IMPERIAL

Development and validation of trigger primitive generation (TPG) algorithms of High Granularity Calorimeter of CMS

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(on behalf of the CMS collaboration)

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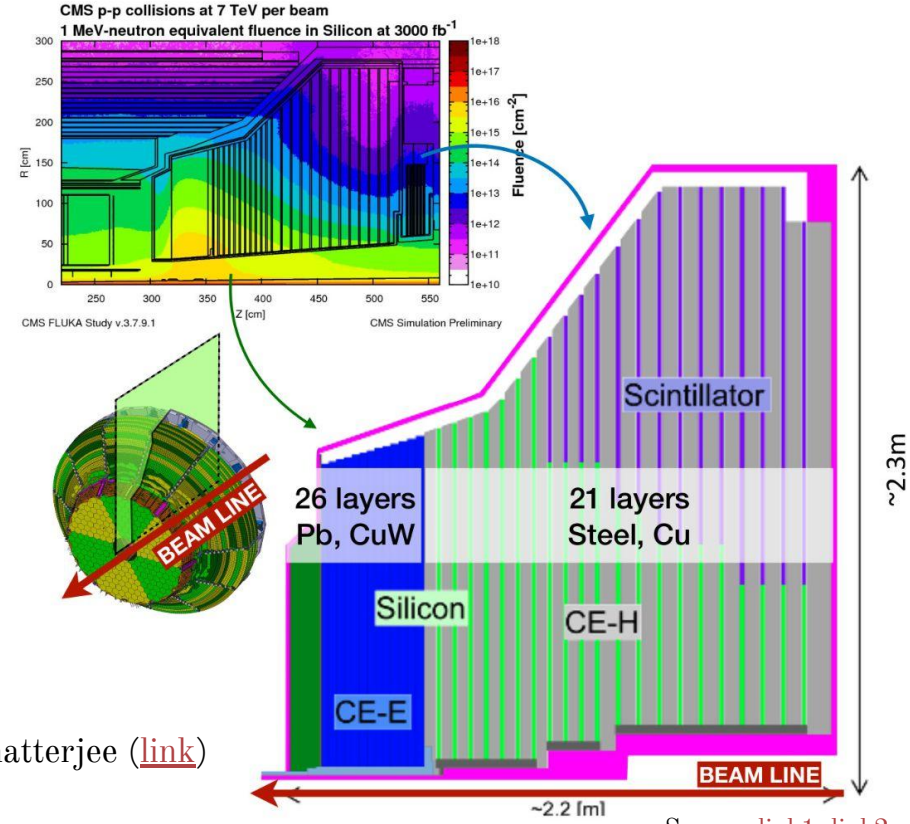
CMS High Granularity Calorimeter (HGCAL)

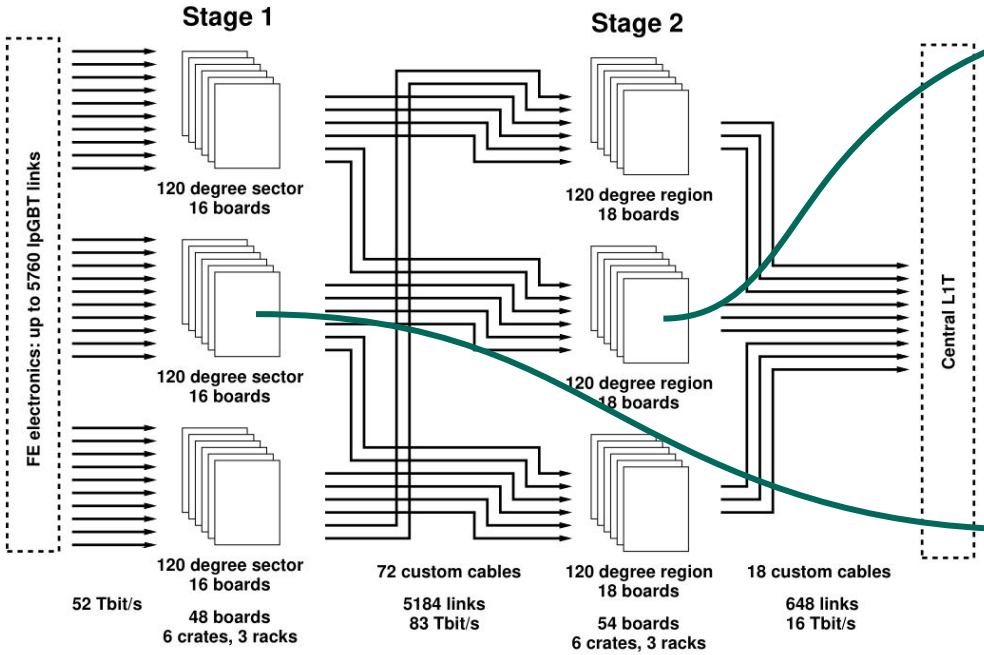
- A sampling calorimeter
- Replace ECal and HCal at $1.5 < |\eta| < 3$
- High pileup (~200) and rad. dose (~2 MGy)
- High granularity
  - (Si: 0.6-1.2 cm^2; Sci: 4-30 cm^2)
- Radiation tolerant Si sensors (120, 200, 300 μm) in high rad. zone
- CE-E:
  - 26 layers ($27.7X_0/1.6\lambda$)
- CE-H:
  - 21 layers (9.4λ)
- Channels- Si: 6M, Sci: 250K
- Precise timing ~30 ps
- Operation at -30°C
- 5D : x,y,z,t,E

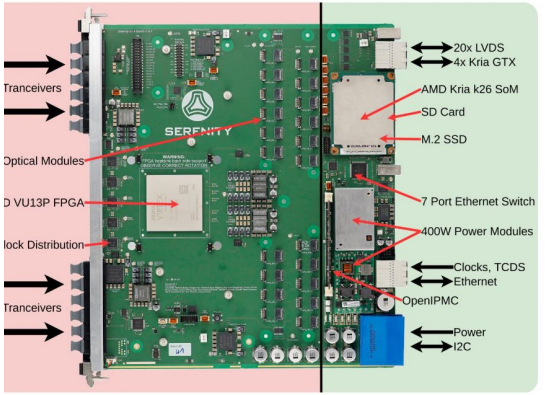


A detailed talk:
CMS High Granularity Calorimeter by Rajdeep Mohan Chatterjee (link)

Source: link1, link2

Backend hardware architecture



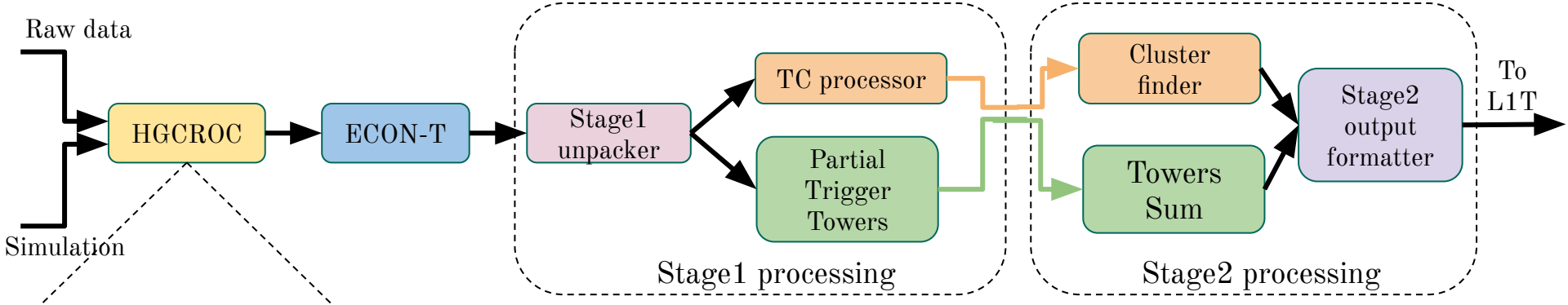


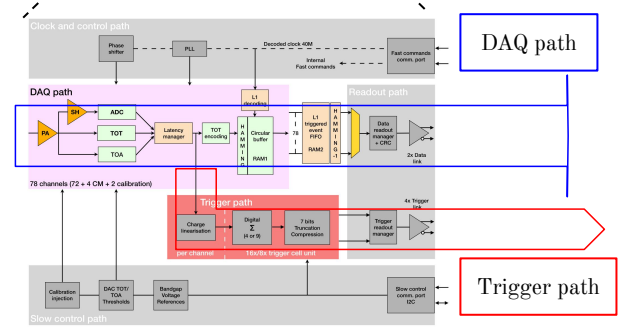
Same electronics board used for both Stages

Layout of Stage 1 and Stage 2 boards for one HGCAL endcap. The data rates shown are the bandwidths, not the expected actual rates. The full TPG system consists of two identical and independent copies of this layout.

Source: CMS-DN-24-005, link2

TPG Data flow and processing

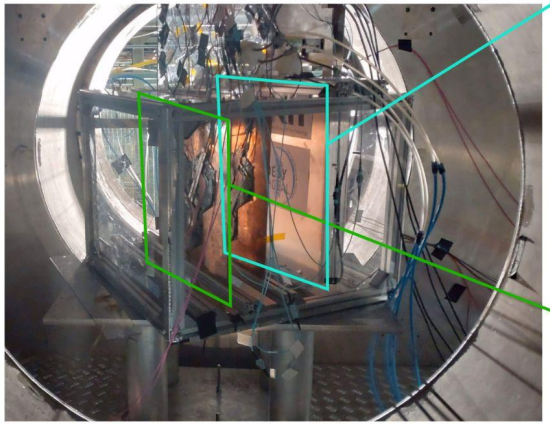


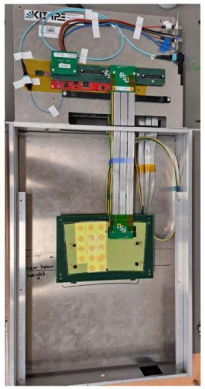


- Trigger Cell (TC): An array of 2x2 or 3x3 Si sensor cells or SiPM tiles
- Module Sum (MS): Total energy of an module [48 TCs for full modules]
- BestChoice: ECON-T operation mode, where a predefined number of most energetic TC are sent to the output along with the MS
- Super Trigger Cell (STC): A sum of 2x2 or 4x4 TCs. This is another ECON-T operation mode.

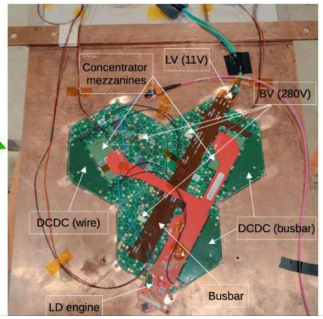
Test-beam setup (2024)

- Electron, pion and muon beams of 20 to 300 GeV energy range
- First run test with detector in 3T field
- HERD+XDAQ based run control

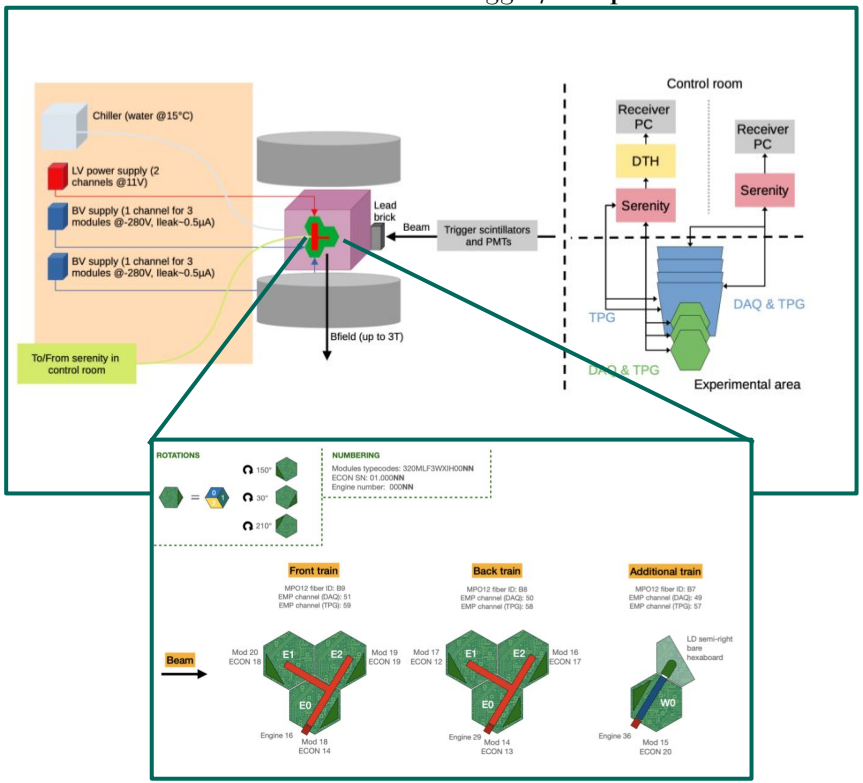




Silicon modules

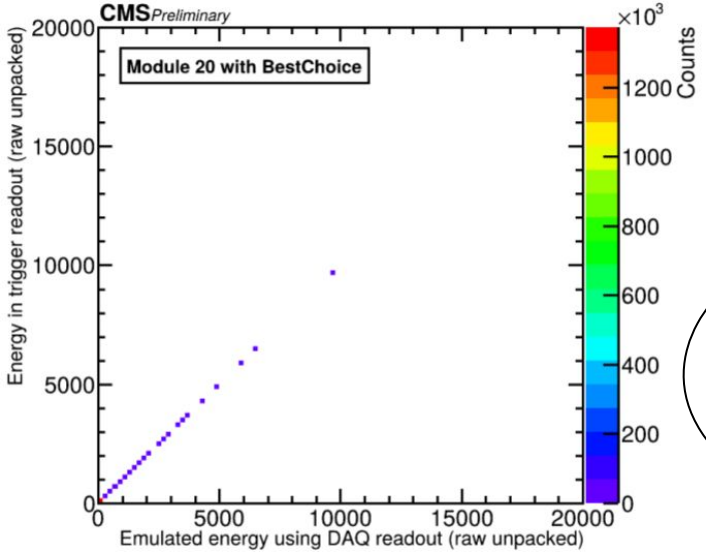


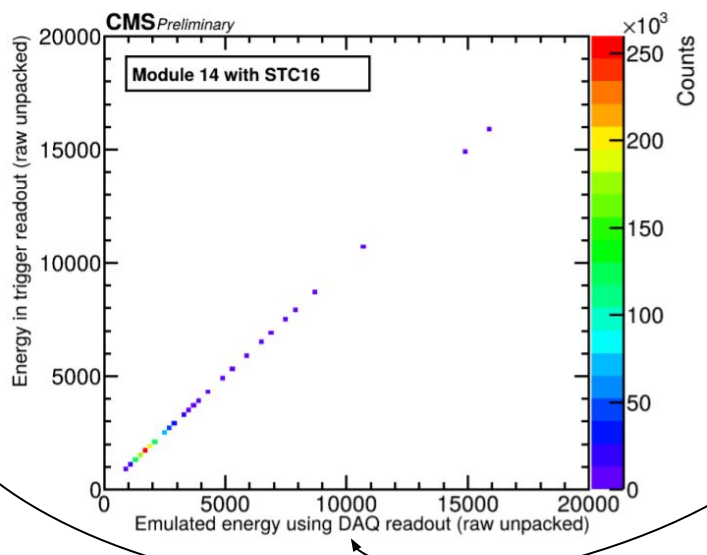
Detector bias and trigger/data path



Source: link

2024 test beam: TPG validation of FE ASICs

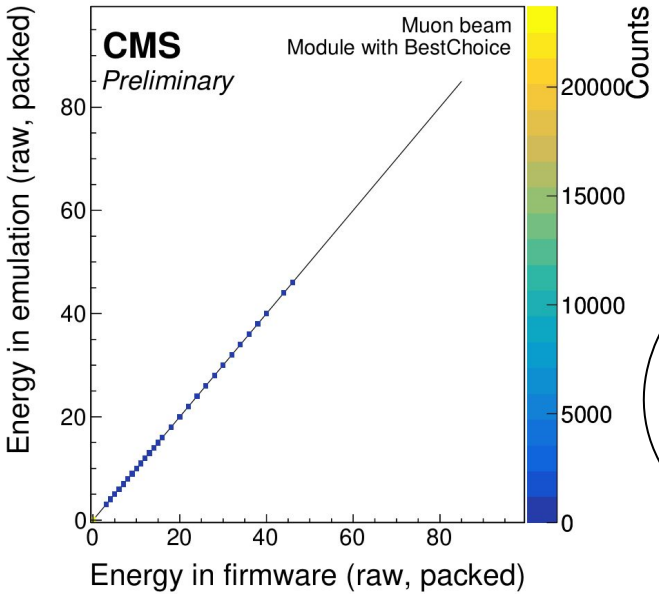


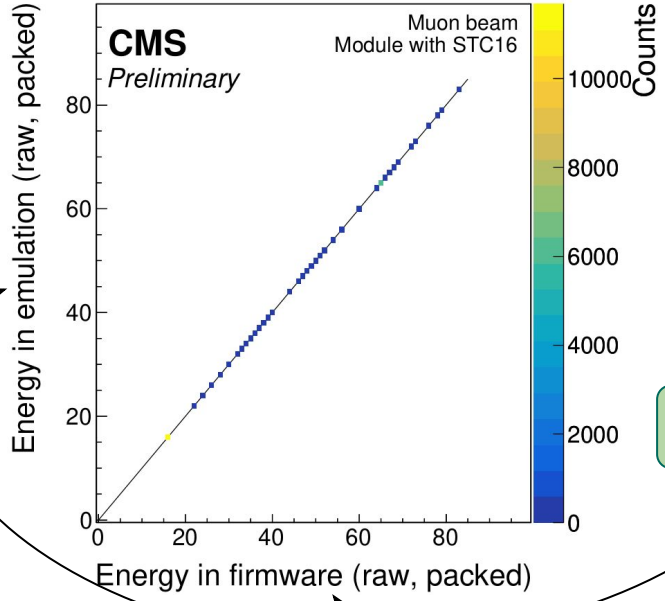


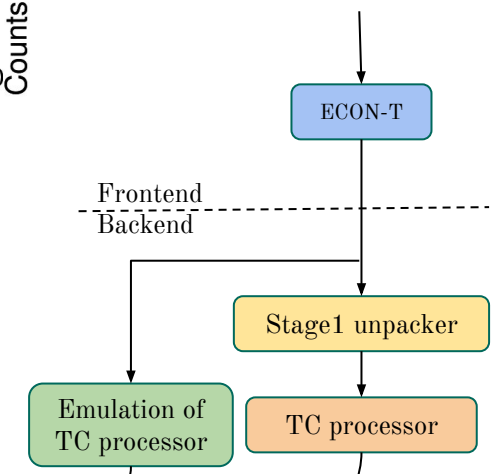
- Energy measured in trigger data is compared with the emulated energy using the DAQ data
- ECON-T data in two modes, BestChoice and super trigger cell (STC) are shown in left and right plots
- A full agreement between trigger data and emulation output confirms expected logic operation of ECON-T and HGCROC ASICs

Source: link

2024 test beam: Stage1 TC processor

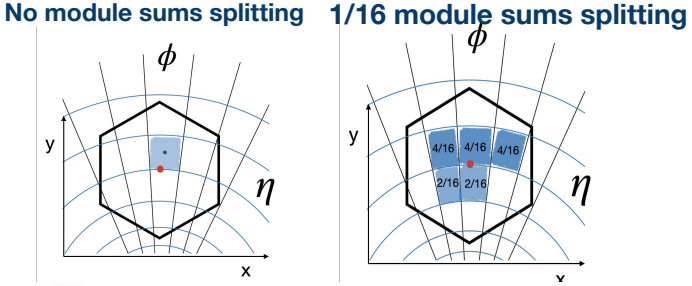




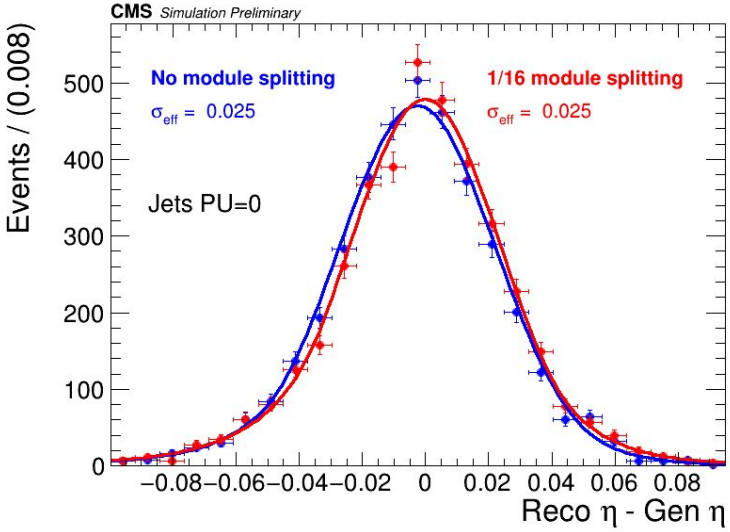


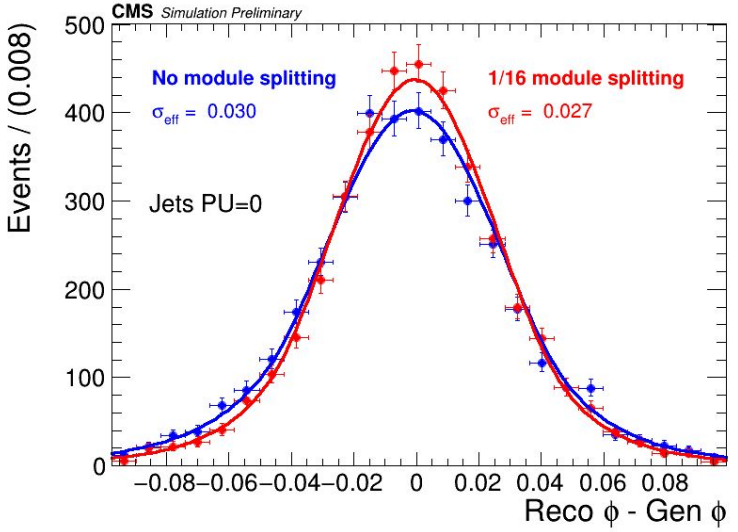
- Trigger cell (TC) processor sorts the address of the TCs to arrange them in columns suited for Stage2
- Comparison of the TC energy, for each assigned output slot of the TC processor, between firmware and emulation are shown for BestChoice and STC
- An perfect agreement of TC processor validates Stage1 unpacker and TC processor firmware components.

TPG processing and Stage1 Trigger Towers (TT)



- The module sum represents total energy of a module → can be used for TT
- The TT of Stage1 might affect trigger rate due to local energy spike in a module
- This can be overcomed if TT energies are divided into 16, Δη and Δφ cells





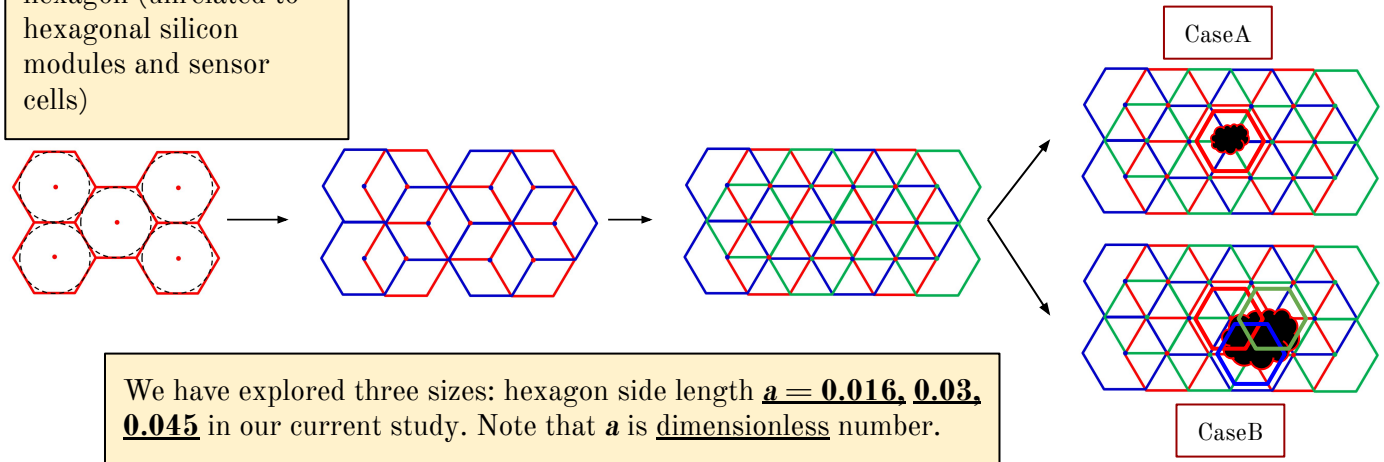
- The jet resolutions for PU 0 are shown for η and φ in left and right plots
- The jet resolution is found to improve by ~10% in φ

Stage2 clustering algorithm

Step1: Create a mesh of hexagons in (x/z, y/z) plane that can contain showers in a single hexagon (unrelated to hexagonal silicon modules and sensor cells)

Step2: Two additional such hexagonal meshes (blue and green) with an offset of ***a***, the side length of the hexagons.

Step3: Accumulate TCs into hexagons for each of the three grids (red, blue, and green)



Step4:

CaseA: The reconstructed energy is completely contained in a single hexagon (follow red outline),

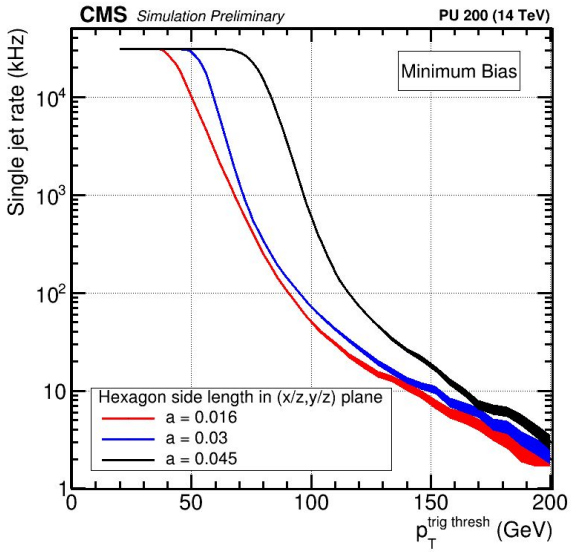
CaseB: The reconstructed energy can not be fully contained in a single hexagon (follow red, blue & green outlines).

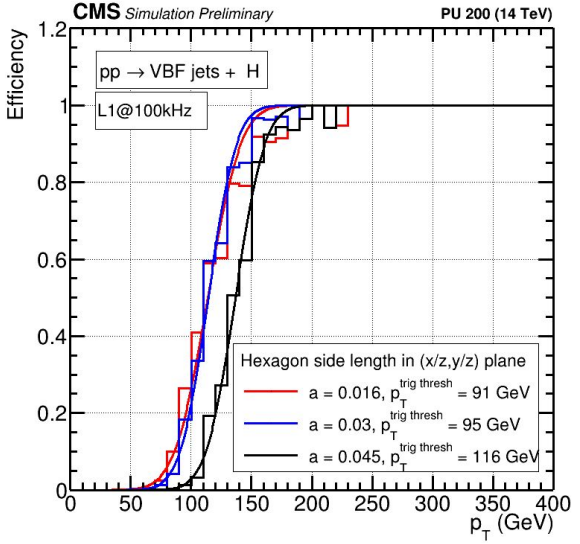
Select the one with highest energy and drop the other hexagons.
Suppose we select the green one, then red and blue are dropped.
This has an impact on the energy for large showers
It also depends on hexagon dimension.

We have explored three sizes: hexagon side length ***a* = 0.016, 0.03, 0.045** in our current study. Note that ***a*** is dimensionless number.

Near the middle layer of CE-E at 340 cm, the side length of hexagon is 5.44 cm corresponding to ***a* = 0.016**

Stage2 clusters: Background rates and trigger efficiencies





- The single jet background trigger rates, evaluated using minimum bias events with 200 pileup, are shown as a function of the trigger threshold in the left plot
- Three different mesh sizes corresponding to hexagon side lengths of a = 0.016, 0.03, 0.045 in the (x/z, y/z) plane are shown. Largest among them with a = 0.045 shows a highest background rate
- The efficiency turn-on curves for jets in a VBF sample with 200 pileup, at thresholds corresponding to background rates of 100 kHz (see left plot), are shown as a function of the transverse momentum of the jets in right plot
- The efficiency curve with a = 0.045 shows worst performance due to highest background contribution
- The trigger efficiency results using this semi-emulator implementation of the Stage2 clustering algorithm are found to be similar to those reported in the HGCAL TDR (CMS-TDR-019)

Summary and Outlook

- CMS is approaching to Phase2 upgrade
- A new high resolution detector HGCAL will replace Ecal+HCal ($1.5<|\eta|<3$)
  - Radiation tolerant, 6M+240K channels, 5D measurement
- In backend emulation and algorithm group, we perform
  - Validations using test beam data
    - Hardware validation of FE ASICs
    - Firmware validation of Stage1 TC processor
  - Physics performance studies
    - Stage1 partial trigger towers
    - Stage2 semiemulator
- Outlook
  - Further emulator validation following final version of Stage1 and 2 firmware
  - TPG validation with cassette readout
  - Integration of updated firmware to the CMS offline/online software framework, CMSSW

Thank you

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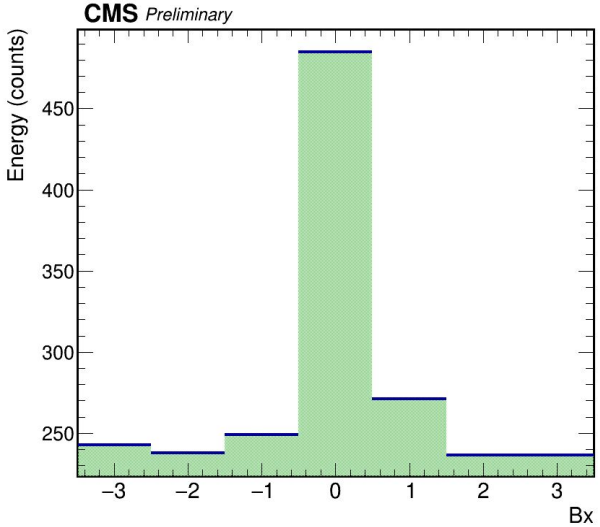
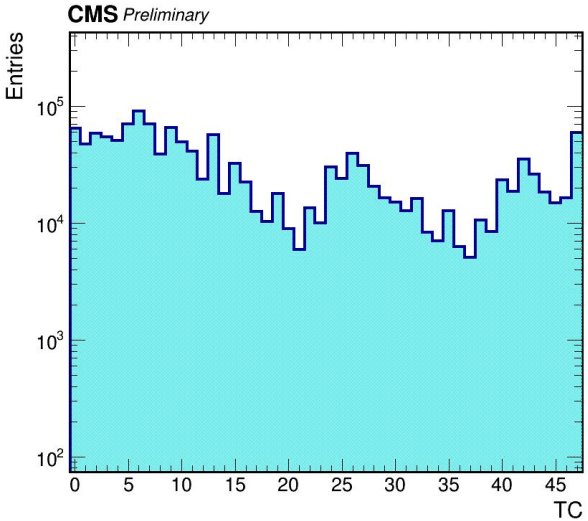
Trigger Primitives Generation

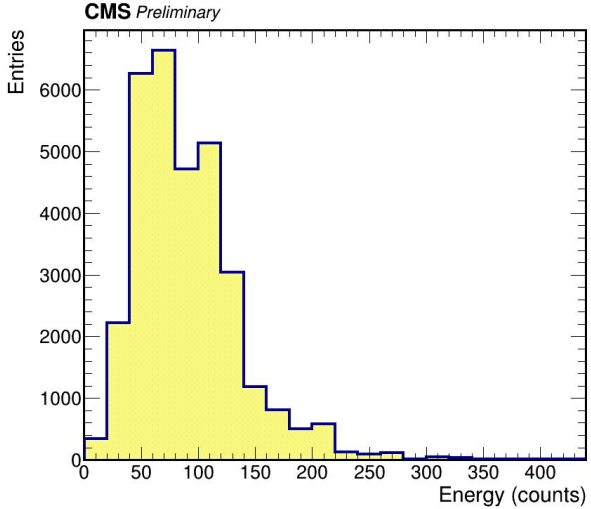
The alignment of trigger data with the bunches of the incoming beam, occupancy of the fired trigger cells and the distribution of energies in the trigger cells are some of the important checks for the HGCAL trigger data validations.



Caption: The module-sum represents the total energy of a given module. The module-sum energies of ECON-T data is shown as a function of Bx. The position of the peak at Bx=0 confirms the timing alignment of the trigger.

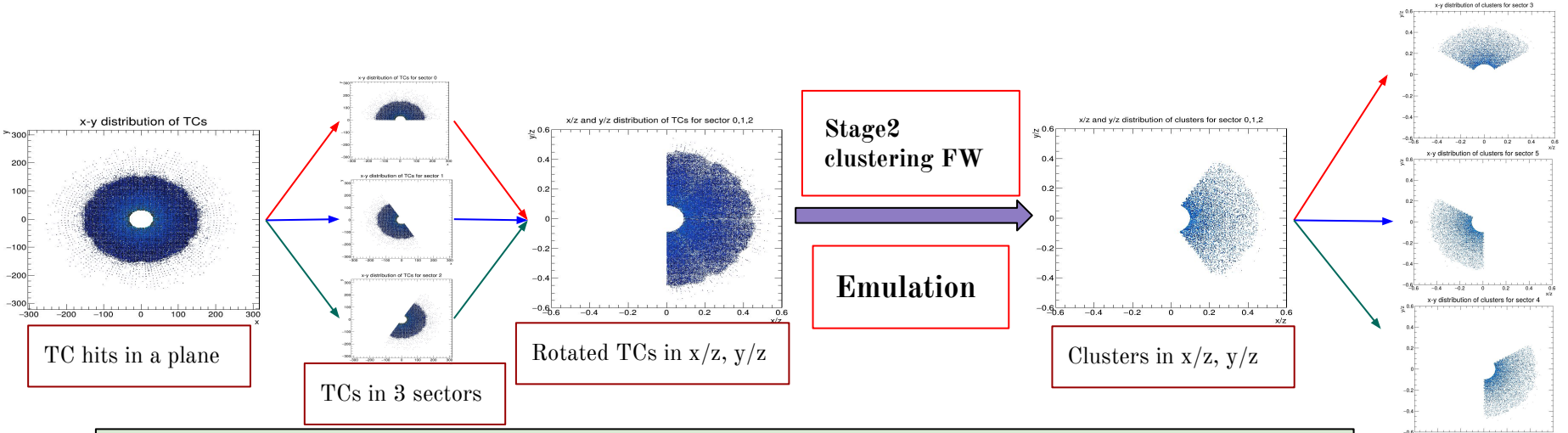


Caption: There are 48 trigger cells, the elementary trigger elements, in a full silicon module. The occupancy of the trigger cells of such a module is shown. The results confirm that all trigger cells have been fired at some point, with no permanently missing trigger cells.



Caption: The energy distribution of a single trigger cell is shown. The energy of a trigger cell is a sum of energies of 4 sensor channels in LD modules. The energy distribution of a trigger cell therefore closely resembles that observed for an individual sensor channel. This plot shows the energy distribution for Bx=0.

Stage2 clustering algorithm



In full stage2 emulation, one needs to perform global→local→global coordinate transformation and floating point →int→floating point conversions. The above cartoons shows the coordinate transformation with TC as input and cluster energy as output.