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PROGRESS REPORT OF EXPT SC70 AND REQUEST FOR MORE BEAM TIME

CERN[1]-Dubna[2]- Oslo[3] Collaboration

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Since the experiment was accepted in 1976 the Collaboration has had beam time in the muon channel (beam YJ1) for a total of about 100 shifts (shared time). After some test runs during the latter part of 1976, production runs were started after the January 1977 shutdown of the SC. We should like to report here on the results obtained so far in the studies of fission induced by muons in ^{238}U.

As stated in our proposal (CERN/SCC/76-1) 1) the main physics interest of the experiment can be summarized as a study of the nature of some fission isomers. If one is concerned with shape isomerism, the presence of the muon would certainly introduce measurable changes in both the level energy and the half life of the isomer2,3). Such changes would be due to the fact that the muon, after cascading down to the lowest atomic orbits, comes very close to the nucleus. In fact, when in the two lowest orbits, 2p and 1s, the muon spends an appreciable fraction of its time inside the nucleus. Thus the nuclear potential energy is affected by the muon, and thereby also the properties of a possible shape isomer.

Another interesting possibility would be to obtain results on the fate of the muon after prompt fission. The time distribution of the decay electrons following muon-induced prompt fission could be compared with calculations using formulae which have never been tested for nuclei with the somewhat exotic properties of fission fragments, e.g. a relatively large neutron excess.

The equipment used in the experiment is shown in Fig. 1. It consists of a muon telescope, and an electron detector surrounding the target which in turn is contained in an ionization chamber used as fission detector.

The two-dimensional time correlation between the appearance of the fission fragment and the electron is measured relative to the time of a muon stop. In addition, the time distributions for double events (μ-fission without the electron, etc.) are recorded, as histograms collected during a run. The triple events are written out event by event on a magnetic tape (see Fig. 2).

A collection of triple events recorded during a run can be represented in a two-dimensional plot as shown in Fig. 3. Along the axes A and B are plotted the time differences between μ-stop and electron (A) and between μ-stop and fission (B). The graph is characterized by the fact that most events fall on the two axes A and B described above and along the line C which corresponds to such events, where the electron and the fission fragment appear simultaneously.

The analysis of the time distributions has given the following preliminary results concerning events along A and C (see Figs. 4 to 6).

1) The events along A are prompt-fission events whose bound-muon decay distribution is composed of two mean lifetimes: (134 ± 4) nsec and (1.9 ± 0.6) μsec. The short one corresponds to the mean lifetime for a muon captured on the fission

fragments. The second one must correspond to a muon captured on light elements, such as H, C, or Al after having been converted from highly excited fission fragments. This constitutes the first direct experimental observation of such a reaction, and confirms the interpretation of the prompt fission of a muonic atom as being due to the radiationless transitions of the muon from the 2p to the 1s orbit. There are reasons to believe that the muon would preferentially be carried away by the heavy fragment and that consequently the muon mean life is determined by the Z- and A-values of this nucleus. In such a case our result can be used to test the Primakoff theory⁴⁾ for a type of nucleus which is otherwise not easily attainable, namely one with a very large neutron excess. Figure 5 shows the calculated results for the disappearance rates of muons on various possible fragments in the fission of ^{238}U, both for the light and the heavy fragments. It is quite clear that our result for the mean life of the muons following prompt fission confirms the validity of the formula even for very neutron-rich nuclei.

Conversely, if one would believe the Primakoff theory to give a good description of the muon disappearance rate for all nuclei, our results would give strong indications that the muon really prefers to go with the heavy fragment.

2) The events along C are characterized by the simultaneous appearance of the electron and the fission fragment. The time distribution in this case turns out to consist of two parts, one short-lived component, $\tau_1 = (8.9 \pm 0.6)$ nsec, and one longer one, $\tau_2 = (85 \pm 6)$ nsec.

The interpretation of the long-lived component seems clear: it corresponds to the mean life expected for a muon disappearing from the normal ^{238}U ground state. This quantity has been determined in several experiments on muonic uranium nuclei, either detecting the electron or the fission fragments. A recent value for the mean life is (76.1 ± 1.0) nsec 5). In principle, our experiment could also give a very precise value for the muon mean life on ^{238}U using the histogram containing μ-fission double events. However, owing to some leak-through of radio-frequency signals from the SC, the μ-fission time distribution shows systematic excursions from the smooth exponential curve. Therefore it is quite difficult to use the overwhelming statistics collected during a run to full advantage.

The short-lived component is more difficult to interpret, but tentatively it is assumed to be related to fission from the shape isomer. Thus the presence of the muon causes such changes in the barrier conditions of the nucleus that the fission isomer lifetime decreases by about a factor of 20. The decrease in itself can be understood by the fact that the back-tunnelling channel is speeded up considerably. However, it is more difficult to find an explanation for the high population of the isomeric state in the radiationless transition as well as the high probability for fission, once this second well is reached.

In an experiment performed at Dubna[6)] where the gamma radiation was detected, there were indications for such a short mean life for the shape isomer in muonic ^{238}U.

Finally, we think that the events along ridge B are due to the registration in the electron detector of the cascade X-rays as the muon falls down to the lowest orbit. There will be a triple event of a muon stop and such a false electron if, as is very frequently the case, the muon is then captured and causes the nucleus to fission. The lifetime along this line is found to be that expected for muonic ^{238}U; our value is (77 ± 1) nsec.

As an auxiliary experiment, we have devoted some shifts to a study of ($\mu e \gamma$) triple coincidences, using two Ge(Li) detectors and a ^{209}Bi target. Our aim was to obtain an estimate of the probability for nuclear excitation induced by the muon beta-decay. Within the accuracy of the data collected during this short run and without optimizing the detectors used for registering electrons and gamma radiation, we can only set an upper limit of a few per cent per stopped muon for this probability. Since positive identification of nuclear gamma-rays in coincidence with the electrons from muon decay would be an important input in our interpretation of the results of the fission experiment, we intend to repeat this experiment under improved conditions and with different targets.

In view of the fact that we have obtained new and somewhat surprising results on the process under study, we are anxious to continue the experiment using a new target. A chamber containing thorium has come from Dubna and would be used for future runs. Thorium is interesting as a target because the lifetime of its shape isomer apparently must be much shorter than the observed 9 nsec in the case of muonic uranium. It could thus serve as an essential check of the interpretation for ^{238}U. In order to find out the background level in the measured 80 nsec component coming from gammas and neutrons triggering our electron counter, we are also testing with a chamber containing a ^{252}Cf source, off line.

Our request is for 40 shifts of beam time, which can be shared, up to the end of 1977. During this time we hope to finish the thorium run. So far our preliminary results have been published as an abstract submitted to the 7th International Conference on High-Energy Physics and Nuclear Structure (Zurich, August 1977).

REFERENCES

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3) G. Leander and P. Möller, Phys. Letters 57B, 245 (1975).

4) See, for instance, B. Goulard and H. Primakoff, Phys. Rev. C 10, 2034 (1974).

5) D. Chultem, V. Cojocaru, Dz. Ganzorig, Kim Si Chwan, T. Krogulski, V.D. Kuznetsov, H.G. Ortlepp, S.M. Polikanov, B.M. Sabirov, U. Schmidt and W. Wagner, Nuclear Phys. A247, 452 (1975).

6) W.D. Fromm, H.-G. Ortlepp, S.M. Polikanov, U. Schmidt and G.N. Zorin, Nuclear Phys. A278, 387 (1977).

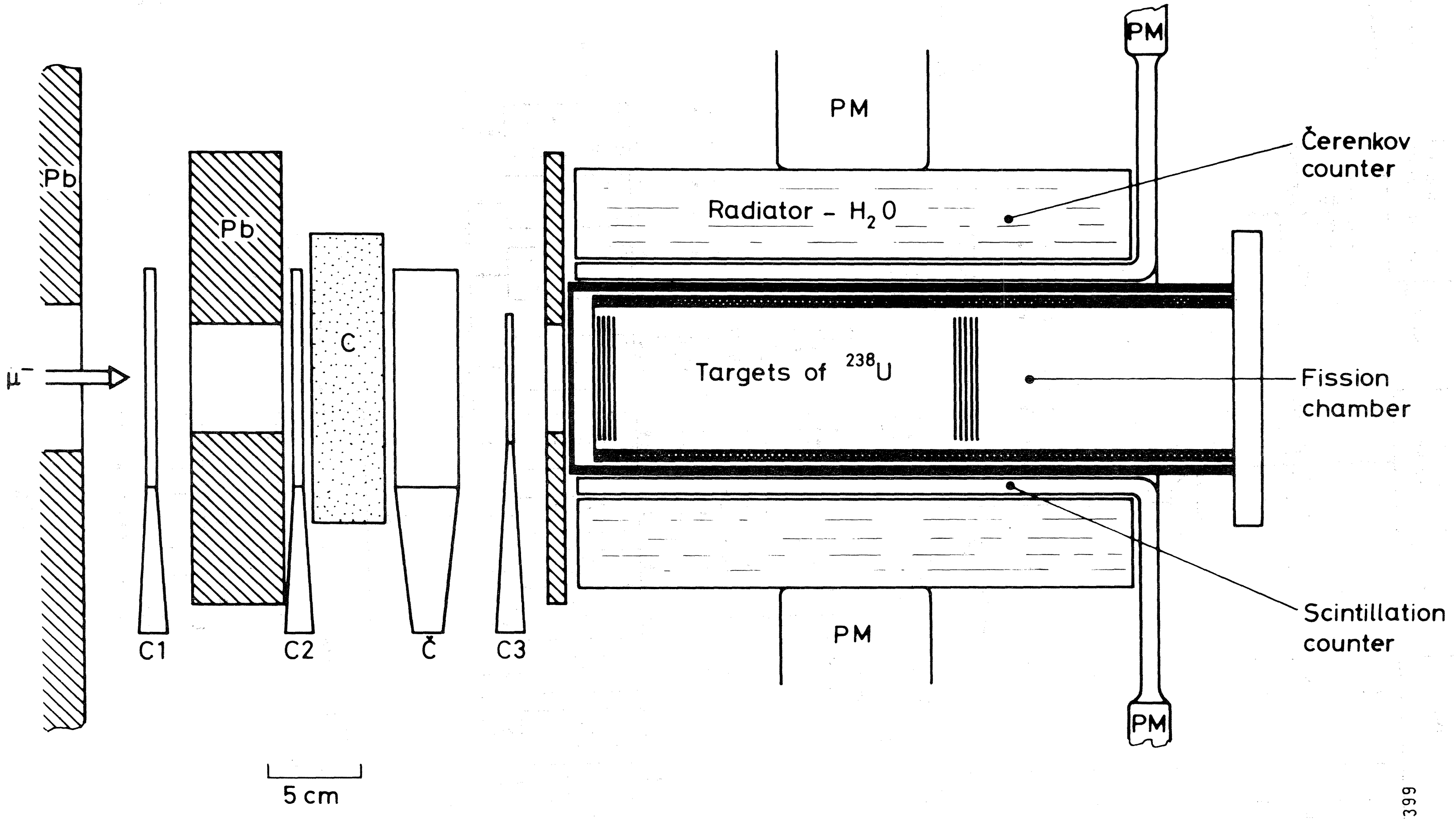

PM
PM
Čerenkov counter
Pb
Radiator - H_2O
Pb
C
μ^-
Targets of ^{238}U
Fission chamber
Scintillation counter
C1
C2
Č
C3
PM
PM
5 cm
67399

Fig. 1

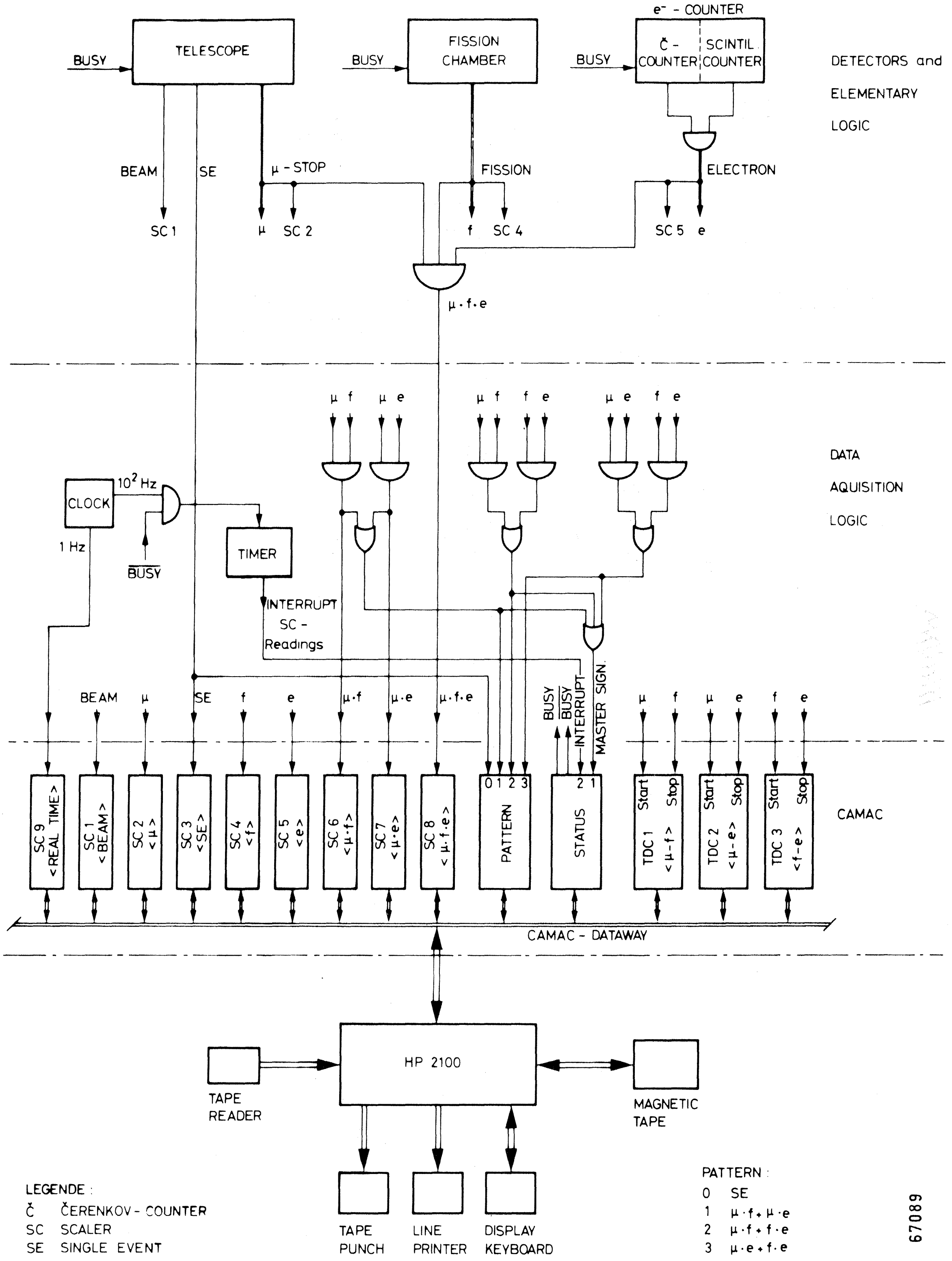

TELESCOPE
BUSY
FISSION CHAMBER
BUSY
e⁻ - COUNTER
Č - COUNTER
SCINTIL COUNTER
BUSY
DETECTORS and ELEMENTARY LOGIC
BEAM
SE
μ - STOP
FISSION
ELECTRON
SC 1
μ
SC 2
f
SC 4
SC 5
e
μ·f·e
μ f
μ e
μ f
f e
μ e
f e
DATA AQUISITION LOGIC
CLOCK
10² Hz
1 Hz
BUSY
TIMER
INTERRUPT SC - Readings
BEAM
μ
SE
f
e
μ·f
μ·e
μ·f·e
BUSY
BUSY
INTERRUPT
MASTER SIGN.
μ
f
μ
e
f
e
SC 9 <REAL TIME>
SC 1 <BEAM>
SC 2 <μ>
SC 3 <SE>
SC 4 <f>
SC 5 <e>
SC 6 <μ·f>
SC 7 <μ·e>
SC 8 <μ·f·e>
0 1 2 3
PATTERN
2 1
STATUS
Start
Stop
TDC 1 <μ-f>
Start
Stop
TDC 2 <μ-e>
Start
Stop
TDC 3 <f-e>
CAMAC
CAMAC - DATAWAY
HP 2100
TAPE READER
MAGNETIC TAPE
TAPE PUNCH
LINE PRINTER
DISPLAY KEYBOARD
LEGENDE :
Č ČERENKOV - COUNTER
SC SCALER
SE SINGLE EVENT
PATTERN :
0 SE
1 μ·f+μ·e
2 μ·f+f·e
3 μ·e+f·e
67089

Fig. 2

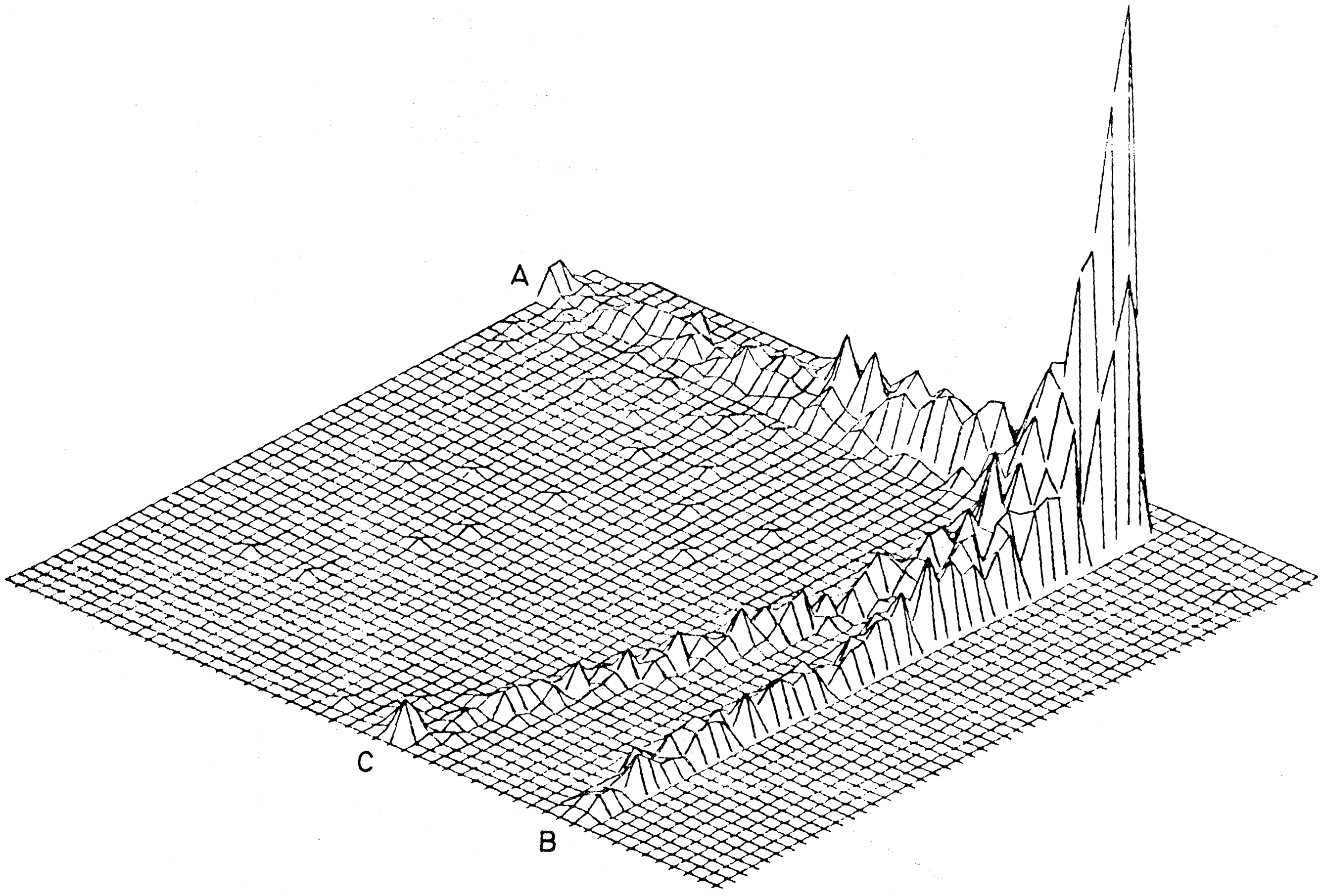


Fig. 3

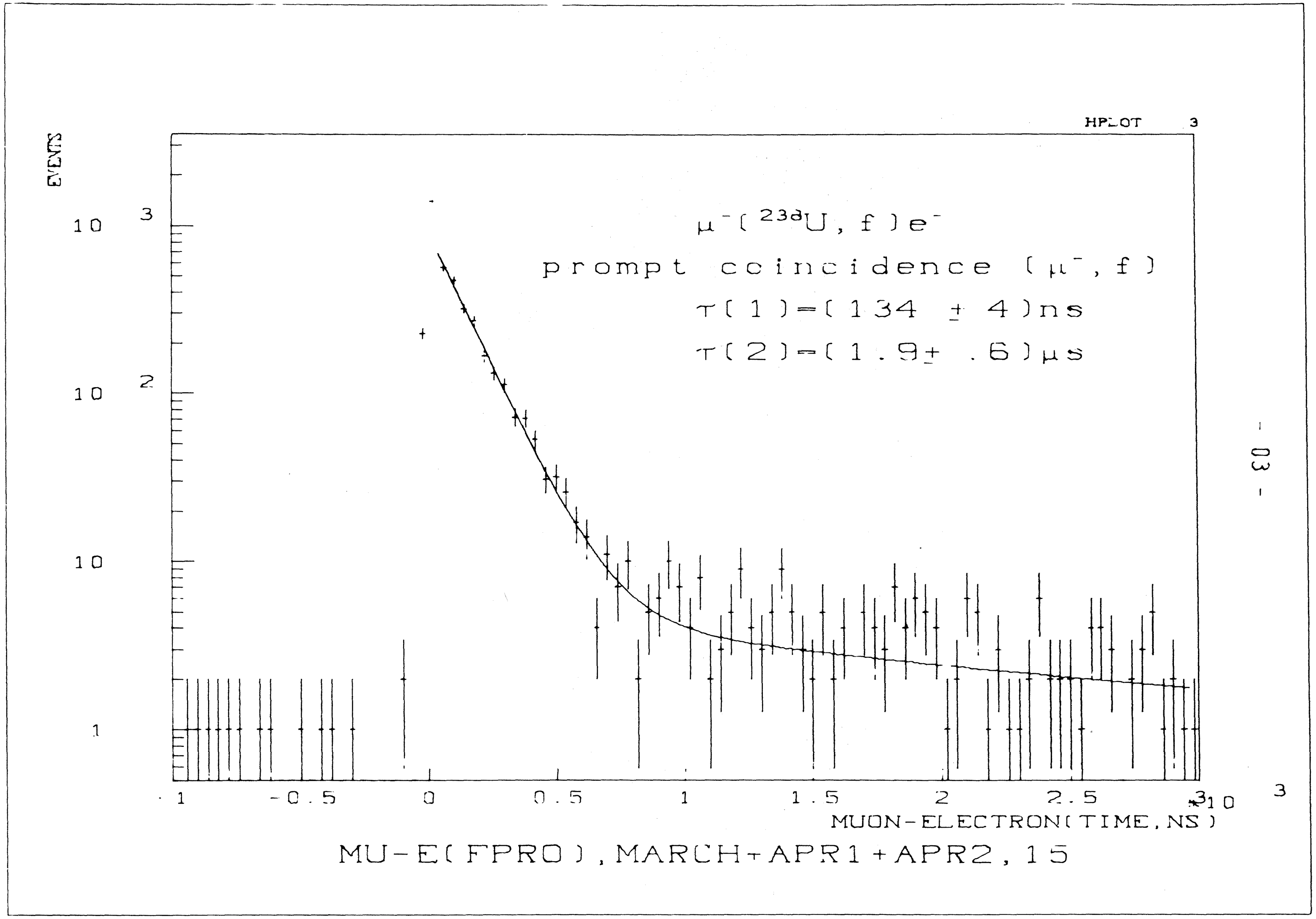
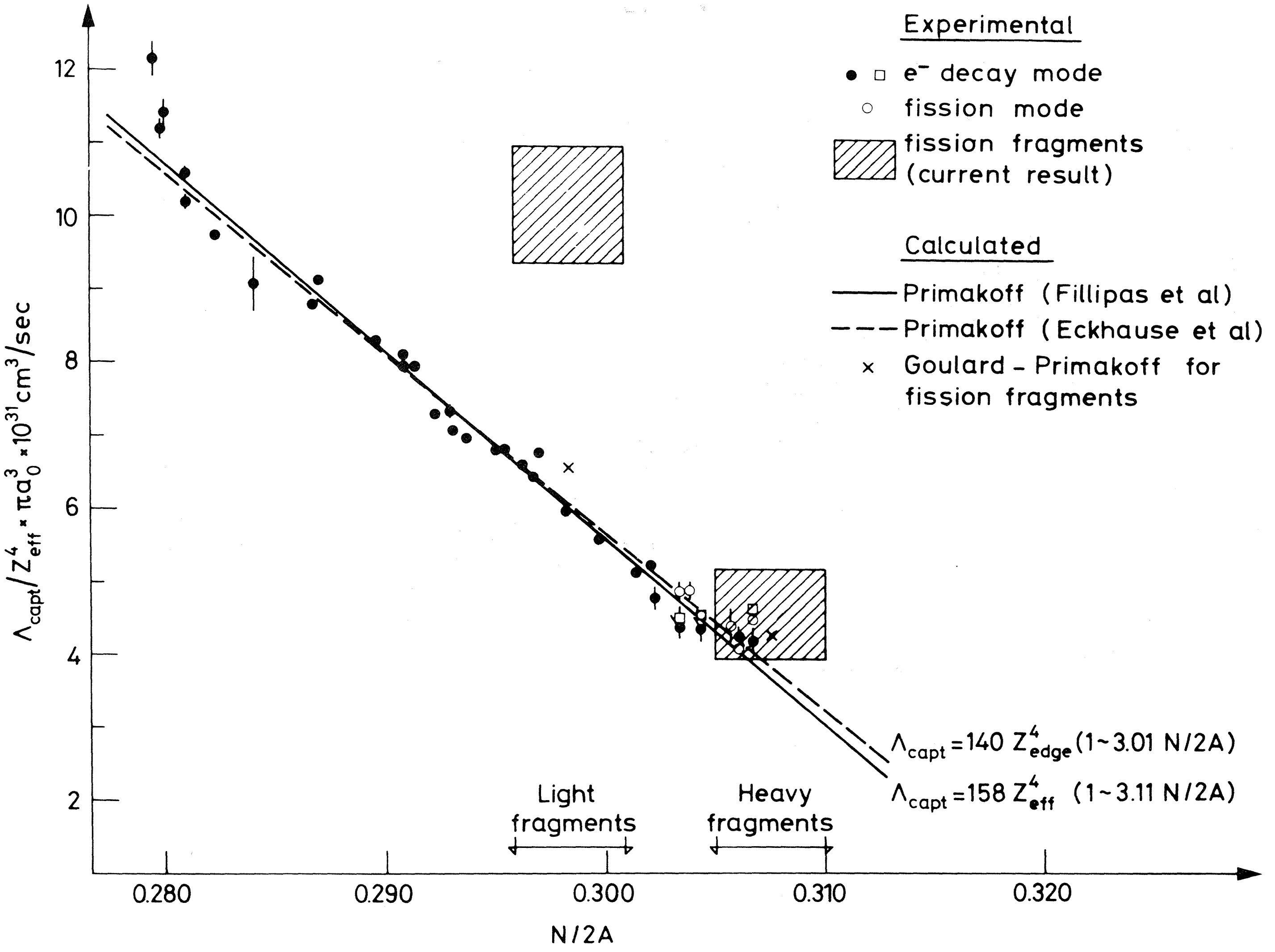

HPLOT 3
EVENTS
10 3
10 2
10
1
μ⁻(238U, f)e⁻
prompt coincidence (μ⁻, f)
τ(1)=(134 ± 4)ns
τ(2)=(1.9± .6)μs
-1
-0.5
0
0.5
1
1.5
2
2.5
3
*10 3
MUON-ELECTRON(TIME,NS)
MU-E(FPRO),MARCH+APR1+APR2,15

Fig. 4



Experimental
● □ e^- decay mode
○ fission mode
▨ fission fragments (current result)
Calculated
—— Primakoff (Fillipas et al)
– – – Primakoff (Eckhause et al)
× Goulard - Primakoff for fission fragments
$\Lambda_{capt}/Z^4_{eff} \times \pi a_0^3 \times 10^{31} cm^3/sec$
12
10
8
6
4
2
0.280
0.290
0.300
0.310
0.320
N/2A
Light fragments
Heavy fragments
$\Lambda_{capt} = 140\ Z^4_{edge}(1 - 3.01\ N/2A)$
$\Lambda_{capt} = 158\ Z^4_{eff}\ (1 - 3.11\ N/2A)$

Fig. 5

67400

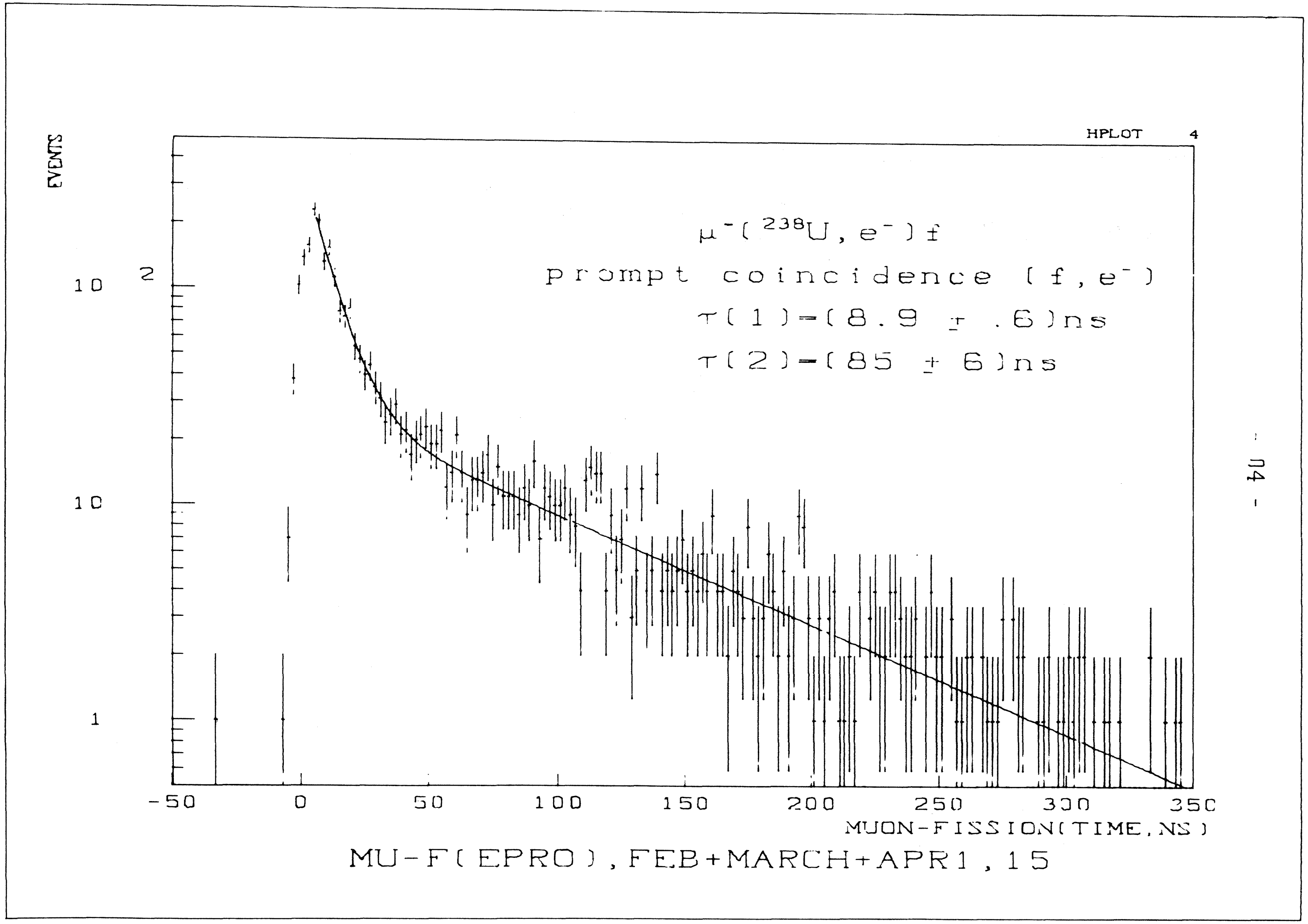

HPLOT 4
EVENTS
10 2
10
1
$\mu^-(^{238}U, e^-)f$
prompt coincidence (f, e⁻)
τ(1)=(8.9 ± .6)ns
τ(2)=(85 ± 6)ns
-50
0
50
100
150
200
250
300
350
MUON-FISSION(TIME,NS)
MU-F(EPRO),FEB+MARCH+APR1,15

Fig. 6

67394