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A SEARCH FOR MISSING BARYONS FORMED IN $\gamma p \to p\pi^+\pi^-$ USING THE CLAS AT CEBAF

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Proposal to CEBAF PAC6:
A Search for Missing Baryons Formed in $\gamma p \to p\pi^+\pi^-$ Using the CLAS at CEBAF

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April 2, 1993

Abstract

We propose to search for "missing" non-strange baryons formed via γp. These are states firmly predicted by quark models, yet not seen in existing spectroscopy, and their absence would give important clues to one day solving QCD. However, they may be missing only because πN initial or final states (or both) dominate the existing data set, and these states simply do not have large branching ratios to πN. We will measure the cross section for $\gamma p \to p\pi^+\pi^-$ in the CLAS with tagged real photons. We will analyze the data to determine the partial wave amplitudes for $\gamma p \to \Delta^{++}\pi^-$ and $\gamma p \to \Delta^0\pi^+$, as well as the channels $\gamma p \to p\rho$ and and $\gamma p \to p(\pi\pi)_S$. At a single electron beam energy of 2.4 GeV, we simultaneously search for baryons with masses between 1.3 GeV (the $\Delta\pi$ threshold) and 2.3 GeV, which spans the range predicted by most calculations. A simple trigger based on a tagged photon and at least one charged particle in the CLAS gives a relatively unbiased sample and allows parasitic running for several other event topologies.

1 Introduction

Quantum Chromodynamics (QCD) is probably the correct theory of the strong interactions. However, we are not yet able to solve the QCD lagrangian for bound states. Instead, we resort to the quark model [1] in an attempt to understand the spectroscopy of hadrons. Quark models are amazingly successful in predicting hadron properties, and indeed their independent quark degrees of freedom inspired the QCD lagrangian. It is hard, we now realize, to see how QCD would predict the quark model, but at least we tend to believe its solution will one day show how hadrons are so well described by these degrees of freedom.

Baryon spectroscopy plays a special role in testing QCD and the quark model. Excited baryons are made copiously in s – *channel* formation experiments on nucleon targets, and they are identified cleanly with partial wave decompositions as a function of beam energy. Also, the spectroscopy predicted by the quark model has been known for quite some time based on the underlying group theory [2]. Dynamics were added in a large variety of ways [3, 4], eventually including many aspects of QCD as well as a detailed treatment of relativistic corrections [5]. *Agreement with these models is quite good, but there is a problem, namely that many of the baryon states predicted by the underlying group theory are not observed.* If these "missing baryons" are not discovered, this might be an important clue to the dynamics hidden within the QCD lagrangian. For example, it has been suggested that somehow the quarks bind in pairs ("diquarks"), and the observed baryons arise from excitation of the quark-diquark pair [1]. This in fact would explain why so many of the missing baryons seem to belong to the 20-plet of $SU(6)$; this representation would not appear in a group theory based on diquarks [6].

However, there is a less exotic explanation for the missing baryons. The bulk of the data for the non-strange baryons is taken with $\pi^{\pm}$ beams, frequently looking at πN final states. If these baryons have small branching ratios to πN they would be hard to identify in this data. Some quark model calculations indeed show that this is the case, and that the missing states have significant branches to other *meson+baryon* combinations [7, 8, 9], as well as to γN [7]. Table 1, taken from Ref. [7, 10], shows some of these missing states and their calculated amplitudes ($\sqrt{width}$ in MeV) to πN, which are typically small, and to $\Delta\pi$ and $N\rho$, which can be much larger. We also include the γp couplings. For comparison, the table also includes two well-known low-lying states and their couplings; for these states, the calculations agree reasonably well with experiment.

We propose here to search for missing baryon states in the reaction $\gamma p \rightarrow p\pi^{+}\pi^{-}$. This

Table 1: Some Missing Baryons (and Where to Find Them)

State	γp Coupling $A_{3/2}$	$A_{1/2}$	Strong Coupling $N\pi$	$\Delta\pi$	$N\rho$
$N\frac{5}{2}^+(1955)$	+9	-67	0	-7	-8
$N\frac{5}{2}^+(2025)$	-3	+2	1	-7	+7
$\Delta\frac{5}{2}^+(1975)$	+76	+61	1	+6	-18
$N\frac{3}{2}^+(1870)$	+6	-19	3	-4	+1
$N\frac{5}{2}^+(1955)$	+4	-16	1	-9	+6
$N\frac{3}{2}^+(1980)$	-5	+19	1	+9	-7
$N\frac{3}{2}^+(2060)$	0	-1	1	+5	-3
$\Delta\frac{3}{2}^+(1975)$	-7	+18	0	-8	+5
$N\frac{1}{2}^+(1890)$		-20	4	+3	-5
$N\frac{1}{2}^+(2055)$		+7	1	+2	-1
Well Established States					
$\Delta\frac{3}{2}^+(1232)$	-179	-103	11		
$N\frac{3}{2}^-(1520)$	+128	-23	9	-7	-5

reaction avoids completely the need for a substantial coupling to πN, and allows us to search in the final states $\Delta^0\pi^+$, $\Delta^{++}\pi^-$, $p\rho$, and $p(\pi\pi)_S$. The experiment is ideal for the CLAS and photon tagging system in Hall B, as we can search the baryon mass range $1.3 \leq M_B \leq 2.3\ GeV/c^2$ simultaneously. The acceptance for the final state is good over this range, and the symmetry of the CLAS lends itself well to this reaction when extracting the various partial waves. Existing data on this reaction is very sparse, generally done with bubble chambers [11, 12, 13, 14, 15] and very low integrated luminosity, or at lower energies [16]. The reaction $\gamma p \rightarrow \Delta^{++}\pi^-$ has even been analyzed into partial waves [11], and intermediate baryon states have been studied using the total cross section [14]. However, the experiments suffered from very poor statistics (never more than several thousand events). Even a modest amount of running time in the CLAS will increase the data volume by orders of magnitude making it possible, for the first time, to unravel the different partial waves over essentially the entire region where we expect to find the missing baryons.

2 Experimental Method

We are looking for baryons B formed in the reaction $\gamma p \rightarrow B \rightarrow p\pi^+\pi^-$, using photons from the Hall B photon tagger. The baryon mass is just the center-of-mass energy, i.e.

$M_B = \left(2E_\gamma M + M^2\right)^{\frac{1}{2}}$, where M is the proton mass. For a given beam energy E_0, the tagger identifies photons with energies E_γ in the range $0.20E_0 \leq E_\gamma \leq 0.95E_0$. With $E_0 = 2.4\ GeV$, we therefore collect data simultaneously for $0.48 \leq E_\gamma \leq 2.28\ GeV$ and so $1.33 \leq M_B \leq 2.27\ GeV/c^2$. The lower photon energy corresponds to the observed $\Delta\pi$ threshold [11, 14] and the range covers the region suggested by quark model calculations to be rich in undiscovered states. In addition, this energy is conveniently a multiple of 800 MeV, and should therefore be relatively easy to achieve at CEBAF.

We will use the CLAS to identify the $p\pi^+\pi^-$ final state by either requiring all three particles to be detected, or by observing only two out of the three and using missing mass to identify the third. Protons and pions will be distinguished using Time-of-Flight (TOF) and dE/dx. Constrained fits to all observed particle momenta will be used to ensure a clean data sample [17].

The reaction $\gamma p \to p\pi^+\pi^-$ is dominated over this energy range by $\Delta\pi$ final states below 1.1 GeV (the approximate $p\rho$ threshold) and by $\Delta\pi$ and $p\rho$ up to our maximum photon energy of 2.3 GeV. Figures 1 and 2, from Ref. [11], show the relative yields as a function of $M(p\pi^+)$ and $M(\pi^+\pi^-)$, respectively, demonstrating the dominance of $\Delta^{++}(1232) \to p\pi^+$ and $\rho(770) \to \pi^+\pi^-$. The solid curves are fits of the full contribution from phase space, $\Delta^{++}\pi^-$ and the reflection of $\Delta^0\pi^+$ (including interference), and the contribution of the $p\rho^0$ reflection above $E_\gamma = 1.0$ GeV. There is a clear contribution from Δ^{++} final states even up to rather high energies. The contribution from $\Delta^0(1232) \to p\pi^-$ is also significant [11], but the yield is around 10% that of Δ^{++}.

In principle, we can view the reaction $\gamma p \to p\pi^+\pi^-$ as proceeding with the photon coupling to a quark in the proton, and a $q\bar{q}$ pair emerging from the vacuum to form a $p\pi^+\pi^-$ state. Figure 3(a) displays a "quark line" diagram of this process, cut in a way that shows it interpreted as proceeding through an intermediate baryon (qqq) state. This is in fact the process we are assuming, to search for new baryons as those intermediate states. However, one needs to include *every* such state to get a complete description of the process, and only the dominant baryons will appear in the analysis. We presume that at least some of these are the "missing" baryons we are searching for.

Herein lies a complication, though, that mainly affects the $\gamma p \to \rho p$ analysis. Figure 3(b) shows the same quark line diagram, but instead cut to show it interpreted as a "t-channel" exchange of a $q\bar{q}$ state. If the effective mass $\hat{m}$ of this $q\bar{q}$ state is very small, then this diagram will dominate at small momentum transfer t since the propagator $1/(t - \hat{m}^2)$

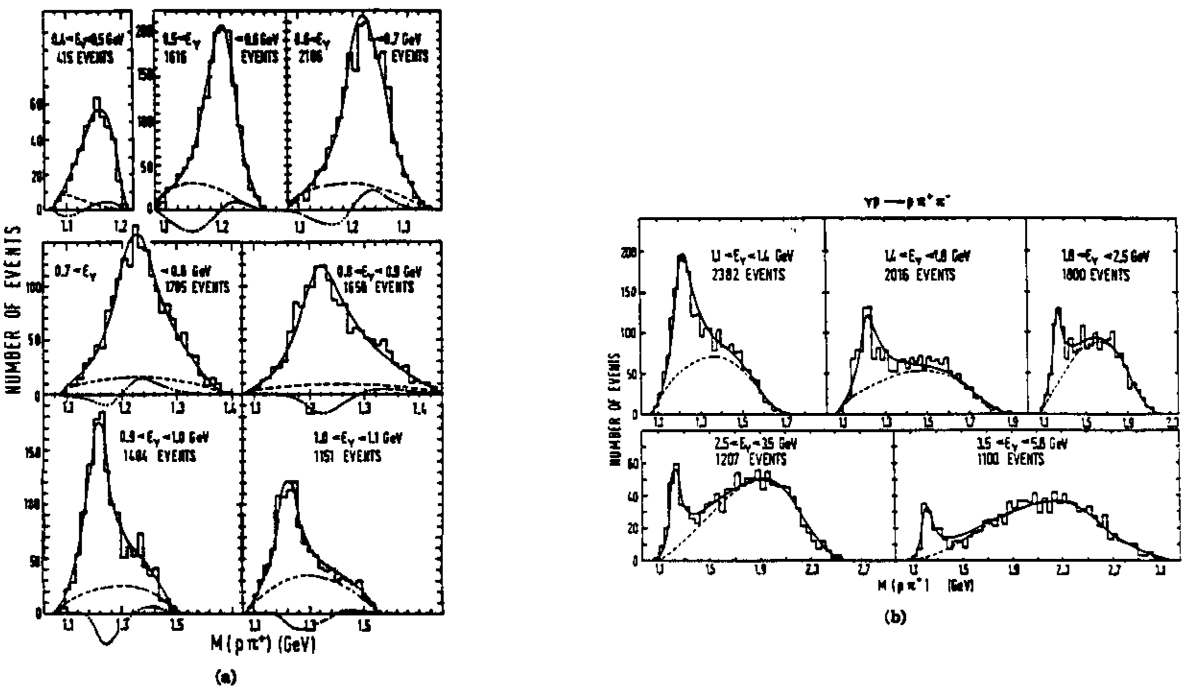

Figure 1: Yield as a function of $M(p\pi^+)$ for the reaction $\gamma p \to p\pi^+\pi^-$ separated into energies (a) below and (b) above the photon energy threshold for ρ production.

($t < 0$) can be quite large, and the kinematically minimum $-t$ (for forward produced ρ) approaches zero for $E_\gamma \gg M_\rho$. In fact this "diffractive" ρ production absolutely dominates the cross section for $\gamma p \to p\pi^+\pi^-$ for very high photon energies [13, 18]. Figure 4, from Ref. [11], shows that above 2.5 GeV or so, the diagram in Fig. 3(b) most accurately describes the reaction $\gamma p \to \rho p$. Since this reaction in fact dominates the total cross section at these energies (Fig. 2), there is no point in running with much higher photon energies if the object is to search for missing baryons in the intermediate state. One should note, however, that this strong "forward peaking" is not observed for the reaction $\gamma p \to \Delta\pi$ [11], presumably (at least in part) because unlike the ρ, the π does not have the same quantum numbers as the photon and the effective intermediate $q\bar{q}$ state in Fig. 3(b) does not have a small mass.

The differential cross sections for the various final states will be decomposed in partial waves so that we can search for underlying states of definite angular momentum [11, 19]. The simplest, and likely the first, approach to separating the final states will be to make Dalitz plots of $M^2(p\pi^\pm)$ *vs* $M^2(\pi^+\pi^-)$ to identify the $\Delta\pi$ and $p\rho$ components. With a large data sample, it should be possible to go further and simultaneously analyze the $\Delta\pi$, $p\rho$, etc..., within the $p\pi^+\pi^-$ sample, for example as carried out by Manley [20] for the reaction $\pi N \to \pi\pi N$. (This will likely be the only way to search for $p(\pi\pi)_S$ final states.)

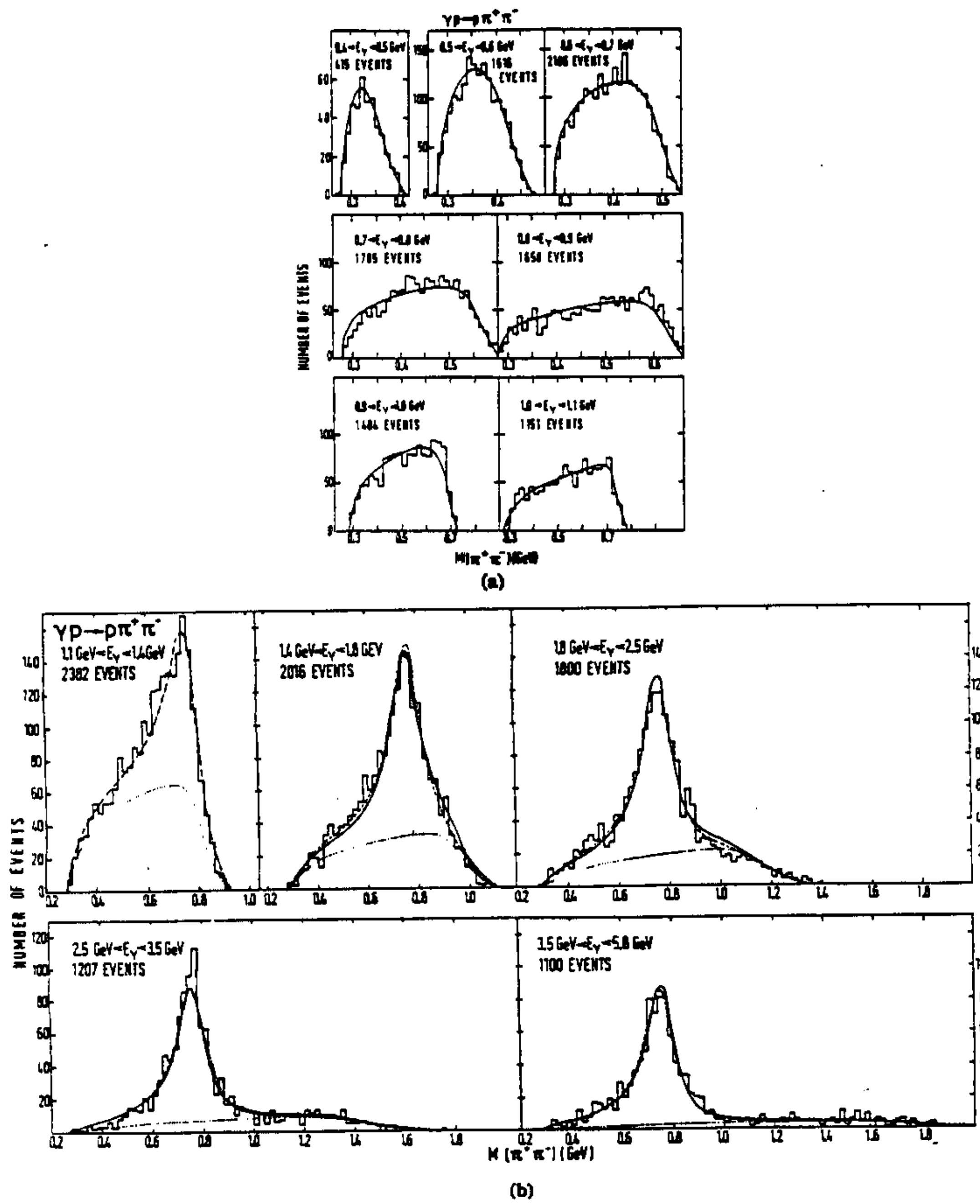

Figure 2: Yield as a function of $M(\pi^+\pi^-)$ for the reaction $\gamma p \to p\pi^+\pi^-$ separated into energies (a) below and (b) above the photon energy threshold for $\gamma p \to p\rho$.

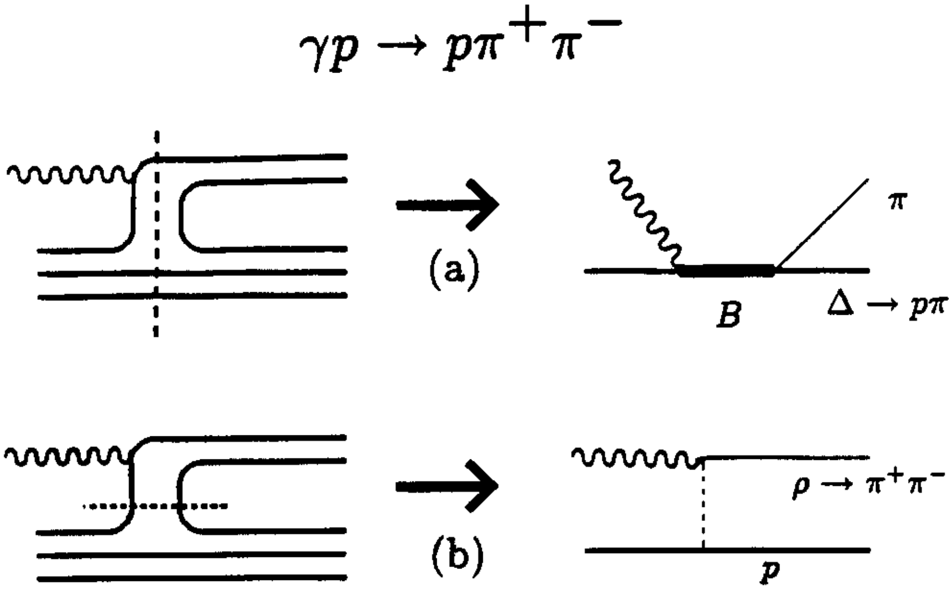

Figure 3: Quark line diagrams for the process $\gamma p \to p\pi^+\pi^-$. (a) Interpretation as $\gamma p \to B \to (\Delta\pi, p\rho)$, where B is an intermediate baryon state. (b) Interpretation as $\gamma p \to \rho p$ with the $t-$channel exchange of a $q\bar{q}$ state. The applicability of model (a) is necessary to search for missing baryons.

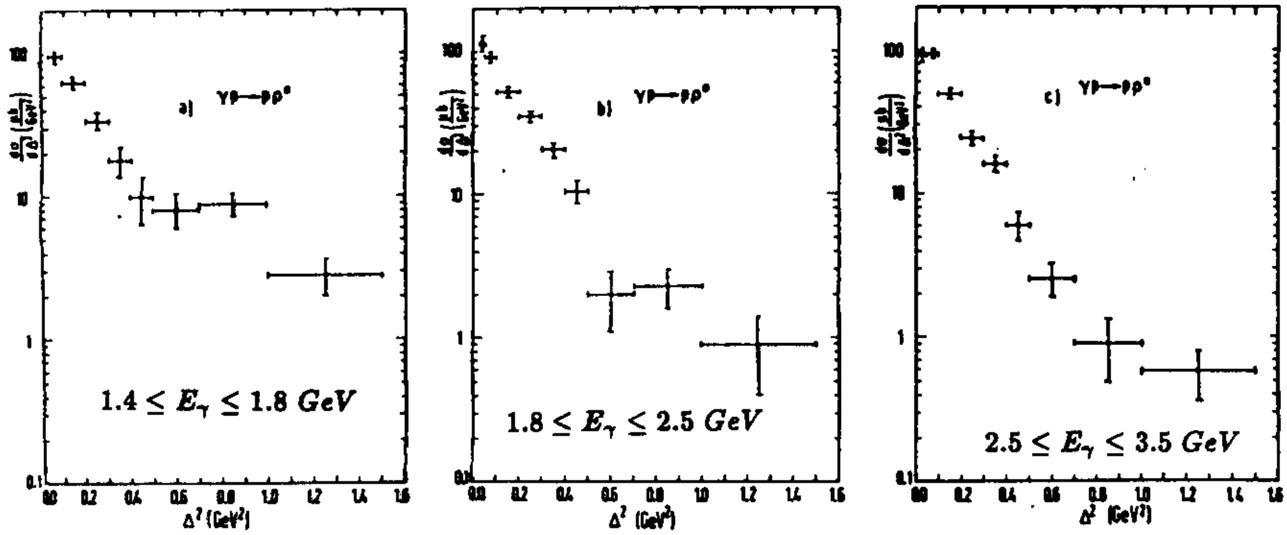

Figure 4: Measured cross section $d\sigma/dt$ versus t for $\gamma p \to p\rho$. Read "t" for "Δ^2" in the figure.

In our case, we will need to include a contribution from diffractive ρ production as well, which may actually help with the phase shift analysis by providing an additional amplitude to interfere with the rest of the $p\rho$ cross section.

3 CLAS Acceptance and Trigger Rate

We have tested the CLAS acceptance for this reaction by generating events according to phase space using the Monte Carlo program FOWL [21]. We expect to be able to trigger on a single charged particle in the CLAS, in coincidence with the tagged photon, and select the data for which we track either two or three charged particles. If only two particles are detected, we identify the third using a missing mass cut. In any case, constrained fits will be used to cleanly identify $\gamma p \rightarrow p\pi^+\pi^-$.

We take $\gamma p \rightarrow p\pi^+\pi^-$, events generated with FOWL, and use the parametric Monte Carlo program FASTMC [22] to simulate the CLAS response. We have investigated the geometric acceptance in this way, for a variety of different magnetic field configurations. Figure 5 shows the acceptance for detection of two or three of the final state $p\pi^+\pi^-$, plotted as a function of E_γ over the range covered by this proposal. We require that a particle be detected by the time-of-flight scintillators to be counted. The acceptance rises from threshold, where all particles go for forward and are not easily observed by the CLAS. As the figure indicates, the acceptance is not particularly sensitive to the polarity and magnitude of the magnetic field. The largest effect is the drop in acceptance for postive particles bending inward as opposed to outward, when the field is relatively large in magnitude, and E_γ is below around 1 GeV. This is not surprising, as we have 2 positive particles and 1 negative, each with comparable momentum, and "inbenders" are not easily accepted at forward angles relative to "outbenders" [22]. In any case, as the Fig. 5 shows, at 1/5 the maximum field, the acceptance is quite insensitive to the polarity and in fact is rather large over the entire photon energy range of this proposal.

Our plan is to require at least two out of the three particles to be detected, where we use a missing mass technique to identify the third if only two are observed. Consequently, it is important to have good missing mass resolution, particularly if we intend to run at a low magnetic field setting for acceptance reasons, or perhaps for compatibility with other experiments. Figure 6 histograms the difference between measured missing mass, as determined using FASTMC, and the actual mass of the missing particle for $E_\gamma = 2.4$ GeV, and the same two magnetic field strengths used in Fig. 5. At this, our highest, photon

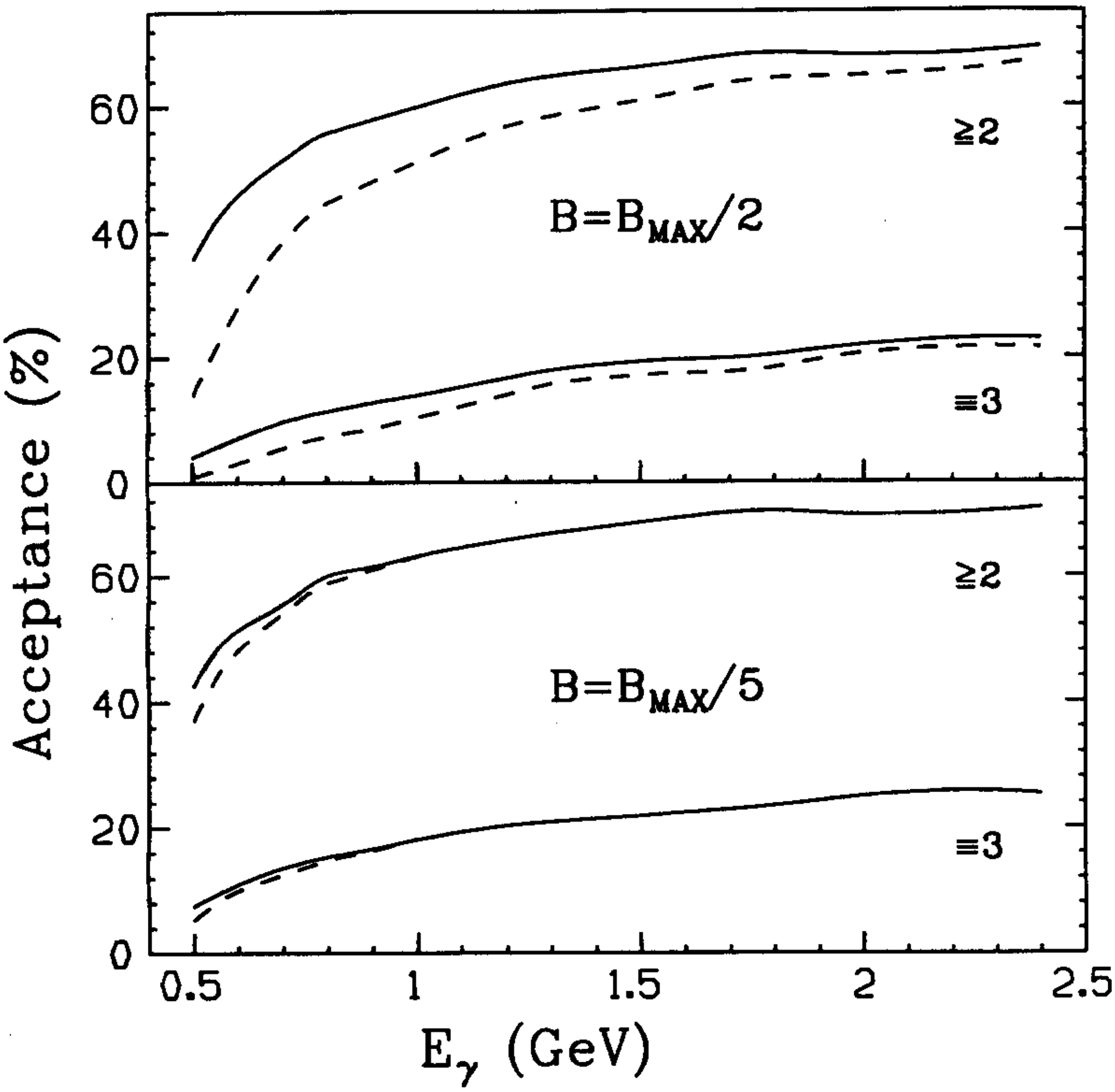

Figure 5: CLAS acceptance for $\gamma p \rightarrow p\pi^+\pi^-$ as a function of E_γ. We require that a particle intersect the time-of-flight scintillators, and we show the result for ≥ 2 and all 3 of the particles observed, at 1/2 and 1/5 of the maximum magnetic field in the CLAS, for either magnet polarity. The solid lines correspond to negative particles bending inward, while the dashed lines indicate the reverse.

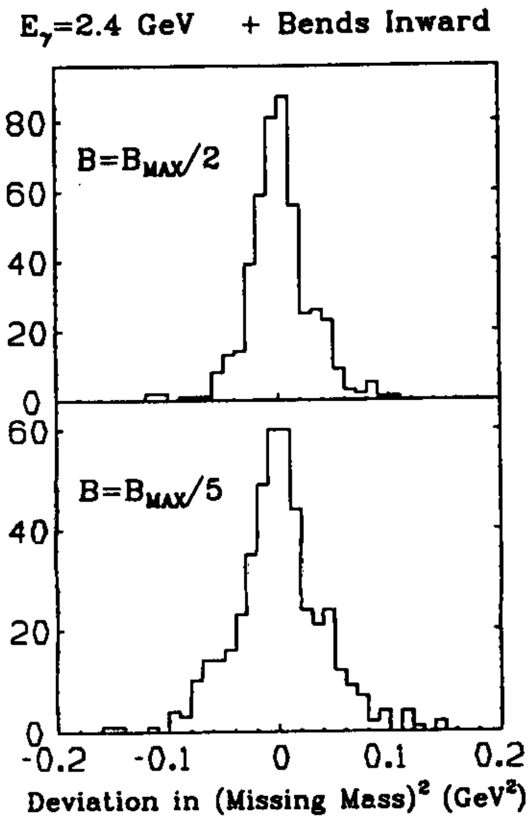

Figure 6: The resolution in (missing mass)^2 as measured by the CLAS when only two out of the three final state particles are observed, again for two different magnetic field strengths.

energy, particles have the largest momenta and therefore the missing mass resolution is the poorest. Figure 6 shows that even at 1/5 maximum field, the missing mass resolution of the CLAS is excellent. We will obviously have no trouble distinguishing missing $\pi^\pm$ from missing protons.

Figure 7 histograms the actual missing mass for 1/5 the maximum field and at 2.4 GeV photon energy, demonstrating the p/π separation. We also include the missing mass for a potential background process, namely $\gamma p \rightarrow p\pi^+\pi^-\pi^0$, where the π^0 goes undetected. The same number of events were generated, as for $\gamma p \rightarrow p\pi^+\pi^-$, but the cross section for the three pion reaction is more than a factor of two smaller [12]. (Other multiple pion final states are at least as small as $p\pi^+\pi^-\pi^0$.) The figure shows that, again, even at 1/5 the full field, we can resolve our signal from the background. Note that we have *not* invoked particle identification at this point.

Figure 8 shows the total cross section as a function of photon energy for at least one charged particle, at least one charged pion, and at least two charged pions [12]. Once beyond the $\Delta(1232)$, the cross section does not vary rapidly with E_γ. If rates allow, we would like to be able to trigger requiring only one charged particle in coincidence with the

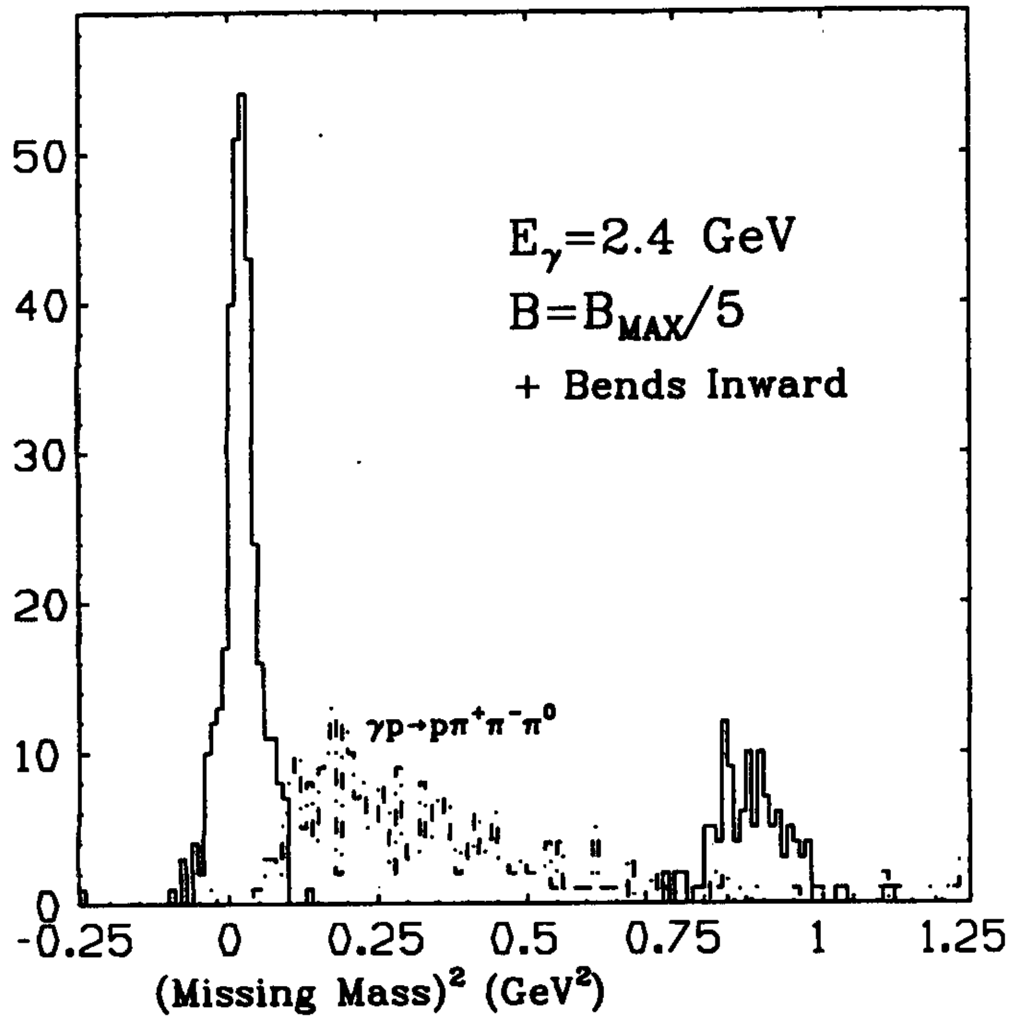

Figure 7: Separation in missing mass for events where either the proton or one of the pions was not detected in the scintillators. Also shown is the result for the same number of events from $\gamma p \rightarrow p\pi^+\pi^-\pi^0$ where the π^0 is undetected. This is a very conservative illustration in that it is for high energy and low magnetic field, and the cross section for the $p\pi^+\pi^-\pi^0$ final state is about half that for no missing π^0.

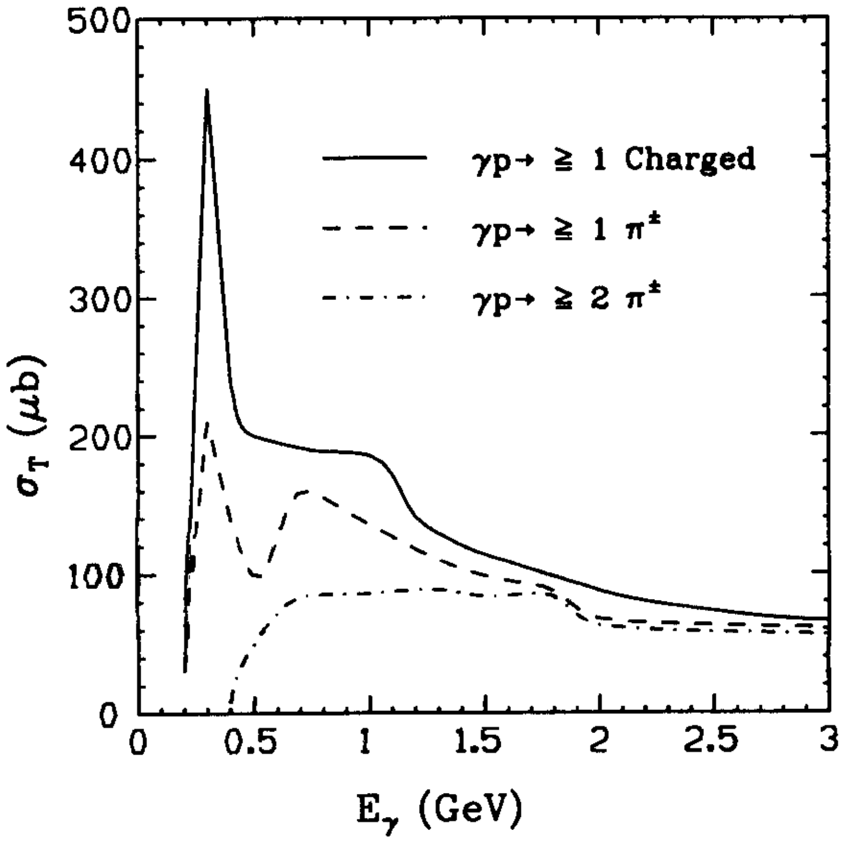

Figure 8: Total cross sections for charged particle photoproduction from the photon as a function of photon energy.

tagged photon, thereby minimizing any biases in the final state topology imposed by the CLAS geometry. The cross section for at least one charged particle falls from 200 μb to around 80 μb over our photon energy range, due mainly to $\gamma p \rightarrow pX$ and $\gamma p \rightarrow \pi^{\pm} X$ up to ~ 1 GeV, and then $\gamma p \rightarrow \pi\pi X$ over the rest of the range. If we assume a tagged photon rate of 10^7/sec and a 10 cm LH_2 target, the single particle trigger rate would therefore be on the order of 750 Hz, assuming unit efficiency. If the data acquisition hardware and software do not allow us to run at this rate, and perhaps filter events in software before writing to tape, then more restrictive triggers (such as two particles detected in the scintillators) can be enforced. In any case, we would certainly want to have as loose a trigger as possible so that event topologies from other physics could be extracted from the data.

4 Beam Time Request

Our beam time request is based on data acquisition fo $\gamma p \rightarrow p\pi^+\pi^-$ only, and does not include setup time, contingency, etc.... We also assume a tagging rate of 10^7/sec and a 10 cm LH_2 target.

It is difficult to know how many events will actually be needed, partly because the photon and strong decay widths of the missing states are not known, but also the extent to which they overlap with each other and with the non-resonant cross section will likely dictate the precision with which we can extract partial waves. Consequently, we follow the example of Ref. [11] who attempted such an analysis, but with a very low number of events, around 19,000 for $\gamma p \to p\pi^+\pi^-$. That group decomposed the angular distribution of $\gamma p \to \Delta^{++}\pi^-$ using 100 MeV wide bins in E_γ, and they indeed see some structure varying with photon energy. We aim here to reduce their statistical errors ($\sim 10-50\%$) by a factor of 10, using 20 MeV bins in E_γ, consistent with the expected resolution from the Hall B photon tagger. Thus, we aim to increase their data volume by a factor 500, i.e. 10^7 events.

The cross section for $\gamma p \to \Delta^{++}\pi^-$ is about 10 μb [11, 14] at our highest energies, while for $\gamma p \to \Delta^0\pi^+$ and (nondiffractive) $\gamma p \to \rho p$ it is about 10% as large. Consequently, we *conservatively* estimate our "usable" cross section to be several percent of the triggering cross section in Fig. 8, or $\sim 5-10$/sec. **We therefore request 400 hours of beam time, with the photon tagger in Hall B and a liquid hydrogen target in the CLAS.** We emphasize that with this low bias trigger and generic setup, the data acquired will likely be compatible with a large number of other measurements using this and other reactions.

With our flexible requirements on the spectrometer configuration, and our desire to have as loose a trigger as possible, there are many possibilities for compatibility with other experiments running simultaneously. In fact, our requirements are completely consistent with an approved proposal [23] to measure "Radiative Decays of the Low-Lying Hyperons". In particular, that experiment requires an electron beam energy of 2.4 GeV, the CLAS magnet at 1/5 full field with positive particles bending toward the axis, and a tagged photon beam rate of $10^7/sec$. The spokesperson of that experiment in fact encourages the prospect of concurrent running [24].

References

[1] F.E. Close, "An Introduction to Quarks and Partons", Academic Press (1979)

[2] O.W. Greenberg and M. Resnikoff, Phys.Rev. 163(1967)1844

[3] R.E. Cutkosky and R.E. Hendrick, Phys.Rev.D 16(1977)786

[4] Nathan Isgur and Gabriel Karl, Phys.Rev.D **18**(1978)4187;
Nathan Isgur and Gabriel Karl, Phys.Rev.D **19**(1979)2653

[5] Simon Capstick and Nathan Isgur, Phys.Rev.D **34**(1986)2809

[6] D.B. Lichtenberg, Phys.Rev. **178**(1969)2197;
R.E. Cutkosky and R.E. Hendrick, Phys.Rev.D **16**(1977)2902

[7] Nathan Isgur, CEBAF 1984 Summer Workshop (1984) pg.199

[8] Roman Koniuk and Nathan Isgur, Phys.Rev.D **21**(1980)1868

[9] C.P. Forsyth and R.E. Cutkosky, Z.Phys.C **18**(1983)219

[10] R. Koniuk, Nucl.Phys. **B195**(1982)452

[11] Aachen-Berlin-Bonn-Hamburg-Heidelberg-München Collaboration,
Phys. Rev. **175**(1968)1669

[12] Cambridge Bubble Chamber Group, Phys.Rev. **155**(1967)1477

[13] Cambridge Bubble Chamber Group, Phys.Rev. **146**(1966)994

[14] Cambridge Bubble Chamber Group, Phys.Rev. **163**(1967)1510

[15] G. Gialenella, *et.al.*, Il Nuovo Cimento **LXIIIA**(1969)892;
D. Lüke and P. Söding, Springer Tracts in Modern Physics, **59**(1971)39

[16] L. Murphy, Ph.D. Thesis, Rensselaer Polytechnic Institute (1993)

[17] D. Aston, *et.al.*, "The LASS Spectrometer", SLAC-REP-298(1986)

[18] "High Energy Photoproduction: Diffractive Processes", D.W.G.S. Leith, in Electromagnetic Interactions of Hadrons, Vol.1, A. Donnachie and G. Shaw, ed., Plenum (1978)345

[19] W.S.C. Williams, "An Introduction to Elementary Particles", Academic Press (1971)

[20] D.M. Manley, Phys.Rev.Lett. **52**(1984)2122;
D.M. Manley and E.M. Saleski, Phys.Rev.D 45(1992)4002

[21] "FOWL-A General Monte Carlo Phase Space Program", F. James CERN Library Document W505 (1977) ;
"Monte Carlo Phase Space", F. James, CERN-68-15 (1968)

[22] "Fast Monte Carlo Program for the CLAS Detector", E.S. Smith,
CLAS-NOTE-90-003

[23] "Radiative Decays of the Low-Lying Hyperons", G.S. Mutchler, CEBAF proposal PR-89-024 (1989)

[24] G.S. Mutchler, private communication