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 31, 1989

A. TITLE: A Study of the $S_{11}(1535)$ and $P_{11}(1710)$ in $p(e,e'p)\eta$.

B. CONTACT PERSON: Steve Dytman

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

/ / YES
/X/ NO

IF YES, TITLE OF PREVIOUSLY SUBMITTED LETTER OF INTENT

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

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Proposal Received 10-31-89

Log Number Assigned PR-89-039

KES
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Study of Electromagnetic Excitation of Baryon Resonances with the CEBAF Large Acceptance Spectrometer

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Proposal 3

Amplitudes for the $S_{11}(1535)$ and $P_{11}(1710)$ Resonances from an $ep \rightarrow e'p\eta$ experiment

Spokesmen: S. Dytman and K. Giovanetti

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ABSTRACT

A measurement of $p(e,e'p)\eta$ cross sections is discussed for the second and third resonance regions, 1.35 GeV<W<1.9 GeV. Since only the $S_{11}(1535)$ and $P_{11}(1710)$ resonances have significant decay branching ratios to the ηp channel, it provides an excellent way to isolate these resonances. The S_{11} is shown to be an unusual resonance, both from physics interest and from the advantages in making measurements through the $ep \rightarrow e'p\eta$ reaction channel. There is no existing information for the P_{11} from electroproduction. Data will be useful in testing the suggestion that it is a hybrid state. The standard CLAS configuration is extremely well–matched to the requirements of this experiment. About 1000 hours of beam time at a luminosity of 10^{34} cm^{-2} sec^{-1} generates enough data for a high quality experiment.

INTRODUCTION

The physics issues that can be addressed in the rich spectrum of baryon resonances are fundamental because all the combinations of quarks and gluons that nature prefers are studied. An overview of the subject is given in the introduction to the overall N^* proposal. The goal of these experiments is to provide photon-coupling amplitudes for each resonance, a property that can be determined from baryon wave functions with minimal model dependence. The principal means of extracting information about a single resonance uses the mass of the intermediate state (W), isospin information in the decay channels, and decay angular distributions for the resonance in its rest frame (θ^* and ϕ^*). Examination of unusual decay channels offers another method that is simple and effective. Only two resonances of mass less than 2 GeV have strong decay branches to ηN in the most recent compilation,[1] the $S_{11}(1535)$ and the $P_{11}(1710)$. Compared to the typical value of a few percent, these resonances decay to this channel 50% and 25% of the time. Measurement of the ηp final state near W$\sim$1.5 GeV selects the S_{11} in the intermediate state with high probability. The relatively weak ηNN coupling constant (somewhat uncertain, about 10% of the πNN coupling constant) makes background processes less important. Since the η is an isoscalar particle, it can couple only to $T=\frac{1}{2}$ resonances. This then is the simplest way to isolate a resonance outside of the $\Delta(1232)$. The S_{11} has a number of advantages over the $P_{11}(1710)$ and will be emphasized in this proposal. In an energy excitation curve, the $S_{11}(1535)$ will come in very strong quite close to the kinematic threshold for η electroproduction at 1487 MeV. Since the P_{11} is well above threshold, nonresonant background will be a larger problem than for the S_{11}. The S_{11} also has a larger excitation cross section and larger branching ratio to single meson + nucleon final states, the channels that are easiest to analyze.

Taking advantage of these features, electroproduction experiments at NINA,[2] DESY,[3-5] and Bonn[6,7] detected the recoil proton in coincidence with the scattered electron in a p(e,e′p)X measurement and saw a significant peak at the missing mass for an η.

About 12 total cross section points for p(e,e′p)η for W~1535 MeV and Q^2 up to 3 GeV^2 are shown in figure 1. After subtraction of nonresonant background, these data have been interpreted as the form factor of the S_{11} because of the arguments given above. The most striking feature of the S_{11} is its very slowly falling form factor which is in strong contrast to the surrounding resonances, including the $D_{13}(1520)$ which is in the same octet in the SU(6) symmetry model. Other resonances, such as the $\Delta(1232)$ and the $D_{13}(1520)$, have form factors with a shape similar to that of the proton. (The dipole form factor is shown in the figure for comparison.) Thus, any model that depends on SU(6) symmetry tends to have trouble explaining this feature.[8] It has not been reproduced in any calculation, including the most recent results shown in figure 1 (although the Warns et al. result is quite close). Measurements of σ_L/σ_T were made to search for a strong longitudinal excitation to explain this feature, but experimental facilities available in the 1970's limited the quality of the data. The ratio was determined to be 0.23±.14 at Q^2=0.4 GeV^2 in a Bonn experiment.[7] On the other hand, the ratio was 0.25±.23 at Q^2=0.6 GeV^2 and -0.13±.16 at Q^2=1.0 GeV^2 in a DESY experiment.[5] The longitudinal contribution is not large, probably roughly 0.1 of the transverse contribution, and cannot fully account for the discrepancies seen. This separation clearly needs to be done better and will be done much better with CLAS, but not until systematic errors are reduced to the few percent level because the transverse excitation is so dominant. Thus, the longitudinal/transverse experiment is discussed in a later section of the N^* proposal.

The Bonn data[7] in figure 2 give strong circumstantial evidence that selection of the pη channel in the final state focuses on the S_{11}. Statistical errors are quite small and the W excitation curve matches the Breit-Wigner shape (with proper threshold behavior) extremely well. In addition, the distribution in $\cos\theta^*$ is quite flat. Although the single meson decay for the S_{11} resonance must have a flat angular distribution, it is not an unambiguous assignment because the P_{11} and the s wave background also give the same θ^* distributions when taken alone. However, these amplitudes will likely interfere and destroy the isotropy if more than one of them is large.

Interest in the $P_{11}(1710)$ is driven largely by theory since it has a weak signature in pion production experiments. None of the previous eta electroproduction experiments publish results for this state, presumably because of limitations in beam time. Its existence is established from real photon and πN experiments, but its Q^2 dependence is unknown. The photon coupling amplitude derived from multipole analyses of real photon data is small and uncertain, e.g. $A^p_{1/2}$= 15±25x10^3 GeV$^{-\frac{1}{2}}$ in the Glasgow analysis.[9] The nonrelativistic quark model calculation of Koniuk and Isgur is in poor agreement[10] (-47 GeV$^{-\frac{1}{2}}$), so the structure of this state is less certain than most other resonances. Some have taken advantage of the lack of experimental information to suggest it is a hybrid state[11,12] of a valence gluon coupled to 3 quarks. If this were true, the photon coupling to this state would vanish for all Q^2 according to bag model calculations.[11] Any solid information at finite Q^2 could quickly make this situation more clear.

The existing $S_{11}(1535)$ data leave a number of questions unanswered. If the other resonances that contribute to data at W$\sim$1535 MeV and the background are properly accounted for, do the above interpretations remain? What is the shape of the form factor at $Q^2\sim0$ since data at the low Q^2 points (where data rates are comparatively high) taken at different labs are not consistent. One also sees systematic disagreement ($\sim$30%) between the older NINA data[2] (not shown in figure 1) and the latest DESY data[4] at higher values of Q^2. If the DESY data is preferred because it is fairly recent, all the high Q^2 information we have is based on their two points at 2 and 3 GeV^2. Statistical errors are dominant for these points because the Mott cross section has dropped by a few orders of magnitude. The distributions in the decay polar angle for the resonance in its rest frame (θ^*) for two ranges of ϕ^* are shown for the DESY experiment in figure 3. [a]

With the measurements proposed here plus other data in a coordinated program of N^* experiments, we hope to address the physics issues discussed above with much more definitiveness than was possible with older accelerators. A precise measurement of the $S_{11}(1535)$ form factor should distinguish between a variety of QCD inspired models, in particular exposing the inadequacy of nonrelativistic quark models[13] at large Q^2.

AMPLITUDE ANALYSIS

With CLAS, a single experiment can sample a wide range of Q^2 and W in the excitation of resonances and examine the various strong decay channels of the resonances in detail. The goal of the full program is to provide detailed measurements on all N^* resonances less than about 2 GeV mass, but the analysis required to produce this will be enormous. It is then important to find simple ways to get interesting information more rapidly. In the case of the experiment discussed in this section of the N^* proposal, identification of the eta (through missing mass) provides a way to isolate two resonances.

In the language of an amplitude analysis, the full program will identify the strength in all amplitudes (or multipoles, depending on the language used). This is an intelligent partial wave decomposition; it separates the strength according to

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[a] The $\cos\theta^*$ distribution is no longer flat because of p wave η production.

total quantum numbers of the state. Since only the resonance exists in the intermediate state, it carries the quantum numbers of both the photon angular momentum and the strong decay angular momentum of the resonance. A number of simplifications directly follow from this fact. Multipoles are identified by meson-nucleon decay angular momentum and parity, but the photon quantum numbers are also uniquely determined. All resonances have definite spin and parity and therefore contribute to only 1 or 2 multipoles. For the S_{11}, the meson (pion or eta) is in an s state relative to the nucleon in the final state; this is also the orbital angular momentum in the resonance. The isospin and total angular momentum of the resonance are given in the subscripts; in this case, both are $\frac{1}{2}$. In multipole notation, E_{0+} (total L=0, total J= $0+\frac{1}{2}=\frac{1}{2}$, parity=–) is the only transverse multipole that can contribute to this channel. This multipole is populated only by an E1 photon ($J_\gamma=1$, parity=–). In a helicity representation, the only transverse amplitude is the A_{0+}. In either analysis, the S_{11} will show up as a very large peak in a single amplitude. The final useful property is that each multipole has a well–defined angular distribution if a resonance decays to a single meson + nucleon. As already emphasized, the S_{11} decay angular distribution must be isotropic. The P_{11} resonance is excited through the transverse multipole M_{1-} (J=$\frac{1}{2}$, parity=+) which is equal to the helicity amplitude A_{1-}. The photon state must be M1 (magnetic dipole). By itself, the $P_{11} \rightarrow p\pi$ or $P_{11} \rightarrow p\eta$ decay angular distribution will be isotropic. The M_{1-} multipole is also populated by p wave background processes (which might be significant at this excitation energy) and the $P_{11}(1440)$ resonance.

MEASUREMENT

The physics interpretation of this experiment clearly involves additional resonances that overlap the S_{11} in addition to the nonresonant background, collectively known as the second resonance region. The roles of these other contributors must at least be understood and, of course, they have interest in their own right. The section of the N* proposal on pion production in the second and third resonance regions discusses this subject in depth. For the measurement proposed here, good information on the scattered electron and the decay proton are all that are required.

For the S_{11}, it is possible to get data with good statistics up to a Q^2 of about 4 GeV^2 in a reasonable time period. Monte Carlo calculations for this exeriment were made with the standard CLAS codes, CELEG and FASTMC. Issues of resolution and acceptance were examined in detail and time estimates were made assuming a luminosity of 10^{34} cm^{-2} sec^{-1}.

1. Kinematics

The region to be covered includes total center-of-mass energies, W, from 1.35 to 1.9 GeV for the second resonance region and 1.49–1.9 GeV for the eta channel because $M_p + M_\eta = 1.487$ GeV. With a 4 GeV beam, the lowest Q^2 that can be sampled for the second resonance region is 0.7 GeV^2 with CLAS set to bend negative particles toward the axis. At 2 GeV, the minimum Q^2 is 0.2 GeV^2. The largest Q^2 (4-momentum squared) for which reasonable data can be expected in CLAS with a 4 GeV beam is about 4 GeV^2, where the total rate for $p(e,e'p)\eta$ is expected to be about 10 per hour in a 20 MeV wide bin in W. Of course, this Q^2 is larger than what can be reached for any other resonance because of the anomalously slow falloff of the form factor.

At each Q^2, the protons are emitted in a cone around the virtual photon momentum direction (which is also the direction of the resonance in the lab). The maximum angle of this cone decreases with Q^2, increases with W, and is smaller for the ηN channel than for the πN channel. For example, the largest lab decay angle at Q^2= 1.0 GeV^2 occurs at W = 1.7 GeV, where it is 22.5° for ηN and 33.6° for πN. At the same Q^2, the virtual photon direction (θ_q) is about 20° from the beam direction, so a major portion of the decay phase space for each channel will be covered. The protons at the largest angles tend to have the lowest momentum; ~0.2 GeV/c is the minimum value for Q^2= 0.5 GeV^2. The phase space for 3-body decays ($\pi\pi$N) of the resonance is of course much larger. LAS is ideally suited for the detection of this decay channel when at least two of the particles are charged.

2. Target

The proton is believed to be the only useful target for this experiment. The neutron amplitude would be equally interesting to measure, but this would require a ^{2}H target and detection of a neutron or an η. Much larger solid angle coverage for the shower counters would be required to detect etas; the efficiency of the shower counters for neutrons is 25%, but the particle identification appears to be quite difficult at this time. To get a luminosity of 10^{34} with the CEBAF beam, a comparatively simple hydrogen gas target would be used. This target is discussed in a separate section of the N* proposal.

3. Simulations

To understand the experiment better, we have conducted a number of tests with Monte Carlo simulation. CELEG was used to generate two samples of events. The first set contains all resonances of mass less than 1.9 GeV and their decay particles and is useful for assessing background discrimination. The second set has only $S_{11}(1535)$ events and was used to examine resolution and count rate issues. Each set was analyzed with FASTMC using the CLAS characteristics presented in the September, 1989 CDR. An analyzer subroutine was written to generate appropriate cuts and histograms.

The predicted resolution of CLAS is excellent for this experiment. The scattered electron detection determines Q^2 and W with resolution (FWHM) of 0.66% and 0.52%, respectively. At W=1.5 GeV, the latter number corresponds to 7.8 MeV.

To identify the proper decay channel, the scattered electron together with the decay proton (with a proton target, there is no ambiguity in particle identification here) are used to generate the missing mass of the remaining final state particles. This is done with an estimated error (FWHM) of 5.2%, or 28 MeV, for the eta (mass = 549 MeV). The primary background for the missing mass cut comes from $N^* \rightarrow p\pi\pi$ events, as seen in figure 4. This figure shows missing mass for ep events from the sample of events with all resonances. The $p\pi\pi$ events produce a flat background at about 10% of the eta peak height. The signal-to-noise ratio is expected to be about a factor of 2 better than previous experiments because of improved missing mass resolution. Figure 5 shows the W spectrum for ep events before and after the missing mass cut. Two peaks are seen after the cut is applied, representing the S_{11} and P_{11} resonances. The missing mass cut produces a cutoff at about the eta threshold (W= 1.49 GeV) for both the background and real eta events.

The θ^* and ϕ^* angles (polar and azimuthal decay angles of the resonance in its rest frame) are then calculated. These allow separation according to partial waves (i.e. resonances). The resolution in θ^* is about one degree for S_{11} events. Since the $\cos\theta^*$ and ϕ^* angular distributions are necessarily flat for a sample with only S_{11} events decaying to $p\eta$ (CELEG doesn't have the ability to throw resonances with quantum mechanical interference effects in any case), these distributions show the acceptance for S_{11} events in each variable. All parts of phase space have the same acceptance within ±20% except at low Q^2 where some of the forward angle protons hit the forward cryostat. This is an extremely important advantage over previous experiments; since they were done with standard spectrometers, there was always limited acceptance in θ^* and ϕ^*.[b]

It is at this point that $S_{11}(1535)$ and $P_{11}(1710)$ dominance can be verified, as each by themselves give isotropic angular distributions. The $D_{13}(1520)$ produces a θ^* distribution with $\cos^2\theta^*$ dependence. The p-wave nonresonant background gives $\cos\theta^*$ dependence and any interference is most notable in the ϕ^* distribution.

We conclude that CLAS in standard configuration is an ideal detector for this reaction. At a single setting, it accepts almost all of the interesting phase space roughly equally for excitation of the $S_{11}(1535)$ and $P_{11}(1710)$ and their subsequent decay to $p\eta$. We show the overall acceptance for $ep \rightarrow e'pX$ events as a function of Q^2 and W in Table 1. It is seen to be generally smooth with a sharp falloff at both low and high Q^2. The high Q^2 falloff is due to the lack of electron identification beyond 45°.

4. Time Estimates

We now estimate running times based on the Monte Carlo calculations discussed above. This is done under the assumption that missing mass cuts are sufficient to generate a sample of almost all desirable events. The CELEG sample of S_{11} events was used for these estimates; the P_{11} counting rates are roughly half as large. The thrown total cross section for S_{11} events, σ_{CEL}, is given by CELEG integrated over all Q^2 and W. Using the ep acceptance (A_{ep}) from table 1, the count rate in a given

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[b] One might expect holes in the acceptance due to the magnet cryostat. The holes occur for specific ranges of ϕ as measured from the beam axis, but the ϕ direction in the lab has many possibilities depending on $\vec{q}$, ω, and W. This smearing makes the ϕ^* acceptance smooth.

Q^2, W bin is

$$N = L \cdot \sigma_{CEL} \cdot A_{ep} \cdot f$$

f is the fraction of all S_{11} events thrown that have ep in the final state with the missing mass of an eta in the appropriate Q^2, W bin. When we assume $L = 10^{34}$ at the peak of the acceptance ($Q^2 \sim 1.25$ GeV^2, W$\sim$ 1.5 GeV), the count rate in a 0.2 GeV^2 bin in Q^2 and 20 MeV bin in W is 85/hr. If the resonance decay angles are divided into 100 bins (e.g., 10 each in θ^* and ϕ^*), each bin will have 600 events (4% statistical errors) after 700 hours.

At $Q^2 = 2$ GeV^2, the count rate is about 4 times smaller or 0.43 per hour in a bin of width 10° in ϕ^* and 0.2 in $\cos\theta^*$. To directly compare with the Brasse data,[4] this must be multiplied by 4.5 since they took bins of 30 MeV in W and 30° in ϕ^*. Most of their points have 10% statistical errors; the proposed experiment would reach that point after a few days of running. Of course, we would also sample a larger phase space. The highest Q^2 appropriate to this experiment is $Q^2 \sim 3$ GeV^2. The physics of the high Q^2 data points and a proposal to measure data at higher Q^2 is discussed in detail in another section of the N* proposal.

We suggest an experiment that covers the 2nd and 3rd resonance regions detecting an ep pair in the final state with the missing mass of an eta. These events are strongly associated with only 2 resonances, the $S_{11}(1535)$ and the $P_{11}(1710)$, and give a method of easily isolating these states. At the same time, ep events with $p\pi^0$,$p\rho^0$, and $p\pi\pi$ will also be collected. To cover the Q^2 range less than about 3.5 Gev^2, two beam energies will be required, 2 and 4 GeV. For a quality experiment (about 4% statistical error in the θ^* and ϕ^* distributions, about 700 hours for data taking alone at 4 GeV and 300 hours at 2 GeV with a luminosity of 10^{34} will be required.

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DISTRIBUTION OF THROWN ep EVENTS

W(GeV)=	1.33	1.38	1.43	1.48	1.53	1.58	1.63
Q2(GeV**2)=							
0.25	356.	613.	1170.	2739.	6066.	4913.	2917.
0.75	552.	885.	1617.	3681.	7122.	5115.	2678.
1.25	98.	149.	326.	665.	1341.	1027.	519.
1.75	24.	51.	102.	217.	456.	349.	190.
2.25	8.	16.	35.	90.	157.	121.	77.
2.75	5.	6.	17.	39.	82.	70.	33.
3.25	4.	5.	12.	26.	38.	41.	12.
3.75	3.	6.	7.	26.	66.	35.	23.

ELECTRON*PROTON ACCEPTANCE FOR ep EVENTS

W(GeV)=	1.33	1.38	1.43	1.48	1.53	1.58	1.63
Q2(GeV**2)=							
0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.75	0.07	0.08	0.05	0.04	0.03	0.02	0.00
1.25	0.39	0.40	0.33	0.42	0.42	0.34	0.29
1.75	0.44	0.33	0.48	0.48	0.47	0.40	0.39
2.25	0.43	0.35	0.55	0.48	0.51	0.54	0.34
2.75	1.00	0.55	0.53	0.42	0.38	0.49	0.28
3.25	0.00	0.50	0.31	0.50	0.42	0.38	0.29
3.75	0.33	0.00	0.17	0.08	0.07	0.00	0.00

Table 1. Monte Carlo results for acceptance of ep events for a 4 GeV beam in CLAS according to Q**2 and W. At top is thrown events (out of a total sample of 100,000 events). At the bottom is the fraction of ep events that are properly detected in CLAS.

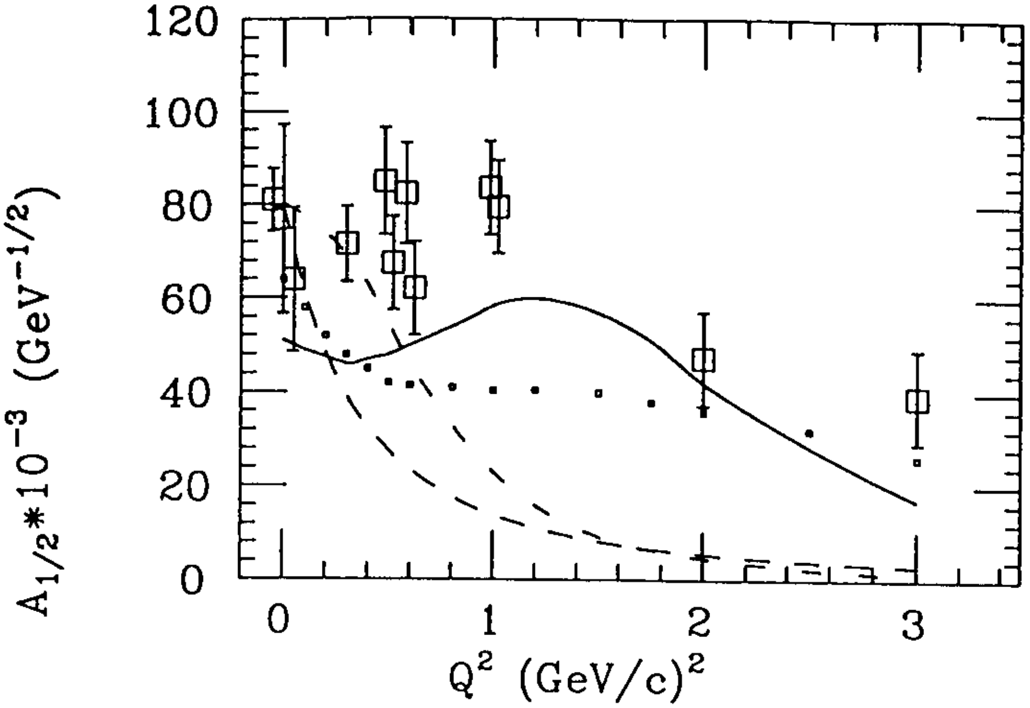

Figure 1: Transition form factor to the $S_{11}(1535)$ resonance. Calculations are from Warns and Pfeil (solid), Forsyth and Babcock (dash-dot), and Foster and Hughes (dots). For reference, the dipole form factor is shown as dashes.

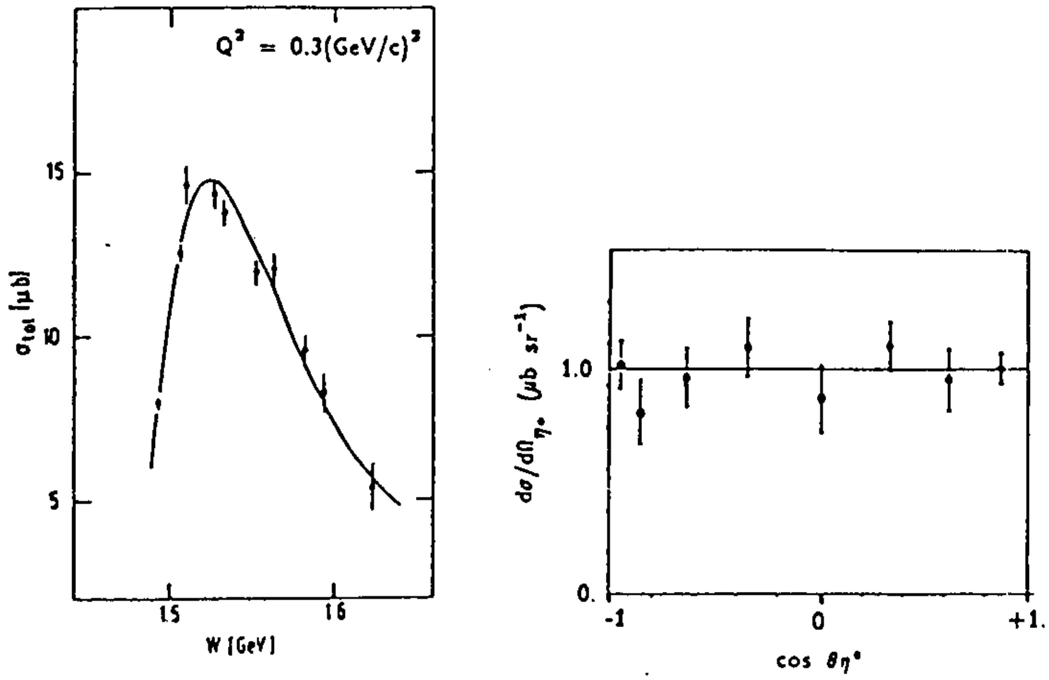

Fig. 2: Left: Total cross section of η production off protons at fixed Q^2. The line represents a fit using a Breit-Wigner distribution with s-wave threshold behaviour. Right: Angular distribution of η -production at $W < 1.535$ GeV. The data are consistent with s-wave behaviour. Data from Bonn. [7]

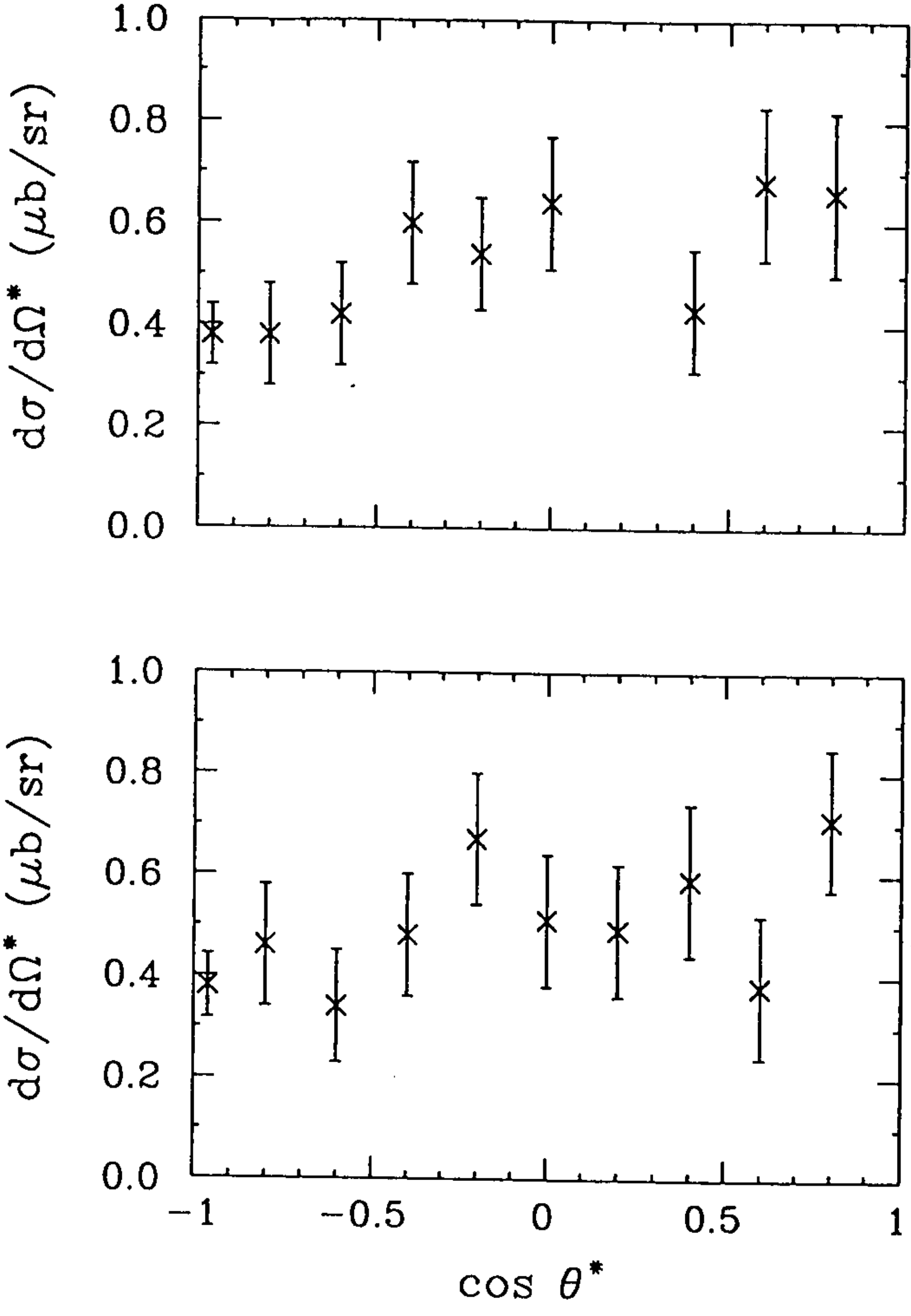

Figure 3: S_{11} data at $Q^2 = 2$ GeV^2. θ^* distributions at W = 1535 MeV for ϕ^* of 90° (upper) and 120° (lower) from reference 4 are shown as x.

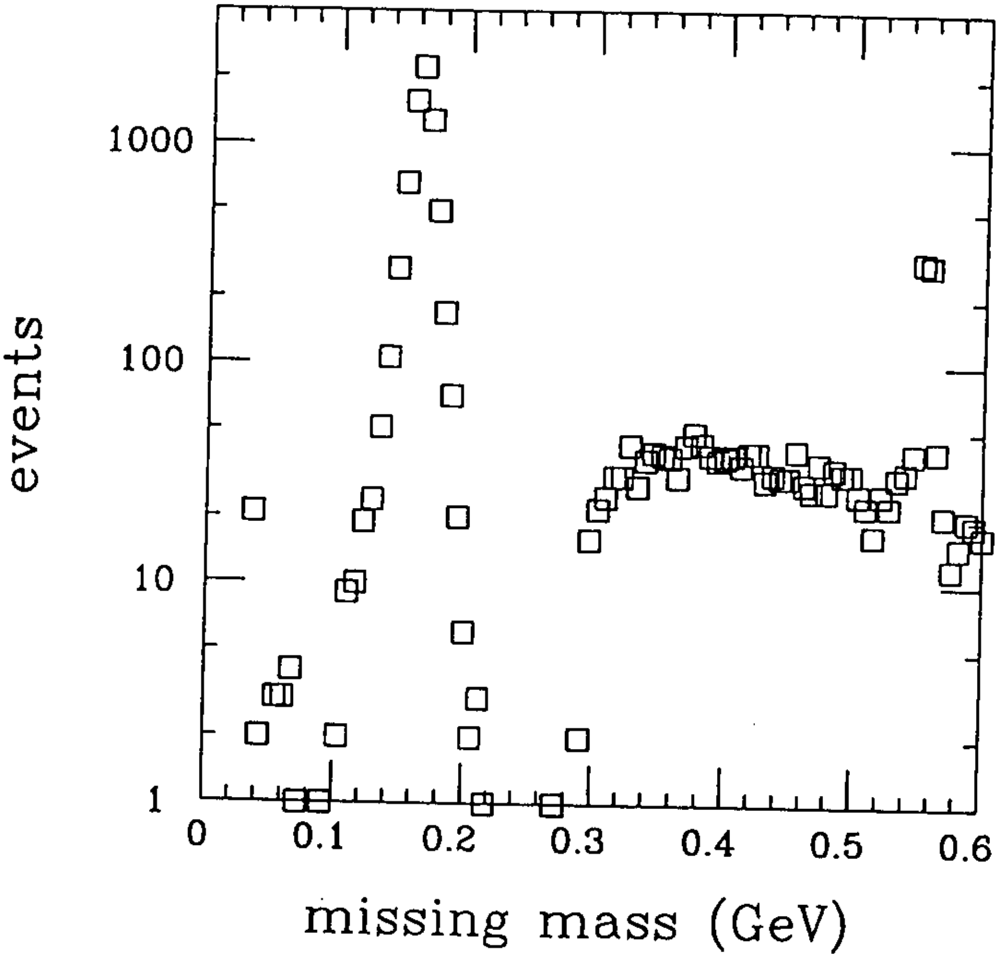

Figure 4: Monte Carlo results for missing mass distribution of events with ep in final state. Peaks are for π° and η°.

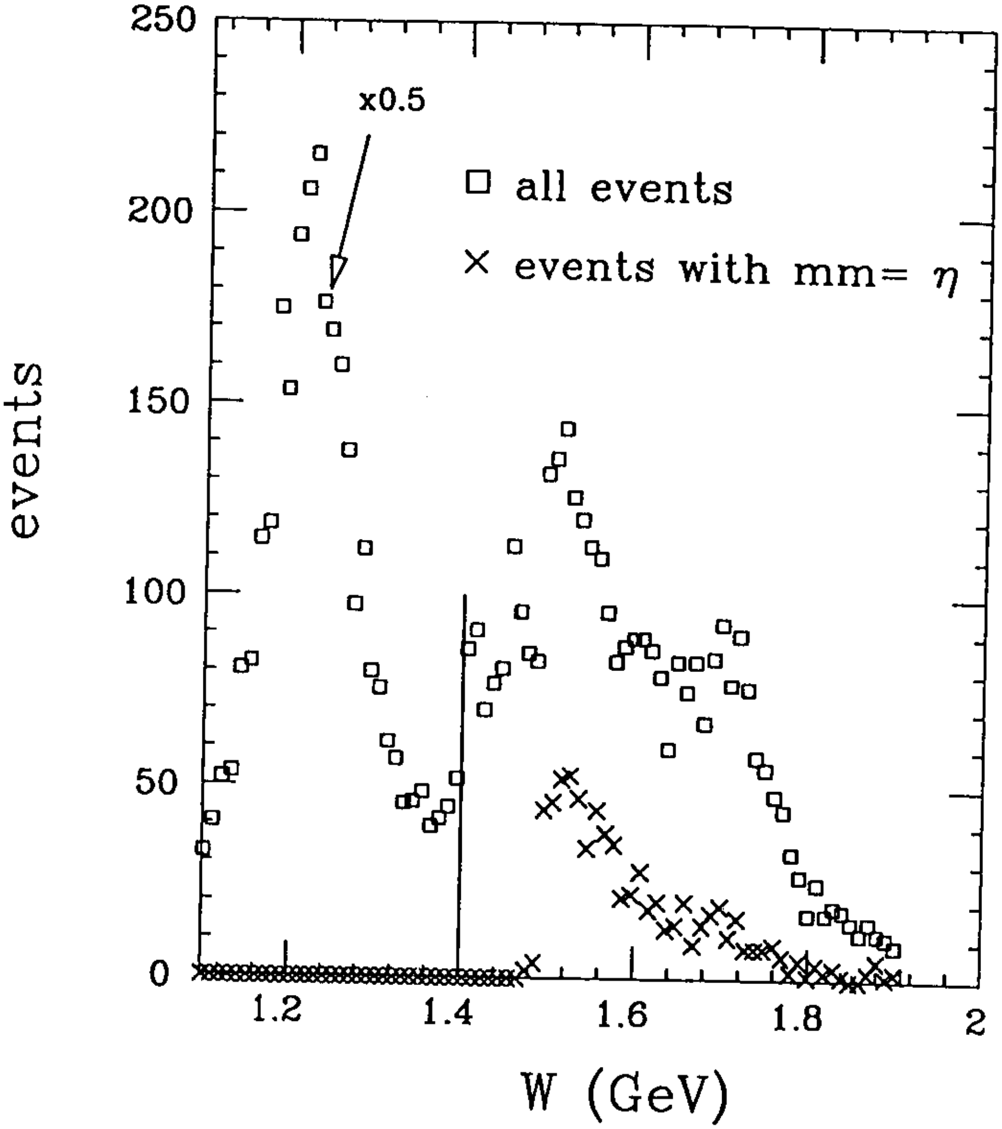

Figure 5: Monte Carlo results for W distributions before and after missing mass cut for etas. The sample of events is the same as the previous figure - all Δ and N^* resonances with mass less than 1.9 GeV.