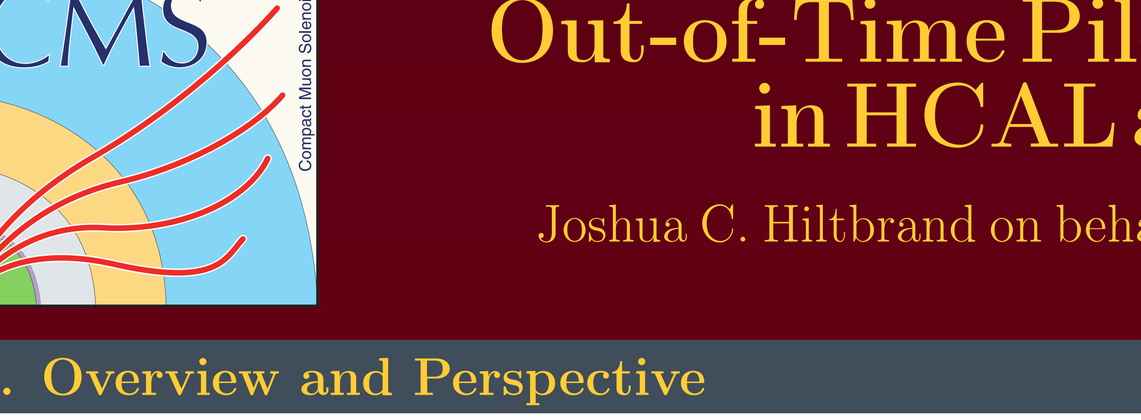
Out-of-Time Pileup Subtraction in HCAL at Level-1

Joshua C. Hiltbrand on behalf of the CMS HCAL group

1. Overview and Perspective

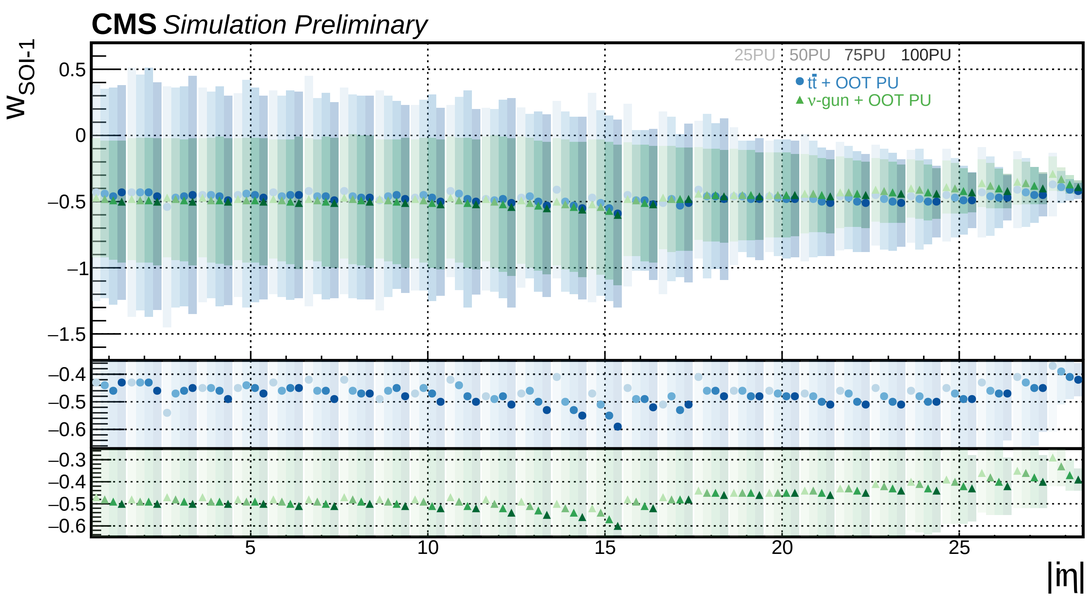
This work investigates improvements to the HCAL signal amplitude reconstruction done online for mitigating the effects of pileup that degrade the performance of the Level-1 (L1) Trigger system. The energy scale and resolution of L1 trigger quantities can be biased by the presence of pileup interactions, leading to increased trigger rates. A pulse-shape-filtering scheme is developed with a weight that is optimized to minimize the effects of **out-of-time pileup**.



Above are pulses in HCAL, integrated in 25 ns time samples. The right diagram represents the more realistic scenario where pulses due to pileup interactions in **preceding** and **postceding** BXs overlap with the **signal pulse**. Rather than estimate the signal by summing the BX0 and BX+1 samples (current scheme), the result of subtracting a weighted amount of the BX-1 sample from the BX0 sample is used (proposed scheme).

2. Extracting Filter Weights

Simulated signal pulses are compared with and without pileup present in order to quantify how much fractional overlap there is from pileup. The filter weight is quantified as the fraction, individually for each tower ($|i\eta|$) of the barrel and endcap regions of HCAL.



Above is a summary of the extracted weight for the proposed pileup-subtracting pulse filter scheme for two different physics scenarios both with four different levels of out-of-time pileup present: $\langle N_{\mathrm{vtx}} \rangle = 25$, 50, 75, and 100. Higher levels of pileup on average lead to more overlap of the signal pulse, resulting in a larger magnitude weight.

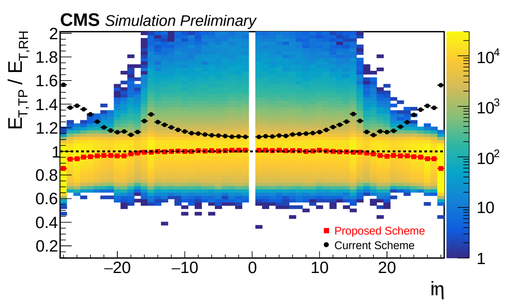
3. Improved Online Energy Reconstruction

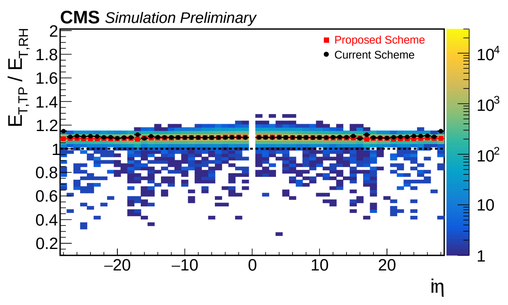
Low Energy Regime:

- The pileup dominant energy regime; best demonstrating pileup's effect on signal amplitude reconstruction.
- **Proposed scheme** prevents bias in energy scale w.r.t. offline.

High Energy Regime:

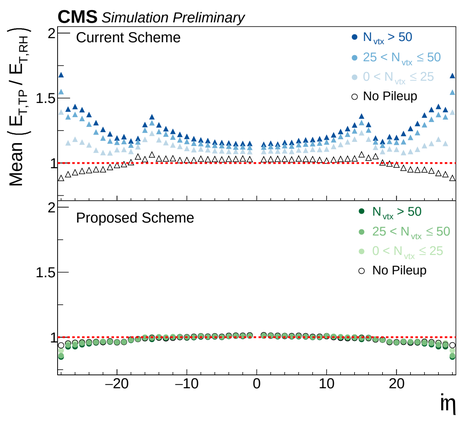
- Not a pileup dominant regime; validates pileup subtraction behavior, which should have little impact here.
- Both the **proposed** and **current** scheme perform similarly in this regime.

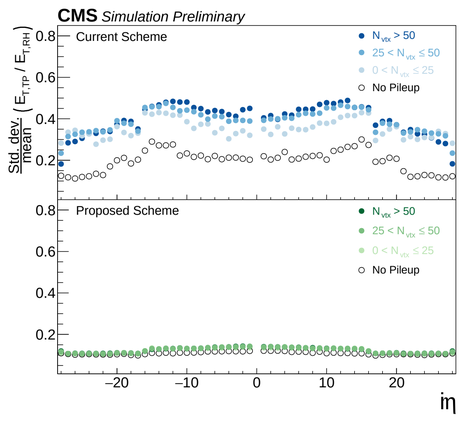




4. Robustness Against Pileup

The current and proposed schemes are used for signal amplitude reconstruction in four different pileup scenarios with underlying $t\bar{t}$ events.





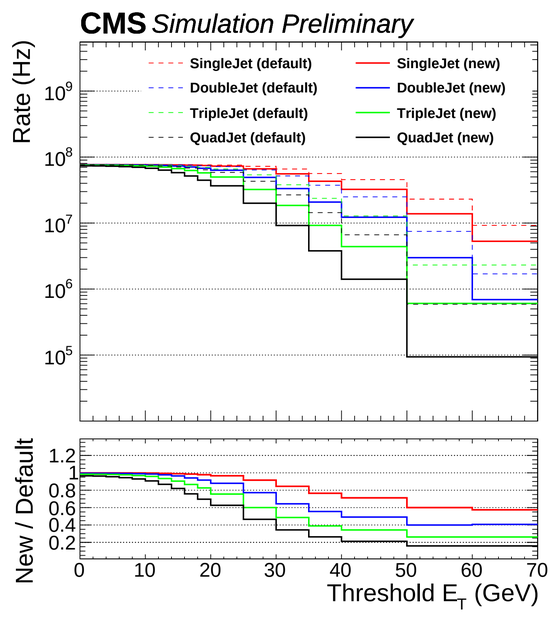
Energy Scale w.r.t. Offline:

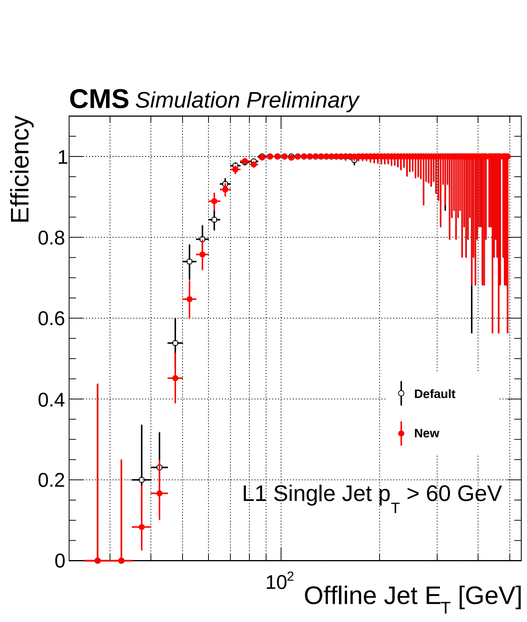
- The **current scheme** yields an energy scale that is sensitive to the level of and biased by pileup.
- The **proposed scheme** maintains a much more uniform energy scale across HCAL, regardless of pileup.

Energy Resolution w.r.t. Offline:

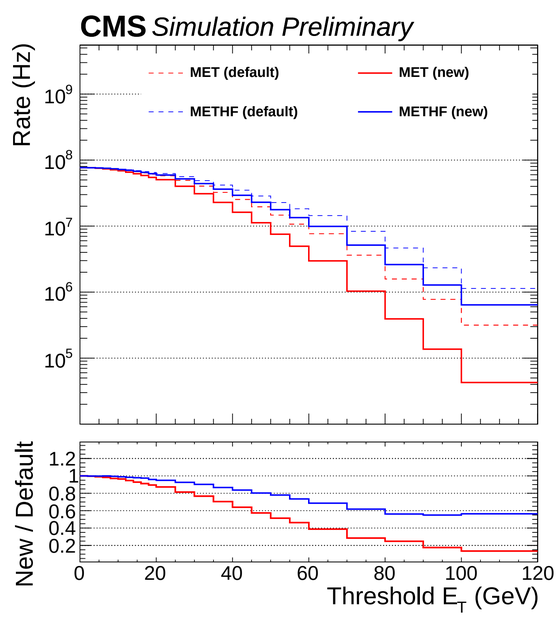
- Energy resolution obtained from **current scheme** is degraded by pileup.
- In any pileup environment, **proposed scheme** allows for better, uniform energy resolution.

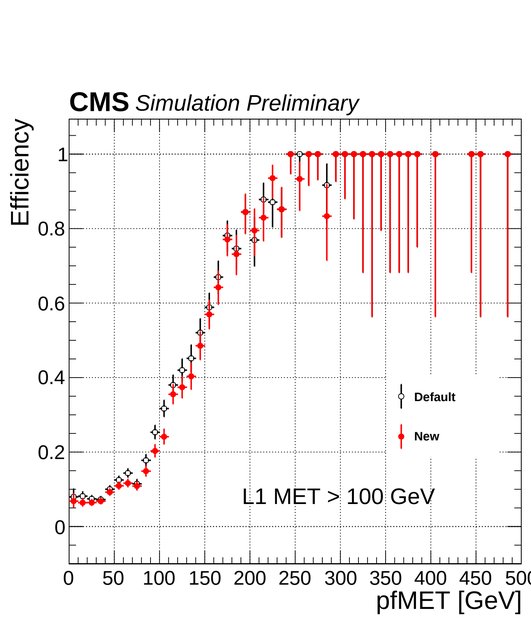
5. Impact on the Level-1 Trigger





The resultant L1 rates for different multiplicity jet triggers (above left), MET triggers (bottom left); and the efficiency of a single jet > 60 GeV trigger (above right), MET > 100 GeV trigger (bottom right) when using the current and proposed schemes. Rates are measured using a simulated zero bias sample while the trigger efficiency is measured in a simulated $t\bar{t}$ sample. For both L1 objects, the proposed scheme reduces rates without reducing efficiency.





6. Summary

The proposed scheme shows promising results for mitigating pileup with a beneficial impact at L1. We anticipate implementing the scheme in HCAL DAQ hardware for use during the next CMS data taking period.