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COINCIDENCE ELECTROPRODUCTION IN THE REGION OF THE RHO MESON*

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ABSTRACT

Cross sections for the reaction $ep \rightarrow epX$, measured by detecting both the scattered electron and proton, are given for missing masses m_x between 0 and 1 GeV/c^2. A large cross section is observed at m_x=0 due to radiative processes, but the resolution of the apparatus is such that the contribution of the m_x=0 peak is small for $m_x \gtrsim 0.6$ GeV/c^2. Enhancements are observed in the region of the rho meson at q^2=0.1 and 0.5 (GeV/c)^2. The electroproduction of all states with m_x between 0.7 and 0.83 GeV/c^2 varies like $e^{-7.5t}$ for q^2=0.1 (GeV/c)^2, similar to missing mass photoproduction in this region, but for q^2=0.5 (GeV/c)^2 it varies like $e^{-3.5t}$.

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This letter reports the results of an inelastic electron scattering experiment at SLAC where a final state proton was detected in coincidence with the scattered electron, $ep \rightarrow epX$.

The measured variables are E_0, the incident electron energy, E', θ, and ϕ, the momentum, polar scattering angle, and azimuthal angle of the scattered electron; and P_p, θ_p and ϕ_p, the corresponding proton variables. These measurements uniquely determine m_x, the mass of the unobserved state X.

$$m_x^2 = 2|\vec{q}|\,|\vec{P}_p|\cos\theta_{\gamma p} - q^2 - t(1+\nu/M_p)$$

where $q^2=4E_0E'\sin^2(\theta/2) = -$(four momentum transfer from the electron)^2, $\nu = E_0 - E'$, $|\vec{q}| = \sqrt{q^2+\nu^2}$, and $t=2M_pT_p = -$(four momentum transfer to the proton)^2. T_p is the kinetic energy of the proton, M_p is its mass, and $\theta_{\gamma p}$ is the angle between $\vec{P}_p$ and $\vec{q}$.

The cross section may be written[1]

$$\frac{d^6\sigma}{d\Omega dE' dt dm_x d\phi_q} = \Gamma_T \frac{d^3\sigma_{abs}}{dt dm_x d\phi_q}$$

where Γ_T is the flux of virtual photons and ϕ_q is the azimuthal angle of $\vec{P}_p$ around $\vec{q}$ with respect to the electron scattering plane. $d^3\sigma_{abs}/dt dm_x d\phi_q$ then represents the absorption of photons of mass q^2 and energy ν with a polarization parameter which is near unity for this experiment.

During the experiment, E_0 and E' were fixed at 20 and 13 GeV respectively. Two values of θ were used, 1.124° and 2.51°, corresponding to $q^2=0.1$ and $0.5\ (\mathrm{GeV/c})^2$. At each angle data were taken for values of t between 0.15 and

0.75 $(GeV/c)^2$, and, for three points with constant q^2 and t, sweeps in m_x were made by varying the proton angle. The resolution in m_x was dominated by multiple scattering in the hydrogen target. This resolution was determined experimentally by measuring elastic e-p scattering. At a proton momentum of 0.4 GeV/c the resolution was ±32 MeV/c^2. At 0.96 GeV/c the resolution improved to ±25 MeV/c^2.

The target was a two inch diameter cylindrical shell ten inches long, filled with liquid hydrogen, with its axis parallel to the beam line. To reduce mulitple scattering of the protons, the target was moved so that the scattered protons traversed as little liquid hydrogen as possible (approximately 1 cm). The length of the target seen by the 1.6 GeV spectrometer depended on the opening of tungsten slits at the entrance of the spectrometer. These slits were always adjusted to exclude events from the end walls of the target. Experimentally, the coincidence yield from an identical target cell containing no hydrogen was always less than 1% of the full target yield.

Three scintillation counter hodoscopes were used in the 1.6 GeV spectrometer[2] and gave resolutions of ±0.25% in momentum, ±1.1 mrad in the horizontal projected angle, and ±7.5 mrad in the vertical projected angle. Protons were cleanly identified by a large pulse height from a one inch thick scintillation counter, time of flight, and the lack of a signal in a two inch thick lucite Cerenkov counter.

The positions and angles of the scattered electron after passing through the 20 GeV spectrometer[3] were measured in five proportional wire chambers.[4] The resolutions were ±.05% in momentum and ±0.05 mrad in both projected angles. Electrons were cleanly identified with a lead-lucite shower counter.

The coincidence timing was done between single scintillation counters, each counter having a photomultiplier tube on both ends. The difference in time of the signals from each set of photomultiplier tubes was measured by time-to-amplitude converters and stored on tape with other event information. The distribution of true coincidence events was approximately 10 nsec wide. The other event information permitted corrections to be made to these time differences for the following effects: a) path length differences for differing kinematics, b) velocity differences, c) finite size of the timing counters, d) pulse height variations, and e) ionization losses after momentum analysis. The two semi-independent measurements were then averaged to form the final time spectrum. The final timing resolution was momentum dependent because of multiple scattering and the resolution of the proton hodoscope. At a proton momentum of 0.4 GeV/c the timing resolution obtained was 1.6 nsec FWHM and at 0.96 GeV/c it was 0.8 nsec.

To determine the proper time cut for each momentum, electron bunches were accelerated, separated by 12.5, 25, or 50 nanoseconds. The length of a bunch was 5 picoseconds so that both true and accidental coincidences provided information about the timing resolution. This allowed optimization of the corrections to the timing signals in regions with a low rate of true coincidences. Further, the time-to-amplitude converters were calibrated using the accurately known bunch spacing.

The electron fluxes of 10^7 - 10^9 per 1.6 μsec pulse were measured by a secondary emission quantameter. At these fluxes, the ratio of the total number of true coincidence events to the random events within the time cuts was more than 100:1 for elastic ep scattering, approximately 5:1 for bremsstrahlung (see Fig. 1a), and between 1:1 and 0.3:1 for the rho mass region (see Fig. 1b).

The systematic uncertainty of the subtraction of random events from the yield was estimated to be less than 10% by studying the variation of the yield with the size of the time cut. This estimate includes a study of effects due to beam structure with time.

The sixfold double arm acceptance $\int d\Omega dE' dt dm_x d\phi_q$ was calculated by a Monte Carlo program from models of the two spectrometers based on beam optics measurements. Single arm elastic scattering measurements with the 20 GeV spectrometer agreed with world average form factors to an accuracy of ±5%. Single arm 1.6 GeV measurements of elastic ep scattering agreed to within the systematic uncertainty of ±10%. The systematic error in the coincidence cross section normalization is estimated to be less than ±20%.

Fig. 2 shows the three measured spectra of sixfold differential cross sections as a function of missing mass. Since the cross section at $m_x=0$ is approximately fifty times larger than the rest of the spectrum, only the data for $m_x>0.1$ GeV/c^2 are shown. Besides the large peak at $m_x=0$, which, within the 20% normalization uncertainty, can be attributed to the process $ep \rightarrow ep\gamma$, all three spectra show enhancements in the neighborhood of the rho meson mass. Broadening of the $m_x \approx 0$ peak due to the emission of multiple soft photons is small compared to the broadening due to experimental resolution. At the rho mass, the contribution from the $m_x \approx 0$ peak is estimated to be $\lesssim 20\%$.

Additional measurements were made concentrating on the mass region between 0.7 and 0.83 GeV/c^2. This region is centered on the mass of the rho meson, but it includes the omega meson, any nonresonant background, and the resolution tail from the $m_x=0$ region. For $q^2=0.1$(GeV/c)^2, data were taken at $t=0.33$ and 0.5 (GeV/c)^2, and for $q^2=0.5$ (GeV/c)^2, at $t=0.15$ and 0.33 (GeV/c)^2.

The acceptance in ϕ_q was momentum dependent and ranged between 0.6 and 1.2 radians, centered about 0. The angular distributions appear to be flat, but the data do not rule out a dependence like $\cos 2\phi_q$.

For $q^2=0.1(GeV/c)^2$, the cross section dependence on t seen in Fig. 3 is similar to that found in missing mass photoproduction in this region[5] and is well fitted by the form e^{-bt} where $b=7.5\pm0.8(GeV/c)^{-2}$. However, the variation at $q^2=0.5(GeV/c)^2$ is markedly different from photoproduction. If the points are fitted to an exponential form e^{-bt}, then $b=3.5\pm0.6(GeV/c)^{-2}$. The probability of observing a χ^2 larger than obtained is 60% for $q^2=0.1(GeV/c)^2$ and 13% for $q^2=0.5(GeV/c)^2$. The observed flattening of the t-dependence with increasing q^2 has been speculated upon by various authors.[6]

Assuming that an exponential form accurately describes the t-dependence, and that the distribution in ϕ_q is flat, as would be expected for a diffractive production mechanism,[1] the ratio of the integrated contribution of the mass region from 0.7to 0.83 GeV/c^2 to single arm deep inelastic scattering[7] at $q^2=0.1(GeV/c)^2$ is $(10.7\pm1.3)\%$ which is consistent with photoproduction. At $q^2=0.5(GeV/c)^2$ this ratio is $(16.5\pm3.0)\%$. The assumption of exponential behavior is important since at both q^2 values more than 50% of the integral comes from t values lower than those measured.

The statistics are marginal for answering the interesting question of how much rho signal is present in the mass region from 0.7 to 0.83 GeV/c^2. Fits were made to the mass spectra in figures 2a, 2b and 2c using a single Breit-Wigner resonance shape plus a naive background of the form $(m_x-m_{2\pi})(m_{max}-m_x)$ where m_{max} is the highest missing mass allowed by kinematics. The mass and width of the Breit-Wigner were fixed at 765 and 140 MeV, respectively. At $q^2=0.1$, $t=0.15(GeV/c)^2$ and $m_x=m_\rho$, we find the resonant fraction of the cross section to be $(55\pm30)\%$. At $q^2=0.5(GeV/c)^2$ we obtain $(47\pm30)\%$ for $t=0.5(GeV/c)^2$ and $(75\pm40)\%$ for $t=0.76(GeV/c)^2$.

We have made no radiative corrections to the data presented here. In a model calculation, events with a rho mass distribution were simulated by a Monte Carlo program and the effects of soft photon emission were taken into account. The mass region between 0.7 and 0.83 GeV/c^2 was depleted by 35-50%. This depletion was t- and q^2-dependent, and its size further complicates the interpretation of the integrated cross sections given above. However, the slopes of the experimental t-dependence were not affected outside of the errors given.

This experiment is similar to a previously published experiment at Cornell[8] where data were taken under different kinematical conditions. Further experiments are necessary to resolve questions like photon shrinkage.[6]

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REFERENCES

1. H. Fraas and D. Schildknecht, Nucl. Phys. B14, 543-565 (1970).

2. R. Anderson *et al.*, Nucl. Instrum. Methods 66, 328-38 (1968).

3. W. K. H. Panofsky, *Proceedings of the International Symposium on Electron and Photon Interactions at High Energies*, Hamburg, 1965.

4. E. Bloom, R. L. A. Cottrell, G. Johnson, C. Prescott, R. Siemann and S. Stein, "A Proportional Chamber System for the SLAC 20 GeV Spectrometer", SLAC-PUB-981.

5. David L. Kreinick, *High Energy Photoproduction of Neutral Mesons*, Ph. D. dissertation, California Institute of Technology, 1970 (unpublished).

6. H. Cheng and T. T. Wu, Phys. Rev. 183, 1324 (1969).
   Richard W. Griffith, Phys. Rev. 188, 2112 (1969).
   James D. Bjorken, Invited talk at the International Conference on Duality and Symmetry in Hadron Physics, Tel Aviv, Israel, 1971, SLAC-PUB-905.

7. E. D. Bloom *et al.*, Report to the XV International Conference on High Energy Physics, Kiev, U.S.S.R., 1970, SLAC-PUB-653 and preliminary results at 4^{o} from SLAC, Group-A, reported to the V International Conference on Electron and Photon Interactions at High Energies, Cornell, 1971. The values of $d^2\sigma/d\Omega dE'$ at E_0=20 GeV, ν=7 GeV and q^2=0.1$(GeV/c)^2$ and 0.5$(GeV/c)^2$ used are $2.0 \times 10^{-29} cm^2/sr\text{-}GeV$ and $1.9 \times 10^{-30} cm^2/sr\text{-}GeV$, respectively.

8. D. E. Andrews *et al.*, Phys. Rev. Letters 26, 864 (1971) and CLNS-169.

FIGURE CAPTIONS

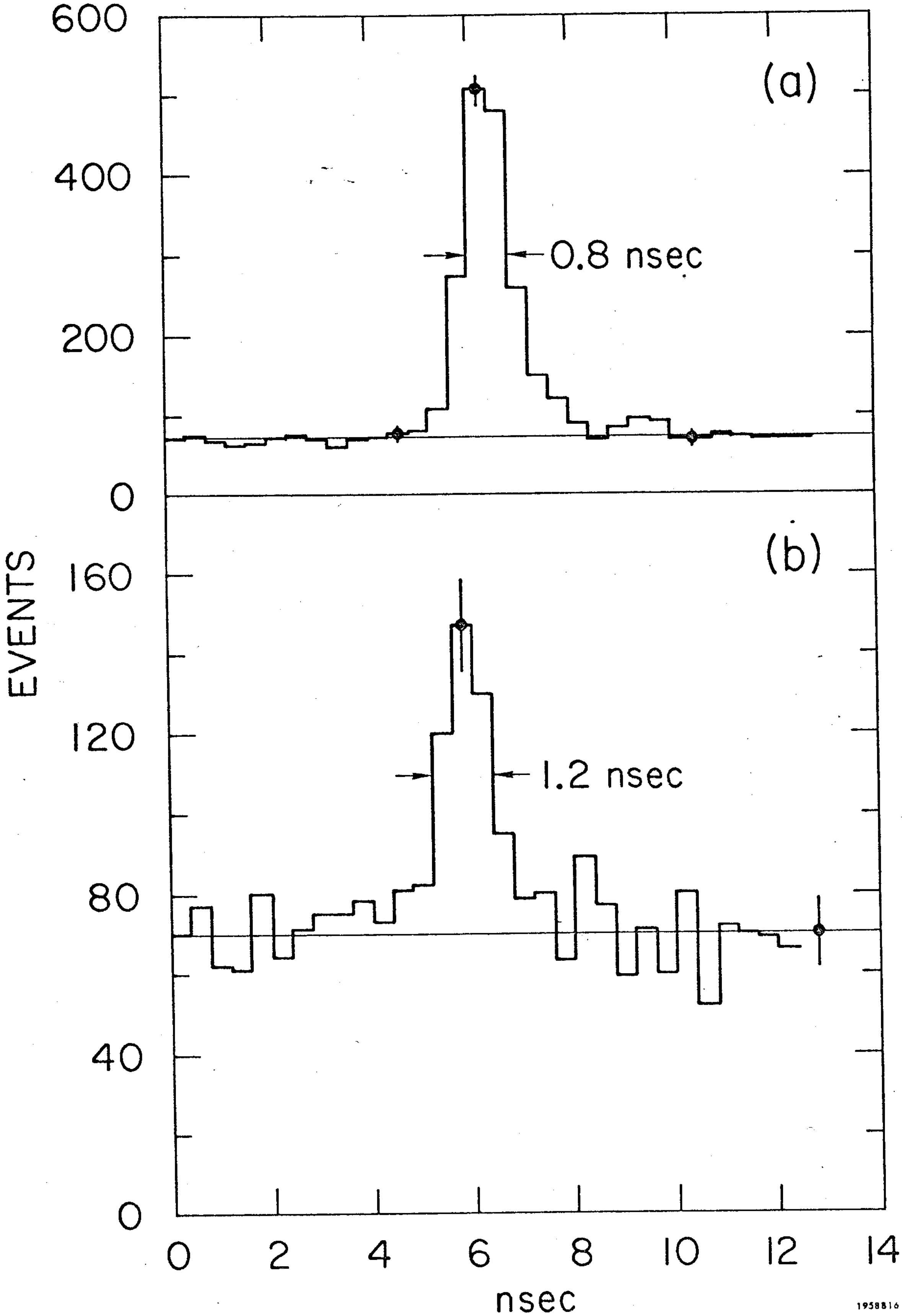
Fig. 1 The timing spectrum for a) $m_x=0$, $q^2=0.5(\mathrm{GeV/c})^2$ and $t=0.76(\mathrm{GeV/c})^2$ and b) $m_x=m_\rho, q^2= 0.5(\mathrm{GeV/c})^2$ and $t=0.5\,\mathrm{GeV/c})^2$.

Fig. 2 The sixfold differential cross section as a function of missing mass is shown for three values of q^2, ν, and t.

Fig. 3 The cross section

$$\frac{d\sigma_{abs}}{dt} = 2\pi\int\frac{d^3\sigma_{abs}}{dt\,d\phi_q\,dm_x}\,dm_x$$

is shown. The solid line is the fit to the $q^2=0.1(\mathrm{GeV/c})^2$ data given by $(91.1 \pm 18)\exp(-(7.5\pm0.8)t)\ \mu b/(\mathrm{GeV/c})^2$. The dashed line is the fit to the $q^2=0.5(\mathrm{GeV/c})^2$ data given by (30.5 ± 9.4) $\exp(-(3.5\pm0.6)t)\mu b/(\mathrm{GeV/c})^2$.



600
400
200
0
160
120
80
40
0
(a)
(b)
0.8 nsec
1.2 nsec
EVENTS
0
2
4
6
8
10
12
14
nsec
1958816

Fig. 1

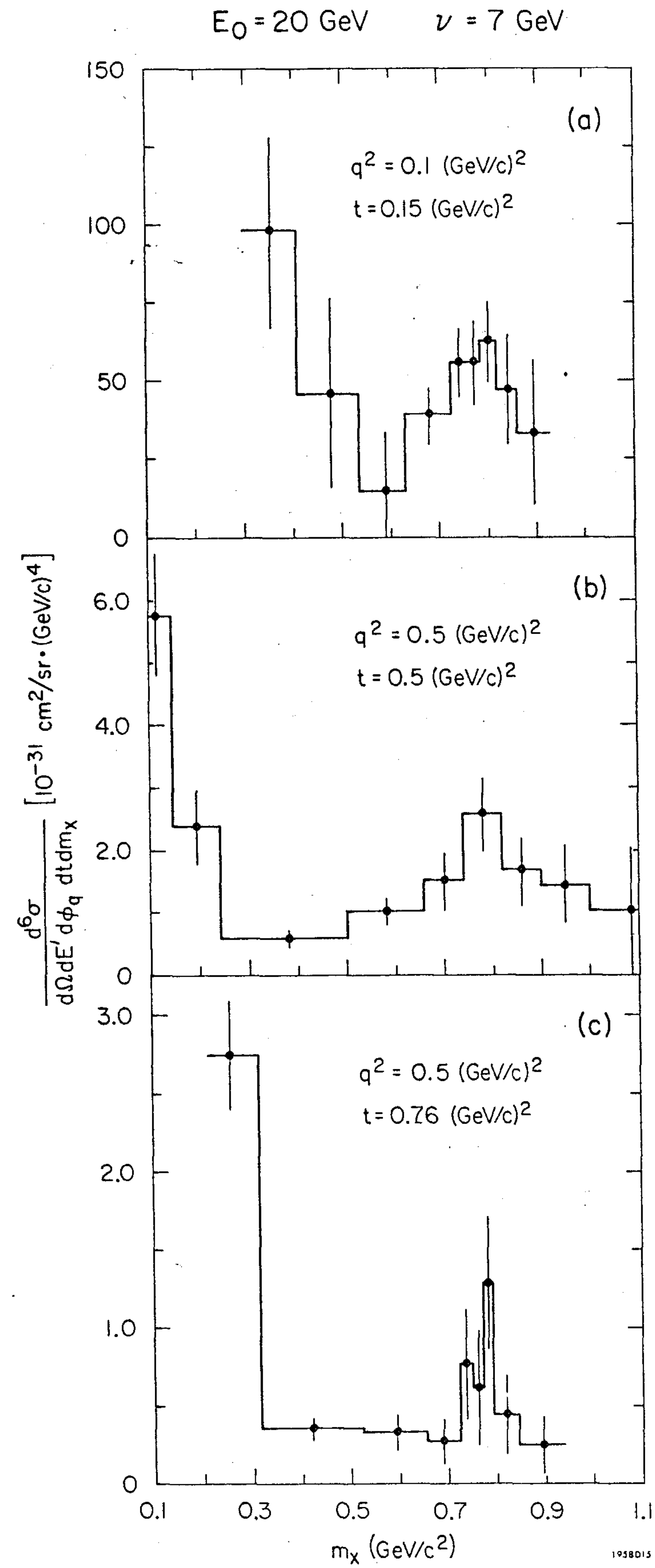
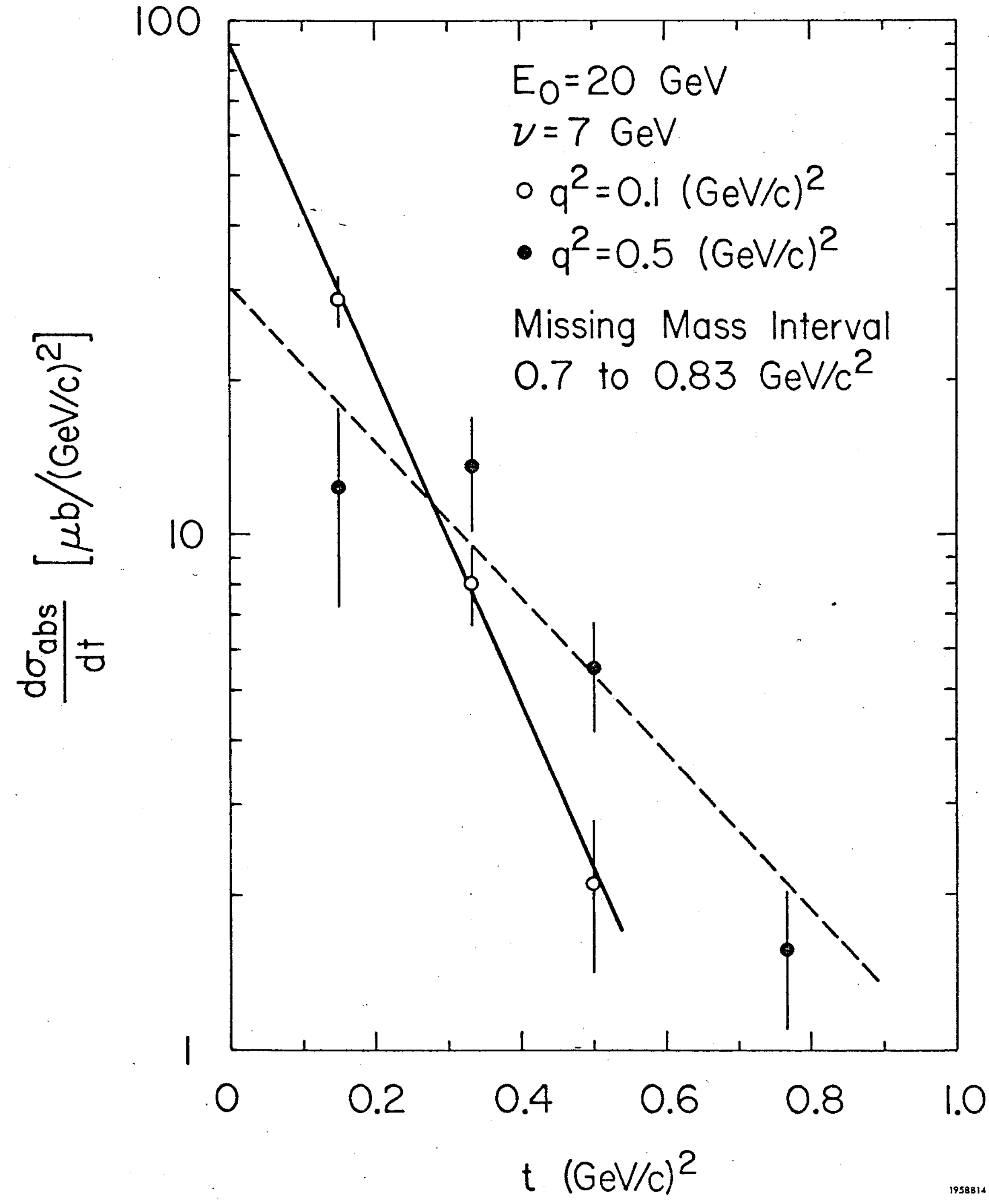

$E_0 = 20$ GeV $\nu = 7$ GeV
(a)
$q^2 = 0.1$ (GeV/c)^2
t = 0.15 (GeV/c)^2
(b)
$q^2 = 0.5$ (GeV/c)^2
t = 0.5 (GeV/c)^2
(c)
$q^2 = 0.5$ (GeV/c)^2
t = 0.76 (GeV/c)^2
$\frac{d^6\sigma}{d\Omega dE' d\phi_q dt dm_x}$ [10^{-31} cm^2/sr$\cdot$(GeV/c)^4]
m_x (GeV/c^2)
1958D15

Fig. 2



E_0=20 GeV
ν=7 GeV
○ q^2=0.1 $(GeV/c)^2$
● q^2=0.5 $(GeV/c)^2$
Missing Mass Interval
0.7 to 0.83 GeV/c^2
$\frac{d\sigma_{abs}}{dt}$ $[\mu b/(GeV/c)^2]$
100
10
1
0
0.2
0.4
0.6
0.8
1.0
t $(GeV/c)^2$
1958B14

Fig. 3