

Determination of the Fluxes in the ILD calorimeters at the Circular Colliders

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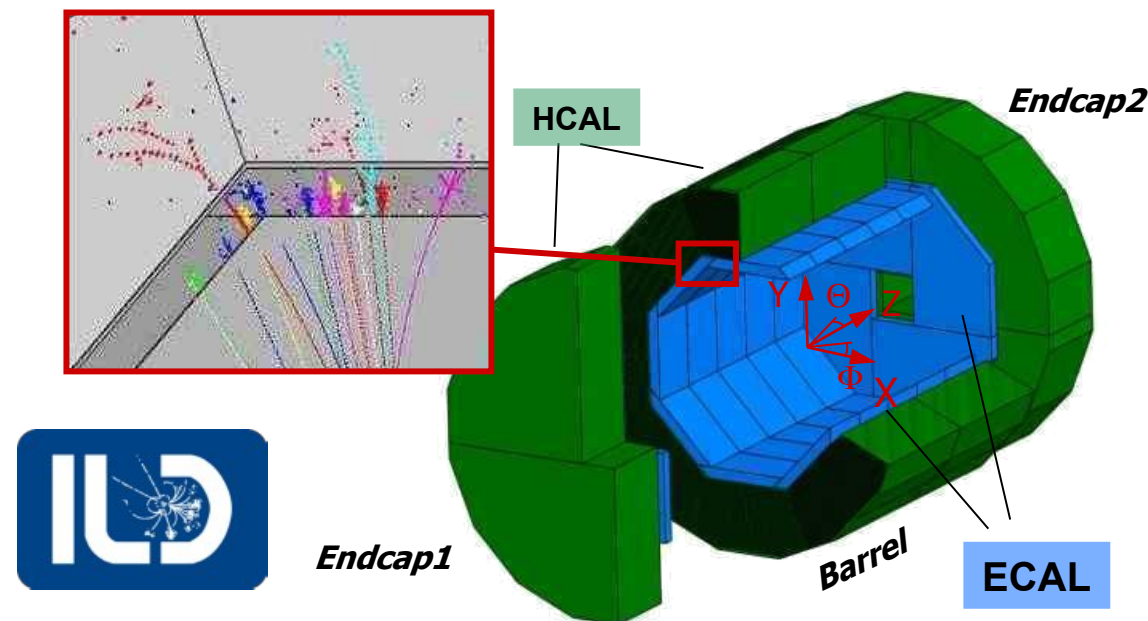
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CEPC EU WS 2025, Barcelona, 17/05/2025

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
- Partially Adapted for CEPC
 - Lower granularity, ...
- Needs strong adaptation for EW physics and continuous operation
 - Rates, Heat, Electronics



ECAL: 30 layers

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

10–100M channels

HCAL: 48 layers

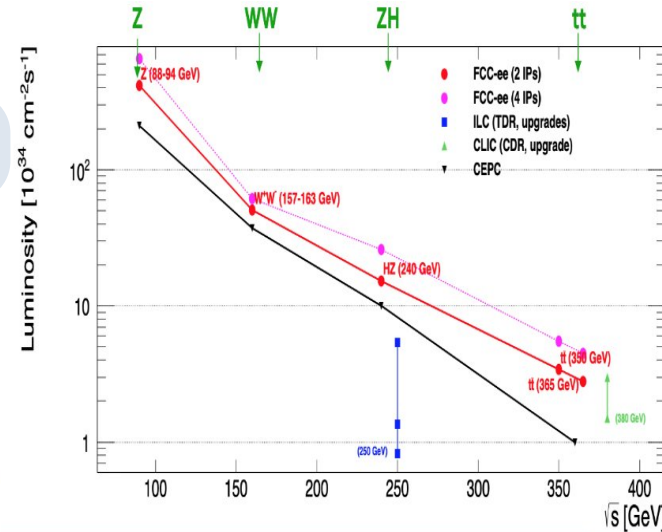
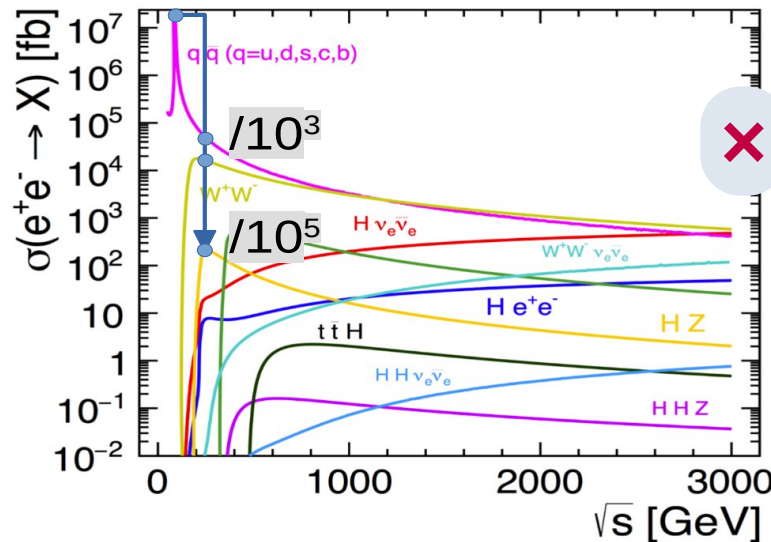
- AHCAL: scint. cells $3 \times 3 \text{ cm}^2$
- SDHCAL: RPC cells $1 \times 1 \text{ cm}^2$

10–70M channels

Revisiting the HG calorimeters for circular colliders

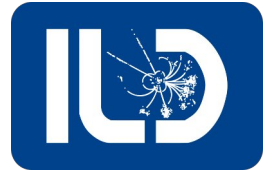
Large panel of running conditions

- $90\text{GeV} \times 10^7 \text{ fb} \times 5 \cdot 10^{36} \text{ cm}^{-2} \text{ s}^{-1}$ ($qq \times 20,000 \text{ ILC @ 250}$)
- $150 \text{ GeV (WW)} + 250 \text{ GeV (ZH)} + 280 \text{ GeV (tt)}$
 $\sim 10^4 \text{ fb} \times 5 \cdot 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ ($qq \times 5\text{--}10 \text{ ILC @ 250}$)



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 5–10 mW/ch ? With timing ?
 - Running mode (continuous, trigger-less)
 - Trigger for other detectors ?



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

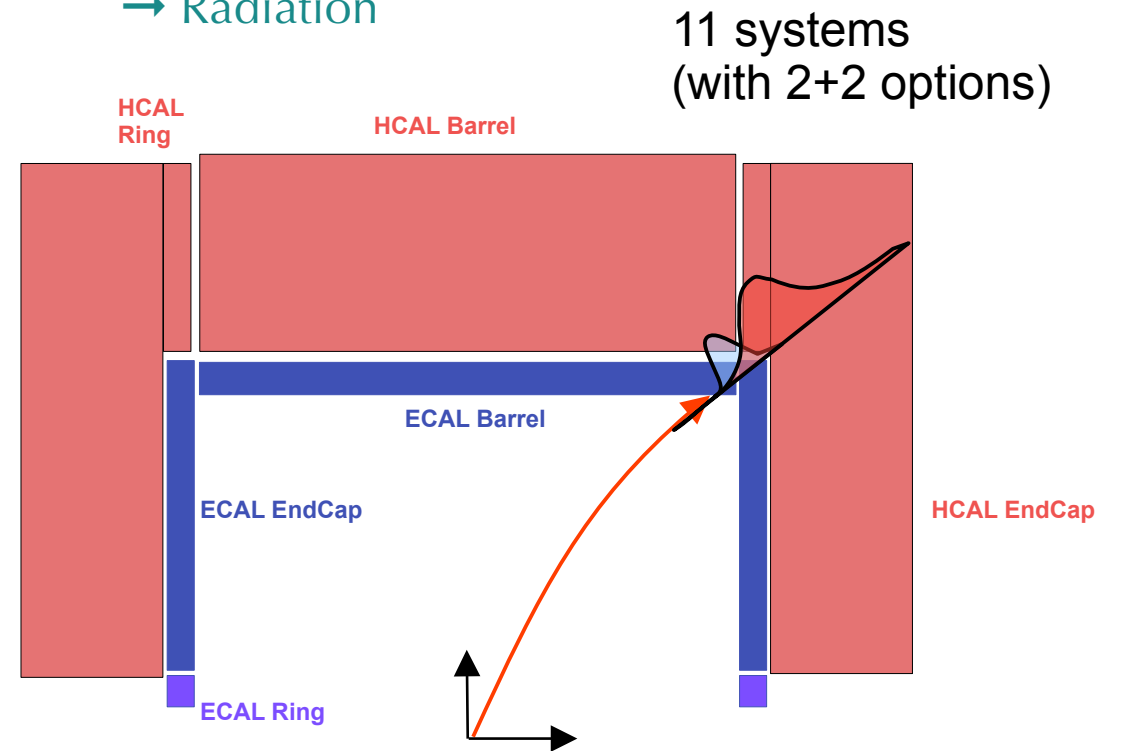
Calorimeter Fluxes from Full Simulations

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 (if Wilkinson ADCs)
 - Frequency of Double hits
- Data output
 - Data Flux per readout partition (DAQ)
 - DAQ scheme (Calo trigger to other parts ?)

Other quantities

- Deposited energies
 - Radiation



Technical challenges

“Every cell is a special case” → 100M+ histograms ?

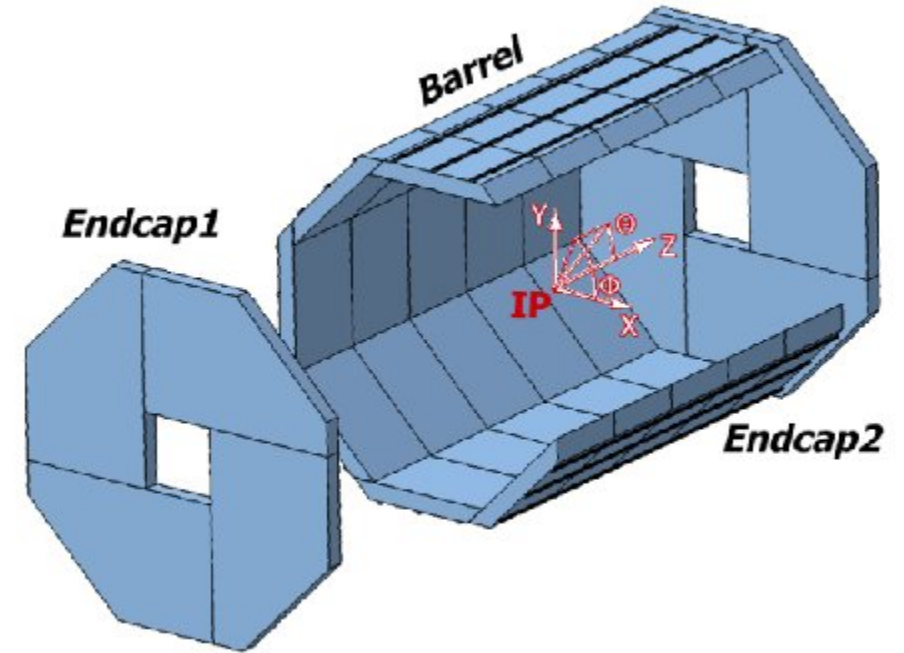
- Reduced by symmetries (8-fold in ϕ for barrel, 2 or 4-fold in Endcaps, forward-backward in θ)
 - Reduced by grouping “similar regions”
 - Blocs or readout (Cassettes)
 - Blocs adjacents layers
- Requires a proper “logical mapping” (if possible following the readout logical)

Proper handling of distributions:

- 1) Calibration in units of MIPs
- 2) The dominant bin is 0; has to be treated adequately (i.e. separately, merging has to be centered on 0)
- 3) Some distributions have large tails (deposited energy, time):
 - dynamic boundaries : incompatible with 1)

Not fully solved :

- Proper visualisation
- Occupation number require to know the full population in a region; not given by k4Geo/GEANT4



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 = $f(\text{\#hits, Energy})$

2D histograms

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

JINST 19 (2024) 10, T10009

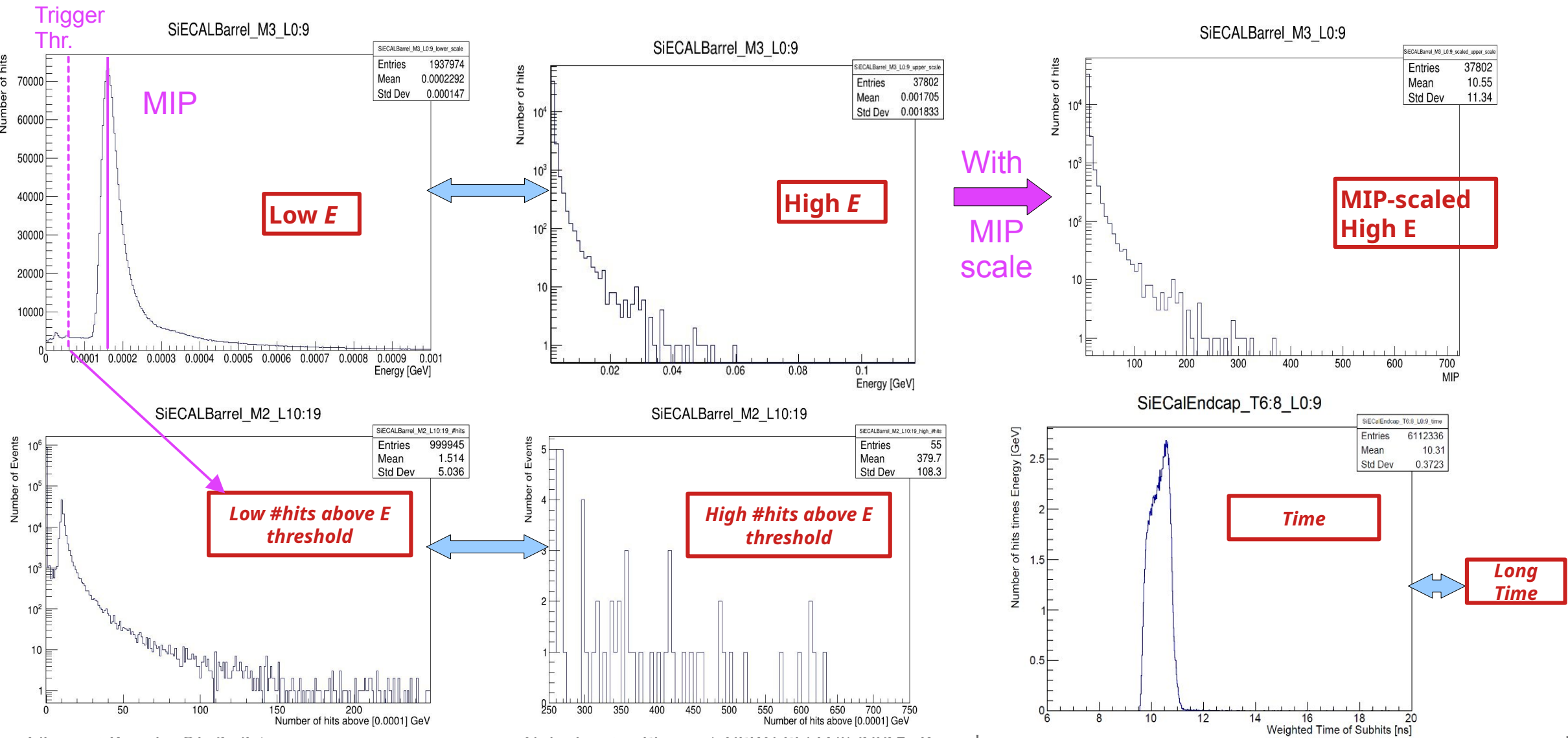
<https://doi.org/10.1088/1748-0221/19/10/T10009>

<https://github.com/LLR-ILD/CalorimeterFluxes/>

```
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 1
#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 histogram.
# The fourth list has the energy threshold that we use in the Nhits histogram.
dictionary_of_system = {}
#
# System      Xollwctiona      Stave  M0dules      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)

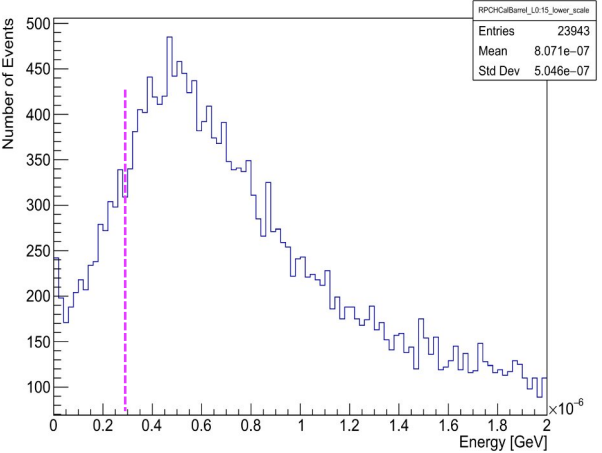


System Low Energy & #hit responses

raw energies (no digitization yet)

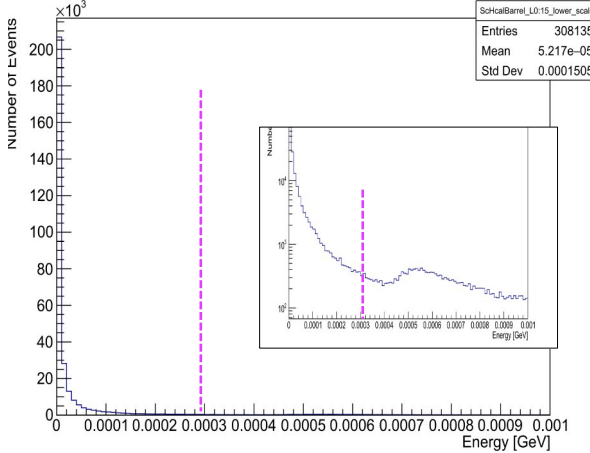
SDHCAL

Energy histogram - RPCHCalBarrel_L0:15



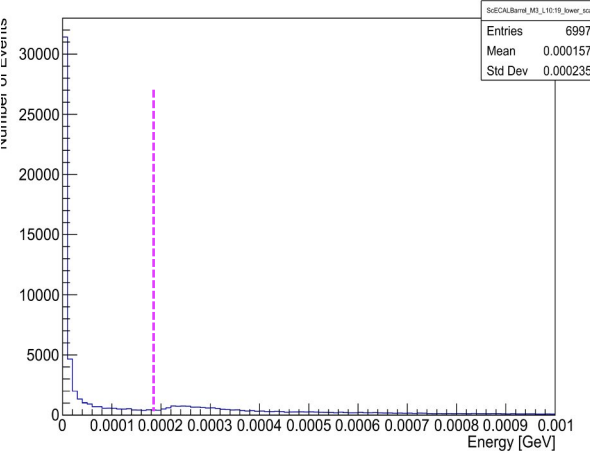
AHCAL

Energy histogram - ScHcalBarrel_L0:15



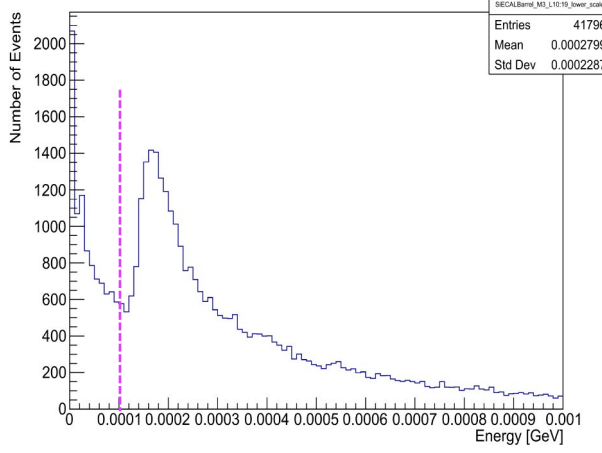
Sc ECAL

Energy histogram - ScECALBarrel_M3_L10:19

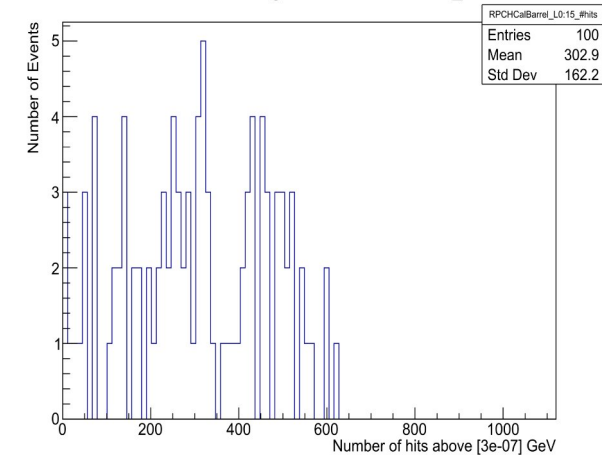


Si ECAL

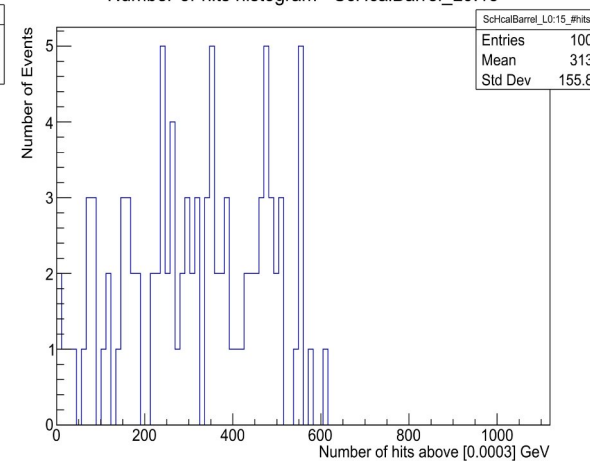
Energy histogram - SiECALBarrel_M3_L10:19



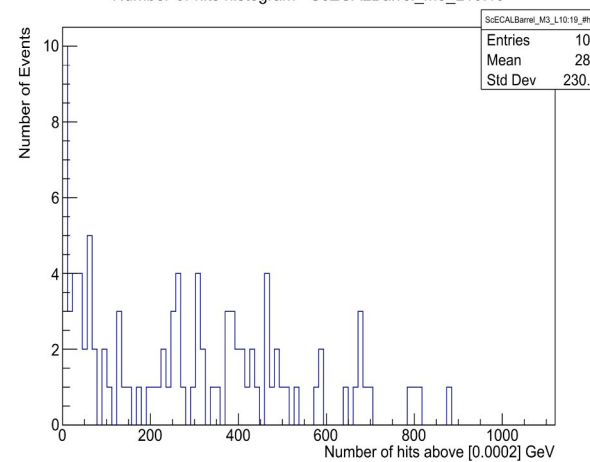
Number-of-hits histogram - RPCHCalBarrel_L0:15



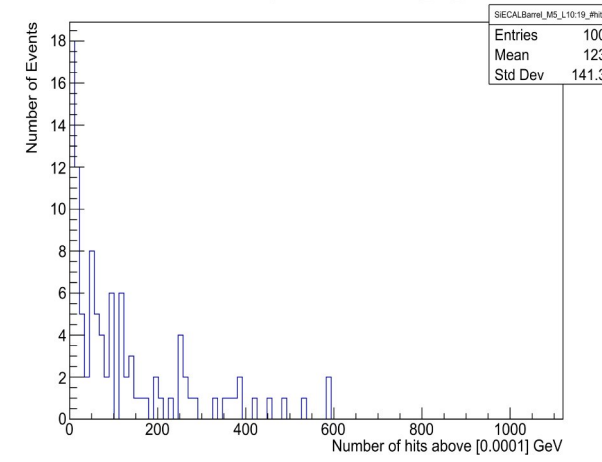
Number-of-hits histogram - ScHcalBarrel_L0:15

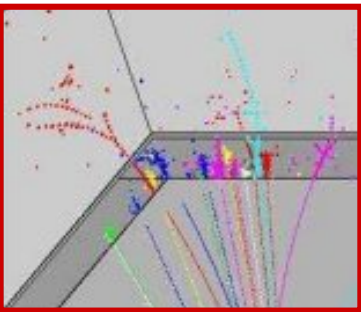


Number-of-hits histogram - ScECALBarrel_M3_L10:19

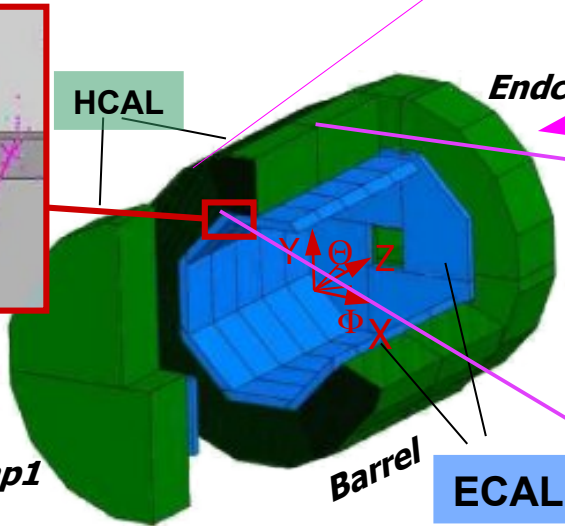


Number-of-hits histogram - SiECALBarrel_M3_L10:19

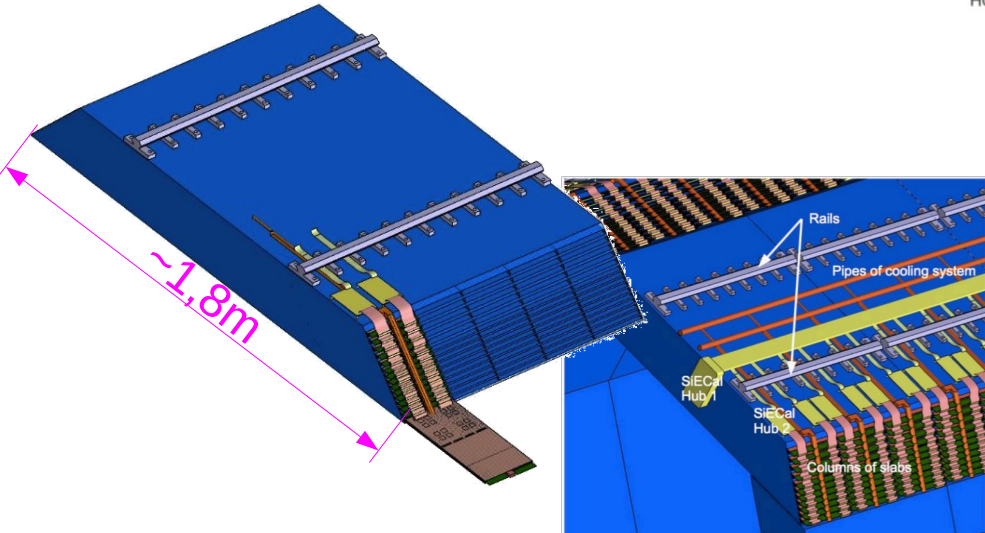
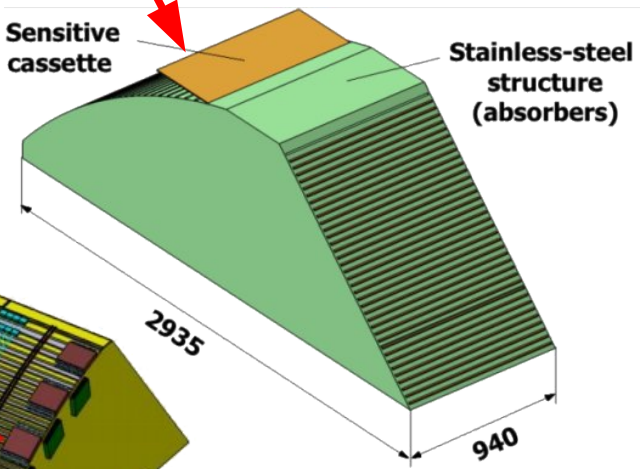
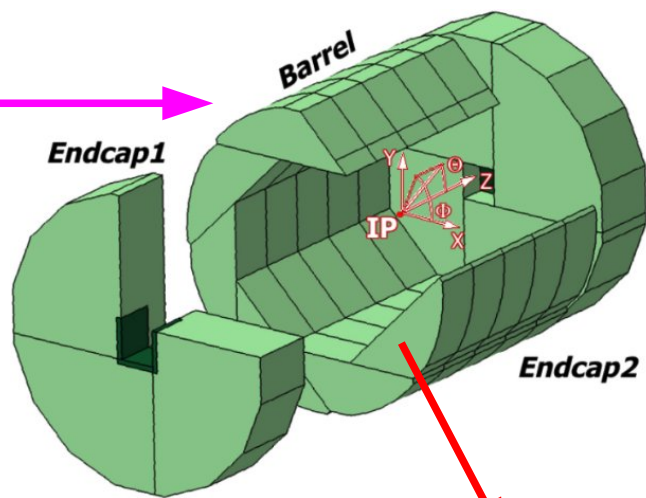
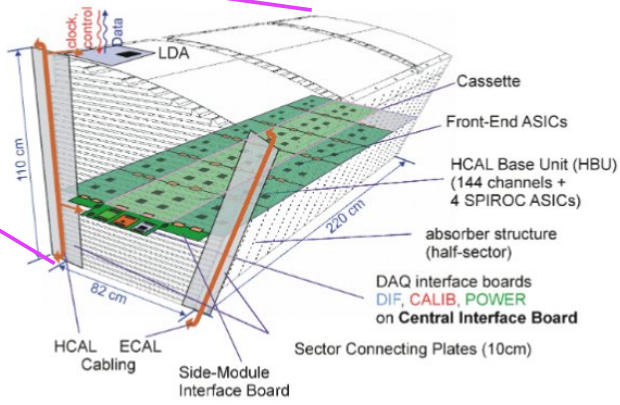




(SiD = 12 fold)

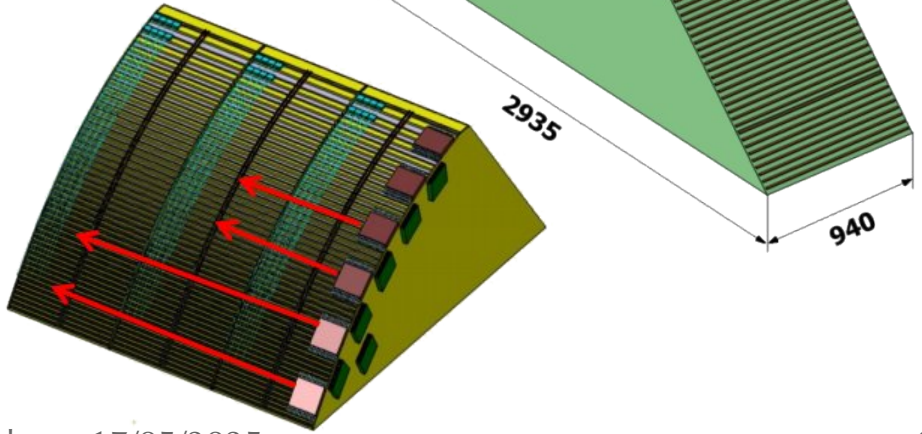


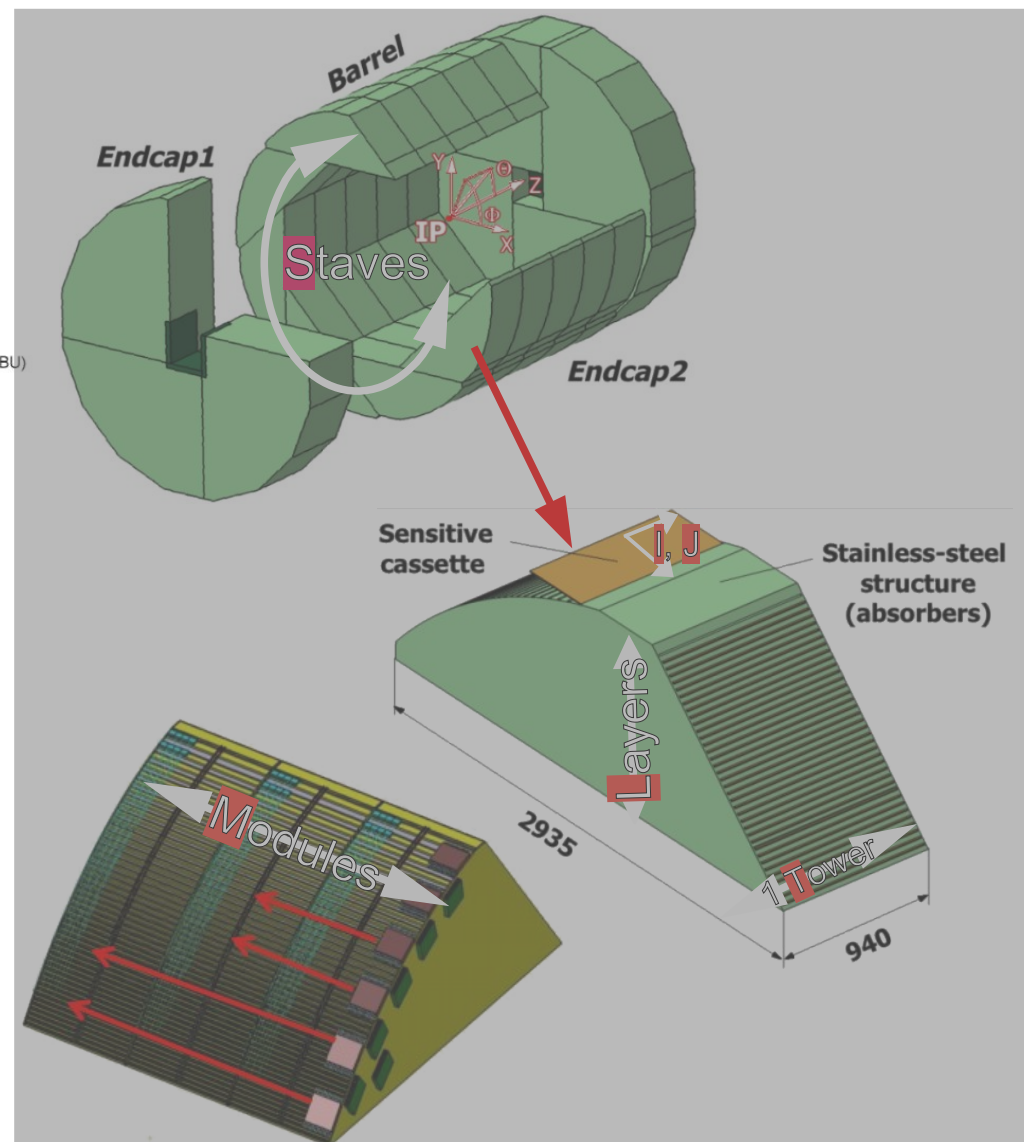
HCAL Geometries:
TESLA or Videau



Common design:

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

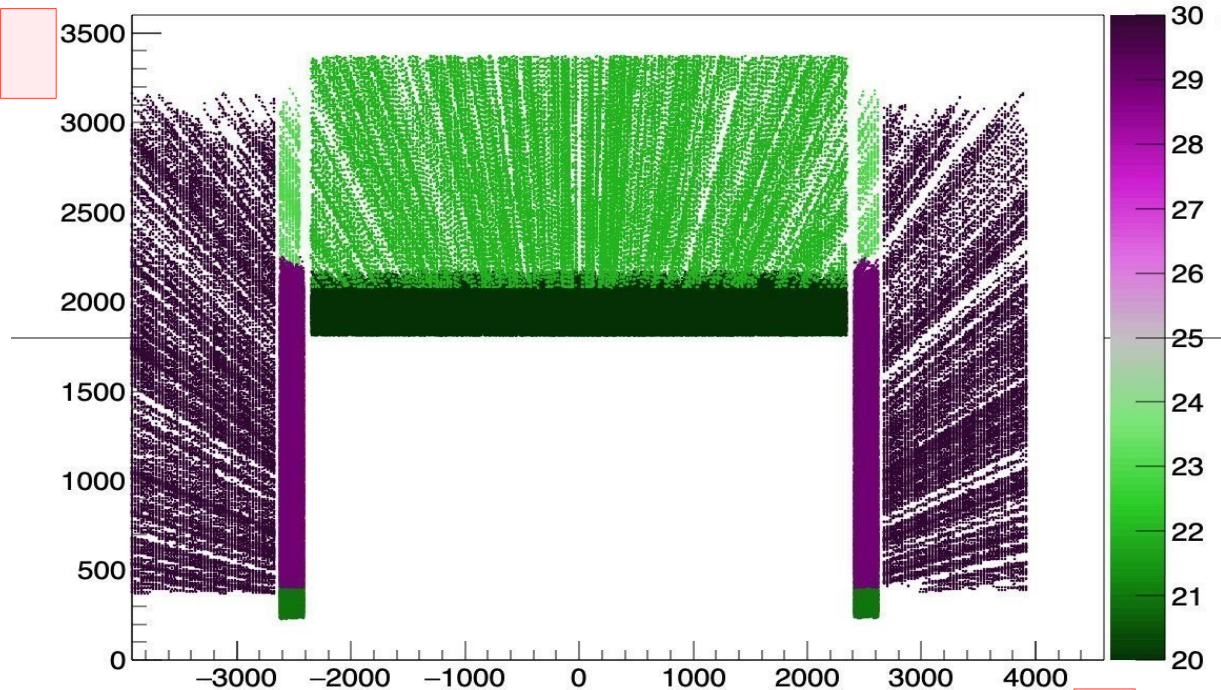




Segmentation by “Logical Geometry” C:M:S:T:L:I:J

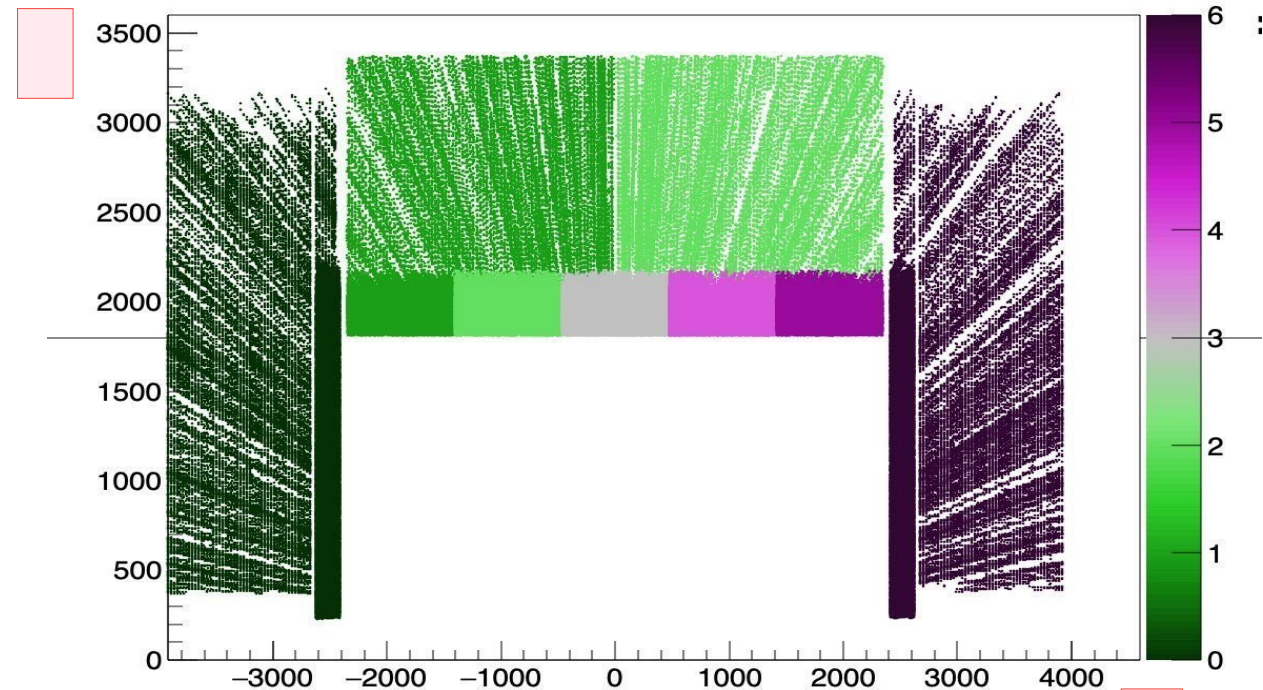
Calorimeters systems C

r:z:C



Calorimeters Modules

r:z:M



Useful segmentation & grouping:

- Physics: Group of uniform (rates) regions ($\sim \cos\theta$)
- Technical: Readout & Cooling Partition (ASIC, SLAB, Tower, Module)

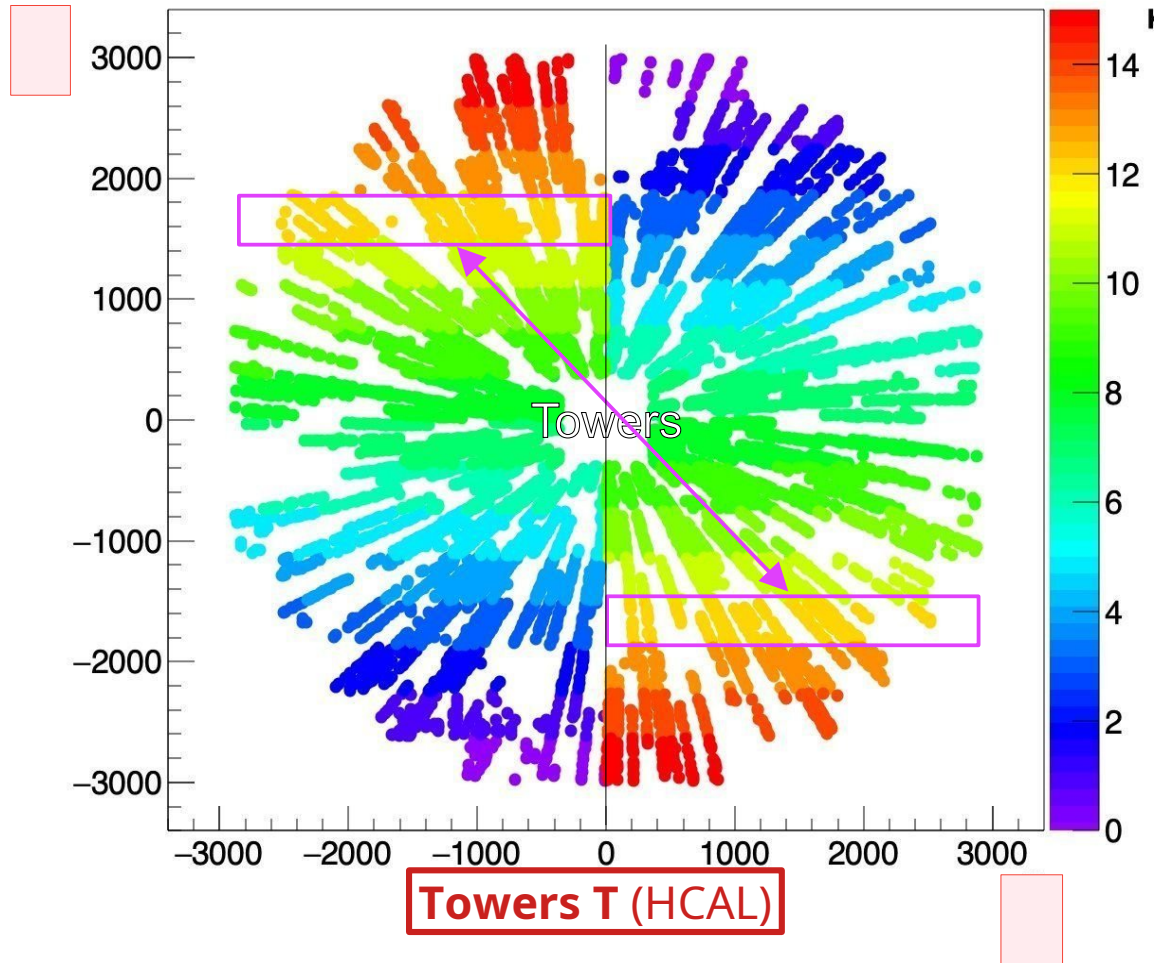
Useless individuation*:

- (Individual layers)
- Symmetrical : staves (ϕ), Forward–Backward ($\pm\theta$)

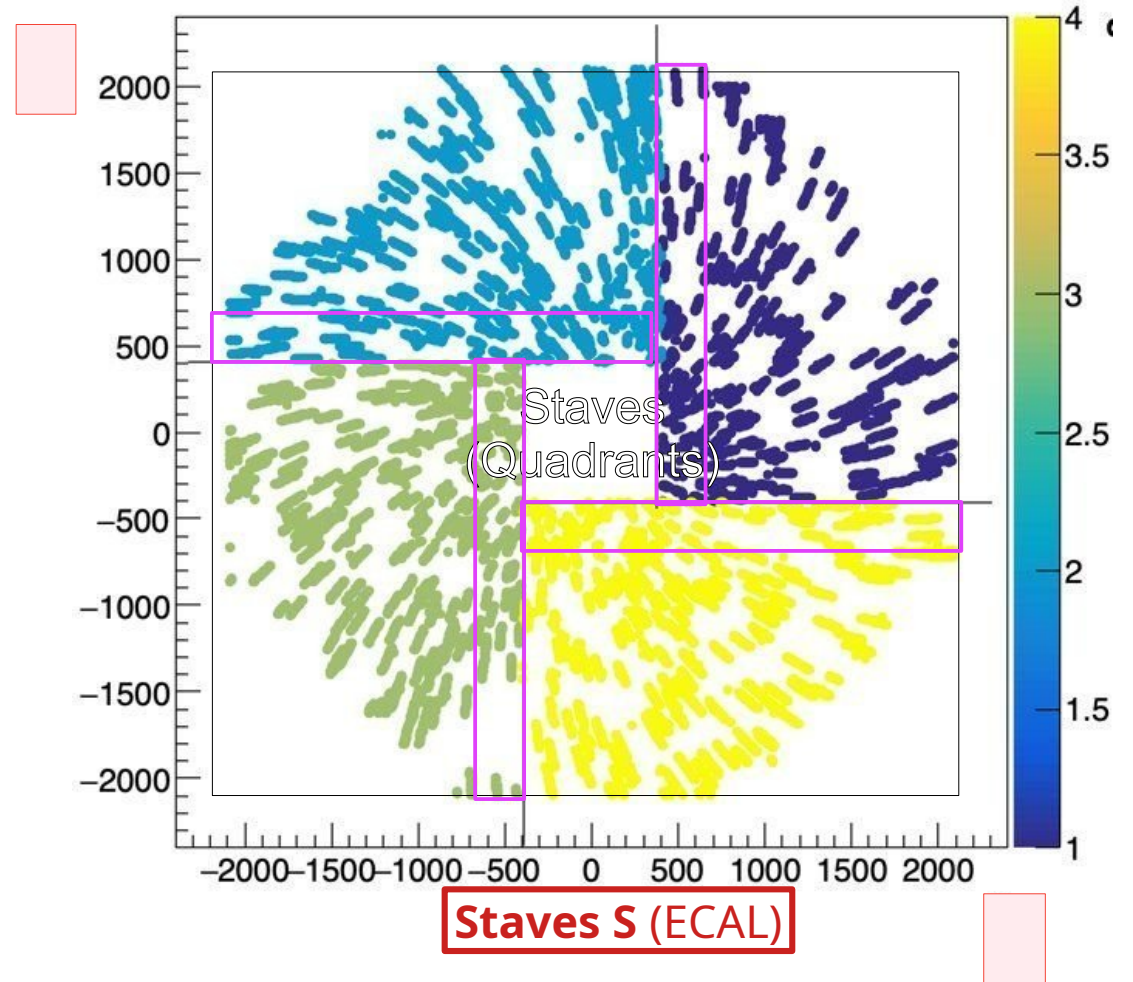
* *assuming symmetrical physics / background distributions*

Logical Geometry : Towers & Staves in Endcaps

$x:y:T \{C==30 \ \&\& \ \log_{10}(E)<-6\}$

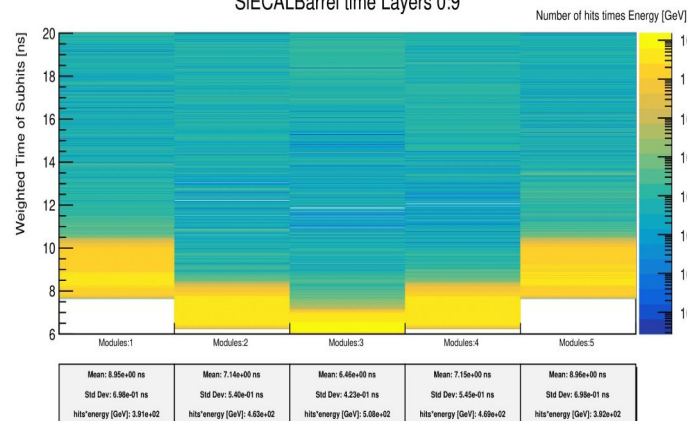


$y:x:S \{M==0 \ \&\& \ C==29\}$

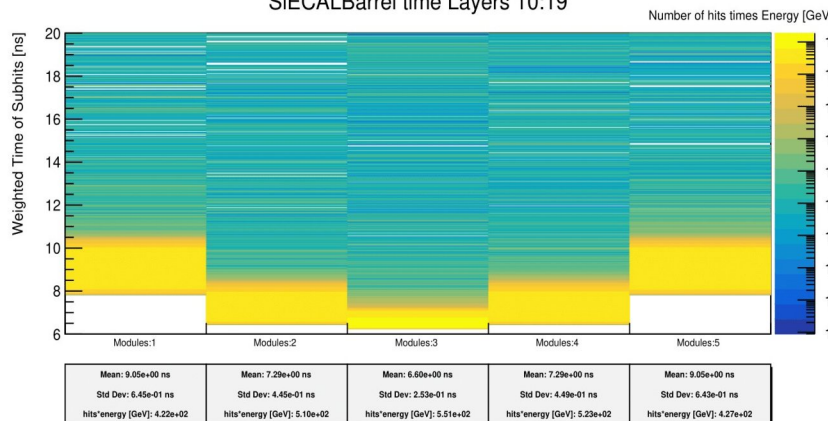


Geometric Selections (2D histograms)

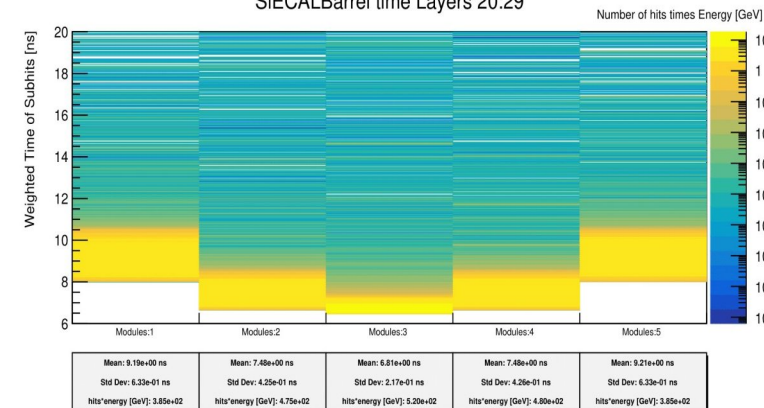
SiECALBarrel time Layers 0:9



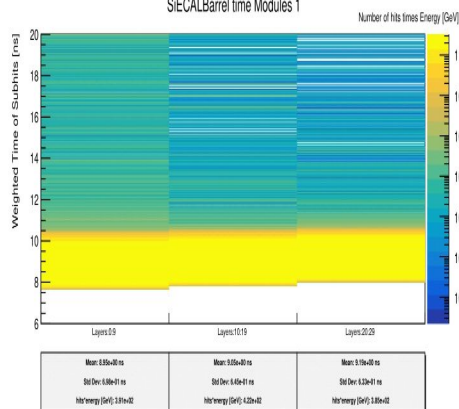
SiECALBarrel time Layers 10:19



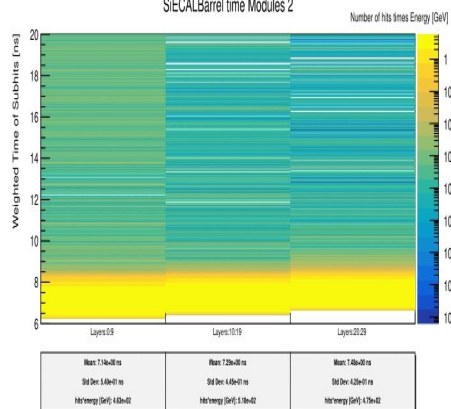
SiECALBarrel time Layers 20:29



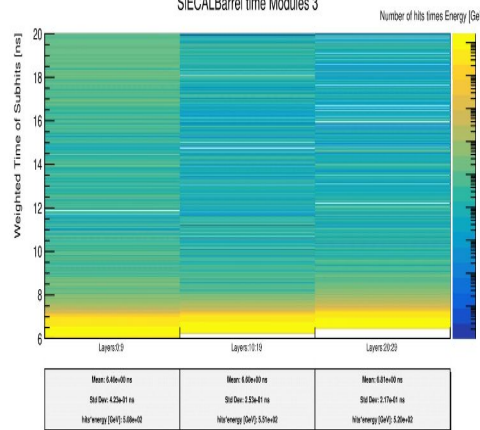
SiECALBarrel time Modules 1



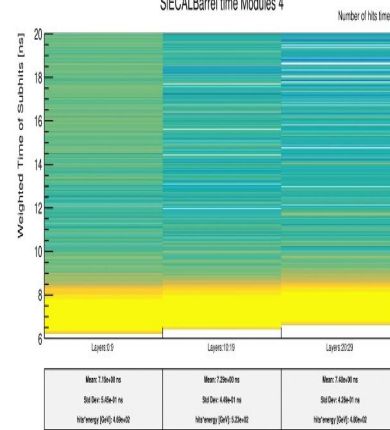
SiECALBarrel time Modules 2



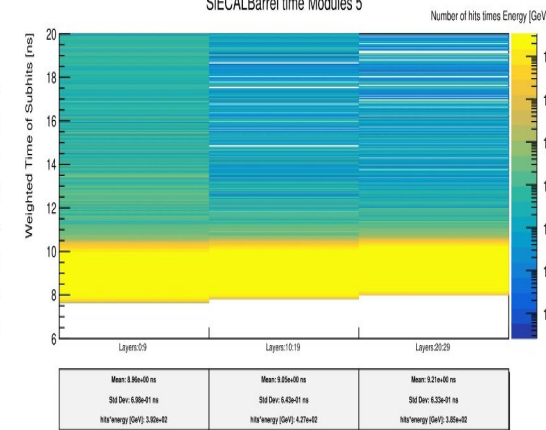
SiECALBarrel time Modules 3



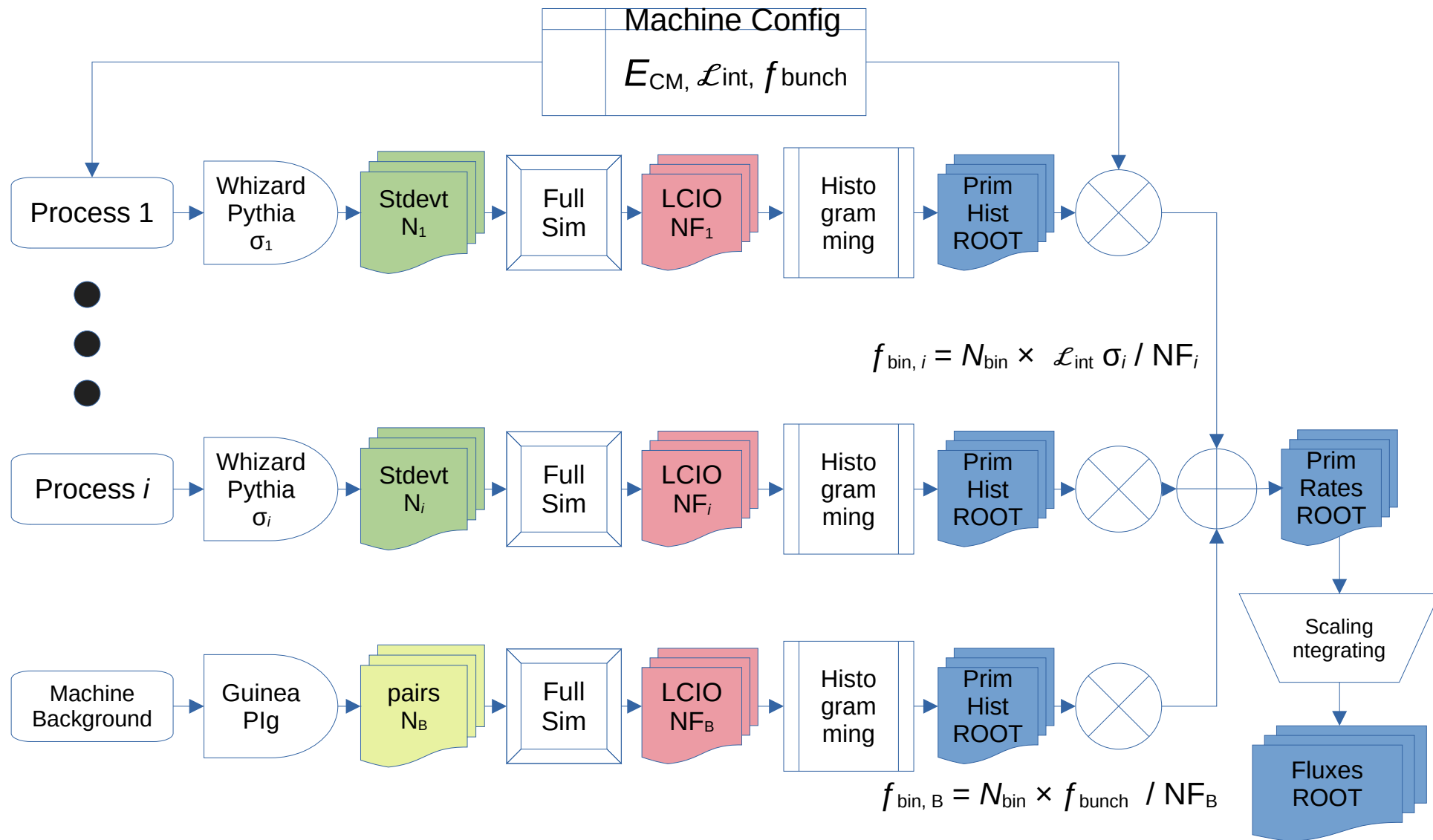
SiECALBarrel time Modules 4



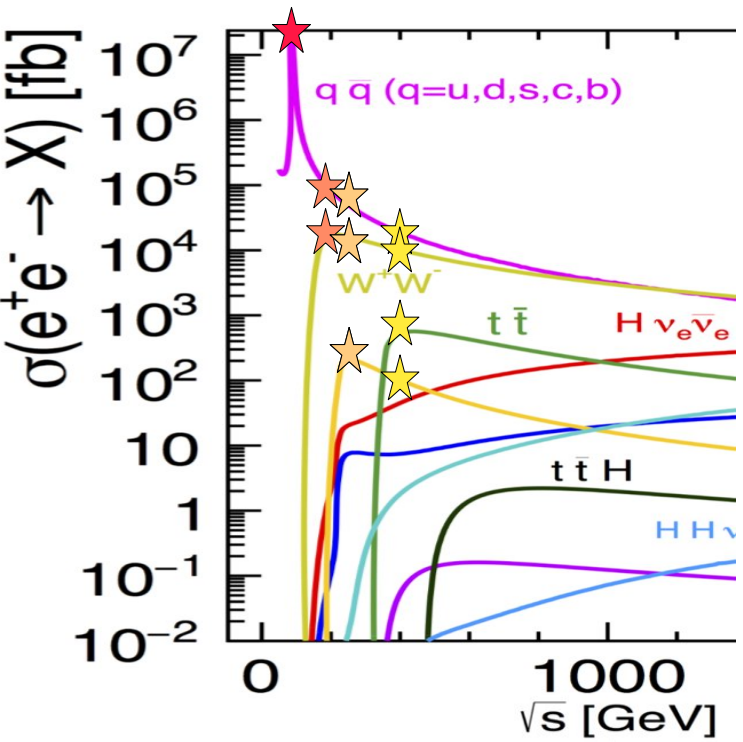
SiECALBarrel time Modules 5



Processes to Fluxes



Selected modes



Processes: min. bias

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

Config	#IP	E_{Beam}	#BX	$\mathcal{L} [10^{34}/\text{cm}^2/\text{s}]$	$\Delta T [\mu\text{s}]$	Freq[Hz]	$\sqrt{s} [\text{GeV}]$
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_I5_v02 (+ cross-angle 30mrad, B=3.5T), bgd files → ILD_I5_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})
$ee \rightarrow qq$	344	4.82
$ee \rightarrow ll$	34.6	0.484
$ee \rightarrow ee$		
($M_{ee} < 30 GeV$)	1.01	0.0141
$ee \rightarrow ee$		
($M_{ee} > 30 GeV$)	57.8	0.809

Table 3: 240 GeV

($N = 10000$, $L_{ins} = 6.9 \times 10^{-5} fb^{-1} s^{-1}$)

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

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})
$ee \rightarrow qq$	1.55	3.32×10^{-3}
$ee \rightarrow ll$	0.241	5.16×10^{-4}
$ee \rightarrow WW$	0.0504	1.08×10^{-4}
$ee \rightarrow ee$		
($M_{ee} < 30 GeV$)	0.240	5.14×10^{-4}
$ee \rightarrow ee$		
($M_{ee} > 30 GeV$)	12.9	2.76×10^{-2}

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})
$ee \rightarrow qq$	0.228	2.74×10^{-5}
$ee \rightarrow ll$	0.0430	5.16×10^{-6}
$ee \rightarrow WW$	0.111	1.33×10^{-5}
$ee \rightarrow ZH$	0.00123	1.47×10^{-7}
$ee \rightarrow tt$	0.00372	4.46×10^{-7}
$ee \rightarrow ee$		
($M_{ee} < 30 GeV$)	0.0499	5.99×10^{-2}
$ee \rightarrow ee$		
($M_{ee} > 30 GeV$)	2.57	3.08×10^{-4}

Machine background sources :

Source	#particles per bunch	$\langle E \rangle$ (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
$\gamma\gamma \rightarrow$ 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)

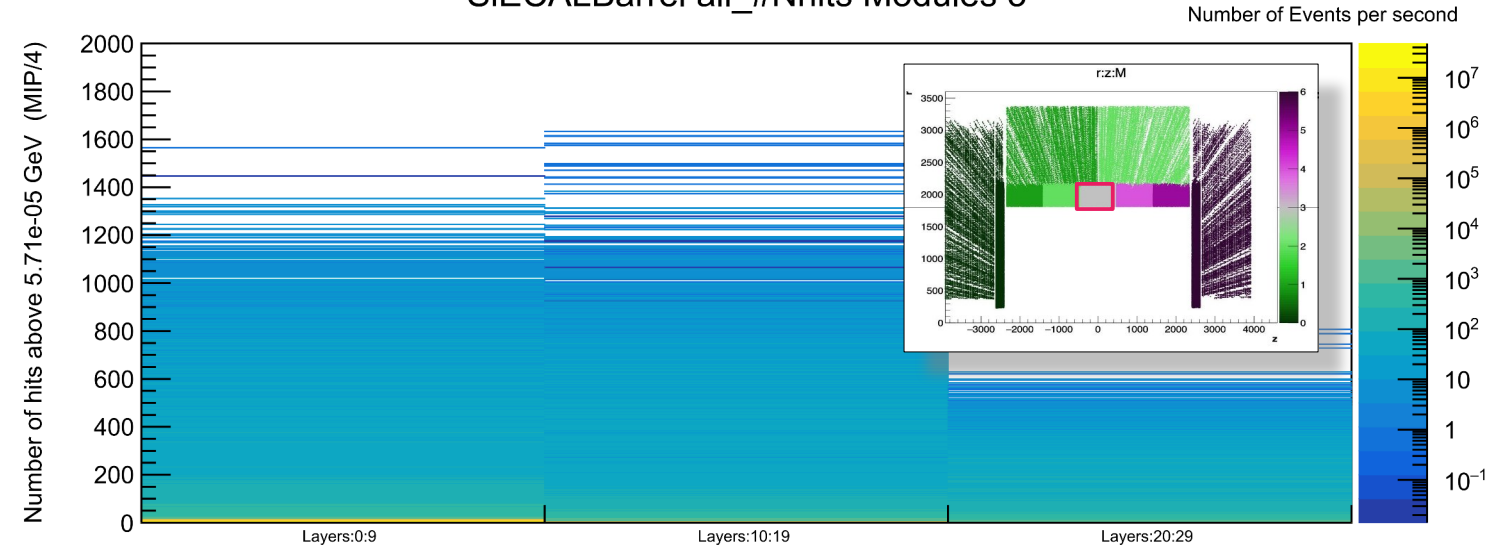
Incoherent pair production :
100 BX at FCC-ee 91.2 GeV and 240 GeV

Produced by Andrea Ciarma,

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

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

SiECALBarrel all_#Nhits Modules 3



Mean: 7.16e+00 #hits Std Dev: 9.59e+00 #hits events/second: 5.27e+07	Mean: 1.82e+00 #hits Std Dev: 8.80e+00 #hits events/second: 5.27e+07	Mean: 6.76e-01 #hits Std Dev: 3.63e+00 #hits events/second: 5.27e+07
--	--	--

M3 all staves	L0:9	L10:19	L20:29		
Average #hits/s	302E+6 hits/s	65E+6 hits/s	8E+6 hits/s	cell size	5,5
Noise Hits/s	3E+6 hits/s	3E+6 hits/s	3E+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	Bytes/hit	7
Ncells	4.026.764	3.767.273	3.378.036	powa (mW/cell)	10
Occupancy/BX	1,4 E-06	3,3 E-07	4,3 E-08	Conv & RO E/hit/μJ	9,0 E-01
				Noise (4 σ)	1,5E-08
Base power/W	40,3 E+03	37,7 E+03	33,8 E+03		
Conversion power/W	274,3 E+00	61,6 E+00	9,4 E+00	Δt/s	19E-09
Total power/W	40,5 E+03	37,7 E+03	33,8 E+03		
% conv.	0,7 %	0,2 %	0,03 %		

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

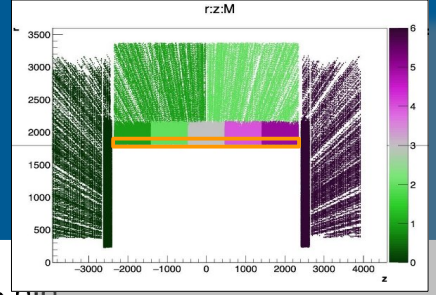
- From the $\langle f_{Nhits} \rangle$ in one region one can extract :
- The data rate, knowing the number of bytes per hits (here 7 as a landmark)
 - The occupancy, knowing the number of cell in the region. $< 10^{-6}$
 - The power dissipated on elec. power (here for CALOROC1 like chip).

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

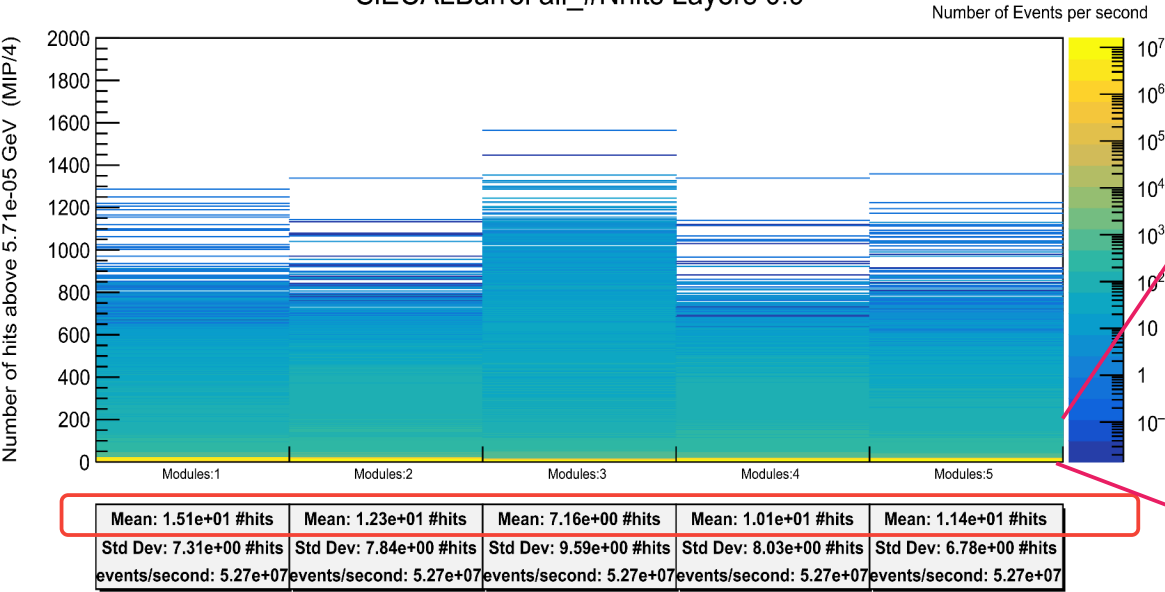
Note 1 : (still) **preliminary**

- Note 2 :** Rates & Power for all M3 modules
- 8 per module, 10 per layer for 1 slab
 - ~ 100 W/slab (new elec)
 - 260 MB/s per module
 - 26 MB/s / slab = 211 Mb/s

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

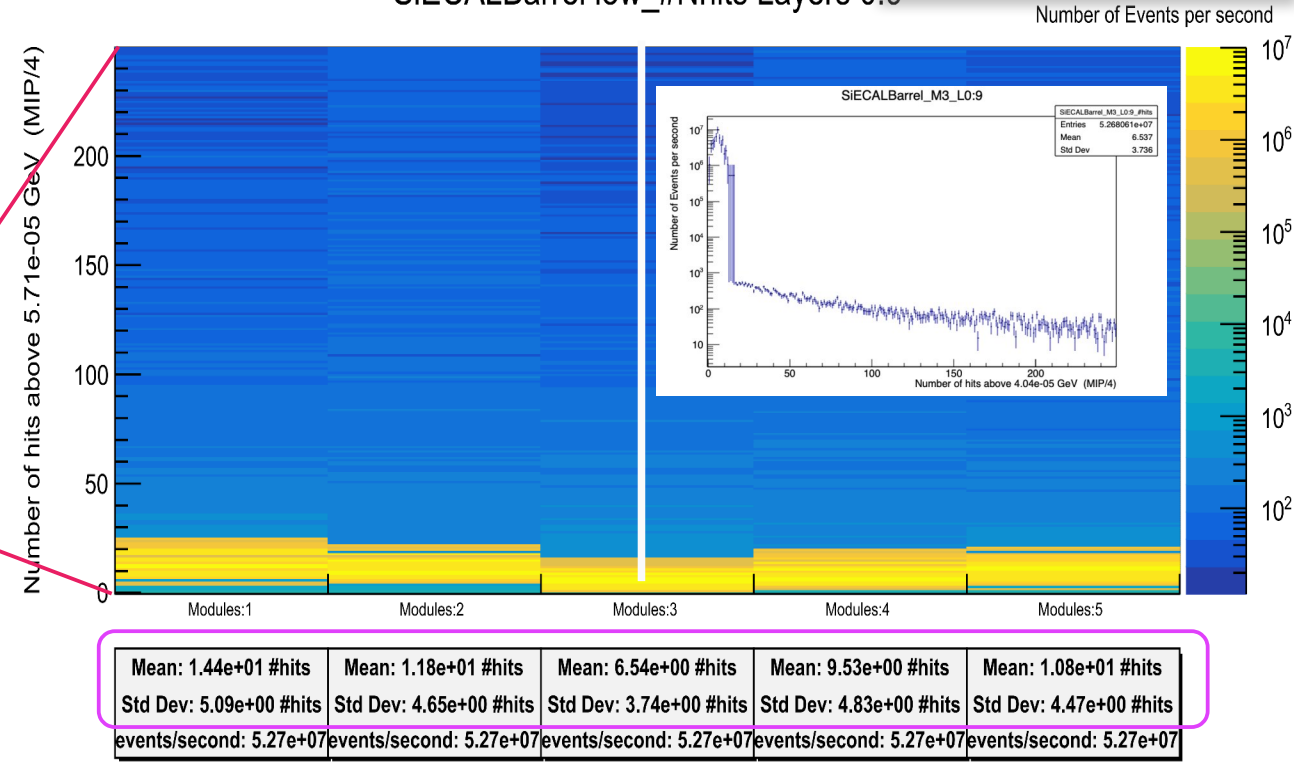


SiECALBarrel all_#Nhits Layers 0:9



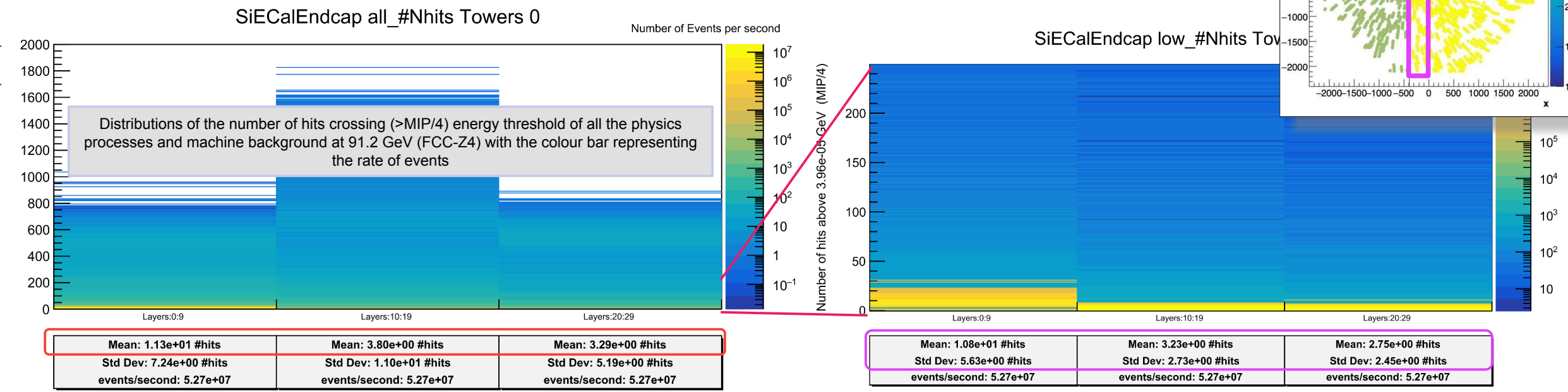
Distributions of the number of hits crossing (>MIP/4) energy threshold of all the physics processes and machine background at 91.2 GeV (FCC-Z4) with the colour bar representing the rate of events

SiECALBarrel low_#Nhits Layers 0:9



- Rates M1/M3 ~ 2
- “Double counting” of physics events in Module 3 due back-to-back events
- Machine backgrounds dominate the distribution
- Total barrel rates ~ 8 × M3’s → 17 GB/s

Results: Rates in SiECAL EndCaps, Tower 0 vs depth



T0 all quadrants	L0:9	L10:19	L20:29	
Average #hits/s	572E+6 hits/s	176E+6 hits/s	147E+6 hits/s	cell size 5,5
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	Bytes/hit 7
Ncells	1.161.775	1.161.775	1.161.775	powa (W/cell) 10E-03
Occupancy/BX	9,4E-06	2,9E-06	2,4E-06	powb (J/hit) 870E-12
Length/Width	2496		565	Conv & RO E/hit/μJ 0,9
				Δt 19E-9
Base power	12E+03	12E+03	12E+03	
Conversion power	515E+00	159E+00	132E+00	
Total power	12E+03	12E+03	12E+03	
% conv.	4,2 %	1,3 %	1,13 %	

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

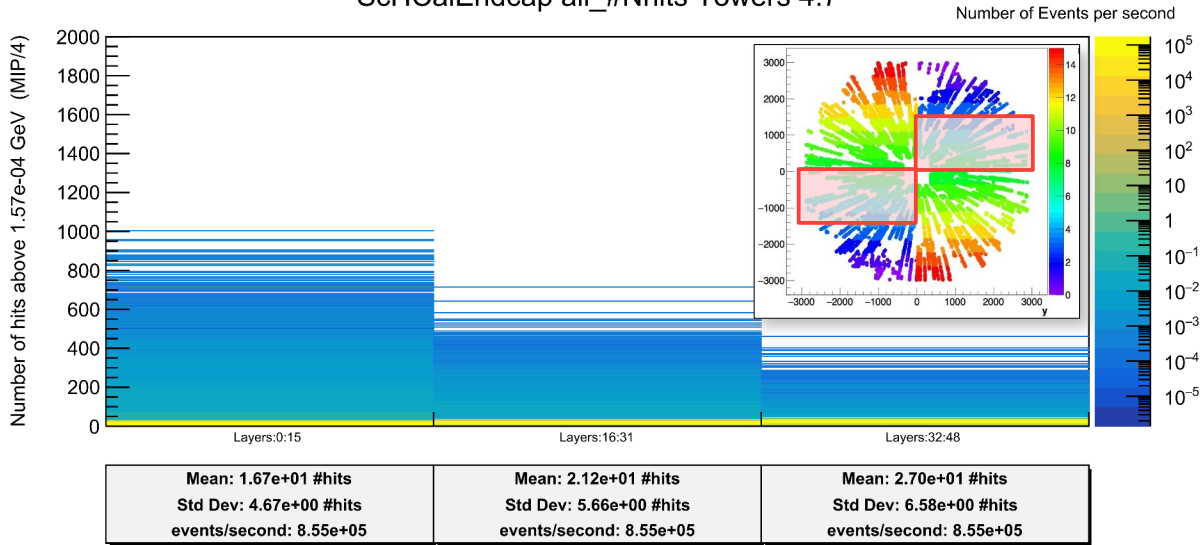
Note 1 : (still) preliminary

Note 2 : Rates & Power for all T0 modules
→ /8 per quadrant, 10 per layer for 1 slab → 150 W / slab
→ ~50 MB/s = 400 Mb/s / inner slab

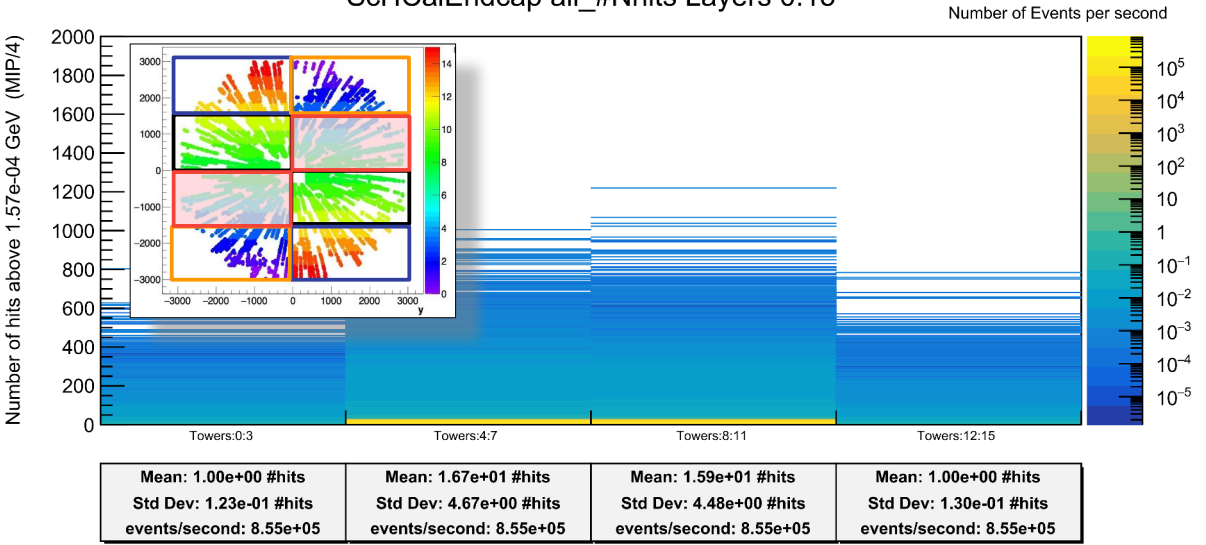
Note 2 : Total Endcap data ~ 2×T0 = 12 GB/s

Results: Scintillator AHCAL Endcap

ScHCalEndcap all_#Nhits Towers 4:7



ScHCalEndcap all_#Nhits Layers 0:15



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

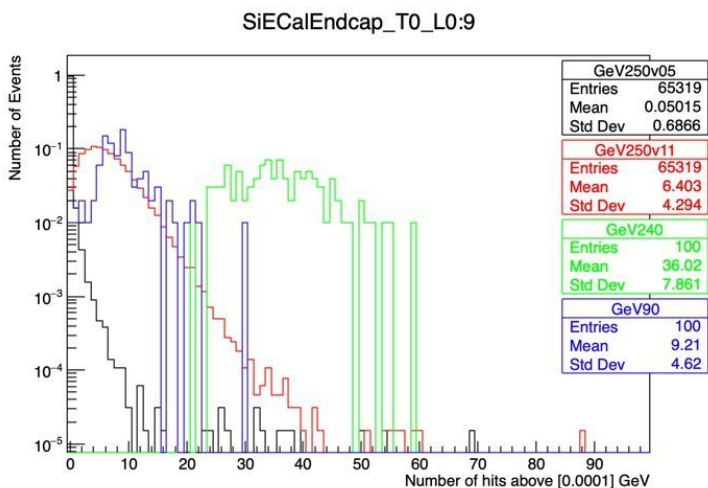
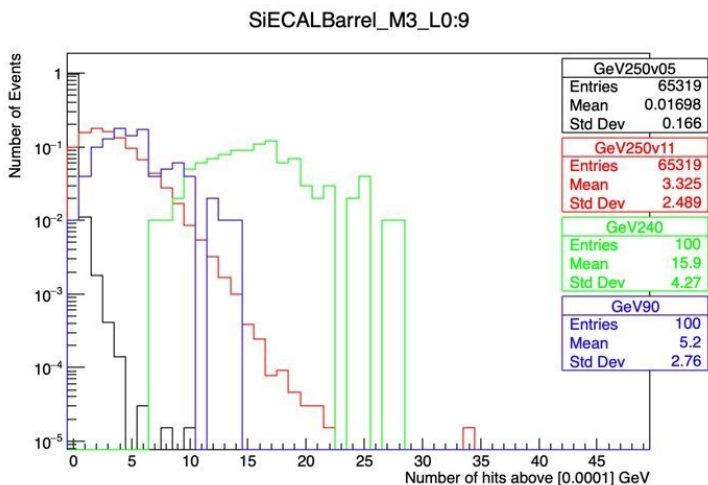
855E+3 hits/s	1E+6 hits/s
400 Nhits/event	400 Nhits/event
5E+6 B/s	9E+6 B/s
Not Yet avail,	278 756
Not Yet avail,	1,0E-07

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 MDI+tracking configurations



ILC@250GeV/ILD_I5_v05/ : 65319 BX
ILC@250GeV/ILD_I5_v11gamma/ : 65319 BX
FCCee@240GeV/ILD_I5_v11gamma/ : 100 BX
FCCee@90GeV/ILD_I5_v11gamma/ : 100 BX

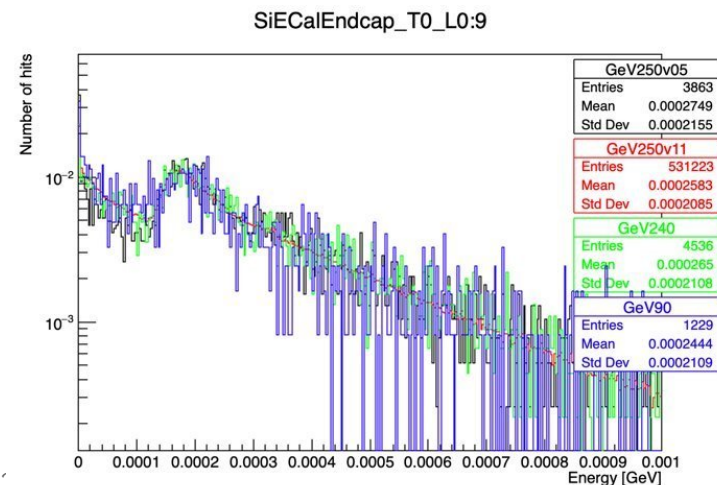
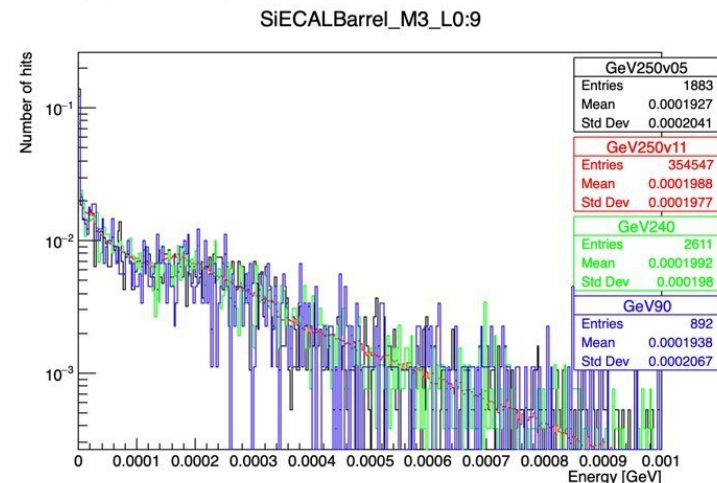
Config		<Nhit>/BX	
		Barrel M3 L0:9	EndCap T0 L0:9
ILC @ 250 GeV	ILD_I5_v05	0,0170	0,0500
ILC @ 250 GeV	ILD_I5_v11 γ	3,33	6,40
FCCee @ 240 GeV	ILD_I5_v11 γ	15,9	36,0
FCCee @ 90 GeV	ILD_I5_v11 γ	5,2	9,21

<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

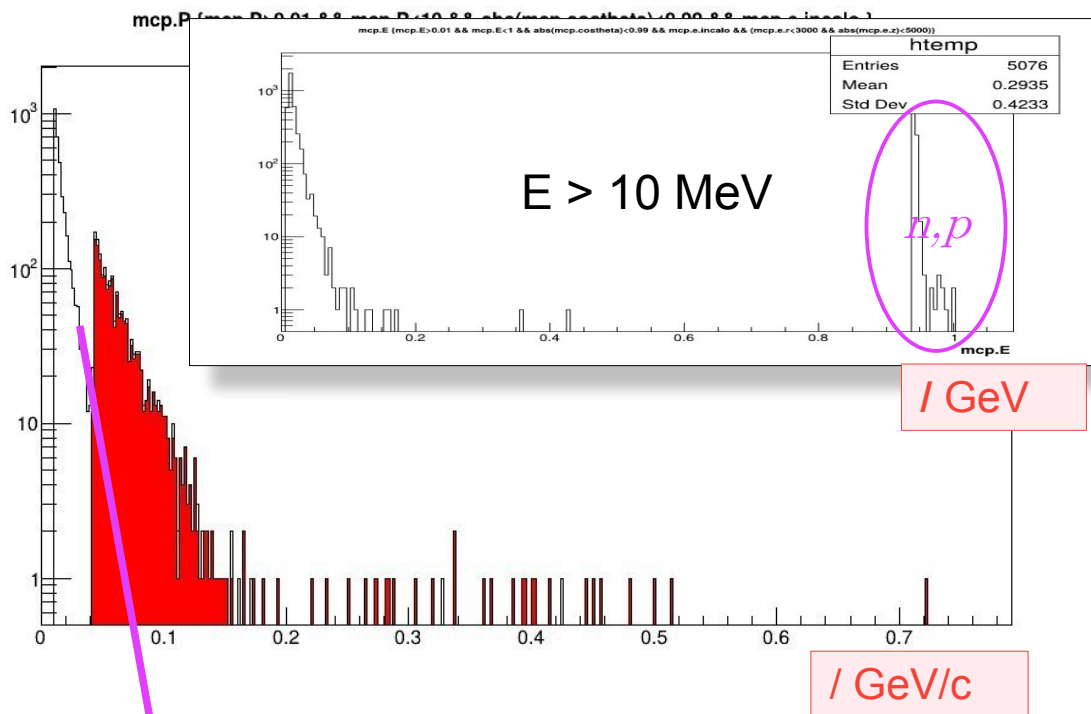
— No difference



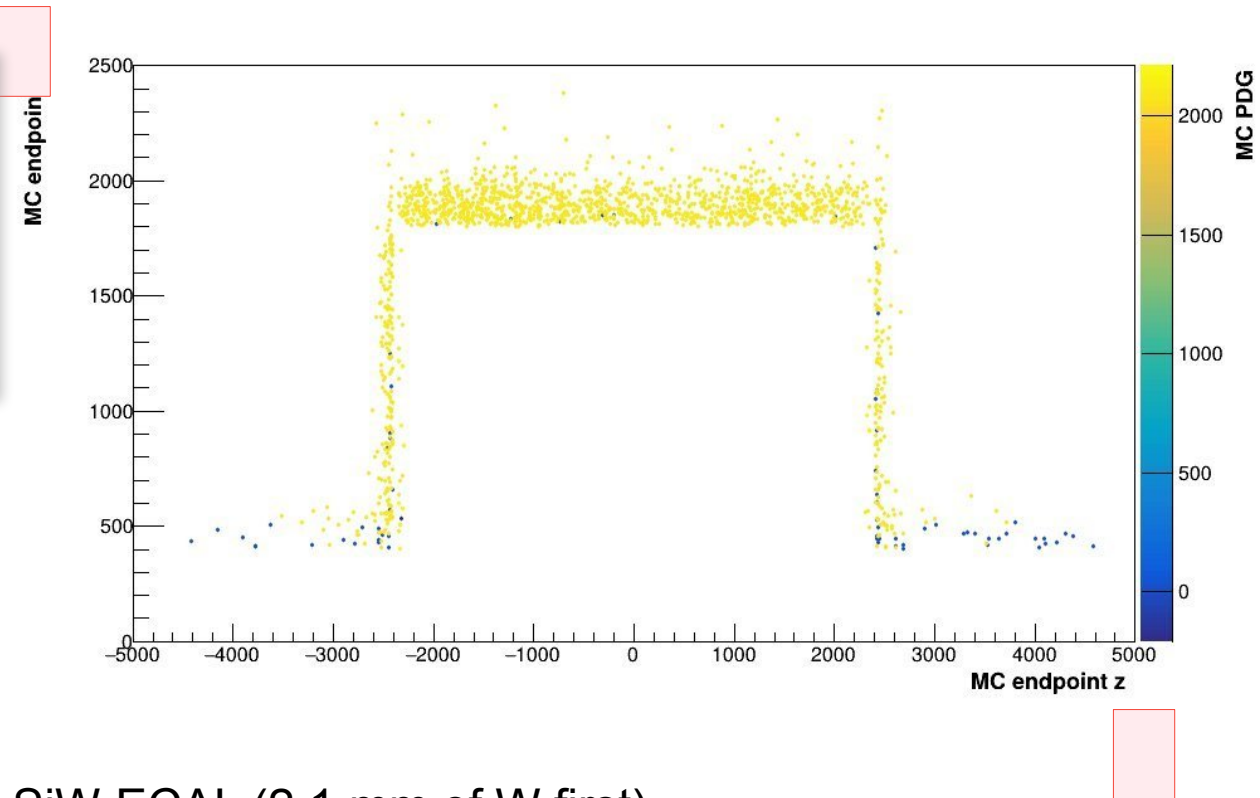
Particle momentum in calo

Low energy photons <10 MeV

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



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



Conclusions & Perspective

On-going work... all preliminary

Done

Flux determinations

- Simulated detector-level data for main physics processes and machine background at **91.2 GeV** and **240 GeV**.
- Generated primary, secondary spectrums in **11 systems of ECAL and HCAL** of the ILD calorimeters, for **main processes and backgrounds**.
- Early conclusion on the ECAL (on-going for the AHCAL)

Conclusions on the ECAL:

- The power is $\geq 90\%$ driven by the continuous component even in the endcaps sections for CALOROC1 ASICs
- Rates $\sim 25\text{--}50$ MB/s per layers, dominated by 1st layers and Tower 0
- $4\sigma \rightarrow 3\sigma$ cut on noise is OK
- Total data rates Barrel+Endcap $\sim \mathbf{17+12\text{ GB/s @ 91 GeV}}$ ($\times 4$ at 240 GeV? Beam-induced-Background dominated)

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 ($\times 40$ avail.)
 - Check for $\rightarrow \square$ 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 $\rightarrow$ ASIC
 - Power $\sim 1/\sigma_t$. 1mW/ch for 1ns $\rightarrow$ 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 [$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$]	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 $\epsilon_{x,y}$ [nm]	0.71	0.71	2.16	0.67	1.55
Rms vert. emittance $\epsilon_{x,y}$ [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

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	$\mathcal{L}$	$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	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 $5.4 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ [10].

Tor Raubenheimer, FCC Week June 2023

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
$\gamma\gamma \rightarrow$ 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
```

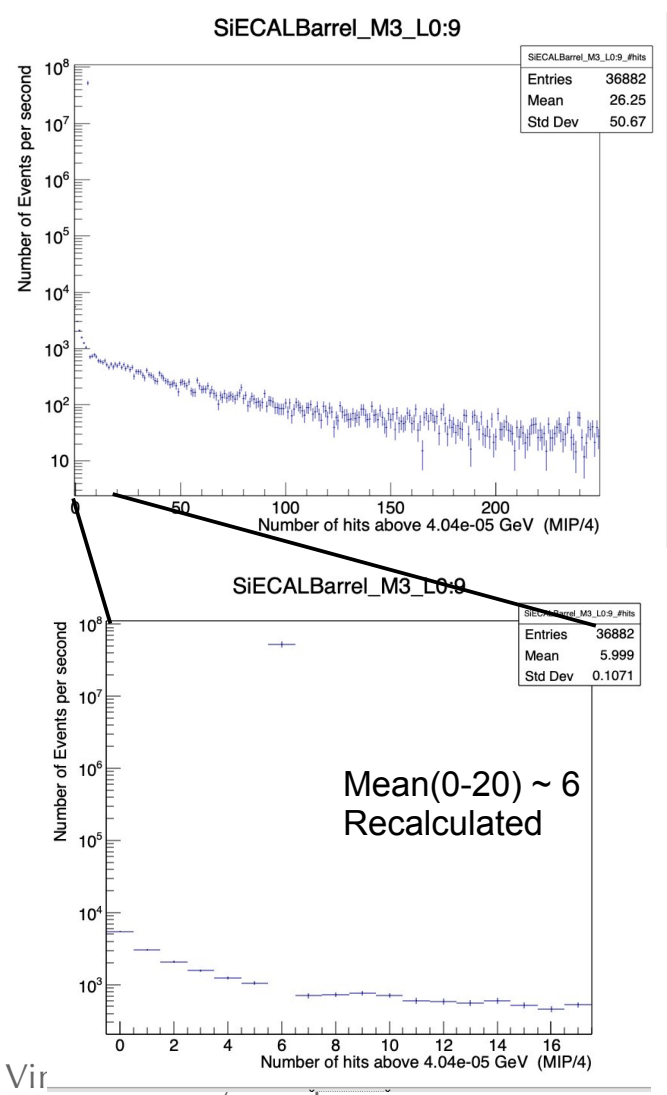
Charge and PID should be manually set, according to the sign of the energy

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

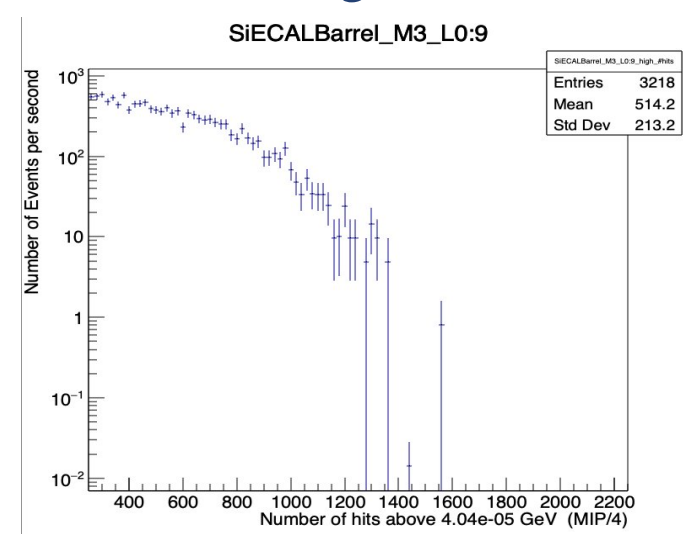
A Lorentz boost should be applied along X to account for the fact that GP produces particles in the rest frame of the two beams, which due to the crossing angle (15 mrad) moves w.r.t. the detector.

Mean calculations from histograms

Low #hits & Zoom

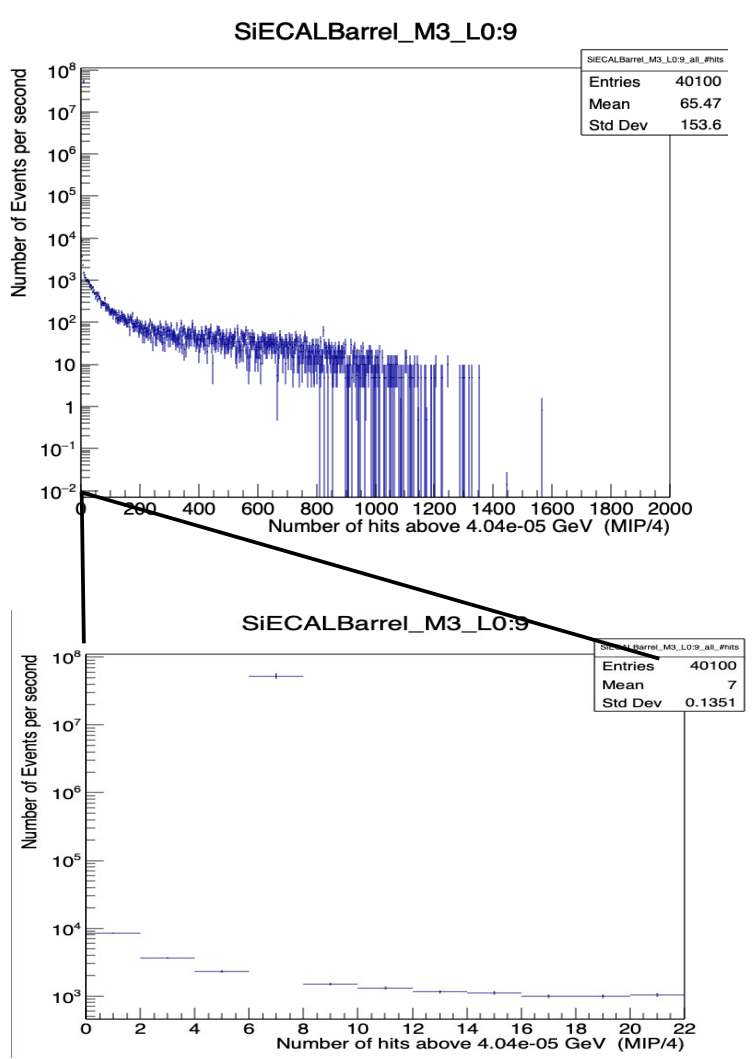


High #hits



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

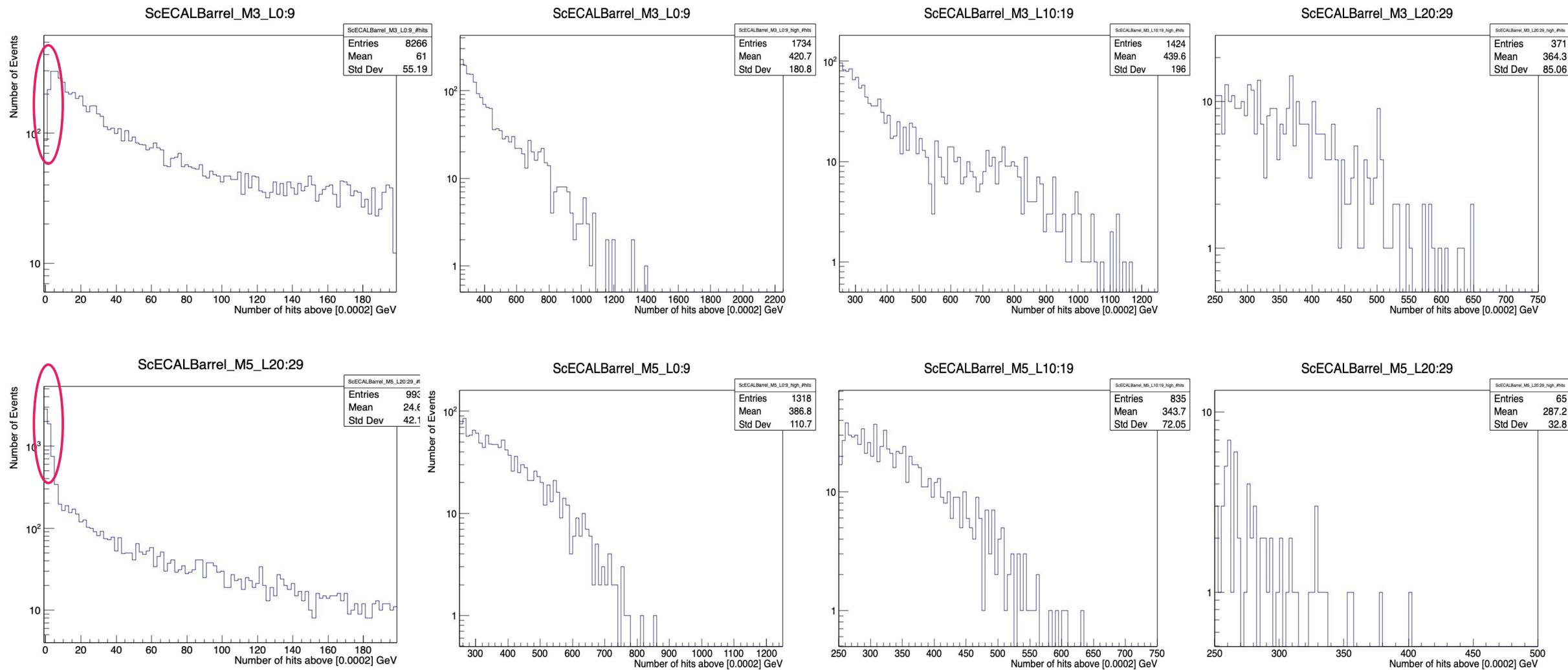
All #hits & Zoom



Histograms of qq161: Nhits

M3 L0:9 and M5 L20-29

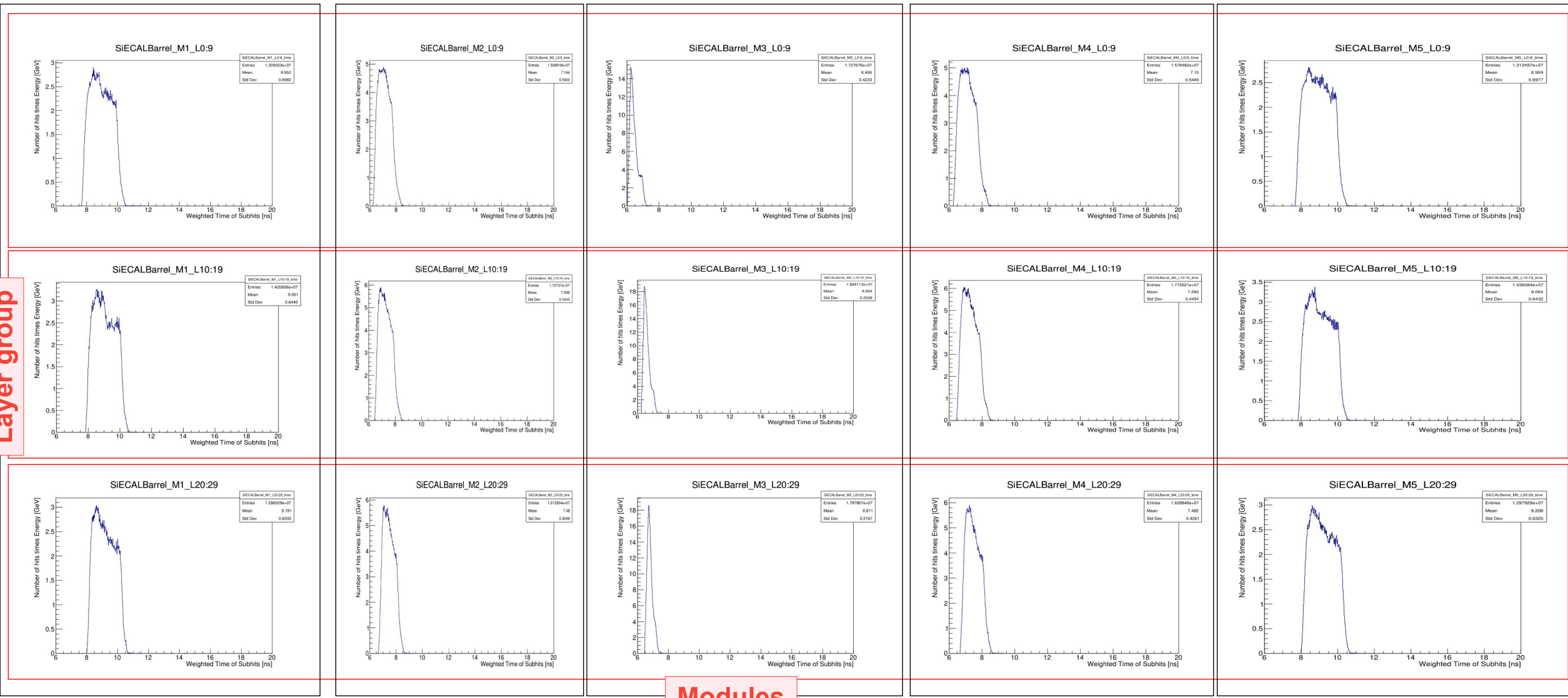
⚠ Beware of automatic rescaling ⚠



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

Time of SubHits $\times$ E_{SubHit}

Layer group

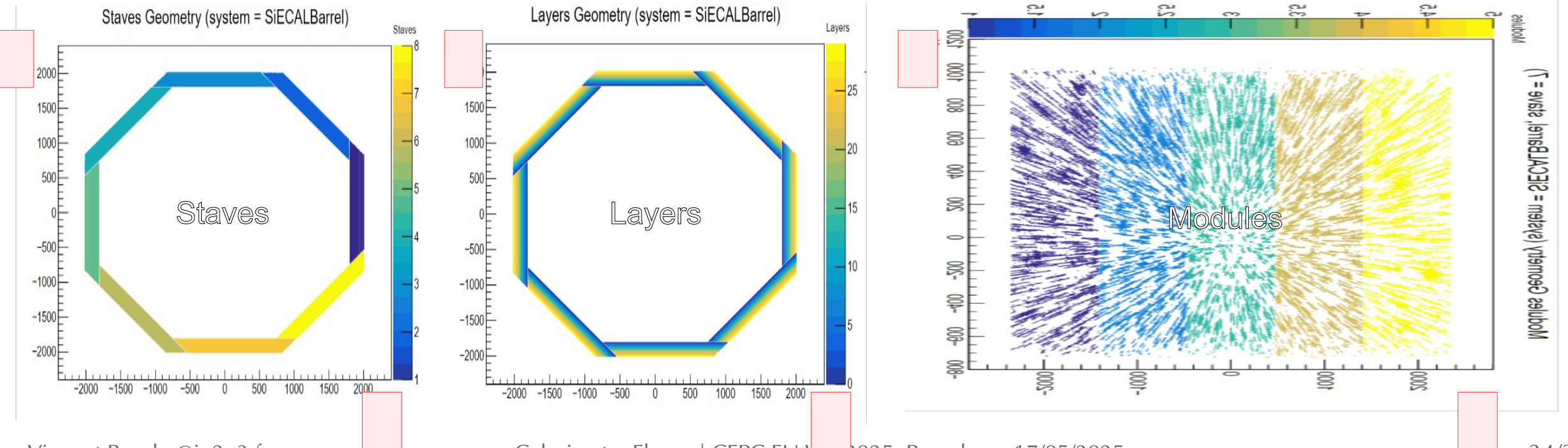


Modules

Geometric Selections (Explicit)

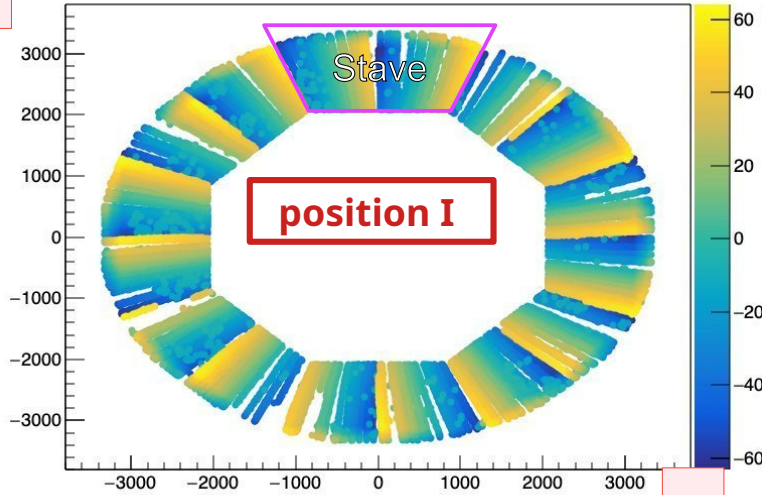
- All the staves are symmetric (φ , azimuthal symmetry-8)
- Radial behaviour can be obtained from different layers (central image).
- Polar behaviour ($\cos \theta$): from Modules in Barrel, from Towers in EndCaps.

Selections in Barrel : 5 Modules $\times$ 3 block of 10 layers

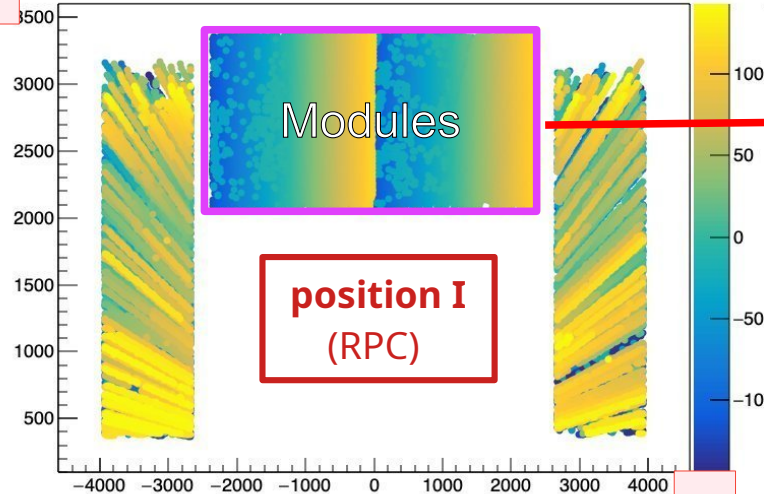


Logical Geometry (HCAL BARRELS, in Prism geometry)

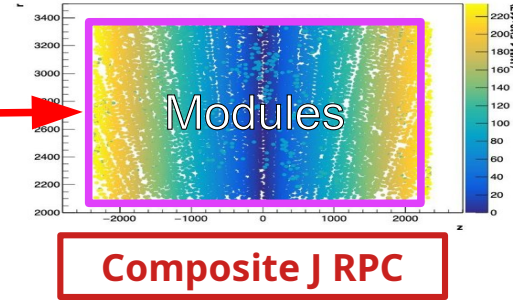
y:x:I {(C==22) && log10(E)<-5}



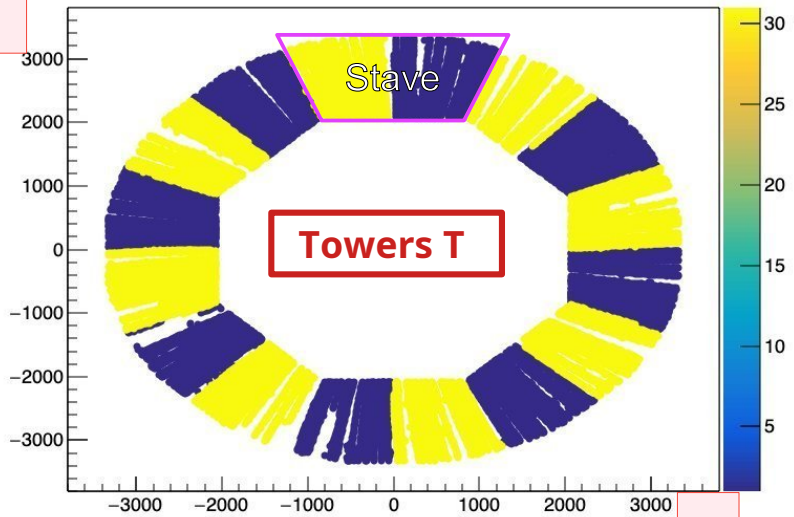
r:z:J {(C==22 || C==30) && log10(E)<-5}



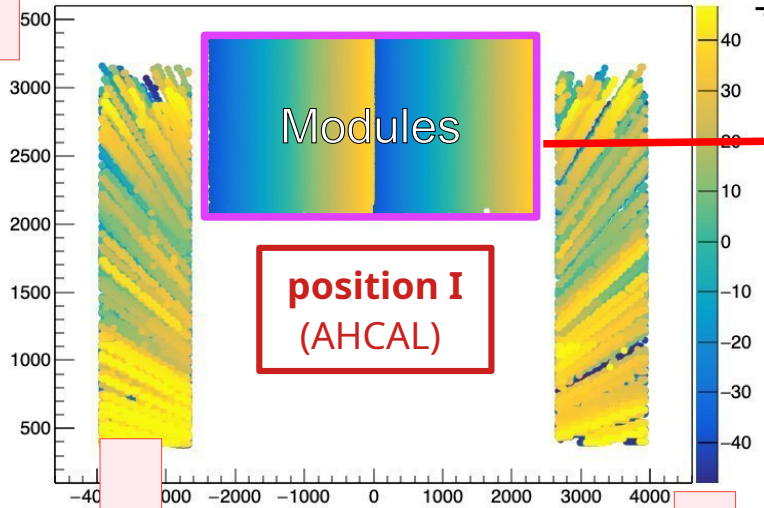
r:z:(J*(M-1.5)*2+117) {(C==22 && log10(E)<-6)}



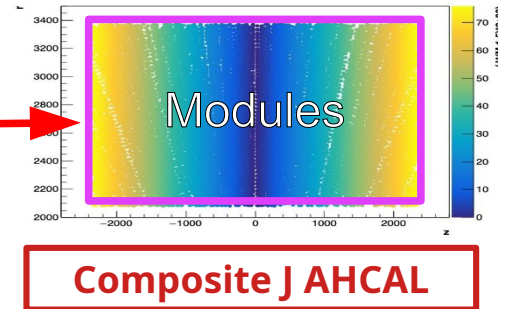
y:x:T {(C==22) && log10(E)<-5}



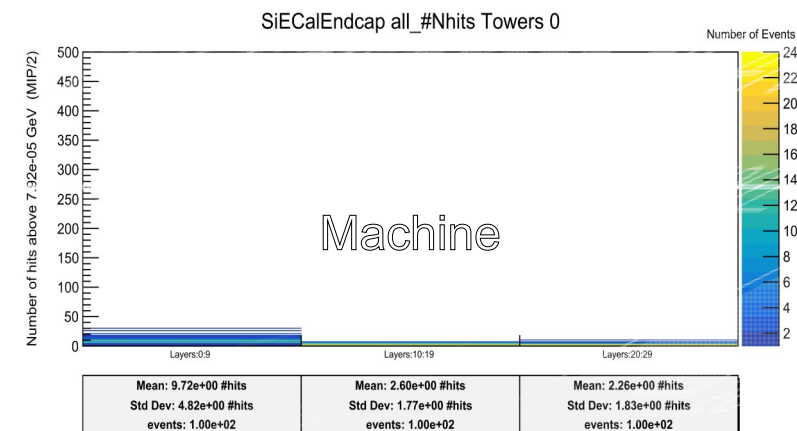
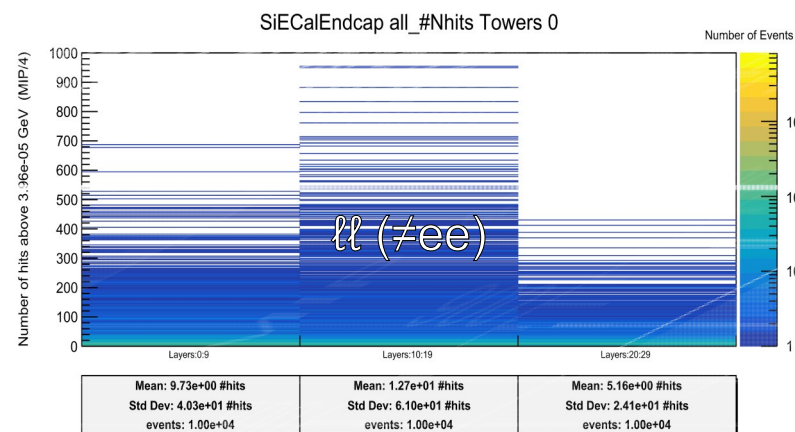
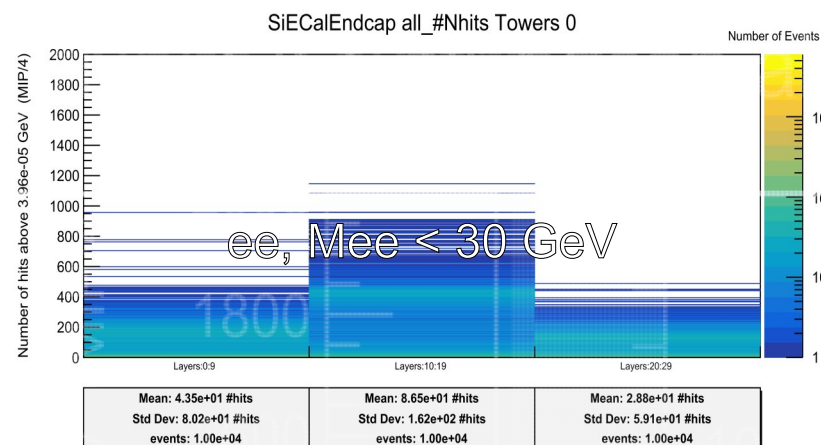
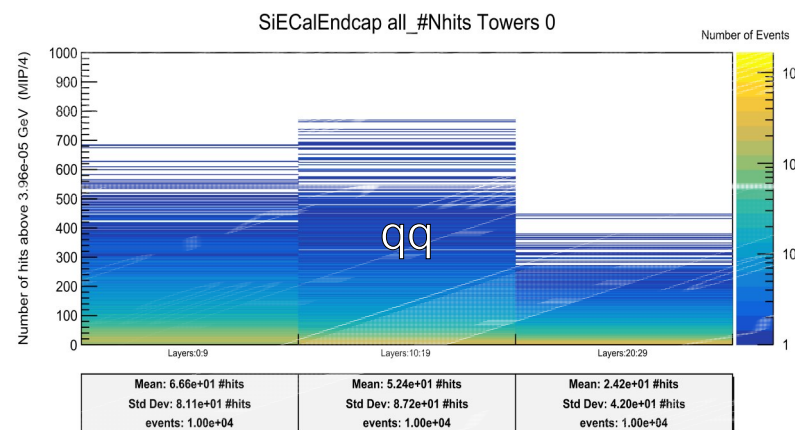
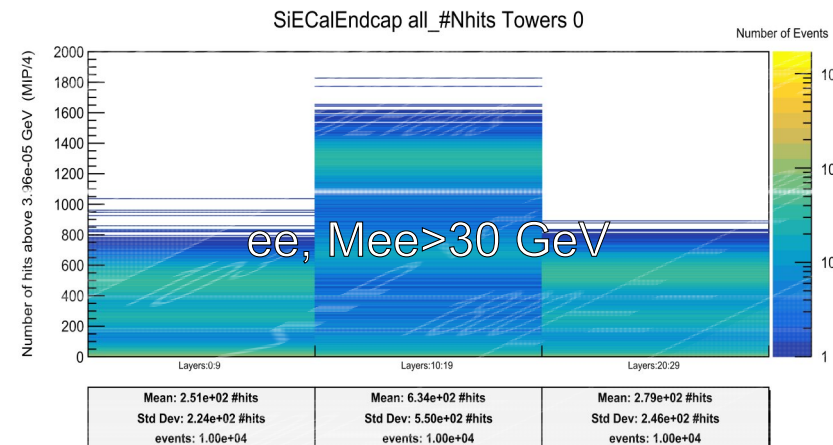
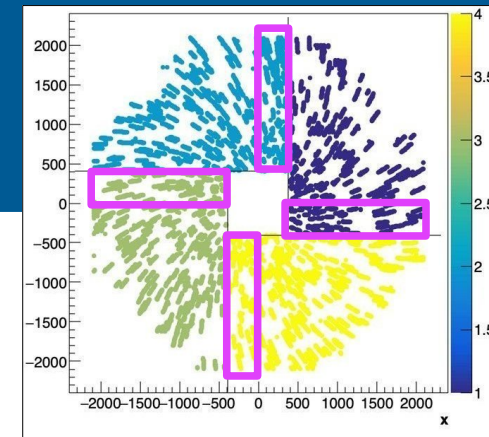
r:z:J {(C==22 || C==30) && log10(E)>-4}



r:z:(J*(M-1.5)*2+38) {(C==22 && log10(E)>-4)}

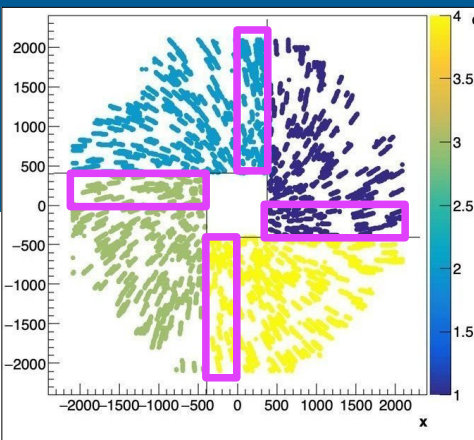


Results: Contributions to rates in SiECAL EndCaps, Tower 0 vs depth

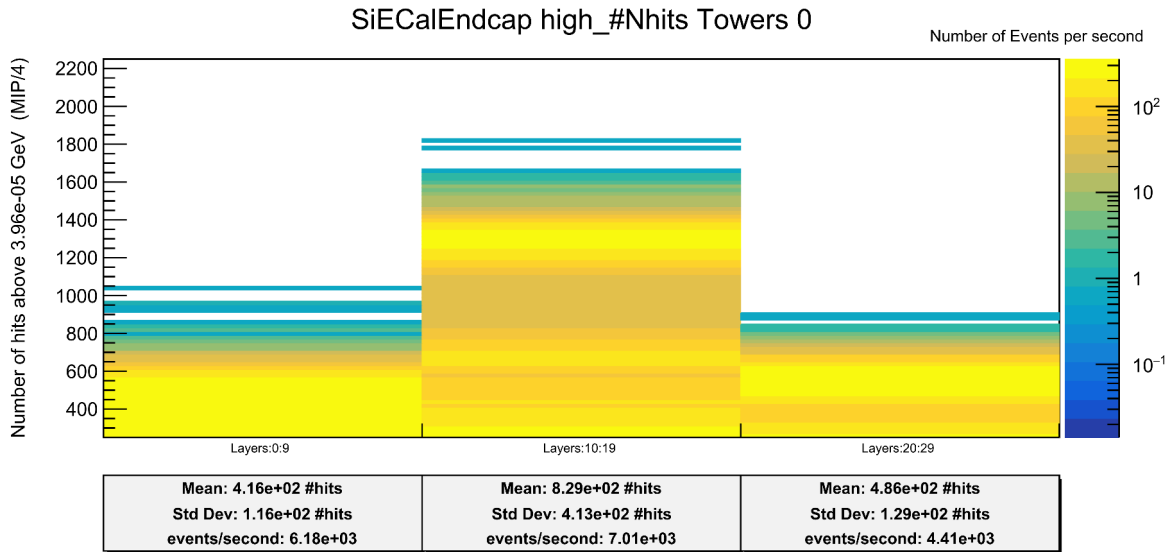


Distributions of the number of hits crossing (>MIP/4) energy threshold of all the physics processes and machine background at **91.2 GeV** (FCC-Z4) with the colour bar representing the number of events (for 10,000 or 100 BX simulated)

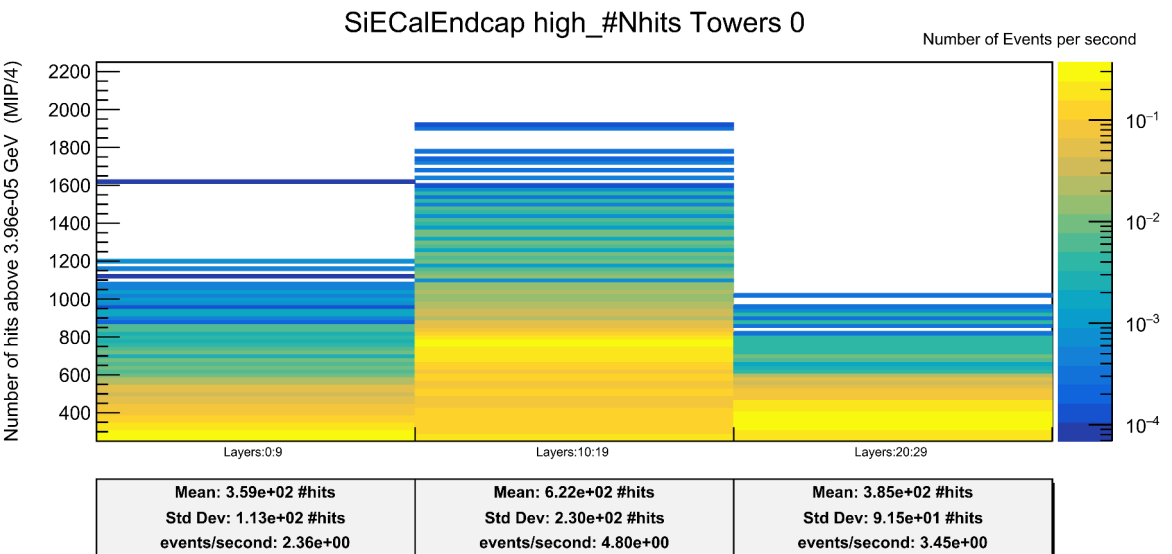
Results: Dynamic Range in SiECAL EndCaps, Tower 0 vs depth



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