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Guang Yin Fang
For the E665 Collaboration

Department of Physics, Harvard University
Cambridge, MA 02138

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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A DEPENDENCE OF EXCLUSIVE VECTOR MESON PRODUCTION IN MUON-NUCLEUS SCATTERING

GUANG YIN FANG
Department of Physics
Harvard University
Cambridge, MA 02138, USA
(Representing the E665 Collaboration)

ABSTRACT

Preliminary results on the cross section ratios of exclusive ρ^0 and ϕ meson production off carbon, calcium, and lead to that off deuterium in deep-inelastic muon-nucleon scattering are reported. The data were taken with the E665 spectrometer using the Fermilab Tevatron muon beam. The mean beam energy was 470 GeV. A significant increase in the cross section ratios is seen as the four-momentum squared of the virtual photon increases. The results support the idea of color transparency.

Electro-production of exclusive vector mesons from complex nuclei was suggested as a way of testing the idea of a "shrinking photon" some time ago.[1] More recently, it has been suggested as a way of testing the idea of color transparency.[2,3] A recent example is the calculation of the A dependence of the ratio of cross sections of exclusive ρ^0 production from iron to that from hydrogen by Kopeliovich et al..[3]

Color transparency is a novel property of color gauge invariance in quantum chromodynamics. It predicts the absence of final-state re-interactions in hard exclusive processes. Thus one expects the total cross section of a hard process that involves nucleons from a nucleus to be proportional to A, the total number of nucleons in the nucleus. To experimentally observe color transparency one needs not only a process that selects out small-configuration hadrons but also high enough energy such that the emerging hadrons do not expand appreciably while propagating through the nucleus. Exclusive vector meson production at high energies is well suited for this purpose. In this case the initial size of the vector meson is determined by the Q^2, the virtuality of the photon. At a Q^2 value of 1 GeV^2 the transverse size of the meson is roughly $1/Q$, or about 0.2 fm, which is much smaller than the size of a normal hadron of about 1 fm. In the E665 kinematic region, an exclusively produced vector meson typically carries about 200 GeV. The corresponding formation length (the distance traveled by the emerged state before it grows into full size) is roughly $2\nu/(Q^2 + m^2)$, about 50 fm, which is much larger than the size of even the heaviest nucleus. Therefore one expects the nucleus to be highly transparent.

The data were taken at the Fermilab Tevatron muon beam line with the E665 spectrometer.[4] The mean beam energy was 470 GeV. Exclusive ρ^0 and ϕ events were identified by requiring two and only two oppositely charged hadrons present in the event in addition to the scattered muon (the recoil nucleon was not detected). Inclusive and combinatorial contaminations were suppressed by requiring that the total fractional energy carried by the two hadrons be between 0.9 and 1.1. Events from photon conversion were rejected using the calorimeter information by demanding that the energy and shower shape associated with the hadrons not be consistent with photons or electrons. To further reduce contributions from events in which additional particles were produced, but not reconstructed, the number of residual hits (hits not used by the reconstructed tracks) in the vertex drift chambers was limited to a value consistent with the normal level of spurious hits. An additional cut requiring the energy of both hadrons to be greater than 10 GeV was imposed to reduce effects associated with less well-understood acceptance of the low-energy particles.

The invariant mass distributions obtained with a pion hypothesis were fitted to p-wave Breit-Wigner form multiplied by a skewing factor $(m_\rho/m_{\pi\pi})^n$. M_ρ and Γ_ρ thus obtained agree well with the Particle Data Book values. We also fitted the mass distributions with a kaon hypothesis for events that are not consistent with ρ^0 to the form of a Gaussian signal plus background and obtained values of m_ϕ and Γ_ϕ that also agree well with the Particle Data Book values.

The t distributions (four-momentum transfer squared between the vector meson and the nucleon) for events from deuterium and lead targets are shown in Figs 1a and 1b, respectively. Regions corresponding to coherent production off the nucleus and incoherent production off individual nucleons are clearly identifiable in Fig. 1b.

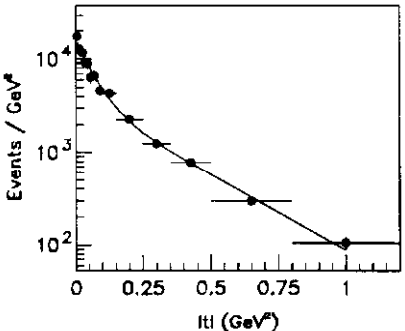

Fig. 1a t distribution for ρ and Φ candidates from a deuterium target. The curve is a fit to a1*exp(−b1*|t|)+a2*exp(b2*|t|)

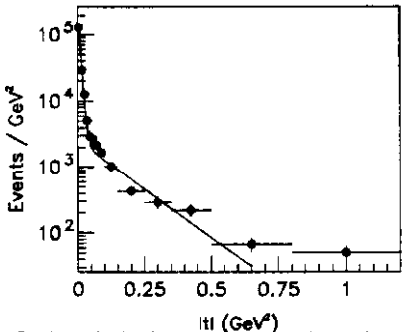

Fig. 1b t distribution for ρ and Φ candidates from a lead target. The curve is a fit to a1*exp(−b1*|t|)+a2*exp(−b2*|t|)

Events with t values greater than 0.1 GeV^2 were accepted as incoherent. Contamination from the remaining coherent events was estimated by integrating the observed coherent exponential function from 0.1 GeV^2 to infinity. The contributions were less than 1% for all the targets.

The ratios of the incoherent ρ^0 and ϕ production cross sections off carbon, calcium and lead to that off deuterium versus Q^2 are shown in Fig. 2a. It is seen

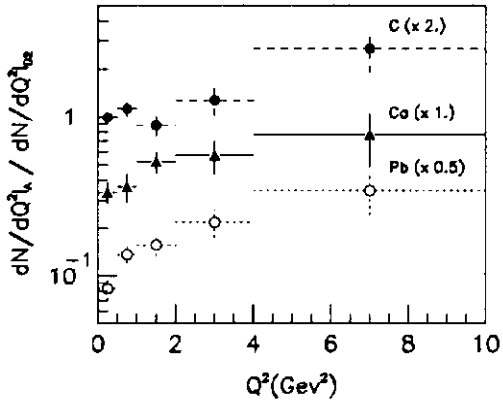

Fig. 2a $dN/dQ^2|_A$ / $dN/dQ^2|_{D2}$ vs Q^2. Note that the data points have been multiplied by 0.5, 1.0 and 2.0 respectively for the three targets.

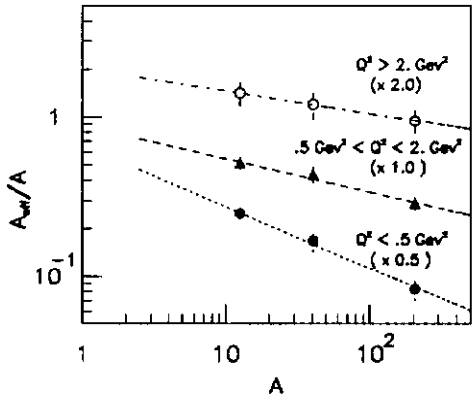

Fig. 2b A_{eff}/A vs A at different Q^2. The curves are fits to $A_{eff}/A = p(1)*A^{p(2)}$. Note that the data points have been multiplied by 0.5 1.0 and 2.0 respectively for the three Q^2 regions.

that as the Q^2 increases the per-nucleon cross sections from heavy targets all increase. In Fig. 2b the transparency, defined as A_{eff}/A, is plotted as a function of A for different Q^2 regions. The lines are fits to $p(1) * A^{p(2)}$. Clearly, as Q^2 increases the lines become less steep and the slopes of the lines approach 0 at high Q^2. This agrees well with what is expected from the color transparency arguments. As the Q^2 increases, the initial size of the produced mesons becomes smaller, and thus they experience a weaker color field on the way out. Therefore, the attenuation due to final-state interactions becomes smaller and more mesons produced in the nuclear interior emerge intact.

Effects due to the residual inclusive contaminations were estimated to be no more than 30% in the highest Q^2 bin (where the effects were the largest). The uncertainty in Q^2-independent relative normalization was estimated to be less than 7%. These uncertainties should decrease with further studies. Effects due to secondary interactions and remaining photon conversion events were estimated to be small.

In summary we have measured the cross section ratios of exclusive ρ^0 and ϕ production off carbon, calcium and lead to that off deuterium. Preliminary results show that the cross section ratios increase as the Q^2 increases, as suggested by the concept of color transparency.

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