Delphes card for CLICdet and lessons learned

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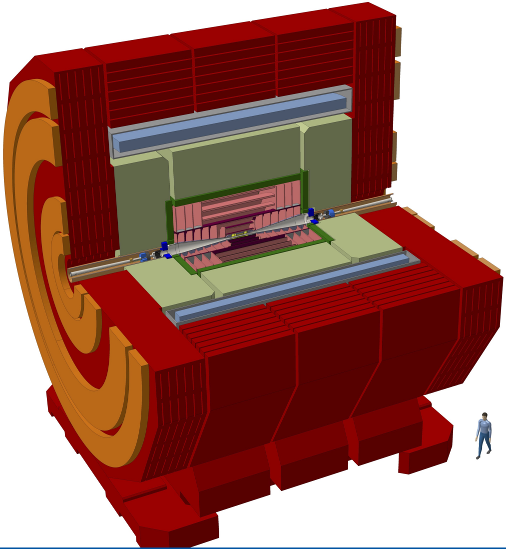
Introduction: DELPHES card for CLICdet

- Implementation based on existing performance studies in full simulation

$\rightarrow$ Goal: performance close to the full simulation performance (more realistic than optimistic)

- Specific to the CLICdet card implementation:
  - Added Lepton Collider jet algorithm (VLC) and exclusive jet clustering based on FastJet plugin
  - Multiple sets of jet observables for N=2,...,6 jets in the card
  - Effects of beam-induced background $\rightarrow$ different cards for the three energy stages
- Validation for certain processes and observables
- Feedback from studies in which it was used (in particular on isolation)

CLIC Detector: CLICdet



Designed for Particle Flow Analysis and optimized for CLIC environment

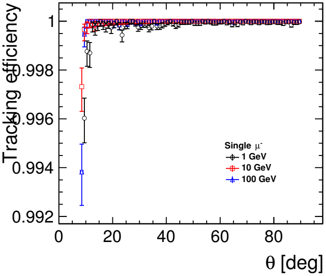
- 4 T B-field
- Vertex detector (3 double layers)
- Large Silicon tracker R=1.5m
- Highly granular calorimeters:
  - Si-W-ECAL 40 layers (22 X_0)
  - Scint-Fe-HCAL 60 layers (7.5 λ_I)

Precise timing for background suppression

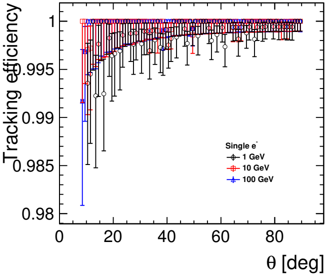
Detector performance parameters as input to the CLICdet Delphes card

Tracking efficiency

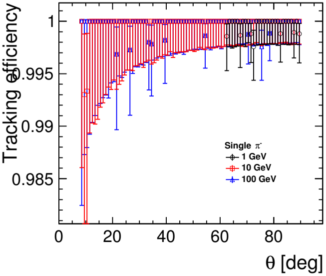
- Dedicated CLICdet track reconstruction based on conformal tracking with cellular automaton pattern recognition [→ 10.1016/j.nima.2019.163304]
- Tracking efficiencies based on fully simulated particle gun events
- Provided in Delphes card as energy and η dependent
- Tracking efficiency ϵ is applied by drawing a random number r from a uniform distribution $[0, 1]$, using $r < \epsilon$ to decide whether the track is kept



Muons



Electrons



Pions

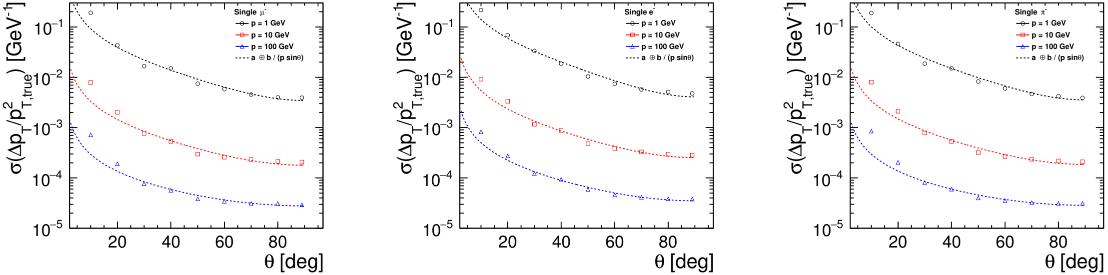
Emilia Leogrande @ LCWS2017

Momentum resolution

- Delphes applies a random, log-normal smearing based on Gaussian resolution

$$\frac{\Delta p_T}{p_T} = a \oplus b/(p \sin\theta)$$

- Physics requirement: $\frac{\Delta p_T}{p_T^2} = 2 \times 10^{-5}$ for central high-p_{T} tracks
  $\rightsquigarrow$ implications for both detector design and tracking algorithm performance
- Resolution determined from fully simulated particle guns and given in bins of η and p_{T}



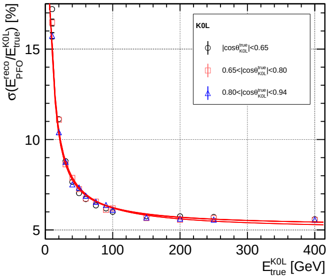
Emilia Leogrande @ LCWS2017

Calorimeter resolutions

Energy resolution $\Delta E = \sqrt{n^2 + s^2 E + c^2 E^2}$

with noise term n, stochastic term s, constant term c

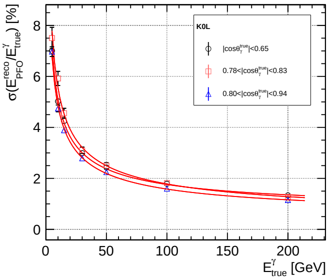
M. Weber/CLICdp-Note-2018-005



Resolution for **HCAL**

from neutral kaons up to E = 85 GeV

$\lvert\eta\rvert$	n	s	c
< 0.3	1.38	0.308	0.05
0.3…0.78	1.25	0.322	0.048
0.78…1.1	1.159	0.341	0.049
1.1…3	1.09	0.319	0.052



Resolution for **ECAL**

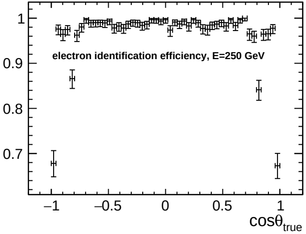
from photons up to E = 50 GeV

$\lvert\eta\rvert$	s	c
< 0.78	0.156	0.01
0.78…0.83	0.176	0.01
0.83…3	0.151	0.01

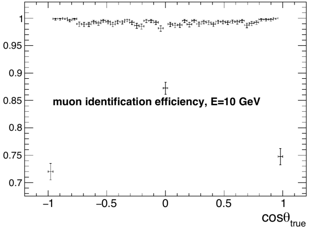
Electron, muon, and photon efficiency

- Electron, photon, muon candidates are identified among Particle Flow Objects (PFO)
- Isolated e, μ, γ are removed from the PFOs which are passed to jet finding
- ID efficiencies derived from `PandoraPFA` objects

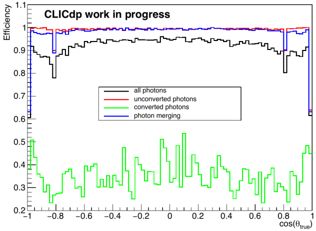
Electrons



Muons



Photons

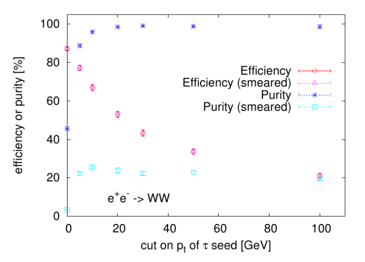


Matthias Weber @ CLICWEEK2018

τ and b tagging

Tagging hadronically decaying τs

- Tagging efficiencies depend on $p_T(\tau)$



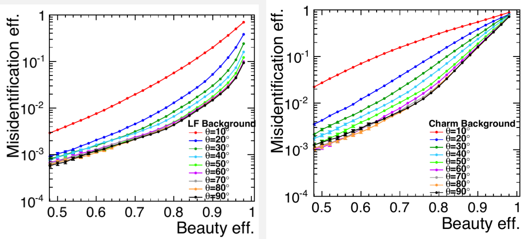
$e^+e^- \rightarrow WW$

- Mis-ID of quark jets as τ candidates $\approx 3\,\%$ globally
- Relative simple tau-finder $\rightarrow$ conservative estimate

LCD-2010-009

b tagging

- If a b quark is found inside a ΔR cone, the jet is b-tagged according to the efficiencies
- Tagging efficiencies & misidentification rates for 3 working points (50 %, 70 %, 90 %)



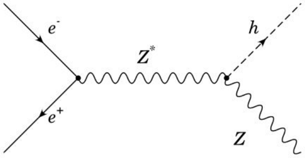
dijet events at $\sqrt{s} = 200$ GeV for double_spirals vertex detector

CLICdp-Note-2014-002

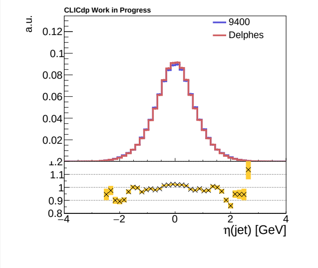
Validation of the CLICdet DELPHES card for selected observables

Performance at 350 GeV

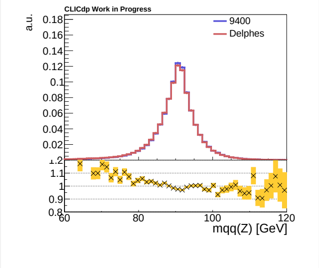
- Process: $e^+e^- \to Z(\to q\bar{q})H(\to incl.)$ at $\sqrt{s}$ =350 GeV
- Used for model-independent measurement of $\sigma(ZH)$
- Validation against full simulation with CLIC_o3_v14 (newest CLICdet model)



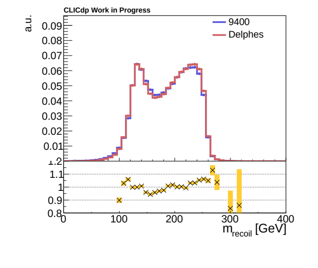
Pseudorapidity of jets $\eta(j)$



Di-jet invariant mass (m_Z)



Recoil mass (Higgs)



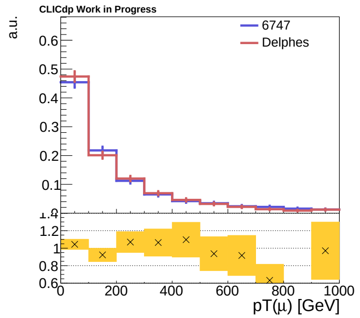
from $\vec{p} = -\vec{p_Z}$, $E = \sqrt{s} - E_Z$

$\rightsquigarrow$ Good agreement, up to 10 % discrepancies in tails

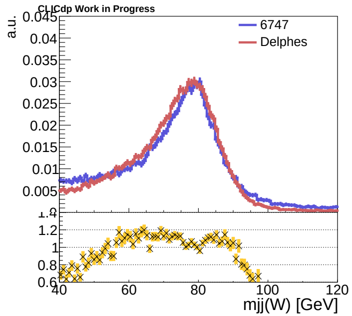
Performance at 3 TeV

- Process: $e^+e^- \rightarrow WW \rightarrow \ell\nu q\bar{q}'$
- Challenge: Influence of $\gamma\gamma \rightarrow$hadrons background on performance (larger at higher $\sqrt{s}$)

Muon transverse momentum



Di-jet invariant mass (m_W)



$\rightsquigarrow$ Good agreement, up to 20,% discrepancies in derived observables

Summary / Lessons learned

Lessons learned

Goal

- Reproduce results as obtained from CLICdet full simulation

→ Relying on the performance studies from full simulation

→ Not necessarily the most optimistic performance, but realistic (e.g. τ tagging efficiencies)

Validation - lessons learned

- Despite validation, it is helpful to look carefully at results from studies using the card (in this case isolation criteria)
- Beam-induced backgrounds effects through smearing of jet energy

Guidance for theorists was welcome

- e.g. flavor tagging working points
- Use within MadGraph is most common

→ Instructions `https://twiki.cern.ch/twiki/bin/view/CLIC/CLICdetDelphesInstructions`

CLICdp Note on the card (parameters, validation, usage): `https://arxiv.org/abs/1909.12728`