Fast simulation of the CEPC detector with Delphes

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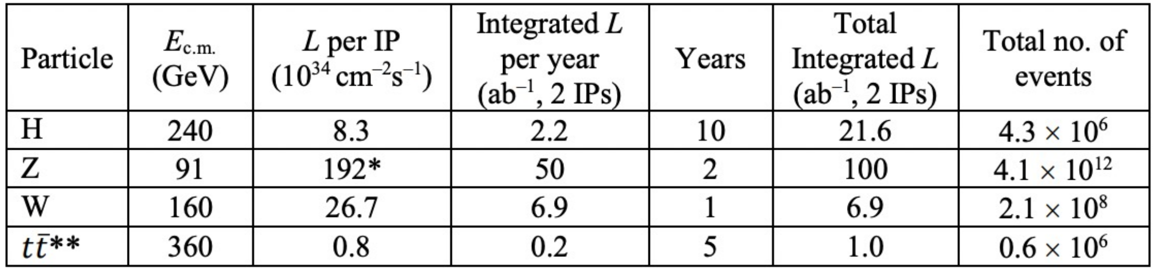
CEPC New Physics Workshop, Zhengzhou

CEPC overview

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

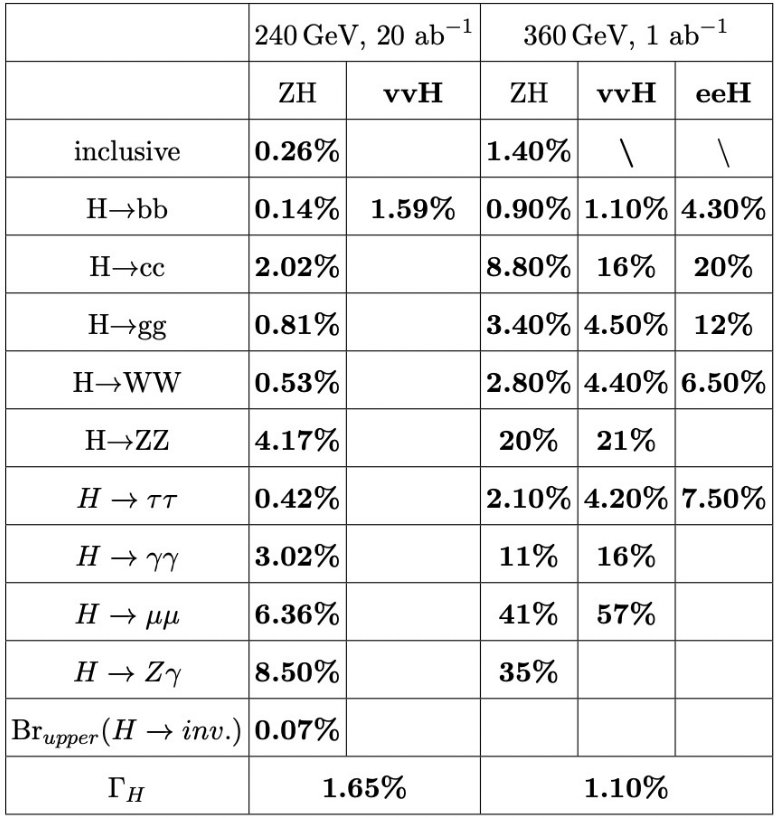
CEPC CDR: arXiv:1811.10545
CEPC Fast simulation arXiv:1712.09517
CEPC SnowmassReport arXiv:2205.08553

Table 3.2: CEPC operation plan (@ 50 MW)

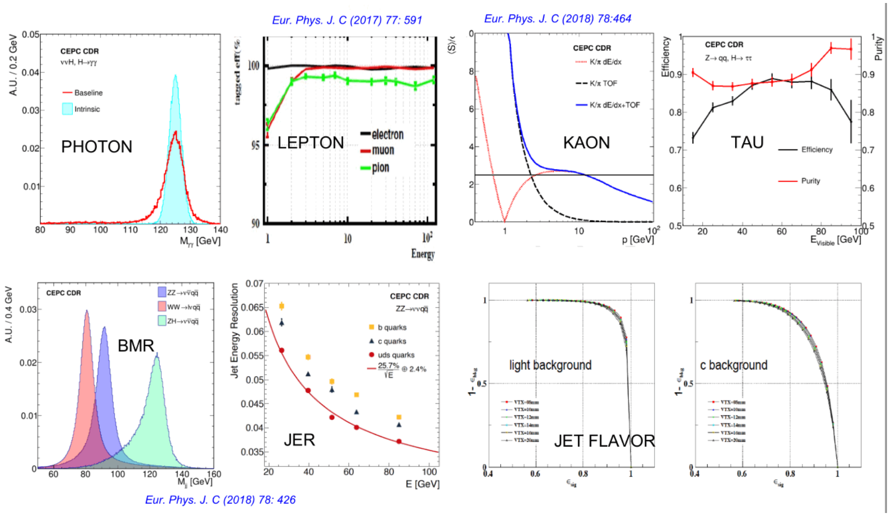


Particle	$E_{\text{c.m.}}$ (GeV)	L per IP ($10^{34}\,\text{cm}^{-2}\text{s}^{-1}$)	Integrated L per year (ab^{-1}, 2 IPs)	Years	Total Integrated L (ab^{-1}, 2 IPs)	Total no. of events
H	240	8.3	2.2	10	21.6	4.3×10^6
Z	91	192*	50	2	100	4.1×10^{12}
W	160	26.7	6.9	1	6.9	2.1×10^8
$t\bar{t}$**	360	0.8	0.2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

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



	$240\,\text{GeV},\ 20\ \text{ab}^{-1}$		$360\,\text{GeV},\ 1\ \text{ab}^{-1}$		
	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

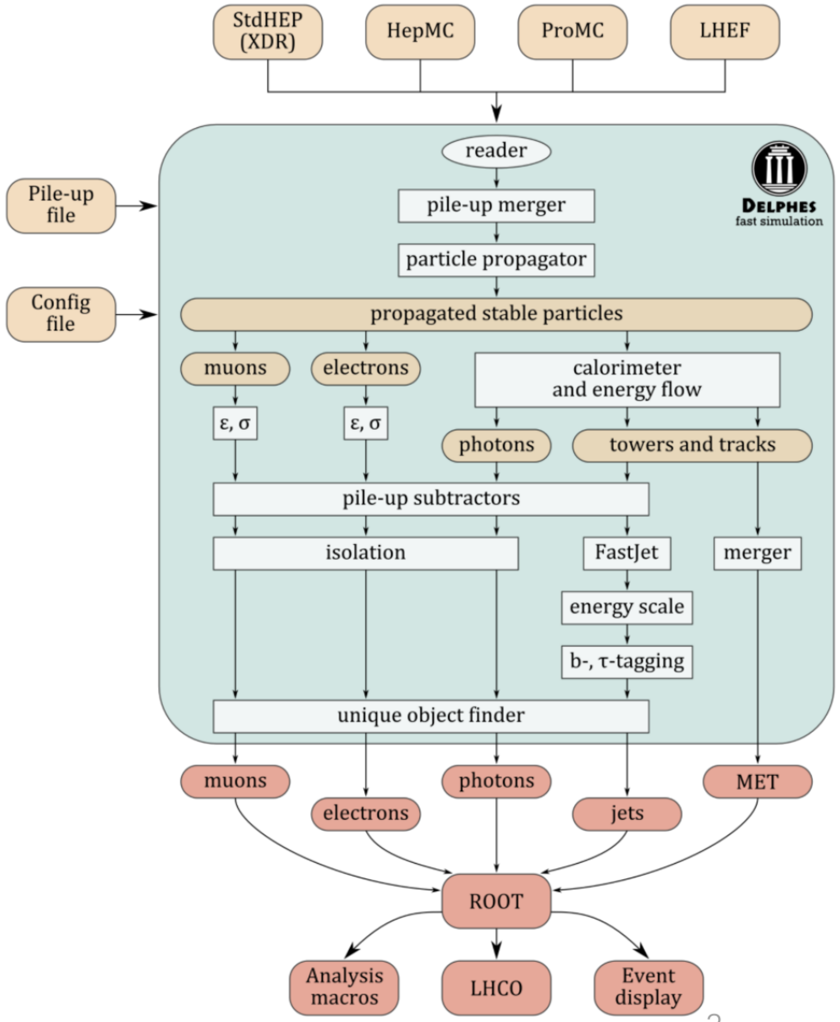
Eur. Phys. J. C (2018) 78: 426

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)

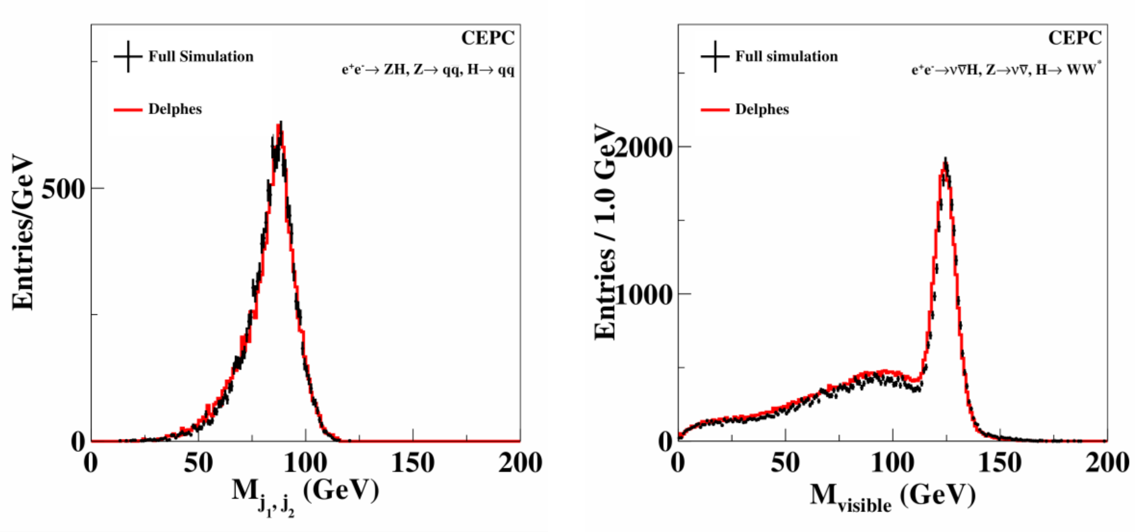
- Fast simulation framework
  - Detector geometry information included.
  - Reconstruction also handed;
- Why Delphes?
  - Fast. ~100 times faster than full simulation.
  - Compact. ~100 times smaller than full simulation.
  - Good enough. For most phenomenological study.
  - Evolving. Optimized for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



Fast simulation: 2018 scheme

arXiv:1712.09517

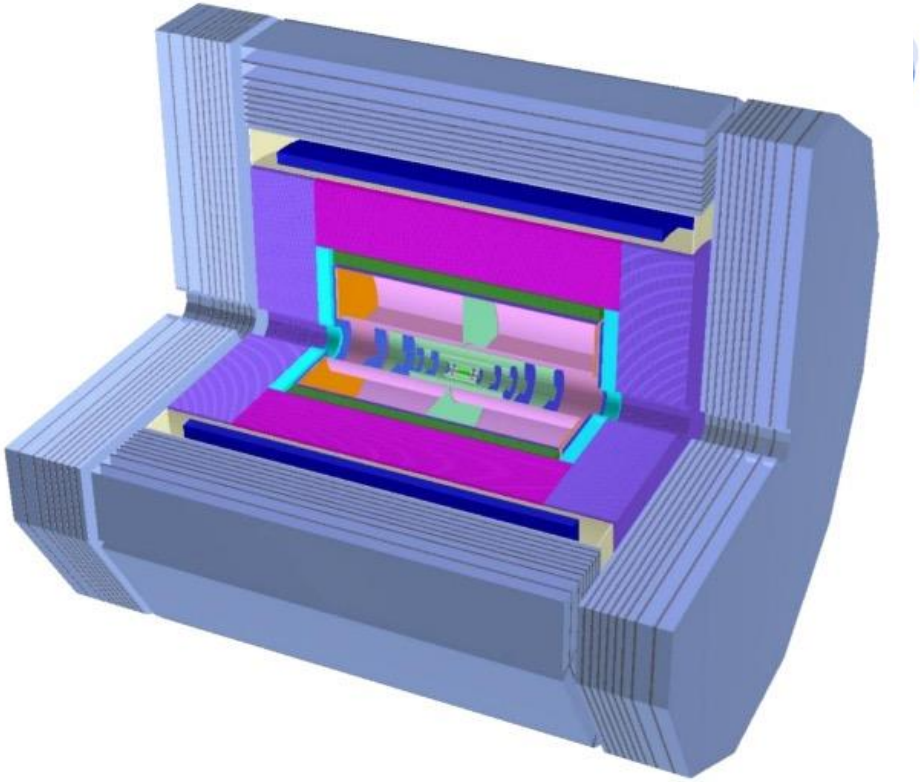
	2018 Scheme
Layout name	CEPC_v1
Magnet(T)	3.5
Track momentum $(\delta(1/P_T), \mathrm{GeV}^{-1})$	$2 * 10^{-5}$
Impact parameter resolution	$5\mu m \oplus 10\mu m$
Ecal resolution	$20\%/\sqrt{E/Gev} \oplus 1\%$
Hcal resolution	$60\%/\sqrt{E/Gev} \oplus 1\%$



More details can be found in CEPC white paper arXiv:1810.09037

4% Boson Mass Resolution (BMR) can be achieved in CEPC_v1 fast simulation.

Evolving layout

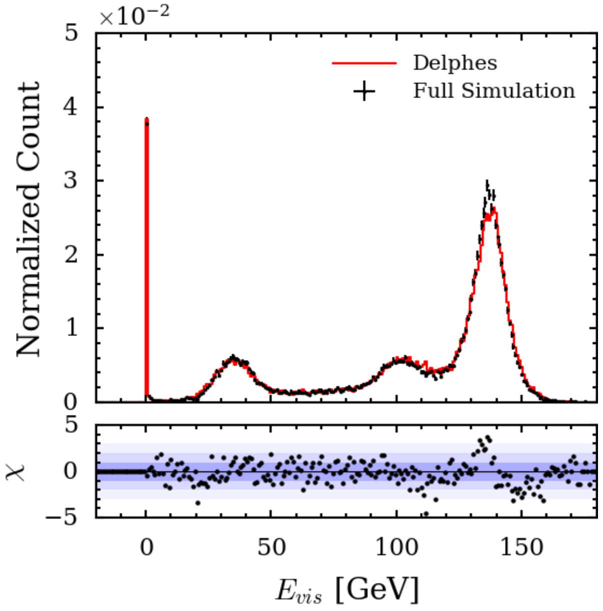


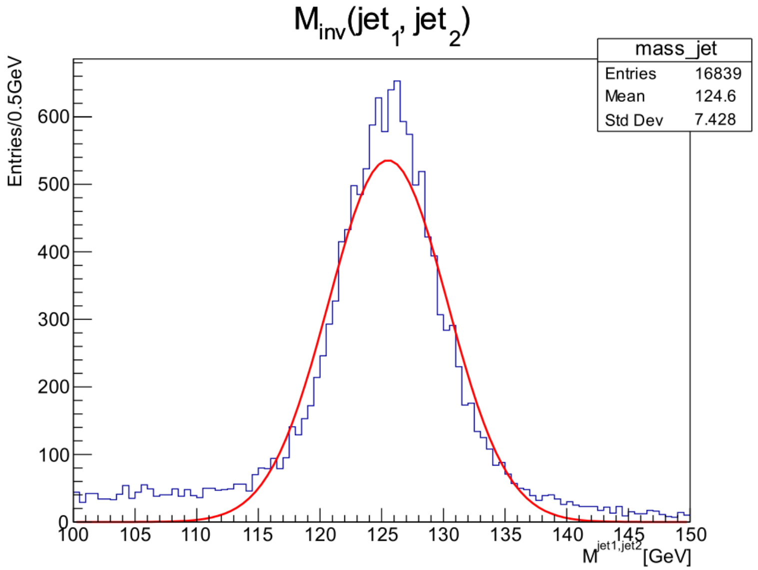
Ref-TDR

- 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





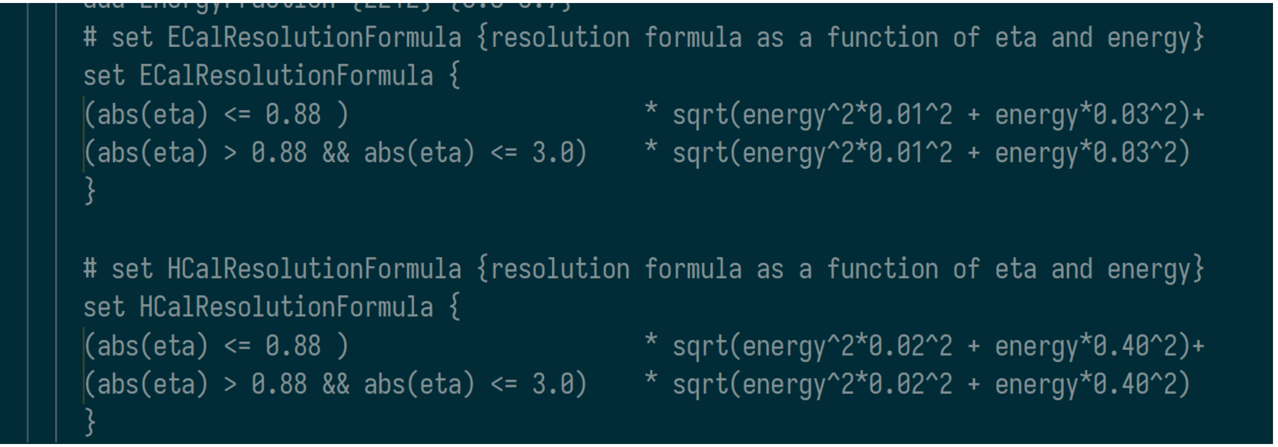
- Based Delphes V3.5.0
- https://github.com/oiunun/Delphes_CEPC
- Maintained by Li Gang and Gao Xu.
- Delphes card available for analyzers & theorists

- Adapted for ee collision and easy for use.
- Simu&Reco, output as ntuple;

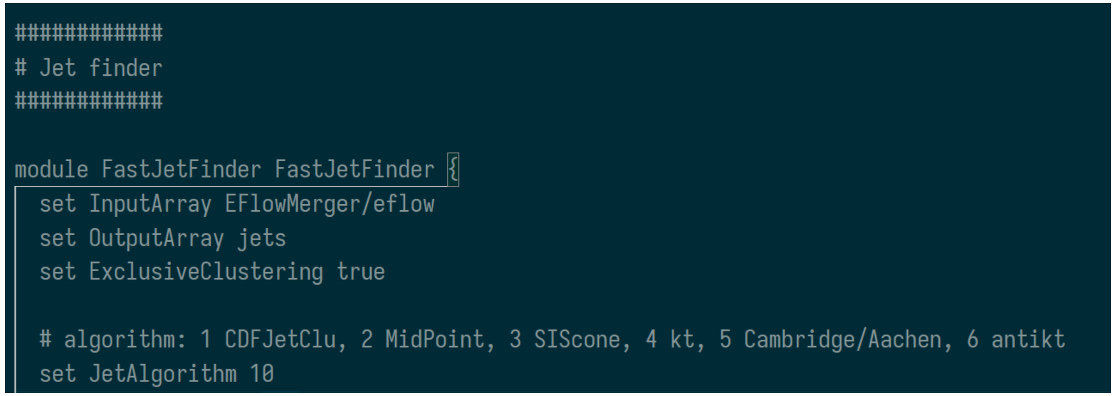
- BMR ~3.4%.

Adjustable variables

For Ecal and Hcal



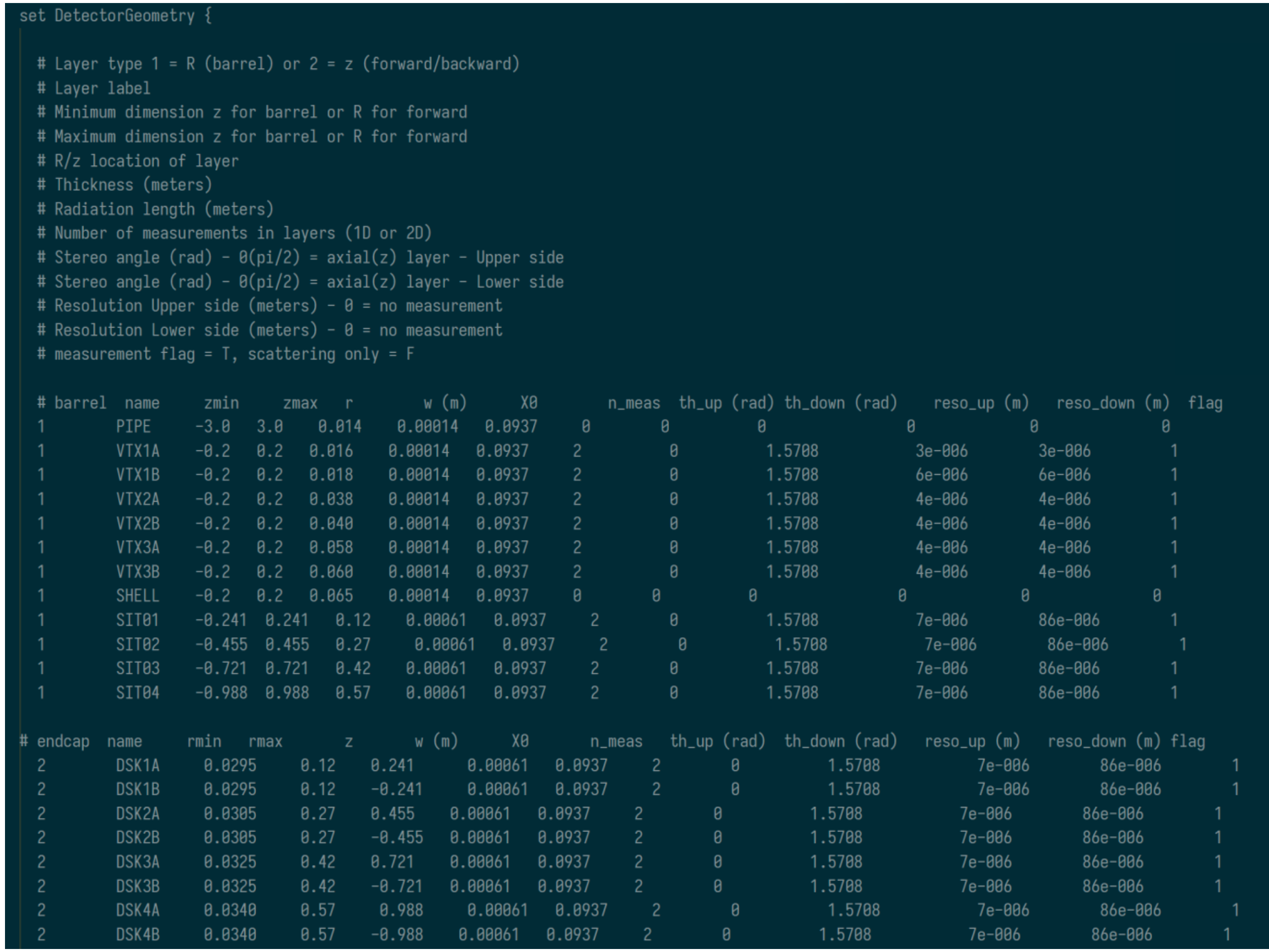
```
# set ECalResolutionFormula {resolution formula as a function of eta and energy}
set ECalResolutionFormula {
(abs(eta) <= 0.88 )                  * sqrt(energy^2*0.01^2 + energy*0.03^2)+
(abs(eta) > 0.88 && abs(eta) <= 3.0)   * sqrt(energy^2*0.01^2 + energy*0.03^2)
}

# set HCalResolutionFormula {resolution formula as a function of eta and energy}
set HCalResolutionFormula {
(abs(eta) <= 0.88 )                  * sqrt(energy^2*0.02^2 + energy*0.40^2)+
(abs(eta) > 0.88 && abs(eta) <= 3.0)   * sqrt(energy^2*0.02^2 + energy*0.40^2)
}
```



```
############
# Jet finder
############

module FastJetFinder FastJetFinder {
  set InputArray EFlowMerger/eflow
  set OutputArray jets
  set ExclusiveClustering true

  # algorithm: 1 CDFJetClu, 2 MidPoint, 3 SIScone, 4 kt, 5 Cambridge/Aachen, 6 antikt
  set JetAlgorithm 10
```

ee-kt jet clustering

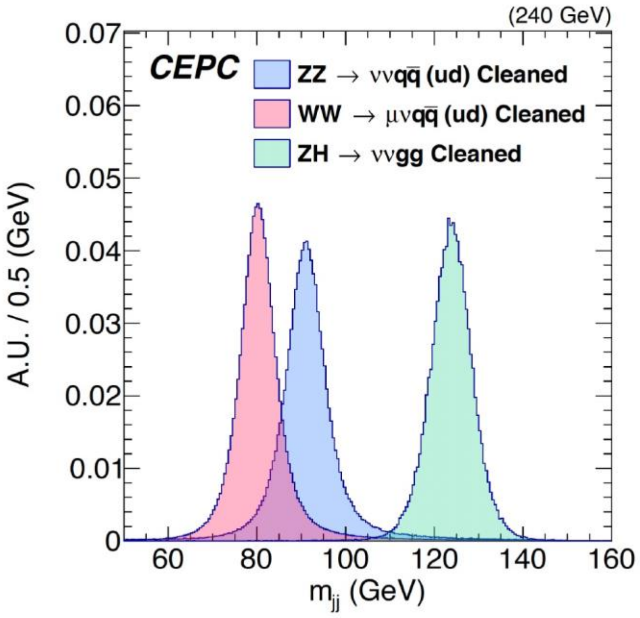
Detector geometry

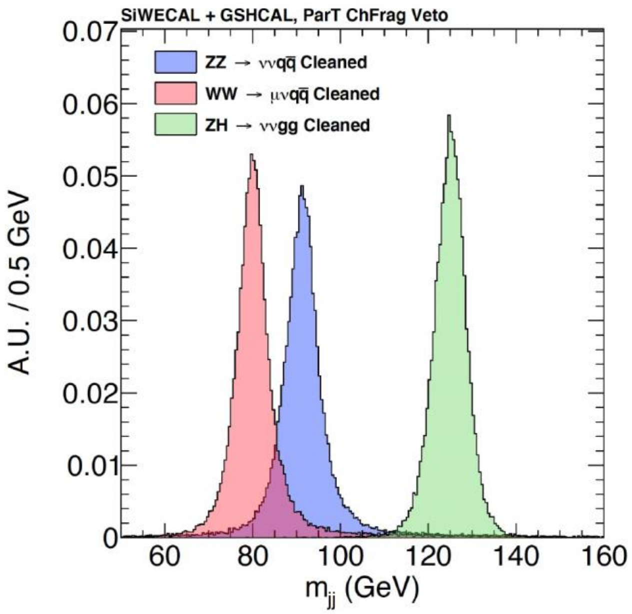


```
set DetectorGeometry {

 # Layer type 1 = R (barrel) or 2 = z (forward/backward)
 # Layer label
 # Minimum dimension z for barrel or R for forward
 # Maximum dimension z for barrel or R for forward
 # R/z location of layer
 # Thickness (meters)
 # Radiation length (meters)
 # Number of measurements in layers (1D or 2D)
 # Stereo angle (rad) - 0(pi/2) = axial(z) layer - Upper side
 # Stereo angle (rad) - 0(pi/2) = axial(z) layer - Lower side
 # Resolution Upper side (meters) - 0 = no measurement
 # Resolution Lower side (meters) - 0 = no measurement
 # measurement flag = T, scattering only = F

 # barrel  name    zmin    zmax    r       w (m)     X0         n_meas  th_up (rad) th_down (rad)    reso_up (m)    reso_down (m)  flag
 1         PIPE    -3.0    3.0     0.014   0.00014   0.0937     0       0           0                0              0              0
 1         VTX1A   -0.2    0.2     0.016   0.00014   0.0937     2       0           1.5708           3e-006         3e-006         1
 1         VTX1B   -0.2    0.2     0.018   0.00014   0.0937     2       0           1.5708           6e-006         6e-006         1
 1         VTX2A   -0.2    0.2     0.038   0.00014   0.0937     2       0           1.5708           4e-006         4e-006         1
 1         VTX2B   -0.2    0.2     0.040   0.00014   0.0937     2       0           1.5708           4e-006         4e-006         1
 1         VTX3A   -0.2    0.2     0.058   0.00014   0.0937     2       0           1.5708           4e-006         4e-006         1
 1         VTX3B   -0.2    0.2     0.060   0.00014   0.0937     2       0           1.5708           4e-006         4e-006         1
 1         SHELL   -0.2    0.2     0.065   0.00014   0.0937     0       0           0                0              0              0
 1         SIT01   -0.241  0.241   0.12    0.00061   0.0937     2       0           1.5708           7e-006         86e-006        1
 1         SIT02   -0.455  0.455   0.27    0.00061   0.0937     2       0           1.5708           7e-006         86e-006        1
 1         SIT03   -0.721  0.721   0.42    0.00061   0.0937     2       0           1.5708           7e-006         86e-006        1
 1         SIT04   -0.988  0.988   0.57    0.00061   0.0937     2       0           1.5708           7e-006         86e-006        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         DSK1A   0.0295  0.12    0.241   0.00061   0.0937     2       0           1.5708           7e-006         86e-006        1
 2         DSK1B   0.0295  0.12    -0.241  0.00061   0.0937     2       0           1.5708           7e-006         86e-006        1
 2         DSK2A   0.0305  0.27    0.455   0.00061   0.0937     2       0           1.5708           7e-006         86e-006        1
 2         DSK2B   0.0305  0.27    -0.455  0.00061   0.0937     2       0           1.5708           7e-006         86e-006        1
 2         DSK3A   0.0325  0.42    0.721   0.00061   0.0937     2       0           1.5708           7e-006         86e-006        1
 2         DSK3B   0.0325  0.42    -0.721  0.00061   0.0937     2       0           1.5708           7e-006         86e-006        1
 2         DSK4A   0.0340  0.57    0.988   0.00061   0.0937     2       0           1.5708           7e-006         86e-006        1
 2         DSK4B   0.0340  0.57    -0.988  0.00061   0.0937     2       0           1.5708           7e-006         86e-006        1
```

Featuring ParticleNet

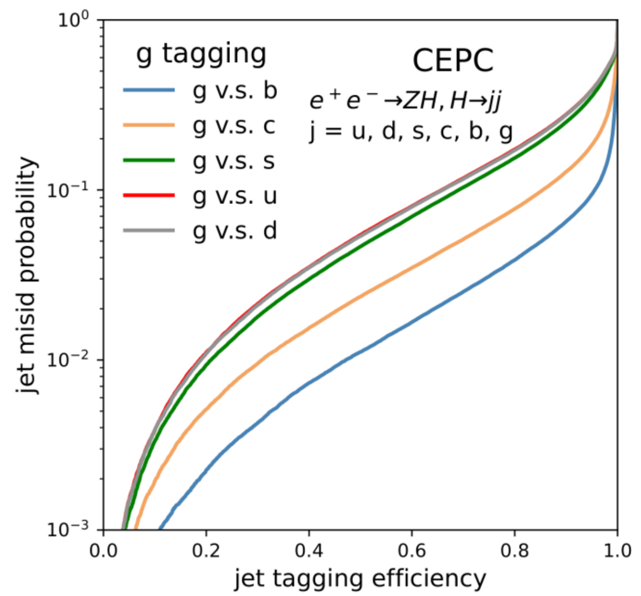
arXiv:1902.08570



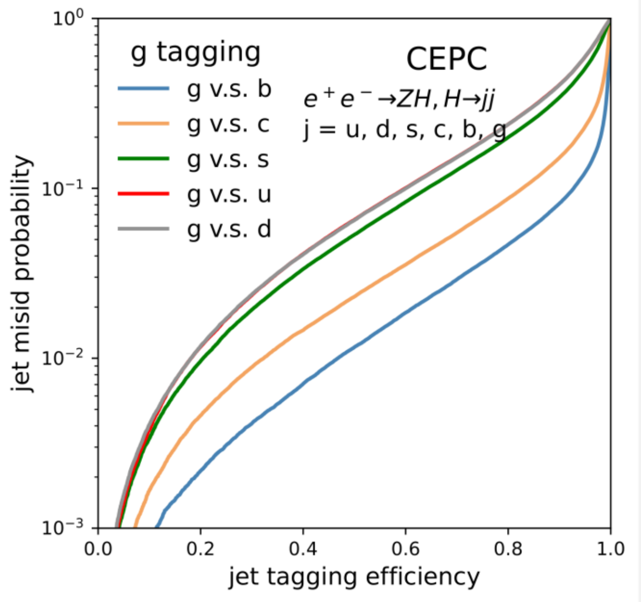


- Confusion from shower fragments is the primary contributor to BMR.
- With ParticleNet, BMR can be reduced to 2.9% in latest result.

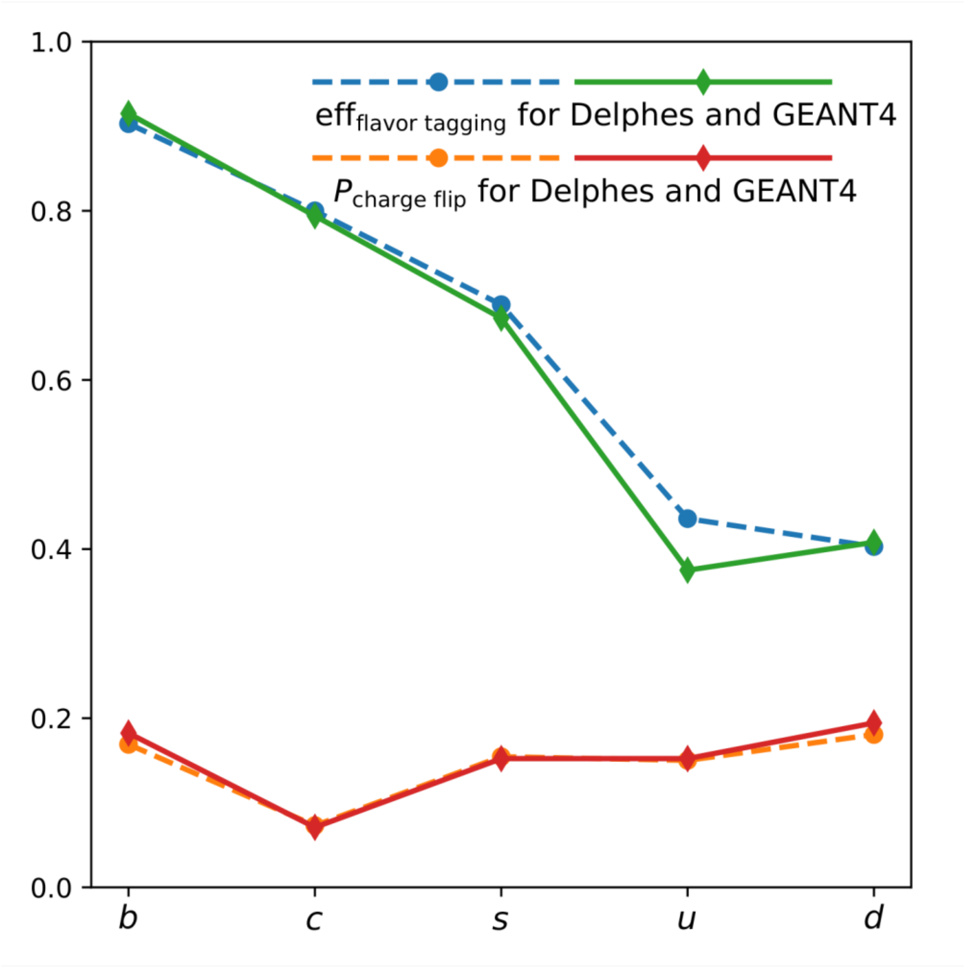
Comparison between Fast&Full simulation



Full



Delphes

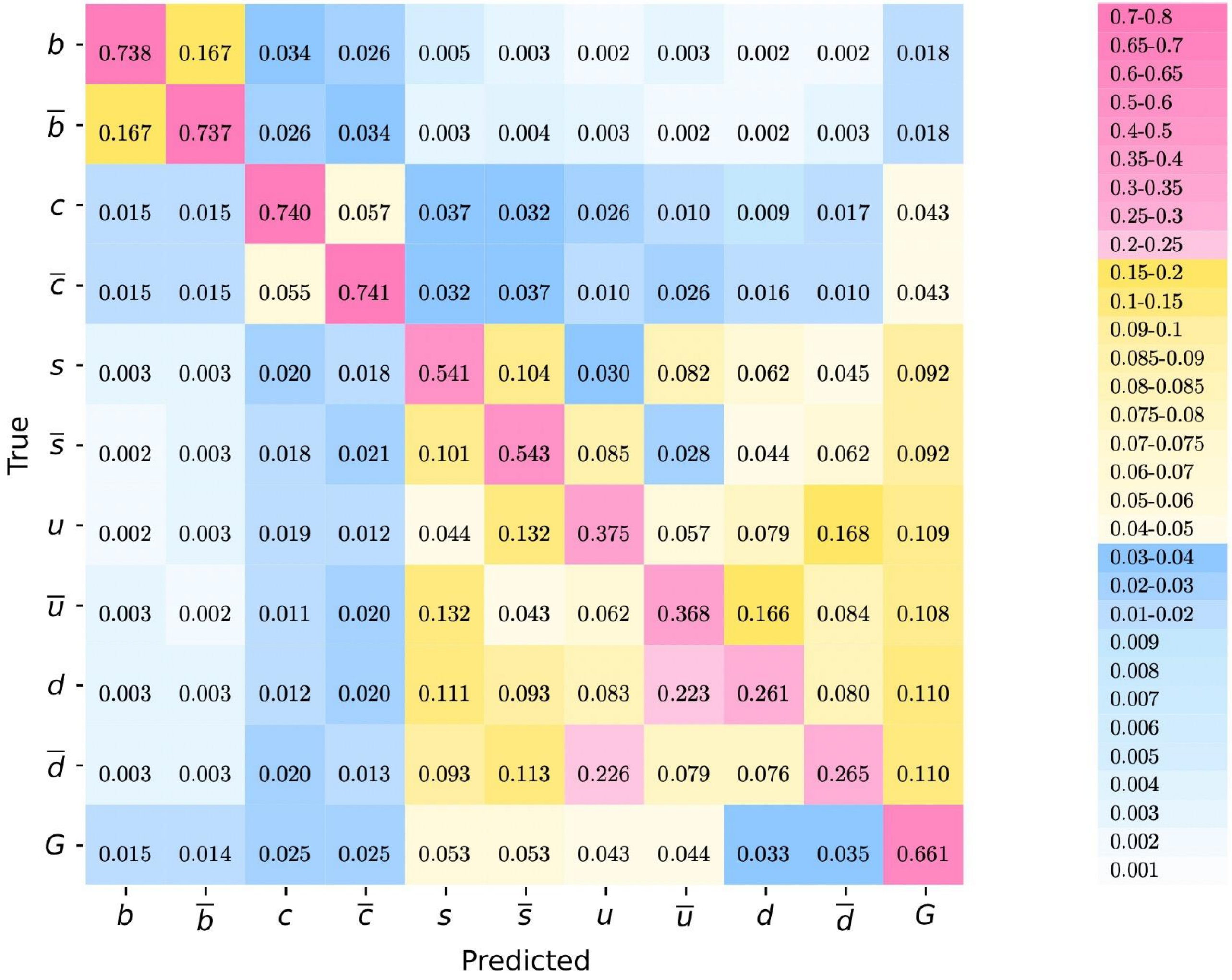


Summary

- Delphes works well in current CEPC development
- the Delphes framework and card is available
  - On lxslc: /cefs/higgs/gaoxu/delphes/delphes/cards/delphes_card_CEPC_4th.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