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Detectors for Superboosted τ-leptons at Future Circular Colliders

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We study the detector performance of τ-lepton identification variables at very high energy proton colliders. We study hadronically-decaying τ-leptons with transverse momentum in the TeV range. Calorimeters are benchmarked in various configurations in order to understand the impact of granularity and resolution on boosted τ-lepton discrimination.

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1. Introduction

Future experiments like FCC-hh (proton-proton collider at very high energy $\sqrt{s} = 100$ TeV [1]) would probe Beyond Standard Model channels involving heavy resonances, many of which have τ leptons in their final states [2, 3]. The detectors should therefore be able to detect the super-boosted final states in order to reconstruct these heavy resonances. Additionally, the τ lepton is the most difficult charged lepton to identify, and it decays both hadronically ($\sim 65\%$) and leptonically ($\sim 35\%$) due to its heavy mass of 1.777 GeV. The hadronically decaying τ leptons (referred here as τ_{had}) have QCD jets as their major background. A high-granularity silicon-tungsten calorimeter with sufficient radiation and interaction lengths to contain all the τ-decay products has been designed. Since the granularity is very high, a fast simulation study would not be able to give the required insights into the detector design. Here we present the detector response to super-boosted τ_{had} jets (~ 500 GeV) using a full GEANT4-based simulation of the FCC-hh detector.

2. Detector design

As a starting point, we repurposed the basic design of the Silicon Detector (SiD)[4] of the International Linear Collider, because of its high solenoid field (5 Tesla) and the highly granular tracker and calorimeters. This made the detector silicon sensor-based, hence it is named "SiFCC". The Electromagnetic Calorimeter (ECAL) has 32 layers of tungsten absorber with 2 cm$\times$2 cm silicon pixels, providing $\sim 35X_0$ radiation lengths. In order to contain high p_T jets, the Hadronic Calorimeter (HCAL) consists of 64 layers of steel absorber, giving 11.3 interaction lengths (λ_I). The HCAL active material consists of 5 cm$\times$5 cm scintillator pixels. The cylindrical barrel extends to pseudorapidity $|\eta| = 1.7$. The total diameter of the detector is 19 m.

3. Event simulation and reconstruction

For this study, Z' (1 TeV) $\rightarrow \tau\tau$ and Z' (1 TeV) $\rightarrow q\bar{q}$ Monte-Carlo events were used to model the signal and background processes respectively. The generator-level (referred to as truth-level) samples were obtained from a public repository for High Energy Physics Monte Carlo simulated events, HepSim [5], where they were produced using PYTHIA6/MADGRAPH8. These samples were processed through the SiFCC detector simulation. Owing to the di-jet topology of both signal and background events, the Durham Jet Algorithm was used to cluster the final-state particles into two jets. These jets are then passed on to the τ-identification performance study.

4. Identification of hadronically-decaying τ-leptons

τ-leptons being color-neutral decay via the weak interaction. This inhibits quark & gluon radiation in τ_{had} jets, distinguishing them from QCD jets as follows: (i) τ_{had} jets are more collimated and isolated; (ii) low track (charged-particle) multiplicity as τ-leptons predominantly decay via 1-prong ($\tau_{\mathrm{had}} \rightarrow \pi^{\pm}\nu_{\tau} + n\pi^0$, branching ratio: $\sim 21\%$) or 3-prong ($\tau_{\mathrm{had}} \rightarrow 3\pi^{\pm}\nu_{\tau} + n\pi^0$, branching ratio: $\sim 70\%$) channels; and (iii) presence of secondary vertex in the τ_{had} decay.
Based on these features, we use a set of variables to discriminate τ_{had} jets [6] against QCD background. We set the axis of a jet as the direction of the vector sum of momenta of its constituents.

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We divide the region containing the jet into two parts viz. the "core region" ($\Delta R \leq 0.1$, where $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ about the jet axis) which contains 90% of the jet energy, and the "isolation region" ($0.1 < \Delta R < 0.4$) which forms the periphery of the jet. The discriminating variables are:

Central energy fraction (f_{cent}) Fraction of transverse energy deposited inside the region $\Delta R < 0.05$ (i.e., half of the core radius) with respect to the total transverse energy deposited in the core region (Fig.1a).

Number of isolation tracks (N^{iso}_{track}) Number of associated tracks in the isolation region (Fig.1b).

Leading-track momentum fraction (f_{track}) Fraction of transverse momentum of the hardest associated track inside the core region with respect to the total transverse energy deposited in the core region.

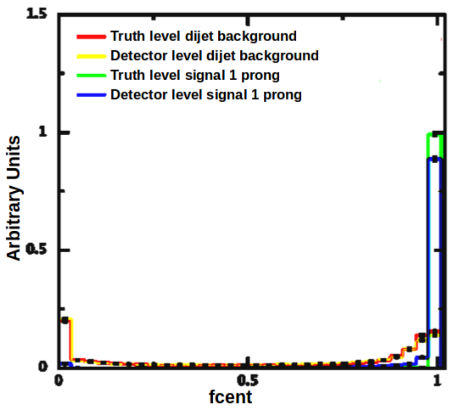
Maximum ΔR (ΔR_{max}) Maximum ΔR between an associated track inside the core region and the jet axis.

Track radius (R_{track}) p_T-weighted distance of the associated tracks within $\Delta R < 0.4$ (i.e, core and isolation region combined) from the jet axis.

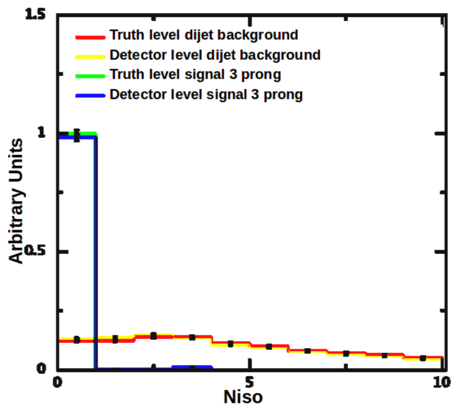
Track mass (M_{track}) Invariant mass calculated using all the associated tracks within $\Delta R < 0.4$, assuming $\pi^{\pm}$ mass for each track.

5. Performance of τ discrimination variables in the SiFCC detector

The discrimination variables worked well in capturing the salient features of τ_{had} jets at the truth-level as well as detector-level, as shown in Fig.1.



(a) f_{cent} (1 prong)



(b) N_{iso} (3 prong)

Figure 1: Distributions of τ_{had} identification variables.

Due to sufficient granularity of the SiFCC detector design, the super-boosted final state particles could be resolved and reconstructed with high efficiency. This can be inferred from the exceptional agreement between the truth and detector-level distributions (Fig.1) of the discrimination variables for both signal and background. This high reconstruction efficiency also bolsters the

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performance of the discrimination variables at the detector level. The signal and background events are clearly separated and even a simple cut-based selection can give a high yield of signal events, with good background rejection. Thus, the discrimination variables are efficient in identification of hadronically-decaying τ-leptons at the FCC-hh energy scale using the current detector design.

6. Conclusion and further plans

The good performance of super-boosted τ-lepton identification provides an important physics benchmark for the granularity and size of the SiFCC detector. It also shows that the discrimination variables are applicable at the FCC-hh energy scales. For further optimization, we are planning to employ multivariate methods like Boosted Decision Tree (BDT) to improve super-boosted τ-lepton identification at FCC-hh in the near future.

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References

[1] Benedikt, Michael. "Future Circular Collider (FCC) study-status." Proceedings of 1st Future Hadron Collier Workshop, CERN, Geneva Switzerland. 2014.

[2] Kotwal, A. V., S. Chekanov, and M. Low. "Double Higgs boson production in the 4τ channel from resonances in longitudinal vector boson scattering at a 100 TeV collider." Physical Review D 91.11 (2015): 114018.

[3] Kotwal, Ashutosh V., et al. "Singlet-Catalyzed Electroweak Phase Transitions in the 100 TeV Frontier." Physical Review D 94.03 (2016): 035022.

[4] Behnke, Ties, et al. "The International Linear Collider Technical Design Report-Volume 4: Detectors." arXiv preprint arXiv:1306.6329 (2013).

[5] Chekanov, S. V. "HepSim: a repository with predictions for high-energy physics experiments." Advances in High Energy Physics 2015 (2015).

[6] Aad, Georges, et al. "Identification and energy calibration of hadronically-decaying τ leptons with the ATLAS experiment in pp collisions at $\sqrt{s} = 8$ TeV." The European Physical Journal C 75.7 (2015): 1-33.

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