# Occupancy and Bandwidth requirements for highly granular calorimeters at FCCee

*V. Boudry*, K. Hassouna[a]*

**Institut Polytechnique de Paris**

[a] IPP PSEI and U. of Manoa (USA), now PhD at Khalifa U. (UAE)

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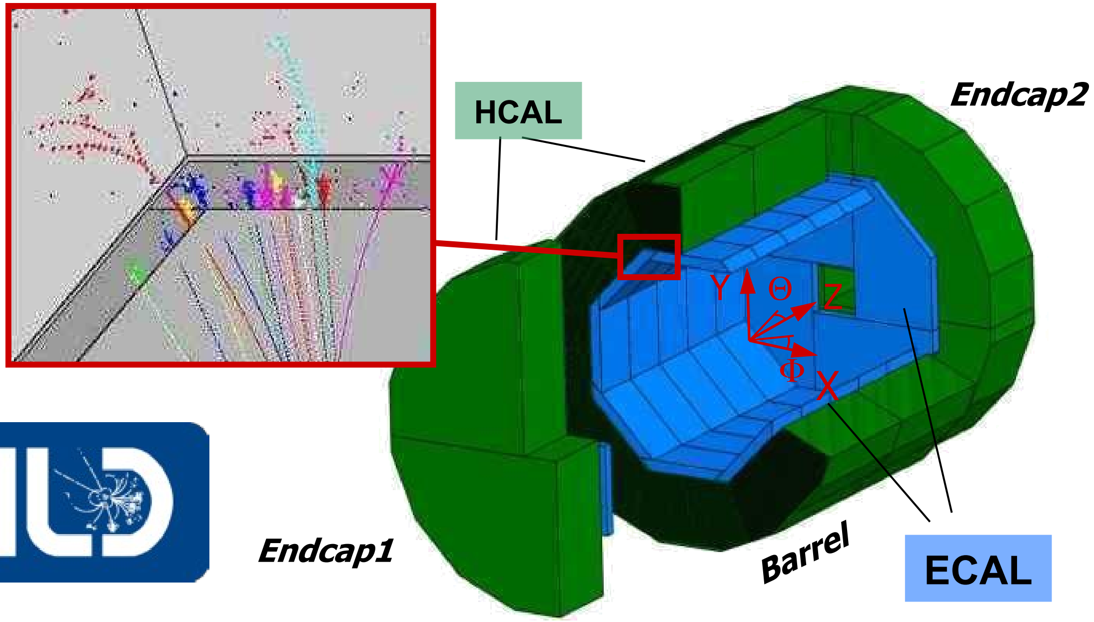
# Rationale for HG calorimeters: ILD as an example

## ILD high granularity calorimeters

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




**ECAL:** 30 layers

- SiW-ECAL": Si cells $0.5 \times 0.5\,cm^2$
- ScECAL: Scint strips $0.5 \times 5.0\,cm^2$

**10–100M channels**

**HCAL:** 48 layers

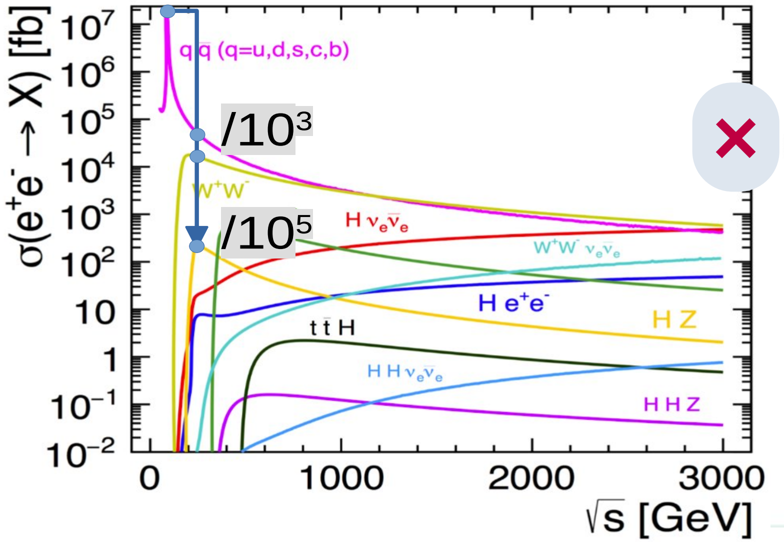
- AHCAL: scint. cells $3 \times 3\,cm^2$
- SDHCAL: RPC cells $1 \times 1\,cm^2$

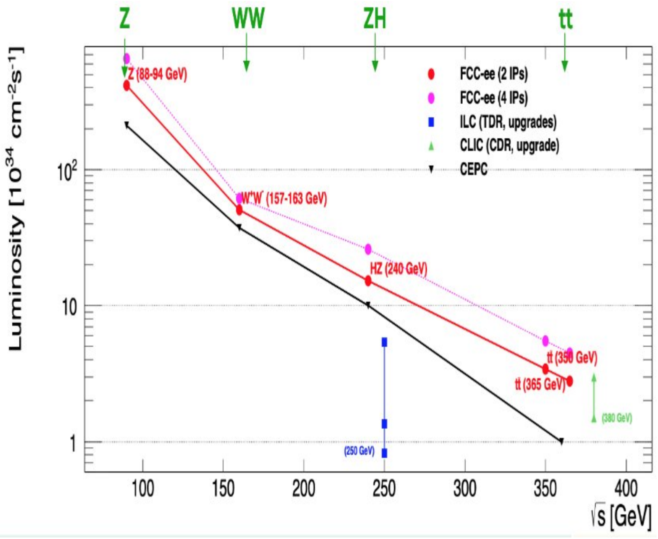
**10–70M channels**

# 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 × 20,000 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 ? 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

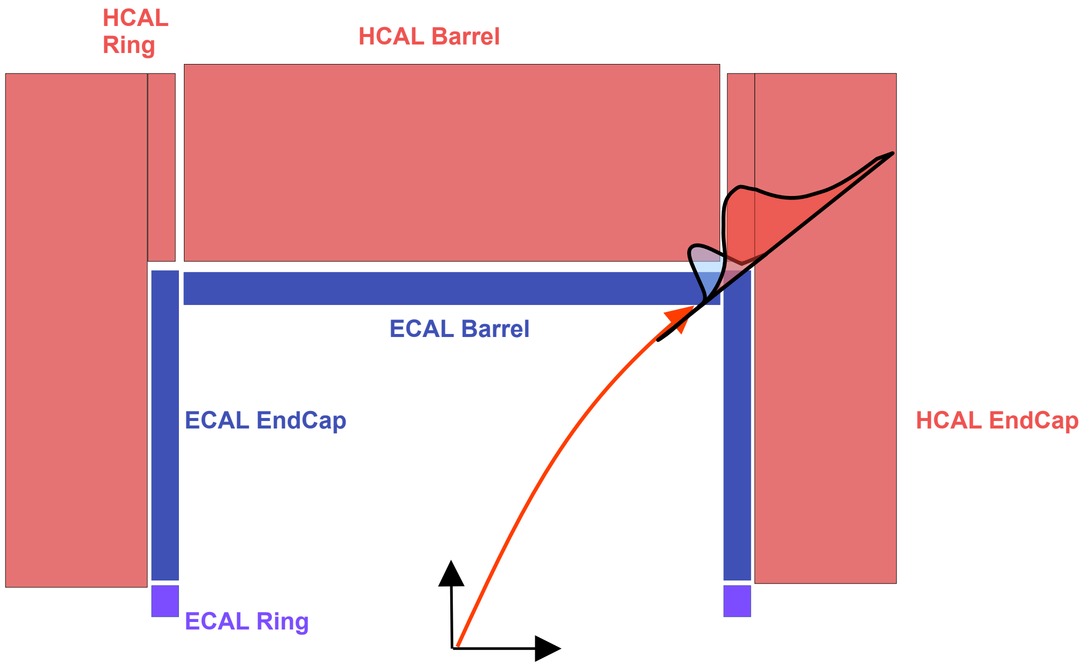
# Calorimeter Fluxes from Full Simulations

## Quantities useful for Self-Triggering & Low Occupancy 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



# CaloFlux Software package

## Python code

### Production of Primary histograms :

- LcioReader from pyLCIO
- Mapping & Selection
  - Cell_id decoding
  - 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.

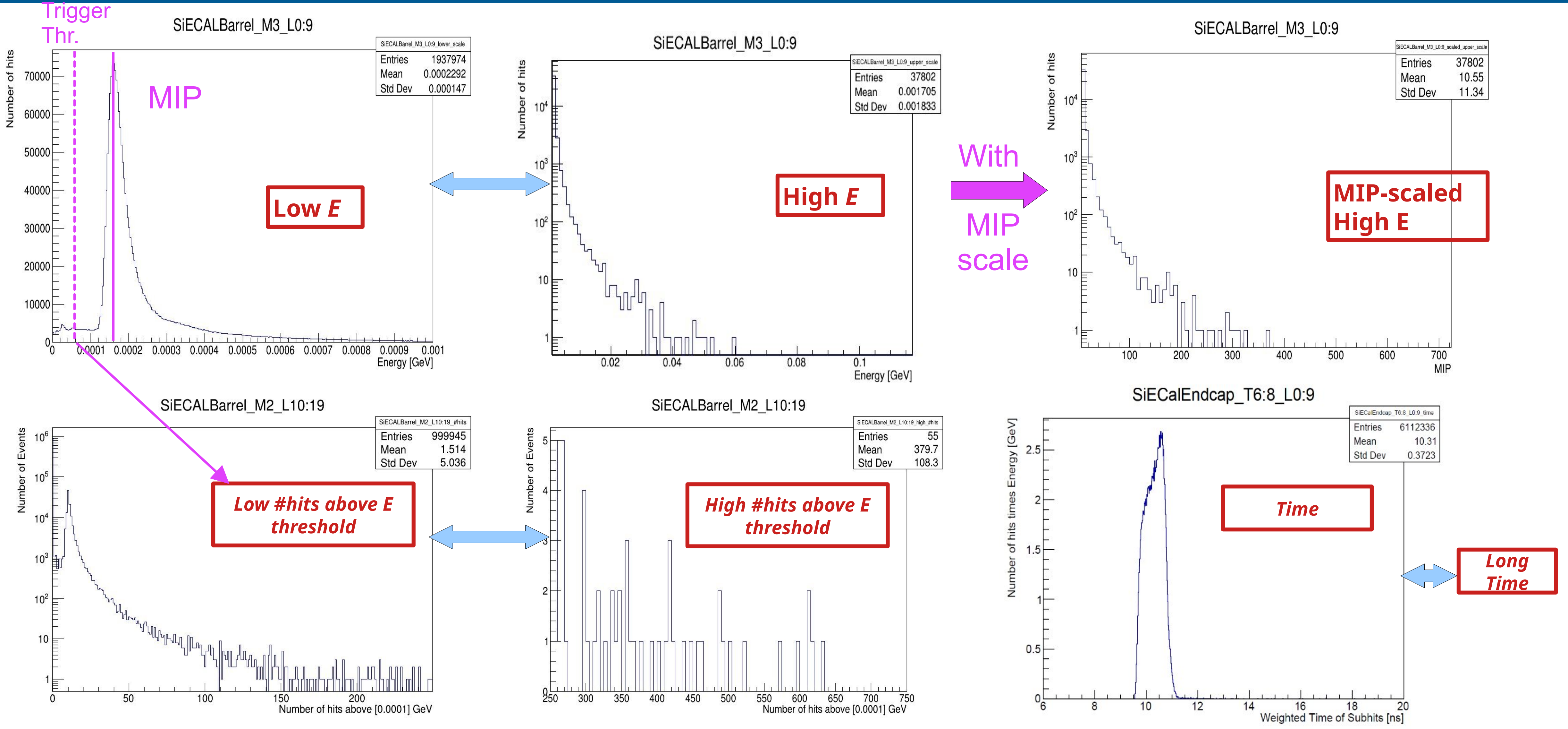
Described in a Technical Report accepted by JINST.

*JINST_006T_0324*

```
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 
#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"],                        [["*"],["*"],                ["*"],                        ["*"]]
        }
```

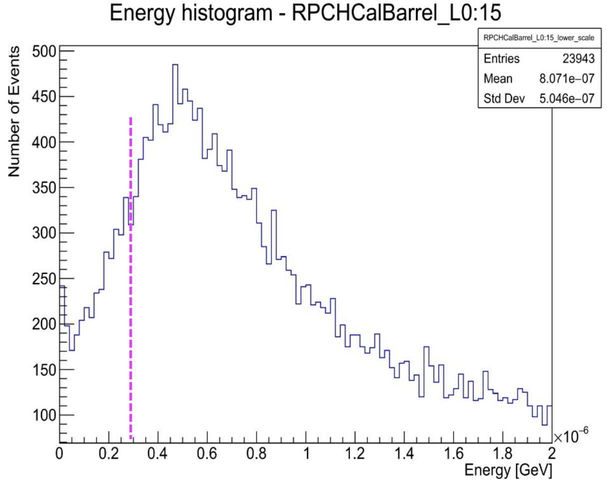
```
highE bin/max  #hits bin/max  EThr  Split Func:ranges
[100, 0.03], [100, 35]], [[0.0001]], {}),
[100, 0.03], [100, 35]], [[0.0001]], {}),
[100, 0.03], [100, 35]], [[0.0001]], {}),
[100, 0.03], [100, 35]], [[0.0003]], {}),
[100, 0.03], [100, 35]], [[0.0002]], {}),
[100, 3e-5], [100, 35]], [[3e-7]], {}),
[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]], {})
```

# Histograms Types (1,000,000 muon events)

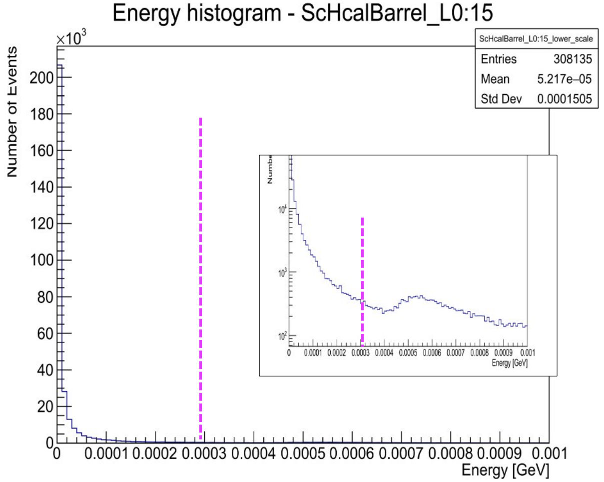


# System Low Energy & #hit responses
raw energies (no digitization yet)

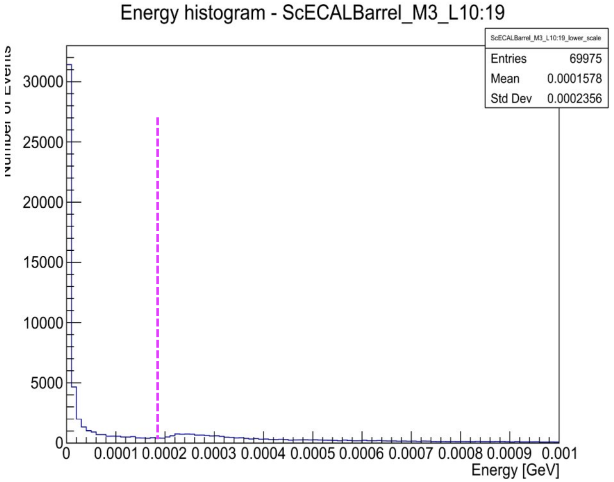
**SDHCAL**



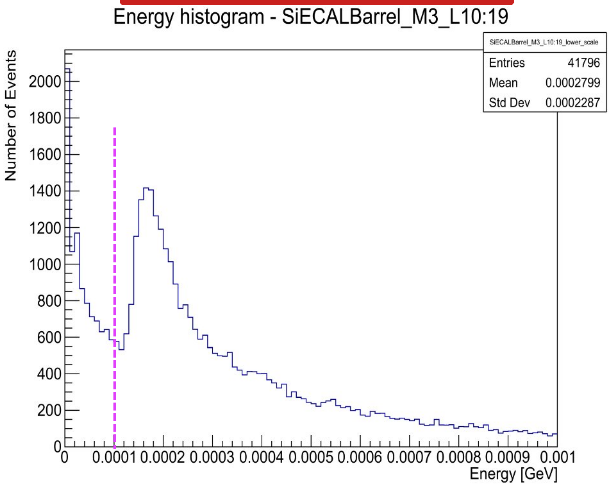

**AHCAL**

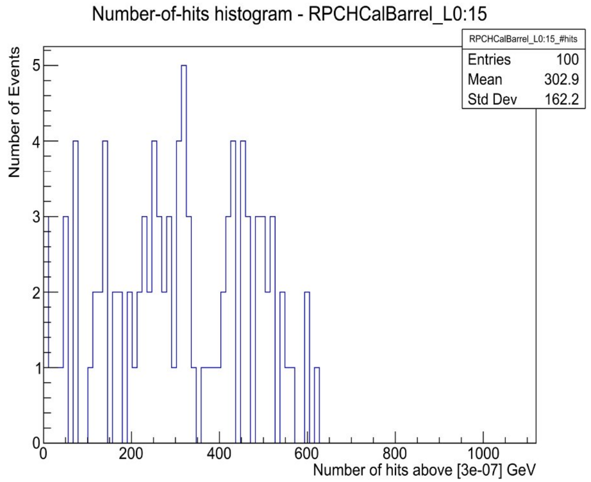


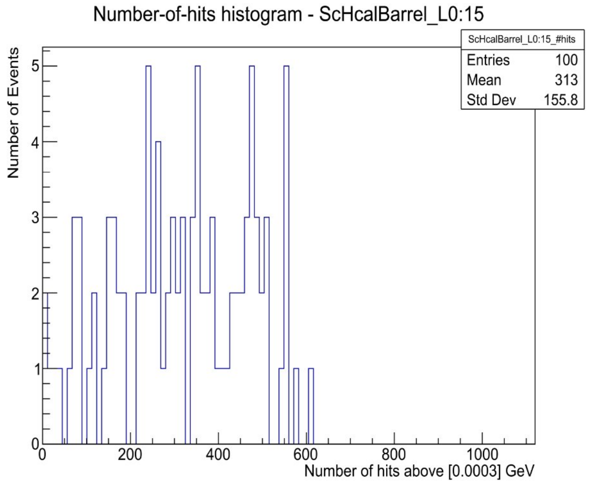

**Sc ECAL**

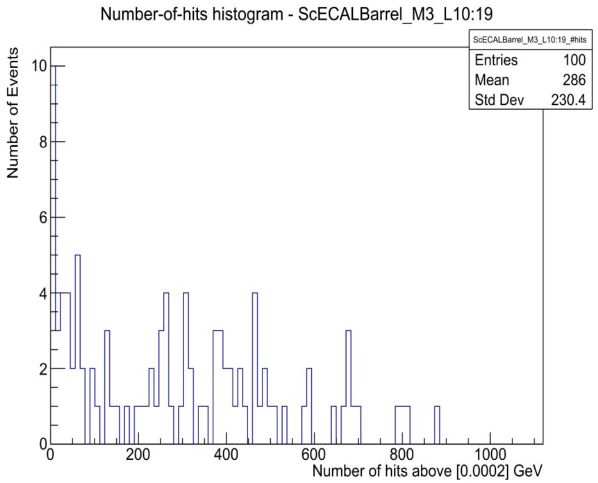


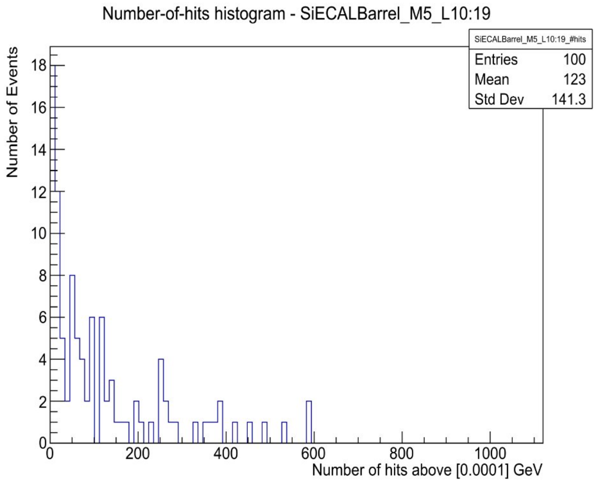

**Si ECAL**



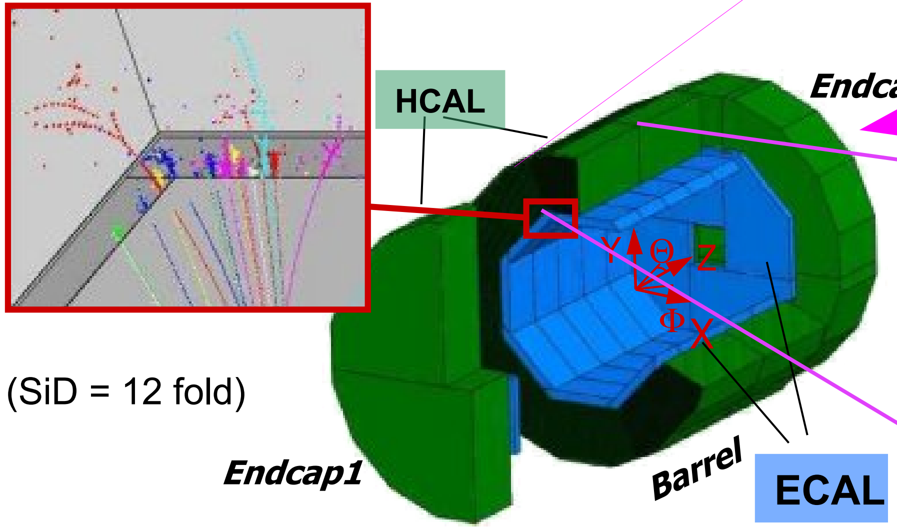



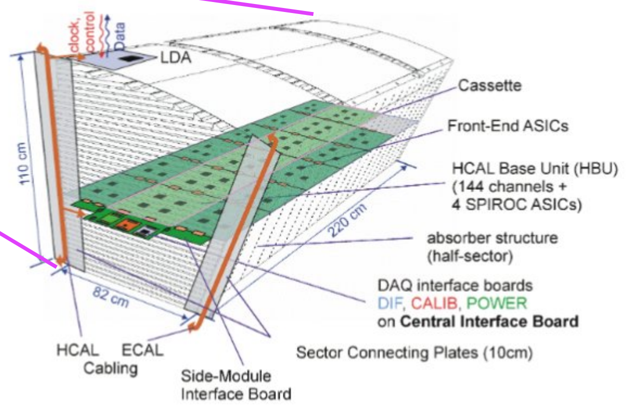



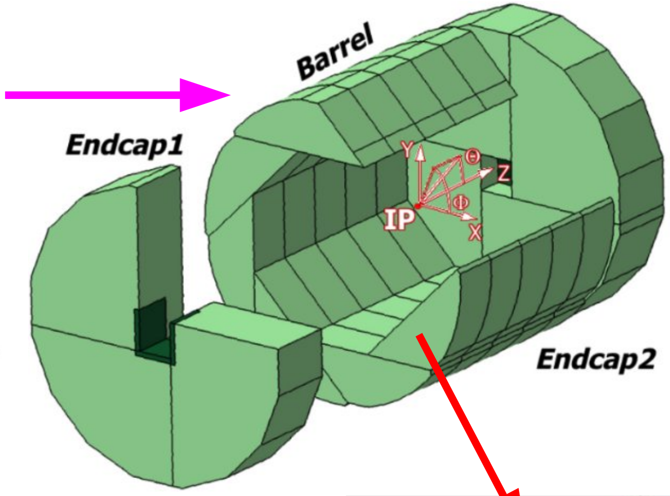
# Geometries & Services

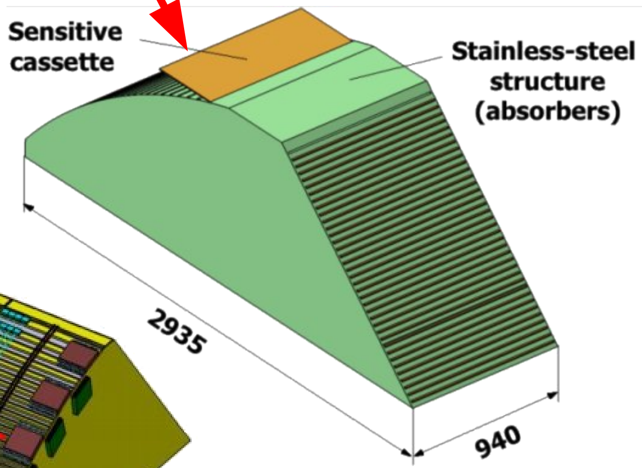


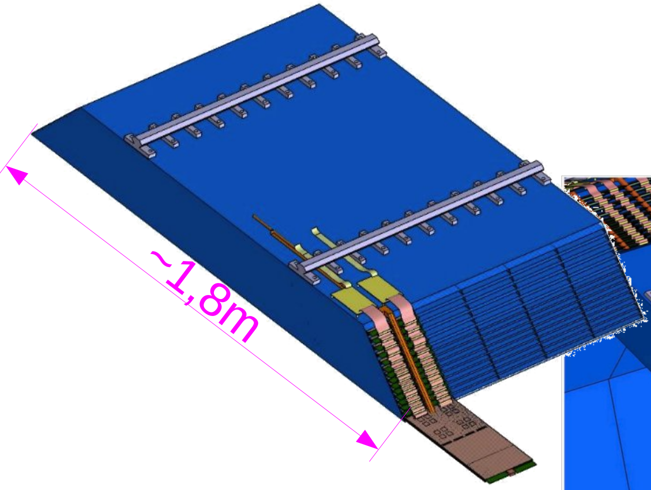

(SiD = 12 fold)

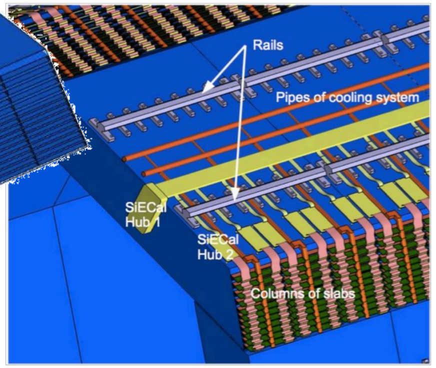
HCAL Geometries:
TESLA or Videau



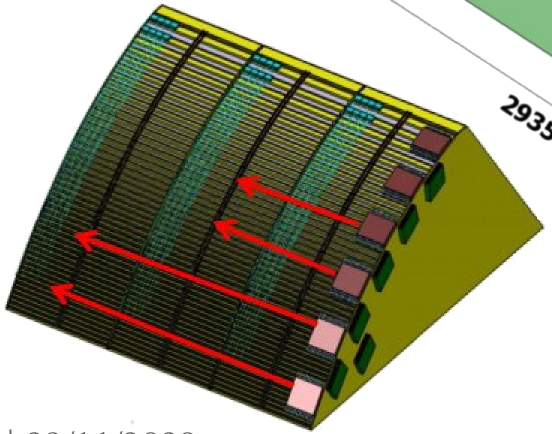



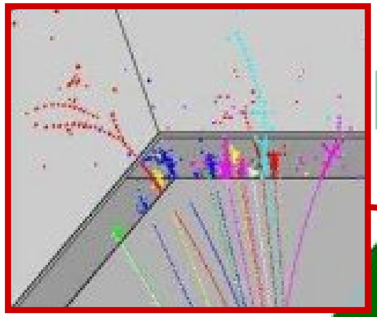



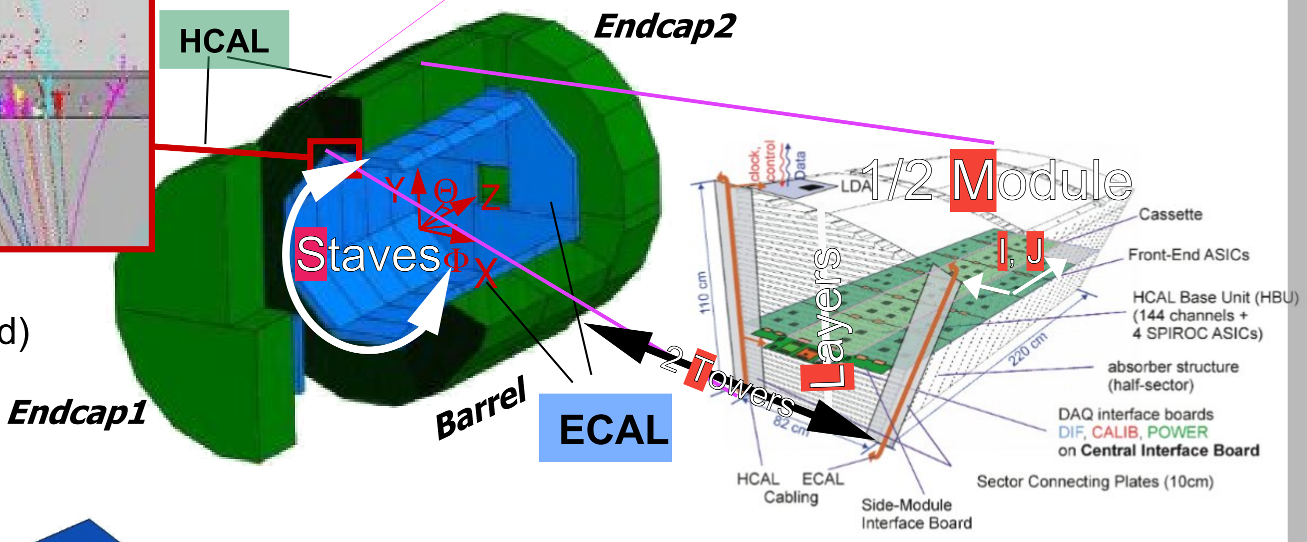

**Common design:**
- **SLABs** with sensors, onboard electronics
- **Daisy-chained I/O**
- **End-of-slab services** (DAQ, Cooling)

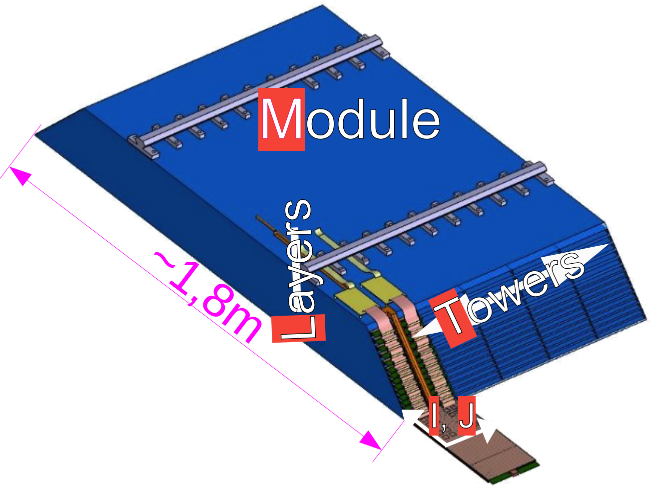


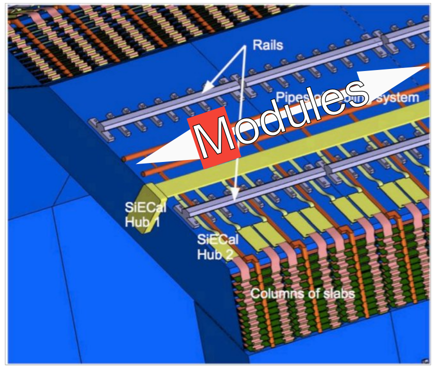
# Geometries : logical numbering

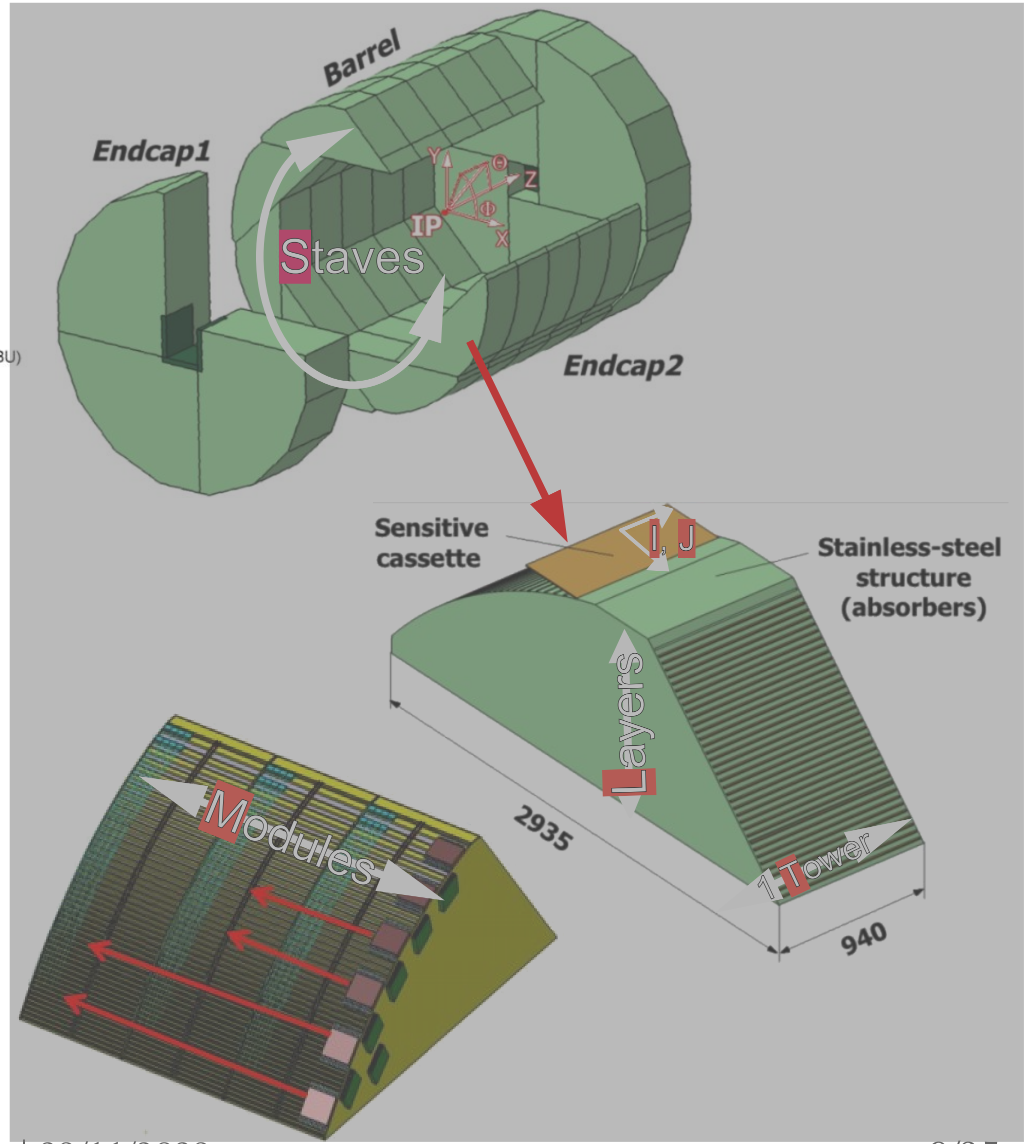


(SiD = 12 fold)



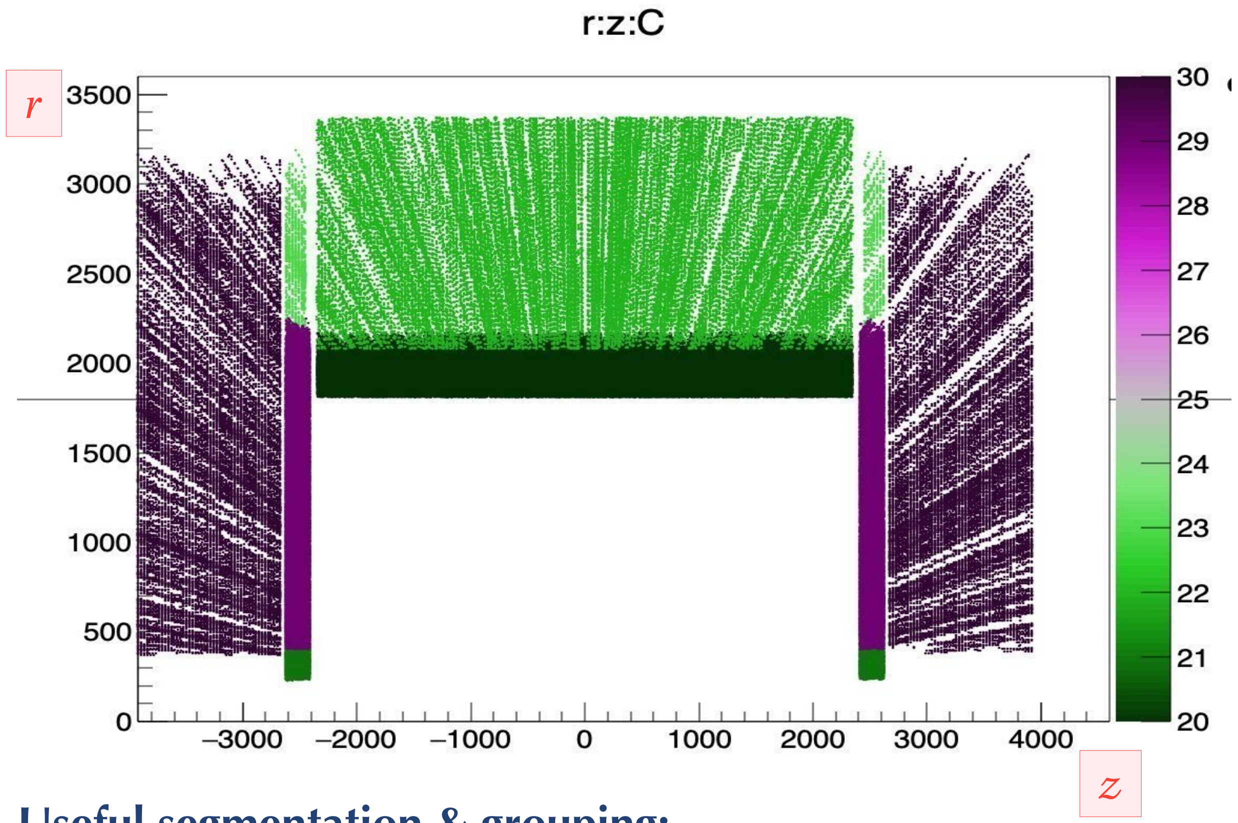



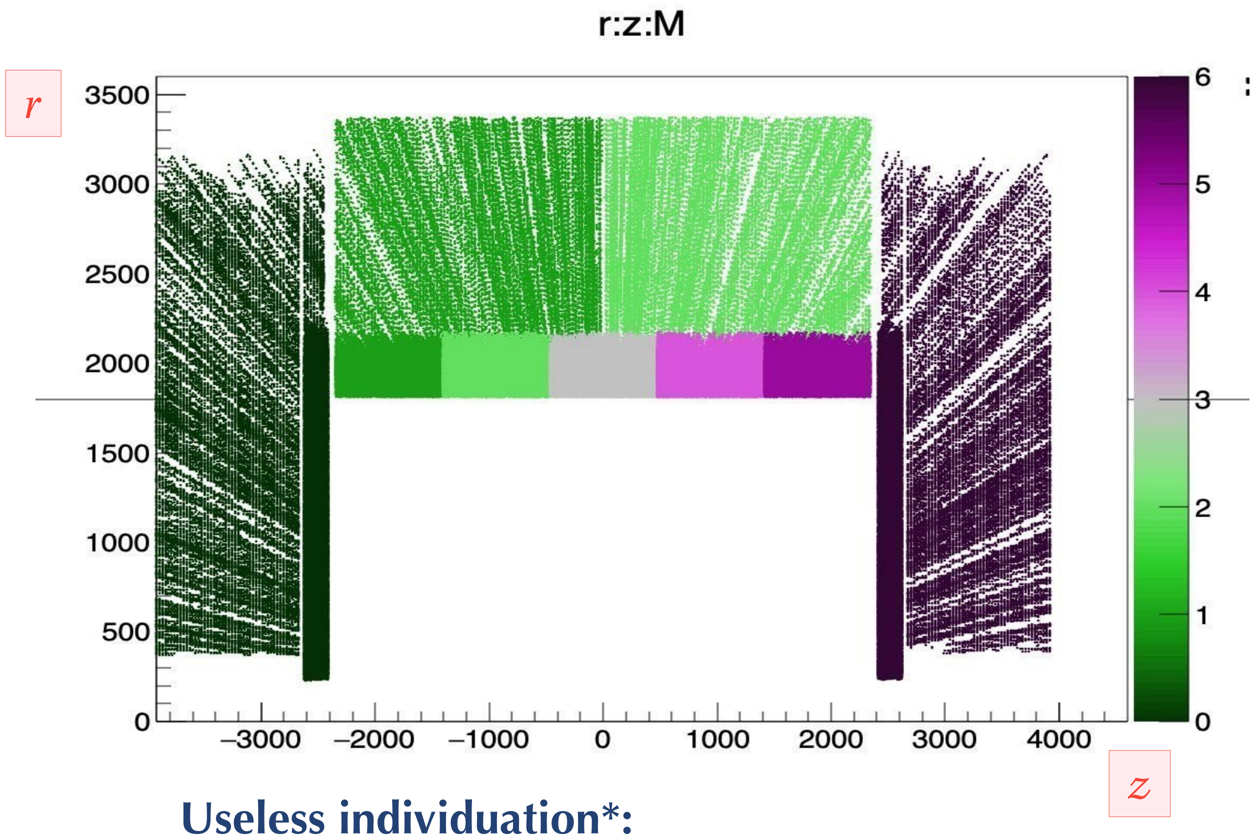



# Segmentation by “Logical Geometry” C:M:S:T:L:I:J

**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*:

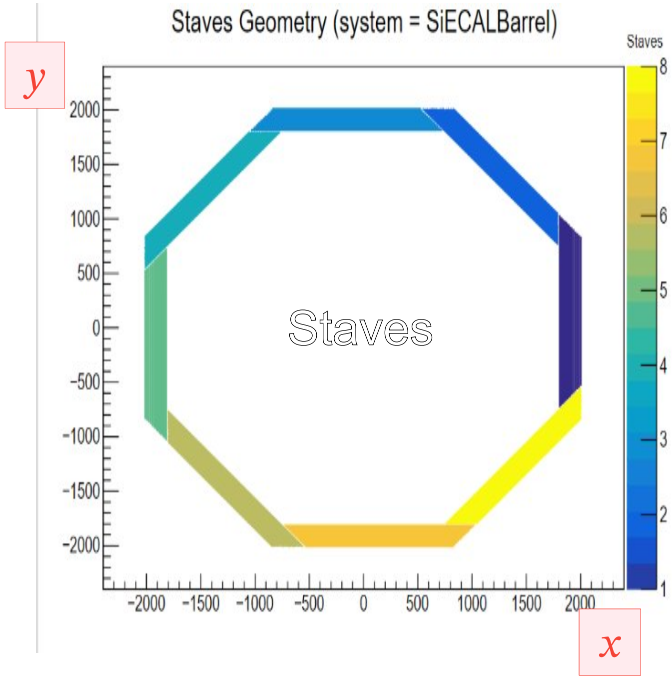
- (Individual layers)
- Symmetrical : staves (ϕ), Forward–Backward (±θ)

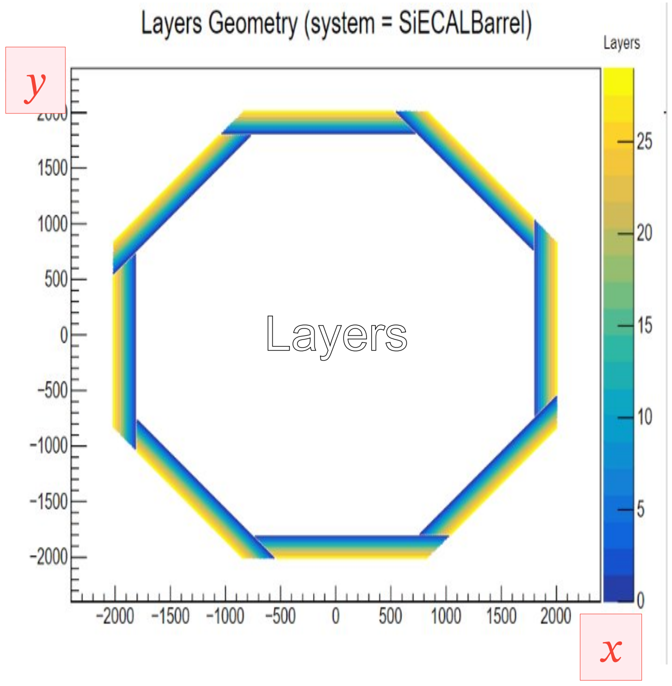
* ***assumming symmetrical physics / background distributions***

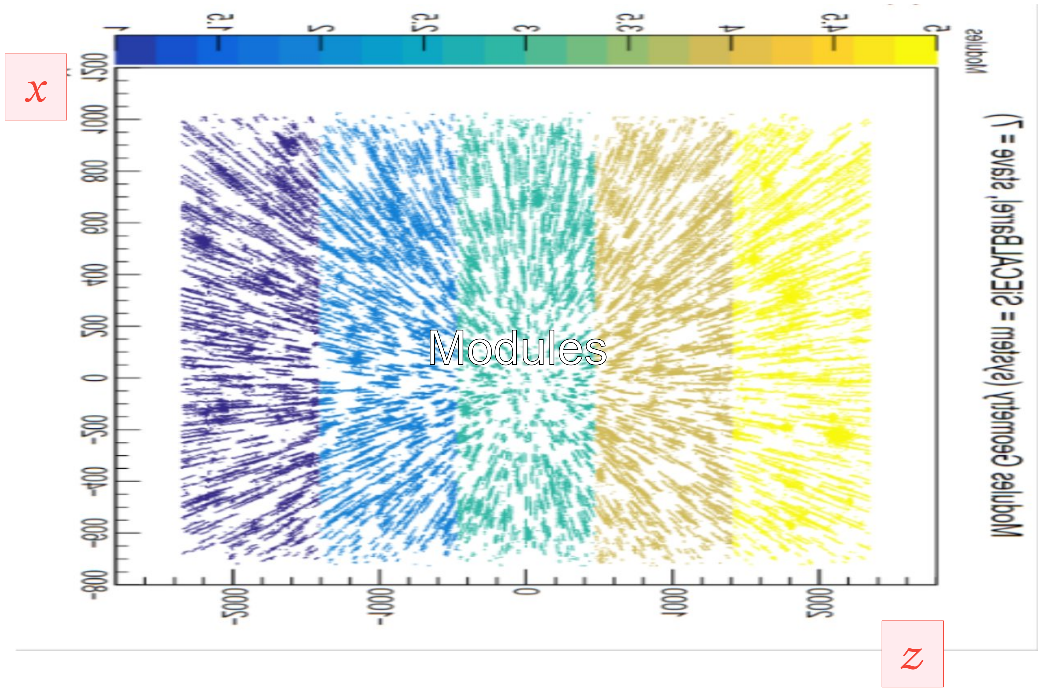
# Geometric Selections (Explicit)

- All the staves are symmetric ($\varphi$, azimuthal symmetry-8)
- Radial behaviour can be obtained from different layers (central image).
- Polar behaviour (cos θ): from Modules in Barrel, from Towers in EndCaps.

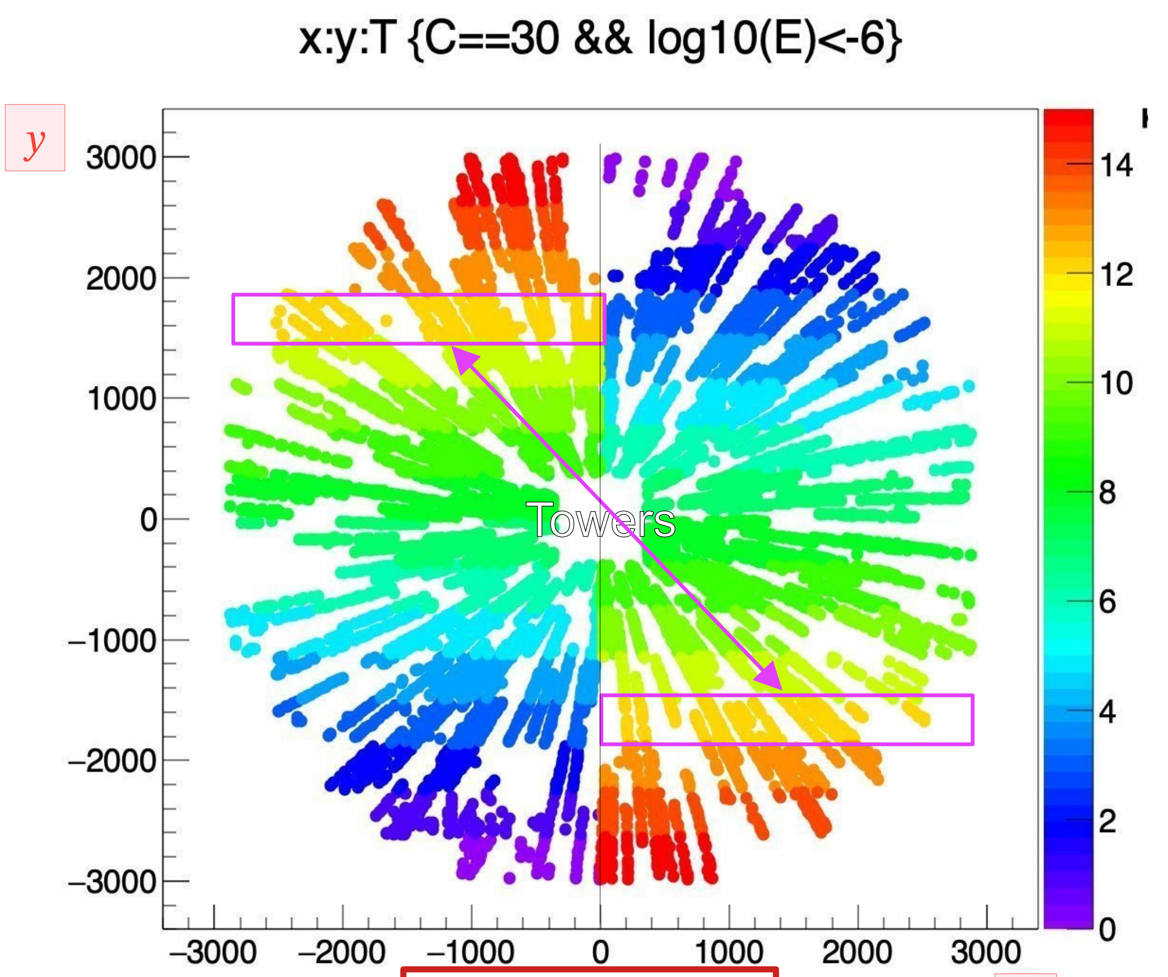
## Selections in Barrel : 5 Modules × 3 block of 10 layers



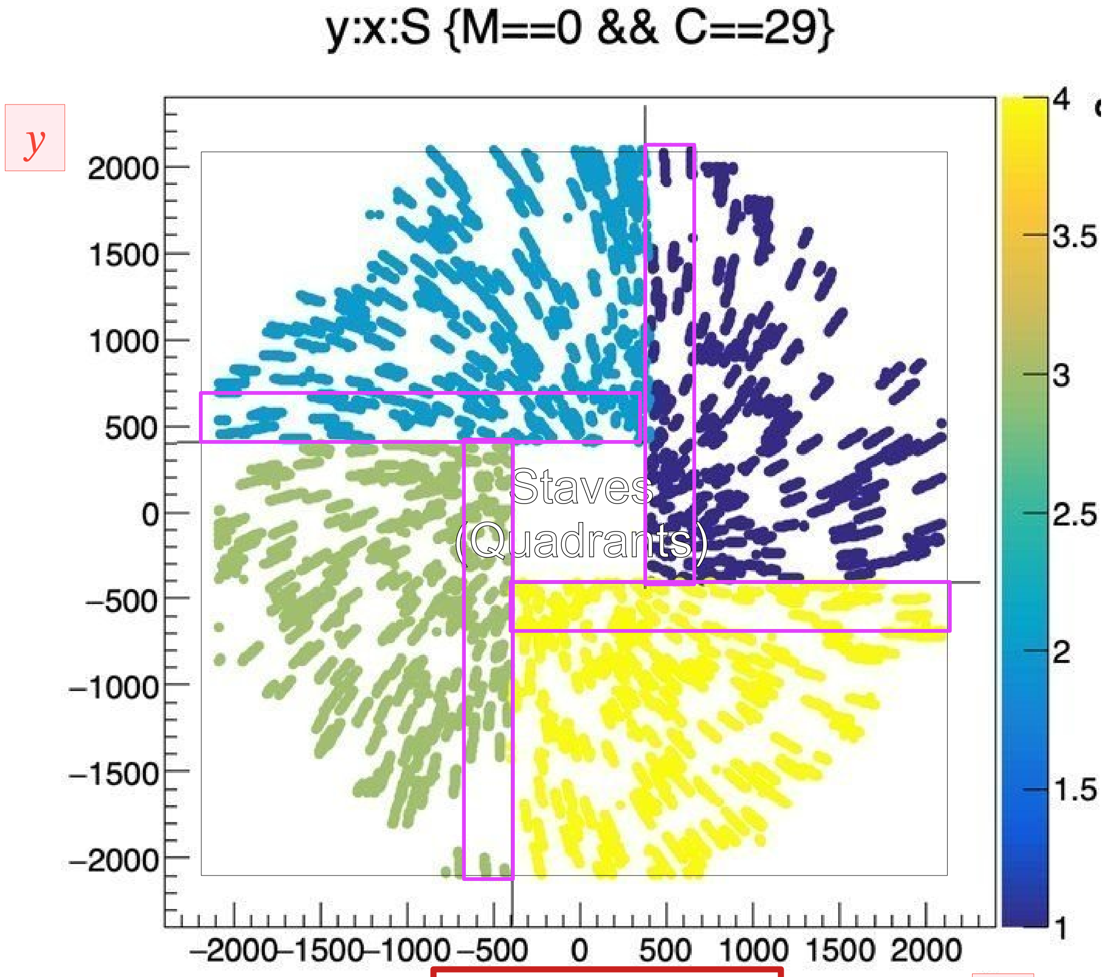



# Logical Geometry : Towers & Staves in Endcaps

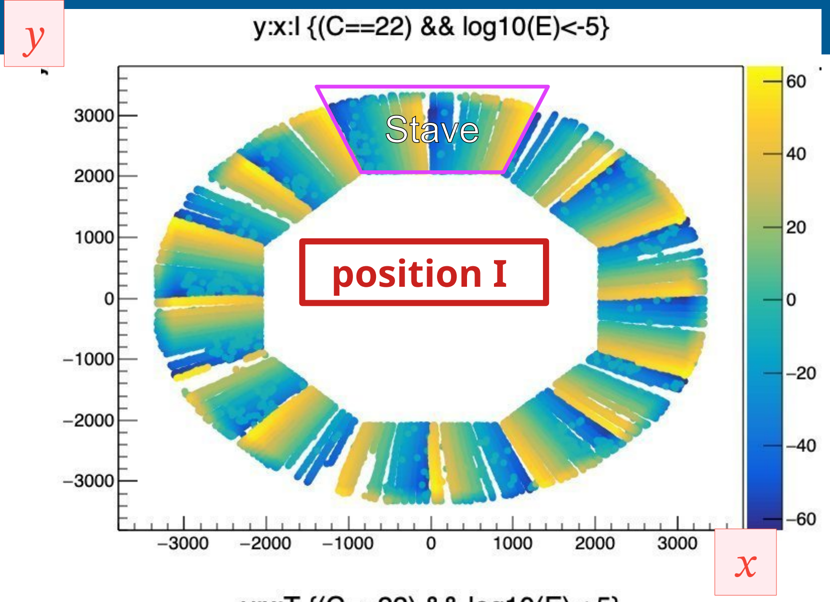


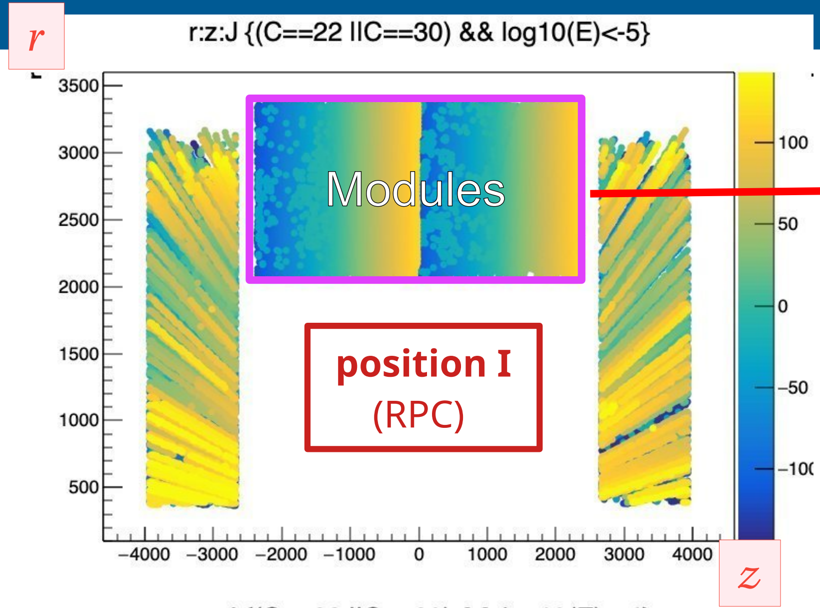

**Towers T** (HCAL)

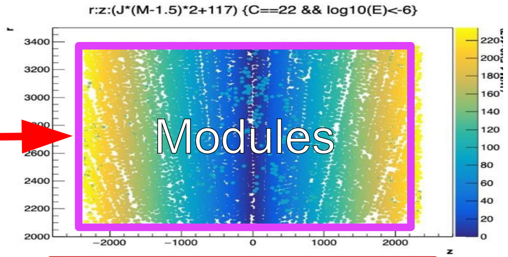



**Staves S** (ECAL)

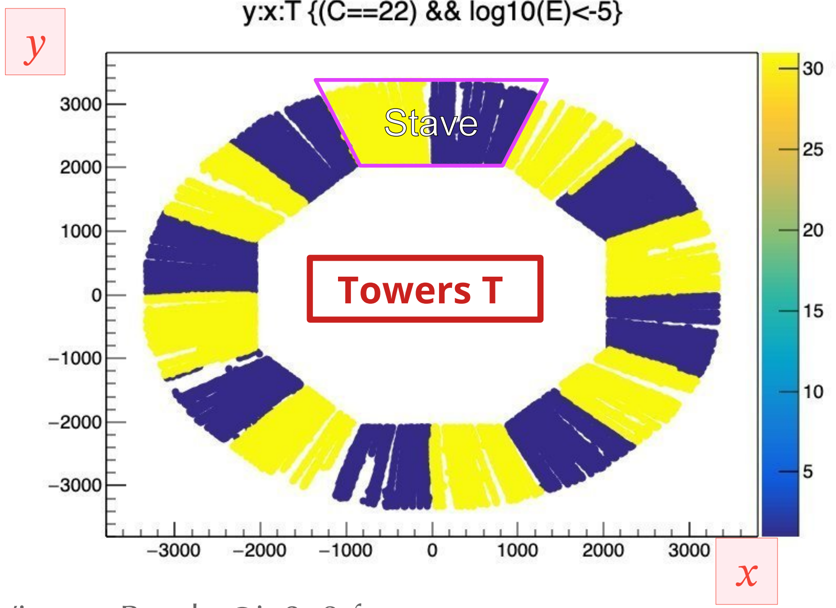
# **Logical Geometry** (HCAL BARRELs, in Prism geometry)

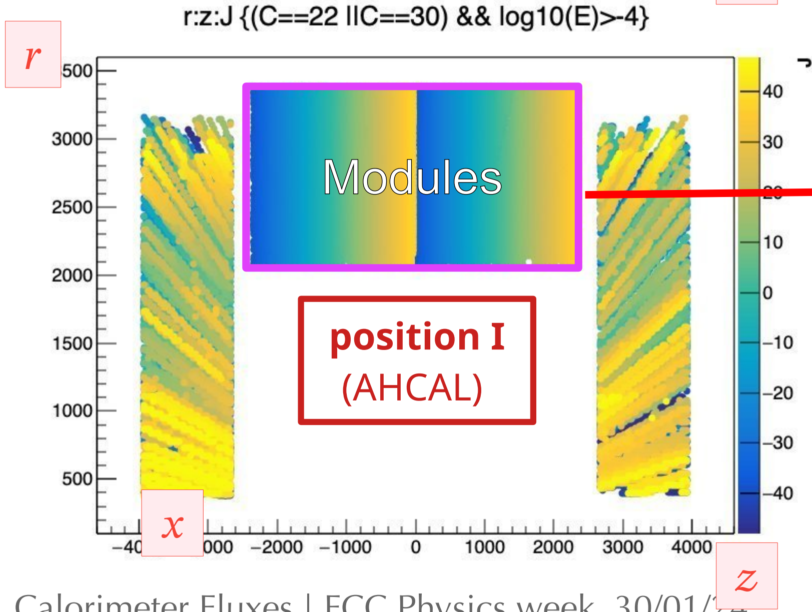


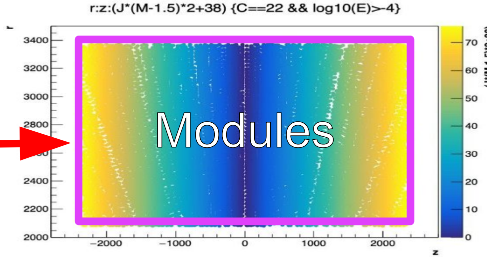




Composite J RPC



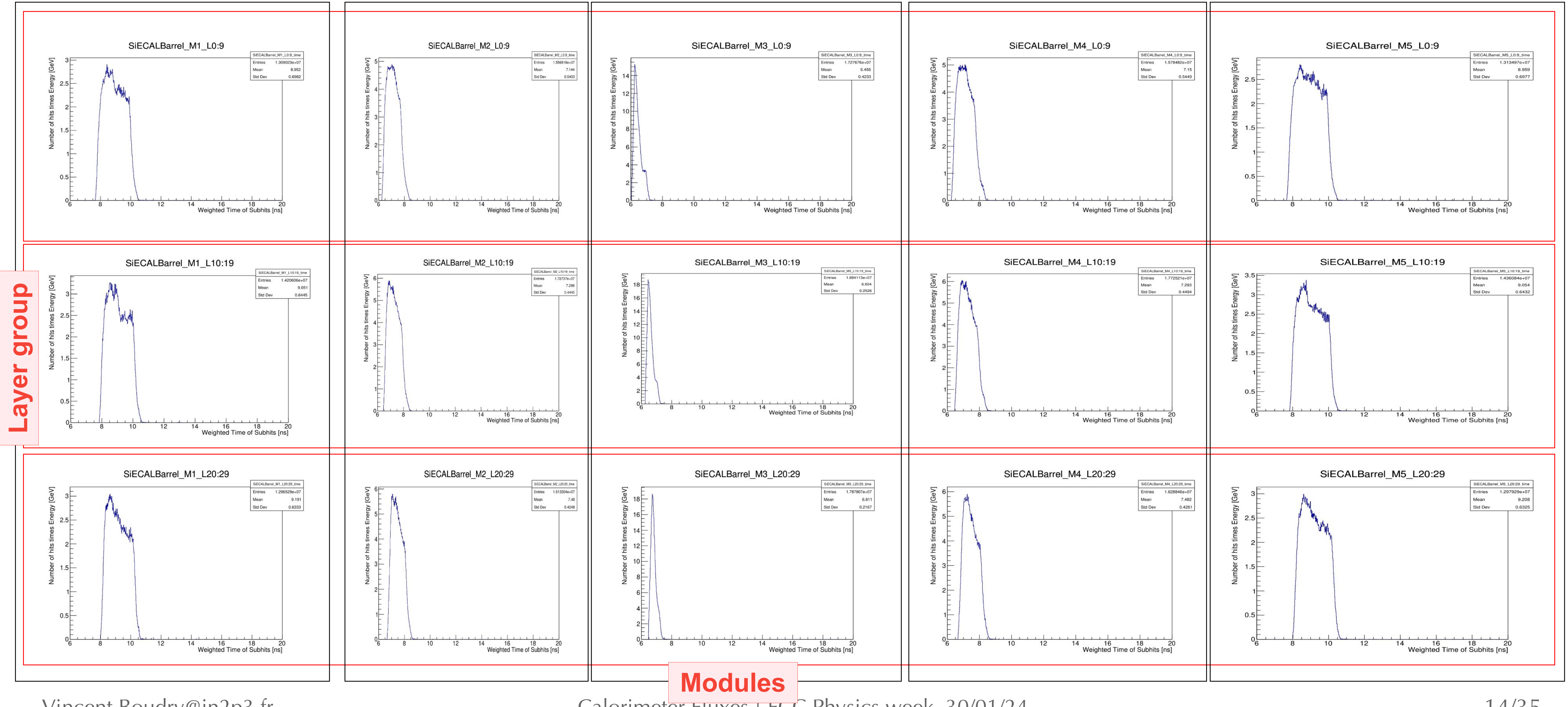



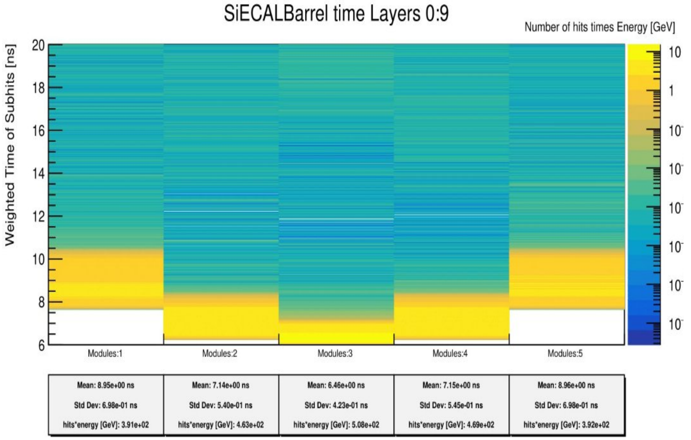

Composite J AHCAL

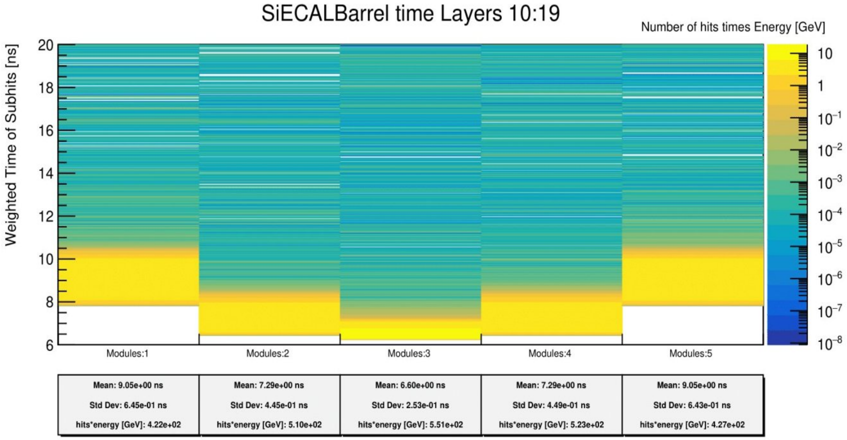
# Geometric Selections (1D histograms : 1M muons events)

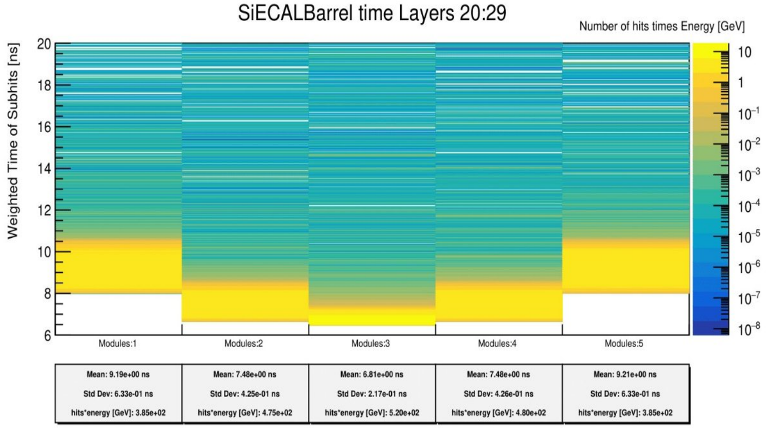
## Time of SubHits × $E_{SubHit}$

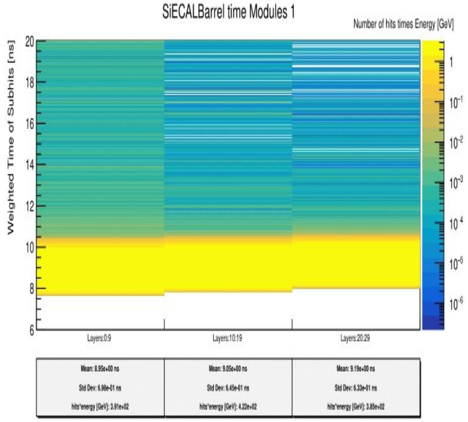


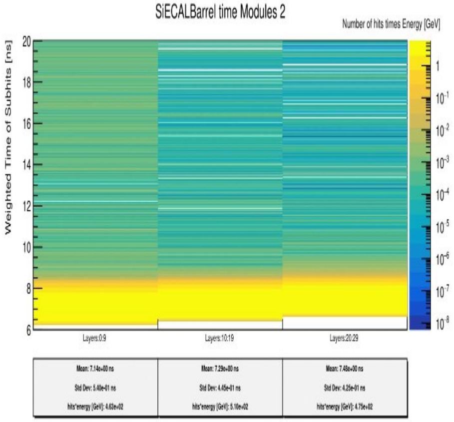
# Geometric Selections (2D histograms)

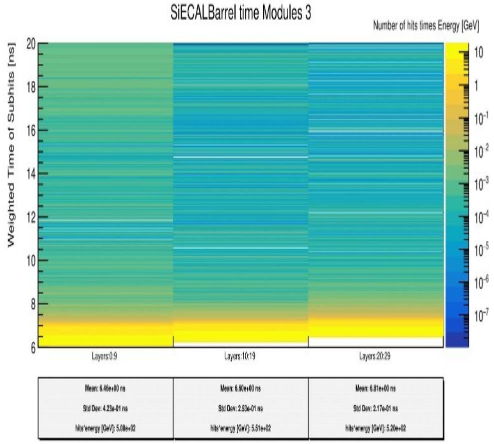


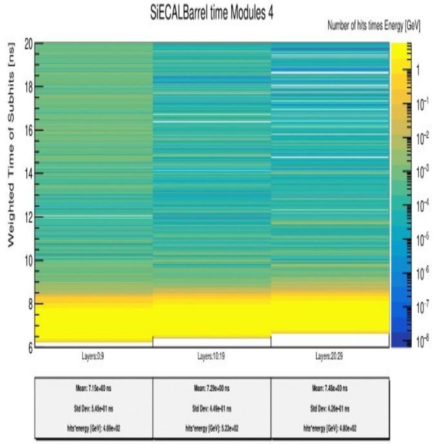



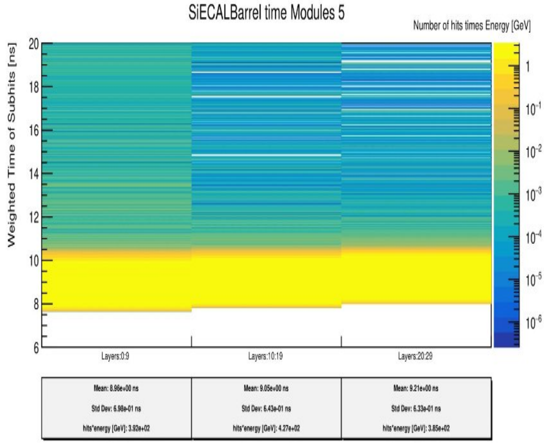



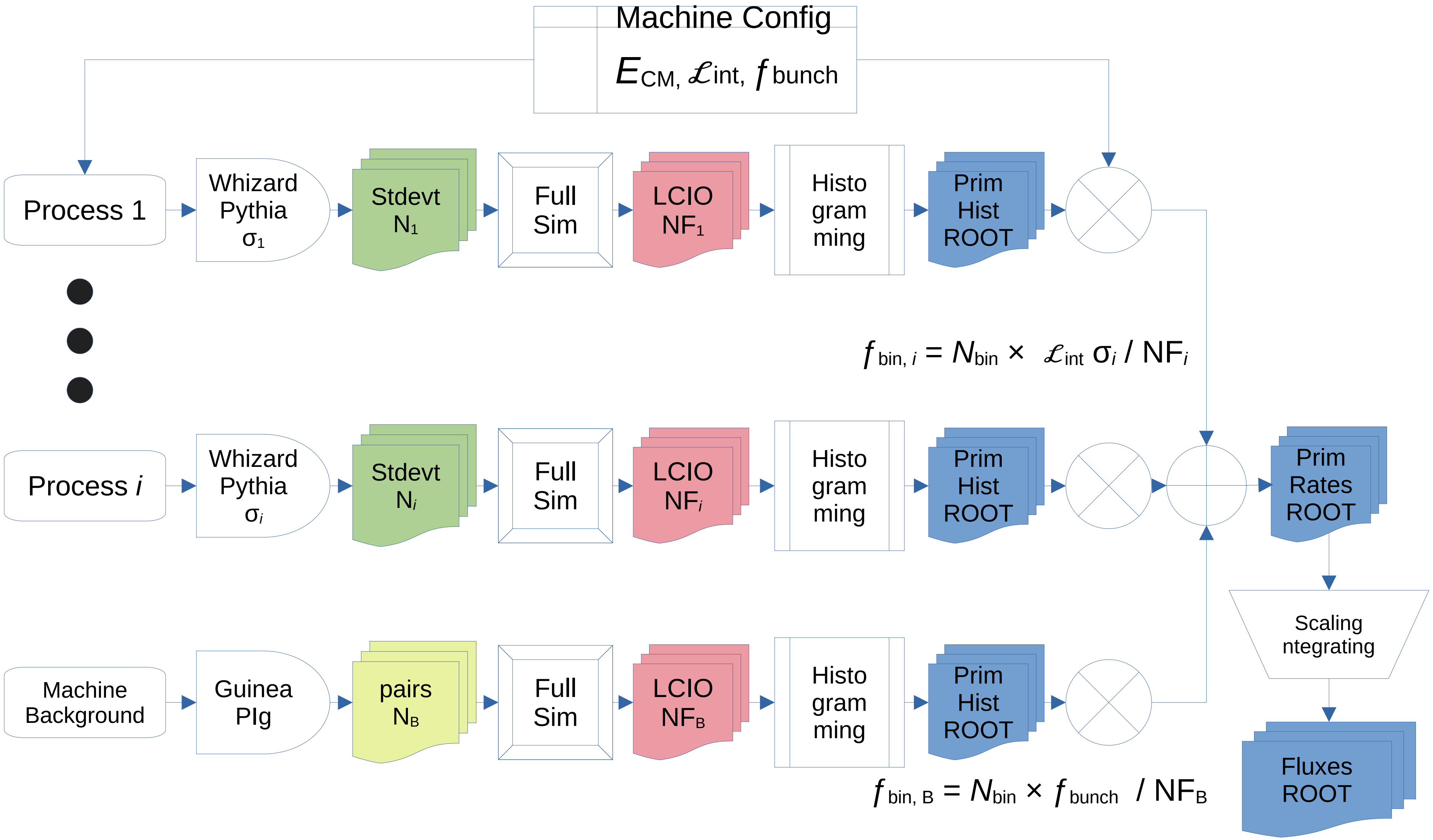



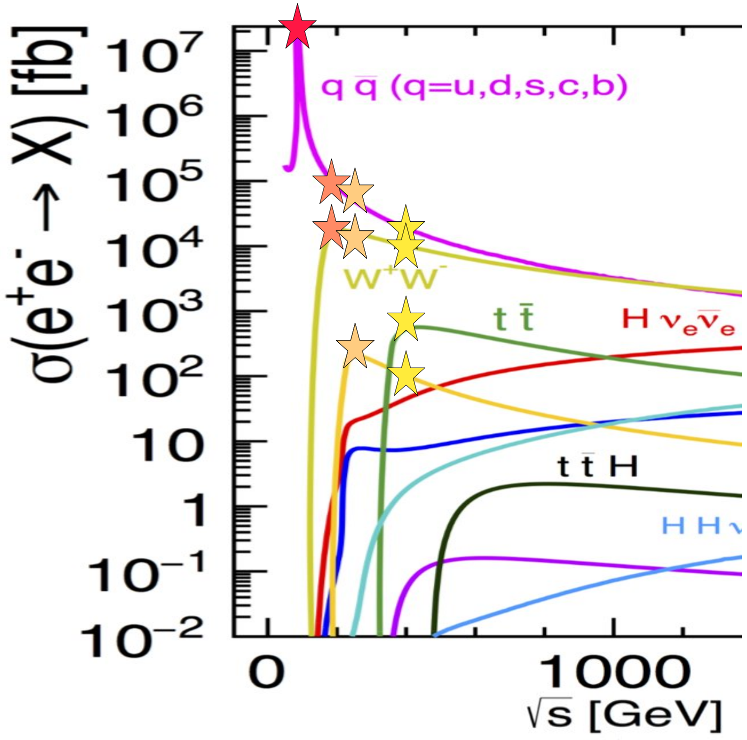



# Processes to Fluxes



# Selected modes




## Processes: min. bias

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

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

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

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

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

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

Machine background sources :

| Source | #particles per bunch | $< E >$ (GeV) |
|---|---|---|
| Disrupted primary beam | $2 \times 10^{10}$ | 244 |
| Bremstrahlung photons | $2.5 \times 10^{10}$ | 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 | – |

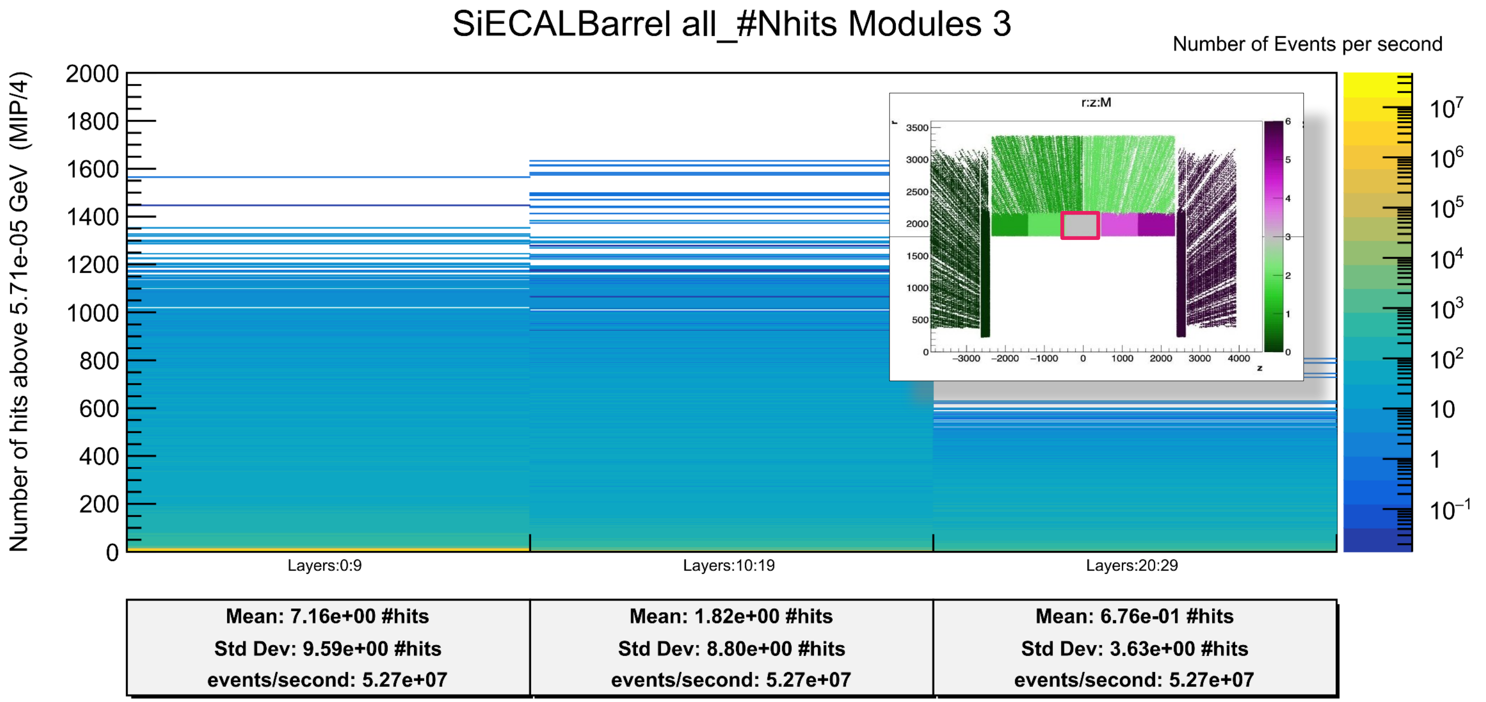
T. Behnke, et al.
*The International Linear Collider Technical Design Report - Volume 4: Detectors*, arXiv:1306.6329 [Physics]. (2013)

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)

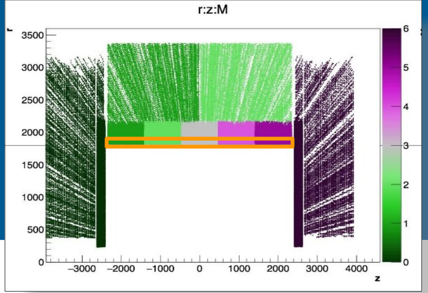
| M3 all staves | L0:9 | L10:19 | L20:29 |
|---|---|---|---|
| Average #hits/s | 302E+6 hits/s | 65E+6 hits/s | 8E+6 hits/s |
| Max | 2000 hits/event | 2500 hits/event | 1000 hits/event |
| Data rate | 2,11E+9 B/s | 458E+6 B/s | 54E+6 B/s |
| Ncells | 4 026 764 | 3 767 273 | 3 378 036 |
| Occupancy/BX | **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 % |

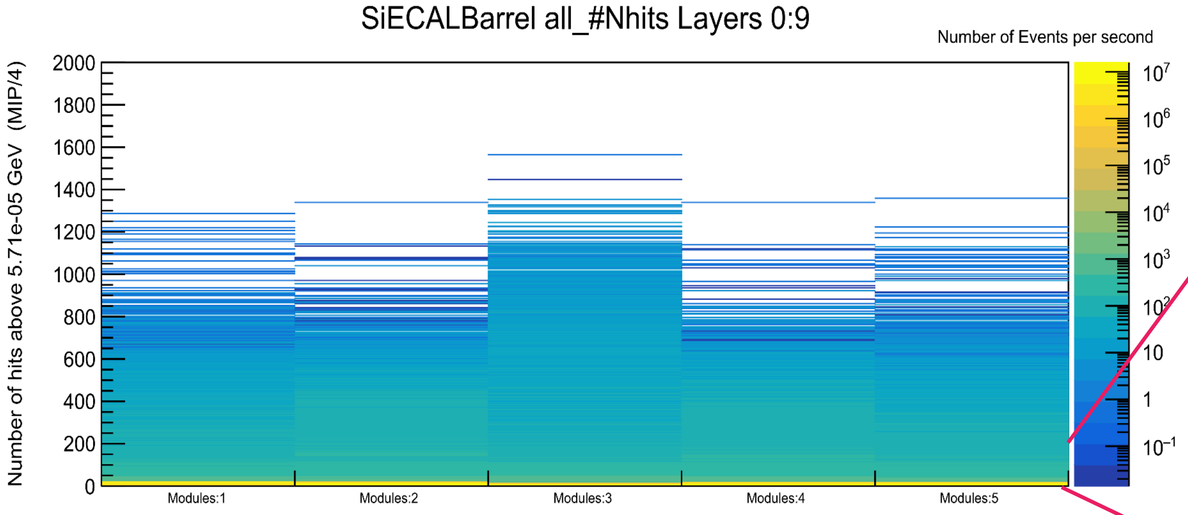
| | |
|---|---|
| cell size | 5,5 |
| Bytes/hit | 7 |
| powa (W/cell) | 4,5 E-03 |
| powb (J/hit) | 8,7 E-10 |
| Conv & RO E/hit/µJ | 9,0 E-01 |
| Δt/s | 19 E-09 |

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

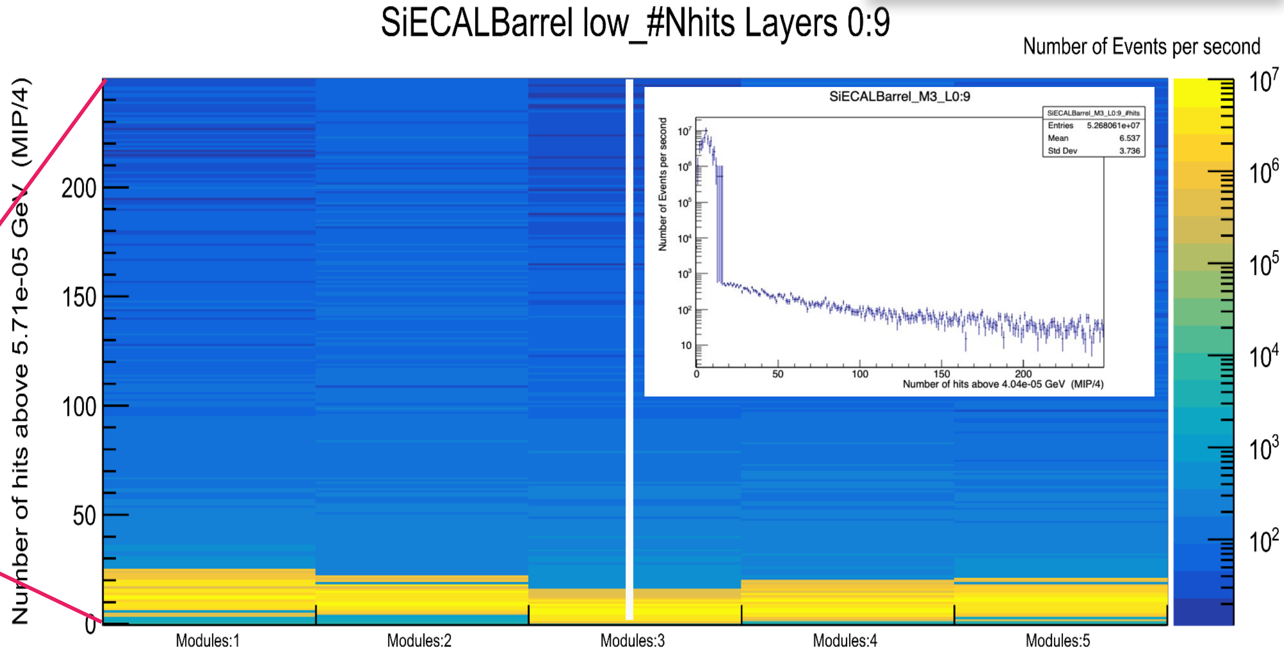
**Note 1** : (still) **preliminary**
**Note 2** : Rates & Power for all M3 modules
→ 8 per module, 10 per layer for 1 slab
→ ~ 50 W/slab

# 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 |

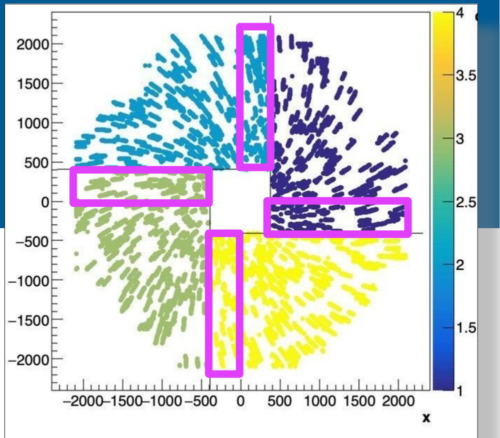


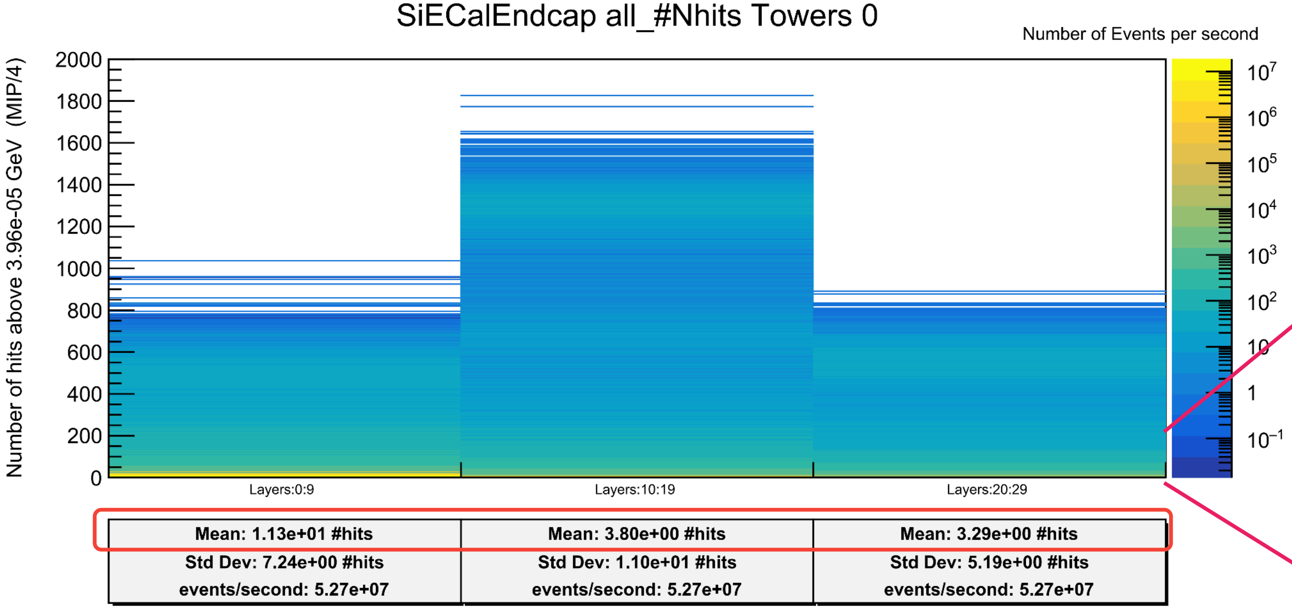

| Modules:1 | Modules:2 | Modules:3 | Modules:4 | Modules:5 |
|---|---|---|---|---|
| Mean: 1.44e+01 #hits | Mean: 1.18e+01 #hits | Mean: 6.54e+00 #hits | Mean: 9.53e+00 #hits | Mean: 1.08e+01 #hits |
| Std Dev: 5.09e+00 #hits | Std Dev: 4.65e+00 #hits | Std Dev: 3.74e+00 #hits | Std Dev: 4.83e+00 #hits | 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

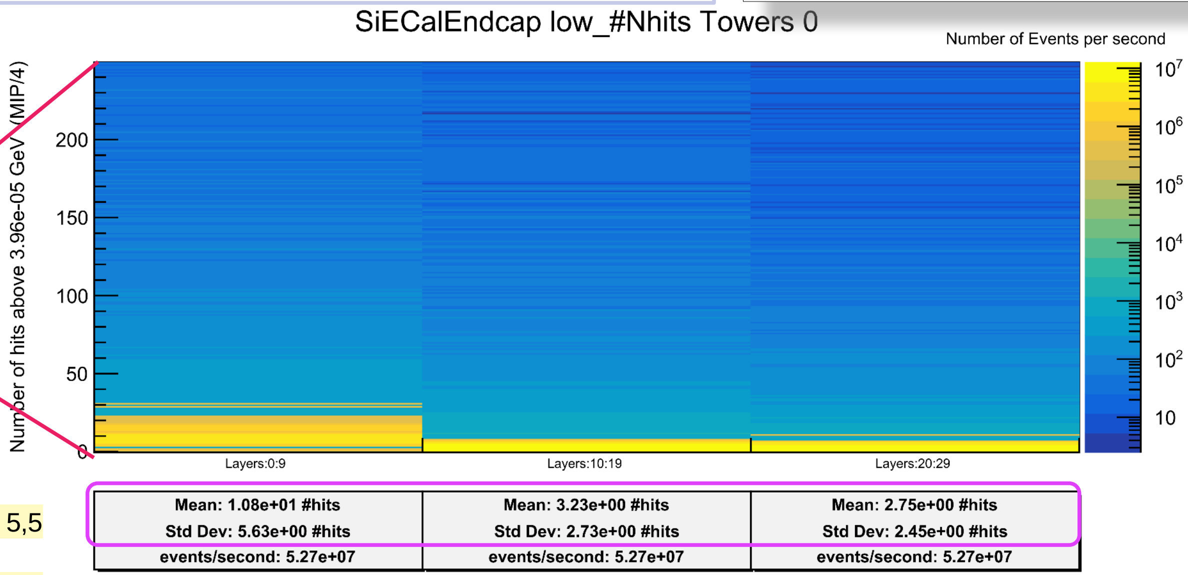
- **Rates M1/M3 ~ 2**
- **Double counting of physics events in Module 3 due back-to-back events**
- **Machine backgrounds dominate the distribution.**

# 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



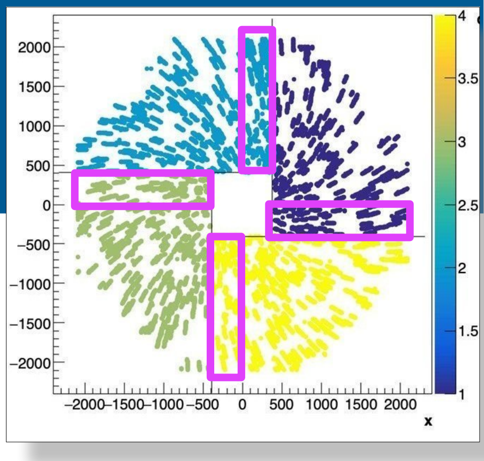

| **T0 all quadrants** | **L0:9** | **L10:19** | **L20:29** |
|---|---|---|---|
| Average #hits/s | 572E+6 hits/s | 176E+6 hits/s | 147E+6 hits/s |
| Max | 2000 hits/event | 2500 hits/event | 1000 hits/event |
| Data rate | 4,00E+9 B/s | 1E+9 B/s | 1E+9 B/s |
| Ncells | 1 161 775 | 1 161 775 | 1 161 775 |
| **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 % |

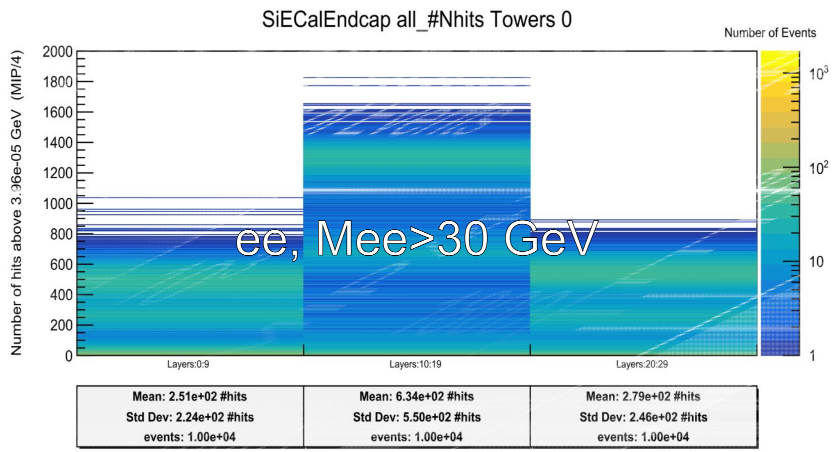
| | |
|---|---|
| cell size | 5,5 |
| Bytes/hit | 7 |
| powa (W/cell) | 5E-03 |
| powb (J/hit) | 870E-12 |
| Conv & RO E/hit/µJ | 0,9 |
| Δt | 19E-9 |

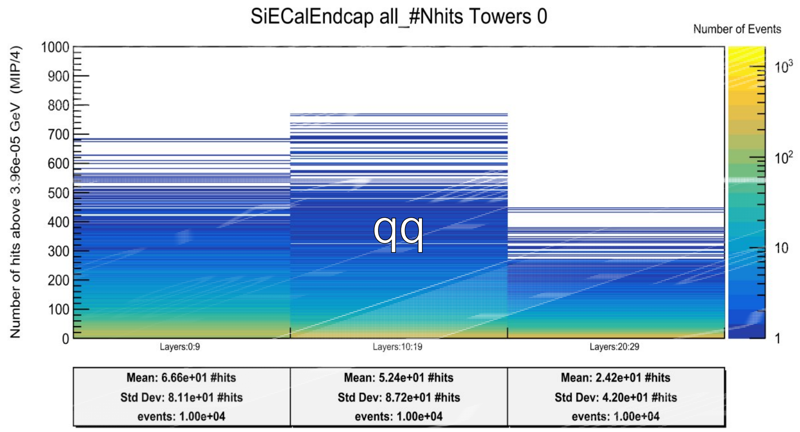
- **Machine background in first layers**
- **High E ee→ee in middle of ECAL (next slide)**
- **Power driven by the continuous part (Pre-Amps)**

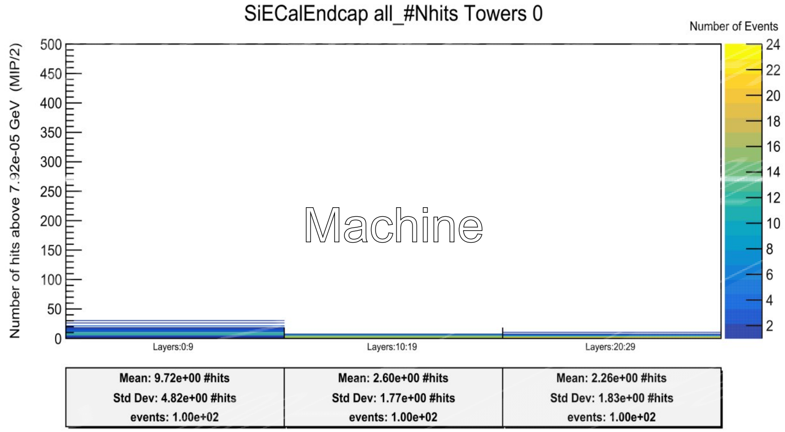
**Note 1** : (still) **preliminary**
**Note 2** : Rates & Power for all T0 modules
→ /8 per quadrant, *10 per layer for 1 slab → 75W / slab*

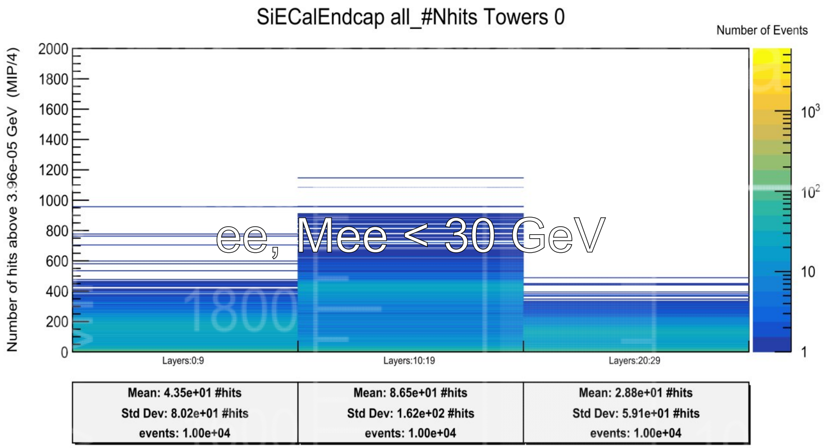
# Results: Contributions to rates in SiECAL EndCaps, Tower 0 vs depth

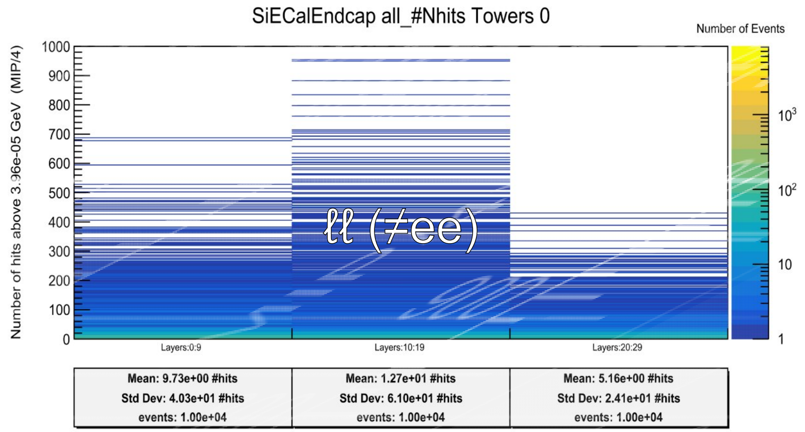


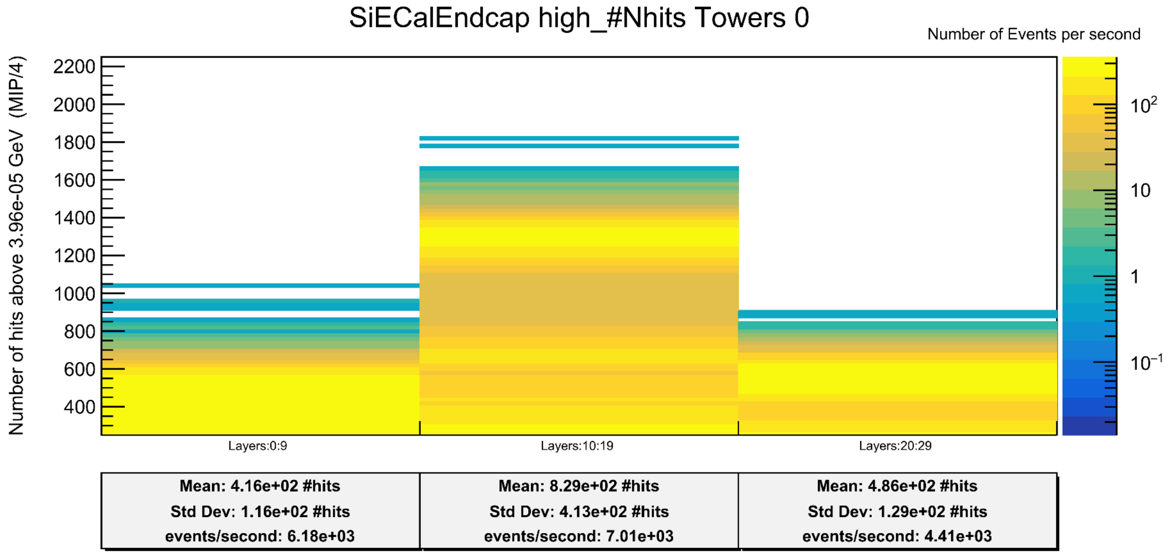



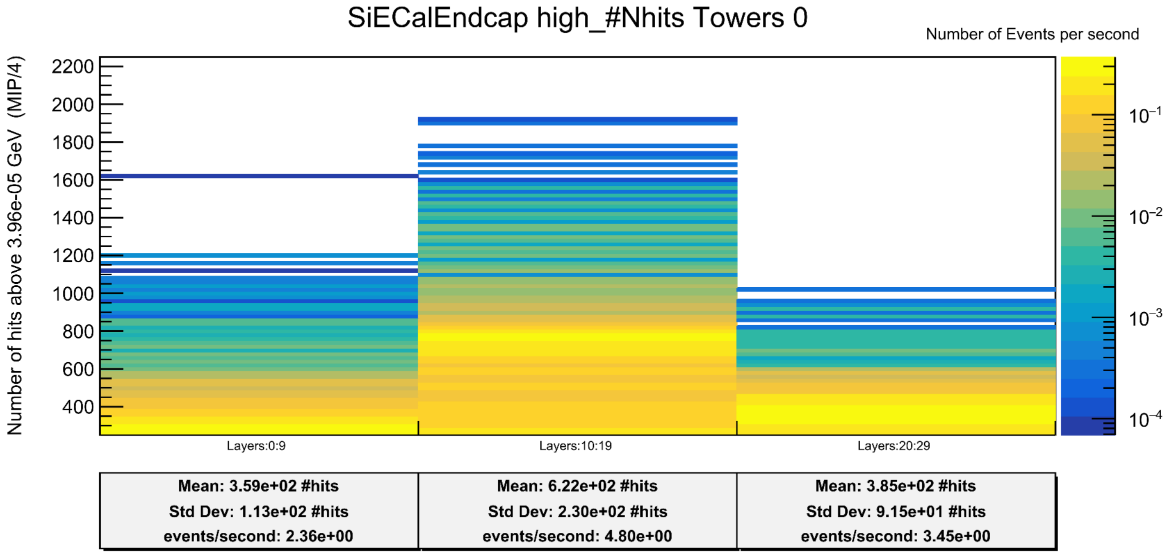



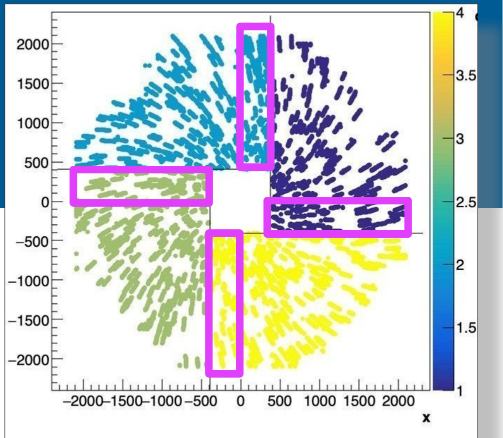




Distributions of the number of hits crossing (>MIP/4) energy threshold of all the physics processes and machine background at **91.2 GeV** (FCC-Z4) with the colour bar representing the number of events (for 10,000 or 100 BX simulated)

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



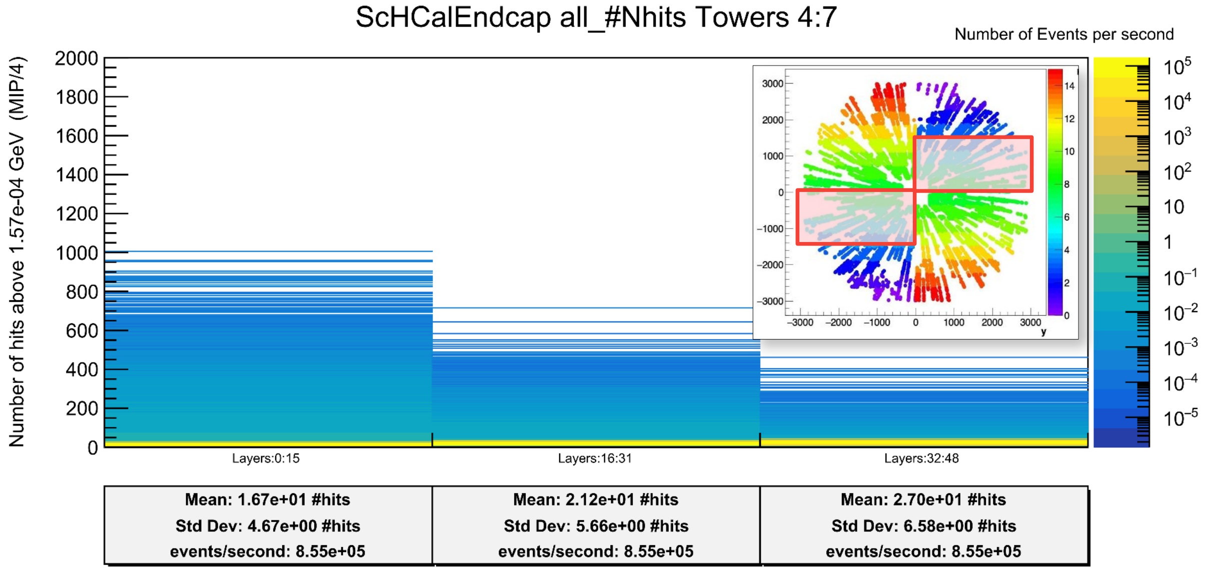



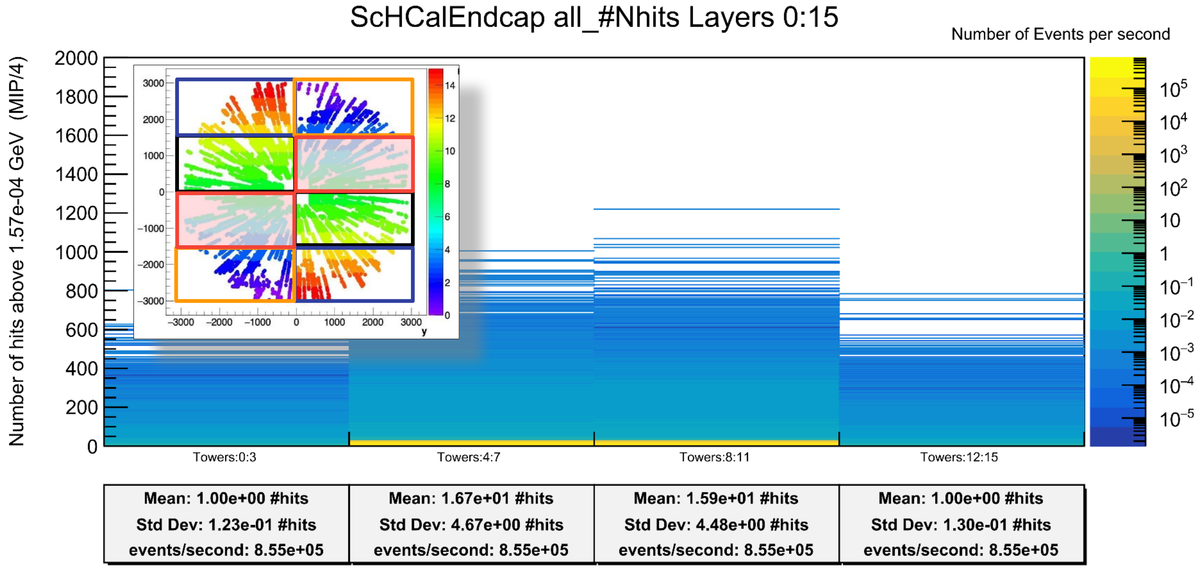

Upper Scale Energy distributions of tower 0 of ECAL end cap at **91.2 GeV** of all physics and background

- **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

# Results: Scintillator AHCAL Endcap



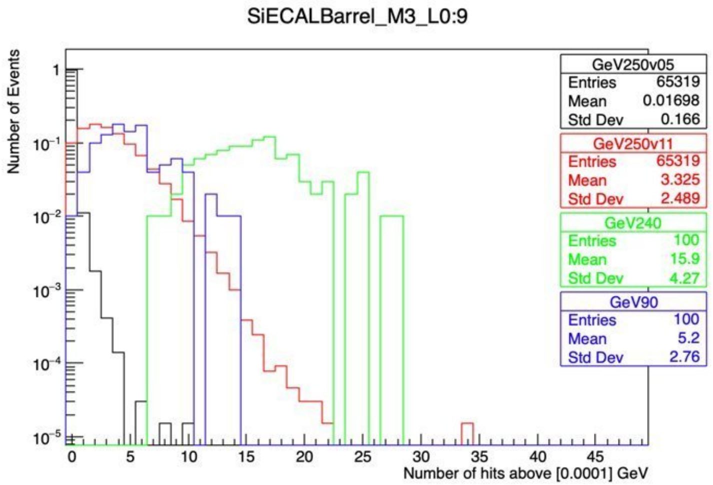

| | | | | | |
|---|---|---|---|---|---|
| Average | 14E+6 hits/s | 18E+6 hits/s | 23E+6 hits/s | 855E+3 hits/s | 1E+6 hits/s |
| MaxNhits | 1000 Nhits/event | 600 Nhits/event | 400 Nhits/event | 400 Nhits/event | 400 Nhits/event |
| for 6B/hits | 86E+6 B/s | 109E+6 B/s | 139E+6 B/s | 5E+6 B/s | 9E+6 B/s |
| Est. Ncells | 278 756 | 278 756 | 278 756 | Not Yet avail, | 278 756 |
| Occupancy/BX | 1,0E-06 | 1,3E-06 | 1,7E-06 | Not Yet avail, | 1,0E-07 |
| cell size | 30 | | | | |

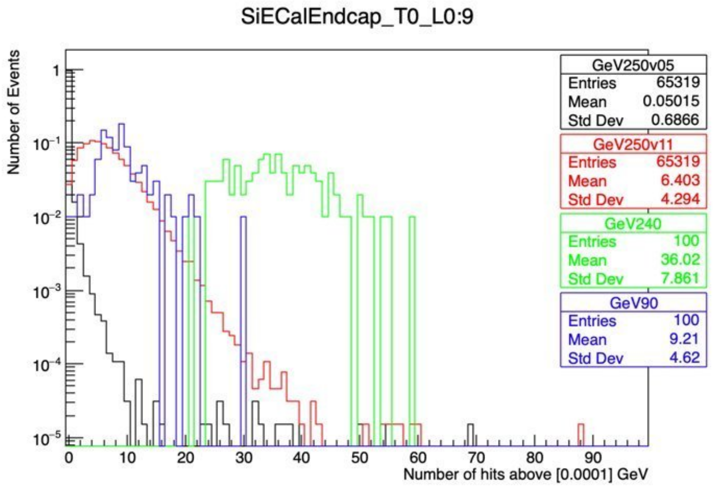
**Note 1** : **Very preliminary**
**Note 2** : Rates for all tower 4:7 modules ➞ /4 per module, /16 per layer

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.**

# 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** |

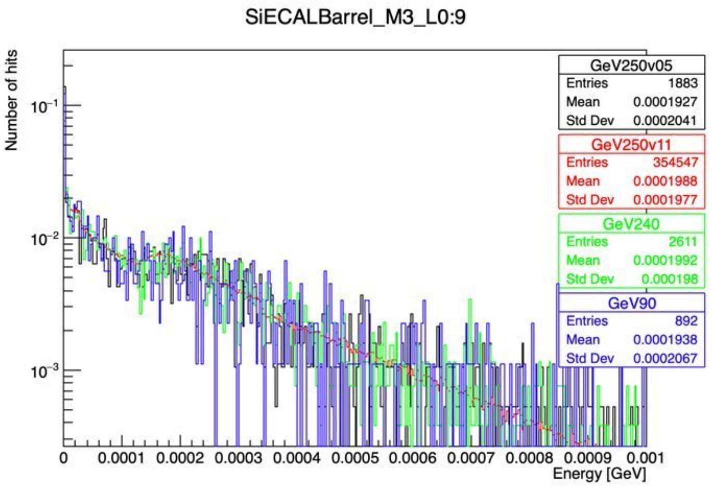
| | | ⟨Nhit⟩/BX | |
|---|---|---|---|
| Config | | Barrel M3 L0:9 | EndCap T0 L0:9 |
| ILC @ 250 GeV | ILD_l5_v05 | 0,0170 | 0,0500 |
| ILC @ 250 GeV | ILD_l5_v11$\gamma$ | 3,33 | 6,40 |
| FCCee @ 240 GeV | ILD_l5_v11$\gamma$ | 15,9 | 36,0 |
| FCCee @ 90 GeV | ILD_l5_v11$\gamma$ | 5,2 | 9,21 |

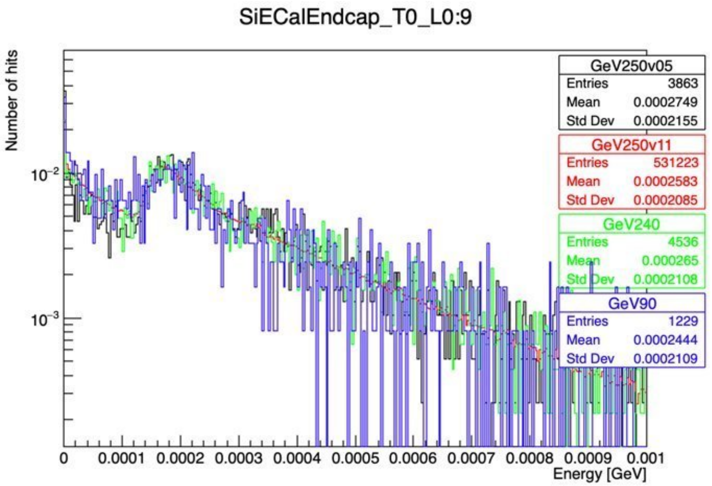
## ⟨Nhits⟩, per BX

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

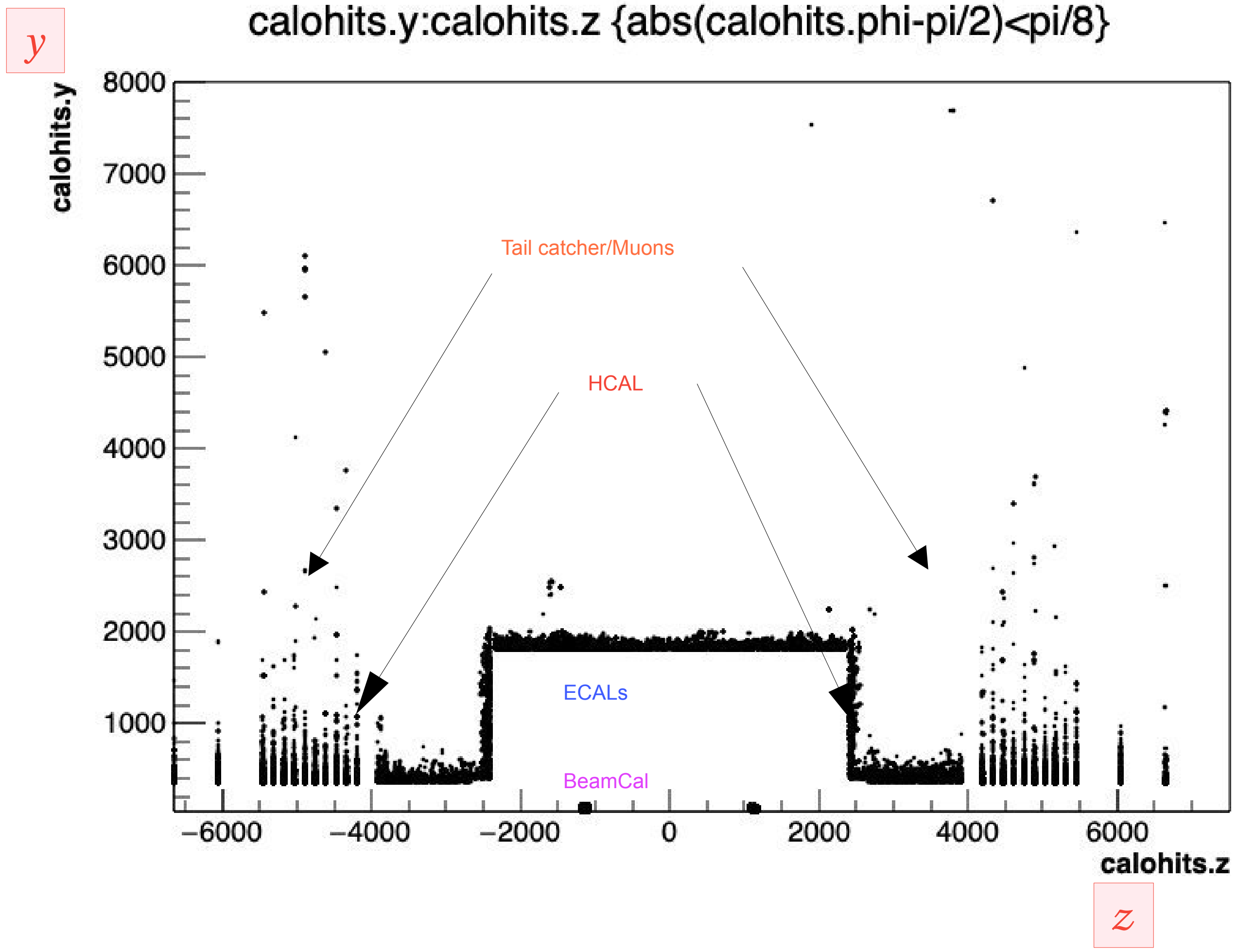
## Distribution of hit energy

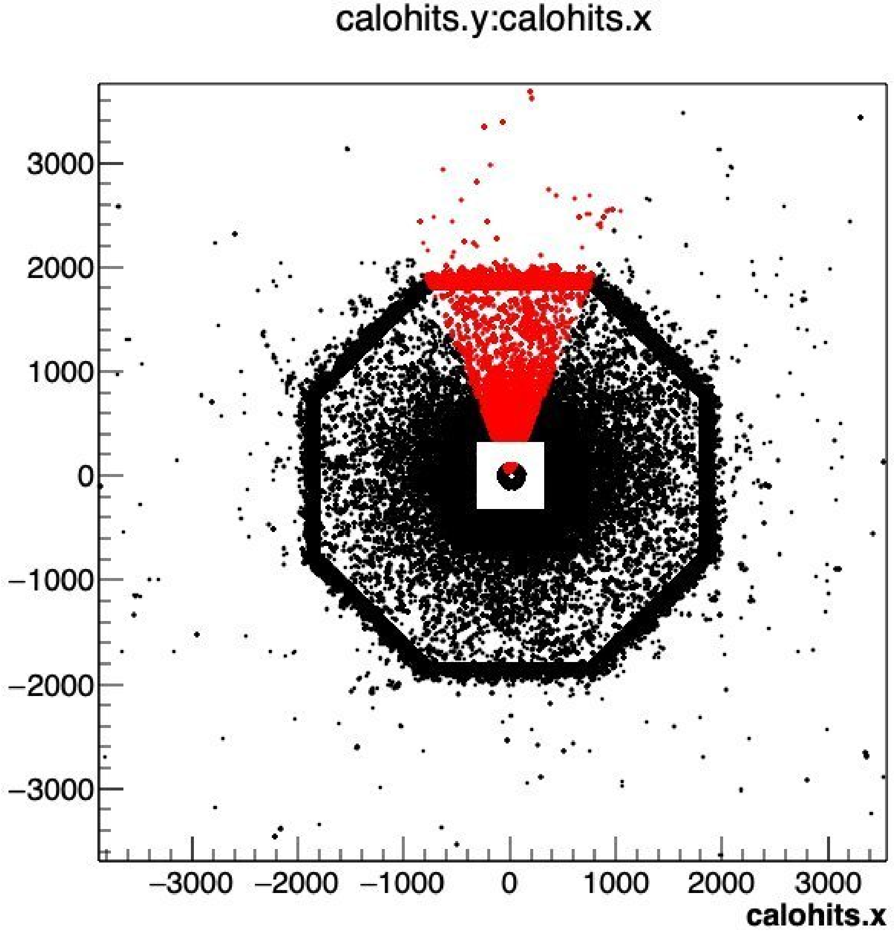
- No difference



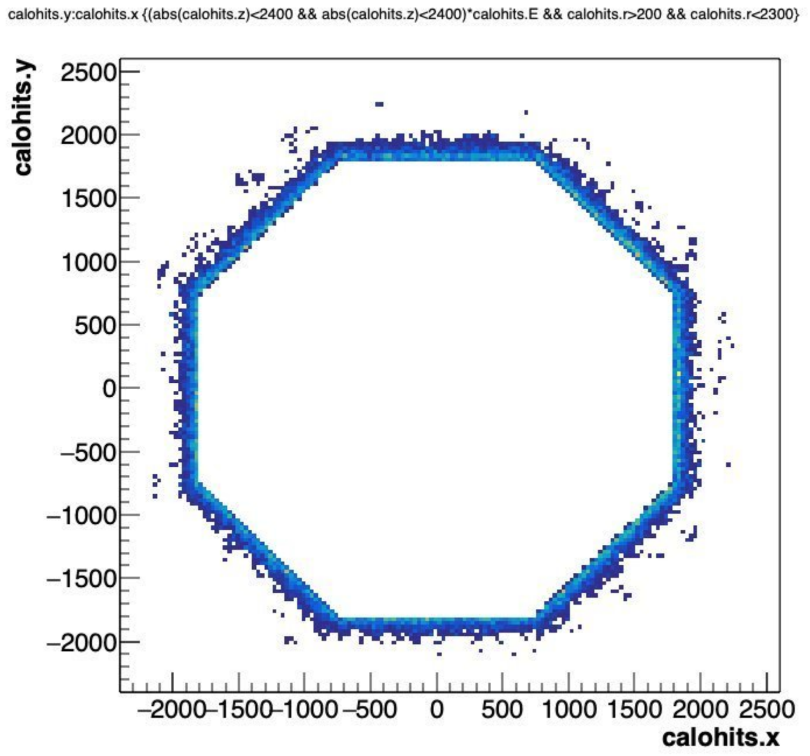
# Key4hep: All Calorimeter hit collection:



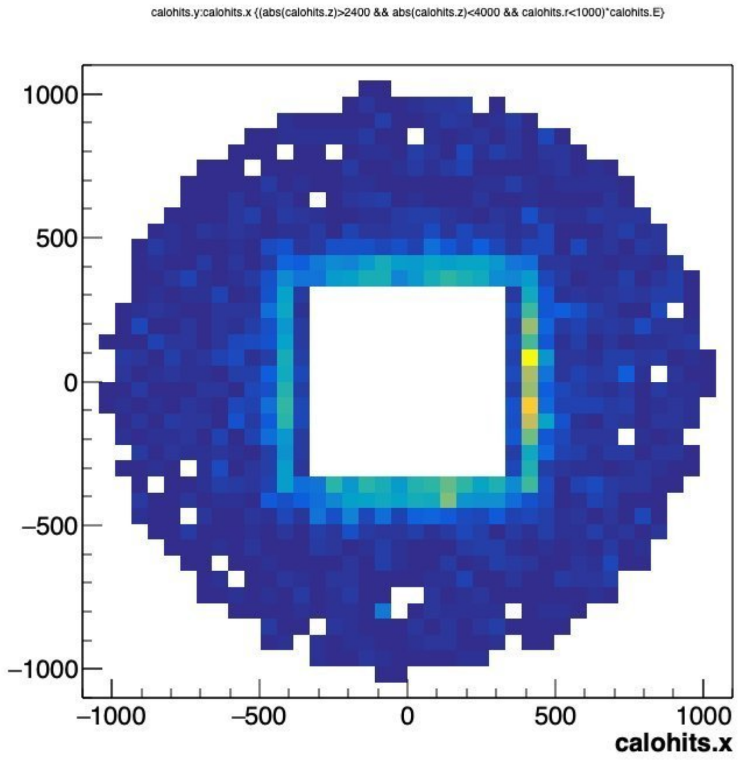
# Asymmetry in central calorimeters

## ECAL barrel



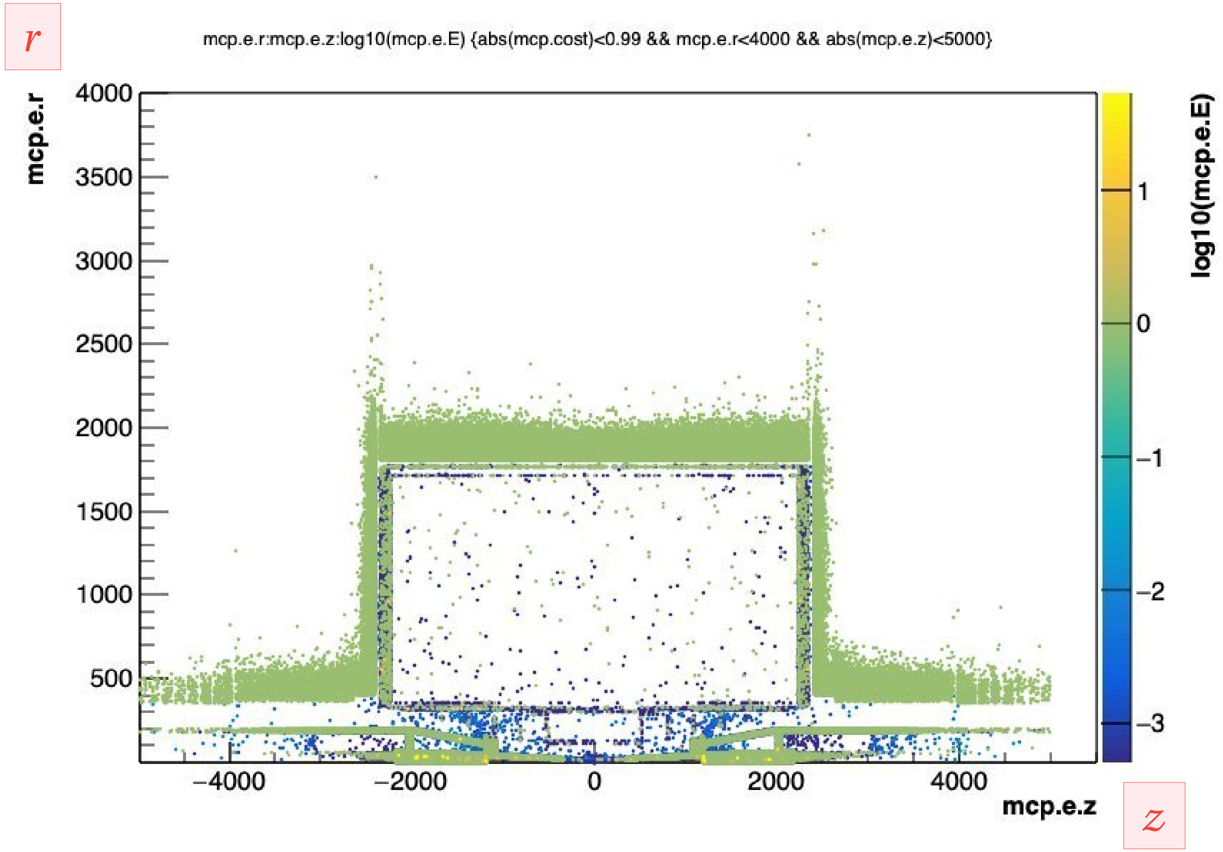

## HCAL endcaps

- A slight asymmetry can be observed
  - Significant ?



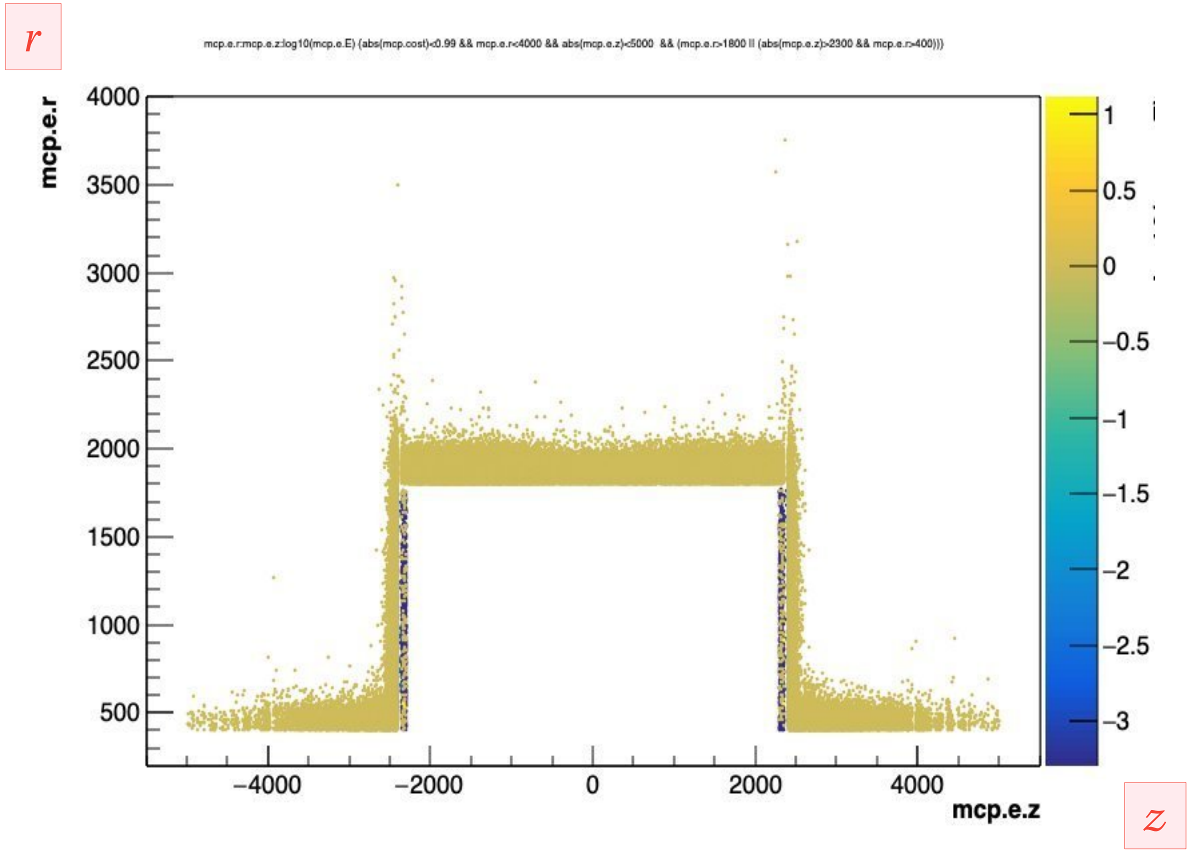
# MCparticle EndPoints

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



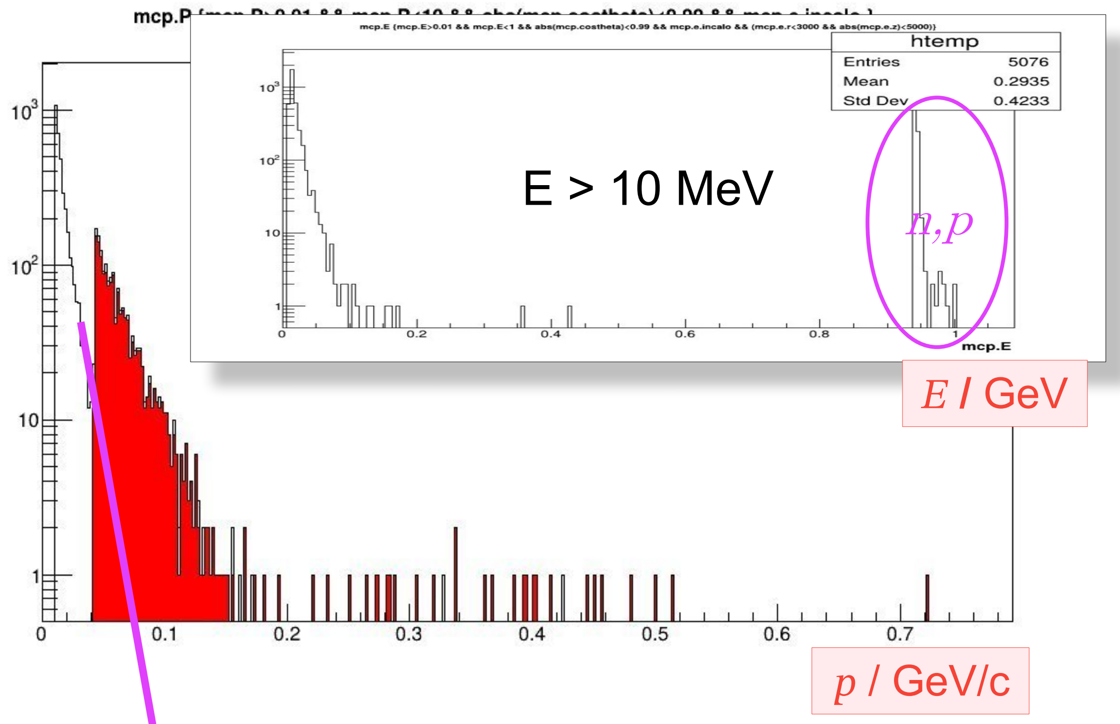

## Same for calor only

– E from 1MeV – 1 GeV

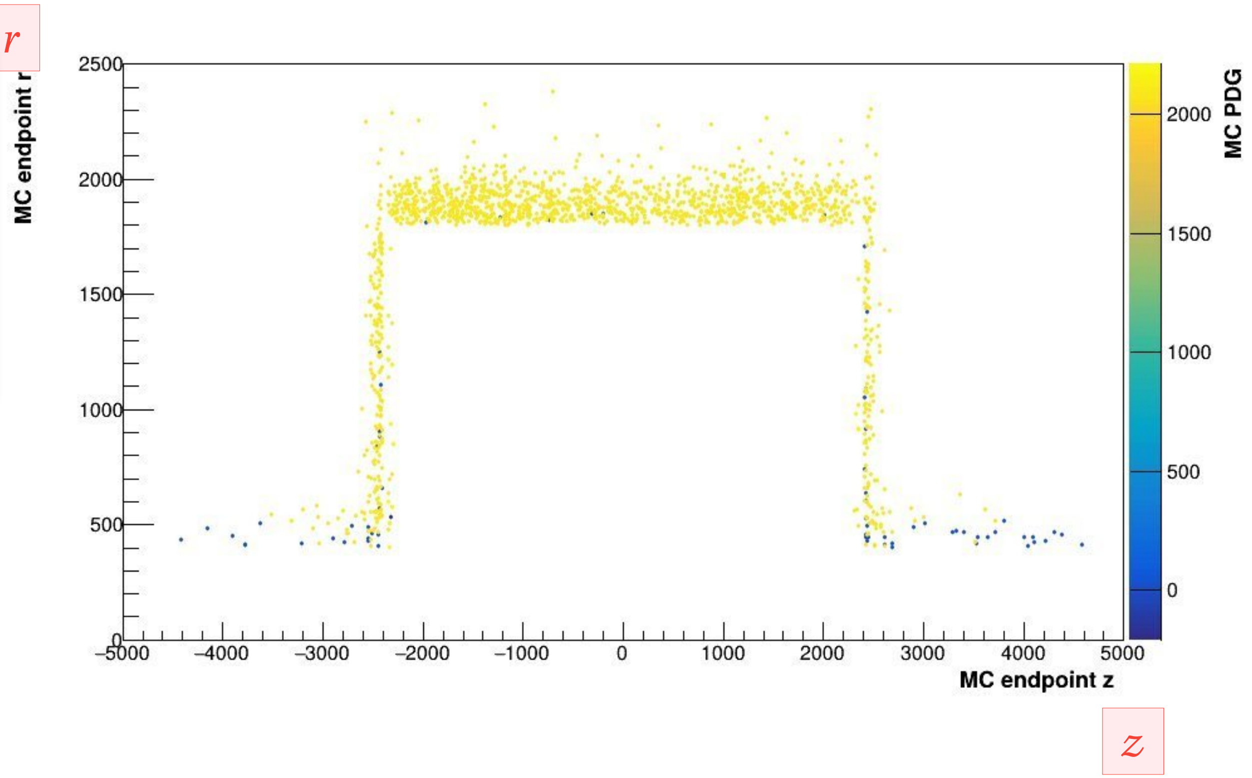


# Particle momentum in calo

## Low energy photons <10 MeV




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




$\gamma$ 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.

# 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 $\beta_x^*$ [mm] | 110 | 110 | 200 | 300 | 1000 |
| Vertical IP beta $\beta_y^*$ [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 | $f_{\rm rep}$ | Hz | 5 | 5 | 5 | 5 | 4 |
| Bunches per pulse | $n_{\rm bunch}$ | 1 | 1312 | 2625 | 1312 | 1312/2625 | 2450 |
| Bunch population | $N_{\rm e}$ | $10^{10}$ | 2 | 2 | 2 | 2 | 1.74 |
| Linac bunch interval | $\Delta t_{\rm b}$ | ns | 554 | 366 | 554 | 554/366 | 366 |
| Beam current in pulse | $I_{\rm pulse}$ | mA | 5.8 | 5.8 | 8.8 | 5.8 | 7.6 |
| Beam pulse duration | $t_{\rm pulse}$ | $\mu$s | 727 | 961 | 727 | 727/961 | 897 |
| Average beam power | $P_{\rm ave}$ | MW | 5.3 | 10.5 | 10.5 | 10.5/21 | 27.2 |
| Norm. hor. emitt. at IP | $\gamma\epsilon_{\rm x}$ | $\mu$m | 5 | 5 | 10 | 10 | 10 |
| Norm. vert. emitt. at IP | $\gamma\epsilon_{\rm y}$ | nm | 35 | 35 | 35 | 35 | 30 |
| RMS hor. beam size at IP | $\sigma_{\rm x}^*$ | nm | 516 | 516 | 729 | 474 | 335 |
| RMS vert. beam size at IP | $\sigma_{\rm y}^*$ | 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 | $\delta_{\rm BS}$ | | 2.6 % | 2.6 % | 0.97 % | 4.5 % | 10.5 % |
| Site AC power | $P_{\rm site}$ | MW | 129 | | 122 | 163 | 300 |
| Site length | $L_{\rm site}$ | 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 | $2 \times 10^{10}$ | 244 |
| Bremstrahlung photons | $2.5 \times 10^{10}$ | 244 |
| $e^+e^-$ pairs from beam-beam interactions | 75k | 2.5 |
| Radiative Bhabhas | 320k | 195 |
| $\gamma\gamma \rightarrow$ 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).

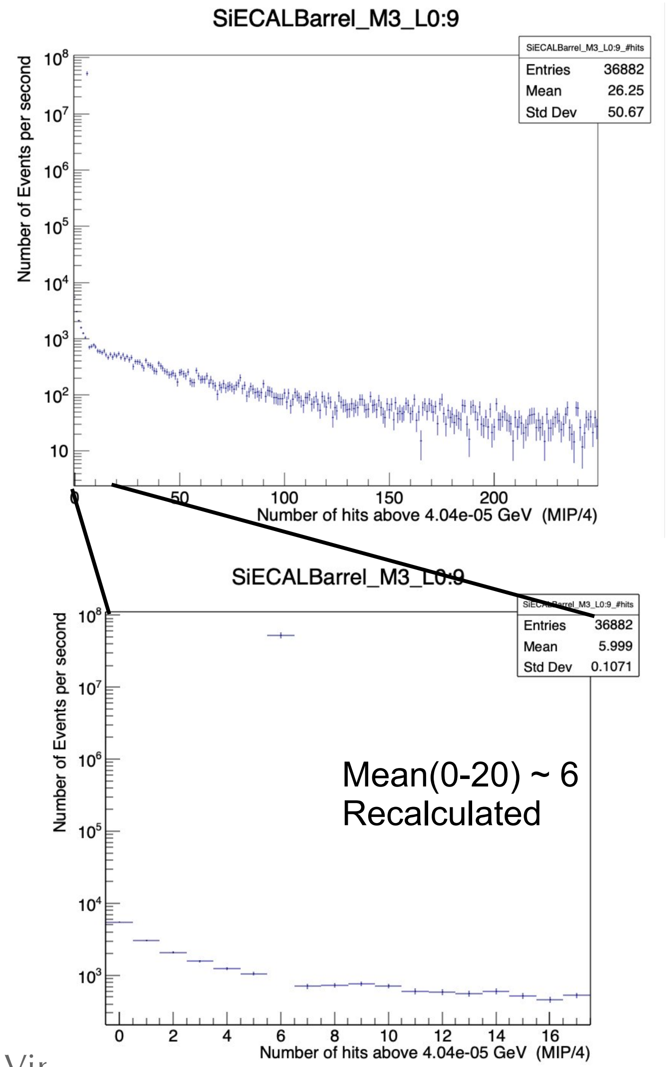
# Machine backgrounds

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

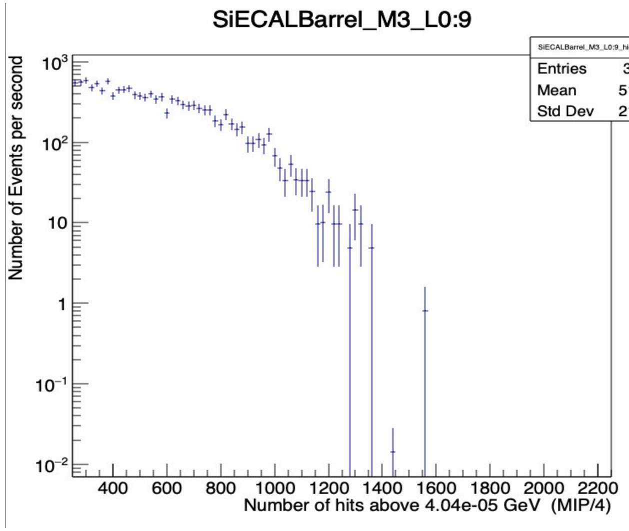
```
 =-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=
  =  A. Ciarma -- 13/12/2022  =
  =-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=

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.
```

# Mean calculations from histograms

## Low #hits & Zoom

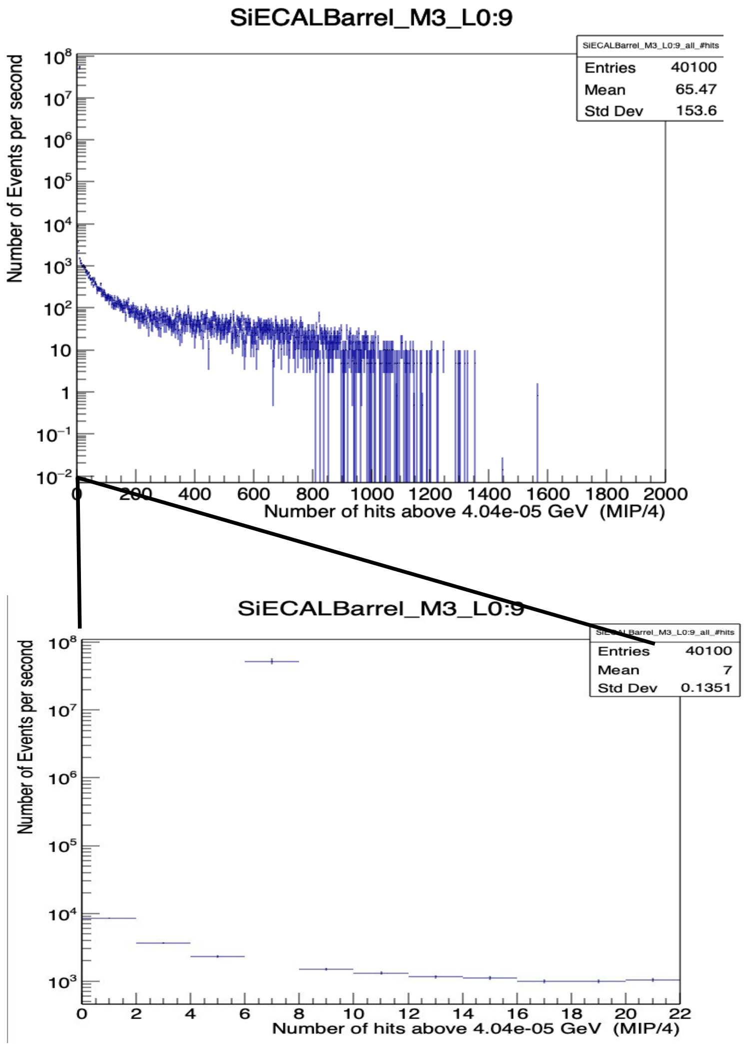



## High #hits




| 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



# Histograms of qq161: Nhits
# M3 L0:9 and M5 L20-29

**⚠ Beware of automatic rescaling ⚠**