Workshop: The hidden beauty of bubble chambers

INTRODUCTION

There is an immediately pleasing aesthetic to bubble chamber pictures. This beauty has been widely recognized:

This workshop, however, explores the hidden or inner beauty found in bubble chambers: an insight into the world of elementary particles.

OUTLINE:

- Each group is given a bubble chamber picture. What do you see in this picture? (mysterious crosses, tracks like those produced by condensation trails from aeroplanes in the sky; more or less parallel tracks; short and thicker tracks; intersections of tracks; spirals, etc.) (10 min)
- Which questions would you like to have answered during this workshop? (The questions could be: I want to know what a bubble chamber is and the connection in which it is used? Which particles do you see and how do you recognize them? What is the magnetic field applied in a particular bubble chamber picture? (5 min)
- Introduction to bubble chambers and bubble chamber pictures (15 min)
- Hands on exercises in groups (50 min)
- Wrap up (10 min)

AIM:

With the workshop we want to answer the question:

- What information can be learned through investigating bubble chamber pictures and how is it relevant to the physics that may be addressed in schools?

To accomplish this goal teachers will learn how to identify particles and their interactions in bubble chamber pictures from data taken from an unknown bubble chamber. They will also use these interactions to illustrate basic concepts such as charge and momentum conservation.

(These pictures were taken during the peak period of bubble chamber technique, i.e. 1950s-1970s.)

Background Information

WHAT IS A BUBBLE CHAMBER?

Donald Arthur Glaser was awarded the Nobel Prize in Physics in 1960 for the invention of the bubble chamber in 1952. This device was widely used until the early 1980's.

The bubble chamber is a device that allows the identification of charged particles by the tracks they leave when flowing in a liquid.

A bubble chamber consists of a vessel filled with an overheated liquid (usually hydrogen or deuterium). When electrically charged particles enter the chamber, the fluid begins to boil along the paths of the particles, originating small bubbles that can be photographed.

The image below shows a schematic view of a bubble chamber.

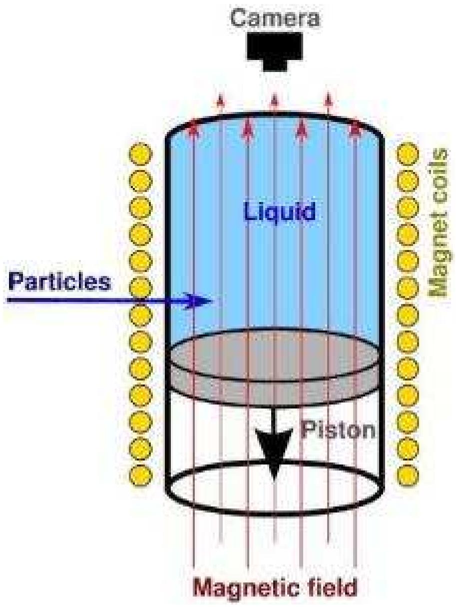
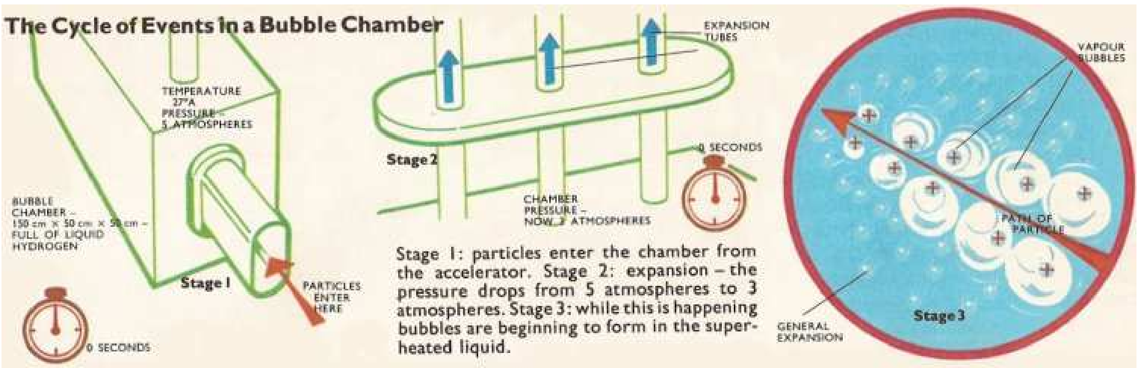
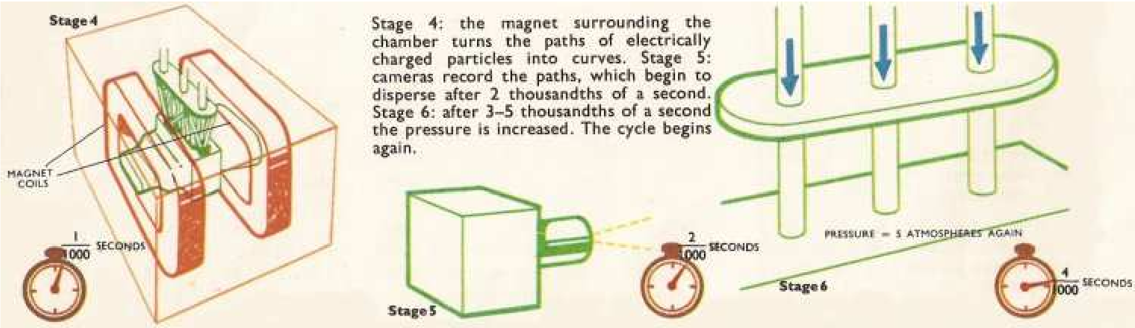


Image 1 – Schematic view of the constitution of a bubble chamber (http://www.encyclopedia.com/topic/bubble_chamber.aspx)

HOW DO BUBBLE CHAMBERS WORK?

Fig. 1 – CERN Big European Bubble Chamber, installed in the early 70s. (http://cds.cern.ch/record/41546)



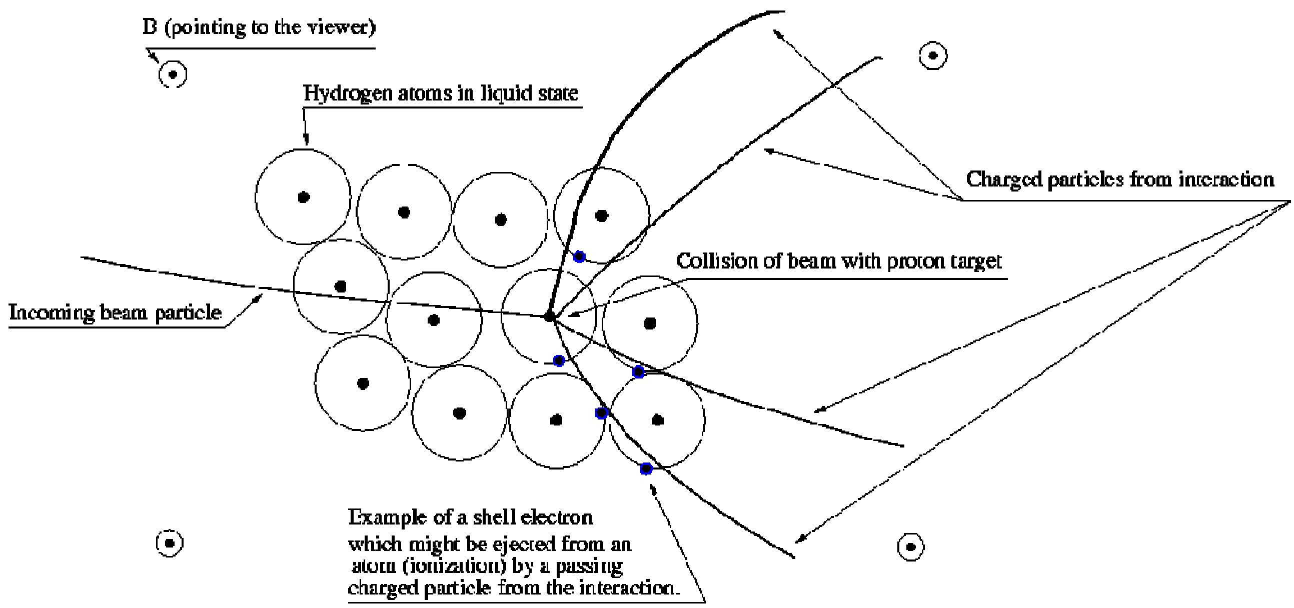


http://www.daviddarling.info/encyclopedia/B/bubble_chamber.html

Bubble chambers are no longer used as detectors in particle physics but they are still relevant for teaching particle physics today. Modern electronic techniques are far more accurate than the methods required of bubble chambers, yet current particle physicists apply many of the same principles in designing experiments and interpreting data. These principles include conservation of charge, passing charged particles through perpendicular magnetic fields so that the particles experience circular motion, and conservation of momentum. Analyses of bubble chamber pictures are an excellent way for high school students to investigate the characteristics of particles in both a qualitative and quantitative manner.

WHAT HAPPENS IN A BUBBLE CHAMBER?

A bubble chamber filled with hydrogen works both as a target (the protons being studied) and a detector. The electrons in the atom near a moving charged particle receive enough energy for ionization to occur. The energy thus deposited causes boiling to occur along the track of the charged particle and bubbles are formed. Bear in mind that the incoming beam particle sees mostly empty space when it enters the bubble chamber, but will occasionally collide with a proton or interact with the electron of the hydrogen atoms. A model of what happens when a charged particle enters a bubble chamber is shown below.



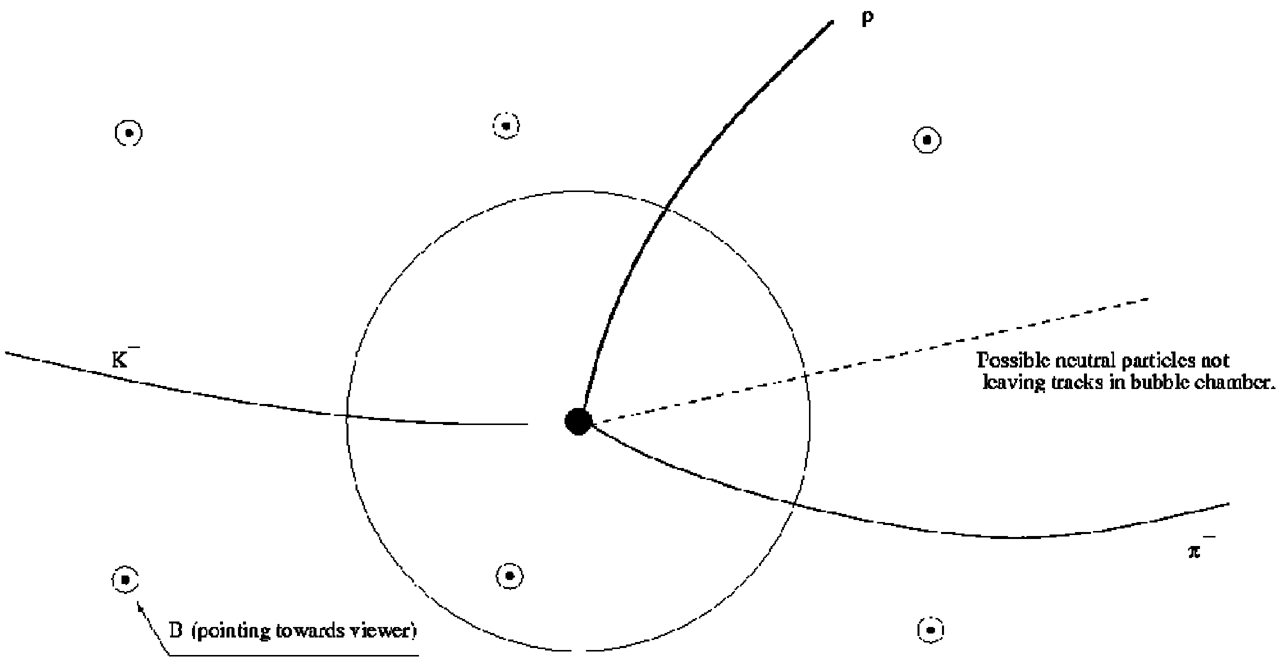
B (pointing to the viewer)
Hydrogen atoms in liquid state
Charged particles from interaction
Collision of beam with proton target
Incoming beam particle
Example of a shell electron
which might be ejected from an
atom (ionization) by a passing
charged particle from the interaction.

APPLYING CONSERVATION OF CHARGE

Collision of particles

An illustration is shown below of a possible interaction between an incident K^- beam particle and a proton. Notice that charge, Q, is conserved in the interaction.

	K^-	+	p	p	+	π^-
Q:	-1		+1	+1		-1

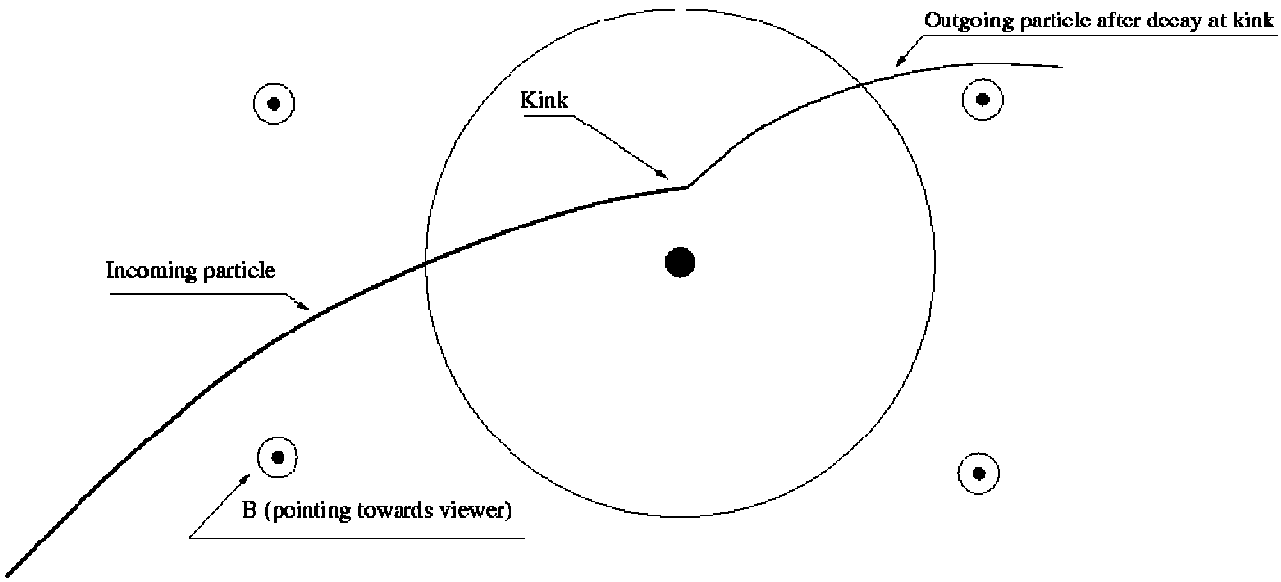


Courtesy HST2001:

http://teachers.web.cern.ch/teachers/archiv/HST2001/bubblechambers/interact.html

Decay of a charged particle

Apart from collision interactions, a particle may decay leaving a characteristic signature in the bubble chamber depending on its charge. A model of the decay of a positive particle is shown below. A kink (sudden change in curvature) indicates the point at which the decay occurred. Notice that charge is conserved, as indicated by the fact that the direction of curvature in the magnetic field is the same before and after the decay. As seen in the illustration, the proton does not take part in the decay process.

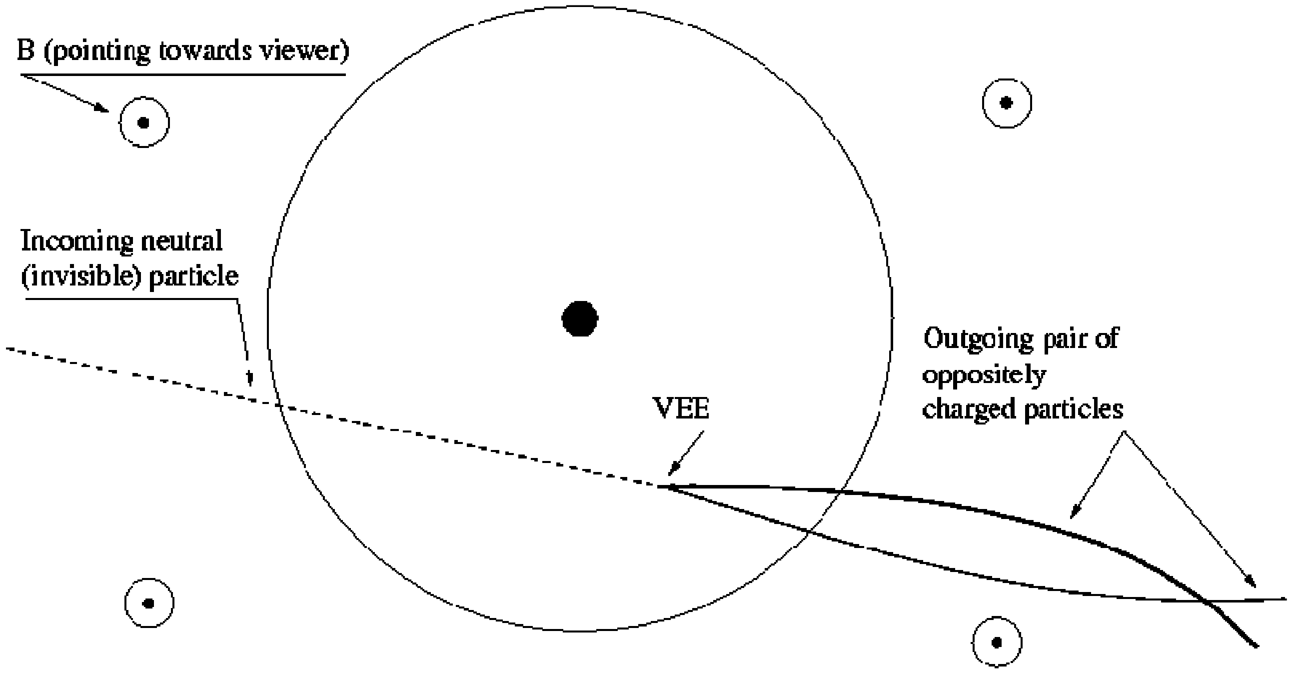


Courtesy HST2001:

http://teachers.web.cern.ch/teachers/archiv/HST2001/bubblechambers/interact.html

Decay of a neutral particle

Finally we may observe decays of a neutral particle. The model below shows a typical neutral particle decay. A "vee" (two tracks of opposite charge emerging from a point) indicates the location of the decay. The incident particle is neutral (Q = 0); the outgoing particles are oppositely charged (Q=1-1=0). As seen in the sketch, the proton does not take part in the decay process.



Courtesy HST2001:

http://teachers.web.cern.ch/teachers/archiv/HST2001/bubblechambers/interact.html

RELATING THE RADIUS OF A TRACK TO THE MOMENTUM OF THE PARTICLE

The tracks in the bubble chamber photographs are formed by charged particles moving through a perpendicular magnetic field. A Lorentz force is exerted on these particles, causing them to move along circular paths. We can use this idea to derive a relationship between the radius and the momentum of the particle.

Starting with Newton's 2nd Law:

$$F = ma$$

The magnetic force is given by $F_m = Bqv$ and the centripetal acceleration is given by $a_c = \frac{v^2}{r}$. We can substitute these relationships into Newton's 2nd Law, such that:

$$Bqv = m\frac{v^2}{r}$$

Rearranging for mv:

$$mv = Bqr$$

Since the momentum is given by $p = mv$:

$$p = Bqr$$

Since the magnetic field strength and the value of the charge will remain constant for a given track, we can say that the momentum is proportional to the radius. That is,

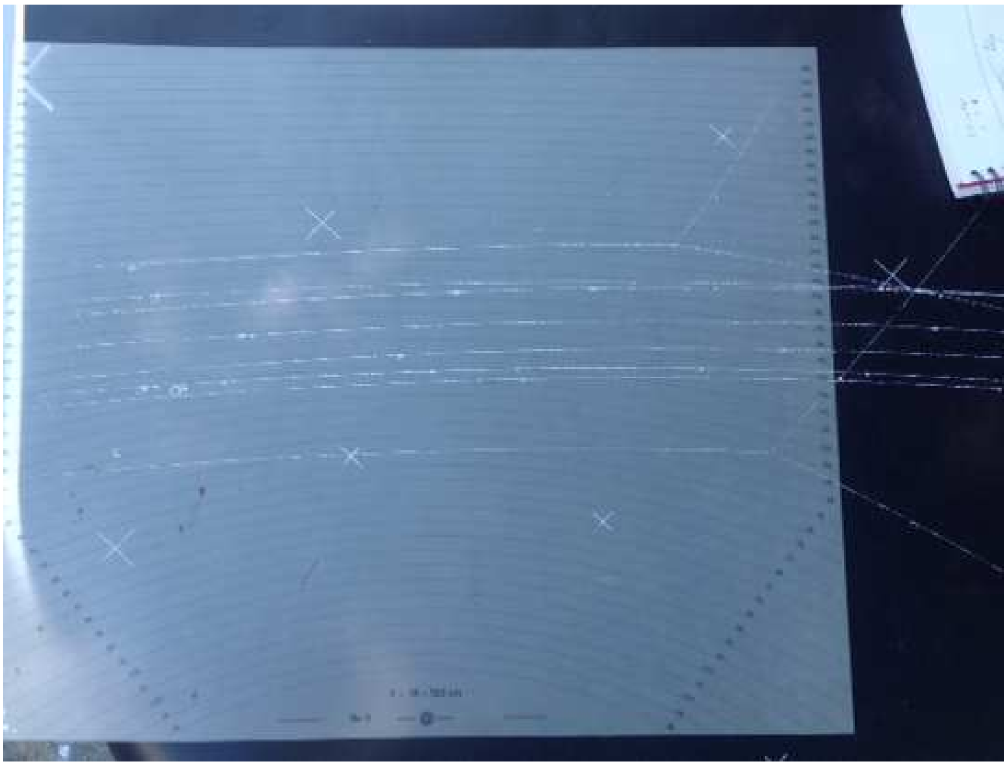
$$p \propto r$$

Key point: If we can measure the radius of curvature for a track we know something about the momentum of the particle that made the track.

MEASURING THE RADIUS OF CURVATURE OF A TRACK

In order to measure the radius we can lay a transparency identifying different radii on top of the bubble chamber photograph.

Place the transparency over the track that you wish to measure.



Looking from the end of a track, **match** the track on the transparency that most closely resembles the bubble chamber track to the bubble track. **Record** this radius from the transparency.

All measuring instruments have an inherent uncertainty. No instrument is perfect. Estimate the size of the uncertainty present in using the transparency overlay.

E.g. The uncertainty in the radius measurement is ± 10 cm.

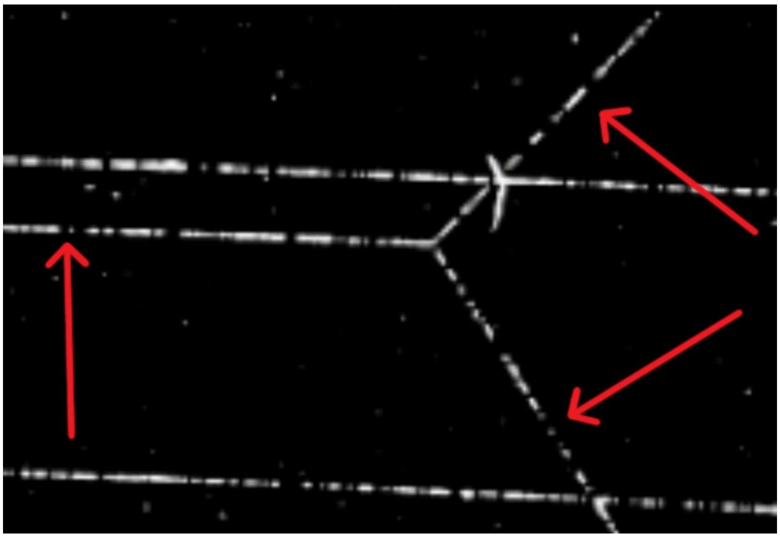
APPLYING CONSERVATION OF MOMENTUM TO INTERACTIONS IN BUBBLE CHAMBERS

In a bubble chamber more than one photograph would be taken in order to determine the orientation of the interaction. Interactions, whether they are collisions or decays, can be oriented along the plane of a photograph. They may also be oriented in a different plane. For instance, a track that appears to be moving relatively straight may actually have been produced by a track that is moving downward (into the plane of the photograph) or upward (out of the plane of the photograph).

We can determine if the interaction might have occurred in the plane of the photograph if we analyze the momentum before and after the interaction. If momentum is conserved (within reasonable uncertainty) then the interaction occurred in the plane of the page. If momentum does not appear to be conserved the interaction occurred out of the plane of the photograph or the "missing momentum" was carried away by a neutral particle that does not leave tracks.

Steps for checking if momentum appears to be conserved

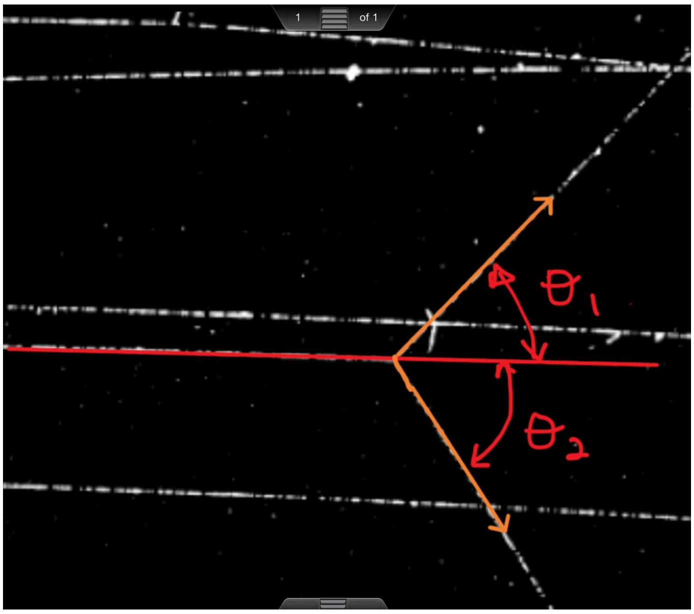
1. The radius of each relevant track involved in an interaction is measured by using a transparency overlay.



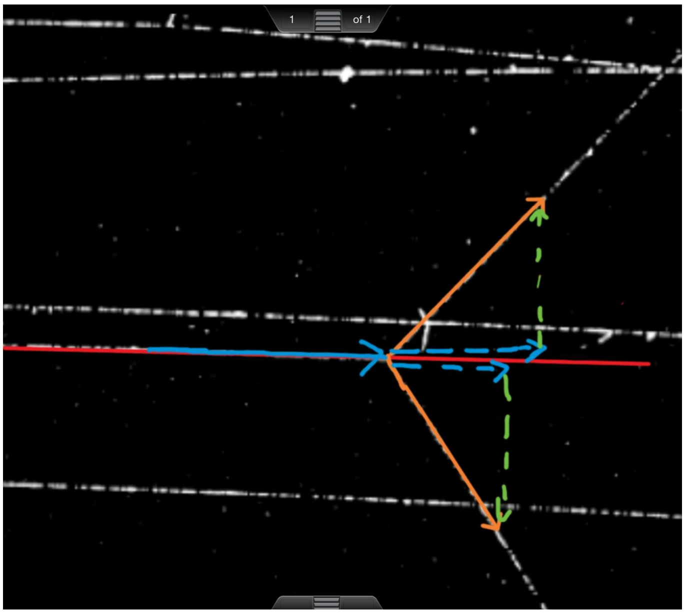
2. An x-axis is selected from which angles can be measured.

A compass is used to measure the angles formed between the path and the axis.

Note: As the track immediately starts to curve, lines should be extended along the tracks closest to the point of interaction.



3. The x and y components of the momentum for each track after the collision is determined. Since $p \propto r$ we can use the radius to represent the momentum.



4. Calculate the total momentum in both the x and y plane before and after the interaction. If, within uncertainty, momentum is conserved in both planes then it can be assumed that the interaction occurred in the plane of the photograph. If momentum is not conserved the interaction occurred in a different plane or the missing momentum was present in a neutral particle that did not leave a track.

FURTHER RESOURCES

How do you determine the size of a bubble chamber?

Problem:

a. What is the chance that a single proton entering a bubble chamber filled with liquid hydrogen (H_2) makes a direct hit with a proton in a nucleus of hydrogen?

b. How many atoms would a proton in the beam pass through –if it did not collide with a proton - in 1 metre of hydrogen in the bubble chamber?

c. Estimate the chance of a direct proton-proton collision in 1 metre of hydrogen.

Solutions:

a. Chance of collision $\sim \frac{area\ of\ proton}{area\ of\ atom} \sim \left(\frac{10^{-15} m}{10^{-10} m}\right)^2 \sim 10^{-10}$

b. Number of atoms in 1 m $\sim \frac{1\ m}{diameter\ of\ H\ atom} \sim \frac{1\ m}{10^{-10} m} \sim 10^{10}$

c. Chance of collision $\sim 10^{-10} \times\ 10^{10} \sim 1$

This style of thinking would go into the planning of a bubble chamber experiment.

Links

http://www.aps.org/publications/apsnews/201001/physicshistory.cfm

http://cerncourier.com/cws/article/cern/29120

http://mcb.berkeley.edu/news-and-events/department-news/glaser-bubble-chamber/