

Delphes Card for CLICdet

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CLICdet Delphes card – Introduction

- A CLICdet card implemented for the updated CLICdet detector model according to CLICdp-Note-2017-001
- Allows fast simulation studies of the CLIC physics potential



Documentation and links

- My fork on github: <https://github.com/uschnoor/delphes>
- Documentation: <https://cp3.irmp.ucl.ac.be/projects/delphes/wiki/WorkBook>
- How to use the current code with MadGraph (CLICdet adjustments not yet shipped with official code):
<https://twiki.cern.ch/twiki/bin/view/CLIC/DelphesMadgraphForBSMReport>
- Existing ILD card:
https://cp3.irmp.ucl.ac.be/projects/delphes/browser/git/cards/delphes_card_ILD.tcl
- Delphes for e+ e- Collider Studies: http://ias.ust.hk/program/shared_doc/2017/201701hep/HEP_20170116_Chris_Potter.pdf
- Intro to Delphes <http://indico.ihep.ac.cn/event/2813/session/5/contribution/7/material/slides/0.pdf>
- How to run: `./DelphesSTDHEP cards/delphes_card_CLICdet.tcl
out_2556_1.root hzqq_gen_2556_1.stdhep`

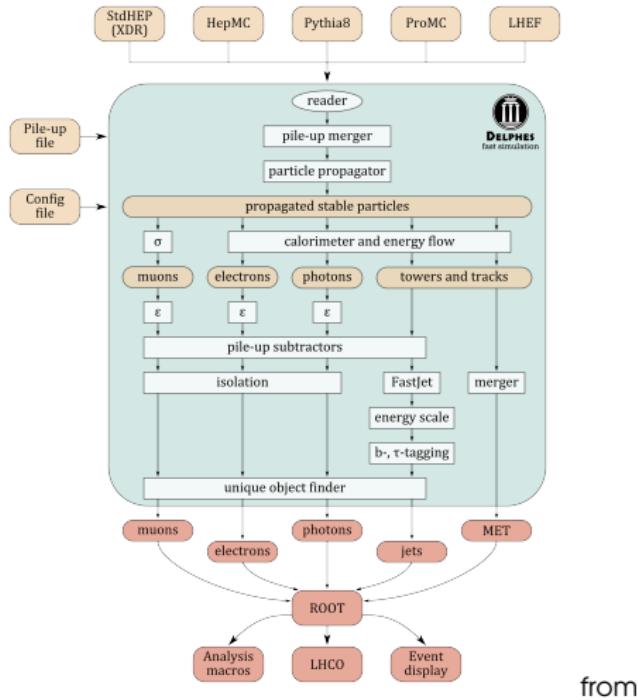


Delphes General

- Fast detector simulation using a parametrization of the **detector geometry**, **detector response** and **reconstruction of composite objects** including efficiencies
- Configuration files (=“detector cards”) based on tcl scripting language
- Various detector cards already available, eg. CMS, ILD
- Based on C++, ROOT, tcl
- Modular system describing detector components and their performance



Delphes Data Flow



- Particles lists stored in arrays which can be merged and filtered
- Can also be interfaced to Pythia8 (in case no parton shower applied yet)
- Can be run on LHEF, StdHEP, hepmc
- Data Flow fixed by Execution Path module
- CLICdet Data Flow to exclude isolated leptons from jet clustering input (using a UniqueObjectFinder)
- Output: ROOT TTree with resulting particles

<https://cp3.irmp.ucl.ac.be/projects/delphes/wiki/WorkBook/DataFlowDiagram>



Calorimeters

- Use “SimpleCalorimeter” modules for ECAL and HCAL because this allows different granularity of ECAL and HCAL
- Fills calorimeter towers, performs calorimeter resolution smearing, pre-selects towers hit by photons and performs a particle flow algorithm
- Implemented calorimeter segmentation and resolution into the CLICdet card:

Geometry from CLICdp-Note-2017-001:

Table 13: HCAL overall layout as implemented in the simulation model.

HCAL barrel r_{\min} [mm]	1740
HCAL barrel r_{\max} [mm]	3330
HCAL barrel z_{\max} [mm]	2210
HCAL endcap z_{\min} [mm]	2539
HCAL endcap z_{\max} [mm]	4129
HCAL endcap r_{\min} [mm]	250
HCAL endcap r_{\max} [mm]	3246
HCAL ring z_{\min} [mm]	2360
HCAL ring z_{\max} [mm]	2539
HCAL ring r_{\min} [mm]	1730
HCAL ring r_{\max} [mm]	3246
LumiCal cutout in HCAL r_{\max} [mm]	180
LumiCal cutout in HCAL z_{tot} [mm]	200

Table 11: ECAL layout as implemented in the simulation model.

ECAL barrel r_{\min} [mm]	1500
ECAL barrel r_{\max} [mm]	1702
ECAL barrel z_{\max} [mm]	2210
ECAL endcap/plug z_{\min} [mm]	2307
ECAL endcap/plug z_{\max} [mm]	2509
ECAL endcap r_{\min} [mm]	410
ECAL endcap r_{\max} [mm]	1700
ECAL plug r_{\min} [mm]	260
ECAL plug r_{\max} [mm]	380



Calorimeters segmentation

- Cell sizes: 5mm x 5 mm in ECAL, 30 mm x 30 mm in HCAL
- Calculated the following $\Delta\eta$ and $\Delta\phi$ segmentations corresponding to these cell sizes and the layouts given in tables 11 and 13

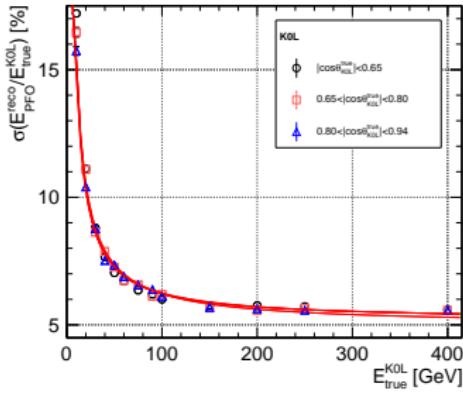
Part	η_{max}	cell size (mm)	$\Delta\phi[^{\circ}]$	$\Delta\eta$
ECAL barrel	1.2	5	0.2	0.003
ECAL endcaps	2.5	5	0.8	0.02
ECAL plug	3.0	5	1.0	0.02
HCAL barrel	0.8	30	1	0.02
HCAL ring	0.9	30	1	0.02
HCAL endcaps	3.5	30	6	0.1

Implemented correspondingly in the Delphes card



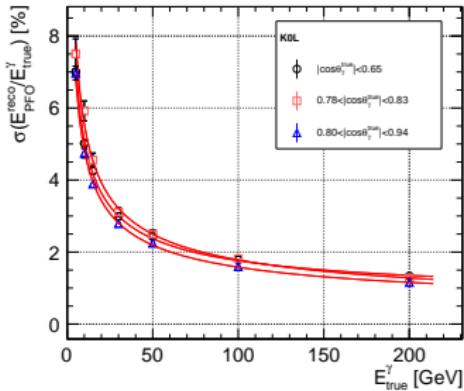
Calorimeter resolutions

Given in terms of absolute ΔE as $\Delta E = \sqrt{n^2 + s^2 E + c^2 E^2}$ with noise term n , stochastic term s , constant term c and can be binned in η



Resolution for HCAL from neutral kaons up to $E = 85$ GeV (Matthias Weber):

- Inner Barrel $|\eta| < 0.3$:
 $n = 1.38, s = 0.308, c = 0.050$
- Barrel ($0.3 < |\eta| < 0.78$):
 $n = 1.25, s = 0.322, c = 0.048$
- Transition ($0.78 < |\eta| < 1.1$):
 $n = 1.159, s = 0.341, c = 0.049$
- Endcap ($1.1 < |\eta| < 3$):
 $n = 1.09, s = 0.319, c = 0.052$



Resolution for ECAL from photons up to $E = 50$ GeV (Matthias Weber):

- Barrel ($|\eta| < 0.78$):
 $s = 0.156, c = 0.0099 \rightarrow 0.01$
- Transition ($0.78 < |\eta| < 0.83$):
 $s = 0.176, c = 2e-7 \rightarrow 0.01$
- Endcap ($0.83 < |\eta| < 3$):
 $s = 0.151, c = 0.0057 \rightarrow 0.01$
- Set constant terms to 0.01



Tracking efficiency

- Tracking efficiency is applied by drawing a random number r from a uniform distribution $[0, 1]$, using $r < \epsilon$ to decide whether the track is kept
- Numbers based on tracking results from **Emilia Leogrande**
- Muon results already reported in *Emilia's LCWS talk*



Tracking efficiency

- Input: charged Hadrons/electrons/muons from ParticlePropagator for charged hadrons/electrons/muons
- Efficiencies read off from Emilia's plots (previous slide):

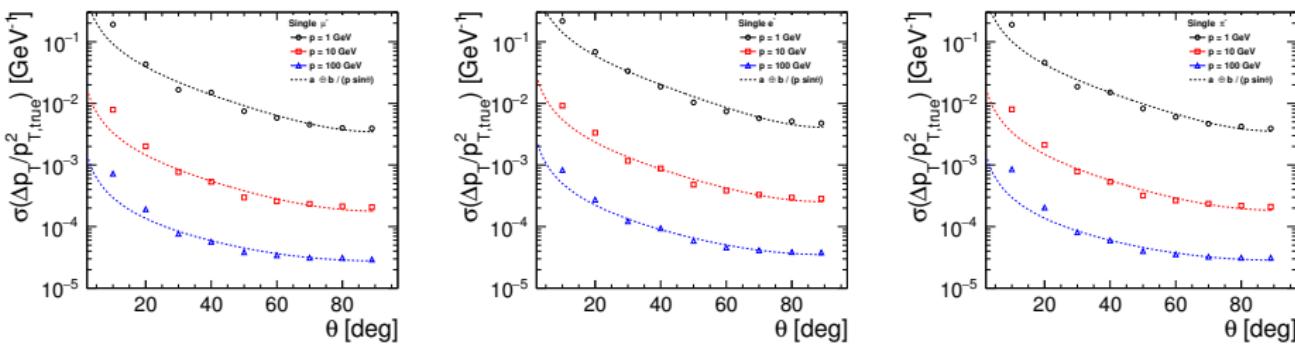
Muons			Electrons			Pions		
$\theta [^\circ]$	E /GeV	ϵ	$\theta [^\circ]$	E /GeV	ϵ	E /GeV	$\theta [^\circ]$	ϵ
0...9	any	0	9...10	≥ 80	0.993	$>= 80$	9...90	1.000
9..10	≥ 80	0.994	9...13	5...80	0.998	3...80	9...11	0.994
9..10	5...80	0.996	10...11	≥ 80	0.997	3...80	11...90	1.000
9..10	< 5	0.996	11...90	≥ 80	1.0	< 3	9...60	0.000
10...12	> 5	1	13...90	5...80	1.0	< 3	60...90	1.0000
10...12	$> 1, < 5$	0.999	11...50	< 5	0.997			
12...90	> 1	1	50...90	< 5	0.999			



Momentum resolution

- Applied by retrieving a random variable r from a Gaussian with mean=0, sigma=1
- Multiplying $\exp(r) \times p_T = p'_T$
- p'_T is log-normally distributed (its logarithm is Gaussian distributed)
- Fit parameters for $\frac{\Delta p_T}{p_T^2}$ provided by Emilia Leogrande

Resolution formula implemented in Delphes card as $\frac{\Delta p_T}{p_T} = a \oplus b / (p \sin \theta)$



- Binning in η with bin edges: 2.66, 1.74, 1.01, 0.55, 0.18, 0
- Factor 2 for resolution for $\theta = 10^\circ$ (deviating from fit)



Electron, muon, and photon efficiency and isolation

- Electron, photon, muon candidates are identified among Particle Flow objects
- Isolated e, μ, γ are removed from the PFOs which are passed to jet finding using a UniqueObjectFinder module
- Isolation determined according to jet content in a DeltaR cone ($\Delta R = 0.5$) with a maximum pT ratio between the cone and the isolated object of 0.12
- Identification efficiencies from Matthias Weber (*talk at CLICWEEK 2018*) → next slide



Electron, muon, and photon efficiency and isolation

TO BE UPDATED

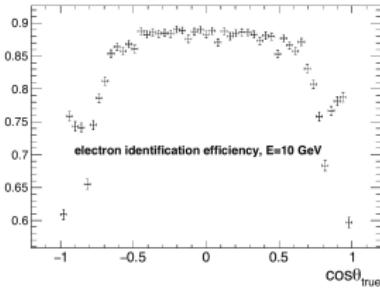
Electrons

for $E < 5 \text{ GeV}$: $\epsilon = 0$

for $E \geq 5 \text{ GeV}$:

$ \eta $	ϵ
> 1.95	0.6
> 1.22	0.77
> 1.1	0.67
> 1.0	0.76
> 0.66	0.8
> 0.4	0.86
< 0.4	0.89

(drop not yet understood)



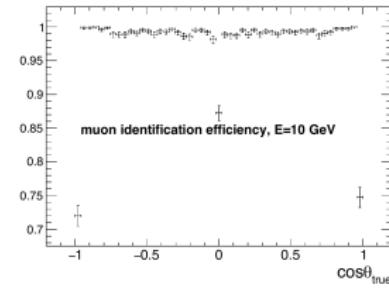
Muons

for $E < 2 \text{ GeV}$: $\epsilon = 0$ for

$E = 10 \text{ GeV}$:

$ \eta $	ϵ
> 1.95	0.73
> 0.2	0.98
< 0.2	0.87

for $E = 50 \text{ GeV}$: $\epsilon = 0.999$

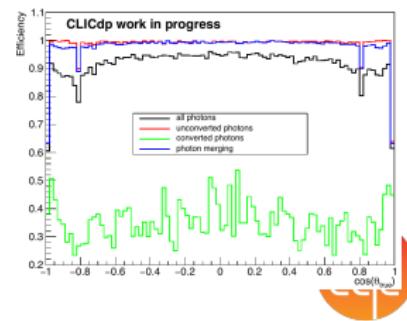


Photons

for $E < 2 \text{ GeV}$: $\epsilon = 0$

for $|\eta| < 0.7$: $\epsilon = 0.94$

for $0.7 < |\eta| < 3$: $\epsilon = 0.9$



Jet finding

- Introduced into Delphes the VLC contribs from fastjet to implement Valencia jet algorithm
 - In the card:
 - VLC with $\beta = \gamma = 1.0$
 - $R = 0.5, 0.7, 1.0, 1.2, 1.5$
 - Exclusive clustering with $N = 2, 3, 4, 5, 6$
- User can choose in subsequent analysis of the events which one(s) of the jet clustering configurations to use – depends a lot on the final state (in particular, of course, N)
- Jet energy scale is assumed to be 1.0



B, c, and tau tagging

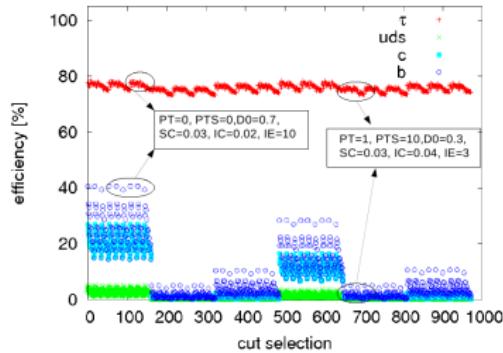
- If a b truth jet is found inside the ΔR cone, it is b-tagged according to the efficiencies we provide based on random numbers thrown by Delphes
- Efficiencies and misidentification rates from [*CLICdp-Note-2014-002*](#) for 3 working points added to the card
- c tagging not yet implemented



Tau tagging

from LCD-2010-009 (Astrid Muennich)

- Mis-ID of quark jets as τ candidates



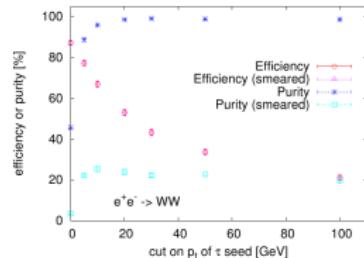
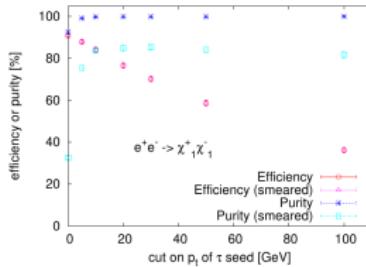
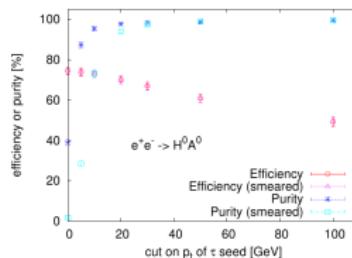
x axis: variation of selection cuts

- figure is not very conclusive
- use mis-ID rate $\approx 3\%$ globally



Tau tagging efficiencies

- Tau tagging efficiency from LCD-2010-009 (Astrid Muennich)



- Efficiencies: **average** of efficiencies for the three processes above
- PT bins: $2.5 \times$ seed pT to account for 3-prong decays

p_T seed (GeV)	≥ 2	≥ 5	≥ 10	≥ 20	≥ 30	≥ 50	≥ 100
$p_T(\tau)$ (GeV)	≥ 5	≥ 12.5	≥ 25	≥ 50	≥ 75	≥ 125	≥ 250
ϵ	0.84	0.79	0.74	0.66	0.61	0.51	0.36



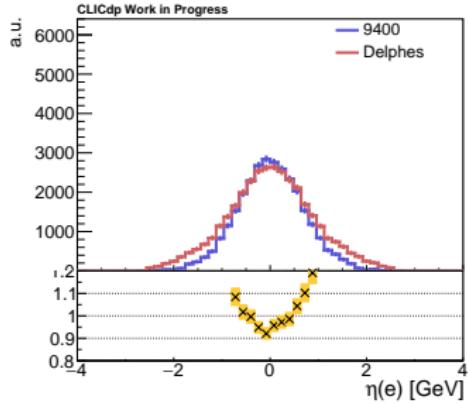
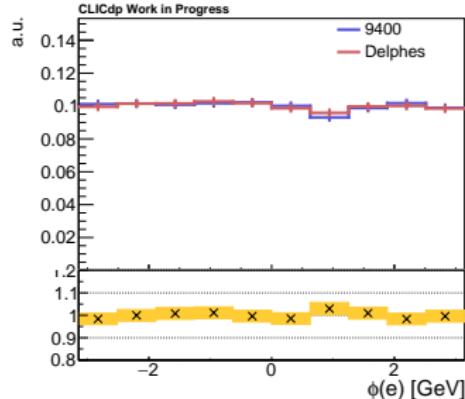
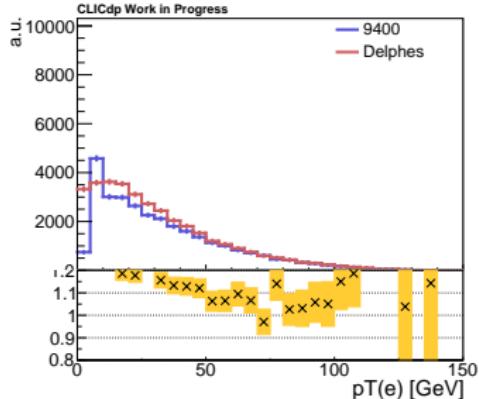
Performance

- Validate performance using HZ with $Z \rightarrow qq, H \rightarrow$ inclusive at 350 GeV
- Jets are clustered with VLC R=1, N=4 if not otherwise noted



Electron performance - all events

Electrons

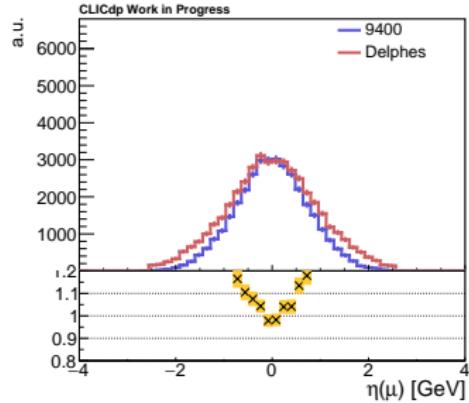
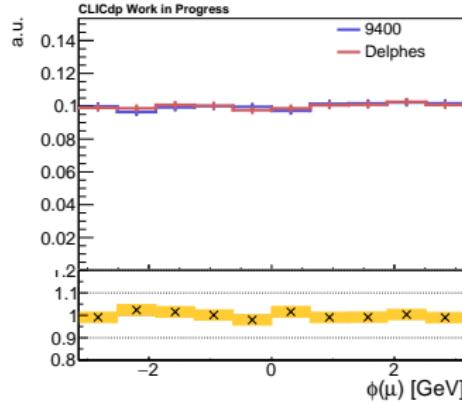
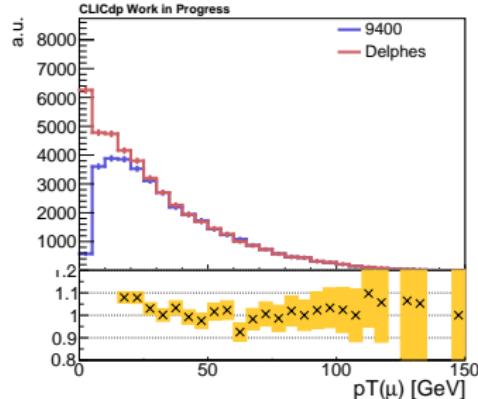


- PT spectrum not well modeled in low p_T bins; differences up to 10% at $p_T > 10$ GeV
- Delphes: Electrons more forward than in full simulation
- Reason could be that ID efficiency only given at $E=10$ GeV → need to get its energy dependence



Muons performance - all events

Muons

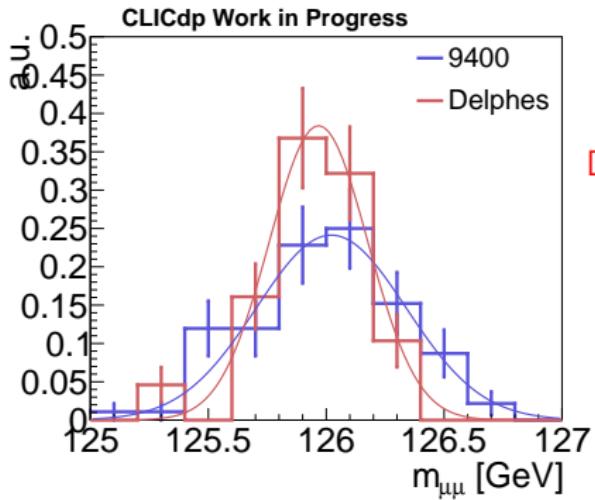


- Muons go more forward in $|\eta|$ and have smaller p_T in Delphes than in full simulation
- Introducing $\epsilon^{ID} = 0$ for $E < 2$ GeV has improved the spectrum, but a difference up to 30% (central) and 50% (forward) remains
- Spectrum \approx flat above $p_T > 20$ GeV
- Reason could be that ID efficiency only given at $E=10$ GeV \rightarrow need to get its energy dependence



$H \rightarrow \mu\mu$ events only

Selecting $H \rightarrow \mu\mu$ based on truth information



Fit results (Gaussian):

Delphes $m_H = 125.9 \text{ GeV}; \sigma_m = 2.08 \text{ GeV}$

Full sim $m_H = 126.0 \text{ GeV}; \sigma_m = 3.18 \text{ GeV}$

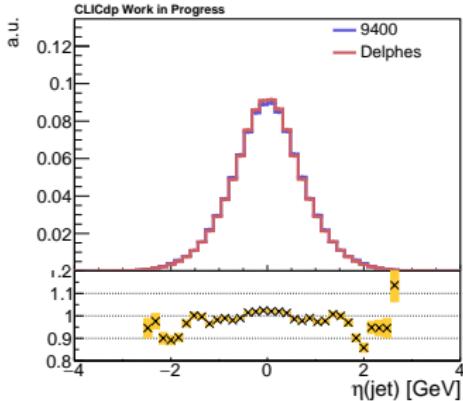
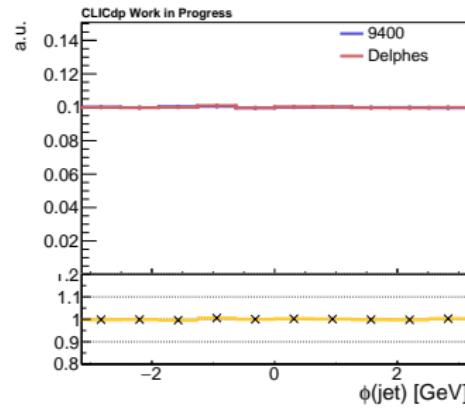
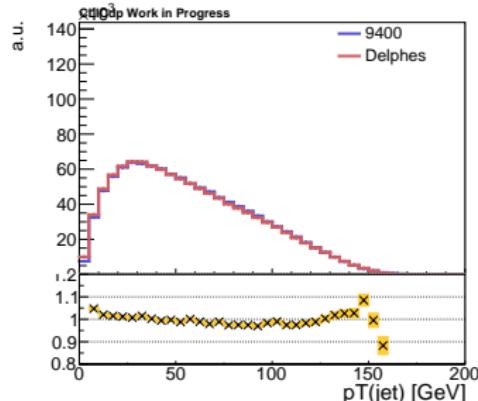
→ Delphes less smeared (width 0.65 of full sim)

- Mean value in good agreement with 126 GeV



Jets performance - all events

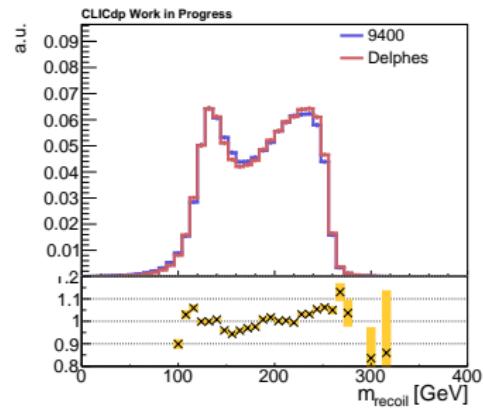
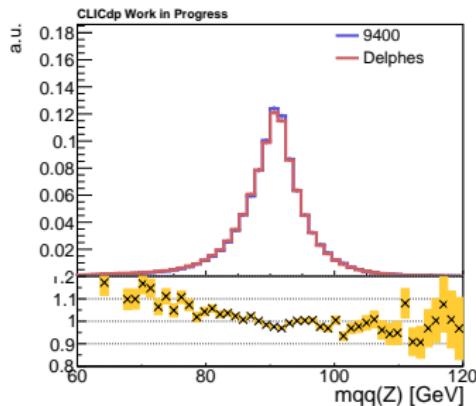
Jets



- jets are in good agreement:
- up to 5% differences above $p_T > 10$ GeV
- good agreement in η up to $|\eta| \approx 1.7$, up to 10% differences at forward $|\eta|$



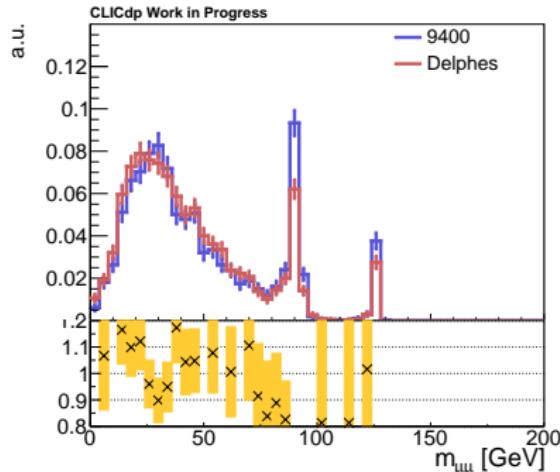
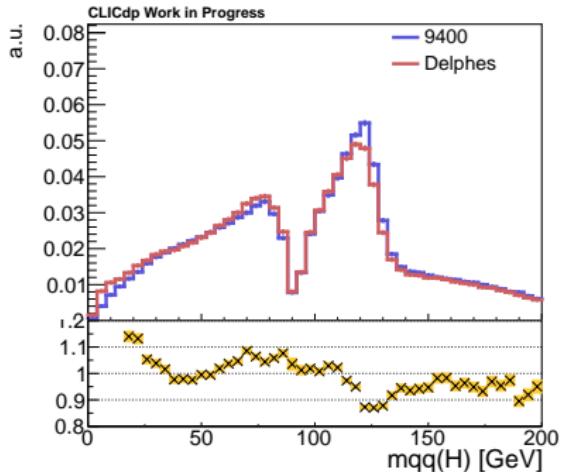
Derived Observables performance - all events



- $m(Z)$ is determined as:
 - N=3,4,5 jet clustering
 - pick the two jets with m_{jj} closest to m_Z
- ⇒ Difference in m_Z up to 5 % in area close to Z peak; up to 15 - 20 % further away
- Recoil mass calculated from this Z candidate
 - Up to ≈ 5 % differences in peak and reflection peak
 - 10 - 20 % difference in tails



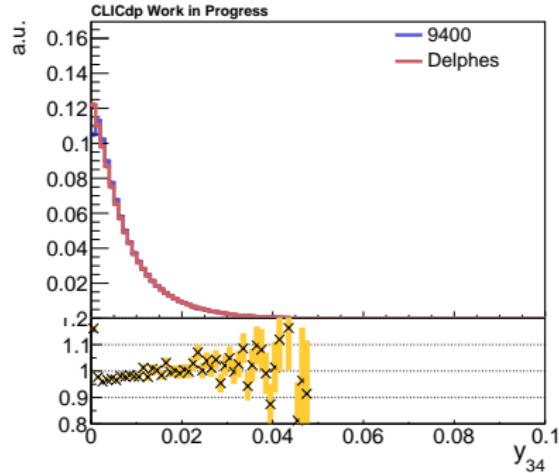
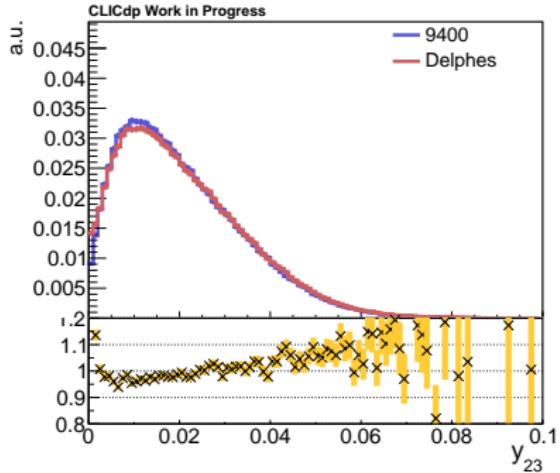
Derived observables performance – all events



- Using N=4 jets clustering, $mqq(H)$ is the invariant mass of the two jets remaining after assigning the two jets with m_{jj} closest to m_Z as Z jets
- No selection $\rightarrow M(\mu\mu)$ includes $H \rightarrow ZZ \rightarrow \mu\mu xx$ and other muons



Jet multiplicity observables – no selection

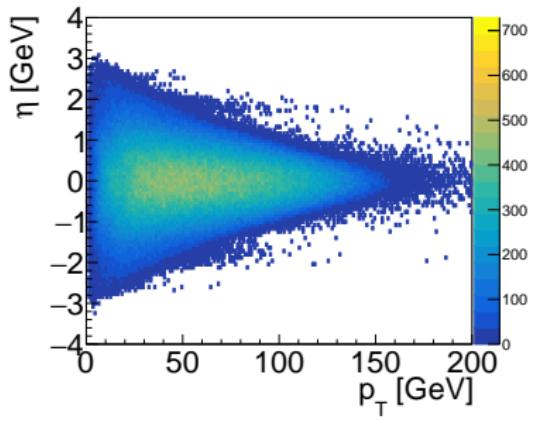


- y_{23}, y_{34} are measures of how well the event can be forced into 2/3/4 jets
- Often used for preselection cuts in multijet final states
- They are well modeled except for the very first bin(s) and a slight shift to higher values for Delphes

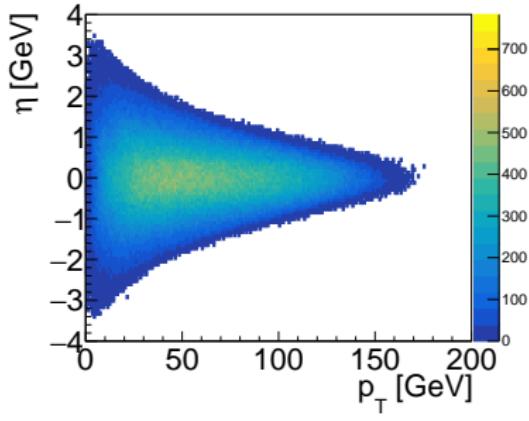


Performance - all events

Most likely the regions of lower agreement in the jets performance and derived jet-based observables are related to underpopulated areas in p_T - η plane of jets:



Full sim



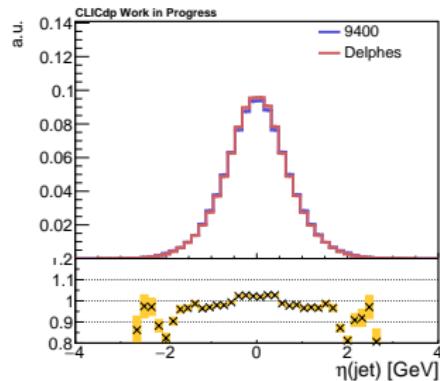
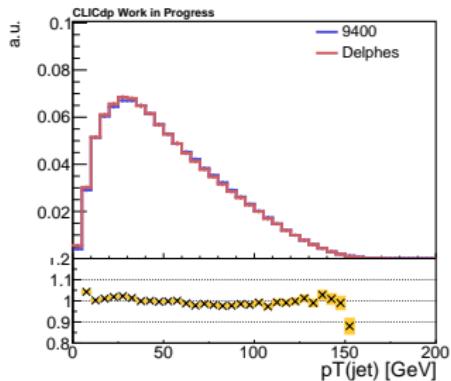
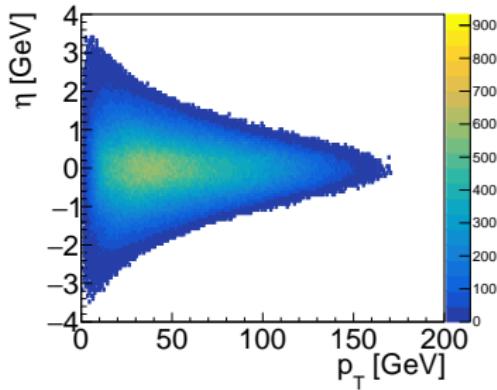
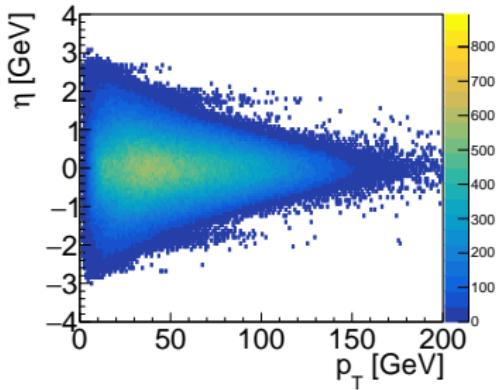
Delphes

- Possible reason: effect of overlayed $\gamma\gamma \rightarrow$ hadrons background

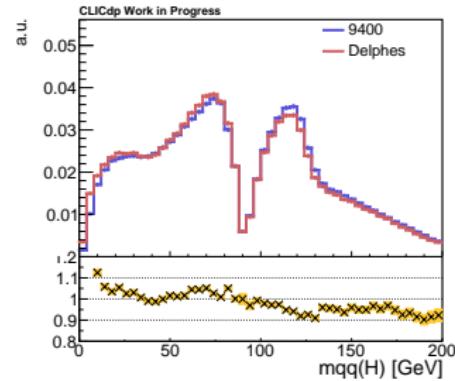
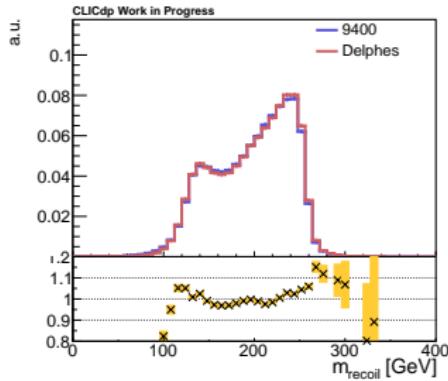


Is it an effect of $\gamma\gamma \rightarrow$ hadrons background?

Test this hypothesis by using R=0.5 jets instead of R=1 as used in the rest of these slides



Smaller Jet radius: less overlay impact

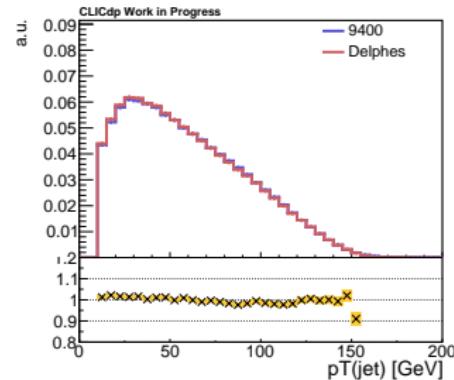
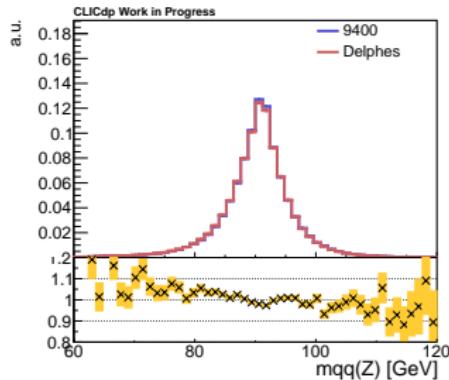
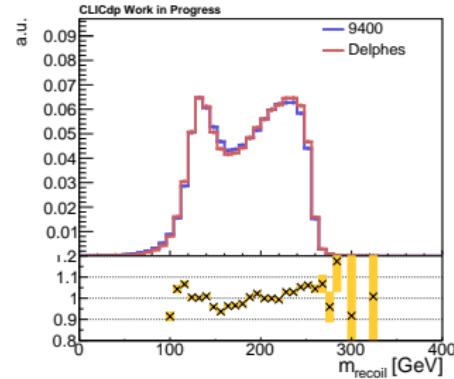
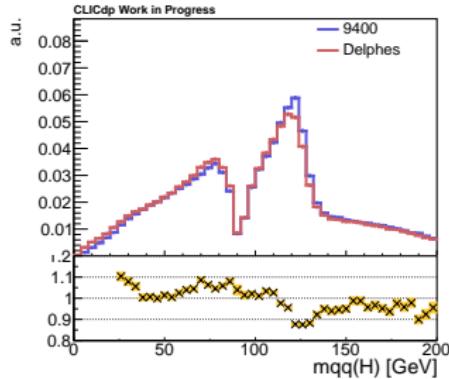


- The agreement is better for $R=0.5$ than for $R=1$
- ⇒ This indicates that it is in fact an effect of the $\gamma\gamma \rightarrow \text{hadrons}$ background
- Will be checked also with a higher-energy sample (3 TeV)



Performance with jet pT cut

All jets required to have $p_T > 10\text{ GeV}$ \Rightarrow slight improvement of derived observables



Conclusions

Current status

- Tracking efficiency and resolution as well as calorimeter resolution regarded as frozen
- Effects of $\gamma\gamma \rightarrow$ hadrons background might require some additional jet smearing (under investigation)
- Lepton ID efficiencies to be improved



Backup

Additional information



Modules and Execution path

- `ExecutionPath` fixes the order of the modules
- Then, each module is defined specific to CLICdet
- Typically, each module has at least one input array (which particles it acts on) and at least one output array and several parameters which can be adapted to the detector model



ExecutionPath

- ParticlePropagator
- TrackingEfficiency for charged Hadrons, Electrons, Muons
- Momentum Smearing for charged Hadrons, Electrons, Muons
- TrackMerger
- Calorimeters (ECal, HCal)
- Mergers, Filters (EFlowMerger, EFlowFilter)
- Photons: Efficiency and Isolation
- Electrons: Filter, Efficiency, Isolation
- charged Hadrons: Filter
- Muons: Efficiency, Isolation
- UniqueObjectFinder to remove isolated e, μ, γ from jet input
- NeutrinoFilter
- Jets: FastJetFinders for Valencia algorithm (VLC)
- MissingET (MissingET, GenMissingET)
- (JetEnergyScale)
- JetFlavorAssociation, BTagging, and TauTagging
- ScalarHT
- TreeWriter



ParticlePropagator

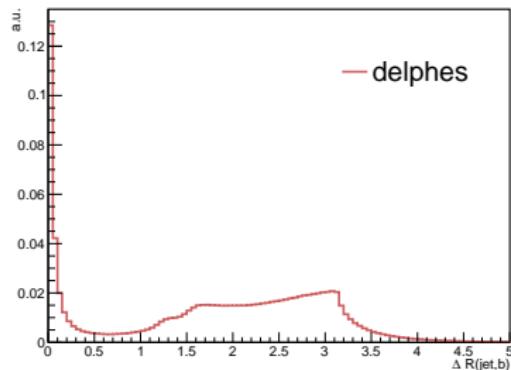
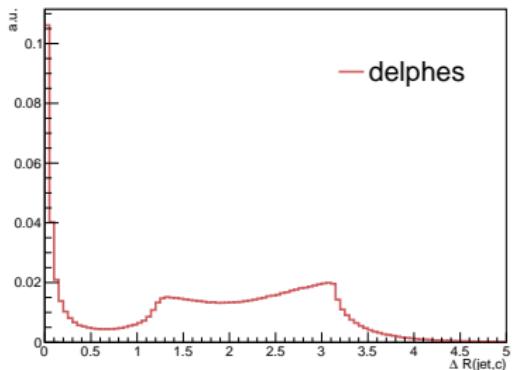
Propagates charged and neutral particles from the interaction point through the magnetic field into the calorimeters defined by Radius (r_{min}) and HalfLength (z_{min})

- Parameters (Table 1 of CLICdet-Note-2017-001)
 - Radius = inner radius of calorimeter barrel
CLICdet: Radius = ECAL barrel r_{min} (m) = 1.5
 - HalfLength = z coordinate of first endcap calorimeter layer
CLICdet: HalfLength = ECAL endcap z_{min} (m) = 2.31
 - magnetic field (T)
CLICdet: Bz = 4.0 T
- OutputArray split into chargedHadrons, electrons, muons



B and c tagging

- First, a jet flavor association module is run, which assigns a flavor to a jet by checking partons inside a ΔR cone around the jet
- checked the ΔR for b, c quarks and VLC($R=1$, $N=4$): Peak close to 0 is likely from actual b(c) jets, other contributions are non-b(c) jets \Rightarrow choose $\Delta R = 0.5$ to avoid contamination



(might need to be re-checked after all smearing is implemented correctly;
don't expect big changes)

