Photon Finding and Particle Flow Progress

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Problem Statement

- Goal is to utilize Particle Flow paradigm to design optimized detectors.
- Need common definitions (interfaces) for constituents of final reconstructed particles.
- Need “generic” algorithms, decoupled from specific detector designs.
- Need canonical samples on which to develop and test reconstruction algorithms.
- Need canonical physics samples with which to compare detector designs.

Design Considerations

- All reconstructed particles, simple and composite, are of the same base type.
- Kinematics and identity of a ReconstructedParticle should be independent.
- Identity of a ReconstructedParticle given by data member, not by the concrete class type.
- The identity of a ReconstructedParticle may be undefined.
- When defined it should be easy to change
  - after application of alternative ID algorithm.

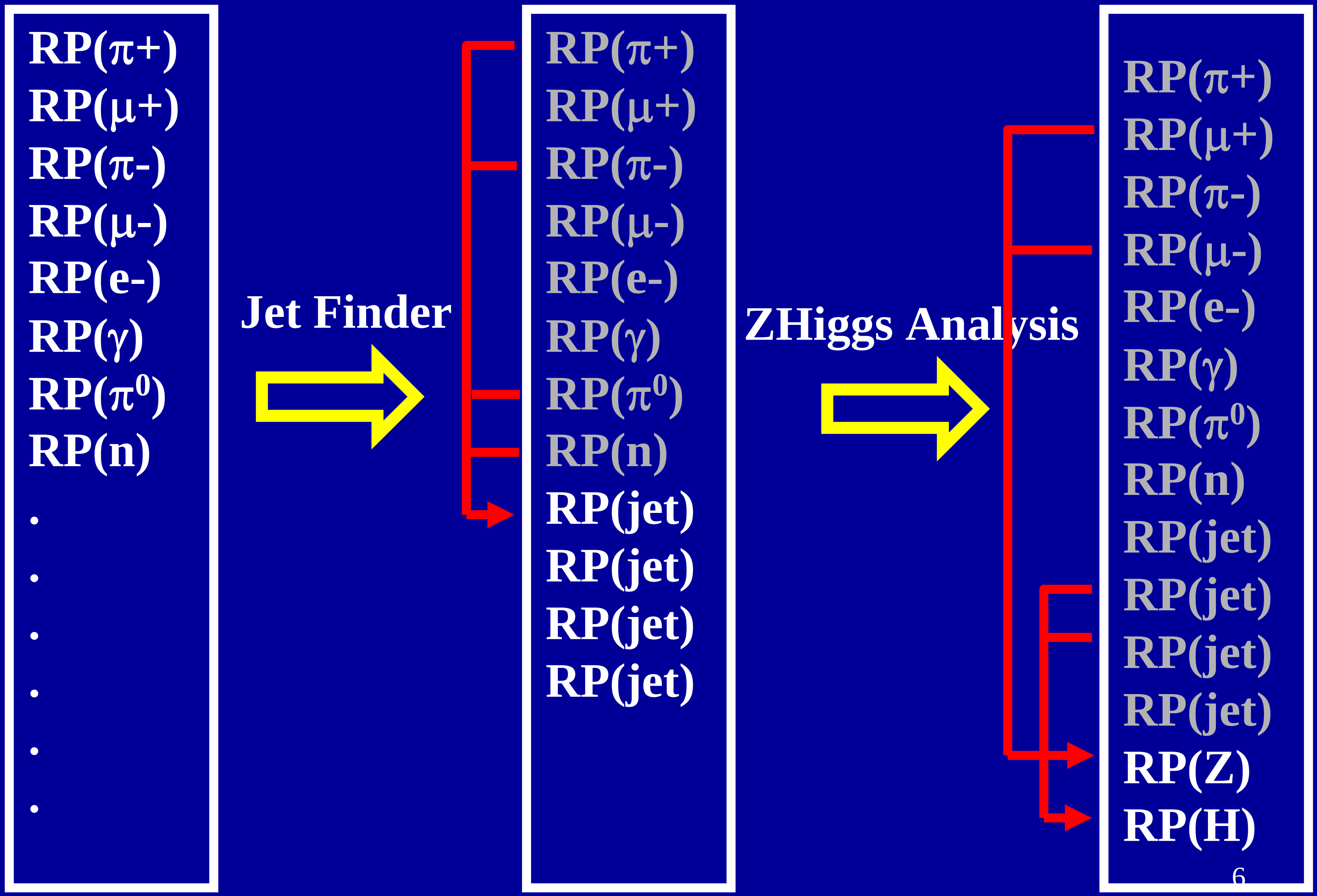
ReconstructedParticle I

- A class which encapsulates the behavior of an object which can be used for physics analysis.
  - mirrors MCParticle
- Kinematics determined by track momentum or calorimeter cluster energy at time of creation.
- ID determined later by particle ID algorithms, e.g. track dE/dx, cluster shape, or combination of detector element variables.
  - could entertain multiple hypotheses.

ReconstructedParticle II

- Can also be created from combinations of other ReconstructedParticles.
- e.g. Photon can be single EM cluster without associated track, or combination of e^+ and e^-, each composed of an EM cluster and a matching track.
- Resonances, when identifiable.
- Jets are also ReconstructedParticles.

Reconstruction Example



Photon ID

- Simple Nearest-Neighbor algorithm fails in busy events by growing indiscriminately.
  - Many-to-one particle-to-cluster relation
- Gradient clustering often partitions showers too finely
  - One-to-many particle-to-cluster relation
  - Requires tuning of connectivity
- Simple cone algorithm clusters cells in EM cal.
  - fast, efficient
  - ~decoupled from geometry system (uses (x,y,z))

Cone Algorithm

- Using fixed cone radius determined by effective Moliere radius of shower.
  - Radius could be based on energy of seed cell.
- Split clusters whose cones overlap by associating cells to nearest cone axis.
  - Could also search for NN clusters within cone.
- Necessity of merging being investigated.
- Clusters not pointing to origin can be flagged and handled separately.

Longitudinal HMatrix

- Use longitudinal energy depositions and their correlations to create a cluster χ^2.

$$M_{ij} = \frac{1}{N}\sum_{n=1}^{N}(E_i^{(n)} - \overline{E}_i)(E_j^{(n)} - \overline{E}_j)$$

$$H \equiv M^{-1}$$

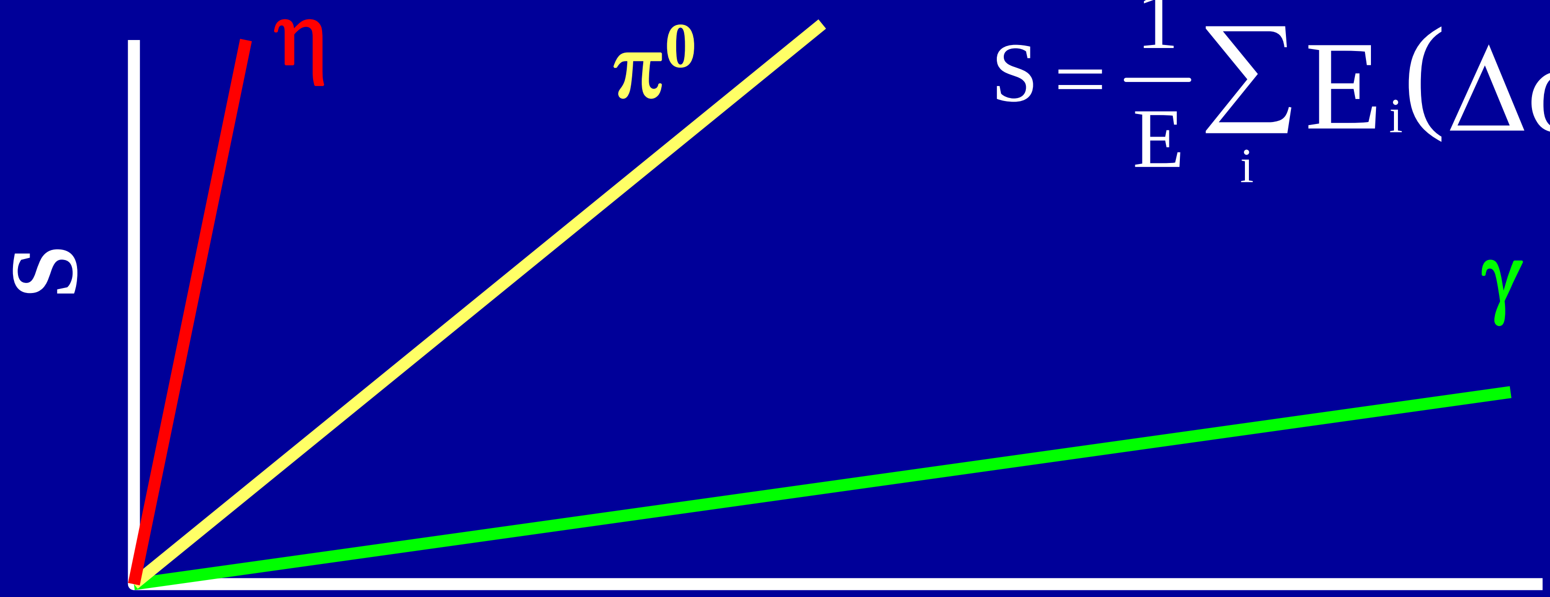
$$\zeta_m \equiv \sum_{i,j=1}^{N}(E_i^{(m)} - \overline{E}_i)H_{ij}(E_j^{(m)} - \overline{E}_j)$$

- Effective discriminant for EM showers.

e^-,γ,π^0 Differentiation

- Longitudinal shower development similar
- Charged track matching in E and position $\rightarrow e^-$
- Transverse shower shape differentiates γ,π^0
- Second moment:

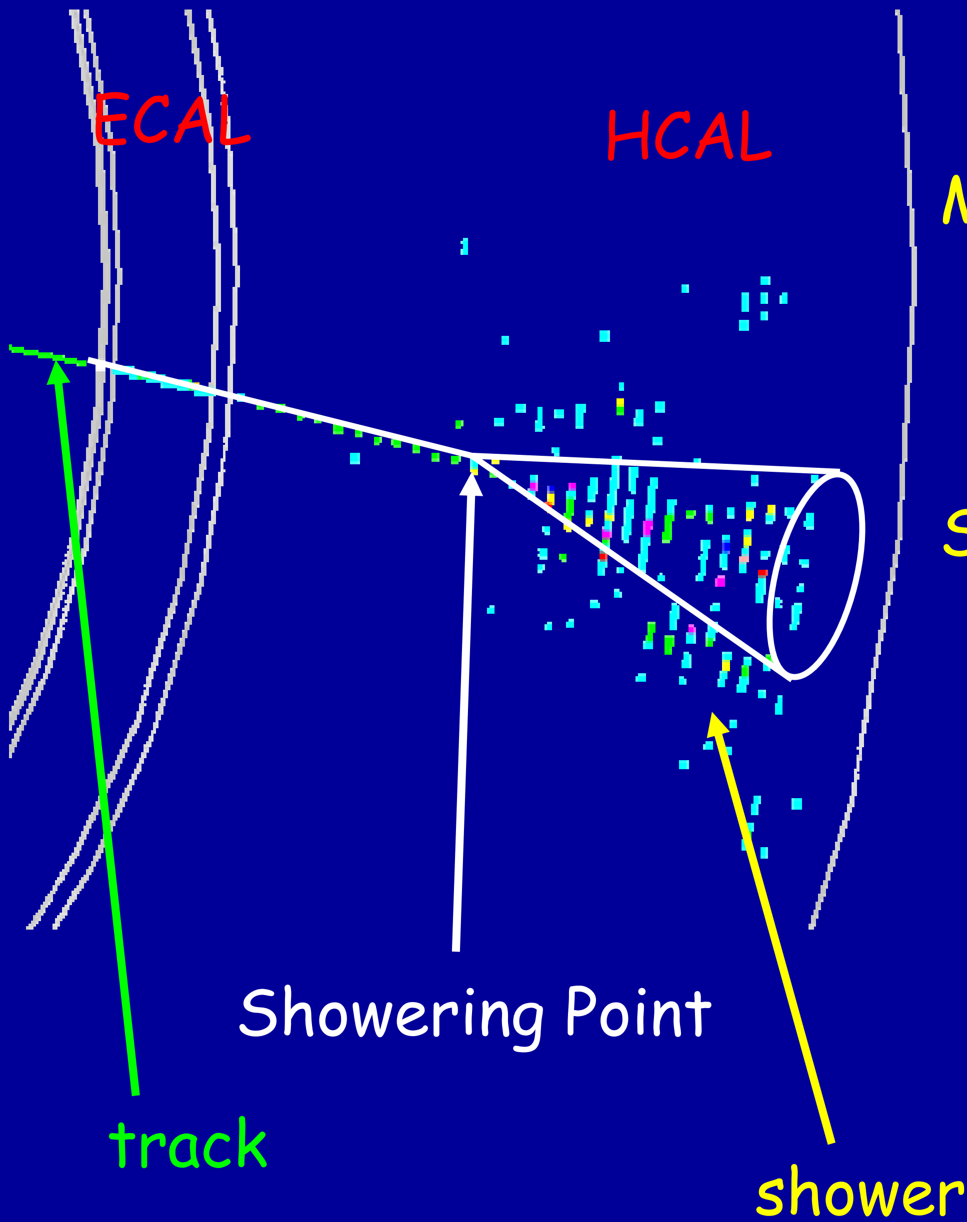
$$S = \frac{1}{E}\sum_i E_i(\Delta\alpha_i)^2$$



Photon Finding Summary

- ReconstructedParticle framework in place.
- Algorithms implemented and being qualified.
- Effects of detector designs (e.g. absorber/gap thicknesses, number of layers) on energy/position resolution and pattern recognition being studied.

Shower reconstruction by track extrapolation



MIP reconstruction:

Extrapolate track through CAL layer-by-layer.
Cluster MIP-consistent cells.

Shower reconstruction:

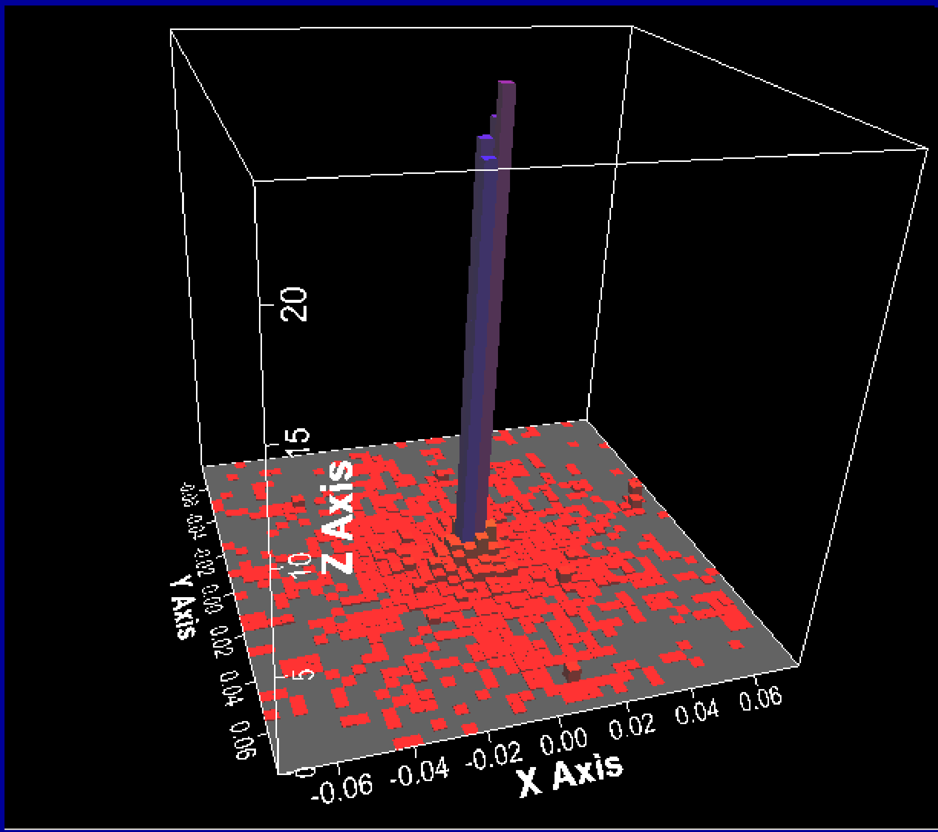
Define cones for shower in ECAL, HCAL after showering point as function of E and Λ traversed.
Follow MIP stars.
Cluster using MST.
Fuzzy Clustering to allow ambiguities.

Charged Hadron Id

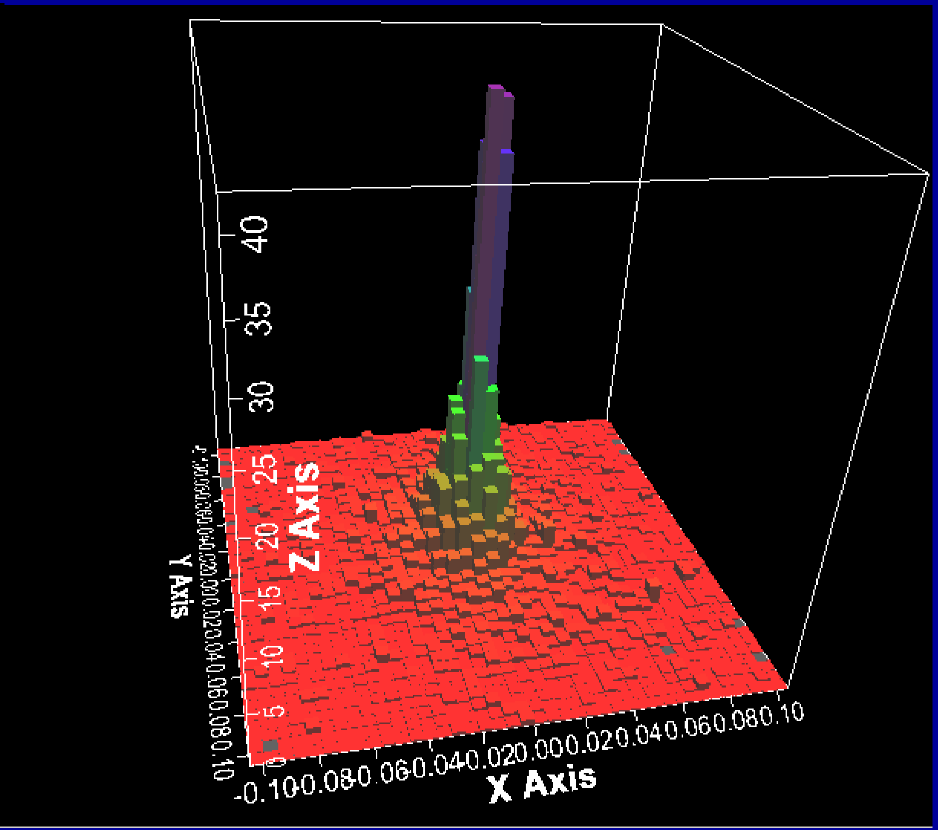
- Continuing to characterize pion shower shapes in calorimeters as function of momentum and direction.
- PionShower class developed to encapsulate the association of hit calorimeter cells with extrapolated tracks.
  - Follows MIP trace to shower start.
  - Characterize hit-track association with χ^2.
  - Allows association to proceed until a limit is reached on either match χ^2 or E/p.

Hadronic Shower Shapes

EM Layer 1



HAD Layer 13



Muon ID

- Software developed to identify stubs in muon system, extrapolates inward to find matching MIP traces in calorimeter.
- Same for extrapolating tracks outward.
- Swimmer accounts for multiple scattering and energy loss in calorimeter.

Neutral Hadron ID

- Investigating several options:
  - Non-Clustering
    - Define jet with tracks and EM, then simply sum up remaining calorimeter cells.
  - Cluster Remaining calorimeter cells
    - Nearest-Neighbor
    - Minimal Spanning Tree
    - Local Equivalence clustering
      - – Cell Density (digital HCAL)
      - – Cell Energy (EM, analog HCAL)

Prototype Reconstruction

```
public ReconstructedParticleJob(double radius, double
    seedEmin, double clusEmin, String hmxName, double
    clusEmin, double chisqmin, double trackdistmin)
    {
        // Smear Tracker hits with resolution
        add(new SmearDriver());
        // Find tracks
        add(new TrackReco());
        // build up the eflow event
        // sets up and populates the CalorimeterHitMap
        add(new EflowEventBuilder());
```

Prototype Reconstruction

```
    // Find muons
    add(new MuonFinder());
    // Find EM clusters using a simple cone algorithm
    add(new EMConeClusterBuilder(radius, seedEmin,
clusEmin));
    // Construct and identify the ReconstructedParticles
    // Photons, electrons, pi0
    add(new
EMParticleFinder(hmxName,clusEmin,chisqmin,trackdistmin));
    // charged hadrons
    add(new ChargedParticleFinder());
    // neutral hadrons
    add(new NeutralHadronFinder());
    // Physics!
    add(new EventAnalyzer());
}
```

Testing Samples

- Testing reconstruction on simple events. Study finding efficiency, fake rates and measurement resolutions (E, p, mass) using:
- Single Fundamental Particles
  - $e^{+/-}$, γ, $\pi^{+/-}$, $\mu^{+/-}$
- Simple Composite Single Particles
  - π^0, ρ, Σ, τ, ψ
- Complex Composite Single particles
  - Z, W
- Physics Events

Canonical Samples (Physics)

- $WW\nu\bar{\nu}$ and $ZZ\nu\bar{\nu}$ at 500 and 1000 GeV cms
  - Stresses jet mass resolution.
  - $VV\nu\bar{\nu}$ removes temptation to include beam constraint.
- $t\bar{t}$, $t\bar{t}h$ at 500GeV
  - Stresses pattern recognition and flavor tagging in busy environment.
- Zh at 500GeV
  - Recoil mass tests tracking resolution.
  - Branching ratios stress flavor tagging eff./purity.
- $\tau^+\tau^-$ exercises τ ID and τ polarization (SUSY, P_{higgs})

Summary

- Particle Flow algorithms being developed with minimal coupling to specific detector designs.
- Photon and muon reconstruction fairly mature.
- Emphasis on track-following for charged hadrons.
  - MIP reconstruction quite promising.
- Canonical data samples identified and will be used to characterize detector response.
- Systematic investigation of σ_{jet} as a function of $B^n R^m a^p l^q$ (B-field, Cal radius, Cal cell area, Cal longitudinal segmentation), material and readout technology employing a Particle Flow paradigm being undertaken.
- Code will be released as part of org.lcsim package.