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NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

A remarkably rich bubble chamber picture (the competition!)

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Two views of a remarkable bubble chamber picture show the existence of many stable particles. Also, in one picture, we have evidence for all four forces of nature - only a supernova can compete!

1. AN EVENT TO ANALYSE

Figures 1 and 2 show two views of an exceptionally rich bubble chamber picture. Before going any further, readers are invited to look carefully for evidence of at least 10 stable particles.

Some speculation may be necessary in the absence of any quantitative information.

2. SOME INFORMATION

The picture was taken during an exposure of Fermilab's 15-foot bubble chamber to a neutrino beam. The event balances transverse momentum relative to the beam direction, and the total energy of the outgoing particles is about 50 GeV.

3. THE INTERPRETATION

The interaction has two tracks of the same sign, one of which curves to the left and another which does so after kinking; the third track is highly energetic, with indiscernible curvature. The two lower momentum tracks must be positive because they curve in the opposite way to the Compton electron C. Charge conservation in the event strongly suggests a negative charge for the high momentum track. Very high energy neutrons are rare, so, even without the above hint, one might have speculated that the negative track is a muon from a υ_μ-induced charged current interaction.

In figure 1 we see that the kinking track produces at P a π^+ which decays characteristically to a μ^+ and then an e^+.

The trickiest part of the interpretation of this event involves noticing that, along the line of flight of the particle marked x on figure 1 (which subsequently decays to the π^+), there is a short dark track, a stopping proton. (It is there on both views.) Pointing to the beginning of this there are two materializing non-collinear photons G which one might optimistically suspect of being the decay products of a π^0.

Measurement (see later) shows that this is indeed the case; so the particle x is a Σ^+ decaying to $n\pi^+$. The momentum of the neutron (1.94 GeV/c) is well above the threshold for producing a π^0 in an np collision.

Let us now move to the 2-prong (see figure 2 - a magnifying glass might help) downstream from the main event vertex. Measurement shows that this is a K^0 decaying to $\pi^+\pi^-$.

(The remaining positive track from the interaction cannot be identified.).

So, to summarize, the simplest interpretation of the interaction is:

$$\upsilon_\mu N \rightarrow \mu^-\Sigma^+K^0h^+$$

where N is a neutron or proton (the fact that electrons spiral tell us that we are in a heavy liquid - a heavy Ne/H_2 mix here) and h is an unidentified hadron.

In making this interpretation we have identified the following stable particles:

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$$\Sigma^+, p, \pi^+, \mu^+, e^+,$$
$$\pi^-, \mu^-, e^-,$$
$$n, K^0, \pi^0, \gamma.$$

In addition, by implication in the $\pi\mu e$-decay chain, we have

$$\nu_\mu, \bar{\nu}_\mu, \nu_e.$$

Since the event balances transverse momentum relative to the neutrino beam direction, it is possible to make an interpretation of the event that uses only the detected particles: if the unidentified hadron is taken to be a pion (the simplest hypothesis), we find that its effective mass with the K^0 is 854 ± 15 MeV/c^2 - suggesting a $K^*(890)$; the reaction then reduces to the associated production of a $K^*(890)$ and a Σ^+ - :

$$\nu_\mu N \rightarrow \mu^- \Sigma^+ K^*(890).$$

The following table gives the momenta corresponding to this simplest interpretation (p in MeV/c, and λ and ϕ in milliradians):

	P	λ	ϕ	Δp	$\Delta\lambda$	$\Delta\phi$
μ^-	45272	-17	17	1744	1	1
Σ^+	2006	156	5988	137	97	37
π^+	939	495	6134	37	6	7
K^0	1588	91	35	145	6	3
γ	144	-878	1490	19	15	17
γ	63	538	913	9	18	11

The effective mass of the two gammas is 130 ± 13 MeV/c^2.

The next table gives the momentum components Px Py, and Pz in MeV/c and the energies E in MeV. The neutrino beam is in the x-direction and, within measurement errors, the total momentum of the outgoing tracks is in this direction.

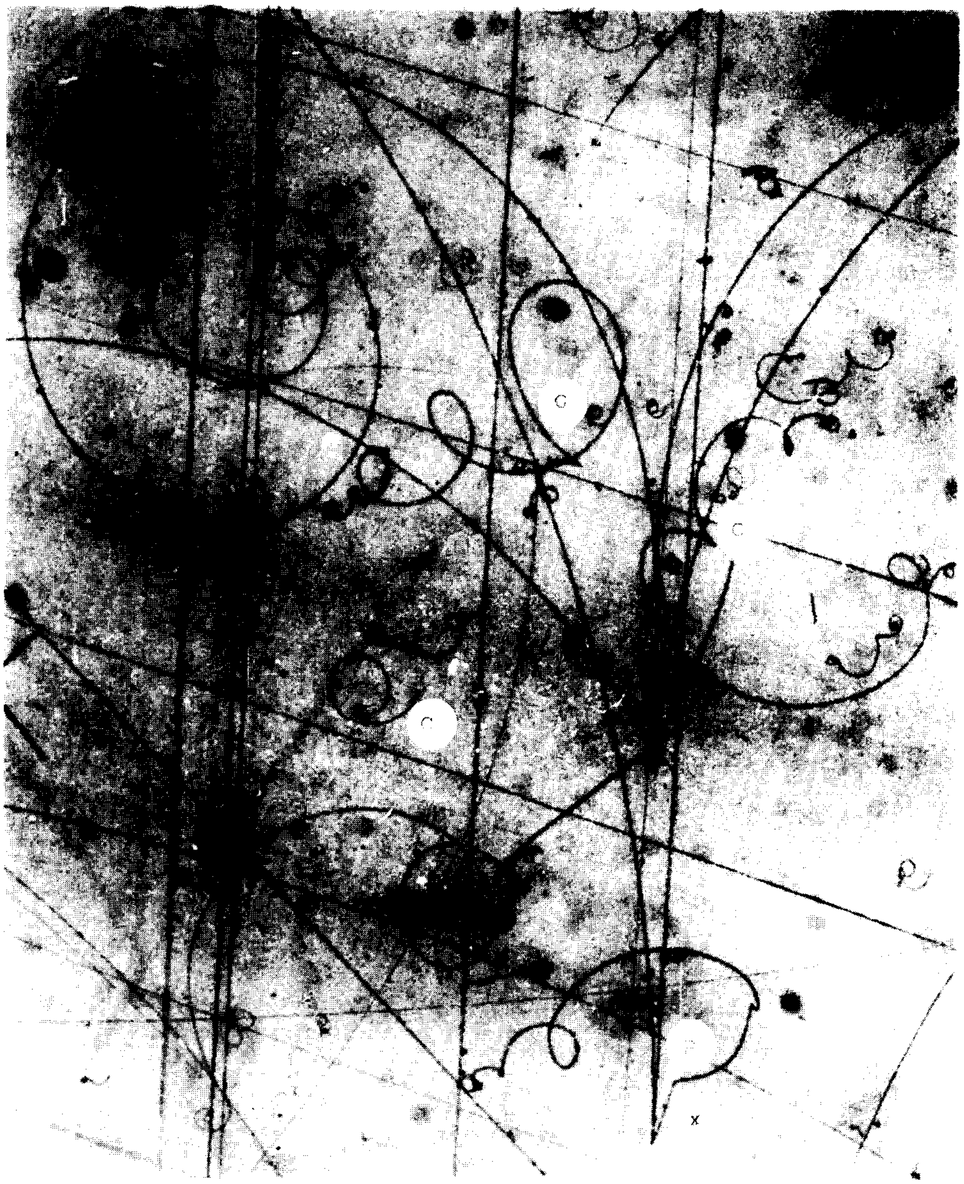
	Px	Py	Pz	E
μ^-	45259	761	-770	45272
Σ^+	1896	-576	312	2332
π^+	817	-123	446	949
K^0	1580	55	144	1664
γ	7	92	-111	144
γ	33	43	32	63

4. THE FOUR FORCES OF NATURE IN ONE PICTURE!

In addition to the strong, weak and electromagnetic forces, it is (perhaps) fun to know that the dark smudging in the corner to the left of the event vertex in figure 2 is due to some (unwanted!) ice that sank to the bottom of the bubble chamber - thus demonstrating the force of gravity!

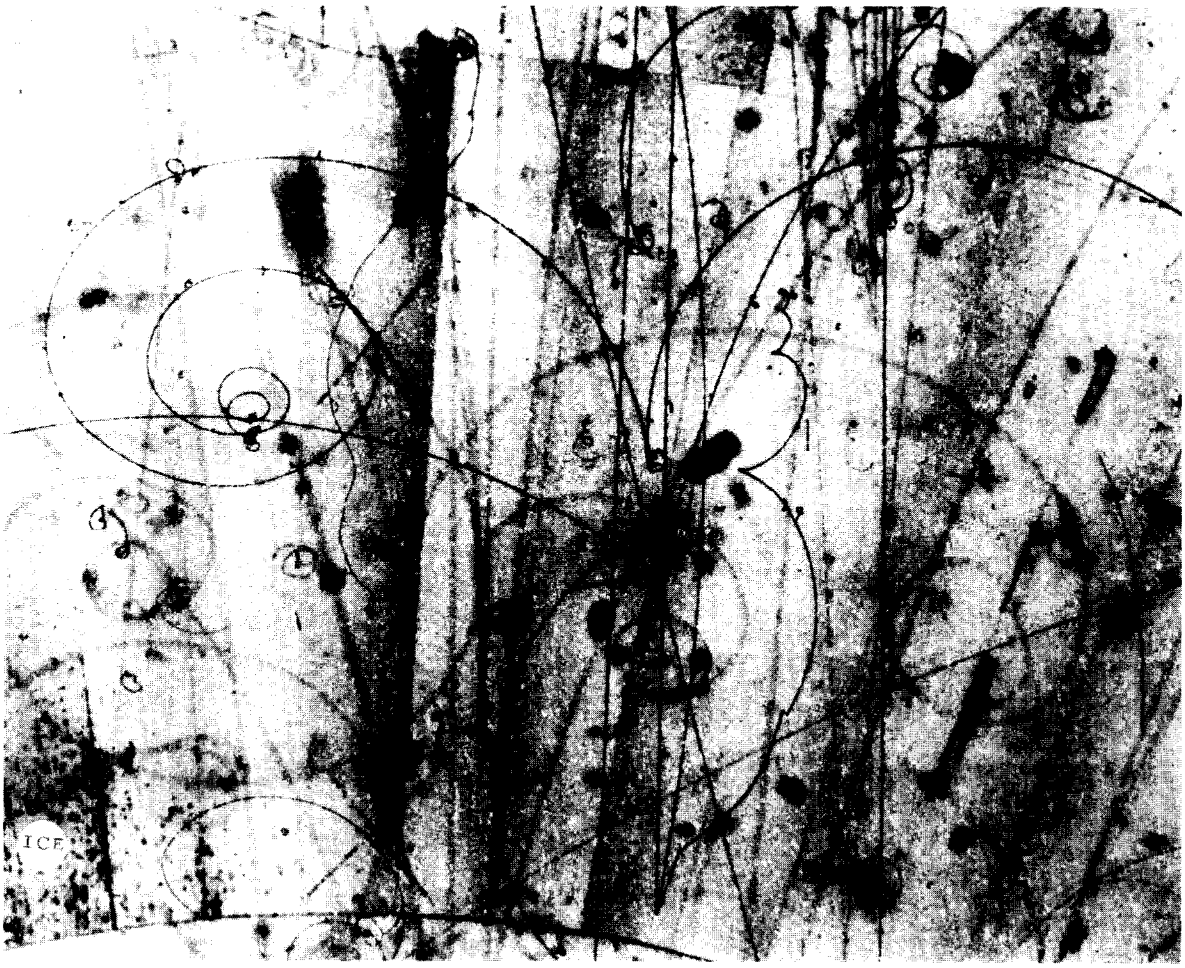
Acknowledgment

I would like to thank Peter Faulkner for finding the neutrino interaction and for his help in analysing this event.



↑ beam

Figure 1.



↑ beam

Figure 2.