Real-time Charge Reconstruction Algorithm on FPGA for Neutrino Physics at JUNO

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Data acquisition at JUNO

The **Jiangmen Underground Neutrino Observatory** (JUNO) is an underground liquid scintillator detector whose aim is to study neutrino physics, detecting scintillation and Cherenkov light with a double system of large-PMTs and small-PMT. (http://dx.doi.org/10.1088/0954-3899/43/3/030401)

Large PMT

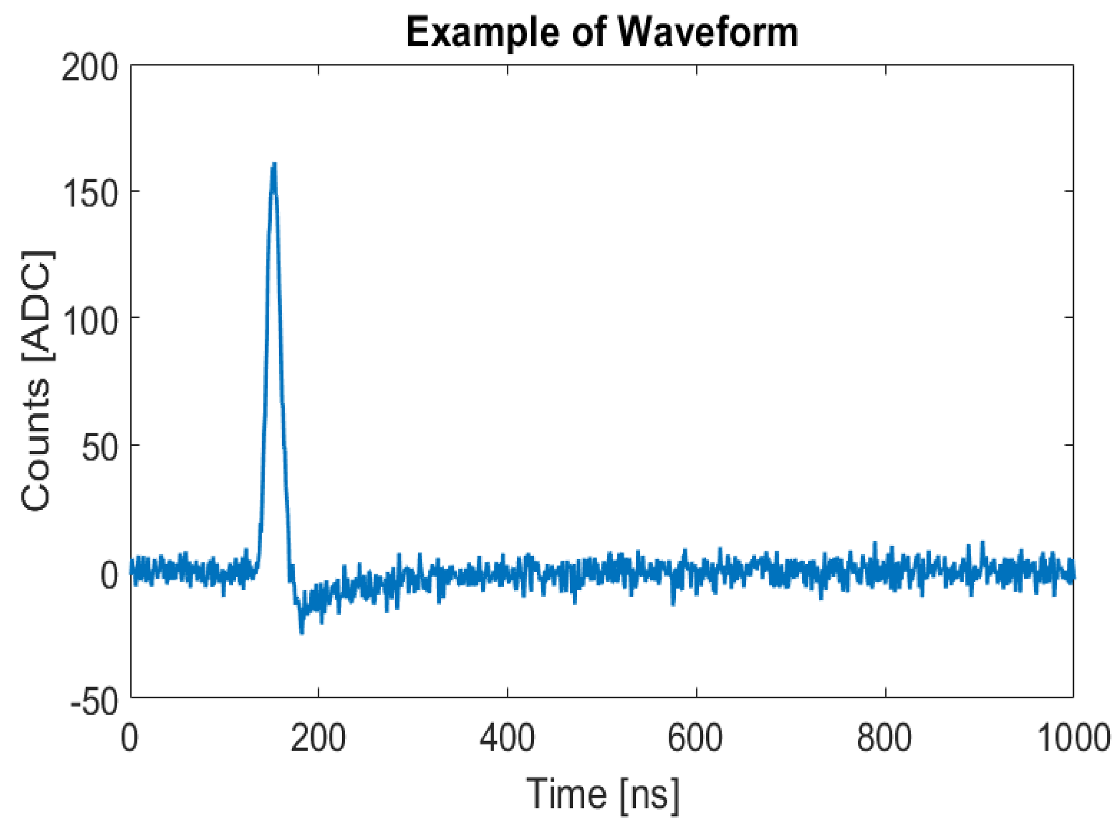
GCU board

Signals from the PMTs are digitized $(1\mathrm{Gs/s})$ by the Global Control Unit (GCU).

The FPGA yields two data streams:

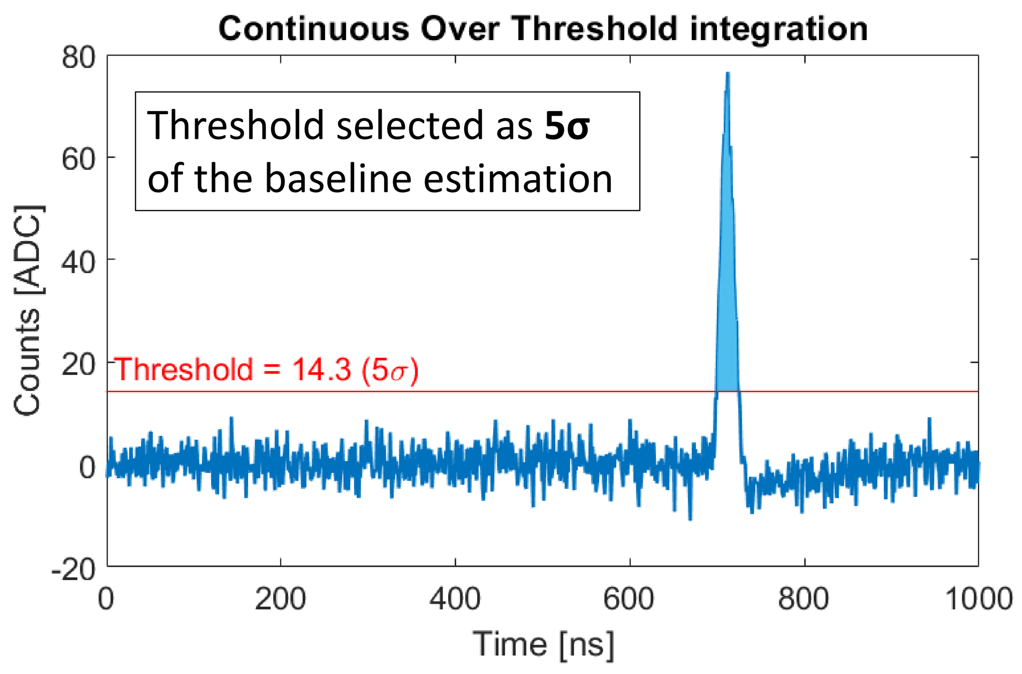
- **Waveforms (WFS)** → low trigger rate
- **Time-Charge pairs (TQ)** → high trigger rate

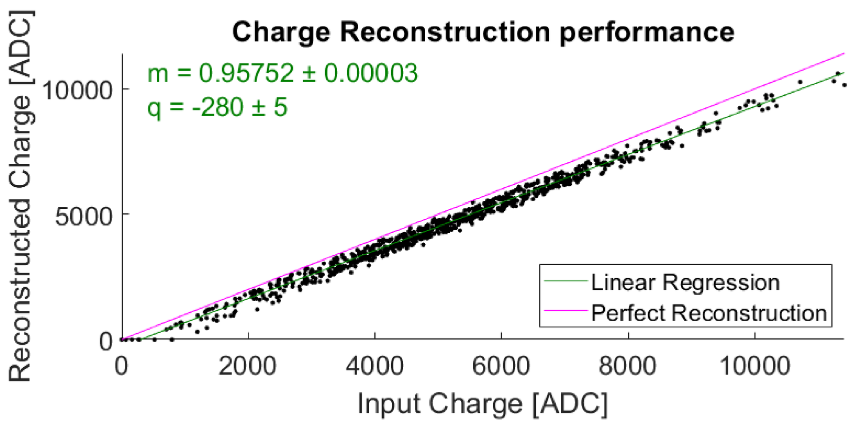
Focus of this poster:
Improvements in **TQ Reconstruction** and **Hardware implementation**.

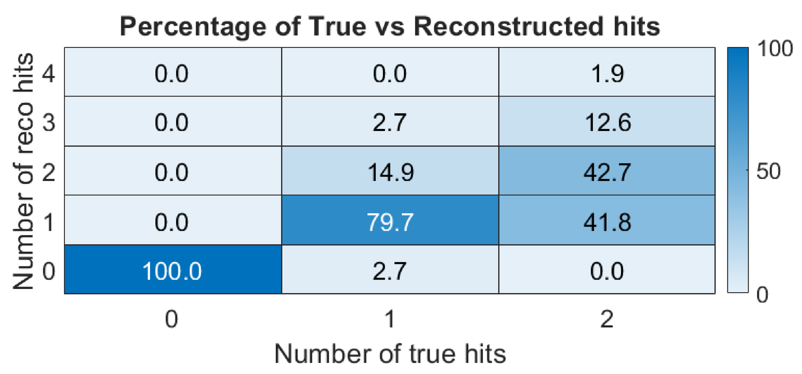


Continuous Over Threshold integration

The **Continuous Over Threshold integration** (COTi) algorithm, present on the GCU, is the simplest integration algorithm: when a sequence of **5 samples over threshold** is detected, the algorithm starts to sum samples values until a sequence of **3 samples under threshold** is detected.







Number of reco hits \ Number of true hits	0	1	2
4	0.0	0.0	1.9
3	0.0	2.7	12.6
2	0.0	14.9	42.7
1	0.0	79.7	41.8
0	100.0	2.7	0.0

COTi Results

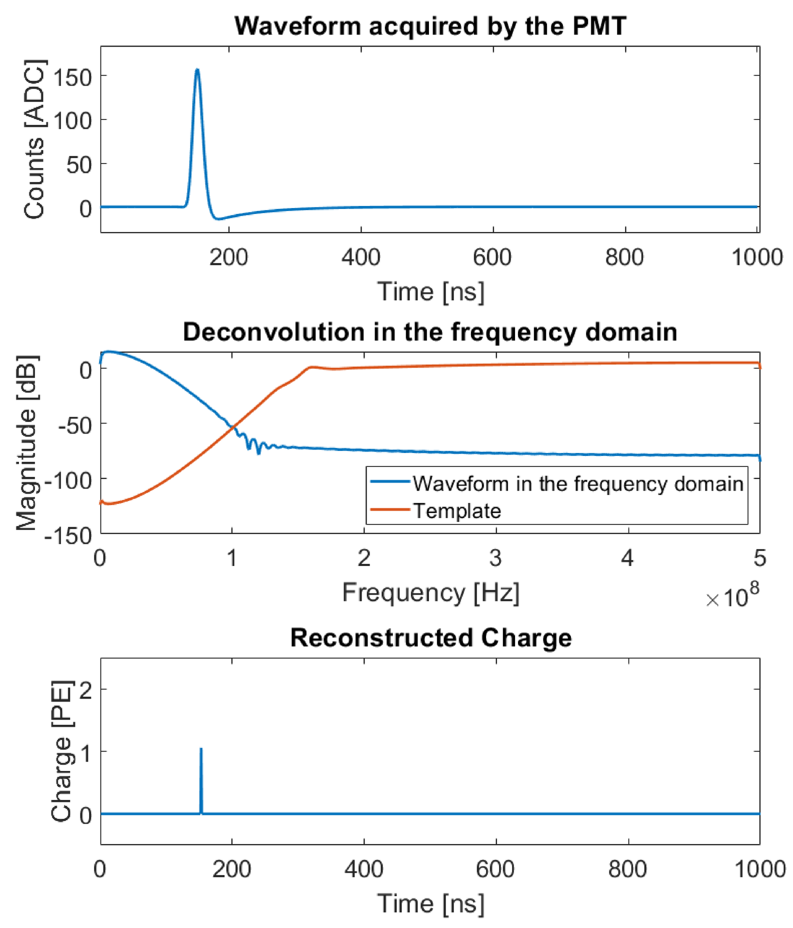
Tests performed:

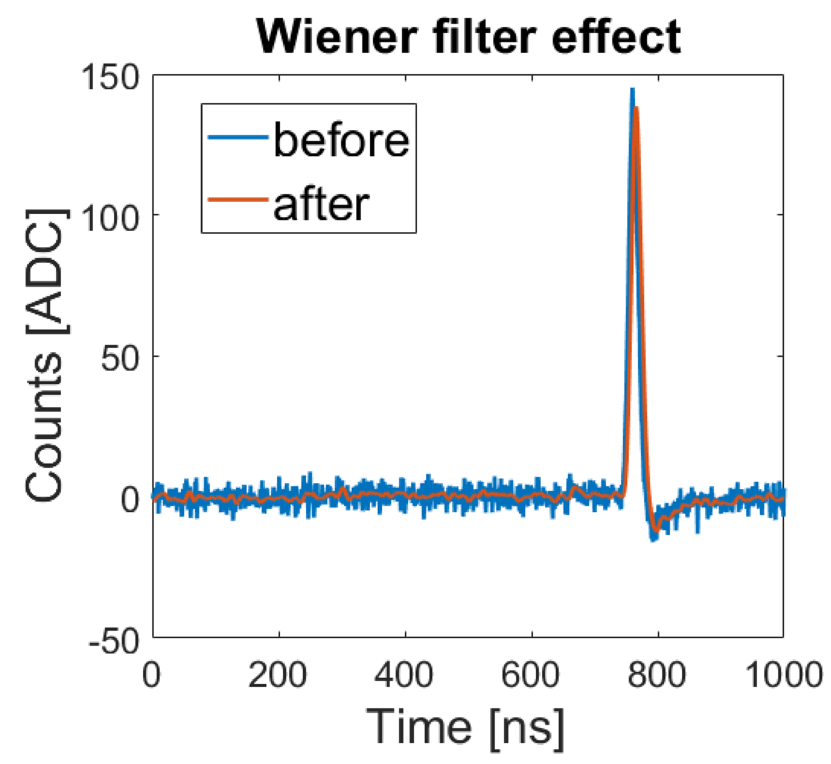
- First test: arbitrary amplitude single PE waveforms
- Second test: double PEs waveforms at fixed distance

Limitations:
Hard to properly reconstruct TQ pairs for PEs closer in time $(\Delta t < 50\mathrm{ns})$.

Deconvolution Algorithm

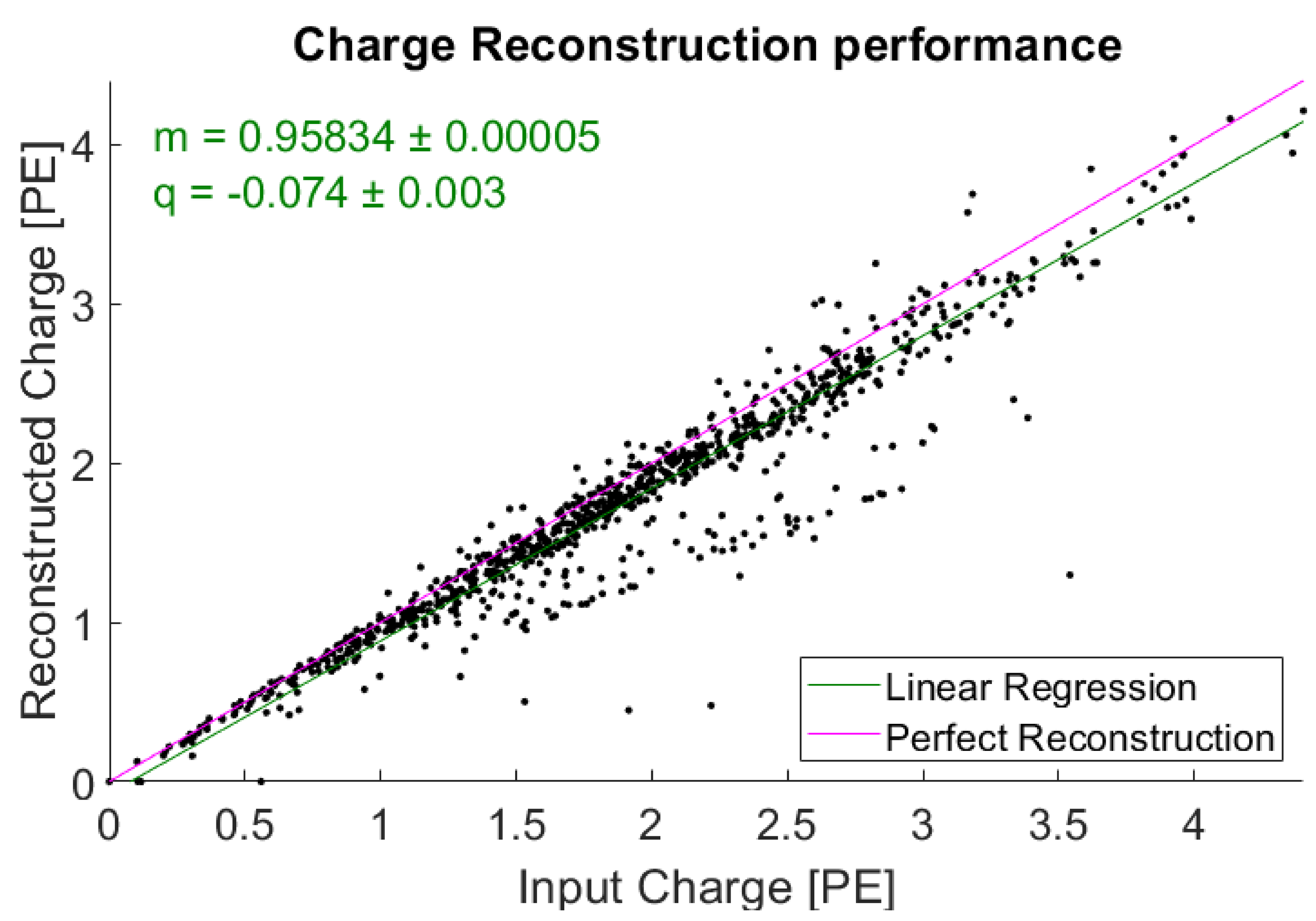
Deconvolution algorithm consist in filtering out the effect superimposed by the PMTs to the Charge Waveform in the frequency domain to obtain a series of spikes which amplitude is the acquired PEs charge values.





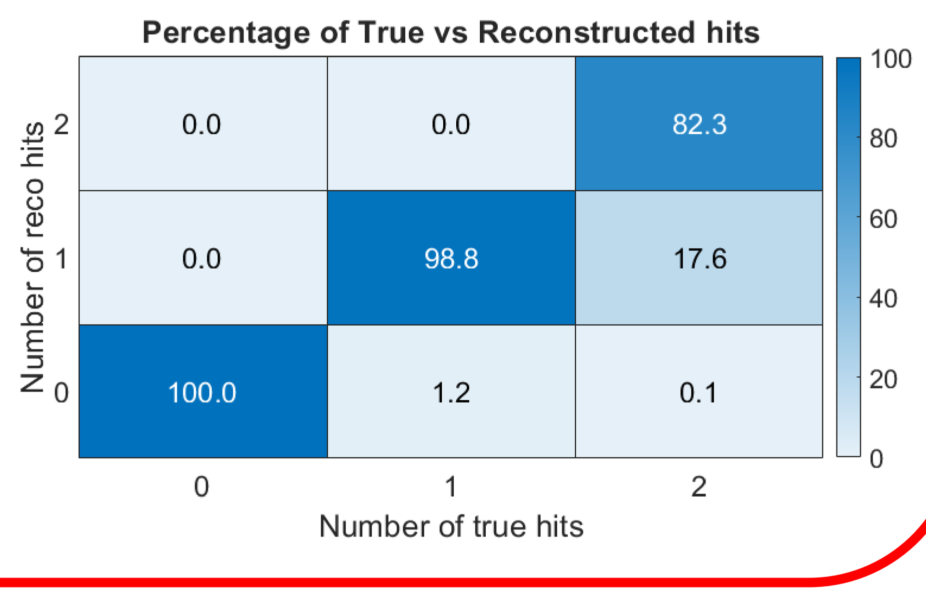
- The Template of the PMTs is obtained as the mean of a series of acquisitions
- The noise is reduced using a **Wiener filter**, a filter built on the Signal-to-Noise ratio (SNR) of the system

Deconvolution results



Behavioral simulation with the same tests as the COTi algorithm.

PEs charge **underestimated** for the second hit, but the algorithm can **correctly reconstruct TQ pairs** for more PEs even when close in time $(\Delta t < 50\mathrm{ns})$.

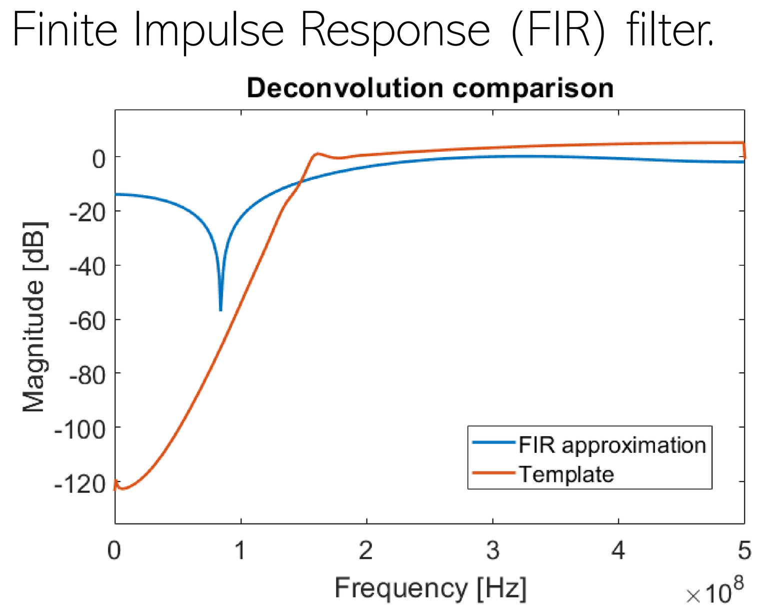


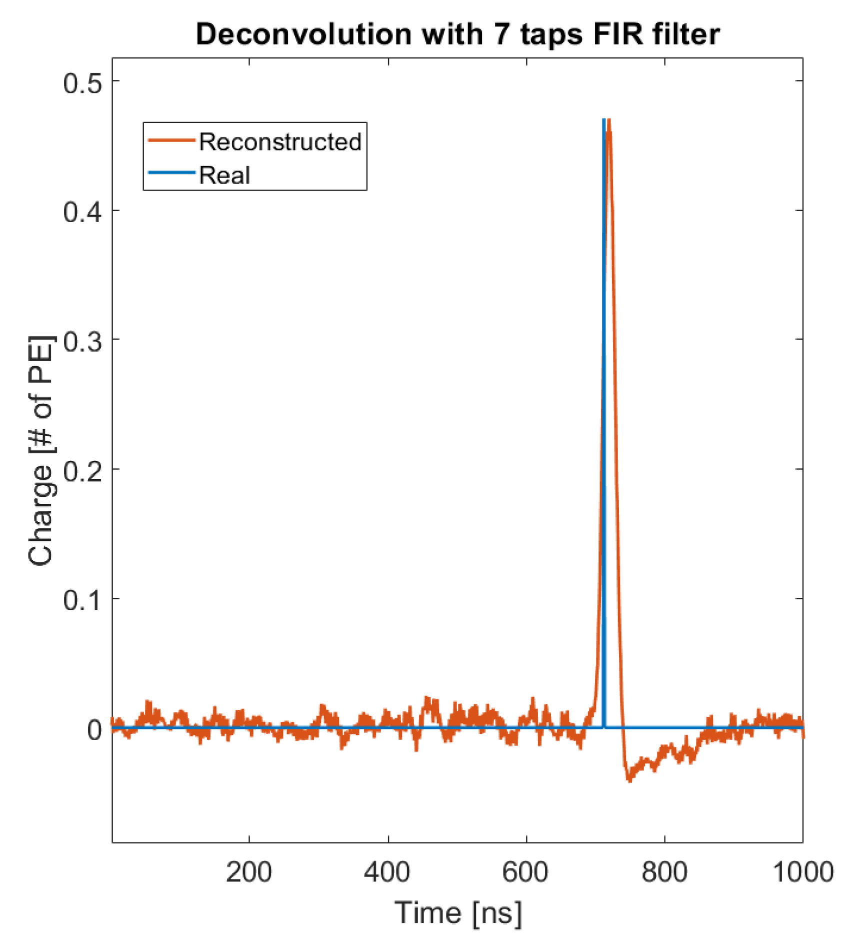
Number of reco hits \ Number of true hits	0	1	2
2	0.0	0.0	82.3
1	0.0	98.8	17.6
0	100.0	1.2	0.1

Hardware Implementation

Challenge:
Limited resources of the FPGA (Kintex 7 series- XC7K325T)

Approach:
Approximate the Deconvolution with a Finite Impulse Response (FIR) filter.





Limitations:
Higher resource consumption than COTi algorithm

Future advancements

The next steps are:

- **Reduce the underestimation to** improve the charge reconstruction
- Improve, if possible, the **filtering of noise** whit the Wiener filter
- **Test and verify** the performances on the FPGA