JLAB USER GROUP

Jefferson Lab PAC21
Proposal Cover Sheet

This document must be received by close of business Monday,

December 3, 2001 at:

Jefferson Lab
User Liaison,
Mail Stop 12B
12000 Jefferson Ave.
Newport News, VA
23606

Experimental Hall: B

Days Requested for Approval: 30

❒ **Proposal Title:**
Incoherent ρ^0 electroproduction on nuclei at 6 GeV

Proposal Physics Goals

Indicate any experiments that have physics goals similar to those in your proposal.
Look for the onset of Color Transparency

Approved, Conditionally Approved, and/or Deferred Experiment(s) or proposals:

- E01-107 K. Garrow (spokesperson)
- E94-019 M. Strikman (spokesperson)

Contact Person

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Jefferson Lab Use Only

Receipt Date:_____

By:_____

BEAM REQUIREMENTS LIST

JLab Proposal No.: _____ Date: _____

Hall: B Anticipated Run Date: _____ PAC Approved Days: _____

Spokesperson: Kawtar Hafidi
Phone: (630) - 252 - 4012
E-mail: kawtar@anl.gov

Hall Liaison: B. A. Mecking

List all combinations of anticipated targets and beam conditions required to execute the experiment. (This list will form the primary basis for the Radiation Safety Assesment Document (RSAD) calculations that must be performed for each experiment.)

Condition No.	Beam Energy ~~(MeV)~~ GeV	Mean Beam Current ~~μA~~ nA	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Material Thickness (mg/cm^2)	Est. Beam-On Time for Cond. No. (hours)
1	e: 6	5		liquid hydrogen	standard	216
2	e: 6	5		solid carbon	eq. rad. l.	216
3	e: 6	5		Solid copper	eq. rad. l.	216
4	γ: 1.7-2.2	10^7 γ/s		liquid hydrogen		24
5	γ: 1.7-2.2	10^7 γ/s		solid carbon		24
6	γ: 1.7-2.2	10^7 γ/s		solid copper		24

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Other energies should be arranged with the Hall Leader before listing.

HAZARD IDENTIFICATION CHECKLIST

JLab Proposal No.: _____ Date: _____
(For CEBAF User Liaison Office use only)

Check all items for which there is an anticipated need.

Cryogenics
- ____ beamline magnets
- ____ analysis magnets
- √ target
  - type: LH_2
  - flow rate: ____
  - capacity: ____

Electrical Equipment
- ____ cryo/electrical devices
- ____ capacitor banks
- ____ high voltage
- ____ exposed equipment

Radioactive/Hazardous Materials
List any radioactive or hazadorous/ toxic materials planned for use:
_____
_____
_____
_____

Pressure Vessels
- ____ inside diameter
- ____ operating pressure
- ____ window material
- ____ window thickness

Flammable Gas or Liquids
- type: _____
- flow rate: _____
- capacity: _____

Drift Chambers
- type: _____
- flow rate: _____
- capacity: _____

Other Target Materials
- ___ Beryllium (Be)
- ___ Lithium (Li)
- ___ Mercury (Hg)
- ___ Lead (Pb)
- ___ Tungsten (W)
- ___ Uranium (U)
- √ Other (list below)
  - Carbon (C)
  - Copper (Cu)

Vacuum Vessels
- ____ inside diameter
- ____ operating pressure
- ____ window material
- ____ window thickness

Radioactive Sources
- ____ permanent installation
- ____ temporary use
- type: _____
- strength: _____

Large Mech. Structure/System
- ____ lifting devices
- ____ motion controllers
- ____ scaffolding or
- ____ elevated platforms

Lasers
- type: _____
- wattage: _____
- class: _____

Installation:
- ____ permanent
- ____ temporary

Use:
- ____ calibration
- ____ alignment

Hazardous Materials
- ___ cyanide plating materials
- ___ scintillation oil (from)
- ___ PCBs
- ___ methane
- ___ TMAE
- ___ TEA
- ___ photographic developers
- ___ other (list below)

_____
_____

General:

Experiment Class:

- √ Base Equipment
- ____ Temp. Mod. to Base Equip.
- ____ Permanent Mod. to Base Equipment
- ____ Major New Apparatus

Other: _____
_____

LAB RESOURCES LIST

JLab Proposal No.: _____ Date _____
(For JLab ULO use only.)

List below significant resources — both equipment and human — that you are requesting from Jefferson Lab in support of mounting and executing the proposed experiment. Do not include items that will be routinely supplied to all running experiments such as the base equipment for the hall and technical support for routine operation, installation, and maintenance.

Major Installations *(either your equip. or new equip. requested from JLab)*

New Support Structures: _____

Data Acquisition/Reduction

Computing Resources: CODA

Standard DAQ

New Software: _____

Major Equipment

Magnets: Standard

Power Supplies: Standard

Targets: LH_2, C, Cu

Detectors: Standard CLAS
minimum field

Electronics: Standard

Computer Hardware: Standard

Other: _____

Other: _____

Incoherent ρ^0 electroproduction on nuclei at 6 GeV

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Hall B collaboration proposal

November 30, 2001

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ABSTRACT

Measurements of exclusive incoherent electroproduction of $\rho^0(770)$ meson from ^1H, ^{12}C, and ^{63}Cu targets up to $Q^2 = 4$ GeV^2 are proposed using the CLAS detector. The aim of these measurements is to determine the Q^2 dependence of the nuclear transparency ratio for the two nuclear targets : ^{12}C and ^{63}Cu at fixed coherence length of quark-antiquark fluctuations of the virtual photon. A sizeable rise of the nuclear transparency is predicted and can be measured in this experiment. A relatively large increase of the nuclear transparency can be an effective signature of the onset of color transparency.

I. INTRODUCTION

One of the major goals of Jefferson Laboratory (JLab) is to explore and study the interface between the nucleonic picture of the strong interaction and the partonic one. Although the standard nuclear models are successful in reproducing the overall picture of hadrons interacting at large distances, and QCD is convincing in the description of the quarks interacting weakly at short distances (Perturbative QCD), the physics connecting the two regimes is almost non existent. When probing distances comparable to those separating the quarks, classical nuclear physics should break down at some point. The nucleonic picture can describe many features of the strong interaction, even if naively we do not expect so. The alternative is to look for the onset of experimentally accessible phenomena considered as a direct consequence of QCD. Color transparency (CT) could be an important candidate. Its basic concepts imply that in exclusive hard processes at large momentum transfer (Q), the hadron has more chance to escape intact from a nuclear target if its wave-function fluctuates into a configuration which contains only valence quarks with small transverse separation. This small size object should lead to a vanishing absorption when it propagates through the nucleus. In this proposal, we aim to look for the onset of such a phenomenon which represents a promising tool to study the dynamics of bound states in QCD and thereby help to build a detailed picture of photon and electron interactions with nuclei at intermediate energies.

We propose to measure the Q^2 dependence of the nuclear transparency ratio in the incoherent diffrative ρ^0 electroproduction on carbon and copper, for fixed coherence lengths $l_c = 0.5$ and 1.2 fm. Both the electron beam at 6 GeV and the photon beam at about 2 GeV are proposed to be used. The Q^2 range is up to 4 GeV^2. Measurable effects of about 40% are predicted for the covered Q^2 region. The proposed experiment seeks to measure the nuclear

transparency of the ρ^0 meson with 2% to 10% uncertainties, dominated by systematics in the low Q^2 region and by statistics at high Q^2.

II. PHYSICS MOTIVATIONS

The color transparency phenomenon illustrates the power of exclusive reactions to isolate simple elementary quark configurations. For a hard exclusive reaction such as vector meson electroproduction on the nucleon, the scattering amplitude at large momentum transfer is suppressed by powers of Q^2 if the hadron (vector meson) contains more than the minimal number of constituents. This is derived from the QCD based quark counting rules. Thus, the hadron containing only valence quarks participates in the scattering. Moreover, each quark, connected to another one by a hard gluon exchange carrying momentum of order Q, should be found within a distance of order $1/Q$. Therefore, at large Q^2 one selects a very special quark configuration where all connected quarks are close together, forming a small size color neutral configuration called *mini hadron* or *Point Like Configuration* (PLC). During a formation time τ_f, the *mini hadron* evolves to a normal hadron. Such a color singlet object is unable to emit or absorb soft gluons. Therefore, its strong interaction with the other nucleons becomes significantly reduced, and then the nuclear medium becomes more transparent. Consequently, the signature of CT is an increase in the nuclear transparency with increasing hardness of the reaction. The nuclear transparency T_A is defined as the ratio of the measured exclusive cross section to the cross section in absence of initial and final state interaction (ISI and FSI). It can be measured by taking the ratio of nuclear per-nucleon (σ_A/A) to free nucleon (σ_N) cross sections :

$$T_A = \frac{\sigma_A}{A\sigma_N}. \tag{1}$$

A number of experiments have searched for an increase in the nuclear transparency. Unfortunately only few of them were able to claim confirmation of CT. The first experiment to investigate CT was performed by Carroll *et al.* [1] at Brookhaven National Laboratory. Quasielastic (p,2p) scattering from each of several nuclei was compared to pp elastic scattering in hydrogen at incident proton momenta of 6, 10, and 12 GeV/c. Its results do not support a monotonic increase in transparency with Q^2 as predicted by CT: the transparency increases for Q^2 from 3 to 8 GeV^2, but then decreases for higher Q^2, up to 11 GeV^2. This subsequent decrease was explained as a consequence of soft processes that interfere with pertubative QCD in free pp scattering but are suppressed in the nuclear medium [3]. Due to the simplicity of the elementary electron-proton interaction compared to proton-proton one, the quasi-free A(e,e'p) reaction was suggested as a tool [2-5] for CT studies. Unfortunately, both the SLAC [6] and JLab [7,8]

experiments failed to produce evidence of CT even for the Q^2 values as large as 8 GeV^2. The most clear signal was observed in the data from the E791 experiment [9] at Fermilab. The A-dependence of the diffractive dissociation into di-jets of 500 GeV/c pions scattering coherently from carbon and platinum targets was measured. It was found that the cross-section can be parametrized as $\sigma = \sigma_0 A^\alpha$, with $\alpha = 1.6$. This result is inconsistent with theoretical calculations [9-11] including CT effects and is also inconsistent with a cross-section proportional to $A^{2/3}$ which is typical of inclusive π-nucleus interactions. Another Fermilab experiment, E665 [13] reported interesting indications of CT using a 470 (GeV/c) muon beam. Exclusive diffractive ρ-meson production from nuclear targets was used to determine the nuclear transparency. The increase of the nuclear transparency with Q^2 was only suggestive of CT because the statistical precision of the data was not sufficient.

CT effects at moderate energies are more problematic than they are at high energies. One should deal in this case with other mechanisms that contain no explicit QCD dynamics and which may mock the CT signal. The experimental studies of CT were mainly focused on the quasi-elastic electron scattering (e,e'p) process. Inelastic corrections could mock [14] the CT signal. The existence of such processes was confirmed by the measurements of the total cross sections of neutron [15] and neutral K-meson [16] interactions with nuclei. Due to these inelastic corrections, the cross-section is smaller, i.e. the nuclear medium is more transparent than is expected by the Glauber approximation. This effect increases with the ejectile energy. Thus, it will also increase with Q^2 because the energy $\nu = Q^2/2m_N$ and Q^2 are correlated in the quasi-elastic peak. The first order inelastic corrections has been estimated in Ref. [14]. It was found that the growth of nuclear transparency with Q^2 in quasi-elastic electron scattering off nuclei can imitate the onset of CT up to $Q^2 \sim 20$ GeV^2.

Exclusive incoherent electroproduction of vector mesons off nuclei has been also suggested [17] as a sensitive way to detect CT. In these processes, a fluctuation of the virtual photon gives rise to a quark-antiquark ($q\overline{q}$) pair that travels through the nuclear medium evolving from the initial state, with Q^2 dependent size (the transverse size of the hadronic fluctuation is $r_\perp \sim 1/Q$), to develop the vector meson detected in the final state. The hadronic structure of high energy photons was realized back in the 1960's (for review see [18]). In the laboratory frame, the photon fluctuation can propagate over a distance l_c known as the *coherence length* . Coherence length can be estimated relying on the uncertainty principle and Lorentz time dilatation as : $l_c = 2\nu/(Q^2 + M^2_{q\overline{q}})$, where ν is the energy of the photon in the laboratory frame, $-Q^2$ is its squared mass and $M_{q\overline{q}}$ is the mass of the ($q\overline{q}$) pair. Therefore increasing the photon virtuality Q^2, one can squeeze the size of the produced ($q\overline{q}$) wave packet.

The small size colorless hadronic system will then propagate through the nuclear medium with little attenuation.

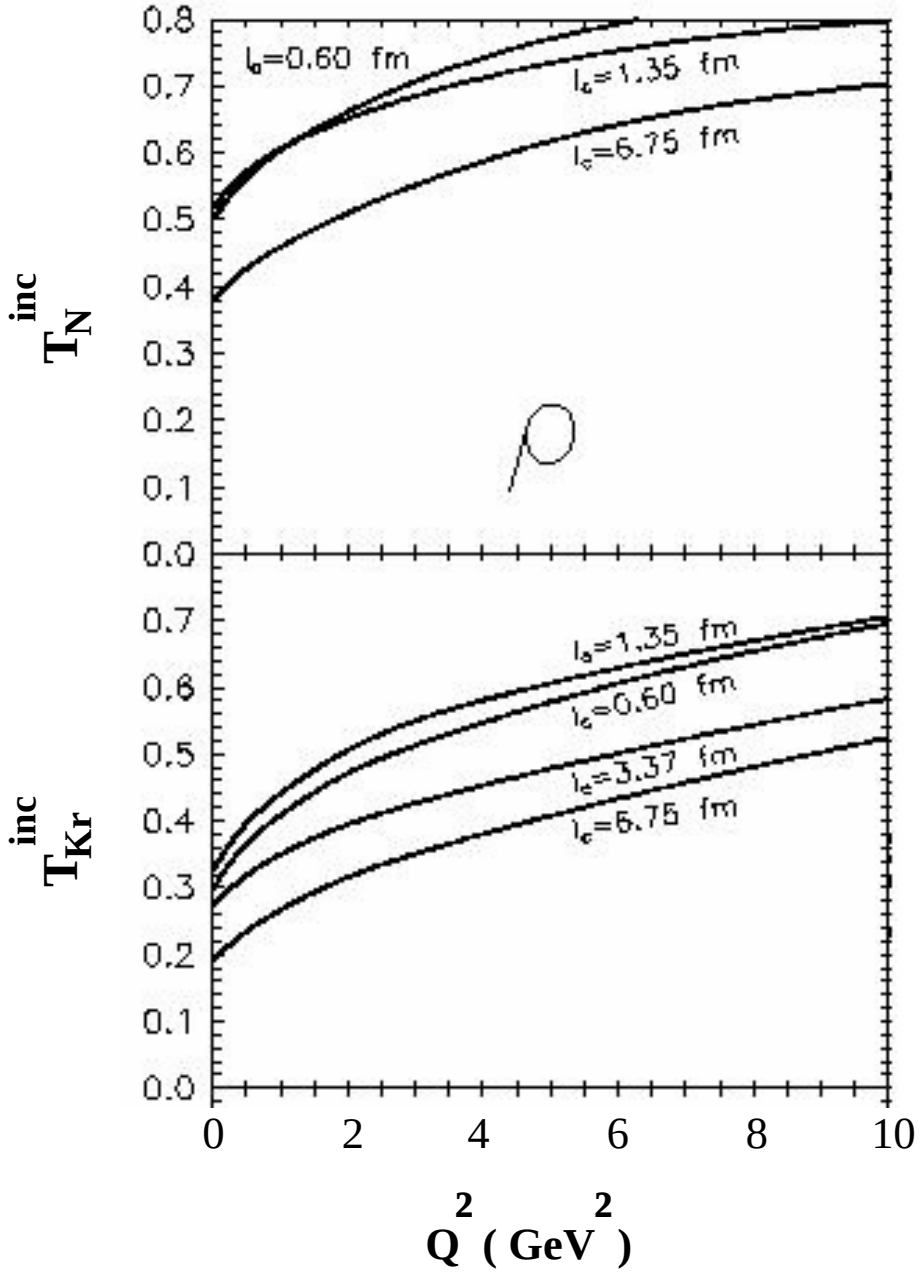

FIG. 1. Q^2 dependence of the nuclear transparency for exclusive ρ electroproduction on nuclear targets ^{14}N and ^{84}Kr. The CL is fixed at l_c = 0.6, 1.35, 3.37 and 6.75 fm.

The effect of the nuclear medium on the particles in the initial and final states can be characterized by the nuclear transparency. Our ultimate goal is searching for a rise of T_A with Q^2 as a signal for the onset of CT. However, one has to be very careful about all the other effects that can imitate this signal. Indeed, the HERMES experiment [19] has shown that T_A increases when l_c varies from long to short compared to the size of the nucleus. This is due to the fact

that the nuclear medium seen by the $(q\overline{q})$ pair becomes shorter. Thus the $(q\overline{q})$ interacts less. This situation occurs when Q^2 increases at fixed ν. This so called *coherence length effect* (CL) must be under control to avoid mixing it with the CT effect.

We propose to measure the nuclear transparency for exclusive incoherent ρ^0 electroproduction on ^1H, ^{12}C, and ^{63}Cu targets up to Q^2= 4 GeV^2 and for fixed l_c values; l_c = 0.5 fm and l_c = 1.2 fm. Binning the data in a way which keeps l_c constant represents a simple prescription to eliminate the CL effect from the Q^2 dependence of the nuclear transparency. Moreover, because the chosen values of l_c are shorter than the mean free path of the vector meson in the nuclear medium, it is obvious that there is no nuclear shadowing in the initial state. By isolating the CL effects, the Glauber model predicts no variation of T_A with Q^2.

Following a recent work by Kopeliovich and collaborators [20], an important increase of the nuclear transparency with Q^2 is predicted as a signal of the onset of CT. The suggested reaction is exclusive incoherent ρ^0 electroproduction on nuclei for fixed l_c values. The authors have developed a quantum mechanical approach based on the light cone QCD Green function formalism. This formalism naturally incorporates the interference between the CL effect (ISI) and CT effect (FSI). Due to quark-hadron duality, it becomes equivalent to the full multichannel problem in the hadronic presentation. These calculations succeed in describing the coherence length dependence of the nuclear transparency reported by the HERMES collaboration [19] and are in good agreement with the FNAL F665 measurements [13].

In Fig.1, we show the predicted nuclear transparency [20] ratio as a function of Q^2 for incoherent ρ electroproduction on nitrogen and krypton at fixed l_c values. As one can see, we would obtain a measurable effect of at least 30% for the Q^2 range up to 4 GeV^2. The proposed measurements can detect these large effects without ambiguity if they exist. It is the first time where dedicated l_c = *constant* measurements are proposed. Such an experiment is important to disentangle the CL effect from an eventual onset of the CT. If the proposed measurements confirm the predicted effect, it will be important to study the kinematic conditions that exclusive vector meson electroproduction is dominated by the contribution of small size configurations. In any case these measurements are important to understand the dynamics of the vector meson production in the nuclear medium and to study the microscopic structure of hadrons where color effects probably have an important role.

III. THE EXPERIMENT

We propose to measure the nuclear transparency ratio, $T_A = \sigma_A/A\sigma_N$, for incoherent ρ^0 electroproduction on different nuclear targets (A) as a function of Q^2.

In the next section (III.A), we describe the reaction and the kinematics that will be used to study the nuclear transparency. The estimated count rates considering the acceptance of the CLAS detector will be presented in section (III.B), and the expected measurements with statistical errors in section (III.C).

A. Kinematics

The schematic of the reaction is given in Figure 2 : The incident electron scatters off the target nucleus and exchanges a virtual photon. The photon interacts with one of the nucleons inside the nucleus and eventually produces a ρ^0 meson. The ρ^0 decays into two pions.

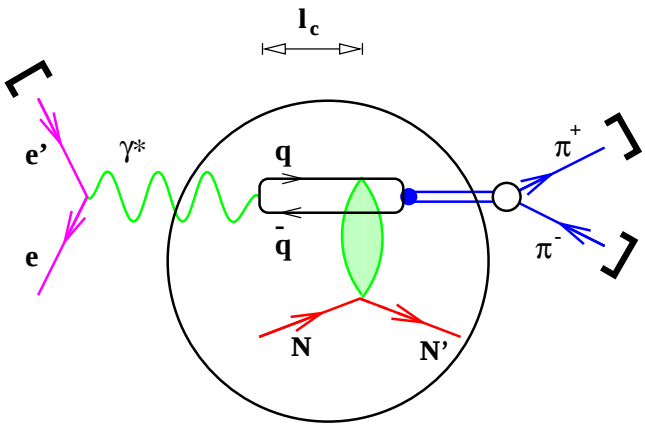

FIG. 2. Exclusive leptoproduction of the ρ^0 meson.

We propose to perform these measurements at Hall B with an electron beam of 6 GeV and three targets : hydrogen, carbon, and copper at maximum luminosity ($5 \times 10^{33} cm^{-2} s^{-1}$). The scattered electron will be detected to determine Q^2. The coincident detection of the two pions will allow the identification of ρ^0 particles using their reconstructed invariant mass. We also propose to measure ρ^0 photoproduction to complete our measurements with a point at $Q^2 = 0$. For this purpose, a tagged photon beam of 1.7 to 2.2 GeV at maximum flux ($5 \times 10^7 \gamma/s$) will be used on the same set of targets.

Since the coherence length effect can imitate the color transparency effect, we will study the Q^2 dependence of T_A at fixed l_c values. Although our measurements will cover a coherence length range from 0.3 to 1.5 fm, none of the l_c values covers the whole range in Q^2 (0 - 4 GeV^2). To do so, we need to consider at least two values of the coherence length : $l_c = 0.5$ fm that covers high Q^2 region (1 - 3.5 GeV^2) with reasonable count rates, and $l_c = 1.2$ fm dictated by

the point at $Q^2 = 0$ to be measured by photoproduction and covers Q^2 from 0.5 to 1 GeV^2 if we add the corresponding electroproduction measurements. The theoretical work in ref. [20] shows (Fig.5) that the two transparency curves calculated for $l_c = 0.5$ fm and $l_c = 1.2$ fm have almost the same starting point at $Q^2 = 0$. Therefore, the point at $Q^2 = 0$ and $l_c = 1.2$ fm can be exploited to have an idea about the point at $Q^2 = 0$ and $l_c = 0.5$ fm. Bins in l_c are 0.1 fm wide centered at 0.5 and 1.2 fm. For $l_c = 0.5$ fm, six Q^2 bins are considered, 0.5 GeV^2 wide each centered at 1, 1.5, 2, 2.5, 3 and 3.5 GeV^2. For $l_c = 1.2$ fm, three 0.2 GeV^2 wide Q^2 bins centered at 0.5, 0.7 and 0.9 GeV^2 are considered.

B. Acceptance and count rates

A new event generator of ρ^0 electroproduction from both protons and nuclear targets has been implemented. The three independent kinematical variables : W, Q^2 and the momentum transfer, t, are generated according to their experimental distributions. W and Q^2 are generated according to the flux of virtual photons $\Gamma(W, Q^2)$ exchanged between the incident electron and the target :

$$\Gamma(Q^2, W) = \frac{\alpha}{8\pi^2} \times \frac{W}{ME^2} \times \frac{W^2 - M^2}{MQ^2} \times \frac{1}{1-\epsilon}, \tag{2}$$

where M is the mass of the target. E and E' are repectively the energies of incident and scattered electrons, $\nu = E - E'$ is the energy of the virtual photon, and $\epsilon = [1 + 2(Q^2 + \nu^2)/(4EE' - Q^2)]^{-1}$ is its polarization. The momentum transfer, t, is generated according to the experimental differential cross section $\frac{d\sigma}{dt}$ reported in ref. [21] and fitted to the exponential form :

$$\frac{d\sigma}{dt'} = A \exp(-b(W, Q^2) \times t'), \tag{3}$$

where $t' = |t - t_{min}|$, and t_{min} is the minimum value of t. The values of the slope $b(W, Q^2)$ measured for different W and Q^2 bins have been considered.

For nuclear targets, the Fermi momentum of nucleons inside the nucleus is also considered. The momentum of the struck nucleon is generated inside the corresponding Fermi momentum sphere of radius P_F . Experimental values of P_F [22] have been used. The generator considers also the decay of ρ^0 into a pair of pions $\pi^+\pi^-$. Pion angles are generated assuming s-channel helicity conservation.

Using the generator's output as input to the fast simulation code of the CLAS detector, FASTMC [23] and taking the CLAS torus magnetic field at half its maximum value, we have been able to study the acceptance and efficiency

of CLAS to detect the three particles : the scattered electron, and the ρ^0 decay pions $\pi^+\pi^-$. Before studying the acceptance, the following kinematical cuts have been applied to select useful events for our study :

1. W > 2 GeV, to avoid the resonance region,

2. $z = \frac{E_\rho}{\nu} > 0.8$, to select the elastic process,

3. -t < 0.6 GeV^2, to select the diffractive process,

4. -t > 0.1 GeV^2, to exclude coherent production on nuclear targets (not applied for hydrogen target).

The acceptance for a given (l_c, Q^2) bin is calculated by :

$$Acc(l_c, Q^2) = \frac{N_{acc}(l_c, Q^2)}{N_{gen}(l_c, Q^2)}, \tag{4}$$

where N_{gen} and N_{acc} are respectively the number of generated and accepted events belonging to this (l_c, Q^2) bin.

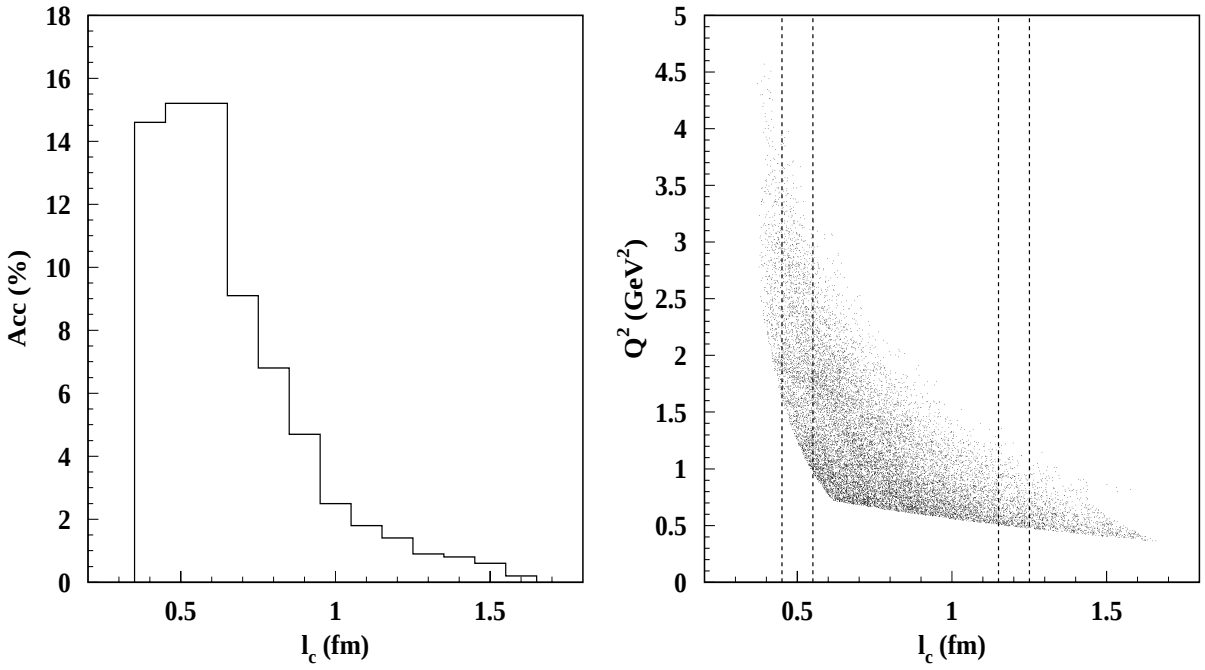

FIG. 3. Left : Acceptance for different bins in l_c. Right : $l_c - Q^2$ correlation and selected l_c bins.

Both CLAS acceptance for different l_c bins (left graph) and $l_c - Q^2$ correlation (right graph) are shown in Figure 3.

Using the output of FASTMC and ρ^0 electroproduction cross sections, $\sigma(W, Q^2)$, measured on hydrogen [21], we have been able to estimate count rates for the chosen bins in l_c and Q^2.

For nuclear targets, in addition to the Fermi momentum considered in the generator, both the nuclear transparency of the nucleus to ρ^0 and the absorption of its decay pions inside the nucleus have to be taken into account in the estimation of the count rates. To consider the transparency, the values of the cross sections are scaled by the corresponding value of the transparency T_A. The loss of the decay pions by interaction inside the nucleus has been estimated using the intranuclear cascade model ISABEL [24] (see section (IV.B) for details). We have used a run time of 9 days on each target to have reasonable statistical accuracy at high Q^2. For the point at $Q^2 = 0$, using the ρ^0 photoproduction cross section on hydrogen measured by Eisenberg *et al* [25], one day of 1.7-2.2 GeV photon beam on each target gives sufficient statistics. The following tables summarize the expected statistical uncertainties on the number of ρ^0 particles to be detected for $l_c = 0.5$ fm and $l_c = 1.2$ fm at different Q^2 bins.

Target \ Q^2 (GeV^2)	1.0 ± 0.25	1.5 ± 0.25	2.0 ± 0.25	2.5 ± 0.25	3.0 ± 0.25	3.5 ± 0.25
Hydrogen	1%	1%	2%	3%	4%	8%
Carbon	1%	2%	2%	3%	5%	9%
Copper	2%	2%	3%	4%	7%	13%

Table 1 : statistical errors expected for $l_c = 0.5$ fm and different bins in Q^2(2 - 4 GeV^2).

Target \ Q^2 (GeV^2)	0.0 ± 0.0	0.5 ± 0.1	0.7 ± 0.1	0.9 ± 0.1
Hydrogen	< 1 %	2%	2%	2%
Carbon	< 1%	3%	3%	4%
Copper	< 1%	2%	2%	3%

Table 2 : statistical errors expected for $l_c = 1.2$ fm and different bins in Q^2(2 - 4 GeV^2).

Target \ Q^2 (GeV^2)	2.0 ± 0.25	2.5 ± 0.25	3.0 ± 0.25	3.5 ± 0.25	4.0 ± 0.25
Hydrogen	2%	3%	4%	5%	8%
Carbon	3%	3%	4%	5%	9%
Copper	3%	4%	5%	6%	10%

Table 3 : statistical errors expected for $l_c = 0.4$ fm and different bins in Q^2(2 - 4 GeV^2).

The bin centered at $l_c = 0.4$ fm has been added to reach a value of $Q^2 \sim 4$ GeV^2. Since nuclear transparency shows no significant difference between $l_c = 0.4$ fm and $l_c = 0.5$ fm, it is quite probable that they will be combined into the same bin. In this study, we only estimated the background coming from the nuclear reactions using the cascade code ISABEL. We found this background to be negligible. Other sources of background include combinatorial and high mass meson production. Indeed, CLAS data corresponding to 4.45 GeV electron beam on carbon target has been analyzed. The $\pi^+\pi^-$ invariant mass has been reconstructed as shown in Figure 4. This graph illustrates the effect of both z and t cuts on the reconstructed ρ^0 mass. The ρ^0 signal is quite clean. The proposed z and t cuts appear to be reasonable. For the background substraction, well established fit procedures exist [25-29]. One can combine a few of them (Gaussian, Breit-Wigner, and phenomenological models) and obtain a good confidence in the extraction procedure and the corresponding systematic errors. The contribution of the $\pi^+\pi^-$ pairs of the $\omega(782)$ resonance to the ρ signal is expected to be small due to its 2 % decay branch to $\pi^+\pi^-$. Background from higher mass resonances are suppressed by the cut on t [26].

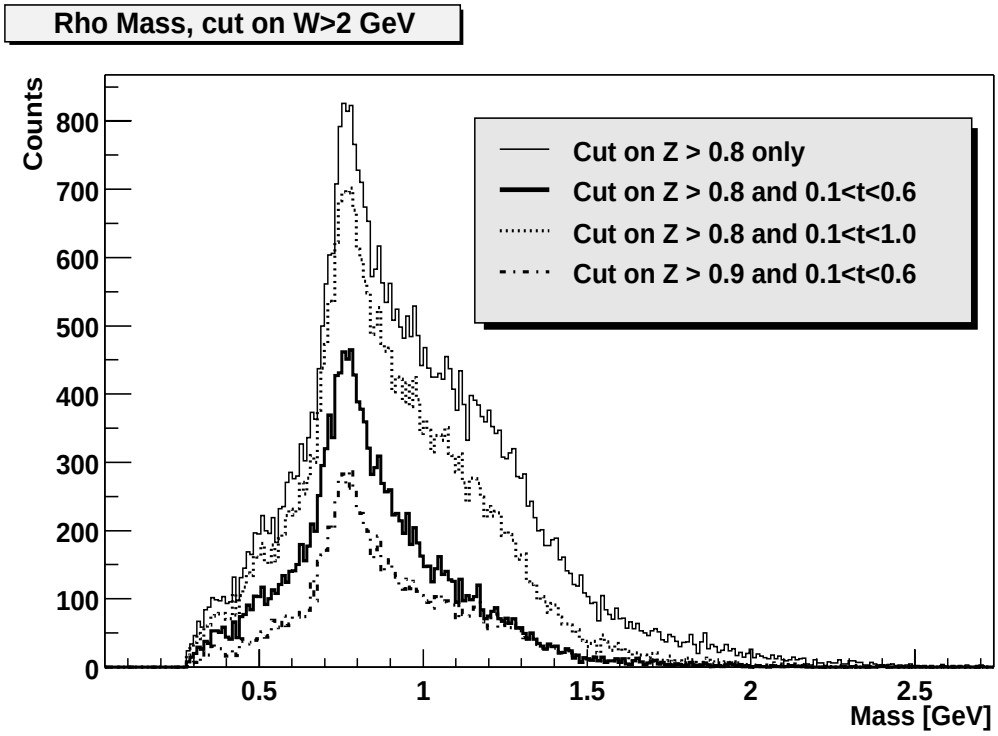

FIG. 4. Reconstructed invariant mass of the ρ^0 decay pions using CLAS data of 4 GeV electron beam on carbon.

C. Expected results

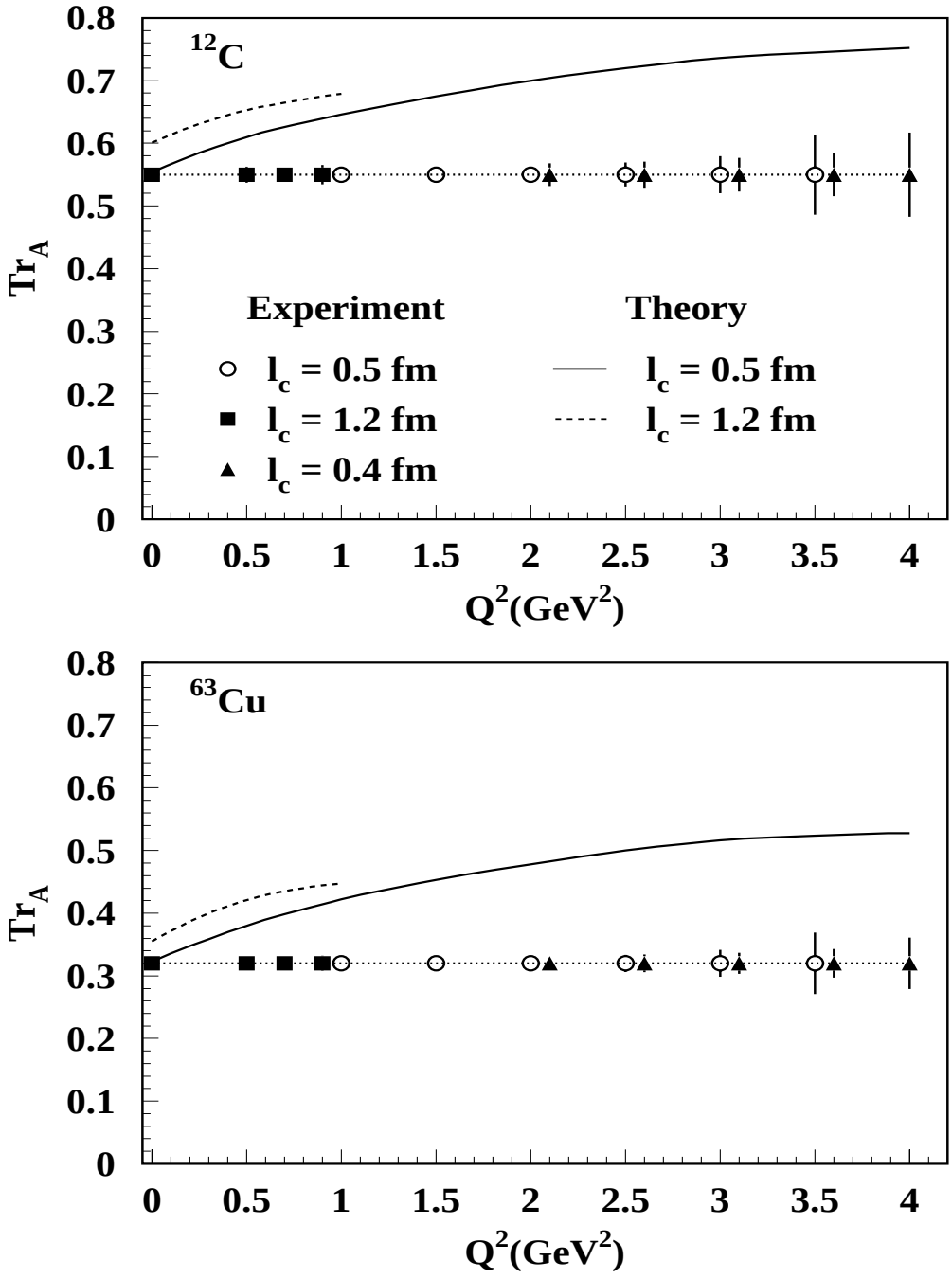

FIG. 5. Expected error bars for the proposed measurements and predictions of [19].

From the estimated count rates, the statistical error on the nuclear transparency T_A varies from 2% (low Q^2) to 9% (high Q^2) for carbon and from 2% to 13% for copper, see Tables 1-3. Sources of systematic errors will be discussed in

the next section. The projected measurements at the proposed values of l_c are presented in Figure 5. We must recall that data with all possible values of l_c, Q^2 and t will be taken at the same time and can eventually be used. Curves are the expectations of Ref. [20]. They show a CT effect on the value of T_A at $Q^2 \sim 4$ GeV^2 of 35% for carbon and 65% for copper, meanwhile Glauber predicts no Q^2 dependence of CT.

IV. THEORETICAL CORRECTIONS

There are two effects that can interfere with the CT signal even if l_c is fixed. First, the inelastic process that produces an excited state of the ρ meson instead of its ground state and second the absorption of the decay pions inside the nucleus due to the finiteness of the ρ^0 lifetime. The first effect has been investigated in Ref. [20] (see section (IV.A)). For the second, we have used an intranuclear cascade model to estimate both the absorption of the decay pions and the change of the ρ reconstructed invariant mass shape due to the interaction of its decay pions in the nuclear medium.

A. Inelastic correction

The incident virtual photon produces diffractively on a bound nucleon either the ground state or any excitation of the vector meson. The produced excited states can eventually decay to the ground state while propagating through the nucleus which increases the number of detected vector mesons and consequently the nuclear transparency. It has been shown [20] that this effect increases with the photon energy ν (Q^2 since l_c is fixed) but it is too weak to be confused with the signal of CT. The values of this correction and the corresponding errors for both carbon and copper are presented in the following table.

Target	Inelastic correction	Error
carbon	0-6%	0-2%
copper	0-10%	0-3%

Table 4 : Inelastic corrections and the corresponding errors.

Lower limits in this table correspond to low Q^2 and upper limits to high Q^2. Errors are estimated assuming a 30% error on the theoretical calculations.

B. Nuclear Effects

There are two contributions that are included in our study of the nuclear effects. The absorption of the ρ^0 decay pions inside the nucleus and the modification of their invariant mass due to their interaction in the nuclear medium.

To consider the absorption of ρ^0 decay pions inside the nucleus, we have used the intranuclear cascade model ISABEL [24]. ISABEL uses experimental nucleon-nucleon and π-nucleon cross sections and angular distributions and can simulate N-A and π-A interactions. First, using the decay length of produced ρ^0 particles, we have determined the proportion of events where the ρ^0 decays inside the nucleus. Then, for these events, each of the decay pions is sent as projectile on the nucleus where it generates an intranuclear cascade. The effect of the pion absorption in copper is shown in Fig.6. The proportion of absorbed ρ^0 decreases with Q^2 because higher Q^2 corresponds to more energetic decay pions to which the nucleus is more transparent. For example, 5 % at low Q^2 against only 1% at high Q^2 are absorbed on carbon. The following table summarizes the result of these calculations for both carbon and copper.

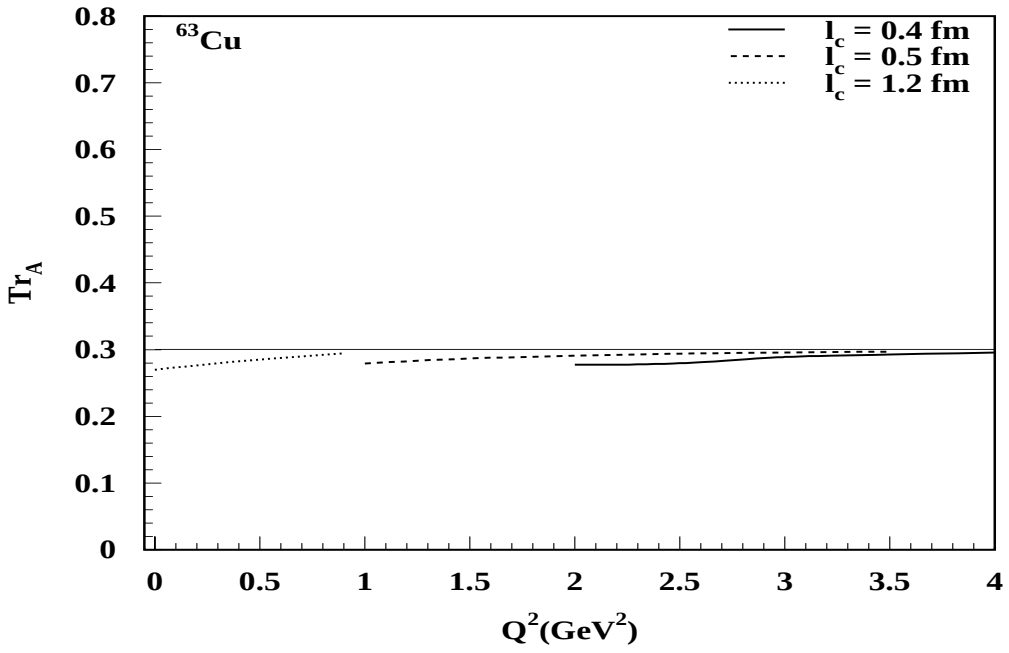

FIG. 6. Nuclear absorption effect on the nuclear transparency for copper.

Target	ρ^0 decay inside	$\pi^+\pi^-$ absorbed	Error
Carbon	10-25 %	1-5%	1-2%
Copper	15-40%	2-10%	1-4%

Table 5 : Nuclear absorption effect and the corresponding errors.

Lower limits in this table correspond to high Q^2 and upper limits to low Q^2. Errors are estimated assuming a 30% error on the result of ISABEL.

We used the same code as for the nuclear absorption to study the influence of the nuclear medium on the reconstructed $\pi^+\pi^-$ invariant mass. As one can see from Fig.7, the effect of the pions energy and angular straggling in the nuclear medium does not affect the shape of the reconstructed ρ^0 mass.

Combining the errors coming from the inelastic correction and the nuclear absorption, the total systematic error is about 3% for carbon and 5 % for copper at high Q^2 and less at lower Q^2. Errors coming from differences in CLAS acceptances and the shape of background for different targets are expected to cancel in the ratio of cross sections that produce T_A.

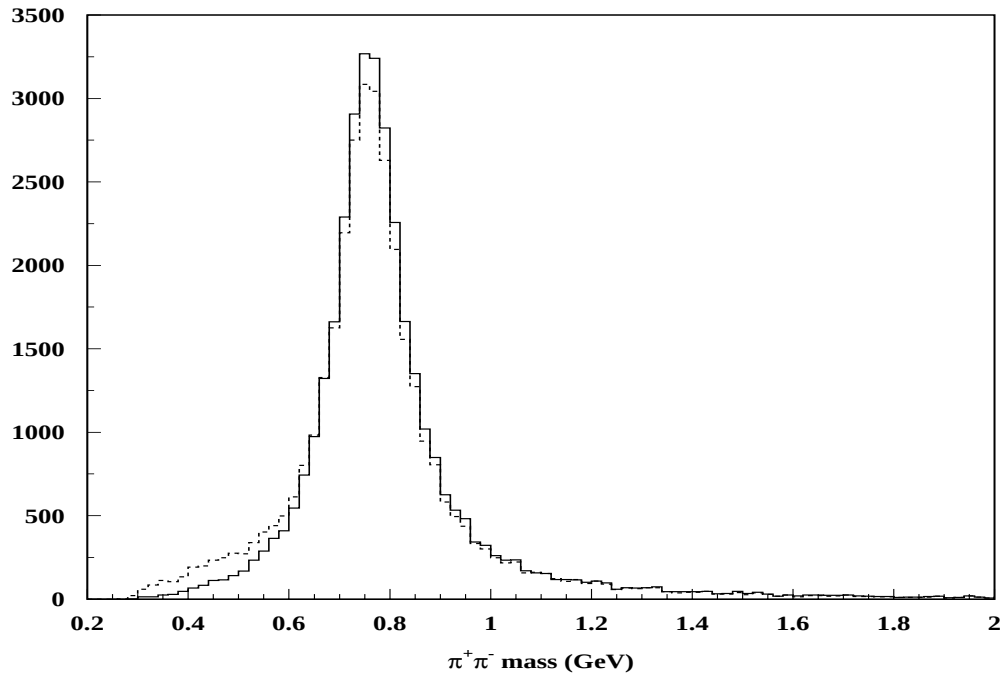

FIG. 7. The solid curve is the initial reconstructed invariant mass of the ρ^0 decay pions. The dashed curve is their reconstruted mass after they left the copper target.

V. BEAM REQUEST

The total beam time requested for these measurements is 720 hours or 30 days. 648 hours with a 6 GeV electron beam and 72 hours with 1.7-2.2 GeV photon beam. This time is for data taking only and does not include calibration time. The efficiency of both the accelerator and CLAS are assumed to be 100%.

Target \ Q^2 (GeV^2)	photon beam	electron beam
Hydrogen	24h	216h
Carbon	24h	216h
Copper	24h	216h

Table 6 : Photon and electron beam time requested on each target.

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