PFA: Particle Flow Performance at CLIC

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Overview

Challenge at CLIC: Background from $\gamma\gamma \rightarrow$ hadrons

Two detector concepts: CLIC_ILD and CLIC_SID

- Technical Study
  - Energy resolution
  - Influence of timing cuts
- Physics performance: W and Z events
  - $e^+e^- \rightarrow WW \rightarrow \mu\nu qq$
  - $e^+e^- \rightarrow ZZ \rightarrow \nu\nu qq$
  - Energy and mass resolution
  - W and Z separation

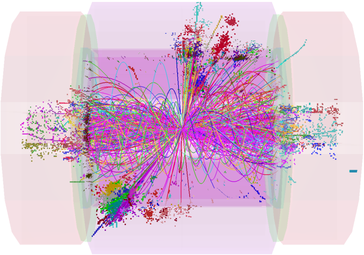
Technical details about Pandora PFA software by J. Marshall in R&D5 on the 27th: *"Current status of Pandora PFA"*

CLICPFOSelector

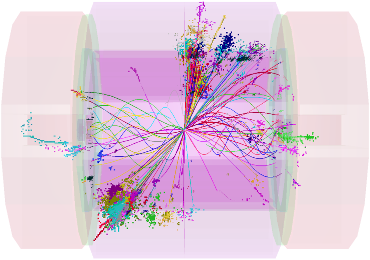
Event: $e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}b\bar{t}$ at 3 TeV

Background: $\gamma\gamma \rightarrow$ hadrons

Significant energy deposition from background, but mostly in forward region:



no selection



with timing selection cuts

A Technical Study: Z→qq

- Z's at different energies (91 GeV to 3 TeV)
- Decay at rest into light quarks
- No background overlaid
- No jet reconstruction, the full energy E_{jj} is analyzed

Performance evaluation based on the resolution of the jet energy E_j:

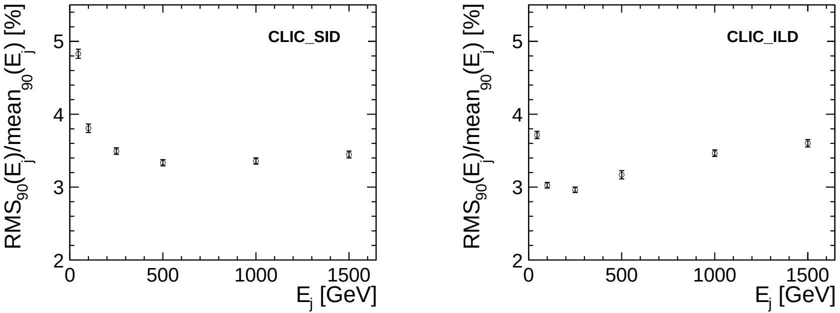
$$\frac{\mathrm{RMS}_{90}(E_j)}{\mathrm{mean}_{90}(E_j)} = \frac{\mathrm{RMS}_{90}(E_{jj})}{\mathrm{mean}_{90}(E_{jj})}\sqrt{2}$$

The $\mathrm{RMS}_{90}(E_{jj})$ and the $\mathrm{mean}_{90}(E_{jj})$ are calculated from the energy distribution.

Barrel region: $|\cos(\theta)| < 0.7$
Forward region between $|\cos(\theta)| > 0.7$ and $|\cos(\theta)| < 0.975$

Energy Resolution versus Jet Energy

Barrel region $|\cos(\theta)| < 0.7$, no background, no jet reco:

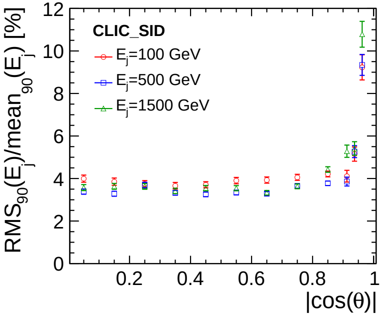


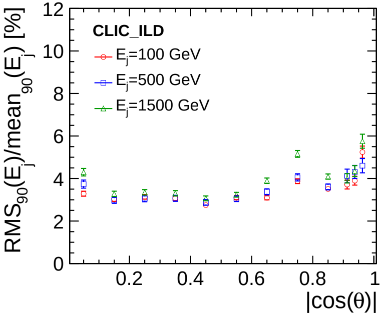
At lower energies CLIC_ILD benefits from the larger radius.
With increasing energy jets become narrower:

- Particle separation more difficult
- Particle flow turns into energy flow
- Confusion term dominates energy resolution

At this point both detectors show similar performance.

No background, no jet reco



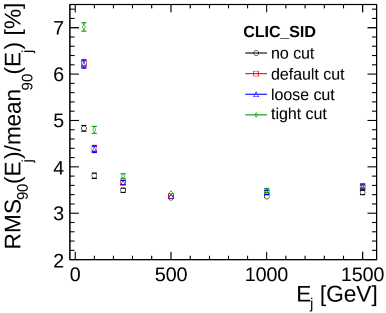


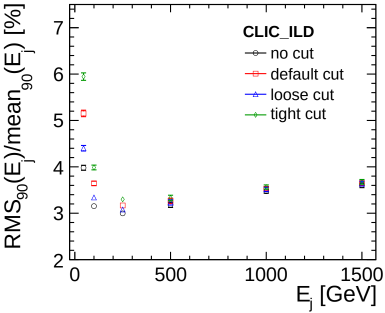
CLIC_SID:
Worse in the forward region due to angular coverage only down to 15.5°.

CLIC_ILD:
Dip in the overlap between barrel and forward region due to a gap between the ECAL barrel and ECAL endcap.

Validation of Timing Cuts

No background, no jet reco





Timing cuts do not harm the physics event especially for high energies.

Events:

- $e^+e^- \rightarrow WW \rightarrow \mu\nu qq$
- W energies: 125, 250, 500 and 1000 GeV
- Each without and with 60BX of background

Reconstruction:

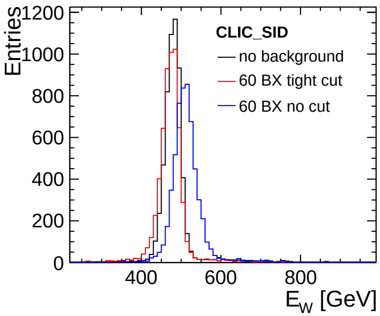
- Lepton removal, leaving only the hadronic decaying W in the event.
- Jet reconstruction: kt algorithm in exclusive mode forcing the event into two jets.

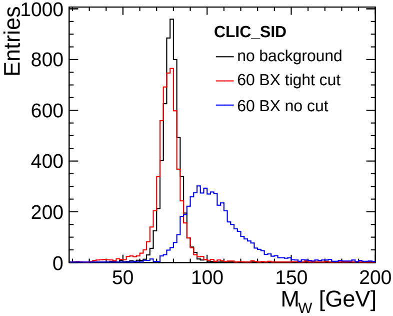
Analysis:

- Using the tight selection (minimal difference between default, loose and tight).
- Jets are in the region $|\cos(\theta)| < 0.9$.
- RMS_{90} and mean_{90} from the distribution of the jet energy and the jet mass are calculated.

Energy and Mass Distribution

Energy and mass distribution of the reconstructed W for an energy of 500 GeV with 60 BX of background:

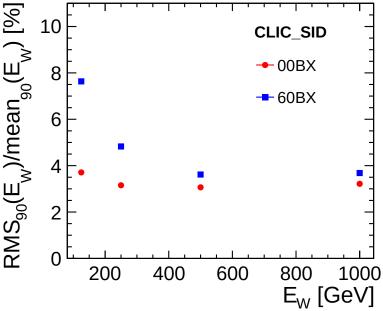


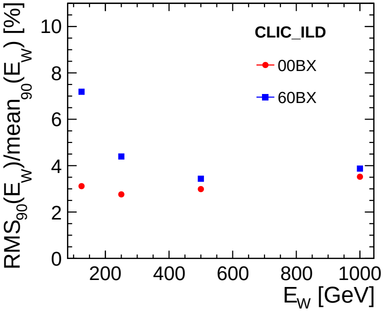


Without applying any timing cuts too many background particles remain in the event and are reconstructed as part of the jet shifting the energy and mass distribution to higher values.

Energy Resolution

PFO tight selection



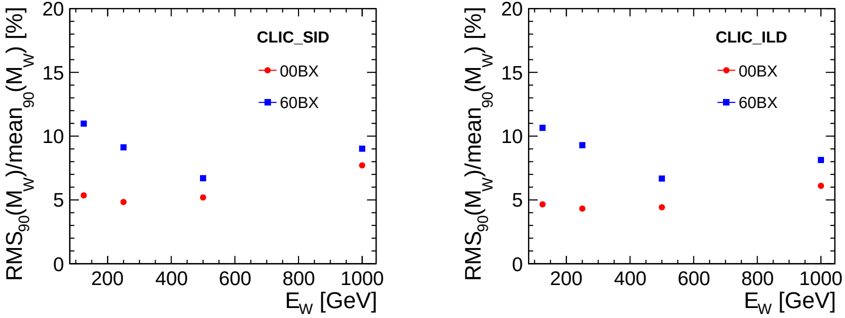


Without background the results are comparable to the technical study without jet reconstruction.

With increasing jet energy the effect of background becomes less dominant.

Mass Resolution

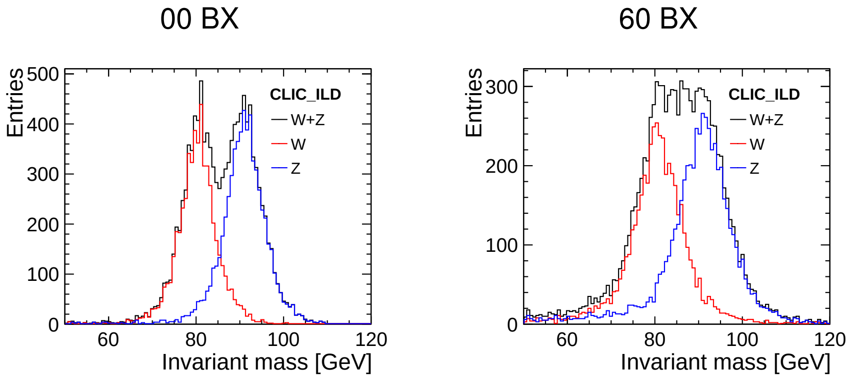
PFO tight selection



With 60 BX of background both CLIC_SID and CLIC_ILD show almost the same performance in energy and mass resolution.

W from $e^+e^- \rightarrow WW \rightarrow \mu\nu qq$

Z from $e^+e^- \rightarrow ZZ \rightarrow \nu\nu qq$
same reconstruction and analysis as for W.

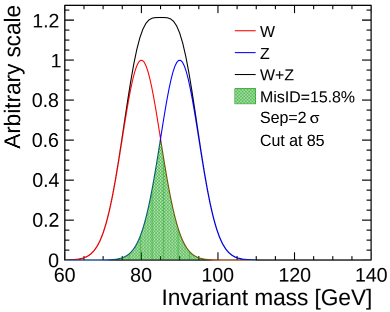


Mass distribution of the reconstructed W and Z for CLIC_ILD at $E_{W,Z}$=500 GeV

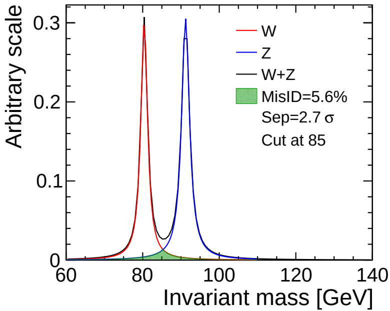
WZ Separation: Definition

Find optimal cut to minimize mis-identified events.

Definition based on two ideal Gaussian with width of σ and 2σ apart



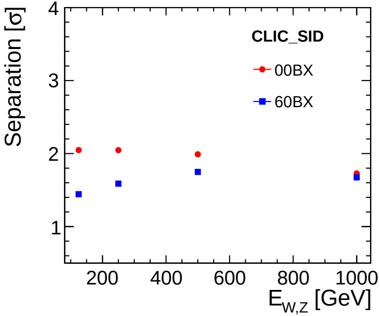
Best possible case with natural W and Z width in Breit-Wigner distribution

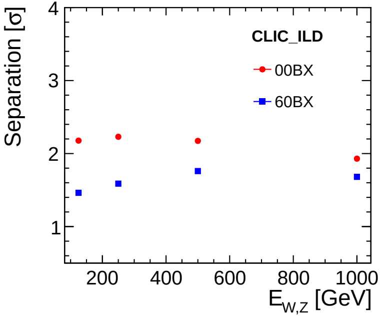


Mis-identification of 15.8% corresponds to a separation of 2σ

WZ Separation: Results

Separation between W and Z peak with no background and with 60 BX of background:





Summary

Work ongoing!

- Rejection of badly reconstructed jets needs to be improved.
- Will reduce the size of the tails.

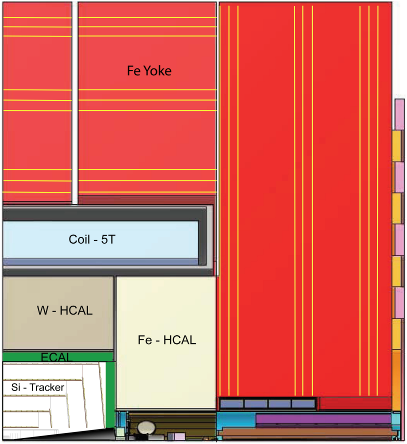
Results so far:

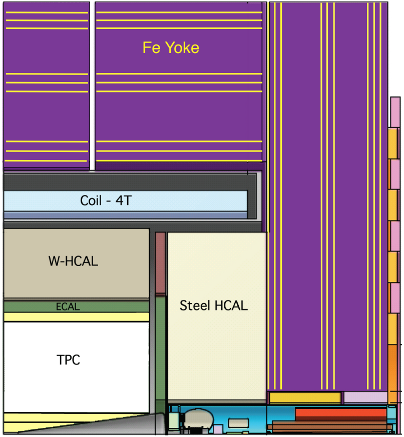
- Background from $\gamma\gamma \to$ hadrons can be dealt with using timing cuts on PFO level.
- Influence of background on energy and mass resolution evident but less dominant at higher jet energies.
- Performance in the presence of background is very comparable between the two detector concepts

More details in LCD-NOTE-2011-028

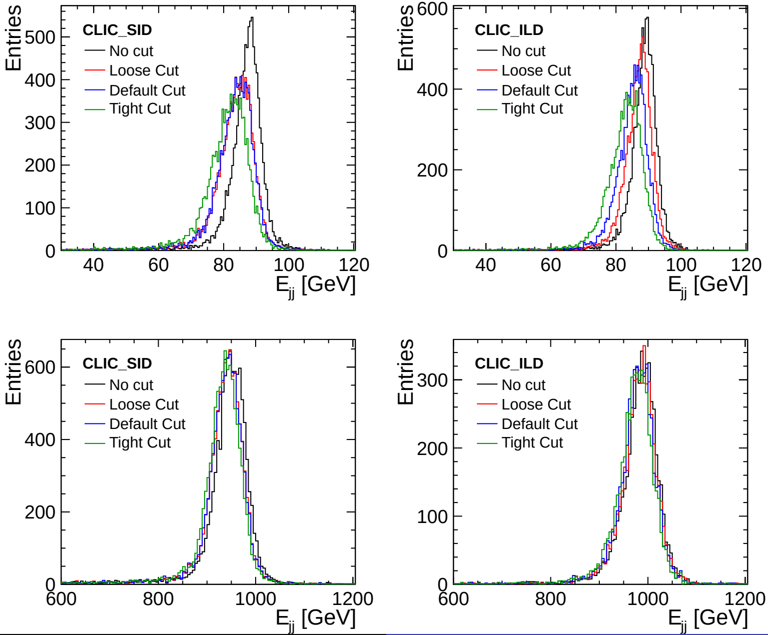
BACKUP

Two Detector Concepts





Distributions for different timing selections



Default Selection

Region	p_T range	Time cut
Photons		
Central $\lvert\cos(\theta)\rvert \leq 0.975$	$0.75\,\text{GeV} \leq p_T < 4.0\,\text{GeV}$ $0\,\text{GeV} \leq p_T < 0.75\,\text{GeV}$	$t < 2.0\,\text{ns}$ $t < 1.0\,\text{ns}$
Forward $\lvert\cos(\theta)\rvert > 0.975$	$0.75\,\text{GeV} \leq p_T < 4.0\,\text{GeV}$ $0\,\text{GeV} \leq p_T < 0.75\,\text{GeV}$	$t < 2.0\,\text{ns}$ $t < 1.0\,\text{ns}$
Neutral hadrons		
Central $\lvert\cos(\theta)\rvert \leq 0.975$	$0.75\,\text{GeV} \leq p_T < 8.0\,\text{GeV}$ $0\,\text{GeV} \leq p_T < 0.75\,\text{GeV}$	$t < 2.5\,\text{ns}$ $t < 1.5\,\text{ns}$
Forward $\lvert\cos(\theta)\rvert > 0.975$	$0.75\,\text{GeV} \leq p_T < 8.0\,\text{GeV}$ $0\,\text{GeV} \leq p_T < 0.75\,\text{GeV}$	$t < 2.0\,\text{ns}$ $t < 1.0\,\text{ns}$
Charged particles		
All	$0.75\,\text{GeV} \leq p_T < 4.0\,\text{GeV}$ $0\,\text{GeV} \leq p_T < 0.75\,\text{GeV}$	$t < 3.0\,\text{ns}$ $t < 1.5\,\text{ns}$
Track only		
Require $p_T > 0.5\,\text{GeV}$ and $t_{\text{ECAL}} < 10\,\text{ns}$		

Loose Selection

Region	p_T range	Time cut
Photons		
Central $\lvert\cos(\theta)\rvert \leq 0.975$	$0.75\,\mathrm{GeV} \leq p_\mathrm{T} < 4.0\,\mathrm{GeV}$	$t < 2.0\,\mathrm{ns}$
	$0\,\mathrm{GeV} \leq p_\mathrm{T} < 0.75\,\mathrm{GeV}$	$t < 2.0\,\mathrm{ns}$
Forward $\lvert\cos(\theta)\rvert > 0.975$	$0.75\,\mathrm{GeV} \leq p_\mathrm{T} < 4.0\,\mathrm{GeV}$	$t < 2.0\,\mathrm{ns}$
	$0\,\mathrm{GeV} \leq p_\mathrm{T} < 0.75\,\mathrm{GeV}$	$t < 1.0\,\mathrm{ns}$
Neutral hadrons		
Central $\lvert\cos(\theta)\rvert \leq 0.975$	$0.75\,\mathrm{GeV} \leq p_\mathrm{T} < 8.0\,\mathrm{GeV}$	$t < 2.5\,\mathrm{ns}$
	$0\,\mathrm{GeV} \leq p_\mathrm{T} < 0.75\,\mathrm{GeV}$	$t < 1.5\,\mathrm{ns}$
Forward $\lvert\cos(\theta)\rvert > 0.975$	$0.75\,\mathrm{GeV} \leq p_\mathrm{T} < 8.0\,\mathrm{GeV}$	$t < 2.5\,\mathrm{ns}$
	$0\,\mathrm{GeV} \leq p_\mathrm{T} < 0.75\,\mathrm{GeV}$	$t < 1.5\,\mathrm{ns}$
Charged particles		
All	$0.75\,\mathrm{GeV} \leq p_\mathrm{T} < 4.0\,\mathrm{GeV}$	$t < 3.0\,\mathrm{ns}$
	$0\,\mathrm{GeV} \leq p_\mathrm{T} < 0.75\,\mathrm{GeV}$	$t < 1.5\,\mathrm{ns}$
Track only		
Require $p_\mathrm{T} > 0.25\,\mathrm{GeV}$		

Tight Selection

Region	p_T range	Time cut
Photons		
Central	$1.0\,\mathrm{GeV} \leq p_\mathrm{T} < 4.0\,\mathrm{GeV}$	$t < 2.0\,\mathrm{ns}$
$\lvert\cos(\theta)\rvert \leq 0.95$	$0.2\,\mathrm{GeV} \leq p_\mathrm{T} < 1.0\,\mathrm{GeV}$	$t < 1.0\,\mathrm{ns}$
Forward	$1.0\,\mathrm{GeV} \leq p_\mathrm{T} < 4.0\,\mathrm{GeV}$	$t < 2.0\,\mathrm{ns}$
$\lvert\cos(\theta)\rvert > 0.95$	$0.2\,\mathrm{GeV} \leq p_\mathrm{T} < 1.0\,\mathrm{GeV}$	$t < 1.0\,\mathrm{ns}$
Neutral hadrons		
Central	$1.0\,\mathrm{GeV} \leq p_\mathrm{T} < 8.0\,\mathrm{GeV}$	$t < 2.5\,\mathrm{ns}$
$\lvert\cos(\theta)\rvert \leq 0.95$	$0.5\,\mathrm{GeV} \leq p_\mathrm{T} < 1.0\,\mathrm{GeV}$	$t < 1.5\,\mathrm{ns}$
Forward	$1.0\,\mathrm{GeV} \leq p_\mathrm{T} < 8.0\,\mathrm{GeV}$	$t < 1.5\,\mathrm{ns}$
$\lvert\cos(\theta)\rvert > 0.95$	$0.5\,\mathrm{GeV} \leq p_\mathrm{T} < 1.0\,\mathrm{GeV}$	$t < 1.0\,\mathrm{ns}$
Charged particles		
All	$1.0\,\mathrm{GeV} \leq p_\mathrm{T} < 4.0\,\mathrm{GeV}$	$t < 2.0\,\mathrm{ns}$
	$0\,\mathrm{GeV} \leq p_\mathrm{T} < 1.0\,\mathrm{GeV}$	$t < 1.0\,\mathrm{ns}$
Track only		
Require $p_\mathrm{T} > 1.0\,\mathrm{GeV}$ and $t_\mathrm{ECAL} < 10\,\mathrm{ns}$		

Separation between W and Z and corresponding mass resolution for CLIC_SID:

BX	$E_{W,Z}$ [GeV]	σ_m/m W/Z [%]	Separation [σ]	ϵ [%]
00 BX	125	5.4 / 4.8	2.0	85
	250	4.8 / 4.8	2.0	85
	500	5.2 / 4.9	2.0	84
	1000	7.7 / 6.7	1.7	78
60 BX	125	11.0 / 10.6	1.4	69
	250	9.1 / 9.1	1.6	74
	500	6.7 / 7.0	1.7	78
	1000	9.0 / 8.5	1.7	76

The separation is calculated by applying an optimal cut in such a manner that the amount of mis-identified events is minimized. In the case of ideal Gaussian distribution a mis-identification of 15.8% corresponds to a separation of 2σ.

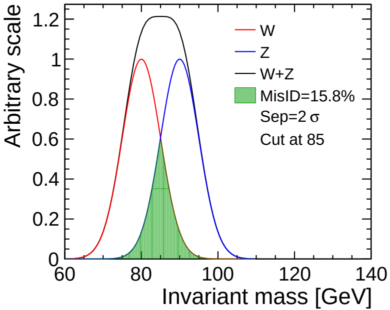
Separation between W and Z and corresponding mass resolution for CLIC_ILD:

BX	$E_{W,Z}$ [GeV]	σ_m/m W/Z [%]	Separation [σ]	ϵ [%]
00 BX	125	4.6 / 4.2	2.2	88
	250	4.3 / 4.0	2.2	89
	500	4.4 / 4.2	2.2	88
	1000	6.1 / 5.4	1.9	87
60 BX	125	11.0 / 10.0	1.4	70
	250	9.3 / 9.0	1.5	74
	500	6.7 / 6.6	1.6	79
	1000	8.1 / 7.7	1.7	77

The separation is calculated by applying an optimal cut in such a manner that the amount of mis-identified events is minimized. In the case of ideal Gaussian distribution a mis-identification of 15.8% corresponds to a separation of 2σ.

Tails influence separation power:

Perfect Gaussian



Z distribution with a tail