CEBAF PROPOSAL COVER SHEET

This Proposal must be mailed to:

CEBAF
Scientific Director's Office
12000 Jefferson Avenue
Newport News, VA 23606

and received on or before OCTOBER ~~30~~ 31, 1989

A. TITLE: Nuclear Mass Dependence of Vector Meson Interactions Using The Photoproduction of Lepton Pairs

B. CONTACT PERSON: Barry M. Preedom/Gary S. Blanpied

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C. THIS PROPOSAL IS BASED ON A PREVIOUSLY SUBMITTED LETTER OF INTENT

[X] YES
[ ] NO

IF YES, TITLE OF PREVIOUSLY SUBMITTED LETTER OF INTENT

LOI 88-37 Photoproduction of Particle Pairs
LOI 87-06

D. ATTACH A SEPARATE PAGE LISTING ALL COLLABORATION MEMBERS AND THEIR INSTITUTIONS

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(CEBAF USE ONLY)

Proposal ~~Letter~~ Received 10-26-89

Log Number Assigned PR-89-ØØ1

By KES

Contact person: Preedom

Collaboration Members

University of South Carolina:

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CEBAF/CLAS Collaboration

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All other interested members of the formal CLAS collaboration

I. Introduction

This proposal requests approval for early beam time using the CLAS at CEBAF at a priority sufficient to continue the design of and preparation for the experimental program described herein. The purpose of this program is to measure the nuclear mass (A) dependence of neutral vector meson photoproduction amplitudes by detecting lepton pairs. Such measurements are relatively free from non-resonant backgrounds such as those which result from pions produced in the initial state and from final state interactions of the pions resulting from the vector meson decay. The proposed measurements can even determine the phase of the photoproduction amplitudes in the region of interference with the QED Bethe-Heitler pairs. By relating the measured phase to the meson-nucleus amplitude it should be possible to test models for the meson-nucleon amplitudes and models for the modification of those amplitudes in nuclear matter. While such measurements have been made on H, Be, and C targets, no systematic study of the A-dependence of the phases exists.

The design of CEBAF and the CLAS detector are uniquely suited for this study. The energy region of 1 to 4 GeV (to 6 to 10 GeV) is the transition region in which the photon acquires hadronic dressing, the CW nature of the beam facilitates coincidence measurements, and the CLAS detector has a large acceptance in angle and momentum with good resolution.

II. The Past

The experimental and theoretical situation concerning the hadronic properties of the photon, photonuclear shadowing, vector meson production, etc. is summarized (up to 1978) in the excellent review by T.H.

Bauer et al.[1] While there is a vast amount of data on the photoproduction of vector mesons as a function of A, k_γ, and t (-square of the four momentum transfer) there are very few data from studies of photoproduction using lepton pairs and even less from studies of the interference phenomena. This paucity of data is simply understood by the small cross-sections (including small branching ratios $\sim 10^{-5}$) and small detector acceptances of past experiments. Specific parts of reference 1 concerning the interference of lepton pairs are sections III.C.4.g, III.C.4.h, III.E.4, IV.D, especially IV.E, and VI.A.2.

The amplitude for lepton pair production can be written as

$$\mathcal{A}_T = \mathcal{A}_\rho(\gamma) + \mathcal{A}_\omega(\gamma) + \mathcal{A}_\varphi(\gamma) + \mathcal{A}_{BH}(2\gamma) + \mathcal{A}_{BH}(3\gamma) + \mathcal{A}_X(\gamma)$$

where the first three amplitudes $\mathcal{A}_V$ are the Compton amplitudes for $\gamma + A \rightarrow A + (V \rightarrow e^+e^-)$

(V is the photoproduced vector meson ρ, ω, φ),

$\mathcal{A}_{BH}$ is the Bethe-Heitler amplitude,

and $\mathcal{A}_X$ is the Compton amplitude for $\gamma + A \rightarrow X + (V \rightarrow e^+e^-)$.

Because of charge conjugation invariance, there is an interference term for production of lepton pairs which have asymmetric four-momenta. This interference results from amplitudes having even and odd numbers of photons. For coherent (elastic) photoproduction, this interference term can be written as

$$|\mathcal{A}_{Asymmetry}|^2 = 2\mathrm{Re}\left\{\left[\mathcal{A}_\rho(\gamma)+\mathcal{A}_\omega(\gamma)+\mathcal{A}_\varphi(\gamma)\right]\mathcal{A}_{BH}(2\gamma)+\mathcal{A}_{BH}(2\gamma)\mathcal{A}_{BH}(3\gamma)\right\}$$

Since the Bethe-Heitler amplitude is real, a measurement of the yield of asymmetric pairs depends on the phase $ie^{i\varphi_V}$ of the amplitude $\mathcal{A}_V(\gamma)$. This phase can be used with the optical theorem

$$\mathrm{Im}\left[\mathcal{A}(VA \rightarrow VA)\right]_{t=0} = \frac{k}{4\pi}\sigma_{VA}$$

to determine the ratio (α_V) of the real to imaginary vector-meson-nucleus amplitude

$$\mathcal{A}(VA \rightarrow VA)_{t=0} = \frac{ik}{4\pi} \sigma_{VA} \ (1 - i\alpha_V)$$

Models for vector meson photoproduction calculate this amplitude using the fundamental vector-meson-nucleon amplitude. A major aspect of this proposal is to measure the A-dependence of the phase φ_V.

A. Previous Experiments

Existing experiments of the type proposed here are summarized in Table I and outlined in more detail in the Appendix. This section presents some aspects of the measurements to indicate the features of the data that can be expected from the present proposal. In this text the invariant mass of the electron pairs will be m_{ee}.

In Fig. 1, the BH-Compton interference is shown for the absolute cross section as a function of m_{ee} in the region of the ρ. The data is from ref. 7 for the reaction $\gamma + C \rightarrow C + e^+e^-$. The quantity $N^{\pm}$ in Fig. 1 is the coincident pair yield when the $e^{\pm}$ is detected in the spectrometer arm having the smaller angle. The spectrometers had central momenta of 1.802 GeV/c and the data were taken at seven angles between 11.2° and 13.3° (arm angle) using a bremmstrahlung beam with k_{MAX} = 4.1 GeV.

Another way to view the interference effect is to plot the data as a function of the transverse momentum transferred to the nucleus. This quantity is shown as $p_R\theta_R - p_L\theta_L$ in Fig. 2a where R and L refer to right and left arm spectrometers along the beam direction. The data are from ref. 4 for $\gamma + Be \rightarrow Be + e^+ + e^-$. They were taken with a bremsstrahlung beam of k_{MAX} = 7.0 GeV, spectrometer central momenta of 2.560 GeV/c and angles for

TABLE I

Targ.	k_{MAX}(GeV)	Range of m_{ee} (MeV/c^2)	Type of Interference	Result	Ref.
C	6.0	770±50	BH-Compton	$\varphi_\rho=15^o\pm25^o$	2
Pb	6.25	≤ 500 MeV/c^2	BH(2γ)-BH(3γ)		2
Be	7.00	700-870	ρ-ω	$\varphi_{\rho\omega} = 41^o\pm20^o$ $\gamma^2_\omega\sigma_{\rho N}/\gamma^2_\rho\sigma_{\omega N}=9.4^{+2.6}_{-1.6}$	3
Be	7.00	610-850	BH-Compton	$\varphi_\rho=11.8^o\pm4.4^o$	4
C	7.4	920-1080	BH-Compton	$\varphi_\varphi=25^o\pm15^o$	5
C	4.1	675-850	ρ-ω	$\varphi_{\rho\omega}=100^{o+38^o}_{-30^o}$ $\gamma^2_\omega/\gamma^2_\rho=7.0\pm2.9$	6
C	4.1	590-830	BH-Compton ρ-ω	$\varphi_\rho=16.6^o\pm6.2^o$ $\varphi_{\rho\omega}=118^{o+13^o}_{-22^o}$	7
H	7.2	900-2200	BH-Compton	"new" structure	8
H	7.2, 6.0	500-1060	BH-Compton	$\varphi_\rho=37.5^{o+2.8^o}_{-3.1^o}$ $\varphi_\omega=29.6^{o+15.5^o}_{-12.9^o}$ $\varphi_\varphi=3.4^{o+5.3^o}_{-4.2^o}$	9
H	7.2	900-1500	BH-Compton	"new" structures	10

Biggs et al., p. 1157

For a complex target nucleus it has been shown[7] that in addition to the ρ-nucleon phase angle $\varphi_{\rho N}$, the measured total scattering phase angle $\varphi_{\rho A}$ contains a contribution due to refraction and absorption of the vector meson within the nucleus. This latter quantity is given by the relationship $\varphi_{\rho A} = \varphi_{\rho N} + \theta(\varphi_{\rho N}, R)$, where θ is the additional phase change due to a nucleus of radius R. Carbon, with a very small value of $\theta(\varphi_{\rho N}, R)$, was found to be a suitable target material.

The experiment was carried out using a magnetic pair spectrometer. Its properties are described elsewhere.[4,5] A total mass range of 590–830 MeV/c^2 and transverse momentum range of 50–150 MeV/c were covered. Only asymmetric pairs were detected.

Let $N^{\pm}$ denote the pair yield when leptons ($e^{\pm}$) are detected at the smaller spectrometer-arm angle, the momenta in the arms being equal. At each configuration of the apparatus, half of the data, N^+, were obtained with one set of magnet polarities, and the other half, N^-, with the polarities reversed. The number of events in each mass bin, $N^{\pm}(m^2)$, arises from several contributions to the cross section:

$$N^{\pm}(m^2) = N_{\mathrm{BH}}(m^2) + N_V(m^2) \pm [N_{\mathrm{BH},V}(m^2) + N_{2B}(m^2)],$$

where $N_{\mathrm{BH},V}$ is the BH-Compton interference yield, and $V = \rho$, ω, $\rho\omega$ interference. The yield

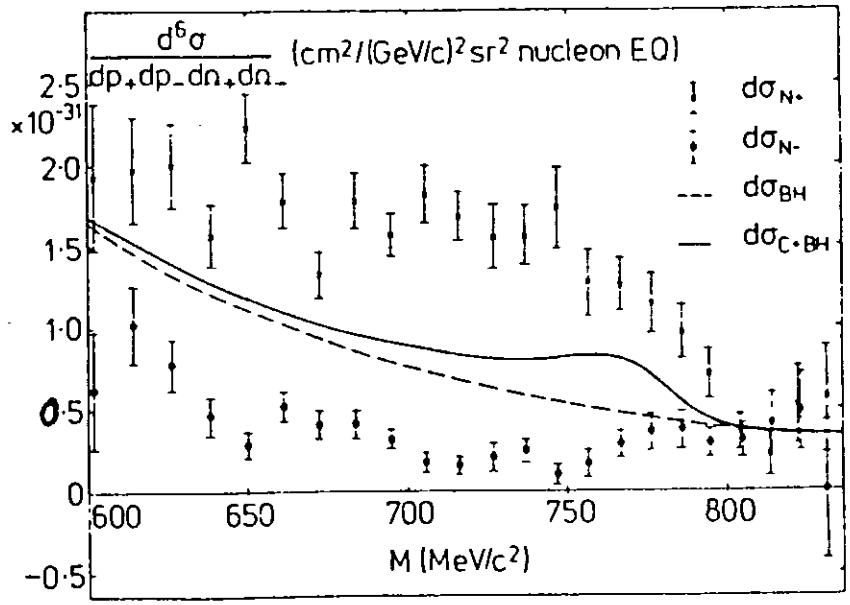

FIG. 1. The differential cross section for the $N^{\pm}$ yields as a function of invariant pair mass. The dashed line is the theoretical BH cross section, and the continuous line is the sum of the BH and fitted Compton cross sections.

Fig. 1

The data $\epsilon(m^2)$ were fitted allowing the parameters $\varphi_{\rho A}$ and $\varphi_{\rho\omega}$ to be variable, and fixing the parameters m_ρ, $\Gamma_\rho{}^0$, m_ω, Γ_ω, and $\gamma_\omega{}^2/\gamma_\rho{}^2$ at the values 768 MeV/c^2, 146 MeV/c^2, 783.4 MeV/c^2, 12.6 MeV/c^2, and 7.0, respectively.[9,10] The best fit to the data [Fig. 2(a)] gives $\varphi_{\rho A} = 16.5° \pm 6.2°$ and $\varphi_{\rho\omega} = 118°{}^{+13°}_{-22°}$.

The sensitivity of the best fit to variations of the above fixed parameters was investigated. By far the largest contribution to the error in $\varphi_{\rho A}$, amounting to $\pm 2.1°$, results from an uncertainty of ± 5 MeV/c^2 in m_ω. However, this contribution

Alvensleben et al., p. 1577

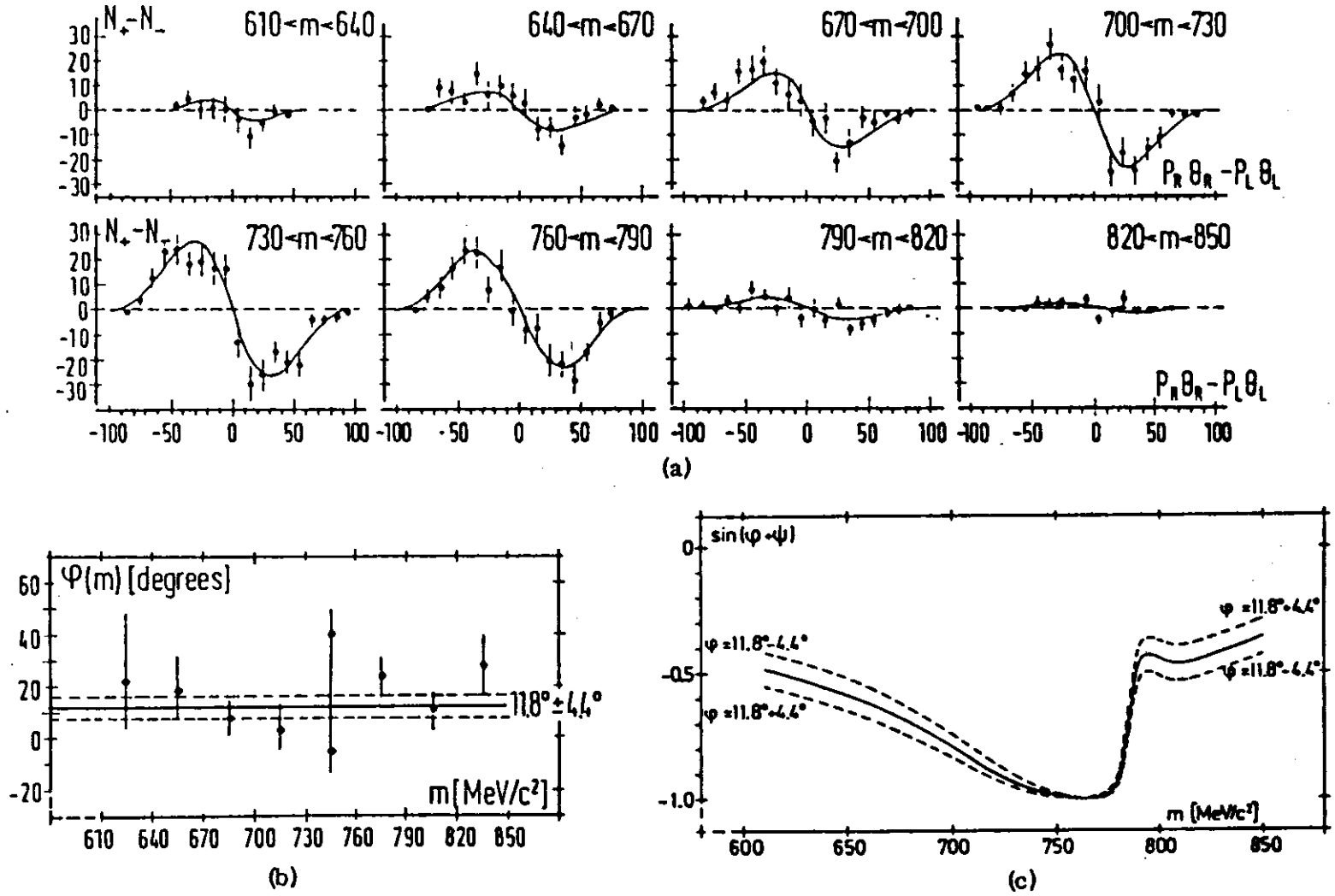

Fig. 2

~~FIG. 1.~~ (a) The measured asymmetric events $N_+(\delta, m) - N_-(\delta, m)$ as a function of $\delta = p_R\theta_R - p_L\theta_L$ for each mass bin of 30 MeV/c^2. The curves correspond to Eq. (6) with $\varphi = 11.8°$. (b) The fitted values of φ for each mass bin of 30 MeV/c^2. For the mass bin at 745 MeV/c^2, two local minima were found. (c) The quantity $\sin(\varphi + \psi)$ as a function of the e^+e^- pair mass. This quantity is independent of all parameters and is thus the most reliable result of this experiment.

... experimental results were represented by the expression

each arm of 7.5°, 8.0°, 8.4°, and 8.8°. Fig. 2b shows the phase angle determined from this measurement. The quantity shown in Fig. 2c results from the ratio of the interference term to the square root of the product of the BH and Compton cross sections.

In Fig. 3, the method of obtaining the interference signal is shown for the reaction $\gamma+p\rightarrow p+e^{+}+e^{-}$ for m_{ee} in the φ region. The data are from ref. 8 using a bremsstrahlung beam with k_{MAX} = 7.2 GeV, spectrometer central momenta of 2.700 GeV/c and symmetric spectrometer angles of 13°. The spectra in the chosen invariant mass region are shifted according to the direction of the transverse momentum transferred.

Using the same techniques, it is possible to measure the relative photoproduction phase between the ρ and ω. Such a measurement is shown in Fig. 4 (from ref. 3) using the $\gamma+Be\rightarrow Be+e^{+}+e^{-}$ reaction with a bremsstrahlung beam having k_{MAX} = 7.00 GeV, spectrometer central momenta of 2.560 GeV/c, and symmetric spectrometer angles 7.5°, 8°, 8.4°, and 8.8°. Fig. 4a shows the data and a BH calculation (open circles). In Fig. 4b, the BH contribution has been subtracted and the open squares are calculated as the $\rho\rightarrow e^{+}e^{-}$ contribution. Fig. 4c results from dividing the distribution in Fig. 4b by the spectrometer acceptance and by a simplified form of the ρ production cross section.

As an indication of the effect of using higher energy beams, the invariant mass distribution for the $\gamma+p\rightarrow p+e^{+}+e^{-}$ reaction (ref. 9) is shown for symmetric spectrometer angles of 13° and k_{MAX} = 6.0 GeV, p_o = 1700 MeV/c in Fig. 5 and k_{MAX} = 7.2 GeV, p_o = 2700 MeV/c in Fig. 6. As could be expected, the higher energy populates the region of the φ meson significantly better.

electrons. As seen in fig. 15, the results is consistent with no asymmetry at any mass value.

In the $\theta = 15°$ and $16°$ interference plots of fig. 13 one observes a narrow structure at 1.1 GeV. On the other hand, because of the mass resolution of ~ 20 MeV FWHM, the strong Φ signal in the 13° data makes the separation of

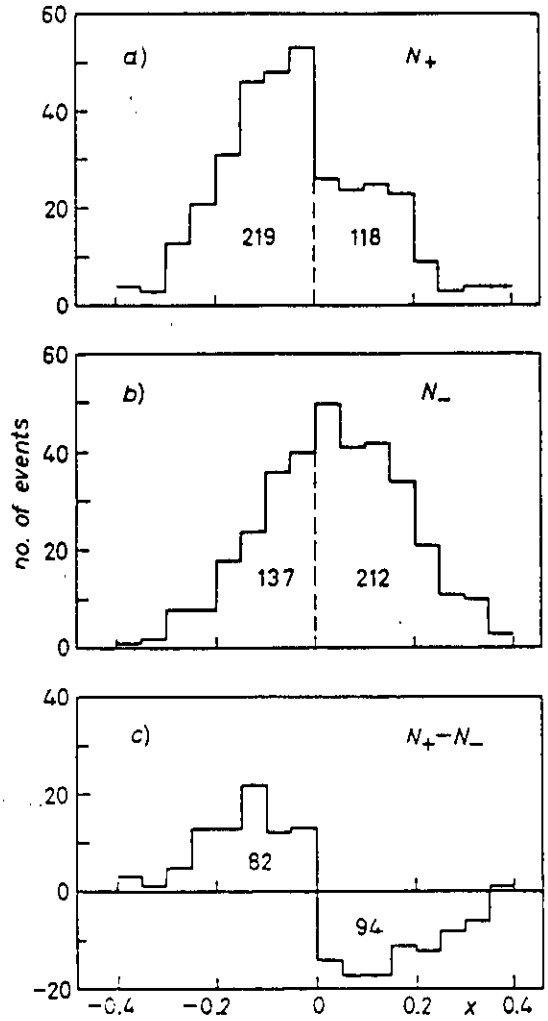

Fig. 3 – This figure illustrates in detail how the interference signal is obtained for the particular case $1.0 < M < 1.04$ GeV and $\theta = 13°$. At $x < 0$, the positrons dominate over the electrons by $219 - 137 = 82$ and *vice versa* at $x > 0$ ($212 - 118 = 94$ electrons more then positrons). The total interference is $82 + 94 = 176$ events. $P_{R(L)}$ and $\theta_{R(L)}$ are the lepton momentum and angle, respectively, in the right (left) spectrometer. $\theta_{L(R)}$ is the projected production angle on the horizontal plane. *a*) 337 positrons in the right arm, *b*) 349 electrons in the right arm. $x = p_R\theta_R - p_L\theta_L$.

the signal at 1.1 GeV not as distinct. It, however, still shows up as a shoulder for $M > M_\Phi$. If we sum up from 1080 MeV to 1120 MeV, the deviation from the expected distribution due to ρ, ω and Φ around 1.1 GeV is 128 ± 27 events

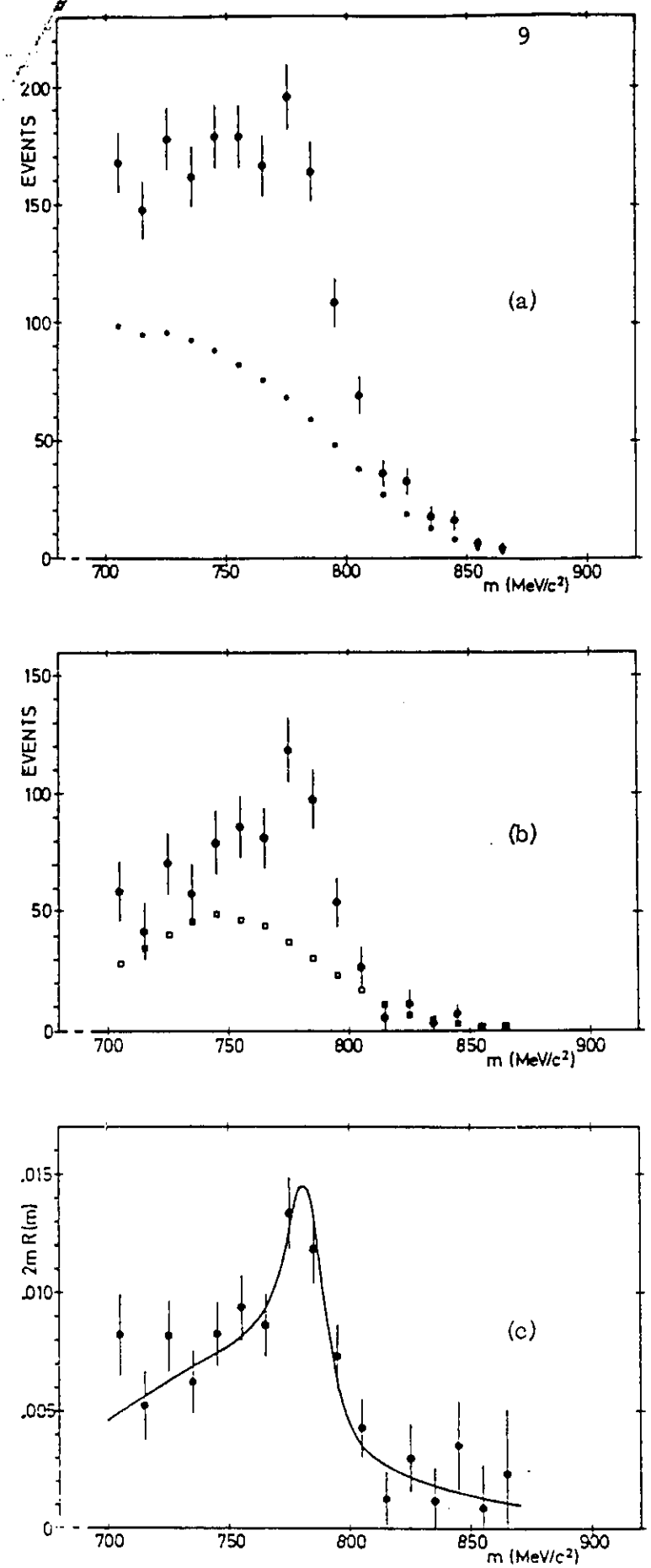

FIG. 4 (a) The black dots are the experimentally measured event distribution (284 events). The open

The errors quoted above mainly co
estimation of uncertainties, such a
shape, the absolute normalization,
tainties in the parameters (Γ_ω, Γ_ρ,

If $y = \Delta(\gamma_\omega{}^2\sigma_{\rho N}/\gamma_\rho{}^2\sigma_{\omega N})$ and $z = \Delta\varphi$
sitivities of the fit results to the ch
put parameter x are, for $x = m_\rho$ (±1
$= \pm 0.5$ and $z = \mp 3°$; for $x = m_\omega$ (±2 Me
and $z = \pm 13°$; for $x = \Gamma_\omega$ (±1.2 MeV),
$z = \mp 0.5°$; for $x = \Gamma_{\rho\to ee}$ (±10% of Γ_ρ
and $z = \mp 2°$; for x = Be radius (±10%)
$z = (-2°, +1°)$; and for x = normaliza
$y = \pm 0.4$ and $z = \mp 1°$.

A recent experiment done at Dare
Physics Laboratory[10] has measured
production of e^+e^- pairs on carbon
The published results were

$$\gamma_\omega{}^2/\gamma_\rho{}^2 = 7.0^{+2.0}_{-0.9}, \quad \varphi_{\omega\rho} = 100^{+38°}_{-30°}.$$

The difference between their result
most likely due to statistics or diff
ergy and target used.[11]

In conclusion, our data show that
initely a strong interference enhanc
ω superimposed on the leptonic-dec
ρ. Furthermore, if we assume $|A_\omega$
result for $\gamma_\omega{}^2/\gamma_\rho{}^2$ is $1\frac{1}{2}$ standard de
from the storage-ring measuremen
we see that the mass spectrum is i
good agreement with the prediction
tor-dominance model.

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*Accepted without review under polic
Editorial of 20 July 1964 [Phys. Rev. L
(1964)].

[1]J. B. Bjorken, S. D. Drell, and S. C.
Phys. Rev. 112, 1409 (1958); H. Alvens
Phys. Rev. Lett. 21, 1501 (1968).

[2]G. Wolf, Phys. Rev. 82, 1538 (1969);
et al., Phys. Rev. Lett. 24, 336 (1970);
Nucl. Phys. B11, 330 (1969).

[3]R. G. Parsons and R. Weinstein, Phy
20, 1314 (1968); M. Davier, Phys. Lett
(1968). Ignored here are ω-ρ mixing e
may contribute to the phase $\varphi_{\omega\rho}$. See,
H. R. Quinn and T. F. Walsh, DESY Re

for vector-meson photoproduction on protons, and m and t are the invariant mass and the momentum transfer of the e^+e^- pair, respectively.

It follows from charge conjugation invariance that the interference term in (2) between the Bethe-Heitler and the Compton amplitudes is antisymmetric under exchange of e^+ and e^-. Hence, the effect of the interference term consists in producing an asymmetric distribution of the experimental events as a function of any kinematical variable which is antisymmetric in the four-momenta p_+ and p_-. Such an asymmetry is a measurement of the interference

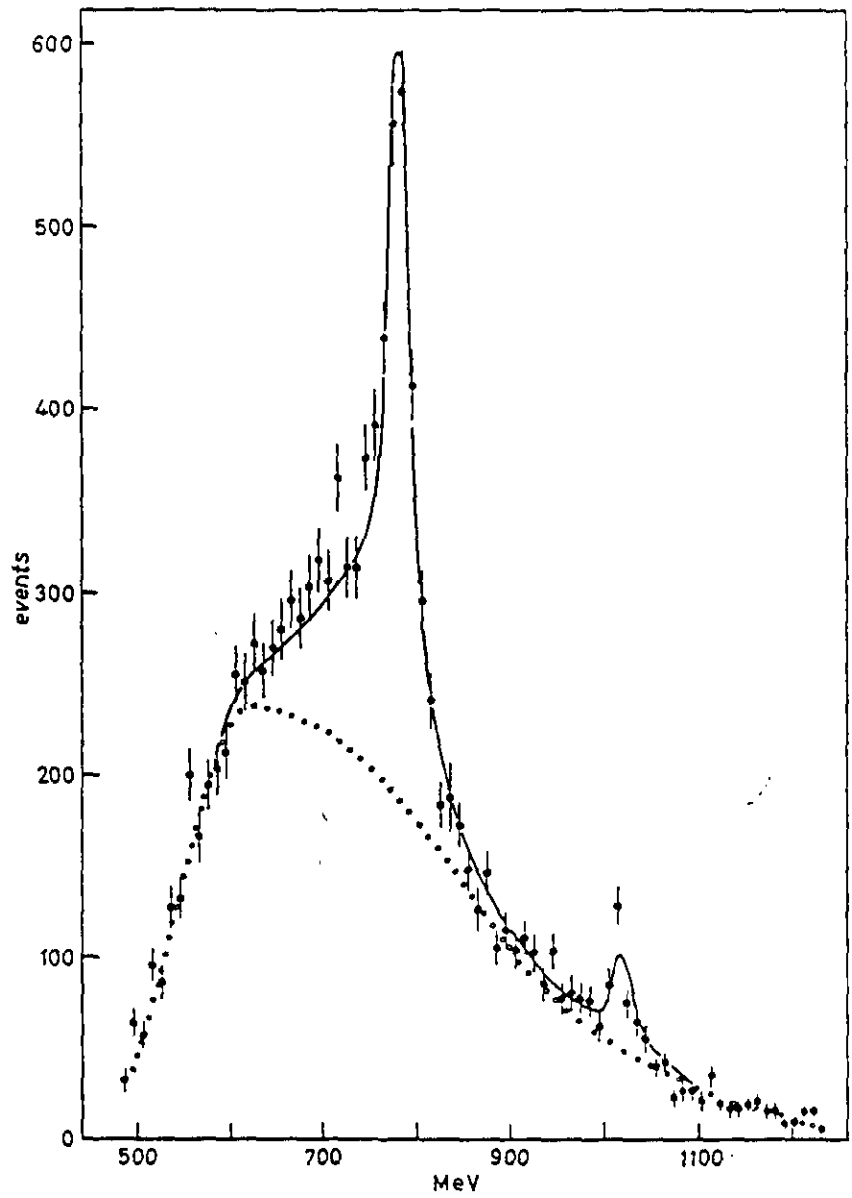


Fig. 5 – e^+e^- effective mass distribution. The open circles are the calculated contributions of the BH processes, normalized to the collected number of equivalent quanta. The solid line shows the calculated contribution of the BH processes together with the diffractive ρ, ω and ϕ photoproduction, the $\rho+\omega$ inelastic effects and ω OPE production. $E_{max} = 6.0$ GeV, $p_0 = 1700$ MeV, $\theta = 13°$.

term and consequently of the photoproduction phase φ_V. Any contributions to the interference term due to second-order QED terms have been estimated [3] to be about 0.1 % of the BH rate and have therefore been neglected.

The apparatus (fig. 1*b*) and the experimental procedure are the same as described elsewhere [4] in detail. In particular let us recall that our mass resolution is 20 MeV (FWHM) at $m = 1$ GeV.

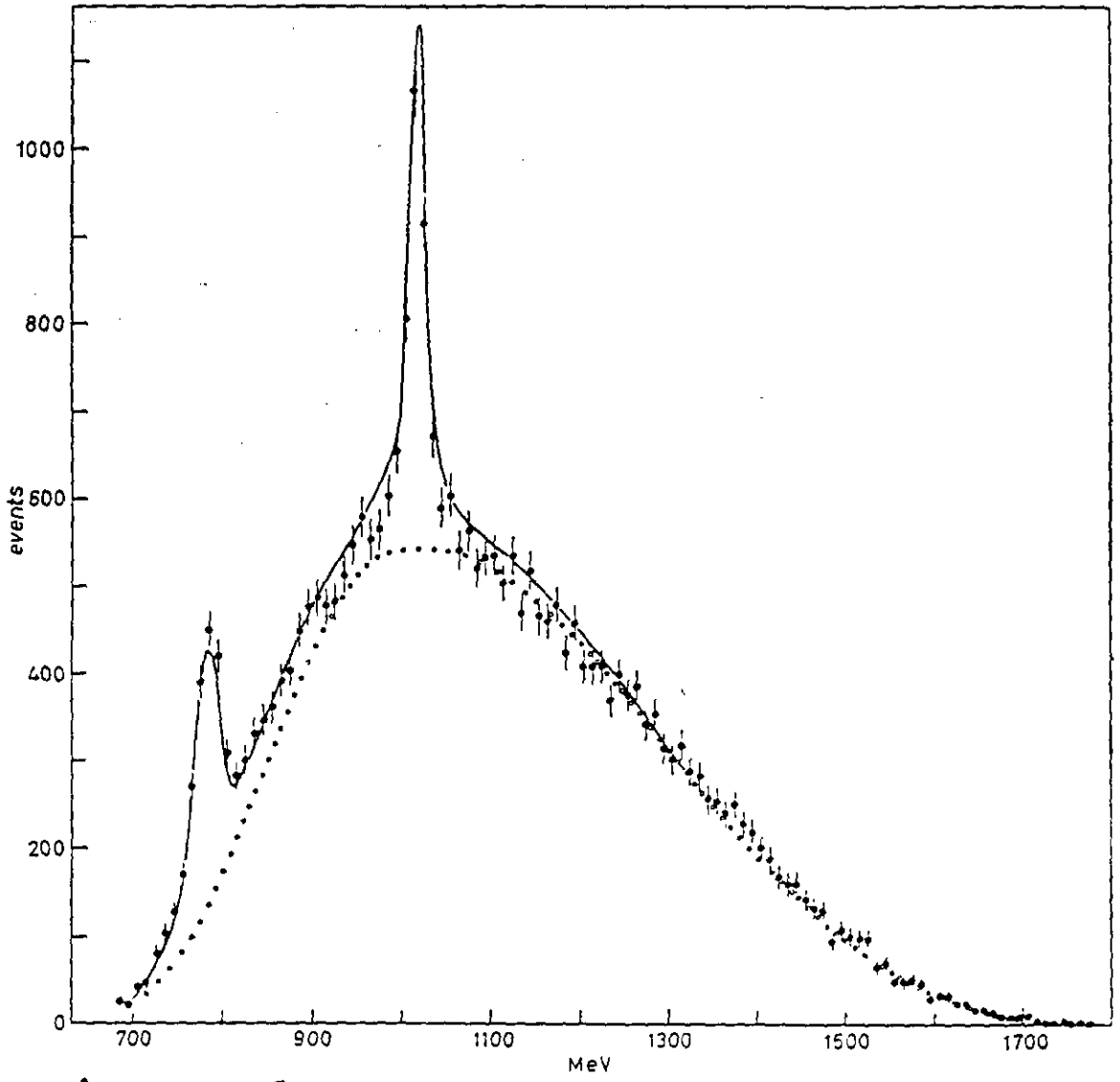


Fig. ~~2b~~ 6 – Same as ~~2a~~ 5, $K_{max} = 7.2$ GeV, $p_0 = 2700$ MeV, $\theta = 13°$, • experimental data, ○ BH contribution, ——— BH + ρ + ω + φ contribution.

(3) J. BRODSKY and J. G. GILLESPIE: *Phys. Rev.*, 173, 1011 (1968).
(4) S. BARTALUCCI, S. BERTOLUCCI, M. FIORI, D. FONG, T. MCCORRISTON, P. GIROMINI, S. GUIDUCCI, C. RIPPICH, M. ROHDE, A. SERMONETA and L. TRASATTI: *Nuovo Cimento*,

As a final observation on existing experiments, a Pb target was used by ref. 2 at k_{MAX} = 6.25 GeV but only invariant masses in the region 300 MeV/c^2 ≤ m_{ee} ≤ 500 MeV/c^2 were measured. A small interference was seen but it is explained in sign and magnitude by interference with the second Born corrections to the QED pair production (Ref. 11).

B. Status of Theory

Models of vector meson photoproduction are reviewed in Ref. 1. The photoproduction of ρ mesons from complex nuclei is presented in Sec. IV.C of Ref. 1 with a list of "serious uncertainties" associated with the calculations. The most serious uncertainty is the "lack of independent knowledge of the ratio α_ρ of the real to imaginary parts of the ρ^o scattering amplitude". Determining the A-dependence of α_ρ is the focus of this proposal. Additional problems concerning calculations of the photoproduction of the ω and φ are discussed in Sec. IV.D of Ref. 1. Besides the uncertainties in α_ω and α_φ, there are possible complications due to mixing of the vector mesons within the nucleus.

Some problems with the analysis of the experiments presented in Section A above are discussed in Sec.IV.E of Ref. 1. The experiments are sensitive to quantities such as m_V, Γ_V, and the coupling constants. The "disturbingly large" relative ρ^o-ω production phase angle "cannot be explained by a simple vector meson dominance model where photon-vector-mesons couplings are real". No such large relative ρ^o-ω production phase was required in ω photoproduction or in the study of ρ^o-ω interference in pion pair production. Section IV.E of Ref. 1 concludes with the statement that "these experiments (interference of lepton pairs) are very difficult to

analyze, and we hesitate to draw any firm conclusions from their results at this time."

In response to the "problems" and the concluding statement, it should be pointed out that the vector meson quantities are now much better known. The proposed experiments at CEBAF using the CLAS should yield much more data, in quality, quantity, and systematics, because of the CW beam and the large acceptance (angle and momentum) of CLAS. The analysis of the experiments may be difficult but there is a significant amount of physics to be learned with such measurements.

Various models of the mesons and their interactions with nucleons predict relationships between the coupling constants and interactions of the pseudoscalar and vector mesons. The proposed experiments will determine if and by how much the nuclear medium affects these quantities. There are both coherent (elastic) and incoherent (all inelastic possibilities) contributions to the proposed experiments. These contributions are model dependent but it would be surprising if precise data could not distinguish between at least some of the models. For the BH contribution, however, the form factors in pair production are the same as those of electron scattering (Ref. 12). The interactions of real vector mesons in nuclei could possibly augment the knowledge of short range nucleon-nucleon interactions in nuclei, at least they should augment the knowledge of nucleon-nucleus interactions in the GeV region since the vector mesons contribute to the short range part of the nucleon-nucleon force.

II. The Present (October 1989)

Calculations are underway to simulate the response of the CLAS detector for these experiments. The present calculations use a phenomenological form for the vector meson photoproduction and interference (ref. 5) and the general equation for Bethe-Heitler pair production from Drell and Walecka (ref. 12). The vector meson parameters used in the calculations are given in Table II. The calculated cross sections $d^6\sigma/dp_+dp^-d\Omega_+d\Omega_-$ are used in the CLAS program FASTMC (ref. 13) to give a first approximation of the response of the detector.

The events used as input to FASTMC are calculated with the CLAS event generator program CELEGS (ref. 14) using a bremmstrahlung beam with k_{MAX} = 4.0 GeV, the angle θ with respect to the beam direction of $10^o \leq \theta \leq 25^o$ and a minimum invariant mass of 500 MeV/c^2.

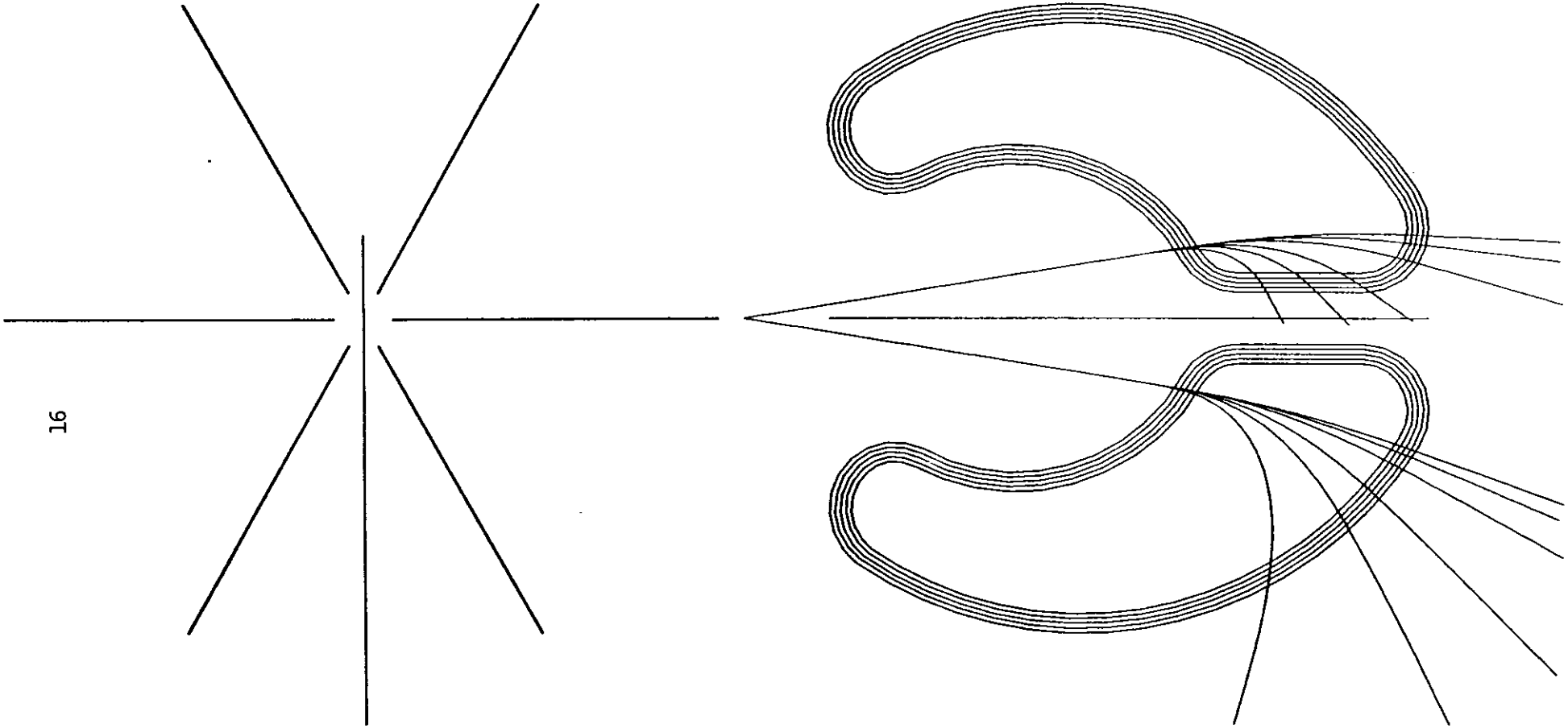
In order to improve the CLAS coverage of small angles, it is proposed to move the target position 2 or 3 m upstream from the standard target position and to remove the 1st detector package since it would not be protected by magnetic fields. In Fig. 7, e^+ and e^- rays are shown for the 2 m position and $\theta_+ = \theta_- = 9.0^o$. The momenta shown are 4, 3, 2, 1, 0.6, and 0.3 GeV/c at the full field. In Fig. 8, the target is 3 m upstream and the momenta are 4, 3, 2, 1, and 0.5 GeV/c. The shower counters cover the forward direction from $\theta = 5^o$ at the standard target position (essentially even with the innermost conductor). By reducing the field of the CLAS by 50%, the momenta of the rays in Figs. 7 and 8 are halved and it appears possible to accept 10° rays at 1 GeV/c.

TABLE II

	ρ^o	ω	φ
$m_V(MeV/c^2)$	768.1±1.3	781.99±0.13	1019.414±0.010
$\Gamma_V(MeV)$	145.±2.7	8.45±0.09	4.41±0.05
$BR(V\rightarrow e^+e^-)$	$(4.42\pm0.21)\times10^{-5}$	$(7.05\pm0.25)\times10^{-5}$	$(3.11\pm0.10)\times10^{-4}$
$\left.\frac{d\sigma(\gamma N\rightarrow VN)}{dt}\right\|_{t=0}$ $(\mu b/(GeV)^2)$	120	12.5	2.8
$a_V(GeV^{-2})$ $[e^{ta_V}A^{2/3}]$	7.8	7.2	5.5
$\varphi_V(deg)$	11.8	52.8	25

3-OCT-89
Coil Shape CIRCE

5.0 Mega-Amps

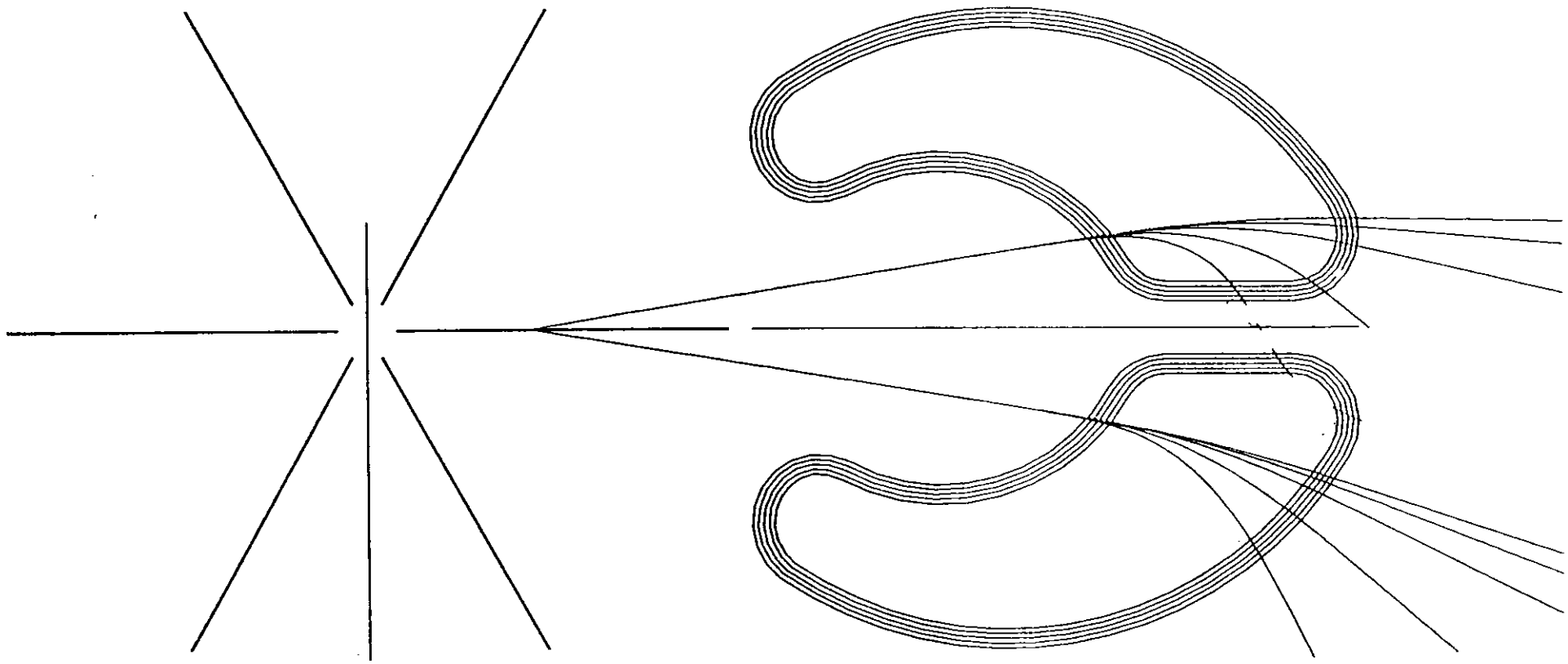


Theta	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Fi	0.0	0.0	0.0	0.0	0.0	0.0	180.0	180.0	180.0	180.0	180.0	180.0
P/GeV	4.000	3.000	2.000	1.000	0.600	0.300	-4.000	-3.000	-2.000	-1.000	-0.600	-0.300
Xtarg	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00

Fig. 7

26-JUL-89
Coil Shape CIRCE

5.0 Mega-Amps



Theta	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
FI	0.0	0.0	0.0	0.0	0.0	180.0	180.0	180.0	180.0	180.0
P/GeV	4.000	3.000	2.000	1.000	0.500	-4.000	-3.000	-2.000	-1.000	-0.500
Xtarg	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

Fig. 8

Using only the 2nd and 3rd chamber packages, if the beam is collimated to a spot size of 1 cm. diameter, for a 2 GeV electron the CLAS will give a momentum resolution of $\Delta p/p = 0.5\%$ (FWHM) and $\Delta\theta = 1.7$ mrad at $\theta = 10^o$. With no constraint on the vertex, the momentum resolution worsens to 0.9% (FWHM) and the angular resolution becomes 2.5 mrad.

The effective solid angle can be estimated using 60% of the 2π coverage in φ. For an angular range from 10° to 20°, the solid angle is 0.17 sr.

For a bremsstrahlung beam, it is necessary to limit the electron beam to 1 kW. At 4 GeV, this limits the beam intensity to 0.25μA or 1.6×10^{12} s^{-1}. Using a 1% radiator will result in a photon beam of ~ 10^{10} s^{-1}.

The code FASTMC does not yet have the upstream target positions. A very crude estimate of the counting rate can be made using the absolute cross sections shown in Fig. 1. Such an estimate ignores the correlations in angle (θ&φ) and momenta which exist for the same invariant mass over the large θ, φ and momentum acceptance of the CLAS. Using a value of

$$\frac{d^6\sigma}{\delta p_+ dp_- d\Omega_+ d\Omega_-} = 0.5\times10^{-31}\ \frac{cm^2}{(GeV/c)^2 sr^2 \cdot nucleon \cdot EQ}$$

and assuming a Carbon target thickness of 2.5 g/cm^2, a photon intensity of 10^{10} EQ/s (EQ is the unit "equivalent quanta" defined in ref. 15), 10 effective nucleons for C using the formalism of ref. 16, independent momentum bites of 10 MeV/c, and independent solid angles of 0.17 sr, one obtains a counting rate of $1.8\times10^{-3}s^{-1}$ for one value of the invariant mass. More realistic estimates of the count rate over a spectrum of invariant mass or t or transverse momentum or as a function of the angle between the p_+k and p_-k planes must await a realistic FASTMC code or ultimately, GEANT calculations.

Using the counting rate of 1.8×10^{-3} s^{-1}, the time for 1000 counts per 10 MeV bin in the invariant mass would be 6.5 days for the measurement of Carbon. Preliminary calculations indicate that in the region of comparable BH and Compton cross-sections for invariant masses near the ρ, the summed cross-sections are approximately independent of A. Thus for an Fe target of 0.1 L_R (1.3 g/cm^2), the fewer number of nuclei result in a tenfold increase in beam time for the same statistics. With these estimates, roughly 2000 hours will be required to obtain 3% statistics on C and Fe targets including setup, calibration, etc. as 15% of the time. This amount of time is, therefore, requested for the first phase of the proposal experiments. In principal, an A-dependence study should also include nuclei in the mass regions of Aℓ, Ca, Zr, Sn, W, and Pb. Including any of these targets in Phase I or making a choice for Phase II must await more calculations, realistic simulations, and experience from Phase I.

The choice of thickness for the Fe target of 10% of a radiation length indicates a concern for accidental coincidences in the CLAS. Previous measurements using both Cherenkov counters and shower counters do not appear to have had problems with targets up to 0.1 L_R and they had poor duty factors (2-4%) and beam intensities up to 10^{11} s^{-1}.

The major true background in this experiment is coincident $\pi^+\pi^-$ pairs from ρ decay and from non-resonant production. Since the e^+e^- branching ratio is 4.4×10^{-5}, there must be excellent pion rejection. Using a pion rejection factor of 50 for the Cherenkov counters and a factor of 30 for the shower counters, one obtains a pair rejection factor of 2×10^6. This implies a 1% $\pi^+\pi^-$ background in the e^+e^- pairs.

At the trigger level, it will be impossible to have such a clean e^+e^- signal. While the rejection factor of 50 for the Cherenkov counters is still good, the rejection factor for the shower counters is more probably ~5. A simple estimate using 50 of the 10 MeV mass bins and assuming as many non-resonant $\pi^+\pi^-$ pairs as resonant pairs yields a pair counting rate over the detector of 3600 $\pi^+\pi^-$ pairs/s. Thus there would be roughly one $\pi^+\pi^-$ pair for each e^+e^- in the pair trigger.

III. The Near Future

In order to study the sensitivity of the measurements to variations in α_V as a function of A, $\theta_\pm$, and the angle between the p_+k and p_-k planes, a model will be used to calculate the vector meson photoproduction amplitudes. Two such models under consideration are Kölbig and Margolis (ref. 16) and Moniz and Nixon (ref. 17). Both coherent and incoherent photoproduction will be calculated. These calculations will be used in the CLAS detector simulations discussed in the previous section.

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I. J.G. Asbury et al. PRL 18 (1967) 65.

Experiment: $\gamma + C \rightarrow e^+ + e^- + C$

Purpose: Test QED

Beam:
- DESY Bremsstrahlung from internal target
- k_{MAX} = 3.06, 4.37, 5.05, 6.20 GeV
- Duty factor 2-4%
- Spot size: 2.5 cm x 2.5 cm

Target:
- 2.5 g/cm^2 (used 0.4 to 3.3 g/cm^2 to test targ. thickness dependence of results)

Detector:
- two arm magnetic spectrometer, initial dipole plus two dipoles/arm
- scintillators, shower counters, threshold Cherenkov counters, scintillator hodoscopes
- pair rejection: $\pi(\mu)/e > 4 \times 10^8 \rightarrow$ pion contamination $< 1\%$
- recombines rays of constant $p\theta \sim t$
- acceptance: $\Delta p/p \sim \pm 0.10$, $\frac{\Delta\theta}{\theta} \sim \pm 0.14$, $\frac{\Delta t}{t} \sim \pm 0.10$, $\Delta\varphi = \pm 8$ mrad
- resolution: $\Delta\theta/\theta = \pm 0.03$, $\Delta t/t = \pm 0.02$, $\Delta\varphi = \pm 2.0$ mrad

Measurement:
- angles: symmetric, 4°, 5°, 6°, 7°
- central momenta: p_0 = 1.167, 1.579, 1.830, 2.250 GeV/c
- range of invariant mass: 100-600 MeV/c^2
- range of momentum transfer: $q^2 \leq 2500$ (MeV/c)^2

Results:
- measurements agree with QED
- Old CEA results (R.B. Blumenthal et al., PR 144 (1966) 1199) were wrong.

II. J.G. Asbury et al. PRL 19 (1967) 869

Experiment: $\gamma + C \rightarrow C + \rho^o \rightarrow \begin{pmatrix} e^+e^- \\ \pi^+\pi^- \end{pmatrix}$

Purpose: Measure Branching Ratio

Beam: - Same as I, k_{MAX} = 6.0 GeV

Target: - Same as I

Detector: - Same as I

- Inv. mass resolution~ ±15 MeV/c^2

Measurement: - angles 9.5° & 15°

- central momenta 2.25, 1.40, 1.95 GeV/c

- invariant mass: ~750 MeV/c^2, ~ 1020 MeV/c^2

Results: - determined BR = $(6.5 \pm 1.4) \times 10^{-5}$

[1988 value = $4.42 \pm 0.21 \times 10^{-5}$]

III. J.G. Asbury et al. PL 25B (1967) 565

Experiment: $\gamma + C \rightarrow C + e^+e^-$

$\gamma + Pb \rightarrow Pb + e^+e^-$

Purpose: Determine phase and magnitude of virtual Compton scattering on complex nuclei

Beam:
- Same as I

  k_{MAX} = 6.0 GeV for C, k_{MAX} = 6.25 GeV for Pb

Target:
- C - same as I

  Pb - 0.5 mm

Detector:
- Same as I

Measurement:
- C - $\theta_o = 15^o$, p_o = 1.400 GeV/c, $m_{ee} = 770 \pm 50$ MeV/c^2
- Pb - $\theta_o = 4^o, 6^o, 7^o$, p_o = 2.25 GeV/c, $300 \leq m_{ee} \leq 500$ MeV/c^2
- observe interference of asymmetrical pairs
- BH-Compton for C target
- BH(2γ)-BH(3γ) for Pb target

  (c.f. Brodsky & Gillespie PR 173 (1968) 1011)

Results: $\varphi_\rho = 15^o \pm 25^o$

IV. H. Alvensleben et al. PRL 25 (1970) 1373 & NP B25 (1971) 333

Experiment: $\gamma + Be \rightarrow Be + e^+e^-$

Purpose: Determine ρ-ω phase difference and ratio of vector-meson-photon coupling constants

Beam:
- same as I, max electron current = 12mA, k_{MAX} = 7.00 GeV

Target:
- Be - 2.1 cm (thickness varied from 0.5 to 3.0 cm for test)

Detector:
- same as I
- pion rejection 10^{10}:1
- resolution $\Delta m_{ee} = \pm 4$ MeV

Measurement:
- p_o = 2560 MeV
- $\theta_o = 7.5^o, 8^o, 8.4^o, 8.8^o$ (symmetric angles)

  $700 \leq m_{ee} \leq 870$ MeV/c^2

Results:
- $\gamma_\omega^2 \sigma_{\rho N} / \gamma_\rho^2 \sigma_{\omega N} = 9.4^{+2.6}_{-1.6}$

  $\varphi_{\omega\rho} = 41 \pm 20^o$

V. H. Alvensleben et al. PRL 25 (1970) 1377 & NP B25 (1971) 342

Experiment: $\gamma + Be \rightarrow Be + e^+e^-$

Purpose: Determine phase of photoproduction amplitude of the ρ using BH-Compton interference

Beam: - same as I & IV

Target: - same as IV

Detector: - same as I & IV

Measurement: - same as IV except analyze asymmetric e^+e^- events
- $610 < m_{ee} < 850$ MeV/c^2

Results: - phase deviates from pure imaginary by $11.8^o \pm 4.4^o$
- corresponds to a ratio of real to imaginary ρN amplitude of -0.2 ± 0.1.

VI. H. Alvensleben et al. PRL 27 (1971) 444

Experiment: $\gamma + C \rightarrow C + e^+e^-$

Purpose: Determine phase of photoproduction amplitude of the φ meson and the forward cross section

Beam: - same as I

$k_{MAX} = 7.4$ GeV

Target: - 1.5 cm

Detector: - same as I

pion (muon) rejection > 10^7:1

Measurement: - $\theta_o = 8.6^o$ & 8.8^o

$p_o = 3.350$ GeV/c

$920 < m_{ee} < 1080$ MeV/c

Results: - phase deviates from pure imaginary by $25^o \pm 15^o$

- corresponds to a ratio of real to imaginary φN amplitude of $-0.48^{+0.33}_{-0.45}$

- forward photoproduction cross section

96 ± 14 nb/(GeV/c)^2

VII. P.J. Biggs et al. PR D1 (1970) 1252 & PRL 23 (1969) 927

Experiment: $\gamma+p\rightarrow p+e^{+}+e^{-}$

$\gamma+C\rightarrow C+e^{+}+e^{-}$

Purpose: Test QED

Beam:
- NINA (Daresbury) bremsstrahlung
- k_{MAX} = 5 GeV
- $I_{\gamma} \sim 10^{11}$ equivalent quanta/s
- Spot size: 1.5 cm x 1.5 cm

Target:
- Liquid Hydrogen: cylinder 300 mm long x 50 mm diameter
- C: 1.7 and 2.4 g/cm^2

Detector:
- 2 identical mirror image spectrometers, two half-quadrupoles plus a dipole
- scintillators, threshold Cherenkov counters, shower counters, scintillator hodoscopes
- acceptance defined by scintillators after the dipole
- acceptance: $\Delta p/p = 0.10$, $\Delta\theta = 18$ mrad, $\Delta\Omega = 0.50$ msr, $\Delta\varphi \sim 0.3$ rad at $\theta \sim 0.1$ rad
- pair rejection: $\pi/e \sim 10^8$

Measurement:
- angles: symmetric 5.1°, 6.0°, 7.0°
- central momenta: 1.0, 1.5, and 2.0 GeV/c
- invariant mass < 489 MeV/c^2

Results:
- measurements consistent with QED

VIII. P.J. Biggs et al. PRL 24 (1970) 1197

Experiment: $\gamma + C \rightarrow C + e^+ + e^-$

Purpose: Measure ρ-ω phase

Beam:
- same as VII, $k_{MAX} = 4.1$ GeV

Target:
- C: same as VII

Detector:
- same as VII with increased acceptance $\Delta p/p = 0.14$, $\Delta\Omega = 0.67$ msr
- resolution: $\Delta m_{ee} = \pm 6$ MeV/c^2
- m_{ee} acceptance = 140 MeV/c^2

Measurement:
- $p_o = 1.802$ GeV/c
- seven symmetric angles (θ_o) between 11.2° and 13.3°
- $675 \leq m_{ee} \leq 850$ MeV/c^2

Results:
- $\gamma_\rho^2/4\pi = 0.50^{+0.12}_{-0.10}$

  $\gamma_\omega^2/4\pi = 3.5 \pm 1.2$

  $\varphi_{\rho\omega} = 100^{\circ}{}^{+38}_{-30}$
- errors are purely statistical

IX. P.J. Biggs et al. PRL 27 (1971) 1157

Experiment: $\gamma + C \rightarrow C + e^+ + e^-$

Purpose: Determine ratio of real to imaginary part of the ρN amplitude (α_ρ) and the relative ρ-ω production phase

Beam: - same as VIII

Target: - same as VIII

Detector: - same as VIII

Measurement:
- p_o = 1.802 GeV/c
- seven angles (θ_o) between 11.2° and 13.3° (asymmetric)
- $590 \leq m_{ee} \leq 830$ MeV/c^2
- transverse momentum range 0-150 MeV/c

Results:
- $\varphi_{\rho\omega} = 118^\circ {}^{+13^\circ}_{-22^\circ}$, $\varphi_\rho = 16.6^\circ \pm 6.2^\circ$

  $\alpha_\rho = -0.28 \pm 0.12$

X. S. Bartalucci et al. Nuovo Cimento 39A (1977) 374

Experiment: $\gamma+p \rightarrow p+e^{+}+e^{-}$

Purpose: Search for new mesons in mass range 0.9 to 2.2 GeV/c^2

Beam:
- DESY bremsstrahlung beam
- k_{MAX} = 7.2 GeV
- Spot size: 10mm x 35mm

Target:
- Liquid Hydrogen: 100 cm long, 5 cm diameter

Detector:
- Two are magnetic spectrometer, each arm: 2 dipoles, threshold Cherenkov counters, scintillator hodoscopes, proportional wire chambers, shower counter hodoscopes
- acceptance: at φ=-0.04 mr, $\frac{\Delta p}{p_o}$ = -0.4 to 0,
  at φ = 0, $\frac{\Delta p}{p_o}$ = -0.2 to 0.6
  at φ = 0.04 mr, $\frac{\Delta p}{p_o}$ = 0.1 to > 1.0
- resolution: Δm_{ee} ~ 20 MeV/c^2 (FWHM)

Measurement:
- angles: symmetric, 13°, 15°, 16°, 19°
- central momentum: p_o = 2.700 MeV/c
- range of invariant mass: $0.9 \leq m_{ee} \leq 2.2$ GeV/c^2
- Total Equivalent Quanta: 3×10^{16}(13°), 5.6×10^{16}(15°), 4×10^{16}(16°), 2×10^{16}(19°)

Results:
- indication of new structure of mass ~ 1100 MeV/c^2 (not mentioned in 1988 Review of Particle Properties)

XI. S. Bartalucci et al. Nuovo Cimento 44A (1978) 587

Experiment: $\gamma+p\rightarrow p+e^{+}+e^{-}$

Purpose: Measure the photoproduction phases of the ρ, ω, and φ mesons

Beam:
- same as X
- k_{MAX} = 7.2 and 6.0 GeV
- k_{MAX} = 7.2 GeV

Target:
- same as X

Detector:
- same as X

Measurement:
- at k_{MAX} = 7.2

  symmetric angles = 13°, 15°, 16°

  p_o = 2.700 MeV/c
- at k_{MAX} = 6.0 GeV

  symmetric angle = 13°

  p_o = 1.700 MeV/c

  - range of invariant mass: $500 \leq m_{ee} \leq 1060$ MeV/c^2

Results:
- $\varphi_\rho = 37.5^{\circ}\ ^{+2.8^{\circ}}_{-3.1^{\circ}}$

  $\varphi_\omega = 29.6^{\circ}\ ^{+15.5^{\circ}}_{-12.9^{\circ}}$

  $\varphi_\varphi = 3.4^{\circ}\ ^{+5.3^{\circ}}_{-4.2^{\circ}}$

XII. S. Bartalucci et al. Nuovo Cimento 49A (1979) 207

Experiment: $\gamma+p\rightarrow p+e^{+}+e^{-}$

Purpose: Confirm structure at 1100 MeV/c^2 and look for other new mesons

Beam:
- same as X

Target:
- same as X

Detector:
- same as X
- photon beam vertical dimensions restricted by factor of ~2 ⇒ improve Δm_{ee}

Measurement:
- symmetric angle: $\theta_o = 13^o$
- range of invariant mass: $900 \leq m_{ee} \leq 1500$ MeV/c^2
- combine data with X

Results:
- confirmed structure at 1097 MeV/c^2
- observed "ρ' (1250)" at 1266 MeV/c^2 (neither of these "particles" are mentioned in the 1988 Review of Particle Properties)