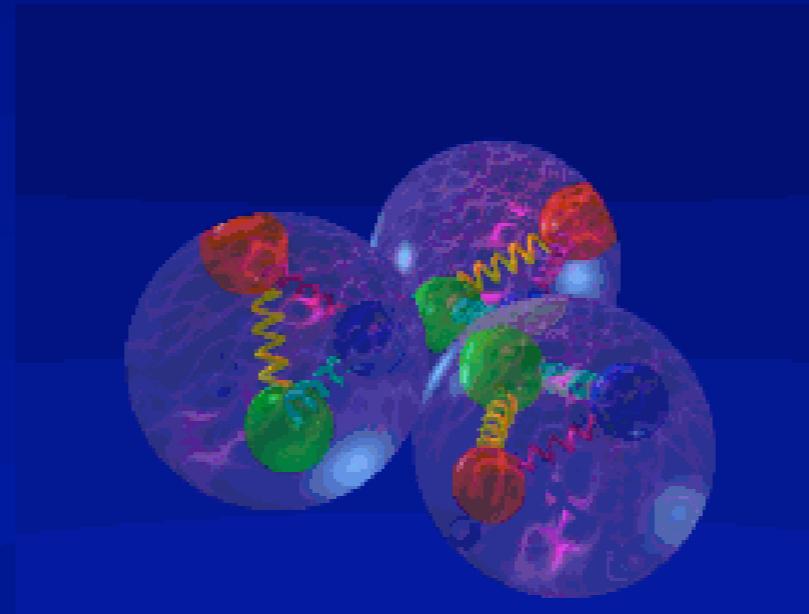


# Investigating the onset of Color Transparency with CLAS.

Maurik Holtrop

University of New Hampshire



# Overview

- Introduction: Color Transparency.
- Previous Experiments (very fast).
- Color Transparency with  $\rho^0$ .
- EG2: the  $\rho^0$  experiment with CLAS.
- Preliminary Results.
- Summary & Outlook

# Acknowledgements

## The EG2 run group team:

- **Lamiaa El Fassi (ANL)**
- **Lorenzo Zana (UNH)**
- Kawtar Hafidi (ANL)
- Brahim Mustapha (ANL)
- Harry Lee (ANL)
- Will Brooks (JLAB)
- Hayk Hakobyan (JLAB/Yerevan)

# Color Transparency

- Color Transparency: The reduction of the strong interaction under certain conditions (high momentum transfer experiments) due to the creation of a “minihadron” (PLC).
- Basic idea:
  - Hadrons are energy eigenstates, quarks and gluons are not → Hadrons fluctuate between different configurations when they interact.

$$| \text{proton} \rangle = \text{PLC} + \text{BLC} + \dots$$

PLC                      BLC

PLC: Point Like Configuration

BLC: Blob Like Configuration

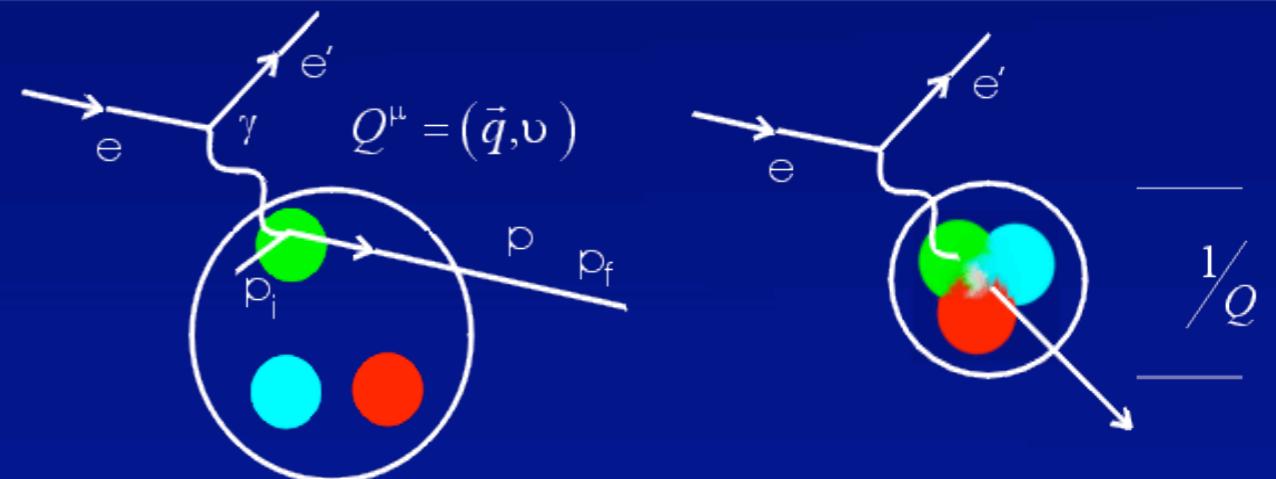
# Color Transparency

Select PLC from wave function by using large momentum transfer.

Hard: high momentum transfer.

Exclusive: completely determined initial and final states.

Unless the struck quark shares the momentum transfer with the other quark (s), the particle fragments and the reaction is inelastic.



$$b \approx 1/Q$$

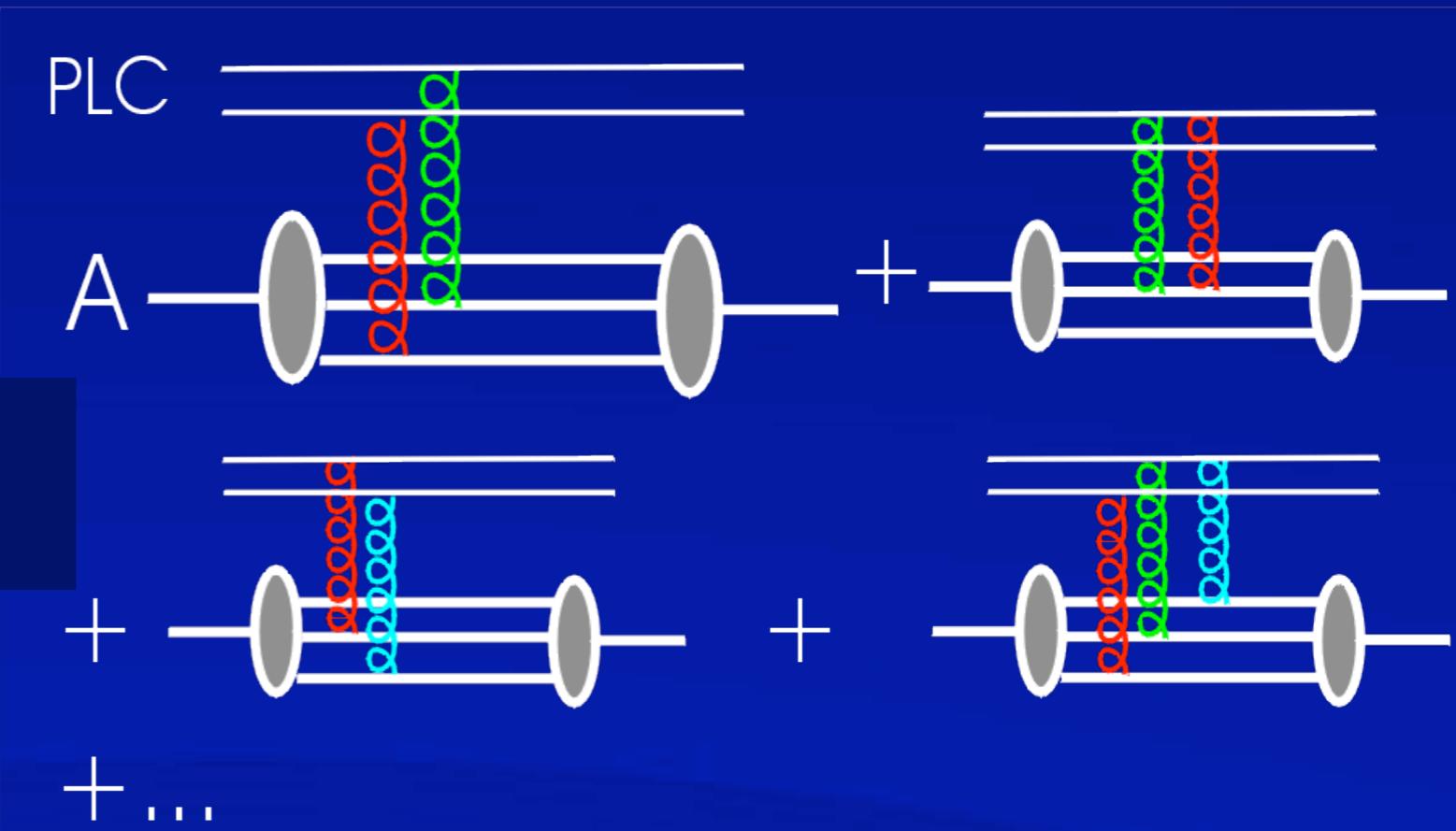
$\xrightarrow{Q \text{ increases}}$

$$\sigma \propto b^2$$

As  $Q^2$  increases the exchange of the gluon has to be fast.  
(Causality, no process is faster than the speed of light)  
⇒ The quarks have to be localized within a transverse size of  $1/Q$

# Color Transparency

- Reduced interaction through color coherence: contributions from different parts of the system cancel through destructive interference.
- (Analogy in  $e^+e^-$  pair in bubble chamber, discovered by Perkins (1955) and explained by Chudakov (1955) )



The interaction cross section  
has a dipole form:  $\sigma \cong r^2$

# Color Transparency

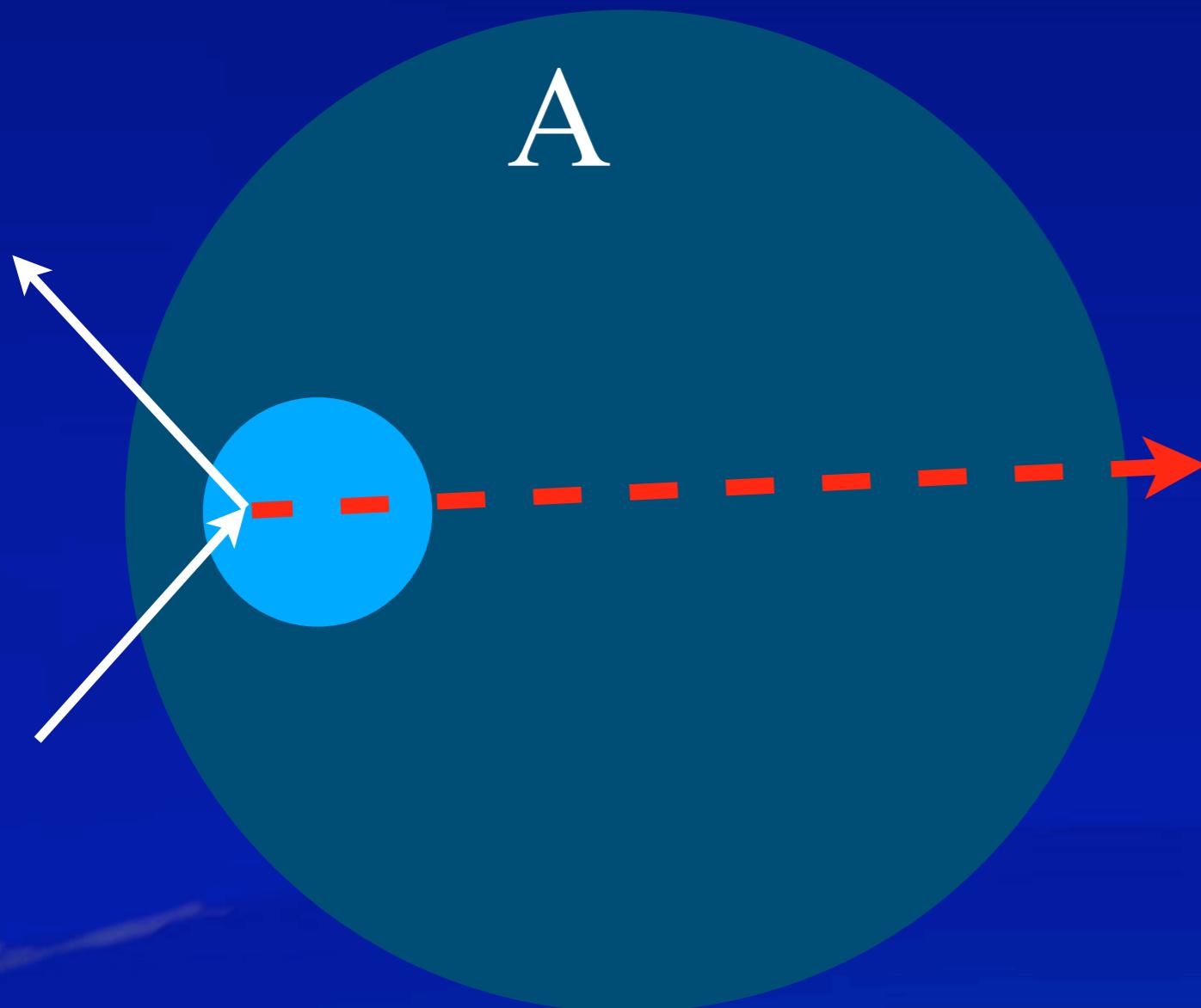
- Conditions for observation:
  - Small Object: Point Like Configuration (PLC) due to high momentum transfer.
  - Color Electric Dipole moment is small: reduced interactions.
  - Small Object remains small, so it can escape the nucleus.
- Why is it interesting?
  - Direct prediction of QCD
  - Related to factorization.
  - Study the short distant part of the of the hadron wave-function → Confinement
  - Study how the PLC “dresses” to normal size → hadronization.

Much theory work since 80's:

A.H. Mueller, S.J. Brodsky, G.A. Miller, L.L. Frankfurt, M. Strikman,  
P. Jain, B. Pire, J. Ralston, B.Z.Kopeliovich, J. Nemchik, ...

# Experimental Signature of CT.

- Color Transparency is closely related to Nuclear Transparency:  
The signature of CT is an increase in T with increasing hardness (higher  $Q^2$ ) of the reaction.



$$T(A, Q^2) = \frac{\sigma_A}{A\sigma_N}$$

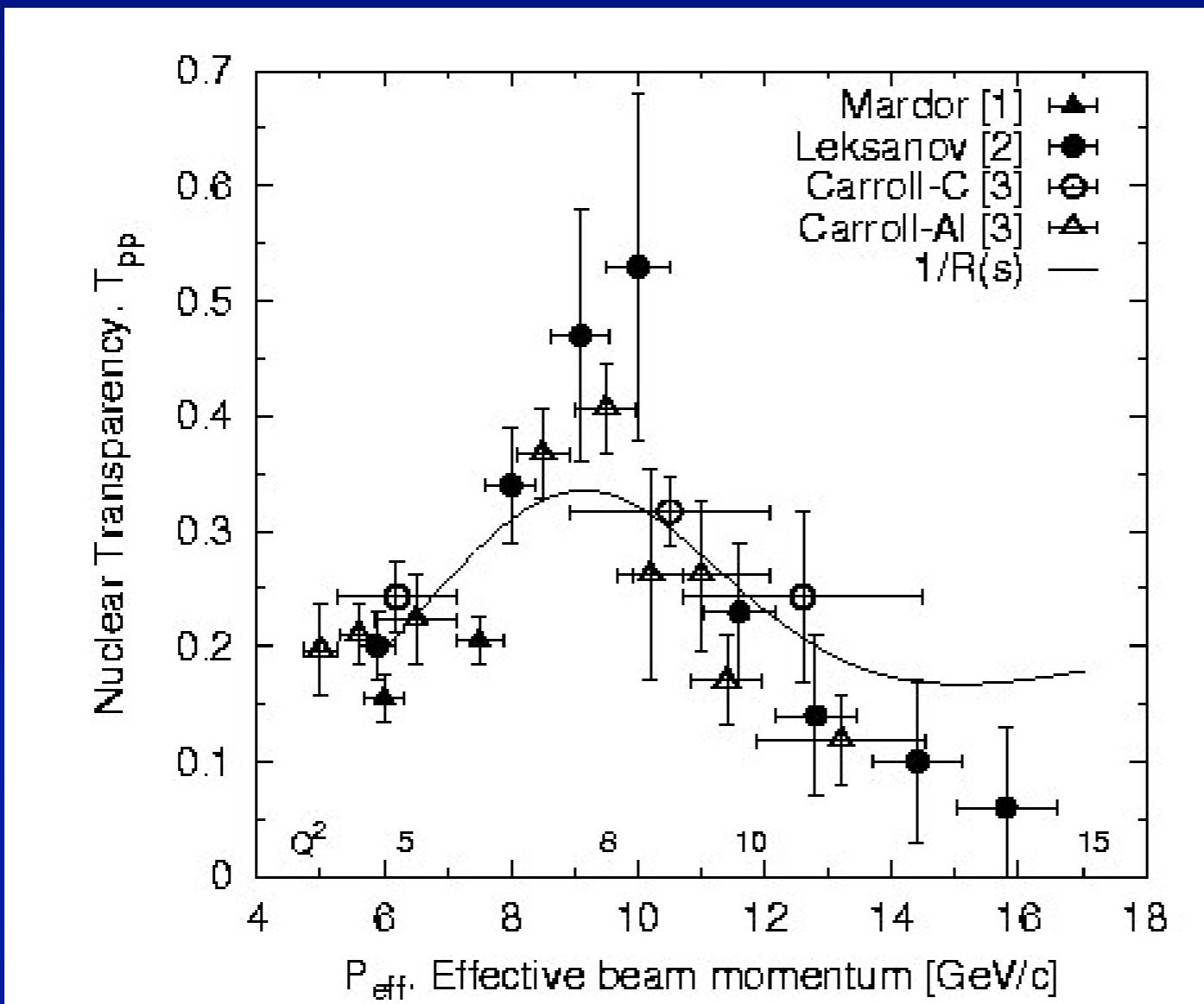
The nucleus is the laboratory, acting as a filter for the outgoing particles.

# Experiments

- A lot of experiments since 1988:
  - Quasi-elastic  $A(p,2p)$  [Brookhaven]
  - Quasi-elastic  $A(e,e'p)$  [ SLAC and Jlab]
  - Quasi-elastic  $D(e,e'p)$  [Jlab - CLAS]
  - Pion Production  $4\text{He}(\gamma n \rightarrow p\pi^-)$  [Jlab]
  - Di-jets diffractive dissociation. [Fermilab]
  - $\rho^0$  lepto production. [Fermilab, HERMES]
  - $\rho^0$  lepto production &  $D(e,e'p)$  [ Jlab - CLAS ]

# $A(p,2p)$ at Brookhaven

- $A(p,2p)$  on Li, C, Al, Cu, Pb, with proton beams up to 12 GeV.  
[ A.S. Carroll et al. PRL 61 1698 (1988) ]
- $A(p,2p)$  on C, proton beam up to 14 GeV  
[ Y. Mardor et al. PRL81 5085 (1998) ]  
[ A. Leksanov et al. PRL87 212301 (2001) ]



No CT Signal!

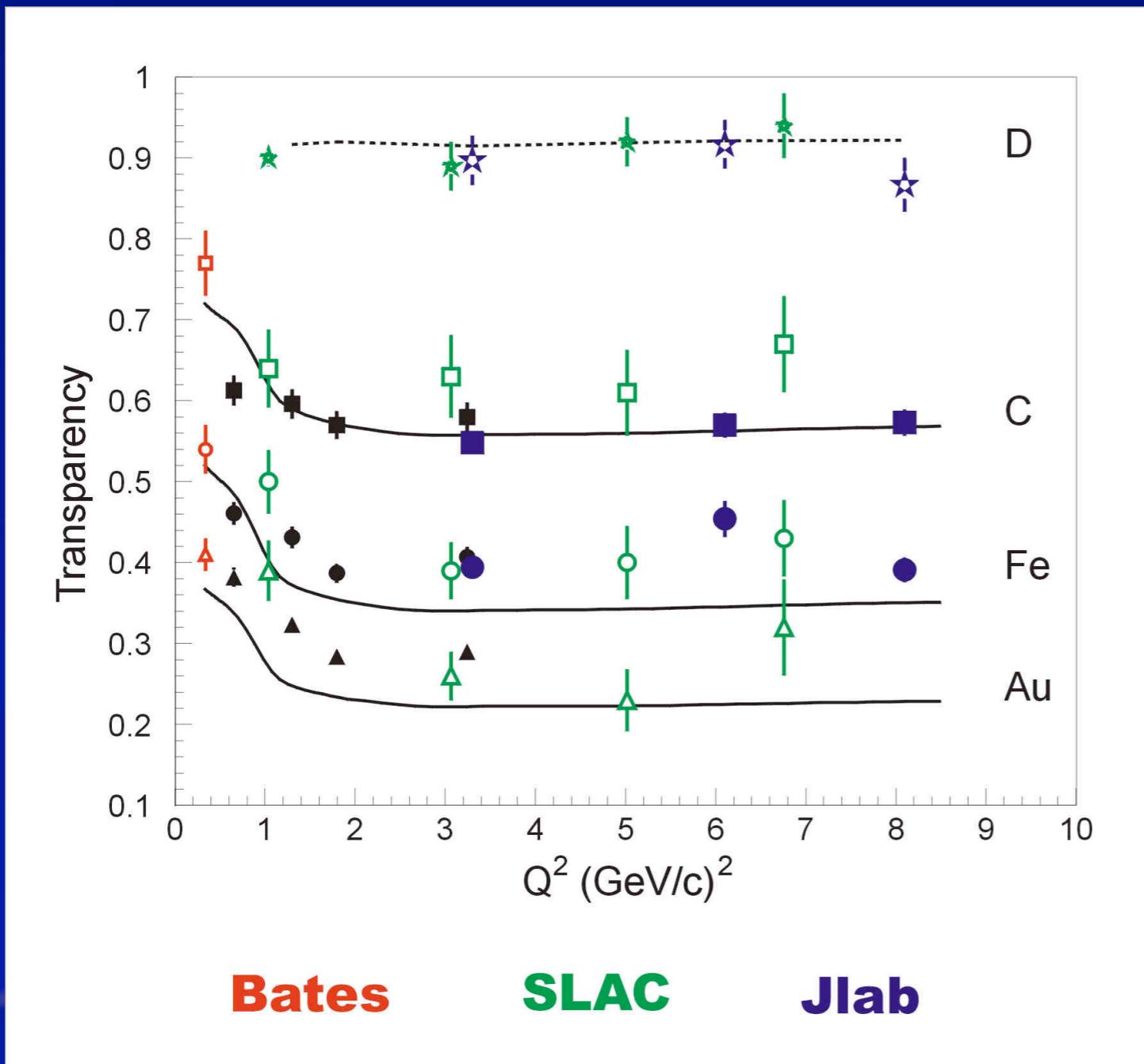
# $A(e,e'p)$ at SLAC and Jlab

$A(e,e'p)$  on D, C, Fe, Au with  $Q^2$  up to 8 GeV.

red Bates [G. Garino et al., Phys. Rev.C45, 780 (1992)]

green SLAC [N. Makins, PRL 72 1989 (1994)] [T.G. O'Neill, Phys. Lett. B351 87 (1995) ]

blue Jlab C [D. Abbot ,Phys. Rev. Lett. 80, 5072 (1998)] [K. Garrow, hep-ex/0109027, 2001 ]

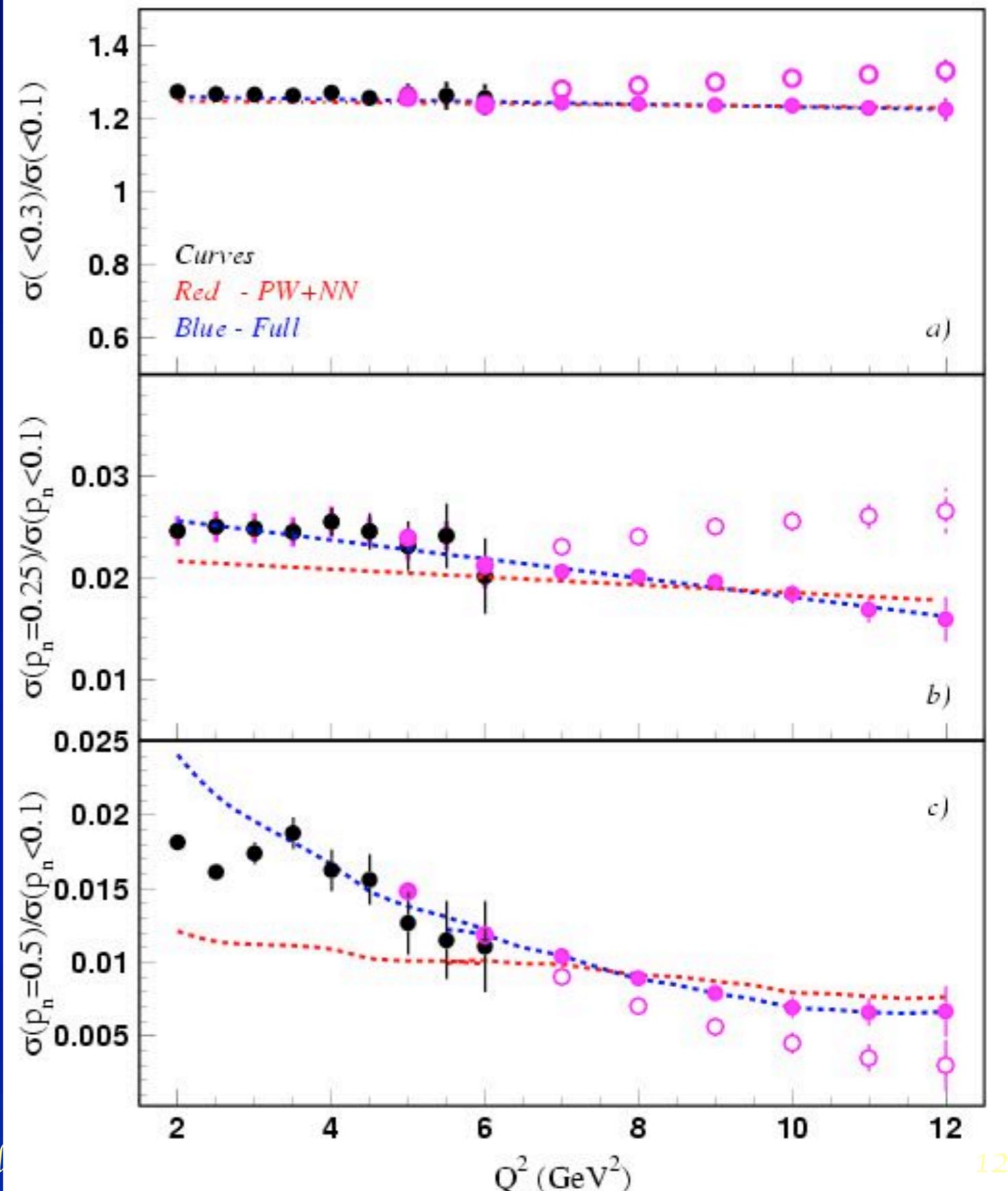


# $D(e,e'p)$ with CLAS at Jlab

Ratio of the cross section  
for  $D(e,e'p)$  at different  
kinematics (different  
neutron recoil momentum)  
Analysis by Kim Egiyan  
Calculations: J-M Laget

NO SIGNAL !

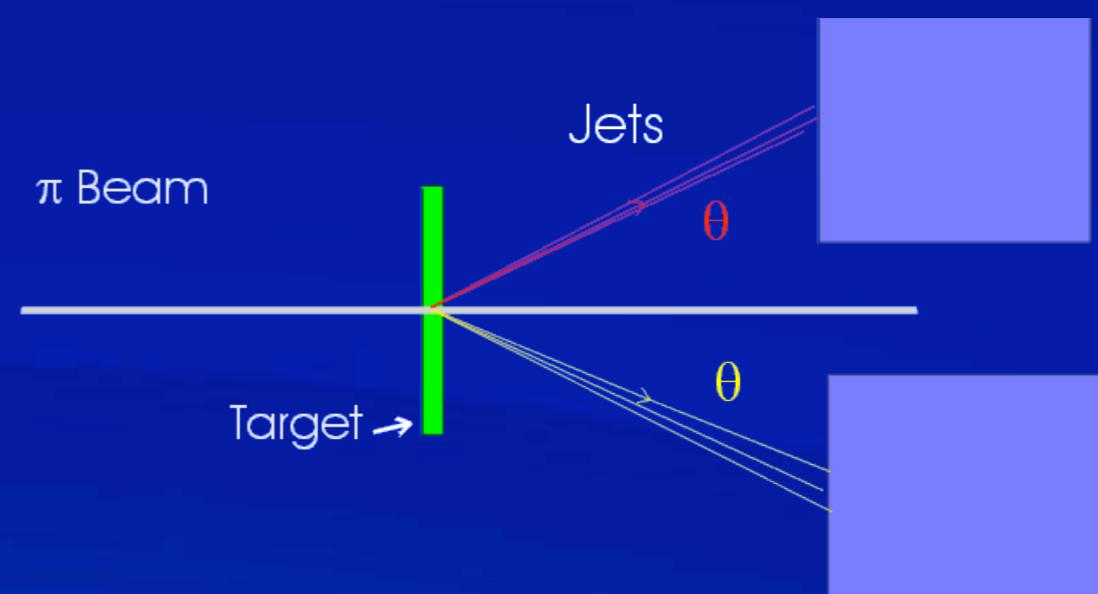
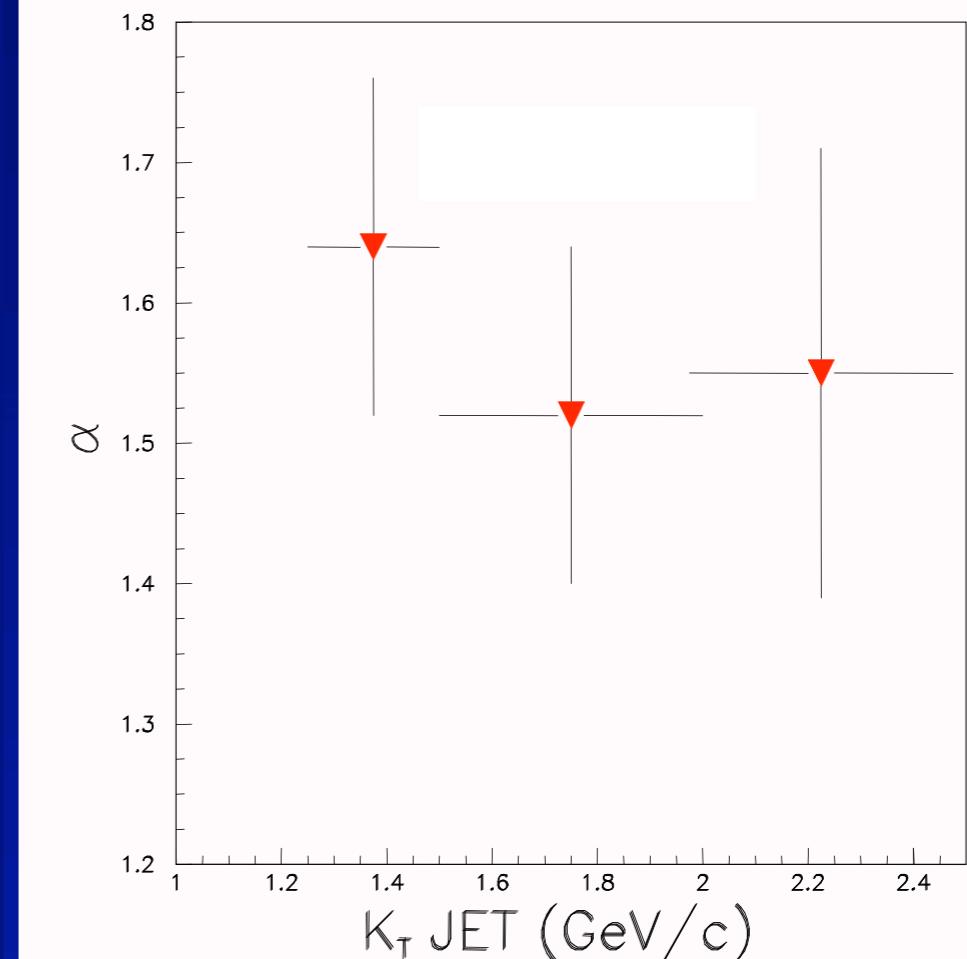
Promising for 12 GeV?



# Di-Jets, Fermilab E791

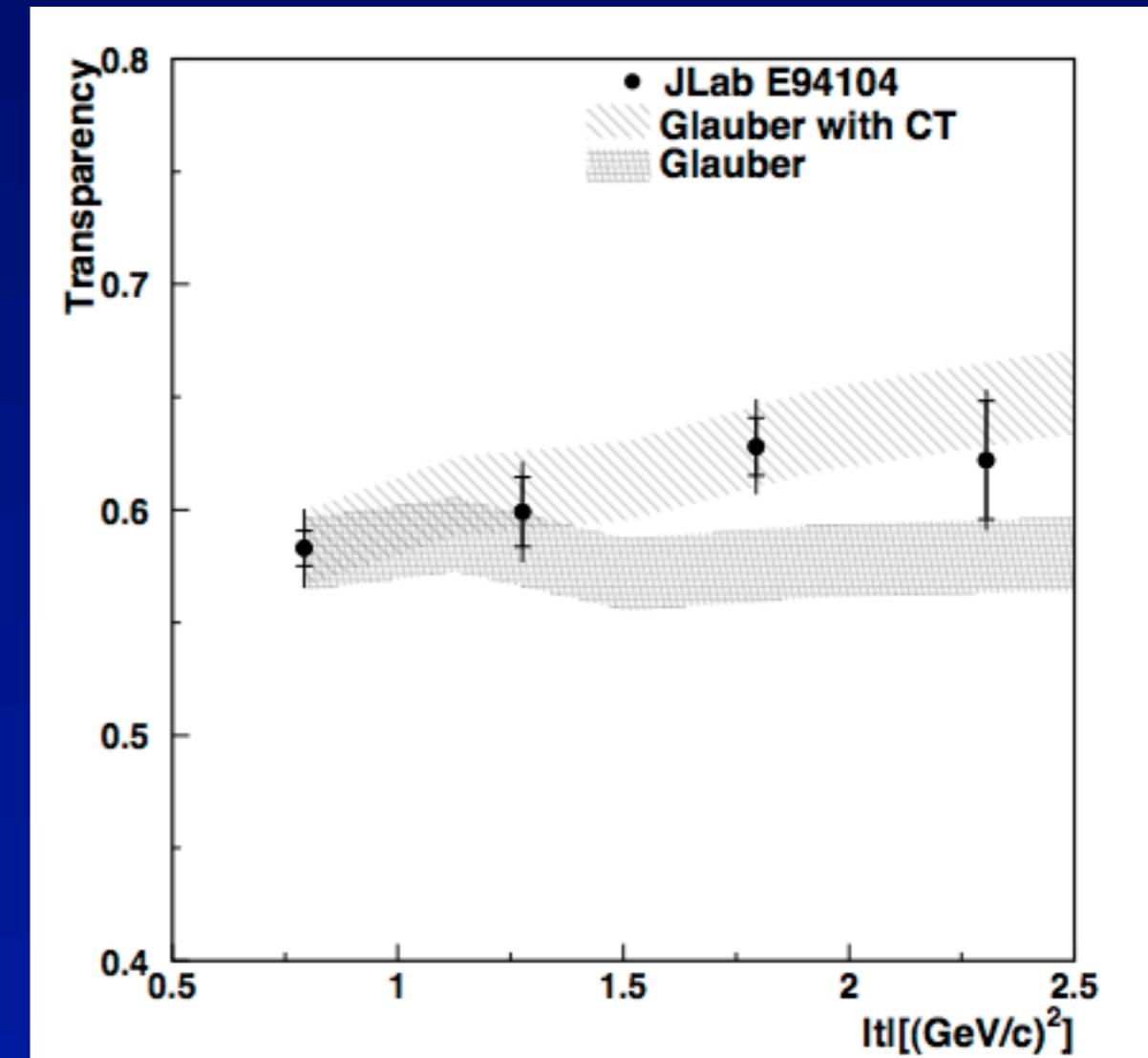
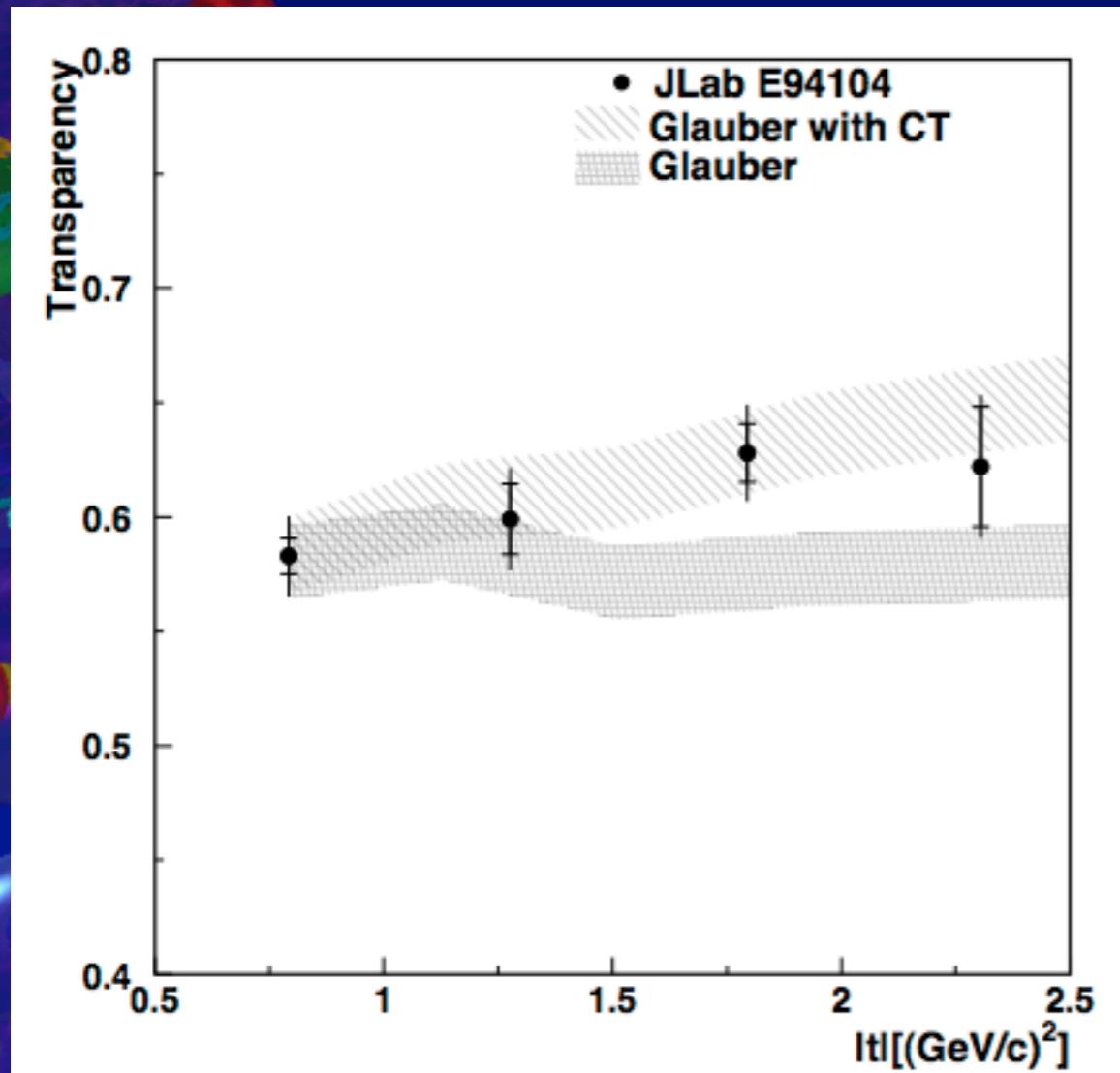
- Di-jets diffractive dissociation of 500 GeV Pions on C and Pt.  
[Aitila et al., Phys.Rev.Lett.86, 4773 (2001)]
- Typical  $\pi$  - nucleus interaction  $\propto A^{2/3}$ .
- Color Transparency calculations predict  $\propto A^{4/3}$
- Observed:  
 $\sigma = \sigma_0 A^\alpha$ ,  $\alpha = 1.6 \pm 0.1$   
consistent with CT predictions.

**CT SIGNAL!**  
**No Q-dependence**



# Pion photo production, Jlab

- Photo pion production on  ${}^4\text{He}$   
D. Dutta PRC 68 (2003) 021001



Signal ?

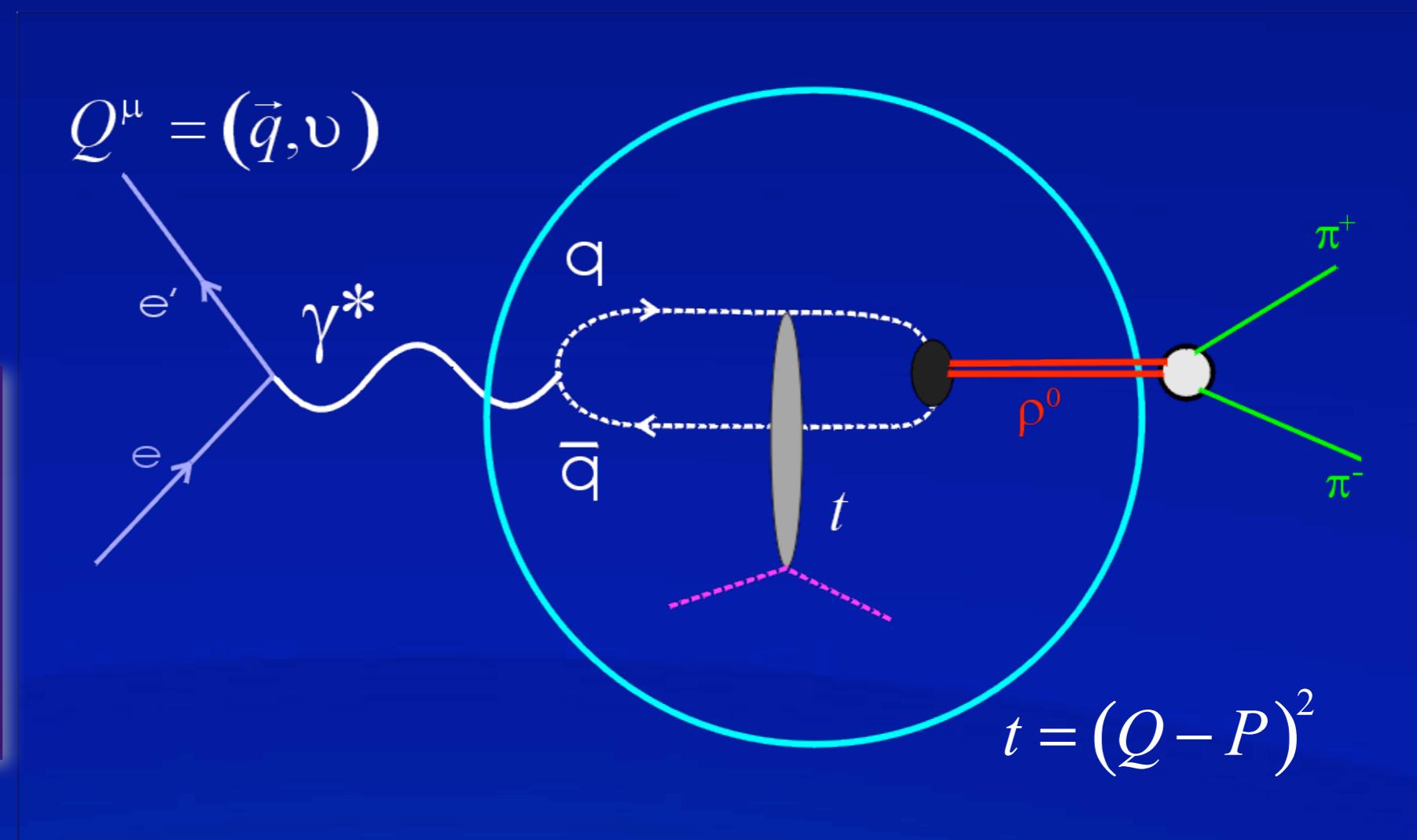
# Using Vector Mesons ( $\rho^0$ )

“Incoherent  $\rho^0$  electroproduction on nuclei:”



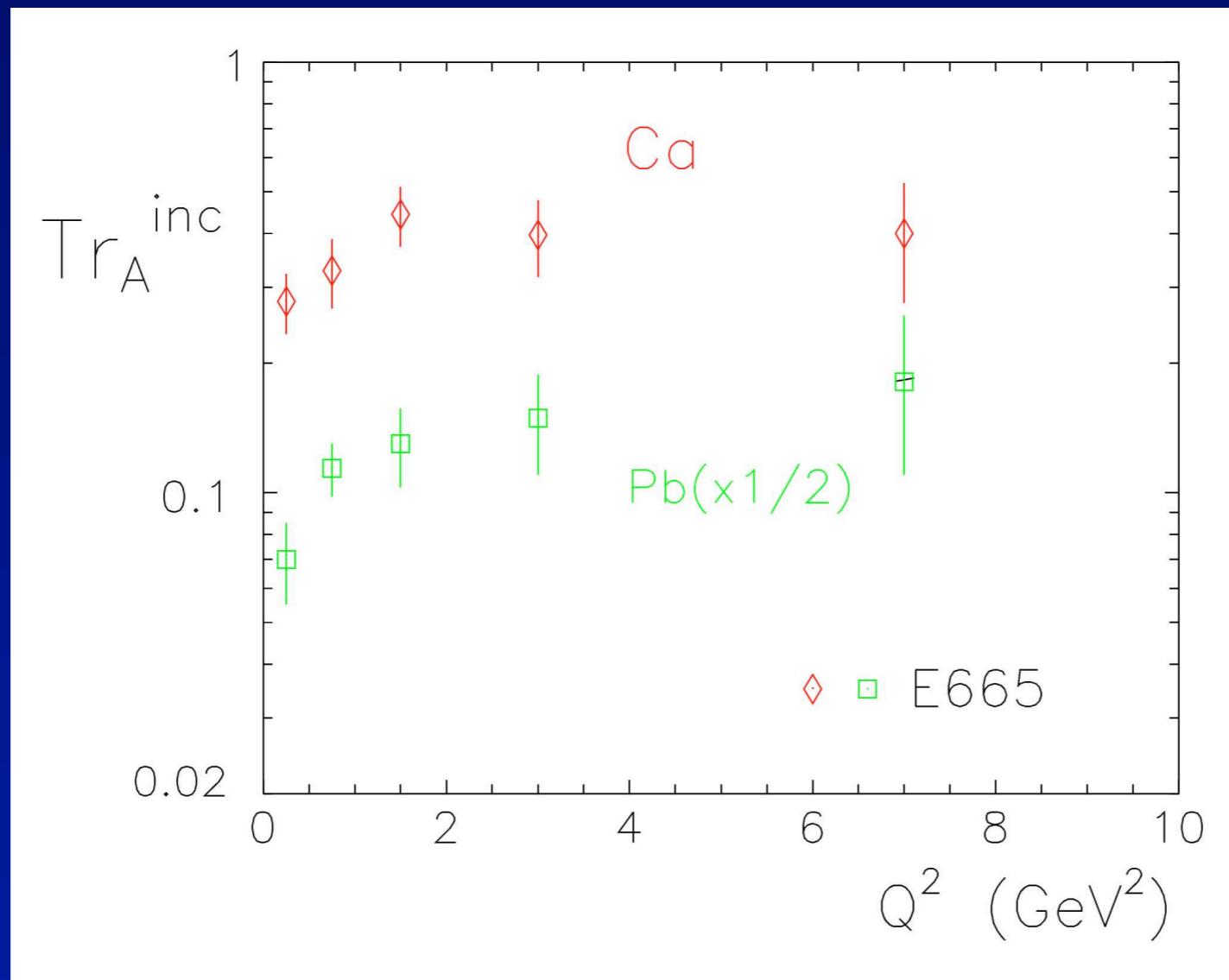
Advantages of using  $\rho^0$  - easier to make PLC  
- Production by VMD well understood

Coherence Length  
 $I_c = 2v/(M_v^2 + Q^2)$   
fluctuation  
distance of qq



# Incoherent $\rho^0$ production: Fermilab

- $\mu A \rightarrow \mu' \rho^0 A$ , muon beam of 470 GeV  
[Adams et al., PRL 4 (1995) 1525] E665



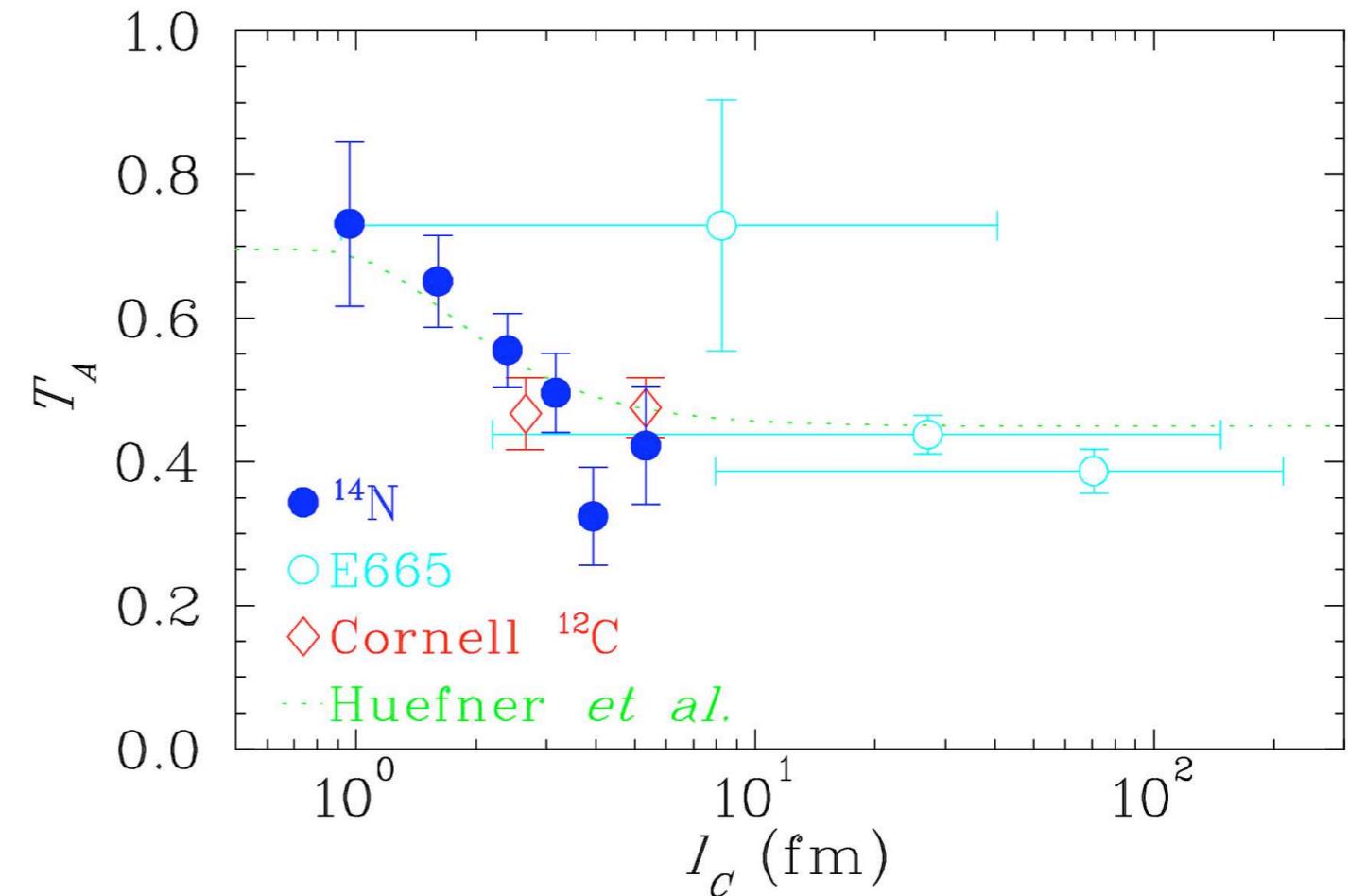
CT Signal?

Interpretation  
not clean.

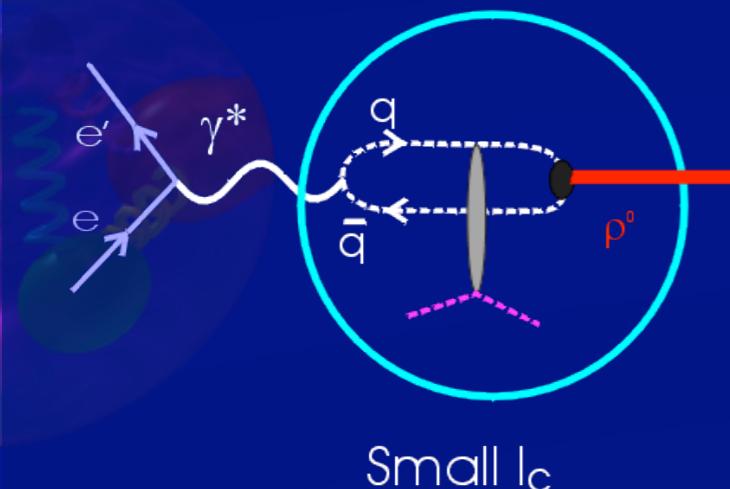
# Coherence Length Effect

- Cross section dependence on  $L_c$
- Due to Initial state interactions.
- Mimics CT signal.

**Coherence Length**  
$$l_c = 2v/(M_v^2 + Q^2)$$

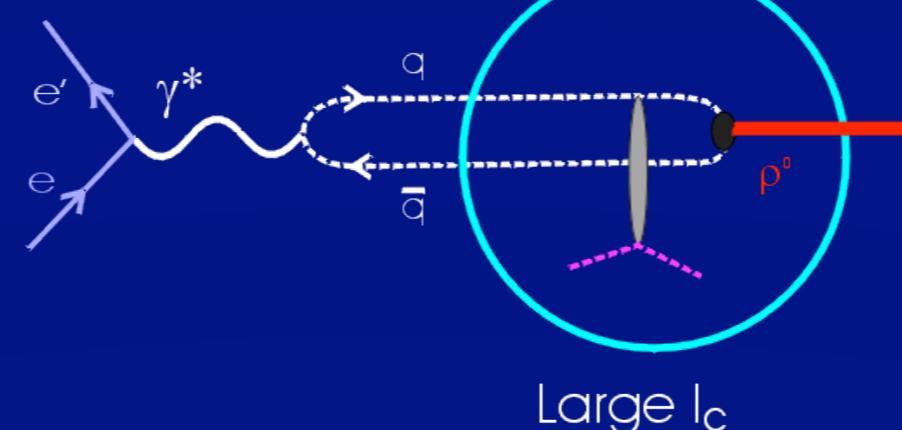


Electromagnetic ISI



Small  $l_c$

Hadronic ISI



Large  $l_c$

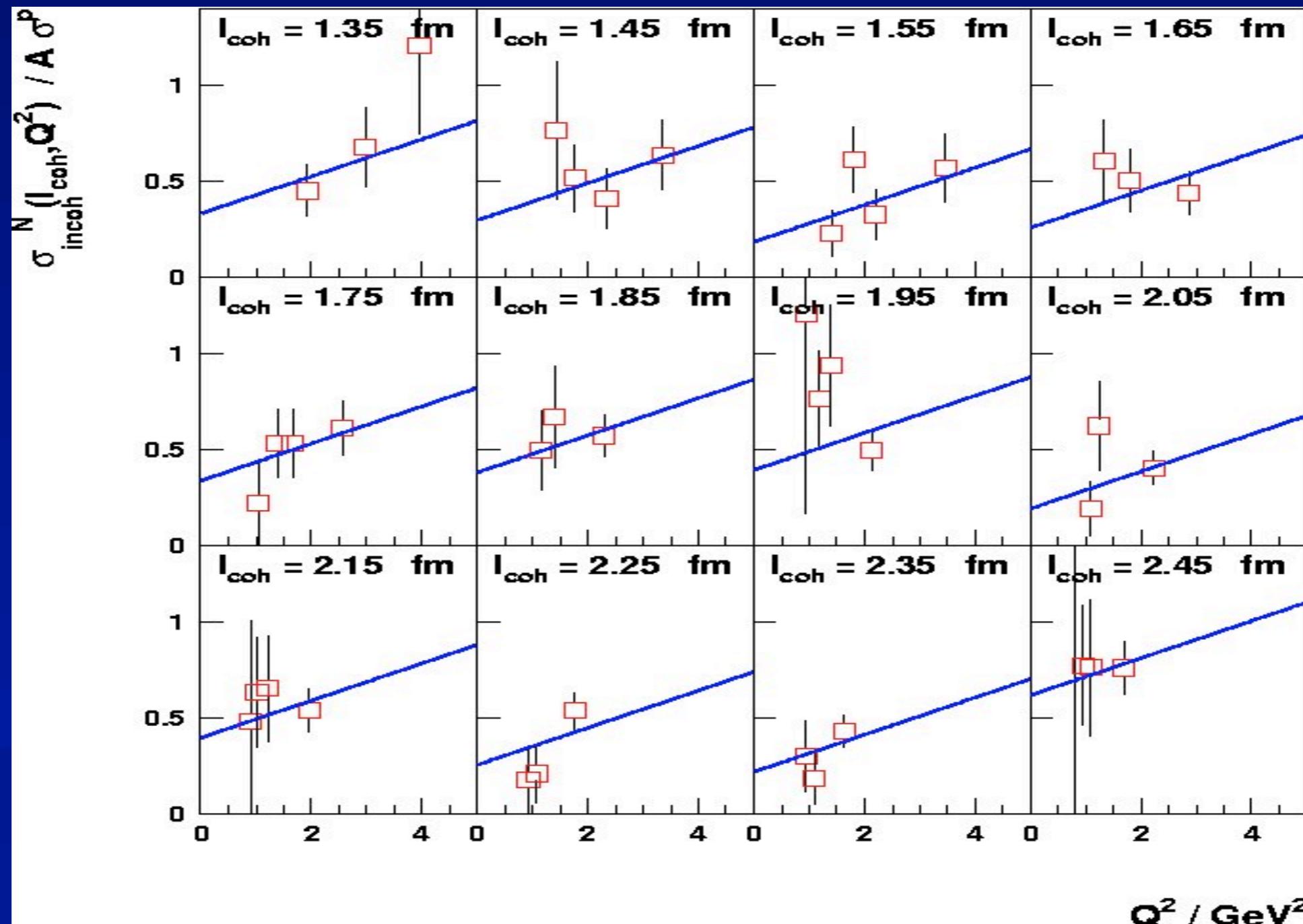
[K. Ackerstaff et al. Hermes Collab. Phys. Rev. Lett. 82, 3025 (1999)]

# Incoherent $\rho^0$ production: HERMES

- Measurement of the Nuclear Transparency.

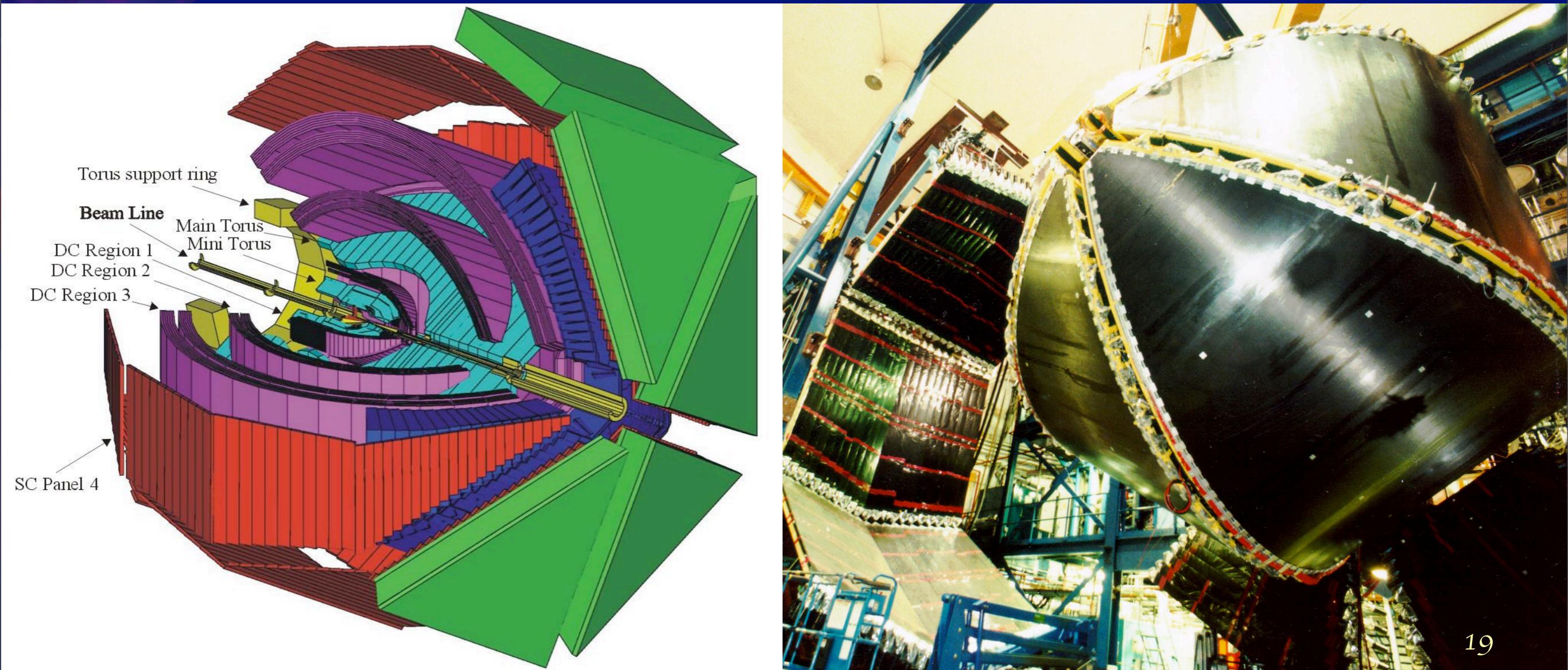
[HERMES Nitrogen data - PRL 90 (2003) 052501 ]

$$T_A = P_0 + P_2 Q^2 \quad P_2 = (0.089 \pm 0.046_{\text{stat}} \pm 0.02_{\text{sys}}) \text{ GeV}^2$$

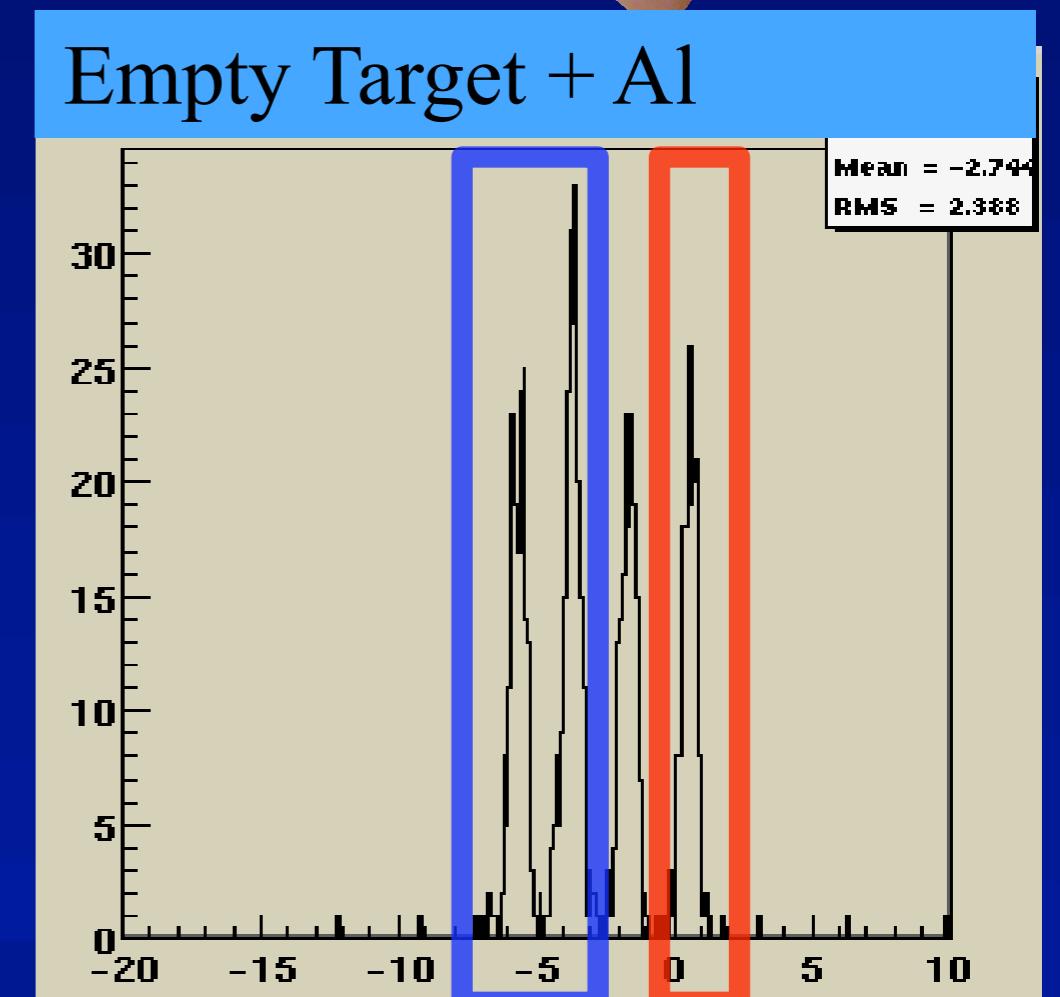
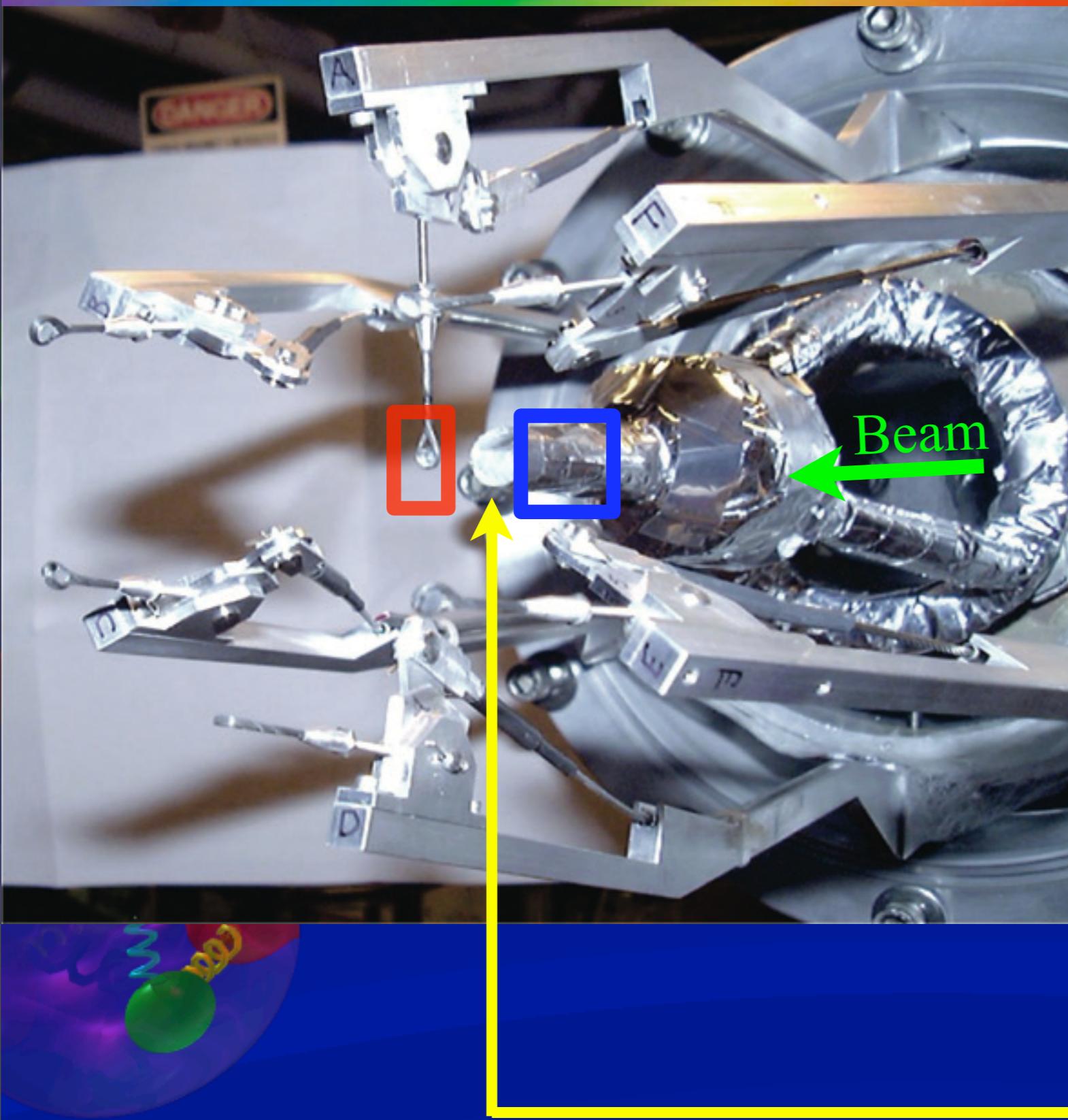


# CLAS EG2 Experiment

- Electron Beam 5 GeV (50 days) & 4 GeV (7days)
- Targets: D&Fe, D&C, D&Pb
- Luminosity  $\sim 2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

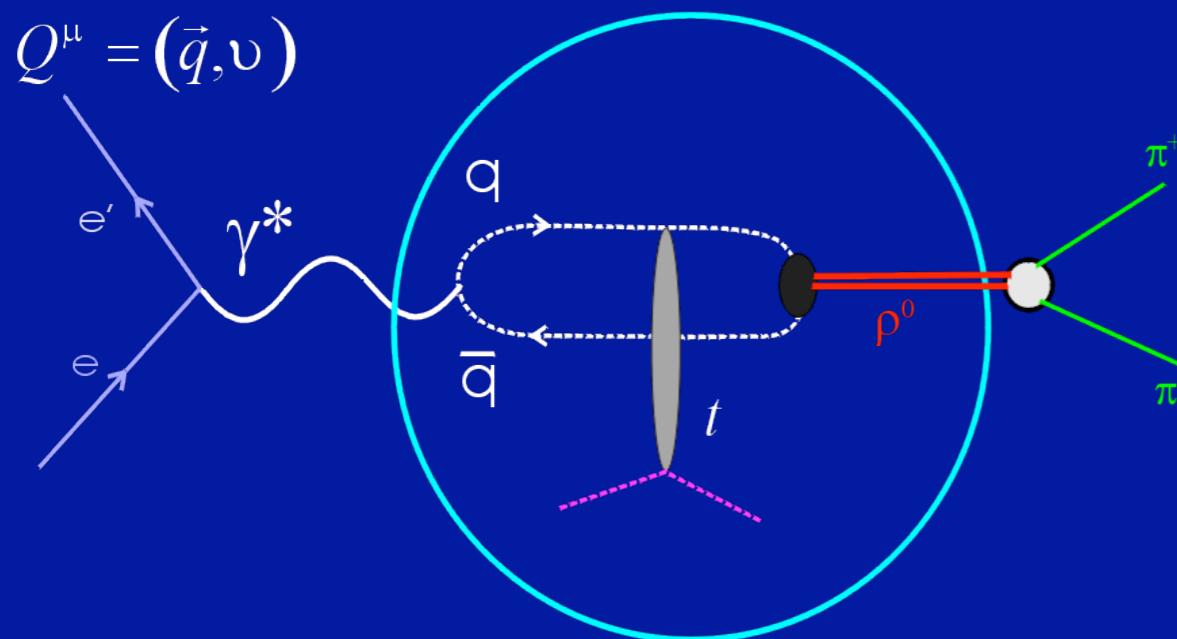


# CLAS EG2 Target



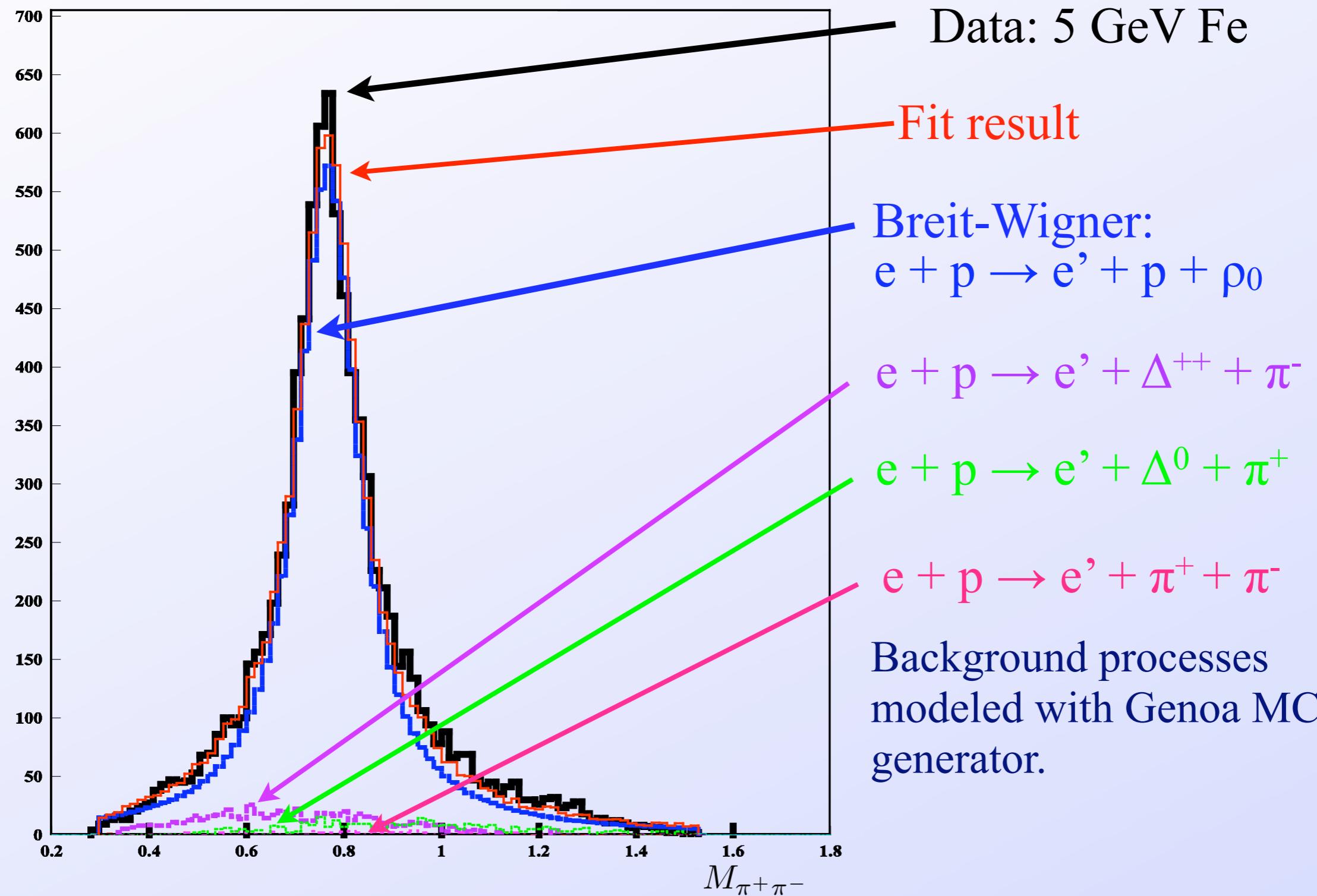
# Data Analysis

- $e + N \rightarrow e' + N + \rho^0 \rightarrow e' + N + \pi^+ + \pi^-$
  - Cuts:
    - o  $W > 2 \text{ GeV}$ , above resonance region.
    - o  $-t < 0.45 \text{ GeV}^2$ , select diffractive process.
    - o  $|\Delta E| \leq 0.1 \text{ GeV}$ , select exclusive process
- $\Delta E = v - E_\rho + t/M_p$  is the missing energy.

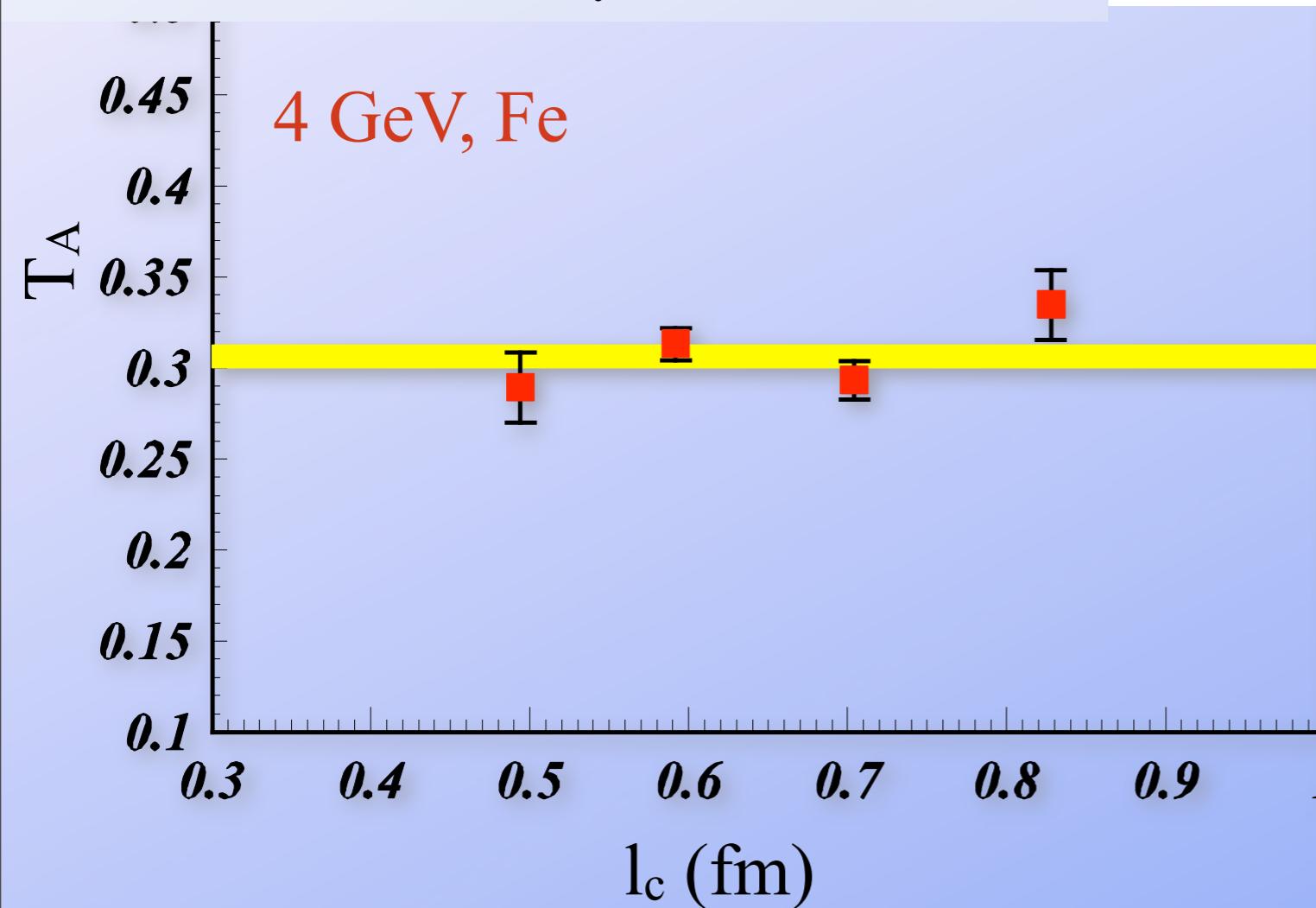
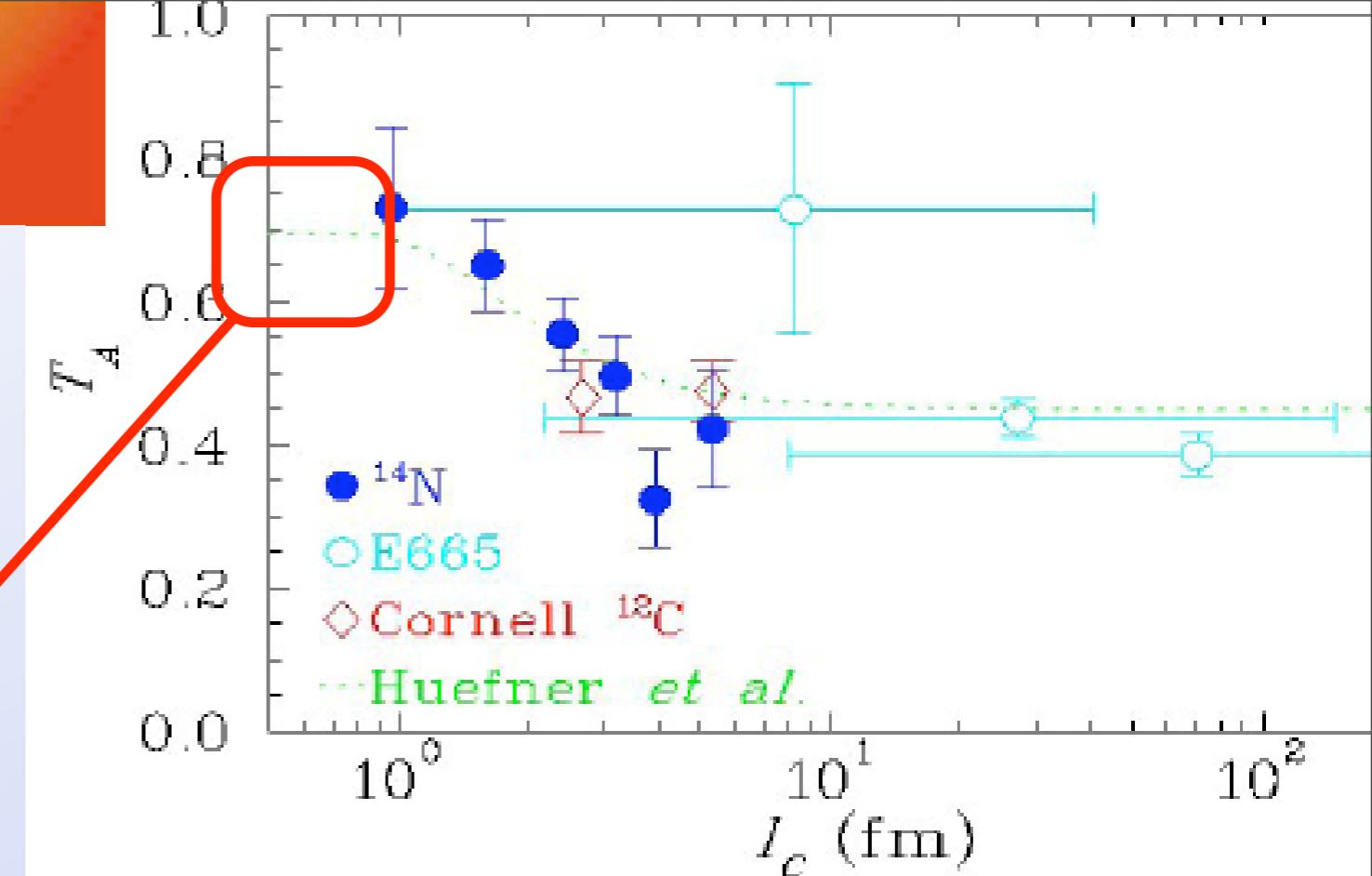
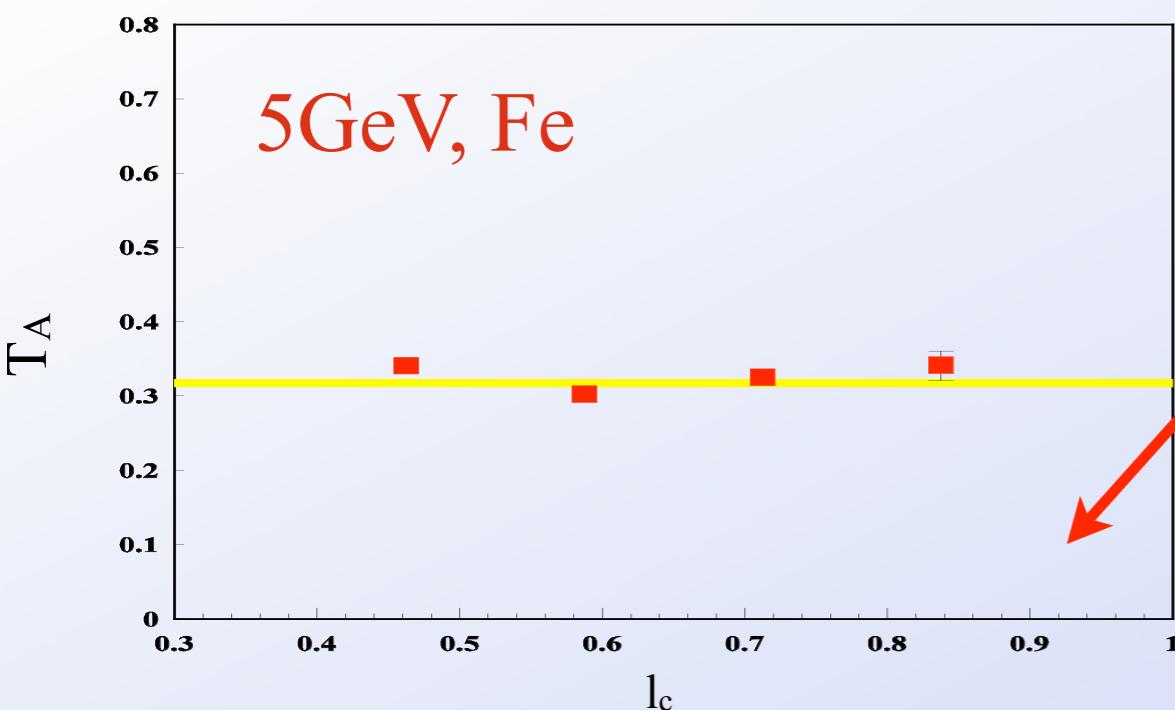


$$Q^2 = -(q^\mu)^2 = 4E E' \sin^2 \theta/2$$
$$v = E - E'$$
$$t = (q^\mu - p_V^\mu)^2$$
$$W^2 = (q^\mu + p^\mu)^2 = -Q^2 + M_p^2 + 2M_p v$$

# Fitting the $\pi^+\pi^-$ invariant mass



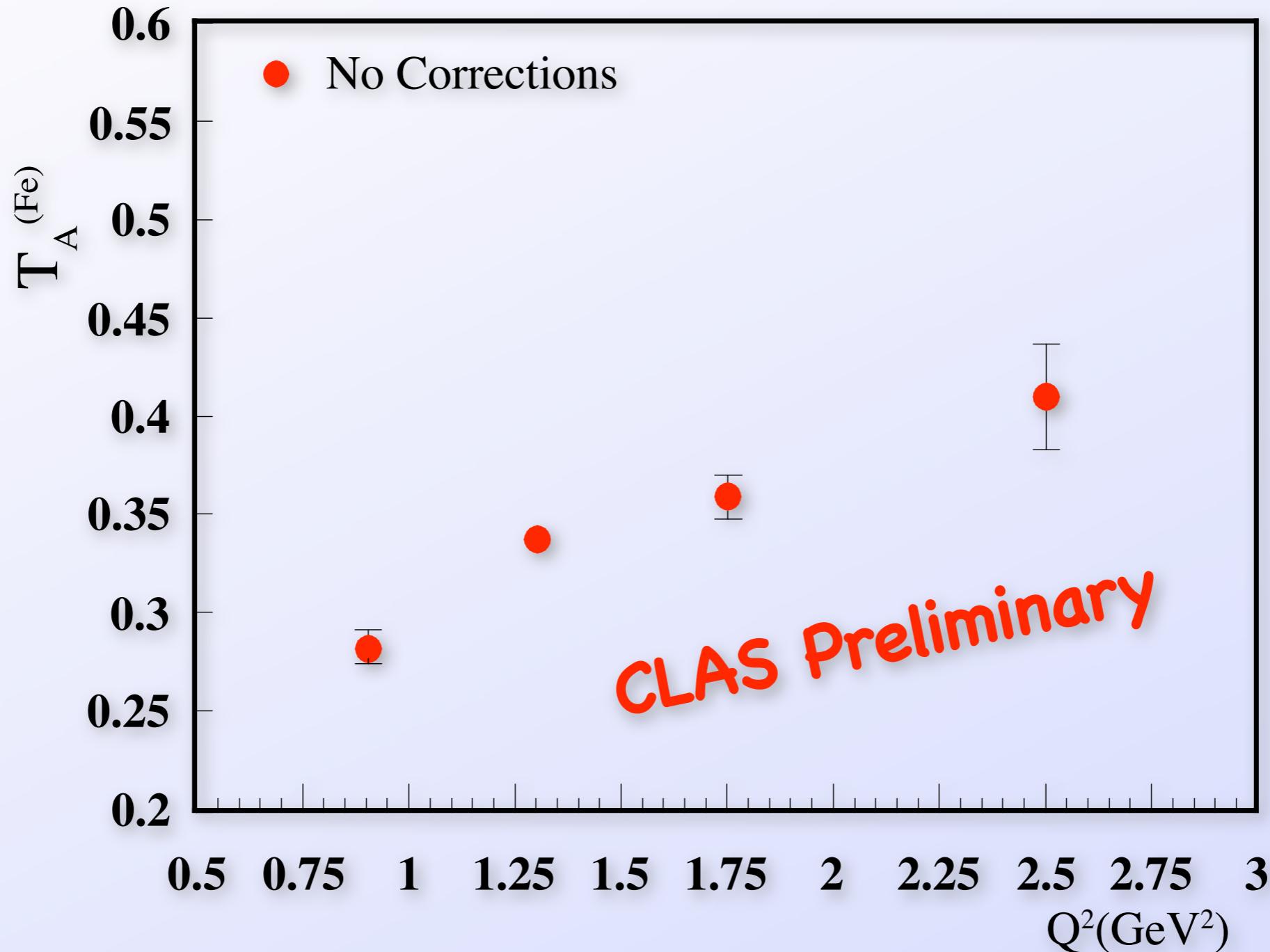
# $l_c$ dependence of $T_A$



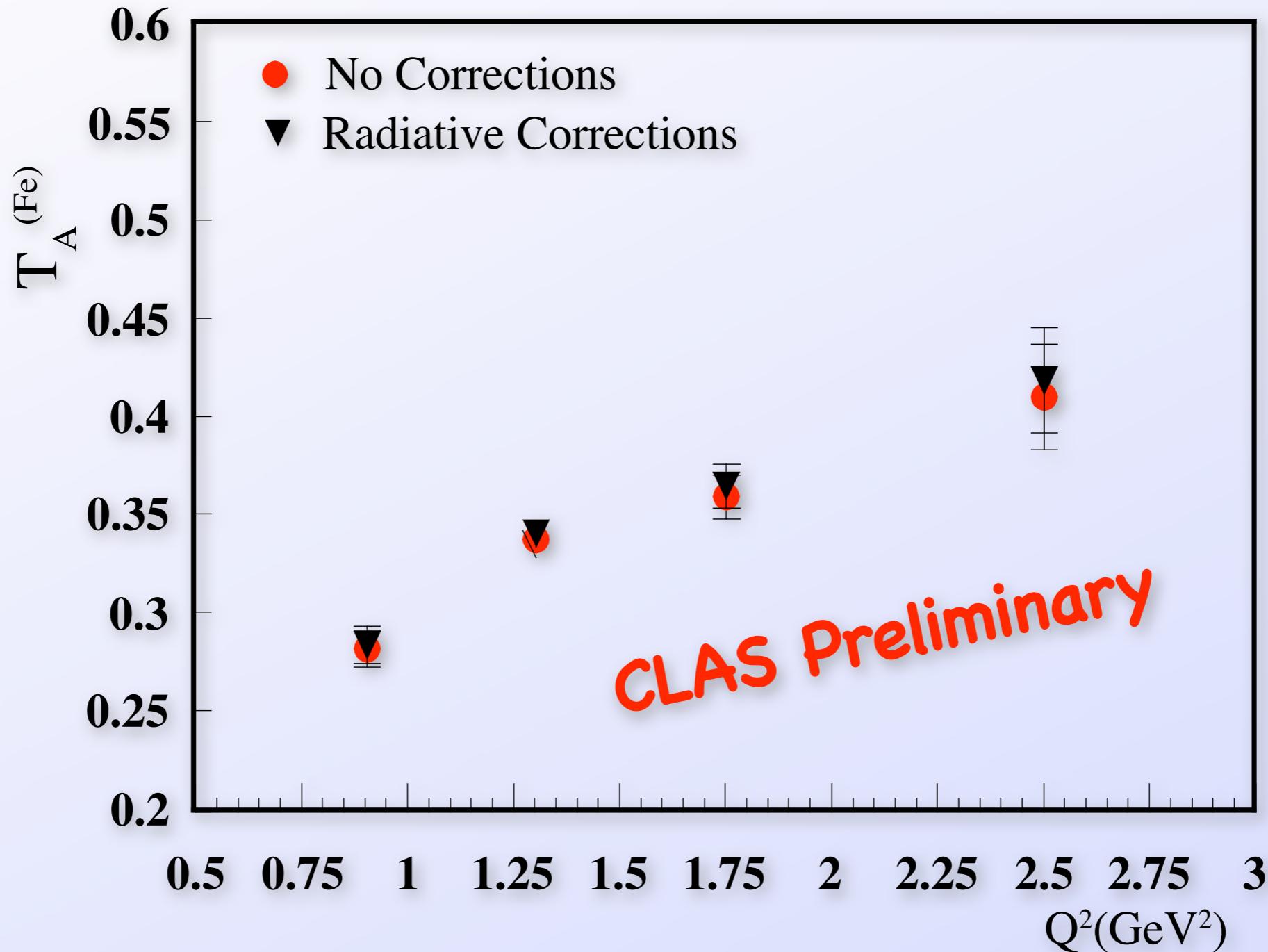
Nuclear Transparency  
 $T_A = \sigma_A / A\sigma_N$

Coherence Length  
 $l_c = 2v/(M_v^2 + Q^2)$

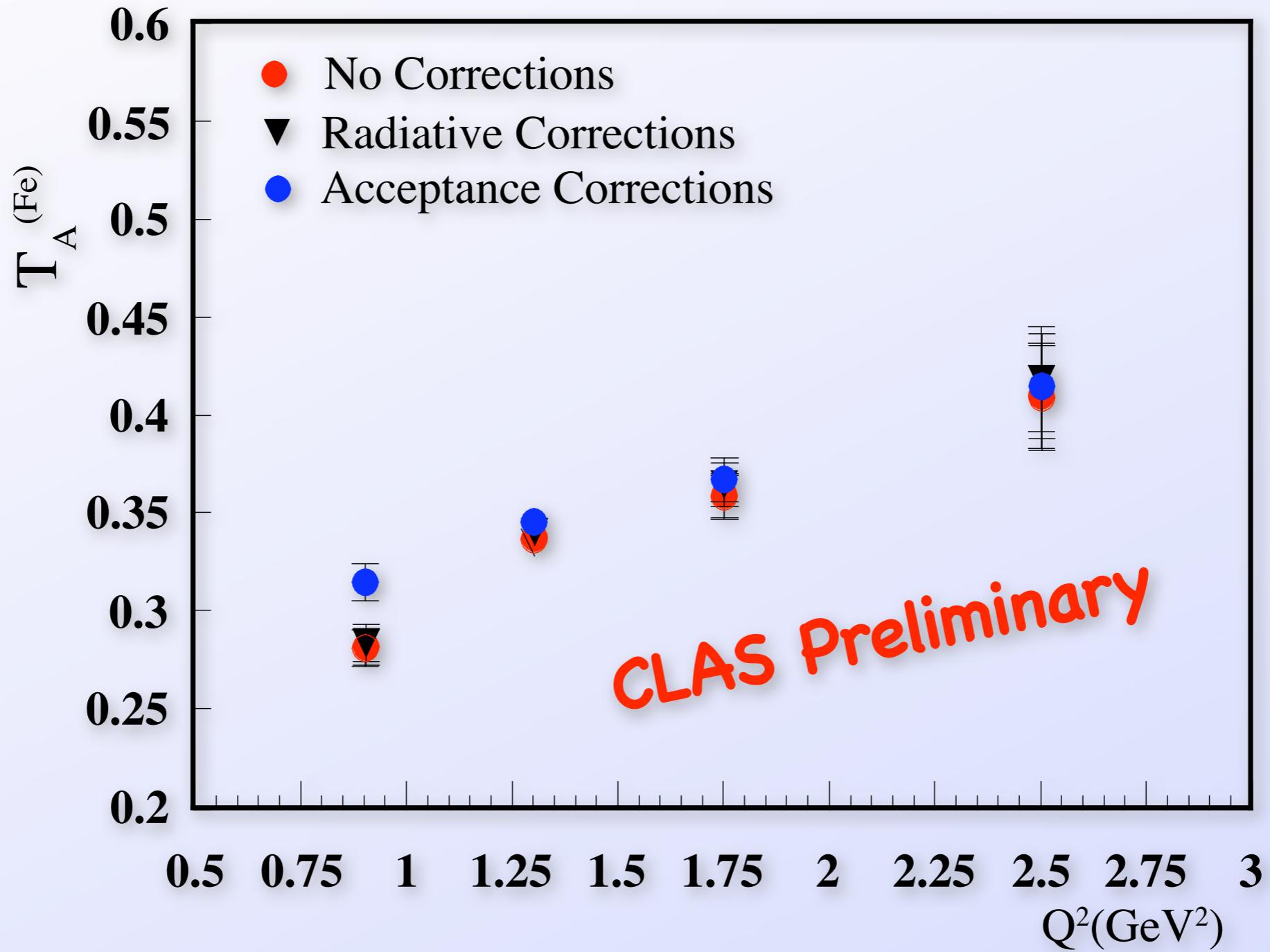
# Results for $T_A$ , Fe, 5 GeV Data



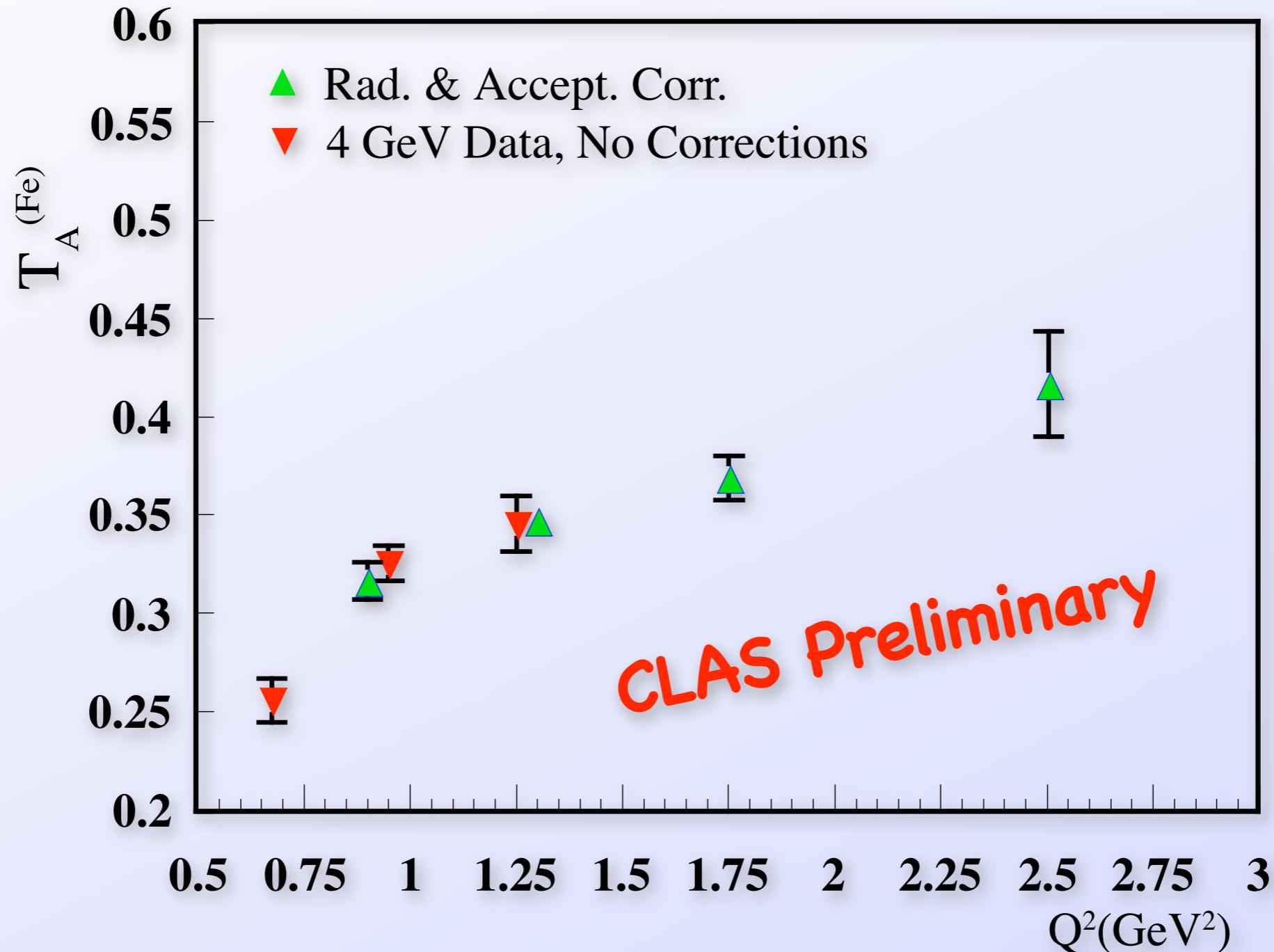
# Radiative Corrections



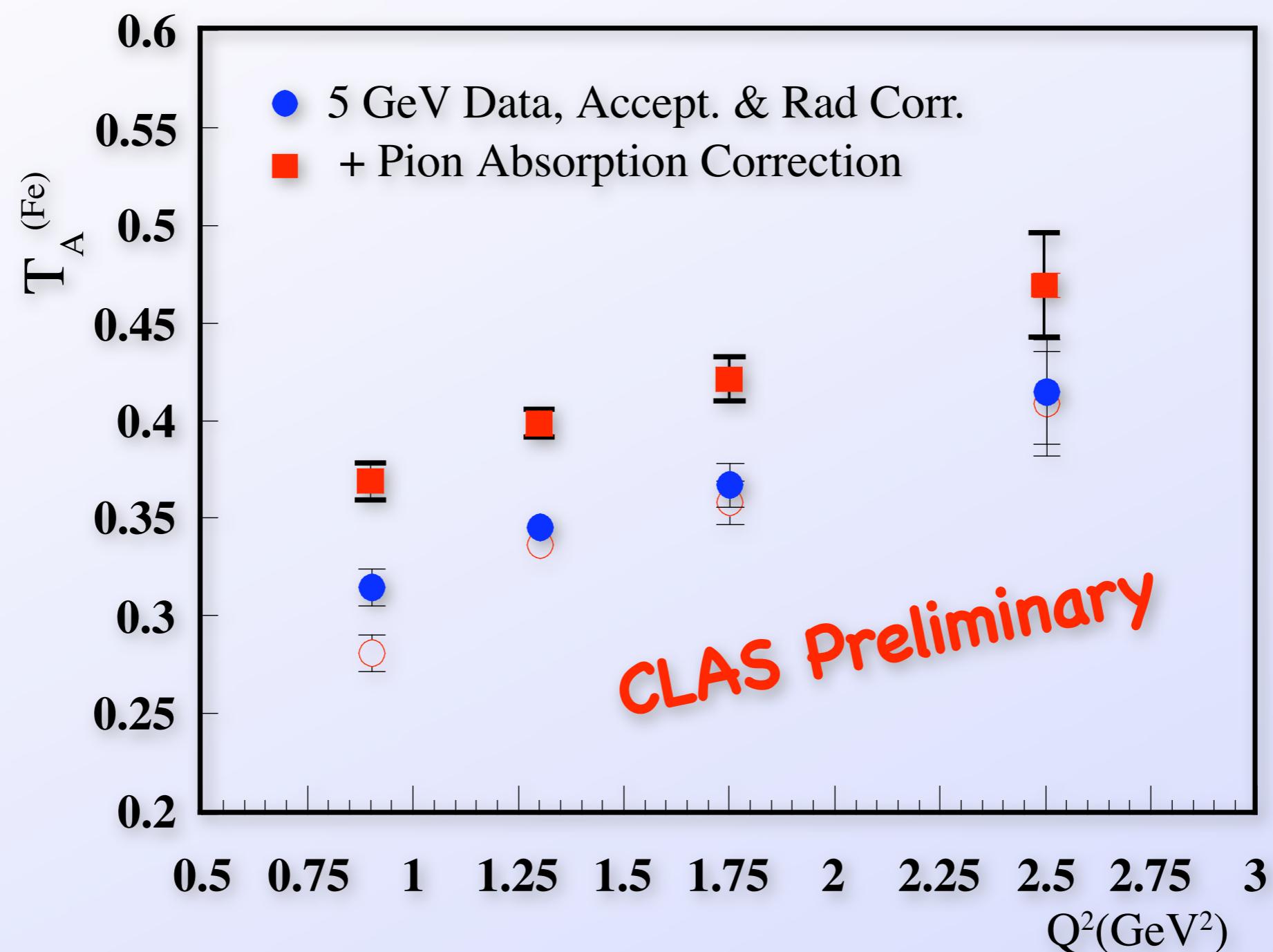
# Acceptance Corrections



# Compare 4 GeV and 5 GeV



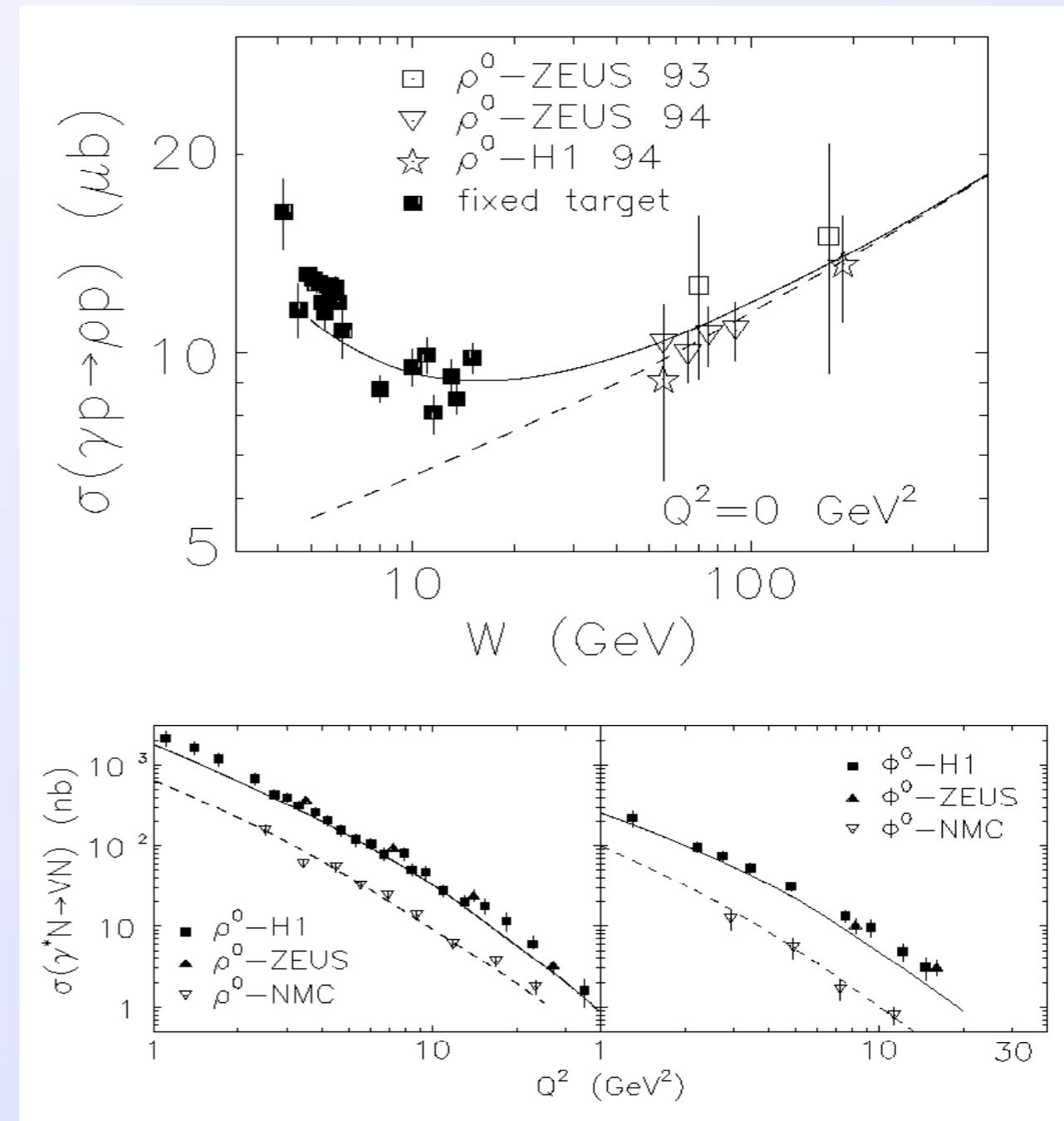
# Pion Absorption Correction



# Theoretical Predictions

Kopeliovich, Nemchik, Schafer, Tarasov PRC 65 (2002) 035201

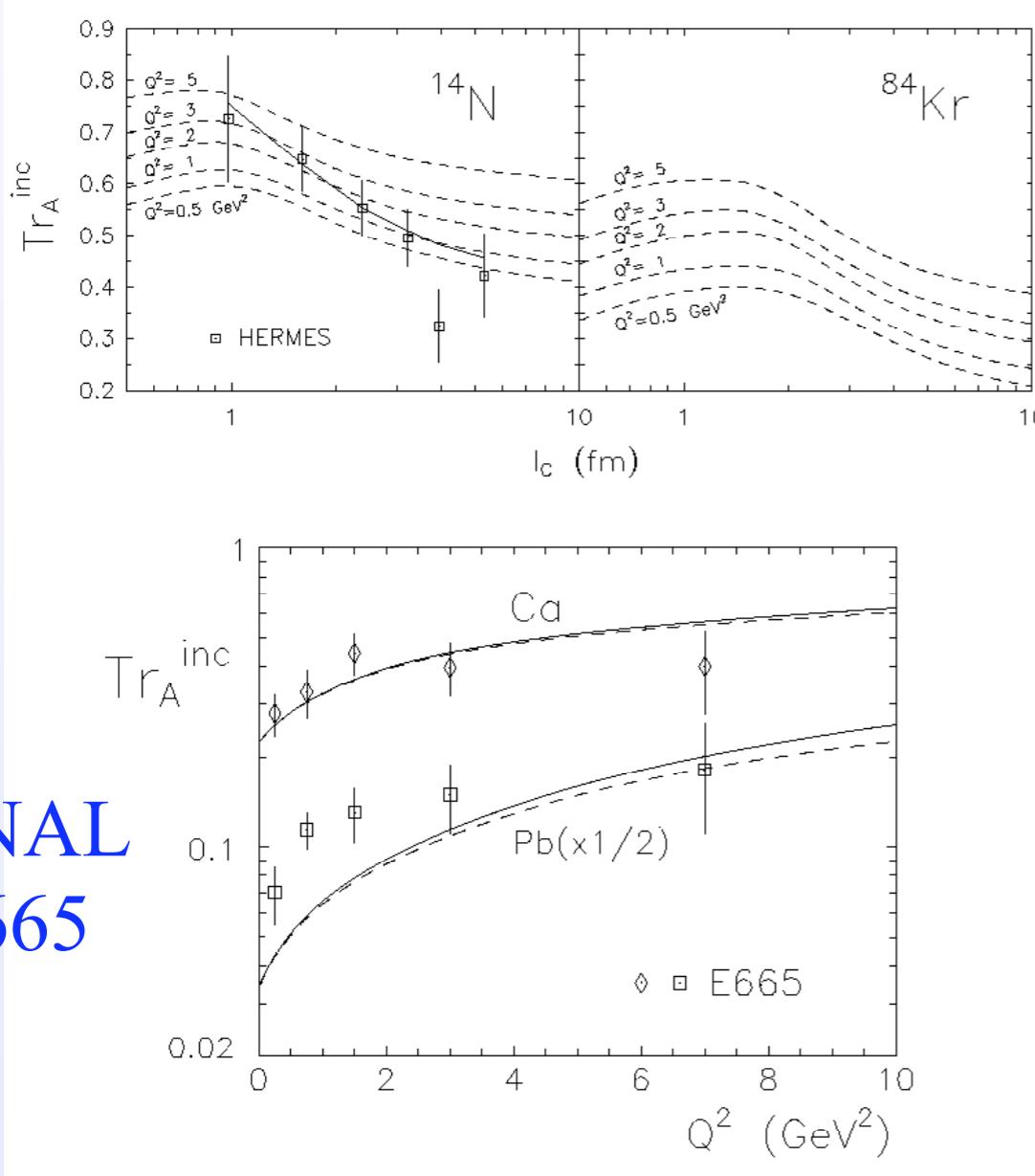
- Light Cone QCD Formalism for  $q\bar{q}$ -dipole.
- $\sigma(q\bar{q})$  - Universal dipole cross section for  $q\bar{q}$  interaction with a nucleon, fit to proton structure functions over a large range of  $x, Q^2$ .
- LC wave function for  $q\bar{q}$ -bar fluctuation of photon.
- LC wave function for vector meson.
- Parameter free (apart from initial fit).



# Theoretical Predictions

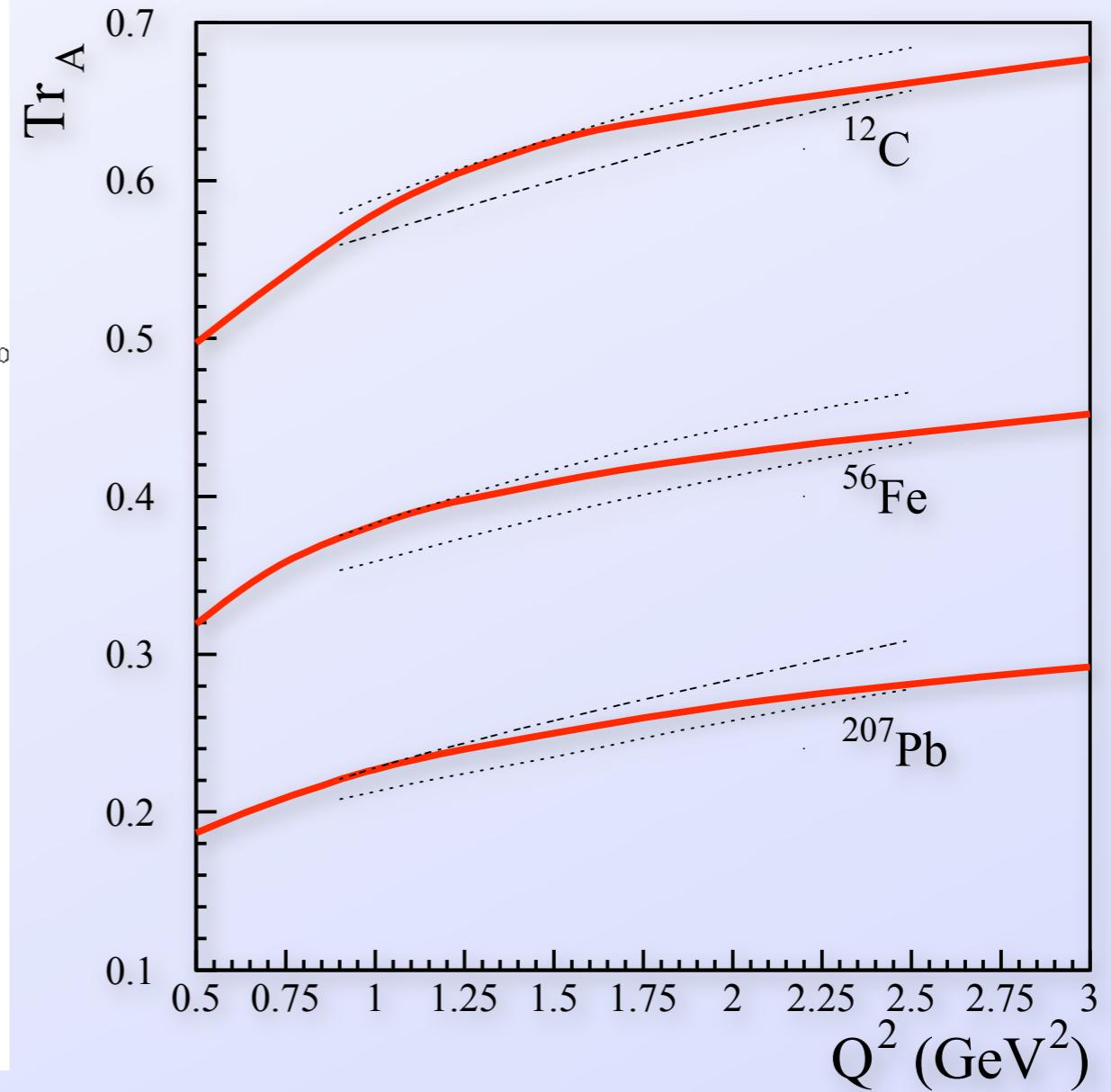
Kopeliovich, Nemchik, Schmidt, hep-ph/0702272v2

Hermes

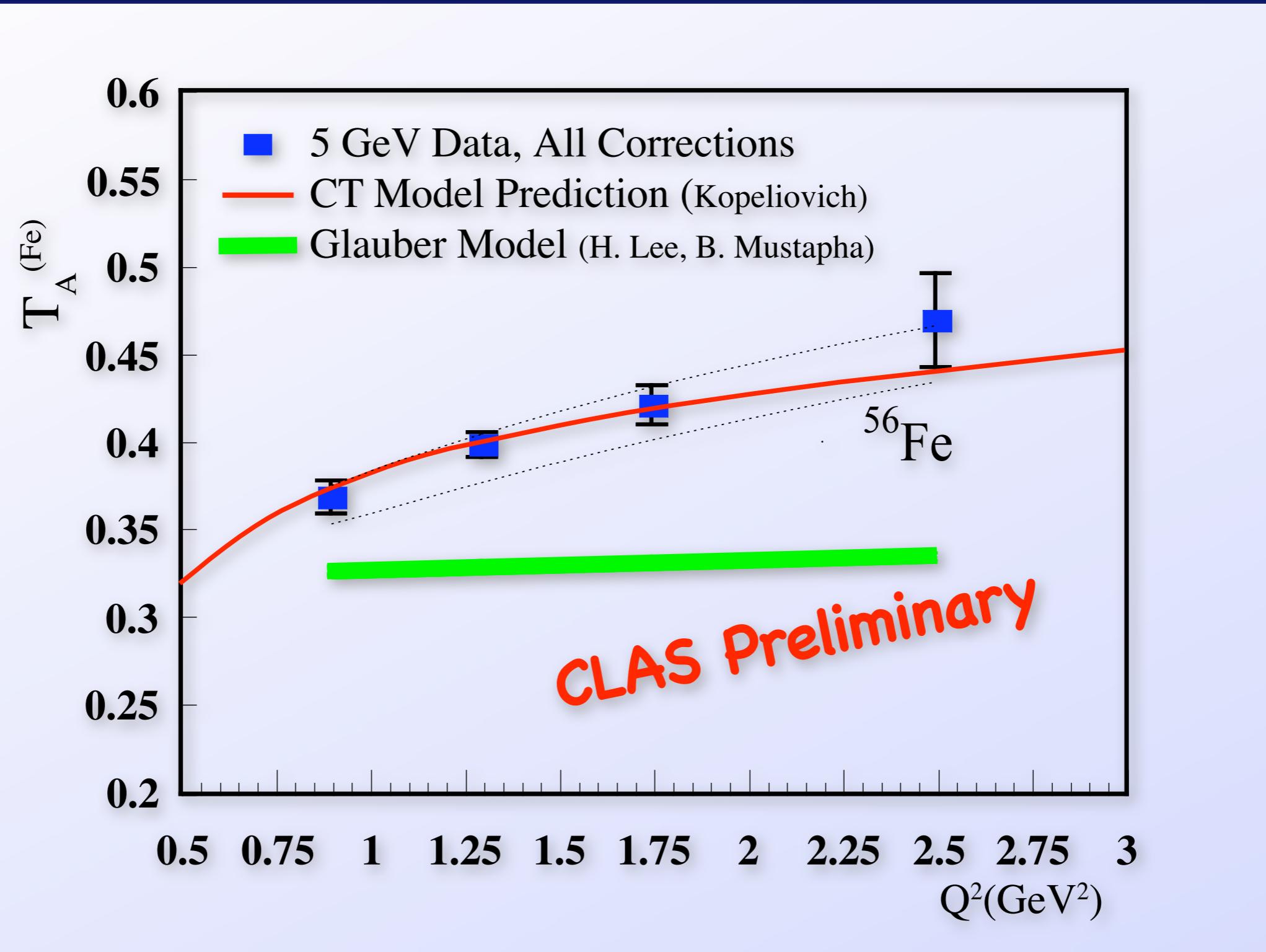


FNAL  
E665

Predictions for CLAS data:



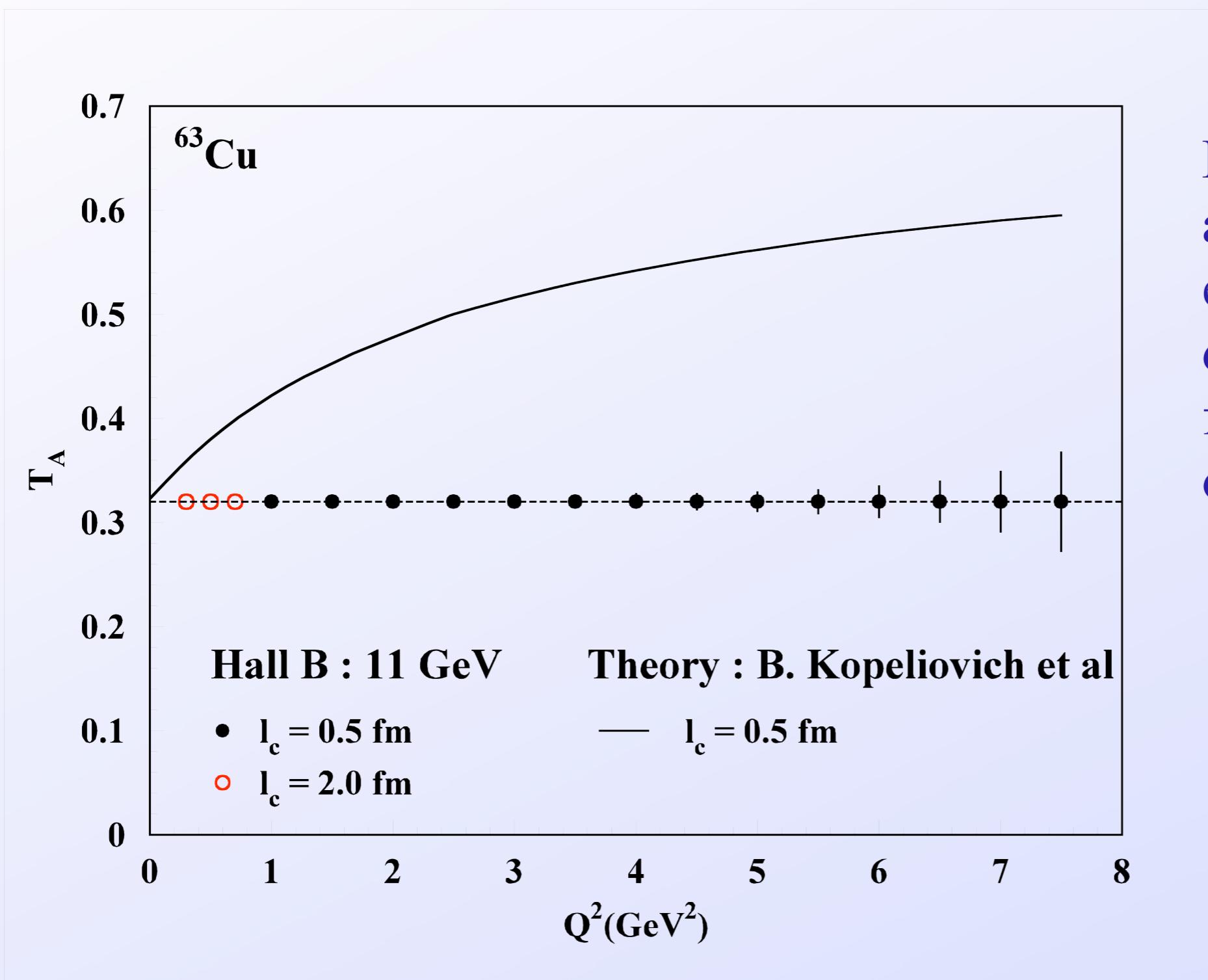
# Data compared to model.



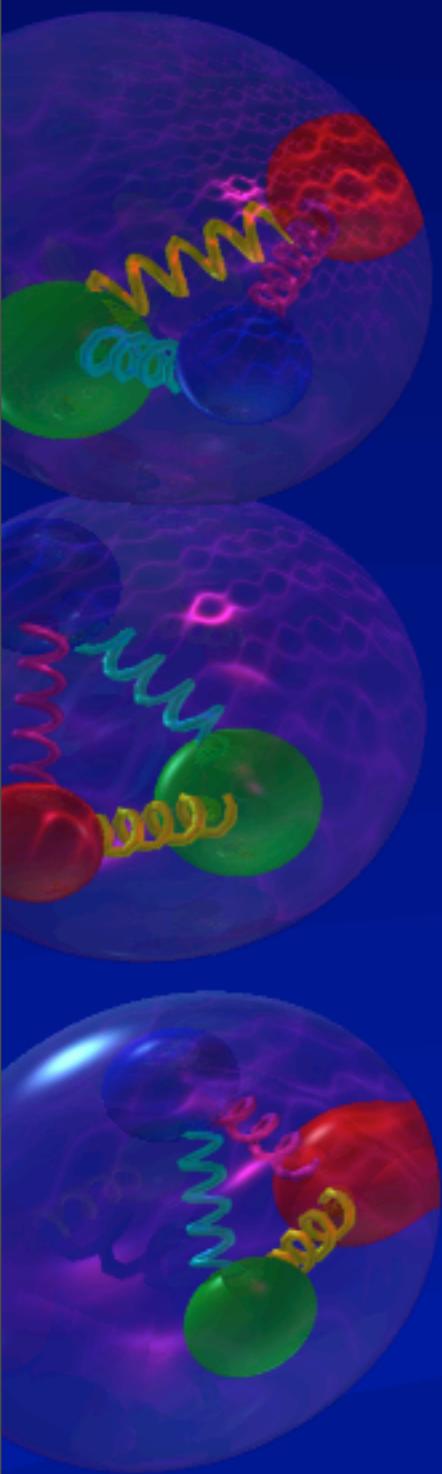
# Summary

- We see clear evidence of CT in  $\rho^0$  electro-production.
- We show good agreement with the theoretical model by Kopeliovich et al.
- We are proceeding with the analysis of 4 GeV data &  $^{12}\text{C}$  data, as well as the study of the systematic errors.
- Work is in progress to improve the Glauber model.

# Future: Proposed Exp for CLAS12

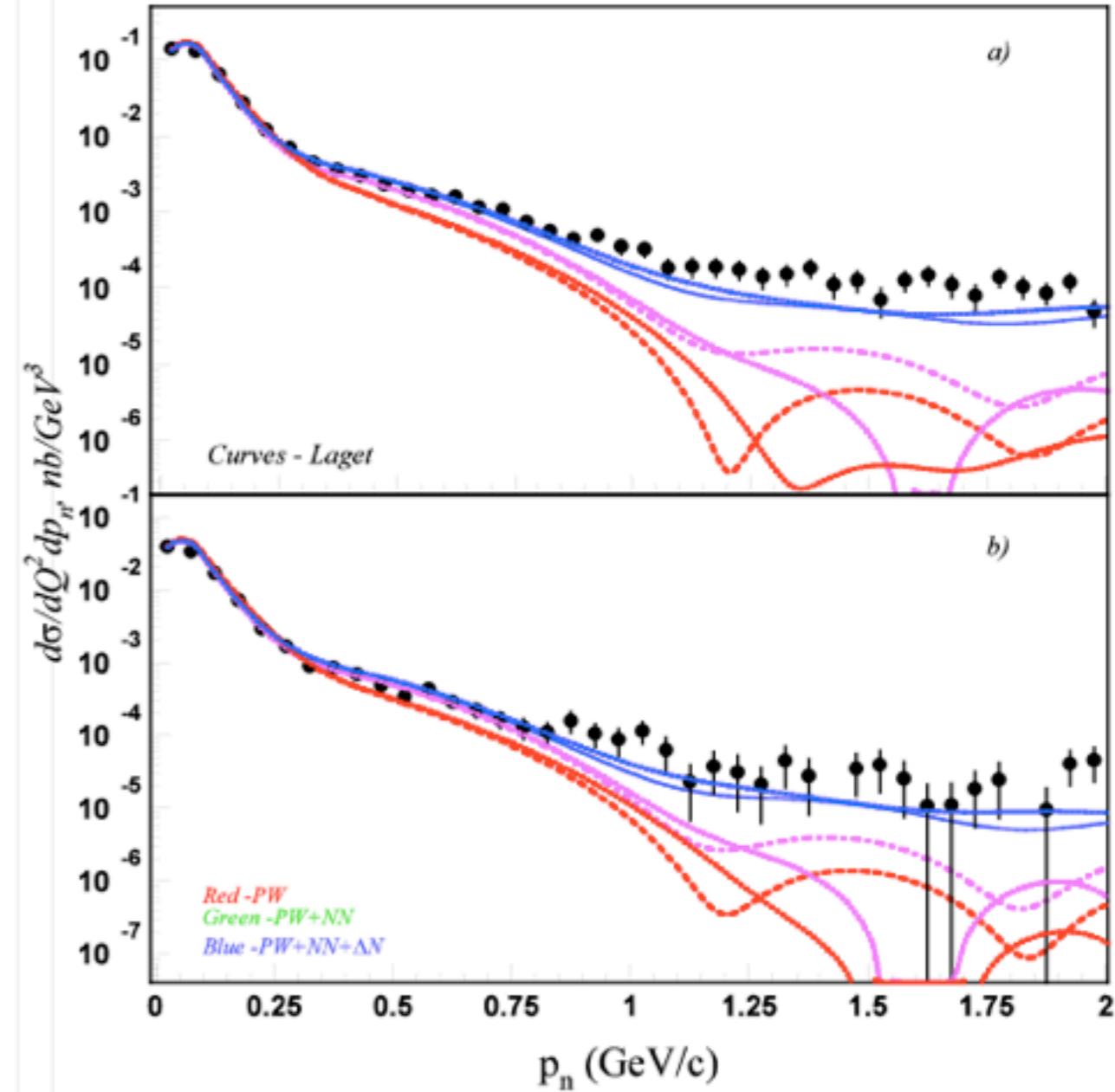
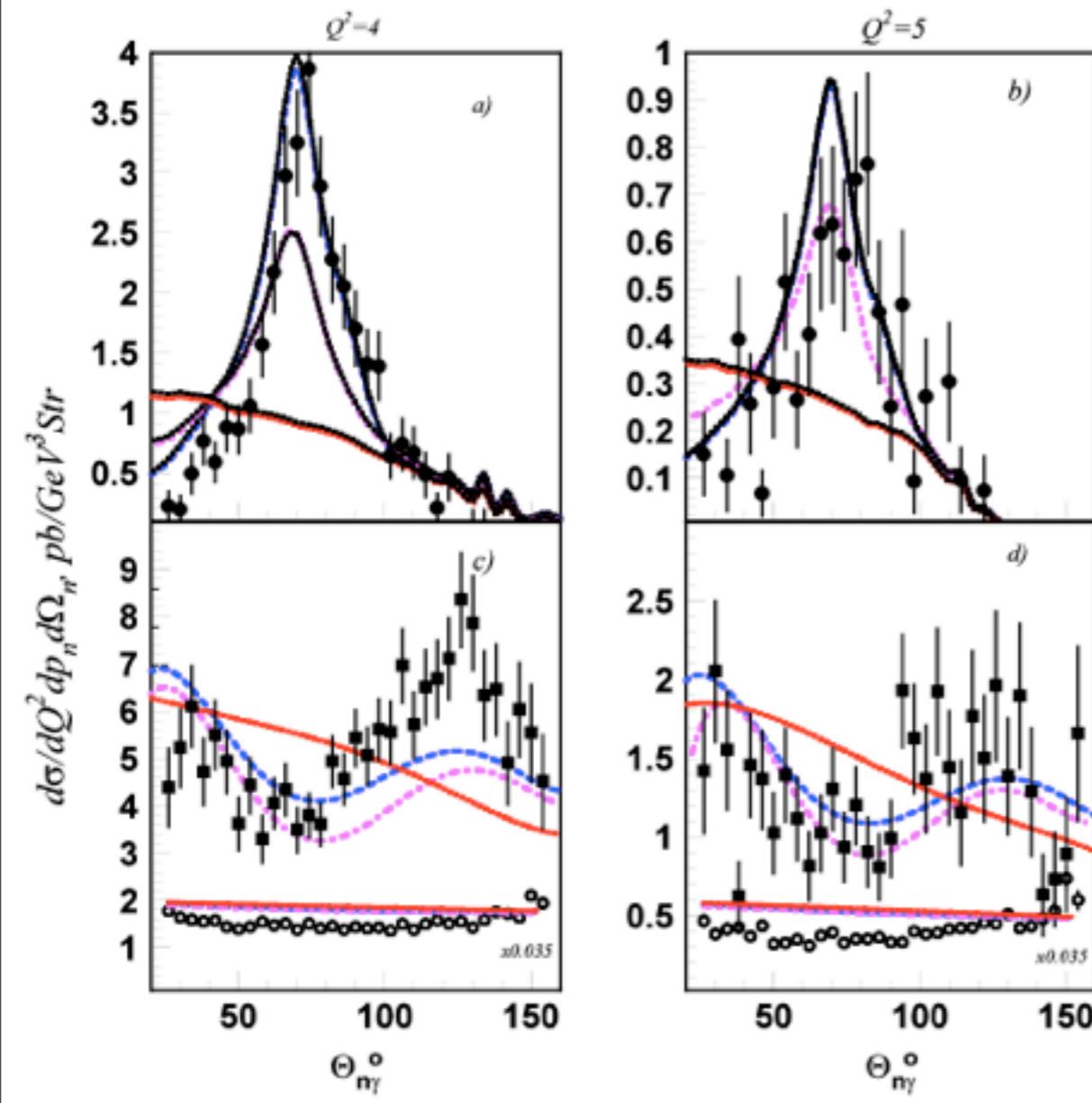


Data would be accurate enough to extract the (model dependent) formation length of the  $\rho^0$



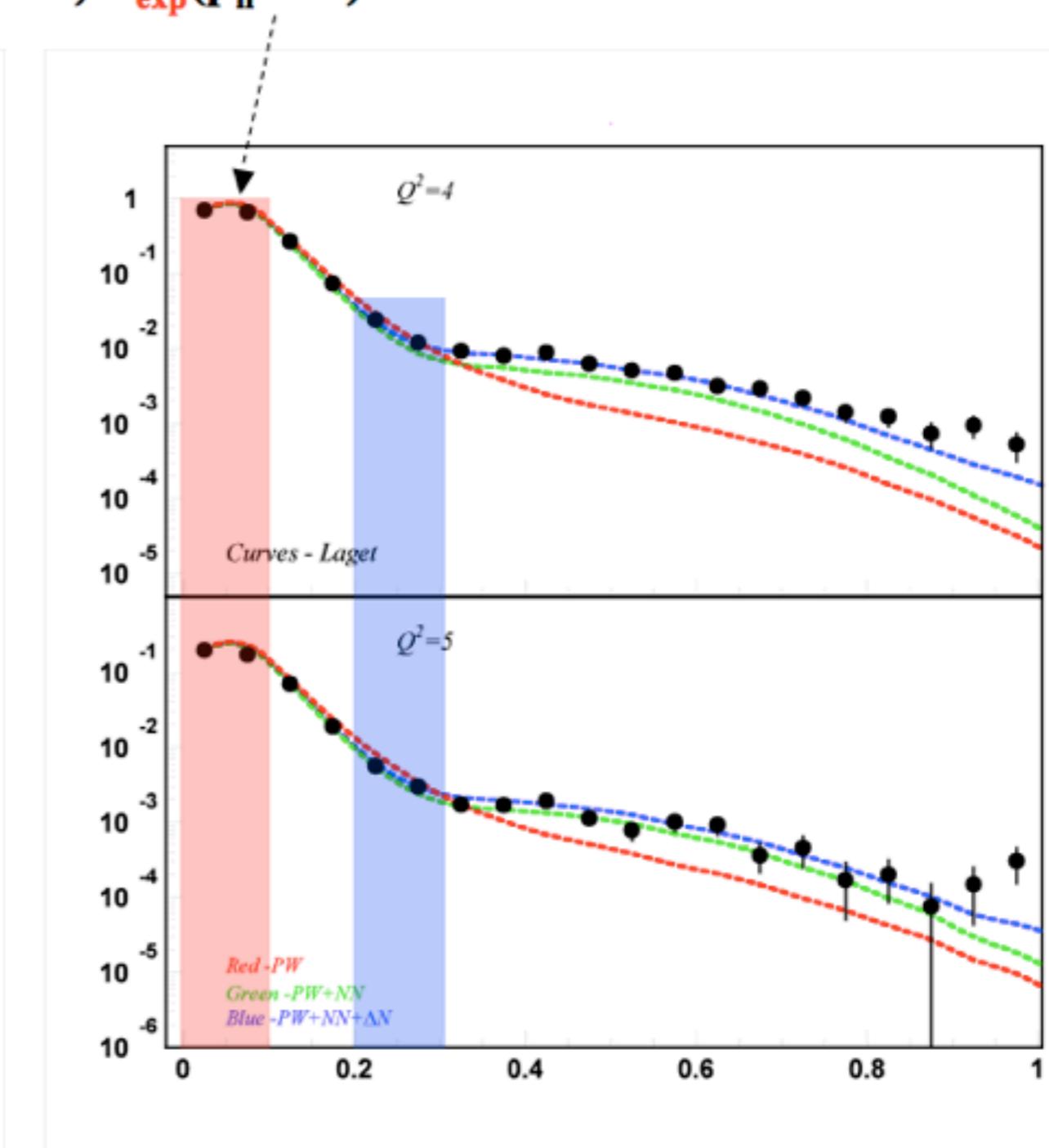
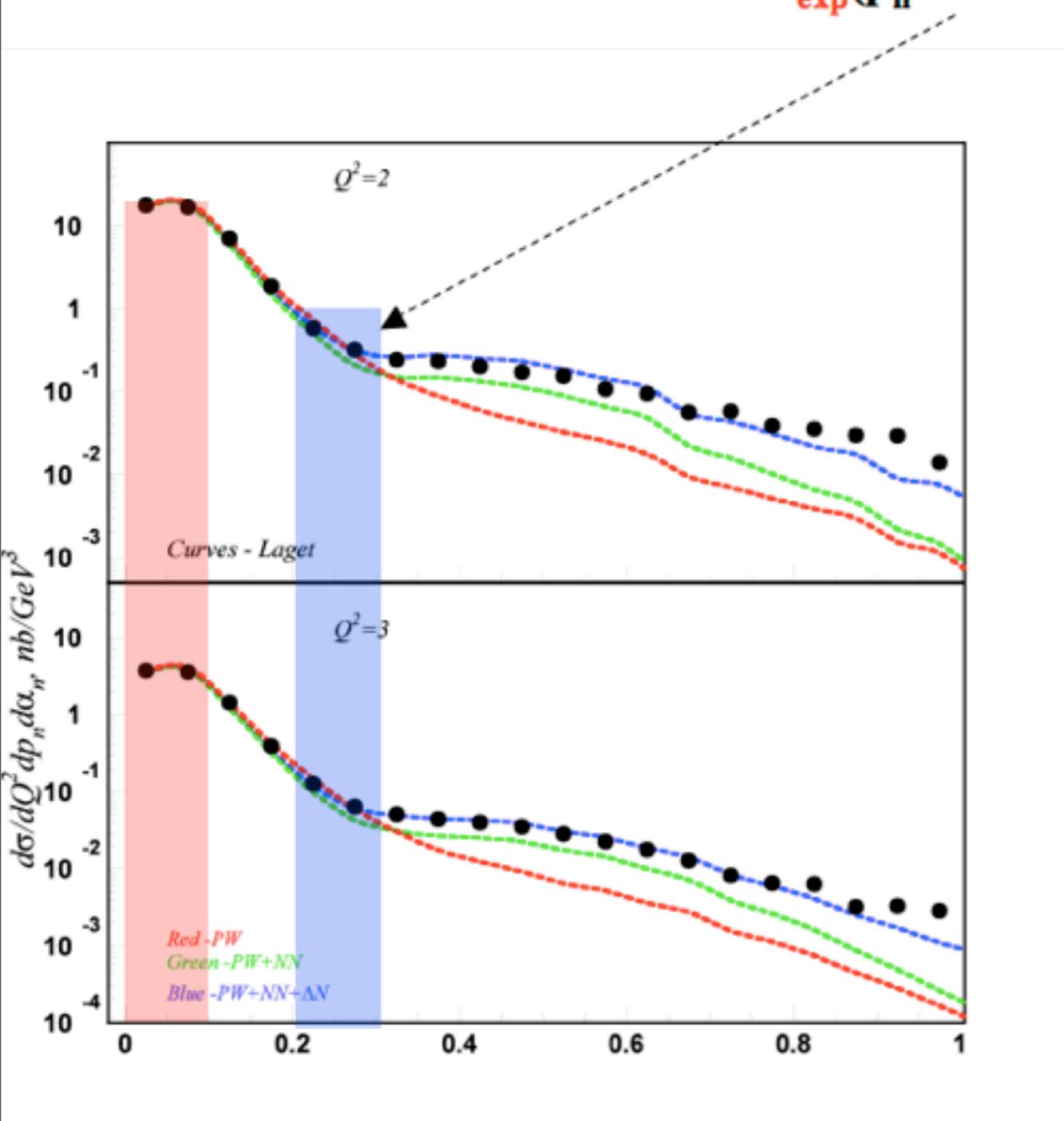
# Diagrammatic Description of 6 GeV Data

- Red: PWIA
- Magenta: with FSI
- Blue: with FSI and IC
- Generalized Eikonal Approximation (GEA) in near future to confirm this



# FSI enhanced kinematics I

- For  $p_n < 0.1$  no FSIs and no CS
- $T = \sigma_{\text{exp}}(p_n = 0.25 \pm 0.05) / \sigma_{\text{exp}}(p_n < 0.1)$



# D(e,e'p) with CLAS12 at Jlab

- Experimental ratios:  $\sigma(<0.3)/\sigma(0.1)$ ,  $\sigma(0.25)/\sigma(0.1)$  and  $\sigma(0.5)/\sigma(0.1)$
- Black points: E6 6 GeV data already taken
- Magenta points: solid: without CT; open: with CT expected results for an 11 GeV experiment
- Dotted red: PWIA
- Dashed blue: Laget PWIA+FSI+IC

