

CEBAF AT HIGHER ENERGIES

Working Group Report on Hadron Spectroscopy and Production

T. Barnes and J. Napolitano

RECEIVED

MAY 01 1996

OSTI

to be published in

Proceedings of

Workshop on CEBAF at Higher Energies

Newport News, Virginia
April 14-16, 1994

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

"The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. DE-AC05-84OR21400. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes."

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER



CEBAF AT HIGHER ENERGIES*

WORKING GROUP REPORT ON HADRON SPECTROSCOPY AND PRODUCTION

TED BARNES

*Physics Division, Oak Ridge National Laboratory
Oak Ridge, TN, 37831-6373*

and

*Department of Physics and Astronomy, University of Tennessee
Knoxville, TN, 37996-1200*

and

JIM NAPOLITANO

*Department of Physics, Rensselaer Polytechnic Institute
Troy, NY, 12180-3590*

ABSTRACT

This report summarizes topics in hadron spectroscopy and production which could be addressed at CEBAF with an energy upgrade to $E_\gamma = 8$ GeV and beyond. The topics discussed include conventional meson and baryon spectroscopy, spectroscopy of exotica (especially molecules and hybrids), CP and CPT tests using ϕ mesons, and new detector and accelerator options.

1. Overview

The photon, real or virtual, makes a unique particle beam. It has spin one, and selectively couples to different quark flavors according to their charges. As the beam energy increases, one can expect to see a transition from dynamics dominated by a few hadron resonances to a regime in which perturbative QED and QCD processes are evident.¹ In the resonance regime, the photon's polarization allows tests of many resonance form factors which have been studied theoretically but never adequately investigated experimentally. In addition to conventional hadronic resonances, unusual states such as glueballs, hybrids and molecules are anticipated in the 1-3 GeV region, and these may be identifiable through unusual photon couplings and decay modes. Obviously, the opportunities for spectroscopy with a sufficiently energetic and intense photon beam are enormous.

Despite these opportunities, experimental progress in resonance production by photons has been rather limited because high intensity, high energy CW electron accelerators have not been available. The initial program of experiments at CEBAF

*A Workshop held at CEBAF, Newport News, Virginia, 14-16 April 1994.

with a 4 GeV beam represents the first high-statistics experimental investigation of this field. However, most of these experiments are limited to baryon spectroscopy in s -channel photo- or electroproduction, because the beam energy is not high enough to reach the thresholds anticipated for photoproduction of interesting new meson resonances. Of course one should exceed these expected thresholds in the design beam energy, both for reasons of cross section and to insure that states somewhat above theoretical mass predictions are not missed.

For our quantitative discussion of energies we consider the photoproduction reaction

$$\gamma + P \rightarrow m + B$$

where m is a meson (of mass m) and B is a baryon (of mass M_B). The photon energy E_γ required to reach the threshold for this reaction is

$$E_\gamma = \frac{1}{2M_P} \left[(m + M_B)^2 - M_P^2 \right] . \quad (1)$$

The highest meson mass is produced against a final-state proton, in which case the beam energy required to reach a threshold m is

$$E_\gamma = m + \frac{m^2}{2M_P} . \quad (2)$$

Electroproduction using timelike photons requires higher photon energy than photoproduction to reach a given invariant mass. For an off-shell photon with $Q^2 < 0$ the threshold energy required for the reaction

$$\gamma^* + P \rightarrow m + P$$

is given by

$$E_\gamma^* = \frac{1}{2M_P} \left[m^2 + 2mM_P + |Q^2| \right] .$$

Thresholds associated with photo- and electroproduction from a proton are shown as a contour plot in figure 1. As examples, the threshold photon energy for photoproducing a 1.9 GeV light hybrid is $E_\gamma = 3.8$ GeV, which is just possible at CEBAF with $E_\gamma = 4$ GeV; photoproduction of a 2.5 GeV $s\bar{s}$ meson requires $E_\gamma = 5.8$ GeV; the ψ at 3.1 GeV requires $E_\gamma = 8.2$ GeV; and a charmonium hybrid at 4.1 GeV would require $E_\gamma = 13.1$ GeV.

Thus, with an upgrade of CEBAF to $E_\gamma = 8$ GeV one could use photoproduction to explore meson spectroscopy up to an invariant mass of about 3.0 GeV but no higher.

This should allow detailed photoproduction and electroproduction studies of u , d , s $q\bar{q}$ spectroscopy as well as searches for light hybrids. In order to produce the reaction products with sufficient phase space to be useful experimentally the beam energy should of course be somewhat higher than these threshold values.

Our working group considered both theoretical and experimental aspects of an energy upgrade. The preliminary organization was informal, and reserved many intervals for discussion and additional contributions; this proved to be a wise decision, since the talks generated extensive discussions. The topics considered were generally in the following categories:

- Conventional Meson and Baryon Spectroscopy
- Exotica: Molecules and Hybrid Mesons
- CP and CPT Violation in Flying ϕ Decay
- New Detectors and Accelerator Developments

We also had two contributions on specialized topics: Marc Sher described a possible experiment to search for low-mass gluinos² (a proposed spin-1/2, strongly interacting supersymmetric partner of the gluon) in a mass and lifetime “window” that has not been excluded experimentally. Kam Seth described the high-precision charmonium results from Fermilab Experiment E760, and discussed how charm and related physics could be addressed with a τ -charm factory at CEBAF.

A list of the speakers and topics is given in Table 1; the remainder of this report summarizes and expands on their comments. For additional details see the individual contributions to this report.

2. Conventional Spectroscopy

A variety of important problems in conventional $q\bar{q}$ meson spectroscopy ($q = u, d, s$) can be addressed at CEBAF using photon beams. Establishing $q\bar{q}$ spectroscopy is important both because anomalous states must be identified against a background of these conventional resonances (which are poorly known above about $1\frac{1}{2}$ GeV), and because there may yet be surprises in the conventional light meson spectrum, for example in configuration mixing, photon couplings or decay amplitudes. The production mechanism at CEBAF may be especially useful for distinguishing conventional $q\bar{q}$ mesons from unusual states, because their electroproduction amplitudes should be quite characteristic and can be studied using polarized and $Q^2 < 0$ virtual photons.

One example of an interesting area in conventional mesons, $s\bar{s}$ spectroscopy, was discussed by Steve Godfrey in his plenary talk. Strangeonia are attractive in part because they are largely unexplored, and photoproduction at CEBAF should allow a detailed study of $s\bar{s}$ spectroscopy. The strange quark is sufficiently light so that one would naively expect $s\bar{s}$ spectroscopy to repeat $I = 0$ ($u\bar{u} + d\bar{d}$) spectroscopy, displaced upwards by ≈ 200 -250 MeV, but surprises such as $\eta - \eta'$ flavor mixing may await experimental studies. The spectroscopy of radially-excited 1S_0 $q\bar{q}$ states is especially interesting because of the possibility of $\eta - \eta'$ type mixing and because several poorly understood 0^{-+} states reported in $\psi(3100)$ radiative decays, such as the $\eta(1440)$, may involve radially-excited $q\bar{q}$ states. The 0^{++} channel is interesting

because the lightest glueball is expected to be a scalar with a mass of ≈ 1.5 GeV, just where the 3P_0 $s\bar{s}$ scalar is expected. Strong mixing between these and the nonstrange $I = 0$ 3P_0 $q\bar{q}$ states may be present, or these may be relatively unmixed states. A comparison of $s\bar{s}$ and $(u\bar{u} \pm d\bar{d})$ spectroscopy may also be useful as an indication of the importance of mixing with two-meson continua, since this effect is expected to split the $(u\bar{u} \pm d\bar{d})$ $I = 0, 1$ 3D_1 states near 1.6 GeV as well as the $(u\bar{u} \pm d\bar{d})$ ${}^3S_1'$ radials near 1.45 GeV,³ and may induce important $s\bar{s}$ components in the $I = 0$ states. These predictions may be testable through the photoproduction amplitudes and branching fractions of these states.

The best experimental work to date on $s\bar{s}$ spectroscopy has been done by the SLAC E135 collaboration⁴ using the reactions $K^-P \rightarrow K^-K^+\Lambda$, $K_S^0K_S^0\Lambda$ and $K_S^0K^\pm\pi^\mp\Lambda$. Photoproduction would add considerably to our knowledge since $s\bar{s}$ pairs are copiously produced. However, many of the interesting $s\bar{s}$ states are expected to lie near or above 2 GeV;⁵ the $L = 2$ and $L = 3$ $s\bar{s}$ multiplets are expected at 1.9 and 2.2 GeV respectively, and the $L = 0$ $s\bar{s}$ radials are expected at 1.6-1.7 GeV. Producing states above 2 GeV would require higher beam energies than are currently available at CEBAF, particularly if virtual photons are used.

Simon Capstick discussed baryon spectroscopy, and noted that although a considerable program of baryon spectroscopy is planned for CEBAF with $E_\gamma \leq 4$ GeV (especially relating to photo- and electroproduction amplitudes), much more could be done with a higher beam energy. For example, the Q^2 -dependence of electroproduction amplitudes of problematical resonances such as the Roper could be measured usefully (from the quark model viewpoint) to ≈ 5 GeV² for comparison with theoretical predictions for q^3 -radial, hybrid or other assignments for this and other controversial states. In addition, associated production of strange baryons with kaons could be useful for the study of strange baryon spectroscopy, which is much less well known than nonstrange spectroscopy. Here interesting topics include the $\Lambda(1405)$ (which is too light to be a conventional uds baryon⁶) and the possible existence of Z^* flavor-exotic molecules.⁷ Only moderate beam energies are required for strange baryon spectroscopy; to reach the photoproduction threshold of $K + \Lambda(1405)$ we require only $E_\gamma = 1.5$ GeV, and photoproduction of a \bar{K} and a 2.1 GeV Z^* requires $E_\gamma = 3.1$ GeV.

Nimai Mukhopadhyay discussed new calculations of baryon resonance production in the $\gamma P \rightarrow \eta P$ and $\gamma P \rightarrow \eta' P$ reactions. The calculations indicate that the cross section for η' production, at least near threshold, depends on s -channel creation of the $N^*(2080)$. Again, the Q^2 dependences of such reactions may provide new clues to baryon structure.

Stan Brodsky urged us to consider reactions which would produce charmonium, for example $\gamma P \rightarrow \eta_c P$ and $\gamma P \rightarrow \psi P$, to investigate the possibility that charmonium may bind to nuclei.⁸ Since charmonium in flight may quickly dissociate in nuclei, open charm reactions such as $\gamma P \rightarrow \bar{D}^0\Lambda_c^+$ should also be studied. The threshold photon energies for these processes are rather high, $E_\gamma = 7.7$ GeV for $\eta_c P$, $E_\gamma = 8.2$ GeV for ψP and $E_\gamma = 8.7$ GeV for $\bar{D}\Lambda_c$.

3. Exotica: Molecules and Hybrid Mesons

A primary goal of modern meson spectroscopy is the identification of “exotica”, which are mesons external to the $q\bar{q}$ quark model. The more restrictive term *exotic meson* is used to refer to a meson whose quantum numbers are inconsistent with *any* $q\bar{q}$ assignment, either because of flavor (for example $I = 2$) or J^{PCn} ; 0^{--} , 0^{+-} , 1^{-+} , 2^{+-} , 3^{-+} ... are all forbidden to $q\bar{q}$ states. Exotica includes multi-quark systems (such as weakly bound hadronic molecules) and states with gluonic excitation, generically called gluonic hadrons. Gluonic hadrons are referred to as hybrids if quarks and gluonic excitations are both present in the dominant basis state, and glueballs if they are relatively pure excited glue.

Much of the recent interest in multi-quark systems has concentrated on molecules, which are weakly bound states of two or more conventional $q\bar{q}$ or qqq hadrons. Nuclei are the most familiar examples of these. Two meson resonances, the $f_0(975)$ and $a_0(980)$ have long been advocated by Weinstein and Isgur⁹ as $K\bar{K}$ molecules. These resonances are a problem in the quark model if one tries to identify them as 3P_0 $q\bar{q}$ states, due to their low masses and anomalous strong and electromagnetic couplings. In our working group John Weinstein presented the theoretical case for identifying these states as $K\bar{K}$ molecules, and Alex Dzierba discussed an experiment¹⁰ at CEBAF which can distinguish between $K\bar{K}$ and $q\bar{q}$ assignments by measuring the branching ratios¹¹ for $\phi \rightarrow \gamma f_0(975)$ and $\phi \rightarrow \gamma a_0(980)$. There are many other candidates for light molecules,¹² notably the $\Lambda(1405)$ baryon ($\bar{K}N$) and the mesons $f_1(1420)$ ($K^*\bar{K} + h.c.$ enhancement), $f_0(1520)$ ($\rho\rho, \omega\omega$) and $f_0(1710)$ ($K^*\bar{K}^*, \omega\phi$), which CEBAF might also usefully study in photoproduction experiments.

Curtis Meyer summarized results from the Crystal Barrel $P\bar{P}$ experiment¹³ at LEAR, including high-statistics results on the $f_0(1520)$ in $\pi^0\pi^0$ and $\eta\eta$. This state is interesting as a candidate ($\rho\rho, \omega\omega$) molecule and as a candidate scalar glueball. (A search for flavor-singlet couplings, indicated by the $\pi\pi$, $K\bar{K}$ and $\eta\eta$ branching fractions, may tell us if this state is indeed the anticipated 1.5 GeV scalar glueball; the $K\bar{K}$ analysis is in progress.) Meyer’s talk emphasized the importance of correctly including interference effects and unitarity in extracting broad, overlapping resonances in the 1-2 GeV mass range.

Suh-Urk Chung discussed the status of J^{PCn} -exotics, notably hybrids in the flux-tube model, and summarized current experiments and future experimental prospects. J^{PCn} -exotic hybrids arise when the excited gluonic degree of freedom is combined with the $q\bar{q}$ system to make a hybrid meson with definite quantum numbers; these exotic states are predicted by all the theoretical models and approaches which have been applied to hybrids.¹⁴ The quantum numbers 1^{-+} are often chosen for experimental searches because most models predict this to be the lightest exotic hybrid, and the flux tube model of decays predicts the $I = 1$ state to be relatively narrow.

Much of the current interest in hybrids is due to the flux tube model of Isgur, Kokoski, Merlin and Paton.¹⁵ This model treats the confining $q\bar{q}$ interaction as a gluonic flux tube between the quarks, and makes quite specific predictions for the masses and partial widths of states with excited flux tubes, which are the hybrids of

this model. The mass of the lightest hybrid multiplet is predicted to be ≈ 1.9 GeV, and the anticipated dominant decay modes are quite characteristic. In the flux tube model a hybrid meson decays by $q\bar{q}$ pair production, which breaks the flux tube. Consideration of overlap integrals suggests that the orbital angular momentum of the flux tube in a decaying hybrid tends to be transferred to an internal L of a final $q\bar{q}$ meson, so the preferred decay modes of the lowest-lying hybrids are the little-explored S+P two-body systems. The constituent gluon model of hybrids also predicted this preferred mode.¹⁶

The low-lying exotic hybrids and their decays predicted by Isgur, Kokoski and Paton are listed in Table 2. The notation has been changed to conform to 1992 Particle Data Group usage.¹⁷ In the table, $\Gamma_{H \rightarrow AB}$ is the partial width to the channel specified, which consists of a π or a K plus an excited meson. (For the strange particle decays, our notation implies the two charge conjugate combinations that give zero strangeness.) We also list the principal decay branches of the excited meson "B" in the two-body final state; Γ_B is the total width of the excited meson, and in the list of final states we abbreviate $K^*(892)$ by K^* and $K_0^*(1430)$ by K_0^* .

Chung noted that a persistent but controversial $I = 1, 1^{-+}$ signal has been reported in $\eta\pi$ and $\eta'\pi$ by several experiments.¹⁸ He also presented new results from BNL¹⁹ which appear consistent with a 1^{-+} exotic $\hat{\rho}(1900)$ decaying to $f_1(1285)\pi^-$ followed by $f_1 \rightarrow K^+K_S^0\pi^-$; an experiment in progress²⁰ will study this candidate exotic state with better statistics.

The flux tube model suggests that photoproduction should be an effective way to produce hybrids, since the transfer of momentum and angular momentum to a single struck quark may be an effective way to "pluck" (orbitally excite) a flux tube. There is some evidence for a 1^{-+} exotic, possibly a hybrid, near 1.8-1.9 GeV in photoproduction of $b_1\pi$ (Atkinson *et al.*²¹) and $\rho\pi$ (Condo *et al.*²²) final states. Gary Adams discussed a proposal to study some of these final states at CEBAF using the CLAS spectrometer in Hall B.

In summary, there is an excellent opportunity for CEBAF to contribute to the spectroscopy of exotica through photoproduction studies if the beam energy is increased to ≈ 6 GeV or beyond.

4. CP and CPT Violation in ϕ Decay

One very exciting possibility for CEBAF is the study of CP and CPT violation in ϕ decay. This idea was originally developed²³ to take advantage of e^+e^- ϕ -factories such as those now under construction at Frascati and Novosibirsk. In these experiments one measures the decays $K^0 \rightarrow \pi^+\pi^-$ and $K^0 \rightarrow \pi^0\pi^0$ in the same apparatus (to reduce systematic errors) and determines the asymmetry between these two modes as a function of the separation of the K_L^0 and K_S^0 from the ϕ decay. Not only is this an intriguing way to measure ϵ'/ϵ from K^0 decay, it also provides a new test of CPT violation. This may be more than an exercise in improving lower limits, since some string theories predict CPT violation.²⁴

To carry out these measurements at CEBAF, the plan is to produce “flying” ϕ mesons using the reaction $\gamma P \rightarrow \phi P$. This was the principal topic of a recent workshop at Indiana University; Alex Dzierba summarized the conclusions of that meeting and the status of this work in his plenary talk. CEBAF has a *potential* advantage in that it generates a much larger ϕ luminosity than the e^+e^- machines, although the associated problems of detector design and especially background rejection are nontrivial. Since the decay products are boosted forwards, particle identification is considerably easier than at an e^+e^- - ϕ factory.

A possible problem with a *CPT* experiment at CEBAF is the presence of a substantial background from S-wave $K\bar{K}$ photoproduction.²⁵ This introduces a $K_S^0 K_S^0$ signal which could obscure the *CP*-violating amplitude from the decay of a K_L^0 from the ϕ . However, Nathan Isgur explained how the dominant S-wave can be used to advantage by observing the interference between the S-wave and P-wave (ϕ) amplitude. These ideas are still under development, but appear promising at present.

5. New Detectors

Our working group also discussed possible new detector systems that could be used for both spectroscopy and ϕ decay experiments. Of the existing CEBAF detectors, only CLAS is appropriate for these studies, and Gary Adams discussed possible exotic meson signatures that could be measured in the CLAS. It appears unlikely however that this general purpose facility will prove suitable for the complete range of experiments we considered.

In his plenary talk Alex Dzierba discussed an experiment¹⁰ using a new segmented lead glass calorimeter²⁶ to study ϕ radiative decays. This can be carried out on a relatively short time scale at CEBAF because the detector is currently available. Although this experiment is limited to all-neutral decay modes of the ϕ , produced with a real, tagged photon beam, it illustrates how impressive physics results may be forthcoming from a relatively simple apparatus.

Experience with facilities such as LEAR have made clear the importance of complete event reconstruction, one should have charged particle detection and momentum measurement in addition to neutrals. Since many results will require relatively detailed partial wave analyses, it is important that a detector for spectroscopy approach 4π solid angle coverage with as little bias as possible. Experiments which would use an incident electron beam (as opposed to photons, in which case the primary electrons have been removed) face additional complications from luminosity limitations.

The traditional approach to high energy spectroscopy has been to use a dipole magnet spectrometer with a large magnetic field volume, equipped with tracking chambers, particle identification, and possibly neutral particle detection.²⁰ This approach has been applied to tagged photon spectroscopy with good results,^{21,27,28,29} but in all cases the maximum allowed incident photon rate was limited to a few $\times 10^5$ /sec. This limitation arises partly from e^+e^- pairs produced in the target by the incident photon beam; these pairs spread in the dipole field and are incident on the detectors

at very high rates.

At CEBAF, the CLAS avoids this problem, while retaining the large bending power of a dipole spectrometer, by using a toroidal magnetic field. This essentially eliminates the problem of e^+e^- pair production, although as a result of this geometry the detector is insensitive in the forward region because the magnetic field is very low. Unfortunately, many of the high energy experiments of interest for spectroscopy, especially those using small- Q^2 "diffractive" photon interactions, preferentially populate the extreme-forward region.

An alternative approach, followed by Crystal Barrel and LASS,^{30,31} is to use a solenoidal magnetic field. Since particles are deflected only according to their transverse momentum, one can sacrifice some momentum resolution for the more forward-going particles, and LASS³¹ augment their system with a dipole magnet far downstream. Advantages of solenoidal spectrometers include a large, flat acceptance over phase space, and the "trapping" of e^+e^- pairs along the axis of the solenoid. In our working group Dan Coffman discussed the state-of-the-art in solenoidal spectrometers, specifically the CLEO detector at Cornell/CESR which is used for high energy e^+e^- collision experiments.

Heavy quark spectroscopy, including charm and τ decays, would be difficult to pursue unless CEBAF increases its energy to well above 8 GeV. (See Figure 1.) Kam Seth proposed a different solution, namely an e^+e^- τ /charm factory using a 6 GeV electron beam incident on a 1 GeV positron beam in a storage ring. Center-of-mass energies up to 4.90 GeV are possible, and that would be extended to 5.66 GeV with an 8 GeV electron beam. What's more, the incident electron beam is used "non-destructively", and might be incident on fixed targets downstream. Similar designs have been studied previously, and luminosities approaching $10^{33}/\text{cm}^2\text{sec}$ may be possible, leading to orders of magnitude improvement in the present event sample.

Specific designs and cost estimates for these detector and accelerator developments are in preparation.

6. Acknowledgements

This work was supported in part by the United States Department of Energy under contract DE-AC05-84OR21400 at Oak Ridge National Laboratory with Martin Marietta Energy Systems, Inc.

7. References

1. D.W.G.S. Leith, in *Electromagnetic Interactions of Hadrons*, Vol.I ed. A. Donnachie and G. Shaw (Plenum Press, New York, 1978).
2. C.E. Carlson and M. Sher, *Phys. Rev. Lett.* 72 (1994) 2686.
3. P. Geiger, *Phys. Rev.* D49 (1994) 6003.
4. D. Aston *et al.*, SLAC-PUB-5145; *Nucl. Phys. (Proc. Suppl.)* B8 (1989) 32.
5. S. Godfrey and N. Isgur, *Phys. Rev.* D32 (1985) 189.

6. S. Capstick and N. Isgur, *Phys. Rev. D* 34 (1986) 2809.
7. K. Maltman and S. Godfrey, *Nucl. Phys. A* 452 (1986) 669; T. Barnes and E.S. Swanson, *Phys. Rev. C* 49 (1994) 1166.
8. S.J. Brodsky, I. Schmidt and G.F. de T eramond, *Phys. Rev. Lett.* 64 (1990) 1011.
9. J. Weinstein and N. Isgur, *Phys. Rev. Lett.* 48 (1982) 659; *Phys. Rev. D* 27 (1983) 588; *Phys. Rev. D* 41 (1990) 2236; J. Weinstein, *Phys. Rev. D* 43 (1991) 95.
10. A. Dzierba, J. Napolitano *et al.*, CEBAF Experiment 94-016.
11. F.E. Close, Nathan Isgur, and S. Kumano, *Nucl. Phys. B* 389 (1993) 513.
12. N. T ornqvist, *Phys. Rev. Lett.* 67 (1991) 556; K. Dooley, E.S. Swanson and T. Barnes, *Phys. Lett. B* 275 (1992) 478; for recent reviews see N. T ornqvist, Helsinki report HU-SEFT-R-1993-13 and T. Barnes, RAL-94-056.
13. V.V. Anisovich *et al.*, *Phys. Lett. B* 323 (1994) 233.
14. For recent reviews of hybrids see T. Barnes, RAL-93-069; F.E. Close, RAL-93-053; *Rep. Prog. Phys.* 51 (1988) 833; G. Karl, *Nucl. Phys. A* 558 (1993) 113c; D. Hertzog, *Nucl. Phys. A* 558 (1993) 499c; N. Isgur, CEBAF-TH-92-31.
15. N. Isgur, R. Kokoski, and J. Paton, *Phys. Rev. Lett.* 54 (1985) 869; N. Isgur and J. Paton, *Phys. Rev. D* 31 (1985) 2910; J. Merlin and J. Paton, *J. Phys. G* 11 (1985) 439; *Phys. Rev. D* 35 (1987) 1668.
16. M. Tanimoto *et al.*, *Phys. Lett.* 116B (1982) 198; A. LeYaouanc *et al.*, *Z. Phys. C* 28 (1985) 309; F. Iddir *et al.*, *Phys. Lett. B* 205 (1988) 564.
17. Particle Data Group, *Phys. Rev. D* 45/II (1992).
18. G.M. Beladidze *et al.*, *Phys. Lett. B* 313 (1993) 276, and references therein.
19. J.H. Lee *et al.*, *Phys. Lett. B* 323 (1994) 227.
20. A. Dzierba, S.-U. Chung *et al.*, BNL Experiment E852.
21. M. Atkinson *et al.*, *Z. Phys. C* 34 (1987) 157.
22. G. Condo *et al.*, *Phys. Rev. D* 43 (1991) 2787.
23. C.D. Buchanan *et al.*, *Phys. Rev. D* 45 (1992) 4088.
24. V. Alan Kostelecky and R. Potting, "CPT, Strings, and the $K\bar{K}$ System", in D. B. Cline, ed., "Gamma Ray Neutrino Cosmology and Planck Scale Physics", World Scientific, Singapore, 1993; V. Alan Kostelecky and R. Potting, *Nucl. Phys. B* 359 (1991) 545.
25. D. P. Barber *et al.*, *Z. Phys. C* 12 (1982) 1; D. Aston *et al.*, *Nucl. Phys. B* 172 (1980) 1; D. C. Fries *et al.*, *Nucl. Phys. B* 143 (1978) 408.
26. B.B. Brabson *et al.*, *Nucl. Inst. Meth. Phys. Res. A* 332 (1993) 419.
27. D.P. Barber *et al.*, *Nucl. Inst. Meth.* 155 (1978) 353.
28. D. Aston *et al.*, *Nucl. Inst. Meth.* 197 (1982) 287; W. Beusch, CERN/SPSC/77-10.
29. Rudolf J. Wedemeyer, "The SAPHIR Detector", in *Electron and Photon Interactions at Intermediate Energies*, Lecture Notes in Physics No.234, Springer-Verlag (1985).
30. E. Aker *et al.*, *Nucl. Inst. Meth. Phys. Res. A* 321 (1992) 69.
31. D. Aston *et al.*, SLAC Report 298 (1986).

Table 1: Agenda for the Hadron Spectroscopy Working Group

Speaker	Topic
<i>Thursday 14 April</i>	
Simon Capstick (FSU)	Problems in Baryon Spectroscopy
Alex Dzierba* (IU)	Flying ϕ s and High Energy Spectroscopy
John Weinstein (U.Miss.)	$K\bar{K}$ Molecules
<i>Friday 15 April</i>	
Steve Godfrey* (Carleton)	Issues in Light Hadron Spectroscopy
Suh-Urk Chung (BNL)	Exotic Meson Spectroscopy
Curtis Meyer (CMU)	Results from Crystal Barrel
Kamal Seth (Northwestern)	A τ -Charm Factory at CEBAF
Gary Adams (Rensselaer)	Exotic Meson Spectroscopy in CLAS
Dan Coffman (Cornell)	Solenoidal Detectors in Spectroscopy
<i>Saturday 16 April</i>	
Marc Sher (William and Mary)	Gluino Searches at CEBAF Energies
Nimai Mukhopadhyay (Rensselaer)	Photoproduction of η and η'
Nathan Isgur (CEBAF)	S-P Interference in $K\bar{K}$ Photoproduction and Searches for CP and CPT Violation
* Plenary Talk	

Table 2: J^{PC_n} -Exotic Hybrid Mesons and Dominant Decays in the Flux Tube Model

Hybrid Meson					Secondary Decays			
State	IKP label	$J^{PC_n}(I^G)$	Decay	$\Gamma_{H \rightarrow AB}$ (MeV)	Γ_B (MeV)	Decay	<i>b.f.</i>	
$\hat{a}_2(1900)$	x_2^{+-}	$2^{+-}(1^+)$	$[\pi a_2(1320)]_P$	450	103	$a_2 \rightarrow \rho\pi$	70%	
						$\rightarrow \eta\pi$	15%	
						$\rightarrow \omega\pi\pi$	11%	
						$\rightarrow K\bar{K}$	5%	
			$[\pi a_1(1260)]_P$	100	~ 400	$a_1 \rightarrow \rho\pi$	most	
			$[\pi h_1(1170)]_P$	150	360	$h_1 \rightarrow \rho\pi$	seen	
$\hat{f}_2(1900)$	y_2^{+-}	$2^{+-}(0^-)$	$[\pi b_1(1235)]_P$	500	155	$b_1 \rightarrow (\omega\pi)_{S,D}$	most	
						$\rightarrow \eta\rho$	seen	
$\hat{f}'_2(2100)$	z_2^{+-}	$2^{+-}(0^-)$	$[K K_2^*(1430)]_P$	250	98	$K_2^* \rightarrow K\pi$	50%	
						$\rightarrow K^*\pi$	25%	
						$\rightarrow K^*\pi\pi$	13%	
			$[K K_1(1400)]_P$	200	174	$K_1 \rightarrow K^*\pi$	94%	
$\hat{\rho}(1900)$	x_1^{-+}	$1^{-+}(1^-)$	$[\pi b_1(1235)]_{S,D}$	100,30	155	$b_1 \rightarrow (\omega\pi)_{S,D}$	most	
						$\rightarrow \eta\rho$	seen	
			$[\pi f_1(1285)]_{S,D}$	30,20		24	$f_1 \rightarrow \eta\pi\pi$	50%
						$\rightarrow 4\pi(\rho\pi\pi)$	38%	
						$\rightarrow a_0(980)\pi$	37%	
$\hat{\omega}(1900)$	y_1^{-+}	$1^{-+}(0^+)$	$[\pi a_1(1260)]_{S,D}$	100,70	~ 400	$a_1 \rightarrow \rho\pi$	most	
			$[\pi\pi(1300)]_P$	100		200-600	$\pi(1300) \rightarrow \rho\pi$	seen
			$[K K_1(1400)]_S$	100		174	$K_1 \rightarrow K^*\pi$	94%
$\hat{\phi}(2100)$	z_1^{-+}	$1^{-+}(0^+)$	$[K K_1(1270)]_D$	80	90	$K_1 \rightarrow K\rho$	42%	
						$\rightarrow K_0^*\pi$	28%	
						$\rightarrow K^*\pi$	16%	
						$\rightarrow K\omega$	11%	
						$[K K_1(1400)]_S$	250	174
			$[K K(1460)]_P$	30	250	$K \rightarrow K\pi\pi$	seen	
$\hat{a}_0(1900)$	x_0^{+-}	$0^{+-}(1^+)$	$[\pi a_1(1260)]_P$	800	~ 400	$a_1 \rightarrow \rho\pi$	most	
			$[\pi h_1(1170)]_P$	100		360	$h_1 \rightarrow \rho\pi$	seen
			$[\pi\pi(1300)]_S$	900		200-600	$\pi(1300) \rightarrow \rho\pi$	seen
$\hat{f}_0(1900)$	y_0^{+-}	$0^{+-}(0^-)$	$[\pi b_1(1235)]_P$	250	155	$b_1 \rightarrow (\omega\pi)_{S,D}$	most	
						$\rightarrow \eta\rho$	seen	
$\hat{f}'_0(2100)$	z_0^{+-}	$0^{+-}(0^-)$	$[K K_1(1270)]_P$	800	90	See $\hat{\phi}(2100)$		
			$[K K_1(1400)]_P$	50		174	$K_1 \rightarrow K^*\pi$	94%
			$[K K(1460)]_S$	800		250	$K \rightarrow K\pi\pi$	seen

Fig.1. Kinematic thresholds
in the electroproduction reaction $\gamma^* P \rightarrow m+P$.

