COTI and Deconvolution Waveform Reconstruction in JUNO

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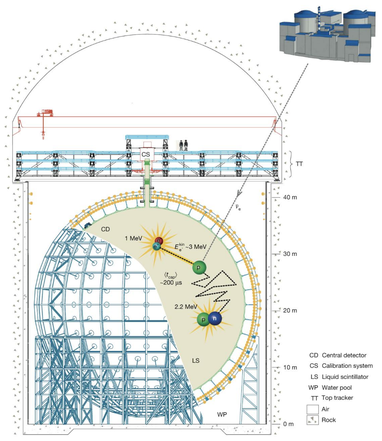
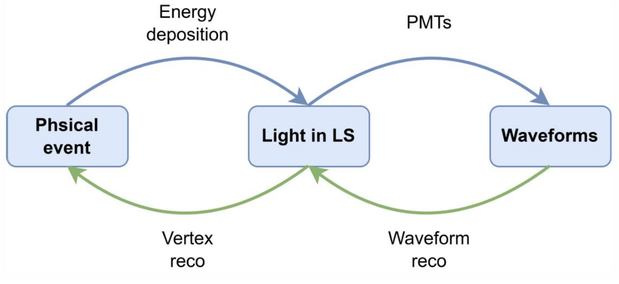
JUNO Experiment

- The Jiangmen Underground Neutrino Observatory (JUNO) [1] is a reactor antineutrino detector currently operating in the south of China.
- It aims to resolve the NMO from the reactor-antineutrino spectrum at a 52.5 km baseline.
- Central detector has 20 ktons of liquid scintilator in a spherical acrylic vessel with d = 35.4 m.
- 17596 20-inch PMTs with full waveform readout provide the charge and time information.
- A good energy resolution (~3.4% in the first result [1]) is essential to the precision of the measurements, which imposes high requirements on the waveform reconstruction.



Waveform Reconstruction

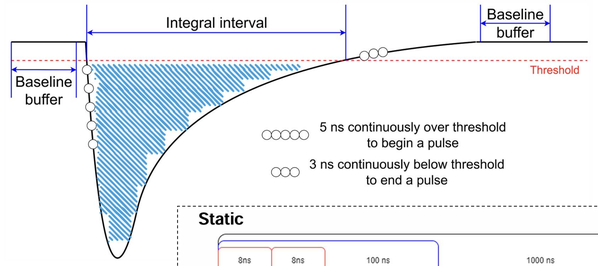


- A physical event is depicted by waveforms from the PMTs
- Waveform reconstruction restores the physical information
  - The total charge is roughly proportional to energy
  - The T/Q of pulses is basic information for vertex reconstruction
  - The data size is effectively compressed

COTI Algorithm

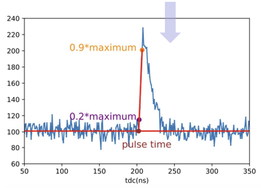
Continuous Over Threshold Integral (COTI) algorithm:

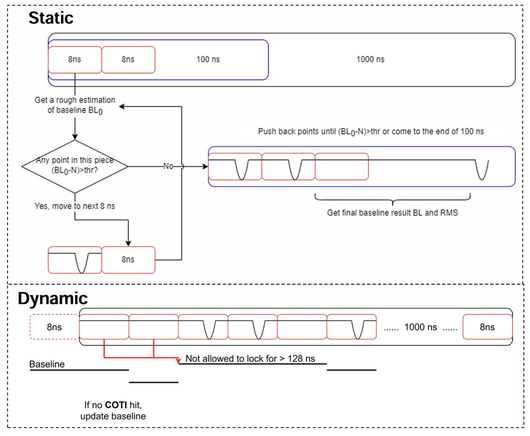
1. Baseline calculation
2. Pulse searching with continuous over-threshold logic
3. Charge reconstruction from integral
4. Hit time determined from rising edge



Two baseline options:

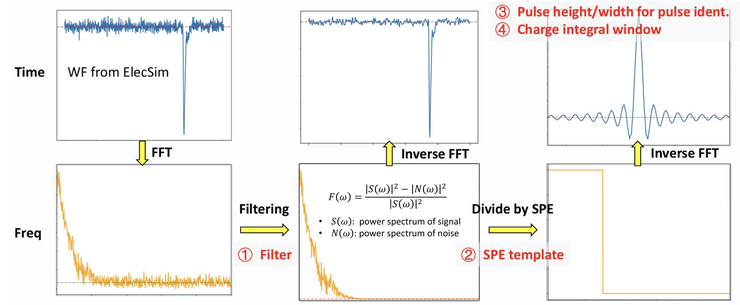
Linear regression at rising edge to find hit time



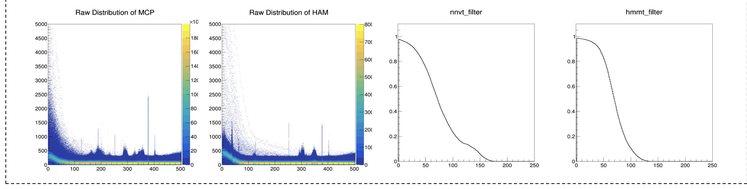


Deconvolution Algorithm

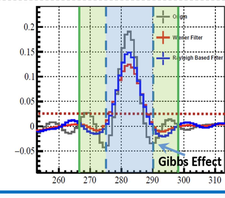
- PMT pulse frequency spectrum different from electronic noise
- Steps: FFT → filtering high-freq. noise → dividing by SPE freq. spec. → IFFT → δ pulse in ideal case



- Raw spectral and Wiener filters for Dynode and MCP PMTs

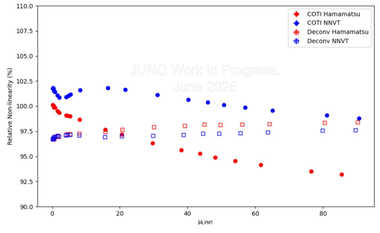


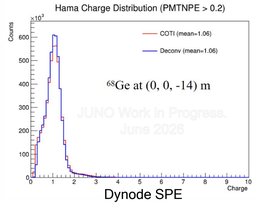
- Deconvolved WFs may suffer from Gibbs effect → carefully choosing the charge integral window
1. Identifying the waveform peak
2. Finding the first point with Amp < 0 at both sides
3. Adding additional 4ns to the left and the right

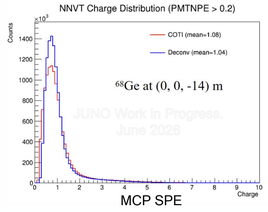


Comparison between COTI & Deconv

- COTI: simple, fast, with very few parameters required
- Deconvolution: slightly better charge resolution, better hit time resolution, less charge non-linearity, less affected by the time-amplitude (T-A) effect







Summary & Outlook

- Waveform reconstruction plays a significant role in the JUNO experiment.
- Two algorithms, COTI and deconvolution, have been studied with both real data and MC simulations.
- COTI, as the simplier and more straightforward algorithm, has been applied in the current analysis.
- Deconvolution algorithm is expected to have a better charge and time resolution. Currently, it is still under development. Stay tuned for more progress!

Ref: [1] First measurement of reactor neutrino oscillations at JUNO, Nature volume 654, pages 343-348 (2026).

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