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ABSTRACT

The reaction $\gamma + p \rightarrow \Phi + p$ has been measured using a spark chamber spectrometer and a tagged photon beam in the energy range from 4.6 to 6.7 GeV. Approximately 3500 photoproduced elastic Φ-events have been collected in the t-range between t_{min} and $t = -0.4\ (\mathrm{GeV/c})^2$. Cross sections and t-distributions are presented.

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The photoproduction of Φ mesons has been considered as a unique example of a reaction which proceeds by Pomeron exchange in the t-channel even at low energies. This idea is based on the vector meson dominance (VDM) picture of Φ-photoproduction and the assumption of a pure strange quark composition ($\lambda\bar{\lambda}$) for the Φ[1]. From this follows that the s-channel of Φ-N scattering is exotic (no resonance possible) hence by duality only the Pomeron is expected to contribute in the t-channel.

Although Pomeron exchange at ISR energies seems to exhibit an increasing complexity, at lower energies the Pomeron can still be represented as a linear trajectory which has a nonzero slope. This has been shown by several analyses[2,3,4] using the dual absorptive model (DAM)[5].

In order to study this question in elastic Φ-photoproduction it is important to assure the absence of inelastic contributions to the cross section and to perform measurements at small t. This experiment studied the reaction

$$\gamma p \rightarrow \phi p \rightarrow K^+K^- p \qquad (1)$$

in the energy range $4.6 \leq E_\gamma \leq 6.7$ GeV and in the range of four-momentum transfer $|t_{min}| < |t| < 0.4\ (\mathrm{GeV/c})^2$.

A schematic layout of the apparatus is shown in fig. 1a. The γ-energy was measured by a tagging system with 43 energy channels each 50 MeV wide. Two rows of large scintillators behind the small counters were included in forming the trigger signal. The intensity of the γ-beam was $0.5\cdot 10^6$ equivalent quanta per second (10% duty cycle), resulting in about 3% multiple tags.

The bremsstrahlung beam with a dimension of 7 mm FWHM hit a liquid H_2-target of 50 cm length and 2.5 cm diameter. The beam passed through a hole in the front trigger counters consisting of 4 square scintillators and was absorbed in a cylindrical lead plug at the entrance of the magnet.

Forward going particles were recorded in 4 proportional chamber planes in front and 8 spark chambers of 1 m^2 each in back of the analysing magnet (length x width x height = 1.05 x 1.50 x 0.54 m^3; 9.8 kGauss·m). A picket fence array of additional trigger counters were located behind the spark chambers.

A threshold Cerenkov counter filled with Freon-13 discriminated against pions and electrons. The counter had a sensitive volume of 2.1 m width x 1.0 m height x 2.0 m length. It was pressurized to 4 atm giving a threshold momentum for pions of 1.8 GeV/c. The light was deflected by 6 spherical mirrors into light collectors and onto 6 phototubes. The probability for rejecting ρ's decaying into pions of momenta between 2 and 4.6 GeV/c was better than 99%.

The trigger was generated by a coincidence of : a twofold coincidence of the front counter system, a twofold coincidence of the picket fence array behind the spark chambers, a signal from one of the large tagging counters, and the absence of a Cerenkov signal. The incident flux was monitored by counting the number of tagged γ-quanta.

The acceptance for forward produced ϕ's varied between 30% and 60%, depending on energy, falling with $|t|$ to about 1% at $|t| = 0.4\ (\mathrm{GeV/c})^2$ and $E_\gamma = 6.5$ GeV.

A system of 24 additional scintillation counters surrounded the hydrogen target inside the vacuum tank. The 60 cm long strip counters were located on the surface of a cylinder, the target being the axis of the cylinder. This hodoscope recorded the large angle particles, in particular the recoil protons from elastic events with $|t| > 0.05\ (\mathrm{GeV/c})^2$. It was used to discriminate against inelastic contributions (production of additional pions). For the process $\gamma p \to K^+K^-X$ the recoil mass m_x can be calculated from the known momenta of the kaons and the photon. The resolution in m_x was 150 MeV FWHM. The target hodoscope provided a valuable check on our elastic data by assuring the coplanarity of the recoil proton.

Data reduction was done by reconstruction of trajectories from events with at least two particles in an overall fit yielding the momenta of the two particles and the vertex position. We applied two independent methods, each using the measured magnetic field configuration. Losses due to program inefficiencies were carefully studied and corrected.

An elastic sample of reaction (1) was selected by two separate methods: (1) by applying cuts on the recoil mass, on the $K\bar{K}$-invariant mass, and on the K-momenta ($p_K > 1.8$ GeV/c), and (2) by subjecting the data to a 1C kinematic fit and by applying a cut on confidence level. The two methods gave results which were in excellent agreement. About 3500 elastic ϕ-events were collected.

The distribution of unweighted events versus $m_{K\bar{K}}$ and m_X is shown in a three-dimensional plot in fig. 1b. The elastic Φ-signal can clearly be separated from the low background. Moreover, Φ's are also associated with recoil masses in the resonance region.

The geometric acceptance for the elastic Φ-events has been computed by two different methods:

a) Assuming a $\sin^2\Theta$-distribution for the Φ-decay in the helicity frame and isotropy in the azimuthal angle, corrections for fixed t and E_γ were calculated by a Monte-Carlo method which took into account the decay of the kaons.

b) Starting from the real event, the initial momenta vectors were rotated at random angles about the beam axis. By calculating the trajectory through the apparatus after each rotation, an acceptance factor was computed for each event.

Both methods gave consistent results.

The resulting distribution in $d\sigma/dt$ was fitted to the form

$$\frac{d\sigma}{dt} = \left.\frac{d\sigma}{dt}\right|_{t=0} e^{-B|t|}. \qquad (2)$$

Dividing our data into four energy bins, results for $d\sigma/dt|_{t=0}$ and B are presented in table 1. Because there is no marked energy dependence, all our data were combined for the following analysis.

Fig. 2a shows our $d\sigma/dt$ together with results from previous experiments at various energies[6-10]. The solid line is the best fit to our data with $B = 5.6 \pm 0.3\ (GeV/c)^{-2}$ and $d\sigma/dt|_{t=0}\ (\gamma p \to \Phi p) = 2.49 \pm 0.15\ \mu b/(GeV/c)^2$. The branching ratio $\Gamma(K^+K^-)/\Gamma(all) = 46\ \%$ was used.

This fit also gives a reasonable description of previous data for $|t| < 0.4\ (GeV/c)^2$, even at different energies, which suggests that $d\sigma/dt$ is independent of energy in this limited t-range. Also at larger $|t|$ the results of other experiments show essentially no energy dependence in $d\sigma/dt$[7], but with a smaller value[8] for B of typically $\simeq 4\ (GeV/c)^{-2}$. This is exemplified in fig. 2a by the broken line, which is the small $|t|$ extrapolation of the best fit to the 2-GeV data[6]. There is good agreement in the region of overlap, near $|t| = 0.3\ (GeV/c)^2$ where the two fits intersect.

The foregoing suggests that $d\sigma/dt$ deviates from simple exponential behaviour and depends only weakly on energy. This would be in a striking contrast with the shrinkage observed in the diffractive peak of p-p or $K^{\pm}p$ elastic scattering which also should proceed via Pomeron exchange.

If one assumes the validity of (2) for all the Φ-photoproduction data (as it is conventionally done), one can examine the s-dependence of $(d\sigma/dt)_{t=0}$ and B in the framework of the DAM-model. Results from all kinematically constrained Φ-photoproduction data are shown in figs. 2b and 2c, for $(d\sigma/dt)_{t=0}$ and B, respectively. The shaded area in fig. 2c encloses values of the slope of the Pomeron contribution in the reactions $\pi^{\pm} p \rightarrow \pi^{\pm} p$, $K^{+}p \rightarrow K^{+}p$, and $\gamma p \rightarrow \rho^{o} p$ as extracted by DAM analyses[2,3,4]. The DAM-based conclusion of Pomeron shrinkage in elastic meson-nucleon scattering appears to be supported by the overconstrained Φ-photoproduction data presented in fig. 2c.

The problem of interpretation outlined above calls for high-precision measurements of $d\sigma/dt$ over an extended t-range for various energies. This is one of the goals to be undertaken in the future with an enlarged version of the present apparatus.

With our new value for the forward differential cross section the quark model prediction for $\sigma_T(\Phi p)$ such as:

$$\sigma_T^Q(\Phi p) = 2\,(\sigma_T(K^+p) - \sigma_T(\pi^+p) + \sigma_T(\pi^-p)) \qquad (3)$$

can be compared with the Φp total cross section obtained from the VDM relation

$$\frac{d\sigma}{dt}\,(\gamma p \rightarrow \Phi p)\bigg|_{t=0} = \frac{\alpha}{64\pi}\,\frac{(1+\eta_\Phi^2)}{\gamma^2{}_\Phi/4\pi}\;\sigma_T^2(\Phi p) \qquad (4)$$

where
σ_T = total Φ-p cross section
α = fine structure constant
$\gamma^2{}_\Phi/4\pi$ = γ-Φ coupling constant
η_Φ = Re f / Im f, with
f = spin averaged forward Φp scattering amplitude

For the γ-Φ coupling constant a weighted average of the storage ring measurements was used: $\gamma^2{}_\Phi / 4\pi = 2.82 \pm .17$. Since for η_Φ no precise experimental value is available[12] several choices for η_Φ have been examined (see table 2).

The quark model prediction gives average values for $\sigma_T^Q(\phi p)$ of 13 mb, constituting a significant discrepancy from the VDM predictions, which render values around 8 mb.

An alternative way of expressing this discrepancy is to compare $\gamma_\phi^2/4\pi\big|_{SR}$ obtained from the storage ring with the value deduced from eq. (4) using the quark model σ_T^Q (table 2). Similar differences in the coupling constants as measured with photoproduction and colliding beams have been noticed also for the other vector mesons.

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REFERENCES

1.) P.G.O. Freund, Nuovo Cimento 48A (1967) 541; H. Joos, Phys.Letters 24B (1967) 103; K. Kajantie and J.S. Trefil, Phys.Letters 24B (1967) 106 and V. Barger and D. Cline, Phys.Rev. Letters 24, (1970) 1313.

2.) M. Davier, Phys. Letters 40B (1972) 369. For criticism of this analysis see G. Höhler and H.P. Jacob, Z.Phys. 268 (1974) 75.

3.) G. Chadwick et al., Phys. Rev. D8 (1973) 1607.

4.) T. Lasinski et al., Nucl. Phys. 37B (1972) 1.

5.) H. Harari, Annals of Physics 63 (1971) 432.

6.) H.J. Besch, Nucl. Phys. B70 (1974) 257.

7.) R.L. Anderson et al., Phys.Rev. Letters 30 (1973) 149.

8.) It should also be noted that the SLAC missing mass experiments (Ref. 7,9) can also be fitted with B~ 4, see D.L. Kreinick, Phd. thesis, Cal.Inst. of Tech. (1969) (unpublished).

9.) R.L. Anderson et al., Phys. Rev. D1 (1970) 27.

10.) ABBHHM collaboration, Phys. Rev. 175 (1968) 1669, H. Alvensleben et al., Phys. Rev.Letters 28 (1972) 66, C. Berger et al., Phys. Letters 39B (1972) 659 and J. Ballam et al., Phys. Rev. D7 (1973) 3150.

11.) J.C. Bizot et al., Phys.Letters 32B (1970) 416 and V.E. Balakin et al., Phys. Letters 34B (1971) 328.

12.) H. Alvensleben et al., Phys. Rev. Letters 27 (1971) 444.

13.) H.J. Lipkin, Phys. Rev. Letters 16 (1966) 1015, H. Joos (see ref. 1) and K. Kajante and J.S. Trefil (see ref. 1).

FIGURE CAPTIONS

1 a Experimental Setup.

b Events with the final state $(K^+ + K^- + X)$, not weighted for acceptance, distributed simultaneously in $M_{K^+K^-}$ (10 MeV bins) and M_X (50 MeV bins).

2 a Results on $\frac{d\sigma}{dt}$ for this experiment, together with small-t results from other experiments. Solid line is best fit to the present data, broken line fits data of Reference (5) out to higher values of t.

b,c Results on $\left.\frac{d\sigma}{dt}\right|_{t=0}$ and B from fitting all data of this experiment to the form $\frac{d\sigma}{dt} = \left.\frac{d\sigma}{dt}\right|_{t=0} e^{Bt}$, together with corresponding results from other selected ($\geq$1C) experiments (at generally larger values of t).

Shaded area represents the slope of (model-dependent) Pomeron contributions in elastic meson-nucleon scattering (References 3) and 4)).

TABLE CAPTIONS

1. Results for $\left.\frac{d\sigma}{dt}\right|_{t=0}$ and B for 4 energy bins from a fit to eq. 2. Only statistical errors are included.

2. First row: σ_T unfolded from the VDM relation (eq.4) for several values of η_ϕ, compared with the quark model prediction σ_T^Q (eq.3).

Second row: $\gamma_\phi^2/4\pi$ from eq. 4 with $\sigma_T = \sigma_T^Q = 13$ mb for several values of η_ϕ, compared with averaged storage ring result $\gamma_\phi^2/4\pi|_{SR}$.

Table 1:

E_γ (GeV)	$\frac{d\sigma}{dt}\big\|_{t=0}$ $\mu b/(GeV/c)^2$	B $(GeV/c)^{-2}$
4.6 - 5.1	2.43 ± 0.19	5.97 ± 0.90
5.1 - 5.6	2.39 ± 0.17	5.04 ± 0.70
5.6 - 6.1	2.51 ± 0.16	5.48 ± 0.55
6.1 - 6.7	2.47 ± 0.16	5.61 ± 0.52

Table 2:

$\|n_\phi\|$ =	0.0	0.3	0.5	
σ_T (mb) (eq. 4)	8.7 ± 0.5	8.3 ± 0.5	7.7 ± 0.5	σ_T^Q = 13.0 ± 1.5
$\gamma_\phi^2 / 4\pi$ (eq. 4)	6.4 ± 1.6	7.0 ± 1.8	8.0 ± 2.0	$\frac{\gamma_\phi^2}{4\pi}\Big\|_{SR}$ = 2.82 ± 0.17

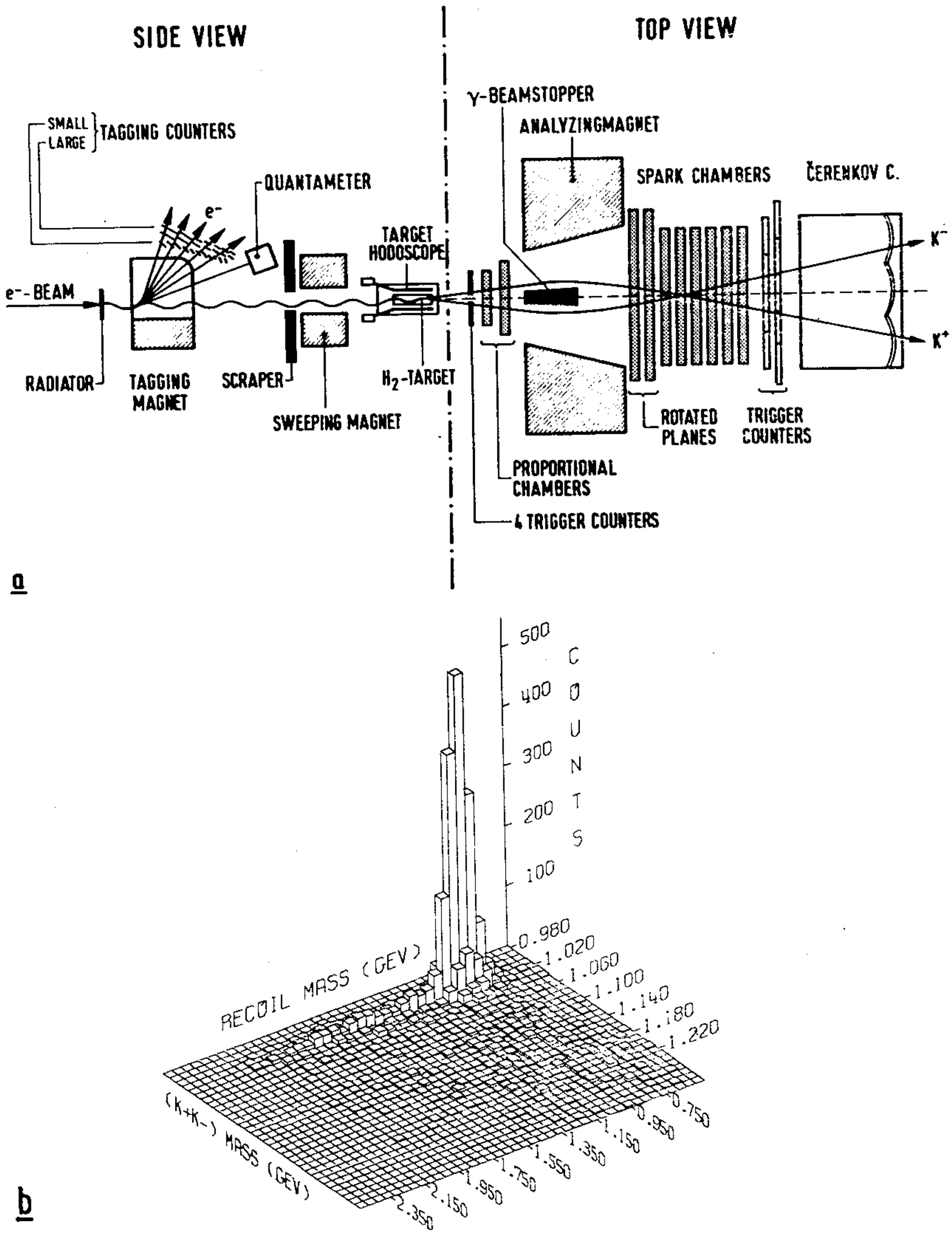
SIDE VIEW
TOP VIEW
SMALL
LARGE
TAGGING COUNTERS
QUANTAMETER
e⁻
e⁻- BEAM
RADIATOR
TAGGING MAGNET
SCRAPER
SWEEPING MAGNET
TARGET HODOSCOPE
H2-TARGET
γ-BEAMSTOPPER
ANALYZINGMAGNET
SPARK CHAMBERS
ČERENKOV C.
K⁻
K⁺
ROTATED PLANES
TRIGGER COUNTERS
PROPORTIONAL CHAMBERS
4 TRIGGER COUNTERS
a
COUNTS
500
400
300
200
100
RECOIL MASS (GEV)
0.980
1.020
1.060
1.100
1.140
1.180
1.220
(K+K-) MASS (GEV)
0.750
0.950
1.150
1.350
1.550
1.750
1.950
2.150
2.350
b

Fig. 1

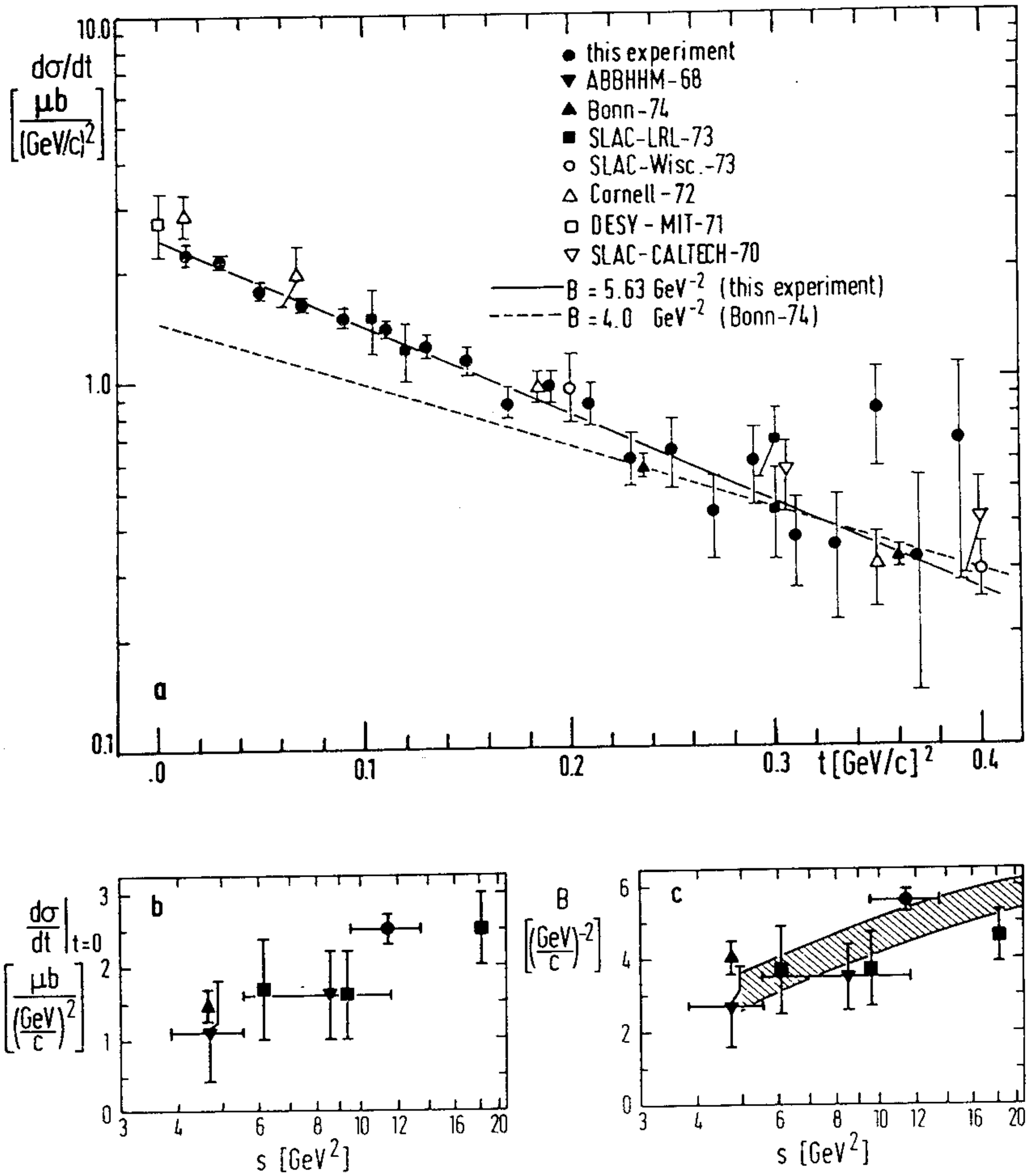
dσ/dt [μb/(GeV/c)^2]
10.0
1.0
0.1
● this experiment
▼ ABBHHM-68
▲ Bonn-74
■ SLAC-LRL-73
○ SLAC-Wisc.-73
△ Cornell-72
□ DESY-MIT-71
▽ SLAC-CALTECH-70
B = 5.63 GeV^-2 (this experiment)
B = 4.0 GeV^-2 (Bonn-74)
a
.0
0.1
0.2
0.3
t [GeV/c]^2
0.4
dσ/dt|t=0 [μb/(GeV/c)^2]
b
0
1
2
3
3
4
6
8
10
12
16
20
s [GeV^2]
B [(GeV/c)^-2]
c
0
2
4
6
3
4
6
8
10
12
16
20
s [GeV^2]

Fig. 2