In this picture we see that a neutral particle has been produced in a bubble chamber in the collision between an incoming K^- -beam and a stationary proton.

From a measurement of the curvatures (click here for details) of the outgoing tracks from the decay of this neutral particle, the following momenta were measured:

Track	**p_x (GeV/c)**	**p_y (GeV/c)**	**p_z (GeV/c)**
Negative	2.80879	-0.51130	0.45166
Positive	0.7638	0.04410	0.04419

Now only 3 neutral particles can be responsible for this decay:

1. K^0 (497 MeV/c^2) → π^+ (139.6 MeV/c^2) + π^- (139.6 MeV/c^2)
2. Λ^0 (1116 MeV/c^2) → p (938.3 MeV/c^2) + π^- (139.6 MeV/c^2)
3. $\bar{\Lambda}$ (1116 MeV/c^2) → $\bar{p}$ (938.3 MeV/c^2) + π^+ (139.6 MeV/c^2)

In continuing, our task is to find which one of the three possibilities is the one which occurs.
We do this by trial and error.

So try in the first instance $K^0 \rightarrow \pi^+ + \pi^-$. This means assuming the negative track is a π^- and the positive a π^+.

With the known masses of π^+ and π^- (each 139.6 MeV/c^2) we can now calculate the corresponding energies, using $E^2 = p^2c^2 + m^2c^4$.

Possible particle	p_x (GeV/c)	p_y (GeV/c)	p_z (GeV/c)	Mass (GeV/c^2)	E (GeV)
π^-	2.80879	-0.51130	0.45166	0.13957	2.89381
π^+	0.7638	0.04410	0.04419	0.13957	0.77895
Sum	3.57259	-0.46720	0.49579	?	3.67277

Assuming that E and p are conserved in the decay, we need to add the momenta and energies.

Using these we can calculate the mass of the neutral decaying particle (= ?) using $m^2c^4 = E^2 - p^2c^2$. With the energies and momenta in the above units, all that needs to be done is to evaluate $m = (E^2 - p_x^2 - p_y^2 - p_z^2)^{0.5}$

$$= (3.67277^2 - 3.57259^2 - (-0.46720)^2 - 0.49579^2)^{0.5}.$$

This gives m = 0.511 GeV/c^2 which, within the measurements errors, corresponds fairly well with the known mass of K^0, which is 0.498 GeV/c^2.

In the second and the third case the calculations are the similar. The differences are in the masses of the particles from the decay. The results obtained in these cases are shown in the tables below:

Possible particle	p_x (GeV/c)	p_y (GeV/c)	p_z (GeV/c)	Mass (GeV/c^2)	E (GeV)
π^-	2.80879	-0.51130	0.45166	0.13957	2.89381
p	0.7638	0.04410	0.04419	0.93827	1.21146
Sum	3.57259	-0.46720	0.49579	?	4.10527

The mass of the initial particle is in this case, m = 1.904 GeV/c^2, which does not correspond well with the mass of the Λ^0 (1.116 GeV/c^2).

Possible particle	p_x (GeV/c)	p_y (GeV/c)	p_z (GeV/c)	Mass (GeV/c^2)	E (GeV)
π^+	2.80879	-0.51130	0.45166	0.13957	2.89381
$\overline{p}$	0.7638	0.04410	0.04419	0.93827	1.21146
Sum	3.57259	-0.46720	0.49579	?	4.10527

The mass of the initial particle is in this case, m = 1.904 GeV/c^2, which does not correspond well with the mass of the $\overline{\Lambda}$ (1.116 GeV/c^2).

From this we can only conclude that the decaying particle is a K^0.

One might ask whether any neutral particles escaped the bubble chamber without being detected?

Again we can use the principles of energy and momentum conservation to check.

The final measurement for this collision is as follows:

Particle	**p_x (GeV/c)**	**p_y (GeV/c)**	**p_z (GeV/c)**	**Mass (GeV/c^2)**	**E (GeV)**
K^- (beam)	8.26131	-0.15642	0.0132	0.49368	8.27753
p (target)	0	0	0	0.93827	0.93828
Sum (initial)	**8.26131**	**-0.15642**	**0.0132**		**9.21581**
π^-	4.49326	0.73621	-0.51122	0.13957	4.58391
p	0.32496	-0.45360	0.04282	0.93827	1.09250
K^0	3.44322	-0.43912	0.48159	0.49767	3.53952
Sum (final)	**8.26144**	**-0.15651**	**0.01319**		**9.21593**

An inspection of the initial and final state shows that energy and momentum are conserved (within errors), and so there are no missing particles. In summary, the reaction is:

$$K^- \, p \rightarrow K^0 \, \pi^- \, p$$

$$K^0 \rightarrow \pi^+ \, \pi^-$$

Here is a question you might have asked:

How has the 4.6 GeV negative track from the collision been identified as a pion? After all, it is highly relativistic ($p^2c^2 > m^2c^4$ for π^-, K^- and $\overline{p}$ masses) and leaves no clue such as a decay or an interaction.

Use has been made of the laws of conservation of baryon number (this rejects the $\overline{p}$ possibility) and strangeness (this rejects the K^- possibility).

(Strangeness is a quantum number which is conserved in strong interactions, but not in weak interactions – and is outside the scope of this bubble chamber website. However, if despite this warning you would like a first look at how strangeness conservation works, click here).

For an animation of this event click here.