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A SEARCH FOR NEW RESONANCES AND THRESHOLDS IN INELASTIC ELECTRON SCATTERING*

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ABSTRACT

We have extended the search for new resonances and thresholds in the hadronic final state X^+ in $ep \rightarrow e'X$ for missing masses from 3 GeV to 5.5 GeV. At a level of roughly 5% of the cross sections we found no unexpected structure.

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In previous experiments we have measured the reaction

$$e + P \rightarrow e' + X^{+} \quad (1)$$

An obvious feature of the data for this process is a series of enhancements in the cross section corresponding to the excitation of hadronic resonances with baryon number B=1 and charge Q=+1. Typically, four bumps corresponding to known resonances are observed with masses, W, between 1 and 2 GeV. In a recent experiment of this kind no other enhancements were observed in a search between W values of 2 and 3 GeV, using missing mass bins, ΔW, of 5 MeV with statistical accuracies of 1 to 3% per bin.[1] The recent discovery of new narrow width meson states[2] with masses greater than 3 GeV prompted us to extend the "high resolution" measurements to higher missing masses. (The new particles themselves are obviously not observable by this technique since they have quantum numbers B=0 and Q=0.) In December 1974, a short experiment was performed at SLAC to check for possible enhancements in the missing mass range between 3 and 5.7 GeV, and the results are reported here.

The 20-GeV spectrometer facility was used in a configuration which closely paralleled the setup in Ref. 1. A somewhat longer target (15.24 cm) with aluminum walls was used. As in the previous experiment, the detection of electrons analyzed by the spectrometer was accomplished with a set of three trigger counters, five multiwire proportional chambers for reconstruction of the particle trajectories, and a pion-electron discriminator. The latter consisted of a nitrogen gas threshold Cerenkov counter, a counter to sample the shower development in 4 radiation lengths of lead glass, and a 16 radiation length lead-lucite sandwich total absorption counter. Improvements to the Cerenkov counter and the use of the lead glass result in slightly improved π-e separation compared to the previous experiments. Measurements of the cross sections were made at a laboratory scattering angle, θ, of 4° and incident electron energies, E, of 13 and 20 GeV. A short run at 20 GeV and 6° was also made.

In order to avoid introducing spurious spikes into the cross sections, the measurements were averaged over the spectrometer acceptance and over the various counters and proportional chambers. This was done by operating the spectrometer in a scanning mode[1] in which its momentum setting was changed by a small fraction of the full momentum acceptance every few minutes. In this way each finally analyzed cross section value contained counts recorded across the whole acceptance of the spectrometer.

Since we wished to be sensitive to narrow missing mass states, mass resolution was an important parameter in the experiment. The dominant factors affecting the resolution in missing mass were the incident beam energy resolution, $\Delta E/E$, of about $\pm 0.05\%$, the spectrometer's momentum resolution, $\Delta E'/E'$, of about $\pm 0.03\%$, the angular resolution $\Delta\theta$, about ± 0.18 mrad, and the radiation of low energy photons which gave rise to a tail on the high missing mass side of a peak. The combined effect of these factors on a narrow resonance as observed in the detector was studied by measuring elastic electron scattering. At $\theta = 4^{\circ}$, the observed full width at half maximum (fwhm) of the elastic peak was 26 MeV at $E = 13$ GeV, and 35 MeV at $E = 20$ GeV. The radiative contribution to this width was removed by radiatively unfolding the data,[1] resulting in a fwhm of 15 M 15 MeV at $E = 13$ GeV, and 21 MeV at $E = 20$ GeV. At small angles the effects of $\Delta E/E$, $\Delta E'/E'$, and $\Delta\theta$ on the missing mass resolution all scale as M/W, where M is the proton rest mass. The broadening of a narrow resonance due to radiation of soft photons was calculated using the formulae of Ref. 1 and combined with that due to $\Delta E/E$, $\Delta E'/E'$, and $\Delta\theta$ to yield an estimated resolution of the apparatus as a function of W. Figure 1a shows the calculated fwhm as a function of W, and Fig. 1b shows a measured elastic peak scaled in width by M/W.

Radiative effects introduce a steep increase in the measured yield as the missing mass approaches the kinematic limit (that is, as E' tends toward zero). We removed the effects of radiation using the methods described in Ref. 1, after correcting for target wall events with data from previous experiments. These procedures would not amplify or diminish sharp structure.

No correction was made for events arising from charge symmetric processes such as π^0 production with subsequent conversion of the decay photons into electron-positron pairs. The charge symmetric contribution is less than 3% of the observed yield, except at the low E' end of the E = 20 GeV, $\theta = 4^\circ$ spectrum, where it rises exponentially in W from 3% at W = 5.25 to 15% at W = 5.75 GeV. In any case, this contributes a smooth cross section and should not give rise to a narrow bump in the observed or radiatively corrected cross sections.

In order to search for narrow missing mass structure, the corrected cross sections were first fitted to polynomials in W for each spectrum, and the quantities R and S were computed, where

$$R(W_i) = \sigma_i - f_i \tag{2}$$

$$S(W_i) = (\sigma_i - f_i)/\Delta\sigma_i \tag{3}$$

$\sigma_i = d\sigma/d\Omega\, dE'$, corrected cross section at mass W_i for a given E and θ;

$\Delta\sigma_i$ = error on the corrected cross section at mass W_i; and

f_i = value of the fitted polynomial at W_i.

Graphs of R and S are shown in Fig. 2 for the three spectra. The frequency distributions of the S are shown in Fig. 3. These follow the expected Gaussian distributions. Some quantitative information about the polynomial fits in W and about the S distributions is given in Table I.

No sharp structure is apparent. In order to study our sensitivity to the presence of sharp structure, we introduced fake spikes of width $\Delta W = 5$ MeV of varying height at various positions in the spectra and repeated the analysis procedure. These spikes were clearly picked out when they exceeded 4 to 5 $\Delta\sigma$ in height. A similar analysis was carried out with wider bins, $\Delta W = 10, 20, 40, 80$ MeV. The results for different ΔW's were substantially the same. (One must remember that $\Delta\sigma$ decreases as the bin width increases.) To study our sensitivity to sharp threshold effects, fake steps were introduced in the spectra by adding a constant cross section above a given missing mass. Analysis of these spectra indicated that a sharp step of greater than about $4\Delta\sigma$ would have been clearly visible.

The fraction of the cross section corresponding to $4\Delta\sigma$ defines a useful measure of the sensitivity in this experiment.

$$F(\Delta W) = 4\Delta\sigma/\sigma \tag{4}$$

F is approximately proportional to $1/\sqrt{\Delta W}$ reflecting the decrease in the statistical error as the bin width increases. For fixed ΔW, F also varies with W because of changing statistics, and also because the corrected cross section in the denominator of Eq. (4) changes. Table II summarizes the ranges of the values of F for the three spectra. A figure of merit for the case of a resonance with intrinsic width less than the bin width is F times the bin width, $\Delta W \cdot F$, and Table II also gives values for the ranges of this quantity. For a resonance narrower than 5 MeV, our sensitivity is 20 to 50 MeV-percent. For a total virtual photon cross section of 40 μb (approximately the value for $|q^2| = 1\ \mathrm{GeV}^2$)[3]

this sensitivity corresponds to 8 to 20 MeV-μb. An additional perspective on the numerical size of $\Delta W \cdot F$ may be gained by noting that the peak height of the third resonance bump ($W \approx 1.7$ GeV) is 30 to 50 percent of the nonresonant background for the q^2 range of this experiment.[1,4] Using a width of 100 MeV for this resonance, its approximate relative integrated strength is 100 MeV $\times$ 30 percent = 3000 MeV-percent. Comparing this value with the values of $\Delta W \cdot F$ in Table II indicates that we would have been sensitive to a resonance with width less than about 100 MeV, that was excited with a strength exceeding a few percent of the strength of the third resonance.

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REFERENCES

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2. J.-E. Augustin et al., Phys. Rev. Letters 33, 1406 (1974); J. J. Aubert et al., Phys. Rev. Letters 33, 1404 (1974).

3. See, for example, G. Miller et al., Phys. Rev. D 5, 528 (1972).

4. M. Breidenbach, Massachusetts Institute of Technology Laboratory for Nuclear Science Technical Report No. MIT-2098-635 (Cambridge, Mass., 1970). Ph.D. thesis.

TABLE CAPTIONS

I. Quantitative features of the fits of the corrected cross sections to polynomials in W for data binned with $\Delta W = 5$ MeV.

II. Summary of the relative sizes of resonances that probably would have been seen in this experiment using a criterion of four times the statistical error. q^2 is the absolute value of the four momentum transfer squared. F is four times the statistical error in a bin with width ΔW divided by the corrected cross section at that W (see Eq. (4)). F varies approximately as $1/\sqrt{\Delta W}$. $\Delta W \cdot F$ is a measure of the relative integrated cross section; for the third resonance, $\Delta W \cdot F$ is about 3000 MeV - percent.

TABLE I

	SPECTRUM		
E(GeV)	20	20	13
θ°	6	4	4
Average cross section error			
(%)	2.1	2.0	1.6
nb/(GeV-sr)	2	7	15
Polynomial Fit			
No. Parameters	3	9	4
No. Points	140	588	304
χ^2	132	621	286
Prob (χ^2) (%)	62	11	72
S Distribution			
Mean (S)	$(-0.03 \pm 8) \times 10^{-2}$	$(0.85 \pm 4) \times 10^{-2}$	$(-0.03 \pm 6) \times 10^{-2}$
rms (S)	0.97 ± 0.06	1.02 ± 0.03	0.97 ± 0.04
Min (S)	-2.26	-3.22	-3.20
Max (S)	2.67	2.62	2.74

TABLE II

	SPECTRUM		
E (GeV)	20	20	13
θ (deg)	6	4	4
W range (GeV)	3.95 - 4.65	3.0 - 5.5	3.0 - 4.3
q^2 range (GeV^2)	2.38 - 1.75	1.4 - 0.40	0.53 - 0.24
Bin Width ΔW (MeV)	Relative Size of $4\Delta\sigma$ Enhancement F (%)		
5	6 - 9	4 - 10	4.5 - 7
10	4 - 6	2.5 - 7.5	3 - 4.5
20	2.5 - 4	2 - 5	2 - 3.5
40	2 - 3	1 - 3.5	1.5 - 2.25
80	1.5 - 2	1 - 2.5	1 - 1.5
Bin Width ΔW (MeV)	Integrated Relative Strength of $4\Delta\sigma$ Enhancement $\Delta W \cdot F$ (MeV - %)		
5	30 - 45	20 - 50	22 - 35
10	40 - 60	25 - 75	30 - 45
20	50 - 80	40 - 100	40 - 70
40	80 - 120	40 - 140	60 - 90
80	120 - 160	80 - 200	80 - 120

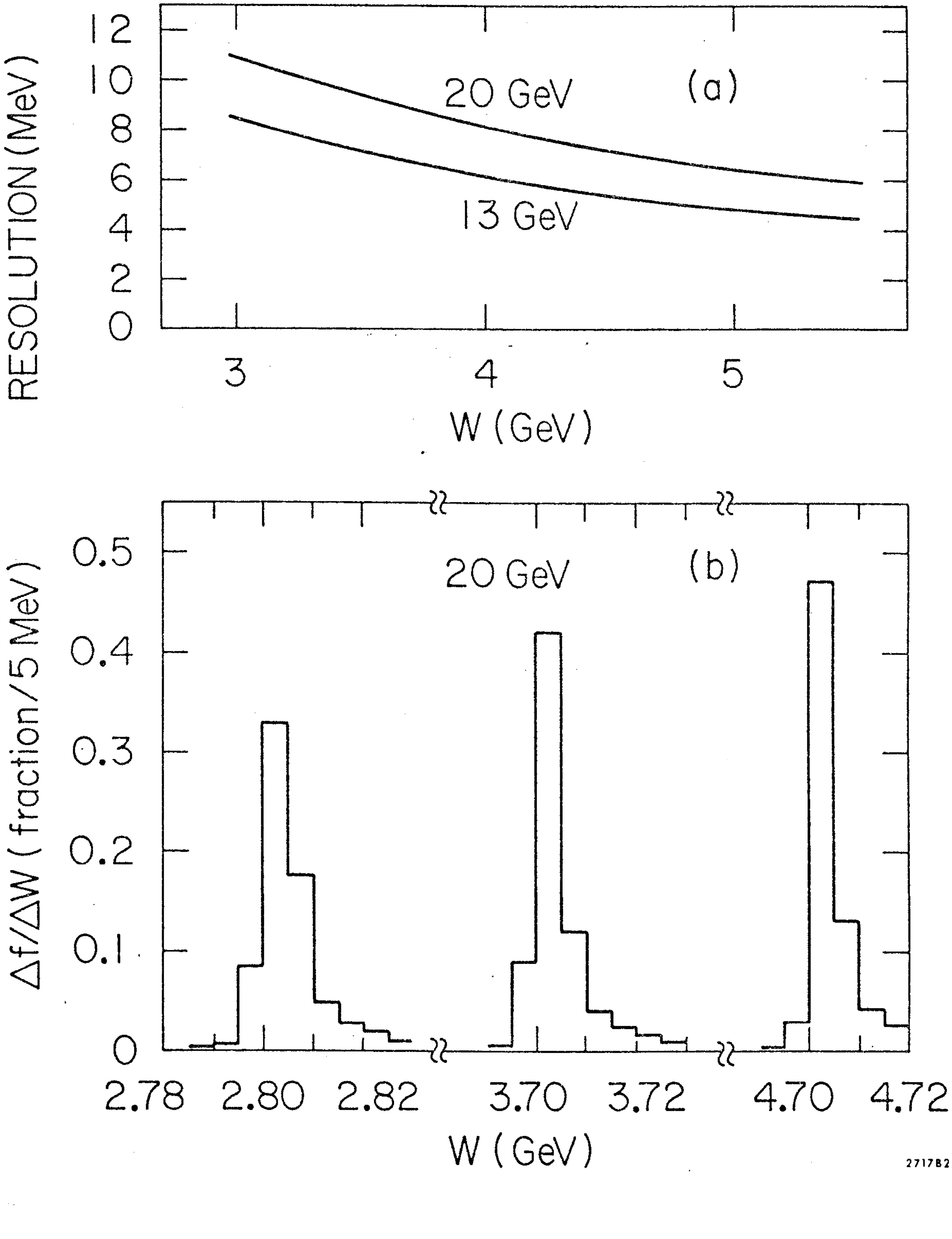
FIGURE CAPTIONS

1. a) The full width at half maximum of the experimental resolution is plotted versus W for incident energies of E = 13, 20 GeV, and $\theta = 4^\circ$. The resolution is computed from the measured elastic peaks taking account of radiation.

   b) Typical expected shapes of narrow resonances scaled from a measured elastic peak at E = 20 GeV, $\theta = 4^\circ$ and averaged over missing mass bins $\Delta W = 5$ MeV. The ordinate is the fraction of the total peak strength, f, that would appear in each 5 MeV bin. Radiation causes a tail extending towards high values of W and accounts for most of the reduction in peak height. Note that the binned peak shape depends on the way the bins are chosen.

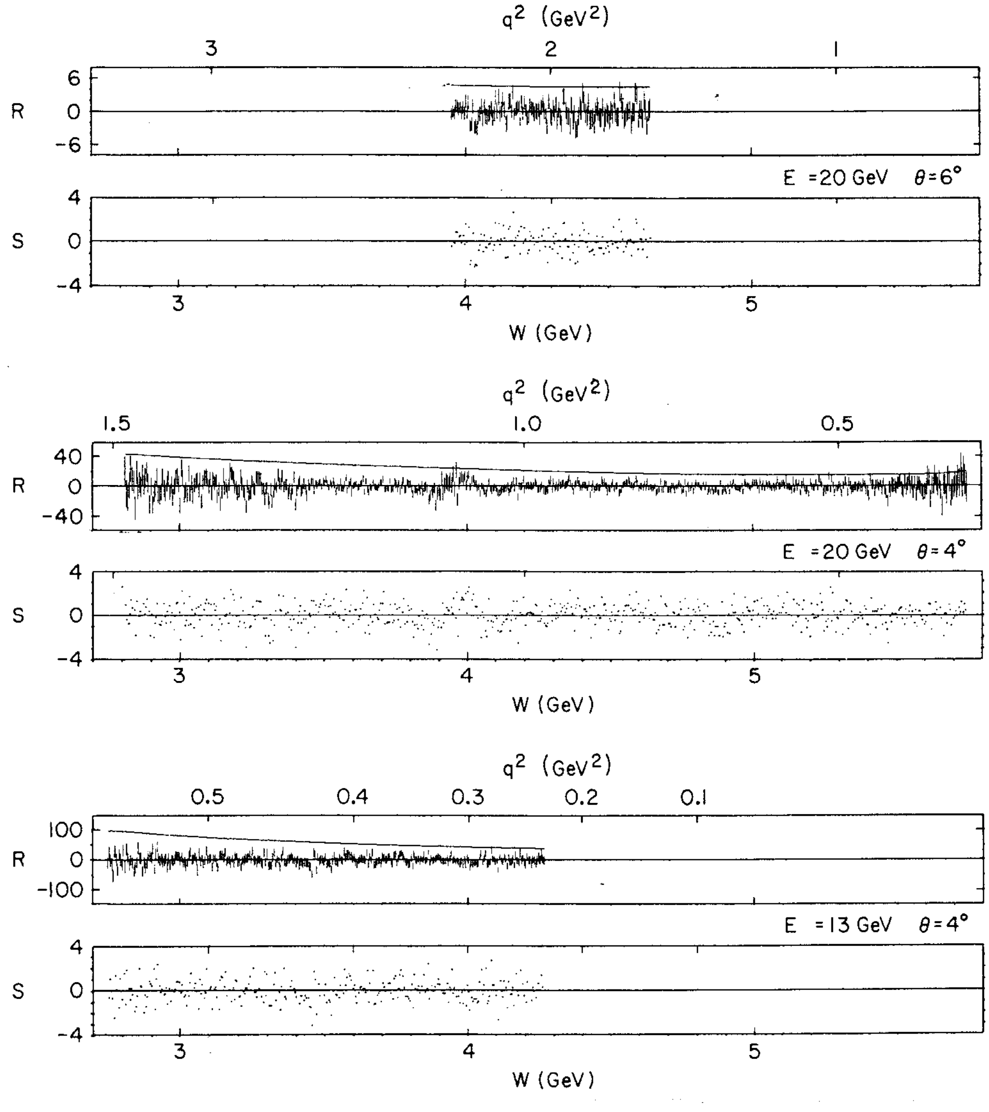
2. Plots of the residuals R (nb/GeV-sr) and the normalized residuals S (dimensionless) for the three spectra (E, θ) as a function of W for $\Delta W = 5$ MeV bins. For reference, the solid curves on the graphs represent 6% of the radiatively corrected $d^2\sigma/d\Omega\, dE'$. The lower scale in each graph gives W and the upper scale gives q^2, the absolute value of the four momentum transfer squared. The disturbance around W = 3.9 - 4.0 GeV in the 20 GeV, 4° spectrum occurs where one scan terminated and the other began. Furthermore, the number of events accumulated per scan setting changed by a factor of 4 in going from one scan to the other. It is felt that the disturbance can be explained as resulting from these causes.

3. Distributions of the normalized residuals, S, shown in Fig. 2. The curves shown are Gaussians with zero mean and unit standard deviation normalized to the total number of counts. There is no evidence for an excessive number of large values of $|S|$. A statistically significant narrow resonance would manifest itself as a point or two at large positive S.



RESOLUTION (MeV)
20 GeV
(a)
13 GeV
W (GeV)
Δf/ΔW (fraction/5 MeV)
20 GeV
(b)
W (GeV)
271782

Fig. 1



q² (GeV²)
3
2
1
6
R 0
-6
E =20 GeV θ=6°
4
S 0
-4
3
4
5
W (GeV)
q² (GeV²)
1.5
1.0
0.5
40
R 0
-40
E =20 GeV θ=4°
4
S 0
-4
3
4
5
W (GeV)
q² (GeV²)
0.5
0.4
0.3
0.2
0.1
100
R 0
-100
E =13 GeV θ=4°
4
S 0
-4
3
4
5
W (GeV)

Fig 2.

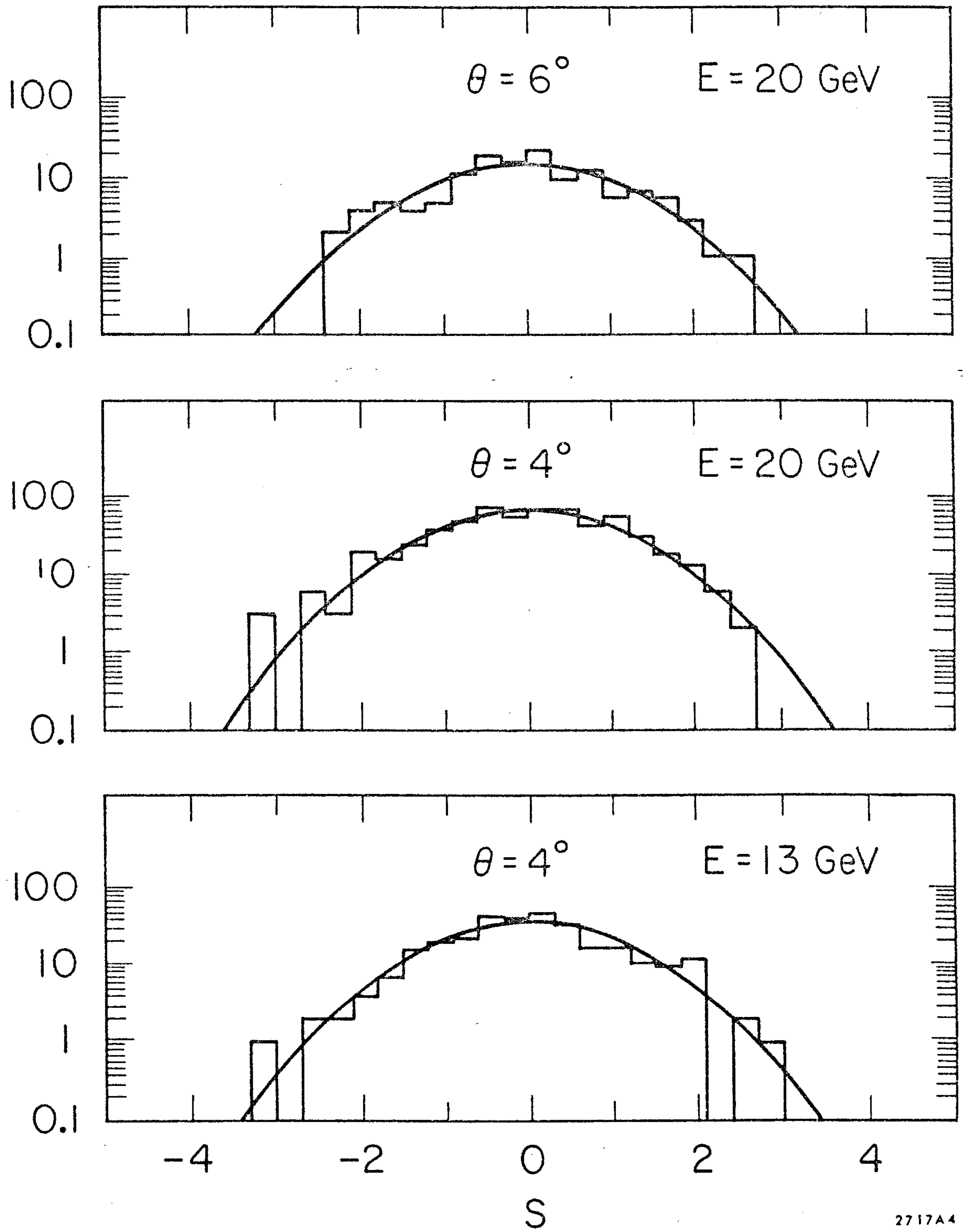


Fig. 3