# β+ Decay and Cosmic-Ray Half-Life of $^{54}$Mn

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March 29, 1993

This work was supported by the Director, Office of Energy Research Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098

## $\beta^+$ Decay and Cosmic-Ray Half-Life of $^{54}$Mn

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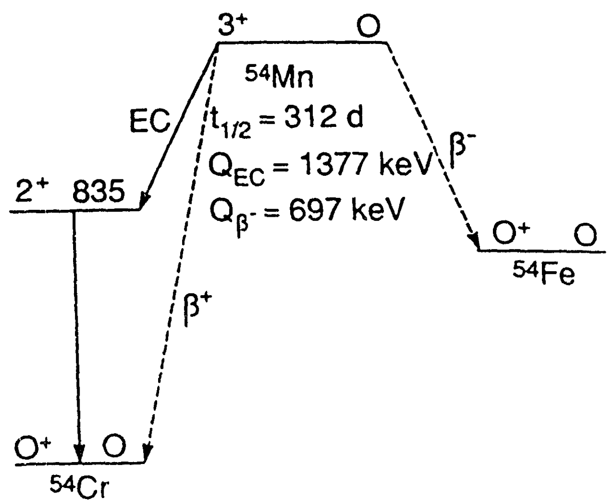
We performed a search for the $\beta^+$ branch of $^{54}$Mn decay. As a cosmic ray, $^{54}$Mn, deprived of its atomic electrons, can decay only via $\beta^+$ and $\beta^-$ decay, with a half-life of the order of $10^6$ yr. This turns $^{54}$Mn into a suitable cosmic chronometer for the study of cosmic-ray confinement times. We searched for coincident back-to-back 511-keV $\gamma$-rays using two germanium detectors inside a NaI(Tl) annulus. An upper limit of $2 \times 10^{-8}$ was found for the $\beta^+$ decay branch, corresponding to a lower limit of 13.7 for the log*ft* value.

1. INTRODUCTION

Radioactive nuclei that decay in laboratory via electron capture can have very different half-lives as cosmic rays. This is because during the acceleration and propagation of cosmic rays, these nuclei will be stripped of their atomic electrons. While some of them become stable, others can undergo $\beta^+$ and $\beta^-$ decays. If $\beta^+$ and $\beta^-$ decay are possible, the nucleus will still decay, but now with a half-life determined by these decay modes. If the resulting "cosmic-ray half-life" of this species is of the order of $10^6$ yr, the isotopic composition of the corresponding element can be of help to determine the confinement time of the cosmic rays in interstellar medium.

Fig. 1: Decay scheme of $^{54}$Mn, dashed lines indicate the yet unobserved branches.



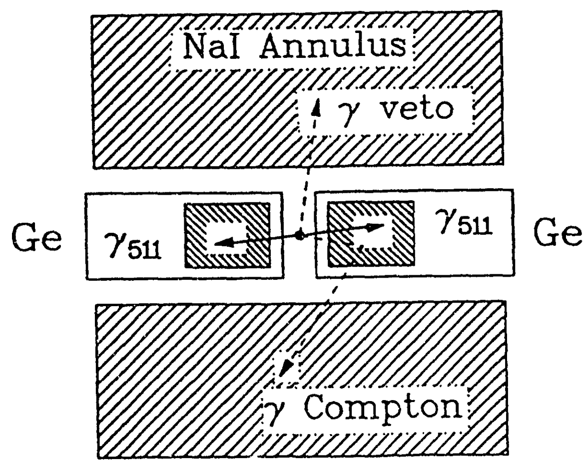
The decay scheme of $^{54}Mn$ is shown in Fig. 1. We see that second-forbidden unique transitions, $\beta^+$ and $\beta^-$, are both possible to the ground states of $^{54}Cr$ and $^{54}Fe$, respectively. The measurement of these rare decays are extremely important because $^{54}Mn$ has been observed in cosmic rays. Although the $\beta^-$ decay is expected to be about a hundred times more intense than $\beta^+$, the measurement of the $\beta^+$ branch is easier and is one of the steps for the determination of the cosmic-ray half-life of $^{54}Mn$. Our experiment was designed to improve the $\beta^+$ branch ratio limit established by Sur *et. al.* (1989) of $4.4 \times 10^{-8}$. In their experiment, Sur *et al.* attempted to directly measure the positrons in a Si-telescope detector, which was placed inside a NaI(Tl) annulus. Their detection efficiency was measured to be 0.10%. By measuring the coincident annihilation γ-rays we improved the detection efficiency of positrons.

## 2. EXPERIMENT

The radioactive source was purified, in order to minimize the presence of other $\beta^+$ emitters, specifically $^{22}Na$ and $^{65}Zn$. The chemistry was done by mixing a liquid source with a mixture of *DOWEX-1X8* anion-exchange resin, HAP (hydrated-antimony pentoxide) and concentrated HCl. The purified $^{54}Mn$ fraction was dried on small pieces of filter paper, and its final radioactivity was $5.0 \pm 0.2$ μCi. After drying, the source was sealed between several layers of adhesive tape and had a total area of 1 $cm^2$. The level of radioactive contaminants was determined by counting in singles, at a low-background facility at Lawrence Berkeley Laboratory. Upper limits were set for the relative strengths of $^{65}Zn$, $^{22}Na$, and $^{60}Co$ with respect to that of the $^{54}Mn$ source: $1.2 \times 10^{-6}$ for the $^{65}Zn$, and $6.4 \times 10^{-7}$ for the other two isotopes.

The experimental setup, shown in Fig. 2, consisted of two Ge detectors, each 110 $cm^3$ volume, placed face to face, at the center of a 30 x 30 cm NaI(Tl) annulus. The source was then sandwiched in close geometry between the two Ge detectors, with the external annulus acting as an anti-Compton and anti-coincidence shield. A master gate was generated every time there was a coincidence between both Ge detectors. For each coincidence event, we recorded on tape the following parameters: the energy signals from both Ge detectors and the two halves of the NaI(Tl) annulus, the time between one of the Ge detector and all other detectors, and pile-up flags produced by the inhibit signal generated by the Ge amplifiers.

Fig. 2: Experimental setup.



The singles rates of the Ge detectors were 30 kHz, that of the annulus was 320 kHz and the rate of Ge-Ge coincidences was about 130 Hz. The majority of the coincidence events from $^{54}$Mn decay in our setup were accidentals, produced by 835-keV photons backscattering from one Ge detector, and absorbed in the other. The efficiency for detecting 511-511 photon pairs in the Ge detectors was (0.57 ± 0.02)%. Our efficiency was calibrated with a 0.1 μCi $^{22}$Na source placed inside the setup, together with the $^{54}$Mn source, and measuring the coincidences between a 511-keV photon on one Ge detector and the (511 + 1274) sum-peak on the other.

We collected data for 870.9 hours, recording about 140 events per day in the 511-511 coincidence region. Fig. 3 shows projections of all events on the energy axes of both Ge detectors. The same figure contains projections gated by (i) proper timing conditions, (ii) vetoed by a pile-up signal and by the NaI(Tl) annulus, and (iii) corresponding to (511 ± 2) keV deposited in the other Ge detector. Fig. 4 shows an expanded view of the region around 511 keV.

Fig. 3: Projected spectra from one run, (a) and (b) all events projected on both Ge-energy axes; (c) and (d) gating on the 511-keV in each Ge detector, with pile-up and NaI vetoing. The broad structure around channel 350 on (c) and (d) is due to 835-keV photons leaving 511 keV on one Ge detector and the scattered photons absorbed in the other one.

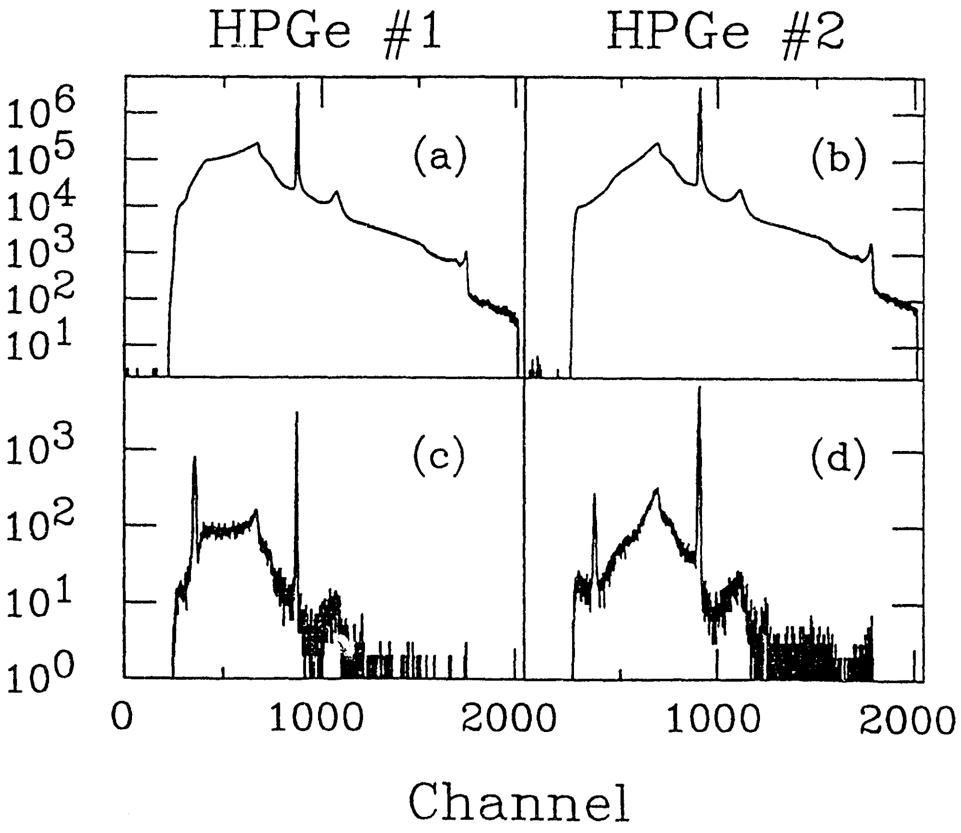
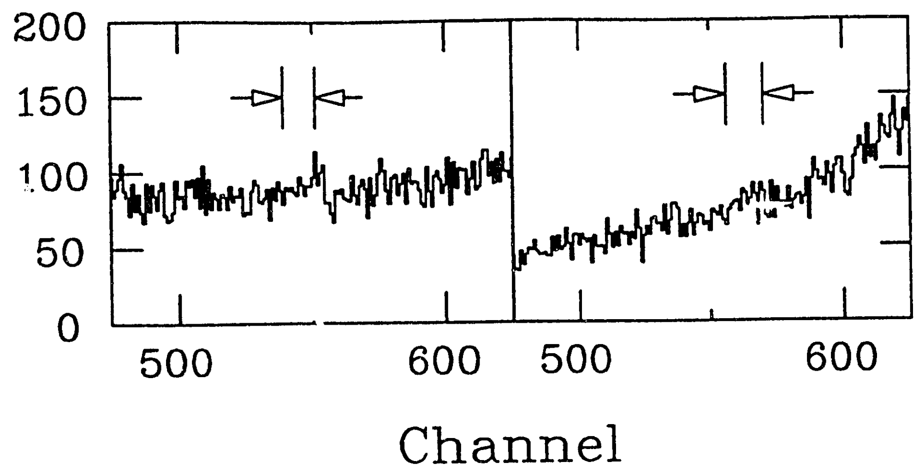


Fig. 4: Expanded view of Fig. 3, (c) and (d), indicating the (511±2) keV region.




3. RESULTS AND DISCUSSION

There is no statistically significant structure in either of the Ge detector spectra in the 511 keV region. After 870.9 hours, the total number of counts in the region where the annihilation peak was expected was 2178±47. From this we deduce an upper limit of $2.0 \times 10^{-8}$ for the branching ratio and a lower limit of 13.7 for the log*ft* of this transition.

This work was supported by the U.S. Department of Energy, Nuclear Physics Division, via grants No. DE-AC03-76SF00098 and DE-FG05-87ER40314. M.T.F. da Cruz was supported by Fundacão de Amparo a Pesquisa do Estado de São Paulo, FAPESP, São Paulo, Brasil.

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