CEBAF Program Advisory Committee Nine
Extension and Update Cover Sheet

This update must be received by close of business on Thursday, December 1, 1994 at:

CEBAF
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Experiment: E 93-031

Check Applicable Boxes:

☒ Extension ☐ Update ☒ Hall B Update

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Receipt Date: 12/15/94

By: gp PR 94-141

Photoproduction of Vector Mesons at High t

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UPDATE

At low values of momentum transfer t, exclusive photoproduction of vector mesons occurs mainly through the coupling of the photon to an intermediate vectormeson which diffractively scatters from the target. This corresponds to the Vector Meson Dominance Model (VDM) and the cross section depends only on the size of the meson and the target. At high t, hard processes are expected to take over and the production is thus more sensitive to quark and gluon exchange mechanisms.

Production of ρ and ω mesons proceeds mainly through valence quark rearrangement mechanisms and exhibits a s^{-7} behavior at large t. On the contrary, production of ϕ mesons proceeds mainly through two gluon exchange: to the extent that ϕ meson is a pure $s\bar{s}$ state, quark exchange is OZI suppressed if the strangeness content of the nucleon is small. Such a two gluon exchange predicts a dip in the t dependence of the cross-section near t = -2.3 GeV^2. It arises from the interference of two amplitudes. In the first, both gluon couples to a single strange quark; in the second, a gluon couples to the quark s and the other to the antiquark $\bar{s}$. These amplitudes provide us with a model [1] of the hard part of the Pomeron, and match smoothly the full Pomeron exchange amplitude around t =1 GeV^2. If indeed ϕ production on the proton is dominated by two gluon exchange, it will be a unique way to study quark correlations and, more particularly, hidden color components in nuclei.

The proposed experiment will provide, for the first time, an accurate determination of the t dependence of the cross-section for exclusive photoproduction of ρ,ω and ϕ mesons on the proton and ^3He up to values of t around 5 GeV^2. Scarce data exist in this range for ρ and ω production. They have however been obtained with an untagged bremsstrahlung photon beam and no complete identification of the final state has been achieved. No data exist for ϕ production for $t > 1$ GeV^2. At such high values of momentum transfer, hard processes are dominating and ϕ production is much suppressed as compared to ρ and ω production. The comparison between the light quark sector and the strange sector will provides us with a deeper understanding of the corresponding mechanisms. The polarization of the outgoing vector meson will also be determined by the analysis of the angular distributions of their decay products. For instance, the polarization of the ϕ , as measured by analysing the angular distribution of the kaons, may give interesting information on possible strange content of the proton. Finally, data for the reactions $\gamma p \to k^- \Lambda$ and $k^+ \Sigma$ at high t will be recorded in the same energy range.

This experiment will make use of the tagged photon beam in Hall B and of CLAS to detect the recoiling proton and theρ,ω and ϕ by their decay channels $\pi^+\pi^-$,$\pi^+\pi^-\pi^0$ and k^+k^- respectively. CLAS will be operated at its highest field to get the best reconstructed meson mass resolution, and we will trigger on two positive charged particles, outbending. Pion-kaon separation is achieved using ToF information and kinematic correlations. The good tagger resolution always allows a clean background rejection, at least around 4 GeV.

While the experiment can be run at CEBAF nominal energy of 4 GeV, it will greatly benefit of any increase of CEBAF energy. First, the theoretical description of hard processes becomes more valid as the energy increases. Also the study of the variation of the cross-sections with energy is certainly worthwhile[1]; the cross-section of quark interchange mechanisms varies as s^{-7} , while the cross-section of two gluon exchange processes is almost constant. However, π/ K separation by time of flight becomes less definitive at photon energies above 4 GeV, according to the expected CLAS performances. Here only kinematical constraints will remain to clearly idenfy each channel. While this is fine for channels where all the particles are charged, this does not allow to get rid of channels where one or more particles are neutral (see Fig. 16 in the proposal). The channel identification will depend on the actual level of this neutral background in a kinematical regime where very little is known. Therefore it will be wise to split the data taking part of the run into two periods: a short one as early as possible, and a longer one. The first period will be used to define the beam conditions in the second run, not only after checking π/ K separation, but also after mastering the backgrounds in this almost virgin domain.

Meanwhile, we are making good progress on our various contributions to the preparation of this experiment. Construction of the focal-plane array for the Photon Tagger is proceeding on schedule at GWU, construction of the large angle shower-counter array is proceeding on schedule at Genoa and Frascati, and construction of the cryogenic-liquid target system is proceeding on schedule at Saclay. Detailed simulations of electromagnetic and neutral backgrounds in photoreaction experiments performed with an extended cryogenic target are underway. Also, the theoretical frame underlying the analysis of this experiment have been put on firmer basis[1]. Finally, we have investigated the feasibility and the expected accuracy of the determination of the density matrix of the produced vector meson, via its decay distribution. This is reported in the attached extension.

EXTENSION

In our proposal we have shown that the photoproduction of vector mesons at large momentum transfer t on the nucleon represents an original and relatively straightforward method to study and disentangle two gluon and quark exchange mechanisms A different behaviour of the cross section at high energy and high momentum transfer is expected: the differential cross section of the $\gamma p \rightarrow \phi p$ channel, where two gluons exchange mechanism dominates, should exhibit a characteristic node, while the cross section of the $\gamma p \rightarrow \rho/\omega\, p$ reaction, where quark rearrangement process play a significant role, should exhibit a more flat pattern and a s^{-7} scaling behaviour [1] However, more complex processes could interfere with these dominant mechanisms and affect their momentum dependence. To achieve a deeper understanding of hard mechanisms we have a complementary method already mentioned in our proposal: the analysis of the decay angular distribution of the photoproduced meson . In the extension , we investigate its feasibility and the expected uncertainties.

The angular distribution of the decay products,$W(\theta,\phi)$, can be written in terms of the density matrix elements $\rho_{\lambda\lambda'}$ of the vector meson. For the case of unpolarized photons we have only three elements[2]:

$$W(\theta,\varphi)=\frac{3}{4\pi}\left(\frac{1}{2}\sin^2\theta+\frac{1}{2}\left(3\cos^2\theta-1\right)\rho_{00}-\sqrt{2}\,\mathrm{Re}\,\rho_{10}\sin 2\theta\cos\varphi-\rho_{1-1}\sin^2\theta\cos 2\varphi\right)$$

where ρ_{00} represents the transition from transverse photons to longitudinal mesons and ρ_{10} ,ρ_{1-1} are the interference between helicity and non helicity flip amplitudes. In the case of s-channel helicity conservation (SCHC) , ρ_{00}, ρ_{10} and ρ_{1-1} vanish identically in the helicity frame and the angular distribution assumes a simple $\sin^2\theta$ behaviour.

SCHC holds in the Vector Meson Dominance (VMD) model which fairly well describes the diffractive process at low momentum transfer as measured in different experiments[3]. Even though no data exist at high t, SCHC is predicted to continue to hold in two gluon exchange. SCHC , however, will not applay in the case of a quark rearrangement scenario

. This latter process is inhibited in ϕ meson production but dominates in the ρ^0,ω channels at least for photon energies lower than 8 GeV. This is clearly shown in fig. 1 where the ρ^0 photoproduction cross section on the proton[4] is reported as a function of the photon energy at -t ≈3–4 $(GeV/c)^2$. The continuous curve describing the data scales as s^{-7}, the behavior predicted by quark exchange model, and becomes of the same order of the two gluon exchange contribution (continuous curve) at Eγ≈ 8 GeV.

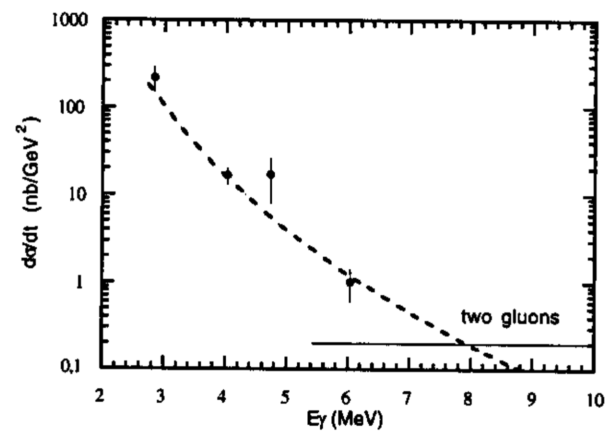

Fig. 1: *the differential cross section for the $\gamma p \to \rho^0 p$ channel at -t ≈ 3–4 $(GeV/c)^2$ as a function of the photon energy: the dashedcurve is the s^{-7} behaviour predicted by the quark exchange mechanism while the two gluon exchange contribution is the energy- independent continuous curve.*

In the $\gamma p \to p\rho^0/\omega^0$ channel, the experimental determination of the three ρ_{00}, ρ_{10} and ρ_{1-1} matrix elements far from the diffractive peak allows, therefore, to determine the onset of the quark rearrangement mechanism and to disentangle between this process and the exchange of the two gluons .

In the $\gamma p \to \phi$ p channel, a possible strange component in the nucleon could result in a direct knock-out of strange-antistrange pairs which violate SCHC, leading to a non vanishing ρ_{10} and ρ_{1-1}

From the experimental point of view only few real photoproduction of vector meson experiments were able to extract these matrix element from the measured data[5]. These experiments were performed at photon energies Eγ ≈ 4 GeV with the bubble-chamber technique and , due to the low counting statistics, only values at momentum transfer lower than 1 GeV^2 were accesible. For the ρ^0 channel at Eγ = 4.7 GeV SCHC is observed for -t < 0.4 GeV^2 while a small violation is present for 0.4<-t<0.8 (ρ_{00} = 0.28   0.054) indicating the possible onset of the hard processes for these values of momentum transfer.

In our proposal we demonstrated that for -t up to 4 GeV^2 we can unambiguously identify the vector mesons ϕ,ρ^0 and ω in the presence of the phase-space background at least for photon energies lower than 4 GeV. From this earlier analysis, we have evaluated the expected statistical uncertainties in extracting the density matrix elements, ρ_{00}, ρ_{10} and ρ_{1-1} from the decay angular distribution of the vector meson.
Integrating $W(\theta,\phi)$ over ϕ provides information on the sensitivity of the angular distribution to variations in ρ_{00}:

$$I(\theta) = \int W(\theta,\varphi)d\varphi = \frac{3}{4}\left(sin^2\theta + \left(3\cos^2\theta - 1\right)\rho_{00}\right)$$

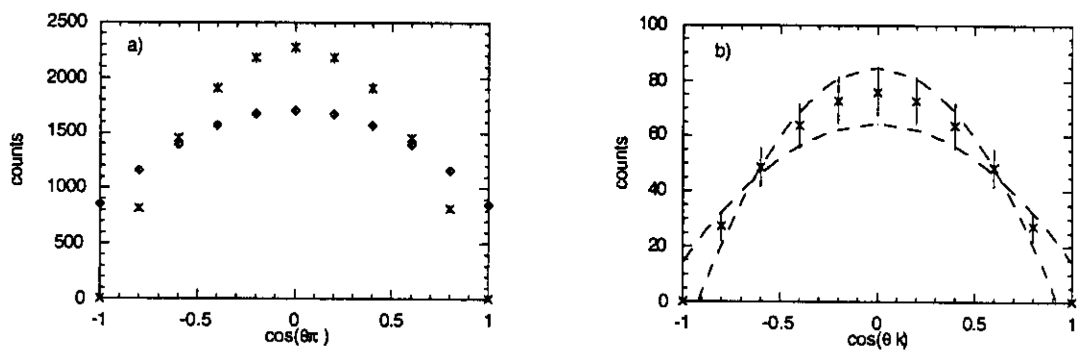

Fig.2: *a)the angular distribution of the pion from the ρ^0 decay in the helicity frame as expected in the kinematical conditions described in the text: crosses and open circles respectively correspond to SCHC ($\rho_{00}=0$) and non-zero helicity -flip ($\rho_{00}=0.2$); b) same for the ϕ decay: here the dashed curves indicate the sensitivity on the ρ_{00} coefficient ($\rho_{00} = 0. \pm 0.1$) .*

Our statistical uncertainties are determined from the following conditions:
photon energy bin : $3.5<E\gamma<3.6$ GeV (E_0= 4 GeV, E_{tag}= 3 to 3.6 GeV)
photon flux: 2 10^6 photons/s in the bin
detection efficiency: 30%
momentum transfer and cross section : -t = 1.6 0.15 GeV^2, $d\sigma/dt \approx 60$ nb/GeV^2
target: liquid hydrogen ($\rho x = 0.7$ gr/cm^2)
running period: 400 hrs (already granted to 93-031)
In fig. 2a) we plot the results of setting ρ_{00} equal to zero (SCHC) and ρ_{00}=0.2 (small violation in SCHC) for the ρ^0 channel. The case for produced ϕ mesons is depicted in fig 2b). Although the cross section is reduced ($d\sigma/dt$ = 2 nb/GeV^2 at t = -1.6 GeV^2), the

counting rate is still sufficient to precisely determine ρ_{00} as can readily be seen in fig. 2b where the dashed curves correspond to to $\rho_{00} = 0.\ 0.1$

In order to investigate the sensitivity of our measurement on ρ_{1-1}, the same $W(\theta,\phi)$ angular distribution can be integrated with respect to the polar angle θ to obtain:

$$J(\varphi) = \int W(\theta,\varphi)d\theta = \frac{1}{2\pi}(1 - 2\rho_{1-1}\cos 2\varphi)$$

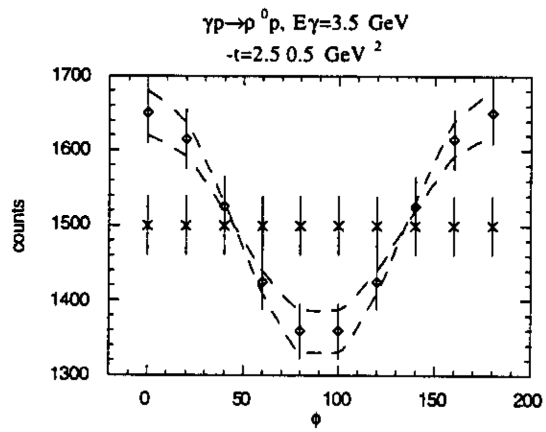

Fig.3: The expected azimuthal distribution of the pion from ρ^0 decay in the in the helicity frame with the indicated kinematical conditions; the evaluation is performed for SCHC (crosses) and non-zero ρ_{1-1} coefficient (open circles, ρ_{1-1}=-0.05) .The dashed curves correspond to ρ_{1-1}=-0.05±0.01

Due to the $\cos 2\phi$ azimuthal dependence, the events can be binned into two intervals in ϕ: $0<\phi<\pi$ and $\pi<\phi<2\pi$. We can then integrate over these two intervals which will allow the cross check of our results, and provide a handle on our systematics. To determine how well we may extract photoproduced ρ^0 mesons at $-t = 2.5\ \ 0.5$ we varied ρ_{1-1} from 0.0 to -0.05 0.01. The results are plotted in fig.3 which indicate high sensitivity to extracting the ρ_{1-1} coefficient.

The simultaneous analysis of the whole $W(\theta,\phi)$ angular distribution represents, however, the most efficient method to determine the values of the three ρ_{00}, ρ_{10} and ρ_{1-1}parameters.

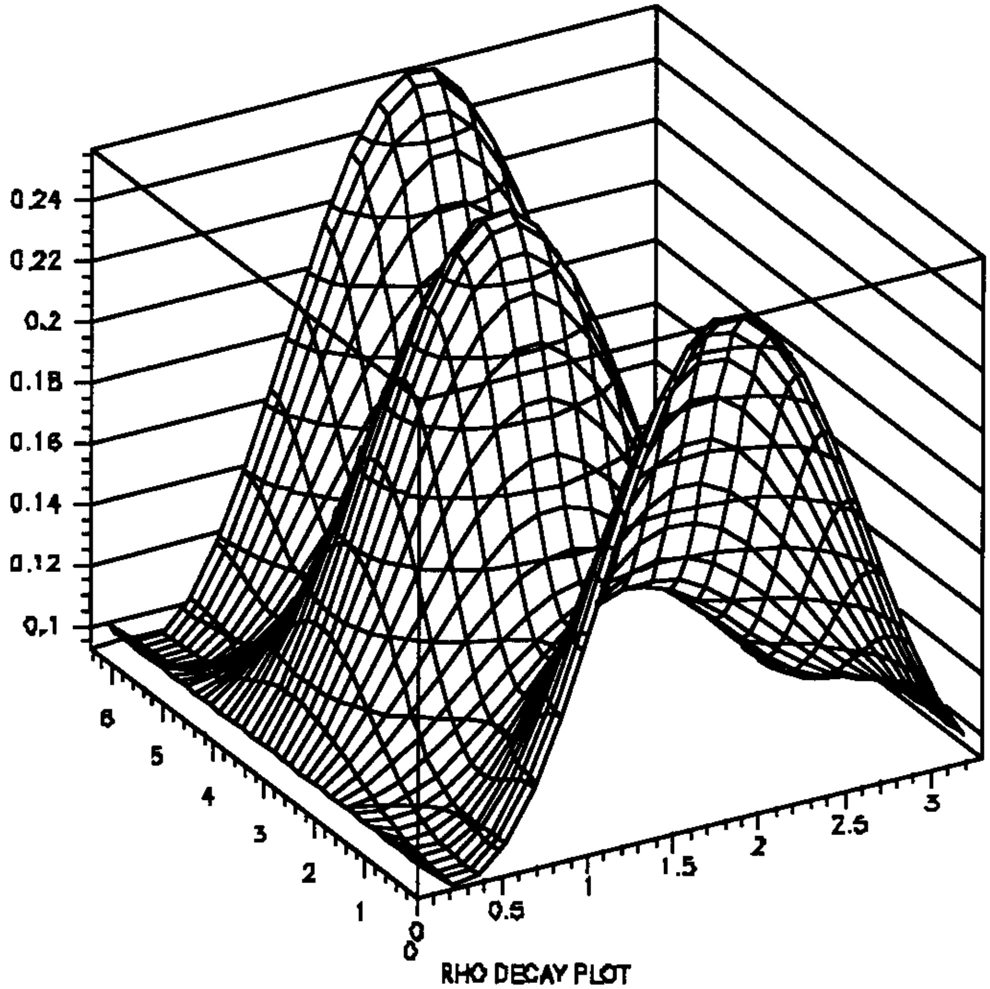

Fig 4: the angular distribution of the pion from the ρ^0 decay evaluated using the experimental values of values three parameters ρ_{00}, ρ_{10} and ρ_{1-1} as measured in ref. 5

As an example, in fig. 4 the angular disrtibution of the pion from ρ^0 decay is presented, the curve being evaluated using the experimental values of ρ_{00}, ρ_{10} and ρ_{1-1} as measured in the momentum transfer range $0.4<-t<0.8$ $(GeV/c)^2$.[5]

The non-zero value of the parameters (ρ_{00}=0.2, ρ_{10}=0.05, ρ_{1-1}=−0.05) is still sufficient for a sizable departure from the ϕ-independent distribution expected with SCHC. Clearly both the counting statistics of the measurement and the shape of the angular distribution will determine the size of the binning in θ,ϕ : the effect of this optimisation in the determination of the errors on the three parameters ρ_{00}, ρ_{10} and ρ_{1-1} is still underway.

References

[1] J.M. Laget and R.Mendez-Galain, *Nucl Phys. A* (in press)

[2] K.Shilling et l., *Nucl.Phys.* **B15** (1970) 397

[3] T.H.Bauer et al., *Rev. Mod. Phys.* **50** (1978) 261

[4] R.L.Anderson et al., *Phys. Rev.* **D14** (1976) 676

[5] J.Ballam et al., *Phys. Rev.* **D5** (1972) 545

LAB RESOURCES REQUIREMENTS LIST

CEBAF Proposal No.: ______________________ Date: ______________
(For CEBAF User Liaison Office use only.)

List below significant resources — both equipment and human — that you are requesting *from CEBAF* in support of mounting and executing the proposed experiment. Do not include items that will be routinely supplied to all running experiments, such as the base equipment for the hall and technical support for routine operation, installation, and maintenance.

***Major Installations** (either your equip. or new equip. requested from CEBAF)*

New Support Structures: ______________

Data Acquisition/Reduction

Computing Resources: ______________

New Software: ______________

Major Equipment

Magnets ______________

Power Supplies ______________

Targets ______________

Detectors ______________

Electronics ______________

Computer Hardware ______________

Other ______________

Other

HAZARD IDENTIFICATION CHECKLIST

CEBAF Proposal No.: ____________________ Date: ____________
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Check all items for which there is an anticipated need.

Cryogenics ____ beamline magnets ____ analysis magnets __√__ target type: ________ flow rate: ________ capacity: ________	**Electrical Equipment** ____ cryo/electrical devices ____ capacitor banks ____ high voltage ____ exposed equipment	**Radioactive/Hazardous Materials** List any radioactive or hazadorous/ toxic materials planned for use: ________ ________ ________ ________
Pressure Vessels ____ inside diameter ____ operating pressure ____ window material ____ window thickness	**Flammable Gas or Liquids** type: ________ flow rate: ________ capacity: ________ **Drift Chambers** type: ________ flow rate: ________ capacity: ________	**Other Target Materials** ____ Beryllium (Be) ____ Lithium (Li) ____ Mercury (Hg) ____ Lead (Pb) ____ Tungsten (W) ____ Uranium (U) ____ Other (list below) ________ ________
Vacuum Vessels ____ inside diameter ____ operating pressure ____ window material ____ window thickness	**Radioactive Sources** ____ permanent installation ____ temporary use type: ________ strength: ________	**Large Mech. Structure/System** ____ lifting devices ____ motion controllers ____ scaffolding or ____ elevated platforms
Lasers type: ________ wattage: ________ class: ________ Installation: ____ permanent ____ temporary Use: ____ calibration ____ alignment	**Hazardous Materials** ____ cyanide plating materials ____ scintillation oil (from) ____ PCBs ____ methane ____ TMAE ____ TEA ____ photographic developers ____ other (list below) ________ ________	**General:** Experiment Class: __√__ Base Equipment __√__ Temp. Mod. to Base Equip. ____ Permanent Mod. to Base Equipment ____ Major New Apparatus Other: ________ ________

BEAM REQUIREMENTS LIST

CEBAF Proposal No.: ______________________ Date: ______________
(For CEBAF User Liaison Office use only.)

List all combinations of anticipated targets and beam conditions required to execute the experiment. (This list will form the primary basis for the Radiation Safety Assesment Document (RSAD) calculations that must be performed for each experiment.)

Condition #	Beam Energy (MeV)	Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Target Material Thickness (mg/cm²)
	4000	$10^7 \gamma/s$ $3.6 < E_\gamma < 3.9$ GeV	; tagged photon beam	H	~1000

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. For 1995, E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Starting in 1996, in an evolutionary way (and not necessarily in the order given) the following additional values of E_{Linac} will become available: E_{Linac} = 400, 500, 600, 700, 900, 1000, 1100, and 1200 MeV. The sequence and timing of the available resultant energies, E_{Beam}, will be determined by physics priorities and technical capabilities.