

Data-driven extraction of the impulse response of a detector and digitised readout system

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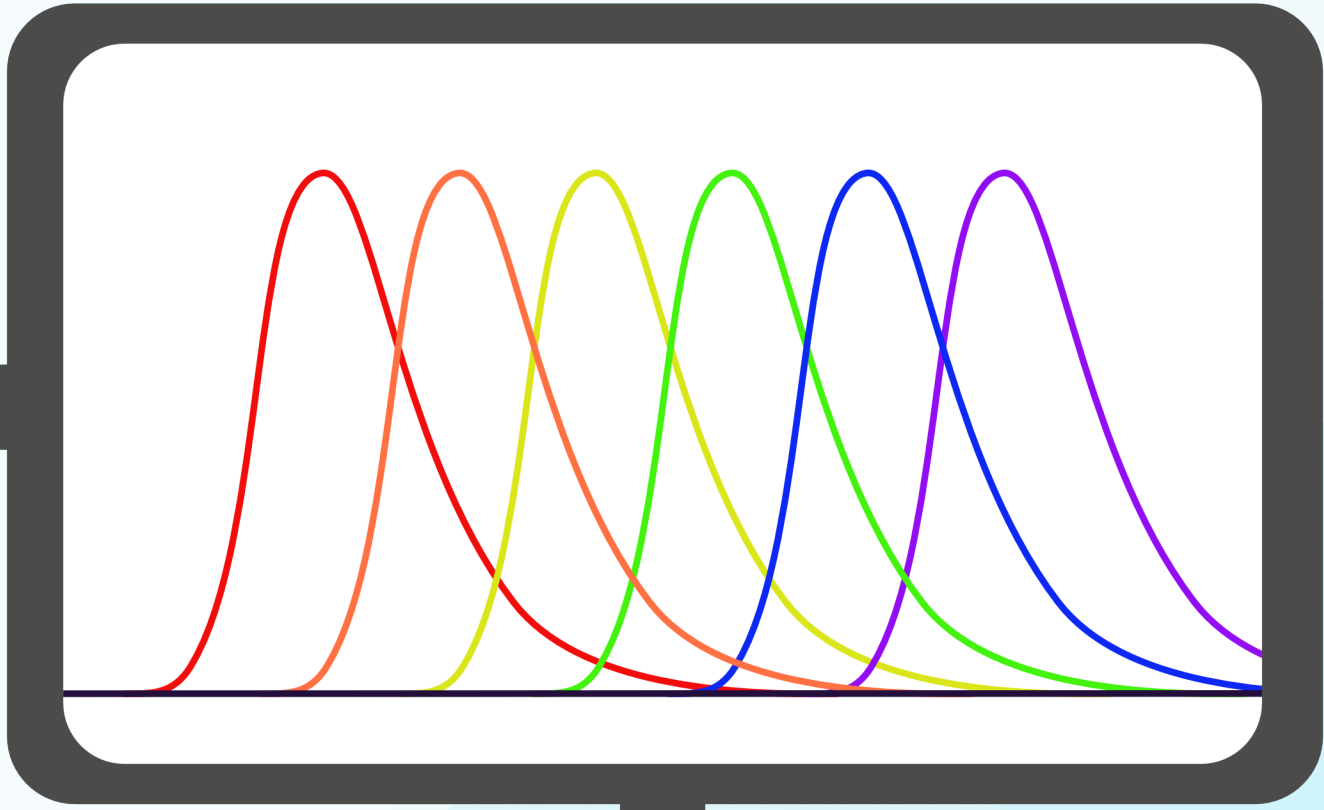
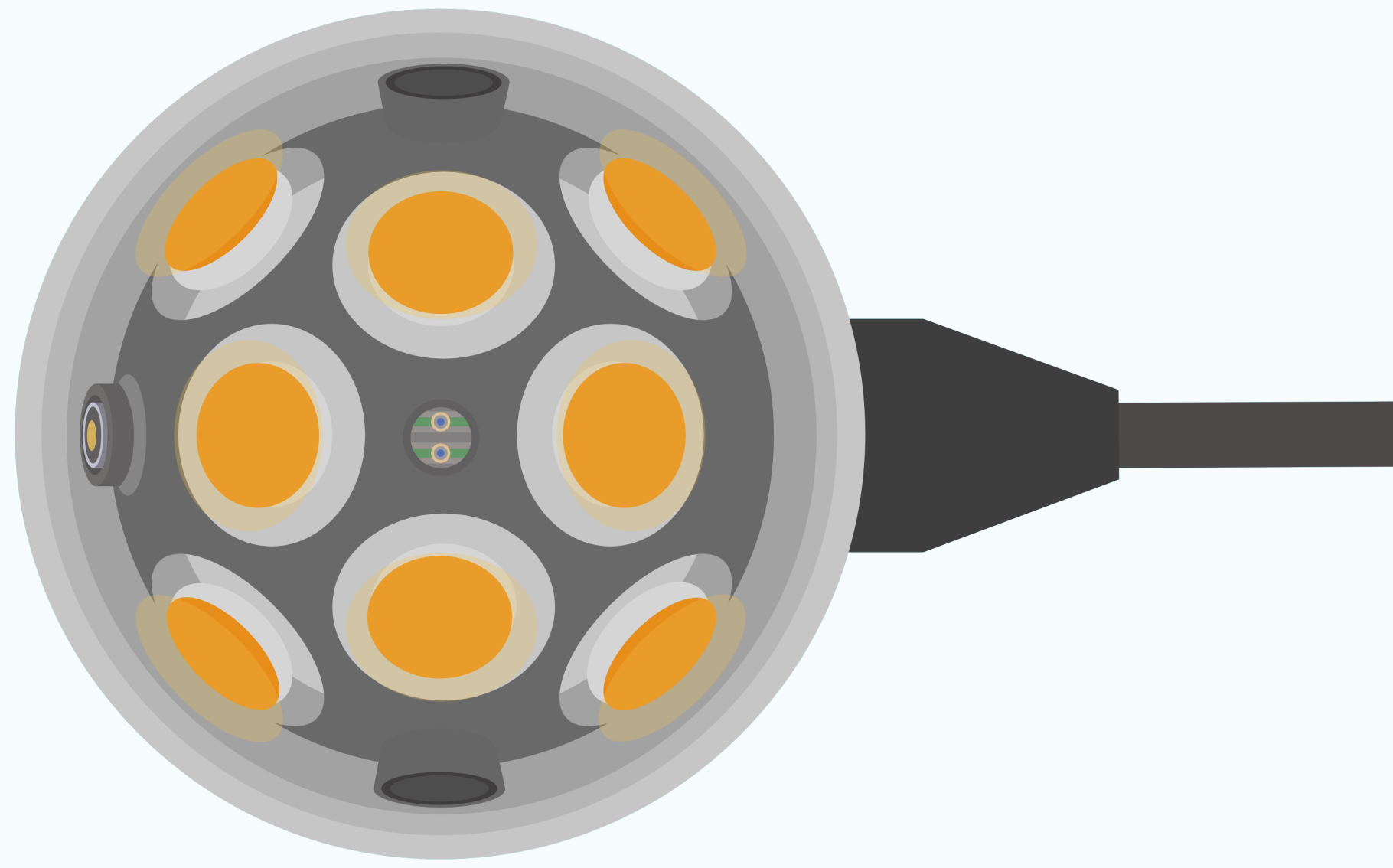
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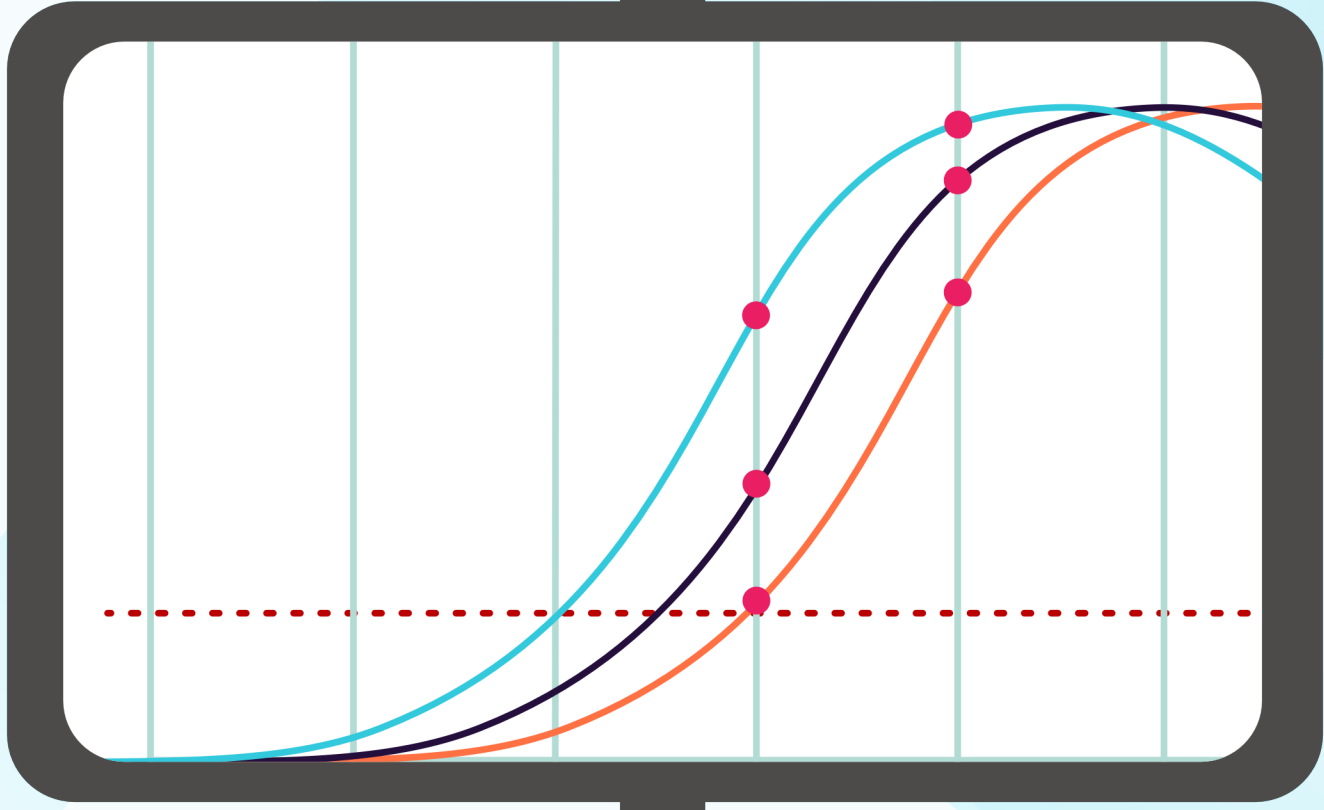
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Why impulse response characterisation matters

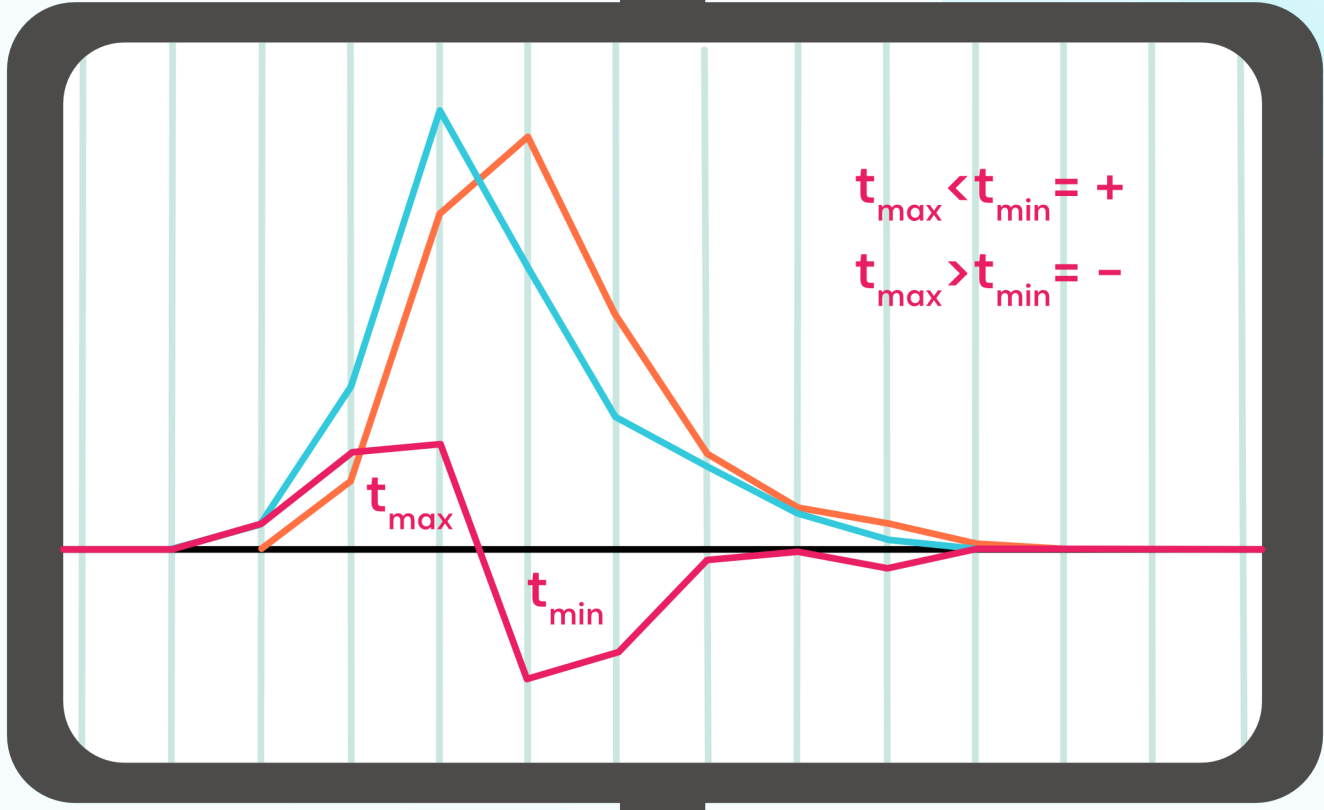
- An impulse response is the signal generated by an instrument in response to a delta signal (e.g. the arrival of a photon).
- To accurately reconstruct photon arrival time and energy, we must know the shape of the impulse response well.
- In a large-volume Cherenkov detector such as P-ONE (the Pacific Ocean Neutrino Experiment), timing resolution directly drives angular reconstruction of neutrino events, allowing better characterisation and location of point sources.
- Current methods of impulse response characterisation require external lab testing and statistical fits, and don't allow us to see the impulse response of the detector during operation.
- This work focusses on a new method that can be deployed in situ.



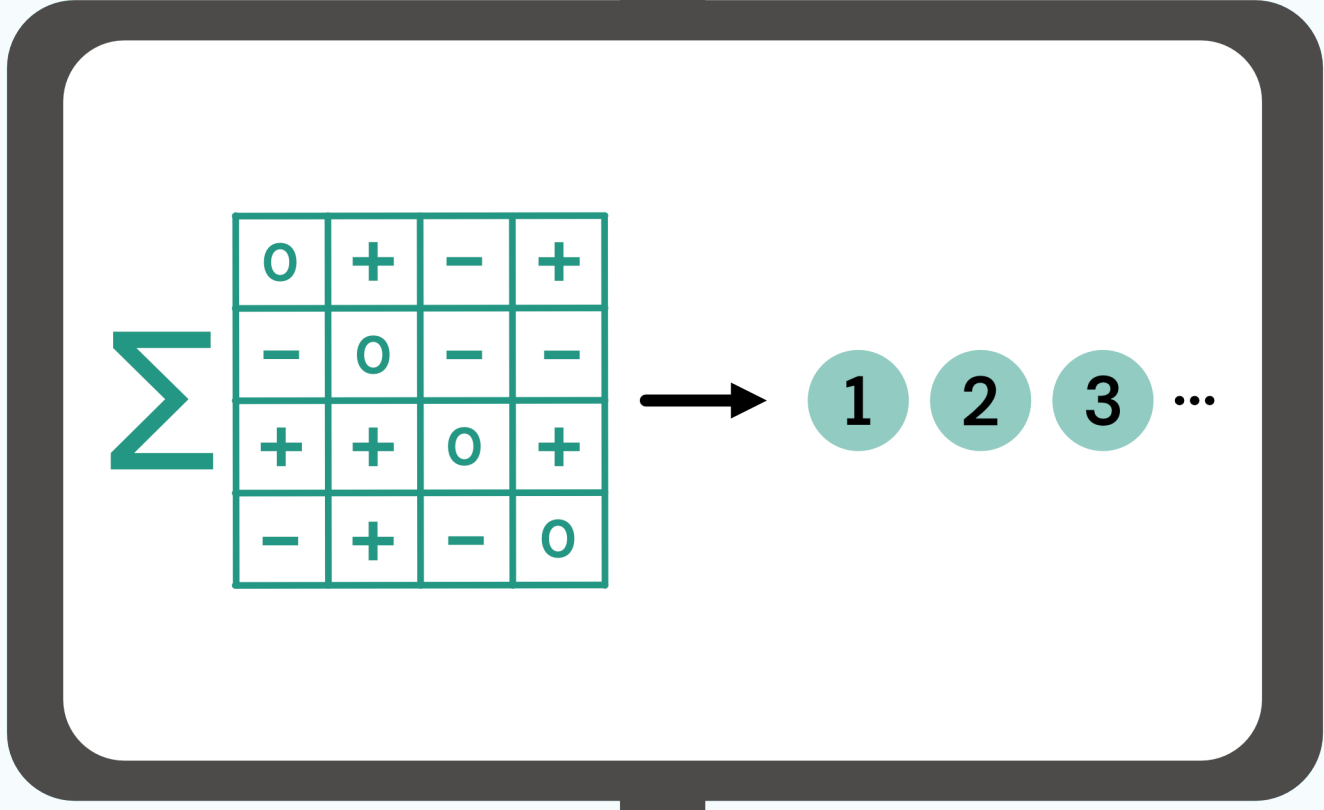
Waveforms arrive at the detector randomly in time. Over a large enough sample of waveforms, we can treat these as arriving uniformly in time.



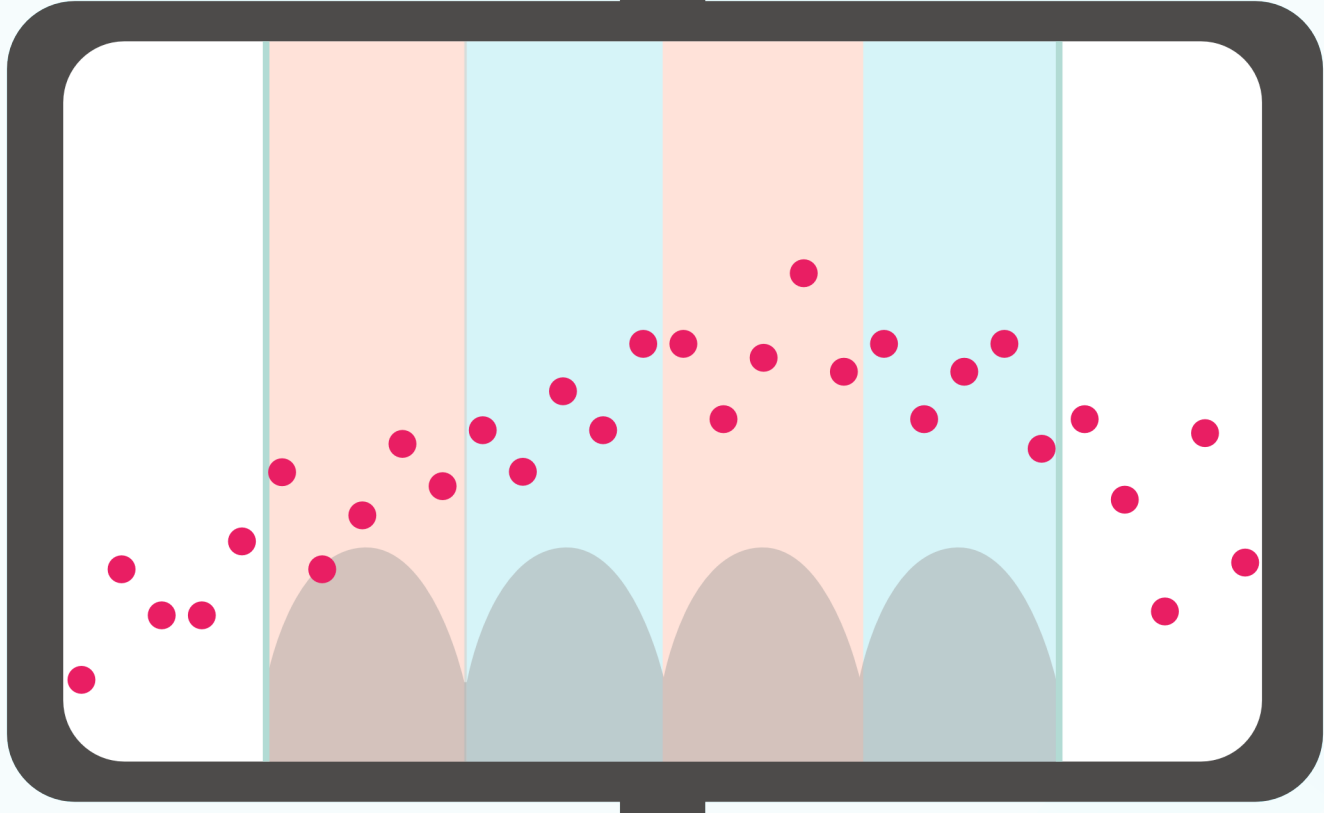
When the waveform amplitude meets a set logical condition (such as a trigger threshold), a set length waveform is recorded. These waveforms will display a sub-sampling jitter, across the sampling period of the digitiser.



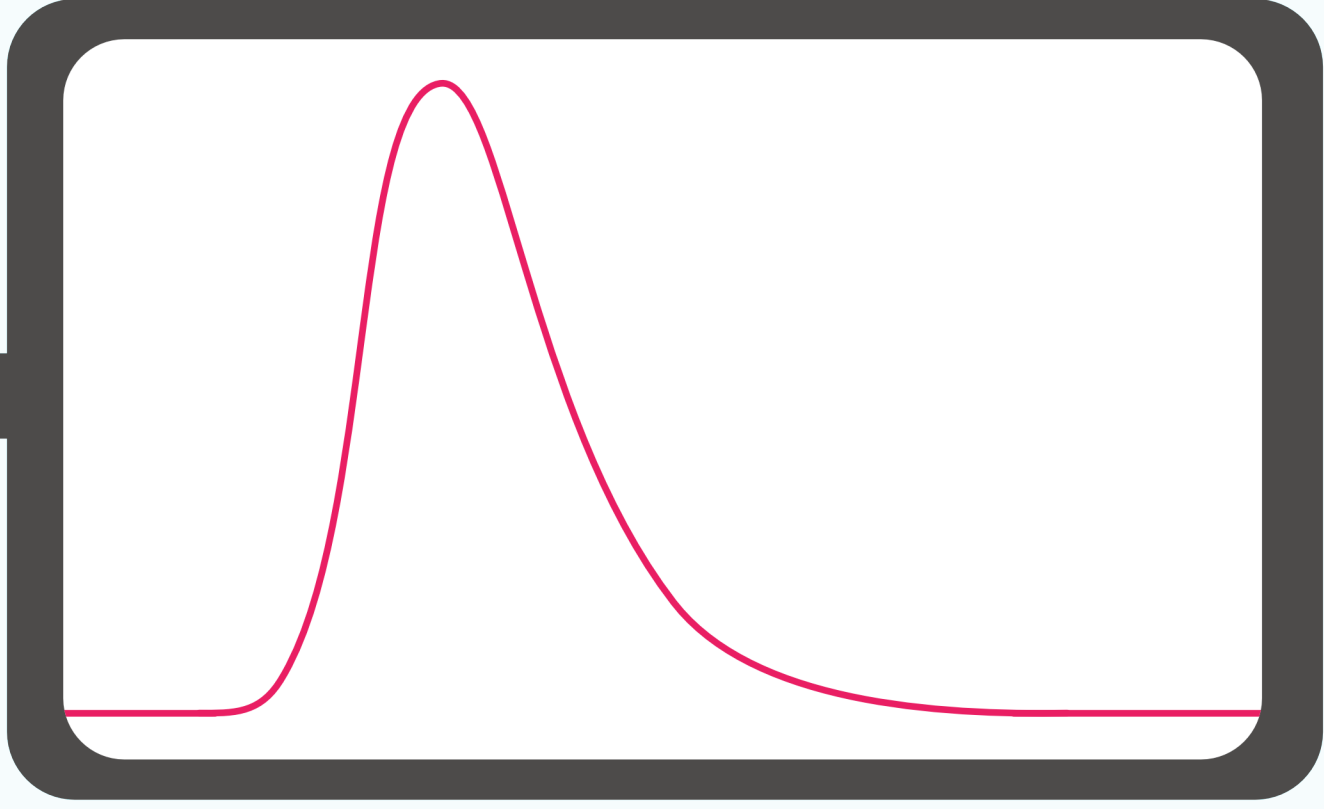
In order to recover sub-sample details from the waveforms, they need to be aligned in time. By comparing pairs of waveforms, and plotting the difference between them we can see which waveform is first.



The ordering of individual waveforms is summed over to produce a ranking of the waveforms in time. They are then reordered according to this.



We bin the reordered waveforms into N bins, where the factor N is multiplicative increase in frequency. We weight the waveforms toward those in the centre to account for uncertainty at the edges.



The bin averages are sliced and combined to produce a single, higher frequency waveform. This impulse response, with sub-sampling digitiser frequency, can be used as a template pulse to identify signals in the data.

Performance with data and simulation

The algorithm successfully reconstructs sub-sampling time details of the impulse response from randomly collected waveforms, validated on both simulated and real detector data.

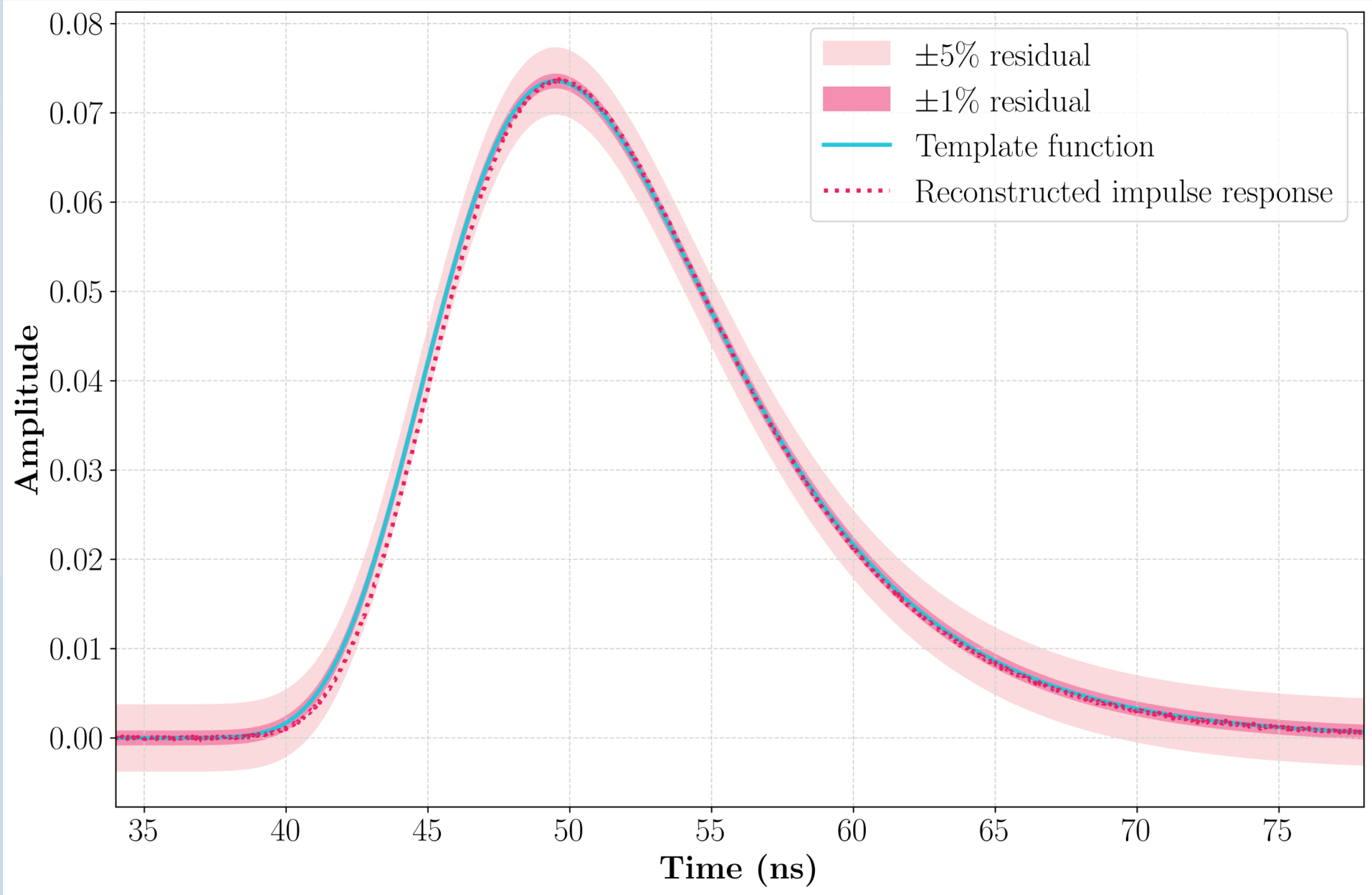


Figure 1: Reconstructed impulse response (pink) compared with template function used to generate the simulated sample. We can see that the reconstructed pulse is fully within the 5% residual region.

To test this on real data, we took a high frequency sample of waveforms, then downsampled them to create artificially low frequency waveforms. The algorithm was then applied to this set of downsampled waveforms, and we can compare the reconstructed impulse response with the original high frequency waveform.

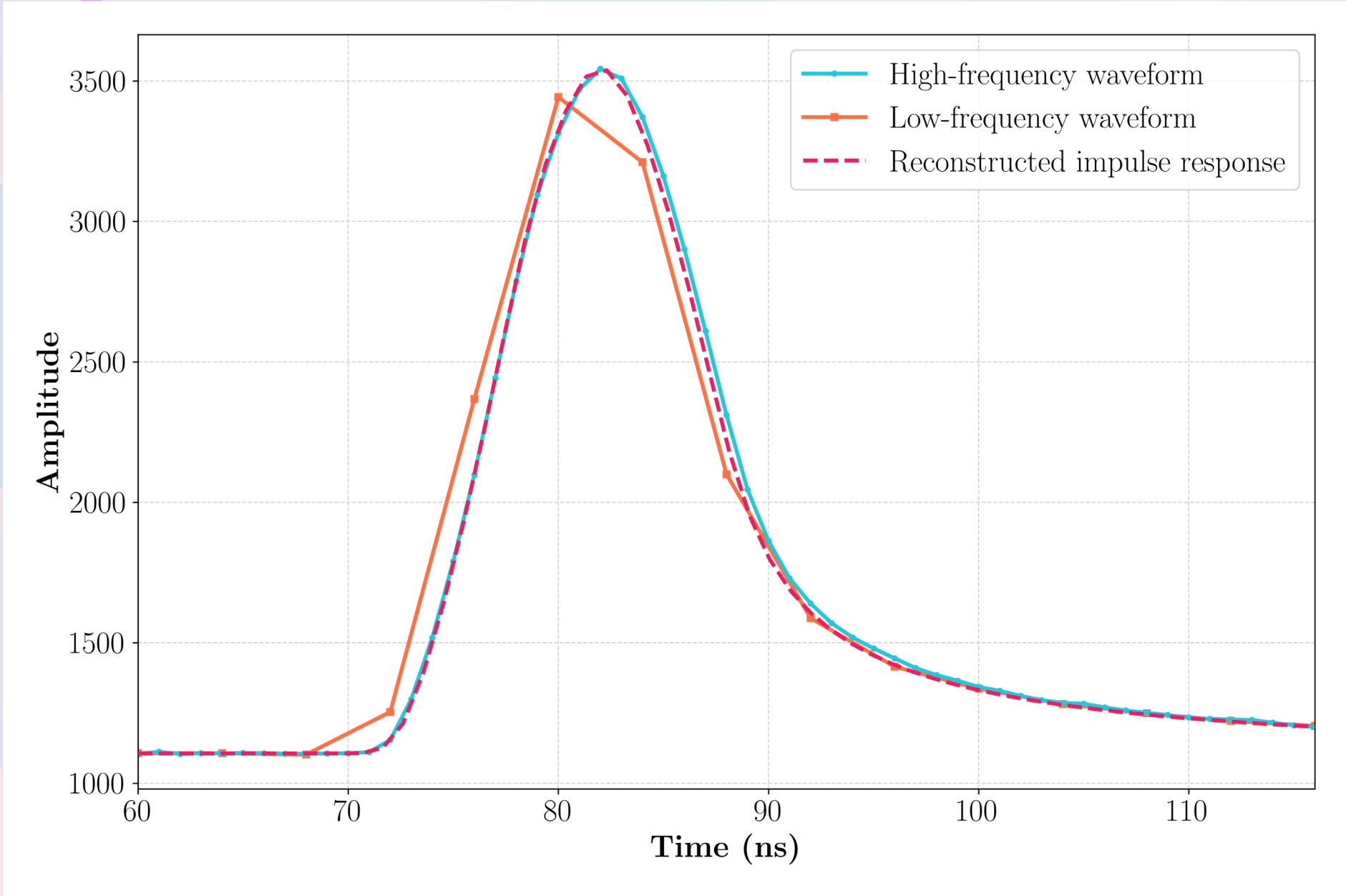


Figure 2: The algorithm applied to real pulses. The blue line is a high-frequency version of the original waveform, and the orange points show the lower frequency version, which the algorithm is applied to to form the pink reconstructed impulse response.

Current work is focused on testing across a range of pulse shapes to demonstrate detector-agnostic behaviour, and on deployment with in-situ detector data. Key factors affecting performance include interpolation factor, original sampling frequency, and pulse gradient.

This method has broad applicability, across any detector with a pulse-based signal system, in many different areas of particle physics. Its novel approach does not require an external measurement of the impulse shape, allowing it to be used on the detector in situ, and provide a window into how detector response evolves over time and with changing operating conditions.

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