Preparation of the CMS high granularity calorimeter for HL-LHC - DAQ overview and hadron reconstruction

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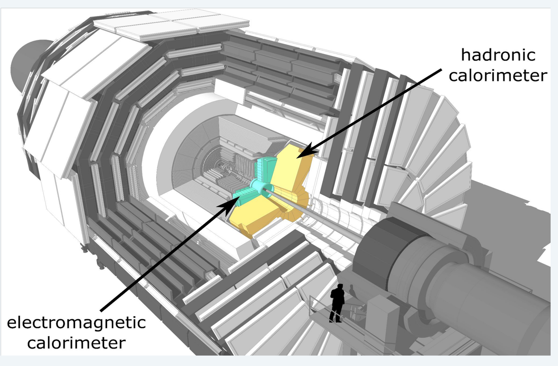
Abstract

Preparations for replacing the CMS endcap calorimeters with a high granularity calorimeter (HGCAL) to be used during the high luminosity LHC (HL-LHC) are in full swing. The HGCAL is a sampling calorimeter based on silicon and scintillator tiles directly read out by SiPMs. With an expected average of up to 200 pileup collisions per bunch crossing, and much finer granularity and precise timing information, the HGCAL is expected to deliver O(10) Mbit per event at an average event rate of 750 kHz. In this poster, I give a general overview of the HGCAL data acquisition system and the challenges foreseen in handling such large data rates, as well as the single-particle performance of an HGCAL prototype using SPS beam test data.

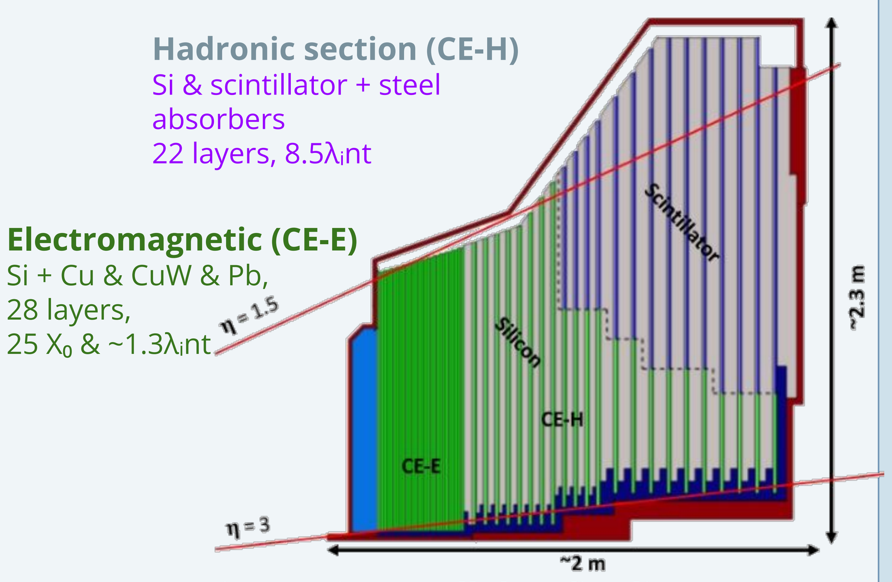
HGCAL - CMS endcap calorimeter for HL-LHC



- The CMS has opted for a silicon and scintillator+SiPM based High Granularity Calorimeter for HL-LHC operations:
  - Ten times higher instantaneous luminosity
  - Average pileup (PU) interactions of 140 or 200 (current value ~40).
  - Significant challenges for radiation tolerance on detectors.

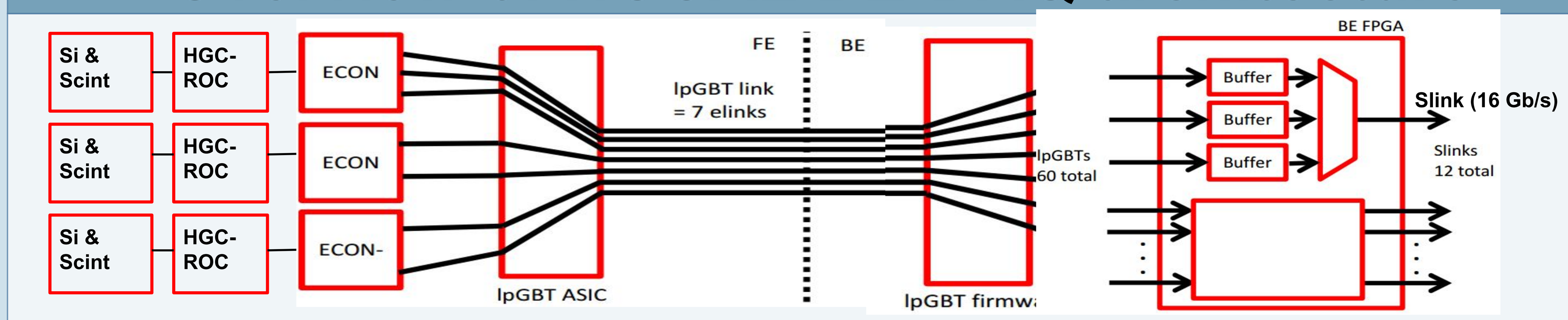
Key features:

- A total of 6M silicon (~27k modules) & ~200k scintillator readout channels.
- The data rates from the on-detector electronics is ~O(10) Tb/s at L1 accept rate of 750 kHz.
- For such extreme data rates, need to use high-bandwidth low-latency specialized computer hardware in the off detector electronics called Back-End (BE) for near real time processing.



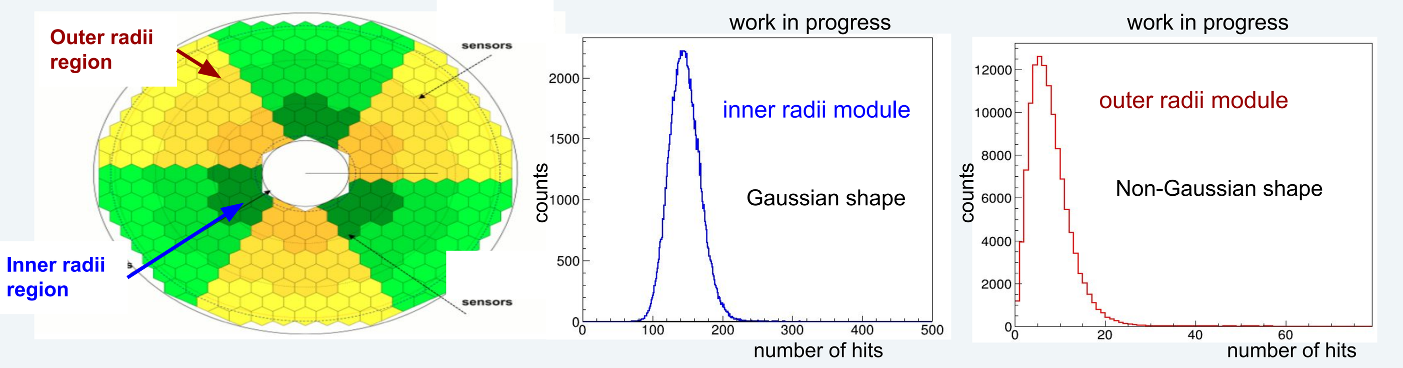
- **To build this state-of-art detector system, preparations are going on in parallel to finalize detector geometry, FE & BE architecture, TPGs, DPG, reconstruction, simulation etc.**

Overview of HGCAL BE-DAQ architecture

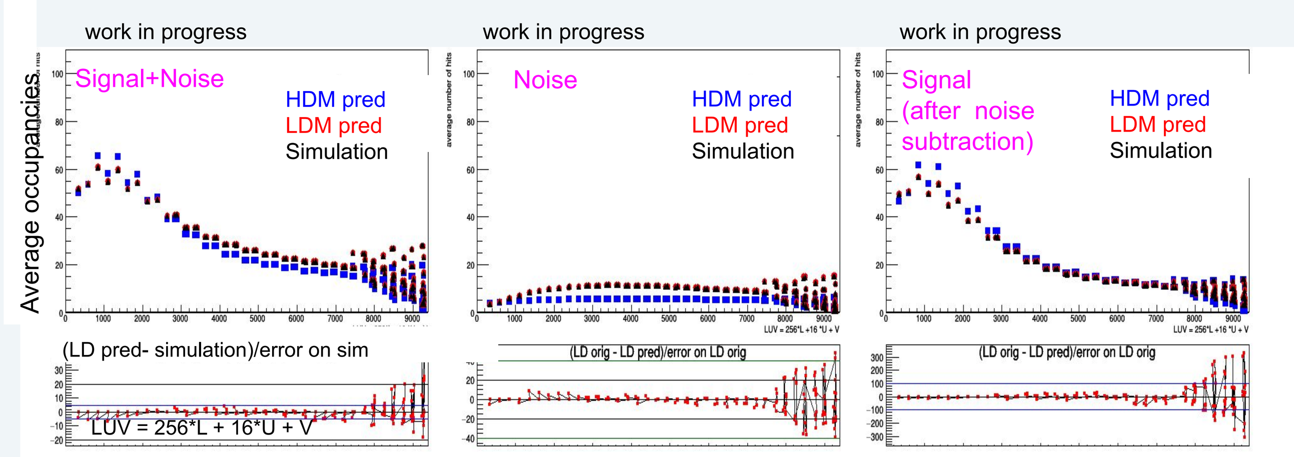


- Charge collected in the silicon/scintillator is sent to HGCROC chips for signal processing.
  - **E**link **CON**centrator which performs the appropriate zero suppression and transmits the results to the external BE electronics with the help of elinks and lpGBTS.
- The DAQ FPGAs are responsible for moving data from the FE to CMS central DAQ system (via Slinks) & also for distributing clock and fast control signals from the central timing, control and distribution system (TCDS2) and for configuring the FE electronics.
- Main aim for BE-DAQ is to implement all required block of DAQ chain in FPGA & estimate the resource use and latency.
- We need to study buffer occupancies, potential deadtime, and possible data losses in various parts of the DAQ system for correctly estimate resources.
- Use MC simulated ttbar events with average PU of 200 (signal sample) to estimate total data rates and study occurrences of throttling, and neutrino events without PU (noise sample) for noise studies.

Impact of noise on data rates from the detector



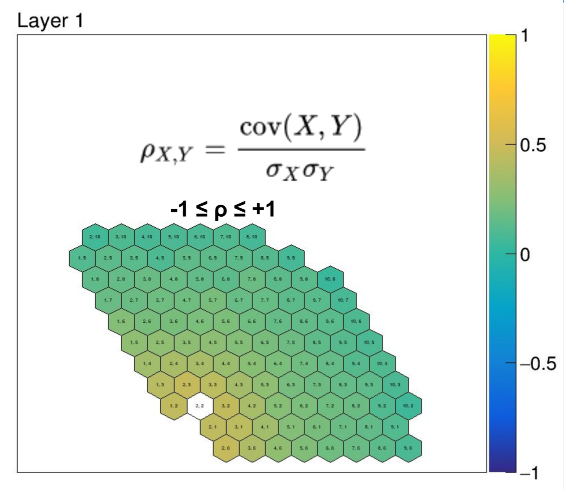
- Modules closer to interaction point have higher occupancy than those away from it.
- The higher the occupancy (number of channels above a certain threshold), the larger the amount of instantaneous data transmitted from a given module.
  - ~400 (200) channels per High (Low) Density module (HDM, LDM).
- The overall occupancy is a combination of signal hits and random noise fluctuations.



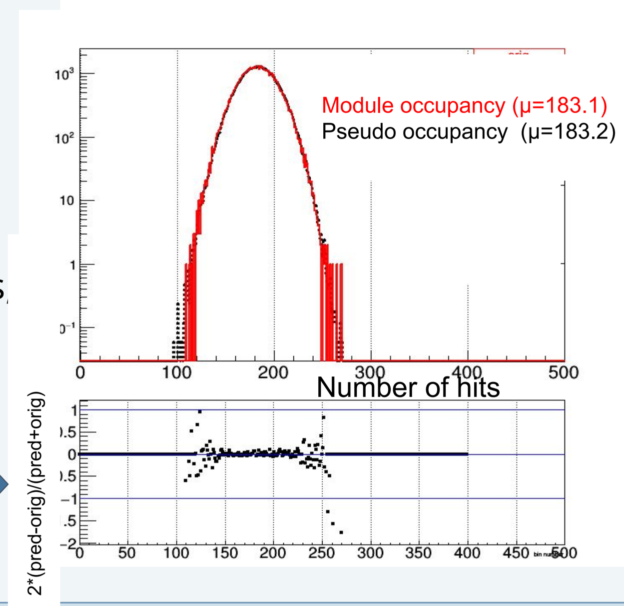
- LDM have higher noise (larger area silicon cells) than the HDM, as observed in neutrino events
- After subtracting the noise assuming a poisson model, the signal in modules is similar.

Generating Pseudo-events for dead time studies

- For a dead time of <1% at L1 rate of 750 kHz, need high statistics to probe rare throttling cases over thousands of links.
- Neighbouring modules in a layer & Modules in consecutive layers in the same line of direction of particle propagation are expected to be highly correlated.
  - One neighbouring module fluctuating high can cause throttling if it is sending its data through the same elink connected to other neighbouring modules
  - So important to take these correlation into account.

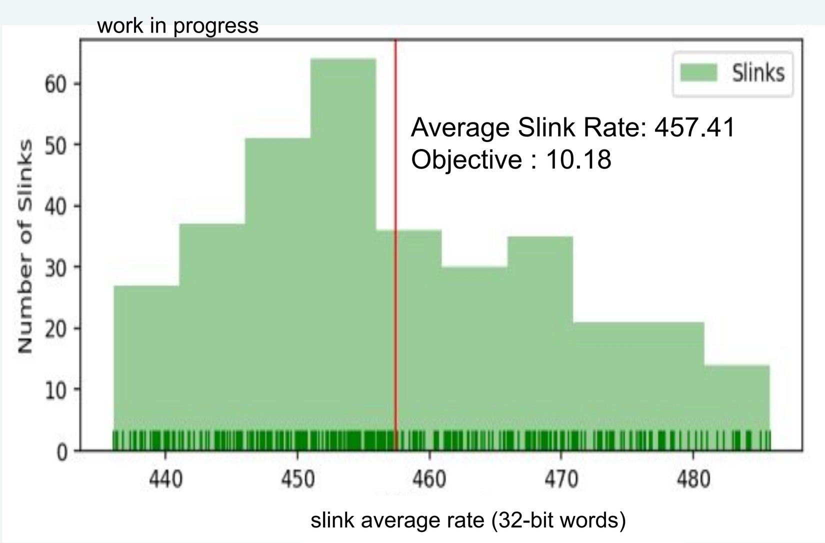


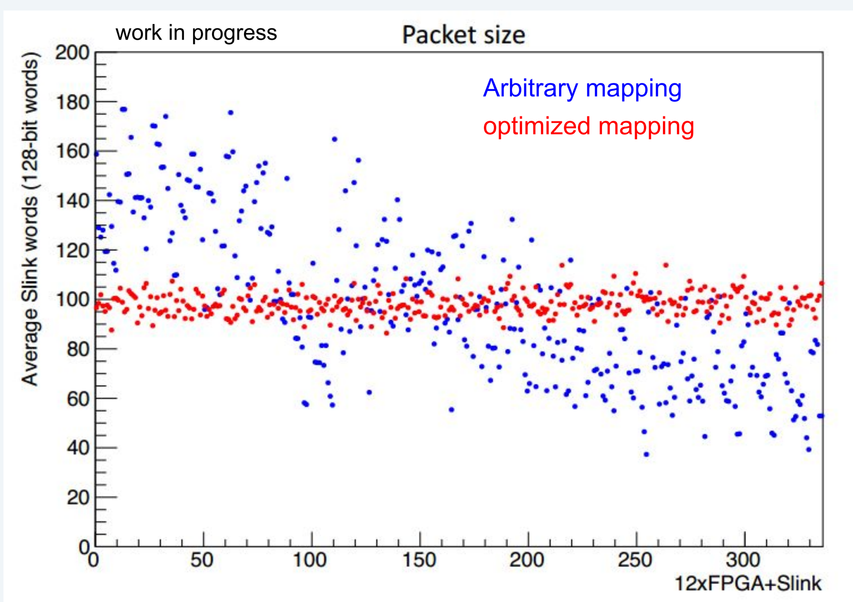
- Since it is not feasible to fully simulate O(10^8 events), we generate random multivariate distribution,
  - With correct modeling of correlations among various modules as well as correct representation of tails.
- The shape of the pseudo occupancy distributions matches well with the module occupancy.



Optimization of lpGBT connections to Slinks

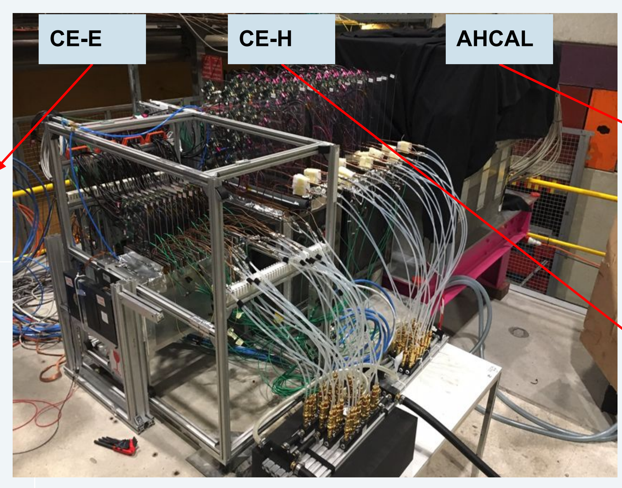
- Assigning of lpGBTs to different Slinks such that,
  - The total average rates are more or less same for each Slink and can fit in the available bandwidth of the Slinks.
- Convex Over and Under Envelopes for Nonlinear Estimation (**Couenne**) method is used which aims at finding global optimum of objective for a given problem.
- Function to minimize(objective) is,
  - Absolute value of difference between total event size of each slink and average slink rate.
- In case of optimized mapping, the average packet size is constant over all Slinks and well below the threshold that a Slink can handle.

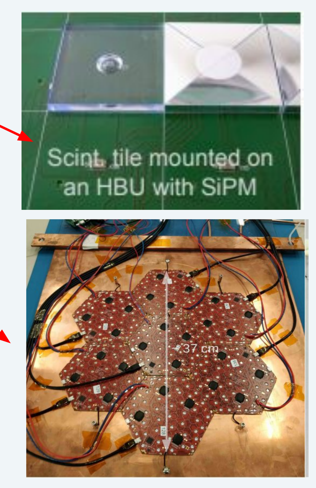




Pion energy reconstruction @HGCAL beam test prototype

CE-E (EM section)
- 28 sampling layers, each with one module.
- Cu/CuW/Pb
- ~ 26 X_0, 1.4 λ_{int}

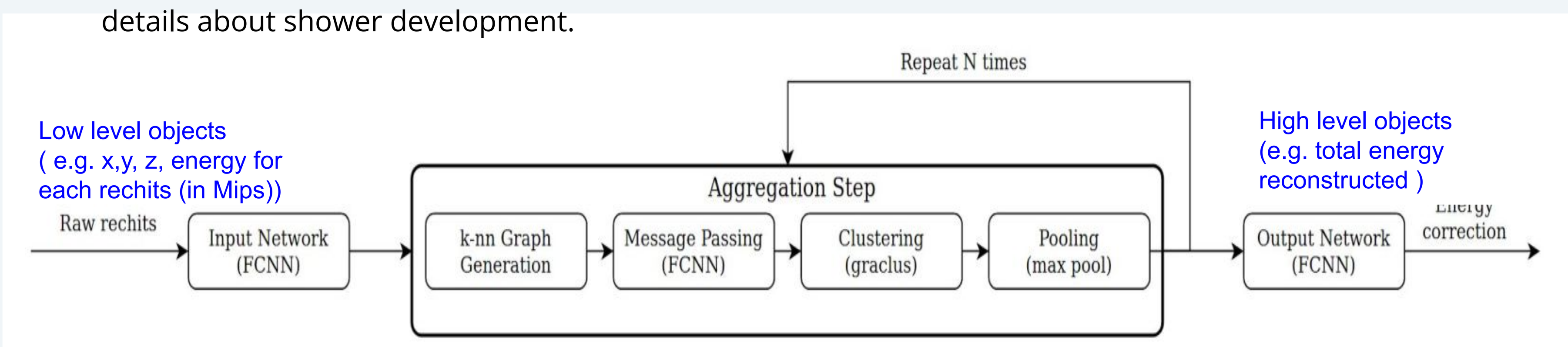




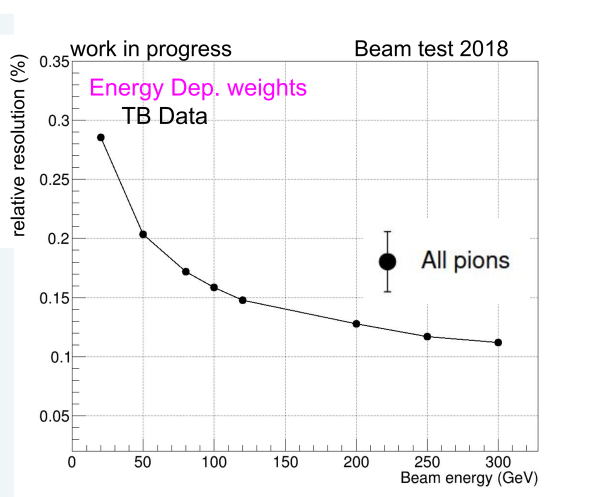
Calice AHCAL (Had section)
- Scintillators on SiPMs
- Steel absorbers
- 39 sampling layers
- ~ 4.4 λ_{int}

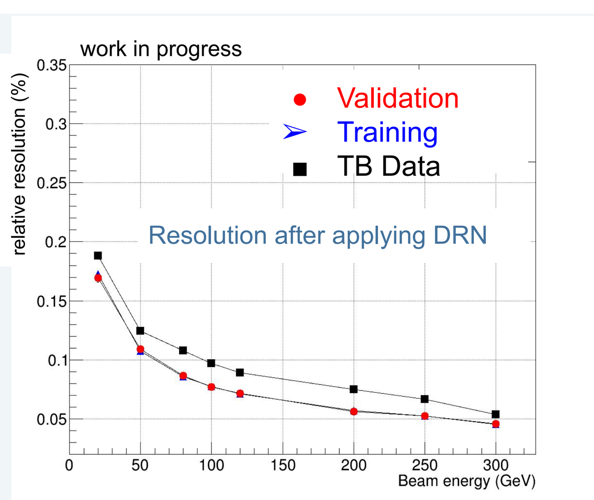
CE-H (Had section):
- 12 sampling layers
- Steel absorbers
- ~ 3.4 λ_{int}

- The prototype was exposed to e^+, π^- beam of energy ranging from 20 to 300 GeV.
- Hadron showers are complex with event-by-event fluctuations in shower evolution and energy dependent π^0 component resulting in a non-linear response.
  - Conventionally, energies from different sub detectors are combined with energy-dependent weights.
  - Investigating a dynamic reduction network (a type of graph neural network) for charged pion energy regression in HGCAL prototype detectors.
  - Can help in exploiting the high transverse & longitudinal granularity of the detector which can provide more details about shower development.



Very preliminary results are promising:
- The resolution may be up to 10% (relative) better than what we have by conventional methods.
- We plan to follow this further.





Summary

- A lot of things are in place in the BE-DAQ that are needed to make the final decision on the electronics design.
- Check the effects of system parameters (e.g. number & speed of links, FPGA clock speeds, etc.) on the buffer performance.
- And finalize the design of FPGA to be used in BE-DAQ,
  - According to the cost and usage
- Applying DRN architecture for pion energy reconstruction @HGCAL TB is giving a lot of improvement in terms of pion energy resolution.
- We are trying to further optimize the model and get stable results from it.

References

1. CMS Collaboration, *The Phase-2 Upgrade of the CMS Endcap Calorimeter, CERN-LHCC-2017-023; CMS-TDR-019*
2. 26th DAE-HEP symposium, NISER-India, December 2020
3. Summary of pion analysis with the combined HGCAL+AHCAL setup in CALICE Analysis Meeting