Delphes Card for CLICdet

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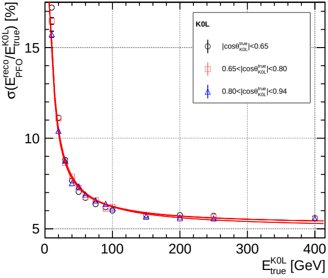
Intro and News

News w.r.t. last presentation on the Delphes card in the analysis meeting January 16:

- Calorimeter resolutions for HCAL and ECAL (from Matthias Weber)
- Muon, Photon, and Electron identification efficiencies (from Matthias Weber)
- B tagging added into the card, based on *CLICdp-Note-2014-002*: 3 working points: 50 %, 70 %, 90 %
- Tau tagging based on LCD-2010-009 (Astrid Muennich) added to the card
- Refined tracking momentum resolutions for e, mu, pi: adjusted the binning as well as increase resolution in $\theta = 10^\circ$ case
- Electron ID efficiencies: more granular energy dependence implemented

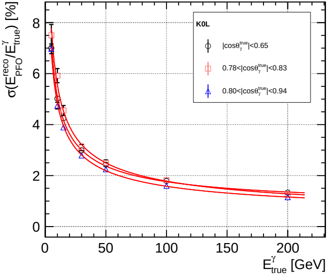
Calorimeter resolutions

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

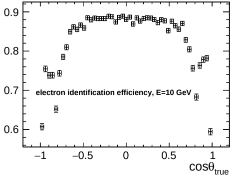
Electron, muon, and photon efficiency and isolation

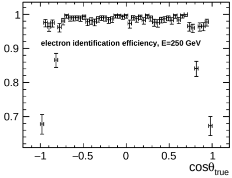
- Electron, photon, muon candidates are identified among Particle Flow objects
- Isolated e, μ, γ are removed from the PFOs which are passed to jet finding using a UniqueObjectFinder module
- Isolation is determined according to jet content in a DeltaR cone ($\Delta R = 0.5$) with a maximum pT ratio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

Electron, muon, and photon efficiency and isolation

Electrons

for $E < 3\,\text{GeV}$: $\epsilon = 0$
above 3 GeV, ID efficiencies are derived for 11 bins in energy, with 6 bins in η each



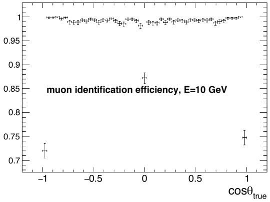


Muons

for $E < 2\,\text{GeV}$: $\epsilon = 0$ for $2 \leq E < 50\,\text{GeV}$:

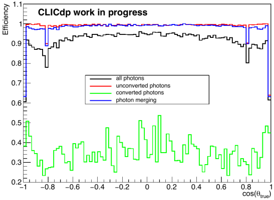
$\lvert\eta\rvert$	ϵ
> 1.95	0.73
> 0.2	0.98
< 0.2	0.87

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



Photons

for $E < 2\,\text{GeV}$: $\epsilon = 0$
for $E \geq 2\,\text{GeV}$: $\lvert\eta\rvert < 0.7$: $\epsilon = 0.94$
for $0.7 < \lvert\eta\rvert < 3$: $\epsilon = 0.9$



Tracking efficiency

- Input: charged Hadrons/electrons/muons from ParticlePropagator for charged hadrons/electrons/muons
- Efficiencies read off from Emilia's plots (see backup)
- NEW: binning in energy adjusted

Muons

$\theta[^\circ]$	E /GeV	ϵ
0...9	any	0
9..10	≥ 80	0.994
9..10	5...80	0.996
9..10	< 5	0.996
10...12	> 5	1
10...12	$> 1, < 5$	0.999
12...90	> 1	1

Electrons

$\theta[^\circ]$	E /GeV	ϵ
9...10	≥ 80	0.993
9...13	5...80	0.998
10...11	≥ 80	0.997
11...90	≥ 80	1.0
13...90	5...80	1.0
11...50	< 5	0.997
50...90	< 5	0.999

Pions

E /GeV	$\theta[^\circ]$	ϵ
$>= 80$	9...90	1.000
3...80	9...11	0.994
3...80	11...90	1.000
< 3	9...60	0.000
< 3	60...90	1.0000

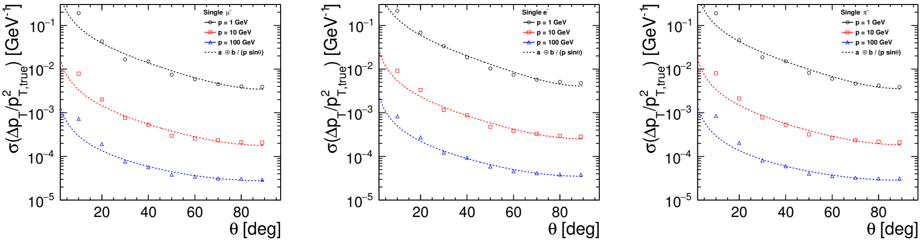
Momentum resolution

- Applied by retrieving a random variable r from a Gaussian with mean=0, sigma=1
- Multiplying $\exp(r) \times p_T = p'_T$

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

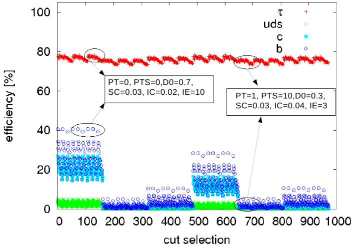


- NEW Modified binning in η with bin edges now: 2.66, 1.74, 1.01, 0.55, 0.18, 0
- NEW Factor 2 for resolution for $\theta = 10^\circ$ (see diagrams why)

Tau tagging

from LCD-2010-009 (Astrid Muennich)

- Mis-ID of quark jets as τ candidates

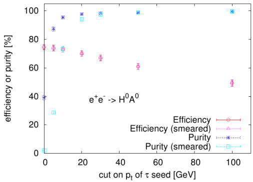


x axis: variation of selection cuts

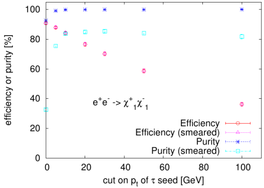
- figure is not very conclusive
- use mis-ID rate $\approx 3\,\%$ globally

Tau tagging efficiencies

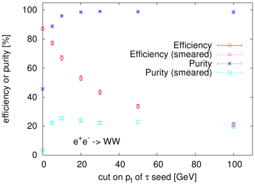
- Tau tagging efficiency from LCD-2010-009 (Astrid Muennich)



$e^+e^- \to H^0A^0$



$e^+e^- \to \chi_1^+\chi_1^-$



$e^+e^- \to WW$

- Efficiencies: **average** of efficiencies for the three processes above
- PT bins: 2.5 x seed pT

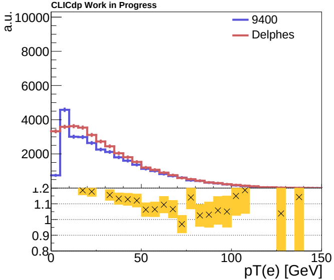
p_T seed (GeV)	≥ 2	≥ 5	≥ 10	≥ 20	≥ 30	≥ 50	≥ 100
$p_T(\tau)$ (GeV)	≥ 5	≥ 12.5	≥ 25	≥ 50	≥ 75	≥ 125	≥ 250
ϵ	0.84	0.79	0.74	0.66	0.61	0.51	0.36

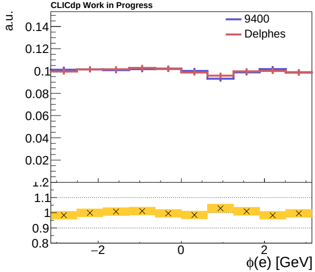
Performance

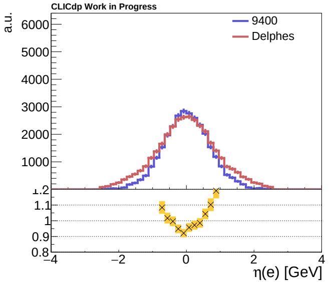
- Validate performance using *HZ* with $Z \to qq$, $H \to$ inclusive at 350 GeV
- Jets from VLC N=4, R=1 are used unless noted otherwise
- Leptons in full simulation obtained with isolated object finder
- 9400 is the DSID of the full simulation from January pilot production

Electron performance - all events

Electrons



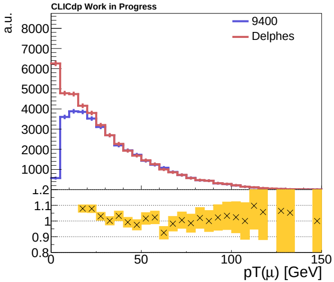


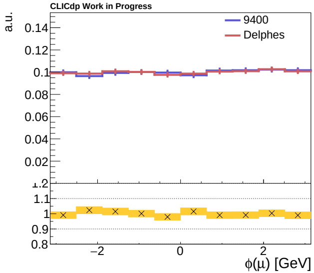


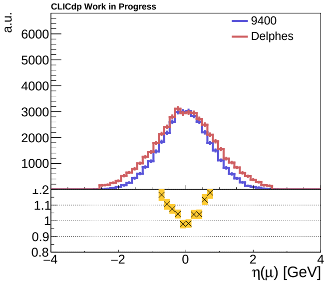
- In total more electrons in Delphes than in full sim → efficiencies too high?
- PT spectrum not well modeled in low pT bins
- Delphes: More electrons in forward regions than in full simulation
- Could be related to:
  Tracking efficiencies (unlikely),
  ID efficiencies, overlap removal in Delphes,
  isolation in full simulation or in Delphes →
  investigating

Muon performance - all events

Muons



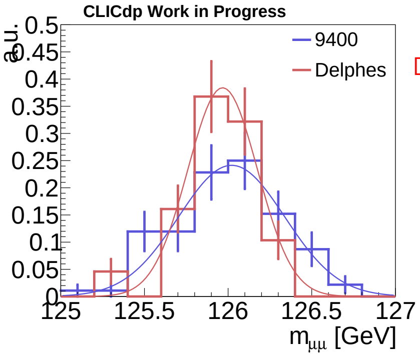




- More forward $|\eta|$ muons, more smaller pT muons in Delphes than in full simulation
- Introducing $\epsilon^{ID} = 0$ for $E < 2\,\mathrm{GeV}$ has improved the spectrum, but a large mismodeling remains
- PT perfectly well modeled above $p_T > 25\,\mathrm{GeV}$
- Could be related to:
  Tracking efficiencies (unlikely),
  ID efficiencies, overlap removal in Delphes,
  isolation in full simulation or in Delphes

$H \to \mu\mu$ events only

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



Fit results (Gaussian):

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

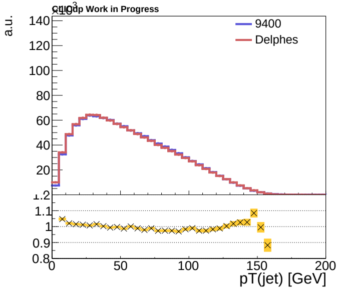
Full sim $m_H = 126.0\,\text{GeV}$; $\sigma_m = 3.18\,\text{GeV}$

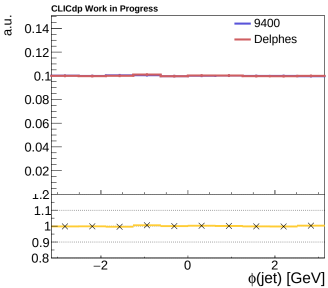
$\Rightarrow$ Delphes less smeared (width 0.65 of full sim)

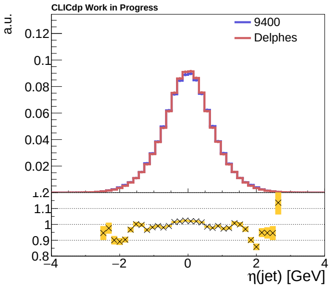
- This is probably an effect of the muon mismodeling mentioned above
- Mean value in good agreement with 126 GeV

Jets performance - all events

Jets

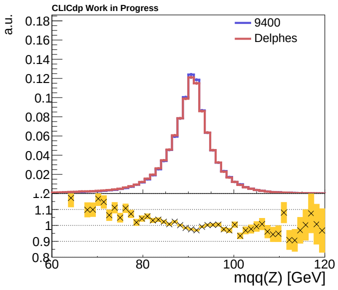


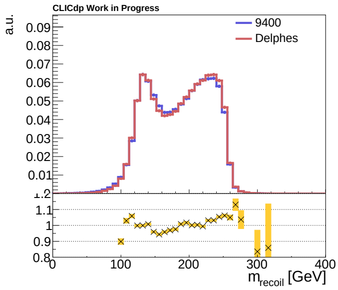




- jets are in good agreement:
- up to 5 % differences above $p_T > 10\,\text{GeV}$
- good agreement in η up to $|\eta| \approx 1.7$, up to 10 % differences at forward $|\eta|$

Derived observables performance - all events



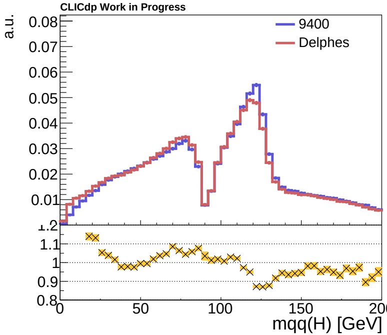


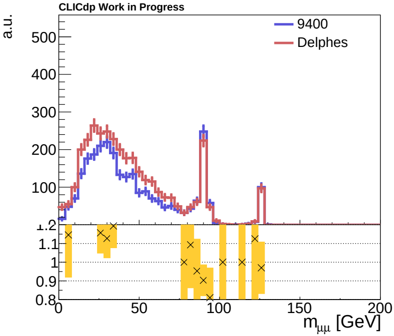
- m(Z) is determined as:
  - N=3,4,5 jet clustering
  - pick the two jets with mjj closest to mZ

⇒ Difference in mZ up to 5 % in area close to Z peak; up to 15 - 20 % further away

- Recoil mass calculated from this Z candidate
  - Up to $\approx$ 5 % differences in peak and reflection peak
  - 10 - 20 % difference in tails

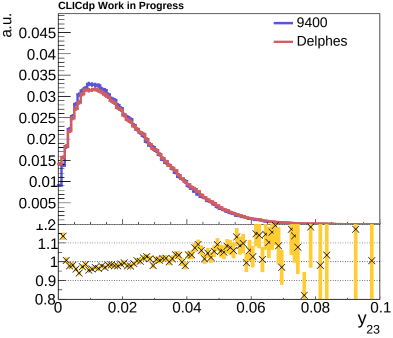
Derived observables performance – all events

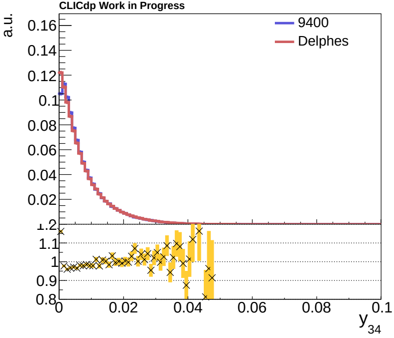




- Using N=4 jets clustering, mqq(H) is the invariant mass of the two jets remaining after assigning the two Z jets ⇒ in ≈ 50 % of cases, this corresponds to the $H \to b\bar{b}$ jets
- No selection ⇒ $M(\mu\mu)$ includes $H \to ZZ \to \mu\mu xx$ and other muons
  - Mainly to many muons in the low di-muon mass range

Jet multiplicity observables – no selection

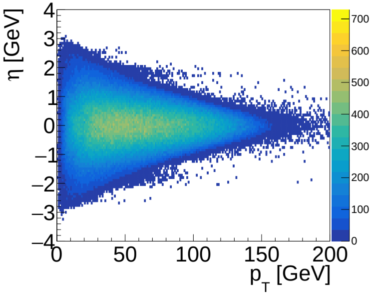




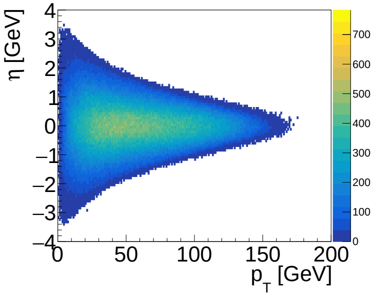
- y_{23}, y_{34} are measures of how well the event can be forced into 2/3/4 jets
- Often used for preselection cuts in multijet final states
- They are well modeled except for the very first bin(s) and a slight shift to higher values for Delphes

Jets performance investigated

Most likely the remaining differences in jet performance are related to underpopulated areas in pT-η (jets) plane:



Full sim

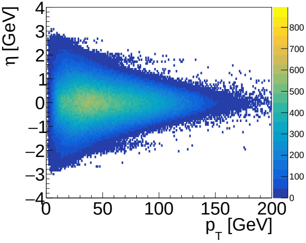


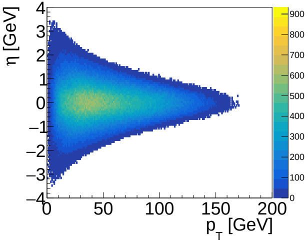
Delphes

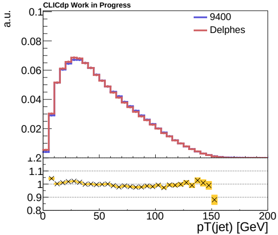
- Possible reason: effect of overlay background?

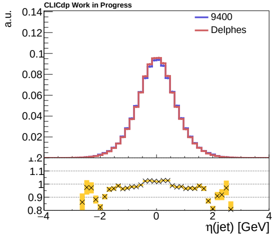
Is it an effect of $\gamma\gamma \rightarrow$ hadrons background?

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

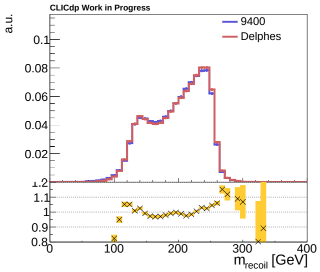


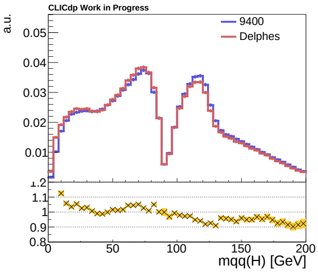






Smaller Jet radius: less overlay impact





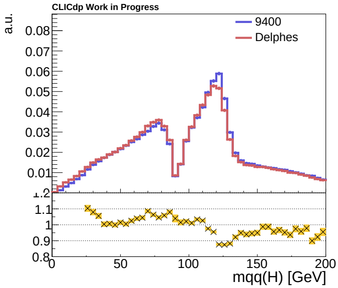
- The agreement is better for R=0.5 than for R=1

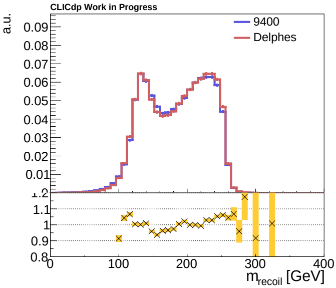
$\Rightarrow$ This indicates that it is in fact an effect of the $\gamma\gamma \rightarrow$ hadrons background

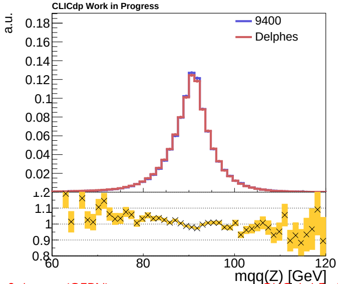
- Will be checked also with a higher-energy sample (3 TeV)

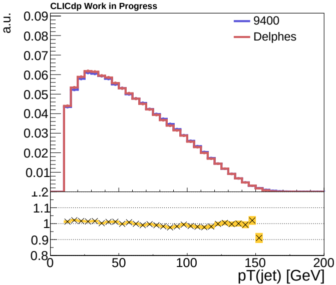
Performance with jet pT cut

All jets required to have $p_T > 10\,\mathrm{GeV}$









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 at higher energies (under investigation)
- Lepton ID efficiencies to be improved

Backup

Additional information

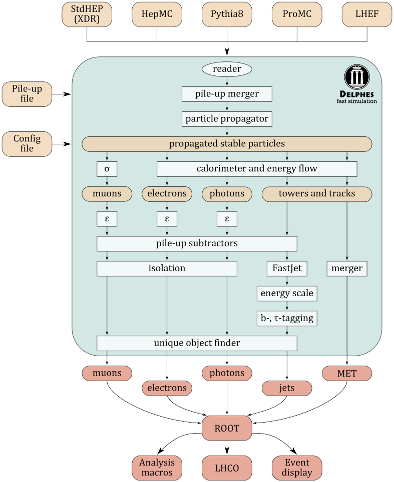
Documentation and links

- 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



from *https://cp3.irmp.ucl.ac.be/projects/delphes/wiki/WorkBook/DataFlowDiagram*

- 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
- Changed Data Flow to exclude isolated leptons from jet clustering input (using a UniqueObjectFinder)
- Output: ROOT TTree with resulting particles

Modules and Exectution 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

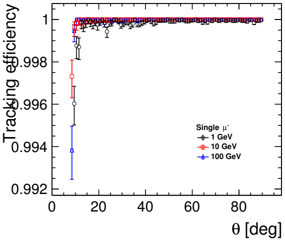
ParticlePropagator

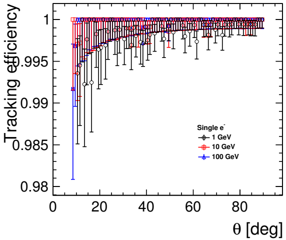
Propagates charged and neutral particles from the interaction point through the magnetic field into the calorimeters defined by Radius (r_{min}) and HalfLength (z_{min})

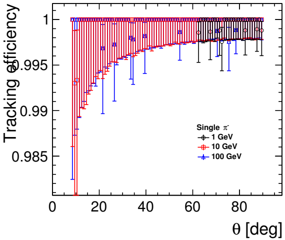
- Parameters (Table 1 of CLICdet-Note-2017-001)
  - Radius = inner radius of calorimeter barrel
    CLICdet: Radius = ECAL barrel r_{min} (m) = 1.5
  - HalfLength = z coordinate of first endcap calorimeter layer
    CLICdet: HalfLength = ECAL endcap z_{min} (m) = 2.31
  - magnetic field (T)
    CLICdet: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

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*







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 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

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

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

Jet finding

- Introduced into Delphes the VLC contribs from fastjet to implement Valencia jet algorithm

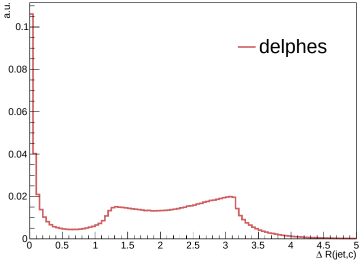
→ my pull request has been merged into the central Delphes repository

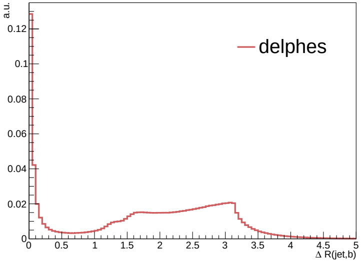
- In the card:
    - VLC with $\beta = \gamma = 1.0$
    - R = 0.5, 0.7, 1.0, 1.2, 1.5
    - Exclusive clustering with N = 2,3,4,5,6
- Jet energy scale is assumed to be 1.0

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 ⇒ 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)

B, c, and tau tagging

- If a b(c) truth jet is found inside the ΔR cone, it is b(c)-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
- τ tagging still missing