Study of Color Transparency in Exclusive Vector Meson Electroproduction off Nuclei Experiment PR12-06-106

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Introduction

In 2006, PAC-30 approved the PR12-06-106[a] experiment. Since then, there have been new developments. They consist of published results from Hall C Color Transparency (CT) studies for positive pions (E-01-107) and the final results of Hall B for ρ^0 mesons (E-02-110), in addition to significant progress on the theoretical side. We also updated the rates using the latest versions of our event generator and CLAS12 FastMC detector simulation package. Although the new rates do not differ significantly from the older ones, we decided to adopt a new strategy for the beam time request guided by our latest CT results and theoretical developments. There have been no changes in the technical realization of the measurements and only CLAS12 baseline equipments are needed. In this report, we are not going to repeat the information included in the original proposal. We will rather focus on the new developments and refer to the original write-up for details.

Scientific case

CT is a fundamental property of QCD[1]. It illustrates the power of hard (high virtuality of the virtual photon Q^2) exclusive reactions to isolate Point-Like Configurations (PLC) in the hadron wave function[2]. The selected PLC has small transverse size proportional to 1/Q. It acts as a color dipole and therefore interacts in the nuclear medium with a dipole cross-section proportional to its square size. As a result, the PLC is expected to travel through nuclear matter experiencing reduced attenuation due to the cancellation of the color fields of its quarks. CT can be observed experimentally by measuring a reduced attenuation

[a] The original proposal is located in http://www.jlab.org/exp_prog/proposals/06/PR12-06-106.pdf

of particles as they exit a nucleus. For high energies, it is well established. Experimentally, it has been demonstrated[3] in diffractive di-jet production by the E791 collaboration at Fermilab. Theoretically, the CT property of QCD is used routinely in the proof of QCD factorization theorem[4] for deep exclusive meson processes (di-jet production). While at high energies, the PLC propagates in the medium with a frozen small size, at intermediate energies; it starts expanding inside the nucleus. Therefore, CT at intermediate energies offers a unique probe to study the space-time evolution of special configurations of the hadron wave function and their interactions with the nuclear medium. Furthermore, the onset of CT is a necessary condition for factorization[5], which is an important requirement for accessing Generalized Parton Distributions in deep exclusive meson production. Recently, CT was suggested[6] as responsible for one of the most surprising results observed at RHIC[7], namely the anomalous increase of the ratio of proton-to-pion produced at large transverse momenta with the centrality of the collision.

More than twenty years of experimental efforts invested in the CT studies were not sufficient to unravel all the secrets of this elusive phenomenon. While the searches in the baryon sector were deceiving, the results for mesons have been very promising. Since PAC-30, pion CT results from Hall C experiment E-01-107 have been published[8]. Quasi-elastic pion electroproduction (e, e' π^+) on ^{1}H, ^{2}H, ^{12}C, ^{27}Al, ^{64}Cu and ^{197}Au was used to measure the pion transparency over a Q^2 range from 1.1 to 4.7 GeV^2. The results show an increase of the nuclear transparency with Q^2 in qualitative agreement with models including CT effects[9,10]. Exclusive diffractive electroproduction of ρ^0 vector meson provides a tool of choice to study CT. The PLC is directly produced from the virtual photon since both are vector particles. However, one has to keep the coherence length effect[11] under control because it can mimic the CT signal. This could be achieved by either looking at the Q^2 dependence of the nuclear transparency for fixed coherence length[b] (l_c) or making the measurements at small coherence lengths

[b] The coherence length can be estimated relying on the uncertainty principle and Lorentz time dilatation as $l_c = 2\nu/(Q^2 + M^2)$ where in our case M is the mass of the ρ^0

compared to the nuclear radius. When the coherence length is small, the initial state is dominated by electromagnetic interactions instead of hadronic ones, which dominate for intermediate coherence length values. Previous measurements by E665[12] collaboration at Fermilab and HERMES[13] collaboration at DESY were also suggestive of CT however they lacked statistical precision. CLAS measurements, which used 5 GeV electron beam on ^{2}H, ^{12}C and ^{56}Fe targets show as expected that the nuclear transparency ratio (^{2}H is used for normalization instead of ^{1}H) is independent of the coherence length due to the small values of the coherence length (see Figure 1). However, the nuclear transparency ratio was found to significantly increase with Q^2 for ^{56}Fe while the increase for

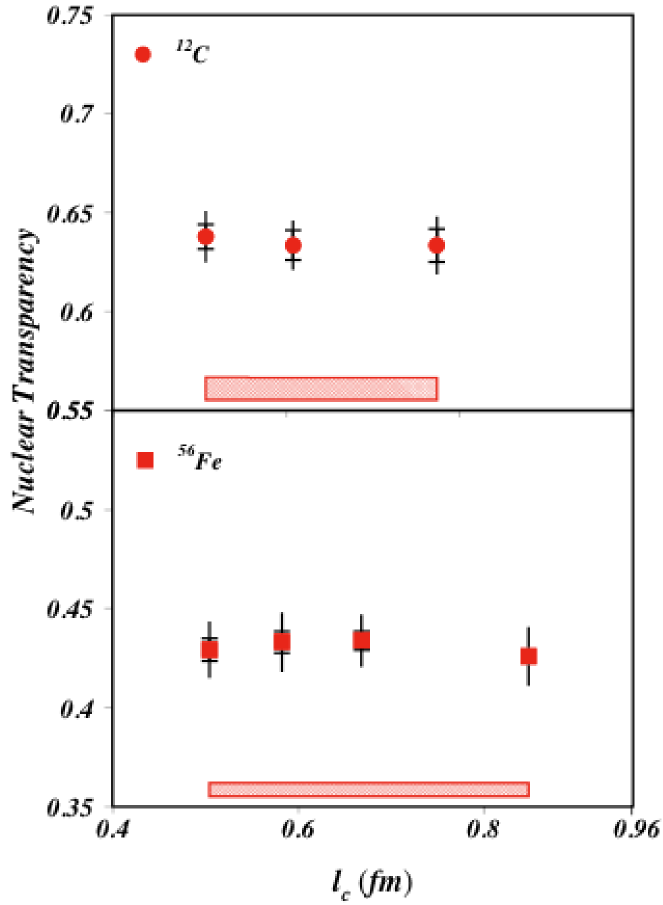

Figure 1: The nuclear transparency as function of the coherence length for C (top) and Fe (bottom). The inner error bars are the statistical uncertainties and the outer error bars are the statistical and point-to-point systematic uncertainties added in quadrature. The bands in the bottom are the normalization errors.

^{12}C is less pronounced (see Figure 2) due probably to the magnitude of CT effect itself. The present results differ significantly from the preliminary results (see figure 5 of the proposal[a]) presented to PAC-30 because the latter were missing several corrections. The dramatic increase of the nuclear transparency found previously was mainly due to acceptance effects created by 4 cm distance between deuterium and the solid target. This dramatic effect is due to our small t cut dictated by our selection of the diffractive process. At last, we decided to not correct for the effect of the ρ^0 decaying inside the nucleus and subsequent pion absorption in order to exclude any model dependence off our results. This task is left to the theoretical models. The transparency ratio for both ^{12}C and ^{56}Fe is found to be compatible with a model calculation by Frankfurt, Miller and Strikman (FMS[14]) including both the effect of ρ^0 decay and color transparency. One should mention that a twin model[9] based on similar ingredients succeeded in describing the Hall C pion transparency. FMS model

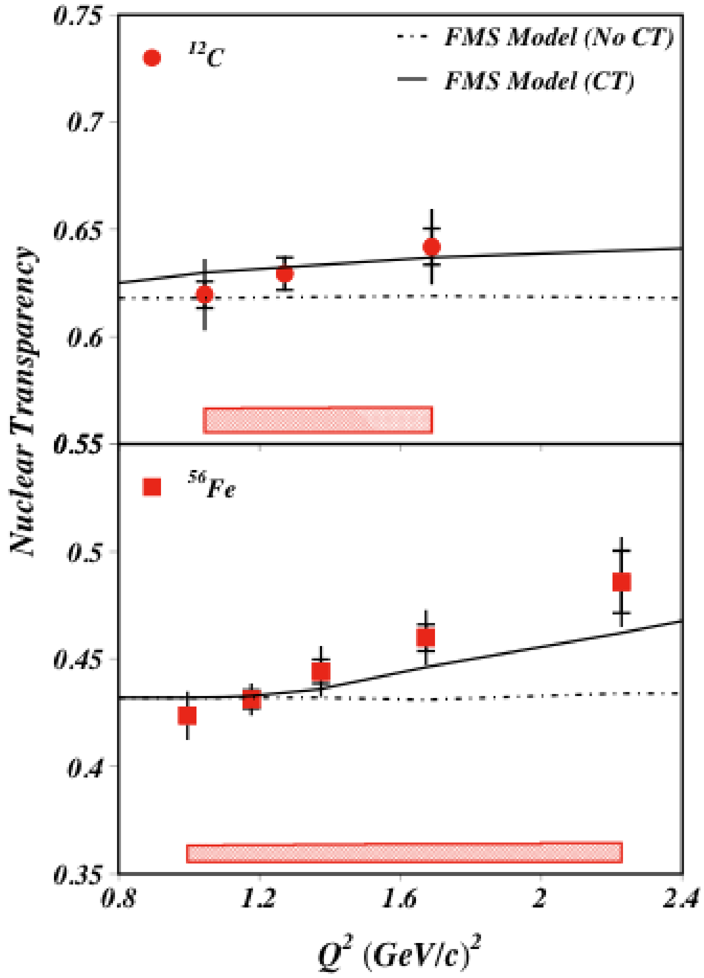

Figure 2: The nuclear transparency as function of Q^2 for C (top) and Fe (bottom). The inner error bars are the statistical uncertainties and the outer error bars are the statistical and point-to-point systematic uncertainties added in quadrature. The bands in the bottom are the normalization errors. The curves are predictions of the FMS model with (solid curves) and without (dashed curves) CT effects.

provides a reaction theory for ρ^0 electroproduction tailored to our experimental kinematics. The model derives a treatment of the energy lost by the ρ^0 in each step of multiple scattering that also accounts for the momentum transfer to the nucleus. The effect of CT was included by introducing an effective interaction, which depends on the interaction length. For propagation lengths smaller than the formation length, the interaction of the expanding PLC is taken into account via the quantum diffusion model. In the case where propagation lengths are larger than the formation ones, a typical Glauber-like interaction is used since the hadron is fully formed. The effects of the ρ^0 decay to $\pi^+\pi^-$ inside the nucleus, which can be important at low Q^2, were also included.

Beam time request

In this update, we revisited the beam time request for mainly two reasons. The first reason is that previously the effect of CT predicted by Kopeliovich[15,16] et al was very large. This large effect is ruled out by our 5 GeV results, which are more in agreement with the FMS model predicting somewhat smaller CT effects. The second reason is that our knowledge of systematic uncertainties did improve due to our experience with the 5 GeV data. The beam time request was adjusted so that the statistical uncertainties on the second largest Q^2 points match the expected systematic point-to-point uncertainties.

Targets	^{56}**Fe**		^{12}**C**	
Error type	Point-to-point (%)	Normalization (%)	Point-to-point (%)	Normalization (%)
Kinematical cuts	1.5	0.5	1.5	0.5
Acceptance effect	2	1	1.5	1
Background subtraction	2	0.5	2	0.5
Radiative effect	2	0.5	1.5	0.5
Total error	4	1.4	3.3	1.4

Table 1: Summary of the largest systematic uncertainties for 5 GeV data

Table 1 summarizes the different systematic uncertainties for both ^{12}C and ^{56}Fe obtained for 5 GeV data. They are separated into point-to-point uncertainties (Q^2

dependent) and normalization uncertainties (Q^2 independent). We expect to have similar systematic uncertainties for 11 GeV measurements. The old and new estimations (obtained with updated simulation codes) of the statistical uncertainties based on 8 days for C, 12 days for Fe and 16 days for Sn are given in Table 2.

Q^2(GeV^2) / Targets	1.25±0.25	1.75±0.25	2.25±0.25	2.75±0.25	3.25±0.25	3.75±0.25	4.5±0.5	5.5±0.5
^{12}C (%)	0.8(1.4)	0.7(1)	1(1.2)	1.6(1.7)	2.5(2.4)	3.9(3.5)	4.5(4.3)	9.1(7.5)
^{56}Fe (%)	0.8(1.7)	0.7(1.1)	1(1.4)	1.6(1.8)	2.6(2.6)	4.1(4.1)	4.6(4.5)	9.5(7.8)
^{108}Sn (%)	0.8(1.6)	0.7(1.1)	0.8(1.3)	1.3(1.8)	2.1(2.6)	3.3(4)	4.6(4.5)	9.2(8)

Table 2: Summary of the statistical errors expected for a coherence length bin between 0.4 and 0.5 fm. The values in parenthesis correspond to the quoted uncertainties in the original proposal. The others values are the updated one for 8 days C, 12 days Fe and 16 days Sn.

They are very similar and calculated only for one coherence length bin covering the range from 0.4 to 0.5 fm. The improved statistical uncertainties based on 12 days for C, 16 days for Fe and 24 days for Sn are shown in Table 3.

Q^2(GeV^2) / Targets	1.25±0.25	1.75±0.25	2.25±0.25	2.75±0.25	3.25±0.25	3.75±0.25	4.5±0.5	5.5±0.5
^{12}C (%)	0.6	0.5	0.8	1.2	2	3	3.5	7
^{56}Fe (%)	0.6	0.5	0.8	1.2	2	3.2	3.6	7.4
^{108}Sn (%)	0.6	0.5	0.6	1	1.6	2.4	3.4	6.9

Table 3: Summary of the statistical errors expected for a coherence length bin between 0.4 and 0.5 fm. They correspond to for 12 days C, 16 days Fe and 24 days Sn.

Deuterium is not included since it is used simultaneously with each solid target. We also propose to take 4 days of hydrogen to better control the other processes that contribute to the ρ^0 background. This data is also useful in studying tracking efficiency and momentum smearing. In addition, we would need 4 days on hydrogen at the same position as the solid target to better control the acceptance correction. The beam time is summarized in Table 3.

Targets	Beam Time (days)
^{1}H	8
C	12
Fe	16
Sn	24

Table 3: The beam time requested on each target

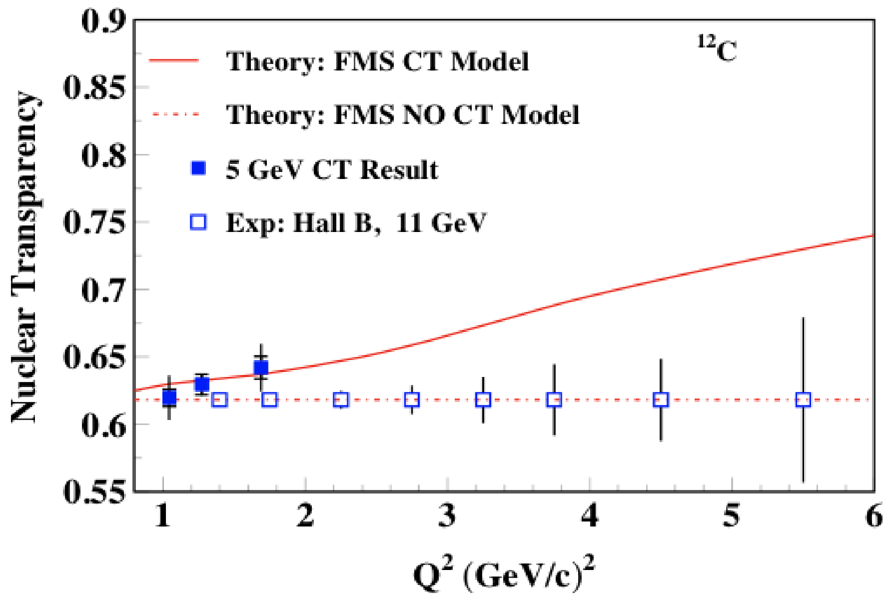

Figure 3: Expected statistical uncertainties for nuclear transparency (^{12}C) for the coherence length between 0.4 and 0.5 fm

Figures 3, 4 and 5 show the projected statistical uncertainties for C, Fe and Sn respectively with predictions from the FMS model. Measurements with different nuclei sizes are important for quantitative understanding of the PLC formation time and its interaction in the nuclear medium.

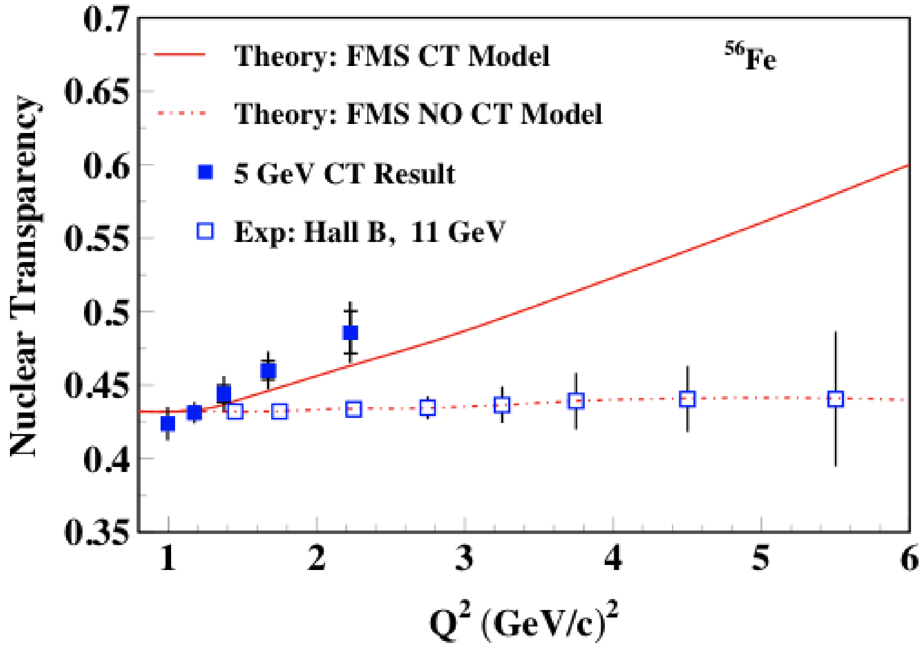

Figure 4: Expected statistical uncertainties for nuclear transparency (^{56}Fe) for the coherence length between 0.4 and 0.5 fm

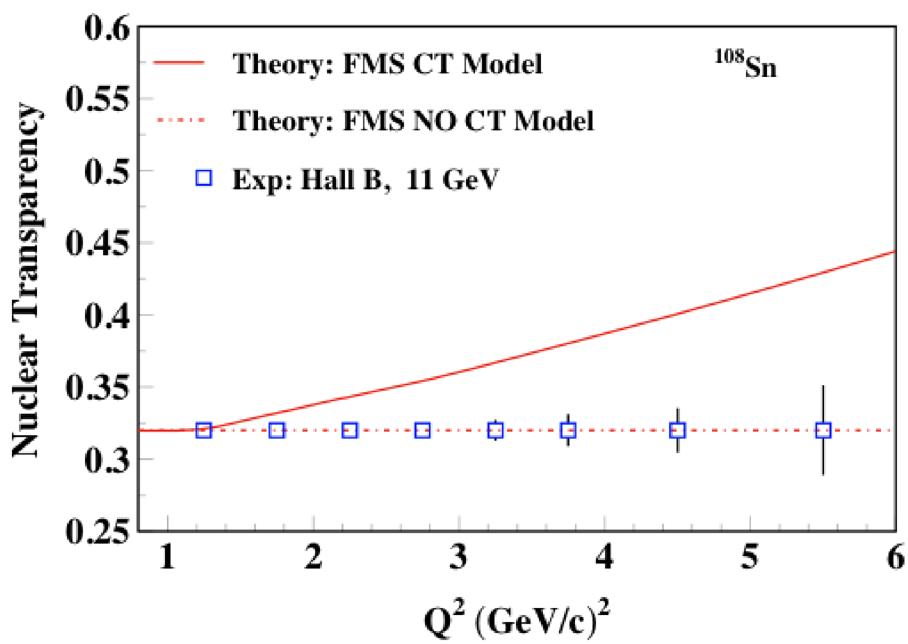

Figure 5: Expected statistical uncertainties for nuclear transparency (^{108}Sn) for the coherence length between 0.4 and 0.5 fm

Summary

Study of CT via vector meson electroproduction is a clean way to access small size configuration in the hadron wave function. CLAS E-02-110 results represent the strongest evidence of the onset of CT at intermediate energies. The next step is to understand quantitatively the PLC formation time and its interaction in the nuclear medium. The proposed measurements with an 11 GeV electron beam are intended to do just that. It will extend the Q^2 range up to 5.5 GeV^2, which will allow for significant increase in the momentum and energy transfer involved in the reaction. Therefore, one expects to produce smaller configurations that live longer: the optimum parameters for CT studies. The measurements on several nuclei with different sizes will allow studying the space-time properties of the PLC during its evolution to a full size hadron. With a total beam time of **60 days**, the experiment is expected to make quantitative studies of a fundamental property of QCD, namely color transparency.

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