

DESIGN, IMPLEMENTATION, AND EVALUATION OF NAPALI: A NOVEL DISTRIBUTED SENSOR NETWORK FOR IMPROVED POWER QUALITY MONITORING.

Dr

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Outline

- Event Detection
- Napali method
- Power Quality
- OPQ Network
- Napali Evaluation



Event Detection



Animal



Detection



Bunny



Classification



Fancy
Bunny

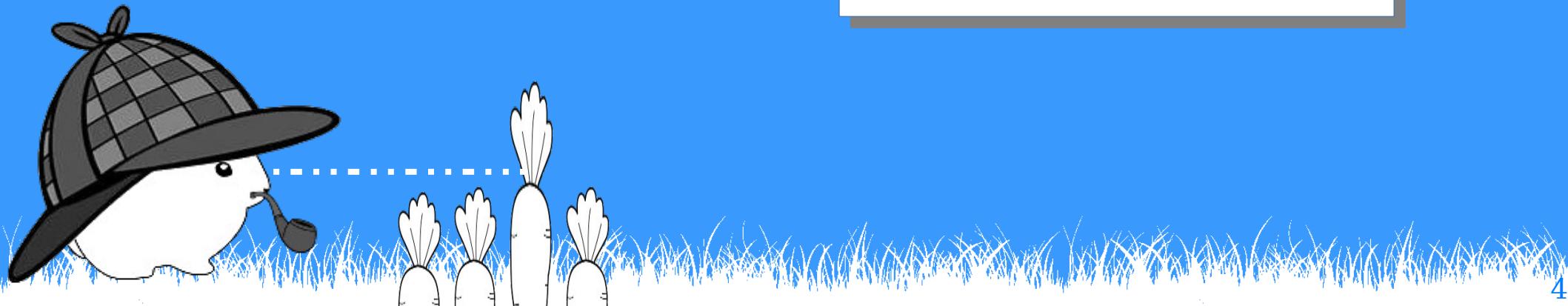


Traditional Methods

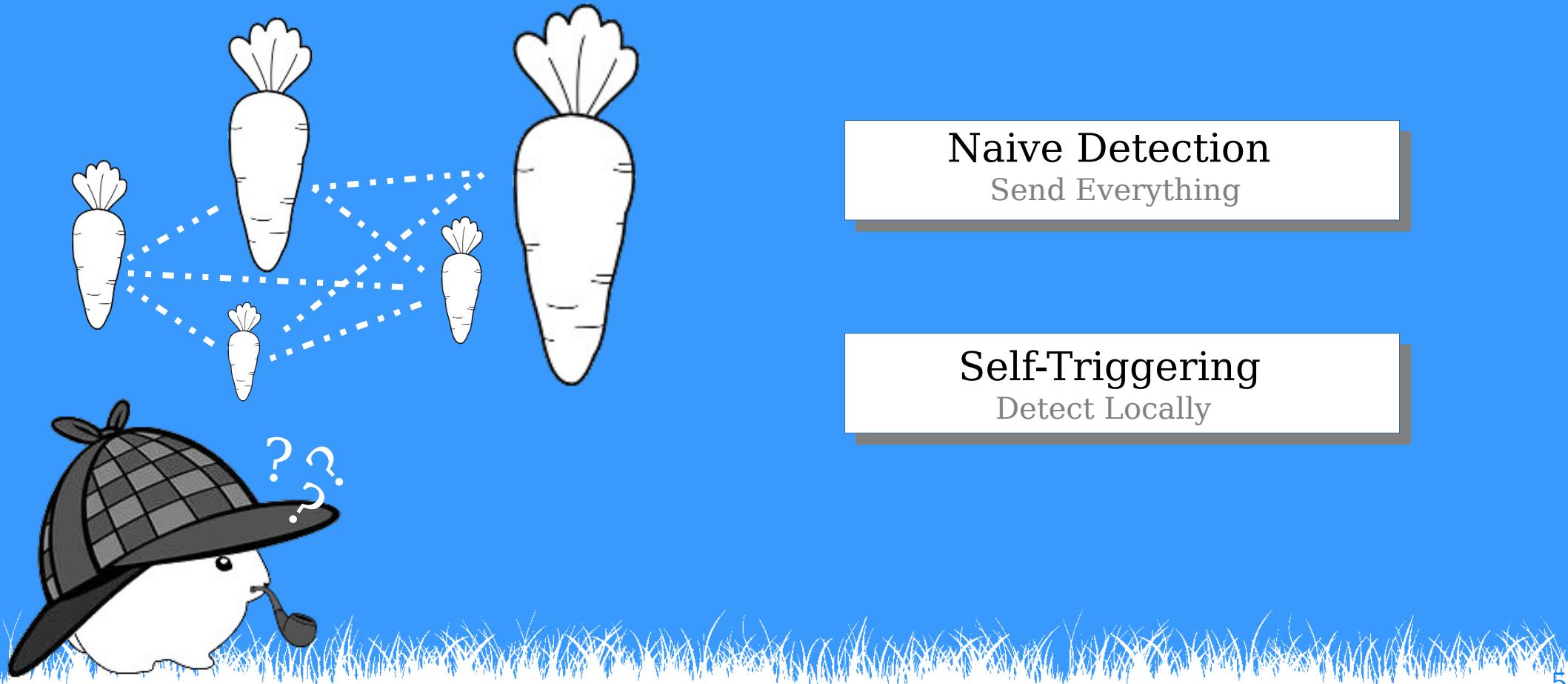
Metric Extraction

Threshold

Event Storage



Distributed Event Detection



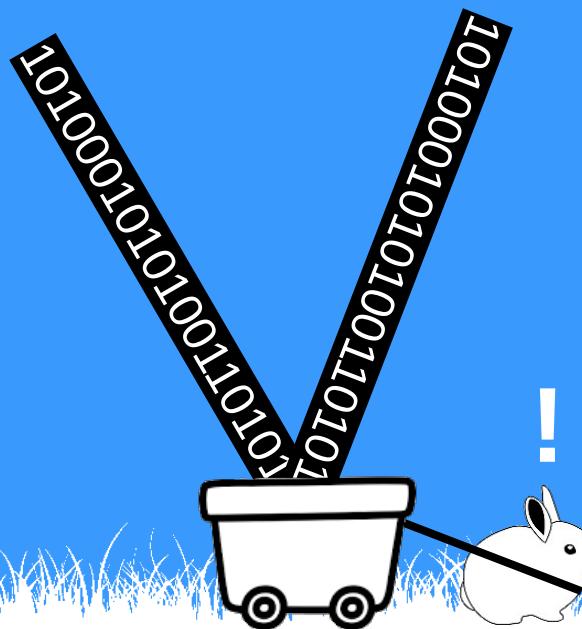
Naive Detection
Send Everything

Self-Triggering
Detect Locally

Issues Current Methods

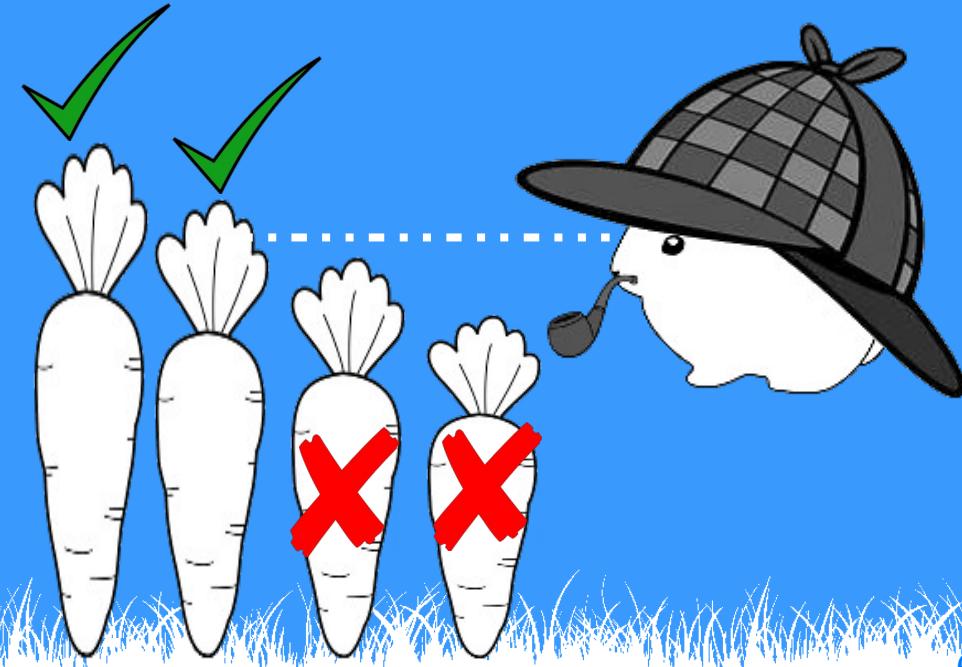
Naive Detection

- Bandwidth
- Memory
- Scalability



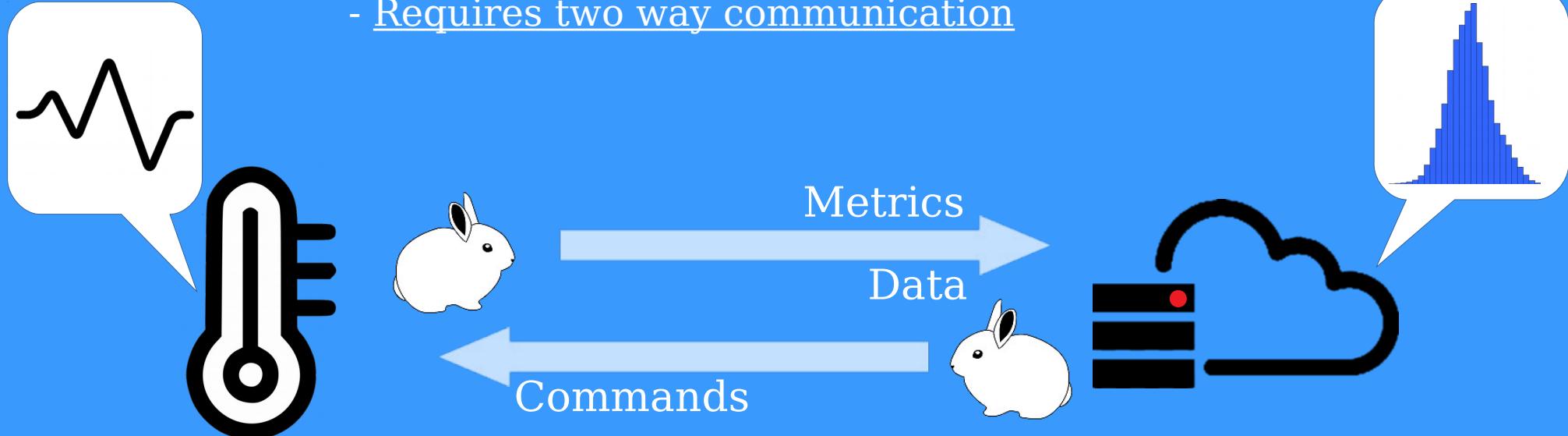
Self-Triggered

- Detection Efficiency



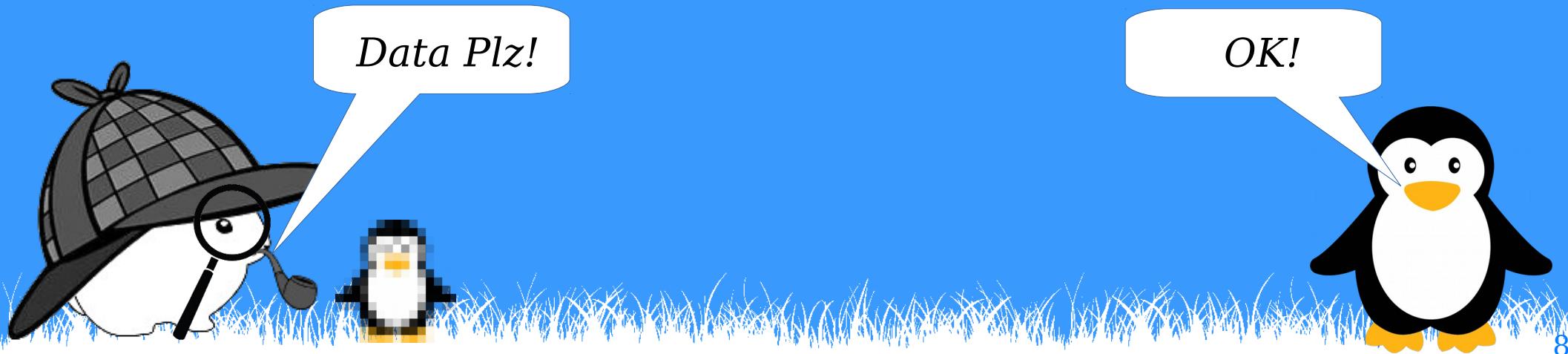
Napali

- Sensor forward metrics to the sink
- Sensor stores raw data locally
- Sink builds a statistical model of the sensor
- Sink requests data from the sensor
- Requires two way communication



Napali

- Sink maintains a coarse view of the entire system.
- Sink filters out local events.
- Sink determines which devices participate in event detection



Claim



Napali provides a novel architecture that is both a feasible solution to the problem of distributed power quality monitoring and provides significant benefits over the two standard alternative architectures.



Claim

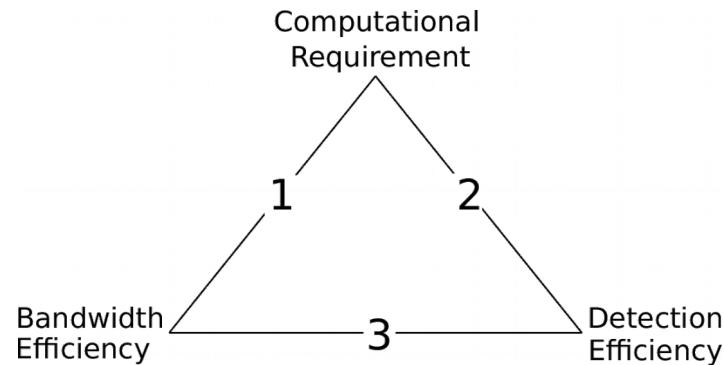


**Napali architecture can, in principle,
provide benefits for other domains beyond
power quality.**



Comparison From Sensors Perspective

Pick Two!

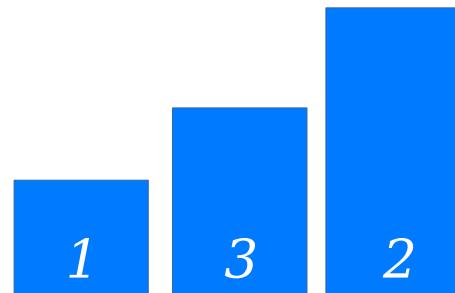


1. Self-Triggered
2. Naive
3. Napali



Comparison From Sink Perspective

Computational Cost:



1. Self-Triggered
2. Naive
3. Napali

Or is it?



Claims of the Thesis

- 1. Napali minimizes bandwidth usage**
- 2. Napali mitigates device latency effects**
- 3. Napali minimizes sink processing requirements**
- 4. Sub-threshold data acquisition is a viable event detection strategy**
- 5. Temporal locality triggering results in a low false negative detection**



Additional Benefits of Napali

Outside the scope of this thesis

- 1. Increased flexibility with respect to privacy protection.**
- 2. Increased resiliency with respect to power failure**

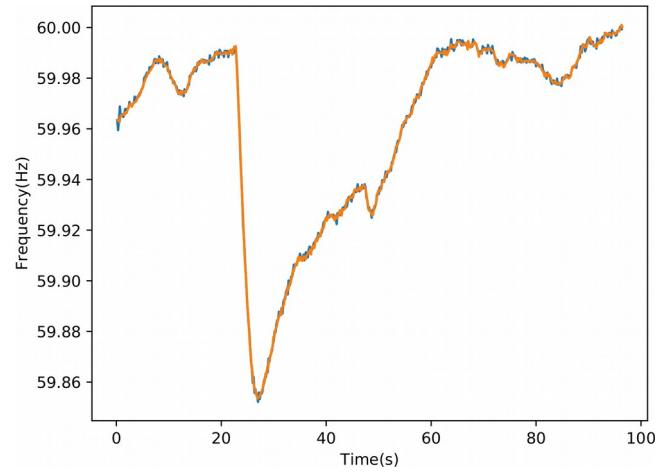
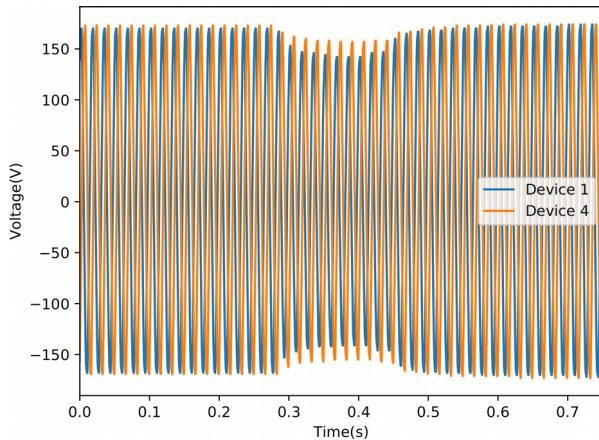


Problem of Power Quality

- 1. Amplitude**
- 2. Fundamental Frequency**
- 3. Harmonic Distortion**
- 4. Transient**

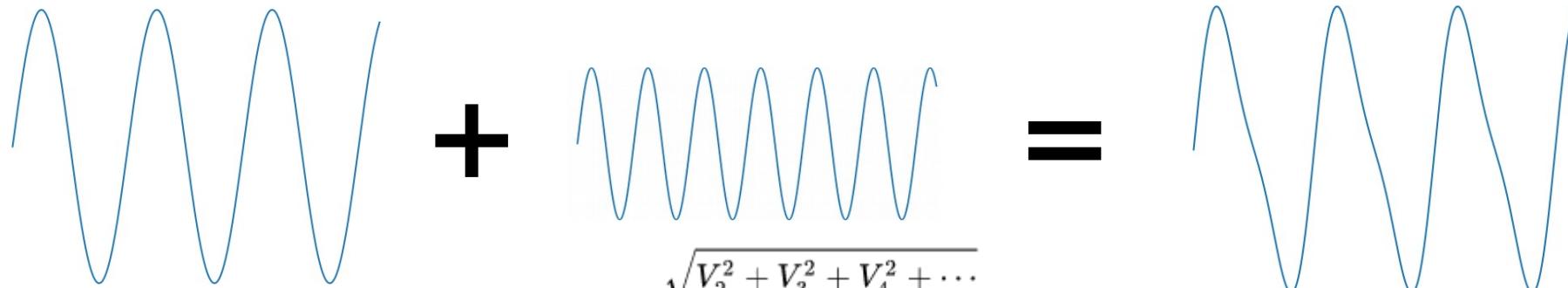


Frequency and Amplitude

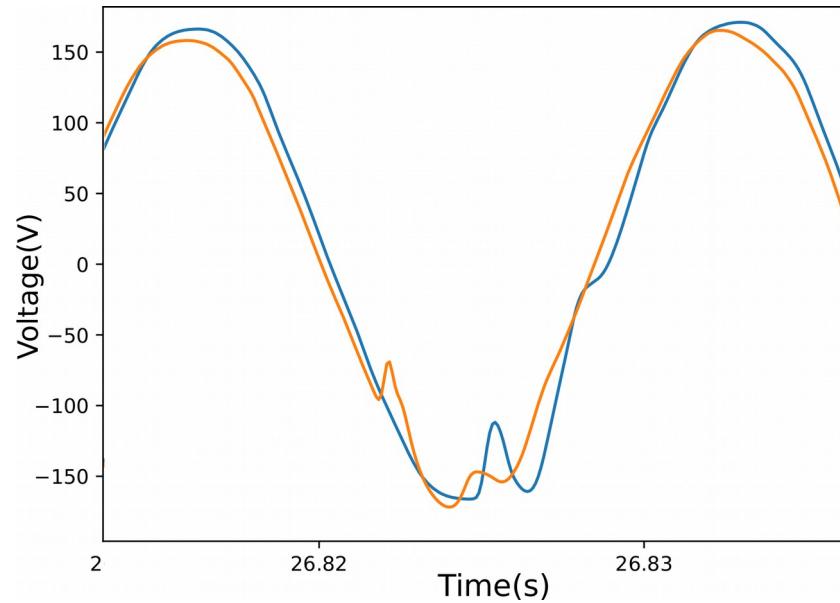


Total Harmonic Distortion

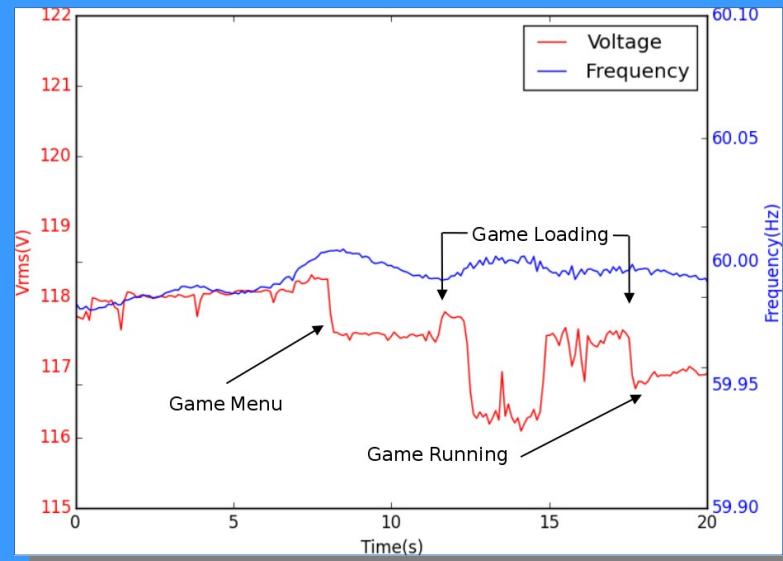
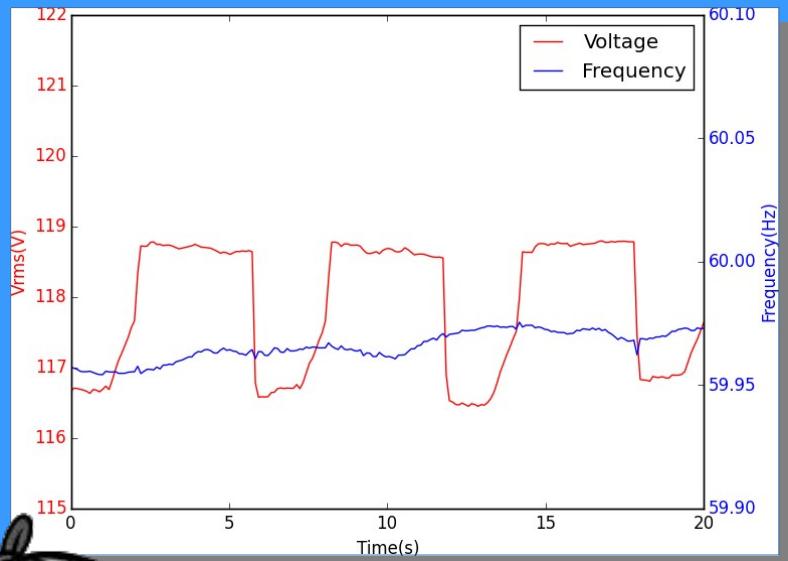
THD



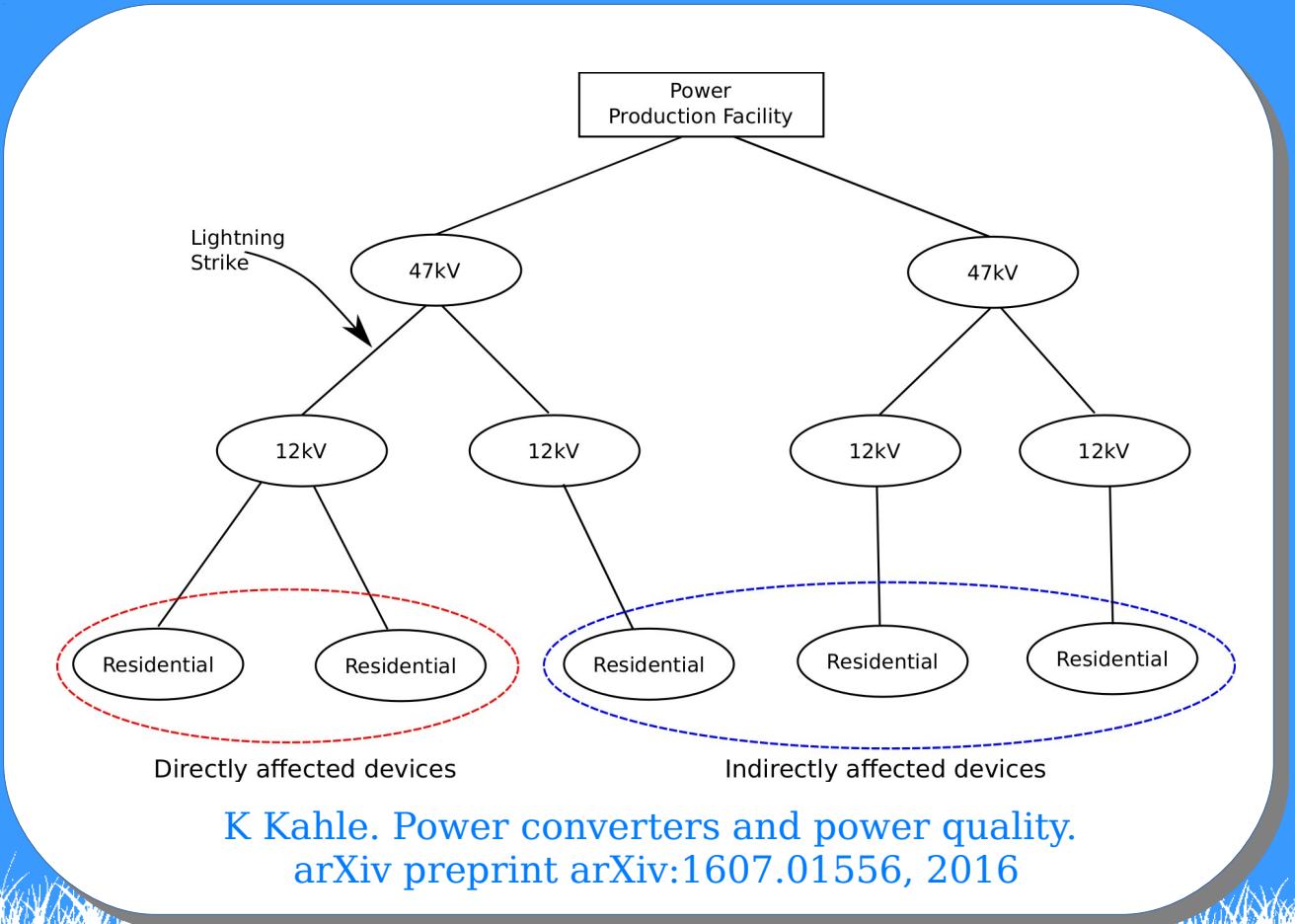
Transients



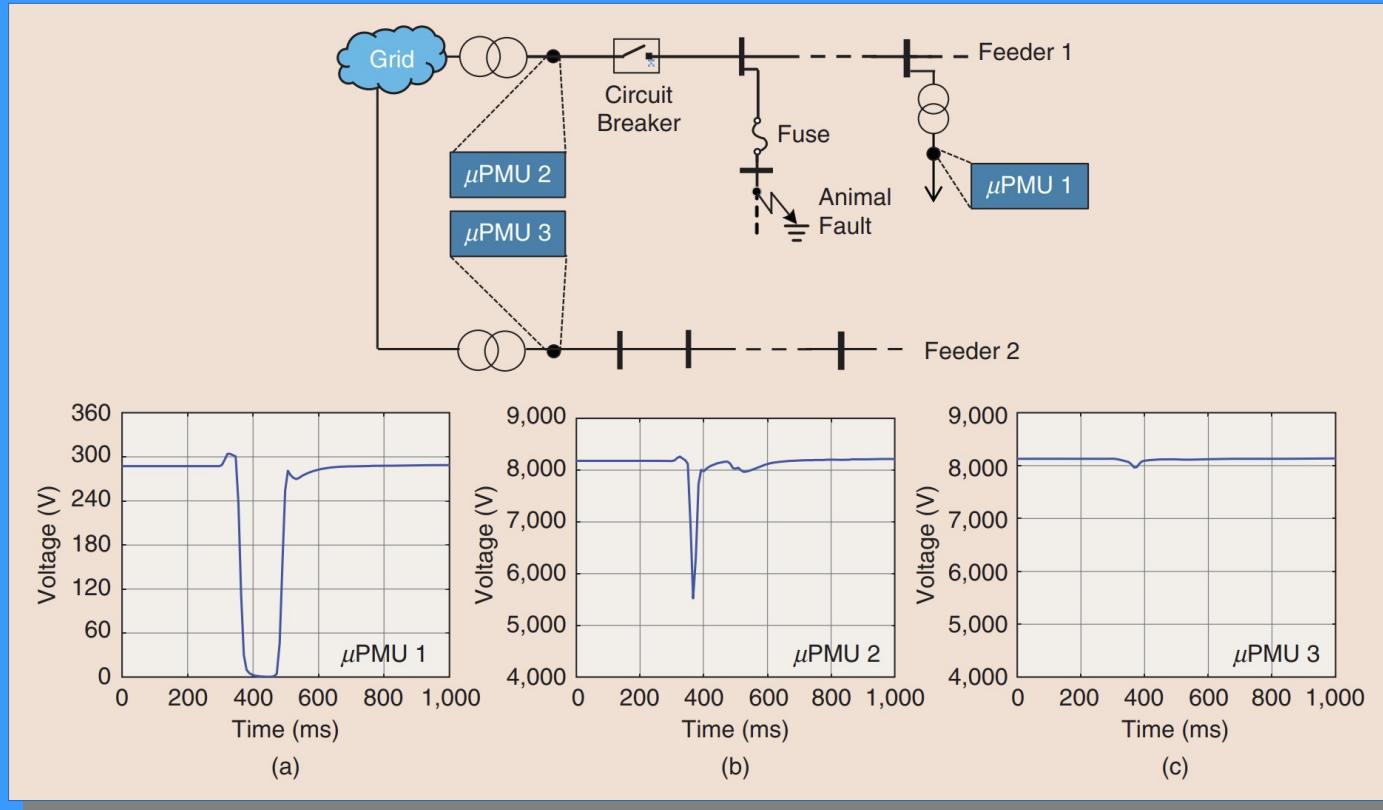
Local Detection Issues



Local Detection Issues



K Kahle. Power converters and power quality.
arXiv preprint arXiv:1607.01556, 2016



Mohsenian-Rad, Hamed, Emma Stewart, and Ed Cortez.
"Distribution synchrophasors: Pairing big data with analytics to create actionable information."
IEEE Power and Energy Magazine 16.3 (2018): 26-34.

The main challenge is to go beyond manual methods based on the intuition and heuristics of human experts...

... it is crucial to develop the machine intelligence needed to automate and scale up the analytics on billions of μ PMU measurements and terabytes of data on a daily basis and in real time.

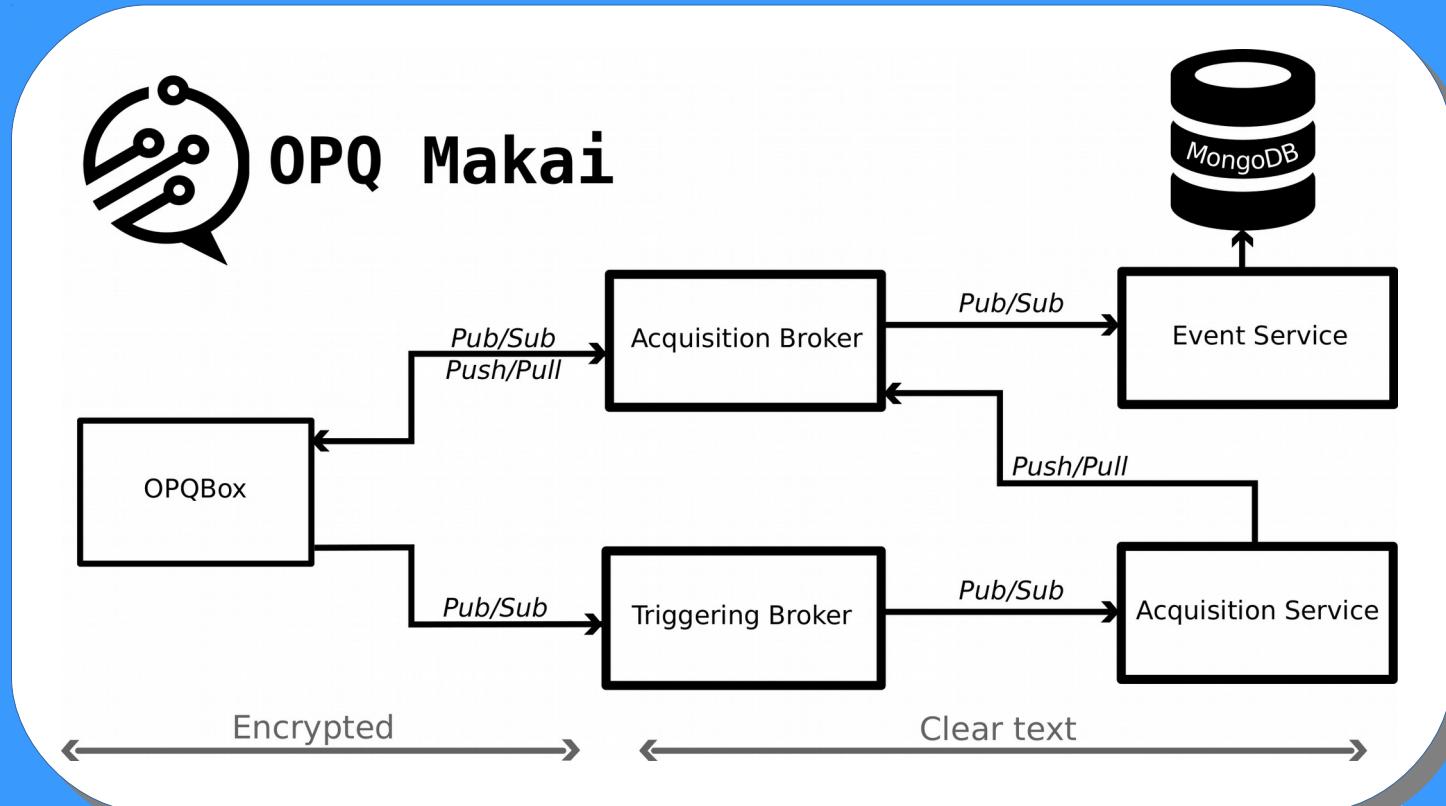
Mohsenian-Rad, Hamed, Emma Stewart, and Ed Cortez.
"Distribution synchrophasors: Pairing big data with analytics to create actionable information."
IEEE Power and Energy Magazine 16.3 (2018): 26-34.

I wonder where this is going?



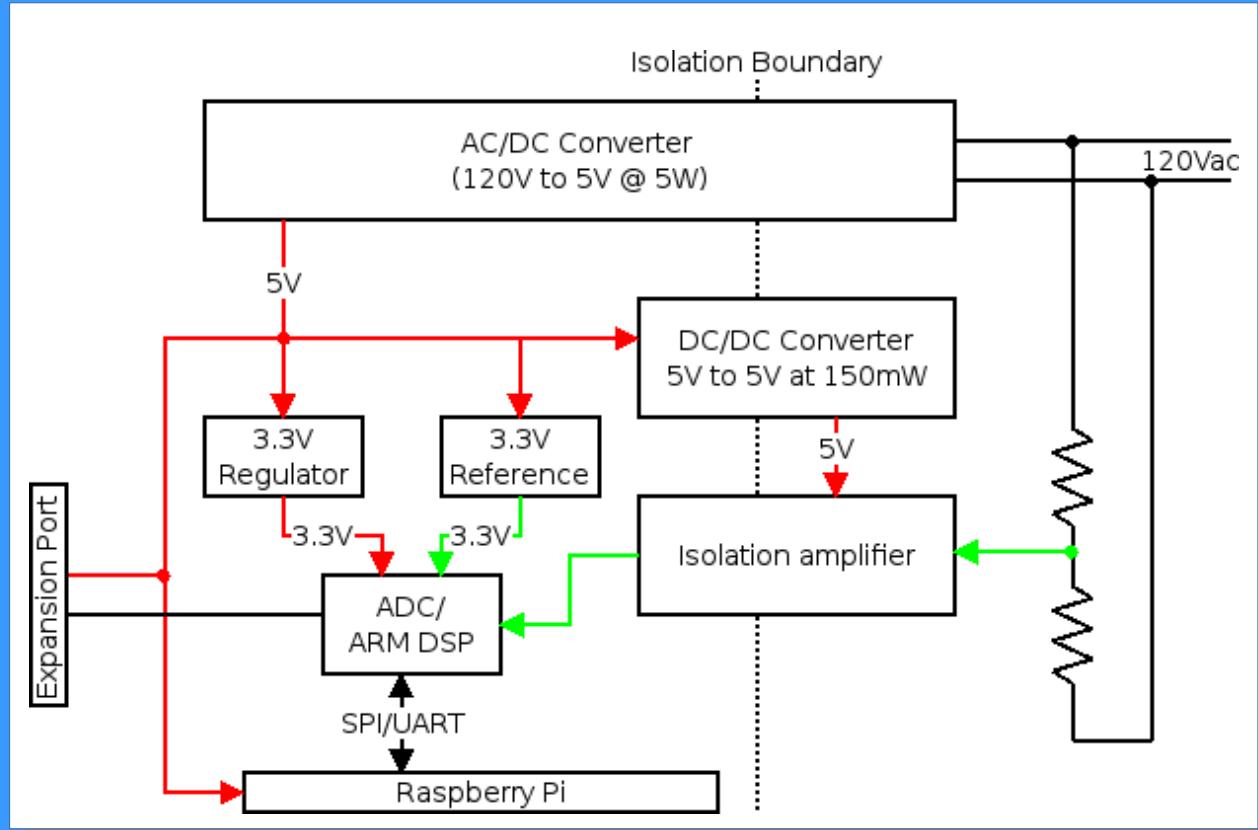
Open Power Quality

Gridwide event detection



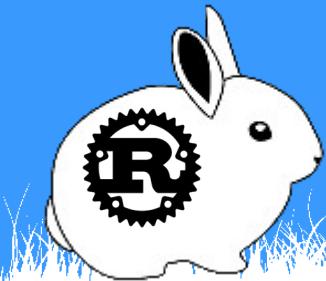
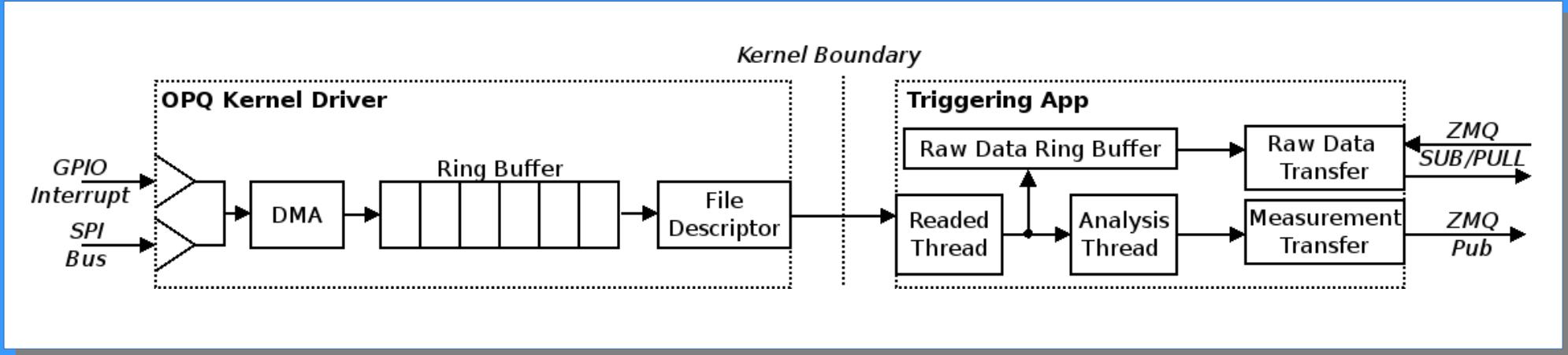
OPQ Box

Hardware



OPQ Box

Software



OPQ Box

Metrics

Metrics:

- V_{rms}
- Fundamental Frequency
- THD
- Transient

Transmission Rate:

- 1s (Mean/Min/Max)

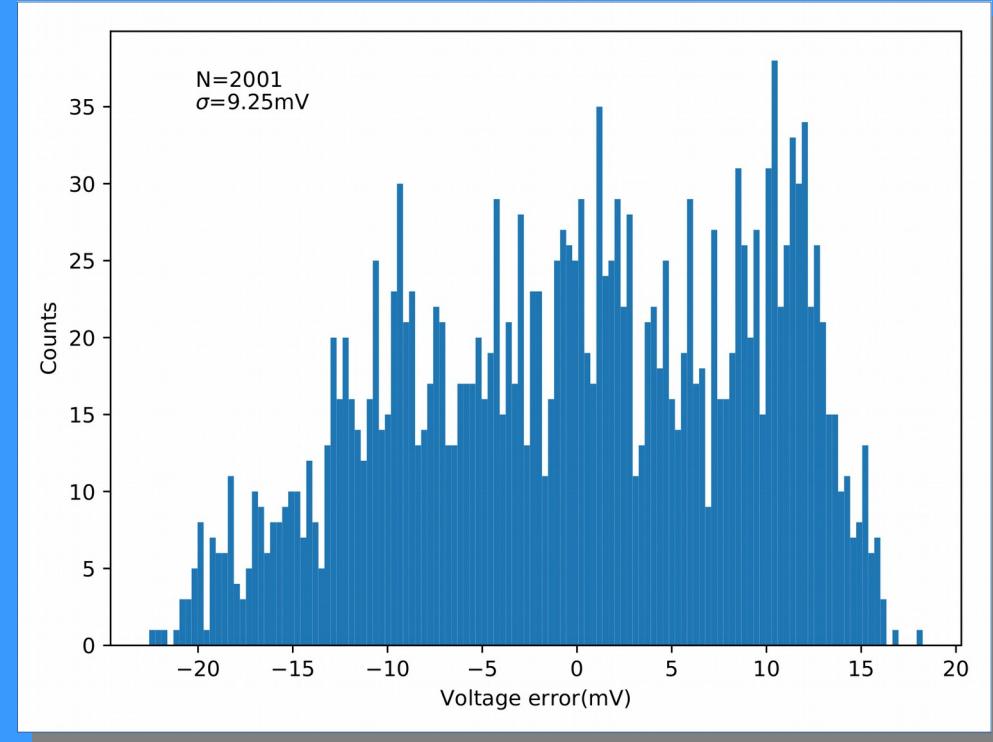
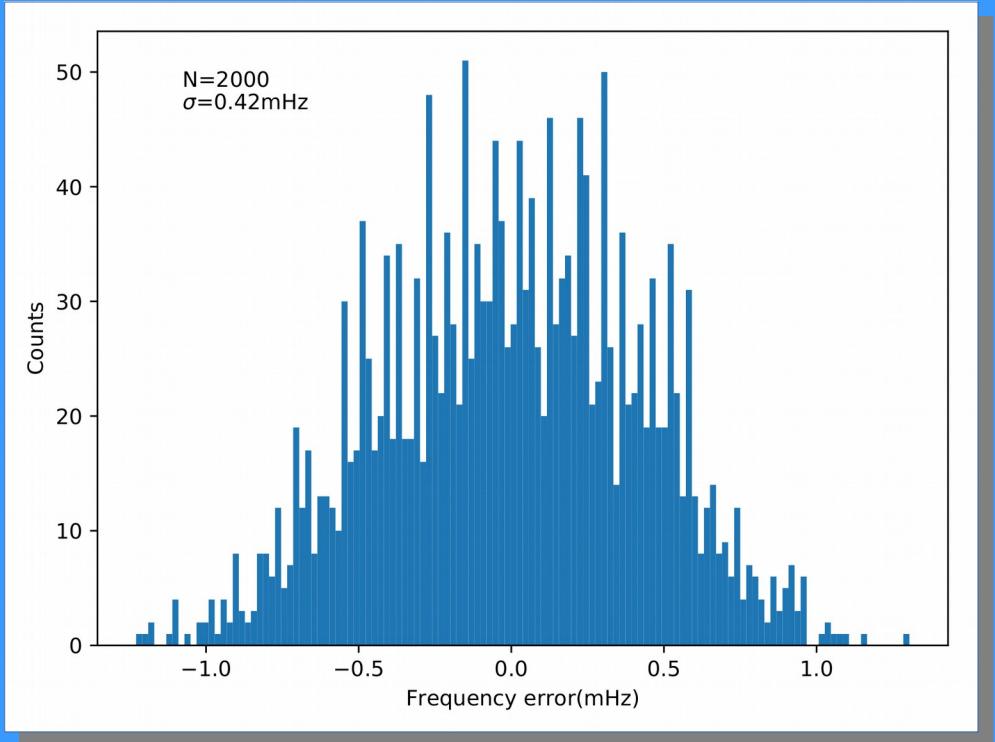
RDRB:

- 1 Hour



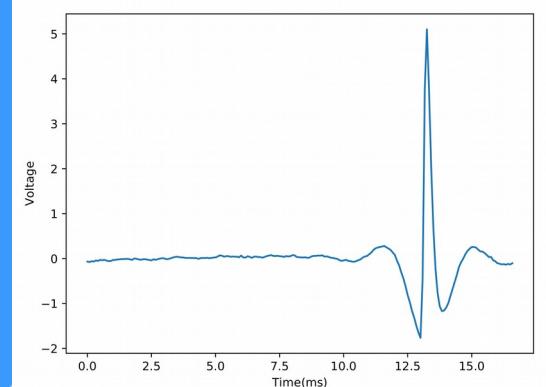
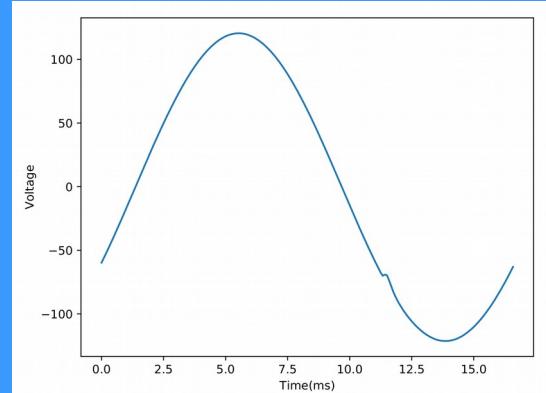
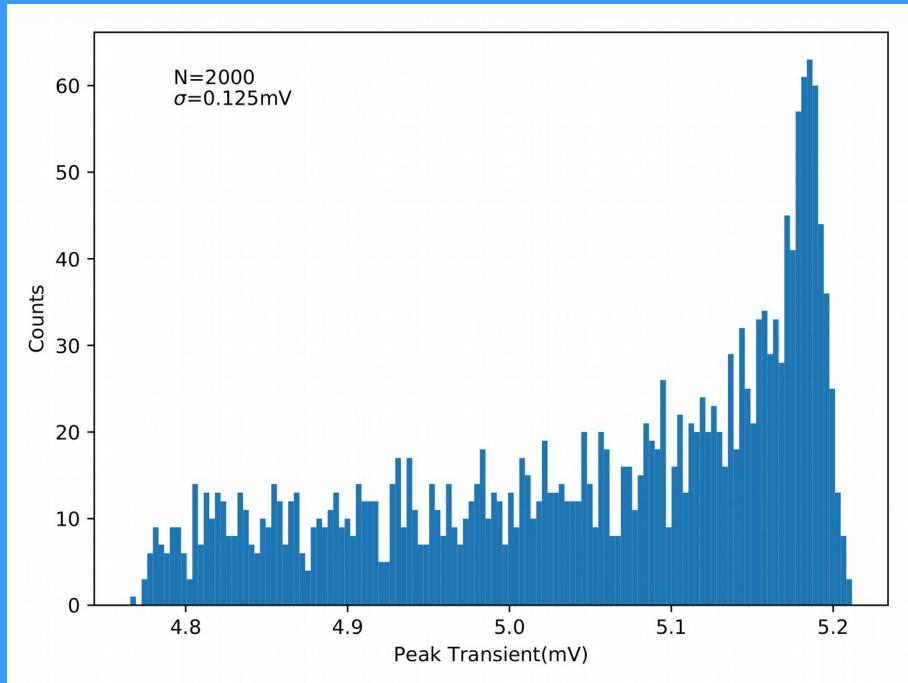
OPQ Box

Evaluation Frequency and V_{rms}



OPQ Box

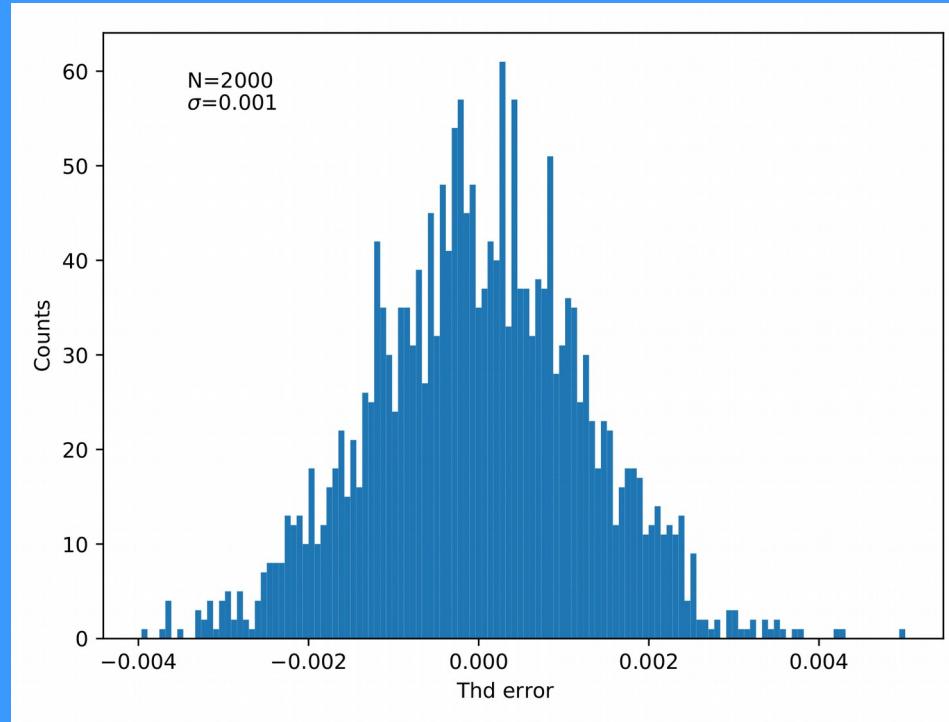
Evaluation of Transients.



5V equivalent transient.

OPQ Box

Evaluation THD



Napali Device Model

For each device:

- mean
- std

Rolling mean:

$$\mu_{n+1} = (1 - \alpha) * \mu_n + \alpha * m$$

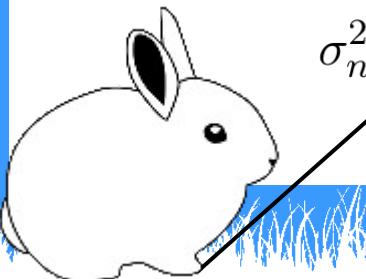
$$\mu_{n+1}^2 = (1 - \alpha) * \mu_n^2 + \alpha * m^2$$

$$\sigma_n^2 = \mu_n^2 - (\mu_n)^2$$

$$\sigma_n = \sqrt{\sigma_n^2}$$

Event chronology:

1. Any device passes threshold.
2. Record any device $> 3*\text{std}$.
3. Wait until all devices are below threshold.
4. If device count is > 1 request data from
 - Devices which passed threshold.
 - Devices with a metric $> 3*\text{std}$.
5. If device count == 1:
 - No request is made.
6. Return to monitoring.

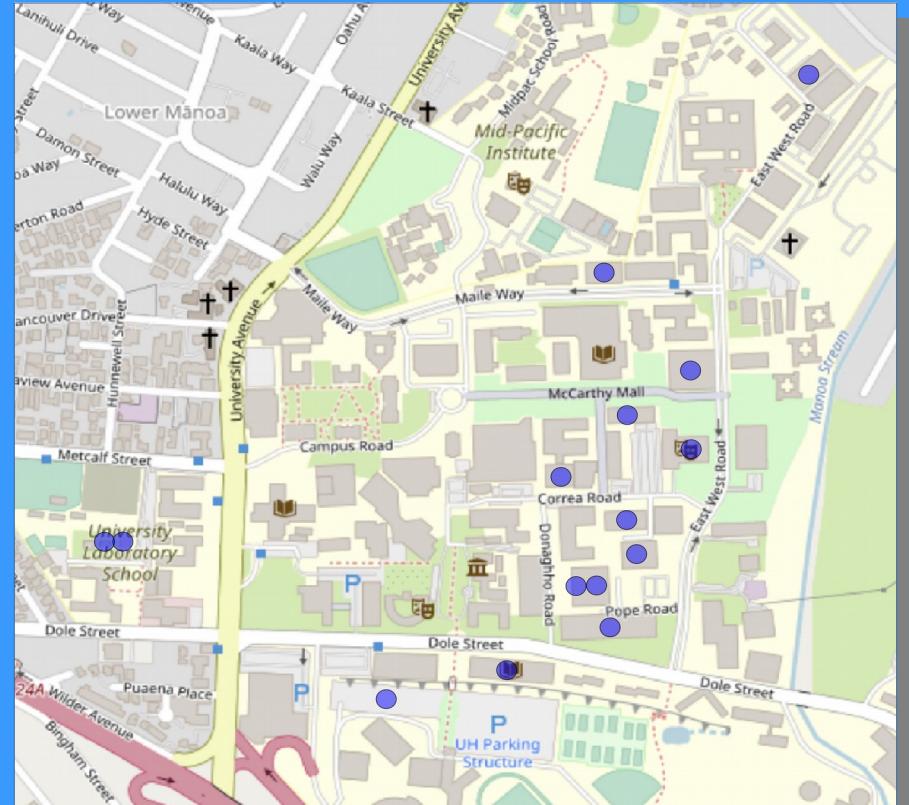


UH Deployment

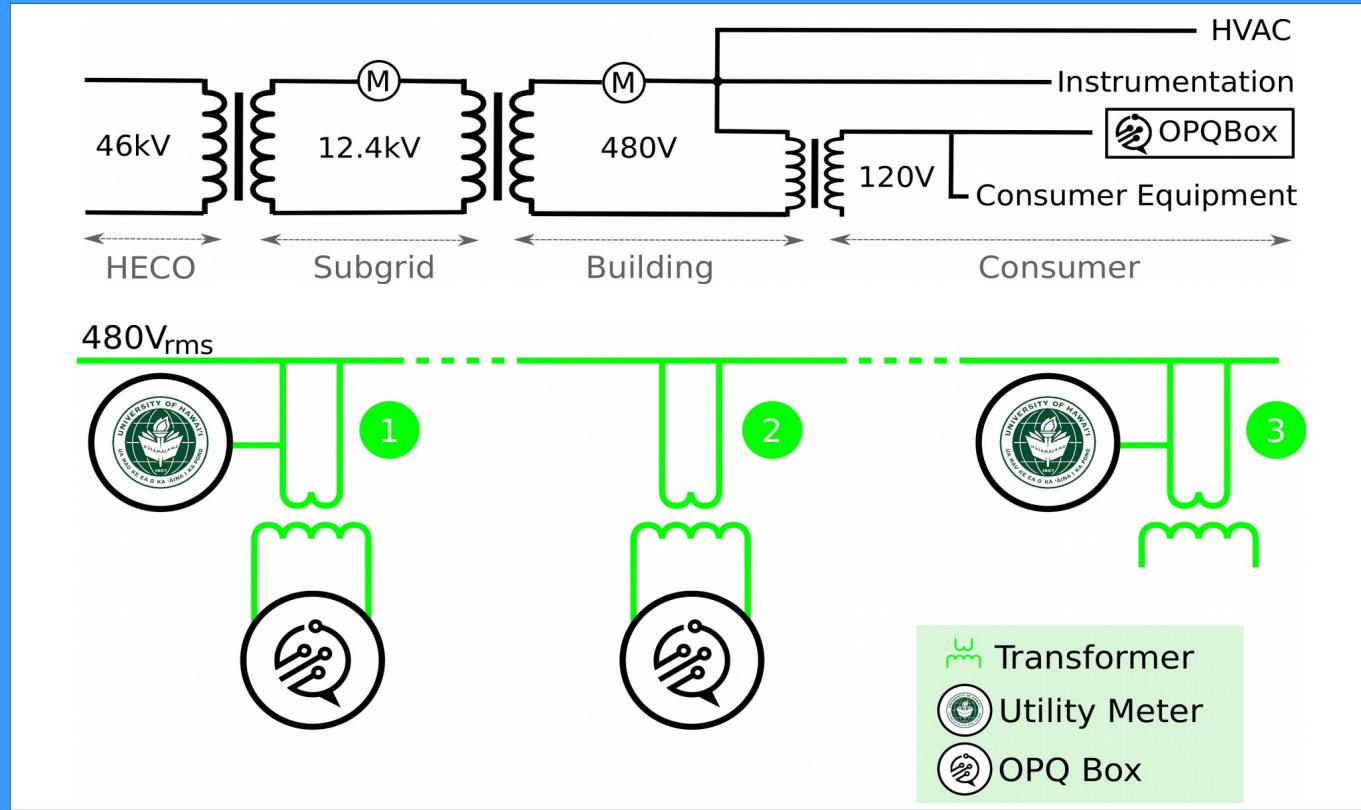
in-situ validation

- 15 Devices.
- 3 months of data.
- Still running.

Anyone want a PQ network?

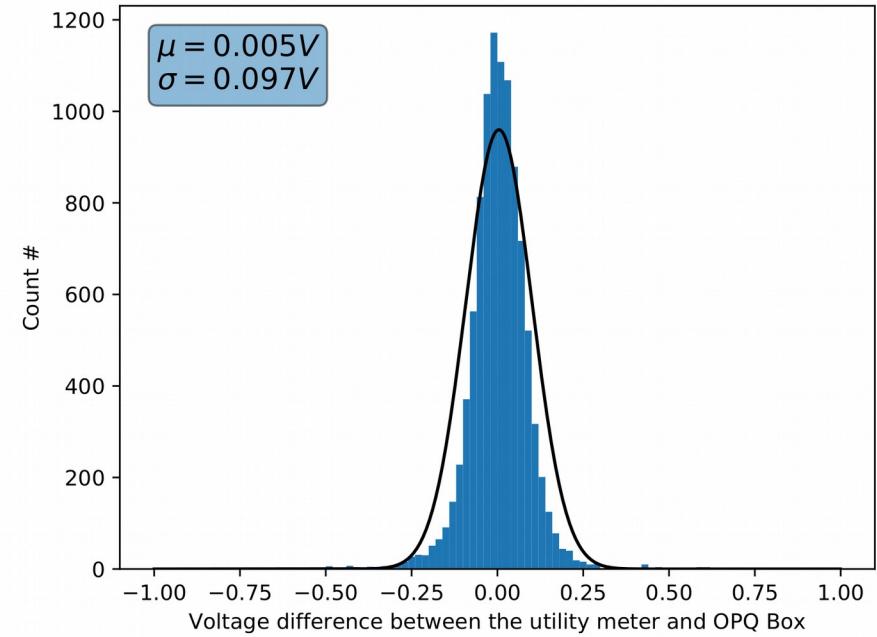
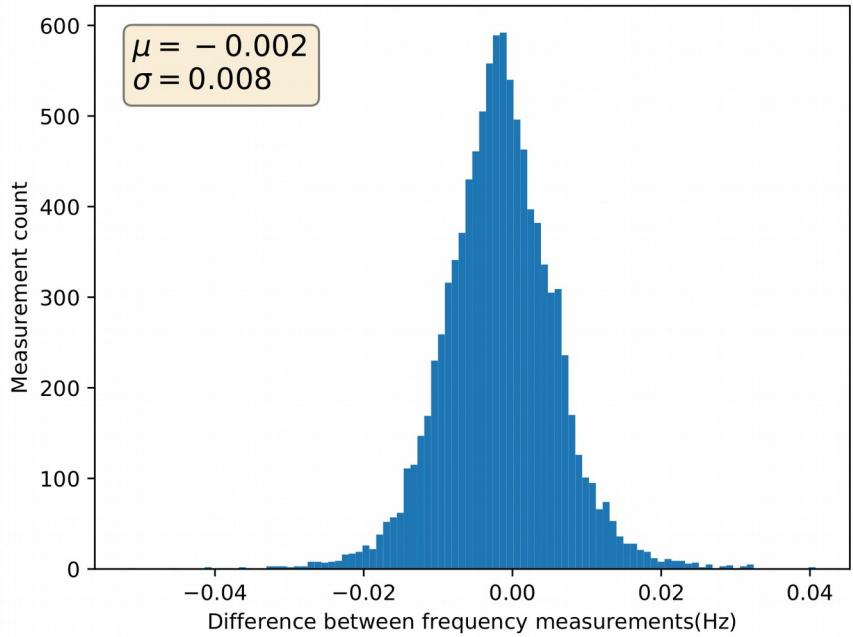


UH Deployment



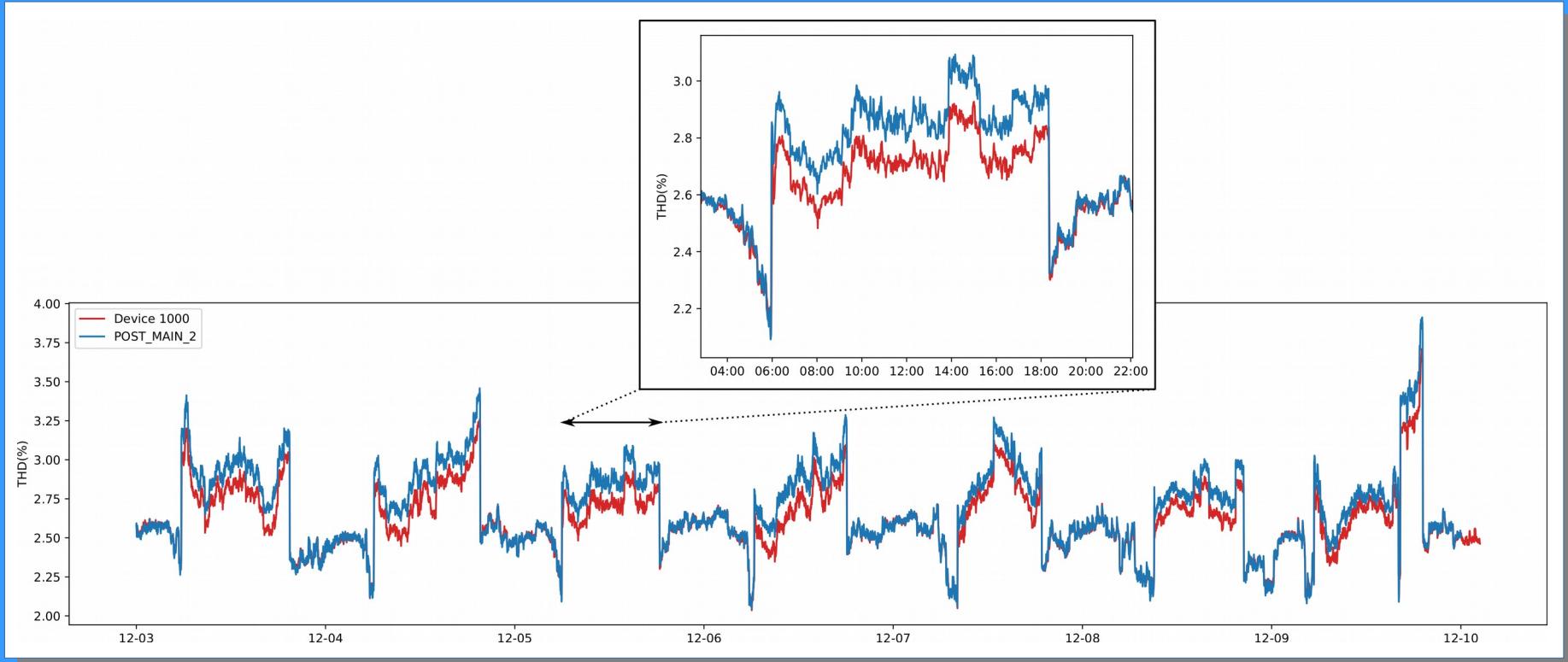
OPQ Boxes

Comparison with UH meters



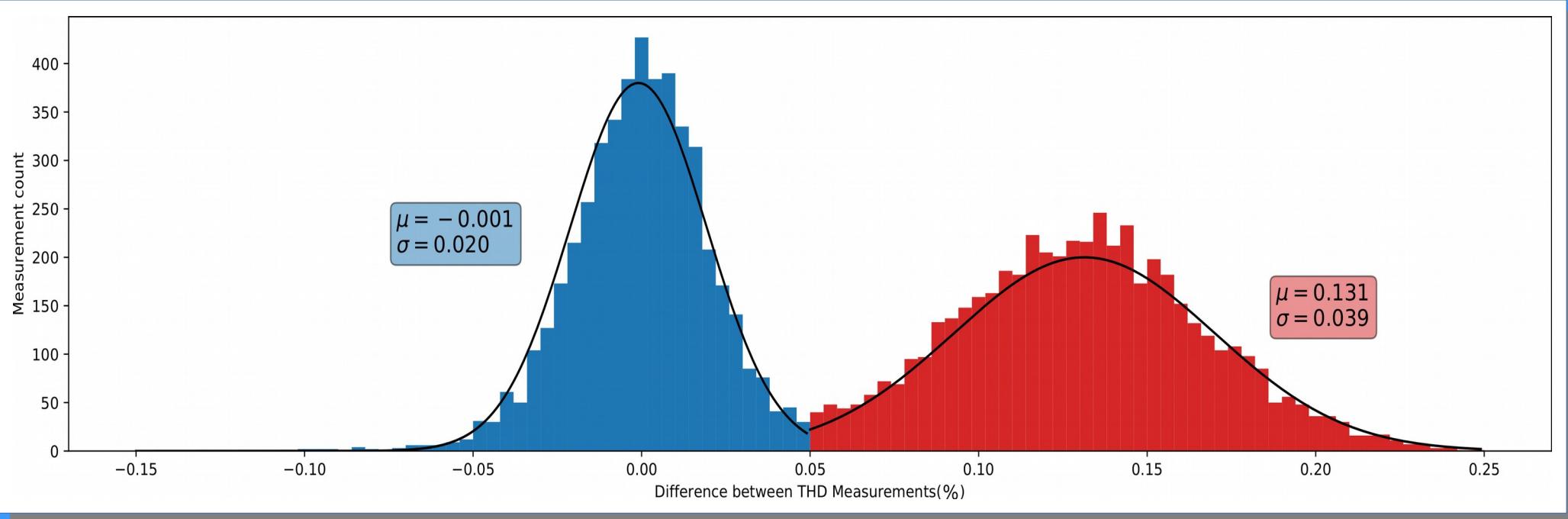
OPQ Boxes

Comparison with UH meters



OPQ Boxes

Comparison with UH meters

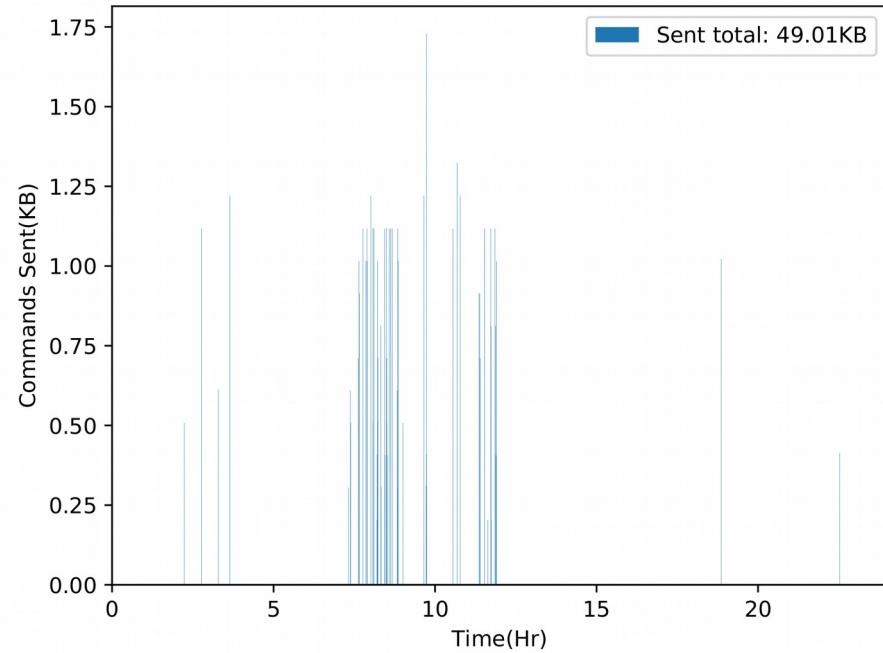
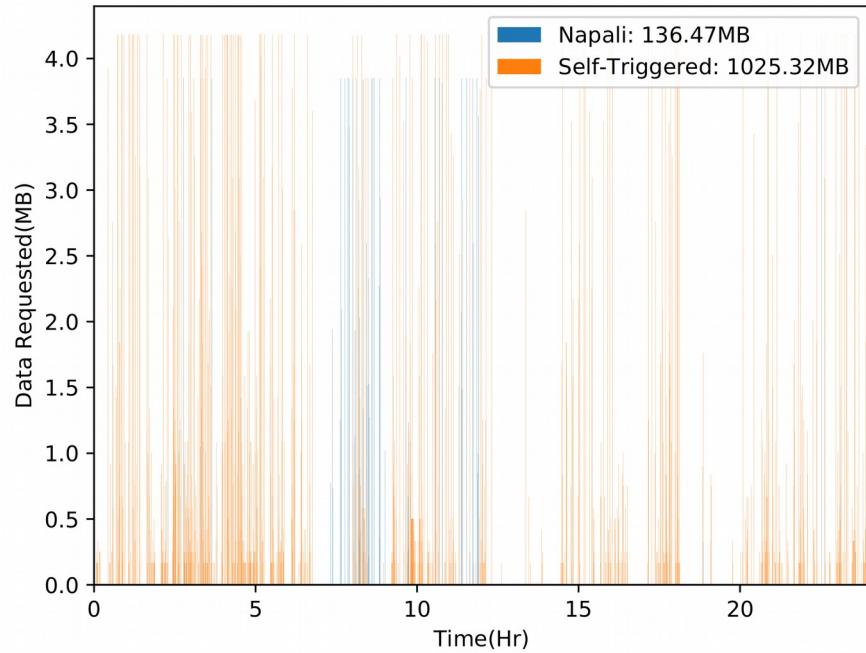


Napali Validation

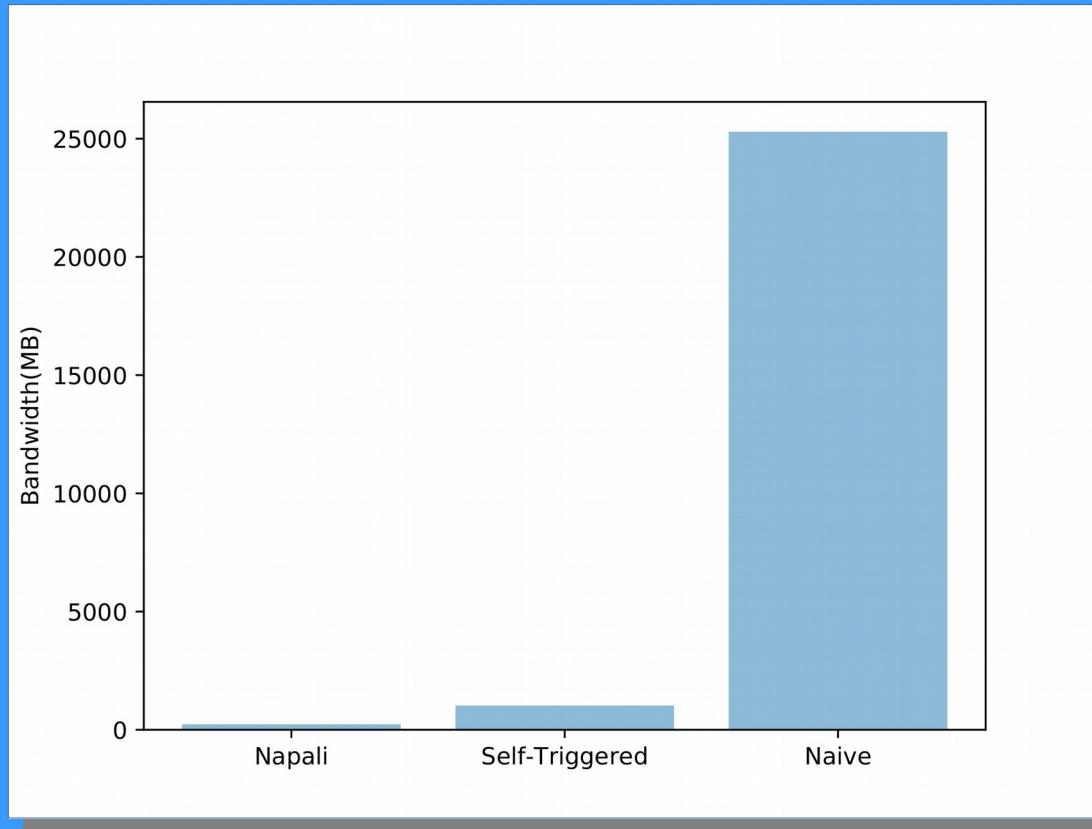
- 1. Napali minimizes bandwidth usage**
- 2. Napali mitigates device latency effects**
- 3. Napali minimizes sink processing requirements**
- 4. Sub-threshold data acquisition is a viable event detection strategy**
- 5. Temporal locality triggering results in a low false negative detection**



Bandwidth Usage



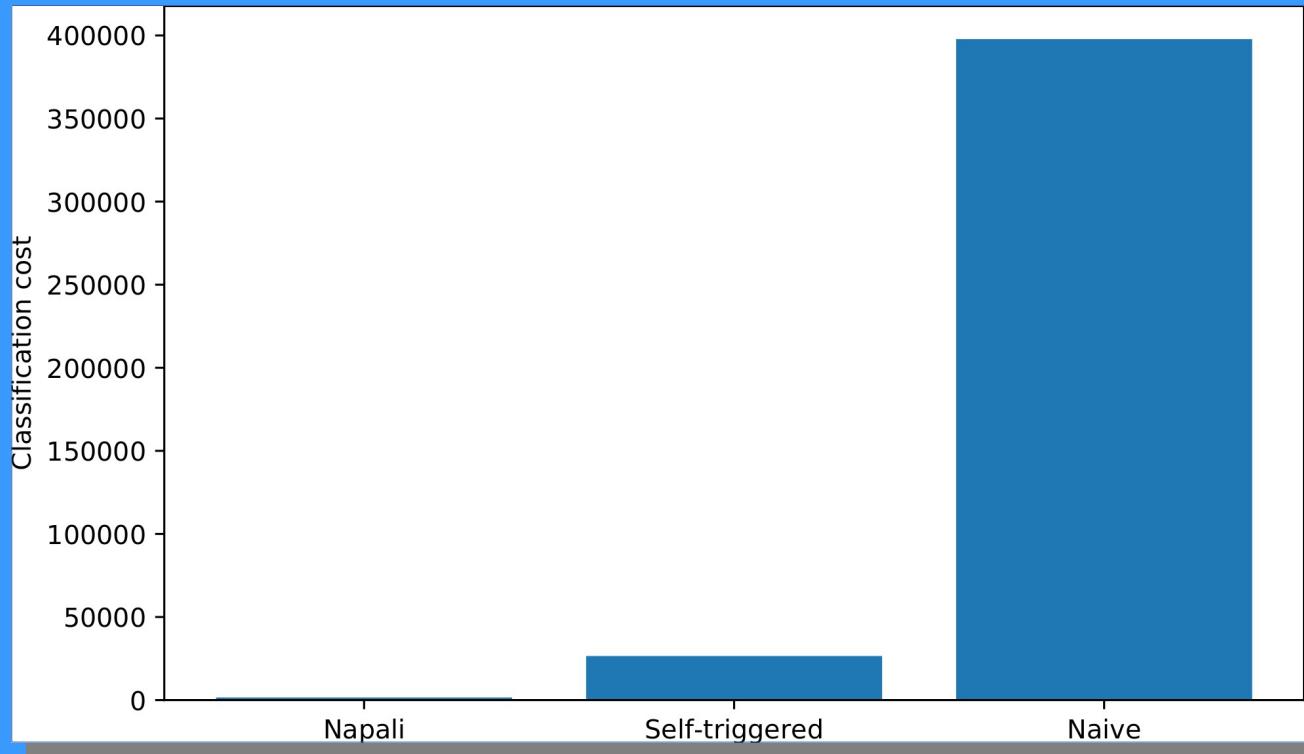
Bandwidth Usage



Exquisite!



Computational Requirement

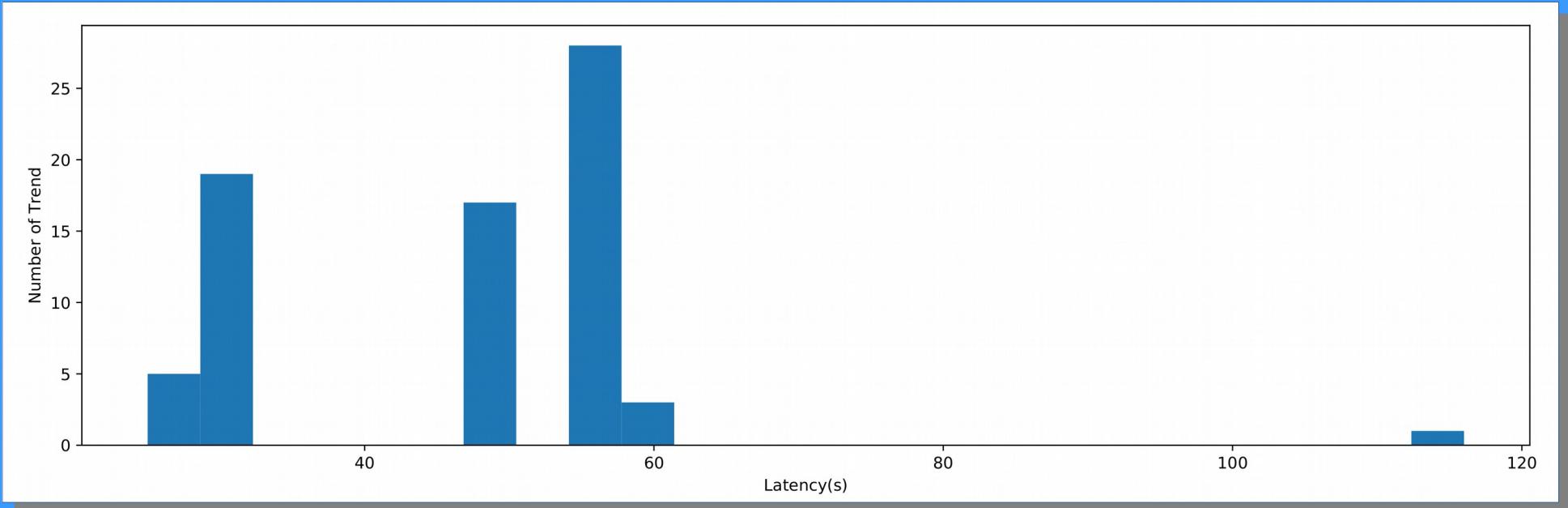


Flawless!

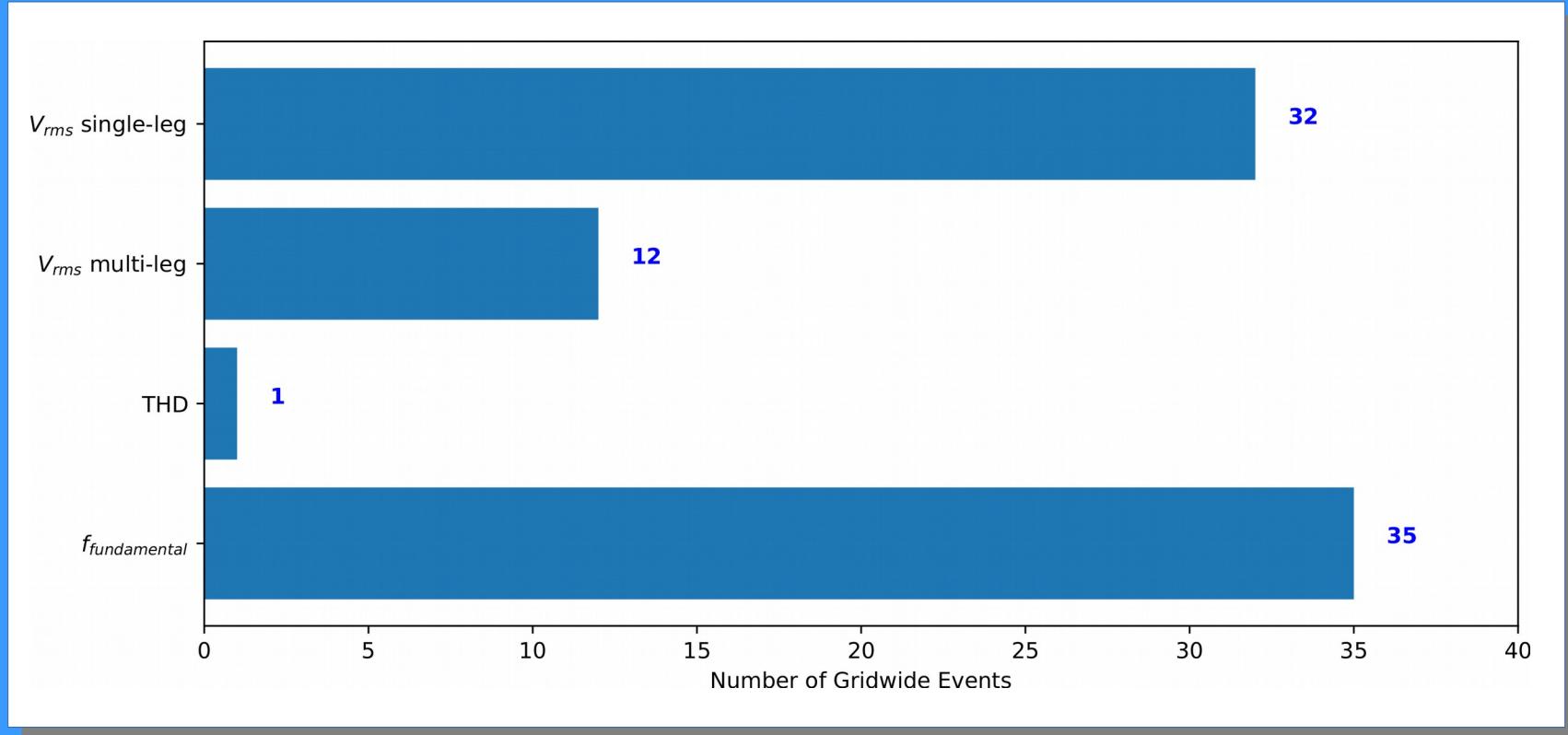


Latency

Late metrics over 24 hours

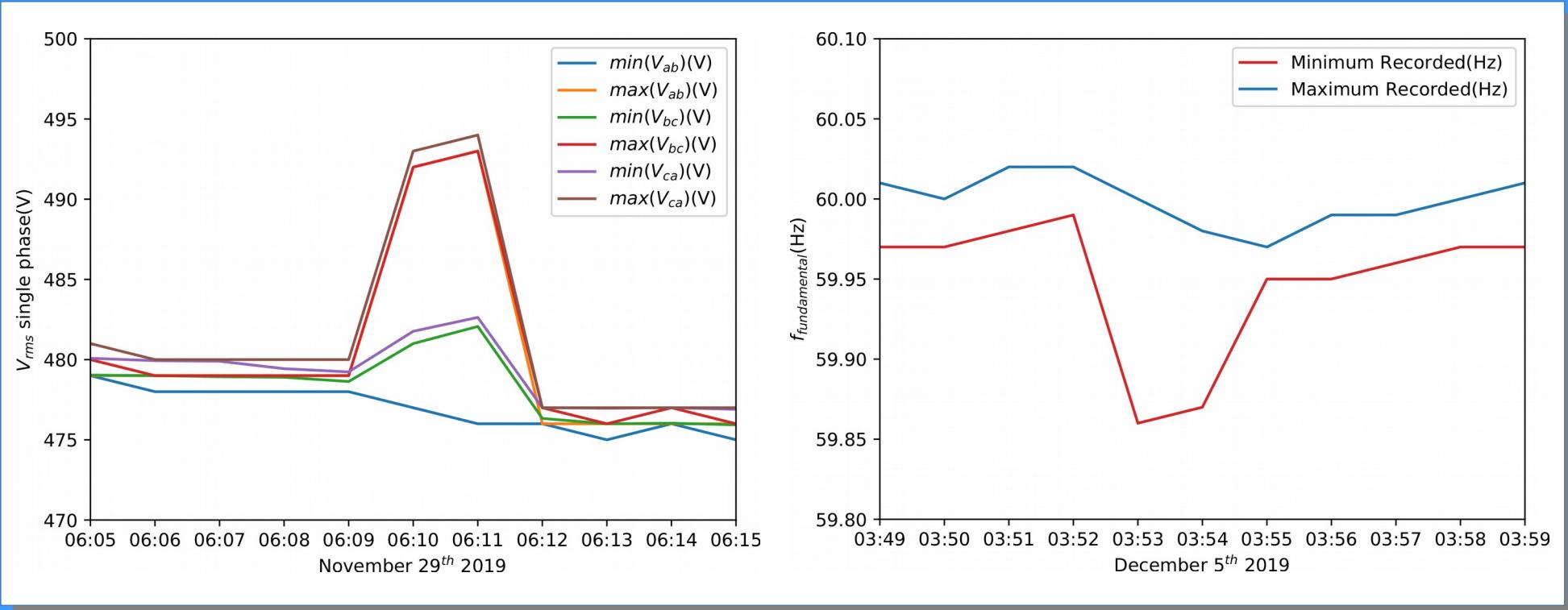


Temporal locality triggering



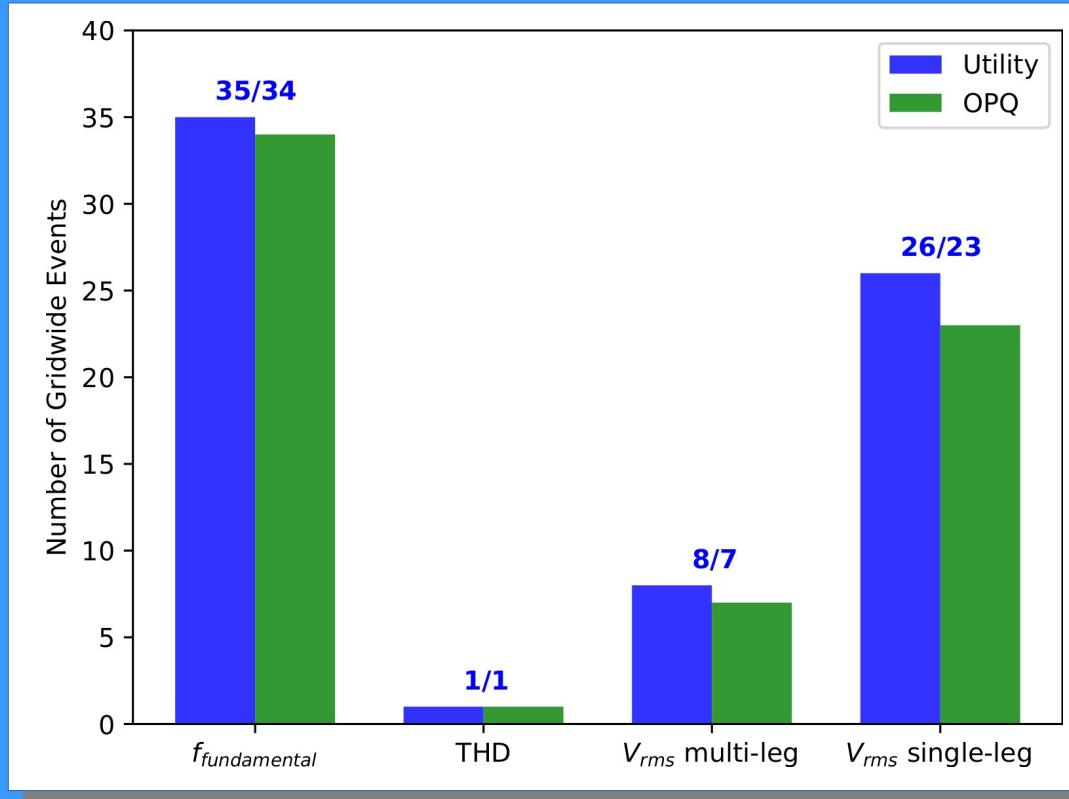
Temporal locality triggering

Ground truth event examples.



Temporal locality triggering

Detected events



Marvelous!

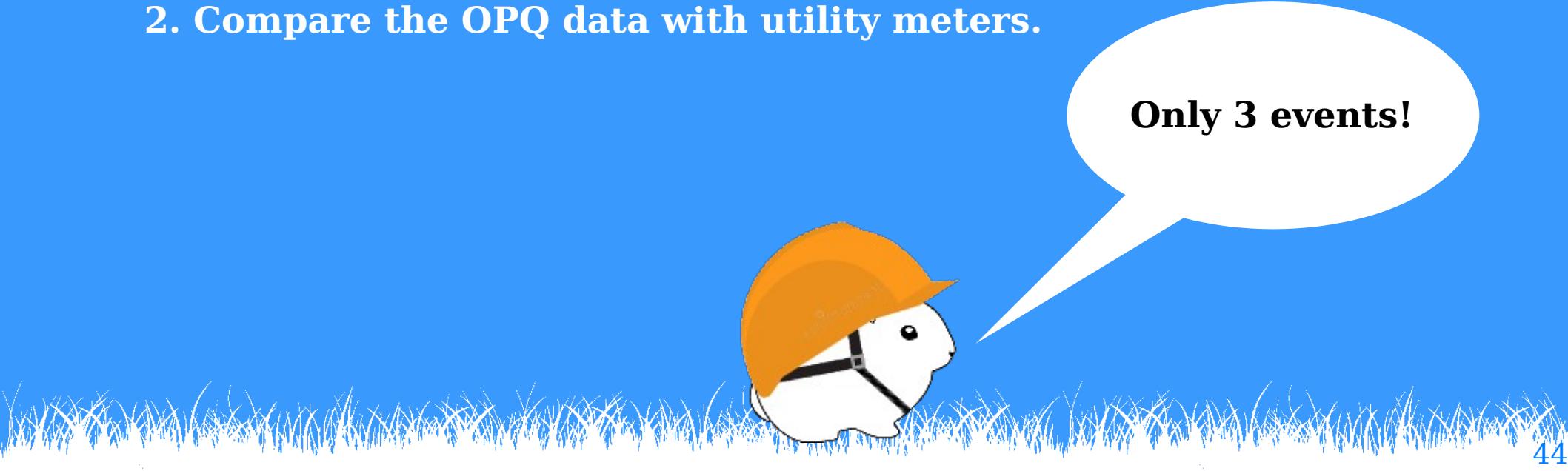


Sub-threshold Events

1. Select events where:

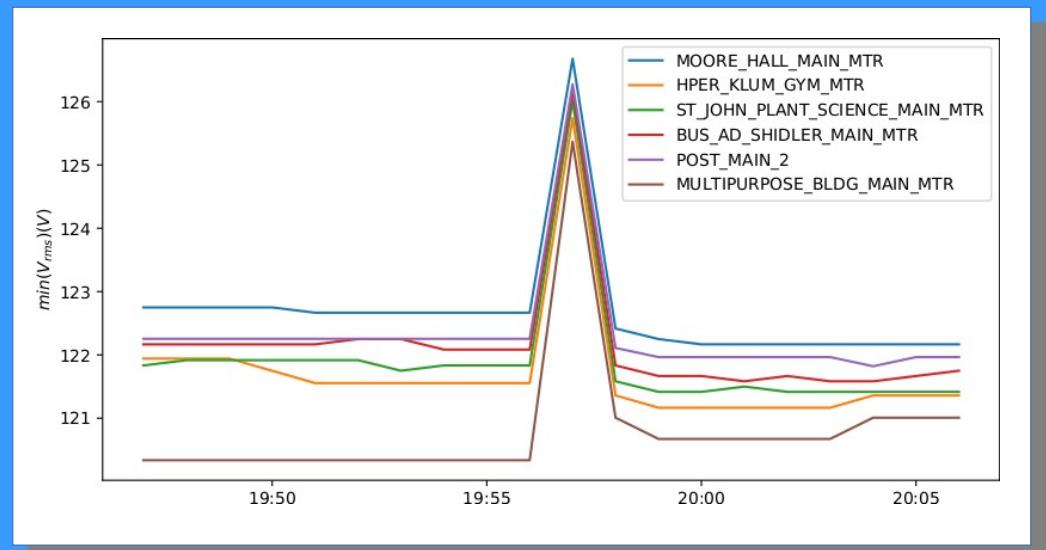
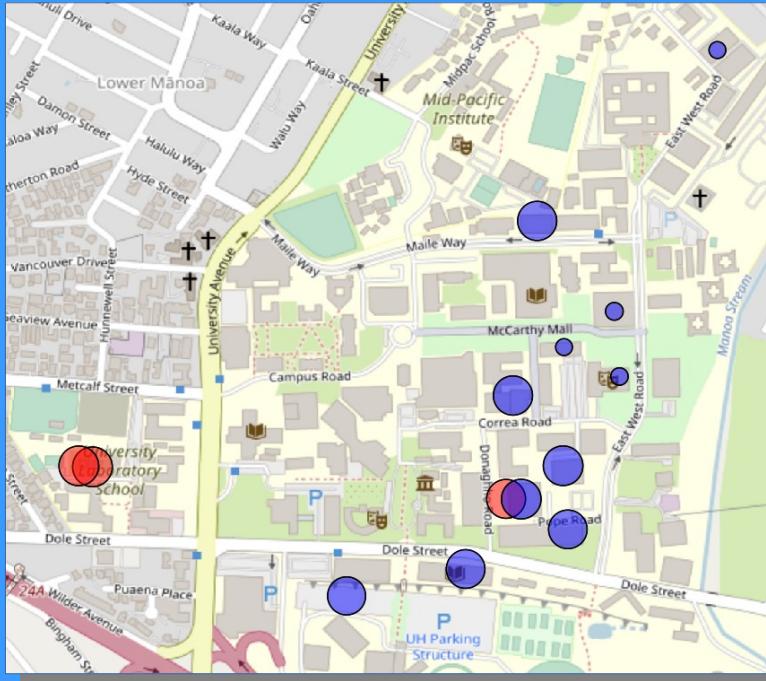
- single collocated utility meter passes threshold.
- one or more non-collocated utility meters passes threshold.

2. Compare the OPQ data with utility meters.

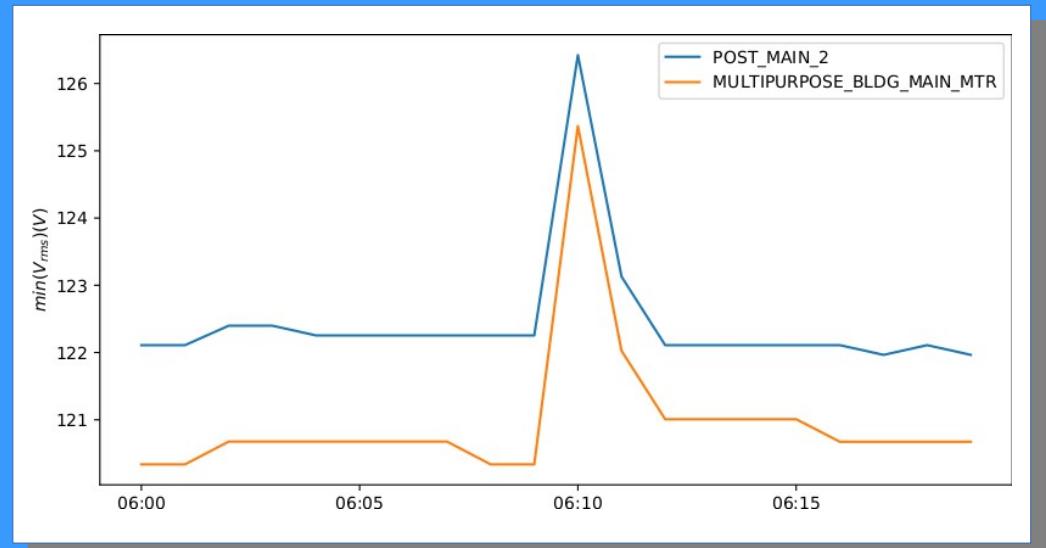
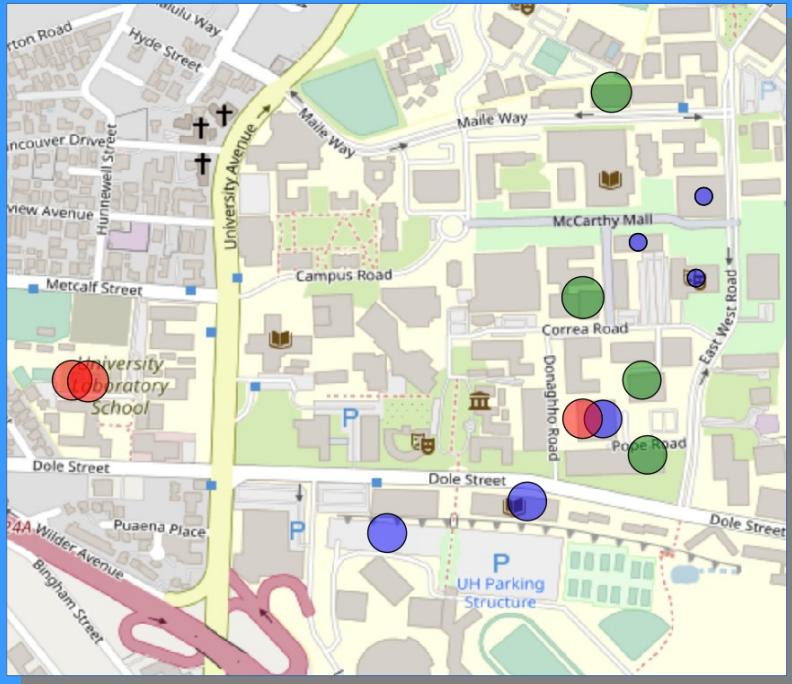


Only 3 events!

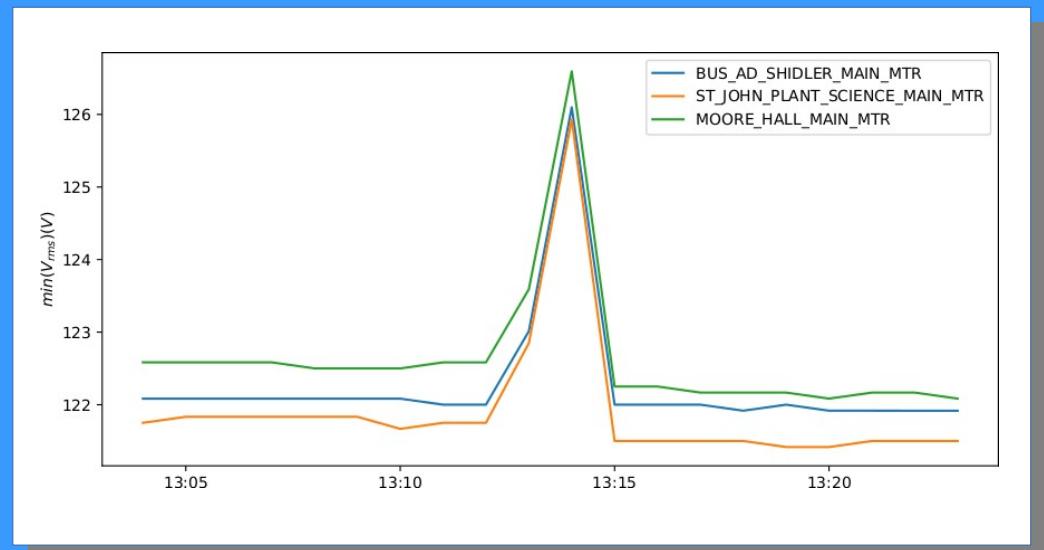
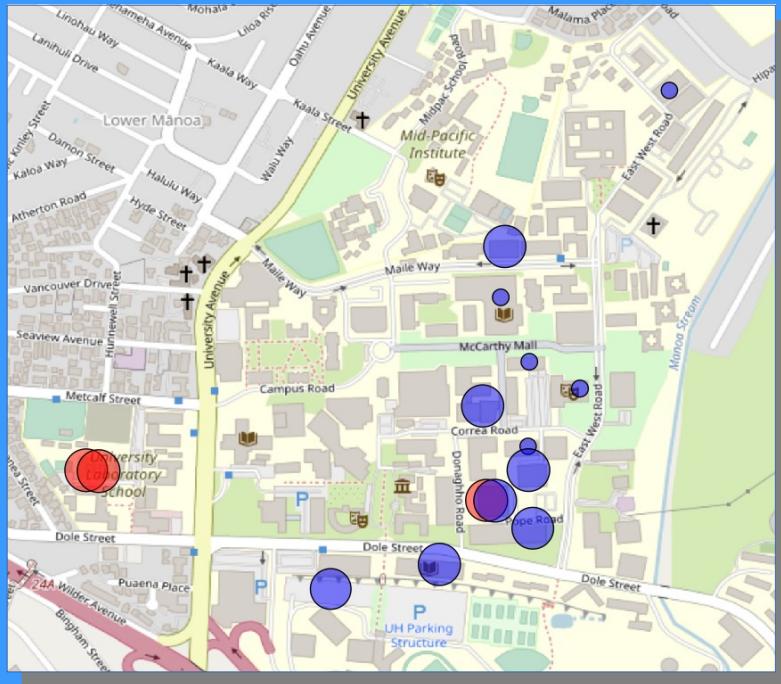
Event #1



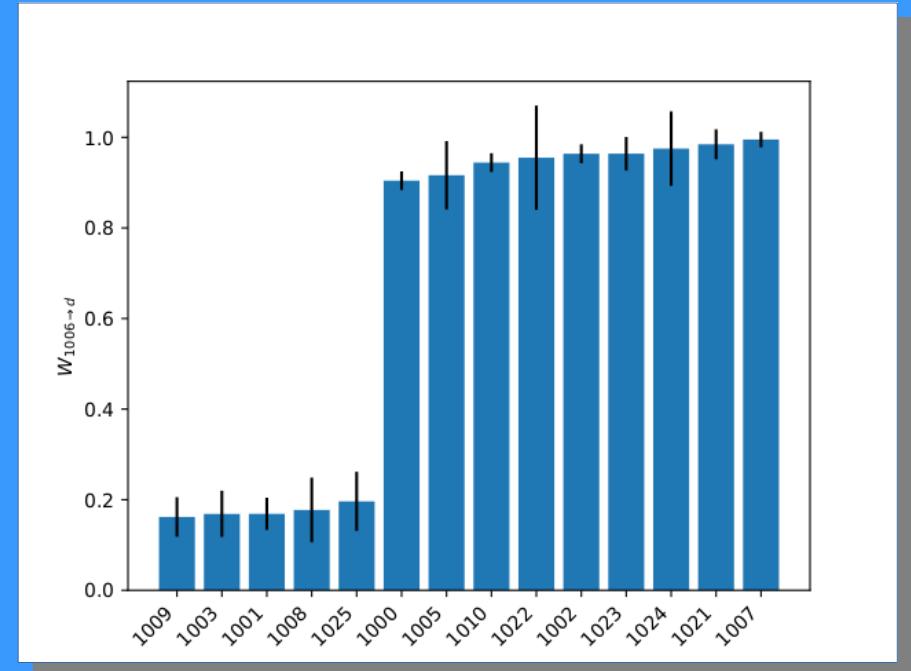
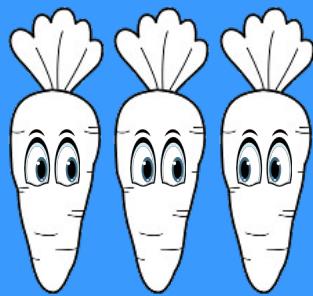
Event #2



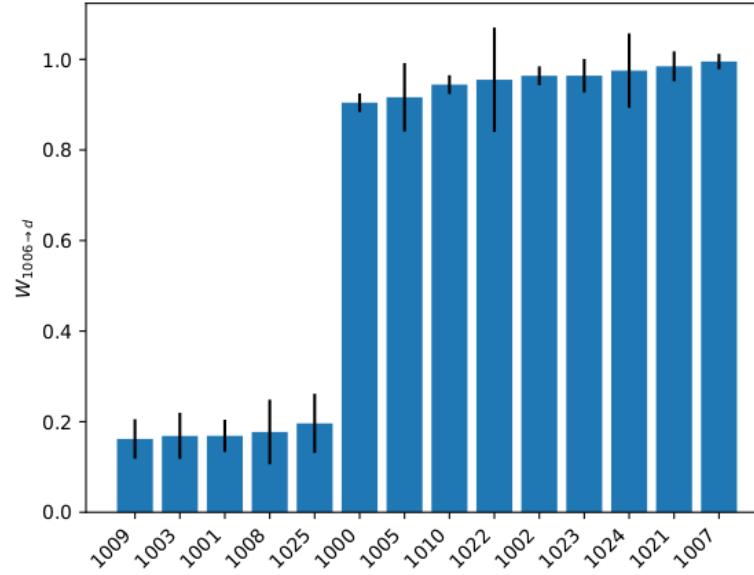
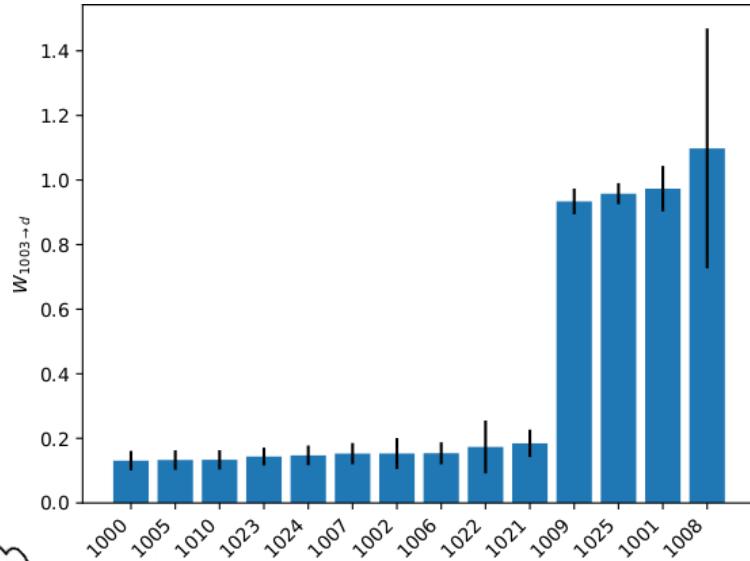
Event #3



Event Clustering



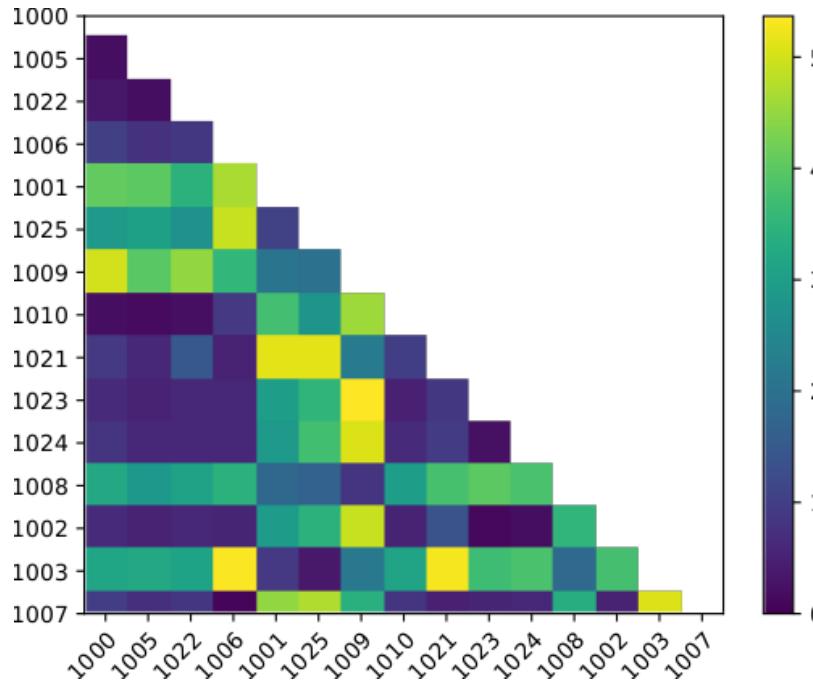
Common Event



Pairwise Dissimilarity

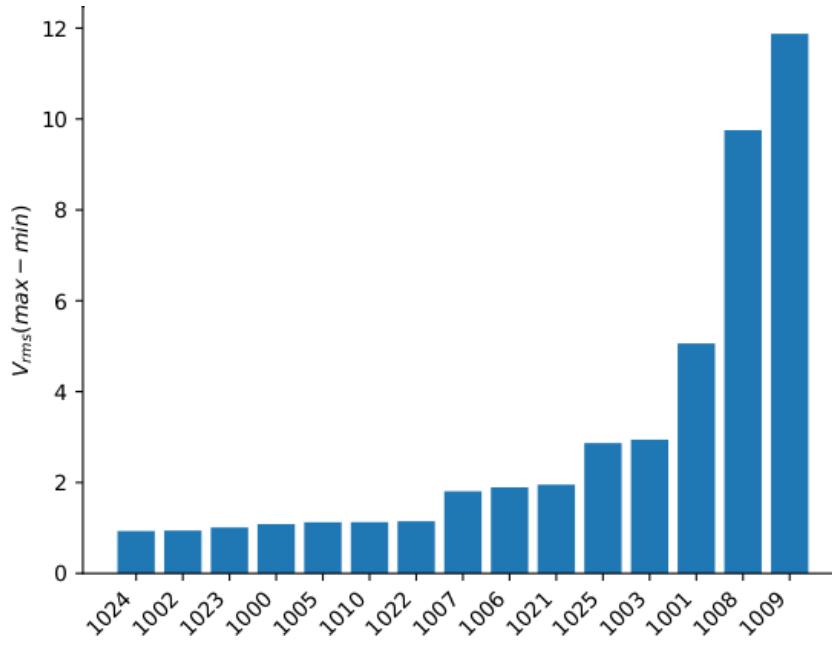
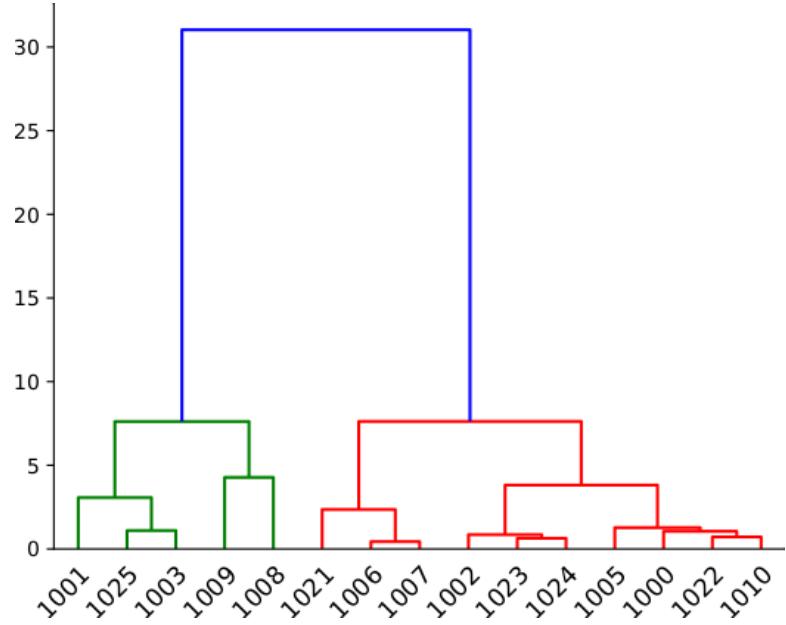
V_{rms}

$$D_{p \rightarrow d}^{rms} = \frac{1}{n} \sum_n |(\max(V_{rms}) - \min(V_{rms}))_p - (\max(V_{rms}) - \min(V_{rms}))_d|$$



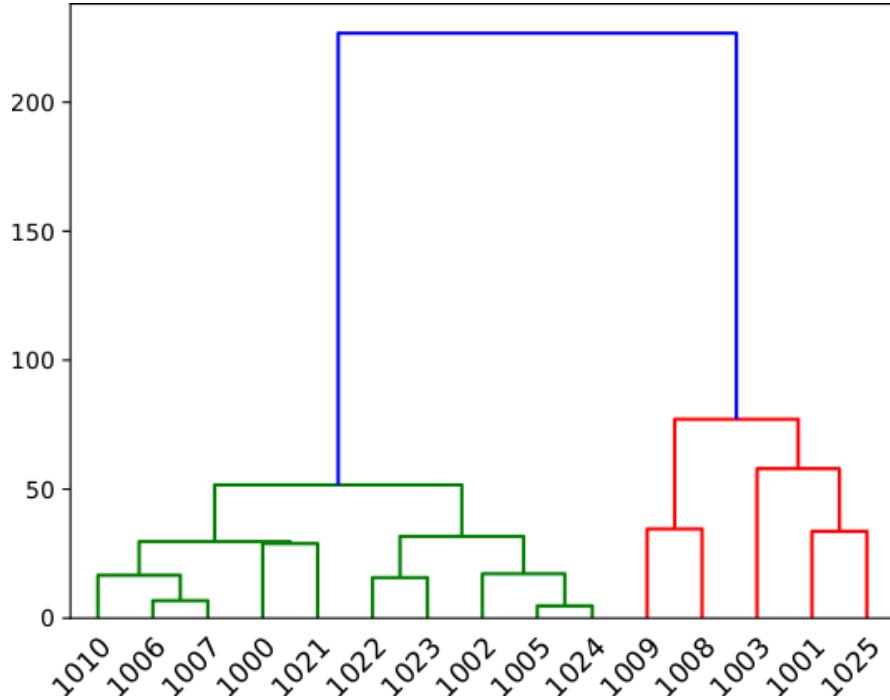
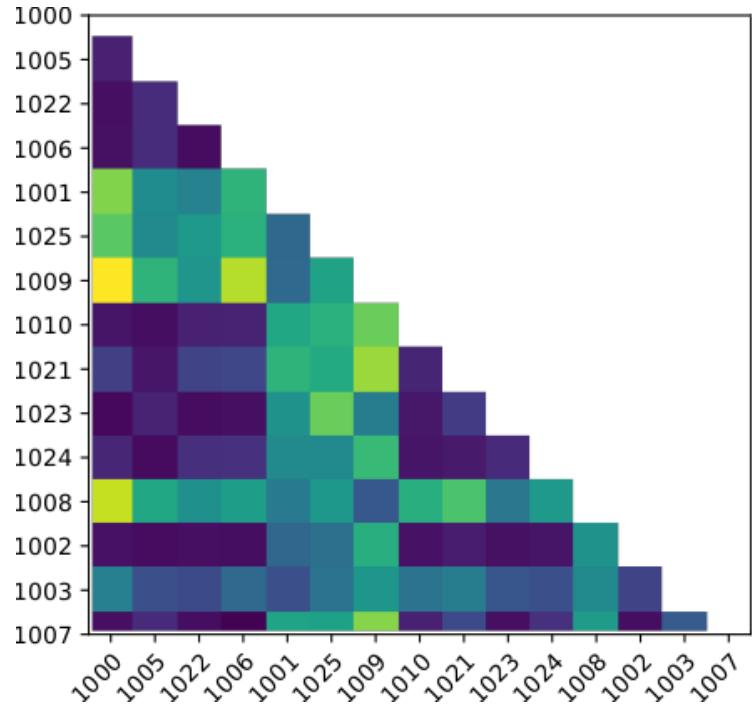
Clustering

V_{rms}



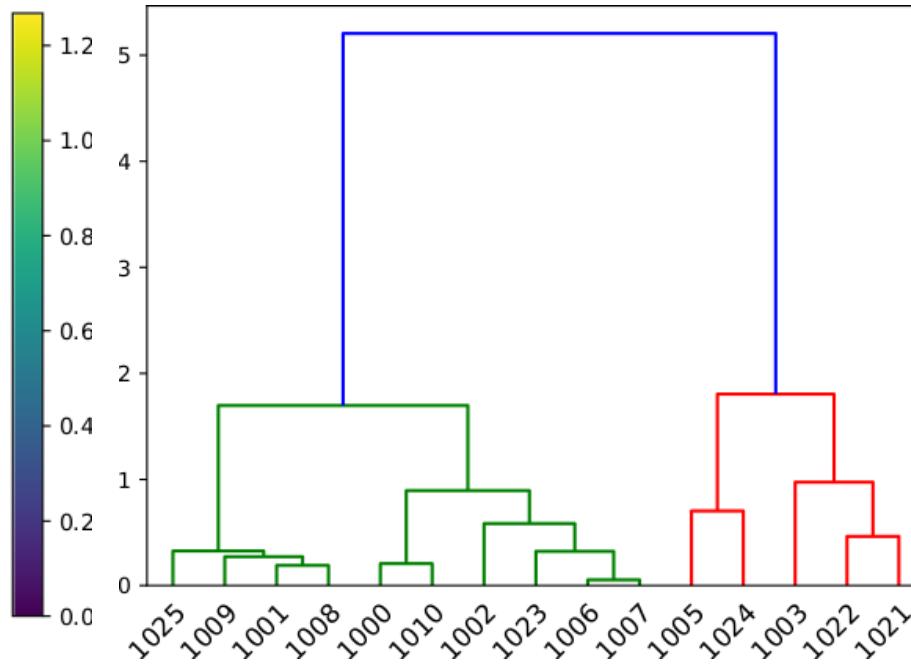
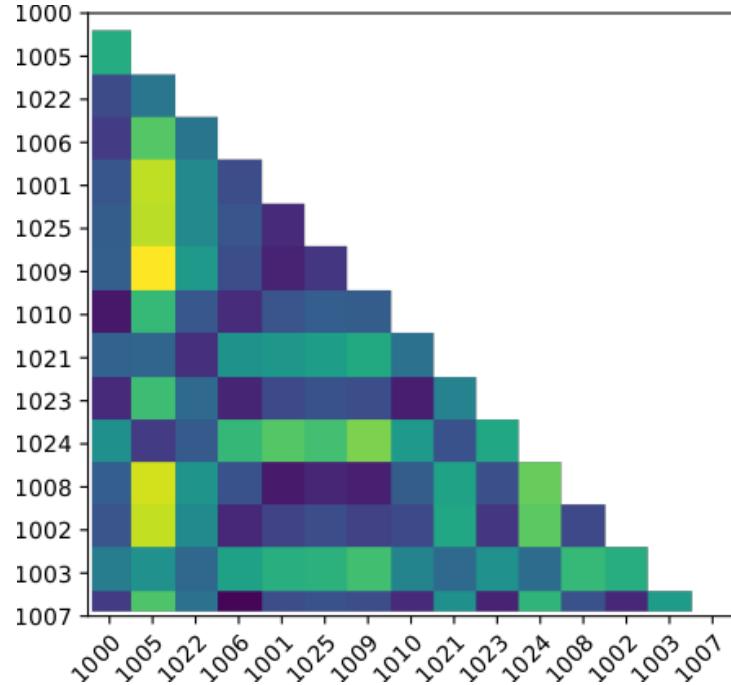
Clustering

Transients



Clustering

THD





Turtle and Fishy



Tiger
2012-2019



Thanks!

