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Authors

Crawford, Franks, Jr.

Cresti, Marcello

Good, Myron L

et al.

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Frank S. Crawford, Jr., Marcello Cresti,† Myron L. Good,
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Radiation Laboratory
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In the course of studying a large number of decays of hyperons, produced in our hydrogen bubble chamber by 1.23 Bev/c pions, we have found an unambiguous case of a Λ undergoing beta decay. Figure 1 is a photograph of the event. All of the tracks except track 5 lie nearly in the plane of the photograph. We believe that the sequence of events occurring at the vertices labeled A, B, and C is as follows (the track numbers appear in parentheses):

$$\pi^-(1) + p - \langle A \rangle \rightarrow K^0 + \Sigma^0, \quad \Sigma^0 \rightarrow \gamma + \Lambda(2)$$

$$\Lambda(2) - \langle B \rangle \rightarrow p(4) + e^-(3) + \tilde{\nu}$$

$$e^-(3) + e^- - \langle C \rangle \rightarrow e^-(3') + e^-(5)$$

Table 1 summarizes the measured quantities for tracks associated with vertices A and B. Table 2 does the same for vertex C.

The event was first noticed to be anomalous when the neutral decay $2 \rightarrow 3+4$ at vertex B failed to fit the normal two body decay of either a K_1^0 or a Λ. In particular, tracks 3 and 4 both lie on the "left" side of the extension of track 2, and momentum conservation requires an unobserved neutral carrying 34.6 ± 8.2 Mev/c momentum transverse to the "right", and 55 ± 42 Mev/c "down" with respect to track 2.[1]

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†Present address: Istituto di Fisica, University di Padova, Padova, Italy

††Present address: Physics Department, UCLA, Los Angeles 24, California.

[1] If track 1 were not present, the decay at B would still be completely incompatible with K_1^0 decay. A normal Λ decay would in that case fit, however, provided we neglected the important information obtained from vertex C.

Ionization measurements convince us that track 4 is a proton, as follows: Figure 2 shows a semi-logarithmic plot of the distribution of gap lengths between successive bubbles, for tracks 3 and 4. The ratio of slopes in the unsaturated (straight line) region, where the gap size exceeds the average bubble diameter, is 2.65 ± 0.32. This should correspond to the ratio of (unsaturated) average number of bubbles per unit track length.[2] The predicted ionization ratios are as follows:

$I_4(\pi^+)/I_3(\pi^- \text{ or } e^-) = 0.87 \pm 0.04$,[3] $\quad I_4(\text{proton})/I_3(\pi^- \text{ or } e^-) = 3.4 \pm 0.6$.

It is clear that track 4 can only be a proton. We emphasize that tracks 3 and 4 pass through almost exactly the same region of liquid hydrogen, at the same time, so that any possible spatial or temporal variations in chamber sensitivity is irrelevant.

Analysis of vertex C rules out the possibility that track 3 is a pion, and gives roughly 30 to 1 odds in favor of its being an electron rather than a muon, as follows. Track 5 is an electron which eventually goes into the top glass. Its minimum momentum, based only on its visible range, is 3.65 ± 0.1 Mev/c. Curvature measurements give 3.8 ± 0.8 Mev/c. Microscope measurements show that track 3 suffers a deflection at C. Track 5 extrapolates accurately to the point of deflection and is therefore not an accidentally associated electron. If track 3 were a 210 Mev/c pion, the maximum momentum it could give a delta ray electron would be 2.8 Mev/c, so that the energy alone of track 5 rules out a pion. If one stretches all of the measured quantities so as to minimize chi square, one obtains a chi square of 44, where the "expected" value is 4. If track 3 is either a muon or an electron it can furnish the necessary energy to track 5 as a delta ray, but in both cases there is some difficulty in providing the large transverse momentum of 5.9 ± 1.5 Mev/c imparted to track 3'. The hypothesis that track 3 is an electron giving a delta ray at C yields a chi square of 11 where 4 is "expected", and corresponds to a probability of 0.030 for a fit this bad or worse. If instead track 3 is a muon, the fit is much worse, yielding a chi square minimum of 20 and a corresponding probability of 0.001 for a fit this bad or worse.[4]

Thus even if the incident pion, track 1, were missing we could reasonably conclude that event B is a leptonic decay of the Λ, with about 30 to 1 odds for beta decay as against muonic decay.

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[2] W. J. Willis, E. C. Fowler, and D. C. Rahm, Phys. Rev. 108, 1046 (1957).

[3] The relativistic ionization increase for the 210 Mev/c electron, as compared to a 210 Mev/c pion, is largely cancelled by the density effect.

[4] If one invokes the possibility of photon emission accompanying the electron-electron scatter, in order to help balance transverse momentum, one obtains only a slightly improved fit.

We next examine the kinematics of the decay $2 \rightarrow 3+4$, at B, We find that the beta decay $\Lambda \rightarrow p + e^- + \bar{\nu}$ satisfies energy and momentum conservation for a Λ of 650 Mev/c. The electron momentum in the Λ rest frame is 120 Mev/c, or about 72% of the allowed maximum momentum. A 650 Mev/c Λ at the observed production angle falls in the middle of the allowed region for indirect production via $\pi^- + p \rightarrow K^0 + \Sigma^0$, $\Sigma^0 \rightarrow \gamma + \Lambda$.

On the other hand, the muonic decay $\Lambda \rightarrow p + \mu^- + \bar{\nu}$ cannot conserve momentum and energy using the measured values. If one stretches the measured quantities so as to force momentum and energy conservation, and at the same time minimizes the overall chi square one obtains a chi square of 2.6. The odds against the muonic decay mode are thereby increased by at least a factor of 10.

We have so far analyzed 689 Λ decays. Since about 38% of the time a Λ undergoes neutral decay, we can infer $0.38/(1 - 0.38) \times 689 = 422$ additional non-leptonic decays. We estimate that a muonic or a beta decay has a 10% chance of fitting a normal Λ decay and so escaping detection. Therefore we have observed an effective $0.9 \times 689 + 422 = 1042$ Λ decays, and found one beta decay and zero muonic decays.[5] The theory of Feynman and Gell-Mann predicts 16×10^{-3} and 3×10^{-3} for the respective probabilities.

We wish to thank Luis W. Alvarez for his interest and guidance in the associated production experiment. We extend our thanks to J. Don Gow and the bubble chamber crew, to Hugh Bradner and the scanners, and to Edward Lofgren and the Bevatron crew.

[5] R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958).

Table 1

Measured momentum, azimuth, and dip for tracks associated with vertices A and B.

Track	Momentum (Mev/c)	Azimuth, ϕ (degrees)	Dip, λ (degrees)
1	1230 ± 20	103.3 ± 0.3	-0.03 ± 1.6
2	--------	80.4 ± 0.4	8.9 ± 4.9
3	210 ± 20	80.4 + 0.54 ± 0.3	2.5 ± 1.4
4	424 ± 50	80.4 + 4.9 ± 1	4.6 ± 0.8

Table 2

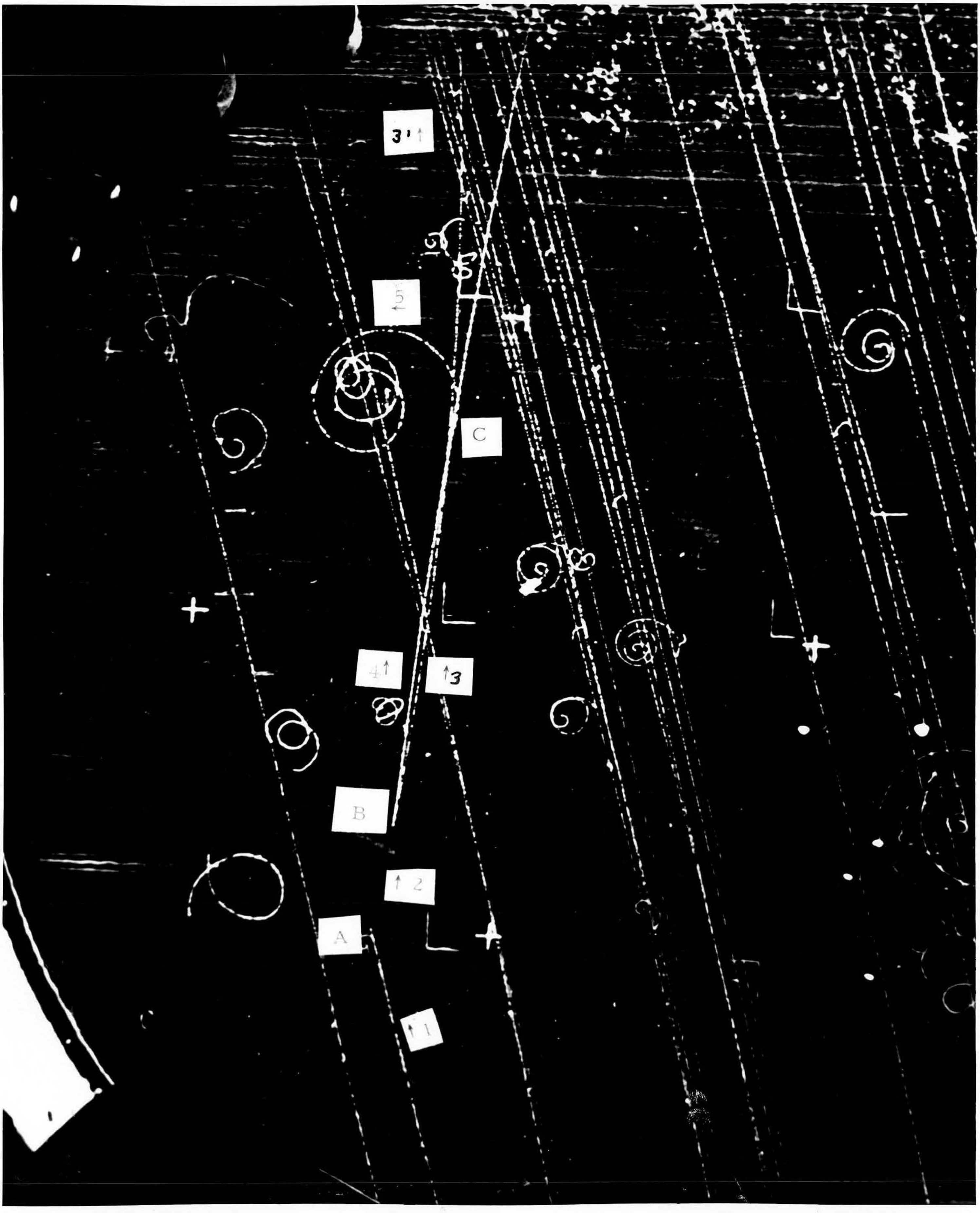
Measured momentum, azimuth, and dip for tracks associated with vertex C, along with best fit values for the hypothesis that 3 → 3' + 5 is an elastic electron-electron collision.

Track	Momentum (Mev/c)	Azimuth $\phi - \phi_3$ (Degrees)	Dip $\lambda - \lambda_3$ (Degrees)
3, measured	210 ± 20	0	0
3, best fit	210	0	0
3', measured	205 ± 15	+1.6 ± 0.4	-3.8 ± 2.0
3', best fit	207	+0.42	+0.40
5, measured	$3.8^{+0.8}_{-0.2}$	-19.4 ± 2.8	-18.9 ± 7.3
5, best fit	3.8	-23.0	-21.0

Figure Captions

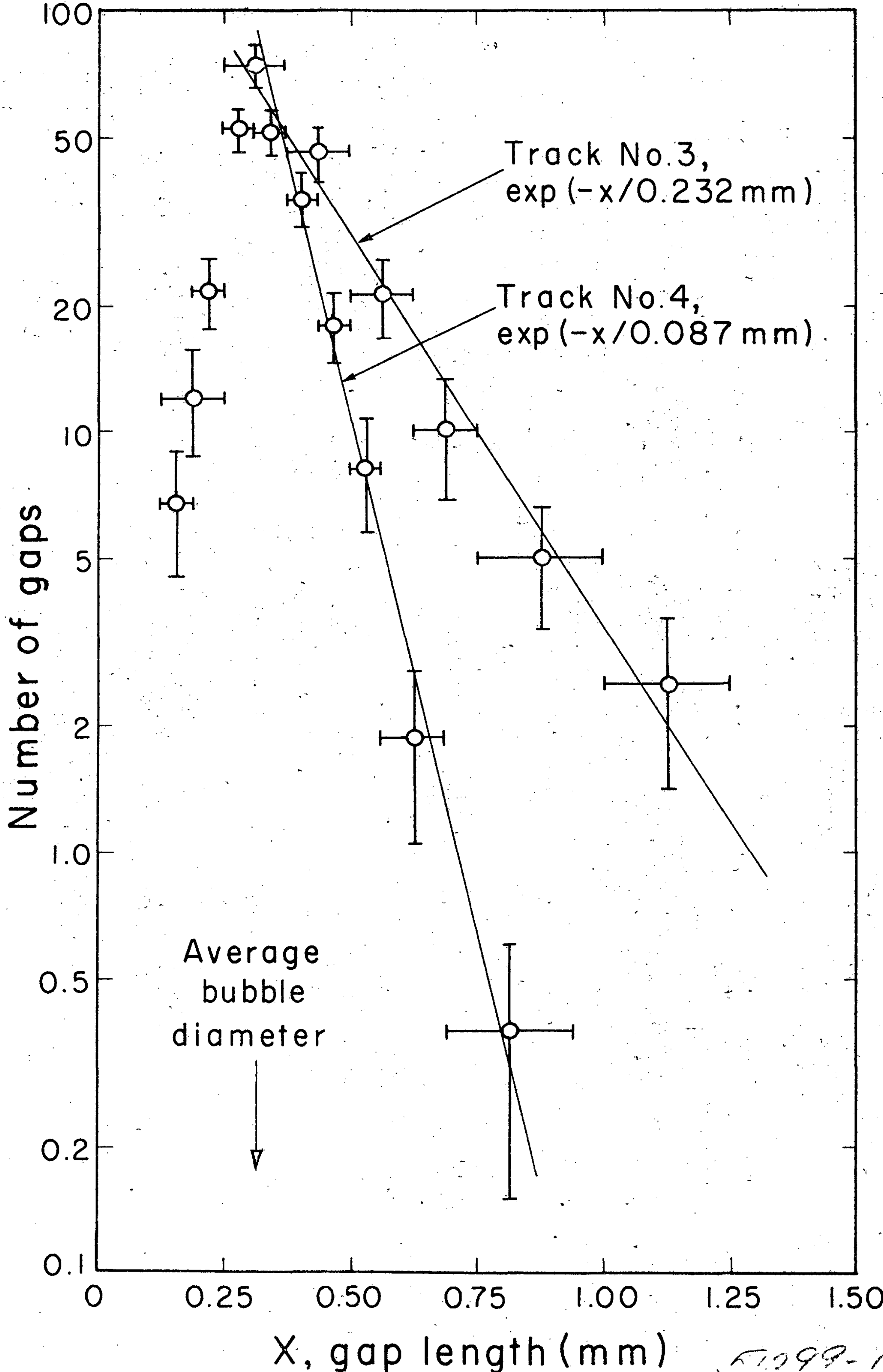
Fig. 1. Photograph of the event. The distance from vertex B to vertex C is 5 cm.

Fig. 2. Distributions of gap lengths between successive bubbles for tracks 3 and 4.


3' ↑
5 ←
C
4 ↑
↑ 3
B
↑ 2
A
↑ 1

Bubble Ch-637-A

F-1



100
50
20
10
5
2
1.0
0.5
0.2
0.1
0
0.25
0.50
0.75
1.00
1.25
1.50
Number of gaps
X, gap length (mm)
Track No.3,
exp (-x/0.232 mm)
Track No.4,
exp (-x/0.087 mm)
Average
bubble
diameter

F-2

57098-1