Designing Data Read Out Electronics for the CHANDLER Neutrino Detector

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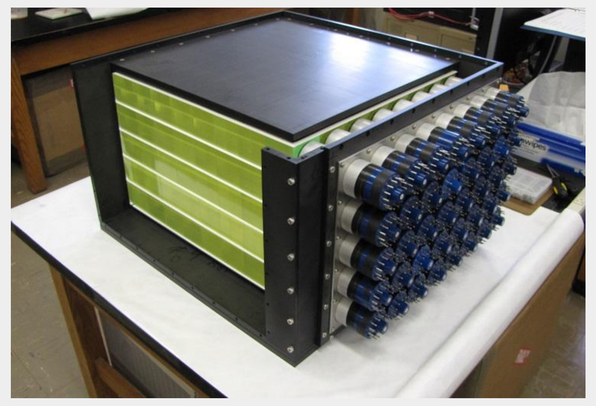
Introduction

CHANDLER (Carbon Hydrogen ANtineutrino Detector with a Lithium Enhanced Raghavan optical lattice) is a reactor neutrino detector technology. The CHANDLER technology consists of layers of wavelength shifting plastic scintillator cubes separated by thin sheets of lithium-6 loaded zinc sulfide. In inverse beta decay, when an electron antineutrino scatters off a proton, it creates a positron and a neutron. Lithium-6 is used to capture the neutron. The light that is produced by the scintillator cubes is then guided to the PMTs by total internal reflection.

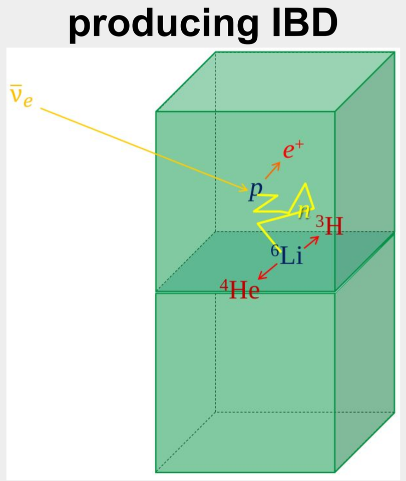
MiniCHANDLER



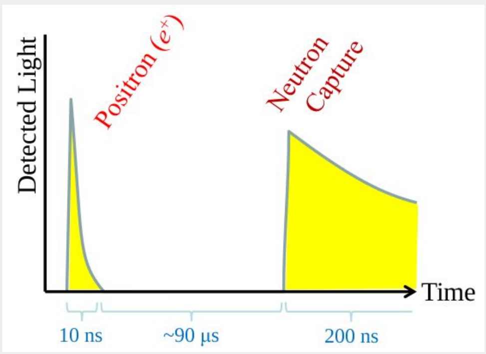
Inverse Beta Decay Equation

$$p^{+} + \overline{\nu}_{e} \rightarrow e^{+} + n^{0}$$

Plastic Scintillators producing IBD



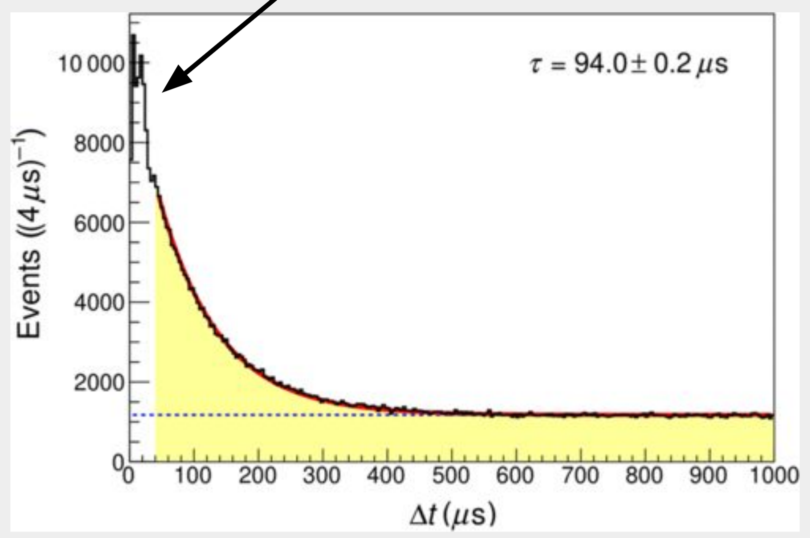
Detected light over time of Positron and Neutron



Old Electronics

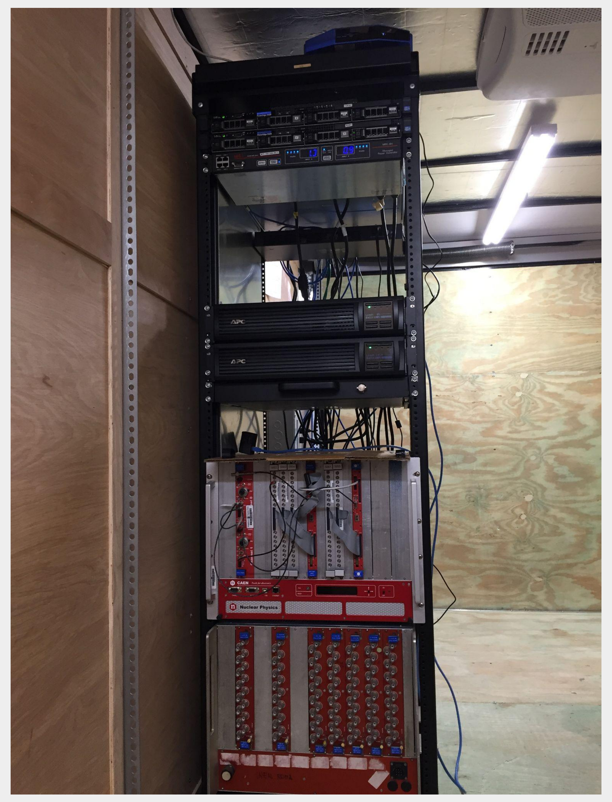
The old electronics for MiniCHANDLER consisted of shapers and CAEN digitizers with a 12-bit ADC. The 12-bit ADC was not able to effectively measure higher energy neutron proton recoils, because it exceeds the range. Another problem with the old electronics was that there was cross-talk between neighboring channels, due to the single-ended input of the PMT signal. Moreover, the trigger algorithm would fail under high energy pulses, because it would cause large oscillations in the baseline. These oscillations caused retriggers and at times the inability to read low pulse height neutron signals. If the trigger threshold was set to a normal level the digitizer would send too much information, using too much bandwidth. To compensate for this the trigger threshold was raised, which led to missing vital information.

High energy pulse causing oscillation in baseline



Delta-time histogram of gamma and neutron events

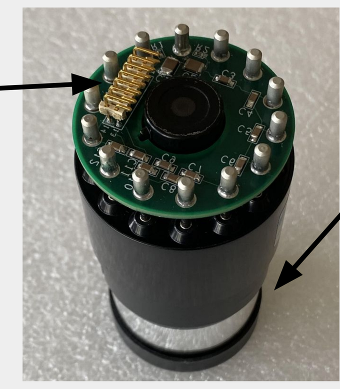
Old Electronics Rack

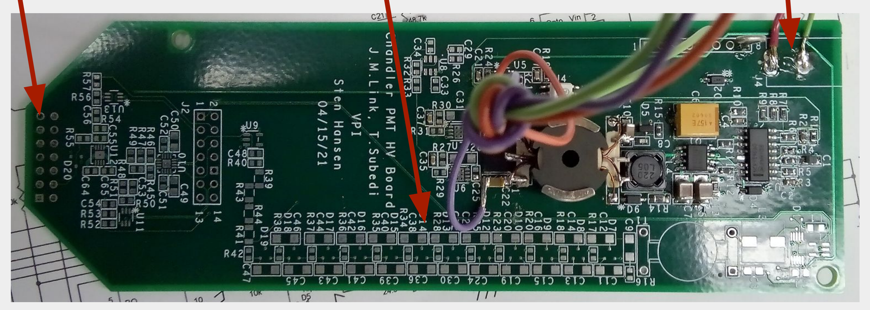


New Electronics

The development of the new electronics is geared toward improving the old electronics. The new electronics will have no crosstalk, better dynamic range, no oscillating after effects, take up less space, and be cheaper. One addition to the new electronics that improves flexibility is the FPGA. The FPGA allows for more complex codes to be used, which can be used to fix some of the previous problems. One problem that is going to be improved because of the FPGA is the trigger algorithm which has the running baseline code.

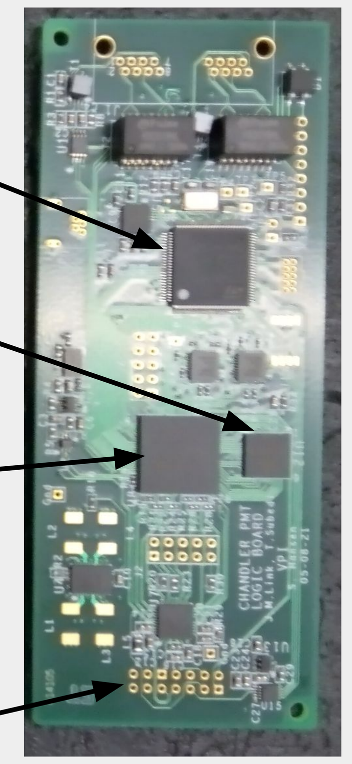
Photomultiplier Tube Interface Board





High-Voltage Board

Logic Board



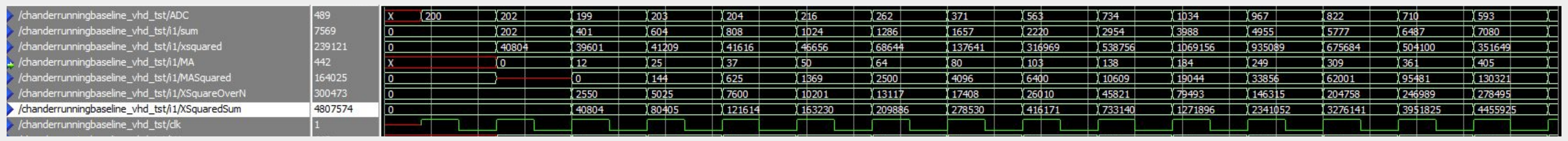
Read Out Firmware

The FPGA uses VHDL as the coding firmware. The running baseline code characterizes the baseline allowing the pretrigger window to be analyzed. The running baseline will send out the sum of the ADC counts, moving average, ADC values squared, sum of ADC squared, and moving average squared. These all could be used as important indicators to compensate for the running baseline not being perfectly flat. Two pretrigger windows are expected. These are a relatively flat baseline and exponential decay.

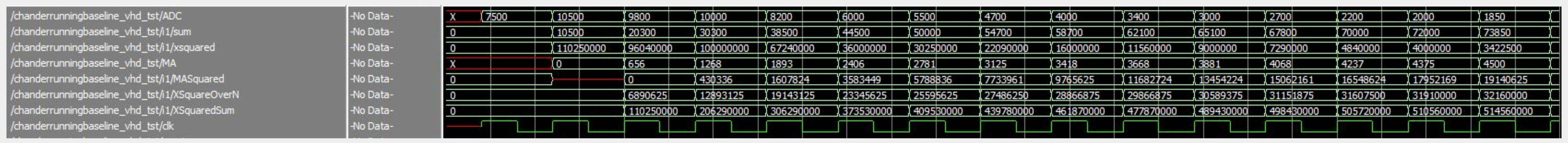
Running Baseline Code (MA/Sum)

```
process(clk, reset)
begin
if reset = '1' then
   counter <= X"00";
   wraddress <= X"0F";
   rdaddress <= X"00";
elsif rising_edge(clk) then
   if ena = '1' then
        counter <= counter + 1;
        wraddress <= wraddress + 1;
        rdaddress <= rdaddress + 1;
        MASquared <= std_logic_vector(unsigned(MA) * unsigned(MA));
        MA <= std_logic_vector(sum(15 downto 4));
      if counter < 3 then
        sum <= sum + resize(signed(ADC), 16);
        counter <= counter + 1;
        wraddress <= wraddress + 1;
        rdaddress <= rdaddress + 1;
      else
        sum <= sum + resize(signed(ADC), 16) - resize(signed(q), 16);
        counter <= counter + 1;
        wraddress <= wraddress + 1;
        rdaddress <= rdaddress + 1;
      end if;

   end if;
end if;

end process;
```

Neutron Hit Simulation



Neutron Decay Simulation



CHANDLER Applications

Fuel composition can be observed without having to do traditional monitoring methods. This could be a viable option over traditional monitoring methods because they can be costly and detrimental to the operations at the nuclear plant.

CHANDLER technology could be used after a nuclear accident to detect criticality in the reactor core.

Acknowledgements

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Sources

[1] Awe, C., P. Barbeau, A. Haghighat, S. Hedges, T. Johnson, S. Li, J.M. Link, et al. "Measurement of Proton Quenching in a Plastic Scintillator Detector." Journal of Instrumentation 16, no. 02 (February 23, 2021): P02035–P02035. https://doi.org/10.1088/1748-0221/16/02/P02035.

[2] Haghighat, Alireza, Patrick Huber, Shengchao Li, Jonathan M. Link, Camillo Mariani, Jaewon Park, and Tulasi Subedi. "Observation of Reactor Antineutrinos with a Rapidly Deployable Surface-Level Detector." *Physical Review Applied* 13, no. 3 (March 11, 2020): 034028. https://doi.org/10.1103/PhysRevApplied.13.034028.

[3] Li, Shengchao. "Detection of Antineutrinos at the North Anna Nuclear Generating Station," (September 21, 2020) n.d., 242https://vtechworks.lib.vt.edu/bitstream/handle/10919/100738/Li_S_D_2020.pdf?sequence=1&isAllowed=y.