CEPC Trigger System Investigation

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Introduction

- Experimental conditions in CEPC:
  - High Lumi. Higgs mode $\sqrt{s} = 240GeV$: $\mathcal{L} = 5\times10^{34}\ cm^{-2}s^{-1}$, bunch spacing 700ns.
  - High Lumi. Z mode @ $\sqrt{s} = 91.2GeV$: $\mathcal{L} = 101.1\times10^{34}\ cm^{-2}s^{-1}$, bunch spacing 27ns.
  - Beam background: pair production dominant (Haoyu Shi @ CEPC workshop).

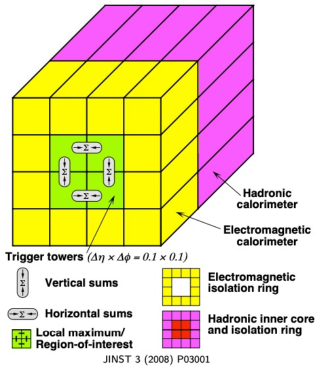
Physics Process @ Higgs mode	σ (pb) @ $\sqrt{s} = 240GeV$	Rate (Hz)
ffH signal	0.203	0.10
ee->ee	930	46.5
ee->qq	54.1	2.7
ee->WW	16.7	0.84
ee->$\mu\mu/\tau\tau$	5.3	0.26
Total signal		~50
Beam bunch		1.43×10^6

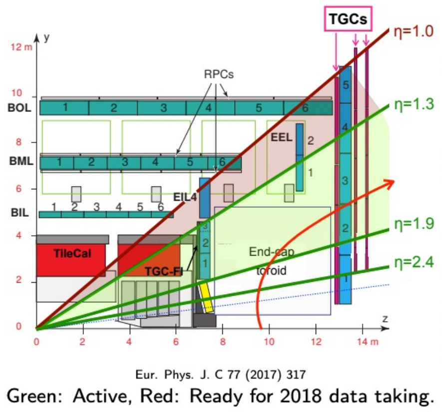
Physics Process @ Z mode	σ (nb) @ $\sqrt{s} = 91.2GeV$	Rate (Hz)
ee->qq	30.20	30.5k
ee->mumu	1.51	1.53k
Total signal		<35k
Beam bunch		37×10^6

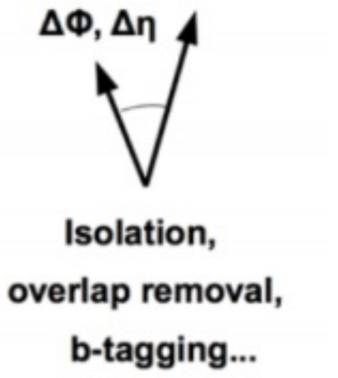
Background Type	Hit Density($cm^{-2}\cdot BX^{-1}$)
Pair production	1.91
Synchrotron Radiation	0.026
Radiative Bhabha	0.34
Beam Gas	0.9607
Beam Thermal Photon	0.02
Total	3.2567

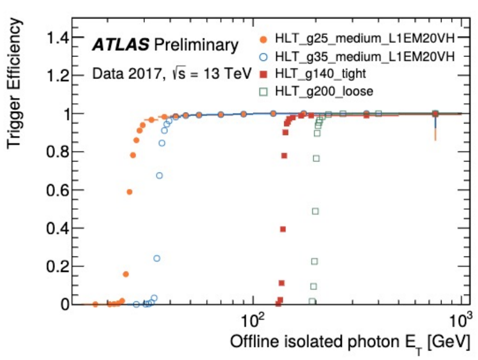
ATLAS Trigger System

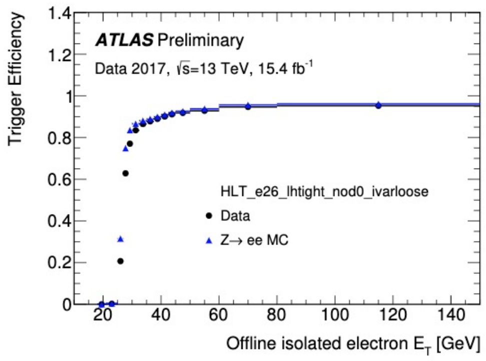
- ATLAS: much more complex condition, but can learn about trigger strategy
  - L1 trigger:
    - L1Calo, L1Muon, L1Topo.
    - Hardware based.
    - Provides a rate reduction from40 MHz to 100 kHz.
  - High-level trigger:
    - ~1.5 kHz rate, event tagging.
    - Separately for e/γ, muon, tau, jet, E_T^{mis}…

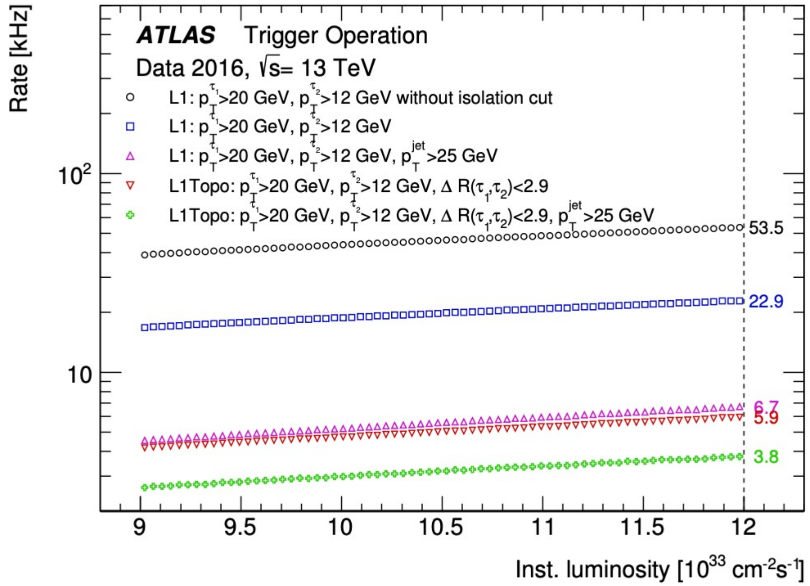








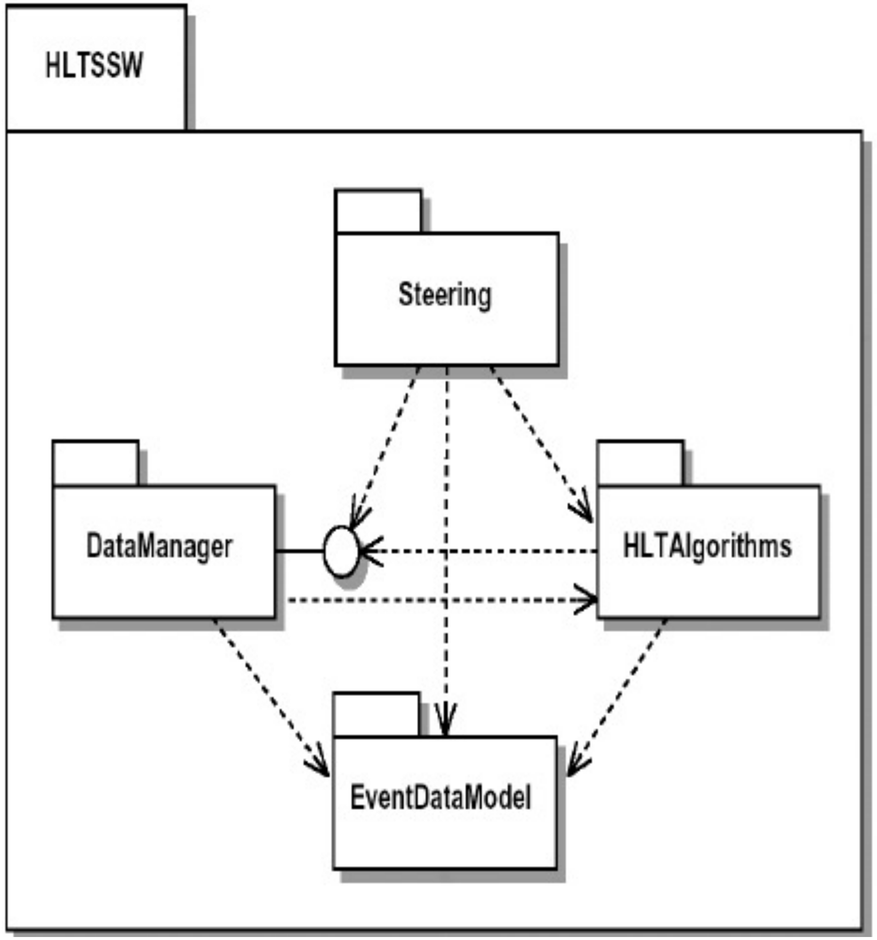




- FCC-ee: seems also in very beginning stage.

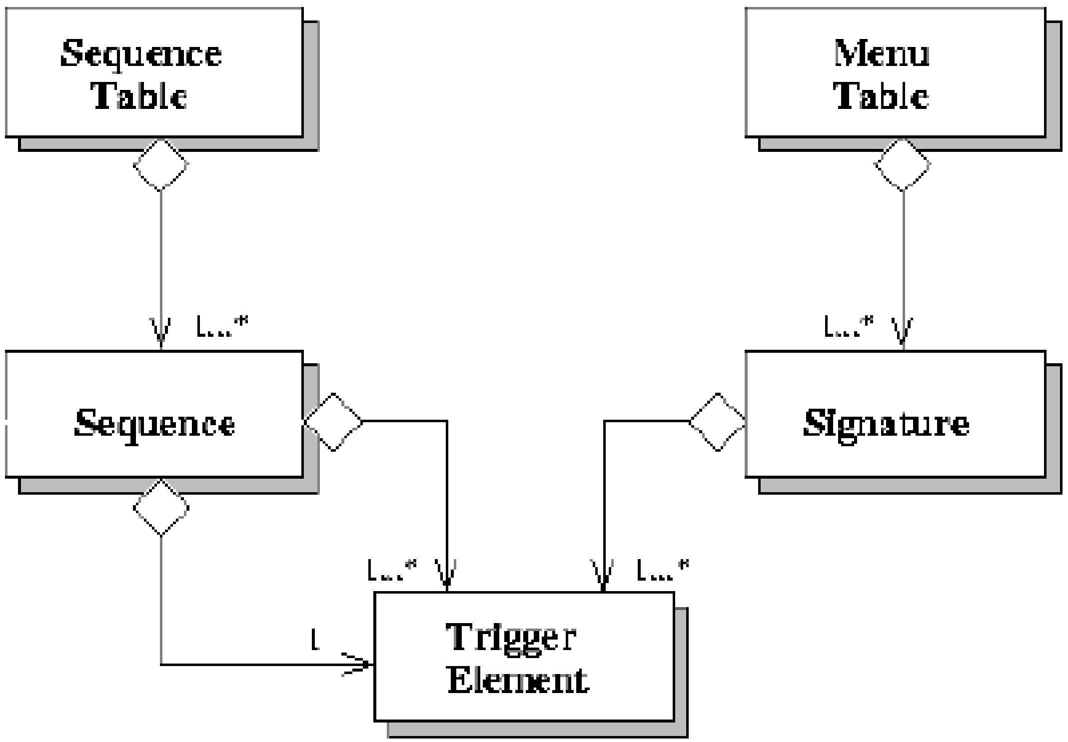
ATLAS High Level Trigger (1)

- High Level Trigger (HLT) is software trigger running on a farm of standard computers connected by network devices.
- ATLAS developed HLT Selection Software (HLTSSW) in the Athena offline software framework.
- HLTSSW is responsible for accepting events from the previous trigger level and for event selection or rejection.
- The package responsible for the event selection is called Steering in which the stepwise algorithm execution takes place.



ATLAS High Level Trigger (2)

- Components of Steering
  - Signatures: corresponding to a set of physics criteria sufficient to trigger the event
  - Sequences: carrying the information needed by the Steering in order to perform the algorithm sequencing
  - Signatures and Sequences are grouped together in Tables
  - A Trigger Element represents a “hypothesis” has to be confirmed or rejected and is uniquely identifies by a string, e.g.
    - “e50i ” + “e50i ” indicating two electrons with 50 GeV with isolation criteria applied

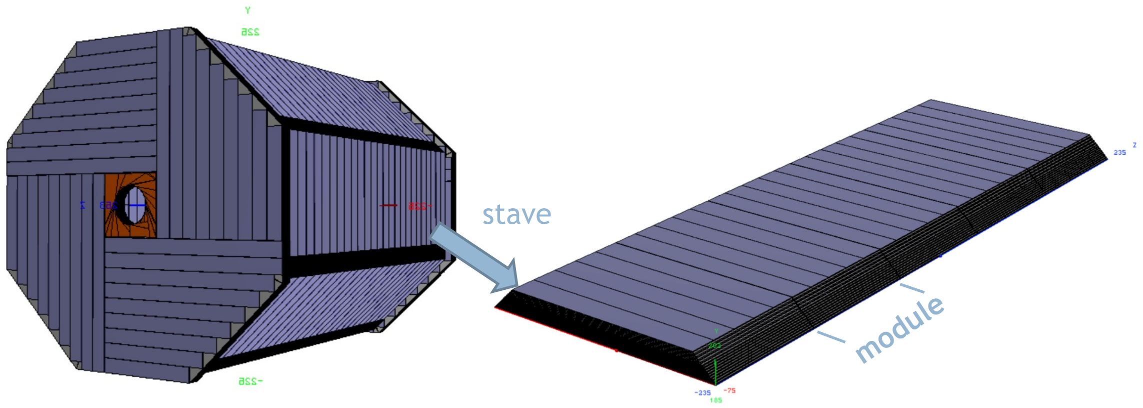


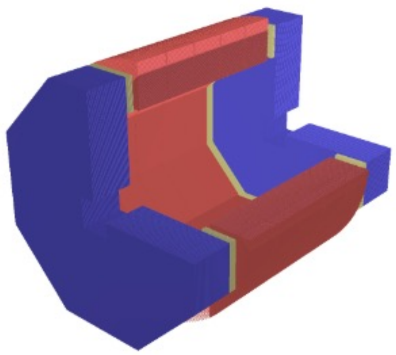
CEPC Trigger design

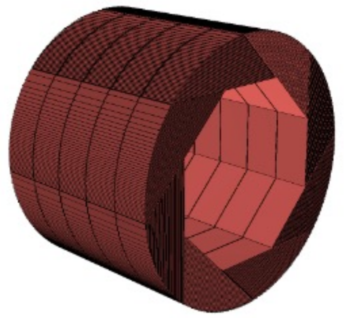
- Similar 2-level trigger system for CEPC:
  - L1 trigger:
    - Hardware based, use CEPC-v4 detector design. But use simulation to study the criteria and performance.
    - Only consider beamstrahlung pair production process (dominant) at the beginning, investigate the trigger logic, trigger cell, etc.
    - Target: recording rate <100 kHz @ Z mode, and >99% event efficiency.
  - HLT event filter:
    - Reuse ATLAS HLT Steering for configuration and run control.
    - Develop a set of fast reconstruction algorithm (can use full reconstruction for performance investigation).
    - Specific in each physics channel, make a HLT menu list.
    - Target: high efficiency in all physics analyses.

Calorimeter L1 trigger as beginning

- Consider ECAL and HCAL first: low background, simple clustering logic.
  - ECAL: baseline CEPC_v4 SiW sampling calorimeter.
    - 8 staves, each stave has 5 modules. Consider the whole module as trigger cell first. Will optimize the trigger cell size later.
    - Energy threshold for hit: 50keV to reject noise.
    - 2 global calibration constant for first 20 layers and later respectively.
    - Total deposited energy, energy in leading module (hottest module), number of fired module.
  - HCAL: GRPC based SDHCAL.
    - Raw energy in HcalHit.
    - Total deposited energy, energy in leading module (hottest module), number of fired module.

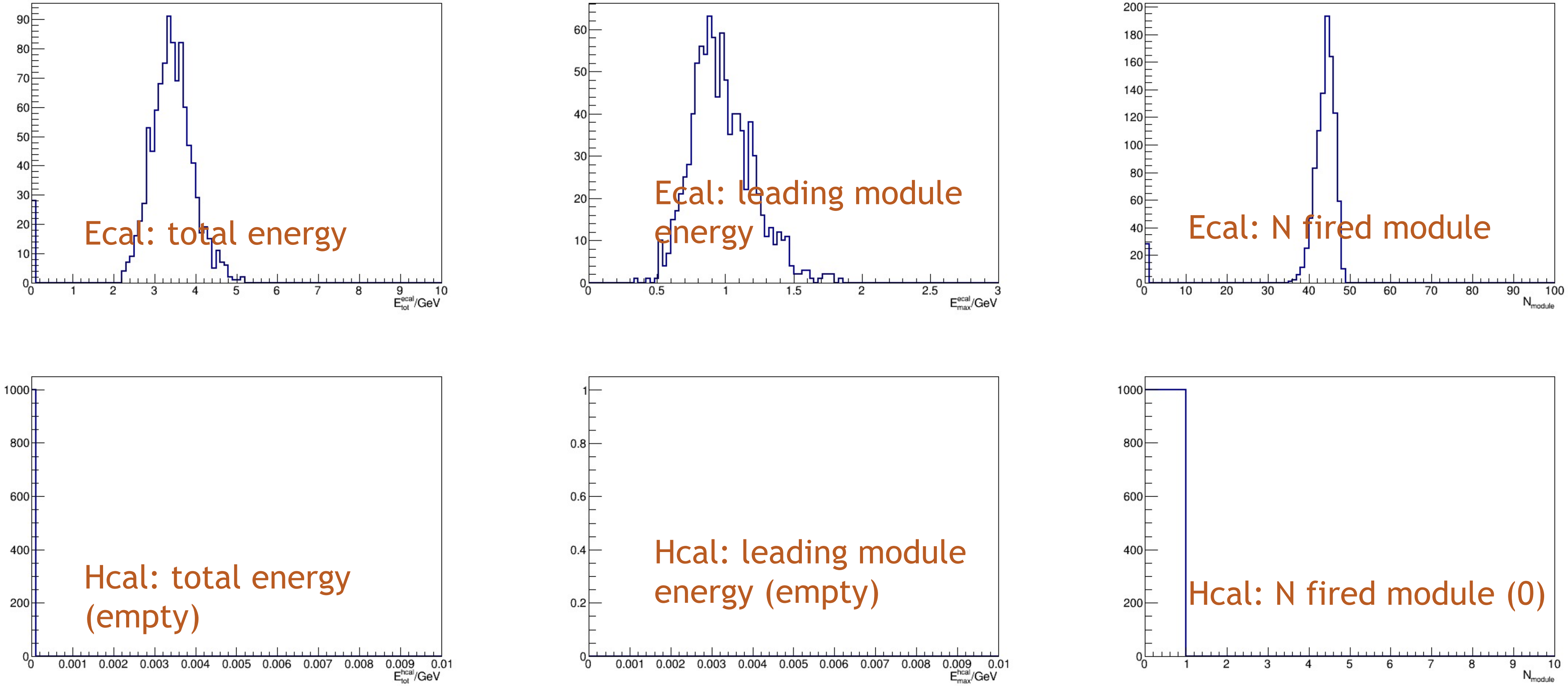






Calorimeter trigger

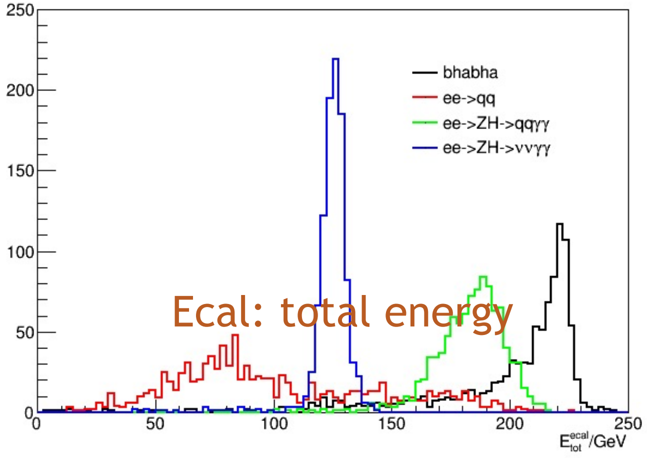
- Beam Background:

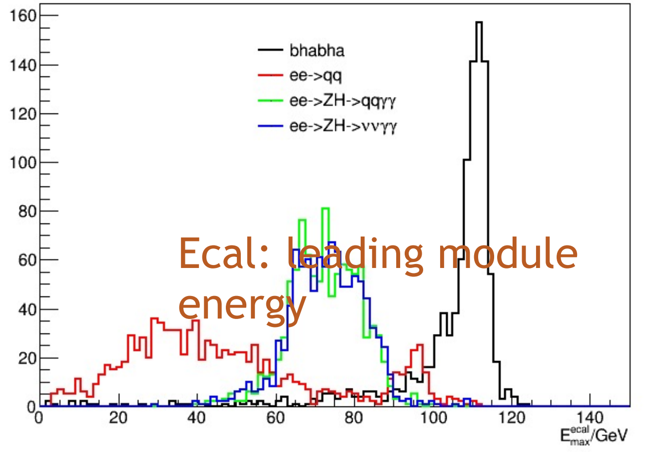


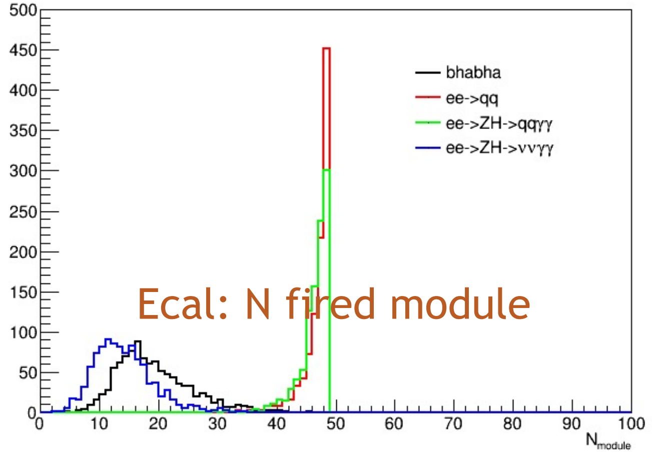
Calorimeter trigger

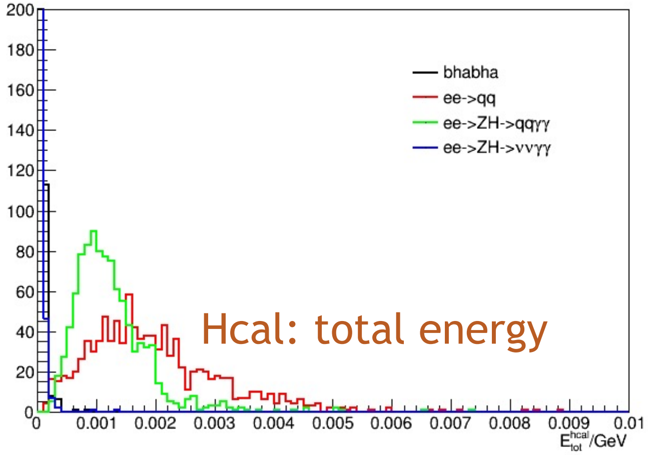
- Physics samples

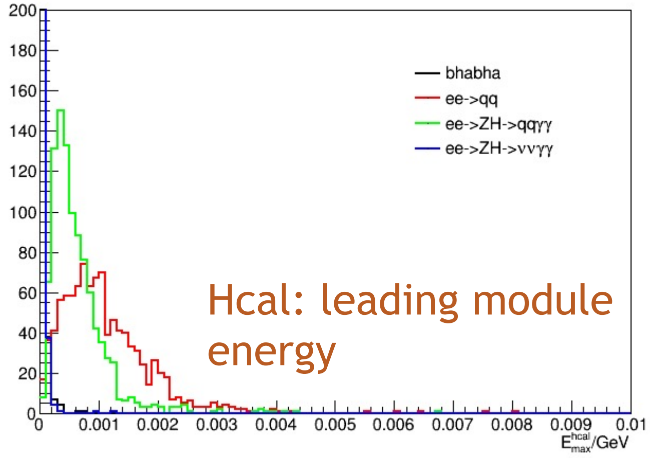
Can easily reject the beam background process

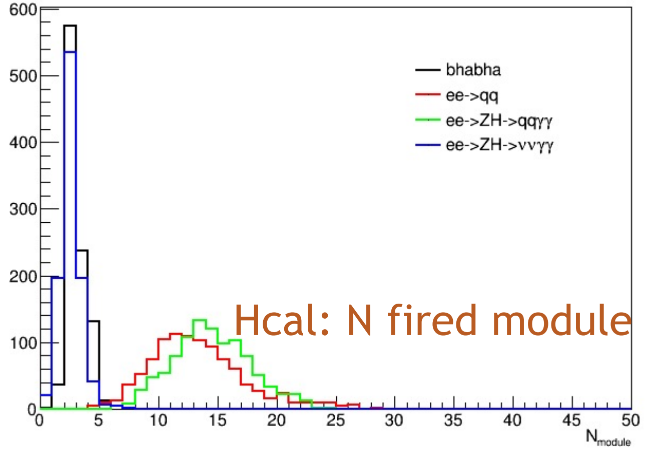












Calorimeter trigger

- Efficiency for physics process and beam background:
  - Cut: $E_{max} > 2\text{GeV} \;||\; N_{hcal} > 0.$

Process @ H mode	Efficiency	Rate
Beamstrahlung	0.21%	3 kHz
bhabha	99.96%	46.5 Hz
ee->mumu	94.04%	0.24 Hz
ee->tautau	99.50%	0.26 Hz
ee->qq	100%	2.7 Hz
ee->nn	17.94%	
ee->ZH->eeX	99.96%	
ee->ZH->mumuX	99.92%	
ee->ZH->tautauX	99.88%	
ee->ZH->qqX	99.96%	
ee->ZH->nnX	99.76%	

Process @ Z mode	Efficiency	Rate
Beamstrahlung	0	0 Hz
bhabha	99.98%	
ee->mumu	99.26%	1.52 kHz
ee->tautau	99.92%	~1.5 kHz
ee->qq	100%	30.5 kHz

*Didn't find precise $\sigma(bhabha)$ and $\sigma(ee \to \tau\tau)$.
Suppose $\sigma(ee \to \tau\tau) = \sigma(ee \to \mu\mu)$.

CEPC Trigger System design

- Hardware-based L1:
  - Design for each sub-detector with its structure.
  - Reduce recording rate to a acceptable level.

- Software preparation for HLT:
  - Event data model
  - Fast reconstruction algorithms: tracking and clustering algorithms
  - High Level Trigger database
  - Support of parallel computing on GPU, FPGA etc.

- Physics performance study:
  - HLT menu and event efficiency for each process.