Study of Energy Flow in Jet Reconstruction
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- Good jet reconstruction essential to explore and make use of all decay modes
  - multi-jet masses: e.g. Zh vs ZZ vs WW
  - reconstruct parton angles to extract quantum numbers, anomalous moments, e.g. WW, $t\bar{t}$, $t \rightarrow bq'q''$

- Use combination of tracker and calorimeter which provides best resolution:
  - tracker for $h^\pm$, EM cal. for $\pi^0$ (HAD cal. for $K_L^0$, etc.)

- Requires excellent $\gamma - h^\pm$ id. $\Rightarrow$ EM Cal. segmentation

- Realistic modelling requires more-than-primitive cal. clustering algorithm(s)

This Study:

- Develop EFlow technique in LCD simulation
- Implications for detector design in terms of physics benchmarks
- Compare to other techniques for jet recon.

- Start with LCD Fast Simulation
- Move to Full Sim. (Gizmo/GEANT 4), clustering alg. (c.f. N. Graf talk)
The LCD Fast Simulation (Cal.)

- The L, S (and P) detectors
  - different
  - optimized for ease of simulation description (*not* cost)
- L and S with highly segmented EM Cal for EFlow
- One Cal. shower ("cluster") per MC particle
- Energies and momenta smeared by standard gaussian parameterizations
- positions also smeared in 3-D.
- helical extrapolation of charged particles through tracker and calorimeter
- Capability to merge clusters to produce a little realism
- Same framework as Full Sim. (root or JAS)
Ident. and measurement of Photons

- Here, used $e^+e^- \rightarrow ZZ \rightarrow 4q$

- Start by looking at all Cal. clusters. Use to id. photons:
- Longitudinal depth of shower max. (cluster max. or shower start)
- No charged tracks overlap with cluster
  - helical extrapolation of tracks to cluster position
  - 2-D separation (bend, non-bend)
- Nearest charged track does not give $p = E$
- Combine these photon candidates with charged tracks $\rightarrow$ find jets
\[ R = \text{(cluster radial position)} - \text{(inner wall of cal.)} \]

- **S detector (top photons; bottom }^{\pm} \text{):**

- **L detector (top photons; bottom }^{\pm} \text{):**
Separation of Cluster and nearest charged track (extrapolated)

Small Detector: $BR^2 = 3.4$ T-m$^2$, $R_m = 0.9$ cm

- Cluster is due to a $\pi^\pm$:

- Cluster is due to a $\gamma$:
Separation between Cluster and nearest charged track (extrapolated)

Large Detector: $BR^2 = 12$ T-m$^2$, $R_m = 1.6$ cm

- Cluster is due to a $\pi^\pm$:

- Cluster is due to a $\gamma$:
Combine bend $\oplus$ non-bend $\equiv d2D$

Also look at $dE \equiv (\text{cluster } E) - (p \text{ of nearest track})$

Small Detector

- Cluster is due to a $\pi^\pm$:

- Cluster is due to a $\gamma$:
Combine bend or non-bend \( \equiv d2D \)

Also look at \( dE \equiv (\text{cluster } E) - (p \text{ of nearest track}) \)

Large Detector

- Cluster is due to a \( \pi^\pm \):

- Cluster is due to a \( \gamma \)
Jet-Jet Mass in $e^+e^- \rightarrow ZZ \rightarrow \text{jets}$

- Use thrust axis to divide event: 2 jets vs 2 jets (typical)
  - simply add additional jets if $> 2$ per hemisphere
  - no “extra” jet-jet combinations

- Start with unsmeared MC particles:
• Exclude final-state neutrinos:

![Graph with JJ Mass distributions]

- JJM
  - Nent = 90
  - Mean = 88.28
  - RMS = 9.211

• Also exclude $K^0_L$'s:

![Graph with JJ Mass distributions]

- JJM
  - Nent = 90
  - Mean = 82.94
  - RMS = 11.95
• Fast MC Simulation – Charged Tracks Only:

![Graph of JJ Mass distribution for Charged Tracks Only]  
- JJM: Nent = 76, Mean = 53.7, RMS = 15.78

• Fast MC Simulation – Cal. Clusters Only:

![Graph of JJ Mass distribution for Cal. Clusters Only]  
- JJM: Nent = 74, Mean = 85.52, RMS = 20.25
- Energy Flow - Detector S; $d2D > 0.5 \text{ cm}$, $(dE > 5 \text{ GeV})$, no $R$ cut:

![Graph showing energy distribution for Detector S](image)

- Energy Flow - Detector L; $d2D > 1.5 \text{ cm}$, $(dE > 5 \text{ GeV})$, no $R$ cut:

![Graph showing energy distribution for Detector L](image)
As expected, E Flow gives better resolution than clusters (or tracks) alone.

No parameter optimization or wide study of inputs, but

E Flow γ multiplicity \( \approx \) charged mult.

\( R \) cut (shower position) cut does \textit{not} help, since
  - excludes some fake photons,
  - but also excludes neutral hadrons

S detector requires track–cluster separation \((d2D)\) of 1 cm or less

L is more forgiving - broad minimum up to \( \sim 5 \) cm
Summary

- A start . . .
- Some optimization possible to nudge Fast Sim. EFlow $\rightarrow$ unsmeared 4-vector
- But clearly most important step is to use fully simulated MC and a realistic clustering algorithm
- Expect challenges with pattern recognition – Is it better than using cal.-only?
- Important implications for detector cost and size
  - figure of merit is $BR^2/R_m$
  - Can one construct sufficiently fine granularity at modest $R$ and cost?