PFA Development at NIU

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Outline

- Introduction

- The Basic Algorithm
  - Density-weighted Clustering in Calorimeter
    - Calorimeter-only (no track-seeding)
    - Same for ECal (e, γ), and HCal (h+, h0).
  - Replace cal clusters with matching (MC) tracks, if any.

- The Directed Tree Algorithm
  - Association of isolated “fragment”s or “satellite”s.

- Work in Progress
Introduction

• Primarily interested in exploring the digital hadron calorimeter option in general, with scintillator as the active material in particular.

• For digital algorithms and results for single particles, Refer to talks given at the LDC meeting (Paris, Jan 2005).

• Results are preliminary.
The “SD” calorimeter

- **ECal:**
  - 30 layers, silicon–tungsten.
  - 5mm x 5mm transverse segmentation.

- **HCal:**
  - 34 layers, scintillator–steel
  - 1 cm x 1 cm transverse segmentation.

- **Magnetic field:** 5T

- **Support structures, cracks, noise, x-talk, attenuation, inefficiencies,… not modelled.**
Clustering (reported in past)

- Seeds: maxima in local density:
  \[ d_i = \Sigma (1/R_{ij}) \]
- Membership of each cell in the seed clusters decided with a distance function.
- Only unique membership considered.
- Calculate centroids.
- Iterate till stable within tolerance.
DHCal: Particle-flow algorithm (NIU)

- Nominal SD geometry.
- Density-weighted clustering.
- Track momentum for charged,
- Calorimeter E for neutral particles.
DHCAL: Particle-flow algorithm (NIU)
Photon Reconstruction inside jets

Excellent agreement with Monte Carlo truth:

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DHCal: Particle-flow algorithm (NIU)
Reconstructed jet resolution

ZZ → 4j events

Cal only

Digital PFA

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The Directed Tree Algorithm

- Define neighborhood for a cell
- Discard cells below threshold (0.25 MIP)
- Calculate density for each cell i
- If(density==0) ?
  else
  calculate \( (D_j - D_i) / d_{ij} \)
  where j is in the neighborhood
  find max []
The Directed Tree Algorithm (contd.)

- If `max[]` is -ve
  - `i` starts a new cluster
- If `max[]` is +ve
  - `j` is the parent of `i`
- If `max[]` == 0
  - avoid circular loop
  - attach to nearest
Clusters from single hadrons are reconstructed well. Some “fragment”s or “satellite”s remain unassociated.
EM clusters in $Z \rightarrow qq$ Events

Generated clusters
Reconstructed clusters

Only a few highest $E$ clusters shown.

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The confusion term

- Internal to calorimeter.
- Reconstruct “gen” and “rec” clusters,
- A “gen” cluster is a collection of cells which are attached to a particular MC particle. All detector effects are included in this cluster.
- Find centroids and match to nearest “rec” cluster, making sure that no cluster gets associated twice.
- Somewhat conservative.
Z→qq Events

- Calculate $E_{\text{rec}}/E_{\text{gen}}$ for each generated cluster.
- Enter into histogram with weight $E_{\text{gen}}/E_{\text{total}}$. 
Cluster Matching and Merging

- Stage 1: one-to-one gen–reco matching based on distances (3D or angular) → unassociated clusters ("satellites")
- Stage 2: attach satellites to reco clusters based on angular distances: possible cuts on angular separation, satellite energies, number of hits, ...
Preliminary ECal Analysis

- 500 events, with 2–pions 10 cm apart at ECal face, using SDNPHOct04 detector
- neighborhood definition: \((d\phi=5, dz=5, dlayer=9)\)
- discard events with decays or interactions before Ecal
- Look at:
  - \(\text{eratio1: } E_{\text{rec}}/E_{\text{gen}}\) after stage 1 (matching)
  - \(\text{eratio2: } E_{\text{rec}}/E_{\text{gen}}\) after stage 2 (merge satellites)
Preliminary HCal Analysis

• 500 events, with 2-pions 10cm apart at Ecal face, using SDNPHOct04 detector
• neighborhood definition: (dφ=2, dz=2, dlayer=2)
• discard events with decays or interactions before Ecal
• Look at:
  - eratio1: E_{rec}/E_{gen} after stage 1 (matching)
  - eratio2: E_{rec}/E_{gen} after stage 2 (merge satellites)
Current Status

• Analysis of complex events shows some problems with too many satellites – how to associate them with the right parent shower?
• Clustering algorithm ported to org.lcsim, to be certified. Committed to LCSim CVS repository.
• More manpower for the PFA development effort.
• Work in progress, a lot to do ...
Current Status (contd.)

$Z \rightarrow qq$

$\sigma(E) = 4.3 \text{ GeV}$

- Scint, 1 cm x 1 cm.
- Density-weighted clustering, but analog E calculation in both ECal & HCal.
- Min 5 cells for cluster.
- Cell threshold = 0.5 MIP.
- Satellite attachment not used.
- No cut on theta.

With Perfect PFA (no confusion term), $\sigma(E) = 3.1 \text{ GeV}$
Backup slides
Separability of clusters

Best separability is achieved when width of a cluster is small compared to distances between clusters.

\[ J = \text{Tr}\{S_w^{-1} S_m}\]
Separability of clusters (contd.)

where

\[ S_w = S_i W_i S_i \]

\( S_i \) = covariance matrix for cluster \( c_i \) (in \( x, y, z \))

\( W_i \) = weight of \( c_i \) (choose your scheme)

\( S_m \) = covariance matrix w.r.t. global mean
Two (parallel) $\pi^+$’s in TB sim:

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Two (parallel) $\pi^+$’s in TB prototype sim: separability ($J$) vs. track distance for different cell sizes
PFA Jet Reconstruction summary (past)

• Cone clustering in the calorimeters,
• Flexible definition of weight (energy- or density-based),
• Generalizable to form “proto-cluster” inputs for higher-level algorithms.
• Replace cal clusters with matching MC track, if any.
• Based on projective geometry.
• New clustering algorithms taking shape.