Mu2e: Tracker Electronics

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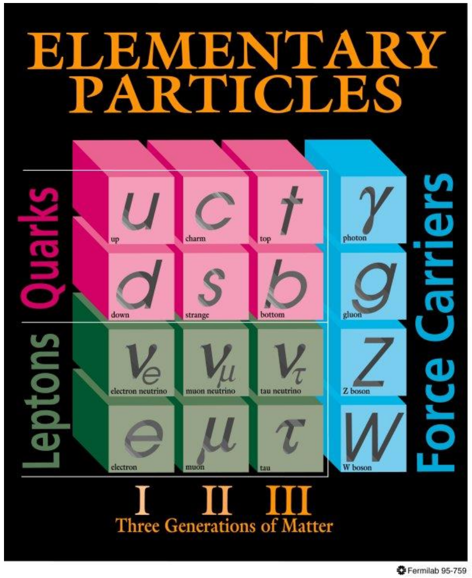
Overview

- Mu2e Experiment
  - What is it looking for and why?
- Mu2e Tracker
  - What makes up the tracker and how does it work?
- Mu2e Tracker Electronics
  - Data Acquisition from the tracker!
- Field Programmable Gate Array (FPGA)
  - Research: Integrating an analog-to-digital conversion into the FPGA
- Additional Tasks: Preamplifiers
  - Anode & Cathode Connectors

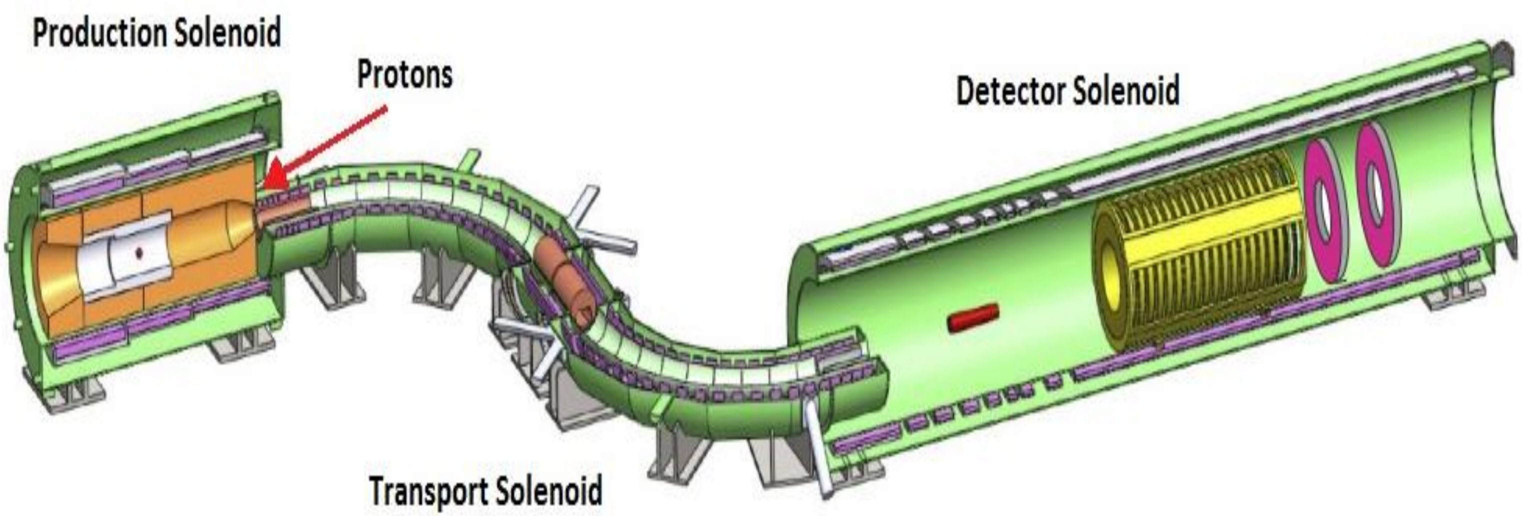
Mu2e Experiment

- What are we looking for?
  - In Mu2e, we would like to detect neutrino-less conversions of Muons to a high energy electrons (105MeV).
  - Typically a Muon would decay into two neutrinos and a low energy electron.
- What is a muon?
  - A muon is a charged lepton with a charge of -1e and a ½ spin.
  - It can also be thought of as a heavier electron.
- Why does this matter?
  - The detection of the rare neutrino-less conversion would hint towards new physics.



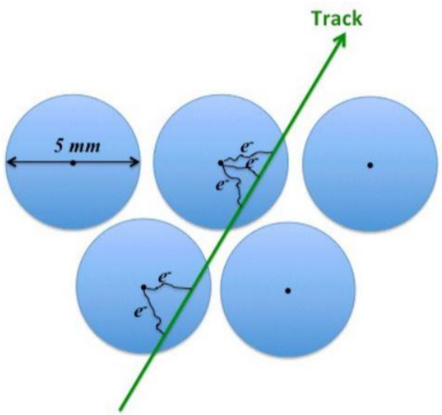
Mu2e Detector

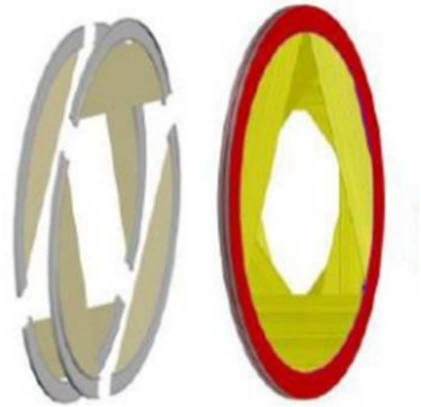
- The detector setup has 3 main parts: Production Solenoid (PS), Transport Solenoid (TS), and the Detector Solenoid (DS)
- First, protons with energies of 8GeV will strike a tungsten target creating a number of particles, one being pions which decay into muons.
- The PS collects the muons and send them to the TS.
- The TS will send the muons to the aluminum capturing target.
- From here, the muons can convert to high energy electrons to be detected



Mu2e Tracker

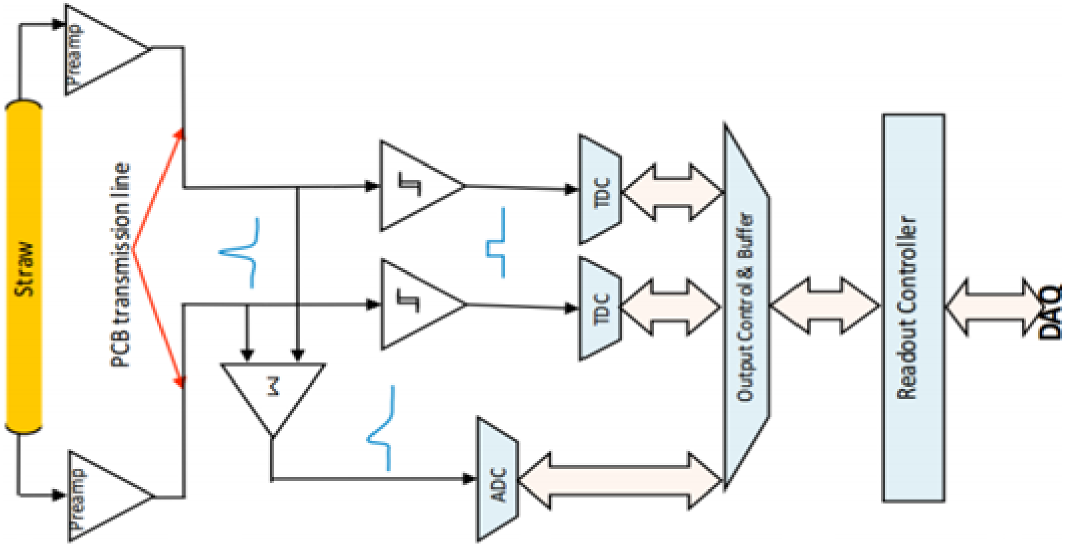
- When a muon decays into a high energy electron, the electron gains a very specific momentum of 105MeV.
- To detect the high energy electrons, the tracker uses low mass Mylar drift tubes, filled with an Ar/CO_2 gas mixture, and a high voltage gold plated tungsten sense wire along the center.
  - Or straws
- As a high energy electron passes through a straw, the gas inside will ionize, which will trigger an electron avalanche. The avalanche will create a measurable signal for us to work with.





Mu2e Tracker Electronics

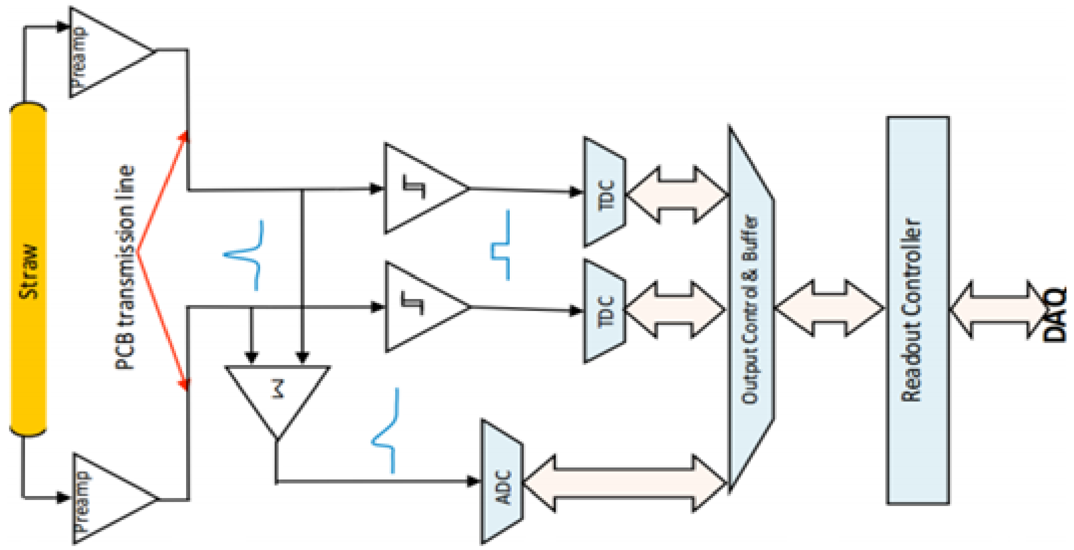
- The signal from the electron avalanche will then go through the preamplifiers (one at each end) which will shape and amplify the signal.
- Digitization is being done with a combination of analog-to-digital converters (ADC) and time-to-digital converters (TDC).
- The TDC compares the time difference between the signals at each end to estimate the position in which the event occurred.
- The ADC digitizes the amplitude of the signal to distinguish between particles.



Fermilab

Mu2e Tracker Electronics

- If the event was a high energy electron, the ADC and TDC will send their information to the Output Control & Buffer to associate the corresponding amplitude and timing of the signal before being sent to the Readout Controller (ROC).
- From the ROC, the digital information will be sent to Data Acquisition (DAQ).



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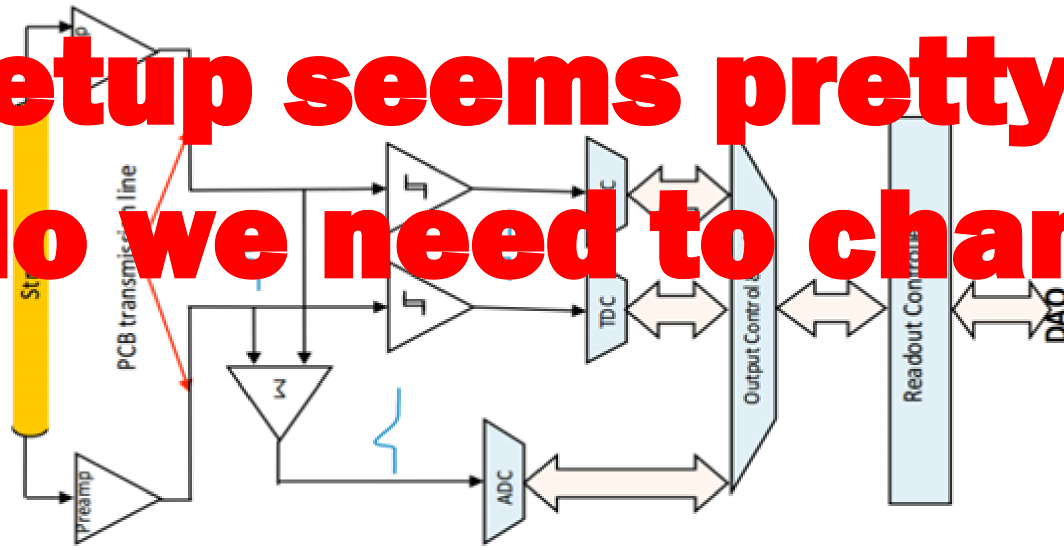
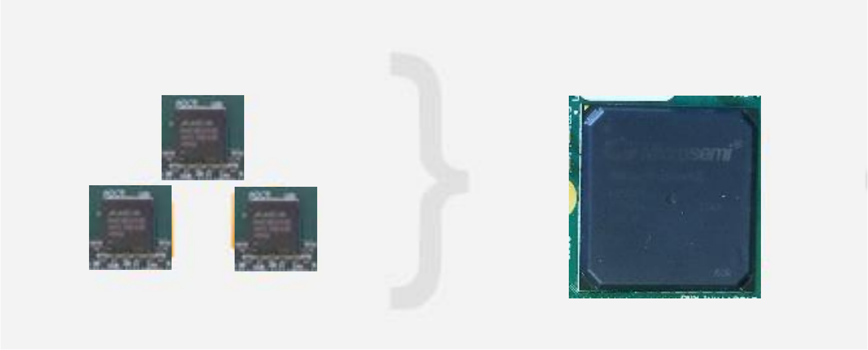
The setup seems pretty good, why do we need to change it?



Consolidation

- The electronics used in the tracker will be exposed to radiation over an extended period of time.
  - Over time, IC's will be affected by the radiation and will stop working properly.
  - To fix this, replace damaged ICs or buy ICs that can withstand prolonged exposure to radiation.
- To minimize the number of possible failures and cost of buying expensive ICs that should withstand prolonged exposure to radiation, we can integrate some ICs into a single FPGA.
- Currently, the TDC, Output Controller & Buffer, and the ROC are all designed and implemented within the FPGA.
- The next possible chip to be "built" into the FPGA is the ADC.

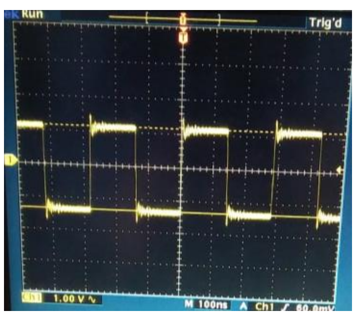
Multiple ICs

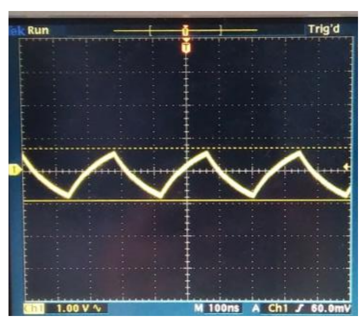


Into one FPGA

FPGA – Analog-to-Digital Conversion

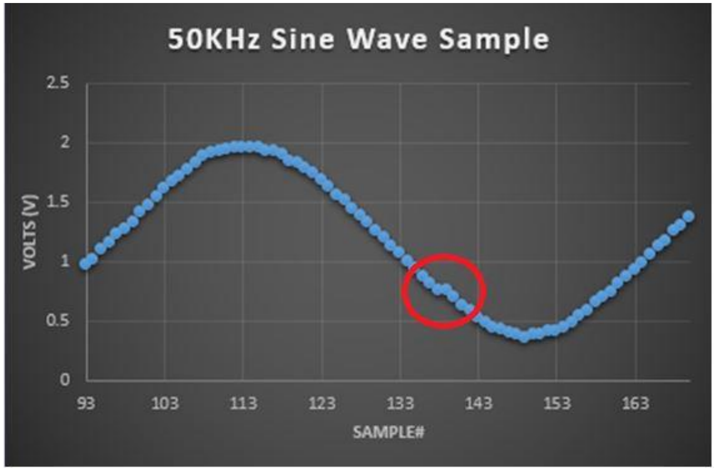
- To implement an ADC within the FPGA, we need to use Low Voltage Differential Signaling (LVDS).
- LVDS takes in two signals; the analog signal to be sampled (100KHz) and the sampling clock (3.5MHz) and it check when the sampling clock goes above the analog signal.
  - When the sampling clock is above, the LVDS outputs logic low.
  - Similarly, when the sampling clock goes below, it outputs logic high.
- The output (Y) is then sampled at a higher frequency (350MHz) and keeps a count (up to 350MHz/3.5MHz) of how many clock cycles Y is at high logic.
  - The count is then stored and reset to zero every period of the sampling clock.

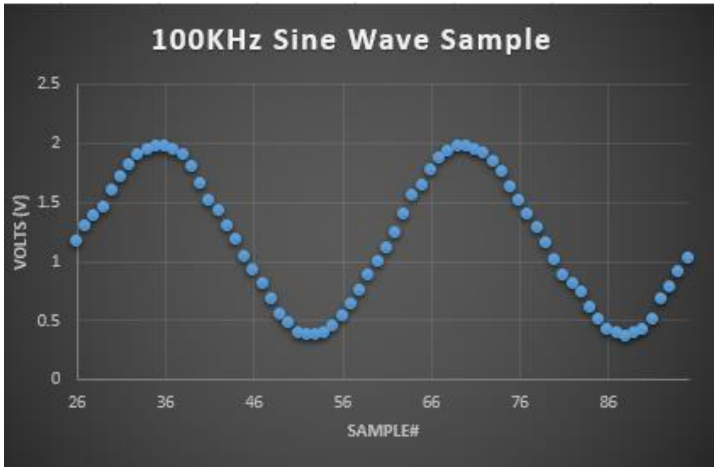




Results

- The "counts" that are stored can be converted back to voltage levels and each count becomes a voltage sample.
  – Sample = V_{range} * (count / $count_{max}$)
- With the described setup, this is the analog-to-digital conversion of a 50kHz and a 100kHz sine wave:





- From these two plots we see two things:
  1. The resolution falls drastically from between the 50kHz and 100kHz sine wave
  2. Even in the 50kHz sine wave we see samples that don't make sense

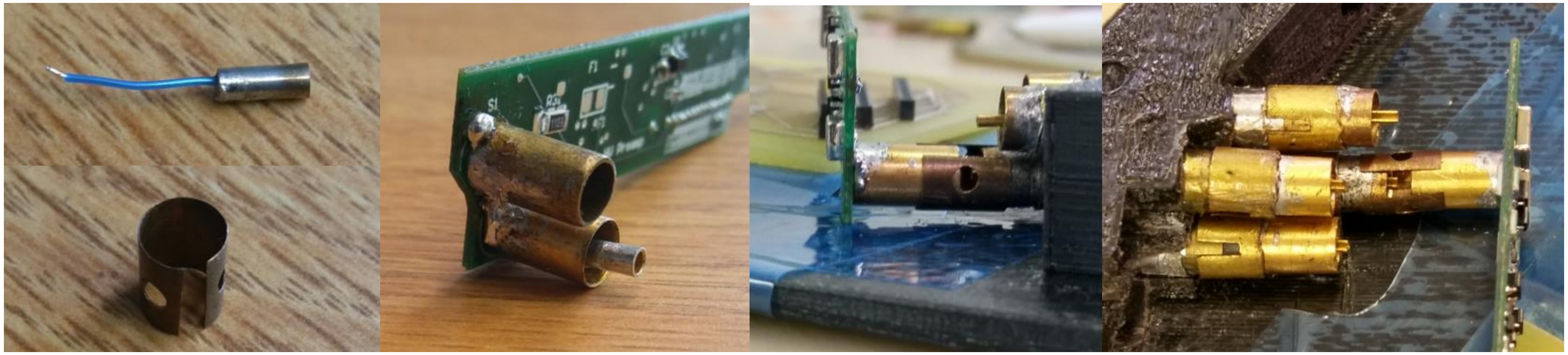
Future Work

- From the previous plots, it is not possible to determine the performance of the ADC made.
- To quantify this, we need to look at the Integrated Non-Linearity (INL) of the sample.
  - This quantity is measure by looking at the maximum deviation of the sample from the ideal wave
- This number can also tell us the performance of each ADC when using different I/O pins.
  - This is critical because each board uses two ADC each containing 8 channels.
- Further work still needs to be done to increase out resolution of the ADC
  - One way it can be done is by implementing a time-to-digital converter into our current ADC.
- Increasing the resolution of the ADC will also help increase the accuracy the INL.

Additional Tasks: Preamplifiers

Preamplifiers – Anode & Cathode Connectors

- Each straw is connected to two preamps (one on each side).
- The issue is that there are 20,000 straws with two anodes and cathodes that need to be connected to the preamps.
  - There needs to be a quick and easy way to make these connections.
- One solution:
  - Increase the tolerance of the cathode connections by using sliding sleeves with an “expandable” circumference to increase ease of connection.
  - Standardize the length of the anode cable to increase ease of connection. (8mm)



Acknowledgements