Preliminary studies of boosted hadronic τ leptons and W bosons using high-granularity calorimeter at FCC

by

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Introduction

→ detection of boosted objects will be important at FCC-hh experiment
  • heavy resonances decaying to WW, ZZ, HH and tt well-motivated in many BSM models

→ detecting hadronic \( \tau \) decays from \( H \rightarrow \tau \tau \) could also be important for reconstructing di-\( \tau \) and di-higgs resonances

→ preliminary studies of hadronic \( \tau \) identification variables from simulated \( Z' \) (1 TeV) → \( \tau \tau \) events are presented

→ preliminary studies of jet response and resolution for boosted \( W \rightarrow \text{dijets} \) from \( Z'(10 \text{ TeV}) \rightarrow WW \) simulation are also presented
A framework for boosted particle studies

• Using HepSim public repository with EVGEN and full simulations
  - http://atlaswww.hep.anl.gov/hepsim/

• EVGEN Madgraph files were created with MG5/Pythia6

• Files are being processed with a full detector simulation which includes high-granularity calorimeter (1x1 cm cell size in HCAL)

• Detector geometry can be changed using XML files
Designing a high-granularity calorimeter for FCC-hh energies

SiD detector

- A multi-purpose detector for ILC

- The key characteristics:
  - 5 Tesla solenoid & silicon tracker
  - 3.5 mm cell size for ECAL
    - Tungsten absorber
    - silicon sensors
  - 10x10 mm cell size for HCAL:
    - Steel absorber
    - RPC sensors
    - 40 layers for barrel (HCAL)

- Optimized for particle-flow algorithms.
Designing a detector for TeV-scale boosted physics

SiD detector was designed for ~500 GeV jets

A FCC-like detector for studies of CAL transverse and longitudinal granularity, depth, material, magnetic fields, pixel sizes etc, responses to particles etc.

Designing a Geant4 simulation for high-granularity calorimeter (1 cm x 1 cm) with 12 $\lambda$ to contain 20-30 TeV jets

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A typical response to 1000 GeV single pion

Pandora Particle Flow algorithm reconstructs 1000 GeV single pion
Boosted $\tau \rightarrow$ hadrons studies

Sample: $Z'(1\text{TeV}) \rightarrow \tau\tau$
(19980 events)

Sanity Check

<table>
<thead>
<tr>
<th>MC level</th>
<th>Detector level:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-prong  = 20602 ( = 51.5%)</td>
<td>1-prong = 18637 ( = 46.6%)</td>
</tr>
<tr>
<td>3-prong = 4848 ( = 12.1%)</td>
<td>3-prong = 5177 ( = 12.9%)</td>
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</table>

The one prong can further be improved by $\pi^0$ reconstruction
$\tau_{\text{had-vis}}$ identification variables

Reference:

Core=0.1, Isolation region=0.4

$\text{f}_{\text{cent}}$ (Central energy Fraction) = \( \frac{\text{total } E_T \text{ deposited in } \Delta R < \text{core/2}}{\text{total } E_T \text{ deposited in } \Delta R < \text{core}} \)

$N_{\text{track}}^{\text{iso}}$ (number of tracks in the isolated region) = Number of tracks in the region: core < $\Delta R < 0.4$

$\text{f}_{\text{track}}$ (leading track momentum fraction) = \( \frac{\text{pT of highest pT track in core region } (\Delta R < \text{core})}{\text{Total } E_T \text{ deposited in } \Delta R < \text{core}} \)

$\Delta R_{\text{max}}$ (Max $\Delta R$) = max $\Delta R$ between a track and $\tau_{\text{had-vis}}$ direction in $\Delta R < \text{core}$

$R_{\text{track}}$ (Track radius) = pT weighted average of $\Delta R$ to the $\tau_{\text{had-vis}}$ direction in $\Delta R < 0.4$

$M_{\text{track}}$ (Track mass) = Invariant mass calculated using tracks in $\Delta R < 0.4$, assuming pion mass for each track
$P_T$ of $\tau_{\text{had-vis}}$
f_{\text{track}} \text{ (leading track momentum fraction)} = \left( \frac{p_T \text{ of highest } p_T \text{ track in core region (}\Delta R < \text{core})}{\text{Total } E_T \text{ deposited in } \Delta R < \text{core}} \right)
$$\Delta R_{\text{max}}(\text{Max } \Delta R) = \max \Delta R \text{ between a track and } \tau_{\text{had-vis}} \text{ direction in } \Delta R < \text{core}$$
\[ R_{\text{track}} \text{ (Track radius)} = \text{pT weighted average of } \Delta R \text{ to the } \tau_{\text{had-vis}} \text{ direction in } \Delta R < 0.4 \]
\[ M_{\text{track}} \] (Track mass)  
= Invariant mass calculated using tracks in $\Delta R < 0.4$, assuming pion mass for each track
$$f_{\text{cent}} \quad \text{(Central energy Fraction)} = \frac{\text{total } E_T \text{ deposited in } \Delta R < \text{core/2}}{\text{total } E_T \text{ deposited in } \Delta R < \text{core}}$$
Boosted $W \rightarrow$ dijet studies

Sample: $Z'(10\text{TeV}) \rightarrow WW$

(64 layers of HCAL used)

**Soft drop declustering condition:** Given a jet of radius $R_0$ with only two constituents, the soft drop procedure removes the softer constituent unless:

$$\frac{\text{min}(p_{T_1}, p_{T_2})}{p_{T_1} + p_{T_2}} > \frac{z_{\text{cut}}}{\Delta R_{12}/R_0}$$
Jet response: \( P(\text{rec}) - P(\text{gen})/P(\text{gen}) \)

\[ P_T \sim 5 \text{ TeV} \]

AntiKT jets (R=0.4)

Shift for PFA jets is due to tracking or imaging HCAL? (under investigation)
Conclusion

✔ Progress with the Geant4 simulation to understand calorimeter response for multi-TeV particles

✔ Several physics processes in the boosted regime ($Z'$ to $WW$, $\tau\tau$, $qq$) after full simulations are available

✔ Preliminary studies of boosted hadronic taus (at 500 GeV) and $W$’s (at 5 TeV) have been presented

✔ Reasonable agreement between truth-level and detector-level tau identification variables

✔ Designing a calorimeter which will better match the FCC-hh specifications