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LETTER OF INTENT

STUDIES OF MUON AND PION INTERACTIONS WITH HEAVY NUCLEI

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SUMMARY

In continuation of experiments at Dubna on muon-induced fission and on the production of high-spin isomers in π^- capture, we outline a possible continuation of this programme at the improved CERN Synchro-Cyclotron. This programme should start with a study of muon-induced fission with an improved detector system, which is already being developed. Subsequent experiments would search for the possible formation of beta-delayed fission activity and for high-spin isomers decaying by fission.

If our general programme can be approved, we shall as early as possible submit an estimate of data rates/sensitivities together with a request for machine time. Already now we propose a test programme requiring approximately 12 shifts.

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1. INTRODUCTION

The recent development of the theory[1)] of the nuclear energy surface has led to better understanding of the fission process. The calculations show the important role of the shell effects at larger deformations, leading to a second minimum of the potential-energy well at the saddle point of a heavy nucleus. Within the framework of this theoretical approach various experimental facts can be understood, notably the resonances in the excitation function of fission below and near the fission barrier and also the previously observed occurrence of spontaneously fissioning isomers.

The identification of a rotational band in the ^{240}Pu fission isomer observed by Specht et al.[2)] strongly supported the hypothesis of shape isomerism. But there is still a strong need for a more direct experimental verification of the assumed larger deformation of the nuclear charge.

In this respect the study of the fission of muonic atoms seems of interest. As it was pointed out by Wheeler[3)], then calculated by Zaretski and Novikov[4)] and recently refined by Leander and Möller[5)], the binding energy of the muon in its 1s orbit changes considerably with the nuclear deformation (figure 1). It leads to changes in the potential barrier which make the isomeric state in the presence of a muon quite different from that for the bare nucleus. If this can be checked experimentally, the existence of shape isomeric states could be regarded as a proved fact.

In the last few years an experimental programme has been developed in Dubna in μ^--induced nuclear fission. As a first stage the systematics of the absolute yields of prompt and delayed fission for heavy isotopes from thorium to plutonium has been obtained$^{6)}$. Also the muon mean-lives in these isotopes have been measured. These experiments form the basis for a planned experiment to search for the shape-isomeric states excited in muonic radiationless transitions. The basic idea is to discriminate against fission arising from nuclear muon capture by detecting the electrons from the free decay of muon after the fission.

A preliminary experiment has recently been performed in Dubna with the indication of a positive result (see subsection 3.1 and figure 3).

On the other hand it seems that the studies of the fission phenomena for isotopes far from the stability line may also represent a sensitive check on Strutinski's model.

Using reactions with high-energy protons one can try to look for delayed-fission activity excited in nuclear beta decay of the parent nucleus. Indications on such a process, which is analogous to the delayed emission of protons and α-particles$^{9,10)}$, was reported in Dubna for heavy-ion reactions$^{11)}$.

The recent discovery in Dubna$^{12)}$ of the π^--induced selective excitation of high-spin metastable states in heavy nuclei may be used to look for the de-excitation of such states by spontaneous fission. Measured mean life-times could be compared with the model predictions for such light isotopes, in which the two-humped barrier practically disappears so that only one, relatively thin, barrier is viewed from excited states in the first well.

Further work along these lines is in progress in Dubna, but as it seems that the improved CERN Synchro-Cyclotron will offer much better conditions for this research, we are now proposing to continue the experiments there. In the following the main features of the experimental techniques and of the scientific programme are outlined.

2. EXPERIMENTAL TECHNIQUES

The main experimental problems will be encountered in connection with the study of muon-induced fission, and for this reason only the technique for this experiment will be discussed in detail. (Most likely this experiment will be carried out first - see section 4.)

To a large extent will the apparatus be the same as used in earlier work, see figure 2. The main new features will be the following:

a. The new, fast multi-plate ionization chamber, which is now under construction, will contain about 15 g of ^{238}U. It will work with an efficiency of at least 50% and have timing characteristics defined by a FWHM $\lesssim$ 4 ns for prompt coincidences γ-f. The chamber will be divided into five sections independently coupled to separate preamplifiers. The chamber is designed to also permit the detection of a muon re-emitted from the fission fragments; this improves the overall efficiency, as was found in our preliminary experiment (see figure 3), by 50%.

b. The scintillation counter used for detecting the electrons (figure 3) will be replaced by a Čerenkov counter. The high-energy electrons originate from the beta decay of a muon, either captured at fission fragments, or, re-emitted and stopped in the aluminium surrounding of the fissile material. The Čerenkov detector will have the shape of a box surrounding the fission chamber. It is expected that the efficiency of this counter will be near 90% corresponding to an improvement of a factor of two to three over the scintillation counter used in first experiments.

c. The electronics should develop the timing signals from all detectors (this circuit includes fast linear schemes, CFT units, integral discriminators), combine them to obtain the main three signals indicating the time of appearance of a μ-stop, a fission event and an electron passage by the counter. All three time distributions between each two of them must be measured, with and without the presence of the third event.

In addition, a separate treatment is necessary for all events in which more than one muon arrives during the period of interest. It is also foreseen to operate the chamber in a pulsed proton (or π^-, ^{3}He) beam with a timing ranging from seconds to minutes.

3. GENERAL SCIENTIFIC PROGRAMME

3.1 Muon induced fission

As has been pointed out by Wheeler$^{3)}$ the change of the binding energy of the muon in a 1s orbit as a function of the nuclear deformation causes the fission barrier to increase substantially. Such an increase for the two-humped barrier means a considerable isomeric shift and a change of the mean life-time of the spontaneously fissioning isomer. For these reasons the early experiments concentrated on the so-called prompt fission$^{6)}$, which most probably is induced by the radiationless muonic transitions 2p-1s, so that the corresponding energy of about 6 MeV is transferred directly to the nucleus. In this process only dipole fission channels $(I,K^{\pi}) = (1,0^-)$ and $(1,1^-)$ can be involved.

On the other hand is the multipolarity not determined in the excitation curves recently measured for photofission, although a pronounced resonant structure was revealed$^{7)}$.

The data available until now have stimulated the question whether the shape isomeric states can be excited in a resonance manner by the radiationless muonic transitions.

Kaplan et al.$^{8)}$ tried to find the γ-decay branch of the shape isomeric state in a muonic ^{238}U atom, and gave an upper limit of 1% per μ-capture. The search for the fission decay branch during the last year performed at Dubna has given an indication of a positive result with the effect being of the order of 0.2% per μ-capture (e.g. comparable with the prompt fission yield). At the present moment, however, this observation can also be interpreted as the delayed fission of a muonic atom induced by the free decay of a muon in its orbit.

The experiments now in preparation should attempt to explain the origin of the delayed events and should aim for much better statistics permitting a good determination of the mean decay period, which in itself should be useful in elucidating the origin of the delayed events. The measurement should also be repeated with other targets, especially ^{232}Th and ^{235}U.

In the experiment three time distributions will be measured between μ-stop and 1) fission event, 2) electron appearance and, finally, 3) between the last two events. The last distribution will definitely indicate whether we are dealing with a new type of nuclear fission induced by the free decay of a μ^-, as only a prompt distribution will allow such an interpretation. In any other case we shall be able to state that we observe the delayed fission of the nucleus of a muonic atom excited in radiationless transition of μ^-.

If the time distribution between μ-stop and the appearance of an electron will confirm the result obtained in the experiment quoted above, then more accurate data on the probability of muon re-emission from the fission fragments should be obtained.

3.2 High-energy protons induced fission

It has been reported in Dubna$^{11)}$ that in heavy-ion reactions the beta-delayed fission of light Np and Hm isotopes had been observed. Speculatively, the nature of this activity may be explained analogously to delayed-proton$^{9)}$ or delayed-alpha radioactivity.$^{10)}$ Through the use of a high-energy proton beam (and, in future, the ^{3}He beam foreseen at CERN) with uranium targets, we could try to search for activities of this kind by measuring the time distribution of the fission events in our chamber respectively the bursts of a pulsed proton beam. A wide region of life-times, from a fraction of a second to many minutes, should be explored in this relatively simple measurement.

3.3 π^--capture induced fission

The other approach to the problems of fission of nuclei far from the stability line is to use the π^--capture mechanism to excite high-spin metastable states$^{12)}$ in these nuclei and to search for a delayed fission activity using the fission chamber. The experimental technique should be as discussed in subsection 3.2.

4. INITIATION OF THE PROGRAMME

The search for shape-isomeric states excited in muonic atoms seems to be the logical choice for the first experiment in the programme sketched above. However, our knowledge of the data rates and of the experimental conditions at CERN does not suffice for an evaluation of the data rates in this experiment. We therefore ask for a preliminary allocation of 12 shifts for testing for preliminary data taking. Of these 12 shifts, 6 would be devoted to:

a. testing the chamber and the Cerenkov counter;

b. tests of the muon beam and the choice of the intensity, the collimation and the focusing for the experiment;

c. background measurements.

If this first step is successful, one could, after a period reserved for modifications, carry out the first, preliminary measurement, again estimated at 6 shifts.

The fission chamber with the preamplifiers and the Cerenkov counter should be taken to CERN from Dubna. If necessary, the telescope counters and some linear electronics could also be taken, but technical problems with the adoptation would then be unavoidable. It would be extremely convenient if we could borrow standard electronics as well as a data handling system from CERN. Depending upon what is available, the block-diagram of the experimental set-up used in Dubna (see figure 4) may need some modification.

We foresee participation of physicists from CERN member countries in this experiment.

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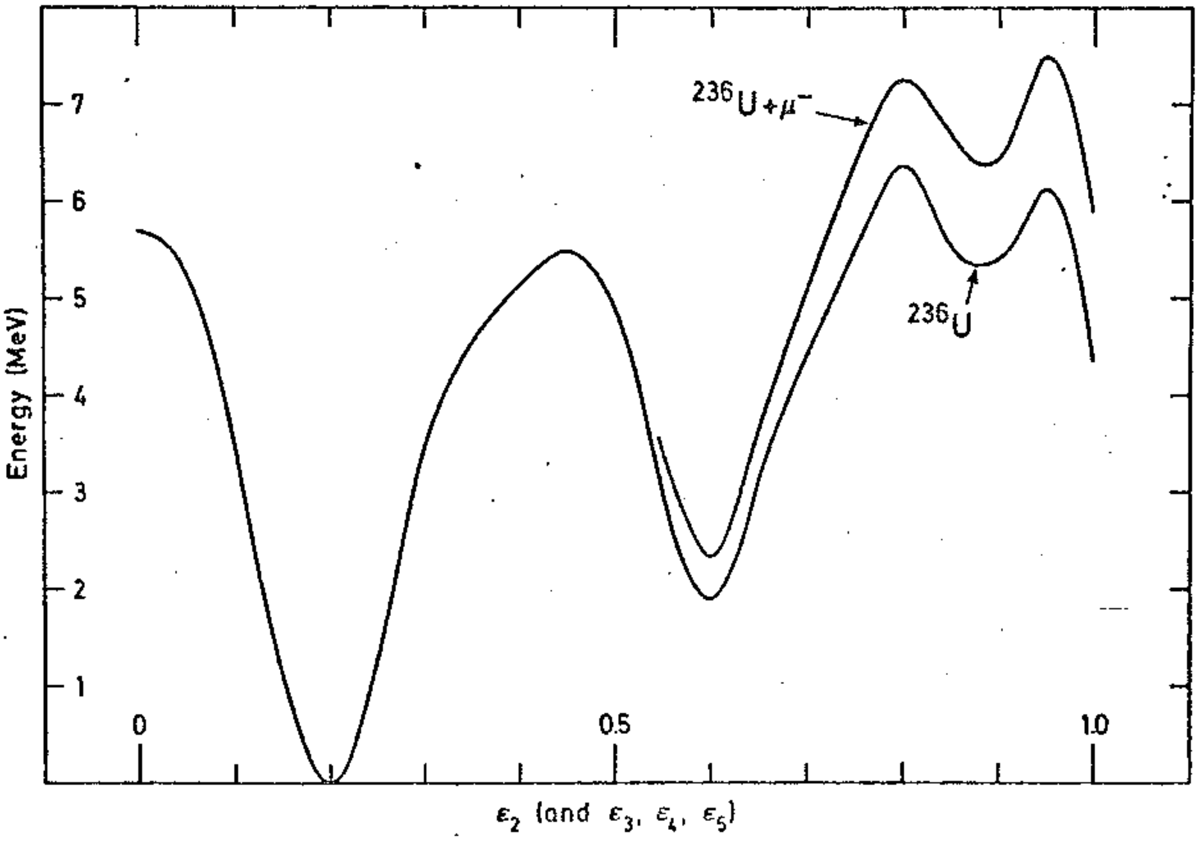

Figure 1

The deformation energy, minimized with respect to higher multipoles, for the nucleus ^{236}U (lower curve) and for the muonic atom $^{236}U + \mu^-$ (upper curve).[5)]

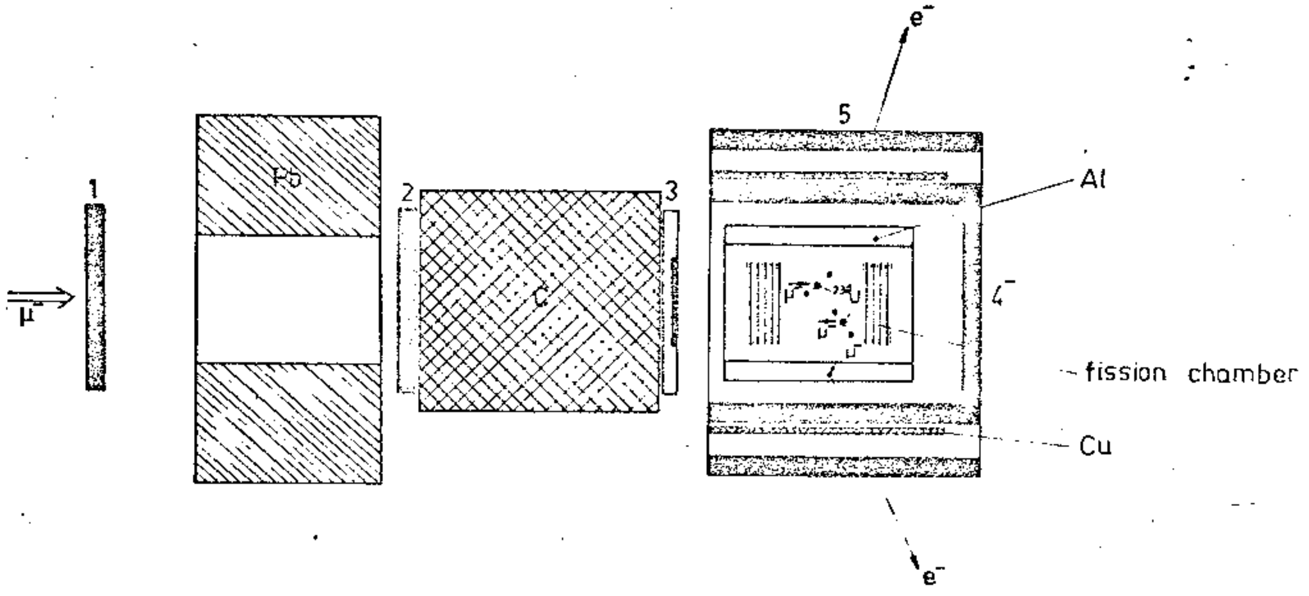

Figure 2

Detection system for the observation of muon-induced fission. A muon stop number is recorded by the conventional $123\bar{4}$ telescope, while subsequent fission and muon-decay events are detected by the multi-plate ionization chamber and its surrounding scintillation detector. The experiment permits the simultaneous observation of the delayed and prompt fission events as well as of the time distributions of high-energy electrons resulting from μ^--decay. The aluminium cylinder serves to detect possible events in which the muon is liberated following a fission event.

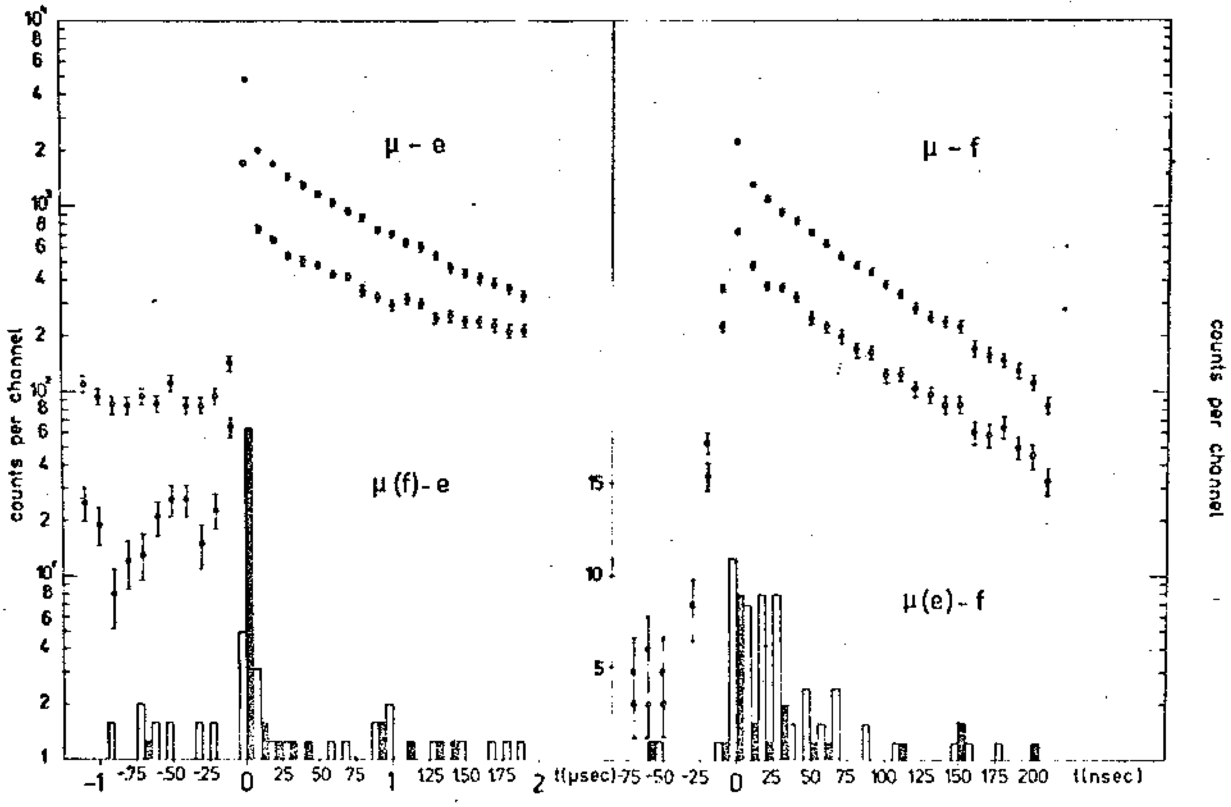

Figure 3

Data from a preliminary experiment dealing with the search for the re-emission process (left hand part of the figure) and delayed fission of the muonic atoms of ^{238}U (right hand part).
Open circles and histograms refer to events in which more than one muon arrived during the period of interest; closed circles refer to events for which only one muon arrived during the period of interest.

Block-diagram of the experimental set-up

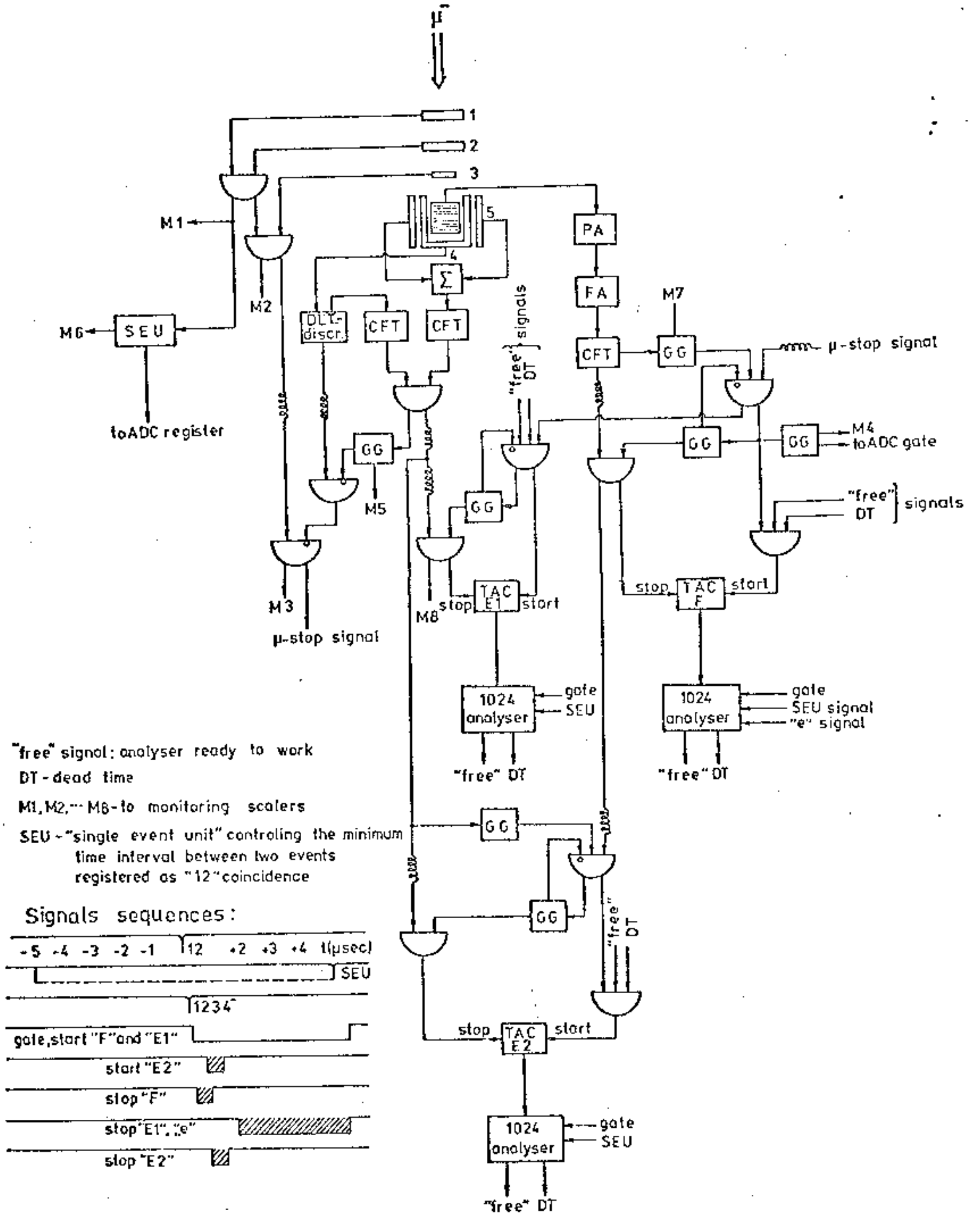

Figure 4

The block-diagram of the experimental set-up for the observation of muon-induced fission.