Study Of Boosted W-Jets And Higgs-Jets With the SiFCC Detector

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WITH

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Outline

• Introduction of the SiFCC detector at a 100-TeV pp collider
• Full GEANT simulation of SiFCC detector on Open Science Grid
• Single particle response and resolution
• Jet response and resolution
• Reconstructed mass of the Higgs-jet
• Two-jet separation in highly-boosted $W \rightarrow qq'$ and $Higgs \rightarrow bb$
• Conclusion
Calorimeters For Colliders At 100 TeV

- Very-high-energy colliders can produce particles with:
  - Large mass
  - Large energy of decay products
  - Large jet transverse momentum

- Requirement of calorimeters
  - Good containment up to $p_T^{\text{jet}} \sim 30$ TeV: $12 \lambda_I$ for ECAL+HCAL
  - Small constant term for HCAL energy resolution: $c < 3\%$ (dominates jet resolution for $p_T > 5$ TeV)
  - Sufficient transverse segmentation for resolving boosted particles
  - Longitudinal segmentation

See more discussions in the talks at BOOST 2015/2016 by G. Perez, S. Chekanov, and N. Tran
SiFCC Detector For Performance Studies

• Re-purpose SiD (ILC) detector and SLIC software

• SiFCC: multipurpose, high granularity, compact detector
  • 30% smaller than ATLAS (D=25 m vs D=19 m)
  • 30% larger than CMS (D=14.6 m vs D=19 m)
SiFCC detector vs CMS

Key:
- Muon
- Electron
- Charged Hadron (e.g., Pion)
- Neutral Hadron (e.g., Neutron)
- Photon

SiFCC

9.5m

2.1 m

HCAL

2.2 m

solenoid

muon detector

Transverse slice through CMS

Iron return yoke interspersed with Muon chambers

HCAL clusters

ECAL clusters
Characteristics Of SiFCC Detector

- 5 T solenoid outside HCAL
- Pixel and Outer trackers:
  - 20 µm pixel (inner), 50 µm (outer)
- ECAL (Silicon+W): 2x2 cm. 32 layers, ~35 $X_0$
- HCAL (Scint+Fe)
  - 5x5 cm cells: $ΔηΔφ=0.022 \times 0.022$
  - CMS: $ΔηΔφ=0.087 \times 0.087$
  - ATLAS: $ΔηΔφ=0.1 \times 0.1$
  - Longitudinal: 64 layers, 11.3 $λ_I$
  - 27.5 mm Steel, 5 mm Polystyrene active material, 2.5 mm G10 (3.1% sampling fraction)
  - > 150 million cells, non-projective
Event Display Of 1 TeV Single Charged Pion

- 7300 calorimeter hits, 440 SiTracker hits
- 1 reconstructed PFA object ($\pi^+$)=998 GeV
- 1 reconstructed CaloCluster at 1058 GeV
- Many back-splash interactions

PFA=Particle Flow Algorithm
Single-Pion Response And Resolution

- Loss of acceptance for low-$p_T$ tracks due to 5T magnetic field
- Resolution of tracks getting worse with energy
- Resolution for CaloClusters is better than tracks for $E > 2$ TeV

$$y = A \times \text{Erf} \left( \frac{E_{\text{true}} - B}{C} \right)$$

- $A = 1.01$
- $B = -64.6$
- $C = 56.8$

$$y = \frac{0.38}{\sqrt{E_{\text{true}}}} \oplus 0.01$$
Event Display Of 40 TeV $Z' \rightarrow WW$

10,000 hits in ECAL
46,000 hits in HCAL
12,000 hits in outer tracker
1,000 hits in pixel tracker
Simulated Physics Events

Start with \( \mu \mu \) collider events to eliminate pileup effects and reduce simulation time

**Focus on the detector performance**

<table>
<thead>
<tr>
<th>Physics Process</th>
<th>Generator</th>
<th>( \mu \mu \sqrt{s} ) [TeV]</th>
<th>Resonance Mass [TeV]</th>
<th>Link to sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>2HDM H2</td>
<td>MADGRAPH + PYTHIA6</td>
<td>5</td>
<td>5</td>
<td>ID 178</td>
</tr>
<tr>
<td>Z' (filtered)</td>
<td>PYTHIA6</td>
<td>10</td>
<td>10</td>
<td>ID 179</td>
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<tr>
<td>Z' (filtered)</td>
<td>PYTHIA6</td>
<td>40</td>
<td>10</td>
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<tr>
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</tr>
</tbody>
</table>
What Is Inside A Jet?

- Generator-level jets clustered with anti-$k_T$ algorithm and $\Delta R=0.4$ ($Z' \rightarrow WW$ sample)

- Neutrinos are excluded in the calculation of $E_{\text{true}}$

- Overall fractions
  - $\pi^\pm$: 40%
  - $\gamma$: 24%
  - $K^\pm$: 11%
  - $p, n, K_s, K_L$: 5% each
  - Rest ($\Lambda, \Xi, \Sigma$): 5%
Comparison Of Energy Response

- Weight generator-level particles with single-particle response and smear with single-particle resolution

- response = 0 for charged particles with $E < 3$ GeV, ey response mean=1, RMS/Mean = $0.15/\sqrt{E} \oplus 0.01$

- gen (charged + $\gamma$): include only charged particles and photons

10-TeV $Z' \rightarrow WW \rightarrow qq'qq'$

5-TeV $H_2 \rightarrow hh \rightarrow bbbb$
Single-$K_{L}^{0}$ Response and Resolution

- Is it possible that $K_{L}^{0}$ has very different response or resolution?
- The response and resolution of single $K_{L}^{0}$ are actually similar to those of single pion
Study the calorimeter jet energy response as a function of generator-level jet energy with $Z'\rightarrow WW$ samples.
Jet Response And Resolution

- First study of calorimeter energy response and resolution for 5-20 TeV jets using realistic GEANT4 simulation
- Also tried clustering of calorimeter hits around the generator-level W direction, results are very similar
- Continuing study of jet response and resolution…

![Graph showing jet response and resolution with fitted curve and statistical values.](image)

**Mean90** = \( p_0 \left( 1 - p_1 e^{-x/p_2} \right) \)

\[
\begin{align*}
\chi^2 / \text{ndf} & = 5.235 / 1 \\
\text{Prob} & = 0.02213 \\
p_0 & = 0.9649 \pm 0.0039 \\
p_1 & = 0.1821 \pm 0.0102 \\
p_2 & = 7632 \pm 826.6
\end{align*}
\]

**RMS90** = \( \frac{p_0}{\sqrt{E_{\text{true}}} + p_1} \)

\[
\begin{align*}
\chi^2 / \text{ndf} & = 2.47 / 2 \\
\text{Prob} & = 0.2908 \\
p_0 & = 3.591 \pm 0.172 \\
p_1 & = 0.0267 \pm 0.00177
\end{align*}
\]

Sampling term: 359% ?!
Reconstructed Mass Of the Higgs-Jets

- Study of the mass distributions is in progress
  - Reconstruction-level jets matched to generator-level with $\Delta R < 0.1$
  - PF-jet mass is about 30 GeV lower than the nominal mass
Two-Jet Separation In Boosted Bosons

- The high-granularity calorimeter makes it possible to see the separation of jets within highly-boosted bosons.

The figure shows the energy distributions for different calorimeter hits in 10-TeV and 5-TeV events. The separation of jets is indicated by the signed ΔR, where ΔR ≈ 0.02 for the 10-TeV Z’ → WW and ΔR ≈ 0.05 for the 5-TeV H2 → hh.
Conclusion

• We present a first study of the boosted W-jets and Higgs-jets with the SiFCC detector using full GEANT4 simulation

  • Response and resolution of single particles follow the expected performance of the designed detector

  • Resolution of calorimeter jet energy has a very big sampling term, will continue the study using lower-energy jets from 100 GeV upwards

  • The high granularity of the calorimeter shows the possibility to separate energy clusters within a jet from a 2.5-5 TeV boosted boson

• We are geared towards the study of high-level variables, such as jet substructures, jet grooming…

• Collaborators are always welcome!

Talk: Sergei Chekanov, “Monte Carlo simulations for future collider studies”
Poster: Nhan Tran, “Detectors for Superboosted Jet Substructure at Future Circular Colliders”
Backup Slides
SiD detector for ILC

- Multi-purpose detector for the ILC
- The key characteristics of the SiD detector:
  - 5 Tesla solenoid
  - Silicon tracker: 50 um readout pitch
  - ECAL: (0.35 cm cell size, W / silicon)
  - HCAL:
    - 1x1 cm cell size (RPC)
    - 40 layers for barrel (HCAL) \( \sim 4.5 \lambda_\text{v} \)
- Optimized for particle-flow algorithms (PFA)
- Fully configurable using SLIC software
Energy Distributions Of Particles In A Jet

**10-TeV Z’→WW→qq’qq’**

**5-TeV H2→hh→bbbb**
Energy Distributions Of Particles In A Jet

10-TeV $Z'$ → $WW$ → $qq'qq'$

20-TeV $Z'$ → $WW$ → $qq'qq'$

30-TeV $Z'$ → $WW$ → $qq'qq'$

40-TeV $Z'$ → $WW$ → $qq'qq'$
Single-Photon Response Resolution

[Graph showing energy response and resolution as a function of energy (GeV).]