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A. TITLE: Study of Kaon Photoproduction on Deuterium

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C. THIS PROPOSAL IS BASED ON A PREVIOUSLY SUBMITTED LETTER OF INTENT

/X/ YES
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Study of the P toproduction and the Decay of Hypernuclei

D. ATTACH A SEPARATE PAGE LISTING ALL COLLABORATION MEMBERS AND THEIR INSTITUTIONS

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Proposal Received 10-31-89

Log Number Assigned PR-89-045

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Proposal

STUDY OF KAON PHOTOPRODUCTION ON DEUTERIUM

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ABSTRACT

We propose to investigate the photoproduction of Λ- and Σ-hyperons on deuterium. Kaons will be produced by tagged photons via the $\gamma N \to KY$ reaction and detected in the CEBAF Large Acceptance Spectrometer (CLAS). The mass of the hyperon-nucleon system will be determined by combining the energy of the incident photon and the outgoing kaon. Coincident hadrons from the decay of the hyperon-nucleon system can also be observed in the CLAS.

A. Introduction

High duty-cycle electron accelerators in the GeV range will make it possible to study the photo- and electro-production of hyperons both in elementary and nuclear processes. In the nuclear system, the hyperon can be viewed as a controlled impurity which, in contrast to nucleons, is not restricted by the Pauli principle (except maybe at the quark level /DON84/). It also lives long enough to sample its hadronic environment. Therefore, it can probe the deep interior of the nucleus.

To interpret the hypernuclear data, the elementary production amplitudes have to be known. The first step is a measurement of the production cross section for $K^+\Lambda$ and $K^+\Sigma^0$ off the proton combined with a measurement of the hyperon polarization. The next logical step - which is the subject of this proposal - is the investigation of these reactions in the two-nucleon system. Ultimately, one would like to study the properties of nuclear systems that contain a bound hyperon.

B. Physics Motivation

Kaon production cross sections on deuterium are governed by three main ingredients:

1. The amplitudes for the elementary $\gamma N \to KY$ reaction ($Y \equiv \Lambda$ or Σ). Figure 1 shows the Feynman diagrams that have been used in the theoretical description of this process /ADE89/.

2. The deuteron wave function. Depending on the kinematic situation, high momentum components will be involved.

3. The interaction between the final-state hadrons. Electromagnetic production offers the advantage that the interaction of the incident photon is small. Since the outgoing kaon also has a small interaction probability, deviations from the quasifree process can be directly attributed to the interaction of the final state YN system.

Figure 2 shows schematically the contributions to K^+ production on deuterium. The importance of these contributions can be enhanced or de-emphasized by the choice of kinematic conditions. The following questions can be investigated:

1. In quasifree kinematics, the differential cross section for the elementary reaction $\gamma+n\rightarrow K^++\Sigma^-$ can be determined from a measurement of the K^+-π^--neutron final state.

2. Λn and $\Sigma^\circ n$ interactions can be studied by going away from quasifree kinematics and observing Λn and $\Sigma^\circ n$ final state interactions.

3. Λ-Σ channel coupling effects are predicted to lead to a cusp effect as the threshold for Σ-production is crossed.

4. In the vicinity of the Σ-cusp, strangeness -1 dibaryons have been predicted.

The following sections will deal with these questions in more detail.

1. Elementary production amplitudes

There are six elementary kaon production reactions on the nucleon

$$\gamma\ p \rightarrow K^+\ \Lambda$$
$$\gamma\ p \rightarrow K^+\ \Sigma^\circ$$
$$\gamma\ p \rightarrow K^\circ\ \Sigma^+$$
$$\gamma\ n \rightarrow K^+\ \Sigma^-$$
$$\gamma\ n \rightarrow K^\circ\ \Lambda$$
$$\gamma\ n \rightarrow K^\circ\ \Sigma^\circ$$

Experimental information, mainly acquired in the 70's /ADE85/, exists only for the first two channels. Since the available data for these two channels are inadequate, the study of their differential cross sections and polarization parameters will be the subject of a separate proposal. Additional information that will be necessary to study the isospin dependence can be gained from the γ n $\rightarrow$ K^+ Σ^- channel. For this reaction channel, an operator has been constructed for use in Σ-hypernuclear production calculations /BEN89/.

In the case of Λ-production, the Λ-polarization can be derived from the angular asymmetry in the weak $\Lambda \rightarrow N\pi$ decay (weak decay parameter α=+0.642). This technique does not look very practical for the Σ^--decay because the decay parameter for the Σ^- is small: α=-0.068±0.008. (Note, however, that the parameter for the Σ^+ is large: α=-0.980±.016, making it an interesting candidate for polarization measurements.)

2. Final-state interactions

If the hyperon-nucleon system is produced with small relative momentum the cross section for inclusive kaon production on deuterium is strongly enhanced due to final-state interactions. Similar to hypernuclear production, small momentum transfer is reached at high photon energies and small kaon angles. The effect has been studied theoretically /REN67/, /ADE88/. An example for the predictions is shown in Figure 3. Close to the production threshold, the full calculation including Λn interaction (solid line) yields a cross section that is enhanced by more than an order of magnitude over quasifree production (dotted line).

3. Λ-Σ channel coupling

An interference structure due to the $\Lambda N \rightarrow \Sigma N$ process has been observed experimentally in $K^- d \rightarrow \pi^- \Lambda n$ reaction /TAN69/. The same phenomenon has been predicted /COT87,COT89/ to occur in Λ-photoproduction as the Σ threshold is crossed (see Figure 4). In photoproduction, the analysis of this structure can be used to determine the relative phase between the Λ and Σ production amplitudes.

4. Strangeness -1 dibaryons

Strange dibaryons are generally predicted to be lower in mass and more stable than their non-strange counterparts; this should make it easier to distinguish them from background. The most promising candidate is the doubly strange H particle (S=-2). Strangeness -1 dibaryons have been predicted in the vicinity of the Σ cusp. The D_o, a spin zero dibaryon, should be located 20-40 MeV below the cusp, while the D_1, a spin one dibaryon, should be 20-40 MeV above the cusp (see /LOC87/ and /DOV86/ for an overview). The D_1 has been searched for in $d(K^-,\pi^-)X$ and $d(\pi^+,K^+)X$ reactions (/PIE86/, /PIG85/) and in $pp \to K^+X$ /SIE88/. The lower mass D_o (which should also be narrower) cannot be observed in (K,π) or (π,K) reactions starting with a deuterium target because of the small spin-flip probability introduced by a pseudoscalar beam. (A BNL experiment that attempts to use the spin zero proton-proton component in ^3He /PIE88/ has just been completed.) In contrast to that, the (γ,K) reaction has a large spin-flip probability and will therefore naturally excite both spin-0 and spin-1 transitions. A measurement of the angular distribution of the final hyperon-nucleon system will be especially helpful to separate a potential dibaryon signal from less exotic effects.

C. Experimental Considerations

We propose to use the CEBAF Large Acceptance Spectrometer (CLAS) for an initial experiment to study the photoproduction of hyperons on deuterium. The main experimental emphasis will be on an accurate measurement of the outgoing kaon. The accuracy requirements for the hyperon nucleon system are considered to be less severe. In the following sections, the features of the experimental setup will be described.

1. Kinematics

A Monte Carlo calculation was used to determine the kinematic features of the quasifree processes $\gamma d \to K^+\Lambda n$ and $\gamma d \to K^+\Sigma n$. A Hulten type momentum distribution was used to describe the momentum distribution of the proton inside the deuteron. Figure 5 shows kaon momentum vs. laboratory angle for fixed photon energy of 1.4 GeV. Only for small kaon angle are the Λ and Σ bands cleanly separated. Figure 6 shows the distribution of momentum vs. angle for neutrons and π^- from the Σ^- decay. All particles are dominantly forward going.

2. CLAS configuration

Figure 7 shows the CLAS configuration that would be used for the experiment. Since, in this reaction, there is no need to detect particles in the backward hemisphere, the detection efficiency at small angles can be increased by moving the target upstream by 50 cm.

3. Tagged Photons

Real photons will be produced by bremsstrahlung of electrons. The photon energy will be tagged by observing the outgoing electron in a magnetic spectrometer. The photon energy range of interest in this experiment is k = (900-1500) MeV with the primary electron energy E_o at 1600 MeV (primary beam extracted after two turns). The expected resolution is $\Delta k \simeq 2 \cdot 10^{-3} \cdot E_o$ (FWHM). For the counting rate estimates, the rate of tagged photons has been assumed to be 10^7/sec.

4. Kaon Detection

Kaons will be detected in the LAS in the angular range $\theta_K \simeq 6°\text{-}110°$. The resulting solid angle is ≃6 sr (a fraction of the azimuth is obstructed by the coils). The kaon momentum range of interest is $p_K \simeq$ (300-1300) MeV/c. The expected momentum resolution is about $4 \cdot 10^{-3}$ (FWHM).

Particle identification will be achieved in the off-line analysis by combining time-of-flight and dE/dx information from the drift chambers. The suppression of pions and protons should be easy since kaon momenta are relatively low resulting in large time-of-flight and dE/dx differences.

The K^+ counting rate is reduced by kaon decay in the spectrometer. The probability ϵ_K for the kaon to survive (without decaying) is

$$\epsilon_K = \exp(-L/(\beta_K \cdot \gamma_K \cdot L_o))$$

where L is the flight path, L_o is the decay length of the kaon: L_o=371 cm and $\gamma_K = E_K/m_K$. Particles stemming from the kaon decay can be suppressed by trajectory overdetermination.

5. Triggering

The rate of charged particles produced by tagged photons within the CLAS acceptance is ≃ 600/sec. The total hadronic production rate in the target due to all photons is estimated to be of the order of $2 \cdot 10^4$ particles/sec, making the observation of coincident hadrons in the CLAS relatively easy.

Triggering on a single charged particle is a challenging problem when using a tagged photon beam. The CLAS level-1 trigger will be set by any single scintillation counter. In level-3, one can use the correlation between the momentum of the particle detected in the CLAS and the photon energy determined by the tagging system. In level-4, a microprocessor farm will make use of the dE/dx information from the wire chambers and the time-of-flight from the scintillation counters to enhance the kaon component in the event sample.

6. Coincident Hadron Detection

In coincidence with the kaon, hadrons from the decay of the hyperon-nucleon system will be detected in the CLAS. This will not only allow us to distinguish between Λ and Σ-production but will also determine the angular distribution of the YN system which is very sensitive to the details of the YN interaction /ADE88/,/WRI89/. An interesting example is the coincident detection of the π^- and the neutron from Σ^- decay. The neutron can be detected with a mean detection efficiency of about 50% in the shower counters; time-of-flight will be used to separate neutrons from photons. Note from Figure 6 that the shower counter coverage up to 45° is sufficient to detect all neutrons from the Σ^- decay. The detection efficiency for the $K^+\pi^-n$ final state has been determined by a Monte Carlo calculation. the dependence on the kaon c.m.s. angle is given in Figure 8 for a photon energy of 1.5 GeV. The maximum detection efficiency, reached at around 90° in the c.m.s., is about 13%, the mean value is 8%.

7. True Coincidence Rates

The true coincidence rate N_K for inclusive K^+ production has been calculated under the following assumptions:

initial e^- energy	$E_o = 1.60$ GeV
final e^- energy	$E_e = (0.1 - 0.7)$ GeV
photon energy	$k = (0.9 - 1.5)$ GeV
tagged photon rate	$N = 10^7$/sec
target thickness	$\rho \cdot d = 1.0$ g/cm^2
K^+ angular range	$\theta_K = 6° - 110°$
mean K^+ survival chance	$\epsilon_K = 0.5$
average cross section	$\sigma \simeq 5$ μbarn

This results in an inclusive kaon rate of $\simeq$ 5/sec or $\simeq 4 \cdot 10^5$/day.

The hyperon-nucleon final-state interaction is expected to be most pronounced for kaons emitted in the forward direction (small momentum transfer). As an example, the inclusive kaon production rate in the angular range from 12°

to 18° is approximately 0.05/sec or 4,000/day (for a 100 MeV wide photon energy bin).

With the detection efficiency for Σ^- discussed above, the total rate of detected events from the process $\gamma n \to K^+\Sigma^-$ is expected to be about 0.15/sec or 12,000/day.

8. Accidental Coincidence Rate

Accidental coincidences between the tagging system and kaons detected in CLAS have been estimated by taking the counting rate in the tagging spectrometer and the total K^+ production rate from quasifree Λ- and Σ-production into account. Since the real coincidence rate is determined by the dominating quasifree process the rate of accidental coincidences is of the order of 1% only.

9. Missing Mass Resolution

The missing mass resolution dM_x for the unobserved hyperon-nucleon system has been estimated. The energy resolution of the tagged photon beam has been assumed to be $\Delta k \simeq 2 \cdot 10^{-3} \cdot E_o$, and the momentum resolution of the kaon is $\delta p/p \simeq 4 \cdot 10^{-3}$ (FWHM). The approximation

$$(dM_x)^2 \simeq (dk)^2 + (\beta_K \cdot dp_K)^2 + ((k \cdot p_K \cdot \theta_K / M_x) \cdot d\theta_K)^2$$

has been used. This leads to the following contributions to the total missing mass resolution

photon beam	($2 \cdot 10^{-3}$ of 1.3 GeV/c)	2.6 MeV
kaon momentum resolution	($4 \cdot 10^{-3}$ of 0.8 GeV/c)	3.2 MeV
kaon energy loss and straggling		1.5 MeV
kaon angular uncertainty		0.5 MeV
total (contributions added in quadrature)		4.5 MeV

This resolution is sufficient to observe the anticipated narrow structures (see Figures 3 and 4)

10. Running time, calibration etc.

The missing mass spectrum in the $\gamma d \to K^+X$ process has been simulated using a Monte Carlo code. Figure 9 shows the expected missing mass distribution after 500 hours of running time. This seems to be sufficient for an initial experiment. Note that data for other reactions on deuterium, e.g. for deuteron photodisintegration, can be taken simultaneously. Figure 10 shows a single event from the process $\gamma d \to K^+\Sigma^- p \to K^+(n\pi^-)p$ (p is the spectator proton) as seen by the CLAS detector.

The overall energy calibration of the system can be checked using inclusive π^+ production from the $\gamma d \to \pi^+ nn$ reaction which populates the same momentum range and also shows a strong enhancement of the cross section due to neutron-neutron final-state interaction (and has much higher rates).

11. Near term developments

a) K° detection

A more complete study of kaon photoproduction can be performed by including K° detection by selecting $\pi^+\pi^-$-pairs. It should be possible to perform this measurement simultaneously with the K^+ detection. An open question is whether the $\pi^+\pi^-$ mass resolution that can be obtained by CLAS will be sufficient or whether K° decay vertex reconstruction will be required. To answer this question, the background in the $\pi^+\pi^-$ mass spectrum caused by $\pi\Delta$ and vector-meson production has to be investigated.

b) Hyperon polarization measurement

Measurements of the Λ and Σ^+ decay asymmetry can be used to determine the hyperon polarization. For example, in the kinematic region where strong final-state interactions are observed, the spin dependence of the hyperon-nucleon interaction can be explored.

12. Potential future development: Extension to hypernuclear systems

The main obstacle in extending the proposed program to the production of hypernuclei is the limited resolution for the unobserved nuclear final state that can be obtained with the standard CLAS detection apparatus. This limitation, which is mainly due to multiple scattering in the drift chambers, can be overcome, in principle, by exploiting a property of the CLAS toroidal magnet and use it as a focusing spectrometer. Preliminary studies show that, in this mode, a large solid angle ($\Delta\Omega \simeq 100$ msr) and a wide momentum bite ($p_{max}/p_{min} \simeq 1.5$) can be obtained. To reduce multiple scattering, the first two drift chamber packages (region I and II) will have to be replaced by a vacuum tank (clearly a major operation!). To obtain a well known vertex, real tagged photons would be abandoned in favor of small angle electron scattering; the electron would be detected by a separate low momentum spectrometer downstream of the CLAS. This would have the added advantage that very thin targets could be used, thus avoiding any contribution of the kaon energy loss in the target to the overall energy resolution. An overall energy resolution of better than 500 keV seems achievable.

D. Summary

A study of hyperon production off the deuteron has been proposed as a first step towards a program to investigate strange particle production in light and medium nuclear systems. The hyperons will be produced by tagged photons. Kaons and other particles coming from decays of the hyperon-nucleon system will be detected in the CEBAF Large Acceptance Spectrometer. Counting rate estimates have been given. Possible improvements and extensions of the program have been discussed.

E. References

/ADE85/ R.A. Adelseck et al.: Kaon Photoproduction Operator for Use in Nuclear Physics, Phys. Rev. C32 (1985) 1681

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/CONF/ For more information on strange particle physics, see the proceedings of the following workshops and conferences:

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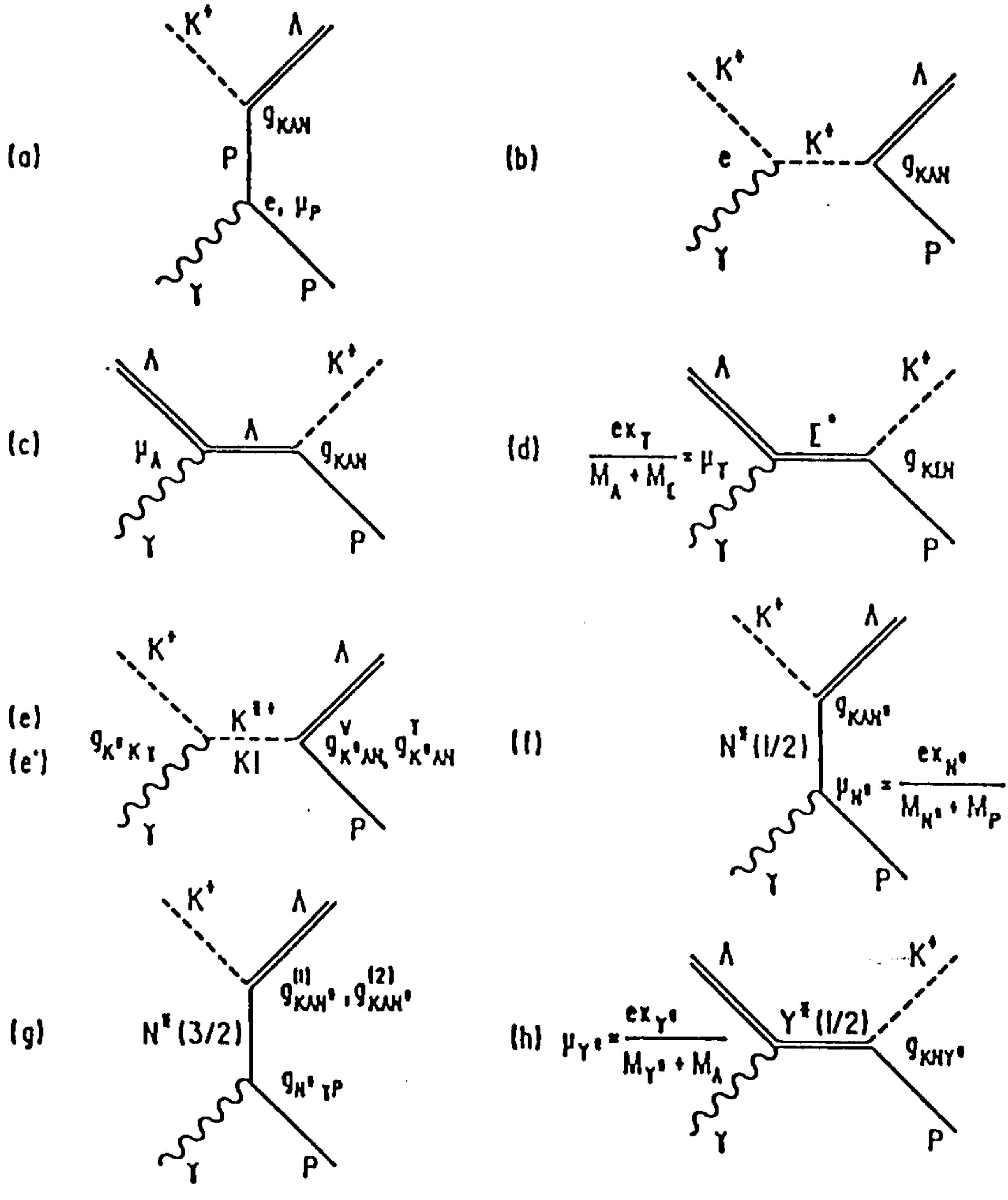

Figure 1 Feynman diagrams used in the description of the elementary kaon photoproduction process $\gamma+p\rightarrow K^{+}\Lambda$ (from /ADE89/)

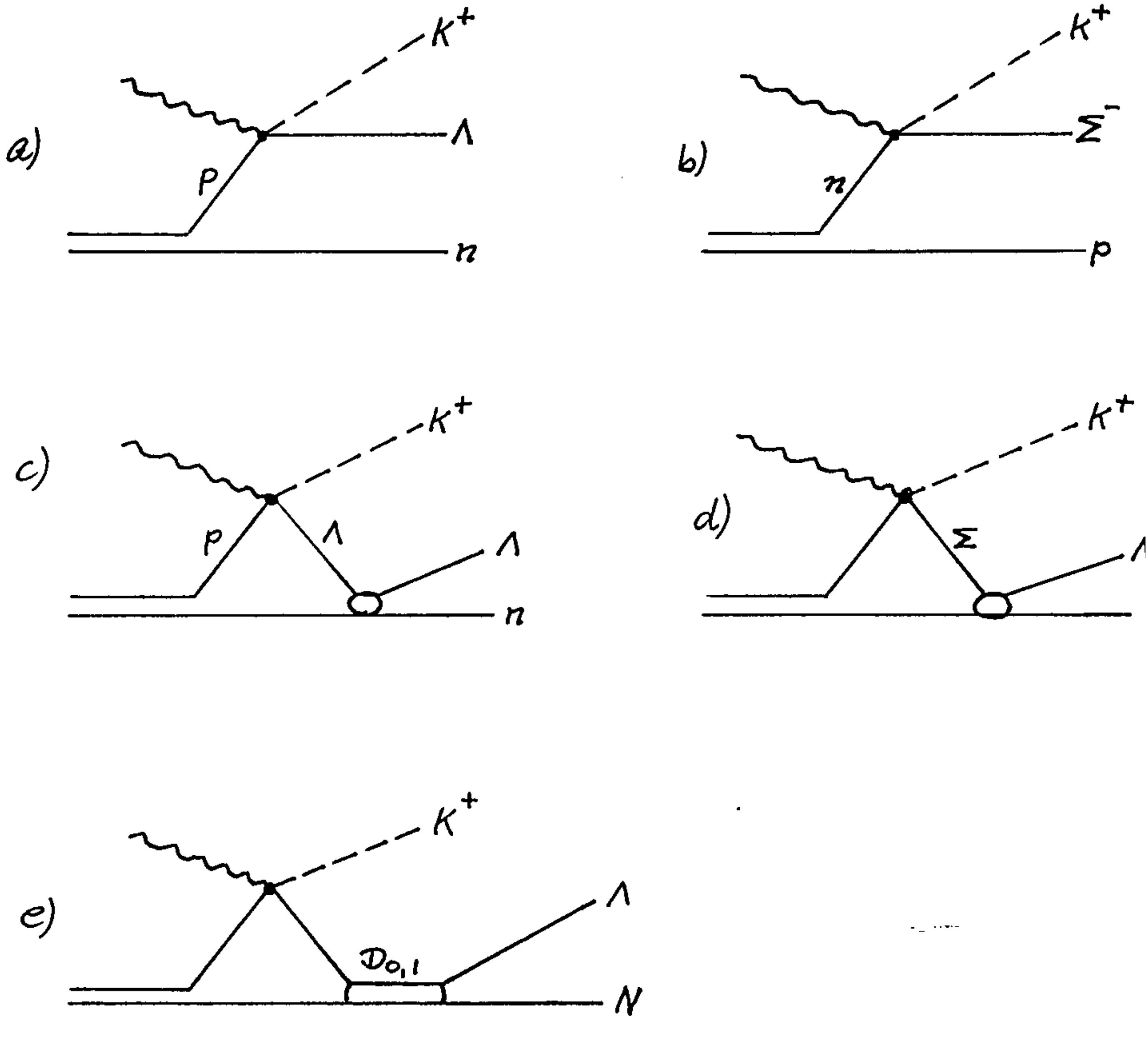

Figure 2 Feynman diagrams for processes contributing to $\gamma d \rightarrow K^+ X$
a) quasifree Λ production
b) quasifree Σ^- production
c) quasifree Λ production and Λn final-state rescattering
d) Σ-Λ channel coupling
e) s=-1 dibaryon production

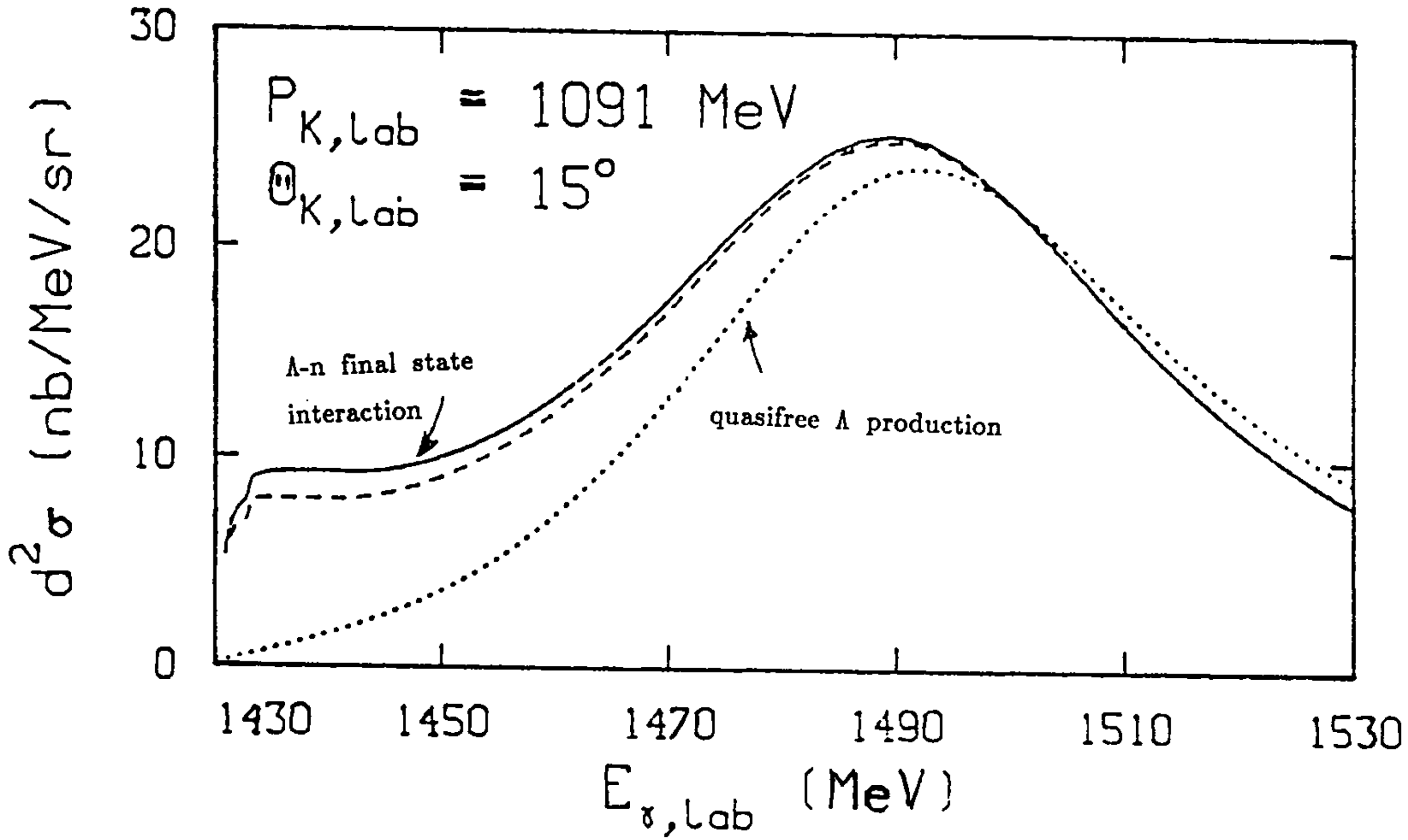

Figure 3 Theoretical prediction for the double differential cross section for inclusive kaon emission off the deuteron for a kaon laboratory angle of $\theta_K = 15°$ and fixed kaon momentum of 1091 MeV/c as a function of the photon energy, from /ADE88/.

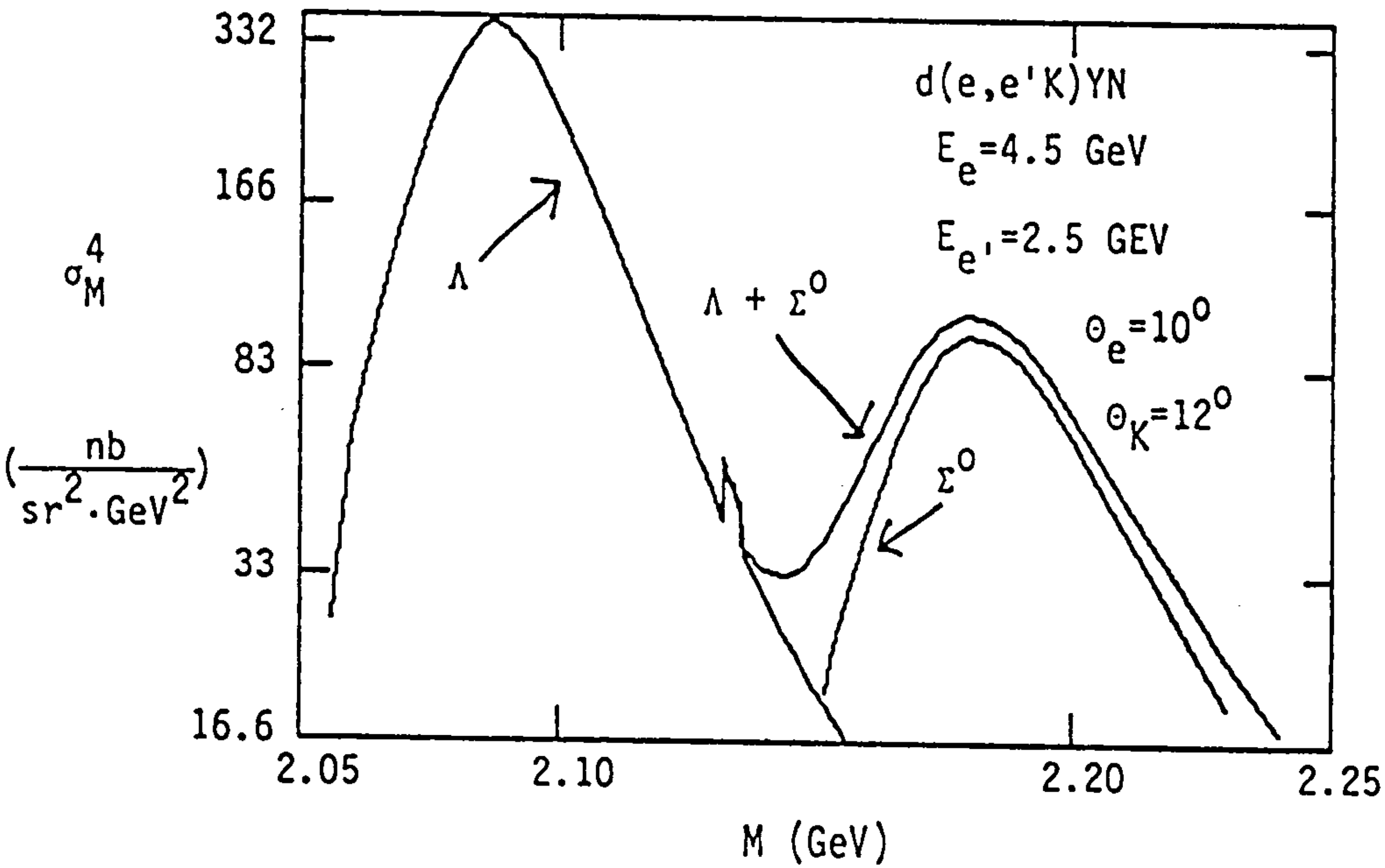

Figure 4 Theoretical prediction for the cross section for inclusive kaon electroproduction off the deuteron as a function of the mass M of the hyperon-nucleon system, from /COT87/.

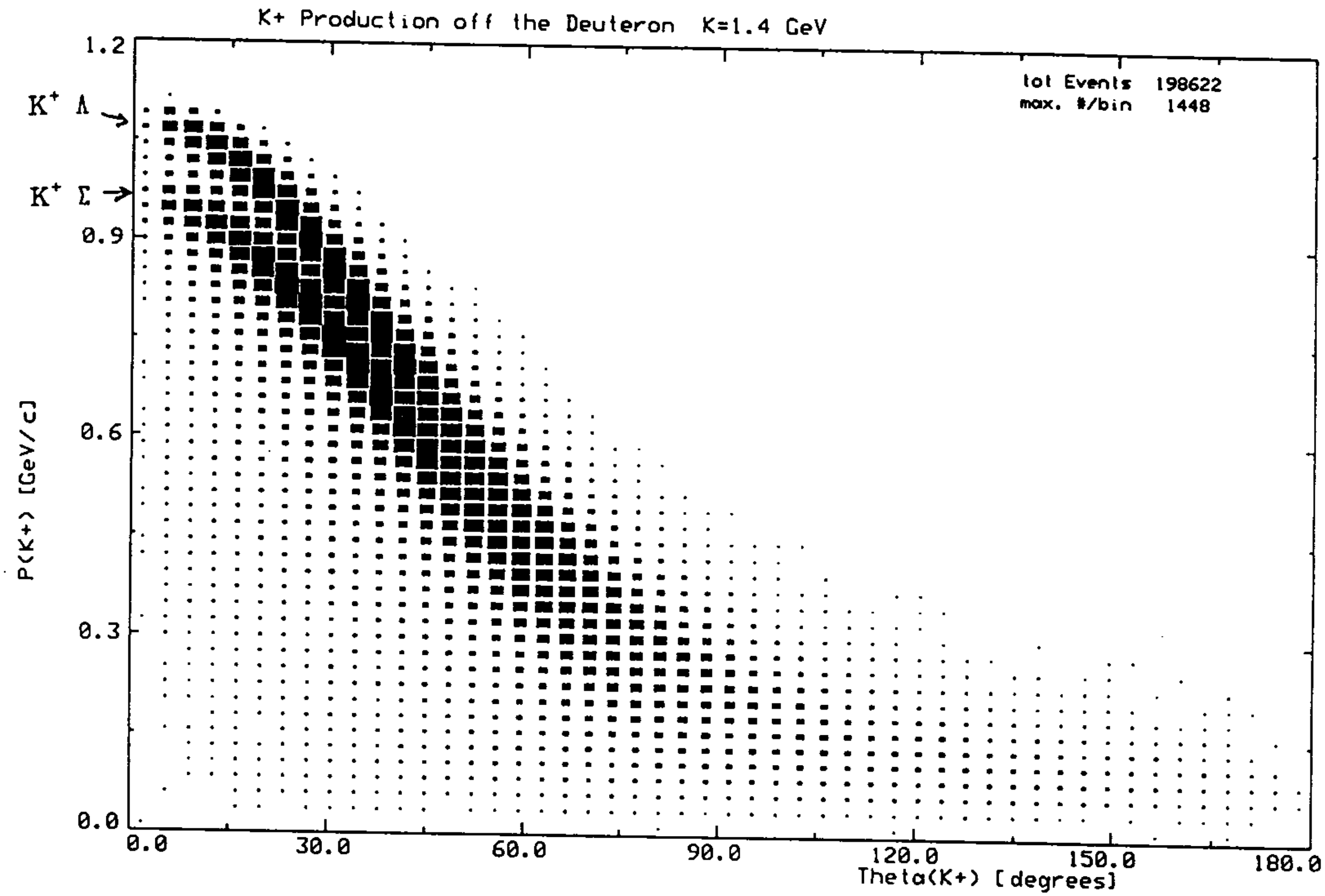

Figure 5 Momentum vs. laboratory angle for inclusive K^+ from the processes $\gamma d \rightarrow K^+\Lambda n$ and $\gamma d \rightarrow K^+\Sigma^o n$ for fixed photon energy of 1.4 GeV

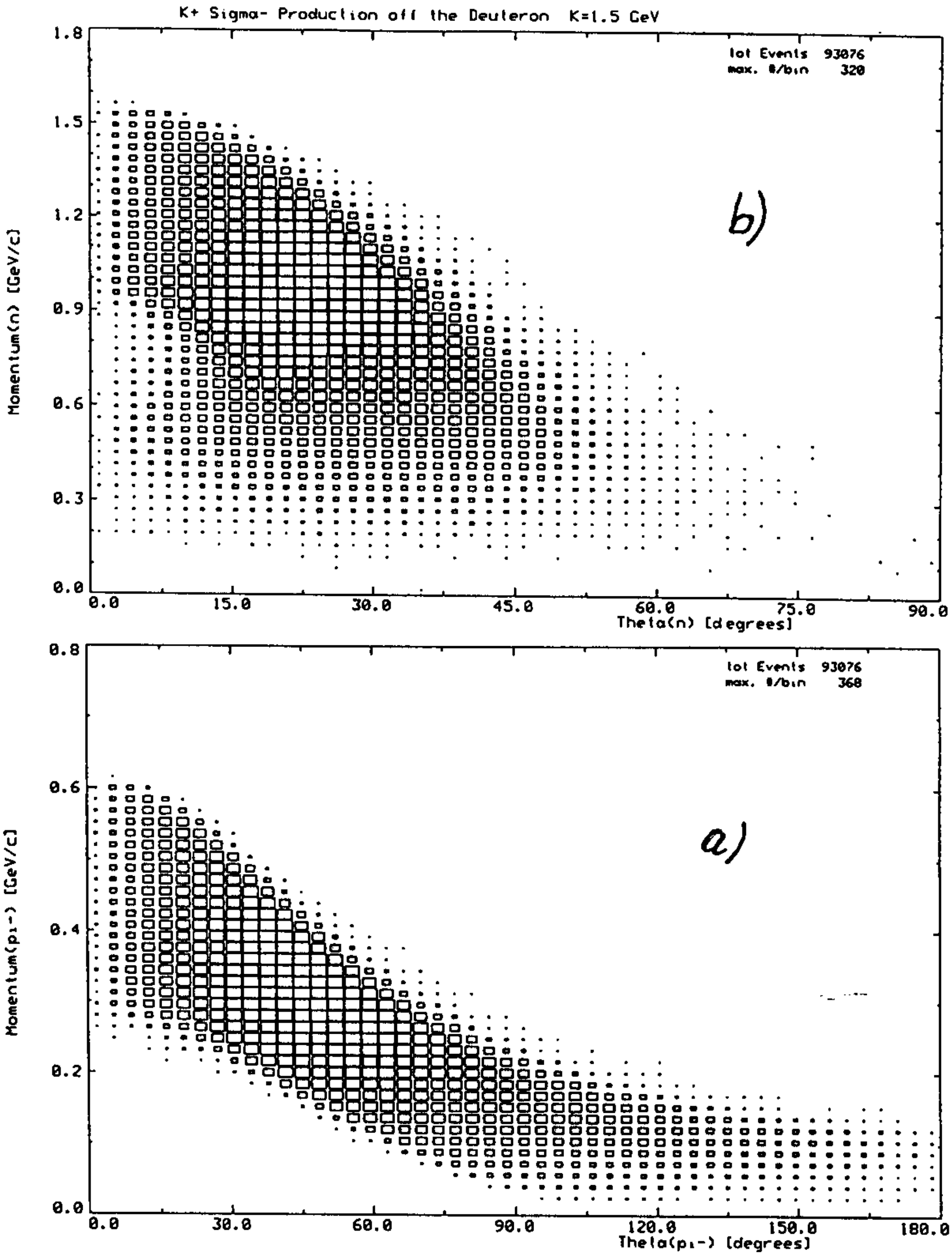

Figure 6 Momentum vs. laboratory angle for π^- and neutrons from the decay of Σ^- produced in the process $\gamma d \rightarrow K^+\Sigma^- + (p)$ for fixed photon energy of 1.4 GeV. a) for π^-, b) for neutrons

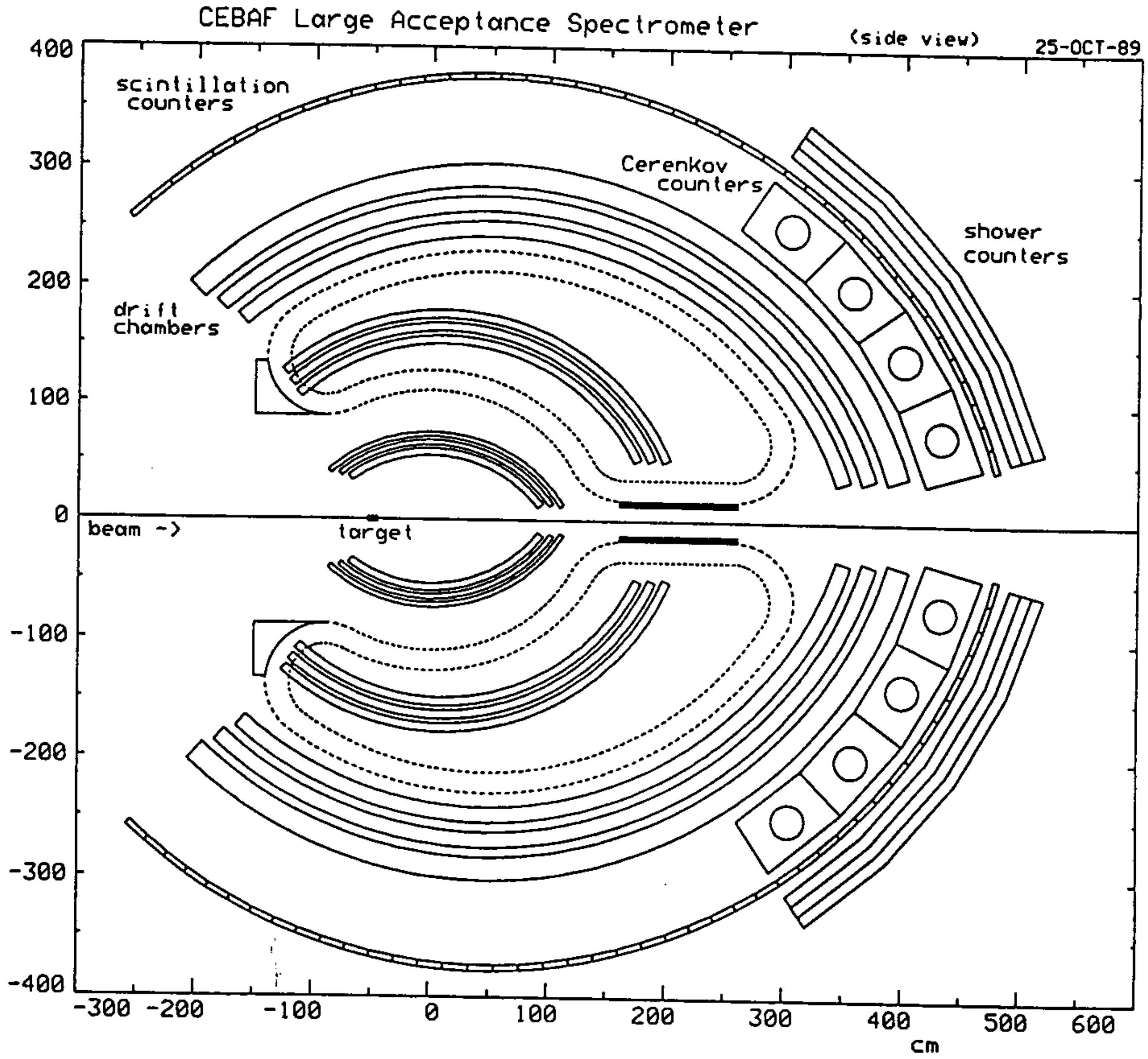

Figure 7: CLAS detector configuration

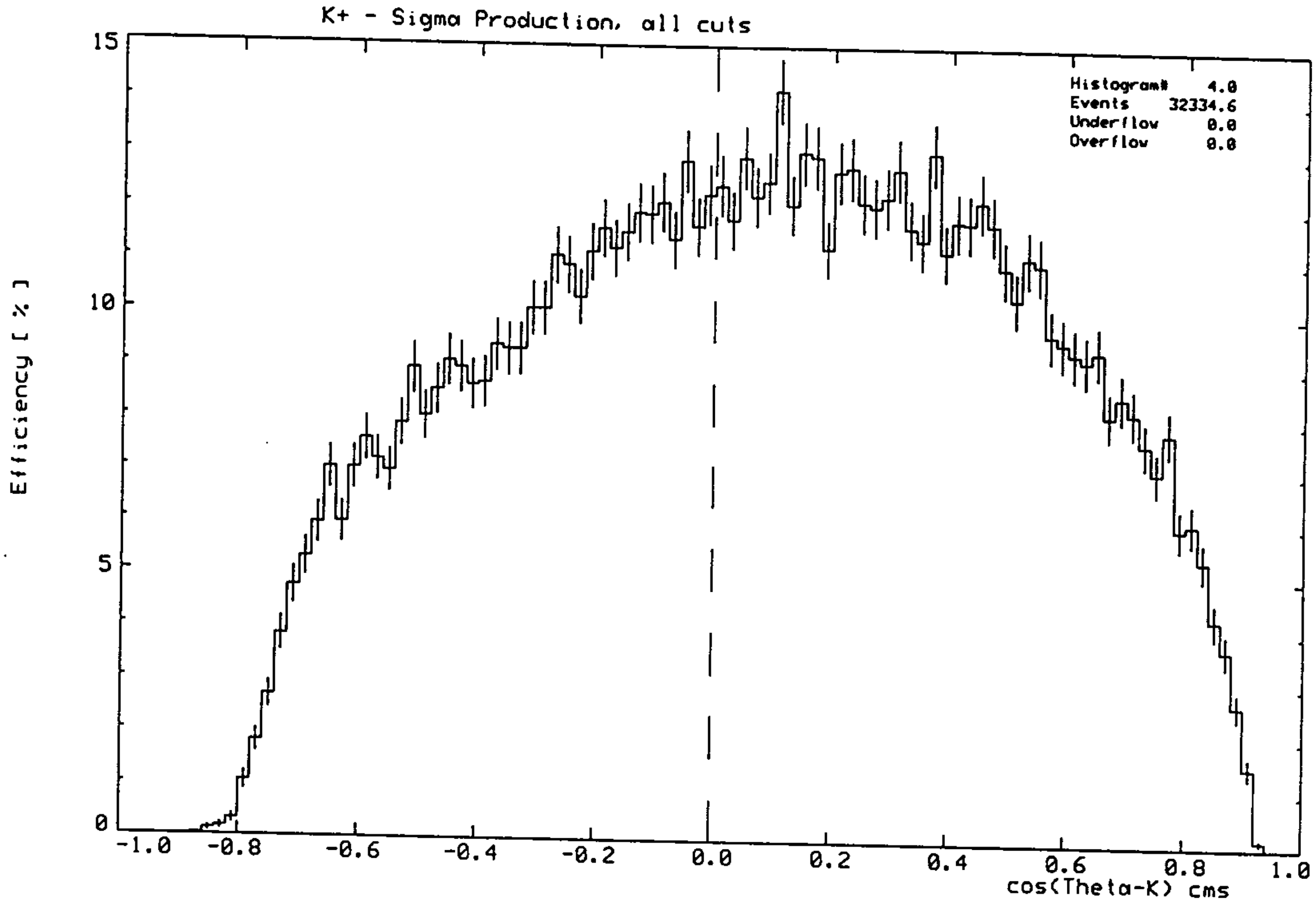

Figure 8: Detection efficiency for photoproduced $K^+\Sigma^-n$ final states as a function of the K^+ c.m.s. angle. Photon energy k= 1.5 GeV.

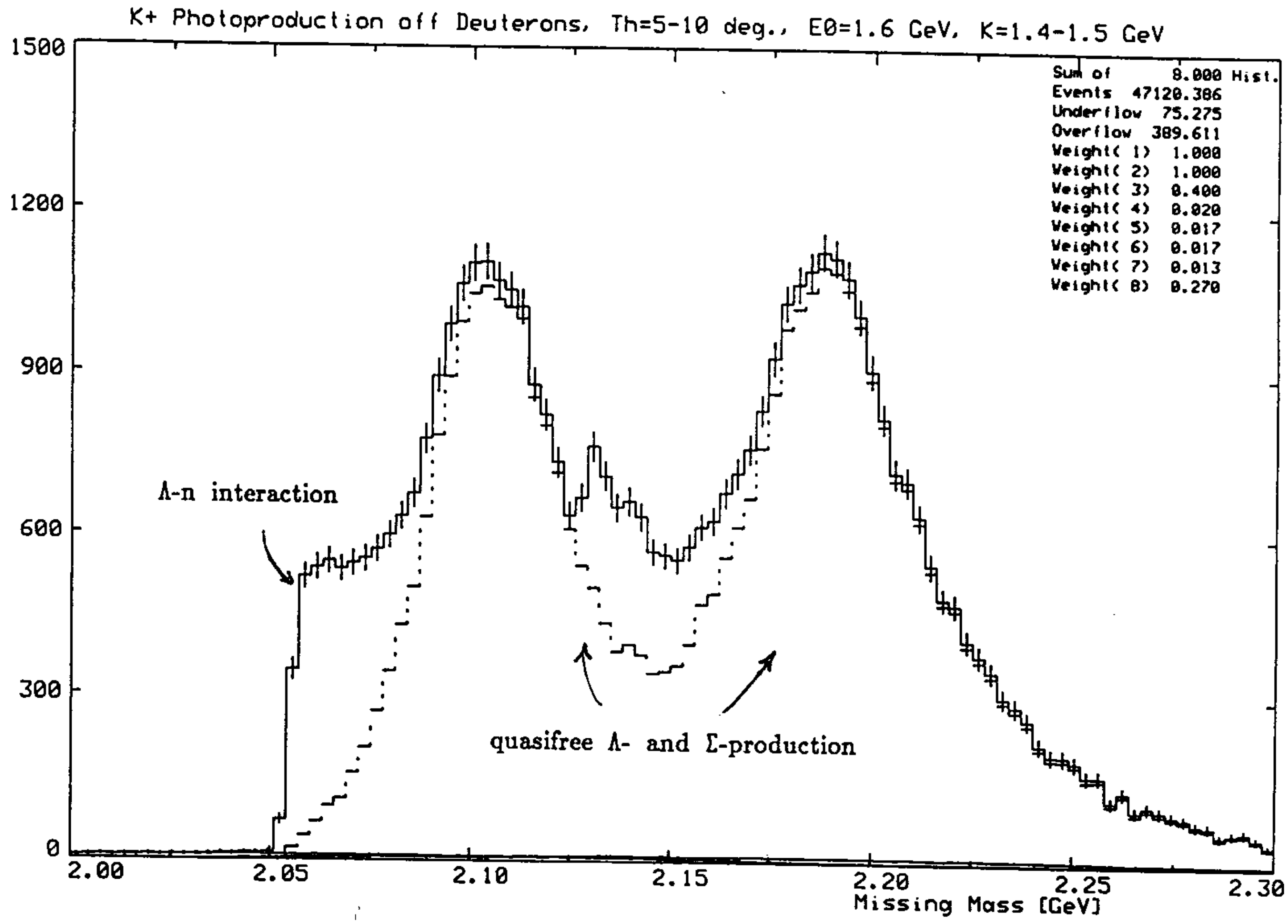

Figure 9: Result of a Monte Carlo calculation for the missing mass of the hyperon-nucleon system from $\gamma d \rightarrow K^+YN$. Photon energy and kaon momentum resolution were taken into account. Photon energy bin k= (1.4-1.5) GeV. θ_K=12°-18°.

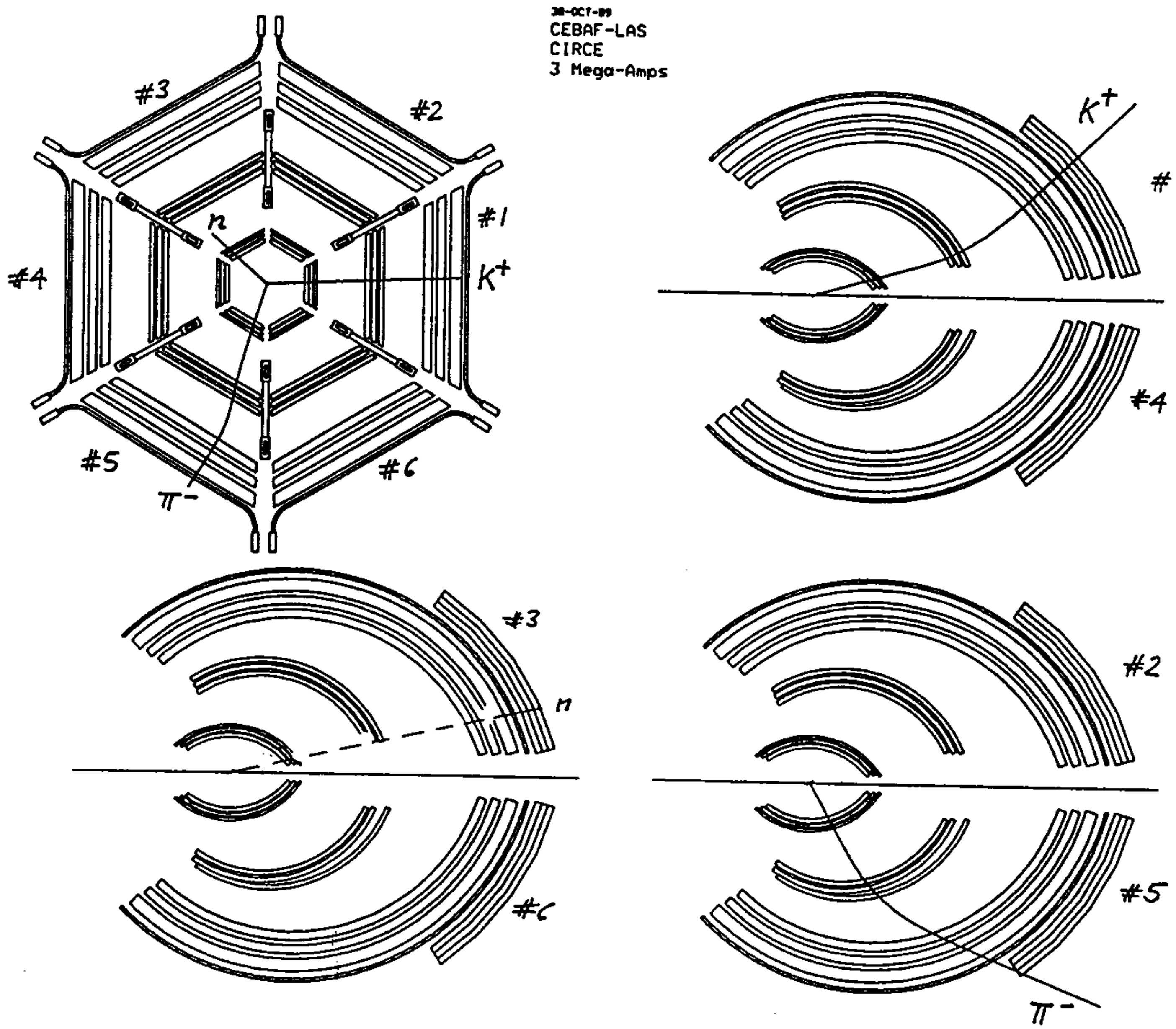

Figure 10: Single event from the process $\gamma d \to K^+\Sigma^- p \to K^+(n\pi^-)p$ as seen by the CLAS detector. Photon energy $k = 1.5$ GeV.