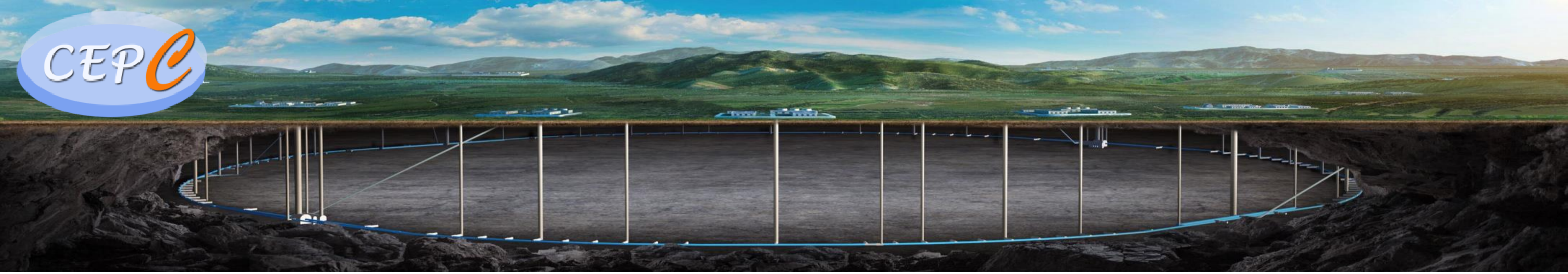

Simulation Studies of The CEPC Trigger System

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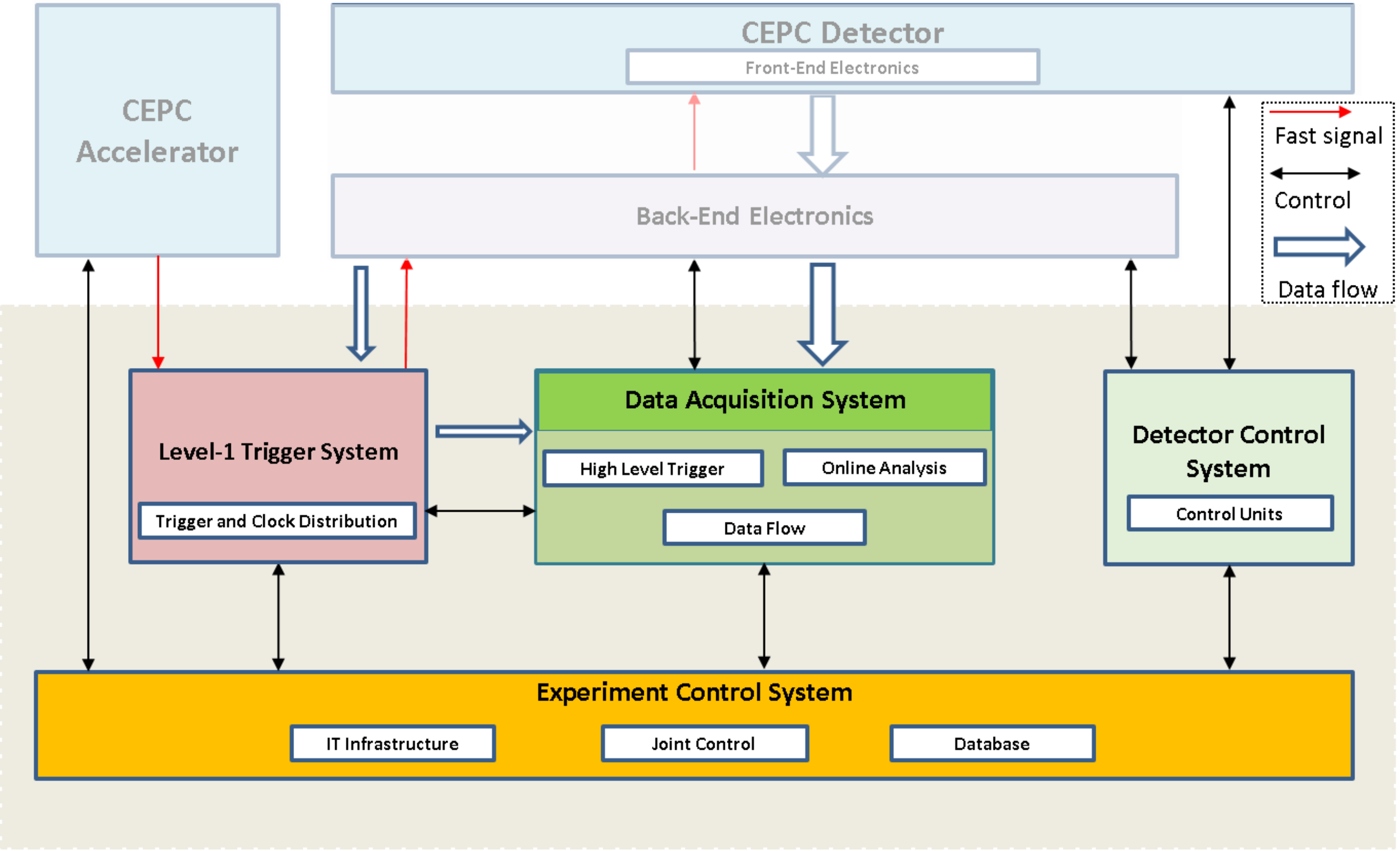
Introduction

- TDAQ overall design:
  - Data fully read out from front-end electronics
  - Level 1 hardware trigger(L1) + High level trigger(HLT)
  - L1: Calorimeter+Muon+(Tracker?)
  - HLT: Full detector information
- Simulation manpower:
  - Boping Chen
  - Dong liu (Graduate student)



Simulation study

- MC sample simulation (CEPCSW)
  - Physical processes simulation
  - Signal background mixing
  - Cosmic ray study
  - Beam background study
  - Di-photon process
  - Electronic noise
  - ...
- Trigger algorithm study
  - Vertex, Tracker(ITK, OTK), TPC, Calorimeter, Muon
  - L1 algorithm: fast track reconstruction, calorimeter cluster, Muon track...
  - HLT algorithm: track trigger, event size compress(for TPC, Calorimeter), ... (PID?)
- Hardware firmware/HLT development
- Trigger efficiency (Higgs/background/... rate)

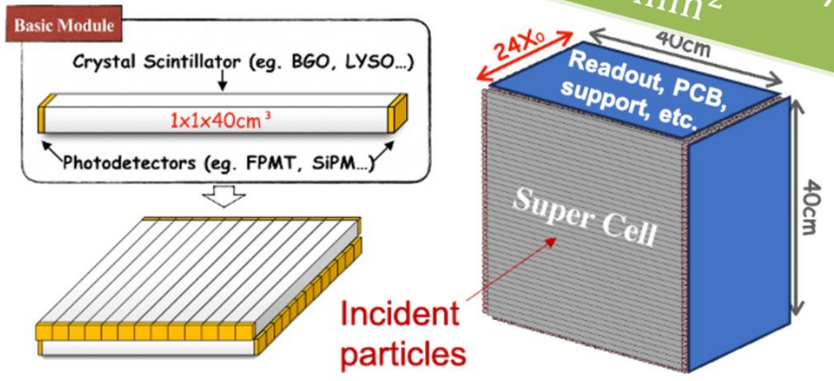
Challenge: track trigger(page 17,18), TPC (page 19)

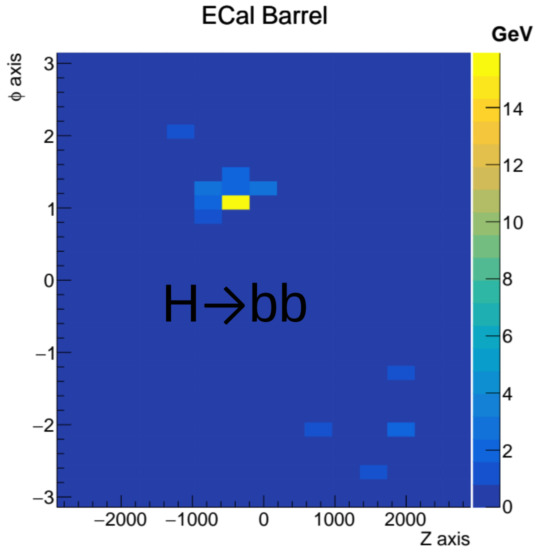
ECAL Calorimeter module

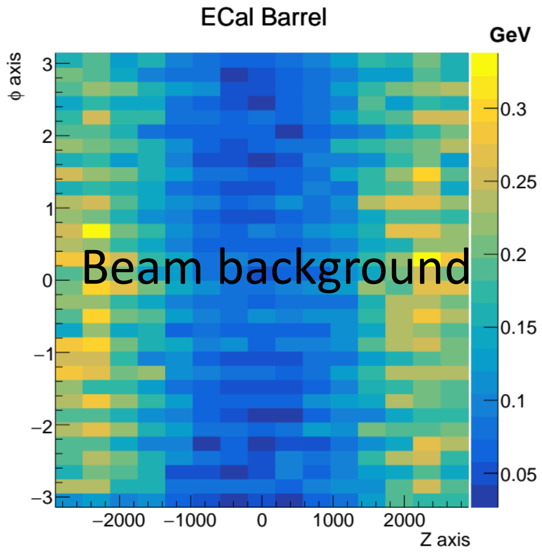
[ECAL module]

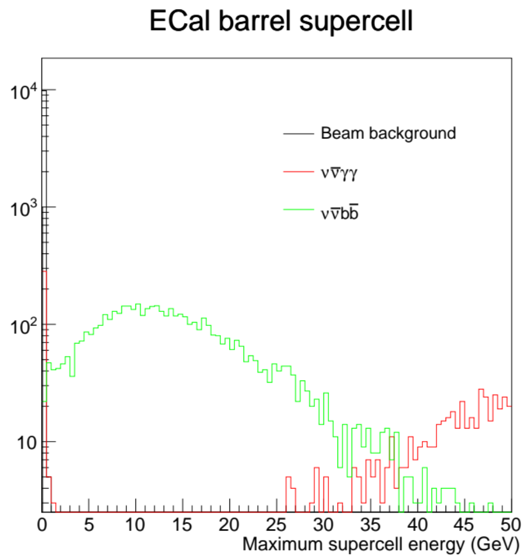
Updated: crystal granularity of 15×15 mm^2

- Basic module for ECal: ~1.5x1.5x40cm^3
  - Cluster modules into 40x40cm^2 supercell
  - Use supercell as trigger input
  - 15(Z)x32(φ) in Z-φ plane
  - Left&middle: single event ECal Barrel energy distribution
  - Right: Maximum ECal module energy distribution









Calorimeter energy threshold efficiency

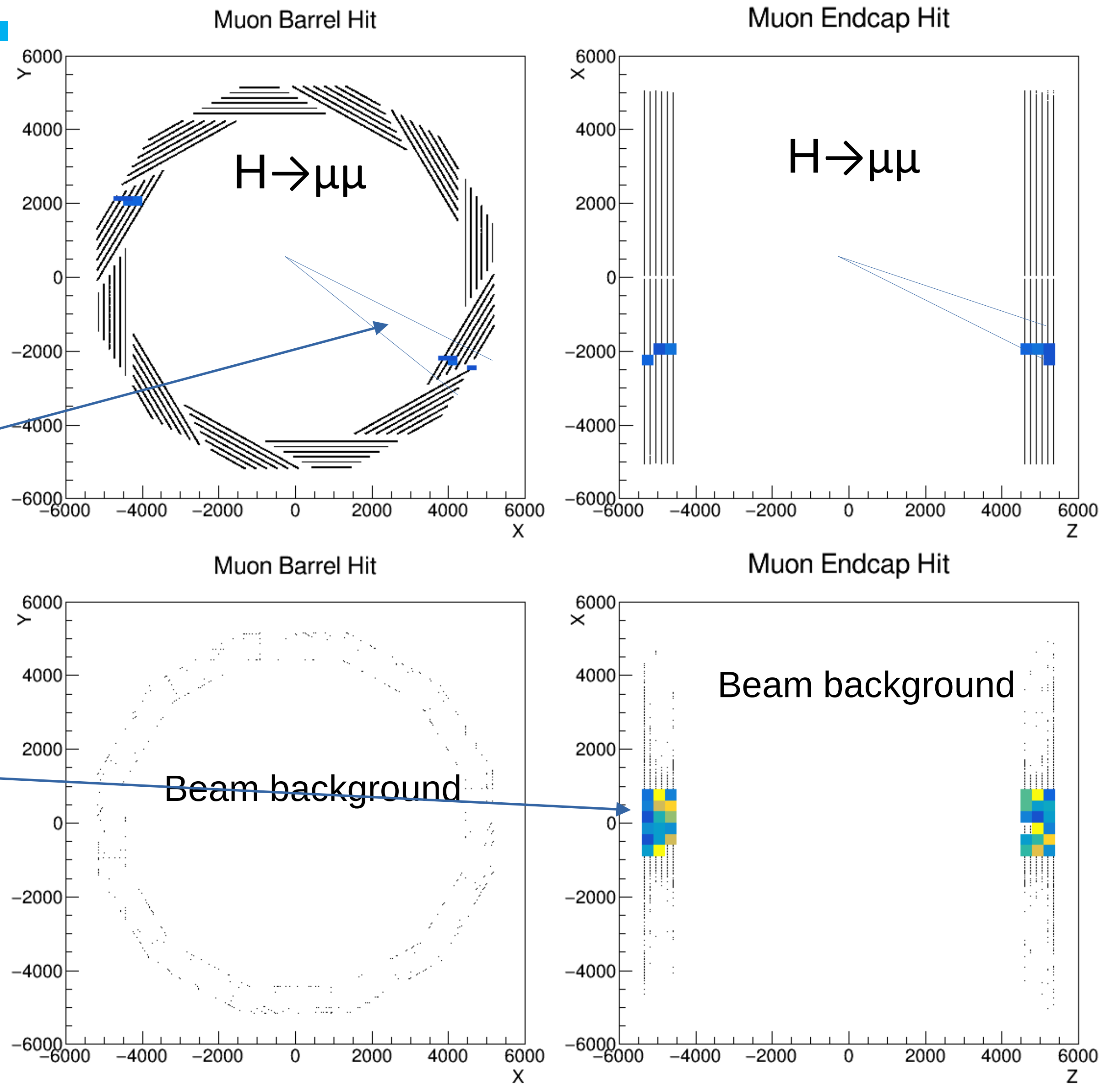
- A set of energy threshold applied to ECal/HCal, Barrel/Endcap
- Very good efficiency for most of the physical process

Table 12.8: Baseline calorimeter energy threshold efficiency at the ZH mode for 50 MW and the Z mode for 12.1 MW.

Process	Efficiency		Process	Efficiency		Process	Efficiency	
Higgs production								
$Z(\nu\bar{\nu})H(\gamma\gamma)$	>0.999		$Z(\nu\bar{\nu})H(\gamma Z)$	0.999		$Z(\nu\bar{\nu})H(b\bar{b})$	>0.999	
$Z(\nu\bar{\nu})H(\mu^+\mu^-)$	0.979		$Z(\nu\bar{\nu})H(\tau^+\tau^-)$	0.996		$Z(\nu\bar{\nu})H(W^+W^-)$	>0.999	
$Z(\nu\bar{\nu})H(W^+W^-)$lep	0.995		$Z(\nu\bar{\nu})H(ZZ)$	>0.999		$Z(\nu\bar{\nu})H(ZZ)$lep	0.992	
Two Fermions	**ZH mode**	**Z mode**		**ZH mode**	**Z mode**		**ZH mode**	**Z mode**
$q\bar{q}$	0.998	>0.999	$\mu^+\mu^-$	0.949	>0.999	$\tau^+\tau^-$	0.958	0.995
Bhabha	0.998	>0.999						
Di-photon process	**ZH mode**	**Z mode**		**ZH mode**	**Z mode**		**ZH mode**	**Z mode**
$\gamma\gamma \to b\bar{b}$	0.888	0.996	$\gamma\gamma \to c\bar{c}$	0.846	0.973	$\gamma\gamma \to q\bar{q}$	0.533	0.706
$\gamma\gamma \to \mu^+\mu^-$	0.154	0.258	$\gamma\gamma \to \tau^+\tau^-$	0.514	0.785			
Background	**Veto efficiency**							
	ZH mode	**Z mode**						
Beam Background	0.982	0.991						

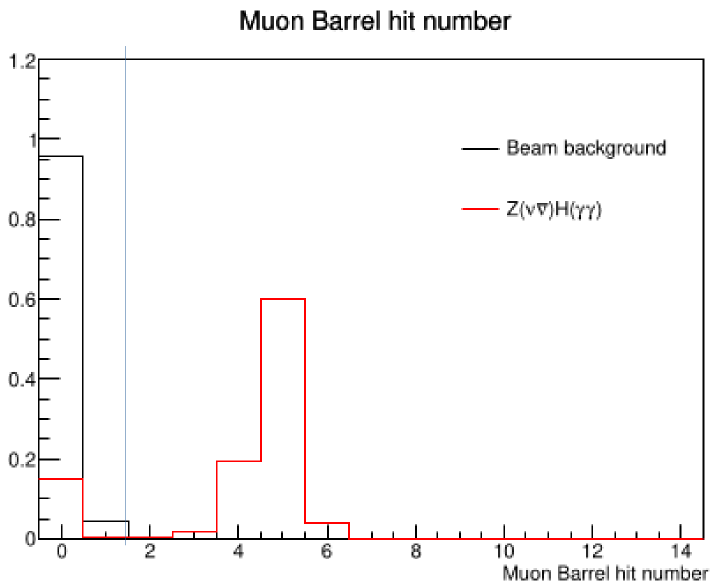
Muon detector

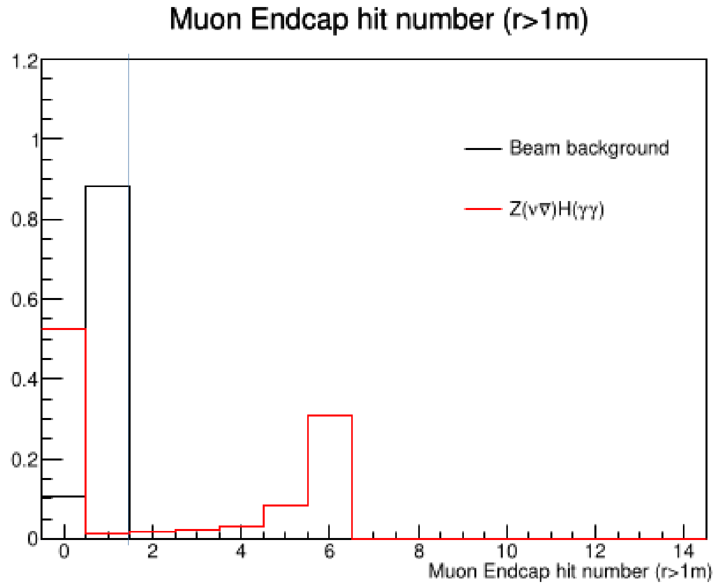
- Top: signal Z(νν)H(μμ)
- Bottom: beam background
  - Black hits: hits for all 2000 events
  - Color hits: hits for single events
- Count number of muon hit inside a small cone(baseline radius)
  - Barrel: dR<0.05
  - Endcap with R>1m: dR<0.01
  - Endcap with R<1m: too many background, need further study

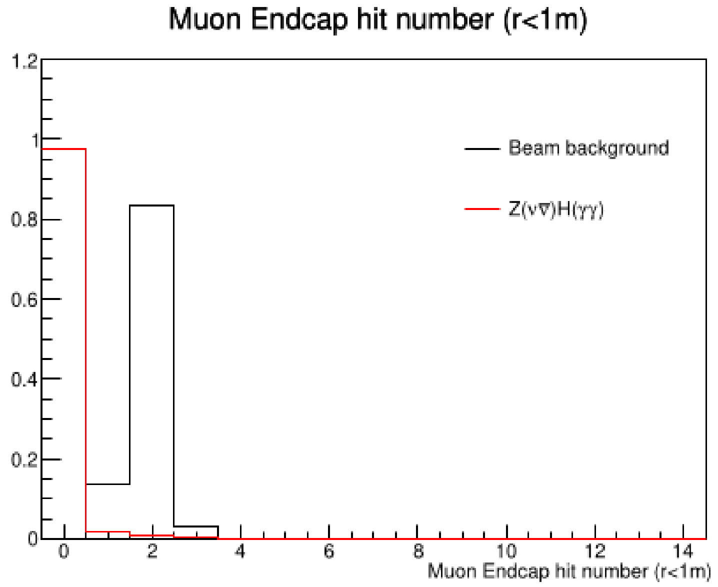


Number of hit

- Blue line: baseline cut for the number of hit
  - Barrel > 1
  - Endcap with R>1m > 1
- Efficiency:
  - H→μμ=0.998; ee→μμ=0.979; Background=0.016

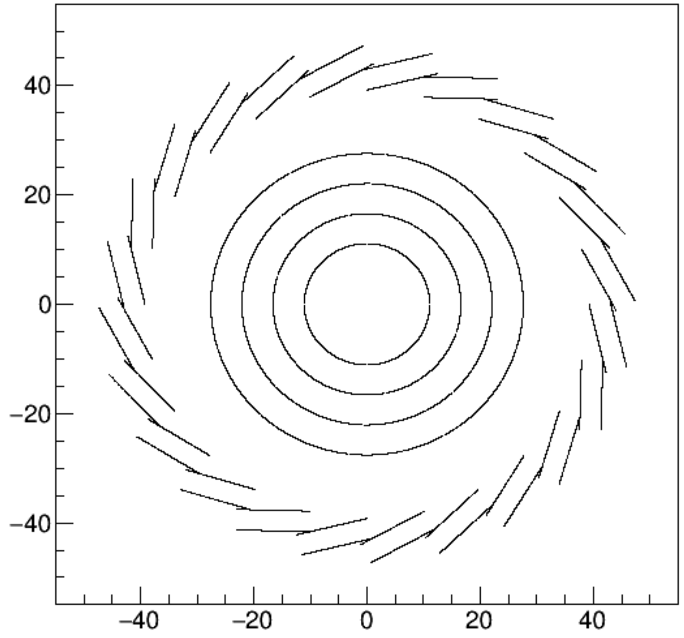


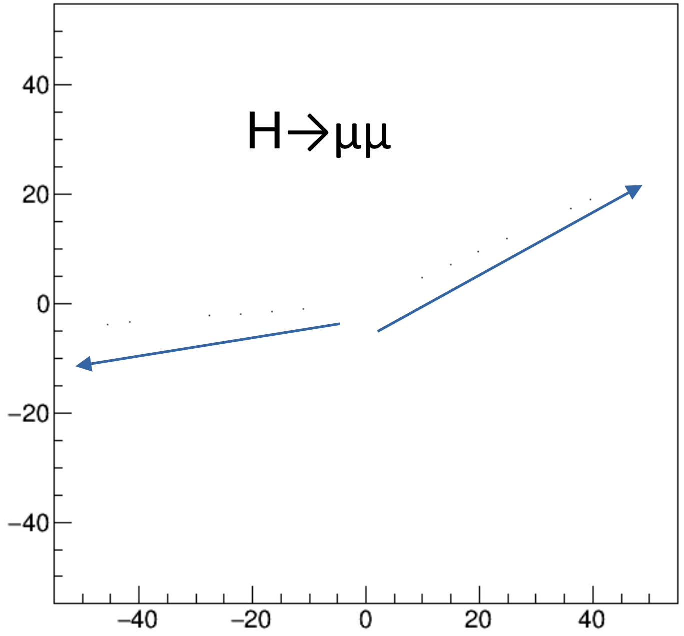


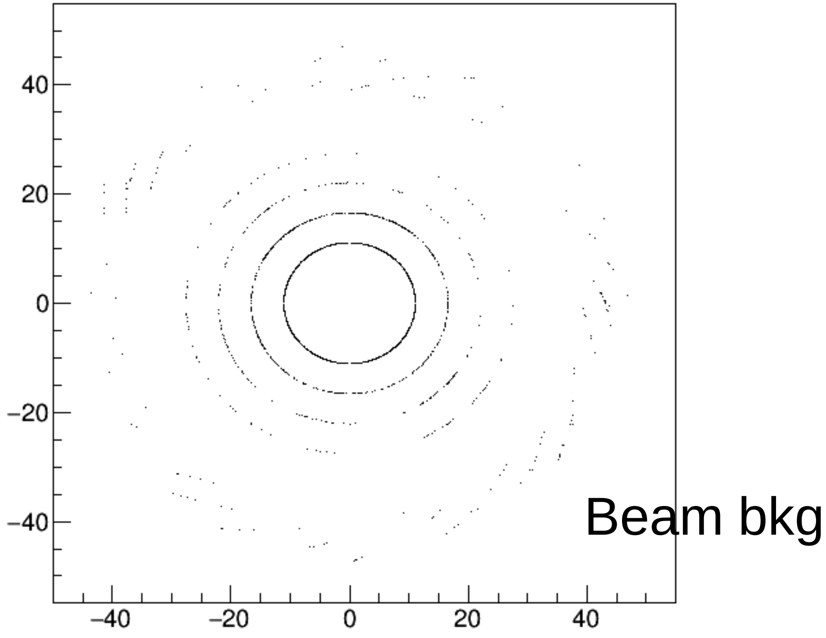


Tracker: Vertex

- Left: Z(vv)H(μμ); Right: Beam background
- Too many hits from beam bkg, difficult to use

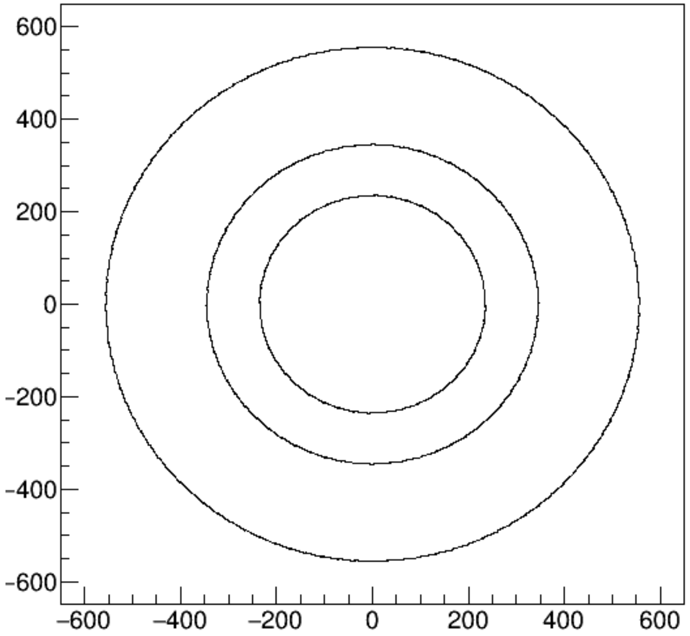


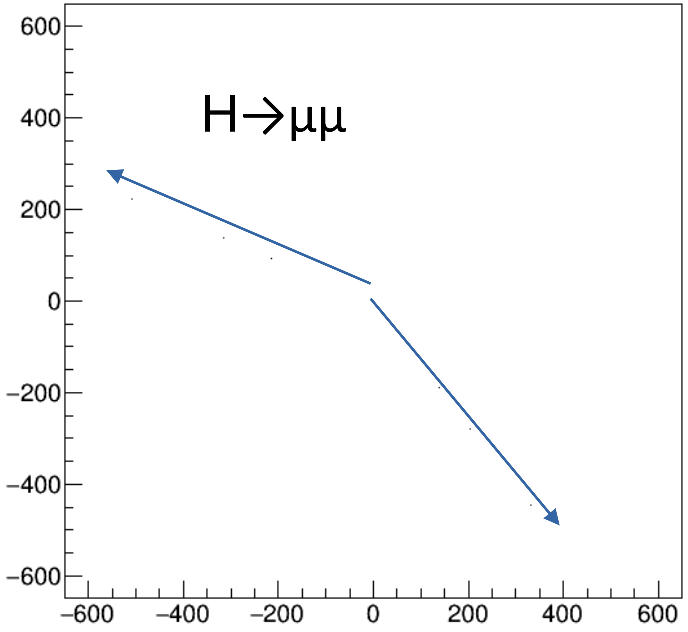


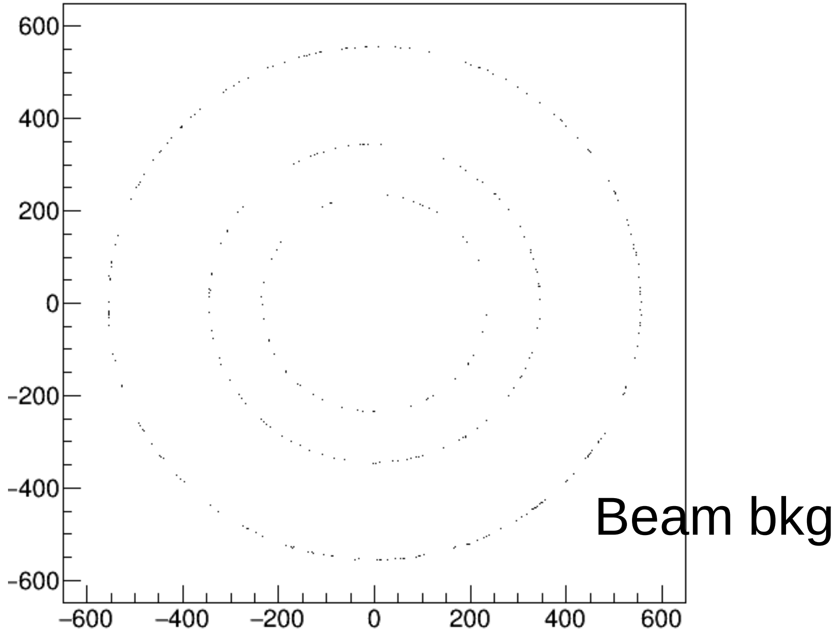


Tracker: ITK

- Left: Z(νν)H(μμ); Right: Beam background
- Less hits than vertex
  - Only 3 layers(+1 layers for OTK), difficult to do tracking
  - May be able to reconstruct 2D track, need further study
- Combine ITK/OTK and Muon doesn't improve Muon efficiency

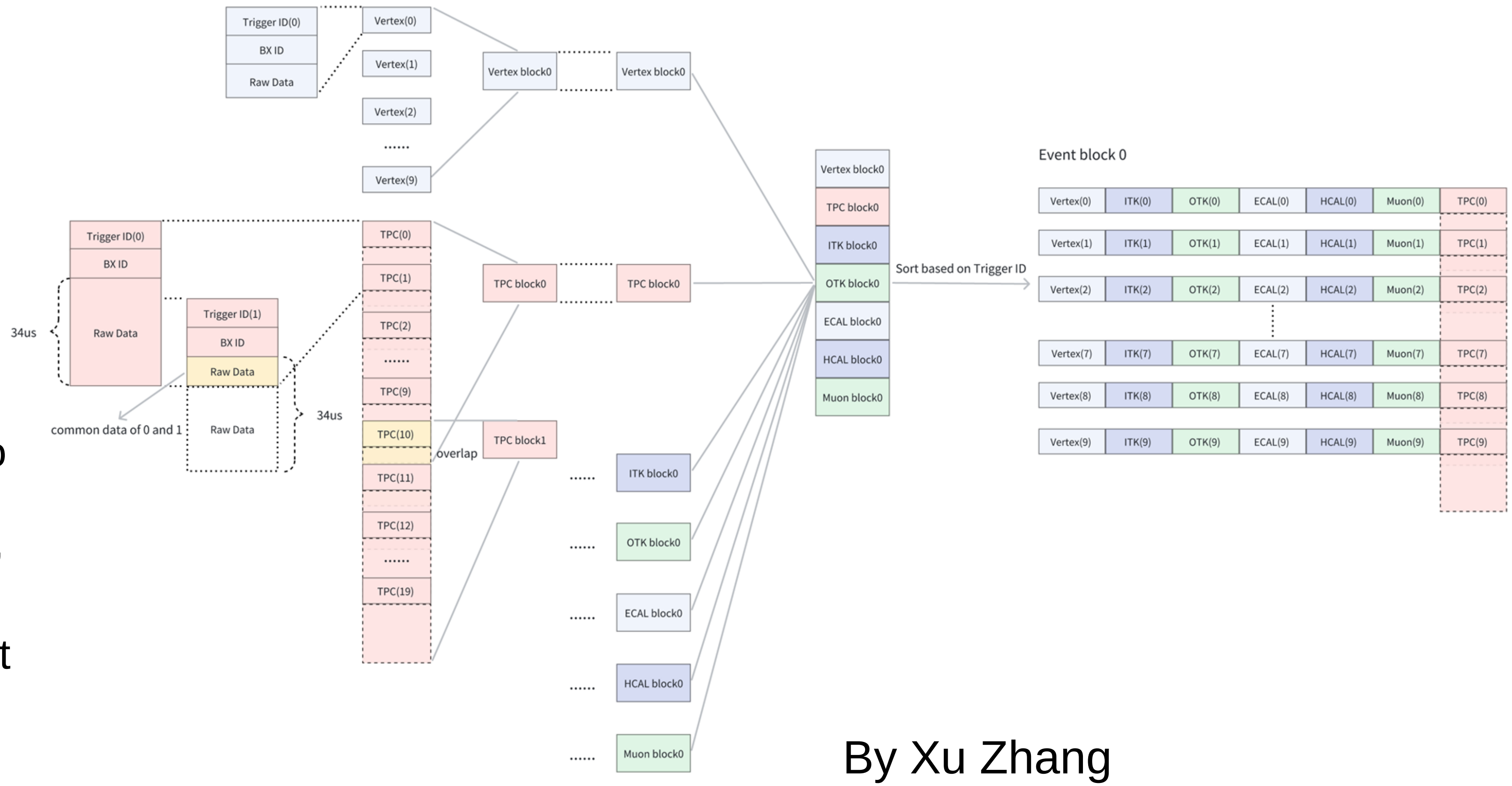






TPC

- Reads all TPC raw data, and uses trigger info to integrate 34 μs data segments sent to DAQ
- Data is packed in blocks by Trigger ID for parallel processing
- Need to study the algorithm to match the TPC data using other subdetector information, and compress the TPC data
- New physics/low energy event may also need TPC to trigger



By Xu Zhang

Summary and Outlook

- L1 Trigger simulation & algorithm results are shown in this talk
- Future:
  - Detail calorimeter cluster algorithm: isolation/depth/location(back to back)/CoM…
  - Tracking algorithm for L1
  - Detector noise
  - ML(BDT, DNN, CNN…)
  - Trigger for BSM
  - ...

Backup

Physical event rate

- Higgs mode (240GeV) bunch crossing rate: 1.33 MHz
  - Higgs boson production rate: ~0.017Hz
  - qq rate: 5Hz
- Z mode (91GeV) bunch crossing rate: 12/39.4 MHz
  - Visible Z rate: 10.5/41.9 kHz
- Cosmic ray: ~56 Hz
- Di-photon processes: 4kHz ~ 9kHz
- Generated by BesTwoGam(only for Di-photon, need further study), Whizard(for all other processes)
- Detector simulation using CEPCSW tdr25.3.6

Table 12.1: CEPC baseline parameters

Operation phase	I			II	III
Run mode	ZH	Z	W	Z	$t\bar{t}$
SR power per beam (MW)	50	10	50		
Bunch number	446	3978	2162	13104	58
Bunch spacing (ns)	277 (x12)	69.2 (x3)	138.5 (x6)	23.1 (x1)	2700.0 (x117)
Train gap (%)	63	17	10	9	53
Bunch crossing rate(MHz)	1.33	12	6.5	39.4	0.17
Luminosity per IP (10^{34}cm^{-2}s-1)	8.3	26	26.7	95.2	0.8
Run time (years)	10	1	1	2	5
Event yields [2 IPs]	4.3x10^6	2.9x10^{11}	2.1x10^8	2.0x10^{12}	6x10^5

Table 12.2: Expected event rate at the ZH mode for 50 MW

Processes	Cross section (fb)	Event rate (Hz)
ZH	203.66	0.017
Two Fermions background (exclude Bhabha)	6.4×10^4	5.3
Four Fermions background	1.9×10^4	1.6
Bhabha	1.0×10^6	80
$\gamma\gamma \to bb$	1.6×10^6	128
$\gamma\gamma \to cc$	2.1×10^6	168
$\gamma\gamma \to qq$	59.8×10^6	4784

Table 12.3: Expected event rate at the Z mode for 10 MW

Processes	Cross section (fb)	Event rate (Hz)
qq	31×10^6	7970
$\mu\mu$	1.5×10^6	400
$\tau\tau$	1.5×10^6	396
Bhabha	6.6×10^6	1714
$\gamma\gamma \to bb$	2.8×10^5	73
$\gamma\gamma \to cc$	5.1×10^5	132
$\gamma\gamma \to qq$	34.7×10^6	9011

MC simulation at Higgs mode

- Physical processes:
  - Higgs: ee→ZH
    - Z→ee, μμ, ττ, νν
    - H→bb, WW, ττ, cc, ZZ, γγ, Zγ, μμ …
  - 2/4 fermions: ee→qq, μμ, ττ, ZZ, WW…
  - Di-photon: ee→ee+γγ→ee+bb/cc/qq
- Background:
  - Beam induced background(10000 events by Haoyu)
    - Each event contains 10 BX(safe factor 10)
    - Need further study for the background process
  - Detector noise and other background(to be studied)

Signal MC simulation: ee→ZH

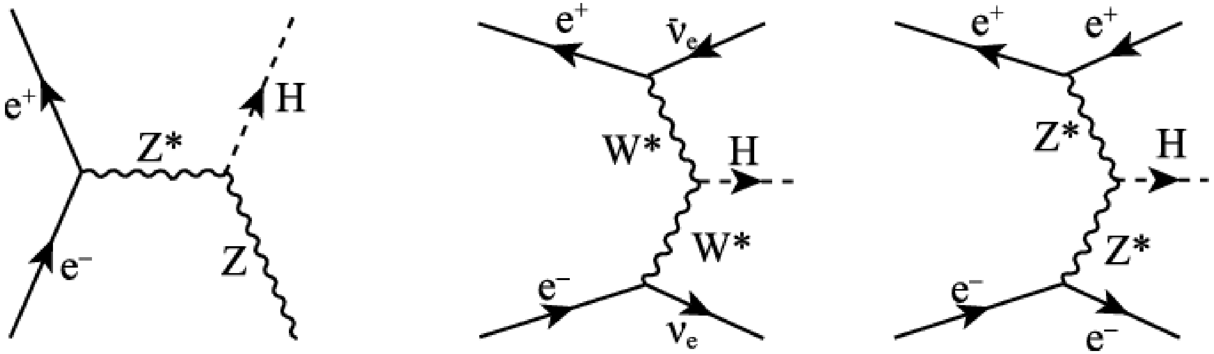
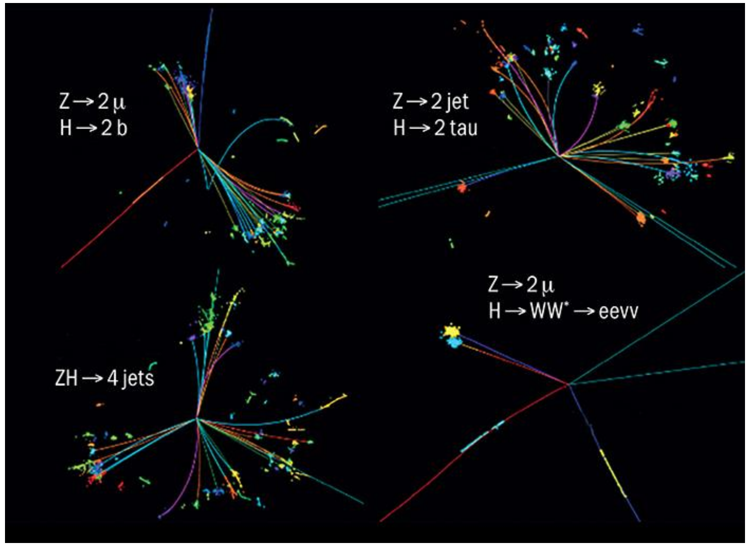


Table 11.3: The branching ratios and the relative uncertainty for a SM Higgs boson with $m_H = 125\,\text{GeV}$ [39, 40].

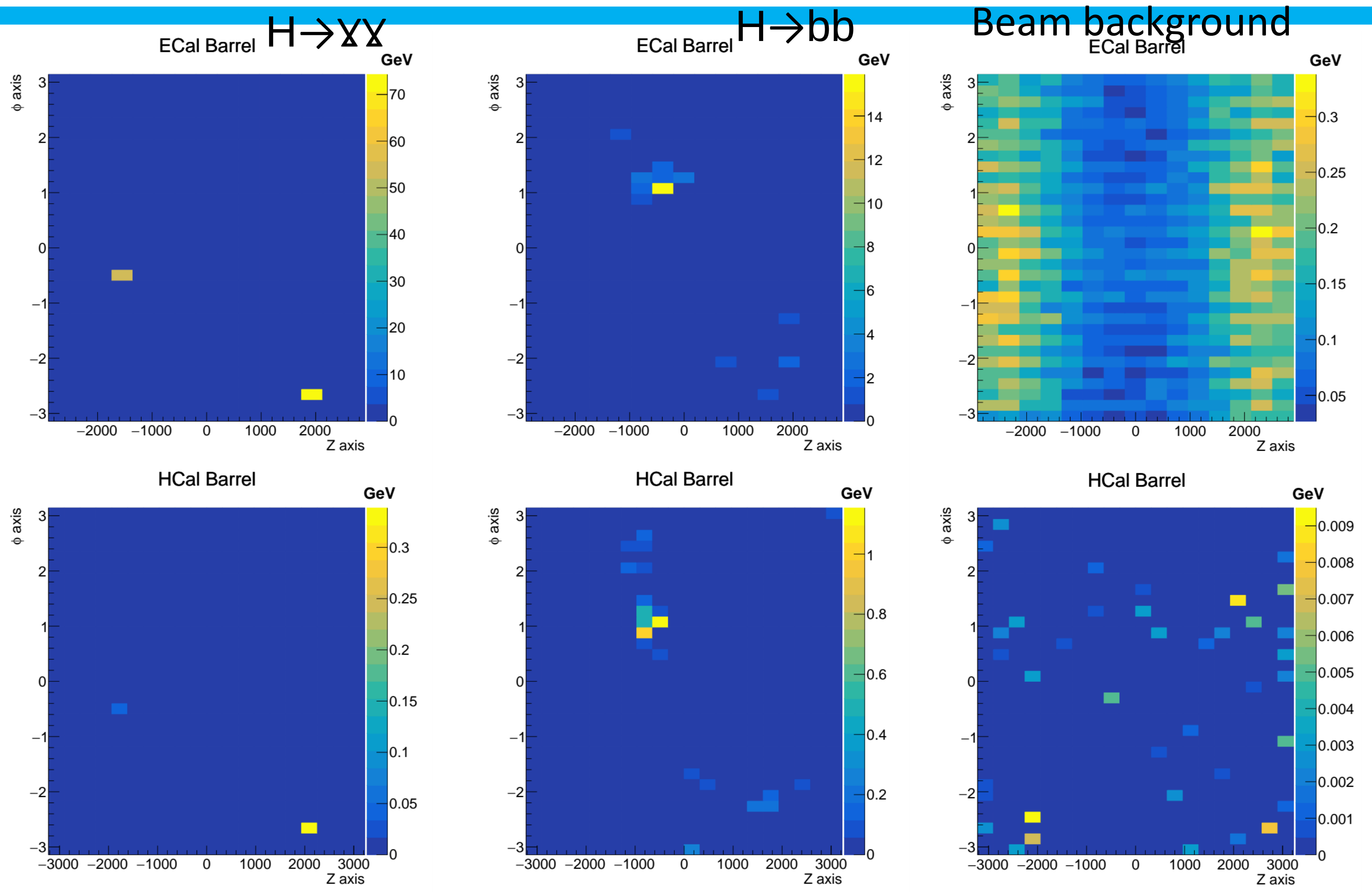
Decay channel	Branching ratio	Rel. uncertainty
$H \to \gamma\gamma$	2.27×10^{-3}	2.1%
$H \to ZZ$	2.62×10^{-2}	±1.5%
$H \to W^+W^-$	2.14×10^{-1}	±1.5%
$H \to \tau^+\tau^-$	6.27×10^{-2}	±1.6%
$H \to b\bar{b}$	5.82×10^{-1}	$^{+1.2\%}_{-1.3\%}$
$H \to c\bar{c}$	2.89×10^{-2}	$^{+5.5\%}_{-2.0\%}$
$H \to Z\gamma$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

- ZH sample presented in this talk
  - Z→νν
  - H→bb, WW, ττ, ZZ, γγ, Zγ, μμ
    - Final state: jet, photon, and muon
    - bb, γγ and μμ will be shown as example
  - 5000 events for each process



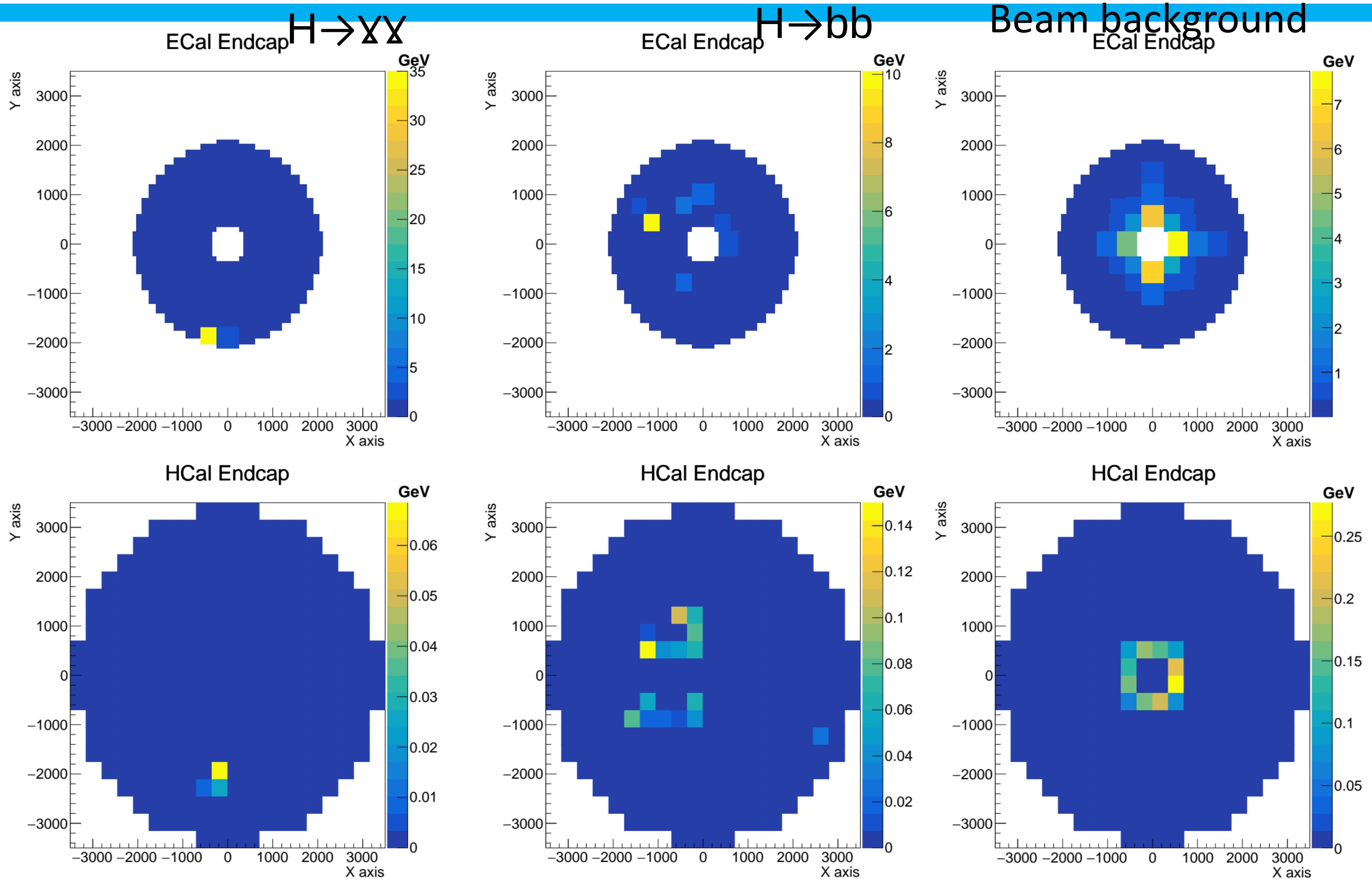
Barrel supercell energy distribution

- Large energy deposition(>10GeV) for signal(H→γγ, H→bb)
- Very tiny energy deposition(<0.5 GeV) for beam background, mostly from pair production
  - **One** beam background event contains **10** BX



Endcap supercell energy distribution

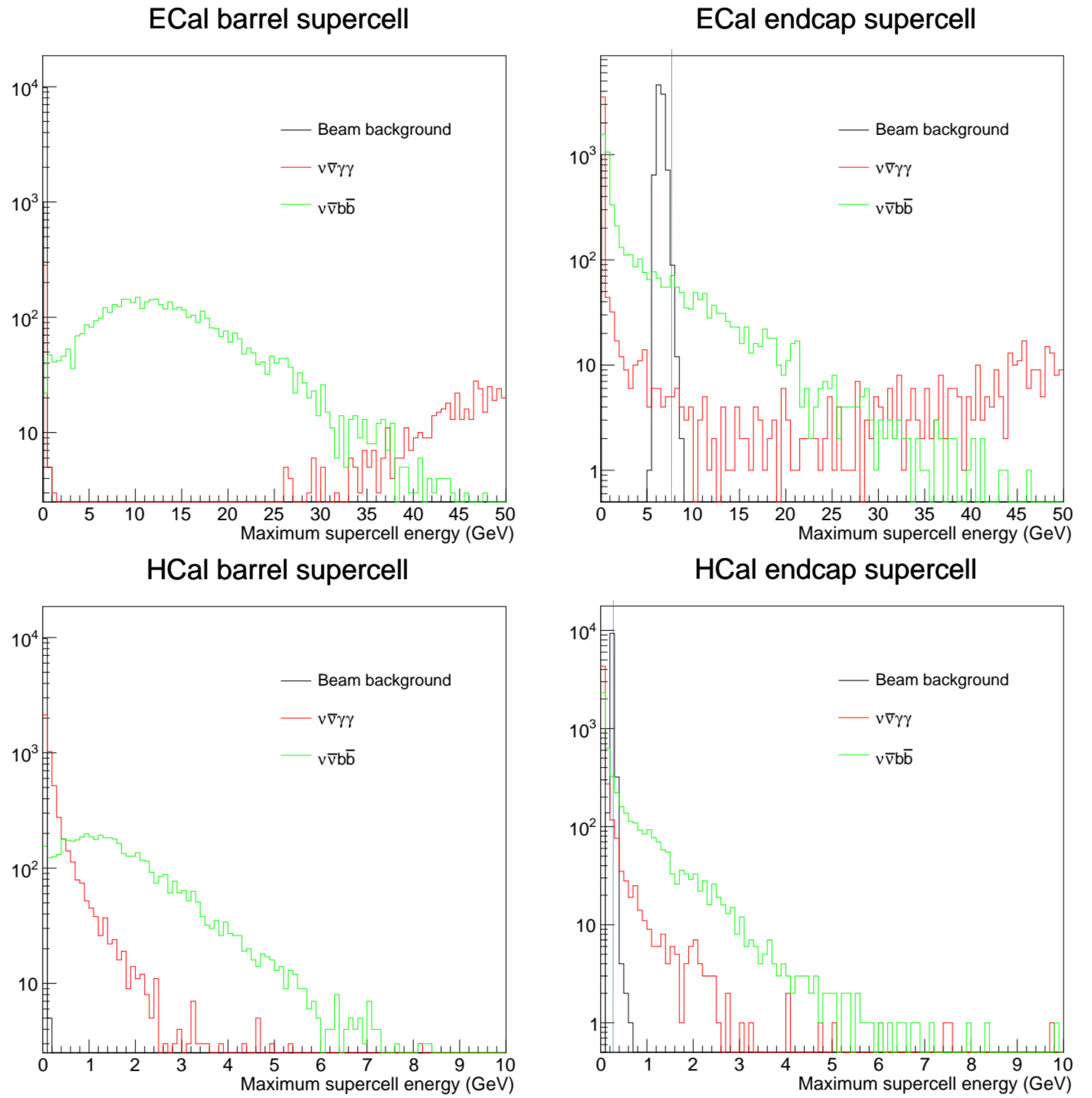
- Similar to barrel for signal
- Relatively large energy deposition(~5GeV) for beam background
- Use supercell energy as input



Maximum energy distribution

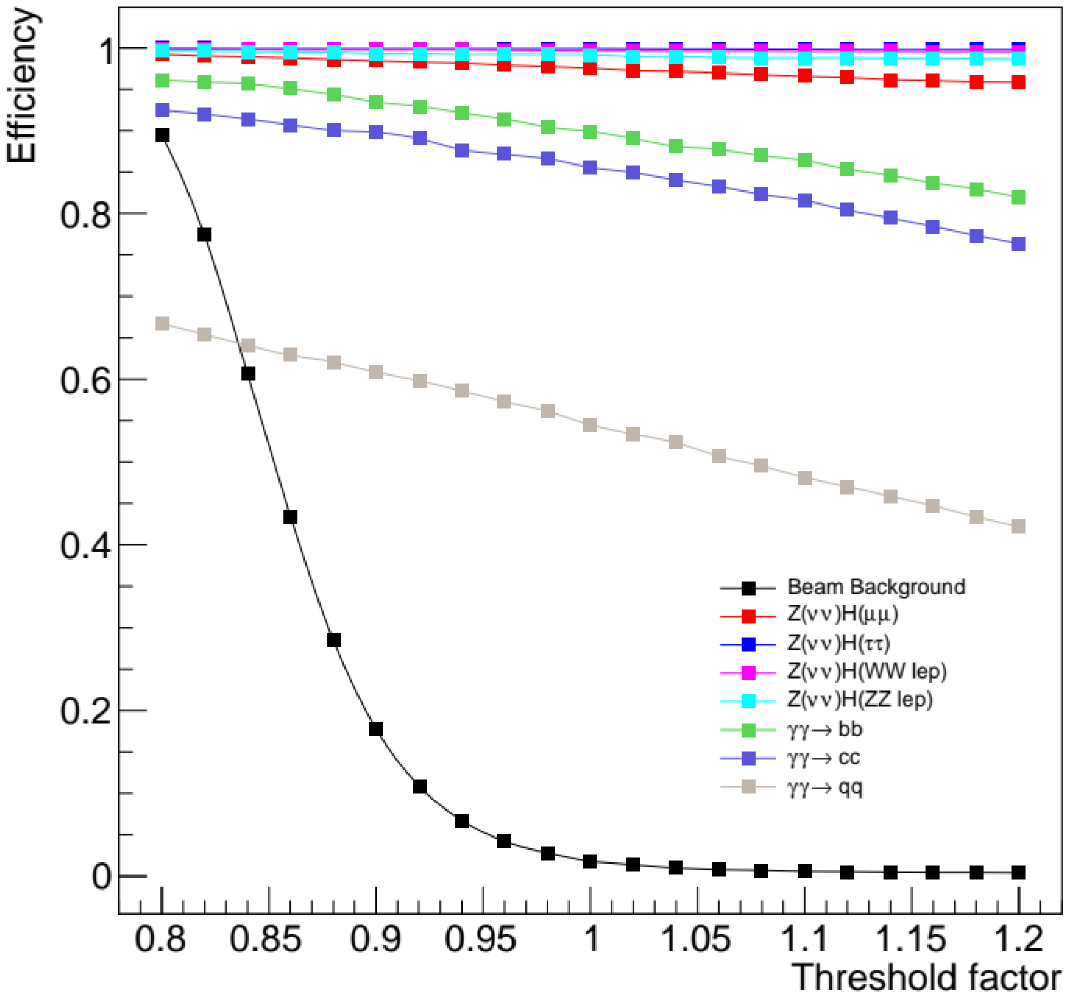
- Maximum energy for each sub-detector
- Beam induced background contributes little(<1GeV) on calorimeter, except ECal Endcap
- A baseline set of energy threshold
  - Background efficiency is less than 0.5% when any single threshold is used alone
  - A blue line shows the value for Endcap

Subdetector	Threshold(GeV)
ECAL Barrel	0.38
ECAL Endcap	7.7
HCAL Barrel	0.05
HCAL Endcap	0.33



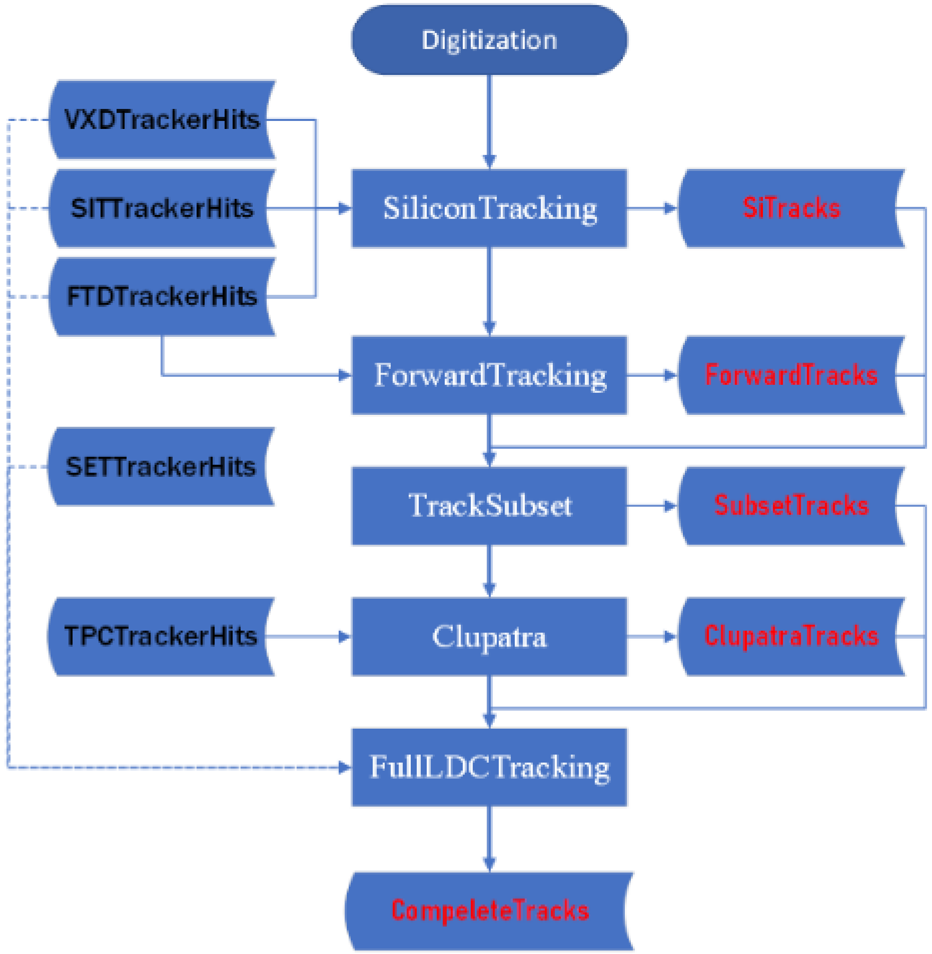
Efficiency vs threshold

- Threshold value can be modified for different physics requirement
- A group of sets are tested based on the baseline set, by multiply a “threshold factor” to all the four threshold
- Only the ZH production with an efficiency below 99%, the di-photon processes and background are shown
- Signal processes are affected if the final state contains only neutrinos and muon



Software trigger

- Offline track reconstruction
- Build "CompleteTracks" from all tracking subdetector
- Beam background:
  - ~1s / event for both ZH and Z mode
  - Efficiency: ~20%(N track > 0)
  - Other tracking information(pT) will be studies
  - Need more background events for HLT

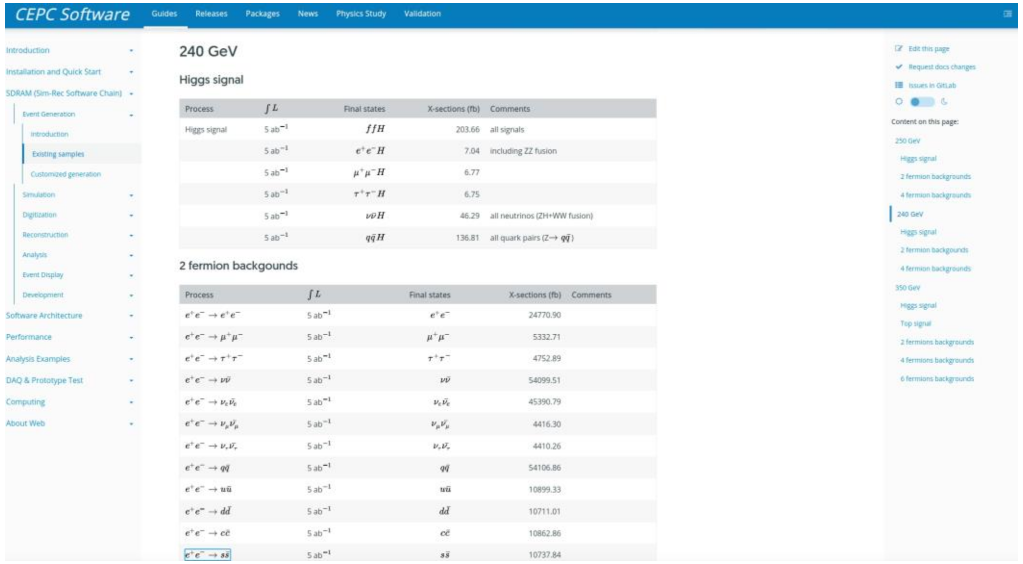


MC name

Total_name	Abbreviation	Process	Final states	X-sections(fb)	Events generate	Scale factor	Events expected	Total
single_w	single_w	sw_l0mu	e,nu_e,mu,$nu_{\mu,\tau}$	436.70	2205350	110.89%	2445520	19517400
		sw_l0tau	e,nu_e,tau,$nu_{\mu,\tau}$	435.93	2201471	110.89%	2441208	
		sw_sl0qq	e,nu_e,up,down	2612.62	13193721	110.89%	14630672	
single_z	single_sze	sze_l0e	uncertain:e^-, e^+, e^-, e^+	78.49	396388	110.89%	439544	9072951
		sze_l0mu	e^-, e^+, μ^-, μ^+	845.81	4270357	110.92%	4736536	
		sze_l0nunu	$e^-, e^+, \nu_{\mu,\tau}, \overline{\nu}_{\mu,\tau}$	28.94	146138	110.90%	162064	
		sze_l0tau	e^-, e^+, τ^-, τ^+	147.28	743781	110.89%	824767	
		sze_sl0dd	e,e,down,down	125.83	635351	110.91%	704648	
		sze_sl0uu	e,e,up,up	190.21	960556	110.89%	1065176	
	single_sznu	sznu_l0mumu	$\nu_e, \overline{\nu}_e, \mu^-, \mu^+$	43.42	219278	110.89%	243152	
		sznu_l0tautau	$\nu_e, \overline{\nu}_e, \tau^-, \tau^+$	14.57	100000	81.59%	81592	
		sznu_sl0nu_down	$\nu_e, \overline{\nu}_e, down, down$	90.03	454649	110.89%	504168	
		sznu_sl0nu_up	$\nu_e, \overline{\nu}_e, up, up$	55.59	280749	110.88%	311304	
zorw	zorw	szeorsw_l0l	$e^-, e^+, \nu_e, \overline{\nu}_e$	249.48	1259867	110.89%	1397088	1397088
ww	ww_h	ww_h0ccbs	cq,cq,bq,sq	5.89	100000	32.84%	32984	50826214
		ww_h0ccds	cq,cq,dq,sq,	170.18	859417	110.89%	953008	
		ww_h0cuxx	cq,uq,down,down	3478.89	17562880	110.93%	19481784	
		ww_h0uubd	uq,uq,bq,dq	0.05	100000	0.28%	280	
		ww_h0uusd	uq,uq,sq,dq	170.45	860029	110.99%	954519	
	ww_l	ww_l0ll	mu, tau, nu_μ, nu_τ	403.66	2036465	111.00%	2260496	
	ww_sl	ww_sl0muq	mu,nu,up,down	2423.43	12238338	110.90%	13571207	
		ww_sl0tauq	tau,nu,up,down	2423.56	12238057	110.90%	13571936	
zz	zz_h	zz_h0cc_nots	cq,cq,(dq,bq),(dq,bq)	98.97	499812	110.89%	554232	6389430
		zz_h0dtdt	down,down,down,down	233.46	1178944	110.89%	1307376	
		zz_h0utut	up,up,up,up	85.68	432679	110.89%	479808	
		zz_h0uu_notd	uq,uq,(sq,bq),(sq,bq)	98.56	496703	111.11%	551936	
	zz_l	zz_l04mu	$\mu^-, \mu^+, \mu^-, \mu^+$	15.56	99902	87.22%	87136	
		zz_l04tau	$\tau^-, \tau^+, \tau^-, \tau^+$	4.61	99901	25.84%	25816	
		zz_l0mumu	$\nu_\tau, \overline{\nu}_\tau, \mu^-, \mu^+$	19.38	99900	108.64%	108528	
		zz_l0taumu	$\tau^-, \tau^+, \mu^-, \mu^+$	18.65	99900	104.54%	104440	
		zz_l0tautau	$\nu_\mu, \overline{\nu}_\mu, \tau^-, \tau^+$	9.61	99900	53.87%	53816	
	zz_sl	zz_sl0mu_down	mu,mu,down,down	136.14	705743	108.80%	762383	
		zz_sl0mu_up	mu,mu,up,up	87.39	448844	109.03%	489383	
		zz_sl0nu_down	$nu_{\mu,\tau}, nu_{\mu,\tau}, down, down$	139.71	708671	110.40%	782376	
		zz_sl0nu_up	$nu_{\mu,\tau}, nu_{\mu,\tau}, up, up$	84.38	429037	110.14%	472528	
		zz_sl0tau_down	tau,tau,down,down	67.31	339928	110.89%	376936	
		zz_sl0tau_up	tau,tau,up,up	41.56	209898	110.88%	232736	
zzorww	zzorww	zzorww_h0cscs	cq,sq,cq,sq	1607.55	8117636	110.90%	9002280	20440840
		zzorww_h0udud	uq,dq,uq,dq	1610.32	7811146	115.45%	9017792	
		zzorww_l0mumu	mu, mu, nu_μ, nu_μ	221.10	1116551	110.89%	1238160	
		zzorww_l0tautau	$tau, tau, nu_\tau, nu_\tau$	211.18	1066451	110.89%	1182608	

Cross section

- CEPC software & Sample generation for CEPC
- Sample generated by Kaili



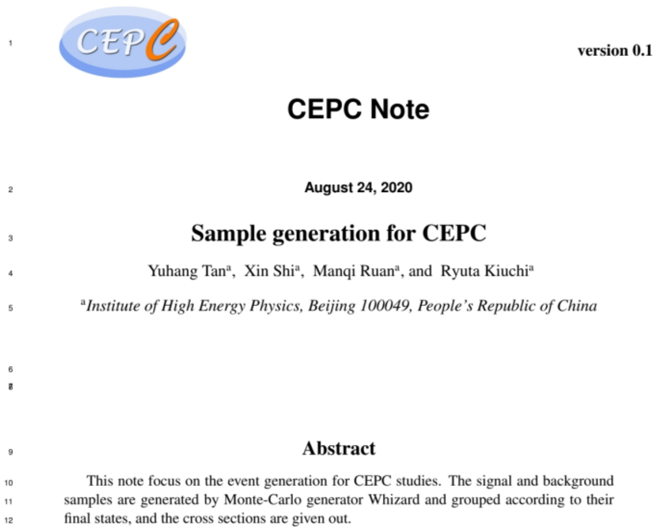
240 GeV

Higgs signal

Process	$\int L$	Final states	X-sections (fb)	Comments
Higgs signal	5 ab^{-1}	ffH	203.66	all signals
	5 ab^{-1}	e^+e^-H	7.04	including ZZ fusion
	5 ab^{-1}	$\mu^+\mu^-H$	6.77	
	5 ab^{-1}	$\tau^+\tau^-H$	6.75	
	5 ab^{-1}	$\nu\bar{\nu}H$	46.29	all neutrinos (ZH+WW fusion)
	5 ab^{-1}	$q\bar{q}H$	136.81	all quark pairs (Z→ $q\bar{q}$)

2 fermion backgounds

Process	$\int L$	Final states	X-sections (fb)	Comments
$e^+e^- \to e^+e^-$	5 ab^{-1}	e^+e^-	24770.90	
$e^+e^- \to \mu^+\mu^-$	5 ab^{-1}	$\mu^+\mu^-$	5332.71	
$e^+e^- \to \tau^+\tau^-$	5 ab^{-1}	$\tau^+\tau^-$	4752.89	
$e^+e^- \to \nu\bar{\nu}$	5 ab^{-1}	$\nu\bar{\nu}$	54099.51	
$e^+e^- \to \nu_e\bar{\nu}_e$	5 ab^{-1}	$\nu_e\bar{\nu}_e$	45390.79	
$e^+e^- \to \nu_\mu\bar{\nu}_\mu$	5 ab^{-1}	$\nu_\mu\bar{\nu}_\mu$	4416.30	
$e^+e^- \to \nu_\tau\bar{\nu}_\tau$	5 ab^{-1}	$\nu_\tau\bar{\nu}_\tau$	4410.26	
$e^+e^- \to q\bar{q}$	5 ab^{-1}	$q\bar{q}$	54106.86	
$e^+e^- \to u\bar{u}$	5 ab^{-1}	$u\bar{u}$	10899.33	
$e^+e^- \to d\bar{d}$	5 ab^{-1}	$d\bar{d}$	10711.01	
$e^+e^- \to c\bar{c}$	5 ab^{-1}	$c\bar{c}$	10862.86	
$e^+e^- \to s\bar{s}$	5 ab^{-1}	$s\bar{s}$	10737.84	



version 0.1

CEPC Note

August 24, 2020

Sample generation for CEPC

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Abstract

This note focus on the event generation for CEPC studies. The signal and background samples are generated by Monte-Carlo generator Whizard and grouped according to their final states, and the cross sections are given out.

Bhabha cross section from generator

- From babayaga， remove energy cut， add theta cut [8, 172]
  - Higgs: ~1000 pb， ~ 100Hz; Z: 6593pb， ~ 2kHz
- From Whizard：
  - Higgs: 743 pb; Z: 13147pb， ~ 6kHz
- BesIII bhabha from babayaga： 800Hz, 800nb

Bhabha cross section from theory paper

- Large-angle Bhabha scattering, Link
  - 10<θ<170（CEPC: 8-172）
  - Z pole: ~6000pb=6nb，close to babayaga result

- Naive calculation:
  - σ~1/CoM^2
  - ZH pole bhabha xsec = Z pole bhabha xsec *91GeV*91GeV/240GeV/240GeV
  - =Z pole bhabha xsec（~6nb）*0.144~0.9nb

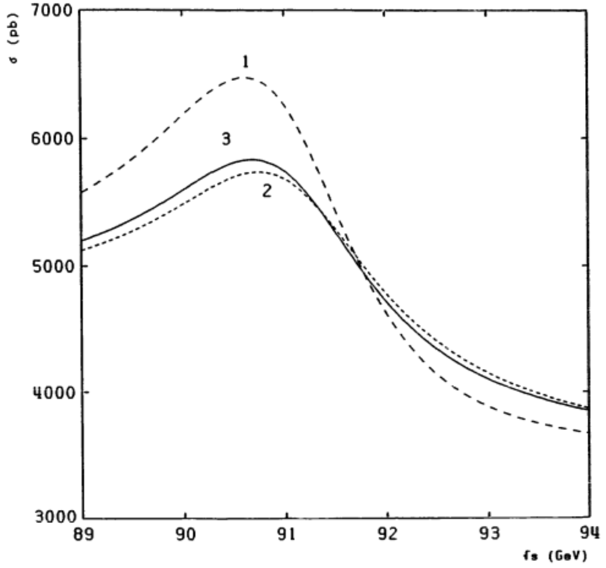
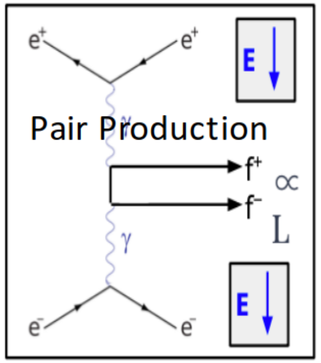


Fig. 3. The total cross section as a function of the energy, using an angular cut of 10° and an energy cut of 10 GeV. The conventions a.e the same as in fig. 2.

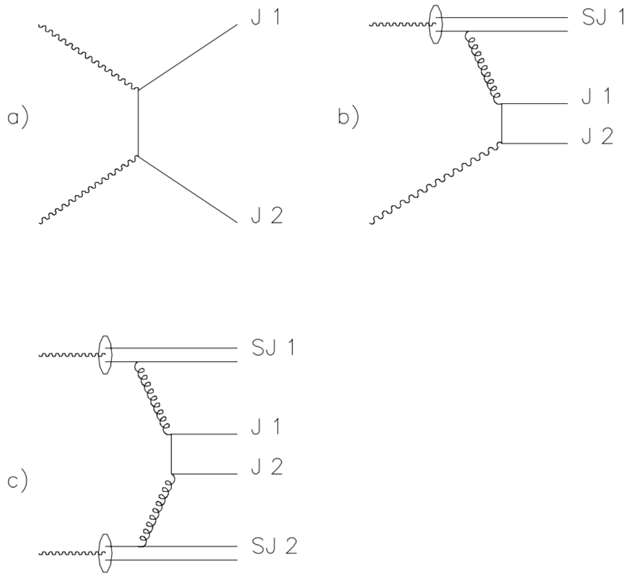
$$\frac{d\sigma}{d(\cos\theta)} = \frac{\pi\alpha^2}{s}\left(u^2\left(\frac{1}{s}+\frac{1}{t}\right)^2 + \left(\frac{t}{s}\right)^2 + \left(\frac{s}{t}\right)^2\right)$$

Di-photon from Guinea-Pig

- Beam background： electron pair production(ɣɣ→ee)
  - Generated using GUINEA-PIG by Haoyu
  - For higgs mode: ~1000 collision for one BX
- Hadron final state(ɣɣ→qq) using GUINEA-PIG：
  - Total hadron final state: 2 kHz, 25 nb
  - Minijet (ɣɣ→jj): 33 Hz, 413 pb (pT>2GeV)



Photon BG



Di-photon paper 1

- Top: di-photon cross section vs energy
- Bottom left: di-photon energy distribution, theory calculation by prof.代建平
- Integrate to get the final cross section:
  - From 0.1GeV to 200GeV
    - Higgs: 850pb (68Hz)
    - Z: 917pb
  - From 0.01GeV to 200GeV
    - Higgs: 4150pb (~300Hz)
    - Z: 4560pb;

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Study of beamstrahlung effects at CEPC*

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Abstract: The discovery of a 125 GeV Higgs boson at the LHC marked a breakthrough in particle physics. The relative lightness of the new particle has inspired consideration of a high-luminosity Circular Electron Positron Collider (CEPC) as a Higgs Factory to study the particle's properties in an extremely clean environment. Given the high luminosity and high energy of the CEPC, beamstrahlung is one of the most important sources of beam-induced background that might degrade the detector performance. It can introduce even more background to the detector through the consequent electron-positron pair production and hadronic event generation. In this paper, beamstrahlung-induced backgrounds are estimated with both analytical methods and Monte Carlo simulation. Hit density due to detector backgrounds at the first vertex detector layer is found to be ~0.2 hits/cm^2 per bunch crossing, resulting in a low detector occupancy below 0.5%. Non-ionizing energy loss (NIEL) and total ionizing dose (TID), representing the radiation damage effects, are estimated to be ~10^{11} 1 MeV n_{eq}/cm^2/yr and ~300 kRad/yr, respectively.

Keywords: CEPC, beamstrahlung, pair production, detector backgrounds, radiation damage

PACS: 29.20.db, 29.27.-a, 25.20.Lj **DOI:** 10.1088/1674-1137/40/5/053001

1 Introduction

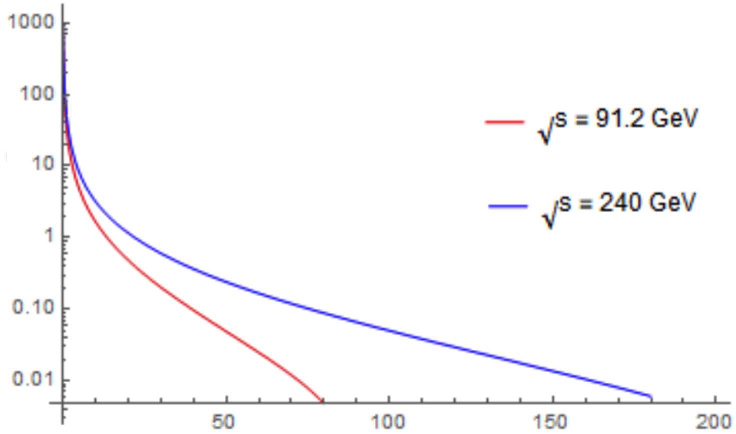
opposite charge inside the crossing bunch. During this process, a particular kind of synchrotron radiation, called

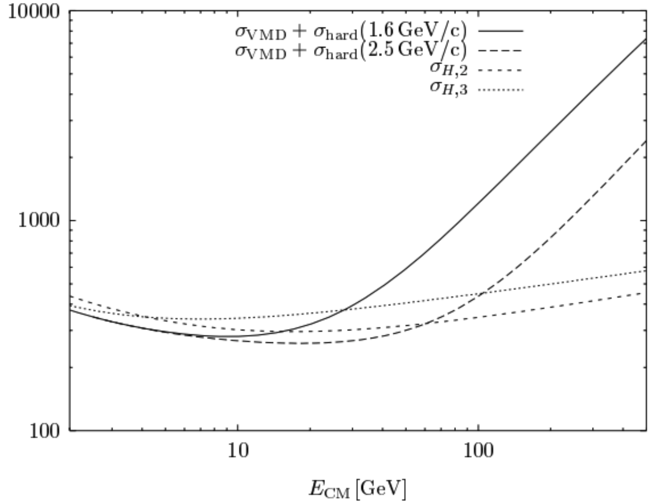
2.3 Hadronic backgrounds

In addition to electron-positron pairs, two colliding photons can also produce hadrons. The cross section of the hadronic process, in units of nb, can be parameterised as [14]:

$$\sigma_{\rm H} = 211\left(\frac{s}{\rm GeV^2}\right)^{0.0808} + 297\left(\frac{s}{\rm GeV^2}\right)^{-0.4525} \quad (5)$$

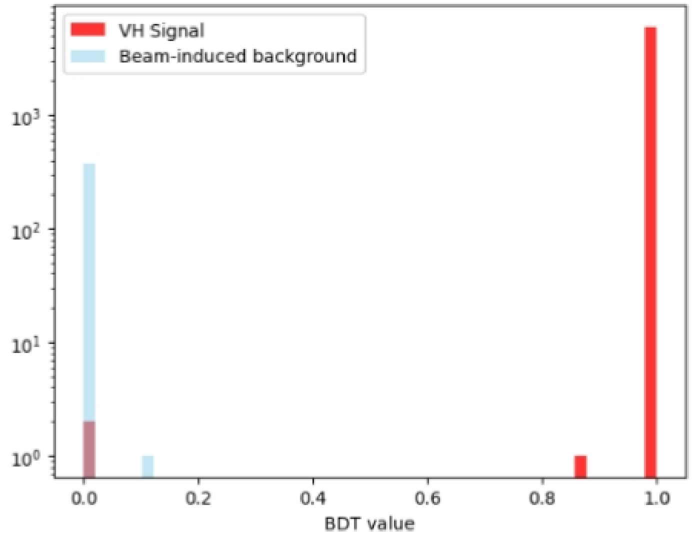
where s is the square of the center-of-mass energy of the two colliding photons. The number of hadronic events produced in each bunch crossing at CEPC will be very small. A small fraction of the events could contain final state particles of high transverse momenta and have a potential impact on the calorimeter detector performance.

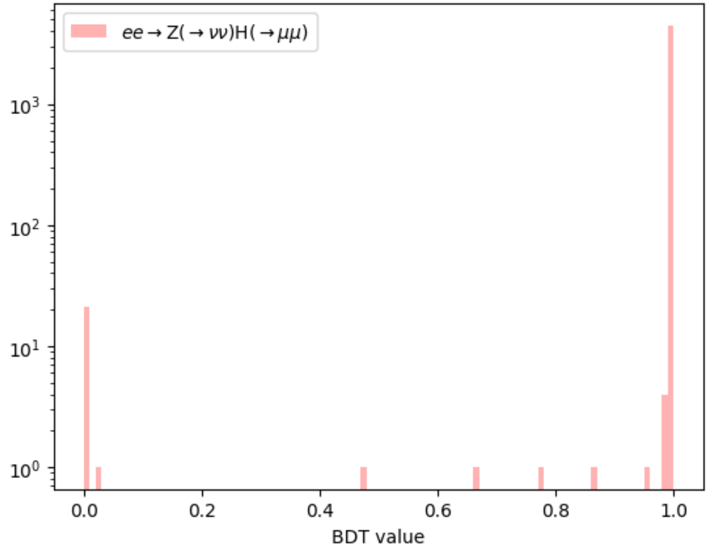




Boost Decision Tree

- Choose two leading energy supercells for Ecal/Hcal; Barrel/Endcap
  - Totally 8 values(input features)
  - Signal: Z(νν)H(γγ, γZ, bb, ττ , WW, and ZZ)
  - n estimators=20, learning rate=1.0, max depth=3
  - Background: 2000 beam background events
  - Signal: 5000 for each process
  - 80% for training, 20 for validation
  - Total signal efficiency: 99.97%; background efficiency: <0.1%
  - Z(νν)H(μμ) efficiency: 99.45%

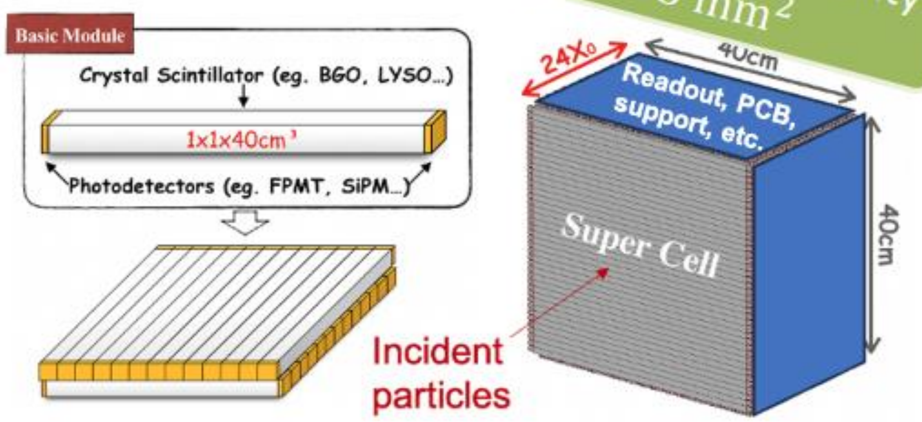




Crystal ECAL option compatible with PFA

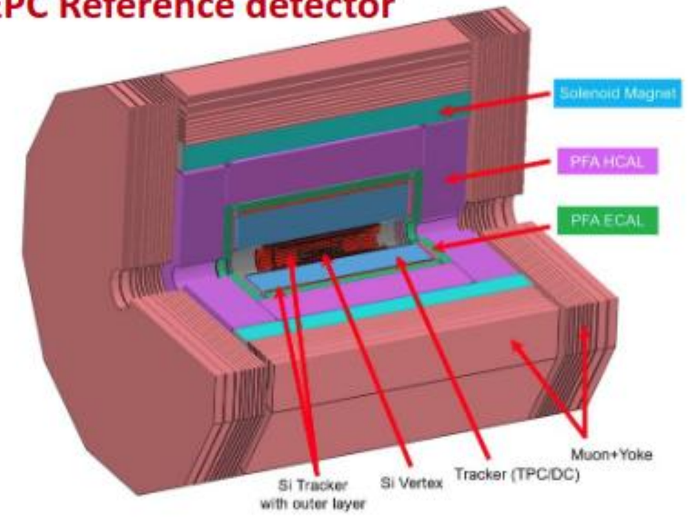
Updated: crystal granularity of 15×15 mm^2

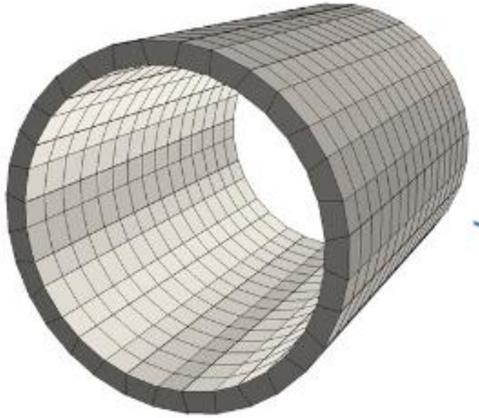
- A new option: R&D activities started since ~2020
- Compatible for PFA: Boson mass resolution (BMR) < 4%
- Optimal EM performance: $\sigma_E/E < 3\%/\sqrt{E}$
- Minimal longitudinal dead material: orthogonal arranged bars
  - 3D positioning with two-sided readout for timing



CEPC Electromagnetic Calorimeter

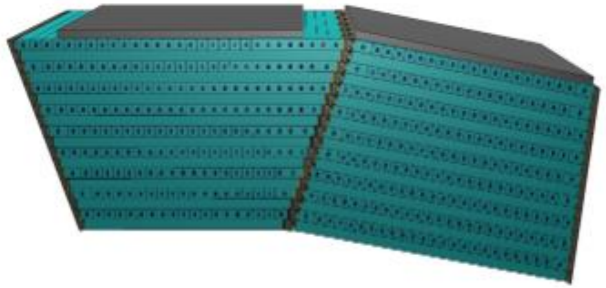
CEPC Reference detector

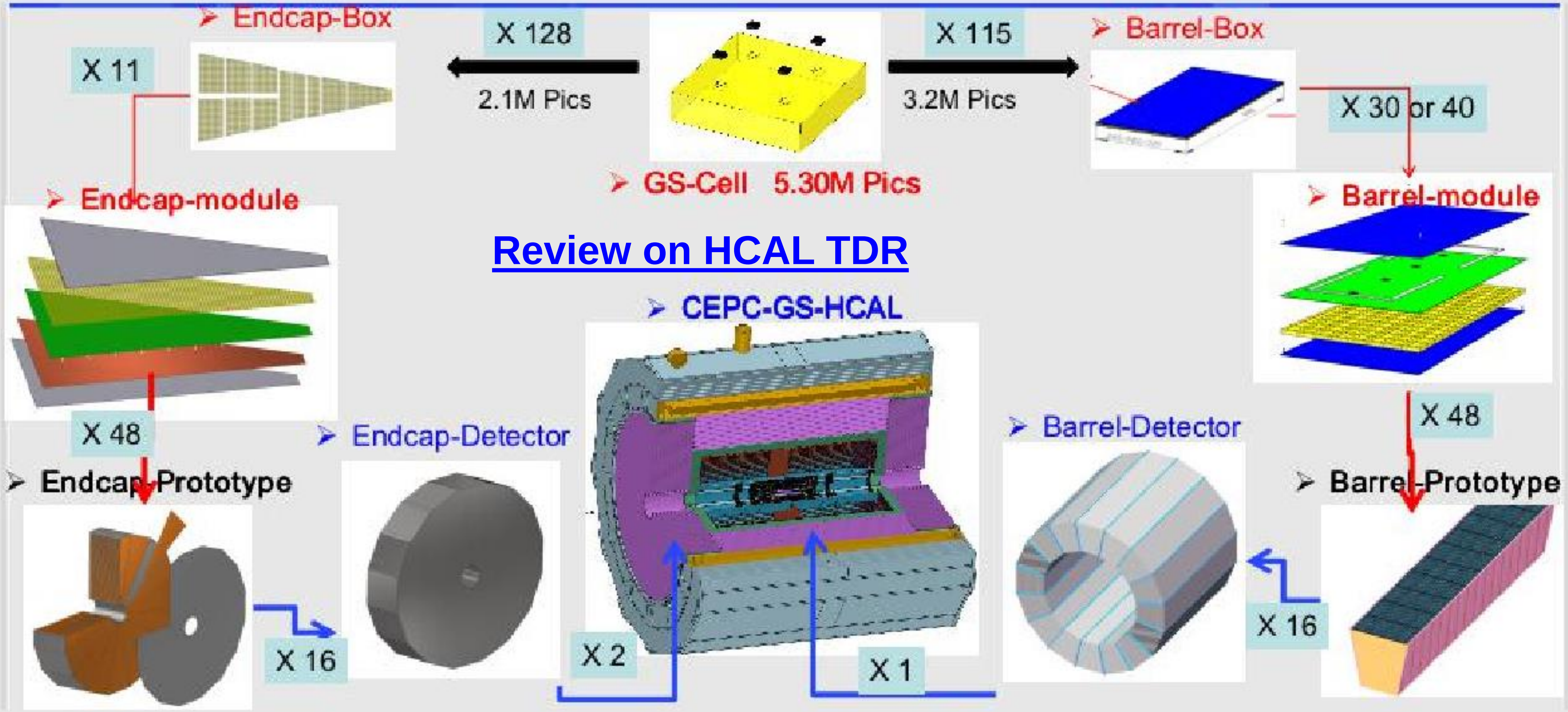




- Total depth of 24 X_0 with 18 longitudinal layers
- Modularity: 32-sided polygons in azimuthal angle

- BGO bars in $1.5\times1.5\times\sim40$ cm^3
- Effective granularity 1.5×1.5 cm^2
- Modules with cracks not pointing to IP (with an inclined angle of 12 degrees)




Endcap-Box
X 128
X 115
Barrel-Box
X 11
2.1M Pics
3.2M Pics
X 30 or 40
GS-Cell 5.30M Pics
Endcap-module
Barrel-module
Review on HCAL TDR
CEPC-GS-HCAL
X 48
Endcap-Detector
Barrel-Detector
X 48
Endcap-Prototype
Barrel-Prototype
X 16
X 16
X 2
X 1