__><)))'>__MAHI__

Minimization At HCAL, Iteratively

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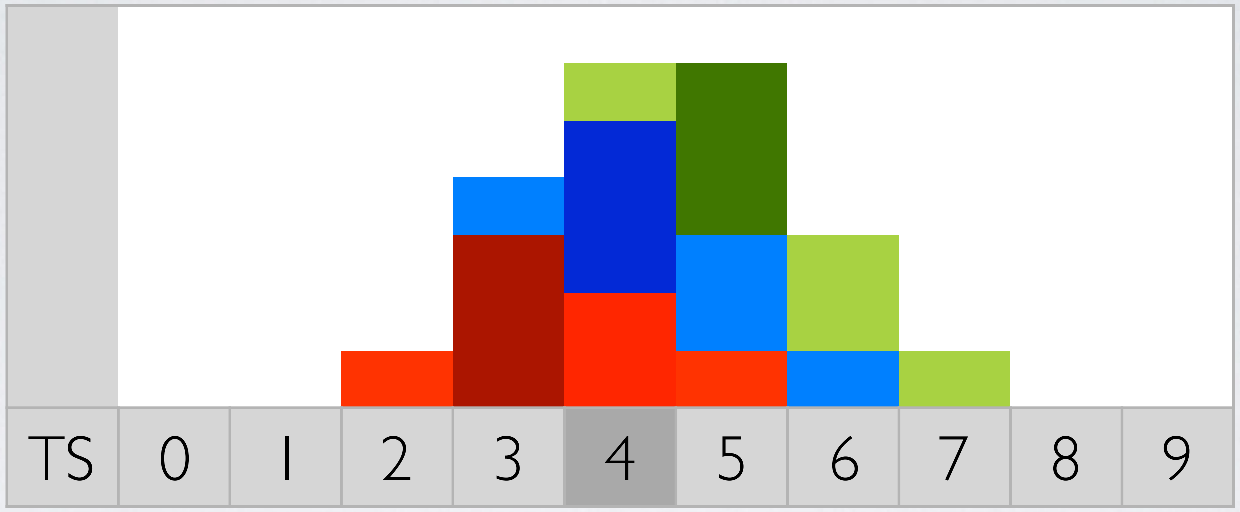
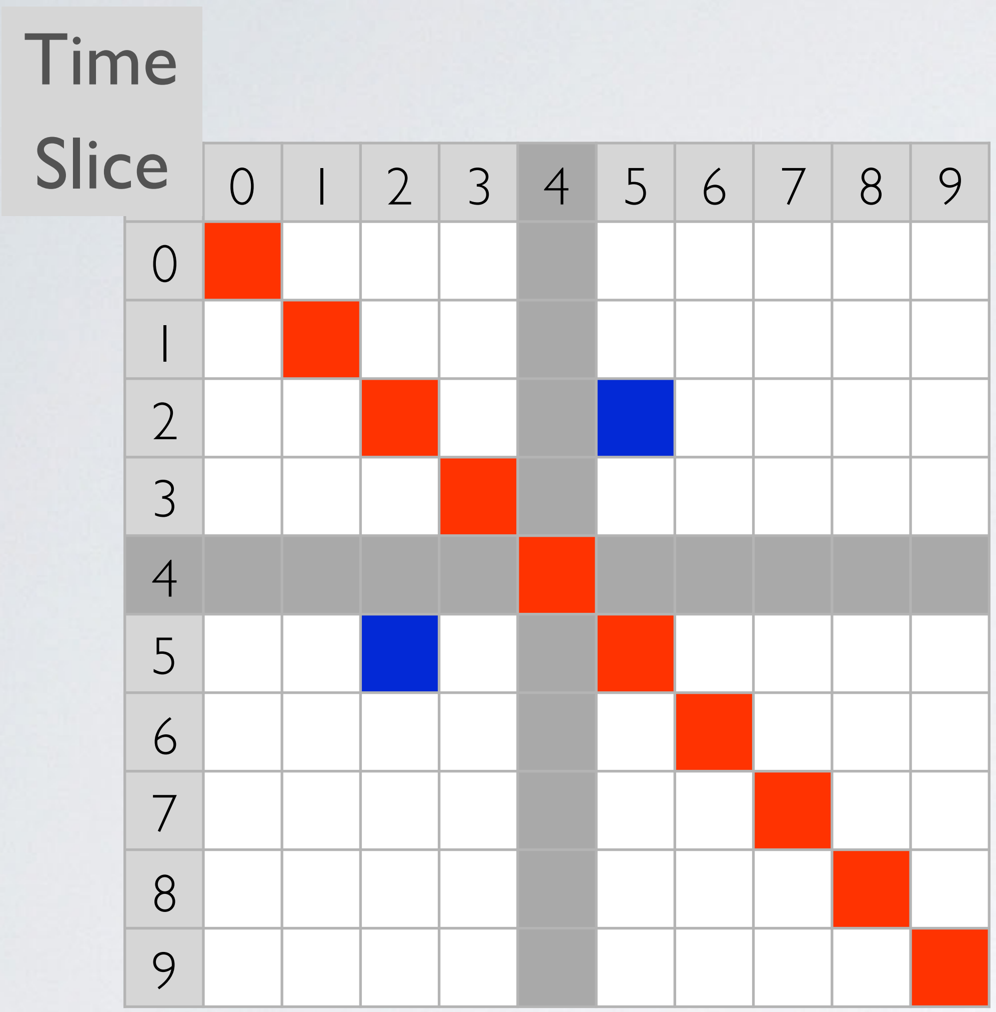
HBHE Local Reconstruction



- Inputs
  - 10 pedestal-subtracted data samples (TS)
    - Not much we can do with just this, also need models of
  - Signal behavior (pulse shape, arrival time)
  - Noise/fluctuations/background (electronics, digitization, photo statistics, SiPM dark current)

- Can apply corrections to measured charge using this info (Method 0)
- Or fit for the signal charge (Method 2, Method 3, Mahi)

Covariance matrices



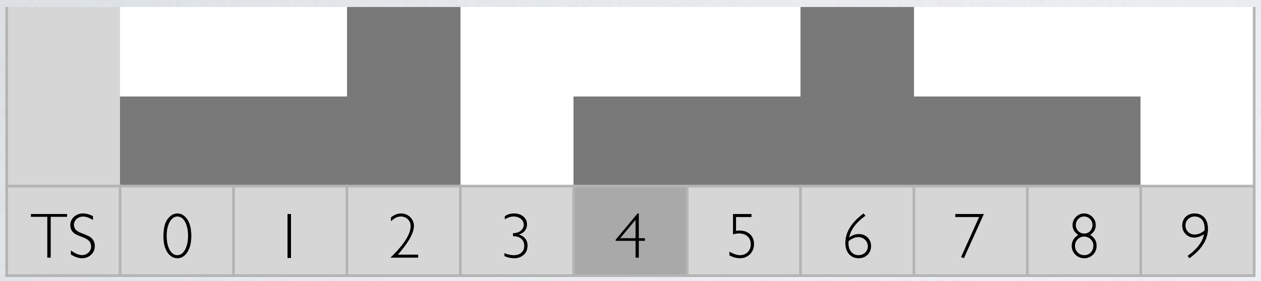
- Build our detector description in terms of covariance matrices

- Diagonal terms are standard deviations σ_{ii}

- Off-diagonals are covariances
  - i.e. $\sigma_{25} = <(TS2-<TS2>)(TS5-<TS5>)>$

- Start with empty detector and build up each component

Empty detector



Electronics pedestal and dark current

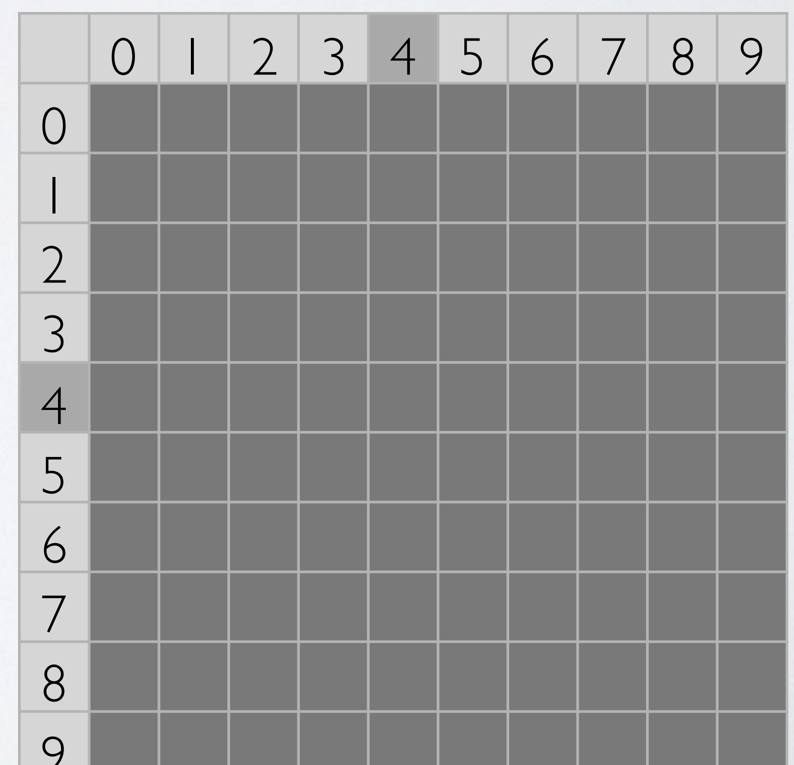
- take average over CapIDs as fully correlated across time slices,
- and the value for each TS as uncorrelated (inflate uncertainties to help convergence)

ADC granularity and photo statistics

- take as uncorrelated for each TS

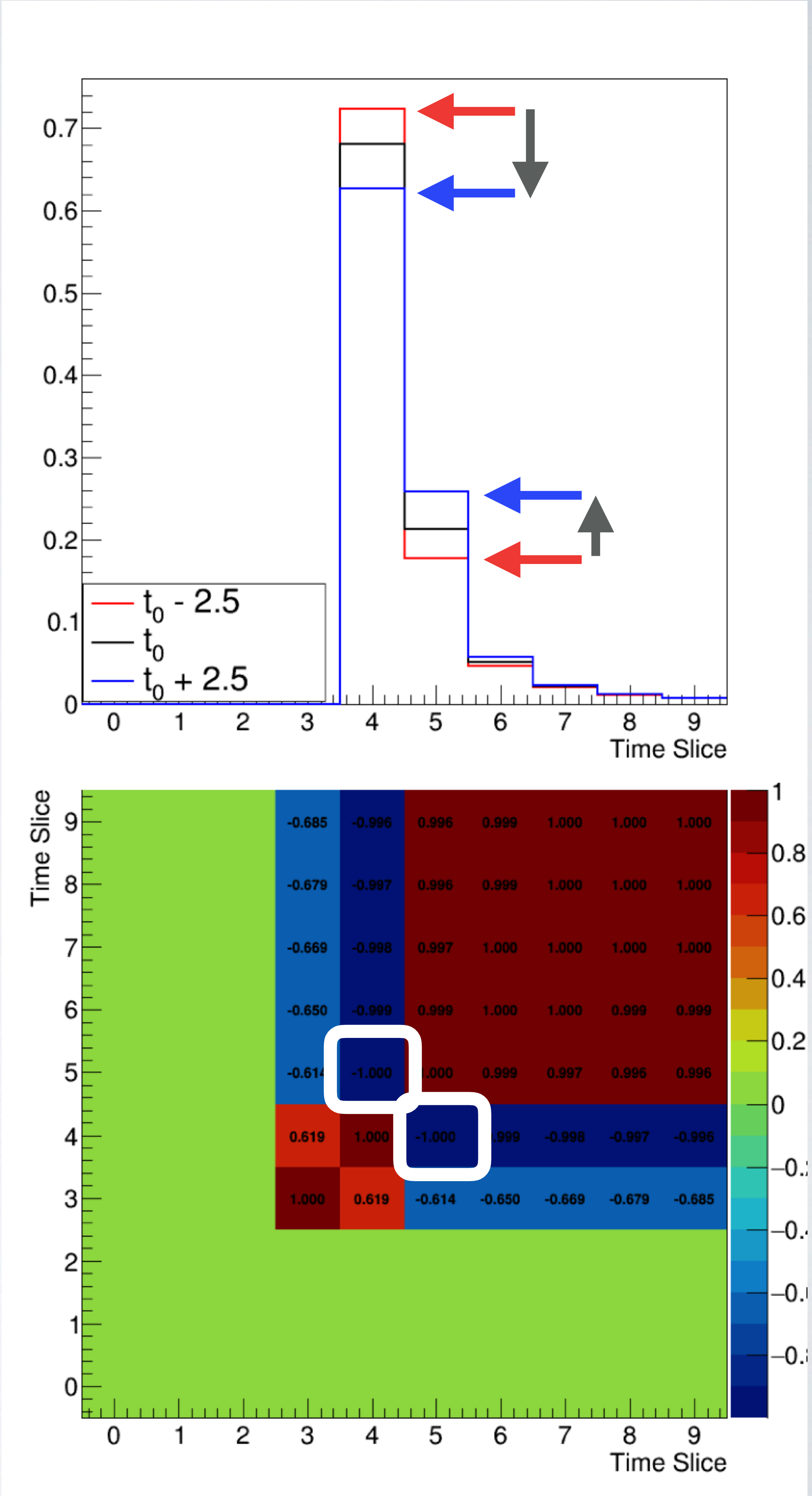
← uncorrelated

correlated →



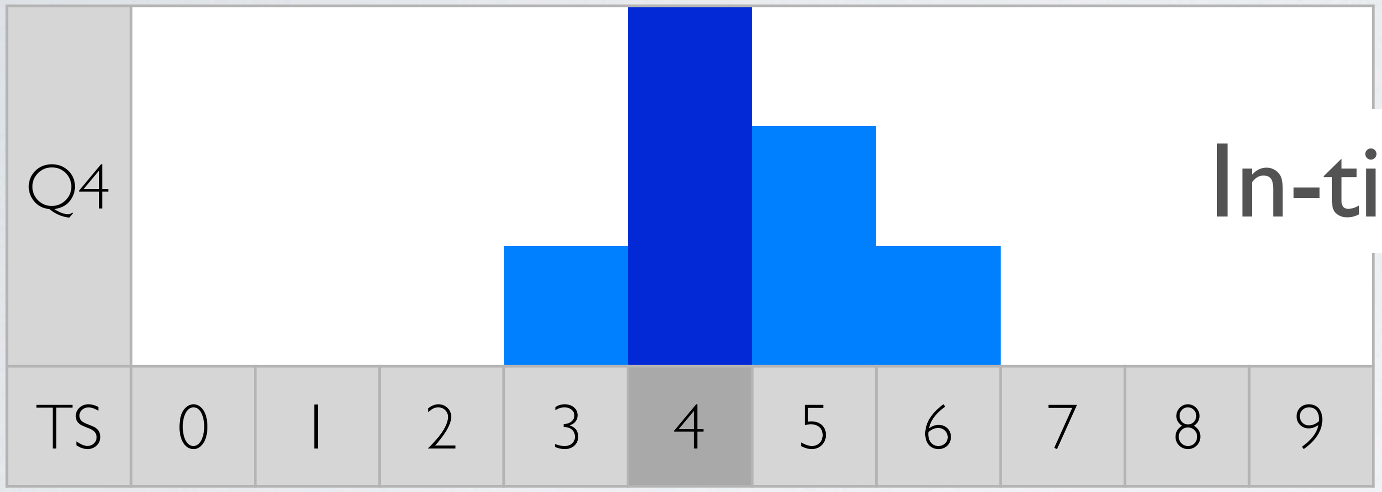
Signal model

- Pulse shape templates (nominal shape and time slew model) and uncertainties in terms of arrival time
- Build covariance matrix by shifting the template forward and backwards in time by 1σ variation
  - 2.5 ns for SiPM, 5.0 ns for HPD
- Covariance matrix encodes relative behavior of pulse shape as it is shifted

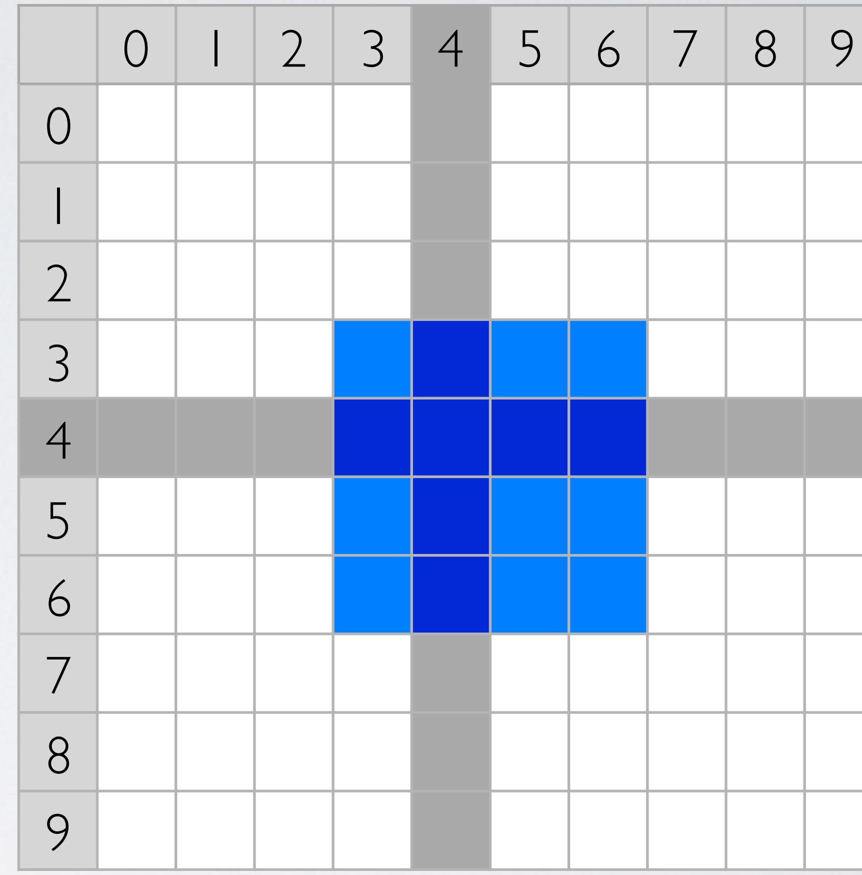


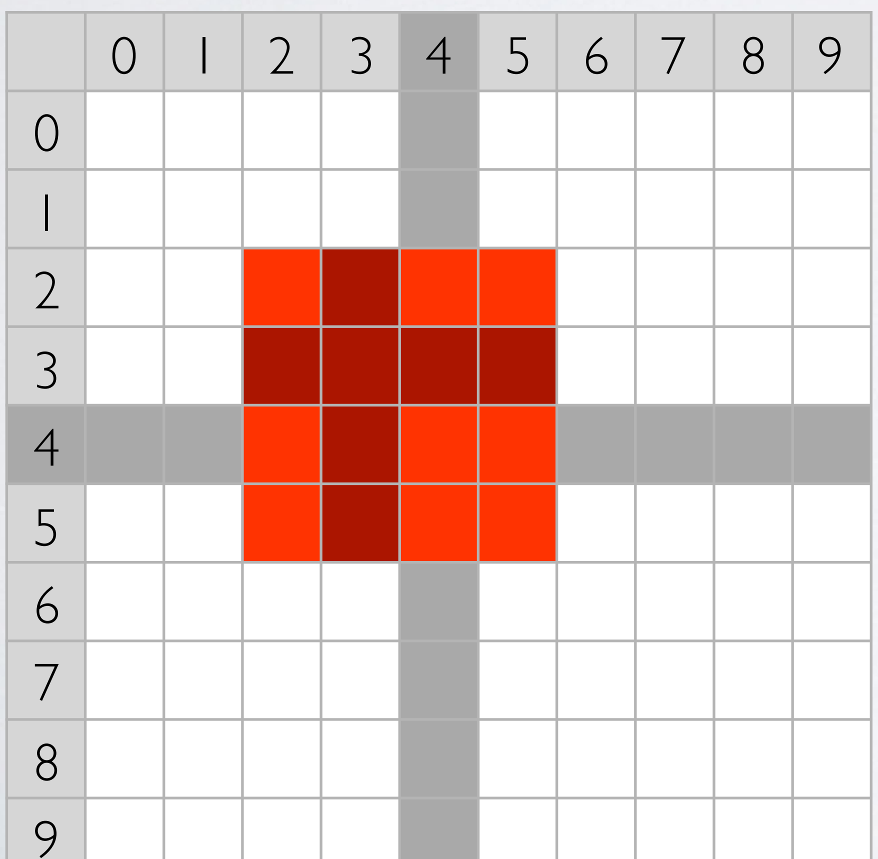
Building the signal covariance matrix

- Need covariance matrix for each pulse:

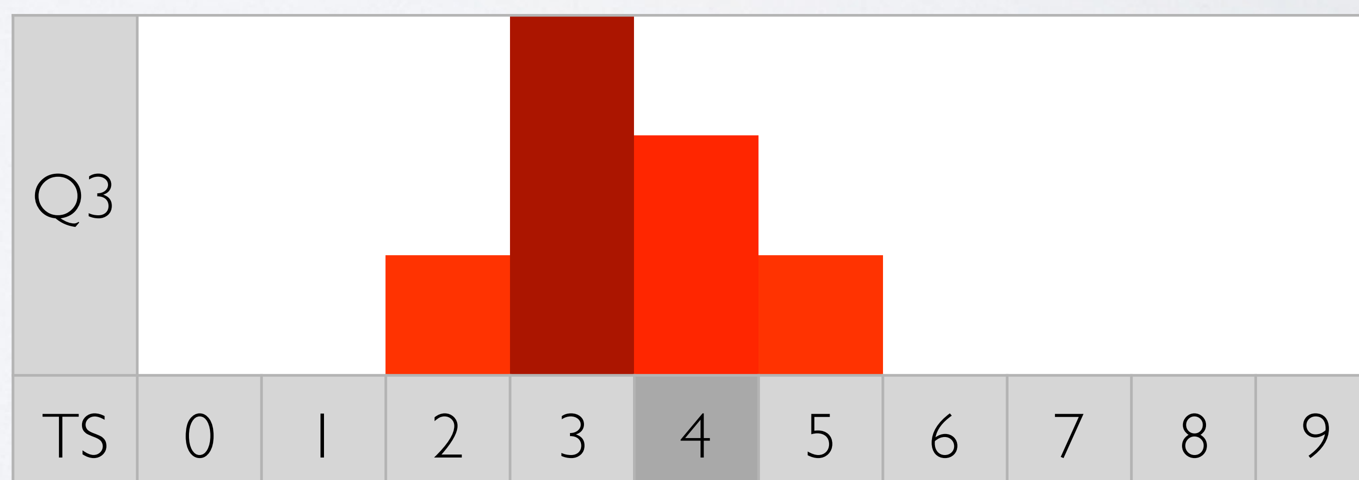


In-time



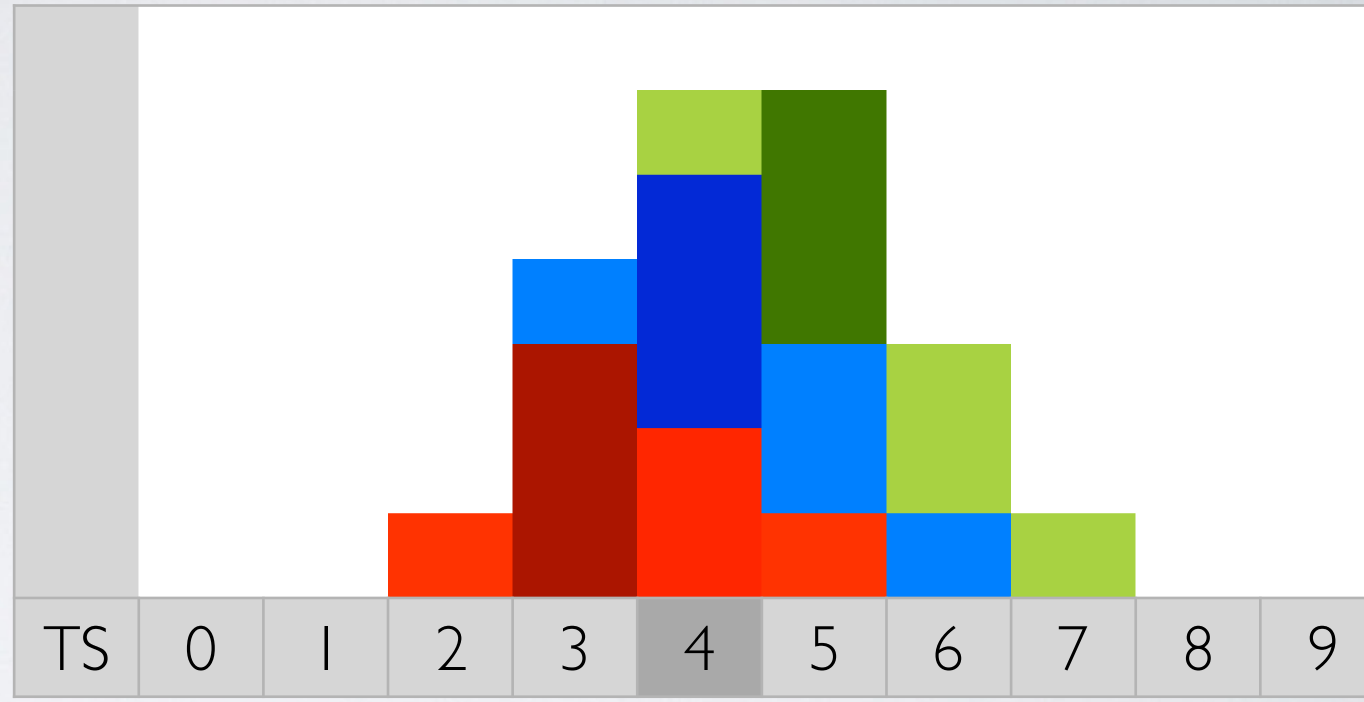


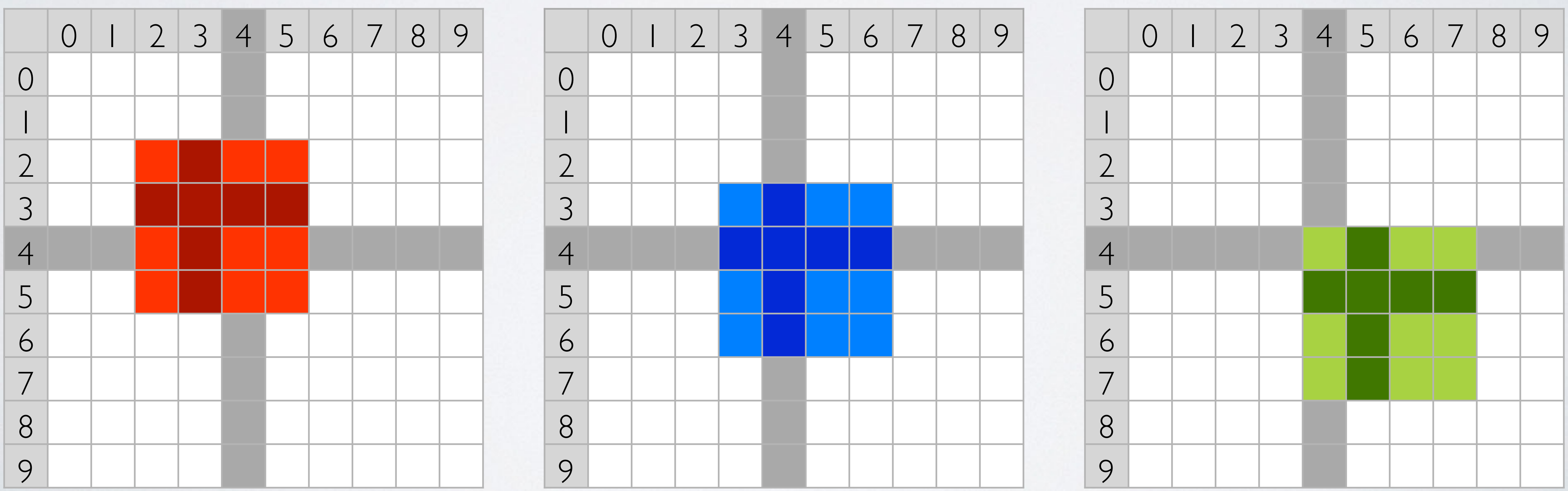
Previous



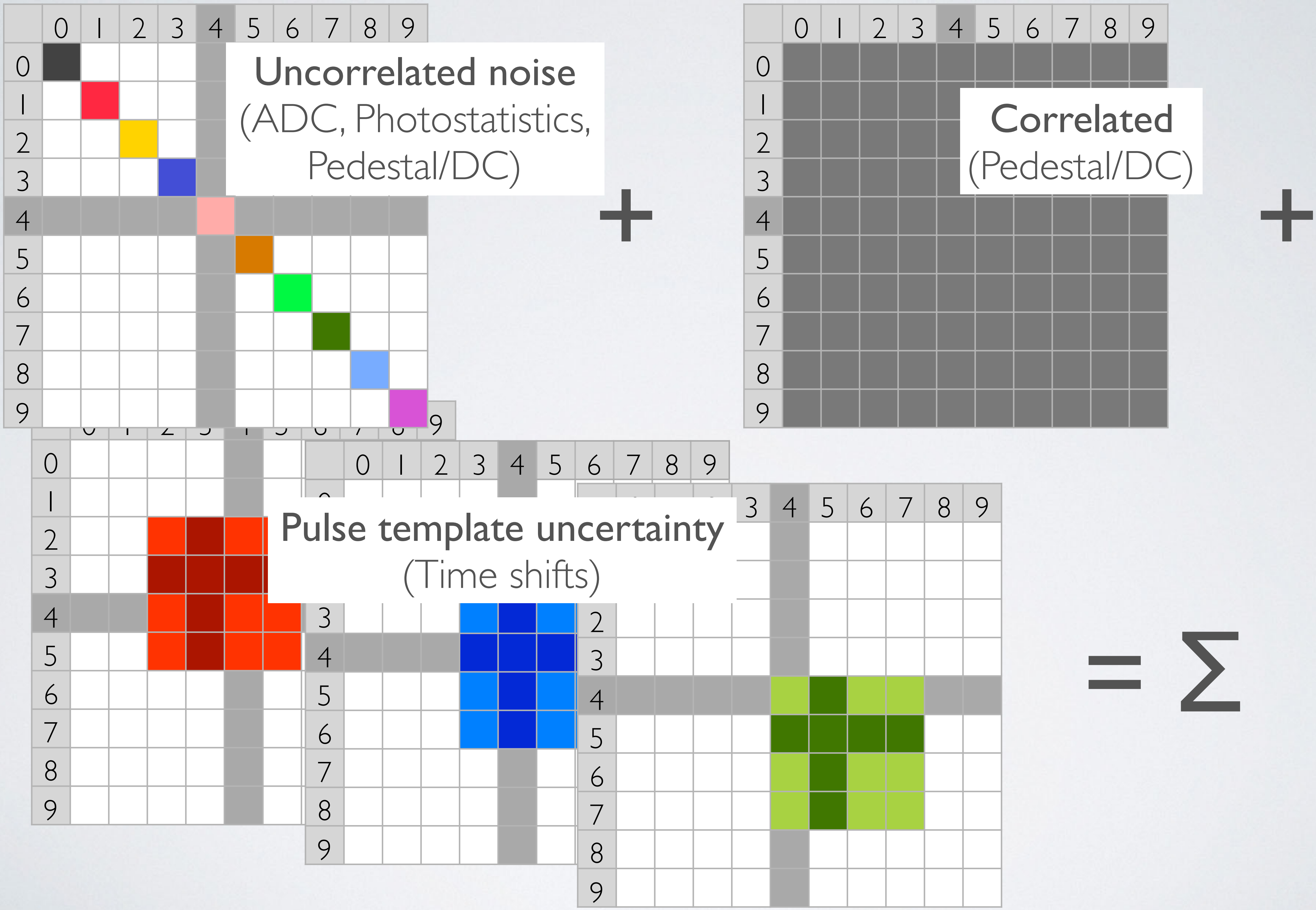
Overlapping signals

- For 3-pulse model, have 3 unique pulse shape covariance matrices:



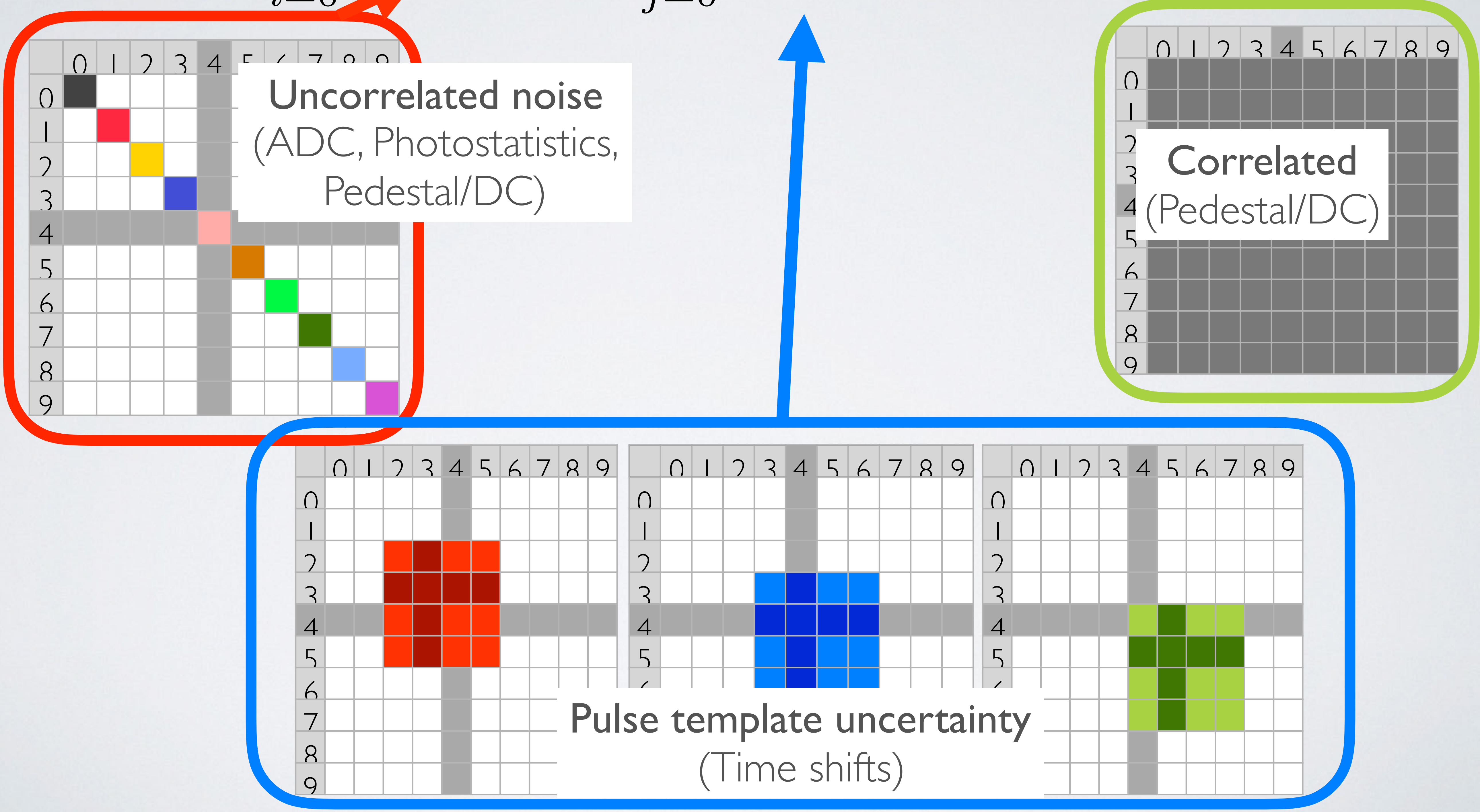


Putting it all together

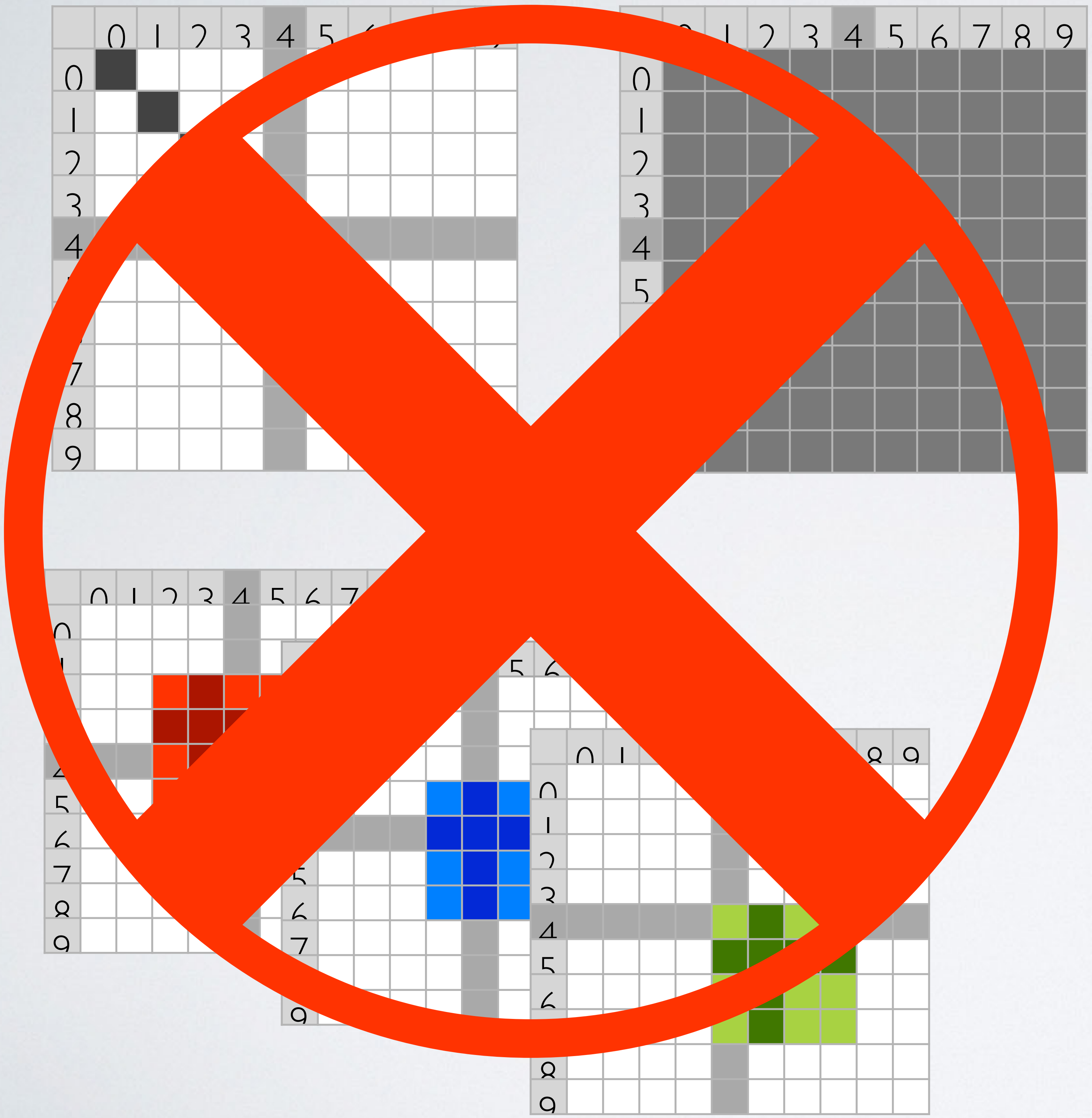


Method 2

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



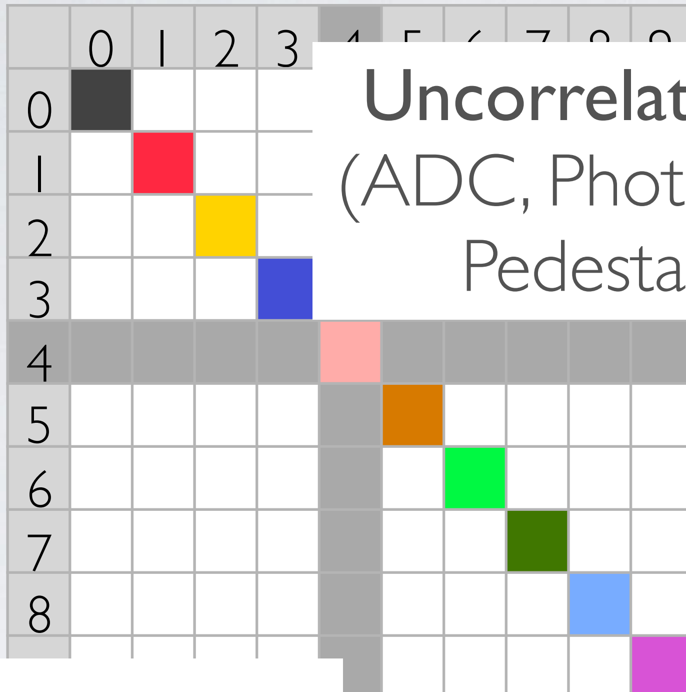
Method 3



- Reduce problem to single matrix inversion
- No floating time/pulse template, pedestal
- Fully deterministic, no fit, no uncertainties considered

Mahi

- Σ_d : "dark" noise term:



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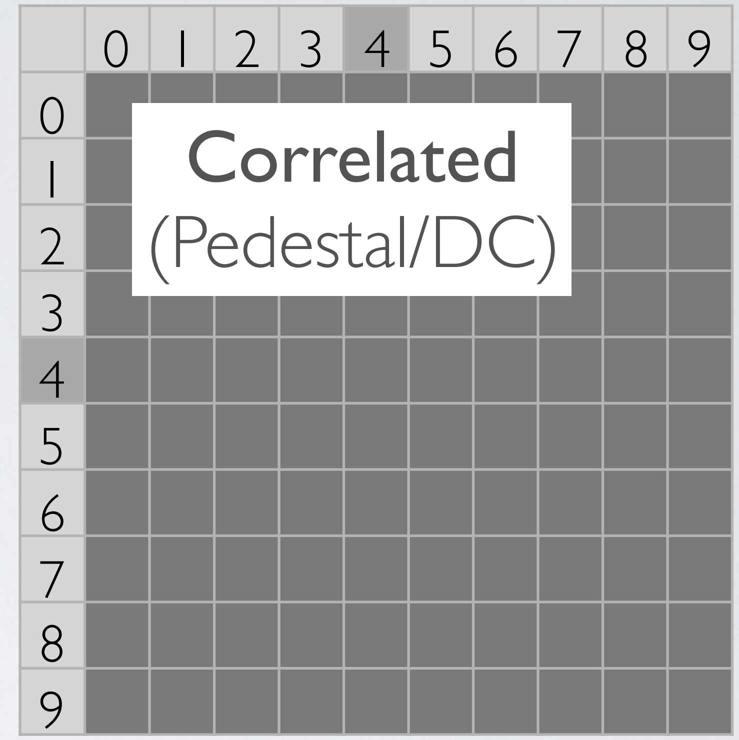
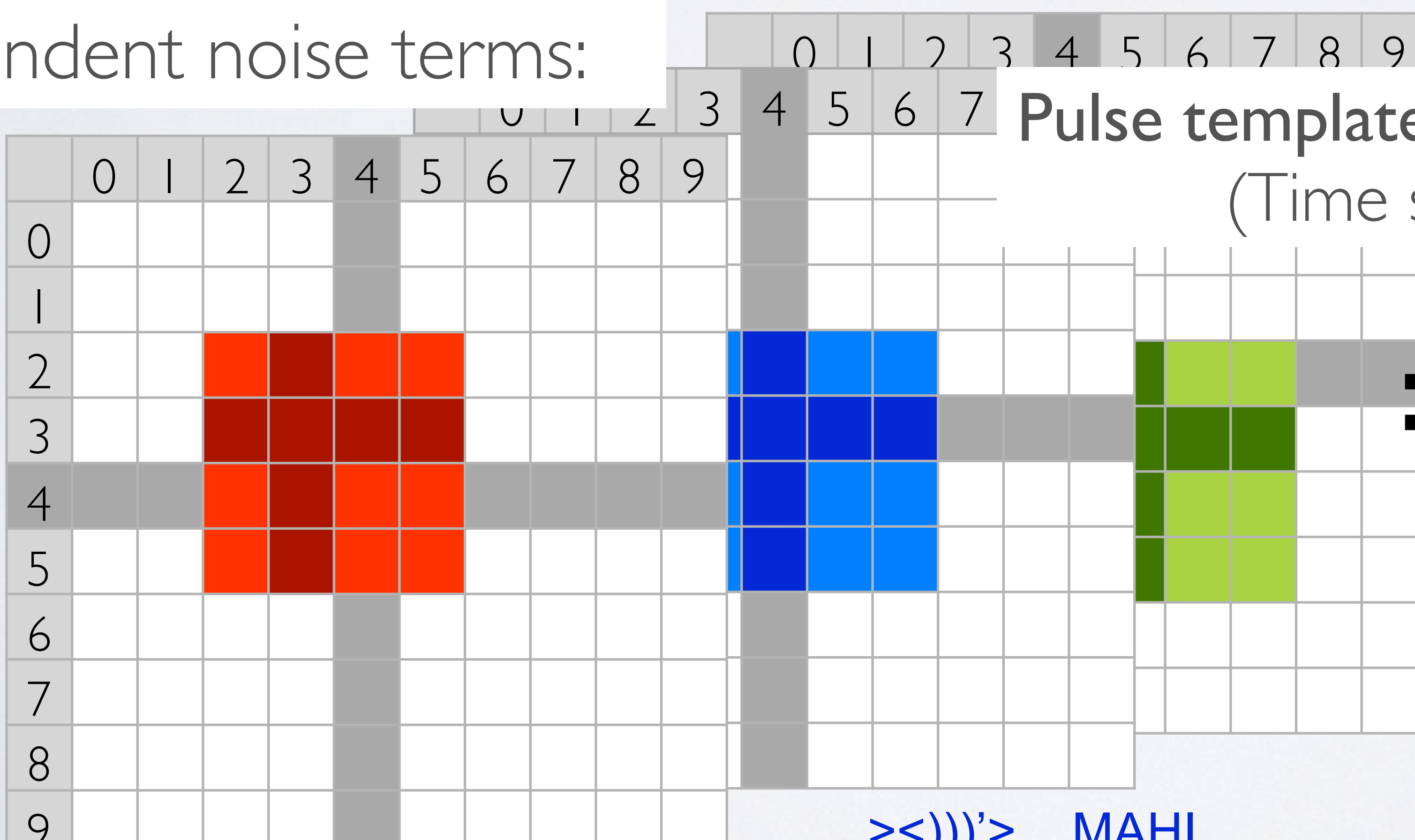


+

- Σ_{pi} : pulse amplitude-dependent noise terms:



$$= \left(\mathbf{\Sigma_d} + \sum A_i^2 \mathbf{\Sigma_{p_i}} \right)$$

Building the problem

- Have X^2 =

$$\left(\sum A_i \mathbf{p}_i - \mathbf{TS}\right)^{\mathrm{T}} \left(\mathbf{\Sigma_d} + \sum A_i^2 \mathbf{\Sigma_{p_i}}\right)^{-1} \left(\sum A_i \mathbf{p}_i - \mathbf{TS}\right)$$

- A_i : amplitudes
- $\mathbf{p_i}$: the pulse shapes
- **TS** : observed data

- Now what?

- fast Non-Negative Least Squares (NNLS) minimizer
- But quickly, a word about current initialization:
  - Allow for a pulse arriving in TS3, TS4, and TS5 (as in Method 2)
  - All pulse amplitudes 0 except for TS4 which is set to charge in TS4 with pulse shape containment correction

Minimization

- **For each iteration:**
  - Update covariance matrix

$$\left(\mathbf{\Sigma_d} + \sum A_i^2 \mathbf{\Sigma_{p_i}} \right)$$

    - $\mathbf{\Sigma_d}$ and $\mathbf{\Sigma_{pi}}$ don't change, just accessed
    - A_i^2 are updated based on previous iteration
    - sum of all terms calculated
    - invert result
  - Run NNLS
  - Calculate X^2
  - If $d\mathbf{X}^2 < 1\text{E-}3$ or maxIters reached, **return result**.
  - Else, **repeat**.

Fast NNLS Algorithm

from *Nonnegativity constraints in numerical analysis*, Chen and Plemmons

Algorithm *fnnls* **:**

Input: $\mathbf{A} \in \mathbf{R}^{m \times n}$, $\mathbf{b} \in \mathbf{R}^m$
Output: $\mathbf{x}^* \geq 0$ such that $\mathbf{x}^* = \arg\min \|\mathbf{Ax} - \mathbf{b}\|^2$.
Initialization: $P = \varnothing, R = \{1, 2, \cdots, n\}, \mathbf{x} = \mathbf{0}, \mathbf{w} = \mathbf{A}^T\mathbf{b} - (\mathbf{A}^T\mathbf{A})\mathbf{x}$
repeat

1. Proceed if $R \neq \varnothing \wedge [\max_{i \in R}(w_i) > \textit{tolerance}]$
2. $j = \arg\max_{i \in R}(w_i)$
3. Include the index j in P and remove it from R
4. $\mathbf{s}^P = [(\mathbf{A}^T\mathbf{A})^P]^{-1}(\mathbf{A}^T\mathbf{b})^P$
   4.1. Proceed if $\min(\mathbf{s}^P) \leq 0$
   4.2. $\alpha = -\min_{i \in P}[x_i/(x_i - s_i)]$
   4.3. $\mathbf{x} := \mathbf{x} + \alpha(\mathbf{s} - \mathbf{x})$
   4.4. Update R and P
   4.5. $\mathbf{s}^P = [(\mathbf{A}^T\mathbf{A})^P]^{-1}(\mathbf{A}^T\mathbf{b})^P$
   4.6. $\mathbf{s}^R = \mathbf{0}$
5. $\mathbf{x} = \mathbf{s}$
6. $\mathbf{w} = \mathbf{A}^T(\mathbf{b} - \mathbf{Ax})$

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.157.9203&rep=rep1&type=pdf

Details

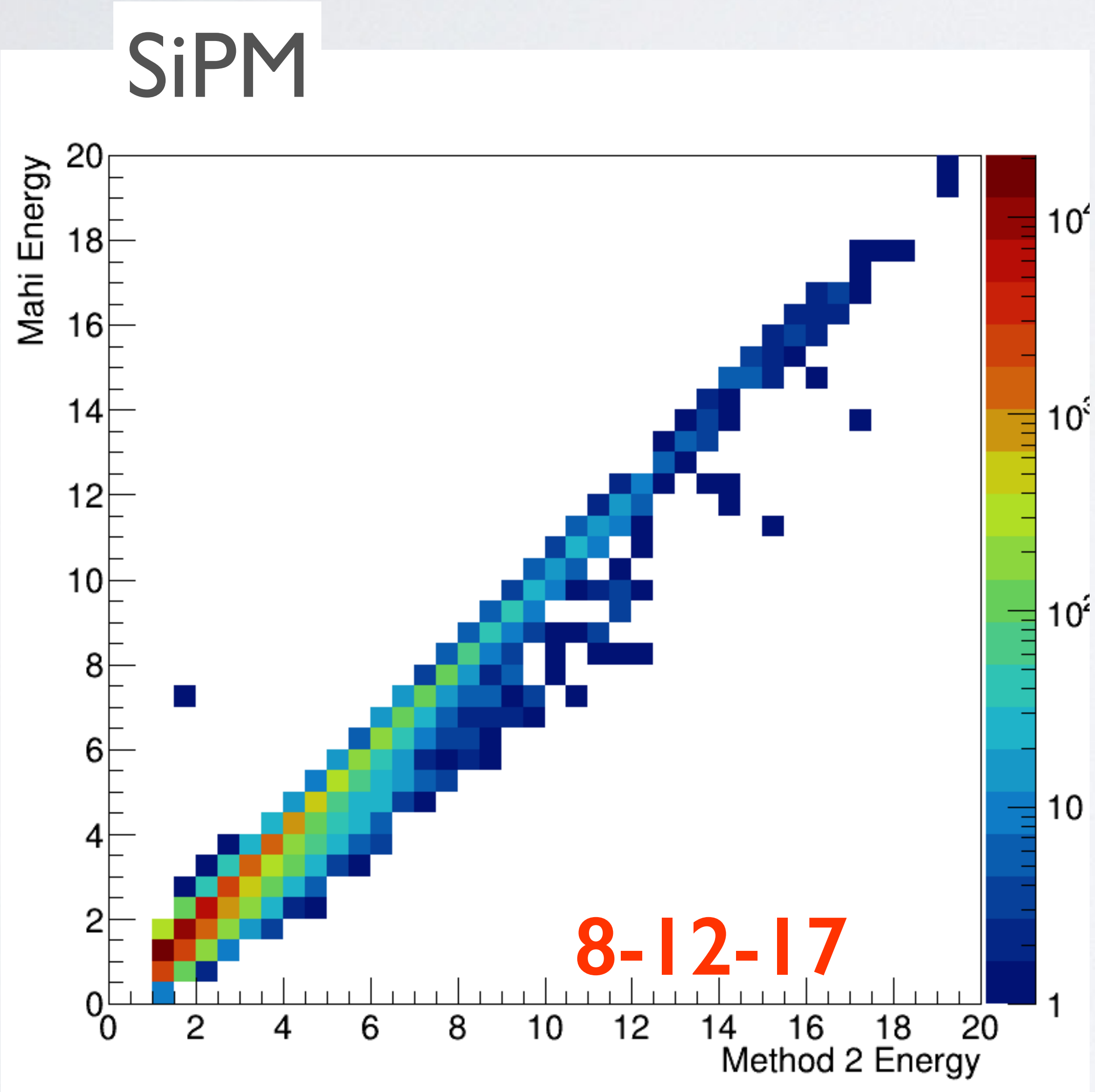
- If in-time charge above TS4Thresh_(0):
  - If chisSqSwitch_(10) is positive:
    - do 1 pulse fit
    - if 1 pulse chiSq greater than chiSqSwitch_(10):
      - repeat fit with activeBXs_ (filling scheme from config)
  - Else:
    - do fit with activeBXs_
- No energy-threshold for 1 vs 3 pulse switch as in Method 3

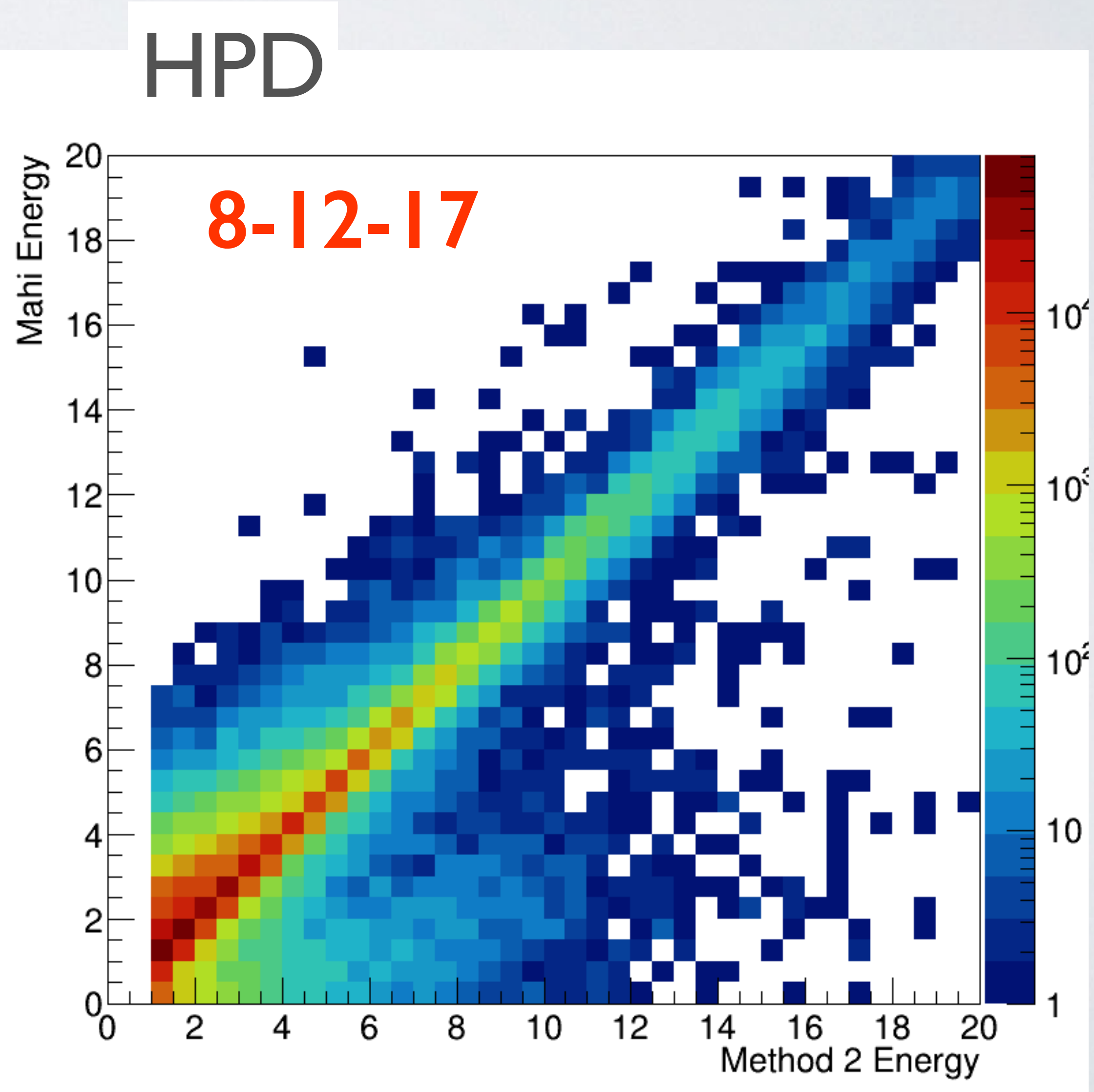
Performance

Performance: Single bunches

Compare Mahi energy to Method 2 energy in single bunch collisions:

Data from Run 296642 (Fill 5822)
Filling scheme Single_10b_9…
Post-HEP17 phase alignment
Using SiPM shape 205

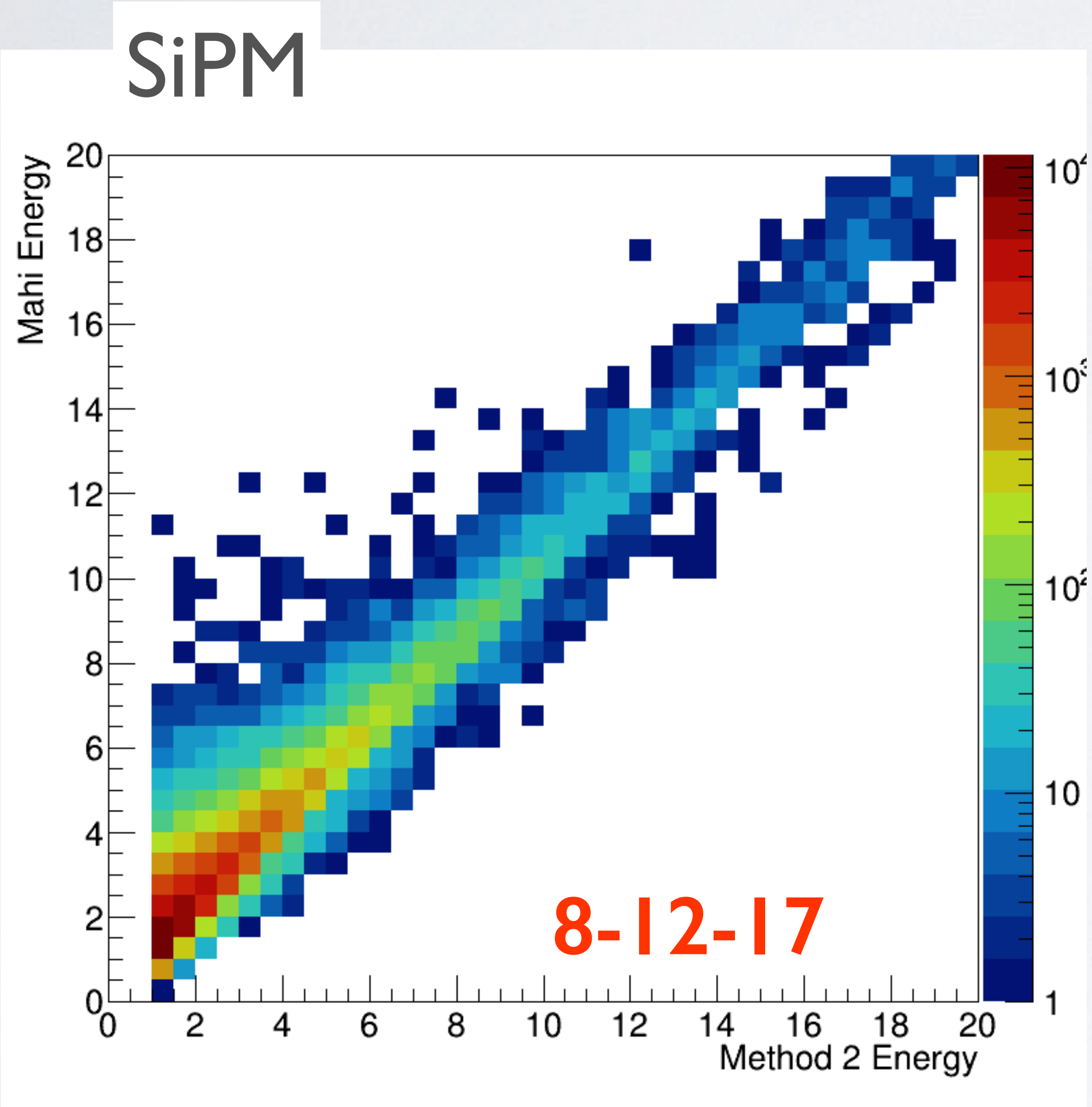


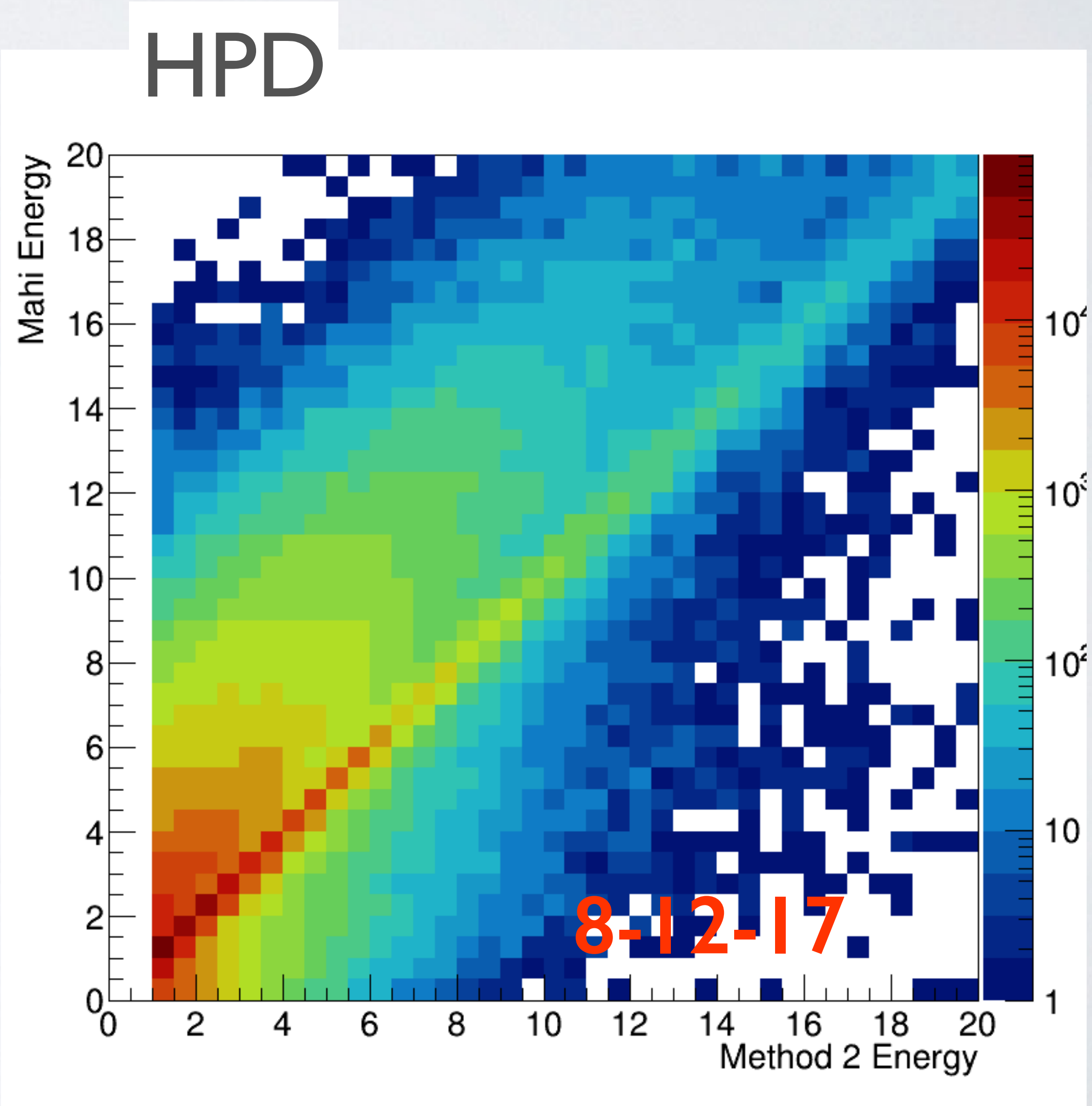


Performance: Bunch trains

Compare Mahi energy to Method 2 energy with out of time pileup:

Data from Run 305809 (Fill 6341)
Filling scheme 25ns_1868b…128bpi_17i8b4e
<n> = 58



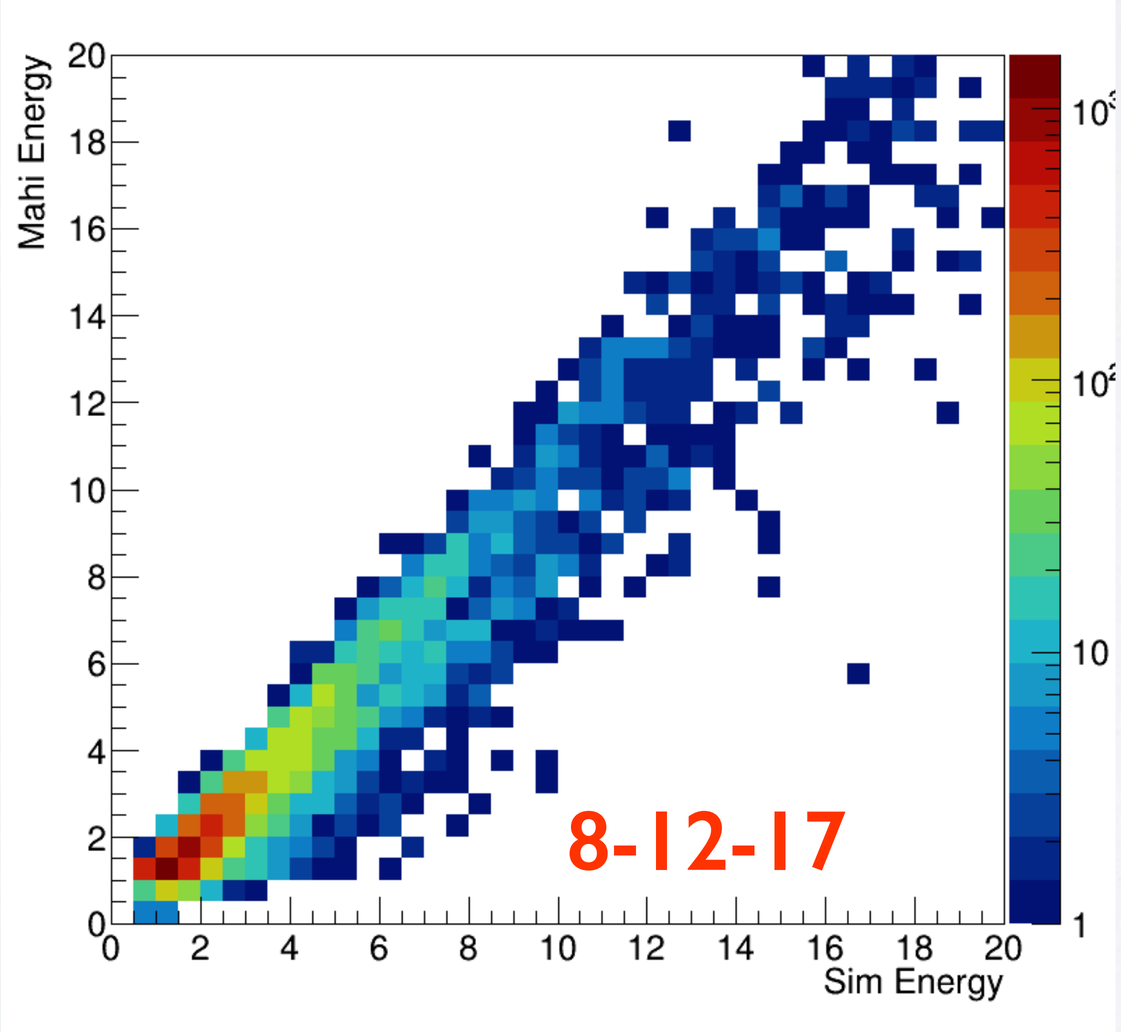


Performance: NoPU Simulation

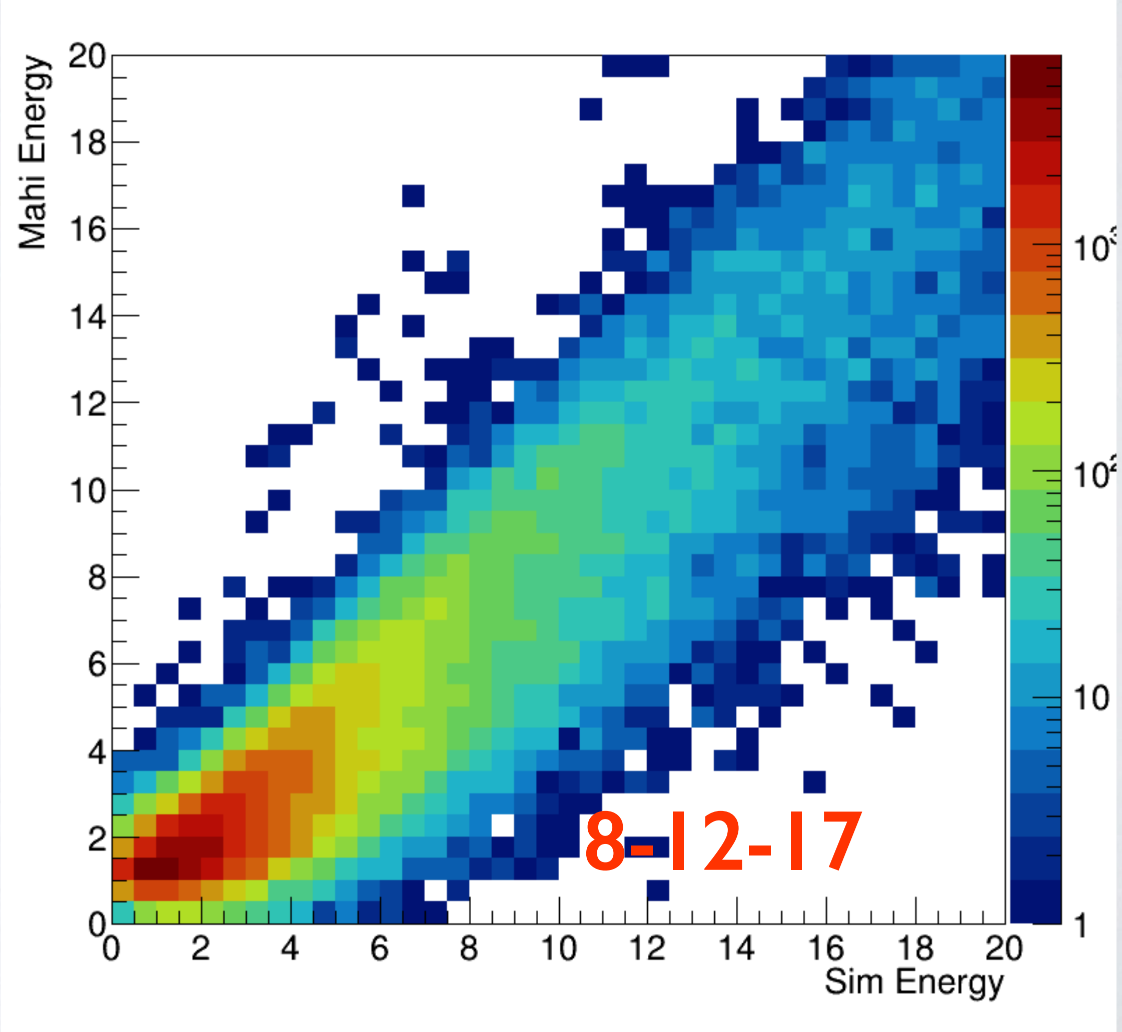
Compare Mahi energy to Sim-level energy in no pileup MC:

No pileup monte carlo

SiPM



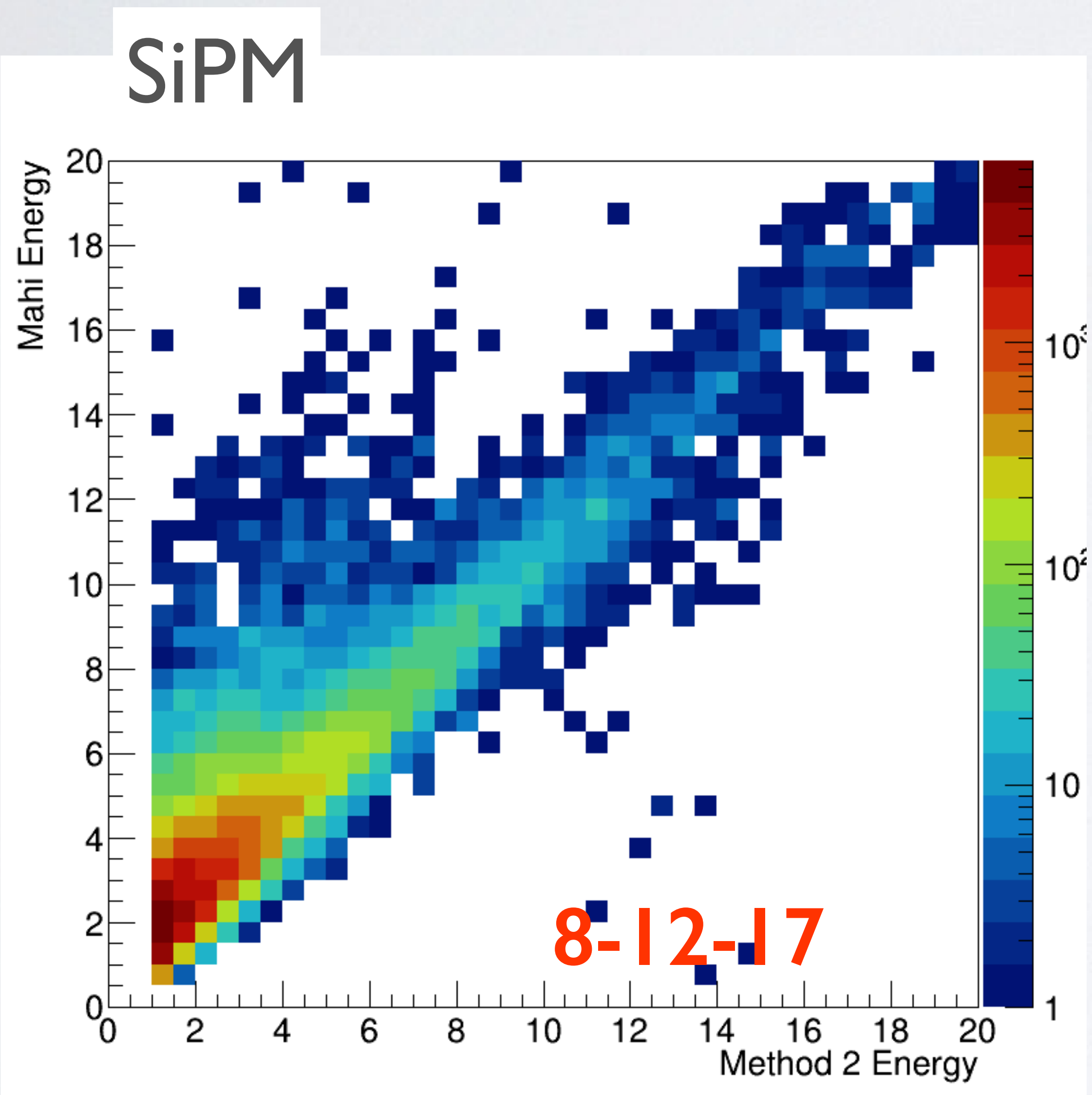
HPD

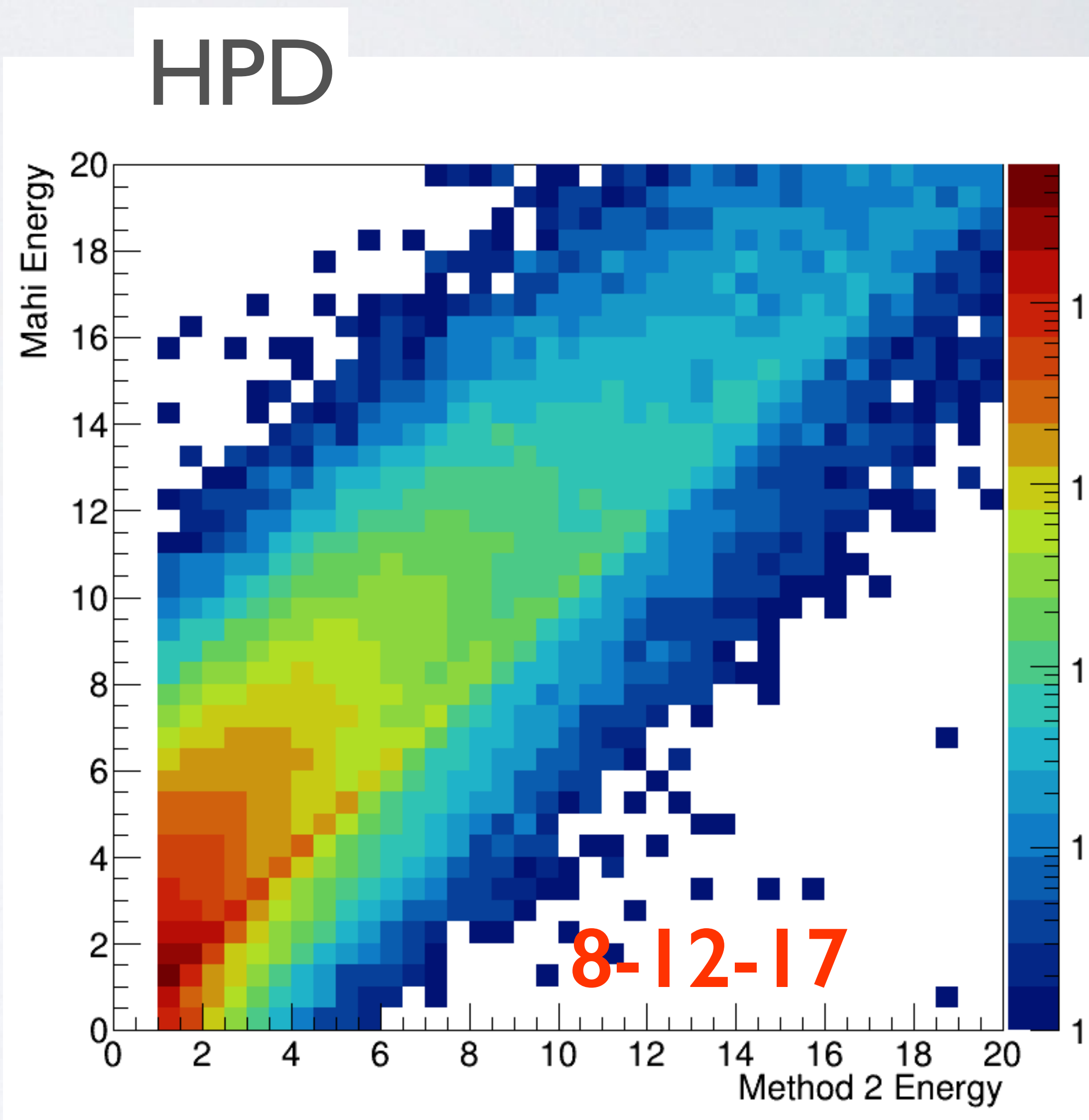


Performance: PU Simulation

Compare Mahi energy to
Method 2 energy with
out of time pileup simulation:

RelValQCD PU25ns





CPU timing

- In <n>=58 data, Mahi is
  - ~10 times faster than Method 2,
  - ~6 times slower than Method 3
- In single bunch data, Mahi is
  - ~6 times faster than Method 2,
  - ~5 times slower than Method 3
- Timing results from igprof using 1000 events per scenario
- CPU timing critical for use at HLT, will need TSG feedback

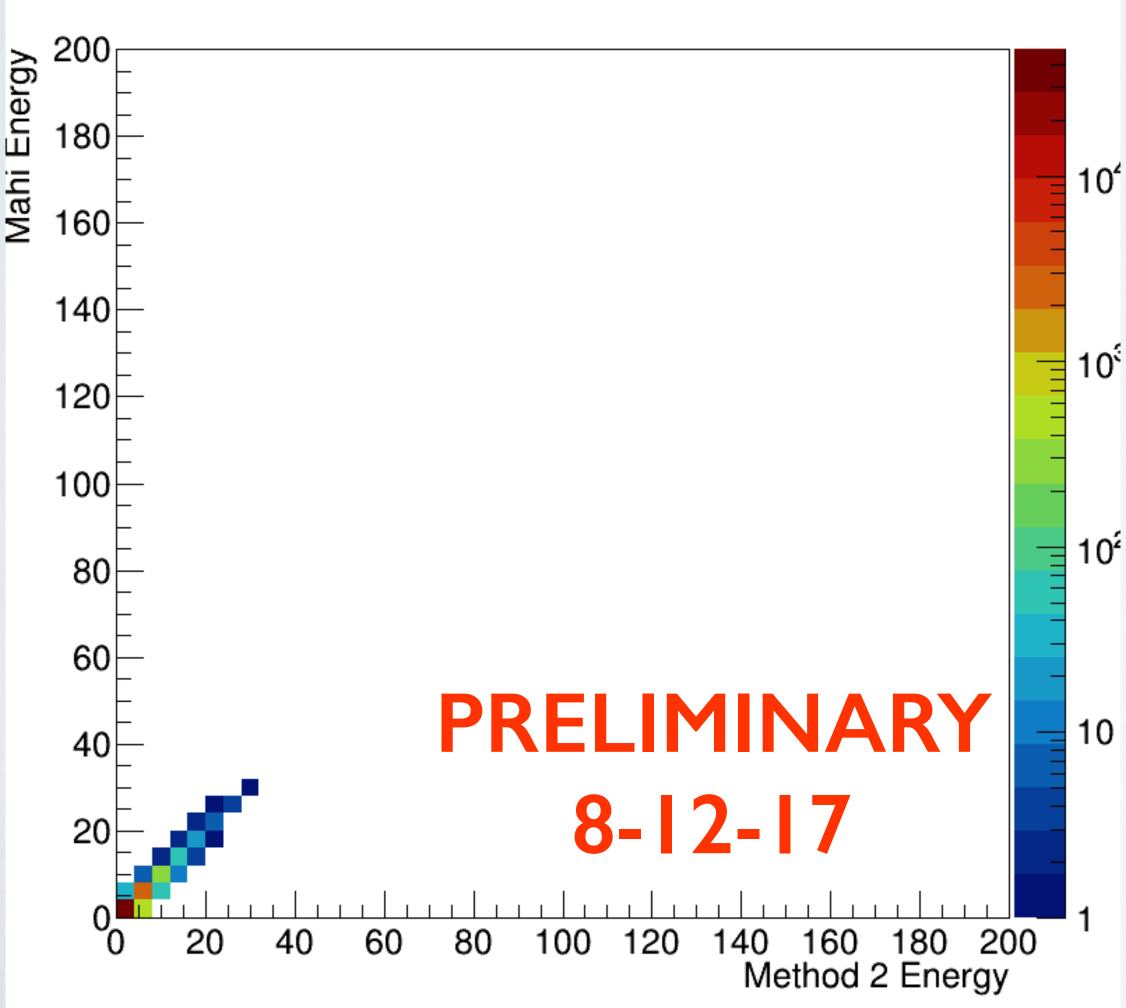
Backup

Single bunches vs Method 2

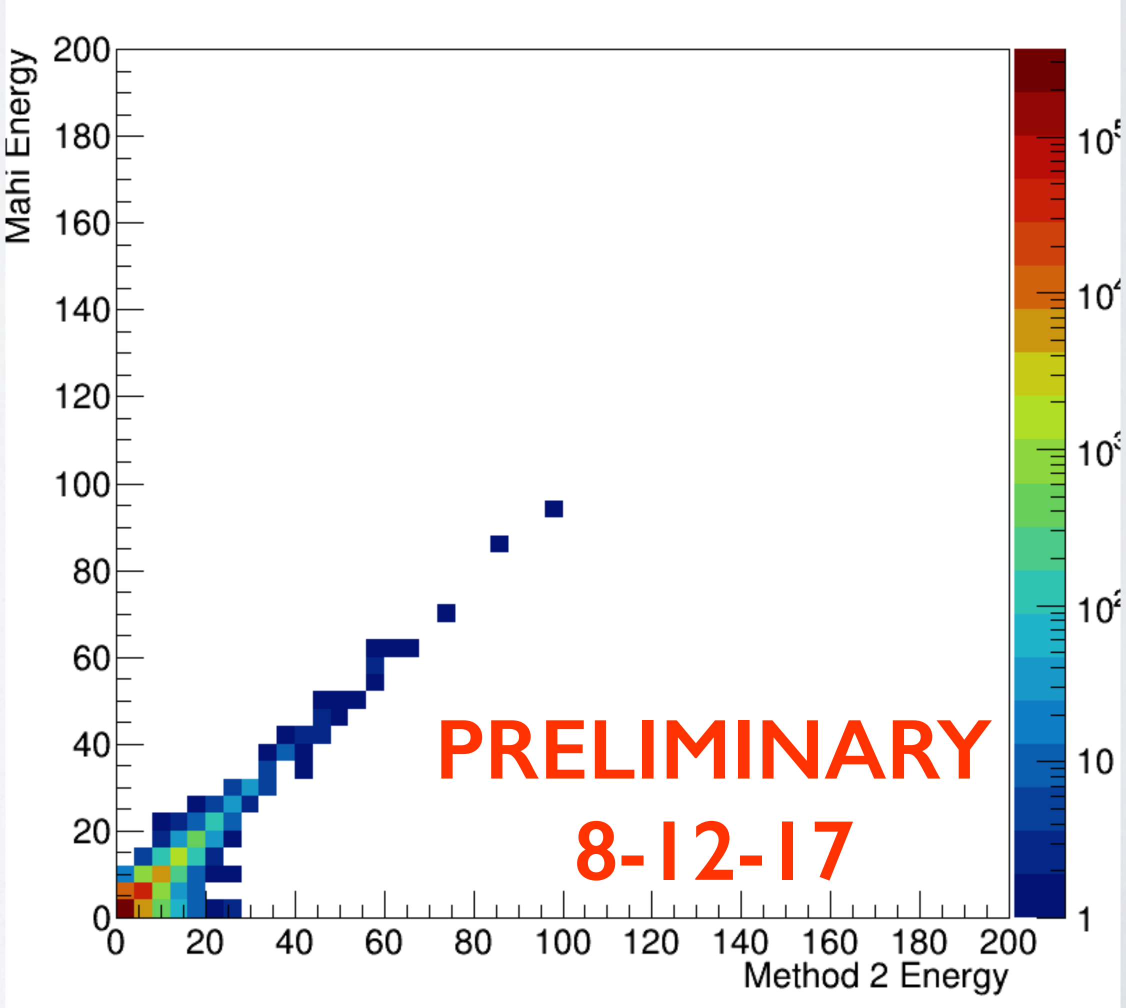
Compare Mahi energy to Method 2 energy in single bunch collisions:

Data from Run 296642 (Fill 5822)
Filling scheme Single_10b_9…
Post-HEP17 phase alignment
Using SiPM shape 205

SiPM



HPD



Bunch Trains vs Method 2

Compare Mahi energy to Method 2 energy with out of time pileup:

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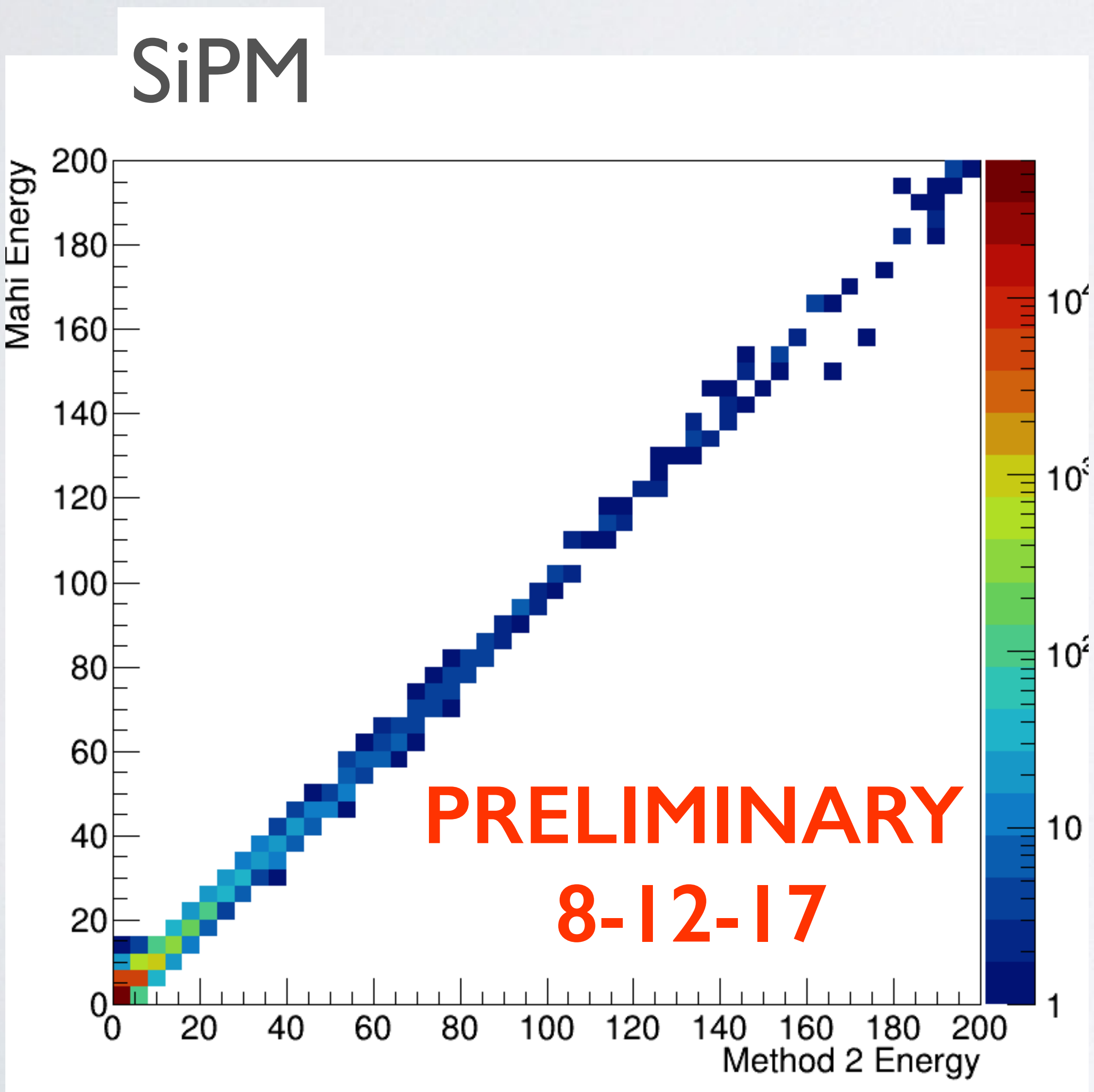
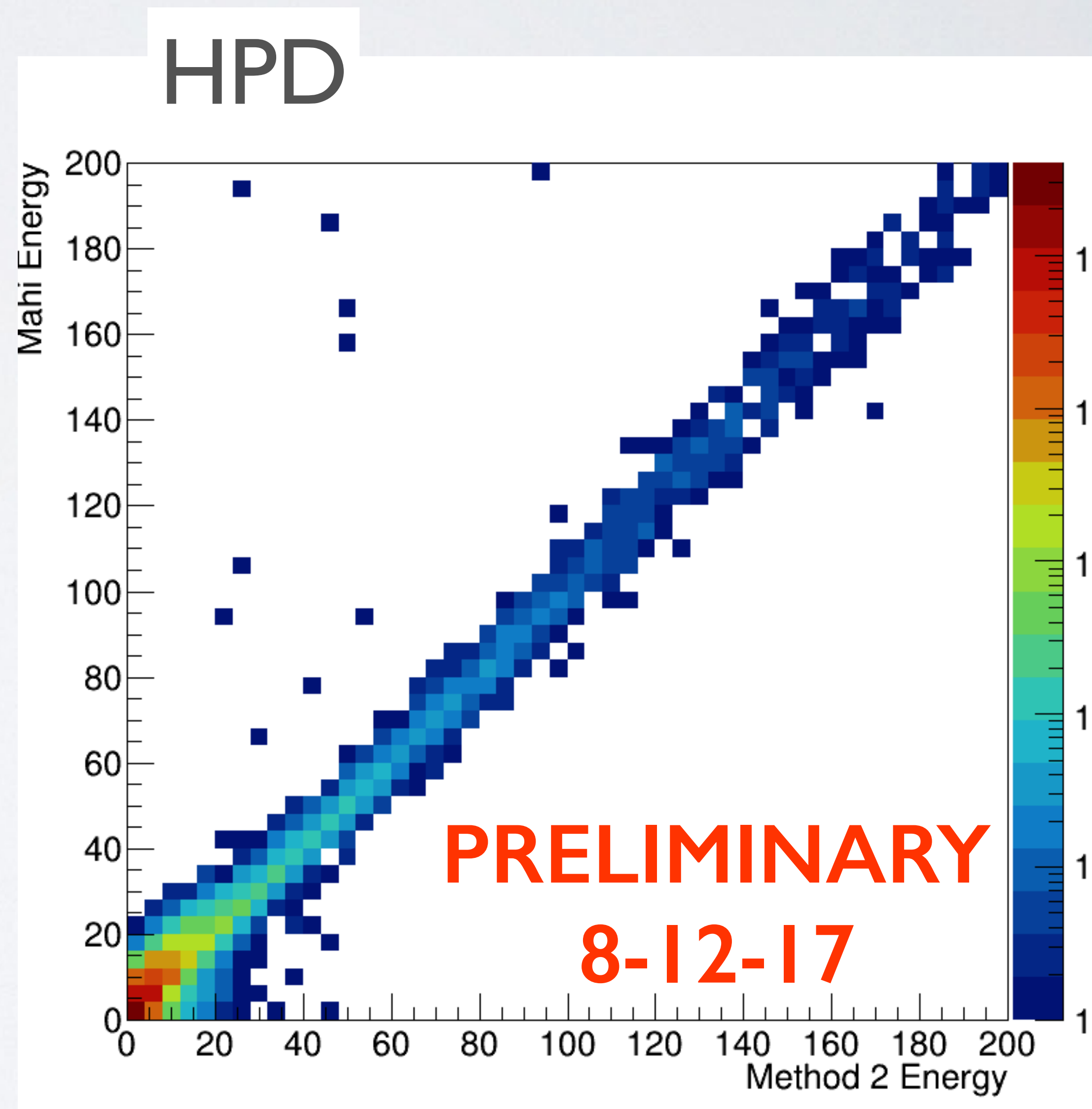
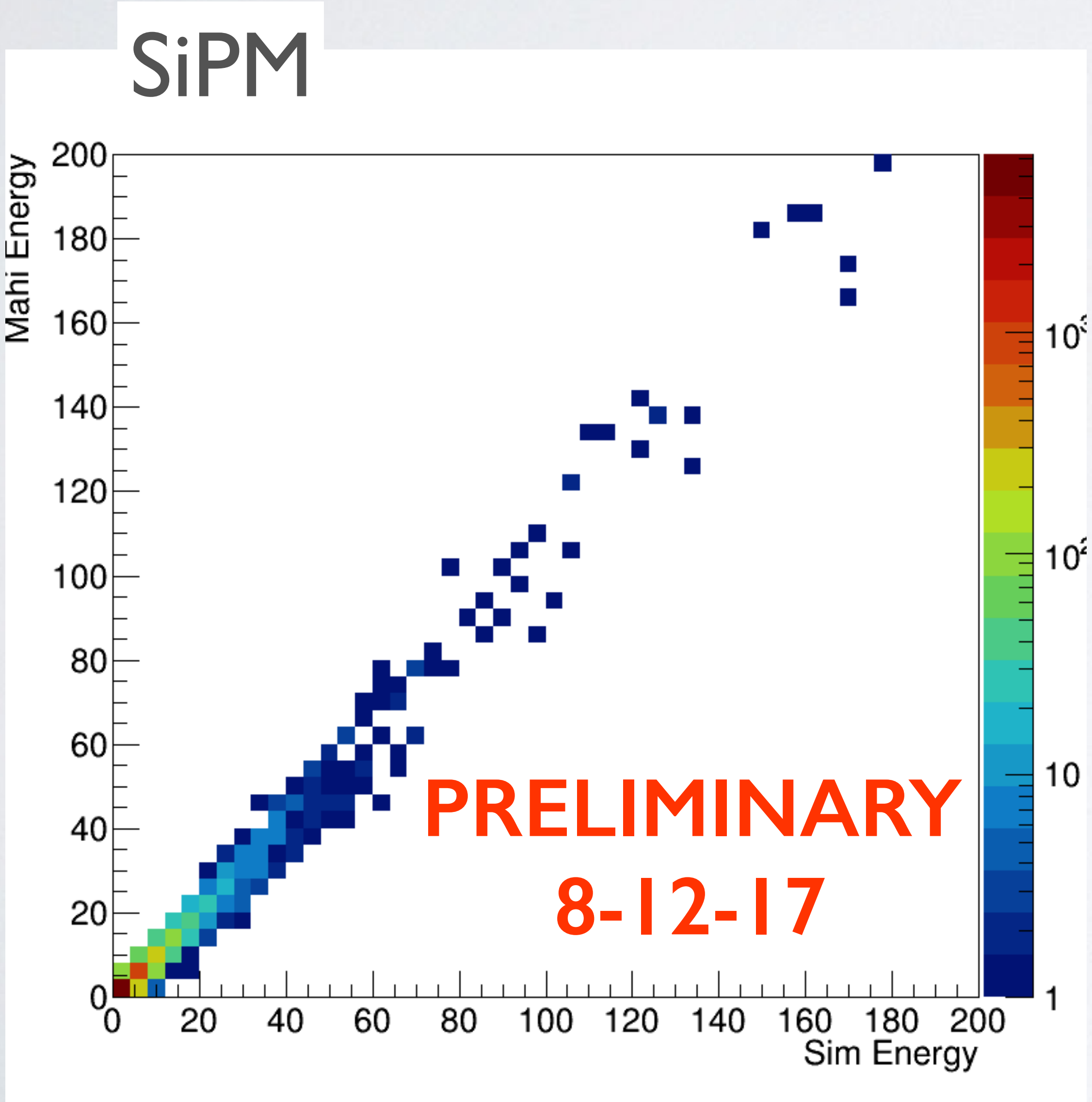


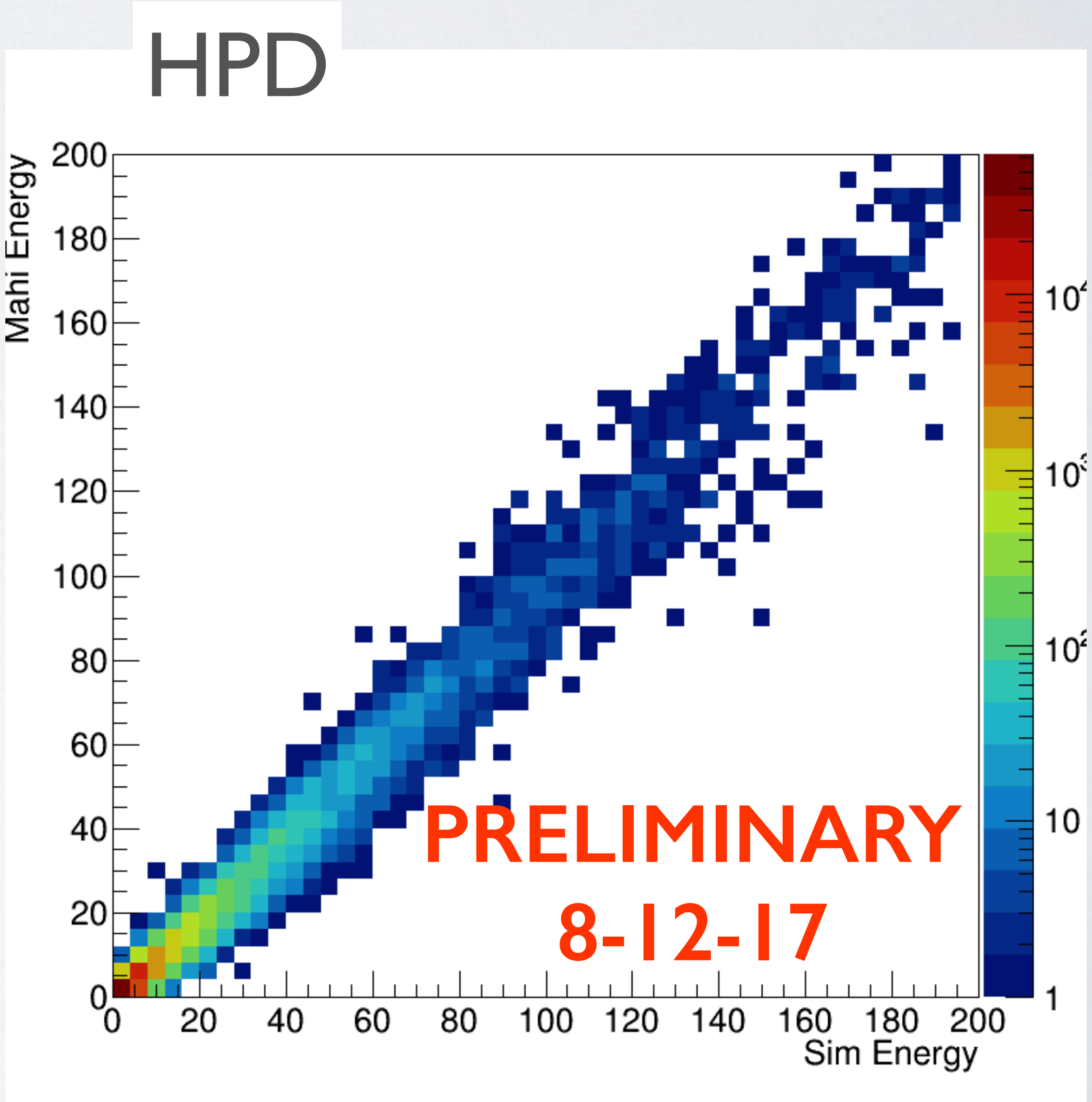


NoPU vs Sim

Compare Mahi energy to Sim-level energy in no pileup MC:

No pileup monte carlo





PU vs Method 2

Compare Mahi energy to
Method 2 energy with
out of time pileup simulation:

RelValQCD PU25ns