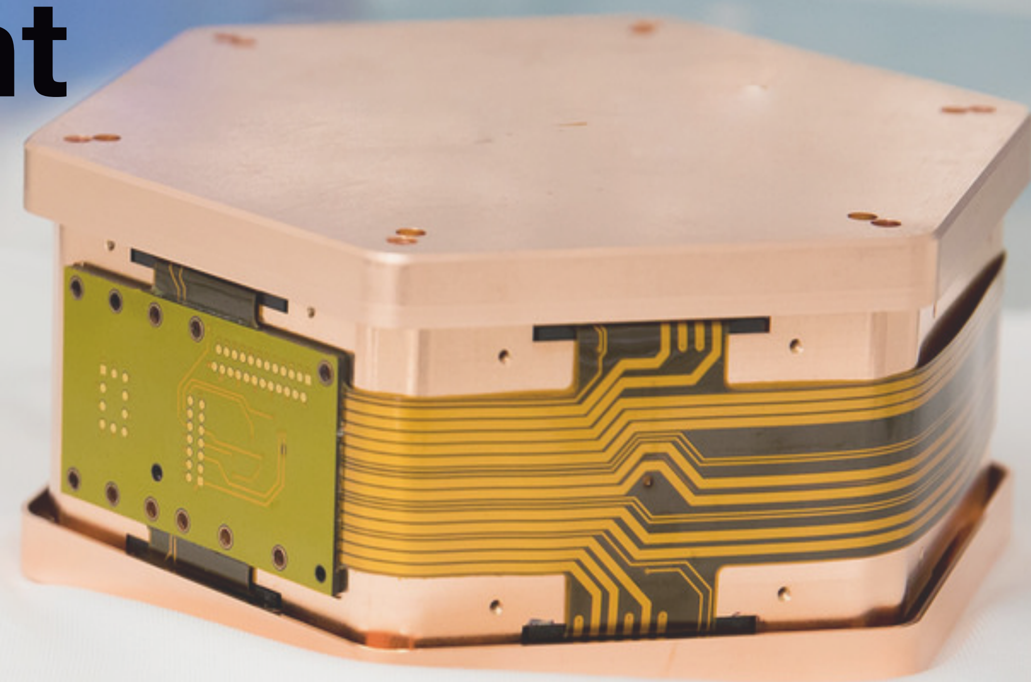
Validating the performance of the Trigger for the Super Cryogenic Dark Matter Experiment



Master's Defense

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July 5, 2019

Super CDMS

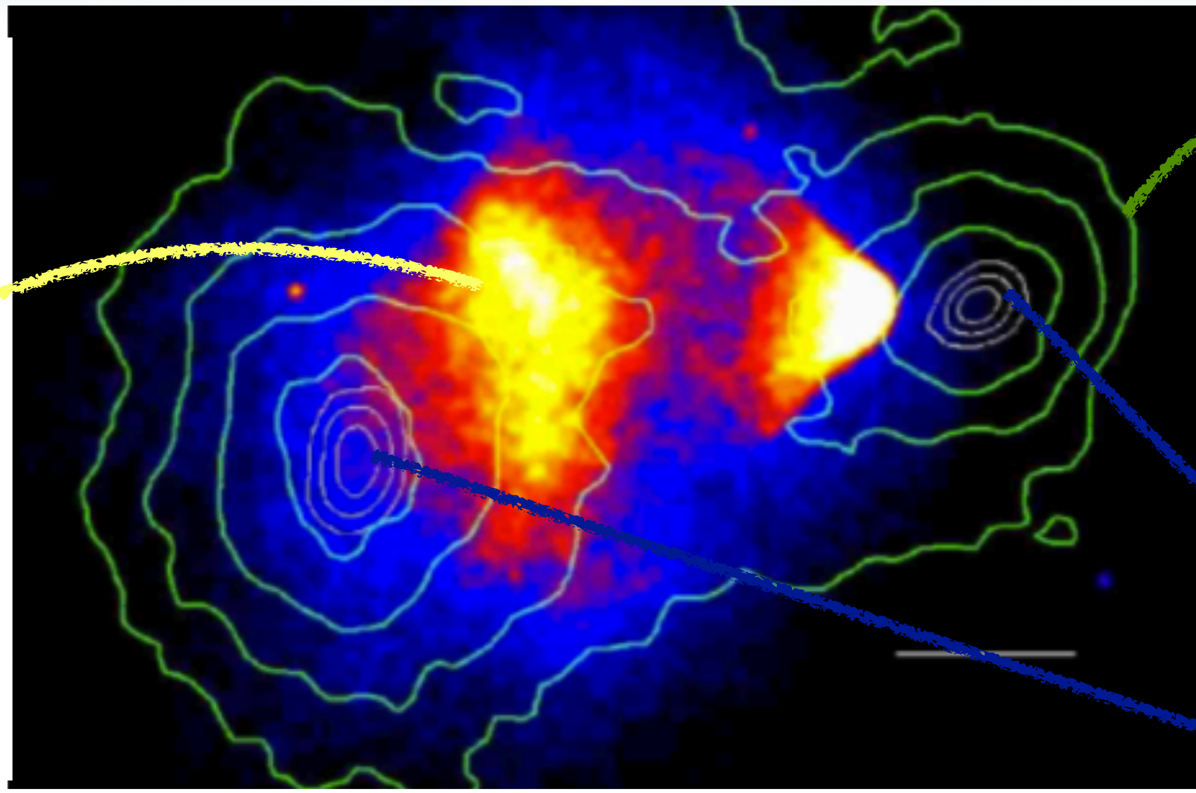
Photo from supercdms.slac.stanford.edu

Outline

- **Dark Matter and the Super Cryogenic Dark Matter Experiment**
- **SuperCDMS Trigger and Trigger Validation Method**
- **Comparing Data to Trigger Simulation**
- **Conclusions and Future Plans**

Bullet Cluster

Gas - Ordinary Matter



Gravitational Lensing Map

Dark Matter

X-ray image from the Chandra X-Ray Observatory (Clowe et. al. 2006)

- Two Galaxy Clusters Collided
- Gas Slowed Down in the Collision
- We expect to see most of the matter in the yellow region but most of the mass is on the centers of the gravitational lensing map
- Most of the mass is not affected by the Collision

Evidence for Non-Baryonic Collisionless Dark Matter

Dark Matter Properties

Photo from Symmetry Magazine

Particle Solution is Preferred:

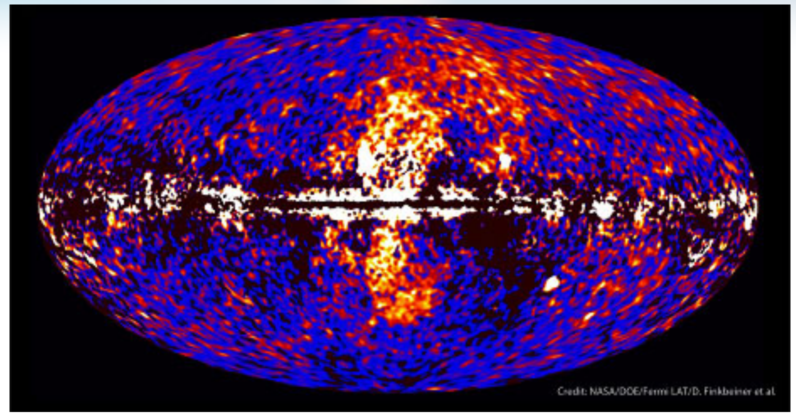
- Massive
- Neutral and Minimally Interacting
- Stable or Has a Very Long Life-Time
- Cold and Non-Relativistic

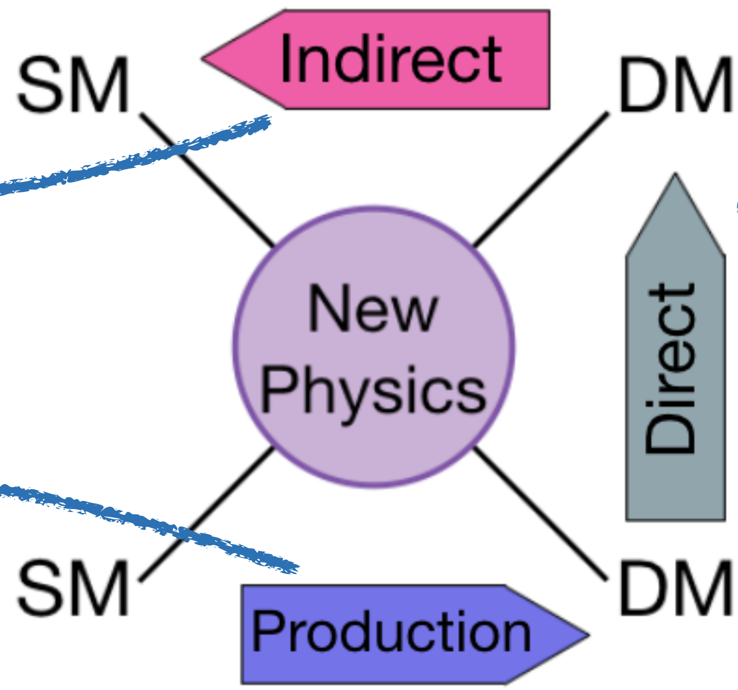
Weakly Interactive Massive Particles (WIMPS) are one of the Most Compelling Candidates

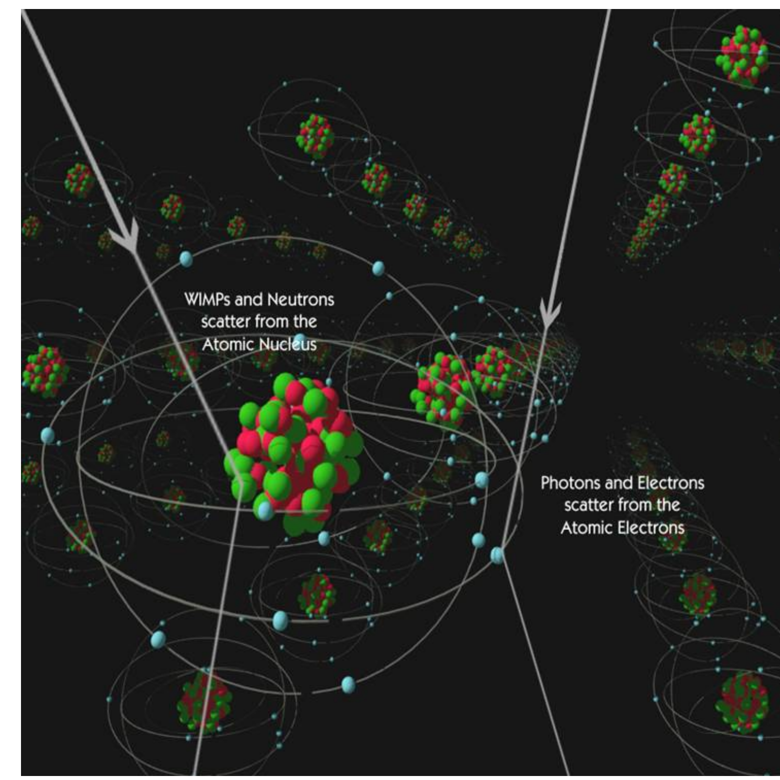
WIMP Detection Methods

Cosmological Observations

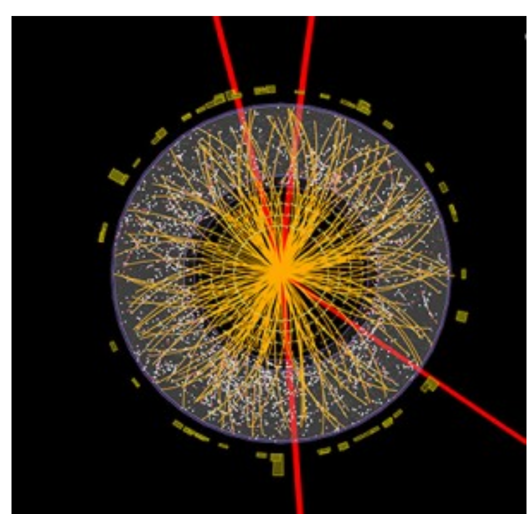
AMS, Fermi







Collider Physics
ATLAS, CMS



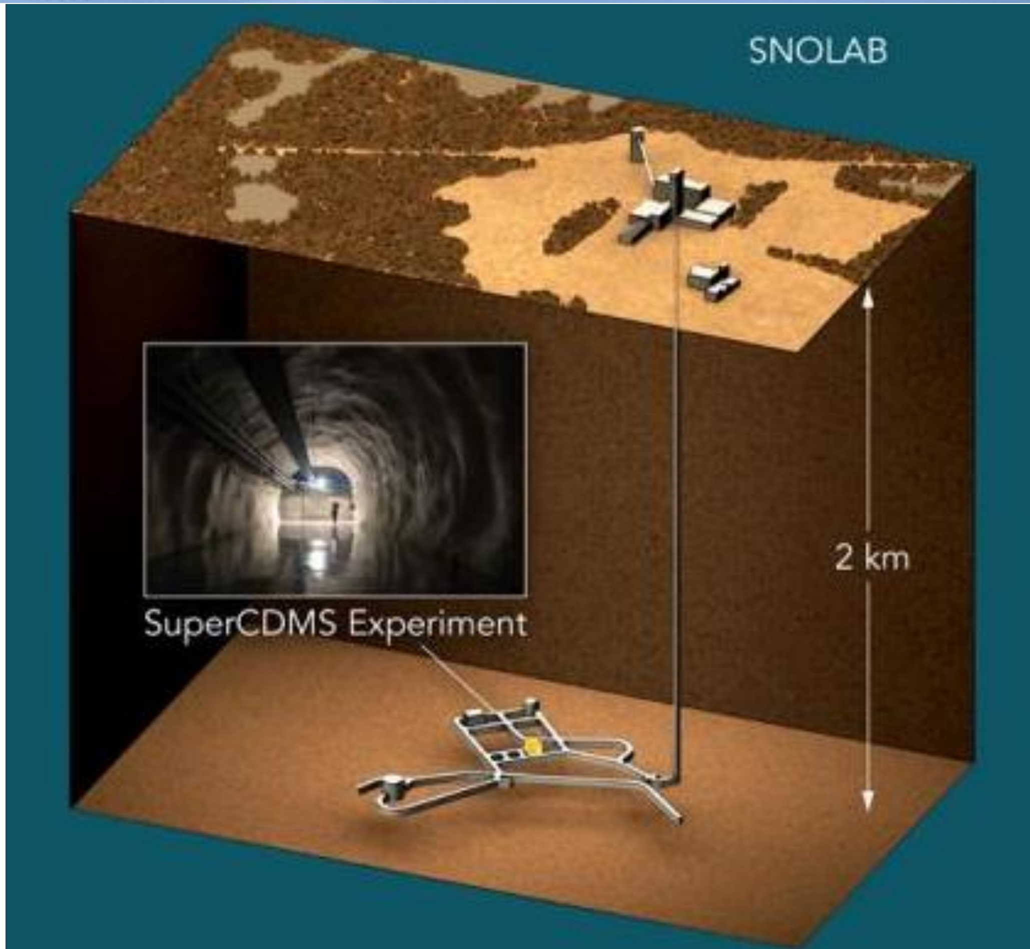
SuperCDMS, LUX, XENON

SuperCDMS Experiment

- **Located in SNOLAB, Sudbury Canada**

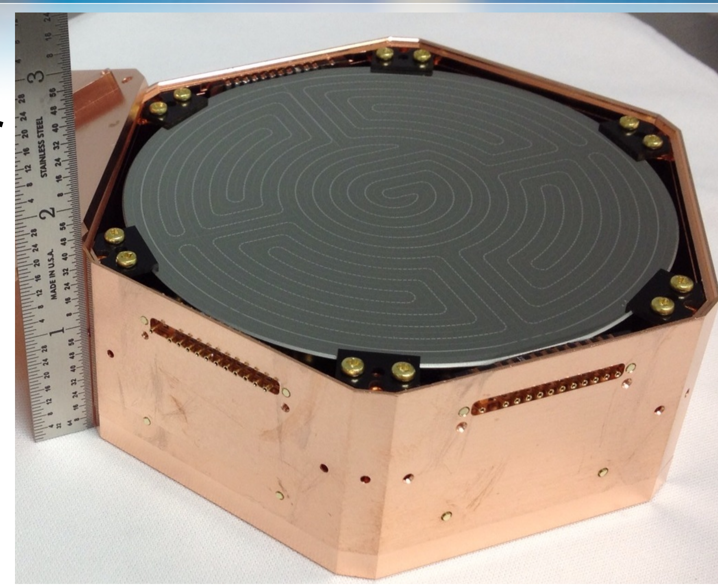
- **Direct detection experiment designed to detect low-mass WIMPs ($\leq 10GeV/c^2$)**

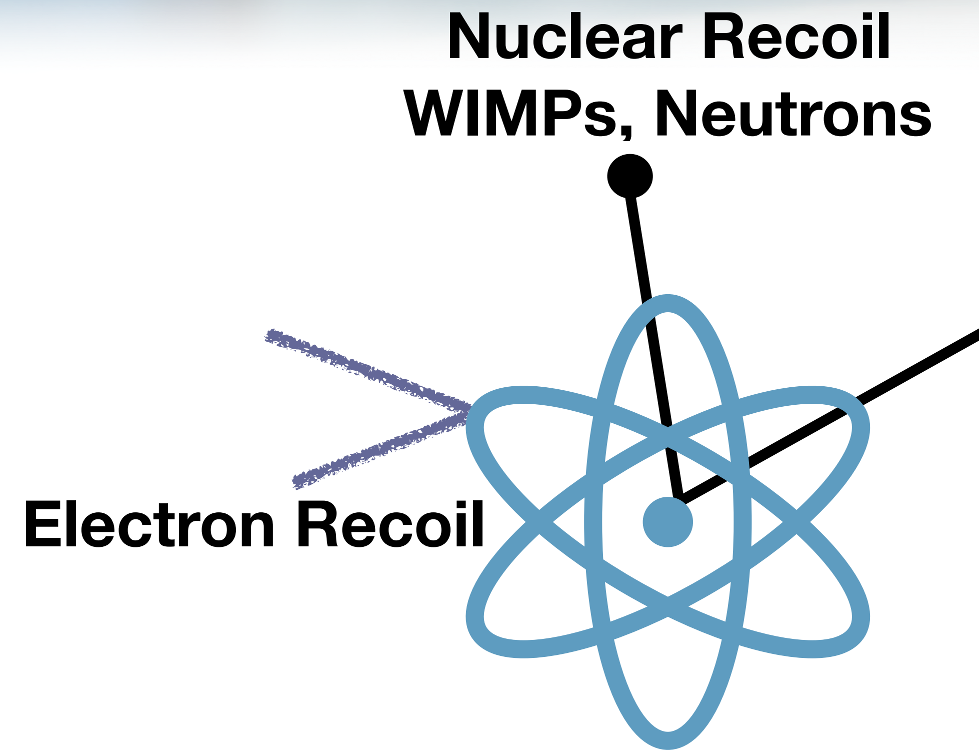
- **Reducing Cosmic background by shielding and depth**



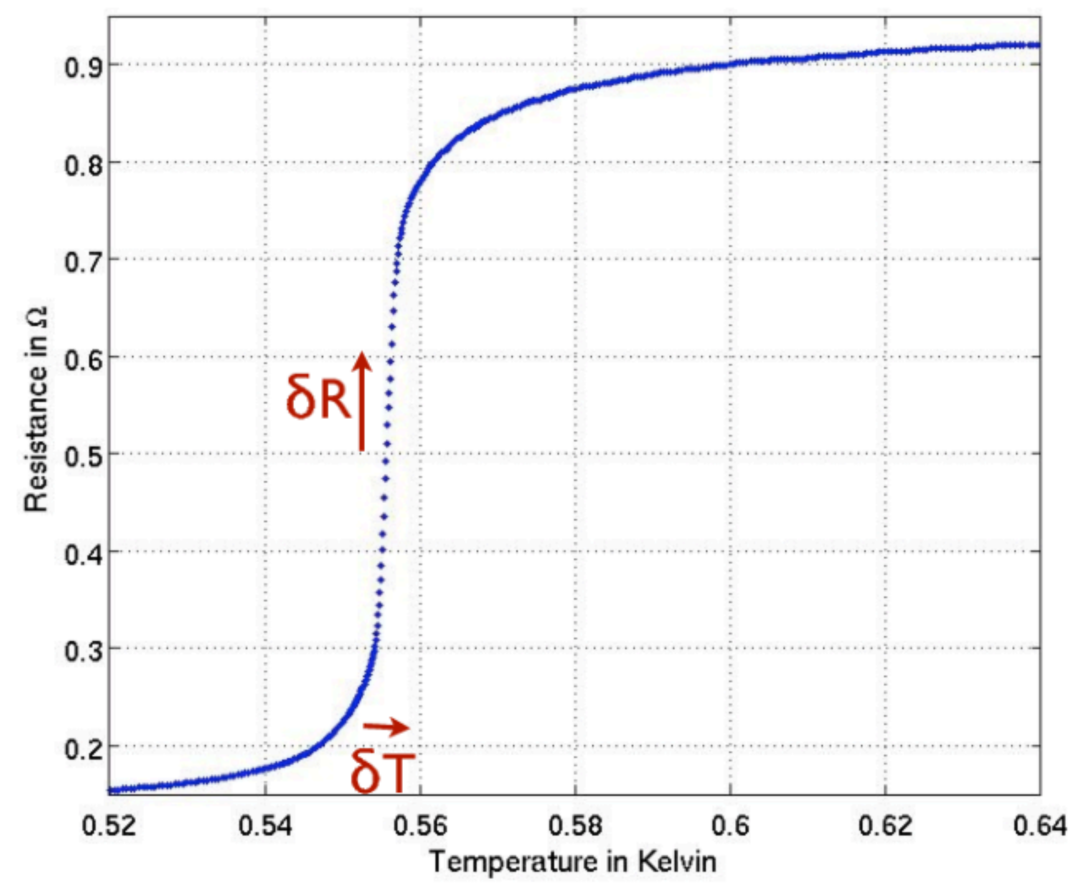
SuperCDMS Detection Principles

WIMPs hit the detectors.

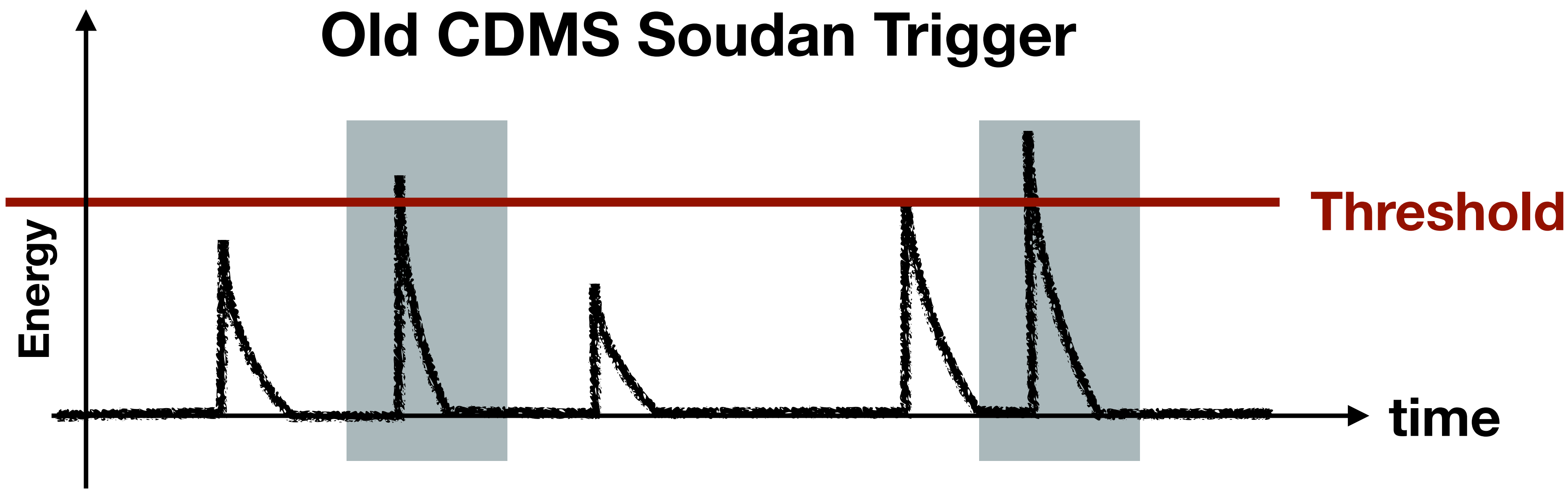


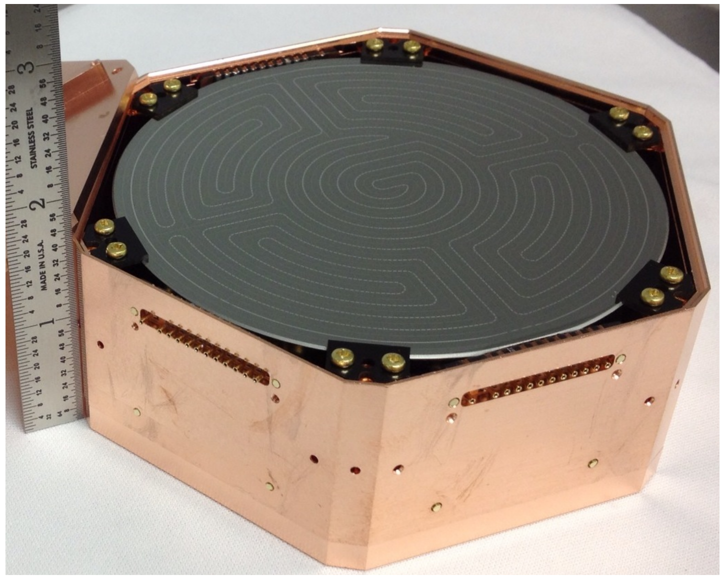


- **Detectors are made of Superconducting materials, Ge and Si crystals, and operated at the edge of superconductivity (50 mk)**
- **Energy is produced in the interaction between WIMPS and Ge and Si crystals**
- **Deposited energy makes a small change in the temperature**
- **Small changes in temperature can lead to a large change in the resistance**
- **We read a current which is proportional to the deposited energy**



SuperCDMS Detectors and Triggering



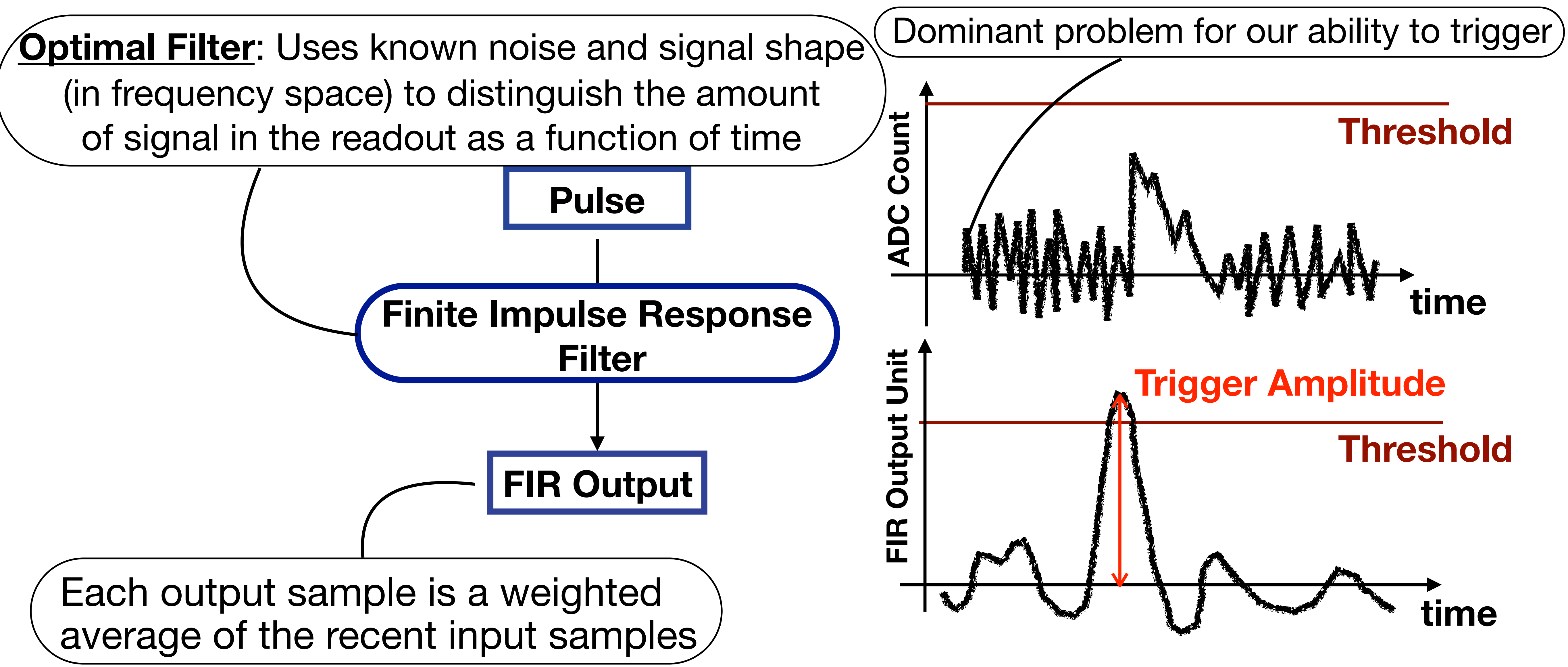


Detector

- We are looking for WIMP events that hit the detector and produce energy
- We need a trigger to decide when to record data
- Old CDMS Soudan Trigger just looked for energies above threshold. (Not Optimal)
- SuperCDMS Trigger is more sophisticated

Using Optimal Filtering in the SuperCDMS Trigger

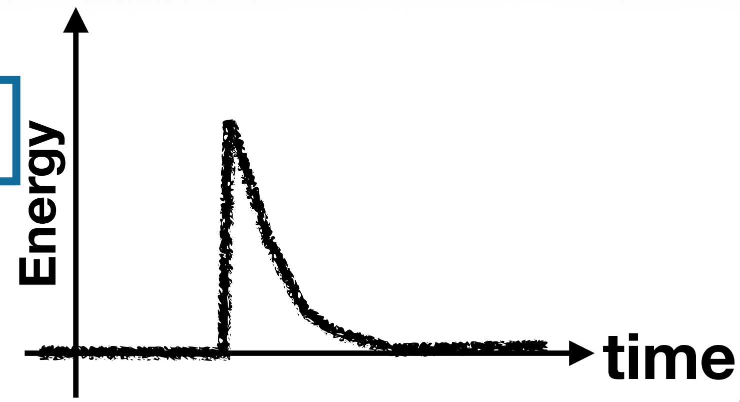
- **Our group designed and built the Trigger for the SuperCDMS experiment, and installed it on customized electronic boards**
- **Use a new method: Optimal Filtering to look for even smaller energy interactions**

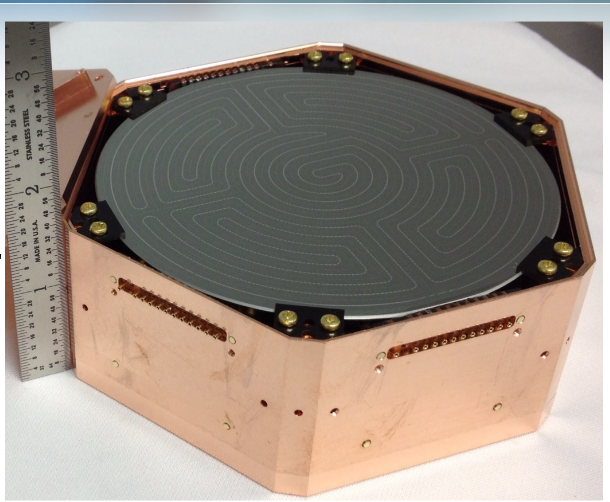


Trigger Amplitude will eventually convert to WIMP energy.

SuperCDMS Data Acquisition

WIMPs hit the detector

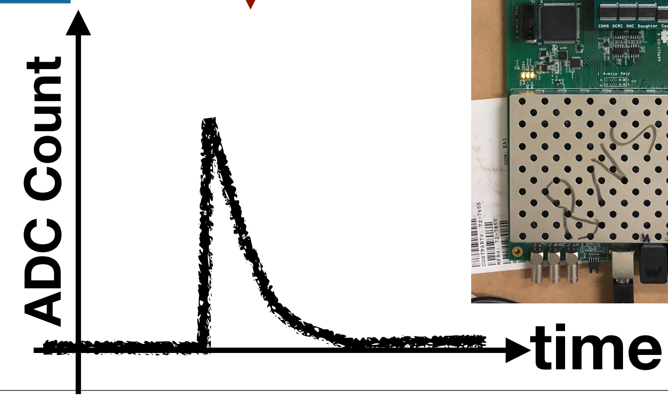




DCRC digitizes the analog signal, adds an FIR filter and makes the trigger decision

Detector Control and Readout Card (DCRC)

- The main electronics for SuperCDMS
- One DCRC per detector
- Converts the detector analog signals into digital data



Midas reads out and stores all the data

Data Acquisition Machine

- Uses Midas DAQ framework
- Midas is a C++ Based DAQ System

Trigger Validation

Goal: Validating the performance of the Trigger

- **Does the Trigger do what it is supposed to do?**
- **How often, when there is no input pulse, do we fire? How does that change as a function of the threshold?**
- **How often does the trigger make the right decision? How is this affected by the noise?**

Since the trigger is fully digital we can completely replicate the trigger decision in simulation as a way to verify that it works exactly as expected.

TAMU Test Stand

Data Acquisition Computer

Pulse Generator

TAMU Test Stand

Data Acquisition/ Trigger Board

Simulating Low Energy WIMP interactions

Simulated WIMP Energy

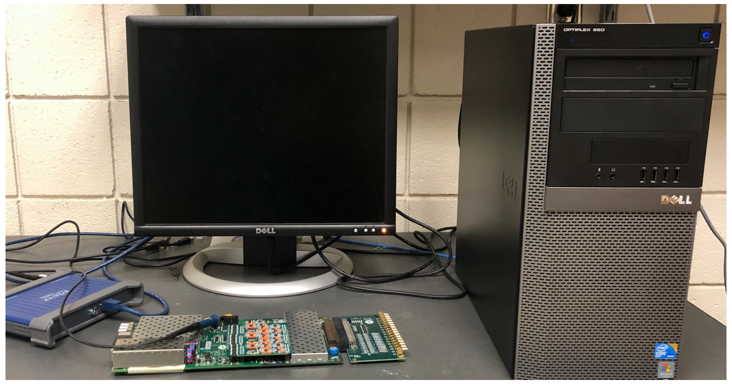
↓

DCRC

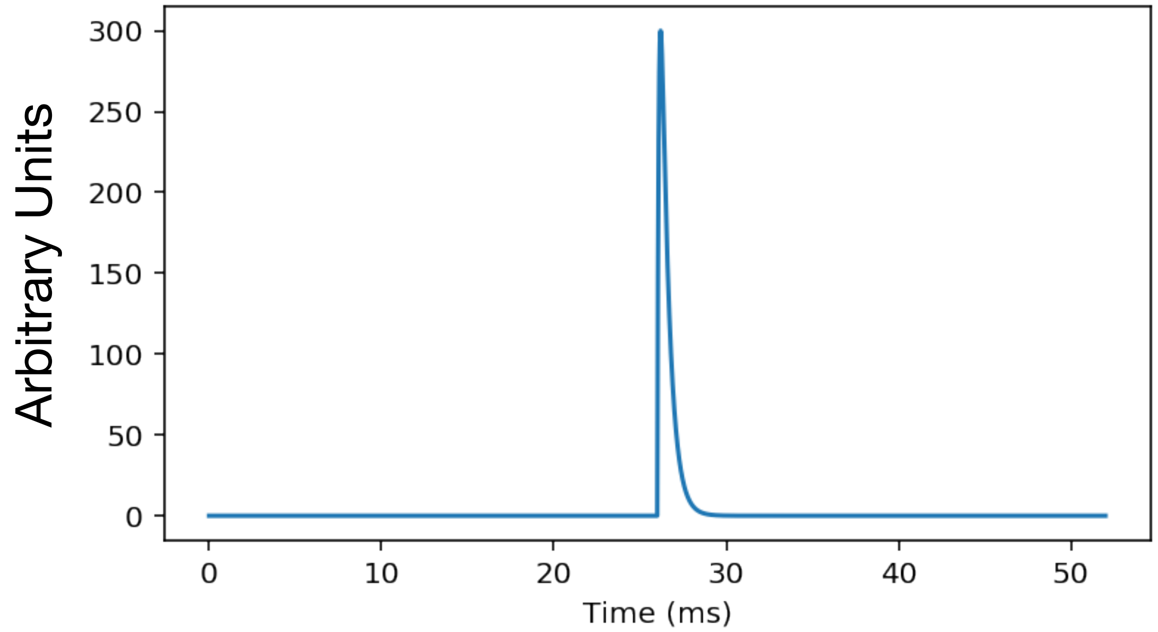
↓

Midas

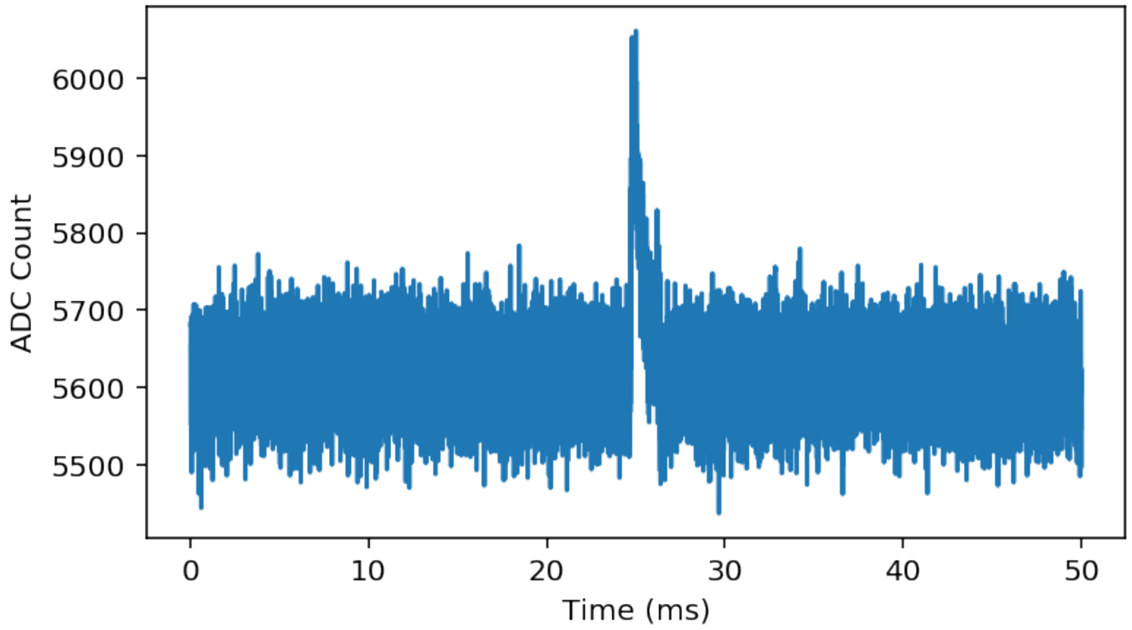
Signal Generator



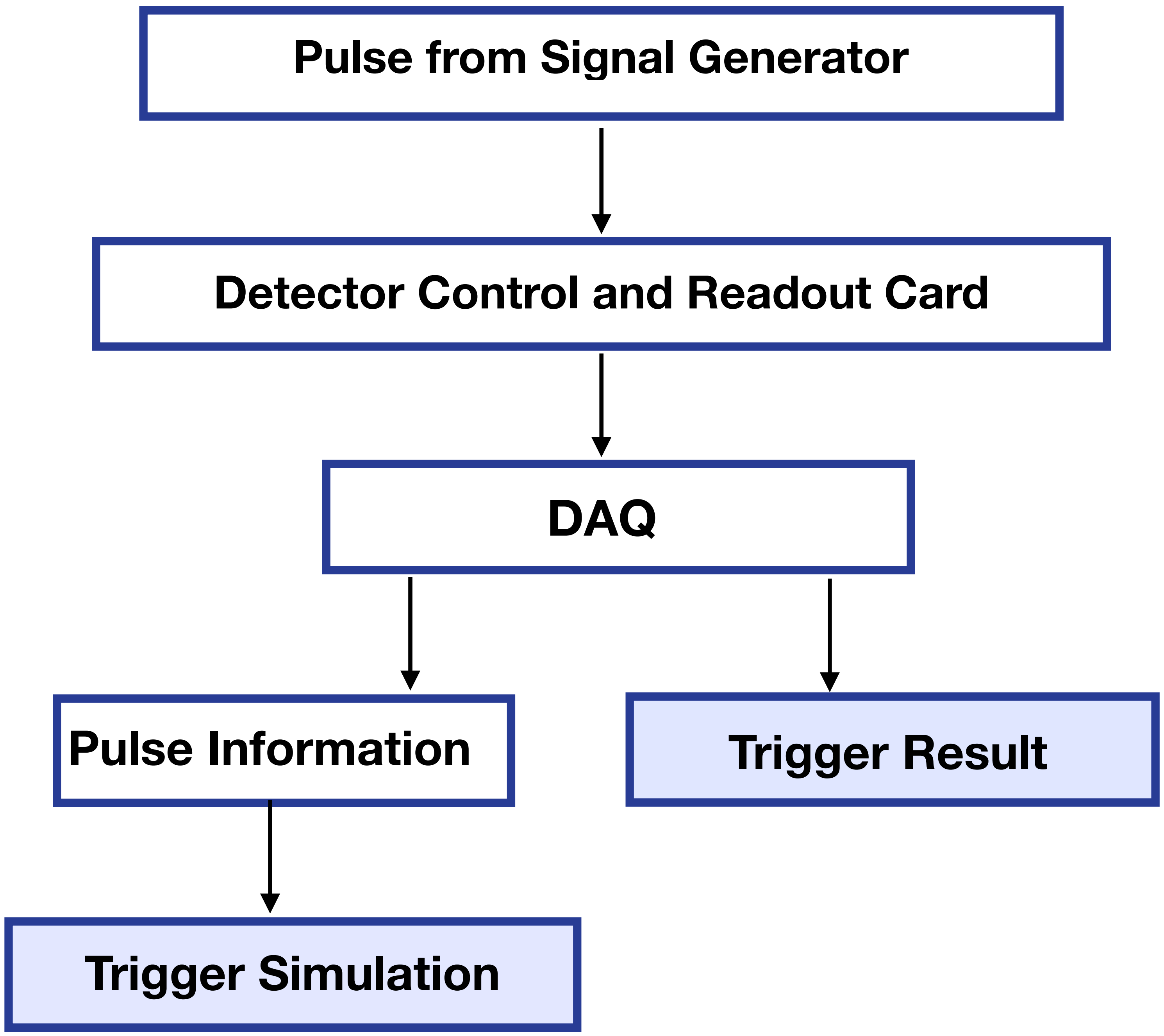
Simulated Low Energy Pulse in the Electronics



Digitized Readout

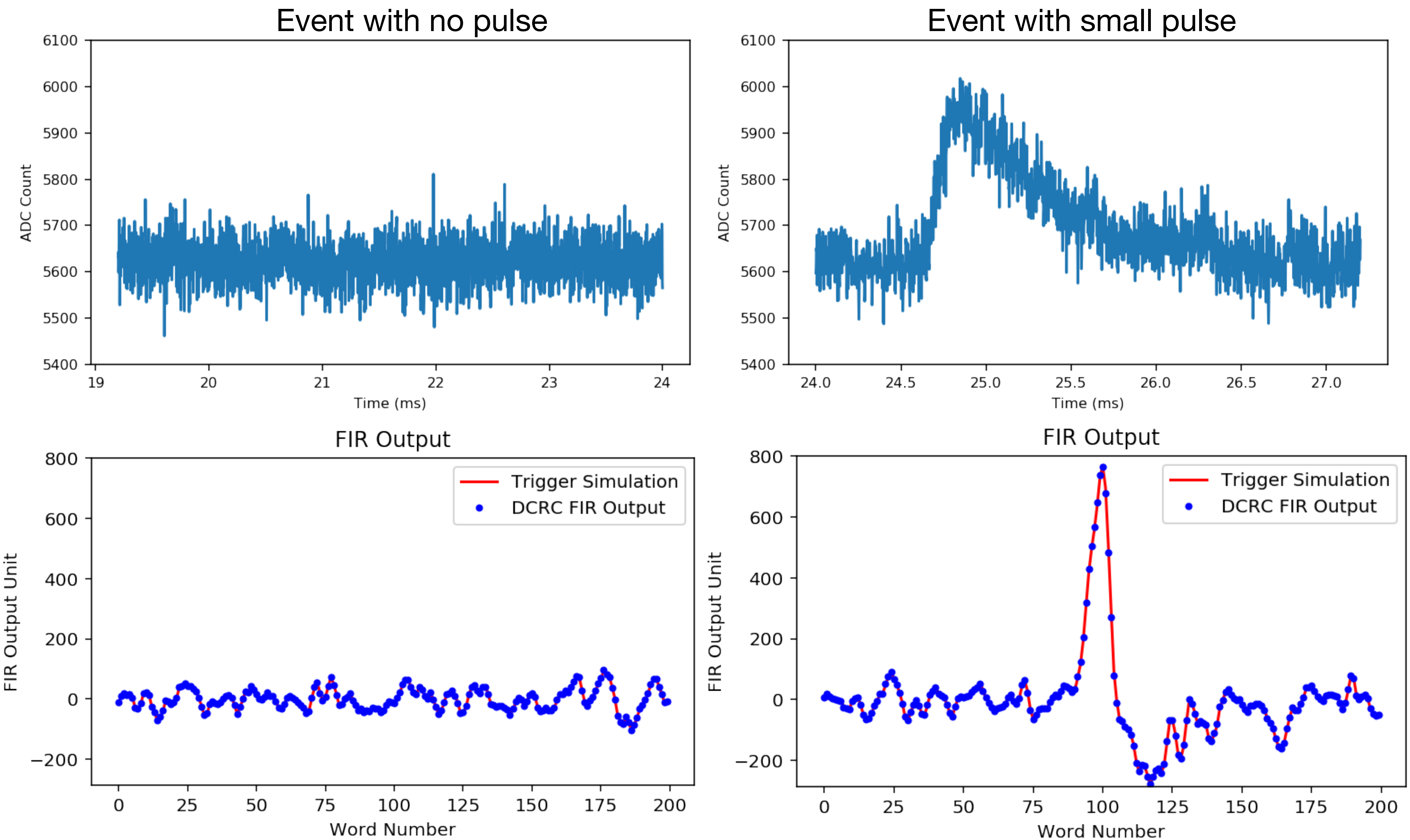


Validate the Trigger Using a Custom Trigger Simulation

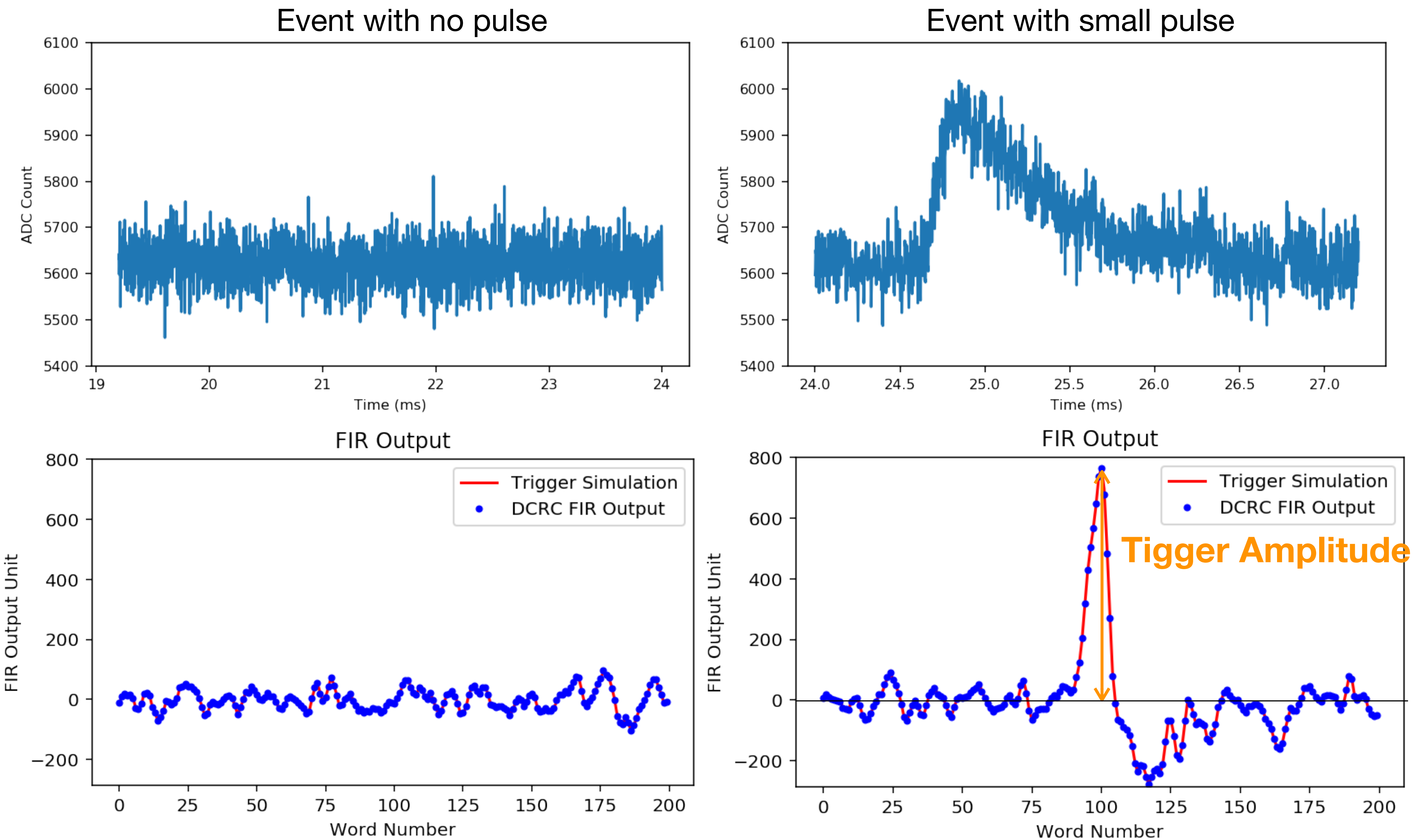


- **We compare real Trigger result with Trigger Simulation result to confirm that Trigger does what it is supposed to do**

Results: Simulating WIMP events and Comparing with Simulation

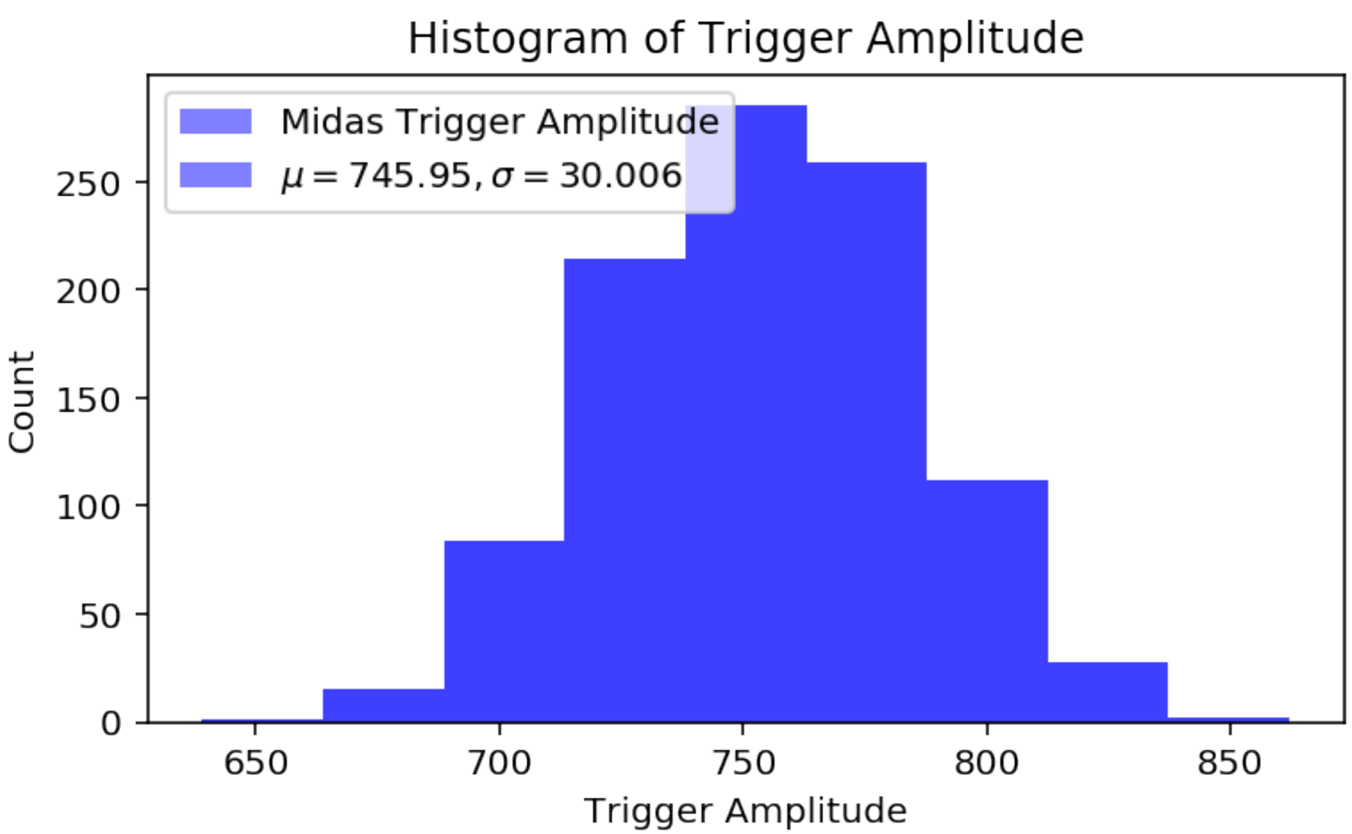


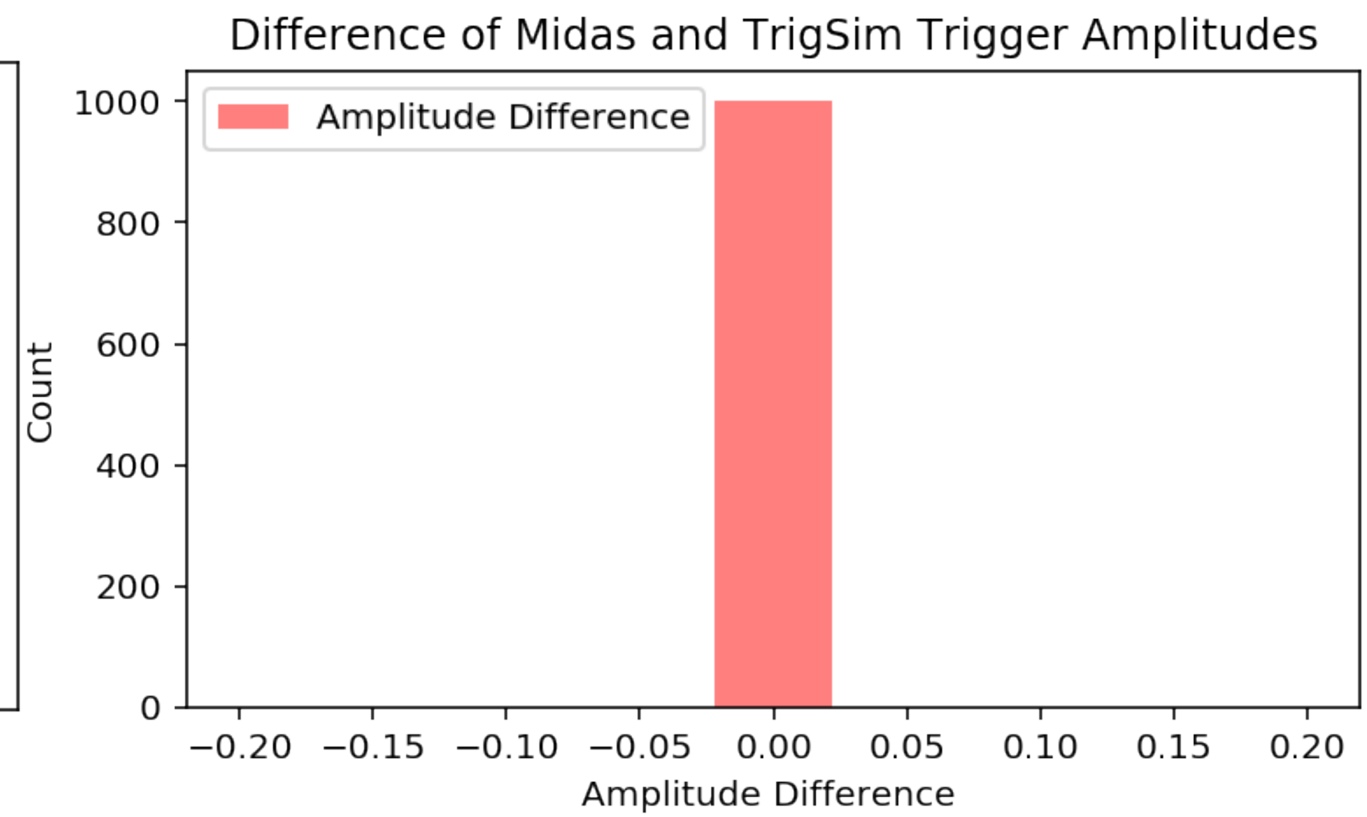
Results: Simulating WIMP events and Comparing with Simulation



Trigger Amplitude Distribution

- **Example of Tigger Amplitude distribution at a low threshold where all of the events pass**
- **1000 identical pulses Injected to the DCRC by the Signal Generator**





How Well is the Trigger Working?

- **Trigger is doing what it is supposed to**

Why Do We See this Variations?

- **Pulse Generator is NOT Perfect**
- **Even if Pulse Generator was perfect we would still see variations in Trigger Amplitude because of Noise**

How well is the Trigger Simulation Working?

- **For all 1000 pulses send to the DCRC, the peak amplitude reported by the real trigger and our trigger simulation are identical**

Trigger Simulation is Reliable!

How to Make This Analysis Quantitative?

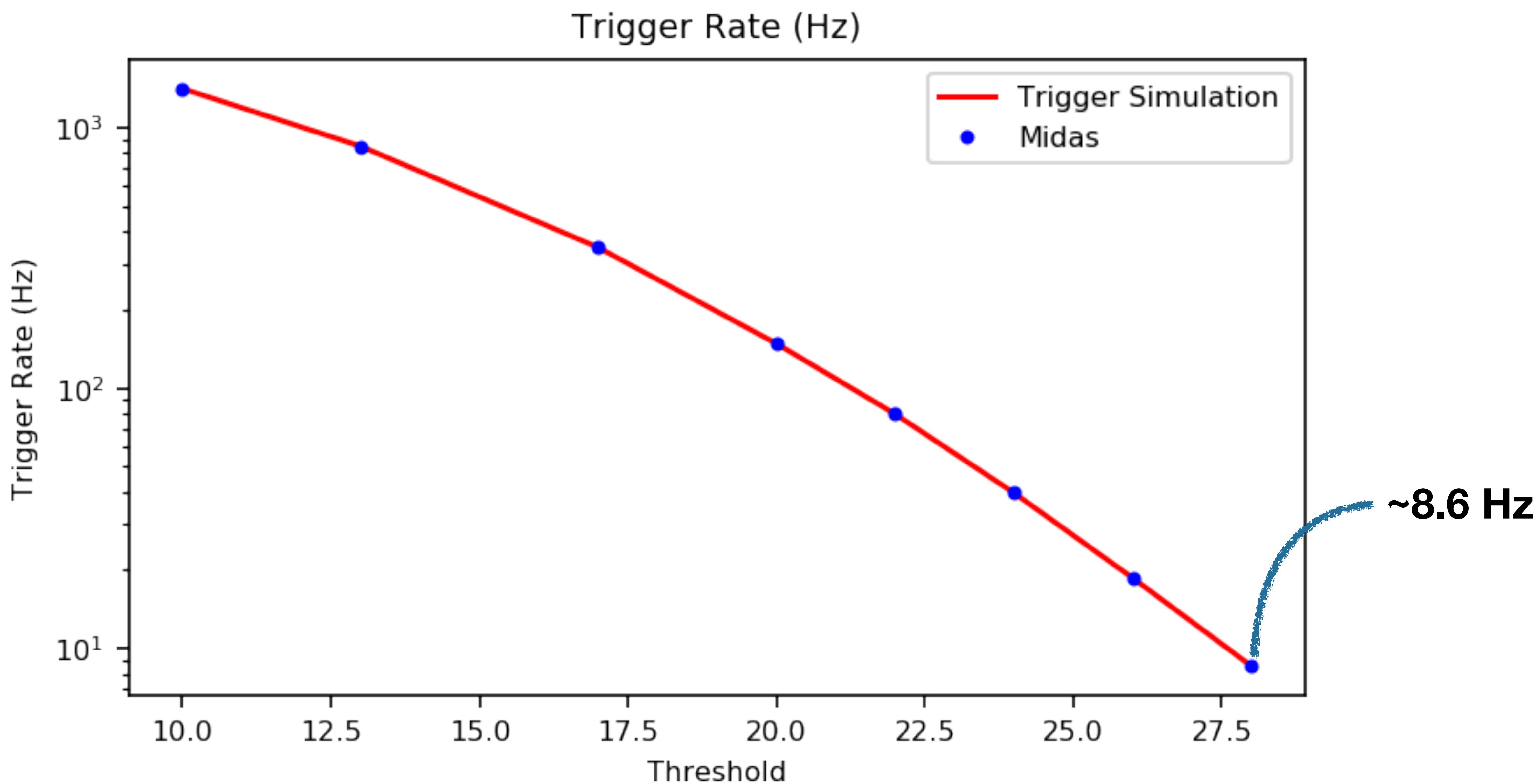
We make the following plots for both Trigger Simulation and Midas Trigger result and compare them.

- **Noise Trigger Rate - Threshold:** Number of times per second when there is no input signal (noise only) but the trigger fires anyway. Do this as a function of Threshold

- **Efficiency - Threshold:** Number of times it triggers/Total number of pulses sent to the DCRC. Do this as a function of Threshold

Trigger Rate - Threshold

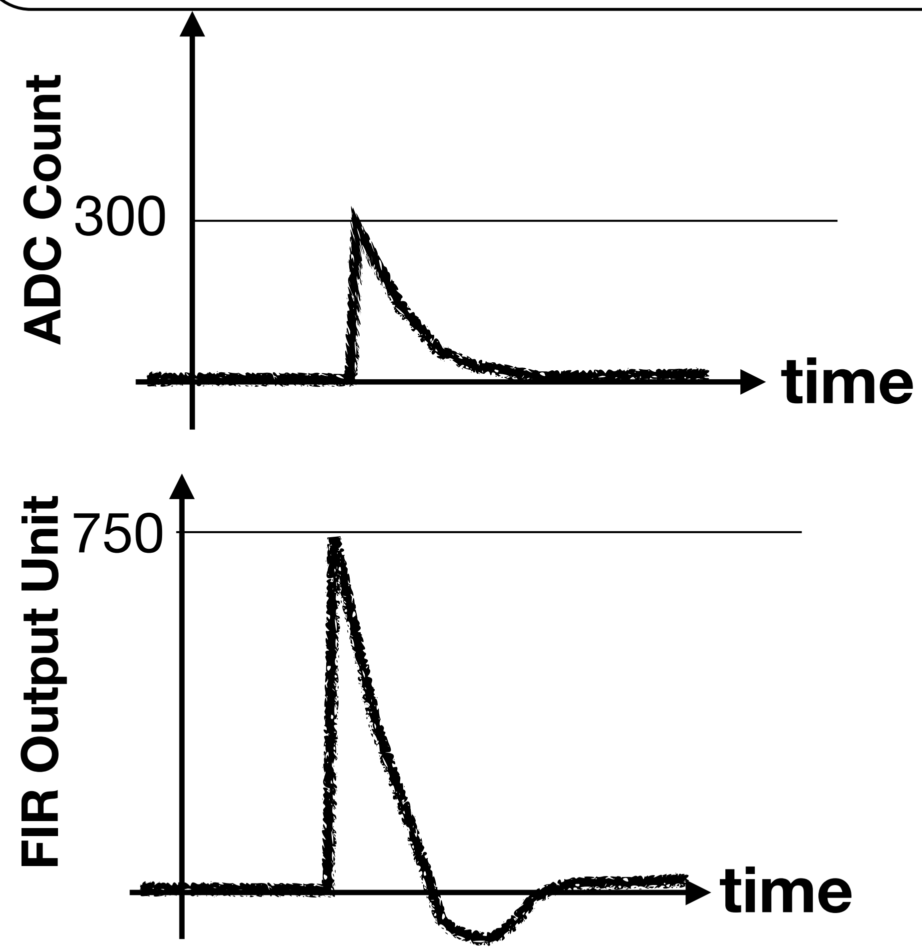
- **No input pulse injected to the DCRC**
- **How many triggers per seconds do we get at each threshold?**
- **Trigger Rate is sharply falling as expected**

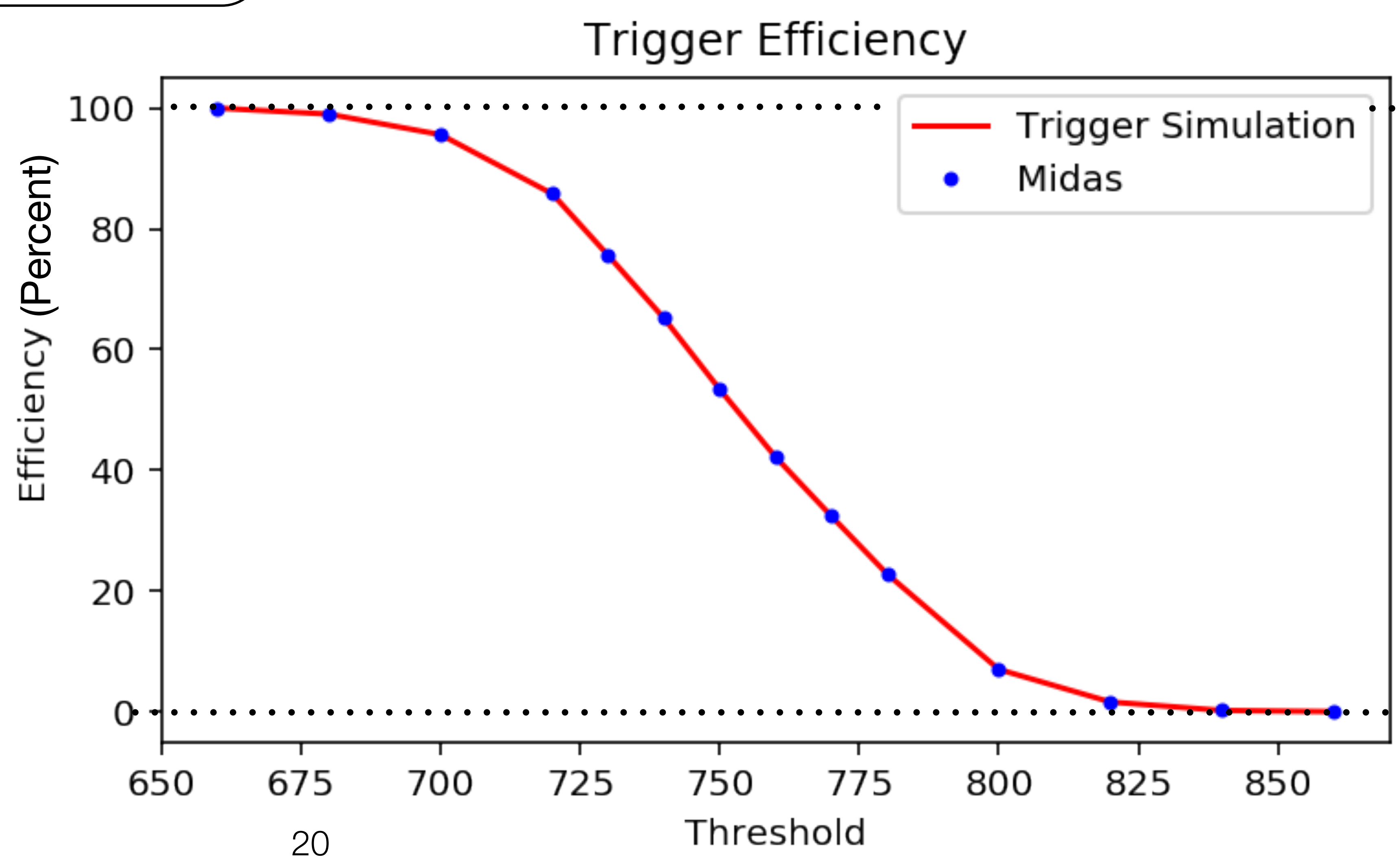


Efficiency - Threshold

- **We change the FIR amplitude required to accept (threshold) and at each step count the number of time the trigger accepts the event**
- **Since there is variation, due to noise, this means that we expect there to be some width to the distribution. This width is NOT a Trigger effect and will be smaller if we have less noise**
- **Trigger Simulation and Midas Trigger Result are identical!**

1000 identical pulses sent to the DCRC





Summary of Trigger and Trigger Simulation Studies

- **Does the Trigger do what it is supposed to do?**
  - **We showed that Trigger Simulation and data agree perfectly. So Trigger is doing what it is programmed to do**
- **How often, when there is no input pulse, do we fire? How does that change as a function of the threshold?**
  - **Noise rate falls rapidly as a function of threshold**
- **How often does the trigger make the right decision? How is this affected by the noise?**
  - **Trigger is doing what it is planned to do. Variations in the Trigger Amplitude are from Noise**

Other Accomplishments and Future Plans

- **Trigger has been working perfectly with real detectors at least for 6 months**
- **The resolution of our trigger appears to be significantly affected by noise. Current electronics at the real experiment should lower the noise, and our simulations indicate that should really help**
- **Next steps:**
    - **Using Trigger in different modes**
    - **Using Trigger Simulation for online monitoring**
    - **Put detectors in the SNOLAB cavern**

Conclusions

- **SuperCDMS is one of the most sensitive Dark Matter Experiments**
- **Robustness of the SuperCDMS Triggering system plays a crucial role in our ability to discover Dark Matter**
- **We have brought a DCRC to TAMU and have simulated inputs from the detector using a pulse generator to test how well the trigger works**
- **By comparing real Trigger data to Trigger Simulation we made sure that they agree perfectly and Trigger Simulation is reliable**
- **We confirmed that Trigger is working as expected**
- **We are excited to have SNOLAB SuperCDMS data in late 2020**