Jets and Jet-Jet Mass Reconstruction in a Crystal Calorimeter

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Motivation

- Calorimeters measure energy deposited in the volume of the detector
- Jets (collections of particles) are of interest of physics (but they are ill defined because of the color content)
- Di–jets produced by decays of color singlets (like W/Z) are well defined and they are objects of primary interest
- Crystal calorimeters with dual readout offer a perspective of very high energy resolution, but:
  - How do you reconstruct jets/di–jets?
  - Strong magnetic field bends particles and they land in ‘wrong’ places in the calorimeter. How does it spoil the di–jet mass resolution

- Summer student project: Nayeli Azucena Rodriguez Briones
Crystals of Calorimetry version of SiD

<table>
<thead>
<tr>
<th>Name</th>
<th>Layers</th>
<th>Thickness/Layer [cm]</th>
<th>Segmentation [cm x cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECAL Barrel</td>
<td>8</td>
<td>3</td>
<td>3 x 3</td>
</tr>
<tr>
<td>HCAL Barrel</td>
<td>17</td>
<td>6</td>
<td>6 x 6</td>
</tr>
<tr>
<td>Total Barrel</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECAL Endcap</td>
<td>8</td>
<td>3</td>
<td>3 x 3</td>
</tr>
<tr>
<td>HCAL Endcap</td>
<td>17</td>
<td>6</td>
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<td></td>
</tr>
</tbody>
</table>

‘Fine’ detector. Simulated and Analyzed

Machinery established to study different segmentations to study the effects and to optimize the detector design. Very good project for students.
Simulation and Analysis

- Detector simulation within the SLIC environment (optical calorimeter version by Hans Wenzel)
- Large even samples produced on the OSG grid
- Single particles, electrons and pions at various energies simulated to provide the calibration samples
- Single W and single Z (with different energies simulated to study the di-jet mass resolution)
- Analysis carried out within Jas3 framework
Establish calibration factors for scintillation and Cherenkov signal using 10 GeV electrons

**Cherenkov**

- Entries: 1000
- Mean: 1.5294E-3
- RMS: 1.8687E-5

**Scintillation**

- Entries: 1000
- Mean: 9.9640
- RMS: 0.02451
Calibrated Response: 10 GeV electrons

Note the scale: energy resolution is, obviously, superg for electrons
Calibrated Response: 10 GeV Pions
Dual Readout Correction

- Use simple correction (Anna Driutti):

\[ E = \frac{S}{0.68 + 0.31C / S} \]
Di–jet Mass Reconstruction

- Single W events, W momentum 0 – 100 GeV
- Treat all cells as massless particles: (E,px,py,pz), with the direction of the momentum vector determined by the cell position (center)
- No B field
- $\Delta M/M \sim 0.049$
Mass Reconstruction in Magnetic Field

- $B = 0 \, T$, $\sigma = 0.049$
- $B = 2 \, T$, $\sigma = 0.054$
- $B = 4 \, T$, $\sigma = 0.070$
- $B = 6 \, T$, $\sigma = 0.081$
Magnetic Field Effect

Mass resolution as a function of B field

Contribution of the magnetic field to the mass resolution

Note: Bending of charged particles in 5T field induces the contribution to resolution larger than the calorimeter itself.
Correcting for the B Field Effect

- Magnetic field bends charged particles: the energy depositions are displaced with respect to their ‘true’ directions.
- The change of the invariant mass of a system is calculable for each individual event.
- \((\Delta M)_B = M_{Ch}(B=0) - M_{Ch}(B)\), where
  \[
  M_{Ch} = \sqrt{(\sum E_i)^2 - (\sum p_i)^2}
  \]
- And the direction of the momentum vector is given by the initial direction \((B=0)\) or the impact point at the calorimeter \((B)\).
Mass Resolution: B=0 (Null correction)

\[ \Delta M/M \]

uncorrected  \[ \sigma = 0.049 \]

corrected  \[ \sigma = 0.045 \]
Mass Resolution: B = 6T

\[ \frac{\Delta M}{M} \]

\[ \sigma = 0.075 \quad \text{uncorrected} \]

\[ \frac{\Delta M}{M} \]

\[ \sigma = 0.049 \quad \text{corrected} \]
Dijet Mass: $W + Z$ sample, $B = 5T$

Uncorrected mass

Corrected mass
WW vs ZZ final states, 5T Field
On the Robustness of the Correction

- Correction for the magnetic field effect is derived from the charged particles (tracking) information.
- No correlation of any kind between the tracks and the energy depositions in the calorimeter is used.
- Correction is not sensitive to the performance of a tracker:
  - If tracking is inefficient, and some tracks are lost, the correction (additive) is somewhat underestimated. This is most likely to happen for stiff tracks in a jet core. They contribute nothing to a correction.
  - If stiff ghost tracks are ‘invented’ by the pattern recognition failure, they do not produce any contribution to the correction.
Conclusion

- Segmented crystal calorimeter offers a powerful tool for precise determination of di-jet masses
- Strong magnetic field induces a sizeable contribution to di-jet mass resolution
- But it is easily correctable using tracking information
- Correction is simple and robust

Note: this was a summer student project. A lot of room for further improvements in the analysis