Participation to the design and test of the trigger primitives generation from the CMS Endcap Calorimerter HGCAL during the LHC Phase-2 (2029+)

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Contents

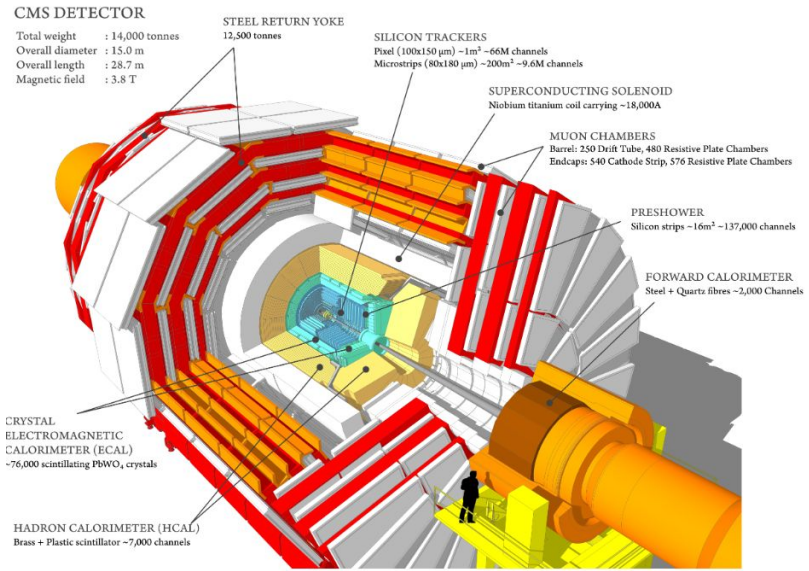
I - LHC, CMS and LHC Phase 2

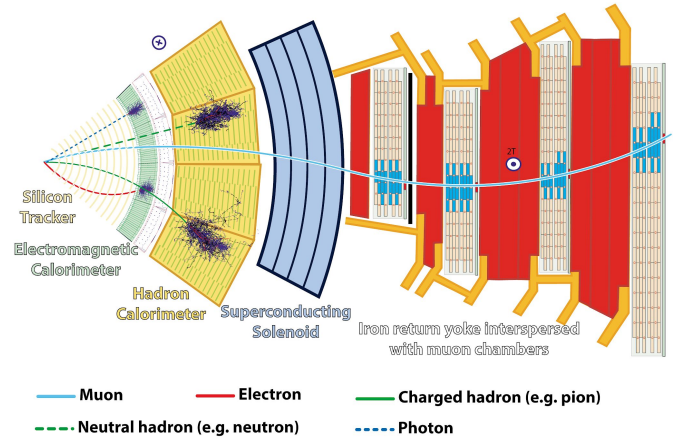
Overview of LHC

- LHC = Large Hadron Collider (protons or heavy ions)
- Started in 2008
- Discovery of the Higgs boson in 2012
- 27 km ring
- 4 experiments (detectors) : CMS, ATLAS, ALICE, LHC-b
- About collisions today :
  - each 25ns → 40 MHz
  - 13.6 TeV
  - 60 events per BX in the CMS today = pile-up 60

I - LHC, CMS and LHC Phase 2

Overview of the Compact Muon Solenoid





cms.cern

I - LHC, CMS and LHC Phase 2

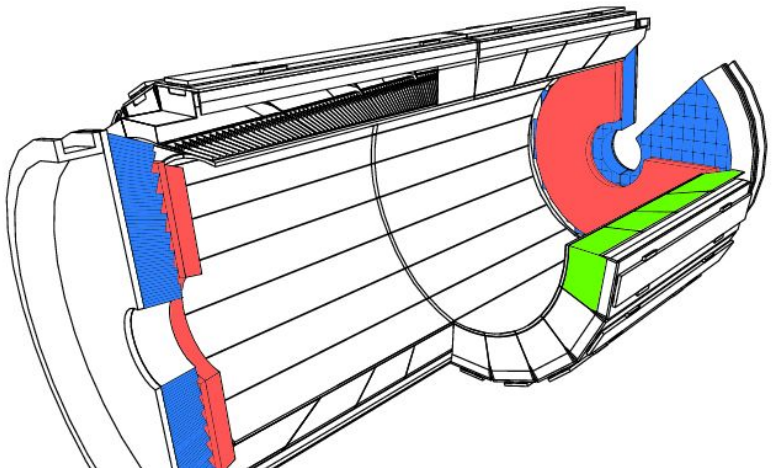
Overview of the LHC phase 2 (first run programmed for 2029)

High Luminosity LHC (HL-LHC) : increase by a factor 10 the luminosity of the LHC (compared to the design value) ~ 3 times more than today

→ 200 collisions per BX : 200 PILEUP

Replace some parts of the CMS :

→New endcaps named HGCAL



II - HGCAL and the TPG system

Overview of the High Granularity Calorimeter (HGCAL)

Principle : measure the energy deposit

- electrons and photons in the electromagnetic part
- hadrons in the hadronic part

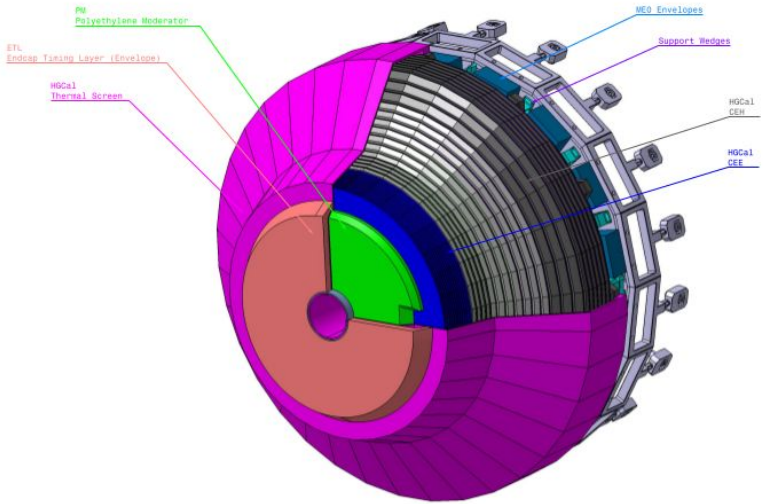
Why granularity ?

→ a lot of pile-up near the BEAM PIPE, it is needed to have a good precision of the position (and the shape) of the energy deposit (~ understand well what happens in a BX)

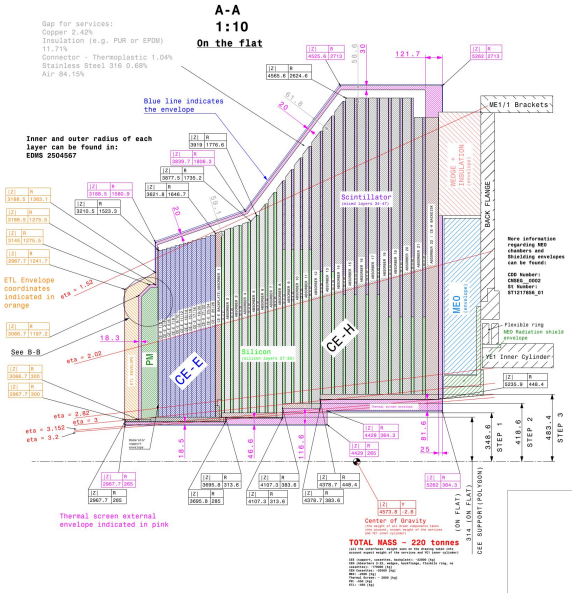
→ TRANSVERSE and LONGITUDINAL granularity

II - HGCAL and the TPG system

Overview of the High Granularity Calorimeter (HGCAL)



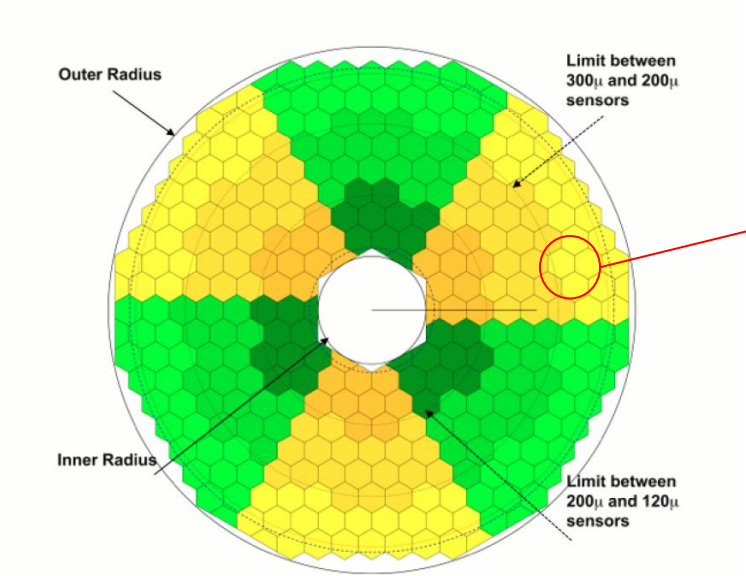
HGCAL endcap



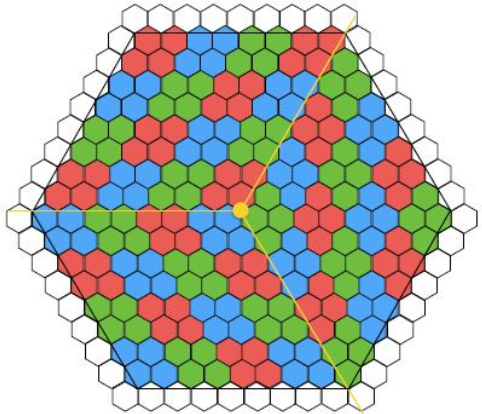
Transverse granularity

II - HGCAL and the TPG system

Layout of a CE-E layer (CE-E = Electromagnetic part)



One layer ~ 300 modules

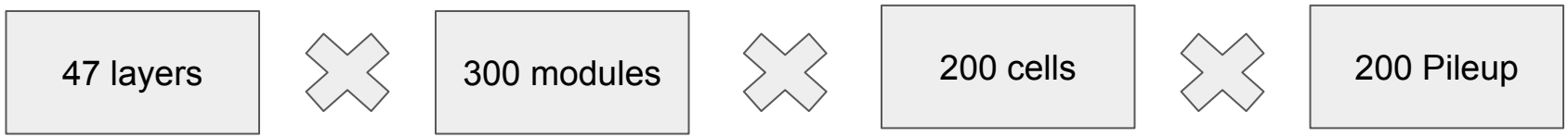


One “module” :

- 196 cells (= smallest hexagons)
- 48 Trigger cells (= 4 cells)

II - HGCAL and the TPG system

Need a trigger system for the HGCAL



Before the L1 trigger :

300 Terabits of data per second

40MHz

After the L1 trigger :

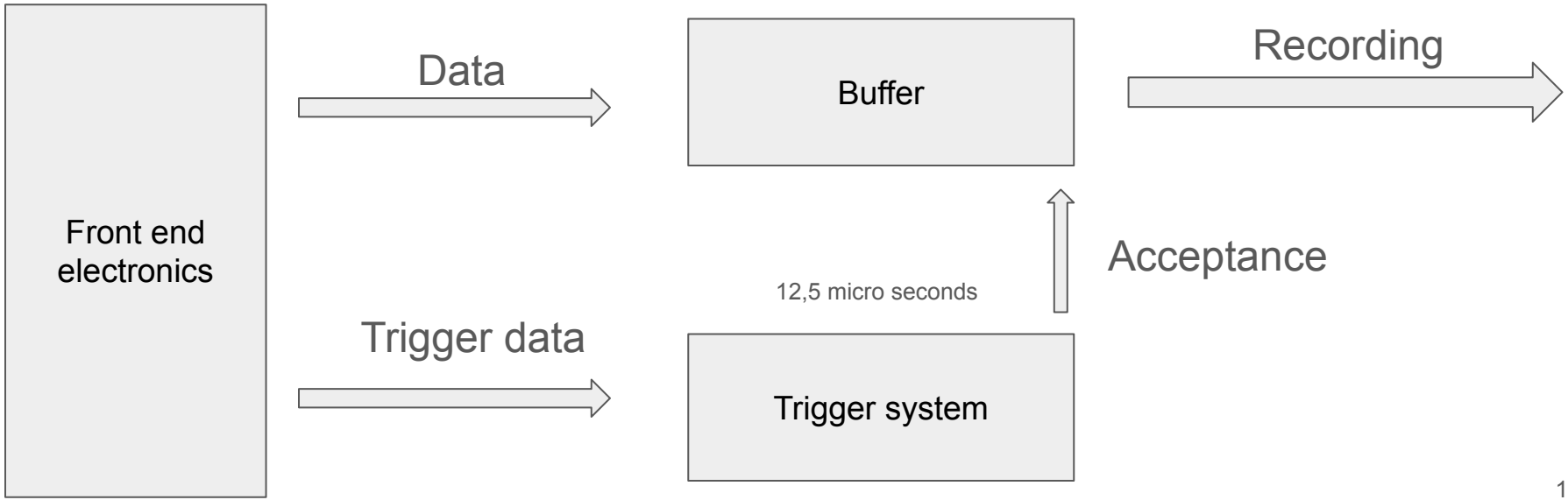
12 Terabits of data per second

750 kHz

II - HGCAL and the TPG system

The trigger system

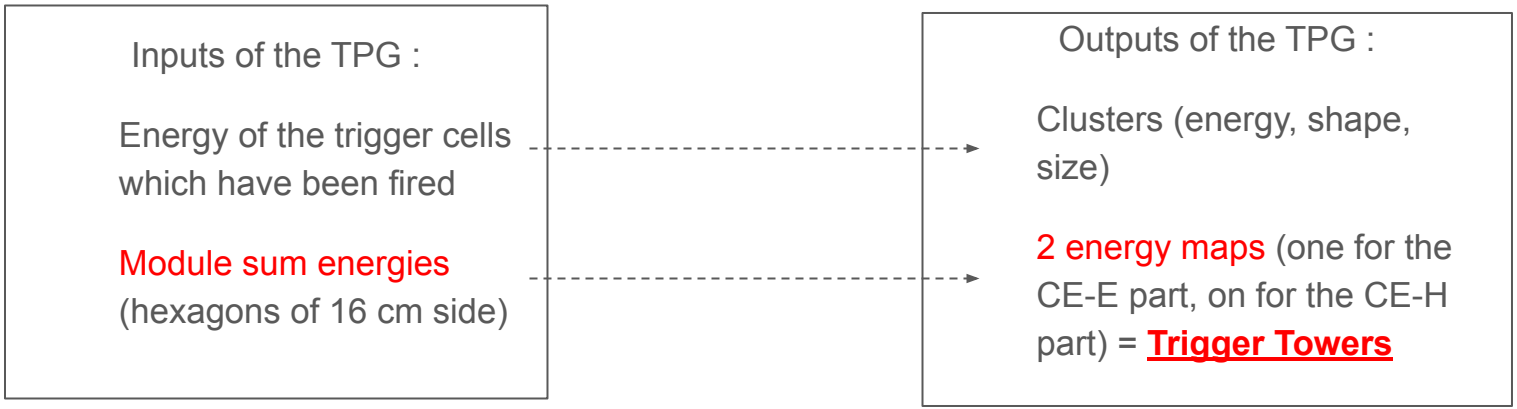
Principle : reduce the amount of data to record



II - HGCAL and the TPG system

Overview Trigger Primitive Generator system

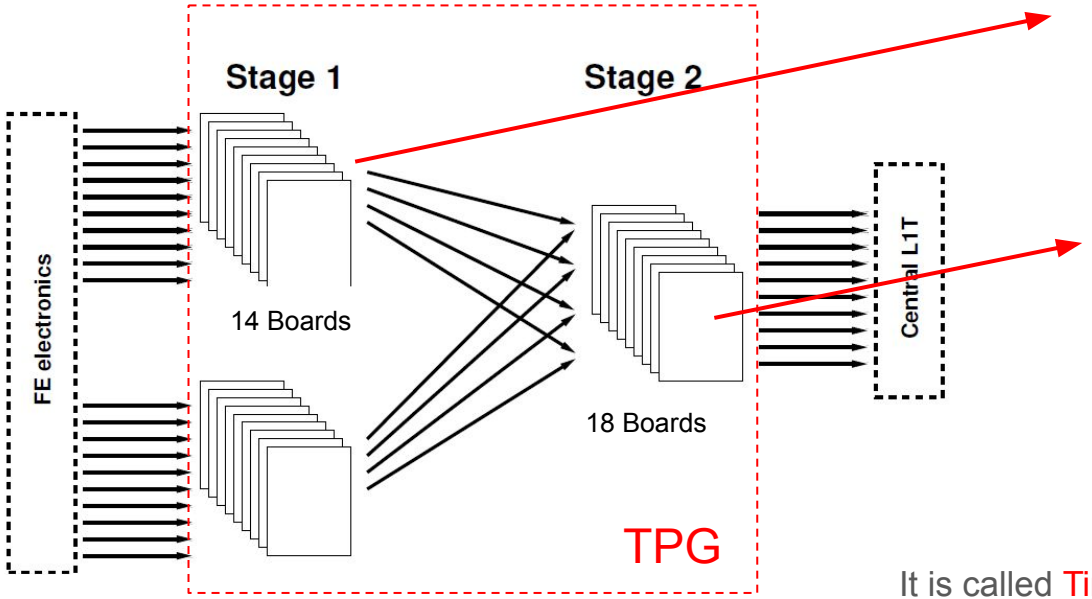
Principle : first treatment of the data before the trigger system



Idea : divide the HGCAL into two encaps and each endcaps into 3 120° sectors → 6 TPG systems

II - HGCAL and the TPG system

Stage 1 and Stage 2 of the TPG (One sector)



Why 14 S1 boards ?

each board treats 2 or 3 layers
(remember : 47 layers in HGCAL)

Why 18 S2 Boards ?

S2 board number 1 → BX n
S2 board number 2 → BX n+1
⋮
S2 board number 18 → BX n+17

It is called Time Multiplexing :
It allows to have more time in FPGA to do operations

II - HGCAL and the TPG system

Recap of the main elements

Granularity : because of pileup

- transverse : modules
- longitudinal : layers

TPG : first treatment of data

- clusters
- energy maps (my work)

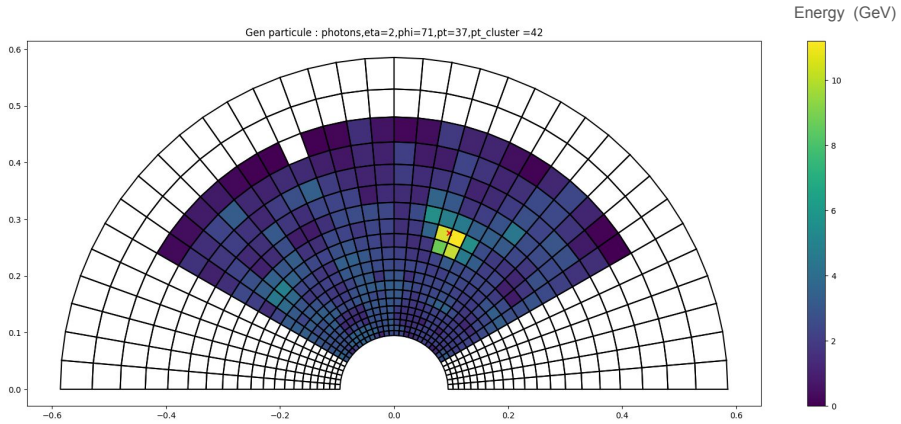
→ two stages in TPG :

- Stage 1 : some layers of a sector
- Stage 2 : all layers of a sector (18 boards for TM)

III - My work : partial trigger towers building

Introduction to (partial) Trigger Towers

Principle : get two energy maps as outputs of the TPG (S2 board outputs)



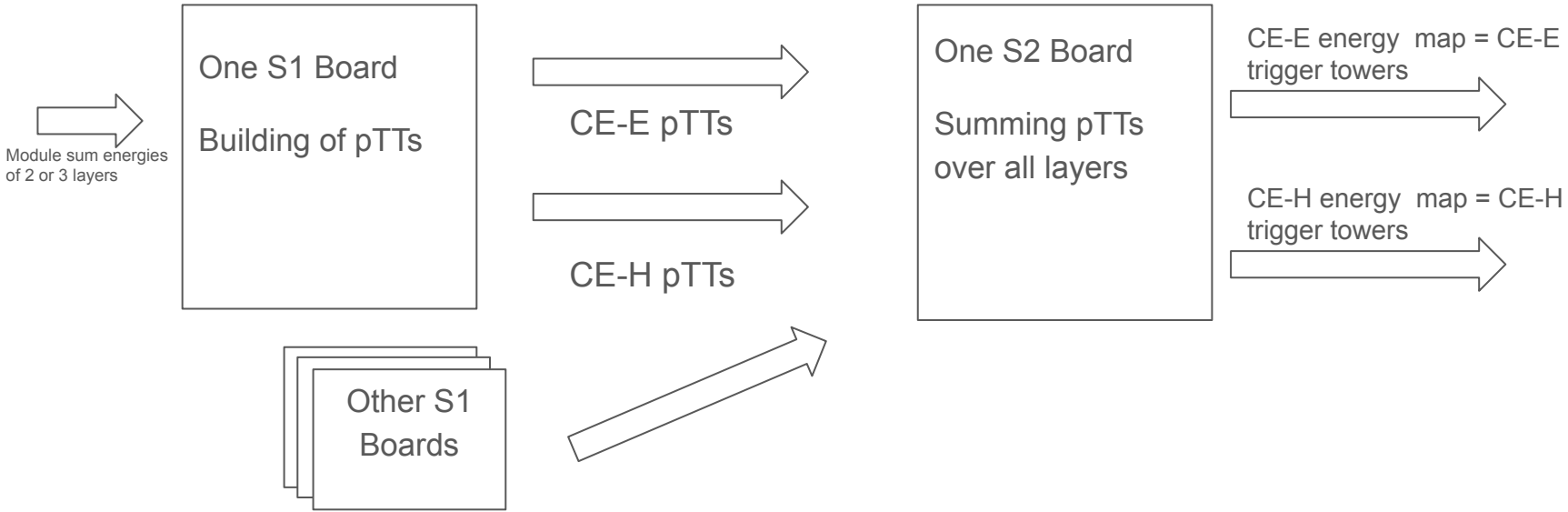
pi/36 in eta and pi/36 in phi
=
20*24 bins for a 120° sector

Example of an energy map for a single photon with 200 PU (for the CE-E part)

III - My work : partial trigger towers building

Overview of the “energy maps” chain (One sector)

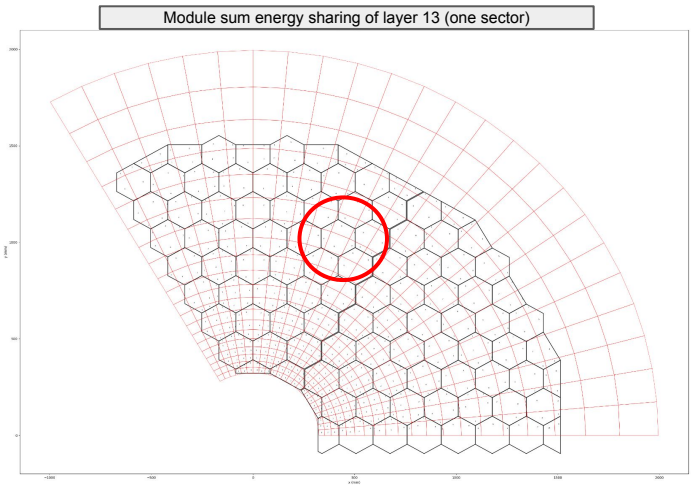
Trigger Towers = energy bins in eta,phi coordinates || partial = not summing over all layers

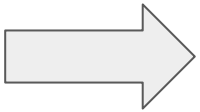


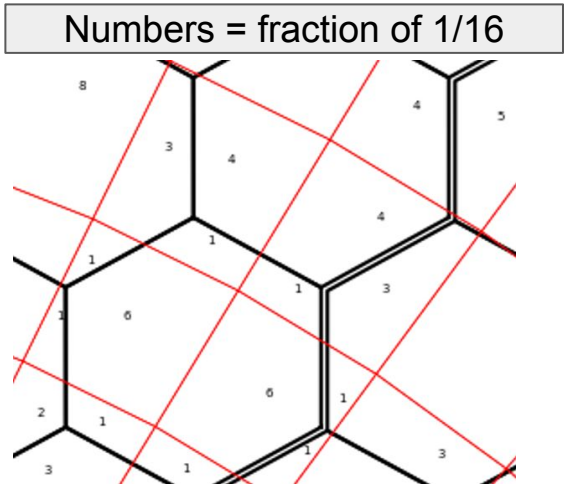
III - My work : partial trigger towers building

Step 1 : pTT building (One sector)

Idea : share the module sum energies into bins according to the overlap







I did it for the 34 trigger layers, each composed out of about 100 modules

III - My work : partial trigger towers building

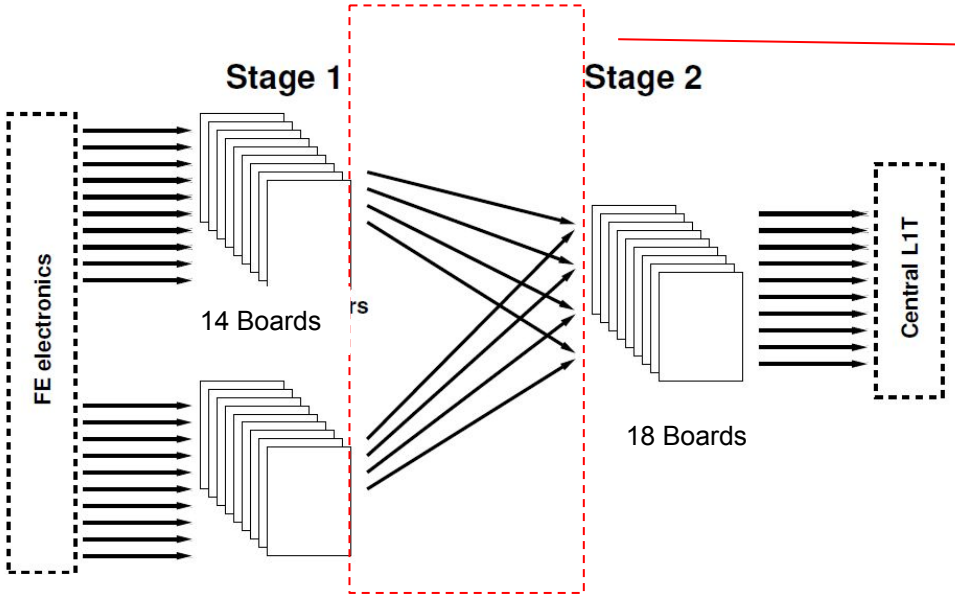
Step 1 : pTTs building (One sector)

How ?

- I use as input the module geometry of one sector
- I use python to create the energy sharing
- I produce 2 vh files per Stage 1 board (1 per the CE-E layers, 1 for the CE-H)
- I send these file to engineers in Split, they use them to develop the firmware

III - My work : partial trigger towers building

Step 2 : pTTs mapping into links (One sector)



- produce files to allocate pTTs into links
- work on the 'bit words' sent by Stage 1

== work on the packer of Stage 1

III - My work : partial trigger towers building

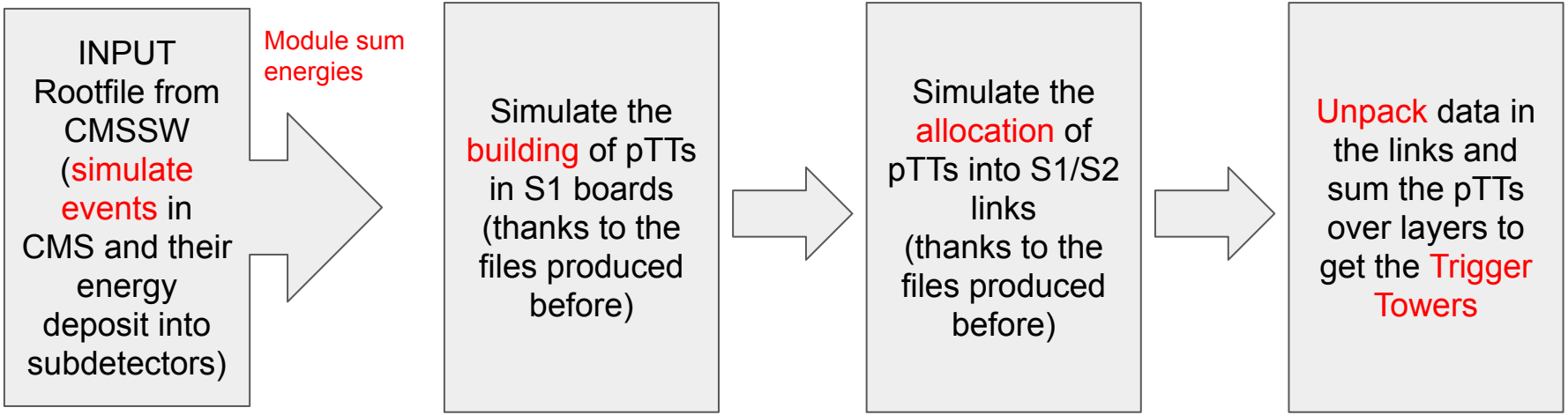
Recap on pTTs

- Built in Stage 1 Boards
- Sent into S1/S2 links
- pTTs of same eta,phi coordinates are summed into S2 boards
- S2 boards return two energy maps (bins of these maps = Trigger Towers)

III - My work : partial trigger towers building

Step 3 : simulate the two first steps (One sector)

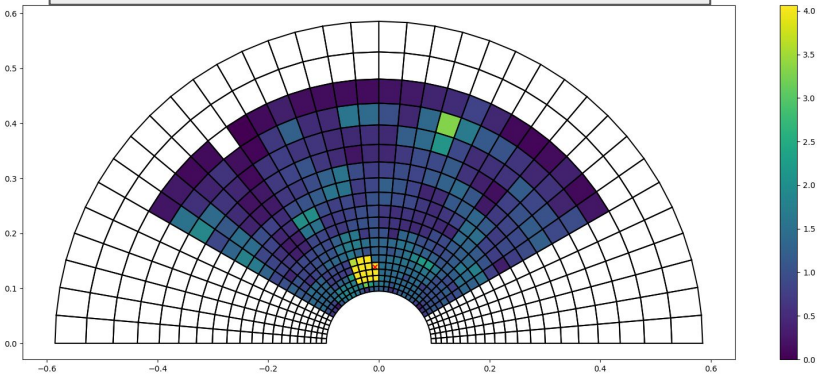
Idea :



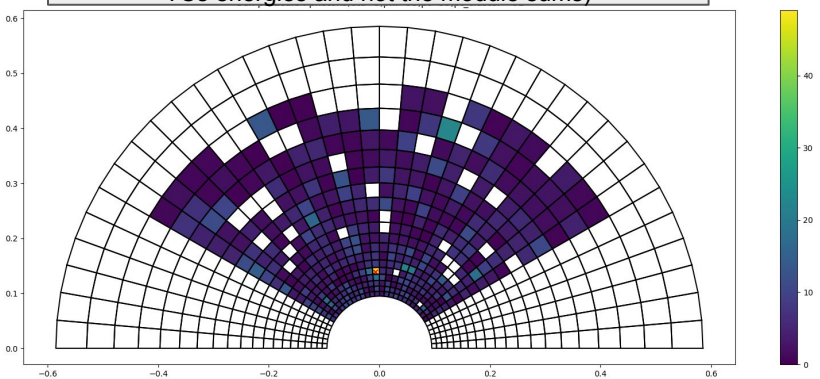
III - My work : partial trigger towers building

Step 3 : simulate the two first steps (One sector)

Trigger Towers for a single photon simulation (CE-E part)



Energy map based on the data in the rootfile (from the TCs energies and not the module sums)

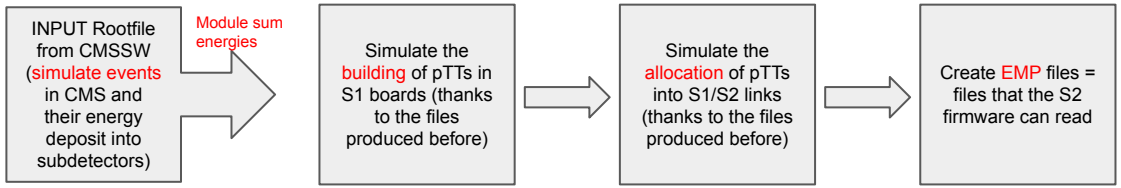


Good correspondence (less precision, because modules are bigger than TCs)

IV - What to do next

Test the unpacker of the Stage 2 Boards

Idea :



Testing S2 Board = make a loop (because the firmware is not yet created

IV - What to do next

Produced new files for the building of pTTs for real tests

Why ?

→ the geometry of layers in the test is not the same as the one in HGCAL

→ need to redo the job for several specific geometries

Conclusion

-A lot of interactions needed to gather the information required to perform the task, not always available

-A lot of interactions on the follow-up to meet the need of the people using the results to develop the firmware

-Using python

-Using github for legacy

-All the code I produced is flexible and will help the HGCAL collaboration to implement new options in the continuously changing geometry

- In the last 2 months I contributed to the successful implementation of the TPG/TT geometry in the firmware of the new CMS Endcap Calorimeter HGCAL
- I have plans to also contribute to the different system tests and beam tests during the next 2 months of the internship