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PROPOSAL FOR A MEASUREMENT OF THE DECAY MODE $\Sigma^- \rightarrow \Lambda^0 + e^- + \bar{\nu}$

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ABSTRACT

An experiment is described to measure the properties of the strangeness-conserving decay mode $\Sigma^- \rightarrow \Lambda^0 + e^- + \bar{\nu}$. If the branching ratio for this decay mode is, as is tentatively predicted, 2×10^{-4}, this experiment which uses an arrangement of spark chambers and counters should provide between 10 and 30 observed events per day of PS operation, for an incident π^- beam current of 2×10^5 per PS pulse. The proposed experimental arrangement requires the coincidence of a K^+ meson from the production process $\pi^- + p \rightarrow \Sigma^- + K^+$, and of an electron and a proton (in a restricted energy range) from $\Sigma^- \rightarrow \Lambda^0 + e^- + \nu$, $\Lambda^0 \rightarrow p + \pi^-$, before an event photograph is taken. Background calculations based on this trigger scheme indicate that the ratio of useless to useful photographs should be less than 80. It appears possible to reconstruct events from the spark chamber protographs with sufficient accuracy to eliminate foreseeable spurious events.

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INTRODUCTION

This note presents a proposal[*)] for an experiment at the PS designed to measure the properties of the hyperon decay mode, $\Sigma^- \to \Lambda^0 + e^- + \bar{\nu}$.

Thus far, one such event has been observed in a helium bubble chamber, (reported at the 1962 CERN Conference). The rate at which this decay proceeds is of particular interest in the light of its strangeness-conserving nature, and of recently acquired knowledge that the rates of leptonic decays of hyperons involving a change of strangeness are lower by about an order of magnitude than might be expected on certain theoretical grounds. Indeed, because of the very low branching ratio expected for the mode $\Sigma^- \to \Sigma^0 + e^- + \bar{\nu}$, in which strangeness is conserved and the two participating baryons belong to the same isotopic spin multiplet, and because of the singlet nature of the Λ^0, and because of the rarity of cascade particles, the mode $\Sigma^- \to \Lambda^0 + e^- + \bar{\nu}$ appears to be the only one involving strange baryons but no change of strangeness, which is likely to be amenable to measurement in the near future. Further, it is clear from earlier theoretical discussions (see, for example, Okun, Ann.Rev.Nucl.Sci., (1959); G. Dreitlein and H. Primakoff, Phys.Rev. 125, 1671 (1962)) that several fundamental issues are intimately related to this decay mode, among them the conserved vector current hypothesis, the nature of the $\Sigma - \Lambda$ interaction, and, possibly, the lifetime of Σ^0.

It is, of course, quite probable that definitive answers to the many basic questions relating to the weak interactions of strange particles will require extensive studies of angular correlations and spectra of a number of leptonic decay modes. Nevertheless, it seems likely that a crude comparison of the rate for the $\Sigma^- - \Lambda^0$ decay mode with known rates for

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*) Refer to an earlier letter of intention by C. Rubbia, in answer to which the EEC on 19 September 1962 invited submission of a full proposal.

other decays might be suggestive, at least, of the next steps to be taken experimentally and theoretically. Thus, it may well be that the branching ratio for the $\Sigma^- - \Lambda^0$ is much lower than the value ($\sim 2 \times 10^{-4}$) presently anticipated in somewhat questionable theoretical estimates, and that the strong interaction form factors in this case, as in strangeness changing Λ^0 and $\Sigma^\pm$ leptonic decays, are also appreciably less than unity. In this event, one might conjecture that conservation of strangeness is of less than primary importance in these decays. If, however, present theoretical estimates are borne out, the role of strangeness conservation will be enhanced and, further, detailed measurements of the properties of the decay mode become feasible.

For these reasons we have designed an experiment whose immediate aim is an accurate measurement of the branching ratio of $\Sigma^- \to \Lambda^0 + e^- + \bar{\nu}$, even if the branching ratio is less than that now expected by an order of magnitude, but which is also capable, if the decay rate meets expectations, of measuring correlations important to the decay process. For a branching ratio of 2×10^{-4}, this experiment, with an incident π^- beam current of 2×10^5 per pulse, should provide between 10 and 30 observed events per day (4×10^4 pulses) of PS operation, depending on details of the experimental arrangement. Of considerable importance is the fact that the proposed arrangement of spark chambers and counters is made to require the coincidence of a K^+ meson from the production process $\pi^- + p\ \Sigma^- + K^+$, and of an electron and a proton (in a specified energy range) from $\Sigma^- \to \Lambda^0 + e^- + \bar{\nu}$, $\Lambda^0 \to p + \pi^-$, before an event photograph is taken. Our calculations indicate that we should obtain one useful photograph for a maximum of 80 unusable ones, with the final discrimination being made from measurements of the pictures. Hence we expect a total of only 16×10^3 pictures to contain about 200 useful, analyzable events for 10 days of PS time, if the branching ratio is 2×10^{-4}.

In the event that the branching ratio is as low as 10^{-5}, we anticipate on the basis of a realistic rate calculation not less than one observed and identified event per day.

DISCUSSION

For an observed event to be useful, it is necessary that one be able to reconstruct from spark chamber photographs and counter responses the kinematics of the production and decay processes that define the event as completely as possible. A spark chamber containing polyethylene as the target material for the incident pions appears to suit these purposes admirably. First, it provides twice as many hydrogen atoms as a comparable liquid hydrogen target and, second, if the polyethylene is confined to a small region of the chamber, it permits at least part, and in many cases all, of the production vertex to be seen, as well as the electron and the vertex of the Λ^0 decay. In addition, it is quite likely (see below) that useful events will be produced on the protons of the carbon nuclei. There is, however, the danger that the presence of the carbon nuclei will enhance processes that might either reduce or simulate the events we seek, e.g., that Σ^- might charge exchange on carbon nuclei to yield Σ^0 with a sufficiently large cross-section to obscure Σ^- decay. Such processes are not yet adequately measured and are, of course, difficult to calculate accurately. In a mylar-enclosed hydrogen target the situation relative to such processes is much clearer and hence subject to quite accurate predictions.

It would seem that the choice of target material must necessarily, therefore, be made empirically and will require a test run. We plan to construct both a polyethylene-loaded spark chamber and also a mylar-enclosed liquid hydrogen target, and to provide for their interchangeability in the experimental arrangement. In what follows immediately, however, we discuss for simplicity only the polyethylene arrangement, but includes a figure (Fig. 2) showing schematically the experimental set-up using a liquid hydrogen target.

One of the proposed experimental arrangements is shown in schematic outline in Fig. 1. Spark chamber (S.C.) I contains, as indicated, 18.5 gm/cm^2 of polyethylene as the target for $\pi^- + p \rightarrow \Sigma^- + K^+$. [We do not, in calculating expected rates (except for background), include events produced in the carbon, although there is good empirical evidence from early work on associated production in propane bubble chambers that about one-half of the carbon events (one and a half times as many as hydrogen events) are not, within the error of measurement, disturbed by the Fermi momentum.] In S.C.I. one observes tracks of the incident π^- the K^+, the electron, and the p and π^- from Λ^0 decay (mean length for Λ^0 decay is 5 cm). In some number of events ($\gtrsim \frac{1}{2}$), the Σ^- with mean path length of 3.8 cm will also be observed. Immediately behind S.C.I. is a freon gas Cerenkov counter (at 3 atmos, pressure) with a threshold of 0.996c, intended to detect only electrons. This counter, which can conveniently be made of 2 cm thick aluminium and therefore shaped as shown in Fig. 1, subtends 60 per cent of the total solid angle available to the electrons from the $\Sigma^- \rightarrow \Lambda^0$ decay, and is expected to have a detection efficiency of 80%. Note that light is not collected from the central region of the Cerenkov counter through which the incident π^- beam passes. This sacrifices only 2 per cent of the electron solid angle (excluded from the value stated above) in deference to a minimum demand on the counter. Following the Cerenkov counter are a K^+ detector of design essentially identical to that used originally by Cork, Kerth, Wenzel, Cronin and Cool in experiments on the Σ and Λ decay asymmetry parameters, and a proton detector for the proton from Λ decay. The kinematics of the Λ^0 are, fortunately, such as to lend themselves to a restrictive detection scheme. Eighty per cent of all the resulting protons lie in the energy region between 100 and 300 MeV. The proton detector can therefore be made to detect only protons in that energy region and also, by means of S.C.II, to measure the proton energy.

Spark chambers I and II are triggered only by a coincidence of pulses in the π beam counter (S1), the Cerenkov counter, the K^+ counter and the proton counter. Because of the kinematics of the production process, the K^+ counter subtends 15 per cent of the total solid angle available to the K^+. The kinematics of the decay process provide a relative solid angle for the proton detector of 80 per cent. Using these values we obtain, with 80 per cent efficiency of the K^+ detector, and 2 x 10^5 incident π^- per pulse, a total of 20 $\Sigma^- \to \Lambda^0 + e^- + \bar{\nu}$ observed events per 4 x 10^4 PS pulses from the hydrogen in our target, if the branching ratio is 2 x 10^{-4}. Note that in this calculation of useful rate, have assumed a polyethylene target length of 20 cm and taken $\sigma(\Sigma^- K^+) = 0.27$ mb, which yields 86 Σ^- produced in the hydrogen per P.S. pulse. Also the efficiency for detection of the Λ^0 has been reduced by a factor of $\frac{2}{3}$, since only $\Lambda^0 \to p + \pi^-$ is detected, by a factor of 0.80 due to interactions in and geometry of the proton counter and by a factor of 0.80 for inability to recognize pions of energy less than 20 MeV in S.C.I. This value is subject to an increase by a factor of about 2 from events produced in carbon of the target.

We proceed now to consider background rates which are given in number of events per day of P.S. operation. We have attempted to calculate conservatively the background rates arising from a number of event chains that are mentioned below.

1) $\pi^- + p \rightarrow \Sigma^- + K^+$; $\Sigma^- \rightarrow n + \pi^-$; [illegible]; $\pi^- \rightarrow \pi^0 \rightarrow e$; 10

2) $\pi^- + p \rightarrow \Lambda^0 + K^+ + \pi^-$; negligible

3) $\pi^- + p \rightarrow \Sigma^0 + K^0$; $K^0 + p \rightarrow K^+ + n$; $\Sigma^0 \rightarrow \Lambda^0 + \gamma$; $\gamma \rightarrow e$; 50

4) $\pi^- + p \rightarrow \Sigma^- + K^+$; $\Sigma^- + p \rightarrow \Lambda^0 + n$; $\Lambda^0 \rightarrow p + e^- + \bar{\nu}$; negligible

5) $\pi^- + p \rightarrow$ non-strange particles; negligible

6) $\pi^- + p \rightarrow \Sigma^- + K^+$; $\Sigma^- + p \rightarrow \Lambda^0 + n$; $\Lambda^0 \rightarrow p + \pi^-$; $\pi^- \rightarrow \pi^0 \rightarrow e$; 1

7) $\pi^- + p \rightarrow \Sigma^- + K^+$; $\Sigma^- + p \rightarrow \Sigma^0 + n$; $\Sigma^0 \rightarrow \Lambda^0 + \gamma$; $\gamma \rightarrow e$; 5

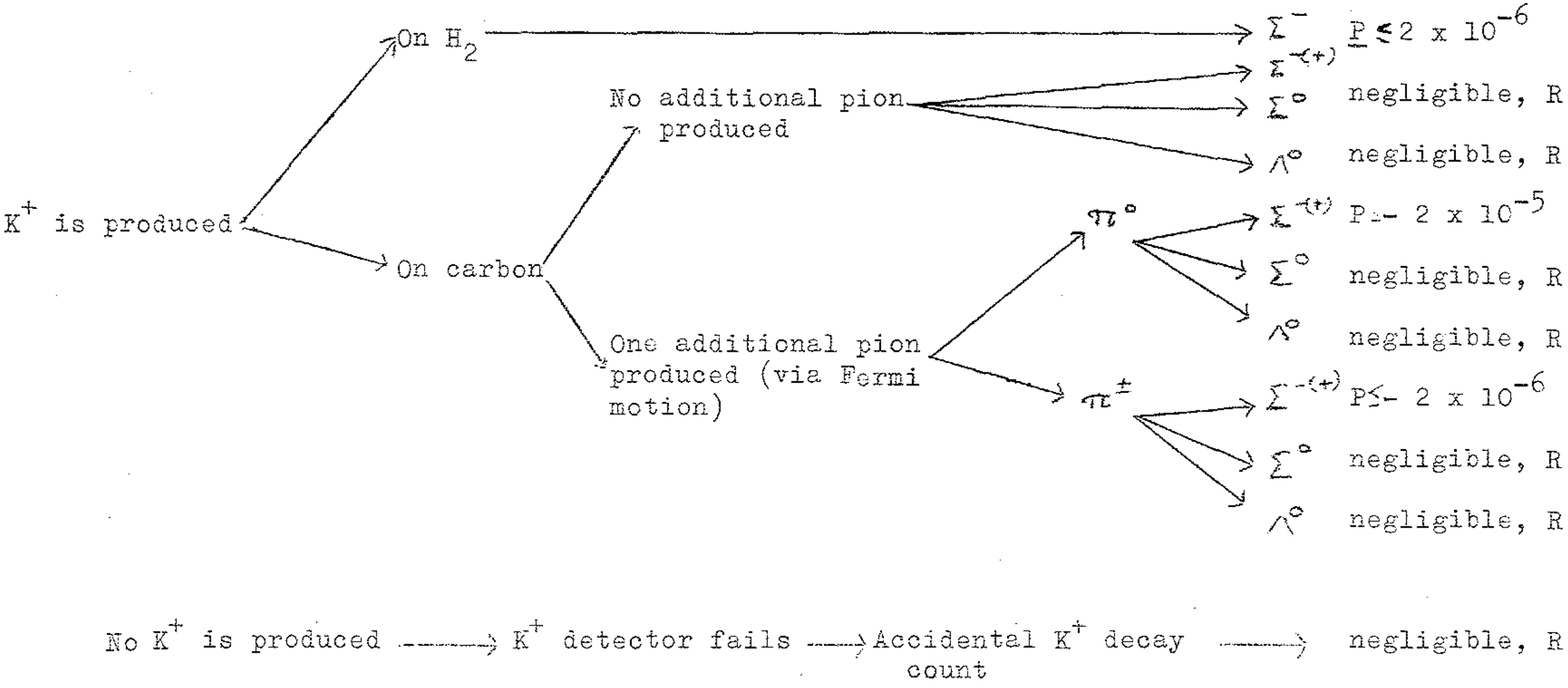
8) $\pi^- + p \rightarrow \Sigma^- + K^+$; $\Sigma^- + p \rightarrow \Sigma^0 + n$; $\Sigma^0 \rightarrow \Lambda^0 + \gamma$; $\Lambda^0 \rightarrow p + e^- + \bar{\nu}$; negligible

9) Accidentals; negligible.

The conclusion appears to be that the total trigger rate will probably not exceed 80 times the useful, observed event rate. Final selection of useful events will then be made from detailed measurements on the spark chamber photographs. In this connection, the problem of event reconstruction from track photographs of S.C.I. has also been considered; we sketch here the salient features. Consider that S.C.I. is constructed of, say, 5 mm thick polythylene plates and 5 mm gaps. The mean decay length of the Σ^- is 3.8 cm and its direction of motion makes an angle of $17^\circ \pm 2^\circ$ relative to the incident π^-. Hence about 90% of the Σ^- emerge from the polythylene plate in which they were produced and about 60% of all Σ^- traverse at least 2 gaps in the chamber. Let us assume here, however, that the track of the Σ^- is not observed, which is the most difficult situation in which to reconstruct the event. There are then three vertices that define an event: (1) the incident π^- K^+ vertex; (2) the electron, Λ^0 vertex; and (3) the Λ^0 decay vertex. Now roughly vertex (3) must lie in a volume defined by a cylinder of radius about 5 mm originating at vertex (1) with the axis of the cylinder making an angle of 17° relative to the π^- direction and lying in the plane determined by the π^- and K^+. This is because the Λ^0 is emitted at a maximum angle of $\pm 6^{\circ}$ relative to the Σ^- direction. Hence measurement of the Λ^0 vertex position alone specifies the incident π^-, Σ^- angle to $17^{\circ} \pm 8^{\circ}$. Further, measurement of the energy of the proton from Λ^0 decay in S.C.II leads directly to the direction of the Λ^0 which in combination with the electron track forms vertex (2), from which the uncertainty in the Σ^- angle can be reduced to less than $\pm 5^{0}$ In practice, it may not be necessary to find vertex ( ) explicitly. The reason for this is that vertex (1) can be localized within an ellipsoid with axes 5 mm x 3 mm x 3 mm, where the major axis is in the direction of the incident pion. We must, to eliminate almost all spurious events, only be sure that the electron track (which is localised to about ± 1 mm) does not intersect vertex (1). This will also eliminate about 10% of all useful Σ^- events, but ensure (with the exception of the 0.0025 cm thick aluminium sheets) that the Σ^- decay and/or the electron production took place in the spark chamber gas, i.e., outside the target materials where spurious events involving $\Sigma^- + p \rightarrow \Sigma^0 + n$ or $\Sigma^- + p \rightarrow \Lambda^0 + n$ can take place. We present in fig.3 a list genealogical tree of events that have been considered and which might result in track photographs simulating a real $\Sigma^- - \Lambda^0$ decay.

BACKGROUNDS IN RECOGNIZING THE EVENTS

FIG. 3



$\underline{P}$ indicates the apparent branching ratio due to the background event assuming for the processes the same production cross section as the $\Sigma^- K^+$ production cross section.

R indicates that the event may be recognized by reconstructing the production and decay points of the $\Sigma^- \rightarrow \Lambda^0 + e + \nu$

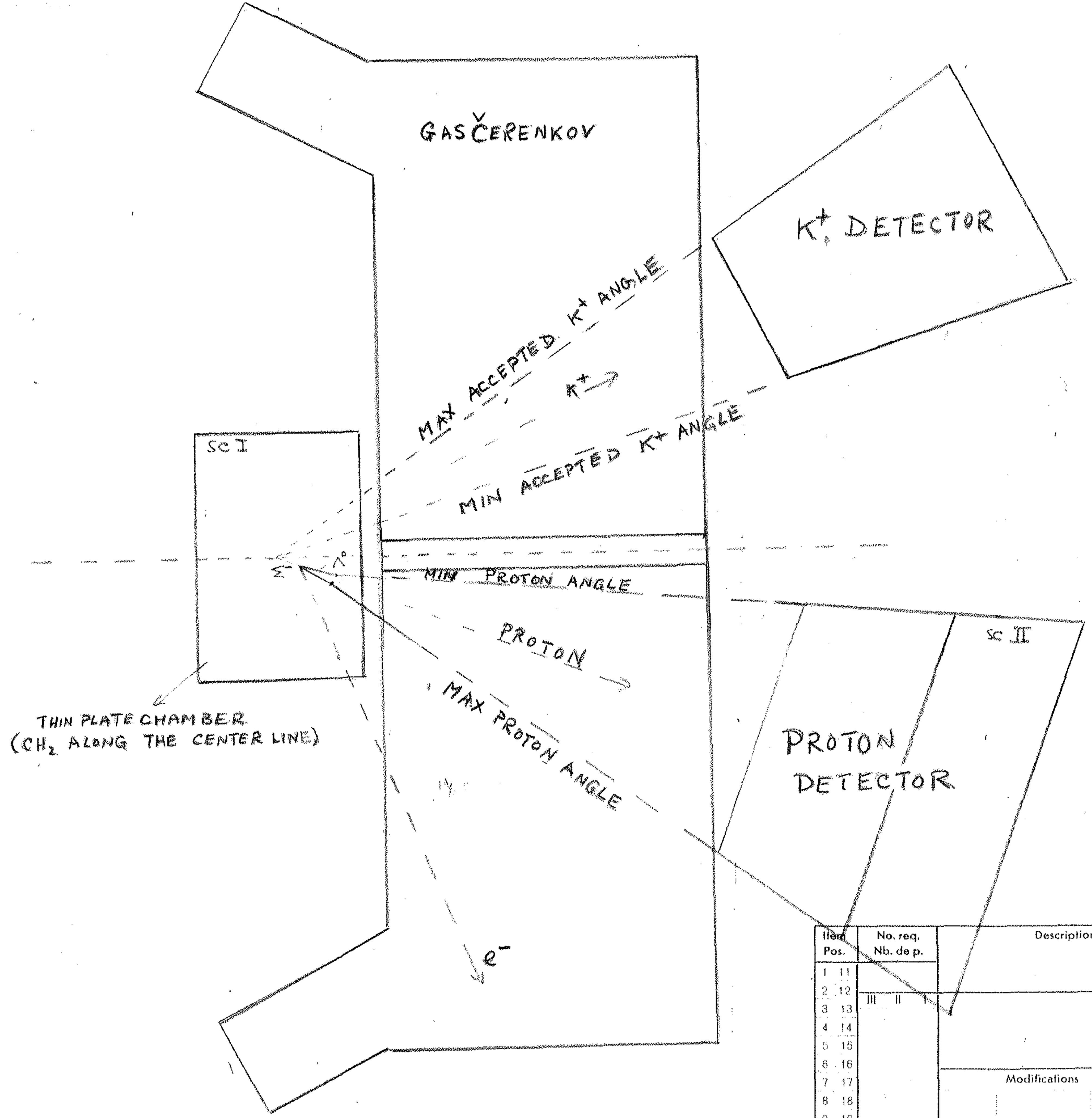


FIG. 1.

Item Pos.	No. req. Nb. de p.	Descriptions	Material Matière	Pattern Modèle	Observations
1 11					
2 12	III II I				
3 13		C		Scale Echelle	CERN-SC GENÈVE
4 14					
5 15					
6 16		Modifications		Signatures	
7 17					
8 18					
9 19					
10 20					

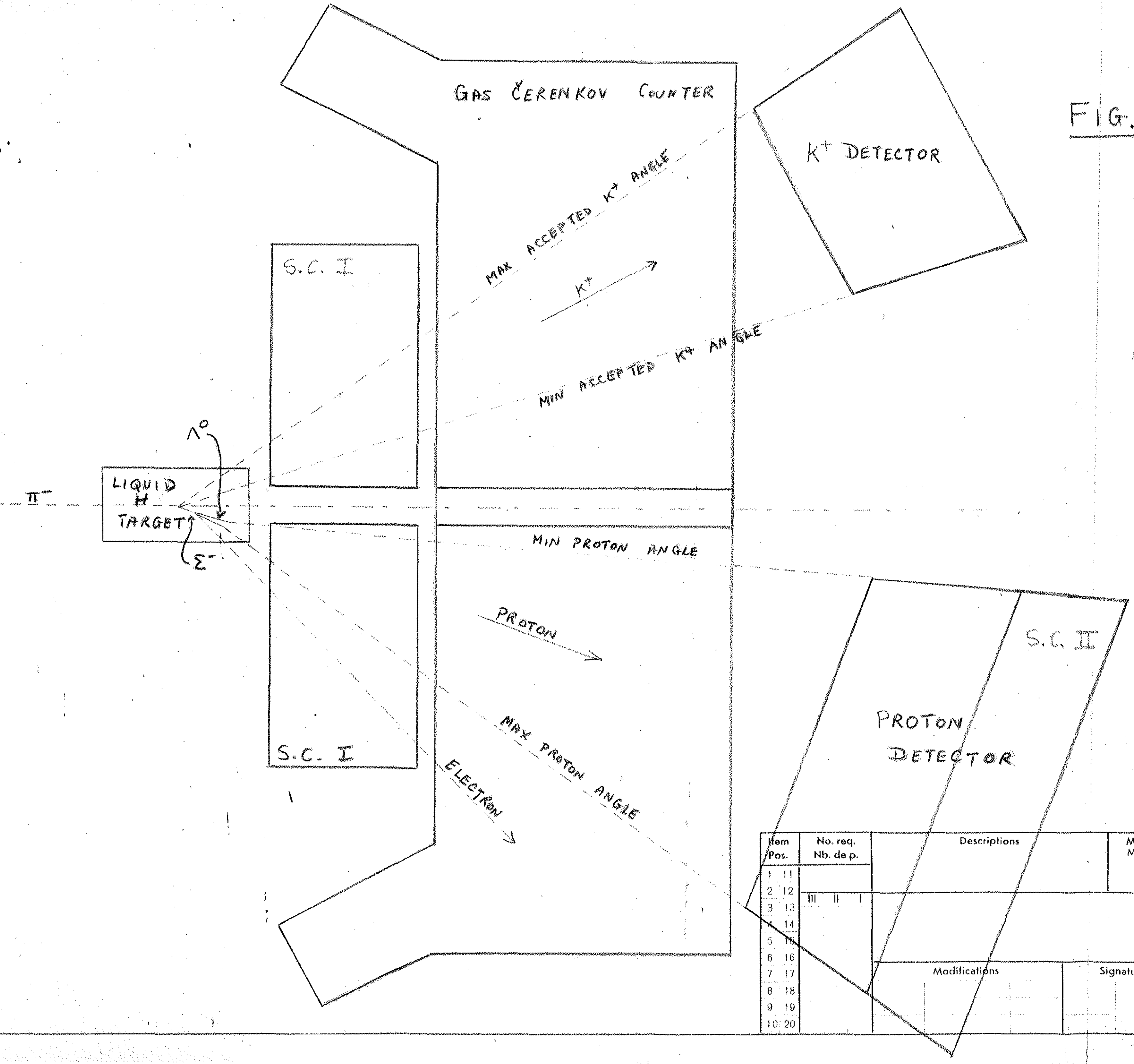


FIG. 2.

Item Pos.		No. req. Nb. de p.	Descriptions	Material Matière	Pattern Modèle	Observations
1	11					
2	12					
3	13	III II I			Scale Echelle	CERN-SC GENÈVE
4	14					
5	15					
6	16					
7	17		Modifications	Signatures		
8	18					
9	19					
10	20					