Out of Time Pileup Mitigation for Hadrons at CMS

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on behalf of the CMS collaboration

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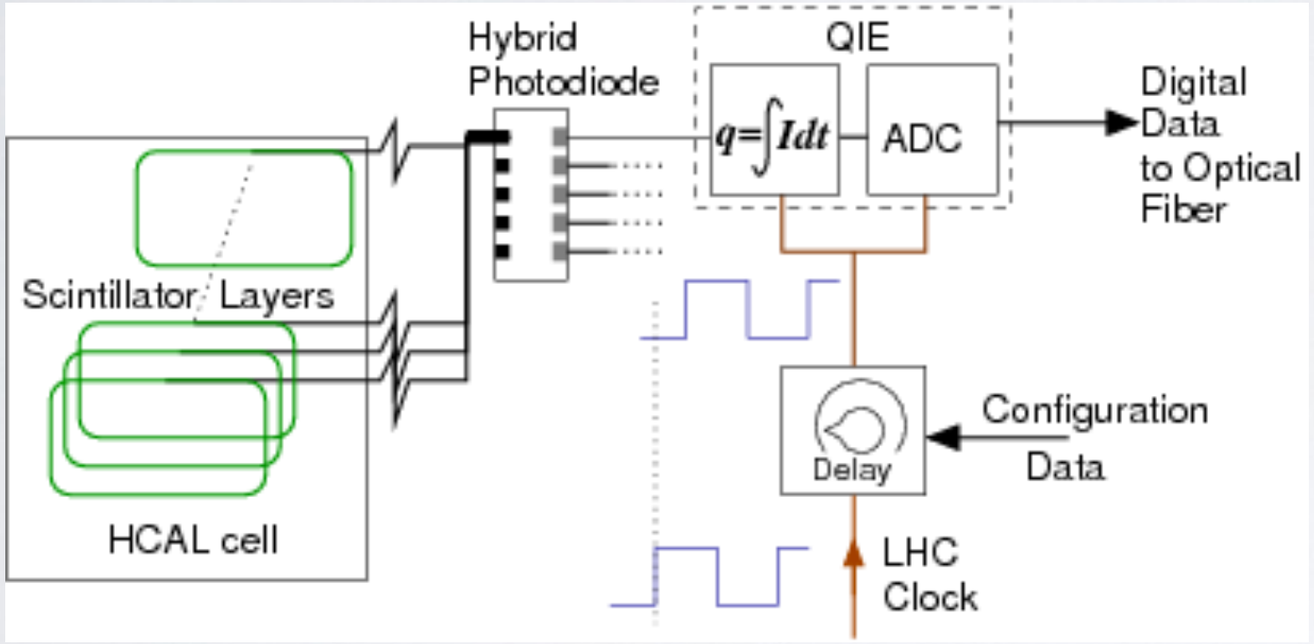
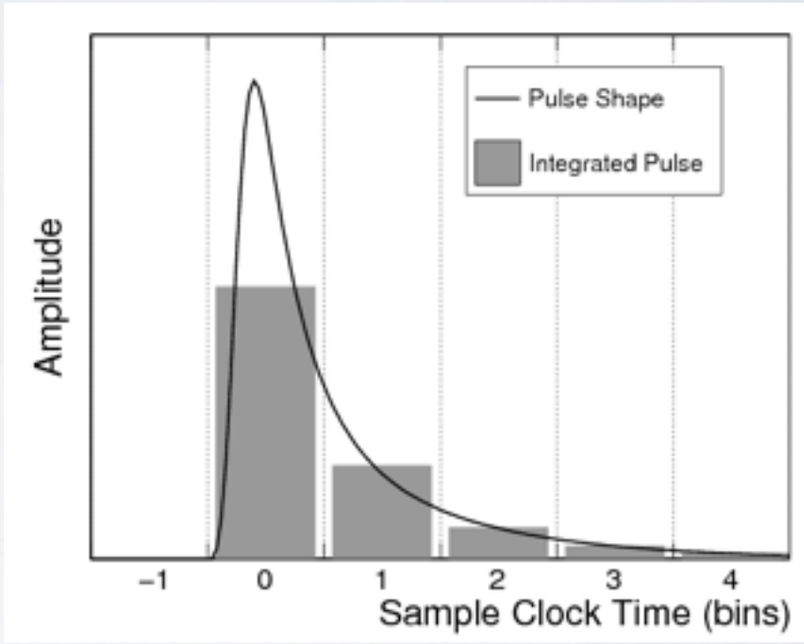
Hadronic Calorimeter

- Barrel/endcap signal pulses spread over two 25 ns time slices



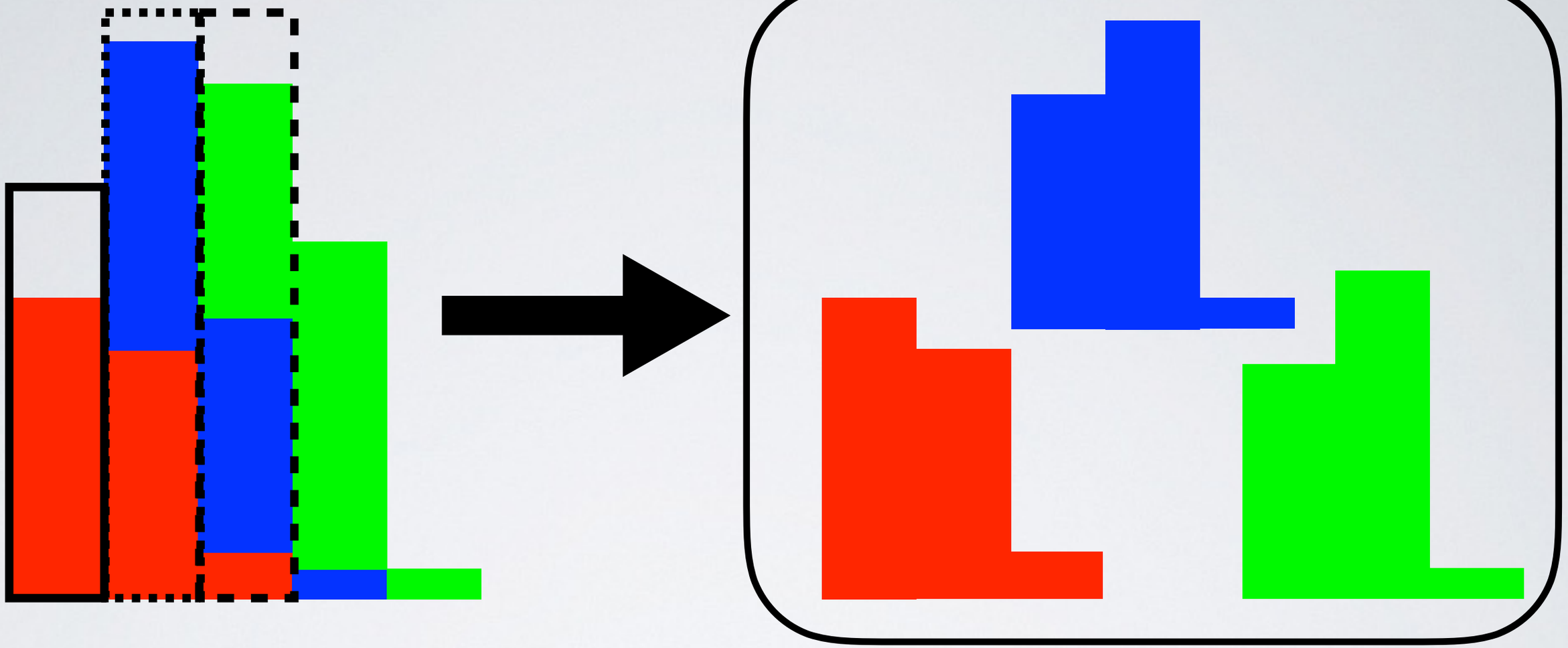


- Goal to reconstruct in-time HPD pulse from 10 QIE samples
  - Time Slice 4 (TS4) in-time with bunch crossing

Out of Time Pileup

- In Run 1, added charges in TS4 and TS5
  - 50 ns bunch spacing — next bucket always empty
- Not viable in 25 ns running
  - Significant contamination from neighboring full bunch crossings
- Extra neutral energy biases jet measurements and degrades jet/MET resolution
- **OOTPU generally worsens MET resolution by 20-30%**

Run 2 HB/HE reconstruction



- Fit for **in-time pulse, previous** and **next** bunch crossings
  - Chi2 minimization for amplitude and timing

$$\chi^2 = \sum_{i=0}^{9} \frac{(\mathrm{TS}_i - A_i)^2}{\sigma_{p,i}^2} + \sum_{j=0}^{3} \frac{(t_j - \langle t \rangle)^2}{\sigma_t^2} + \frac{(\mathrm{ped} - \langle \mathrm{ped} \rangle)^2}{\sigma_{\mathrm{ped}}^2}$$

Offline χ^2

$$\chi^2 = \sum_{i=0}^{9} \frac{(\mathrm{TS}_i - A_i)^2}{\sigma_{p,i}^2} + \sum_{j=0}^{3} \frac{(t_j - \langle t \rangle)^2}{\sigma_t^2} + \frac{(\mathrm{ped} - \langle \mathrm{ped} \rangle)^2}{\sigma_{\mathrm{ped}}^2}$$

$\sum_{i=0}^{9} \frac{(\mathrm{TS}_i - A_i)^2}{\sigma_{p,i}^2}$ ADC granularity and uncorrelated electronic noise

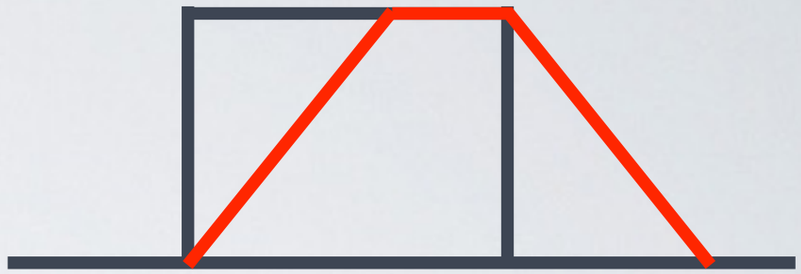
$\sum_{j=0}^{3} \frac{(t_j - \langle t \rangle)^2}{\sigma_t^2}$ Gaussian time constraints

$\frac{(\mathrm{ped} - \langle \mathrm{ped} \rangle)^2}{\sigma_{\mathrm{ped}}^2}$ Gaussian pedestal constraint

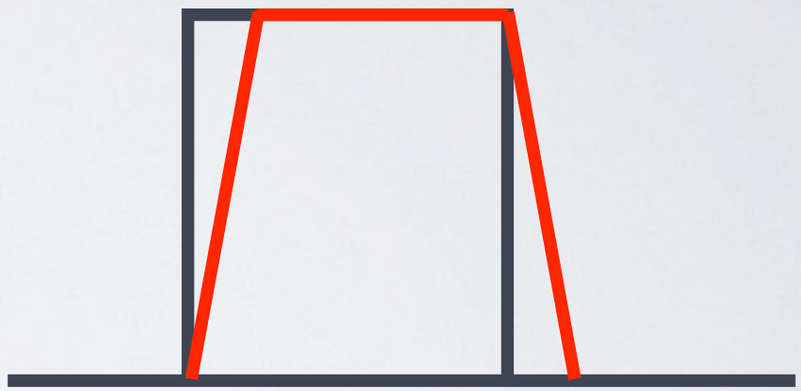
- Complicated by amplitude-dependent pulse variation

What is time slew?

- **Slew rate:** (maximal) rate at which amplifier can change output voltage

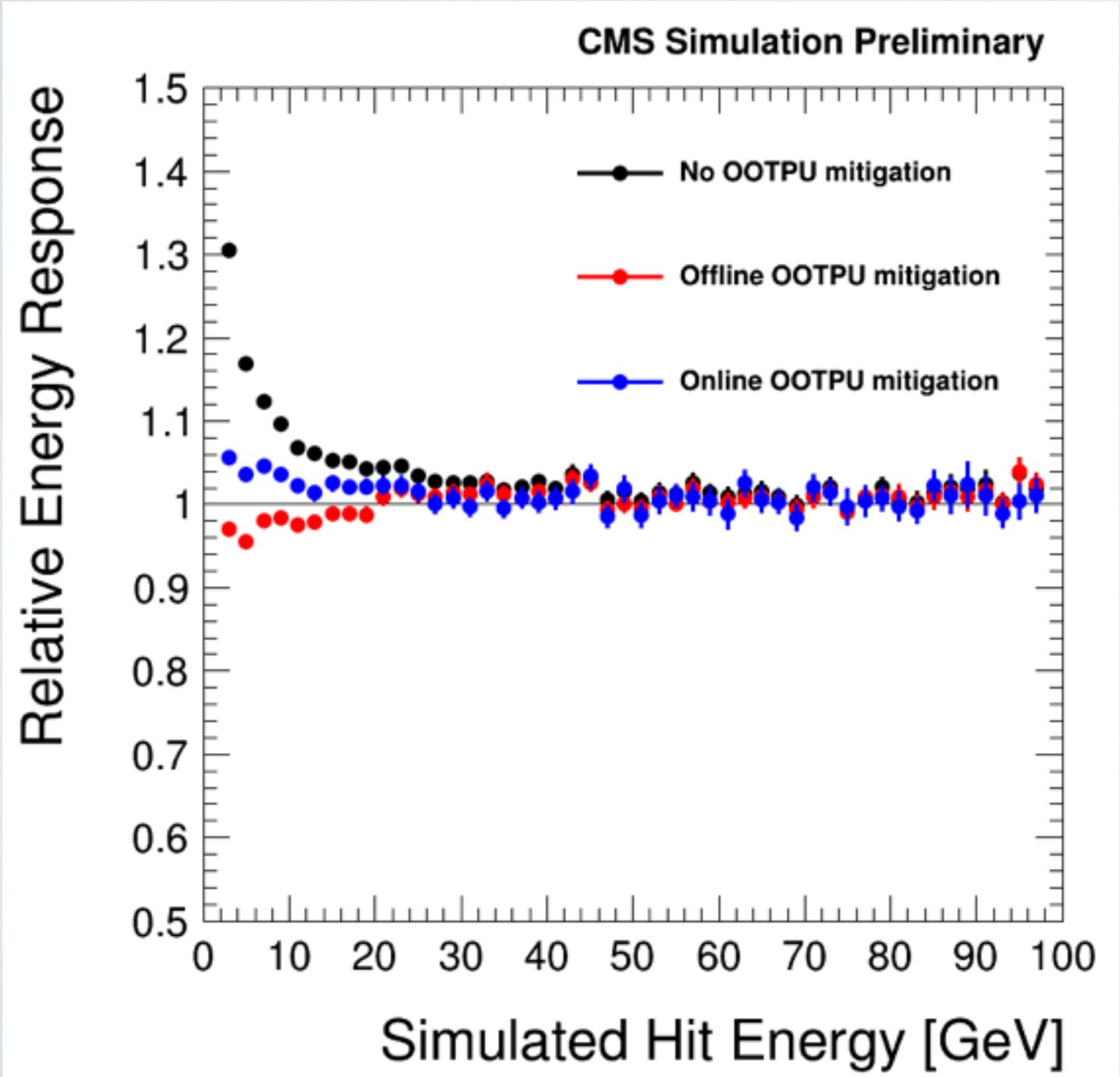


- Input bandwidth of QIEs depends on input pulse amplitude
  - larger amplitude, larger slew rate



- **Time slew:**
  - Peak of small pulses appear delayed compared to large pulses
  - Pulse shape depends on input

Performance



In MC studies, new algorithms out-perform old

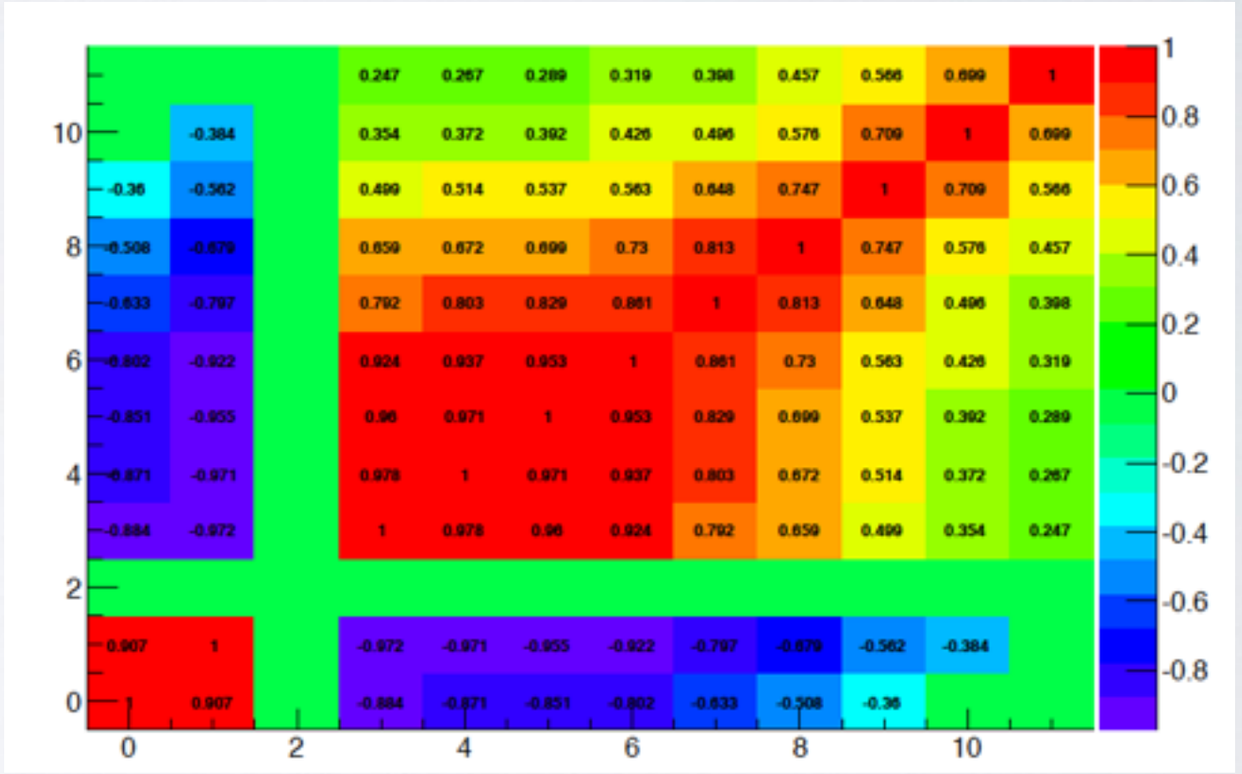
Reconstructed energy within 5% of simulated energy

In use at CMS throughout 2016 data taking

How to improve?

- Include cross-correlated uncertainties in fit

- ECAL pulse reconstruction takes into account correlated uncertainties between time slices



- Take full advantage of available information