MASS ANALYSIS OF THE SECONDARY PARTICLES PRODUCED
BY THE 25-GEV PROTON BEAM OF THE CERN PROTON SYNCHROTRON

V. T. Cocconi,* T. Fazzini, G. Fidecaro, M. Legros,† N. H. Lipman, and A. W. Merrison

CERN, Geneva, Switzerland

(Received June 1, 1960)

We present here some results of a mass analysis of the secondary particles produced at 15.9° to the circulating beam in an aluminum target bombarded by 25-Gev protons in the CERN proton synchrotron.

The apparatus (Fig. 1) essentially was a mass spectrometer where the momentum of a particle was determined in the magnet M and its velocity was measured by timing the particle between counters 1 and 3. The distance between 1 and 3 was 27 m, which corresponds to a time of flight of 90 nanoseconds for light. Counter 3 was at 61 m from the target and subtended at the target a solid angle of 1.61×10^{-6} steradian. A time sorter,[1] preceded by zero-crossing circuits and gated by the coincidence 123, was used to display the time difference between the pulses in counters 1 and 3, with the pulses in 1 suitably delayed. The total time range displayed in the 100 channels of the time sorter was ~15 nsec.

Typical spectra for positive and negative particles are shown in Fig. 2. The pion peak (which in fact contains a small contamination of muons and electrons) indicates that the time resolution of the apparatus is about 0.9 nsec. The greater width of the proton peak is caused by the spread in flight times due to the finite momentum band ($\Delta p/p \sim 3\%$) accepted by the magnet.

The results obtained for negative particles

$(K^-, \bar{p})$ and for positive particles (K^+, p, d), shown as percentages of the pion intensity, are given in Figs. 3(a) and 3(b) as a function of momentum. The momentum spectra of the positive and neg-
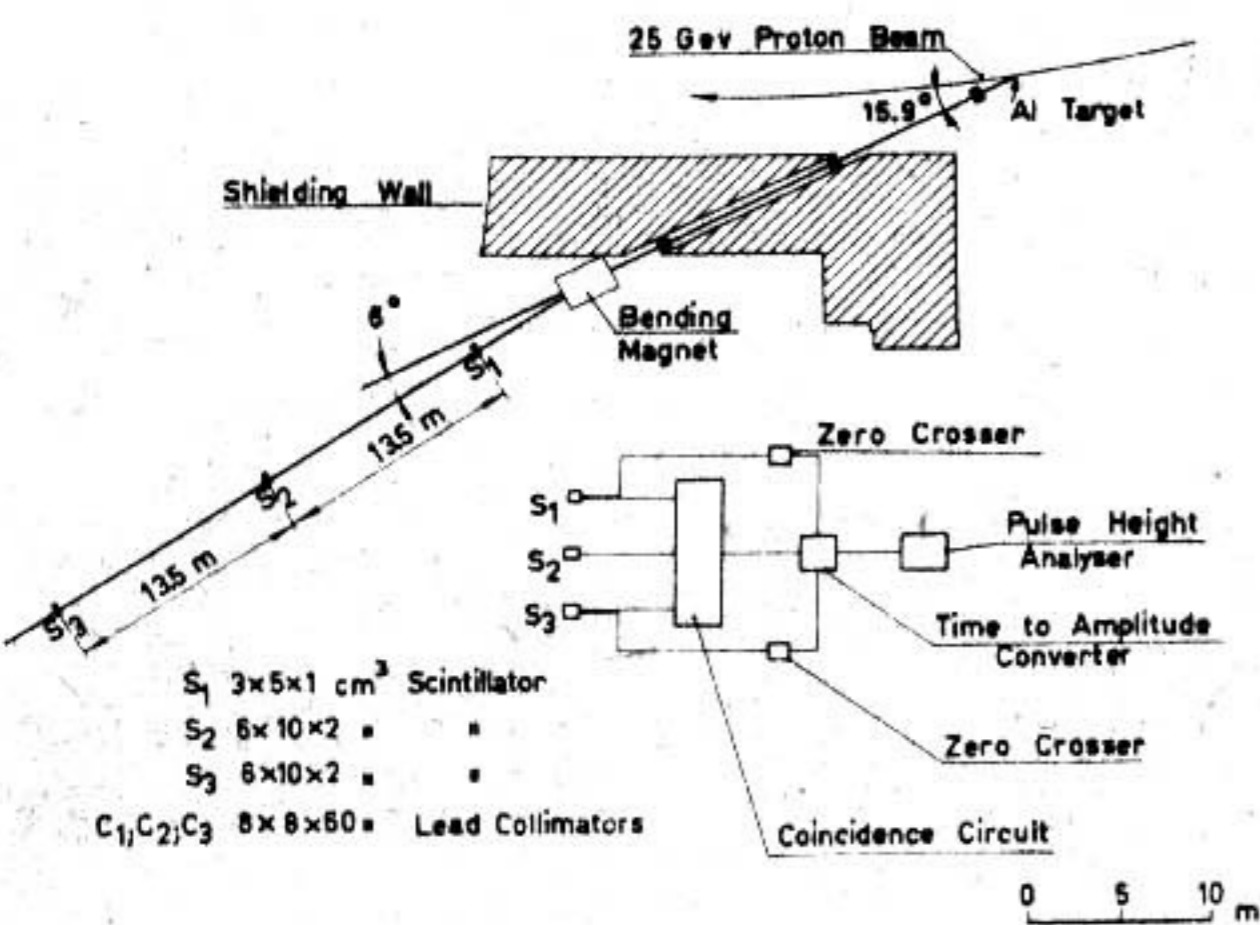

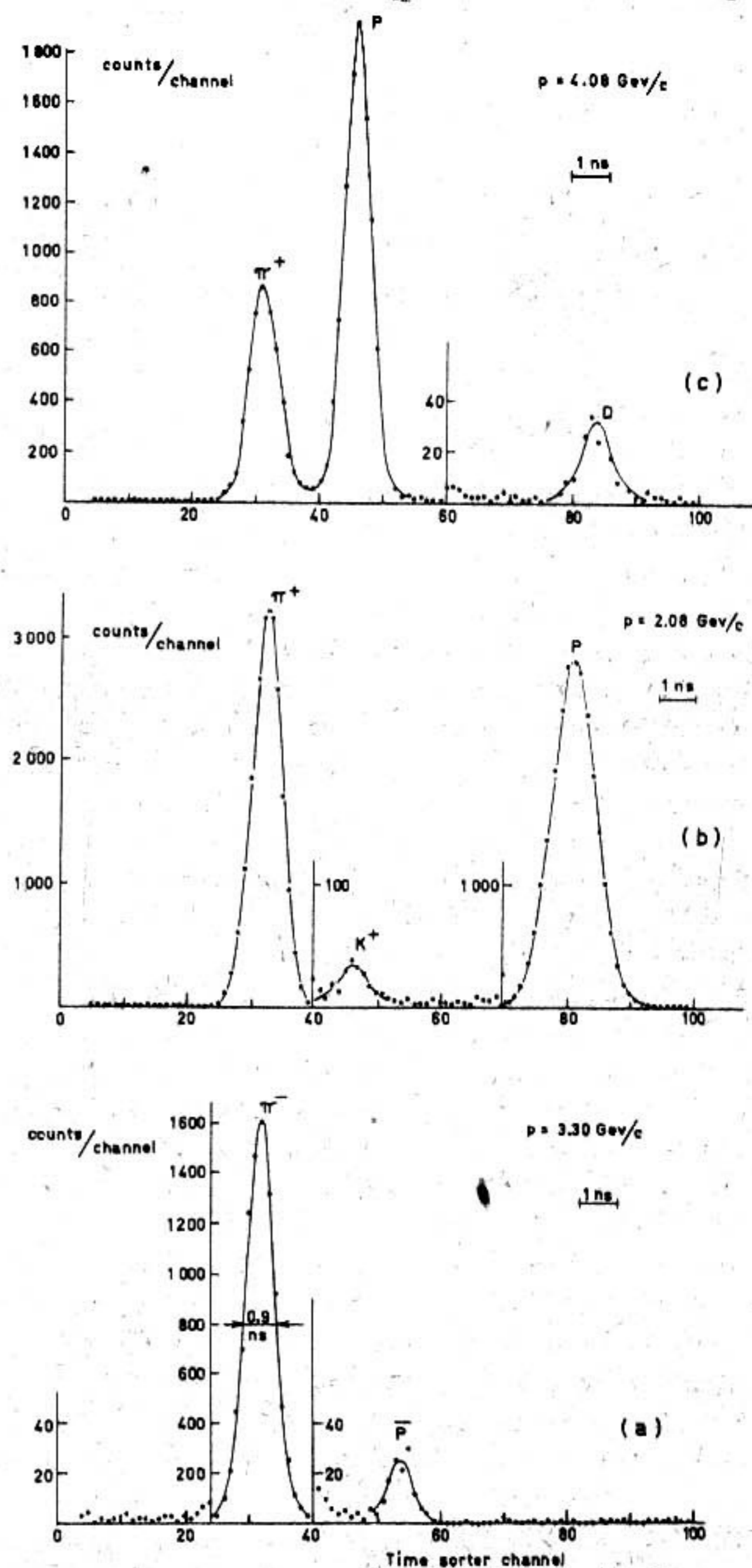FIG. 1. Layout of the apparatus and simplified block diagram of the circuits.
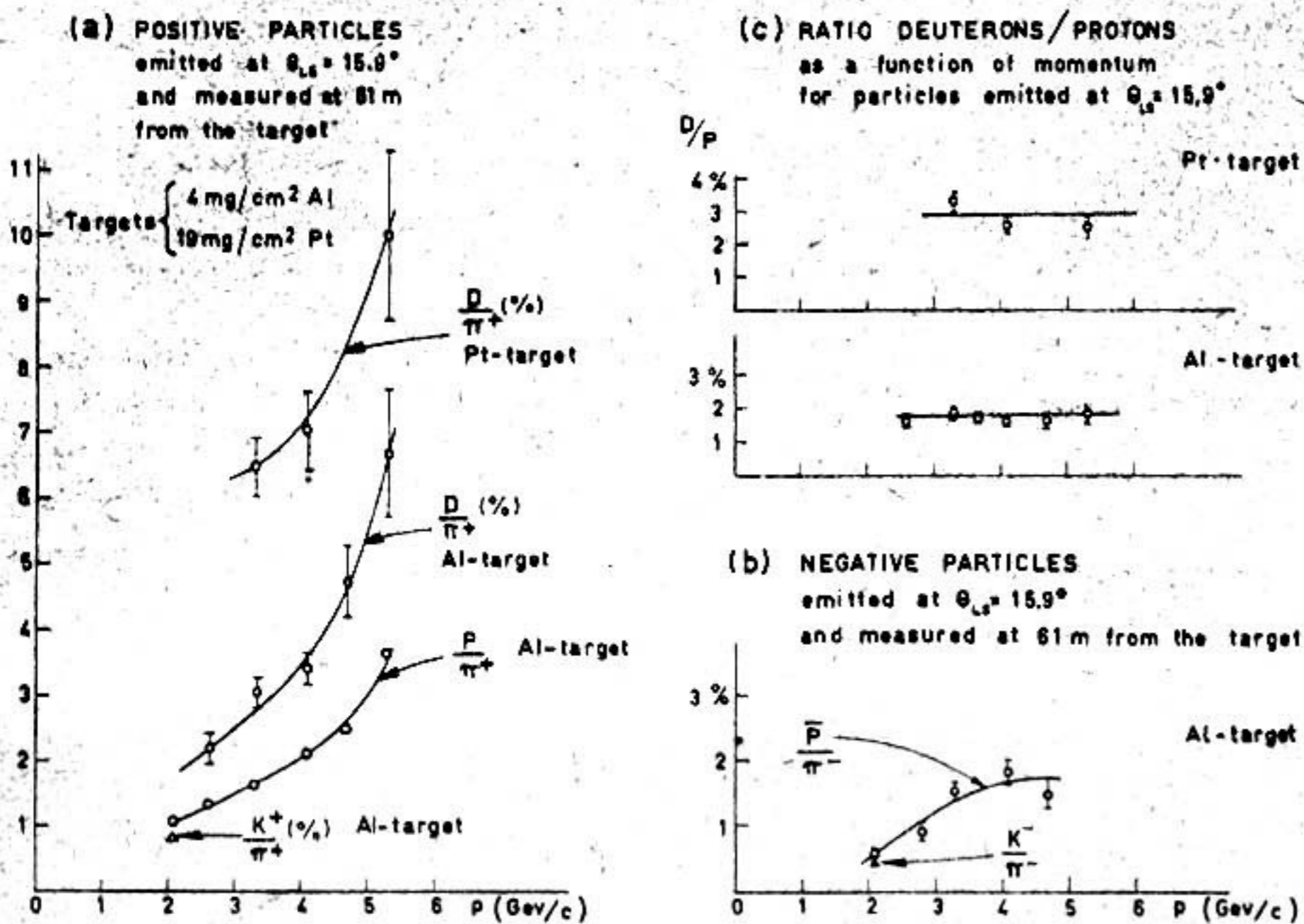

FIG. 2. Typical delay spectra.

FIG. 3. Intensity of the different particles emitted at 15.9° and observed at 61 meters from the target. (a) Intensity of deuterons, protons, and K^+ mesons relative to that of π^+ mesons. Deuteron intensity has been measured both with an Al and with a Pt target. (b) Intensity of antiprotons and of K^- mesons relative to that of π^- mesons. (c) Intensity of deuterons relative to that of protons for the Al and the Pt targets. The indicated errors are statistical. The intensity of the various particles relative to pions at the target can be deduced from the figures by correcting for pion decay over the 61-m path. This effect reduces the ratios by a factor that varies from 1.8 for $p = 2$ Gev/c to 1.25 for $p = 5$ Gev/c.

ative pions are shown in Fig. 4, in arbitrary units. With $\sim 3 \times 10^{10}$ protons/pulse in the circulating beam, the flux of negative pions of 2 Gev/c recorded by our apparatus was ~ 45 counts/pulse. The target efficiency is not well known, but it is thought to be of the order of 50%.[2] Figure 5 is a plot of the time of flight versus momentum for the observed peaks, together with the curves calculated for pion, K-meson, proton, and deuteron masses. It can be seen that all the experimental points fall on the calculated curves.

A number of comments can be made on these results.

(a) K mesons. The intensity of $K^\pm$ mesons could be determined at $p = 2.08$ Gev/c. Above this value the resolution of our apparatus does not allow a reliable separation of the K-meson peak from the pion peak. Positive K mesons seem about twice more abundant than the negative ones at 2 Gev/c. Correcting for K-meson and pion decay over the 61-m path from the target to counter 3, one deduces that at the target $K^+/\pi^+ \approx 25\%$, for the momentum indicated.

(b) Antiprotons. The ratio of the antiprotons to negative pions emerging from the 4-mg/cm² Al target at 15.9° is 0.3% at 2 Gev/c and 1.1% at 4.7 Gev/c, as can be deduced from Fig. 3(b) by correcting for the pion decay over the 61-m path.

By comparing the position of the proton and antiproton peaks at 2.08 Gev/c we could compare the time of flight of these particles and hence their masses. Systematic errors in the timing were looked for by comparing the positions of

the positive and negative pion peaks, observed in the same runs. The drift over several hours was ~ 0.02 nsec. Our preliminary result is

$$\text{Mass } \bar{p}/\text{Mass } p = 1.008 \pm 0.005.$$

The quoted error is largely the statistical error in the position of the $\bar{p}$ peak. The error in setting the magnetic field was 1 part in 500.
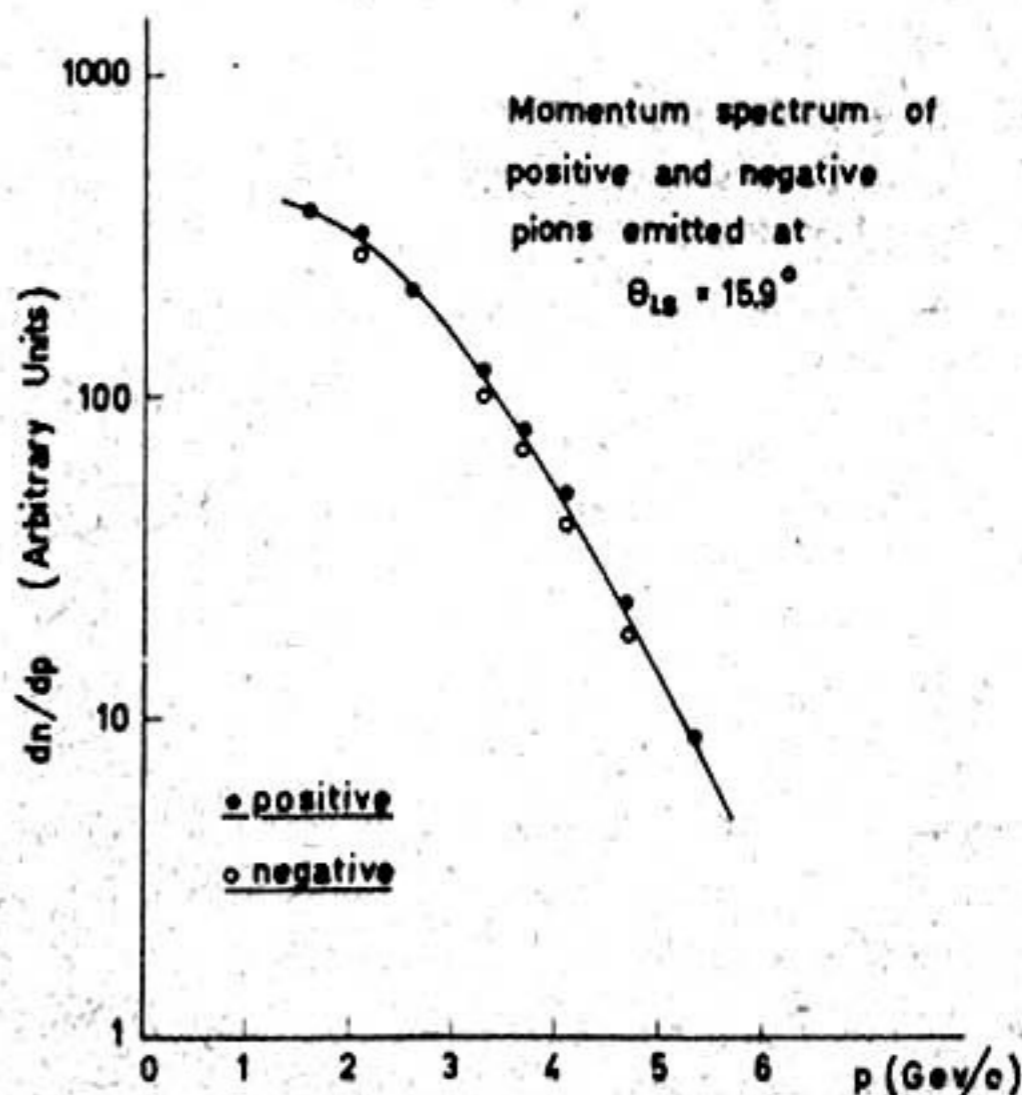

FIG. 4. Momentum spectrum of the pions (slightly contaminated with muons and electrons) emitted at 15.9° from the Al target, and detected at 61 m from it. The spectra at the target can be deduced by correcting for pion decay over the 61-m path.
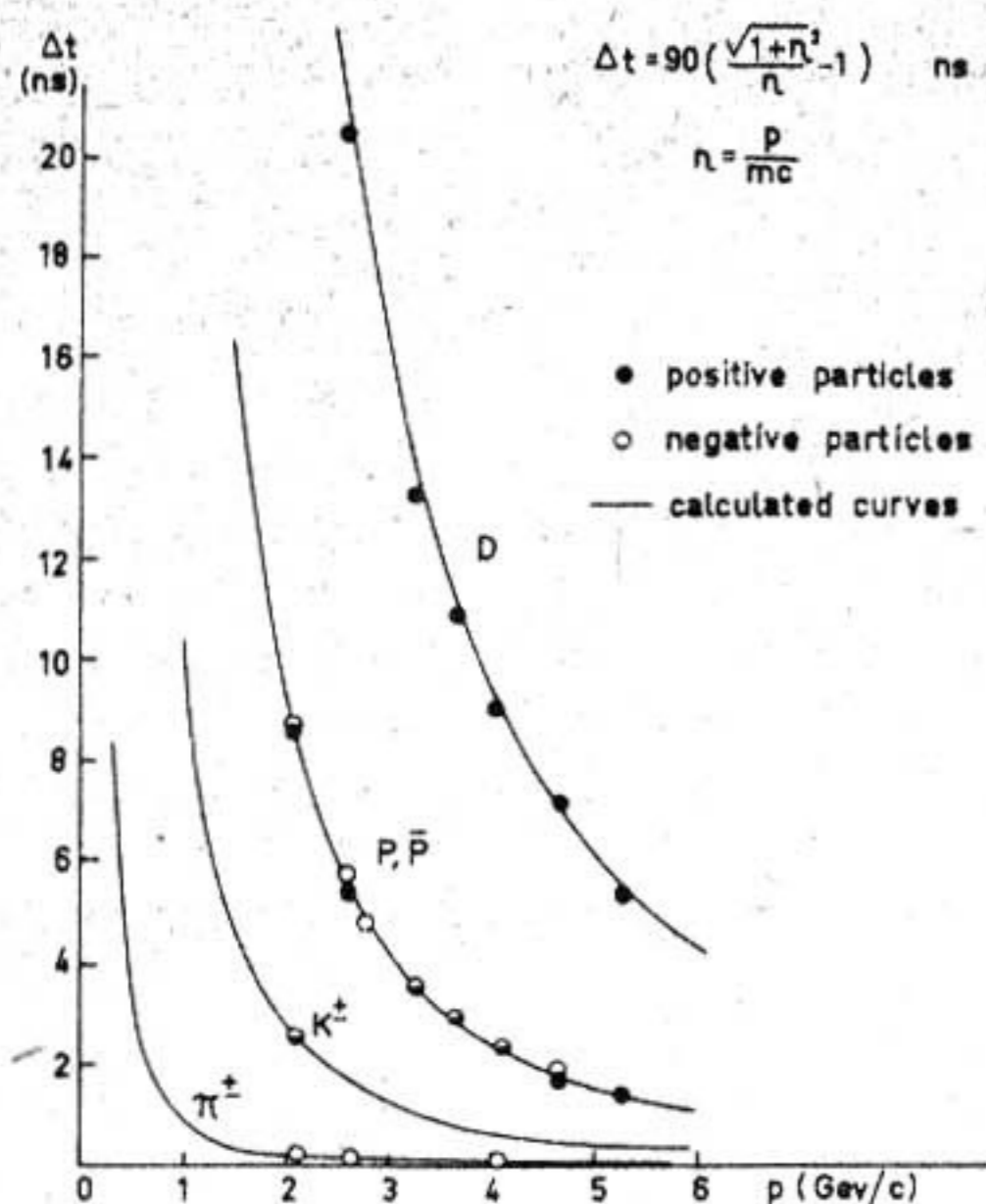
FIG. 5. Time of flight versus momentum for the various particles. The curves are the delays relative to light for a flight path of 27 m, calculated for pions, K mesons, protons, and deuterons. The experimental points are the average values of the measured delays. The statistical errors are not indicated, as they are smaller than the size of the circles.

(c) Deuterons. Our results indicate that in 25-Gev proton-nucleus collisions a large number of deuterons are produced with high momenta and at large angles. We have observed deuterons with transverse momenta up to 1.7 Gev/c.

The assignment of the observed peak to deuterons is justified on the following grounds:

(i) The experimental times of flight determined from the "deuteron" peaks correspond to a mass that agrees with the deuteron mass to about 1% over the whole momentum range explored.

(ii) The possibility that the observed peak is caused by α particles of twice the momentum was ruled out by a pulse-height analysis that showed that the particles were indeed singly charged. No α particle was observed while counting 480 deuterons at 3.30 Gev/c.

In an attempt to understand the deuteron production further, we have recorded data also using a platinum target [Figs. 3(a) and 3(c)]. Work with a beryllium target is in progress. The deuterons observed with the Pt target at $p = 5.2$ Gev/c are about 10% of the pions and 3% of the protons of the same momentum.

The ratio of deuterons to protons is practically independent of momentum both for the Al and the Pt target, and is higher in Pt than in Al by a factor ~ 1.6 [see Fig. 3(c)].

The only information previous to this work on deuteron production in high-energy collisions came from emulsion work on cosmic-ray jets.[3] There it was found that a considerable fraction of the particles producing "gray tracks" are deuterons (about 30% up to an energy of 50 Mev, $\sim 15\%$ at 800 Mev integrating over all emission angles and all primary energies in the collision). The jet deuteron had been interpreted as a tail of the evaporation process.

As far as we know, this is the first time that deuterons have been observed in high-energy collisions at energy above 800 Mev and with high transverse momentum. It is felt that the fact deserves further systematic investigation.

It seems improbable that the deuterons observed in our experiment can be accounted for by evaporation processes, as well as by "direct" or "indirect" pickup processes. On the other hand, the comparison between Al and Pt supports the idea that the process is at least favored by nuclear matter.

With the present sensitivity of the apparatus no evidence for antideuterons could be obtained.

(d) Other long-lived particles. At present, we have no evidence in our data for the existence of particles with mass between that of the K meson and proton, or of the proton and deuteron. Our detection limit comes from the background, which is about 0.1% of the pion intensity and due mostly to random coincidences.

*On leave from Cornell University, Ithaca, New York.

†Groupe de Physique des Hautes Energies, I.I.S.N., Belgium.

[1]G. Culligan and N. H. Lipman, (to be published).

[2]CERN proton-synchrotron machine group (private communication).

[3]See, e.g., C. F. Powell, P. H. Fowler, and D. H. Perkins, The Study of Elementary Particles by the Photographic Method (Pergamon Press, New York, 1959), p. 440.