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MEASUREMENTS OF THE REACTION $\gamma P \rightarrow \phi P$ WITH UNPOLARIZED BREMSSTRAHLUNG

R. L. Anderson, B. Gottschalk*, D. B. Gustavson
D. M. Ritson, G. A. Weitsch and B. H. Wiik**

Stanford University †
Stanford, California 94305

H. J. Halpern, R. Prepost and D. H. Tompkins

University of Wisconsin ††
Madison, Wisconsin 53706

ABSTRACT

We have measured the differential photoproduction cross section $d\sigma/dt$ for the production of ϕ mesons as a function of t at a photon energy of 12 GeV from $|t| = .2\ (\mathrm{GeV/c})^2$ to $|t| = 1.0\ (\mathrm{GeV/c})^2$, and as a function of photon energy from 6 GeV to 19 GeV at a $|t|$ of $.6\ (\mathrm{GeV/c})^2$. Our results, and all other world data, fall on a universal curve. The slope of the Pomeron trajectory deduced from this experiment is $\alpha' = -0.03 \pm .13$.

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*On sabbatical leave from Northeastern University, Boston, Mass.

**Present address: DESY, Hamburg, West Germany.

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High energy elastic scattering processes have been traditionally described in terms of "Pomeron" and Regge exchanges. PP scattering and K^+P scattering are postulated to be mainly dominated by Pomeron exchange, with the contributions from other Regge exchanges approximately cancelling due to exchange degeneracy (these processes are exotic in the s channel).

The PP and K^+P elastic scattering data show diffraction peaks which shrink with energy and, excluding ISR data, these processes have an α_{eff} with a slope of approximately 1/2.[1] However, the recent ISR data are described by an α_{eff} with a substantially smaller slope. Some authors [2] have concluded that at ISR energies, exchanges other than the Pomeron play a small role and that both low and high energy data may be described quite well with a Pomeron trajectory slope in the range from .15 to .45.

To throw further light on this problem we have measured photoproduction of the ϕ meson. Freund[3], and more recently Barger and Cline[4], have pointed out that on very general grounds ϕP elastic scattering should proceed only by Pomeron exchange. This follows directly from the quark model with the phi made up of two strange quarks (or SU_3 with magic mixing), and it is supported by experimental evidence showing the phi to be decoupled from non-strange hadrons. Therefore a measurement of ϕP elastic scattering would more unequivocally determine the parameters of the Pomeron trajectory than other elastic scattering processes involving additional exchange contributions.

Since the phi meson has the same quantum numbers as the photon, the ϕ photoproduction cross section should be directly related to elastic scattering of transversely polarized phi mesons on the proton. This can be expressed formally as:

$$\frac{d\sigma}{dt}(\gamma P \rightarrow \phi P) = \frac{\alpha}{4}\left(\frac{\gamma_\phi^2}{4\pi}\right)^{-1} \cdot \frac{d\sigma}{dt}(\phi_{tr} + P \rightarrow \phi_{tr} + P) \qquad (1)$$

where γ_ϕ is the strength of the photon to phi coupling constant and $\alpha = 1/137$. Thus measurements of the photoproduction of ϕ mesons should determine the α_{eff} for the elastic scattering of phi mesons and hence for the Pomeron. Polarization measurements by our group have given excellent agreement with the predictions from pure Pomeron exchange (best asymmetry value .98 ± .12) (see preceeding letter) and are consistent with reanalyzed results of a similar experiment from Cornell[5].

In this experiment we have considerably extended the previous single arm missing mass studies of ϕ production at the SLAC[6] in order to study:

1) the s dependence of the ϕ meson production differential cross section $d\sigma/dt$ at a $|t|$ of .6 $(GeV/c)^2$ at photon energies ranging from 6 to 19 GeV.

2) the t dependence of the differential cross section $d\sigma/dt$ at 12 GeV, for $|t|$ ranging from .2 $(GeV/c)^2$ to 1.0 $(GeV/c)^2$.

Figure 1 shows the experimental setup similar to that described in previous publications[6]. A bremsstrahlung photon beam was passed through a 30 cm long by 5 cm diameter liquid-hydrogen target at the Stanford Linear Accelerator Center (SLAC), and the recoiling protons produced in the target were observed 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. The P, θ focal plane of the spectrometer was split by hodoscope counters into eight missing mass 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, for low $|t|$ values, "differential" yield curves were obtained by subtracting two integral curves taken at different peak photon energies E_1 and E_2. The differential yield curves corresponded to excitation by a narrow band of photon energies between the energies E_1 and E_2.

The beam was carefully monitored with an SEQ (secondary emission quantameter). In order to obtain high relative accuracy in our yield curves we took the following precautions:

1) The order in which data were taken was chosen to minimize the effects tha could have been caused by small instrumental drifts.

2) Dead time and random corrections were always less than 6%, and the beam intensity was held constant during a run.

3) The region of interest around the kinematic threshold of the ϕ meson was completely measured with each of the hodoscope counters in order to avoid possible effects due to variable efficiencies for different counters.

4) All yield curves for a given point were repeated between four to ten times.

Due to the very large redundancy of the data, internal consistency could be carefully checked, and was generally excellent. Typically sweeps required about ten hours of running and contained a total of $\sim 10^7$ counts. Internal consistency checks showed that final relative errors were close to statistical.

Figure 2 shows typical final accumulations. The curves all show a marked kinematic step at the threshold for ϕ meson production. These curves were analyzed to give good fits to a locally smooth polynomial background plus the yield expected for a given $(d\sigma/dt)$ for the ϕ meson. The fitting program found the parameters that corresponded to reasonable "derivatives" at the beginning and end of the fiducial region and performed a chi-square minimization. The fit region included a missing mass range from 900 MeV (above the ρ meson) to 1120 MeV (where B (or ρ') production started). Standard statistical errors were assigned to the final values, except for a few cases where the errors were increased to allow for nonlinear fitting effects or somewhat high chi-square for the fits.

Figure 3 shows the values of $d\sigma/dt$ plotted against s at a fixed $|t|$ value of 0.6 $(GeV/c)^2$. Analysis of these results in terms of:

$$\frac{d\sigma}{dt} \sim s^{2(\alpha_{eff} - 1)}$$

gave a value of $\alpha_{eff} = 1.02 \pm .08$. If α_{eff} (t) is expressed as $\alpha_{eff}(t) = 1 + \alpha' t$ then $\alpha' = -.03 \pm .13$ which is inconsistent with the value of 1/2 for α' obtained from the shrinkage observed for K^+P and PP elastic scattering[1]. All data were taken with almost identical spectrometer settings and accordingly the cross section ratios were unaffected by systematic uncertainties in the spectrometer efficiencies.

Figure 4a shows our values of $d\sigma/dt$ plotted against $|t|$ at 12 GeV. Figure 4b shows both our data and data from other experiments[5,7,8] at a variety of energies. The dotted line superimposed on these figures is the line given by the equation $d\sigma/dt = 2.85 \exp(5.4t)$. This is the latest fit to previous Cornell data in the range of 0 to 0.6 $(GeV/c)^2$. The solid line superimposed on the data was the "best fit" to the previous SLAC spectrometer data. This line had a relative t dependence obtained by combining Eq. (1) with the quark model relation:

$$\frac{d\sigma}{dt}(\phi P \rightarrow \phi P) = \left(\left(\frac{d\sigma(K^+P)}{dt}\right)^{\frac{1}{2}} + \left(\frac{d\sigma(K^-P)}{dt}\right)^{\frac{1}{2}} - \left(\frac{d\sigma(\pi^-P)}{dt}\right)^{\frac{1}{2}}\right)^2 \qquad (2)$$

Our present values are consistent with both these forms. The best fit to the present data would suggest a normalization 7% higher using the "quark model" shape than that given in the previous publication[6]. Both curves give an excellent representation to all existing world-data at all energies including our new improved data. Within the experimental errors we would regard either curve as representing the cross sections at all energies.

The previous SLAC data[6] gave weak indications of shrinkage with energy but the present higher statistics permit much better elimination of systematic errors and no shrinkage is observed.

Clearly we cannot conclude from this experiment that all Pomeron processes can be described with a unique α', neither can we rule out that α' is a function of s. We can conclude, however, that within the context of current theories of phi meson photoproduction the Pomeron exchange associated with photoproduction of ϕ mesons has an α' close to zero for our energy range.

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REFERENCES

1. c.f. for the experimental data. Foley _et al._, Phys. Rev. Letters 15, 45 (1965). These authors give $\alpha_{eff} = (1.06 \pm .07) + (0.50 \pm .16)\, t$ for K^+P scattering, $\alpha_{eff} = (.963 \pm .080) + (.378 \pm .193)\, t$ for PP scattering above 14.8 GeV, and $\alpha_{eff} = 1.046 \pm .020 + (.685 \pm .05)\, t$ for all PP data from this group. c.f. for instance for theoretical discussion M. Davier SLAC-PUB-1027, 1972.
2. V. Barger, R.J.N. Phillips and K. Geer, Rutherford Laboratory Report RPP/T/12 (1972), and V. Barger K. Geer, and F. Halzen (to be published).
3. P.G. Freund, Nuovo Cimento 48A, 541 (1967).
4. V. Barger and D. Cline, Phys. Rev. Letters 24, 1313 (1970).
5. C. Berger _et al._, Physics Letters 39B, 659 (1972).
6. R.L. Anderson _et al._, Phys. Rev. D1, 27 (1970).
7. H. Alvensleben _et al._, Phys. Rev. Letters 28, 66 (1972).
8. A-B-B-H-H-M Collaboration, Phys. Rev. 175, 1669 (1968); and 188, 2060 (1969).

FIGURE CAPTIONS

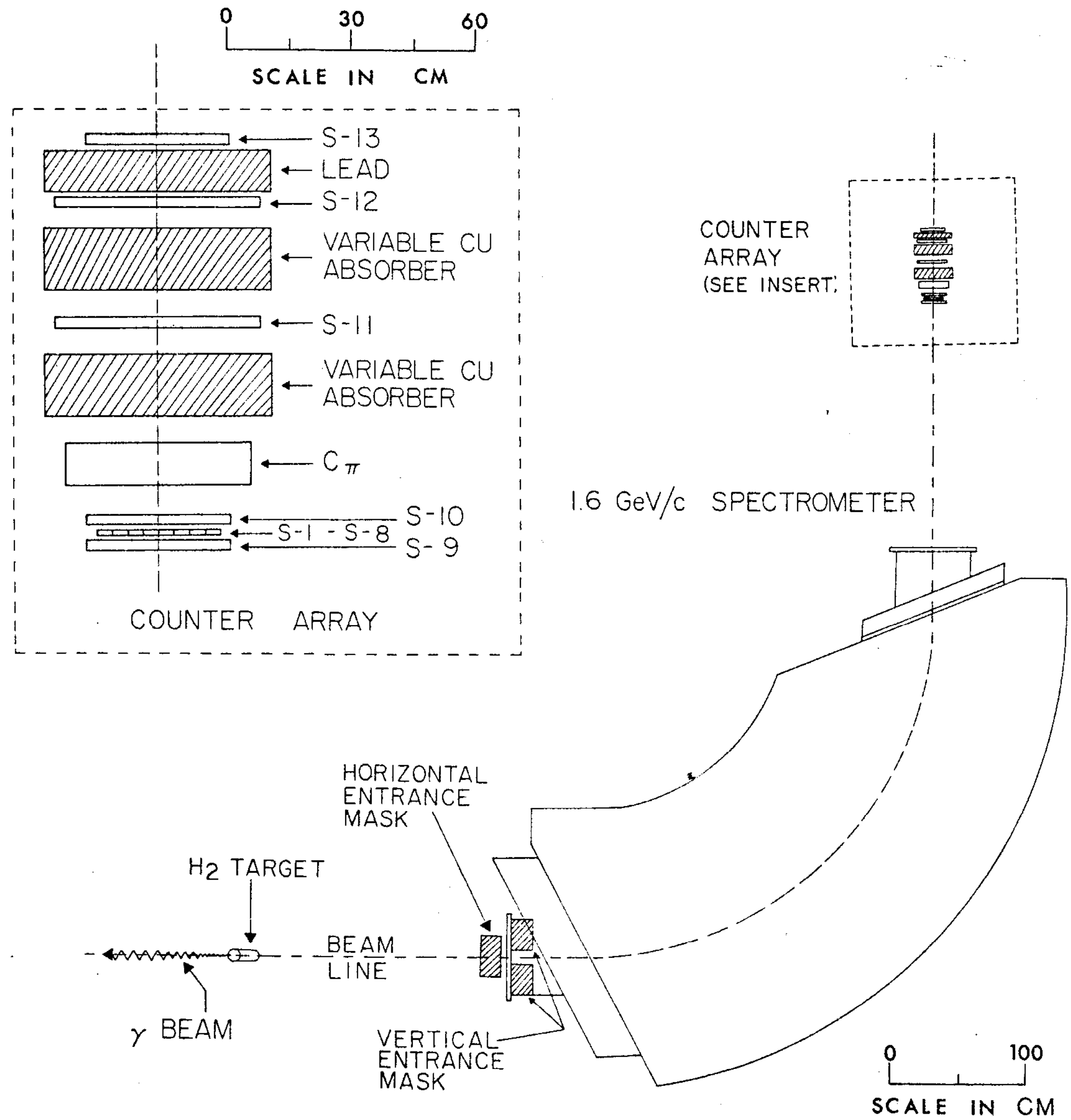
1. Experimental arrangement. Recoil protons produced in the liquid hydrogen target by the SLAC bremsstrahlung beam are detected in the SLAC 1.6 GeV spectrometer. The insert shows the counter array.

2. (a), (b) and (c) show the experimental yield curves at fixed spectrometer momentum versus missing mass squared at 6, 12 and 19 GeV photon energy, respectively for $-t = 0.6\ (\mathrm{GeV}/c)^2$. Also shown are the fitted ϕ yields. Error bars are too small to be displayed.

3. $d\sigma/dt$ for $-t = 0.6\ (\mathrm{GeV}/c)^2$ plotted versus s, the center of mass energy squared and the photon lab momentum from 6 to 19 GeV/c.

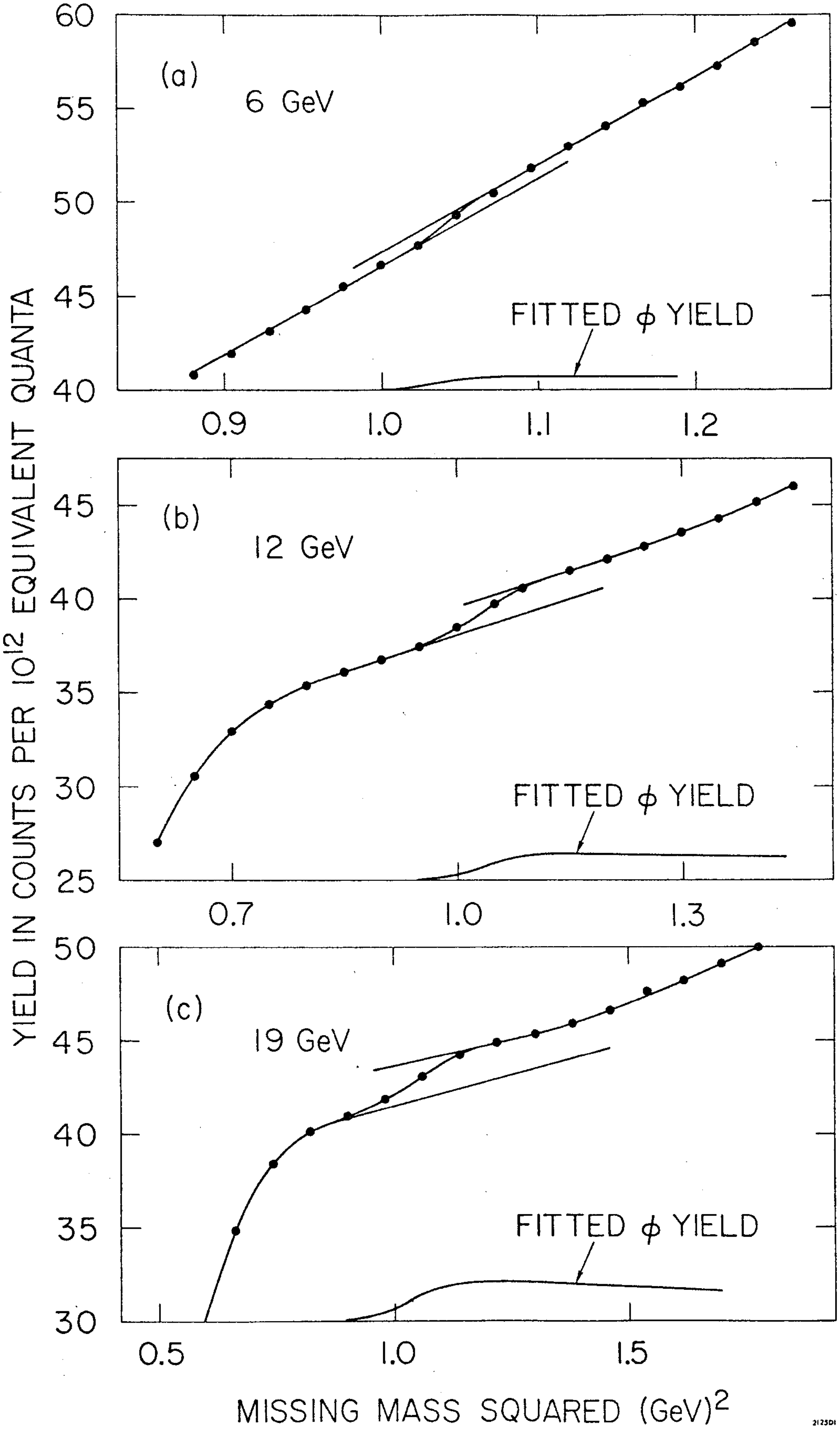
4. (a) shows our experimental values for $d\sigma/dt$ for ϕ photoproduction at 12 GeV as a function of -t from 0.2 to 1.0 $(\mathrm{GeV}/c)^2$. The dotted curve is the best fit to all Cornell data[5], the solid curve is the best "quark model" fit to our previous data[6].

   (b) shows the same curves and our points as in (a) with the addition of Cornell and DESY results[7,8]. Agreement of all data is excellent.



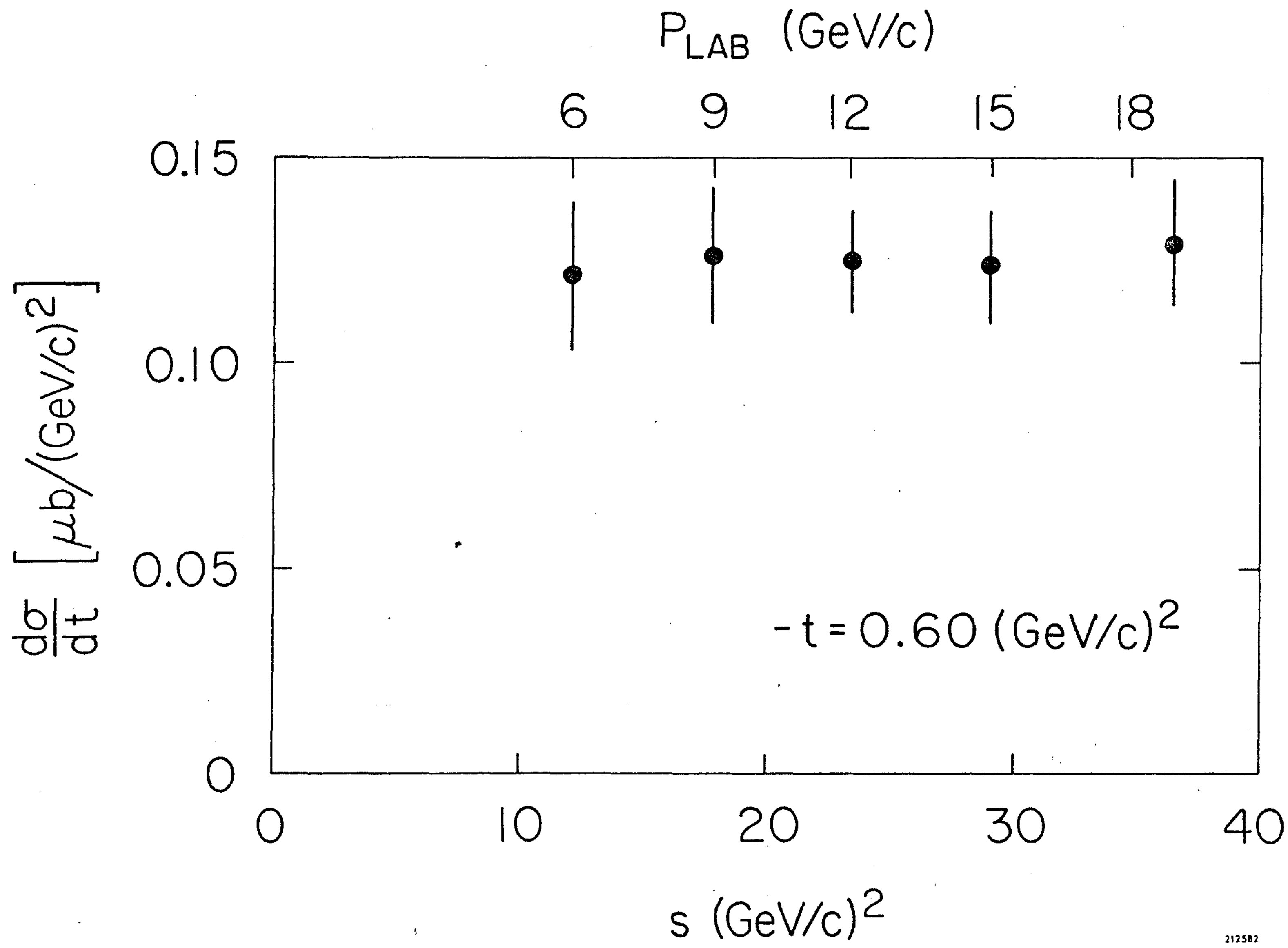
0
30
60
SCALE IN CM
S-13
LEAD
S-12
VARIABLE CU ABSORBER
S-11
VARIABLE CU ABSORBER
C π
S-10
S-1 - S-8
S-9
COUNTER ARRAY
COUNTER ARRAY (SEE INSERT)
1.6 GeV/c SPECTROMETER
HORIZONTAL ENTRANCE MASK
H2 TARGET
BEAM LINE
γ BEAM
VERTICAL ENTRANCE MASK
0
100
SCALE IN CM

Fig. 1



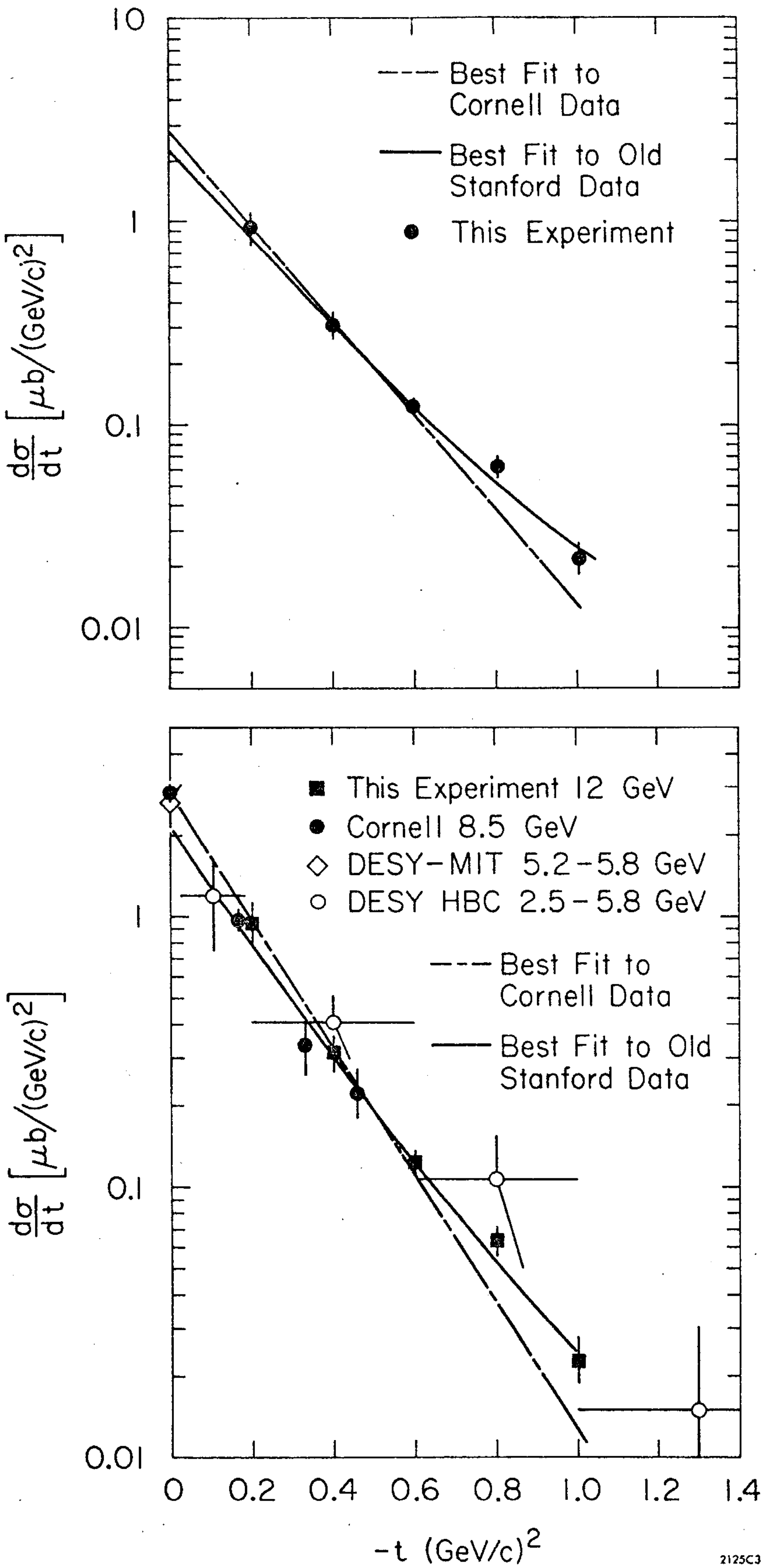
(a)
6 GeV
FITTED ϕ YIELD
(b)
12 GeV
FITTED ϕ YIELD
(c)
19 GeV
FITTED ϕ YIELD
YIELD IN COUNTS PER 10^12 EQUIVALENT QUANTA
MISSING MASS SQUARED (GeV)^2

Fig. 2



P_{LAB} (GeV/c)
6
9
12
15
18
0.15
0.10
0.05
0
$\frac{d\sigma}{dt}$ [μb/(GeV/c)^2]
$-t = 0.60$ (GeV/c)^2
0
10
20
30
40
s (GeV/c)^2
212582

Fig. 3



10
1
0.1
0.01
$\frac{d\sigma}{dt}$ $\left[\mu b/(GeV/c)^2\right]$
Best Fit to Cornell Data
Best Fit to Old Stanford Data
This Experiment
This Experiment 12 GeV
Cornell 8.5 GeV
DESY-MIT 5.2-5.8 GeV
DESY HBC 2.5-5.8 GeV
0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
-t (GeV/c)^2
2125C3

Fig. 4