Occupancy and Bandwidth requirements for the SiW-ECAL at 91.2 and 240 GeV

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ILD meeting
near the 3rd ECFA WS,
Paris, 08/10/24

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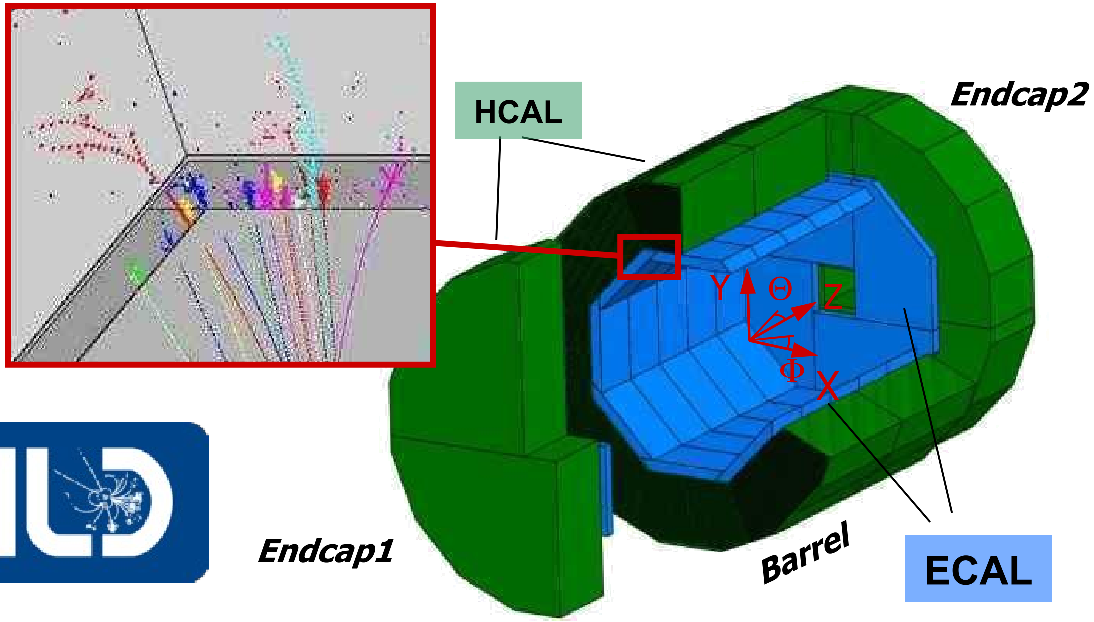
NUCLÉAIRE & PARTICULES

Rationale

ILD high granularity calorimeters

- Designed for ILC
  - Power pulsing, low occupancy
- Marginally adapted for CLIC and CLD
  - Physics : number of layers
- Partially adapted for CEPC
  - Lower granularity
- Needs strong adaptation for EW physics and continuous operation
  - Rates, Heat, Electronics



ECAL: 30 layers

- SiW-ECAL": 0.5×0.5 cm³ Si cells
- ScECAL: 0.5×5 cm² Scint strips

10–100M channels

HCAL: 48 layers

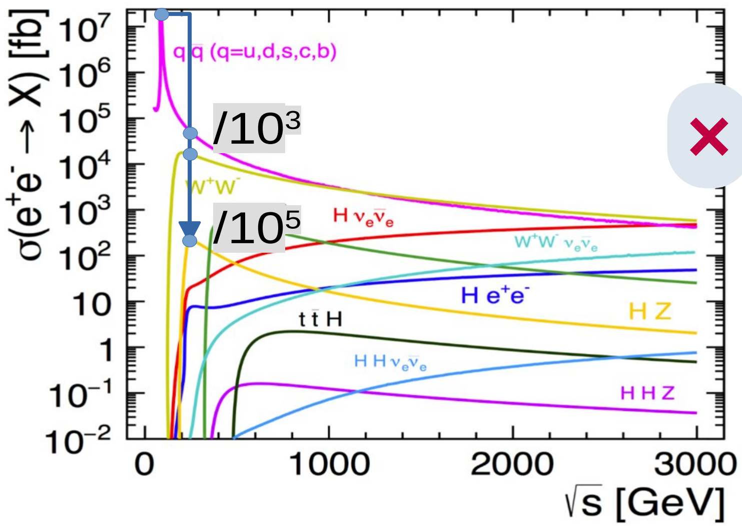
- AHCAL: 3×3 cm³ scint. cells
- ScECAL: 1×1 cm² RPC cells

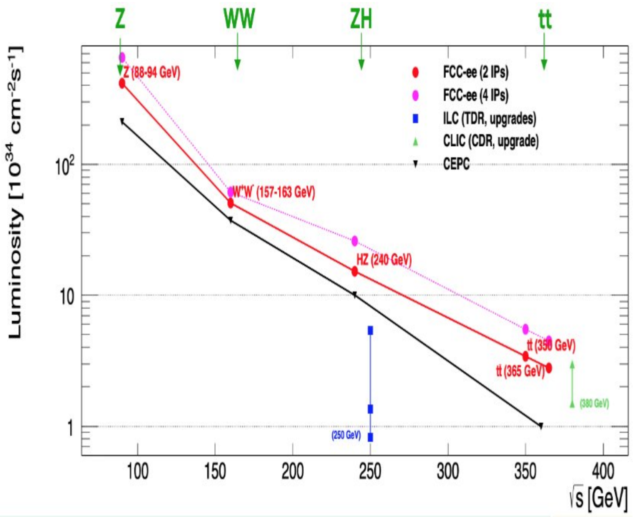
10–70M channels

Revisiting the HG calorimeters for circular colliders

Large panel of running conditions

- 90GeV × 10^7 fb × $5{\cdot}10^{36}$ cm^{-2} s^{-1} (qq × 20000 ILC @ 250)
- 150 GeV (WW) + 250 GeV (ZH)+ 280 GeV (tt)
  ~10^4 fb × $5{\cdot}10^{35}$ cm^{-2} s^{-1} (qq × 5–10 ILC @ 250)





Are the current hypothesis viable ?

- Occupancy,
  DAQ,
  Cooling
- 1 detector fit-all ?
  - What are the limits :
    - Power vs Granularity ➞ Active Cooling ?
- New electronics (DRD6):
  - TSMC 130 nm vs AMS 130 nm (or 65nm)
    - Down to **1mW / ch** ? If 30 ps Timing ?
  - Running mode (continuous, trigger-less)
    - Trigger for other detectors ?

Need rough numbers $\mathcal{O}$(±50%) for Occupancy, Data, Power, Dynamic Range (E, t) for all calorimeter's regions

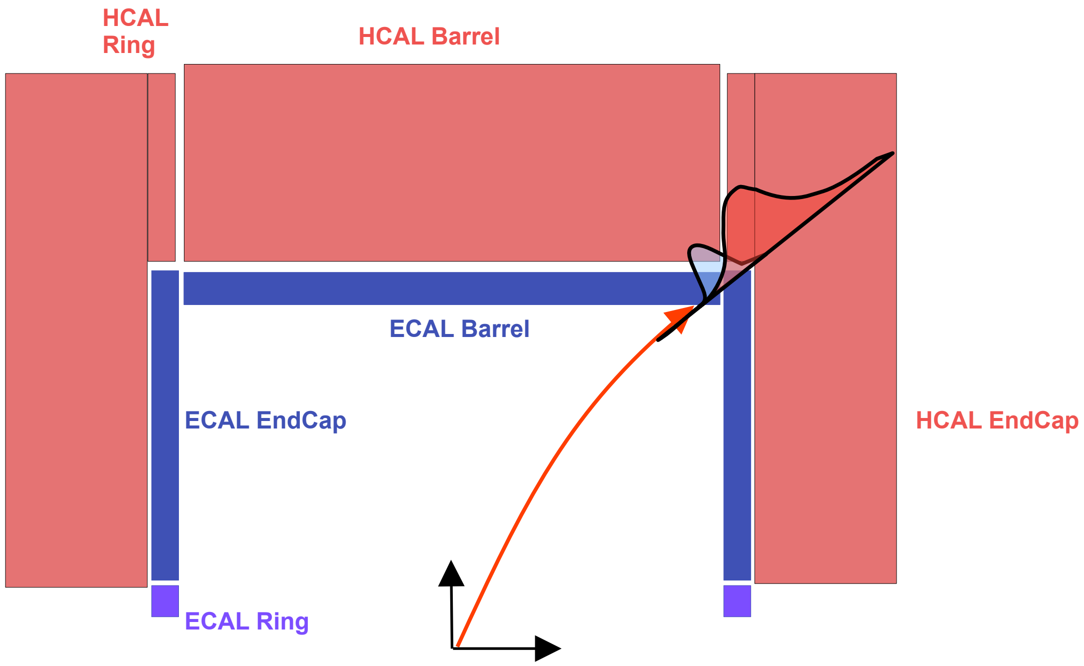
Calorimeter Fluxes from Full Simulations

Quantities useful for Self-Triggering & Low Occupacy Front-End electronics & Design

- Number of hits/s per ASICs
  - ➞ Power (Energy per conversion)
  - ➞ Memory size
- Distribution of Energy & Time
  - ➞ Dynamic ranges
  - ➞ Power per conversion (Wilkinson ADCs)
  - ➞ Double hits
- Data output
  - ➞ Data Flux per readout partition (DAQ)
    - ➞ DAQ scheme (Calo trigger to other parts ?)

Other quantities

- Deposited energies
  - ➞ Radiation



Software package

Python code

Production of Primary histograms

- LcioReader from pyLCIO
- Mapping & Selection
  - Cell_id decoding [J. Kunath]
  - Highly configurable
- ROOT histograms
  - System and histogram type hierarchy
  - Auto-rescalable (high E, high Nhits)

Secondary histograms

- Scaling : e.g. power, data size = *f*(#hits, Energy)

2D histograms

- Fix one component and get its 1D histograms as bins of a single 2D histogram.

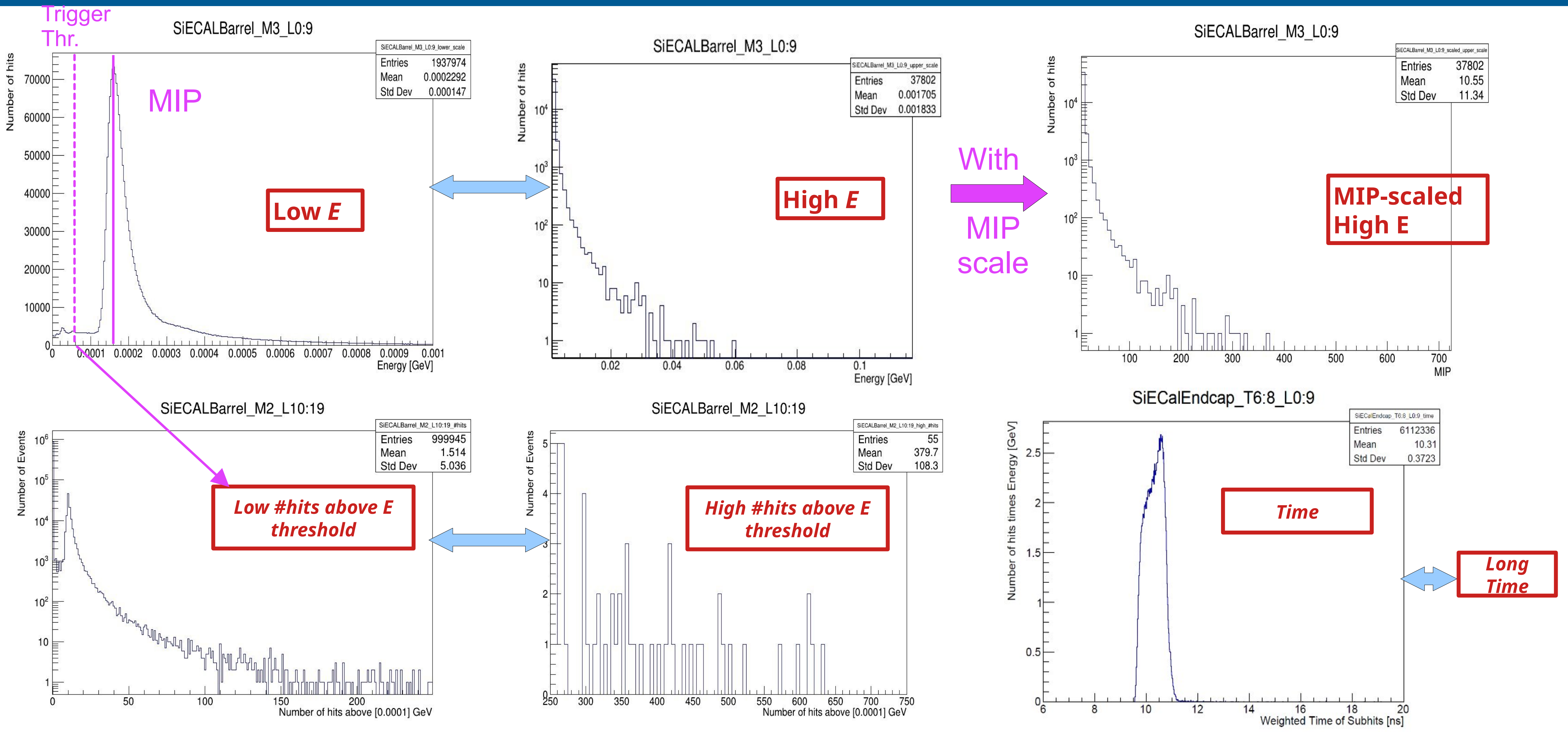
```
system_limits = {"ECALBarrel" : (8, 5, 5, 30) , "EndCaps" : (4, "0-6", 5, 30)}
#selection format "S:M:T:L" conditions => "*:*:2:0-4,5-10" means no selection on M, S, 1 histo per 2 tower , 1 for layer 0 to 5, and one for l
#The keys of the dictionary are the system names. Each key has a value composed of 4 lists.
# The first list has the collections' names.
# The second one has the selections we impose on the histograms made in the order given above.
# The third list has 4 lists each with 2 arguments. Each list has the bin number (the first argument) and the maximum of the range of the hist
# The fourth list has the energy threshold that we use in the Nhits histogram.
dictionary_of_system = {
#       System           Xollwctiona                                                 Stave  MOdules                  Towers                           Layers
        "SiECalEndcap": (["ECalEndcapSiHitsEven", "ECalEndcapSiHitsOdd"],   [["*"],["*"],                  ["0","1:2","3:5","6:8"],         ["0:9"
        "SiECALBarrel": (["ECalBarrelSiHitsEven", "ECalBarrelSiHitsOdd"],   [["*"],["1","2","3","4","5"], ["*"],                            ["0:9"
        "SiECalRing": (["EcalEndcapRingCollection"],                         [["*"],["*"],                  ["*"],                            ["0:9"
        "ScECalEndcap": (["ECalEndcapScHitsEven", "ECalEndcapScHitsOdd"],   [["*"],["*"],                  ["0","1:2","3:5","6:8"],         ["0:9"
        "ScECALBarrel": (["ECalBarrelScHitsEven", "ECalBarrelScHitsOdd"],   [["*"],["1","2","3","4","5"], ["*"],                            ["0:9"
        "RPCHCalEndcap": (["HCalEndcapRPCHits"],                             [["*"],["*"],                  ["0:3","4:7","8:11","12:15"],    ["0:15
        "RPCHCalBarrel": (["HCalBarrelRPCHits"],                             [["*"],["*"],                  ["*"],                            ["0:15
        "RPCHCalECRing": (["EcalEndcapRingCollection"],                      [["*"],["*"],                  ["*"],                            ["*"]]
        "ScHCalEndcap": (["HcalEndcapsCollection"],                          [["*"],["*"],                  ["0:3","4:7","8:11","12:15"],    ["0:15
        "ScHcalBarrel": (["HcalBarrelRegCollection"],                        [["*"],["*"],                  ["*"],                            ["0:15
        "ScHCalECRing": (["EcalEndcapRingCollection"],                       [["*"],["*"],                  ["*"],                            ["*"]]
        }
```

```
highE bin/max  #hits bin/max  EThr  Split Func:ranges
[100, 0.03], [100, 35]], [[0.0001]], {}),
[100, 0.03], [100, 35]], [[0.0001]], {}),
[100, 0.03], [100, 35]], [[0.0001]], {}),
[100, 0.03], [100, 35]], [[0.0003]], {}),
[100, 0.03], [100, 35]], [[0.0002]], {}),
[100, 3e-5], [100, 35]], [[3e-7]], {}),
[100, 3e-5], [100, 35]], [[3e-7]], {complex_sad:["0:79", "80:159", "160:234"]}
[100, 0.03], [100, 35]], [[0.0001]], {}),
[100, 0.03], [100, 35]], [[0.0001]], {}),
[100, 0.03], [100, 35]], [[0.0003]], {complex_happy:["0:29", "30:59", "60:76"]]
[100, 0.03], [100, 35]], [[0.0001]], {})
```

Described in a Technical Report accepted by JINST.

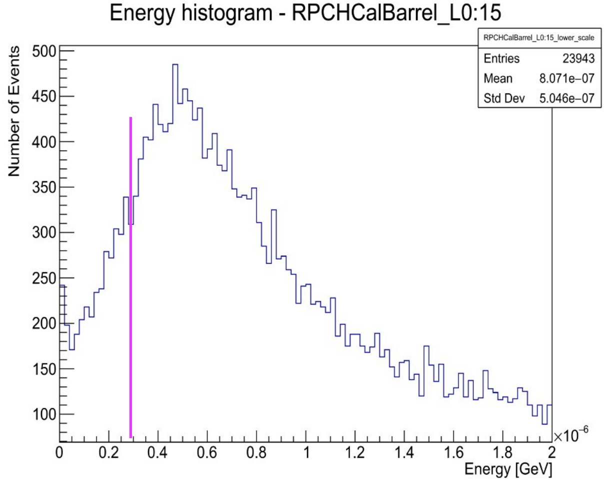
JINST_006T_0324

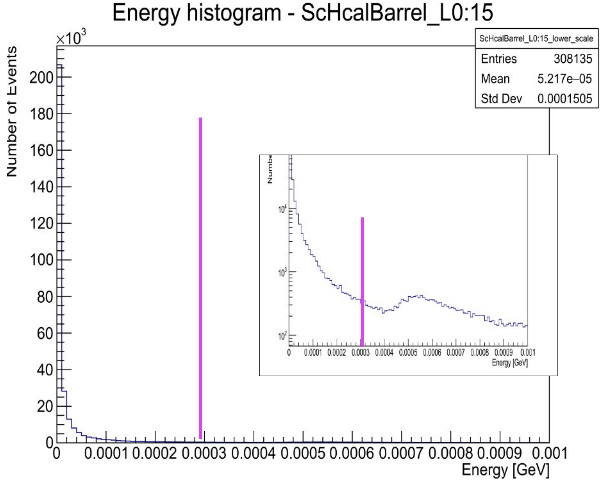
Histograms Types (1,000,000 muon events)

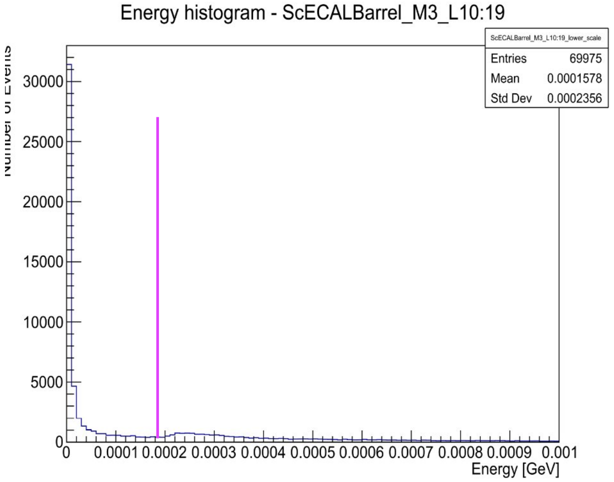


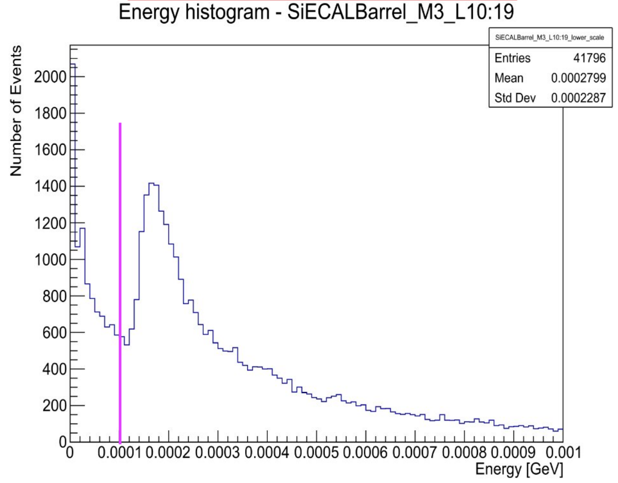
System Low Energy & #hit responses
raw energies (no digitization yet)

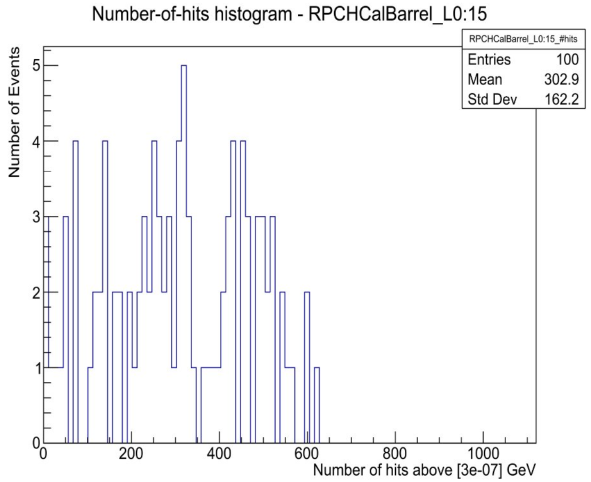
SDHCAL | **AHCAL** | **Sc ECAL** | **Si ECAL**

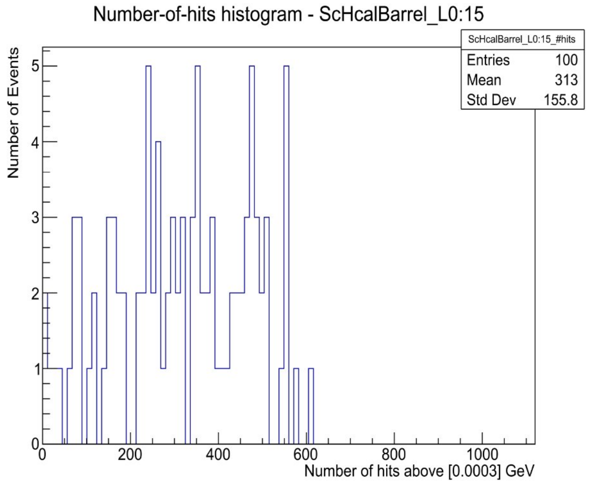


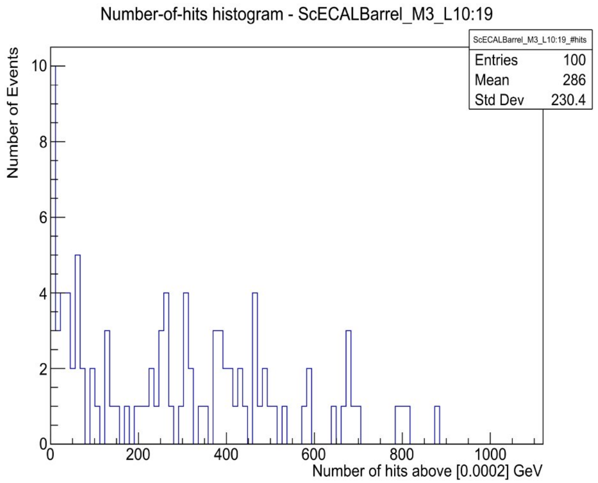


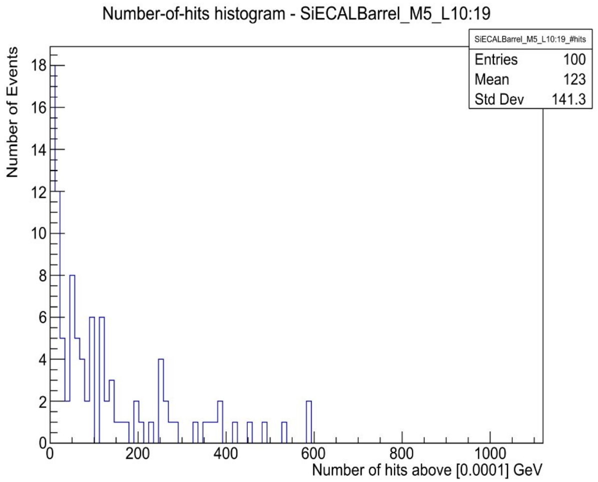




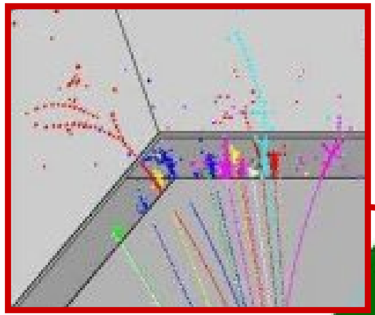


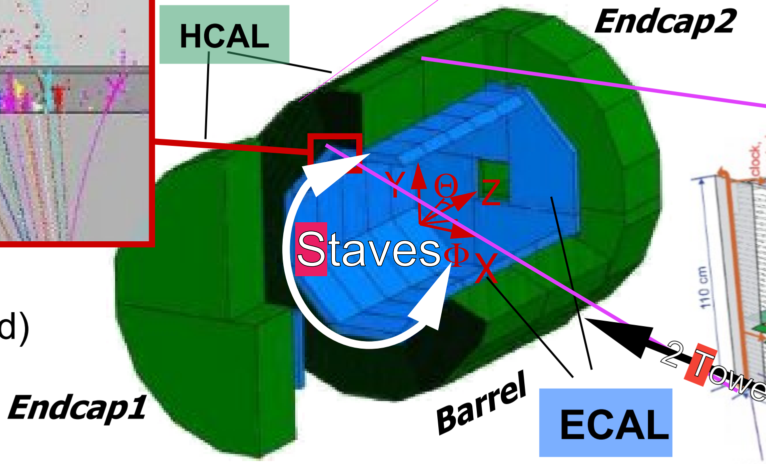




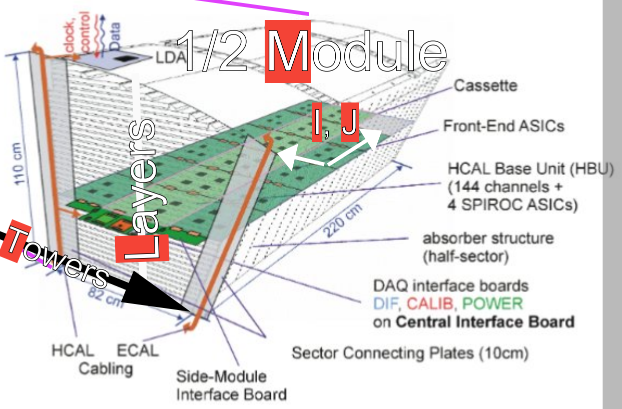


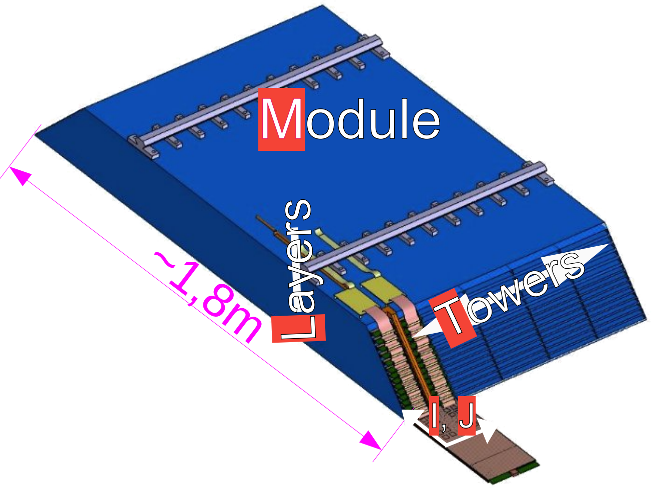
Geometries : logical numbering

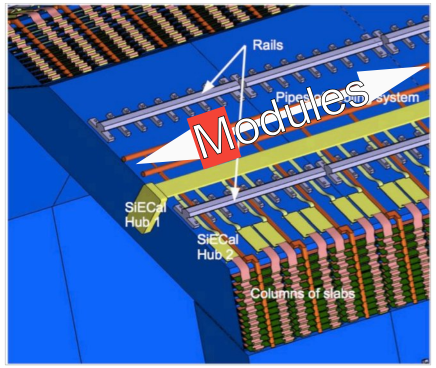


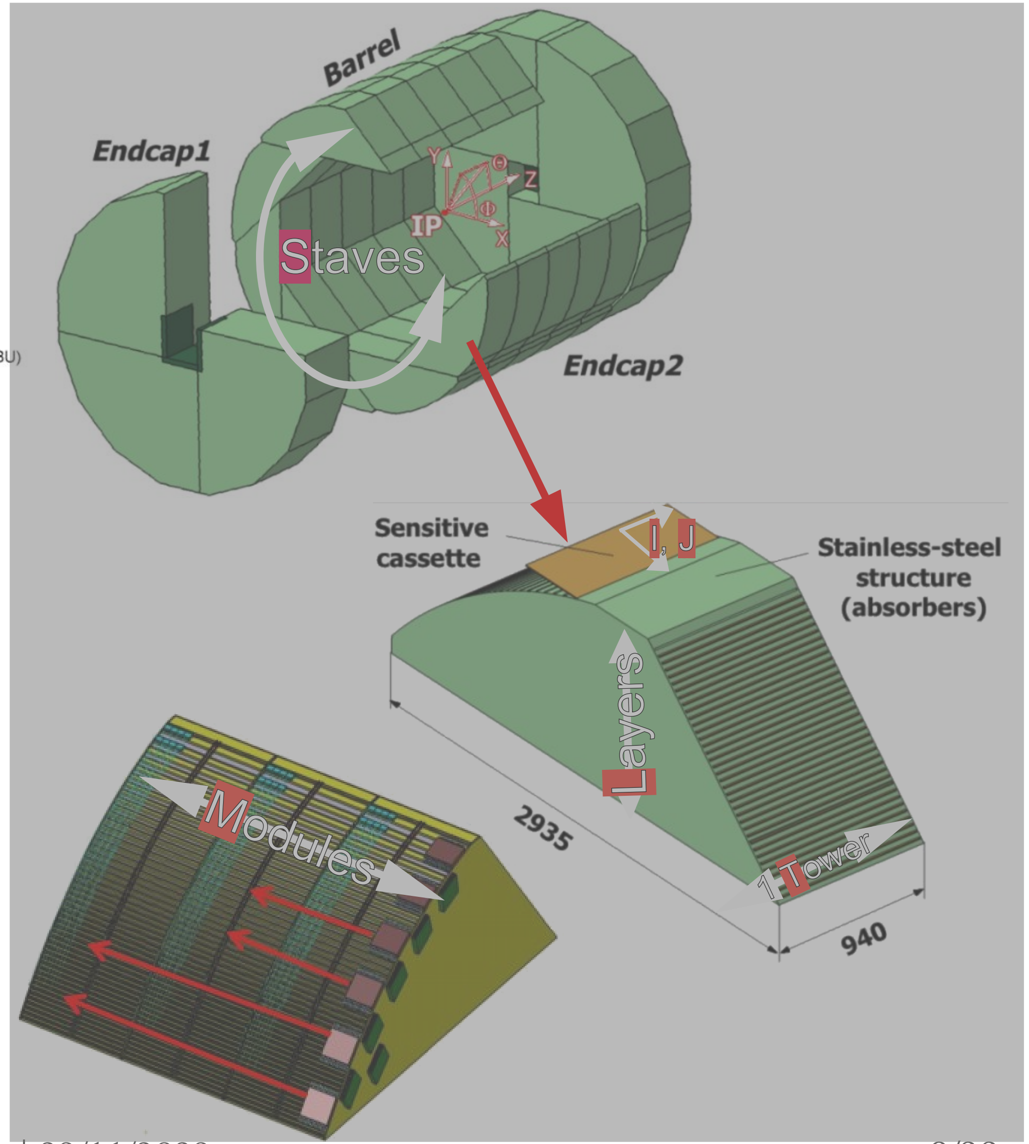


(SiD = 12 fold)



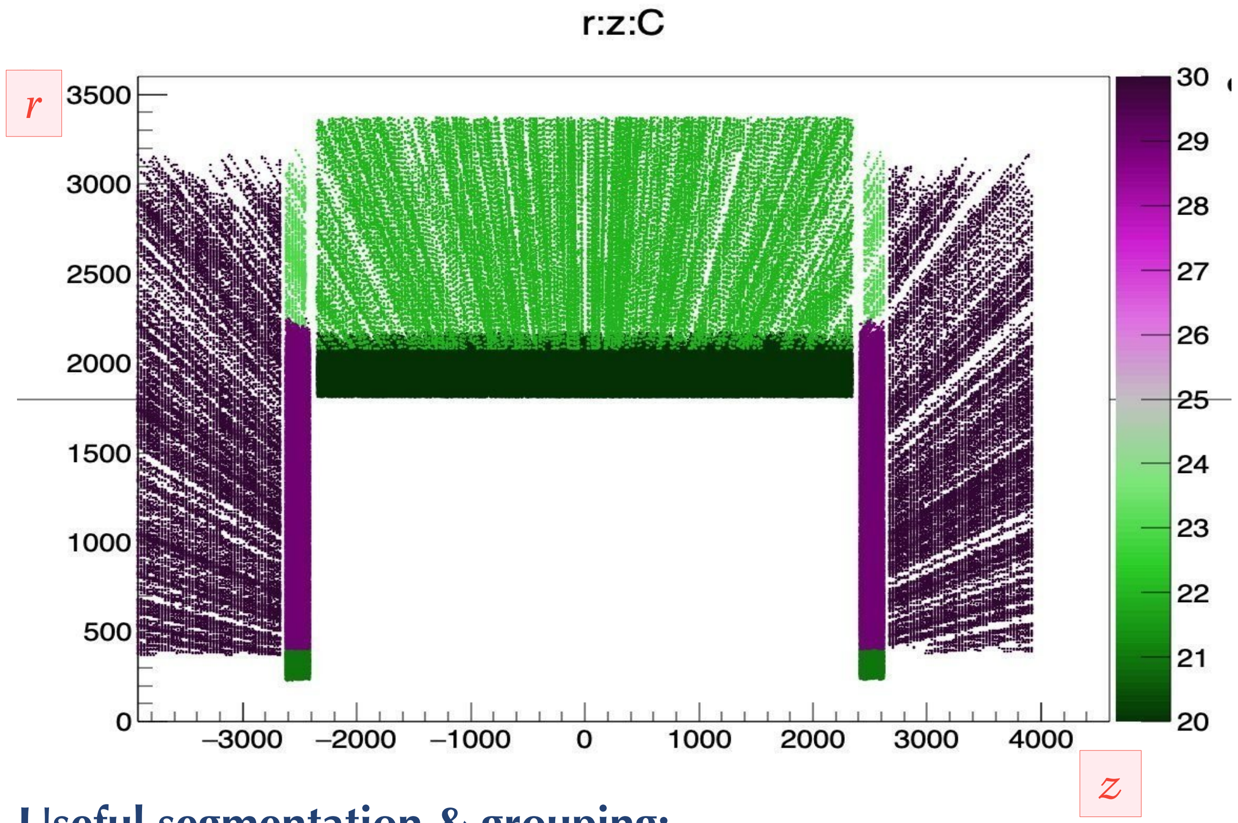




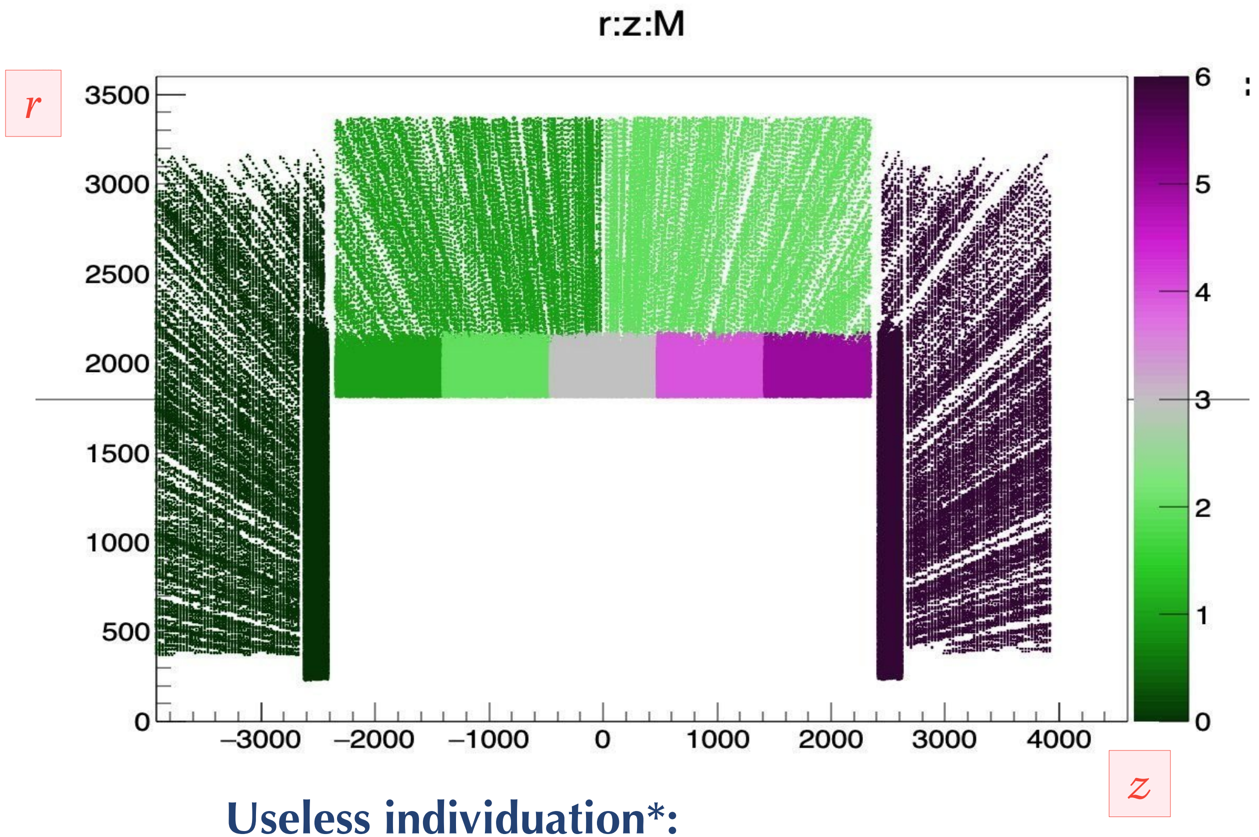


Segmentation by "Logical Geometry" C:M:S:T:L:I:J

Calorimeters systems C



Calorimeters Modules



Useful segmentation & grouping:

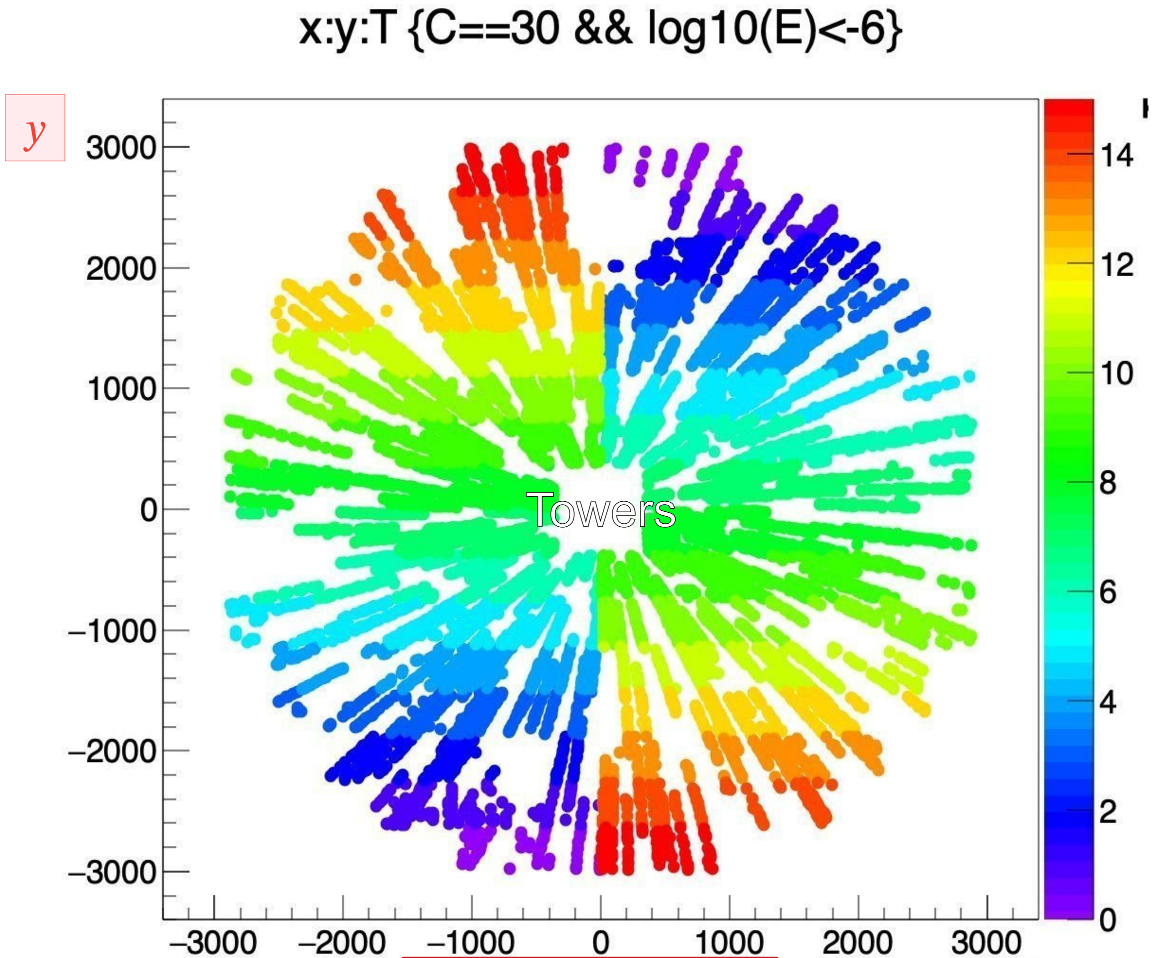
- Physics: Group of uniform (rates) regions (~cosθ)
- Technical: Readout & Cooling Partition (ASIC, SLAB, Tower, Module)

Useless individuation*:

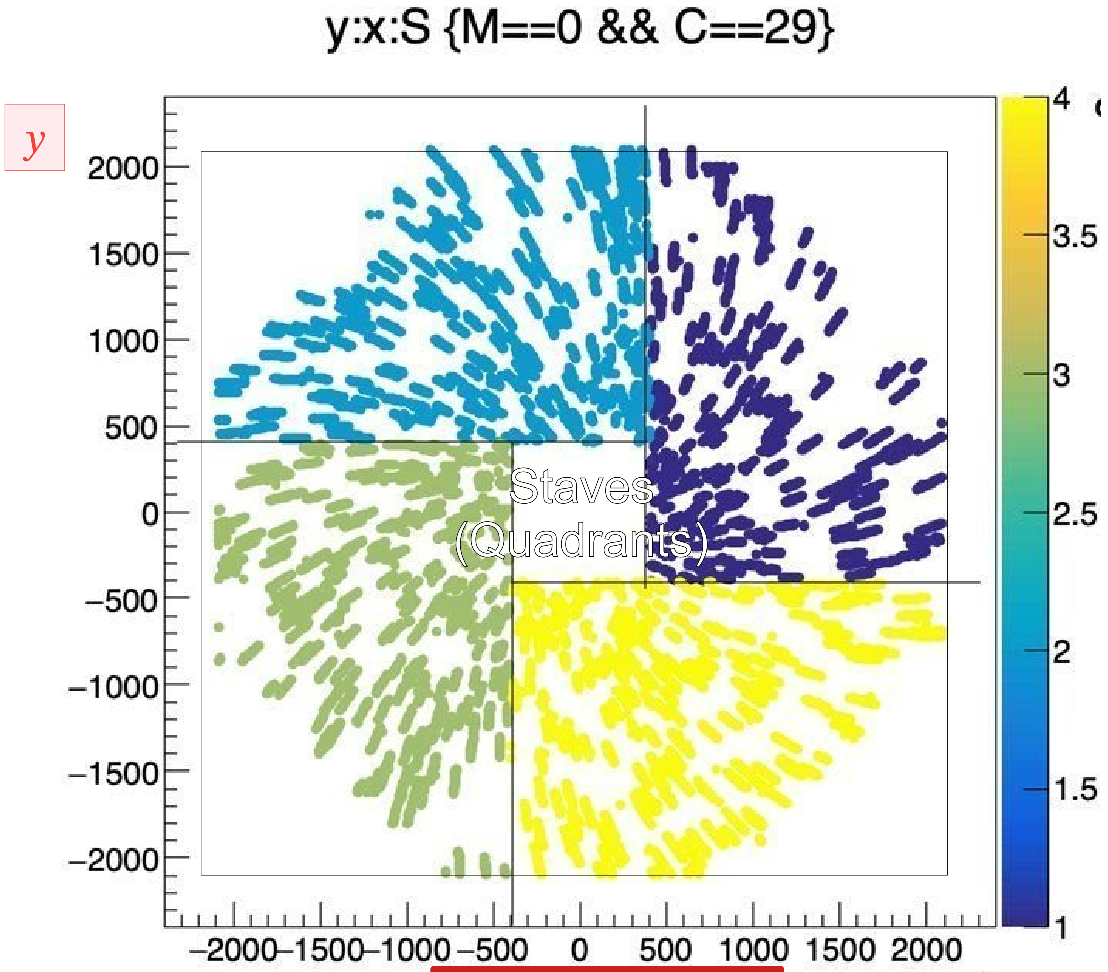
- (Individual layers)
- Symmetrical : staves (ϕ), Forward–Backward (±θ)

** assumming symmetrical physics / background distributions*

Logical Geometry : towers & staves

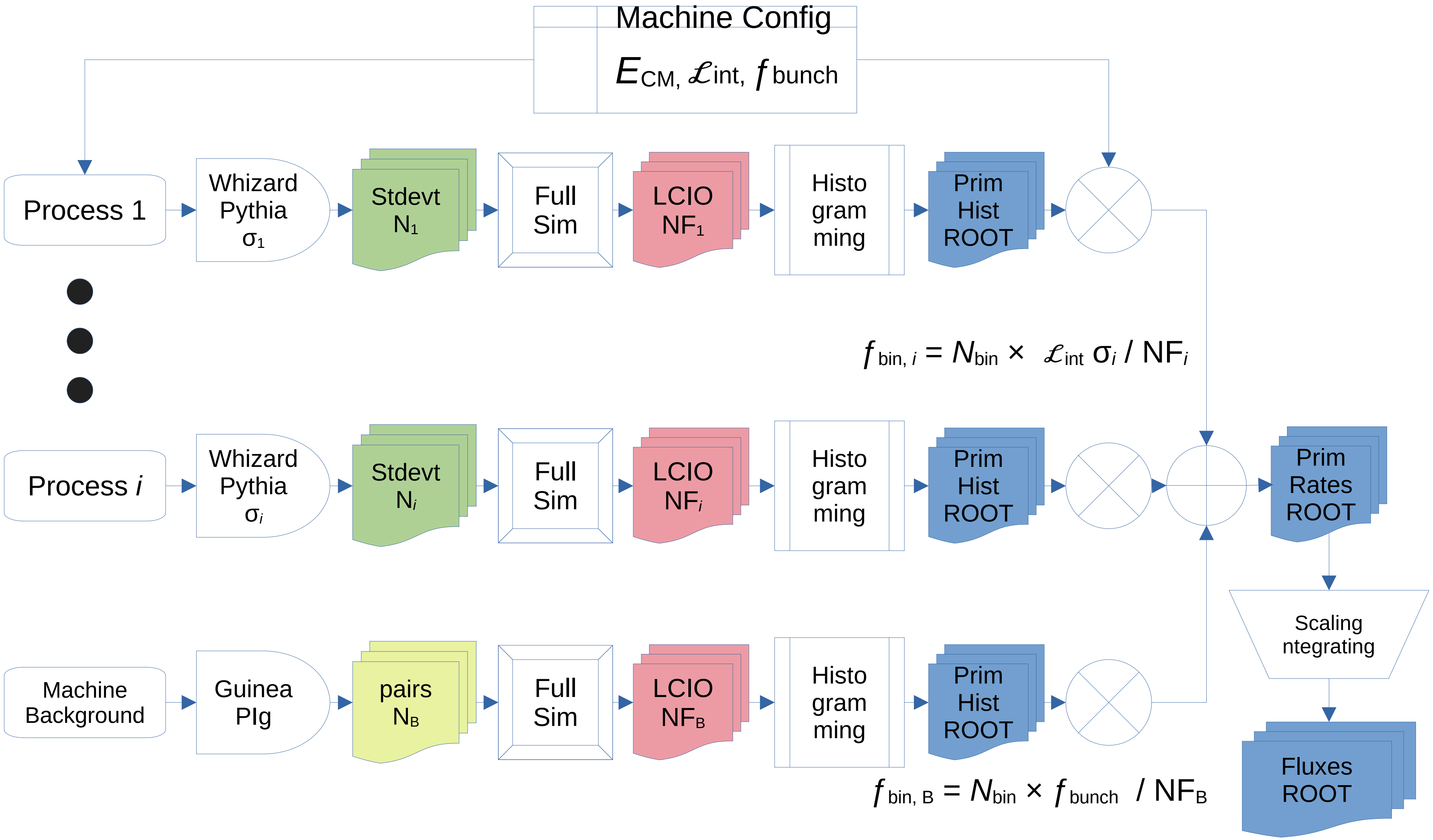


Towers T (HCAL)



Staves S (ECAL)

Processes to Fluxes



Generated data: ILD_l5_v02 (+ cross-angle 30mrad, B=3.5T), bgd files → ILD_l5_v11gamma

Table 1: 91.2 GeV
($N = 10000$, $L_{ins} = 1.4 \times 10^{-3} fb^{-1}s^{-1}$)

Channels	σ ($10^5 fb$)	$(\frac{\sigma \times L_{int}}{N})$ (s^{-1})
$ee \to qq$	344	4.82
$ee \to ll$	34.6	0.484
$ee \to ee$ ($M_{ee} < 30GeV$)	1.01	0.0141
$ee \to ee$ ($M_{ee} > 30GeV$)	57.8	0.809

Table 2: 162.5 GeV
($N = 10000$, $L_{ins} = 2.14 \times 10^{-4} fb^{-1}s^{-1}$)

Channels	σ ($10^5 fb$)	$(\frac{\sigma \times L_{int}}{N})$ (s^{-1})
$ee \to qq$	1.55	3.32×10^{-3}
$ee \to ll$	0.241	5.16×10^{-4}
$ee \to WW$	0.0504	1.08×10^{-4}
$ee \to ee$ ($M_{ee} < 30GeV$)	0.240	5.14×10^{-4}
$ee \to ee$ ($M_{ee} > 30GeV$)	12.9	2.76×10^{-2}

Table 3: 240 GeV
($N = 10000$, $L_{\text{ins}} = 6.9 \times 10^{-5}$ fb^{-1} s^{-1})

Channels	σ (10^5 fb)	$(\frac{\sigma \times L_{\text{int}}}{N})$ (s^{-1})
$ee \to qq$	0.550	3.80×10^{-4}
$ee \to ll$	0.100	6.88×10^{-5}
$ee \to WW$	0.167	1.15×10^{-4}
$ee \to ZH$	0.00204	1.41×10^{-6}
$ee \to ee$ ($M_{ee} < 30GeV$)	0.120	8.29×10^{-5}
$ee \to ee$ ($M_{ee} > 30GeV$)	5.92	4.09×10^{-3}

Table 4: 365 GeV
($N = 10000$, $L_{ins} = 1.2 \times 10^{-5} fb^{-1}s^{-1}$)

Channels	σ ($10^5 fb$)	$(\frac{\sigma \times L_{int}}{N})$ (s^{-1})
$ee \to qq$	0.228	2.74×10^{-5}
$ee \to ll$	0.0430	5.16×10^{-6}
$ee \to WW$	0.111	1.33×10^{-5}
$ee \to ZH$	0.00123	1.47×10^{-7}
$ee \to tt$	0.00372	4.46×10^{-7}
$ee \to ee$ ($M_{ee} < 30GeV$)	0.0499	5.99×10^{-2}
$ee \to ee$ ($M_{ee} > 30GeV$)	2.57	3.08×10^{-4}

Machine background sources :

Source	#particles per bunch	$< E >$ (GeV)
Disrupted primary beam	2×10^{10}	244
Bremstrahlung photons	2.5×10^{10}	244
e^+e^- pairs from beam-beam interactions	75k	2.5
Radiative Bhabhas	320k	195
$\gamma\gamma \to$ hadrons/muons	0.5 events/1.3 events	–

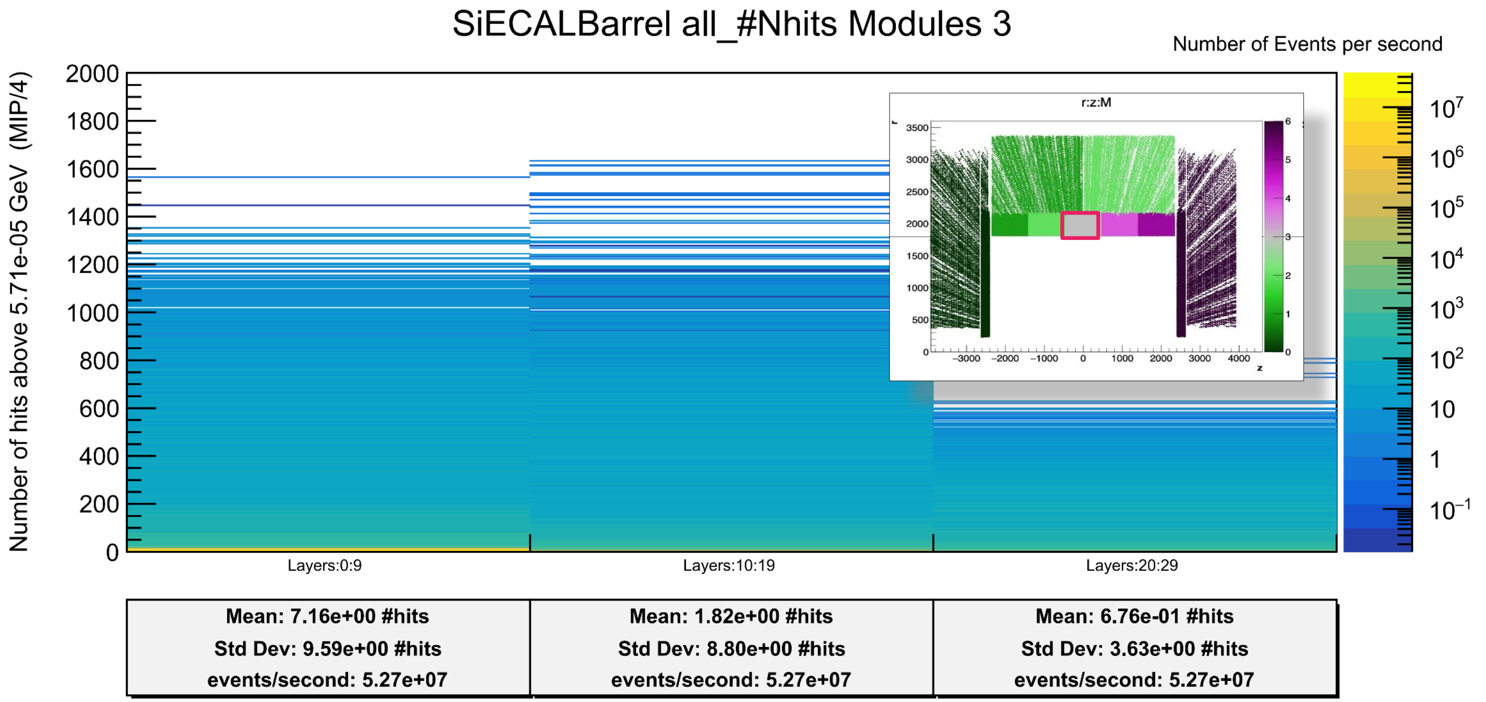
T. Behnke, et al. *The International Linear Collider Technical Design Report - Volume 4: Detectors*, arXiv:1306.6329 [Physics]. (2013)

Incoherent pair production :
100 BX at FCC-ee 91.2 GeV and 240 GeV

Produced by Andrea Ciarma,

Simulated (special setup)
in ILD's by D. Jeans

Results : Rates in Silicon ECAL Barrel, Central Module vs depth



Distributions of the number of hits crossing (MIP/4) energy threshold of all the physics processes and machine background at 91.2 GeV (FCC-Z4)
The z scale is the number of event/s

From the $\langle f_{\text{Nhits}} \rangle$ in one region one can extract :

- The data rate, knowing the number of bytes per hits (here 7 as a landmark)
- The occupancy, knowing the number of cell in the region.
- The power dissipated on elec. power (here for SKIROC2 like chip)

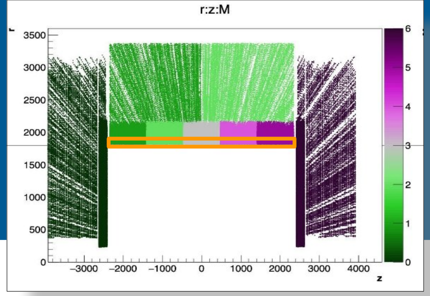
M3 all staves	**L0:9**	**L10:19**	**L20:29**
Average #hits/s	302E+6 hits/s	65E+6 hits/s	8E+6 hits/s
Max	2000 hits/event	2500 hits/event	1000 hits/event
Data rate	2,11E+9 B/s	458E+6 B/s	54E+6 B/s
Ncells	4 026 764	3 767 273	3 378 036
Occupancy/BX	**1,4 E-06**	**3,3 E-07**	**4,3 E-08**
Base power/W	18,2 E+03	17,1 E+03	15,3 E+03
Conversion power/W	271,4 E+00	58,9 E+00	6,9 E+00
Total power/W	**18,5 E+03**	**17,1 E+03**	**15,3 E+03**
% conv.	1,5 %	0,3 %	0,05 %

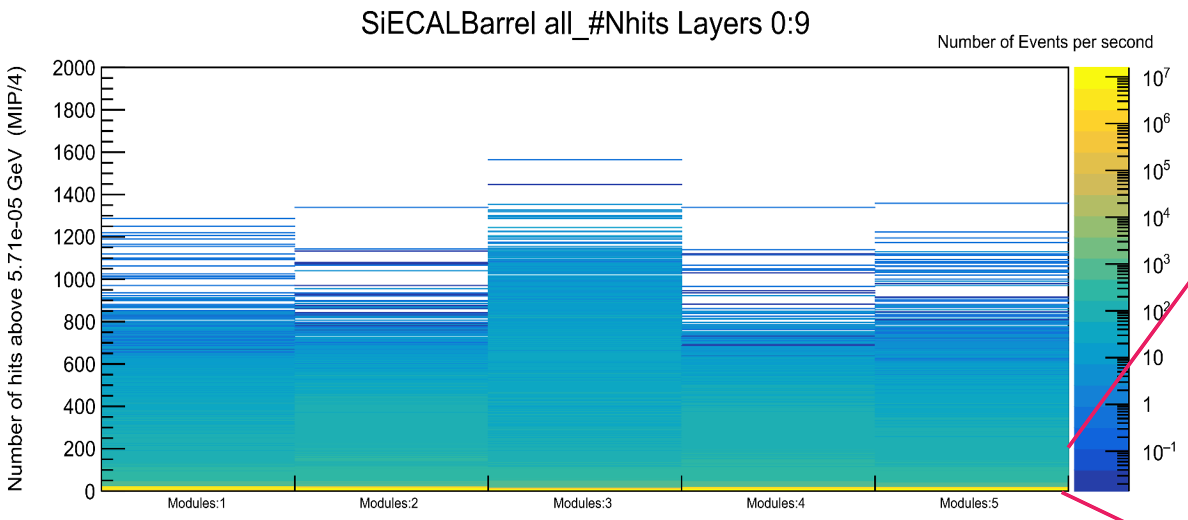
cell size	5,5
Bytes/hit	7
powa (W/cell)	4,5 E-03
powb (J/hit)	8,7 E-10
Conv & RO E/hit/μJ	9,0 E-01
Δt/s	19 E-09

- **Most of the hits are in the first third of the calorimeter.**
- **Highest average rates L0:9**
- **Highest max rates in L10:19**

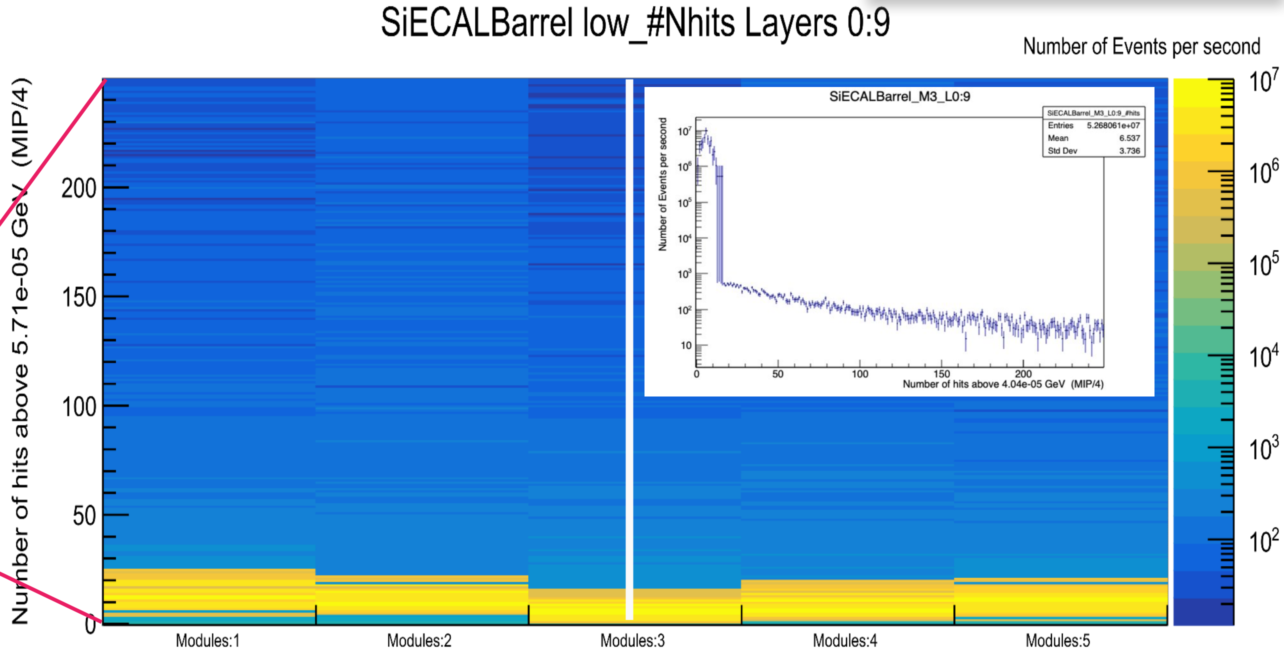
Note 1 : (still) **preliminary**
Note 2 : Rates & Power for all M3 modules
→ 8 per module, 10 per layer for 1 slab
→ ~ 50 W/slab

Results : Silicon ECAL Barrel, per module, first 10 layers





Modules:1	Modules:2	Modules:3	Modules:4	Modules:5
Mean: 1.51e+01 #hits	Mean: 1.23e+01 #hits	Mean: 7.16e+00 #hits	Mean: 1.01e+01 #hits	Mean: 1.14e+01 #hits
Std Dev: 7.31e+00 #hits	Std Dev: 7.84e+00 #hits	Std Dev: 9.59e+00 #hits	Std Dev: 8.03e+00 #hits	Std Dev: 6.78e+00 #hits
events/second: 5.27e+07	events/second: 5.27e+07	events/second: 5.27e+07	events/second: 5.27e+07	events/second: 5.27e+07

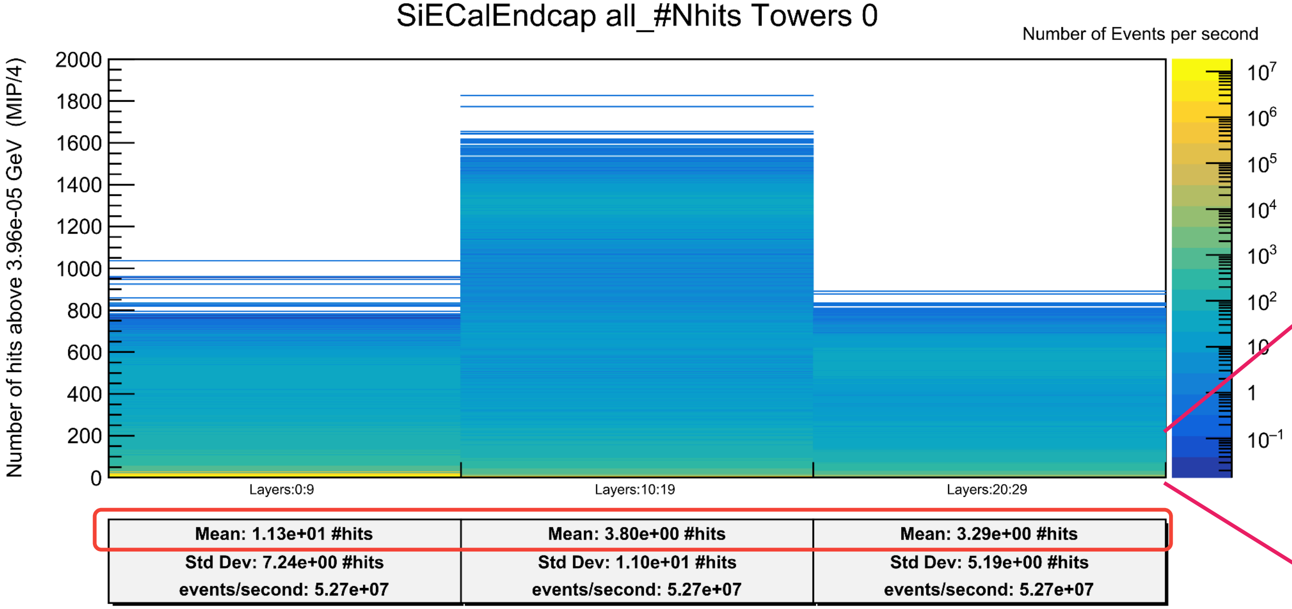


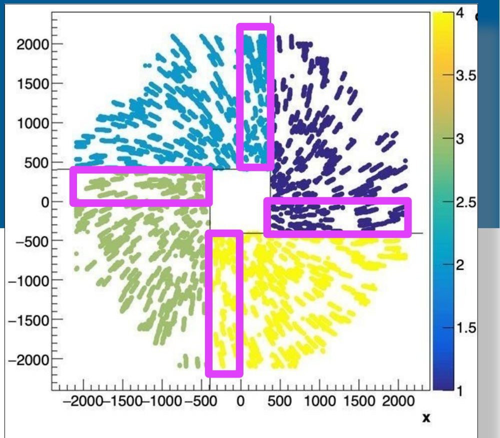
Modules:1	Modules:2	Modules:3	Modules:4	Modules:5
Mean: 1.44e+01 #hits	Mean: 1.18e+01 #hits	Mean: 6.54e+00 #hits	Mean: 9.53e+00 #hits	Mean: 1.08e+01 #hits
Std Dev: 5.09e+00 #hits	Std Dev: 4.65e+00 #hits	Std Dev: 3.74e+00 #hits	Std Dev: 4.83e+00 #hits	Std Dev: 4.47e+00 #hits
events/second: 5.27e+07	events/second: 5.27e+07	events/second: 5.27e+07	events/second: 5.27e+07	events/second: 5.27e+07

Distributions of the number of hits crossing (>MIP/4) energy threshold of all the physics processes and machine background at 91.2 GeV (FCC-Z4) with the colour bar representing the rate of events

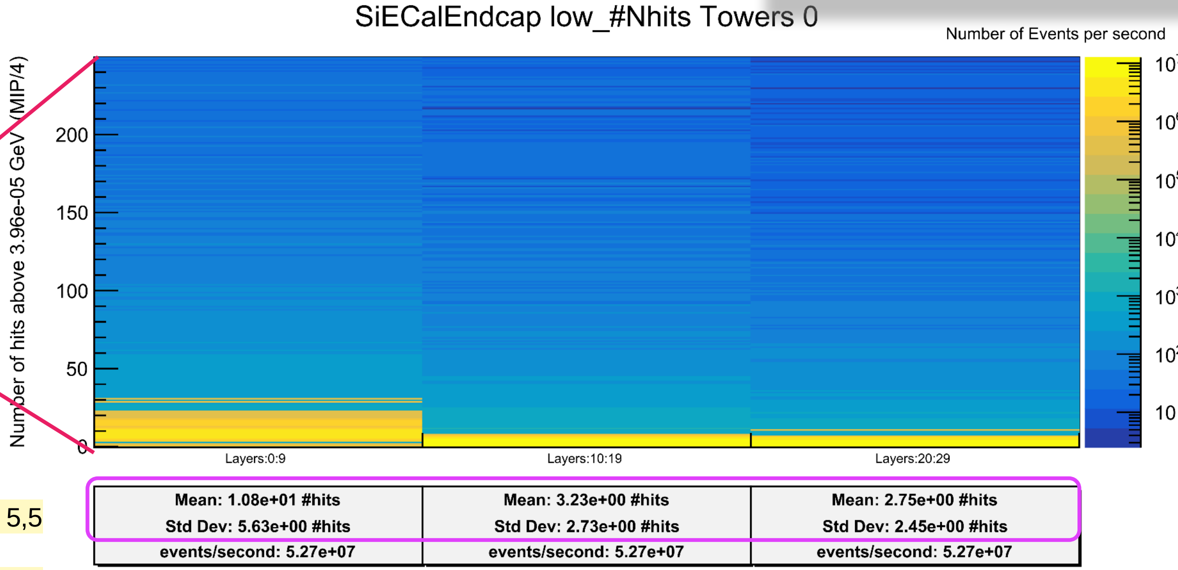
- **Rates M1/M3 ~ 2**
- **Double counting of physics events in Module 3 due back-to-back events**
- **Machine backgrounds dominate the distribution.**

Results: Rates in SiECAL EndCaps, Tower 0 vs depth





Distributions of the number of hits crossing (>MIP/4) energy threshold of all the physics processes and machine background at 91.2 GeV (FCC-Z4) with the colour bar representing the rate of events



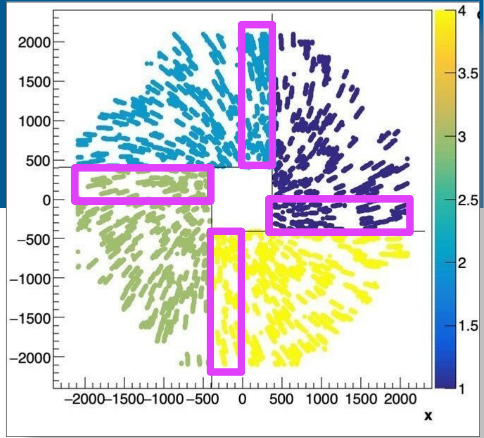
T0 all quadrants	**L0:9**	**L10:19**	**L20:29**
Average #hits/s	572E+6 hits/s	176E+6 hits/s	147E+6 hits/s
Max	2000 hits/event	2500 hits/event	1000 hits/event
Data rate	4,00E+9 B/s	1E+9 B/s	1E+9 B/s
Ncells	1 161 775	1 161 775	1 161 775
Occupancy/BX	**9,4E-06**	**2,9E-06**	**2,4E-06**
Length/Width	2496		565
Base power	5E+03	5E+03	5E+03
Conversion power	515E+00	159E+00	132E+00
Total power	**6E+03**	**5E+03**	**5E+03**
% conv.	8,9 %	2,9 %	2,45 %

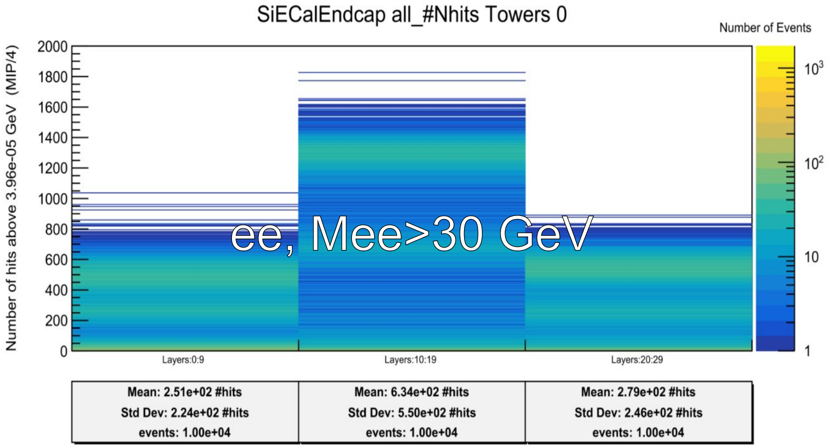
cell size	5,5
Bytes/hit	7
powa (W/cell)	5E-03
powb (J/hit)	870E-12
Conv & RO E/hit/µJ	0,9
Δt	19E-9

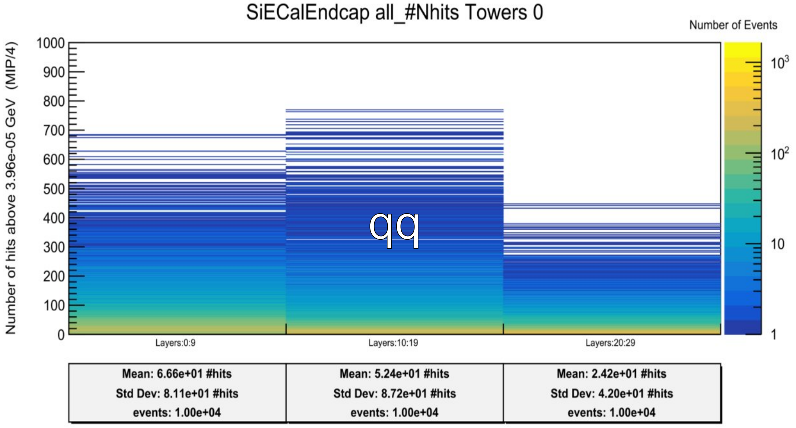
- **Machine background in first layers**
- **High E ee→ee in middle of ECAL (next slide)**
- **Power driven by the continuous part (Pre-Amps)**

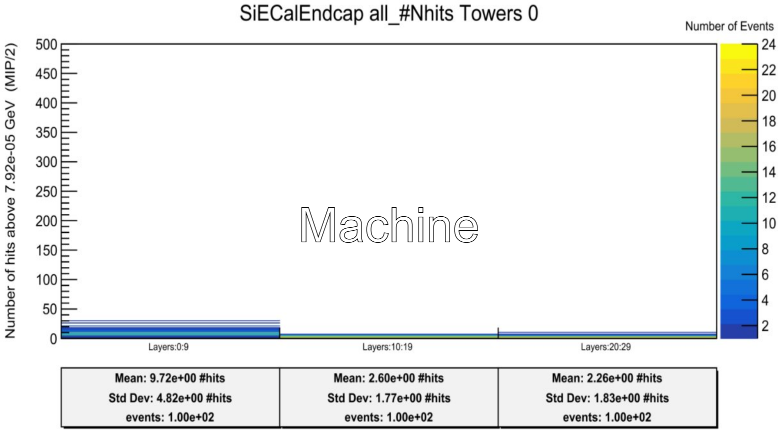
Note 1 : (still) **preliminary**
Note 2 : Rates & Power for all T0 modules
→ /8 per quadrant, *10 per layer for 1 slab* → *75W / slab*

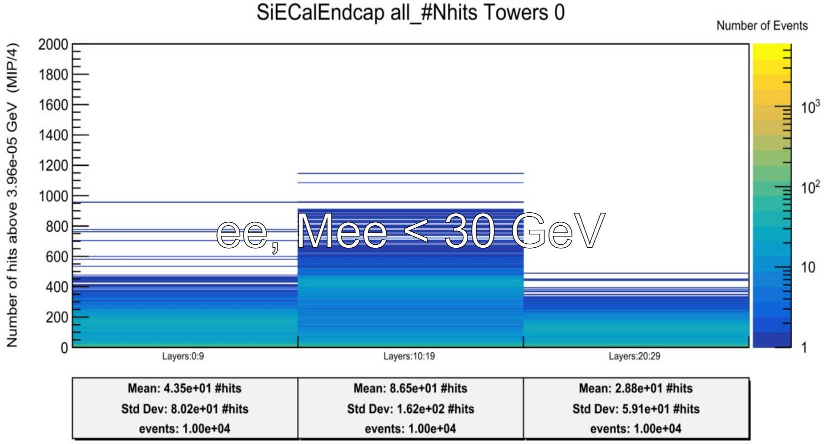
Results: Contributions to rates in SiECAL EndCaps, Tower 0 vs depth

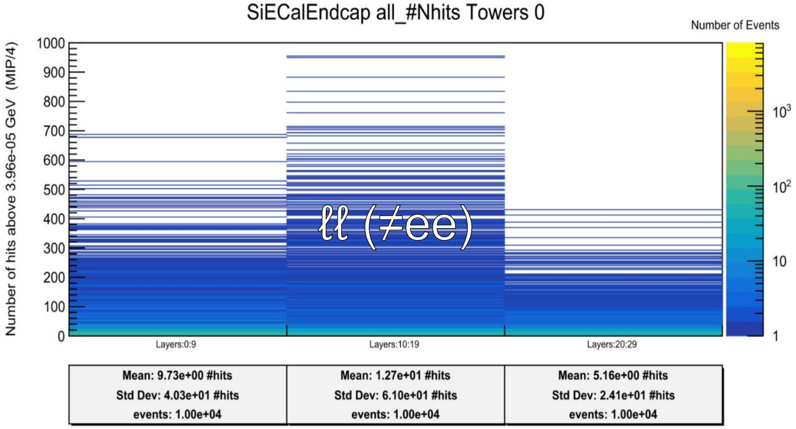






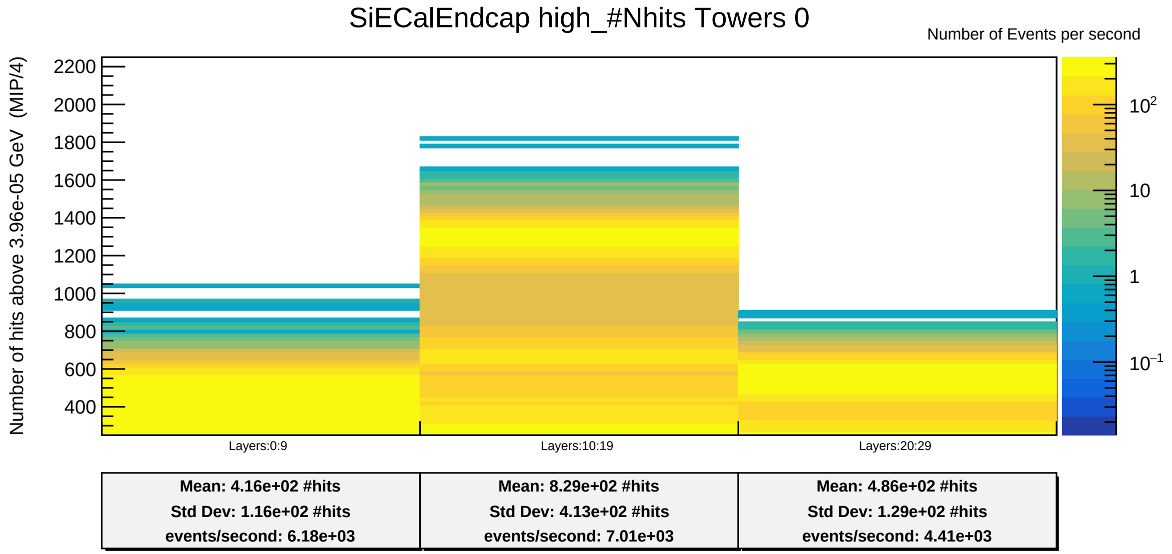


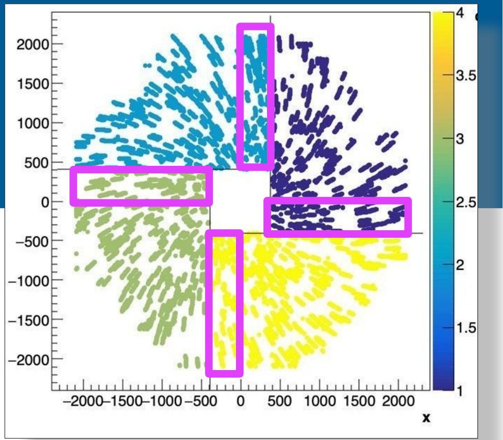




Distributions of the number of hits crossing (>MIP/4) energy threshold of all the physics processes and machine background at **91.2 GeV** (FCC-Z4) with the colour bar representing the number of events (for 10,000 or 100 BX simulated)

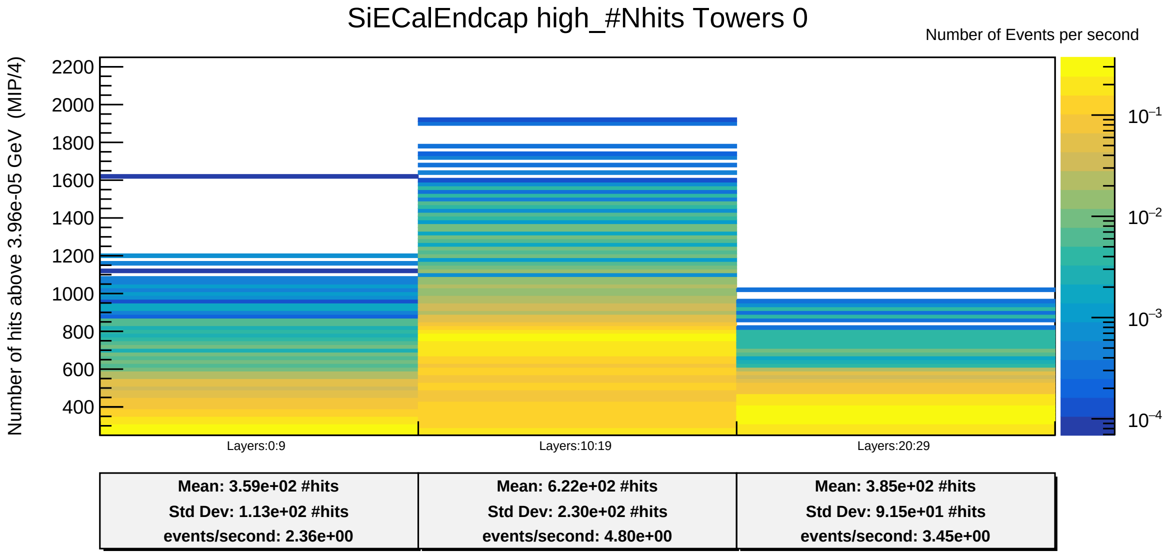
Results: Dynamic Range in SiECAL EndCaps, Tower 0 vs depth





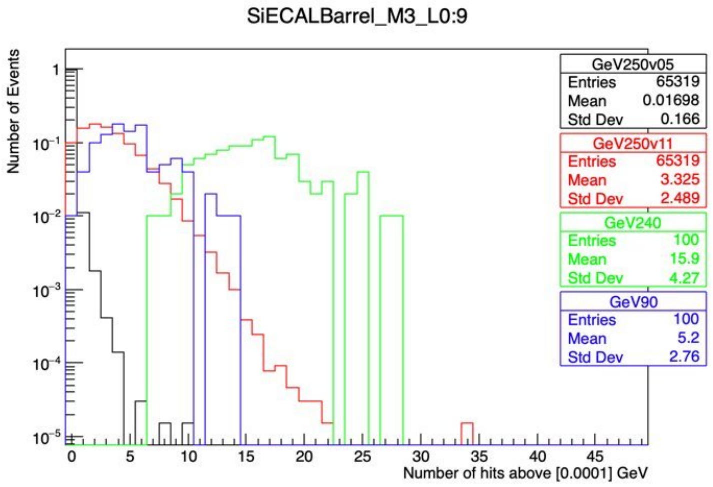
Upper Scale Energy distributions of tower 0 of ECAL end cap at **91.2 GeV** of all physics and background

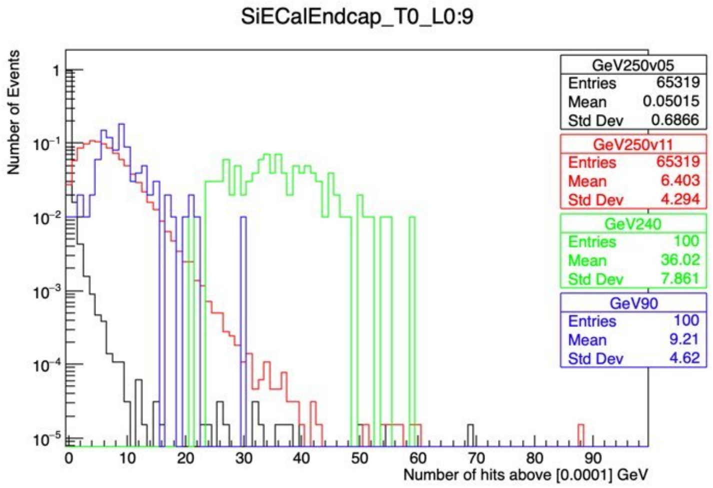
- **Max Energy = ~2000 MIPs**
- **Tower 0 is the closest to the beam-pipe**
- **Almost the same for both energies.**
- **Rates 240 GeV / 91.2 GeV down by 60**



Upper Scale Energy distributions of tower 0 of ECAL end cap at **240 GeV** of all physics and background

Machine backgrounds for ILC/FCC tracking configurations





ILC@250GeV/ILD_l5_v05/ : 65319 BX

ILC@250GeV/ILD_l5_v11gamma/ : 65319 BX

FCCee@240GeV/ILD_l5_v11gamma/ : 100 BX

FCCee@90GeV/ILD_l5_v11gamma/ : 100 BX

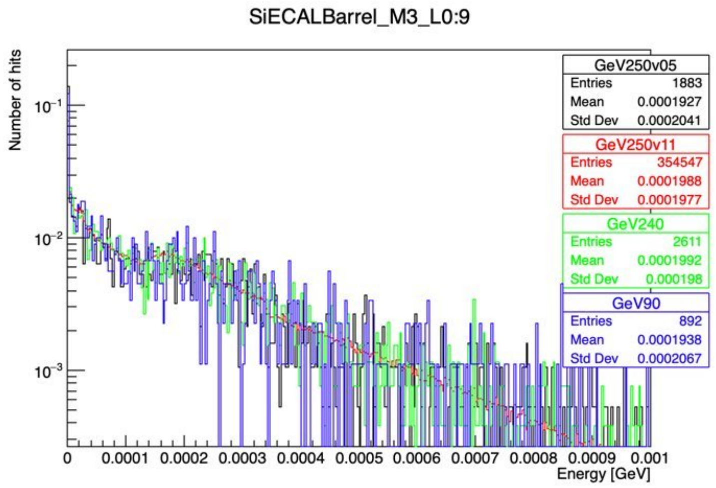
		⟨Nhit⟩/BX	
Config		Barrel M3 L0:9	EndCap T0 L0:9
ILC @ 250 GeV	ILD_l5_v05	0,0170	0,0500
ILC @ 250 GeV	ILD_l5_v11γ	3,33	6,40
FCCee @ 240 GeV	ILD_l5_v11γ	15,9	36,0
FCCee @ 90 GeV	ILD_l5_v11γ	5,2	9,21

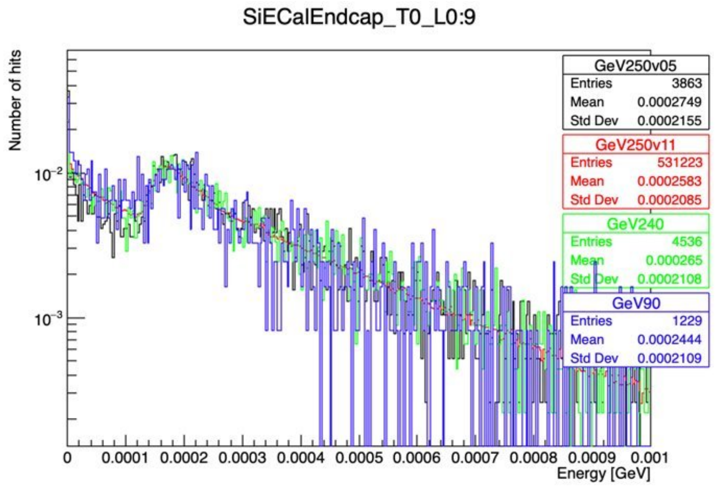
⟨Nhits⟩, per BX

- Barrel and Endcaps ~ same behaviour
- Much higher numbers in
  - 240 GeV (FCC config)~ 4 × 90 GeV
  - 250 v11 ~ 100× 250 v5

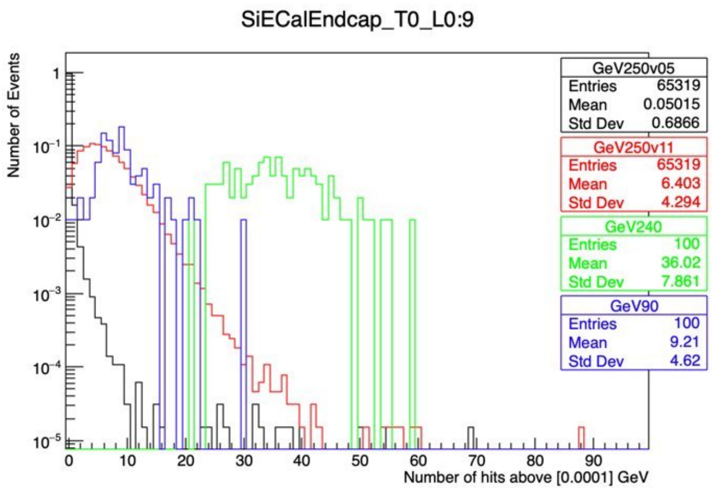
Distribution of hit energy

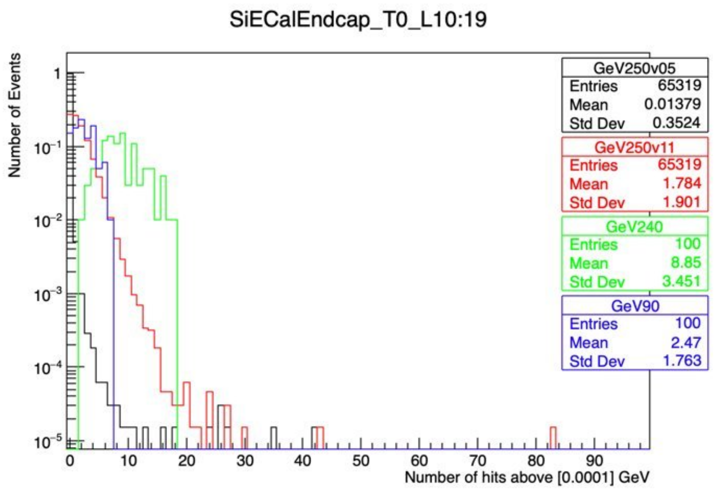
- No difference

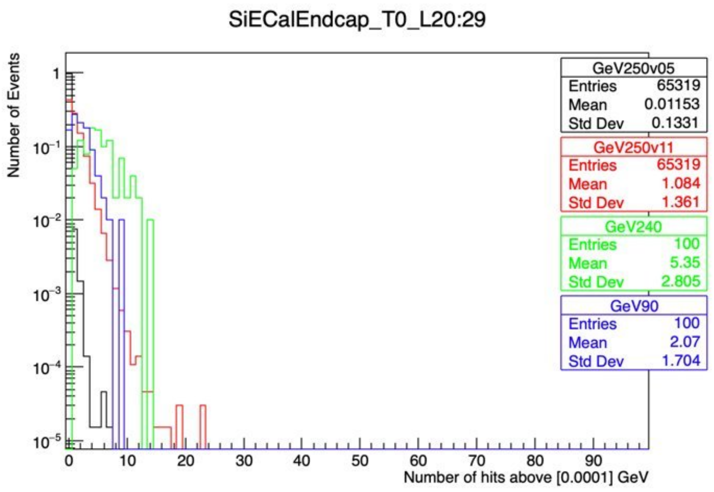




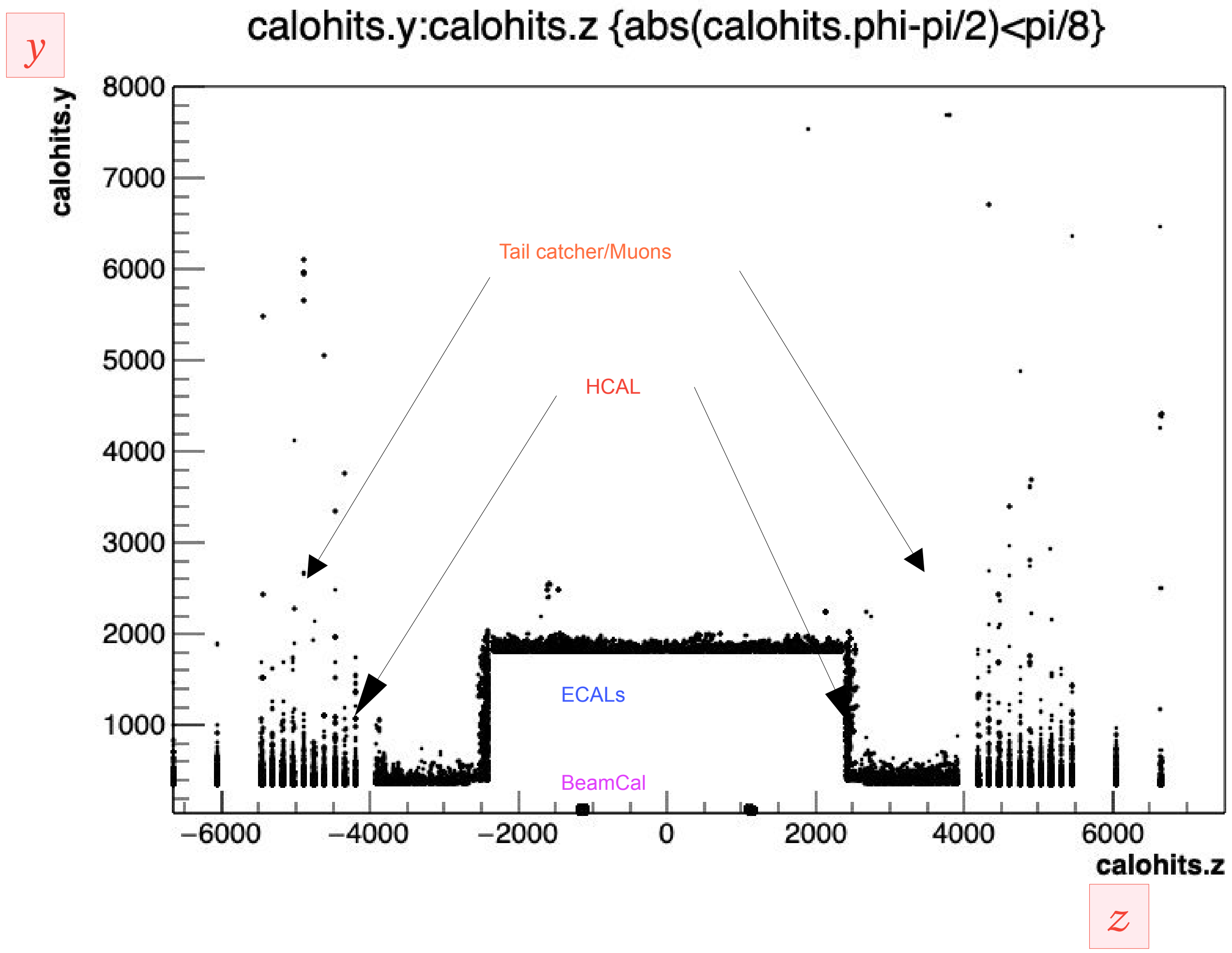
Nhits in the endcaps T0 vs depth

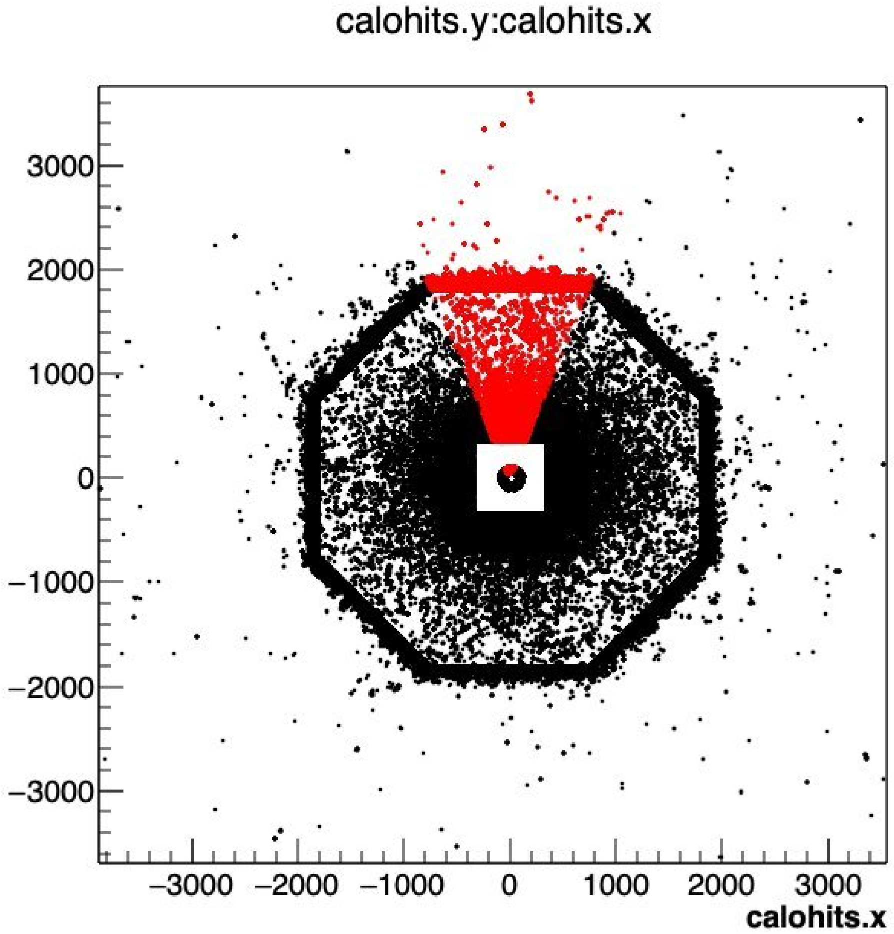






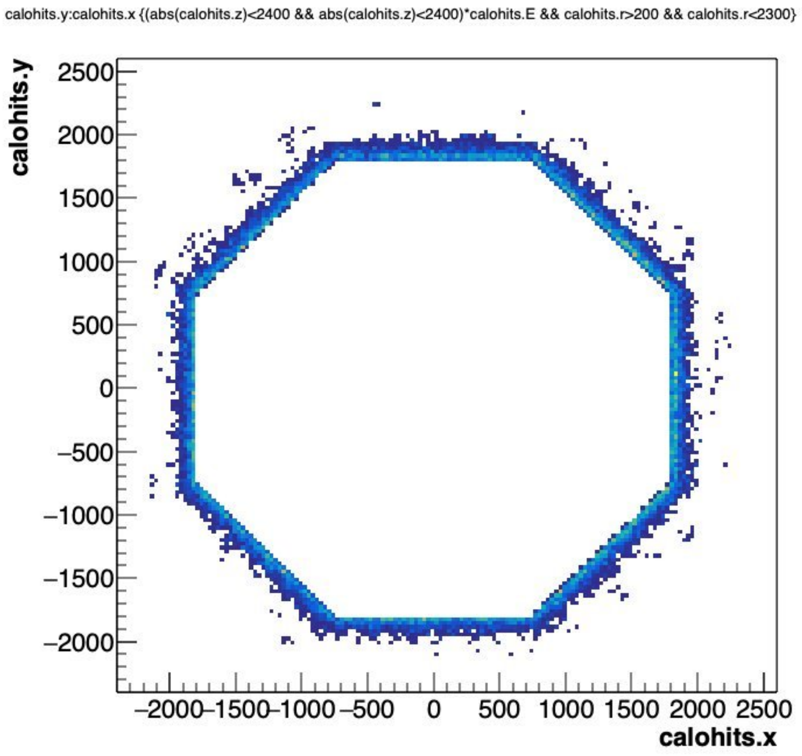
Key4hep: All Calorimeter hit collection:





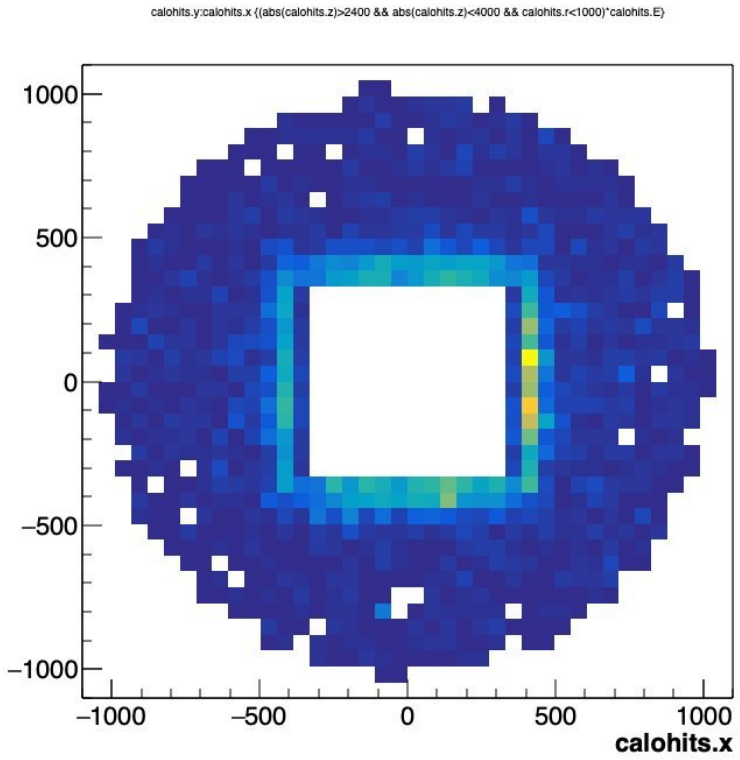
Asymmetry in central calorimeters

ECAL barrel



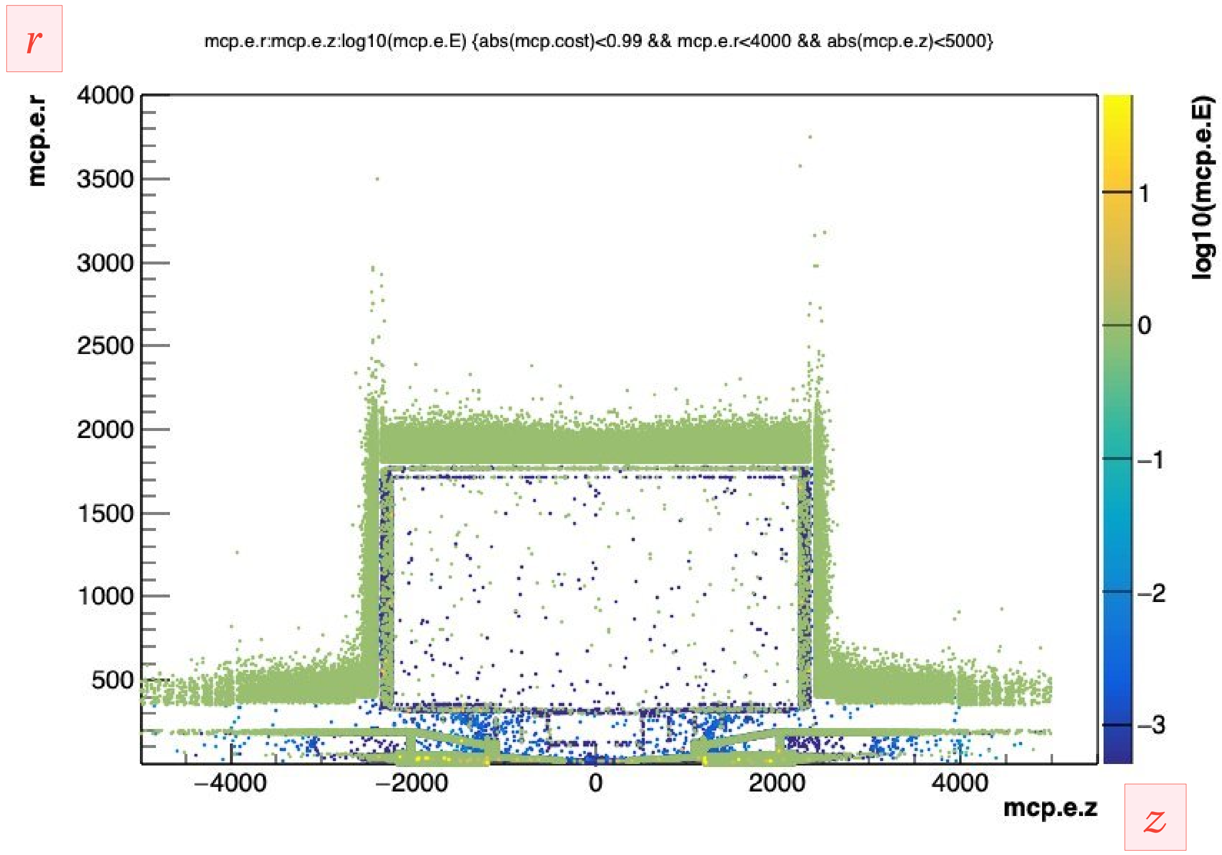
HCAL endcaps

- A slight asymmetry can be observed
  - Significant ?



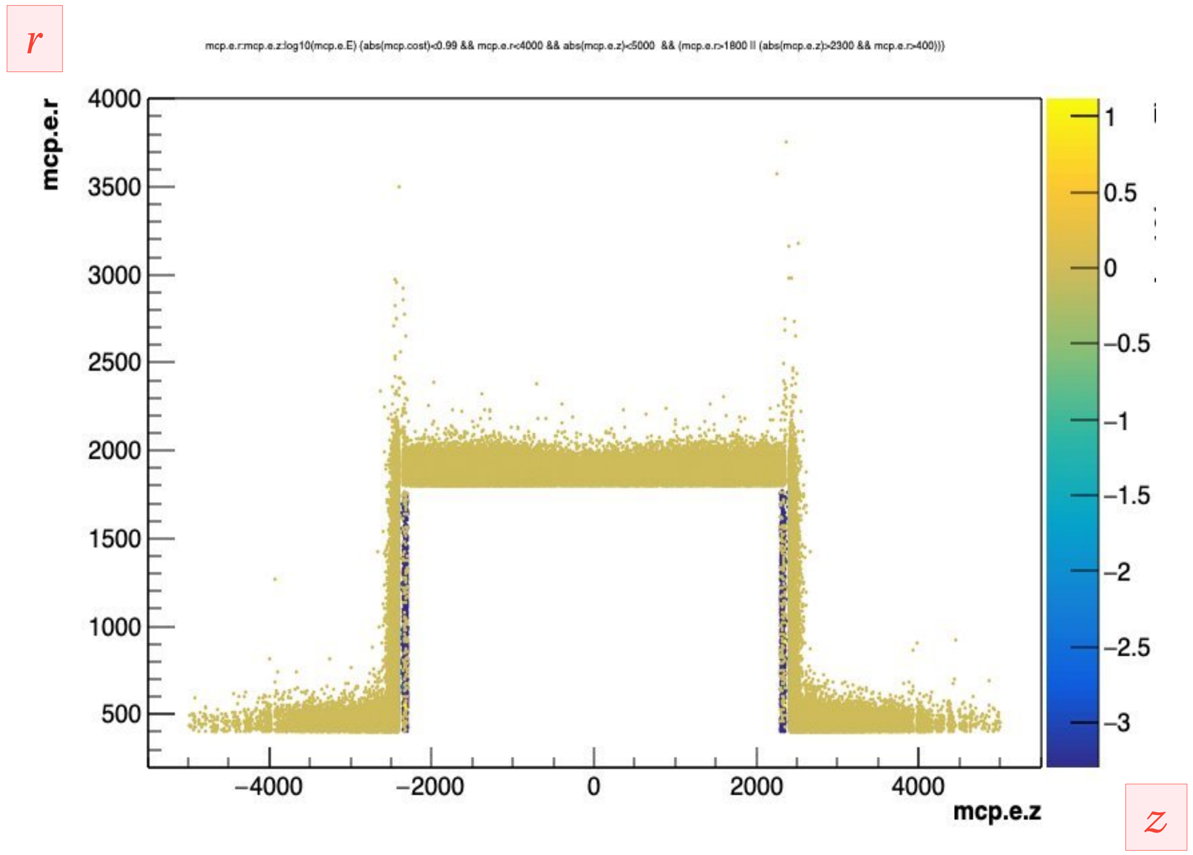
MCparticle EndPoints

r-z (in detector) × log10(E) (Initial)



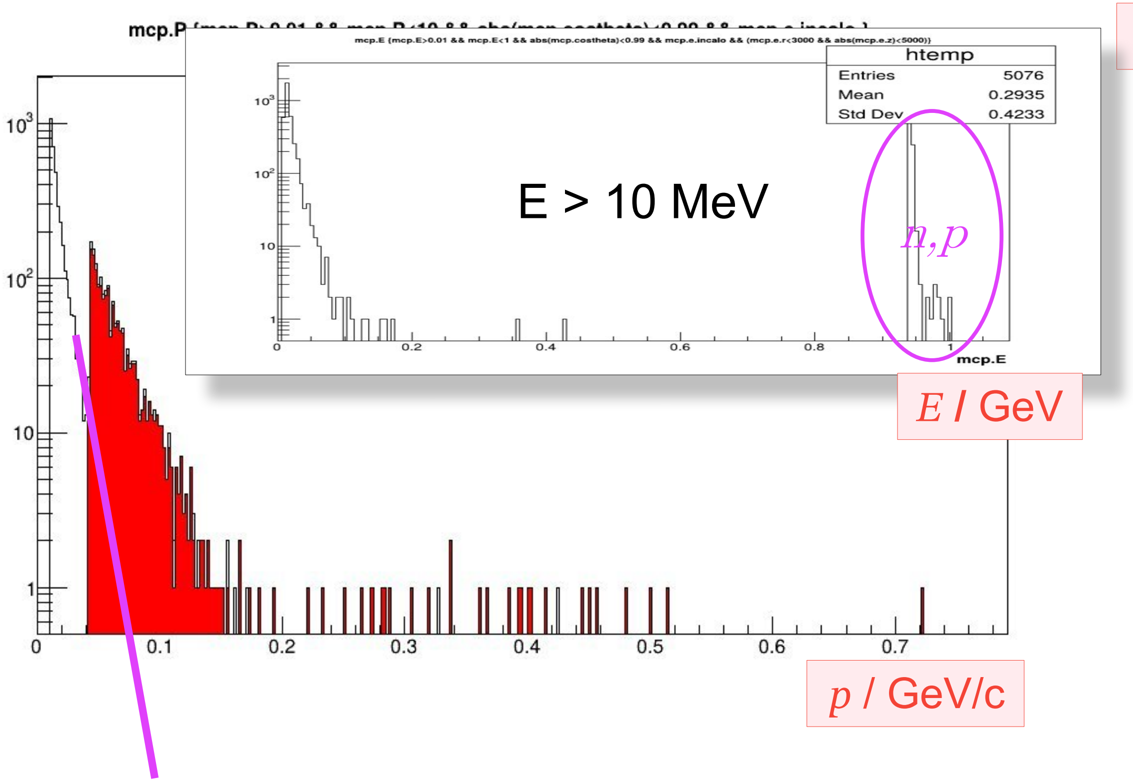
Same for calor only

- E from 1MeV – 1 GeV

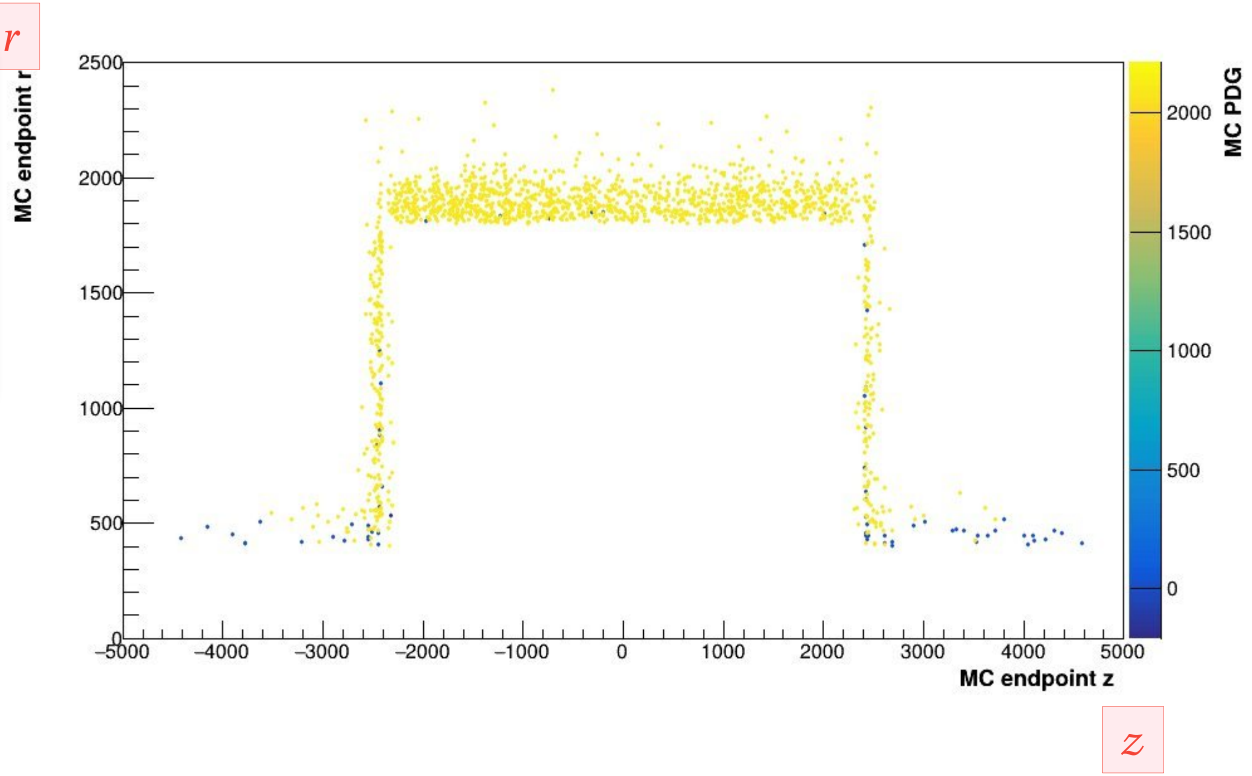


Particle momentum in calo

Low energy photons <10 MeV



Most particles (>10 MeV) in-calo are low energy neutrons



γ population dies off at 100 MeV ~ cutoff ot current SiW-ECAL (2.1 mm of W first)
Low momentum n could probably be easily eliminated by their ToF.

ECAL adaptation : preliminary thermal studies

© Oscar Ferreira @ LLR

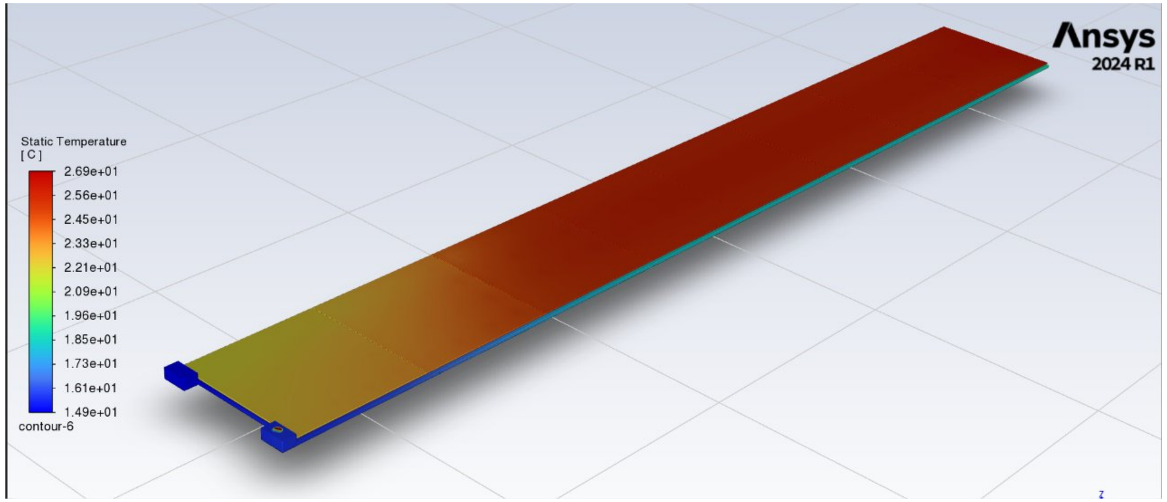
"Standart Slab":

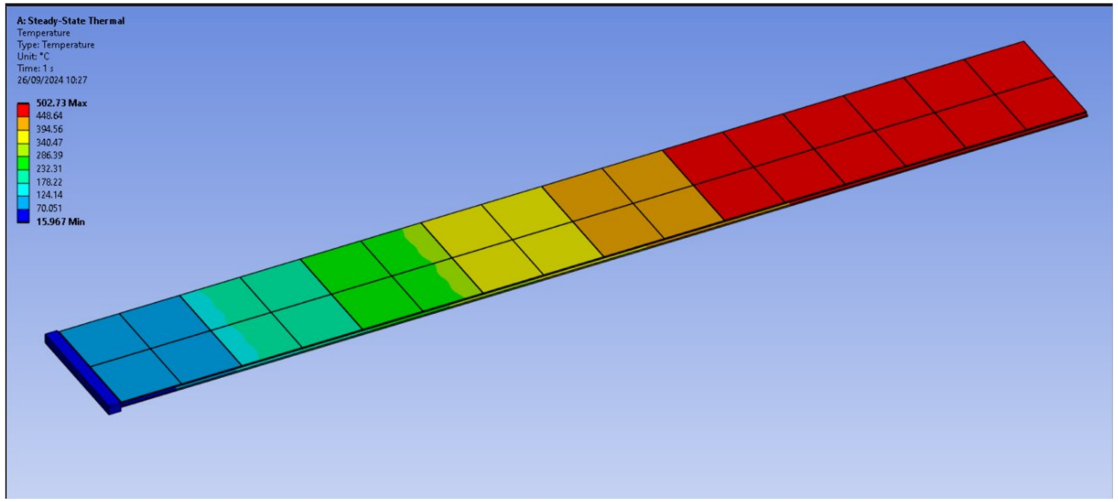
- 8 ASU (1440mm), 8192 ch / 128 ASICs
- 100 W

Passive cooling: Cu of 2mm (W, C ignored)

Adiabatic, but for heat bridge at the end

ΔT = 500°C on Wafer surface at *t* = ∞





"Standart Slab":

- 8 ASU (1440mm), 8192 ch / 128 ASICs
- 128 W (1W/ASIC ~16 mW /ch)

Active cooling:

- Hollowed Cu of 4mm, with 1 ℓ /min of water @ 15°C

Adiabatic, but for heat bridge at the end

ΔT = 12°C on Wafer surface at *t* = ∞

Conclusion

Done

Flux determinations

- Simulated detector-level data for main physics processes and machine background at 91.2 GeV and 240 GeV.
  - Simulated detector-level data for all physics processes but not machine background at 162.5 GeV and 365 GeV.
- Generated primary, secondary 1D and 2D histograms in 11 systems of ECAL and HCAL of the ILD calorimeters
- Merged different processes and background and got collective histograms.
- Early conclusion on the ECAL

Conclusions or the ECAL:

- The power is ≥90% driven by the continuous component even in the endcaps sections for SKIROC2 ASICs in CC
- Machine background / BX much higher in the FCC-ee config.

To be done

Simulation:

- Resimulate with new model (and 2T B field).
- Simulate in the IRIS Geometry
- Machine background
  - at 162.5 GeV and 365 GeV
  - More statistics at 91.2 GeV and 240 GeV
  - Check for $\gamma\gamma \rightarrow VV$ contributions

Results:

- Automate the occupancy and power for all calorimeters
- Include digitization (on going with key4HEP) in timing studies
- Determine the exact precision on timing ➞ ASIC
  - Power ~ $1/\sigma_t$. 1mW/ch for 1ns ➞ 30 mW for 30 ps ?

Extras

ee Higgs factories: configs & backgrounds

Running mode	Z		W	ZH	$t\bar{t}$
Number of IPs	2	4	4	4	4
Beam energy (GeV)	45.6		80	120	182.5
Bunches/beam	12000	15880	688	260	40
Beam current [mA]	1270	1270	134	26.7	4.94
Luminosity/IP [10^{34} cm^{-2} s^{-1}]	180	140	21.4	6.9	1.2
Energy loss / turn [GeV]	0.039	0.039	0.37	1.89	10.1
Synchr. Rad. Power [MW]			100		
RF Voltage 400/800 MHz [GV]	0.08/0	0.08/0	1.0/0	2.1/0	2.1/9.4
Rms bunch length (SR) [mm]	5.60	5.60	3.55	2.50	1.67
Rms bunch length (+BS) [mm]	13.1	12.7	7.02	4.45	2.54
Rms hor. emittance $\varepsilon_{x,y}$ [nm]	0.71	0.71	2.16	0.67	1.55
Rms vert. emittance $\varepsilon_{x,y}$ [pm]	1.42	1.42	4.32	1.34	3.10
Longit. damping time [turns]	1158	1158	215	64	18
Horizontal IP beta β_x^* [mm]	110	110	200	300	1000
Vertical IP beta β_y^* [mm]	0.7	0.7	1.0	1.0	1.6
Beam lifetime (q+BS+lattice) [min.]	50	250	—	<28	<70
Beam lifetime (lum.) [min.]	35	22	16	10	13

Tor Raubenheimer, FCC Week June 2023

P. Bambade et al., The International Linear Collider: A Global Project, arXiv:1903.01629 [Hep-Ex, Physics:Hep-Ph, Physics:Physics]. (2019).

Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	TDR	Upgrades	
Centre of mass energy	$\sqrt{s}$	GeV	250	250	250	500	1000
Luminosity	$\mathcal{L}$	10^{34}cm^{-2}s^{-1}	1.35	2.7	0.82	1.8/3.6	4.9
Polarisation for $e^-(e^+)$	$P_-(P_+)$		80 %(30 %)	80 %(30 %)	80 %(30 %)	80 %(30 %)	80 %(20 %)
Repetition frequency	f_{rep}	Hz	5	5	5	5	4
Bunches per pulse	n_{bunch}	1	1312	2625	1312	1312/2625	2450
Bunch population	N_e	10^{10}	2	2	2	2	1.74
Linac bunch interval	Δt_b	ns	554	366	554	554/366	366
Beam current in pulse	I_{pulse}	mA	5.8	5.8	8.8	5.8	7.6
Beam pulse duration	t_{pulse}	μs	727	961	727	727/961	897
Average beam power	P_{ave}	MW	5.3	10.5	10.5	10.5/21	27.2
Norm. hor. emitt. at IP	$\gamma\epsilon_x$	μm	5	5	10	10	10
Norm. vert. emitt. at IP	$\gamma\epsilon_y$	nm	35	35	35	35	30
RMS hor. beam size at IP	σ_x^*	nm	516	516	729	474	335
RMS vert. beam size at IP	σ_y^*	nm	7.7	7.7	7.7	5.9	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$		73 %	73 %	87.1 %	58.3 %	44.5 %
Energy loss from beamstrahlung	δ_{BS}		2.6 %	2.6 %	0.97 %	4.5 %	10.5 %
Site AC power	P_{site}	MW	129		122	163	300
Site length	L_{site}	km	20.5	20.5	31	31	40

TABLE I: Summary table of the ILC accelerator parameters in the initial 250 GeV staged configuration (with TDR parameters at 250 GeV given for comparison) and possible upgrades. A 500 GeV machine could also be operated at 250 GeV with 10 Hz repetition rate, bringing the maximum luminosity to $5.4 \cdot 10^{34}$ cm^{-2}s^{-1} [10].

Summary of Backgrounds

The background sources have been investigated in various studies. For example, the beam-beam interaction and pair generation, radiative Bhabhas, disrupted beams and beamstrahlung photons for the 500 GeV ILC were studied with GUINEAPIG [333]. Also, the $\gamma\gamma$ hadronic cross section was approximated in the Peskin-Barklow scheme [2]. Based on these studies densities of particles which will reach the different sun-detectors have been estimated. Table I-1.3 summarises these estimates.

Table I-1.3 Background sources for the nominal 500 GeV beam parameters.

Source	#particles per bunch	< E > (GeV)
Disrupted primary beam	2×10^{10}	244
Bremstrahlung photons	2.5×10^{10}	244
e^+e^- pairs from beam-beam interactions	75k	2.5
Radiative Bhabhas	320k	195
$\gamma\gamma \to$ hadrons/muons	0.5 events/1.3 events	–

T. Behnke, et al.
The International Linear Collider Technical Design Report - Volume 4: Detectors,
arXiv:1306.6329 [Physics]. (2013)

Machine backgrounds

Files produced by Andrea Ciarma at Z-peak and Top threshold

```
 =-=-=-=-=-=-=-=-=-=-=-=-=-=-=
  =  A. Ciarma -- 13/12/2022  =
  =-=-=-=-=-=-=-=-=-=-=-=-=-=-=

Incoherent Pairs Creation (IPC) output files from GuineaPig++ for FCC-ee 4IP lattice
nominal beam energy: 45.6GeV @Z   -   182.5GeV @Top

Each file corresponds to pairs created during 1BX
each line corresponds to a particle

The format of the line is:

m_input >> PHEP4                   // energy [GeV]
      >> PHEP1 >> PHEP2 >> PHEP3         // momentum component [rad]
      >> VHEP1 >> VHEP2 >> VHEP3         // vertex coordinates [nm]
      >> process >> trash >> id_ee;      // process type; internal flag; id of the single particle - all useless for tracking in the detector

Charge and PID should be manually set, according to the sign of the energy

PHEP4>0  ->  IDHEP = 11;  CHARGE =-1;
PHEP4<0  ->  IDHEP =-11;  CHARGE = 1;

A Lorentz boost should be applied along X to account for the fact that GP produces particles in the rest frame of the two beams,
which due to the crossing angle (15 mrad) moves w.r.t. the detector.
```

Histograms Types

Primary histograms:

1) **Low-Scale Energy**: Energy distribution of hits with an upper-bound
2) **Upper-Scale Energy**: Complementary distribution to show the tailing effects (with auto-rescaling)
3) **Low-Scale Number of hits**: Number of hits above a given energy threshold per event (adjusted per system ~ ¼ MIP)
4) **Upper-Scale Number of hits**: The complementary distribution with auto-rescaling
5) **Time**: Time distribution of the sub hits weighted with the corresponding energy.

```
System
"SiECalEndcap":
"SiECALBarrel":
"SiECalRing": (
"ScECalEndcap":
"ScECALBarrel":
"RPCHCalEndcap"
"RPCHCalBarrel"
"RPCHCalECRing"
"ScHCalEndcap":
"ScHcalBarrel":
"ScHCalECRing":
```

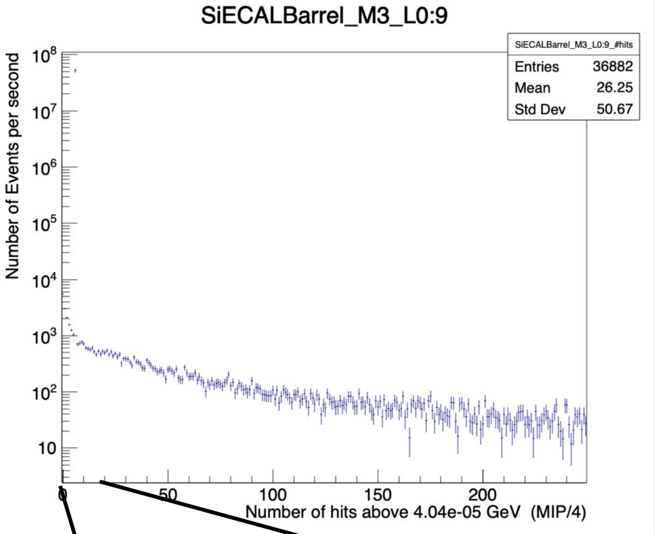
11 calorimeter systems

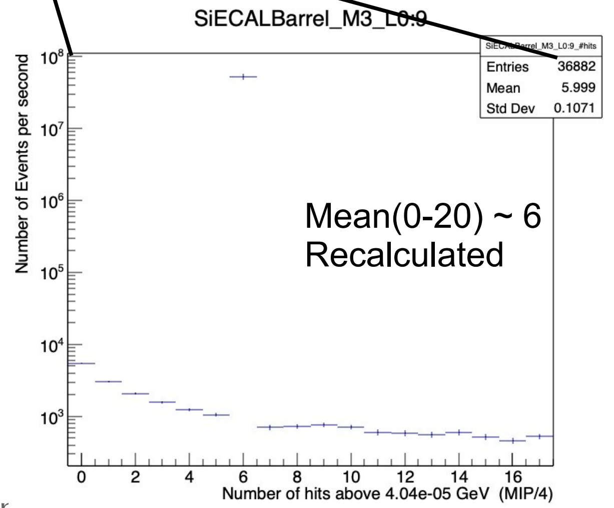
Secondary histograms (functions of primary histograms):

6) **Upper Scale Energy rates in MIPs**: The same distribution as the Upper-Scale Energy histogram with the x-axis scaled by the MIP value.
7) **Full Scale Hits rates**: Number of hits per region from Low and high scales
8) **Full Scale Power**: base power + conversion energy per hit [TBD, based on ASICs characteristics]

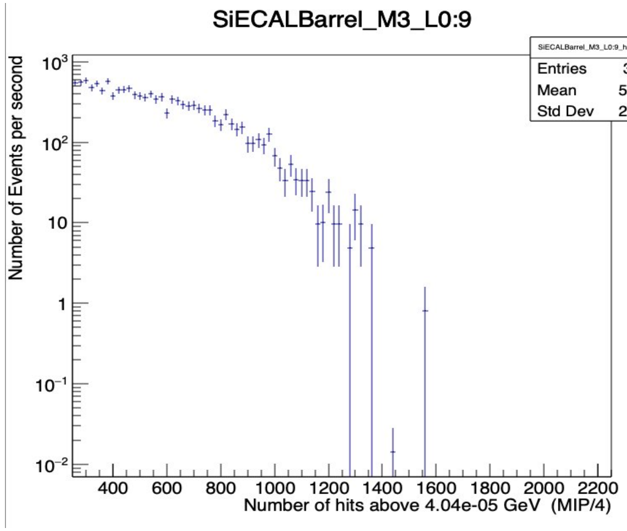
Mean calculations from histograms

Low #hits & Zoom



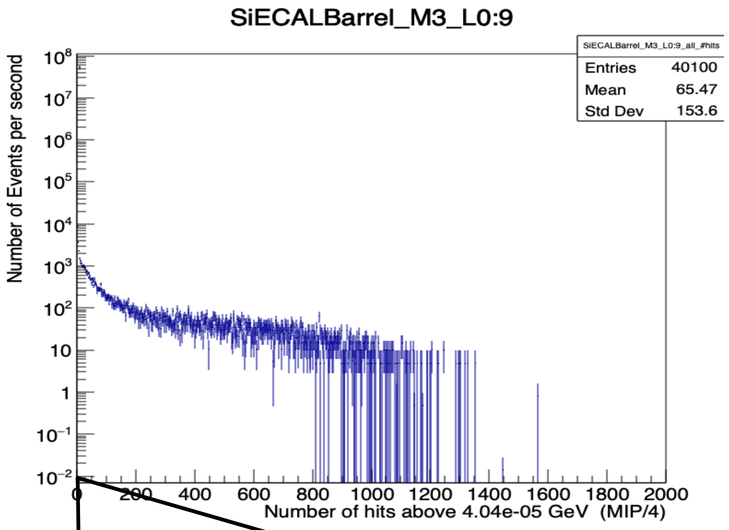


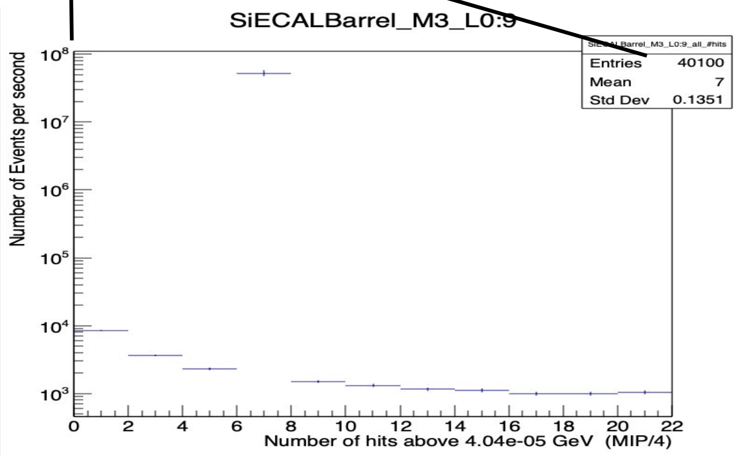
High #hits



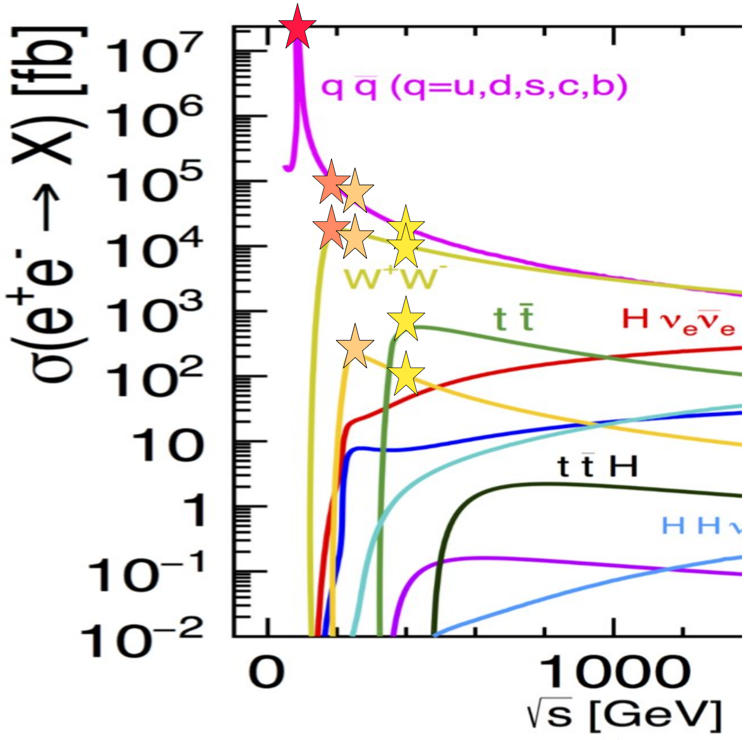
From All.root.	
Low Stat	36882
Low Mean	26,25
Low Integral	5,27E+07
High Stat	3218
High mean	514,2
High Integral	1,22E+04
L+H Stat	40100
L+H mean	26,36
L+H integral	52662220
All Stat	40100
All Average	65,47
All integral	5,27E+07

All #hits & Zoom





Selected modes



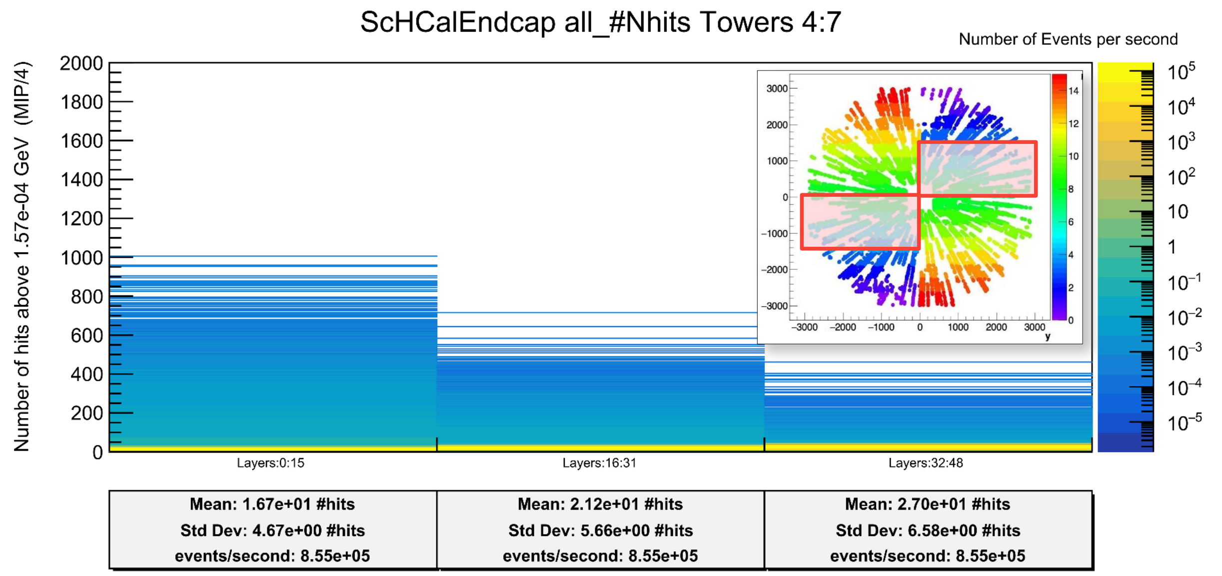
Processes: min. bias

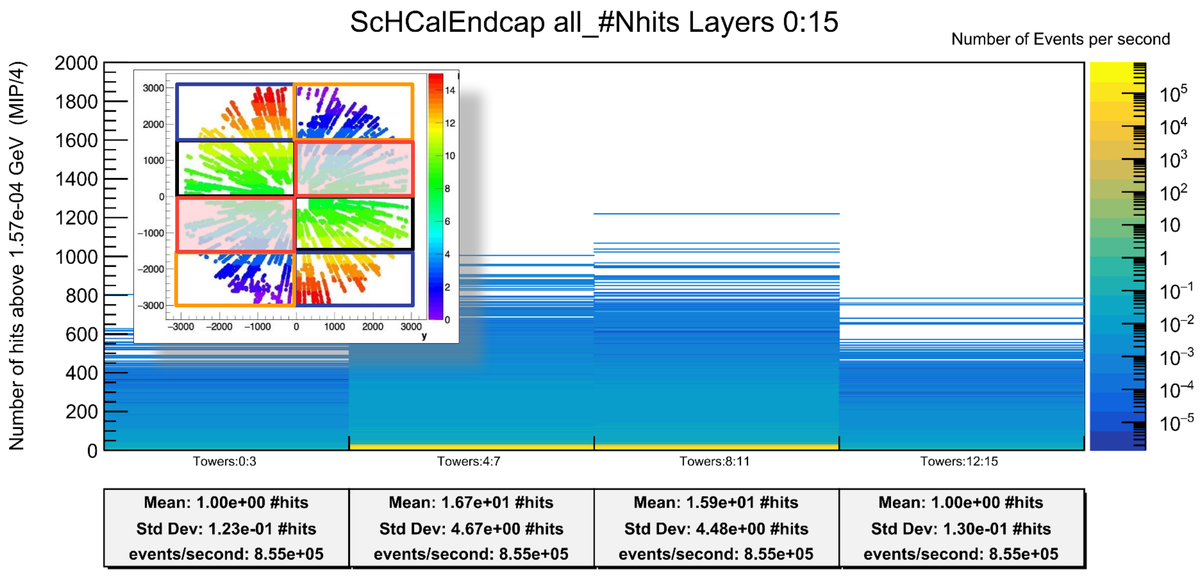
- All
  - ee → qq
  - ee → $\mu\mu$, $\tau\tau$
  - ee → ee (⊃ Bhabha)
  - $\gamma\gamma$→ VV
  - Machine background (ee pairs)
- $E_{CM} \geq$ 160 GeV
  - ee → WW
- ($E_{CM} \geq$ 240 GeV)
  - ee → HZ
- ($E_{CM} \geq$ 360 GeV)
  - ee → tt

Config	#IP	E_{Beam}	#BX	$\mathcal{L}$ [10^{34}/cm²/s]	ΔT [μs]	Freq[Hz]	√s [GeV]
FCC-Z2	2	45,6	12000	180,0	0,025		91,2
FCC-Z4	4	45,6	15880	140,0	0,019		91,2
FCC-W	4	81,3	688	21,4	0,442		162,5
FCC-ZH	4	120,0	260	6,9	1,169		240,0
FCC-tt	4	182,5	40	1,2	7,600		365,0
ILC250 [1]	1	125,0	1312	1,4	0,554	5,0	250,0
ILC500	1	250,0	1312	1,8	0,554	5,0	500,0
ILC1000	1	500,0	2450	4,9	0,366	5,0	1000,0
CLIC380	1	160,0				10,0	380,0
ILC-GZ	1	45,6				5,0	91,2
ILC250-HL	1	125,0	2625	2,7	0,366	5,0	250,0
CEPC							
C^3							
⋮							

ILC from: P. Bambade et al., The International Linear Collider: A Global Project, arXiv:1903.01629 [Hep-Ex, Physics:Hep-Ph, Physics:Physics]. (2019).
FCC from: Tor Raubenheimer, FCC Week June 2023

Results: Scintillator HCAL Endcap





Average	14E+6 hits/s	18E+6 hits/s	23E+6 hits/s	855E+3 hits/s	1E+6 hits/s
MaxNhits	1000 Nhits/event	600 Nhits/event	400 Nhits/event	400 Nhits/event	400 Nhits/event
for 6B/hits	86E+6 B/s	109E+6 B/s	139E+6 B/s	5E+6 B/s	9E+6 B/s
Est. Ncells	278 756	278 756	278 756	?	278 756
Occupancy/BX	1,0E-06	1,3E-06	1,7E-06	?	1,0E-07
cell size	30				

Note 1 : Very preliminary

Note 2 : Rates for all tower 4:7 modules ➞ /4 per module, /16 per layer

Distributions of the number of hits crossing (MIP/4) energy threshold of all the physics processes and machine background at 91.2 GeV (FCC-Z4) with the color bar representing the rate of events

- **Max of the hits rate are in the first 2 thirds of the calorimeter, but in average more in the back (!)**
- **Significant angular dependence.**
- **The central towers have most of the hits due to the closeness to the beam pipe.**