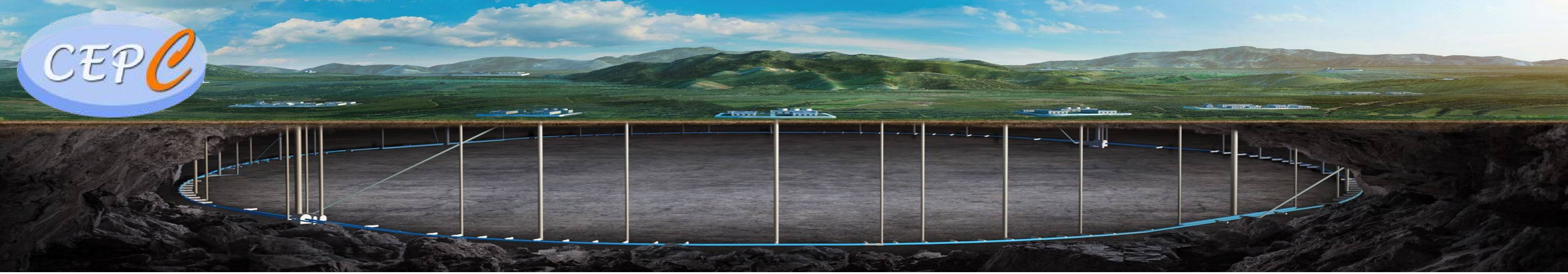

Trigger simulation and algorithm for cepc reference detector

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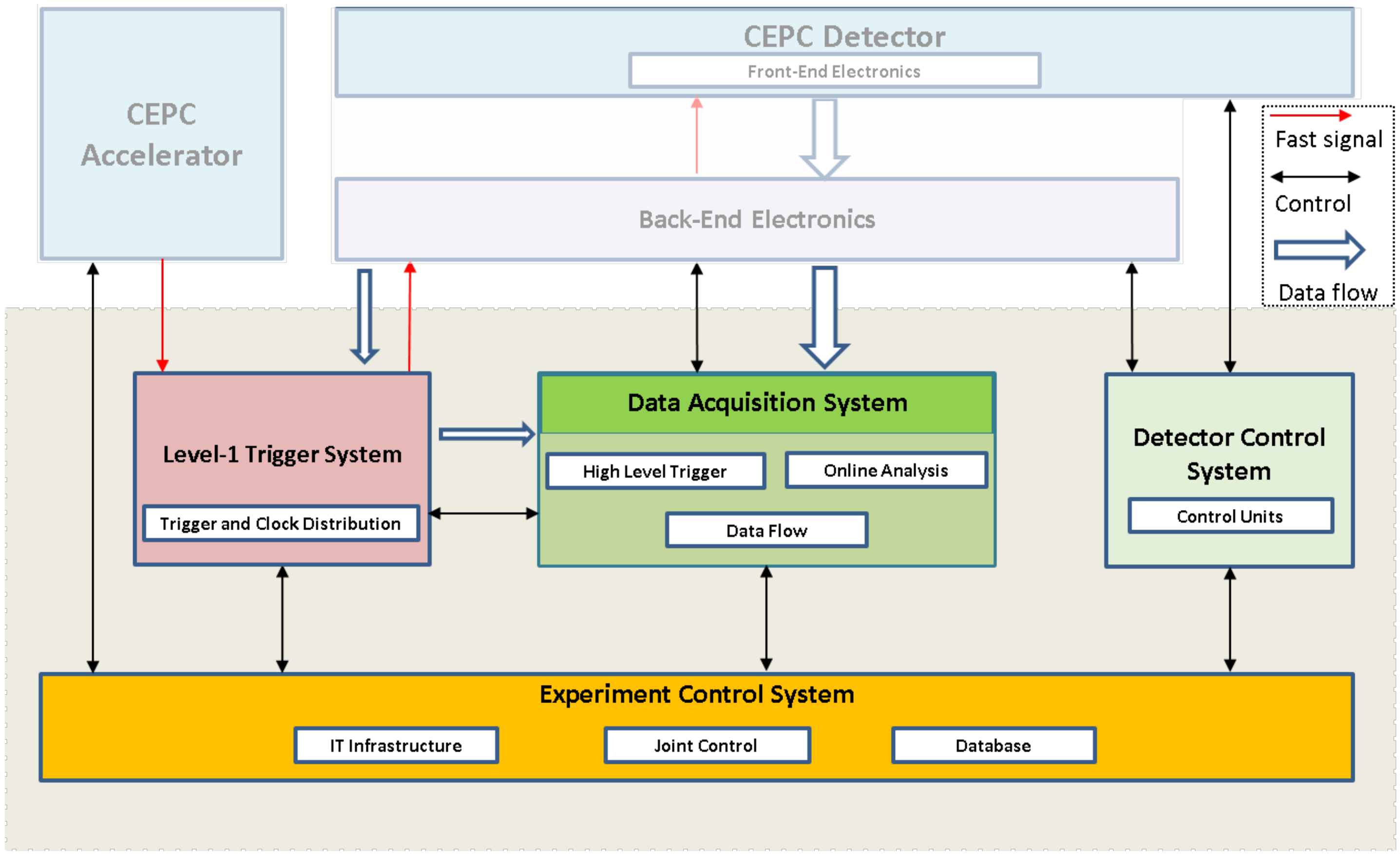
Outline

- Introduction
- MC Simulation
  - Physics requirement
  - Detection response
- Trigger Algorithm
- Efficiency Performance
- Summary and outlook

Introduction

- TDAQ overall design:
  - Level 1 hardware trigger(L1) + High level trigger(HLT)
  - Provide both normal and fast trigger menu
  - L1: Calorimeter+Muon+(Tracker?)
  - HLT: Full detector information



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: relatively high rate
- Generated by BesTwoGam(only for Di-photon), 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

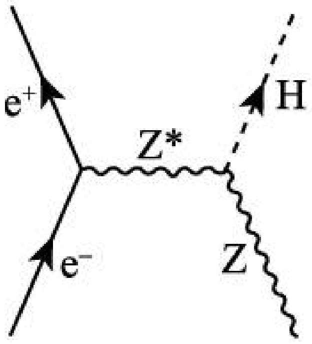
Table 12.3: Expected event rate at the Z mode for 10 MW

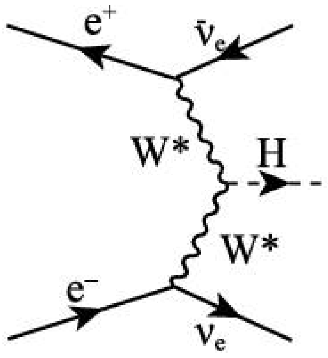
Processes	Cross section (fb)	Event rate (Hz)
qq	31×10^6	7970
$\mu\mu$	1.5×10^6	400
$\tau\tau$	1.5×10^6	396
Bhabha	6.6×10^6	1714
$\gamma\gamma \to bb$	2.8×10^5	73
$\gamma\gamma \to cc$	5.1×10^5	132
$\gamma\gamma \to qq$	34.7×10^6	9011

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

Signal MC simulation: ee→ZH





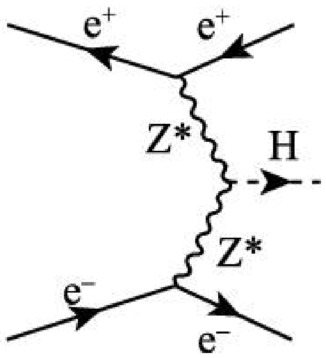
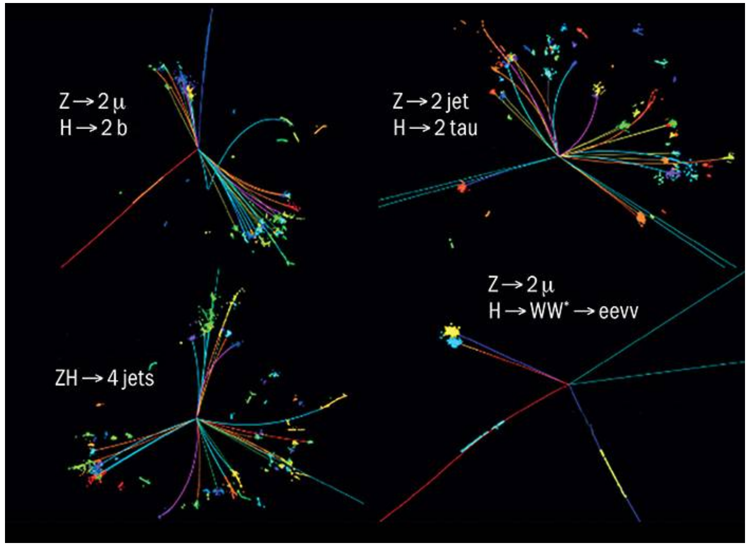


Table 11.3: The branching ratios and the relative uncertainty for a SM Higgs boson with $m_H = 125\,\text{GeV}$ [39, 40].

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%

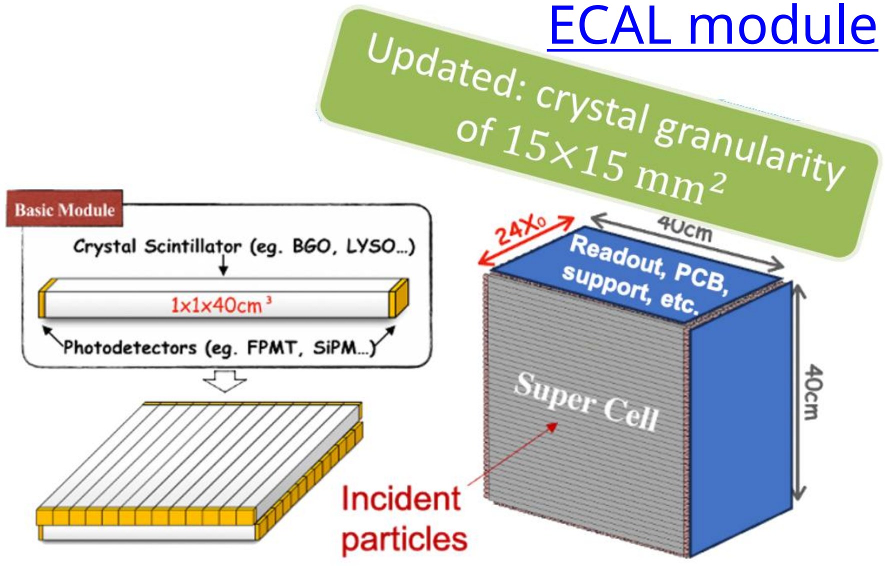
- ZH sample presented in this talk
  - Z→νν
  - H→bb, WW, ττ, ZZ, γγ, Zγ, μμ
    - Final state: jet, photon, and muon
    - bb, γγ and μμ will be shown as example
  - 5000 events for each process



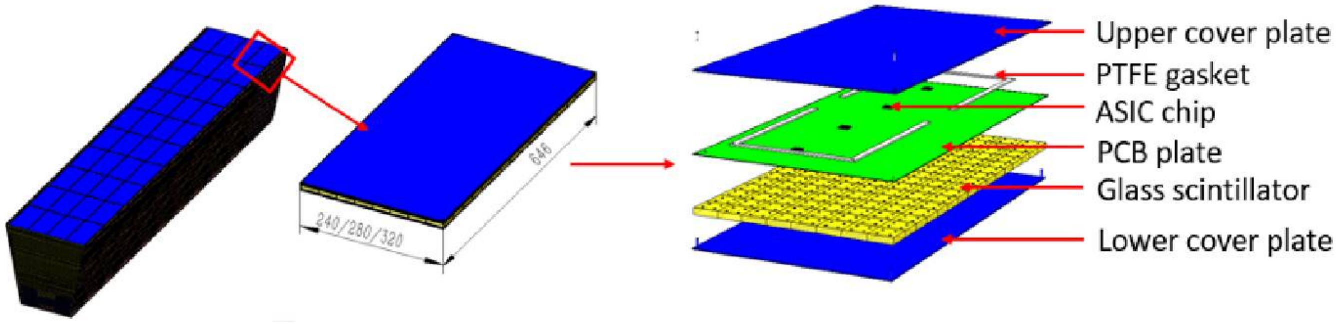
Calorimeter module

- 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
- Basic module for HCal: Barrel-Box(240/280/320 x 646mm^2)
  - Combine two in ϕ and split into two in Z
  - 20(Z)x32(ϕ) in Z-ϕ plane

ECAL module

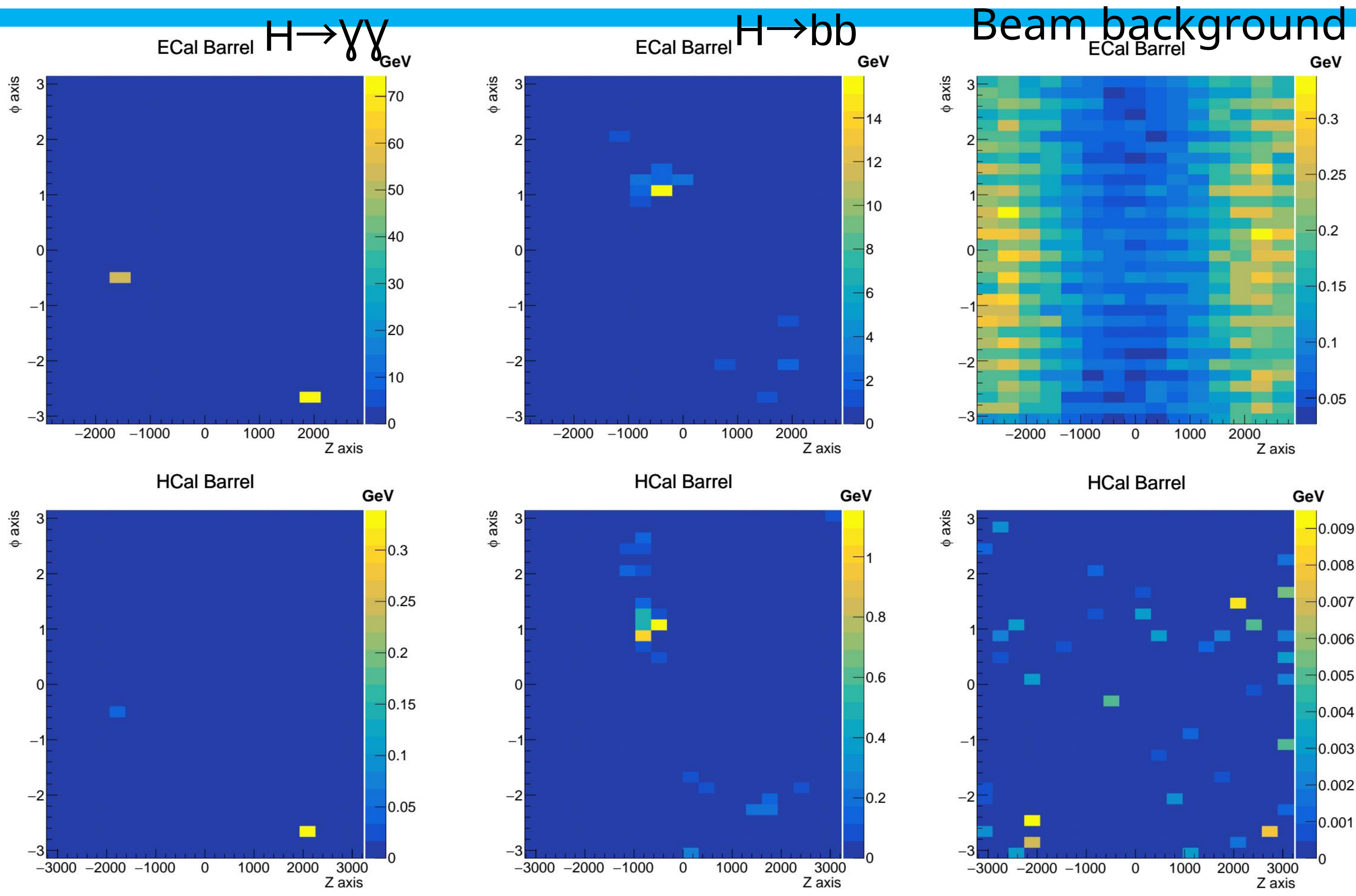


HCAL module



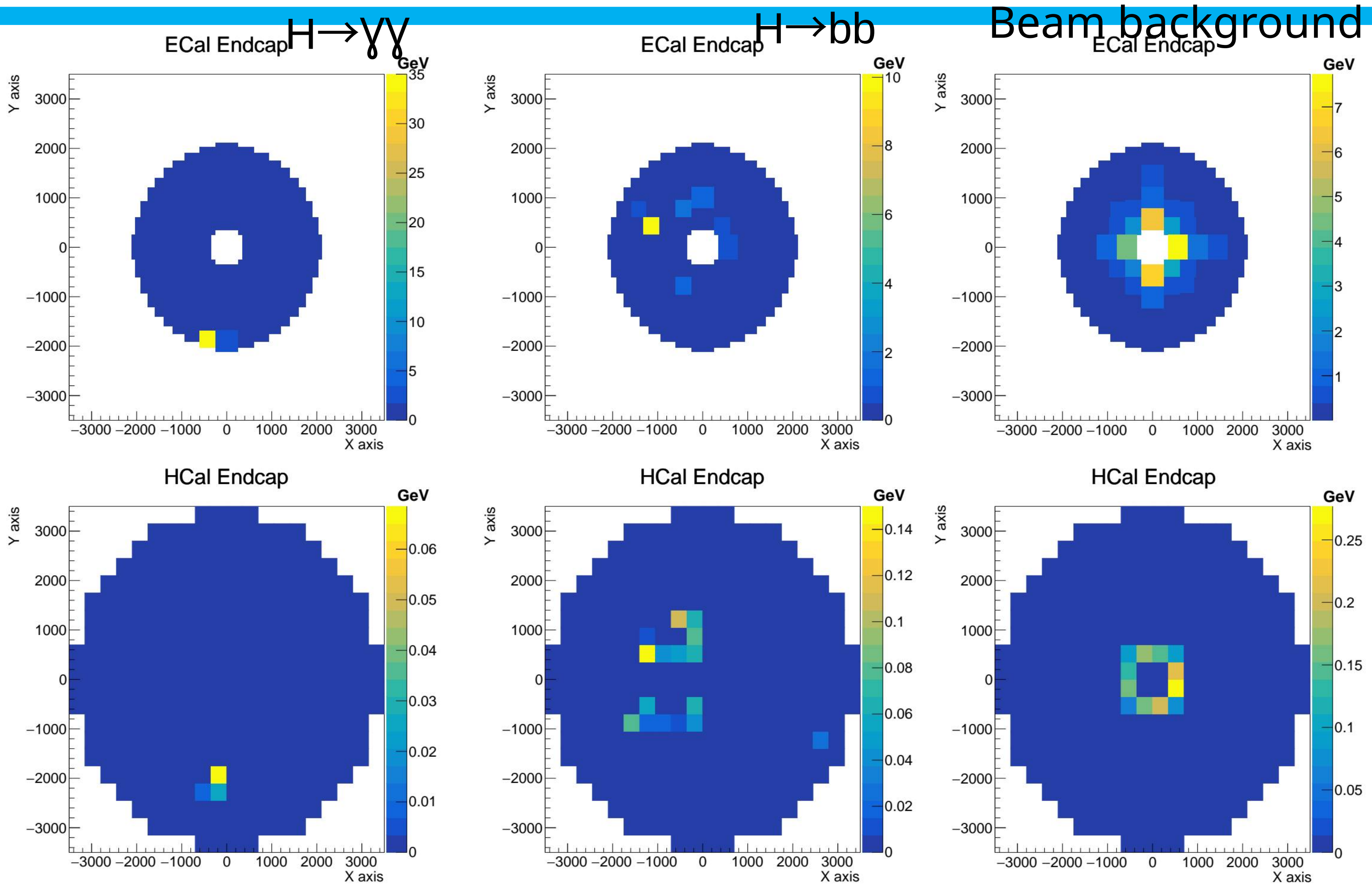
Barrel supercell energy distribution

- Large energy deposition(>10GeV) for signal(H→ɣɣ, 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

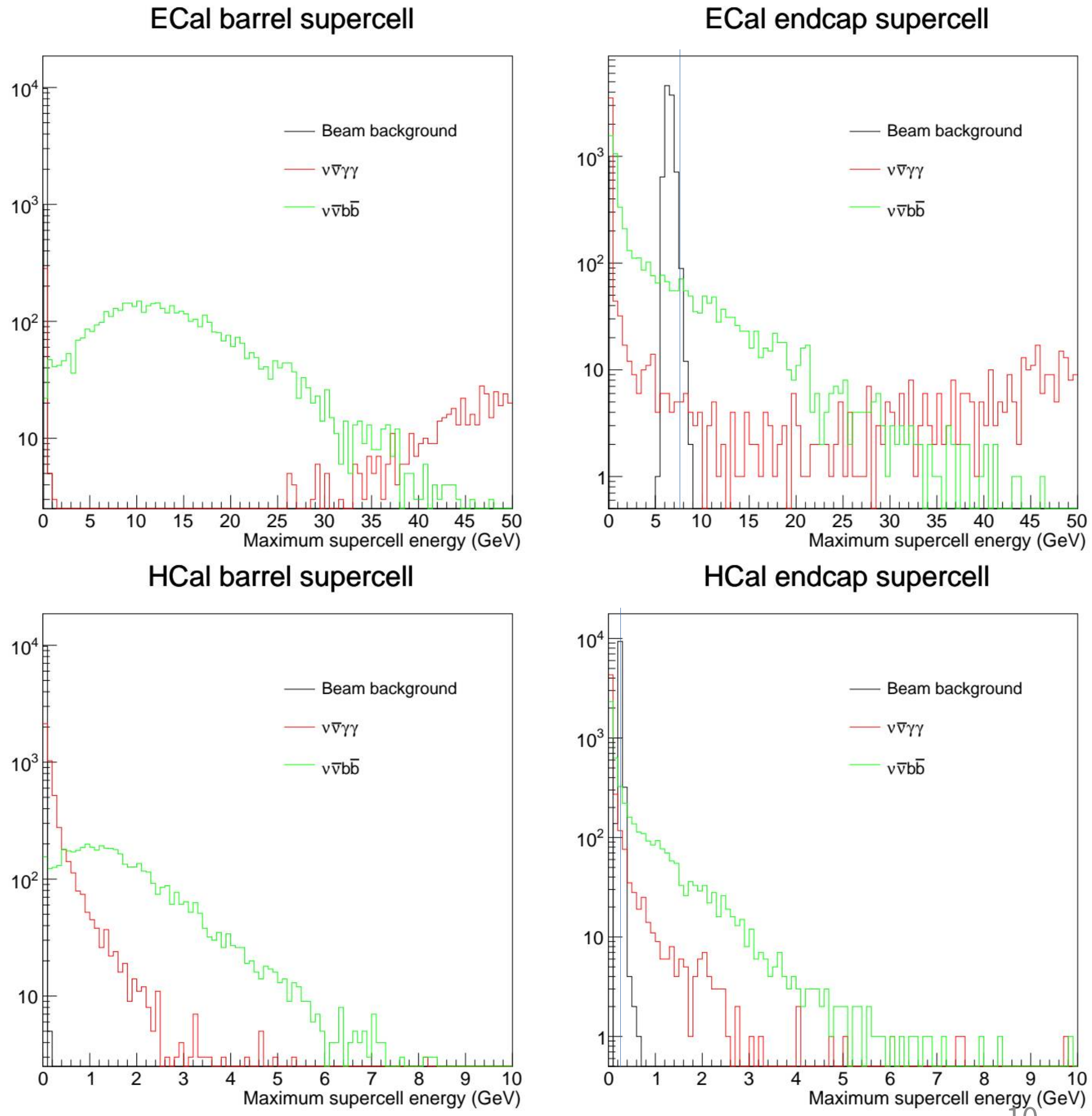
- Similar to barrel for signal
- Relatively large energy deposition(~5GeV) for beam background



Maximum energy distribution

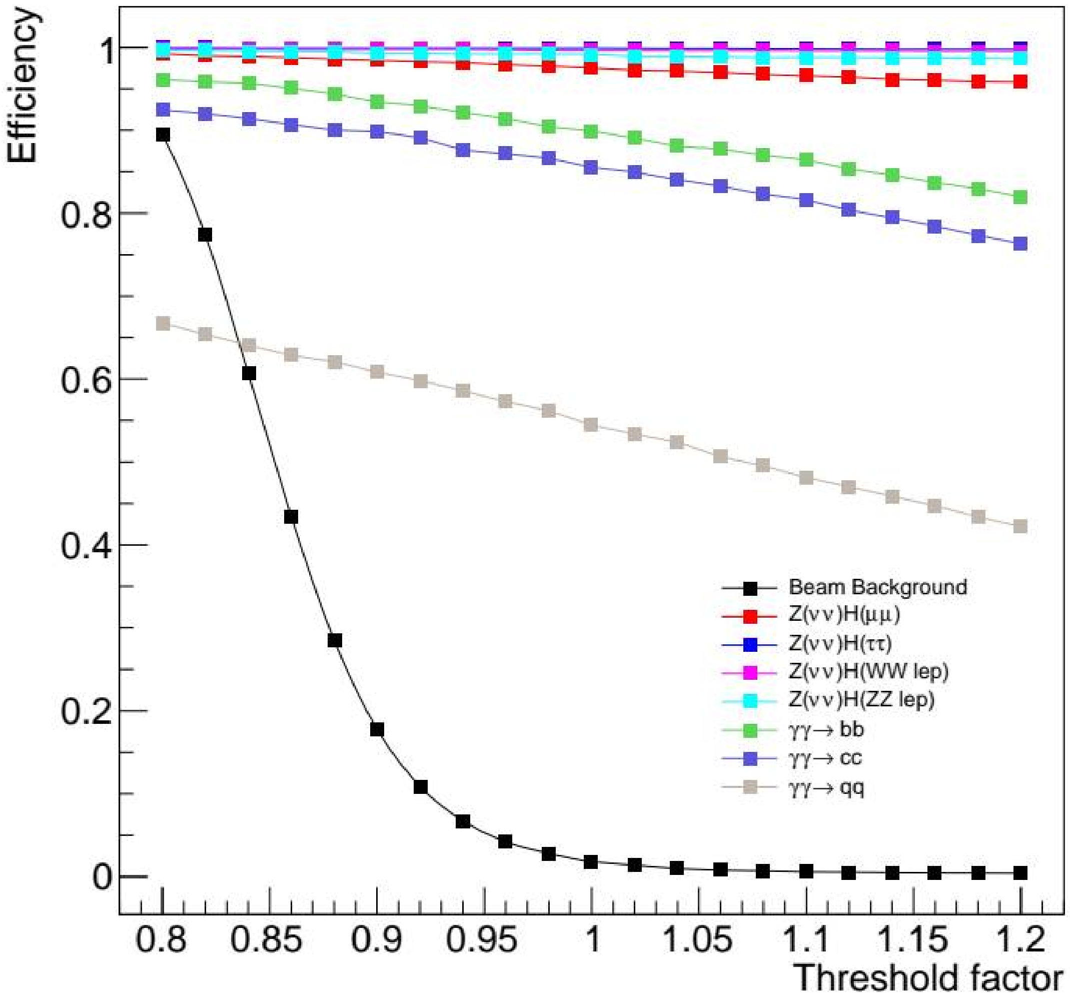
- Maximum energy for each sub-detector
- Beam induced background contributes little(<1GeV) on calorimeter, except ECal Endcap
- A baseline set of energy threshold
  - Background efficiency is less than 0.5% when any single threshold is used alone
  - A blue line shows the value for Endcap

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



Efficiency for baseline threshold

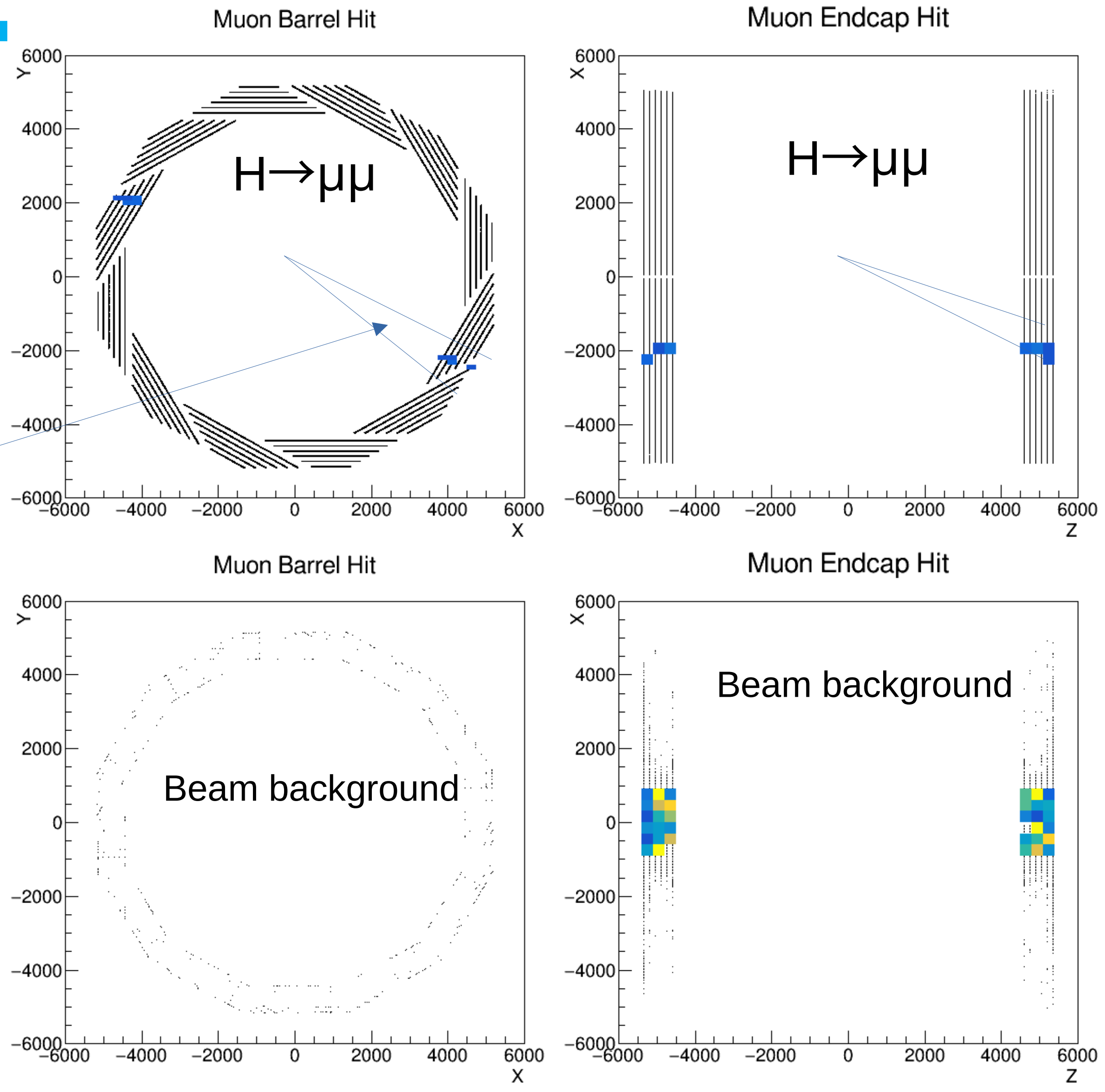
- For most of the signal events, efficiency > 0.99
- μμ too forward
  - Efficiency up to 0.935 if at least one muon inside calorimeter
- Three 4-fermions contain only neutrinos and muon at final state
  - Neutrinos energy > 200GeV

Table 12.8: Calorimeter threshold efficiency at the ZH mode for 50 MW

Process	Efficiency	Process	Efficiency	Process	Efficiency
Two Fermions					
Bhabha	0.998	$\mu^+\mu^-$	0.852	$\tau^+\tau^-$	0.958
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
Four Fermions					
sw_l0mu	0.997	sw_l0tau	>0.999	sw_sl	>0.999
sze_l0e	>0.999	sze_l0mu	0.877	sze_l0nunu	0.998
sze_l0tau	0.994	sze_sl	>0.999	szeorsw_l	>0.999
sznu_l0mumu	0.621	sznu_l0tautau	0.933	ww_h0ccbs	>0.999
ww_l	0.988	ww_sl0muq	>0.999	ww_sl0tauq	>0.999
wwbosons	>0.999	zz_h0dtdt	>0.999	zz_l04mu	0.900
zz_l04tau	0.988	zz_l0mumu	0.658	zz_l0taumu	0.971
zz_l0tautau	0.950	zz_sl0mu_down	>0.999	zz_sl0mu_up	>0.999
zz_sl0nu_down	>0.999	zz_sl0nu_up	>0.999	zz_sl0tau_down	>0.999
zz_sl0tau_up	0.998	zzbosons	0.958	zzorww_h0cscs	>0.999
zzorww_l0mumu	0.925	zzorww_l0tautau	0.992		
Di-photon process					
$\gamma\gamma \to b\bar{b}$	0.888	$\gamma\gamma \to c\bar{c}$	0.846	$\gamma\gamma \to q\bar{q}$	0.533
Background	**Veto rate**				
Beam Background	0.982				

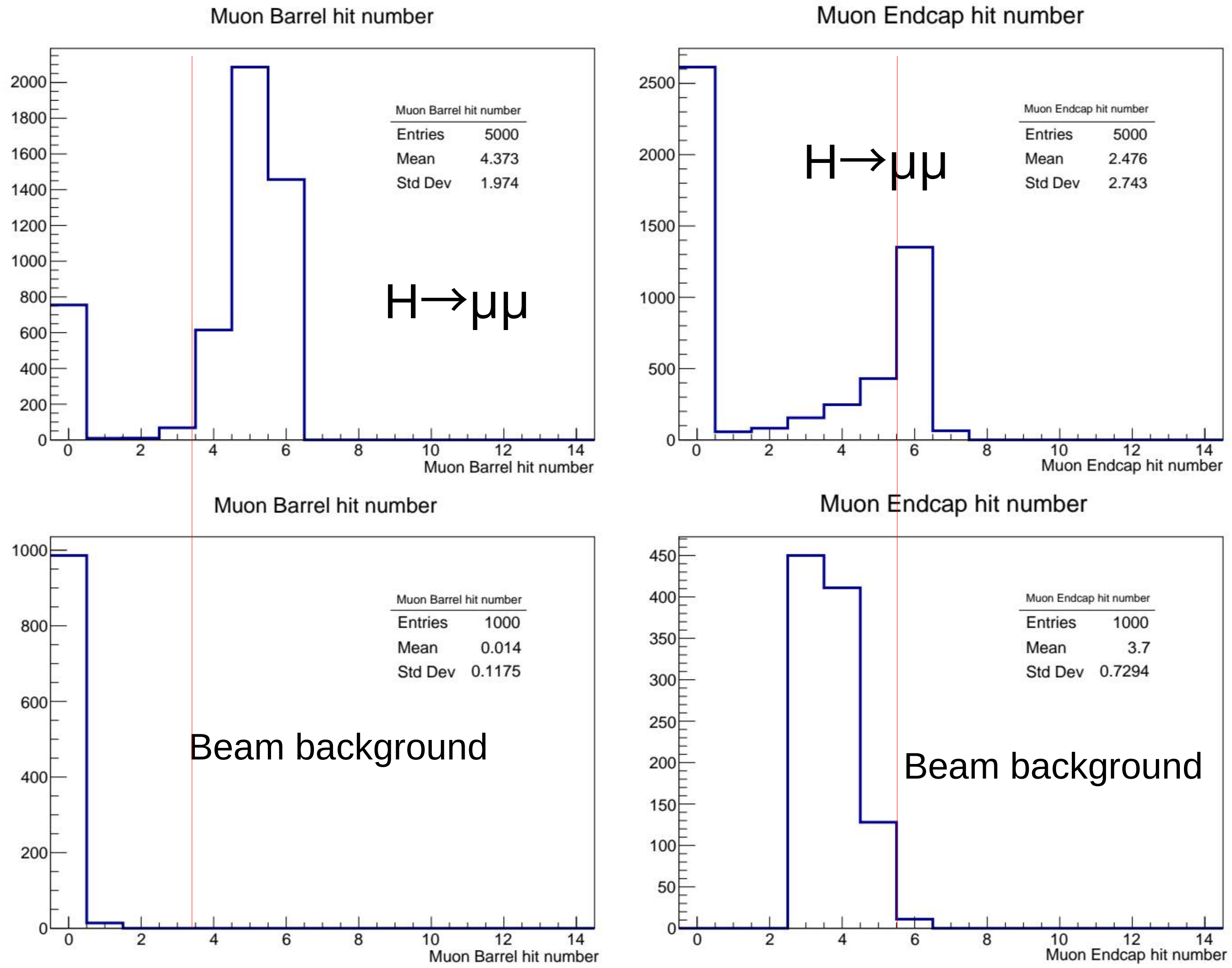
Muon detector

- 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: dR<0.007



Number of hit

- Red line: baseline cut for the number of hit
    - Barrel > 3
    - Endcap > 5
- Background efficiency: 0.0119
- H→μμ efficiency: 0.9648

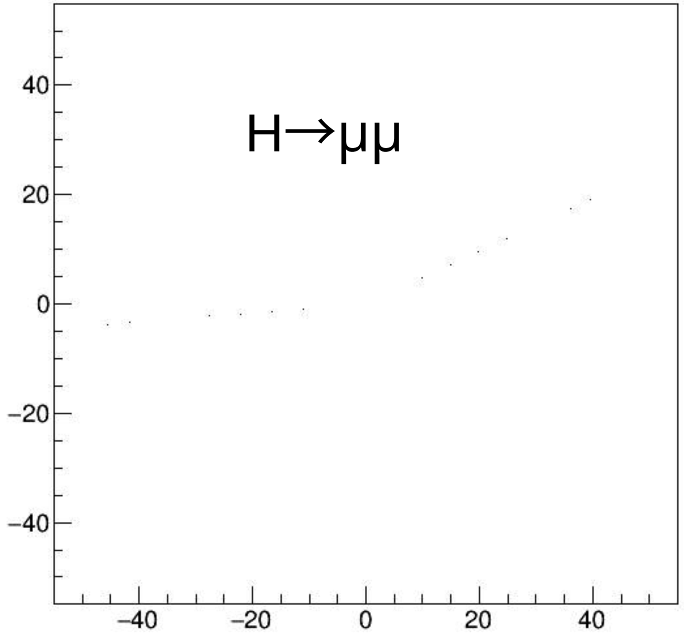


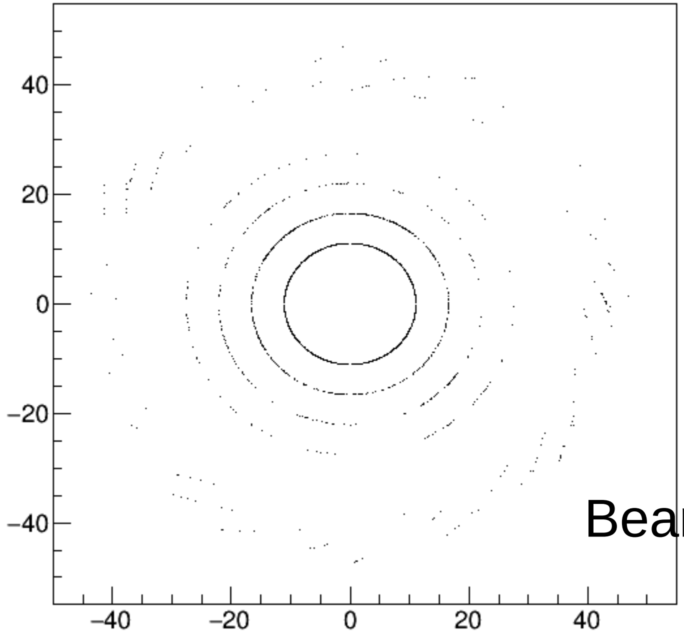
Combine efficiency

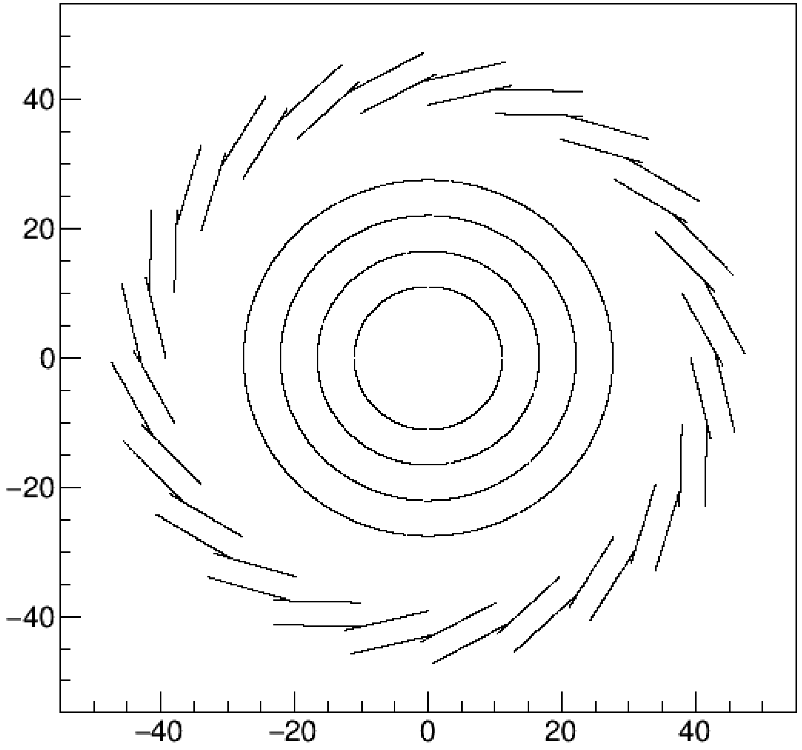
- $Z(\nu\nu)H(\mu\mu)$: Combine: 0.994; Calo: 0.979; Muon: 0.965
- $ee\rightarrow\mu\mu$: Combine: 0.96; Calo: 0.935; Muon: 0.854
- Beam bkg: Combine: 0.030; Calo: 0.019; Muon: 0.012

Tracker: Vertex

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



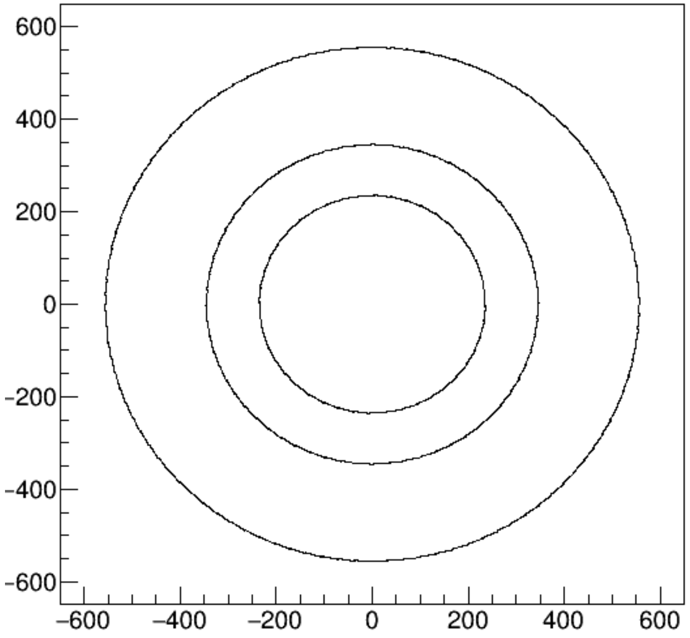


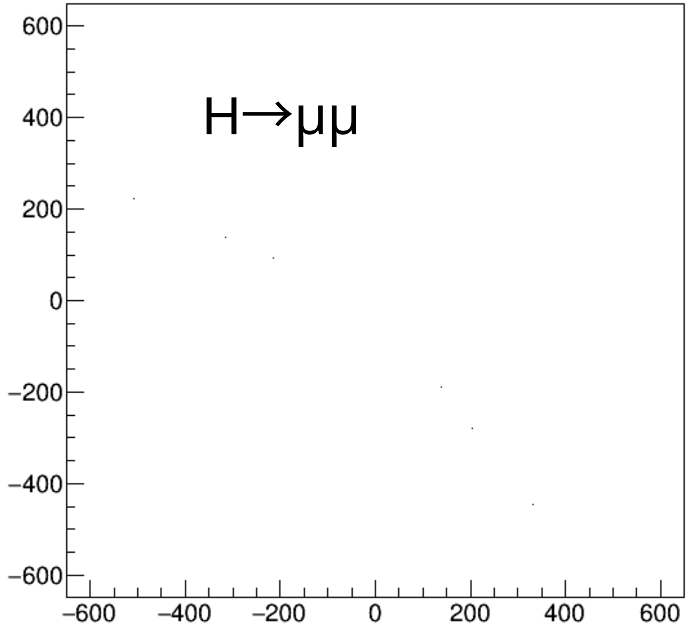


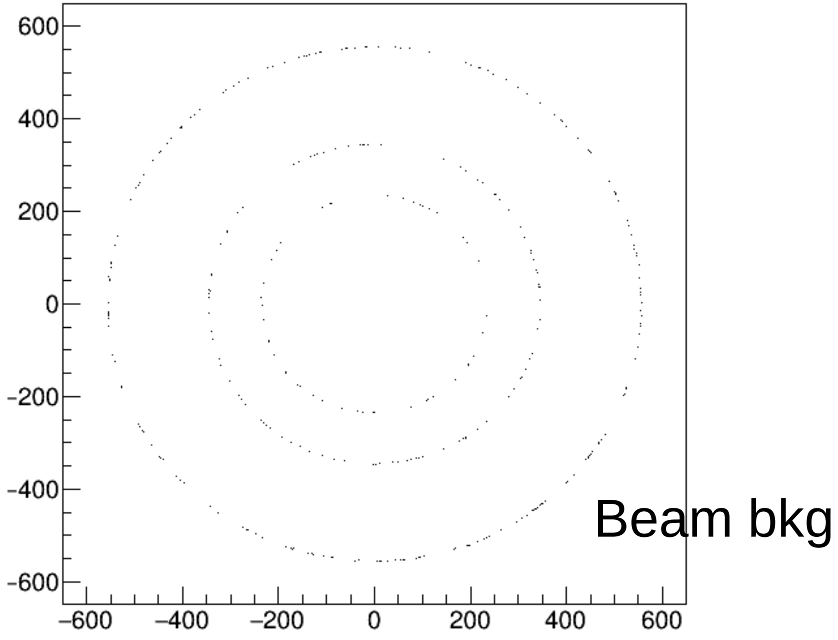
Beam bkg

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

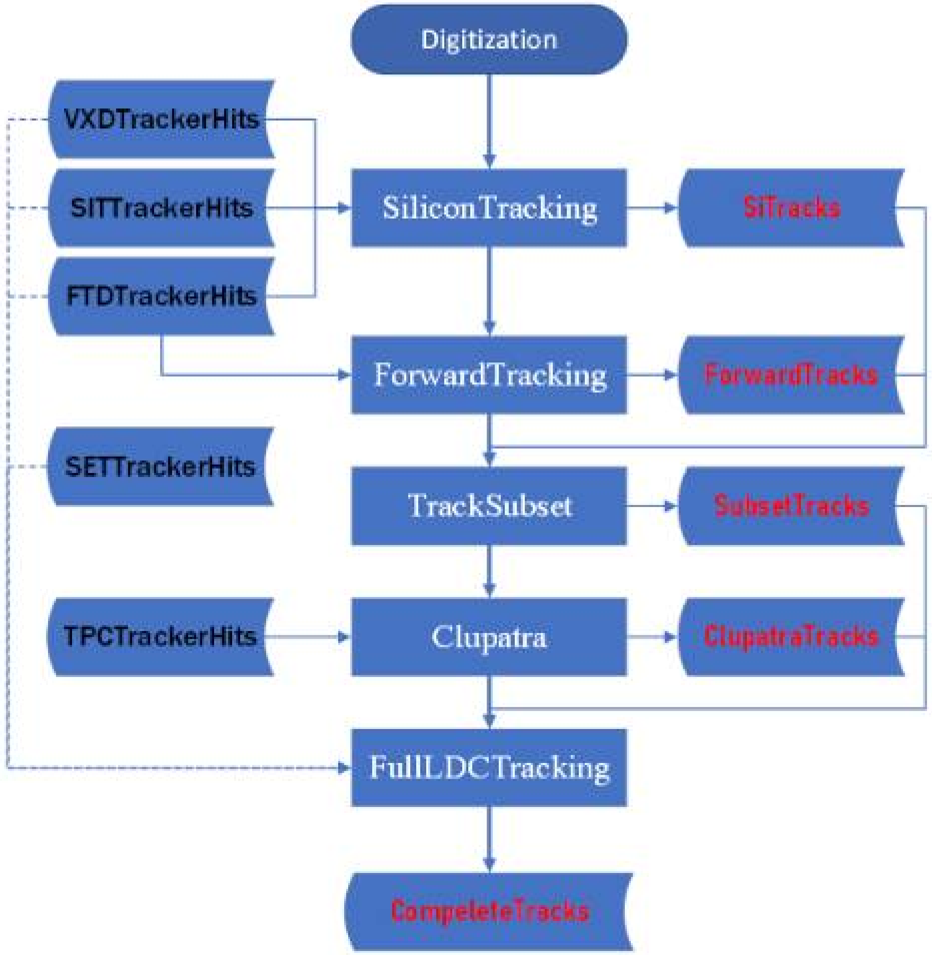






Software trigger

- Offline track reconstruction
- Build “CompleteTracks” from all tracking subdetector
- Beam background:
  - ~1s / event for both ZH and Z mode
  - Efficiency: ~20%(N track > 0)



Summary and Outlook

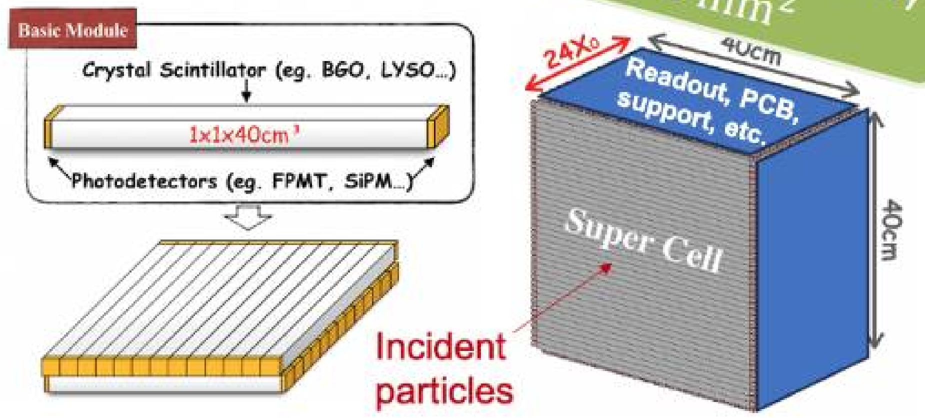
- Trigger simulation & algorithm results are shown in this talk
  - L1: use Calorimeter&Muon(Track to be studied)
  - HLT: apply offline track reconstruction algorithm

- Future:
  - Detail calorimeter cluster algorithm: radius/depth/location/CoM…
  - Tracking algorithm for L1
  - ML(BDT, DNN, CNN…)
  - Optimize different sets of threshold
  - Detector noise
  - …

Crystal ECAL option compatible with PFA

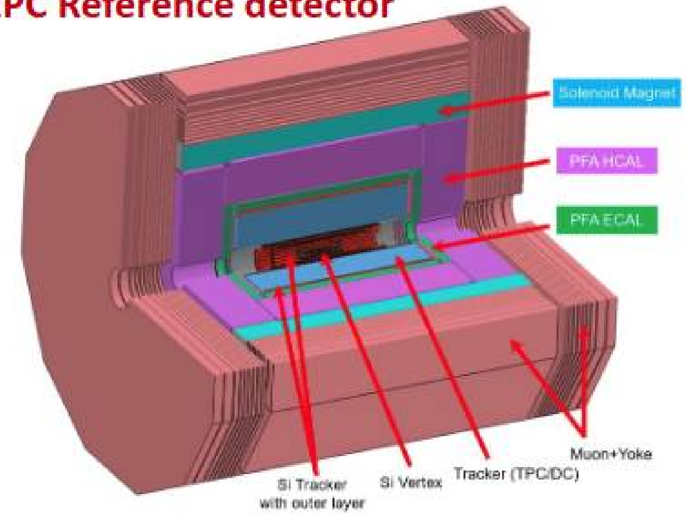
Updated: crystal granularity of 15×15 mm^2

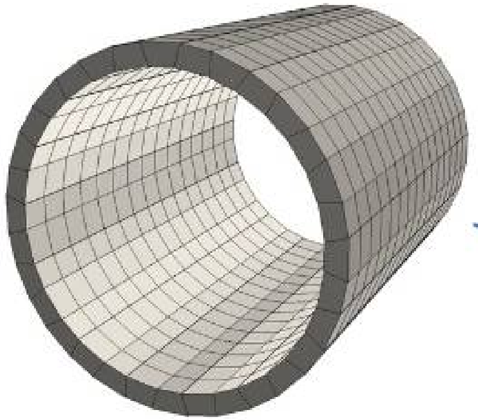
- A new option: R&D activities started since ~2020
- Compatible for PFA: Boson mass resolution (BMR) < 4%
- Optimal EM performance: $\sigma_E/E < 3\%/\sqrt{E}$
- Minimal longitudinal dead material: orthogonal arranged bars
  - 3D positioning with two-sided readout for timing



CEPC Electromagnetic Calorimeter

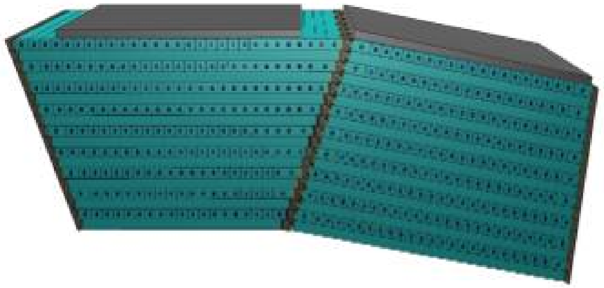
CEPC Reference detector

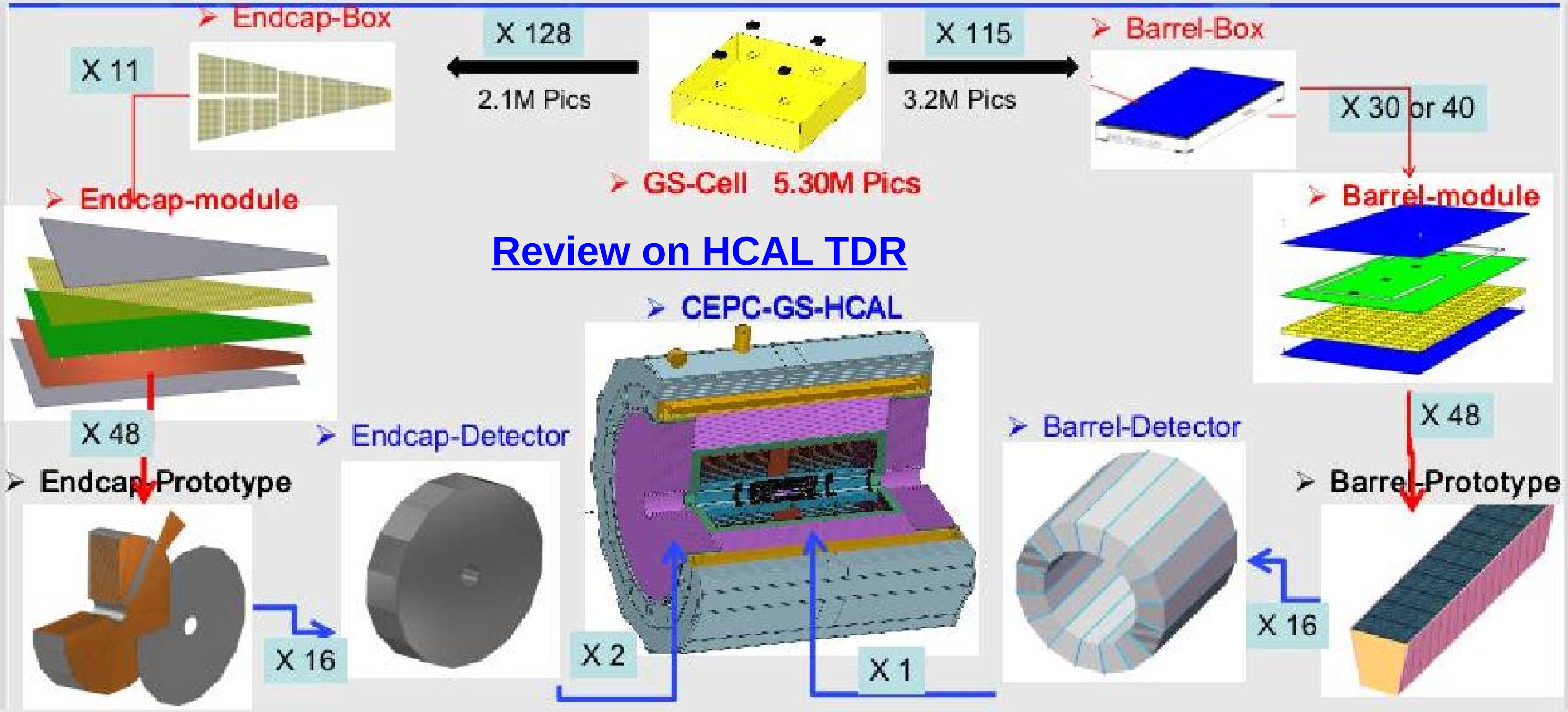




- Total depth of 24 X_0 with 18 longitudinal layers
- Modularity: 32-sided polygons in azimuthal angle

- 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)





[Review on HCAL TDR](#)