CEBAF Program Advisory Committee Nine Proposal Cover Sheet

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

CEBAF
User Liaison Office, Mail Stop 12 B
12000 Jefferson Avenue
Newport News, VA 23606

Proposal Title

Exotic Meson Spectroscopy with CLAS

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Experimental Hall: B **Days Requested for Approval:** 21

Hall B proposals only, list any experiments and days for concurrent running:

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Receipt Date: 12/15/94 PR 94-121

By: g

HAZARD IDENTIFICATION CHECKLIST

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

Check all items for which there is an anticipated need.

Cryogenics ___ beamline magnets ___ analysis magnets ✓ target type: Liquid hydrogen flow rate: ______ capacity: ______	**Electrical Equipment** ___ cryo/electrical devices ___ capacitor banks ___ high voltage ___ exposed equipment CLAS	**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: ______ CLAS	**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 CLAS	**Radioactive Sources** ___ permanent installation ___ temporary use type: ______ strength: ______	**Large Mech. Structure/System** ___ lifting devices ___ motion controllers ___ scaffolding or ___ elevated platforms CLAS
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: Move CLAS tgt. upstream ~1.5 m from nominal.

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)
1	6000	tagger		liquid hydrogen	~1080 $\frac{gm}{cm^2}$ (~12 cm)

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.

LAB RESOURCES REQUIREMENTS LIST

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

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)*

CLAS

Note: move tgt. ~1.5 m from nominal

New Support Structures: ______________

Data Acquisition/Reduction

Computing Resources: CLAS

New Software: ______________

Major Equipment

Magnets: Photon Tagger @ top 20% of E_γ range

Power Supplies: ______________

Targets: ______________

Detectors: ______________

Electronics: ______________

Computer Hardware: ______________

Other: ______________

Other

____

11/27/94

Exotic Meson Spectroscopy with CLAS

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Abstract

The identification and study of mesons with explicit gluonic degrees of freedom will provide major constraints on nonperturbative QCD and models thereof. CLAS will provide a unique opportunity for studying these resonances by measuring photoproduction of multi-meson final states at E_γ= 5-6 GeV.

1. Introduction

In this proposal we will define "exotic" mesons to be those which have bound gluons in their constituent wave functions, including those which have quantum numbers that are incompatible with a simple $q\bar{q}$ assignment. Such states are predicted by QCD because gluons carry color quantum numbers. It is this property which adds much of the complexity to QCD and results in an attractive interaction between two gluons, and between gluons and quarks. The states which offer the best chance of detection are hybrid mesons with $q\bar{q}g$ structure, and low mass glueballs, gg. These are predicted to lie in the mass range 1.3 - 2.5 GeV.[1-13]

Experimental work on meson spectroscopy essentially stopped after large pieces of the conventional spectrum had been mapped out, and therefore only a few experiments have been devoted to searching for exotic states. The work of the KEK[14] and VES [15] collaborations are particularly noteworthy since they report evidence for a new state with unusual quantum numbers, $J^{PC}= 1^{-+}$, which is excited in $\pi^- p \rightarrow \pi^- \eta p$ at 1.30 GeV. This is a transverse-electric hybrid candidate. BNL experiment E818 also has low statistics results which hint at 1^{-+} strength going to $f_1(1285)\pi$, at 1.6-2.2 GeV.[16] Two recent BNL experiments are searching for exotic mesons which decay to neutral channels (E852) and to $\phi\phi$ (E881). Only two papers offer pertinent data from photon induced reactions: Atkinson, et al.[17] see evidence for a new state around 1.9 GeV which decays to $b_1(1235)\pi$ (see below) but were unable to identify quantum numbers, and Condo, et al.[18] have identified a state at 1.77 GeV decaying to $\rho\pi$ which has $J^{PC}= 1^{-+}$, 2^{-+}, or 3^{++}. If 1^{-+} is the proper assignment then this is an exotic meson.

The glueball sector is no better understood than the exotic hybrids. The low lying 0^{++} spectrum is rather crowded, with at least one state between 1.0 and 1.5 GeV likely to be the lowest glueball. Lindenbaum et al.[19] have identified three 2^{++} states which are high enough in energy to decay to $\phi\phi$ by measuring $\pi^- p \rightarrow \phi\phi n$. Since this is an OZI suppressed channel it seems likely that at least some of these are not excited by quark exchange, and are therefore glueball candidates. Also, the low lying glueballs, transverse-magnetic hybrids, and conventional mesons all have "conventional" quantum numbers so one must rely on measured transition strengths to help distinguish the states.

The excitation of exotic mesons remains one of the most fundamental tests of non-perturbative QCD remaining to be performed. More specifically, the masses and coupling strengths of the exotic mesons will provide needed input into the numerous models of non-perturbative QCD. Very little work has been done on exotic-meson searches with photon beams. For photon energies above a few GeV the hadronic components of the photon propagator become apparent. The Vector Meson Dominance approximation shows that a large part of the beam can be thought of as a beam of low-mass vector mesons ρ,ω, and ϕ. In this sense photons are unique because they carry spin-1 and couple readily to all quark flavors. These features of diffractive photoproduction will be useful in searching for exotic mesons.

2. Transverse-electric Hybrids

The masses and decay channels of the hybrid mesons have been extensively studied in the flux-tube model.[3-5, 13] In this model the vibrational spectrum of an excited gluon flux tube couples to a conventional quark anti-quark state to produce hybrid mesons. Of particular interest is a spectrum of nine low-lying I=0,1 states between 1.9 and 2.2 GeV which have quantum numbers that cannot be formed from a quark-antiquark pair. They arise from coupling transverse-electric (TE) gluons with $J^{PC}= 1^{+-}$ to conventional quark configurations. In a quark-gluon potential model this results when bound gluons are in states having orbital angular momentum, l = 1, and the $q\bar{q}$ pair have their spins coupled to S = 1.

If one concentrates on the neutral members of the hybrid multiplets, then the number of charged tracks in the final state, including the recoiling proton, is maximized. Table 1 lists some neutral decays with predicted partial widths less than 300 MeV, large

Table 1: Predicted masses and decays of TE hybrids.

	J^{PC}, I	Decay	Γ(MeV)	Final State	0.098 x BR(%)
$\hat{\rho}$ (2000)	1^{-+}, 1	$\pi b_1(1235)$	150	$\pi^+\pi^-\pi^+\pi^-(\pi^0)$	4.2 %
$\hat{\omega}$ (1900)	1^{-+}, 0	$KK_1(1400)$	100	$K^\pm \pi^\mp K^\mp \pi^\pm$	0.6 %
$\hat{\phi}$ (2100)	1^{-+}, 0	$KK_1(1400)$	250	$K^\pm \pi^\mp K^\mp \pi^\pm$	1.4 %
$\hat{f}_0$ (2200) [a]	0^{+-}, 0	$\pi b_1(1235)$ $KK_1(1270)$	250-500 0-400	$\pi^+\pi^-\pi^+\pi^-(\pi^0)$ $K^\pm \pi^\mp K^\mp \pi^\pm$	5.8 %
$\hat{f}'_2$ (2100)	2^{+-}, 0	$KK_1(1400)$ $KK_2(1430)$	200 250	$K^\pm \pi^\mp K^\mp \pi^\pm$ $K^+K^-\gamma\gamma$	0.9 % 0.8 %

a. Mass and widths are very sensitive to the strength of the L • S interaction (see Ref. 5). The quoted branching ratio is for the smaller width.

branching ratios, and narrow intermediate states.[3-5] Of those, only decays leading to less than five detected mesons are listed. This is an important constraint, and one which may explain why hybrids have been so poorly studied. Since the TE hybrids have gluon l = 1, their decay into pseudoscalar mesons is predicted to be small. This has the effect that decays to one light pseudoscalar meson, and one heavy l = 1 meson with J=1 or 2, are favored, yielding at least three mesons in the final state. However Close and Page point out that decays to $\rho\pi$ and other vector-pseudoscalar and vector-vector combinations should be measurable.[13] In our case an odd number of mesons requires at least one to be neutral, and photons must be detected in the final state. Therefore the final states listed in the table all have an even number of charged mesons and an even number of photons.

The existence of vector-meson quark configurations in the 1^{-+} hybrids emphasizes an important distinction between photon and meson probes. Pion or kaon beams are expected to excite the TE hybrids by heavy meson (b_1, K_1, etc.) exchange (see Table 1), whereas the vector meson component of a photon beam can be excited to a hybrid state by vector meson exchange. This process, which does not involve spin-flip of any quarks, is depicted in Fig. 1. This is particularly interesting for the $\hat{\phi}(2100)$ and $\hat{f}_2(2100)$ because

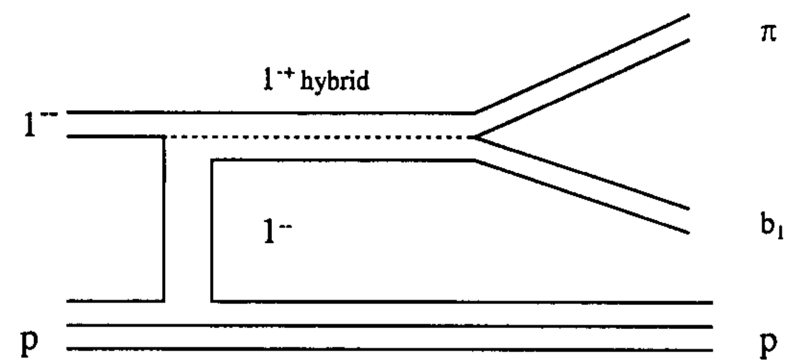

Fig. 1 - Quark diagram for hybrid photoproduction by vector meson exchange.

hadron beams are not a ready source of $s\bar{s}$ pairs.

In addition to the decay channels listed in Table 1, one should also measure the $\rho\pi$ channel discussed above. This is accessible in the $\pi^+\pi^-\gamma\gamma$ final state. The $\eta\pi$ channel, which was discussed in the introduction, is not well suited to a CLAS experiment; it requires the detection of one proton and four photons.

3. Transverse-magnetic Hybrids and Glueballs

The spectrum of exotic hadrons is not limited to those with unusual quantum numbers. In fact there are far more states which cannot be distinguished from conventional mesons by their quantum numbers. If the arguments given above are modified to allow exchange of pseudoscalar as well as vector mesons then the transverse-magnetic (TM) hybrids will be excited. All of these states are expected at rather high energy (at about the same mass as the TE states), so not much mixing is expected with the low-lying conventional states.[6] Here also photo-excitation can play an important role, since any new spectroscopy will help to identify the full set of states. However it is possible that something more can be learned by looking at specific final states. The dominant decays predicted by the flux tube model are the same ones discussed for the TE hybrids, plus large strength in a few other channels.[13] Three very promising TM decays are listed in Table 2. As one can see from the table, the same trigger topologies discussed

Table 2: Expected additional decays expected for TM hybrids. .

J^{PC}, I	Decay	Γ(MeV)	Final State	0.098 x BR(%)
1^{-+}, 1	$\pi a_1(1260)$	150	$\pi^+\pi^-\pi^+\pi^-$	1.4 %
0^{-+}, 1	$KK_0^*(1430)$	200	$K^+K^-\gamma\gamma$	1.7 %
2^{-+}, 0	$\pi a_2(1320)$	125	$\pi^+\pi^-\pi^+\pi^-$	1.1 %

above capture the new TM decay channels as well. Note that the branching ratios listed in Tables 1 and 2 are rough estimates which assume equal population of all allowed charge states. Theoretical branching ratios were used for the initial decays.[3-5, 13]

Similar considerations apply to the glueball states. The latest theoretical calculation predicts the lowest gg states to have $J^{PC}= 0^{++}$ (1.6 GeV), and 2^{++} (2.3 GeV), both of which are allowed quantum numbers for non-exotic mesons as well.[8-10] Lindenbaum et al.[19] have identified three 2^{++} states at 2.01, 2.30, and 2.34 GeV which decay to $\phi\phi$. Since this is an OZI forbidden channel for both non-exotic mesons and nonresonant amplitudes, they conclude that these must be glueballs. No attempt was made to explain the large number of closely spaced glueball candidates, and it seems likely that at least one of these is an $s\bar{s}$ meson.[20] The $s\bar{s}$ spectrum is poorly understood for masses above the $\phi_3(1850)$, and the Particle Data Group list at least five 2^{++} states that must be considered candidates. In our case $\phi\phi$ production is not OZI suppressed due to the $s\bar{s}$ component in the beam. Thus one might expect $s\bar{s}$ mesons to be copiously produced with photon beams by a process like the one depicted in Fig. 2. Therefore a comparison of the $\omega\phi$ and $\phi\phi$ channels could help to distinguish glueballs from $s\bar{s}$ mesons. This adds the decay channel $\phi\phi \rightarrow K^+K^-K^+K^-$ to the list of desired triggers.

3. Experiment

Due to the diffractive nature of photoproduction experiments, one expects strong forward peaking of the final state mesons. In the example given below we assume an e^{6t} distribution of events, but the actual value of the exponent is not critical for the simulation. CLAS is not an ideal spectrometer for this purpose because it has limited azimuthal acceptance at forward scattering angles. Nevertheless CLAS can serve the purpose of making the initial survey of exotic meson production quite well. It has rather large angular coverage, photon detection, π/K separation up to about 2.5 GeV/c, and a tagged photon beam. The states in question are expected at masses around 2 GeV, so the beam threshold energy is 4 GeV. Adding some energy to open up phase space raises the desired beam energy to 5 - 6 GeV. Since all of the chosen decays have neutral charge, equal numbers of positive and negative mesons will be detected. Thus one gains in overall acceptance by reducing the magnetic field, to remove the charge bias. Of course detection of a recoil proton breaks this experimental symmetry, so we choose to bend protons outward in order to increase the acceptance for these low momentum particles. The present estimates were made at $B=B_0/5$.. Also, the target center position has been moved upstream 1.5 meters in

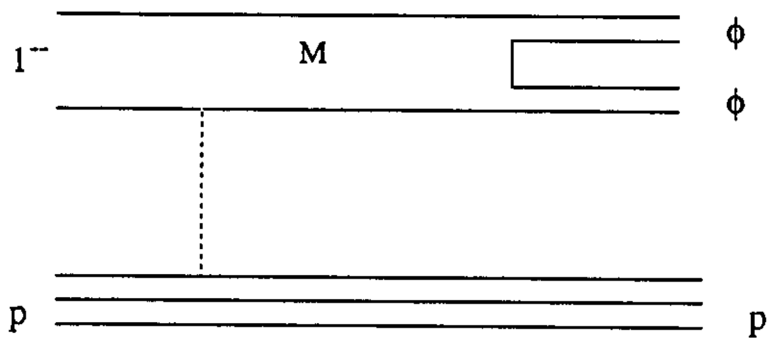

Fig.2 - Quark diagram for photoproduction of strange quarkonium states.

order to accept small-angle production.

Two of the decays listed in Table 1 have large predicted branching to $b_1\pi$, so this is a logical place to start a simulation. This channel has the advantage that the b_1 (Γ= 155 MeV) decays to narrow $\omega\pi$ mesons. Because of this we assume that it will not be necessary to detect the π^0 from the decay of the ω. This means that the π^0 will be detected by missing mass, and its momentum calculated from four-momentum conservation. The detected particles are $\pi^+\pi^-\pi^+\pi^-p$.

A monte-carlo simulation of this decay branch was made using the code FASTMC, for beam energies from 4.5 to 6.0 GeV. The decay chain discussed above (with proton detection) was simulated for a 2.0 GeV resonance. Events were distributed according to phase space times e^{6t}. The overall detector acceptance was found to be nearly independent of beam energy in the range from 5.0 to 6.0 GeV. The average acceptance was 9.8 percent.

Fig. 3 compares the generated and detected proton spectra resulting from 5 GeV photons. No obvious detector bias is present except at proton angles near zero, where the angular coverage of CLAS is very small. Fig. 4 makes a similar comparison for the pion resulting from $\hat{\rho}$ (2000) decay. The upper end of the pion momentum spectrum is cut off by the time-of-flight resolution limit at 2.5 GeV/c. The remaining pion spectra are all very similar, exhibiting broad peaks in momentum and angle at around 0.5 GeV/c and 20 deg, respectively (Fig. 5). The resulting reconstructed ω mass resolution of 100 MeV FWHM

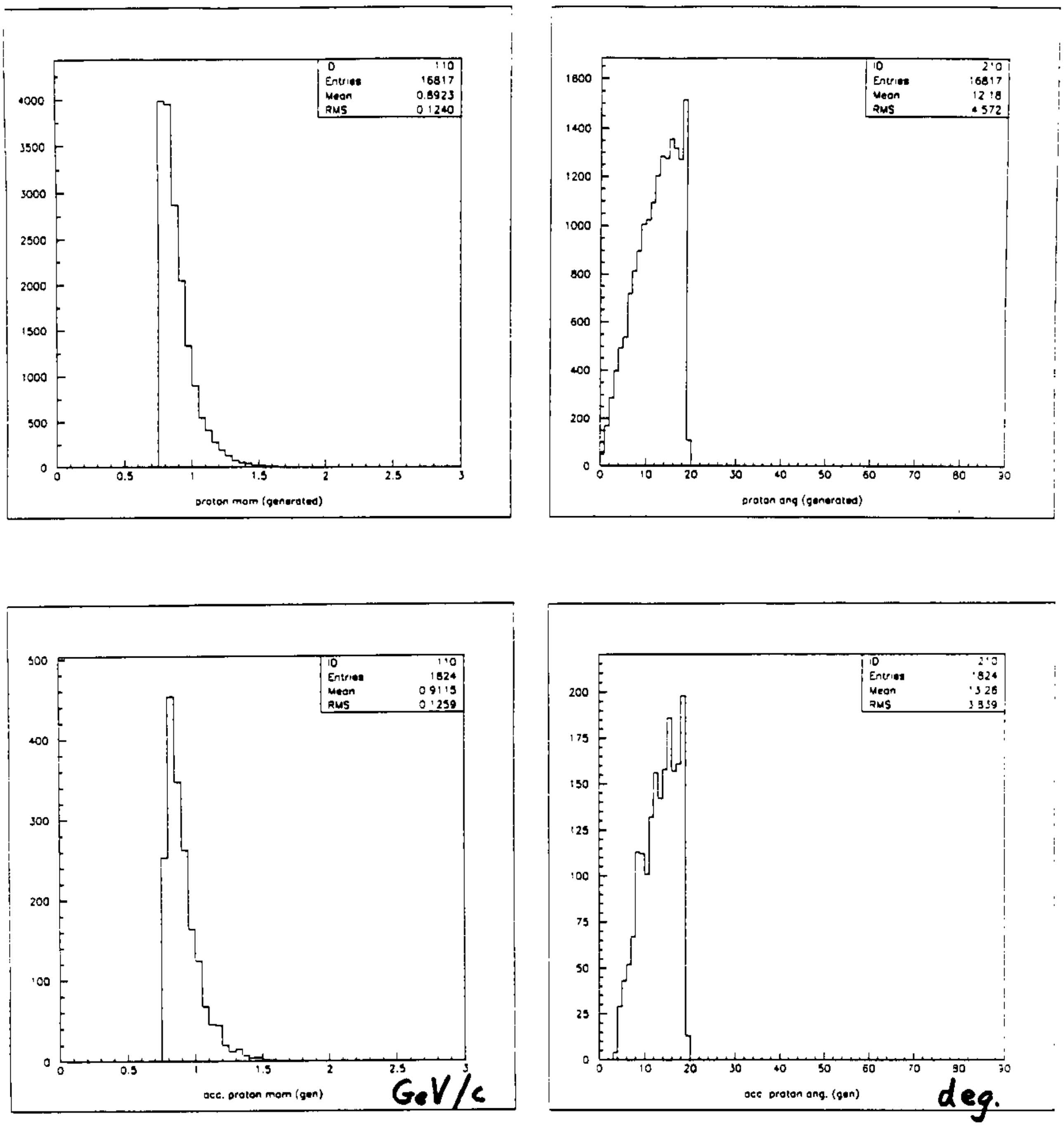

Fig. 3 - Generated and accepted proton momenta and scattering angles.

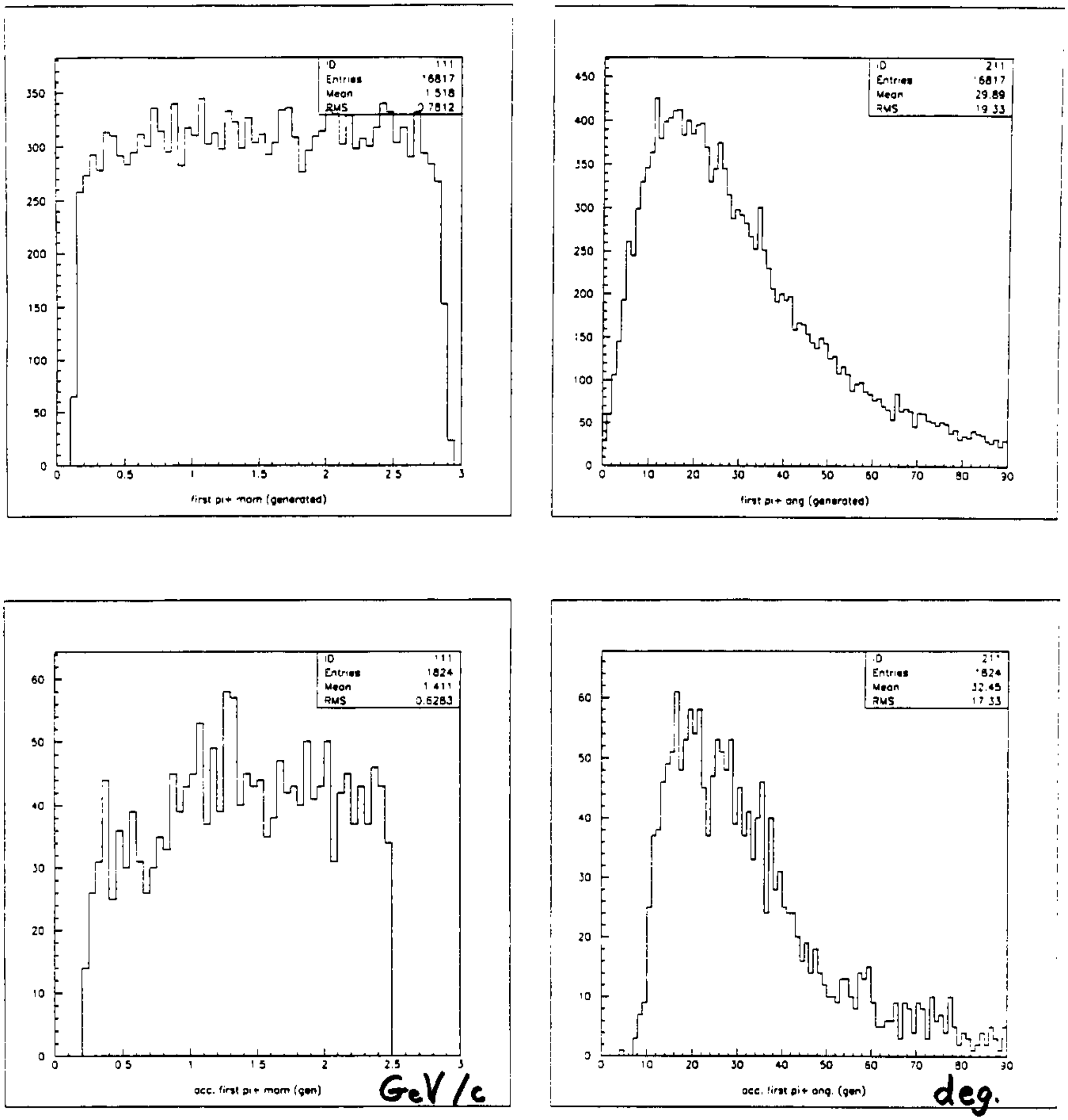

Fig. 4- Generated and accepted pion momenta and scattering angles from initial decay.

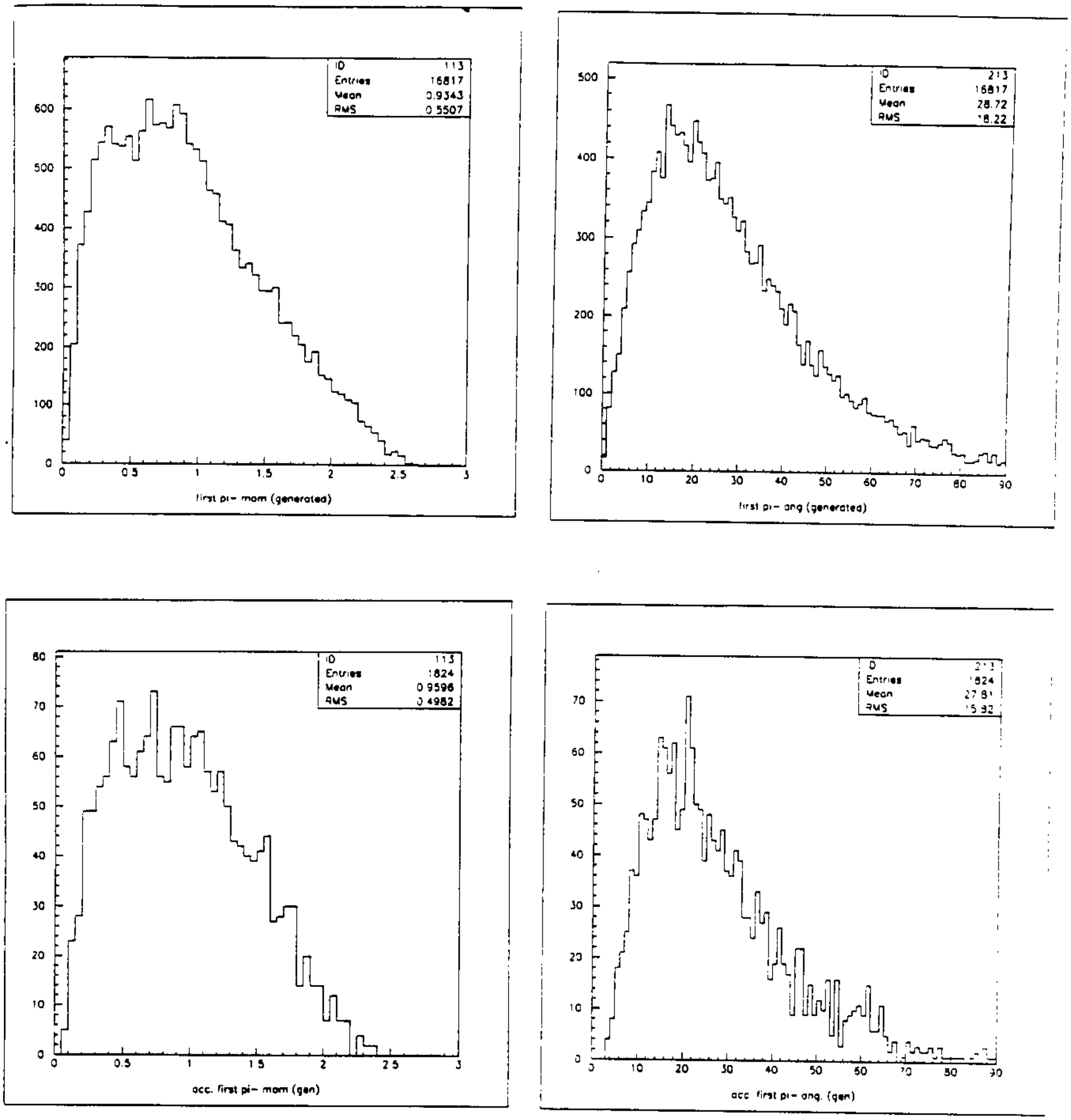

Fig. 5- Generated and accepted pion momenta and angles from b_1 decay.

is depicted in Fig. 6.

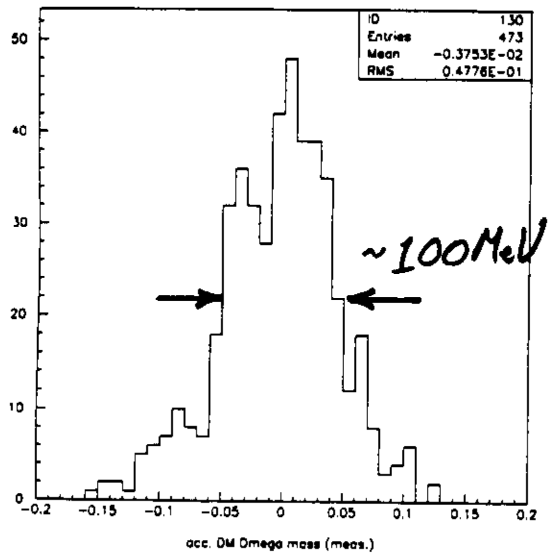

Fig. 6- Difference between generated and measured ω mass, in GeV.

Fig. 7 shows the final measured resolution for the hybrid mass. The peak width of 40 MeV FWHM is sufficient for studying the states listed in Tables 1 and 2 (Note that it was necessary to shift the target position back to center in order to use FASTMC for mass estimates).

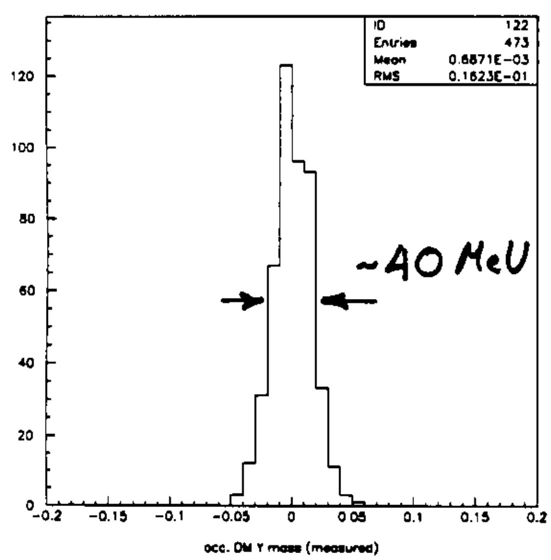

Fig. 7- Difference between generated and measured hybrid mass, in GeV.

The overall CLAS acceptance was found to be weakly dependent on beam energy, but strongly dependent on target position. Moving the target upstream by 1.5 meters from the nominal position increased the acceptance from 2.7 %to 10.8 % at E_γ= 5 GeV. These results were also used to estimate the acceptance for other triggers. The acceptance for photons in the CLAS shower counter is about the same as the charged particle acceptance. Since all of the proposed triggers in the tables have four light particles plus one proton, the acceptance for each of these will also be about 10%. No corrections have been made for particle decays in flight. The shower counter forms an integral part of triggers such as $\rho\pi^0$. Fig. 8 shows the results of a Monte Carlo simulation of π^0 reconstruction in the shower counter. The resulting π^0 mass resolution is about 30 MeV FWHM.

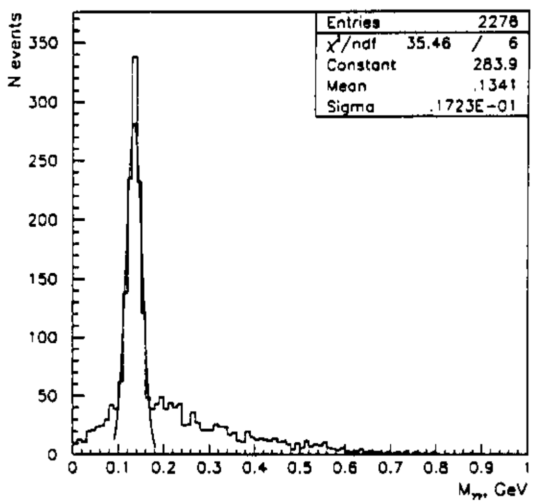

Fig. 8 - π^0 mass resolution from the CLAS shower counters.

A count rate estimate has been made for the $b_1\pi$ channel using the photoproduction data from the CERN Omega collaboration.[17] Those measurements were made with 25-50 GeV photons, and since typical diffractive production cross sections fall slowly with energy, those data will give a reasonable lower limit to aim for. They measured a total integrated cross section of 10 nb/100 MeV in a very poorly determined peak at 1.9 GeV (see Fig. 9).

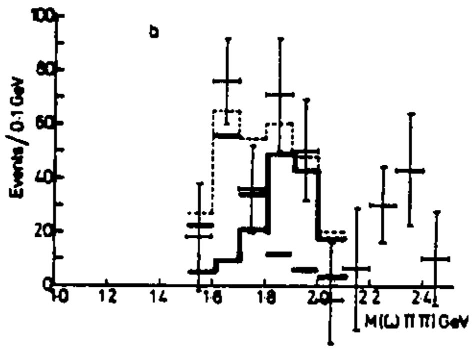

Fig. 9 - The $b_1\pi$ mass spectrum taken with 25-50 GeV photons. The low lying peak is from ω(1670). Additional strength above background was reported in a peak at about 1.9 GeV (solid line).

Therefore new experiments should be designed to detect resonances at the level of 1 nb. Assuming a 12 cm LH_2 target and a tagged photon flux of $5x10^7$/s for E_γ between 5 and 6 GeV, we estimate a total detected rate of 9/hr. The statistics needed to do a partial wave analysis depend a great deal on the details of the mass spectra. We take 4000 counts as a reasonable guess based on experience with other experiments. This gives a total required live time of 450 hrs. Adding 50 hrs for overhead associated with setting up the triggers with beam gives a total request of 500 hrs. We have not included beam time which will be needed to calibrate CLAS for the proposed operating conditions, since it is likely that this will be done for several experiments at once.

Background trigger rates can be estimated from published bubble chamber data.[21] Assuming a loose trigger requiring only three charged tracks captures everything of interest. The total cross section for p Nπ production, with $N \geq 2$, is about 25 μb for E_γ between 5 and 6 GeV. Even if we assume 100% detection efficiency this produces a detected rate of only 625/s.

4. Conclusions

The present estimates show that a credible search can be made for exotic mesons by using the CLAS to measure photoproduction of multi-meson final states. Two event types offer the best chance for finding exotic mesons: i) five charged particles and no photons, and ii) three charged particles and two photons. Detected rates are expected to be a few percent of the production rates. Other event types, for example those producing a neutron in the final state, will also be acquired.

5. References

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