Reconstruction Cheater Studies

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Outline

- ReconCheater

  – Tracking and Cluster cheaters

  – Event reconstruction algorithm

  – Cheating Table

- Z Pole event reconstruction

  – Comparison of CDC, GLD and SiD detectors

- W/Z Separation in WW and ZZ events.

  – W mass reconstruction for CDC and SiD detectors.

ReconCheater

Simulated GEANT4 events can be fully reconstructed by a **ReconCheater** that uses Monte Carlo truth to reconstruct individual particles. Charged tracks found by the **TrackingCheater** and calorimeter clusters found by the **ClusterCheater** are used to provide the basis for full event reconstruction. Various options and parameter settings in a Cheating properties file or **Cheating Table** for each detector are used to mix reconstructed tracks and clusters with Monte Carlo particles. Options for obtaining various measures of the neutral energy deposition, and for controlling decays and nuclear interactions are included.

To add the **ReconCheater** to a process, use

add(new org.lcsim.recon.cheater.ReconCheater());

The TrackingCheater and ClusterCheater drivers will be added by the ReconCheater.

To access reconstructed particles, use

event.get(ReconstructedParticle.class)

For more information see

http://confluence.slac.stanford.edu/display/ilc/Reconstruction+Cheater

TrackingCheater

For each <u>SimTrackerHit</u> in charged tracking devices, the **TrackingCheater** finds the MCParticle giving rise to the hits and creates a corresponding <u>CheatTrack</u>. It uses the <u>MCParticle</u>'s momentum vector to provide the track momentum required to satisfy the <u>FoundTrack</u> (and Track) interface.

The TrackingCheater finds combined tracks in all tracking devices that have SimTrackerHit's from the same MCParticle. The <u>CombinedTrack</u> object is similar to the CheatTrack except that it has additional methods to add and get CheatTracks from its internal list.

To add the TrackingCheater to a process, use

add(new org.lcsim.recon.ztracking.cheater.TrackingCheater());

To access tracks use

event.get(CombinedTrack.class).

ClusterCheater

For each SimCalorimeterHit in calorimeter devices, the **ClusterCheater** finds the MCParticle giving rise to the hits and creates a corresponding CheatCluster. The CheatCluster extends a BasicCluster class by adding a method to get the MCParticle that gave rise to the simulated hits. The BasicCluster itself adds the raw energy for each hit and provides methods required to satisfy the Cluster interface. It has additional methods to add and get individual Clusters from its internal list.

The ClusterCheater combines clusters from different calorimeters that have SimCalorimeterHit's from the same MCParticle. The resulting RefinedCluster collection is added to the event.

To add the ClusterCheater to a process, use

> *add(new org.lcsim.recon.cluster.cheater.CheatClusterDriver());*

To access reconstructed clusters use

> *event.get(CheatCluster.class).*

If more than one MCParticle is associated with a single hit, the entire hit is associated with the cluster belonging to the MCParticle that contributed the most energy to the hit. Note that there is currently no attempt to merge clusters that would in fact be impossible to resolve.

Event reconstruction

- Only those tracks and clusters that were reconstructed, e.g. by the corresponding cheaters, are used, so particles do get lost.

- For charged particle decays, the track from the primary particle is used if it was found, otherwise the secondary track is used, allowing neutrinos to carry away energy.

- For converted photons, the found tracks are used.

- At this stage, perfect energy flow is used where a cluster's parentage is checked to see if there is a charged track which should be associated.

- Nuclear interactions are turned off by default since the reconstruction is not optimized for them yet: for example

  - should low energy protons be ignored

  - can low energy neutrons be cut out,

  - can the leading particle be used to get an estimate of the corresponding neutral energy in the calorimeter.

The original particle (or reconstructed primary track if it's charged) is used and all secondary tracks and clusters are removed.

- Radiation is not allowed at this time.

Cheating Table

Options and parameter settings for **ReconCheater** are contained in a **Cheating.properties** file. The currently supported properties are:

Property	Default setting	Description
FullTruth	false	Use Monte Carlo particles only.
Truth	false	Use true energy for reconstructed particles.
ECalParameterization	false	Use a parameterization of ECal energy for found clusters.
ReconPhotons	true	Use reconstructed ECal energy for found clusters.
HCalParameterization	false	Use a parameterization of HCal energy for found clusters.
ReconNeutralHadrons	true	Use reconstructed ECal energy for found clusters.
Decays	true	Allow long-lived particles to decay.
DecayDistance	100.	Distance [mm] defines long-lived particles.
NuclearInteractions	true	Allow particles to interact.
NuclearInteractionProducts	true	Use charged particles from nuclear interactions.
NuclearInteractionNeutrals	true	Use neutral particles from nuclear interactions.
Radiation	false	Allow particles to radiate.
ECalResolution	0.18	Parameterized ECal resolution.
ECalSampling	0.012	Simulated ECal sampling fraction.
HCalResolution	0.60	Parameterized HCal resolution.
HCalSampling	0.	Simulated HCal sampling fraction.
HCalDigital	11.7	Simulated digital HCal response.
pTrackMin	0.100	Minimum reconstructed track momentum.
EClusterMin	0.100	Minimum reconstructed cluster energy.
NDigitalMin	4	Minimum number of digital HCal hits.

Detector Models

SiD

```
<detector id="2" name="EMBarrel" type="CylindricalBarrelCalorimeter"
                            readout="EcalBarrHits">
   <dimensions inner_r = "127.0*cm" outer_z = "179.5*cm" />
   <layer repeat="30">
     <slice material = "Tungsten" thickness = "0.25*cm" />
     <slice material = "G10" thickness = "0.068*cm" />
     <slice material = "Silicon" thickness = "0.032*cm" sensitive = "yes" />
     <slice material = "Air" thickness = "0.025*cm" />
   </layer>                                                      >
</detector>
```
W Si. 1X1 cm segmentation

CDC

```
<detector id="2" name="EMBarrel" type="CylindricalBarrelCalorimeter"
                            readout="EcalBarrHits">
   <dimensions inner_r = "127.0*cm" outer_z = "182.0*cm" />
   <layer repeat="20">
     <slice material = "Tungsten" thickness = "0.25*cm" />
     <slice material = "G10" thickness = "0.068*cm" />
     <slice material = "Silicon" thickness = "0.032*cm" sensitive = "yes" /
>
     <slice material = "Air" thickness = "0.025*cm" />
   </layer>
   <layer repeat="10">
     <slice material = "Tungsten" thickness = "0.50*cm" />
     <slice material = "G10" thickness = "0.068*cm" />
     <slice material = "Silicon" thickness = "0.032*cm" sensitive = "yes" /
>
     <slice material = "Air" thickness = "0.025*cm" />
   </layer>
```
W Si. 1X1 cm segmentation

```
<detector id="3" name="HADBarrel" type="CylindricalBarrelCal
                            readout="HcalBarrHits">
   <dimensions inner_r = "138.5*cm" outer_z = "277.0*cm" />
   <layer repeat="34">
     <slice material = "Steel235" thickness = "2.0*cm" />
     <slice material = "G10" thickness = "0.3*cm" />
     <slice material = "PyrexGlass" thickness = "0.11*cm" />
     <slice material = "RPCGasDefault" thickness = "0.12*cm" sen

     <slice material = "PyrexGlass" thickness = "0.11*cm" />
     <slice material = "Air" thickness = "0.16*cm" />
   </layer>
</detector>
```
Steel RPC 5X5 cm segmentation

```
<detector id="3" name="HADBarrel" type="CylindricalBarrelCal
                            readout="HcalBarrHits">
   <dimensions inner_r = "141.0*cm" outer_z = "257.0*cm" />
   <layer repeat="50">
     <slice material = "Tungsten" thickness = "0.75*cm" />
     <slice material = "Polystyrene" thickness = "0.50*cm" sensitiv
     <slice material = "G10" thickness = "0.25*cm" />
   </layer>
</detector>
```
W Scin. 5X5 cm segmentation

Detector Models cont.

GLD

```
<detector id="4" name="TPC" type="TPC" readout="TPCHits">
   <dimensions inner_r = "43.715*cm" outer_z = "260.0*cm" />
   <layer repeat="200">
    <slice material="P10" thickness="0.7703*cm" sensitive="true" />
   </layer>
</detector>
<detector id="2" name="EMBarrel" type="CylindricalBarrelCalorimeter"
                        readout="EcalBarrHits">
   <dimensions inner_r = "210.0*cm" outer_z = "289.0*cm" />
   <layer repeat="38">
    <slice material = "Lead" thickness = "0.4*cm" />
    <slice material = "Polystyrene" thickness = "0.1*cm"  sensitive = "yes" />
   </layer>
</detector>
```

Pb Scin. 1X1 cm segmentation

```
<detector id="3" name="HADBarrel" type="CylindricalBarrelCal
                        readout="HcalBarrHits">
   <dimensions inner_r = "229.5*cm" outer_z = "419.5*cm" />
   <layer repeat="130">
    <slice material = "Lead" thickness = "0.8*cm" />
    <slice material = "Polystyrene" thickness = "0.2*cm"  sensitiv
   </layer>
</detector>
```

Pb Scin. 5X5 cm segmentation

LDC

```
<detector id="4" name="TPC" type="TPC" readout="TPCHits">
   <dimensions inner_r = "36.2*cm" outer_z = "250.0*cm" />
   <layer repeat="200">
    <slice material="P10" thickness="0.628*cm" sensitive="true" />
   </layer>
</detector>
<detector id="2" name="EMBarrel" type="CylindricalBarrelCalorimeter"
                        readout="EcalBarrHits">
   <dimensions inner_r = "175.0*cm" outer_z = "296.55*cm" />
   <layer repeat="20">
    <slice material = "Tungsten" thickness = "0.25*cm" />
    <slice material = "G10" thickness = "0.068*cm" />
    <slice material = "Silicon" thickness = "0.032*cm" sensitive = "yes" />
    <slice material = "Air" thickness = "0.025*cm" />
   </layer>
</detector>
```

W Si. 1X1 cm segmentation

```
   <layer repeat="10">
    <slice material = "Tungsten" thickness = "0.50*cm" />
    <slice material = "G10" thickness = "0.068*cm" />
    <slice material = "Silicon" thickness = "0.032*cm" sensitive =
    <slice material = "Air" thickness = "0.025*cm" />
   </layer>
</detector>
<detector id="3" name="HADBarrel" type="CylindricalBarrelCal
                        readout="HcalBarrHits">
   <dimensions inner_r = "189.0*cm" outer_z = "319.0*cm" />
   <layer repeat="50">
    <slice material = "Tungsten" thickness = "0.75*cm" />
    <slice material = "Polystyrene" thickness = "0.50*cm" sensitiv
    <slice material = "G10" thickness = "0.25*cm" />
   </layer>
</detector>
```

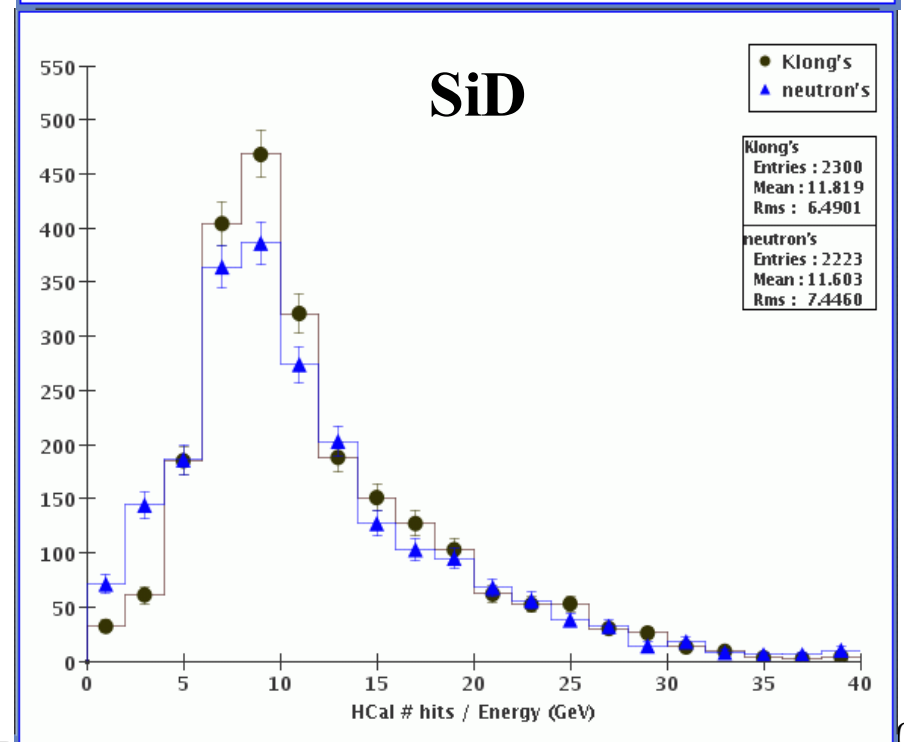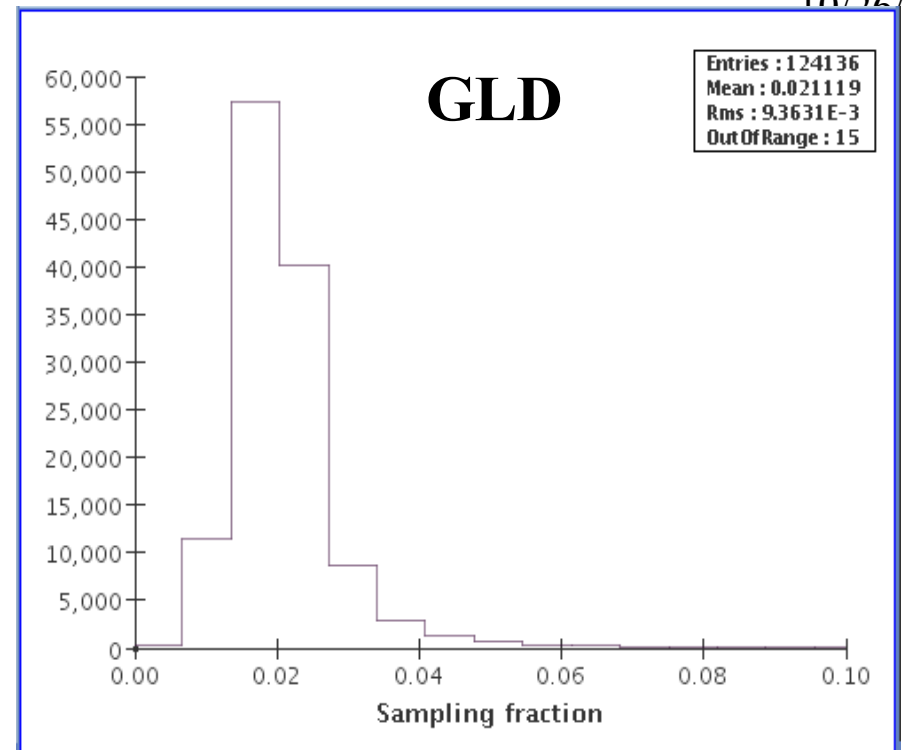**W Scin. 5X5 cm segmentation**

9

Calibration

Detector specific calibration factors are used to convert the simulated calorimeter measurements to reconstructed neutral energy.

For the ECal, Monte Carlo photons are used to determine the sampling fraction.

Both Monte Carlo Klong's and neutrons are used to calibrate the HCal. An energy sampling fraction is used for an analog HCal, while the number of hits per GeV is used for a digital HCal.

Typical sampling fractions and hit ratios are:

	ECal	HCal
CDC	0.012	36 hits/GeV
GLD	0.02	0.045
SiD	0.012	11.7 hits/GeV

GLD

Entries : 124136
Mean : 0.021119
Rms : 9.3631E-3
Out Of Range : 15

SiD

● Klong's
▲ neutron's

Klong's
Entries : 2300
Mean : 11.819
Rms : 6.4901

neutron's
Entries : 2223
Mean : 11.603
Rms : 7.4460

Z pole event reconstruction

The **ReconCheater** was used to reconstruct events simulated at the Z pole. Here the true Monte Carlo momentum was used for tracks, while the energy of ECal clusters was derived from the deposited energy. The HCal energy response was parameterized for all 3 detectors with a resolution of 60%/√E.

The resulting Z total energy resolution was 2.1 GeV for all 3 detectors.
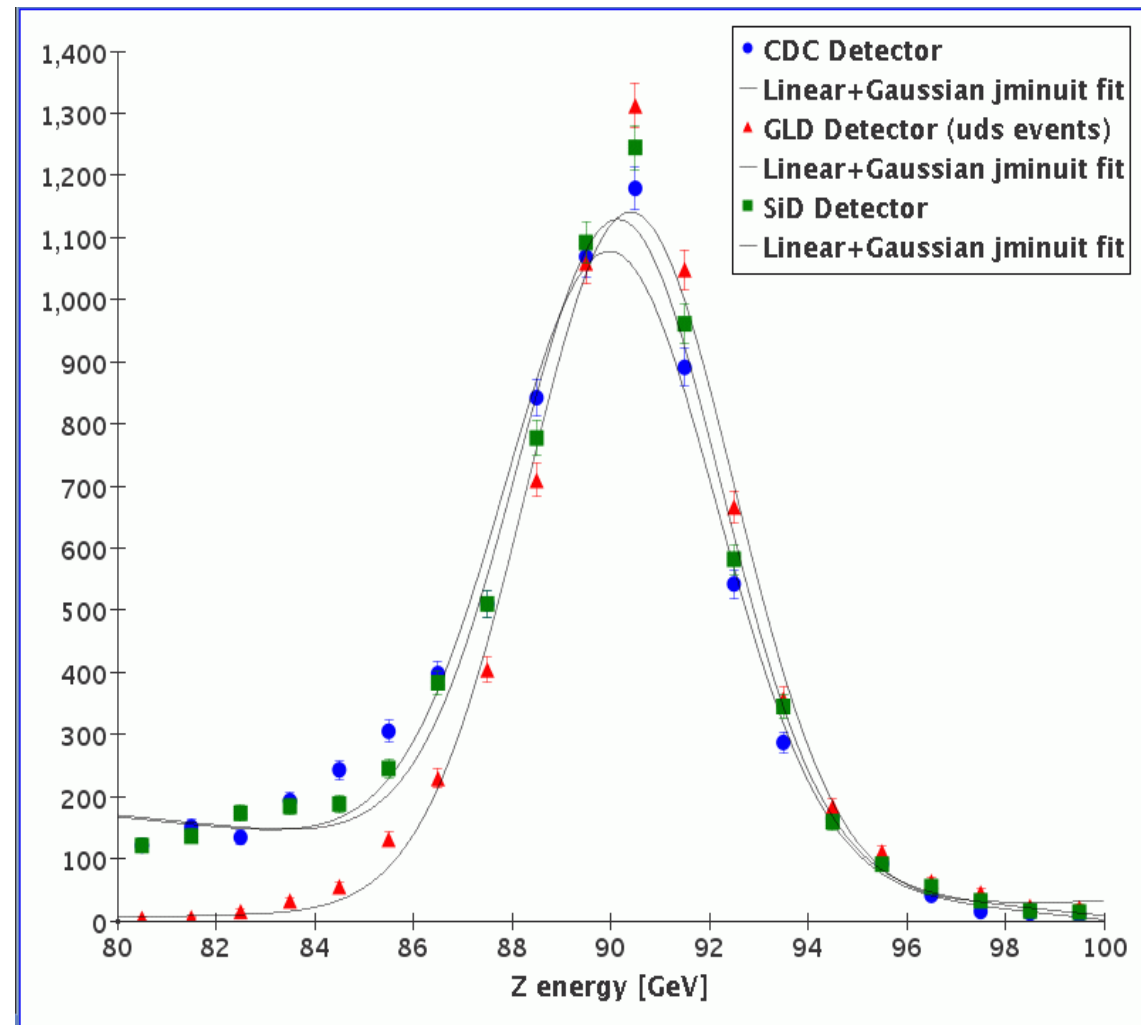
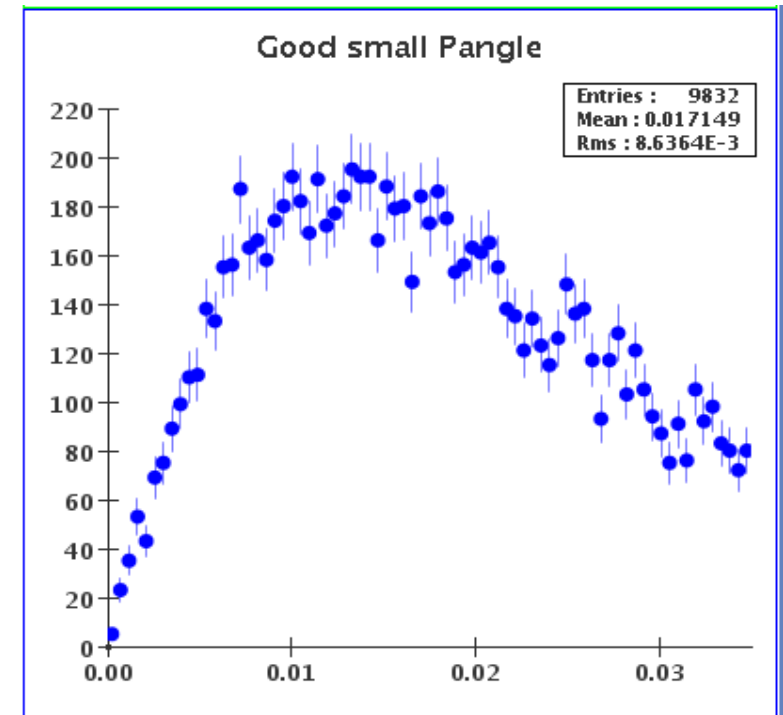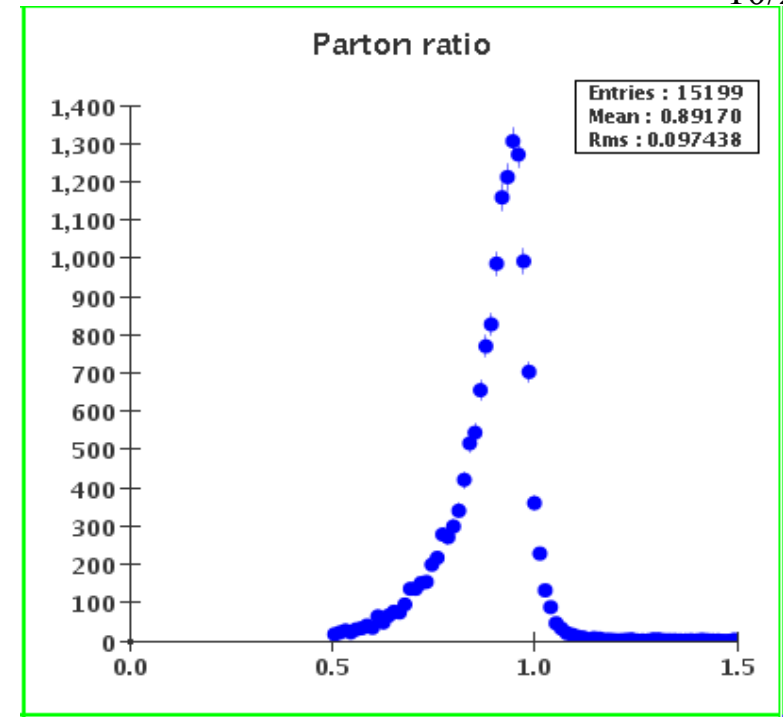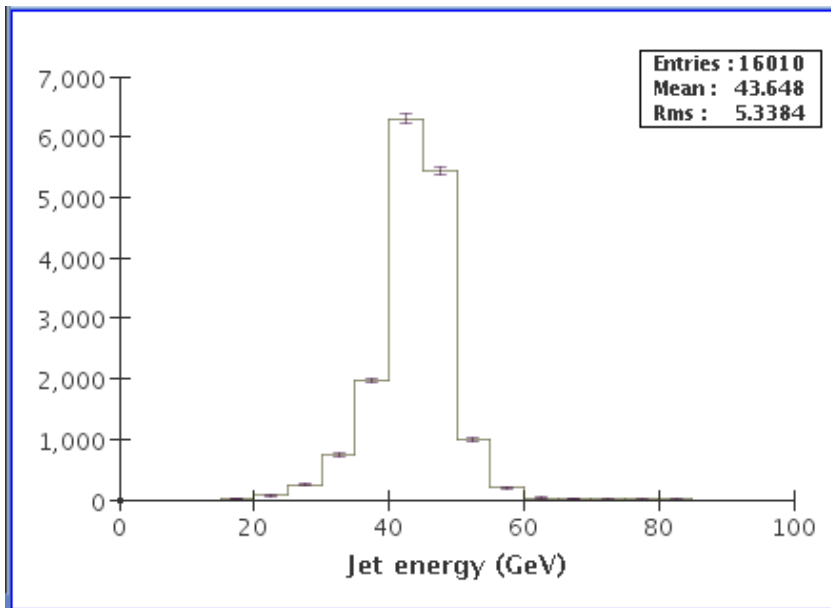Total energy reconstruction for Z pole events. Only uds decays were simulated for the GLD detector.

Z pole jets

Use JadeE jet finder for Z pole events. Require no more than 2 jets.

The ratio of the jet energy to the primary quark energy is nicely peaked at 1. The low energy tail is due to bbbar and ccbar decays.

The space angle between the reconstructed jet and the quark direction is less than about 30-40 mrad.

The average reconstructed quark jet energy is 43.6 GeV.

Parton ratio

Entries : 15199
Mean : 0.89170
Rms : 0.097438

Jet energy (GeV)

Entries : 16010
Mean : 43.648
Rms : 5.3384

Good small Pangle

Entries : 9832
Mean : 0.017149
Rms : 8.6364E-3

W/Z Separation Studies

High energy e^+e^- --> WW and ZZ events have been fully simulated to study the ability of the detectors to separate W's from Z's in a multi-jet environment.

Events are selected by a thrust cut of $\cos\theta_{thrust} < 0.9$ determined from the Monte Carlo particles.

The **ReconCheater** is used to reconstruct the event and produce a list of reconstructed particles. The total event energy provides a good measure of the overall event reconstruction.

Jets are found from these particles, and W and Z's are reconstructed from jet-jet mass combinations.

WW / ZZ Event energy

As in Z pole events, the simulated measurement of the total event energy provides a good measure of the overall event reconstruction.

Here one sees measurements of WW and ZZ event energies for 4 different types of event reconstruction:

MCParticles
Smeared A   30%/√E
Smeared B   45%/√E
Cheated reconstruction

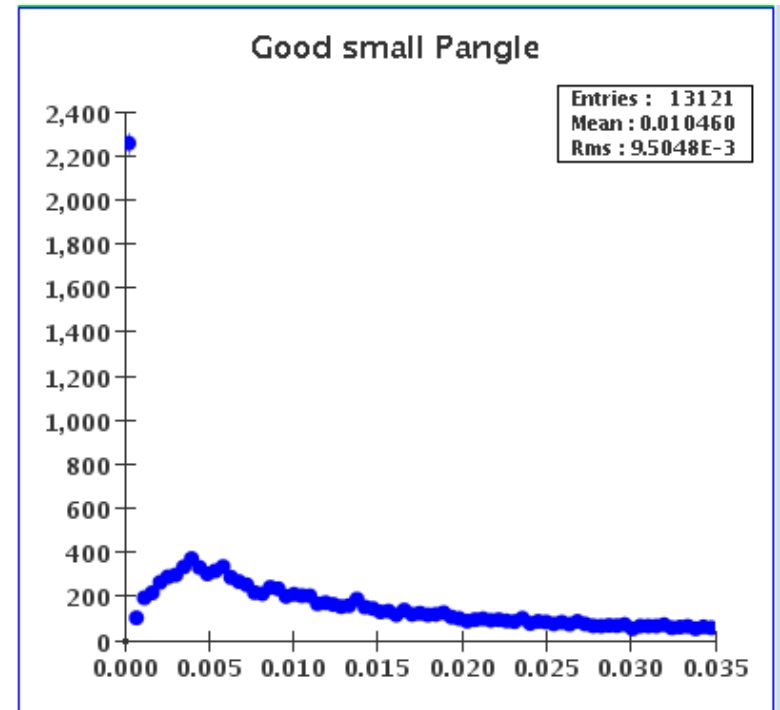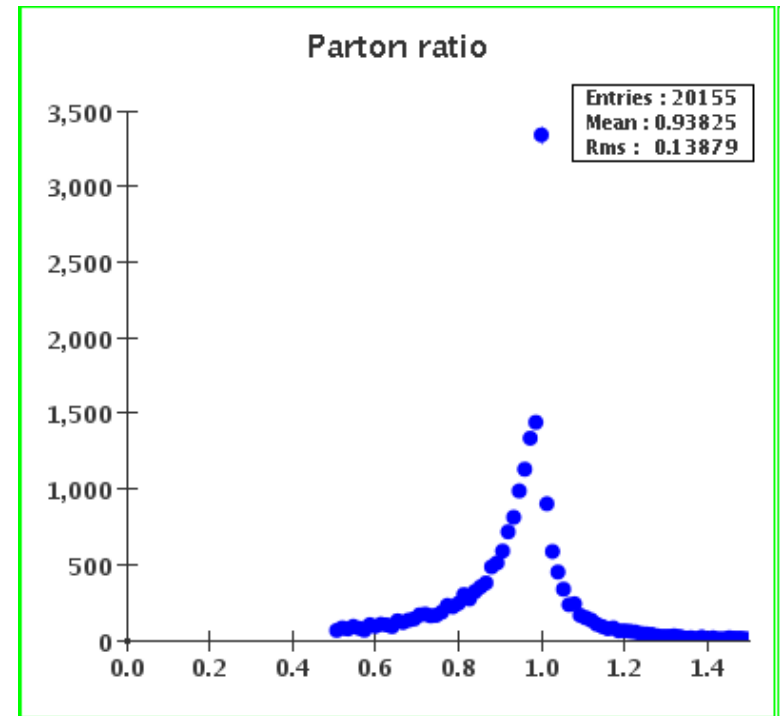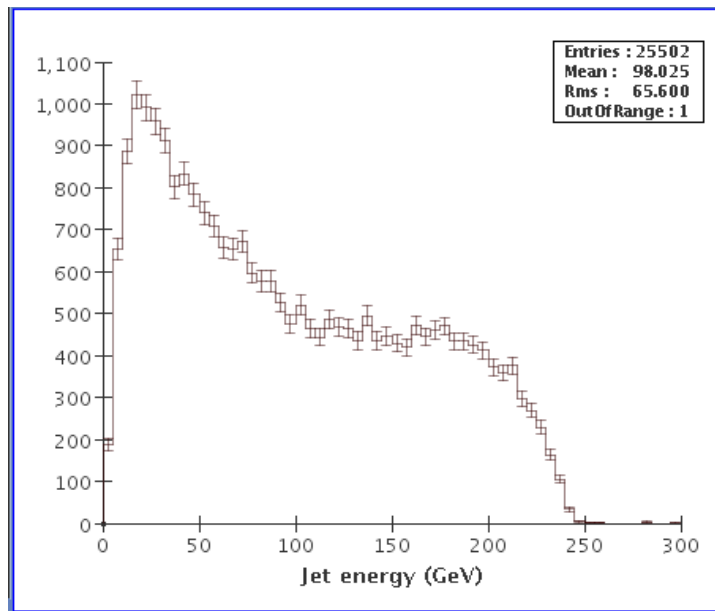From the high energy edge of the distributions one can see that the **ReconCheater** provides a better event reconstruction than that obtained from smeared jets.
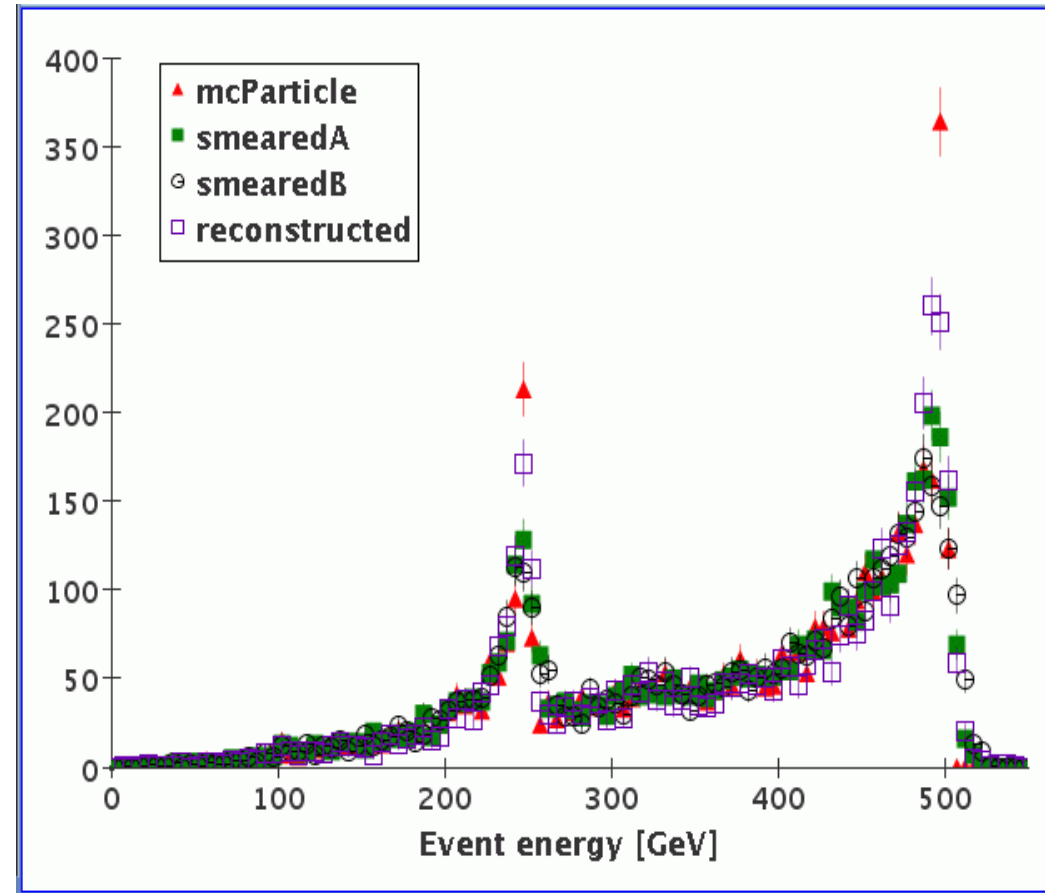
Total reconstructed event energy for WW and ZZ events. The peak at half the CM energy is due to events where one of the Z's decays into neutrinos.

Jet finding

The JadeE jet finder is used for high energy multi-jet WW and ZZ events. A requirement of no more than 4 jets provides a good reconstruction of the underlying jet structure.

The ratio of the jet energy to the primary parton energy is nicely peaked at 1. The space angle between the reconstructed jet and the parton jet is less than about 20 mrad. Note there is little angular error for single particle lepton jets from W and Z decays.

The average jet energy is about 100 GeV.

Parton ratio

Entries : 20155
Mean : 0.93825
Rms : 0.13879

Good small Pangle

Entries : 13121
Mean : 0.010460
Rms : 9.5048E-3

Entries : 25502
Mean : 98.025
Rms : 65.600
Out Of Range : 1

Jet energy (GeV)

W mass reconstruction

The jet-jet W mass reconstruction obtained from the **ReconCheater** is shown with and without nuclear interactions.

There are slight differences between the two simulations. Since the reconstruction of interacting charged particles is not well understood at this time, nuclear interactions are turned off by default in overall event reconstructions.

Find 1.5 nuclear interactions per event.

SiD

GLD

Entries : 7731
Mean : 1.4731
Rms : 1.3695
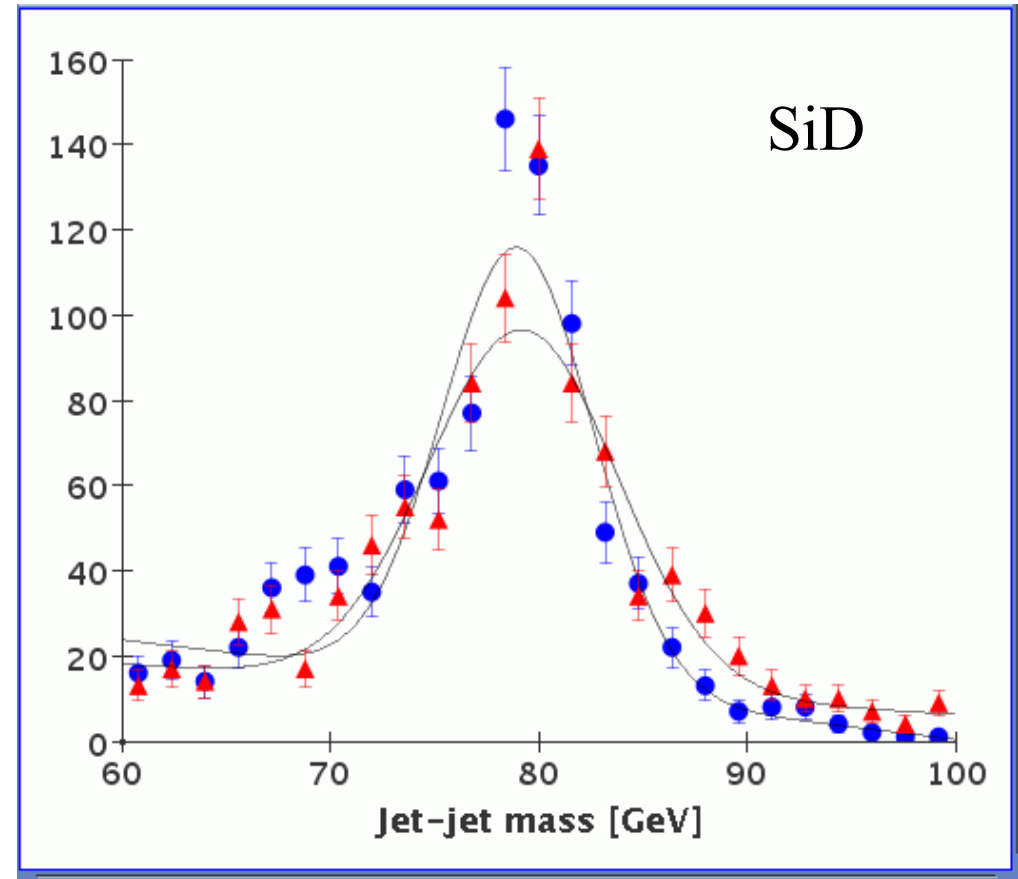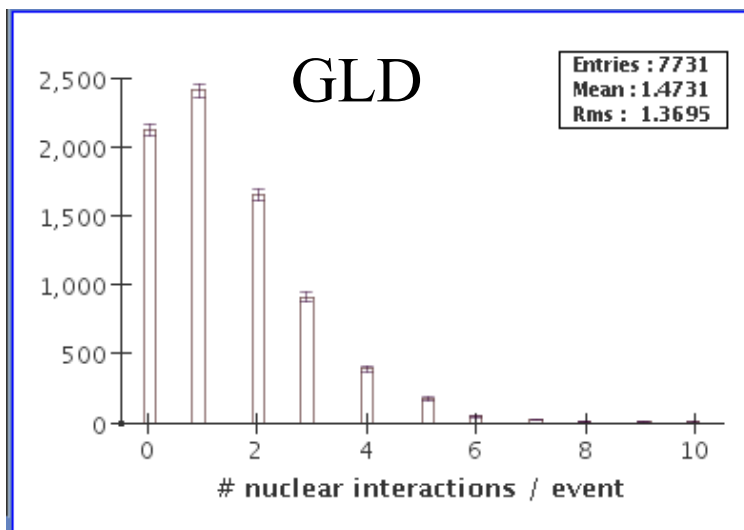
W Mass reconstruction cont.

High energy WW events simulated for the Compact CDC and Silicon SiD detectors have been reconstructed using the **ReconCheater** with parameterized HCal resolutions of 60%/√E.

W jet-jet mass resolutions of about 2.2 GeV are found for both detector models.

Note the difference in normalization is due to different numbers of events simulated for the two detectors.
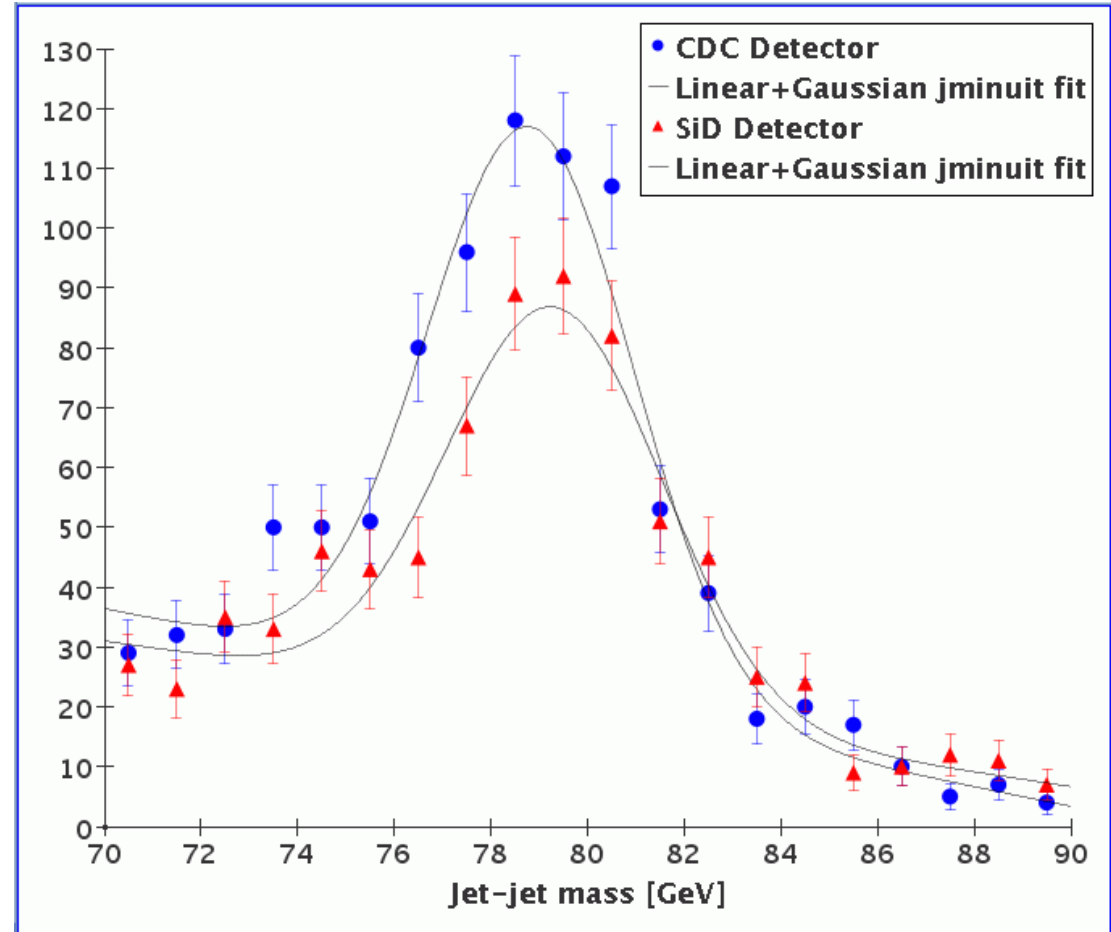
Missing neutral hadrons

High energy WW events simulated for the Compact CDC detector have been reconstructed using the **ReconCheater** with parameterized HCal resolutions of 60%/√E and a simple algorithm for missing neutral hadrons.

Allowing for the loss of neutral hadrons close to clusters with 2-4X energy, the W jet-jet mass resolution degrades from 2.14 to 2.63 GeV, as shown.
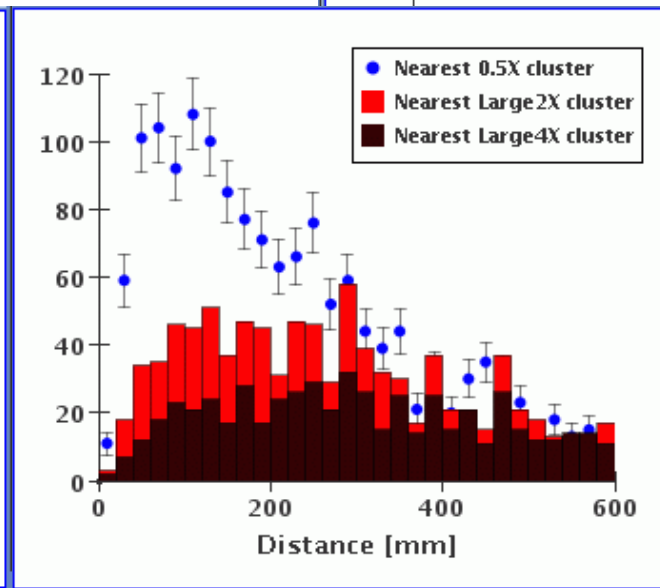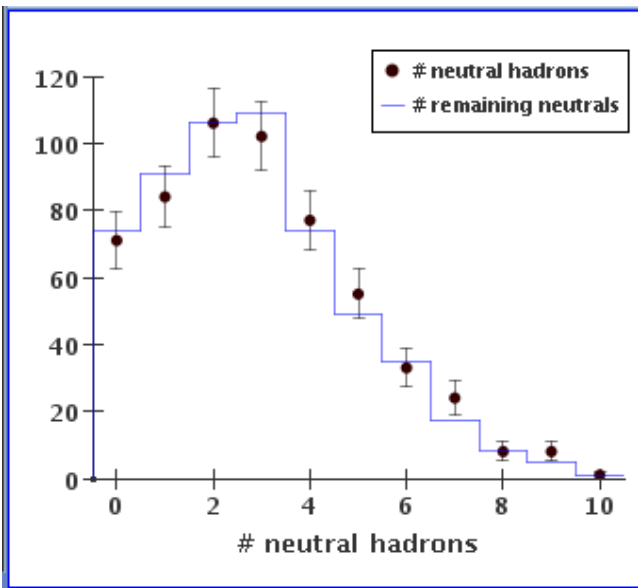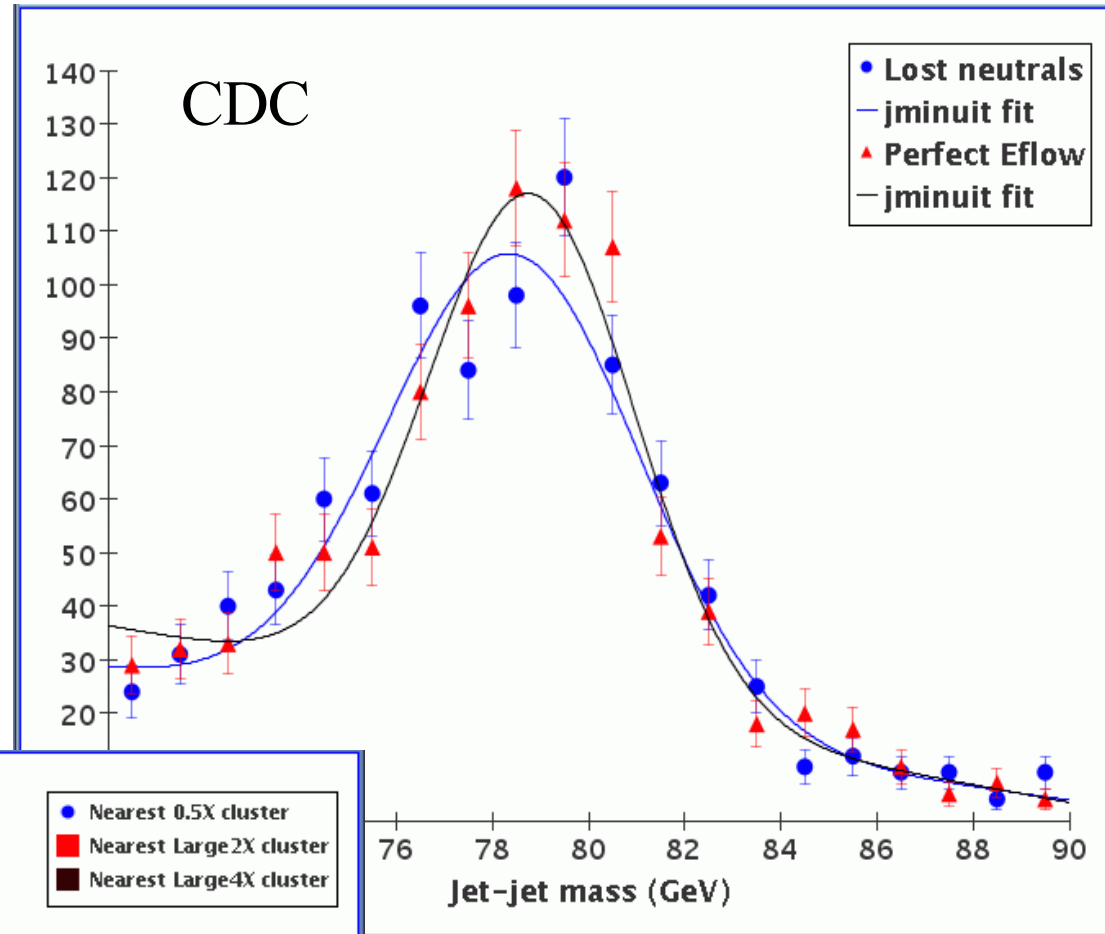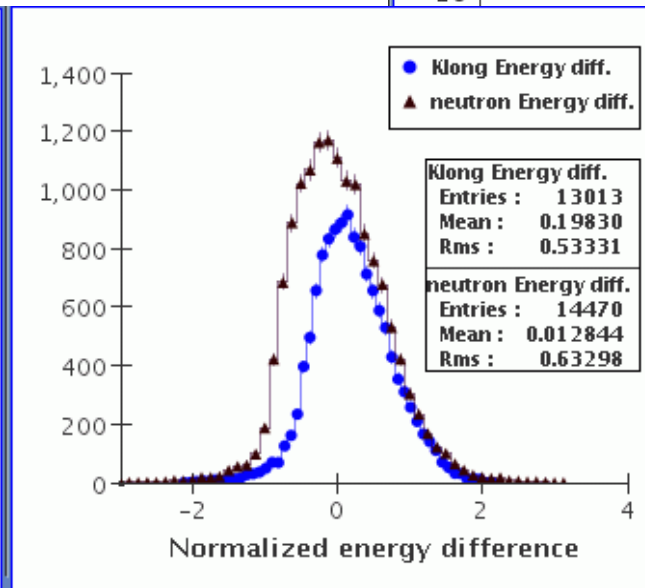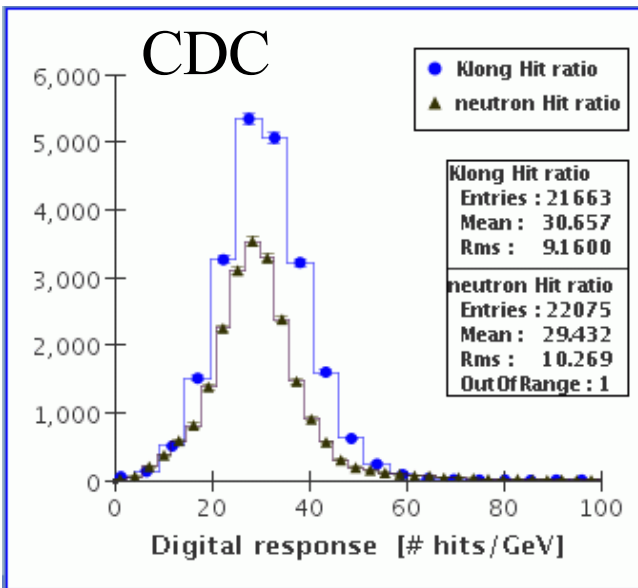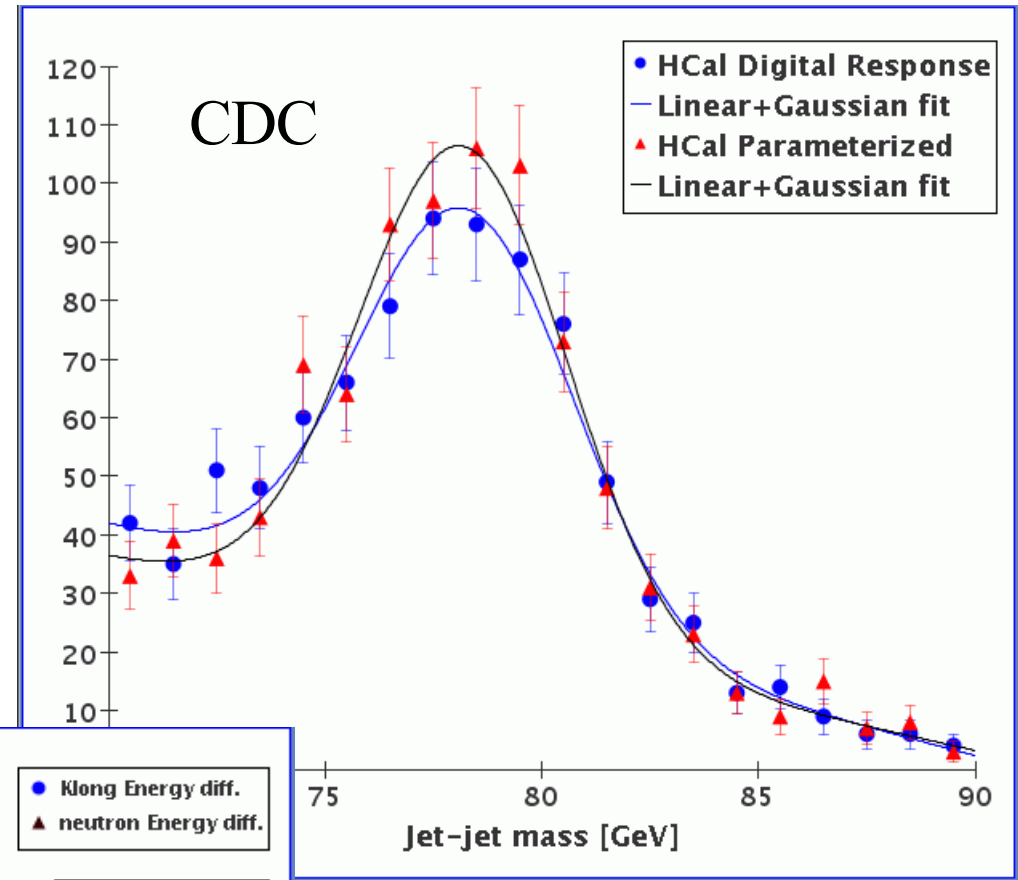

At left, # neutral hadrons per event before and after distance cuts of 50 and 100 mm for greater than 2X or 4X energy clusters, respectively. Distance plot is shown for lower energy clusters and for those with 2X and 4X neutral hadron energy.

HCal reconstructed energy

Digital HCal cluster energies are determined using an energy cut on each hit which contributes. Here the jet-jet W mass reconstruction compares a parameterized 60%/√E response with a digital reconstruction.

The jet-jet mass distribution is fit with a Gaussian and a linear background just below and above the peak. The W mass resolution is found to be 2.4 GeV for both cases.


CDC

- HCal Digital Response
- Linear+Gaussian fit
- HCal Parameterized
- Linear+Gaussian fit

Jet–jet mass [GeV]

CDC

- Klong Hit ratio
- neutron Hit ratio

Klong Hit ratio
Entries : 21663
Mean : 30.657
Rms : 9.1600

neutron Hit ratio
Entries : 22075
Mean : 29.432
Rms : 10.269
Out Of Range : 1

Digital response [# hits/GeV]

- Klong Energy diff.
- neutron Energy diff.

Klong Energy diff.
Entries : 13013
Mean : 0.19830
Rms : 0.53331

neutron Energy diff.
Entries : 14470
Mean : 0.012844
Rms : 0.63298

Normalized energy difference

At left, digital HCal response for Klong's and neutrons, averaging to 30 hits/GeV. Reconstructed Klong's and neutrons with 1<E<10 GeV normalized as $\sqrt{E} * (E_{meas} - E)/E$ indicating a HCal resolution of about 60%/√E.

W/Z Separation

At upper right, the W/Z separation obtained for high energy WW and ZZ events reconstructed by the **ReconCheater** with perfect particle flow and a HCal response parameterized as 60%/√E is better than that obtained for MCParticle jets smeared with a resolution of 30%/√E, upper left.

At lower right, the separation is maintained with a simulation of a loss of neutral hadrons due to confusion in reconstructing the particle flow.
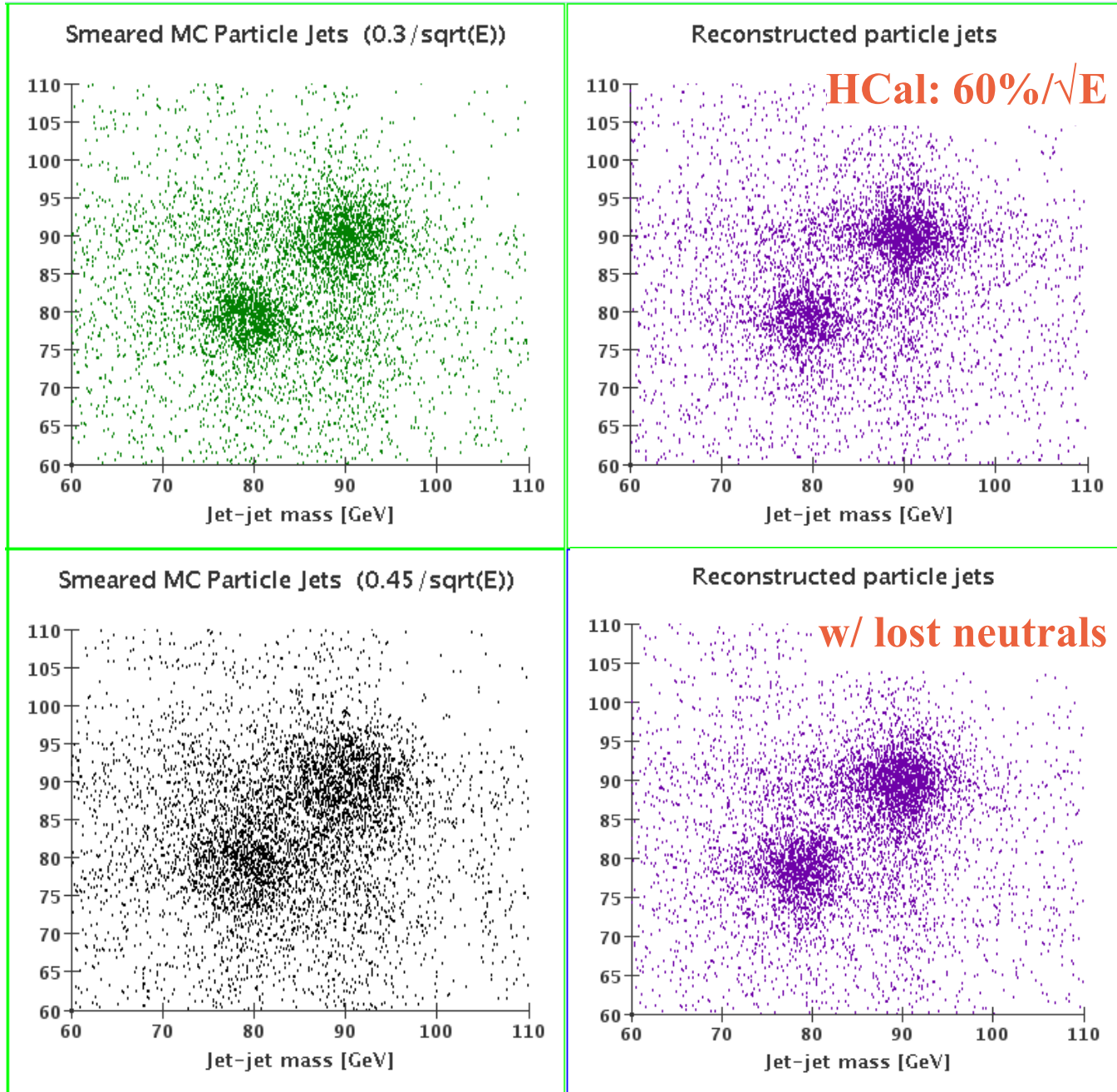
Plans

- Generate full LDC and GLD geometry descriptions for Z pole and WW/ZZ simulations.

- Tune up HCal reconstructed energy determination.

- Develop algorithms to simulate particle flow confusion.

- Continue to make **ReconCheater** more realistic.