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BY

D. BERG, C. CHANDLEE, S. CIHANGIR, T. FERBEL, J. HUSTON, T. JENSEN,
F. LOBKOWICZ, C. A. NELSON JR., T. OHSHIMA, P. SLATTERY, P. THOMPSON
UNIVERSITY OF ROCHESTER

AND

J. BIEL, T. DROEGE, A. JONCKHEERE, P. F. KOEHLER
FERMI NATIONAL ACCELERATOR LABORATORY

AND

S. HEPPELMANN, T. JOYCE, Y. MAKDISI, M. MARSHAK, E. PETERSON,
K. RUDDICK, T. WALSH
UNIVERSITY OF MINNESOTA

THE UNIVERSITY OF ROCHESTER

DEPARTMENT OF PHYSICS AND ASTRONOMY

ROCHESTER , NEW YORK

Radiative Decay of the $K^{*-}(890)$ [†]

D. Berg, C. Chandlee, S. Cihangir, T. Ferbel, J. Huston, T. Jensen,
F. Lobkowicz, C. A. Nelson Jr.[#], T. Ohshima[##], P. Slattery, P. Thompson
University of Rochester, Rochester, N.Y. 14627

J. Biel, T. Droege, A. Jonckheere, P. F. Koehler
Fermi National Accelerator Laboratory
Batavia, IL. 60510

S. Heppelmann, T. Joyce, Y. Makdisi[††], M. Marshak, E. Peterson
K. Ruddick, T. Walsh
University of Minnesota, Minneapolis, MN. 55455

Abstract:

We report a measurement of the radiative decay of the $K^{*-}(890)$. The width for the transition $K^{*-} \rightarrow K^{-}\gamma$ is 62± 14 KeV. The resulting ratio of decay probabilities $(K^{*0} \rightarrow K^{0}\gamma)/(K^{*-} \rightarrow K^{-}\gamma)$, while consistent with predictions of certain quark models, does not agree with expectations from unbroken SU(3) symmetry.

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[#] Presently at Fermi National Accelerator Laboratory, Batavia, IL. 60510

[##] Presently at The Institute for Nuclear Studies, University of Tokyo Tanashi-City, Tokyo 188, Japan.

[††] Presently at Brookhaven National Laboratory, Upton, N.Y. 11973

Radiative decay transitions between meson states provide some of the most straight-forward tests of SU(3) and of the quark model. Predictions for $K^{*\pm}(890) \rightarrow K^{\pm}\gamma$, $\rho \rightarrow \pi\gamma$ and $K^{*0}(890) \rightarrow K^{0}\gamma$ decays are independent of assumptions concerning mixing between the singlet and octet members of the vector and pseudoscalar meson nonets. In addition, the small mass differences between K^{*0} and $K^{*\pm}$, and between K^0 and $K^{\pm}$, make the ratio of the radiative widths $\Gamma(K^{*0} \rightarrow K^0\gamma)/\Gamma(K^{*\pm} \rightarrow K^{\pm}\gamma)$ essentially independent of any phase-space factors. In the simple quark model, this ratio can be expressed, using quark magnetic moments μ_q, as $\Gamma(K^{*0} \rightarrow K^0\gamma)/\Gamma(K^{*\pm} \rightarrow K^{\pm}\gamma) = [(\mu_d + \mu_s)/(\mu_u + \mu_s)]^2$. The SU(6) additive quark model [1], using effective quark magnetic moments deduced from measurements of baryon magnetic moments [2], predicts 1.64 for the above ratio. In the unbroken SU(3) limit, the ratio equals 4.0.

We report the first clear evidence for the process $K^{*-} \rightarrow K^-\gamma$, obtained through a measurement of the inverse reaction $K^-\gamma \rightarrow K^{*-}$ via the Primakoff effect [3]. Data were taken using 156 GeV/c negatively-charged kaons in the M-1 line of the Fermi National Accelerator Laboratory. These data were obtained simultaneously with those used to extract a new value for the radiative width of the ρ^- [4]. The specific reactions we studied were:

$$K^- + A \rightarrow K^-\pi^0 + A \qquad (1)$$

$$K^- + A \rightarrow \underset{\hookrightarrow\, \pi^+\pi^-}{K^0_S}\pi^- + A \qquad (2)$$

At these energies, Coulomb production of $K\pi$ systems tends to dominate coherent strong production on nuclear targets (A). The beam energy of our experiment provides the essential advantage of our measurement over a previous upper limit obtained for $\Gamma(K^{*+} \rightarrow K^{+}\gamma)$, at 10-16 GeV/c [5].

Charged particles in Reactions (1) and (2) were detected and momentum-analyzed using multiwire proportional chambers, drift chambers and an analyzing magnet. Photons from π^{0} decays were measured using a Liquid Argon Calorimeter (LAC). Experimental details can be found elsewhere [4].

For Reaction (1) we required that an acceptable trigger have one charged particle downstream of the target and a LAC signal corresponding to a deposition of more than 10 GeV of energy. For Reaction (2) we required that only one charged particle emerge from the target and that two additional charged particles appear within an evacuated 6m decay tank located immediately downstream of the target.

The requirements set in the off-line analysis for selecting data for Reaction (1) were as follows: 1) The incident particle registered as a K^{-} in a beam Cerenkov counter; 2) Only one charged particle emerged from the target regions; 3) Only 2 photons reconstructed in the LAC and the reconstructed $\gamma\gamma$ mass was consistent with that of a π^{0}; 4) The total energy in the final state was consistent with the mean energy of the beam.

The dominant background to Reaction (1) came from $K^{-} \rightarrow \pi^{-}\pi^{0}$ events in which, due to a lack of particle identification downstream of the target, the π^{-} was assigned a K^{-} mass. To minimize this source of background, events that satisfied the above four criteria, but had a reconstructed $\pi^{-}\pi^{0}$ mass below 550 MeV were removed from consideration for Reaction (1). This procedure reduced substantially the background from $K^{-} \rightarrow \pi^{-}\pi^{0}$ decays and yielded only a 20% loss of true $K^{*-} \rightarrow K^{-}\pi^{0}$ events.

Reaction (2) was comparatively background free. To define this sample, it was required that the two oppositely charged particles (V) of the K_s^0 decay originate in an acceptable region of the decay tank. The imposition of this cut reduced the K^{*-} signal by about 25%. The additional requirements that the $\pi^+\pi^-$ mass of the V be consistent with the mass of the K_s^0, and that criteria 1), 2) and 4) used for Reaction (1) also be satisfied, did not affect the size of the data sample.

To minimize reliance of our measurements on the determination of absolute efficiency of the apparatus, we normalized the cross section for Reaction (1) to the yield of $K^- \rightarrow \pi^-\pi^0$ decays within the vacuum tank. These decays, which are topologically very similar to $K^{*-} \rightarrow K^-\pi^0$ events, were collected concurrently with data for Reaction (1). The $K^- \rightarrow \pi^-\pi^0$ decays were also used to check our understanding of the resolution of the apparatus.[4] The absolute normalization of the data for Reaction (2) is uncertain to $\pm 13\%$.

Mass spectra for $K^-\pi^0$ and $K_s^0\pi^-$ events produced at $t < 0.01$ GeV^2 , combining all nuclear targets, are displayed in Figure 1(a). The events contained in Fig. 1(a) are distributed according to targets as follows: carbon, aluminum, copper and lead contribute, respectively, 2, 3, 4, and 18 events for Reaction (1), and 3, 0, 7 and 14 events for Reaction (2). The curves above the data indicate the total acceptance (including all cuts) as a function of mass, assuming a $\sin^2\theta$ decay of the $(K\pi)$ systems in the Gottfried Jackson frame, a form expected for the coherent production of vector mesons. The rapid drop in the acceptance at low $K^-\pi^0$ mass is mainly due to the 550 MeV cut criterion imposed on the $\pi^-\pi^0$ mass interpretation. Curves on the data indicate the shapes of the mass distributions expected for Coulomb-produced K^{*-}, with relativistic Breit-Wigner line shapes of width $\Gamma(K^{*-})$=50 MeV, and mass $m_{K^{*-}}$ = 892 MeV [6], modified to take account of acceptance and resolution broadening. Although the statistics are poor, clear peaks are nevertheless evident at the K^{*-}(890) mass. The polar decay angle distributions (θ) of the K^{*-} events in the Gottfried-Jackson frame are consistent with the expected $\sin^2\theta$ decay form for a p-wave $K\pi$ final state. This is displayed in Fig. 1b for data at $t < 0.01$ GeV^2. Figure 2 displays the t-distributions for K^{*-} production on a Pb target, corrected for acceptance and branching ratios. The distributions for the two reactions are in agreement, and both show peaks at the small t-values characteristic of electromagnetic production.

Because of poor statistics, we chose not to compare K^{*-} t-distributions for individual nuclear targets with predictions of production models. Instead, for each element (i) we defined integrated cross sections (σ_i), for both K^{*-} decay modes, for the mass range between 790 MeV and 990 MeV, integrated up to $t = 0.002$ GeV^2. To determine a radiative decay width from these cross sections, we used the dependences of Coulomb and strong K^{*-} production on beam momentum and nucleus (Z,A). The formulation is based on an optical-model approximation for the nucleus, and can be found in the literature [4,5,6].

To extract the radiative width (Γ_γ) of the K^{*-}, a maximum likelihood fit was performed to all values of σ_i. The goodness of fit and the statistical errors on Γ_γ were established through standard procedures employed in low-statistics measurements. Namely, using the likelihood estimator for Γ_γ, and the luminosity per target, many sets of σ_i^* were generated (via Monte Carlo) from a Poisson distribution. Each set of the σ_i^* was then fitted to extract a value of Γ_γ^*. The standard deviation of the distribution of all the Γ_γ^* was taken as the statistical error on Γ_γ.

The strong-production normalization constant C_s, scaled from lower energies [5,7], and the relative phase ϕ between the Coulomb and the strong amplitude were varied in these fits. In particular, C_s was varied about the expected value of 0.58 mb/GeV^4, from 0.48 mb/GeV^4 to 0.68 mb/GeV^4, without observing an appreciable difference in $\Gamma_\gamma(K^* \to K\gamma)$ or a deterioration in the χ^2. The reason for the insensitivity of Γ_γ (and the fit χ^2) to C_s is that the strong production cross section for $t < 0.002$ GeV^2 is small. The contribution from the interference between strong and Coulomb amplitudes in Pb, for example, where we have best statistics, is $\lesssim 5\%$ of the pure Coulomb term. Our data are also insensitive to ϕ. In our fits Γ_γ changed by only ±5 KeV for any choice of ϕ. The correlation between Γ_γ, C_s and ϕ is very weak for small t, and so we obtain an unique solution for Γ_γ, in spite of the large statistical errors in the data. The maximum value of t used in the integration of the data was varied up to 0.005 GeV^2, and the results for Γ_γ were found to be consistent to within 7 KeV. We performed fits separately and simultaneously to data for the two different K^{*-} decay modes and always obtained acceptable and self-consistent results.

We conclude that $\Gamma(K^{*-} \to K^-\gamma)$ is 62 ± 14 KeV, including statistical and systematic uncertainties (all added in quadrature). The uncertainty is dominated by statistics (±11 KeV), but is also influenced, to a lesser extent, by contributions from uncertainty in the absolute normalization, the values of C_s and ϕ, the target-empty subtraction and the resolution in t.

This experiment is the first to report a measurement for the radiative width of $K^{*-} \to K^-\gamma$. While this measurement is in reasonable agreement with predictions of various quark models [1,8], the ratio of the only previous measurement of the radiative width of K^{*0} [9]

to our measurement of the width of the K^{*-} is 1.2 ± 0.6, which disagrees with unbroken SU(3) symmetry, but is consistent with quark models in which quarks with different flavor are assigned different magnetic moments.

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Figure Captions

1. Mass spectra for $K\pi$ systems produced on nuclear targets for $t < 0.01$ GeV^2 are displayed in (a). The calculated acceptances as a function of mass (with scales shown at upper right of each graph) are drawn above the data. The shapes of the mass spectra expected for Coulomb-produced $K^*(890)^-$ are indicated on the data. The polar decay angles of the pion in the Gottfried-Jackson frame of the $K^*(890)^-$ are shown in (b), along with the acceptance-corrected shapes expected for electromagnetically produced $K^*(890)^-$. The data are for all nuclear targets and $t < 0.01$ GeV^2.

2. Cross section for $K^*(890)^-$ production on a lead target. The yields for the two decay channels have been corrected for acceptance, all cuts, and branching ratios.

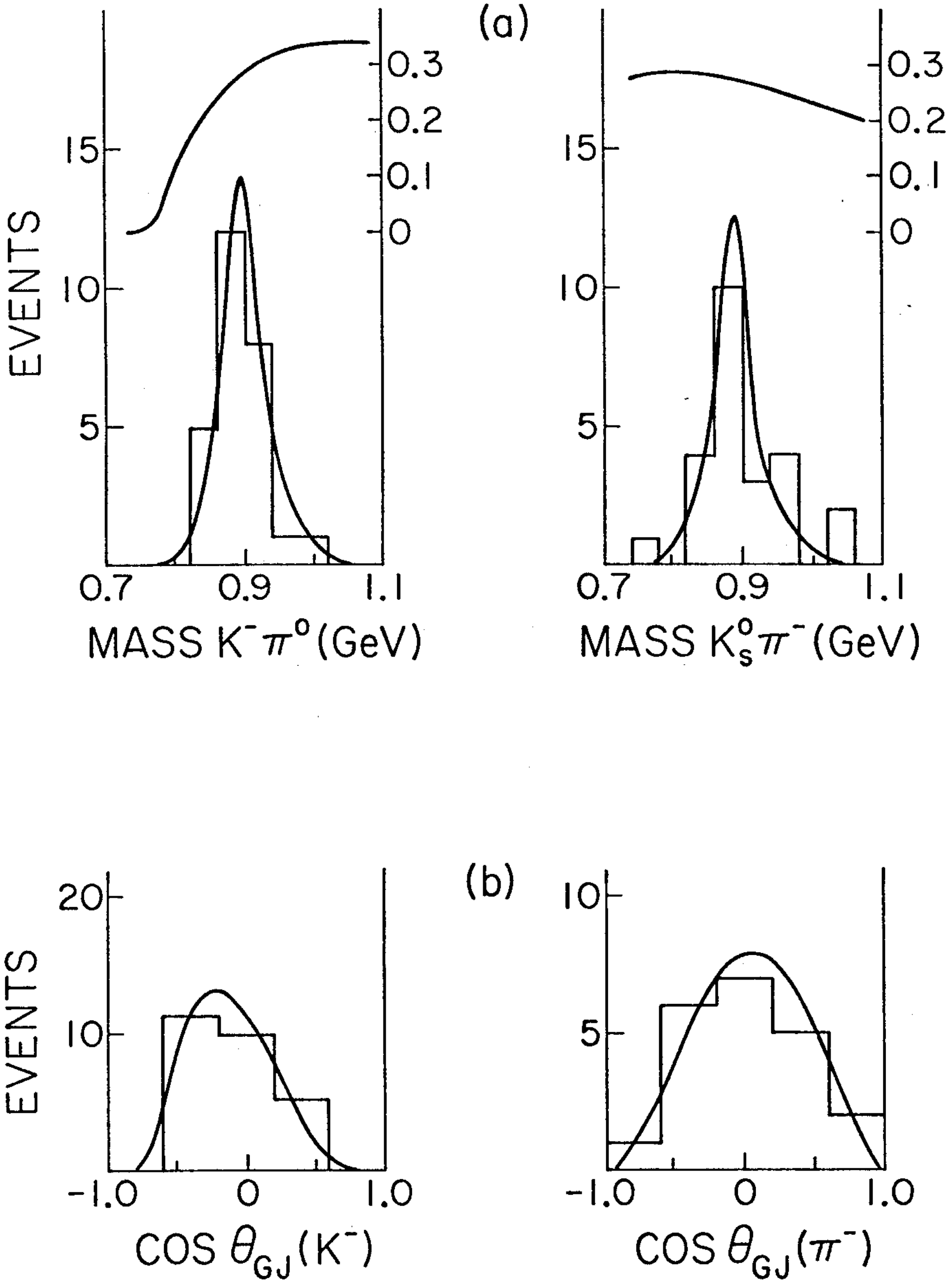
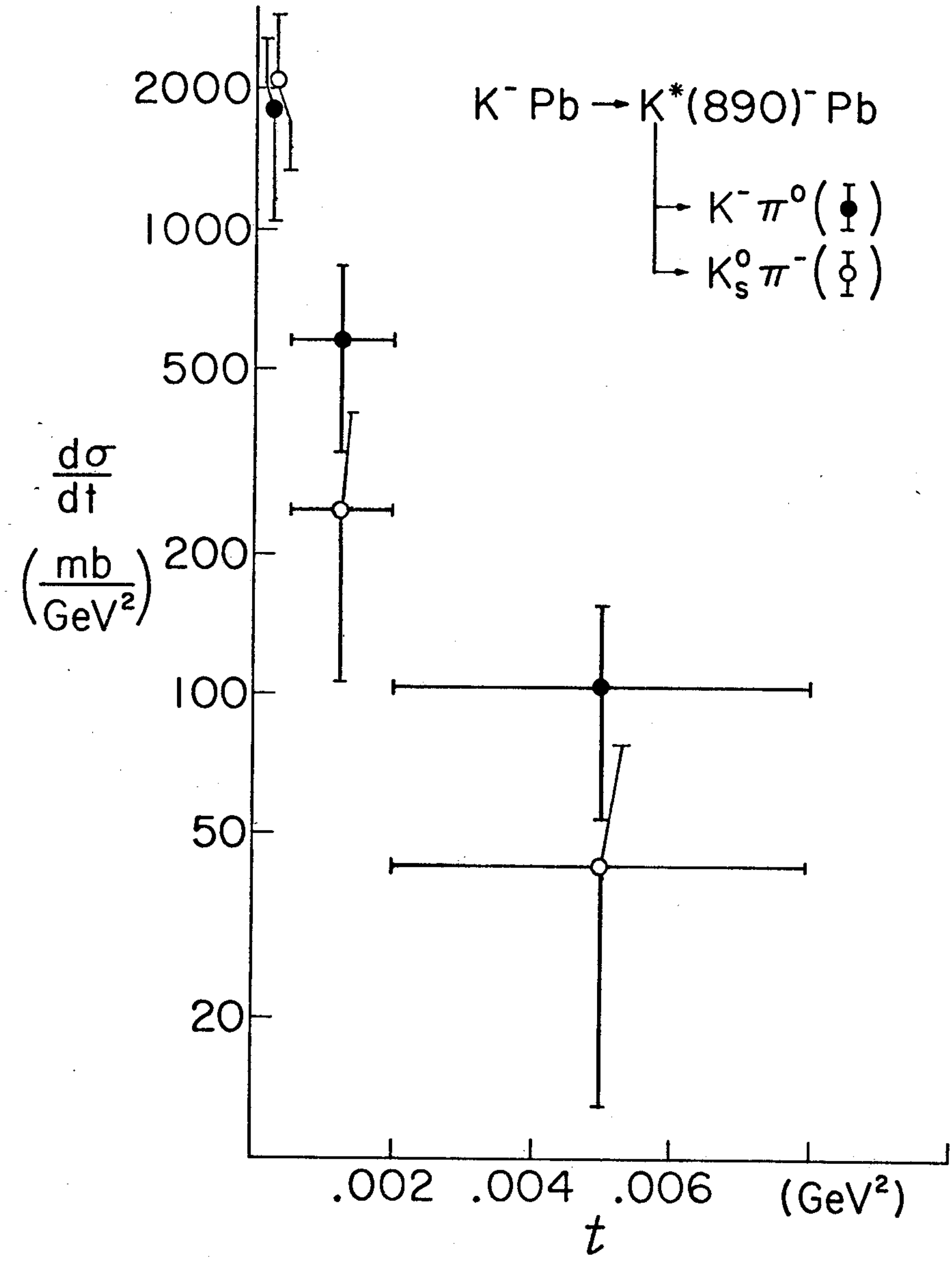

(a)
EVENTS
15
10
5
0.3
0.2
0.1
0
0.7
0.9
1.1
MASS K⁻π⁰ (GeV)
MASS K⁰ₛπ⁻ (GeV)
(b)
20
10
5
-1.0
0
1.0
COS θGJ (K⁻)
COS θGJ (π⁻)

Fig 1



K⁻ Pb → K*(890)⁻ Pb
K⁻π⁰ (●)
K_s^0 π⁻ (○)
dσ/dt
(mb/GeV²)
2000
1000
500
200
100
50
20
.002
.004
.006
(GeV²)
t

Fig.

Department of Physics & Astronomy
UNIVERSITY OF ROCHESTER
Rochester, New York, 14627, USA

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