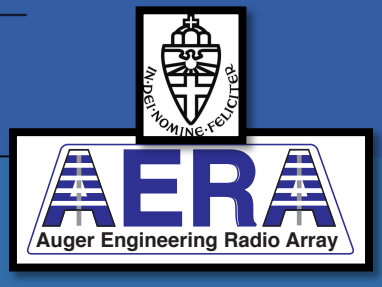


Exploring Wavelet Techniques for Filtering and Triggering

John Kelley
RU Nijmegen
26 October 2009

Previous Work!

Ansatz to a wavelet analysis of radio signals

A.M. van den Berg[1], J. Coppens[2,3], S. Harmsma[1,3], C. Timmermans[3]

November 26, 2007

[1]KVI, University of Groningen, the Netherlands.
[2]IMAPP, Radboud University Nijmegen, the Netherlands.
[3]NIKHEF Nijmegen and Amsterdam, the Netherlands.

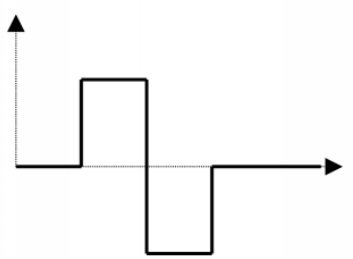
- This work is basically at the same stage… hopefully motivate us to continue

Why Wavelets?

- A decomposition of a time series that provides both spectral and temporal information
  - Possibly better than DFT for transient analysis
- Successful use in other fields for weak transient extraction
  - Radar reflections (see e.g. Ehara, Sasasi, and Mori 1994)
  - GRB light curves (see e.g. thesis by N. Butler, MIT 2003)
- Transforms can be fast
  - Possible implementation in FPGA for trigger

Discrete Wavelet Transform

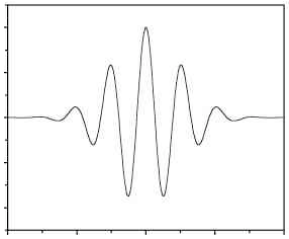
- Basis functions
  - finite in time
  - scaled and shifted versions of a "mother wavelet"



Haar

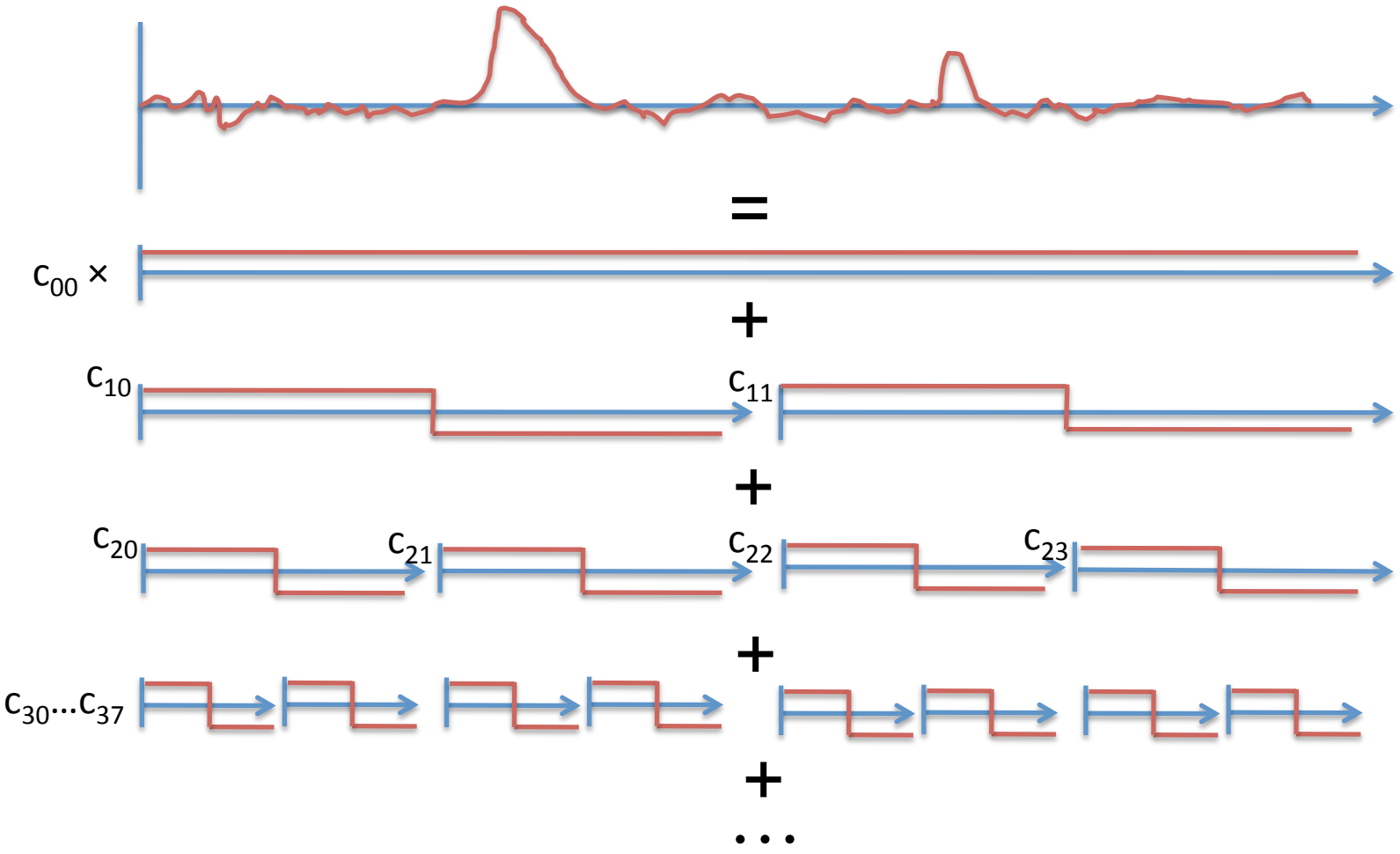
- Decomposition results
  - wavelet coefficients
  - time on one axis
  - period scale (often factors of 2) on the other

Daubechies 4

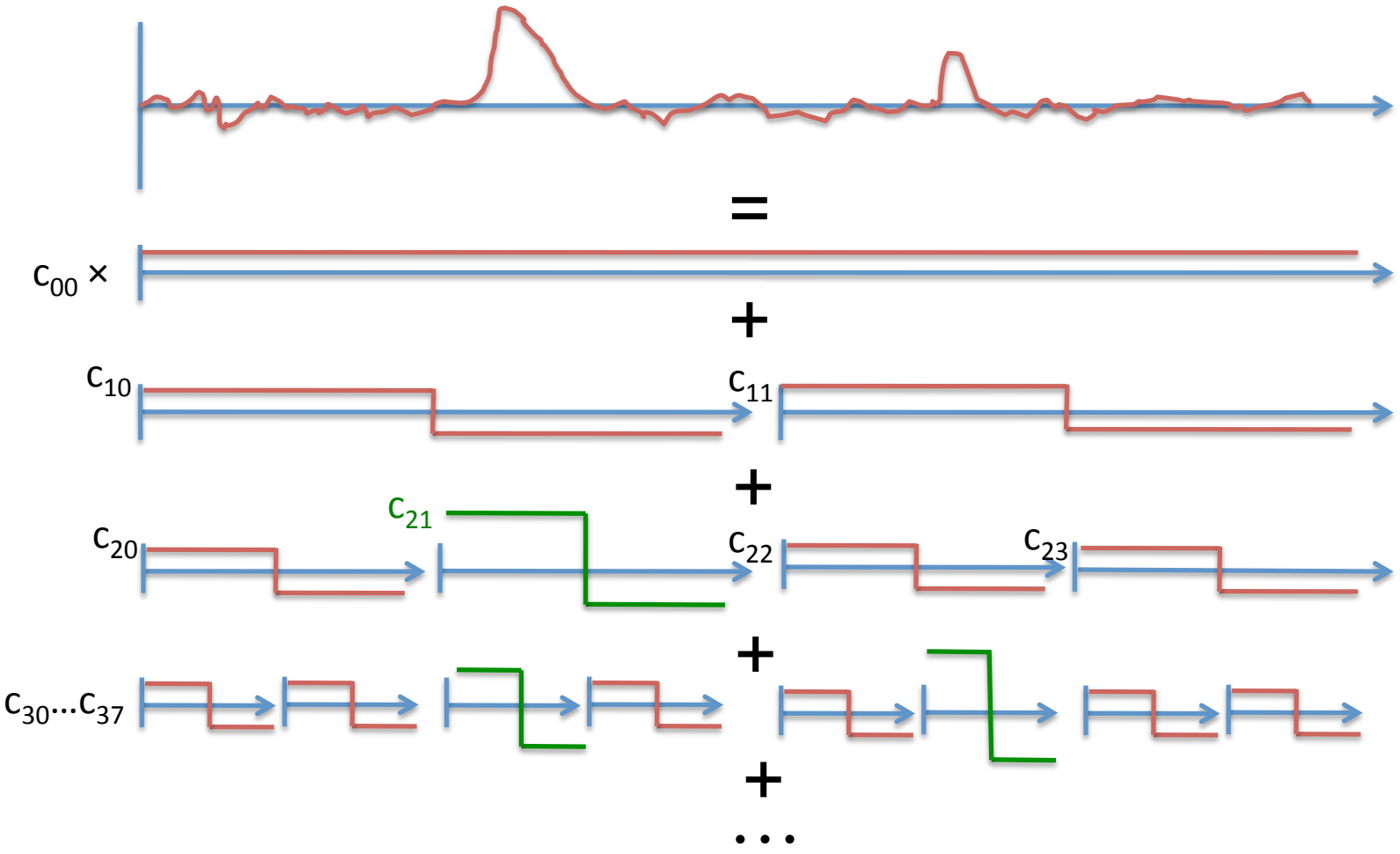


Morlet

Visualization of Haar DWT

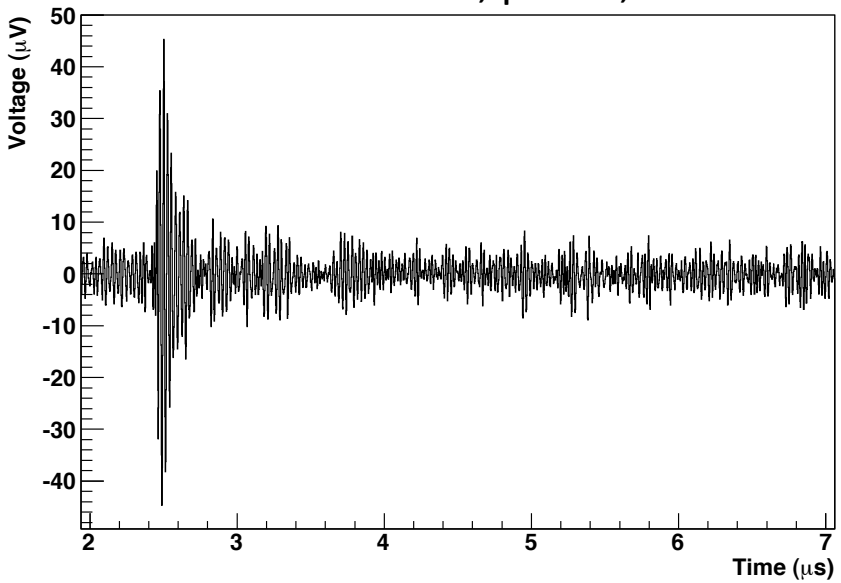


Visualization of Haar DWT

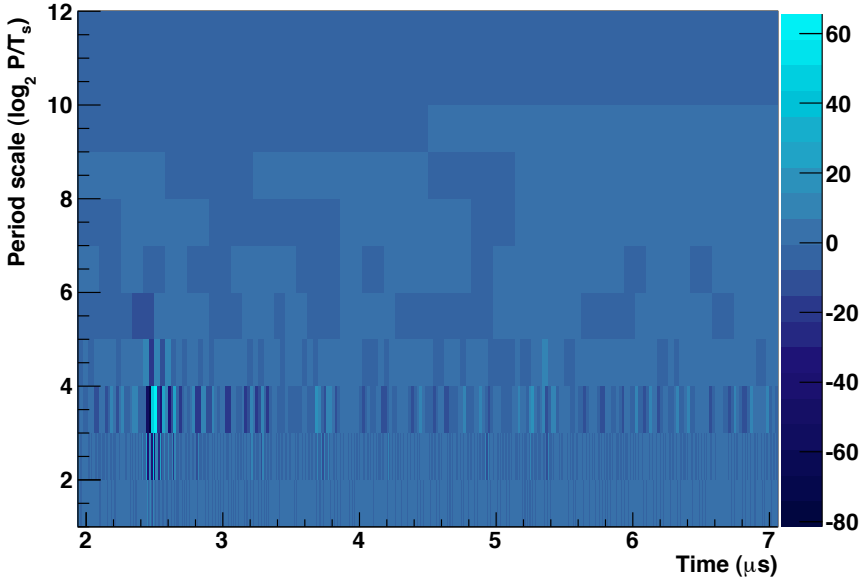


Example Radio Pulse (2007)

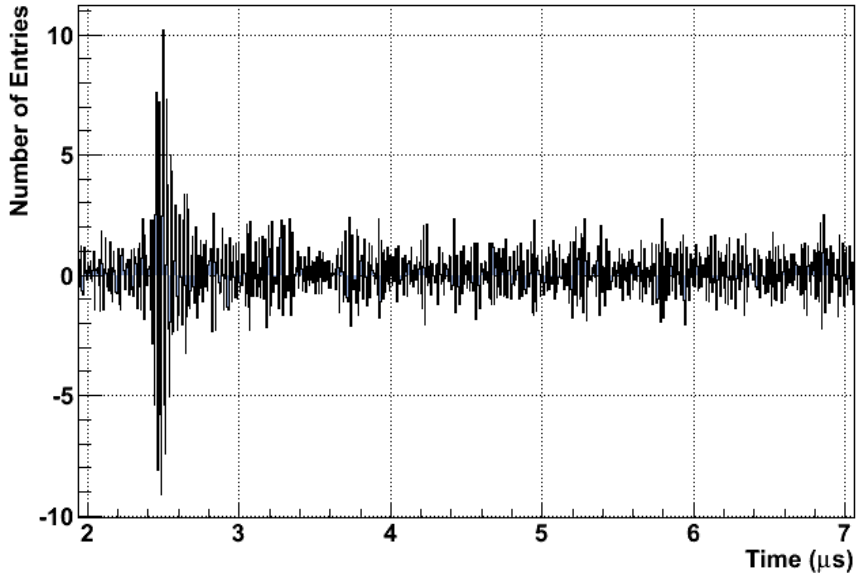
Event 3388350, pole 2, NS

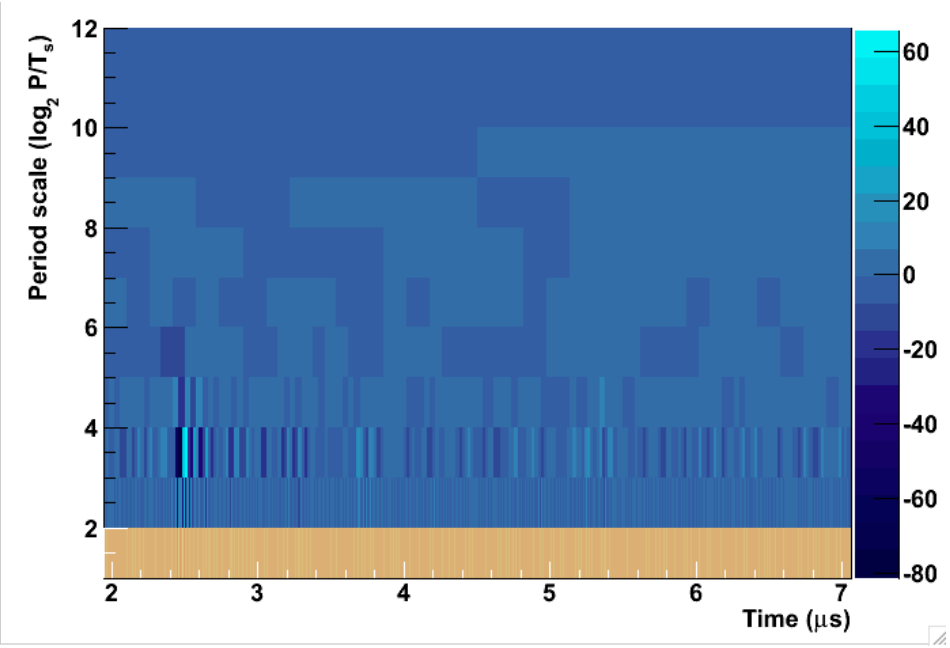


Daubechies4 DWT coefficients

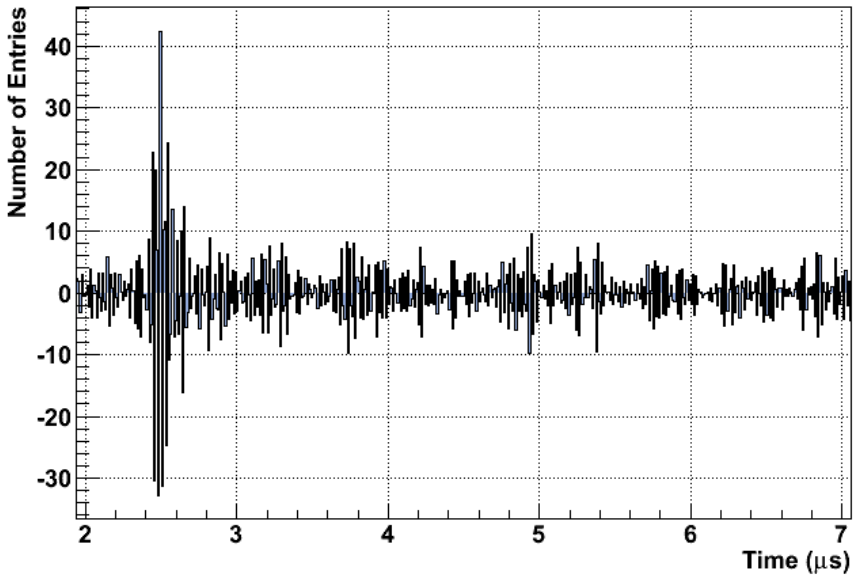


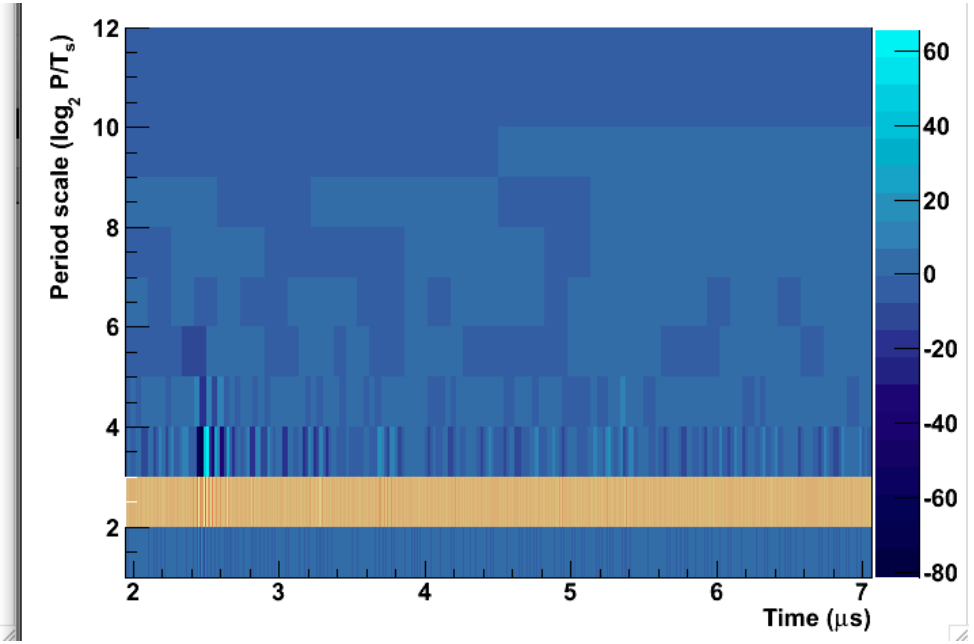
Projection (200 MHz)



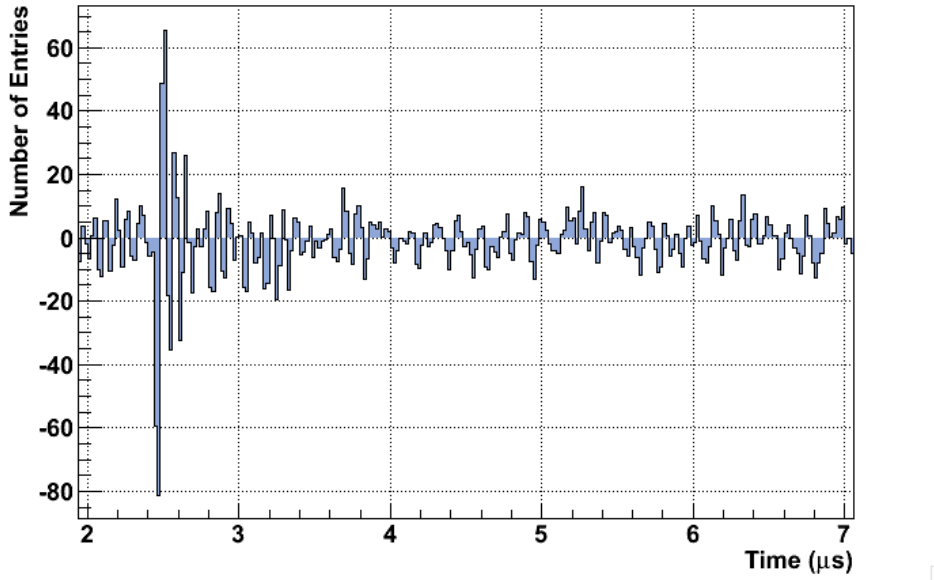


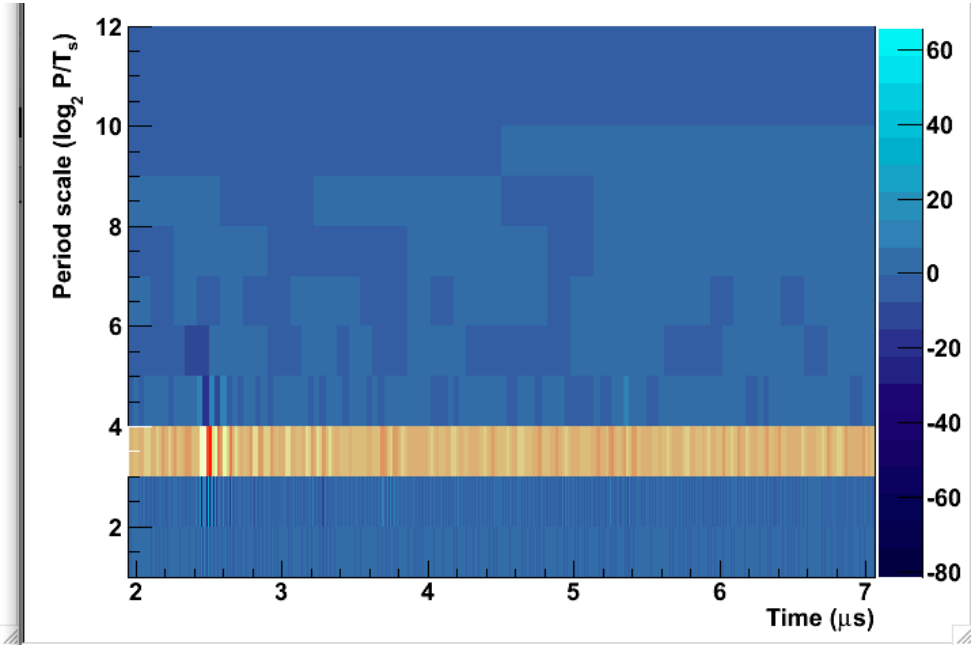
Projection (100 MHz)



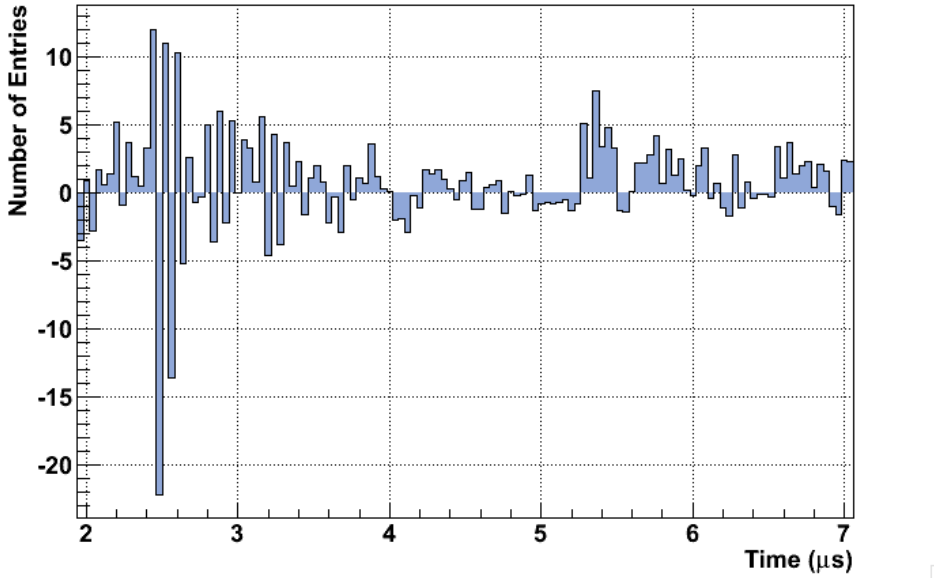


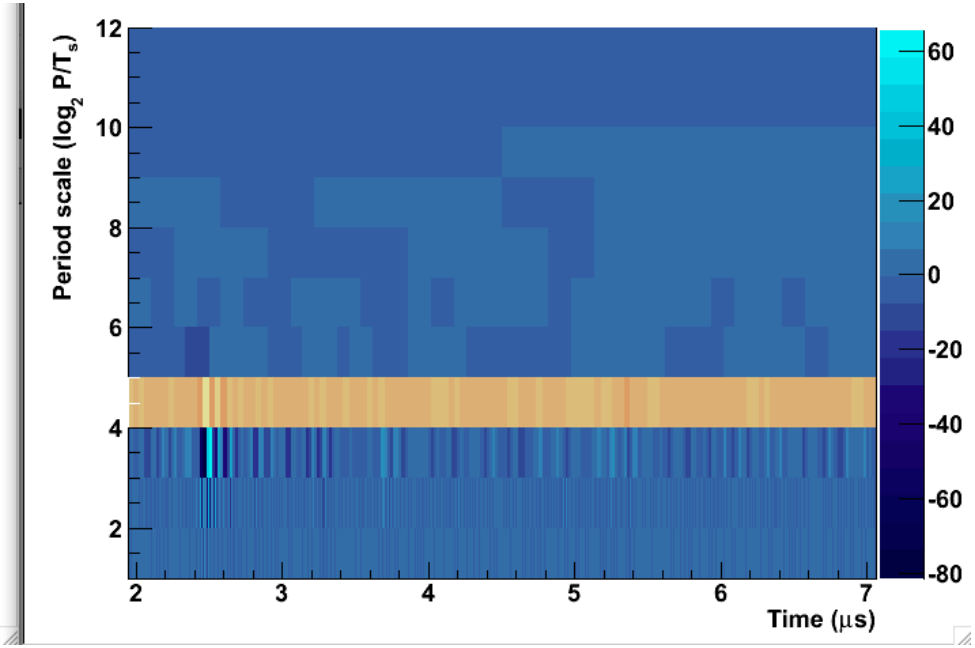
Projection (50 MHz)



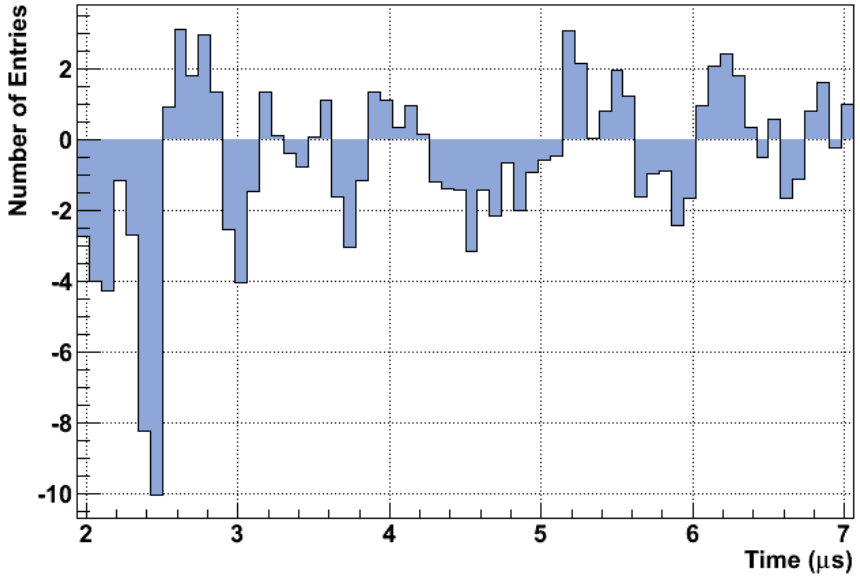


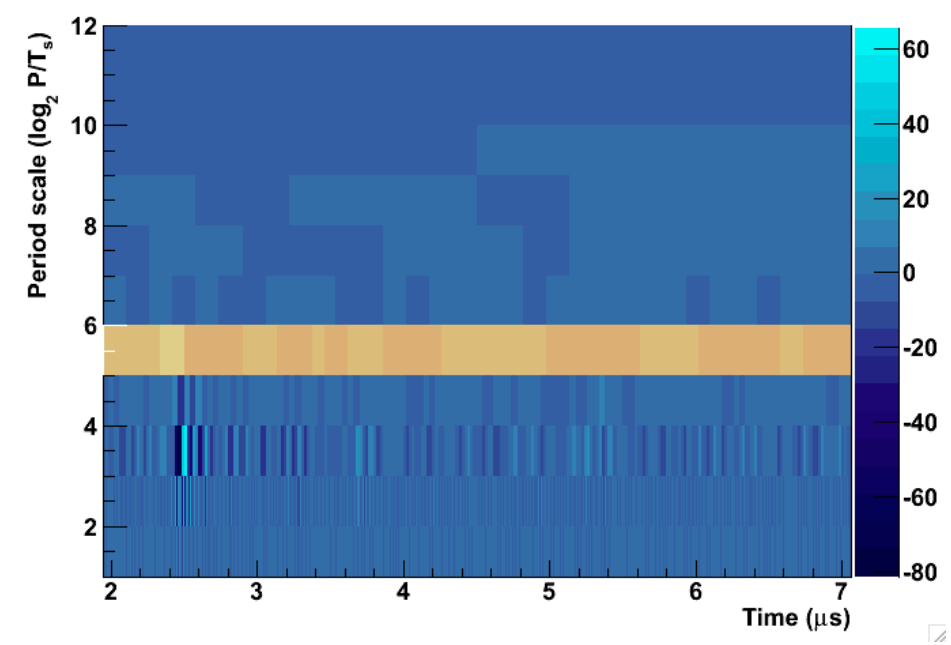
Projection (25 MHz)



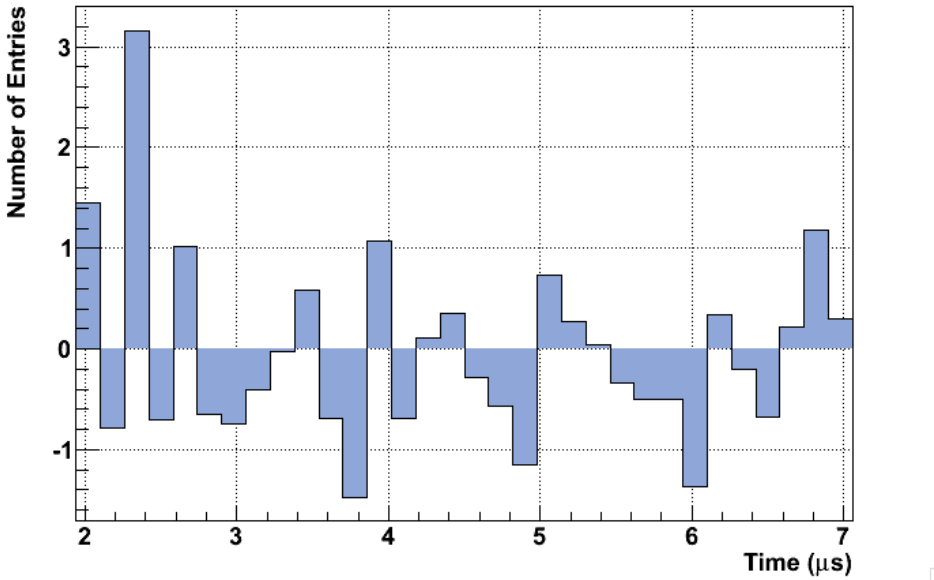


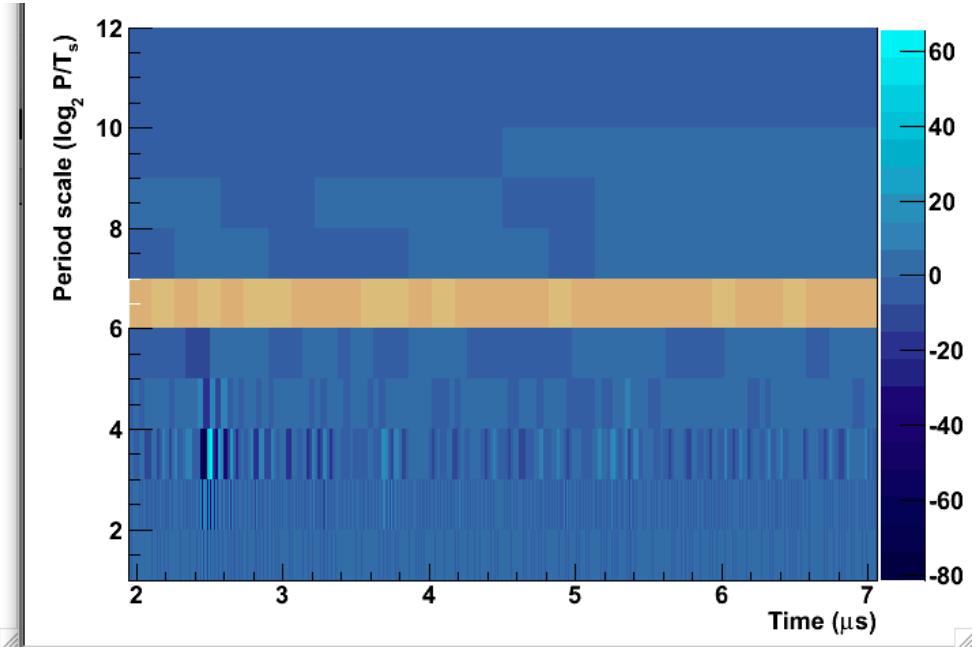
Projection (12.5 MHz)



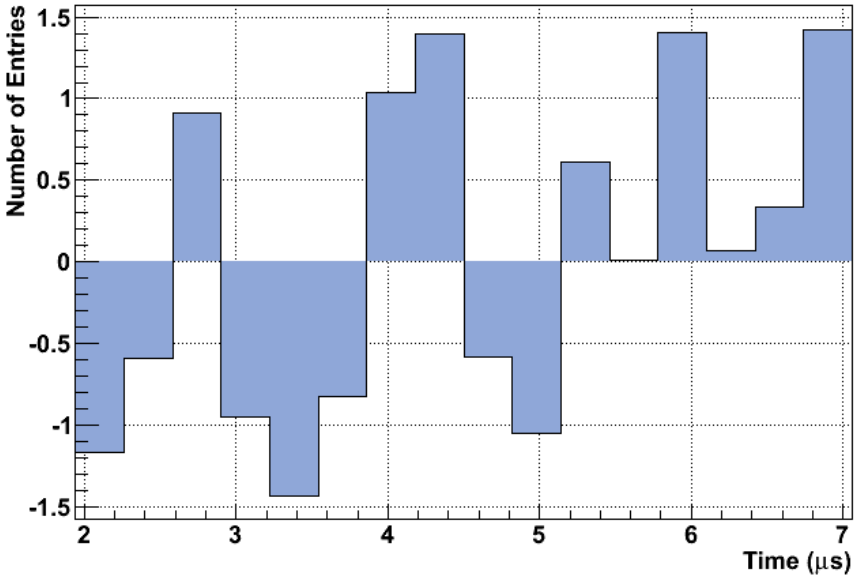


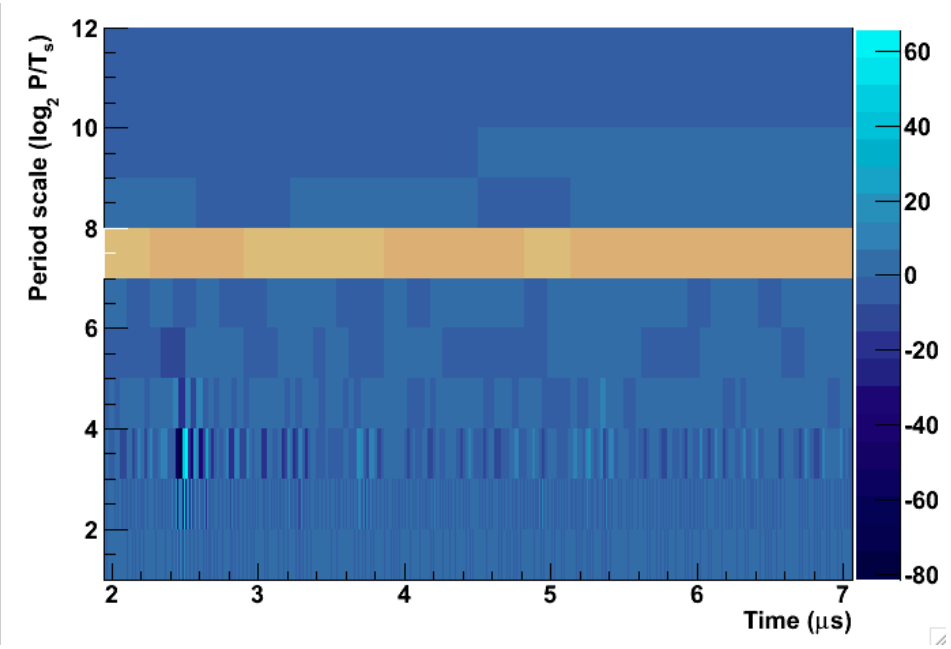
Projection (6.3 MHz)





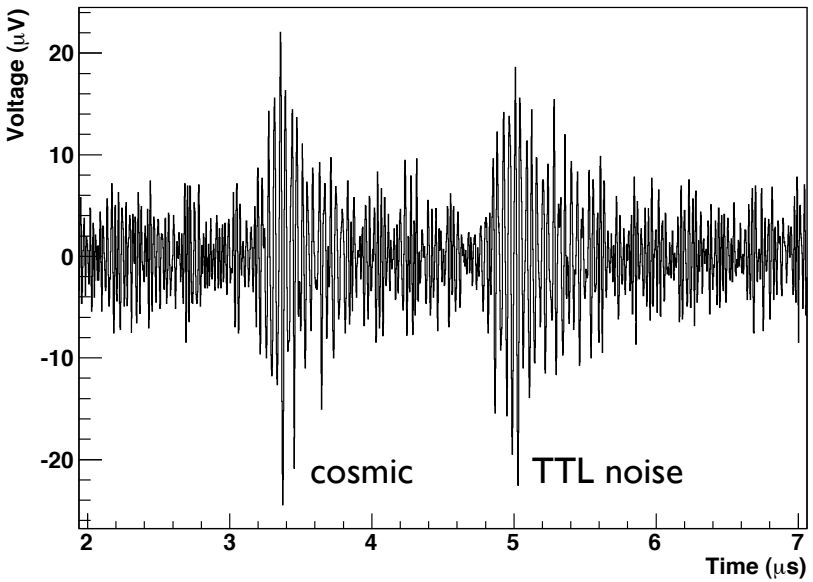
Projection (3.1 MHz)



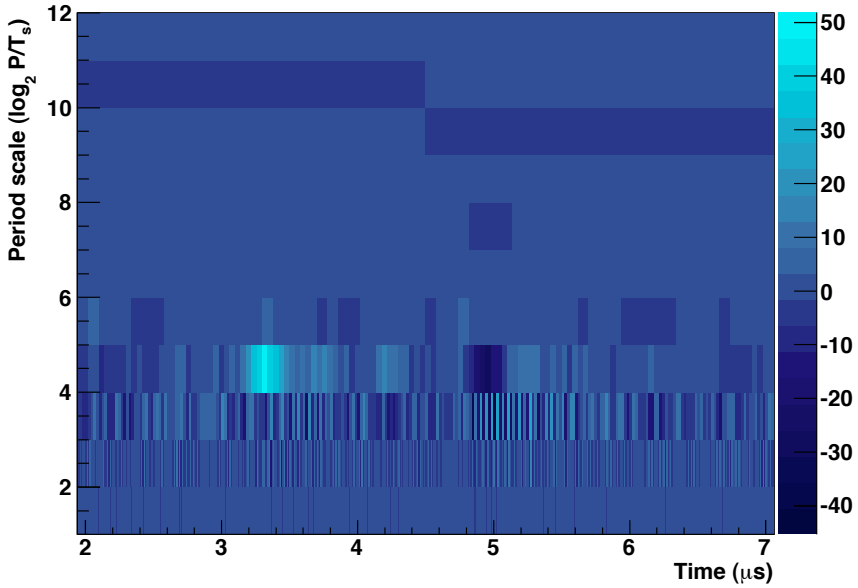


Another Example

Event 3382961, pole 1, NS

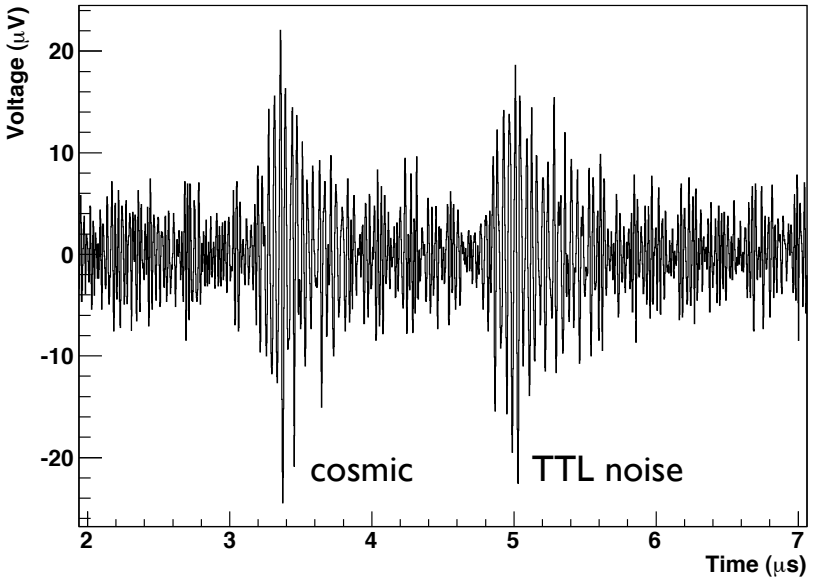


coefficients (c_{ij})

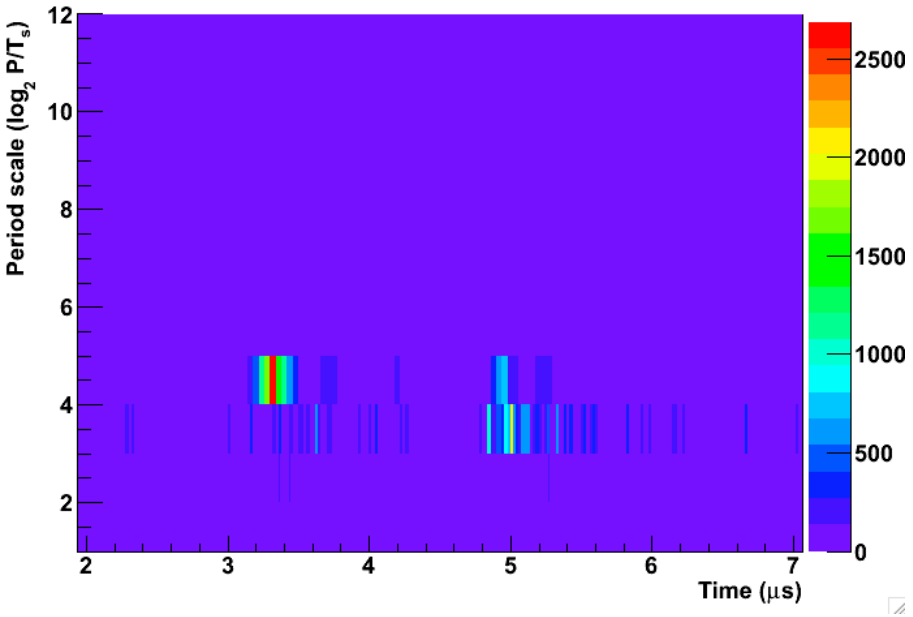


Another Example

Event 3382961, pole 1, NS



power (c_{ij}^2)



Filtering

- Hard threshold on wavelet coefficients (or power) can keep pulses but reject white noise
- Coefficient threshold by Donoho & Johnstone:

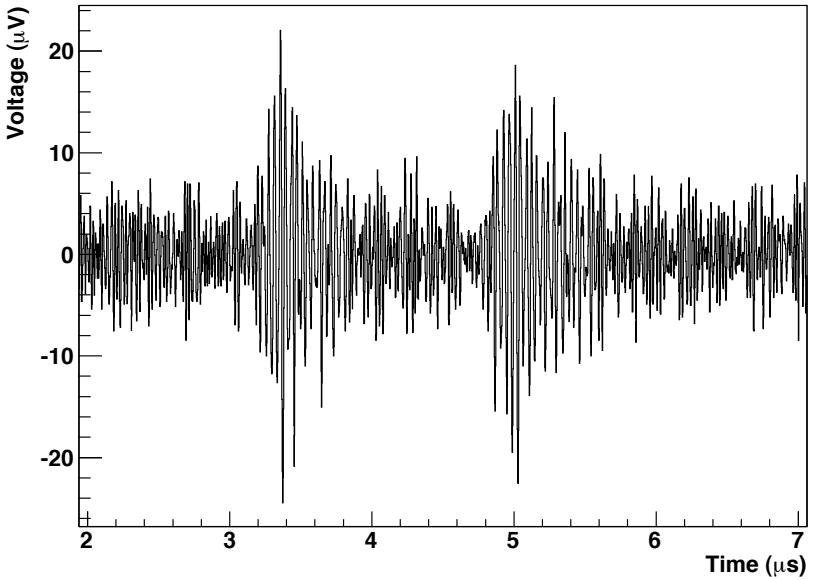
$$\tau = \delta\sqrt{\ln N_{\mathrm{samp}}}$$

$$\delta = \frac{\mathrm{median}(|c_{\mathrm{HF},j}|)}{0.6745}$$

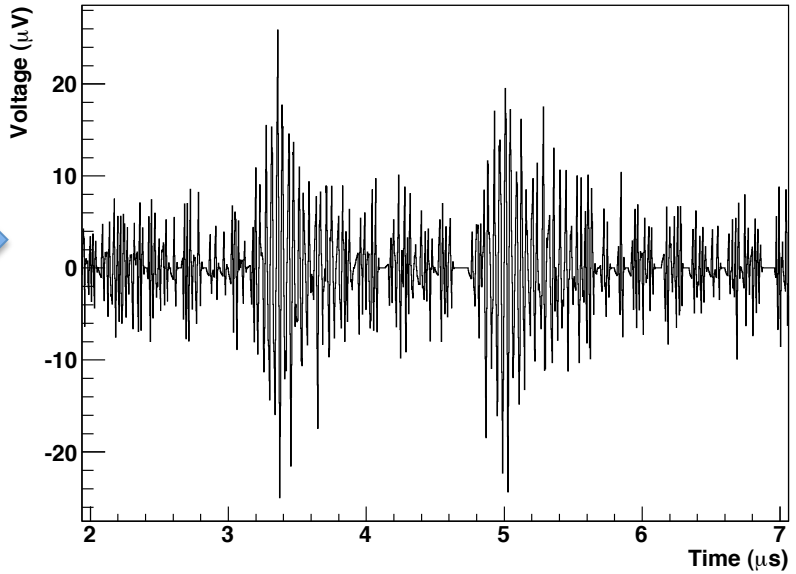
- All coefficients below τ in magnitude set to 0
- Inverse transform to reconstruct filtered time series

Filtering example

Event 3382961, pole 1, NS

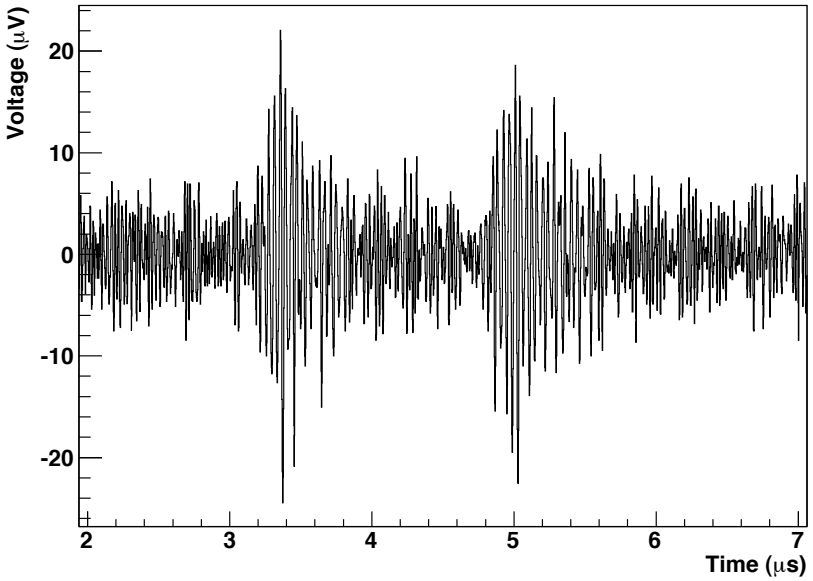


c_{ij} threshold = 2 τ_{Donoho}

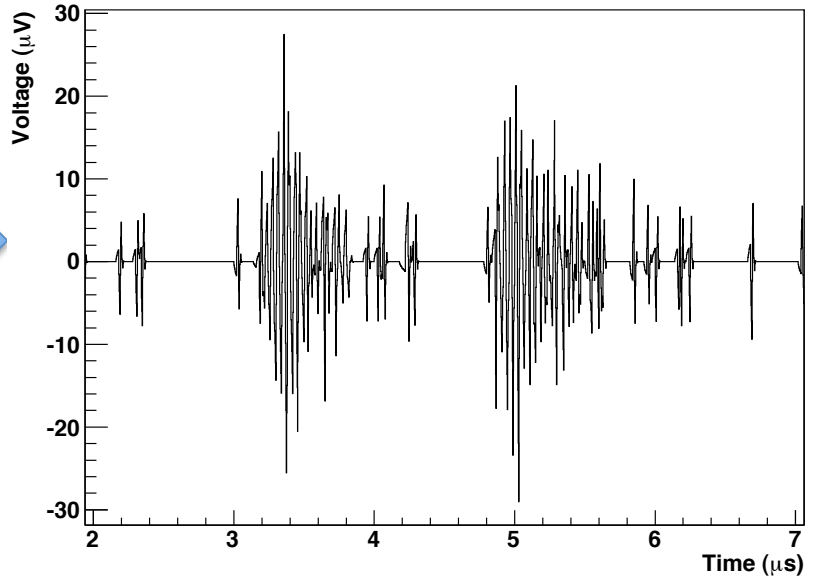


Filtering example

Event 3382961, pole 1, NS

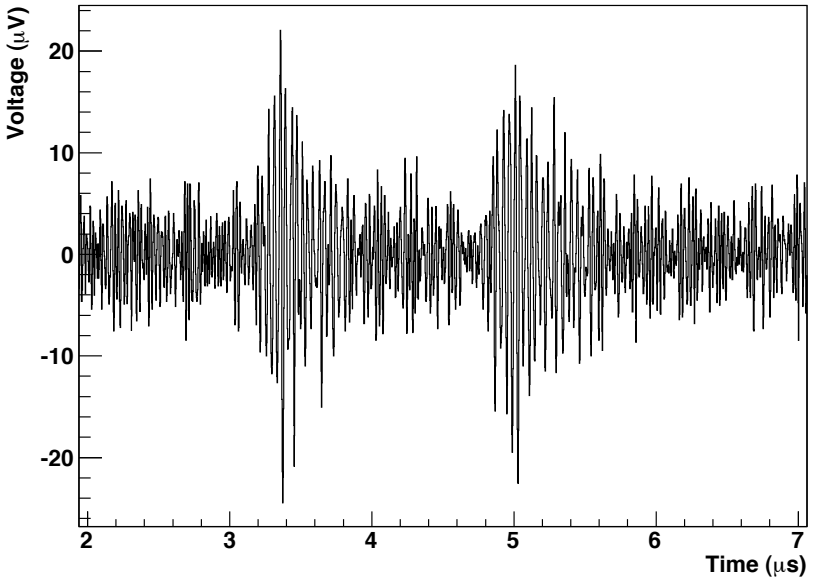


c_{ij} threshold = 4 τ_{Donoho}

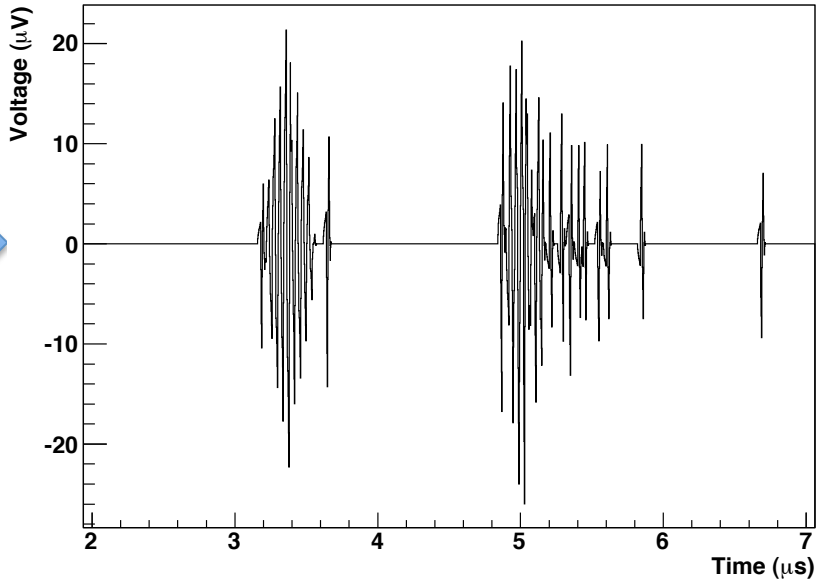


Filtering example

Event 3382961, pole 1, NS

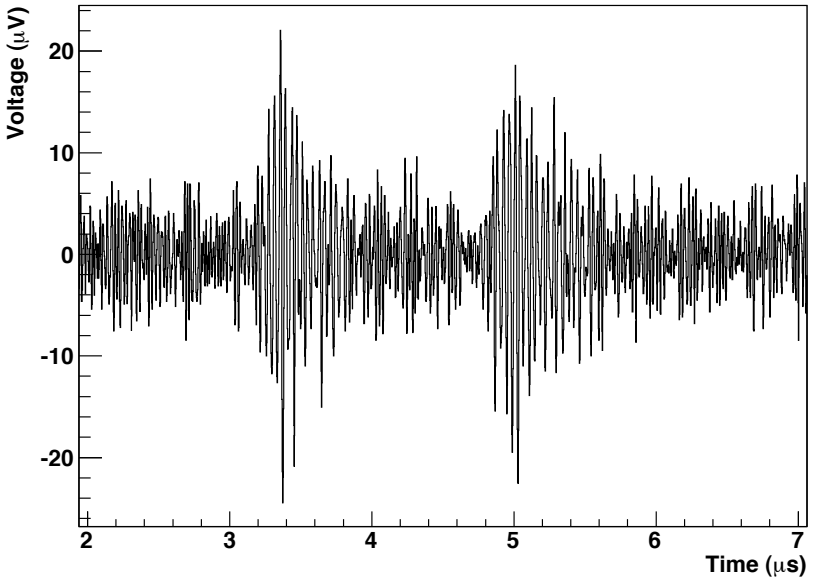


c_{ij} threshold = 6 τ_{Donoho}

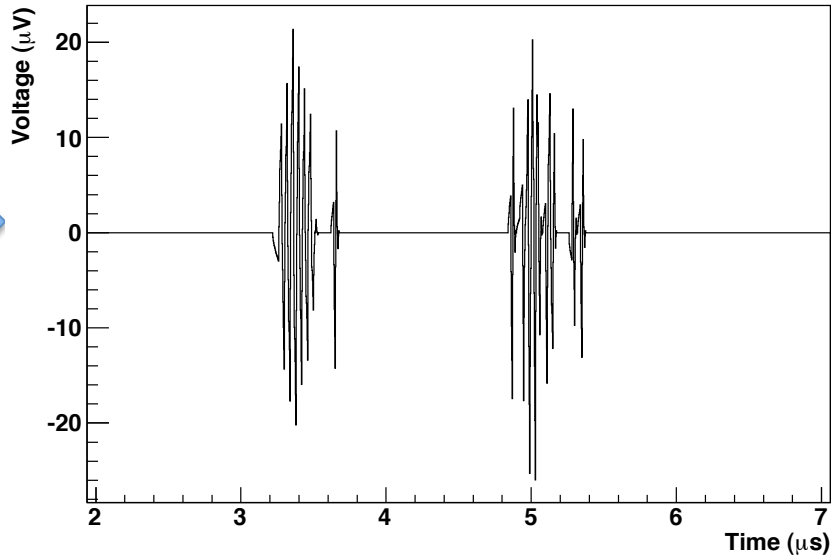


Filtering example

Event 3382961, pole 1, NS



c_{ij} threshold = 8 τ_{Donoho}

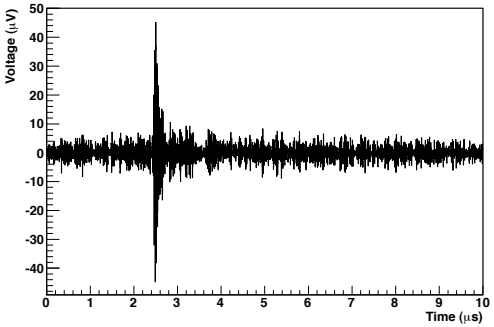


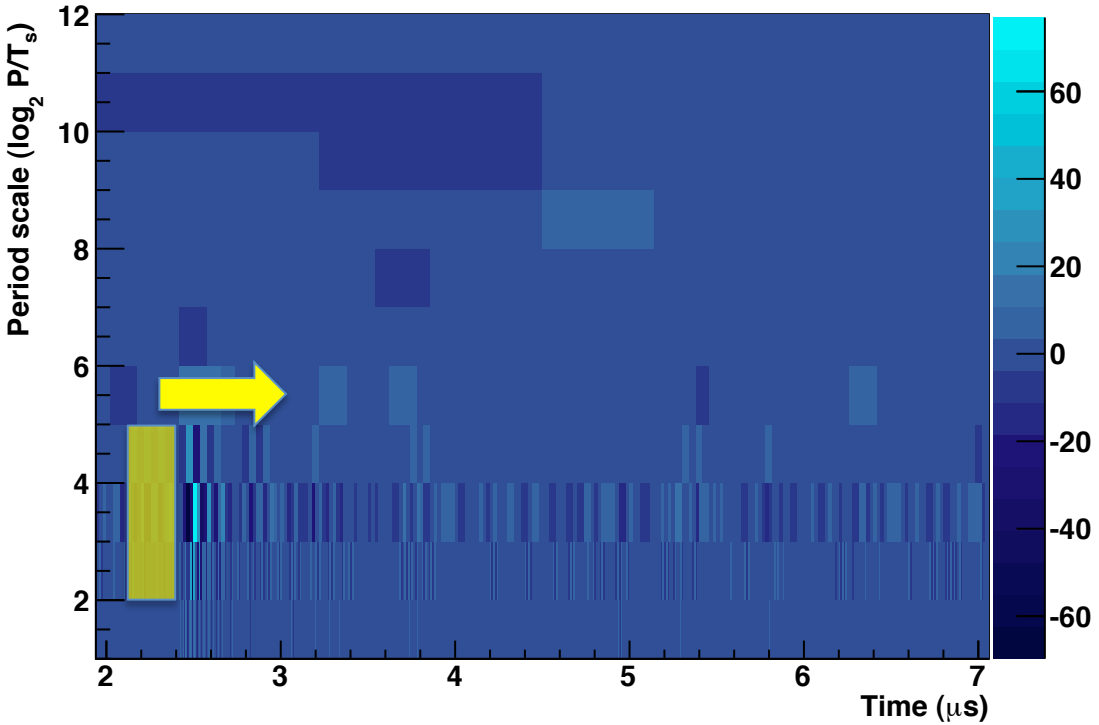
Difficulties

- Filtering alone doesn't distinguish between good and bad pulses
- Transform + filtering + inverse probably too much for L1 trigger in FPGA
  - Possible exception: short timescale Haar
- Could be useful for L2 or offline pulse extraction

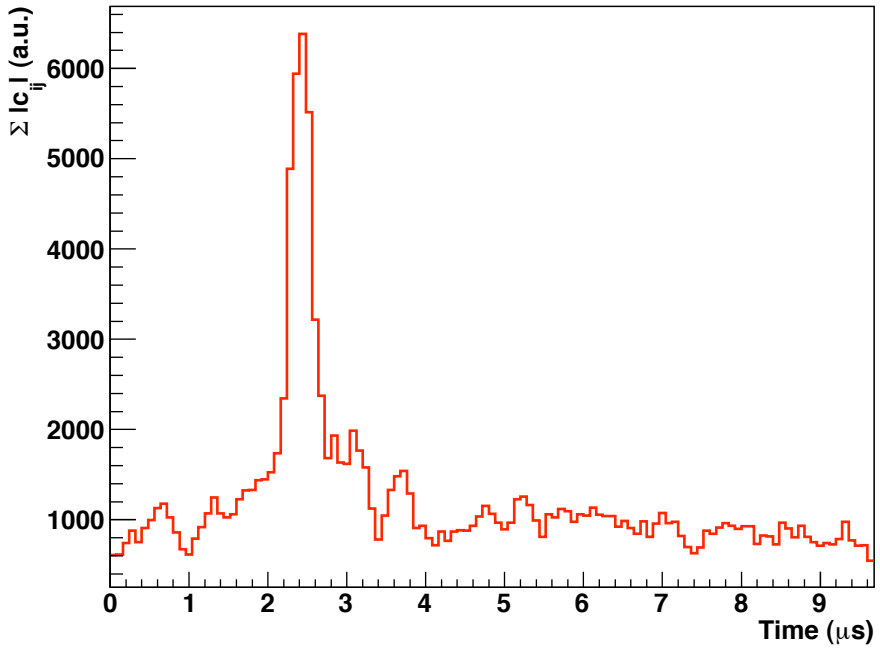
Trigger?

rolling integral over 25-100 MHz coefficient bins (abs. value)





Rolling Sum



- Looks promising — but triggering on golden events trivial
- Will likely still trigger on TTL pulse
- May be good for power line noise — still looking
- Don't know about pulse trains yet

Summary

- In principle, wavelet analysis is appropriate
  - provides temporal and spectral information
- Threshold filtering can pull pulses out of noise
  - could also use for data compression, but impact on spectral information?
- Haar wavelet transform feasible in FPGA
- A wavelet L1 trigger is possible but needs much more work on discrimination power
  - ratio in different frequency bands?