[3]R. R. Wilson, Phys. Rev. 72, 98 (1947).
[4]W. E. Stein, Los Alamos Scientific Laboratory Report No. LADC-5367 (unpublished).
[5]I. Halpern, Ann. Rev. Nucl. Sci. 9, 245 (1959).
[6]R. L. Fleischer, P. B. Price, and R. M. Walker, Ann. Rev. Nucl. Sci. 15, 1 (1965).
[7]B. Domeij and R. Bjorkqvist, Phys. Letters 14, 127 (1965).
[8]A. F. Tulinov, V. T. Kulikauskas, and M. M. Malov, Phys. Letters 18, 304 (1965).
[9]E. Bøgh and J. L. Whitton, Phys. Rev. Letters 19, 553 (1967).
[10]D. S. Gemmell and R. E. Holland, Phys. Rev. Letters 14, 945 (1965).
[11]E. Uggerhøj, Phys. Letters 22, 382 (1966).
[12]J. Lindhard, Kgl. Danske Videnskab. Selskab, Mat-Fys. Medd. 34, No. 14 (1965).
[13]A. F. Tulinov, Dokl. Akad. Nauk SSSR 162, 546 (1965) [translation: Soviet Phys.—Dokl. 10, 463 (1965)].
[14]J. W. T. Dabbs, Oak Ridge National Laboratory Report No. ORNL 4082 (unpublished).
[15]R. L. Fleischer, P. B. Price, R. M. Walker, and E. L. Hubbard, Phys. Rev. 133, A1443 (1964).
[16]S. Prêtre, E. Tochlin, and N. Goldstein, U. S. Naval Radiological Defense Laboratory Report No. USNRDL-TR-1089 (unpublished).
[17]J. A. Davies, J. Denhartog, and J. L. Whitton, Phys. Rev. 165, 345 (1968).
[18]L. Eriksson, J. A. Davies, and N. Johansson, private communication.
[19]For ^{235}U the average fission width for low-energy neutron resonances is 0.045 eV [J. S. Fraser and J. C. D. Milton, Ann. Rev. Nucl Sci. 16, 379 (1966)]. This leads to a lifetime estimate of $\sim 10^{-14}$ sec.
[20]R. Vandenbosch and J. R. Huizenga, in Proceedings of the Second United Nations Conference on the Peaceful Uses of Atomic Energy (United Nations, Geneva, Switzerland, 1958), Vol. 15, p. 284.

MUON DECAY DEEP UNDERGROUND*

W. R. Kropp, Jr., and F. Reines
University of California, Irvine, California

and

R. M. Woods, Jr.
Case Western Reserve University, Cleveland, Ohio
(Received 3 May 1968)

A measurement of delayed coincidences characteristic of muon decay has been made at a depth of 1440-hg/cm^2 standard rock with a 200-liter liquid scintillation detector. These results are consistent with the decay rate predicted from the depth-intensity curve for the penetrating component of the cosmic rays, providing independent evidence that this component is energetic muons.

It is generally accepted that cosmic rays observed deep underground are muons plus an accompanying soft secondary component. The identification is based mainly on two types of information: the interactions of the observed particles,[1] and the consistency between the sea-level muon spectrum and the depth-intensity curve.[2] Since accurate measurement of the sea-level spectrum is available to only a few hundred GeV,[3] this form of evidence is of limited usefulness at higher energies.

In this Letter we point out an additional and somewhat more direct test of the muon as the penetrating component: an observation of muon decay underground as compared with the rate expected from the depth-intensity curve. Such an observation is most persuasive because the decay of the muon with a 2.21-μsec mean life into an electron having a known energy spectrum uniquely characterizes the particle. An experiment of this type, employing a liquid scintillation detector at a depth of 1440-hg/cm^2 standard rock, is in the final stages of preparation.[4] The average energy loss for a cosmic ray arriving at this detector from the vertical direction will be about 400 GeV.[5] Particles arriving at other zenith angles will have correspondingly higher minimum energies.

Preliminary information is available from an experiment done, in the same location, in another context.[6] The relevant portion of that experimental system was a 200-liter liquid scintillator. Particles depositing more than 10 MeV in the detector triggered the electronics, and oscilloscope traces of the pulses were photographed. Delayed coincidences in the interval 1.5-5.0 μsec were observable, corresponding to an efficiency of 40% for decays with the muon mean life. Losses due to edge effects were about 8%.

In 1942 h of operation, 13 events were observed with the appropriate decay signature. The time interval and energy distributions shown in Table

Table I. Delayed coincidence events observed in 1942 h with a 200-liter liquid scintillation detector at a depth of 1440 hg/cm^2 standard rock.

Time delay interval (μsec)	Trigger pulse (MeV)	Delayed pulse (MeV)
1.5	10	25
1.5	25	~20
2	60	30
2	90	10
2	25	25
2	25	25
3	120	20
3.5	~250	25
3.5	90	~15
3.5	165	10
4	10	5
4	40	30
~5.5	>200	25

I are, considering the small number of events, consistent with that expected from muon decay.

The number of cosmic rays expected to stop in the detector during the experiment is calculable from the slope of the depth-intensity curve[5] [1.16×10^{-11} cm^{-2} sec^{-1} sr^{-1} (g/cm^2)$^{-1}$] and the angular distributions. Since we had a low-Z scintillator, a negligible fraction of stopping muons would be expected to be nuclearly absorbed before decay. Accordingly, if the particles are muons, the number of decays observed should equal this number modified by the efficiencies. The calculation requires the detector aperture and the average path length in the detector for a penetrating particle. The aperture is obtained from the ratio of the rate at which cosmic rays were measured to penetrate the detector (8.4 h^{-1}) to the vertical intensity (5.1×10^{-7} cm^{-2} sec^{-1} sr^{-1}). The result is 4.5×10^3 cm^2 sr. The average path length through the detector is 61 g/cm^2. The number expected to stop is thus found to be 22; taking into account the angular distribution increases this number by ~10%. Thus the number of decays we expect to observe is about 9.

These results support the usual conclusion that the penetrating component consists only of muons, and cast doubt on the recent speculation of a weakly interacting primary.[7]

We wish to thank the Morton Salt Company for continued hospitality in their Fairport Harbor Mine and Mr. T. D. Reilly, Dr. M. Crouch, and Dr. M. Moe for interesting discussions.

*Work supported in part by the U. S. Atomic Energy Commission.

[1]P. H. Barrett, L. M. Bollinger, G. Cocconi, Y. Eisenberg, and K. Greisen, Rev. Mod. Phys. 24, 133 (1952).

[2]S. Miyake, V. S. Narasimham, and P. V. Ramana Murthy, Nuovo Cimento 32, 1524 (1964).

[3]P. J. Hayman and A. W. Wolfendale, Proc. Phys. Soc. (London) 80, 710 (1962).

[4]R. M. Woods, Jr., T. D. Reilly, and F. Reines, to be published.

[5]M. G. K. Menon and P. V. Ramana Murthy, Progr. Elem. Particle Cosmic Ray Phys. 9, 161 (1967).

[6]W. R. Kropp, Jr., and F. Reines, Phys. Rev. 137, 740 (1965).

[7]C. G. Callan, Jr., and S. L. Glashow, Phys. Rev. Letters 20, 779 (1968).

Λp INTERACTION NEAR ΣN THRESHOLD*

D. Cline, R. Laumann, and J. Mapp
Department of Physics, University of Wisconsin, Madison, Wisconsin
(Received 15 April 1968)

The conversion process $\Sigma^+n\to\Lambda p$ has been observed using the sequence $K^-d\to\pi^-(\Sigma^+n)\to\pi^-(\Lambda p)$. The results of this study are that (1) the conversion process at very low energy is dominated by the (ΣN) triplet state; and (2) the reaction is strongly enhanced for Λp masses below Σ^+n threshold, suggesting the existence of a bound state in the Σ^+n system and, hence, an elastic resonance in the Λp system.

As is well known, hyperon-nucleon scattering represents a formidable area of study for particle physics due to the present unavailability of rich hyperon beams. In absence of direct information the study of Y-N final-state interactions takes on considerable interest. In this note we present the essential details of a study of Λn interaction through the study of the process

$$K^-d\to\Lambda p\pi^-, \qquad (1)$$

where the proton was specifically required to have a momentum that was unlikely for processes satisfying the impulse approximation. For the reasons outlined below we believe that in Re-