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HIGH-ENERGY PHOTOPRODUCTION OF CHARGED PIONS AT BACKWARD ANGLES*

by

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ABSTRACT

Measurements on large angle photoproduction of π^{+-}-mesons from hydrogen have been made at the Stanford Linear Accelerator Center for photon energies between 5 GeV and 15.5 GeV and u-values from +.05 $(\mathrm{GeV/c})^2$ to -1.8 $(\mathrm{GeV/c})^2$. The measured cross section decreased with energy approximately as k^{-3}, showing no shrinkage in this range of u-values. Furthermore the cross section had a smooth u dependence with no sign of a dip at $u \simeq -.15$ $(\mathrm{GeV/c})^2$ as would be expected from nucleon exchange. π^- Δ^{++} production was measured at 5 GeV and shows a rapid decrease with increasing $|u|$.

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Preliminary results on the photoproduction from hydrogen of single π^+-mesons at large angles have previously been reported(1) in the energy range of 3 GeV to 10 GeV and at u values of +.05 $(GeV/c)^2$ to -0.7 $(GeV/c)^2$. These measured cross sections showed a relatively small backward peak near u = 0, a slight decrease towards positive u values, and a smooth decrease towards more negative u values with no sign of a dip at u = -.15 $(GeV/c)^2$. The energy dependence was close to k^{-3}. The general behavior of the cross section was explained by E. A. Paschos(2) assuming the process to be dominated by u-channel Δ_δ exchange. However from a recent measurement(3) of $\pi^- + P \rightarrow \rho^- + P$ and using the Vector Dominance Model, Kane(4) showed that I = 3/2 exchange can contribute at the most 20% to the total backward π^+ photoproduction cross section. The largest contribution to the cross section must therefore result from trajectories with isospin I = 1/2, and we would have expected the u dependence of the π^+ photoproduction cross section to be similar to the $\pi^+ P$ elastic scattering cross section, e.g. show a sharp dip at $u \simeq -.15\ (GeV/c)^2$. The lack of such a dip is puzzling. In this experiment we have greatly increased the precision of our previous data and extended the range in u and s. The new data agree well with the old data and clearly demonstrate the lack of a dip at $u \simeq -.15\ (GeV/c)^2$. We have also made measurements on the process $\gamma + P \rightarrow \pi^- + \Delta^{++}(1236)$, which in the u-channel must proceed by I = 3/2 (Δ) exchange.

Fig. 1 shows the experimental layout. The momentum analyzed electron beam was run through a variable copper radiator typically about .08 radiation lengths thick, placed in front of a thin walled liquid hydrogen target 15" long and 3.5" in diameter. The target could be remotely positioned relative to the beam to achieve optimum running conditions. Two clipping collimators with diameters of 1.5" and 2" were placed upstream of the radiator to remove any low energy halo of particles around the main electron beam.

The π-mesons were analyzed with a 100 in. radius, 90° vertical bend spectrometer(5). The spectrometer focussed the horizontal production angles and momenta onto a single focal plane. It was second-order corrected so that the focal plane was normal to the beam of particles. As shown in Fig. 1, vertical slits were placed between the target and spectrometer to reduce the backgrounds arising from sources other than the liquid hydrogen.

The counter system is shown in more detail in the insert in Fig. 1. Eight 10 X 3/4 X 1/4 in. hodoscope counters were used to split up the focal plane. The trigger system consisted of five large scintillation counters and a threshold Lucite Cerenkov counter. The counter system was rotatable so that the hodoscope counters could be oriented along lines of constant missing mass. There were two variable absorber changers in the counter telescope. The absorber and the biases of the Cerenkov counter were varied to minimize the background.

Geometric and absorption losses of the π-mesons were determined experimentally and were known to about ±3%. Corrections due to losses from decay in flight were calculated to an estimated accuracy of ±3%. The total charge in the beam was determined to 2% or better using two toroid monitors as well as a secondary emission monitor. In addition to the copper radiator, the effective radiator in the beam line due to additional material in the beam line and to electroproduction was both measured and calculated. The values of the effective radiator obtained from these two methods were in reasonable agreement and the total contribution to the experimental errors from this source was estimated to be about 3%. During the course of this experiment, the momentum calibration of the spectrometer was determined to better than .1% from the sharp threshold for single π-meson production. The spectrometer acceptance was known to ±3%.

Yield curves were taken by fixing the primary beam energy and the angle of the spectrometer and varying the momentum setting of the spectrometer. Fig. 2 shows such excitation curves for π^+ and π^--mesons for an incident bremsstrahlung beam with an end-point energy of 5.5 GeV. The π^+ curve corresponds to $u = -.01\ (GeV/c)^2$ and the π^- curve corresponds to $u = +0.04\ (GeV/c)^2$. The horizontal scale of Fig. 2 shows the (missing mass)^2 of the unobserved particle X in the reaction

$$\gamma + P \rightarrow \pi + X$$

assuming the photon energy to be equal to the end-point energy.

The upper (π^+) yield curve of Fig. 2 is characterized by a sharp rise at a missing mass of 940 MeV, corresponding to the onset of single pion production. At lower missing masses direct production is kinematically forbidden and the background yield must arise from various double processes. All the 40 or so observed π^+ yield curves in the mass region beyond the kinematic limit were well represented by a simple exponential of the form $Y = Ae^{-Bp}$. An overall yield curve was fitted with three parameters, two for an exponential background of the above form and one parameter for the "height" of the meson yield. The shape of the meson yield was calculated using an accurate thick target bremsstrahlung formula, a standard spectrometer resolution function, and the appropriate kinematic and decay in flight corrections. In practice the data is obtained from a band of photon energies extending up to the end-point energy, i.e. each ladder element measures the cross section at a slightly different u-value and photon energy k. The variation of $d\sigma/du$ with u and k was taken into account in the shape of the meson yield by a second iteration of the analysis. The derived values of $k^3(d\sigma/du)$ were insensitive to the assumed variation of the cross section with k or u. In all our runs we observed very little sign of a multi-pion production, until missing masses in the region of the Δ were reached.

Fig. 2 also shows a π^- yield curve. The kinematic threshold for π^- production is at a missing mass of one pion plus a nucleon. However the exponential fit to the data beyond the kinematic threshold also fits the data well into the region of two pion production. Thus there appears to be little evidence for lower missing mass states being produced. At the Δ^{++} threshold there is a significant change in the yield curve. This break in the yield curve is well represented by the calculated shape for $\Delta\pi$ production as given by a simple Breit-Wigner shape for the Δ folded in with the known experimental resolution. The assumption of an exponential background and Δ^{++} production gives a good fit to the data up to missing masses of 1320 MeV. Above this missing mass value the π^--yield has substantial contributions from higher missing masses and is no longer well represented by this fit. Our analysis is insensitive to the exact dependence of $d\sigma/du$ on k but we assumed a k^{-3} dependence, as was observed for large angle single pion production. We corrected for the observed variation of $d\sigma/du$ with a second iteration of the analysis. This correction was small.

Fig. 3a shows our new data for π^+-meson production. The agreement between these new data and our previous data is excellent(6). We have plotted $k^3(d\sigma/du)$ versus u, where k is the photon energy. Our data plotted in this way fall on a common curve, clearly demonstrating the lack of shrinkage out to large $|u|$ values. This shows that the cross section is not dominated by the exchange of a single trajectory with unit slope. There is no sign of a dip in the yield curve at $u \simeq -0.15\ (GeV/c)^2$. The resolution of the apparatus in $|u|$ values in this mass region is about $\pm.01\ (GeV/c)^2$; hence there is no possibility that the dip was not being seen due to poor resolution.

Fig. 3b shows the data of D. Tompkins(7) et al. for the reation $\gamma + P \rightarrow \pi^0 + P$. For comparison purposes the measured π^+ cross sections are shown as a dotted line. The π^0 cross section at low $|u|$ values is roughly equal to the corresponding π^+ cross section(7). At large $|u|$ values the π^+ cross sections are about 1.5 larger than the π^0 values.

Fig. 3c shows our data for the reaction $\gamma + P \rightarrow \pi^- + \Delta^{++}$, which must proceed through exchange of a 3/2 isospin particle. The dotted line again represents the π^+ cross section. Note that the $\pi^- \Delta^{++}$ cross sections fall considerably more steeply with increasing $|u|$ than the $\pi^+ N$ cross sections.

Fig. 3d shows the theoretical predictions of Paschos(2) based on pure Δ_δ exchange, as well as the phenomenologically predicted V.D.M. cross sections(8) based on the reaction $\pi^- + P \rightarrow \rho^0 + P$ for backward π^+-photoproduction. In the V.D.M. predictions $\gamma_\rho^2/4\pi = .67$. A dotted line representing the $\pi^+ N$ cross section is plotted for comparison purposes.

Our data for $\pi^+ N$ combined with the $\pi^0 P$ data suggests a dominant isospin 1/2 exchange for large $|u|$ values which would, when combined with an isovector photon, predict a photoproduction cross section ratio of $\pi^+ N$ to $\pi^0 P$ of 2:1, close to the observed ratio of 1.5:1. At small $|u|$ values some amount of isospin 3/2 exchange interfering with the isospin 1/2 exchange could easily result in the approximately 1:1 ratio observed. This picture is of course not unique, but is in agreement with the conclusions of G. Kane(4) that isospin 3/2 exchange can at the most contribute 20% to the backward $\pi^+ N$ photoproduction cross section. To be in accord with the above picture the Δ contribution should drop off rapidly with $|u|$ so that it is only important at small $|u|$ values. Such behavior is indeed observed in the process $\gamma + P \rightarrow \pi^- + \Delta^{++}$, which must proceed via Δ exchange.

The most natural class of theories to explain the present set of experiments are those which explain the dips, sometimes observed in experiments involving nucleon exchange, as due to interference(9) and not to "nonsense" zeros. It is however possible to salvage the conventional Regge model with a nonsense zero for nucleon exchange if it is assumed either that the isospin 1/2 exchange in photo-reactions is largely dominated by the N_γ-trajectory and not by the nucleon trajectory, or that the dip is cancelled by an almost exact "exchange degeneracy" of the N_α and N_γ trajectories as suggested by Barger and Michael for other processes(10). A comparison of Compton scattering(11) with the observed photoproduction cross section for the second resonance(12) does not make it plausible that the N_γ is far more strongly coupled to the photon than the N_α, neither does it seem plausible that almost exact exchange degeneracy exists in some u-channel reactions such as $P + P \rightarrow \pi^+ + d$ and the photoproduction processes and not in other reactions such as the various πP elastic scattering and charge exchange processes. The lack of shrinkage with u is also likely to make the construction of conventional theories difficult.

We conclude therefore that the lack of a dip occurring in photoproduction processes, where there is every reason to believe that nucleon exchange should be playing a significant role, throws serious doubt on the presently postulated existence of a nonsense zero occurring for the nucleon trajectory at $u \simeq -.15$ $(\text{GeV}/c)^2$.

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FIGURE CAPTIONS

Fig. 1: The experimental apparatus.

Fig. 2: The measured yield of π^+ and π^- mesons in counts per hodoscope element per 10^{14} E.Q., normalized to standard spectrometer aperture, is plotted versus missing mass squared. The solid lines represent least squares fits to the data as described in the text.

Fig. 3: a) $k^3(d\sigma/du)$ in cm^2-c^2-GeV is plotted versus u for the reaction $\gamma + P \rightarrow \pi^+ + N$ for photon energies between 4.1 GeV and 14.8 GeV. This data is also shown as a dotted line in parts b, c, and d of this figure for comparison purposes.

b) $k^3(d\sigma/du)$ in cm^2-c^2-GeV is plotted versus u for the reaction $\gamma + P \rightarrow \pi^o + P$ for photon energies between 6 GeV and 18 GeV. The data are taken from the experiment by Tompkins, et al(7).

c) $k^3(d\sigma/du)$ in cm^2-c^2-GeV is plotted versus u for the reaction $\gamma + P \rightarrow \pi^- + \Delta^{++}$ for photon energies of 4.5 GeV and 5.3 GeV.

d) The solid line represents the predictions for the reaction $\gamma + P \rightarrow \pi^+ + N$ based on a Regge model. The V.D.M. predictions are also indicated.

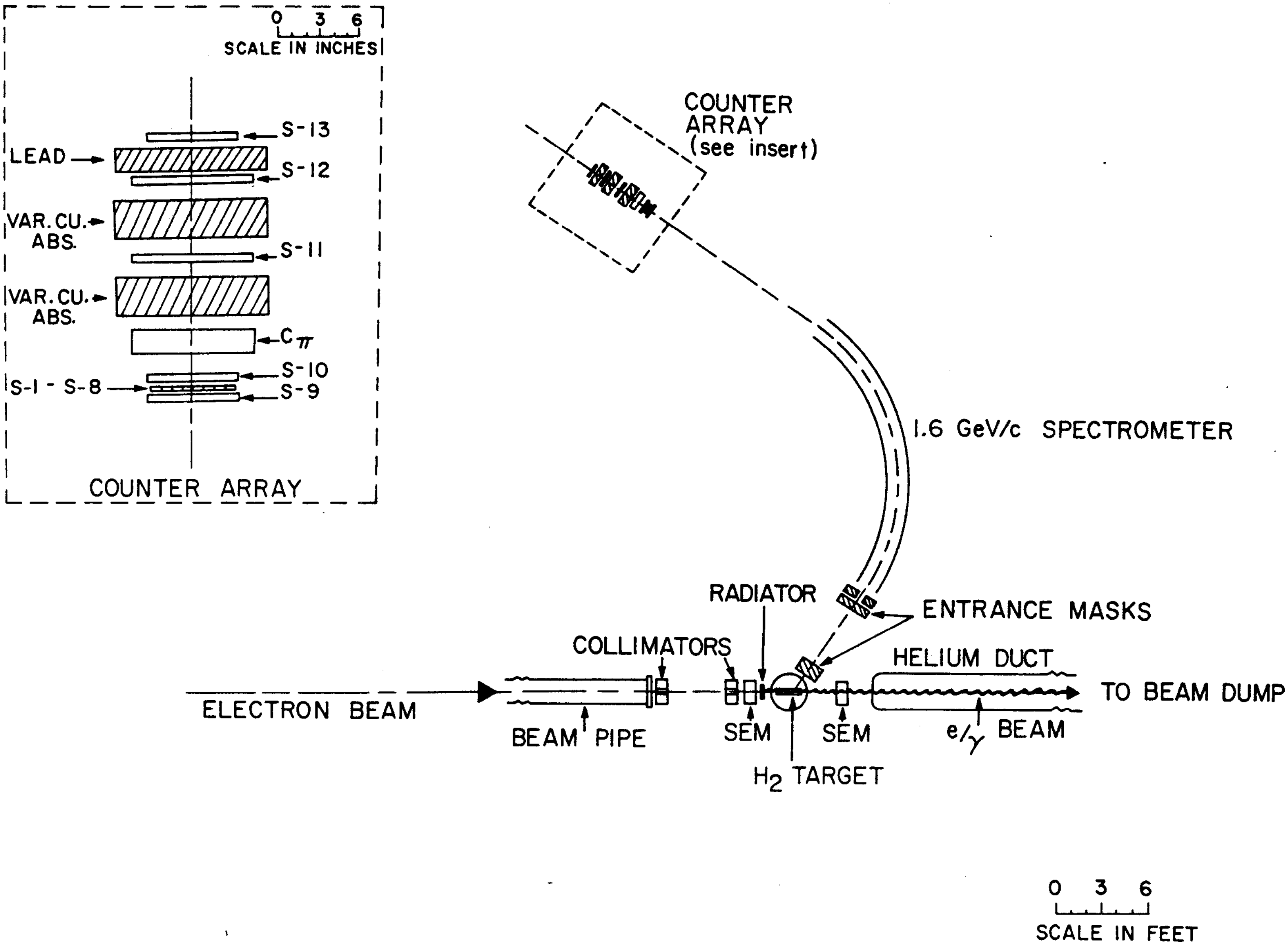
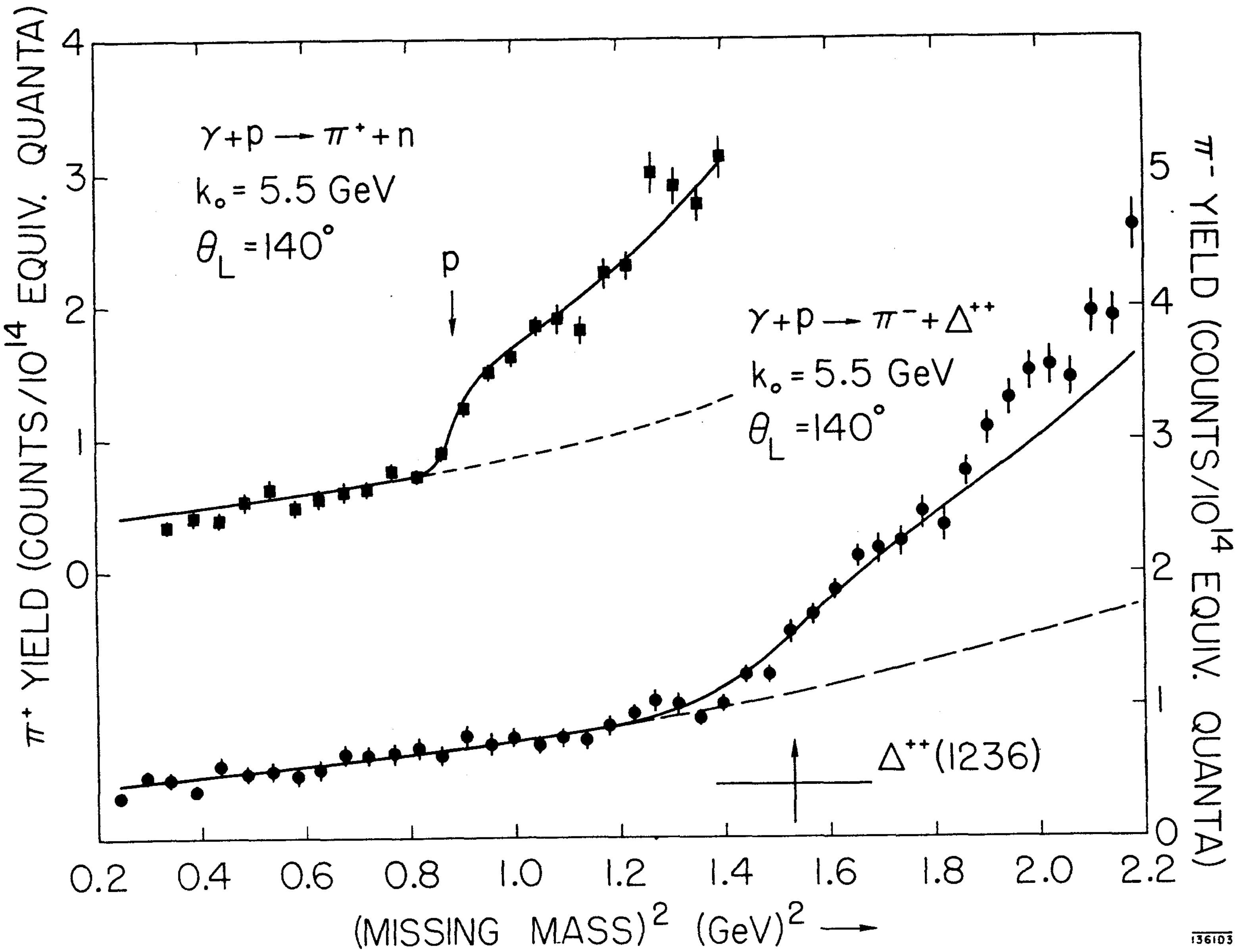
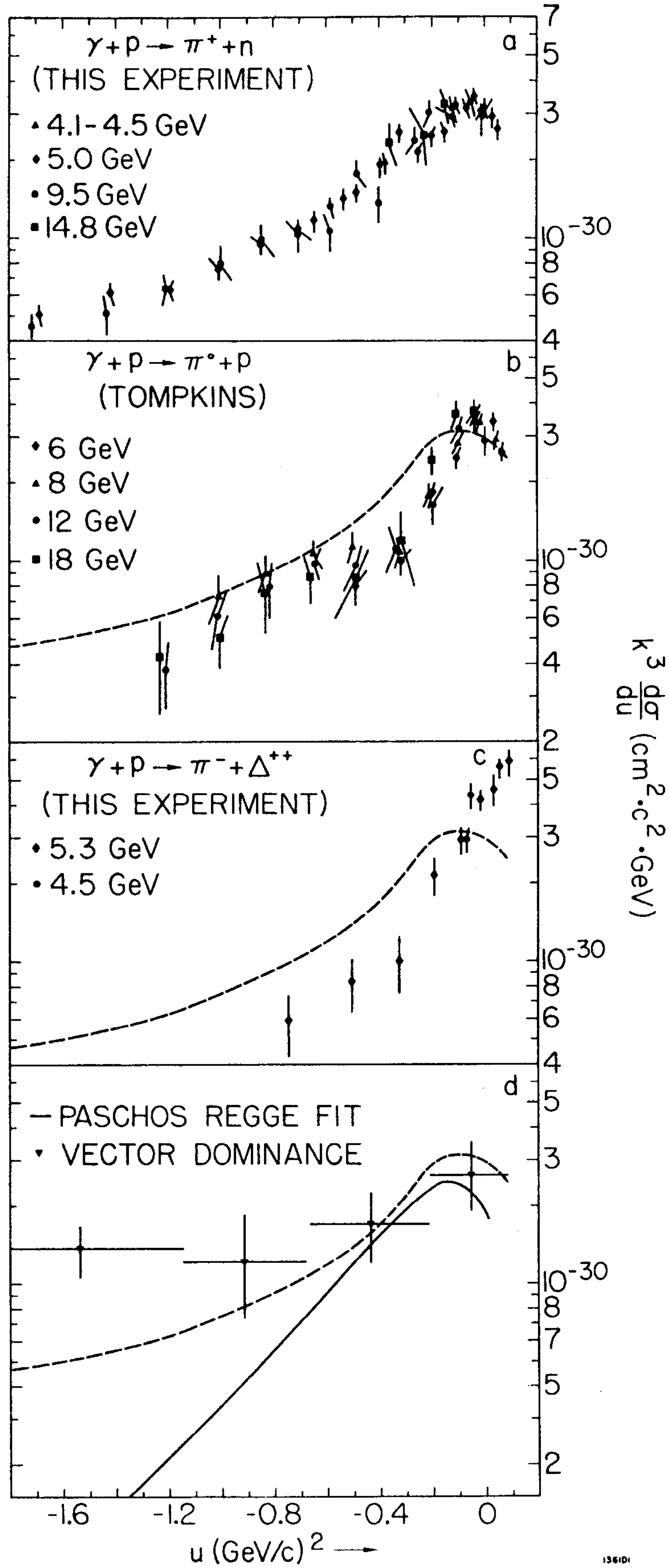

0 3 6
SCALE IN INCHES
S-13
LEAD
S-12
VAR. CU. ABS.
S-11
VAR. CU. ABS.
C_π
S-10
S-1 - S-8
S-9
COUNTER ARRAY
COUNTER ARRAY (see insert)
1.6 GeV/c SPECTROMETER
RADIATOR
ENTRANCE MASKS
COLLIMATORS
HELIUM DUCT
ELECTRON BEAM
TO BEAM DUMP
BEAM PIPE
SEM
SEM
e/γ BEAM
H_2 TARGET
0 3 6
SCALE IN FEET

Fig. 1



$\gamma + p \rightarrow \pi^+ + n$
$k_o = 5.5$ GeV
$\theta_L = 140°$
p
$\gamma + p \rightarrow \pi^- + \Delta^{++}$
$k_o = 5.5$ GeV
$\theta_L = 140°$
$\Delta^{++}(1236)$
π^+ YIELD (COUNTS/10^{14} EQUIV. QUANTA)
π^- YIELD (COUNTS/10^{14} EQUIV. QUANTA)
(MISSING MASS)^2 (GeV)^2 →
0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2
136103

Fig. 2



γ+p → π⁺+n
(THIS EXPERIMENT)
a
4.1-4.5 GeV
5.0 GeV
9.5 GeV
14.8 GeV
γ+p → π°+p
(TOMPKINS)
b
6 GeV
8 GeV
12 GeV
18 GeV
γ+p → π⁻+Δ⁺⁺
(THIS EXPERIMENT)
c
5.3 GeV
4.5 GeV
d
— PASCHOS REGGE FIT
VECTOR DOMINANCE
7
5
3
10⁻³⁰
8
6
4
2
7
-1.6
-1.2
-0.8
-0.4
0
u (GeV/c)² →
k³ dσ/du (cm²·c²·GeV)
136101

Fig. 3