Study of Nuclear Transparency of Low Atomic Mass Nuclei to Rho Mesons

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Outline

- Introduction
- Previous experiments
- SRC/CT experiment at Hall D JLab
- Photoproduction of Rho meson
- Results
- Future work

Introduction: Color Transparency

Introduced by Muller and Brodsky, 1982

- Strong force can be understood using two distinct theories at low and high energies.
- The transition from the low-energy scale to the high-energy scale has not been definitively established.
- Color transparency (CT), a key prediction of (QCD) is used to investigate the transition from nucleon-meson degree of freedom to that of quark-gluon degree of freedom

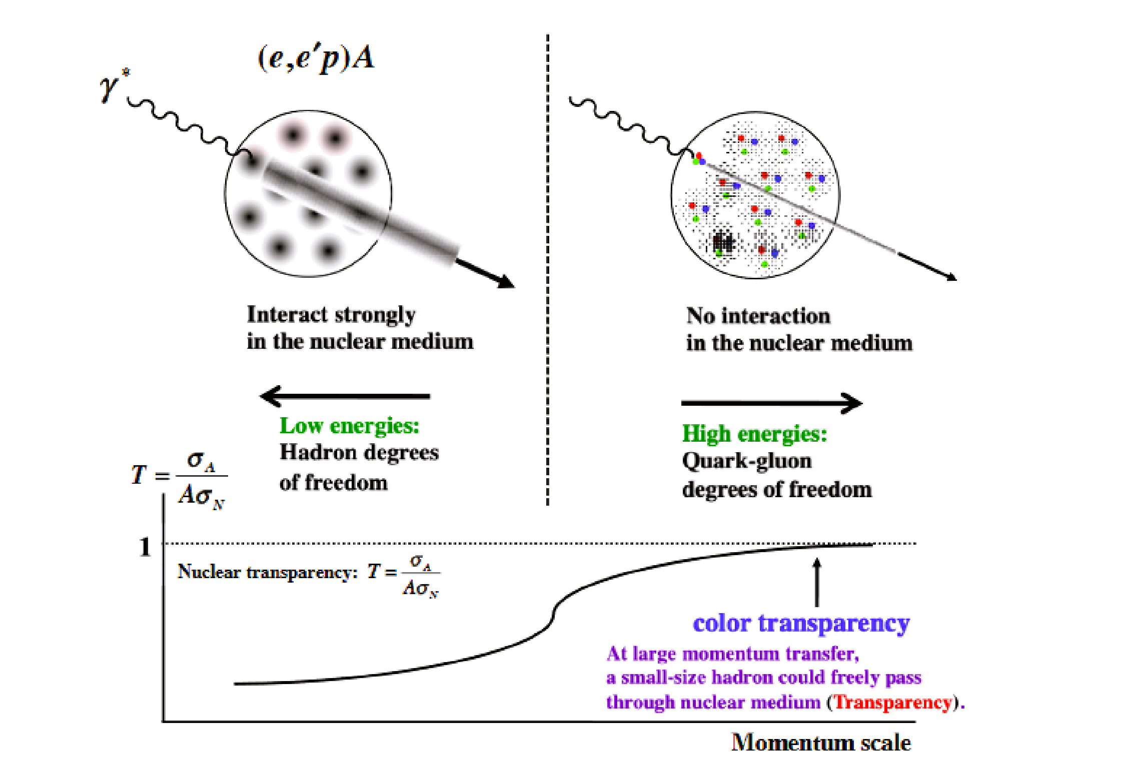
- Color transparency refers to the suppression of final state interactions of hadrons with the nuclear medium.
- This occurs in exclusive processes at high momentum transferred squared.

- Squeezing: At high momentum transfer the preferential selection of small configuration of quarks. :- Point like Configuration(PLC)
- Freezing: The PLC maintains its small size enough to cross the nucleus before it returns to regular size.
- Color-screening: Reduced interaction with hadrons in the surrounding nuclear medium.

Introduction: Nuclear Transparency

Nuclear Transparency is an observable to search for CT

- Nuclear Transparency is defined as the ratio of the cross section per nucleon for a process in the nucleus to that of a free nucleon.
- The onset of CT would involve the rise in the nuclear transparency as a function of energy.
- The onset of CT indicates the transition from nucleon-meson(low energies) picture to quark-gluon picture (high energies)



Kumano, S. Physics,4,565-577(2022)

$$Nuclear\ Transparency = T_A = \frac{\sigma_A}{A\sigma_N} \quad \begin{matrix}(nuclear\ cross\ section)\\(free\ cross\ section\ of\ nucleon)\end{matrix}$$

.

Previous experiments

CT is well established at high energies.

Baryons:
A(p,2p): BNL
A(e,e' p): SLAC, JLAB ☹

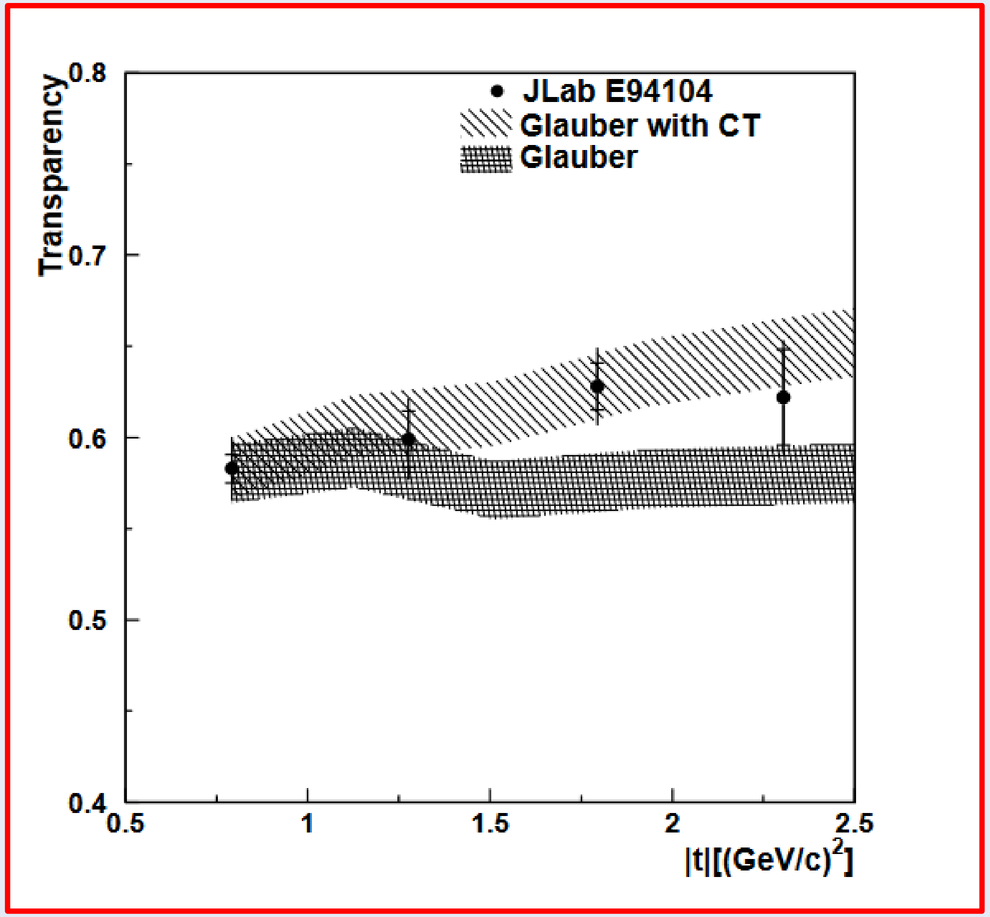
Mesons
A(π, di_jet): FNAL
A(γ, π^-p):Jlab
A(e, eπ^+):Jlab
A(e, eρ^0):DESY & JLab ☺

Study of CT at JLab:
E94139 : Quasi_elastic A(e,e',p) electron scattering on nuclei
E94104 : Pion photoproduction in Hall A
E01107 : Pion electroproduction in Hall A
E02110 : Rho0 meson electroproduction in Hall B
E1206107: Quasi elastic A(e,e',p) electron scattering on nuclei

Onset on CT has been measured in Mesons but not in Baryons

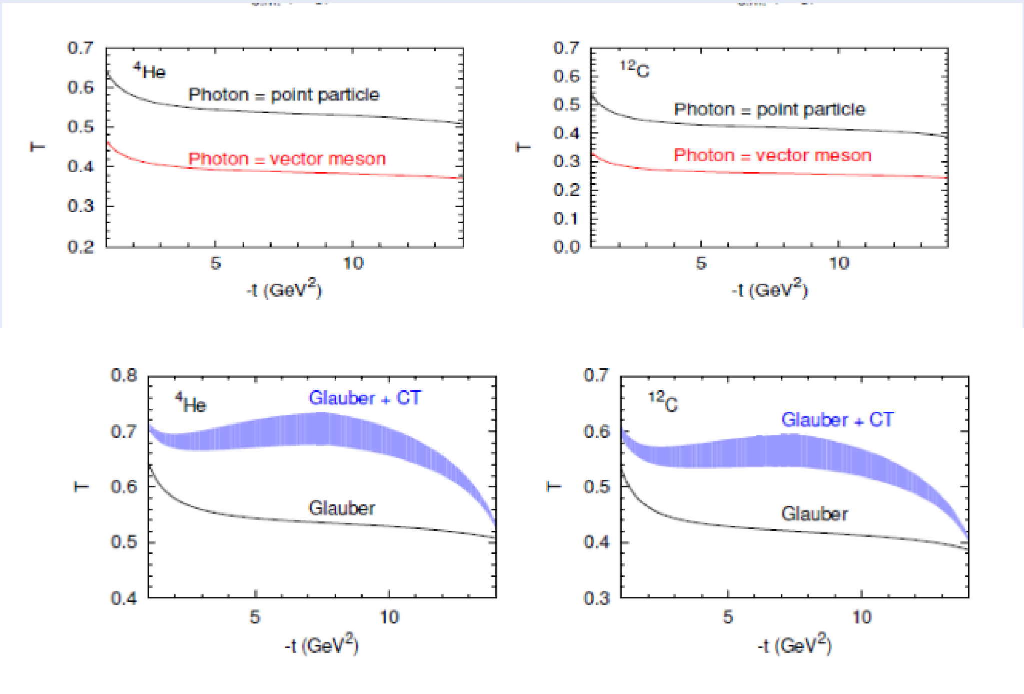
Previous experiments at JLab and theoretical study

Pion photoproduction didn't find clear signature for onset of CT(uncertainty was too large)



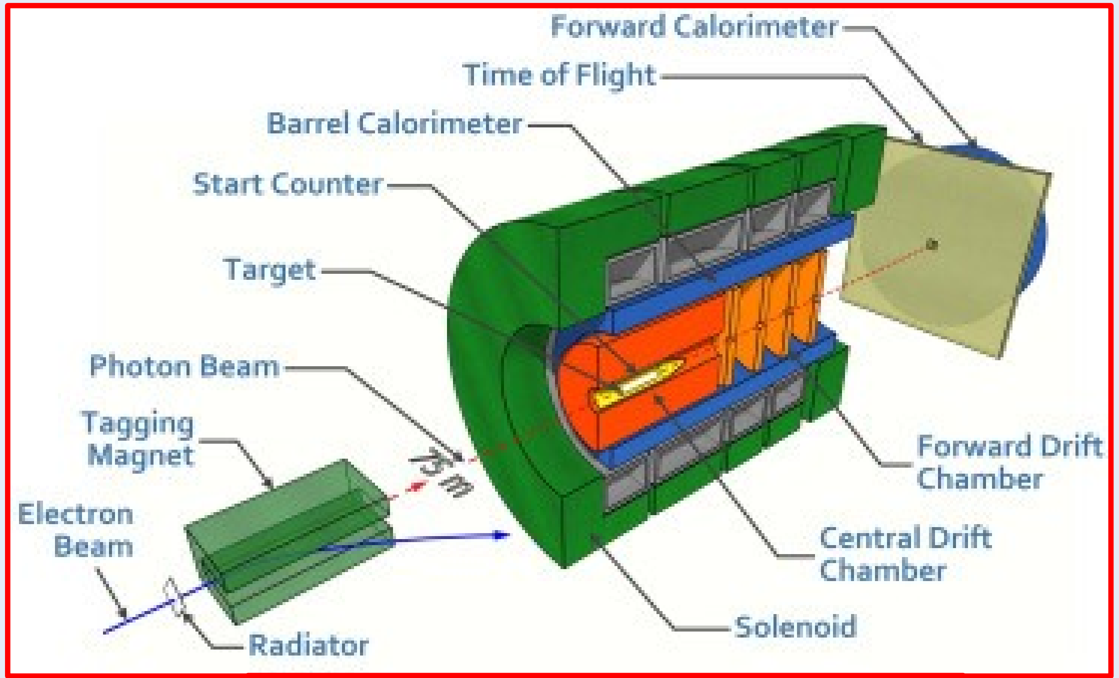
D. Dutta *et al.*, Phys. Rev. C 68, 064603(2003)

- More data are required for photoproduction from nuclei.
- An experiment was conducted in Hall D with additional reaction channel and an extended |t| range, including more nuclei to address this need.



A. B. Larionov et al. Phys. Lett. B760, 753(2016)

Jefferson Lab Hall D

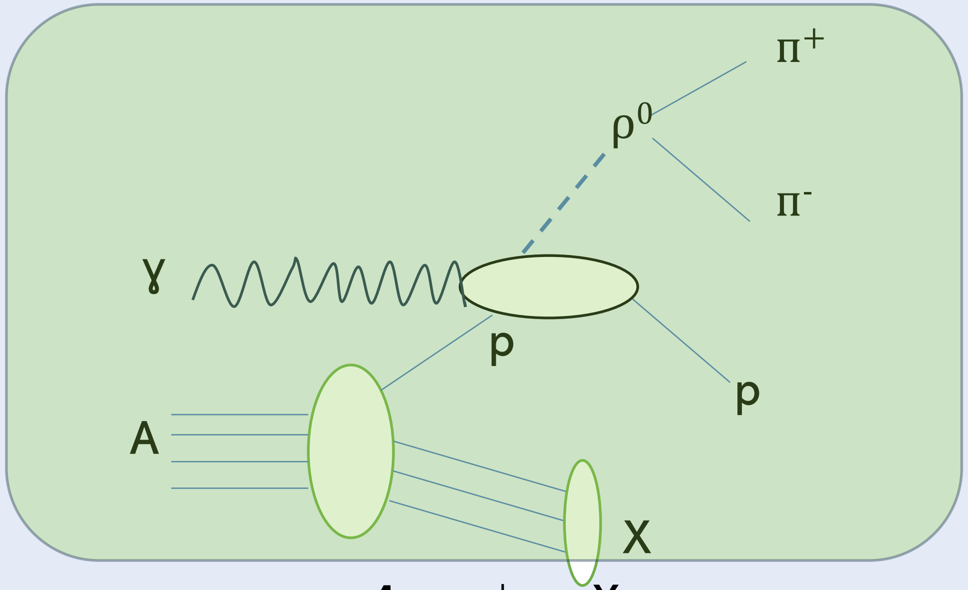


Proton Reactions	Neutron Reactions
$\gamma + p \rightarrow \pi^0 + p$	$\gamma + n \rightarrow \pi^- + p$
$\gamma + p \rightarrow \pi^- + \Delta^{++}$	$\gamma + n \rightarrow \pi^- + \Delta^+$
$\gamma + p \rightarrow \rho^0 + p$	$\gamma + n \rightarrow \rho^- + p$
$\gamma + p \rightarrow K^+ + \Lambda^0$	$\gamma + n \rightarrow K^- + \Lambda^0$
$\gamma + p \rightarrow K^+ + \Sigma^0$	$\gamma + n \rightarrow K^0 + \Sigma^0$
$\gamma + p \rightarrow \omega + p$	—
$\gamma + p \rightarrow \varphi + p$	—

S.Adhikari, et al. Nucl.Instrum.Meth.A 987,164807(2021)

- The experiment was conducted in Nov-Dec 2021 in Hall D of Jefferson Lab.
- Used photon beam on deuterium, helium, and carbon targets.
- Primary objectives are to study short-range correlations, color transparency at large momentum transfers, and the bound structure of nucleus

Event Selection: Rho0 meson



$\gamma A \to \pi^+ \pi^- pX$

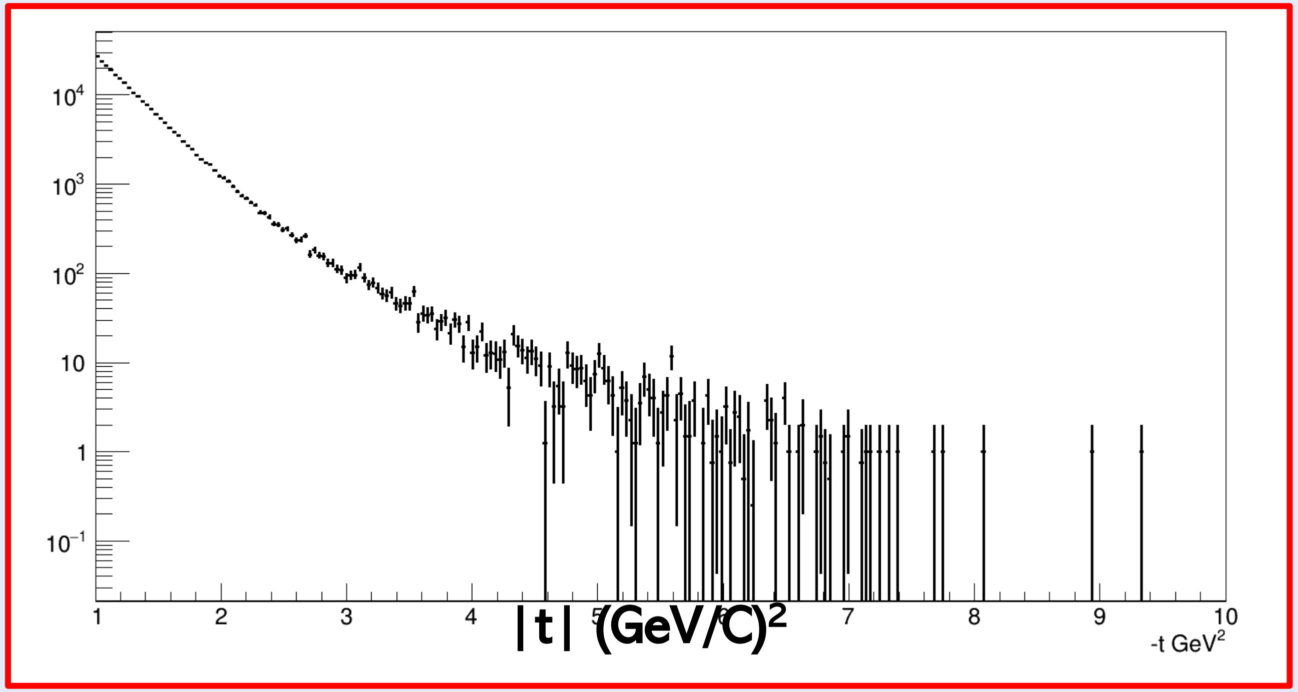
- Kinematic fit constraint enforce on conservation of four momentum and energy.
- Constraint on vertex: Decaying pions originates from same point in space.
- four beam bunches on each side of the primary bunch.

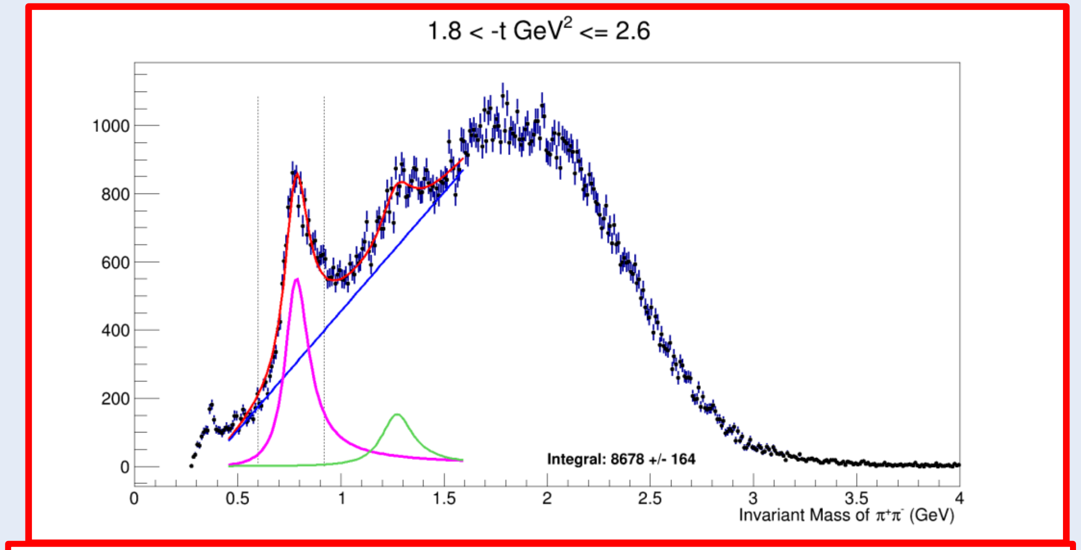
Selection Criteria	Range
Confidence level of fit	> 0.001
Beam Energy	6.5 < Eγ < 10.8 GeV
Extra tracks	0
Numbers of Shower	5
Proton Vertex	[52,78] cm
Missing Momentum	<300 MeV/c
|t|	>1
Polar angles of Proton	>20

Table: Summary of event selection cuts

Results: Mandelstam variable and Invariant mass of Rho0 meson

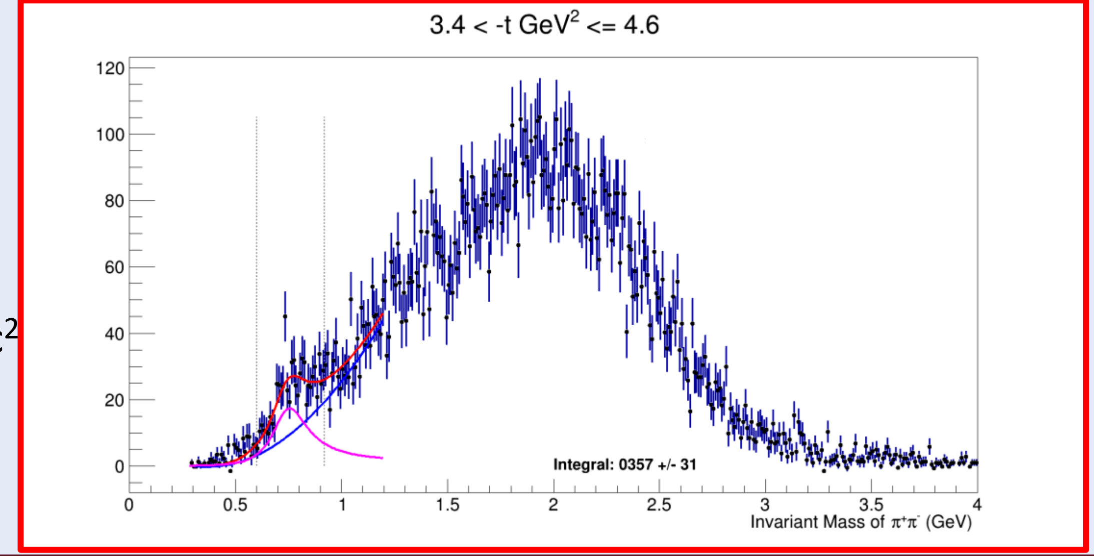
Mandelstan variable |t| in Deuterium





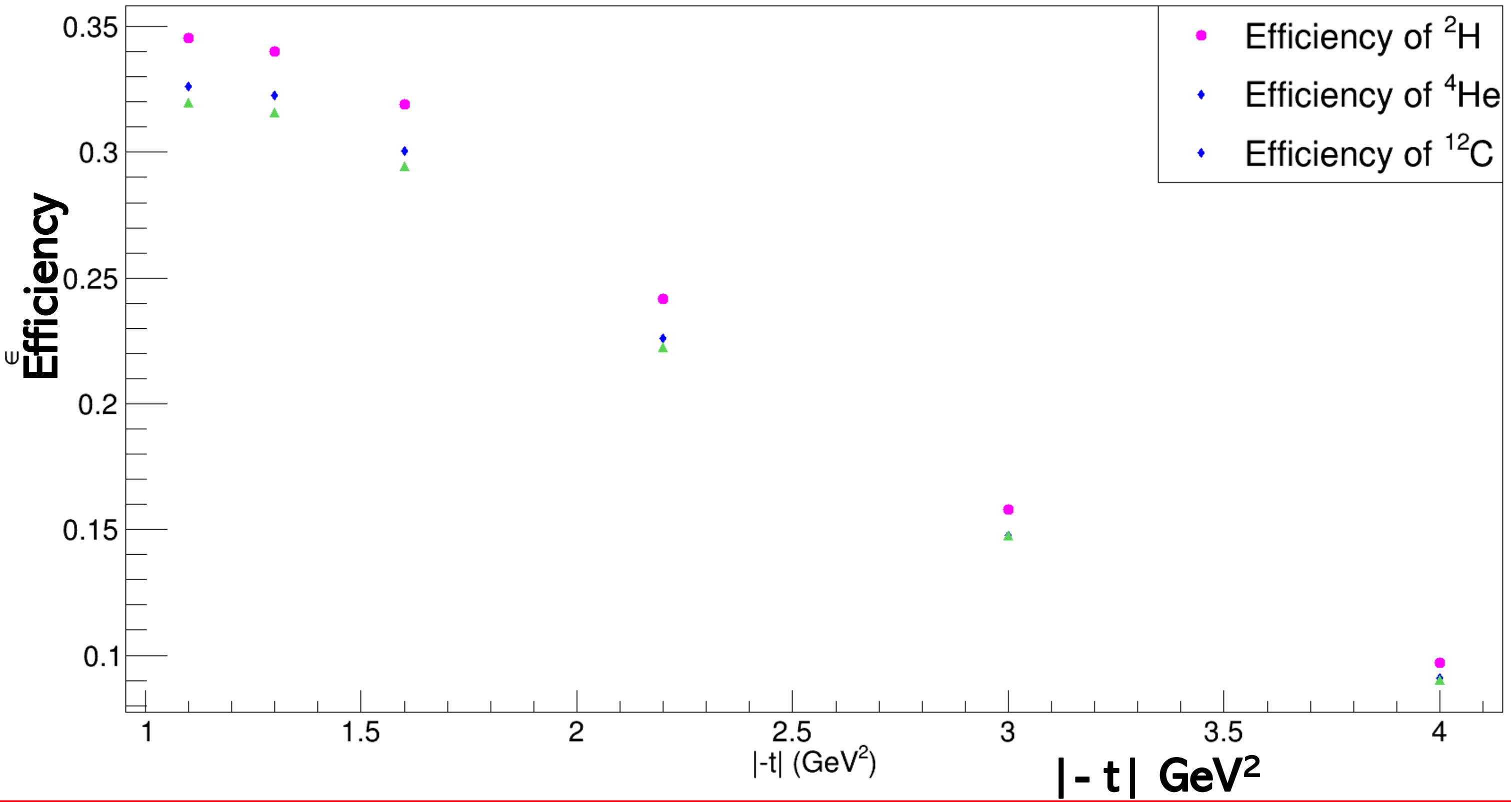
$$t = -(P_\gamma - P_{\pi^+\pi^-}),$$

M_{Rho} = 0.775 GeV/c^2



Relativistic Breit–Wigner and 2nd order polynomial combination in fitting invariant mass ($\pi^+ \pi^-$)

Efficiency



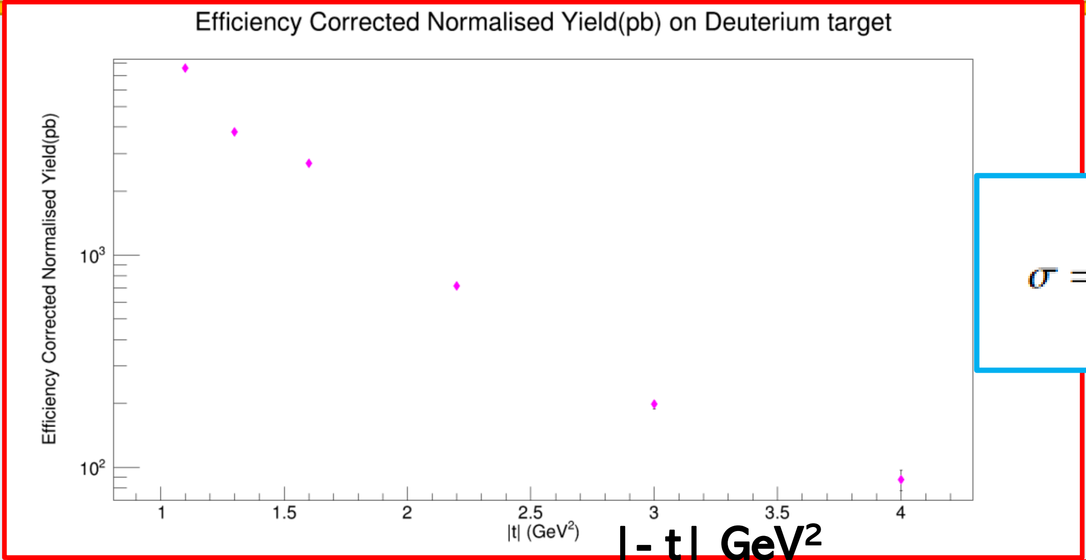
Plot: A plot of efficiency vs momentum distribution |-t| GeV^2

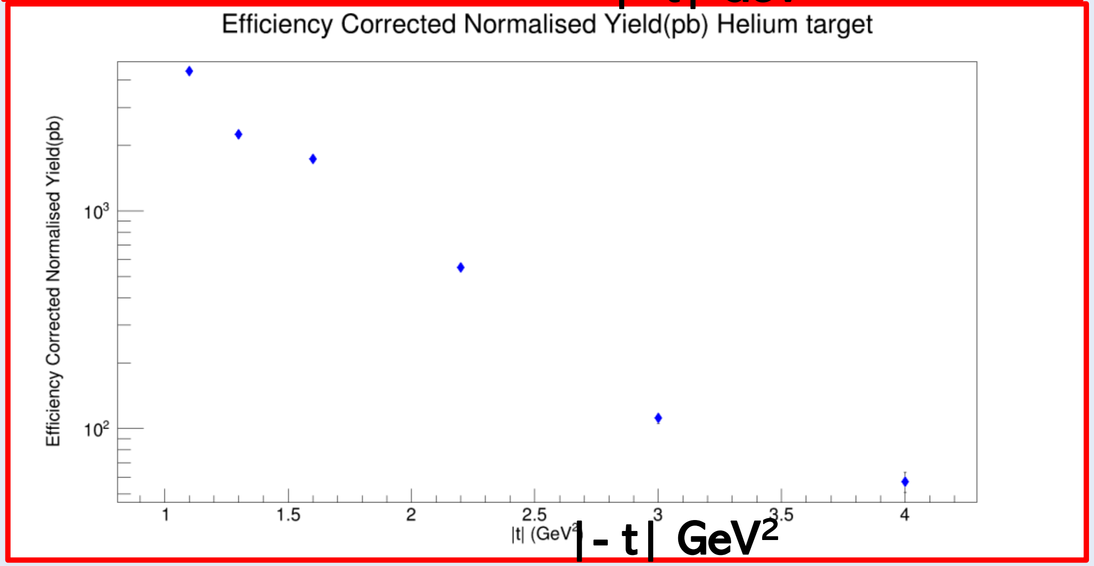
- Efficiency for deuterium is slightly higher than those for helium and carbon.
- For 1.0 < |-t| GeV^2 ≤1.2 efficiency is approximately 33%.
- For 3.4 < |-t| GeV^2 ≤4.6 efficiency is approximately 10%.

Tagged	Luminosity (pb^{-1}.nucleon
^{2}D:	33.98
^{4}He:	63.80
^{12}C:	97.93

Preliminary Absolute Cross Section

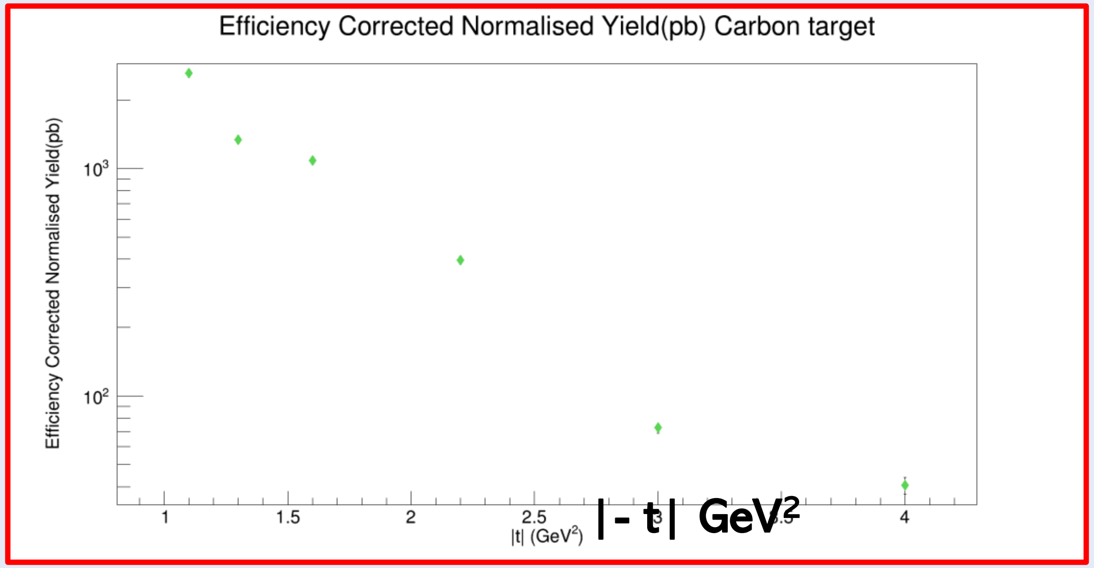
Efficiency Corrected Normalised Yield (pb)





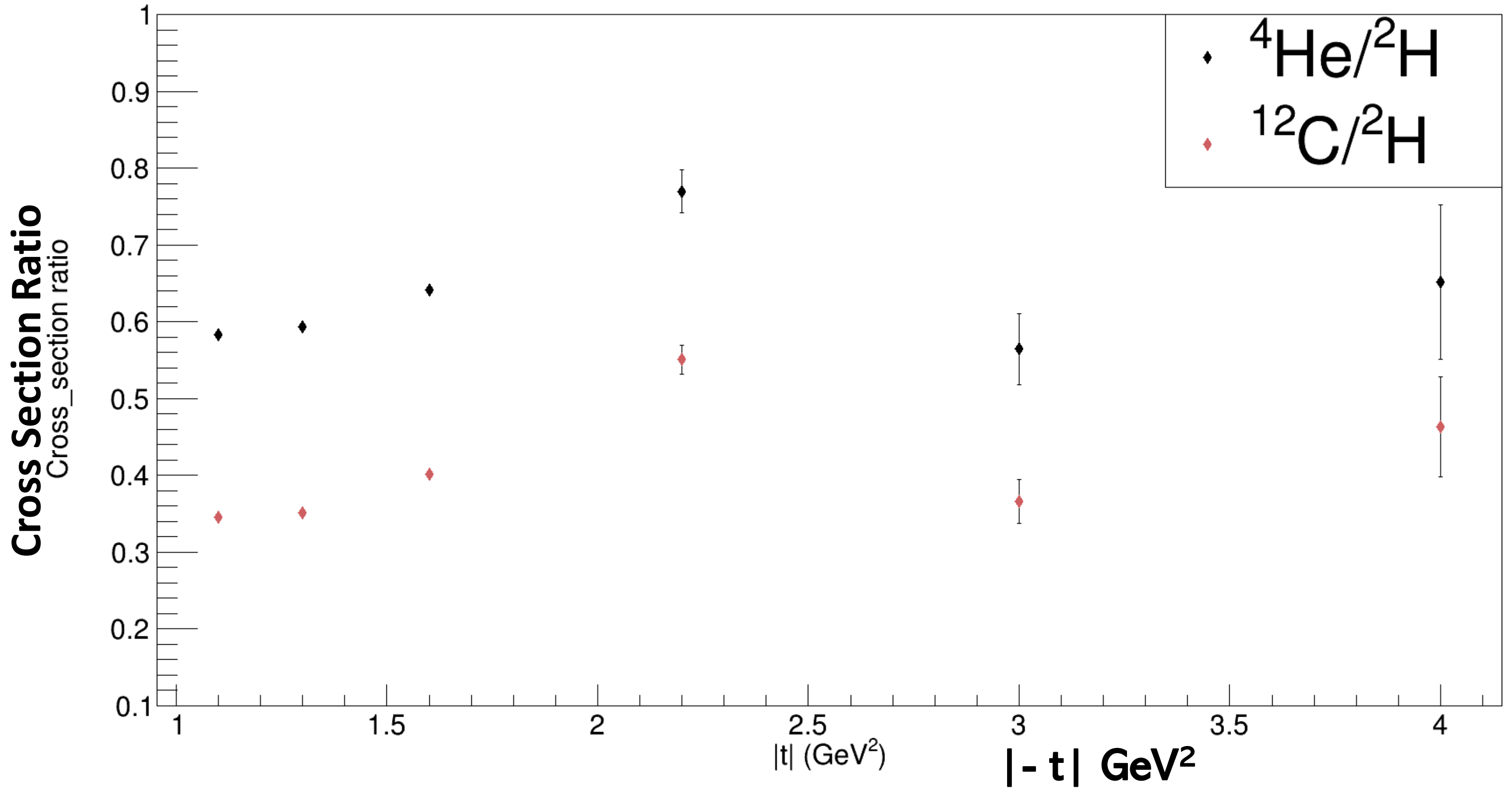
$$\sigma = \frac{N_{signal}}{\mathcal{L} \times \epsilon \times B(\rho^0 \to \pi^+\pi^-)}$$

- ➢ Uncertainties in cross section were solely based on data yields.
- ➢ Rigorous study of the background.



Plot: Cross section for $\rho^0 \to \pi^+\pi^-$ for Deuterium, Helium and Carbon.

Preliminary Nuclear Transparency



Plot: Nuclear Transparency as a function of momentum transfer.

$$T(^4\mathrm{He}) = \frac{\sigma(^4\mathrm{He})}{\sigma(^2\mathrm{H})}$$

$$T(^{12}\mathrm{C}) = \frac{\sigma(^{12}\mathrm{C})}{\sigma(^2\mathrm{H})}$$

Only preliminary statistics uncertainty from data yield is shown.

Future works

- Study the background of data by using the background model simulation from GlueX.
- Work on systematic uncertainties associated with the cross-section ratio.
- To extract photon transparency to look for the transition of photon vector meson to that of point like configuration.
- Study the onset of CT by comparing against theoretical calculations.

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SRC/CT Collaboration

THANK YOU !

Cross Section Calculation

$$Luminosity = flux * \text{Target Length} * \text{Number Density}$$

Nucleus	Tagged Photon Flux (10^{12})	Tagged Luminosity (pb^{-1}·nucleon)
Deuterium	13.17	33.98
Helium	30.8	63.80
Carbon	49.46	97.73

Table :Tagged flux and luminosity for each target, with beam photons having energies between 6.5 and 10.8 GeV

$$\sigma = \frac{N_{signal}}{\mathcal{L} \times \epsilon \times B(\rho^0 \rightarrow \pi^+\pi^-)}$$

$$T(^4\text{He}) = \frac{\sigma_{(^4\text{He})}}{\sigma_{(^2\text{H})}}$$

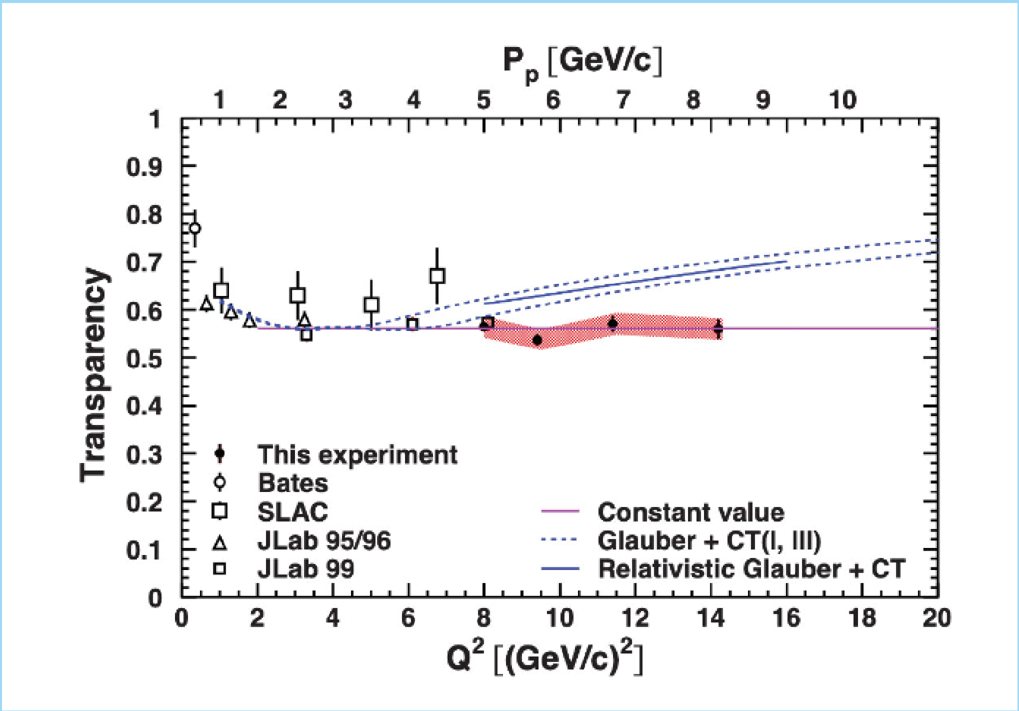
$$T(^{12}\text{C}) = \frac{\sigma_{(^{12}\text{C})}}{\sigma_{(^2\text{H})}}$$

$$\text{Number Density} = \rho_N = \frac{N_{\text{Avogadro}}(\text{particle/mole}) \times \text{target mass density}(\text{gm/cm}^3)}{\text{atomic weight of proton}(\text{gm/mole})} \times \frac{1\text{cm}^2}{1 \times 10^{24}\ \text{barns}}$$

Source: Hao Li's Dissertation (Glue X)

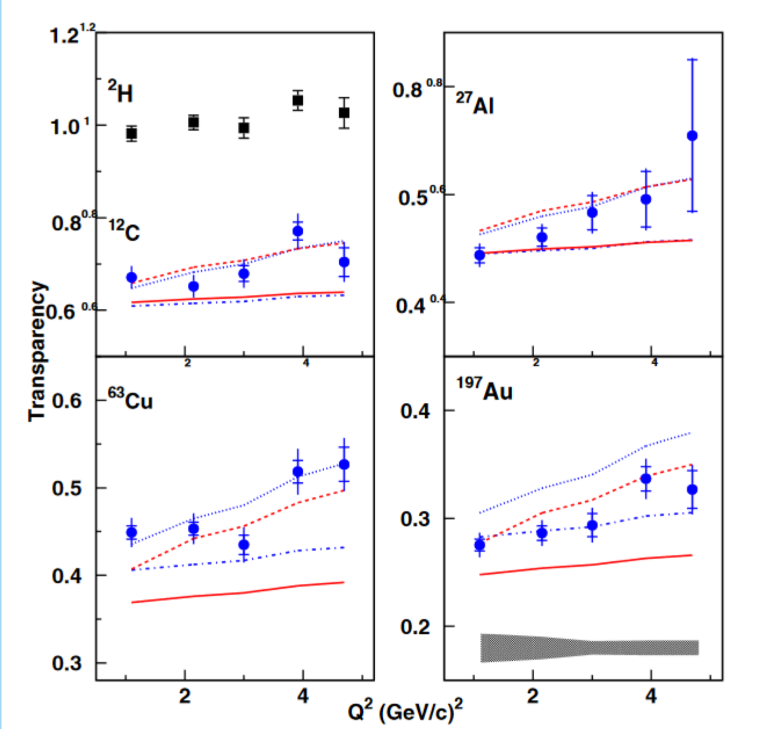
Backup: Previous experiments at JLab

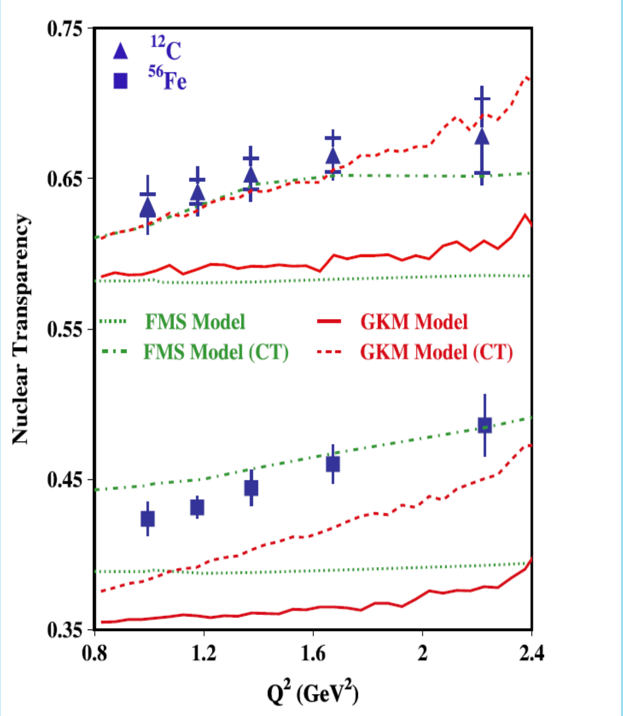
Quasielastic C(e,e',p) scattering didn't find CT in baryons



D. Bhetuwal et al., Phys. Rev. Lett.126, 082301(2021).

Pion and Rho electroproduction found onset of CT in mesons





B. Clasie et al., Phys. Rev. Lett. 99, 242502(2007)
L. El Fassi et al. (CLAS), Phys. Lett. B712, 326(2012)

Detector's Resolution

- Charged particle momentum::1-3%.
- Forward high momentum particle:8-9%.
- Proton.P() <250 MeV are not detected.
- Pions reconstruction:: challenging for momenta<200 MeV
- Looking the energy deposited at CDC :: proton and pions can be separated up to energies of ~800 MeV.
- TOF can separate pions and kaon up to energies ~2GeV.
- Fcal can detect photons for $E_\gamma > 100$ MeV.
- Energy is lost in calorimeter due to 11^0 gap between calorimeters.