*Pattern Recognition and
Tracker Resolutions for the
GEM Central Tracker at
Luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$*

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PATTERN RECOGNITION AND TRACKER RESOLUTIONS FOR THE GEM CENTRAL TRACKER AT LUMINOSITY OF $10^{34} \text{ cm}^{-2}\text{s}^{-1}$

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ABSTRACT

A GEANT based pattern recognition algorithm has been used to study the track finding capabilities of the GEM central tracker at high luminosity ($10^{34} \text{ cm}^{-2}\text{s}^{-1}$). The efficiency for finding tracks has been studied as a function of the number of silicon layers present in the tracker, as a function of the resolution of the pad chambers, as a function of the efficiency of the pad chambers, and as a function of η and p_T for each of the above studies. The number of "fake" tracks that are found with the pattern recognition has also been calculated for each pattern recognition study.

1. INTRODUCTION

A pattern recognition algorithm, which has been described previously [1], has been used to study the track finding capabilities of the GEM central tracker in a high luminosity environment ($10^{34} \text{ cm}^{-2}\text{s}^{-1}$). At a luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$, the inner silicon layers in the GEM central tracker are expected to have a lifetime of approximately one year. Because the lifetime is expected to be relatively short, we expect to have to rely either entirely on the pad chambers to do tracking, or on the pad chambers and only one or two outer silicon superlayers, rather than having the entire GEM tracker available for track finding. Therefore, in our studies of the track finding capabilities of the tracker at high luminosity, we have calculated the efficiencies for finding tracks using a tracker that contains only pad chambers, a tracker that contains pad chambers and one outer silicon superlayer, and a tracker that contains pad chambers and two outer silicon superlayers. For each tracker configuration we have also calculated the momentum, impact parameter, and z resolutions as a function of η and p_{tot} .

We have also looked at the track finding efficiency as a function of the resolution of the pad chambers and as a function of the efficiency of the pad chambers. These studies were done to try to understand how the tracker would perform if the pad chambers did not perform as well as expected.

2. SIMULATION CODE AND RESULTS

2.1. Central Tracker Geometry

The GEM tracker consists of an inner tracker made of silicon wafers and an outer tracker made of interpolating pad chambers (IPCs). There are two regions of both silicon and IPCs: central regions where the detectors are arranged in cylinders that are concentric to the beam axis, and forward regions where the detectors are arranged in disks that are perpendicular to the beam axis. In the full central tracker (which will all be operational at $10^{33} \text{ cm}^{-2}\text{s}^{-1}$) the central silicon region contains six layers of stereo pairs of silicon extending $\pm 18 \text{ cm}$ in z and four layers of IPC stereo pairs which extend to $\pm 100 \text{ cm}$ in z . The silicon barrel layers are located at radii of 10, 12, 15, 17, 20, and 22 cm. The pad layers are located at radii of approximately 45, 57, 65 and 78 cm. Each stereo pair in both the silicon and the pad regions will produce one three-dimensional coordinate for the pattern recognition. The forward silicon disks cover $z = \pm 20 \text{ cm}$ to $z = \pm 87 \text{ cm}$ and the forward IPC disks cover $z = \pm 113 \text{ cm}$ to $z = \pm 168 \text{ cm}$. The forward silicon disks extend

Figure 1. The layout of the full GEM central tracker as produced by GEANT, showing both the silicon portion as well as the IPC portion. The geometry for high luminosity studies had forward disks that began at a radius of 16 cm rather than 10 cm and contained fewer silicon barrel superlayers.

from 10 cm to 26 cm radially except for the most forward disks which extend from 10 cm to 24 cm. The forward pad chambers extend from approximately 20 cm to 79 cm radially. A picture of the full GEM tracker geometry that is in the GEANT code can be seen in Figure 1.

For our pattern recognition studies at $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ luminosity we assumed that the forward silicon disks would lose the inner 6 cm because of radiation damage, leaving 14 disks with inner radii of 16 cm rather than 10 cm. The barrel region was assumed to have the same geometry at high luminosity as it does at low luminosity, with the inner one, two, or all three silicon superlayers removed for the different studies. The pad geometry remained the same for all studies. A picture of the tracker, with the truncated forward silicon disks that were used in the studies, is shown in Figure 2.

Figure 2. The layout of the GEM central tracker with the forward silicon disks truncated, as was used for the high luminosity studies.

2.2. Tracker Resolutions

The momentum, impact parameter, and z resolutions of the tracker in the three possible high-luminosity configurations have been calculated. Figure 3 shows the momentum resolution vs. momentum for the full tracker, the tracker with two silicon superlayers, the tracker with one silicon superlayer, and the tracker with just pad chambers. Figure 4 shows the momentum resolution vs. η for the same configurations. The impact parameter vs. p_{tot} is shown in Figure 5

and the impact parameter vs. η is shown in Figure 6. Figures 7 and 8 show the z resolution vs. p_{tot} and η . The momentum and impact parameter resolutions improve significantly with the addition of just one inner silicon superlayer because the silicon layer significantly increases the radial length of the measurement points and because the silicon adds a coordinate point in the r/ϕ

Figure 3. The momentum resolution of the tracker versus momentum (at $\eta = 0$) for four tracker configurations: just pads, pads plus the outermost silicon superlayer, pads plus the two outermost silicon layers, and the full tracker which has pads plus three silicon superlayers.

Figure 4. The momentum resolution of the tracker versus eta (at $p = 125$ GeV/c) for four tracker configurations: just pads, pads plus the outermost silicon superlayer, pads plus the two outermost silicon layers, and the full tracker which has pads plus three silicon superlayers.

plane that has a resolution that is approximately three times better than the pad coordinate resolutions. The z vertex resolution does not improve as dramatically with the addition of silicon superlayers because the z resolution of the silicon coordinate is slightly poorer than the pad chamber coordinate resolution.

Figure 5. The impact parameter resolution of the tracker versus momentum (at $\eta = 0$) for four tracker configurations: just pads, pads plus the outermost silicon superlayer, pads plus the two outermost silicon layers, and the full tracker which has pads plus three silicon superlayers.

Figure 6. The impact parameter resolution of the tracker versus η (at $p = 125$ GeV/c) for four tracker configurations: just pads, pads plus the outermost silicon superlayer, pads plus the two outermost silicon layers, and the full tracker which has pads plus three silicon superlayers.

Figure 7. The z resolution of the tracker versus momentum (at $\eta = 0$) for four tracker configurations: just pads, pads plus the outermost silicon superlayer, pads plus the two outermost silicon layers, and the full tracker which has pads plus three silicon superlayers.

Figure 8. The z resolution of the tracker versus eta (at $p = 125$ GeV/c) for four tracker configurations: just pads, pads plus the outermost silicon superlayer, pads plus the two outermost silicon layers, and the full tracker which has pads plus three silicon superlayers.

2.3. Geometric Efficiency

The track finding efficiency for the tracker is ultimately limited by the geometric coverage of the tracker. The full GEM tracker was designed with the goal of having six or more silicon

layers hit by stiff tracks over the entire eta coverage of the tracker, and four or more pad layers hit. The silicon portion of the tracker comes very close to meeting this goal, as can be seen in Figure 9 where the number of silicon layers hit by high momentum muons is shown vs. eta. Smearing of the vertex was included in the event generation. It was more difficult to meet the goal of having four or more pad layers hit over the entire eta range because it is necessary to leave a fairly large gap (0.8 cm) between the ends of the barrel pad chambers and the first forward pad chamber to allow for routing of the cabling, etc. out of the tracker. Because of this, and the limited radial extent of the forward chambers, there is a poorer hit coverage at $\eta = (1.0, 1.4)$, as can be seen in Figure 10. Even so, there are four or more pad layers hit by stiff tracks 89% of the time in the eta interval $= (-2.4, 2.4)$ and three or more pad layers hit 99% of the time. Three layers are still adequate for pattern recognition (as will be shown), so the area between the barrel and forward regions can still be used to find tracks even at the highest luminosities where the silicon may not be available for track finding.

The number of detector layers hit vs. eta is shown in Figure 11 for the three possible high luminosity configurations of the tracker: just pads, pads plus outer silicon superlayer, and pads plus the two outer silicon superlayers. Notice that the forward silicon disks do not give an even coverage of hits when the wafers are truncated, so the forward region produces fewer hits than the barrel region in the last configuration where two barrel silicon superlayers are present. In the second configuration, the coverage is more flat, but there is still a hit deficit at $\eta > 2$ and around $\eta = 1.25$.

Figure 9. The number of silicon layers hit vs. eta for stiff tracks for the full GEM tracker. The vertex positions were produced with a Gaussian distribution, with $\sigma = 5$ cm in z and $\sigma = 5$ μ m in x and y .

Figure 10. The number of pad layers hit vs. eta for stiff tracks. The vertex positions were produced with a Gaussian distribution, with $\sigma = 5$ cm in z and $\sigma = 5$ μ m in x and y .

Figure 11. The total number of detector layers hit by stiff tracks passing through the tracker for three tracker configurations: just pads, pads plus the outermost silicon superlayer, and pads plus the two outermost silicon superlayers.

2.4. Coordinate Reconstruction

Three dimensional coordinates are formed in the tracker by finding the intersections of strips or pads that are hit on one layer in a stereo pair with strips or pads that are hit on the adjacent

stereo layer. This means that up to six coordinates are available from the silicon portion of the tracker in the barrel region, and up to four coordinates are available for pattern recognition from the pad portion of the tracker in the barrel region. Approximately the same number of coordinates is available in the forward regions.

Figure 12. The phi and z resolutions of the barrel silicon wafer stereo pairs that are produced by the digitization in GEANT.

Figure 13. The phi and r resolutions of the forward silicon wafer stereo pairs that are produced by the digitization in GEANT.

In the silicon portion of the tracker, the measured position in a given wafer is determined by finding the centroid of all strips that are above threshold. The stereo pairs are then combined to form the three-dimensional coordinates. The resolutions that result from this digitization are shown in Figures 12 and 13. The phi and z resolutions for the barrel portion of the tracker are shown with Gaussian fits in Figure 12 and the phi and r resolutions for the forward portion are shown in Figure 13 also with Gaussian fits.

In the pad chambers, it is necessary to iterate the calculation of the three-dimensional coordinate after pattern recognition has been formed to get the expected resolutions. This must be done because the large smearing of the vertex in the z direction (Gaussian distribution with $\sigma = 5$ cm) combined with the large spacing between stereo pairs of 0.8 cm introduces a relatively large error in the z position of the track at the pad chambers. To form a coordinate initially, we assume that the track originated from (0,0,0) and find the intersection of this track with the two hits in the

Figure 14. The output resolution of the barrel pad chambers, in ϕ and z , before pattern recognition is performed.

Figure 15. The output resolution of the barrel pad chambers, in phi and z, after pattern recognition has been performed, and the calculated z vertex position has been used to find the intersection of pad hits.

Figure 16. The output resolution, in phi and r, of the forward pad chambers before pattern recognition has been performed.

stereo pairs. This produces a coordinate resolution of 56 μm per stereo pair in phi in the barrel region and 1 mm in z (see Figure 14). After tracks have been found with the pattern recognition algorithm, the z vertex position that is determined by the pattern recognition is used to recalculate the coordinates. The resolution that is produced by this second coordinate calculation is 43 μm in phi and 1 mm in z (see Figure 15). In the forward region, the chambers are at a large enough z value that the smearing of the vertex does not significantly affect the resolutions. This can be seen in Figure 16 where the resolution in phi and r is shown before pattern recognition is performed.

The efficiency for forming coordinates in the entire eta region of the IPC portion of the tracker is shown in Figure 17. The efficiency is not 100% because the efficiency that is plotted includes the dead regions which are present at the edges of all of the pad chambers. The dead area,

Figure 17. The efficiency for forming coordinates in both the barrel and forward regions of the IPC chambers. The solid line shows the efficiency for tracks passing through the barrel portion of the tracker, and the dashed line shows the efficiency for tracks passing through the forward portion of the tracker. Most of the inefficiency comes from dead areas in the pad chambers.

Figure 18. The true and ghost coordinates that are formed vs. eta from the hits in the barrel and forward silicon detectors for Higgs events with minimum bias background at luminosity = $10^{34}\text{cm}^{-2}\text{s}^{-1}$. The upper dashed line on the left shows the number of true coordinates formed in the barrel portion of the tracker, the upper solid line on the right shows the true coordinates formed in the forward portion of the tracker, and the lower two dashed curves show the number of fake coordinates formed in the barrel and forward portions of the tracker.

Figure 19. The true and ghost coordinates that are formed vs. eta from the hits in the pad chambers for Higgs events with minimum bias background at luminosity = $10^{34} \text{cm}^{-2} \text{s}^{-1}$.

which is a 5 mm strip that surrounds each chamber, accounts for approximately 6% of the inefficiency in the barrel region, and approximately 14% in the forward region. These percentages agree with the integrated efficiencies of the plots shown, which indicates that we are not losing coordinates to the coordinate formation algorithm.

Every combination of hits in a stereo pair of detectors that can combine to form a coordinate must be assumed to be a valid coordinate until pattern recognition is done. Because of this, there are "true" coordinates as well as "ghost" coordinates that must be sent to the pattern recognition

algorithm, where ghost coordinates are coordinates that are formed from two hits that come from two separate tracks. At high luminosity, the number of "ghost" coordinates that are formed and sent to the pattern recognition can be large. The number of ghost coordinates and the number of true coordinates that are formed in the silicon are shown in Figure 18 versus η for a Higgs event with minimum bias background at $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ luminosity. Figure 19 shows the number of true and ghost coordinates that are formed in the pads vs. η in a Higgs event with minimum bias background for $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ luminosity. All of the ghost coordinates as well as the true coordinates are used in the pattern recognition algorithm to find tracks.

2.5. Track Finding Efficiencies

The track finding efficiencies and fake track production have been studied using the above geometries and coordinate reconstructions. The efficiency for finding tracks will be presented for the three separate tracker configurations discussed above, along with the number of fake tracks produced and the variation of the efficiencies with the k_{pca} cut.

2.5.1. Tracker Configuration I: Just Pads

The fraction of stiff tracks (with vertex smearing) that pass through three or more pad layers and four or more pad layers is shown in Figure 20 versus η . Note that virtually all tracks pass through at least three pad superlayers, but there are a significant number of tracks in the η region of (1.0,1.4) that do not pass through four pad superlayers. Because of this, we have defined the number of coordinates needed to form a track with the pattern algorithm to be only three in the tracker configuration where there are no silicon superlayers present. The number of fake tracks that are produced when only three coordinates are required for a track is still reasonably low in this configuration (as will be shown), so the requirement of needing only three coordinates to form a track does not cause the pattern recognition algorithm to find an overwhelmingly large number of fake tracks. We have also looked at the track finding efficiency when we require four or more coordinates to be found, but the efficiency drops significantly in the central η region, as expected.

The initial studies of the pattern recognition algorithm for Higgs events with minimum bias background at luminosity = $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ used p_{T} cutoff values of 300 MeV/c for all vectors formed between pad layers. This can be compared to a p_{T} cutoff value of 30 MeV/c which was used for studies at luminosity = $10^{33} \text{ cm}^{-2}\text{s}^{-1}$ to obtain a track finding efficiency of 97% or better over the entire η range of the detector and for particles of momentum all the way down to a few

Figure 20. The fraction of tracks that pass through three or more (solid curve) and four or more (dashed curve) pad superlayers vs. eta, when high momentum tracks are run through the tracker, with vertex smearing included.

GeV/c. The larger p_T cutoff value for the 10^{34} studies was used to keep the CPU time needed for reconstructing all of the tracks in a full event reasonable, and to keep the number of fake tracks produced relatively small. The larger p_T cutoff may decrease the efficiency for finding low momentum tracks, but we did not find the efficiency above 5 GeV/c to be affected when the p_T cut was changed from 300 to 30 MeV/c. However, because the low momentum tracks curve more and cross more tracks, the track finding efficiency is poorer for low momentum tracks than for high

momentum tracks, especially at high luminosity. Because the efficiency decreases with decreasing momentum, the overall efficiency for finding tracks in the forward region is lower than in the barrel region, because the average p_T of tracks in the forward region is lower than in the barrel region. The pattern recognition may also be adversely affected by the increased occupancy. The dependence of the efficiency on η and p_T can be seen in Figure 21 where the efficiency for finding all tracks above 5 GeV/c is shown vs. η (the upper curve shows the efficiency when three or more coordinates are required for a track to be found, and the lower curve shows the efficiency when four or more coordinates are required), and in Figure 22 where the efficiency is shown vs. the p_T of the particle. The efficiency for finding the Higgs leptons is higher than the efficiency for finding all tracks above 5 GeV/c, because the average momentum is higher. Figure 23 shows the efficiency for finding the muons that come from the Higgs decay, and Figure 24 shows the efficiency for finding the Higgs electrons, and this efficiency has been calculated using the requirement of three or more and four or more coordinates needed to form a track. The overall track finding efficiency for the Higgs leptons is approximately 95% when the pattern recognition requires three or more coordinates to form a track.

Figure 21. The efficiency for finding all tracks above 5 GeV/c in a Higgs event with minimum bias background at luminosity = $10^{34} \text{cm}^{-2} \text{s}^{-1}$, versus eta. The solid curve is the fraction of tracks found if three or more coordinates are required to form a track, and the dashed curve shows the efficiency if four or more coordinates are required to form a track. The p_T cutoff value used for the pattern recognition algorithm was 300 MeV/c and the tracker was comprised of just IPC detectors.

Figure 22. The efficiency for finding all tracks in a Higgs event with minimum bias background at luminosity = $10^{34}\text{cm}^{-2}\text{s}^{-1}$, versus the p_T of the particle. The p_T cutoff value used for the pattern recognition algorithm was 300 MeV/c and the tracker was comprised of just IPC detectors.

Figure 23. The efficiency for finding the muons from Higgs decay in a Higgs event with minimum bias background at luminosity = $10^{34} \text{cm}^{-2} \text{s}^{-1}$, versus eta. The tracker was comprised of only pads, and the number of coordinates required to form a track was three (solid curve) or four (dashed curve). The p_T cutoff value used for the pattern recognition algorithm was 300 MeV/c.

Figure 24. The efficiency for finding the electrons from Higgs decay in a Higgs event with minimum bias background at luminosity $= 10^{34} \text{cm}^{-2} \text{s}^{-1}$, versus eta. The tracker was comprised of only pads, and the number of coordinates required to form a track was three (solid curve) or four (dashed curve). The p_T cutoff value used for the pattern recognition algorithm was 300 MeV/c.

For the studies that required only three coordinates to form a track, fake tracks were defined to be any track which was formed that did not have all three coordinates produced by the same track. For the studies that required four coordinates to form a track, fake tracks were defined to be any track that had fewer than three coordinates formed from a single track. Figures 25 and

26 show the number of true tracks, with the number of fake tracks that are found with the pattern recognition algorithm that requires three or more coordinates to form a track. Figure 25 shows all

Figure 25. The number of true (solid curve) and fake (dashed curve) tracks produced by the pattern recognition algorithm versus eta with momentum ≥ 5 GeV/c when the number of coordinates required for forming a track is three. The tracker was comprised of only pad chambers, and the p_T cutoff used in the pattern recognition algorithm was 300 MeV/c.

Figure 26. The number of true (solid curve) and fake (dashed curve) tracks produced by the pattern recognition algorithm versus p_T when the number of coordinates required for forming a track is three. The tracker was comprised of only pad chambers, and the p_T cutoff used in the pattern recognition algorithm was 300 MeV/c.

of the tracks that are formed with a momentum greater than or equal to 5 GeV/c versus eta, and Figure 26 shows all tracks that are formed vs. the p_T of the particle. For the tracks above 5 GeV/c, 24 fake tracks were found, and 1378 true tracks were found, which gives a fake track rate of 1.7%, or 0.12 tracks per crossing. Out of all tracks that were found with the pattern recognition algorithm, 191 fake tracks were produced and 62088 true tracks were found, which gives an

overall fake track rate of 0.3%, or 0.96 per crossing. There were no fake tracks produced in 200 events when the pattern recognition algorithm required at least four coordinates for a track. (Note: all tracks that were found that produced a calculated momentum of below 0.1 GeV/c were discarded since we were only interested in tracks above approximately 1 GeV/c.)

2.5.2. *Tracker Configuration II: Pads Plus One Outer Silicon Superlayer*

The efficiency for finding tracks when the tracker configuration included one outer silicon superlayer was calculated separately for pattern recognition which required three, four, or five coordinates for a track to be formed. The efficiencies for each of these criteria are shown in Figure 27 where the fraction of tracks above 5 GeV/c that are found with three, four, or five or more coordinates is shown vs. η . The same efficiencies vs. p_T are shown in Figure 28. Figures 29 and 30 show the efficiencies for finding the Higgs muons and electrons, versus η , when the pattern recognition required four or more and five or more coordinates to form a track. The integrated efficiency is approximately 97% for $\eta = (-2.5, 2.5)$ when the pattern recognition requirement is four or more coordinates to form a track.

The number of fake tracks that are produced in this configuration when three or more and four or more coordinates are required to form a track are shown in Figure 31 where the true and fake coordinates are shown vs. η and p_T . When only three or more coordinates are required to form a track, 69 fake tracks are formed above 5 GeV/c and 1534 true tracks are formed, giving a fake track rate of 4.5% above 5 GeV/c, or 0.35 tracks per crossing. The total number of fake tracks formed is 2605 and the total number of true tracks formed is 82985, giving an overall fake track rate of 3.1% or 13 fake tracks per crossing. If four or more coordinates are required to form a track, the fake track rate drops to 0.14% or 0.01 tracks per crossing above 5 GeV/c, and an overall fake track rate of 0.17%, or 0.53 tracks per crossing.

Figure 27. The efficiency for forming tracks with momentum ≥ 5 GeV/c vs. η when the pattern recognition algorithm required 3 (solid curve), 4 (dashed curve), or 5 (dotted curve) coordinates to form a track. The tracker was comprised of pad chambers and one outer silicon superlayer.

Figure 28. The efficiency for forming tracks vs. p_T when the pattern recognition algorithm required 3 (solid curve), 4 (dashed curve), or 5 (dotted curve) coordinates to form a track. The tracker was comprised of pad chambers and one outer silicon superlayer.

Figure 29. The efficiency for finding the Higgs muons vs. eta when the pattern recognition algorithm required four or more (solid curve) and five or more (dashed curve) coordinates to form a track. The tracker consisted of pad chambers plus one outer silicon superlayer.

Figure 30. The efficiency for finding the Higgs electrons vs. eta when the pattern recognition algorithm required four or more (solid curve) and five or more (dashed curve) coordinates to form a track. The tracker consisted of pad chambers plus one outer silicon superlayer.

Figure 31. The number of true (solid curves) and fake (dashed curves) tracks that are formed vs. eta and vs. momentum, when three or more coordinates are required to form a track and when four or more coordinates are required. The plots of tracks found vs. eta only include tracks with $p_T \geq 5$ GeV/c. The tracker was comprised of pad chambers and the outermost silicon superlayer, and the p_T cutoff was 300 MeV.

2.6. Pattern Recognition for Different Pad Chamber Resolutions

The track finding efficiency that has been presented for the different tracker configurations has been for a tracker which has a pad chamber coordinate resolution of approximately $55\text{ }\mu\text{m}$ per layer ($50\text{ }\mu\text{m}$ intrinsic resolution plus $25\text{ }\mu\text{m}$ alignment resolution), or about $40\text{ }\mu\text{m}$ per superlayer. The track finding efficiency was calculated separately for a tracker comprised of pad chambers which had coordinate resolutions of approximately $80\text{ }\mu\text{m}$ per layer ($75\text{ }\mu\text{m}$ intrinsic resolution plus $25\text{ }\mu\text{m}$ alignment resolution) and for a tracker with resolutions of approximately $103\text{ }\mu\text{m}$ per layer ($100\text{ }\mu\text{m}$ intrinsic resolution plus $25\text{ }\mu\text{m}$ alignment resolution). The track finding efficiencies that were calculated for a tracker which was comprised of only pads, and had these degraded resolutions is shown in Figure 32 where the efficiency for finding all tracks above $5\text{ GeV}/c$ is shown vs. η for a Higgs event with minimum bias background at luminosity $= 10^{34}\text{ cm}^{-2}\text{s}^{-1}$. The two curves in each plot show the efficiencies for finding tracks when the pattern recognition required three or more coordinates and four or more coordinates to form a track. As can be seen, the overall efficiency is somewhat degraded from the efficiency that was calculated when the resolution of the pad chambers was $55\text{ }\mu\text{m}$ per layer (see Figure 21). The fake track rate is also higher for the trackers that have poorer resolutions. Figures 33 and 34 show the true and fake tracks that are produced by the pattern recognition algorithm when three or more coordinates are required to form a track. Figure 33 shows the number of tracks found above $5\text{ GeV}/c$ vs. η and Figure 34 shows the total number of tracks found vs. momentum. When the resolution was $80\text{ }\mu\text{m}$ per layer, the fake track rate was 3.3% for tracks above $5\text{ GeV}/c$ that required only three or more coordinates to be formed, and 6.4% when the resolution was $103\text{ }\mu\text{m}$. However, when the number of coordinates required to form a track was four or more, there were no fake tracks that were produced in 150 Higgs events (with minimum bias background) when the resolution was $80\text{ }\mu\text{m}$, and there was only one fake track formed when the resolution was $100\text{ }\mu\text{m}$. (Note: all tracks that were formed with a calculated momentum of less than $0.1\text{ GeV}/c$ were discarded since we were only interested in tracks above approximately $1\text{ GeV}/c$).

Figure 32. The efficiency for finding tracks above 5 GeV/c in a tracker that is comprised of only pad chambers, when the resolution of the pad chambers is 75 μm and 100 μm . The two curves on each plot show the efficiency for finding tracks when the pattern recognition requires three or more coordinates (solid curves) to form a track and when the pattern recognition requires four or more coordinates (dashed curves) to form a track.

Figure 33. The number of true (solid curves) and fake (dashed curves) tracks that are found vs. eta, above 5 GeV/c, with the pattern recognition algorithm when the tracker is comprised of only pads and the resolution of the pad chambers is 75 μm and 100 μm . The pattern recognition for these plots required only three or more coordinates to form a track.

Figure 34. The number of true (solid curves) and fake (dashed curves) tracks that are found vs. momentum with the pattern recognition algorithm when the tracker is comprised of only pads and the resolution of the pad chambers is 75 μm and 100 μm . The pattern recognition for these plots required only three or more coordinates to form a track.

Figure 35. The efficiency for finding all tracks above 5 GeV/c in a Higgs event with minimum bias background at luminosity = $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ and the hit forming efficiency was set to 0.98. The efficiency is shown for pattern recognition which required three (solid curve) and four (dashed curve) coordinates to form a track, and the tracker consisted of just pad chambers.

Figure 36. The efficiency for finding all tracks above 5 GeV/c in a Higgs event with minimum bias background at luminosity = $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ and the hit forming efficiency was set to 0.98. The efficiency is shown for pattern recognition which required three (solid curve), four (dashed curve) and five (dotted curve) coordinates to form a track, and the tracker consisted of pad chambers plus one outer silicon superlayer.

2.7. Pattern Recognition for Different Chamber Efficiencies

The pattern recognition efficiency for the tracker was calculated with an overall efficiency for forming hits in the pad layers of 98%. That is, 2% of all hits in each of the eight pad layers were thrown out, to simulate an overall inefficiency that would account for threshold cuts, bad electronics, etc. The resulting efficiency for finding tracks in the tracker which is comprised of just pad chambers is shown in Figure 35. Figure 35 shows the efficiency for finding all tracks above 5 GeV/c in a Higgs event with minimum bias background for luminosity = $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ when three or more coordinates are required to form a track and when four or more coordinates are required to form a track. The track finding efficiency across the entire eta range of the detector is less than the track finding efficiency that was calculated for a hit efficiency of 100% (see Figure 21).

When an outer superlayer of silicon was added to the tracker configuration, the track finding efficiency improved, as expected. The efficiency for finding all tracks in this configuration above 5 GeV/c vs. eta when three, four or five or more coordinates were required to form a track is shown in Figure 36.

3. CONCLUSION

The central tracker that is comprised of just IPCs is capable of finding the majority of tracks in a Higgs event (95% of the Higgs leptons) with minimum bias background for luminosity = $10^{34} \text{ cm}^{-2}\text{s}^{-1}$. Not only are the majority of tracks found, but the fake track rate produced by the pattern recognition algorithm is 0.3% when three or more coordinates are required to form a track, and no fake tracks were produced in 200 events when the pattern recognition algorithm required four or more coordinates to form a track. There is, however a deficit in the number of tracks that are found around $\eta = 1.0$ which is caused by a gap in pad detector coverage between the barrel portion of the pad chambers and the forward portions. When an inner silicon superlayer is added to the tracker, this reduced efficiency is essentially removed because of the better coverage of the silicon detectors, and the overall increased number of detector hits available for the pattern recognition. The track parameter resolutions are also greatly improved because adding an inner silicon superlayer causes the inner radius to decrease from approximately 45 cm to approximately 21 cm, and the overall radial extent of the measurement points for a given track increases by a factor of approximately 1.7 (from 33 cm in extent to 57 cm). The efficiency for finding tracks was also studied as a function of the pad detector resolutions and as a function of the overall efficiency of the pad chambers. The pad chamber resolution was degraded from 50 to 75 and 100 microns (per pad chamber). The overall track finding efficiency dropped slightly and the fake track rate increased slightly with increased resolution, but the efficiency still remained high, and the fake track rate increased to a maximum of 6.4% if only three coordinates were required to form a track,

but was essentially still zero if four coordinates were required to form a track. When the overall pad chamber efficiency was reduced to 98%, the track finding efficiency when the tracker was comprised of only pad chambers was reduced by several percent, but the overall efficiency when the tracker was comprised of pad chambers plus one outer silicon layer remained more or less intact.

References

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