Update of Experiment 02-012 to PAC 27

Coherent Vector Meson Production off the Deuteron

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Abstract

The physics case for the experimental measurement of coherent vector meson production off the deuteron is just as valid today as it was when the proposal was originally submitted and approved by PAC 21 in January, 2002. The experiment will need the remaining 50 days of beam time in order to collect sufficient statistics to achieve its physics goal. We request that the approved beam time for this experiment be reaffirmed for the next 3 years, during which time we expect the experiment to run as the required solenoid, which we will use as an efficient shield against Møller electrons, has been built and will be commissioned in the spring of 2005 by E01-113[1].

A first set of electroproduction data were taken during the CLAS-e6 run period in parallel to E94-019[2] and E94-102[3], the data has been reconstructed and is being analyzed with regard to coherent ρ production. In addition, photoproduction data on deuterium was taken in Spring 2004 – in parallel to E03-113[4] – and are being analyzed.

As stated in the PAC-27 Call for Proposals, the rules for submission of an update under the jeopardy rule are:

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1. indicate clearly your desire for the experiment to remain approved;
2. update as appropriate, the scientific case for your experiment;
3. review the status of (and update, as appropriate) the membership
   of the collaboration;
4. indicate the technical readiness of the experiment; and
5. provide, if they are not already available, an up-to-date set of
   all of the documents that are now a standard part of new proposal
   submissions, ...
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We address these points in the following sections. For a comprehensive description of the experiment we refer the reader to the original proposal E02-012 which is attached.

1 Desire for the Experiment to Remain Approved

The proposers of this experiment hereby express their desire for this experiment to remain approved. The experimental study of Color Transparency (CT) phenomena in the transition region via fully exclusive measurements of coherent vector meson production off deuterium is a very important topic in hadronic physics.

This experiment forms the basis of a broad program that will ultimately unfold with the CEBAF 12GeV-Upgrade[5]. With this experiment we take the opportunity to perform these studies at the photon point and at Q^2 below 3.5 GeV^2, a kinematical regime that will be extended to $Q^2 \approx 6$ GeV^2 by the proposed measurements with CLAS++ at 11 GeV. Please note that the measurements with CLAS++ will not cover most of the kinematical regime accessible in this experiment at 6 GeV beam energy.

The list of collaborators on the present experiment has been reviewed and confirmed.

2 Update of the Scientific Case for the Experiment

We provide an update of the recent theoretical and experimental activities closely related to the physics of coherent vector meson production off the deuteron. We emphasize that this experiment will have a strong impact on the progress of investigations of color transparency phenomena. It will complement significantly the recent measurements of color transparency phenomena at HERMES and JLAB.

2.1 Introduction

Starting with the observation of the anomalous nuclear transparency in high momentum transfer $A(p,2p)X$ reaction at BNL[8] the studies of color transparency (CT) became one of the intriguing part of experimental nuclear physics for last decade. The prediction of CT is based on fundamental properties of QCD resulting in a reduced strength of strong interaction for compact color neutral configurations due to cancellation of color charges. As a result one expects an increased transparency for propagation of point-like configurations (PLC's) in the nuclear medium. PLC's can be produced in high momentum transfer reactions in which the hard scale provides the factorization of the hard interaction vertex and evolution of PLC to the final hadronic scale. In exclusive hard meson production the dominance of the leading twist contribution requires the presence of CT. Hence, investigations of CT phenomena in meson production play an important role in determining the kinematic range where such studies using nucleon targets could be used to extract the nucleon Generalized Parton Distributions (GPD's).

CT in the meson sector resembles a charge transparency for QED observed for $\pi^0 \to e^- e^+$ decay in the medium. However, the prediction of CT for the baryon sector is unique to QCD.

`As Described in the Original Proposal:`
Our goal is to study CT phenomena in the transition region from the *soft* to the *hard* limit. The main emphasis in many color transparency studies has been nucleon electro-knockout processes, although it is widely expected that one should observe the onset of color coherence in meson electroproduction earlier than for the case of nucleon knockout. The simple argument here is that it is easier to bring the $q\bar{q}$ quarks of a meson close together to form a PLC, than the qqq of the baryon. Existing and proposed experiments studying CT with meson production are concentrated on semi-inclusive reactions. In these measurements one is not able to control the interaction process in the initial and final state separately.

We propose to study color transparency phenomena in fully exclusive measurements of coherent vector meson production off deuterium, $e + d \to e' + V + d'$. These reactions offer the most promising channel for studying color coherent effects. Vector meson production has a large cross section at high energies, and the deuteron is the best understood and simplest nuclear system. The detection of the nuclear response in coincidence with the produced final state hadron will be used as a method to investigate the space-time picture of high energy two-body reactions. Exclusivity allows the kinematics of both initial and final state to be controlled separately.

Coherent production of vector mesons off deuterium at momentum transfer $-t \leq 1.5$ GeV^2 can be described by single and double scattering mechanisms. In Figure 1, the schematic diagrams for these processes are shown. Figure 1.a corresponds to single scattering, where only one nucleon participates in the interaction and, therefore, the t dependence will follow the deuteron form factor. Figure 1.b corresponds to the rescattering mechanism, where the photon interacts with one of the nucleons inside the target, produces an intermediate hadronic state which subsequently rescatters from the second nucleon before forming the final state vector meson. This process has a harder t dependence than the first one, and this is where evidence of CT will manifest itself.

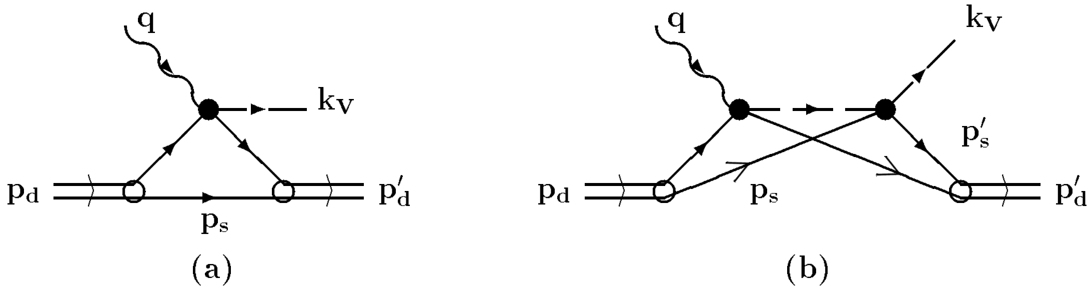


Figure 1: Single scattering (a) and double scattering contribution (b) to exclusive vector meson production in photon-deuteron collisions.

The main focus of these studies will be the CT phenomenon in the coherent vector meson production off the deuteron. The change of the slope of the t dependence at high t, with an increase of Q^2 at fixed coherence length, $l_c = 2\nu/(m_V^2+Q^2)$, will indicate a change of the re-interaction cross section. The ratio of two differential cross sections at the same Q^2 and l_c but at different t, the first one in the double scattering region (t_1), Figure 1.b, and the second one in the single (t_2) scattering region, Figure 1.a, is particularly sensitive to this change while being insensitive to systematic uncertainties:

$$R = \frac{d\sigma(Q^2, l_c, t_1)/dt}{d\sigma(Q^2, l_c, t_2)/dt} \quad ; \quad R_{(L)} = \frac{d\sigma_{(L)}(Q^2, l_c, t_1)/dt}{d\sigma_{(L)}(Q^2, l_c, t_2)/dt} \, . \tag{1}$$

In Figure 2, a model calculation of the Q^2 dependence of the ratio R for $-t_1 = 0.8$ GeV^2 and $-t_2 = 0.4$ GeV^2 is presented for ρ electroproduction. The upper curve is calculated without CT. The lower band corresponds to calculations with different assumptions for CT [6, 7]. The coherence length is fixed at $l_c = 0.5$ fm. The calculations show the expected effect is in the 10% - 15% range already at $Q^2 = 3.5$ GeV^2. The effect will be bigger for the ratio of the longitudinal part of the cross sections, $R_{(L)}$. The Q^2 dependence of $R_{(L)}$ at the same t_1 and t_2 is shown in Figure 3. In this case the expected CT effect is about 20%.

The separation of the longitudinal cross sections, $\gamma_L^* d \to d(\rho_L^0, \omega_L, \Phi_L)$ will be performed via analysis of angular momenta assuming s-channel helicity conservation (SCHC). The decay angular distribution of the vector meson, integrated over the azimuthal, is

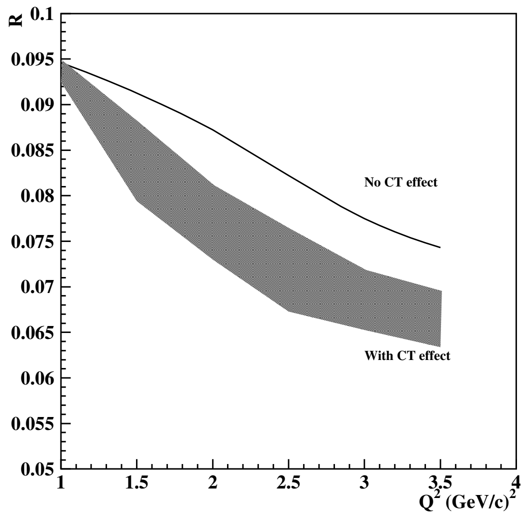


Figure 2: The ratio R of the ρ meson electroproduction cross sections, at transferred momenta $-t_1$=0.8 GeV^2, and $-t_2$=0.4 GeV^2, as a function of Q^2. The hatched part corresponds to model calculations with the assumption of the color coherence. l_c is fixed at 0.5 fm.

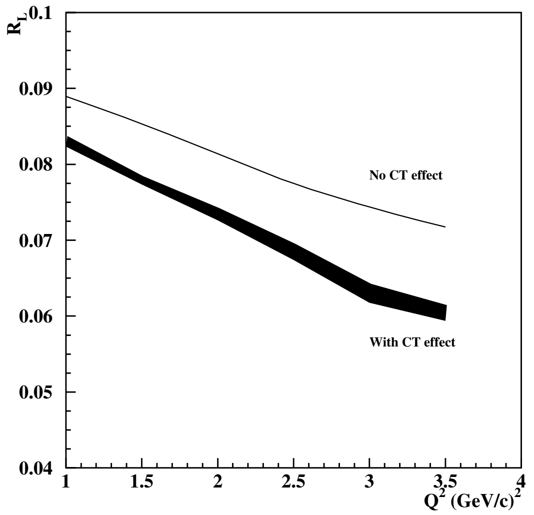


Figure 3: The Q^2 dependence of the ratio of ρ production cross sections with longitudinal photons, $R_{(L)}$, at transferred momenta $-t_1$=0.8 GeV^2, and $-t_2$=0.4 GeV^2. The hatched part corresponds to model calculations with the assumption of the color coherence. l_c is fixed at 0.5 fm.

given by [26]:

$$W(\cos\theta_{hel}) = \frac{3}{4}(1 - r^{04}_{00} + (3r^{04}_{00} - 1)\cos^2\theta_{hel}) \; . \tag{2}$$

In the case of SCHC, the polarization of the vector meson is directly related to the polarizatiaon of the virtual photon by:

$$\frac{\sigma_L}{\sigma_T} = \frac{r^{04}_{00}}{\epsilon(1 - r^{04}_{00})} \; . \tag{3}$$

the diagonal element r^{04}_{00} of the vector meson's spin density matrix is The validity of the SCHC hypothesis can easily be checked by an analysis of out-of-plane events.

2.2 Brief Review on Experimental Status of CT

The experimental studies of CT in the last decade yield rather intriguing results. First, BNL measured anomalous energy dependence of nuclear transparency for $A(p, 2p)X$ reactions[8]. It was increasing with energy – as was expected for CT – but for proton energies above 11 GeV the transparency decreased approaching the values predicted within the Glauber model. This behavior has been confirmed by later measurements [9].

Efforts to observe CT in the baryon sector via electroproduction reaction have not been successful so far. First experiments at SLAC[10] basically agreed with the Glauber prediction. JLab experiments[11, 12] extended the Q^2 range up to 8 GeV^2. They basically agreed with the SLAC data. The comparison of SLAC/JLab electroproduction and BNL hadroproduction reactions allowed to constrain the parameters describing the expansion of 3-quark PLC [13]. Note, however, that uncertainties in the quenching effect lead to significant uncertainties in the interpretation of the data [14].

In the meson sector, the first measurements were carried out at FermiLab[15], which studied the leptoproduction of ρ mesons at 600 GeV muon energy. Although a signal of the increase of nuclear transparency was observed at this energy, the experiment did not allow for separation of genuine CT signals from finite interaction length effects. This observation was further confirmed in studies of ρ meson electroproduction at intermediate energies at HERMES[16].

The most convincing observation of CT came from experimental studies of coherent dijet production in the process $\pi A \to \; jet_1 + jet_2 + A$ at FermiLab[17]. This experiment confirmed the early prediction of dramatic increase of nuclear transparency in these processes[18] as compared to soft coherent diffraction.

Reconciliation of the situation, in which a CT signal is observed at high energies but not at intermediate energies, though the probes in both cases having about the same hard scale, confirms an argument of several early papers that the space-time evolution (expansion) of PLC's leads to a strong reduction of CT. At high energies the expansion is small due to a large Lorenz factor, while at intermediate energies this effect can easily mask the CT signal.

In several theoretical works it was shown that – in order to control the large expansion effects – special reactions off the deuteron should be studied, which involve the interaction with both nucleons of the deuteron. In the case of CT studies in the baryon sector, one of such processes is the deuteron break-up in a special kinematics [19]; in the case of the vector meson production, it is coherent meson electroproduction [20]. The present proposal would be the first experiment to probe the CT signal in coherent kinematics.

During last three years the results of two new experiments were published, which studied CT in the meson sector. One was the HERMES[21] experiment, which measured the transparency of ρ meson electroproduction at kinematics of fixed interaction length in incoherent processes. The second experiment was the photoproduction of pions from nuclei at large t. Both experiments studied incoherent processes and hence did not have as good control of the background from multiple interactions as our coherent experiment. At the same time the pion production experiment does indicate an increase of CT in the large t regime.

It should also be noted that HERMES will end operation in several years leaving this experiment as a focal point of vector meson CT studies.

2.3 Brief Review on Theory Status of Vector Meson Electroproduction

From the beginning of the CT era, studies of vector meson electroproduction have been considered as one of the most promising venues for detecting CT signals.

One of the spectacular properties of vector meson electroproduction at high energies is that its amplitude is expressed through the gluon distribution of the target [22]. In this limit, when the amplitude is dominated by the production of longitudinally polarized mesons, the cross section of ρN interaction decreases with increasing Q^2 as a direct consequence of CT. Another prediction of these calculations was the increase of the production cross section at fixed Q^2, which was observed experimentally.

At intermediate energies, finite interaction length effects [23, 6] as well as expansion phenomena largely obscure CT signals. It was shown in Refs. [20, 6] that in experiments in which vector mesons are produced at large t in coherent reactions off light nuclei, the expansion effects can be suppressed. The proposed experiment largely uses the observation of these studies[20, 6] to identify the optimal kinematics for detecting CT signal. The analysis of the kinematics performed for the present proposal clearly indicates that this experiment will be an important first step in the broad program of CT studies at JLab at higher energies[5]. It will provide a first opportunity to probe near-threshold effects of vector meson production with unprecedented accuracy. The expectation that this experiment will produce significant results for near-threshold kinematics was an important impetus to set up the theory project to perform comprehensive studies of coherent photo/electroproduction of vector mesons near the threshold. The importance of using very light nuclear targets comes from the fact that such measurements allow to measure the vector meson–nucleon cross sections at threshold with high accuracies.

Presently an intensive theoretical research program is being carried out by the Penn State and FIU group[24], which will provide intensive theory support in analyzing the data. It is worth emphasizing that one may expect surprises in the near threshold dynamics already at low Q^2. Indeed, the very recent experiment at LEPS (SPRING-8) [28], which studied ϕ photo-production from Li, C, Al, and Cu nuclei at E_γ=1.5 GeV–2.4 GeV, reported a much larger strength of the $\phi - N$ interactions than according to naive expectations based on the vector dominance model. Among other things our experiment will allow to check the observation of [28] in a more controlled setting and study the effect as a function of Q^2.

During the last years progress was also made in understanding the close relation between properties of GPD's at large x and observation of CT phenomena in vector meson electroproduction[27], which opens new possibilities for linking exclusive processes and CT.

3 Technical readines of the experiment

3.1 CLAS modifications

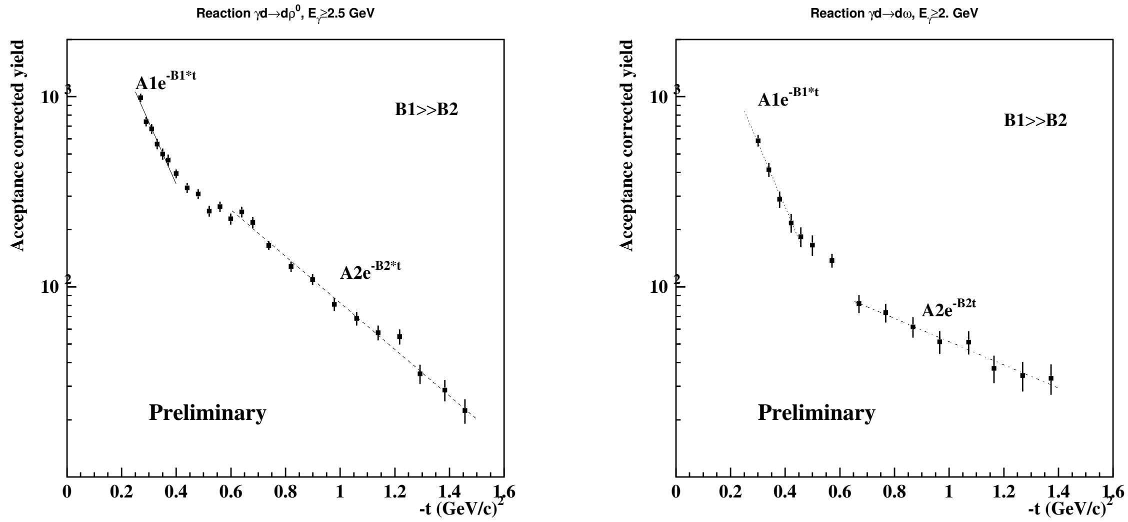
As stated in the original proposal, the experiment will be run using the existing equipment in Hall B with the following modifications:

- The standard cryogenic deuterium target will be positioned upstream of the CLAS center by 60 cm, thus increasing the detector acceptance for forward going charged particles.
- The new solenoid, which has been built at Saclay for the dedicated DVCS measurement[1] and will be transferred to Jefferson Lab in early January 2005, will be used instead of the existing 'mini-torus' to reduce more efficiently the Møller background. In conjunction with a lead shielded downstream beam pipe, the optimized solenoidal field will greatly reduce the current on the inner drift chambers (due to Møller background) and allow for running CLAS at considerably higher luminosity. Based on Monte Carlo studies and the running conditions of the `eg1` polarized target experiments, which provided an efficient shielding via the 5-T Helmholtz coils used for the dynamical target polarization, we expect this experiment to be run at a luminosity of $2{\times}10^{34}$ cm^{-2}s^{-1}.

The data acquisition and trigger system of CLAS will be used in its standard configuration for electroproduction experiments.

3.2 Data analysis

In the original proposal we presented invariant mass and missing mass spectra from an analysis of CLAS-g2a photoproduction data on deuterium. A much larger set of γd data, taken in Spring 2004 to support the search for exotic baryon states [4], has meanwhile been reconstructed. We are currently analyzing the data with respect to coherent vector meson production. Well-identified ωd events with ω decaying into $\pi^+\pi^-\pi^0$ and Φd events with $\Phi \to K^+K^-$ as well as $\pi^+\pi^- d$ events with an invariant mass of the two-pion system in the mass range of ρ^0 are being studied with regard to their t-dependence.



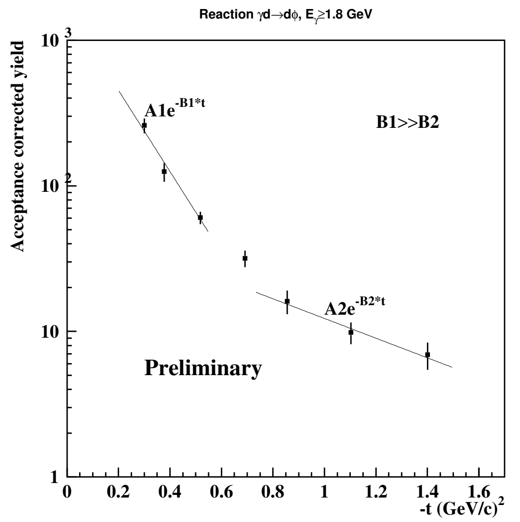


Figure 4: Preliminary results of the t-dependence of coherent vector meson photoproduction. The statistics is based on the CLAS γd data taken in spring 2004 (`g10` run period).

For photon energies above the resonance region our preliminary results show a characteristic change from a steep slope – as expected from diffractive production – to a less steep one at higher momentum transfer for all three vector mesons, see Fig. 4. The behavior will further be investigated.

We are analyzing the electroproduction data on deuterium at 5.76 GeV electron beam energy (`e6` run period) as well. However, the extraction of coherently produced vector mesons suffers from the low yield of reconstructed deuterons in the final state. Coherent vector meson production data are being selected by requiring an additional meson (π^+ or K^+) in coincidence. A very preliminary plot of the ratio R of electroproduction cross sections at fixed Q^2 and coherence length l_c, but different transferred 4-momenta

t_1, t_2 is shown in Fig. 5. It is clear that a significantly larger data set is necessary to distinguish whether the CT effect is present or not. Our full complement of beam allocation will ensure this success. Please note that the lack of statistics did not allow for similar analyses of for ωd and Φd events.

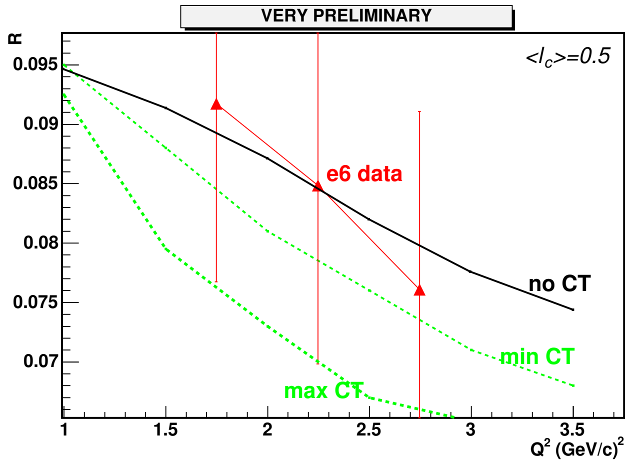


Figure 5: First preliminary result for the Q^2 dependence of the ratio R of ρ^0 production at transferred momenta $t_1 \approx -0.8$ GeV^2 and $t_2 \approx -0.3$ GeV^2, extracted from CLAS-e6a data.

3.3 Revised run plan

The new optimized solenoid for shielding of Møller background will be used in the DVCS measurement in the spring of 2005, and is then available for use in other experiments with CLAS. The anticipated increase of luminosity by a factor of two compared to the current operation of CLAS is already taken into consideration in the original proposal. Therefore, **we ask for a confirmation of our original request of 50 days of beam time** to run CLAS in the modified configuration described in Section 3.1.

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