Fast simulation of the CEPC detector with Delphes

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CEPC overview

100km tunnel;
20iab data in 240GeV, 1iab in 360GeV.

CEPC CDR: arXiv:1811.10545
CEPC Fast simulation arXiv:1712.09517
CEPC SnowmassReport arXiv:2205.08553

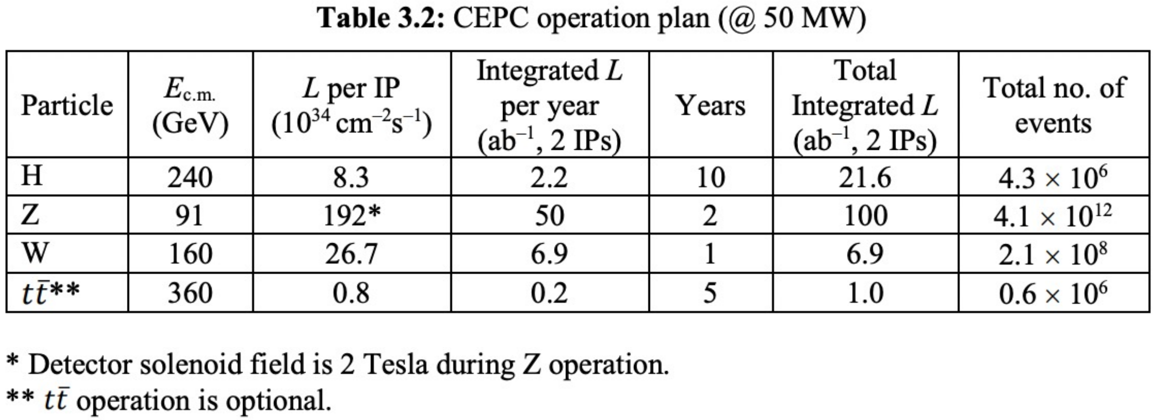
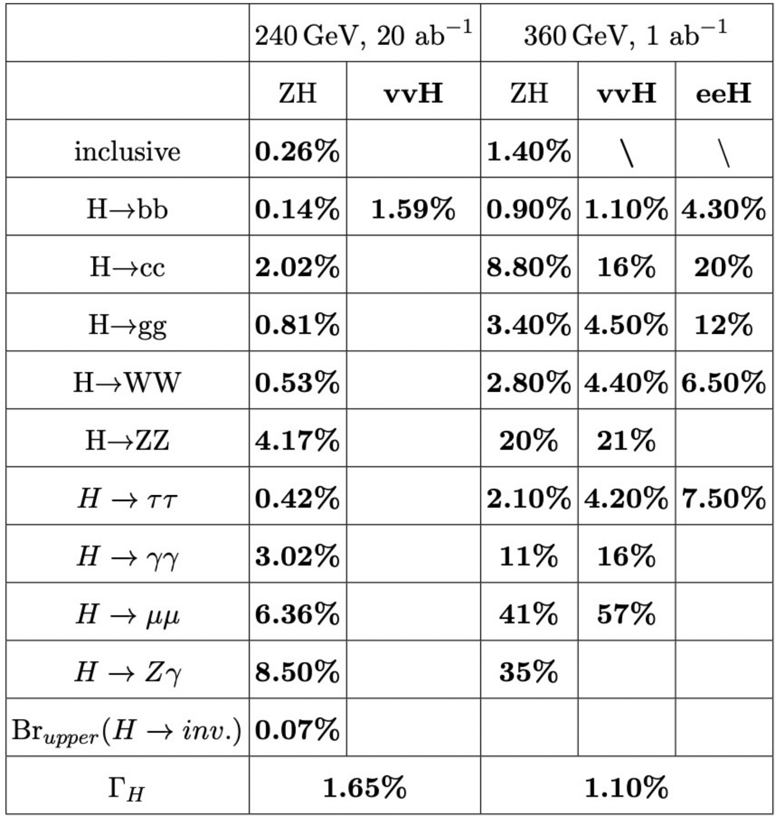


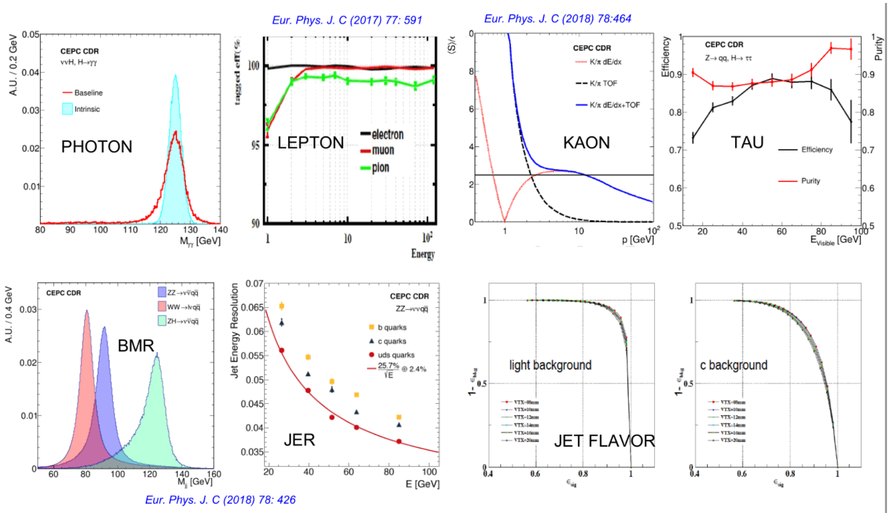
Table 3.2: CEPC operation plan (@ 50 MW)

Particle	$E_{\text{c.m.}}$ (GeV)	L per IP ($10^{34}\,\text{cm}^{-2}\text{s}^{-1}$)	Integrated L per year (ab^{-1}, 2 IPs)	Years	Total Integrated L (ab^{-1}, 2 IPs)	Total no. of events
H	240	8.3	2.2	10	21.6	4.3×10^6
Z	91	192*	50	2	100	4.1×10^{12}
W	160	26.7	6.9	1	6.9	2.1×10^8
$t\bar{t}$**	360	0.8	0.2	5	1.0	0.6×10^6

* Detector solenoid field is 2 Tesla during Z operation.
** $t\bar{t}$ operation is optional.



	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	vvH	ZH	vvH	eeH
inclusive	0.26%		1.40%	\	\
H→bb	0.14%	1.59%	0.90%	1.10%	4.30%
H→cc	2.02%		8.80%	16%	20%
H→gg	0.81%		3.40%	4.50%	12%
H→WW	0.53%		2.80%	4.40%	6.50%
H→ZZ	4.17%		20%	21%	
$H \to \tau\tau$	0.42%		2.10%	4.20%	7.50%
$H \to \gamma\gamma$	3.02%		11%	16%	
$H \to \mu\mu$	6.36%		41%	57%	
$H \to Z\gamma$	8.50%		35%		
$\text{Br}_{upper}(H \to inv.)$	0.07%				
Γ_H	1.65%		1.10%		



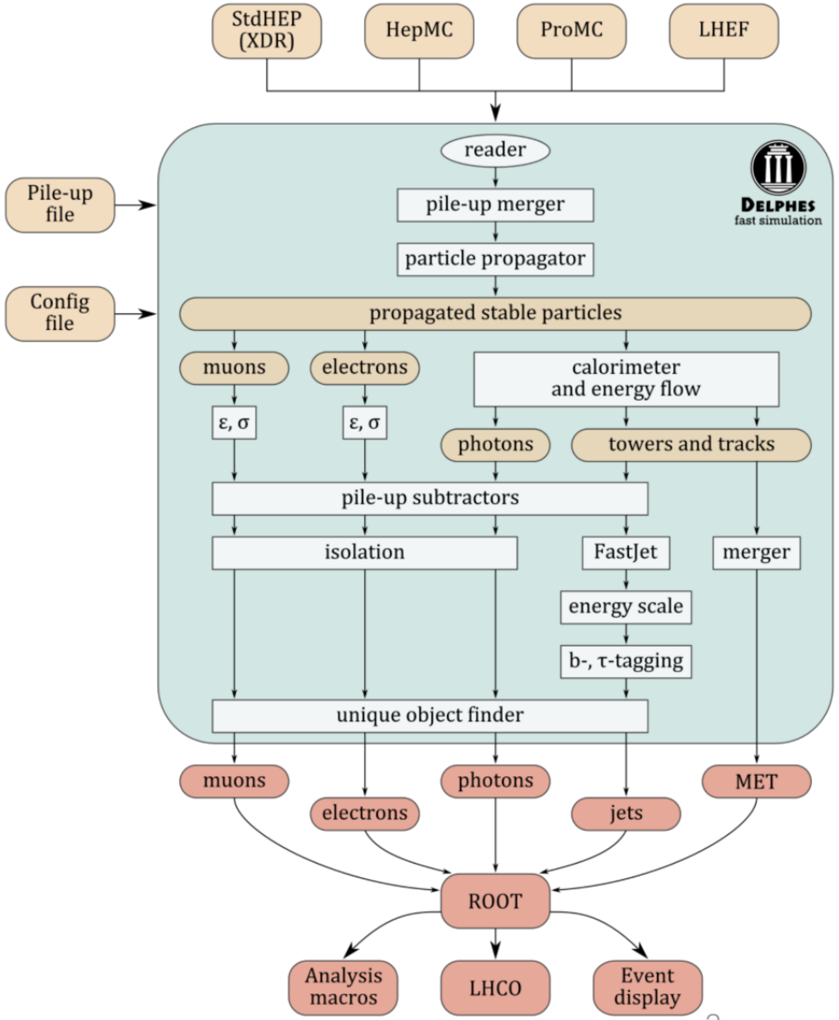
Eur. Phys. J. C (2017) 77: 591
Eur. Phys. J. C (2018) 78:464
Eur. Phys. J. C (2018) 78: 426

Reconstruction overview:
arXiv:1806.04879
Jet: arXiv:2104.05029
Track: arXiv:2209.00397
dE/dx: arXiv:2209.14486
Cluster time: arXiv:2209.02932

Delphes

J. High Energ. Phys. 2014, 57 (2014)

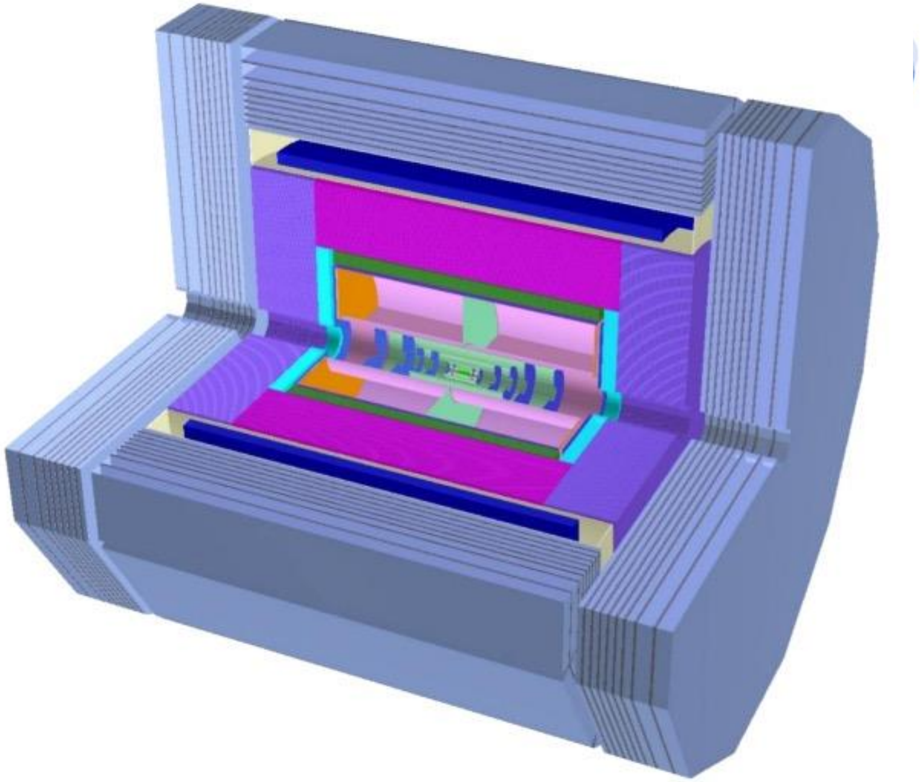
- Fast simulation framework
  - Detector geometry information included.
  - Reconstruction also handed;
- Why Delphes?
  - Fast. ~100 times faster than full simulation.
  - Compact. ~100 times smaller than full simulation.
  - Good enough. For most phenomenological study.
  - Evolving. Optimized for agile CEPC development



Evolving layout

Ref-TDR

- Most2/Stitching layout vertex detector;
- ToF LGAD readout;
- SiW Ecal + Glass Scintillator Hcal;
- TPC with dE/dx to 3%.
- ……



	2024 Scheme
Layout name	Ref_TDR
Magnet(T)	3
TOF detector	Included
Ecal resolution	$3\%/\sqrt{E/Gev} \oplus 1\%$
Hcal resolution	$40\%/\sqrt{E/Gev} \oplus 1\%$

Current results @Delphes

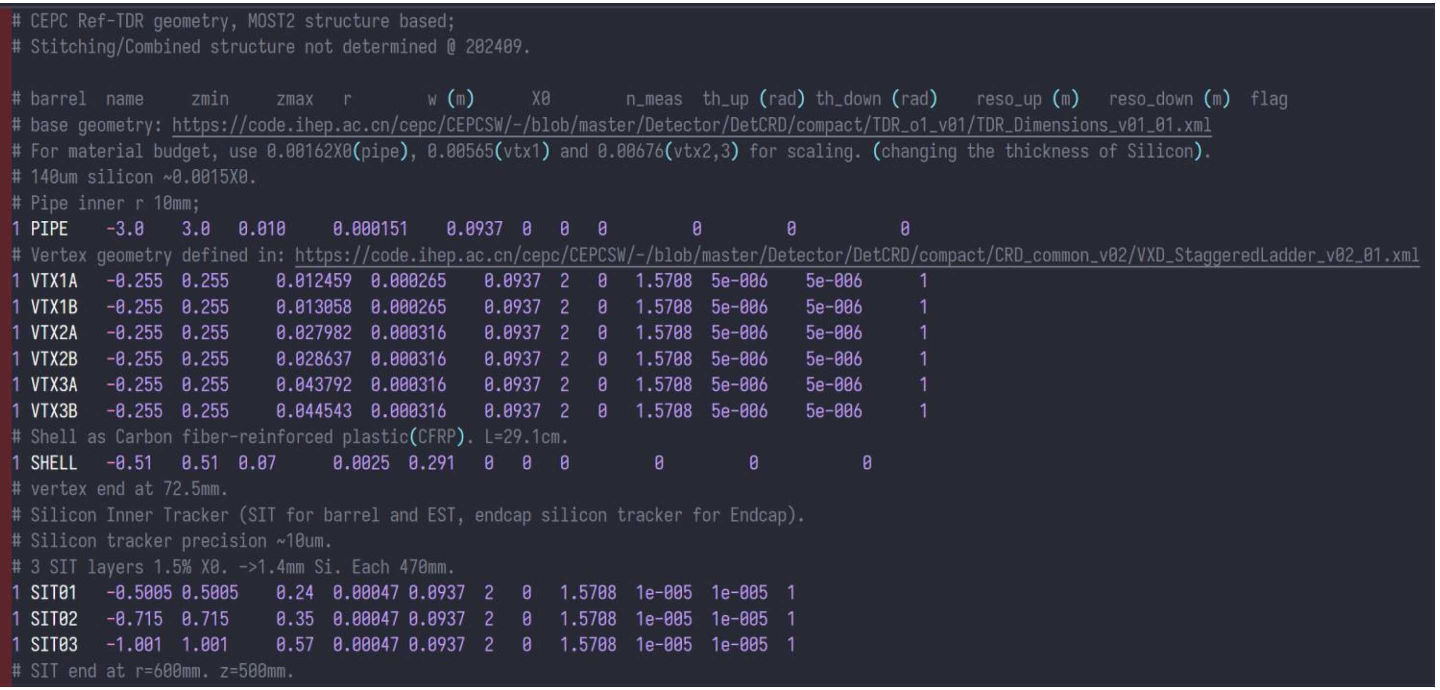
- Based Delphes V3.5.0
- https://github.com/oiunun/Delphes_CEPC
- Maintained by Li Gang and Gao Xu.
- https://code.ihep.ac.cn/zhangkl/delphes_cepc
- Adapted for RefTDR.
- Delphes card available:here
- Adapted for ee collision and easy for use.
- Simu&Reco, output as ntuple;

Important parameters in card

All variables adjustable.

MaxEta	3.0
Solenoid R	3.535m
Solenoid Z	4.575m
Solenoid B	3T
Minimum hits for a track	6
TimeResolution	30ps
TOF init time	From MC truth or 0(Neutral)
Ecal resolution	3% $\oplus$ 1%
Hcal resolution	35% $\oplus$ 5%
Jet Clustering Algo	eekt
……	……

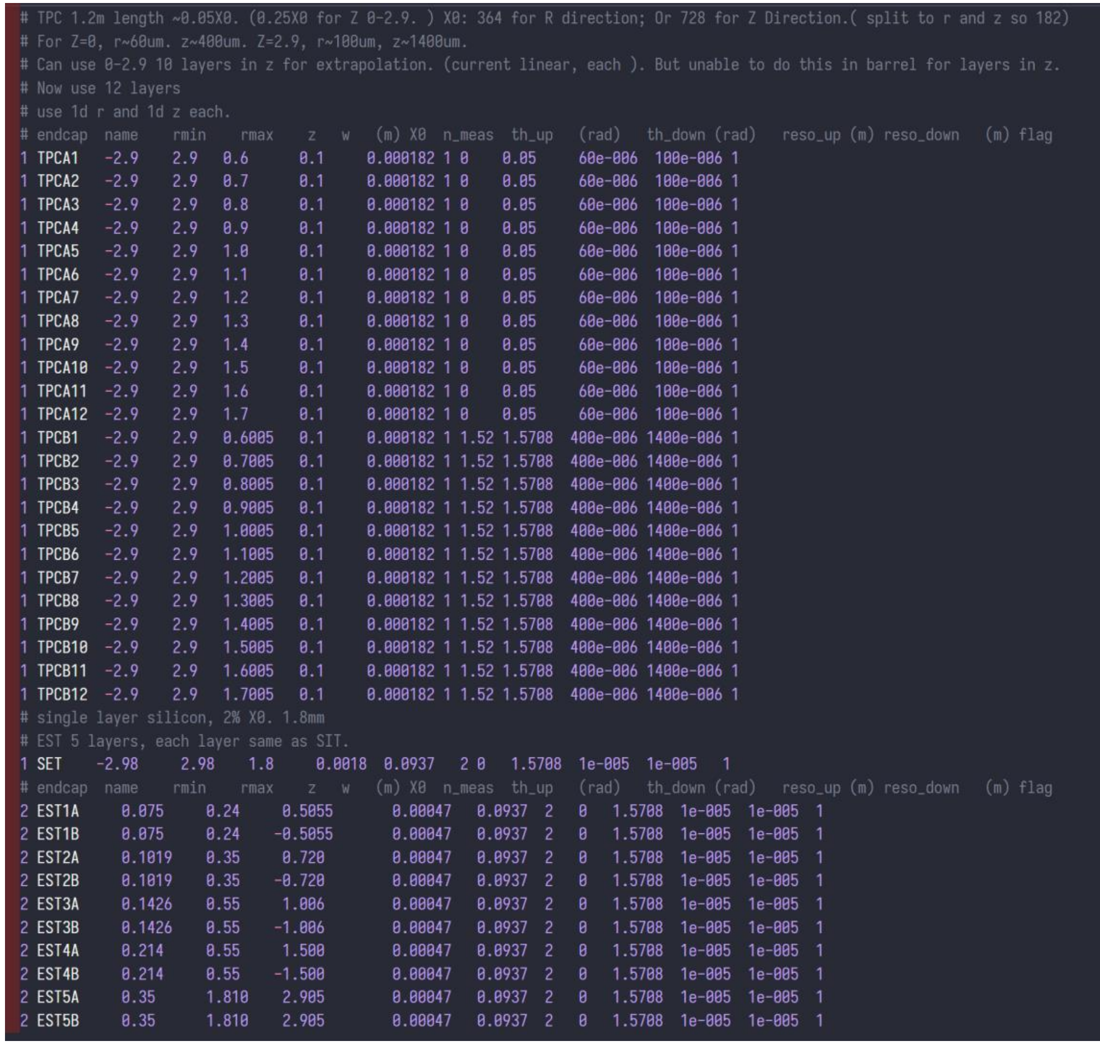
Ref-TDR Geometry in card



```
# CEPC Ref-TDR geometry, MOST2 structure based;
# Stitching/Combined structure not determined @ 202409.

# barrel  name     zmin     zmax   r        w (m)      X0        n_meas  th_up (rad) th_down (rad)    reso_up (m)   reso_down (m)  flag
# base geometry: https://code.ihep.ac.cn/cepc/CEPCSW/-/blob/master/Detector/DetCRD/compact/TDR_o1_v01/TDR_Dimensions_v01_01.xml
# For material budget, use 0.00162X0(pipe), 0.00565(vtx1) and 0.00676(vtx2,3) for scaling. (changing the thickness of Silicon).
# 140um silicon ~0.0015X0.
# Pipe inner r 10mm;
1 PIPE    -3.0    3.0   0.010     0.000151    0.0937  0   0   0         0         0           0
# Vertex geometry defined in: https://code.ihep.ac.cn/cepc/CEPCSW/-/blob/master/Detector/DetCRD/compact/CRD_common_v02/VXD_StaggeredLadder_v02_01.xml
1 VTX1A   -0.255  0.255     0.012459  0.000265    0.0937  2   0   1.5708  5e-006    5e-006      1
1 VTX1B   -0.255  0.255     0.013058  0.000265    0.0937  2   0   1.5708  5e-006    5e-006      1
1 VTX2A   -0.255  0.255     0.027982  0.000316    0.0937  2   0   1.5708  5e-006    5e-006      1
1 VTX2B   -0.255  0.255     0.028637  0.000316    0.0937  2   0   1.5708  5e-006    5e-006      1
1 VTX3A   -0.255  0.255     0.043792  0.000316    0.0937  2   0   1.5708  5e-006    5e-006      1
1 VTX3B   -0.255  0.255     0.044543  0.000316    0.0937  2   0   1.5708  5e-006    5e-006      1
# Shell as Carbon fiber-reinforced plastic(CFRP). L=29.1cm.
1 SHELL   -0.51   0.51  0.07      0.0025  0.291   0   0   0         0         0           0
# vertex end at 72.5mm.
# Silicon Inner Tracker (SIT for barrel and EST, endcap silicon tracker for Endcap).
# Silicon tracker precision ~10um.
# 3 SIT layers 1.5% X0. ->1.4mm Si. Each 470mm.
1 SIT01   -0.5005 0.5005    0.24  0.00047 0.0937  2   0   1.5708  1e-005  1e-005  1
1 SIT02   -0.715  0.715     0.35  0.00047 0.0937  2   0   1.5708  1e-005  1e-005  1
1 SIT03   -1.001  1.001     0.57  0.00047 0.0937  2   0   1.5708  1e-005  1e-005  1
# SIT end at r=600mm. z=500mm.
```

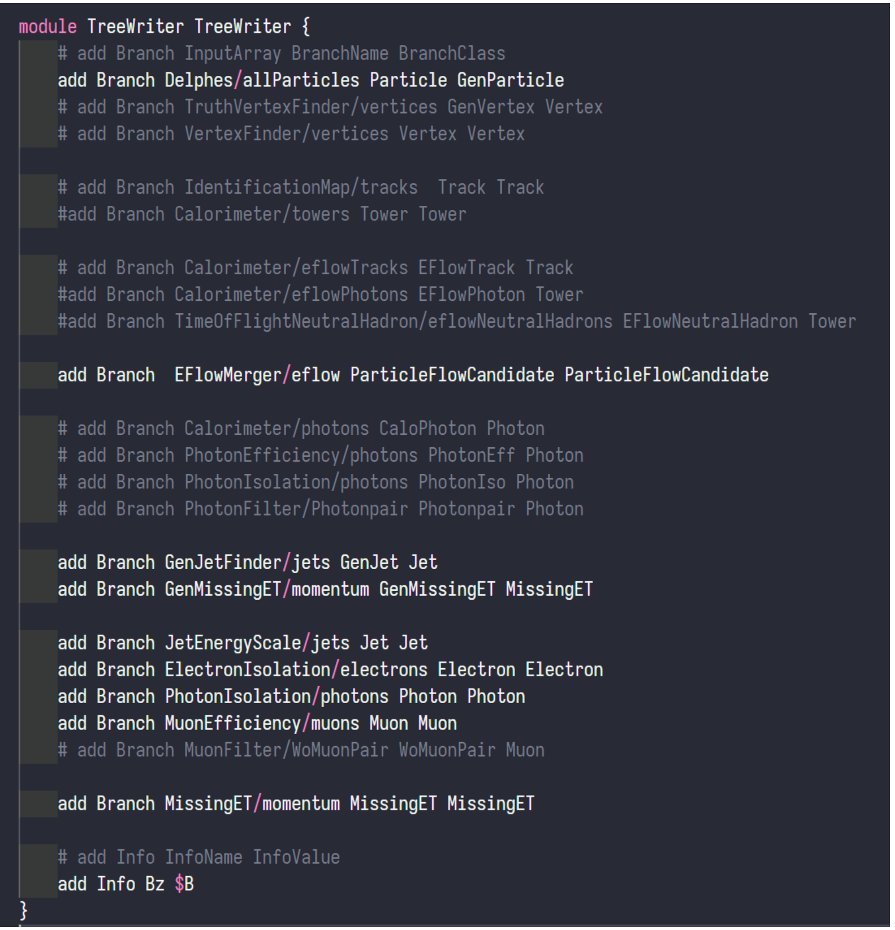
Pipe;
Vertex;
Silicon inner tracker;
TPC;
Silicon external tracker;
Endcap silicon tracker.

Material budget considered;
Precision under tuning.



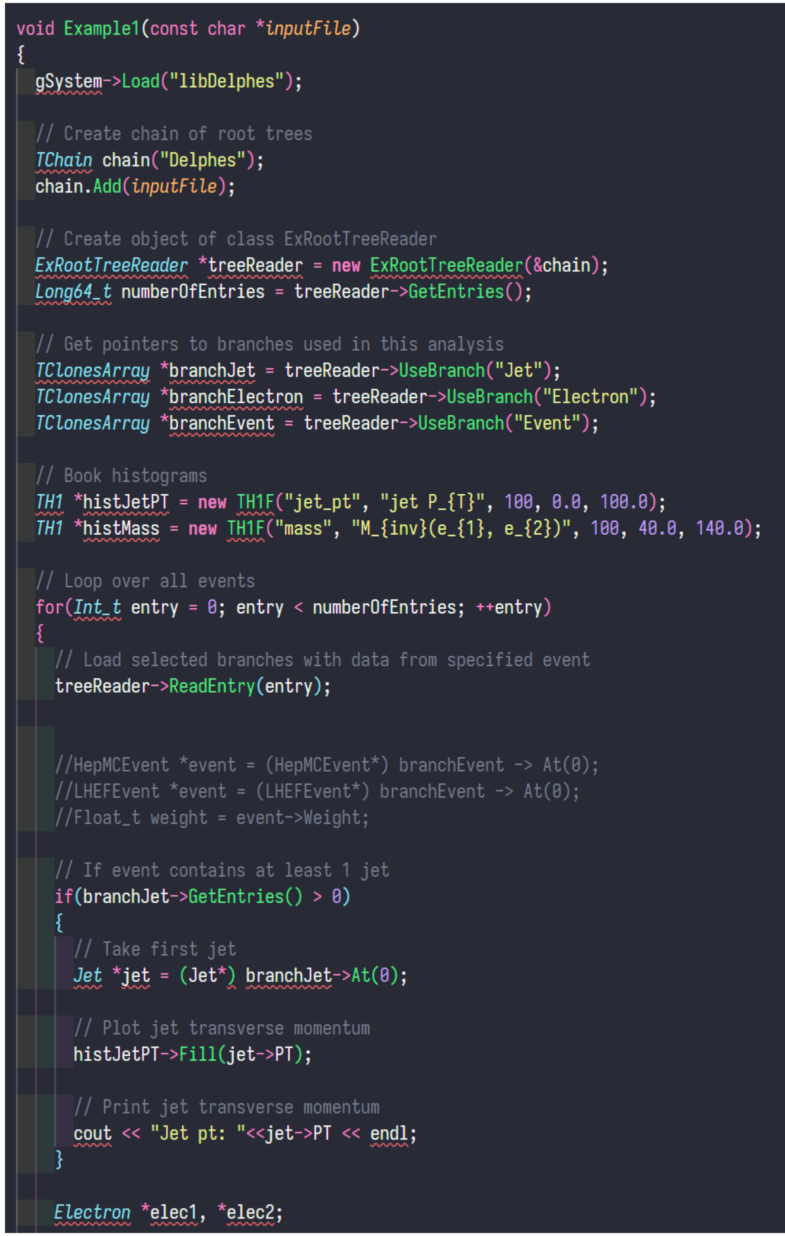
```
# TPC 1.2m length ~0.05X0. (0.25X0 for Z 0-2.9. ) X0: 364 for R direction; Or 728 for Z Direction.( split to r and z so 182)
# For Z=0, r~60um. z~400um. Z=2.9, r~100um, z~1400um.
# Can use 0-2.9 10 layers in z for extrapolation. (current linear, each ). But unable to do this in barrel for layers in z.
# Now use 12 layers
# use 1d r and 1d z each.
# endcap  name    rmin    rmax    z   w   (m) X0  n_meas  th_up   (rad)   th_down (rad)   reso_up (m) reso_down   (m) flag
1 TPCA1   -2.9    2.9   0.6      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCA2   -2.9    2.9   0.7      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCA3   -2.9    2.9   0.8      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCA4   -2.9    2.9   0.9      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCA5   -2.9    2.9   1.0      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCA6   -2.9    2.9   1.1      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCA7   -2.9    2.9   1.2      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCA8   -2.9    2.9   1.3      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCA9   -2.9    2.9   1.4      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCA10  -2.9    2.9   1.5      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCA11  -2.9    2.9   1.6      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCA12  -2.9    2.9   1.7      0.1     0.000182 1 0    0.05     60e-006  100e-006 1
1 TPCB1   -2.9    2.9   0.6005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
1 TPCB2   -2.9    2.9   0.7005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
1 TPCB3   -2.9    2.9   0.8005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
1 TPCB4   -2.9    2.9   0.9005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
1 TPCB5   -2.9    2.9   1.0005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
1 TPCB6   -2.9    2.9   1.1005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
1 TPCB7   -2.9    2.9   1.2005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
1 TPCB8   -2.9    2.9   1.3005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
1 TPCB9   -2.9    2.9   1.4005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
1 TPCB10  -2.9    2.9   1.5005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
1 TPCB11  -2.9    2.9   1.6005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
1 TPCB12  -2.9    2.9   1.7005   0.1     0.000182 1 1.52 1.5708  400e-006 1400e-006 1
# single layer silicon, 2% X0. 1.8mm
# EST 5 layers, each layer same as SIT.
1 SET    -2.98     2.98    1.8     0.0018  0.0937   2 0   1.5708  1e-005  1e-005   1
# endcap  name    rmin    rmax    z   w   (m) X0  n_meas  th_up   (rad)   th_down (rad)   reso_up (m) reso_down   (m) flag
2 EST1A    0.075     0.24     0.5055       0.00047   0.0937  2   0   1.5708  1e-005  1e-005  1
2 EST1B    0.075     0.24    -0.5055       0.00047   0.0937  2   0   1.5708  1e-005  1e-005  1
2 EST2A    0.1019    0.35     0.720        0.00047   0.0937  2   0   1.5708  1e-005  1e-005  1
2 EST2B    0.1019    0.35    -0.720        0.00047   0.0937  2   0   1.5708  1e-005  1e-005  1
2 EST3A    0.1426    0.55     1.006        0.00047   0.0937  2   0   1.5708  1e-005  1e-005  1
2 EST3B    0.1426    0.55    -1.006        0.00047   0.0937  2   0   1.5708  1e-005  1e-005  1
2 EST4A    0.214     0.55     1.500        0.00047   0.0937  2   0   1.5708  1e-005  1e-005  1
2 EST4B    0.214     0.55    -1.500        0.00047   0.0937  2   0   1.5708  1e-005  1e-005  1
2 EST5A    0.35      1.810    2.905        0.00047   0.0937  2   0   1.5708  1e-005  1e-005  1
2 EST5B    0.35      1.810    2.905        0.00047   0.0937  2   0   1.5708  1e-005  1e-005  1
```

Outputs



```
module TreeWriter TreeWriter {
    # add Branch InputArray BranchName BranchClass
    add Branch Delphes/allParticles Particle GenParticle
    # add Branch TruthVertexFinder/vertices GenVertex Vertex
    # add Branch VertexFinder/vertices Vertex Vertex

    # add Branch IdentificationMap/tracks  Track Track
    #add Branch Calorimeter/towers Tower Tower

    # add Branch Calorimeter/eflowTracks EFlowTrack Track
    #add Branch Calorimeter/eflowPhotons EFlowPhoton Tower
    #add Branch TimeOfFlightNeutralHadron/eflowNeutralHadrons EFlowNeutralHadron Tower

    add Branch  EFlowMerger/eflow ParticleFlowCandidate ParticleFlowCandidate

    # add Branch Calorimeter/photons CaloPhoton Photon
    # add Branch PhotonEfficiency/photons PhotonEff Photon
    # add Branch PhotonIsolation/photons PhotonIso Photon
    # add Branch PhotonFilter/Photonpair Photonpair Photon

    add Branch GenJetFinder/jets GenJet Jet
    add Branch GenMissingET/momentum GenMissingET MissingET

    add Branch JetEnergyScale/jets Jet Jet
    add Branch ElectronIsolation/electrons Electron Electron
    add Branch PhotonIsolation/photons Photon Photon
    add Branch MuonEfficiency/muons Muon Muon
    # add Branch MuonFilter/WoMuonPair WoMuonPair Muon

    add Branch MissingET/momentum MissingET MissingET

    # add Info InfoName InfoValue
    add Info Bz $B
}
```

- Store what you need in cards
    - “Gen” for truth
- Final state particles, jets and PID information available.
- Ntuples. Or directly delphes objects.
    - (need delphes env.)
- See Examples/Example1.C
- Easy for analyze.



```
void Example1(const char *inputFile)
{
  gSystem->Load("libDelphes");

  // Create chain of root trees
  TChain chain("Delphes");
  chain.Add(inputFile);

  // Create object of class ExRootTreeReader
  ExRootTreeReader *treeReader = new ExRootTreeReader(&chain);
  Long64_t numberOfEntries = treeReader->GetEntries();

  // Get pointers to branches used in this analysis
  TClonesArray *branchJet = treeReader->UseBranch("Jet");
  TClonesArray *branchElectron = treeReader->UseBranch("Electron");
  TClonesArray *branchEvent = treeReader->UseBranch("Event");

  // Book histograms
  TH1 *histJetPT = new TH1F("jet_pt", "jet P_{T}", 100, 0.0, 100.0);
  TH1 *histMass = new TH1F("mass", "M_{inv}(e_{1}, e_{2})", 100, 40.0, 140.0);

  // Loop over all events
  for(Int_t entry = 0; entry < numberOfEntries; ++entry)
  {
    // Load selected branches with data from specified event
    treeReader->ReadEntry(entry);


    //HepMCEvent *event = (HepMCEvent*) branchEvent -> At(0);
    //LHEFEvent *event = (LHEFEvent*) branchEvent -> At(0);
    //Float_t weight = event->Weight;

    // If event contains at least 1 jet
    if(branchJet->GetEntries() > 0)
    {
      // Take first jet
      Jet *jet = (Jet*) branchJet->At(0);

      // Plot jet transverse momentum
      histJetPT->Fill(jet->PT);

      // Print jet transverse momentum
      cout << "Jet pt: "<<jet->PT << endl;
    }

    Electron *elec1, *elec2;
```

Tutorial

Generator: Whizard

- https://code.ihep.ac.cn/zhangkl/whizardais
  - Edit the whizard.prc for different final states and compile.
- Slides from: Jun Ping
- Slides @ snowmass: Snowmass

Source of STDHEP:
1. /cefs/data/stdhep (incomplete)
2. Ask Kaili
3. Generate your own;(Current Whizard config has many hard-cored numbers. Take care!)

Run Delphes Card on IHEP server

- https://code.ihep.ac.cn/zhangkl/delphes_cepc/blob/master/cards/delphes_card_CEPC_RefTDR.tcl

- `git clone https://code.ihep.ac.cn/zhangkl/delphes_cepc`

- `export PATH=/cvmfs/container.ihep.ac.cn/bin:$PATH`

- `hep_container shell CentOS7 -g higgs` (Request higgs second linux group permission in http://ccsinfo.ihep.ac.cn/)

- `source /cvmfs/sft.cern.ch/lcg/views/LCG_99/x86_64-centos7-gcc10-opt/setup.sh`

- `make`

- `./DelphesSTDHEP cards/delphes_card_CEPC_RefTDR.tcl output.root /cefs/higgs/zhangkl/nnh_e2e2.e0.p0.00001.stdhep`

- (Format: ./DelphesSTDHEP card output stdhep)

CEPCSW

nnh_gg.e0.p0.00001.stdhep as input；

- ./run.sh /cefs/higgs/zhangkl/tutorial_202409/sim.py

Sim_TDR_o1_v01_E240_nnHgg.root

- ./run.sh /cefs/higgs/zhangkl/tutorial_202409/tracking.py

Tracking_TDR_o1_v01_E240_nnHgg.root

- ./run.sh /cefs/higgs/zhangkl/tutorial_202409/digi.py

CaloDigi_TDR_o1_v01_E240_nnHgg.root
Digi_HCAL.root
Digi_ECAL.root

- ./run.sh /cefs/higgs/zhangkl/tutorial_202409/rec.py

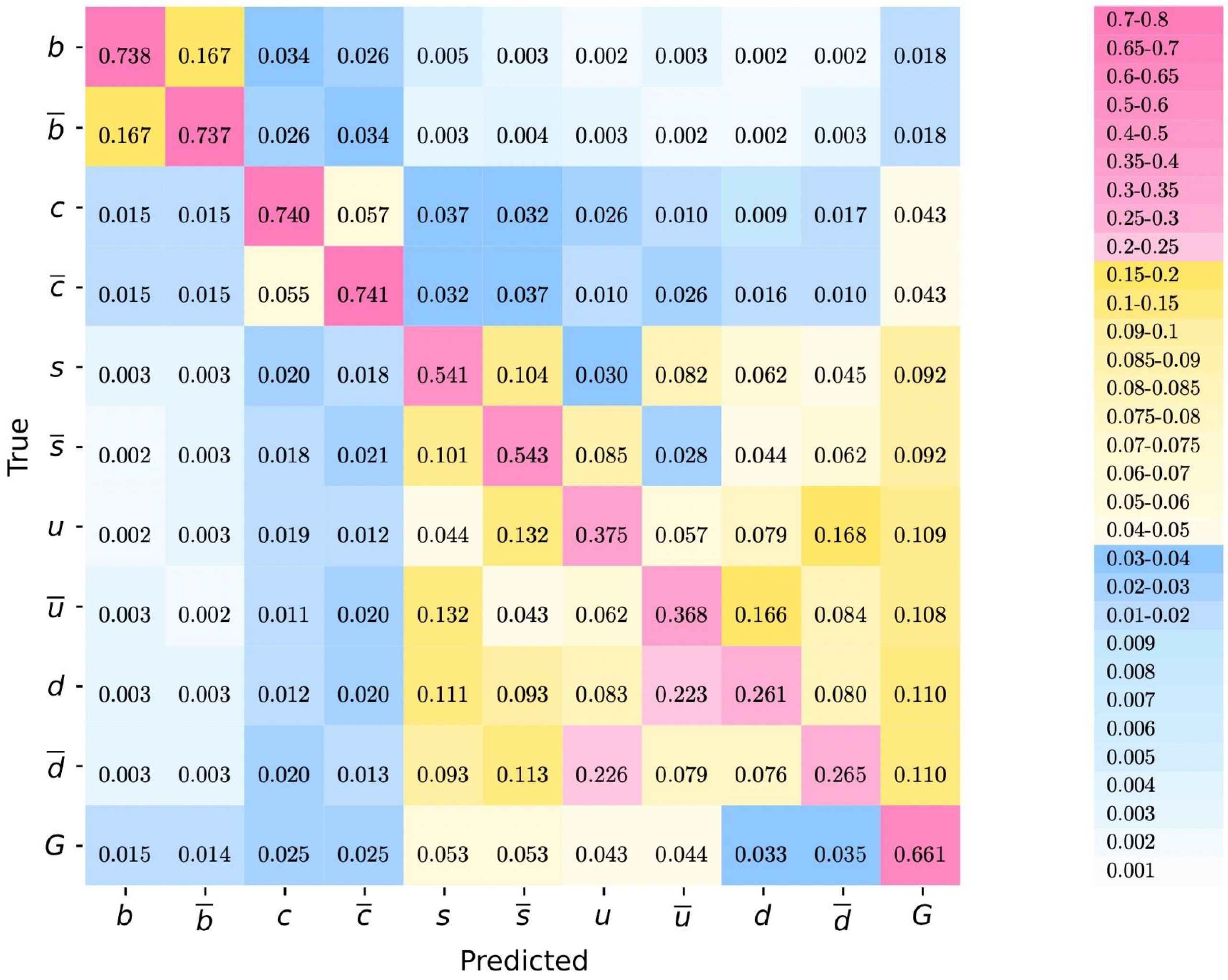
Rec_TDR_o1_v01_E240_nnHgg.root
RecAnaTuple_TDR_o1_v01_E240_nnHgg.root

Summary

- Delphes works well in current CEPC development
- the Delphes framework and card is available
  - On code.ihep.ac.cn: https://code.ihep.ac.cn/zhangkl/delphes_cepc/blob/master/cards/delphes_card_CEPC_RefTDR.tcl
  - The full set CEPC SM sample set preparing.
  - A tutorial website in the future with event display
- Current fast simulation consists with full simulation
- We are pleased to support: zhangkl@ihep.ac.cn

Backup

Jet Origin ID



	b	$\bar{b}$	c	$\bar{c}$	s	$\bar{s}$	u	$\bar{u}$	d	$\bar{d}$	G
b	0.738	0.167	0.034	0.026	0.005	0.003	0.002	0.003	0.002	0.002	0.018
$\bar{b}$	0.167	0.737	0.026	0.034	0.003	0.004	0.003	0.002	0.002	0.003	0.018
c	0.015	0.015	0.740	0.057	0.037	0.032	0.026	0.010	0.009	0.017	0.043
$\bar{c}$	0.015	0.015	0.055	0.741	0.032	0.037	0.010	0.026	0.016	0.010	0.043
s	0.003	0.003	0.020	0.018	0.541	0.104	0.030	0.082	0.062	0.045	0.092
$\bar{s}$	0.002	0.003	0.018	0.021	0.101	0.543	0.085	0.028	0.044	0.062	0.092
u	0.002	0.003	0.019	0.012	0.044	0.132	0.375	0.057	0.079	0.168	0.109
$\bar{u}$	0.003	0.002	0.011	0.020	0.132	0.043	0.062	0.368	0.166	0.084	0.108
d	0.003	0.003	0.012	0.020	0.111	0.093	0.083	0.223	0.261	0.080	0.110
$\bar{d}$	0.003	0.003	0.020	0.013	0.093	0.113	0.226	0.079	0.076	0.265	0.110
G	0.015	0.014	0.025	0.025	0.053	0.053	0.043	0.044	0.033	0.035	0.661

Delphes can not:

- Energy correlation
- Fake objects
- Particle interactions: ISR,   Photon radiation
- Impact of detector design