Color Transparency in rho Electroproduction

Exclusive Reactions at High Momentum Transfer

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Jefferson Lab

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For CLAS Collaboration

Argonne NATIONAL LABORATORY

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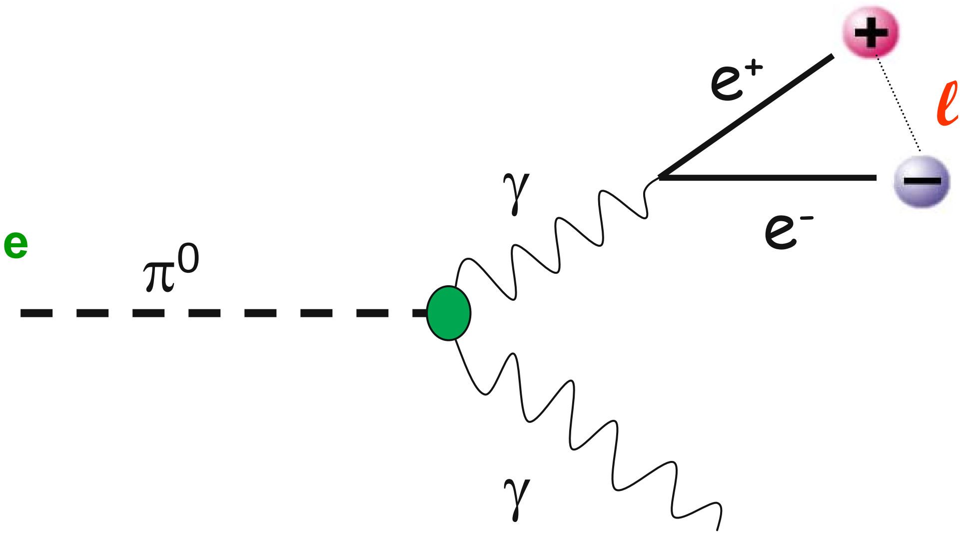
Outline

- QCD and Color Transparency
- Overview of experimental progress
- Recent results from CLAS
- Summary and outlook

Origin of CT



- **Discovery by Perkins (1955) of the (Dalitz) decays in emulsion of π^0 (~ 200 GeV) produced in cosmic rays** $\pi^0 \rightarrow e^+ e^- \gamma$

- **The ionization produced by the pair was small near the decay point, increasing with distance from vertex**

- **This surprising observation 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

$\Rightarrow$ **this cross-section ($\sigma \cong \ell^2$) vanishes near the creation point**

In early 80's, Brodsky and Mueller applied the notion of transparency to QCD and to color charge

Color Transparency is a spectacular **prediction of QCD**: **Under the right conditions**, the nuclear matter will allow the transmission of hadrons with **reduced attenuation**. Such a phenomenon is totally **unexpected in a hadronic picture of strongly interacting matter**, but **straightforward in quark gluon basis**, this is one of the features which makes it so interesting.

CT: the nuclear medium becomes more transparent !

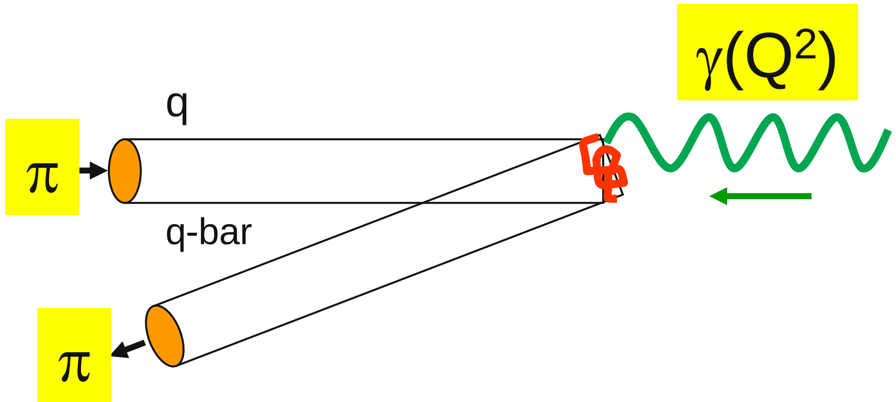
Three ingredients

- Creation of small size object (Point-Like Configuration PLC)
- Small size particles have small cross sections
- The distance over which a PLC expands to its free size is at least as large as the nuclear radius

Selection of PLC via Hard exclusive processes

Hard: high momentum transfer

Exclusive: completely determined initial and final states.
Elastic processes are special cases



Electromagnetic form factor of the pion in the Breit frame

- Unless the struck quark shares the momentum transfer with the other quark, the pion fragments and the reaction is inelastic

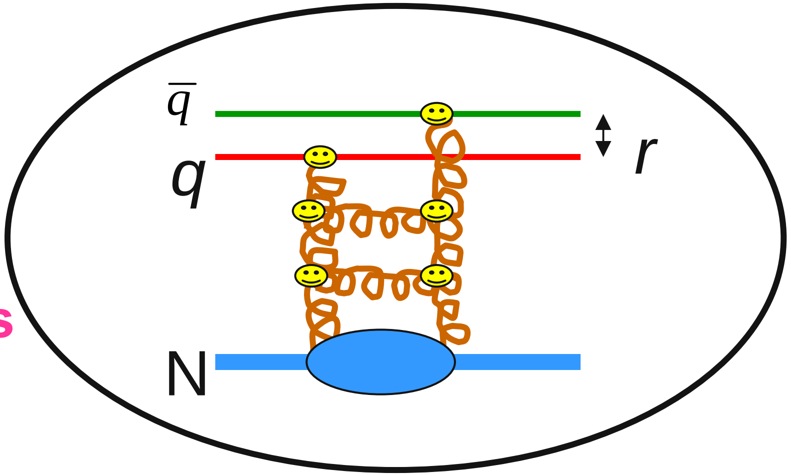
- As Q increases, the exchange of the gluon has to be fast.
  Causality (no interaction is faster than speed of light)
  $\Rightarrow$ the quark's pair has to be localized within a transverse size of 1/Q

Color screening

In QCD the color field of a color neutral object vanishes as the size of the object is reduced

Because

The field of individual quarks and gluons cancel each other as the size is reduced by analogy to QED



Nucleus

Therefore

The interaction cross-section has a dipole form

$\sigma \cong r^2$

r is the separation between the constituents

The nucleus, a unique laboratory of quark dynamics

- Characteristic proper time scale is $\tau_0 \sim 1$ fm

  τ_0 is the time needed by a quark to travel distances typical of the confined systems

- Taking into account Lorentz dilation, the proper time scales in the Lab frame become $\tau = (E/M)\,\tau_0 \sim$ few fm

- The only medium available for these scales is the nucleus !

- The nucleus is playing the role of the bubble chamber !

What can we learn from studying CT?

$|\text{Meson}\rangle = Z_0\,|q\ q\text{-bar}\rangle + Z_1\,|q\ q\text{-bar}\ \ q\ q\text{-bar}\rangle + \ldots\ldots$

- PLC is by definition a product of short distances: it can only come from the valence component (higher order are reduced by a factor α_s)

- CT mechanism selects the simplest component of the hadron wave-function
  By analogy to lattice QCD, we are in the "quenched approximation"

- All the physics programs build around CT idea would allow us not only to access special configurations of the hadron wave-function but also to study how this configuration dresses with time to form the asymptotic wave-function of the hadron with all its complexity

- We are here in the heart of the dynamics of confinement !

Experimental signatures of CT

Ratio of cross-sections for exclusive processes from nuclei to nucleons is called Transparency

Exclusive Processes

Nucleon	Nucleus
$A + B \rightarrow C + D$	$A + B' \rightarrow C + D + X$

$$T_A = \frac{\sigma(A)}{A\sigma_0}$$

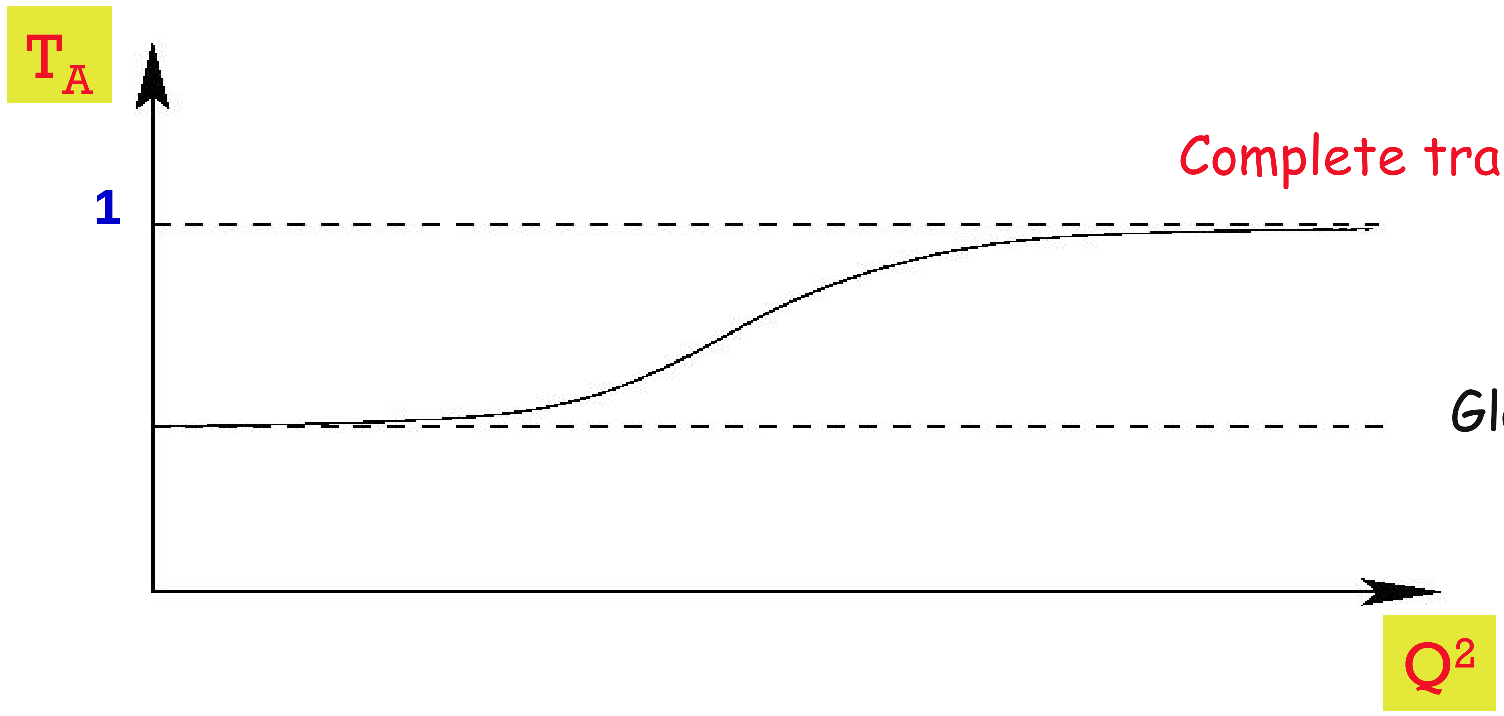
$\sigma(A)$ parameterized as = $\sigma_0 A^{\alpha}$

σ_0 = free (nucleon) cross-section

Experimental signature of CT

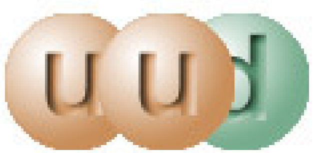
The signature of CT is the **rising of the nuclear transparency T_A**

with **increasing hardness** of the reaction (Q)

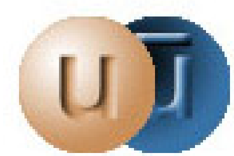


Experimental Status

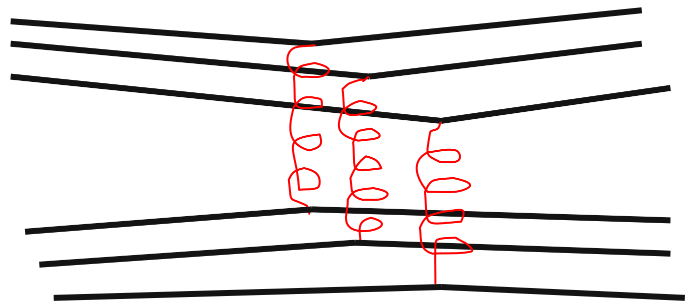
Baryon



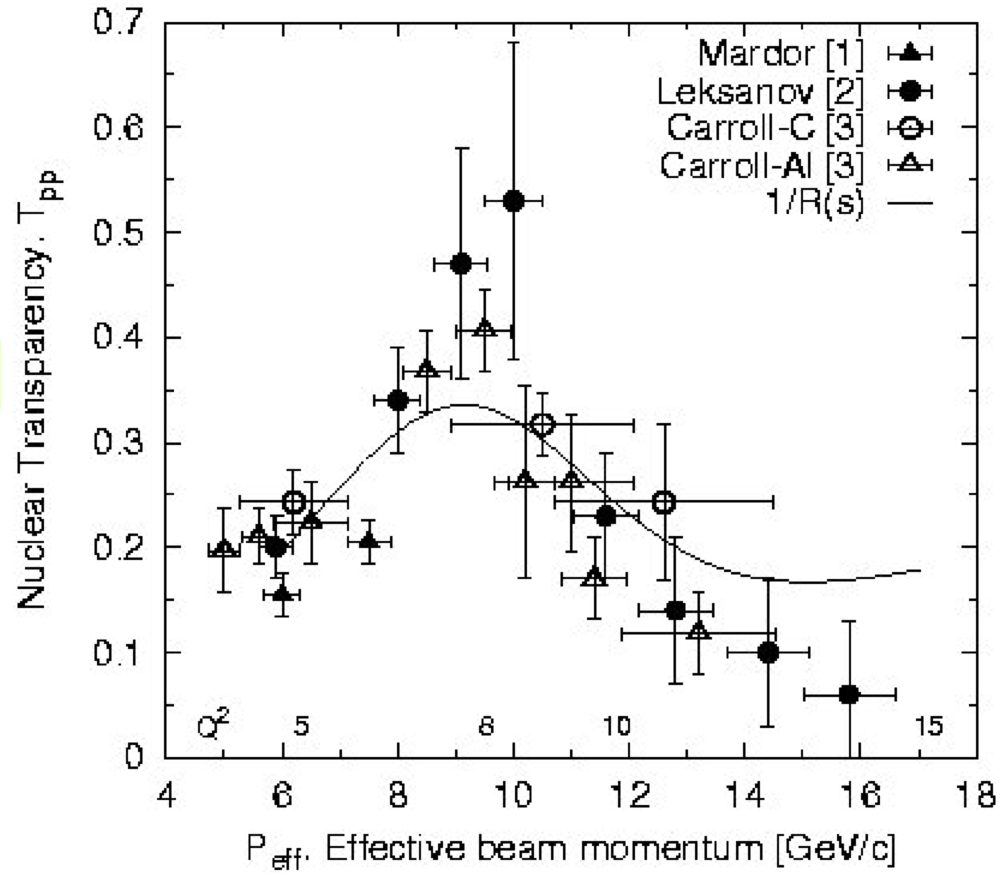
Meson



Quasi-elastic A(p,2p) : BNL E834 and E850



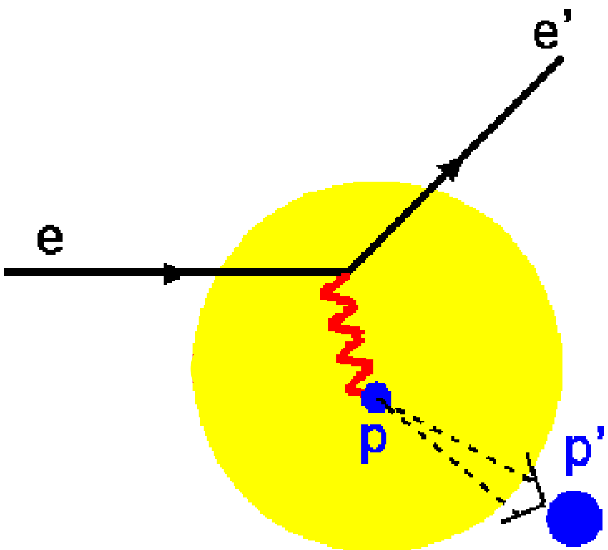
Landshoff process in pp scattering



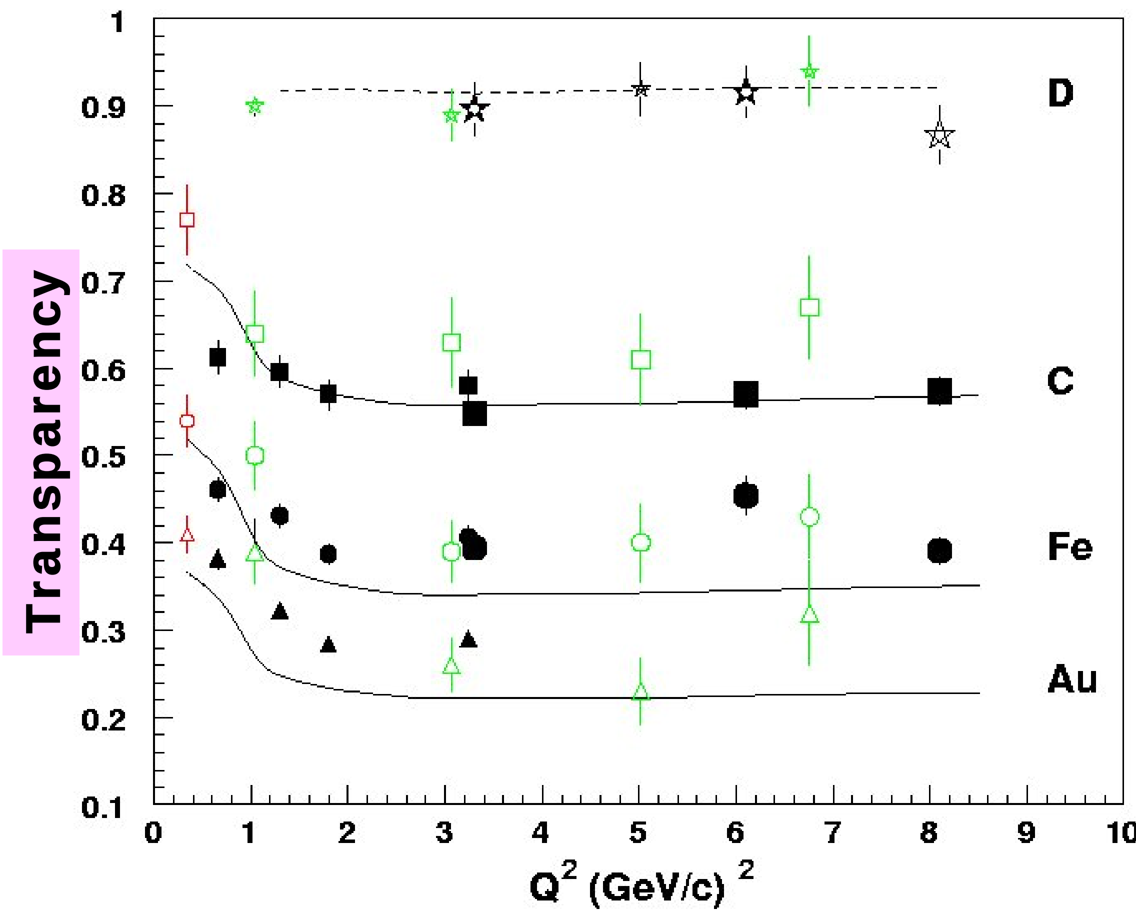
Ralston and Pire :
Interference between short and long distance amplitude in the free pp cross-section where the nuclear medium acts as a filter for the long distance amplitudes

Brodsky and De Teramond : **Unexpected decrease could be related to the crossing of the open-charm threshold**

Quasi-free A(e,e'p) : No evidence for CT



Conventional Nuclear Physics Calculation by **Pandharipande et al.** gives good description



JLab data SLAC data Bates data

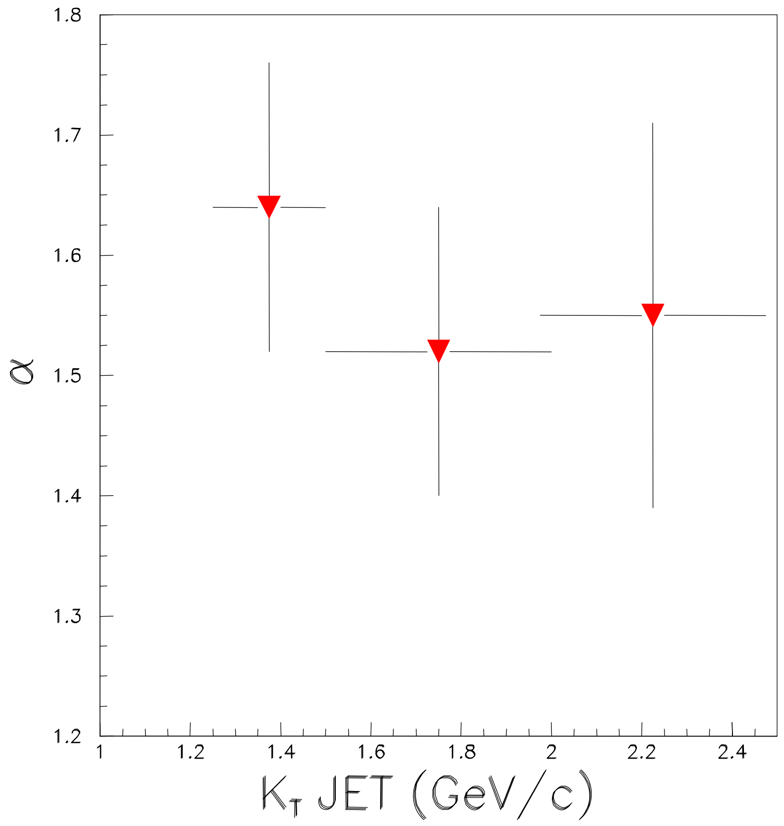
(qqq) versus (q,q-bar) systems

- Small size is more probable in 2 quark system such as pions,
  rho mesons than in protons

- Onset of CT expected at lower Q^2 in (q,q-bar) system

- Onset of CT related to onset of factorization required for access to GPDs in deep exclusive (q,q-bar) production

A(π,dijet) data from FNAL



Coherent π^+ diffractive dissociation with 500 GeV/c pions on Pt and C.

Fit to $\sigma = \sigma_0 A^\alpha$

α > 0.76 from pion-nucleus total cross-section.

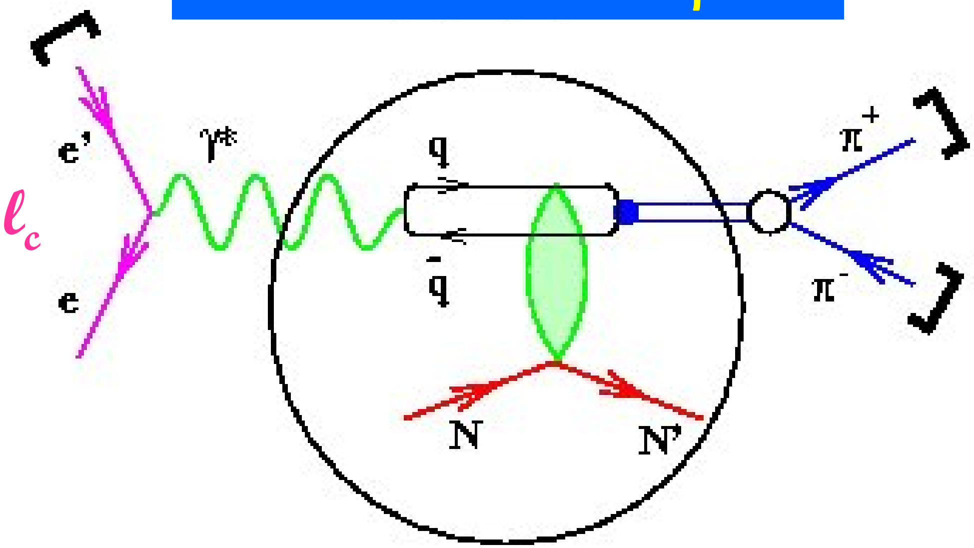
Aitala et al., PRL 86 4773 (2001)

L. L. Frankfurt, G. A. Miller, and M. Strikman, Found. Of Phys. 30 (2000) 533

ρ^0 electroproduction on nuclei

Detected particles are :
scattered electron and the π^+ and π^- from ρ^0 decay

e + N → e' + N + ρ^0

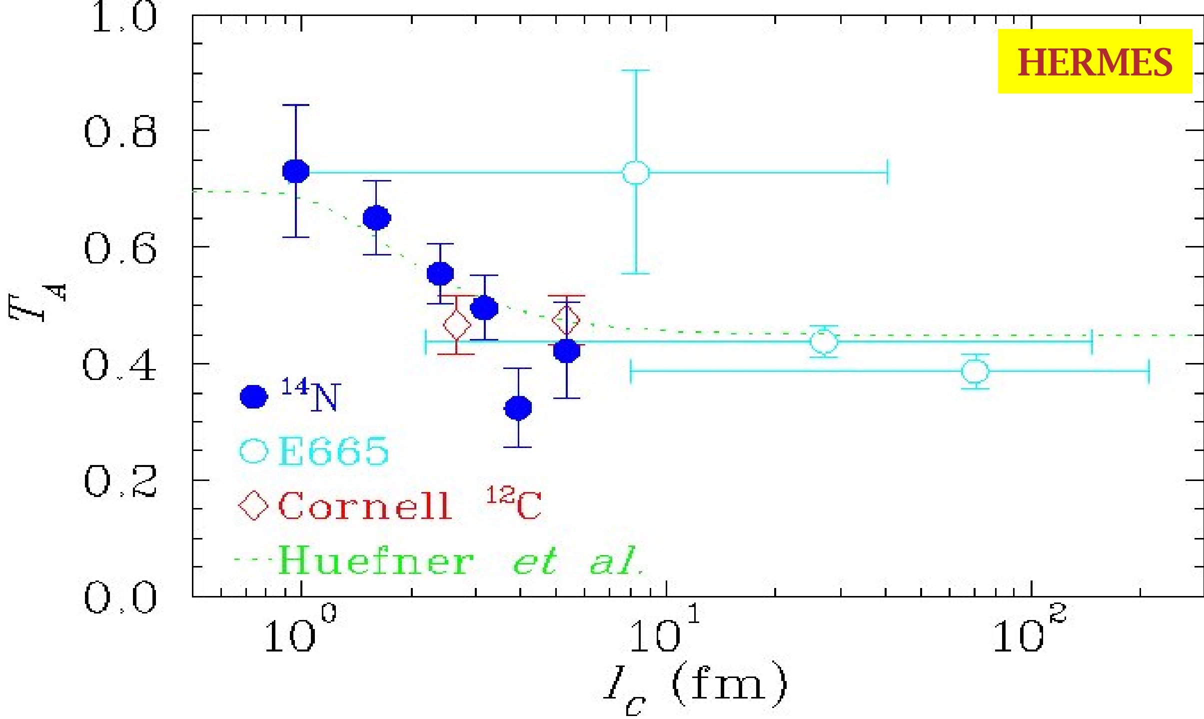


Finite propagation distance ℓ_c (lifetime) of the (q,q-bar) virtual state

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

M is the mass of the vector meson
ν is the energy transferred by the electron

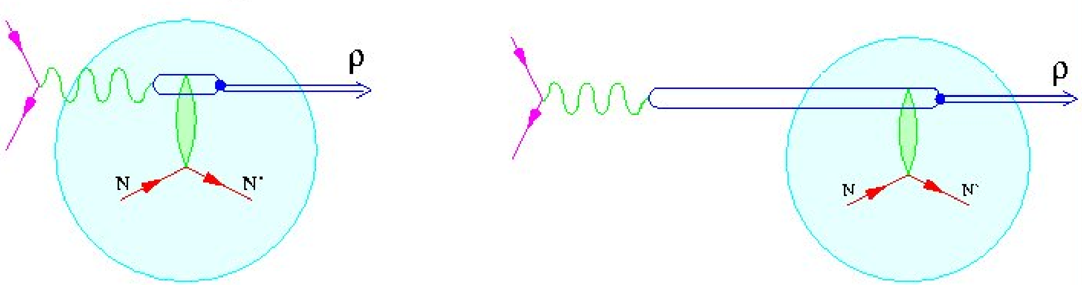
What Could mimic CT signal ?



Coherence Length

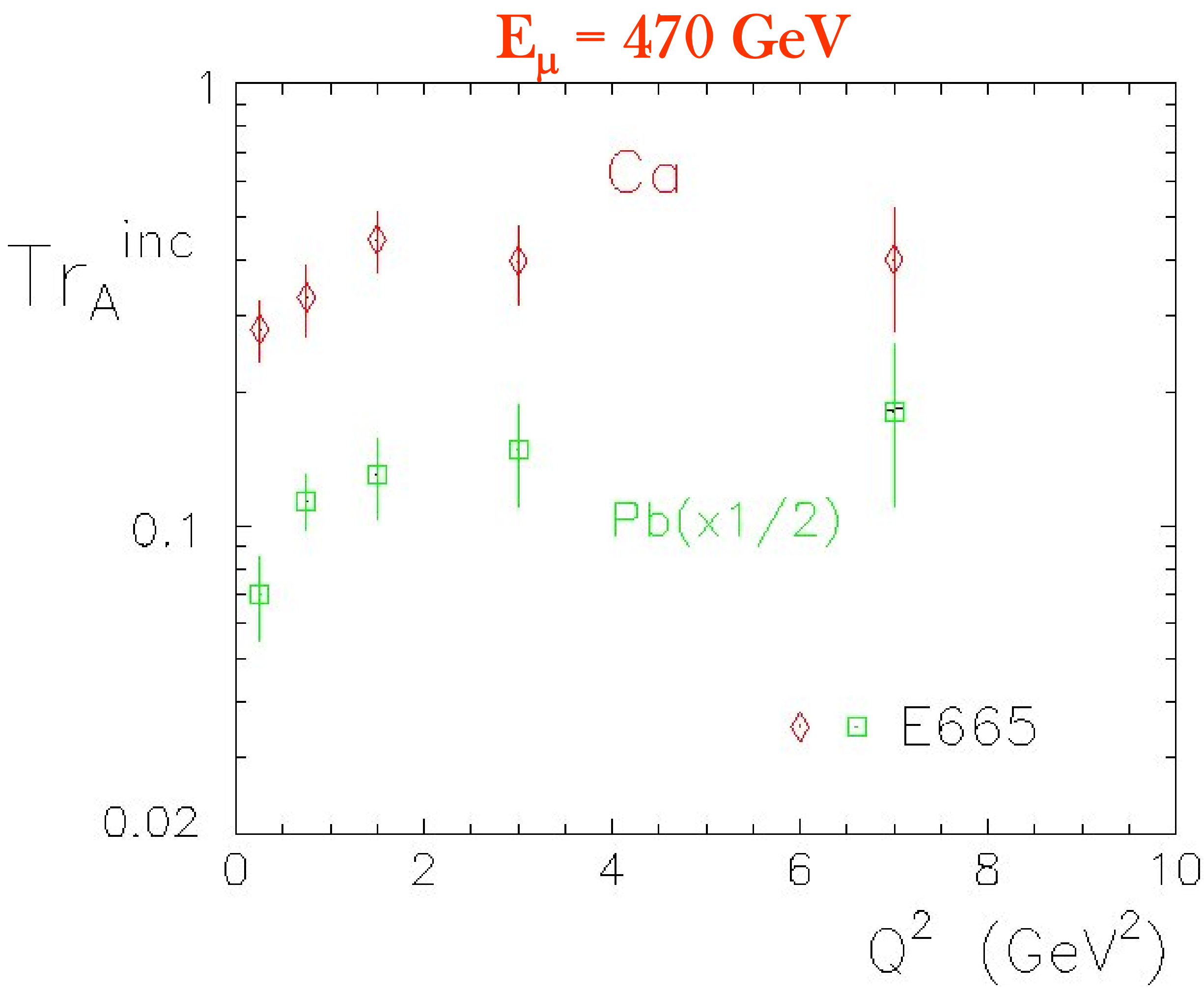
$\ell_c = 2\nu/(M_v^2 + Q^2)$

Coherence length effect (CL): Q^2 increases ⇒ T_A increases



- Coherence Length effect can mimic CT signal
- To be safe, one should keep ℓ_c fixed and/or measure the Q^2 dependence of T_A at small l_c

FNAL E665 experiment

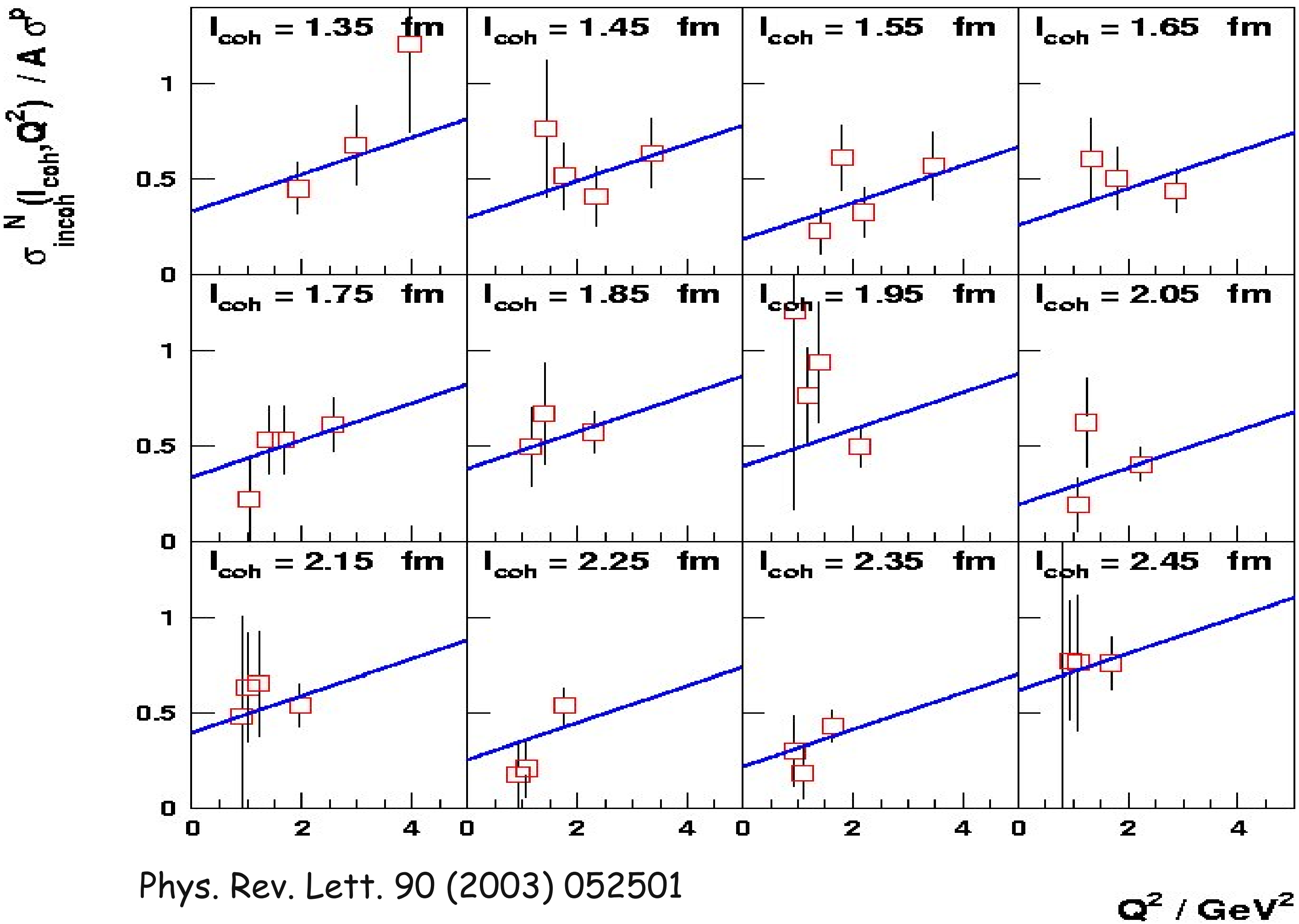


Adams et al. PRL74 (1995) 1525

ρ^0 electroproduction at fixed CL

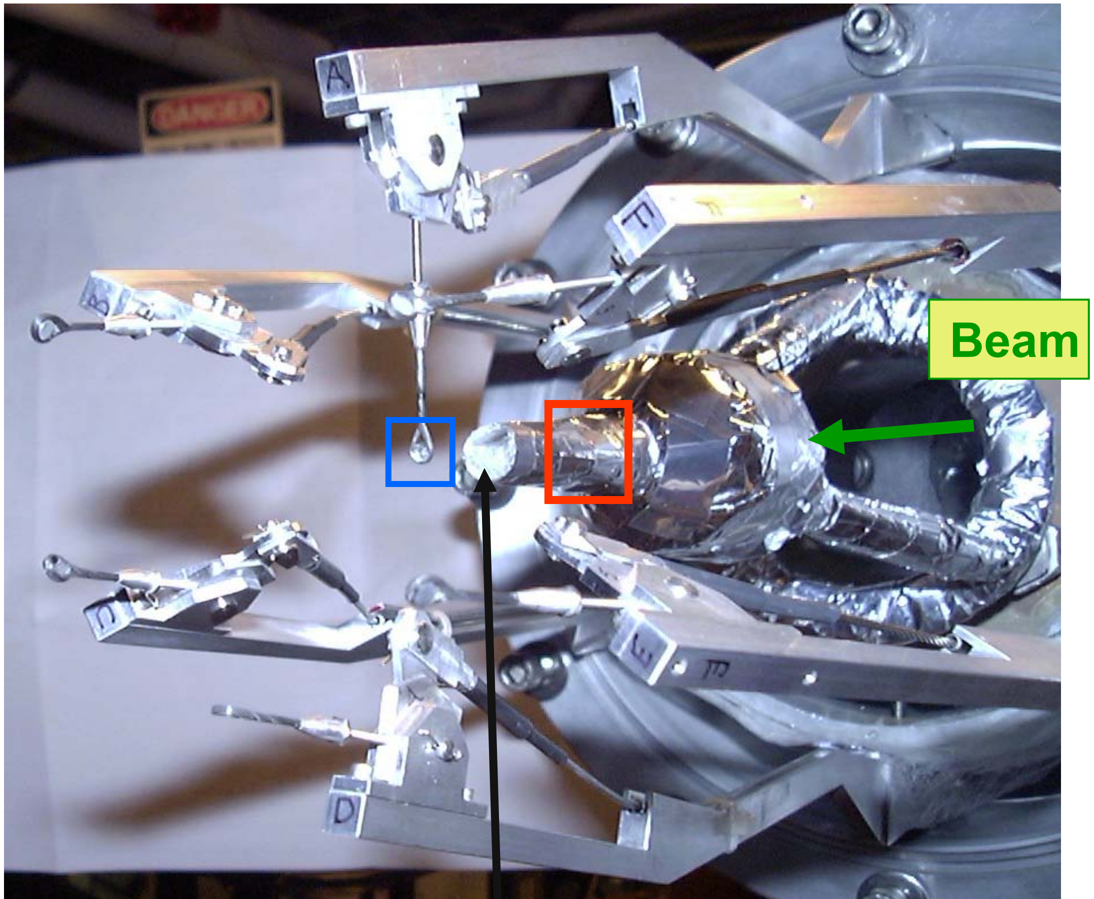
HERMES Nitrogen data : $T_A = P_0 + P_2 Q^2$

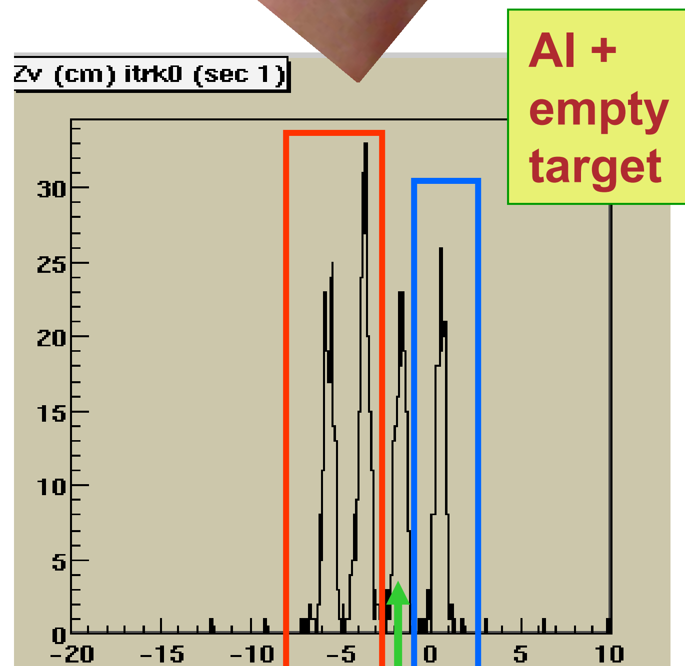
$P2 = (0.089 \pm 0.046_{stat} \pm 0.02_{syst})\ GeV^{-2}$



Phys. Rev. Lett. 90 (2003) 052501

CLAS EG2 Targets





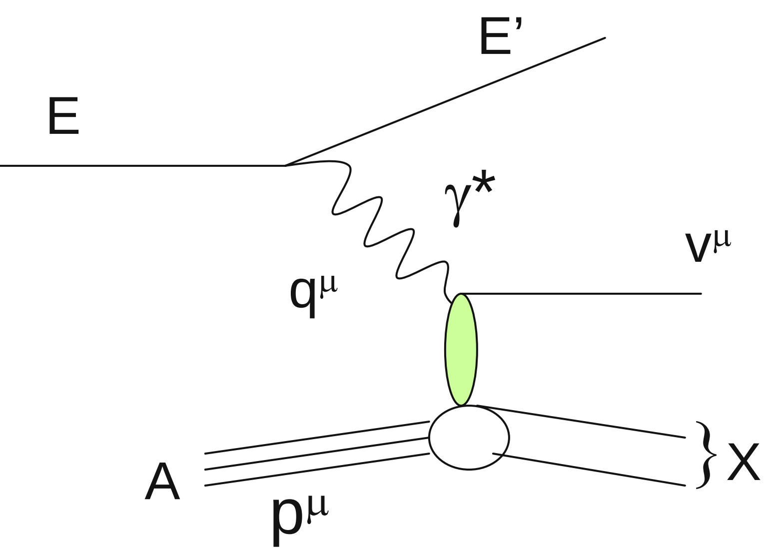
Reference foil

$e + Fe \rightarrow e' + \rho^0 + X$

$\rho^0 \rightarrow \pi^+\pi^-$

$e + D \rightarrow e' + \rho^0 + X$

$\rho^0 \rightarrow \pi^+\pi^-$



$\nu = E - E'$
$Q^2 = -(q^\mu)^2 \cong 4\,E\,E' \sin^2(\theta/2)$
$t = (q^\mu - v^\mu)2$
$W^2 = (p^\mu + q^\mu)^2 = -Q^2 + M_p^{\,2} + 2M_p\nu$

- **$W \geq 2$ GeV**

  $\Rightarrow$ avoid resonance region

- **$-t \leq 0.45\ GeV^2$**

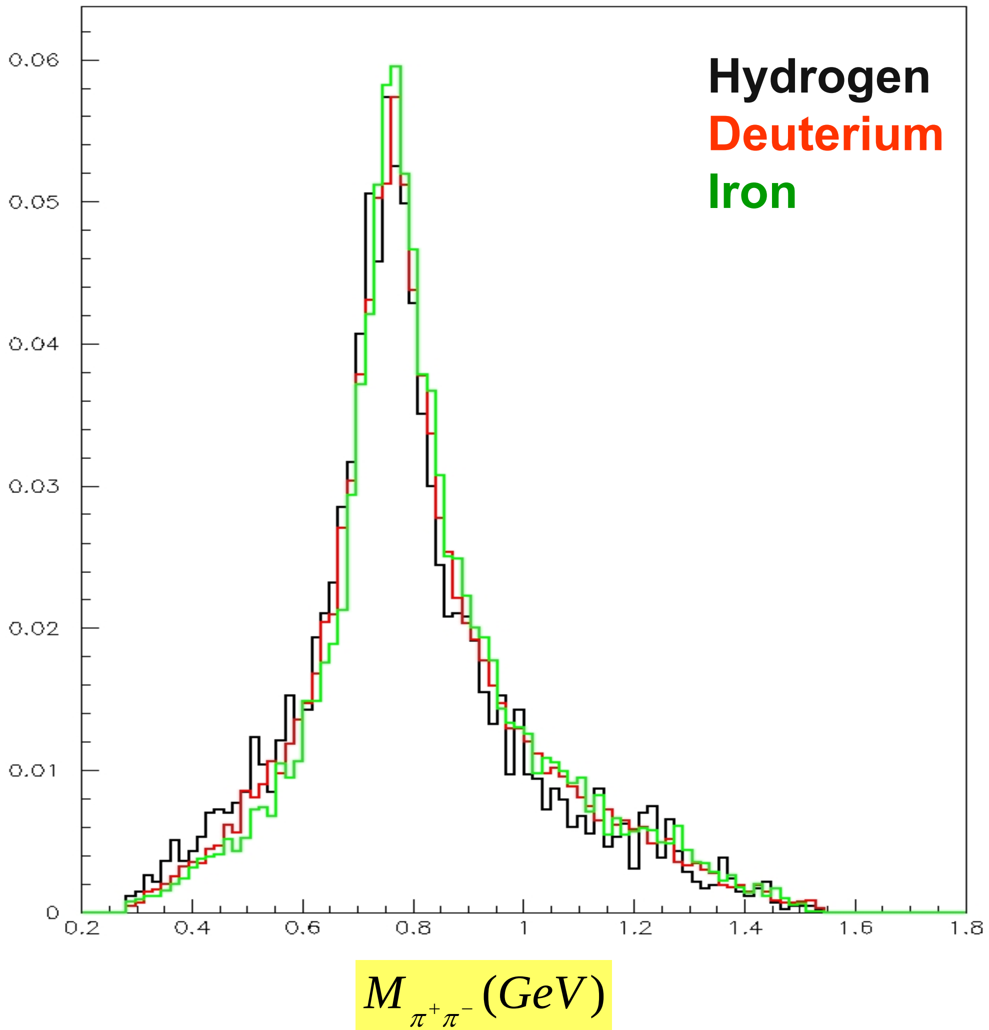
  $\Rightarrow$ select diffractive process

- **$|\Delta E| \leq 0.1 GeV$**

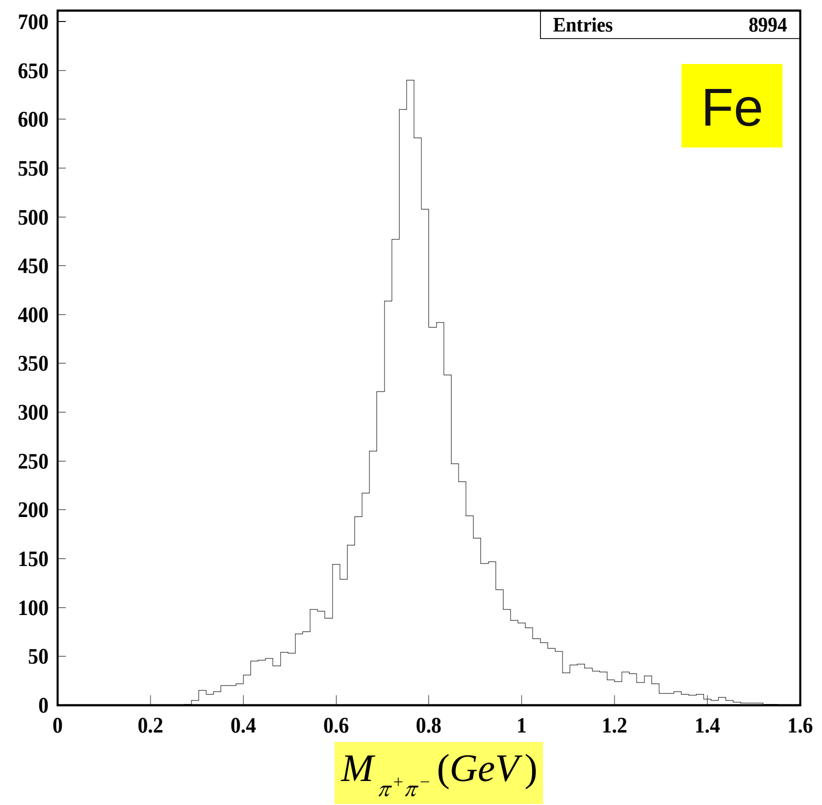
  $\Rightarrow$ select exclusive channel

- **$\Delta E = \nu - E\rho + t/2M_p$** is the missing energy from $\pi^+\pi^-$ pair due to the creation of any additional final state particles

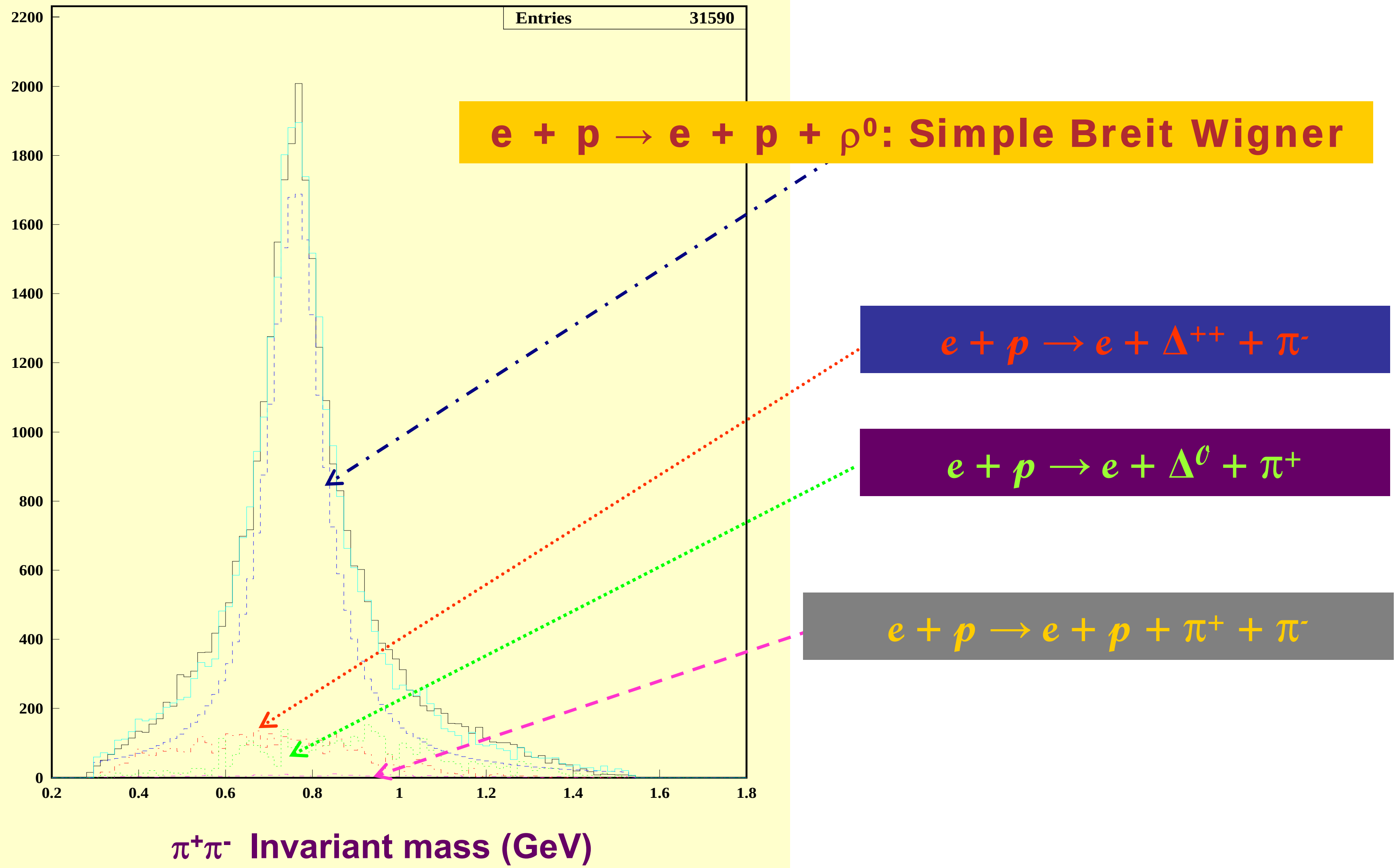
Two pions invariant mass

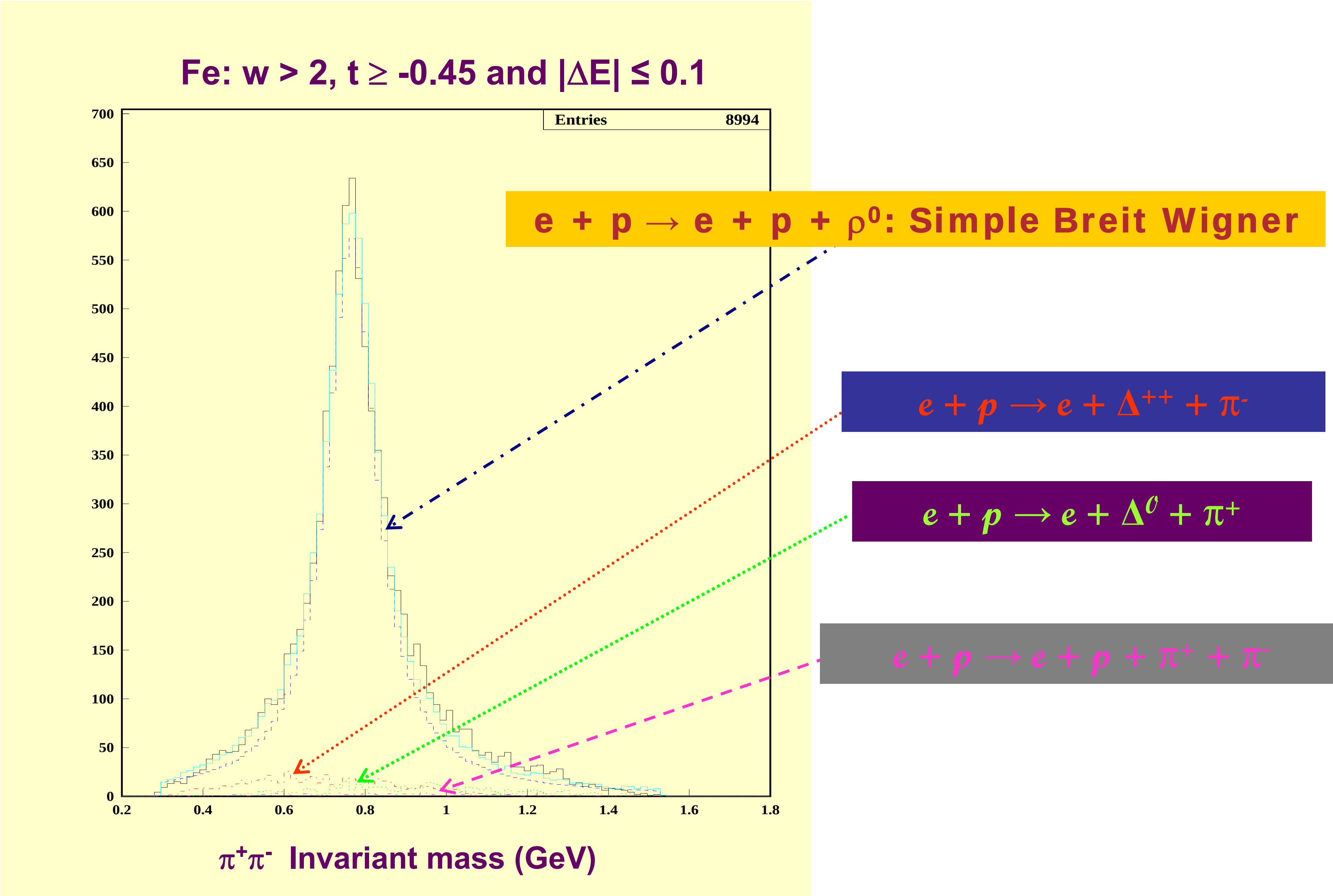


After w, t and ΔE cuts

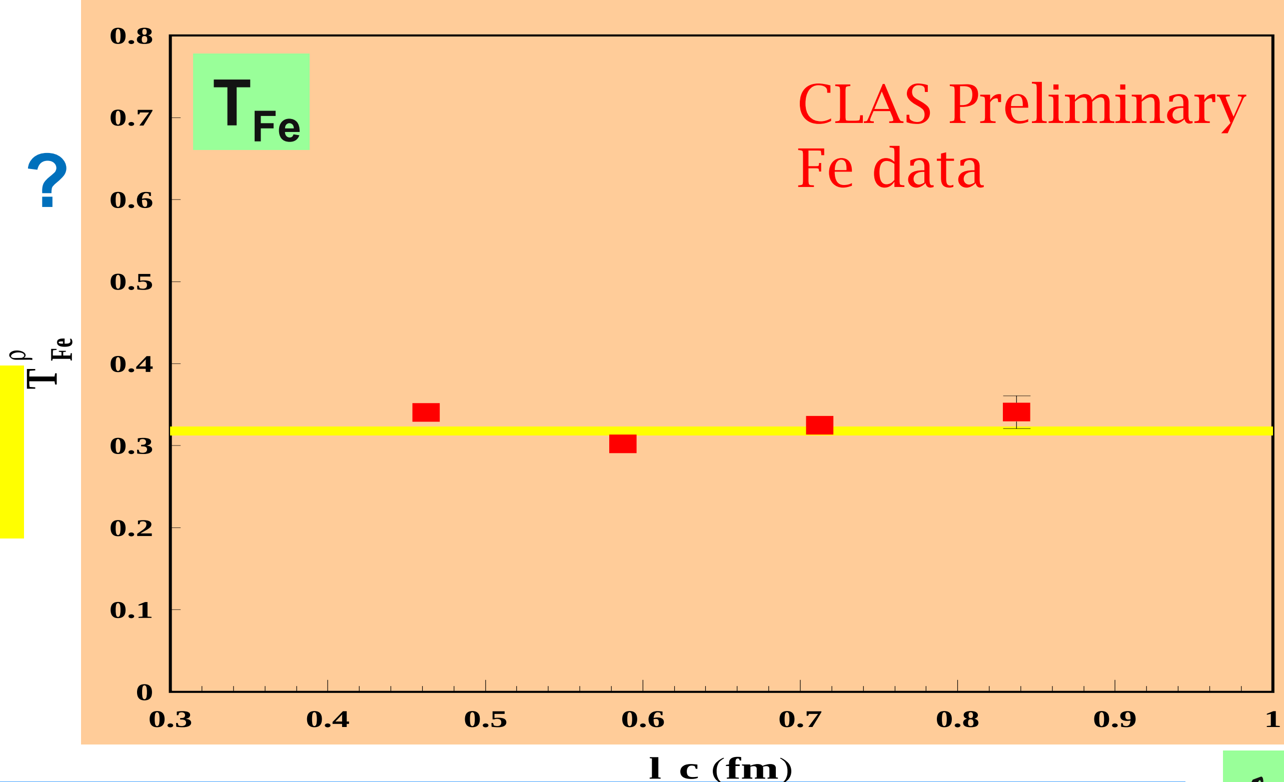


D2: w > 2, t ≥ -0.45 and |ΔE| ≤ 0.1




Fe: w > 2, t ≥ -0.45 and |ΔE| ≤ 0.1
Entries 8994
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
π+π- Invariant mass (GeV)
e + p → e + p + ρ0: Simple Breit Wigner
e + p → e + Δ++ + π-
e + p → e + Δ0 + π+
e + p → e + p + π+ + π-

What Could mimic CT signal ?

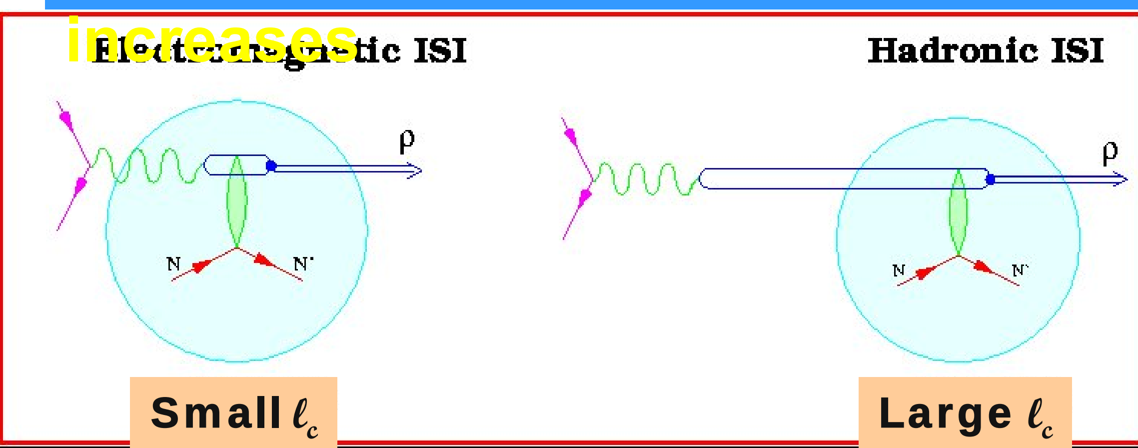


Coherence Length

$\ell_c = 2\nu/(M_V^2 + Q^2)$

ℓ_c

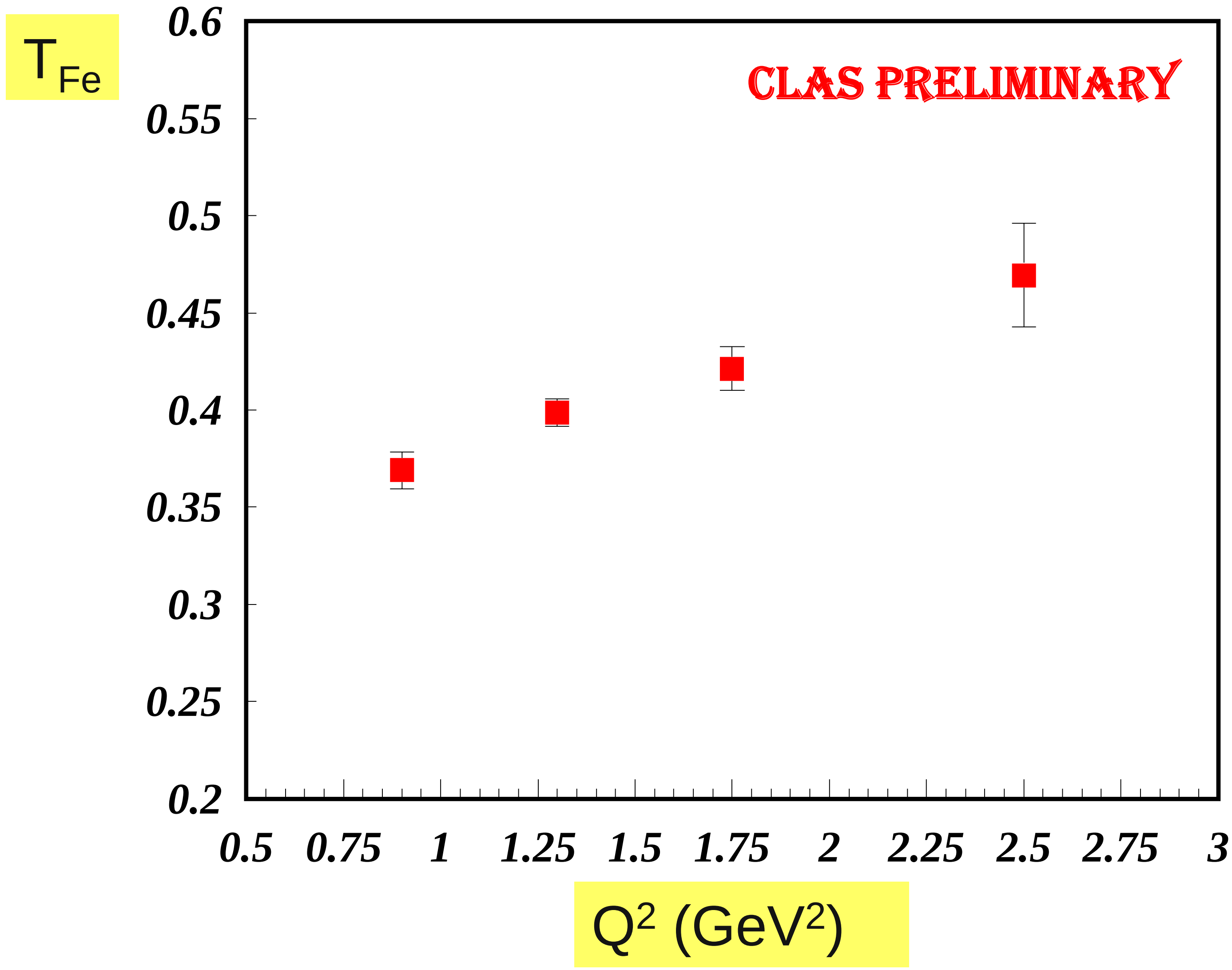
Coherence length effect (CL): Q^2 increases ⇒ T_A increases



- Coherence Length effect can mimic CT signal
- To be safe, one should keep ℓ_c fixed and/or measure the Q dependence of T_A at small l_c

Preliminary results from CLAS EG2 data

T_A vs. Q^2 corrected with acceptance, radiative and absorption effects

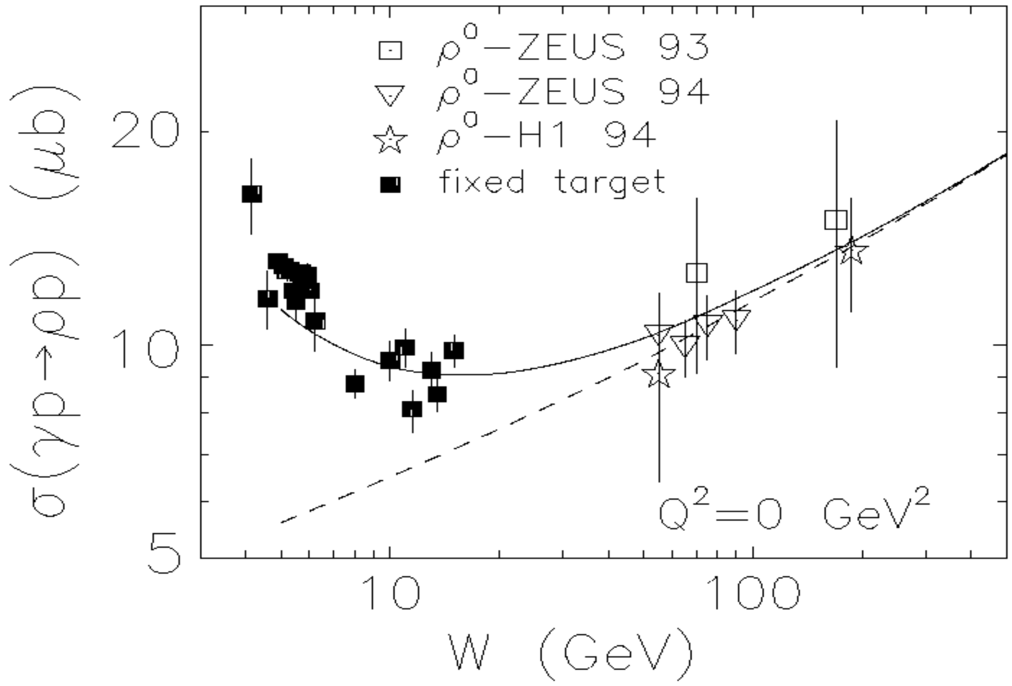


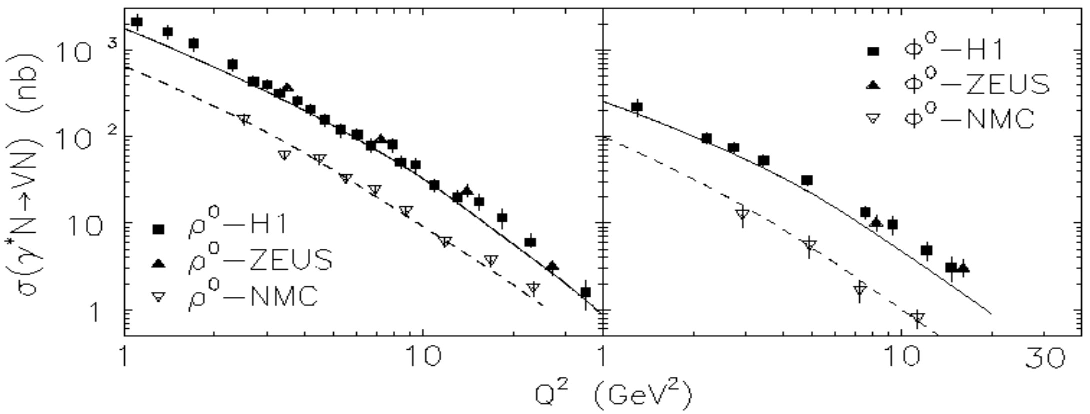
Theory by Kopeliovich et al., PRC 65 (2002) 035201

Describing the q q-bar pair evolution using light cone green function technique.

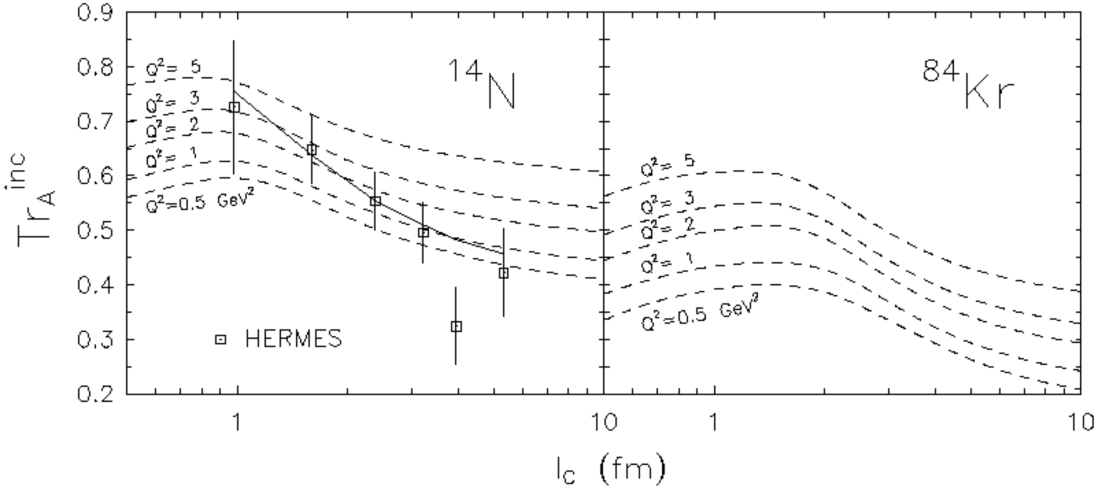
- Model using Light Cone (LC) QCD formalism
- Light cone dipole phenomenology for elastic production of
  $M(\gamma^* N \to VN) = \langle V|\sigma(qq))|\gamma^*\rangle$
- $\sigma(qq)$: universal flavor independent dipole cross section for q q-bar interaction with a nucleon fitted to the proton structure function data over a large range of x and Q^2.
- ψ_{γ^*}: LC wave function for {q,q-bar} fluctuation of the virtual photon
- ψ_V : LC wave function for the vector meson

A rigorous test of the model

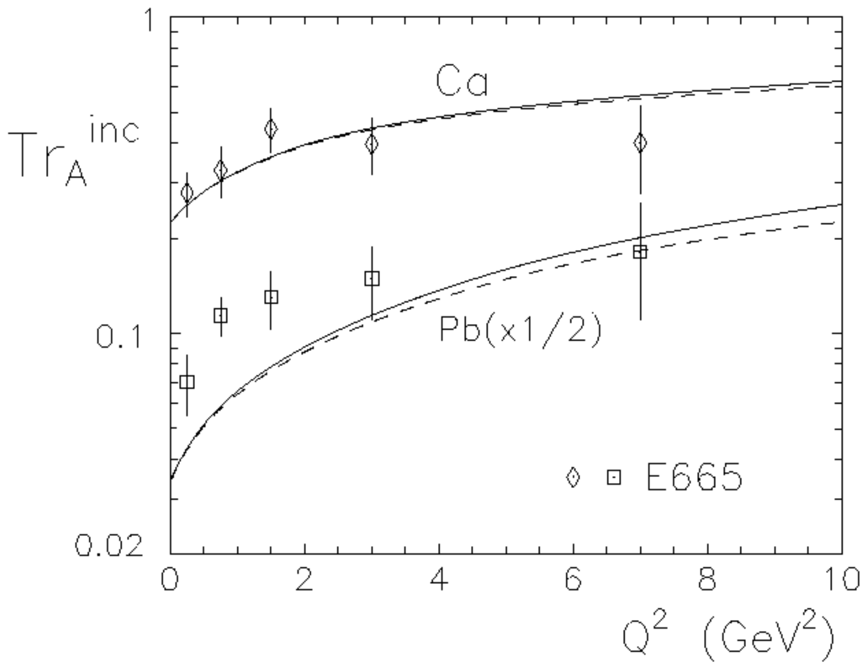


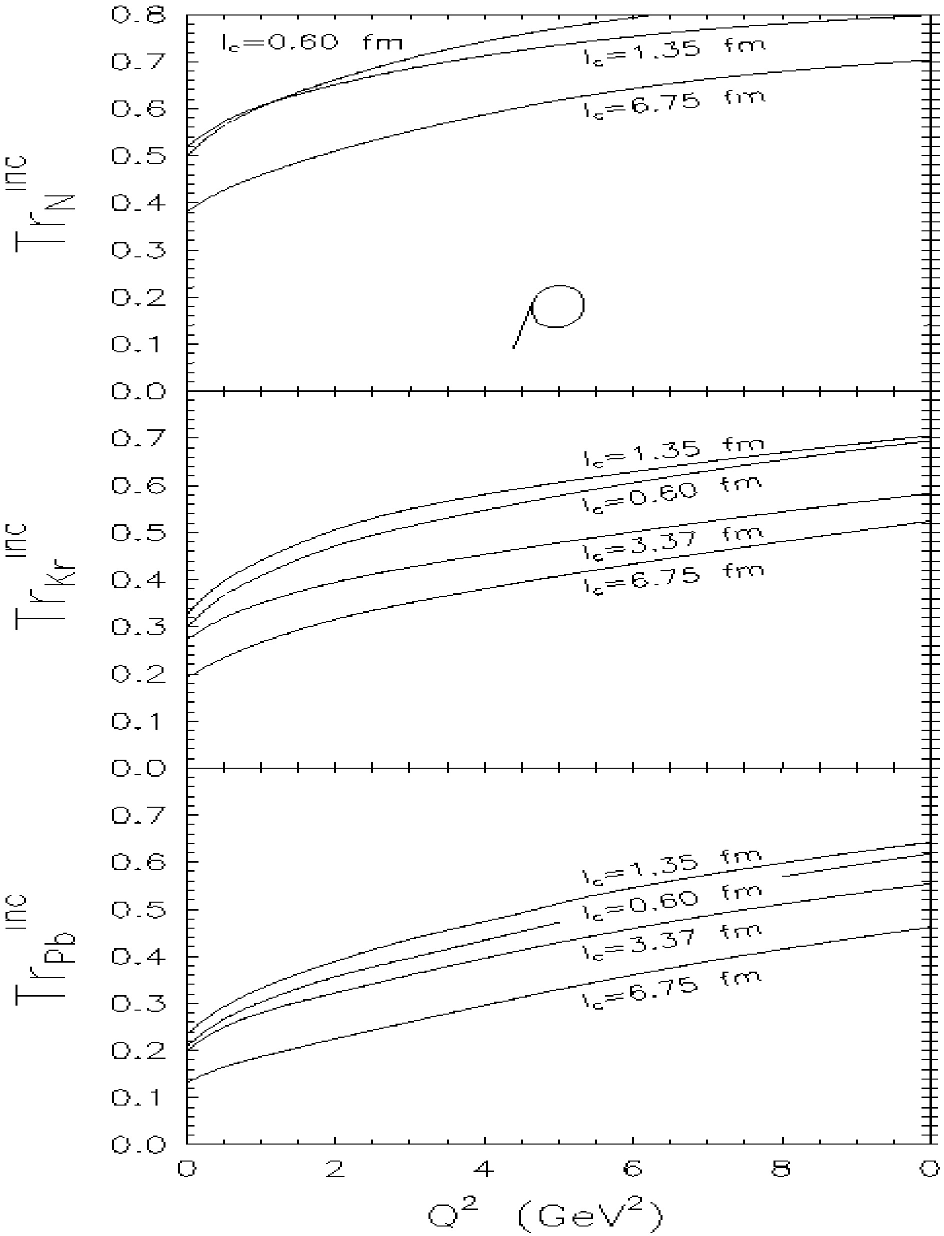


HERMES

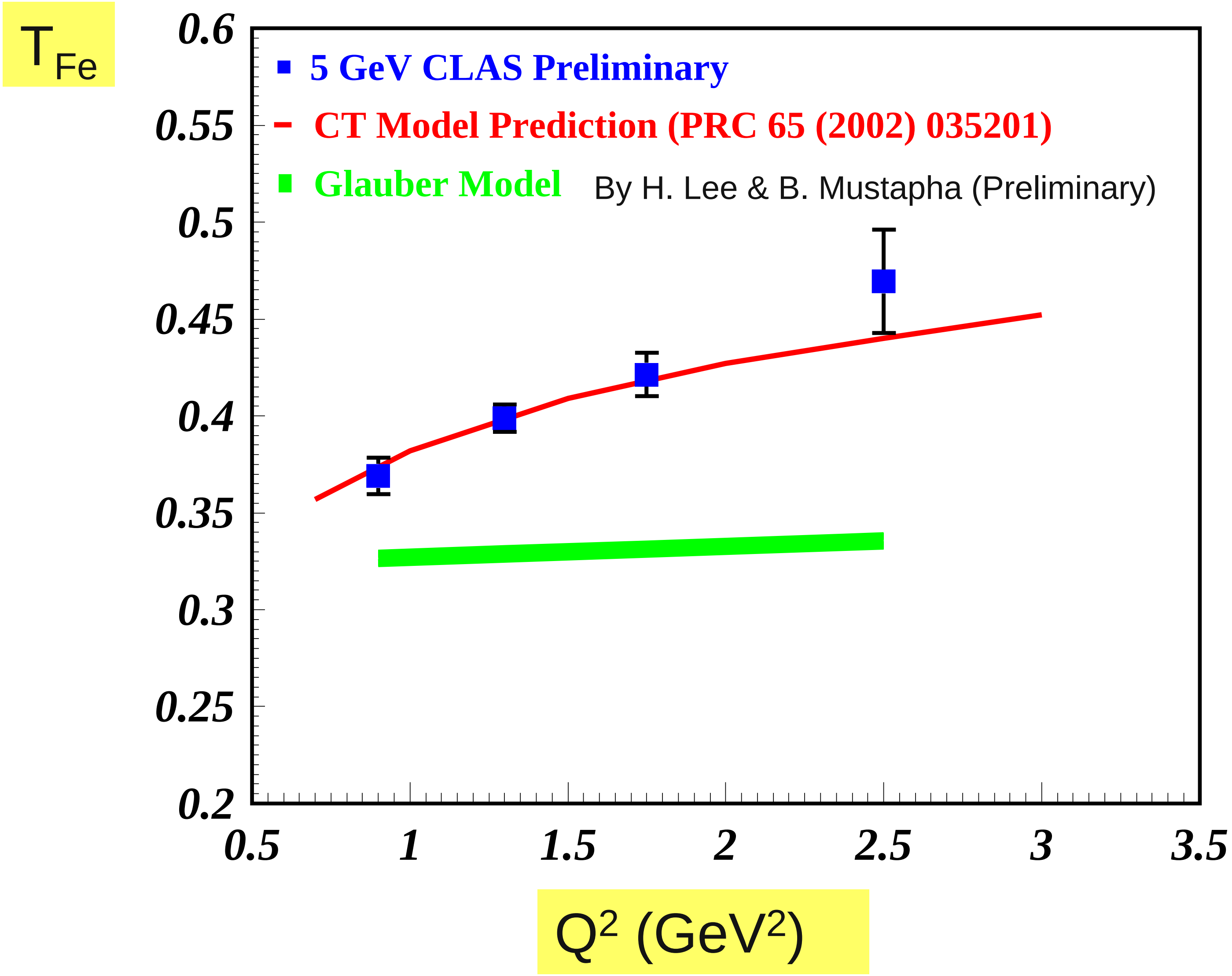


FNAL E665

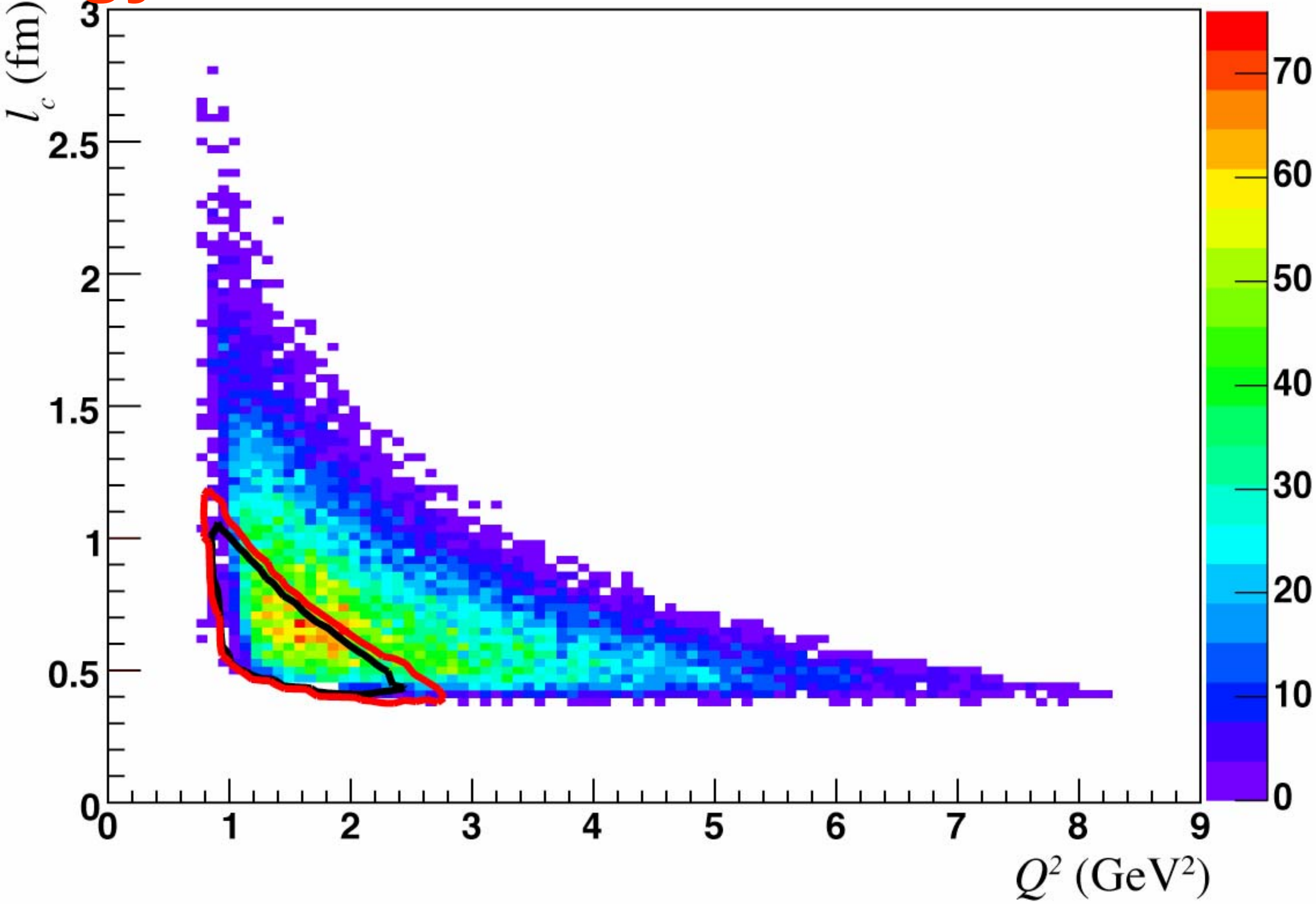


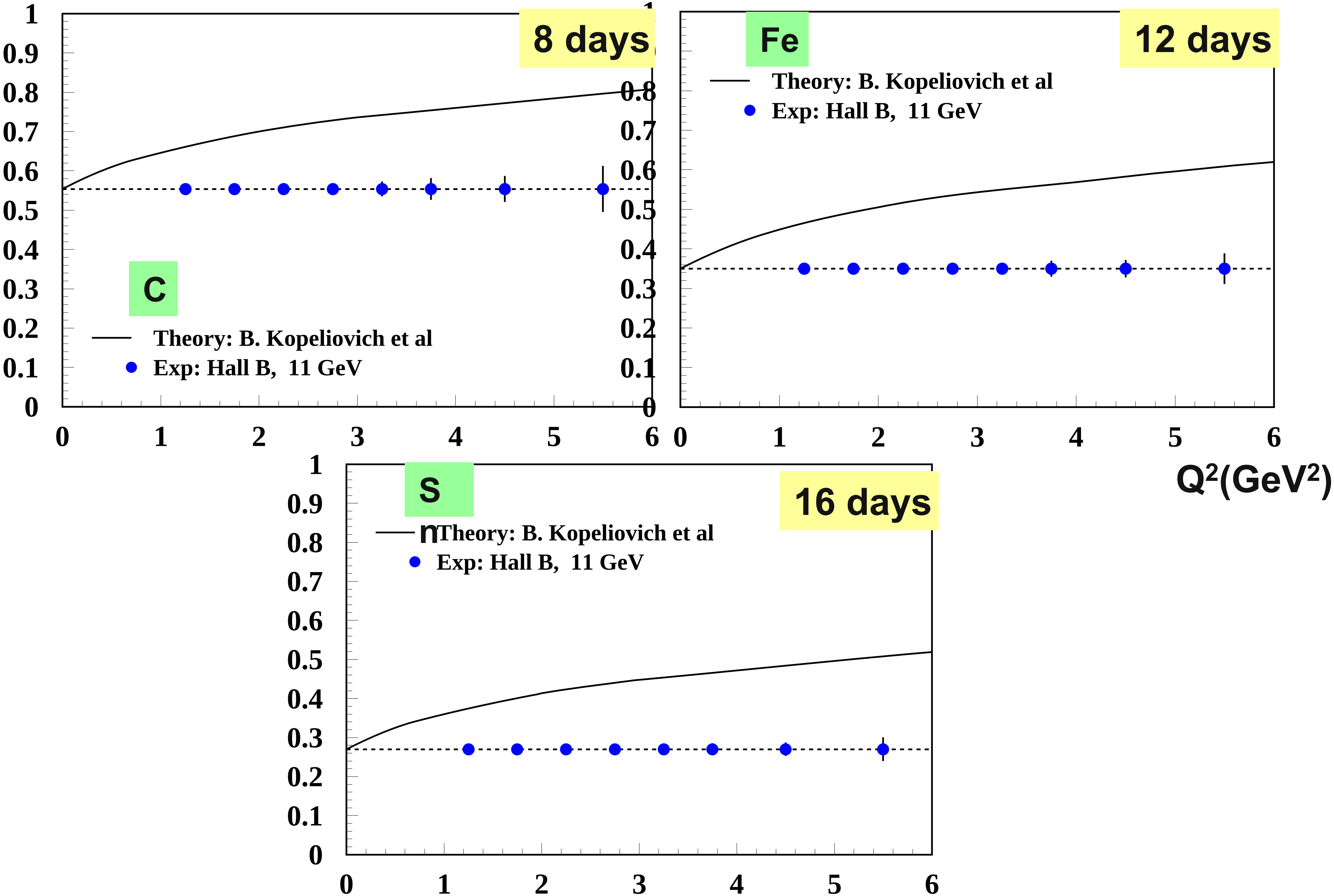


l_c=0.60 fm
l_c=1.35 fm
l_c=6.75 fm
ρ
Tr_N^{inc}
l_c=1.35 fm
l_c=0.60 fm
l_c=3.37 fm
l_c=6.75 fm
Tr_{Kr}^{inc}
l_c=1.35 fm
l_c=0.60 fm
l_c=3.37 fm
l_c=6.75 fm
Tr_{Pb}^{inc}
Q^2 (GeV^2)


T_{Fe}
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
5 GeV CLAS Preliminary
CT Model Prediction (PRC 65 (2002) 035201)
Glauber Model
By H. Lee & B. Mustapha (Preliminary)
0.5
1
1.5
2
2.5
3
3.5
Q^2 (GeV^2)

Q^2 - ℓ_c Correlation for 11 GeV beam energy




8 days
C
Theory: B. Kopeliovich et al
Exp: Hall B, 11 GeV
12 days
Fe
Theory: B. Kopeliovich et al
Exp: Hall B, 11 GeV
16 days
S
Theory: B. Kopeliovich et al
Exp: Hall B, 11 GeV
Q²(GeV²)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6

Summary and outlook

- The preliminary CLAS results show a clear evidence of CT in ρ^0 electroproduction on nuclei
- CLAS results show a nice agreement with the theoretical model by Kopeliovich et al.
- The 11 GeV measurements will extend both the Q^2 and the ℓ_c range considerably allowing for rich input to the theory for the calculation of the vector meson formation time and its interaction in the nuclear medium