Nuclear and Particle Physics
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Module – 06
Particle Accelerators
Lecture – 03
Detectors

In the last lecture, we had discussed some aspects of the colliders and accelerators and colliders here we will actually consider what is called the; I mean the other part of and the scattering experiment which is a detector.

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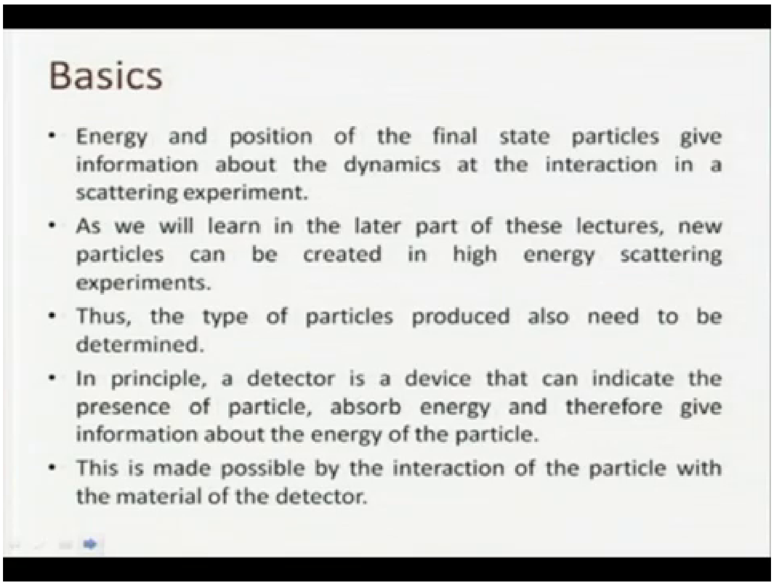

First, we will look at the basics of the detectors essentially what one need to know is what are the energy and the positions of the particle final particles departing the products of the collision or a scattering and from these we will be able to get derive information about the dynamics at the interaction of this particle. So, that is the idea.

So, as I mentioned in the previous lecture new particles can be created right and these new particles can; however, the type of the particle like what is the charge of the particle what is the mass of the particle etcetera are also valuable information apart from the energy and the position of these particles etcetera. So, in principle detector is a device that can indicate the presence of a particle absorb energy and therefore, give information about the energy of the particle.

And then tell from the position of the detector position of this thing where the particle is detected our eye is a detector it detects the photons coming from various objects around us light scattered from the table for example, from the computer all these faults in our eyes and then we reconstruct our brain reconstruct this image and then few tells us that this is a computer or this is a table or this is the letter that we are reading etcetera.

Similar to that all this information that the detectors various different parts of the detectors collect you can be fed to a central system computers and that can actually reconstruct the whole thing as much as possible in this thing and the this is made possible like this absorption of the particle, it is made possible by the interaction of this particle. So, the particles interact with the matter interact with the material of the detector.

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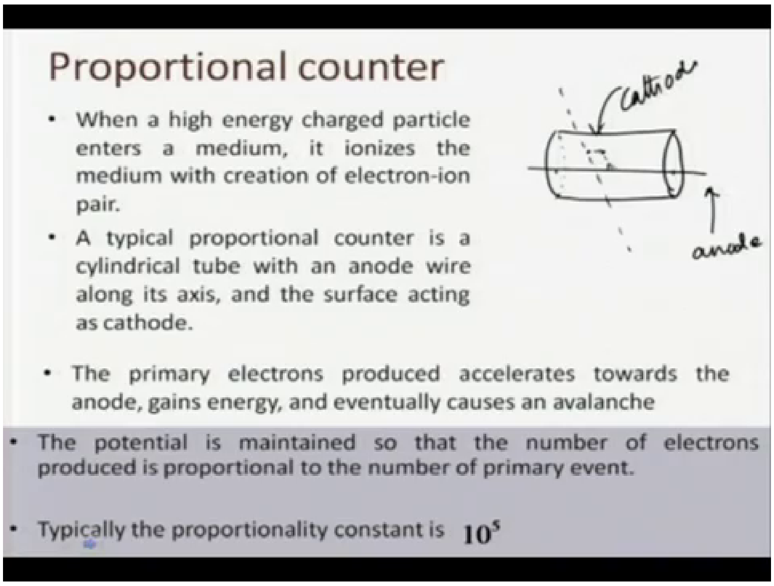

We will quickly go through some very basic type of detectors basics of elementary detectors that are used even today one is called the proportional counter. So, this is a simple idea you have cylindrical tube that acts as a cathode with a negative potential electric potential compared to an adult passing along the axis to say. So, this is your anode and this is an anode and this is the cylinder itself is your cathode.

So, inside this tube there is an electrostatic field electric potential difference and electrostatic field which will be useful in detecting the particle how is it done imagine a charged particle passing pass through this one this 2 will be filled with some appropriately; appropriately used gas and this gas will ionize as the particle charged particle with high energy passed through this thing can it will say knock out electrons from the molecules of the or the atoms of the material and said there was a gas inside this see.

So, let us say an electron is produced by the interaction of this and it is ejected from this thing what is the electron is ejected from the atom because of the electric potential between the cathode and different potential difference between in a cathode and the anode.

The electrons will move will be accelerated slowly towards the anode and as it goes up it picks up energy high energy and then basically as the energy of the electron increased it will have enough energy to knock out other electrons or electrons from other molecules or other atoms of the material inside. So, what happens is that it slowly goes and then as it gets sufficiently large energy there is an avalanche suddenly there is an avalanche of avalanche happens and then there will be a shower of these electrons electron ion produced and then there will be lot of these electrons near the anode produce near the anode and absorbed by the anode.

So, this is one of the basic type of detectors which are called proportional counters and as I said the primary electrons produced are accelerated towards the anode and gains energy and eventually causes an avalanche and basically this number of electrons secondary electrons which are produced in the avalanche is proportional to the number of primary electrons produced that is why it is called a proportional counter.

Typically the voltage between the anode and the cathode is kept in such a way that this is in the proportional to this thing and the proportionality constant is typically ten power five etcetera. So, that is the proportional counter and now a slightly better version of this proportional counter that is called a multi layer proportional counter.

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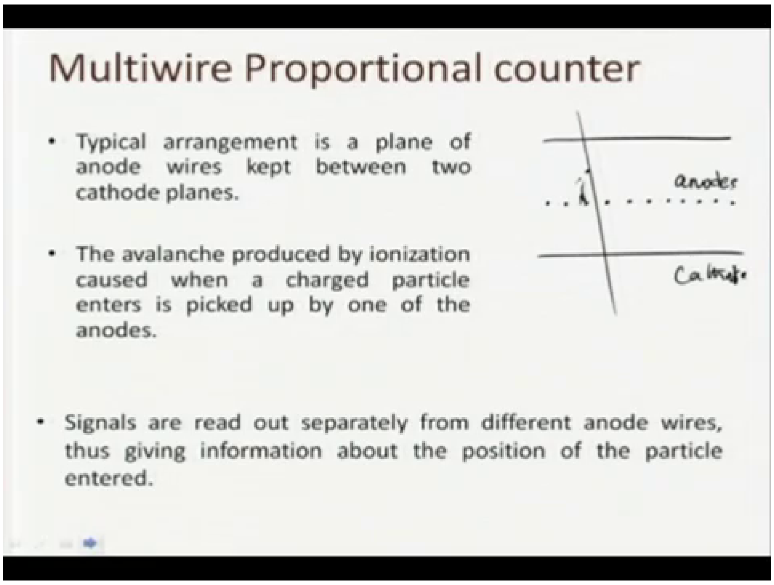

A typical arrangement is basically a cathode to cathode plates 2 cathode plates and anode wires kept in a plane. So, these are the section transactional view of the cross when you have the whole thing caught in a cross section you can actually see the cross section of the wires anode wires also. So, that is at the center these are different anodes kept at some small distance away from each other and cathode plates. So, cathode now when a charged particle passed through this, right, when a charged particle pass through this it produces electrons like what we discussed earlier and then they will move towards some anode wire and the nearest a node wire will pick up the avalanche.

Similar to the earlier case this will be. So, instead of one anode wire there is there are many anode wires and the advantage therefore, is that the position of the particle can also be detected in the earlier case we do not know where it is come there are there was only one anode where and then wherever this was produced inside the detector the same anode wire will pick them.

So, information about the position where the particle pass through was not available whereas, in this case we have different anode wires and then each of these anode wires the signal is read out separately. So, we know which of the anode wire is picking up the avalanche or the shower from the ionization or due to the ionization of the gas and from that we will know roughly which we the particle has passed through. So, this information is an additional information that you can get some same information you can get also from what is called the drift chamber.

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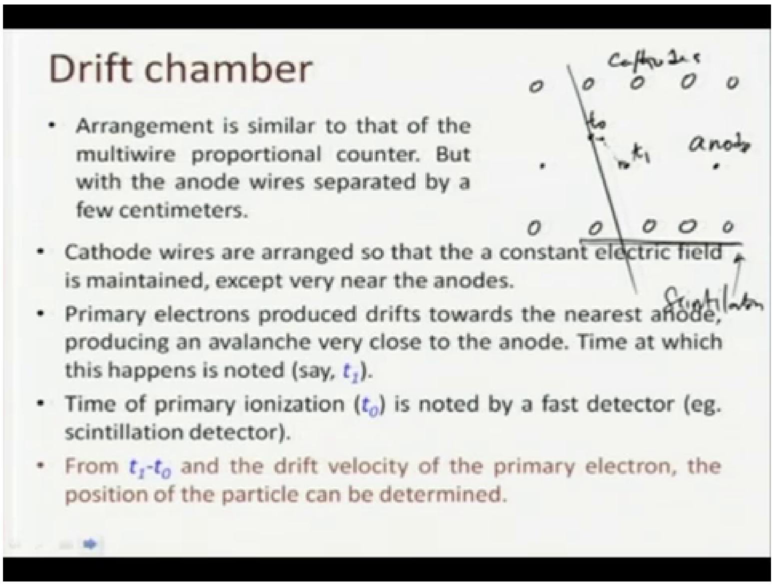

So, the drift chamber is; so, is an arrangement similar to the multi wire proportional chamber and the difference is that in the case of multi wire proportionate chamber you do not have any you do not have time lag much time lag between the Henry of the particle and the avalanche. So, almost immediately; so, the anode wire is there is the potential and the anode wire is a. So, that position of the anode wires are. So, that the avalanche happens almost immediately is thing in the case of drift chamber what is done is that there is an arrangement of the cathode wires which are reserved cathode wires and anode wires.

So, that there is reasonable separation between the anode wires typically a few centimeters there is an anode typically a few centimeters is the distance between the anode wires and the cathode wires are arranged so that most of the regions excepting very near the cathode anodes. So, the electric field is constant and when you see that when a particle enters the charged particle high energy particle charged particle and there is this region this detector.

Again, the particle will ionize the gas and the electrons will move from move towards one of the anodes and avalanche happens very near that anode, but since the distance between the anodes are large usually a electron primary electrons produced away from the from any of the anodes and it will slowly drift because the electric field is constant and low it will slowly drift towards the anode for some time and it takes a little while for it to attain the energy needed to have the avalanche.

How make to create secondary ionizations or further ionizations and the avalanche it takes a little time. So, that is the key here and you have either at below the arrangement or above the arrangement below the arrangement say you have what is called a simulator or some detectors which actually detects the presence of this particle or the time at which this particle actually goes through.

So, roughly we know when the primary electron is produced this is with the help of an additional fast detector which is helping this a drift chamber in finding the distance or the position of the particles entry how. So, P 0 is known when it is passed entering or ionizing the primary the same and avalanche happens at a slightly later time say t 1, this time gap and the drift velocity of the electron produced is known from the arrangements the voltage the electric field applied etcetera.

We can we know the drift speed of this particle and this will this information along with the time difference will actually help us to calculate the position of the particle when it actually produce the primary electron and or the other way it is the basic alert is basically the time of entry or the position where the particle has ended. So, time of the primary ionization is t 0 and then time of avalanche is t when say. So, t 1 minus t 0 the time difference and the drift velocity of the primary electron the position of the particle can be determined.

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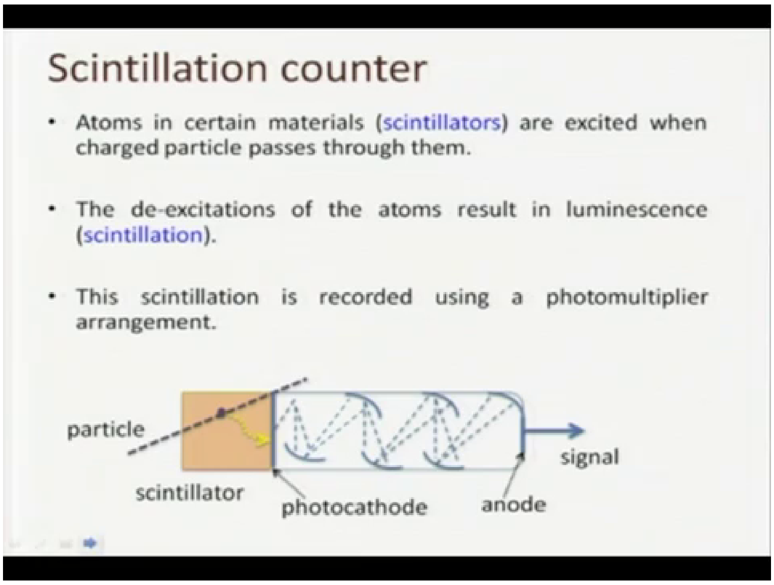

Another thing just now when we mentioned the scintillation counter. So, that is another type of detector when charged particle pass through certain materials atoms of these materials are excited these materials are called scintillators and when these excited atoms be excite there will be luminescence it will emit radiation it will emit electromagnetic radiation this is basically in the visible range and then say scintillator; this particular and this reminiscence is called scintillation.

And these luminescence is recorded using a photomultiplier arrangement there will be a photo cathode on which the scintillation falls and that emits photo electrons and this photo electrons will actually be multiplied using or with the help of an anodes and finally, the anode will pick up the increased signal and that can be fed to a computer or reading system and this is a scintillator scintillation counter arrangement.

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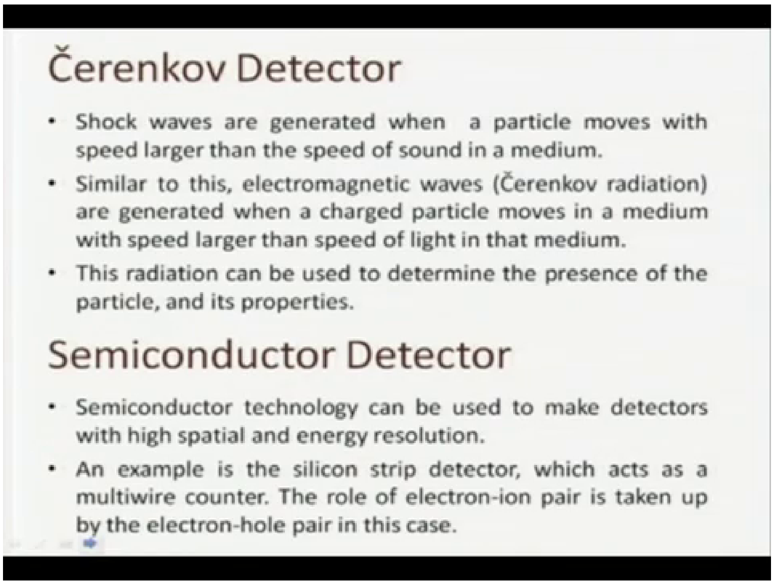

Another type of detector is called a Cerenkov of detector here this is very similar to the shock waves mechanical shock waves generated when particles move faster than the speed of light in that medium and then shock waves are produced we know that similar to that electromagnetic shock waves we can call it may be electromagnetic waves are generated when the charged particle moves in the medium with speed larger than the speed of light in that medium of course, and this radiation can be used to determine the presence of the particle and there are lot of useful things come for this in connection with this sharing of detection and we can detect the presence of the particle the property of the particle etcetera from that this another basic detector is a semiconductor detector ok.

So, this is basically many of the ideas of this the ideas that we said just now like the proportional counter the multi buyer proportion counter etcetera or the v frame etcetera can be miniaturized in solid state devices this the advantage here is that there is moral in size and therefore, the resolutions special resolution precision with which you can make the position measurements or the energy master measurements is high in the case of semiconductor detectors.

One example is the silicon strip detector which is basically a multi wire which is equivalent to a multi wire counter and here we do not have these are solid state devices instead of ion electron pair production you will have we will have electron hole pair production.

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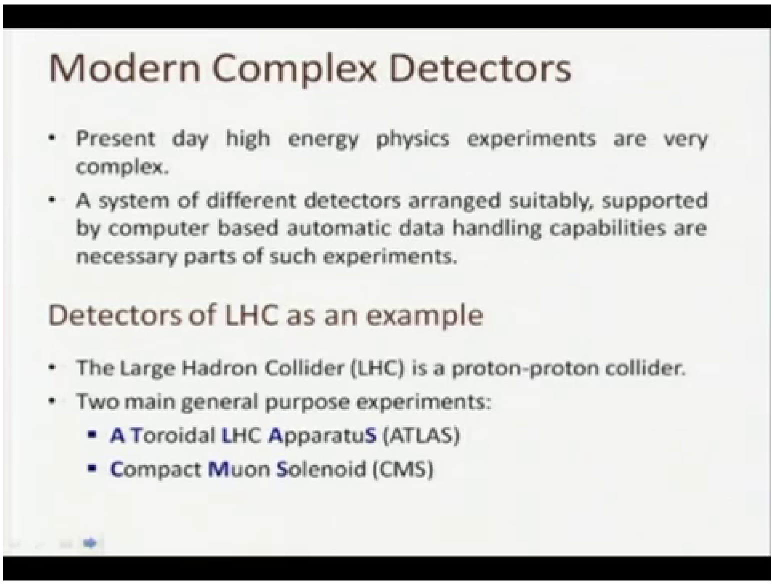

Now, coming to the modern complex detectors we need many different type of these basic detectors and many number of the large number of them are arranged in detector system which can be considered as a big detector which different small parts so, and all these information from various different parts of this detector.

So, the detector will have silicon strip detector and various other parts which actually absorbs the particle and give you information about the energy and various things and this or information will be fed to computer controlled the system and automatic data can handling is necessary because a huge number of when say for example, beams are collated and the collisions have been very fast and then you had to read out all these information very fast and large number of large amount of data is will be generated and we had to how to how system to handle all these things and this for arrangement all of this arrangement together is basically making complex detector which are used these days as an example we can think about the detectors of the LHC.

So, we mentioned when we discussed the accelerators or the LHC axilor large hadron collider; we mentioned that there are 2 general purpose experiments one is called the atlas which stands for a toroidal LHC apparatus and another called compact muon solenoid and there are 2 other systems also on his Alice and the LSC b, but the main general purpose things are there the Alice is basically to handle the iron; iron core collisions which can also happen in the same ring same LHC system accelerating acceleration and collision system instead of the proton beams you can accelerate the ions and they collide and then give you information about various other things which are not possible in proton; proton collisions.

And similarly we have another experiment called the LS CB which is specifically designed to understand a particular aspect of elementary particle dynamics and a particular system which is called a B quark bound system and there are a lot of information that we need to know lot of details of this system that we need to know need to understand to learn about the elementary particle dynamics. So, there is a special detector which is designed just for that purpose there atlas and CMS are 2 general purposes thing which is designed to learn about anything that is happening in a pp collision.

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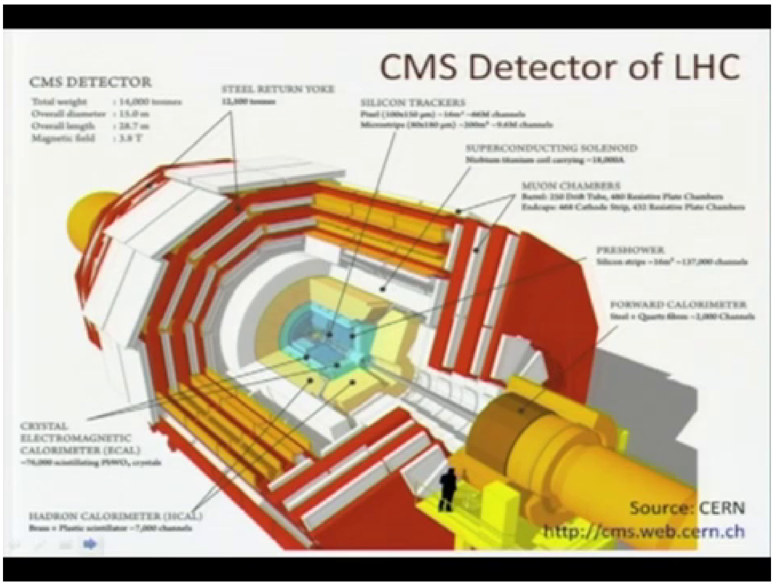

So, a CMS detector is has many different parts as you can see basically the beam pipe is at the center along the axis of this surrounding the blue of blue 2 blue arrows that we have in this picture and this is surrounded by different layers of detectives first we have what is called the silicon tracker the silicon tracker is something which actually tracks the particles it detects the particles type of the particle.

If it is a charged particle it can actually tell whether it is positive charged particle or a negative charge particle etcetera which is actually a silicon microscope there are many such micro strips which are arranged in this silicon trackers and you have to provide the magnetic field to make charged particle when this way or one way or the other. So, that we know what is the type of electric charging it for that there is there are superconducting solenoids which actually provides large magnetic fields for Tesla etcetera and then further on then you have what are called the electromagnetic calorimeter meters which absorbs all the electric you know or the photons which come out of this collisions and all the electron sourcing.

So, the electrons protons photons electrons and photons are absorbed completely in calori electromagnetic calorimeters or we cans. So, they are there and then you have what is called the hadron collider; hardron calorimeter where other type of the protons or ions etcetera which are made of which are made of quarks like protons these particles are absorbed in h scan or hadron calorimeter and then we have the muon chambers at the end of this one and a lot of things are there. There are a different parts like forward calorimeter which are kept along the beam slightly away from the center of this thing.

So, that you can get information even at small angles of detection and or angles near one eighty and one near 0 this can also be picked up particles which are actually scattered at very small angles or very large angle in the backward direction or picked up using the forward and the backward calorimeters the regions and they you have various other parts of these things which you can see and the huge this detector is a huge arrangement.

Its total weight is fourteen thousand tons and the size overall diameter is fifteen meters and you can see the comparison with the person standing there how huge this one is; so, more about it you can look at the details either in this picture or many such pictures and details available at cern’s website which is mentioned here.

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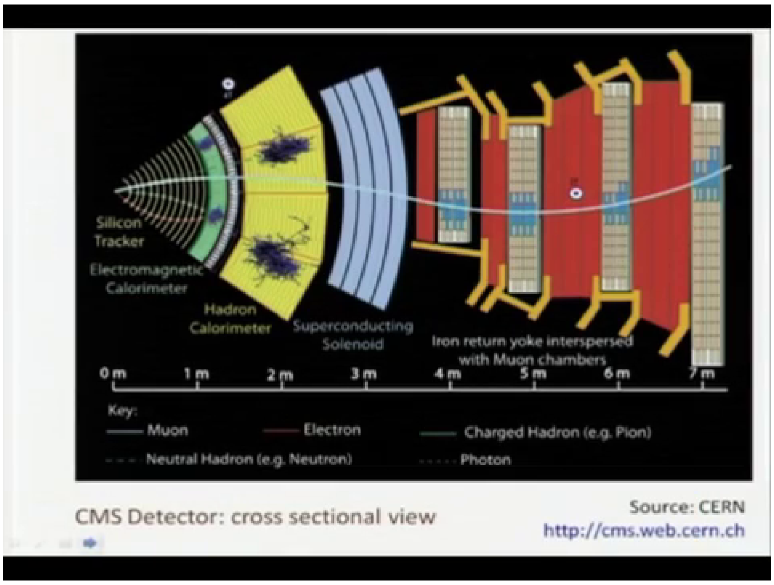

And this is the same thing that we are in cross sectional view; view of this one part of this that is a radius of something like a seven meters is given here.

So, you can see the u sub; it is 2 scale actually to some extreme silicon tracker is very small here and then that actually tells you what is the type of particle what charged is the particle having whether it is a neutral particle which goes a straight like it is mentioned here and that green dashed line inside that silicon tracker is basically a neutral particle it does not bend as I said there is a large magnetic field about 2-4 Tesla.

So, that will bend the electric charge particles somewhat which will ready visible bent we can see this is a reconstruction all these tracks are acts are reconstructions of information that is fed to the computers if it is a charged particle that will bend if it is a positively charged particle it will bend one way if it is a negatively charged particle it will bend the other way around and the blue line is a is a blue dashed line his photon which actually goes straight again because it is electrically neutral.

But then he is fully absorbed in the electromagnetic calorimeter whereas, neutral hadron like Pion, etcetera, we will come to what are the different hadrons that we know of at a later stage, but they are basically main particles like protons or particles which are made of quarks see if there are neutral protons neutral hadrons and the neutral hadrons are absolved go straight in the silicon tracker and observed in the hadron collide calorimeter where as charged hadrons the green solid line say they are bent and go past the electromagnetic calorimeter and get absorbed in the hadron collider calorimeter whereas, the electrons which are red lines here they pass they bend the other wendon bend they in the a silly a bended in the silicon tracker and get absorbed completely in the electromagnetic calorimeter.

The other type of particle generally produced is are the muons; muons go past the electromagnetic calorimeter if they are slightly bent then they cannot be maintained too many because the energy is quite high and the radius of curvature radius will be very large in that case and they go past the hadron calorimeter as well and they are they leave their traces in the outer part of the detector which are called the which is called the muon chamber. So, there are different chambers actually. So, there are different sets of these muon chambers and each of this will detect the presence of the moon passing through that and there is an addition and there is another magnetic field which is kept there.

So, that that will actually bend the magnetic field sorry the muons for again and then we can make sure that it is actually a charged particle muon charged particle which is moving through that directly and these muon chambers. There are separated by iron sheets which also absorbed this muons square away.

So, this is basically the general setup there one thing I should say the in this picture the interaction point is basically at the vertex of the silicon a detector silicon tracker and the beam is passing perpendicular to this thing . So, that is how geometry is here and we are seeing a cross sectional view in this case.