Event Reconstruction in SiD02 with a Dual Readout Calorimeter

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Detector Geometry
EM Calibration
Cerenkov/Scintillator Correction
Jet Reconstruction Performance
Dual Readout Detector Geometry

Dual Readout Calorimeter *in SiD02 Shell (Barrel and EC)*

**DR ECAL**
- 3 cm x 3 cm x 3 cm BGO
- 8 layers – 21.4 $X_0$ (1.1 $\lambda_I$)
- 127 cm IR – 151 cm OR
- Scin/Ceren analog hits

**DR HCAL**
- 6 cm x 6 cm x 6 cm BGO
- 17 layers – 4.6 $\lambda_I$
- 151 cm IR – 253 cm OR
- Scin/Ceren analog hits

Muon Chambers – 11 layers

HCAL – 17 layers

ECAL – 8 layers

255 cm
Cerenkov Collections

Ceren_HcalBarrHits

Ceren_EcalBarrHits

Scintillator Collections

Edep_HcalBarrHits

Edep_EcalBarrHits

Muons

Cerenkov EM,HAD

Deltas

mips

Scintillator EM,HAD

dE/dx ~ 27 MeV
3 cm of BGO

Deltas

mips

DigiSim - ½ MeV threshold (scin, *ceren*), 100 ns timing cut

Ceren_HcalBarrDigiHits

Ceren_EcalBarrDigiHits

Edep_HcalBarrDigiHits

Edep_EcalBarrDigiHits
$e^+e^- \rightarrow ZZ \rightarrow \nu\nu qq$ @ 500 GeV

Scintillator Hits

DigiSim

Cerenkov Hits

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Electron Calibration for Scintillator, Cerenkov

10 GeV electrons
\( \sigma/E = 0.017 \) Scintillator
\( \sigma/E = 0.052 \) Cerenkov

\[ S = 1.004 \times s_{\text{raw}} \]
\[ C = 7692 \times c_{\text{raw}} \]

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Cerenkov/Scintillator Correction for Hadrons

S/E slices in em fraction (C/S) bins

5, 10, 20, 50, 100 GeV pions

Note: fluctuations in shower em fraction > fluctuations in had fraction at any fixed em fraction

S (e calibrated scintillator response)
-> em and had visible energy
C (e calibrated cerenkov response)
-> em part of shower
C/S = em fraction of visible energy
S/E = total fraction of energy seen
Polynomial Correction Functions: \( E = \frac{S}{P_n} \)

- \( \text{em fraction} = 1 \)
- \( S/E, \ C/S = 1 \) -> calibration

Mean and \( \sigma/\text{mean of fit} \) in each \( C/S \) bin plotted -> resolution improves with \( \text{em fraction} \)

\[
\begin{align*}
P1 &= 0.315 + 0.684(C/S) \\
P2 &= 0.677 - 0.439(C/S) + 0.762(C/S)^2 \\
P3 &= 0.506 + 0.608(C/S) - 1.050(C/S)^2 - 0.935(C/S)^3 \\
P4 &= 0.577 - 0.149(C/S) + 1.464(C/S)^2 - 2.302(C/S)^3 + 1.410(C/S)^4
\end{align*}
\]
Corrected Scintillator signal for pions using P3 Polynomial

\[ \sigma/E \sim 0.08 \]

\[ \sigma/E \sim 0.07 \]

\[ \sigma/E \sim 0.05 \]
Jet Corrections in Dual Readout Detector

\[ \langle C/S \rangle \approx 0.8 \]

\[ \text{Correction factor} \approx 1.25 \]

C/S (em fraction)

C/S \approx 1
Correction factor 1.0

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DiJet Mass: $e^+e^- \rightarrow ZZ \rightarrow qq\nu\nu$ @ 500 GeV

C/S correction per jet
No PFA

$\Delta M/M = 0.076$

$\sigma/M = 0.078$

$\Delta E/E = 0.036$

No leakage correction yet
PFA Possibility? - MC Particle Contribution to DR Cal Cells

Scintillator Hit Collections

All Hits

Multiple Particles

Cerenkov Hit Collections

All Hits

Multiple Particles

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PFA in Dual Readout Calorimeter

PFA Template developed for SiD and variants:

- Fully modular construction
- Common IO for all modules:
  - Mip-finding/Track Endpoint, Cluster Algorithms, Cluster pointing, Core cluster matching, Track-Shower association, Cut-based photon ID, H-Matrix photon ID, Neutral hadron finding

- All modules run on both Dual Readout collections with zero -> minimal modifications

First use of PFA: Mip-finder Track endpoint determination -> $\Delta M$ correction from charged particles in event (see Adam Para’s talk later) or per jet

Same parameters as for SiD, only modification was to change collection names

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20 GeV pion shower in Dual Readout Calorimeter

Scintillator Cluster

Cerenkov Cluster

Note: Cerenkov shower starts at end of track (blue line), scintillator shower overlaps track end
Interaction layer determined by either 0 or multiple hits in layer in a window defined by the position of extrapolated track ~ 1 layer deeper using Cerenkov hits

Scintillator mean = 1.5
Cerenkov mean = 2.3
Both Mip EPs shallower than track EP, but average Cerenkov Mip EP closer to track endpoint, again by 5 cm which is 1 layer in the ECAL
Mip Cluster compared to Hit Collections

Mip cluster in EM Cal found with Cerenkov hits

Track Endpoint

Mip Cluster Hits

Cerenkov hits (including mip cluster)

Scintillator hits

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DiJet Mass: $e^+e^- \rightarrow ZZ \rightarrow q\bar{q}ν\bar{ν}$ @ 500 GeV

C/S correction per jet
PFA Mip finder -> $\Delta M$ per jet

$\sigma/M = 0.062$

$\Delta M/M = 0.062$

$\Delta E/E = 0.035$
DiJet Mass: $e^+e^- \rightarrow ZZ \rightarrow q\bar{q}νν \ @ 500 \ GeV$

C/S correction per cluster
Jet finding with corr. clusters
PFA Mip finder -> $\Delta M$ per jet

$\sigma/M = 0.058$

$\Delta M/M = 0.059$

$\Delta E/E = 0.029$
Nearest Neighbor Clustering

Scintillator Clusters

Cerenkov Clusters
Clusters Associated with Charged Particles (Tracks)

Mip clusters

Track-associated clusters

Uses: Core Cluster Algorithm, Cluster-Pointing Algorithm, E/P, etc.
Cluster correction – can use merged cerenkov clusters linked with merged scintillator clusters to apply polynomial correction.
~ Z-Pole performance – C/S + PFA Mip-finder
104 GeV (Total E) Zs @ 90 degrees, Z -> qq

Detector – CCAL002
CAL Threshold – 1/50 mip
CAL Timing cut – 100 ns

\[ \sigma/E = 0.019 \]

\[ \text{Diff Corrected Event E MC RecoP E} \]
Entries : 1017

\[ \text{gauss} \]
\[ \text{mean} : \quad -6.3869 \pm 8.599E-4 \]
\[ \text{sigma} : \quad 0.017326 \pm 0.000536 \]
\[ \chi^2 : \quad 4.1567 \]

\[ \sigma/M = 0.026 \]

\[ \text{Diff Corrected Event Mass MC RecoP Mass} \]
Entries : 1017

\[ \text{gauss} \]
\[ \text{mean} : \quad -3.8637 \pm 9.762E-4 \]
\[ \text{sigma} : \quad 0.025921 \pm 0.000703 \]
\[ \chi^2 : \quad 2.5311 \]
Reconstructed Z mass from dijets (fixed 2-jet mode)

\[ \sigma = 2.98 \text{ GeV for Z} \]

\[ \sigma/M = 0.035 \rightarrow 33\%/\sqrt{M} \]

Individual cluster (nearest-neighbor) C/S corrections
Jet \( \Delta M \) correction from PFA Track endpoints
Summary

- Revised compact.xml and DigiSim to accommodate dual readout calorimeter -> 2 hit collections per readout volume
- Applied independent thresholds and timing cuts to both collections
- Calibrated Scintillator and Cerenkov hit collections with electrons
- Determined C/S correction polynomial for hadrons by plotting S/E vs C/S for pions
- Applied polynomial corrections to jets and clusters to obtain dijet mass
- Used PFA Mip-finder to determine track endpoint and calculate $\Delta M$ correction per jet

Plans
Will continue use of PFA modules to associate tracks with calorimeter clusters, replacing the cal clusters with the track 4-vector in jet finder -> reduced $\Delta M$ correction per jet
Continue to improve performance and extend to higher $e^+e^-$ CM and higher jet energies
Ultimately determine optimal mix of C/S corrections and PFA applications

PFA Template
_Same algorithm (code) used on DR and SiD detectors -> can directly compare PFA performance using same code in different detectors_