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SIGMA PHOTOPRODUCTION AND DETERMINATION OF THE Σ^+ MAGNETIC MOMENT*†

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This communication is a report on the current progress in the study of Σ^+ photoproduction near threshold and it includes the first Σ^+ magnetic-moment data.[1] The in-flight decays of the hyperons are observed in nuclear emulsion exposed at the California Institute of Technology electron synchrotron. Details of earlier measurements may be found in the literature.[2-5] A study of the in-flight proton-decay mode of the sigma gives a measurement of the cross section and the mean polarization ($\alpha\bar{P}$) for the reaction

$$\gamma + p \to K^0 + \Sigma^+. \qquad (1)$$

A strong axial pulsed magnetic field focuses the shower electrons along the photon-beam axis. This field reduces the background over an order of magnitude and precesses the sigma spin axis.

The K-5 emulsion stacks and the 4.83 g/cm^2 CH_2 target (4×50 mm) were located in a 125-kilogauss pulsed solenoid. The magnet, target, and bremsstrahlung beam were centered on the same line. The beam was collimated to a 1.5-mm radius circular image at the target. The 1280-MeV bremsstrahlung beam was hardened by two radiation lengths of LiH, and had a total exposure energy of 1.68×10^{12} MeV. The stack was exposed parallel to the beam axis with the lower stack surface 2.0 mm from the beam center.

The emulsions were area scanned for in-flight decays with faster secondaries. The charged decay product was required to have at least a 10%->15% lighter ionization than the primary. When the incoming sigma track was darker than 3× plateau a minimum grain difference of 15% was required. The minimum grain count of the proton mode decay was 500 grains/track; the average grain count was over 1000. A minimum angle of 10° between the projected primary and the secondary track was required for a sigma whose kinetic energy was less than 200 MeV (2.3× or darker for primary track). The faster primaries required a minimum difference of 5°. These scan criteria exclude 60% of the $\Sigma^+ \to p + \pi^0$ decays, but insure that the 40% which are accepted cannot be confused with elastic or inelastic proton scatters. There was an average of approximately 40 scatters per sigma event. A very limited rescan indicated a reasonable detection efficiency (100% for three sigma events).

The earlier data[5] suggested that Reaction (1) could possibly be polarized; therefore the microscope orientation of the present plates was reversed in the middle of scanning to eliminate possible bias.

The kinematics of sigma photoproduction were calculated for hydrogen and are shown in Fig. 1

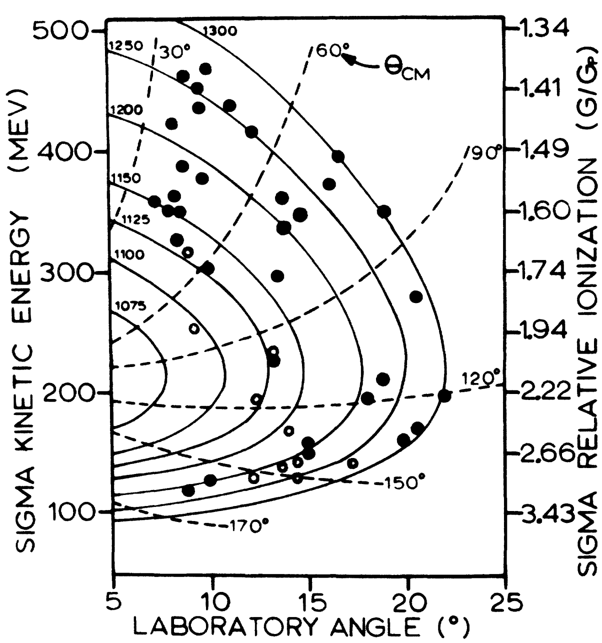

FIG. 1. Sigma photoproduction kinematic curves are shown for hydrogen. The sigma events are plotted on the basis of laboratory angle (degrees) and ionization. The production angle for a sigma in the c.m. system is given by $\theta_{\text{c.m.}}$. The present data are shown by closed circles while the earlier events of Roos and Peterson[5] are indicated by open circles.

together with the production angle and ionization of the observed sigmas which satisfy hydrogen-production kinematics. In spite of the nuclear motion, it is interesting to observe that half the events are found in the region corresponding to sigma c.m. angles between 30° and 60° and one fourth between 120° and 150°.

A total of 46 sigma decays has been observed so far, of which 34 were Σ^+-p decays and 12 were $\Sigma^\pm$-n decays. This includes the 11 events reported[4,5] earlier (6 Σ^+-p decays). A total of 28 Σ^+-p decays satisfying the above criteria was found in the present exposure, 24 of which were consistent with the hydrogen photoproduction kinematics for 1280-MeV bremsstrahlung. The magnetic moment and polarization measurements are based on these 24 "hydrogenlike" events. These same events yield a lower limit for the (mean) photoproduction cross section for Reaction (1) of $(6.0 \pm 1.5)\times10^{-31}$ cm²/sr for a mean photon energy of 1175 MeV averaged over sigma c.m. angles between 30° and 170°, where all target protons are considered hydrogen equivalents.

In comparison to the above cross section, the total cross sections[6] for the photoreactions which produce K^+ mesons have typical values around one microbarn at photon energies of 1150 MeV. The theoretical computations of the photokaon cross sections have utilized perturbation theory with various resonances.[7,8] The most recent, Fayyazuddin,[8] indicates that, at 1150 MeV, both Reaction (1) and

$$\gamma + n \rightarrow \Sigma^- + K^+ \qquad (2)$$

could possibly have an order-of-magnitude higher total cross section than the $K^+ + \Lambda^0$ and $K^+ + \Sigma^0$ photoreactions as well as high cross sections for backward kaon c.m. angles. The preliminary studies[9] of Reaction (2) indicate, however, a mean cross section of $(0.9 \pm 0.4)\times10^{-31}$ cm²/sr at 79° c.m. kaon angle.

In the process of analysis of the data for the magnetic moment the most probable value of $\alpha\bar{P}$ is automatically determined. The data are basically analyzed by the method used by Kernan et al.,[10] except in that experiment P_Λ and H were in the same direction while in this experiment the photon beam and H were aligned.

The 7072/1401 at Vanderbilt was programmed to transform to the c.m. system, to rotate the production plane using each event's magnetic path, to fit the distribution to $(1 + \alpha\bar{P}\cos\theta)$, where θ is the angle between the spin axis and the proton's momentum, and to obtain the most probable values of $\alpha\bar{P}$ and $\mu(\Sigma^+)$ from the double-likelihood fit.

The new data were obtained from a stack exposed with near optimum geometry. The 24 sigmas had a total magnetic path length (Bl) of 18 MG-cm. The error in a determination of the magnetic moment is proportional to $(BlN^{1/2})^{-1}$ where N is the number of events.[10] The mean rotation per event was 50°.

The single-parameter maximum-likelihood fits ($\alpha\bar{P}$ held fixed) for the sigma gyromagnetic ratio are given in Fig. 2.

The parameters for the best fit obtained with the double-likelihood function are $\alpha\bar{P} = 0.95 \pm 0.3$ and $\mu(\Sigma^+) = 4.3 \pm 0.6$ nuclear Bohr magnetons. The term correlating the errors of $\alpha\bar{P}$ and $\mu(\Sigma^+)$ was negligible with these values. This error in $\mu(\Sigma^+)$ does not include the uncertainty in magnetic path length and momentum of the sigma; with these the Σ^+ magnetic moment is $\mu(\Sigma^+) = 4.3 \pm 0.9$ nuclear Bohr magnetons if $\alpha\bar{P} = 0.95$. The value of α for $\Sigma^+ \rightarrow p + \pi^0$ decay has been independently measured to be 0.78 ± 0.08.[11] If the assumption is made that $\alpha\bar{P}$ is 0.8 then the magnetic moment of the Σ^+ is 4.3 ± 1.5 nuclear Bohr magnetons. The percentage error of the sigma moment is smaller than those presently deter-

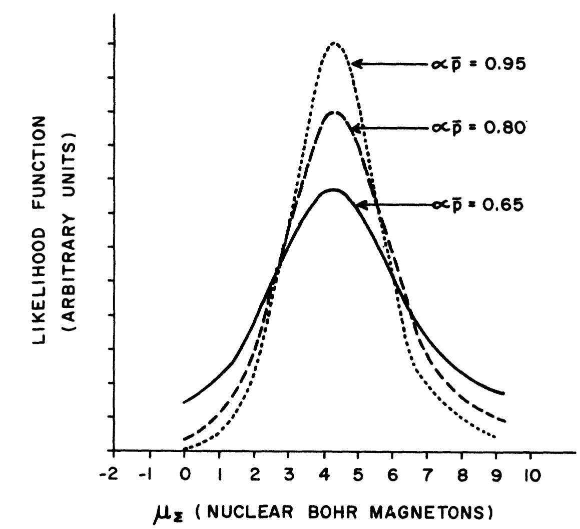

FIG. 2. The single maximum-likelihood fits with fixed $\alpha\bar{P}$ for the distribution $(1 + \alpha\bar{P}\cos\theta)$. The dotted curve, $\alpha\bar{P} = 0.95$, represents the most probable fit to the data for a double-parameter likelihood function, $\alpha\bar{P}$ and $\mu(\Sigma^+)$. The dashed curve, $\alpha\bar{P} = 0.80$, is the best possible fit to the data, if α is ~0.80. The solid curve, $\alpha\bar{P} = 0.65$, is obtained using the lower statistical limit for $\alpha\bar{P}$. The most probable value of $\mu(\Sigma^+)$ is almost independent of $\alpha\bar{P}$ but the error increases as $\alpha\bar{P}$ decreases.

mined[10,12,13] for the Λ^0 (even if $\alpha\bar{P} = 0.65$). The results of SU(3) predict[14] that $\mu(\Sigma^+) = \mu_p$; the 20% mass difference between the sigma and the proton is ignored.

In summary, the anomalous moment of the Σ^+ has the same sign as the charge moment and is comparable in magnitude to the nucleon moments. In addition, the following properties for Reaction (1), near threshold, have been observed: (1) The total cross section is large compared to the presently measured values of the K^+ photoreactions, (2) the reaction has significant polarization, and (3) its angular distribution is anisotropic.

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