CEPC samples overview

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Software framework

The past sample, under /cefs/data, based on CEPC_v4 layout, mainly generated before 2018.

Need maintenance and update.

- CEPCsoft (old) / CEPCSW(new)

- Old: ILCsoft/Marlin/Whizard/Delphes……
  - Whizard 1.95 as default generator： https://github.com/lhprojects/WhizardAis
  - Delphes card for fast simulation: My talk @ Zhengzhou
  - Full simulation based on SiWECAL_GSHCAL;

- CEPCSW
  - Need further work to migrate to new release.

Sample Category

Type	Format	Software	Ratio
Generator	stdhep	Whizard	2
Full Simu	Slcio/root		100
Reco	Slcio/root		10
Fast Simu	Ntuple	Delphes	1
Analysis	Ntuple		1

Sample generation types followed by Mo Xin, Gang and CEPC higgs white paper.

For one event,
Disk quota:
full simulation dominate the event size and take ~1MB.
Taken all parts together, 1 event need ~1.2MB disk space.
Time occupancy
1 event full simulation take ~1 cpu 1 minute.
In CEPCSW, PFA reconstruction now need more ~5 min.

To meet the requirement for TDR, plan to generate a new series sample for CEPC SM-complete sample set.

Priority:
1. 240 GeV Higgs sample
2. 240 GeV Bkg
3. 360 GeV Higgs/Bkg/ttbar
4. 91.2 GeV Z-pole
5. 160 GeV WW threshold

Plan one small, urgent sample list to run first for RefTDR interview.

Generator Whizard stdhep file ready.

Prior sample

As currently the analysis chain is not complete, Samples for both analysis and performance study.

Energy	Z decay	H decay	Event size
240 GeV	$Z \to \nu\nu$	$H \to uu$	100k
		$H \to \mathrm{dd}$	100k
		$H \to \mathrm{ss}$	100k
		$H \to cc$	100k
		$H \to gg$	100k
		$H \to bb$	100k
		$H \to \mu\mu$	100k
		$H \to \gamma\gamma$	100k
	$Z \to qq$	$H \to ZZ \to \nu\nu\nu\nu$	100k
	WWfusion ($\nu\nu$)	$H \to bb$	100k
	$Z \to ee$	$H \to \mathrm{inclusive}$	100k
	$Z \to \mu\mu$	$H \to \mathrm{inclusive}$	100k
360 GeV	$Z \to \nu\nu$	$H \to bb$	100k
	WWfusion ($\nu\nu$)	$H \to bb$	100k

1.4M events total.

1 event 6min.
->
1000cpu 144hours.
~6 days.

Physics Benchmarks @ RefTDR

	Processes @ c.m.s.	Domain	Relevant Det. Performance
H→ss/cc/sb	vvH @ 240 GeV	Higgs	PFA + Jet Origin Id (JoI)
H→inv	qqH	Higgs/NP	PFA
Vcb	WW→lvqq @ 240/160 GeV	Flavor	JoI + Pid (Lepton, tau)
W fusion Xsec	vvH @ 360 GeV	Higgs	PFA + JoI
α_S	Z→tautau @ 91.2 GeV	QCD	PFA: Tau & Tau final state id
CKM angle $\gamma - 2\beta$	Z→bb, B→DK @ 91.2 GeV	Flavor	PFA + JoI + Pid (Kaon)
Weak mixing angle	Z@ 91.2 GeV	EW	JoI
Higgs recoil	llH	Higgs	Pid (Lepton), track dP/P
H→bb, gg	vvH + qqH	Higgs	PFA + JoI + Color Singlet id
H→di muon	qqH	Higgs	PFA, Leptons id, Tracking
H→di photon	qqH	Higgs	PFA, Photons id, EM resolution
W mass & Width	W threshold scan @160 GeV	EW	Beam energy
Top mass & Width	Top threshold scan @360 GeV	EW	Beam energy
Bs→ $\upsilon\upsilon\phi$	91.2 GeV	Flavor	Object (ϕ) in jets; MET
Bc→ $\tau\upsilon$	91.2 GeV	Flavor	Object (τ) in jets; MET
B0→ $2\pi^0$	91.2 GeV	Flavor	π^0 in jets; EM resolution

Summary

- Need 1.4M Higgs sample as prior for October;
  - For both analysis and performance study
  - ~1000CPU 1week.
- Need several prior task
  - Jet Clustering implementation.
  - PFA reconstruction optimization.
  - Particle PID.
  - More convenient output structure like ntuples for analyzers.
  - ……

Backup (SM-complete set)

240/360 GeV Cross Sections

20iab data in 240GeV, 1iab in 360GeV.

Signals(fb)	240	360
ZH	196.9	126.6
WW fusion	6.2	29.61
ZZ fusion	0.5	2.80
Total	203.6	159.0
Total Events	4M	0.16M

Background(pb)		240	360
2fermion	$ee(\gamma)$	930	325
	$\mu\mu(\gamma)$	5.3	2.1
	$qq(\gamma)$	54.1	23.2
	$t\bar{t}$	\	0.317
4fermion	WW	16.7	10.0
	ZZ	1.1	0.63
	sZ	4.54	5.78
	sW	5.09	6.00

Higgs sample: 240GeV, Z->ll

Z decay	H decay	Event size
$Z \to ee$	$H \to u, d, s, c, g$	100k
	$H \to bb$	600k
	$H \to \tau\tau, \mu\mu, \gamma\gamma, Z\gamma$	100k
	$H \to$ ZZ full hardonic	100k
	$H \to$ ZZ semi leptonic	500k
	$H \to$ ZZ invisible	100k
	$H \to$ WW full hardonic	300k
	$H \to$ WW semi leptonic	500k

Sample generated exclusively, for each category, minimum sample set: 100k.

Higgs sample generated this way and use weight to combine as one inclusive sample.
This event size make sure at least 1:1 to 20iab events.

$Z \to ee$ then corresponds 3M events. So did $Z \to \mu\mu$ and $Z \to \tau\tau$.

Higgs sample: following

$Z \to \nu\nu$ usually takes as the benchmark sample, so take 2X of $Z \to ee$, corresponds 6M events.

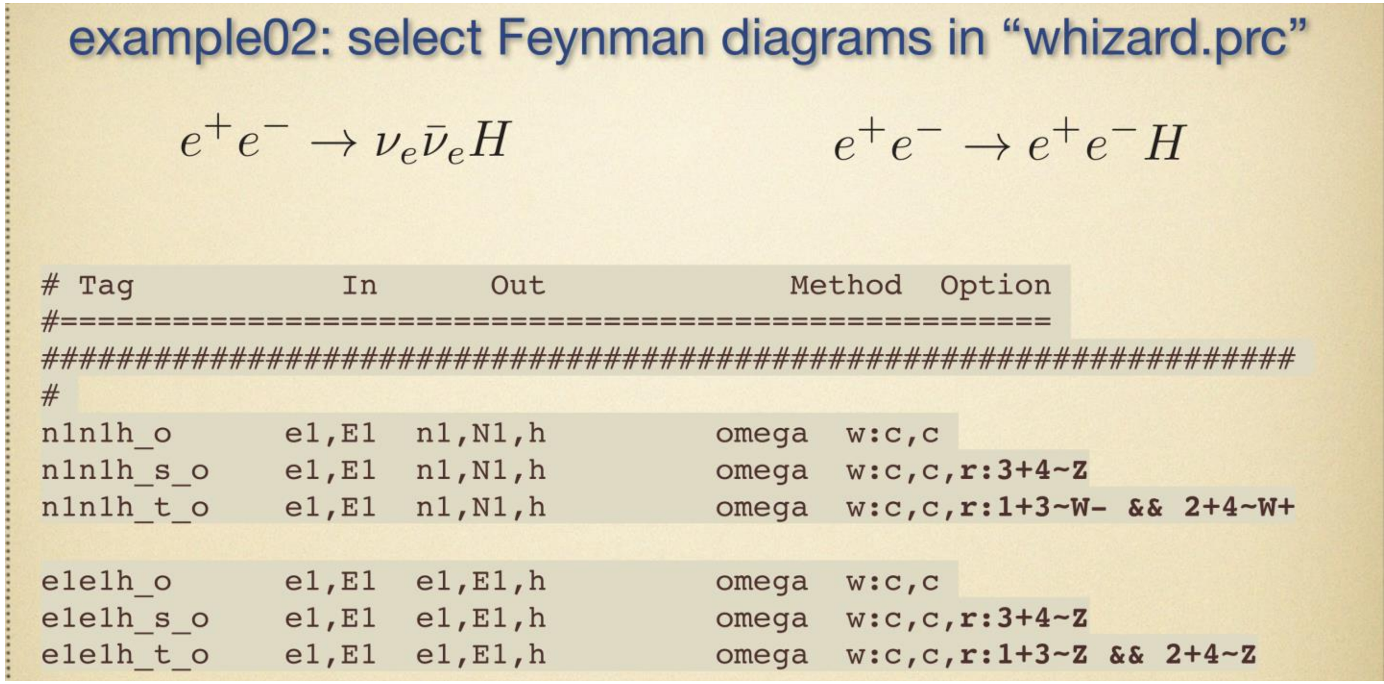
Genrated 30M events corresponds to 4M, this set make sure at least 1:1 ratio.

240GeV WWfusion ($\nu\nu$h) ~17% of Z->vv. Instead generate as $Z \to ee$, 3M.
240GeV ZZfusion (eeh) ~7% of Z->ee. Instead generate as $Z \to ee$, 3M.

For interference: need further study.

See:Jun Ping's Whizard tutorial slides.

Z->qq take 5X. 15M.


example02: select Feynman diagrams in "whizard.prc"

$$e^+e^- \to \nu_e\bar{\nu}_e H \qquad e^+e^- \to e^+e^- H$$

```
# Tag              In      Out                   Method   Option
#==========================================================
##################################################################
#
n1n1h_o            e1,E1   n1,N1,h               omega    w:c,c
n1n1h_s_o          e1,E1   n1,N1,h               omega    w:c,c,r:3+4~Z
n1n1h_t_o          e1,E1   n1,N1,h               omega    w:c,c,r:1+3~W- && 2+4~W+

e1e1h_o            e1,E1   e1,E1,h               omega    w:c,c
e1e1h_s_o          e1,E1   e1,E1,h               omega    w:c,c,r:3+4~Z
e1e1h_t_o          e1,E1   e1,E1,h               omega    w:c,c,r:1+3~Z && 2+4~Z
```

Considering:
360GeV ZH Higgs use 1/10 of 240 GeV Higgs. 3M
360GeV vvH Higgs: as 240GeV $Z \to ee$, 3M
360GeV eeH Higgs: 1/10 of $Z \to ee$, 300k

In this way, CEPC 240GeV Higgs sample need 30M events and 360GeV 6.3M.

2, 4fermion bkg

```
#    Fully hadronic
#
#       ZZ : only one flavour, or two but not ud or cs
#
zz_h0utut      e1,E1 up_type_q,up_type_q,up_type_q,up_type_q              omega w:c,c
zz_h0dtdt      e1,E1 down_type_q,down_type_q,down_type_q,down_type_q      omega w:c,c
zz_h0uu_notd   e1,E1 uq,uq,not_dq,not_dq                                  omega w:c,c
zz_h0cc_nots   e1,E1 cq,cq,not_sq,not_sq                                  omega w:c,c
#
#       WW: more than 2 flavours
#
ww_h0cuxx      e1,E1 cq,down_type_q,uq,down_type_q                        omega w:c,c
ww_h0uubd      e1,E1 uq,bq,uq,dq                                          omega w:c,c
ww_h0uusd      e1,E1 uq,sq,uq,dq                                          omega w:c,c
ww_h0ccbs      e1,E1 cq,bq,cq,sq                                          omega w:c,c
ww_h0ccds      e1,E1 cq,dq,cq,sq                                          omega w:c,c
#
#       ZZ/WW mix: two flavours ud or cs
#
zzorww_h0udud  e1,E1 uq,dq,dq,uq                                          omega w:c,c
zzorww_h0cscs  e1,E1 cq,sq,sq,cq                                          omega w:c,c
```

```
# Semi-leptonic
#
#       ZZ : qq + two charged or two neutral leptons
#
zz_sl0nu_up     e1,E1 not_nu_e,not_nu_e,up_type_q,up_type_q        omega w:c,c
zz_sl0tau_down  e1,E1 tau,tau,down_type_q,down_type_q              omega w:c,c
zz_sl0mu_down   e1,E1 mu,mu,down_type_q,down_type_q                omega w:c,c
zz_sl0nu_down   e1,E1 not_nu_e,not_nu_e,down_type_q,down_type_q    omega w:c,c
zz_sl0tau_up    e1,E1 up_type_q,up_type_q,tau,tau                  omega w:c,c
zz_sl0mu_up     e1,E1 up_type_q,up_type_q,mu,mu                    omega w:c,c
#
#       WW : qq l nu
#
ww_sl0tauq      e1,E1 up_type_q,down_type_q,tau,neutrino           omega w:c,c
ww_sl0muq       e1,E1 up_type_q,down_type_q,mu,neutrino            omega w:c,c
#
# leptonic
#
#       ZZ : four charged, or charged and neutral of differnt flavour
#
zz_l04tau       e1,E1 tau,tau,tau,tau                              omega w:c,c
zz_l04mu        e1,E1 mu,mu,mu,mu                                  omega w:c,c
zz_l0taumu      e1,E1 tau,tau,mu,mu                                omega w:c,c
zz_l0mumu       e1,E1 nu_tau,nu_tau,mu,mu                          omega w:c,c
zz_l0tautau     e1,E1 nu_mu,nu_mu,tau,tau                          omega w:c,c
#
#       WW :  two charged of different flavour
#
ww_l0ll         e1,E1 nu_mu,mu,nu_tau,tau                          omega w:c,c
#
#       ZZ/WW mix ll nunu, all same flavour
#
zzorww_l0mumu   e1,E1 nu_mu,mu,mu,nu_mu                            omega w:c,c
zzorww_l0tautau e1,E1 nu_tau,tau,tau,nu_tau                        omega w:c,c
```

```
#  Single Z+ee:        two elctrons+ anything except two nu_e
#
sze_l0tau     e1,E1 electron,electron,tau,tau                   omega w:c,c
sze_l0mu      e1,E1 electron,electron,mu,mu                     omega w:c,c
sze_l0e       e1,E1 electron,electron,electron,electron         omega w:c,c
sze_sl0dd     e1,E1 electron,electron,down_type_q,down_type_q   omega w:c,c
sze_sl0uu     e1,E1 up_type_q,up_type_q,electron,electron       omega w:c,c
sze_l0nunu    e1,E1 not_nu_e,not_nu_e,electron,electron         omega w:c,c
#
#  Single W         e nu_e + anything except e nu_e
#
sw_sl0qq      e1,E1 up_type_q,down_type_q,electron,nu_e         omega w:c,c
sw_l0tau      e1,E1 not_nu_e,tau,electron,nu_e                  omega w:c,c
sw_l0mu       e1,E1 not_nu_e,mu,electron,nu_e                   omega w:c,c
#
#  Single Z/Single W mix: ee e_nu e_nu
#
szeorsw_l0l   e1,E1  nu_e,electron,electron,nu_e                omega w:c,c
#
#  Single Z + nunu  two nu_e + any pair except two electrons
#
sznu_l0mumu   e1,E1 nu_e,nu_e,mu,mu                             omega w:c,c
sznu_l0tautau e1,E1 nu_e,nu_e,tau,tau                           omega w:c,c
sznu_sl0nu_up e1,E1 nu_e,nu_e,up_type_q,up_type_q               omega w:c,c
sznu_sl0nu_down e1,E1 nu_e,nu_e,down_type_q,down_type_q         omega w:c,c
```

- 2f bkg ~20B events for 240GeV.
- Generate 1M for each category in 240GeV (ee, mm, tautau, usdcb) and 100k for 360GeV.
- 1M for 360GeV ttbar.   100k for 240/360GeV nn.
- 10M for 2f.

- Full 4f ~500M events.
- Plan: 11 types full hadronic channel, each 5M
  30 semi-leptonic channel   each 5M
- 360GeV 1:10.
- 205M for 4f 240GeV and 20.5M for 360GeV.

- Need ~260TB disk space.

Z-pole/WW-threshold sample

- Expect 210M WW and 4T Z-pole.

- Instead, for the first step, plan to generate:
  - $Z \rightarrow$ ee/mm/tautau@91.2GeV : each 2M
  - $Z \rightarrow \mathrm{udscb@91.2GeV}$: each 1M

  - WW@160GeV: 7 types full hadronic: each 1M
  - 5 times semi-leptonic each 1M

  - In total 23M events.
    - Extendable like 10x in the future.

Table 3.2: CEPC operation plan (@ 50 MW)

Particle	$E_{c.m.}$ (GeV)	L per IP (10^{34} cm^{-2}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.

CEPC SM-complete set

Generate Order	Sample set	Event amount	Disk Space(*1.2MB)
1	240 Higgs	36M	43.2T
2	240 bkg	200M	240T
3	360 Higgs	6.3M	8T
4	360 bkg(ttbar)	22M	27T
5	91.2 Z-pole	11M	14T
6	160 WW-threshold	12M	15T

- CEPC SM-complete set generate 287.3M events in total and need 340T storage.
  - /cefs can handle.
  - 1 event full simulation take ~1 cpu 1 minute.
  - 300M->5M cpu*h. (1000cpu*200day)
  - The fast simulation set will be generated first. (Also due to CEPCSW need further validation)

  - Requirements and contributions are welcome. Any number can change.

Extra sample for CEPC benchmark

	Processes @ c.m.s.	Domain	Relevant Det. Performance
H→ss/cc/sb	vvH @ 240 GeV	Higgs	PFA + Jet Origin Id (JoI)
H→inv	qqH	Higgs/NP	PFA
Vcb	WW→lvqq @ 240/160 GeV	Flavor	JoI + Pid (Lepton, tau)
W fusion Xsec	vvH @ 360 GeV	Higgs	PFA + JoI
α_S	Z→tautau @ 91.2 GeV	QCD	PFA: Tau & Tau final state id
CKM angle $\gamma - 2\beta$	Z→bb, B→DK @ 91.2 GeV	Flavor	PFA + JoI + Pid (Kaon)
Weak mixing angle	Z@ 91.2 GeV	EW	JoI
Higgs recoil	llH	Higgs	Pid (Lepton), track dP/P
H→bb, gg	vvH + qqH	Higgs	PFA + JoI + Color Singlet id
H→di muon	qqH	Higgs	PFA, Leptons id, Tracking
H→di photon	qqH	Higgs	PFA, Photons id, EM resolution
W mass & Width	W threshold scan @160 GeV	EW	Beam energy
Top mass & Width	Top threshold scan @360 GeV	EW	Beam energy
Bs→ $\upsilon\upsilon\phi$	91.2 GeV	Flavor	Object (ϕ) in jets; MET
Bc→ $\tau\upsilon$	91.2 GeV	Flavor	Object (τ) in jets; MET
B0→ $2\pi^0$	91.2 GeV	Flavor	π^0 in jets; EM resolution

- Additional:
  - Z->vv usdcbg each 1M
  - Z->vv dimuon +1M
  - Z->vv diphoton +1M

Special signals like:

Z->bb B->DK@91.2 500k

……

Summary

- CEPC SM-complete set need 281.3M events in total and need 340T storage.
  - Disk space can handle but cpu hours is a challenge.
  - Other crucial benchmarks need <20M events.
- Migration/Validation to new framework CEPCSW.
  - Also cross checks with other generators like Pythia, Herwig, Madgraphs……?