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# Nuclear A Dependence of Exclusive Vector Meson Production in Muon Scattering

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## Disclaimer

# NUCLEAR A DEPENDENCE OF EXCLUSIVE VECTOR MESON PRODUCTION IN MUON SCATTERING

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## Abstract

Results on exclusive vector meson production from Fermilab muon scattering experiment E665 are presented. The $A$ dependence of exclusive vector meson production is studied as a function of $Q^2$. The data show a significant change in the dependence on $A$ at higher values of $Q^2$. The observed behavior is consistent with the idea of color transparency.

## Introduction

Exclusive vector meson production occurs in deep-inelastic scattering when a virtual photon, emitted by an incoming lepton, fluctuates into a virtual hadronic state with the same quantum numbers. This hadronic state scatters quasi-elastically within a nucleus, and then propagates through the nuclear matter without further interaction, and finally forms an on-shell vector meson. The production rate thus depends on the coupling to the photon, the scattering probability and the transmission probability for the scattered state. The latter two factors vary with the number of nucleons in the nucleus and can be studied by comparing the elastic vector meson production rates from proton and heavy nuclear targets.

In deep-inelastic scattering, two Lorentz invariants, $-Q^2$, the four-momentum squared of the photon, and $\nu$ ( which is the photon energy in the lab frame) determine the length scales for the interaction. The resolving power of the photon is determined by $r \approx 2/\sqrt{m_{q\bar{q}}^2 + Q^2}$ while the lifetime in the lab frame of the virtual state is related to $\tau \approx 2\nu/(m_{q\bar{q}}^2 + Q^2)$. Thus as $Q^2$ rises, the photon can be expected to couple to the hadronic wave function at smaller and smaller values of $r$, while as $\nu$ rises, the lifetime of that hadronic state should grow. For $\rho^0$ and $\phi$ production in the kinematic region covered by FNAL experiment E665, $r$ covers the range from 0.05 to 0.5 fm while $\tau$ ranges from 10 to 500 fm. As $\tau$ is typically longer than a nuclear radius, the hadronic state can be expected to maintain its size throughout the interaction. For more rigorous theoretical treatments, see [1,2].

The color transparency model suggests that smaller color singlet states should be able to propagate more easily through nuclear matter than larger ones. If $r$ can be interpreted as the size of the hadronic state, then this model would predict higher propagation probabilities as $Q$ rises.

## Experimental Measurement and Results

The E665 muon-scattering experiment at Fermilab has made a study of elastic vector meson production on nuclear targets. The relevant components for this measurement are: a 465 GeV muon beam, five targets $H_2, D_2, C, Ca$ and $Pb$, ranging between 0.04 and 0.35 interaction lengths in thickness, a high precision muon spectrometer with resolution of $0.002\%p$ ($p$ in GeV) and angular resolution of 20-40 $\mu R$, and an electromagnetic calorimeter. The experimental trigger was efficient for scatters with $Q^2 > 0.1$ GeV$^2$/c$^2$. The targets were exchanged every 1-4 minutes thus cancelling time dependences in the ratios of acceptances for different targets.

Elastic events with vector mesons were selected as follows,

- $0.1 < Q^2 < 10$ GeV$^2$/c$^2$
- $\nu > 50$ GeV
- $\delta\nu/\nu < 25\%$
- Exactly two oppositely charged hadrons with $m_{\pi\pi} < 1.5$ GeV/c$^2$ or $m_{KK} < 1.05$ GeV/c$^2$
- very low energy visible in the electromagnetic calorimeter or $m_{ee} > 0.5$ GeV/c$^2$

No particle ID is used in this analysis, instead, pairs of hadrons are assigned pion and kaon masses and both the $\rho^0$ and $\phi$ hypotheses are tried. The first four requirements assure that the vector meson kinematics are well reconstructed. The last eliminates background from coherent bremsstrahlung followed by photon conversion which also produces a two-'hadron' topology.

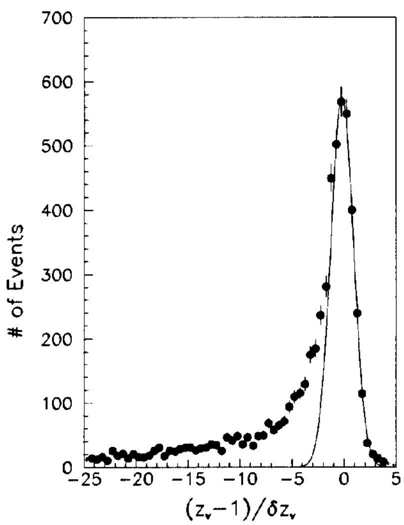


**Fig. 1** The normalized elasticity, $(z-1)/\delta z$, for all events in the $\rho^0$ or $\phi$ mass regions. The curve is a gaussian fit to the data with $z > 1$, the width is consistent with 1, as expected if $\delta z$ is properly estimated.

In the E665 spectrometer, the recoil nucleus is not detected and consequently, the elasticity of the event can only be determined by comparing the incoming photon energy to the vector meson energy. If this ratio is unity, the interaction is classified as elastic although nuclear excitations are still possible. The elasticity is defined by $z = E_V/E_\gamma$ and is required to lie in the range $1.5\sigma_z < z - 1 < 3\sigma_z$ where $\sigma_z$ is the estimated error on $z$. Figure 1 shows this elasticity normalized to the error, an asymmetrical cut is made to minimize the inelastic background at $z < 1$.

Figure 2 shows the $\rho^0$ and $\phi$ mass distributions, there are approximately 2000 events on each target. The bulge above the $\phi$ mass is due to $\rho^0$ events.

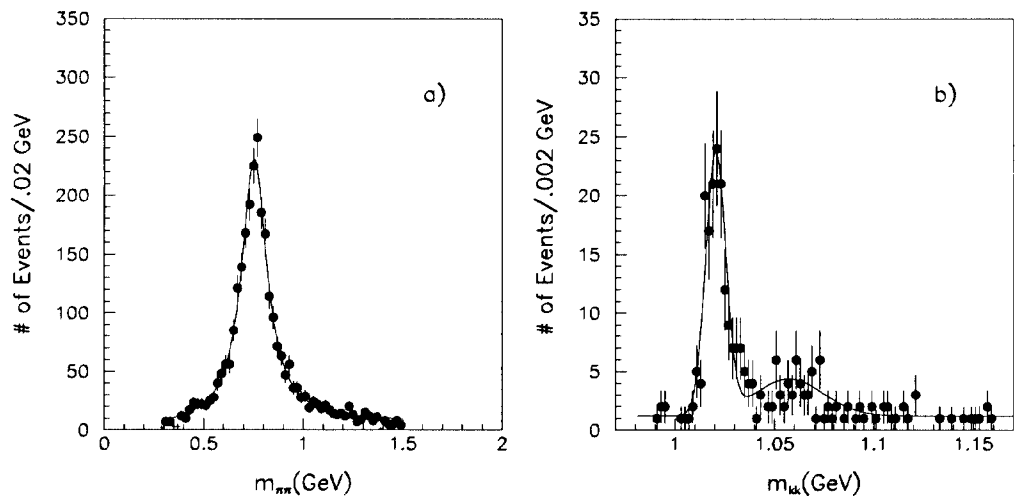


**Fig. 2** The invariant masses for $\pi\pi$ and $KK$ pairs in the elastic peak.

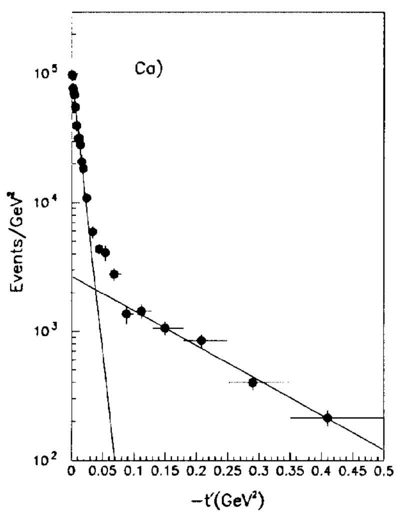


**Fig. 3** The momentum transfer squared $-t' = -(t - t_{min})$ for the Calcium target, the spike at low $-t'$ is due to coherent scattering from the entire nucleus.

The momentum transfer squared $t' = t - t_{min}$ between the meson and the target is illustrated for the calcium target in Figure 3. Here $t_{min}$ is the value of $t$ at zero scattering angle for a given $Q^2$ and $\nu$. For the heavier nuclei, a distinct spike at low $t'$ is produced by coherent scattering from the whole nucleus. The $t'$ slopes in the incoherent scattering region, defined as $t' > 0.1$ GeV$^{-2}$, are $5.5 - 6$ GeV$^{-2}$ for all targets, while the slopes at low $t'$ are consistent with previous measurements of the nuclear radii.

Figure 4 shows the nuclear transparency $T = (\sigma_A/A)/\sigma_p$ defined as the ratios of cross sections/nucleon for $D_2$, $C$, $Ca$ and $Pb$ compared to hydrogen as a function of $Q^2$ for the incoherent scattering region. Growth in the ratio with $Q^2$ is seen for both high A nuclei. The data are inconsistent with flat $Q^2$ behavior at the $\approx 95\%$ confidence level for each target taken separately, however, the errors on the ratios are correlated via the normalization to hydrogen. Figure 5 shows the A dependence of the rates for three $Q^2$ bins. These are the same data but presented in a fashion which removes the correlation due to the hydrogen normalization. The A dependence is seen to change significantly from $A^{-0.34\pm0.02}$ at low $Q^2$ to $A^{-0.19\pm0.03}$ at higher $Q^2$. A fully transparent nucleus would show no $A$ dependence. Thus the data can be interpreted as showing a significant rise in nuclear transparency as $Q^2$ increases.

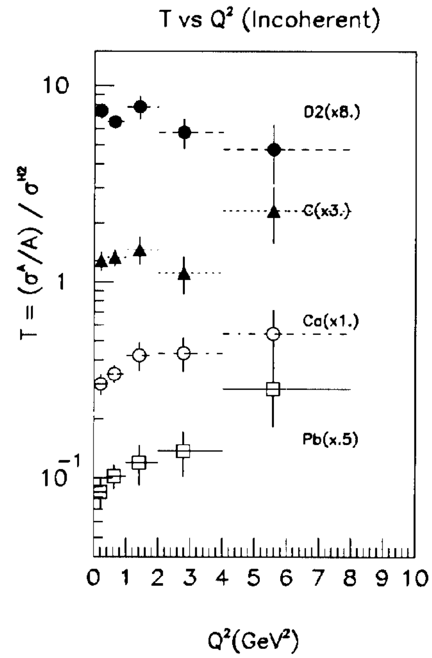


**Fig. 4** The ratio of the elastic production cross sections/nucleon for deuterium, carbon, calcium and lead compared to hydrogen vs $Q^2$.

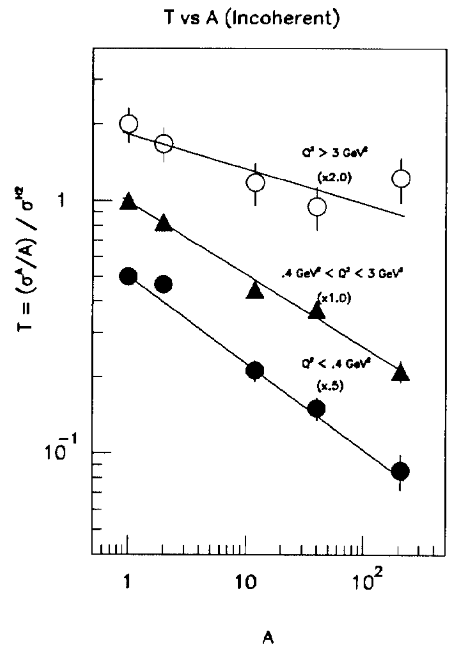


**Fig. 5** The A dependence of the cross section for three $Q^2$ bins. The slopes change significantly as $Q^2$ rises.

## Conclusions

Fermilab experiment E665 have measured the relative rates of vector meson production on five nuclear targets. The nuclear transparency rises significantly as $Q^2$ increases. This rise is consistent with the predictions of the color transparency model. The effect is more striking than observed in previous experiments at SLAC and Brookhaven[3,4], possibly due to the increased $\nu$ of 50-400 GeV available at E665 which assures that the hadronic state maintains coherence throughout the interaction in the nucleus.

## References


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