CEPC trigger simulation

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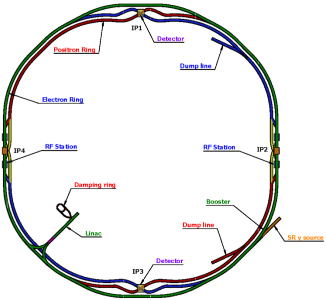
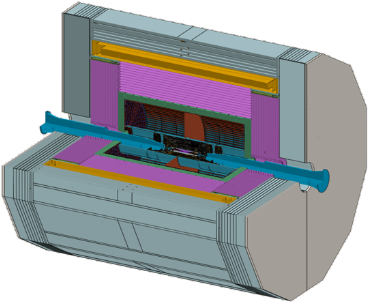
Outline

1. Introduction
2. MC Simulation
3. Trigger algorithm
4. Future and summary

Circular Electron Positron Collider (CEPC) introduction

- Proposed by the Chinese particle physics community in 2012 to explore the aforementioned physics program
- Double-ring collider with electron and positron beams circulated in opposite directions in separate beam pipes, with two interaction points (IPs)
- Four different modes: **Higgs**, Z, W and $t\bar{t}$
- Higgs factory for precision measurements and searches for BSM physics





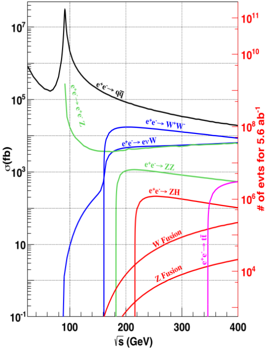
Physical Event Rate

- Higgs mode (240GeV) bunch crossing rate: $\sim$1.34 MHz
  - Higgs boson production rate: $\sim$0.017 Hz
  - $q\bar{q}$ rate: $\sim$5 Hz
- Z mode (91GeV) bunch crossing rate: $\sim$39.3 MHz
  - Visible Z: $\sim$66 kHz
- Very low physical event rates compared to the bunch crossing rate
- Trigger: remove as much background as possible, and keep physical events as more as possible

	Higgs	Z	W	$t\bar{t}$
SR power per beam (MW)	50			
Bunch number	446	13104	2162	58
Bunch spacing (ns)	346.2 (×15)	23.1 (×1)	138.5 (×6)	2700.0 (×117)
Train gap (%)	54	9	10	53
Luminosity per IP (10^{34} cm^{-2} s^{-1})	8.3	192	26.7	0.8

CEPC Accelerator TDR

CEPC Physics & Detector CDR



Trigger strategy

- Electronics framework schema
  - Full data transmission from Front-End Elec
  - Connect trigger with Back-End Elec
  - More detail will be presented by W. Wei on Oct. 26.
- Trigger solutions
  - Baseline option: hardware trigger(L1) + high level trigger(HLT)
    - L1: **Calorimeter** and **Muon** detector (presented in this talk)
    - L1: may be able to use vertex, tracker and even TPC (30 us time window), to be studied
    - L1 trigger rate: Higgs: O(1k) Hz; Z: O(100k) Hz
    - HLT: Full detector information (to be studied)
    - HLT trigger rate: Higgs: $<$100Hz; Z: 100kHz
  - Other option: full software trigger
    - More complicated algorithm, may be helpful for new physics

MC Simulation at Higgs mode

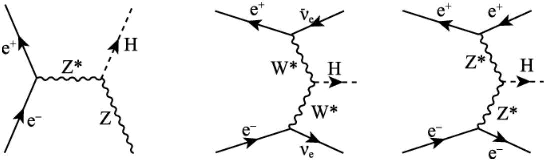
Signal

- $ee \rightarrow$ZH
  - Z$\rightarrow$ ee, $\mu\mu$, $\tau\tau$, $\nu\nu$
  - H$\rightarrow$ bb, WW, $\tau\tau$, cc, ZZ, $\gamma\gamma$, Zγ, $\mu\mu$...
- $ee \rightarrow$ qq, WW, ZZ...

Background

- Beam induced background
- Detector noise and other background(to be studied)

Signal MC Simulation: $ee \to$ ZH



Signal sample in this talk

- Z$\to \nu\nu$
- H$\to$ $bb/\gamma\gamma/\mu\mu$ for jet, photon, and muon
- Generated by Whizard
- Detector simulated by CEPCSW 24.9.0

PDG

Table 11.3: The branching ratios and the relative uncertainty for a SM Higgs boson with $m_H = 125$ GeV [39, 40].

Decay channel	Branching ratio	Rel. uncertainty
$H \to \gamma\gamma$	2.27×10^{-3}	2.1%
$H \to ZZ$	2.62×10^{-2}	±1.5%
$H \to W^+W^-$	2.14×10^{-1}	±1.5%
$H \to \tau^+\tau^-$	6.27×10^{-2}	±1.6%
$H \to b\bar{b}$	5.82×10^{-1}	$^{+1.2\%}_{-1.3\%}$
$H \to c\bar{c}$	2.89×10^{-2}	$^{+5.5\%}_{-2.0\%}$
$H \to Z\gamma$	1.53×10^{-3}	±5.8%
$H \to \mu^+\mu^-$	2.18×10^{-4}	±1.7%

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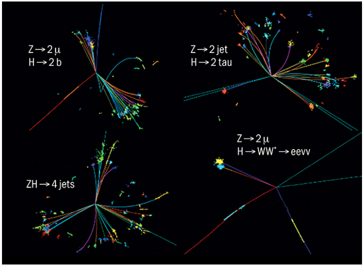
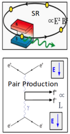
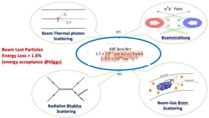


- Single Beam
  - Touschek Scattering
  - Beam Gas Scattering(Elastic/inelastic)
  - Beam Thermal Photon Scattering
  - Synchrotron Radiation
- Luminosity Related
  - Beamstrahlung
  - Radiative Bhabha Scattering
- Combine 10 bunch crossing into one event
- More detail will be presented by H. Shi tomorrow

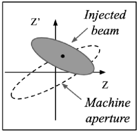
A. Natochii



Photon BG



Beam Loss BG



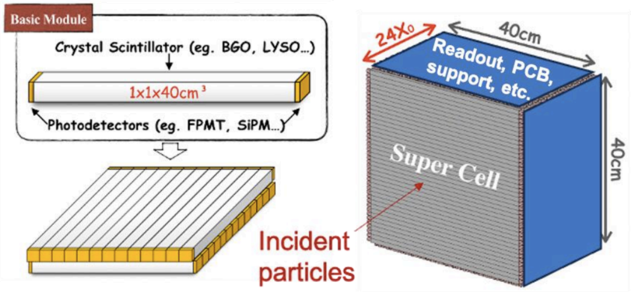
Injection BG

H. Shi

	50MW Higgs, 346ns/BX
Pair Production	∼1.82GHz in IR
Beam Thermal Photon	∼0.36MHz/beam in IR
Beam Gas Bremsstrahlung	∼0.04MHz/beam in IR
Beam Gas Coulomb	∼0.24MHz/beam in IR

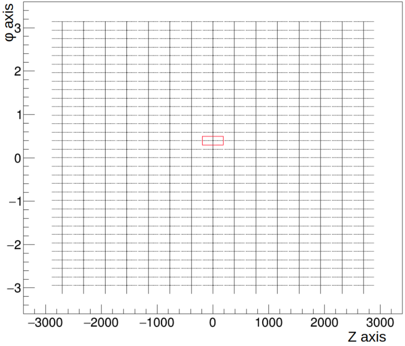
ECal trigger primitive

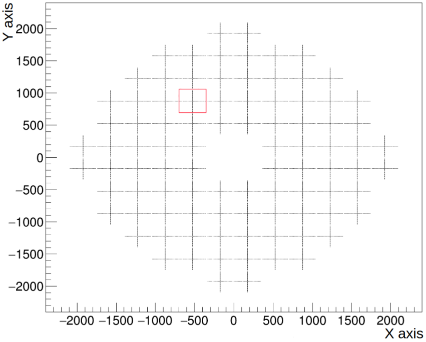
- Basic module for EM Calorimeter (ECal): $\sim$1x1x40cm^3
- Cluster modules into 40x40cm^2 for both ECal and Had Calorimeter (HCal)
- Use 40x40cm^2 cluster as trigger primitive for both ECal and HCal



Calorimeter trigger primitive

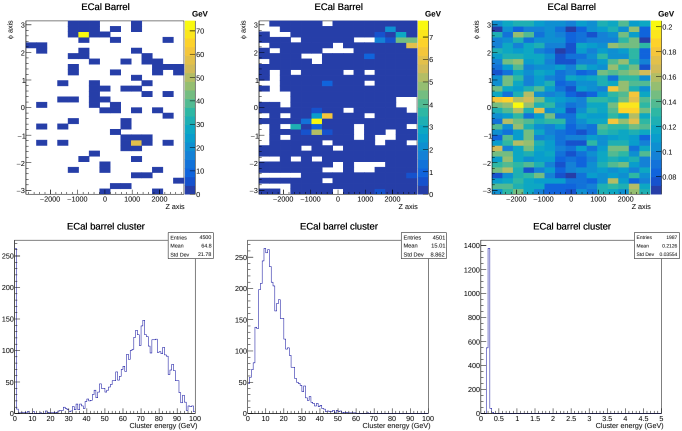
- Barrel(left): divided into 15(Z)x32(ϕ) in Z-ϕ plane; endcap(right) in X-Y plane
- Each point represents the center of the basic module
- Red square shows the cluster





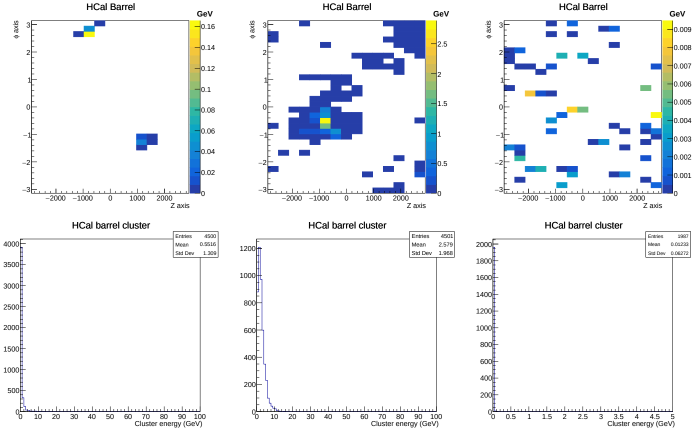
ECal Barrel energy distribution

- Left: Z($\nu\nu$)H($\gamma\gamma$); middle: Z($\nu\nu$)H(bb); right: beam induced background, W. Song
- Up: single event; down: maximum energy distribution
- Large energy deposition($>$ 30 GeV) for photon, and Jet ($>$5 GeV)
- Very tiny energy deposition($<$0.5 GeV) for beam background, mostly from pair production



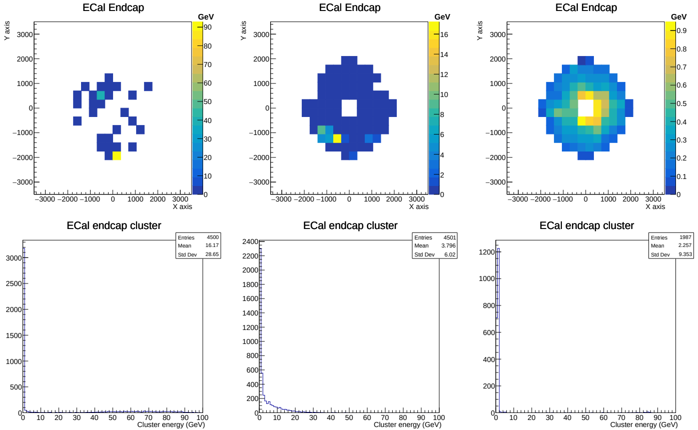
HCal Barrel energy distribution

- Similar to ECal Barrel, large energy deposition($>$ 0.1 GeV) for photon, and Jet ($>$0.5 GeV)
- Very tiny energy deposition($<$0.05 GeV) for beam background



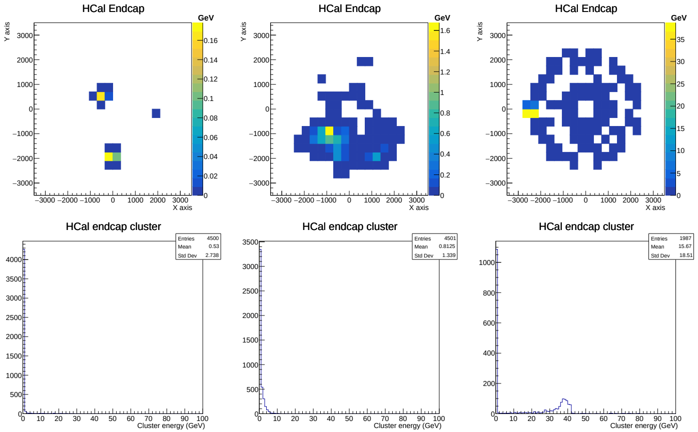
ECal Endcap energy distribution

- Similar to ECal Barrel, large energy deposition($>$ 30 GeV) at Barrel ECal for photon, and Jet ($>$1 GeV)
- Small energy deposition($<$5 GeV) for beam background, but comparable with Jet(Z($\nu\nu$)H(bb))



HCal Endcap energy distribution

- Small energy deposition($<$5 GeV) for photon and jet
- Large energy deposition for beam background
  - Concentrate in a small area
  - Leak from Muon detector



Preliminary selection and efficiency

Preliminary selection

- Select the two clusters with the highest energy from each sub-detector
- Apply energy threshold
- Low threshold for Barrel(0.5 GeV), high for Endcap(5 GeV for ECal and 50 GeV for HCal)

Sub-detector	Energy threshold
ECal Barrel	$>$0.5 GeV
or HCal Barrel	$>$0.5 GeV
or ECal Endcap	$>$5 GeV
or HCal Endcap	$>$50 GeV

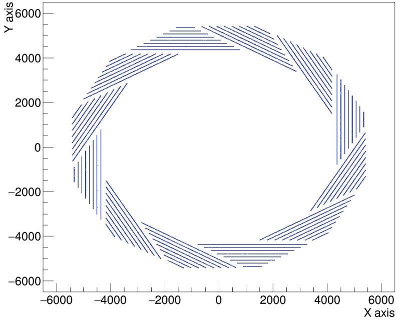
Efficiency

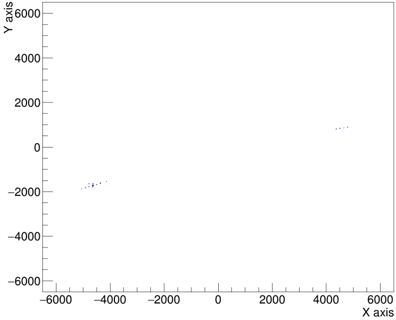
- Efficiencies for all the channels are good
- Will try energy isolation for HCal Endcap
- Higher efficiency with visible Z
- Will study more algorithms

Higgs decay channel	Efficiency
Z($\nu\nu$)H($\gamma\gamma$)	100%
Z($\nu\nu$)H(bb)	100%
Z($\nu\nu$)H($Z\gamma$)	99.7%
Z($\nu\nu$)H($\tau\tau$)	96.7%
Z($\nu\nu$)H(WW)	99.1%
Z($\nu\nu$)H(ZZ)	95.8%
Beam background	4.8%

Muon Barrel detector

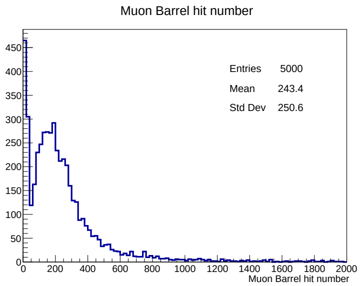
- Signal: Z($\nu\nu$)H($\mu\mu$)
- Left: Muon Barrel detector in the X-Y plane
- Right: single Z($\nu\nu$)H($\mu\mu$) event, with two clear tracks
- Beam background: 0 hit for most of the time

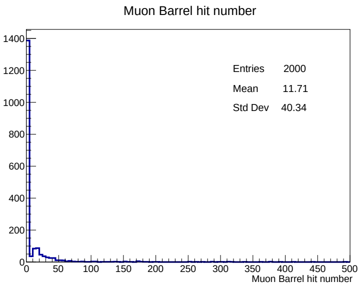




Muon Barrel number of hit distribution

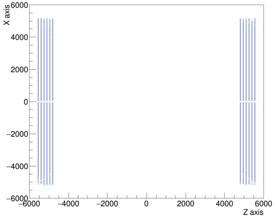
- Left: Z($\nu\nu$)H($\mu\mu$); right: beam background
- Signal: lots of hits($>$100); beam background: relatively less hits(N$<$50)
- With simple selection requirement: number of hit $>$ 10
  - Z($\nu\nu$)H($\mu\mu$): 100% (at least one truth muon inside Barrel detector)
  - Beam background: 19%

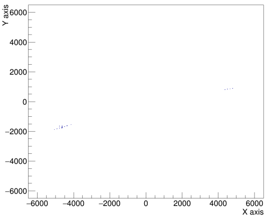


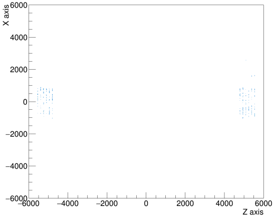


Muon Endcap detector

- Left: Muon Endcap detector; middle: $Z(\nu\nu)H(\mu\mu)$; right: beam background
- Different from Barrel, lot of hits at Endcap for beam background

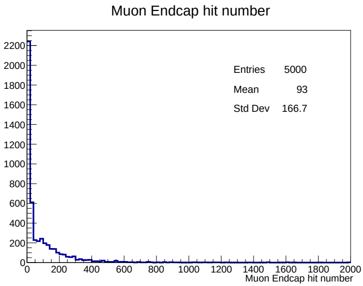


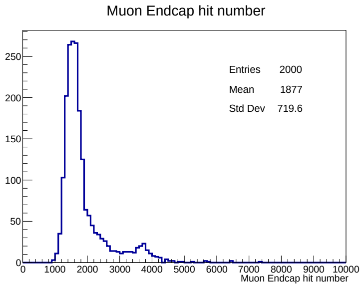




Muon Endcap number of hit distribution

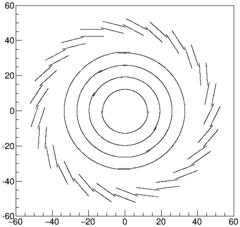
- Left: Z($\nu\nu$)H($\mu\mu$); Right: beam background
- Beam background: lots of hits(N>1000)
- Further study need to be done

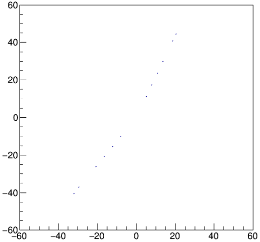


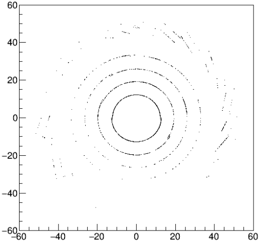


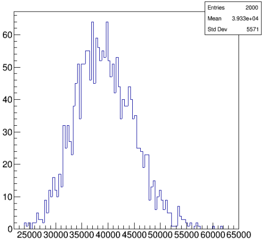
Vertex

- Left: one ZH$\rightarrow \nu\nu\mu\mu$ event
- Center: one beam background event
- Right: Beam background vertex hit distribution



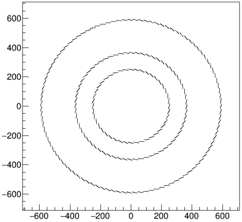


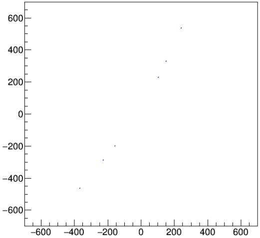


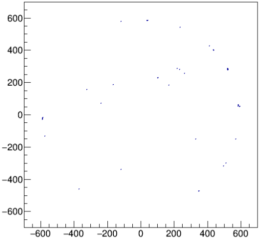


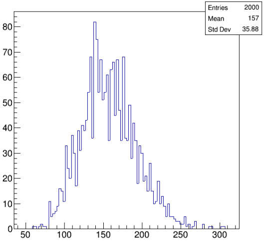
ITK

- Left: one ZH→ $\nu\nu\mu\mu$ event
- Center: one beam background event
- Right: Beam background ITK hit distribution









Future

- Lots of simulation and research need to be done
- Try Muon track reconstruction
- Study the possibility of other detectors for L1
- Detector electronics noise/threshold
- Use tracker information for HLT

Summary

- Calorimeter and Muon detector simulation for the trigger study are shown
- Comparison between signal and beam background for Vertex and ITK
- Preliminary trigger selections give promising results

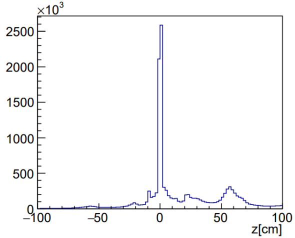
Backup

Data rate

- Data rate before trigger
  - $<$1 TB/s for Higgs mode
  - Several TB/s for Z mode
- Event size < 2 MB
  - Related to occupancy and read out window
- L1 trigger rate
  - O(1k) Hz Higgs
  - O(100k) Hz Z
- Storage rate after HLT
  - $<$100 Hz(200 MB/s) Higgs
  - 100 kHz (200 GB/s) Z

Belle II trigger level tracking algorithm

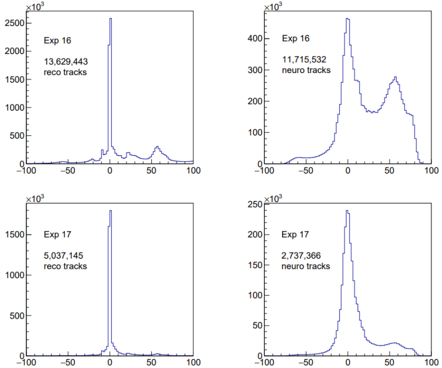
- Hough transformation
  - Transfer to parameters space
- Assuming Z=0, reconstruct the track at r-ϕ plane
- Can't seperate the track from the IP(z=0) or far away from IP($|z| >> 0$)
- Track from beam background probably from the vertex far away from IP($|z| >> 0$)



Offline reconstructed Z value from data arXiv:2402.14962

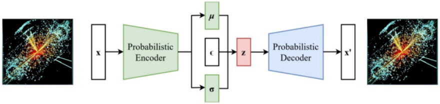
Belle II trigger level tracking algorithm

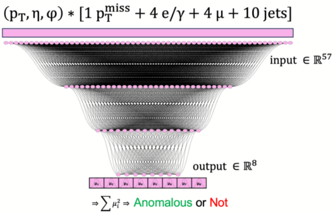
- First time to use NN to reconstruct track
- Output the z value to reduce background
- Can be use in CEPC to reduce beam background



Left: offline reconstructed Z; Right: NN results; Up: without Z selection; Down: at least one track with $|z| < 20$

Anomaly detection





- Use auto-encoder
- Model independent
- Input: kinematic information from physics objects $(e/\gamma/\mu...)$

CMS: 2024 JINST 19 C03029

Trigger rate(CMS L1: 100 kHz)	1kHz	5kHz	10kHz
$H \to aa \to 4b$ improvement	46%	100%	133%

Latency	LUTs	FFs	DSPs	BRAMs
2ticks (50 ns)	2.1%	~0%	0%	0%