Updated 2D Tracker Firmware Design for Central Drift Chamber(CDC) at Belle-II

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February 16, 2016

Abstract

The functions of Belle-II CDC is to detects charged particles from particle interactions. This kind of detector is crucial among many sub-detectors.

A simple idea of comprehending CDC is: the CDC detects charged tracks using sense wires and field wires.

My task is to simulate the 2d track reconstruction algorithm for CDC readout electronics. This algorithm should fit the performance in the FPGA chip as well. In my thesis, I introduce the algorithm and the design of my trigger simulation program (Firmware).

Keyword: KEK, Belle II, Central Drift Chamber (CDC), 2D Track Reconstruction, Hough Transformation, Clustering, TSIM.

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Chapter 1

Introduction

1.1 The Belle and Belle-II Experiment

The Belle experiment was operated at a Japanese High-Energy Accelerator Research Organization, named KEK [1]. In KEK, an accelerator KEKB and a detector Belle were build-up for Belle experiment.

The KEKB was a 3 km circumference asymmetric electron−positron collider and operated during 1998 to 2010. It reached the world record in instantaneous luminosity of 2.11×10^{34} cm^{-2}s^{-1}. The Figure 1.1 shows the luminosity record of Belle experiment.

The electron−positron beam energies were choosen to mainly produce B-mesons. This was the reason for Belle experiment also called a B-factory. A picture of KEK is shown in the Figure 1.2.

The Belle experiment analysed the B- and anti-B mesons precisely. It confirmed the CP-violation as described by the theory of Kobayashi and Maskawa, the KM mechanism [2].

In 2008, Makoto Kobayashi and Toshihide Maskawa, who both were awarded the Nobel prize in physics [3]. The CP-violation is believed to be one of the orgins of matter and anti-matter asymmetry in our present universe. However, the measured CP-violation is not enough to explain the matter and anti-matter asymmetry. Therefore, a deeper understanding is required.

The SuperKEKB is an upgrade project at KEK. The goal is to increase the instantaneous luminosity by a factor of 40, to 8×10^{35} cm^{-2}s^{-1}. This upgraded $B-$factory, named as Belle-II experiment [4], will explore the New Physics beyond the Standard Model. For LHC, it can provide a probe of the TeV mass scale. For SuperKEKB, it can provide high-precision measurements of rare decays and CP-violation in heavy quarks and leptons. Both of LHC and SuperKEKB are unique for New Physics studies. A schematic plot of SuperKEKB and Belle-II detector is shown in the Figure 1.3. The Belle-II logo is shown in the Figure 1.4.

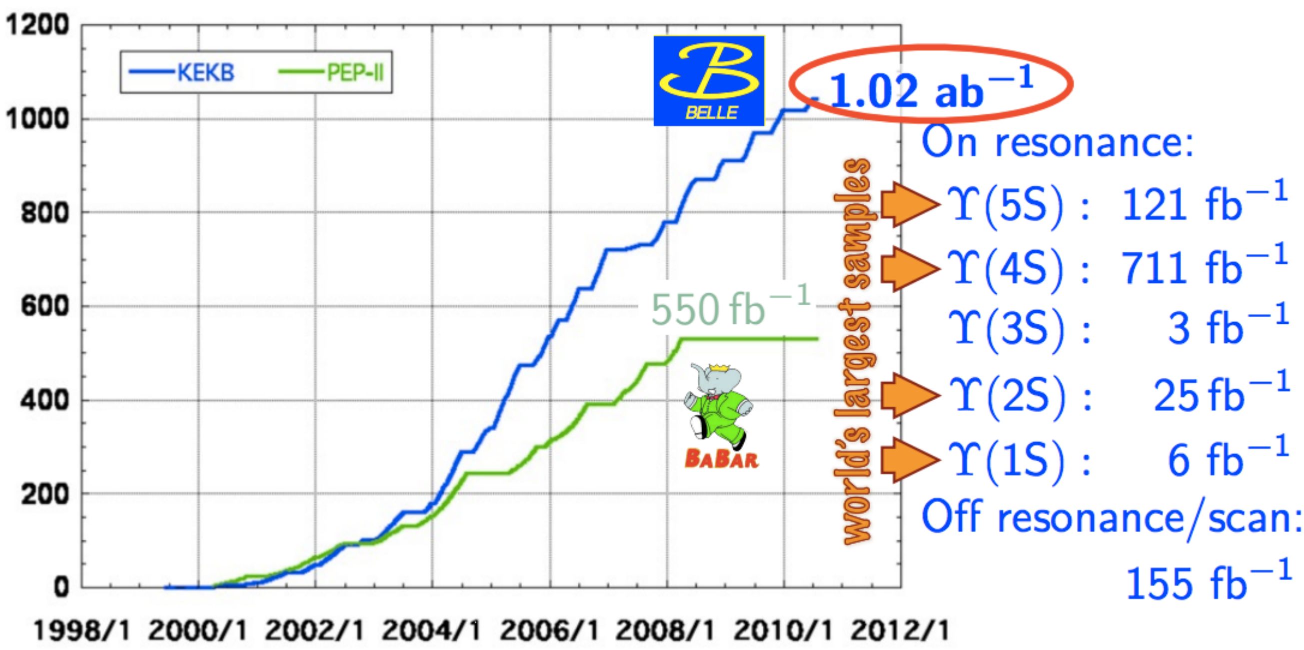

Figure 1.1: The luminosity record of the Belle experiment is shown.

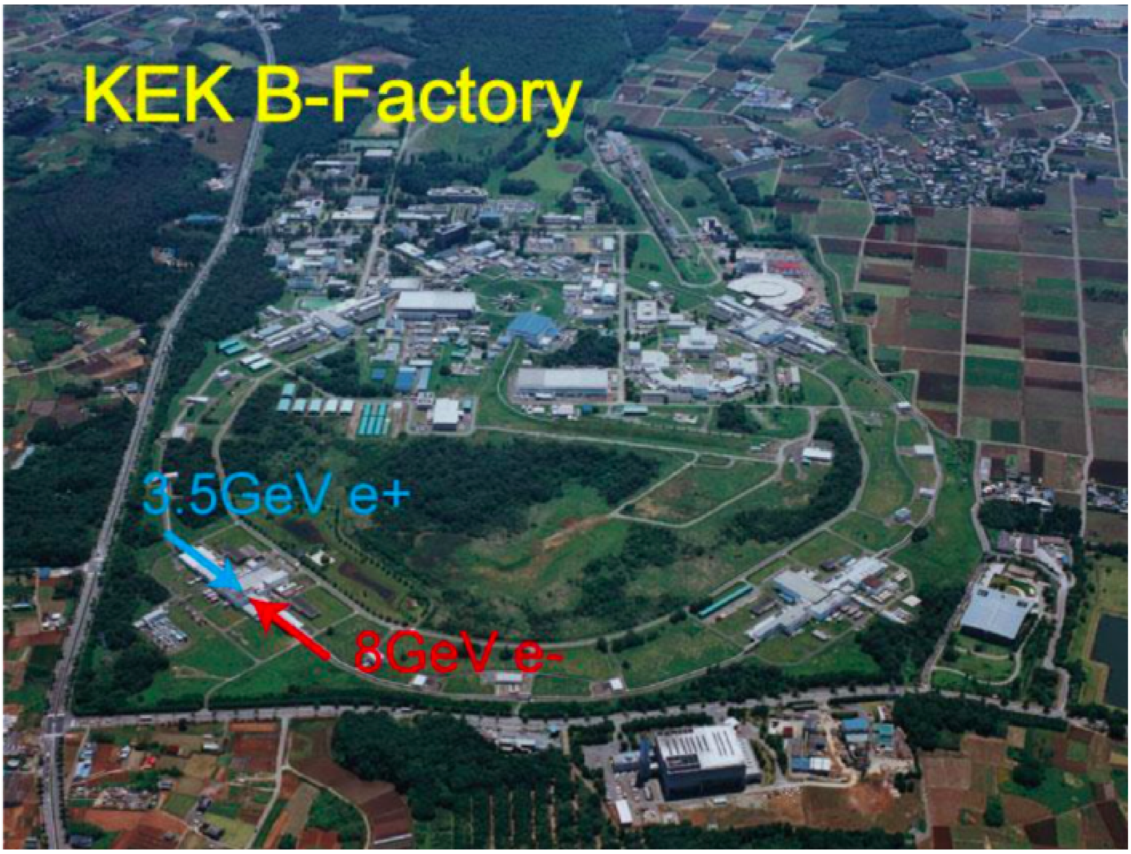

Figure 1.2: This is a picture of KEK, Japan.

1.2 The Central Drift Chamber in Belle and Belle-II

The detector, Belle, was located in the KEKB accelerator ring, at the point where the electron and positron beams intersect. The Belle-II detector will sit at the exact same position on the upgraded version of KEKB, the SuperKEKB.

The Belle-II detector will be a large-solid-angle magnetic spectrometer consisting of inner vertex detectors with pixels (PXD) and silicon strips (SVD), a central drift chamber (CDC), a barrel-like arrange-

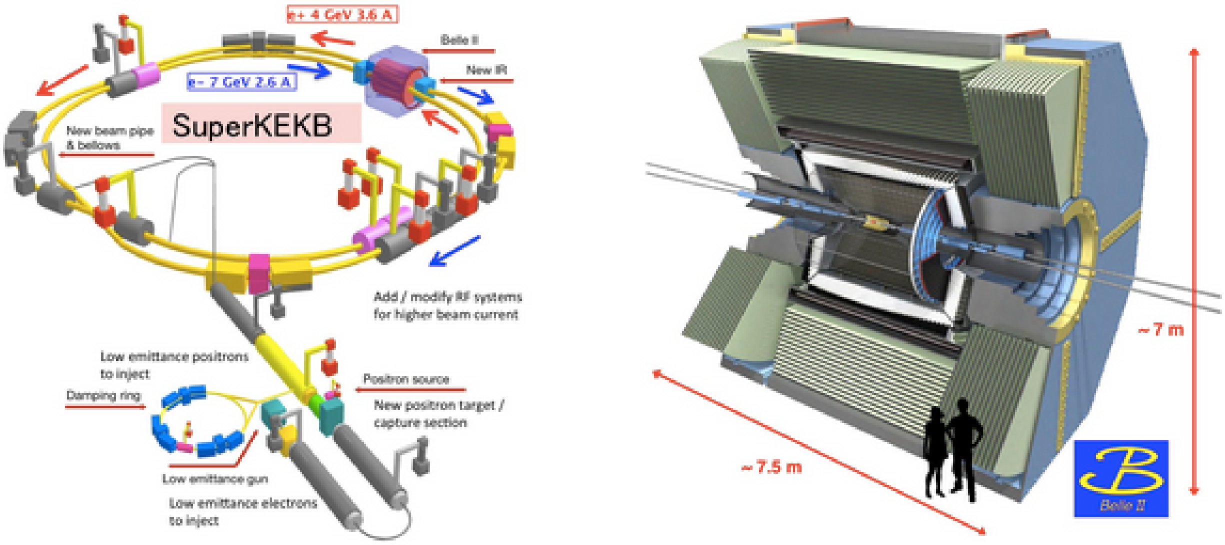

Figure 1.3: This is a schematic plot of SuperKEKB (left) and Belle-II detector(right).

ment of time-of-propagation counters (TOP), an array of ring-image Cherenkov counters (ARICH), an electromagnetic calorimeter (ECL), and a K_L-and-muon detector (KLM).

The Belle and Belle-II Central Drift Chamber (CDC) detect charged particles resulting from particle interactions. This kind of detector is crucial among many sub-detectors. If without the CDC, it would make no sense to take data from other sub-detectors in Belle and Belle-II.

Designing and constructing the CDC is complex. But a simple idea of understanding CDC is: the CDC detects charged tracks using metal wires [5].

When particles pass through a helium based gas mixture inside the chamber, they ionize the gas molecules, knocking out electrons. An electric field is created by applying high voltage on sense wires strung across the chamber. The field causes electrons to accelerate towards

Figure 1.4: Belle-II logo.

the wires. These electrons knock out additional electrons from the gas as they travel. A number of electrons and ions produced move speedily near the sense wire. The sense wire senses the motion and creates a pulse signal. The signal is then sent to the data acquisition (DAQ) system.

The design of the Belle-II CDC does not change much from the original, because Belle's CDC has worked very well throughout the past decade. However, SuperKEKB will produce collisions at 40 times higher luminosity, so the new CDC must be able to work in conditions with 20 times higher background noise. By adding more sense wires, CDC group members believe the signal-to-noise ratio can be improved.

The CDC is a barrel structure around the beam pipes, and sits just outside a cylinder of the inner detector called silicon vertex detector (SVD). One big change in the baseline design is that the outer detector to the CDC, the particle identification detector (PID), will shrink in size by a factor of 3, owing to the new technology called time of

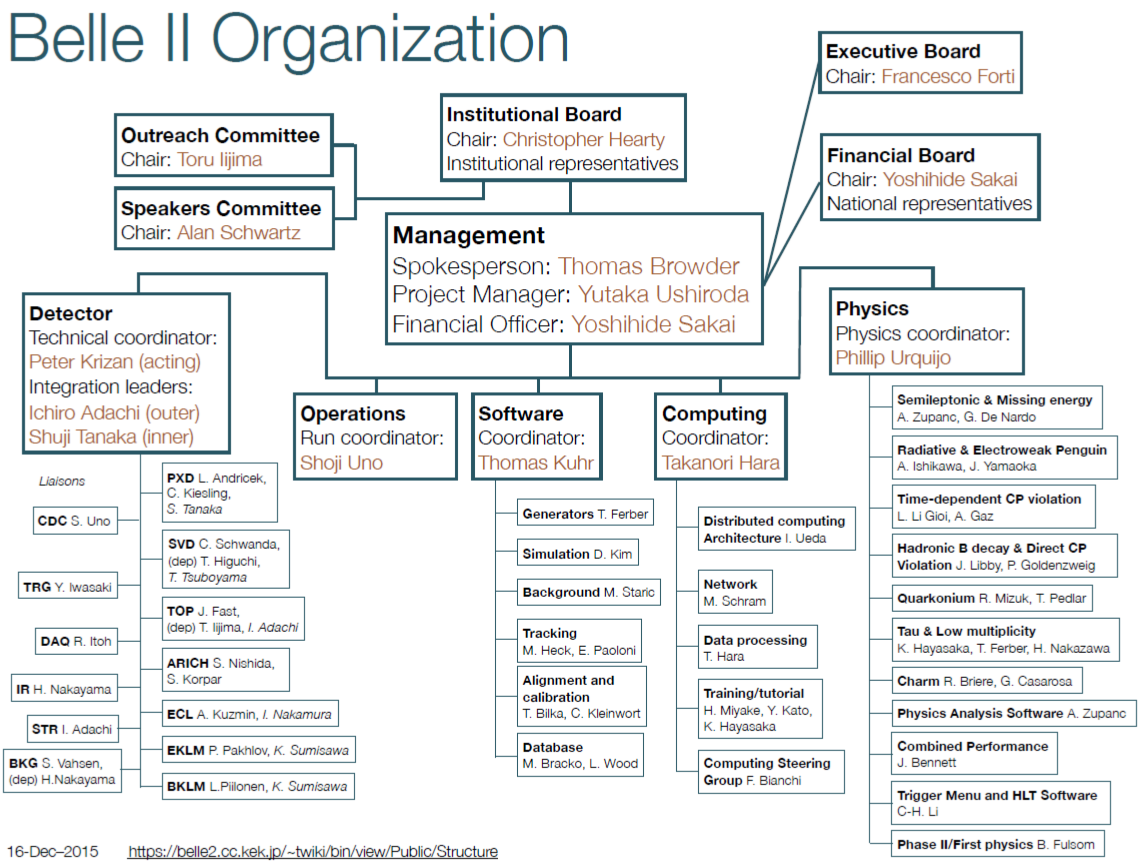

Figure 1.5: The Belle-II organization.

propagation counter. Due to this and in order to maintain the Belle level of performance in a high luminosity environment, the number of wires in the Belle-II CDC are doubled. The CDC for Belle has 8,464 sense wires and 25,392 field wires. The upgraded CDC for Belle-II will have 14,336 sense wires and 42,240 field wires. Wire Conguration of the Belle CDC are shown in the Figure 1.7(a) and the Belle-II CDC are in the Figure 1.7(b). The filled circle shows an axial wire and the open circle shows a stereo wire.

One of the key issue is to balance weight of the wires, the wire tension, and the performance deterioration due to gravitational sag of

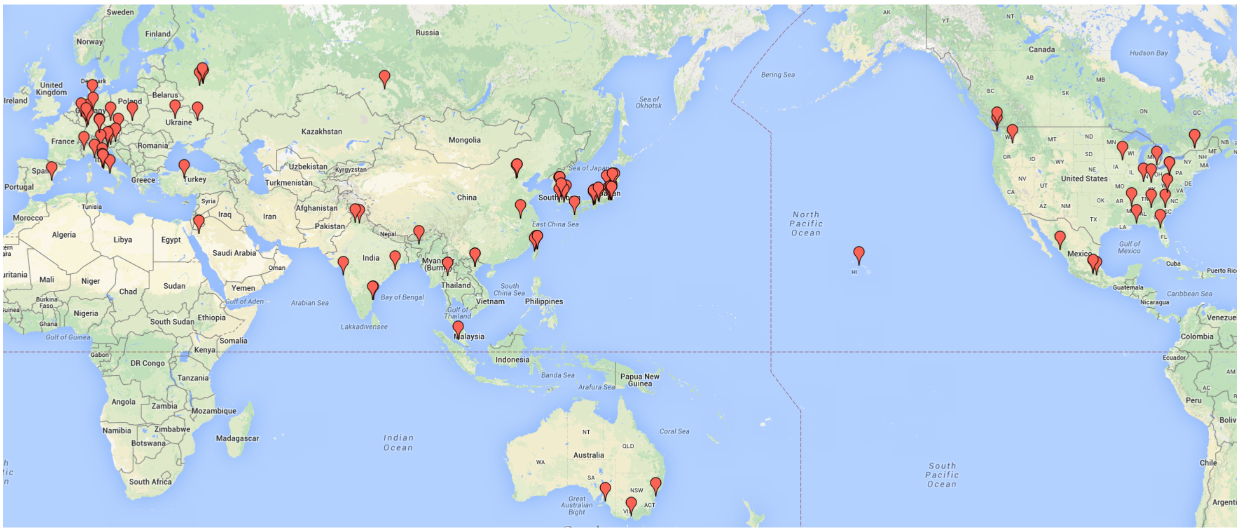

Figure 1.6: The home towns of joined Belle-II collaborators are labelled in the world map.

the wires. Since wires are strung horizontally, gravity makes the sense wires sag at the middle. The sagging can affect measurements.

The sag due to gravitation for a range of tensions is calculated, and the effect on the performance is simulated by CDC group members. So far, the influence of sagging on the performance of the detector is smaller than the influence of the detector's inherent mechanical resolution.

The biggest concern, however, is the tension on the end plates due to the wires. The Belle CDC's thirty thousands wires produce 3 tons of force, displacing the location of the endplates as much as 3 millimeters. The Belle endplates are shaped so that particles entering the CDC have to go through minimum distance of material. The cross sectional view of the endplates are therefore curved so that particles from the interaction point would fly through no more than one centimeter of

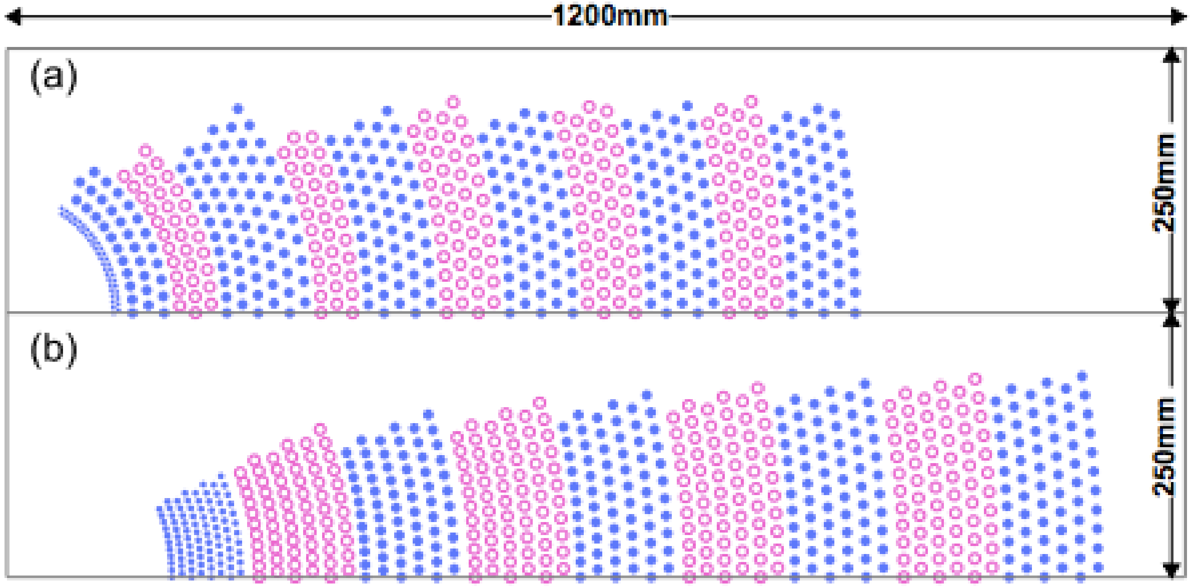

Figure 1.7: Wire Conguration of the Belle CDC (a) and the Belle-II CDC (b). The filled circle shows an axial wire and the open circle shows a stereo wire.

the endplate thickness in radial direction.

The endplates for the Belle-II CDC will have to endure 4 tons of force. The cross section of the Belle-II endplates will be a straight line rather than round. The CDC team calculated that this would be a balanced shape, providing a physically robust framework without having undue influence on the performance.

Drift chambers are complex systems, with many parameters to consider when designing. Using the accumulated expertise of chamber scientists, as well as past experimental data, the CDC team developed an optimal design. One widely accepted design, and the one used for the Belle CDC, is called the super-layer structure. It consists of a combination of wires arranged in axial direction parallel to one another, and of wires arranged in varying angles - called stereo wires.

Six layers of axial wires make one group and six layers of stereo wires make another. The Belle-II's CDC has nine groups of these.

In addition, there will be eight layers of tightly spaced axial wires at the inner part of the CDC. This group is called a small cell. Past experience has shown that the introduction of a small cell in a chamber helps separate signals from noise by tracking particles freshly coming out of the interaction point.

1.3 The Readout Electronics of the CDC

The Belle CDC readout electronics will be completely replaced, owing to advancements in technology over the last two decades. The Belle-II CDC will employ an all-in-one technology that amplifies the signal, applies a pulse shaping, and then converts the analog signal into a digital signal.

The Belle CDC sends signals all the way from the detector to an electronics hut 30 meters away via 30-meter cables to interpret the signals for data analysis. In the Belle-II CDC, all the electronics will be inside the Belle-II detector, right beside the chamber itself. Digitalized data will be readily available through fiber optic connections, to be collected in the DAQ system.

Signals from wire chamber is very small, so they are amplified by preamplifier component of the electronics. Amplified signals are shortened to make sure sensitivity to higher frequency signals in Belle-II. The electronics also need the ability to separate noise from signal. These functions, called shaping and discrimination, will be built into the new electronics. The electronics will use an application-specific integrated circuit (ASIC). An ASIC is a chip specially designed for a particular use. The new ASIC will process eight channels on a 4-millimeter by 4-millimeter chip for Belle-II, whereas the previous chip processed one channel on a 1-centimeter by 3-centimeter chip for Belle.

S. Uno said, ASIC technology was uncommon in Japan 20 years ago when CDC team were starting the design for Belle. Now that we have this technology, CDC team can develop custom chips for various projects. By using the technologies made available by KEK's Electronic System Group, CDC team can create compact, high-speed, and low power readout electronics.

N. Taniguchi successfully demonstrated the newly designed ASIC electronic device in 2010. She also investigated optimal values for such parameters as gain, noise cancellation, and time resolution, using a hybrid board that contained all necessary parts.

Belle's CDC is already a good system. However, the system for Belle-II CDC is much more complex. A lot of the Belle-II CDC design is based on the past experience. Sometimes it's necessary to go beyond experience and make educated guesses in chamber science.

The Belle CDC uses bare aluminum for the field wires. Because aluminum cannot be soldered and is easily oxidized, no drift chamber had previously used bare aluminum. Other similar chambers have used gold-coated aluminum. For the Belle-II, however, CDC needs light wires. So aluminum wires are used without the gold coating. Since aluminum cannot be soldered to the endplates, the Belle-II CDC's wires are fixed by crimping pins. As to oxidation, S. Uno has found that aluminum oxidization does not affect the performance of the detector.

Before the B Factory experiment, most drift chambers were filled with an argon-based gas mixture. This was because argon is inexpensive, and also sensitive to X-rays. For initial testing of drift chambers, experimenters often used X-rays with an energy similar to the energy lost by the charged particles produced at the collider. For the B Factory, however, X-rays are considered as background noise. In addition, because argon is so heavy, it can destruct the momentum measurement of particles. To solve this problem, the CDC team developed an X-ray insensitive, light gas mixture consisting of helium and ethane.

Drift chambers are packed with the very basics of particle physics experiment, and cultivate creativity and good intuitions. In Taiwan, four High Energy experimental research groups are encouraged to join this CDC team. They are National Taiwan University (NTU), National United University (NUU), National Central University (NCU) and Fu Jen Catholic University (FJU).

I am a team member in FJU and my advisor is Jeri M.C. Chang. We FJU team is highly coorperated with Y. Iwasaki-san at KEK. My master thesis is mainly for my tasks done in 2D tracker firmware (VHDL). My classmate Z.X. Chen works closely with me and his tasks is mainly for 2D tracker simulation design at CDC Level 1 Trigger system. In my thesis, I will use some of his studies to explain my design and making in Firmware algorithm. The decision making in simulation algorithm are in his thesis. K.Y. Chen and I work together with the content of this chapter, so we share the same content in our chapter 1 in the thesis.

Chapter 2

The CDC readout electronics: Front-End, Merger and Track Segment Finder

2.1 The most important task of CDC

The most important task of CDC is to obtain the best possible momentum resolution for charged tracks. It also provides $\mathrm{d}E/\mathrm{d}x$ measurements for particle identification and efficient and reliable trigger signals.

The CDC consists of 50 concentric cylindrical layers with 8,400 drift cells. The chamber is filled with a low-Z gas, a 50% helium-50% ethane mixture and contains low mass wires, made of gold-plated tungsten and aluminum without any plating, to minimize multiple scattering.

The schedule of wire stringing of CDC has been started in December 2012, for a total number of 56,576 wires, and will be finished in January 2014.

2.2 The Front-End electronics of CDC

Belle-II detector signals are digitized in an internal front-end electronics card (CDC, TOP, and ARICH) or nearby (SVD, ECL, and KLM) the detector. The digitized signals, expect for the PXD, are collected by FPGAs on front-end electronics cards. There are approximately 15,000 CDC readout channels. Because of mechanical constraints, the size of each CDC front-end electronics cards is 20×17 cm^2 for 48 channels.

Since the front-end electronics of the CDC, TOP, and ARICH are located inside the detector, the effects of radiation on their components will be a severe problem. The expected annual neutron flux and γ-ray dose from the beam background at the CDC innermost layer is about $\sim 10^{11}/\mathrm{cm}^2$ and ~ 30 Gy, respectively, at design luminosity.

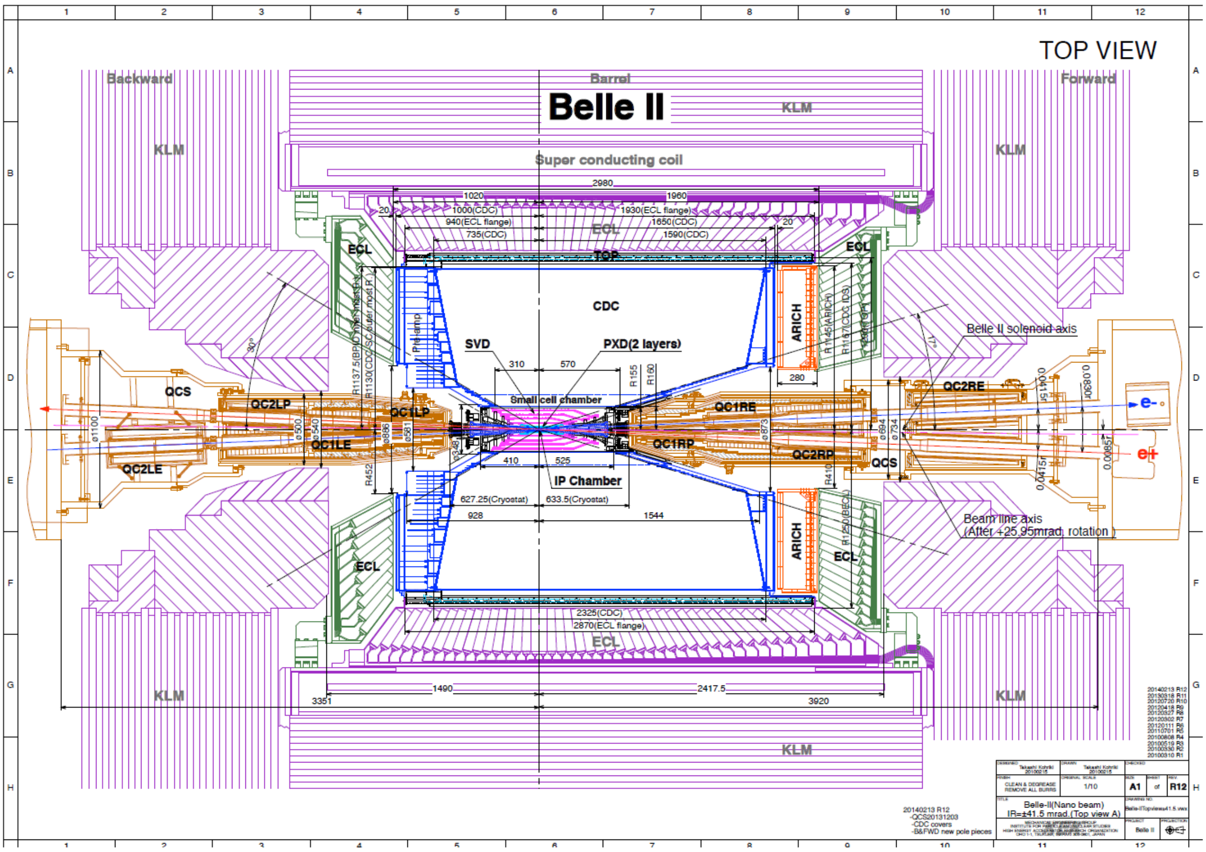

Figure 2.1: Belle-II detector is inside a 1.5 T solenoid magnet. The regions within thick lines show the allowed region for CDC electronics, and for cabling for the PXD (pixel detector) and the SVD (silicon vertex detector).

2.3 The Merger of CDC

The most important task for Merger is to merge the number of channels from the Front-end. Each Front-end boards contains 3 rows for signals. But for every 2 Front-end boards, there is 1 row without usage. Designing a Merger board is to reduce the number of costly optical link cables.

The Front-end output channels are combined to 5/6 by using the Merger boards. For example, in the layer 0, there are 960 output channels in the Front-end and are merged to 800 channels.

After merged the readout channels, CDC Trigger team design a Universal Trigger Board (UT3) for other track trigger tasks. The UT3 boards are used for Track Segment Finder (TSF), 2d Tracker, and 3d Tracker. The CDC Trigger team can modify the FPGA logic in the UT3 to change the performance.

2.4 The Track Segment Finder of CDC

The wire-hit information collecting from the Merger, is sent to the Track Segment Finder (TSF). The TSF uses one Universal Trigger Board (UT3) per super-layers. There are 9 super-layers in total.

In the Figure **??**, it shows that 11 Track Segments (TS) are combined as one Track Segment Finder (TSF). Each TS consists 8 Field wires in the outside box and 1 Sense wire in the center. This sand-clock shape is the normal shape of TSF. For the TSF in the innermost superlayer, their shape is triangle.

Each TSF, it counts the hits from the center TS and the TSs in the upper and lower 2 superlayers. The TSF will be triggered only if there are more than 1 hit in each superlayer. But, in case of the broken sense wires, we also allow 4-superlayer-hit be triggered.

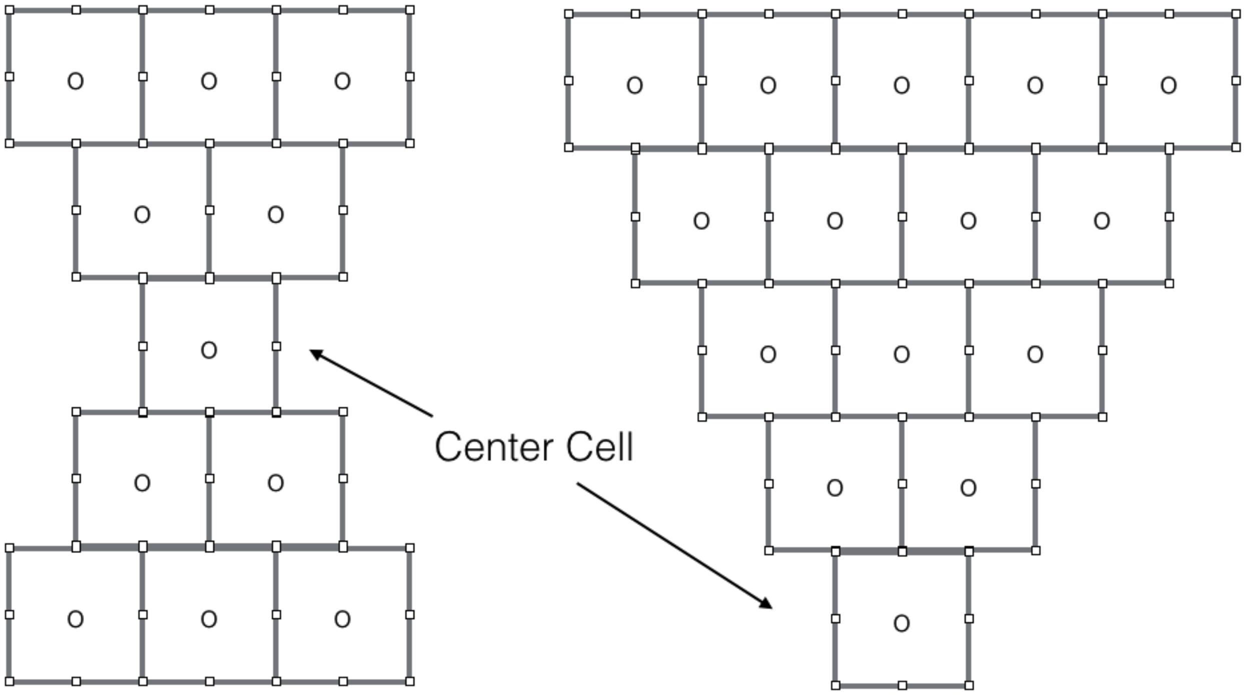

Figure 2.2: Eleven Track Segments are combined as Track Segment Finder and each Track Segment consists 8 Field wires and 1 Sence wire. Only the shape of TSF on SL0 likes left.

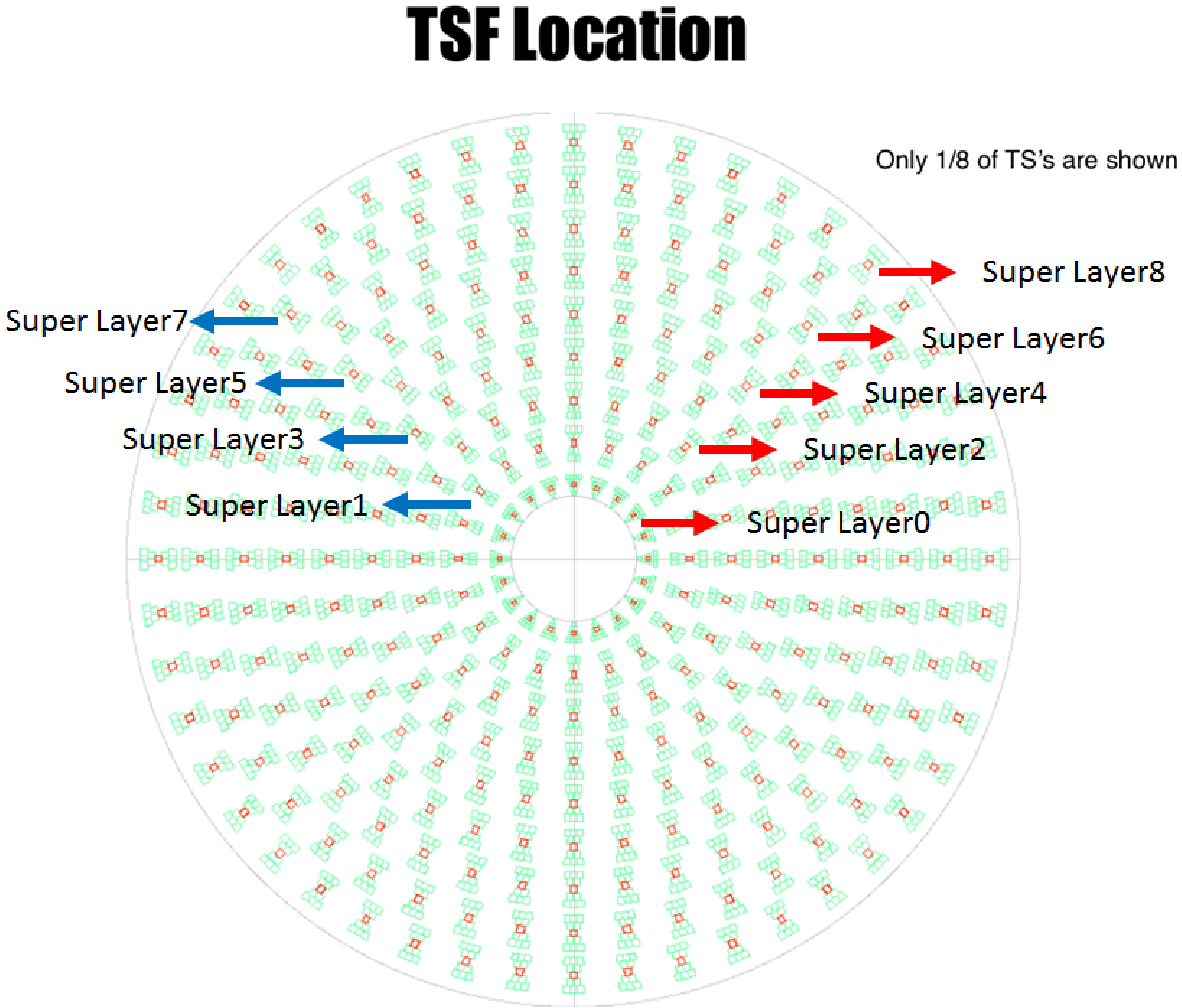

Figure 2.3: The location of TSF in CDC chamber. The TSF shape in the innnermost layer is triangle which is different other layers. The normal TSF shape is sandclock.

Chapter 3

The 2D Track Reconstruction: 2D Finder

3.1 2D Tracker

2D Tracker include 2D Finder and 2D Selector. 2D Finder send the the ϕ and radius of Hough cell to Neuro trigger. 2D Selector can find one triggered TS in each SuperLayer of three highest Hough cell on Hough Minus plane and Hough Plus plane respective and send data to 3D Tracker. We will talk about 2D Finder in this chapter.

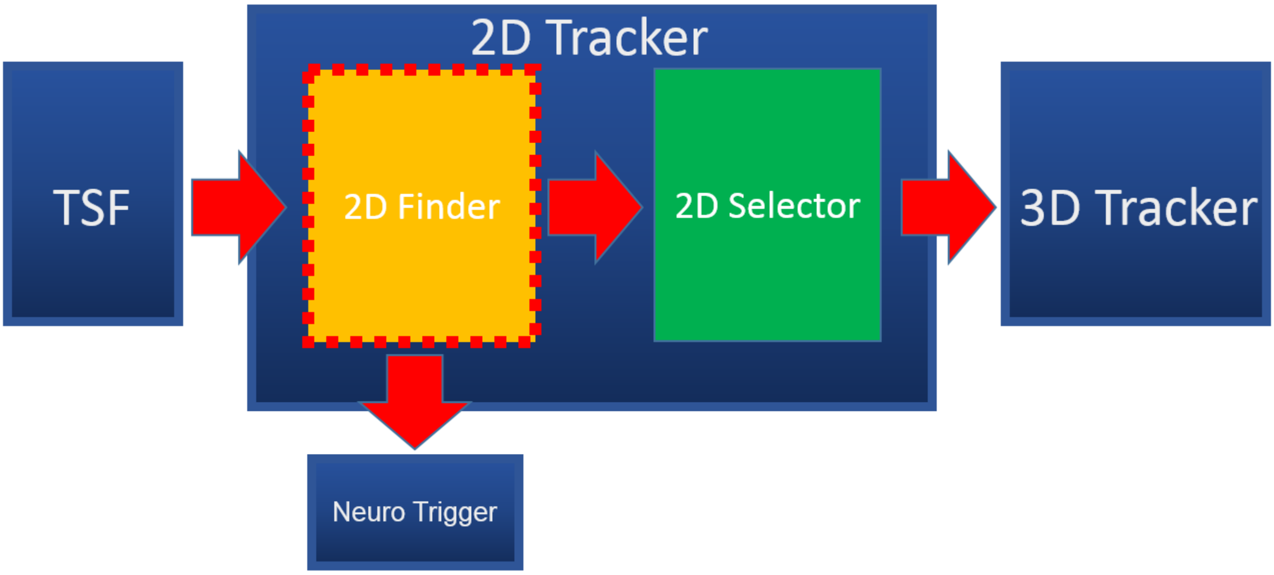

Figure 3.1: 2D Finder send the the ϕ and radius of Hough cell to Neuro trigger.

3.2 Hough Transform

The Hough transform is a feature extraction technique used in the image analysis, computer visision, and digital image processing. The purpose of the technique is to find imperfect instances of objects within a certain class of shapes by a voting procedure. [6].

Every point in 2 dimensional space (x-y plane), we can delimit two kinds of circle that with different circle size passing through the original point $(0, 0)$ and the point itself. One kind is called right-handed circle(Hough Plus circle), and the other is called left-handed circle(Hough Minus circle).Here shows an example in Figure 3.1. 3.2.

The equation (3.1) shows the function of a circle. Here the a and b are the free parameters for the center of circle. The r is the radius of circle.

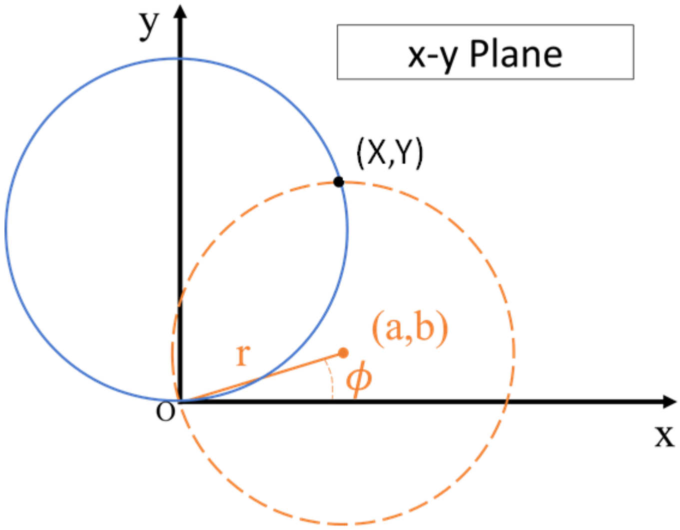

Figure 3.2: Each point in the 2-dimensional space, we can find two kind of circles with different circle size passing through the original point O(0,0) and the point itself (X,Y).One kind is called the right-handed circle, and the other kind is called the left-handed circle. The dashed circle(right-handed circle) is named Hough Plus circle and the solid circle(left-handed circle) is named Hough Minus circle.

$$(x-a)^2 + (y-b)^2 = r^2 = a^2 + b^2 \tag{3.1}$$

We expand the equation (3.1), and obtain the updated equation (3.2).

$$x^2 - 2ax + y^2 - 2by = 0 \tag{3.2}$$

Then, we translate the a and b parameters from the x-y coordinate into polar r-ϕ coordinate. We use equations (3.3) and (3.4). The r is the radius and ϕ is the polar angel of the circle.

$$a = rcos\phi \tag{3.3}$$

$$b = rsin\phi \tag{3.4}$$

By replacing the a and b parameter in the equation (3.3) and (3.4) to (3.2). Then we have the equation as (3.5).

$$x^2 - 2xrcos\phi + y^2 - 2yrsin\phi = 0 \tag{3.5}$$

We rewrite the equation (3.5) as the variable r based function in the equation (3.6).

$$r = \frac{x^2 + y^2}{2xcos\phi + 2ysin\phi} \tag{3.6}$$

For a certain point (x_0, y_0), we replace the x and y in the equation (3.6) and obtain the equation (3.7).

$$r = \frac{x_0^2 + y_0^2}{2x_0cos\phi + 2y_0sin\phi} \tag{3.7}$$

In the equation (3.7), Each point(x_0, y_0) corresponding to two arcs in the Hough plane. One is called Hough Pius plane and the other is Hough Minus plane. In the Figure 3.3, it shows an example.We use $\log(r)$ instead of r in the Hough plane due to a better scale size.

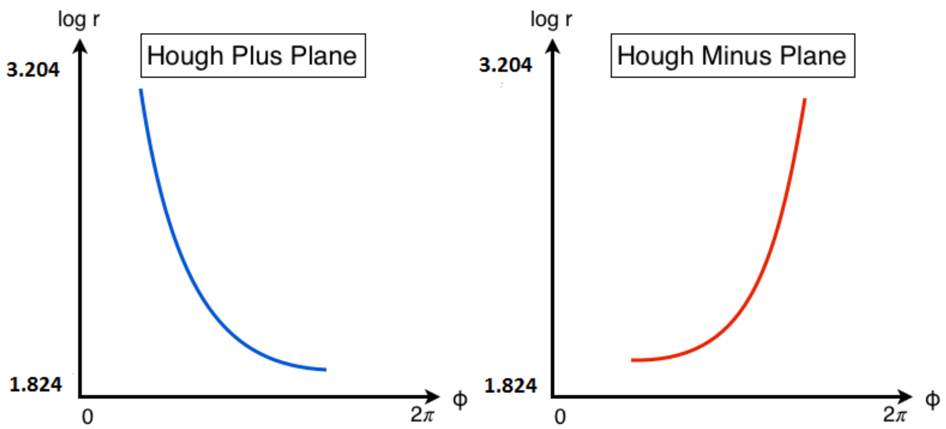

Figure 3.3: A point (x_0, y_0) corresponding to two arcs in Hough plane, One is called Hough Pius plane and the other is Hough Minus plane.

3.3 Hough Voting

There are 5 axial superlayer in the 2D Tracker. Therefore, for each track, we need to find crossing cell by 5 arcs, it shows an example in figure 3.4 and figure 3.5.

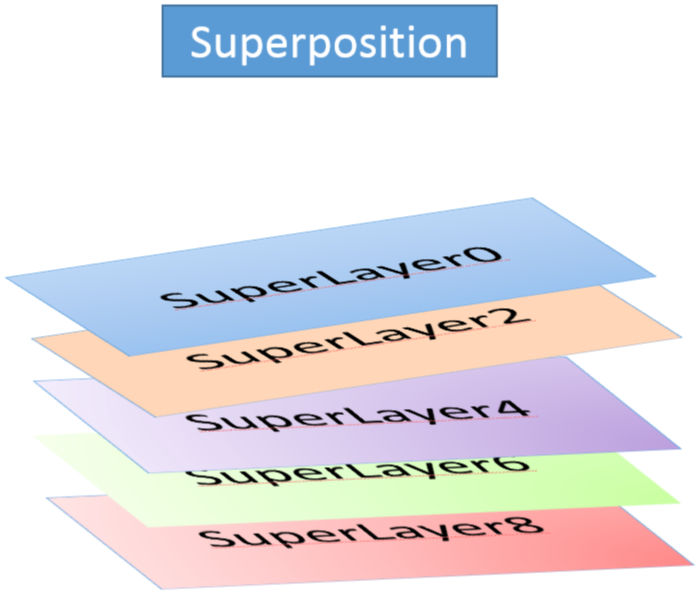

Figure 3.4: Superposition in 5 SuperLayer.

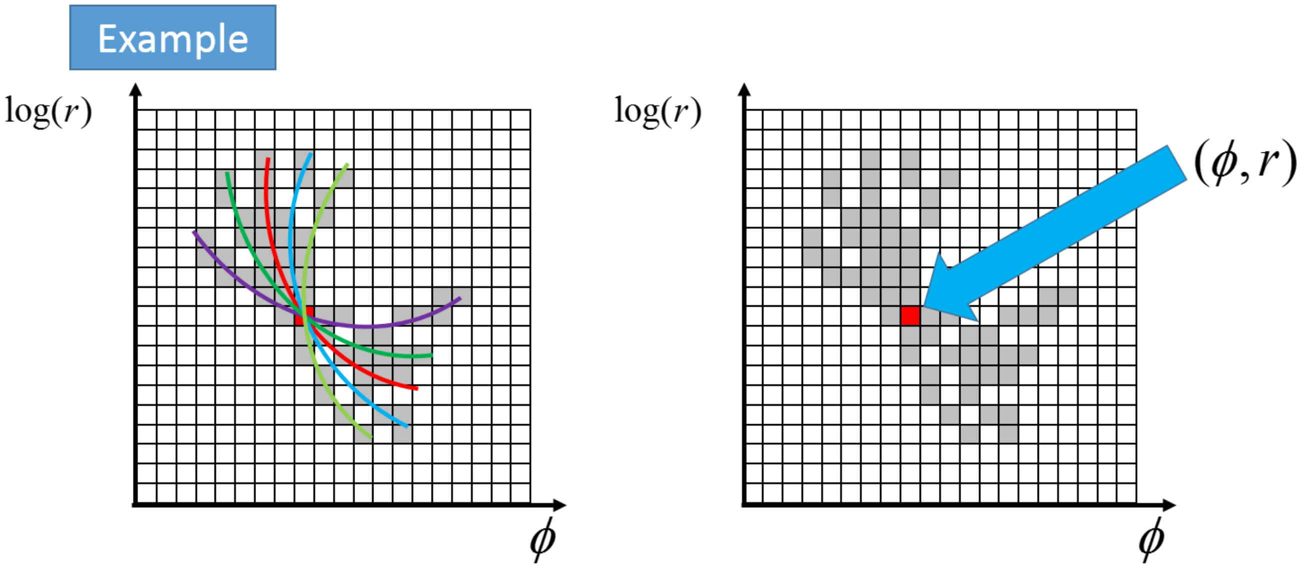

Figure 3.5: The red cell is crossing cell by 5 arcs, we use the r and ϕ to obtain the circle information.

In the Firmware, to calculate the relation between the Hough cells and TSF, I use C++ progrem to calculate and find TS and grid connection, and generate firmware code, The basic mesh size setting of Hough plane is $(log(r), \phi)$ = (16, 160) We use OR logic for the relationshi between the Hough cells and TSFs in 5 Superlayers. In hough Voting, We use AND logic for 5 Hough Plane(5 Superlayers). It show in the Figure 3.6 and Figure 3.7.

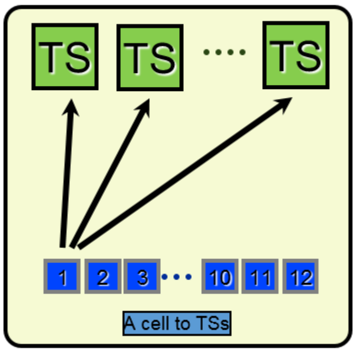

Figure 3.6: The relation between the Hough cells and TSF.

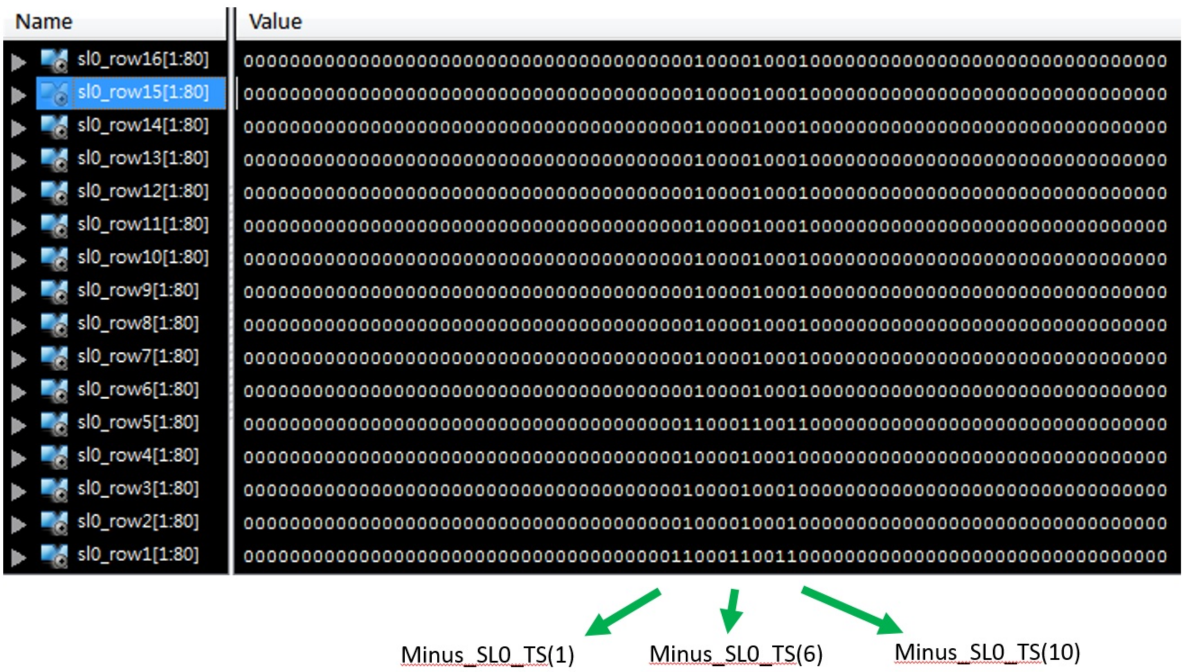

Figure 3.7: An example of transforming the arcs into meshes in ISIM.

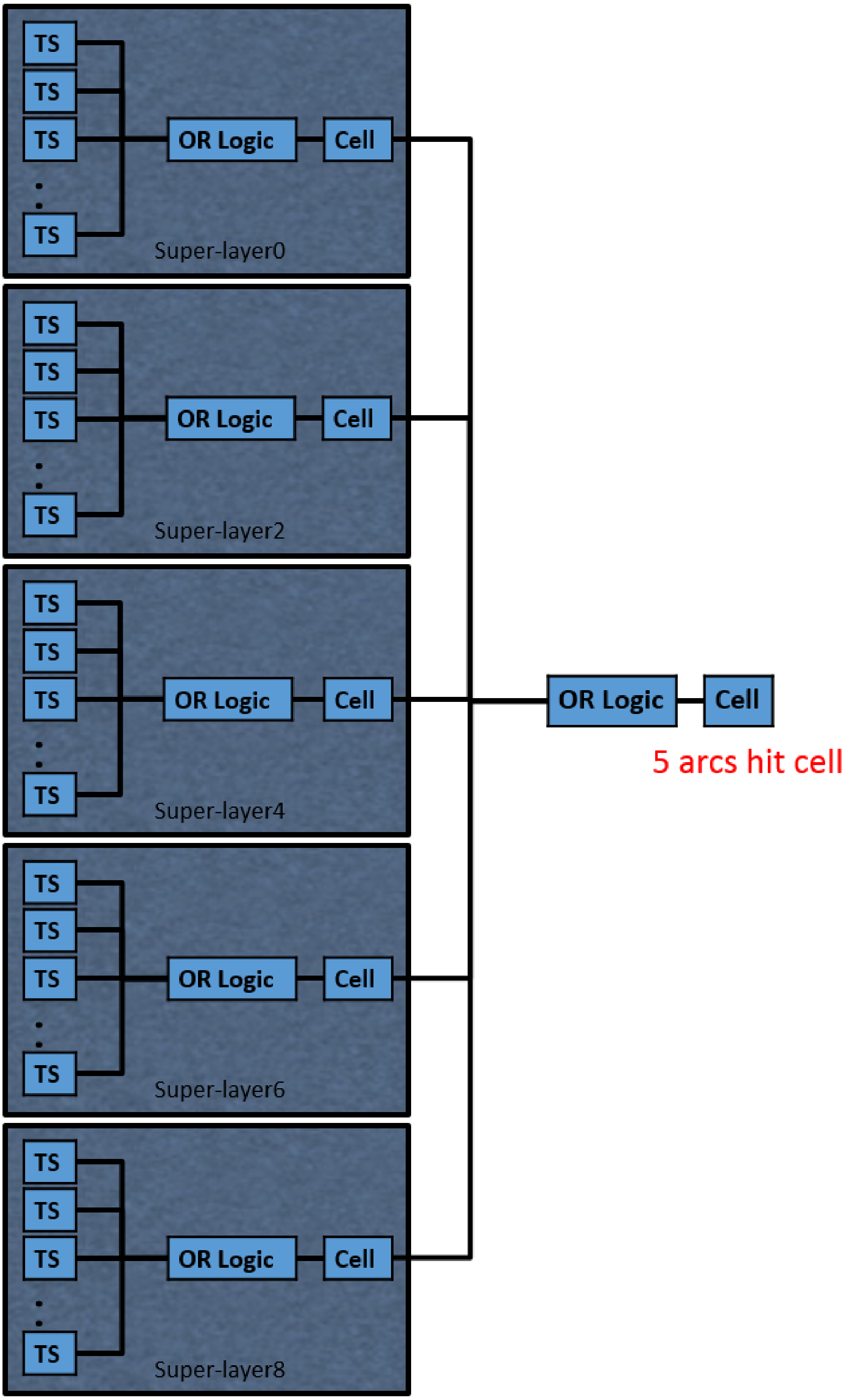

Figure 3.8: We use AND logic to connect these Hough Plane cells in 5 Superlayer.

3.4 Clustering

In a perfect case, we find some isolated 5-hit Hough cells to decide each track circles. However, we meet the connected 5-hit Hough cells (cluster) very often. An perfect isolated 5-hit Hough cell example is shown in the Figure 3.9. One track shown in the CDC $x - y$ plane (left plot) corresponds to 1 isolated 5-hit Hough cell (right plot). A cluster example is shown in the Figure 3.10. In this cluster case, one track shown in the CDC $x - y$ plane (left plot) corresponds to 3 connected 5-hit Hough cells (right plot).

Another cluster case, for two charged tracks, is shown in the Figure 3.11. In this cluster case, two tracks shown in the CDC $x - y$ plane (left plot) corresponds to 2 connected clusters (right plot). In order to sovle the imperfect case, We ceate Pattern-I and Pattern-II algorithm.

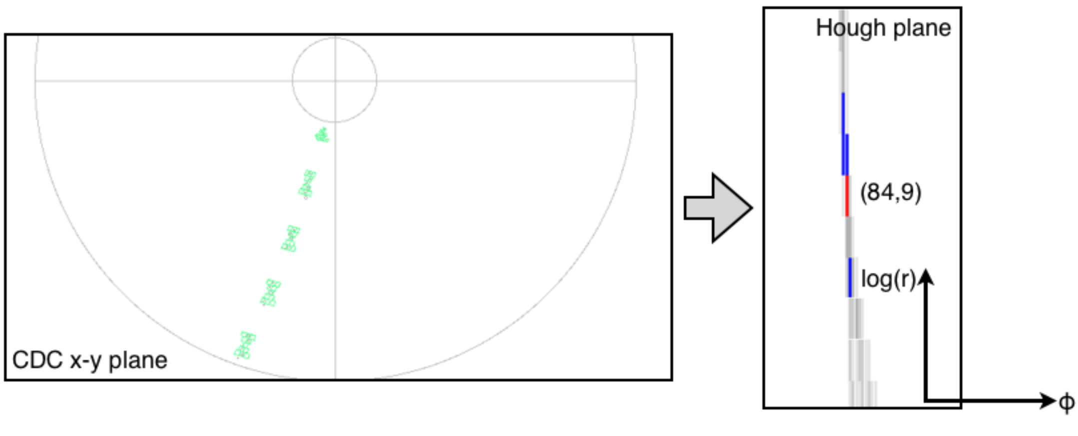

Figure 3.9: An perfect isolated 5-hit Hough cell example is shown. One track shown in the CDC $x - y$ plane (left plot) corresponds to 1 isolated 5-hit Hough cell (right plot).

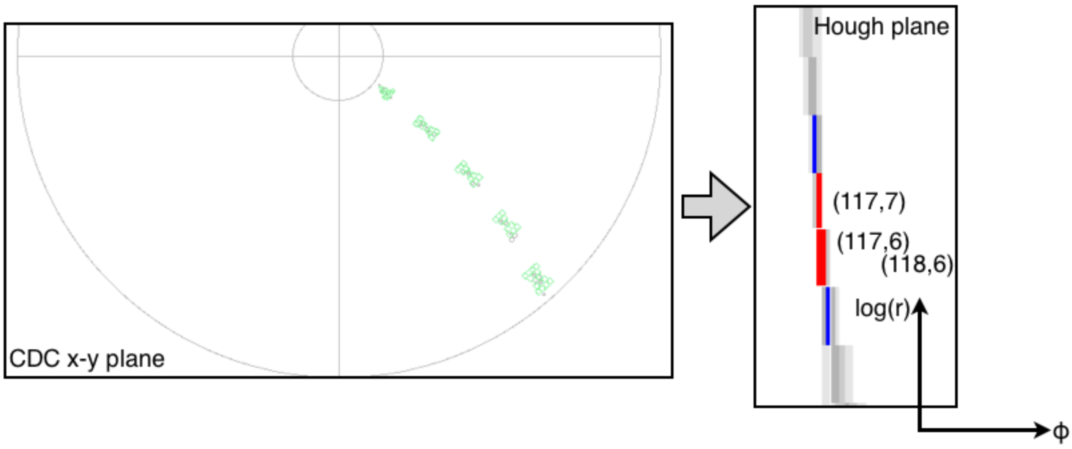

Figure 3.10: A cluster example is shown here. In this cluster case, one track shown in the CDC $x-y$ plane (left plot) corresponds to 3 connected 5-hit Hough cells (right plot).

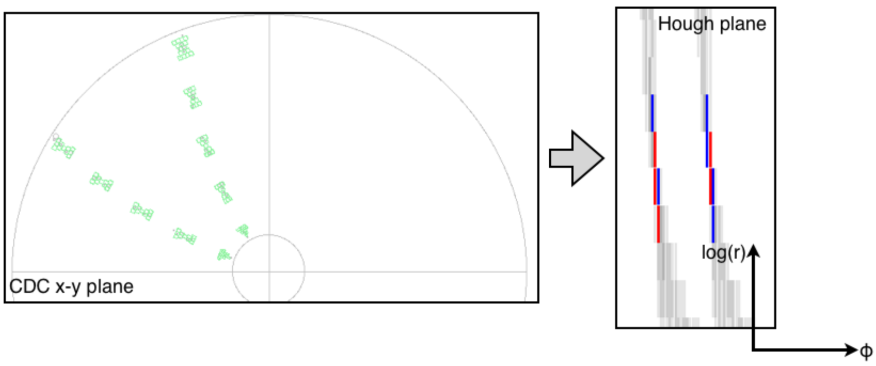

Figure 3.11: Another cluster case, for two charged tracks. In this cluster case, two tracks shown in the CDC $x-y$ plane (left plot) corresponds to 2 connected clusters (right plot).

The number of the Hough cells are too many. We make a larger basic unit called Pattern-I in the Hough plane for saving time on calculation.

Every 2×2 cells is called a Pattern-I. There are 640 Pattern I in a Hough plane ($2520/6 = 420$).

The Pattern-II is a unit of cluster. One Pattern II means one cluster. In the very beginning, we assume the maximum size of a cluster consisting 2×3 Pattern-I. Pattern-I and Pattern-II unit based structure are shown in the Figure 3.12.

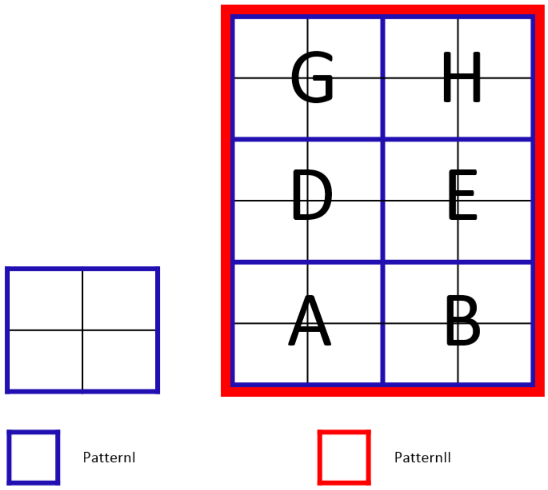

Figure 3.12: Here shows Pattern-I and Pattern-II based structure.

The A means the starting unit and the B,D,E are neighbors. The A unit check the hits information with three directions, (A-B) relation,(A-E) relation,(A-D) relation. There are too many possibilities that (A-B),(A-E),(A-D) relations can be related as a cluster. We consider the non-related cases in stead.It showns in the Figure 3.13.

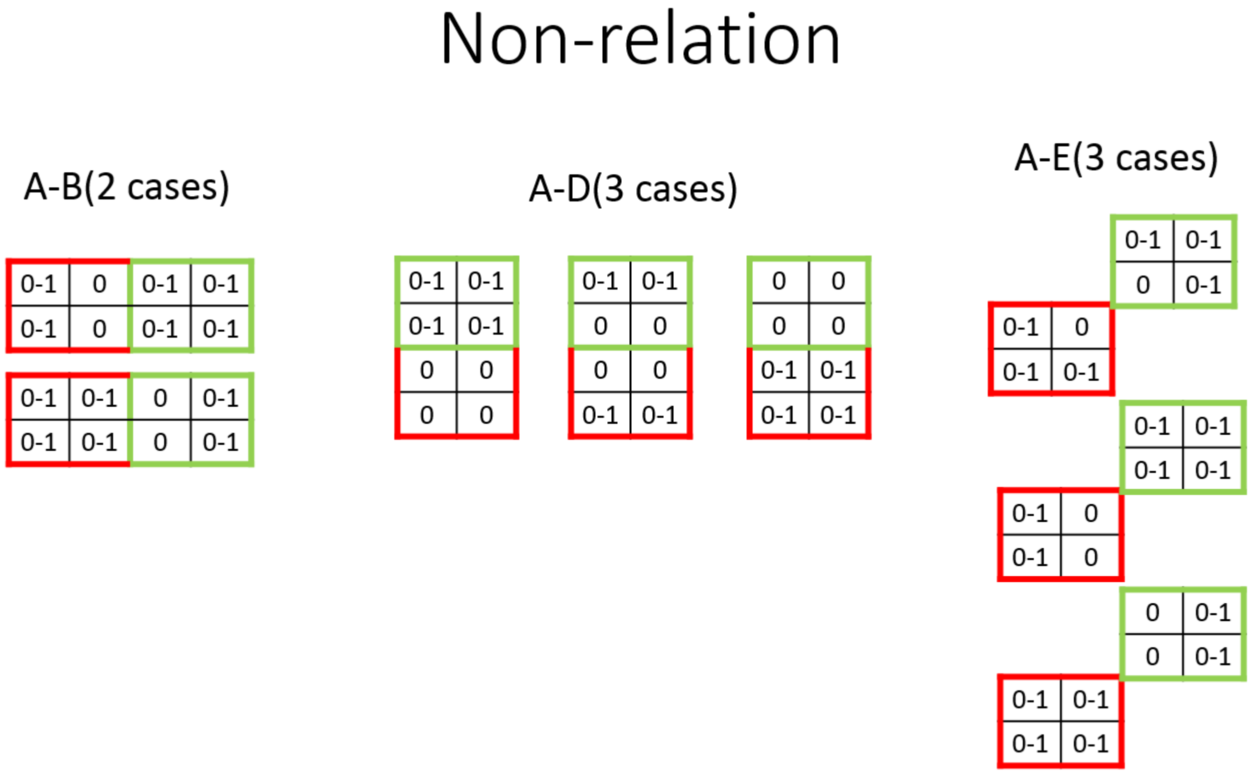

Figure 3.13: Here shows Non-relation in three directions.

In order to obtain the ϕ and r of track circle. We need to find the center of Cluster. We defind center of Pattern-II and center of Pattern-I in all cases.It shows in the Figure 3.15 and Figure 3.14.

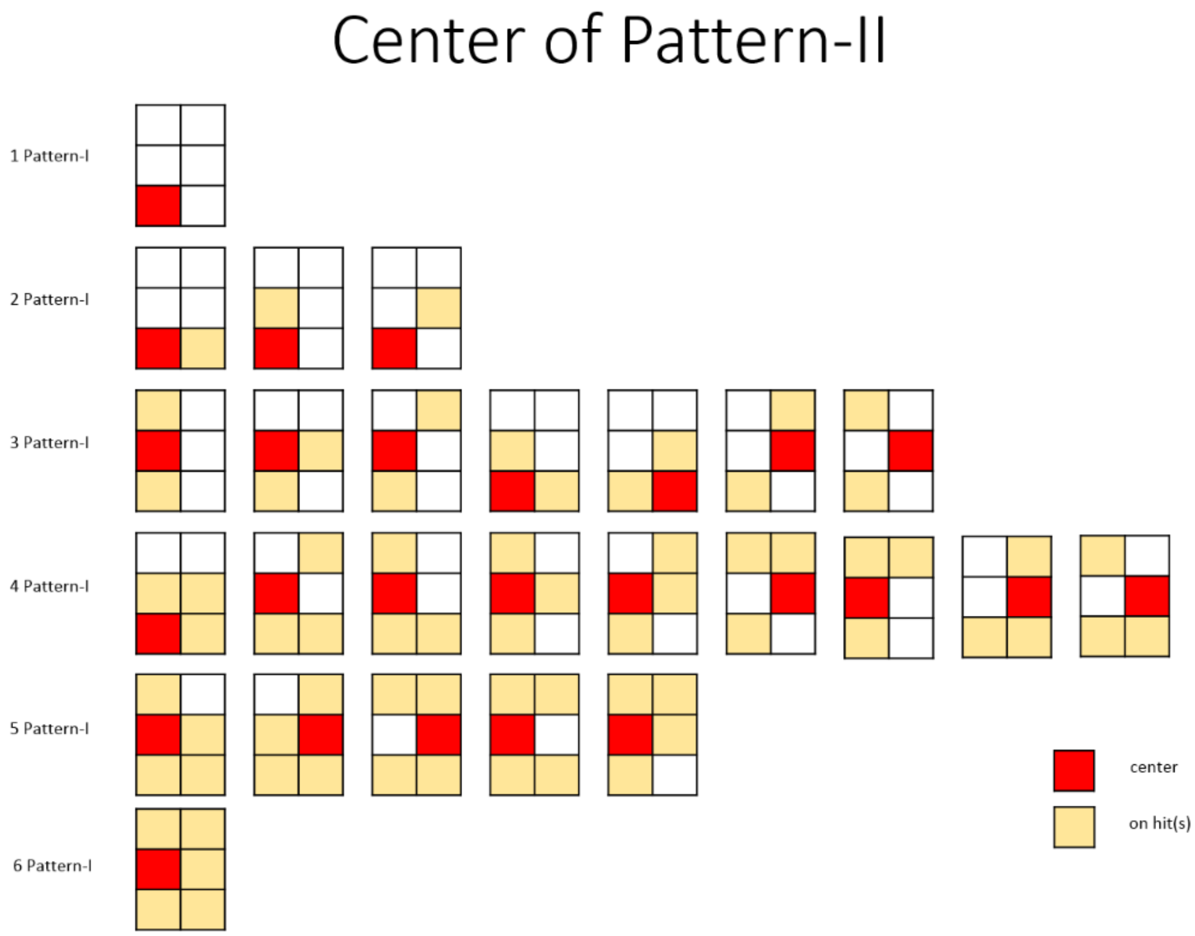

Figure 3.14: Use the selection rules and defind the center of Pattern-II.

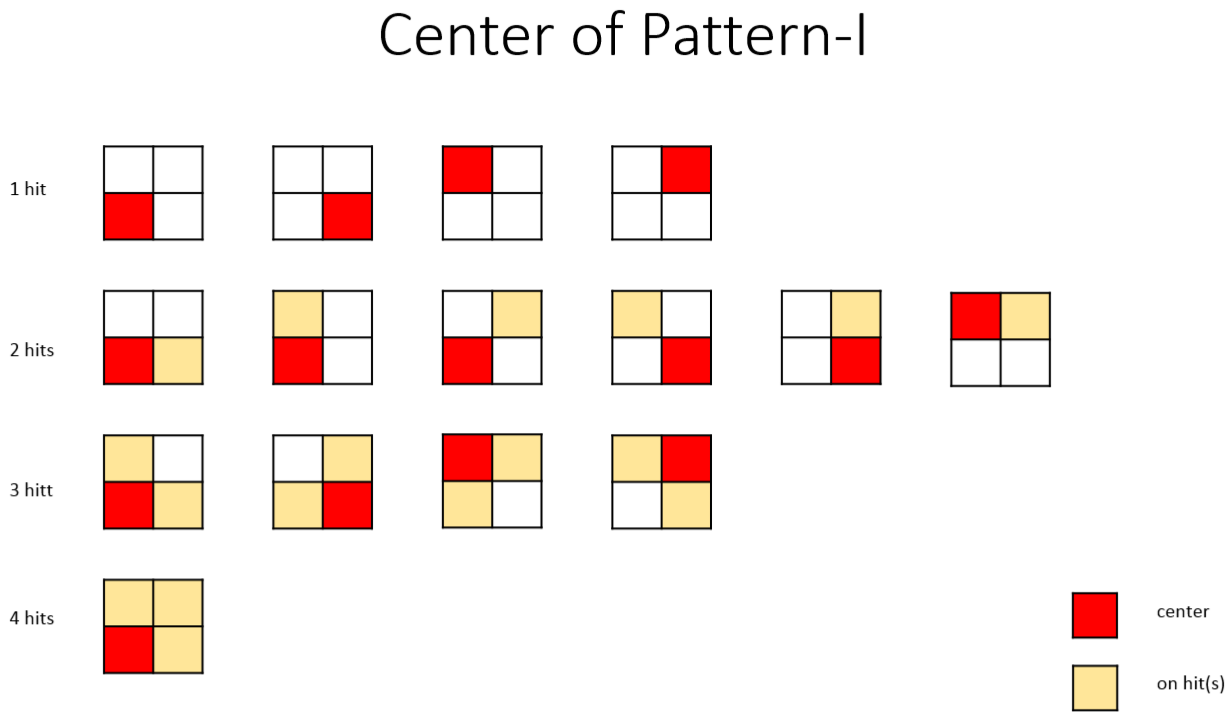

Figure 3.15: Use the selection rules and defind the center of Pattern-I.

It shows some examples of finding center of Cluster and Isim test.

Example

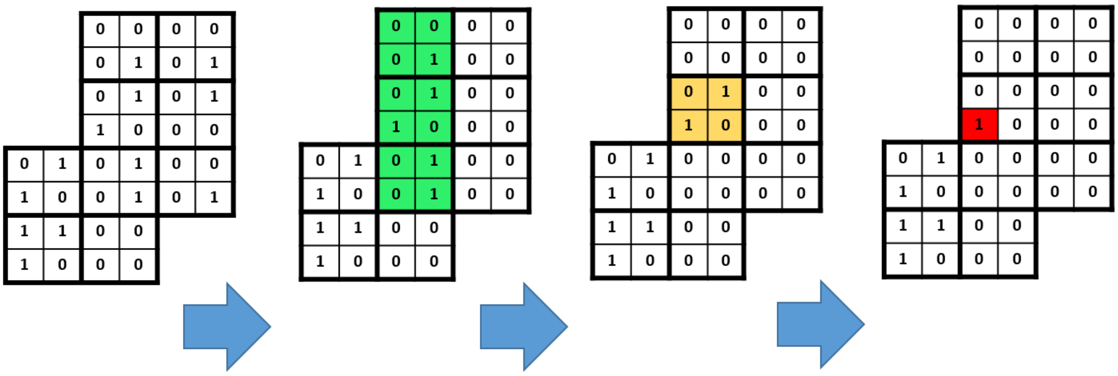

Figure 3.16: Example1

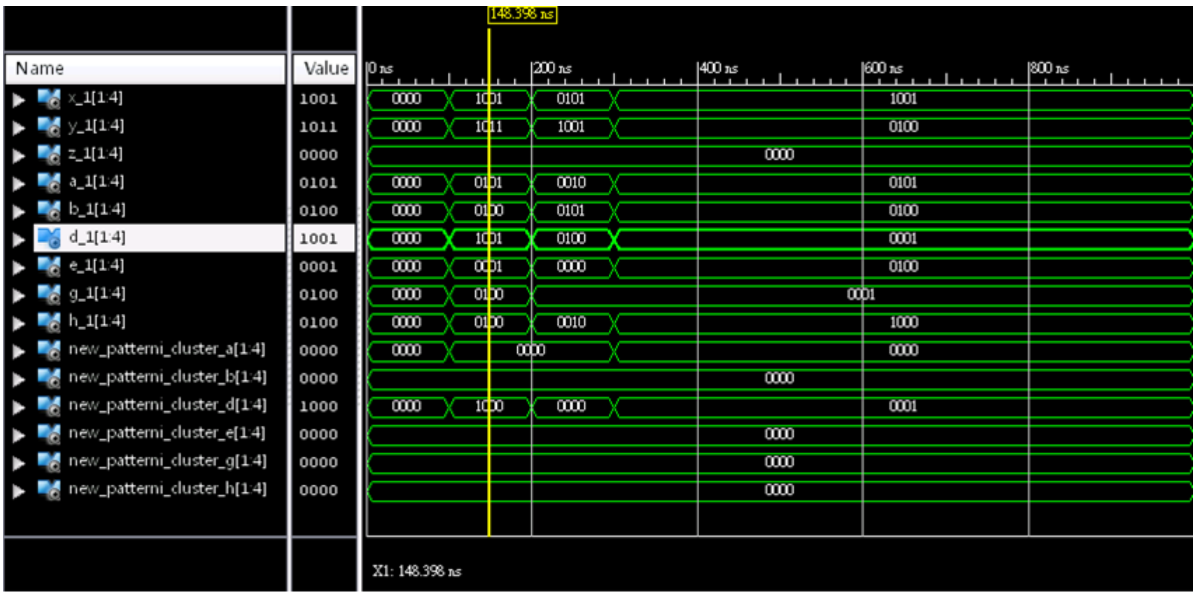

Figure 3.17: Example1 in Isim.

Example2

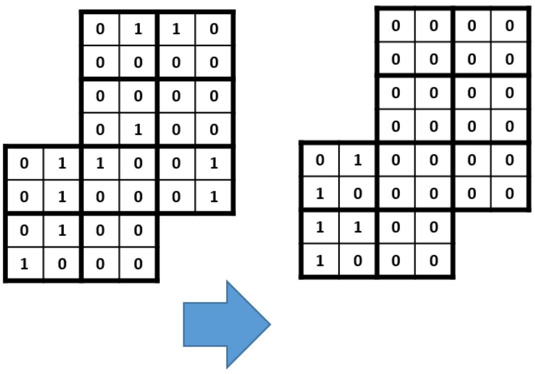

Figure 3.18: Example2

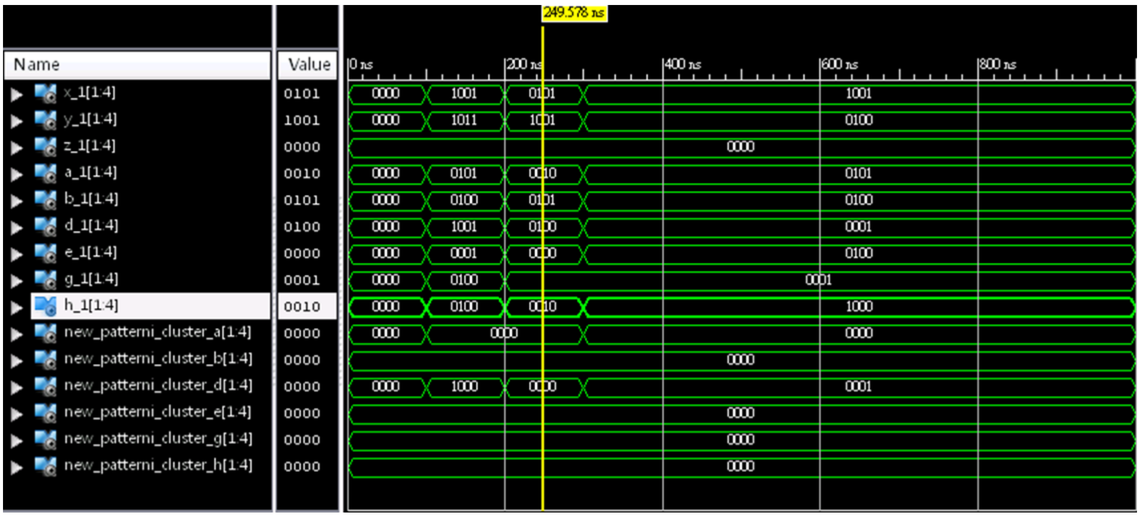

Figure 3.19: Example2 in Isim.

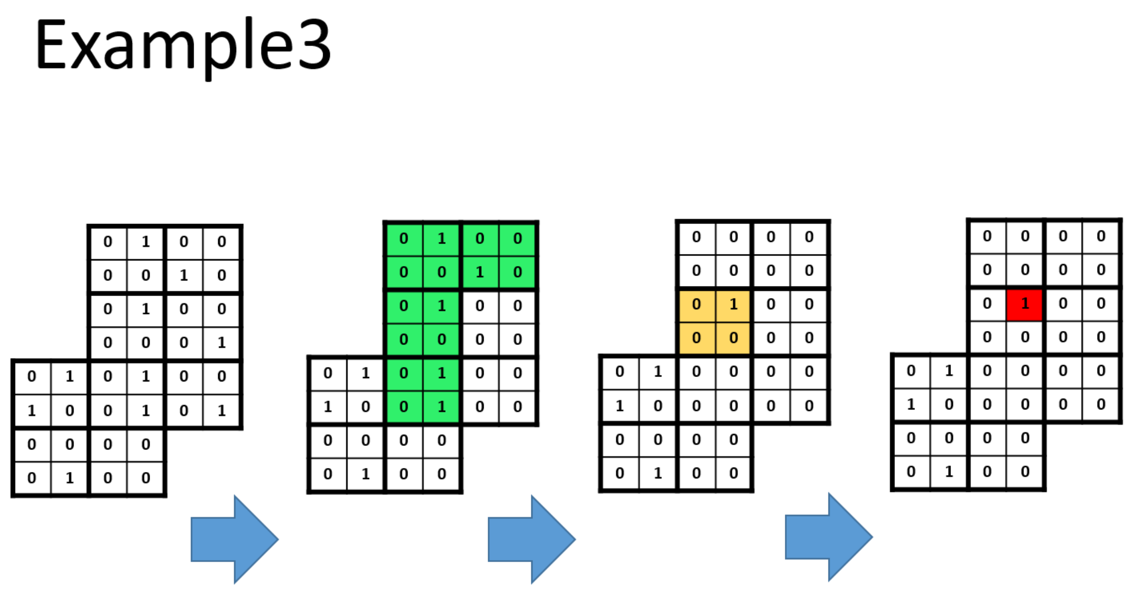

Figure 3.20: Example3

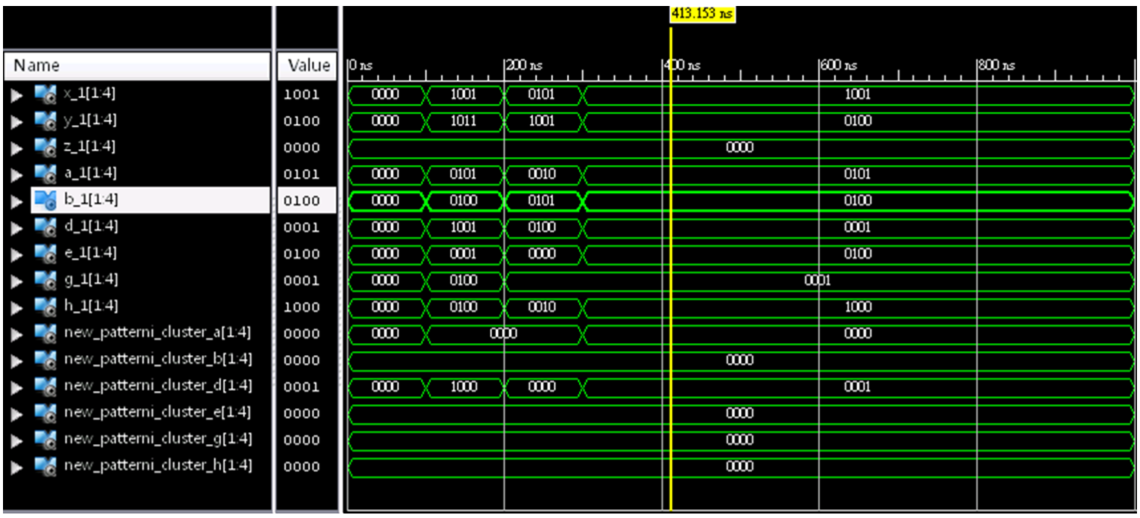

Figure 3.21: Example3 in Isim.

Chapter 4

The 2D Track Reconstruction: 2D Selector

4.1 2D Selector idea

2D Selector can find one triggered TS in each SuperLayer of three highest Hough cell on Hough Minus plane and Hough Plus plane respective and send data to 3D Tracker. We will talk about 2D Selector in this chapter.

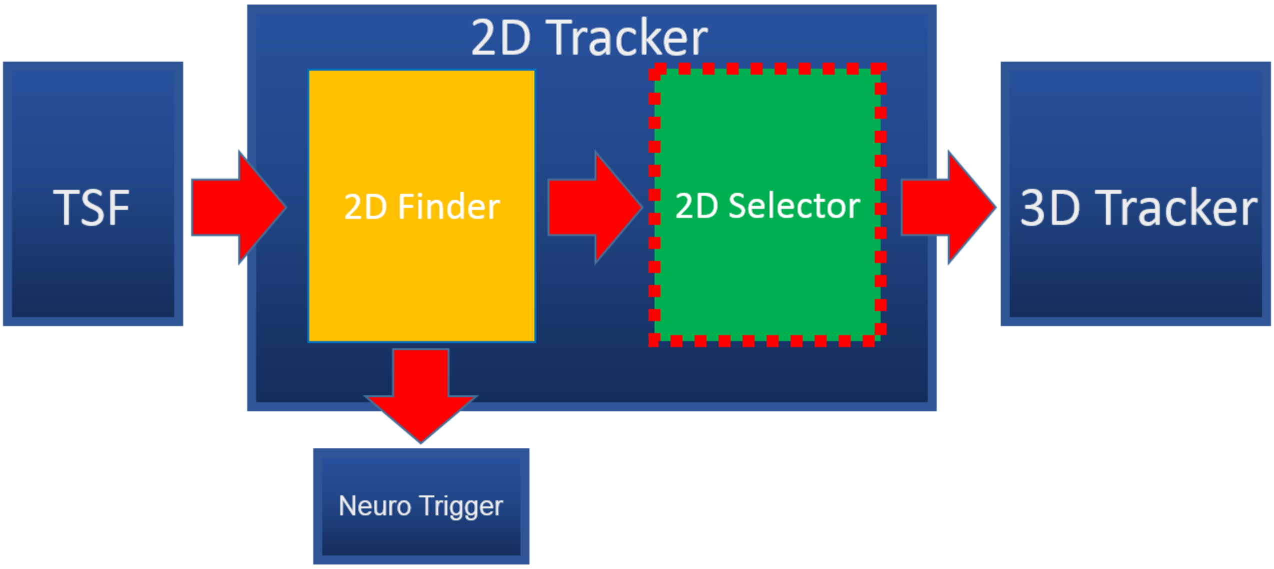

Figure 4.1: 2D Selector can find one triggered TS in each SuperLayer of three highest Hough cell on Hough Minus plane and Hough Plus plane respective and send data to 3D Tracker.

We can find one hit cell in one track after Clustering, but we need to decide one TS in each axial SuperLayers(0,2,4,6,8). It shows the flow chart in the Figure 4.2.

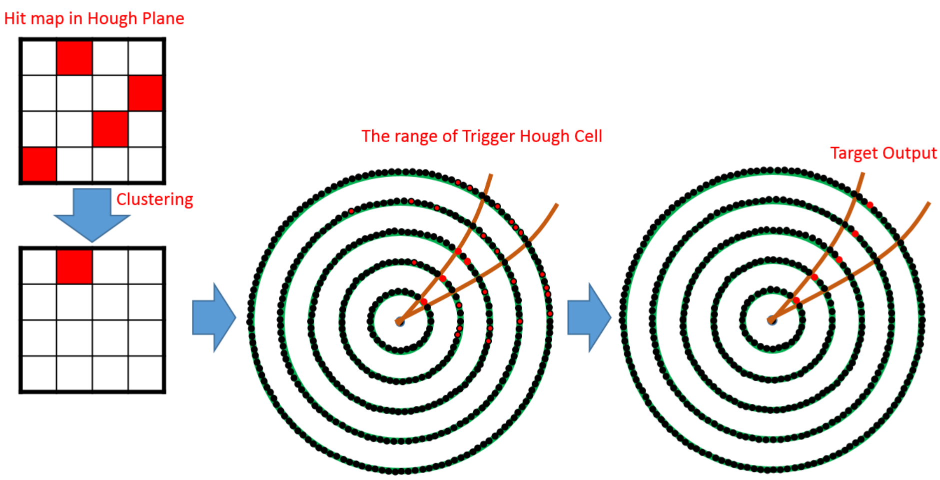

Figure 4.2: The best TS information is decided by 2D Select and send to 3D Finder.

4.2 2D Selector Logic

To obtain one TS in each track, we design three Step in 2D Selector.

- Step 1 Select the highest 3 PT Hough cell.
- Step 2 Find the related and triggered TSs from TSF in each axial SuperLayers (0, 2, 4, 6, 8).
- Step 3 Select one TS in each axial SuperLayers (0, 2, 4, 6, 8).

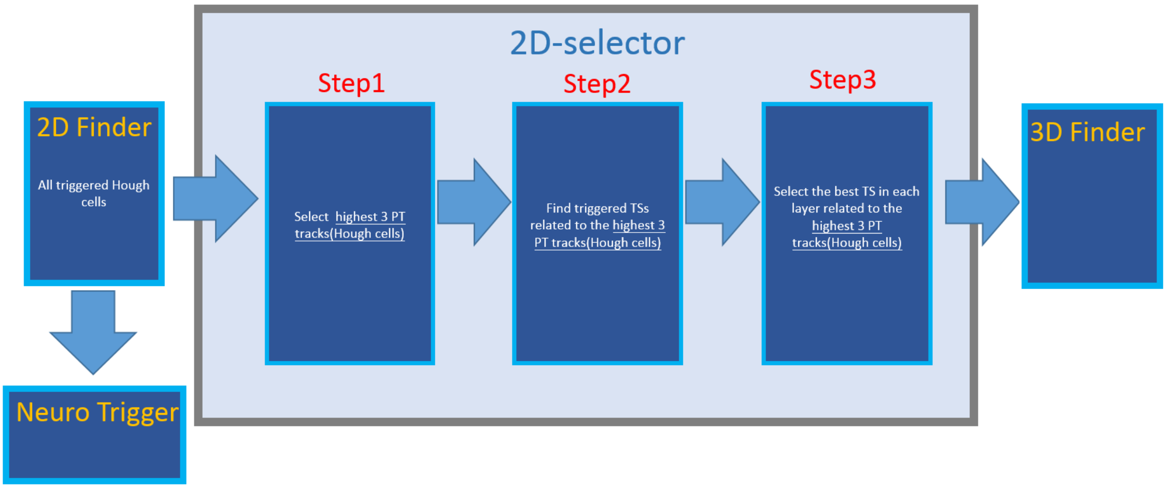

Figure 4.3: The best TS information is decided by 2D Select and send to 3D Finder.

4.3 Select the highest 3 PT Hough cell

After Clustering,one track conditions one Hough cell hit.We need to select the higher 3 PT Hough cell. I make a component to choose the highest Hough cell in one time and use XOR Logic to get next Hough map. Repeating the same action twice, we total have the three highest Hough cell.It shows the Logic and an example in the Figure 4.5 and Figure 4.6.

```
entity select_cell is
port(
         minus_map: in std_logic_vector(639 downto 0):= (others => '0');

         track_map : out  STD_LOGIC_VECTOR (639 downto 0):= (others => '0');
         Top_clkData_s :in STD_LOGIC

         );
end select_cell;


 process (Top_clkData_s)
       variable temp : integer range 0 to 3:= 0;
 begin
          temp := 0;
       for i in 639 downto 0 loop
          if ( minus_map(i) = '1' and temp = 0 ) then
                temp := 1;
                track_map(i) <= '1'  ;
          else
                 track_map(i) <= '0'  ;
          end if ;
       end loop;
 end process;
```

Figure 4.4: The component can select the highest cell.

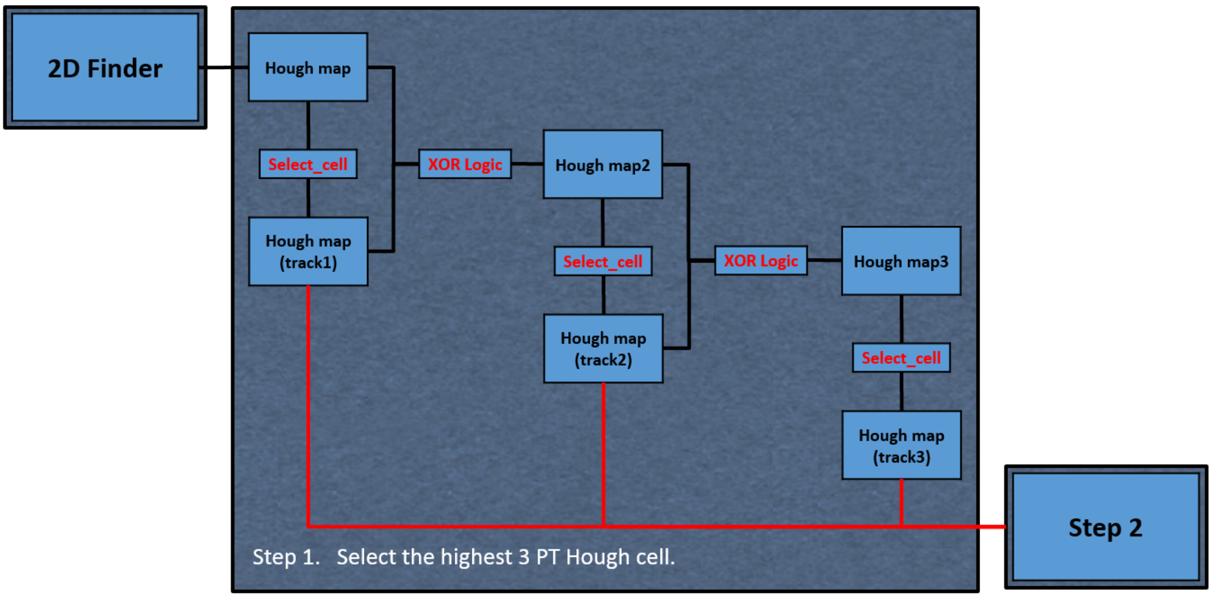

Figure 4.5: The Logic of select the highest 3 PT Hough cell.

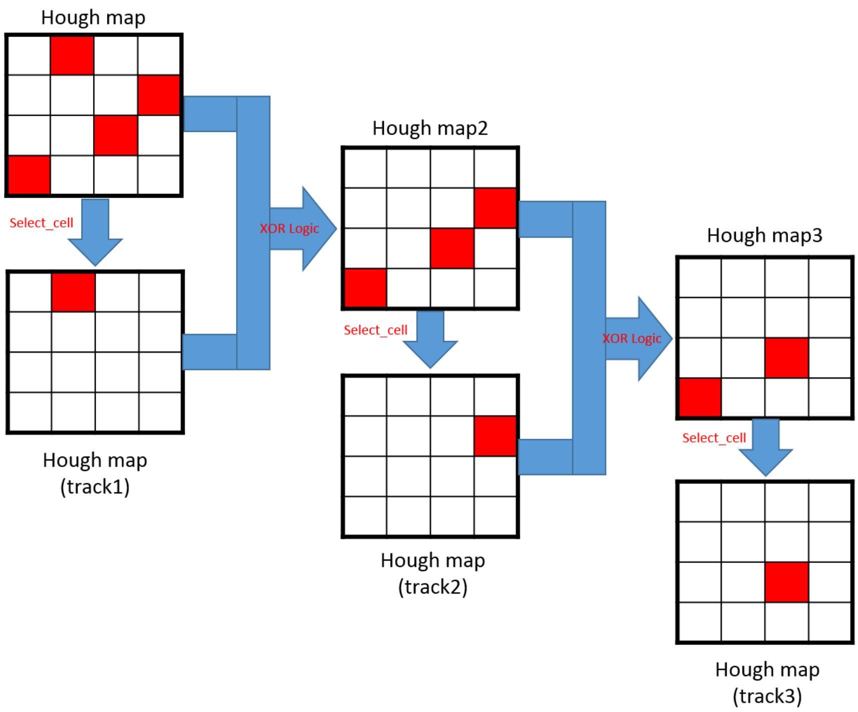

Figure 4.6: An example of select cell.

4.4 Find the related TSs

One TS in Hough plane have some cells. We use AND Logic on the TS cells and track cell, we can know whether there is relevant, it shows in the Figure 4.7. We have 20 set of data from TSF. Taking Superlayer0 for Example, we need to find out related TSs from 20 TSs of track1, track2 and track3.The same approach on SL2, SL4, SL6 and SL8. It shows in the Figure 4.8 and Figure 4.9.

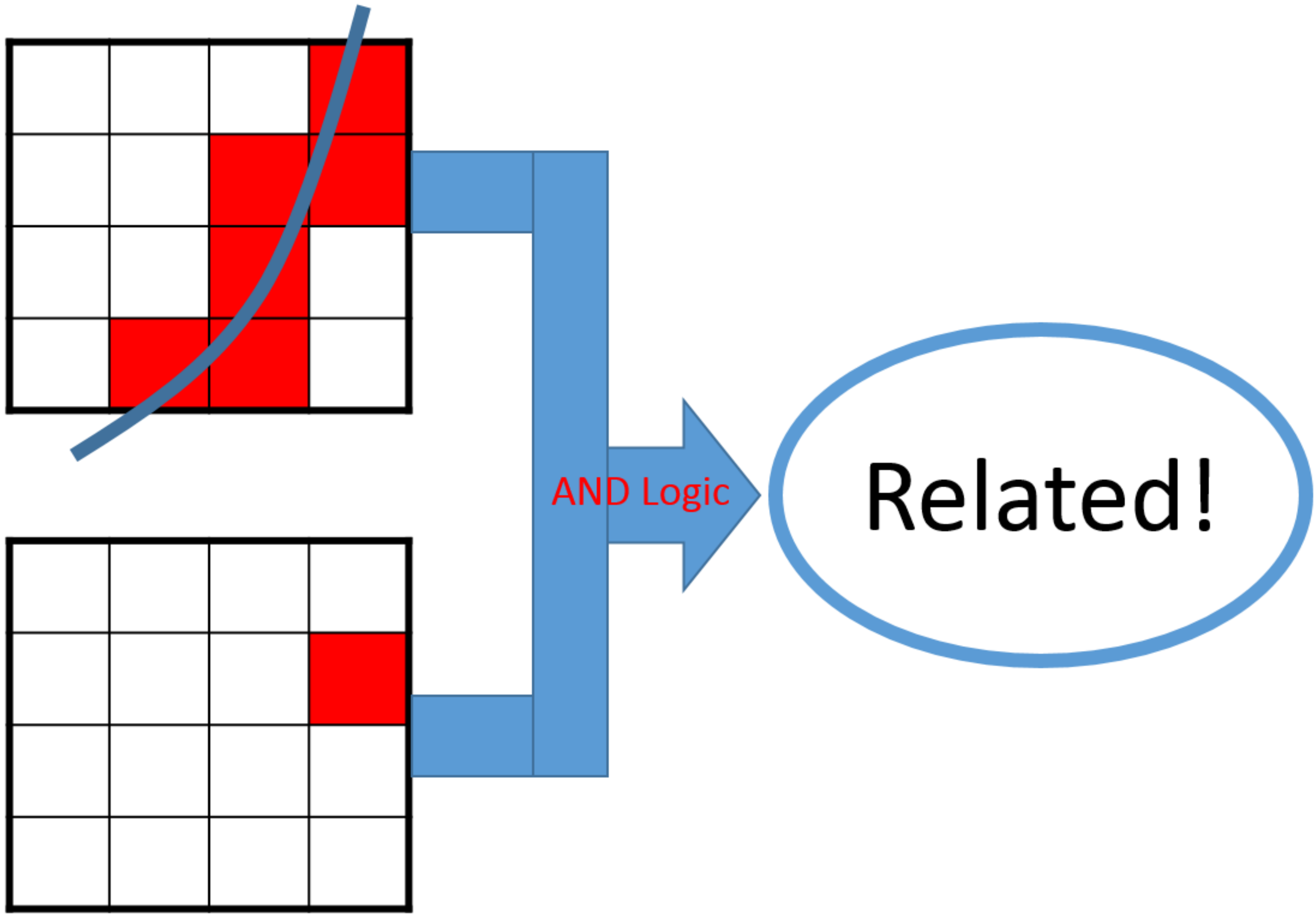

Figure 4.7: One TS in Hough plane have some cells. We use AND Logic on the TS cells and track cell, we can know whether there is relevant.

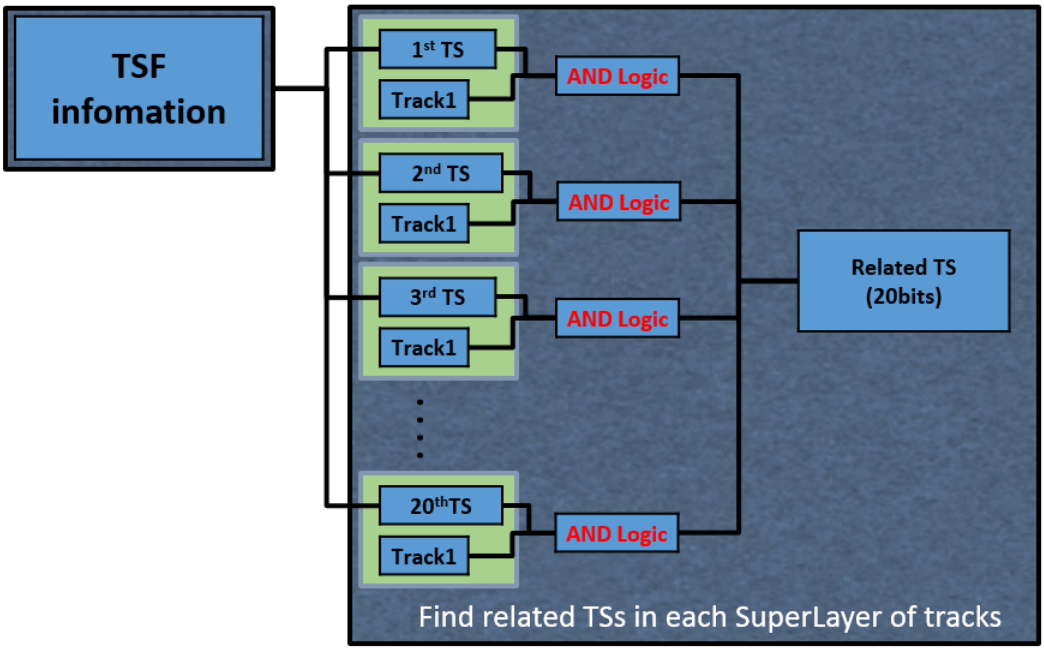

Figure 4.8: The Logic of find related TS.

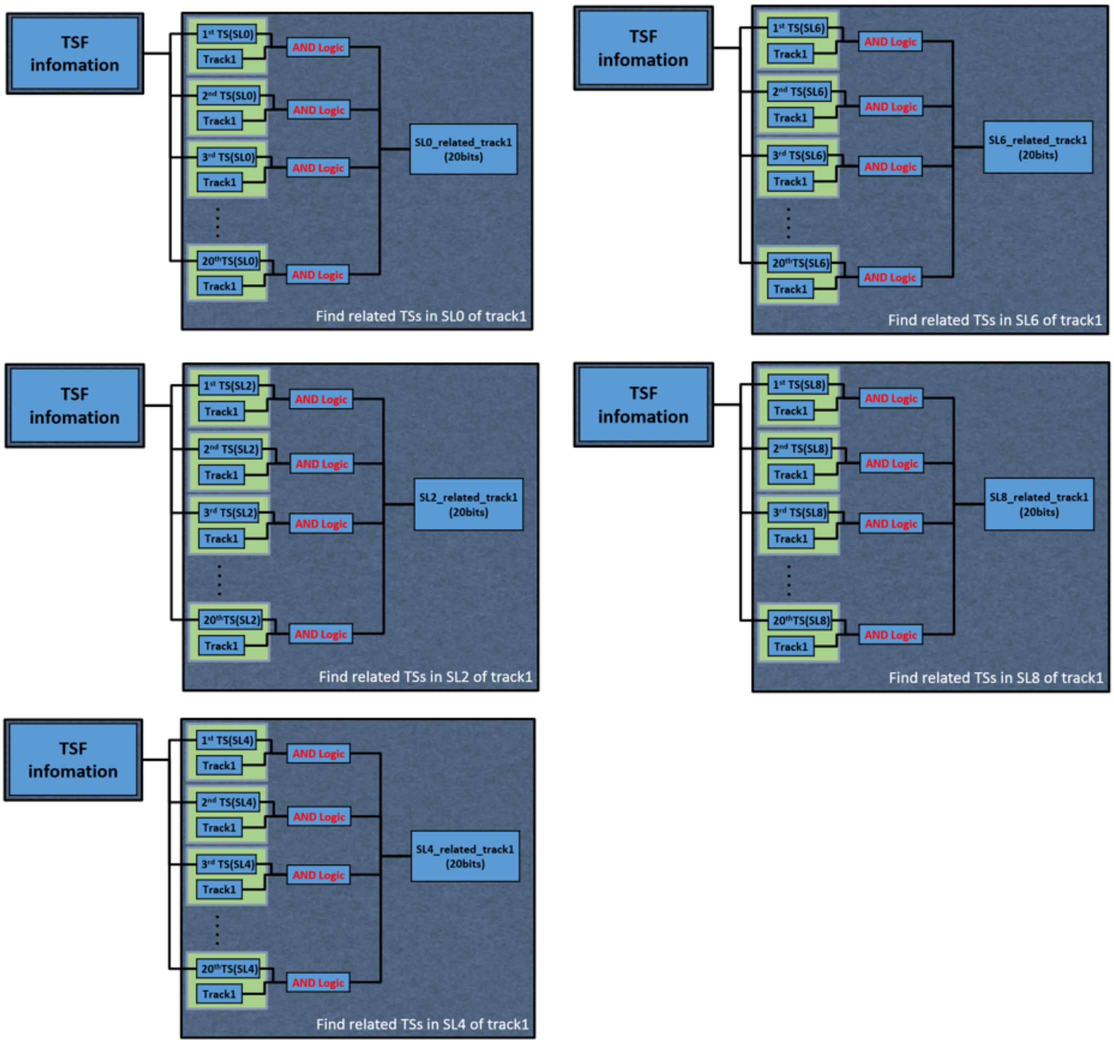

Figure 4.9: Find related TS in each SuperLayer of track1.

4.5 Select TS

To obtan one TS of each track, I make a component to select the first TS and send the information about that TS to 3D Tracker.

```vhdl
entity select_ts is
         port(
                  track_hit   : in  STD_LOGIC_VECTOR (19 downto 0):= (others => '0');
                  input_info : in  STD_LOGIC_VECTOR (491 downto 0):= (others => '0');
                  best_TS : out  STD_LOGIC_VECTOR (20 downto 0):= (others => '0')

         );
end select_ts;


best_TS(20 downto 0) <= input_info( 20 downto 0)  when track_hit(0)='1'   else
                        input_info( 41 downto 21) when track_hit(1 downto 0)    ="10"  else
                        input_info( 62 downto 42) when track_hit(2 downto 0)    ="100"  else
                        input_info( 83 downto 63) when track_hit(3 downto 0)    ="1000" else
                        input_info( 104 downto 84) when track_hit(4 downto 0)   ="10000" else
                        input_info( 125 downto 105) when track_hit(5 downto 0)  ="100000"  else
                        input_info( 146 downto 126) when track_hit(6 downto 0)  ="1000000"  else
                        input_info( 167 downto 147) when track_hit(7 downto 0)  ="10000000"  else
                        input_info( 188 downto 168) when track_hit(8 downto 0)  ="100000000"  else
                        input_info( 209 downto 189) when track_hit(9 downto 0)  ="1000000000"  else
                        input_info( 230 downto 210) when track_hit(10 downto 0) ="10000000000"  else
                        input_info( 251 downto 231) when track_hit(11 downto 0) ="100000000000"  else
                        input_info( 272 downto 252) when track_hit(12 downto 0) ="1000000000000"  else
                        input_info( 293 downto 273) when track_hit(13 downto 0) ="10000000000000"  else
                        input_info( 314 downto 294) when track_hit(14 downto 0) ="100000000000000"  else
                        input_info( 335 downto 315) when track_hit(15 downto 0) ="1000000000000000"  else
                        input_info( 356 downto 336) when track_hit(16 downto 0) ="10000000000000000"  else
                        input_info( 377 downto 357) when track_hit(17 downto 0) ="100000000000000000"  else
                        input_info( 398 downto 378) when track_hit(18 downto 0) ="1000000000000000000"  else
                        input_info( 419 downto 399) when track_hit(19 downto 0) ="10000000000000000000"  else
                        "000000000000000000000"
```

Figure 4.10: The component can select the first TS.

4.6 Firmware test by chipscope

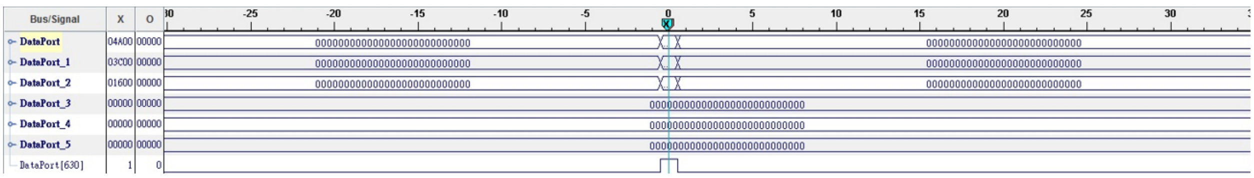

Figure 4.11: The DataPort630 is Input. DataPort is Output of track1 in Minus charge, DataPort1 is Output of track2 in Minus charge, DataPort2 is Output of track3 in Minus charge, DataPort3 is Output of track1 in Plus charge, DataPort4 is Output of track2 in Pinus charge, DataPort5 is Output of track3 in Plus charge.

Chapter 5

Summary

We updated the mesh size for better peak finding.

We updated the size of Pattern-I and Pattern-II.

We finish the firmware code of 2D Finder and check the result is ok.

We finish the firmware code of 2D Selector and check the result is ok.

The total Clk of 2D Finder Logic and 2D selector Logic is 0.

Bibliography

[1] http://legacy.kek.jp/intra-e/index.html

[2] Kobayashi M. and Maskawa T., CP Violation in the Renormalizable Theory of Weak Interaction, Prog. Theor. Phys. 49, 652657, (1973).

[3] http://www.nobelprize.org/

[4] Belle II collaboration, Belle II Technical Design Report, KEK-REPORT-2010-1, July 2010.

[5] http://legacy.kek.jp/intra-e/feature/2010/BelleIICDCDesign.html

[6] http://en.wikipedia.org/wiki/Hough_transform

[7] http://belle2.kek.jp/Organization/Belle2CollaborationMap.png

[8] https://belle2.cc.kek.jp/ twiki/pub/Organization/WebHome/BelleII-Organization.pdf