Performance of the local reconstruction algorithms for the CMS hadron calorimeter in Run-2 data

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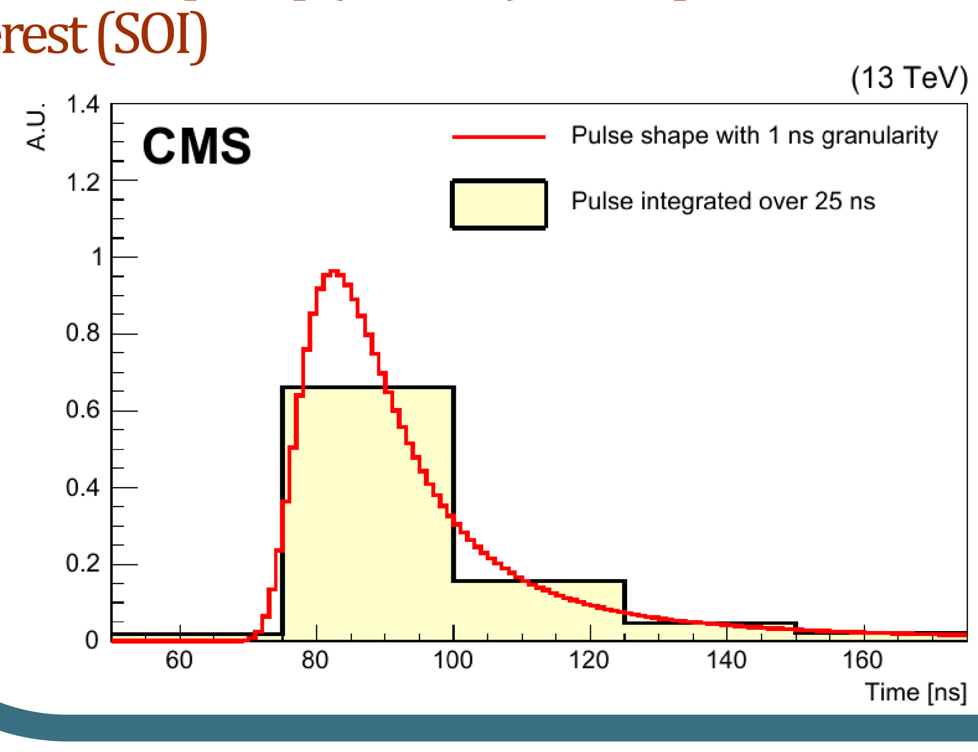
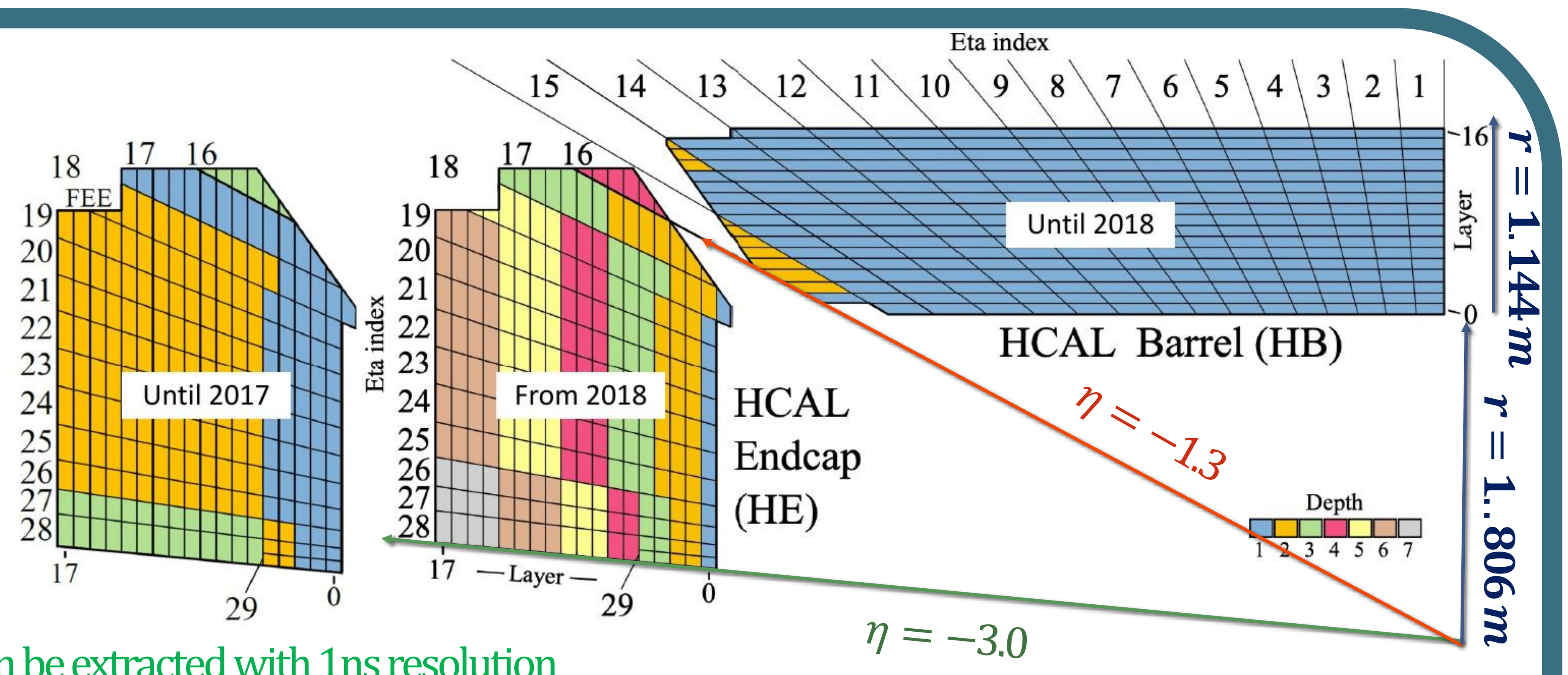
1. Introduction

The hadron calorimeter is a key subdetector of the CMS experiment

- It plays a vital role in event reconstruction
- Contributes to the identification of leptons and photons

At LHC during Run2 (2016-2018) pp bunch-crossing spacing 25 ns
Recorded charge pulse in HCAL 75ns-100 ns wide
Out-of-time pileup(OOTPU) overlaps with the Recorded sample of interest (SOI)



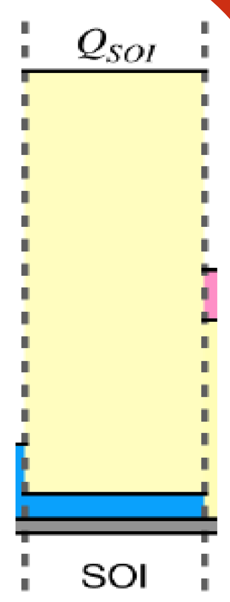


- Pulse shape can be extracted with 1ns resolution
- Reason for the fluctuation in the pulse shape:
  - Nonzero charge reading of the charge integrators,
  - Dark currents in the photodetectors are responsible for the fluctuation in the pulse shape
- Pedestal noise is estimated from the dedicated run when other subdetectors were off.

2. Existing Methods to Mitigate OOTPU

Method 0 :

- Subtract the average pedestal from the SOI
- Correct it for using a multiplicative factor to incorporate the energy outside of the two TSs
- Method works very well for RUN1 with 50ns bunch-crossing spacing
- For 25ns bunch-crossing spacing it is not good



Method 2 :

- Template based fit algorithm design to correctly estimate the OOTPU and SOI templates

Pulse amplitude | Sum of amplitude | Shift in arrival time of TS

$$\chi^2 = \sum_{i=0}^{N_{TS}-1} \frac{(A_i - \mu_i)^2}{\sigma^2_{p,i}} + \sum_{j=0}^{2} \frac{(t_j - \langle t \rangle)^2}{\sigma^2_t} + \frac{(\text{ped} - \langle \text{ped} \rangle)^2}{\sigma^2_{\text{ped}}}$$

combine unct. | SD in arrival time | SD in pedestal

- Used during 2016-2016 for offline reconstruction
- Has large computation time -> cannot be used HLT

3. New Methods to Mitigate OOTPU

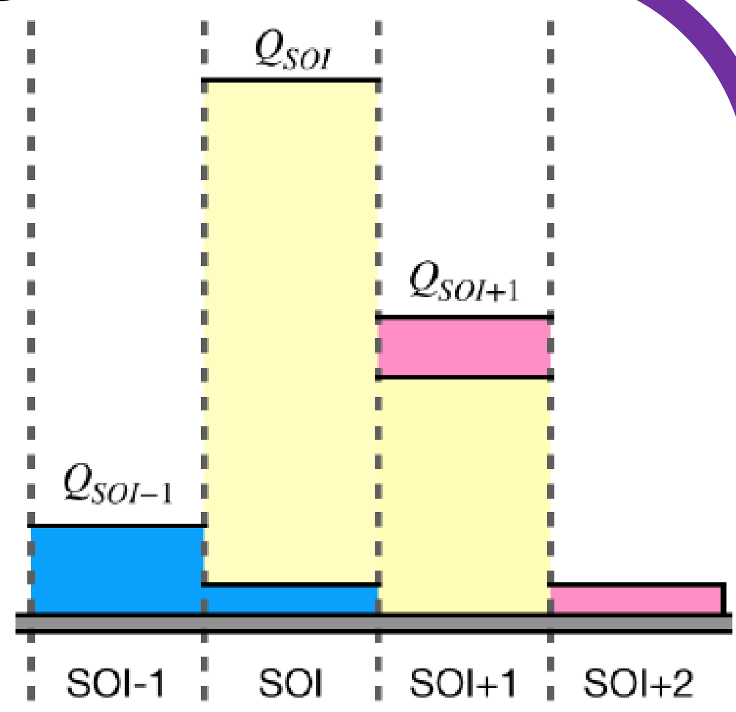
Method 3 :

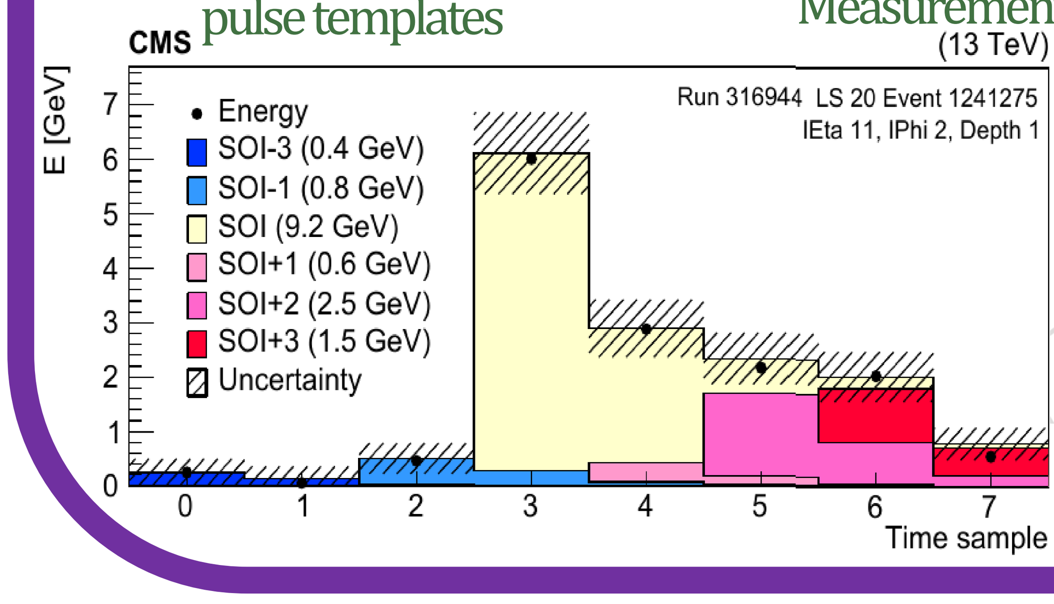
- Assumed a fixed arrival time for the pulse
- Use only three TSs in the algorithms
- Iterative minimization algorithm to solve a system of linear equations

QIE measurement | Pulse amplitude

$$\begin{bmatrix} A_{SOI-1} \\ A_{SOI} \\ A_{SOI+1} \end{bmatrix} = \begin{bmatrix} f_0 & 0 & 0 \\ f_1 & f_0 & 0 \\ f_2 & f_1 & f_0 \end{bmatrix} \begin{bmatrix} \mu_{SOI-1} \\ \mu_{SOI} \\ \mu_{SOI+1} \end{bmatrix} + \begin{bmatrix} B \\ B \\ B \end{bmatrix}$$

Pre-measured frac. of the pulse templates | Average QIE Measurement





MAHI (Minimization At HCAL Iteratively)

1. Pulse shape unct. are considered
2. Noise is added with the pulse unct.

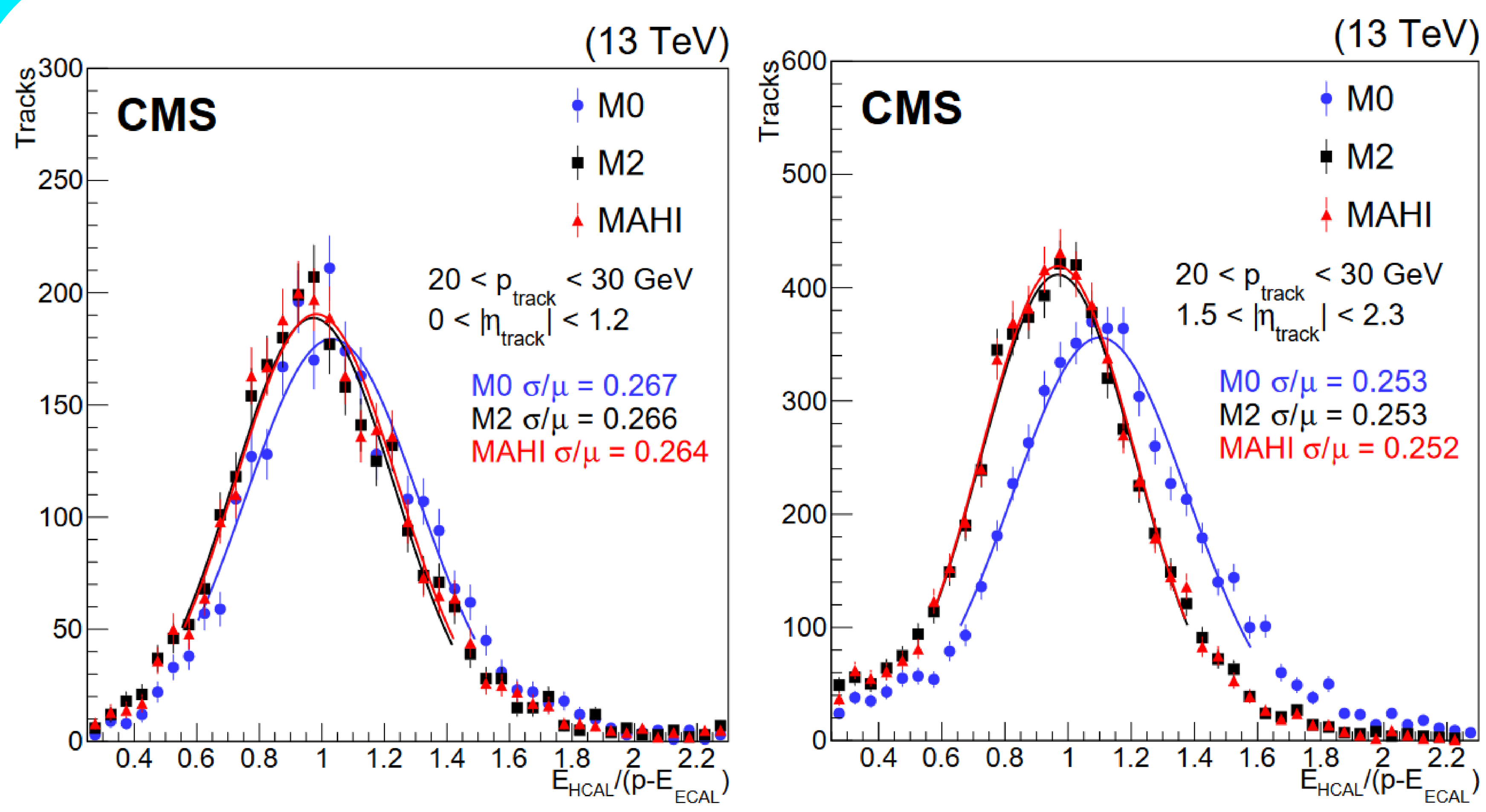
Pulse templates matrix | Unct. covariance matrix

$$\chi^2 = \left[\sum_j \vec{P}_j \mu_j - \vec{d}\right]^T \mathbf{V}^{-1} \left[\sum_j \vec{P}_j \mu_j - \vec{d}\right]$$

QIE measurement vector

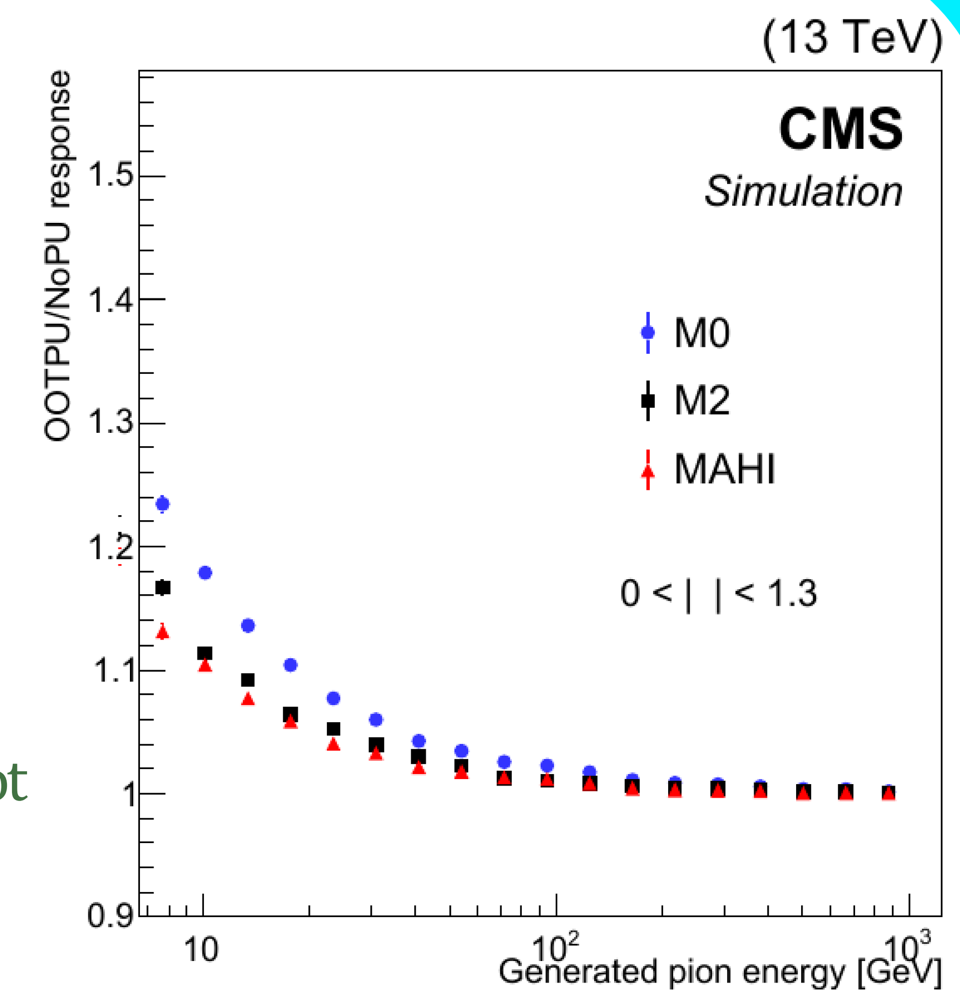
Minimize χ^2 iteratively

4. Performance of Algorithms



Standard deviation in the fit is dominated by HCAL resolution
M0 has larger σ and μ whereas MAHI and M3 have similar σ and μ

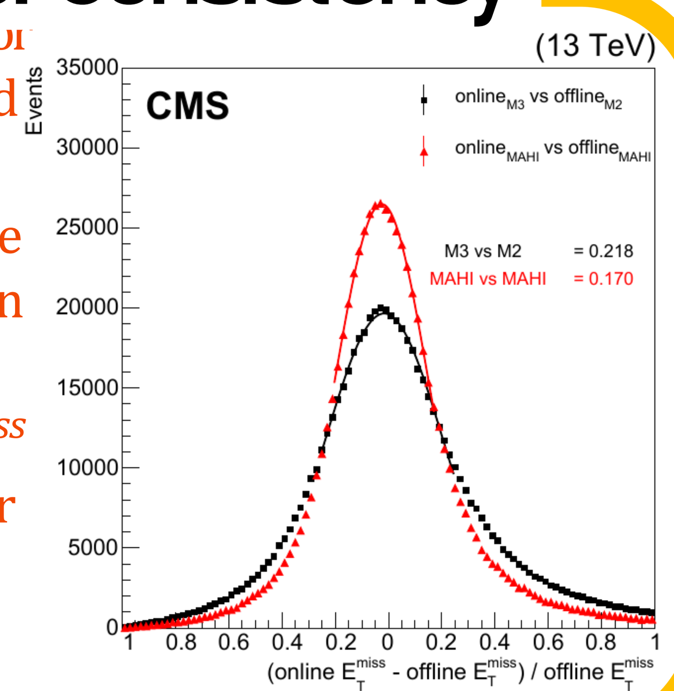
- OOTPU contributes significantly at lower p_T and higher η
- The ratio of the clustered energy and generated energy determines the response
- Approx. 30 OOTPU interactions per event are considered
- Algorithms are designed not to provide negative energy values, which biases the response function in a positive direction.



MAHI is the best performer at the higher η while M0 is the worst

5. Consistency

- E_T^{miss} is the negative vector sum of the energies in ECAL and HCAL including HF
- MAHI is consistent with the online and offline reconstruction
- The residual difference between online and offline E_T^{miss} is attributable to the calorimeter calibration, especially the difference in calibration used at HLT



Conclusions

- When the bunch-crossing spacing is at least 50ns, Method0 performs well
- A pulse fitting algorithm needs to be used for the 25ns bunch-crossing spacing
- Method2 performs well for offline reconstruction but can not be used for HLT due to its long reconstruction time
- Mismatch between the online and offline reconstruction makes the Method3, less desirable
- MAHI suppresses the OOTPU well and is also fast enough to run at HLT. It was the preferred local energy recontraction algorithm during Run 2

References:

1. PRF-22-001 (To be submitted JINST)
2. Reconstruction of signal amplitudes in CMS detector

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