Tracking Performance for Subatomic Particle Detectors

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Abstract

This paper summarizes the analysis and changes made to the 4^{th} generation Silicon Future Circular Collider (SiFCC-v4) detector in order to increase the tracking efficiency. Changes in geometry were generated from adaptations of the compact.xml file of the SiFCC-v4 detector. Muon distributions were then generated using SLIC from single-particle particle gun promc files from the HepSim repository for Monte Carlo predictions. Analysis concluded inefficiencies in areas of the detector; inefficiencies in these areas were minimized by adaptations to the geometry of the detector. This greatly improved the overall effectiveness of the detector.

1 Introduction

It is planned that by 2018 conceptual designs of the Future Circular Collider (FCC) will be made. This accelerator will be able to reach never before explored energies and particles, extending the research currently being done at the Large Hadron Collider (LHC).

"The goal of the FCC is to greatly push the energy and intensity frontiers of particle colliders, with the aim of reaching collision energies of 100 TeV."-CERN [3]

New detectors must also be designed for this energy. One such detector may be the SiFCC detector. This detector will be able to measure proton-proton collisions at new energies, possibly uncovering never before seen phenomenons. The best place to start when building a new detector is to look back at previous designs that have been for other similar experiments. The SiFCC detector was created using the SiD detector designed by the Linear Collider community. The SiD detector, used to measure electrons, was adapted for this purpose. However, the original modification of this detector did not account for scaling the tracking system. Changes needed to be made to measure tracks up to 20 TeV in transverse momentum defined as:

$$p_T = \sqrt{(p_x)^2 + (p_y)^2}$$

Where p_x and p_y are perpendicular to the beampipe (z direction).

2 Description of SiFCC-v4

This is FCC-h like detector, based on the SiD, is smaller than the baseline design (similar to ATLAS detector). The total size of the detector was increased by a factor of 2 for the radius and a factor of 2 for the z-axis (in comparison with the SiD detector), making the total 2m in radi and 4m in length. It features large solenoid field (5T) and high-granullar tracker and calorimeters. It includes several modification to allow high-p_T measurements at FCC-hh. In particular, it has 64 layers for HCAL with 5x5 cm (RegularNgonCartesianGridXY) cell size using scintillators, and ECAL based on 2x2 cm cell size (EcalBarrelCartesianGridXY). ECAL is close to 35 X0. HCAL is 11.25 interaction length (λ), 0.176 λ/layer. The total calorimeter thickness is about 12 λ. The total size of the calorimeter is increased by a factor of 2 for the z-axis, compared to SiD.

3 Troubleshooting FCC Detector

3.1 Conversion of promc to slcio

Before new files could be generated a problem with the conversion between promc [1] and slcio [2] files had to be overcome. Incompatibilities between Pythia6 and Pythia8 prevented the generation of new simulations from the FCC geometry. Pythia6 was originally coded in FORTRAN and was depreciated. Pythia8 picked up where Pythia6 left off, coded in C++, with more versatility. Libraries for the conversions were updated and replaced which resolved this complication. This work enabled further studies using the simulations.

3.2 Inefficiencies in the SiFCC detector

The original goal was to identify where tracking inefficiencies were originating from. Tracking efficiency is defined as:

$$Efficiency = \frac{Number\ of\ Reconstructed\ Tracks}{Number\ of\ MonteCarlo\ Particles}$$

Reconstructed tracks are trajectories of particles estimated from the hits (energy deposits) that they produce on silicon tracking sensors as they pass through them.

Multiple variables were found to have effects on the efficiency of the detector, these being the energy (and p_T) of the particles tested and the pseudorapidity (η) of the trajectory. η is defined as:

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

Two areas in the detector were found to have vastly lower efficiency than the areas surrounding them. One such area corresponded to an η of $|1.5|$ (approx. 25 degrees), as seen in Figure 1. This figure was obtained using single muons of different momentum between 2-32768 GeV downloaded from the HEPSIM Repository [4] The other place of inefficiency was at pseudorapidities higher than 2, this inefficiency increased as transverse momentum (p_T) decreased. There is a notable difference in efficiency at energies lower than 128 Gev, as seen in figure 2.

Additional strategies were used to view inefficiencies in the detector. Figure 3 displays hits generated by Muons on the z axis. This was used to identify areas that Muons may be missing sensors and therefore being unrecorded. A large spike around z=0 is produced by most particles passing through the vertex tracking barrel. Ideally the image should be near symmetrical. Additionally, the number of hits around areas of 2, 3, 4, and 5 meters should be the same, the differences between them correspond to particles missing the detectors. These data analysis strategies uncovered problems in the detector that may have greatly been effecting the amount of reconstructed tracks, and in turn the efficiency. However, in order understand why these areas are deficient in counts it was needed to have a increased in-depth view of the tracker.

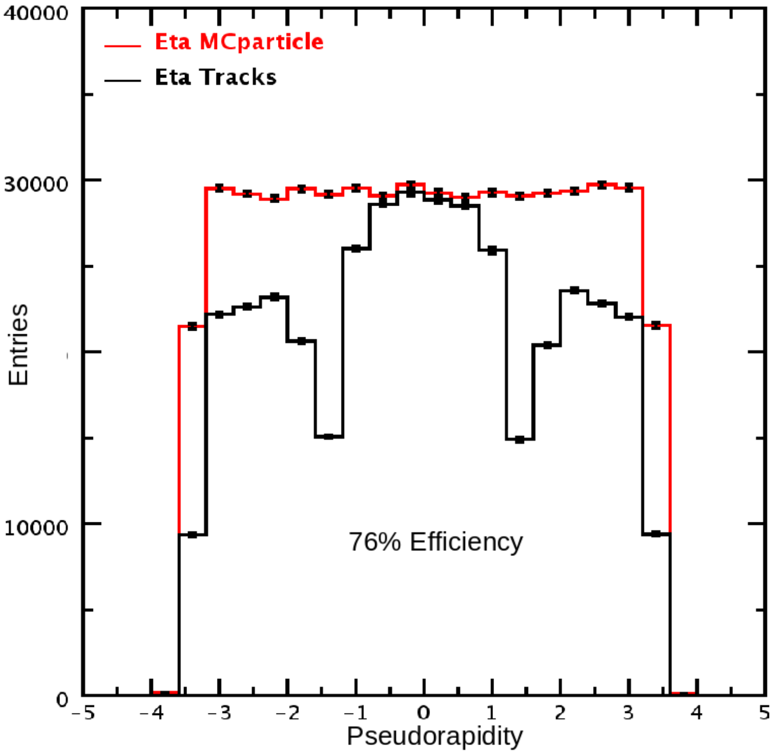

Figure 1: Histogram of **Tracks** and **MCParticles** vs Pseudorapidity

3.3 Viewing Tracker

In order to properly view issues within the detector, 3D modeling was necessary to view the structures withing the detector. Viewers were written in C++ and compiled by ROOT, giving the user the ability to view the gdml geometry files in a 3D representation, as seen in Figure 4. Outer volumes such as the ECal barrel and supports were stripped away in order to reveal the tracking barrels and tracking endcaps. This revealed the existence of gaps between modules within the detector as well as a large number of overlaps in volumes. One issue was gaps between silicon modules in the tracking barrel. Large gaps between where the tracking barrels and corresponding tracking endcaps meet perpendicularly were determined to be the cause of the large inefficiencies at an η of $|1.5|$.

4 Optimization of SiFCC-v4

As compared with SiFCC-v4 this new version, hereby referred to as SiFCC-v8 (versions preceding v8 were technical designs used for testing), has a 50% total increase in Z length of tracking. The inner vertex barrel was reverted back to to original size (in comparison with the SiD detector) as was the beampipe vacuum. The beampipe enclosure was scaled to accommodate the 3 times increase in length of the detector (compared to SiD). The inner vertex endcap modules were increased in Z by varying factors and increased in inner (and outer) radius as to not intersect the volume beampipe. Individual modules that make up the vertex endcaps were also adjusted to reduce gaps between them. The forward tracking endcap modules were scaled in inner and outer radius to decrease gaps and increase accuracy. Some forward tracking endcaps were moved closer to the vertex to increase efficiency in detecting particles of low p_T. Minimum number of hits required for track reconstruction was reduced from 7 to 6. The minimum p_T of tracks was increased from 0.2 GeV to 0.5 GeV. The outer vertex barrel's length was increased , the outer tracker was also increased to provide a good coverage in the barrel region. The multiple layers of tracking barrels were scaled to their corresponding endcap modules and then an additional 10% as to cover the gap where Tracking Barrels meet their endcaps, resulting in a total increase by a factor of 3.3. Many individual silicon modules within tracker barrels were also increased by varying amounts, in their width as well as length, per layer to decrease gaps and increase accuracy. Silicone modules also had their angular offset increased as to allow for larger plates to overlap each other without their volumes intersecting. The outer endcaps were moved away by a factor 3 and increased in radius by a factor of 1.57. Some of the outer vertex readouts were scaled accordingly in Z and radius. Spaces for wires and readouts also added for adapting the virtual detector to real world limitations. All supporting structures were scaled to fit their corresponding components. Total number of volume overlaps and extrusions were significantly decreased.

5 Results

The result of the changes made to the SiFCC detector greatly improved tracking geometry. The new geometry can be seen in figure 5. The SiFCC-v8 detector now has an average efficiency of 90% for energies between 2 and 16384 Gev. This average efficiency is around 95% for energies above 128 Gev. Efficiency has been greatly increased in forward regions at high pseudorapidity, as seen in figure 6. Efficiency at high pseudorapidities and low p_T has been greatly improved due to bringing inner vertex endcaps closer to vertex of the beampipe vacuum. Average efficiency of every energy level was significantly increased, as seen in Figure 7. With the intentional overscale of the outer tracking barrels, increased coverage of $|1.5|$ η has been attained, this greatly increased efficiency in this area. A small but marginal increase in Fake Track rates of 0.2% fake tracks per reconstructed track. This increase in fake rates could be contributed to low p_T particles spiraling inside the tracker. RMS resolutions are similar to previous detector. The support structure was scaled and moved to the corresponding active modules. The geometry was additionally adapted for wires and readouts. These increases in efficiency move the detector closer to real world applications in the coming new high energy colliders. This may lead to new discoveries in the field of high energy physics. The new tracking geometry was included in the official SiFCC-v7 detector description. A large number of fully reconstructed events is available from the HEPSIM [4] repository (with reconstructed tag rfull008). These events are available for public download and future studies.

References

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[2] Gaede, F. (2016, February 19). LCIO - Users manual v02-07. Retrieved August 01, 2016, from http://lcio.desy.de/v02-07/doc/manual_html/manual.html

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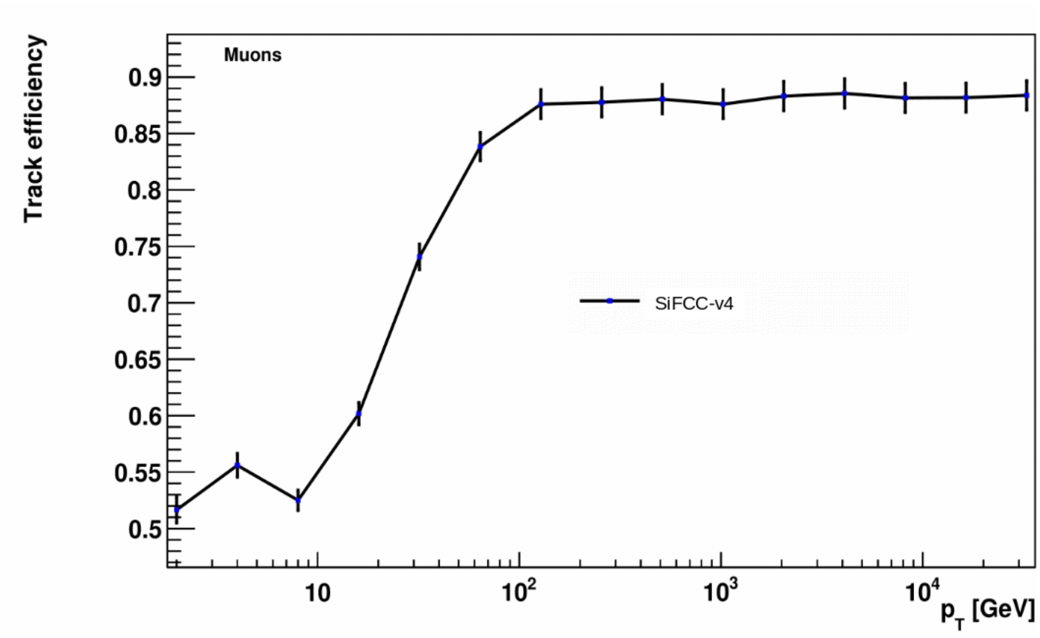

Figure 2: Histogram of Efficiency vs Transverse Momentum

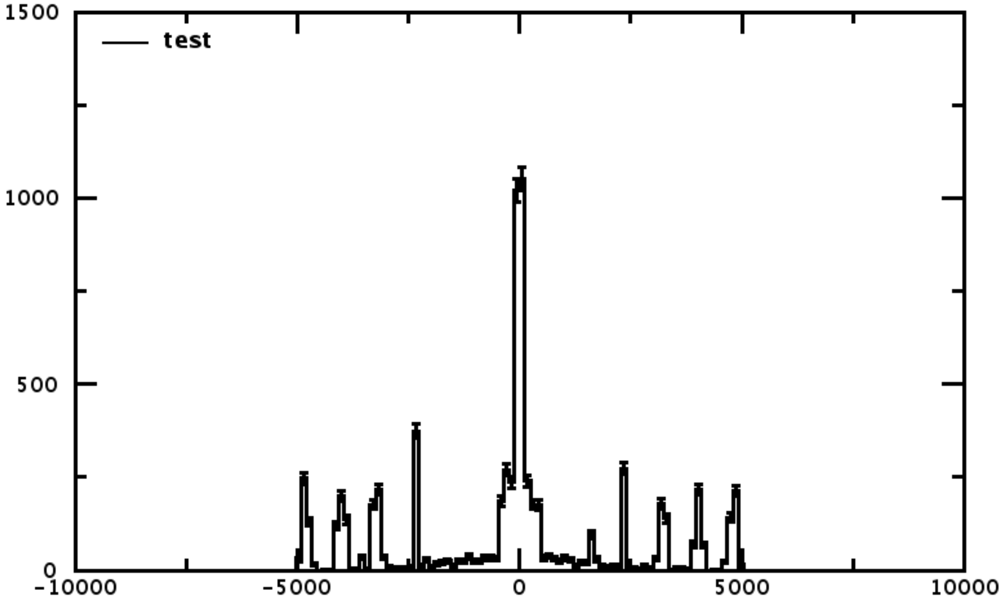

Figure 3: Histogram hits as a function of Z position (mm). Where Z is axis parallel to beampipe

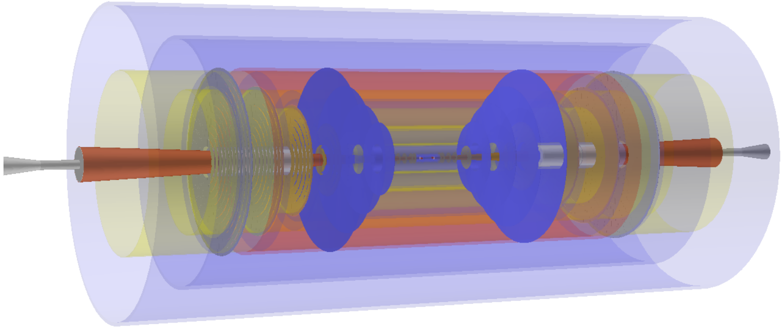

Figure 4: 2D Representation of 3D model of SiFCC-v4

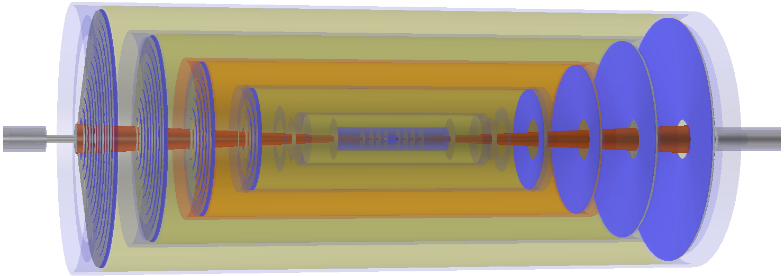

Figure 5: 2D Representation of 3D model of SiFCC-v8

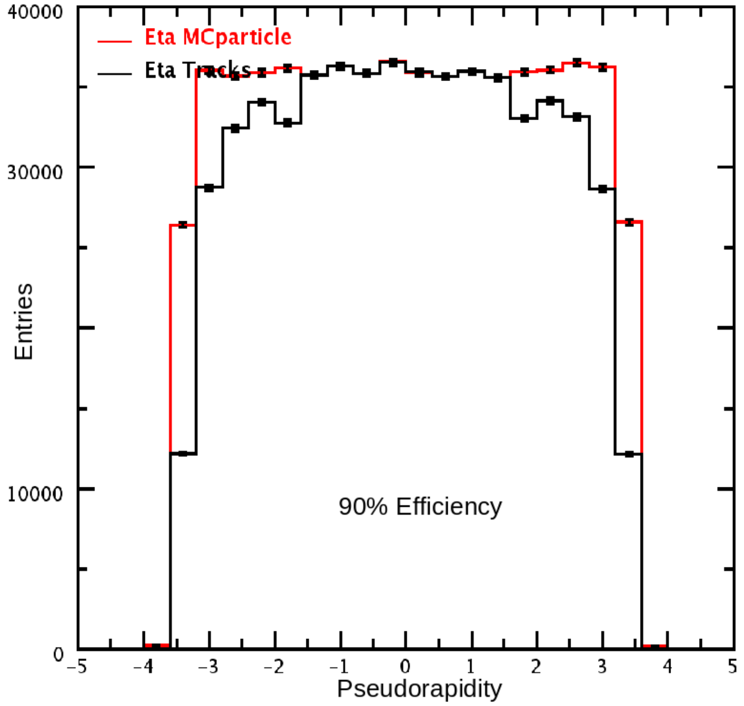

Figure 6: Efficiency of SiFCC-v8

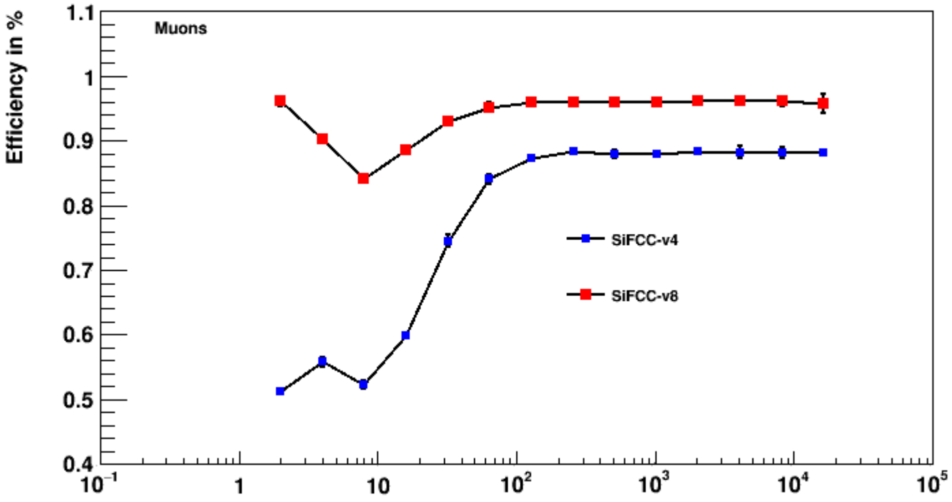

Figure 7: Efficiency of SiFCC-v4 vs SiFCC-v8 in terms of p_T (GeV)