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PROPOSAL TO STUDY THE $K^{\pm}$ CHARGE EXCHANGE REACTIONS AT HIGH ENERGIES

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Experimenters:

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Collaborators: Several experienced senior physicists have expressed serious interest in participating should the proposal be favorably received.

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ABSTRACT

An experiment is proposed for measurement of the $K^{\pm} \to K_1^0$ charge-exchange reactions using unseparated beams; useful rates are obtained for $p_{inc} \lesssim 100$ GeV/c and $-t \lesssim 1\ (\mathrm{GeV/c})^2$. A V-spectrometer with resolution $\pm 1\%$ is used downstream of the target for detection of the decays $K_1^0 \to \pi^+\pi^-$. Using hydrogen and deuterium targets, the detection system is designed to measure:

1) $d\sigma/dt$ for $K^-p \to \bar{K}^0n$. The reaction will be distinguished from background processes involving N^* and K^* production by kinematics and supplementary detectors surrounding the target.

2) $d^2\sigma/dpdt$ for $K^-d \to \bar{K}^0nn$. This final state will be distinguished from those involving production of π^0's or charged particles primarily by the supplementary target veto array. Use of a deuterium target will provide partial clarification of the problems to be encountered in achieving part 3. In principle, some information on the relative sizes of the spin-flip and non-spin-flip amplitudes will be obtained.

3) $d^2\sigma/dpdt$ for $K^+d \to K^0pp$. Since charged particles are produced at the interaction vertex, this final state can be reliably extracted only with the insight gained in parts 1) and 2) and a detailed study of the distributions in the target veto counter array.

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INTRODUCTION

It has long been recognized that NAL presents an important opportunity for testing the asymptotic predictions of Regge theory and SU(3) symmetry in an energy regime where the mass differences within multiplets should have little effect. A particularly important set of tests is contained within the four charge-exchange (CEX) reactions

$$\pi^- + p \rightarrow \pi^0 + n \qquad (1)$$

$$\pi^- + p \rightarrow \eta + n \qquad (2)$$

$$K^- + p \rightarrow \bar{K}^0 + n \qquad (3)$$

$$K^+ + n \rightarrow K^0 + p \qquad (4)$$

At low energies, where most reactions are dominated by s-channel resonances, elastic processes are best analyzed in terms of isotopic spin amplitudes. At high energies, where reactions become largely peripheral, they are more directly described in terms of the dominant exchange processes. The π^- CEX reaction (1) is dominated by ρ-exchange; the η production reaction (2) by A_2-exchange. The physics of the $K^{\pm}$ CEX reactions has been discussed within the context of the Regge model by Cline et al.[1] In this case, both the ρ- and A_2-exchanges contribute so that the amplitudes have the form

$$A(K^-p \rightarrow \bar{K}^0n) = -a(\rho) + a(A_2) \qquad (5)$$

$$A(K^+n \rightarrow K^0p) = +a(\rho) + a(A_2) \qquad (6)$$

To the extent that these exchanges dominate, the cross sections differ only in the sign of the interference term. But Regge theory makes a further statement: should the ρ- and A_2- trajectories be exchange degenerate, the amplitudes are orthogonal and the interference term vanishes. Clearly, the $K^{\pm}$ charge-exchange reactions (and indeed all symmetrical processes involving the same $K^{\pm}$- K^{0} vertex) then have the same cross sections. Whether these two trajectories dominate (no cuts, absorptive corrections, etc.) must be determined by experiments at NAL.

It is important to note the difference between the CEX and regeneration experiments. In CEX the exchanged trajectory must be charged, i.e. $I \geq 1$, with charge conjugation $C = \pm 1$ for the neutral member of the isomultiplet; in $K_2 \rightarrow K_1$ regeneration, although the I-spin is arbitrary, only $C = -1$ trajectories are allowed. In neither case is Pomeron exchange allowed. Alternatively, $K^{\pm}$ charge exchange measures the difference in $I = 0$ and $I = 1$ elastic amplitudes, while $K_2 \rightarrow K_1$ regeneration measures the difference in K^0 and $\bar{K}^0$ elastic amplitudes. Both kinds of data are required for a full understanding of the asymptotic Regge behaviour.

A further prediction arises with the assumption of SU(3) symmetry. Since (1) is dominated by ρ-exchange and (2) by A_2-exchange, there exists a sum rule even in the absence of exchange degeneracy

$$\sigma(K^- p \rightarrow \bar{K}^0 n) + \sigma(K^+ n \rightarrow K^0 p) =$$

$$= \sigma(\pi^- p \rightarrow \pi^0 n) + 3\,\sigma(\pi^- p \rightarrow \eta n) \quad (7)$$

Consequently, a self-consistent test of the asymptotic Regge-SU(3) predictions can be achieved only with the measurement of all four charge-exchange processes.

EXPERIMENTAL PROGRAM

To measure the $K^{\pm}$ CEX cross sections, three reactions must be considered

$$K^- + p \rightarrow \bar{K}^0 + n \qquad (8)$$

$$K^- + d \rightarrow \bar{K}^0 + n + n \qquad (9)$$

$$K^+ + d \rightarrow K^0 + p + p \qquad (10)$$

Reaction (8) provides an accurate measurement of the s- and t-dependence of the K^-p CEX cross section. In the past, reaction (10) has been used to obtain the K^+n CEX cross section invoking an impulse model and correcting for the presence of the two nucleons in the final state. The correction term has the form

$$d\sigma/dt\ (K^+d \rightarrow K^0pp) = \left[1 - S(t)\right] d\sigma/dt \Big|_{\text{non-flip}}^{\text{CEX}} + \left[1 - \tfrac{1}{3} S(t)\right] d\sigma/dt \Big|_{\text{non-spin-flip}}^{\text{CEX}} \qquad (11)$$

where $S(t)$ varies rapidly ($\propto e^{22t}$) with t. There are two difficulties with this correction: a) it is large for small t and b) it can be applied accurately only with a knowledge of the relative size of the spin-flip and non-spin-flip amplitudes.

The predictions of the Regge-model have recently been compared with experiment by Goldhaber et al.[2] In an exposure of 250k pictures at 12 GeV/c in the 82" B.C. they obtained 77 events fitting $K^+d \rightarrow K_1^0\, pp$. To correct the data for small t, they assumed that the scattering was predominantly non-spin-flip; in this case (11) yielded a correction of 40% for $|t| < 0.1\ (\text{GeV/c})^2$. Within the limited statistics available, the data were consistent with the equality

$$d\sigma/dt\ (K^-p \rightarrow \bar{K}^0n) = d\sigma/dt\ (K^+n \rightarrow K^0p)\ ;$$

the K^-p data were those of Astbury et al.[3] at 12.3 GeV/c. Above 1 GeV/c incident momentum the cross section for $K^+d \rightarrow K^0pp$ could be fitted with a function of the form

$$\sigma = A\, p^{-n} \qquad (12)$$

where $A = 7.3 \pm 0.2$ mb, $n = 2.0 \pm 0.15$, and p is the lab momentum.

Since available data suggest that the difference in K^+n and K^-p CEX cross sections will be small it is crucial that the correction (11) be made accurately. To minimize the uncertainty, we propose to determine experimentally the effects of using a deuteron target by studying the two reactions (8) and (9). To the extent that the correction term (11) is valid, this has the additional advantage of providing some information on the relative spin-flip and non-spin-flip contributions to the cross section.

Finally, reactions (9) and (10) provide the best possibility for for measuring the <u>relative</u> K^+ and K^- CEX cross sections. The asymptotic Regge model with $\rho - A_2$ exchange degeneracy leads to the <u>same</u> final states for the two-nucleon system; the only difference in the nuclear physics arises from the Coulomb interaction in (10).

A particularly attractive technique for measuring the <u>relative</u> $K^{\pm}$ charge exchange cross sections is provided the reactions

$$K_2^0 + d \rightarrow K^+ + n + n$$

and

$$K_2^0 + d \rightarrow K^- + p + p$$

where the $S = \pm 1$ components of the incident beam are internally normalized. After some experience in the neutral beams at NAL such studies may be practical.

APPARATUS

The detection problem may be divided into two parts, target and downstream. For K^-p CEX, the problem at the target is analogous to that in

$$\pi^- + p \rightarrow \pi^0 + n.$$

In this case, the two γ's from π^0 decay are detected downstream with high angular precision; the target is surrounded with a Pb-scintillator array to veto all events with charged particles and/or additional γ's, i.e. π^0's. No attempt is made to detect the recoil nucleon.

A similar target arrangement suffices for the K^-p CEX; the downstream detector now becomes a V-spectrometer as shown in Fig. 1. To provide some information on numbers and spatial distributions for charged particles and γ's produced in the target the veto counters are segmented as shown in Fig. 2. To minimize secondary interactions, the anti-counter at the target exit aperture must have low mass. This angular region can be further covered downstream of the V-spectrometer so that there is essentially 4π detection for π^0's produced at the interaction vertex.

Since the expected rate decreases rapidly with increasing $K^{\pm}$ momentum it is important that the acceptance of the downstream spectrometer be near 100% at the highest useful momentum, i.e. 100 GeV/c. With the dimensions indicated in Fig. 1 and a magnet aperture of 1m x 1m, the acceptance is 95% for $-t < 1$ (GeV/c)^2. Scaling dimensions linearly with p_{inc} results in only a small decrease in acceptance at 30 GeV/c.

The precision required in the spectrometer is determined to a large extent by the dominant backgrounds expected.

$$K^- + p \rightarrow \bar{K}^o + N^{*o}$$
$$N^{*o} \rightarrow \pi^o + n \;,\; \pi^- + p \;, \text{ etc.} \qquad (14)$$
$$K^- + p \rightarrow \bar{K}^{*o} + n$$
$$\bar{K}^{*o} \rightarrow \bar{K}^o + \pi^o \quad \text{etc.} \qquad (15)$$

For $N^*(1236)$ production in (14) the $\bar{K}^o$ at a given lab angle has a momentum $\sim$ 0.13 GeV/c less than that in the CEX reaction. In principle, it is possible to measure momenta with sufficient accuracy to identify $N^*(1236)$ production; however, this source of background is more conveniently eliminated by the target veto counters. For $N^* \rightarrow \pi^o n$, the γ-counters provide the veto. For $N^* \rightarrow \pi^- p$ there is no problem when one or both charged particles count; at small t however, it is possible for both particles to stop in the target. In most cases the π^- will be captured in the hydrogen yielding one or more γ's and subsequent veto.

For $K^*(890)$ production it is simplest to rely on kinematics. K^o's from $K^*(890)$ decay are 3% or more lower in momentum than those from CEX. Consequently, a momentum resolution of 1% is adequate to reject this source of background. The γ-counters provide additional rejection for K^* events, particularly those of higher mass. A momentum resolution of 1% can easily be achieved with conventional wire spark chambers using magnetostrictive readout, and a magnet having field integral $e\int B\,dl \gtrsim 1$ GeV/c. Since beams of 10^6 particles perpulse are required, it may be necessary to desensitize the chambers in the immediate region of the beam. The basic trigger will be $B_1 B_2 A H_1 H_2$. All counters will be latched on accepted events in real and delayed time. Events will be stored in the on-line computor during the beam spill and read onto magnetic tape between pulses.

Multiple scattering and secondary interactions can be substantially decreased through use of He-filled gas bags wherever possible. We believe, however, that in the present experiment use of a downstream Cerenkov detector is not necessary to distinguish Λ or $\bar{\Lambda}$ decay from $K_1^0 \rightarrow \pi^+\pi^-$. High momentum Λ's or $\bar{\Lambda}$'s result from baryon exchange in reactions such as

$$K^- + p \rightarrow \Lambda(\Sigma^0) + \pi^0$$

$$K^- + p \rightarrow \Lambda(\Sigma^0) + \phi \quad \text{etc.}$$

$$K^+ + n \rightarrow \bar{\Lambda}(\bar{\Sigma}^0) + p + n \quad \text{etc.}$$

with cross sections decreasing much more rapidly ($\propto p^{-6}$) than those for charge exchange. In addition, the good angle and momentum resolution in the V-spectrometer permits an unambiguous separation of K_1^0 decays with c.m. angles $\lesssim 30^\circ$.

In principle, the measurement of the K^-d CEX cross section proceeds as just described for the K^-p reaction. There is an important difference, however, since the momentum of the $\bar{K}^0$ is smeared by the Fermi momentum in the deuteron; the CEX events appear as a 'bump' on the tail arising from K^* and N^* production. In this case, the γ veto counters are more important than kinematic constraints in reducing the undesired background. Sizes and locations of counters will be optimized through detailed Monte Carlo calculations.

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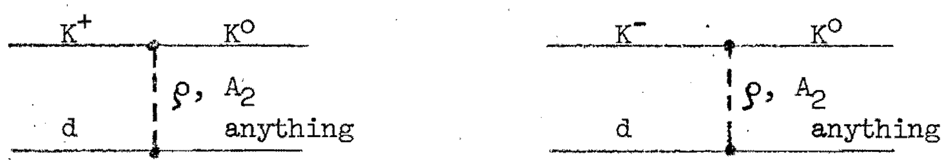
Since the difference in cross sections for $K^+d \rightarrow K^0pp$ and $K^-d \rightarrow \bar{K}^0nn$ is expected to be small, it is crucial that the veto counters not introduce any bias in the selection of the final data. A comparison of the K^-p and K^-d CEX data will clarify some of the special problems in using a deuterium target and the way in which events must be selected in the off-line analysis to reliably extract the K^-p result from the K^-d data. With this information the K^+d charge exchange can be studied. Note that the $\bar{A}$ requirement must be dropped in data taking, since charged particles are produced at the interaction vertex. The manner in which it is applied in the off-line analysis depends upon a systematic study of the distributions in the target veto counters. In any case, it should be relatively straightforward to reliably isolate diagrams of the type



which contain the essential prediction of the Regge theory. In this case, the $K^{\pm}d \rightarrow K_1^0$ + anything studies represent the simplest of the 'inclusive' experiments suggested by Feynman[4] and discussed further by Abarbanel[5] and others.

BEAM AND RATES

To estimate rates, the beams described by Reeder and MacLachlan[6] have been used. The exact properties of the beams are not crucial since the important numbers are the $K^+/(\pi^+ + p)$ and $K^-/(\pi^- + \bar{p})$ ratios at the target. We have normalized all rates to a typical beam of 10^6 particles /pulse, a 3' hydrogen (deuterium) target, a cross given by (12), and full acceptance for the decays $K_1^0 \to \pi^+\pi^-$. The calculated rates per day are shown in Fig. 3 and summarized in Table I. For incident protons of 200 GeV/c, rates are adequate for excellent measurements with 30 GeV/c $< p_{K^\pm} <$ 100 GeV/c, particularly if a large-angle beam is used. The momentum spread in the beam should not be more than ± 1%.

TABLE I.

EVENTS PER DAY AT	30 GeV/c	65 GeV/c	100 GeV/c	Beam
K^+	3100	560	370	7.5 mr
K^-	2100	500	205	
K^+	1430	460	120	2.5 mr
K^-	940	220	70	

Calculated for $15(10^3)$ pulses per day, and full acceptance for events with $-t \leq 1\ (\text{GeV}/c)^2$ and $K_1^0 \to \pi^+\pi^-$.

Since $K^\pm$ mesons constitute only 2-3% of the charged particle flux at the end of a long beam, reliable particle identification is necessary. It is assumed that the required Cerenkov counters will be provided by NAL for general experimental use. Beam defining hodoscopes (scintillator or proportional chamber) are required upstream of the apparatus. If these are not an integral part of the NAL beam instrumentation, they will be provided by the participating experimental groups.

RUNNING TIME AND TUNE-UP

It is proposed that measurements be made at three momenta, 30 GeV/c, 65 GeV/c, and 100 GeV/c. Since events rates decrease with increasing momentum, a larger portion of the time must be alloted to these measurements. The time is divided almost equally between hydrogen and deuterium running. A summary appears in Table II.

TABLE II.

MOMENTUM	30 GeV/c	65 GeV/c	100 GeV/c
K^-p	2 (4200)	3 (1500)	6 (1230)
K^-d	2 (4200)	2 (1000)	3 (615)
K^+d	2 (6200)	2 (1120)	2 (740)

The first number is the number of days run with the indicated beam and target filling, the second number (in parentheses) is the estimated number of events using Table I for the 7.5 mr beam.

The total running time requested is 24 days or 600 hours. An additional 400 hours are requested for tune-up.

EQUIPMENT PROVIDED BY EXPERIMENTERS:

Beam defining hodoscopes B_1 and B_2
Target veto counter array
Wire chambers and readout for V-spectrometer
On-line computor.

PROVIDED BY NAL:

Cerenkov counters for particle identification
Target and fillings; 3' long, hydrogen and deuterium
Magnet for V-spectrometer.
Assorted He bags.

References:

1) D. Cline, J. Matos, and D.D. Reeder, Phys. Rev. Letters 23, 1318 (1969).

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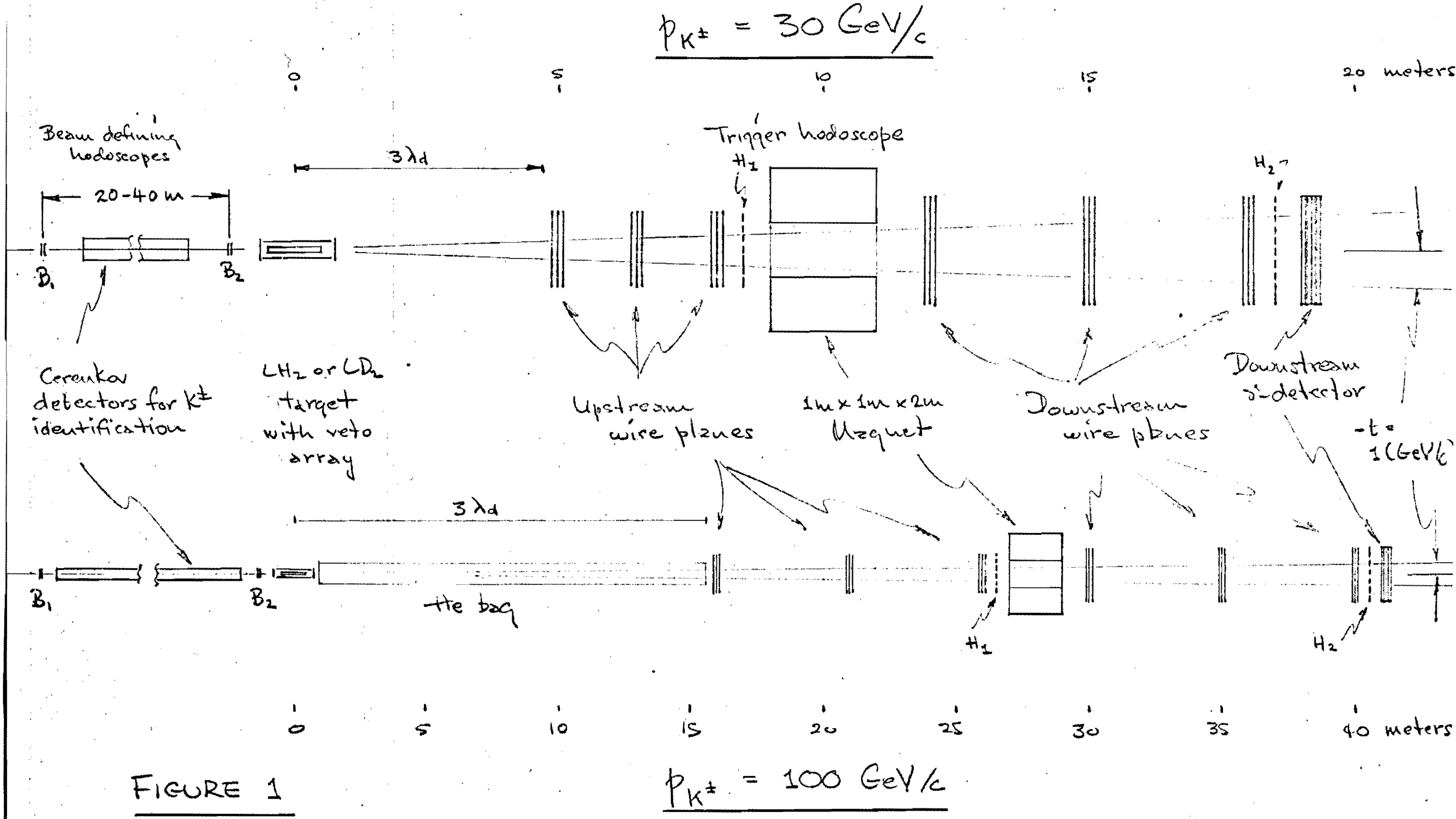
3) P. Astbury et al., Phys. Letters 23, 396 (1966).

4) R.P. Feynman, Phys. Rev. Letters 23, 1415 (1969).

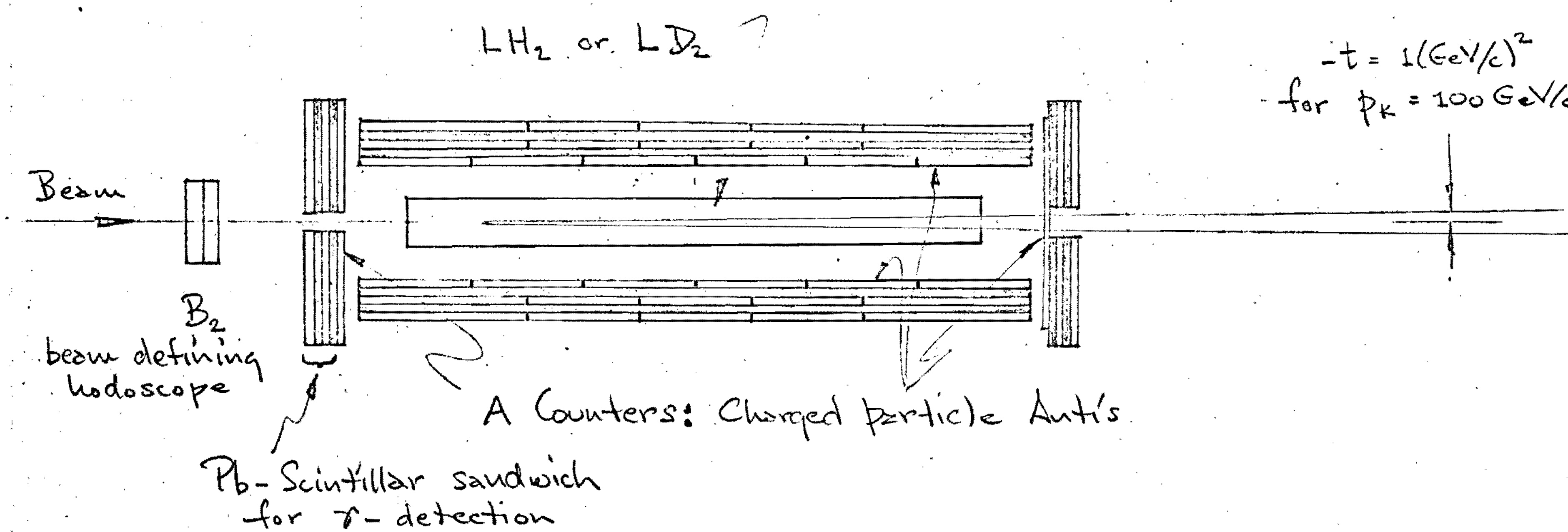
5) H.D.J. Abarbanel, Phys. Letters 34B, 69 (1971).

6) D. Reeder and J. MacLachlan, NAL Summer Study, Vol. 1, pp 41-53.



$p_{K^\pm} = 30$ GeV/c
0
5
10
15
20 meters
Beam defining hodoscopes
20-40 m
3λd
Trigger hodoscope
H1
H2
B1
B2
Cerenkov detectors for K± identification
LH2 or LD2 target with veto array
Upstream wire planes
1m x 1m x 2m Magnet
Downstream wire planes
Downstream γ-detector
-t = 1 (GeV/c)
3λd
He bag
H1
H2
B1
B2
0
5
10
15
20
25
30
35
40 meters
$p_{K^\pm} = 100$ GeV/c

FIGURE 1


LH2 or LD2
$-t = 1(GeV/c)^2$
for $p_K = 100$ GeV/c
Beam
B2
beam defining
hodoscope
A Counters: Charged particle Anti's
Pb-Scintillar sandwich
for γ-detection

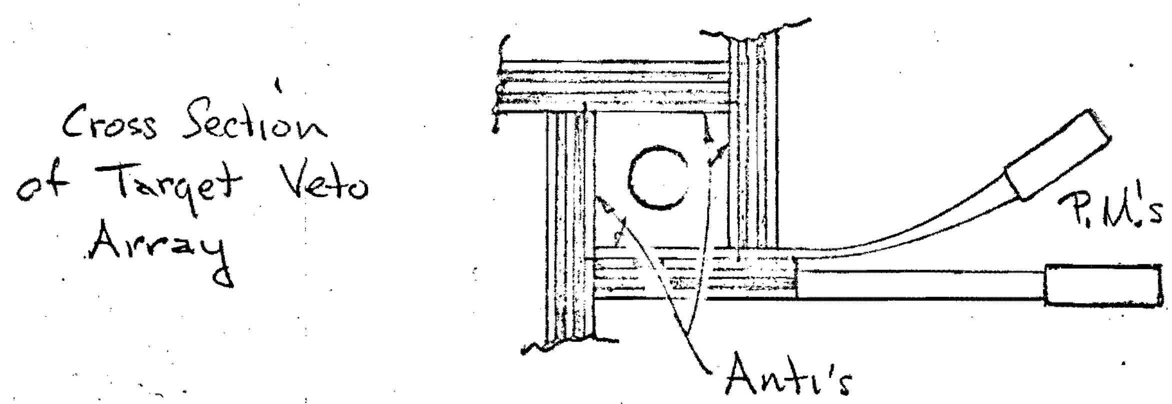
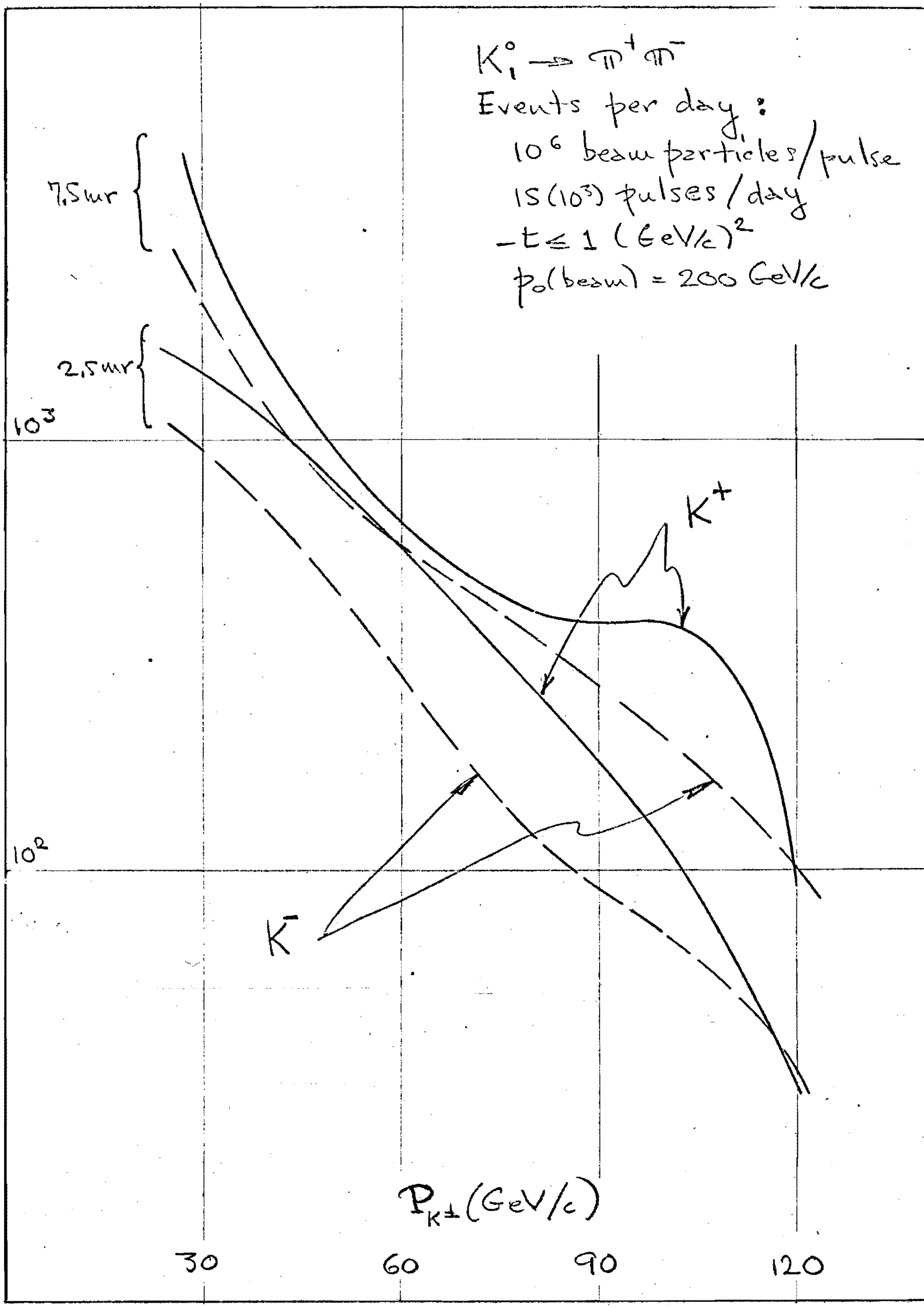

Cross Section
of Target Veto
Array
P.M's
Anti's

FIGURE 2



$K_1^0 \rightarrow \pi^+\pi^-$
Events per day:
10^6 beam particles/pulse
15 (10^3) pulses/day
$-t \leq 1\ (GeV/c)^2$
p_0(beam) = 200 GeV/c
7.5 mr
2.5 mr
10^3
10^2
K^+
K^-
$P_{K^\pm}$ (GeV/c)
30
60
90
120