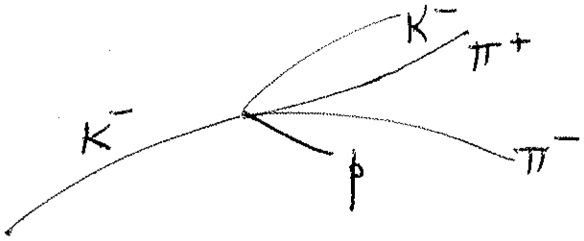
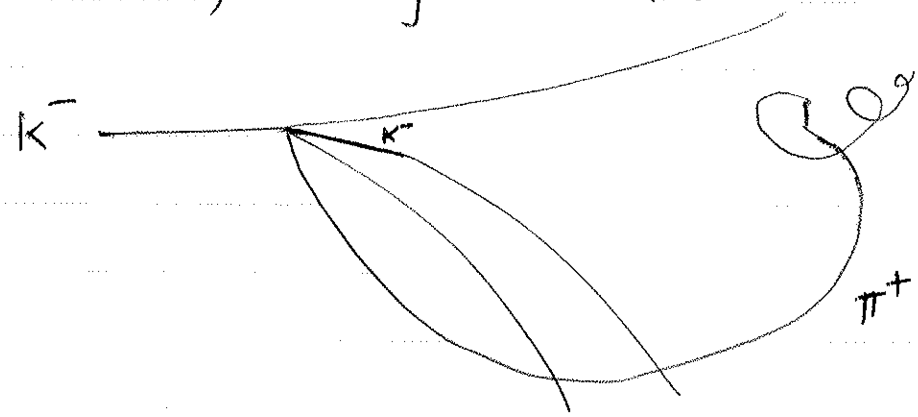
DISCOVERING PARTICLES WITH VERY SHORT LIFETIMES

<u>Qu:</u> Consider a typical bubble chamber interaction

$$K^- p \to K^- \pi^+ \pi^- p$$

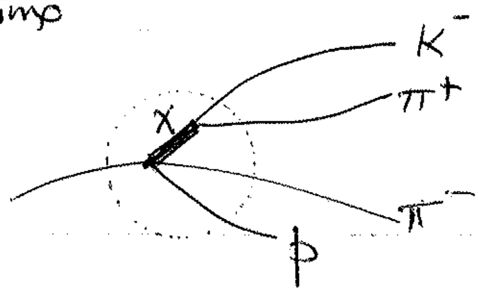


We've seen (bubble chamber website tutorial) examples of K^- and π^+ decaying after measurable distances in the detector, looking a bit like



Such discoveries marked the early days of modern particle physics.

Now we ask: if a particle X is produced in the collision which has such a short life time that it decays in the first bubble, could we detect it and measure its mass?
(In the bubble chamber it would like just like the first figure.)



<u>Ans:</u> YES

After measuring our bubble chamber picture we end up, whenever possible, with the energies E and momenta $\vec{p}$ of all the particles taking part.

In particular, for our $K^- p \to K^- \pi^+ \pi^- p$ event, we would know E and $\vec{p}$ for the K^- and π^+:

$$E(K^-),\ \vec{p}(K^-) \quad \text{and} \quad E(\pi^+),\ \vec{p}(\pi^+).$$

From these we can calculate the total energy and momentum of the $K^- \pi^+$ system:

$$E(K^-\pi^+) = E(K^-) + E(\pi^+)$$
$$\vec{p}(K^-\pi^+) = \vec{p}(K^-) + \vec{p}(\pi^+)$$

Now $m = \sqrt{\dfrac{E^2 - p^2c^2}{c^4}}$; so we can calculate the

"effective mass" of the $K^-\pi^+$ system:

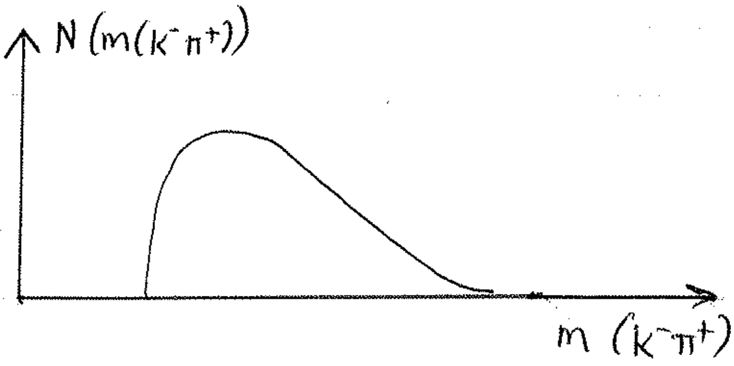
$$m(K^-\pi^+) = \sqrt{\frac{E^2(K^-\pi^+) - \vec{p}^{\,2}(K^-\pi^+)\,c^2}{c^4}}$$

Qu: Does $m(K^-\pi^+)$ "mean anything"?

Ans: For an individual event, "no"; but on a statistical basis, "yes".

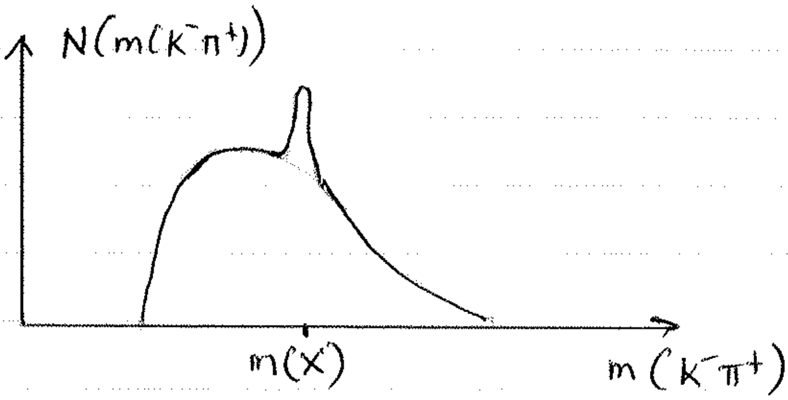
Let $N(m(K^-\pi^+))$ be the number of times one gets – from a large sample of $K^- p \to K^- \pi^+ \pi^- p$ events – a mass of $m(K^-\pi^+)$.

If we plot a histogram we ~~could~~ get something looking like



This is a spread from a minimum value (K^- and π^+ produced at rest!) to a maximum value depending on the beam energy – nothing special going on, just the laws of probability at work ("phase space" in the jargon of the particle physicist.

If, however, for a significant proportion of events, a particle X with mass m(X) was produced, which subsequently decayed to $K^-\pi^+$, the plot would look like



So, a bump in an "effective mass plot" represents the existence of an unstable particle.

(<u>Aside</u> No matter what the velocity of particle X is, its "effective mass" will be the same.)