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, $t\bar{t}$, $t \to bqq'$
- Use combination of tracker and calorimeter which provides best resolution:
  tracker for $h^{\pm}$, EM cal. for π^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.)

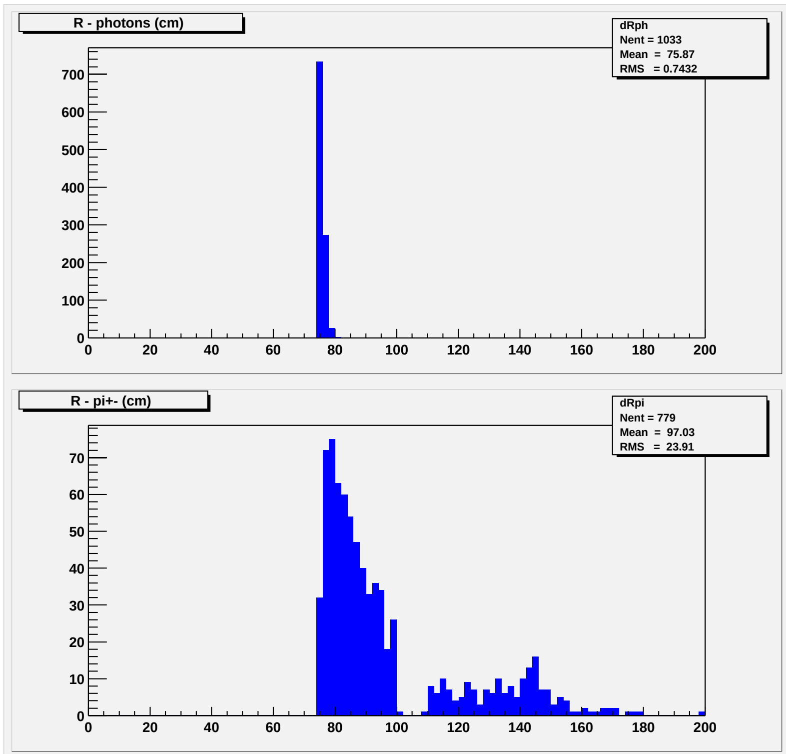
- The L, S (and P) detectors
  - different
  - optimized for ease of simulation description (*not* cost)
- L and S with highly segmented EM Cal for EFlow
- One Cal. shower ("cluster") per MC particle
- Energies and momenta smeared by standard gaussian parameterizations
- positions also smeared in 3-D.
- 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

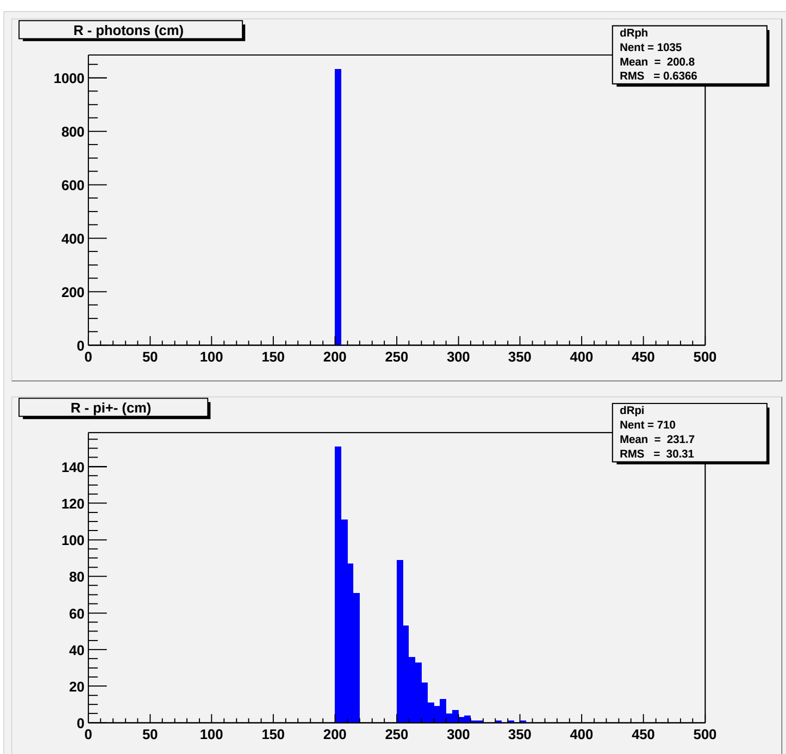
- Here, used $e^+e^- \to ZZ \to 4q$
- Start by looking at all Cal. clusters. Use to id. photons:
- Longitudinal depth of shower max. (cluster max. or shower start)
- No charged tracks overlap with cluster
  - helical extrapolation of tracks to cluster position
  - 2-D separation (bend, non-bend)
- Nearest charged track does not give $p = E$
- Combine these photon candidates with charged tracks $\to$ find jets

$$R = (\text{cluster radial position}) - (\text{inner wall of cal.})$$

- S detector (top photons; bottom $\pi^{\pm}$):



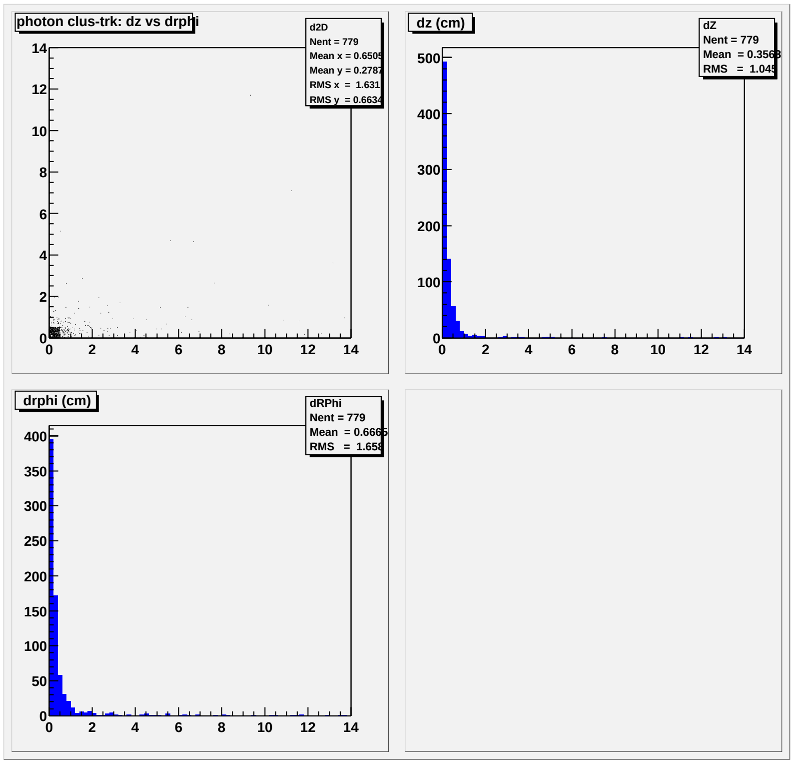
- L detector (top photons; bottom $\pi^{\pm}$):



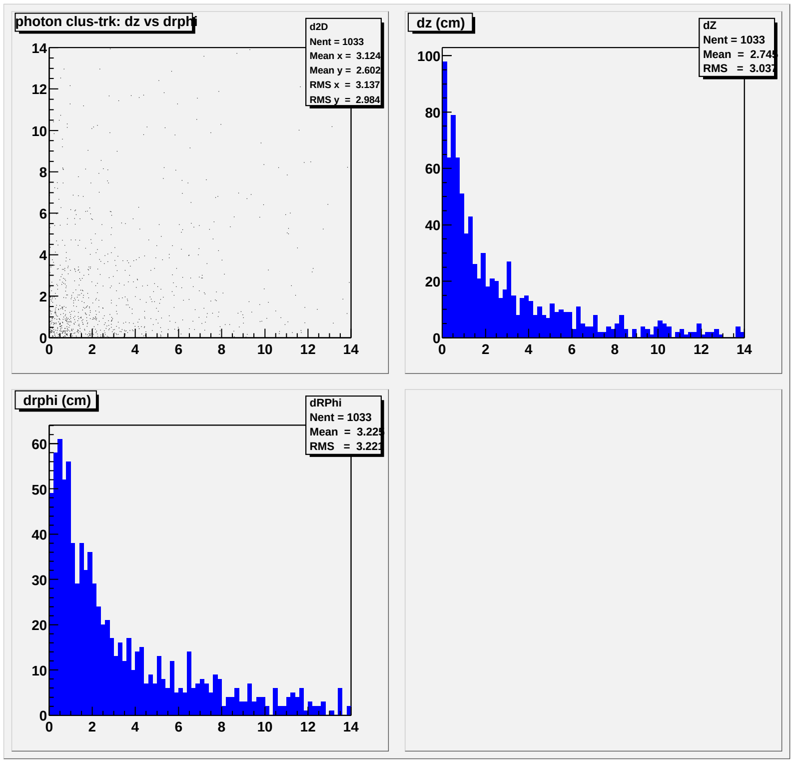
Separation of Cluster and nearest charged track (extrapolated)

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

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



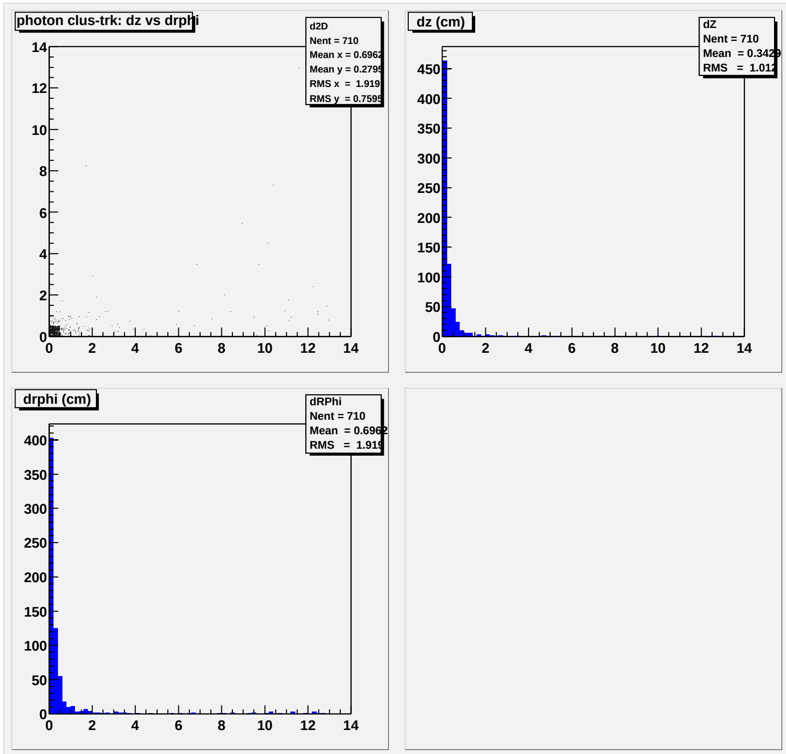
- Cluster is due to a γ:



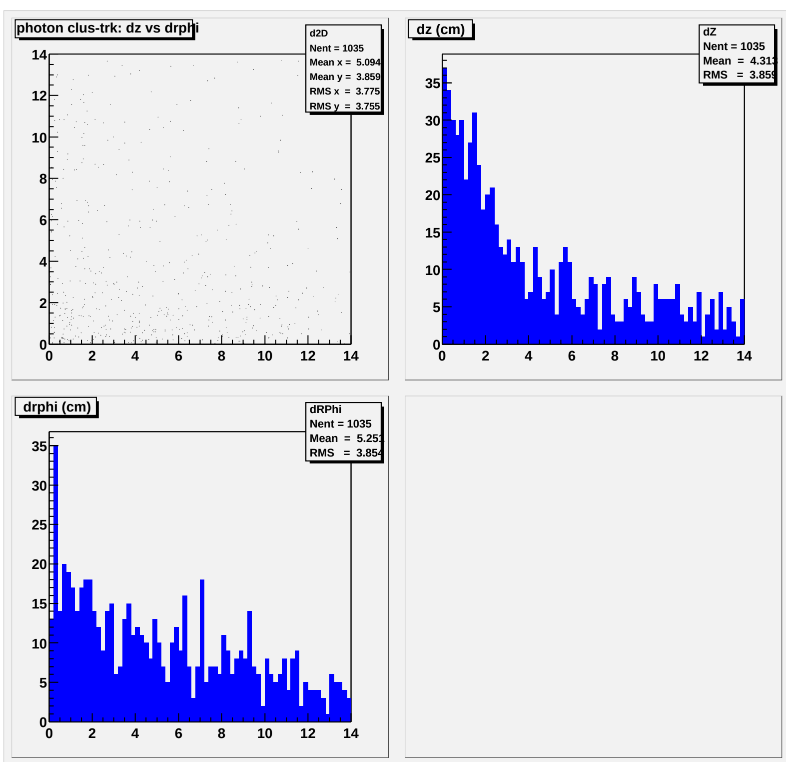
Separation between Cluster and nearest charged track (extrapolated)

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 γ:

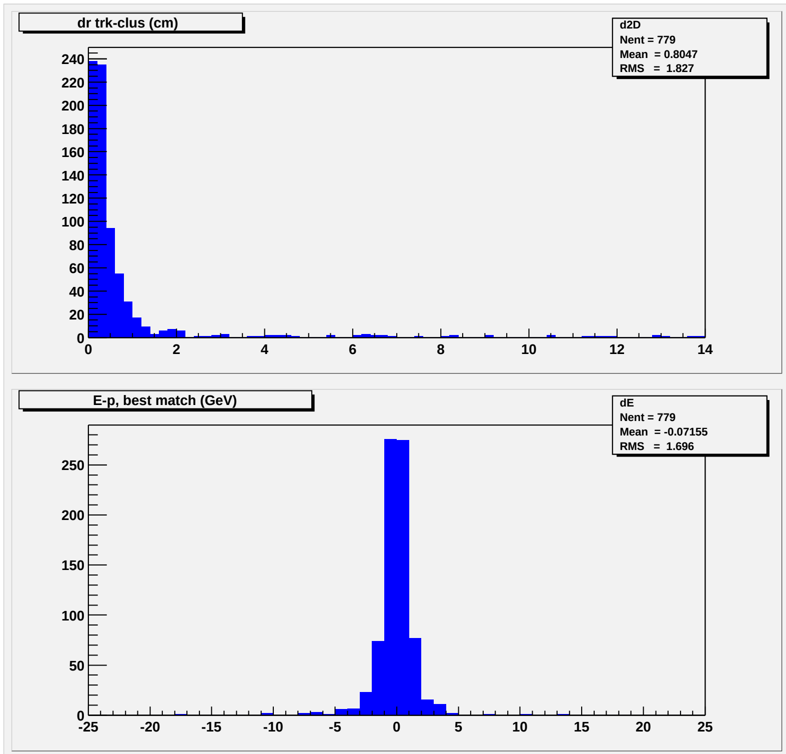


Combine bend $\oplus$ non-bend $\equiv d2D$

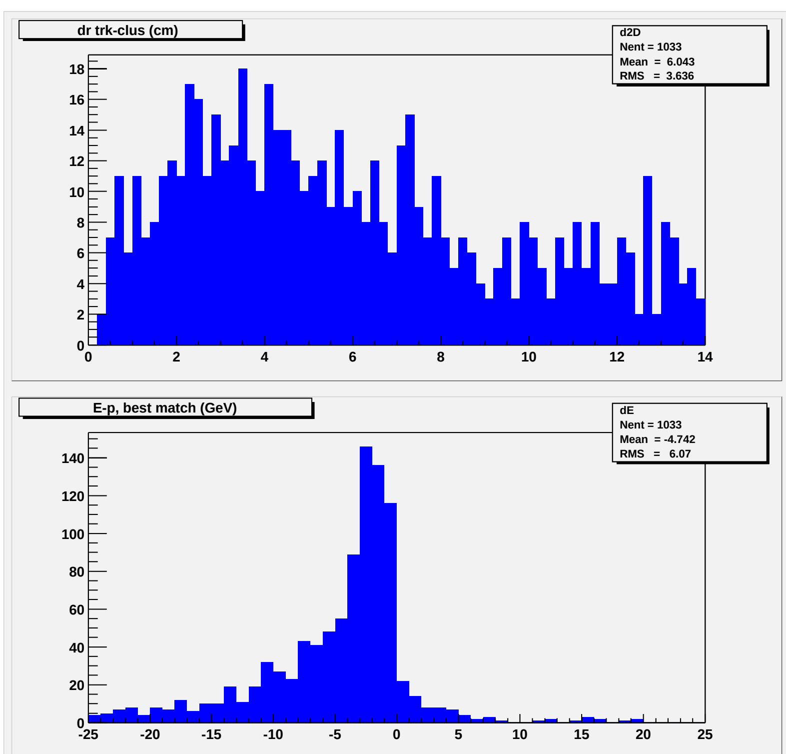
Also look at $dE \equiv$ (cluster E) $-$ (p of nearest track)

Small Detector

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



- Cluster is due to a γ:

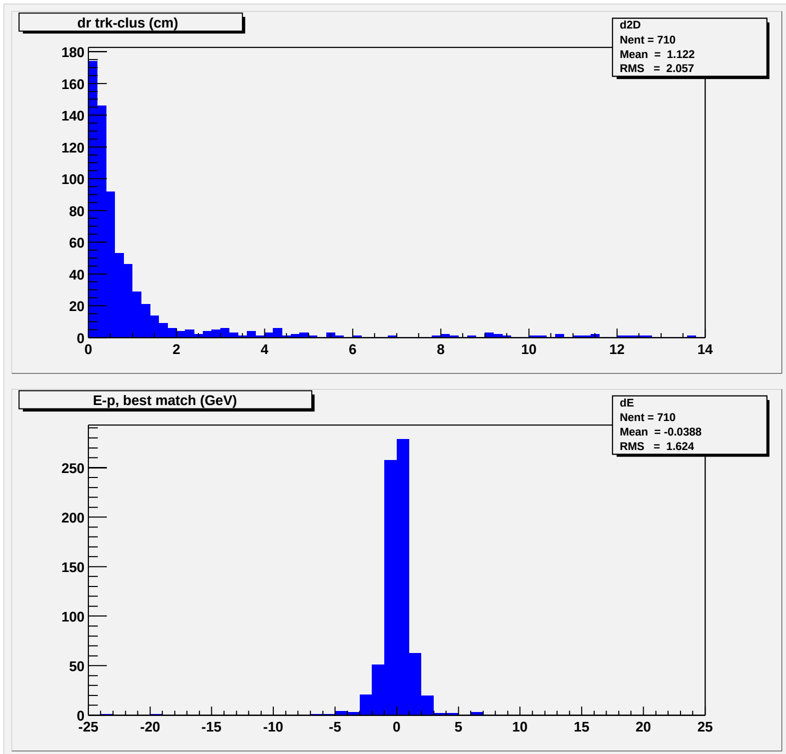


Combine bend $\oplus$ non-bend $\equiv d2D$

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

Large Detector

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



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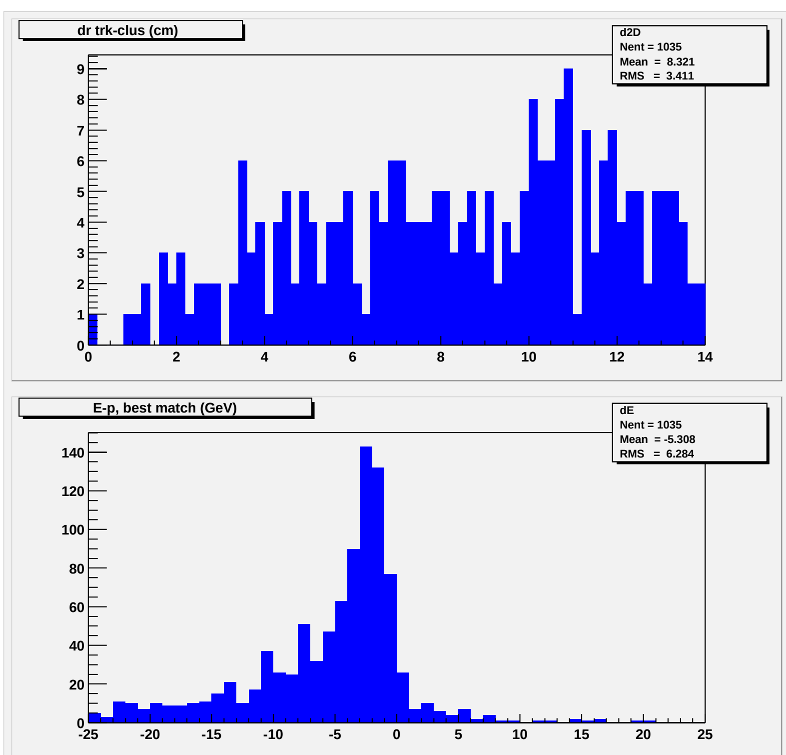
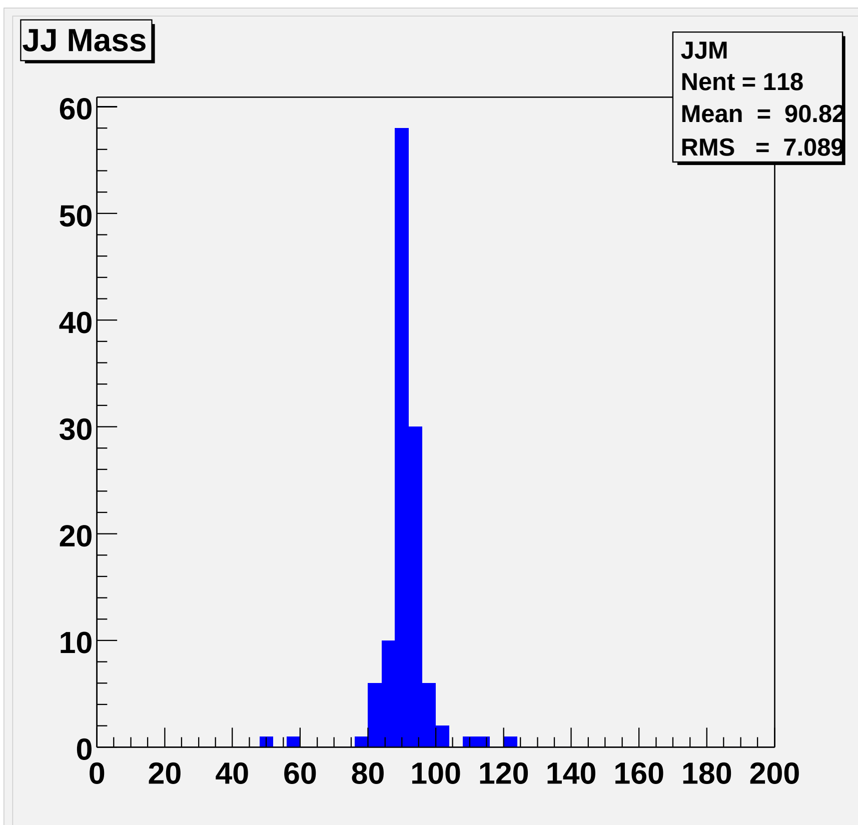


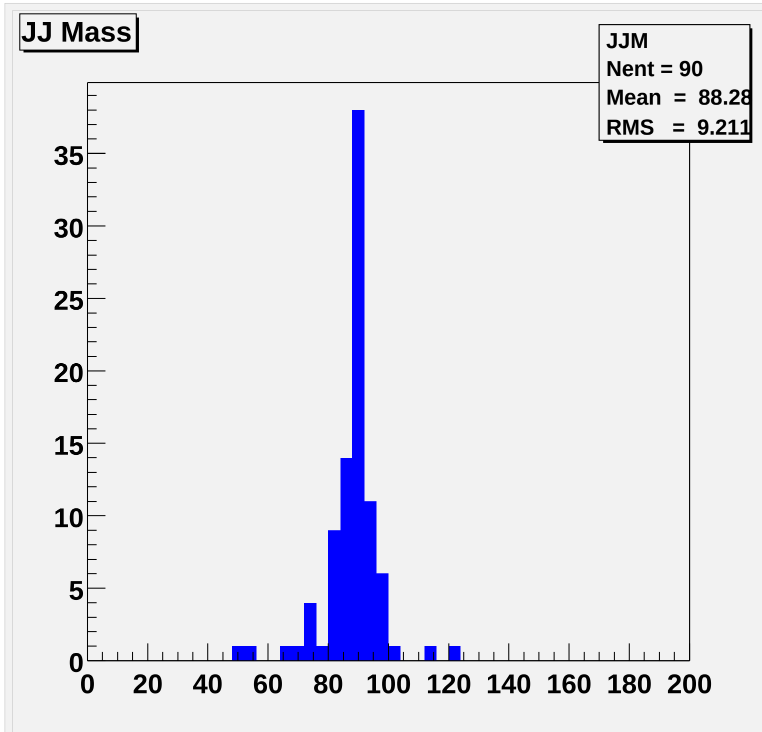
Jet-Jet Mass in $e^+e^- \to ZZ \to$ jets

- 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

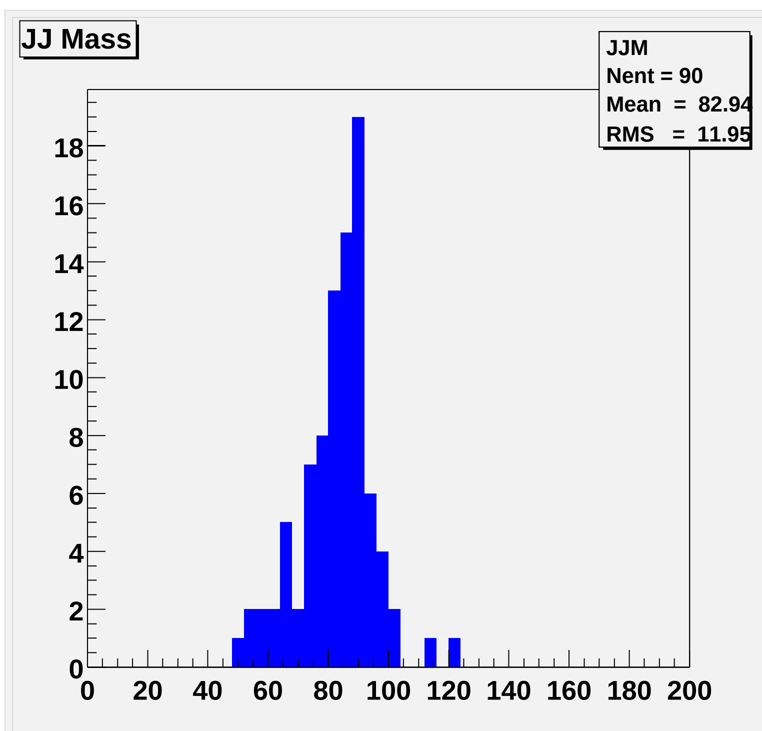
- Start with unsmeared MC particles:



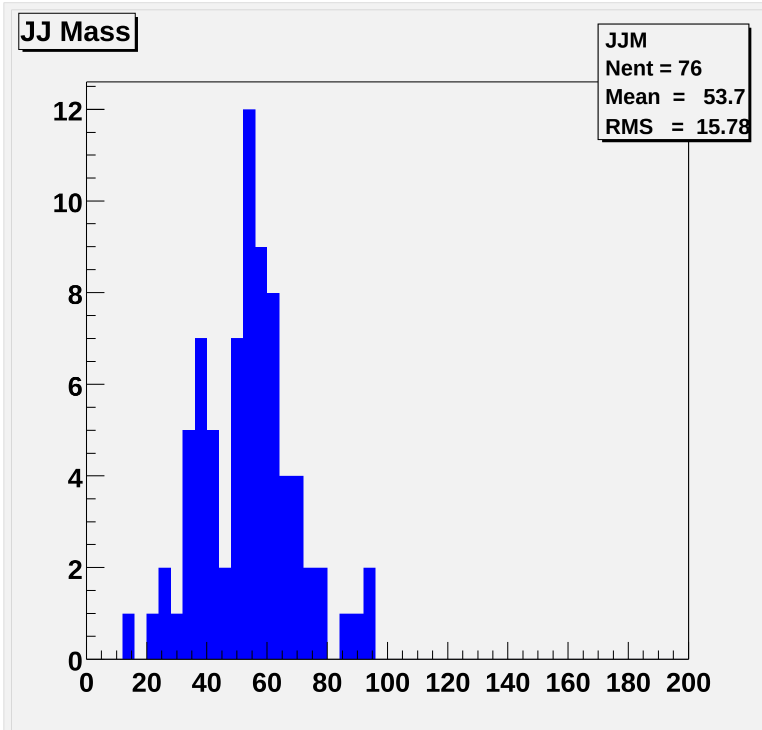
- Exclude final-state neutrinos:



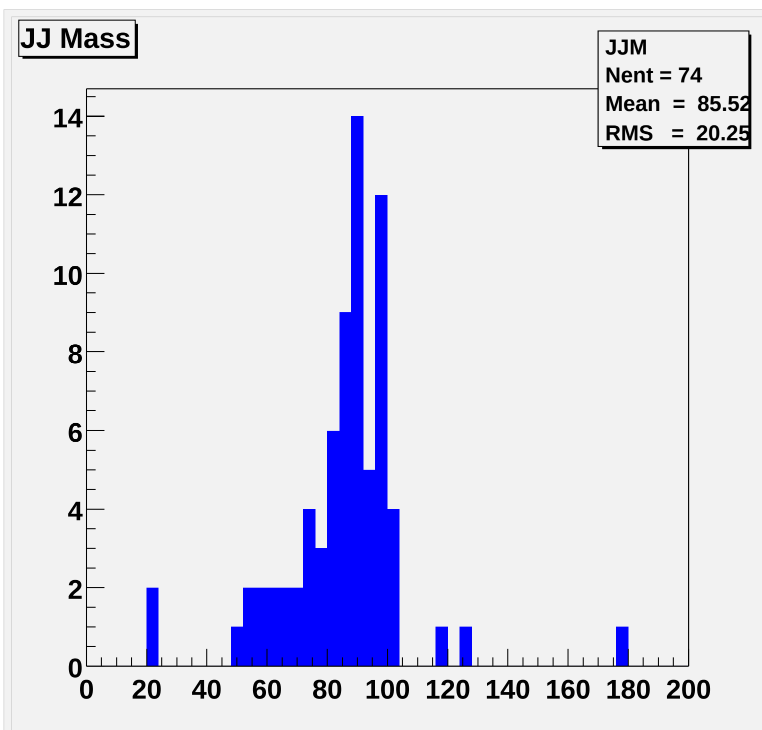
- Also exclude K_L^0's :



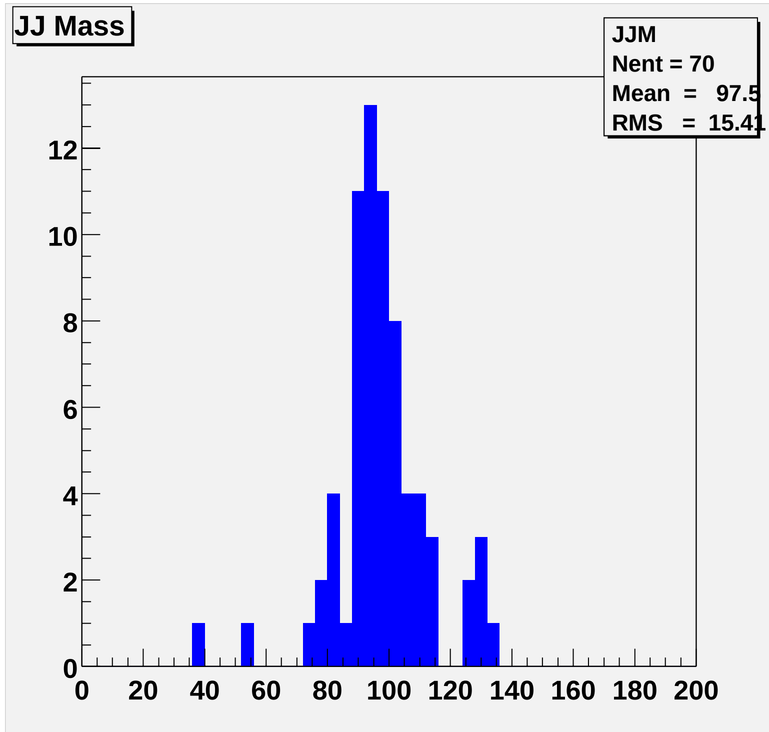
- Fast MC Simulation – Charged Tracks Only::



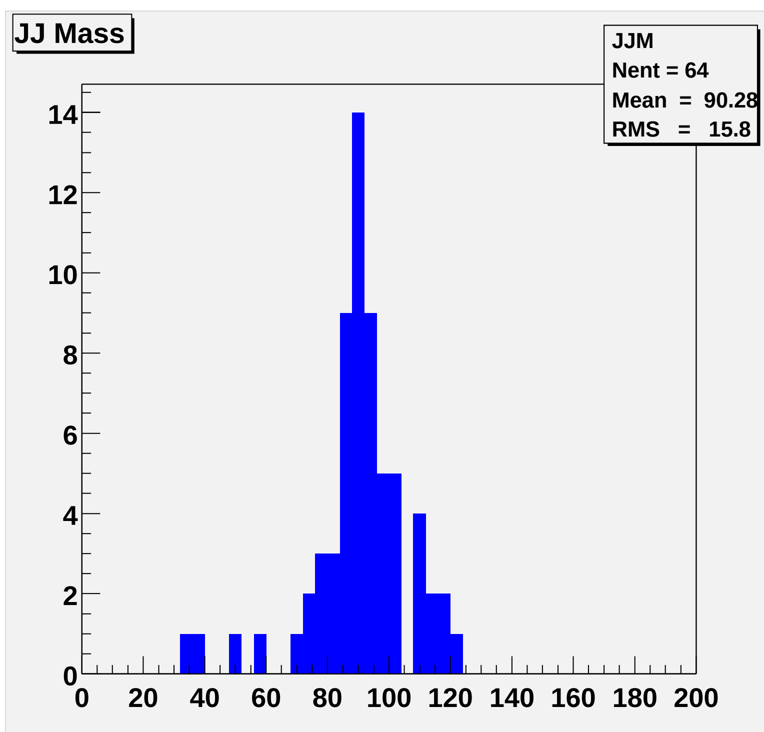
- Fast MC Simulation – Cal. Clusters Only::



- Energy Flow - Detector S; $d2D > 0.5$ cm, ($dE > 5$ GeV), no R cut:



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



- 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 *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 → 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 ?