EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/TCC 74-21
July 12, 1974

AN EXPERIMENT TO STUDY RARE K_S DECAYS USING THE 180 LITRE ITEP BUBBLE CHAMBER IN A K^+ BEAM OF THE CERN PROTON SYNCHROTRON

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ABSTRACT

It is proposed to study rare K_S meson decays (with statistics of about 10^6 K_S) by means of the ITEP xenon bubble chamber in a K^+ beam of the CERN proton synchrotron.

The principal purpose of the experiment is the search for the CP violating decays: $K_S \to 3\pi^o$, $K_S \to \pi^+\pi^-\pi^o$ and $K_S \to 2\gamma$ decays. Some other rare processes are also considered. This experiment allows us to study the branching ratios at a level of 10^{-5}.

To carry out the proposed program we request a total of 1.5 10^6 bubble chamber pictures using a 0.85 GeV/c momentum separated K^+ beam.

CONTENTS

1. PHYSICAL AIMS OF THE EXPERIMENT

It is proposed to study rare K_S^o decays using a sample of about $10^6 K_S$ mesons. The main aim of the experiment is to measure the CP violating processes such as $K_S \to 3\pi^o$, $K_S \to \pi^+\pi^-\pi^o$.
Are also of interest the following rare decays: $K_S \to 2\gamma$ [2], $K_S \to e^+e^-$, $K_S \to \pi^+\pi^-\gamma$, $K_S \to \pi^o\pi^o\gamma$.

Furthermore results will be obtained on $\Delta I = 1/2$ selection rule through the measurement of $K_S \to \pi^o\pi^o$ / $K_S \to \pi^+\pi^-$ and of $K_L \to \pi^+\pi^-\pi^o$ and the total decay rate of K_L mesons. Dalitz plot analysis of $3\pi^o$ final state will also be done.

To carry out these investigations we propose to expose the 180 litre ITEP xenon bubble chamber [1] to a separated K^+ beam with a momentum of 0.85 GeV/c. A total amount of 1.5 10^6 pictures can be considered as the first step in this study. The 0.85 GeV/c K^+ momentum has been chosen because it corresponds to the maximum of the K^+ charge exchange cross section, and because in this momentum region the background due to π^o production associated with the K^o is minimum.

The discovery of CP non invariant $K_L \to \pi^+\pi^-$ decay in 1964 stimulated an intensive search for CP non invariant effects and a lot of information has been gained. Nevertheless the parameters η_{000} and η_{+-o} have not yet been measured with high precision. It is very important at this stage of knowledge to improve their measurement, also because their values are required, quite heavily, for reaching a better accuracy of the CPT invariance test through the Bell-Steinberger unitarity relation [3]. Furthermore a better knowledge of the η_{000} and η_{+-o}

parameters, will help in prouving or disprouving some theoretical models of CP violation.

The best experimental result for the η_{+-o} parameter was obtained by the CERN - Orsay - Vienna collaboration [4] as a result of the analysis of 384 events of the type $K^o \to \pi^+\pi^-\pi^o : |\eta_{+-0}|^2 < 0.27$.

For the η_{000} parameter, only one experimental result exists [5]: $\eta_{000} < 1.1$, obtained through the analysis of 22 $K^o \to 3\pi^o$ decays.

The investigation of the $K^o \to 3\pi^o$ decay is a difficult experimental task as one has to detect all 6 γ and to measure their energies. These difficulties were solved in the experiment with the xenon bubble chamber as shown in [5].

In order to obtain more precise values of the η_{000} and η_{+-o} parameters, it is necessary to increase the statistics and, at the same time, to have several independent checks such as the possibility of having time distributions for different kind of decays to check the geometrical and differential efficiencies and to evaluate correctly the absorption of the K^o mesons as a function of time. In the proposed experiment we expect to analize about 2200 $K^o \to 3\pi^o$ and about 1800 $K^o \to \pi^+\pi^-\pi^o$ decays.

Another decay which could be studied in this experiment is $K_S \to 2\gamma$. The present upper limit for the branching ratio is BR $(K_S \to 2\gamma) < 4 \div 7\ 10^{-4}$ [6,7].

The theoretical prediction of BR$(K_S \to 2\gamma)$ is $10^{-5} \div 10^{-6}$ assuming CP conservation. However, considerably larger values of BR $(K_S \to 2\gamma)$ are not excluded as a result of CP violation in this decay [9].

In the same film, other rare decay processes may also be studied, as it will be discussed in part 4.

2. EXPERIMENTAL CONDITIONS

As noted above, to study $K_S \to 3\pi^o$, $K_S \to \pi^+\pi^-\pi^o$ and $K_S \to 2\gamma$ decays we propose to expose the 180 litre ITEP liquid xenon bubble chamber in a separated K^+ beam with a momentum of 0.85 GeV/c from the CERN proton syncrotron. K^o mesons will be produced by the charge exchange reaction of K^+ mesons on xenon nuclei. The K^o decays will be identified by their final products: i.e. 2γ, 4γ, 6γ and $\pi^+\pi^-2\gamma$ events ($K^o \to 2\gamma$, $K^o \to 2\pi^o$, $K^o \to 3\pi^o$ and $K^o \to \pi^+\pi^-\pi^o$ respectively).

The volume of the chamber is 104 x 44 x 40 cm^3. In general, the efficiency for γ detection in this chamber is about 100%, due to the fact that the radiation length of the liquid xenon is very short (3,8 cm): the average efficiency for detection of a γ from K^o decays produced in our experimental conditions is 0.95.

The total track length method is used for measuring the γ's energy. The accuracy of this method is $\sim$ 20% at 0.1 GeV, and $\sim$ 10% at 1.0 GeV. The average error of the angular measurement is $\sim 2^o$. The invariant mass of a $K^o \to 3\pi^o \to 6\gamma$ is measured with a relative error $\Delta M/M \sim 10\%$ [12].

The K^+ beam in the proposed experiment enters the chamber along the axis (see fig. 1). The region ABCD corresponds to the effective volume where the interactions of K^+ mesons with the xenon nuclei will be selected. This region is 60 cm long starting at a distance of 8 cm from the entrance to the chamber. If the momentum of the incoming K^+ beam is 0.85 GeV/c the momentum of the K^+ mesons in this volume will be 0.56 to 0.81 GeV/c which corresponds to the maximum of the charge exchange cross section of the reaction $K^+ + d \to p + p + K^o$ [10] (fig. 2).
In this K^+ momentum region the background from the reaction

$K^+ + n \to K^o + \pi^o + p$ is negligible even if it represents $\sim$1% of the charge exchange cross-section, because the analysis will cut it. Therefore it is possible to use the K^o decays starting at about 5 mm from the origin, i.e. in the most interesting τ/τ_S region (see fig. 4).

The yield of K_S mesons in the $K^+ + Xe \to K^o_S$ anything reaction is about 10% as calculated from the optical model of the nucleus for an average momentum of $\sim$0.7 GeV/c. The probability of an interaction of K^+ mesons with xenon on a length of 60 cm is 0.7. The number of K_S mesons per picture will be 0.7 having 10 K^+ mesons per pulse, that is the total number of K_S mesons will be about 10^6 for 1.5 10^6 pictures. Of course, the same number of K^o_L will be produced.

The characteristics required for the separated K^+ beam are the following:

1) the incoming beam should have 0.85 GeV/c momentum
2) the intensity of the beam should be 10 K^+ per pulse
3) the π^+ and p contamination in the beam has to be less than 1%, and that the μ mesons less than 10%
4) the vertical size of the beam should be 7÷8 cm
5) a good shielding of the chamber consisting of concrete, lead and paraffin would be required

A schematic view of a possible position of the xenon bubble chamber in the K^+ beam is shown in fig. 3. The experiment can be run parasitically with the 2 meter hydrogen bubble chamber exposures (from the 1975).

3. KINEMATICAL ANALYSIS OF THE K^o DECAYS. THE PROCESSING PROGRAMS.

The mathematical programs for the kinematical analysis of the 2γ, $2\pi^o$, $3\pi^o$ and $\pi^+\pi^-\pi^o$-K^o decays have been elaborated [12]. The programs are written in C.F.L. for the computer BESM-6. The programs allow us to calculate the probabilities for a given event to fit the chosen hypothesis and to improve the disentangling of the signal from the background. As input informations are used to measured values of the kinematical parameters of the γ's and $\pi^{\pm}$ mesons and the measurement errors. Each γ or charged π meson is characterized by three kinematical parameters: the momentum p, azimuthal angle ϕ and dip angle λ.

The generalized method of least squares with indefinite Lagrangian multipliers is used in the programs which consist of the following steps [13]:

1) the vector of measured variables m^o is constructed using the measured values of the kinematical parameters
2) the vector of the unknown variables x consists of the kinematical parameters of particles that are not measured
3) there are the constraints f(m,x) over vectors m and x expressing energy-momentum conservation laws
4) the weighting matrix of the measured kinematical parameters of the tracks is calculated due to the error matrix G_m^{-1}
5) the function to be minimised, $\chi^2(m,x,\alpha)$ is
$$\chi^2(m,x,\alpha) = (m-m^o)^T G_m^{-1} (m-m^o) + 2\alpha^T f(m,x)$$
where m is the current value of the vector of measured variables, α the vector of indefinite

Lagrangian multipliers, and the superscripts have the following meaning: o,T,-1 label the experimental data, matrix transposure and matrix inversion, respectively.

The minimum χ^2 is found solving the equation system obtained requiring that derivatives of χ^2 over m, x and α to be equal to 0. This system of equations is solved by iterative steps relative to x,m and α. At the first step the measured values are taken for the vector m, and the vector x is calculated from the conservation laws. The main characteristics of the programs for different decays are given in table 1.

The output data of the programs are the number of iterations, χ^2, m, Δm, x and Δx. The programs described have been used for studies of a number of rare decays of the K_S and K_L mesons [5,7,14].

4. THE UPPER LIMITS BR($K_S \to 3\pi^o$) AND BR($K_S \to 2\gamma$) TO BE REACHED IN THE EXPERIMENT AND OTHER ITEMS.

Assuming the absence of $K_S \to 3\pi^o$ and $K_S \to 2\gamma$ decays, the upper limits for BR($K_S \to 3\pi^o$) and BR($K_S \to 2\gamma$) that can be reached in the experiment are evaluated.

The number of K_L mesons generated in the chamber is equal to the number of K_S mesons, $N_{K_L} = N_{K_S} = 10^6$. The number of $K_L \to 3\pi$ decays in the chamber, evaluated in a quite conservative way, is equal to $N_{K_L \to 3\pi} = \ell / L \cdot \alpha \cdot a \cdot N_{K_L}$, where ℓ is the average potential length of the K meson in the chamber, $\sim$30 cm, L is the decay length (pc τ/m_K=1550 cm) for an average momentum of 0.5 GeV/c, α is the decay probability of the $K_L \to 3\pi$: $\alpha_{3\pi^o} = 0.21$ and $\alpha_{\pi^+\pi^-\pi^o} = 0.13$. Taking into account the $K_L \to 3\pi$ detection efficiencies in the chamber ($a_{3\pi^o} = 0.55$ and $a_{\pi^+\pi^-\pi^o} = 0.75$) we obtain $N_{K_L \to 3\pi^o} = 2200$ and $N_{K_L \to \pi^+\pi^-\pi^o} = 1800$, i.e. 5 times more than the number of $K^o \to \pi^+\pi^-\pi^o$ decays obtained by the CERN-Orsay-Vienna group [4], and 100 times more than the number of $K^o \to 3\pi^o$ experiment [5]. ($N_{K_L \to 3\pi} = 4000$ events althougether).

The time distribution $N(t, x_0, y_0)$ of $K_S \to 3\pi$ decays with six different sets of parameters x_0 and y_0 is shown in fig. 4. The curve A gives $N(t, x_0, y_0)$ with $x_0 = 0$ and $y_0 = .2$, B with $x_0 = 0$ and $y_0 = -.2$, C with $x_0 = y_0 = 0$, D with $x_0 = -.2$ and $y_0 = 0$, E with $x_0 = -.2$ and $y_0 = 0$ and F with $x_0 = -.2$ and $y_0 = -.2$.

The η_{000} parameter was calculated by the maximum likelihood method using several samples of 2200 $K_L \to 3\pi^o$ decays generated by a Monte Carlo Method.

The decays were distributed at the time t at random according to the distribution C. This gives $|\eta_{000}|^2 < 2.5\ 10^{-2}$ and $BR(K_S \to 3\pi^o) < 10^{-5}$ with a 90% confidence level.

Approximately the same value can be reached for the $|\eta_{+-0}|^2$. Furthermore the ratio $R = N_{000}(t)/N_{+-0}(t)$ can be measured. Due to the fact that the events are produced and analysed under the same experimental conditions the ratio is bias free, so that no essential corrections are needed. If the true values of η_{000} and η_{+-0} are the same, the events ($K_S \to 3\pi^o$ and $K_S \to \pi^+\pi^-\pi^o$) can be added together and the analysis can be done over the total sample.

The upper limit for $BR(K_S \to 2\gamma)$ was estimated also by the maximum likelihood method using χ^2 distributions of the $K_S \to 2\gamma$ events and the background events arising from $K_S \to 2\pi^o$ decays (fig.5). Monte Carlo calculations show that 0.1% of the $K_S \to 2\pi^o$ decays may simulate 2γ events. A χ^2 analysis of these events showed that the upper limit for the $BR(K_S^o \to 2\gamma)$, for 10^6 K_S^o, is $4 \cdot 10^{-5}$ (fig.5).

Hence this method allows us to study the branching ratios of $K_S \to 3\pi$ and $K_S \to 2\gamma$ decays at a level of approximately 10^{-5}.

There is the additional possibility to carry out other investigations using the same pictures besides studying CP violating decays, which is the main aim of this axperiment.

First of all, it is possible to search for other rare K_S decays such as $K_S \to e^+e^-$ and $K_S \to \pi^o\pi^o\gamma$.

As it is presently understood, the probability of a $K_S \to e^+e^-$ decay must be smaller than $BR(K_S \to \mu^+\mu^-) < 3 \cdot 10^{-7}$ [15] . The experimental data on $BR(K_S \to e^+e^-)$ have reached only the level (for the branching ratio) of 3.5 10^{-4} and it would therefore be desirable to decrease this level.

It is interesting also to study $K_S \to \pi^+\pi^-\gamma$ decays, for which the decay probability is about 10^{-3}, so that $\sim 10^3$ events will be produced.

The radiative $K_S \to \pi^o\pi^o\gamma$ decay has not yet been studied at all. In comparison with $K_S \to \pi^+\pi^-\gamma$ decays, the $K_S \to \pi^o\pi^o\gamma$ decay probability has to be much smaller, as the dipole radiation is absent in this case and the probability of the direct quadrupole radiation is essentially smaller [16].

Secondly, it should be rather important to study the Dalitz plot distribution of $3\pi^o$ from K^o decay; some information can be reached on the $\Delta I = 1/2$ selection rule through the measurement of the ratio $K_L^o \to 3\pi^o / K_L^o \to \pi^+\pi^-\pi^o$ and the value of τ_L, total decay rate of the long-lived component, could be obtained as an internal check.

Another interesting value which can be obtained in the experiment is the ratio $K_S^o \to 2\pi^o / K_S^o \to \pi^+\pi^-$ which in this single experiment can be measured with a precision of $\sim 0.1\%$.

In Table 2 a summary of existing values is reported together with the values that we can get in this experiment.

5. CONCLUSIONS

It is proposed to undertake the study of the rare K_S decays by means of the ITEP Xenon bubble chamber exposed in a K^+ beam from the CERN proton synchrotron by a joint team of ITEP and Padova physicists.

The principal purpose of the program consists in studying CP violating decays: $K_S \to 3\pi^0$, $K_S \to \pi^+\pi^-\pi^0$ and the $K_S \to 2\gamma$ decays; some other rare process may also be investigated using the same film, and some results can be obtained on the $\Delta I=1/2$ selection rule and the $K^0 \to 3\pi^0$ decay structure (final state interactions).

The ITEP measuring rate for $K \to 3\pi$ events is ~ 2000 events per year, the Padova rate is ~ 1000 events per year.

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TABLE I

N	Decay	n_f	n_m	m	n_x	x	n_c	n_r
1	$K\to 2\gamma$	4	6	$P_{\gamma 1}\ldots\lambda_{\gamma 2}$	1	P_K	3	1
2	$K\to 3\pi^o$	7	18	$P_{\gamma 1}\ldots\lambda_{\gamma 6}$	1	P_K	6	15
3,1	$K\to\pi^+\pi^-\pi^o$	5	12	$P_{\pi 1}\ldots\lambda_{\gamma 2}$	1	P_K	4	1
3,2	$K\to\pi^+\pi^-\pi^o$	5	11	$P_{\pi 1}\ldots\lambda_{\gamma 2}$	2	$P_K;P_{\pi 1}$	3	1
3,3	$K\to\pi^+\pi^-\pi^o$	5	10	$P_{\pi 1}\ldots\lambda_{\gamma 2}$	3	$P_K;P_{\pi 1};P_{\pi 2}$	2	1

n_f = number of the constraint equations
n_m = number of measured parameters
m = vector of measured parameters
n_x = number of unknown parameters
x = vector of unknown parameters
n_c = number of degrees of freedom
n_r = number of fitting hypotheses

FIGURE CAPTIONS

Fig. 1 The photographed volume of the Xenon Bubble Chamber and effective volume for scanning of K^o-production.

Fig. 2 The dependence of $K^+d \to K^o pp$ cross section from K^+-momentum.
The dotted curve that of $K^+n \to K^o \pi^o p$ reaction.

Fig. 3 A schematic view of the Xenon Bubble Chamber on K^+ beam.

Fig. 4 The time distribution of $K^o \to 3\pi$ decay: without taking into account the geometrical efficiency.

C $x=0$, $y=0$
A $x=0$, $y=.2$
B $x=0$, $y=-.2$
D $x=.2$, $y=0$
E $x=-.2$, $y=0$
F $x=.2$, $y=.2$

Fig. 5 χ^2-distribution of the $K^o \to 2\gamma$ decay (curve A), curve B is background distribution from $K_S^o \to 2\pi^o$ decay.

TABLE 2

	Present experimental values	Expected upper limits and/or relative errors (statistical)
$\lvert\eta_{000}\rvert$ assuming $R_e(\eta_{000})=0$	<1.2(90% C.L.)	$<5\cdot10^{-2}$
$\lvert\eta_{+-0}\rvert$ at real part=0	<027(90% C.L.)	$<5\cdot10^{-2}$
B.R.($K_S\to2\gamma$)	$<.4\cdot10^{-4}$	$<4\cdot10^{-5}$
B.R.($K_L^o\to3\pi^o$)	(21.5±0.8)% / rel.err.=3.7%	rel.err. <3%
B.R.($K_L^o\to\pi^+\pi^-\pi^o$)	(12.6±0.3)% / rel.err.=2.4%	rel.err. <3%
$\frac{\Gamma(K_L\to3\pi^o)}{\Gamma(K_L\to\pi^+\pi^-\pi^o)}$	1.65±0.07 / rel.err. = 4%	rel.err. 3.%
$\frac{\Gamma(K_S\to\pi^+\pi^-)}{\Gamma(K_S\to2\pi^o)}$	2.207±.029 / rel.err.=1.4%	rel.err. <.1%
B.R.($K_S\to\pi^o\pi^o\gamma$)	no existing data	$\leq10^{-4}$
B.R.($K_S\to\pi^+\pi^-\gamma$)	$(2.3\pm0.8)10^{-3}$ / rel.err. = 35%	rel.err. <10%

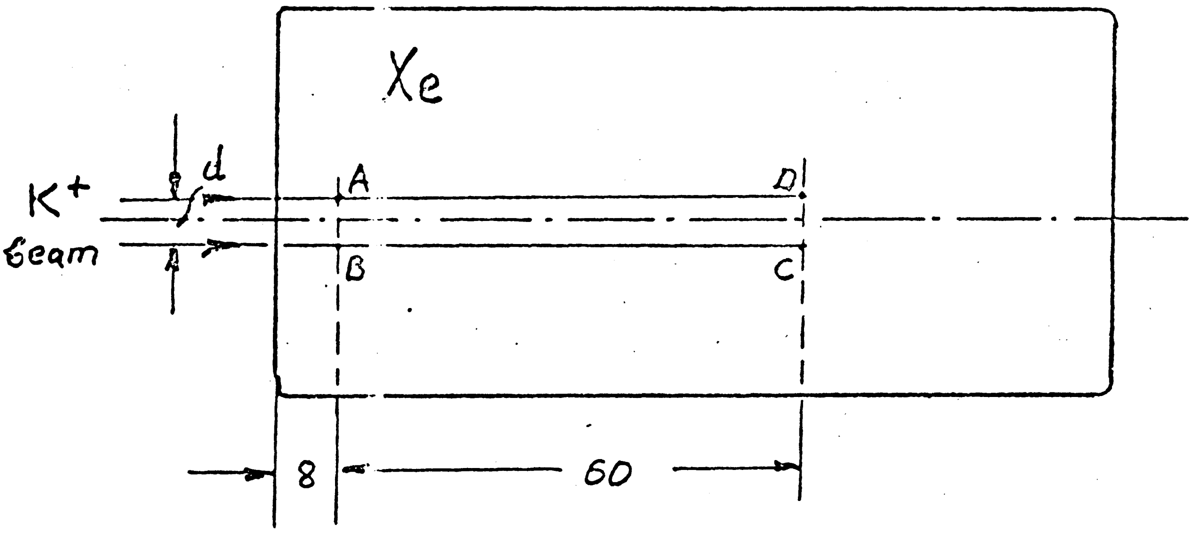
Xe
K+
beam
d
A
B
C
D
8
60

Fig. 1.

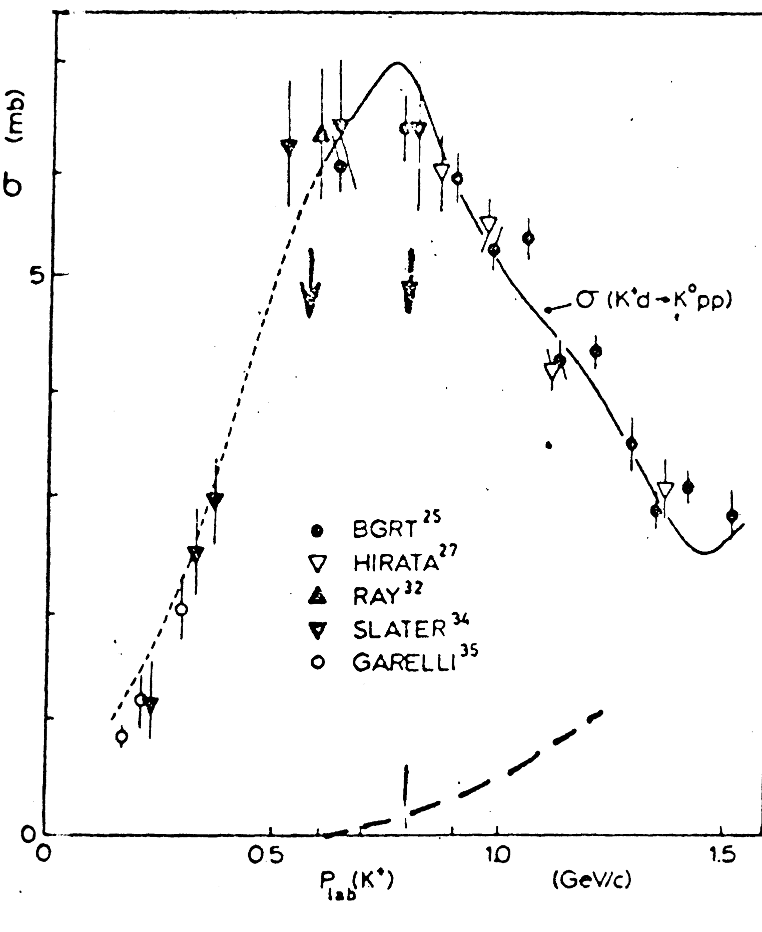
σ (mb)
5
0
0
0.5
1.0
1.5
P_lab(K+)
(GeV/c)
σ (K+d → K°pp)
BGRT 25
HIRATA 27
RAY 32
SLATER 34
GARELLI 35

Fig. 2.

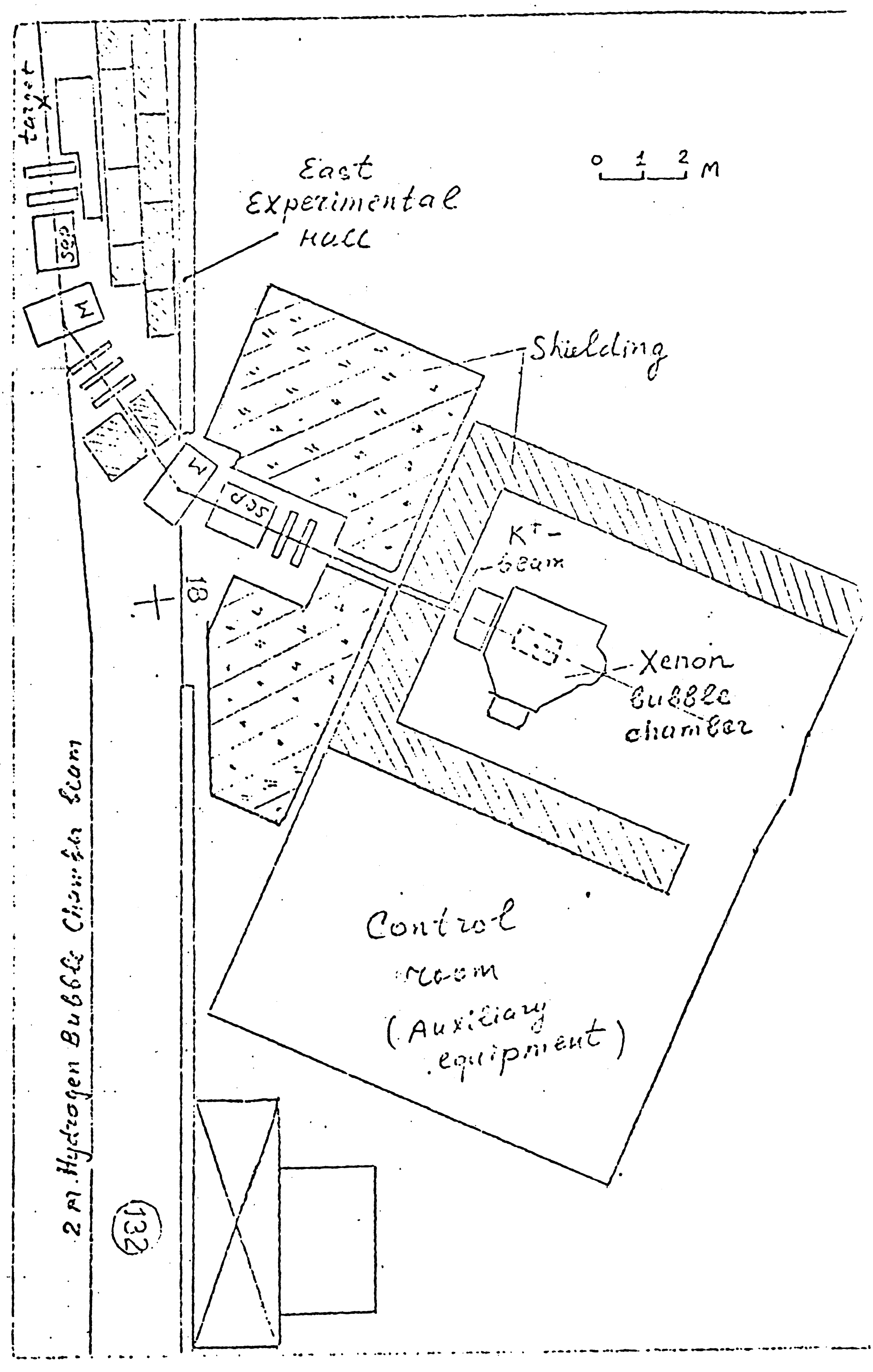
target
East
Experimental
Hall
0 1 2 M
Shielding
K^+-beam
Xenon
Bubble
chamber
18
Control
room
(Auxiliary
equipment)
2 m. Hydrogen Bubble Chamber beam
132

Fig.3

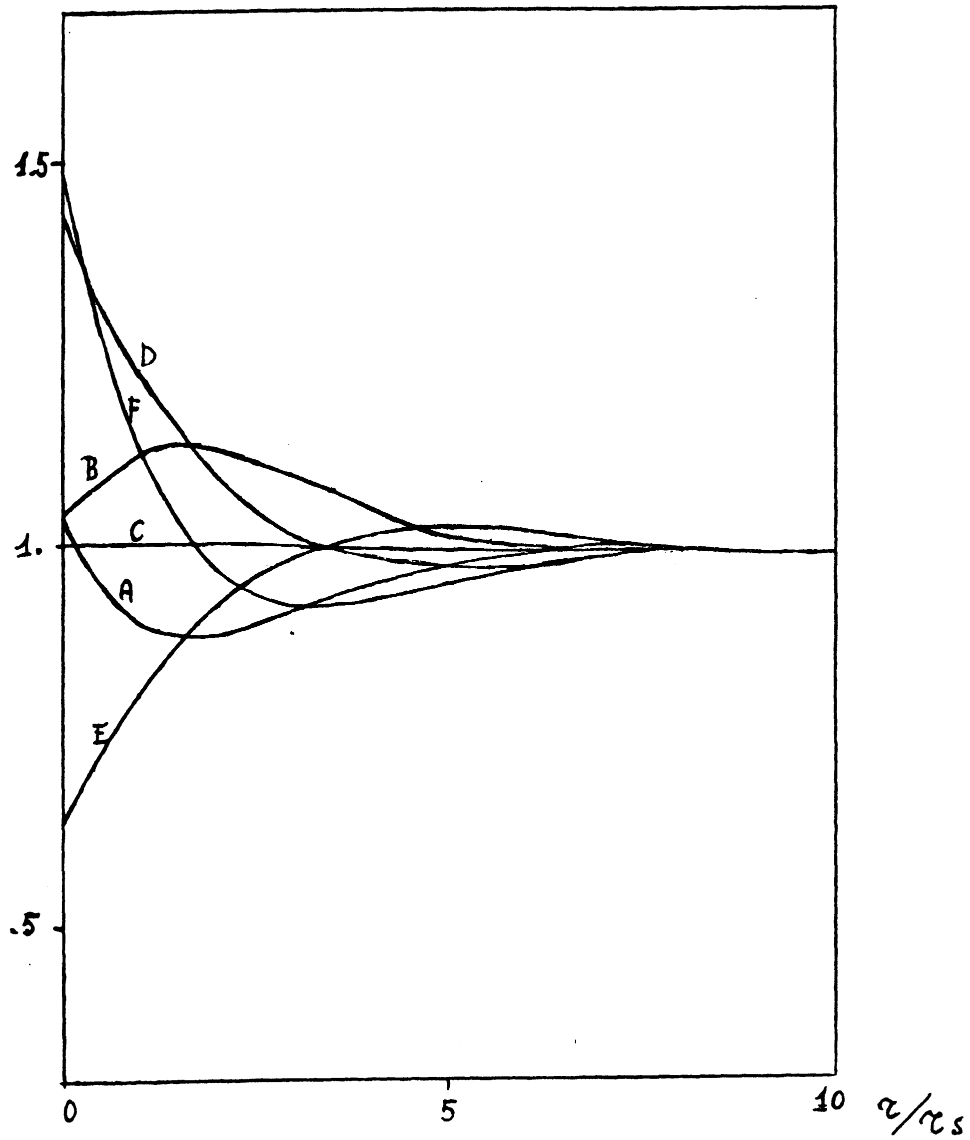

Fig. 4