Towards an
Estimation of the fluxes in highly granular calorimeters

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ÉCOLE POLYTECHNIQUE

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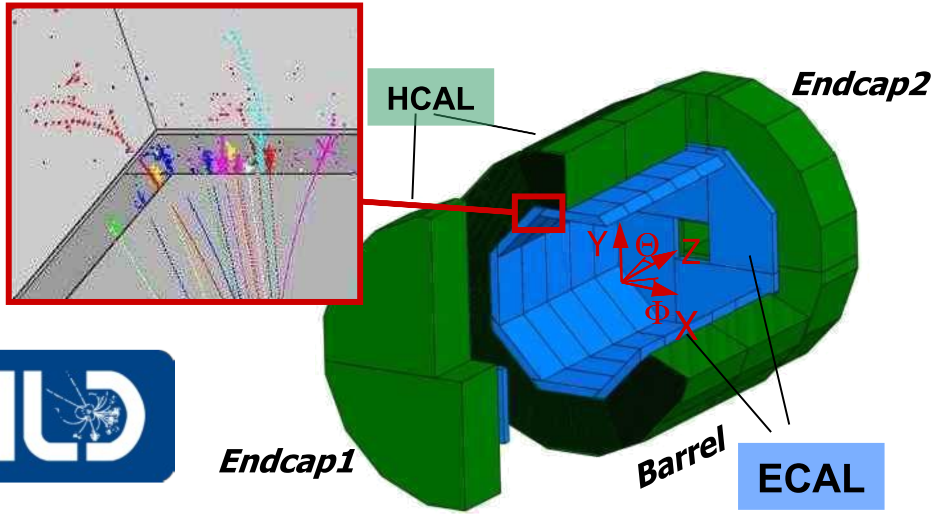
cnrs IN2P3 Les deux infinis

Rationale

ILD high granularity calorimeters

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



ECAL: 30 layers

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

10–100M channels

HCAL: 48 layers

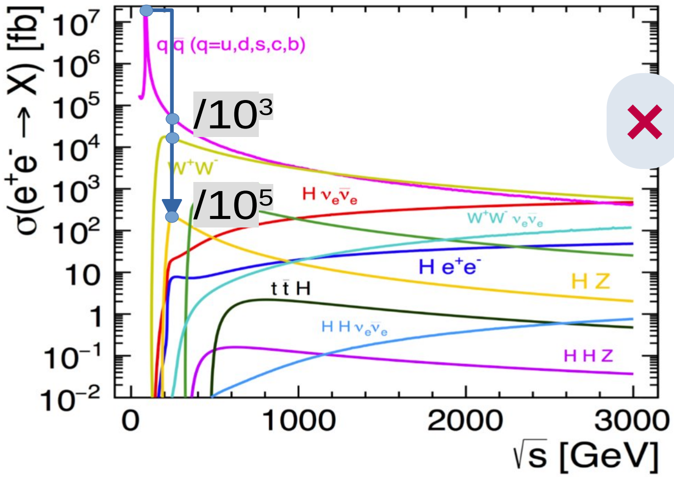
- AHCAL: 3×3 cm³ scint. cells
- ScECAL: 1×1 cm² RPC cells

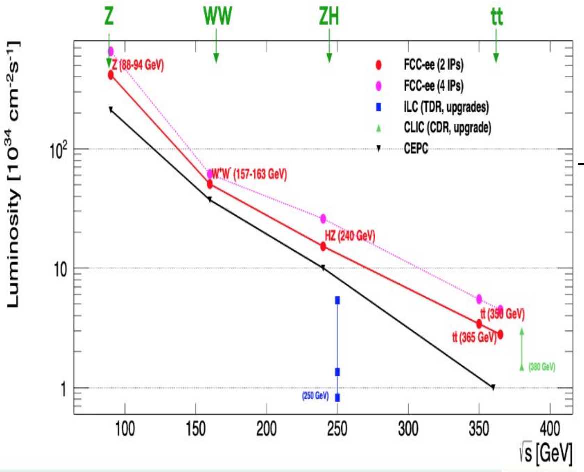
10–70M channels

Revisiting the HG calorimeters for ee-Colliders

Large panel of running conditions

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





Are the current hypothesis viable ?

- Occupancy,
  DAQ,
  Cooling
- 1 detector fit-all ?
  - What are the limits :
    - power vs Granularity vs active cooling ?
- New electronics (DRD6):
  - TSMC 130 nm vs AMS 130 nm (or 65nm)
  - Running mode (continuous, trigger-less)
    - Trigger for other detectors ?

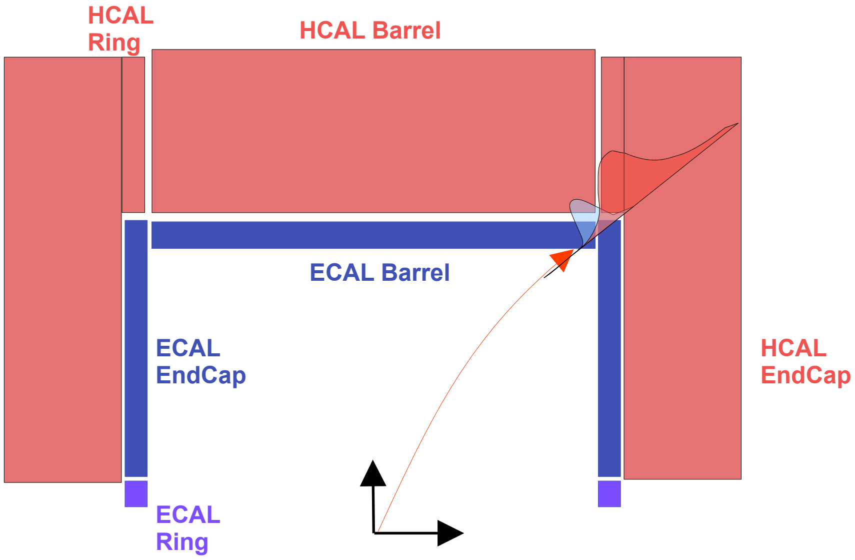
Calorimeter Fluxes from Full Simulations

Quantities useful for self-triggering, low occupancy, Front-End electronics & Design

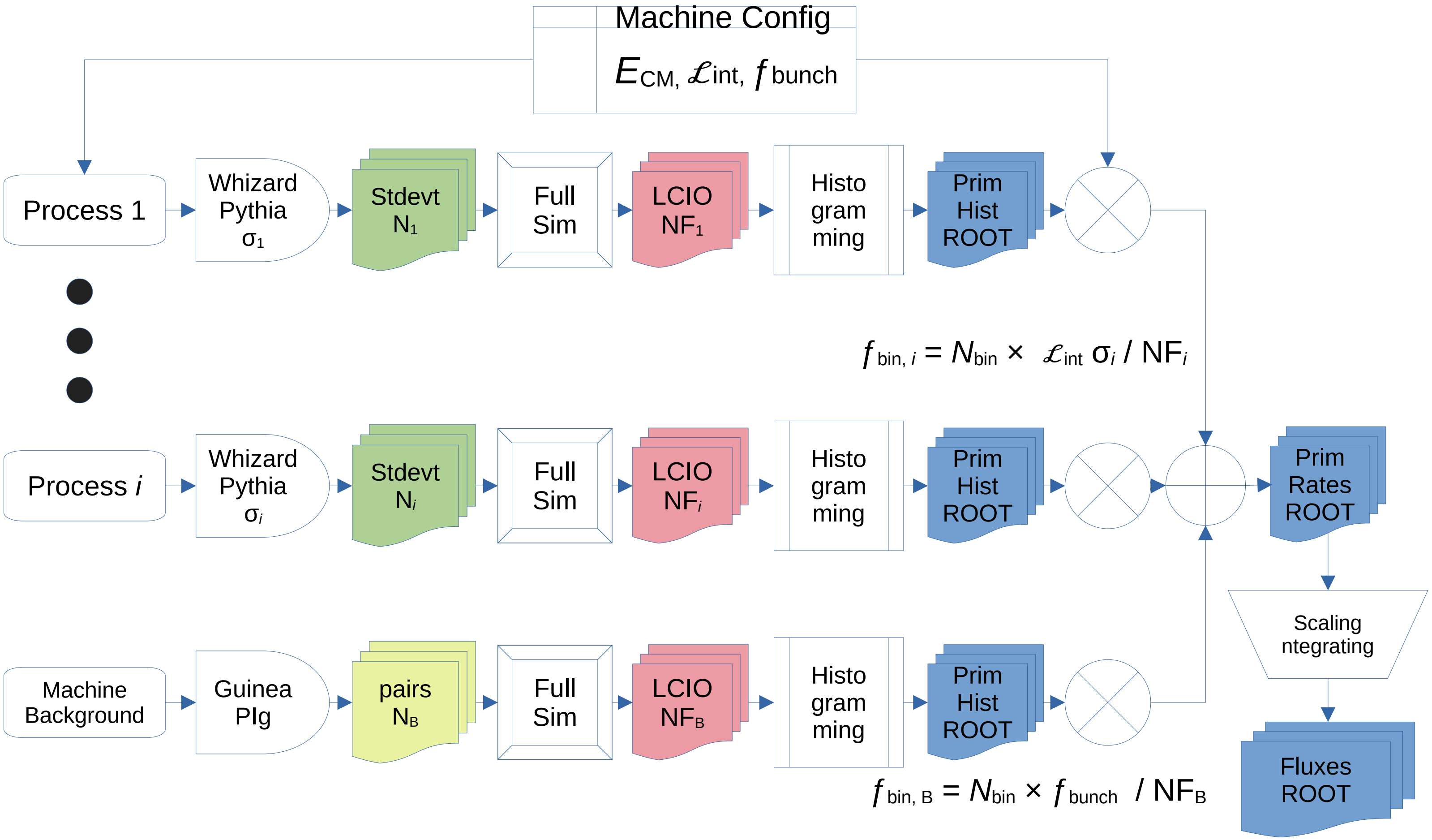
- Number of hits/s per ASICs
  - ➡ Power (Energy per conversion)
  - ➡ Memory size
- Distribution of Energy & Time
  - ➡ Dynamic ranges
  - ➡ Power per conversion (Wilkinson ADCs)
  - ➡ Double hits
- Data output
  - ➡ Data Flux per readout partition (DAQ)
    - ➡ DAQ scheme (Calo trigger to other parts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

Other quantities

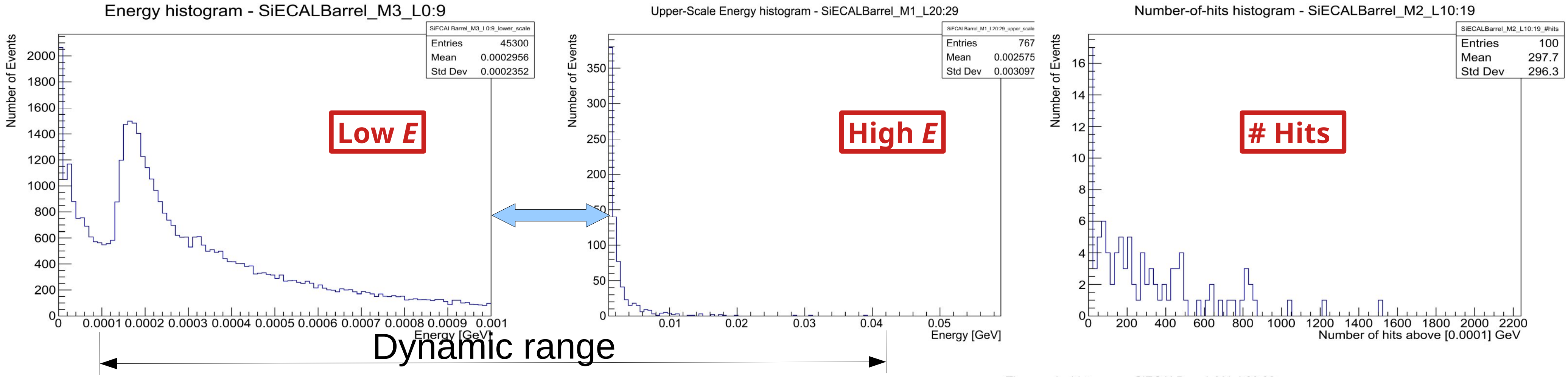
- Deposited energies
  - ➡ Radiation

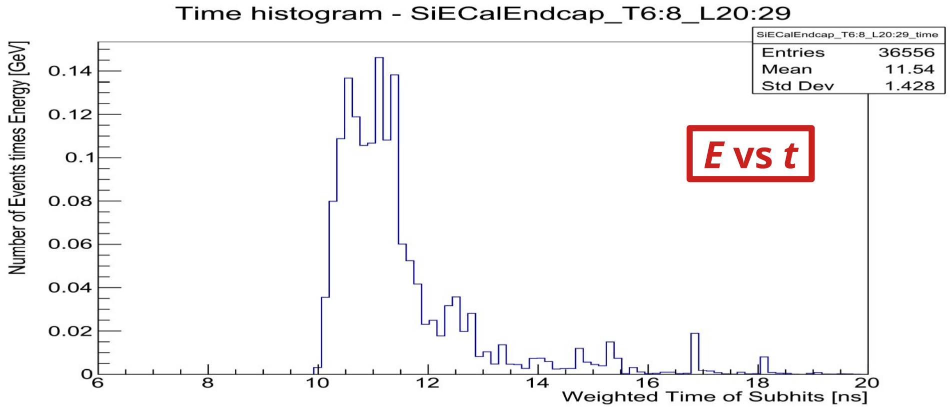


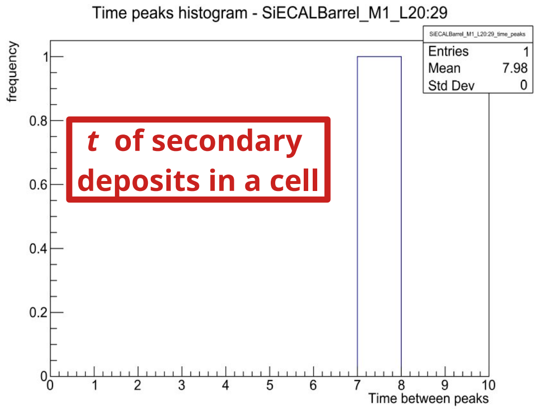
Processes to Fluxes



Primary histograms: per cell distributions



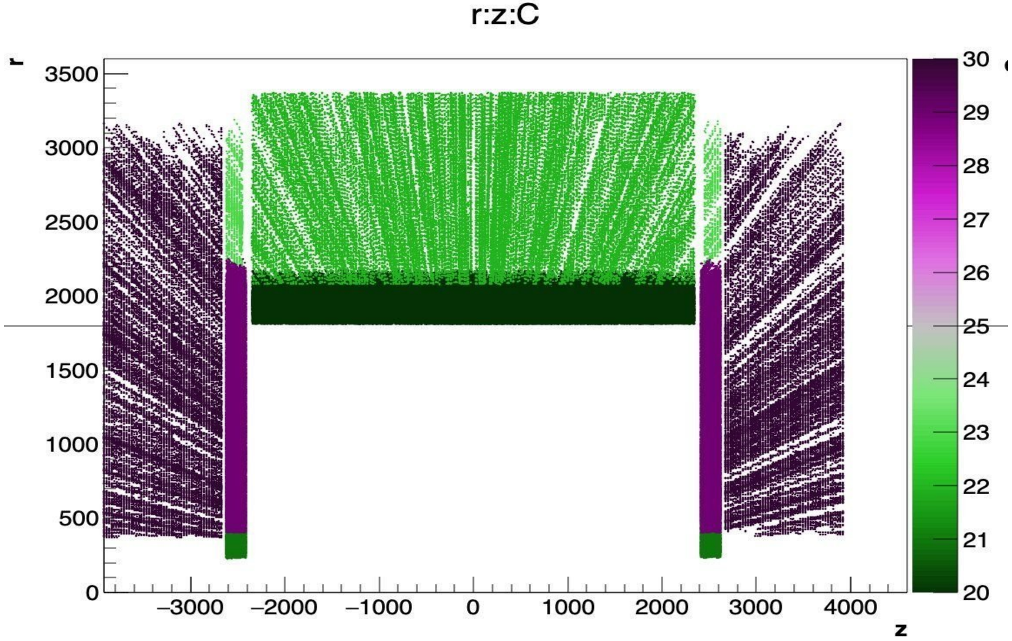




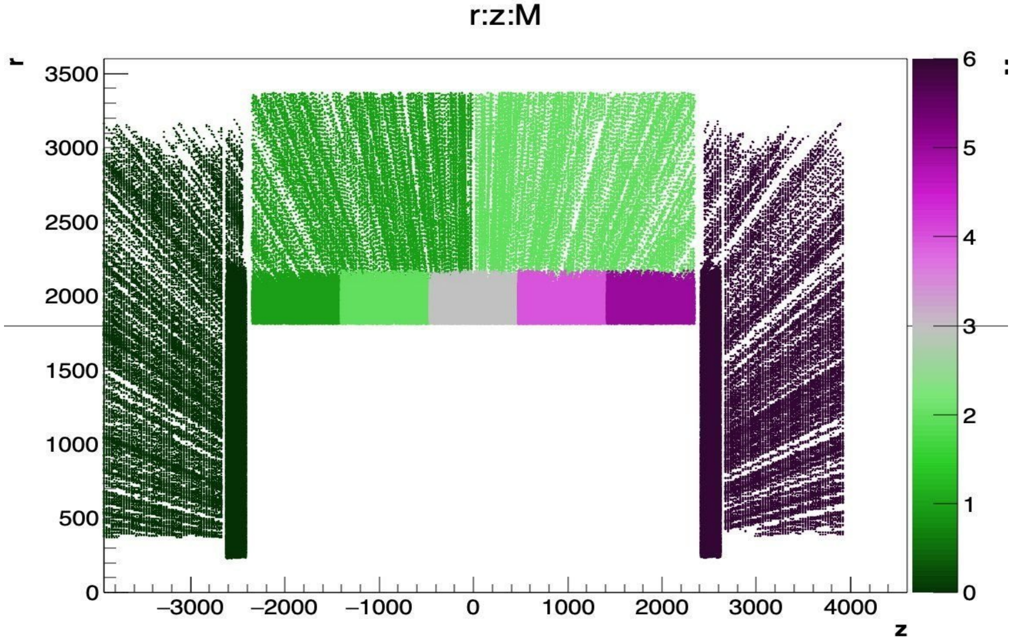
100 events
qqH @ 240 GeV

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

Calorimeters systems C



Calorimeters Modules



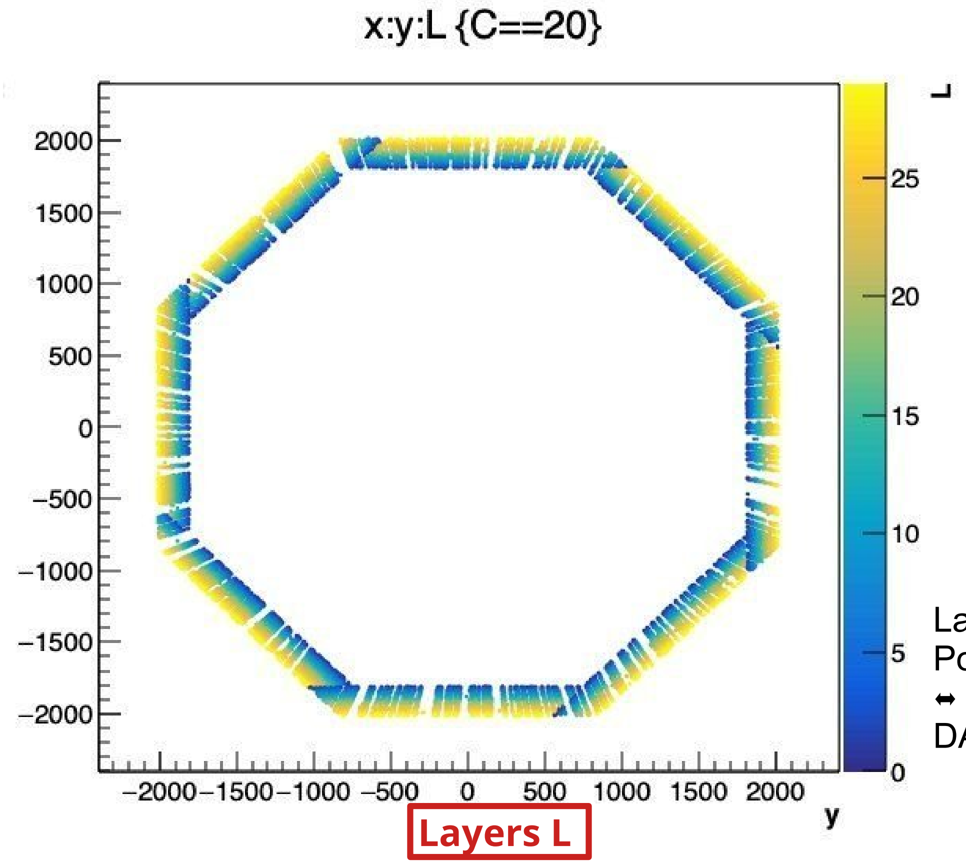
Useful segmentation & grouping:

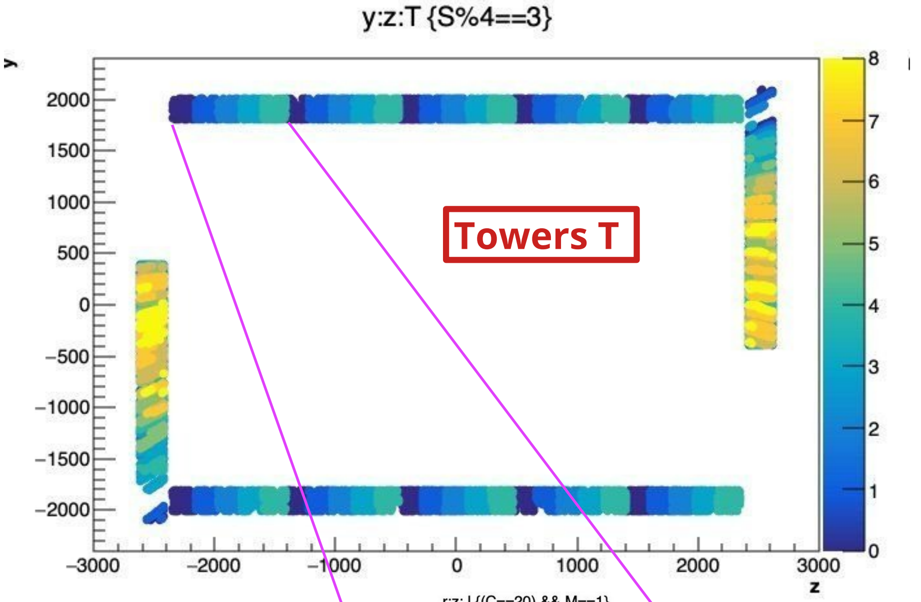
- Physics: Group of uniform (rates) regions (~cosθ)
- Technical: Readout & Cooling Partition (ASIC, SLAB, Tower, Module)

Useless individuation:

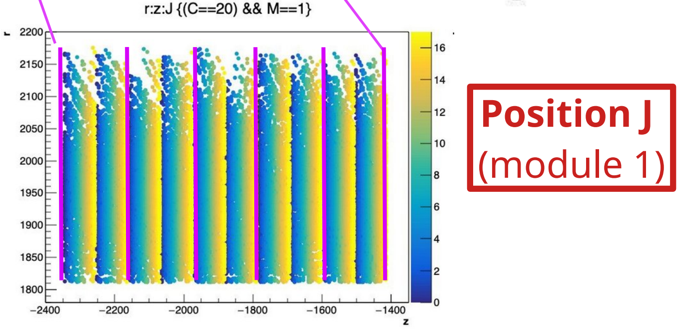
- (Individual layers)
- Symmetrical : staves (φ), Forward–Backward (±θ)

Logical Geometry (ECAL)

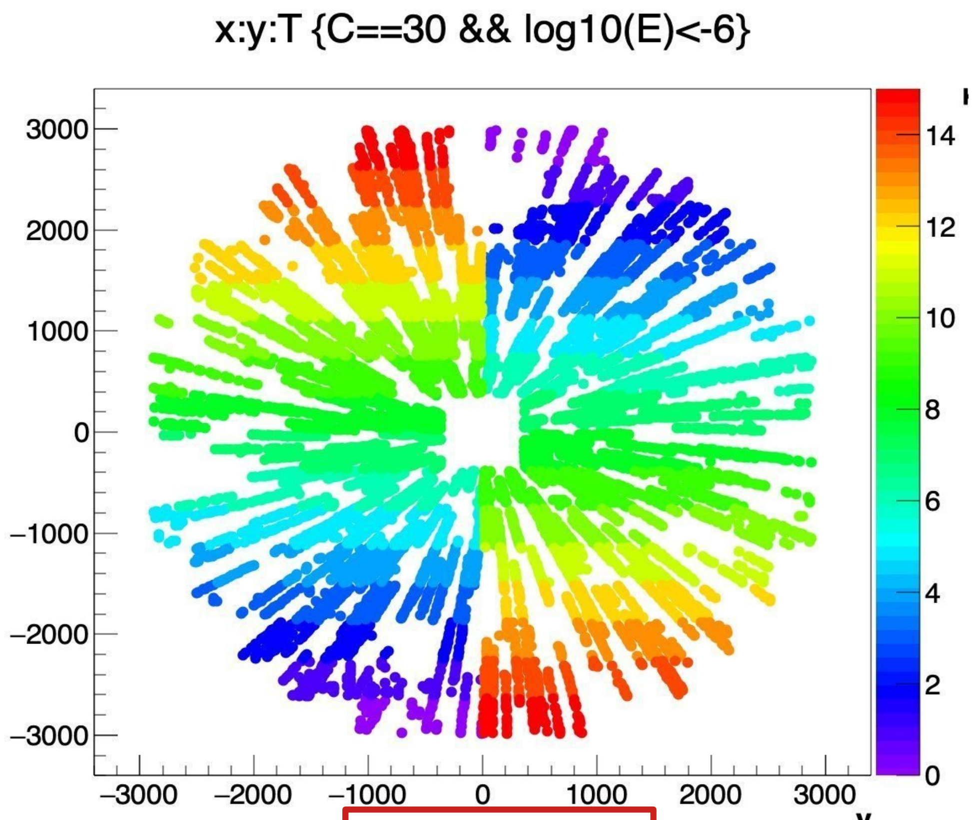




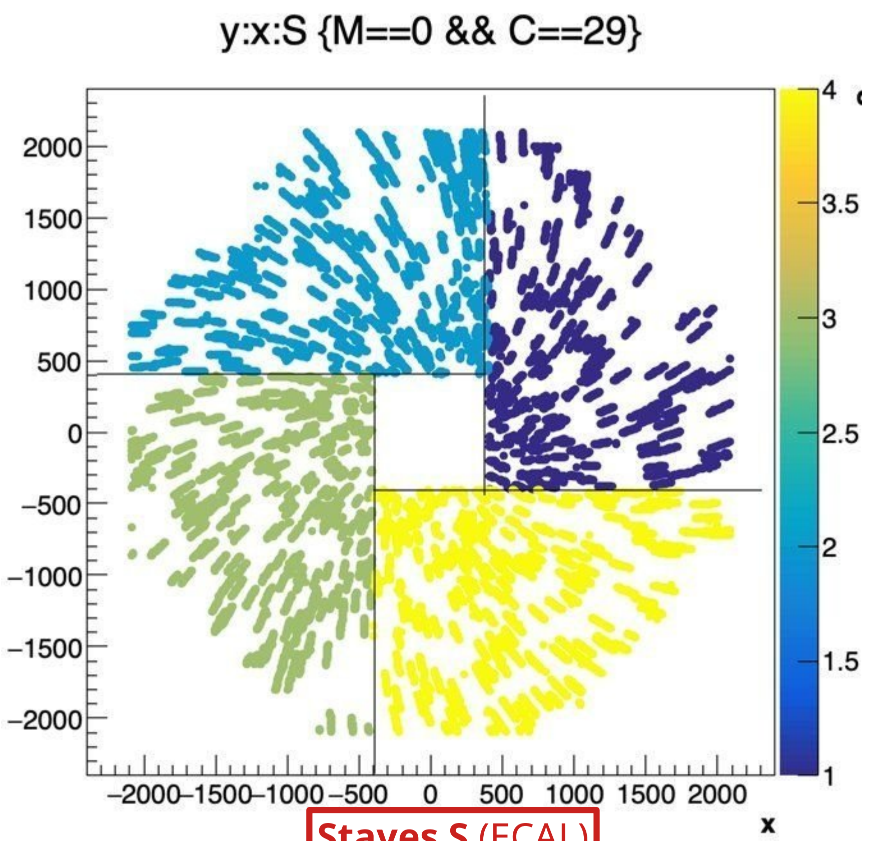
Layers ⊕ Towers ⊕ Positions
↔ services geometry : DAQ and cooling



Logical Geometry : towers & staves

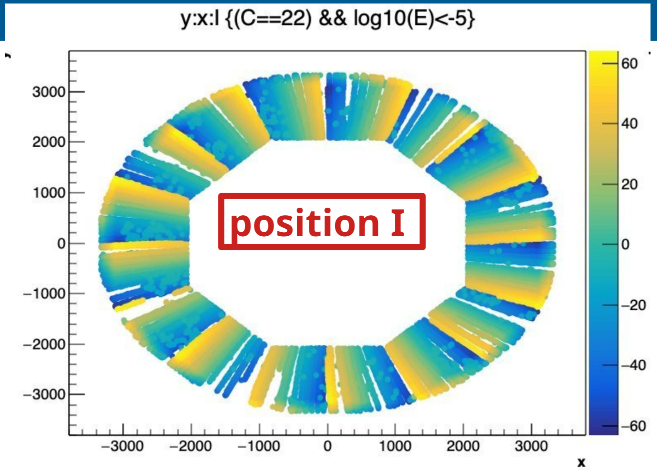


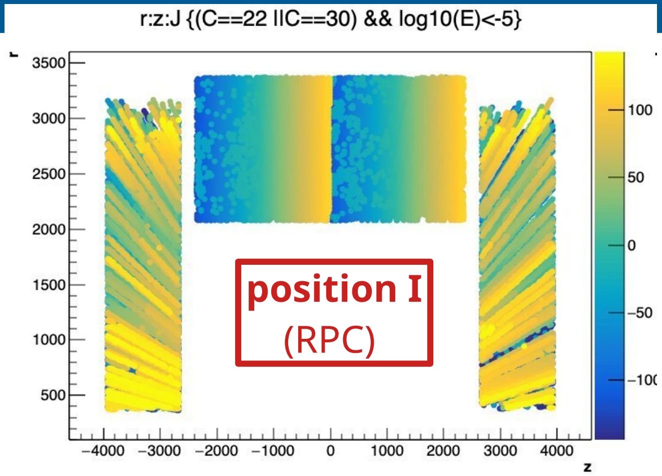
Towers T (HCAL)

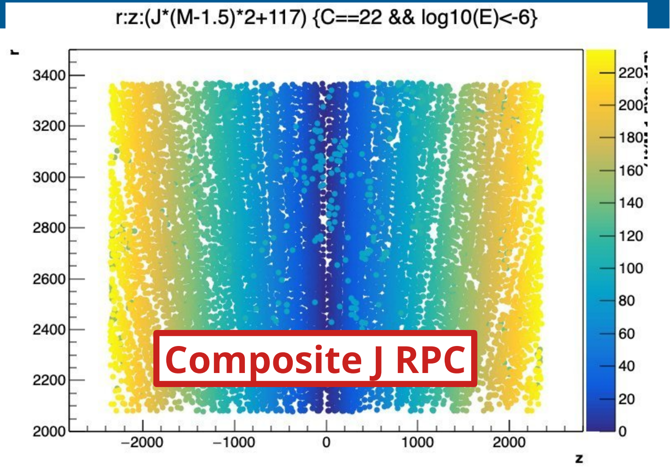


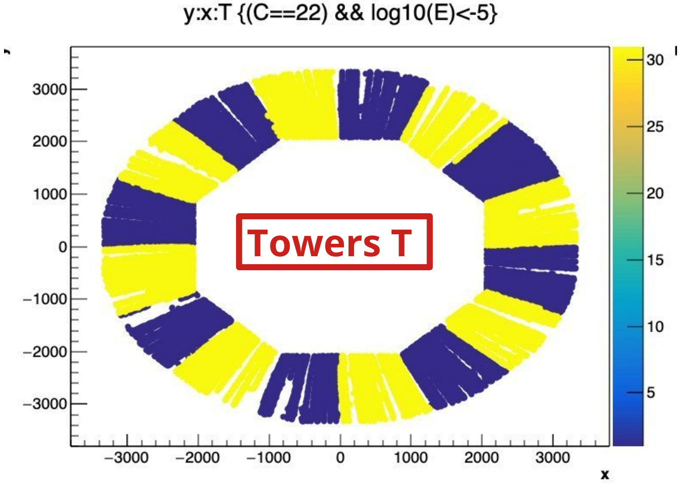
Staves S (ECAL)

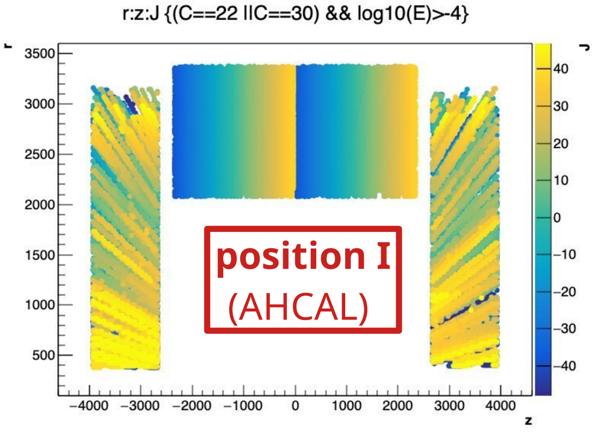
Logical Geometry (HCAL BARRELs)

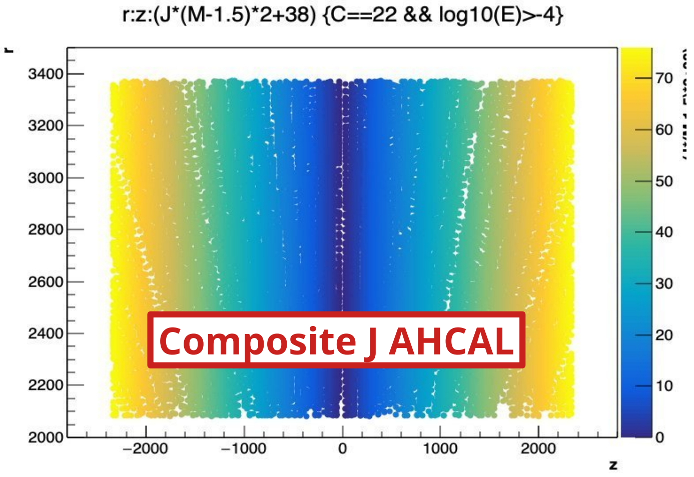




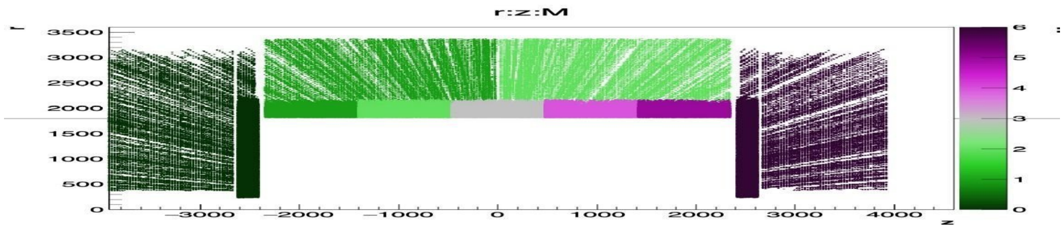


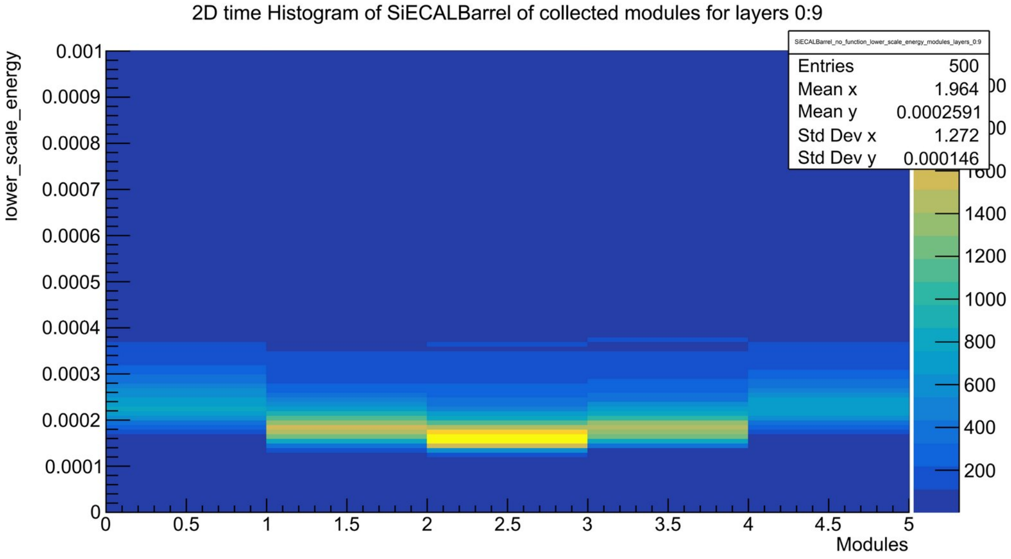




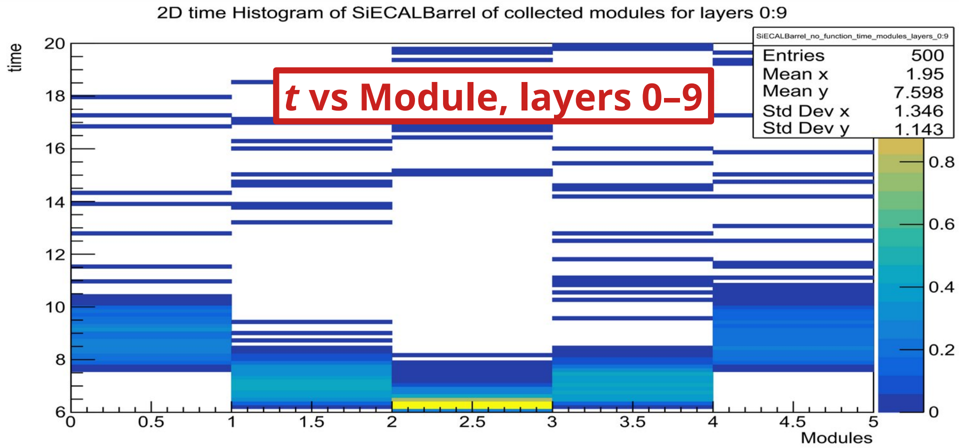


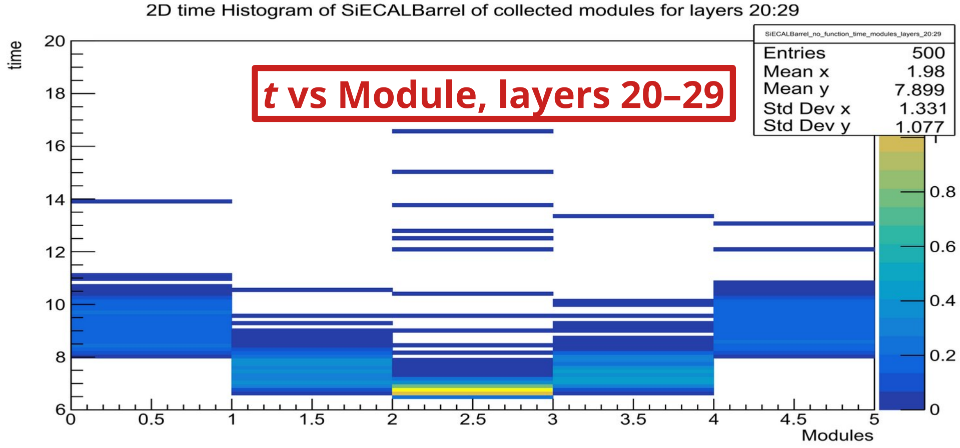
Cross-check : muons



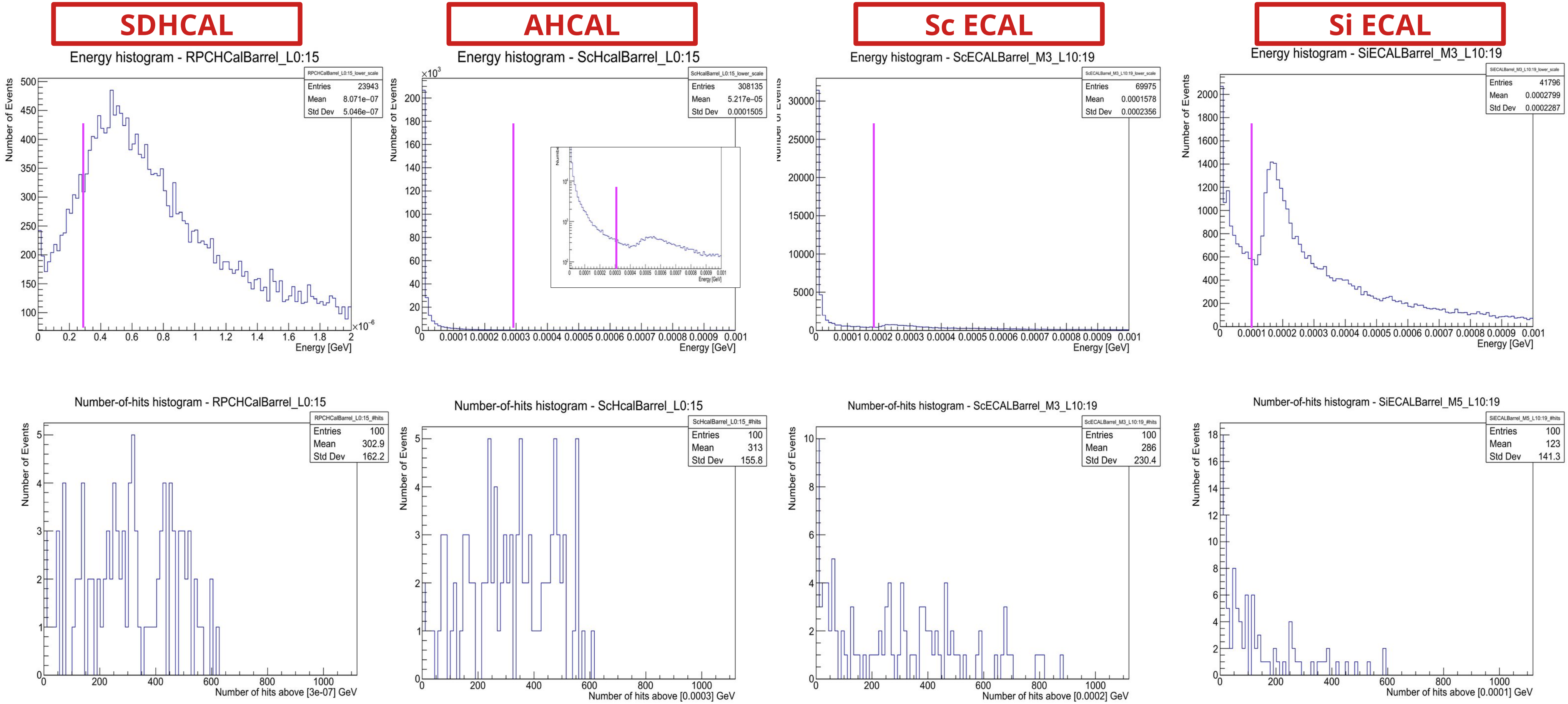


Low *E* vs Module



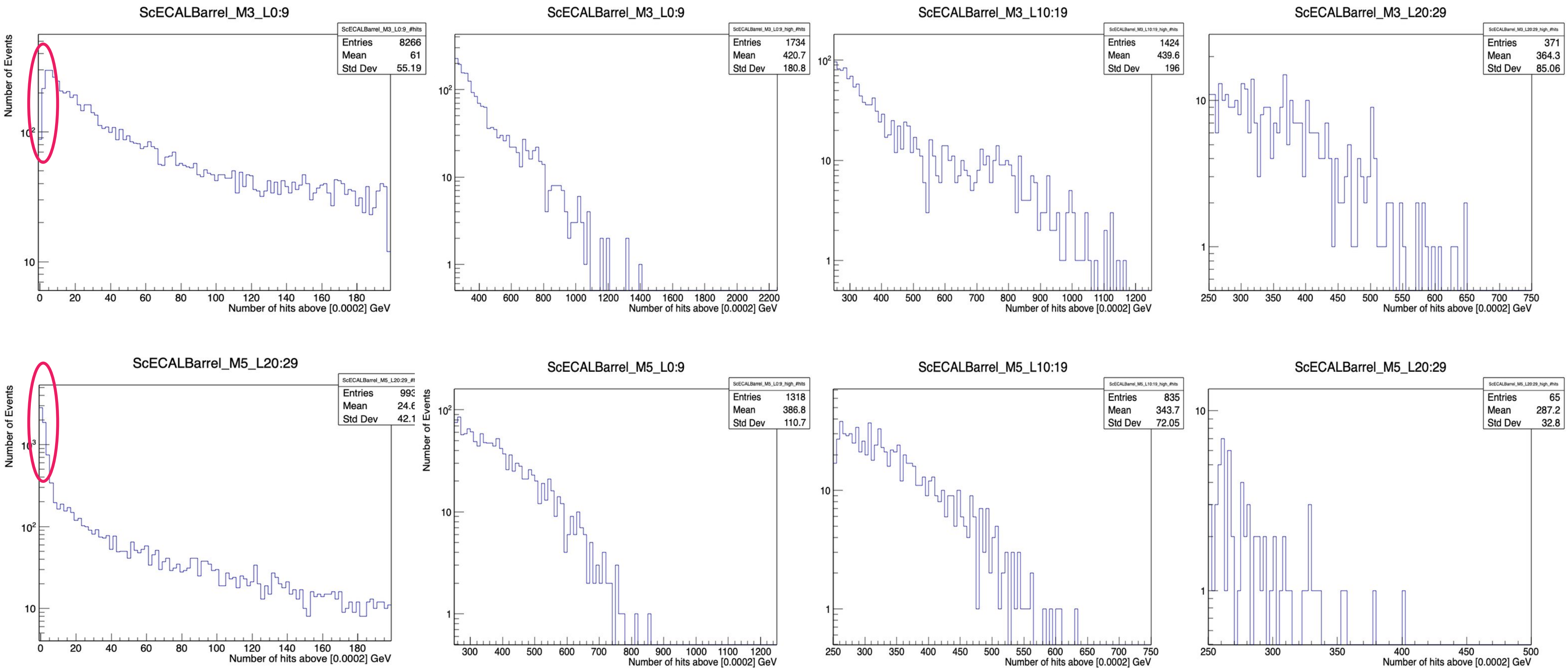


System low energy & #hit responses
raw energies (no digitization)

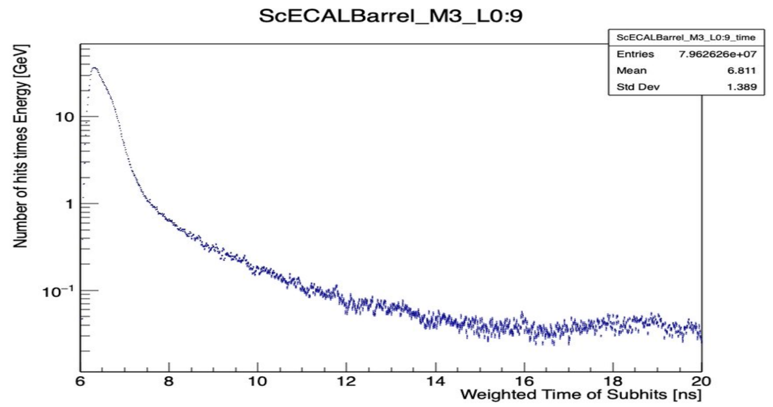


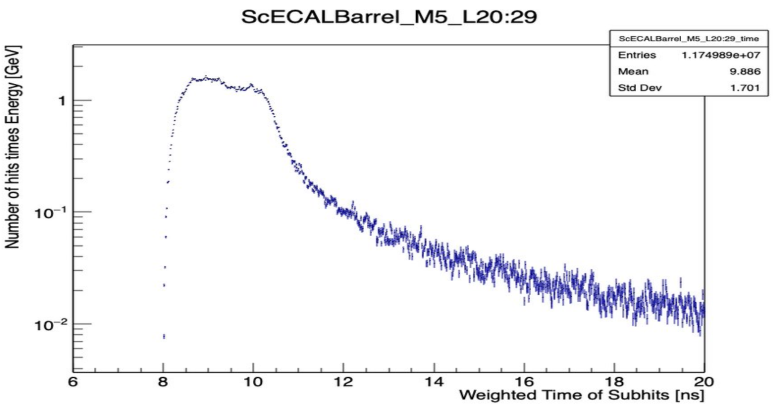
Histograms of qq161: Nhits M3 L0:9 and M5 L20-29

⚠ **Beware of automatic rescaling** ⚠



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



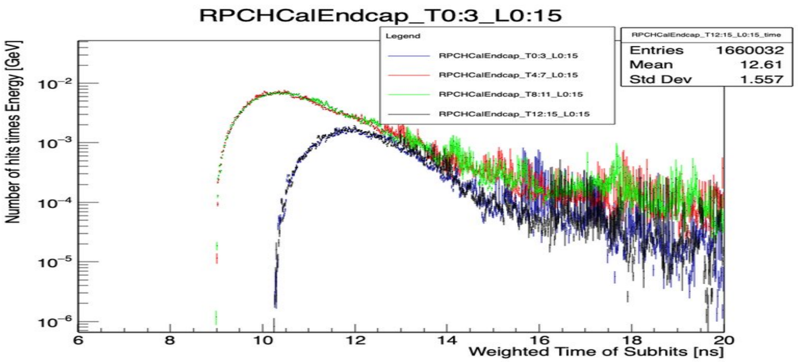


Time distributions have

- very sharp edges ↔ ToF
- 2 second bump ↔ shower time distribition
- 1 or 2 exponential tails

Statistics :

- 10 000 evts are plenty enough for most processes



Code
K. Hassouna

Python code

Production of Primary histograms

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

Secondary histograms

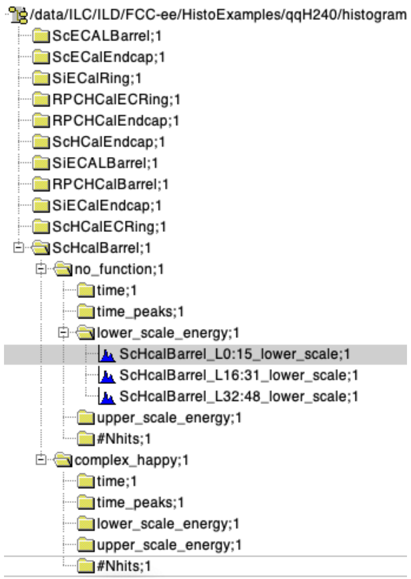
- Scaling : e.g. power, datasize = f(#hits, Energy)
- 2D histograms

Summing-up of processes & background

- from table

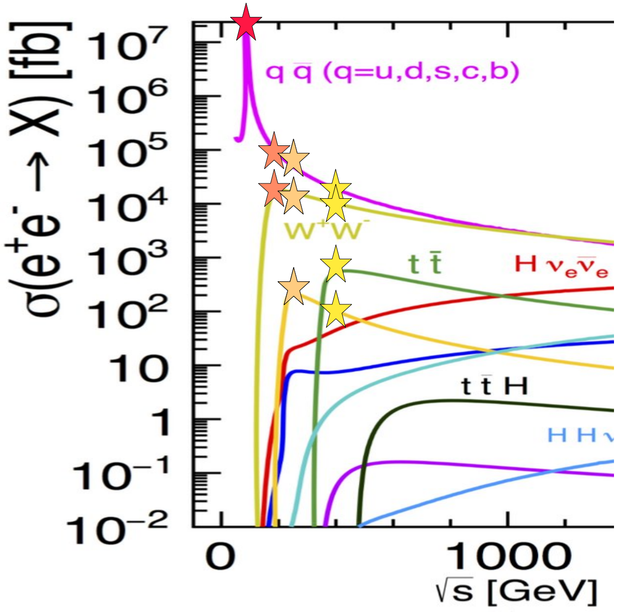
```
system_limits = {"ECALBarrel" : (8, 5, 5, 30) , "EndCaps" : (4, "0-6", 5, 30)}
#selection format "S:M:T:L" conditions => "*:*:2:0-4,5-10" means no selection on M, S, 1 histo per 2 tower , 1 for layer 0 to 5, and one for l
#The keys of the dictionary are the system names. Each key has a value composed 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]], {})
```



Processes & Configurations

- **Order of magnitude → Statistics ?**
- **Mininum bias**
- **Leading processes (at all angles)**
- **Worse case (scans)**



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 → $t\bar{t}$

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

ILD simulation

ILD_l5_v02 with crossing angle = 14mrad.

on going...

Process	91 GeV	162 GeV	240 GeV	365 GeV
	Gen/Sim/Hist	Gen/Sim/Hist	Gen/Sim/Hist	Gen/Sim/Hist
Machine background [1]	100 BX/NA/NA	NA	NA	100 BX/NA/NA
ee ➞ eeγ	NA	NA	NA	NA
ee ➞ eeγγ (γ ➞ V)	NA	NA	NA	NA
ee ➞ ee, Mee < 30 (bhabha)	10k/10k/NA	10k/10k/NA	10k/10k/NA	10/k/2.4k/NA
ee ➞ ee, 150> Mee > 30	10k/10k/NA	10k/10k/NA	10k/4414/NA	10k/1745/NA
ee ➞ (Z/Gamma*) ➞ qq	10k/7018/NA	10k/10k/NA	10k/10k/NA	10k/9847/NA
ee ➞ (Z/Gamma*) ➞ ℓℓ (ττ, μμ)	10k/10k/NA	10k/9583/NA	10k/9678/NA	10k/9999/NA
ee ➞ WW (➞ qqqq, qqℓℓ, ℓℓℓℓ)		10k/9934/NA	10k/10k/NA	10k/9999/NA
ee ➞ ZH ➞ qqH			10k/10k/NA	
ee ➞ tt				10k/9999/NA

[1] Incoherent pair production from Andrea Ciarma; 13/12/2022, same data as D. Jeans

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)

Status & Perspectives

Simulation:

- Simulate backgrounds in ILD at 90 and 160 GeV
- Include digitization (esp. RPCs)
- Check differences ILD vs ILD' for calos on key process
  (influence of trackers)

Histograms

- Produce the primary histograms (on-going)
- Sum to get first estimations of rates & errors

Checks:

- Check the statistics vs angular distribution
  for processes
  - Rate from single particles × population ("fast sim")

Instrumentation:

- Feed in realistic electronics numbers
  - ➡ secondary histogramss : Power, bits per hit
- Test electronics hypothesis
  - ADC types, cell grouping, DAQ, …

Code (later)

- Adapt to key4hep
  - Digitization and Performance
- Make it "generic" for all detector types
  - Trackers, CLD, IDEA, ALLEGRO

Extras

ee Higgs factories: configs & backgrounds

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

Tor Raubenheimer, FCC Week June 2023

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

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

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

Summary of Backgrounds

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

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

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

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

Machine backgrounds

Files produced by Andrea 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.
```