of external cathode counters during his visit to India. It is a pleasure to record our thanks to Professor R. C. Majumdar for his kind interest in the work. One of us (G.S.B.) is indebted to the AEC for the research fellowship granted to him.

[1] R. Maze, J. phys. et radium **7**, 165 (1946).
[2] B. Bhowmik and G. S. Bajwa, Indian. J. Phys. **25**, 561 (1951).
[3] G. Lemaitre and M. S. Vallarta, Phys. Rev. **50**, 496 (1936).
[4] R. Albagli Hutner, Phys. Rev. **55**, 614 (1939).
[5] Vallarta, Perusquia, and De Oyarzabal, Phys. Rev. **71**, 393 (1947).

A Narrow Angle Pair of Particles Produced in Hydrogen*

A. B. WEAVER, EARL A. LONG,† AND MARCEL SCHEIN
Department of Physics, University of Chicago, Chicago, Illinois
(Received June 16, 1952)

A COUNTER-controlled cloud chamber[1] has been used to study penetrating showers and other energetic events produced by cosmic-ray particles in various materials, including liquid hydrogen, at sea level. The dewar containing the hydrogen was cylindrical, with an inside diameter of 15.2 cm and an inside height of 100 cm. The evaporation rate was such that the column of hydrogen was over 3 g/cm^2 (43 cm) for about 25 hours after a filling.

Figure 1 is a drawing of an unusual event which occurred in the liquid hydrogen. Tracks A and B trace to a point in the hydrogen $21^{+4.5}_{-3.0}$ cm above the visible part of the chamber. The stereoscopic pictures of this event were analyzed by reprojecting in the original cameras and by graphical means, using a low power microscope on the negatives. Both methods agreed within the limits of experimental precision.

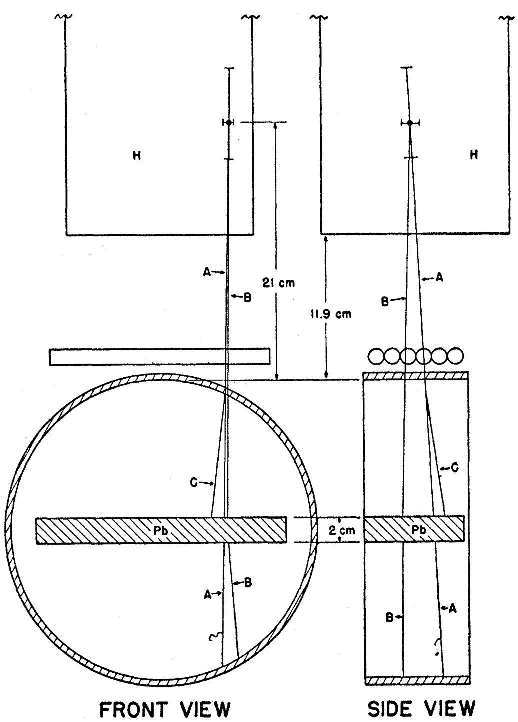

FIG. 1. Schematic drawing of a cloud-chamber event described in the text. The inner walls of the hydrogen dewar, the upper tray of counters, and the chamber are indicated. The rest of the counter control is omitted. The estimated accuracy in the location of the point of origin of the event is shown. An energetic δ-ray is visible along the track A in the lower part of the cloud chamber.

All three tracks, A, B, and C, of Fig. 1 are at minimum ionization. Measurements on track A indicate very little scattering in the 2-cm Pb plate (about 0.3°). According to the theory of multiple scattering, this corresponds to a momentum of 6×10^9 ev/c. Track C meets A at a point in the glass of the chamber and it can be interpreted as a knock-on electron stopping in the lead plate. If A is a π- or μ-meson or a proton, a knock-on electron ejected at an angle of 10°, which is the angle between C and A, should have an energy of approximately 10^7 ev. It would then be expected to stop in the lead plate.

The angle between tracks A and B is $4.3°\pm0.8°$. B is scattered in the lead plate through a projected angle of $5.4°\pm0.2°$. If this deviation should be due to small angle scattering in the 2 cm lead plate, it would indicate that B must carry a momentum of the order of 3×10^8 ev/c, if it is a π- or μ-meson. A proton whose momentum was low enough to correspond to this angle of multiple scattering would be well above minimum ionization. If the deviation should represent nuclear scattering, however, track B could correspond to a proton of energy greater than 10^9 ev. The probability that a proton will make a nuclear collision in 2 cm of lead is about 1 in 8.

A and B cannot be an electron pair because of the high energy of A which is inconsistent with an angle of only 4.3° between the two tracks. This is confirmed by the fact that no secondaries are formed in the lead.

The authors have found similar events at sea level under carbon and lead. In cloud-chamber pictures taken underground George[2] and Braddick *et al.*[3] found a number of pairs of penetrating particles very similar in nature to the pair described here. They report a cross section of 5×10^{-29} cm^2/nucleon if the initiating particle is a μ-meson, a value quite consistent with the observation of such an event in hydrogen during the operating time of this experiment.

It is possible that some of the narrow pairs of penetrating particles produced in beryllium observed by Chang *et al.*[4] are of a similar nature.

It is highly improbable that the event in hydrogen represents the single production of a ζ_0-meson,[5] since the quoted Q-values would not agree with the observed angles and momenta. It is also improbable that the single production of a meson in a high energy nucleon-proton collision is responsible for the observed pair, A, B, because of the small angle between the two tracks. If the above described event in hydrogen is the same as that observed by George and by Braddick and collaborators underground, it is possible that this event is due to a nuclear interaction of a very high energy μ-meson in which the μ-meson produces other penetrating particles.

* Assisted by the joint program of the ONR and AEC.
† Institute for the Study of Metals, University of Chicago, Chicago, Illinois.
[1] The chamber was actually located in a magnetic field of 9000 gauss; however, due to unfortunate circumstances in the room the magnetic field could only be used for a fraction of the total running time.
[2] E. P. George (private communication).
[3] Braddick, Nash, and Wolfendale, Phil. Mag. **42**, 1277 (1951).
[4] Chang, del Castillo, and Grodzins, Phys. Rev. **84**, 582 (1951).
[5] Danysz, Lock, and Yekutieli, Nature **169**, 364 (1952).

Interaction of Pions Originating in Penetrating Showers*

R. L. COOL AND O. PICCIONI
Brookhaven National Laboratory, Upton, New York
(Received June 19, 1952)

THE total interaction cross sections[1] of high energy pions with carbon, paraffin, and lead have been obtained in a study of the secondary particles emitted in the penetrating showers of cosmic radiation at 11,000 feet. The hodoscope of 196 GM counters in Fig. 1 recorded the trajectories of the secondary particles generated in the penetrating showers in the C and Pb above the tray A. Coincidences ($AA'CDE$) selected the penetrat-

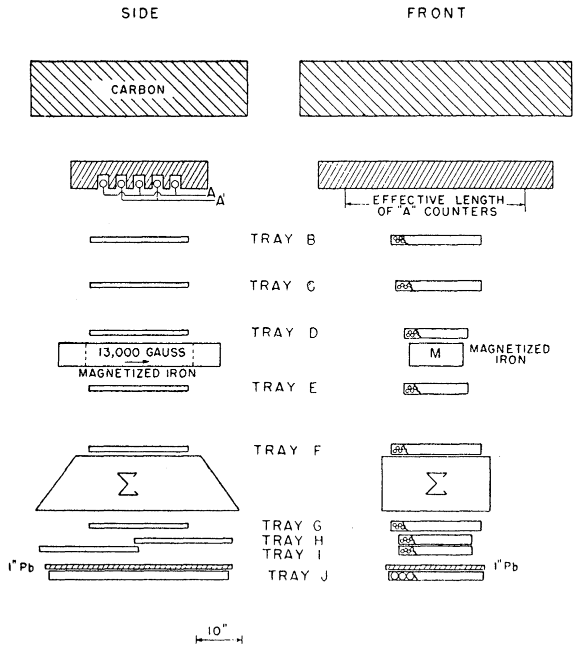

FIG. 1. Penetrating shower detector and hodoscope.

ing shower to be recorded. Those secondaries which could clearly be followed to the absorber Σ were selected from the film. Almost all large air showers were eliminated by anticoincidence with a counter tray of 0.5 m^2.

The material (M) of Fig. 1 is a 5-in. block of iron, magnetized to a field $B=13{,}350$ gauss. The deflection in M of 6263 secondaries was measured; the size and separation of the counters give an angular resolution of 1°. For the measurements reported below, we required the deflections in M be less than 6°. From the data, an energy spectrum (Fig. 2) can be computed, if these small deflections are caused only by the field B and Coulomb scattering. Such an assumption is substantially confirmed by determining the scattering in a $\frac{1}{2}$-in. Pb plate where nuclear effects are small. Figure 3 shows that such scattering can be fitted within the errors by the spectrum of Fig. 2. The median energy of the spectrum is 920 Mev. The increase in ionization losses as the energy decreases accounts for the maximum observed for particles below the iron. Above 1500 Mev, the data lead to a law $S(E)dE \propto E^{-2.35\pm0.2}dE$.

The direction of the deflection in M gives the sign of the charge of the particle correctly with a 90 percent efficiency. Of the secondaries, 40±1 percent are negative. These are almost certainly

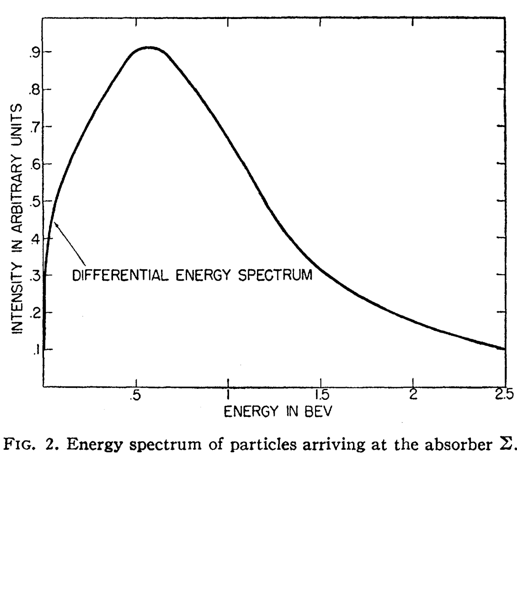

FIG. 2. Energy spectrum of particles arriving at the absorber Σ.

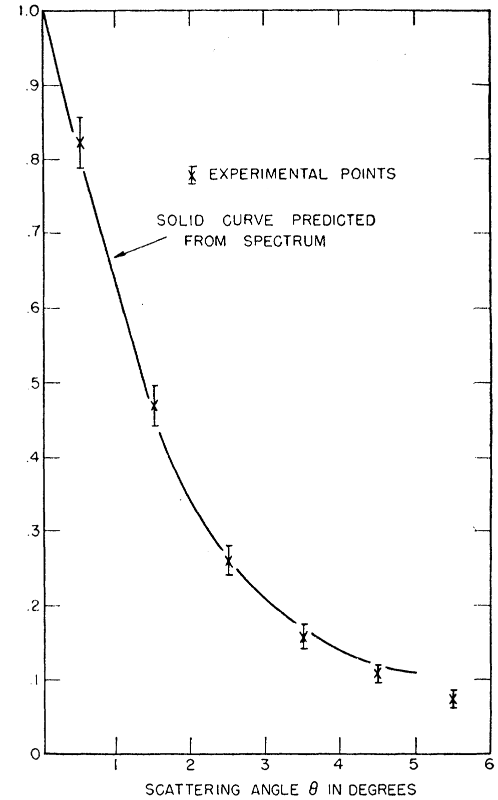

FIG. 3. Comparison of scattering data in $\frac{1}{2}''$ Pb with curve predicted from the spectrum of Fig. 2.

pions;[2] thus some 80 percent of the secondaries are presumably pions.[3] The cross sections have been separately evaluated for negative and positive particles and in no case is there a statistically significant difference.

The contamination of muons among the secondaries has been evaluated by using large Pb absorbers (up to 900 g cm^{-2}). The result is that 13±3 percent are muons, which are assumed noninteracting.

In the computation of the cross sections, the number of particles observed to stop in the absorber Σ was reduced by the number stopped by ionization as deduced from the spectrum. This reduction was ~10 percent of the total effect in C; ~20 percent in Pb. The number of nuclear scatterings less than 10° (projected angle) could not be obtained directly, but was held equal to the scatterings between 10° and 20°. This correction was ~20 percent in C; ~5 percent in Pb. The background due to the material of the counters was measured with $\Sigma=0$ and subtracted. A number of knock-on-electron cases which correspond to 8 percent of the total effect were recognized as such and not included as nuclear events.

The results are given in Table I. An independent measurement of the attenuation in 130 g cm^{-2} of C in a "good geometry" arrangement (not shown) gives $\lambda(\pm)=80\pm8$ g cm^{-2}, uncorrected for pions lost by ionization. This value and the values of Table I are smaller than 360±40 mb reported for 133 Mev,[4] and indicate a transparency of ~20 percent in carbon in the Bev range. The observed value in lead is consistent with the carbon value within 1.5 times the statistical error.

A measurement was also made in paraffin. For the pion-proton interaction (by paraffin-carbon difference), a distinction between σ for elastic plus exchange scattering and σ for production of mesons by pions can be made due to the large angular separation between scattered pion and recoil proton in the scattering process.

TABLE I. The total interaction cross sections in carbon, paraffin, and lead for pions of median energy 920 Mev.

Material	$C^{\pm}$	C^{+}	C^{-}	$CH_2^{\pm}$	$Pb^{\pm}$
Σ in g cm^{-2}	21.2	21.2	21.2	23.8	71
λ in g cm^{-2}	74 ± 7	74 ± 8	74 ± 9	77 ± 8	208 ± 38
σ in mb	270 ± 25	270 ± 30	270 ± 34		1660 ± 300
$\sigma/A^{\frac{2}{3}}\pi r_0^2$ [a]	0.76 ± 0.07	0.76 ± 0.09	0.76 ± 0.10		0.70 ± 0.13
Relative corrected numbers of events classified according to their appearance only					
Stop plus scattering $>20°$	51	49	52	53.5	78
Interactions	14.5	13.5	14.5	20.5	11
Scattering 0°–20°	34.5	37.5	33.5	26	11

[a] $r_0=1.47\times10^{-13}$ cm.

For the scattering greater than 10° (proj; lab), $\sigma(\pm)=10\pm10$ mb. The correction for pions and recoil protons scattered at projected angles $<10°$ may amount to a factor 2 if one assumes $\sigma(\theta)\propto\cos^2(\theta)$ (in the c.m. system). Even though the error is uncomfortably large, comparison with the value of 100 mb (average for + and −) observed at 135 Mev[5] still appears significant, indicating that the elastic scattering decreases at large energies.

The number of events attributed to production of mesons, again not of good statistical accuracy, seems to indicate that this process[6] occurs for pion-proton collisions of high energy; the measured cross section is 13.5 ± 6 mb. Also, such a process would best explain the observed occurrence in carbon and lead of visible interactions within a restricted solid angle. A detailed account will be given later.

* Research supported by the AEC.
[1] A bibliography of recent work may be found in Reports on Progress in Physics, Vol. XIV (1951).
[2] O. Piccioni, Phys. Rev. **77**, 1 (1950).
[3] Compare U. Camerini *et al.*, Phil. Mag. **41**, 413 (1950).
[4] Martin, Anderson, and Yodh, Phys. Rev. **85**, 486 (1952).
[5] Anderson, Fermi, Long, Martin, and Nagle, Phys. Rev. **85**, 934 (1952).
[6] W. O. Lock and G. Yekutieli, Phil. Mag. **43**, 246 (1952); W. G. V. Rosser and M. W. Swift, Phil. Mag. **42**, 856 (1951).
[7] Fernbach, Serber, and Taylor, Phys. Rev. **75**, 1352 (1949).

An Unusual Meson-Induced Star*

W. F. FRY† AND J. J. LORD
Department of Physics, University of Chicago, Chicago, Illinois
(Received June 16, 1952)

AN event which is interpreted as a heavy meson-induced star has been observed in an Ilford G5 400-micron thick plate which had been exposed for ten hours above 90,000 feet by means of a "skyhook" balloon. About three pounds of water in metal containers were directly below the stack of plates. The plates were searched for τ- and κ-meson events. A total of 51 $\pi-\mu$ decays, 39 negative π-stars, and 211 mesons which stopped in the emulsion without associated tracks other than electrons, the bulk of which are μ-mesons, have been observed along with the unusual meson star. A projection drawing of the unusual meson star is shown in Fig. 1. The grain density along track 1 is the same, within statistical limits, as along minimum ionizing tracks in the plate. The track has been followed into the adjacent plate. However, the track is nearly perpendicular to the plane of the emulsion; therefore careful scattering measurements were not made. The particle which produced the track was scattered at a point through an angle of about 2 degrees in the adjacent plate. Track 2 is 490 microns long and goes into the glass backing of the plate. From the multiple scattering along track 2, the energy of the particle was found to be about 15 Mev. Since the grain density along the track is about 2 times higher than the grain density along minimum tracks, the track was most probably produced by a π-meson. If it is assumed that the track was produced by a proton, the grain density along the track would indicate that the proton had an energy of about 200 Mev which is in disagreement with the scattering measurements. Track 3 is about 200 microns long and ends in the emulsion and was produced by a proton or a deuteron.

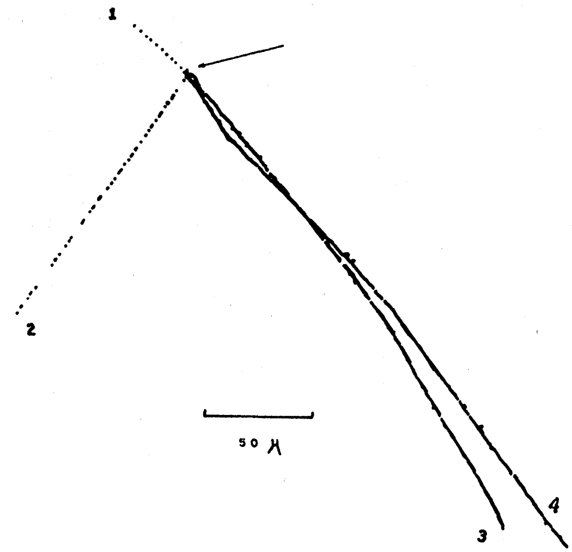

FIG. 1. A projection-drawing of an event which is interpreted as a star due to the nuclear capture of a negative τ- or κ-meson. The large amount of scattering along track 4 near the star strongly indicates that the particle was going toward the star with a low velocity. A recoil or low energy electron track is indicated by the arrow.

The multiple scattering was measured along track 4, using cells of 10 microns. The track is 330 microns long. The average scattering along a 50-micron section of the track near the star is more than 4 times larger than the average scattering along the remainder of the track. The increase in the scattering near the star strongly indicates that the particle was traveling toward the star with a low velocity. The rapid increase in the multiple scattering in the last 50 microns of track length is to be expected from a consideration of the increase in the scattering parameter, $1/p\beta$ for a particle of mass 1000 m_e. The particle which produced track 4 entered the emulsion from the glass backing and came from the direction of the material below the plates. The number of gaps along track 4 has been measured and compared with the number of gaps in the neighborhood of the star along μ-meson and proton tracks which had approximately the same range and which also made about the same angle with the plane of the emulsion. The results of the gap counting are shown in Fig. 2. The gap density is less along the portion of the track near the star. If the track is divided into two

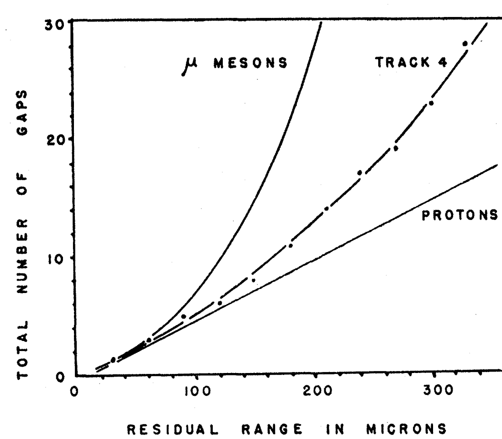

FIG. 2. The total number of gaps up to the range R is plotted against the range R, starting at the end of the track. The number of gaps along track 4 is clearly inconsistent with the assumption that the track was produced by a π-meson.