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PROPOSAL

SEARCH FOR π MESONS WITH THE ^{12}C BEAM AT THE CERN SC.

Cagliari[1] - Strasbourg[2] - Torino[3]
Collaboration

E. Aslanides[2], T. Bressani[1], E. Chiavassa[3], G. Dellacasa[3],
P. Fassnacht[2], F. Hibou[2], M. Gallio[3], A. Musso[3], G. Puddu[1]

1. INTRODUCTION

We propose the study of the coherent pion production on some light targets (Li, Be, C) using the future ^{12}C beam at the CERN SC. From the experimental point of view, the proposed experiment is an extension of exp. SC 75.

The interest in studying the pion production in nuclei has been stressed in the past[1].

The study of the coherent pion production in collisions between nuclei is aiming at interaction processes between these nuclei at high momentum transfers. Experimentally, one needs complete pion spectra, up to the kinematic limit, which, at a given center of mass energy, is given by the two body final state reaction. It is the high energy end of the inclusive pion spectra which contains the new physical information.

Indeed, in this region (Feynman's variable $X_F \to 1$) the analysis of the results in terms of the elementary process $NN \to NN\pi$ leads to the determination of very high internal momenta. If the high energy part of the spectrum shows a pion yield many times higher than the one estimated on the basis of the $NN \to NN\pi$ process we are in presence of coherent interactions between the nuclei. One then would need many such experiments as a function of the projectile energy per nucleon and as a function of the nuclear mass A to examine which is the underlying nuclear structure responsible for such a coherent production (density, shock waves, fluctuons, ...).

We already completed a first experiment[1] using the ^{3}He beam at the SC. The apparatus allowed the measurement of cross sections down to $10^{-37} cm^2/(sr.MeV/c)$ and made it possible to study the $(^{3}He, \pi^-)$ reaction on ^{6}Li and very recently on ^{9}Be, ^{12}C, ^{27}Al and Pb. The results on the ^{6}Li target have been analysed and are in course of publication[2], the latter ones are being analysed.

The theoretical analysis of the Li results shows :

a) that the high energy spectrum of the pions is decaying 100 - 1000 times slower than the $NN \to NN\pi$ estimates

b) that the Lorentz invariant doubly differential cross sections cannot be fitted by a unique $(1 - X_F)^n$ expression[3]. Up to $X_F \simeq 0.7$ the results are fitted by $(1 - X_F)^9$, beyond that point the exponent decreases rapidly to reach $n \simeq 4$ between $X_F = 0.9$ and 1.0.

c) strong evidence exists in favor of the existence of the doubly coherent two body final state pion production, i.e. of the reaction $^{3}He + {}^{6}Li \rightarrow {}^{9}C + \pi^{-}$, with an integrated (over ~ 20 MeV) cross section of ~ 1 pb/sr at $\theta_{LAB} = 0°$.

The proposed measurements using the future ^{12}C beam are an extension of and naturally following these first results. The interests in using the ^{12}C beam for the pion coherent production are essentially the following:

i) keeping the bombarding energy per nucleon constant, the use of heavier projectiles, increases the available center of mass energy, and therefore extends the upper limit of the double coherence reaction spectra. In that sense the influence of the elementary processes is decreased, since such a process would need much higher internal momenta to make themselves noticeable in the high energy pion region (see Table I).

ii) at 86 MeV/nucl all but the double coherence process are suppressed. As it is shown in Table I they all need the internal nucleon momenta. The maxima of the expected pion momenta from these reactions are well below the pion momentum of the two body final state.

The 606 MeV/c pion spectrum end point corresponds to internal momenta in the projectile k_p, and in the target, k_t, (collinear to the beam and in opposite directions) of about $k_p \simeq k_t \simeq 650$ MeV/c which is higher than in the ^{3}He experiment at 303 MeV/nucl, where $k_p \simeq k_t \simeq 550$ MeV/c.

2. EXPERIMENTAL APPARATUS AND LAYOUT

This should be conceptually identical to the previous one[1]. It should include a magnetic spectrometer with a solid angle of the order of 10^{-3} sr and with a momentum acceptance of about one percent and a detector system to identify the pions.

At the present time no final solution has been found for the experimental layout, although the installation of the experimental equipment at the end of pipe C is under study.

3. BEAM TIME

We ask for the full ^{12}C beam intensity.

A 20 shift run should be necessary for a first survey of the (^{12}C, π^-) reaction. Such a run should allow to learn how to deal with the new experimental conditions (beam, background, spectrometer) and the order of magnitude of the cross sections to be measured.

The absolute normalisation of the beam monitors would need a few more shifts.

No computer time is requested from CERN. We would like to get some electronic equipment from the EP Electronics Pool.

The scientific spokesman for the collaboration will be Dr.E.ASLANIDES.

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TABLE I

p_{π^-} max (MeV/c) for different processes using a 86 MeV/nucl ^{12}C beam and assuming different internal momenta

Reaction \ Internal momenta $k_p \simeq k_t$	none	150 MeV/c	200 MeV/c	250 MeV/c	300 MeV/c
$n\ n \rightarrow d\ \pi^-$	-	-	-	111	159
$n + {}^{12}C \rightarrow {}^{13}N\ \pi^-$	-	-	72	111	141
${}^{12}C + n \rightarrow {}^{13}N\ \pi^-$	-	78	144	184	217
${}^{12}C + {}^{12}C \rightarrow {}^{24}Al + \pi^-$	606	606	606	606	606

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GENEVA

1977

1. INTRODUCTION

We would like to perform a survey of $\pi^{\pm}$ production and an exploratory test on the possible production of K^{+} on nuclear targets, using the 910 MeV ^{3}He beam of the CERN SC.

The general idea underlying the motivation to search for meson production under or near threshold energies in N-N collision is the hope to put into evidence processes where the target nucleus and the projectile nucleus interact coherently. Whether high instantaneous nuclear densities lead to unusually copious $\pi^{\pm}$, K^{+} meson production or not, can be studied in nucleus-nucleus collisions where the energy of the projectile is of the order of a few 100 MeV/nucleon. Such experiments, looking for $\pi^{\pm}$ meson have been reviewed recently[1)] and include experiments performed at Berkeley, Dubna, PPA and Saclay. Due essentially to beam intensity limitations, these experiments extended down to cross section sensitivities of 1 μb/sr (generally integrated over a few tens of MeV pion kinetic energy). The production of pions with energies above the nucleon-nucleus production spectrum has been generally interpreted taking into account the single nucleon Fermi motion in the nuclei involved.

a) Survey of the $\pi^{\pm}$ meson production

Inclusive pion spectra, $^{3}He + A \rightarrow \pi^{\pm} + X$ will be measured with moderate resolution (a few %). As illustrated in Tables I and II in the case of the $^{3}He + {}^{6}Li \rightarrow X + \pi^{\pm}$ reaction, typical processes responsible for the pion production, range from the "incoherent" pion production in nucleon-nucleon collisions to the "doubly coherent" production in the two body reactions $^{3}He + {}^{6}Li \rightarrow {}^{9}Be + \pi^{+}$ and $^{3}He + {}^{6}Li \rightarrow {}^{9}C + \pi^{-}$.

From the same Tables (neglecting single nucleon momentum distributions in nuclei) one sees the considerable difference in the available maximum pion energies for these processes. We will comment only the positive pion production reactions.

The maximum pion energy in the NN collision process, corresponds to the $pp \rightarrow d\pi^+$ reaction (T_π <35 MeV). The differential cross section for this reaction as deduced from earlier experimental work[2)] is $(\frac{d\sigma}{d\Omega})_{0°\ CM} \simeq 0.117$ mb/sr or

$(\frac{d\sigma}{d\Omega})_{0°\ LAB} \simeq 0.703$ mb/sr.

The coherent pion production on ^6Li by a single nucleon would have a pion energy spectrum ending around 144 MeV. The differential cross section for this reaction leading to the first three bound states of ^7Li is $\lesssim 1$ μb/sr at Tp $\simeq$ 600 MeV[3)]. This is also a typical value for such reactions in light nuclei, in the 400 - 600 MeV region.

Production of pions due to ^3He interactions with single nucleons in the ^6Li target would lead to a pion spectrum ending at $\sim$254 MeV. To estimate the cross section of this reaction one needs the $p + {}^3He \rightarrow {}^4He + \pi^+$ cross section at a proton energy corresponding to the same total energy available in the CM system (this would be at Tp $\simeq$ 304 MeV). The lowest energy experimental data available (Tp = 415 MeV [4)]) corresponding to $T_{^3He} \simeq 1.24$ GeV, leads to a differential cross section at $0°_{LAB}$ of $\simeq$ 83 μb/sr for the ${}^3He + p \rightarrow {}^4He + \pi^+$ reaction.

Finally, coherent production from ^3He in the target can extend up to 620 MeV, which is the maximum kinetic energy of pions due to the two body reaction ${}^3He + {}^6Li \rightarrow {}^9Be + \pi^+$.

We intend to concentrate on the search of pions beyond the maximum energy pions produced in ^{3}He - nucleon collisions, in the hope to find evidence for double coherence effects in the interaction of ^{3}He with the ^{6}Li target.

The presently expected intensity for the future extracted ^{3}He beam at the CERN SC, 2×10^{12} sec^{-1}, would allow the search of coherently produced pions with a sensitivity level of less than 1 nb/sr (integrated over an energy interval of some %). The experiment would then scan the produced pion spectrum up to energies where the production cross sections are two or three orders of magnitude lower than in earlier experiments. Such exploratory measurements could also be useful in view of future experiments using heavier ion beams and/or high resolution spectrometers for the identification of the final nuclear states.

b) Search for Kaon production

The two body reaction

$$ {}^{3}_{2}He + {}_{Z}A \rightarrow {}_{Z+1,\Lambda}(A+3) + K^{+} \qquad (1) $$

induced by ${}^{3}_{2}He$ ions of 910 MeV is energetically allowed if nuclear targets with $A \geqslant 9$ are used. Fig. 1 shows the kinematics of reaction (1) for targets of ${}^{10}_{5}B$, ${}^{12}_{6}C$, ${}^{27}_{13}Al$ and ${}^{208}_{81}Pb$. One can observe that the maximum momentum of the produced K^{+} varies from $\sim$300 MeV/c to $\sim$585 MeV/c increasing A from 10 to 208. The angular variation of the K^{+} momentum is forward peaked for low mass targets and rather flat for heavy targets. Known or extrapolated values for B_{Λ} were used in the calculation of the kinematics.

Various three or multi-body reactions can also be responsible for K^+ production, but we think that the two-body reaction is the most interesting and potentially useful for future physics experiments. It is clear that the Kaons cannot be produced in single nucleon-nucleon collisions. The threshold for the $p + N \rightarrow K^+ + \Lambda + N'$ reaction is in fact about Tp = 1590 MeV, whereas the energy/nucleon for the incident ${}^3_2He$ beam is 303 MeV. A coherent Kaon production process could be the only process responsible for reaction (1). To our knowledge, there are no calculation or model for such a process. We could perhaps infer a possible value for the differential cross-section for reaction (1) from the observation that coherent production of π^0 from nuclei was observed with ${}^3_2He$ ions of 180 and 200 MeV[5]. The relative cross-sections, at 90°, were 2 and 7 pb/sr MeV for ${}^{12}C$ at 180 and 200 MeV, and 60 pb/sr MeV, at 90°, for ${}^{208}Pb$ at 200 MeV. The ratio of the ${}^3_2He$ kinetic energy for the Q-value of the reactions is rather similar to that for Kaon production and we thus put 1 pb/sr MeV as a tentative value for the differential cross-section for reaction (1).

2. EXPERIMENTAL APPARATUS AND LAYOUT

a) Search for $\pi^\pm$ production

The nuclear target under study could be installed in the vicinity of the present π production target on the extracted beam, and the magnetic elements of the secondary beam transport (B or C) could be used as momentum analysers for momenta up to $\sim$ 850 MeV/c. With this arrangement we could thus measure π production cross sections at 0°. Otherwise the nuclear target could be installed inside the first bending magnet of the beam transport and cross sections around 20° could thus be measured. Fig. 2 shows the foreseen arrangement. A second bending magnet will be installed at the end of the beam pipe to eliminate neutron background, and the detector arrangement will be installed after that. For the higher momenta (850 MeV/c) the unspent $^3He^{++}$ beam will be deflected by $\sim 14°$, towards the beam lines for π^+ detection, in opposite direction for π^- detection. The use of the actual vacuum box in the first bending magnet could thus raise problems of background and high dose rates. It seems thus better to have a simple He bag along the whole line from the target to the detectors.

The detector arrangement is shown in Fig. 3 and consists of three threshold Čerenkov counters with water or Lucite radiators, three planes of scintillator hodoscopes and a gas Čerenkov counter. The water Čerenkov counters select pions and faster particles (μ,e). The scintillator counters can be used for counting the total charged particles flux in a defined geometry and also select protons through dE/dx selection. The gas Čerenkov counter is used for the electron counting and rejection. A typical pion trigger can be definied as $\check{C}_{H_2O} \times S_{H_1} \times S_{H_3} \times \overline{(S_{H_1} \times S_{H_2} \times C_g)}$

Proton detection in the H_2O Čerenkov counters through knock-on-electrons will be suppressed by the use of several Č counters in coincidence and by the simultaneous dE/dx signature. Such a simple apparatus does not allow μ discrimination, but in the scope of the present exploratory measurement we will rely on a theoretical estimate of the $\pi \rightarrow \mu\nu$ decay. The μ contamination will of course be particularly important at lower momenta.

Expected counting rates and background

Assuming 2×10^{12} ^3He particles per sec, a ^6Li target of 1 g cm^{-2} and a minimum rate of 0.1 π/sec one deduces that in the above arrangement, with a solid angle of $\sim 10^{-3}$ sr, the detectable cross section limit is $\sim$ 1 nb/sr. The solid angle depends obviously on the final beam optics and we have taken there a rather pessimistic lower value. A check of the whole beam line acceptance could be done using the monoenergetic π^+ from the p + p → d + π^+ reaction of 600 MeV.

A first estimate of possible particle fluxes, including electrons and heavier secondary products such as protons or ^{3}He-particles lead to the conclusion that most of the "background" is due to protons. Table III shows a tentative estimate of the proton flux at $20°_{LAB}$. It is due to 4 10^{12} 303-MeV protons/sec (corresponding to the 2.10^{12} ^{3}He particles/sec in the 910 MeV ^{3}He beam) incident on a 1 gcm^{-2} ^{6}Li target.

The relevant cross sections have been estimated as follows : i) up to 650 MeV/c, the inclusive proton spectra observed by Cochran et al[6) with 700 MeV protons have been scaled down to 303 MeV using the total NN cross section energy dependence and kinematics.

ii) at 750 MeV/c the (p,pp) reaction should be predominant, for which the pp elastic cross section[7)] has been used taking into account the energy spread of the observed proton spectrum.

iii) at 800 MeV/c the (p,p) reaction should be predominant. The p- ^{4}He elastic scattering cross section[8)] has been used for this reaction, again taking into account the energy spread of the observed protons.

iv) finally the p- ^{6}Li elastic scattering differential cross section[9)] has been used for the 813 MeV/c (Tp = 303 MeV) point.

The background rates of ∿ 1 MHz are still tolerable for single particle counting and identification only if the scintillator planes are hodoscopes. These calculated backgrounds should be several orders of magnitude larger at 0° and thus the protons must be eliminated by an absorber at the end of the pipe. For the π^- measurements the above rates should be down by several orders of magnitude and no particular problems are expected. There is still the choice between pipes B and C, depending mainly on the background and radiation safety conditions. A proper measurement of backgrounds in the presence of the intense ^{3}He beam is of first priority, in any case.

b) Search for K^+ production

In a previous letter of intent[10)] we presented a possible set-up for K^+ detection. We believe that a carefull measurement of backgrounds is absolutely necessary before presenting a defined apparatus and set-up. With the beam transport lines tuned at 400 - 500 MeV/c we could do an exploratory test with the described apparatus, despite of the long distance between the production target and the detectors.

3. ABSOLUTE NORMALIZATION OF THE MEASURED CROSS SECTION

A survey of the available data of the ^{11}C production through carbon bombardment by protons, deuterons, tritons and alpha particles, shows that the ^{11}C production with ^{3}He beam at 910 MeV should have a cross section of 45 mb, within a uncertainly of 20 %. However, it would be better to measure this cross section by reducing the ^{3}He beam intensity to such a level that individual counting of ^{3}He ions becomes possible. After, this activation cross section can be used to calibrate the beam monitors (scintillation telescopes or secondary emission chambers). A Faraday cup could be very helpfull for a further absolute calibration of the beam intensity.

4. REQUIRED MACHINE TIME

A total of 30 shifts is estimated as necessary for the study of the π^- and the π^+ production on ^6Li. Following results, possible extension to other targets and K^+ production will be considered. No computer time is requested to the CERN. We would like to get from the EP Electronic Pool fast electronic modules.

The scientific spokesman for the collaboration will be Dr. E. ASLANIDES.

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TABLE I

Possible π^+ production reactions induced by 910 MeV ^3He ions in ^6Li

Reaction	$T_{projectile}$ (MeV)	threshold (MeV)	$T_{\pi^+}(0°_{LAB})$ (MeV)	$P_{\pi^+}(0°_{LAB})$ (MeV/c) β
$pp \to d\pi^+$	303.3	288.6	$\leq$ 34.8	$\leq$104.5 0.599
$p\,^6Li \to {}^7Li\pi^+$	303.3	159.4	$\leq$143.6	$\leq$246.4 0.870
$^3He\,p \to {}^4He\pi^+$	910	488.1	$\leq$253.8	$\leq$366.9 0.935
$^3He\,^6Li \to {}^9Be\pi^+$	910	183.5	$\leq$620.1	$\leq$746.8 0.983

TABLE II

Possible π^- production reactions induced by 910 MeV ^3He ions in ^6Li

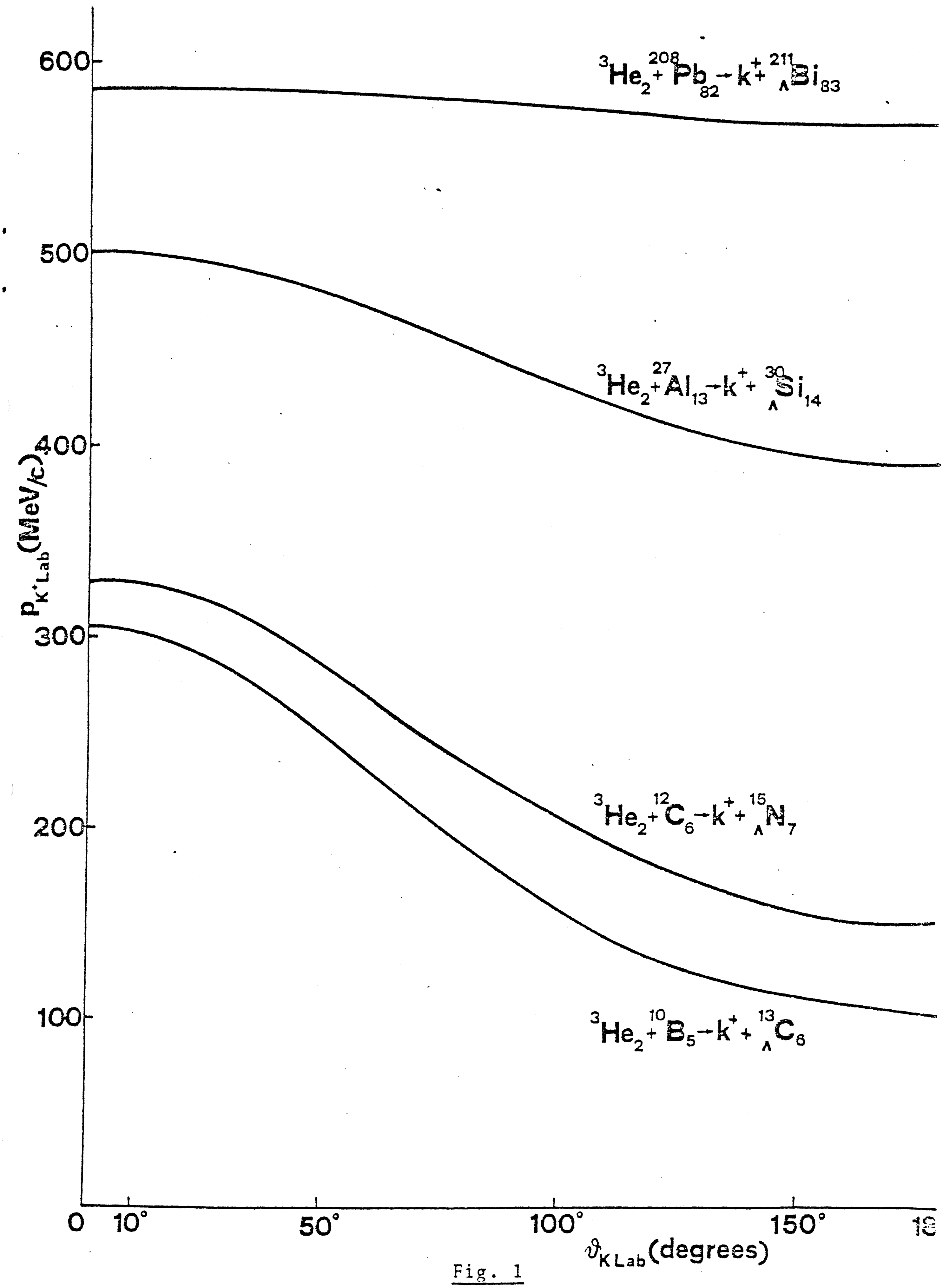
Reaction	$T_{projectile}$ (MeV)	threshold (MeV)	$T_{\pi^-}(0°_{LAB})$ (MeV)	$P_{\pi^-}(0°_{LAB})$ (MeV/c) β
$nn \to d\pi^-$	303.3	281.9	≤ 41.5	≤115.4 0.637
$n\,^6Li \to {}^7Be\,\pi^-$	303.3	158.9	≤144.1	≤247.0 0.871
$^3He\,n \to {}^4Li\,\pi^-$	910	581.2	≤212.4	≤323.1 0.918
$^3He\,^6Li \to {}^9C\,\pi^-$	910	220.6	≤590.1	≤716.2 0.981

TABLE III

Proton counting rates at $\theta_{LAB} \simeq 20°$ due to 303 MeV protons.

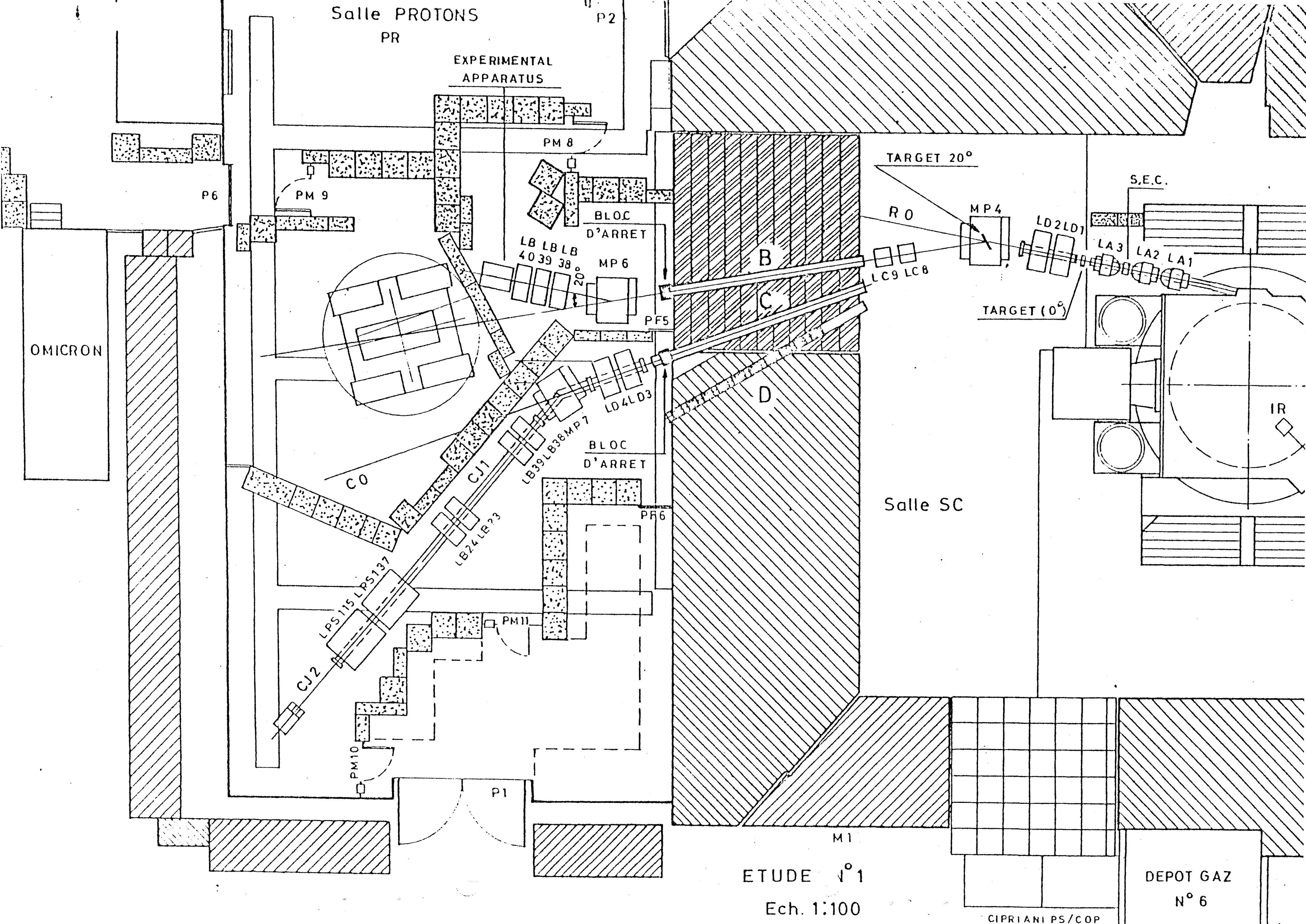
All rates correspond to a 10 MeV proton energy interval.

P_p(MeV/c)	T_p(MeV)	N_p(Sec^{-1})
200	21	$4.8\ 10^5$
250	33	$1.6\ 10^6$
300	47	$1.8\ 10^6$
350	63	$1.9\ 10^6$
400	82	$1.8\ 10^6$
450	102	$1.7\ 10^6$
500	125	$1.4\ 10^6$
550	149	$9.7\ 10^5$
600	175	$5.5\ 10^5$
650	203	$7.8\ 10^4$
750	263	$8.0\ 10^6$
800	297	$2.3\ 10^6$
813	303	$1.8\ 10^4$



$^{3}He_{2} + {}^{208}Pb_{82} \to k^{+} + {}^{211}_{\Lambda}Bi_{83}$
$^{3}He_{2} + {}^{27}Al_{13} \to k^{+} + {}^{30}_{\Lambda}Si_{14}$
$^{3}He_{2} + {}^{12}C_{6} \to k^{+} + {}^{15}_{\Lambda}N_{7}$
$^{3}He_{2} + {}^{10}B_{5} \to k^{+} + {}^{13}_{\Lambda}C_{6}$
600
500
400
300
200
100
$P_{K^{+}Lab}$ (MeV/c)
0
10°
50°
100°
150°
$\vartheta_{K\,Lab}$ (degrees)

Fig. 1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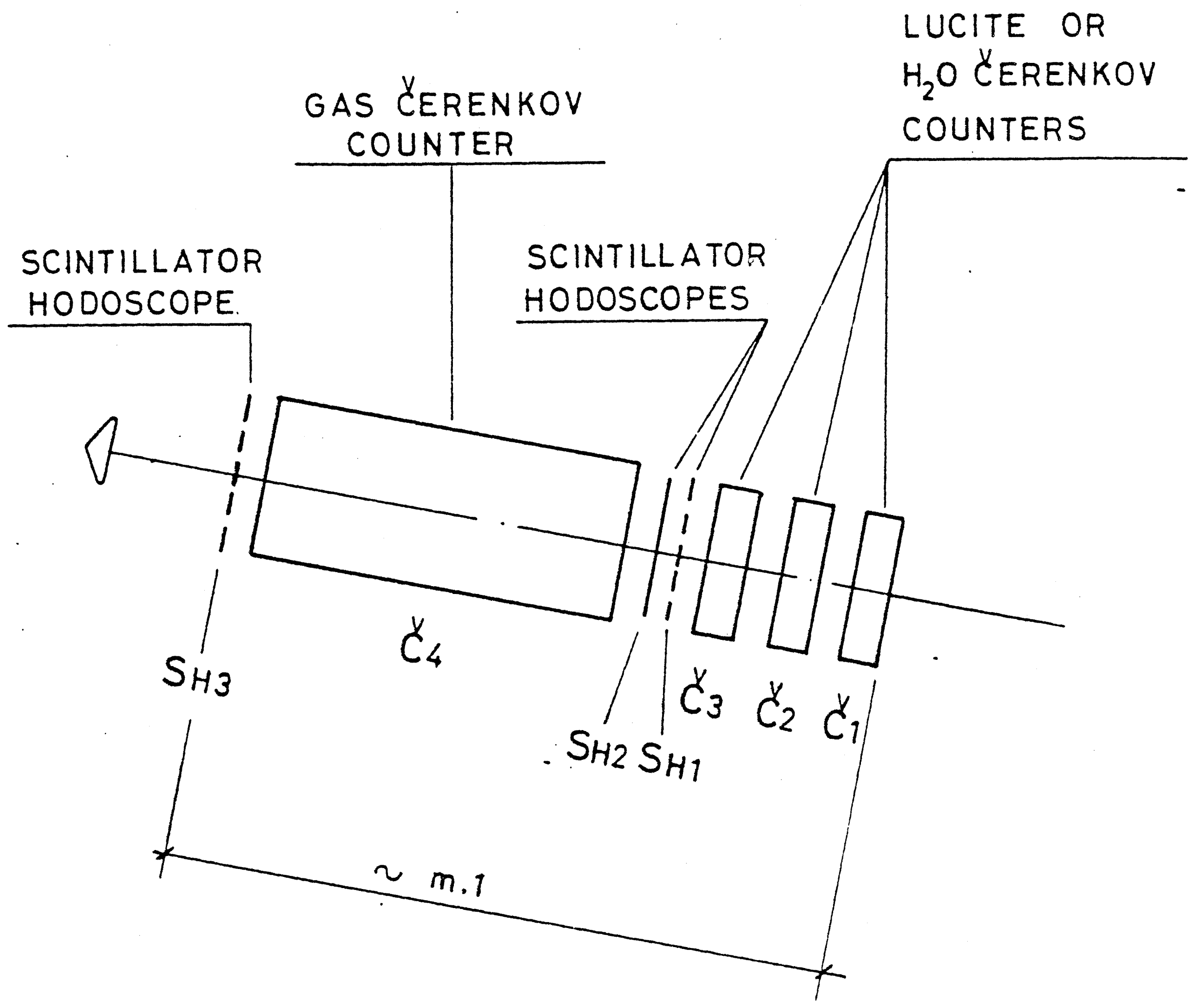
LUCITE OR
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Fig. 3