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COLOR TRANSPARENCY

EXPERIMENTAL OVERVIEW

NUCLEAR PHOTOPRODUCTION WITH GLUEX
TOPICAL WORKSHOP

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Thursday April 28, 2016
Jefferson Lab, Newport News, Virginia

COLOR TRANSPARENCY "CT"

CT refers to vanishing of initial and final state interactions for hadrons produced in hard "exclusive" reactions

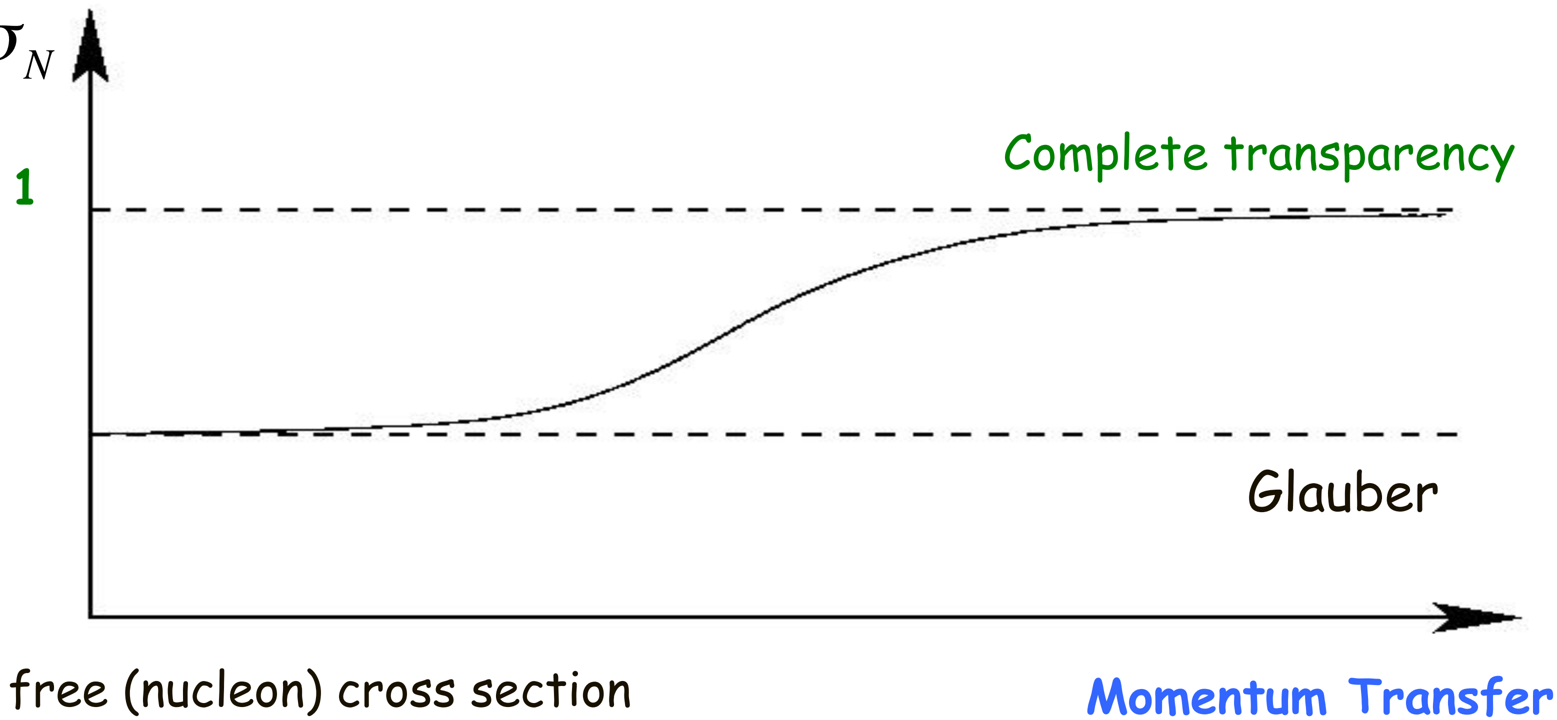
3 ingredients leading to CT:

- At high Q , the hadron involved fluctuates to a small transverse size – called the Point-Like-Configuration "PLC"
- The PLC experiences reduced interaction with the nucleus –it is color screened
- The PLC remains small as it propagates out of the nucleus

THE SIGNATURE OF “CT”

The signature of Color Transparency is the increase of the medium “nuclear” Transparency T_A as a function of the momentum transfer

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



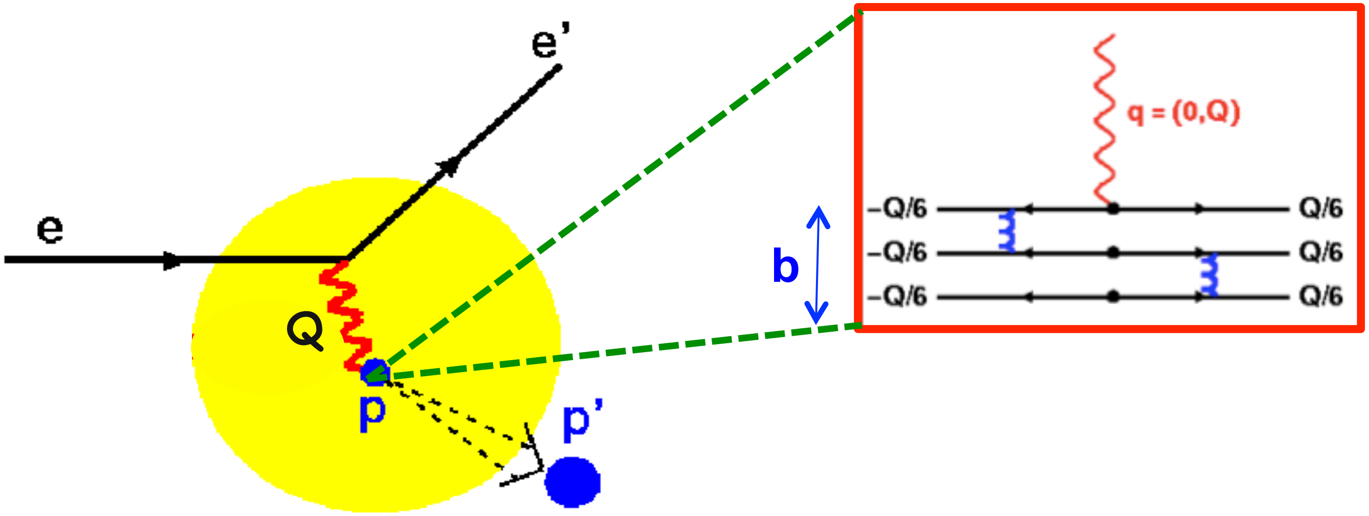
σ_N is the free (nucleon) cross section

σ_A is the nuclear cross section

THE POWER OF HARD EXCLUSIVE REACTIONS IN CT STUDIES

Hard exclusive processes play a key role in QCD

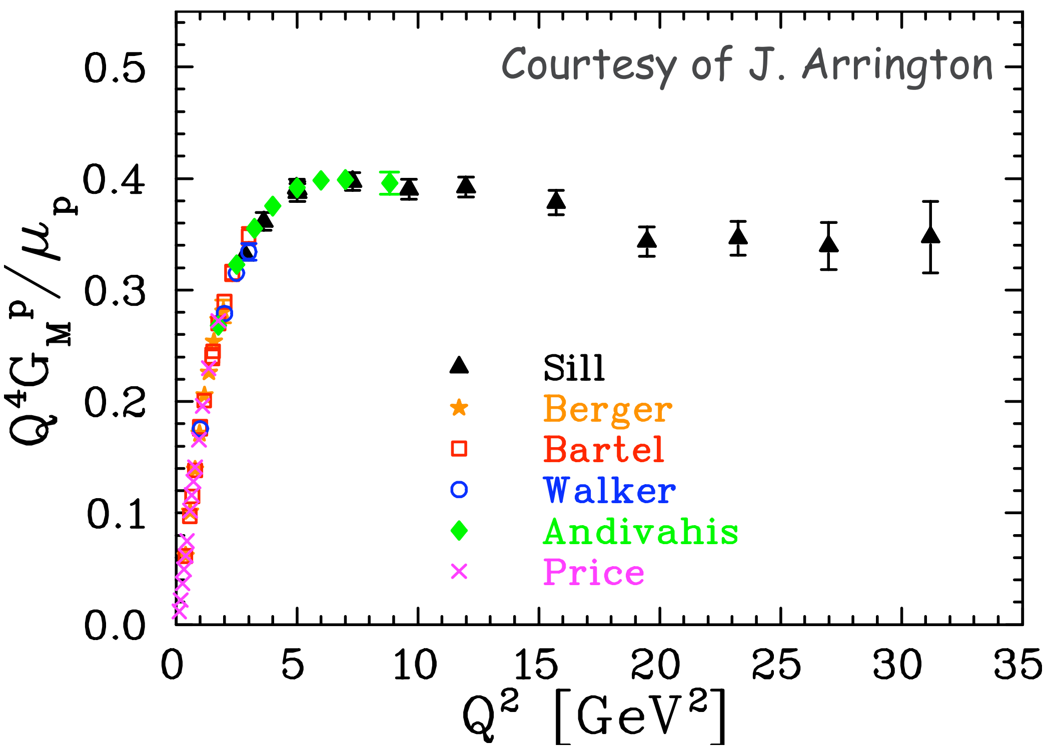
- They allow the studies of quark and gluons scattering and their formation into hadrons at the amplitude level
- They depend in detail on the composition of the hadron wave functions themselves



Lowest order elastic Scattering shown in the Breit frame where the proton momentum is changed in sign not magnitude and no energy is been exchanged

- For the reaction to be elastic, all partons in the proton wave function have to be located within the same transverse interval **$b \leq 1/Q$**
- At large Q^2, the transverse size of the ejectile can be much smaller than the equilibrium radius of the proton

PILLAR #1: THE SSC: A SPECIAL YET SIMPLE CONFIGURATION OF THE HADRON WAVE FUNCTION



From QCD based quark counting rules, the elastic form factor of a hadron with n_h constituents scales as

$$F_h(Q^2) \sim \frac{1}{(Q^2)^{n_h - 1}}$$

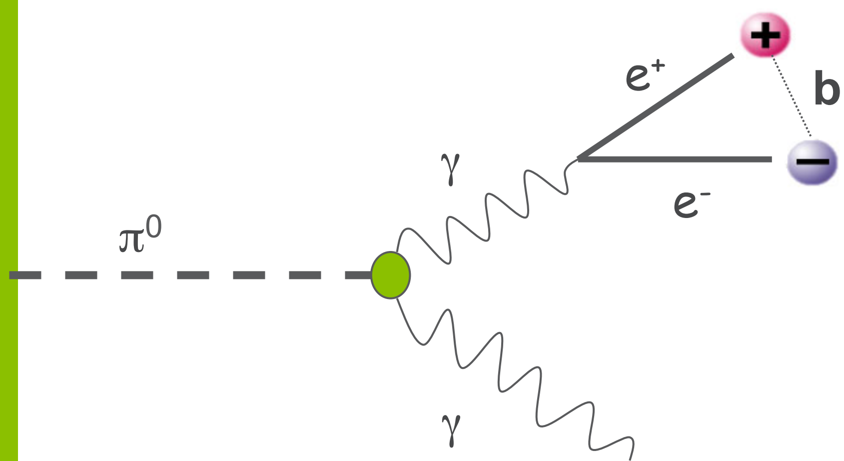
n_h = 3 for proton

If the proton contains more than the minimal number of constituents, the scattering amplitude at large Q^2 is suppressed by powers of Q^2

The SSC is a simple configuration of the hadron wave function containing only valence quarks which came close together forming a small size color singlet system

PILLAR # 2: COLOR SCREENING: THE SSC EXPERIENCES REDUCED ATTENUATION

In QCD the color field of a color neutral object vanishes with decreasing size of the object



200 GeV π^0 produced in cosmic rays

- Consequence of charge screening in QED were observed by Perkins in 1955
- The ionization produced by the pair was small near the decay point, increasing with distance from vertex
- It was quickly interpreted by Chudakov (1955) in the framework of QED: A pair of oppositely charged particles interacts in the medium with a dipole cross-section proportional to b^2

- In Perturbative QCD two-gluon exchange is believed to be the dominant scattering mechanism

- The SSC-nucleon cross section is $\sigma_{SSC,N} \approx \sigma_{h,N} \frac{b^2}{R_h^2}$, R_h is the hadron radius

PILLAR # 3: LIFETIME OF SMALL-SIZE-CONFIGURATION

Naïve parton model:

- Quarks expand back to their usual separation at the speed of light

$\tau \approx R_h/c$ (with time dilation it becomes $E_h{}^*\tau/M_h$)

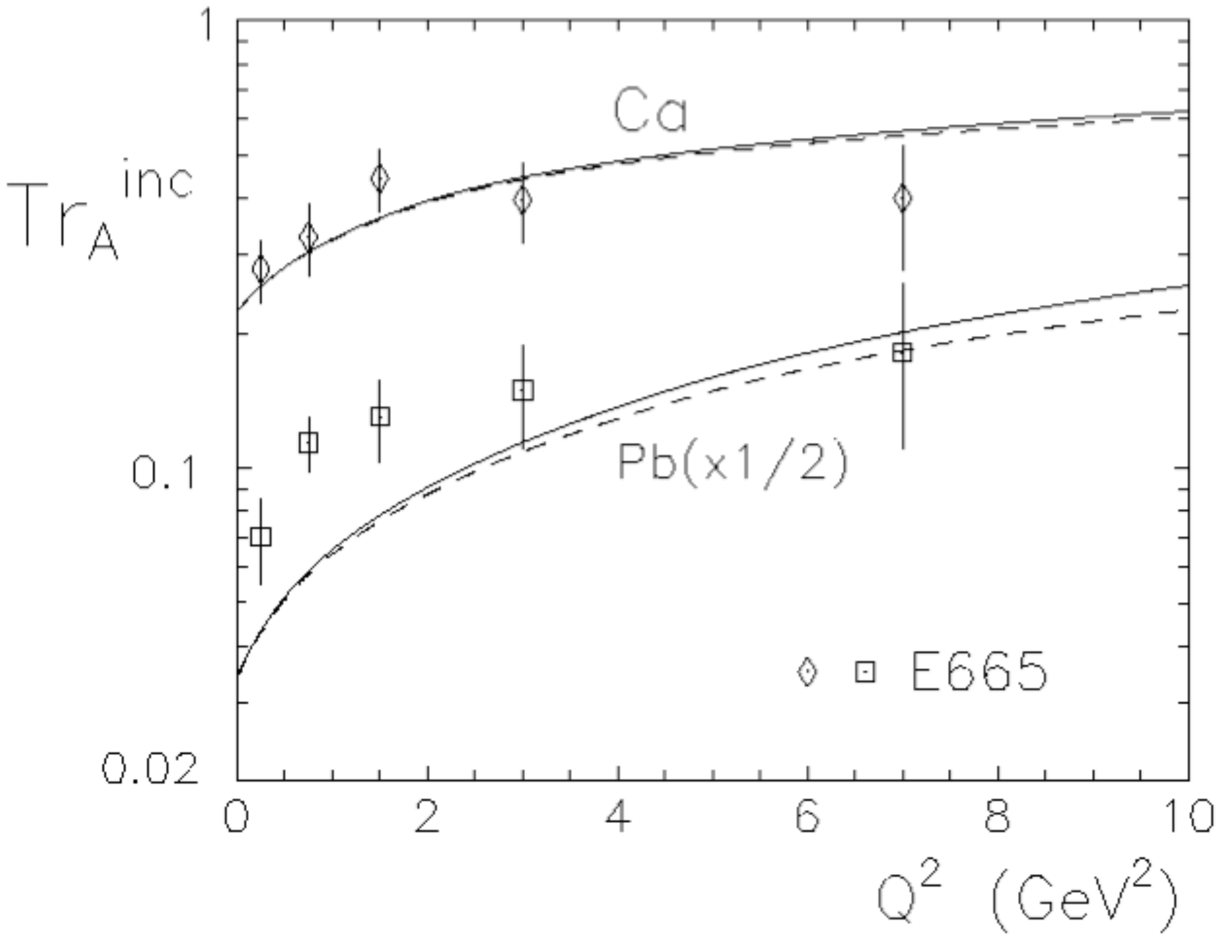
- If the hadron is a nucleon $R_h \approx 0.8$ fm, probability of SSC escaping the nucleus is significant even for modest values of Lorentz factor

More realistic "quantum diffusion" model:

- The expansion takes a total time of $1/(E_{h^*} - E_h)$, where E_{h^*} is the energy of the typical intermediate state
- The key point is that the SSC is not the ground state of the free hadron Hamiltonian

E665 EXPERIMENT AT FERMILAB (470 GEV MUON BEAM)

Kopeliovich et al., PRC 65 (2002) 035201



HIGH ENERGY SEARCH FOR CT

$$\boxed{\pi\,(500\,GeV/c) + C\,(Pt) \rightarrow 2\ jets}$$

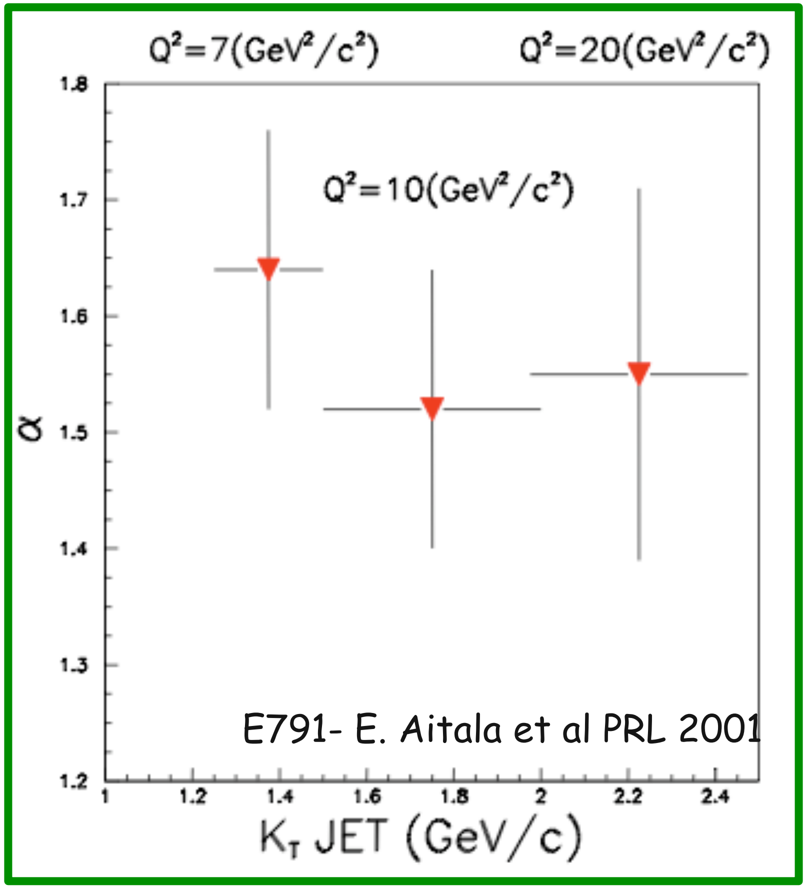
Diffractive dissociation into dijets for Pions scattering coherently from C & Pt

The pion wave function in terms of Fock states

$$\psi_\pi = \alpha\,|q\bar{q}\rangle + \beta\,|q\bar{q}g\rangle + \gamma\,|q\bar{q}gg\rangle + \ldots$$

- When high energy pions hit the nuclear target, the physically small component will be filtered by the nucleus and materialize as Diffractive Jets (Bertsch et al. PRL 1981)
- SSC (< 0.1 fm) scatters coherently from nuclei producing high mass dijets (Frankfurt et al. PLB 1993)
- α = 1.6 is to be compared with α = 2/3 typical of normal pion-nucleus interaction

Cross sections fitted to $\sigma_A = \sigma_0 A^\alpha$



$$Q^2 \approx M_J^2 \geq 4k_t^2$$

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MEDIUM ENERGY SEARCH FOR COLOR TRANSPARENCY

Baryons

- ❑ A(p, 2p) BNL
- ❑ A(e, e'p) SLAC and JLab

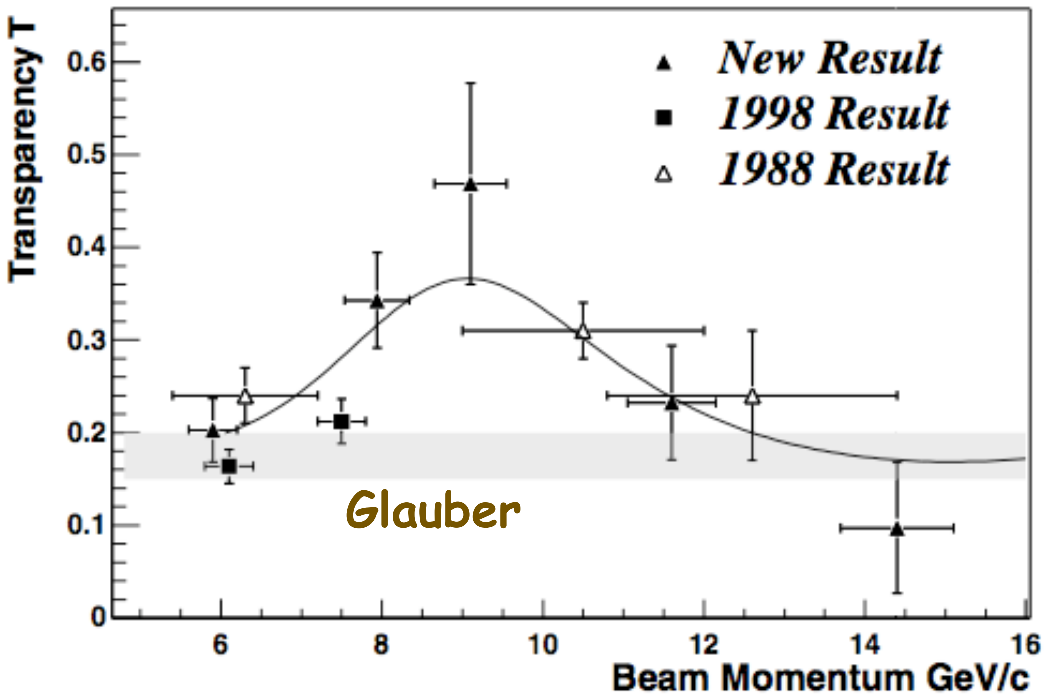
Mesons

- ❑ A(γ, πp) JLab
- ❑ A(e, e'π) JLab
- ❑ A(e, e'ρ) DESY and JLab

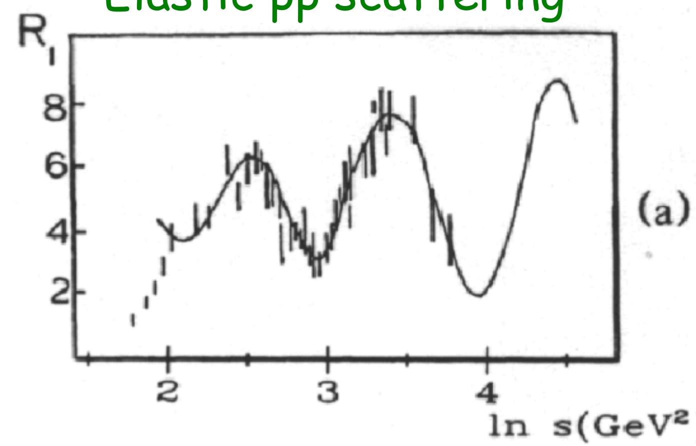
COLOR TRANSPARENCY IN C(P, 2P) REACTION

$$R_1 \propto s^{10} \frac{d\sigma}{dt}$$

A. Leksanov et al. PRL 2001

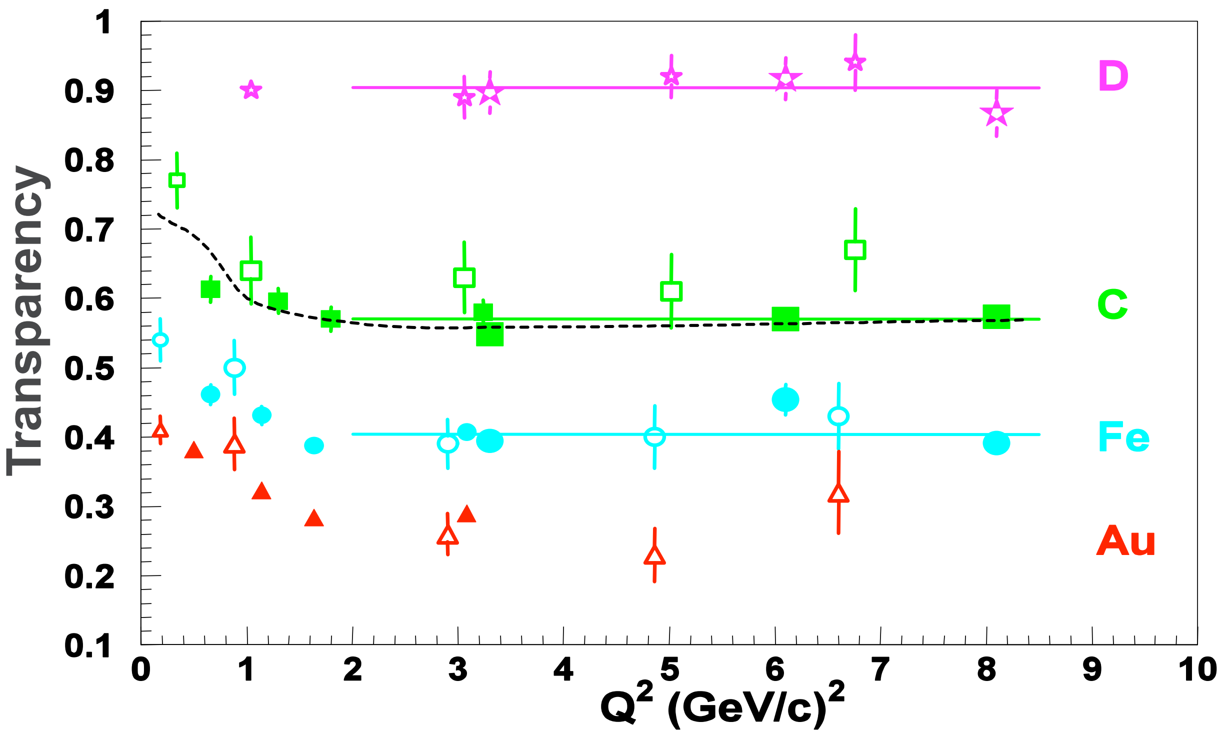


Elastic pp scattering



- The increase at low momentum cannot be taken as an unambiguous signal of CT
- Results explained in terms of nuclear filtering (J. Ralston PRL 1988) or the crossing of the open charm threshold (S. Brodsky PRL 1988)

SEARCH FOR COLOR TRANSPARENCY IN A(E, E'P) REACTION



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)

Solid Pts – JLab
Open Pts -- other

Constant value fit for $Q^2 > 2\ (\mathrm{GeV}/c)^2$ has $\chi^2/\mathrm{df} \approx 1$

Conventional Nuclear Physics "Glauber" Calculation gives good** description (V. Pandharipande and S. Pieper PRC 1992)

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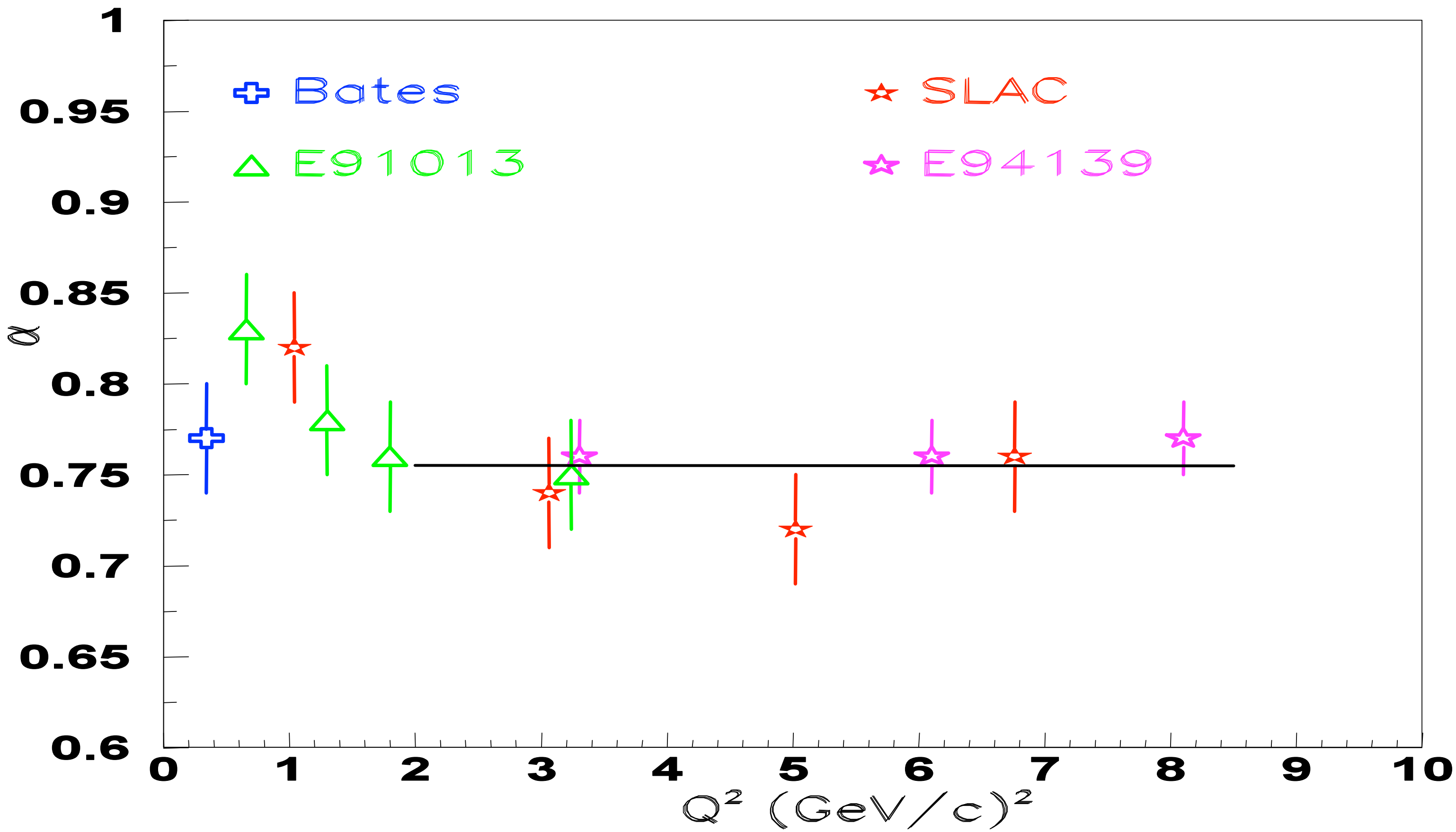
The A dependence in A(e, e'p) reaction



Cross sections fitted to $\sigma_A = \sigma_0 A^\alpha$

α = 0.76 independent of Q^2 and close to proton-nucleus total cross section case

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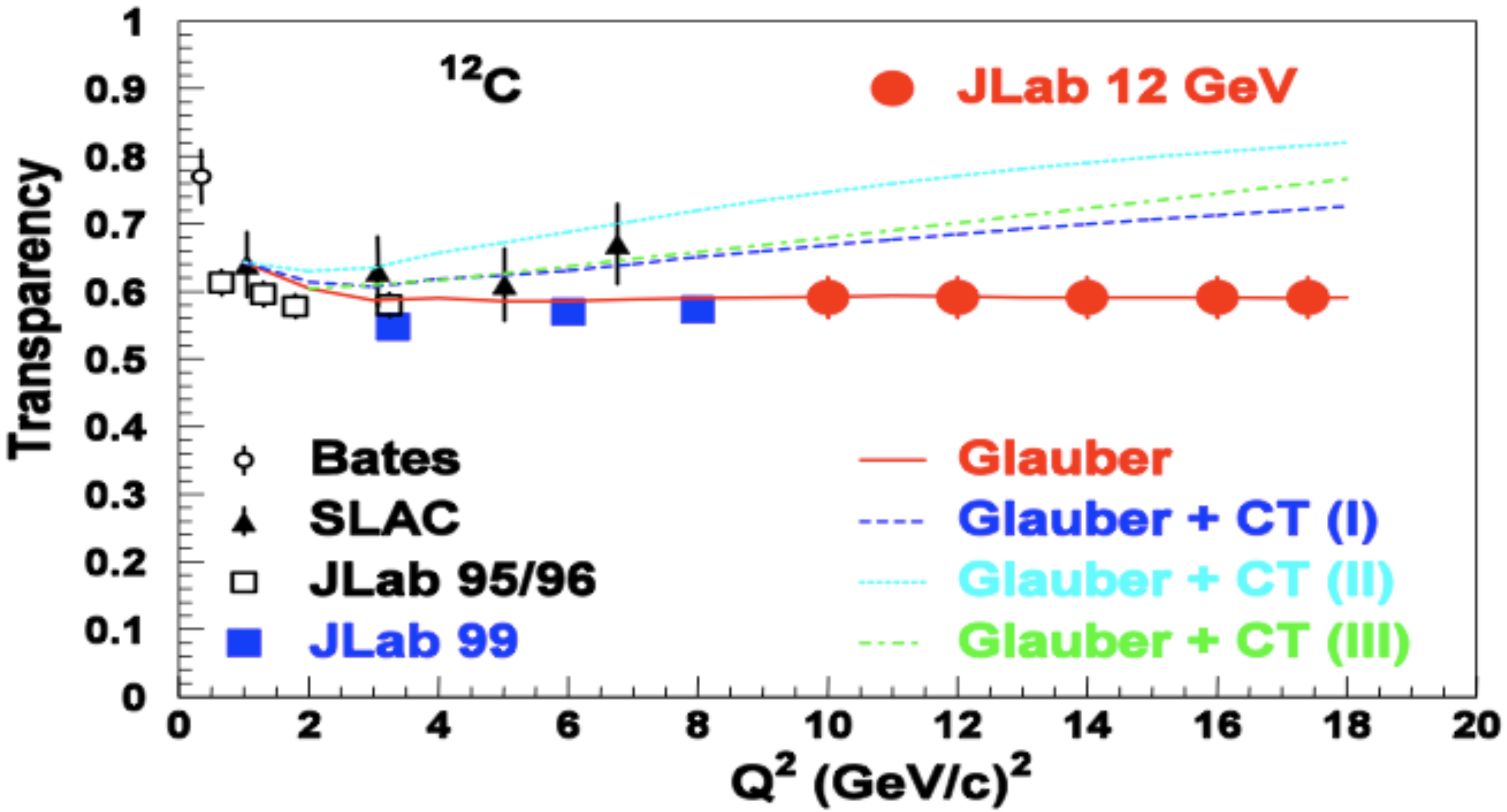
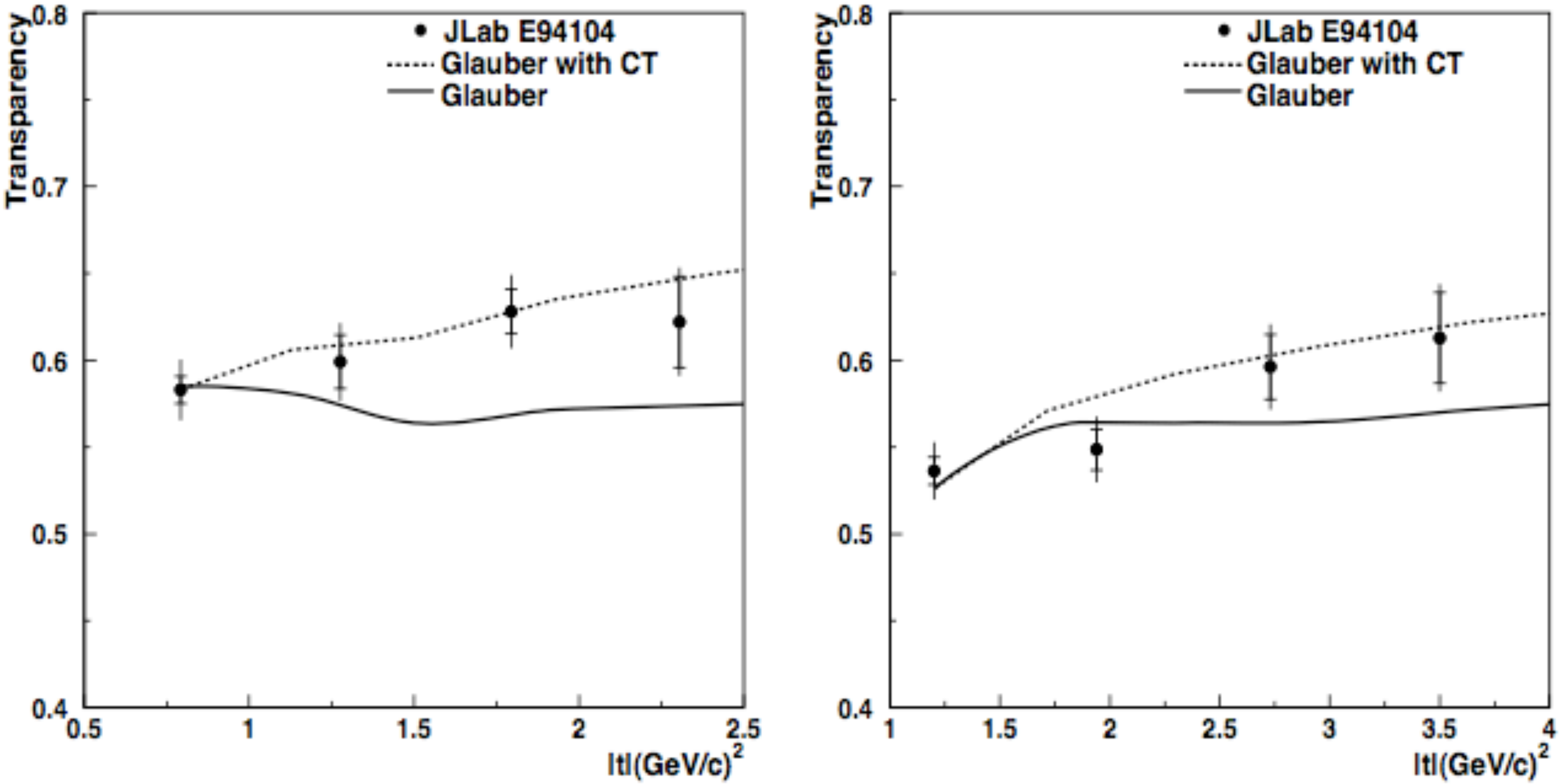
A(e, e'p) @ JLab 12 GeV



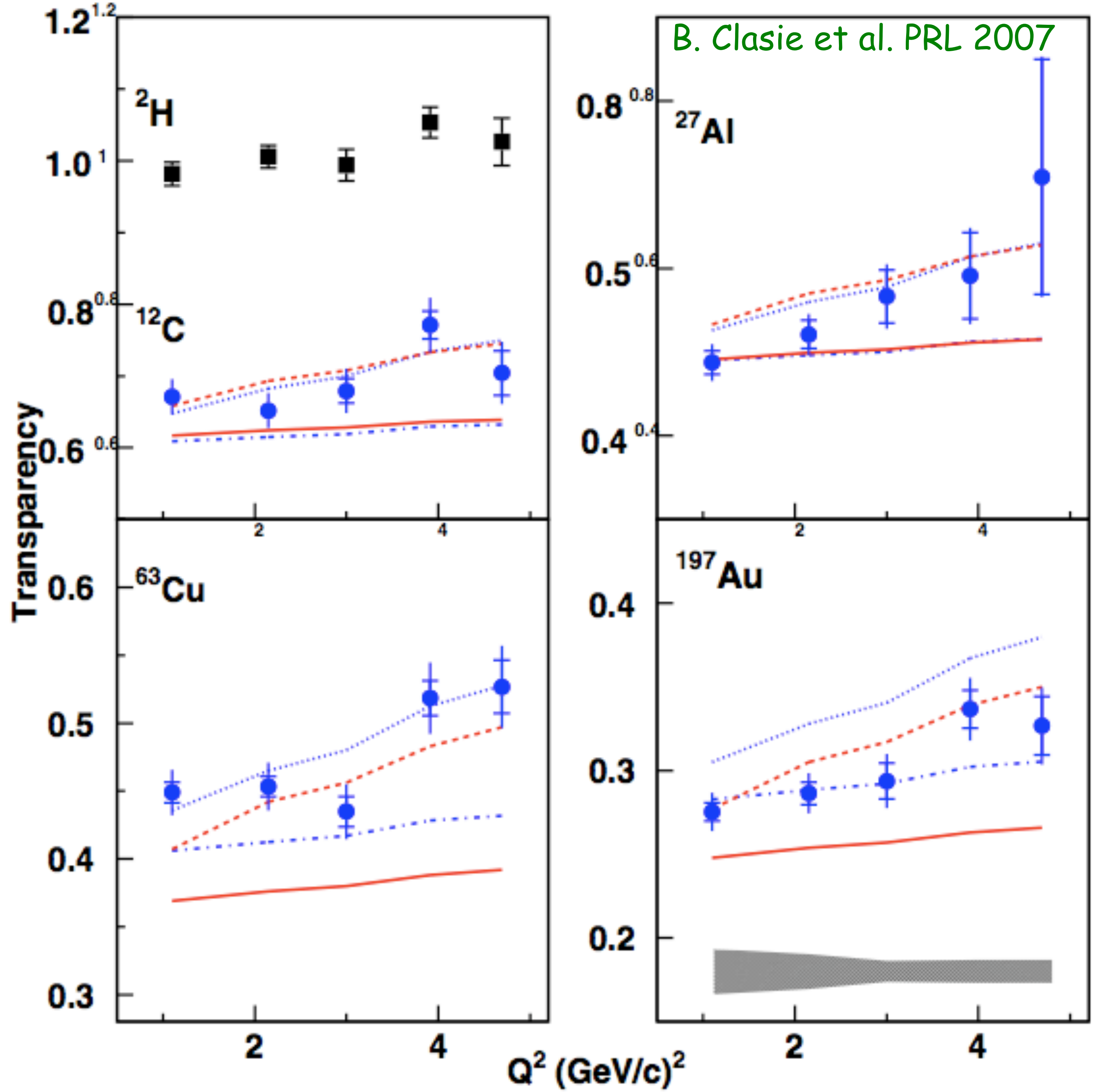
Search for Color Transparency γ n -> π^- p in ^{4}He

$\theta^{\pi}_{CM} = 70°$ $\theta^{\pi}_{CM} = 90°$

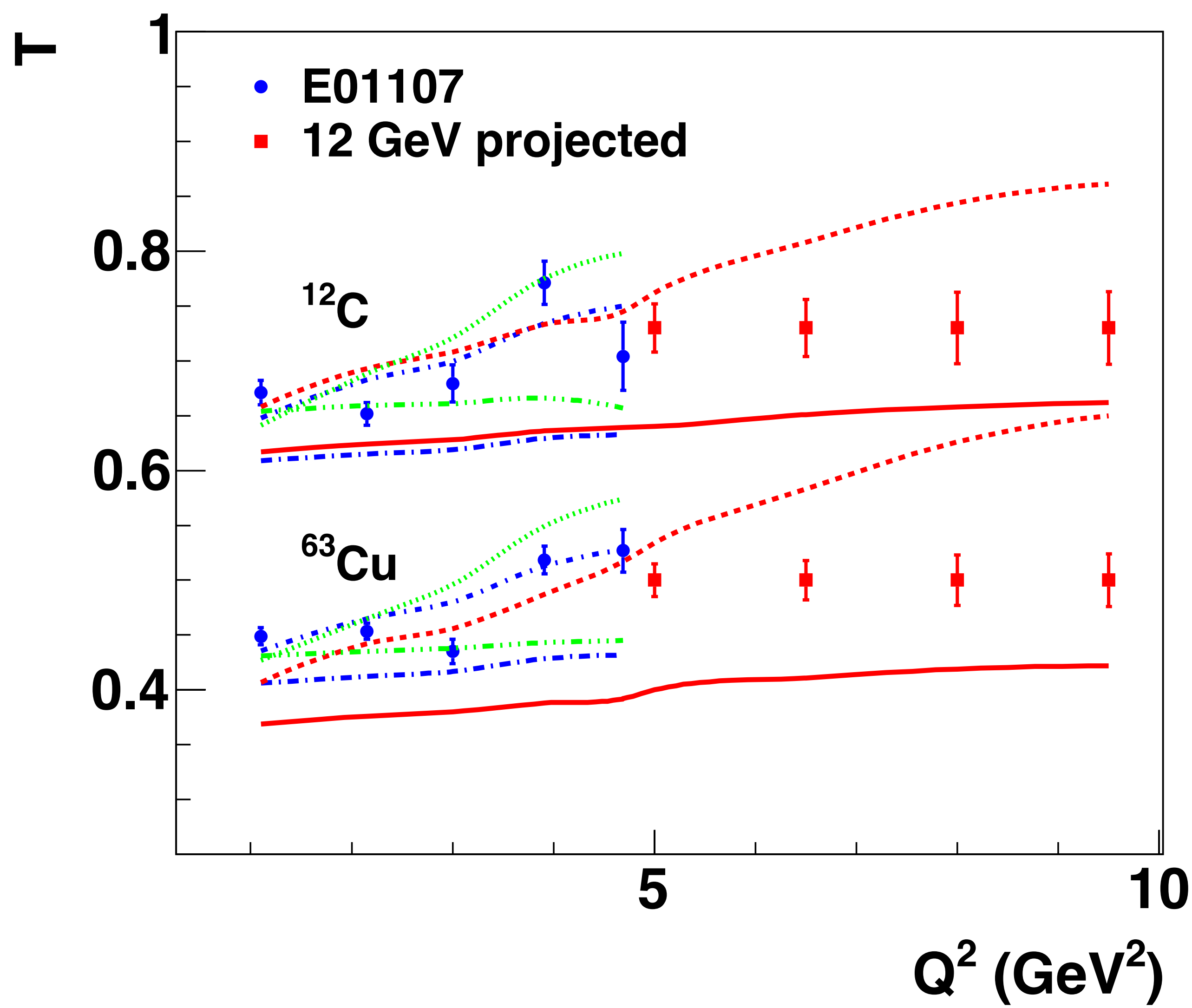


D. Dutta et al. PRC 2003

SEARCH FOR COLOR TRANSPARENCY IN A(E, E’Π) REACTION

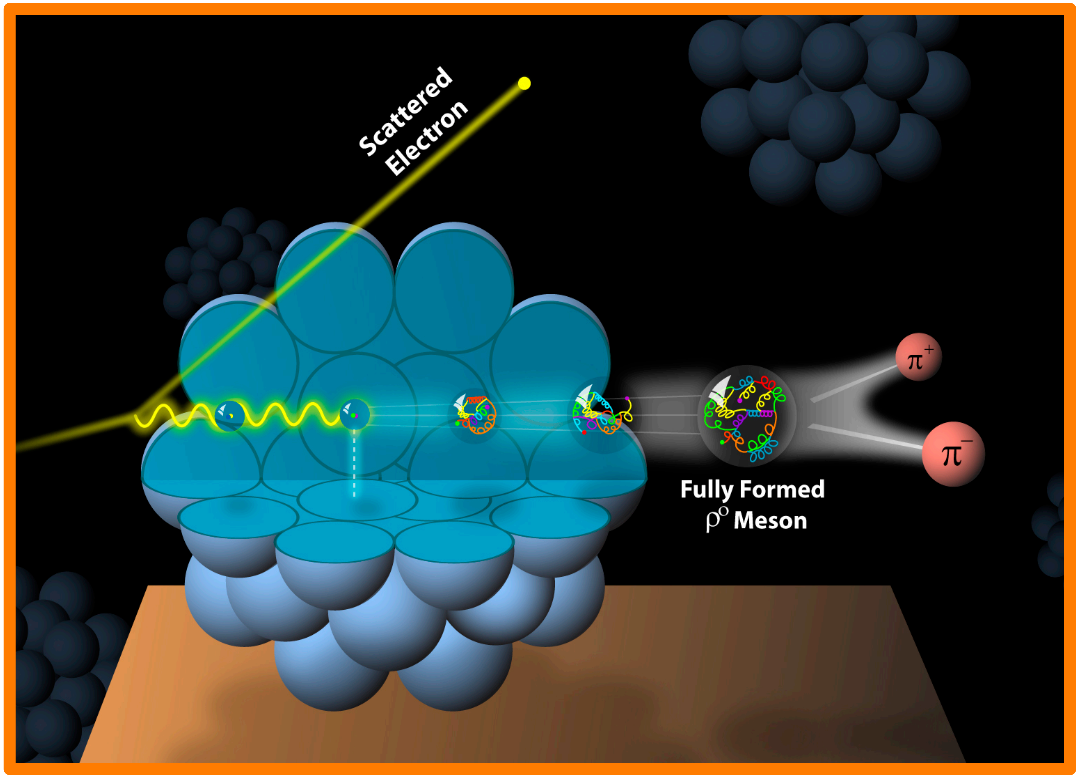


A(e, e′π) projections for JLab 12 GeV



P^0 ELECTROPRODUCTION ON NUCLEI

- The small size pre-hadron ρ^0 is directly produced from the virtual photon since both are vector particles



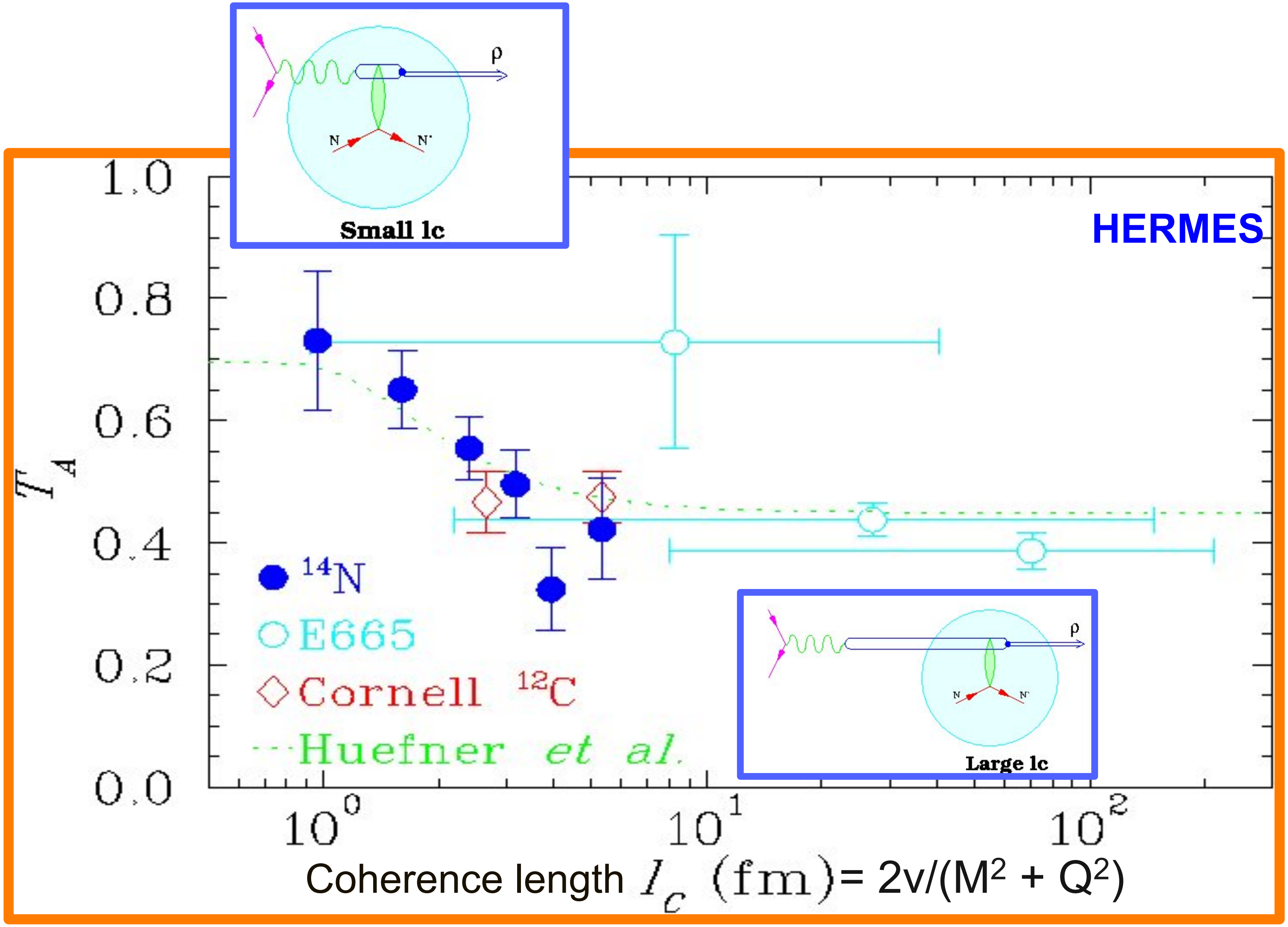
Finite propagation distance (lifetime) l_c for the (q q-bar) virtual state

$$l_c = 2\nu/(M^2 + Q^2)$$

M is the mass of the vector meson

ν is the energy transferred by the electron

CT SIGNATURE IS THE RISING OF THE NUCLEAR TRANSPARENCY WITH Q^2. HOWEVER …

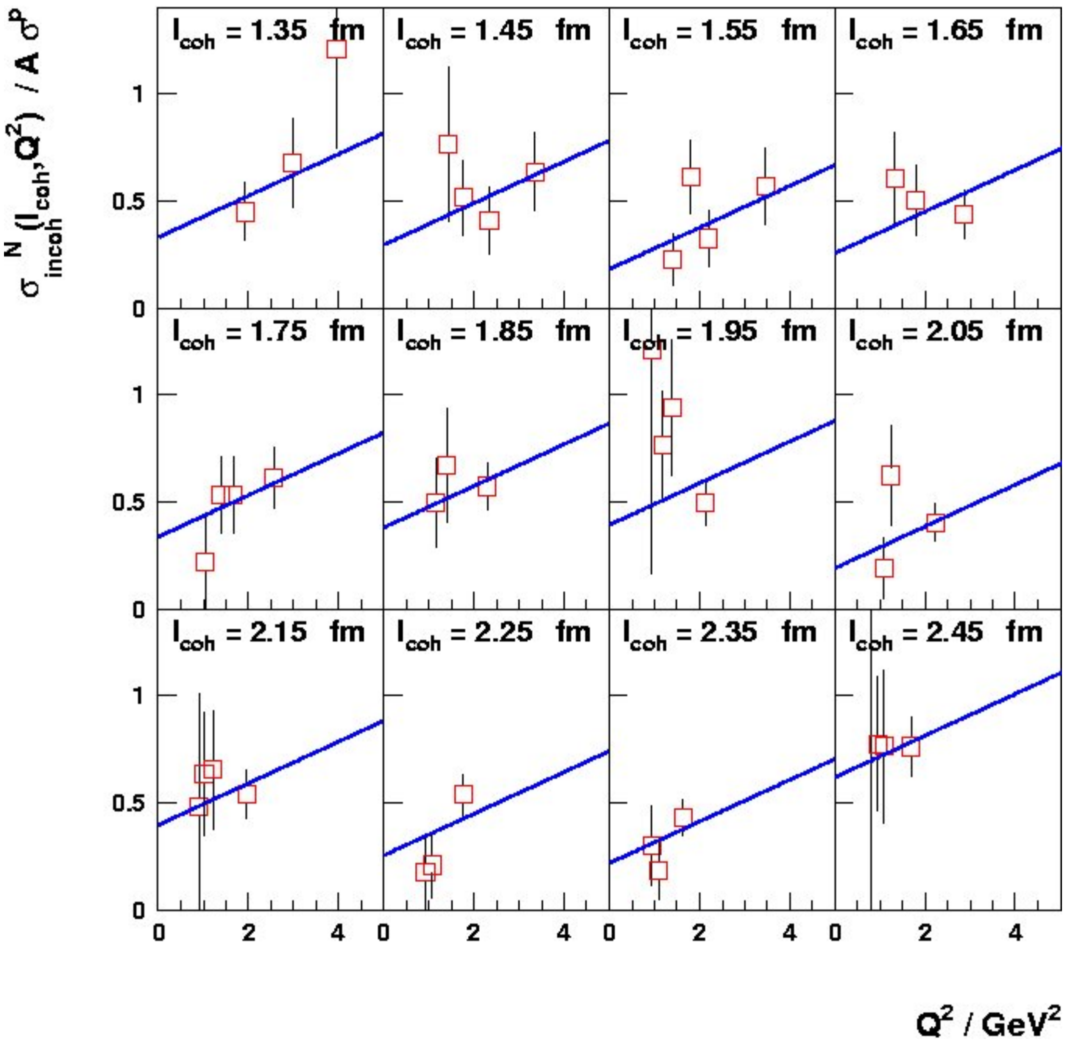


HERMES EXPERIMENT AT FIXED COHERENCE LENGTH

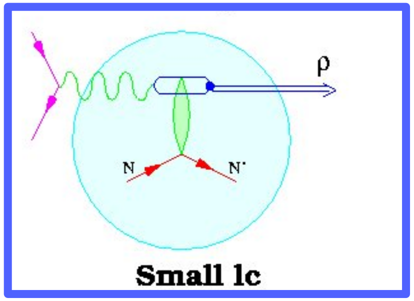
HERMES Nitrogen data : $T_A = P_0 + P_2 Q^2$
$P_2 = (0.097 \pm 0.048_{stat} \pm 0.008_{syst})\ \mathrm{GeV}^{-2}$

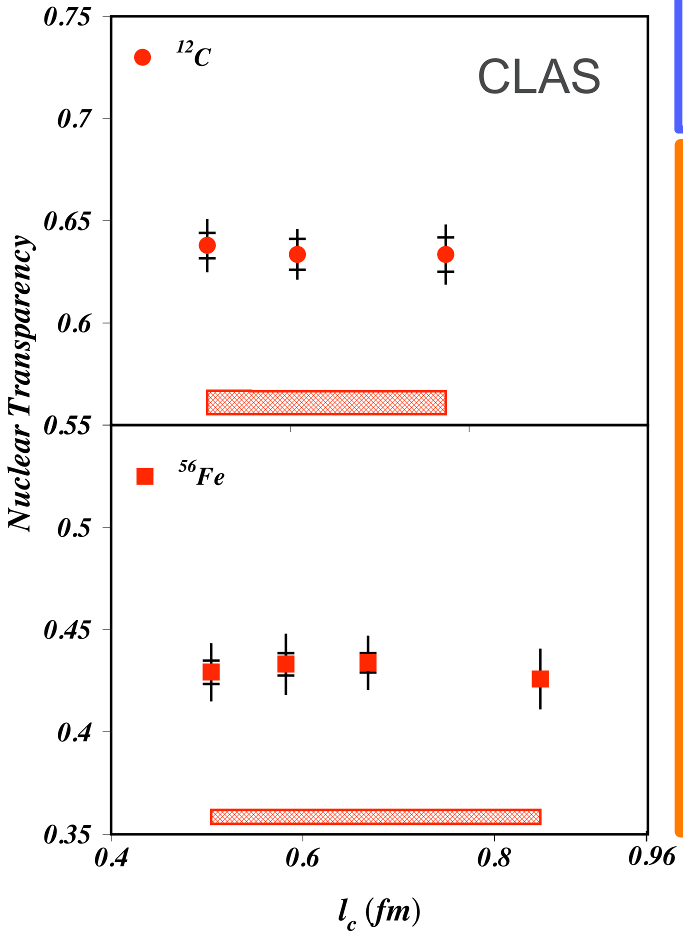
Phys. Rev. Lett. 90 (2003) 052501

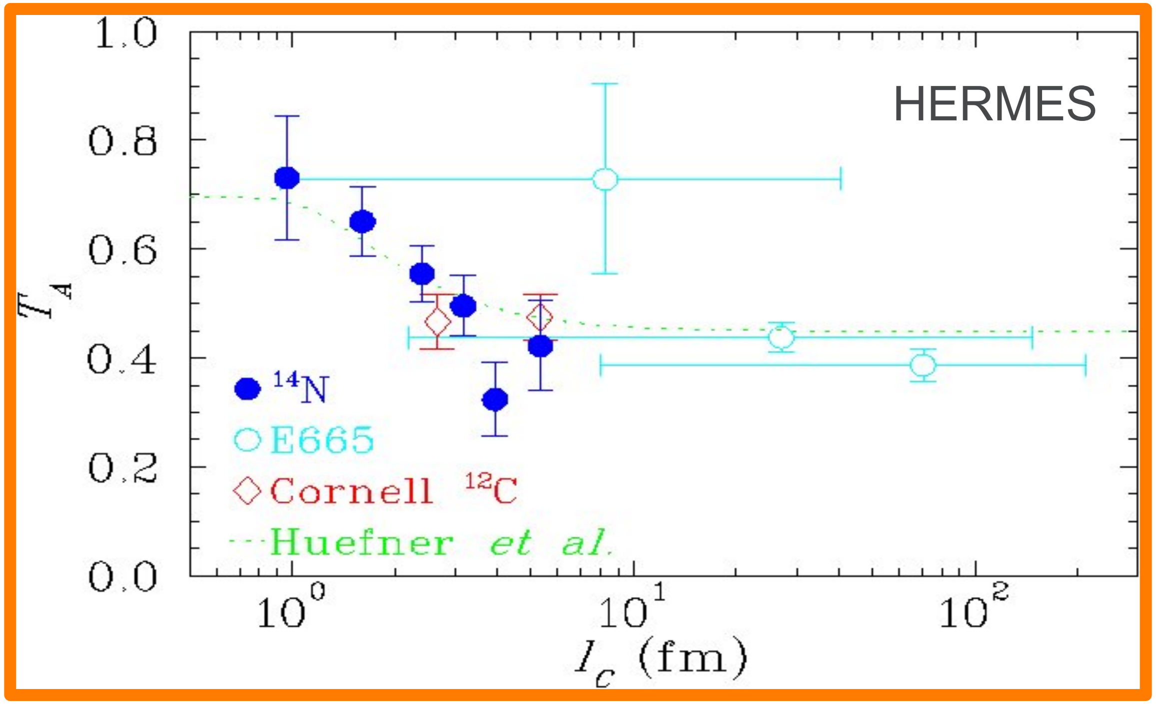
27 GeV positron beam

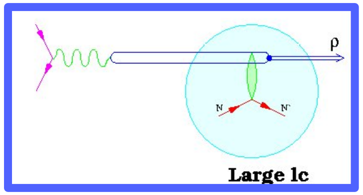


CLAS EXPERIMENT – COHERENCE LENGTH DEPENDENCE









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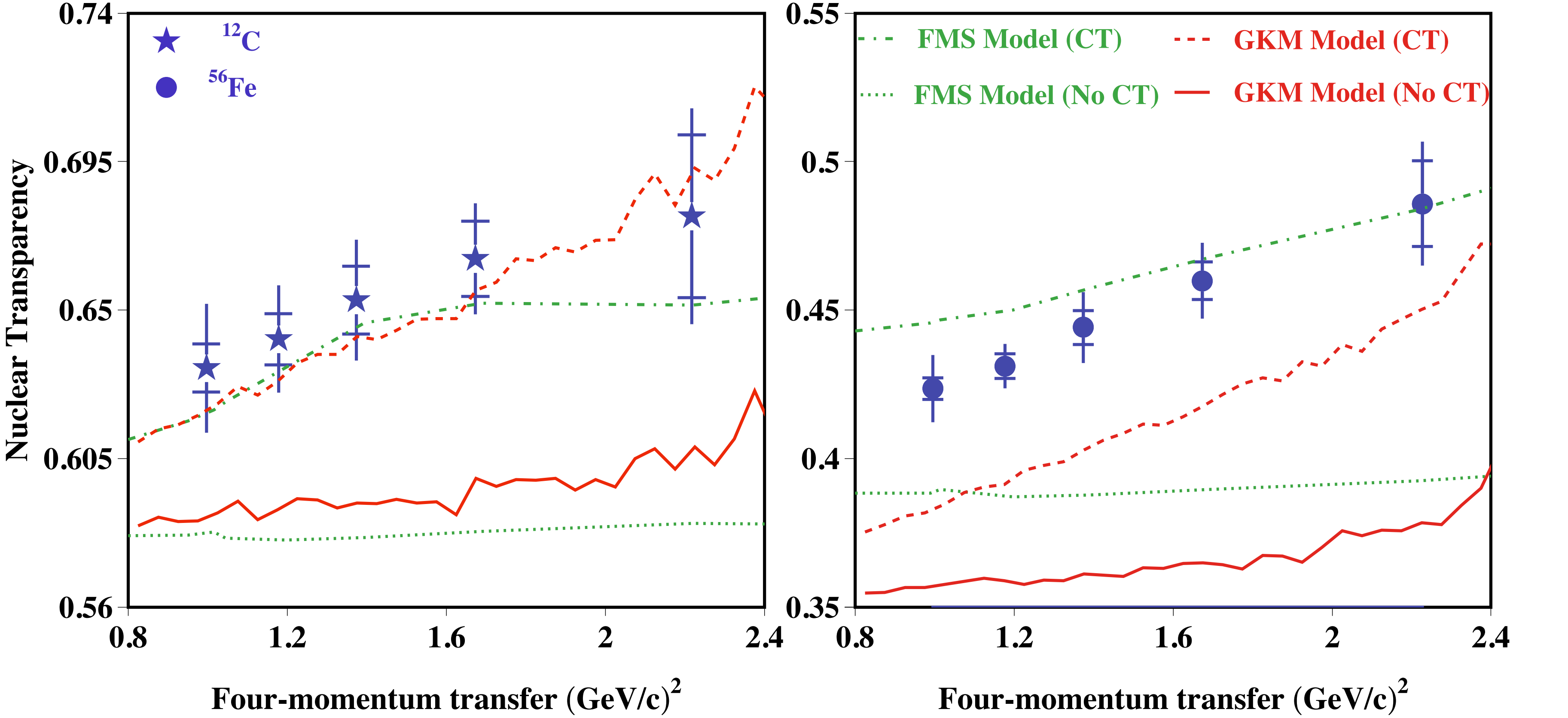
CLAS EXPERIMENT

L. El Fassi et al. PLB 2012

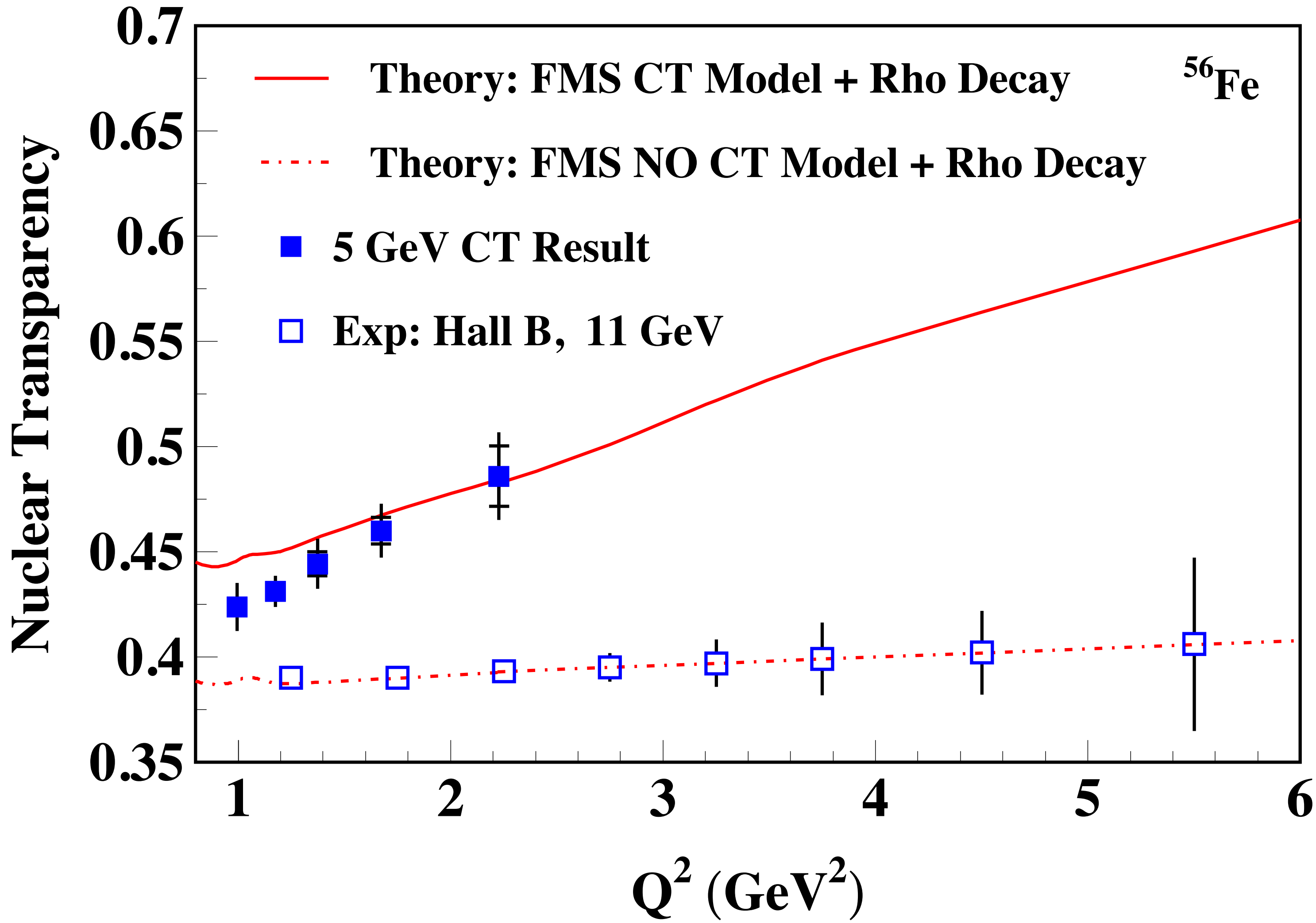


FMS (Glauber Model): Frankfurt, Miller & Strikman, PRC 78, 015208 (2008)

GKM (Transport Model): Gallmeister, Kaskulov & Mosel, PRC 83, 015201 (2011)

KNS (LC QCD Model): Kopeliovich, Nemchik & Schmidt, PRC **76, 015205 (2007)**

JLab 12 GeV ρ^0 electroproduction measurements C, Fe and Sn



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SUMMARY AND OUTLOOK

- Clear evidence for the onset of Color Transparency for both π and ρ electroproduction off nuclei at JLab

- At intermediate energies, CT provides unique probe of the space-time evolution of special configurations of the hadron wave function

- Using the upgraded JLab 12 GeV, we plan to extend all measurements to higher Q^2 and disentangle different CT effects (PLC creation, its formation and interaction with the nuclear medium)