Towards an
Estimation of the fluxes in highly granular calorimeters

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A detector for a Higgs factory and beyond: ILD

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cnrs dépasser les frontières

IN2P3 Les deux infinis

Results (Outline)

- ❖Rationale
- ❖Jargon
  - Histogram Types
  - Geometric selections (Explicit Vs. Implicit)
  - Data Simulation
- ❖Results
- ❖Conclusion

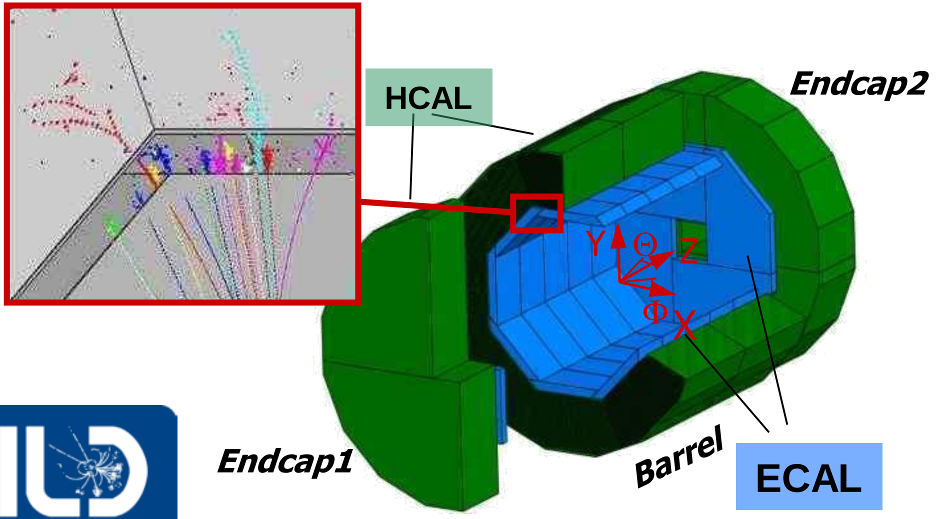
Rationale

Rationale

ILD high granularity calorimeters

- High Granularity requirements:
  - Precision Validation
  - Electronics Power Calculation
- Particle flow Algorithms:
  - Reconstruction of single particles in jets

  requires clear energy and time profiles.



ECAL: 30 layers

- SiW-ECAL": $0.5\times0.5\ cm^3$ Si cells
- ScECAL: $0.5\times5\ cm^2$ Scint strips

10–100M channels

HCAL: 48 layers

- AHCAL: $3\times3\ cm^3$ scint. cells
- SDHCAL: $1\times1\ cm^2$ RPC cells

10–70M channels

Requirements fulfilment:

- Creation of a versatile software package that does a couple of things:
  - Gets any desired set of distributions.
  - Gets this desired set of distributions for any geometric selection of the calorimeter.

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)

```
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]], {})
```

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.

Jargon

Histograms Types

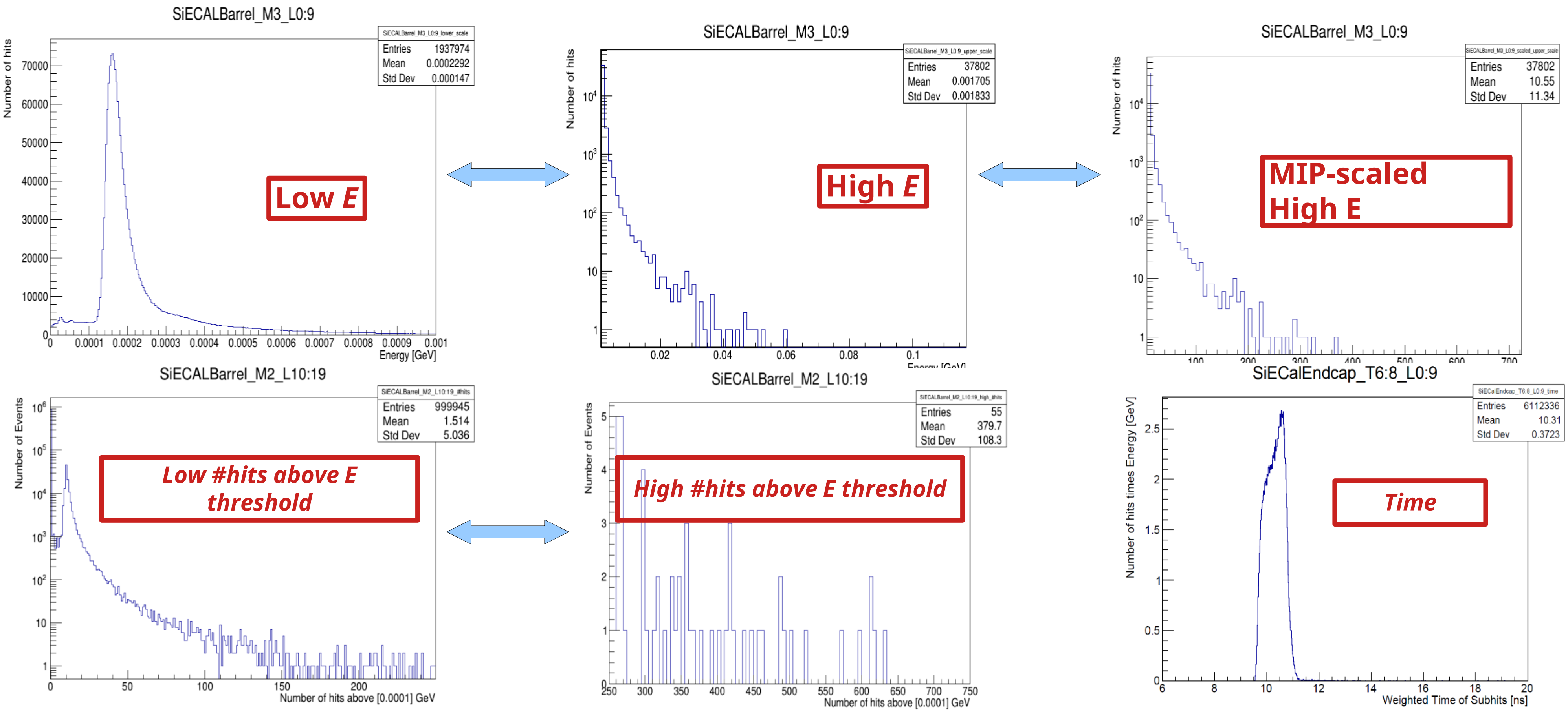
Primary histograms:

1) Low-Scale Energy: Energy distribution of hits in the calorimeter with an upper-bound cut to focus on the distribution shape and exclude the trailing outliers.
2) Upper-Scale Energy: The rest of the distribution to show the different tailing effects for different parts of the calorimeter and different physics processes.
3) Low-Scale Number of hits: Distribution of number of hits above a given energy threshold per event.
4) Upper-Scale Number of hits: The rest of the distribution.
5) Time: Time distribution of the sub hits weighted with the corresponding energy.

Secondary histograms (functions of primary histograms):

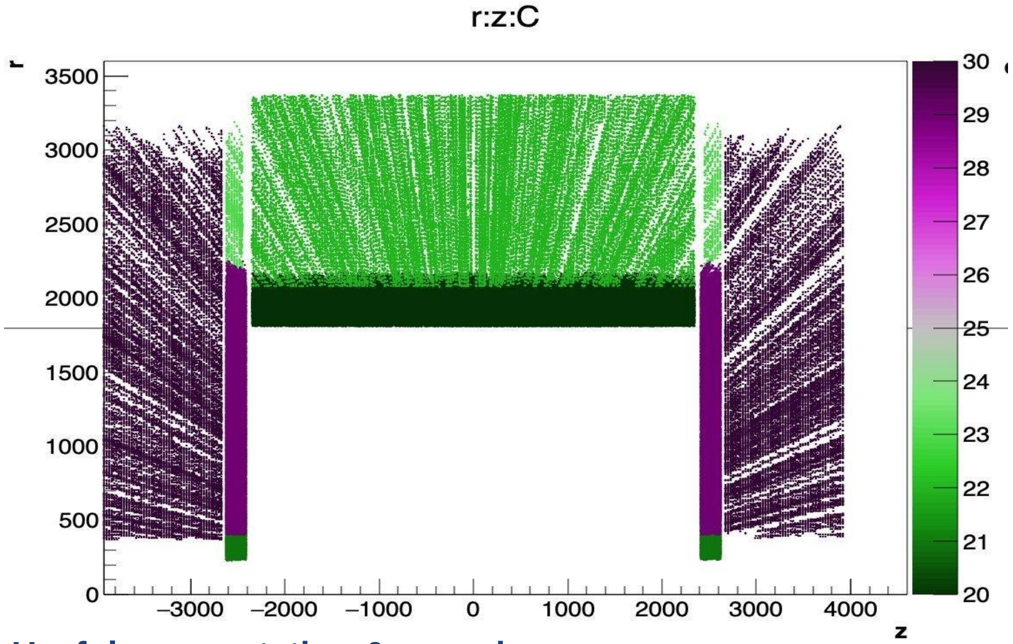
1) Scaled Upper-Scale Energy: The same distribution as the Upper-Scale Energy histogram with the x-axis scaled by the MIP value.
2) Low-Scale Power: This depends on the used ADCs. It could be a linear function of the energy distribution or the distribution of the number of hits above a given energy threshold.
3) Upper-Scale Power: The rest of the power distribution.

Histograms Types (1,000,000 muon events)

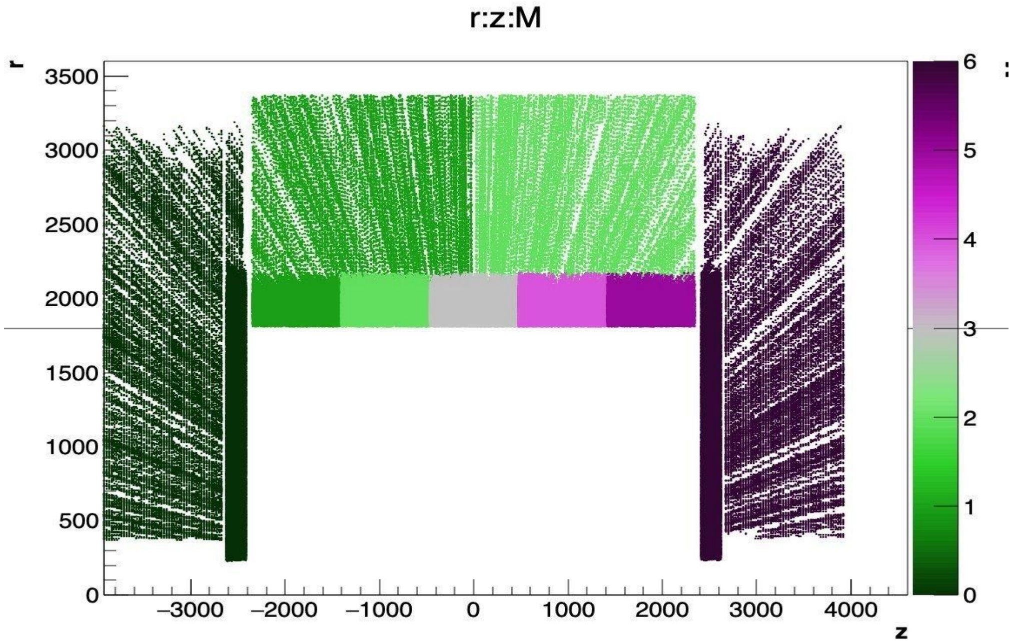


Geometric Selections

Calorimeters systems C



Calorimeters Modules



Useful segmentation & grouping:

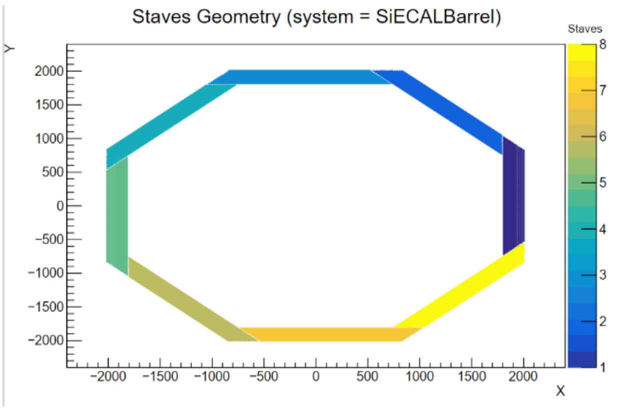
- Physics: Group of uniform (rates) regions (~cosθ)
- Technical: Readout & Cooling Partition (ASIC, SLAB, Tower, Module)

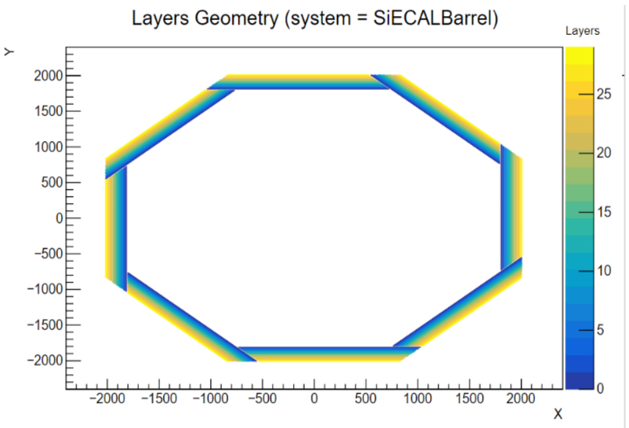
Useless individuation:

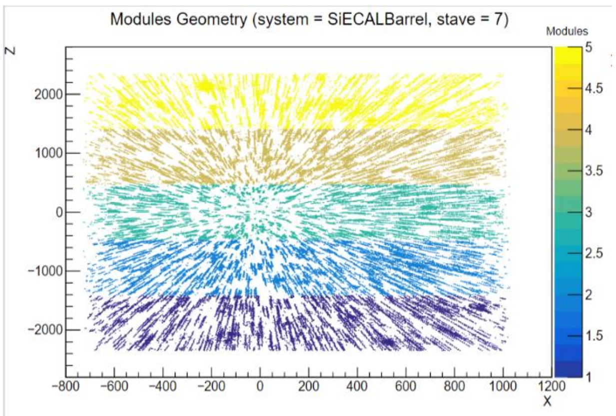
- (Individual layers)
- Symmetrical : staves (φ), Forward–Backward (±θ)

Geometric Selections (Explicit)

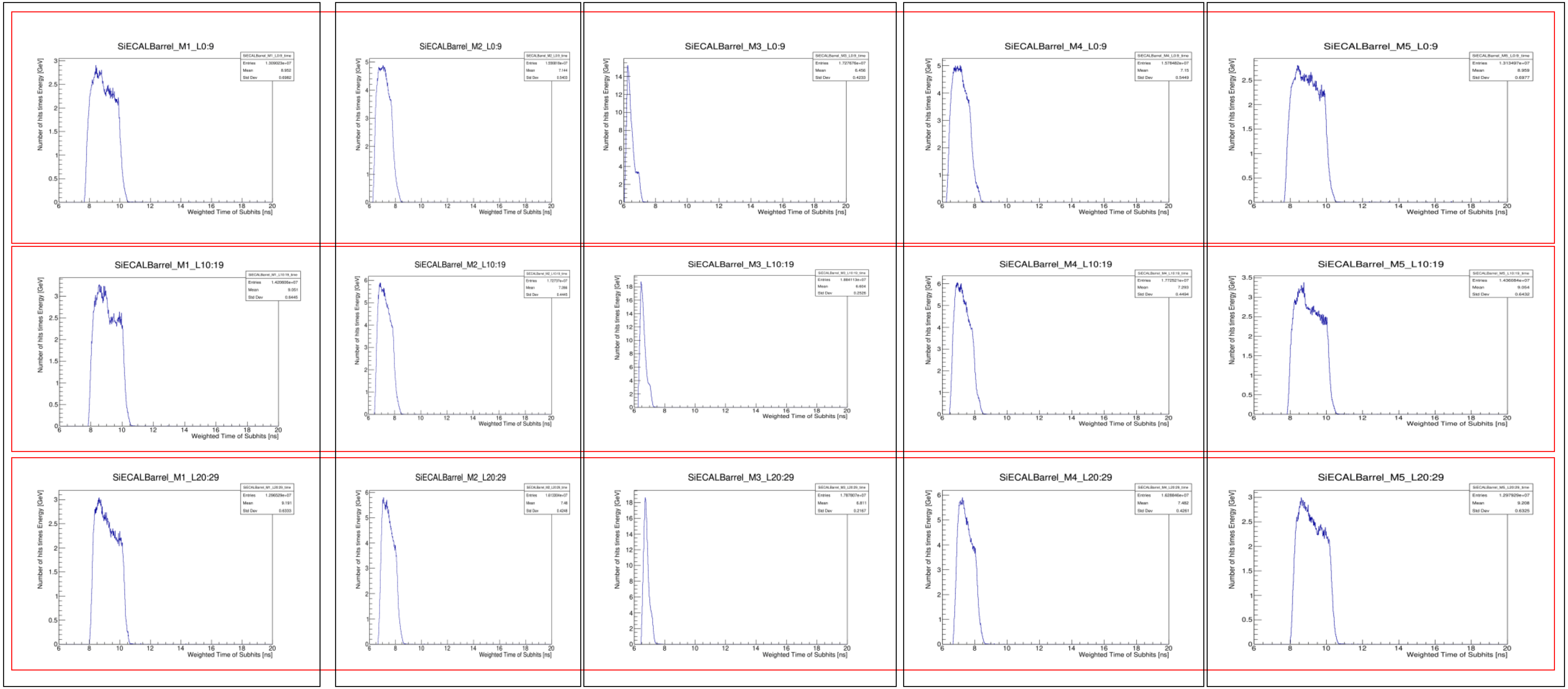
- As the beam originates from the origin vertex, all the staves are symmetric (azimuthal symmetry).
- The spherical radial behavior can be obtained from different layers (central image).
- To get polar behavior, the z-extension is shown for one of the staves. Different modules give different polar angle. For example, the central one (module 3) is the one with $\theta = 90°$.
- The chosen selections are 5; one for each module (each one representing a polar angle profile) and the 3 for each 10-layer block (each of which represents different radial profile). Total selections = 5*3=15 for the system ECALBarrel.



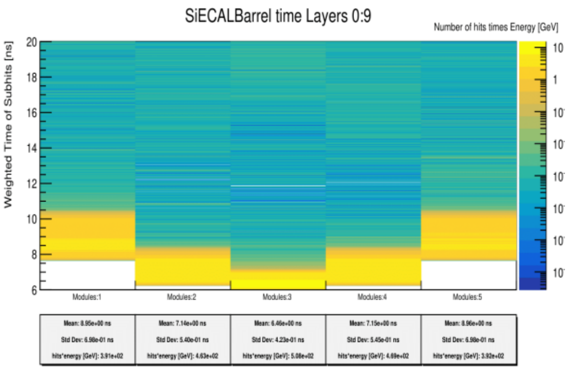


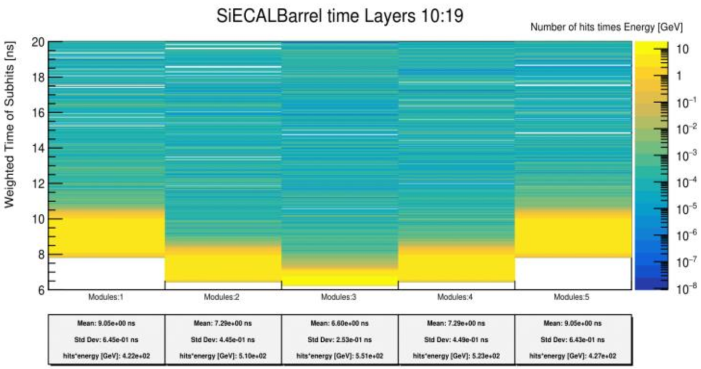


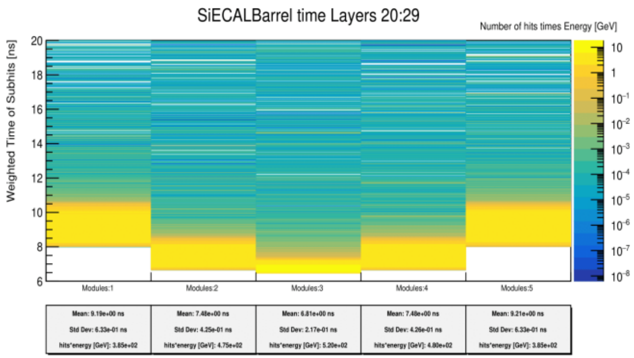
Geometric Selections (1D histograms : million muons events)

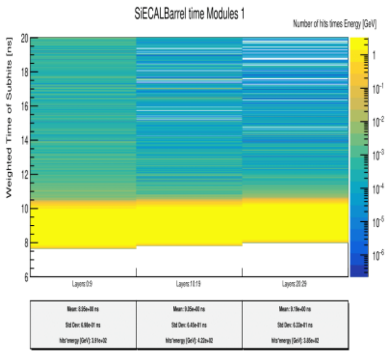


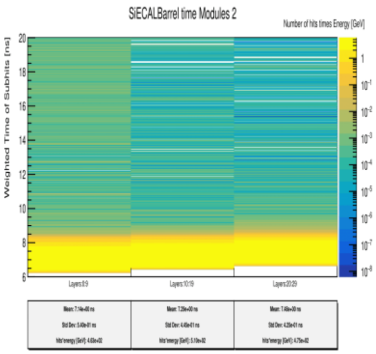
Geometric Selections (2D histograms)

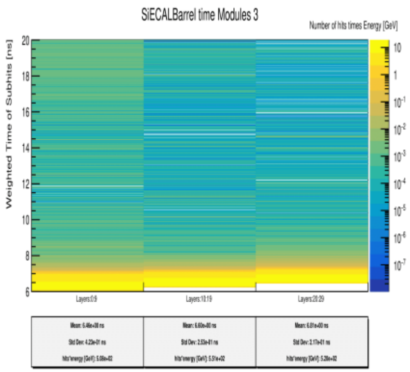


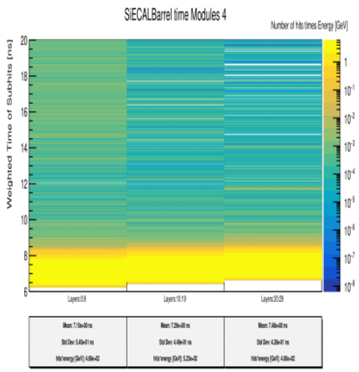


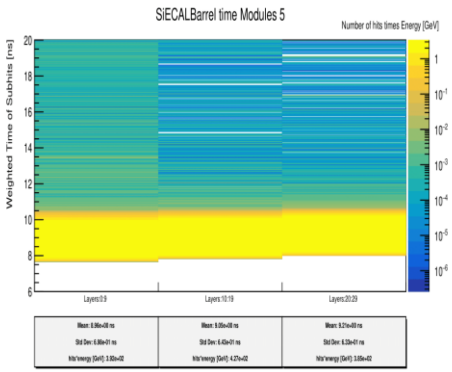




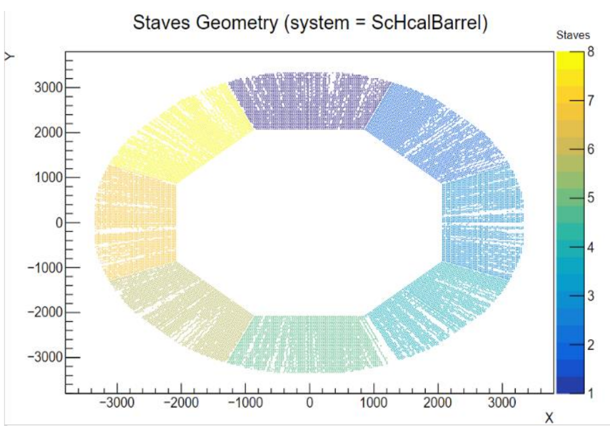


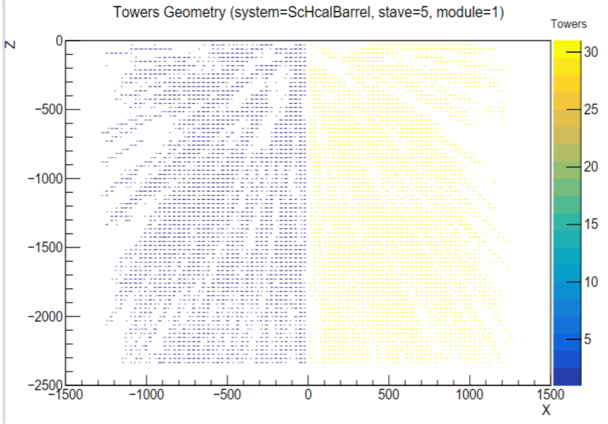


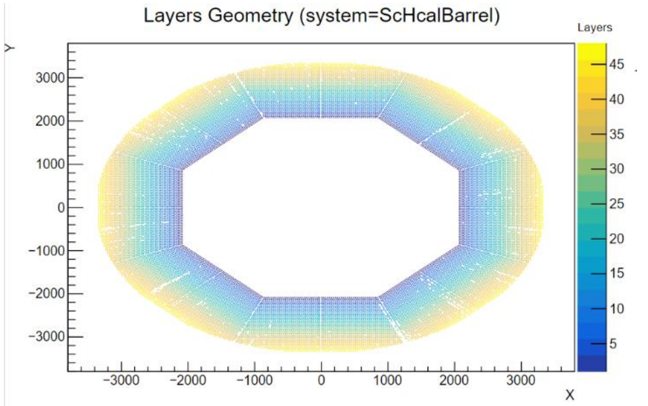


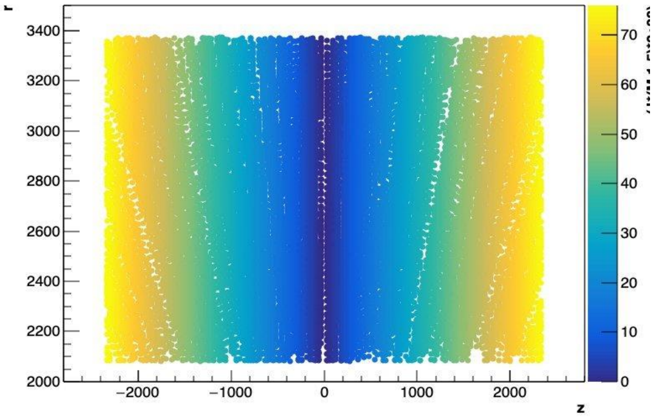


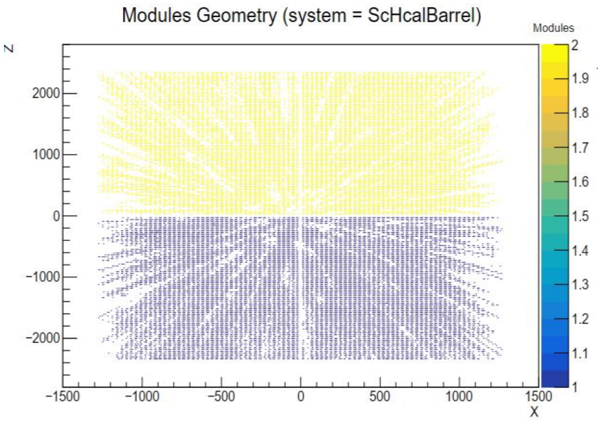
Geometric Selections (Implicit)







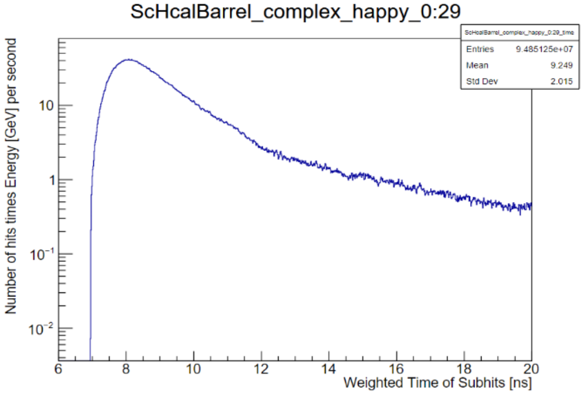


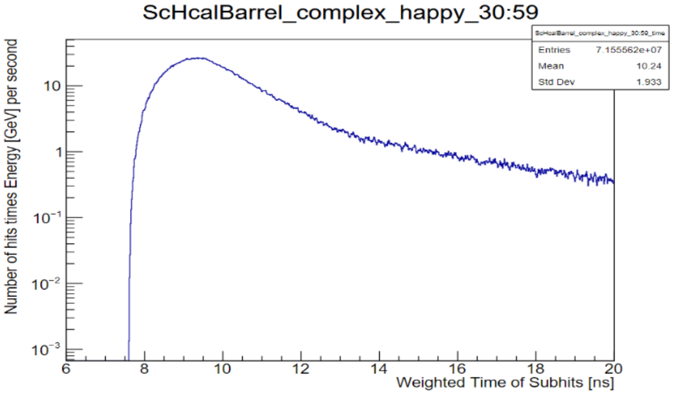


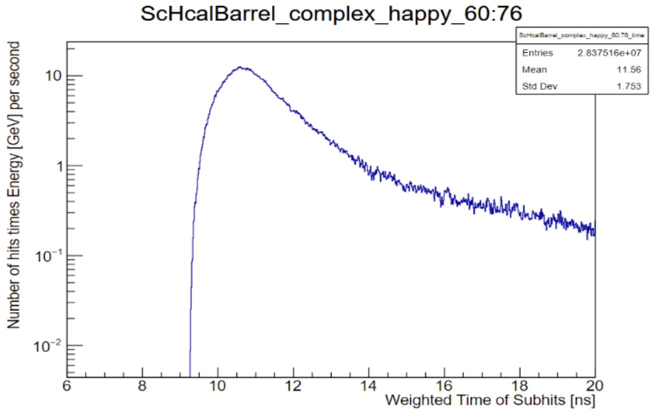
Radial Profile: 3 categories of layers
Polar-angle profile: 3 categories of modules and J-position values of the expression: 2J(M-1.5)+38

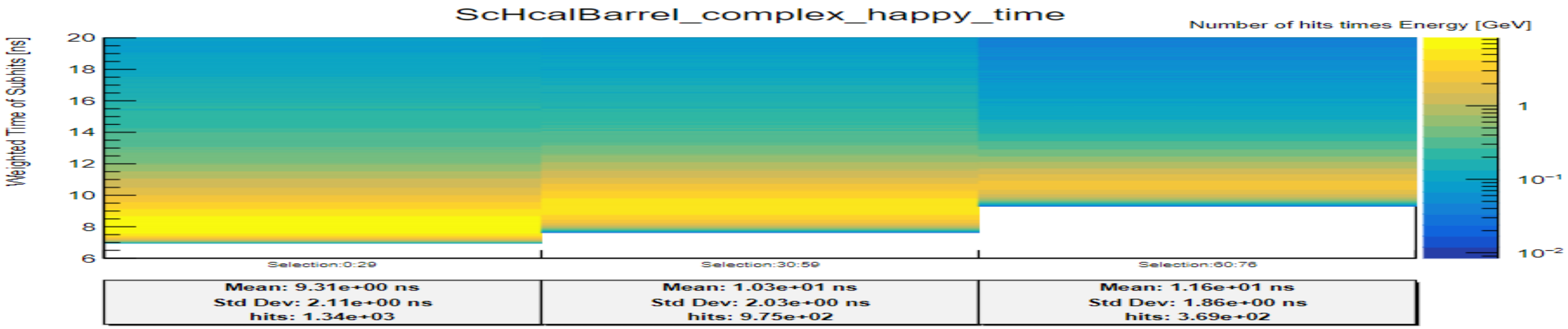
1D Vs. 2D Histograms (implicit selections)

2J(M-1.5)+38 = {x: x is integer, $0 \leq x \leq 76$}



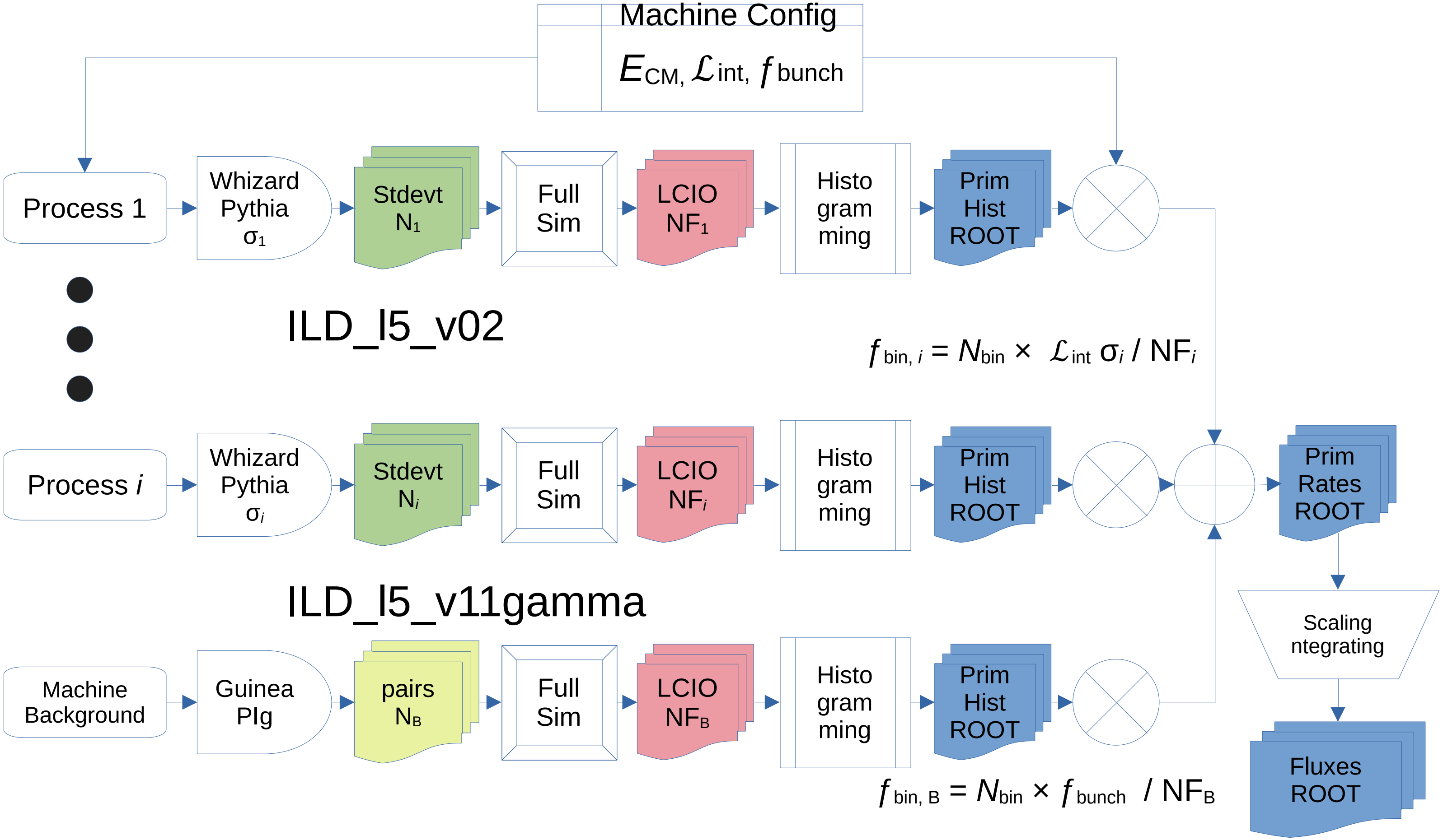






Data Simulation

Processes to Fluxes



By Daniel Jeans

Generated data

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}

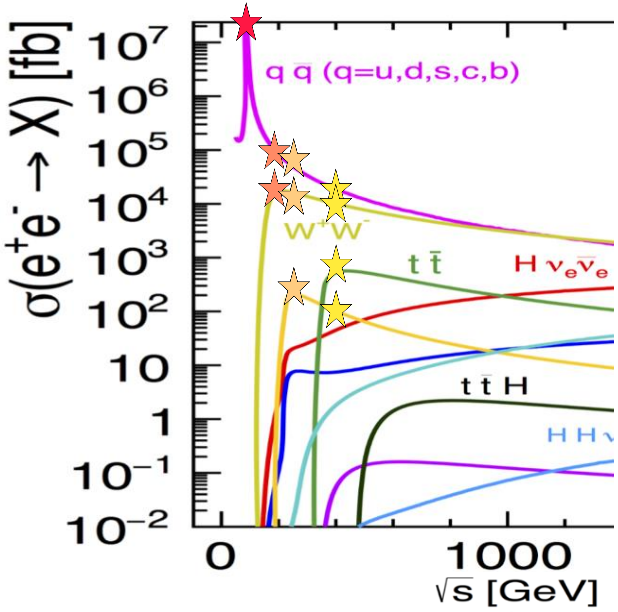
Table 3: $240\,GeV$
$(N = 10000,\ L_{\text{ins}} = 6.9 \times 10^{-5}\ \text{fb}^{-1}\ \text{s}^{-1})$

Channels	σ $(10^5\ \text{fb})$	$(\frac{\sigma \times L_{\text{int}}}{N})$ (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}

Selected modes



Processes: min. bias

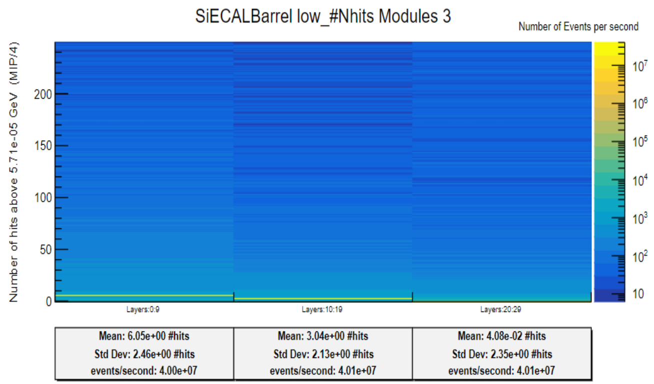
- All
  - ee → qq
  - ee → $\mu\mu$, $\tau\tau$
  - ee → ee (⊃ Bhabha)
  - $\gamma\gamma$→ VV
  - Machine background (ee pairs)
- $E_{CM} \geq 160$ GeV
  - ee → WW
- ($E_{CM} \geq 240$ GeV)
  - ee → HZ
- ($E_{CM} \geq 360$ GeV)
  - ee → tt

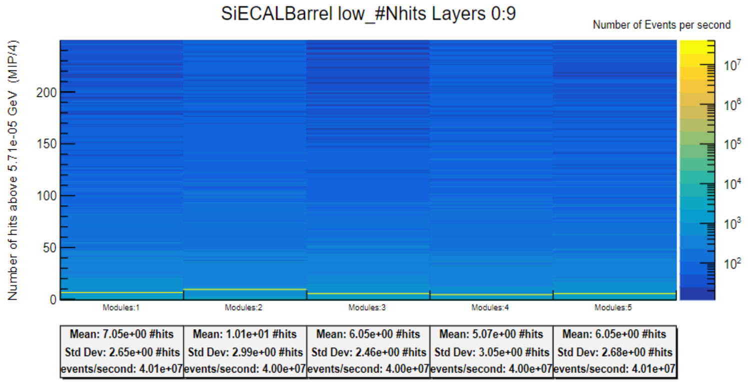
Config	#IP	E_{Beam}	#BX	$\mathcal{L}$ [10^{34}/cm²/s]	ΔT [μs]	Freq[Hz]	√s [GeV]
FCC-Z2	2	45,6	12000	180,0	0,025		91,2
FCC-Z4	4	45,6	15880	140,0	0,019		91,2
FCC-W	4	81,3	688	21,4	0,442		162,5
FCC-ZH	4	120,0	260	6,9	1,169		240,0
FCC-tt	4	182,5	40	1,2	7,600		365,0
ILC250 [1]	1	125,0	1312	1,4	0,554	5,0	250,0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

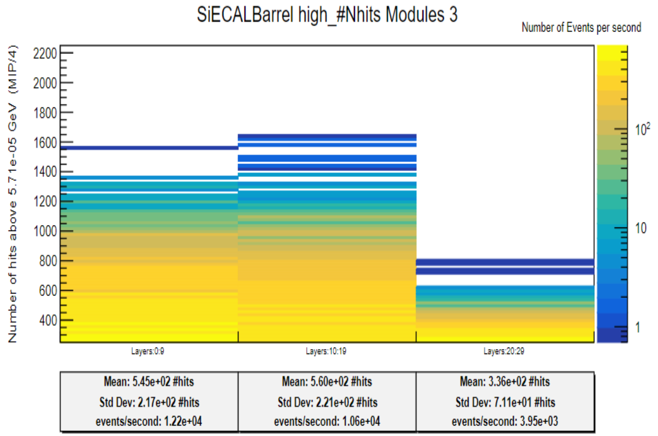
Results

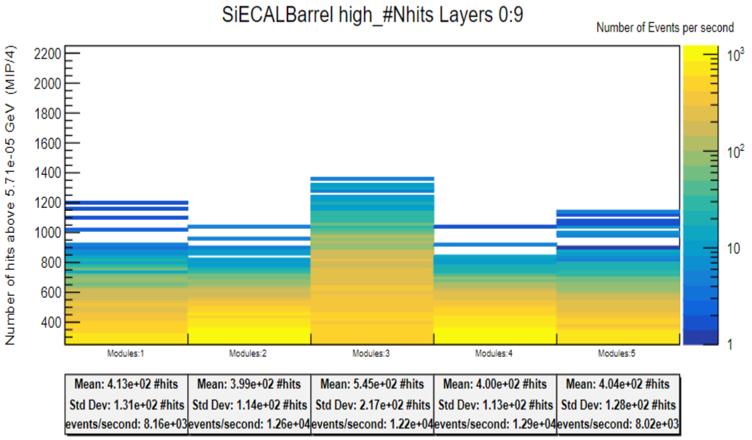
Results (Silicon ECAL Barrel)





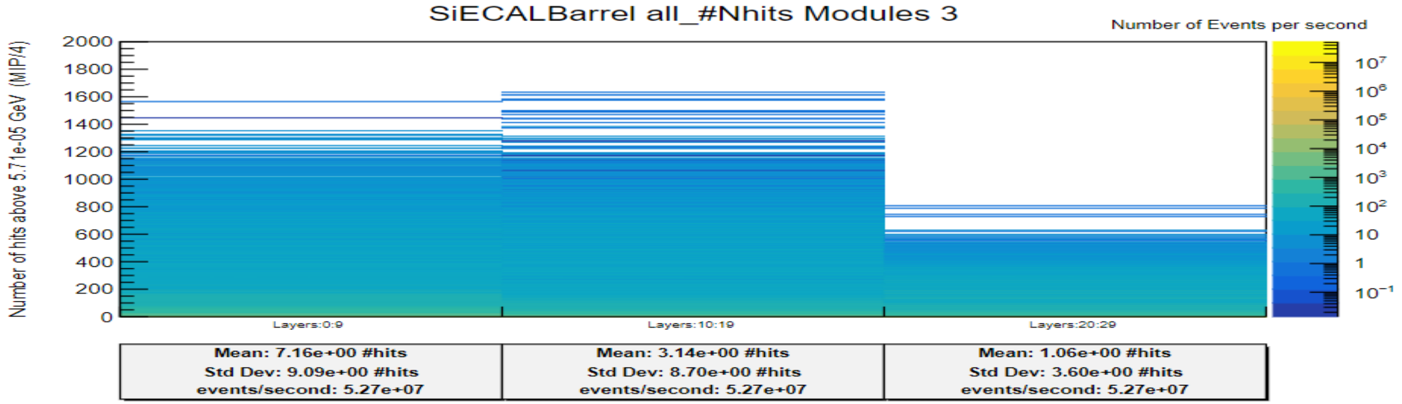
Distributions of the number of hits crossing (MIP/4) energy threshold of all the physics processes and machine background at 91.2 GeV with the color bar representing the rate of events

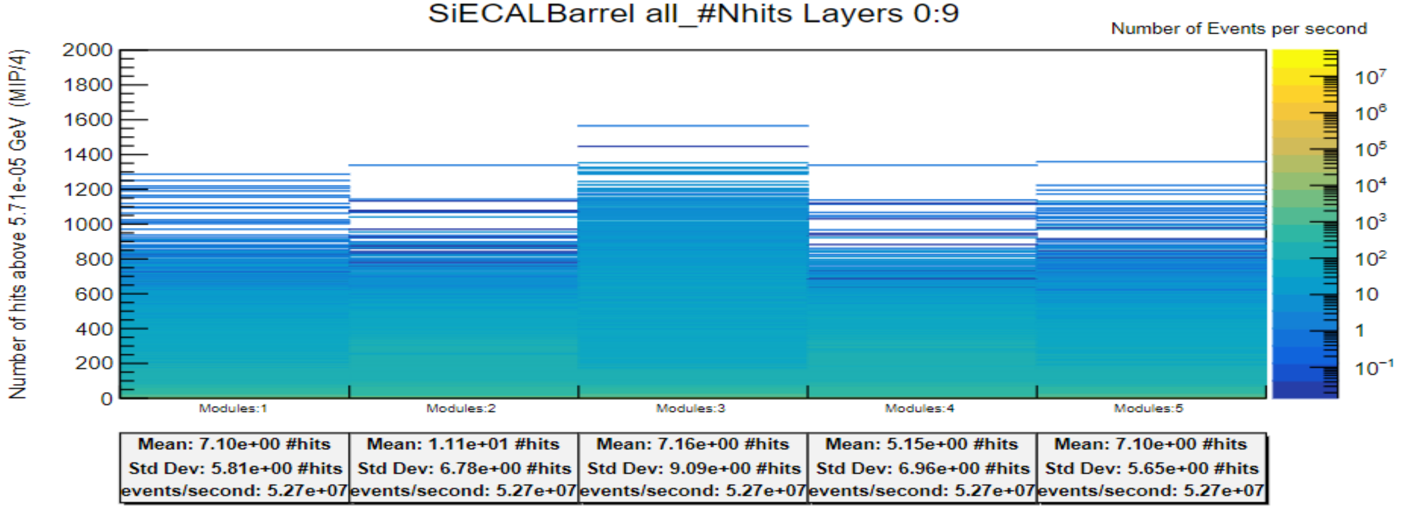




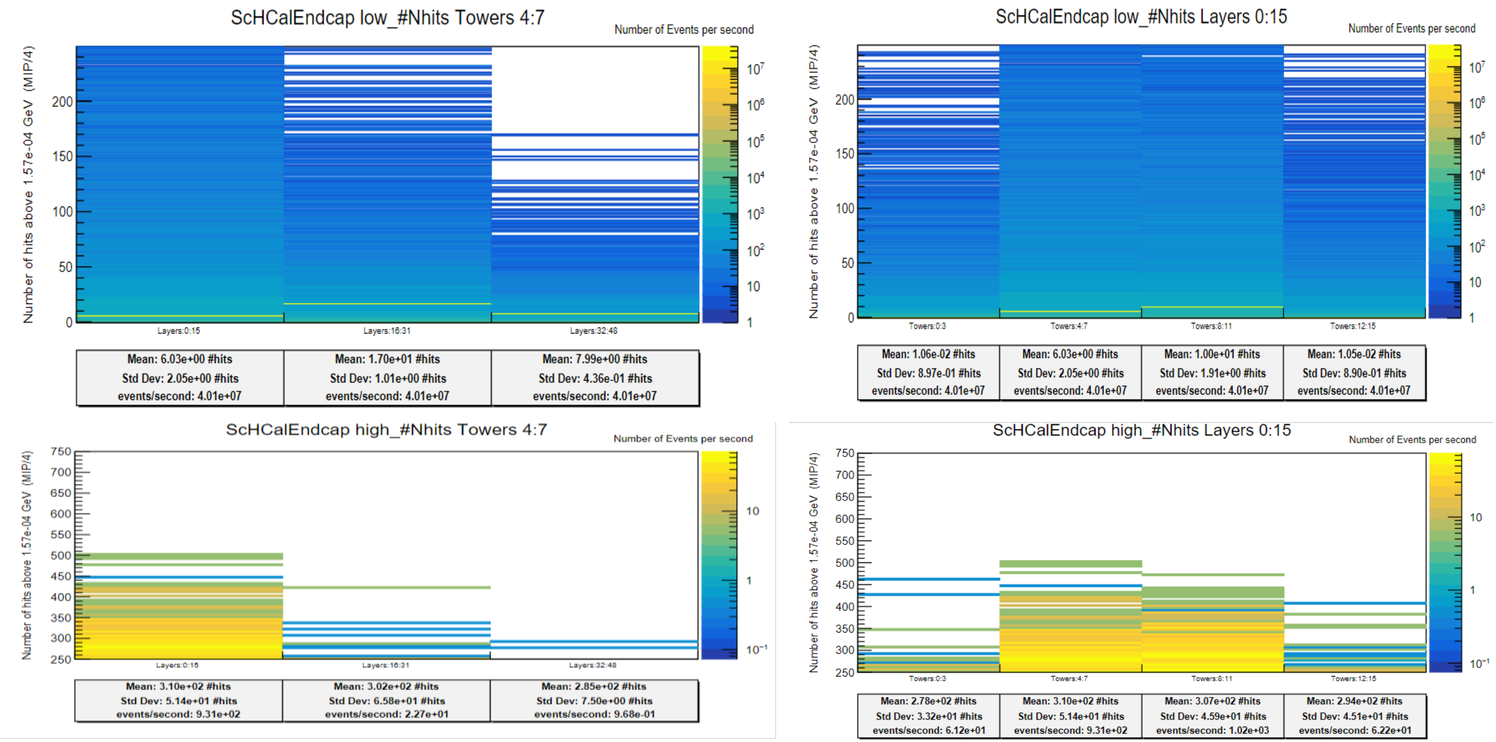
- Most of the hits are in the first 2 thirds of the calorimeter.
- No significant angular dependence.
- An exception is module 3 due to the double counting effect.

Results (Silicon ECAL Barrel : Combined scales)





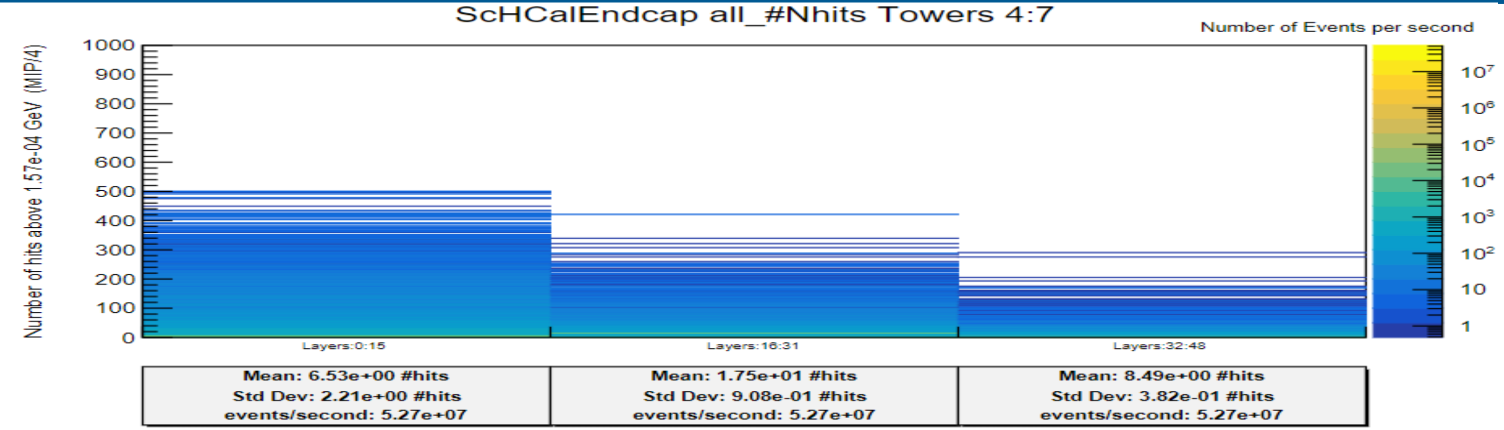
Results (Scintillator HCAL Endcap)

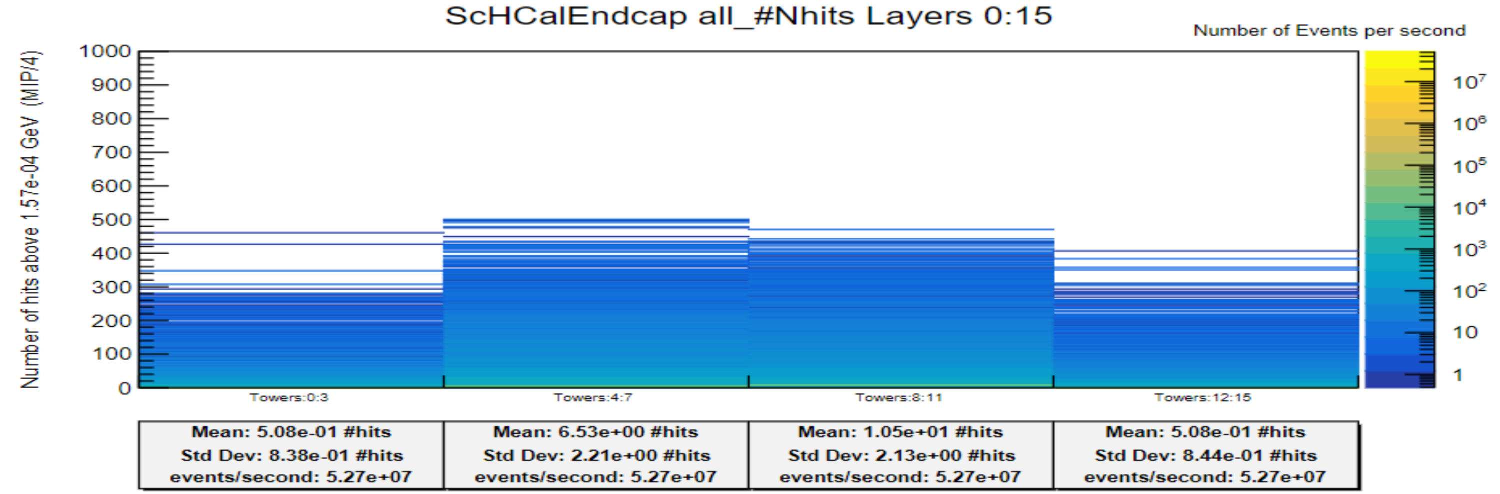


- Most of the hits are in the first 2 thirds of the calorimeter.
- Significant angular dependence.
- The central towers have most of the hits due to the closeness to the beampipe.

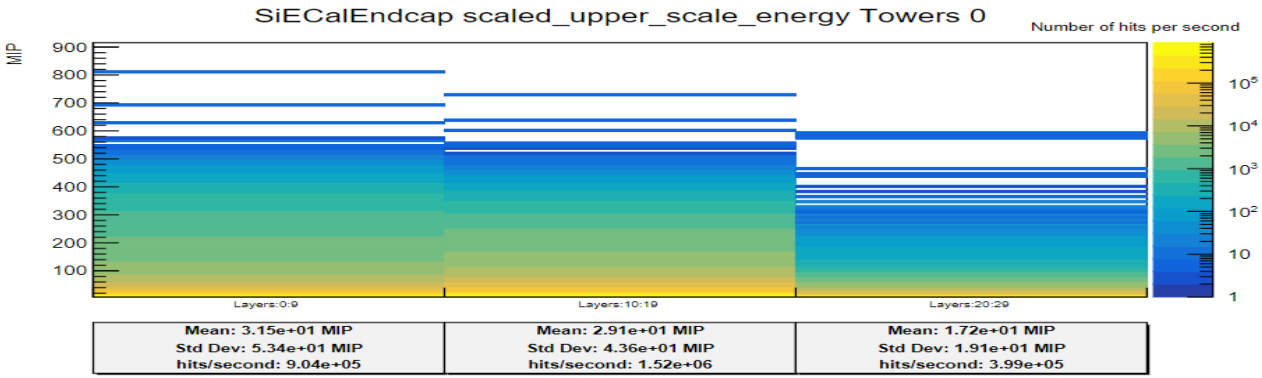
Distributions of the number of hits crossing (MIP/4) energy threshold of all the physics processes and machine background at 91.2 GeV with the color bar representing the rate of events

Results (Scintillator HCAL Endcap: Combined scales)

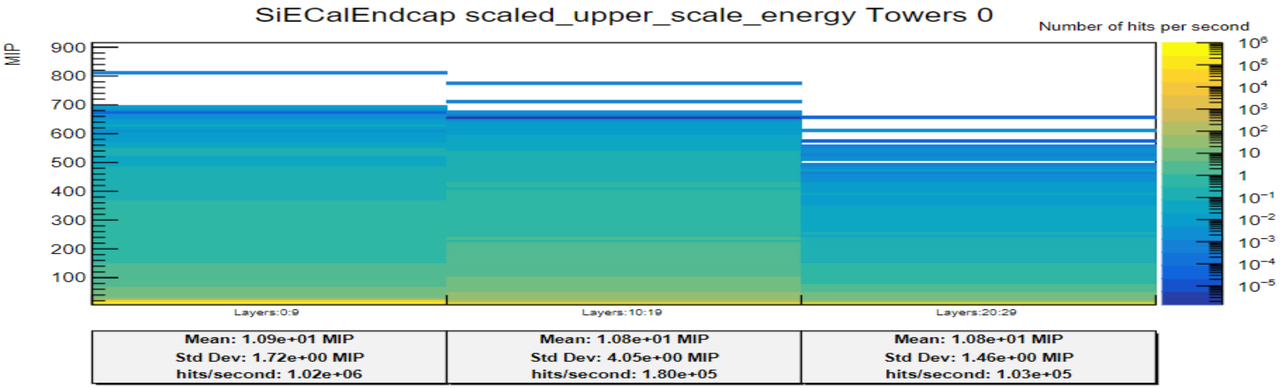




Results (Dynamic Range)



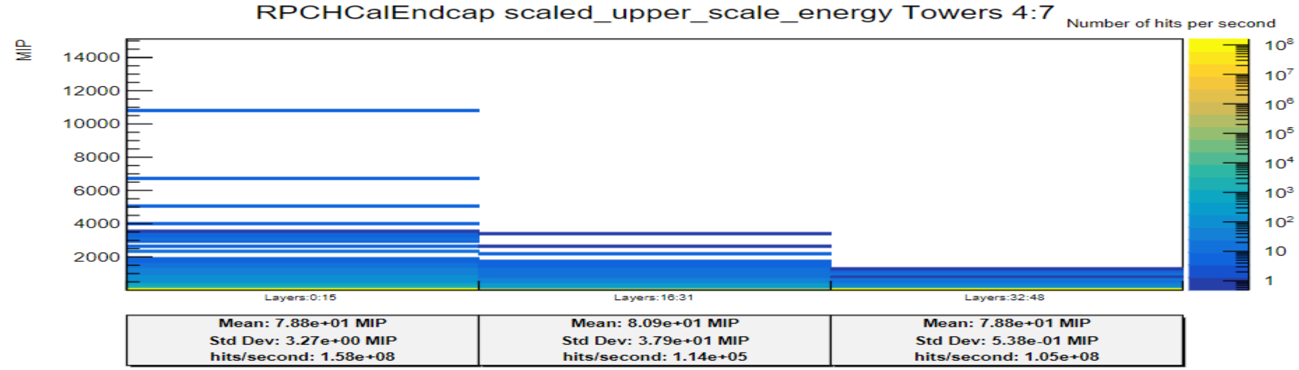
Upper Scale Energy distributions of tower 0 of ECAL end cap at 91.2 GeV of all physics and background



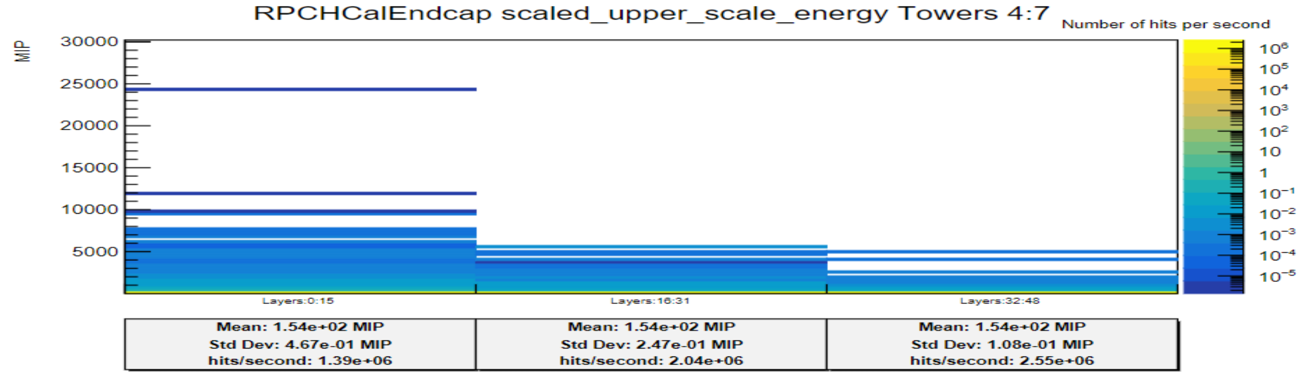
Upper Scale Energy distributions of tower 0 of ECAL end cap at 240 GeV of all physics and background

- Max Energy = ~800 MIP
- Tower 0 is $\theta = 90°$
- It is the same for both energies.

Results (Dynamic Range)



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



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

- Max Energy = ~10000 MIP for 91.2 GeV and ~25000 MIP for 240 GeV
- It is not the same for both energies.
- These are the towers closest to the beam pipe and the beam energy makes noticeable difference.

Conclusion

Done

Simulation:

- Simulated detector-level data for all 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.

Histograms:

- Generated primary, secondary 1D and 2D histograms in various systems of ECAL and HCAL of the ILD calorimeter
- Merged different processes and background and got collective histograms.

Conclusions:

- Check the statistics vs angular distribution for processes.
- Give estimates of the average number of hits and the dynamic range.

To be done

Simulation:

- Simulate machine background at 162.5 GeV and 365 GeV and more statistics at 91.2 GeV and 240 GeV

Extension:

- Extend a similar work to the tracker. We need logical coordinates.

Expansion:

- Expand the work by applying it to other detectors rather than the ILD. We also need also logical coordinates.

Code:

- Adapt to key4hep framework by changing LCIO to EDM4HEP

Thank you!