Measurement of Nuclear Transparency for the $A(e, e'K^+)$ Reaction

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(Dated: October 3, 2009)

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ABSTRACT

Quantum Chromo Dynamics (QCD) is the fundamental theory of the strong force. The transition from nucleons and mesons to the quarks and gluons of QCD can be studied by looking for the onset of phenomena predicted by QCD, such as Color Transparency (CT). CT is the disappearance of final (initial) state interactions for hadrons produced in exclusive processes at high momentum transfers. An experiment to measure the transparency of pions, in search of CT was completed in Dec 2004 at JLab in Hall C. The same set of data also has a considerable sample of kaons that can be used to study the transparency of kaons. Kaon transparency via electro-production has not been studied before and will provide useful information regarding the nature of the transition from quarks to hadrons. In addition, this data will help us investigate the anomalous strangeness transparency reported for kaon-nucleus scattering data. We will extract the kaon transparency by comparing the electro-production of kaons from various nuclear targets to electro-production from hydrogen which is similar to the technique used to measure pion transparency. Preliminary results from this analysis will be presented.

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I. INTRODUCTION

The nuclear transparency can be difined as

$$T = \frac{\sigma_A}{A\sigma_0}$$

where σ_A denotes the cross-section for different targets and σ_0 denotes the cross-section for Hydrogen.σ_A can be paramaterized in terms of free cross-sectin i.e. σ_0.

$$\sigma_A = \sigma_0 A^\alpha$$

Then, transparency can be written as

$$T = A^{\alpha-1}$$

Experimentally α has a value of 0.72-0.78 for different hadrons like p,K,π
An experiment to measure the transparency of pions, in search of CT was completed in Dec 2004 at JLab in Hall C through the elctro-production of pions by the reaction A(e,$e'\pi^+$). The same set of data also has a considerable sample of kaons that can be used to study the transparency of kaons.
My first job was to seperate kaons from the pions and protons by applying different Particle Identification (PID).

II. EXPERIMENT

We report the first measurement of the nucleon number, A, and Q^2 dependence of nuclear transparency for the process K^+ using the data of A(e,$e'\pi^+$). The measurement was performed on ^{2}H, ^{12}C, ^{27}Al, ^{63}Cu and ^{197}Au nuclei, over a Q^2 range of 1.1 to 4.7 (GeV/c)^2. Measurement of both the A and Q^2 dependence of the nuclear transparency is crucial to distinguish between CT-like effects and other reaction-mechanism based energy dependence of the transparency. In this measurement the coherence length for kaon production (distance over which the virtual photon fluctuates into a $q\bar{q}$ pair) was smaller than the nucleon radius and was essentially constant, ranging from 0.2 - 0.5 fm over the kinematic range of the experiment.

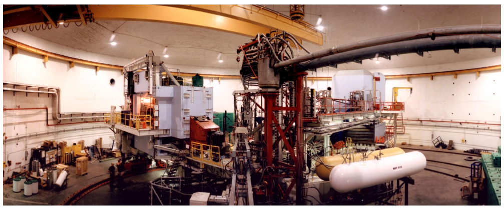


FIG. 1: Hall-C of Jefferson Lab

III. ANALYSIS

If we compare our data with Monte Carlo simulation of Hall-C of Jefferson Lab named SIMC, then the nuclear transparency can be difined as:

$$T = \frac{\frac{\sigma_A}{\sigma_A^{simc}}}{\frac{\sigma_0}{\sigma_0^{simc}}}$$

where σ_A^{simc} is the cross-section for the different targets and σ_0^{simc} for Hydrozen from SIMC.

A. Coincidence Time:

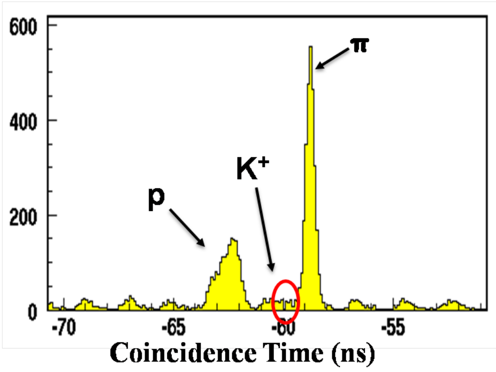


FIG. 2: Typical coincidence time plot of the experiment

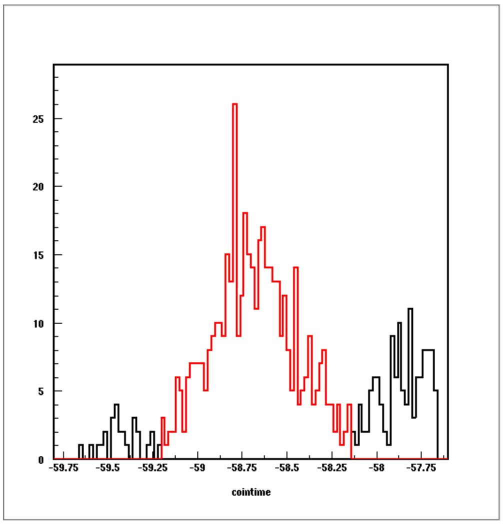


FIG. 3: Coincedence time plot after applying all the cuts for Hydrozen

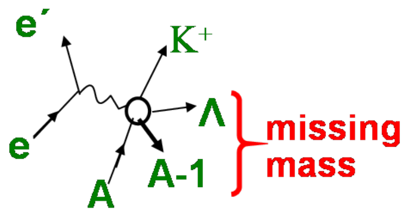
B. Missing Mass:

Reactions:

$$e + p \longrightarrow e' + K^+ + \lambda$$
$$e + p \longrightarrow e' + K^+ + \Sigma$$

From Energy and momentum conservation calculations from the λ-channel reaction we can easily write,

$$\text{Energy conservation: } E_e + M_p = E_{e'} + E_{K^+} + E_\lambda$$
$$\text{Momentum conservation: } P_e + 0 = P_{e'} + P_{K^+} + P_\lambda$$



Then we can form a variable called **missingmass** as is $M_\lambda = [E_\lambda^2 - P_\lambda^2]^{1/2}$

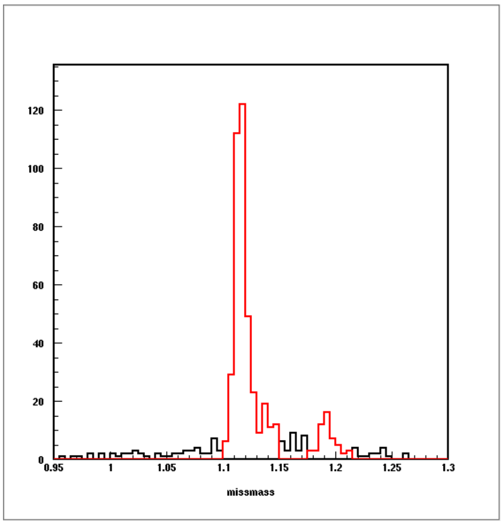


FIG. 4: Missingmass plot of the reaction

Similarly, we can form the missingmass(M_Σ) variable for Σ production.

The basic idea is forming this missingmass variable and giving cuts over it in order to separate K^+ from p and π^+ as well as to separate λ and Σ production of K^+.

C. Cherenkov:

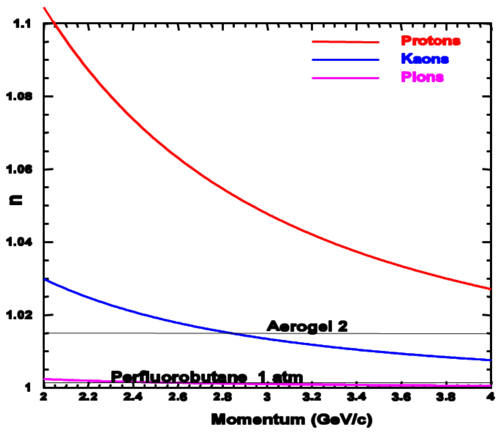


FIG. 5: Aergel cherenkov thresholds for different hadrons

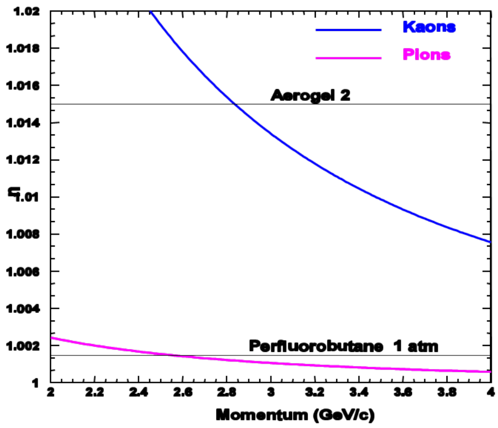


FIG. 6: Gas cherenkov thresholds for different hadrons

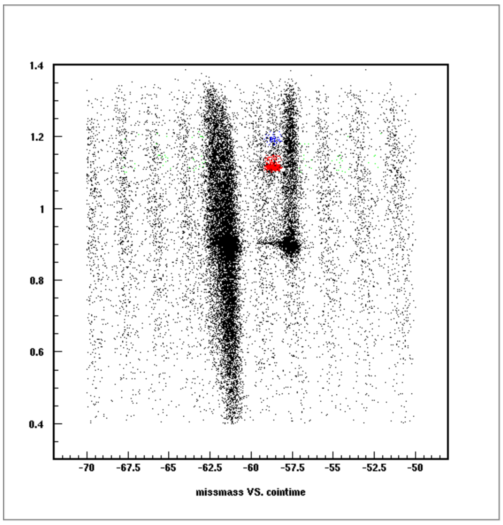


FIG. 7: Coincidencetime Vs Missingmass plot

IV. RESULTS

A. Basics

The Results are shown below: Before determining the cross-sections (σ) I have to compare the data with a simulation of Hall-C called SIMC. As σ depends on four variables i.e.

$$\sigma \equiv \sigma(Q^2, \text{ w}, \text{ t}, \phi_{pq}) \text{ where}$$

$Q^2 \rightarrow$ Four momentum transfers square,

w $\rightarrow$ Center of mass energy,

t $\rightarrow$ Mandelstam variable,

$\phi_{pq} \rightarrow$ The angle between reaction plane and scattering plane

Then,transparency can be difined as:

$$T = \frac{\frac{\sigma_A}{\sigma_A^{simc}}}{\frac{\sigma_0}{\sigma_0^{simc}}}$$

Now I need to compare data with SIMC for Hydrozen first and then for all other targets. I heve done the calculations for Hydrozen and four other different targets and for three different kinematics settings. But, here for example I will show the results for Hydrozen and Liquid Deuterium.

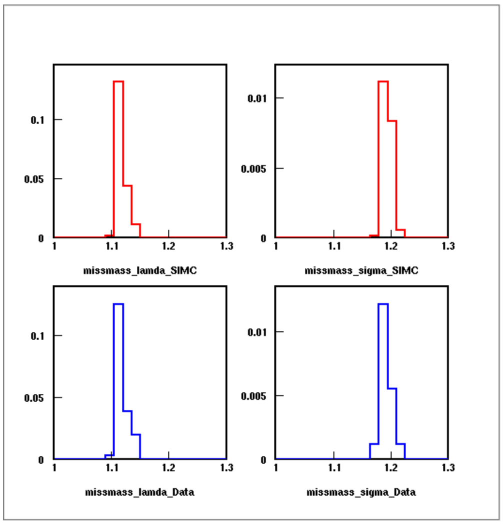


FIG. 8: From top left to right(in RED) : Missingmass SIMC λ, SIMC Σ and from bottom left to right(in BLUE) : Missingmass Data λ ,Data Σ for Hydrozen

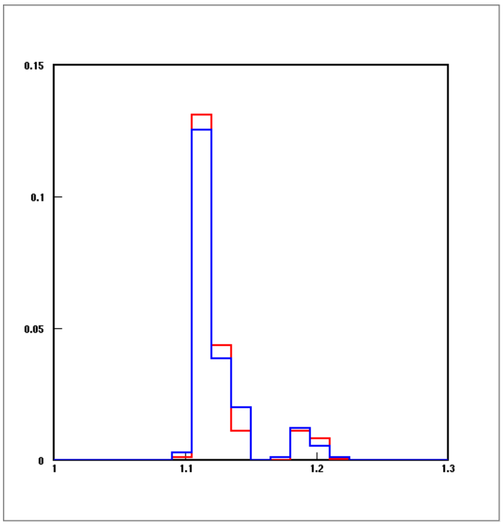


FIG. 9: Comparison of Missingmass in SIMC(in RED) and Data(in BLUE) for Hydrozen

B. The four different variables comparison between SIMC and data for Hydrozen:

FIG. 10: From top left to right(in RED) : Q^2 SIMC λ, SIMC Σ and from bottom left to right(in BLUE) : Q^2 Data λ ,Data Σ for Hydrozen

FIG. 11: Comparison of Q^2 in SIMC(in RED) and Data(in BLUE) for Hydrozen

In the **Figure IV B.** top left, I have shown the variable Q^2 from SIMC for λ-channel and top right for Σ-channel in RED. Then, the bottom I have shown the same for data in BLUE. Basically, the ratio of λ-channel and Σ-channel has been measured by using Hydrozen data. In **Figure 11.** I have added kaons for λ and Σ production both from SIMC shown in RED and data BLUE with proper ratio, that I got by using Hydrozen data. The ratio of Σ to λ production is too small. For three kinematics i.e. for three different Q^2 of 1.1, 2.15, 3.0 are 0.14, 0.11, 0.09 respectively.

One can easily identify that the plots for different variables in the **Figures 11., 13., 15., 17.** for Hydrozen SIMC and data are matching quite well.

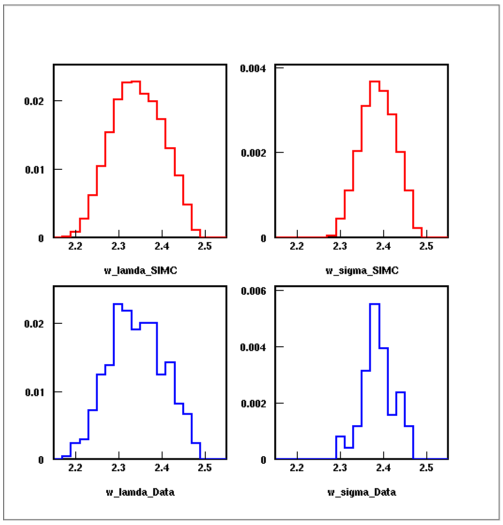


FIG. 12: From top left to right(in RED) : w SIMC λ, SIMC Σ and from bottom left to right(in BLUE) : w Data λ ,Data Σ for Hydrozen

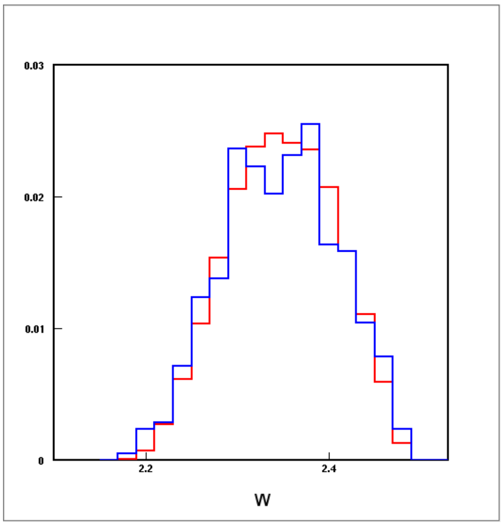


FIG. 13: Comparison of w in SIMC(in RED) and Data(in BLUE) for Hydrozen

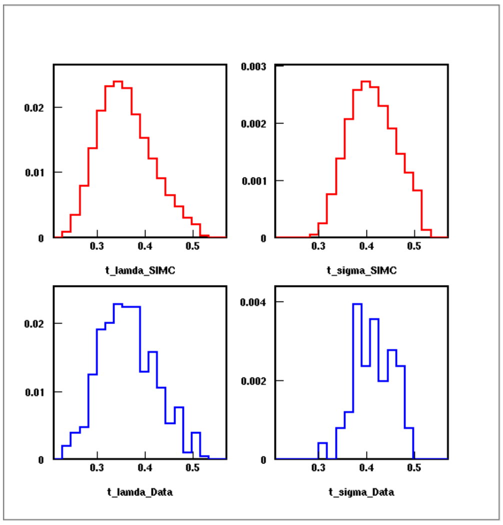


FIG. 14: From top left to right(in RED) : t SIMC λ, SIMC Σ and from bottom left to right(in BLUE) : t Data λ ,Data Σ for Hydrozen

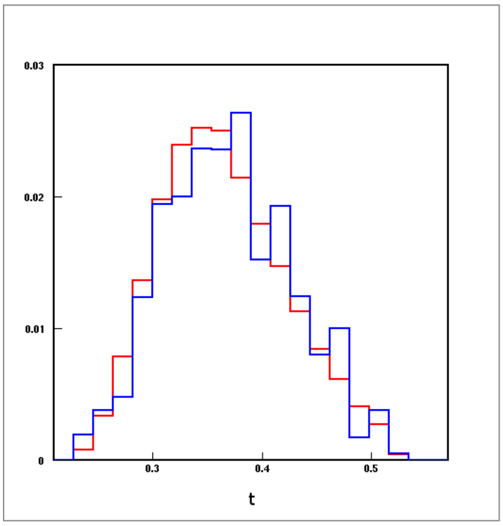


FIG. 15: Comparison of t in SIMC(in RED) and Data(in BLUE) for Hydrozen

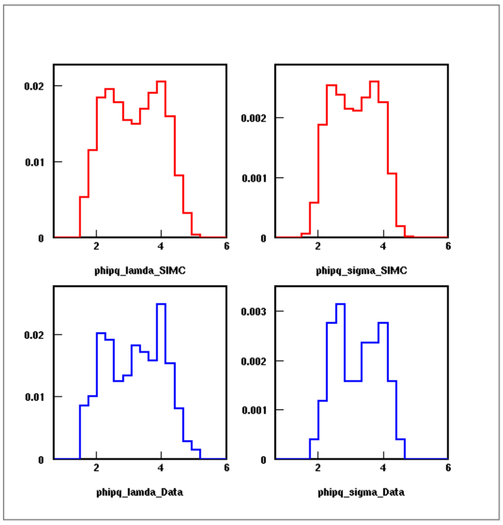


FIG. 16: From top left to right(in RED) : ϕ_{pq} SIMC λ, SIMC Σ and from bottom left to right(in BLUE) : ϕ_{pq} Data λ ,Data Σ for Hydrozen

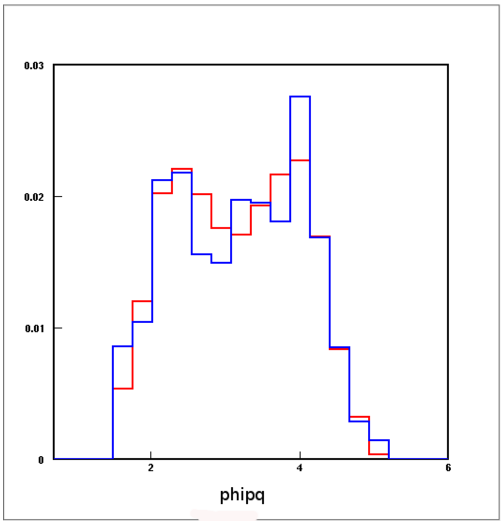


FIG. 17: Comparison of ϕ_{pq} in SIMC(in RED) and Data(in BLUE) for Hydrozen

C. The four different variables comparison between SIMC and data for Liquid Deuterium:

D. The nuclear transparency for different targets

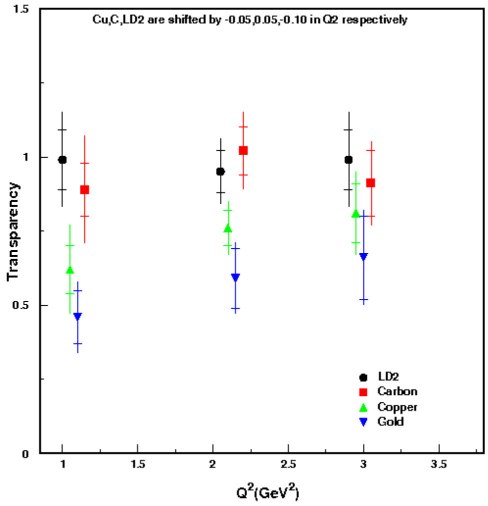


FIG. 18: Transparency Vs Q^2

Q^2 $(\mathrm{GeV/c})^2$	Σ to λ Ratio	Hydrozen Crossection mb	Statistical Uncertinity %	Systematic Uncertinity %	Total Uncertinity %
1.10	0.14	9.46	6.28	5.61	8.42
2.15	0.11	8.72	4.76	4.41	6.49
3.00	0.09	9.29	7.44	4.89	8.91

TABLE I: The cross-sections of Hydrozen for different kinematics.

Q^2 $(\mathrm{GeV/c})^2$	LD_2 Crossection mb	Statistical Uncertinity %	Systematic Uncertinity %	Total Uncertinity %	Transparency
1.10	8.38	10.30	12.34	16.07	0.88
2.15	7.53	07.51	07.48	10.61	0.86
3.00	8.55	10.22	12.06	15.81	0.92

TABLE II: The cross-sections and transparencies of Liquid Deuterium for different kinematics.

Q^2 $(\mathrm{GeV/c})^2$	Carbon Crossection mb	Statistical Uncertinity %	Systematic Uncertinity %	Total Uncertinity %	Transparency
1.10	7.57	09.31	16.11	18.61	0.80
2.15	8.01	07.58	10.03	12.57	0.91
3.00	7.76	11.49	08.10	14.06	0.84

TABLE III: The cross-sections and transparencies of Carbon for different kinematics.

Q^2 (GeV/c)^2	Copper Crossection mb	Statistical Uncertinity %	Systematic Uncertinity %	Total Uncertinity %	Transparency
1.10	5.17	07.85	12.69	14.92	0.55
2.15	5.61	06.45	06.43	09.11	0.64
3.00	6.75	10.24	09.33	13.85	0.73

TABLE IV: The cross-sections and transparencies of Copper for different kinematics.

Q^2 (GeV/c)^2	Gold Crossection mb	Statistical Uncertinity %	Systematic Uncertinity %	Total Uncertinity %	Transparency
1.10	3.64	09.03	07.13	11.51	0.39
2.15	4.49	09.93	06.40	11.82	0.51
3.00	5.42	13.91	08.22	16.16	0.58

TABLE V: The cross-sections and transparencies of Gold for different kinematics.

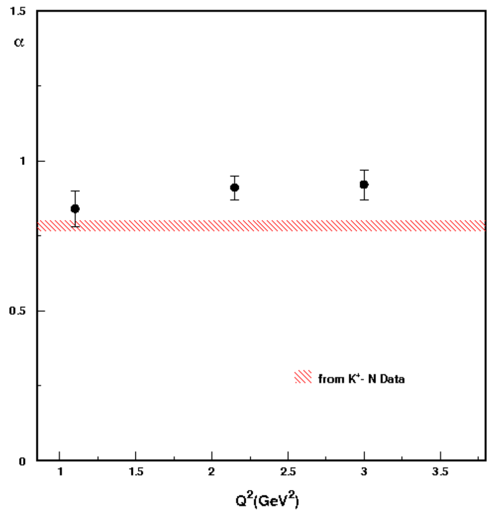


FIG. 19: Alpha Vs Q^2

Q^2 (GeV/c)^2	α	Uncertinity %
1.10	0.84	6.0
2.15	0.91	4.0
3.00	0.92	5.0

TABLE VI: α for different kinematics with theoritical band.