SuperNEMO Collaboration

SuperNEMO Demonstrator Electronics Reference

Version 0.1 (draft)

Abstract

This document aims to describe all the components of the SuperNEMO Demonstrator electronics : addressing scheme, frontend readout and trigger system. It also describes the strategy to exploit the frontend electronics : triggering strategies, design of the data models.

Source (LaTeX) :
`https://nemo.lpc-caen.in2p3.fr/svn/snsw/devel/snelectronics/trunk/doc/SNDER1`
Reference : NemoDocDB-doc-2557

Versions :

- NemoDocDB-doc-2557-v1 : 0.1 (draft)
  - description of the geometry
  - layout of the readout electronics
  - detector zoning
  - readout (partial)

Contents

1 Introduction

note: To be done.

2 Detector geometry

2.1 Frame of reference

The frame of reference of the demonstrator module is shown on figure 1. This frame is also used in the software models of the detector for Monte-Carlo simulations and data analysis [5, 6].

The yOz plane contains the source foils. It splits the detector in two halves. The z axis is vertical.

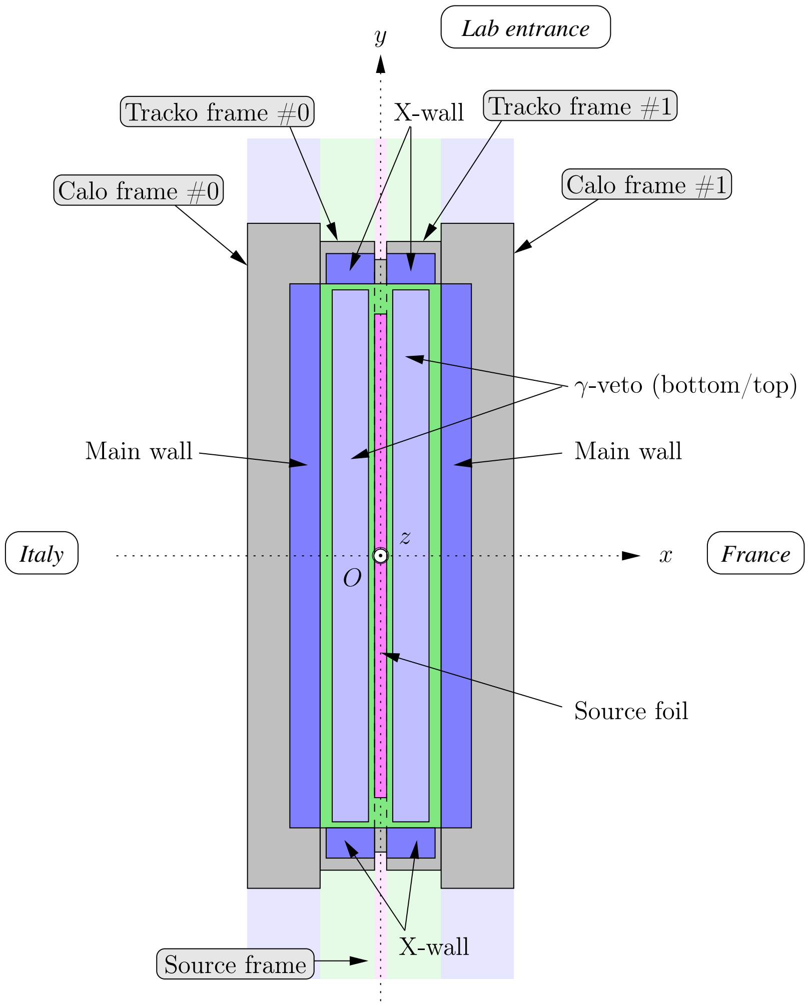

Figure 1: Frame of reference of the SuperNEMO demonstrator module (top $x - y$ view).

2.2 Numbering scheme

2.2.1 IDs and FIDs

We define here the concept of `ID`. An `ID` is a natural number that participates to the unambiguous identification of an element of the detector like :

- a detection unit : Geiger cell, optical module (PMT),
- a readout channel,
- a mechanics element : an anode wire, a cathode ring,
- an electronics device : rack, crate, FPGA or ASIC chip, link.

Due to the hierarchical architecture of most components of the experiment, an unique *full identifier* (`FID`) is assigned to each component of interest. A `FID` is built from an ordered list of *atomic IDs* (`ID`) that reflects the hierarchical relationship between elements.
Examples:

- A given channel in a frontend board (FEB) is associated to an unique `FID=0.0.1.3.10` which reads:
  - `module ID=0`
  - `rack ID=0`
  - `crate ID=1`
  - `board ID=3`
  - `channel ID=10`
- An optical module from the main calorimeter wall is associated to an unique `FID=0.1.5.7` which reads:
  - `module ID=0`
  - `side ID=1` ($x > 0$)
  - `column ID=5`
  - `row ID=7`

Depending on the context, we will use in this document both IDs (relative identifiers with respect to some parent component) and FIDs (absolute identifiers) to identify components of any kind. As we are mainly concerned by the demonstrator module, we will conventionnaly omit the leading `module ID=0` in `FID` identifiers; for example we will use `FID=1.2.3` in place of `FID=0.1.2.3`.

The concept of ID is also used in the SuperNEMO off-line software suite for simulation and data analysis (class `geomtools::geom_id` from the Bayeux library) for which the same numbering scheme is used.

2.2.2 Main calorimeter walls

Each main walls is composed of 20 columns of 13 rows of scintillator+PMT units, for a total of 260 optical modules (figure 2).
A main calorimeter optical module (OM) is identified by :

- the module is labelled with the `module ID=0` which is conventionnaly used for the demonstrator module [minimum encoding: 5 bits],
- each main wall is labelled with the `side ID=0` for $x < 0$ (Italy) and `side ID=1` (France) for $x > 0$ [minimum encoding: 1 bit],
- each column is numbered with the `column ID` ranging from `0` (first $y < 0$ position) to `19` (last $y > 0$ position) [minimum encoding: 5 bits],
- each row is numbered with the `row ID` ranging from `0` (first $z < 0$ position, bottom of the frame) to `12` (last $z > 0$ position, top of the frame) [minimum encoding: 4 bits].

The FID of a main calorimeter optical module is formatted like :

`OM FID=module ID.side ID.column ID.row ID`

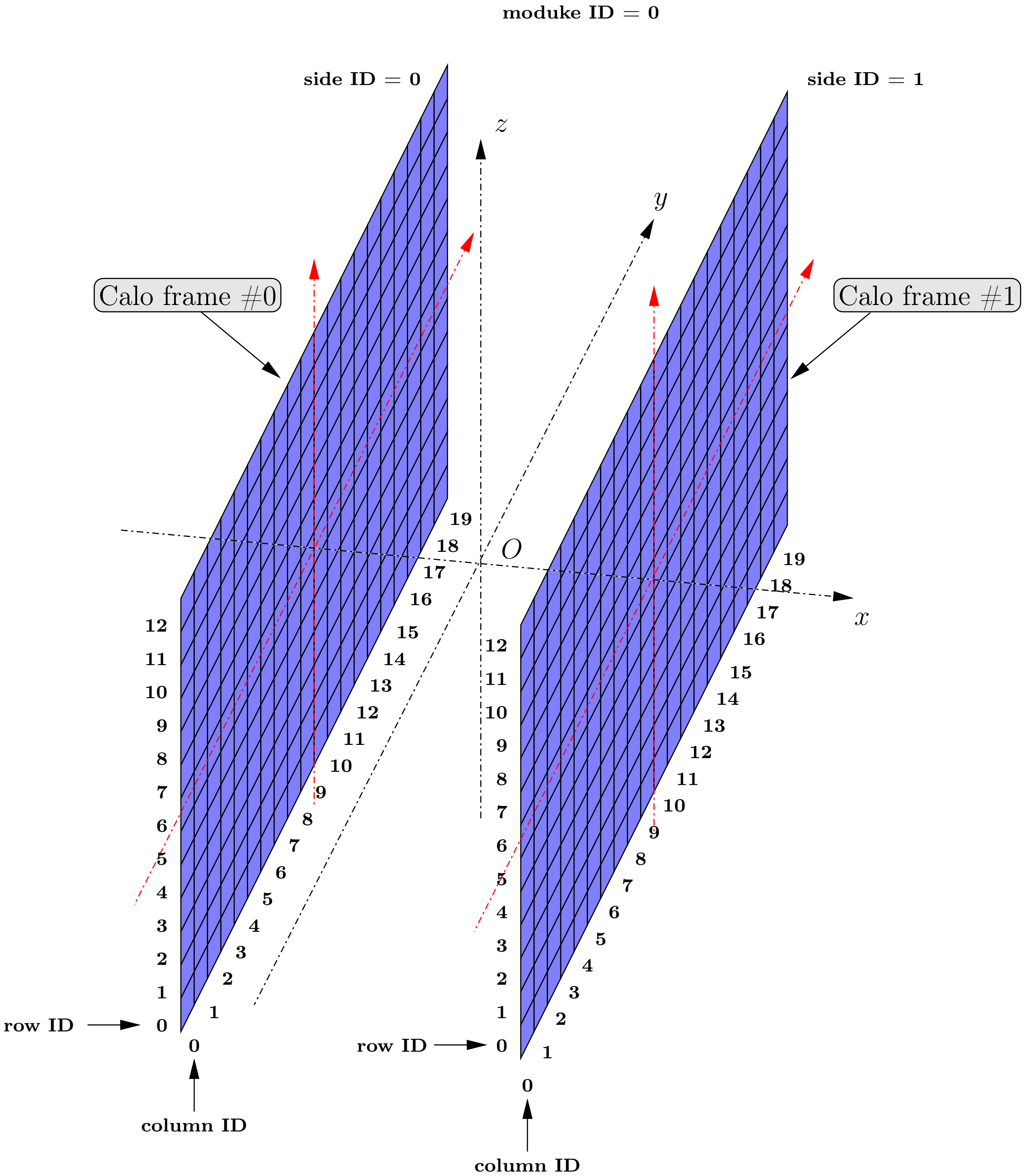

Figure 2: Numbering scheme of the two main walls (side `side ID=0` and side `side ID=1`, 3D view).

2.2.3 Calorimeter X-walls

A tracker frame hosts two X-walls, one with $y < 0$ and the other one with $y > 0$. There are two tracker frames, each lying on one side of the source foil (sides $x < 0$ and $x > 0$). Each X-walls is composed of 2 columns of 16 rows, for a total of 32 optical modules (figure 3).

For the full detector (both sides along the $x'Ox$ axis and walls along the $y'Oy$ axis) there are 128 optical modules.

A X-wall OM is identified by :

- the module is labelled with the `module ID=0` [minimum encoding: 5 bits],
- each X-wall is labelled with the `side ID=0` for $x < 0$ and `side ID=1` for $x > 0$ [minimum encoding: 1 bit],
- each X-wall is labelled with the `wall ID=0` for $y < 0$ and `wall ID=1` for $y > 0$ [minimum encoding: 1 bit],
- each X-wall column is numbered with the `column ID` ranging from `0` (minimal $|x|$ position, near foil) to `1` (maximal $|x|$ position, near the main calorimeter wall) [minimum encoding: 1 bit],
- each X-wall row is numbered with the `row ID` ranging from `0` (first $z < 0$ position) to `15` (last $z > 0$ position) [minimum encoding: 4 bits].

The FID of X-wall OM is formatted like :

`OM FID=module ID.side ID.wall ID.column ID.row ID`

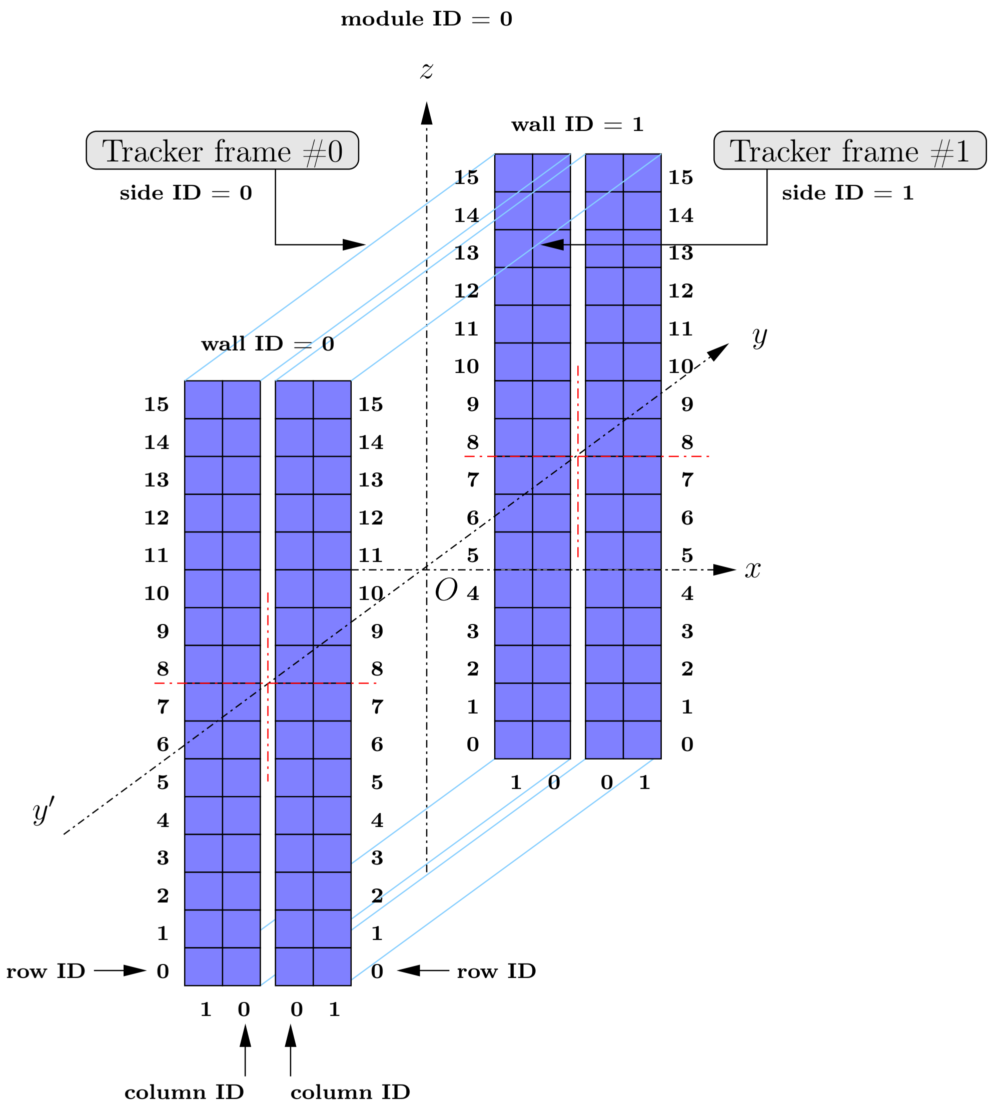

Figure 3: Numbering scheme of X-walls (3D view).

2.2.4 Gamma veto

A tracker frame hosts two gamma veto devices, one with $z < 0$ (bottom) and the other one with $z > 0$ (top). There are two tracker frames, each lying on one side of the source foil (sides $x < 0$ and $x > 0$). Each gamma veto is composed of 16 optical modules (figure 4).

For the full detector (both sides along the $x'Ox$ axis and walls along the $z'Oz$ axis) there are 64 optical modules.

A gamma veto OM is identified by :

- the module is labelled with the `module ID=0` [minimum encoding: 5 bits],
- its `side ID=0` for $x < 0$ and `1` for $x > 0$ [minimum encoding: 1 bit],
- its `wall ID=0` for $z < 0$ and `1` for $z > 0$ [minimum encoding: 1 bit],
- its `column ID` ranging from 0 (minimal $y < 0$ position) to `15` (maximal $y > 0$ position) [minimum encoding: 4 bit],

The FID of gamma veto OM is formatted like :

`OM FID=module ID.side ID.wall ID.column ID`

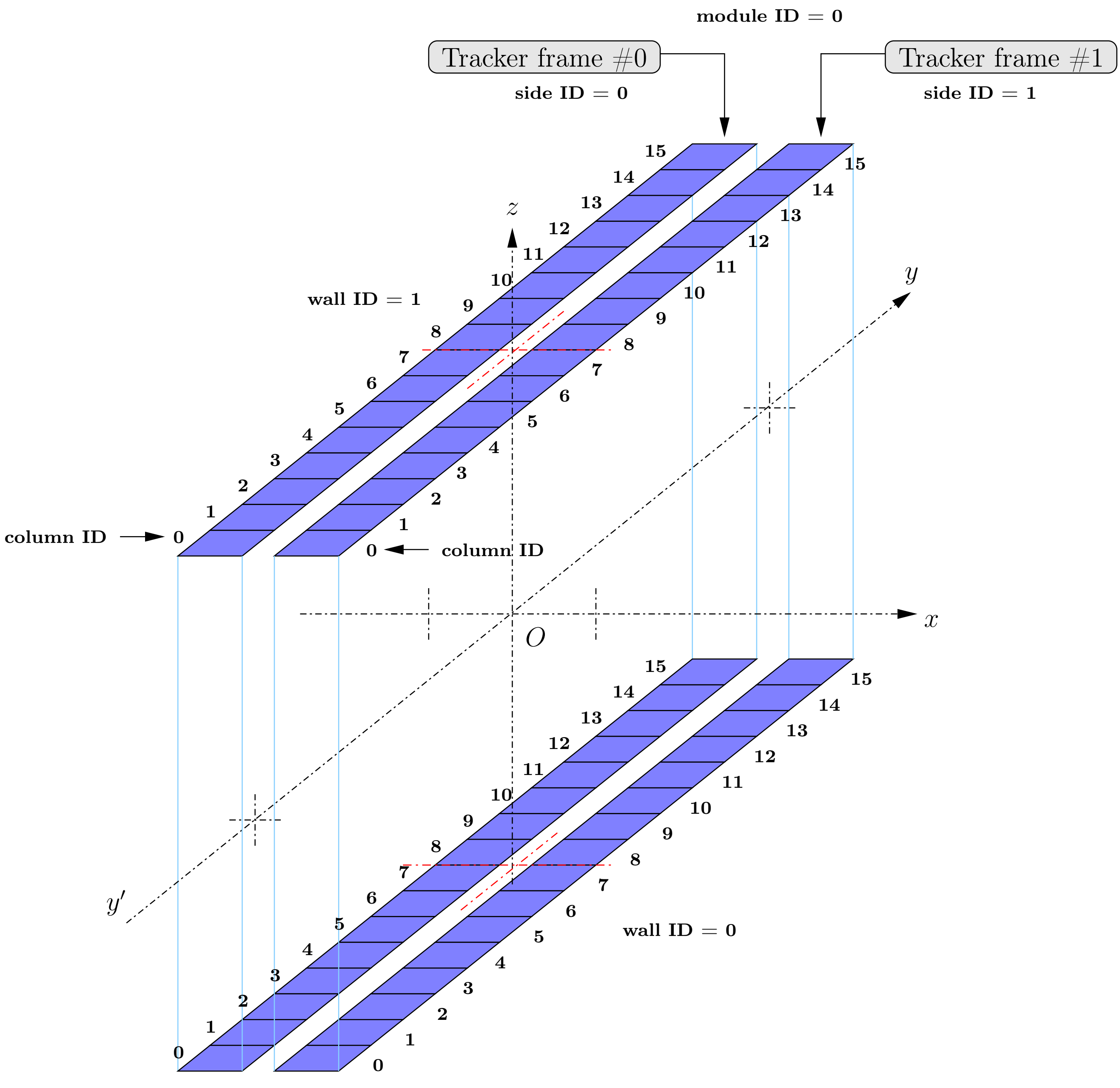

Figure 4: Numbering scheme of gamma veto (3D view).

2.2.5 Geiger cells

A tracker frame hosts 9 layers of 113 vertical drift cells each. For the full detector (both sides along the $x'Ox$ axis) there are 2034 cells (figure 5).

A drift cell is identified by :

- the module is labelled with the `module ID=0` [minimum encoding: 5 bits],
- its `side ID=0` for $x < 0$ and `1` for $x > 0$ [minimum encoding: 1 bit],
- its `layer ID=0` for minimum $|x|$ (near the source foil) and `8` for maximum $|x|$ (near the main calorimeter wall) [minimum encoding: 4 bits],
- its `row ID` ranging from `0` (minimal $y < 0$ position) to `112` (maximal $y > 0$ position) [minimum encoding: 7 bits],

The FID of Geiger cell is formatted like (associated to the anode readout channel) :

`cell FID=module ID.side ID.layer ID.row ID`

A cathode ring (bus bar) is identified by :

- the `cell ID` of the cell it belongs to (see above) [minimum encoding: 17 bits],
- its `ring ID=0` for $z < 0$ (bottom) and `ring ID=1` for $z > 0$ (top) [minimum encoding: 1 bit],

The FID of Geiger cell's cathode ring is formatted like (associated to a cathode readout channel) :

`cathode ring FID=module ID.side ID.layer ID.row ID.ring ID`

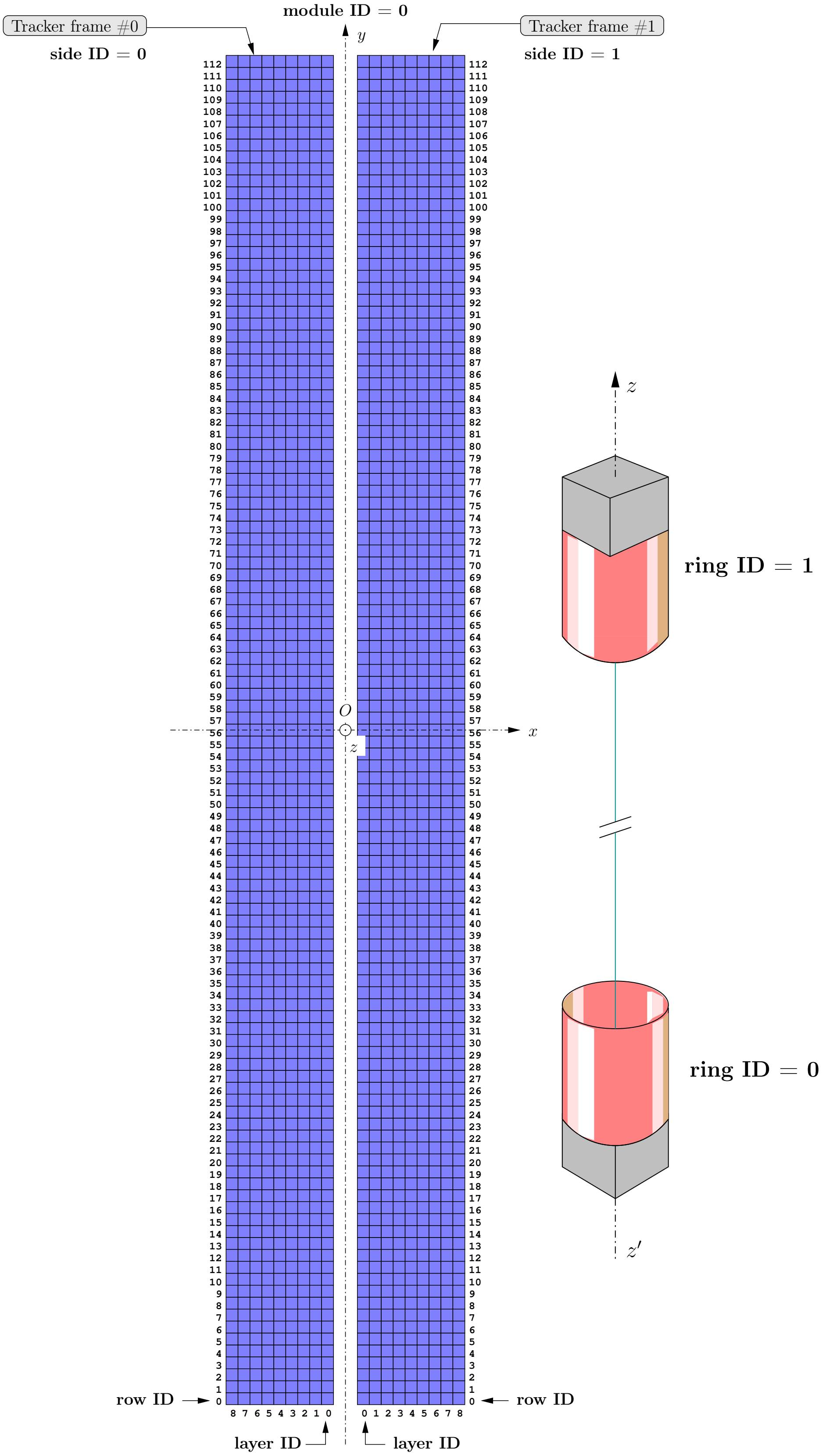

Figure 5: Numbering scheme of drift cells ($x - y$ top view).

3 Layout of the readout electronics

3.1 Racks and crates

The readout system uses 6 VME 6U crates (figure 6 and see [2]) :

- Rack with `rack ID=3` hosts three crates for the readout of the main calorimeter walls, the X-walls and the gamma veto (712 optical module channels) and the trigger board (TB),
- Rack with `rack ID=5` hosts three crates for the readout of the tracking chamber (2034 Geiger anode channels, 4068 Geiger cathode channels).

A crate is thus addressed through :

- its `rack ID` ranging from `0` to `5` [minimum encoding: 3 bit],
- its `crate ID` ranging from `0` to `2` [minimum encoding: 2 bits].

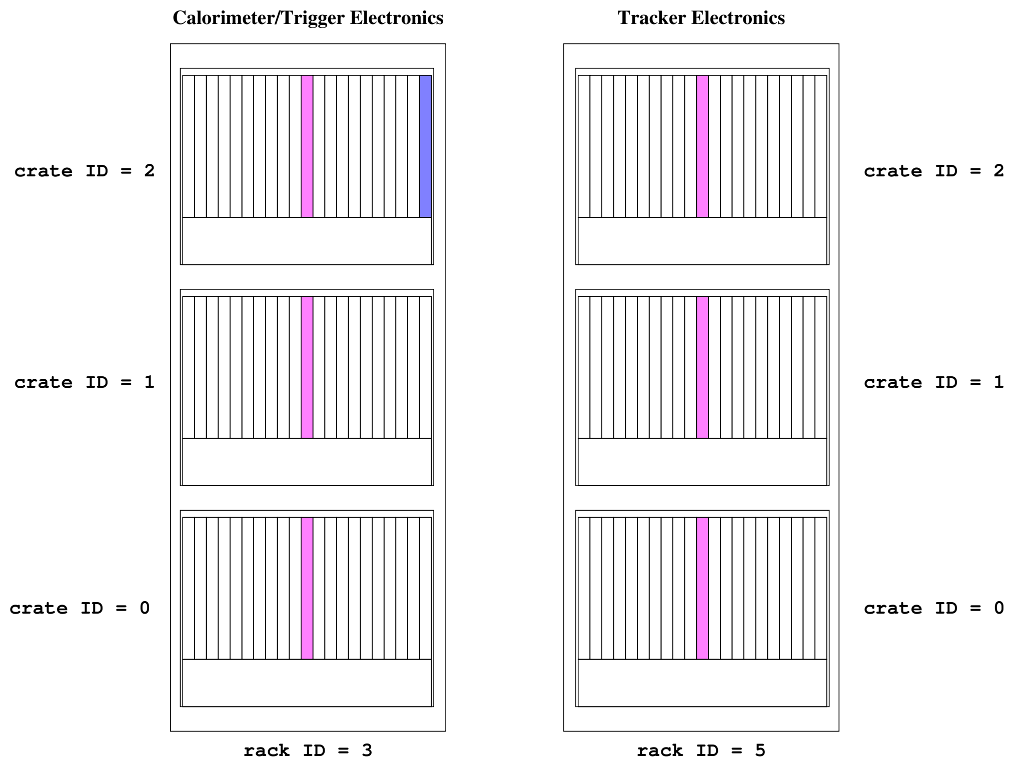

Figure 6: Racks and crates for the readout (front view). Magenta slot are reserved for the so-called *control boards*. The blue slot is reserved for the so-called *trigger board*.

For both parts of the detector readout – optical modules or Geiger cells – each crate hosts one Control Board (CB) and up to 20 Front-end Boards (FEB). The design of the custom back-plane imposes that the CB is plugged in the `slot ID=10` (figure 18, magenta slot, see [3]). The FEBs are thus plugged on both sides of the CB (`slot ID` numbered from `0` to `9` and from `11` to `20`). FEBs are thus numbered from left to right using `FEB ID` from `0` to `9` and from `11` to `20` [minimum encoding: 5 bits] (see table 1).

FEB ID	**VME slot ID**
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
–	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20

Table 1: ID lockup table (mapping) between the FEBs and the VME slots within a crate.

The Trigger Board (TB) is hosted in the `crate FID=0.2` (X-wall, gamma veto). The suggested position in the crate is thed `VME slot ID=20` (figure 6, top left crate, blue slot).

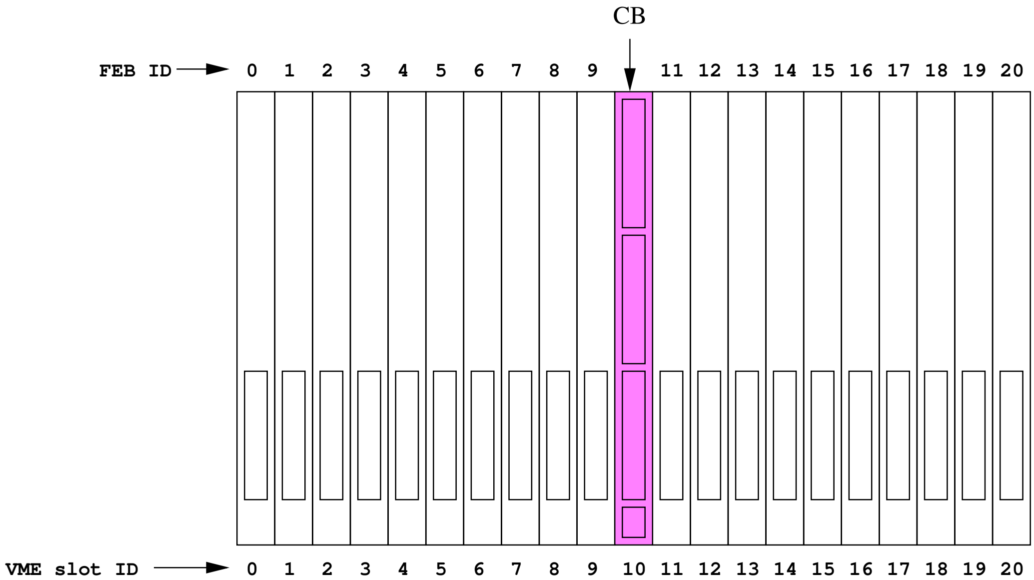

Figure 7: The layout of a crate (front view). The control board (CB) uses the `VME slot ID=10`.

3.2 Optical modules readout (main calorimeter wall, X-wall, gamma veto)

The so-called *SNCaloFEB* front-end board is a 16 channels card that used the principles of the WaveCatcher architecture (see for example [1, 4]). It uses an extended VME 6U format (233×220 mm^2).

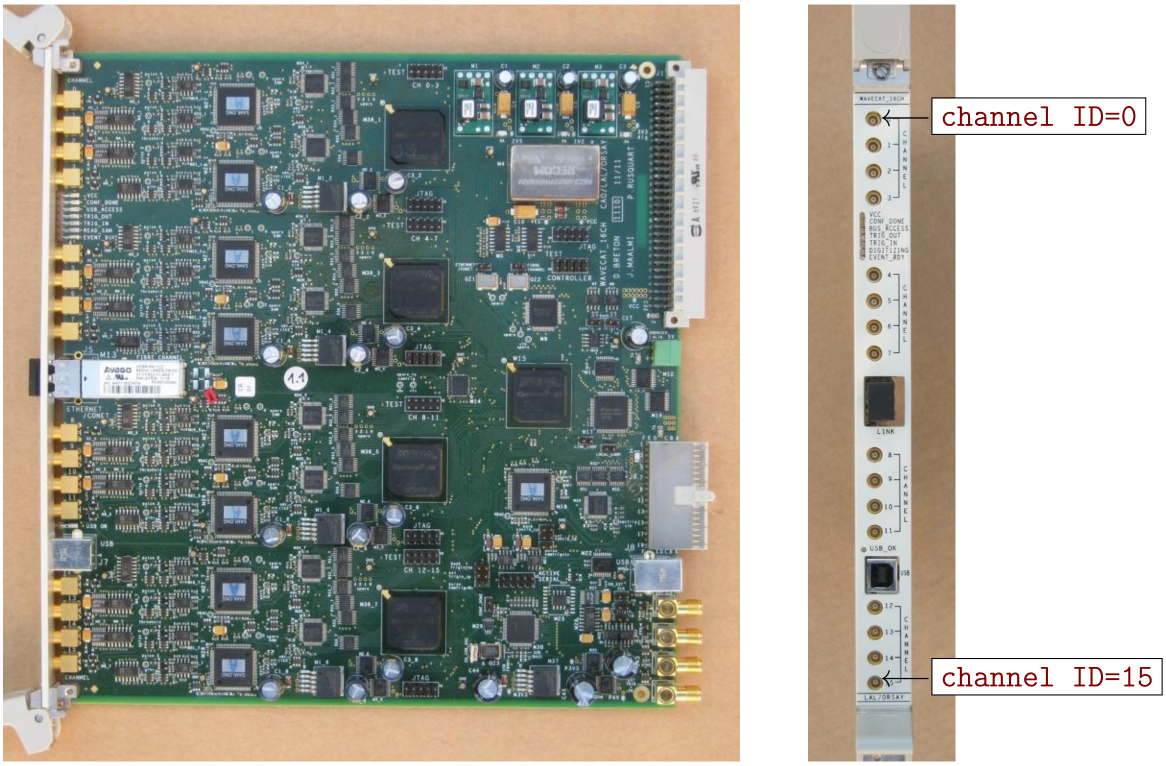

Figure 8: The layout of the *SNCaloFEB* FEB. Left: side view; Right: front panel with 16 inputs numbered from 0 to 15 beginning from the top of the panel (connectors: Lemo [Reference needed]).

The *SNCaloFEB* embeds 8 SAMLONG chips, each addressing 2 channels. There are 4 *Front-end FPGA*, each responsible for two SAMLONG chips (total: 4 channels). A *Control FPGA* manages the overall trigger and data flow, collecting signals from the 4 Front-end FPGAs and transmitting data through a SerDes (18 bits @ 40MHz) and the back-plane.

3.2.1 Distribution of the main calorimeter channels

Each main wall hosting 20 columns of 13 optical modules, it has been decided to use one SNCaloFEB per column in order to preserve the mechanical layout through the triggering scheme. Thus only 13 channels among 16 available are used on a given board.

- The crate with `crate FID=0.0` (with `rack ID=0` and `crate ID=0`) is dedicated to the first main wall (`side ID=0`, $x < 0$, Italy side).
- The crate with `crate FID=0.1` (with `rack ID=0` and `crate ID=1`) is dedicated to the second main wall (`side ID=1`, $x > 0$, France side).

Thus 20 FEBs are hosted in each crate. Table 2 shows the mapping between the FEB ID and the columns ID for any of the crates with `crate FID=0.0` and `crate FID=0.1`.

These numbering technique is compatible with the one used in the simulation and data analysis software for identification of geometrical elements.

`FEB ID`	Main wall `column ID`
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
–	–
11	10
12	11
13	12
14	13
15	14
16	15
17	16
18	17
19	18
20	19

Table 2: ID lockup table (mapping) between the SNCaloFEBs and the main calorimeter columns within a crate (`crate ID=[0,1]`).

Each SNCaloFEB addresses 13 optical modules (PMTs). Table 3 shows the mapping between the FEB's `channel ID` and the optical module's `row ID` for any of the crates with `crate FID=0.0` and `crate FID=0.1`.

FEB's `channel ID`	Main wall `row ID`
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	–
14	–
15	–

Table 3: ID lockup table (mapping) between the SNCaloFEB's channels and the main calorimeter rows within a column (`crate ID=[0,1]` and `column ID=[0-19]`).

3.2.2 Distribution of the X-wall channels

Each column of the X-wall corresponds to 16 optical modules. Thus all channels of a SNCaloFEB are used to address the optical modules from a single X-wall column.

The crate with `crate FID=0.2` (`rack ID=0` and `crate ID=2`) is used to host 8 SNCaloFEBs (total 128 X-wall channels). The suggested position of each FEB is shown on figure 10.

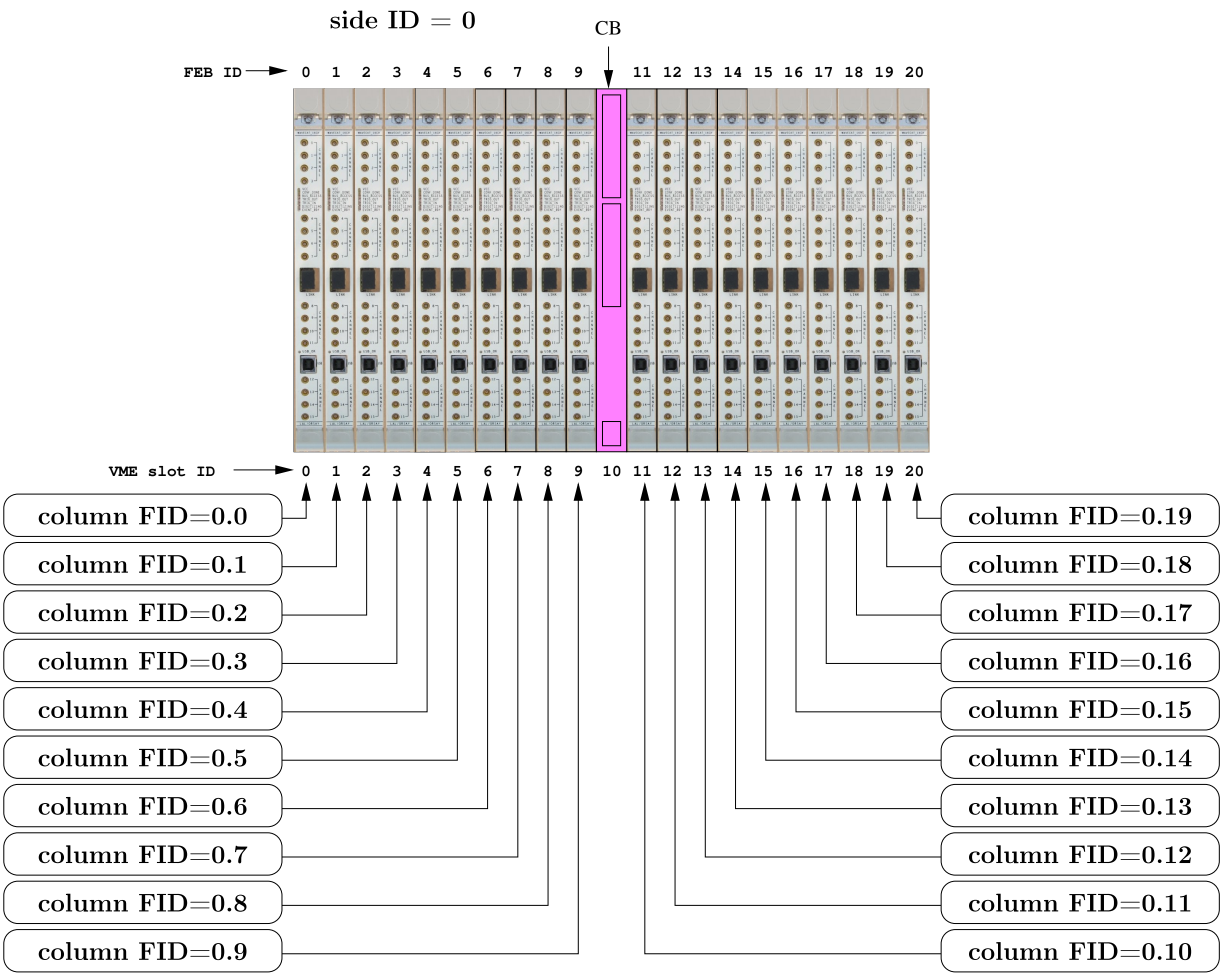

Figure 9: Mapping of main calorimeter columns and FEBs for `crate FID=0.0` (for `side ID=0`, $x < 0$). A similar scheme is used for `crate FID=0.1` (`side ID=1`, $x > 0$).

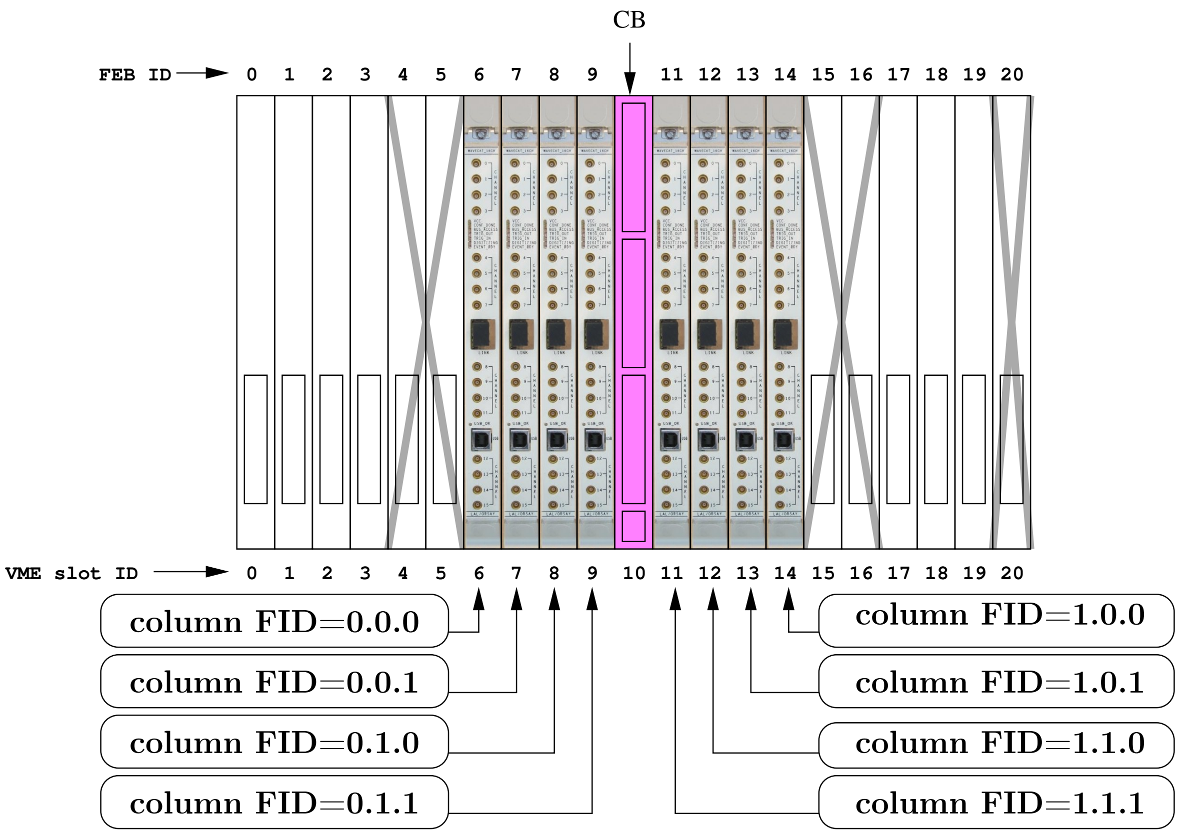

Figure 10: Mapping of a X-wall columns and FEBs (`crate FID=0.2`) Left to the CB: `side ID=0`; Right to the CB: `side ID=1`.

3.2.3 Distribution of the gamma veto channels

Each gamma veto wall corresponds to 16 optical modules. Thus all channels of a SNCaloFEB are used to address the optical modules from a single gamma veto wall.

The crate with `crate FID=0.2` (`rack ID=0` and `crate ID=2`) is used to host 4 SNCaloFEBs (total 64 gamma veto channels). The suggested position of each FEB is shown on figure 11.

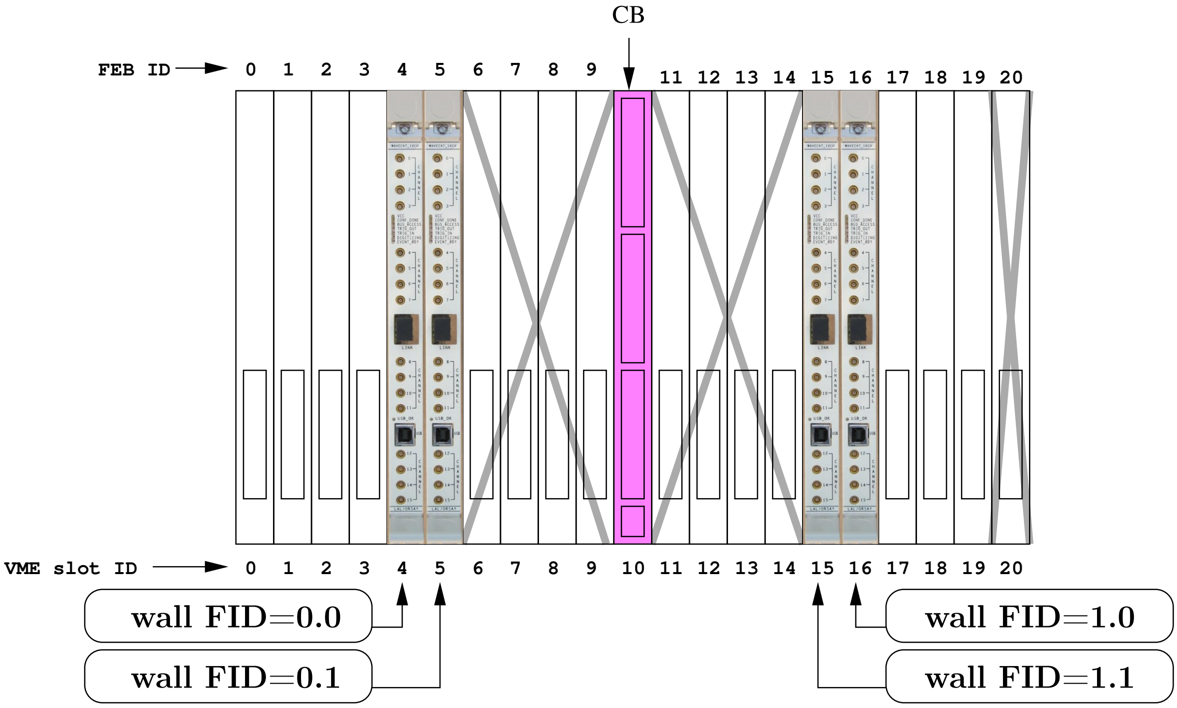

Figure 11: Mapping of a gamma veto walls and FEBs (`crate FID=0.2`) Left to the CB: `side ID=0`; Right to the CB: `side ID=1`.

3.3 Geiger cells readout

3.3.1 General tracker channels distribution

Each tracker chamber row contains 9 geiger cells. It has been decided that 2 rows per side will be plugged per trackerFEB (in NEMO3 mode). It means that $9 \times 2 \times 2 = 36$ cells are plugged per crate

19 trackerFEBs are hosted in each crate. Table 4 shows the mapping between the FEB ID and the rows ID for any of the crates.

`FEB ID`	`row IDs`
0	0/1
1	2/3
2	4/5
3	6/7
4	8/9
5	10/11
6	12/13
7	14/15
8	16/17
9	18/19
11	20/21
12	22/23
13	24/25
14	26/27
15	28/29
16	30/31
17	32/33
18	34/35
19	36/37

`FEB ID`	`row IDs`
0	38/39
1	40/41
2	42/43
3	44/45
4	46/47
5	48/49
6	50/51
7	52/53
8	54/55
9	56
11	57/58
12	59/60
13	61/62
14	63/64
15	65/66
16	67/68
17	69/70
18	71/72
19	73/74

`FEB ID`	`row IDs`
0	75/76
1	77/78
2	79/80
3	81/82
4	83/84
5	85/86
6	87/88
7	89/90
8	91/92
9	93/94
11	95/96
12	97/98
13	99/100
14	101/102
15	103/104
16	105/106
17	107/108
18	109/110
19	111/112

Table 4: Mapping of the Geiger cells with the tracker front-end boards in crates with `crate FID=1.0` (left), `crate FID=1.1` (middle) and `crate FID=1.2` (right) in NEMO3 mode. Each crate hosts 19 boards. Take into account that the `FEB ID=10` does not exist.

The figure 13 is a front view of a typical crate for the tracker.

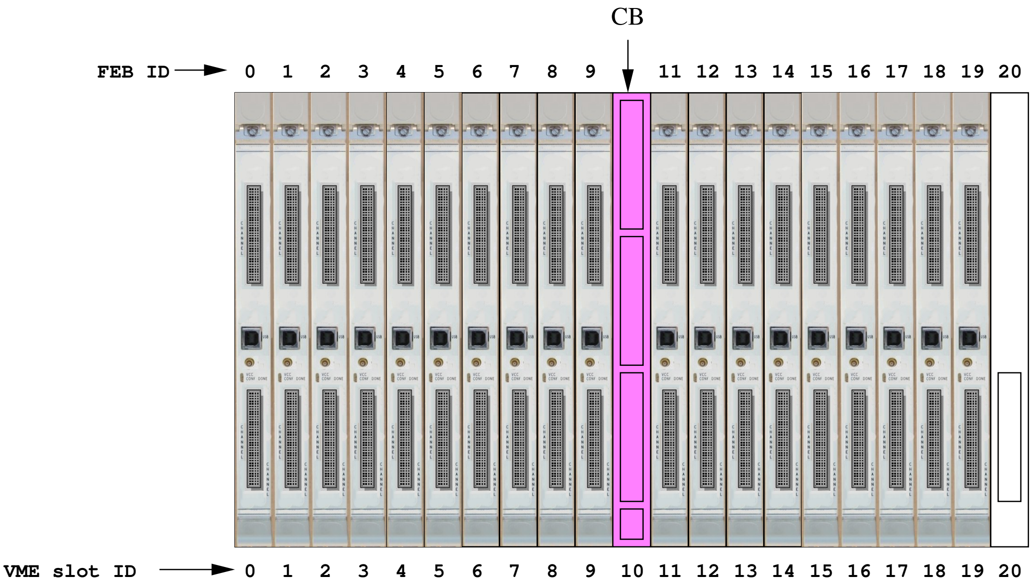

Figure 12: Mapping of the tracker FEBs for `crate FID=1.0`, `FID=1.1` and `FID=1.2` (see figure 16).

3.3.2 Distribution of the tracker channels per FEB

The tracker front-end board (SNTFEB) embeds two FEAST ASIC chips (figure 13). The FEAST ASIC can run in two different modes :

1. the *3 wires* (traditional/NEMO3) mode uses 3 analog signals : the Geiger anode and cathode drift times are extracted from the anode signal and both top and bottom cathode signals (like in NEMO3).

2. the *2 wires* (alternative) mode uses 2 analog signals : the Geiger anode and cathode drift times are extracted from the anode signal and the bottom cathode signal.

A FEAST chip can manage up to 54 channels (figure 14) :

- 18 channels of type "Anode channel" (AC)
- 27 channels of type "Cathode channel" (CC)
- 9 channels of type "Generic channel" (GC) :
  - a GC channel is used as a CC channel in *3 wires* mode
  - a GC channel is used as a AC channel in *2 wires* mode.

A FEB can be plugged to 36 GG cells in 3 *wires* mode (54 GG cells in 3 *wires* mode).

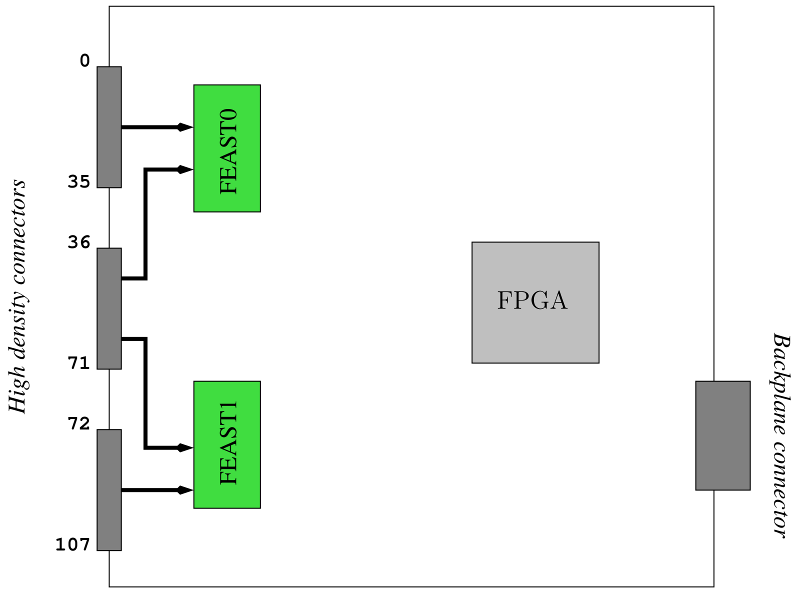

Figure 13: Layout of the tracker front-end board (SNTFEB).

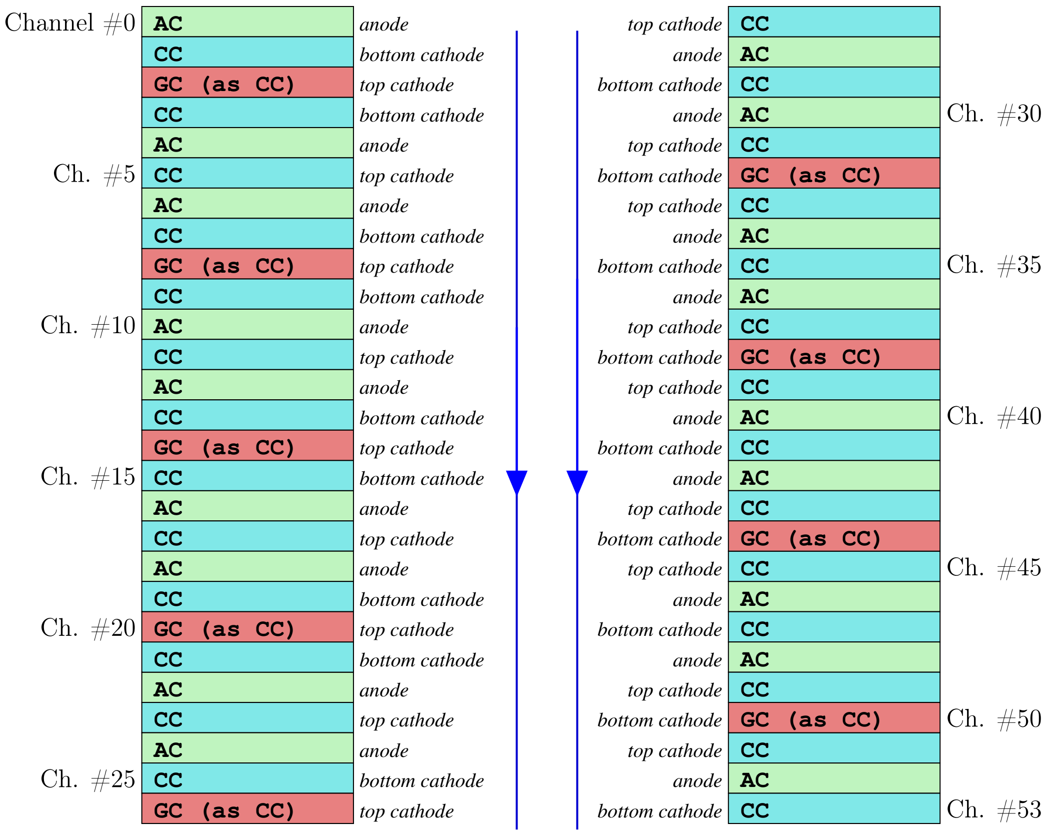

Figure 14: Layout of the FEAST ASIC channels in the *3 wires* mode (NEMO3). The red channels, designed as *Generic channels*, are configured to run as *Cathode channels*).

For the electronic point of view a drift cell is defined by three channels, the layout is :

ANODE The 2 geiger rows from side 0 are plugged to the FEAST 1 (resp. geiger side 1 plugged to FEAST 0).

BOTTOM CATHODE Same configuration than anode channels

BOTTOM CATHODE Channels from geiger row $\#i$ for each side are plugged to the FEAST 0 and channels from row $\#i+1$ are plugged to the FEAST 1.

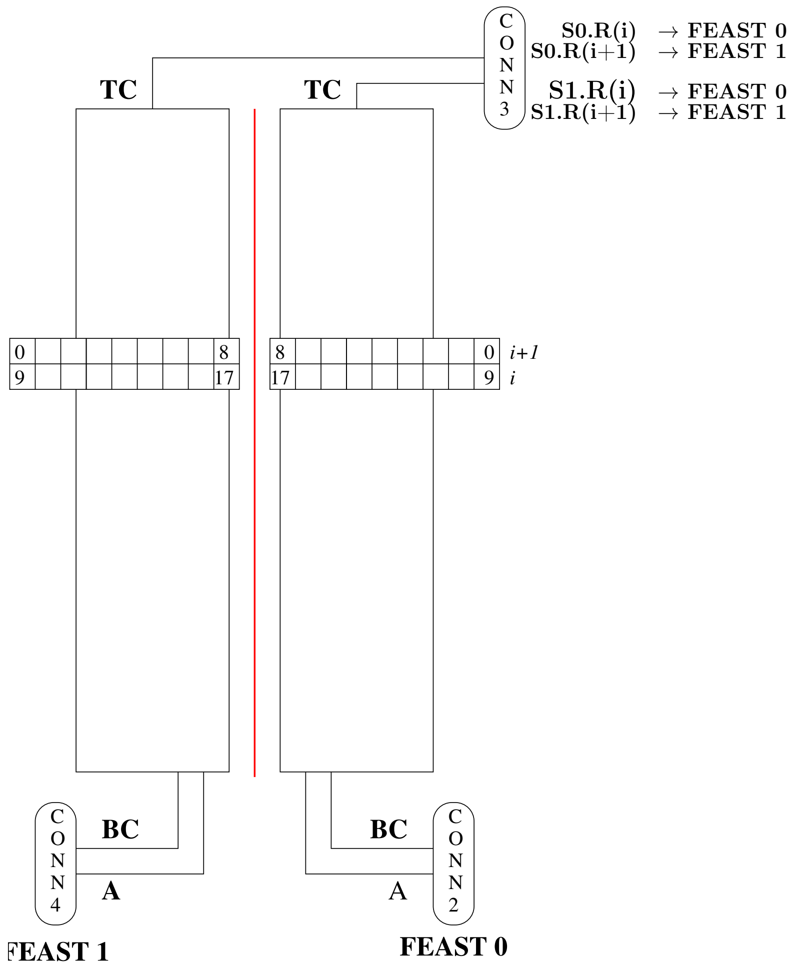

Figure 15: General tracker chamber electronic layout. BC : Bottom Cathode, TC : Top Cathode and A : Anode.

The figure 15 is a simple schematic of the tracker chamber layout.

3.3.3 Distribution of the tracker channels per FEAST

Table 5 and table 6 summarize the complete layout in a FEB from the GG cell to the FEAST pin.

GG ID	Feast#	ch.	Conn.#	ch.
L0.R0.P2	1	0	4	BOT1
L0.R0.P0	1	1	4	TOP1
L0.R0.P1	0	37	3	TOP1
L1.R0.P2	1	4	4	BOT3
L1.R0.P0	1	3	4	TOP3
L1.R0.P1	0	39	3	TOP3
L2.R0.P2	1	6	4	BOT5
L2.R0.P0	1	5	4	TOP5
L2.R0.P1	0	41	3	TOP5
L3.R0.P2	1	10	4	BOT7
L3.R0.P0	1	7	4	TOP7
L3.R0.P1	0	43	3	TOP7
L4.R0.P2	1	12	4	BOT9
L4.R0.P0	1	9	4	TOP9
L4.R0.P1	0	45	3	TOP9
L5.R0.P2	1	16	4	BOT11
L5.R0.P0	1	11	4	TOP11
L5.R0.P1	0	47	3	TOP11
L6.R0.P2	1	18	4	BOT13
L6.R0.P0	1	13	4	TOP13
L6.R0.P1	0	49	3	TOP13
L7.R0.P2	1	22	4	BOT15
L7.R0.P0	1	15	4	TOP15
L7.R0.P1	0	51	3	TOP15
L8.R0.P2	1	24	4	BOT17
L8.R0.P0	1	17	4	TOP17
L8.R0.P1	0	53	3	TOP17

GG ID	Feast#	ch.	Conn.#	ch.
L0.R1.P2	1	28	4	BOT19
L0.R1.P0	1	19	4	TOP19
L0.R1.P1	1	37	3	TOP19
L1.R1.P2	1	30	4	BOT21
L1.R1.P0	1	21	4	TOP21
L1.R1.P1	1	39	3	TOP21
L2.R1.P2	1	34	4	BOT23
L2.R1.P0	1	23	4	TOP23
L2.R1.P1	1	41	3	TOP23
L3.R1.P2	1	36	4	BOT25
L3.R1.P0	1	25	4	TOP25
L3.R1.P1	1	43	3	TOP25
L4.R1.P2	1	40	4	BOT27
L4.R1.P0	1	27	4	TOP27
L4.R1.P1	1	45	3	TOP27
L5.R1.P2	1	42	4	BOT29
L5.R1.P0	1	29	4	TOP29
L5.R1.P1	1	47	3	TOP29
L6.R1.P2	1	46	4	BOT31
L6.R1.P0	1	31	4	TOP31
L6.R1.P1	1	49	3	TOP31
L7.R1.P2	1	48	4	BOT33
L7.R1.P0	1	33	4	TOP33
L7.R1.P1	1	51	3	TOP33
L8.R1.P2	1	52	4	BOT35
L8.R1.P0	1	35	4	TOP35
L8.R1.P1	1	53	3	TOP35

Table 5: Module-0 ,Side-0. P0 is bottom Cathode, P1 is top Cathode and P2 is Anode. Board ID=5.1.0

GG ID	Feast#	ch.	Conn.#	ch.
L0.R0.P2	0	0	2	BOT1
L0.R0.P0	0	1	2	TOP1
L0.R0.P1	0	2	3	BOT1
L1.R0.P2	0	4	2	BOT3
L1.R0.P0	0	3	2	TOP3
L1.R0.P1	0	8	3	BOT3
L2.R0.P2	0	6	2	BOT5
L2.R0.P0	0	5	2	TOP5
L2.R0.P1	0	14	3	BOT5
L3.R0.P2	0	10	2	BOT7
L3.R0.P0	0	7	2	TOP7
L3.R0.P1	0	20	3	BOT7
L4.R0.P2	0	12	2	BOT9
L4.R0.P0	0	9	2	TOP9
L4.R0.P1	0	26	3	BOT9
L5.R0.P2	0	16	2	BOT11
L5.R0.P0	0	11	2	TOP11
L5.R0.P1	0	32	3	BOT11
L6.R0.P2	0	18	2	BOT13
L6.R0.P0	0	13	2	TOP13
L6.R0.P1	0	38	3	BOT13
L7.R0.P2	0	22	2	BOT15
L7.R0.P0	0	15	2	TOP15
L7.R0.P1	0	44	3	BOT15
L8.R0.P2	0	24	2	BOT17
L8.R0.P0	0	17	2	TOP17
L8.R0.P1	0	50	3	BOT17

GG ID	Feast#	ch.	Conn.#	ch.
L0.R1.P2	0	28	2	BOT19
L0.R1.P0	0	19	2	TOP19
L0.R1.P1	1	2	3	BOT19
L1.R1.P2	0	30	2	BOT21
L1.R1.P0	0	21	2	TOP21
L1.R1.P1	1	8	3	BOT21
L2.R1.P2	0	34	2	BOT23
L2.R1.P0	0	23	2	TOP23
L2.R1.P1	1	14	3	BOT23
L3.R1.P2	0	36	2	BOT25
L3.R1.P0	0	25	2	TOP25
L3.R1.P1	1	20	3	BOT25
L4.R1.P2	0	40	2	BOT27
L4.R1.P0	0	27	2	TOP27
L4.R1.P1	1	26	3	BOT27
L5.R1.P2	0	42	2	BOT29
L5.R1.P0	0	29	2	TOP29
L5.R1.P1	1	32	3	BOT29
L6.R1.P2	0	46	2	BOT31
L6.R1.P0	0	31	2	TOP31
L6.R1.P1	1	38	3	BOT31
L7.R1.P2	0	48	2	BOT33
L7.R1.P0	0	33	2	TOP33
L7.R1.P1	1	44	3	BOT33
L8.R1.P2	0	52	2	BOT35
L8.R1.P0	0	35	2	TOP35
L8.R1.P1	1	50	3	BOT35

Table 6: Module-0 ,Side-1. P0 is bottom Cathode, P1 is top Cathode and P2 is Anode. `Board ID=5.1.0`. Board#(i) connected to the Row#$(2 \times i)$ and Row#$(2 \times i + 1)$

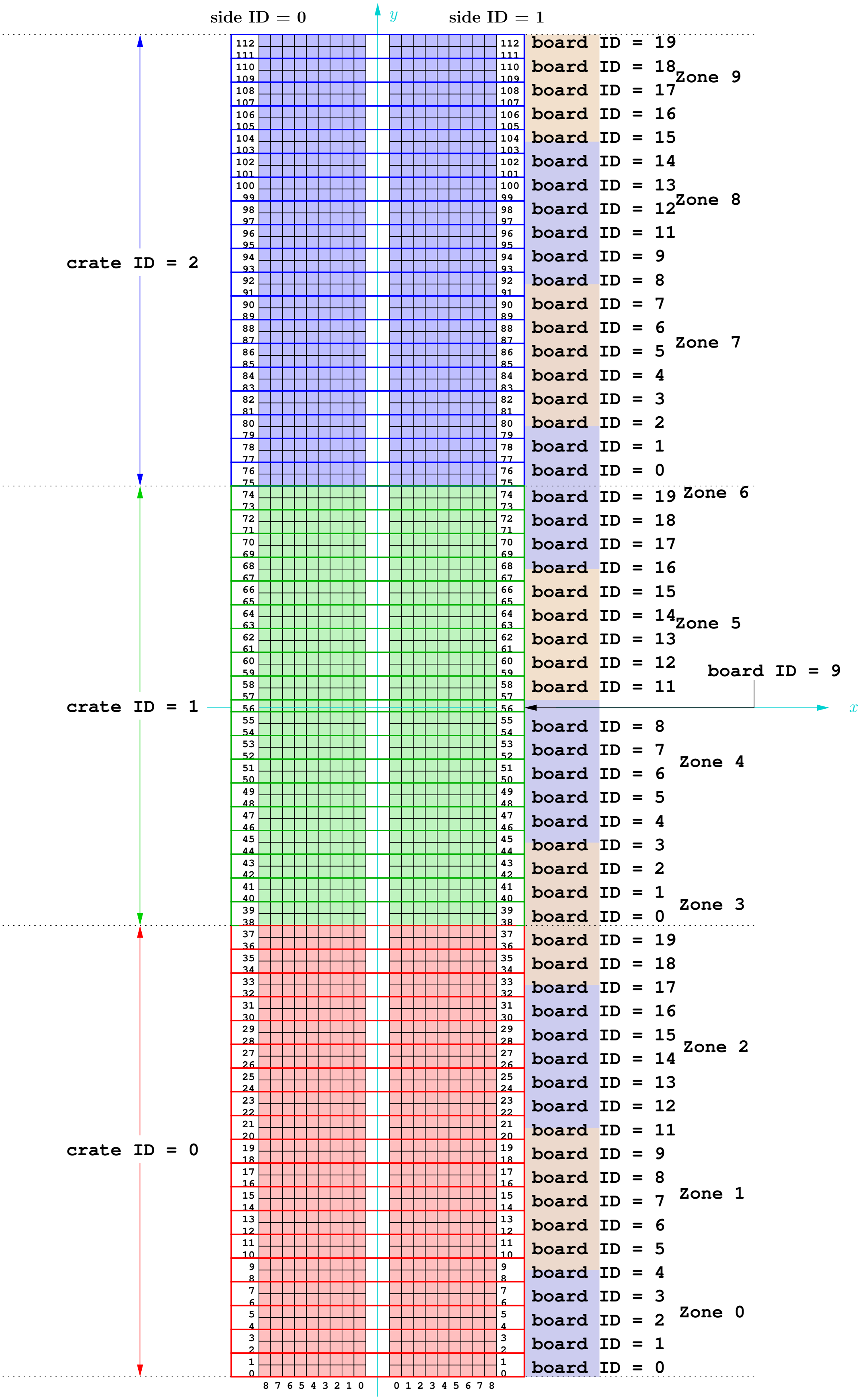

Figure 16: Distribution of 226 rows of 9 Geiger cells (113 on both sides) in the 3 tracker crates (*3 wires* mode).

4 Layout of the HV system

4.1 Racks and crates

The HV sytem uses 2 racks (check ref).

- Calorimeter HV : `rack ID=2`
  to define with John Ceasar
- Tracker HV : `rack ID=4`
  This rack hosts three crates for the HV system of the tracking chamber.

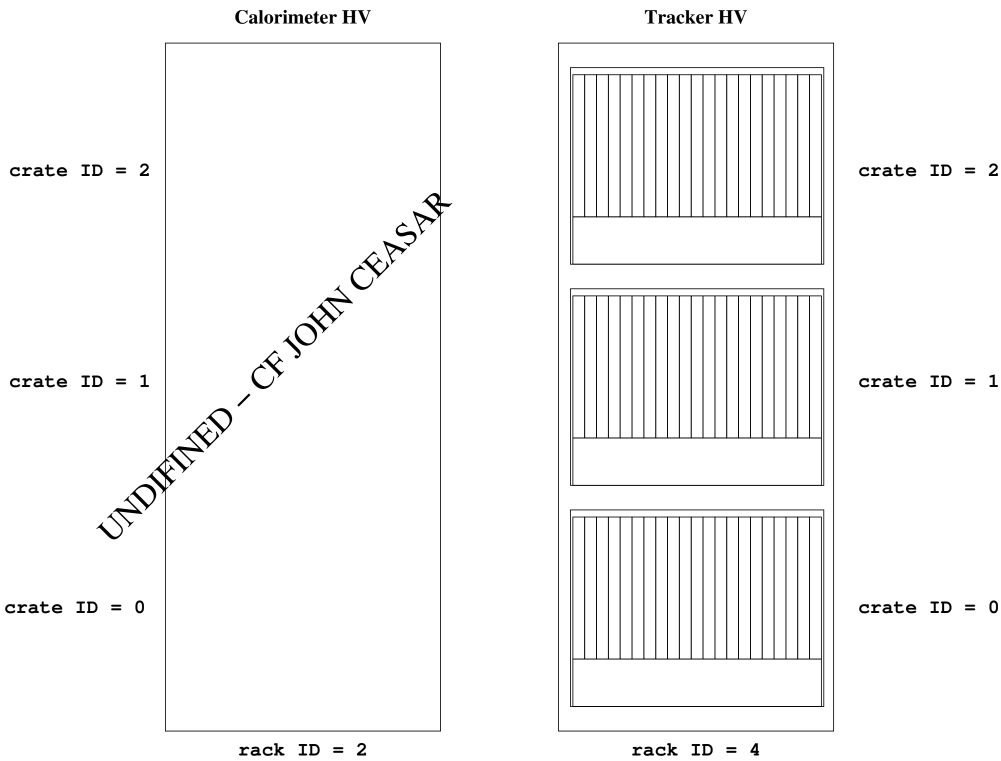

Figure 17: Racks and crates for the HV (front view).

4.2 Layout of the Tracker HV

At this stage, we have to define the crate model. Each crate contains at least 19 boards and each board has 36 slots to connect anode wire from GG cells.

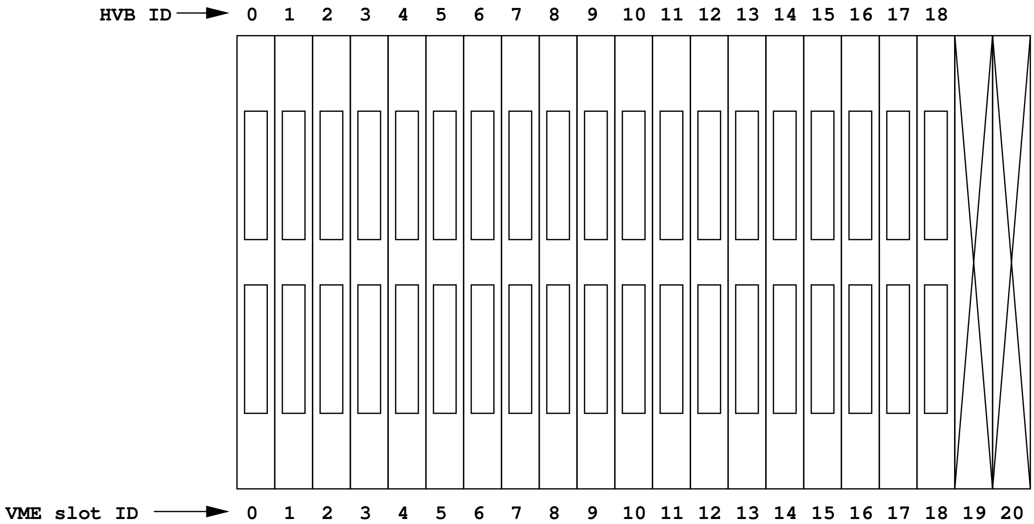

Figure 18: The layout of a tracker HV crate (front view).

4.2.1 Distribution of the tracker chamber channels

The SuperNEMO tracker chamber is hosting 2034 GG cells. Anode wires from two rows on both side ($9{\times}2$ rows $\times 2$ sides $= 36$ GG cells) are plugged to a HV tracker power supply board. Except for the central rows (from both side) which are plugged on a board (only 18 GG cells on this board). In this representation the full HV distribution needs 57 boards.

note: ask to Mike why row 56 from side 0 is not plugged with the row 56 from side 1. probably to be able to use only one half tracker chamber...

Table 7 represents the mapping between the HV board ID and the GG row ID from both side.

4.3 Layout of the Calorimeter HV

board ID	row IDs
0	0/1
1	2/3
2	4/5
3	6/7
4	8/9
5	10/11
6	12/13
7	14/15
8	16/17
9	18/19
10	20/21
11	22/23
12	24/25
13	26/27
14	28/29
15	30/31
16	32/33
17	34/35
18	36/37

board ID	row IDs
0	38/39
1	40/41
2	42/43
3	44/45
4	46/47
5	48/49
6	50/51
7	52/53
8	54/55
9	56
10	57/58
11	59/60
12	61/62
13	63/64
14	65/66
15	67/68
16	69/70
17	71/72
18	73/74

board ID	row IDs
0	75/76
1	77/78
2	79/80
3	81/82
4	83/84
5	85/86
6	87/88
7	89/90
8	91/92
9	93/94
10	95/96
11	97/98
12	99/100
13	101/102
14	103/104
15	105/106
16	107/108
17	109/110
18	111/112

Table 7: Mapping of the Geiger cells with the tracker HV boards in crates with `crate FID=4.0` (left), `crate FID=4.1` (middle) and `crate FID=4.2` (right) in NEMO3 mode. Each crate hosts 19 boards.

5 Detector zoning

In order to be able to apply some spatial coincidence criteria between hits from different parts of the detector (PMT, geiger hits) at the central trigger level, 10 tracker triggering zones (TTZ) have been defined on each side of the tracking chamber. Each TTZ is defined in the $x - y$ view only (flatten detector). A TTZ possibly has several neighbours : main calo or X-wall columns, some other TTZs.

Each TTZ zone is approximatively square-shaped (figure 19). One side being addressed through its `side ID=0` or `side ID=1`, each zone is identified through its `zone ID` from `0` ($y < 0$) to `9` ($y > 0$). A zone is defined in such a way it faces 2 main calorimeter columns. TTZ with `zone ID=0` and `zone ID=9` also face the X-wall calorimeter columns. The address mapping between zones and both Geiger rows and (X-)calorimeter columns is shown on table 10.

Using the same approach, 10 calorimeter triggering zones (CTZ) have been defined on each side of the detector. They address the triggering conditions of both the main walls and X-walls.

Finally, 6 gamma veto triggering zones (GTZ) are defined, 3 per side, regardless of the top/bottom position of the blocks. They can roughly be geometrically associated to some CTZs and TTZs. The address mapping between zones and gamma veto blocks is shown on table 9.

The FID of a zone (TTZ, CTZ or GTZ) is formatted like :

`zone FID=side ID.zone ID`

`zone ID`	Geiger `row IDs`	[#]	Main calo. `column IDs`	X-wall `wall ID.column IDs`
0	0-8	[9]	0-1	0.0, 0.1
1	9-20	[12]	2-3	–
2	21-32	[12]	4-5	–
3	33-44	[12]	6-7	–
4	45-56	[12]	8-9	–
5	57-67	[11]	10-11	–
6	68-79	[12]	12-13	–
7	80-91	[12]	14-15	–
8	92-103	[12]	16-17	–
9	104-112	[9]	18-19	1.0, 1.1

Table 8: Association of Geiger cell rows, main wall and X-wall blocks and zones for `side ID=0` (the same scheme is used for both sides).

zone ID	Gamma veto wall ID.column IDs	[#]
0	0.0-4, 1.0-4	10
1	0.5-10, 1.5-10	12
2	0.11-15,1.11-15	10

Table 9: Association of gamma veto blocks and zones (the same scheme is used for both sides).

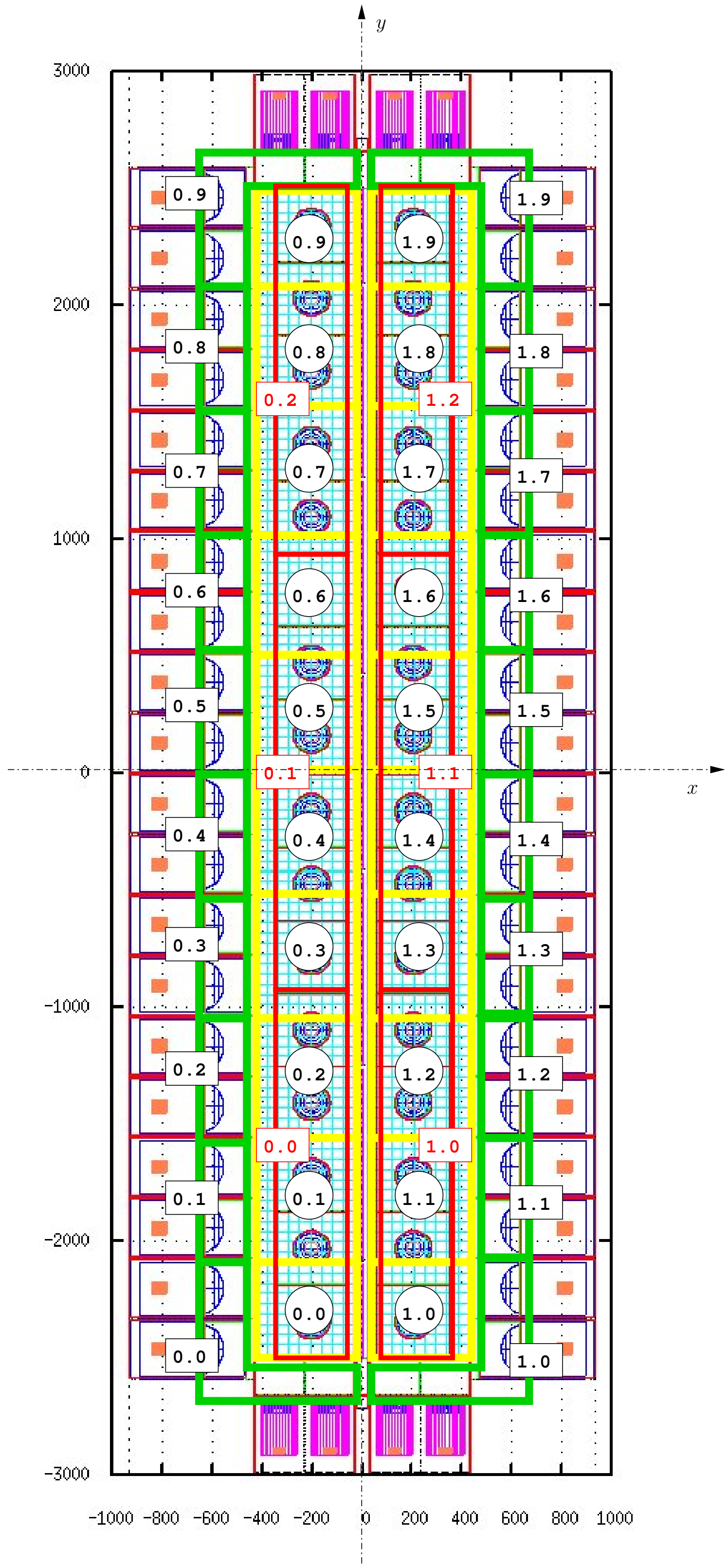

Figure 19: Zoning of the detector ($x - y$ top view, both sides). Yellow boxes correspond to the TTZ (Geiger cells). Green boxes correspond to the CTZ (main walls and X walls blocks). Red boxes correspond to the GTZ (gamma veto blocks).

6 Cabling

note: To be done.

Question :
Should we use cables of the same length for the optical lines (main wall, X-wall, and gamma veto) ?
Maximum difference between extreme blocks for the full detector is about L_{max}=9 m.
Signal propagation speed in cable is v_p=20cm/ns. $\Delta t_{cable} = L_{max}/v_p \simeq 50$ ns. This is 2 clock ticks at 40 MHz.
A beta-gamma event can hit two distinct scintillator block separated by $D_{max} = \sqrt{5^2 + 3^3 + 1^3} \simeq 6$ m. This gives a coincidence time window for a $\beta = 0.5$ electron of $\Delta t_{coinc,max} \simeq 40$ ns, thus again about 2 clock ticks at 40 MHz.
The trigger should use a time coincidence window of at least :
$\Delta t_{coinc,trig} \simeq \Delta t_{coinc,max} = 50$ ns.
What if cables are not of the same length :
$\Delta t_{coinc,trig}$=50 ns $\rightarrow \Delta t_{coinc,trig} = \Delta t_{coinc,trig} + \Delta t_{cable}$=100 ns ?
Mass of cables within the shield/tent should be minimum. Using a patch panel, we could compensate differences in length of cables by compensating the cables' length outside the shield.
Using a patch panel seems necessary.

Preliminary answer :
Pros: it is preferable to use the same cable length for all PMTs because :

- it introduces no geometrical bias between different regions of the detector and triggering timestamps are completely equivalent, in this case Δt_{cable}=0 and we are back to the optimal $\Delta t_{coinc,trig}$=50 ns.
- it introduces no heterogeneity in the signal attenuation, which could be rather difficult to manage

Cons: ensuring uniform cable length means adding typically 720 $\times$ 5m of compensation length cable, thus 3.5 km. High quality low radioactivity cable are $\sim$3000 euros/km $\rightarrow$ 20000 euros additionnal price. A solution could be to use lower quality cable for length compensation, being outside the tent and shielding. The price should be significantly lower.

7 Trigger

note: In progress. . .

The goal of the trigger system is to select only events of physical interest (electron, gamma, alpha . . .) , reject spurious events (self triggering of the tracker drift cells or PMTs) and reduce the general acquisition rate. At each clock tick (25 ns) , we collect trigger primitive (TP) signals associated to each tracker or calorimeter channel. The trigger system is designed to merge all these TP signals and make a decision from these informations within a central programmable trigger board. Once the decision is made to record an event of interest, dedicated signals are sent back to the CBs and FEBs to initiate the data acquisition sequence for the selected channels. Due to the large number of channels (both for the calorimeter and the tracker) and the geometry of detector, it has been decided, as for NEMO3, to consider only the informations from the X-Y view of the detector. That means that no Z information (vertical axis) is used to build the TPs.

7.1 Calorimeter

As explained previously, each column of optical module (OM) is connected to a FEB. Each FEB build a Trigger Primitive Bitset which will be send to the dedicated control board at the frequency $f = 40$ MHz (each 25 ns).

7.1.1 Composition of trigger primitive data

At the CaloFEB level : the Trigger Primitive Bitsets (TPB) is defined by [5 bits] (cf. Fig.20) :

- HTM : High Threshold Multiplicity [2 bits]

  Value `00` no hit has passed the high threshold in the column (up to 16 OMs)

  Value `01` one hit has passed the high threshold

  Value `10` two hits have passed the high threshold

  Value `11` three hits or more have passed the high threshold

- LTO : Low Trigger Only [1 bit]

  Value `0` no hit has passed only the low threshold in the column

  Value `1` at least one hit has passed the low threshold but not the high threshold

- XT : External Trigger [1 bit]

  Value `0` No external trigger signal associated to the FEB

  Value `1` An external trigger signal is associated

- SPARE TRIGGER (ST) : spare bit [1 bit]

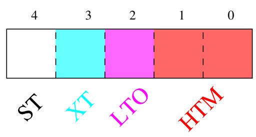

Figure 20: Trigger Primitive Bitsets

At the Control Board level : FEBs send its own TPB word to the Board :

- 20×[5bits] = [100 bits] from `crate ID=0-1`,
  (for 20 columns per wall)
- 12×[5bits] = [60 bits] from `crate ID=2`.
  (8 columns for X-walls and 4 columns for γ-veto)

The Control Board merges the TPBs coming from the FEBs (up to [100 bits]) and computes the 18 bits Calorimeter Crate Trigger Word (C-CTW). CB produce different C-CTW depending on the crate number :

- C-CTW, displayed in figure 21, from `crate ID=0-1` are composed of 5 fields of bits :
  - HTM-PC : High Threshold Multiplicity Per Crate [2 bits]

    Value `00` no hit has passed the high threshold in the mains wall
    Value `01` one hit has passed the high threshold
    Value `10` two hits have passed the high threshold
    Value `11` three hits or more have passed the high threshold
  - W-ZW : Wall Zoning Word [10 bits] Each bit can be activated in case of hit in the corresponding zone (`zone ID=0-9`).
  - LTO-PC : Low Trigger Only Per Crate [1 bit]
    This is defined by 'OR' of all LTO from FEBs.

    Value `0` no hit has passed only the low threshold in the mains wall
    Value `1` at least one hit has passed the low threshold but not the high threshold
  - XT-PC : External Trigger Per Crate [1 bit]
    This is defined by 'OR' of all XT from FEBs.

    Value `0` No external trigger signal associated to the CB
    Value `1` An external trigger signal is associated
  - CONTROL : control bits [4 bits]

    note: To be define. (counter modulo 16?) cf : Olivier D.
- C-CTW, displayed in figure 22, from `crate ID=2` is composed of 9 fields of bits :

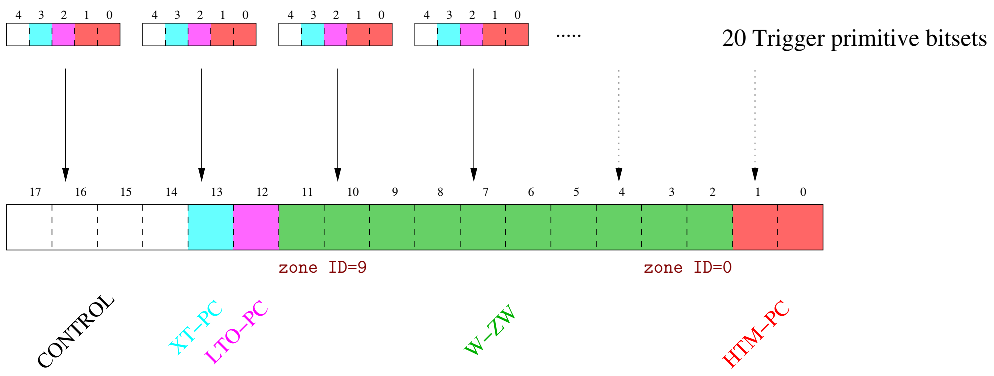

Figure 21: Calorimeter Crate Trigger Word (C-CTW) from Control Board in `crate ID=0-1`

- HTM-GVETO : High Threshold Multiplicity in γ-veto calorimeter [2 bits]
- X-ZW : X-wall Zoning Word [4 bits]
- HTM-X0 : High Threshold Multiplicity in X-wall from side 0 [2 bits]
- HTM-X1 : High Threshold Multiplicity in X-wall from side 1 [2 bits]
- LTO-X0 : Low Trigger Only in X-wall from side 0 [1 bit]
  This is defined by 'OR' of LTO from `FEB ID=6-9`.
- LTO-X1 : Low Trigger Only in X-wall from side 1 [1 bit]
  This is defined by 'OR' of LTO from `FEB ID=11-14`.
- LTO-GVETO : Low Trigger Only in γ-veto [1 bit]
  This is defined by 'OR' of LTO from `FEB ID=4,5,15,16`.
- XT-PC : External Trigger Per Crate [1 bit]
- CONTROL : control bits [4 bits]

note: TO DEFINE With O. DUARTE: Define the CTW Activation Register Do we need 2 CTW-AR to compute a zoning bit

Each C-CTW is composed of a zoning word (10 zones from 20 FEBs i.e. 2 columns per zone) which are computed by a Calorimeter Trigger Word Activation Register (CTW-AR) is shown in Fig.23. This CTW-AR is used to defined the zoning word using TP from FEBs.

7.2 Tracker

Each geiger cell (GG) is connected to some signal input of a FEAST ASIC chip, embedded on a tracker FEB. Using the so-called *NEMO3 mode*, 36 cells are plugged per FEB (i.e. 18 GG per FEAST) and 54 GG are plugged per FEB (i.e. 27 GG per FEAST) for the *alternative mode*. The SuperNEMO demonstrator module will use the *NEMO3 mode*. Thus

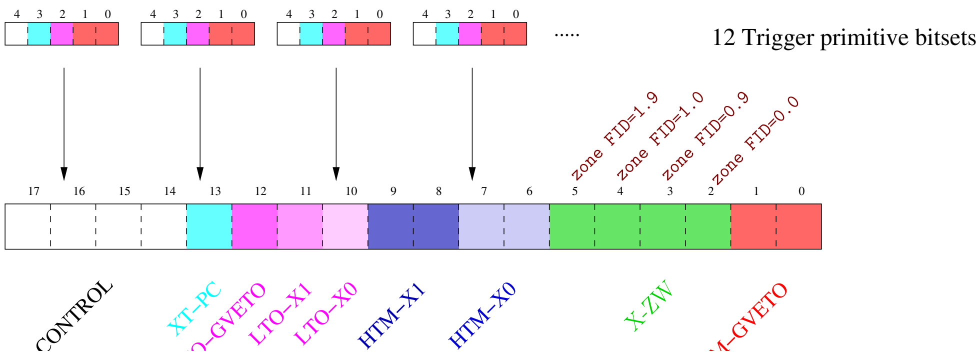

Figure 22: Calorimeter Crate Trigger Word (C-CTW) from from Control Board in `crate ID=2`

Figure 23: Crate Trigger Word Activation Register (CTW-AR) used to compute zoning bits.

each cell will correspond to one anode signal and two cathode signals (resp. *bottom* and *top*). Only the anode signal is used to build tracker trigger primitives.

Each 800 ns, both FEAST ASICs on a given board will be inspected to build the tracker trigger primitives. One clock tick (25 ns) is needed to read simultaneously one anode signal for both FEAST. So it takes 18 clock ticks (450 ns) to get the GG status from FEASTs in NEMO3 mode (27 clock ticks in alternative mode, 675 ns). In any case the time needed to collect trigger primitives in the FPGA is less than τ_T=800 ns. This period is used as the effective readout tracker trigger clock (32×25 ns main clock ticks) called $RTTC$.

7.2.1 Composition of trigger primitive data

The principle of the tracker trigger system is to search for spatial coincidences between Geiger hits, using a dedicated algorithm implemented in the main trigger board (TB). To

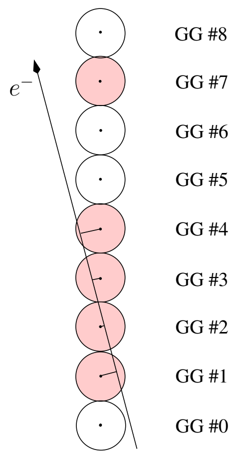

Figure 24: Tracker sample event: a charged particle is traversing a row of cells and implies Geiger avalanches in 4 cells among 9 (layers 1, 2, 3 and 4). More, a lone cell (layer 7) is triggered by some spurious event (cell refiring, low energy electron).

perform this operation, the status of all tracker cells in the detector must be recorded every τ_T=800 ns and collected through the backplane and the control board.

The principle is to build for each cell, a trigger primitive that indicates if the cell *has been hit during a time window of which the duration has been conventionnally decided and programmed*. This trigger primitive consists in one single bit with value 0 if the cell is not hit, and 1 if the cell has been *recently* hit by a track. Thus for a given board in NEMO3 mode, the FPGA hosts as many bits it needs to collect a snaphot of the tracking chamber trigger status.

A typical tracker event is shown in Fig.24. This event will be used as an example.

The proposed implementation involved the association of a 5-bits counter to each cell. All 5-bits counters should start a value `00000` which means that the cells are considered to be un-fired. When the FPGA detects a hit in a cell's anode signal, the corresponding counter is filled with a conventional value which determines the duration of the coincidence time window.

The choice of the time window duration is set through a programmable register from the control system. A typical value could be 8 μs corresponding to 10$\times$800 ns (counter starting at `01010`). This corresponds to twice the duration of the Geiger drift time for a peripheral hit with 44 mm diameter cells and should address most physics cases.

Then, after each 800 ns period, the counter is decreased by `1` (cf Fig.25). As long as the counter contains a non zero value, the trigger primitive (TP) of this cell is set to `1`. When the counter reaches zero, the TP reverts to its `0` initial value (cf Fig.26). Whatever is the TP value, it is transmitted to the control board each τ_T period, together with the other TPs associated to other cells.

At each cycle, non-null counter will activate a bitset (cf Fig.26).

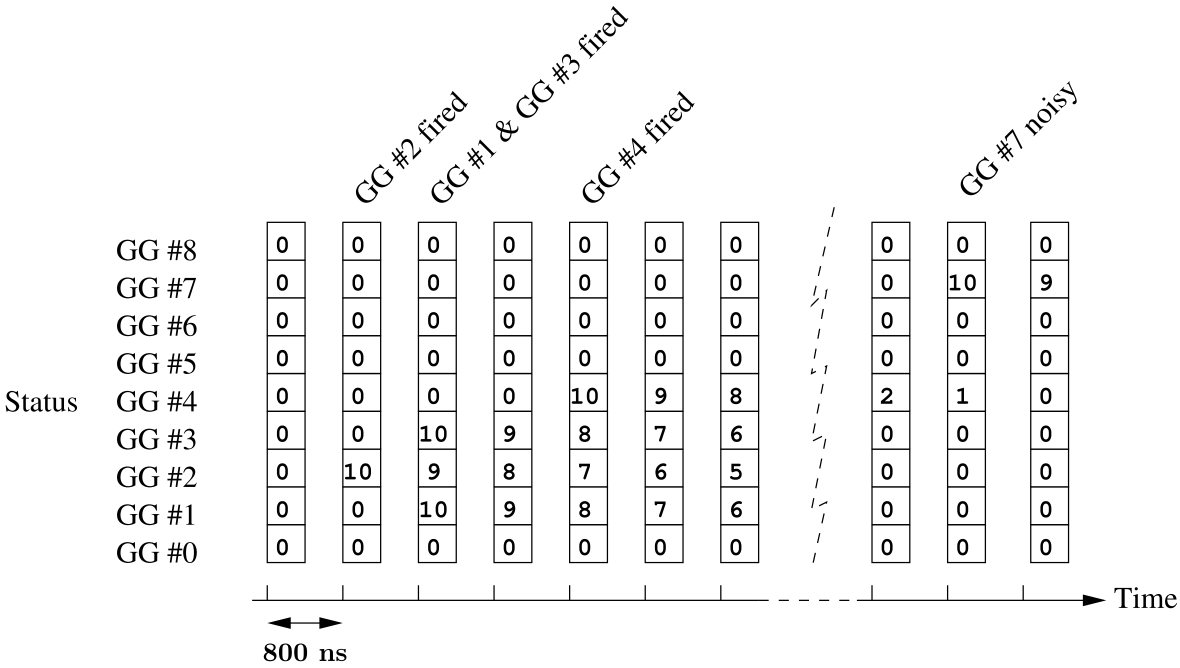

Figure 25: GG counter timeline in FEB. Each 800 ns, the GG counter is decreased by one unit.

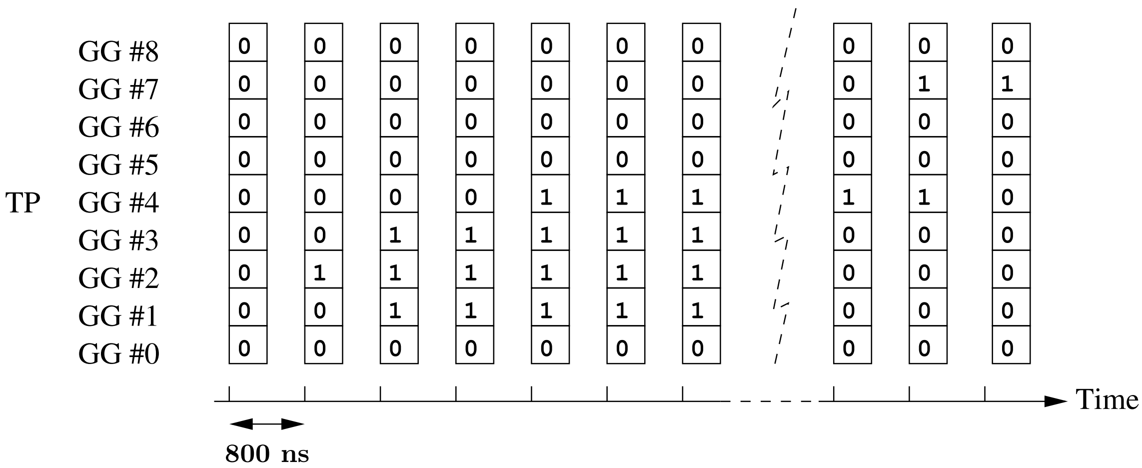

Figure 26: GG TP timeline in FEB. In case of non-null GG counter, the TP is set at 1.

At the TrackerFEB level : the Trigger Primitive Bitset (TPB) [100 bits] is defined by :

- Control : [15 bits]
- TTID : Tracker Trigger ID [15 bits] but could be a [5 bits] word [1] This Trigger ID is used to check T-TPB synchronization from different FEB in the CB.
- Board address + Spare : [10 bits]

3 bits : Spare

2 bits : `crate ID=0-2`

5 bits : `board ID=0-19`

- THWS : Tracker HardWare Status [5 bits]
  - TTM : Tracker Trigger Mode [1 bit]

    Value `0` 3 analog signals used for GG (NEMO3 like)

    Value `1` 2 analog signals used in alternative mode
  - TSM : Tracker Side Mode [1 bit] (to be discussed)

    Value `0` All GG plugged to the FEB comes from only one detector side

    Value `1` GG comes from Both side
  - TRM : Tracker Row Mode [3 bits]
    The TRM defines the number of connected GG rows to the FEB (up to 7 rows).

  Example for NEMO3 mode : `THWS=01010`

```
[.........] | [.........]
[.........] | [.........]
[.........] | [.........]
[.........] | [.........]
[ooooooooo] | [ooooooooo]
[ooooooooo] | [ooooooooo]
```

- TP : Trigger primitive [55 bits] :

  Value `0` The GG has not been fired within the last coincidence period (800 ns),

  Value `1` The GG has been fired within the last coincidence period.

- In NEMO3 mode : up to [36 bits] (LSB) are used: 4 rows of 9 cells + [1 bit] (MSB) is set at zero
- In alternative mode : up to [54 bits] (LSB) are used: 6 rows of 9 cells + [1 bit] (MSB) at 0

[1] The TTID is a cycle counter ($32 \times 800ns = 25.6\mu s$)

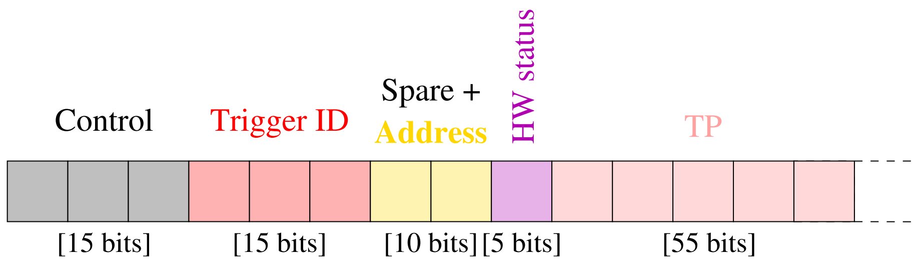

Figure 27: Tracker Trigger Primitive Bitset defined in each SNTrackerFEB

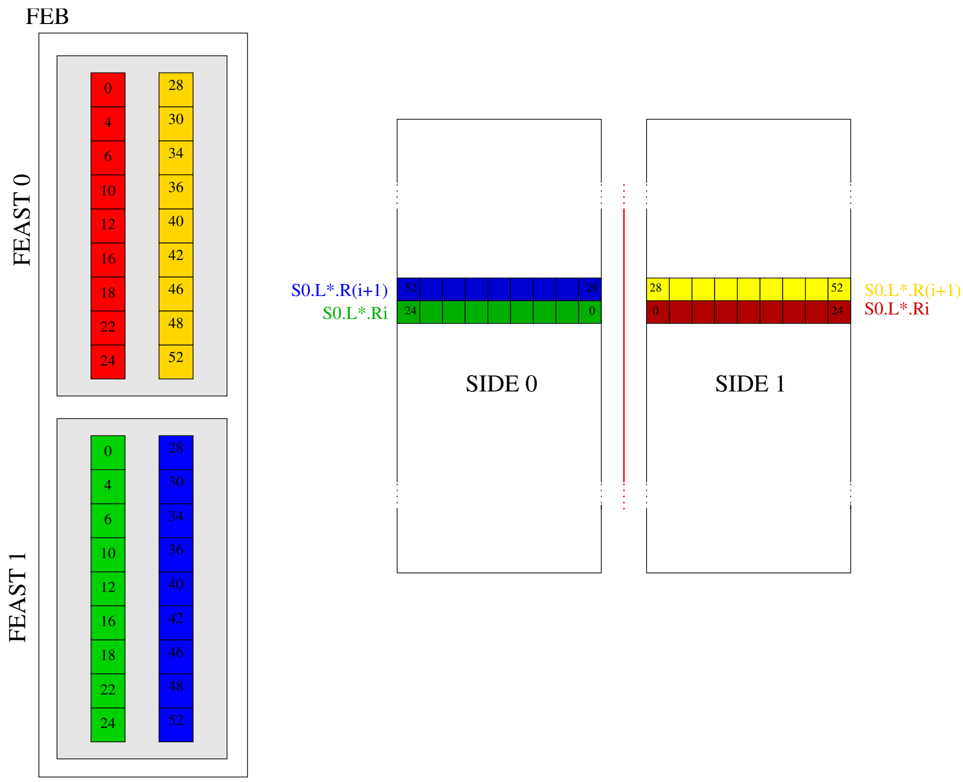

Figure 28: ....

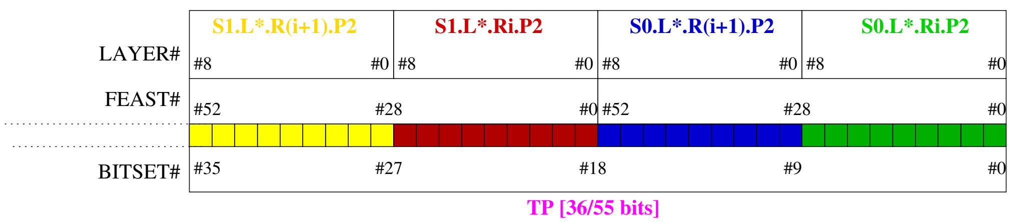

Figure 29: ....

At the Control Board level : the Tracker Crate Trigger Word (T-CTW) calculation is based on 19×Tracker TPB. These T-CTWs do not depend on the crate number :

- a HEADER [36 bits] :
  - ClockID defined at 800 ns : [15 bits]
  - ERROR_SYNCHRO_FEB_FRAME : [1 bit]
  - ERROR_CLOCK800ID_FEB : [1 bit]
  - CrateID : [2 bits]
  - Spare : [17 bits]
- a BODY 2×[36 bits]×19FEB :
  - Spare + Address : [5 bits] + [5 bits]
  - HW : HardWare Status [5 bits] This bitset is a copy of the THWS from TPBs. The 19 THWS from each TrackerFEB have to be equal.
  - Trigger primitives : [55 bits]
    - EMPTY_TP : [1 bit] This is defined by 'OR' of next [54 bits]
    - Trigger Primitives : [54 bits]
      NEMO3 mode [36 bits] used from #0 to #35.
      Alternative mode [54 bits] used from #0 to #53.
  - Spare : [2 bits]

note: To continue with Tracker Zoning word

7.2.2 Trigger data transfer from the SNTrackerFEB to the Control Board and trigger board

7.3 Trigger board strategy

7.3.1 Calorimeter

Each 25 ns a 18 bits Calorimeter Crate Trigger Word comes from each CB.

These zoning words (one per crate) are used to compute Sided Calorimeter Zoning Word (cf Fig.31). The SC-ZW will be used to check possible coincidence between tracks from the tracker and hit PMT walls.

note: How to be sure that we compare calo trigger and tracker trigger from the same event ?

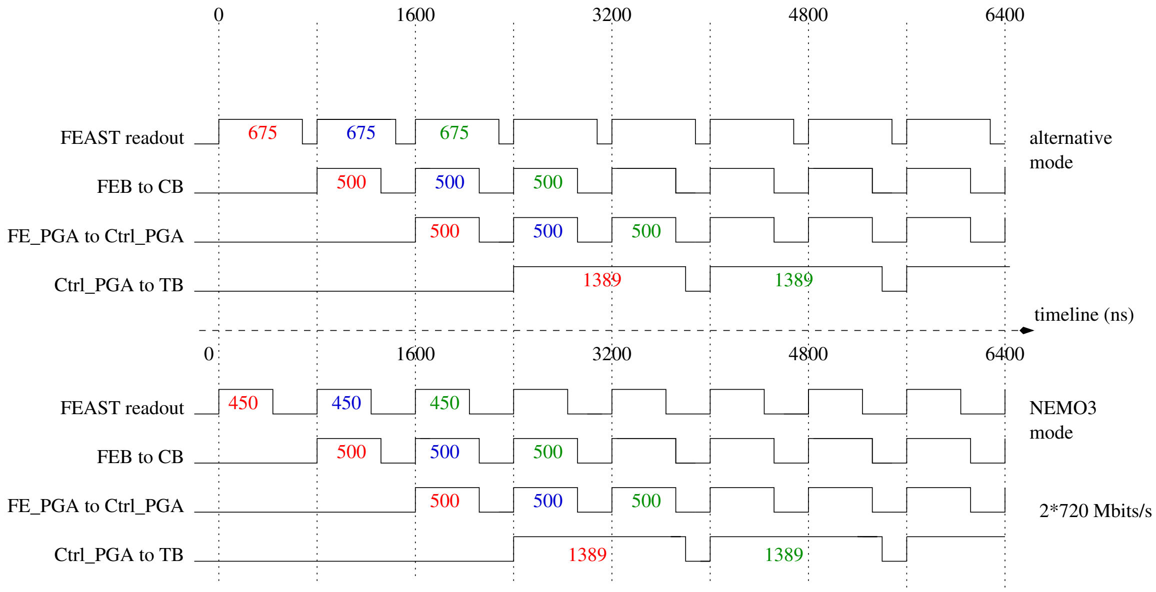

Figure 30: Tracker trigger digital timing diagram with 800 ns CLOCK from FEBs to CBs and 1600 ns CLOCK from CBs to Trigger board.

7.3.2 Tracker

Each 1600 ns a [1900 bits word] is sent to the TB from each CB. The HW and TP bitsets will be used to prepare two matrix of 9×113 bits. These matrix of bits are a logic view of each tracker chambers [2].

The TTZ[3] bitsets have to be activated in case of *valid* track in the corresponding zone (zones defined in table 10) based on the logic matrix view.

For a 9×12 cells in a zone, 2^{108} topologies are available but only some of them represents a *valid* track. To reduce the number of topology to analyse, matrix zones are divided by 4 sub-zones. For example a 9×12 cells zone is divided by 4 sub-zone defined by a 5×6 cells pattern (i.e. 2^{30} topologies).

A criteria to define (ex: more than 2 adjacents GG cells) will allow to fill a [2 bits] word which will express the horizontality or the verticality of the track for each sub-zone. An extra bitset can be used to define the multiplicity of cells close (two closest layers?) to the source foil from 0 up to 3 and more.

note: 2 adjacent GG cells to be tuned

In figure 35, we represent a top view of a tracker chamber zone crossed by a typical electron from the source to the calorimeter. The corresponding matrix is represented with

[2]Probably these matrix should be kept in memory during N×1600 ns to look after delayed charged particles.

[3]tracker triggering zones

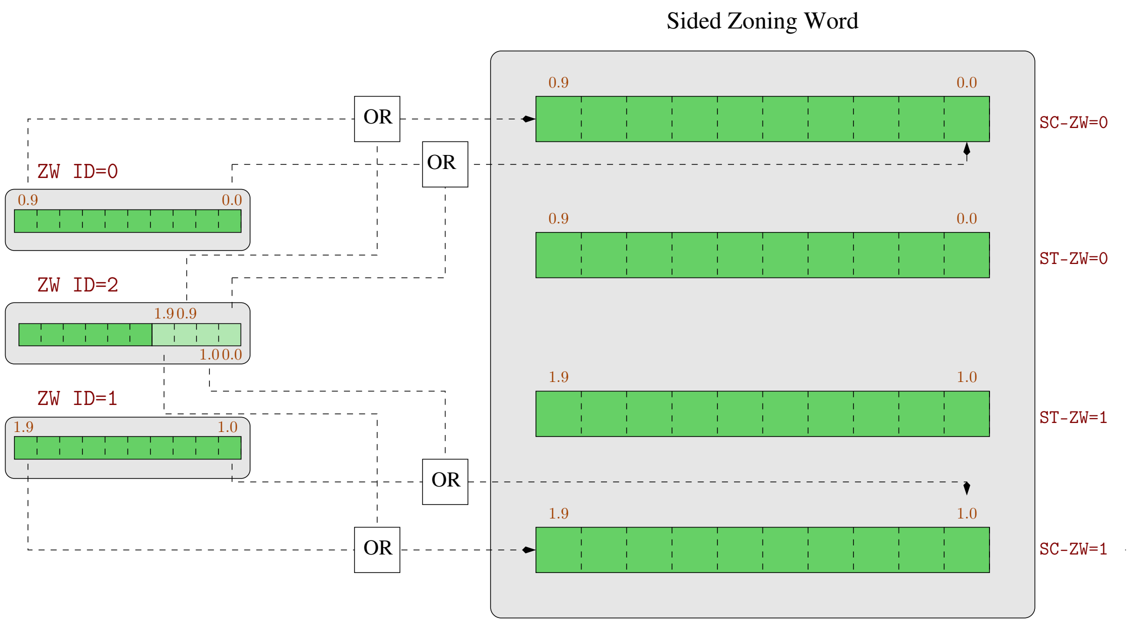

Figure 31: Zoning Word (ZW), ZW ID=0 1 are coming from main walls and ZW ID=2 is coming from X-walls and γ-veto. The Sided Calorimeter Zoning Word (SC-ZW) is used for Calorimeters zoning and the Sided Tracker Trigger Word (ST-ZW) is dedicated to the trackers part's (will be defined in next section).

zone ID	Geiger row IDs	[#]	Tracker FEB Labels	Sub-zone size
0	0-8	[9]	R5.C0.B0-$4^{1/2}$	5×5
1	9-20	[12]	R5.C0.B$4^{1/2}$-$11^{1/2}$	5×6
2	21-32	[12]	R5.C0.B$11^{1/2}$-$17^{1/2}$	5×6
3	33-44	[12]	R5.C0.B$17^{1/2}$-R5.C1.B$3^{1/2}$	5×6
4	45-56	[12]	R5.C1.B$3^{1/2}$-9	5×6
5	57-67	[11]	R5.C1.B11-$16^{1/2}$	5×6
6	68-79	[12]	R5.C1.B$16^{1/2}$-R5.C2.B$2^{1/2}$	5×6
7	80-91	[12]	R5.C2.B$2^{1/2}$-$8^{1/2}$	5×6
8	92-103	[12]	R5.C2.B$8^{1/2}$-$15^{1/2}$	5×6
9	104-112	[9]	R5.C2.B$15^{1/2}$-19	5×5

Table 10: Tracker Sub-zone definition depending on the zones size. R5.C1.B9 contain only row ID 56. Note that FEB ID=10 does not exist.

highlighted sub-zones.

A build up of the four [2 bits] word per sub-zone constitute a [8 bits]+[2 bits] word per zone (Figure 36) corresponding to the event displayed in figure 35. danse2.avi

Another exemple : Figure 37 presents a logic view of a charged particle crossing two adjacent zone. Regarding only the [8 bits] words extracted from each 9×12 GG cells from Zone i and Zone $i+1$:

- there is GG cells close to the source foil on the zone i;
- there is a OUTTER track on the zone $i+1$.

At this point, it's not possible to conclude on the track validity per zone. But taking both zone into account, there is a complete track from the source foil to the calorimeter.

That's why, we propose to reduce the [8 bits] word down to [2 bits] :

- 00 no track
- 11 complete track
- 10 track to confirm with zone at the left
- 01 track to confirm with zone at the right

7.3.3 Full detector

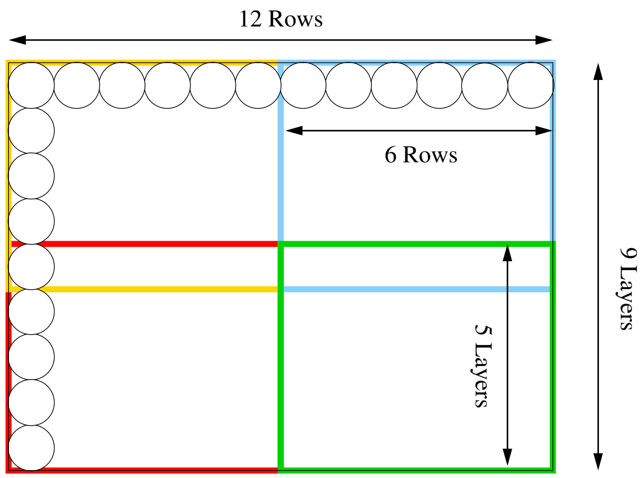

Figure 32: Tracker zoning for size 9×12 i.e. `Zone ID=1,2,3,4,6,7,8`.

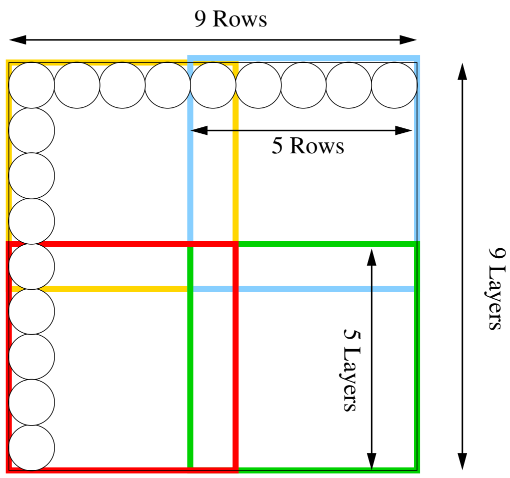

Figure 33: Tracker zoning for size 9×9 i.e. `Zone ID=0,9`.

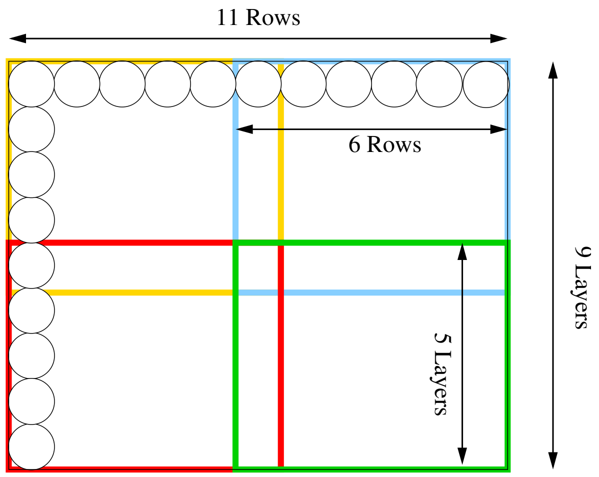

Figure 34: Tracker zoning for size 9×11 i.e. `Zone ID=5`.

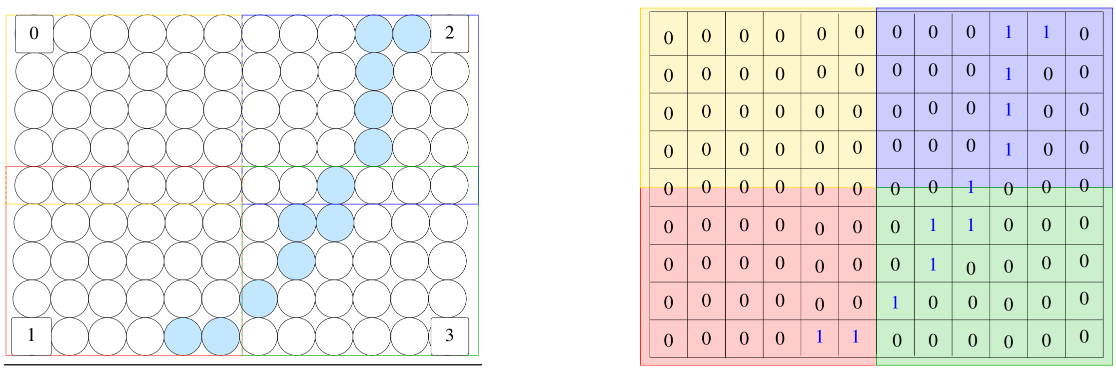

Figure 35: At the left : Top view of the tracker zone #2. At the Right : Partial view of the matrix from TB corresponding to the top tracker view.

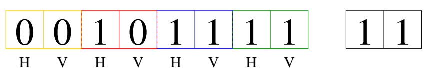

Figure 36: Display of the bitset per zone of the track and the extra bitset for GG cells multiplicity close to the source foil.

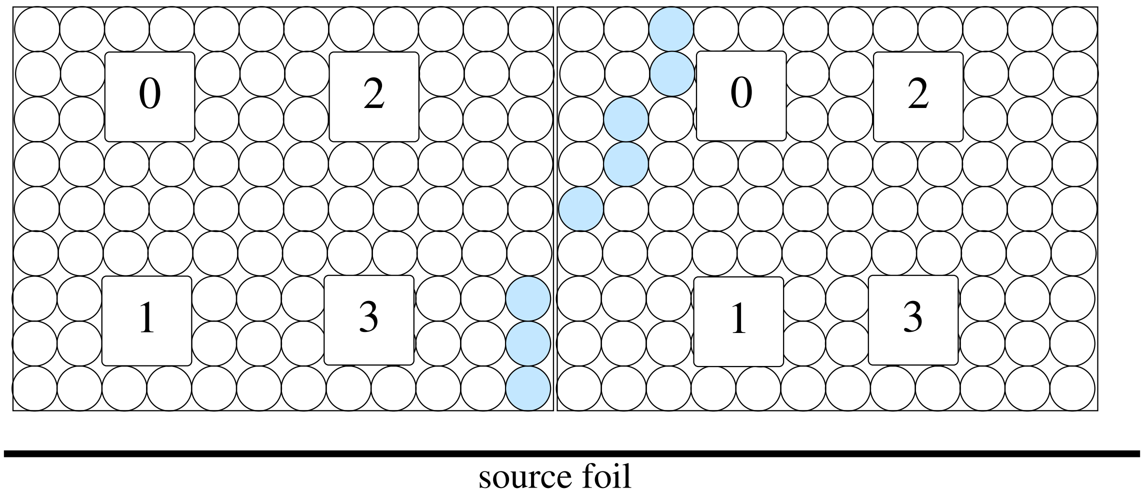

Figure 37: Two adjacent zones view of the matrix with a typical track from the source foil to the calorimeter.

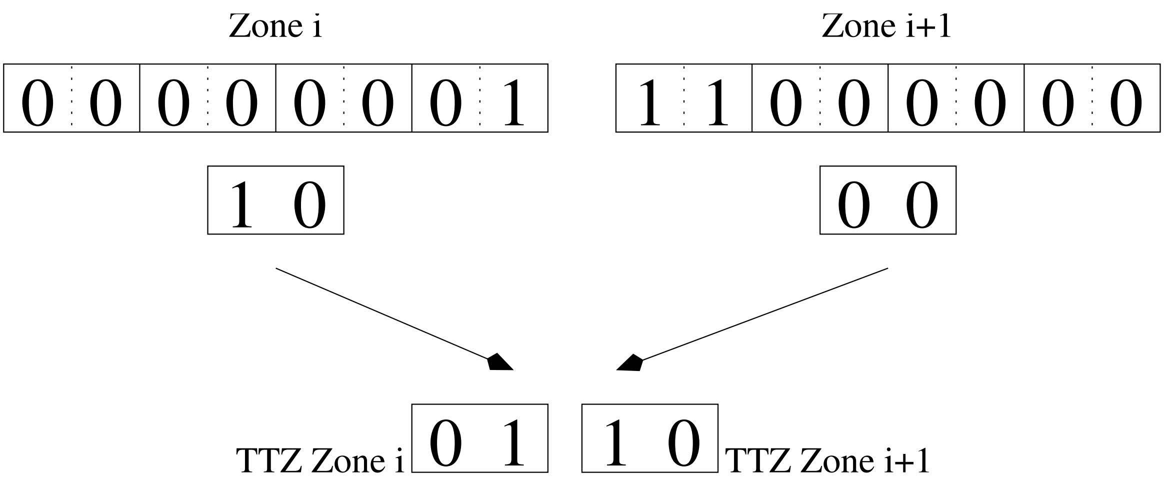

Figure 38: Corresponding [8 bits] word expressing verticality/horizontality from event displayed in

8 Readout

8.1 Calorimeter and gamma veto

8.1.1 Basic informations

- Default sampling frequency: $f_{sampling}$=40 MHz$\times i \times$16 with i an integer contains in $[1; 5]$ so $f_{sampling} \in [0.64; 3.2]$ GHz. $\Delta t_{sampling} \in [0.3125; 1.56]$ ns.
- Maximum sampling depth: 1024 $\times$ 12 bits samples
- Sampling time window $\in [0.320; 1600]\mu s$.

8.1.2 Composition of calorimeter event data

A calorimeter hit (main wall, X-wall or gamma veto blocks) consists in several raw informations given for a triggering event :

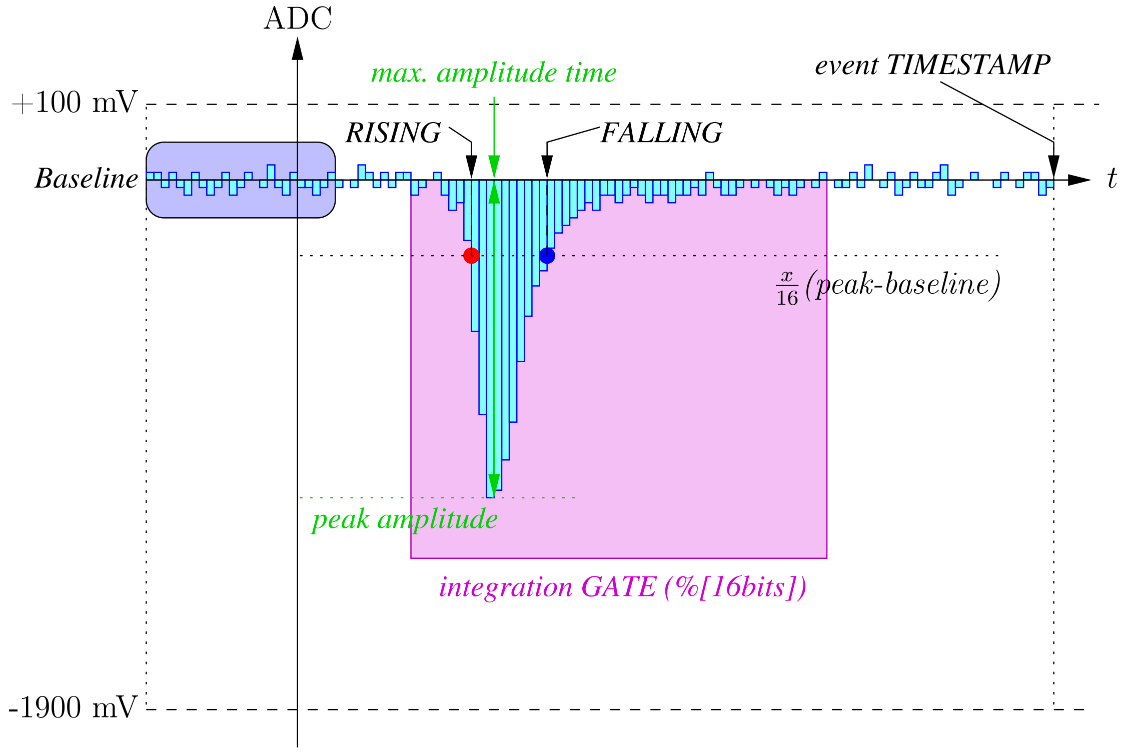

Figure 39: ADC sampling of a PMT signal wave form.

⋆ A header : [96 bits]

HWHEADER : [8 bits]
Constant pattern used for recognizing the beginning of the trame.

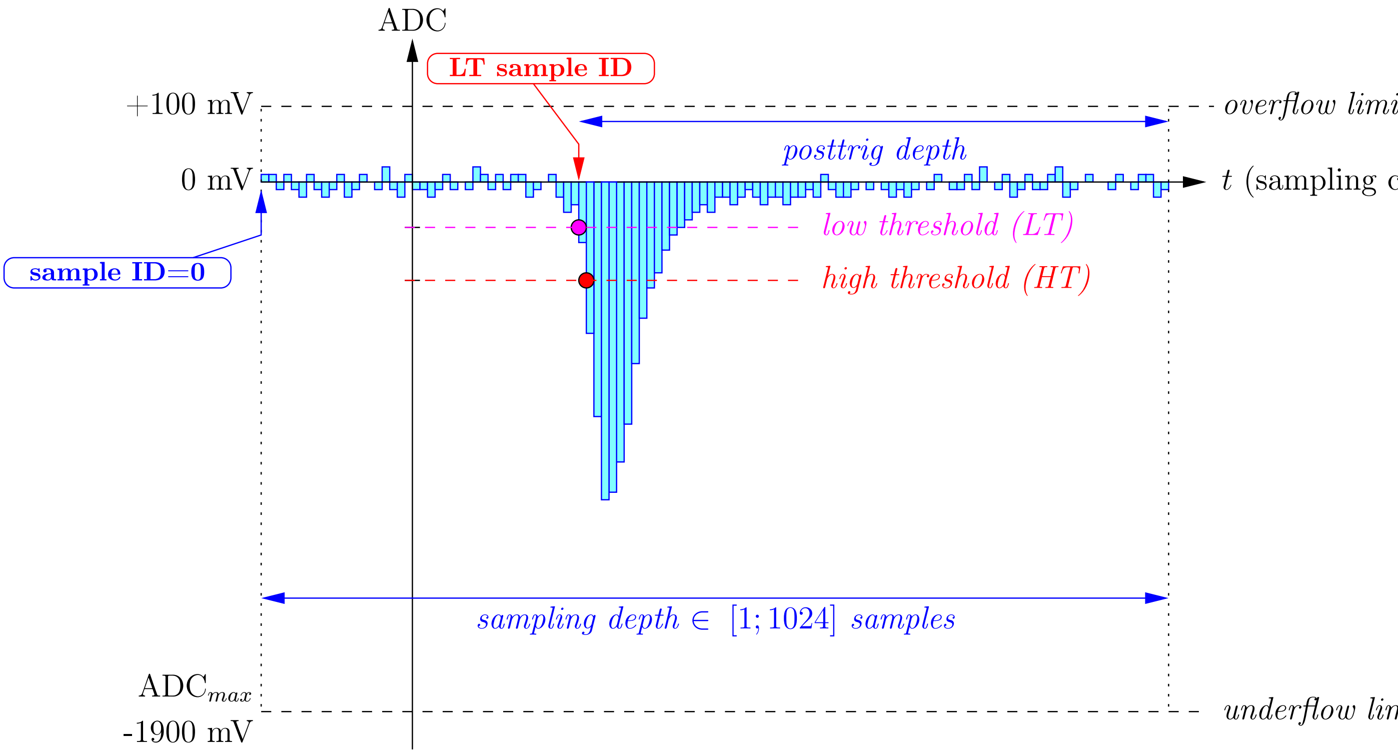

Figure 40: ADC sampling of a PMT signal wave form.

TRIGGER ID : [5 bits]
transmitted by the TB to associate the hit to some central trigger decision

ADDRESS of the Samlong : [16 bits]
(uses the 12-bits register `BOARDADDR`)

- Module ID [5 bits, `bitmask=0xF800`]: `module ID=0-19` (demonstrator `ID` is set at `0`, `BOARDADDR & 0xF80`)
- Crate ID [2 bits, `bitmask=0x600`]: `crate ID=0-2` (considering only calorimeter crates, no `rack ID` is stored, `BOARDADDR & 0x60`)
- Board ID [5 bits, `bitmask=0x1F0`]: `board ID=0-20` (`BOARDADDR & 0x1F`)
- Samlong ID [4 bits, `bitmask=0xF`]: `channel ID=0-7`

TIMESTAMP : [48 bits]
Absolute time of the experiment tagging the last sample store by samlongs.

DETECTED THRESHOLD : [4 bits]

1. LT0 : at 1 if crossing Low Threshold for channel 0
2. HT0 : at 1 if crossing High threshold channel 0
3. LT1 : Low threshold channel 1
4. HT1 : High threshold channel 1

DESCRIPTION word (signal waveform) [1 bit] (`SIG_HASWAVEFORM`).

SPARE To take into account that bitset are manage by [24 bits] words : [14 bits].

- ⋆ The data : %[24 bits]
  each data will be sent for the 2 calorimeter channels from the same SAMLONG. [4].

  WAVEFORM : only if the `SIG_HASWAVEFORM` bit is set to `1`
  The `SIG_NOS` [6 bits] define the Number Of Sample to save (defined in register). Available value from 16 to 1024 samples (%16 samples). The `START_SAMPLE` [10 bits] define the first sample to store the digitized signal.

  - Signal waveform sampling array (`SIG_SAMPLEARRAY`) : 2 × NOS × [12 bits]. Each ADC sample is stored by a [12 bits] word and the waveform is stored for the two samlong channel. each encoded ADC (ADC unit = 0.61 mV) value ranges from `0x0` to 2^{12}=`0xFFF`=4095 :
    - ∗ `0x0` : -1900 mV
    - ∗ `0xFFF` : +100 mV
    - ∗ `0xA000` : ADC overflow
    - ∗ `0x8000` : ADC underflow

    note: To confirm with Jihanne and Dominique

  METADATA ([108 bits]× 2 for each Samlong channel)

  - BASELINE [16 bits] :
    Mean value of the first 16 samples of the waveform.
    A baseline mean value is computed within the FE_PGA of the SNCaloFEB as the mean value of the signal using first N_{ped} ADC samples.
    - ∗ MSB [13 bits]
    - ∗ LSB [3 bits] (0.125 ADC unit)

    First [16 bits] word for channel 0 and the next one for channel 1.

    note: Jihanne : define which one is the #0 and the #1
  - CHARGE [23 bits] :
    The choice of baseline substraction can be setup (activate/desactivate).
    An integrated charge value is computed within the Ctrl_PGA of the SNCaloFEB as the sum of N_q ADC samples. N_q is a multiple of 16 samples (setup in `CHARGE_LENGHT`). The beginning of the integration gate can be defined in two different ways :
    1. N samples before the maximum amplitude. (called dynamic charge)
    2. N_start first sample from 16 to 1024. (be careful to start after the baseline definition)

[4] channel #0 is the top one from the SAMLONG and the channel #1 is the bottom one

- PEAK AMPLITUDE [16 bits] :
  Baseline has been automaticaly substracted. Signed value [13 bits] + Decimals [3bits].
  In case of OVERFLOW : PEAK AMPLITUDE will be set at MAX AMPL. VALUE.
- TIME MAX AMPLITUDE [10 bits] : Sample number of the max ADC.
  In case of OVERFLOW : Sample number of the first maximum value.
- RISING TIME [19 bits] : obtained through the crossing threshold values.
- FALLING TIME [19 bits] : obtained through the crossing threshold values.
  The threshold is given by a ratio of (PEAK − BASELINE). The ratio is setup by users by 1/16 step in a scale of 0 to 1[5].
  The time is obtained by a [10 bits] sample position and [9 bits] fine position by time interpolation.
- SPARE [5 bits] : to take into account that bitset are manage by [24 bits] words.

  note: discuss with Dominique : What happends for a pile up event ?

8.1.3 Data transfer from the SNCaloFEB to the Calorimeter Control Board

8.1.4 Local storage of calorimeter primitive data in the Calorimeter Control Board

8.2 Tracker

8.2.1 Composition of tracker primitive data

A geiger cell hit consists in several raw informations :

⋆ A header : [48 bits]

TRIGGER ID [16 bits] : Transmitted to associate the hit to some central trigger decision

ADDRESS [16 bits] (uses the 12-bits register `BOARDADDR`) :

- Crate ID [2 bits, `bitmask=0x0x1800`]: `crate ID=0-2`
- Board ID [5 bits, `bitmask=0x0x7C0`]: `board ID=0-20`
- Feast+Channel ID [6 bits, `bitmask=0x0x3F`]: `feast ID=0-1` and `channel ID=0-17` in NEMO-3 mode, `channel ID=0-26` in alternative mode.

DESCRIPTION [8 bits / 16 bits] :

- `bitmask=0x0x1` : mode (`MODE`) [1 bit] set at 0 for alternative mode and 1 for NEMO 3 mode.

[5] To defined with the maximum signal slope.

- `bitmask=0x0x` : anode t_0 (`HAS_ANODE_T0`) [1 bit].
- `bitmask=0x0x` : anode t_1 (`HAS_ANODE_T1`) [1 bit].
- `bitmask=0x0x` : anode t_2 (`HAS_ANODE_T2`) [1 bit].
- `bitmask=0x0x` : anode t_3 (`HAS_ANODE_T3`) [1 bit].
- `bitmask=0x0x` : anode t_4 (`HAS_ANODE_T4`) [1 bit].
- `bitmask=0x0x` : cathode t_5 (`HAS_CATHODE_T5`) [1 bit].
- `bitmask=0x0x` : cathode t_6 (`HAS_CATHODE_T6`) [1 bit].
- `bitmask=0x0x` : unused [8 bits]

⋆ The data : [336 bits]

TIMESTAMPS : based on one anodic signal and two cathodic signals crossing thresholds[6]. T0 to T6 are defined as presented on fig.41.
Timestamps are based on the absolute time of the experiment.

- T0 [48 bits] : First crossing negative threshold on anodic signal
- T1 [48 bits] : Second crossing negative threshold on anodic signal
- T2 [48 bits] : Third crossing negative threshold on anodic signal
- T3 [48 bits] : First crossing positive threshold on anodic signal
- T4 [48 bits] : Second crossing positive threshold on anodic signal
- T5 [48 bits] : Crossing positive threshold on bottom cathodic signal
- T6 [48 bits] : Crossing positive threshold on top cathodic signal

The size of the tracker data is [384 bits] / geiger cell.

8.2.2 Data transfer from the SNTrackerFEB to the Tracker Control Board

8.2.3 Local storage of tracker primitive data in the Tracker Control Board

8.3 Typical data size

[6] Thresholds configured channel per channel

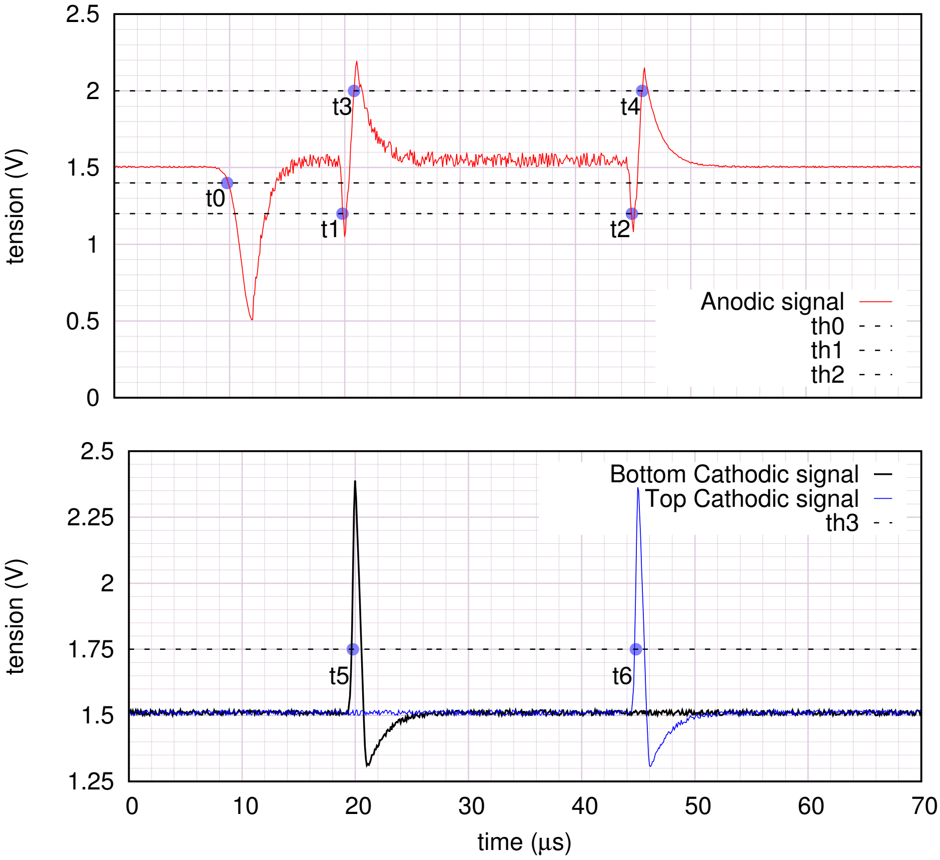

Figure 41: Geiger signals

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