Towards occupancy and bandwidth requirements for highly granular calorimeters at FCCee

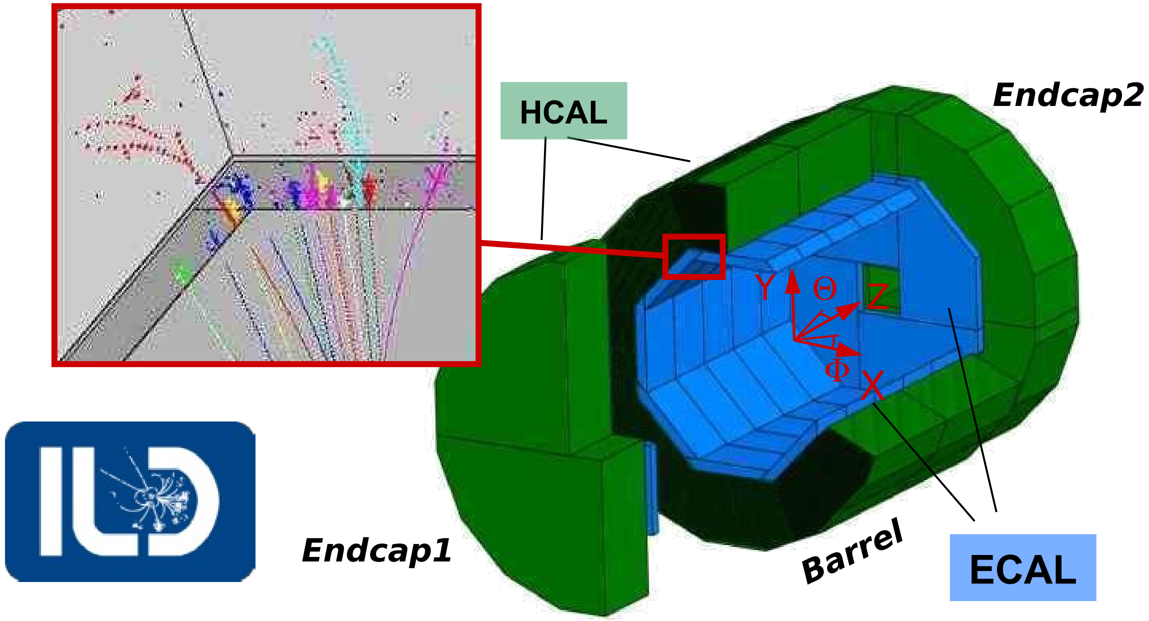
V. Boudry*, K. Hassouna[a], L. Portales[b]

Institut Polytechnique de Paris
[a] IPP PSEI and U. of Manoa
[b] Now at CEA-IRFU

Rationale

ILD high granularity calorimeters

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



ECAL: 30 layers

- SiW-ECAL": 0.5×0.5 cm^3 Si cells
- ScECAL: 0.5×5 cm^2 Scint strips

10–100M channels

HCAL: 48 layers

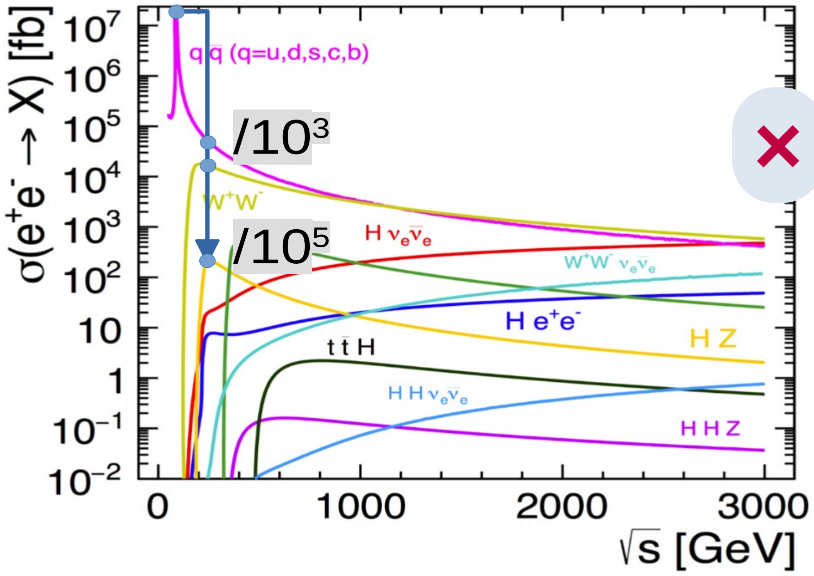
- AHCAL: 3×3 cm^3 scint. cells
- ScECAL: 1×1 cm^2 RPC cells

10–70M channels

Revisiting the HG calorimeters for circular colliders

Large panel of running conditions

- 90GeV × 10^7 fb × $5\cdot10^{36}$ cm^{-2} s^{-1} (qq × 20000 ILC @ 250)
- 150 GeV (WW) + 250 GeV (ZH)+ 280 GeV (tt) ~10^4 fb × $5\cdot10^{35}$ cm^{-2} s^{-1} (qq × 5–10 ILC @ 250)



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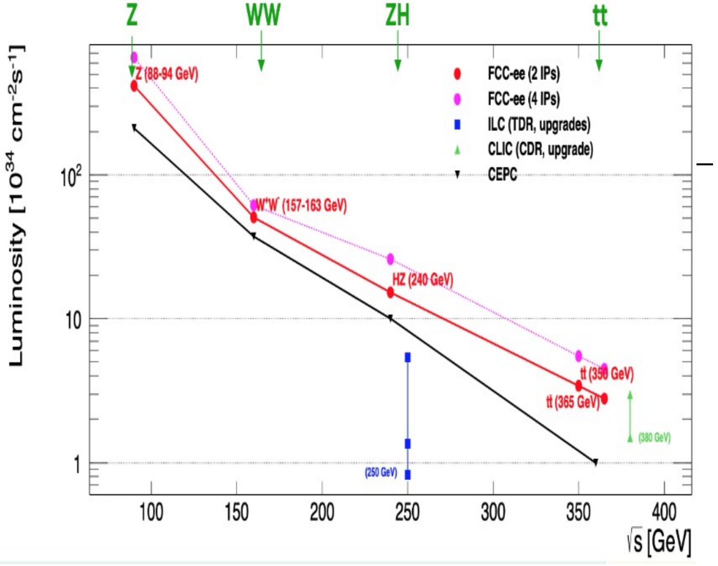


Are the current hypothesis viable ?

- Occupancy, DAQ, Cooling
- 1 detector fit-all ?
  - What are the limits :
    - power vs Granularity vs 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 ?

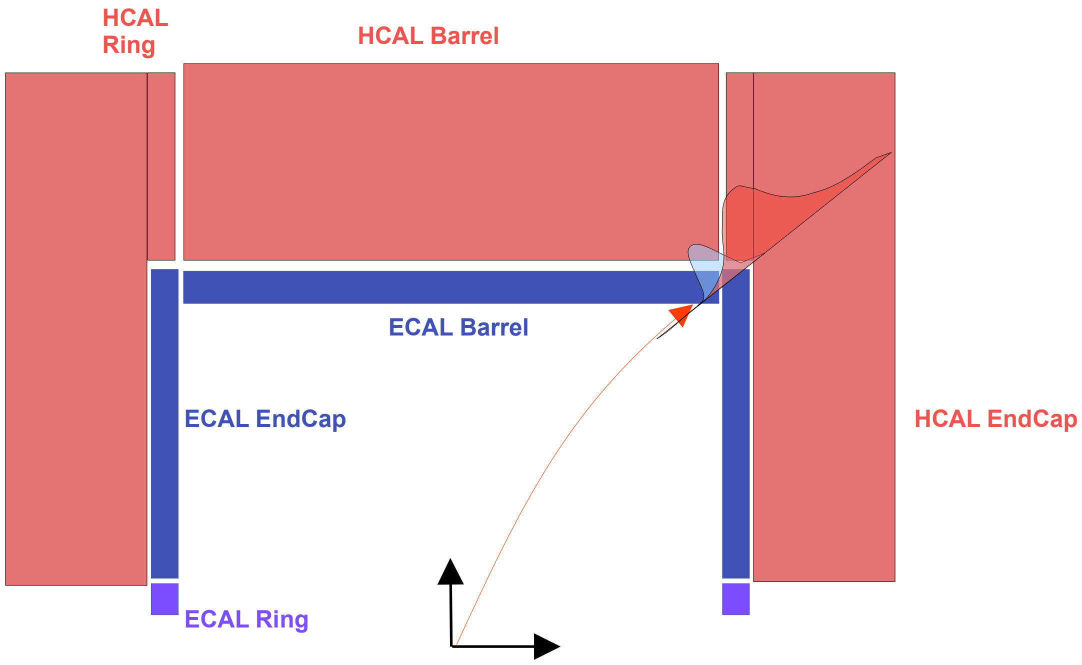
Calorimeter Fluxes from Full Simulations

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



Histograms Types

Primary histograms:

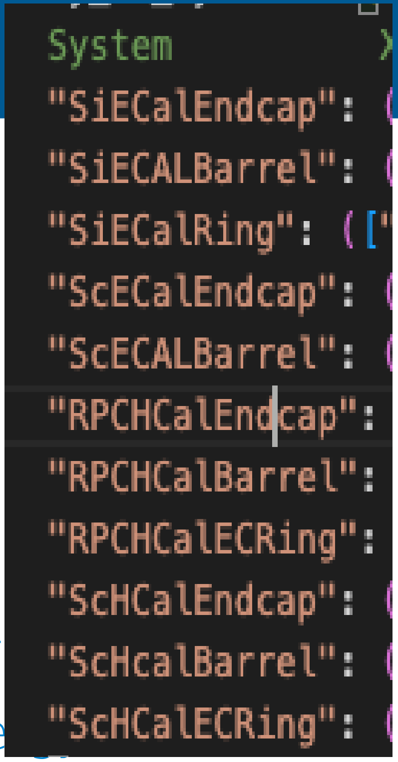
1)**Low-Scale Energy**: Energy distribution of hits with an upper-bound

2)**Upper-Scale Energy**: Complementary distribution to show the tailing effects (with auto-rescaling)

3)**Low-Scale Number of hits**: Number of hits above a given energy threshold per event (adjusted per system ~ ¼ MIP)

4)**Upper-Scale Number of hits**: The complementary distribution with auto-r

5)**Time**: Time distribution of the sub hits weighted with the corresponding ene



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

11 calorimeter system

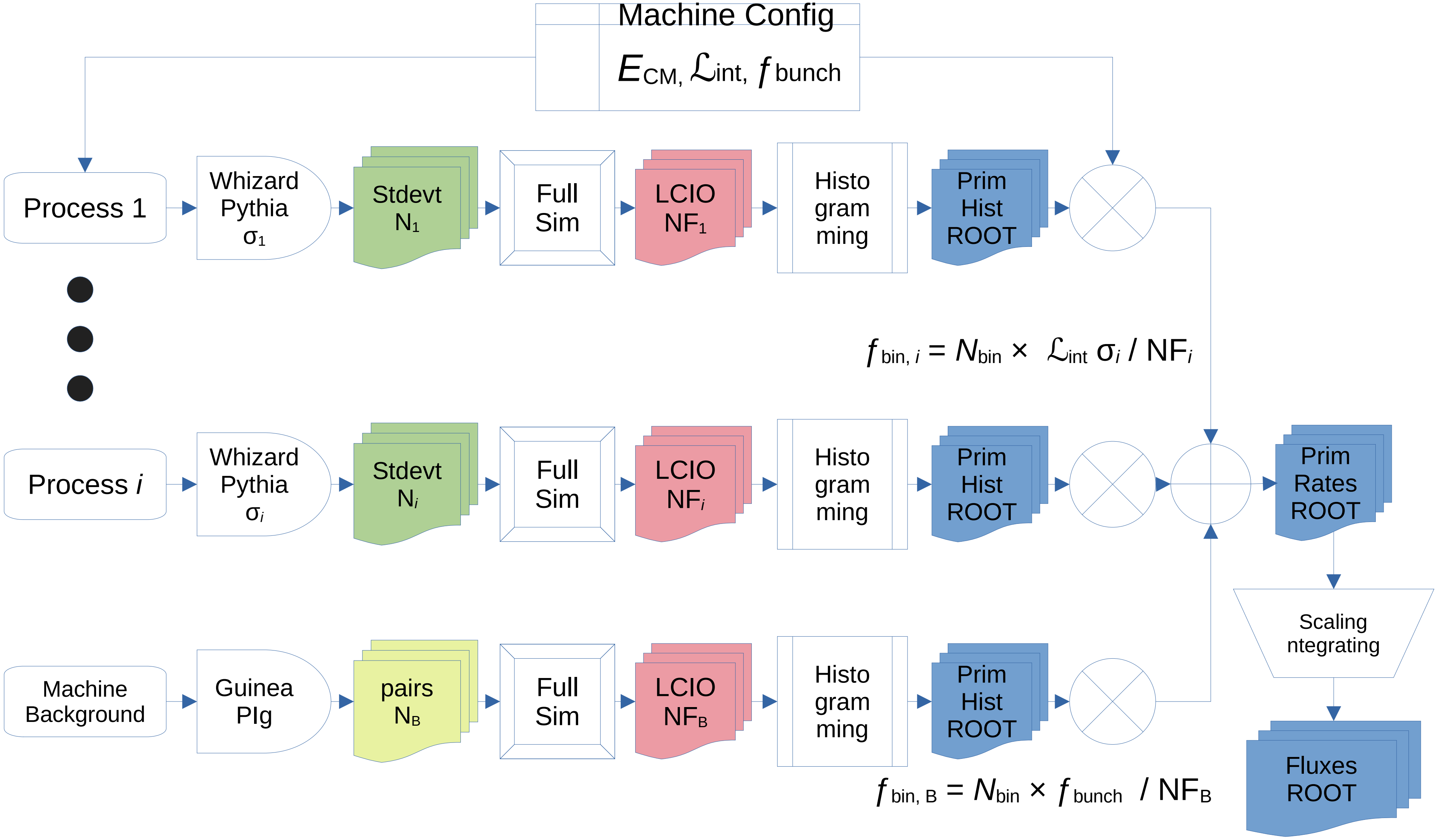
Secondary histograms (functions of primary histograms):

6)**Upper Scale Energy rates in MIPs**: The same distribution as the Upper-Scale Energy histogram with the x-axis scaled by the MIP value.

7)**Full Scale Hits rates**: Number of hits per region from Low and high scales

8)**Full Scale Power**: base power + conversion energy per hit [TBD, based on ASICs characteristics]

Processes to Fluxes



Machine Config

$E_{\mathrm{CM}}, \mathcal{L}_{\mathrm{int}}, f_{\mathrm{bunch}}$

Process 1

Whizard
Pythia
σ_1

Stdevt
N_1

Full
Sim

LCIO
NF_1

Histo
gram
ming

Prim
Hist
ROOT

$f_{\mathrm{bin},\,i} = N_{\mathrm{bin}} \times \mathcal{L}_{\mathrm{int}}\, \sigma_i \,/\, \mathrm{NF}_i$

Process *i*

Whizard
Pythia
σ_i

Stdevt
N_i

Full
Sim

LCIO
NF_i

Histo
gram
ming

Prim
Hist
ROOT

Prim
Rates
ROOT

Scaling
ntegrating

Machine
Background

Guinea
PIg

pairs
N_B

Full
Sim

LCIO
NF_B

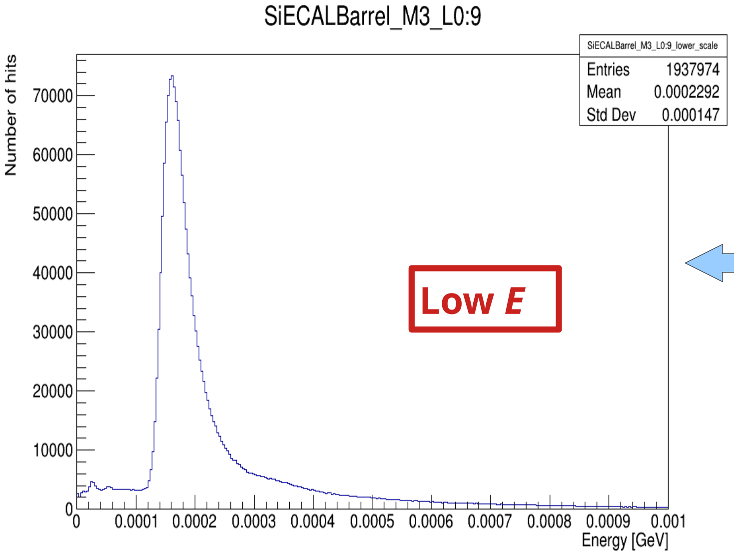
Histo
gram
ming

Prim
Hist
ROOT

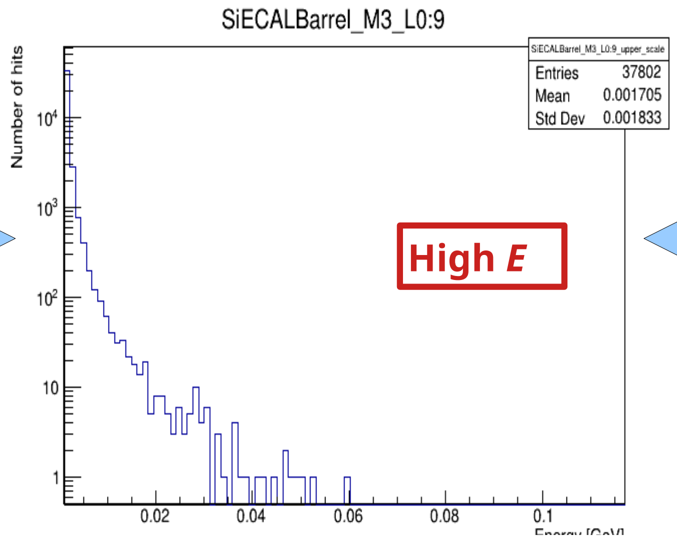
Fluxes
ROOT

$f_{\mathrm{bin,\,B}} = N_{\mathrm{bin}} \times f_{\mathrm{bunch}} \,/\, \mathrm{NF}_\mathrm{B}$

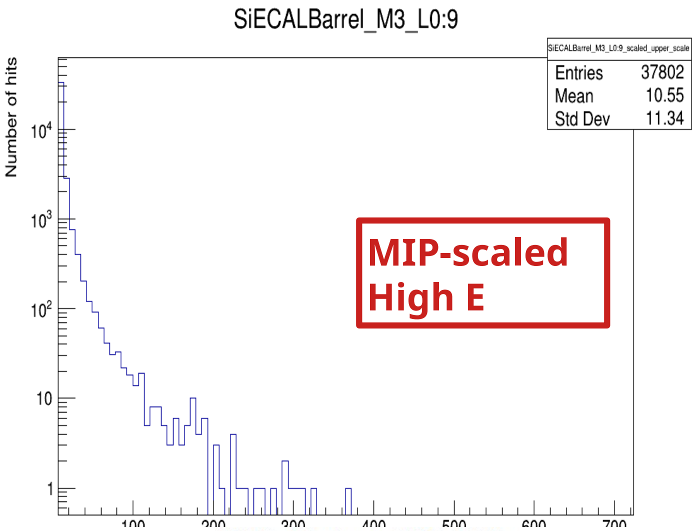
Histograms Types (1,000,000 muon events)



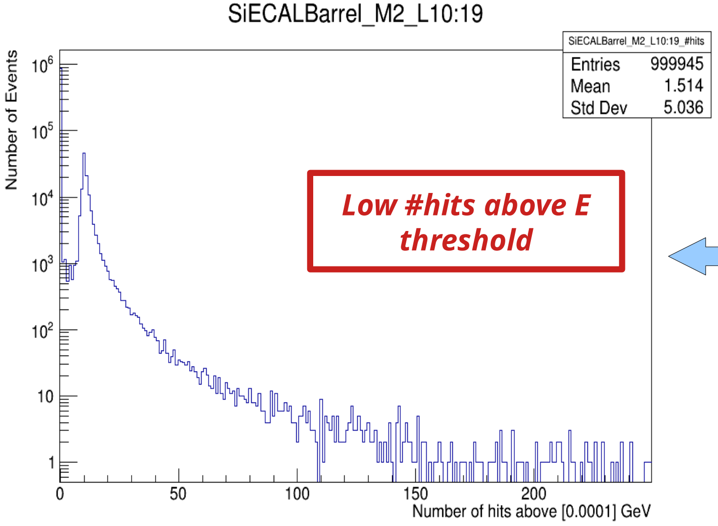
Low *E*



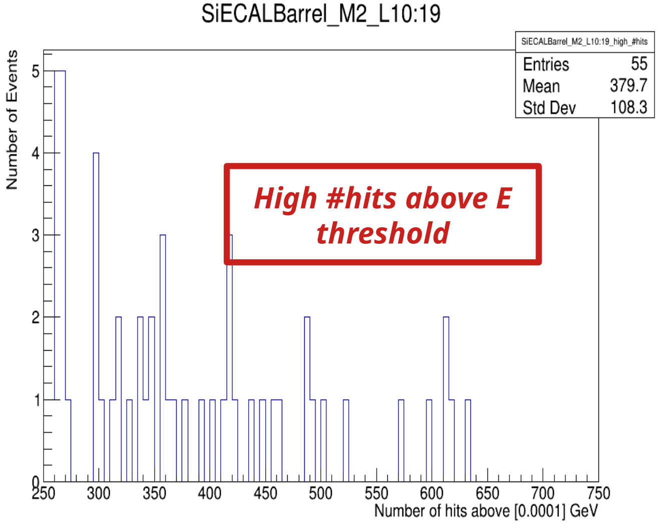
High *E*



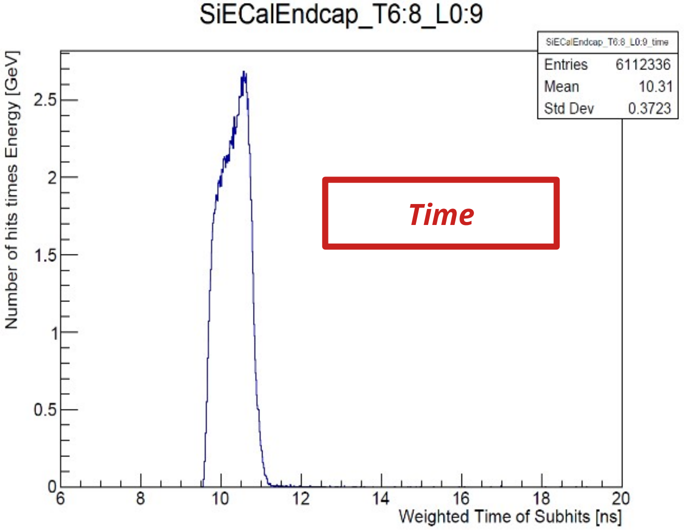
MIP-scaled High E



Low #hits above E threshold



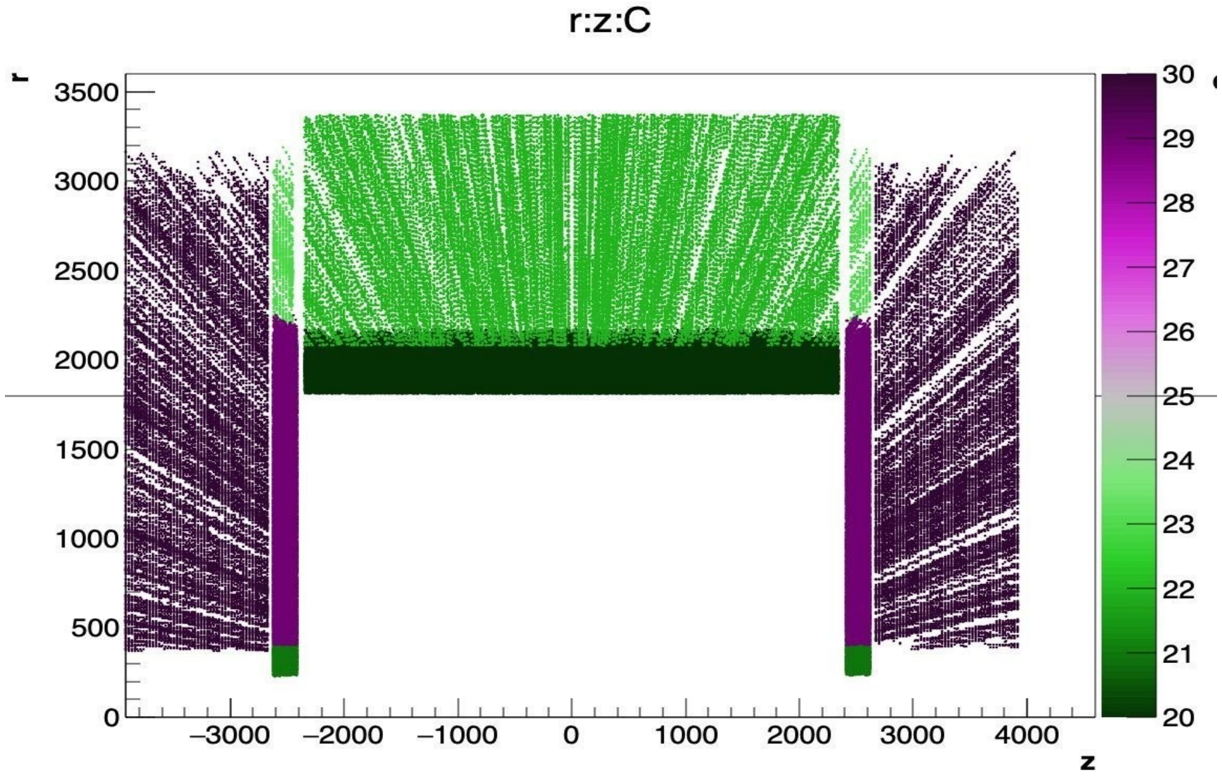
High #hits above E threshold



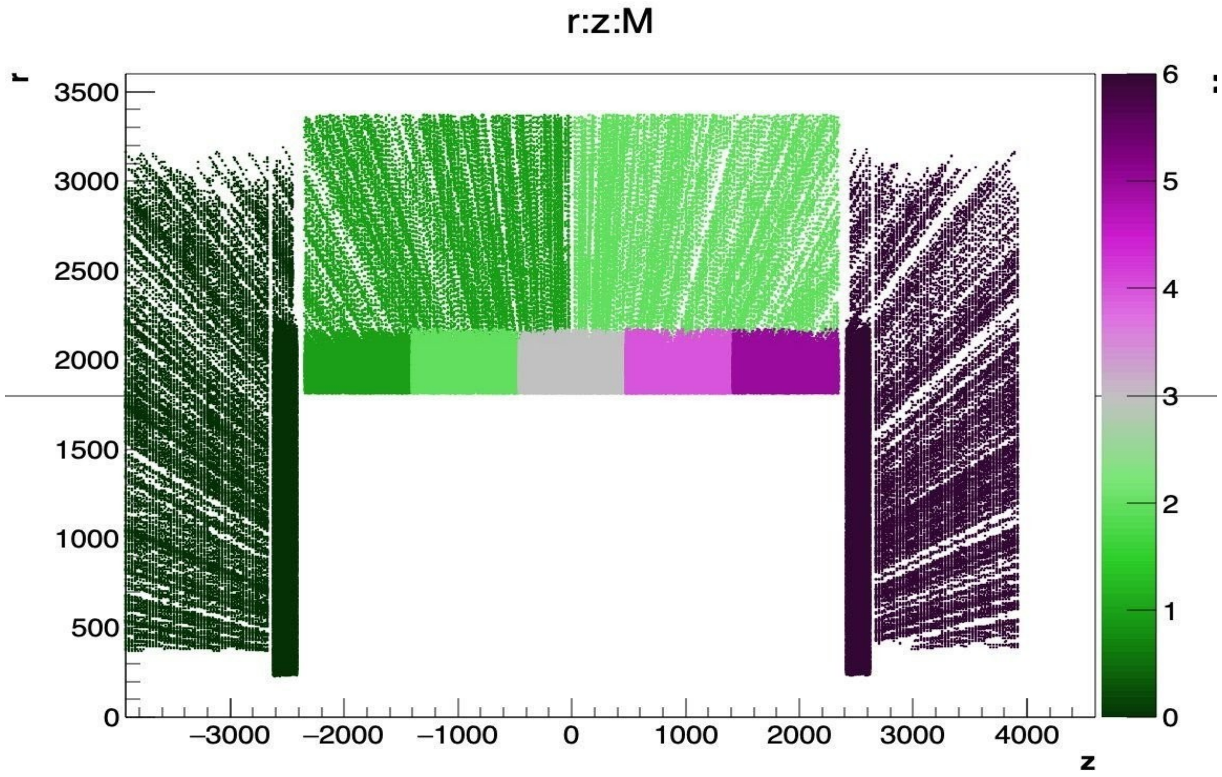
Time

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)

Vincent.Boudry@in2p3.fr

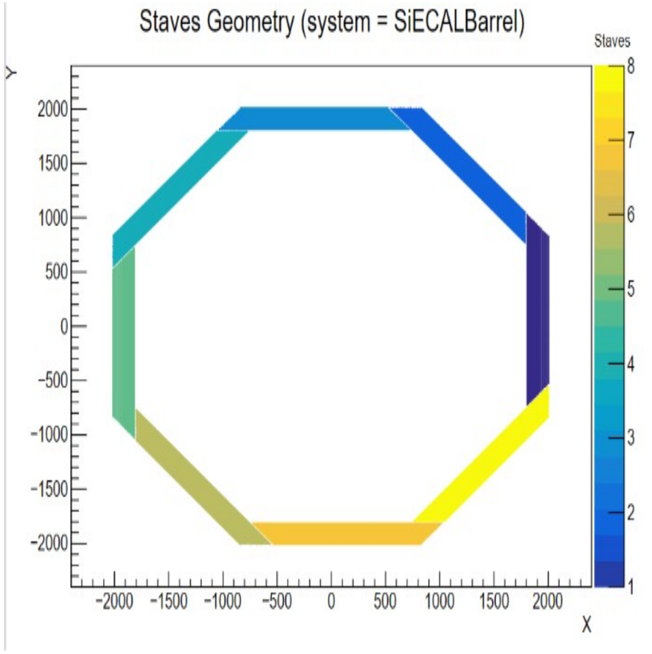
Geometric Selections (Explicit)

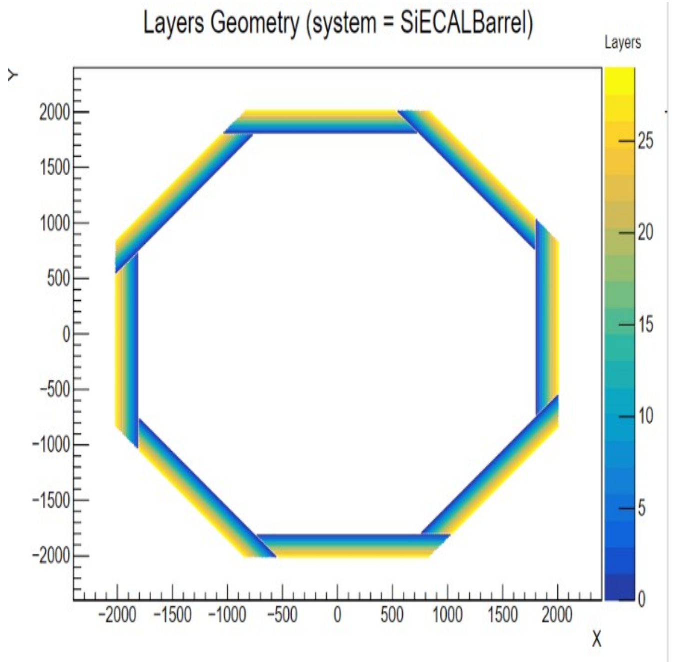
All the staves are symmetric (φ, azimuthal symmetry)

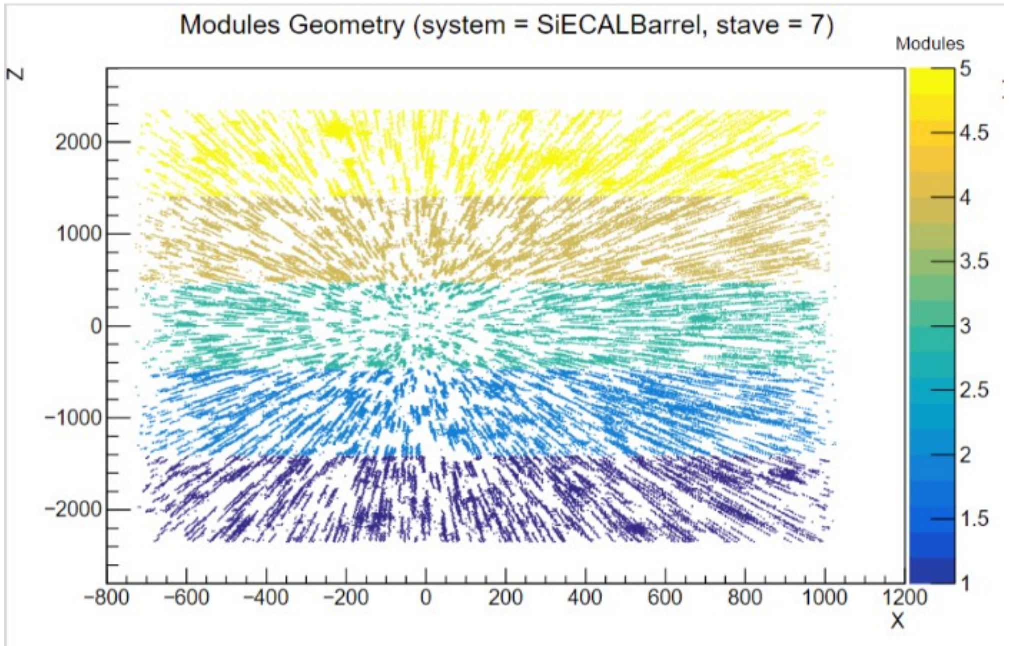
Radial behaviour can be obtained from different layers (central image).

Polar behaviour (cos θ): from Modules in Barrel, from Towers in EndCaps.

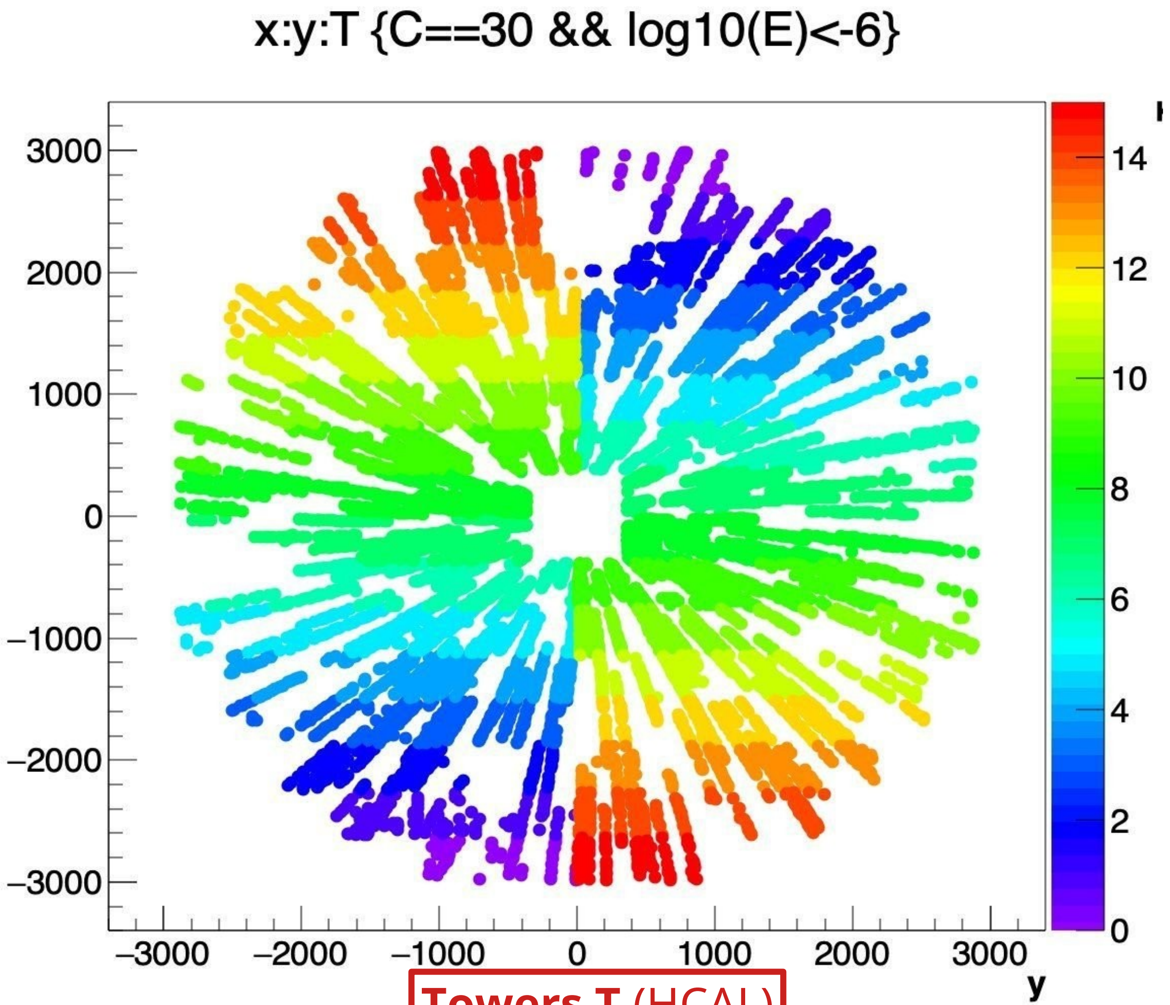
Selections are in Barrel : 5 Modules × 3 block of 10 layers



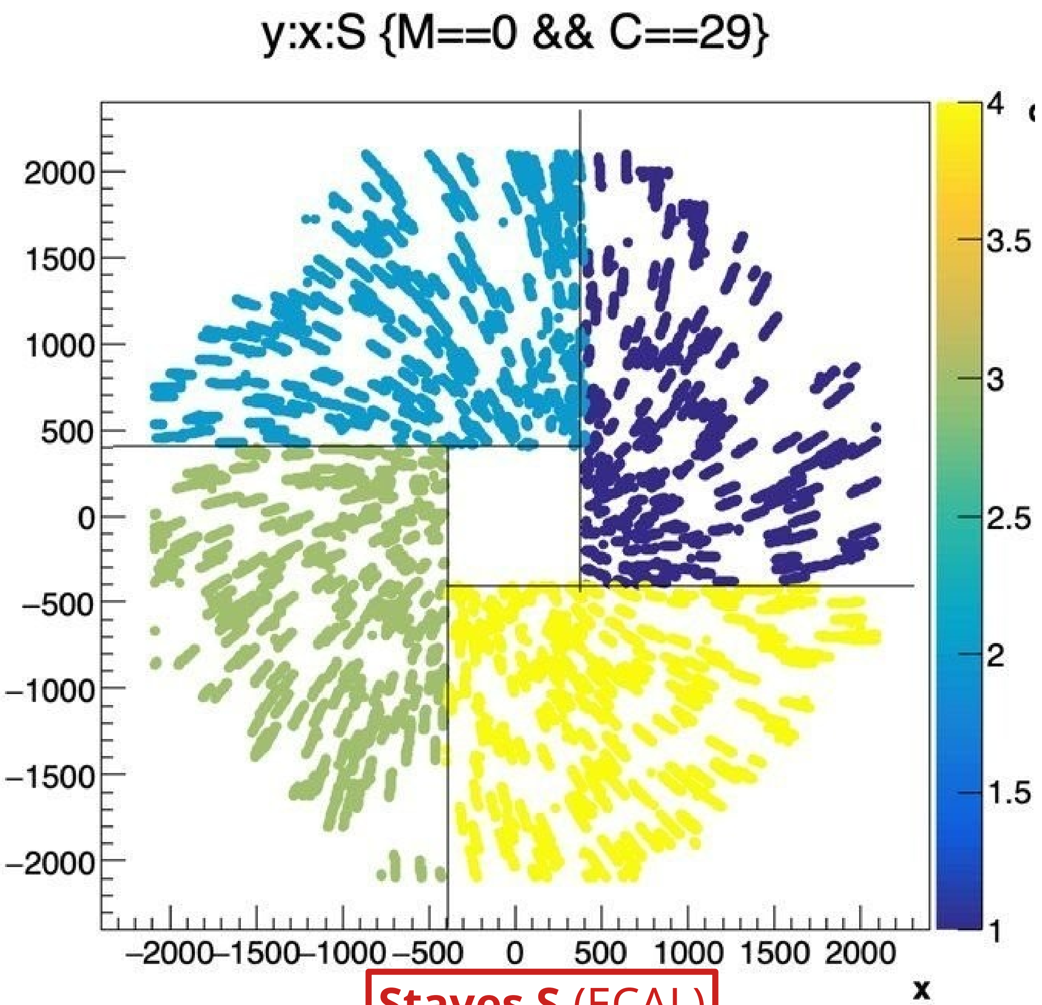




Logical Geometry : towers & staves



Towers T (HCAL)



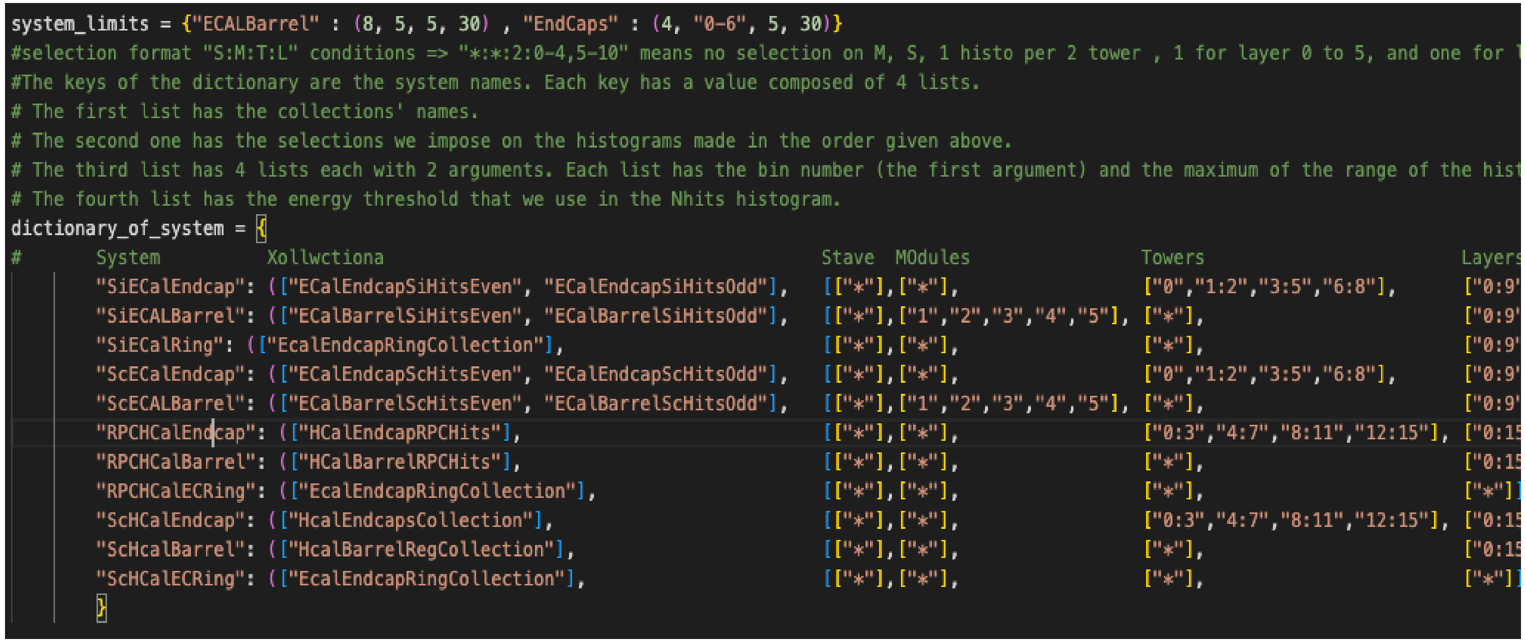
Staves S (ECAL)

Software package

Python code

Production of Primary histograms

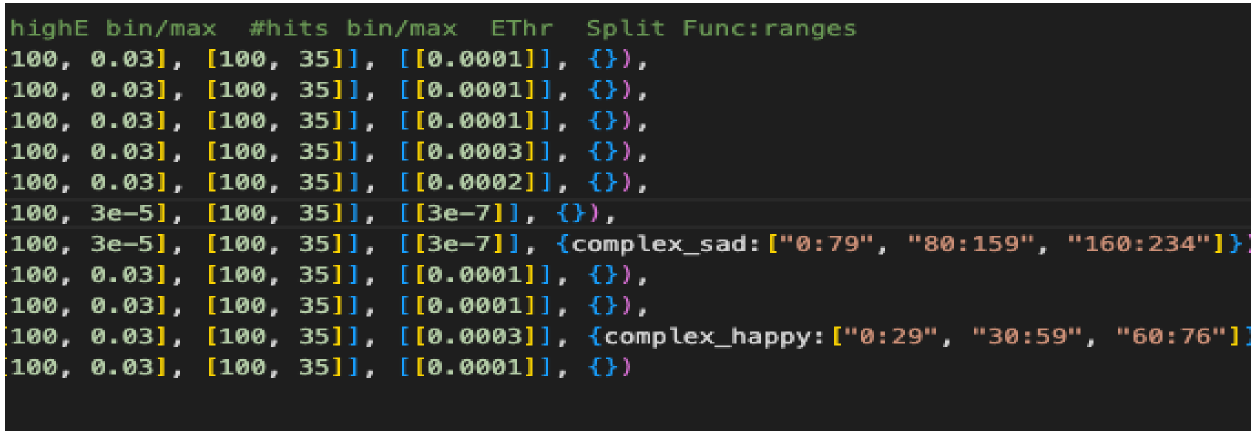
- LcioReader from pyLCIO
- Mapping & Selection
  - Cell_id decoding [J. Kunath]
  - Highly configurable
- ROOT histograms
  - System and histogram type hierarchy
  - Auto-rescalable (high E, high Nhits)



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

Secondary histograms

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



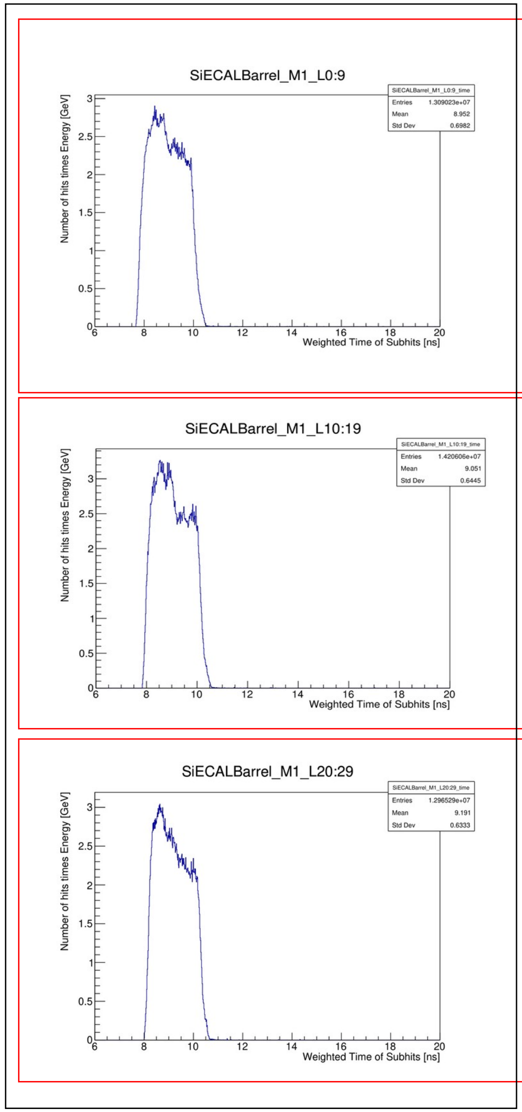
```
highE bin/max  #hits bin/max  EThr  Split Func:ranges
[100, 0.03], [100, 35]], [[0.0001]], {}),
[100, 0.03], [100, 35]], [[0.0001]], {}),
[100, 0.03], [100, 35]], [[0.0001]], {}),
[100, 0.03], [100, 35]], [[0.0003]], {}),
[100, 0.03], [100, 35]], [[0.0002]], {}),
[100, 3e-5], [100, 35]], [[3e-7]],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

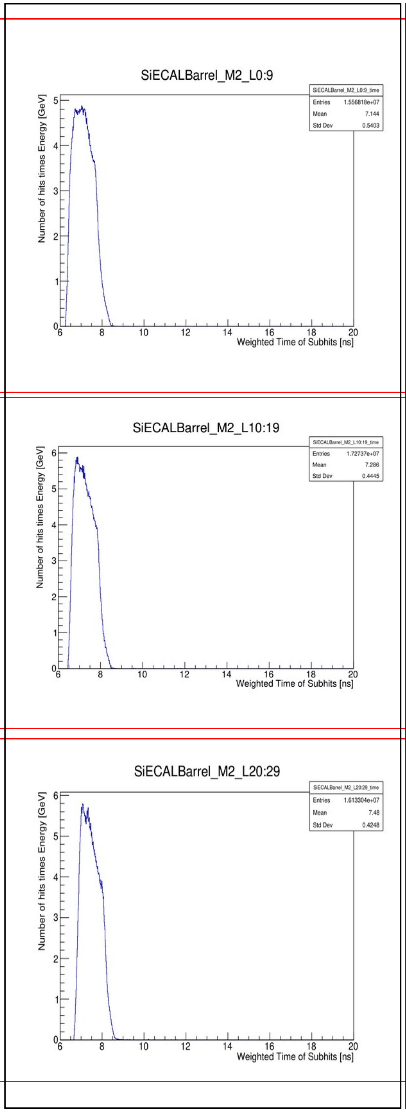
2D histograms

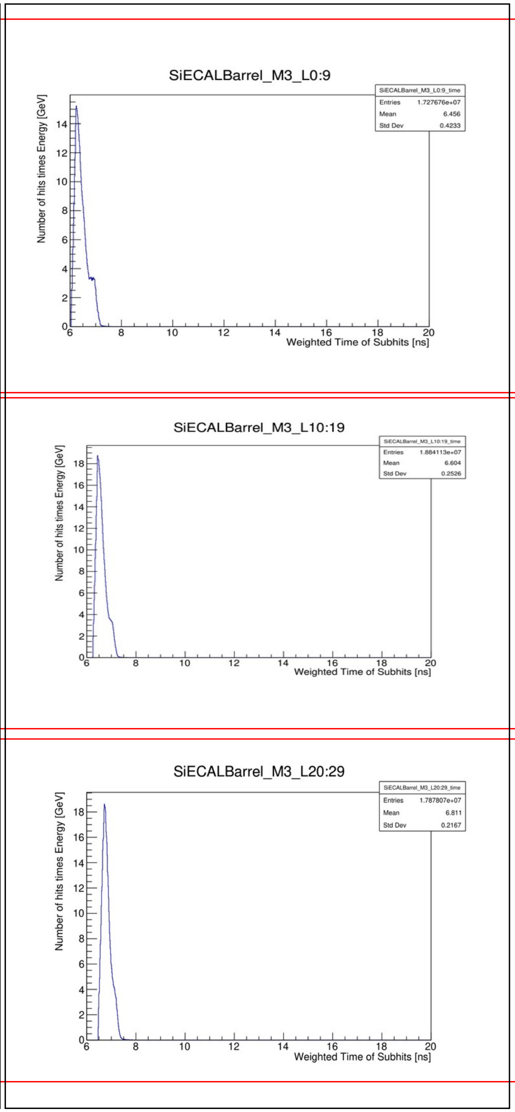
- Fix one component and get its 1D histograms as bins of a single 2D histogram.

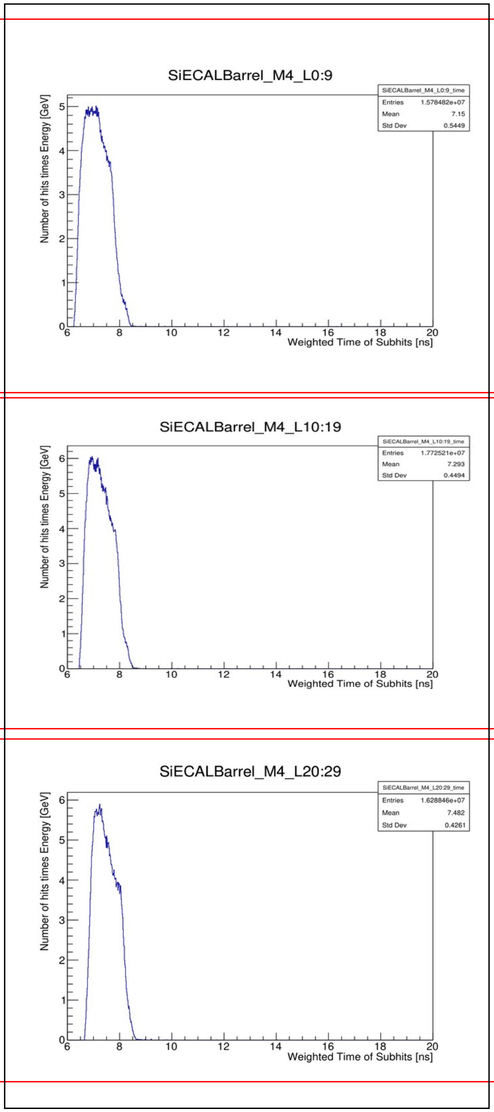
incent.Boudry@in2p3.fr

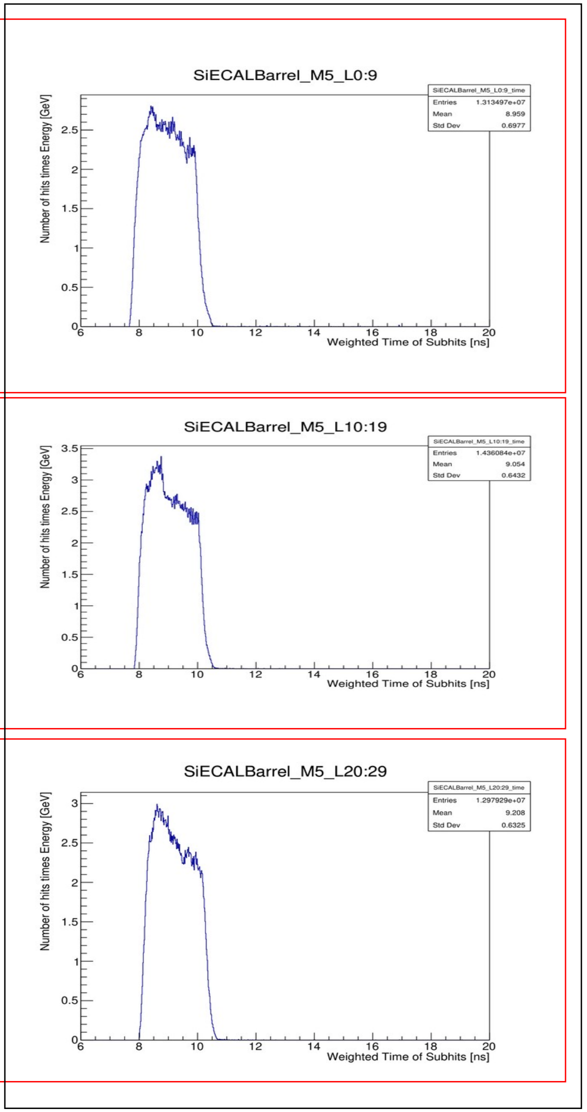
Geometric Selections (1D histograms : 1M muons events)



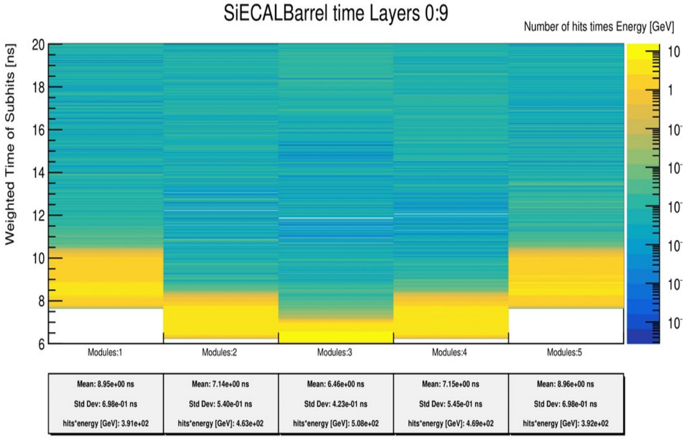


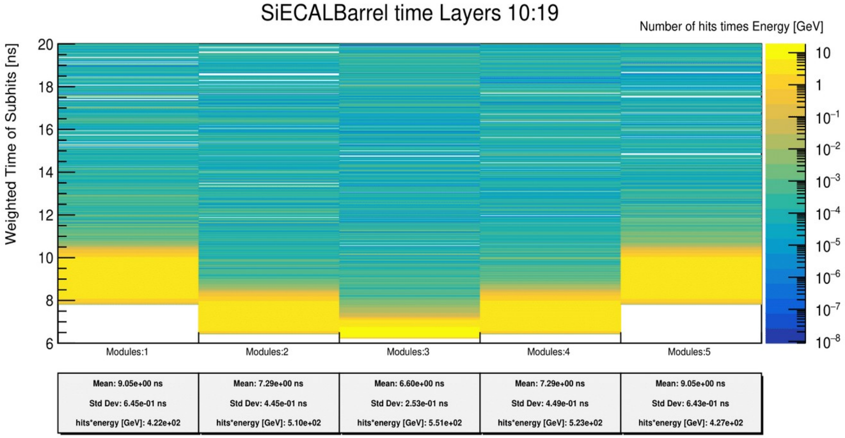


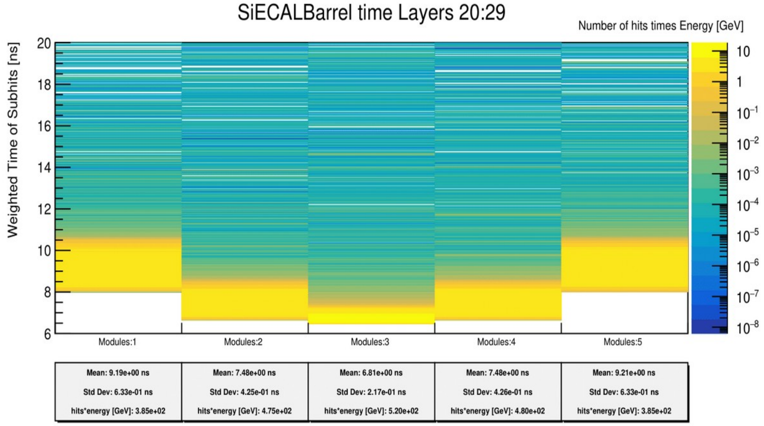


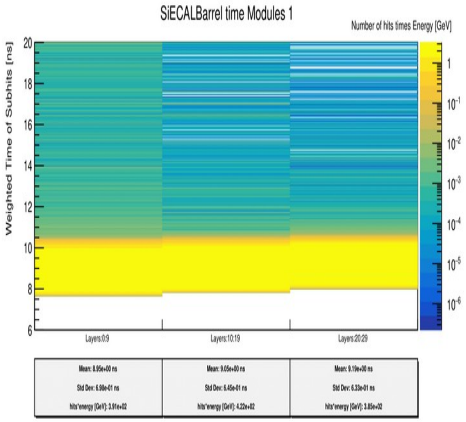


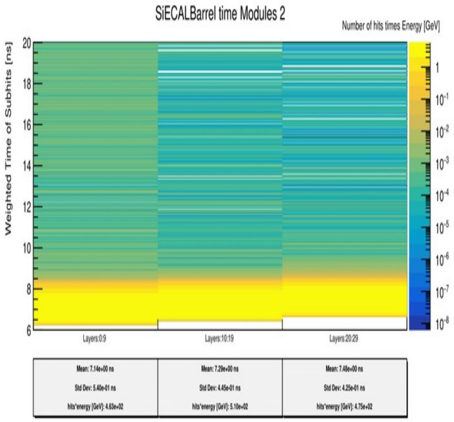
Geometric Selections (2D histograms)

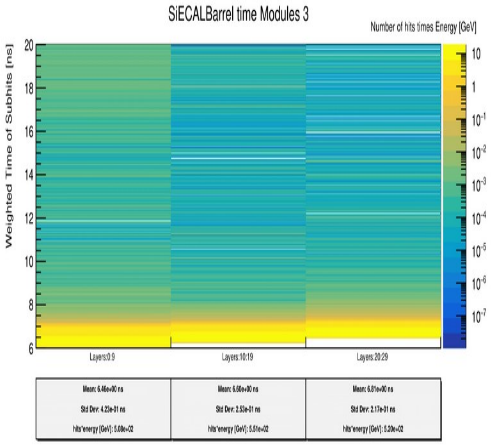


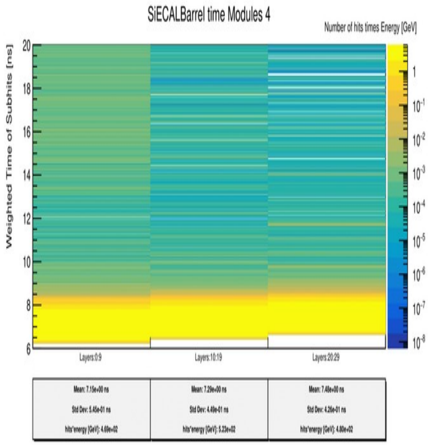


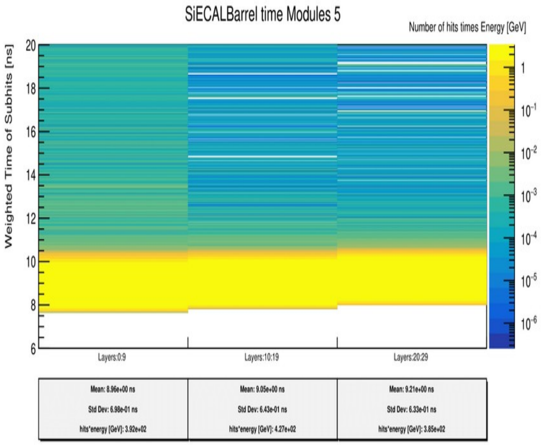






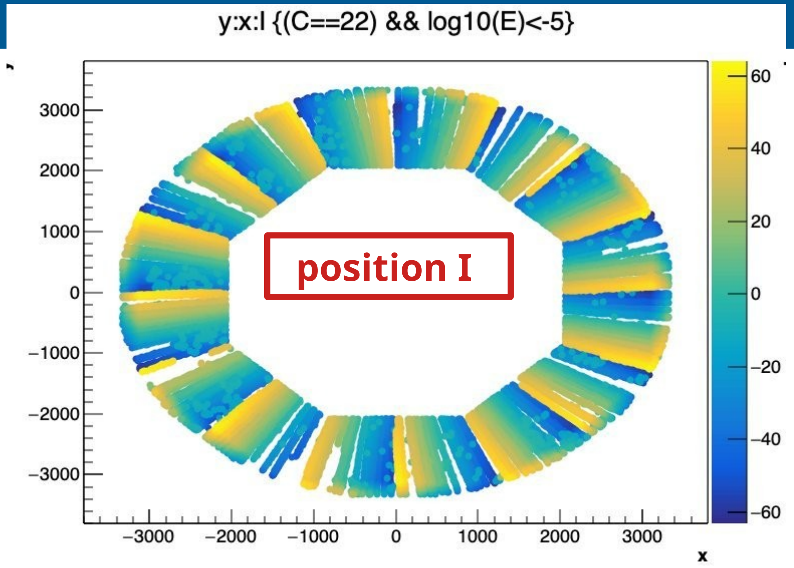


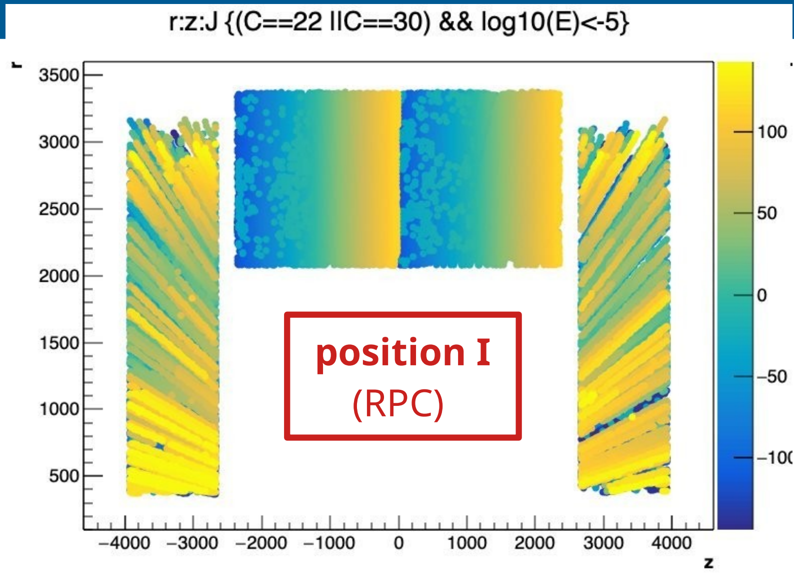


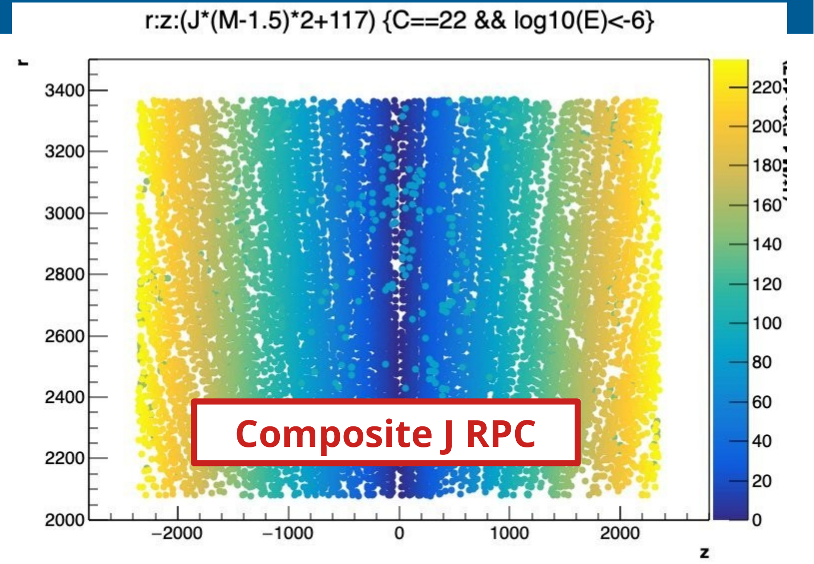


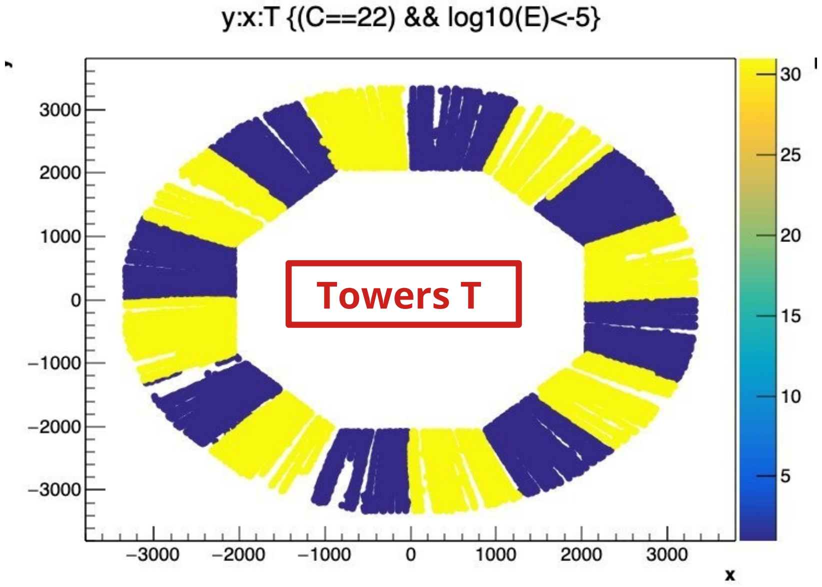
Vincent.Boudry@in2p3.fr

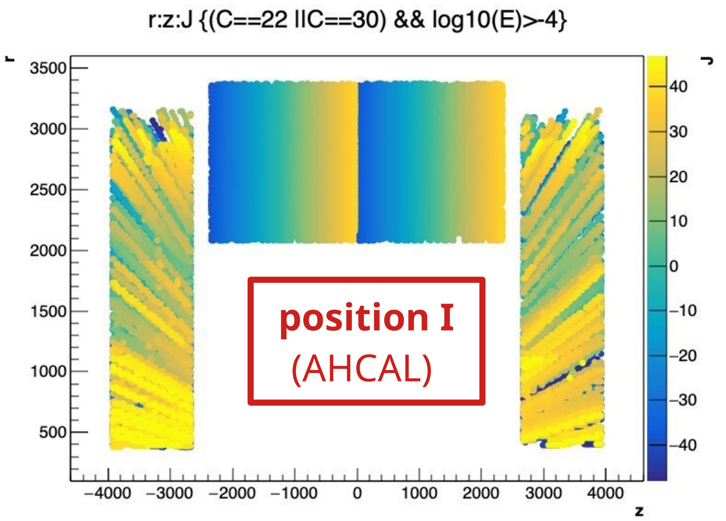
Logical Geometry (HCAL BARRELs)

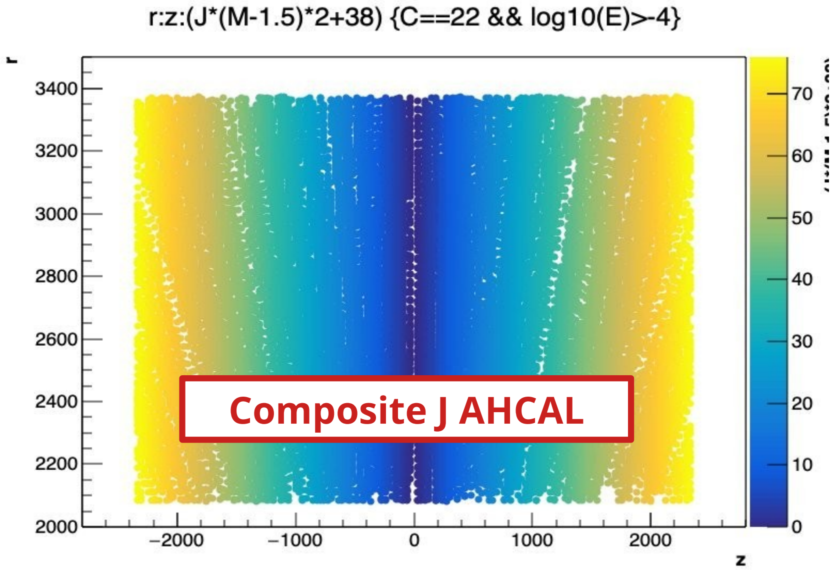






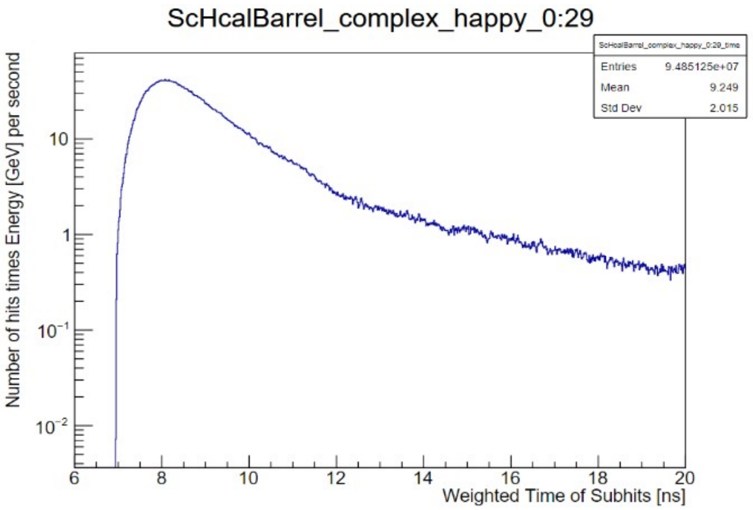


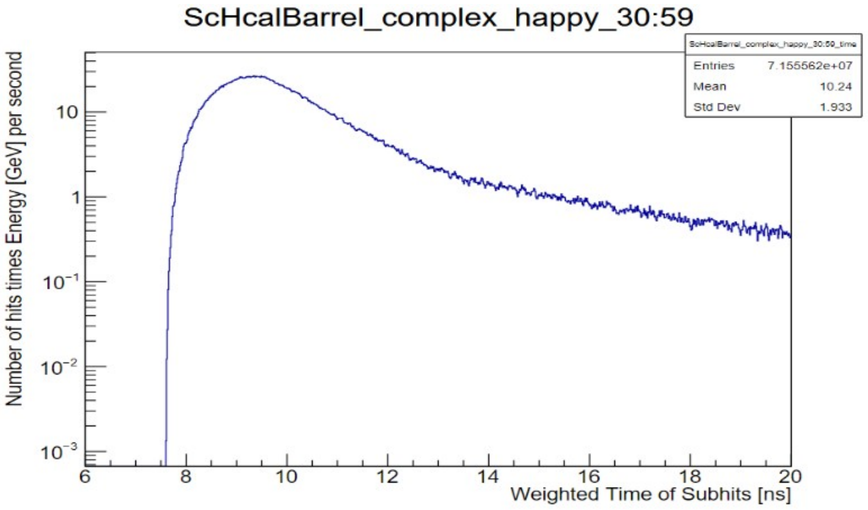


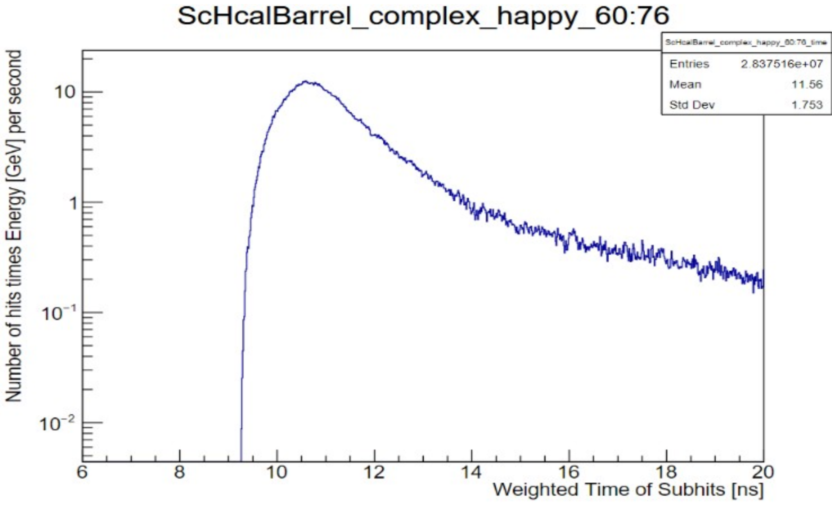


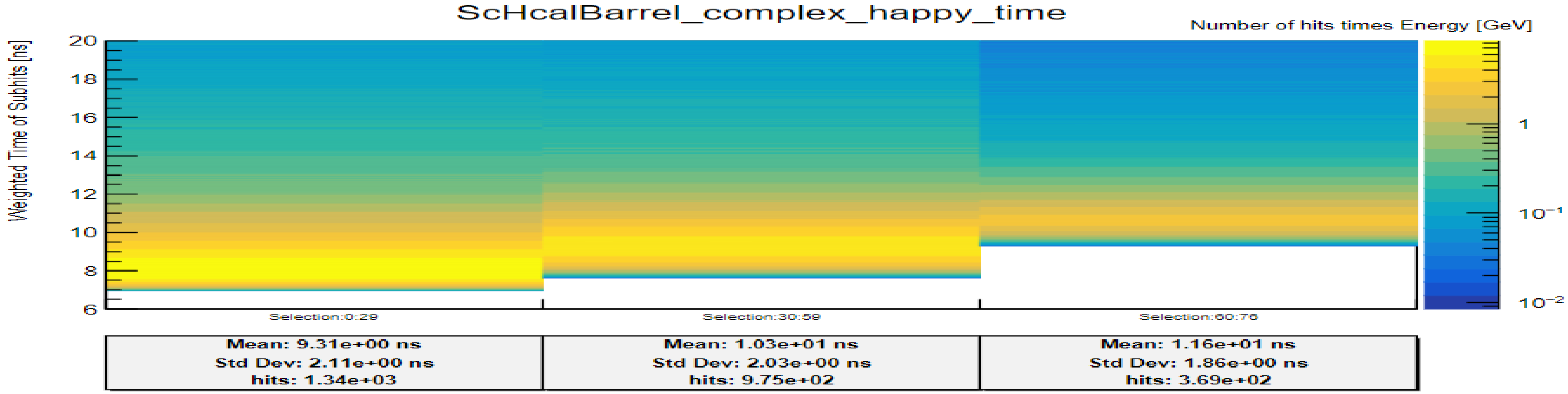
1D Vs. 2D Histograms (implicit selections)

2J(M-1.5)+38 = {x: x is integer, 0


ScHcalBarrel_complex_happy_0:29


ScHcalBarrel_complex_happy_30:59


ScHcalBarrel_complex_happy_60:76


ScHcalBarrel_complex_happy_time

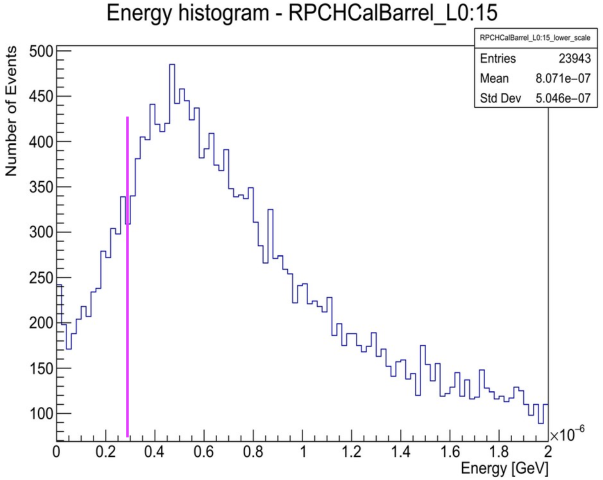
System low energy & #hit responses
raw energies (no digitization)

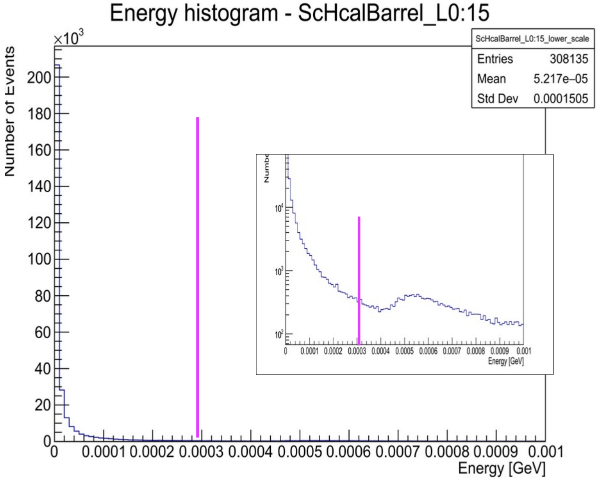
SDHCAL

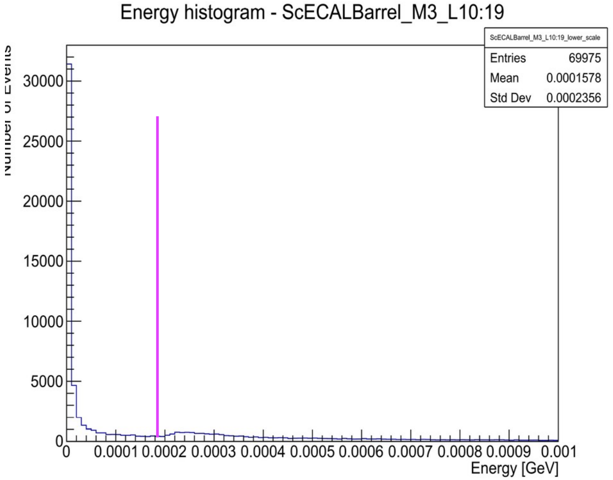
AHCAL

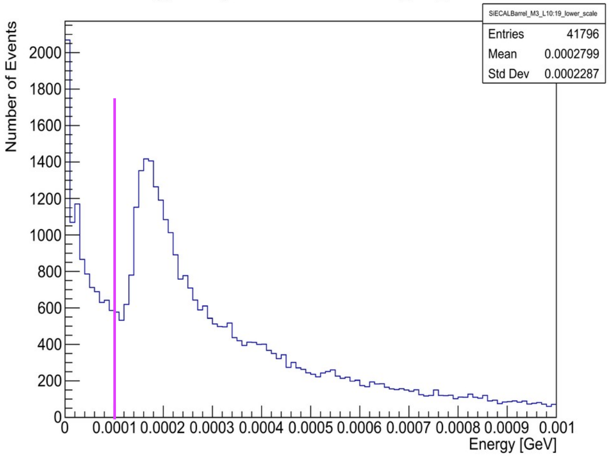
Sc ECAL

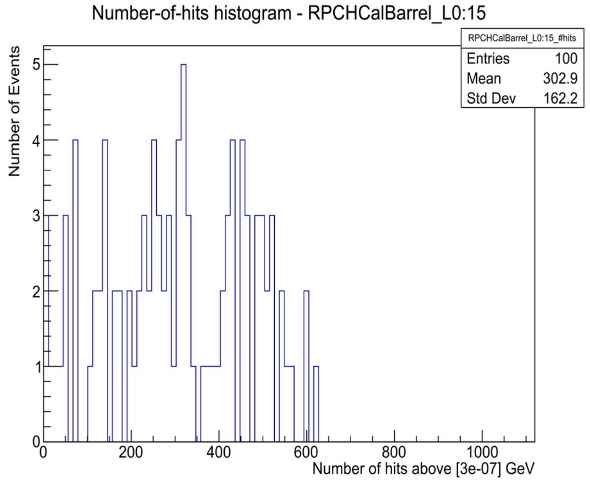
Si ECAL

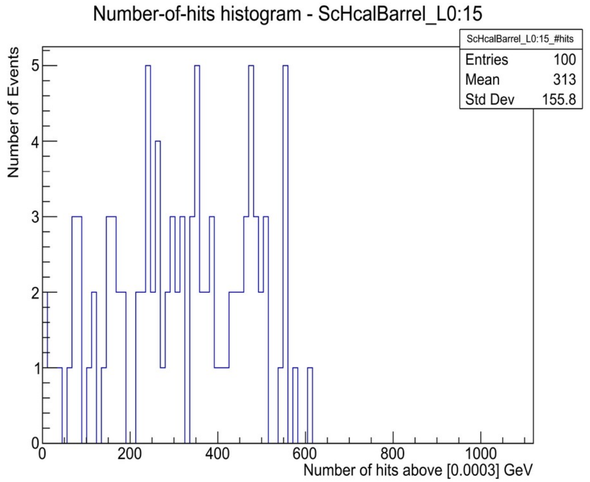


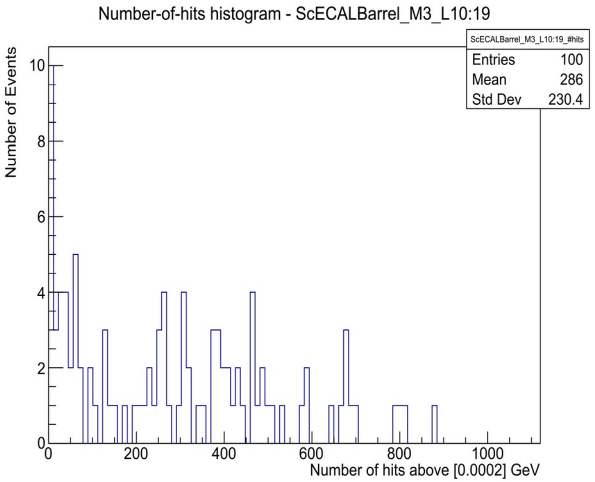


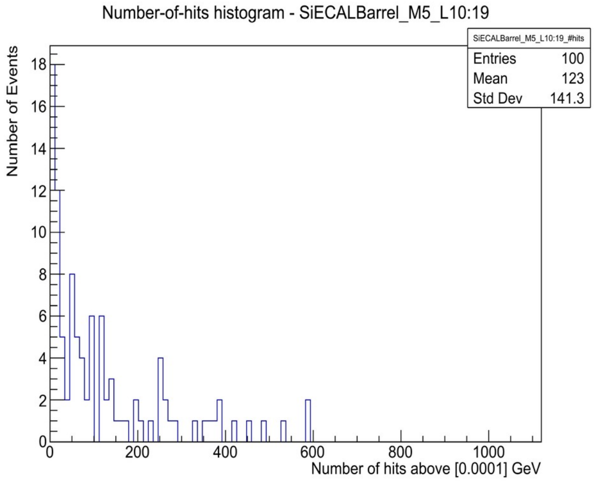






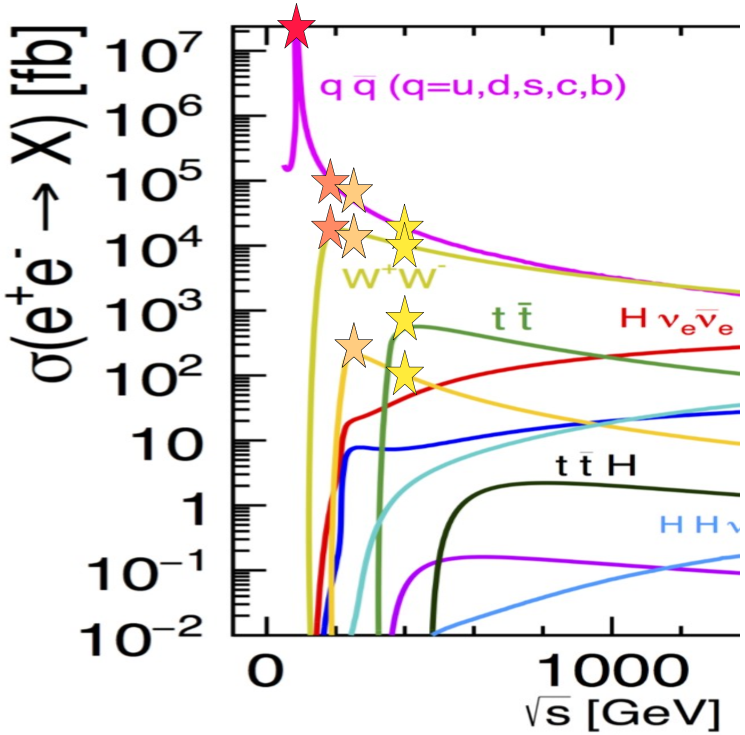






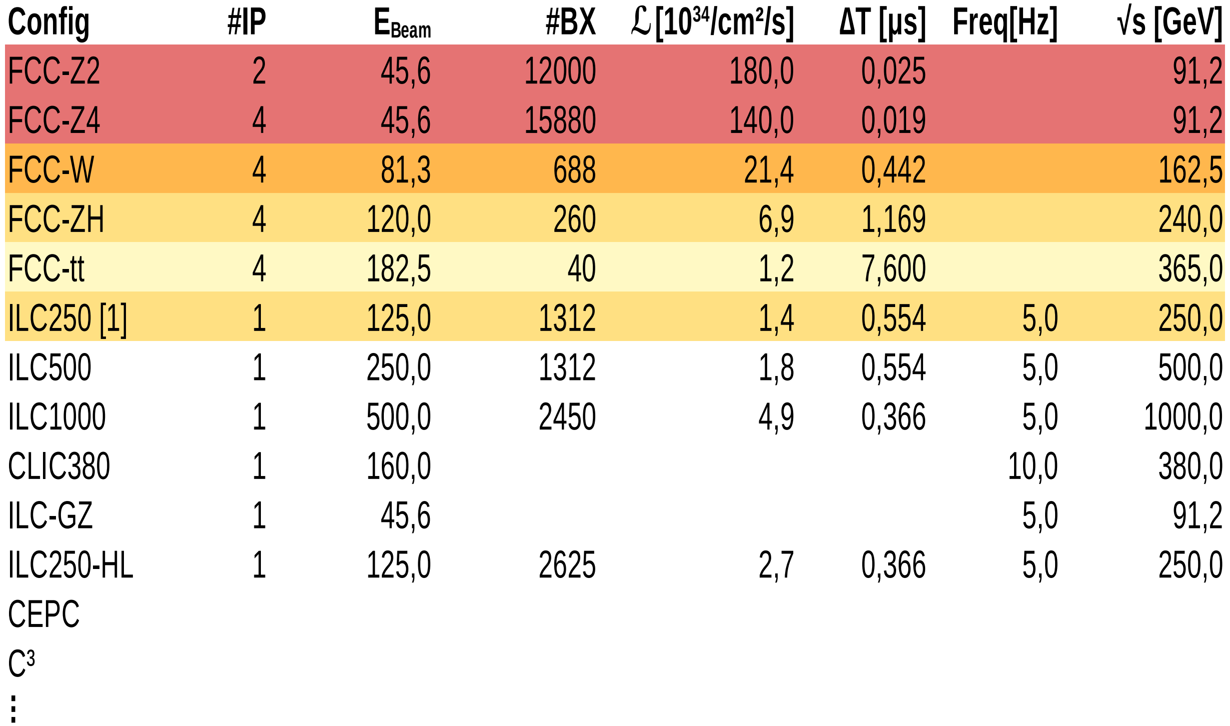
Vincent.Boudry@in2p3.fr

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

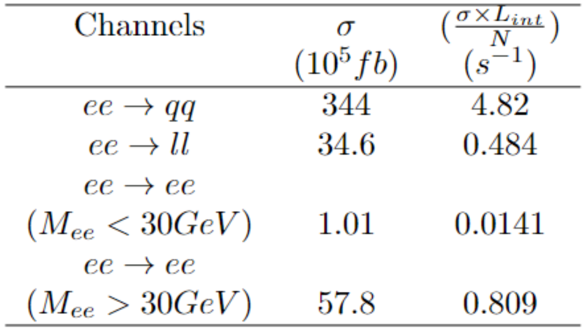


Config	#IP	E_{Beam}	#BX	$\mathcal{L}$[10^{34}/cm²/s]	ΔT [μs]	Freq[Hz]	√s [GeV]
FCC-Z2	2	45,6	12000	180,0	0,025		91,2
FCC-Z4	4	45,6	15880	140,0	0,019		91,2
FCC-W	4	81,3	688	21,4	0,442		162,5
FCC-ZH	4	120,0	260	6,9	1,169		240,0
FCC-tt	4	182,5	40	1,2	7,600		365,0
ILC250 [1]	1	125,0	1312	1,4	0,554	5,0	250,0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

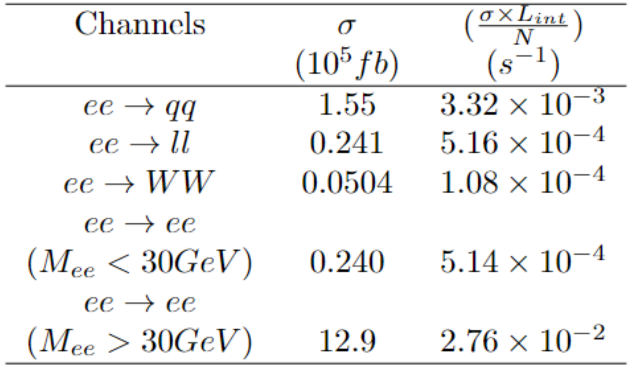
Generated data

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



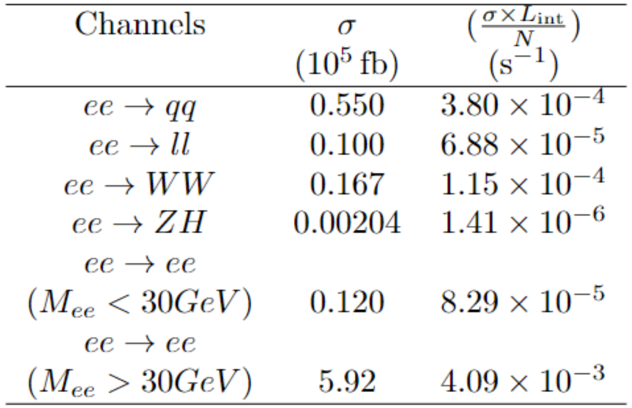
Channels	σ $(10^5 fb)$	$(\frac{\sigma \times L_{int}}{N})$ (s^{-1})
$ee \to qq$	344	4.82
$ee \to ll$	34.6	0.484
$ee \to ee$ $(M_{ee} < 30GeV)$	1.01	0.0141
$ee \to ee$ $(M_{ee} > 30GeV)$	57.8	0.809

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



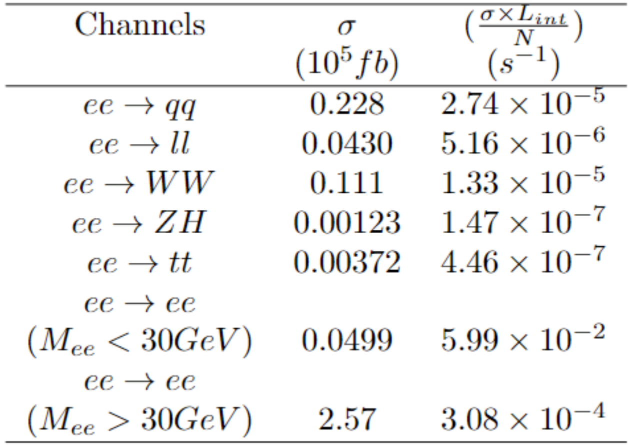
Channels	σ $(10^5 fb)$	$(\frac{\sigma \times L_{int}}{N})$ (s^{-1})
$ee \to qq$	1.55	3.32×10^{-3}
$ee \to ll$	0.241	5.16×10^{-4}
$ee \to WW$	0.0504	1.08×10^{-4}
$ee \to ee$ $(M_{ee} < 30GeV)$	0.240	5.14×10^{-4}
$ee \to ee$ $(M_{ee} > 30GeV)$	12.9	2.76×10^{-2}

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



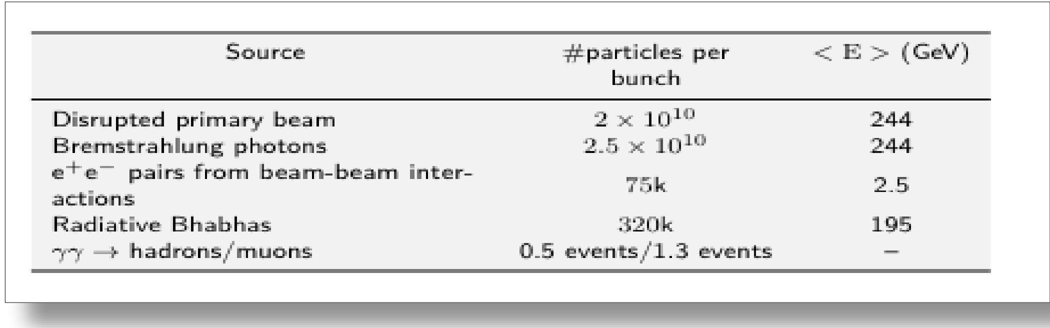
Channels	σ $(10^5\ {\rm fb})$	$(\frac{\sigma \times L_{\rm int}}{N})$ $({\rm s}^{-1})$
$ee \to qq$	0.550	3.80×10^{-4}
$ee \to ll$	0.100	6.88×10^{-5}
$ee \to WW$	0.167	1.15×10^{-4}
$ee \to ZH$	0.00204	1.41×10^{-6}
$ee \to ee$ $(M_{ee} < 30GeV)$	0.120	8.29×10^{-5}
$ee \to ee$ $(M_{ee} > 30GeV)$	5.92	4.09×10^{-3}

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



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

Machine background sources :



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

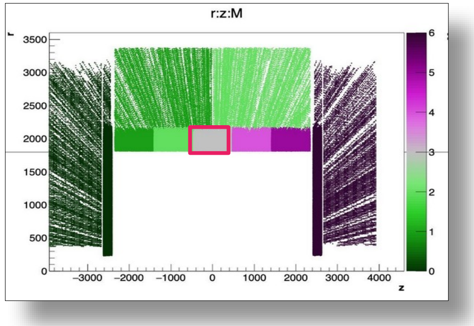
T. Behnke, et al.
The International Linear Collider Technical Design Report - Volume 4: Dete
arXiv:1306.6329 [Physics]. (2013)

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

Produced by Andrea Ciarma,

Simulated (special) in ILD’s by D. Jeans

Results : 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

- Most of the hits are in the first 2 thirds of the calorimeter.
- Highest average rates L0:9
- Highest max rates in L10:19

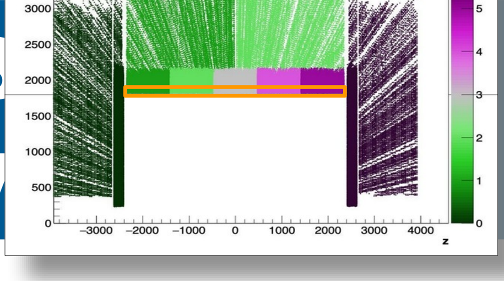
Average	18E+6 hits/s	3E+6 hits/s	2E+6 hits/s
Max	2000 hits/event	2500 hits/event	1000 hits/event
for 6B/hits	106E+6 B/s	19E+6 B/s	10E+6 B/s
Ncells	4 026 764	3 767 273	3 378 036
Occupancy/BX	8,8E-08	1,7E-08	1,0E-08
cell size	5,5		

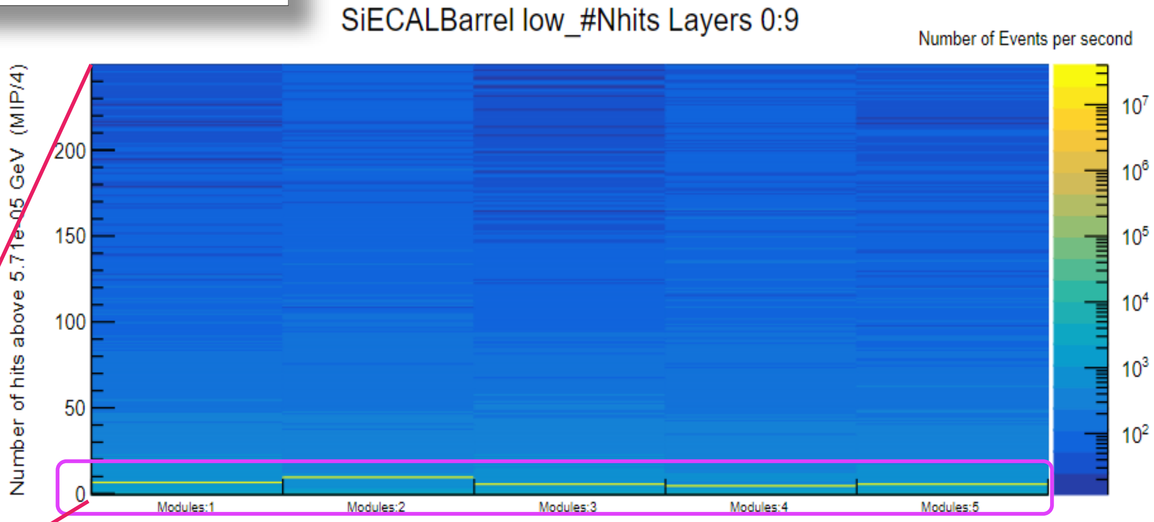
From the $\langle f_{\text{Nhits}} \rangle$ in one region one can extract :

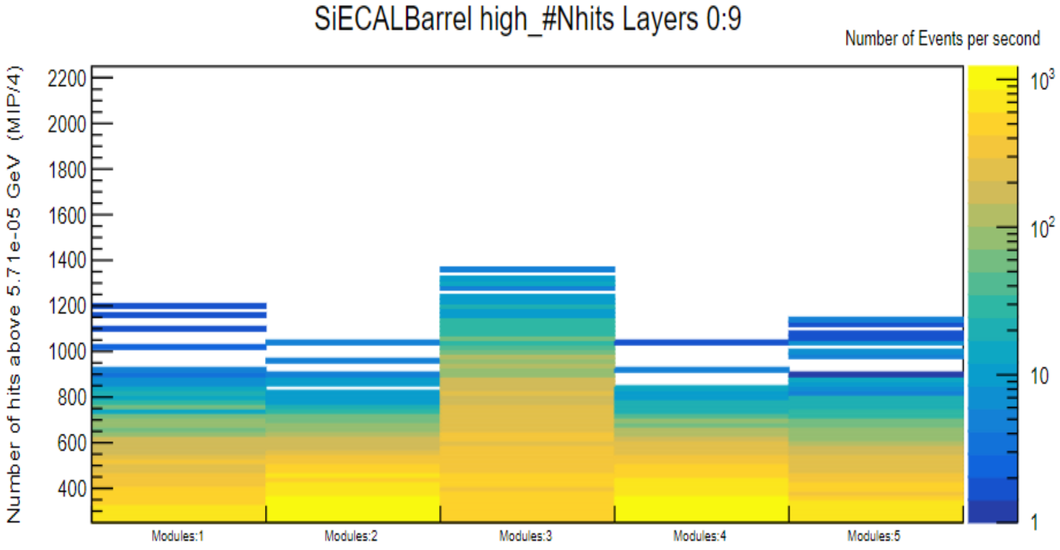
- The data rate, knowing the number of bytes per hits (here 6 as a landmark)
- The occupancy, knowing the number of cell in the region.

Note 1 : Very preliminary
Note 2 : Rates for all M3 modules → /8 per module, /10 per layer

Results : Silicon ECAL B
per module, first 10 lay




SiECALBarrel low_#Nhits Layers 0:9

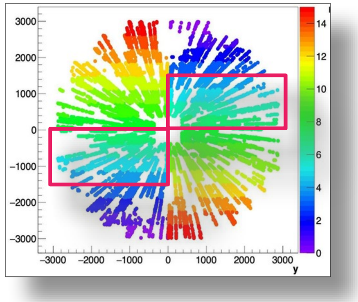

SiECALBarrel high_#Nhits Layers 0:9

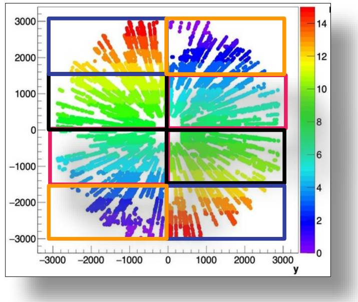
Distributions of the number of hits crossing (>MIP/4) energy threshold of all the physics processes and machine background at 91.2 GeV (FCC-Z4) with the colour bar representing the rate of events

- No significant angular dependence.
- An exception is module 3 due to the double counting effect (back-to-back events)

Vincent.Boudry@in2p3.fr

Results: Scintillator HCAL Endcap





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

Note 1 : **Very preliminary**

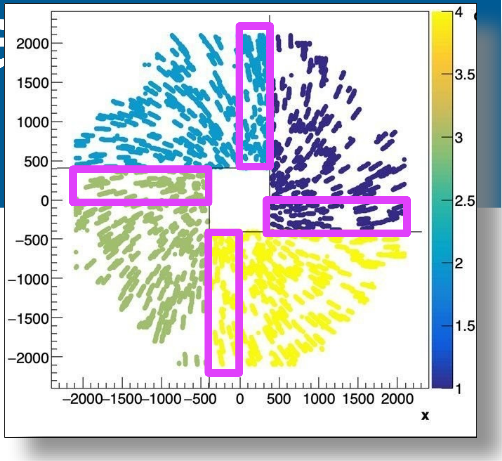
Note 2 : Rates for all tower 4:7 modules → /4 per module, /16 per layer

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

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

Vincent.Boudry@in2p3.fr

Results: Dynamic Range in SiECAL EndCa
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 = ~800 MIP
- Tower 0 is the closest to the beam-pipe
- Almost the same for both energies.

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

Results: Dynamic range HCAL EndCaps for RPC and Scint

Upper Scale Energy distributions of tower 4:7 of
RPC HCAL end cap at 91.2 GeV of all physics and background

- Max Energy –
  - ~10000 MIPs in RPC’s
  - ~100 MIPs in Scint.

  Note 1 : To be investigated ‘curlers’ vs Nucleus
  Note 2 : RPC will be Semi-Digital (hit counting)
  → Digitization is mandatory
- These are the towers closest to the beam pipe and the beam energy makes noticeable difference.

Upper Scale Energy distributions of tower 4:7 of
Scint HCAL end cap at 91.2 GeV of all physics and background

Vincent.Boudry@in2p3.fr

Conclusion

Done

Simulation:

- 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.

Histograms:

- 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.

Conclusions:

- Checked the statistics vs angular distribution
- Give **very preliminary** estimates of the average number of hits (occupancy and data rates) 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
- Check for γγ → VV contributions

Results:

- Consolidate results from primary generator distributions

Extension:

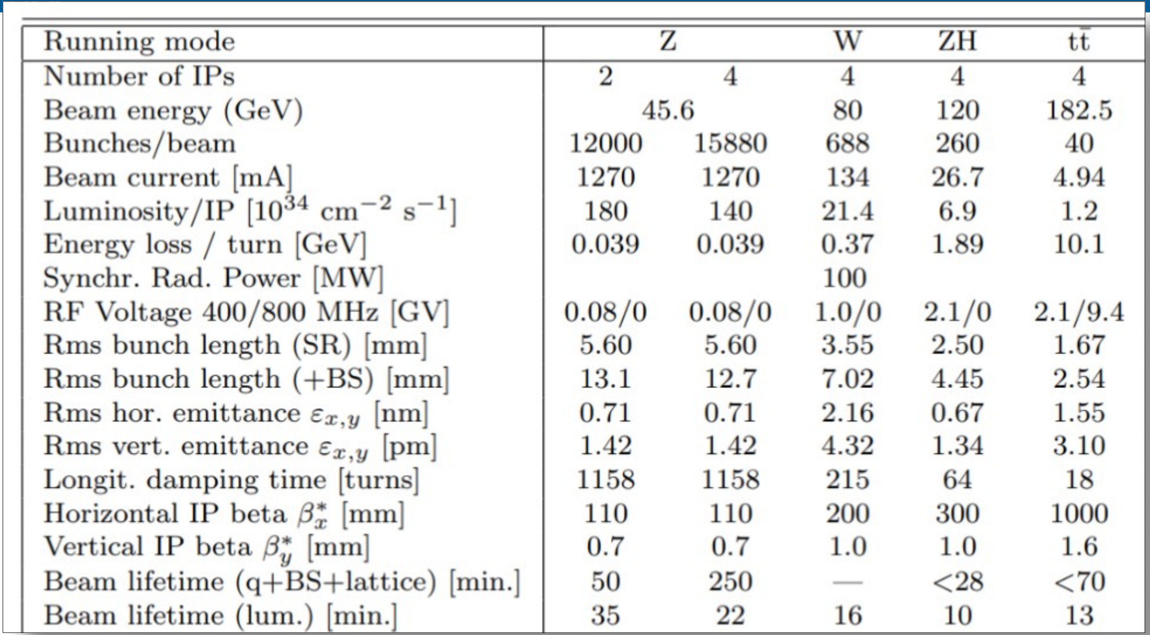
- Extend a similar work to the trackers ?
  Needs logical coordinates ↔ Electronics partition

Expansion:

- Expand the work by applying it to other detectors rather than the ILD.
- Code:
  - Adapt to key4hep framework by changing LCIO to EDM4HEP

Extras

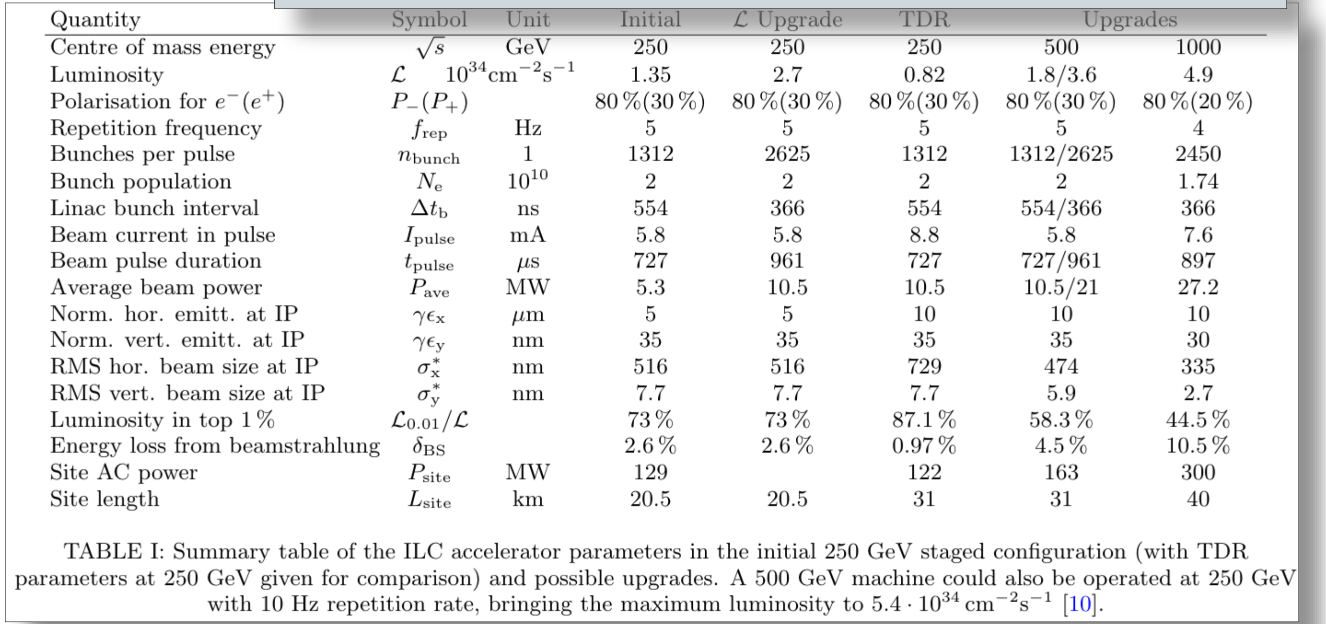
ee Higgs factories: configs & backgrounds



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

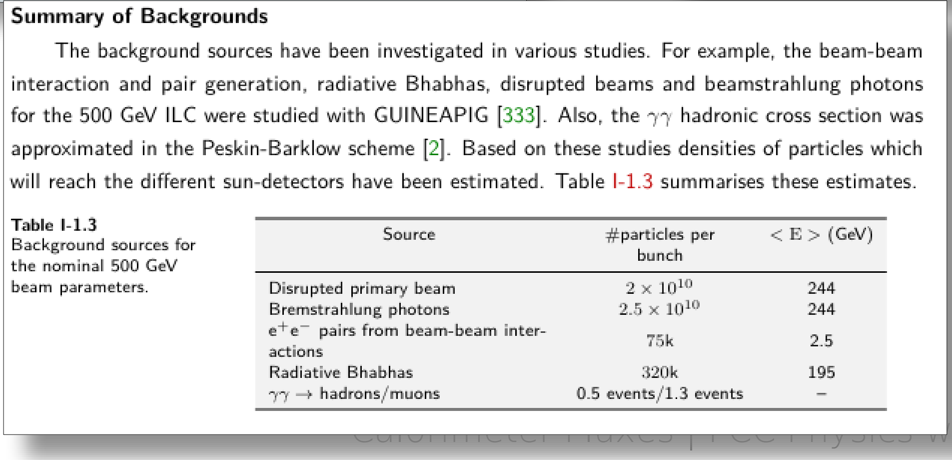
Tor Raubenheimer, FCC Week June 2023

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



Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	TDR	Upgrades	
Centre of mass energy	$\sqrt{s}$	GeV	250	250	250	500	1000
Luminosity	$\mathcal{L}$	$10^{34}\text{cm}^{-2}\text{s}^{-1}$	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	$\gamma\epsilon_{\text{x}}$	μm	5	5	10	10	10
Norm. vert. emitt. at IP	$\gamma\epsilon_{\text{y}}$	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].



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	$< \text{E} >$ (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: Detect
arXiv:1306.6329 [Physics]. (2013)

Vincent.Boudry@in2p3.fr

Machine backgrounds

Files produced by Andrea Carma 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.
```

Vincent.Boudry@in2p3.fr