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FORWARD PHOTOPRODUCTION OF VECTOR MESONS FROM HYDROGEN AT ENERGIES FROM 6.5 GeV TO 17.8 GeV*

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ABSTRACT

We report measurements of the differential cross sections of ρ^0 and ϕ meson photoproduction on hydrogen for a range of four-momentum transfer squared, t, from $-0.2(\mathrm{GeV}/c)^2$ to $-0.9(\mathrm{GeV}/c)^2$ and a range of incident photon energies from 6.5 GeV to 17.8 GeV. We find that differential cross sections obtained for ρ^0 production are in good agreement with the vector dominance model.

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Extensive measurements have been made at photon energies below 6 GeV on the forward photoproduction of ρ and ω-mesons.[1] The results of these measurements have been successfully explained in the framework of the vector meson dominance theory.[2] The vector meson dominance assumption implies that the cross section $d\sigma/dt$ for $\gamma + p \rightarrow V^o + p$, where V^o is the vector meson, is proportional at high energies to the cross section for elastic scattering of transversely polarized vector-mesons, namely

$$d\sigma/dt\ (\gamma + p \rightarrow V^o + p) = \frac{\alpha}{4}\left(\frac{4\pi}{\gamma_v^2}\right) d\sigma/dt\ (V^o + p \rightarrow V^o + p) \qquad (1)$$

where $\alpha = 1/137$ and γ_v is the coupling of a virtual vector meson to a real photon. The cross section for the elastic scattering process $\rho^o + p \rightarrow \rho^o + p$ would be expected, on the basis of the quark model, to be equal to the mean of the cross sections for π^+p and π^-p elastic scattering.

Attempts to explain ϕ-meson production in the same framework have been less obviously successful.[3] Theoretically the relationship of ϕ nucleon cross sections to π-mesons and K-mesons cross sections is less clear. Experimentally little data is available.

In this experiment we measured a combined cross section for ρ^o and ω-meson production over a wide range of energies, 6.5 GeV - 17.8 GeV and t values from $-.2(\text{GeV}/c)^2$ to $-.9(\text{GeV}/c)^2$. We made a smaller number of measurements of ϕ-meson production.

To perform the experiment we passed a bremsstrahlung photon beam through a 12'' long by 2'' diameter liquid hydrogen target at the SLAC accelerator, and observed the recoiling protons produced in the target with a 90^o bend spectrometer capable of analyzing momenta up to 1.6 GeV/c. Protons were identified in the trigger counters on the basis of pulse height and by vetoing π-mesons with a lucite Cerenkov counter. As has been described previously,[4] the focal plane was split by hodoscope counters into eight bins. "Integral" yield curves were taken with the spectrometer momentum and primary beam energy held constant, while the angle of the spectrometer was varied. In addition differential yield curves were obtained where two integral curves taken at different peak energies E_1 and E_2 were subtracted one from the other. The "differential" yield curves corresponded to excitation by a narrow band of photon energies between these energies E_1 and E_2. Figure 1 shows such a "differential" curve obtained by subtracting the yields obtained as a function of angle at 17.8 GeV and 16.0 GeV both at a t value of $-0.7\ (\mathrm{GeV}/c)^2$. We only observed the recoiling proton in the final states and thus only determined the "missing mass" of the other products of the reaction. We did not have sufficient resolution to distinguish ω-meson production from ρ^0-meson production. We obtained our ρ^0-meson cross sections by correcting the measured cross sections assuming a 9:1 ratio of the ρ^0 and ω cross sections.[5] To analyze our yield curves, both differential and integral, we least-squares fitted our curves with π^0 production, a polynomial background, ρ^0 production with a width Γ_ρ, mass M_ρ and a 10% admixture of ω-mesons. We found that the best fits were obtained with a width $\Gamma_\rho \sim 125$ MeV, a standard Breit-Wigner decay curve and a ρ mass of 770 MeV. Inclusion of an $m_{\pi\pi}^{-4}$ factor in the ρ shape[6] did not usually improve the fits. Our statistical errors were usually small and our main source of error arose from the uncertainties in separating out the non-resonant background contributions to the yields. This separation is dependent on the assumed shape and width of the ρ-meson. In view of current uncertainties in this shape and width we assigned in most cases an error of $\pm$ 30% to our determination of this non-resonant background.

The ϕ-meson production cross section was considerably smaller than the ρ^o-cross section. The yield of ϕ-mesons was measured in a region where the bremsstrahlung beam also produced a considerable yield of protons associated with ρ^o-production. While the small decay width of the ϕ-meson gives a sharp and distinctive threshold to the production of ϕ-mesons, very good statistical precision is necessary to distinguish the ϕ-production from the other background processes. We analyzed the ϕ-meson yield curves assuming relatively smooth backgrounds and made conservative error assignments on the basis of a detailed statistical analysis.[7]

Figure 2 shows our values for $d\sigma/dt$ versus t for ρ^o production. Our results at 6.5 GeV are in good agreement with the DESY bubble chamber measurements.[1] The cross sections between 11.5 GeV and 17.8 GeV are almost constant with energy at all t values and are completely consistent with a non-shrinking diffraction peak going as $\sim e^{8.5t}$. Moreover, only at $-t = 0.7 (\mathrm{GeV}/c)^2$ and $0.9 (\mathrm{GeV}/c)^2$ is there a large drop in going from 6.5 GeV to 11.5 GeV, which suggests a small non-diffractive contribution at large $-t$ decreasing rapidly with energy above 6.5 GeV. The cross sections at each energy were fitted with the form $\frac{d\sigma}{dt} = A\, e^{Bt+Ct^2}$ and the values of A, B and C found are shown in Fig. 2. The values of B and C which we obtain are very similar to those found in πp elastic scattering.[8] Applying the optical theorem to Eq. (1) and using the quark model relation $2\sigma_T(\rho p) = \sigma_T(\pi^- p) + \sigma_T(\pi^+ p)$ [9] we have the following relation for the parameter A which is equal to $\left(\frac{d\sigma}{dt}\right)_{t=0}$:

$$A = \frac{\alpha}{4}\left(\frac{4\pi}{\gamma_\rho^2}\right)\frac{\left(\sigma_T(\pi^- p) + \sigma_T(\pi^+ p)\right)^2}{64\pi} \quad \ldots \quad (2)$$

Our values for A between 6.5 GeV and 17.8 GeV are in agreement with this relation and give a value for $\frac{\gamma_\rho^2}{4\pi} \sim 0.6$. This value of γ_ρ is similar to the values found in studies of the ρ^o leptonic decay and in colliding beam experiments for the coupling of real ρ^o-mesons with virtual photons.[10]

Figure 3 shows our results for ϕ-meson production. If it is assumed that the t dependence is of the form $d\sigma/dt \propto e^{Bt}$ throughout the range $-0.2 \leq t \leq -0.9$, then B would have the value of $\sim 4.5 (\mathrm{GeV}/c)^{-2}$. All but one of our ϕ cross sections are at values of $|t| \geq 0.3 (\mathrm{GeV}/c)^2$ and there is therefore considerable uncertainty in any extrapolation to obtain $d\sigma/dt$ at $t = 0$. It has been predicted that ϕ production should be largely diffractive.[11] The value of $d\sigma/dt$ at $t = 0$, A_ϕ, should then be related to the similar quantity for ρ production, $A\rho$, by

$$A_\phi = r\, A_\rho \left[\frac{\sigma_T(\phi p)}{\sigma_T(\rho p)} \right]^2 \qquad (3)$$

where r is $\gamma_\rho^2/\gamma_\phi^2$. In the exact SU(3) limit r equals 2/9 but can be decreased by symmetry breaking effects. $\sigma_T(\rho p)$ is the total $\rho^o p$ cross section and $\sigma_T(\phi p)$ is the total ϕp cross section. Assuming the validity of our extrapolations to $t = 0$, and inserting the experimental values for A_ρ and A_ϕ, a ratio $r \sim 4/27$ [12] and the relationship $2\sigma_T(\rho^o p) = \sigma_T(\pi^- p) + \sigma_T(\pi^+ p)$ we deduce from Eq. (3) that $\sigma_T(\phi p) = 9.7 \pm 2.0$ mb at 13 GeV and 7.2 ± 1.9 mb at 16 GeV. Predictions for $\sigma_T(\phi p)$ are about 12 mb staying constant or rising slightly with energy in contradiction with the apparent trend of our results.

To summarize, the interpretation of our results for ϕ-meson photoproduction is not entirely clear but our agreement up to 17.8 GeV with vector dominance predictions for ρ^o-meson photoproduction is very good.

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REFERENCES

1. Aachen-Berlin-Bonn-Hamburg-Heidelburg-Munchen - Collaboration, Nuovo Cimento, 46, 795 (1966); 48, 262 (1967); also DESY Report 68/8 (unpublished). Brown-Harvard-MIT-Padova-Weizmann Institute Bubble Chamber Group, Phys. Rev. 146, 994 (1966); 155, 1468 (1967).

2. F. M. Pipkin, Proceedings 1967 International Symposium on Electron and Photon Interactions, p. 270, and references quoted therein.

3. P.G.O. Freund, Nuovo Cimento 48, 541 (1967).
   F. Buccella and M. Colocci, Phys. Letters 24B, 61 (1967).
   H. Joos, Phys. Letters 24B, 103 (1967).
   K. Kajantie and J. S. Trefil, Phys. Letters 24B, 106 (1967).
   H. Harari, Phys. Rev. 155, 1565 (1967).
   J. S. Trefil, to be published.

4. R. Anderson, D. Gustavson, J. Johnson, D. Ritson, W. G. Jones, D. Kreinick, F. Murphy, R. Weinstein, Phys. Rev. Letters (to be published).

5. The DESY bubble chamber collaboration obtained a value for the ratio of diffractive ω and ρ photoproduction in good agreement with the expected value of 1:9 (see references 1. and 2.).

6. M. Ross and L. Stodolsky, Phys. Rev. 149, 1172 (1966).

7. A typical yield curve contained 20 points, each with a standard deviation of $\sim \pm 0.4\%$, in the mass range 950 to 1150 $(\mathrm{MeV}/c)^2$. The yield curves were smooth except for a "step" at the threshold for ϕ production (see Ref. 4). The error assigned to the determination of the ϕ yield was typically $\sqrt{2}$ times the standard deviation for one yield point.

8. K. J. Foley, S. J. Lindenbaum, W. A. Love, S. Ozaki, J. J. Russell and L. C. L. Yuan, Phys. Rev. Letters 11, 425 (1963).

9. H. Joos, Phys. Letters 24B, 103 (1967).

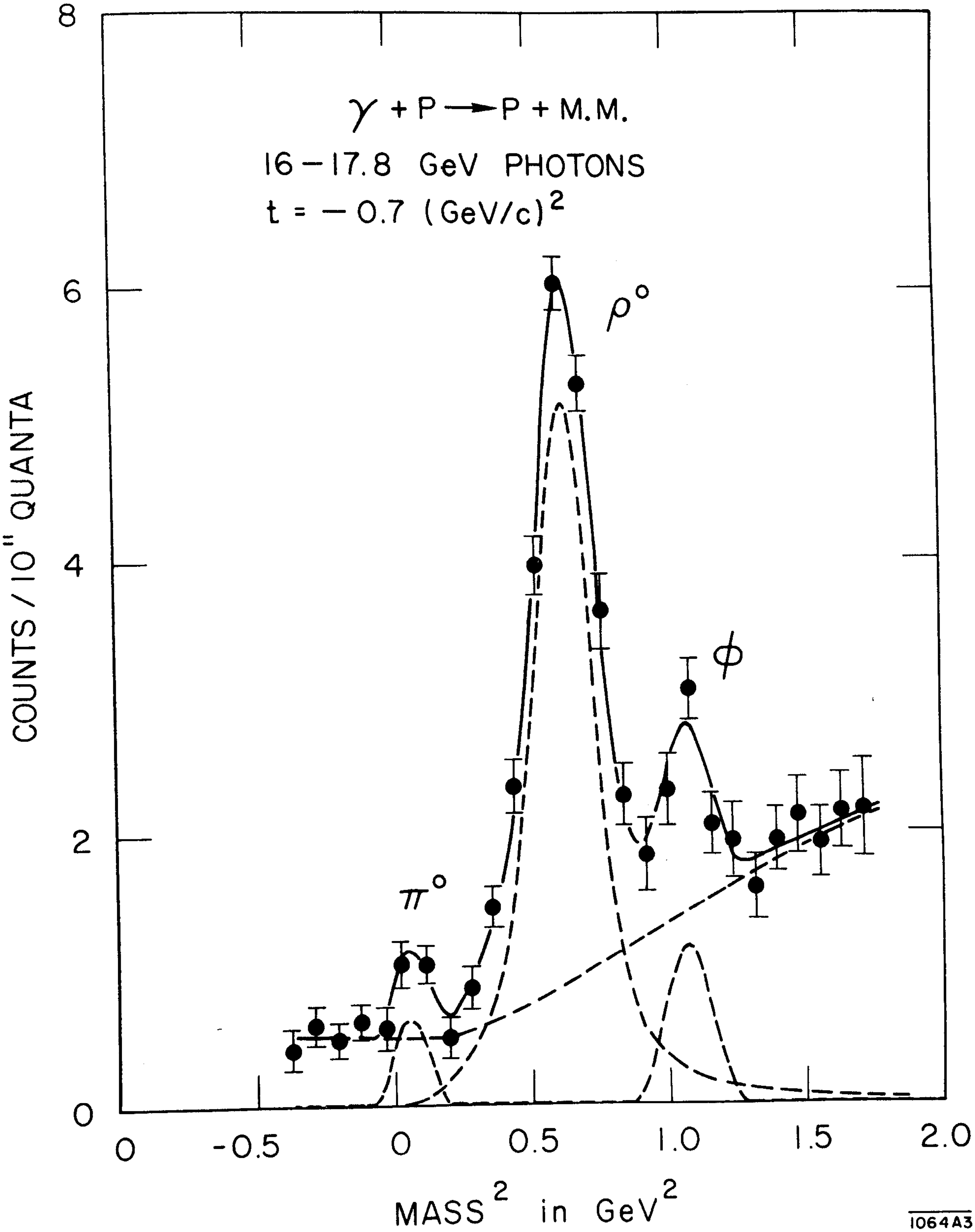
10. For a compilation of recent values of $\gamma_\rho^2/4\pi$, see the report by S.C.C. Ting in "Proceedings 1967 International Symposium on Electron and Photon Interactions", p. 452.

11. M. Davier, Phys. Rev. Letters 20, 952 (1968).
P.G.O. Freund, Nuovo Cimento 48A, 2013 (1967).

12. R. J. Oakes and J. J. Sakurai, Phys. Rev. Letters 19, 1266 (1967).

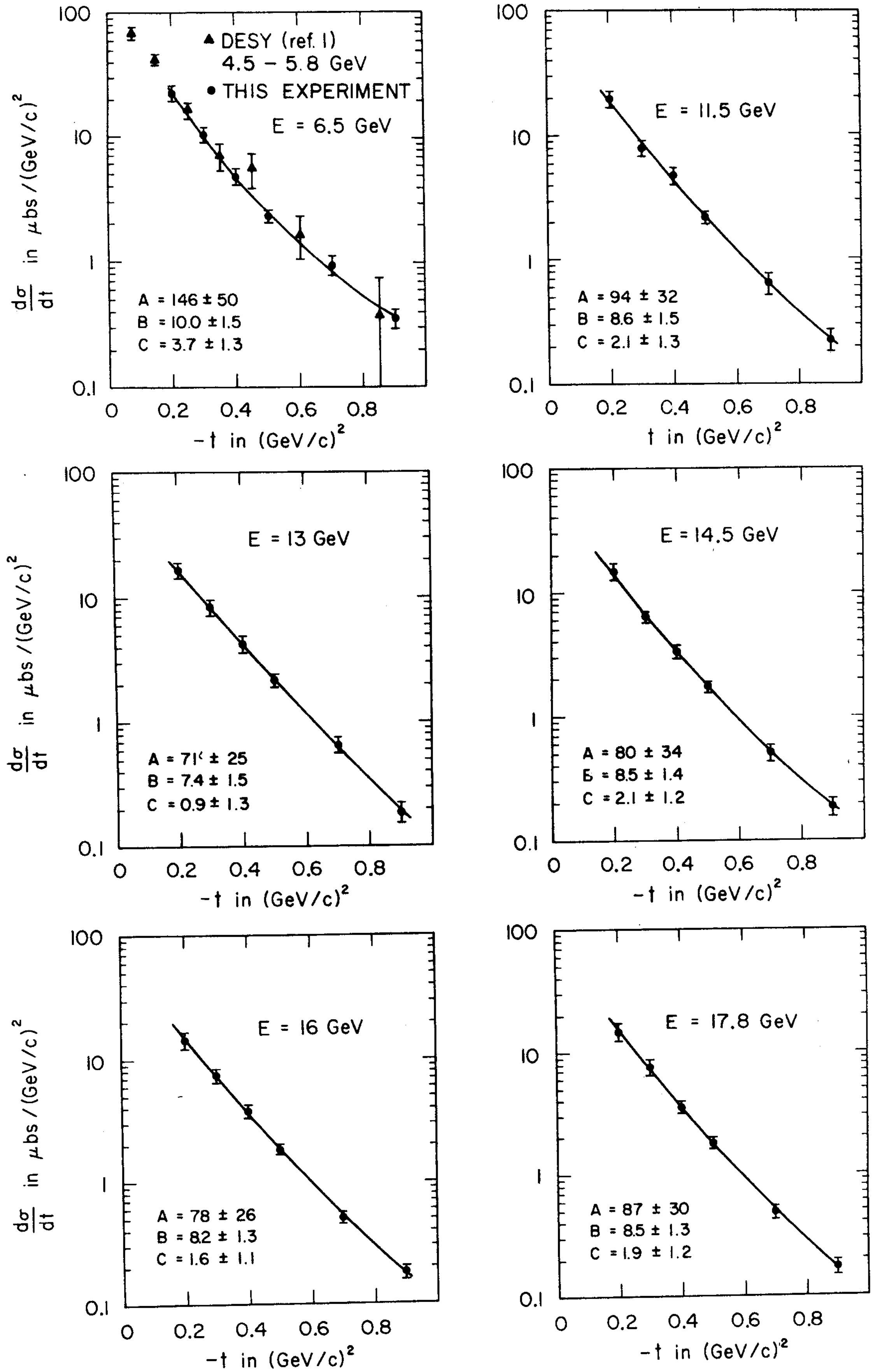
FIGURE CAPTIONS

1. This figure shows the missing-mass (MM) spectrum in the reaction $\gamma + p \to p + MM$ at a t value of -0.7 $(GeV/c)^2$, where the photon energy is defined by a bremsstrahlung subtraction. The spectrum was obtained by subtracting the yields measured as a function of angle at 17.8 GeV and 16.0 GeV with the spectrometer momentum held constant. The ordinate represents counts per hodoscope counter per 10^{11} incident quanta. The abscissa represents $(MM)^2$ in GeV^2. There is an approximately linear relationship between $(MM)^2$ and the angle of the proton in the laboratory. The dotted lines represent the fitted values of the individual contributions for π^o, ρ and ϕ production and a phenomenological background. The full line shows the sum of these contributions.
2. $\frac{d\sigma}{dt}$ in $\mu b/(GeV/c)^2$ versus t, for the reaction $\gamma + p \to p + \rho^o$ at incident photon energies from 6.5 GeV to 17.8 GeV. The lines drawn through the data points are the best fits to the expression $\frac{d\sigma}{dt} = A\ e^{Bt+Ct^2}$. The values of A, B and C found at each energy are shown in the figure. Their units are $\mu b/(GeV/c)^2$, $(GeV/c)^{-2}$ and $(GeV/c)^{-4}$ respectively.
3. $\frac{d\sigma}{dt}$ in $\mu b/(GeV/c)^2$ versus t, for the reaction $\gamma + p \to p + \phi$ at incident photon energies of 13 and 16 GeV.



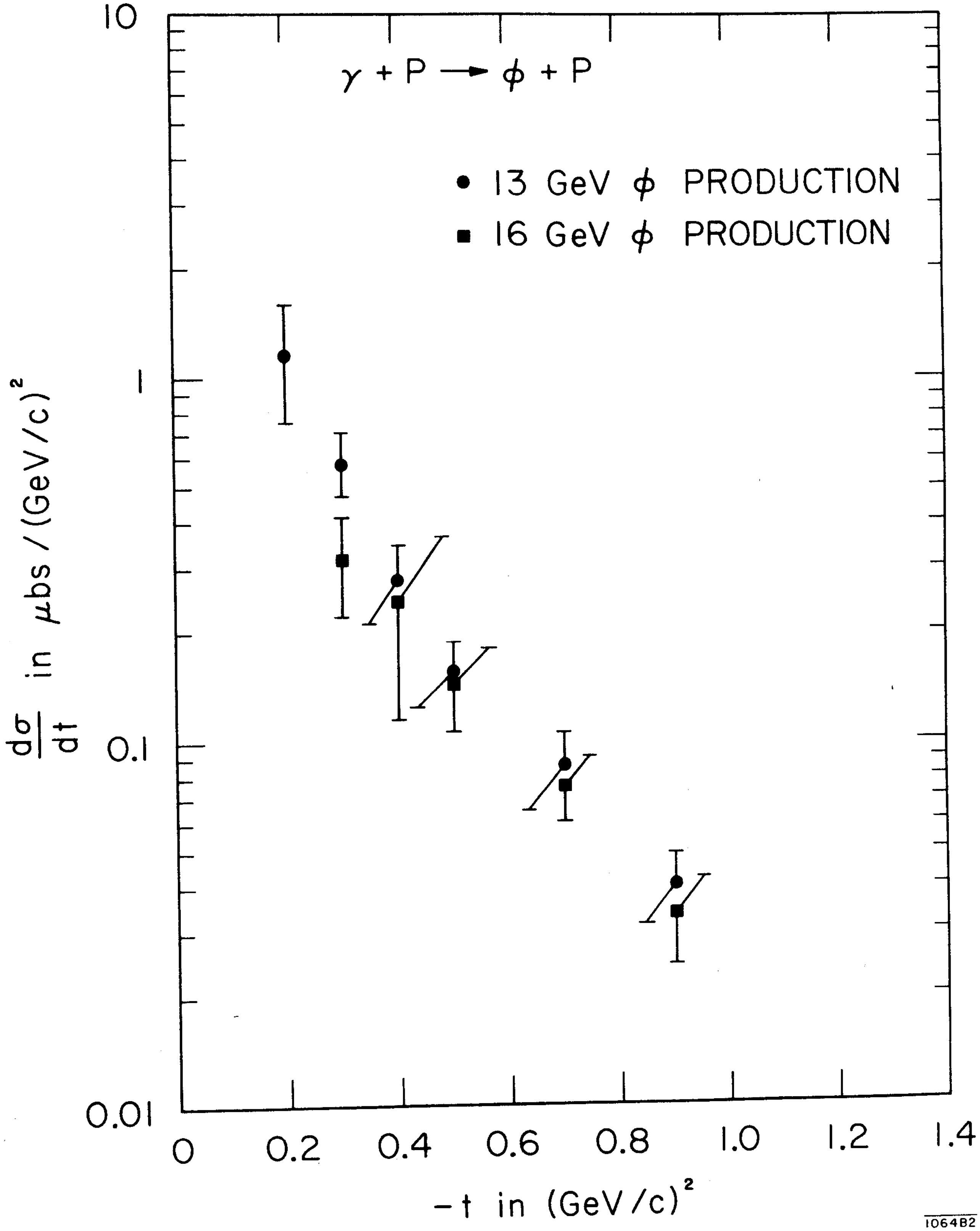
γ + P ⟶ P + M.M.
16 − 17.8 GeV PHOTONS
t = − 0.7 (GeV/c)²
ρ°
φ
π°
COUNTS / 10¹¹ QUANTA
8
6
4
2
0
0
-0.5
0
0.5
1.0
1.5
2.0
MASS² in GeV²
1064A3

Fig. 1



▲ DESY (ref. 1)
4.5 – 5.8 GeV
● THIS EXPERIMENT
E = 6.5 GeV
A = 146 ± 50
B = 10.0 ± 1.5
C = 3.7 ± 1.3
E = 11.5 GeV
A = 94 ± 32
B = 8.6 ± 1.5
C = 2.1 ± 1.3
E = 13 GeV
A = 71 ± 25
B = 7.4 ± 1.5
C = 0.9 ± 1.3
E = 14.5 GeV
A = 80 ± 34
B = 8.5 ± 1.4
C = 2.1 ± 1.2
E = 16 GeV
A = 78 ± 26
B = 8.2 ± 1.3
C = 1.6 ± 1.1
E = 17.8 GeV
A = 87 ± 30
B = 8.5 ± 1.3
C = 1.9 ± 1.2
dσ/dt in μbs/(GeV/c)²
−t in (GeV/c)²
t in (GeV/c)²

Fig. 2



$\gamma + P \rightarrow \phi + P$
● 13 GeV ϕ PRODUCTION
■ 16 GeV ϕ PRODUCTION
$\frac{d\sigma}{dt}$ in μbs / (GeV/c)^2
10
1
0.1
0.01
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
$-t$ in (GeV/c)^2
1064B2

Fig. 3