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Jet Substructure Variables with the SiFCC Detector at 100 TeV

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Future experiments beyond the LHC era will measure high-momentum bosons (W, Z, H) and top quarks with strongly collimated decay products that form hadronic jets. This paper describes the studies of the performance of jet substructure variables using the Geant4 simulation of a detector designed for high energy pp collisions at a 100 TeV collider. The two-prong jets from $Z' \to WW$ and three-prong jets from $Z' \to t\bar{t}$ are compared with the background from light quark jets, assuming Z' masses in the range 5 – 40 TeV. Our results indicate that the performance of jet-substructure reconstruction improves with reducing transverse cell sizes of a hadronic calorimeter from $\Delta\eta \times \Delta\phi = 0.087 \times 0.087$ to 0.022×0.022 in most cases.

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Future high-energy experiments, such as FCC-hh and SppC, will measure high-momentum bosons (W, Z, H) and top quarks with strongly collimated decay products that form hadronic jets. This leads to many challenges for detector technologies. In particular, reconstruction of jet substructure variables for boosted jets with transverse momentum above 10 TeV requires appropriate cell sizes of hadronic calorimeters (HCALs). In order to estimate transverse segmentation of HCALs for very boosted objects at future experiments, we used a FCC-like detector geometry, a software based on Geant4 simulation and Monte Carlo event samples as described in [1].

In this study we simulated the Z' bosons with the mass of 5, 10, 20, and 40 TeV. These particles are forced to decay to two light-flavor jets ($q\bar{q}$) as background and WW or $t\bar{t}$ as signal, where $W(\rightarrow q\bar{q})$ and $t(\rightarrow W^+ b \rightarrow q\bar{q}b)$ decay hadronically. Using different configurations of HCAL geometry, we draw the receiver operating characteristic (ROC) curves to quantify the detector performance and find out the cell size that can give the best separation power to distinguish signal from background for different jet substructures.

We used several jet substructure variables, including jet soft-drop mass [2], N-subjettiness [3] and energy correlation function [4] in this study. The variables considered are τ_{21} and C_2^1 for the $Z' \rightarrow WW$ signal and τ_{32} for the $Z' \rightarrow t\bar{t}$ signal. Figure 1 shows the ROC curves for τ_{21} [3] using three HCAL cell sizes for jets with $P_T \sim 10$ TeV. For the τ_{21} and C_2^1 variables, the $\Delta\eta \times \Delta\phi = 0.022 \times 0.022$ (or 5×5 cm^2) geometry gives optimal performance, while for the jet soft-drop mass variable, the $\Delta\eta \times \Delta\phi = 0.0043 \times 0.0043$ (or 1×1 cm^2) geometry gives optimal performance (followed by 5×5 cm^2). The results for the τ_{32} variable are inconclusive.

In conclusion, the performance of a HCAL with 5×5 cm^2 cells is, in most cases, better than for $\Delta\eta \times \Delta\phi = 0.087 \times 0.087$ (or 20×20 cm^2) cells. Therefore, this study confirms the baseline SiFCC detector geometry [1] that uses 5×5 cm^2 HCAL cells.

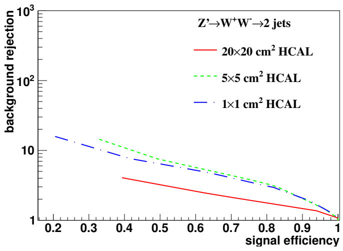

Figure 1: ROC curves for the τ_{21} substructure variable [3] for the decay $Z' \rightarrow WW$ with a Z' mass of 20 TeV. The calculations were performed for a HCAL with different transverse segmentations.

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