ISP220 Homework supplement #12
17 points

the paper part, to go along with the MasteringAstronomy part this week...

April 20, 2019
due on final day, May 3

Your Name: ______________________________

Your Student Number: ______________________________

- This is the paper portion of Homework 12. There is also a MasteringAstronomy part which is due April 26 as normal.
- This paper portion of the set is due at the final exam day, **Friday, May 3** The MasteringAstronomy portion will be due as normal on Friday night, April 26.
- If you have comments about your reasoning, say them.
- **STAPLE these pages**!!

Electron-Positron Annihilation

Under some conditions, electrons and positrons can caused to annihilate to produce a photon. (This is in the intermediate stage of a real process.) Here's the eventual reaction:

$$\bar{e} + e \rightarrow \gamma. \tag{1}$$

We're going to build up that reaction starting from the primitive diagram.

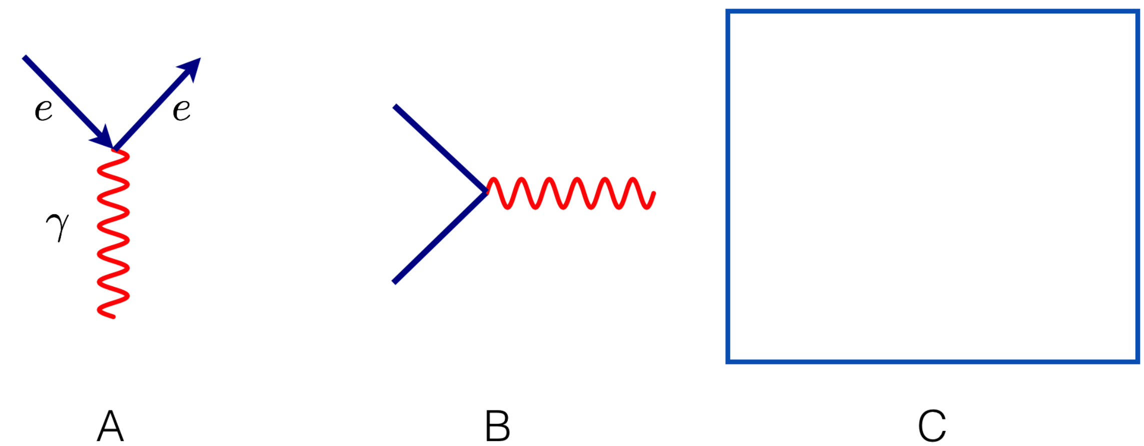

Figure 1: Creating the Feynman Diagram for electron-positron annihilation.

Figure 1 A shows your first primitive diagram for the fermion-photon interaction where here the general fermion is an electron.

1. (1 point) B is meant to be the counterclockwise rotation of A. In B, label the particles that result from that rotation of A and properly include the arrows.

2. (2 point) In the blue box fix any unphysical legs from B and show the proper Feynman Diagram for the eventual reaction...the annihilation as described in Eq. 1.

Compton Scattering

Remember the experiment done by Arthur Holly Compton that demonstrated the particle nature of light (X-rays) definitively. The reaction was:

$$\gamma + e \to \gamma + e \tag{2}$$

where the outgoing gamma was an X-ray of a
(1 points, circle your choice)

a. higher?

b. lower?

frequency than the initial gamma.

(2 points) In Fig. 2 complete the Feynman Diagram by referring to the Primitive Diagram and attaching the appropriate pieces. Treat the electron/positron arrows properly.

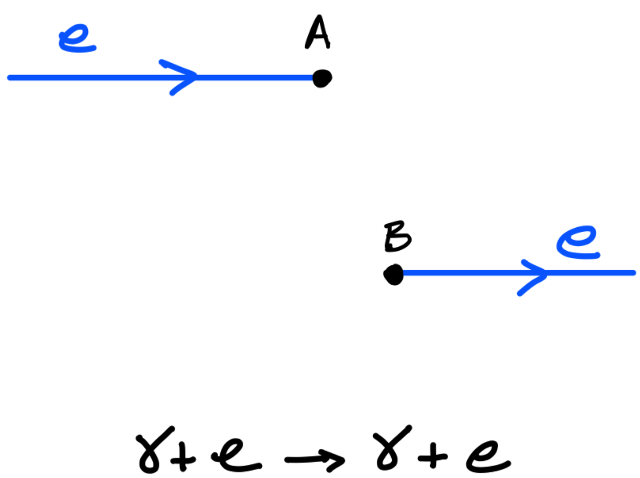

Figure 2: Complete the diagram for Compton Scattering.

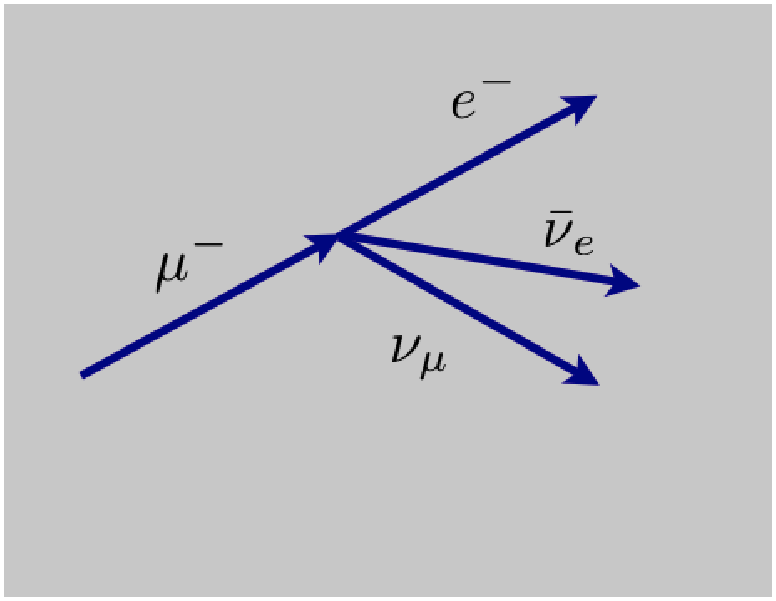

Figure 3: Decay of a muon (particle, not antiparticle) into an electron and two neutrinos.

Muon Decay

This problem involves the muon decay Feynman Diagram shown in Figure 3. A muon is a fermion that decays into 3 other fermions: an electron, a neutrino (with subscript e), and another kind of neutrino (with subscript μ). The electron and muon particles are negatively charged and the antiparticles are positively charged. For this problem, represent them with their charges as I've done, not with the bar over them. For the neutrinos, however, use the bar over the symbol to represent the antiparticle and pay attention to the fact that there are two kinds of neutrinos here and they have to be kept separate. Neutrinos are electrically neutral fermions.

So, here's the plan. The standard neutrino beams produced at accelerators consist overwhelmingly of muon neutrinos ν_μ (not antineutrinos). These neutrinos can scatter from electrons. What I want is to construct the Feynman Diagram for the process that I studied in the 1980's:

$$\nu_\mu + e \to \mu^- + \nu_e \tag{3}$$

Let's do this in the steps that I've outlined in lecture. Draw your answers below the questions.

4. (1 point) Pull the muon neutrino line from the final state into the initial state, push the initial muon line from the initial state into the final state, and bring the electron line from the final state into the initial state. Draw that diagram keeping track of the arrows. They will now not make sense. That is, you'll now have an electron leaving the initial state going backwards in time, etc.

5. (1 point) So, now fix the lines by using the Feynman trick of reversing the directions of the arrows and doing the appropriate thing to the particle-antiparticle nature of each adjusted leg.

There's **one more rule**. You can always change the all of the quanta in a diagram, all at once: all of the particles into antiparticles *and* all of the antiparticles into particles...everywhere, initial and final states together.

6. (1 points) Notice, that the previous diagram is not the reaction we want according to Eq. 3. It's also not practical: can you think of any positron targets? So turn it into the reaction we want...use the rule above and do it: Draw the final Feynman Diagram corresponding to Eq. 3.

7. (2 points) **This is almost a trick question: Why is it impossible for the following decay to occur? The neutron is at rest. (Remember relativity.)**

$$n \to p + p + \bar{p} + e^- + \bar{\nu}_e$$

Bubble Chamber Reactions, 6 points total

What follows refers to photographs at the end of the set. You don't have to print them out and turn them in if you don't want to.

I have three bubble chamber photographs of events which were exposed to a K^- beam in a liquid hydrogen bubble chamber. So, the target consists of protons. I'll work one as an example, and you work the other two. The Example refers to Figure 4 on page 10. See the letters imbedded in the photograph? That's what the questions will refer to in what follows and you need to circle the letter you think corresponds.

(a) Which track shows a collision of beam particle with a proton:

a b c d e f g

(b) Which track shows the decay of a neutral particle.

a b c d e f g

(c) Which track shows a collision of a beam particle with an electron.

a b c d e f g

(d) Which track shows a collision of a neutron with a proton.

a b c d e f g

(e) Collision of a photon with an electron.

a b c d e f g

Here is my analysis:

(a) A kaon hitting a proton will result in some strong interaction, so you're looking for a charged kaon coming in from the bottom and at some point multiple charged tracks emerging from a point on a kaon track. That would be the production of pions and protons and at least some strange particle. It could also include production of neutral pions, which you'll remember decay into two photons, which you'd see convert into e^+e^- pairs. There's nothing like that. But, c does appear to be a beam-proton collision.

(b) This will be one of the V's found in cosmic rays. That's apparent at point d.

(c) This will be the collision of a kaon and an atomic electron, which will probably be a "glancing" blow and the electron will spiral quickly and the kaon will continue on its way since it's so much more massive than a stationary electron, it's momentum will be hardly affected. Look at a. Here is exactly this circumstance. Notice that this also shows you the direction of the magnetic field: negative particles will bend to the right. The kaon beam is moving pretty fast and it's hard to tell that they are negative.

(d) A neutron hitting a proton is obviously not the consequence directly of the incoming kaon beam. But, neutrons are always a background in beams since they can be produced way up stream and then they're really hard to stop.[1] So, the occasional neutron will happen and it does here. The initial state would

[1]That's why the so-called "neutron bomb" is such a deadly battlefield weapon. There is no protection

have a net positive charge of +1 since it's due to the target proton alone—the neutron hasn't any charge. So, that's why the V in the previous question doesn't qualify. That was a net zero charge in those two decaying particles. Point e has three tracks emerging, one negative (bends right) and two positive, as expected.

(e) Photons could also come with a charged beam since they might be radiated from a beam particle. So, we expect to see nothing and then an electron suddenly spiraling to the right. Point b is exactly that.

Now it's your turn. **(Using Figure 5 on page 11), answer the following:**

(a) (1 point) Which track shows the decay of a neutral particle.

v w x

(b) (1 point) Which track shows a collision of a beam particle with an electron.

v w x

(c) (1 poin ch track shows a collision of a beam particle with a proton.

v w x

(Using Figure 6 on page 12), answer the following:

(a) (1 point) Which track shows the decay of a neutral particle.

v w x y

(b) (1 point) Which track shows a collision of a beam particle with an electron.

v w x y

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for people, even inside of tanks. The water in the body is a large amount of nearly free protons, so the neutrons elastically scatter from them and do terrible damage. Of course, it's indiscriminate and civilians and not just soldiers would be killed. I don't like the neutron bomb.

(c) (1 point) Which track shows a collision of beam particle with a proton:

v w x y

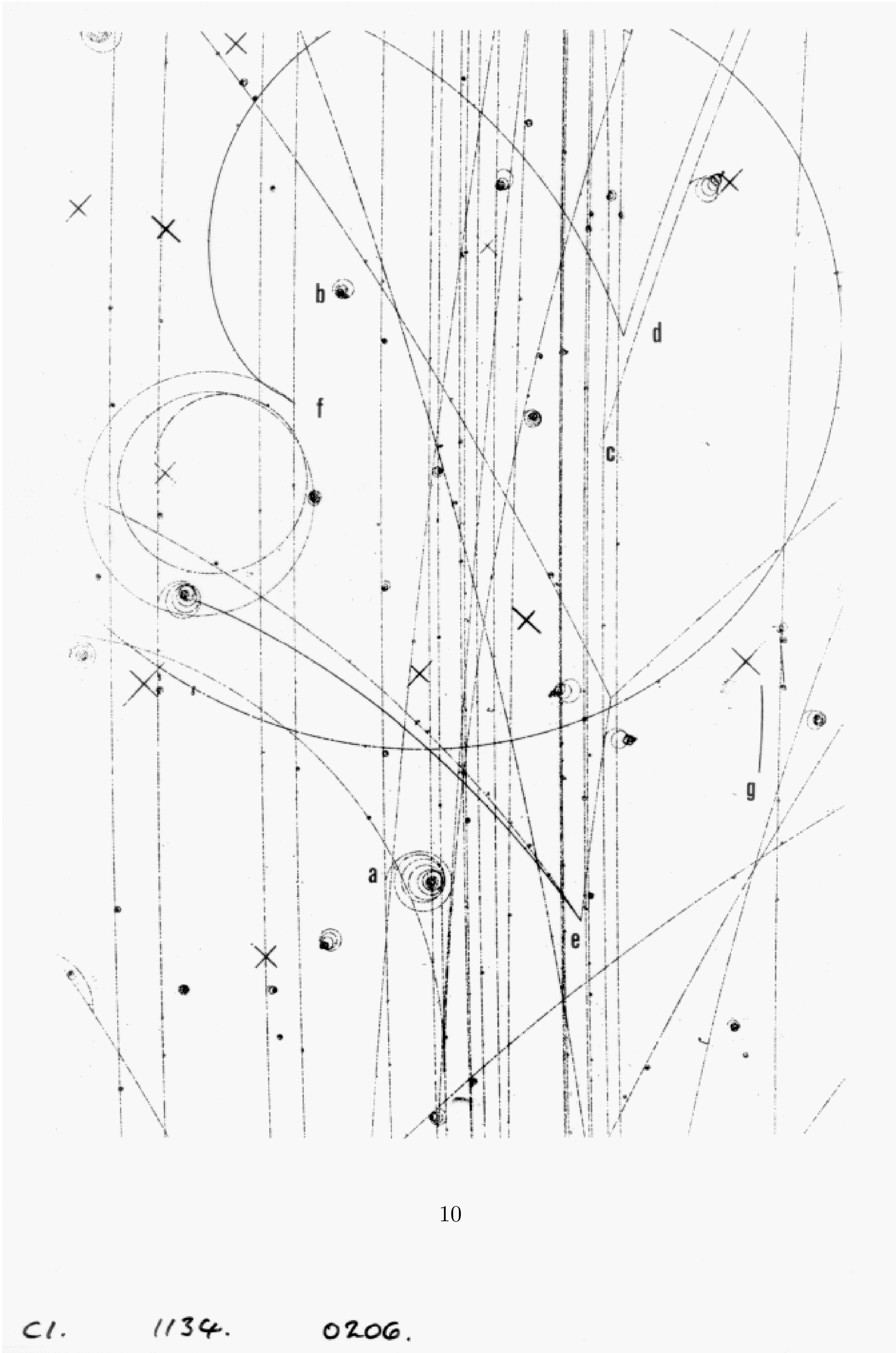

Figure 4: Example events in a negative Kaon beam.

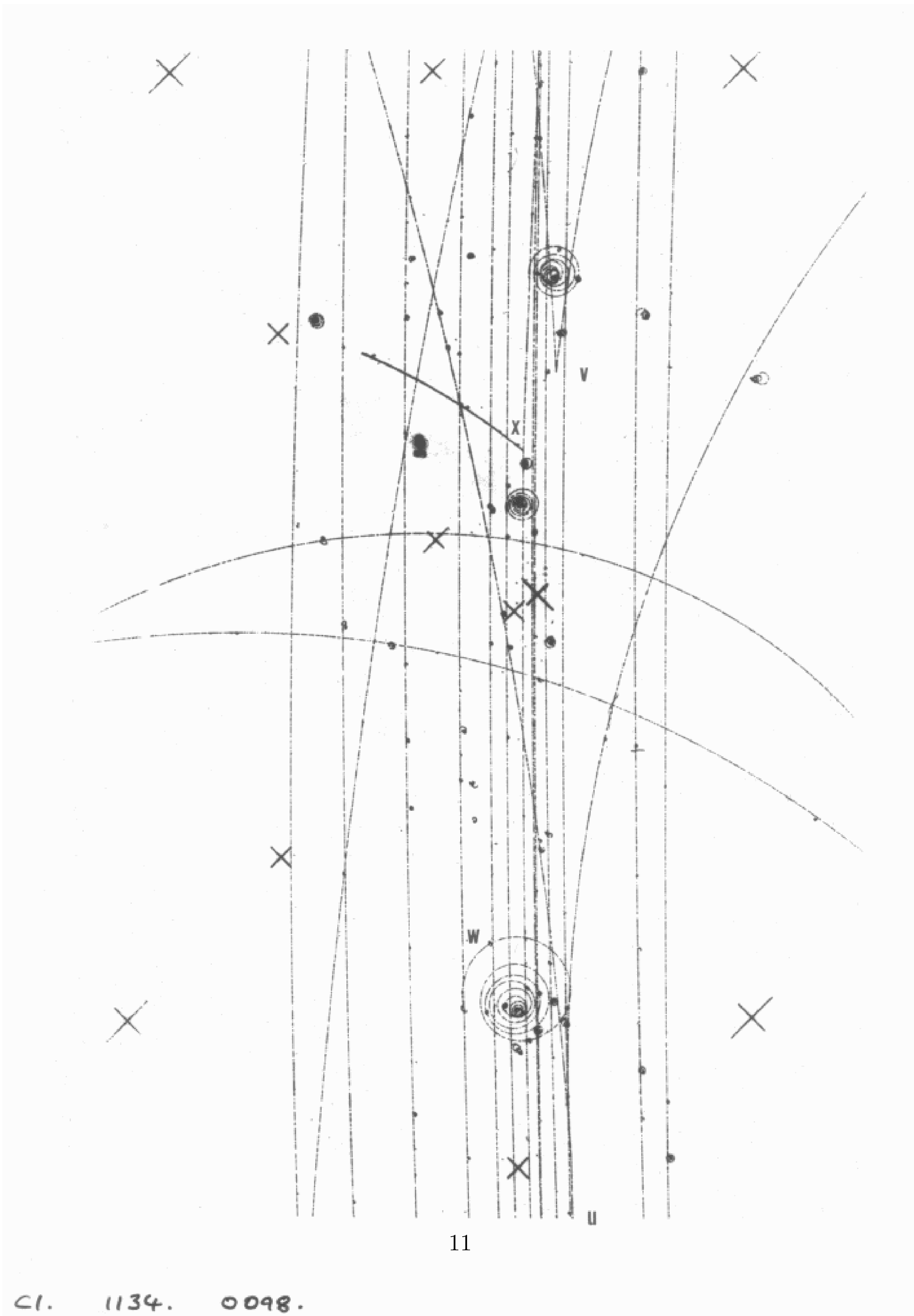

Figure 5: Problem 1 bubble chamber picture.

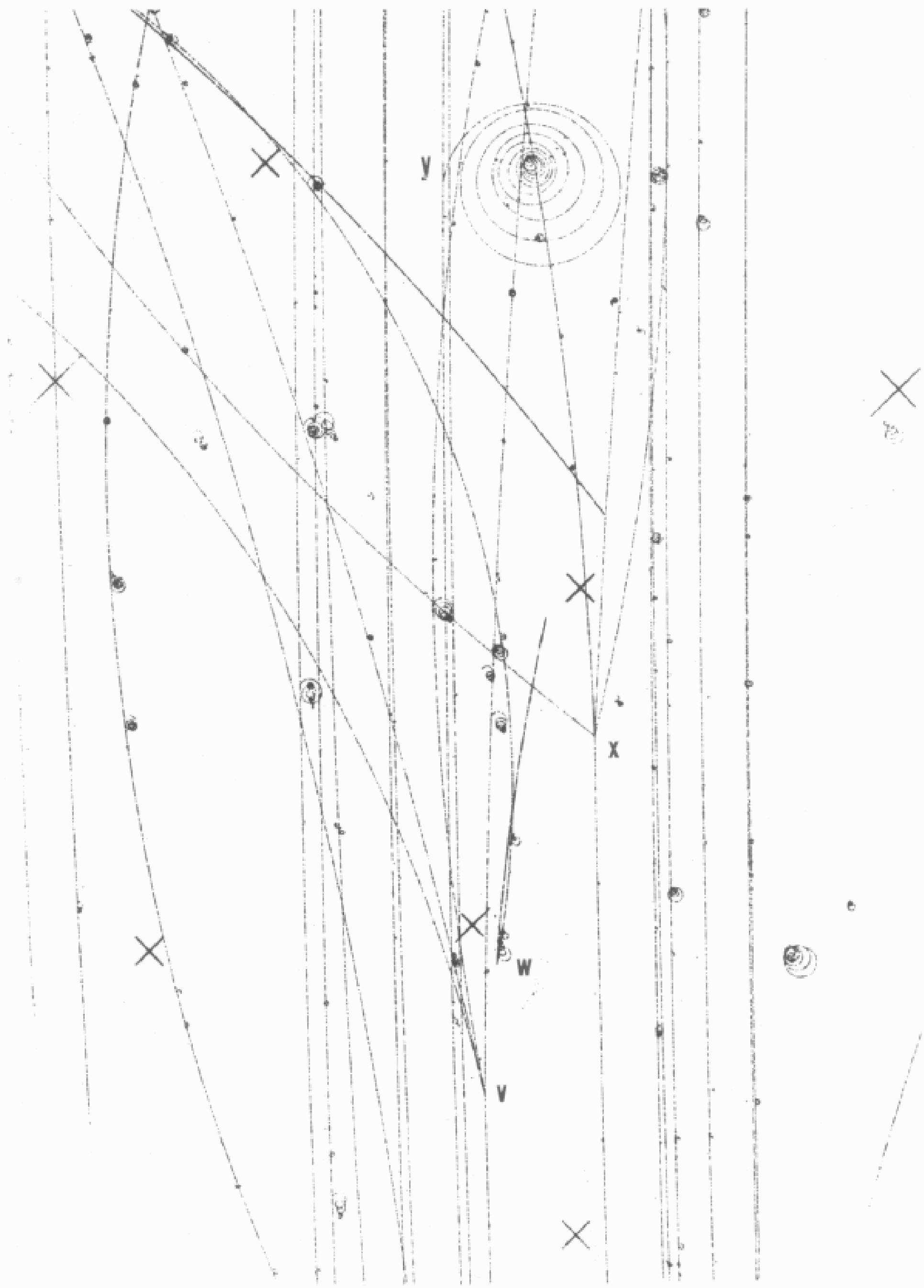

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Figure 6: Problem 2 bubble chamber picture