Color Transparency via Coherent Exclusive ρ^0 Production

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We examine the potential of the COMPASS experiment at CERN to study color transparency via exclusive coherent vector meson production in hard muon-nucleus scattering. It is demonstrated that COMPASS has high sensitivity to test this important prediction of perturbative QCD.

1. INTRODUCTION

One prediction of pQCD is that high Q^2 longitudinally polarized virtual photons γ_L^* fluctuate into hadronic components, e.g. $q\bar{q}$ pairs, whose transverse size $b = |\,\bar{r}_{\perp q} - \bar{r}_{\perp \bar{q}}\,|$ decreases with Q^2, $b^2 \propto (1/Q^2)$. At large Q^2 the values of b are significantly smaller than the size of the nucleon. Such a Small Size Configuration (SSC) interacts with hadrons with small cross sections, a phenomenon known as *Color Transparency* (CT) [1–3].

Cross section for the interaction of SSC with a hadron target has been calculated in QCD using a factorization theorem [2,3]. Observing CT in particular kinematics would prove experimentally the applicability of the QCD factorization theorem for those kinematics. Such a proof provides important complementary support to a class of spin physics experiments, for example measurements of generalized parton distributions [4].

The prerequisite for observing CT is to select a sample containing SSC mini-mesons via large Q^2, high p_t, or large produced mass. For hard exclusive ρ^0 leptoproduction, in addition to large Q^2, selection of the longitudinally polarized mesons is required. In order to clearly observe CT, it is also necessary that the SSC lives long enough while propagating through the nucleus. This requirement is characterized in terms of the coherence length l_c [5,6].

Strong recent evidence for CT comes from Fermilab E791 experiment on the A-dependence of coherent diffractive dissociation of pions into two high-p_t jets [7]. Also the E691 [8] and NMC [9] results on A-dependence of coherent J/ψ photon and muon production are consistent with CT. The HERMES [6], NMC [10], and E665 [11] leptoproduction experiments have made extensive studies of CT via incoherent vector meson production (VMP), most of the data for ρ^0 production. The BNL (p,2p) [12] and SLAC (e,e'p) [13] high four momentum transfer quasi-elastic data were also compared to CT predictions.

We proposed [14] to study CT at COMPASS [15,16] via *exclusive coherent VMP* via reactions such as $\mu A \to \mu\, A \rho$ on C and Pb nuclei. The selections of coherent or incoherent production will be mainly using the t-distribution; at the lowest $|\,t\,|$ values coherent events predominate.

The basic observable for each process studied is the ratio of the nuclear transparencies for lead and carbon, $R_{\rm T} = T_{\rm Pb}/T_{\rm C} = (\sigma_{\rm Pb}/A_{\rm Pb})/(\sigma_{\rm C}/A_{\rm C})$. T is the ratio of the cross section per nucleon on a nucleus A to the corresponding cross section on a free nucleon.

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2. SIMULATION OF EXCLUSIVE ρ^0 EVENTS

Simulations were carried out [14] with a dedicated fast Monte Carlo program which generates deep inelastic exclusive coherent ρ^0 events with subsequent decay $\rho^0 \to \pi^+\pi^-$. Experimental effects such as acceptance, kinematic smearing, etc., were included. The differential cross sections for the proton target $\frac{d\sigma_N}{dt}$ is related to that for coherent production on the nucleus A by:

$$\left(\frac{d\sigma_A^{coh}}{dt}\right)_i = A^2_{\text{eff, coh}} \cdot e^{<R_A^2>\,t/3} \cdot \left(\frac{d\sigma_N}{dt}\right)_i . \quad (1)$$

Here $<R_A^2>$ is the radius squared, $A_{\text{eff, coh}}$ takes account of nuclear screening for the coherent process, and $i = L$ or T designates the polarization. An experimentally based parameterization of the cross section was used for the production on the free nucleon, $\mu N \to \mu N \rho^0$. Simulations were done as well [14] for incoherent ρ^0 production.

Coherent cross sections were generated for two models. For the complete color transparency model (CT model) $A_{\text{eff, coh}} = A$ was used. In another model, a substantial nuclear absorption (NA model) was assumed, with $A_{\text{eff, coh}} = A^{0.75}$. The experiment measures the t-integrated coherent cross section, for which the CT model via integration of Eq. 1 predicts an approximate $A^{4/3}$ dependence. For the NA model, the expected A-dependence is weaker; $A^{5/6}$ similarly as for the pion-nucleus cross section. For production of mesons not having the normal $q\bar{q}$ structure, the A-dependence of the cross section may be different. In that case, the A-dependence might even become a tool for investigating 4-quark or other exotic meson structure.

3. RESULTS ON EXCLUSIVE ρ^0 PRODUCTION

We considered 190 GeV muon beam. Simulations were done for carbon ($A = 12$) and lead targets ($A = 207$). For each target we assumed the CT and the NA models. The kinematic range considered for Q^2 and ν, the energy of the virtual photon in the laboratory system, was:

$$2 < Q^2 < 20\,\text{GeV}^2, \quad 35 < \nu < 170 \ \text{GeV}. \quad (2)$$

We observe clear coherent peaks at small $t \approx p_t^2$ ($< 0.05\,\text{GeV}^2$). The numbers of accepted events for the carbon and lead targets, assuming the two models for the nuclear absorption, are given in Table 1, for a projected 150 day run.

Table 1
Number of accepted events for the two models.

model	N_{C}	N_{Pb}
CT	70 000	200 000
NA	28 000	20 000

As Q^2 increases, the approach to the CT limit is expected to be different if the ρ^0 is produced by longitudinally or transversely polarized virtual photons. We plan to study the A-dependence of the cross sections for samples with different ρ^0 polarizations, which will be selected by cuts on the $\cos\theta$ distributions for pions from ρ^0 decays. These studies with *different polarizations* of the virtual photons are *important* for the clear demonstration of CT.

Another important aspect for CT studies is the covered range of the coherence length l_c. It is important to disentangle effects due to CT from those caused by the modified absorption at small l_c values. We may use the combined data at l_c values exceeding the sizes of the target nuclei, with the selection $l_c > l_c^{\min} \simeq 2\cdot < r^2_{\text{Pb}} >^{1/2} = 11$ fm. About 50% of events survive that cut on l_c. They cover the range of $Q^2 < 6$ GeV^2, which is expected to be sufficient to observe CT.

We estimated values and statistical precision of R_{T}, the ratio of the nuclear transparencies for lead and carbon, for different Q^2 bins for $p_t^2 < 0.02\,\text{GeV}^2$. One expects large differences in R_{T} for the two considered models. For coherent samples $R_{\text{T}} \approx 5$ for CT model and ≈ 1 for NA model. At $Q^2 \simeq 5$ GeV^2 the precision of the measurement of R_{T} for coherent events will be better than 17%, thus allowing excellent discrimination between the models.

4. COMPARISON WITH PREVIOUS EXPERIMENTS

The NMC [9], and and E691 [8] cross sections for coherent J/Ψ production have A-dependences close to $A^{4/3}$. The NMC and E665 data [10,11] on incoherent ρ^0 production cover a large range of Q^2 and l_c values. Due to the moderate statistics of the data, the Q^2 dependence of nuclear absorption could not be obtained at sufficiently large or at fixed l_c, which may obscure the expected CT effects in incoherent production [5,6]. The NMC and E665 experiments published only limited data [10,11] for coherent ρ^0 production.

The COMPASS ρ^0 production data for C and Pb will cover the kinematic range similar to that of the NMC ρ^0 production data, and with the high statistics given in Table 1. Due to large statistics, splitting of COMPASS data in several Q^2 and l_c bins as well as the selection of coherent and incoherent events, and with longitudinal or transverse ρ^0 polarization, will be possible.

5. CONCLUSIONS

We simulated exclusive coherent ρ^0 muoproduction ($\mu A \rightarrow \mu\, \rho^0 A$) events for the COMPASS experiment, using thin nuclear targets of carbon and lead. Good resolutions in Q^2, l_c, t (p_t^2) and $\cos\theta$ are feasible. An efficient selection of coherent events is possible by applying cuts on p_t^2. In order to obtain the samples of events initiated by either γ_L^* or γ_T^*, the cuts on the ρ^0 decay angular distribution of $\cos\theta$ will be used. The search for CT could be facilitated by using the events with l_c values exceeding the sizes of the target nuclei. The fraction of such events is substantial and the covered Q^2 range seems sufficient to observe CT.

We showed high sensitivity of the measured ratio $R_{\rm T}$ for different models of nuclear absorption. Good statistical accuracy may be achieved already during a 150 day run. These measurements, taken at different Q^2 intervals, may allow to discriminate between different mechanisms of the interaction of the hadronic components of the virtual photon with the nucleus, and should unambiguously demonstrate CT.

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