A Low-Threshold Neutrino Search with the Askaryan Radio Array (ARA)

Kaeli Hughes, for the ARA Collaboration
University of Chicago
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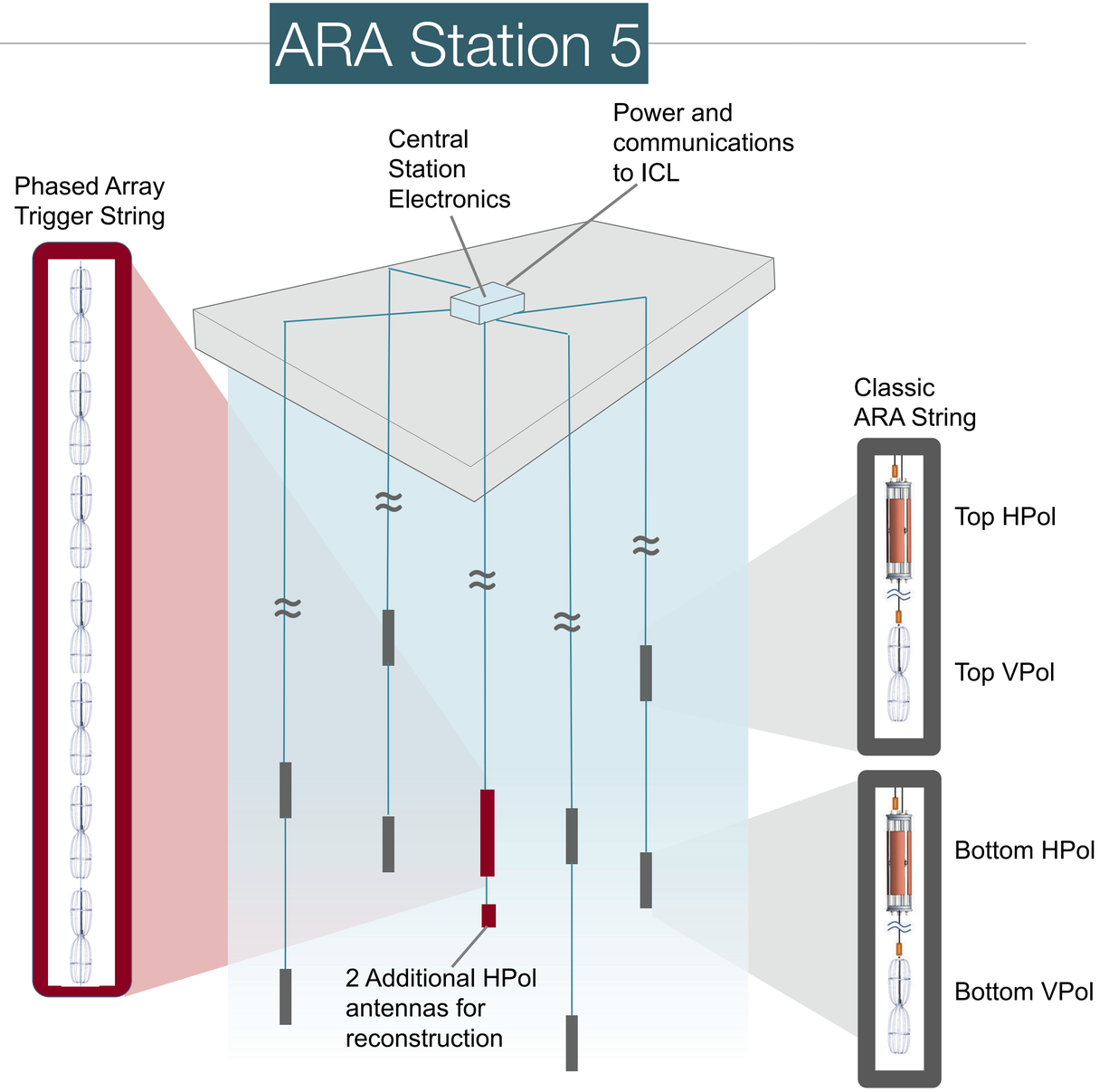
Analysis Overview

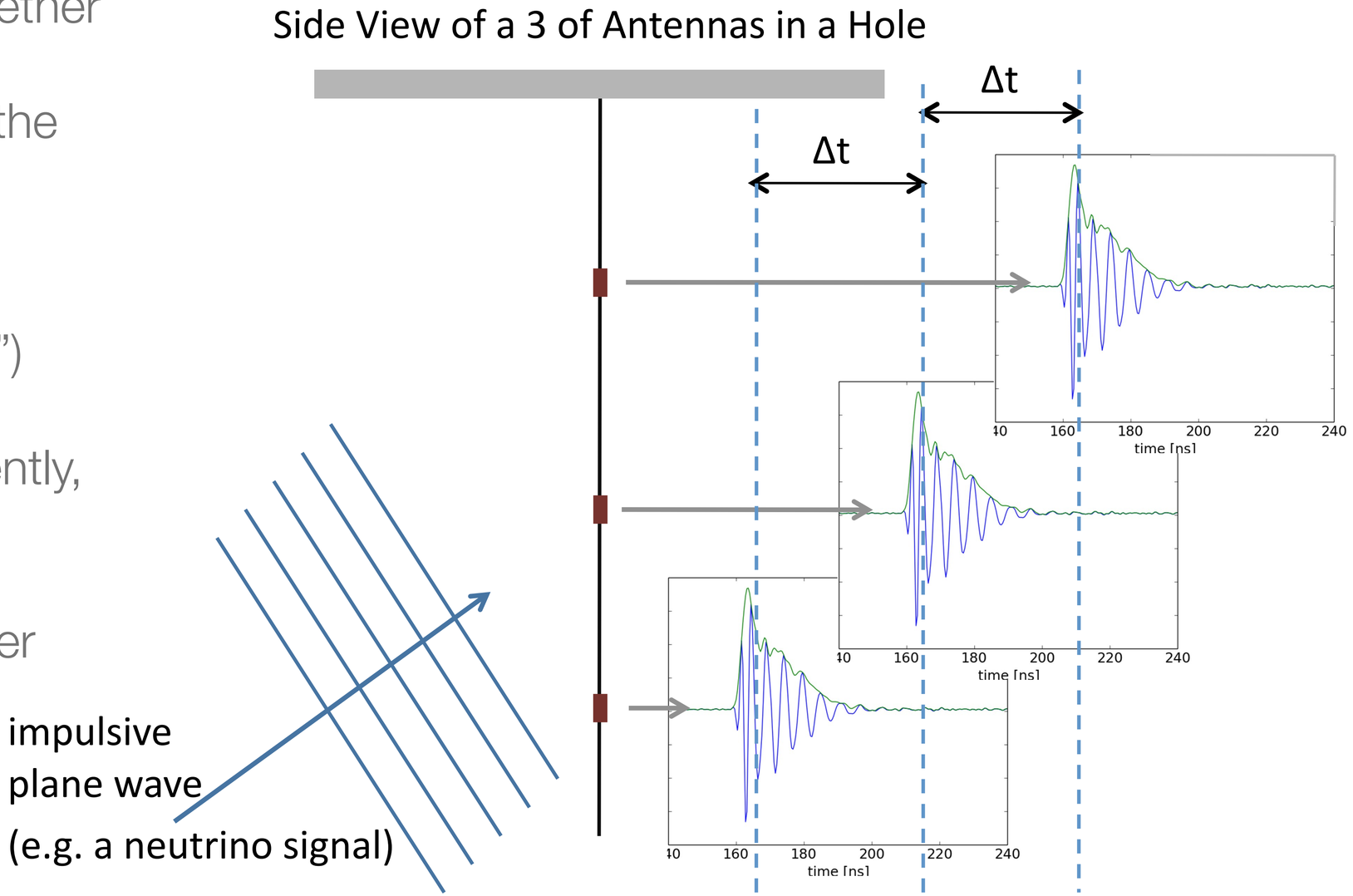
- 6 months of livetime from 2019 using **Phased Array data only**
- Blinded analysis via “burn sample” method
  - 10% of the data is unblinded and studied
  - Cuts are optimized via extrapolation



A Phased Array Trigger Design

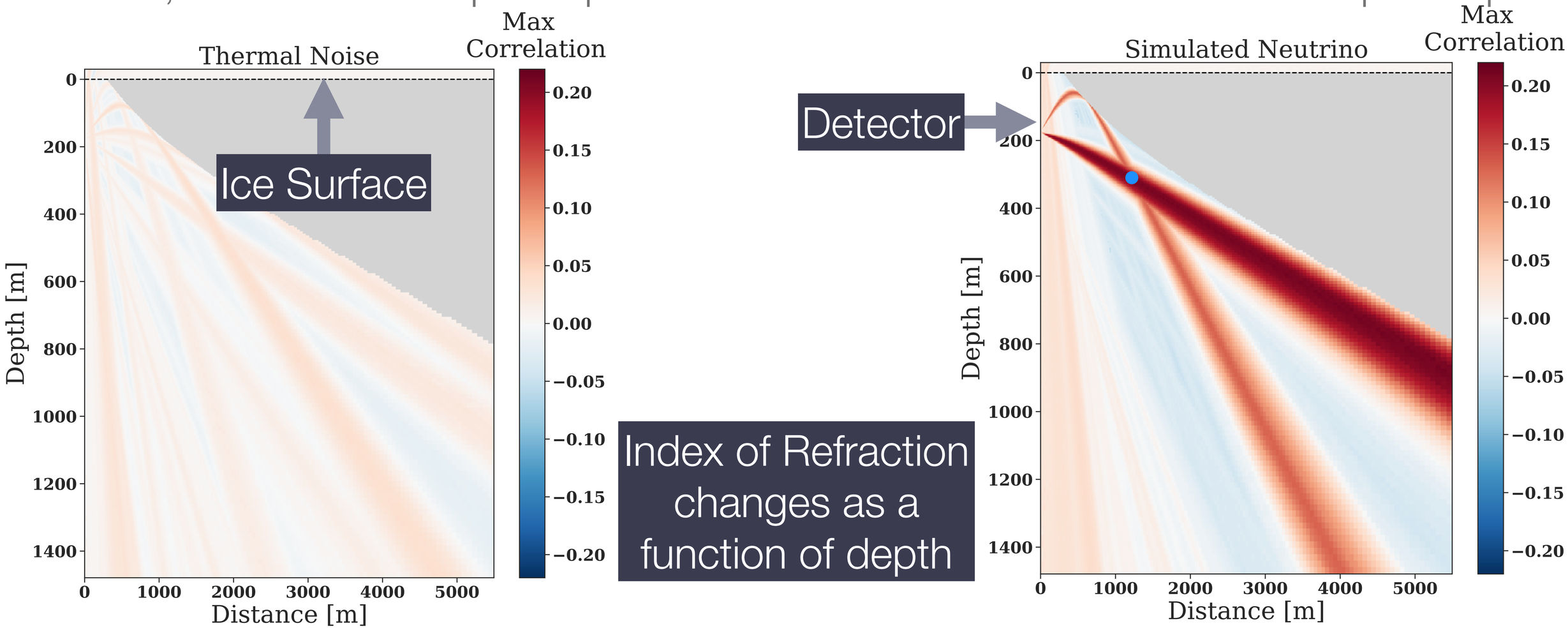
Credit. A. Vieregg

- In analysis, we improve signal strength by combining multiple signals together
- Phased array trigger does this at the trigger level:
  - Adds signals together in pre-determined directions (“beams”)
  - Plane wave signals add coherently, noise likely does not
  - This effectively lowers our trigger threshold

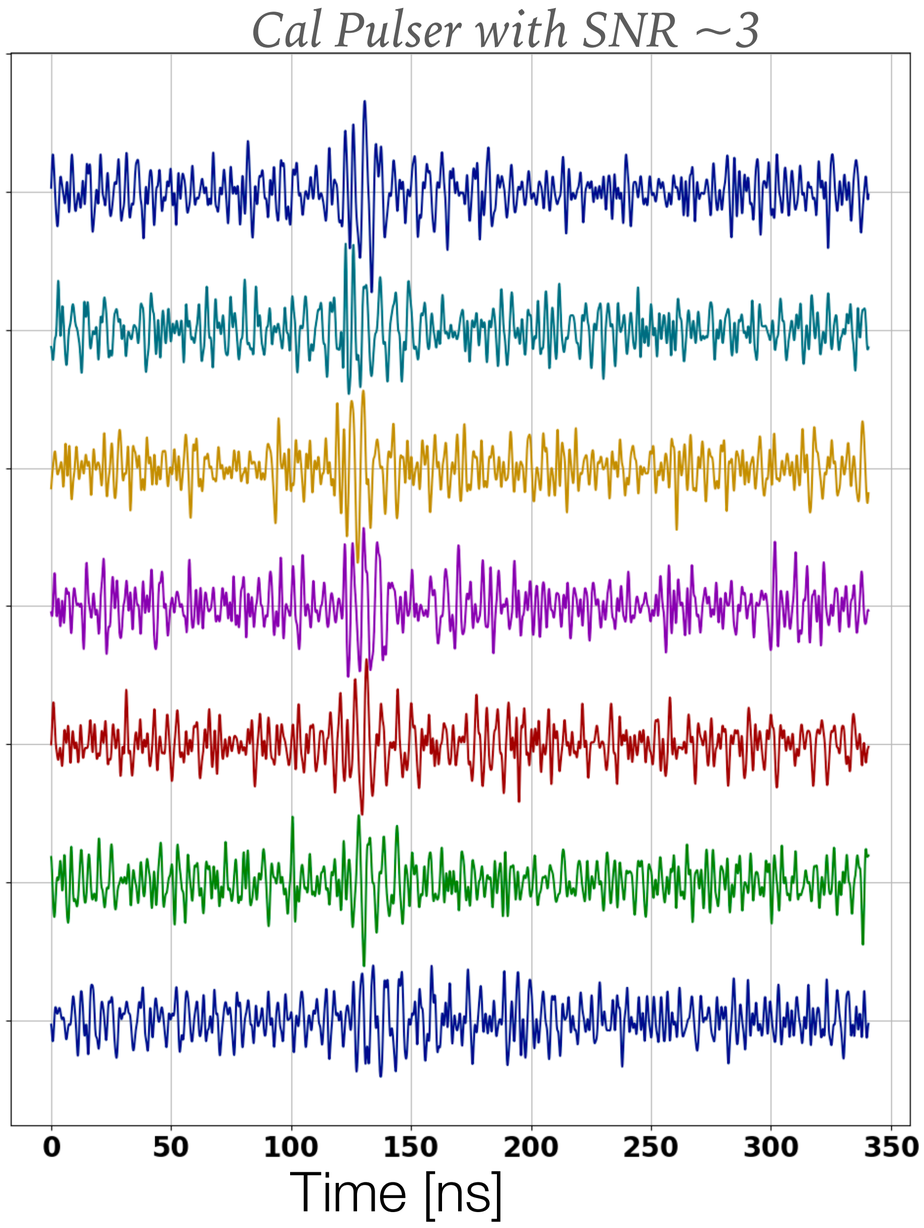


Correlation maps with a one-dimensional array

- The phased array is only one-dimensional, so no available azimuthal information
- But, distance and depth of pulse can be reconstructed in a distance/depth map



How Correlation Maps work in analysis



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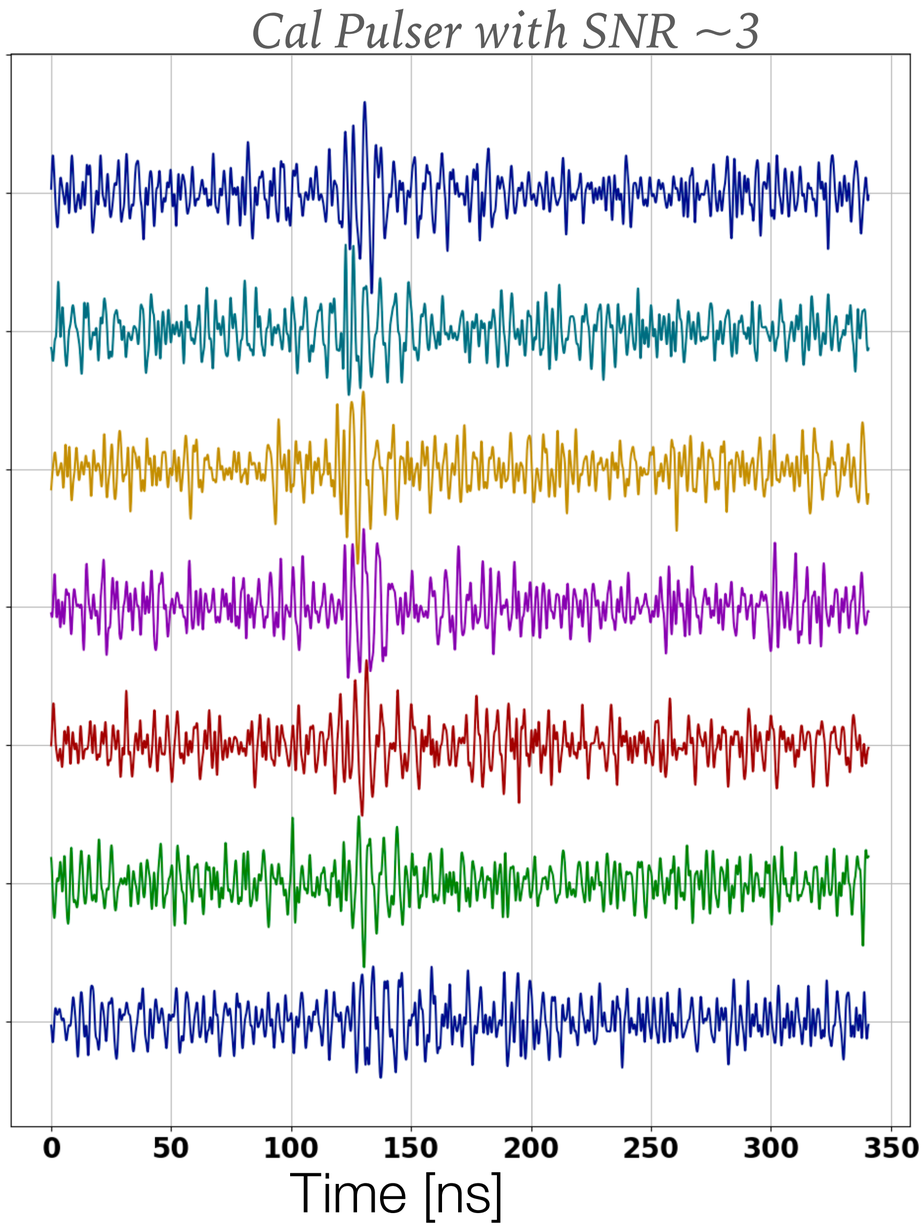
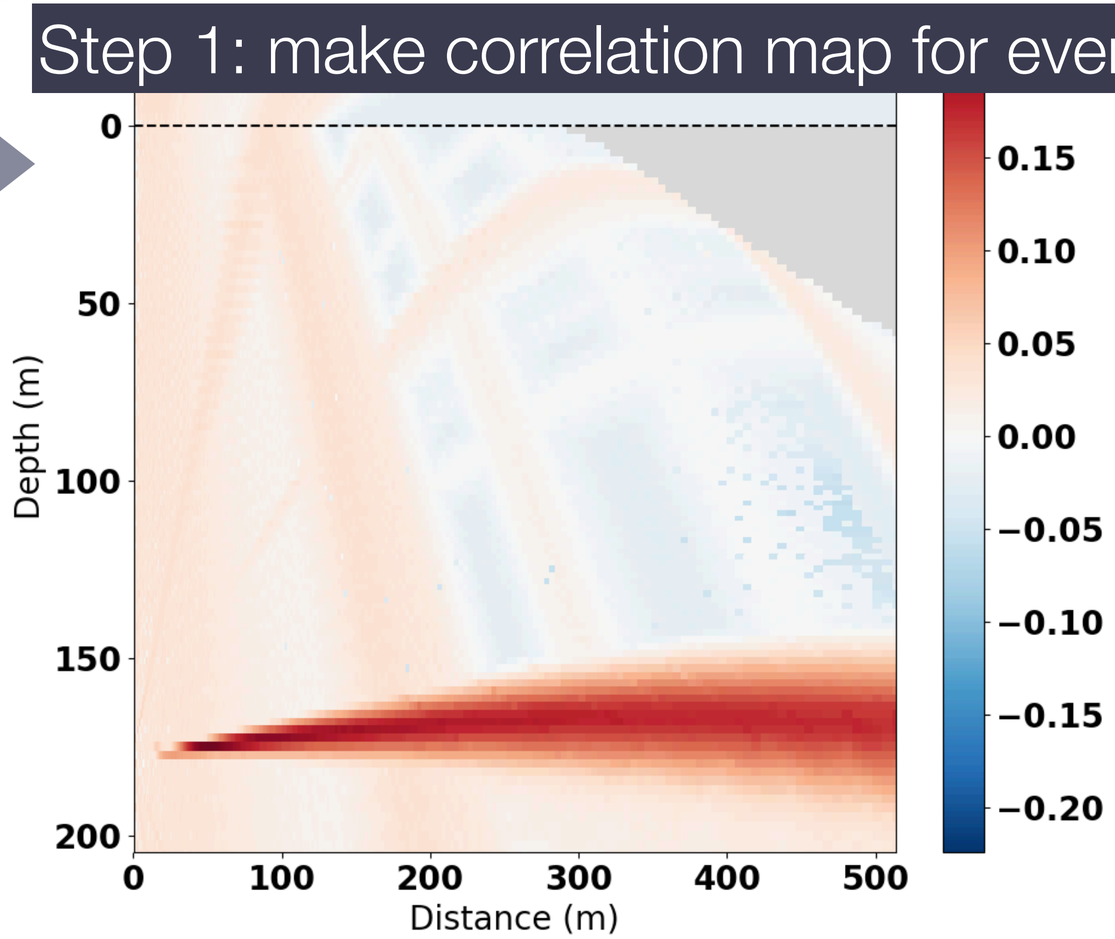


Step 1: make correlation map for event



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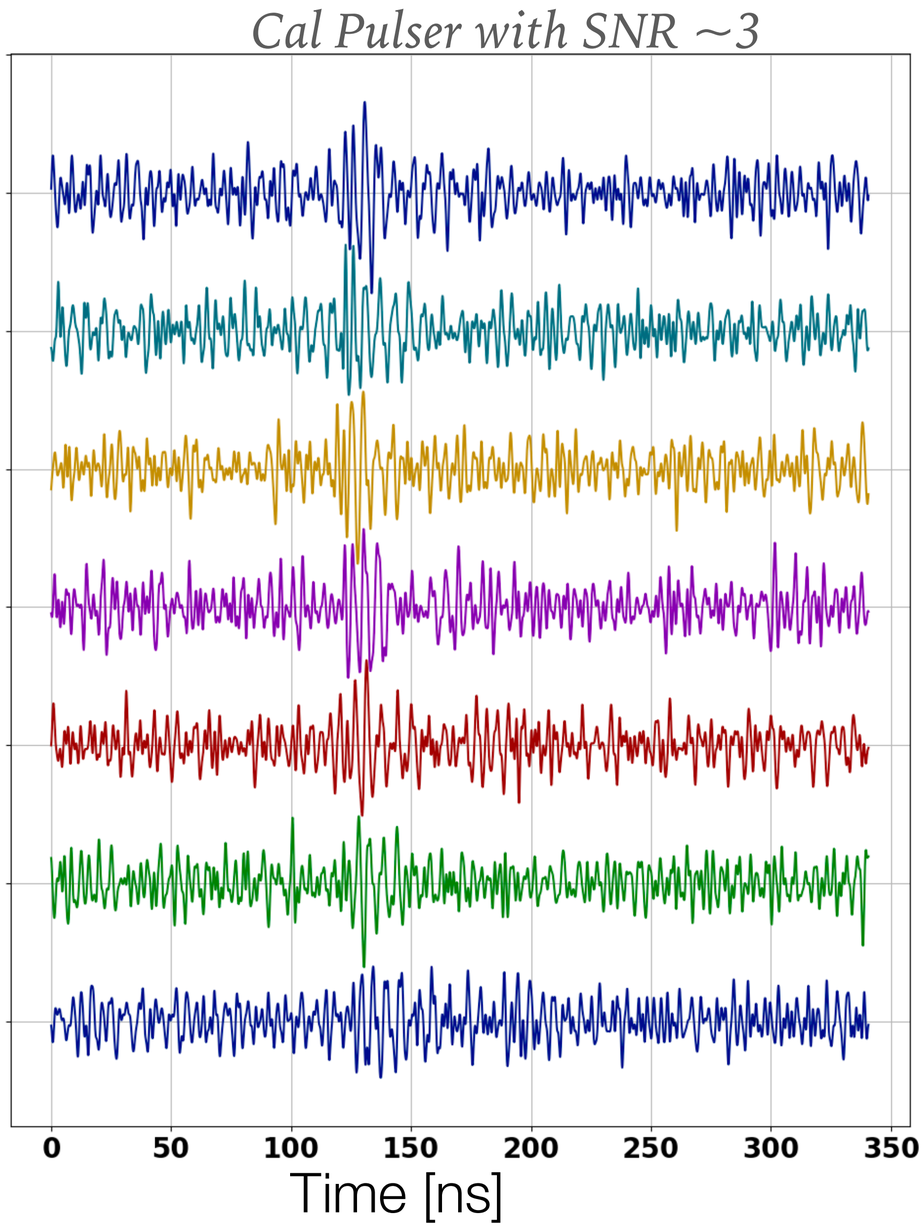
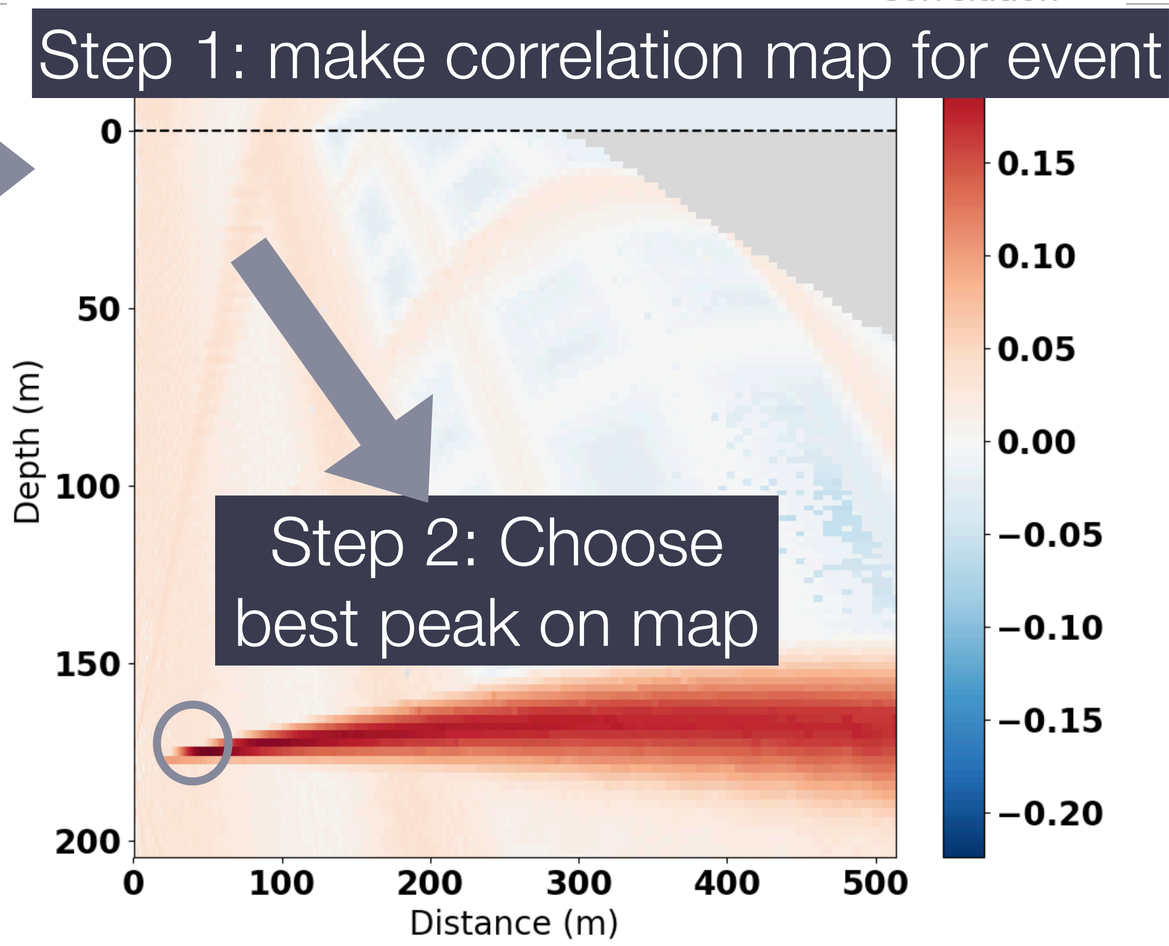
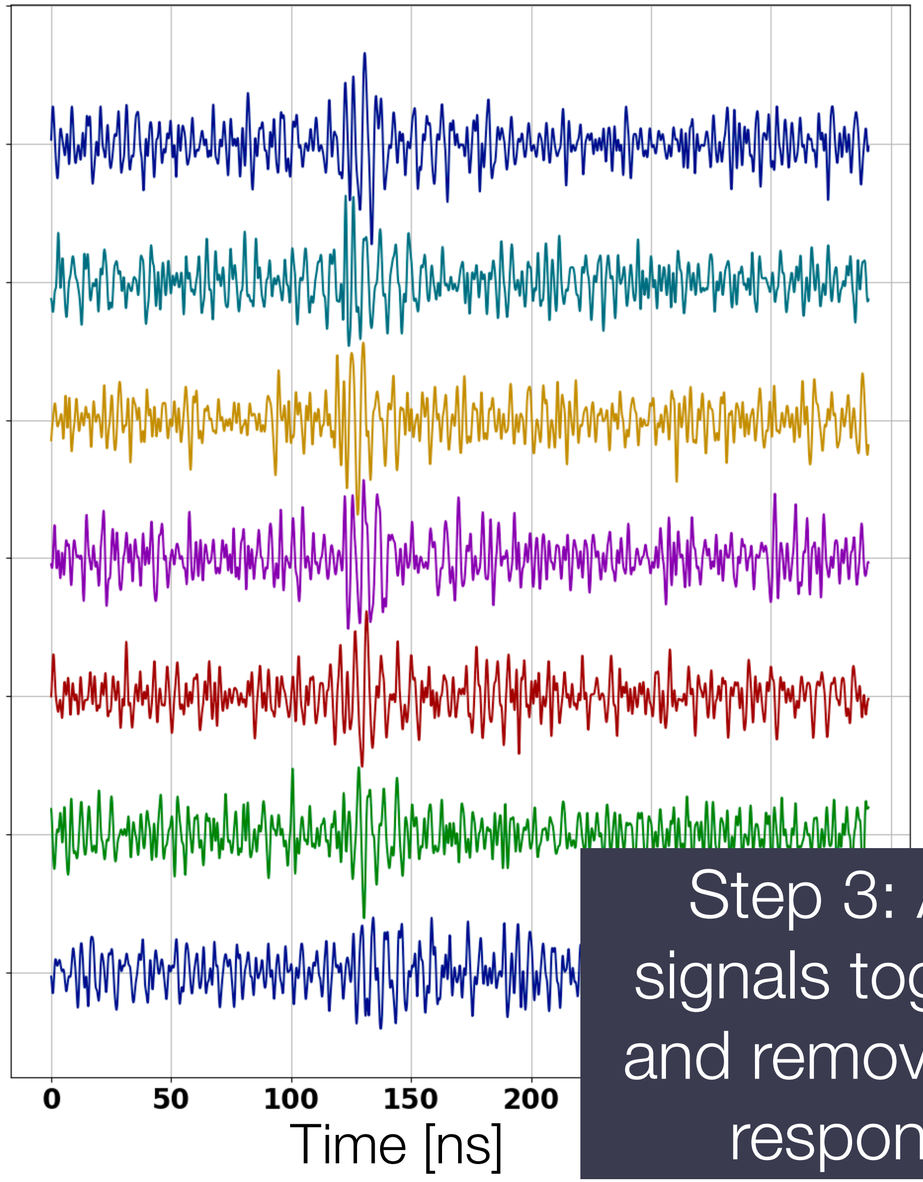




How Correlation Maps work in analysis

Cal Pulser with SNR ~3



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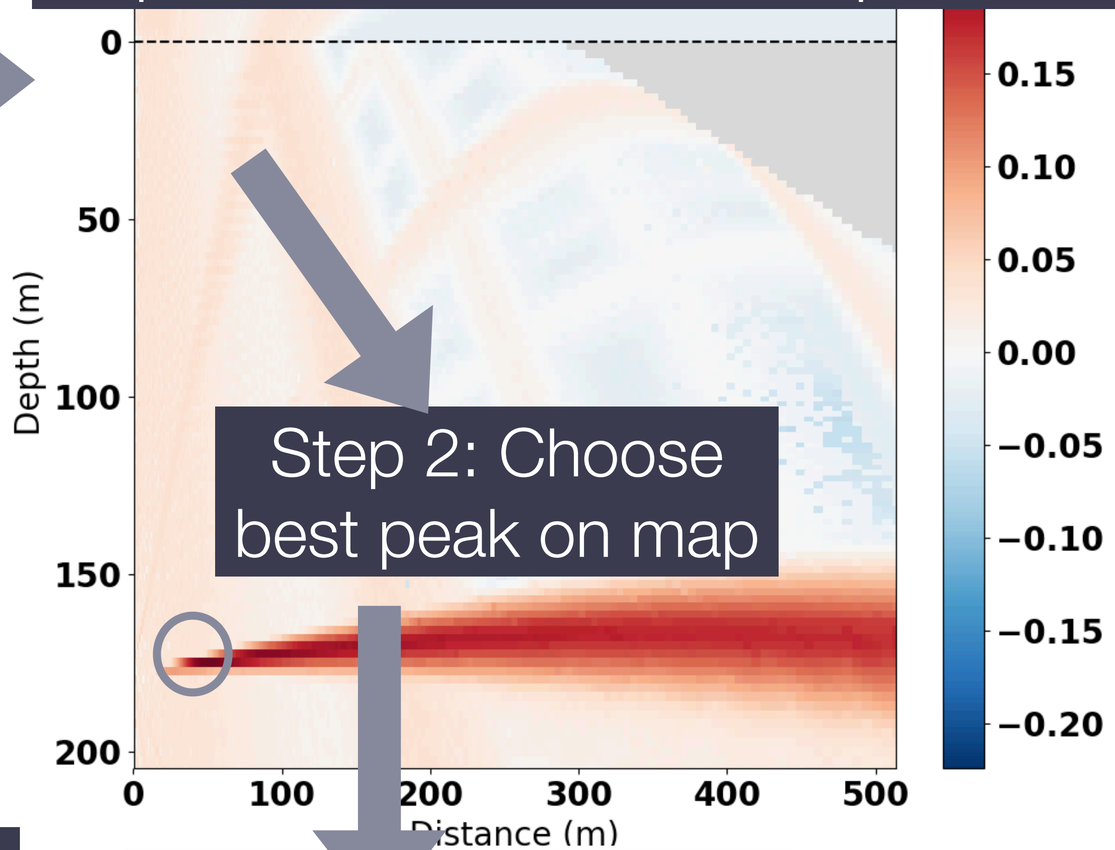
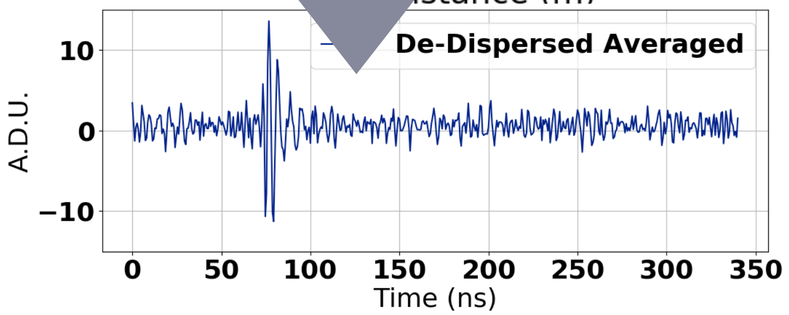


Step 2: Choose best peak on map



Step 3: Add signals together and remove filter response

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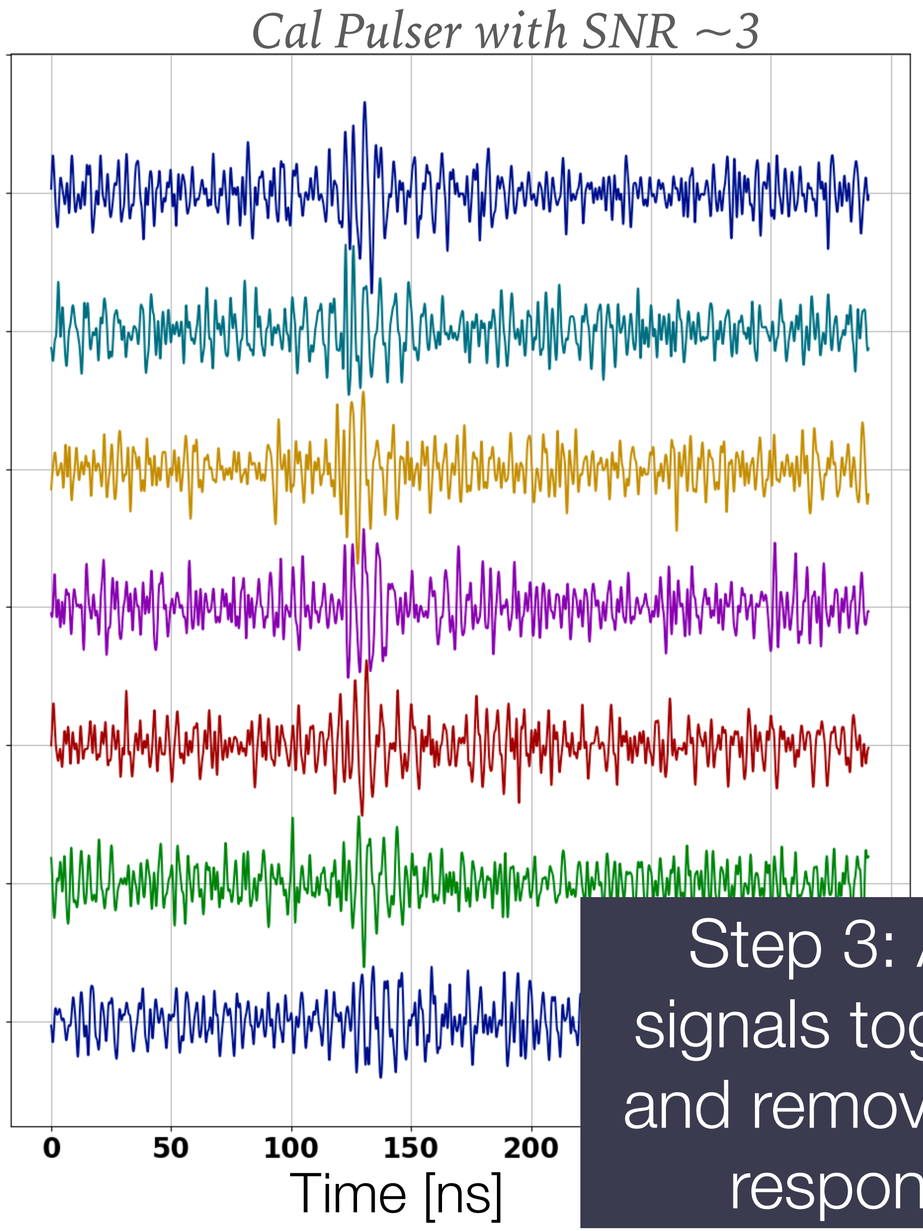

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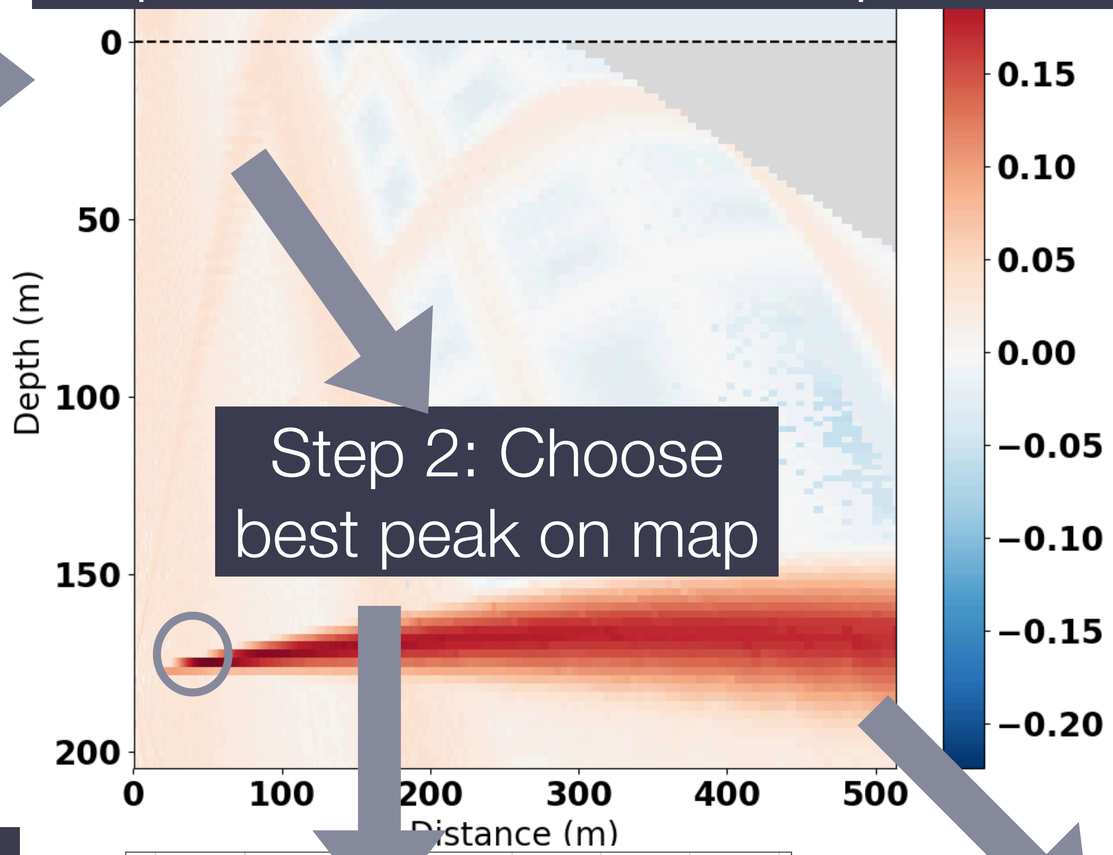

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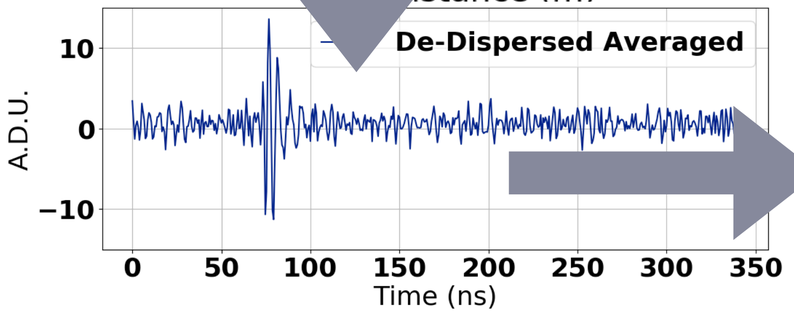
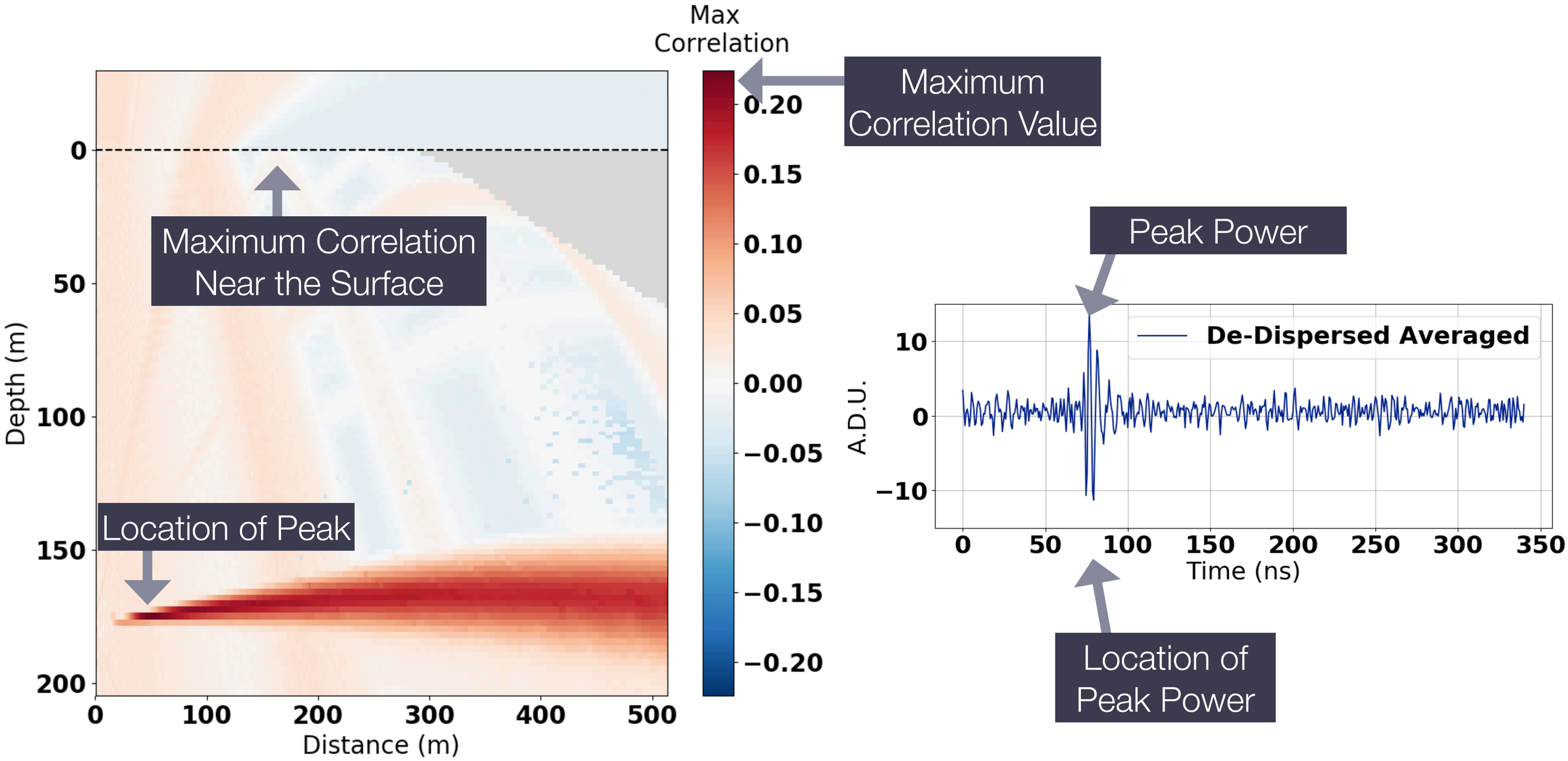
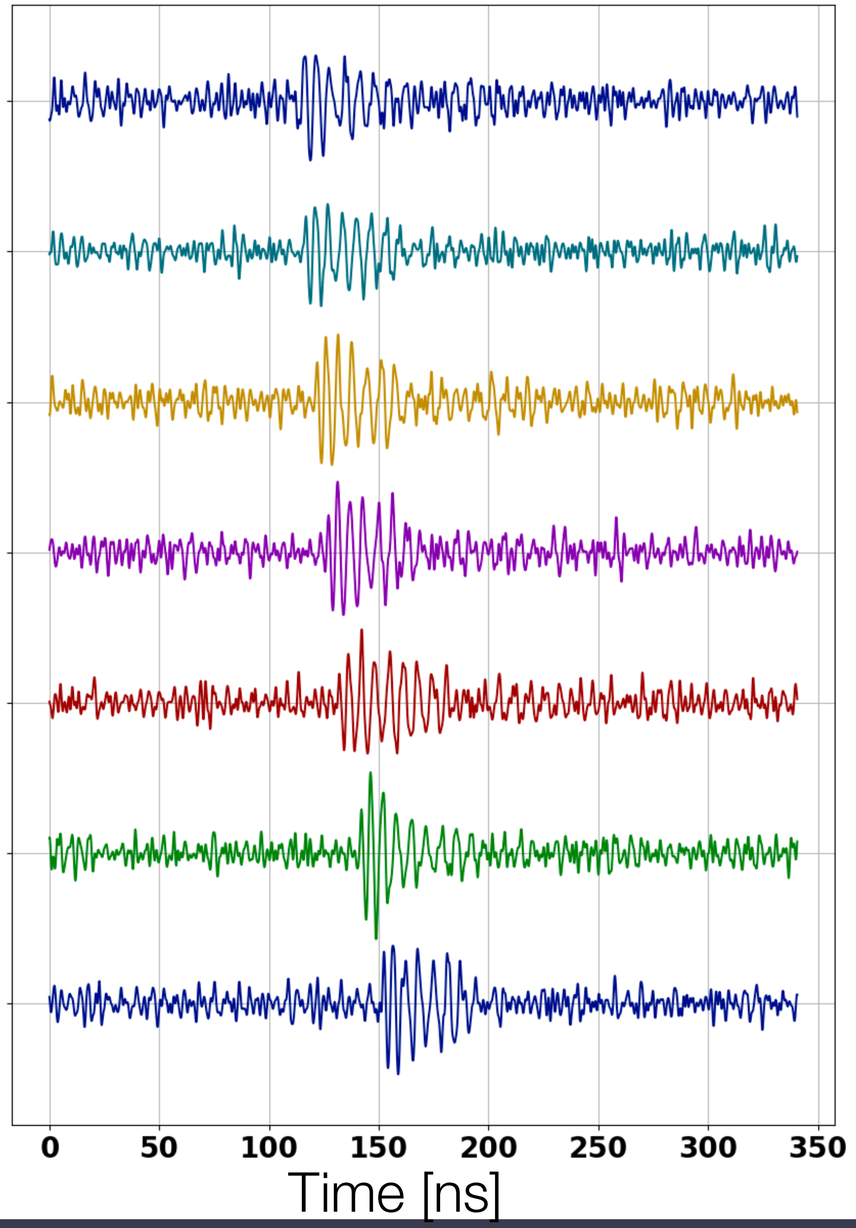


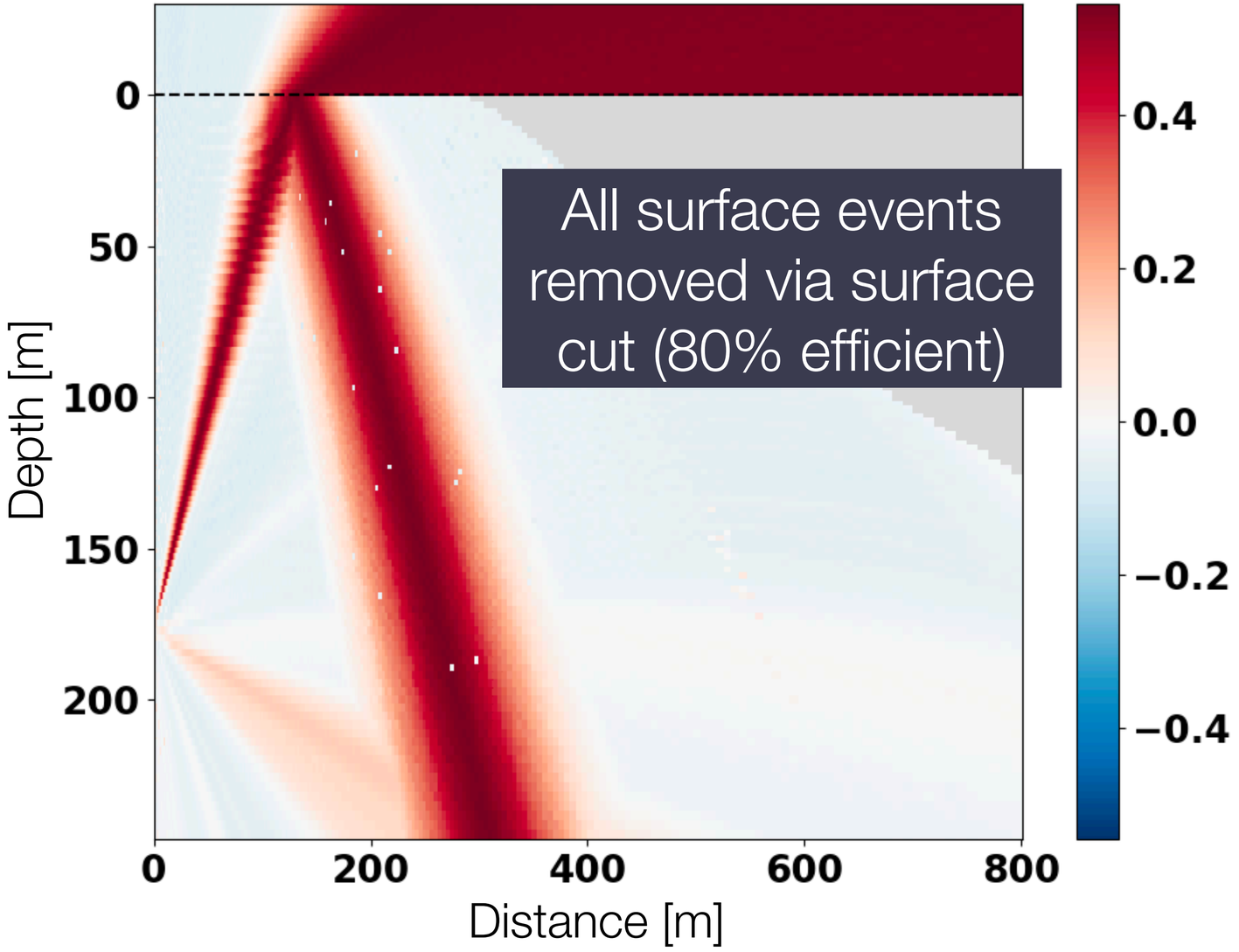
Step 4: calculate analysis variables

Example Analysis Variables



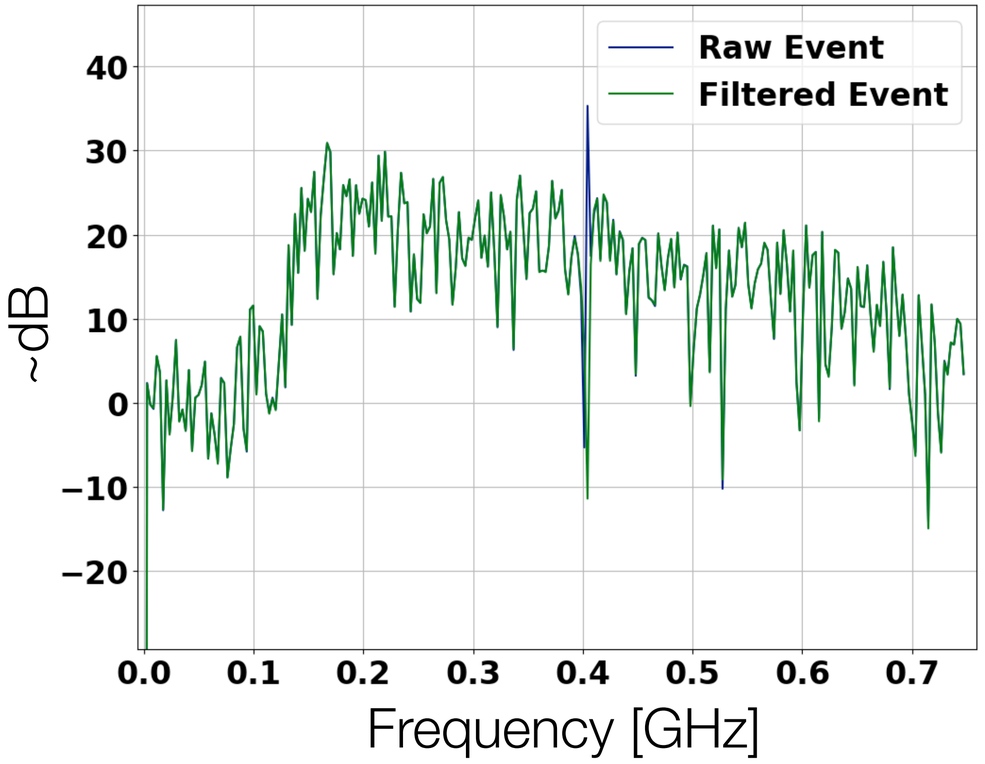
Surface Backgrounds: Cosmic Rays and Anthropogenic Events

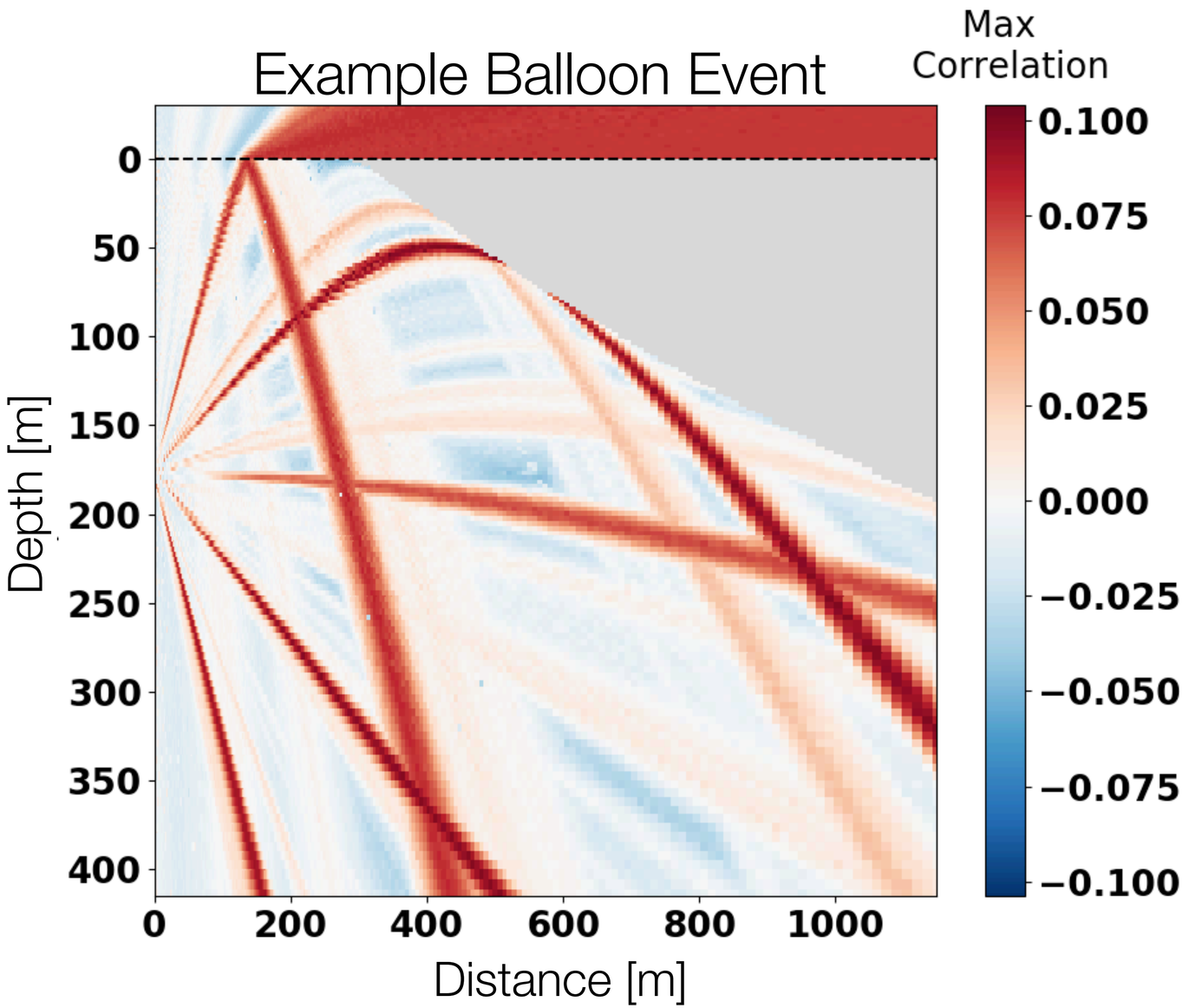




Surface Backgrounds: Continuous Wave (CW) Signals

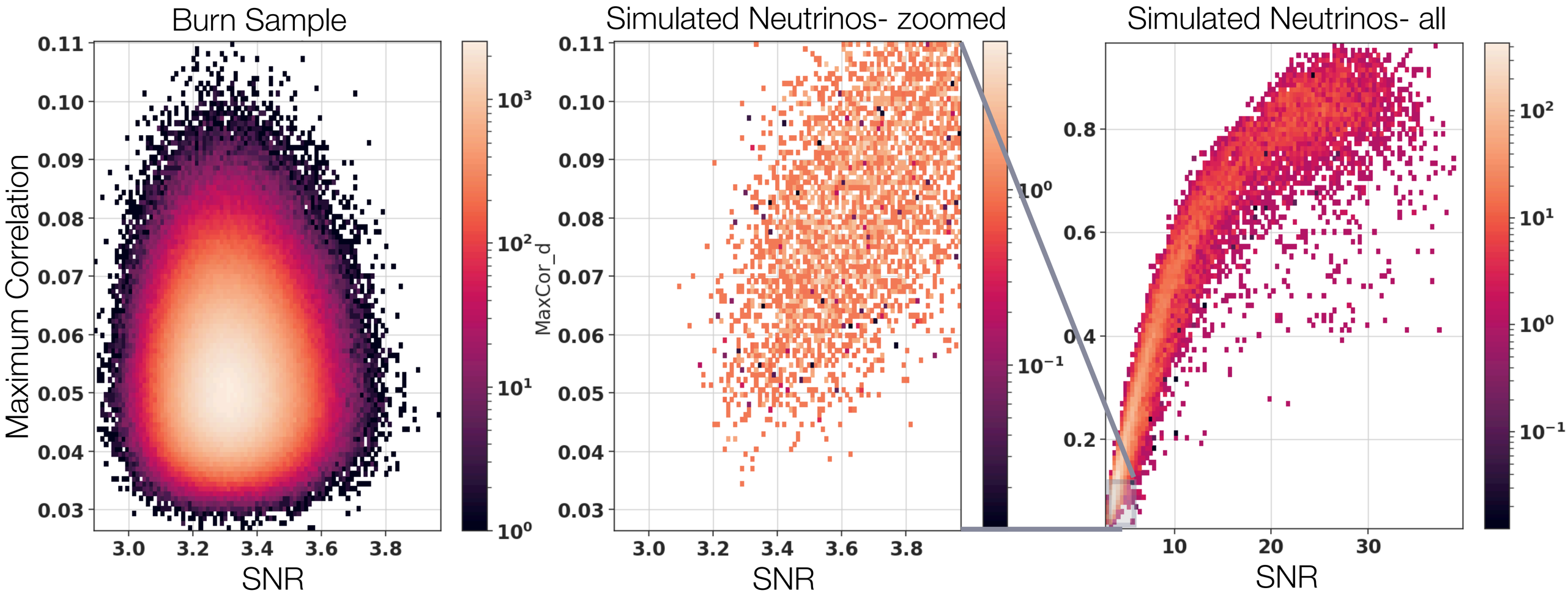
- CW signals readily identified in frequency domain
- Filter allows CW events to remain in burn sample





What's left in the burn sample?

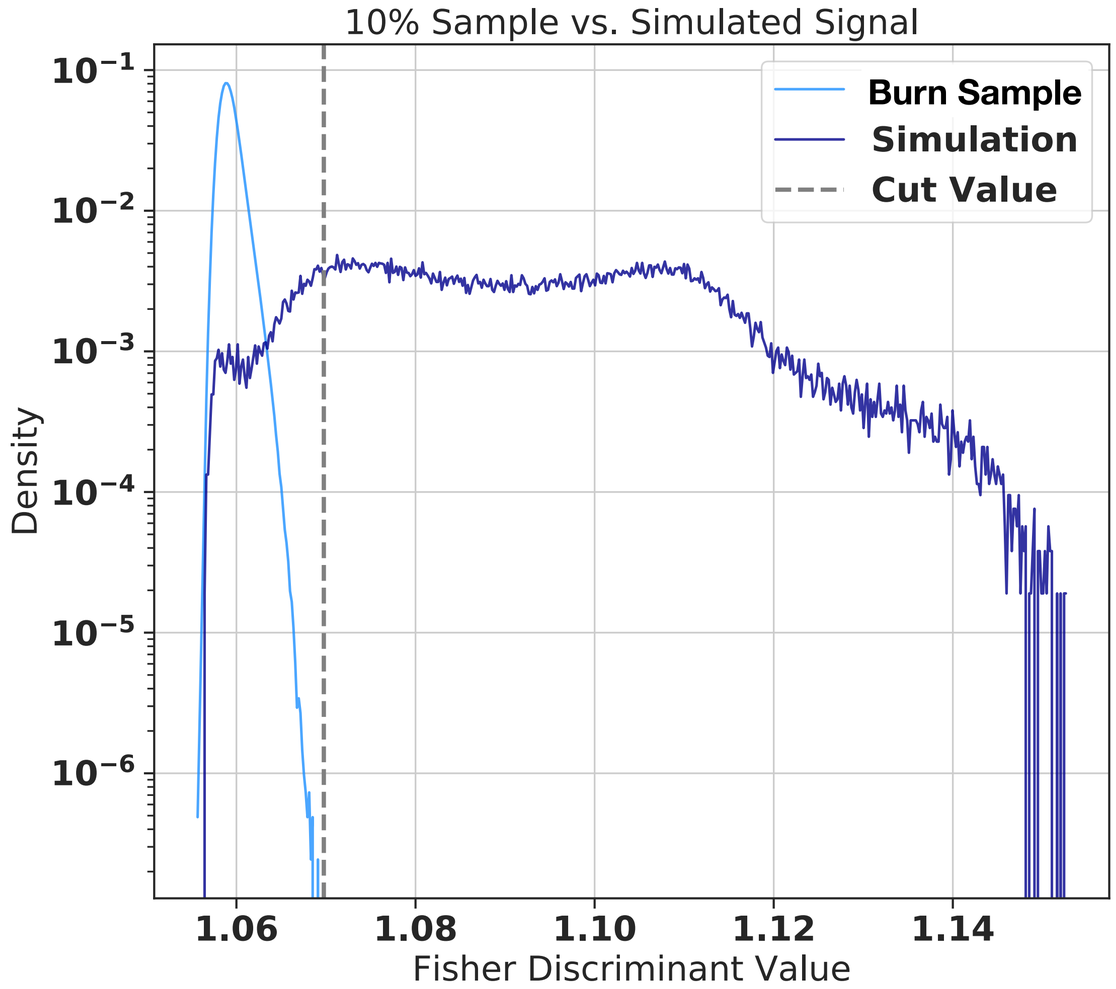
- After removing surface events, the remaining burn sample looks like a thermal noise distribution- very different from simulated neutrinos!
- We have many analysis variables; how can we best combine them?

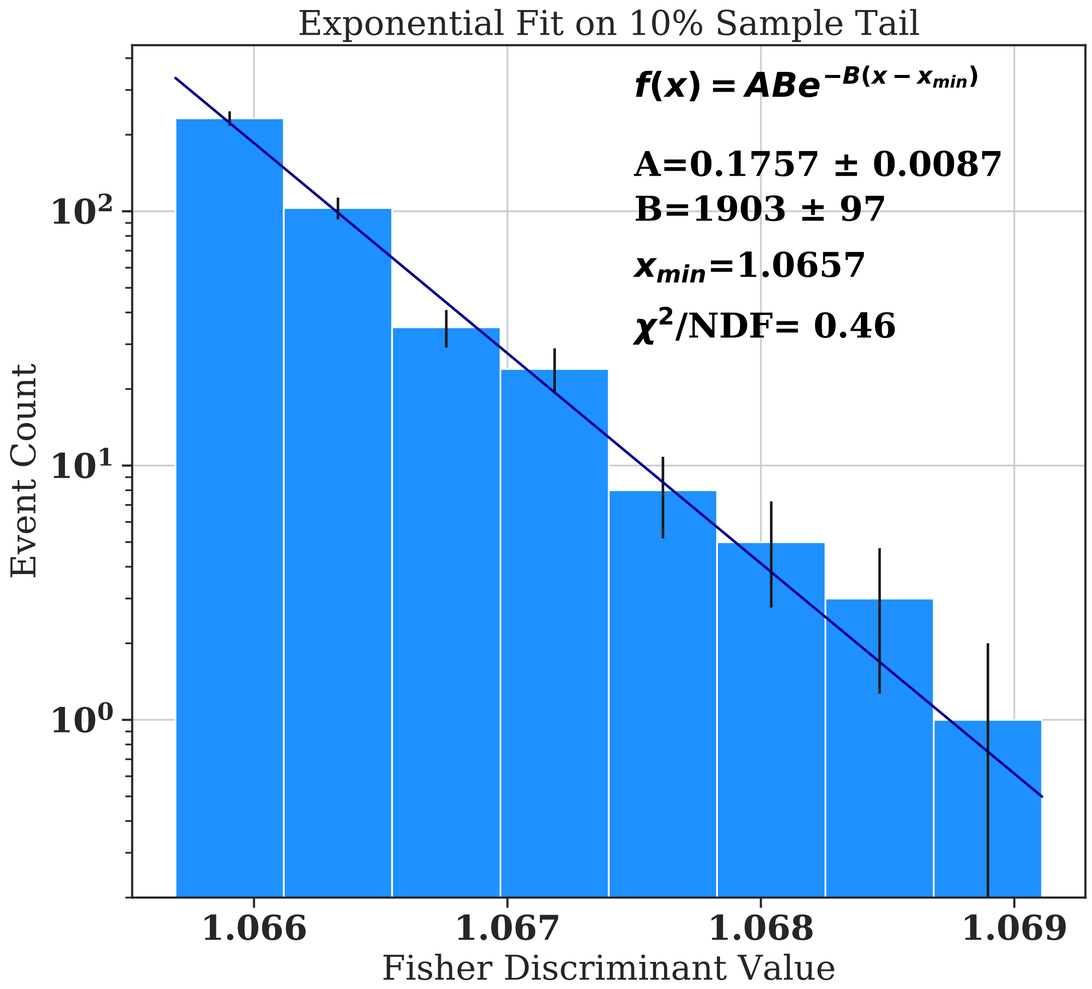


Separating Thermal Noise from Signal: Fisher Discriminant

- A Fisher Discriminant converts many variables into one discriminant coordinate

- By fitting the tail to an exponential, the expected background can be optimized for best sensitivity

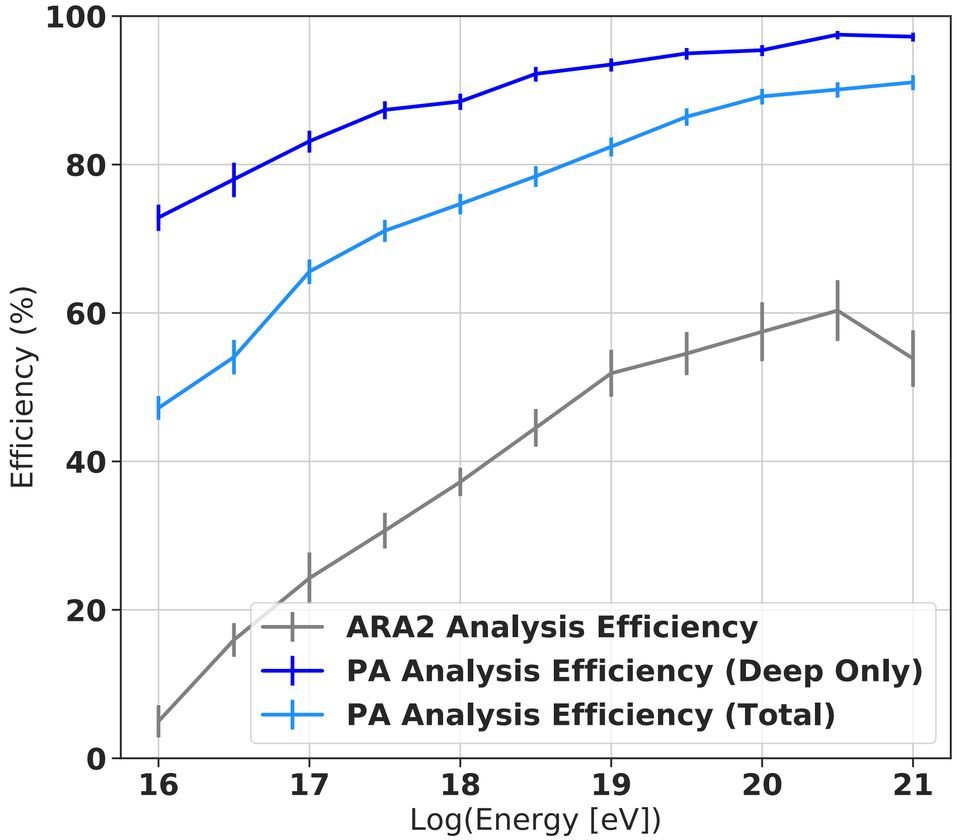


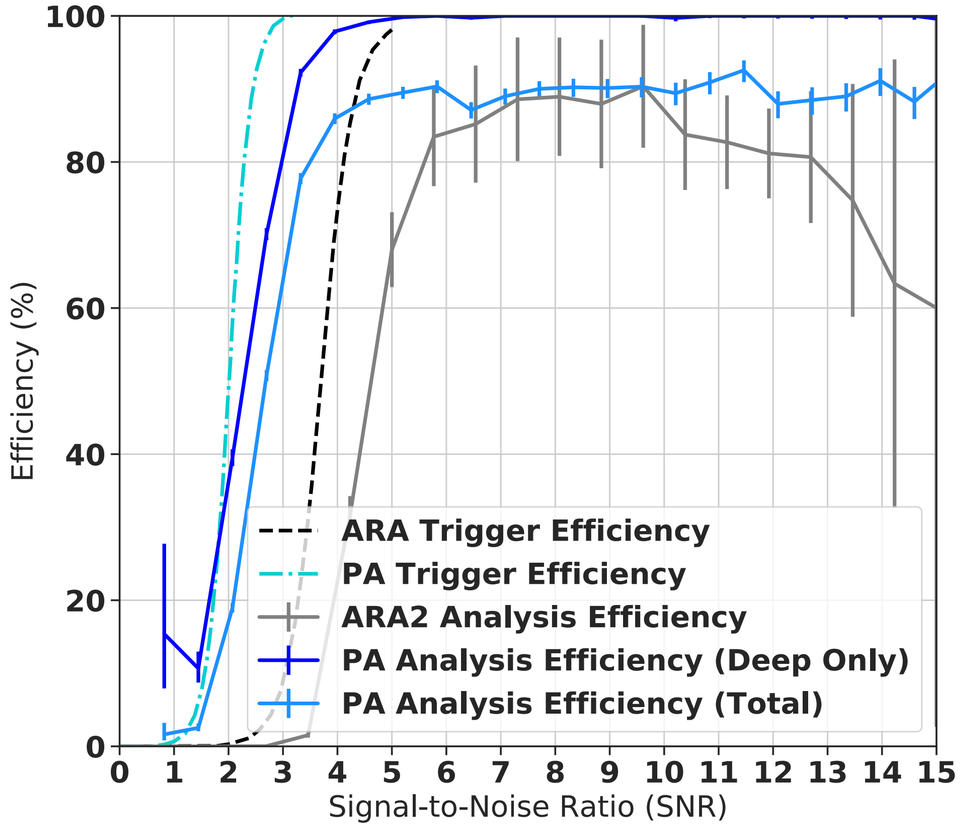


* assuming Kotera mix max flux (JCAP 1010:013,2010)

Results: Analysis Efficiencies

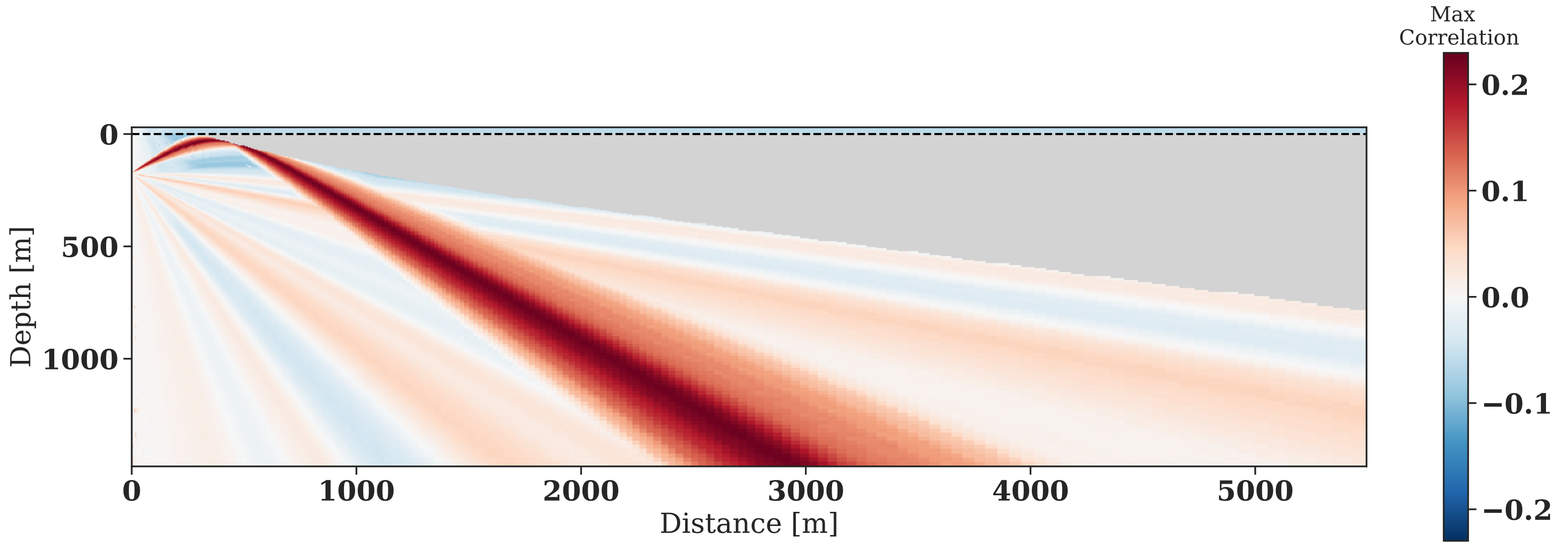
- Final background estimate: $0.10^{+0.06}_{-0.04}$ Efficiency: 68^{+5}_{-3} % *
- **Efficient in analysis on events that the traditional ARA trigger cannot see!**
- Better than previous ARA analyses at low energies by a factor of ~10

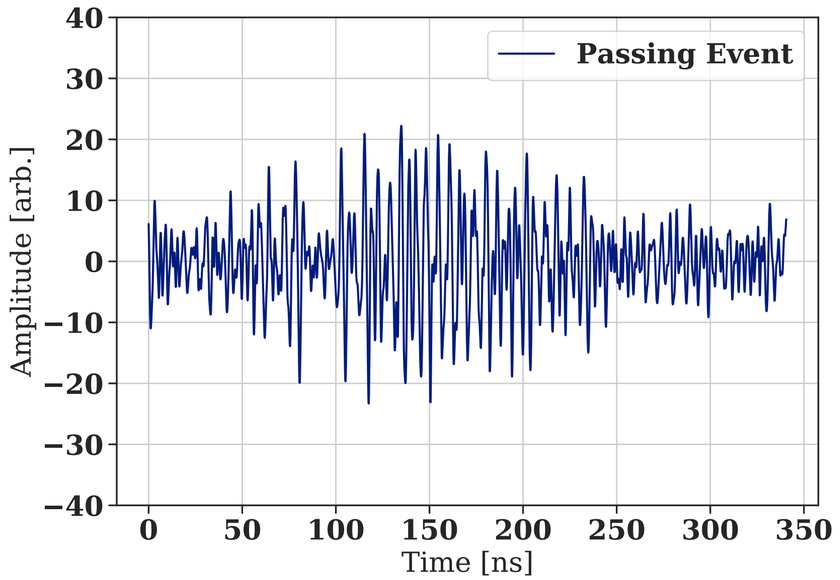


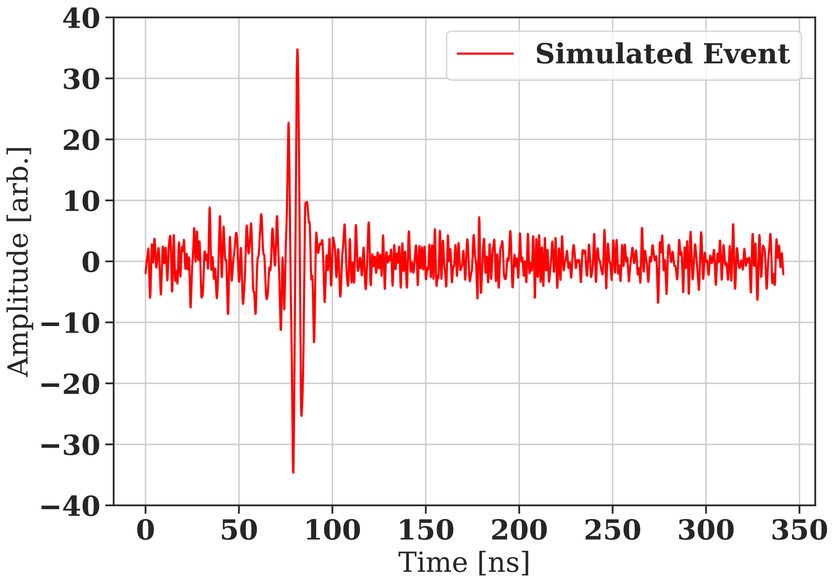


Analysis Results

- One event passed!
- Event does not appear to be thermal, and points > 30 m below the surface
- More study is needed to understand this class of event

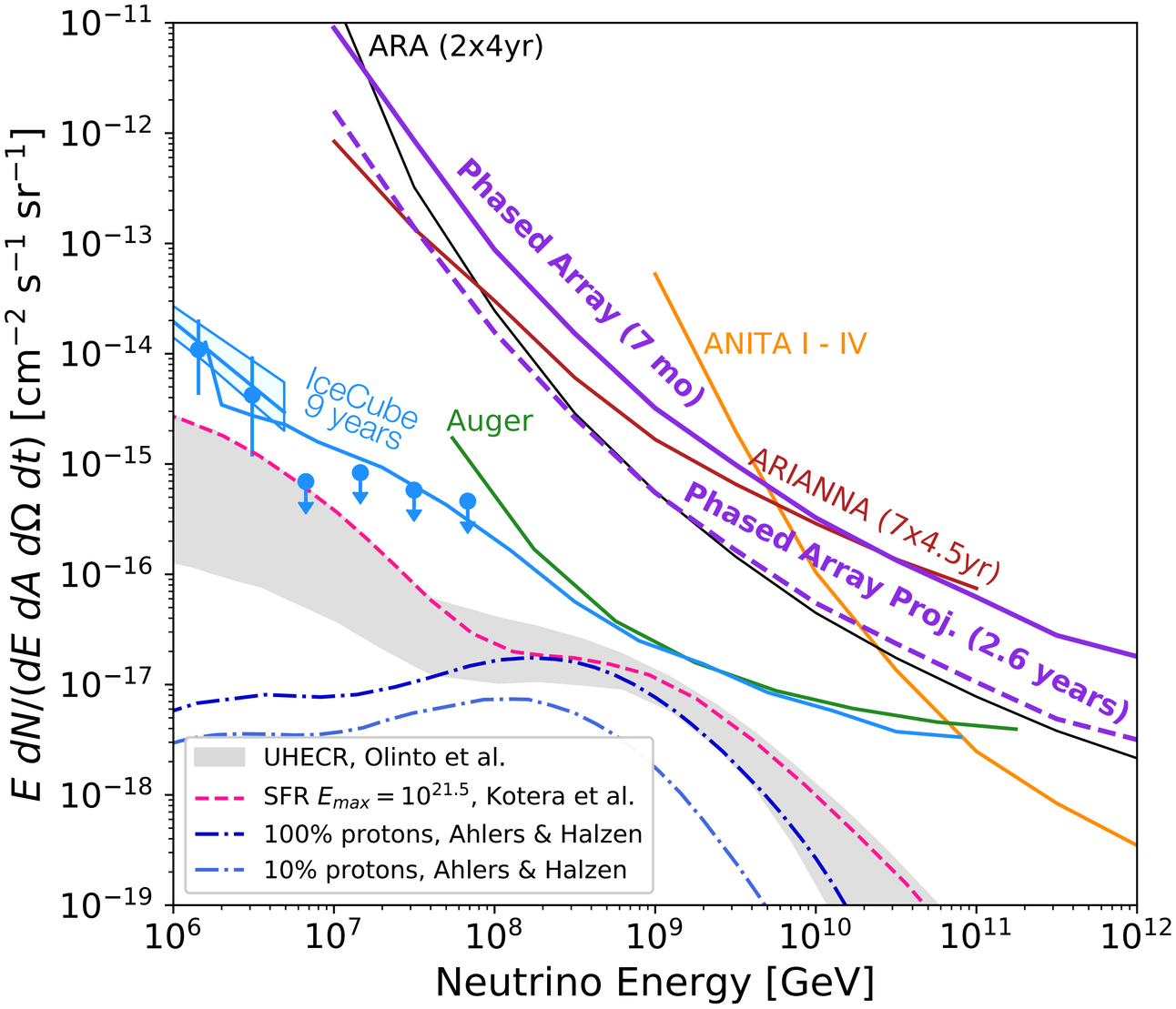






Implications for Future Radio Experiments

- Deep stations with a phased array trigger are capable of performing well through an analysis
- This analysis only used 6 months of data from a prototype station and is competitive with other radio experiments!
- Understanding the passing event is important for any future radio detector, regardless of station configuration (unless you want to reject everything near the surface)
- A more targeted analysis strategy could remove the passing event



Conclusions

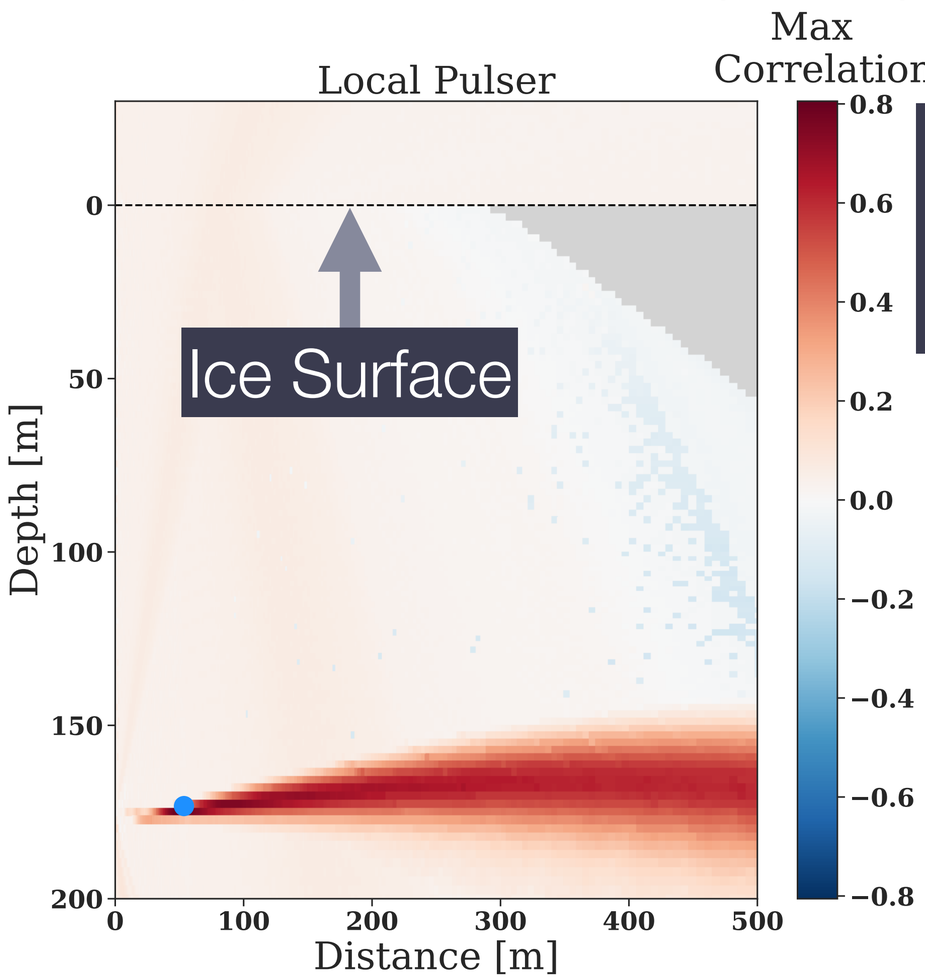
- A phased array trigger is capable of performing well at both the trigger level and at the analysis level

- Future in-ice radio detection experiments should consider implementing a phased array trigger too!

Backup

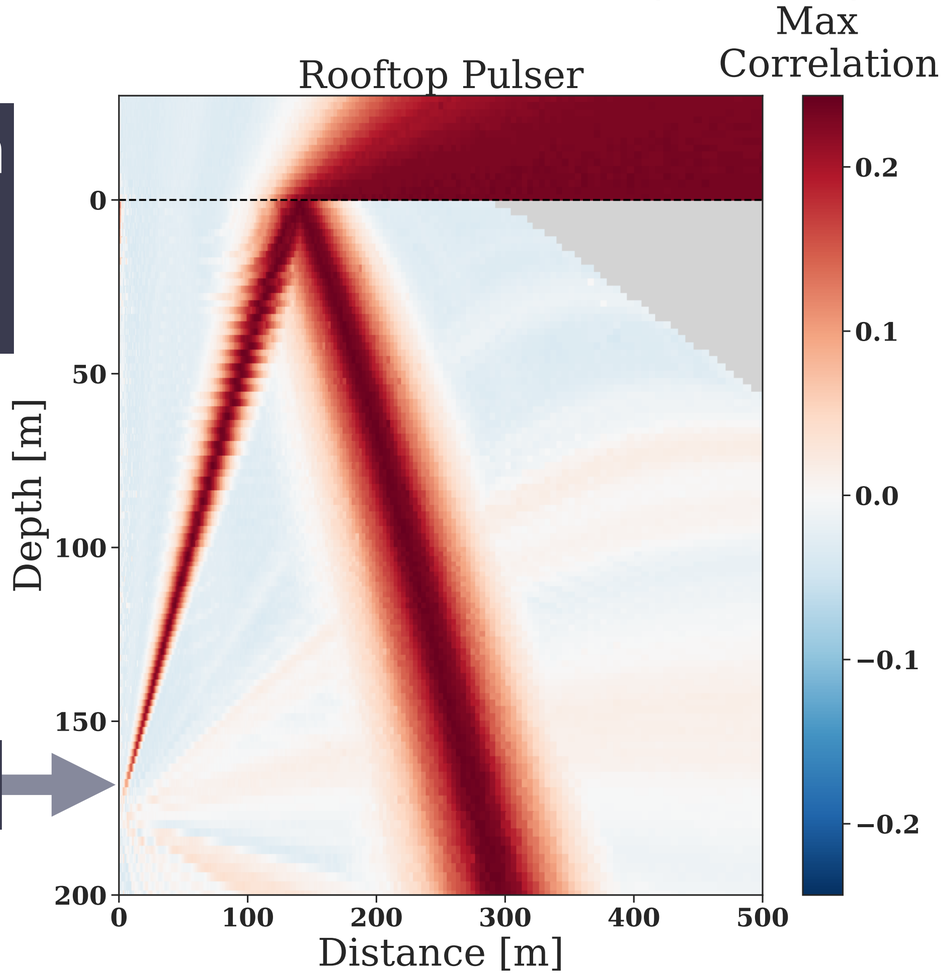
Correlation maps with a one-dimensional array

- The phased array is only one-dimensional, so no available azimuthal information
- But, distance and depth of pulse can be reconstructed in a distance/depth map

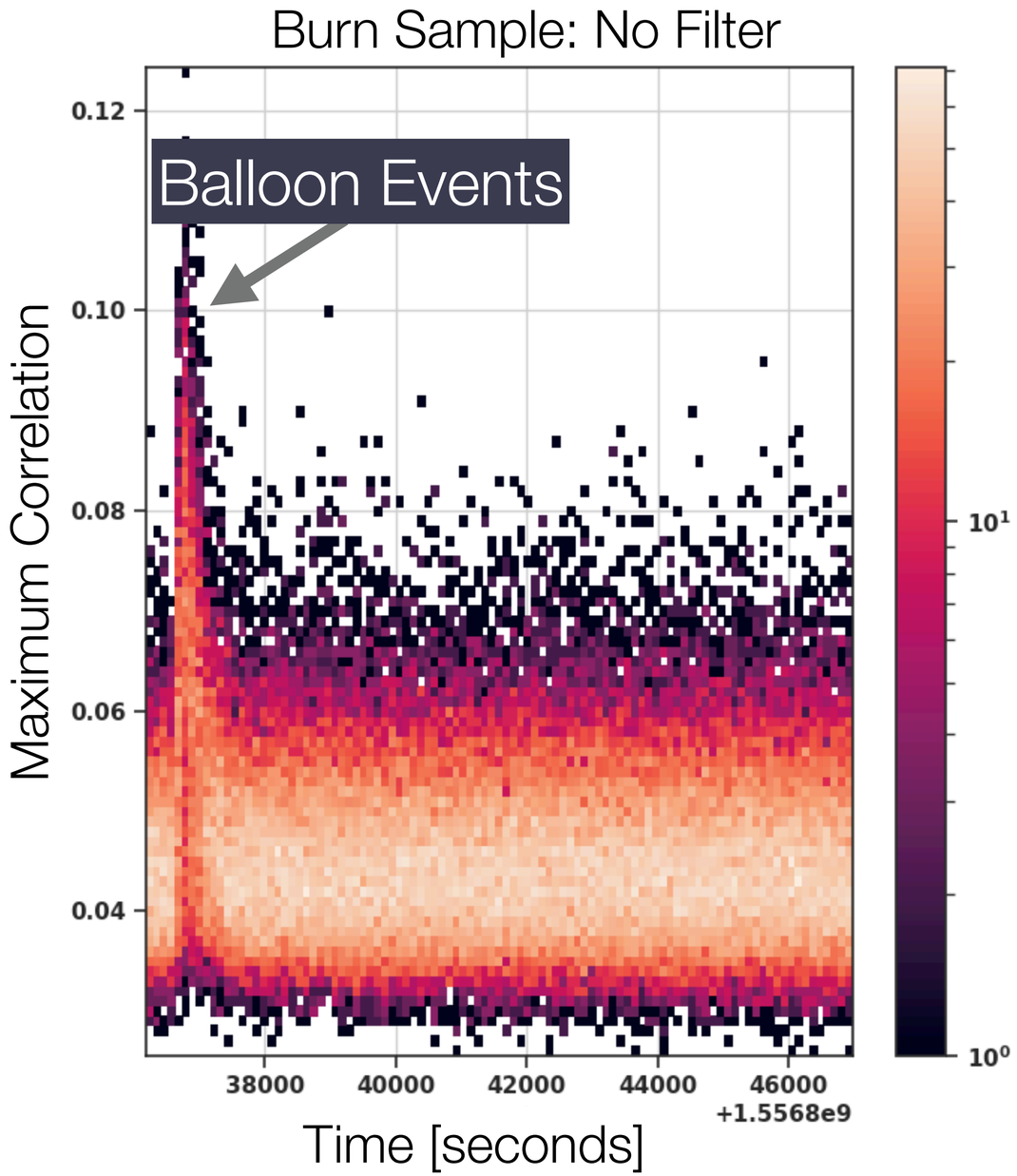


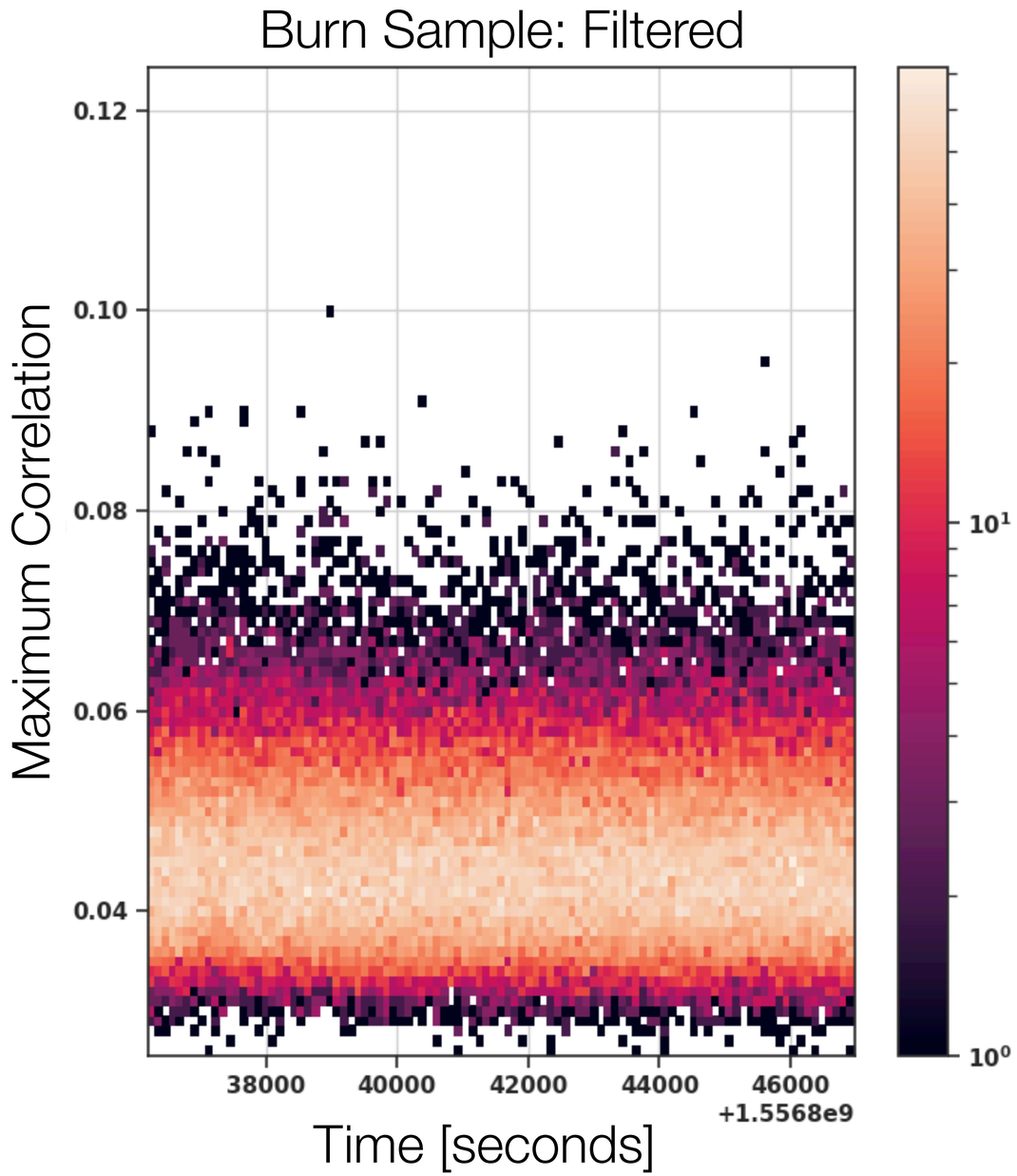
Index of Refraction changes as a function of depth

Detector



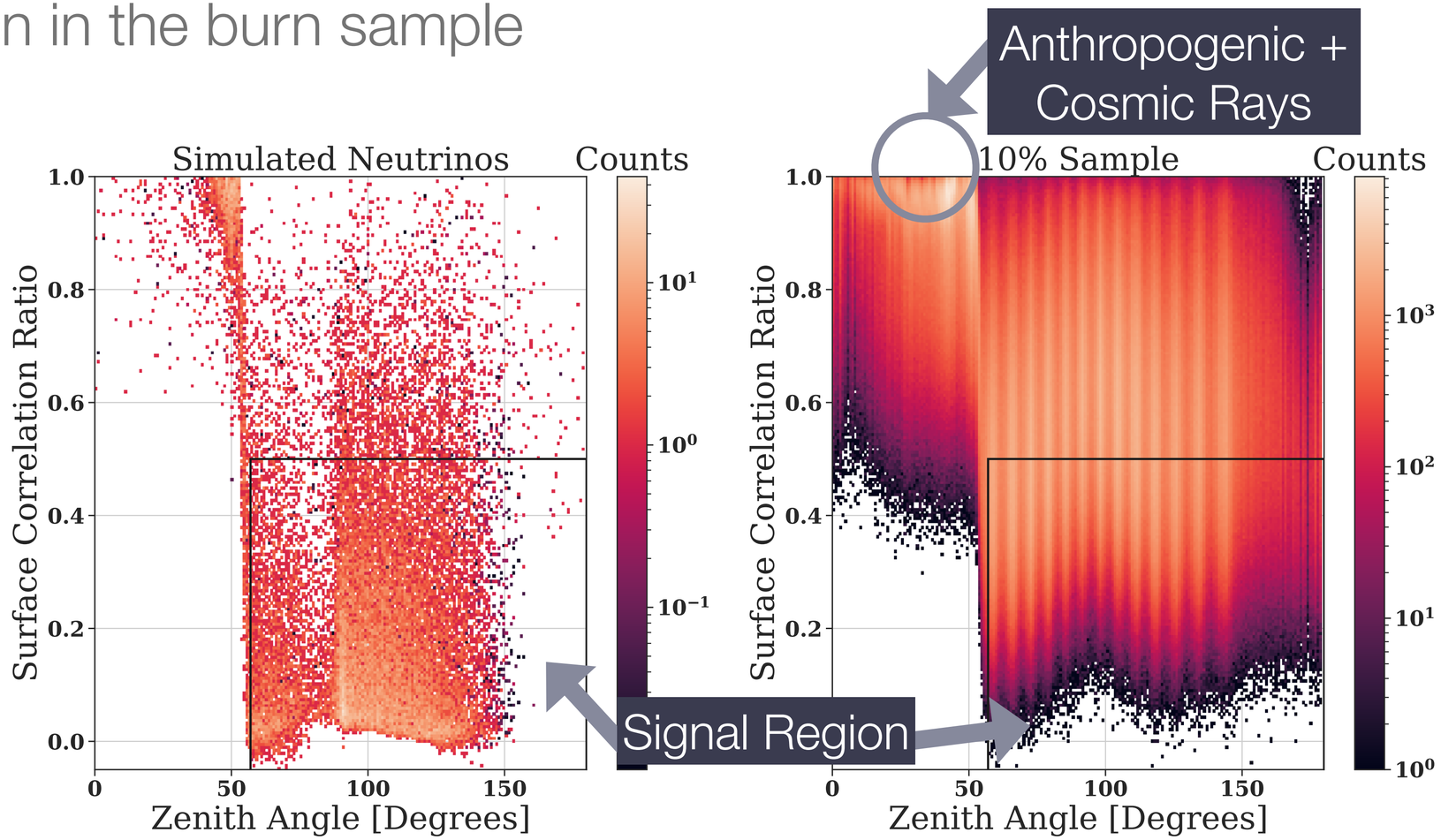
Compare: Before and after CW filter





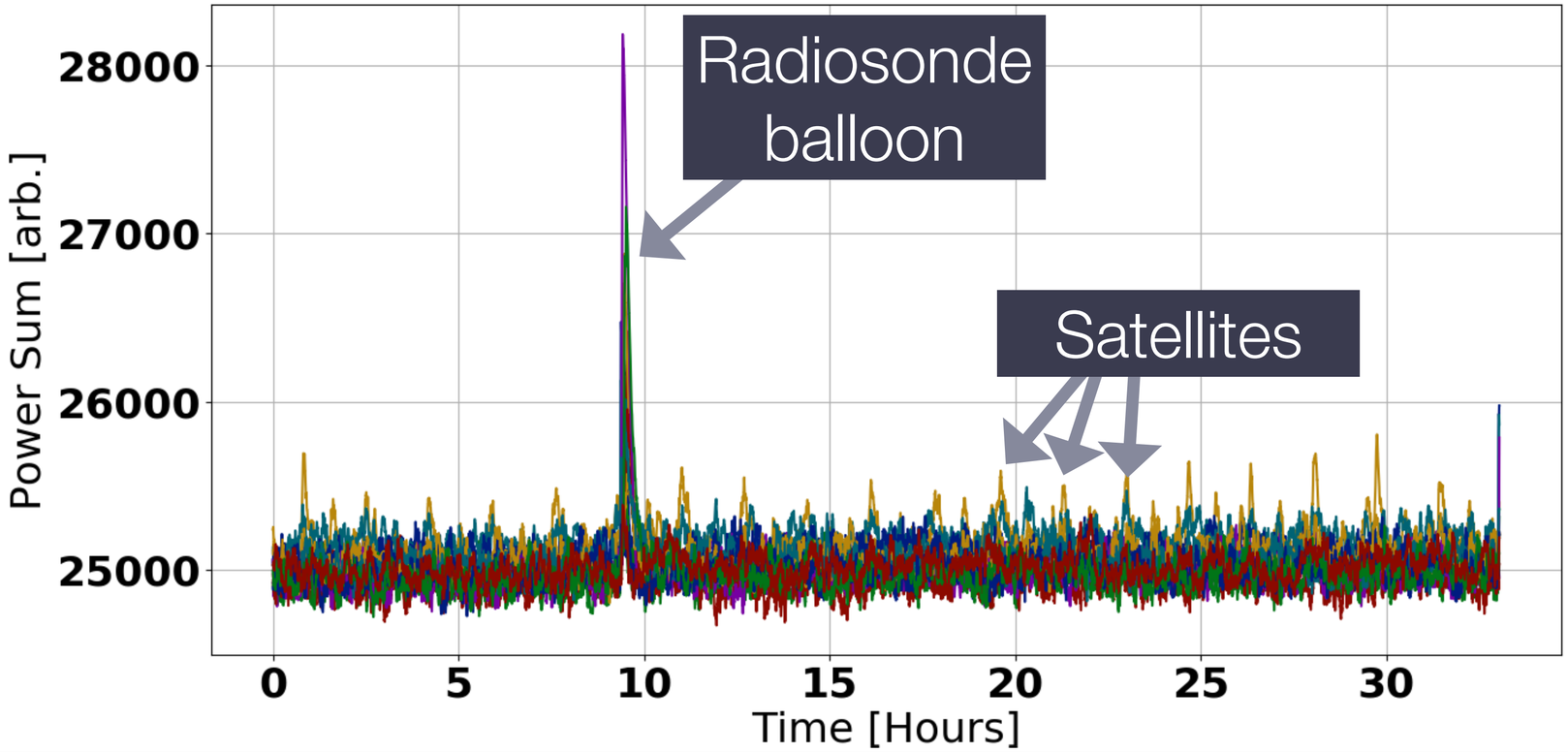
Separating Impulsive Backgrounds

- Both anthropogenic and cosmic ray backgrounds point back to the surface
- We define a deep region with 79% of all simulated neutrinos and 0% of surface events seen in the burn sample

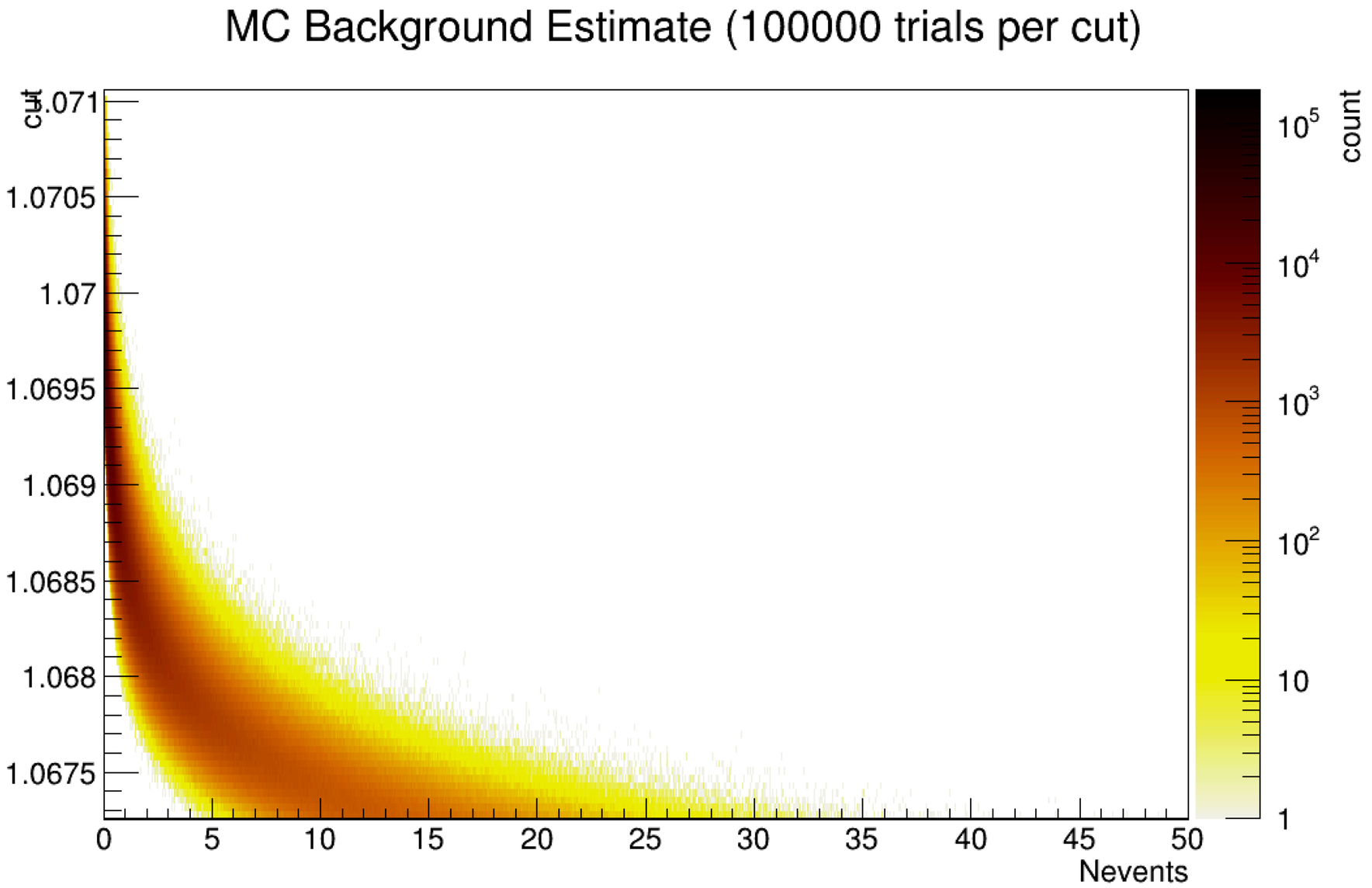


Beam Thresholds Over Time

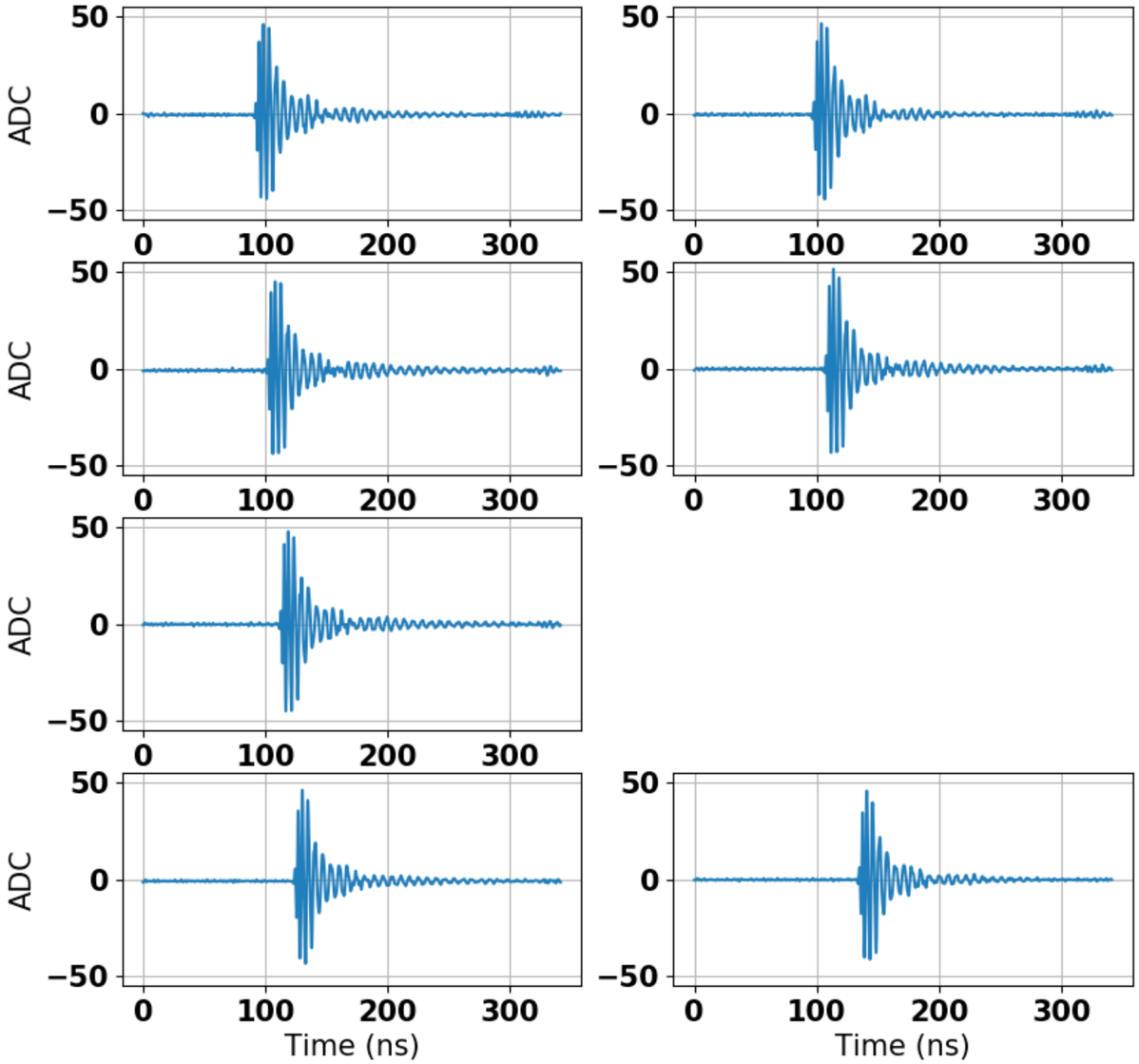
- South Pole Phased Array has 15 beams total
- The threshold on each beam is adjusted in real time to meet a trigger rate of ~0.75 Hz (global trigger rate: 11 Hz)
- Here: spikes are caused by radiosonde balloon launch and weak satellites signals!



CUT VALUE VS. BACKGROUND EVENTS



PHASED ARRAY WAVEFORMS



- What changed?
  - Better digitizers
  - Antenna impedances and impulse responses extremely similar
  - Compact array means antenna angular response less pronounced
- Average time delay error: 30 ps