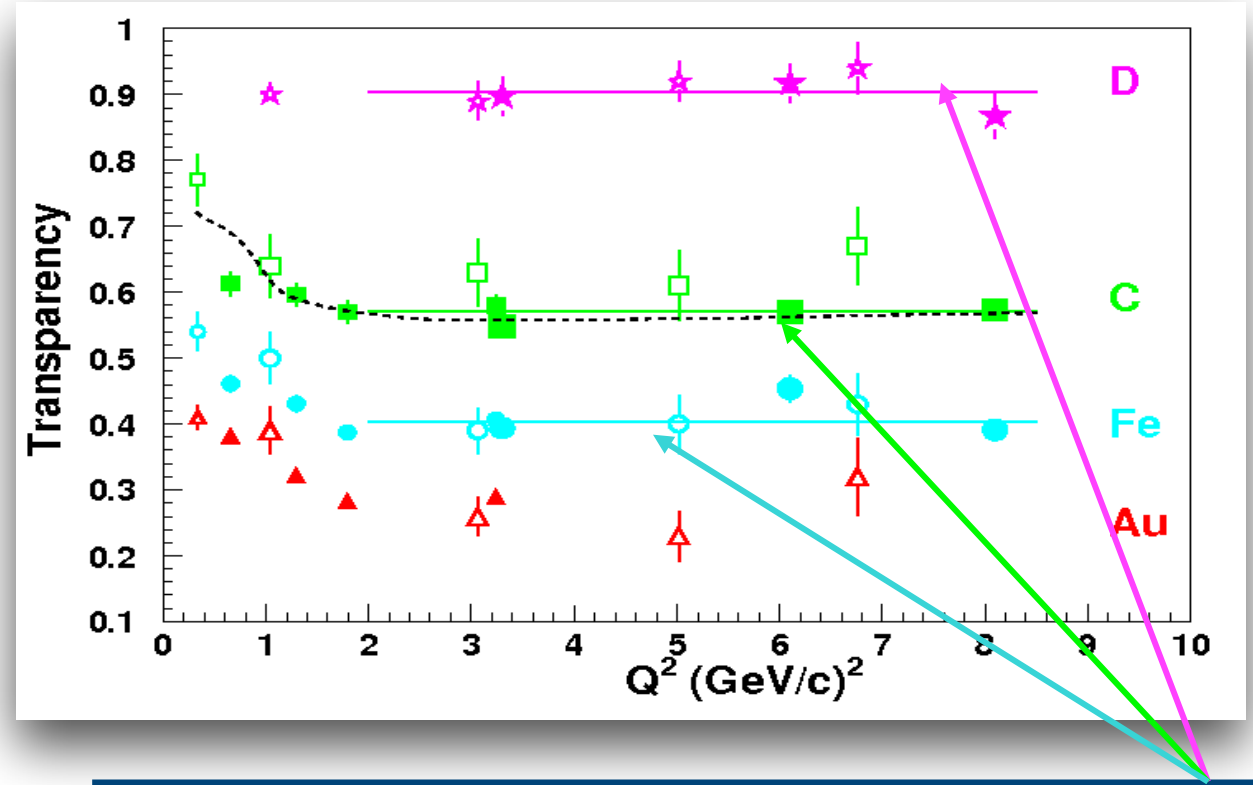


Results inconsistent with CT only. But can be explained by including additional mechanisms such as nuclear filtering or charm resonance states.

Evidence for CT at intermediate energies is a mixed bag.

A(e,e'p) results

Q^2 dependence consistent with standard nuclear physics calculations



Solid Pts – JLab

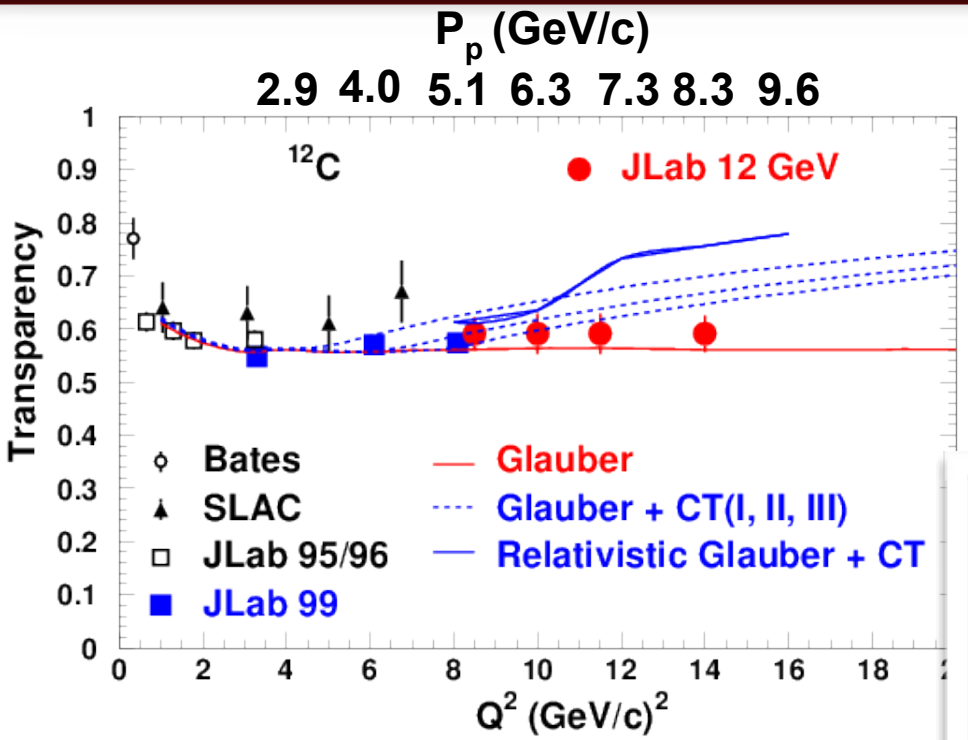
Open Pts -- other

Constant value fit for Q^2 > 2 (GeV/c)^2 has χ^2 / df ~ 1

N. C. R. Makins et al. PRL 72, 1986 (1994)
G. Garino et al. PRC 45, 780 (1992)

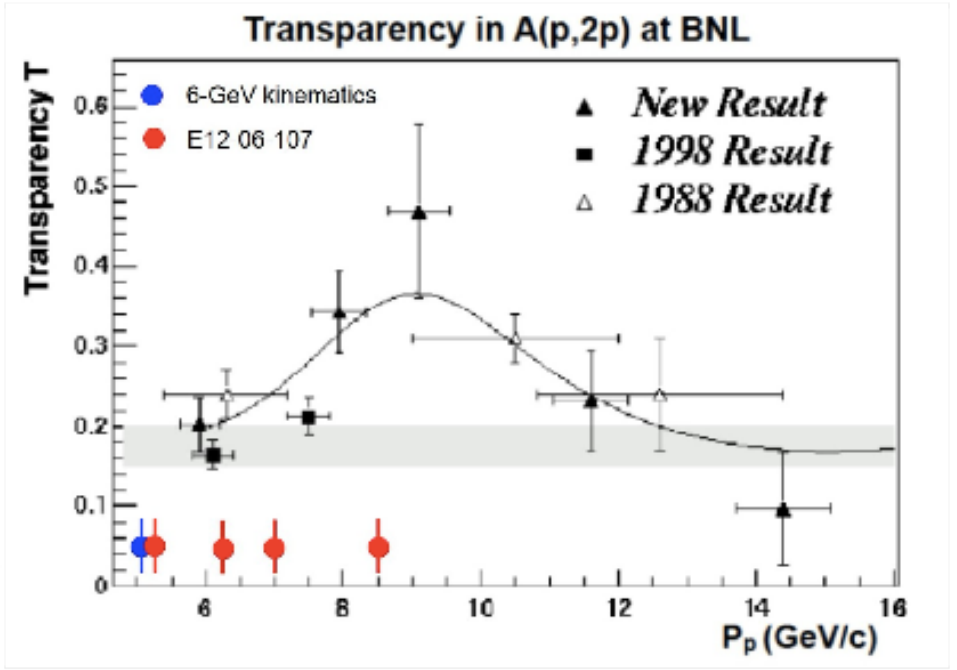
D. Abbott et al. PRL 80, 5072 (1998)
K. Garrow et al. PRC 66, 044613 (2002)

Recently completed experiment at JLab should provide answers.



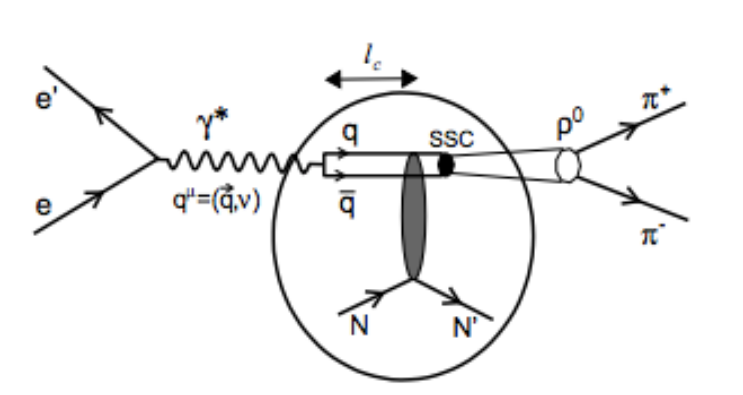
A(e,e'p) @ 11 GeV JLab

Can help interpret the rise seen in the BNL A(p,2p) data at P_p = 6 - 9 GeV/c



See next talk by H. Szumila-Vance for more details

CT is relatively easier to find with mesons.



Small size configurations are more probable in 2 quark system such as pions than in protons. - B. Blattel et al., PRL 70, 896 (1993)

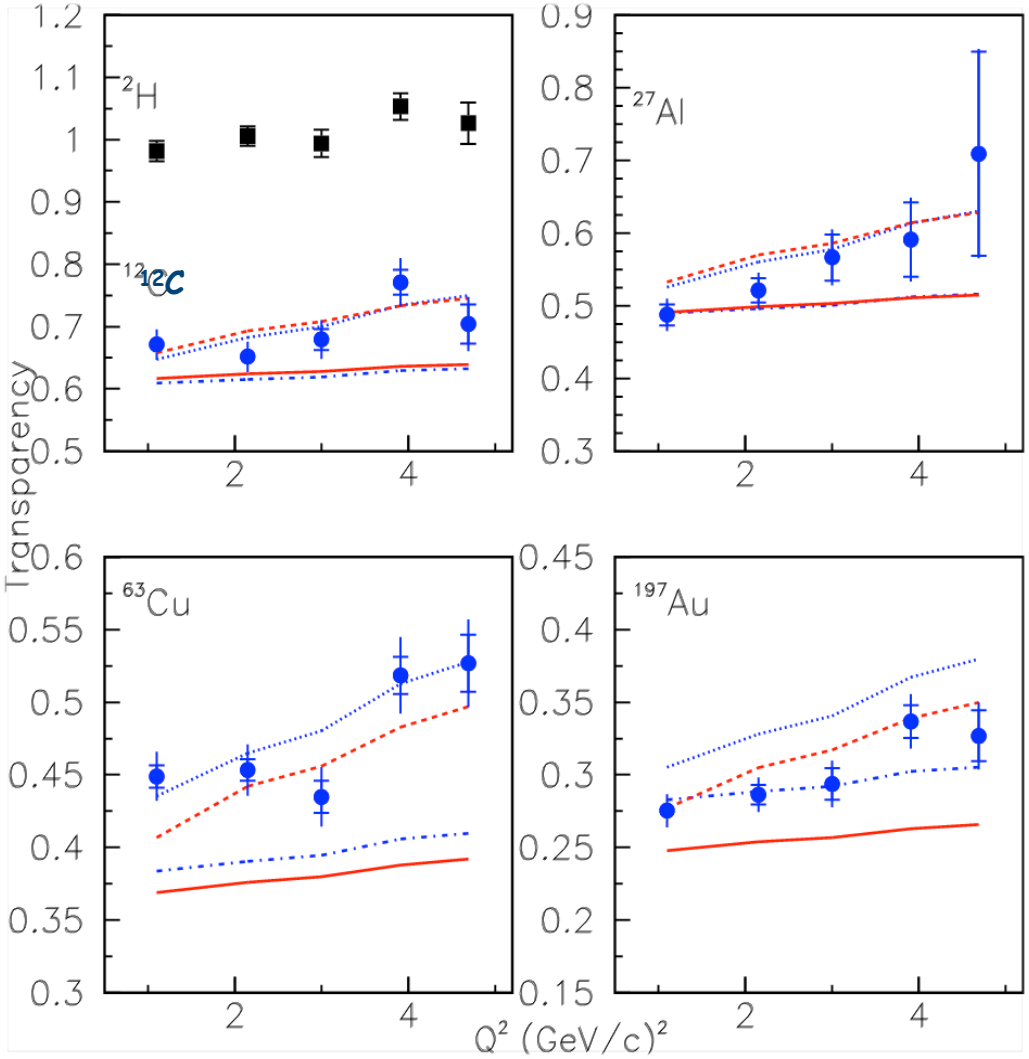
Onset of CT expected at lower Q^2 in mesons

Formation length is ~ 10 fm at moderate Q^2 in mesons

Onset of CT is directly related to the onset of factorization required for access to GPDs in deep exclusive meson production.

- Strikman, Frankfurt, Miller and Sargsian

Pion transparency results are consistent with onset of CT



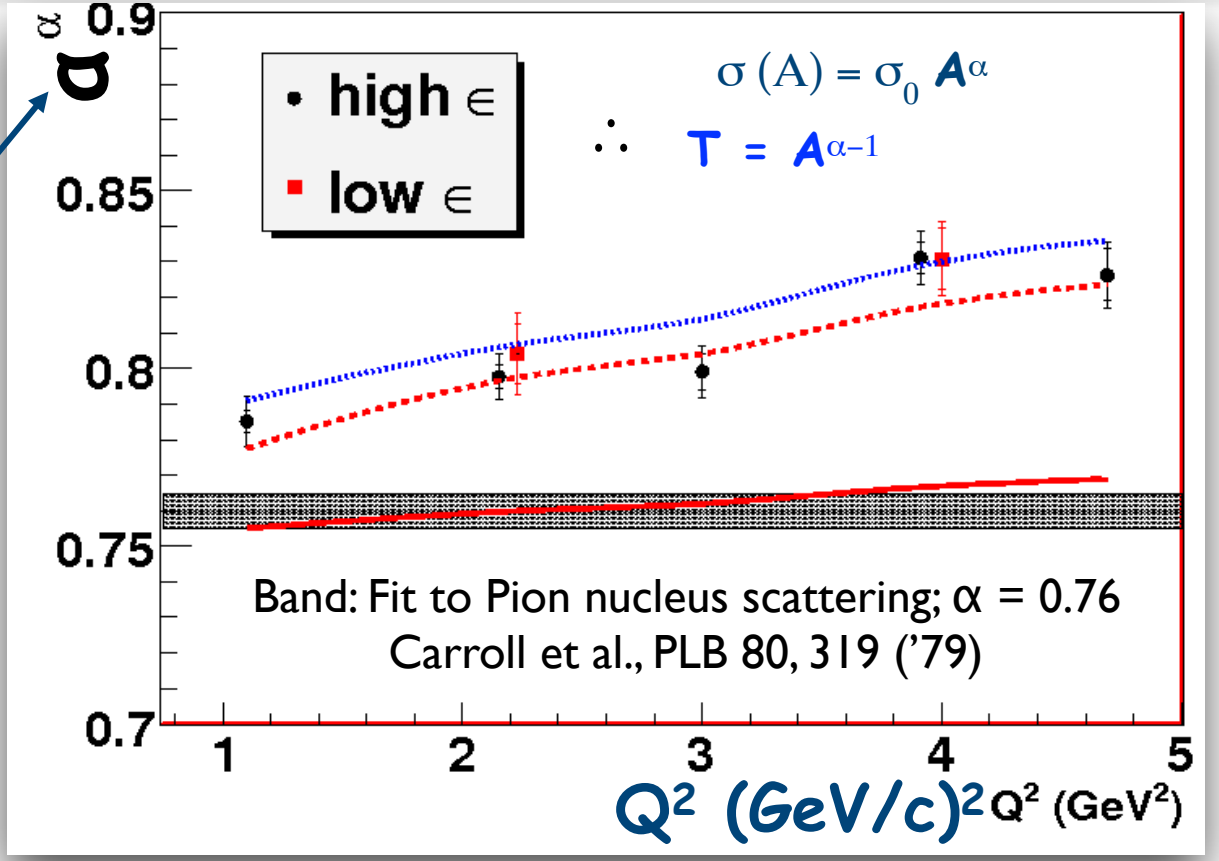
$$T = \frac{\sigma_A^{Expt} / \sigma_A^{Model}}{\sigma_p^{Expt} / \sigma_p^{Model}}$$

solid : Glauber (semi-classical)
dashed : Glauber +CT (quantum diff.)
Larson, Miller & Strikman, PRC 74, 018201 ('06)

dot-dash : Glauber (Relativistic)
dotted : Glauber +CT (quantum diff.) +SRC
Cosyn, Martinez, Rychebusch & Van Overmeire, PRC 74, 062201R ('06)

B. Clasie et al. PRL 90, 10001, (2007) X. Qian et al., PRC81:055209 (2010),

Pion transparency results are consistent with onset of CT



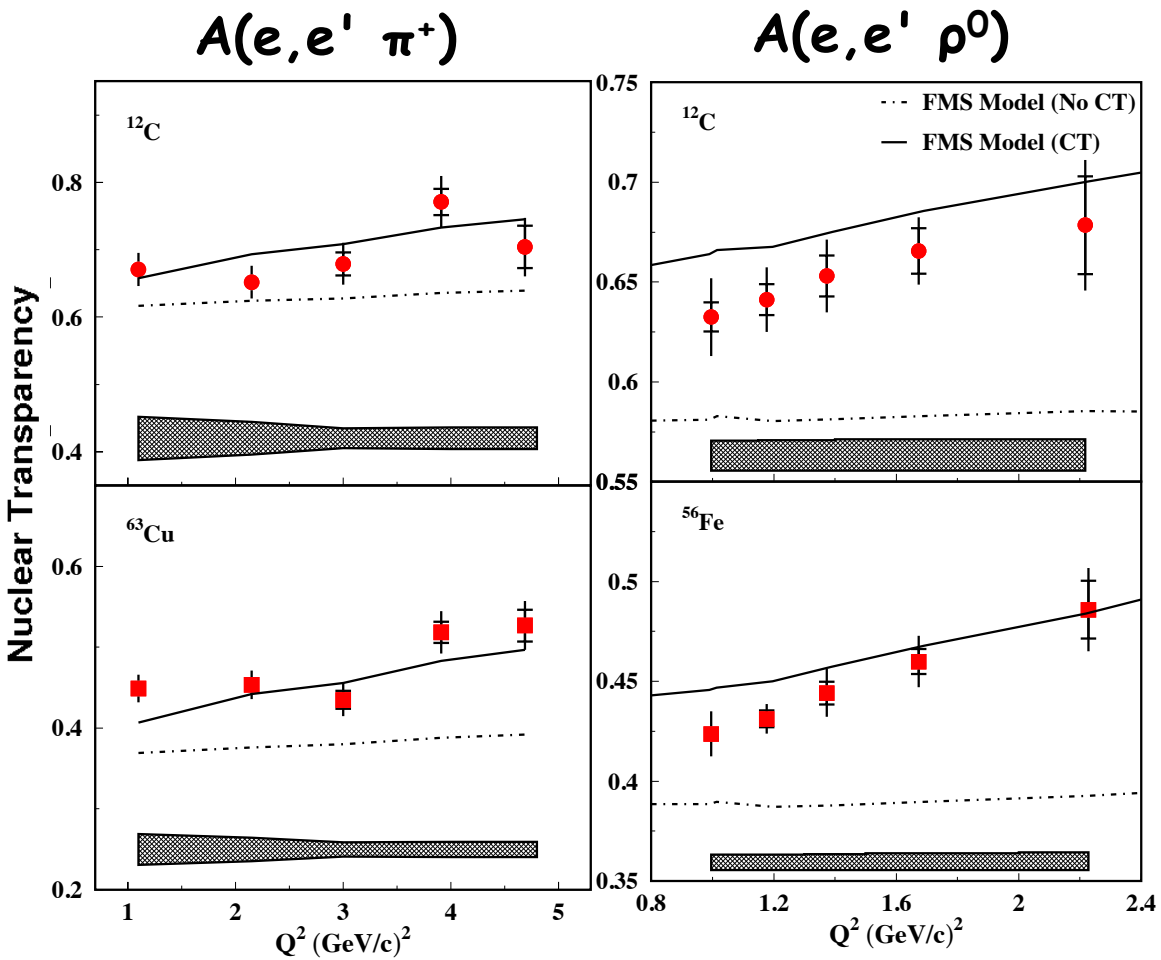
from fit of $T(A) = A^{\alpha-1}$ at fixed Q^2

B. Clasie et al. PRL 90, 10001, (2007)
X. Qian et al., PRC81:055209 (2010),

Larson, Miller & Strikman, PRC 74, 018201 ('06)

Cosyn, Martinez, Rychebusch & Van Overmeire, PRC 74, 062201R ('06)

JLab Experiments conclusively find the onset of CT.



- Hall-C Experiment E01-107 pion electroproduction from nuclei found an enhancement in transparency with increasing Q^2 & A, consistent with the prediction of CT.

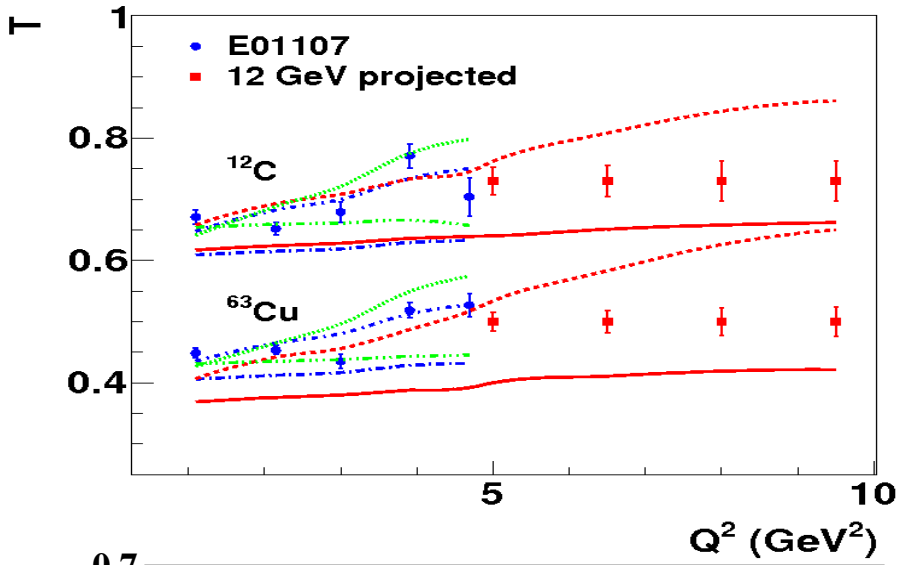
  (X. Qian et al., PRC81:055209 (2010), B. Clasie et al, PRL99:242502 (2007))

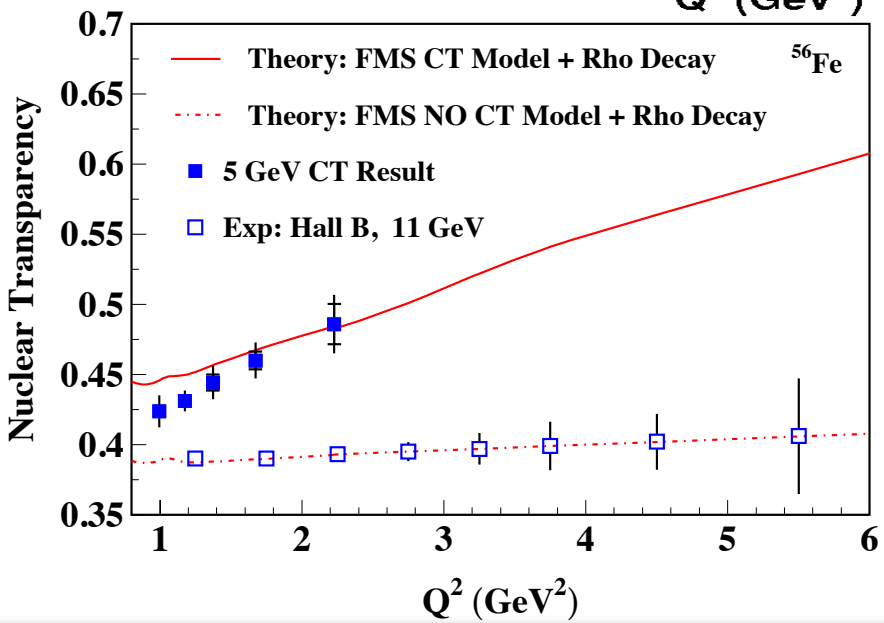
- CLAS Experiment E02-110 rho electroproduction from nuclei found a similar enhancement, consistent with the same predictions

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

FMS: Frankfurt, Miller and Strikman, Phys. Rev., C78: 015208, 2008

Upcoming experiments at JLab will help confirm 6 GeV results.





Both pion and rho transparency measurements will be extended at 11 GeV to the highest Q^2 accessible

Will help confirm the onset of CT observed at 6 GeV

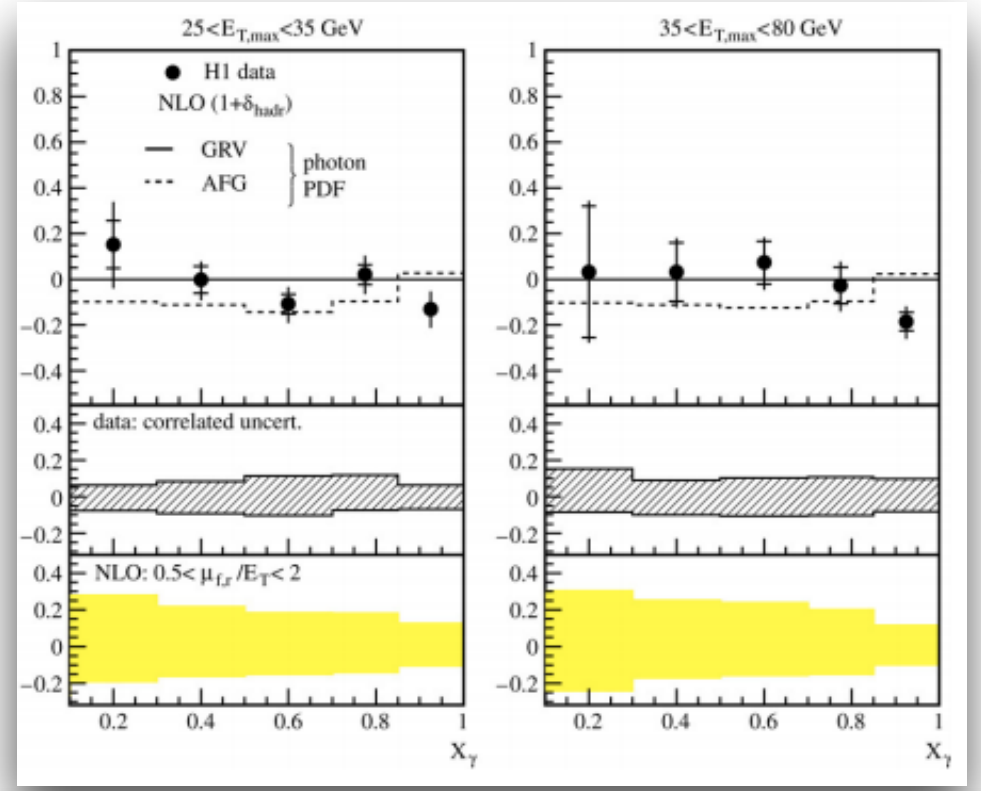
will verify the strict applicability of factorization theorems for meson electroproduction

At high momentum transfers, photons fluctuate to a point like configuration.

photon structure

superposition of vector meson states
@ low momentum transfers

point like photon
@ high momentum transfers,
1/t suppression of the VM states

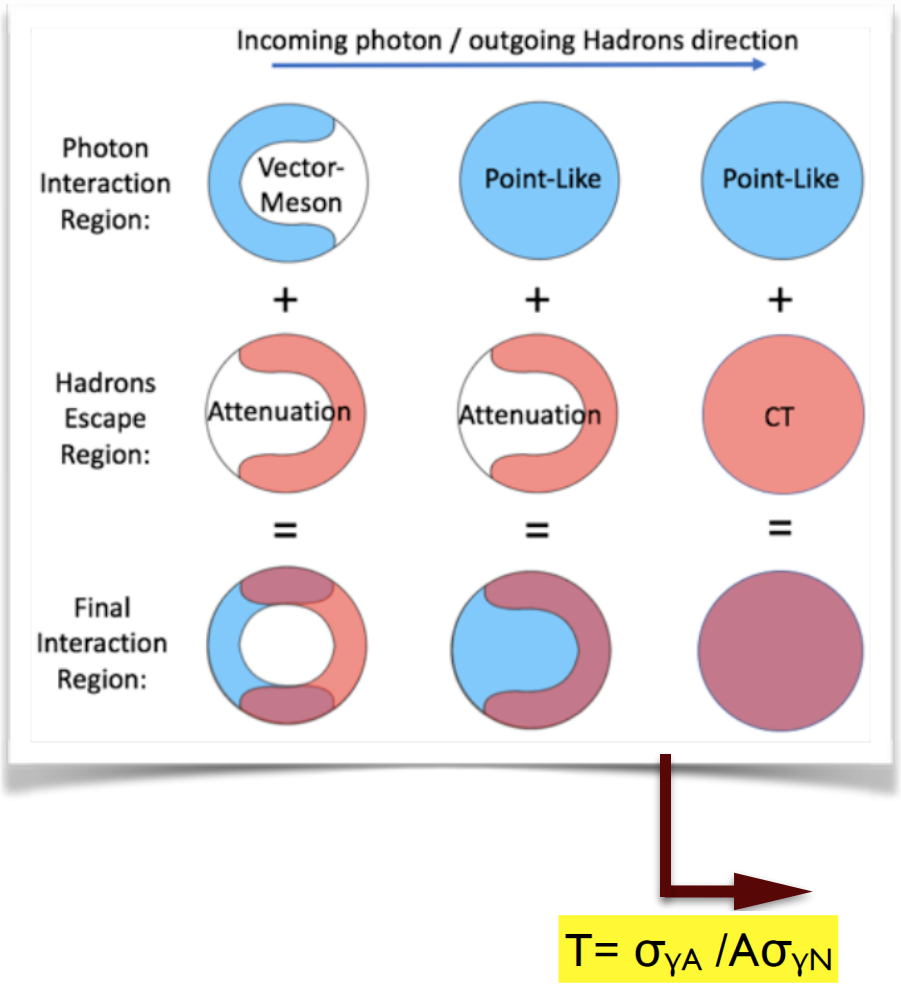


partonic description of the photon demonstrated in high energy H1 data

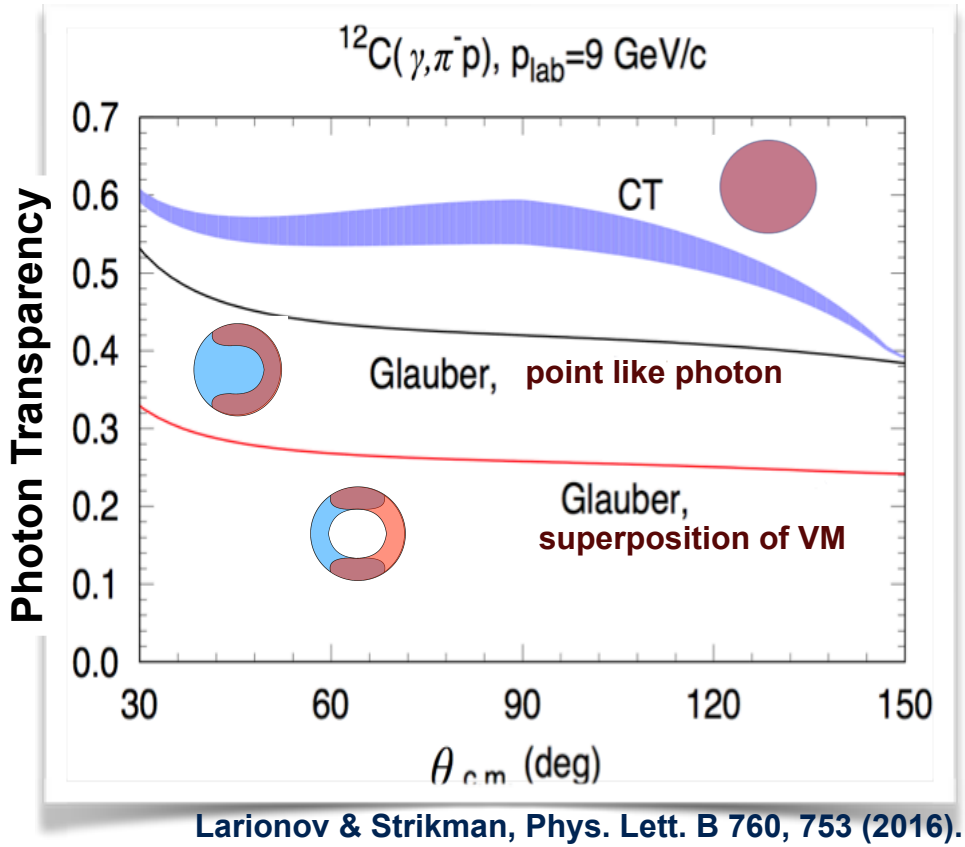
but the transition between these two regimes is unknown

A.J. Baltza et al., Phys. Rep. 458, 1 (2008)

Onset of CT may also be probed using the photo-nuclear processes.



$T = \sigma_{\gamma A} / A\sigma_{\gamma N}$



Figures courtesy of **M. Patsyuk**

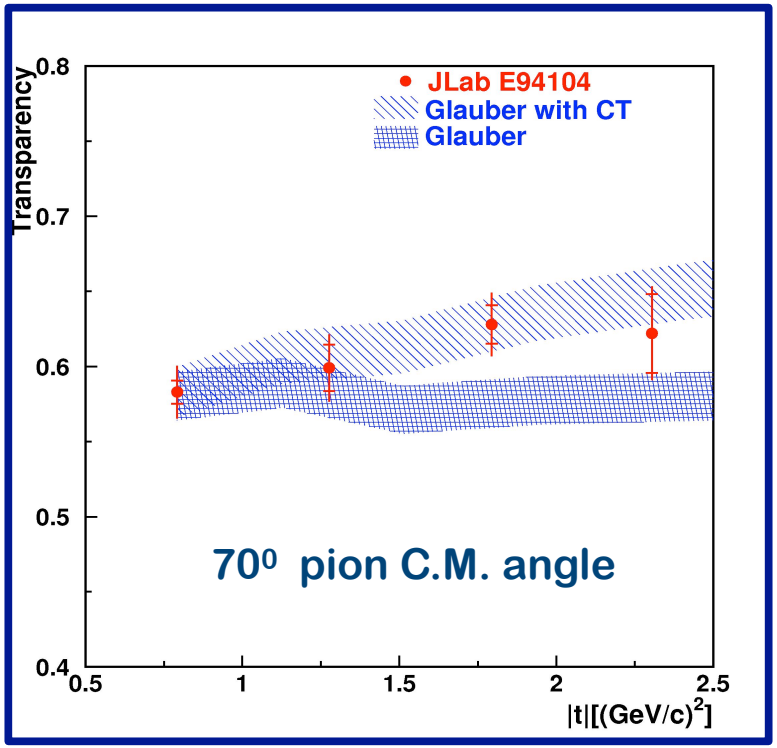
Larionov & Strikman, Phys. Lett. B 760, 753 (2016).

A proof of principle experiment on photo production on ^{4}He was carried out at JLab.

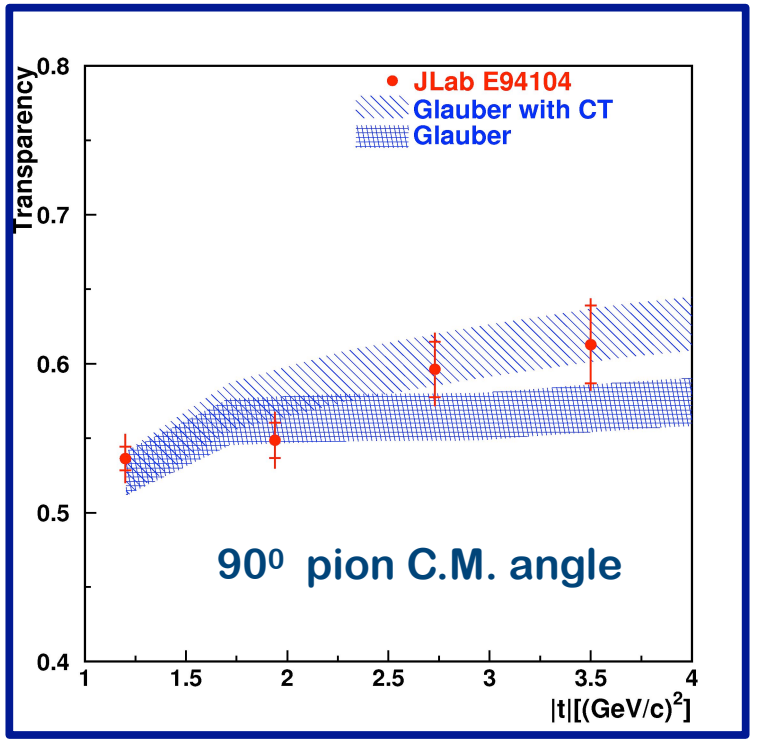
Positive hints from pion photoproduction in JLab Hall A

(H. Gao & R. Holt Spokespersons)

$$(\gamma + {}^4\mathrm{He} \rightarrow \pi^- + p + X) \;/\; (\gamma + D \rightarrow \pi^- + p + p)$$

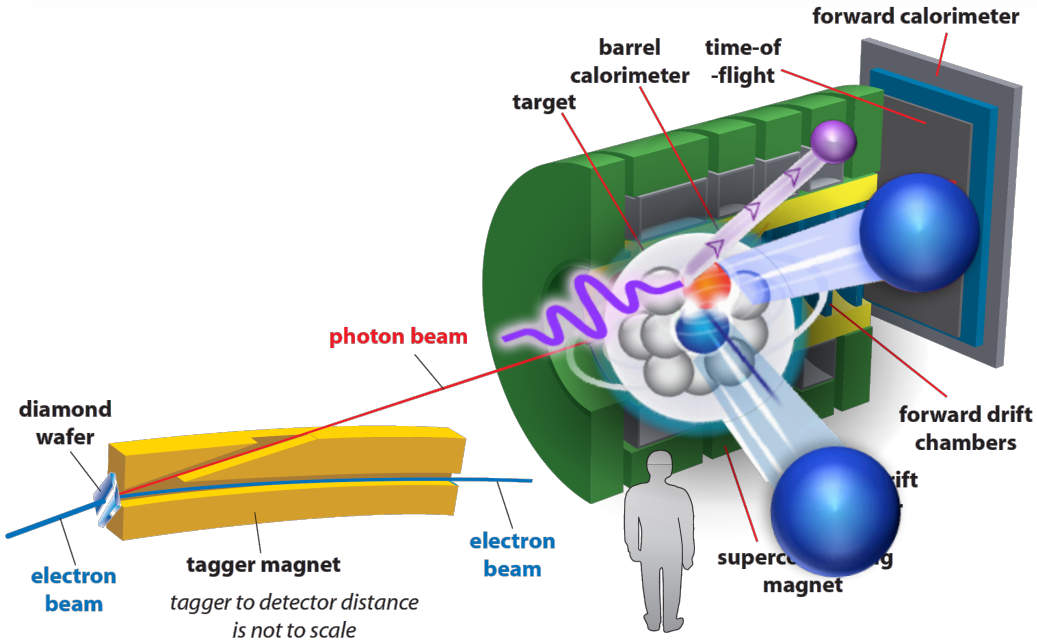


Deviations from Glauber !



Dutta et al. PRC 68, 021001R (2003)
Gao et al. PRC 54, 2779 (1996)

A new photo-nuclear program is being proposed for Hall-D at JLab



Targets: D, ^{4}He, ^{12}C, ^{40}Ca

Exclusive Proton Reactions	Exclusive Neutron Reactions
$\gamma + p \rightarrow \pi^0 + p$	$\gamma + n \rightarrow \pi^- + p$
$\gamma + p \rightarrow \pi^- + \Delta^{++}$	$\gamma + n \rightarrow \pi^- + \Delta^{++}$
$\gamma + p \rightarrow \rho^0 + p$	$\gamma + n \rightarrow \rho^- + p$
$\gamma + p \rightarrow K^+ + \Lambda^0$	$\gamma + n \rightarrow K^0 + \Lambda^0$
$\gamma + p \rightarrow K^+ + \Sigma^0$	$\gamma + n \rightarrow K^0 + \Sigma^0$
$\gamma + p \rightarrow \omega + p$	x
$\gamma + p \rightarrow \varphi + p$	x
...	...

Two Observables to probe photon structure, and CT:

Transparency for a given nucleus, $T = \sigma_{\gamma A} / A\sigma_{\gamma N}$

A-dependence of transparency (i.e. ratio for different nuclei)

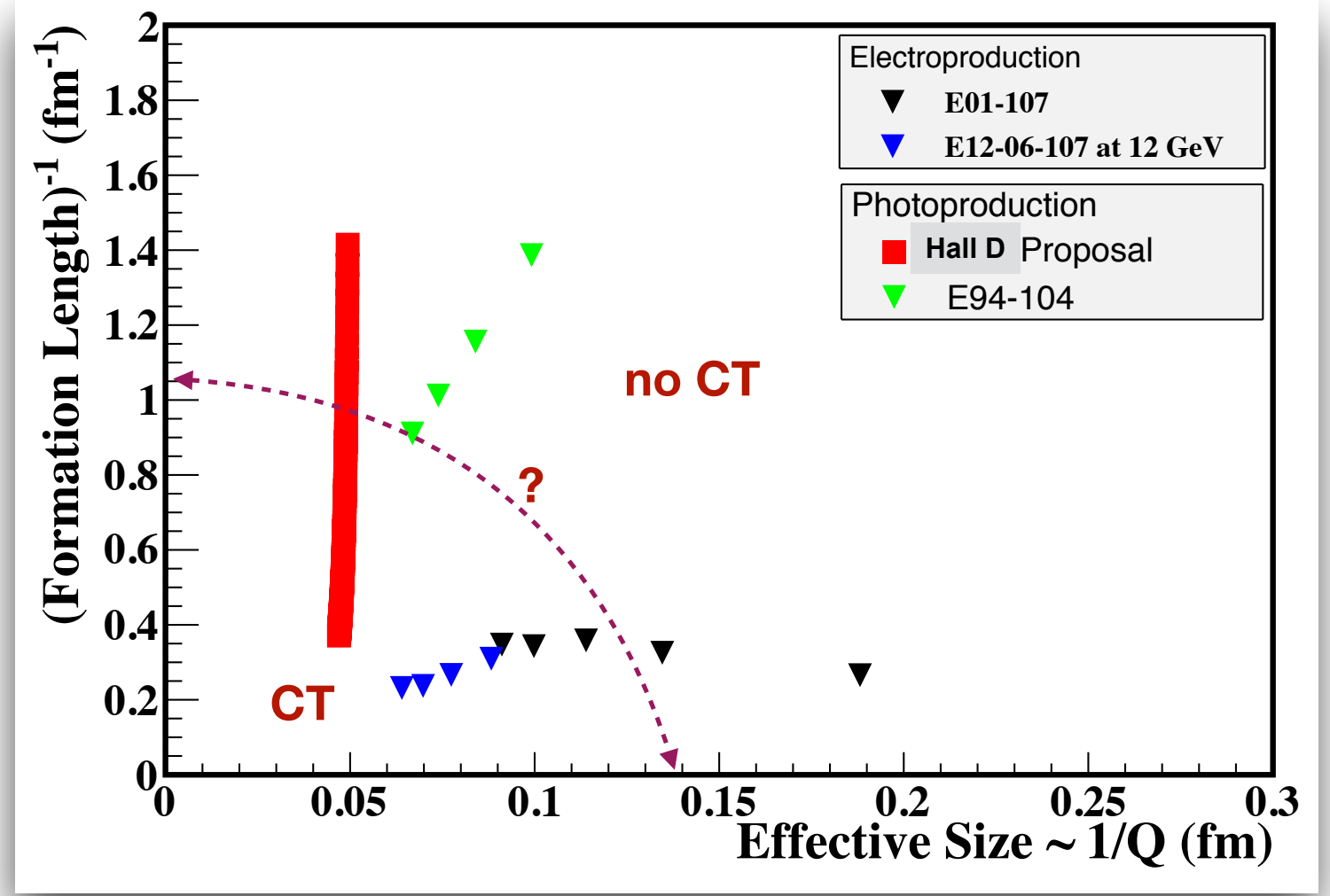
8.4 – 9.1 GeV photons on 4 targets for total of 40 days

Spokespersons:
Hen, Patsyuk, Piasetzky, Dutta, Gao, Somov, Weinstein.

Photo and electro production of hadrons probes different regions of the freezing-vs- squeezing phase space.

inv. formation length)
~ $P_h^* \Delta t / m_h$

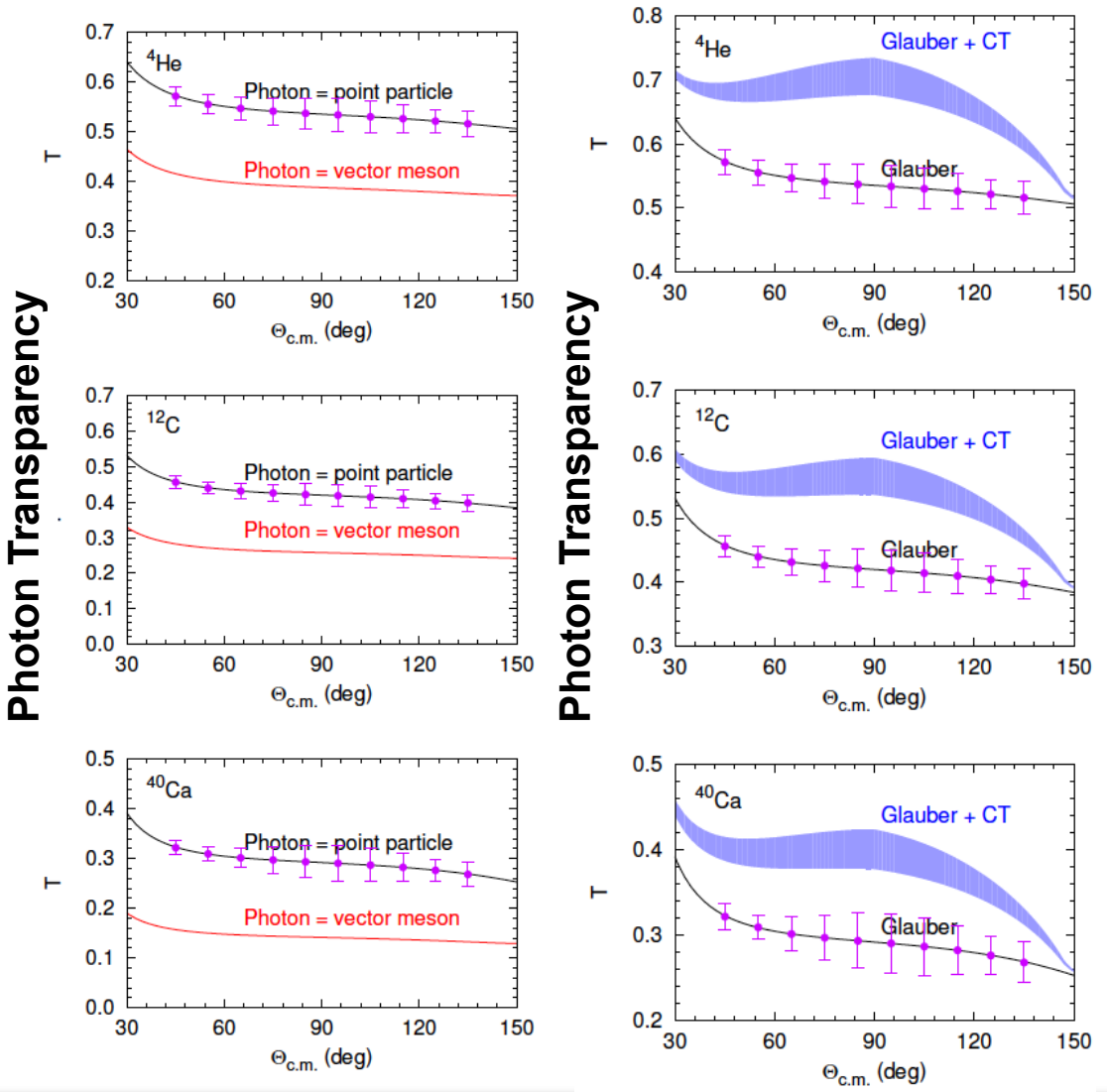
(freezing)

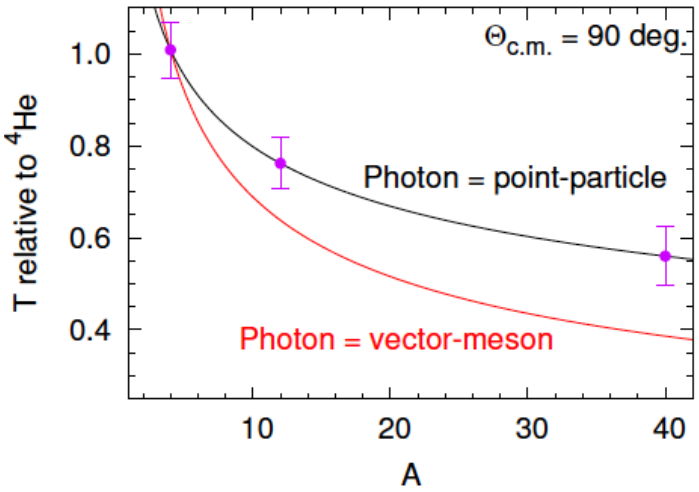


Effective Size ~ 1/Q (squeezing)

A new photo-nuclear program is being proposed for Hall-D at JLab

Projected transparency and transparency ratios



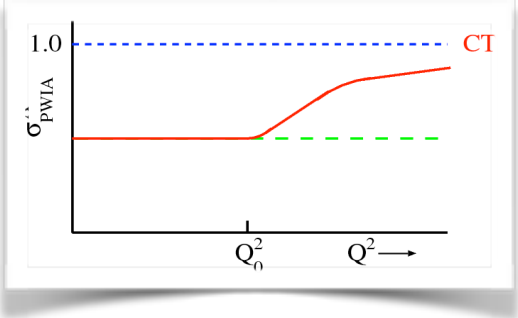


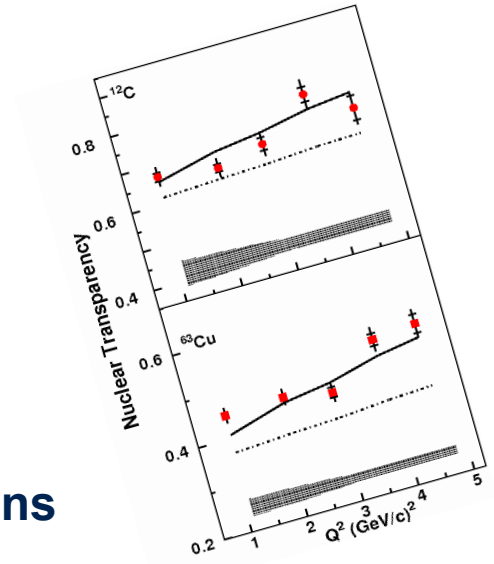
Figures courtesy of **M. Patsyuk**

calculations from Larionov & Strikman, Phys. Lett. B 760, 753 (2016).

Summary

Color Transparency is the reduction in interaction due to "squeezing and freezing" at high momentum transfers.

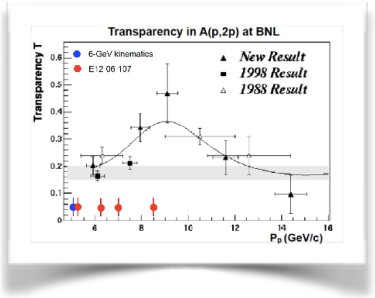




Onset of CT has been observed at JLab experiment on meson electroproduction

There is no unambiguous signs of the onset of CT in baryons

Results from one of the commissioning experiments at the upgraded JLab should help remedy this situation soon.



A new photo nuclear program being proposed for Hall-D will also provide definitive answers about photon structure and CT.

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