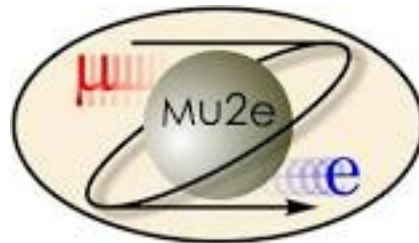


# Timing Calibration Efforts in Cosmic Ray Veto for Mu2e Experiment

Payton Beeler

**KANSAS STATE**  
UNIVERSITY

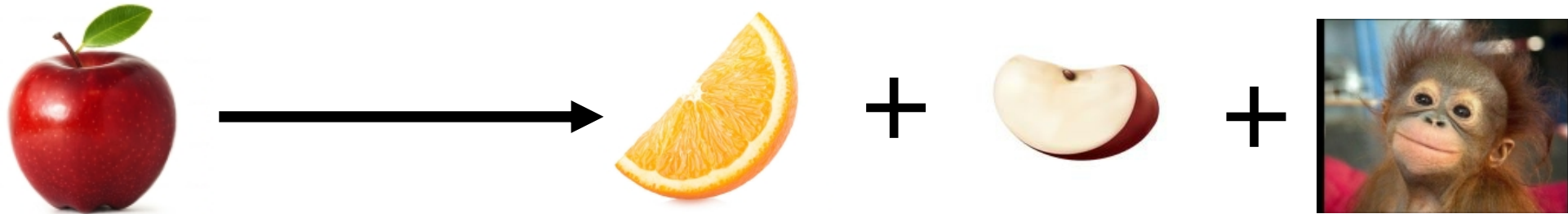


**WESTMINSTER**  
COLLEGE

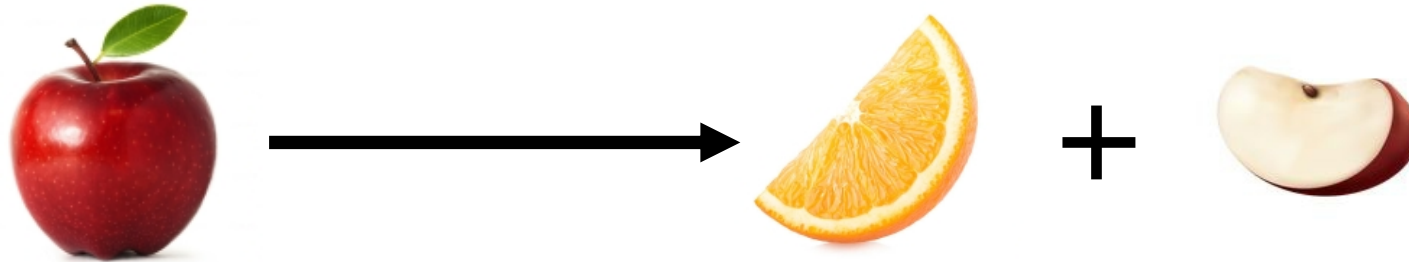
# Standard Model

- Charged lepton flavor violation
- Why is it important?
  - Breaks standard model

# How it's supposed to work



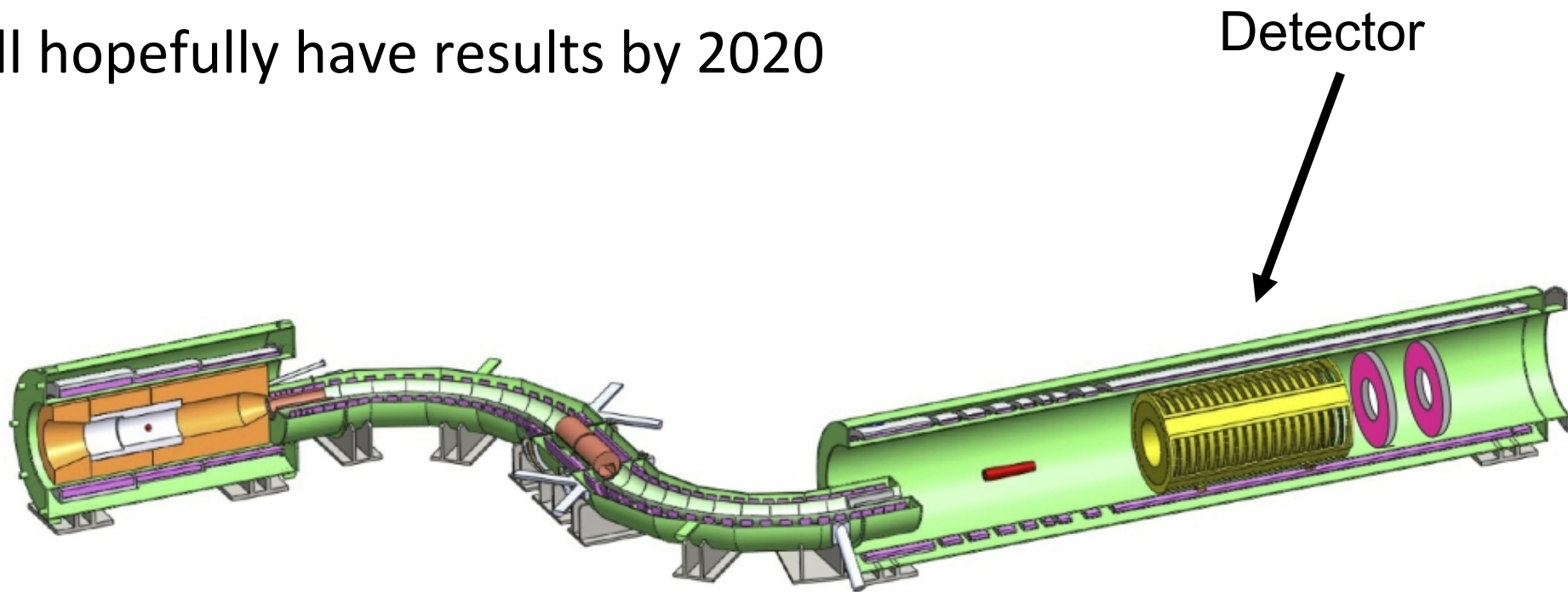
# How it actually works (maybe)



Why is this important? Means that the standard model needs some work.

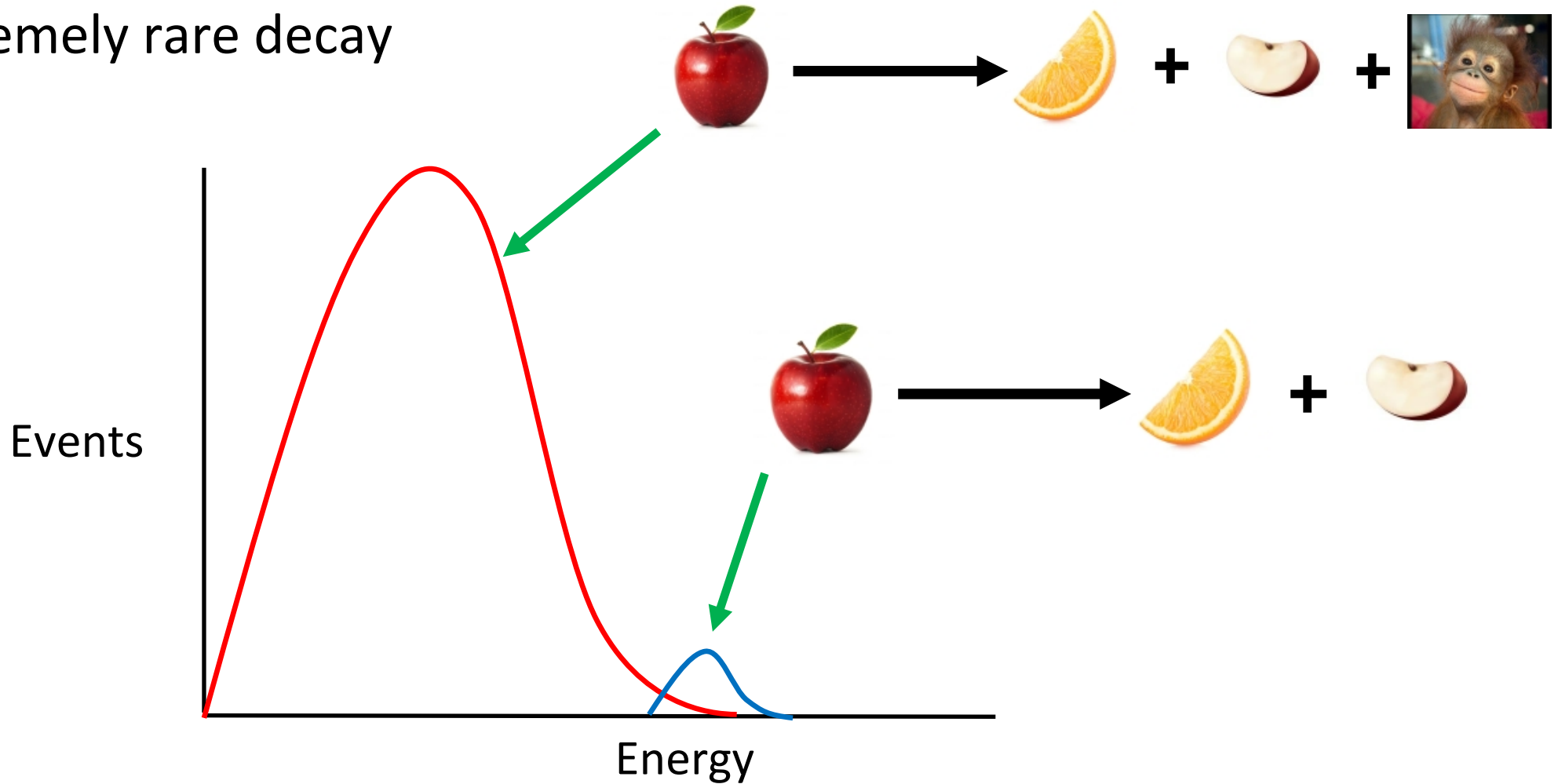
# Mu2e

- Run by Department of Energy
- Located in Batavia, Illinois
- Will hopefully have results by 2020



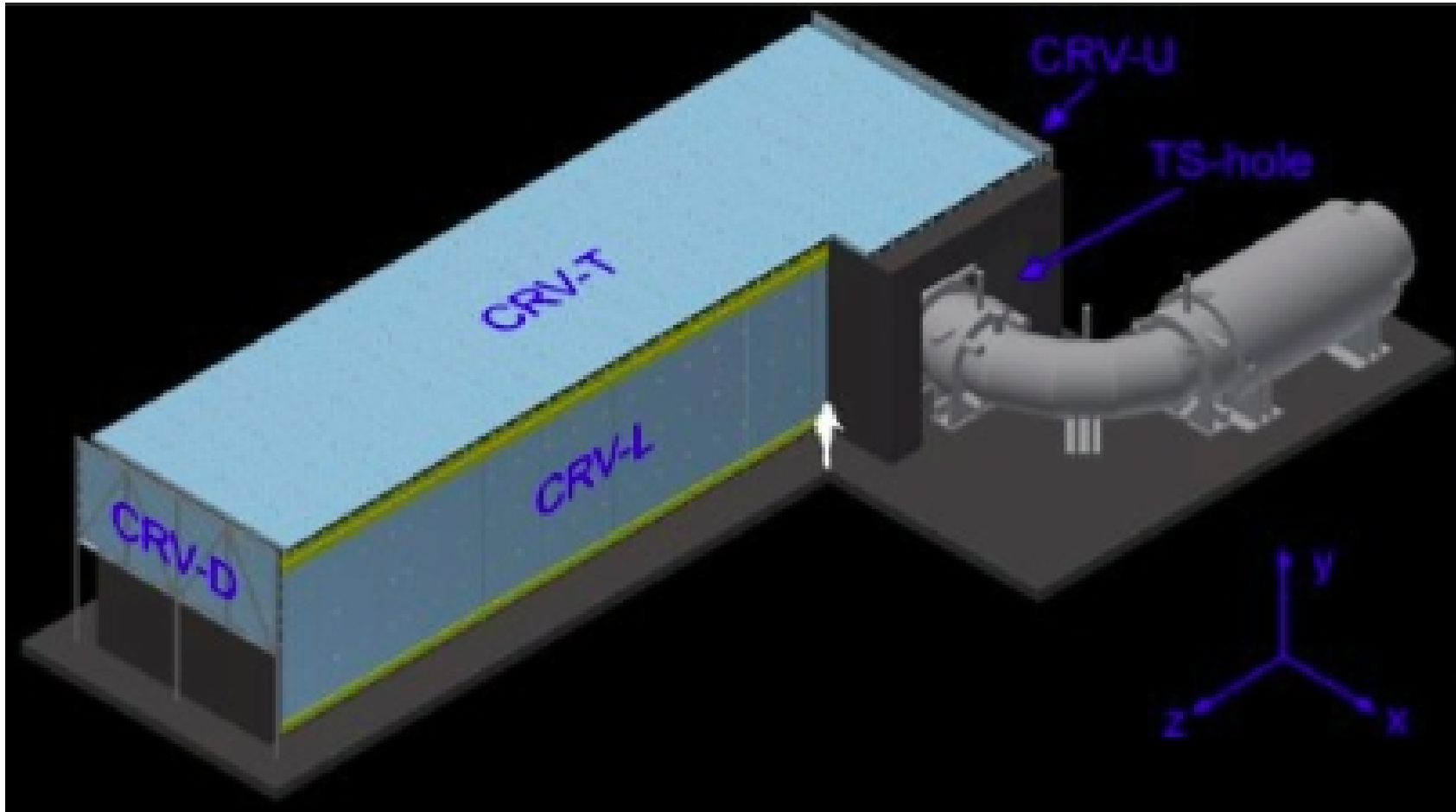
# Resolution Problems

- Extremely rare decay



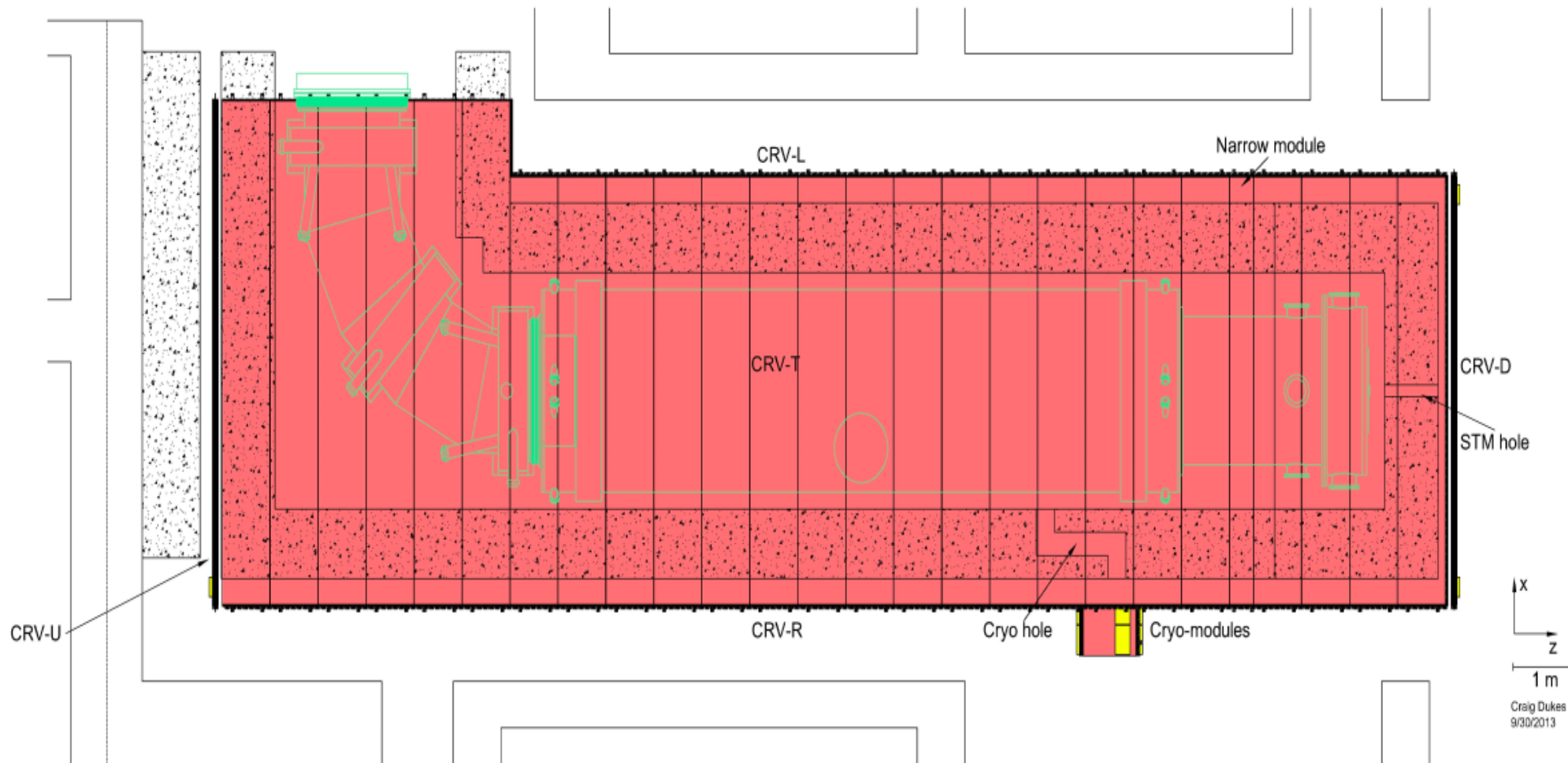
**PROBLEM: it's raining apples**

# Solution: Cosmic Ray Veto (CRV)



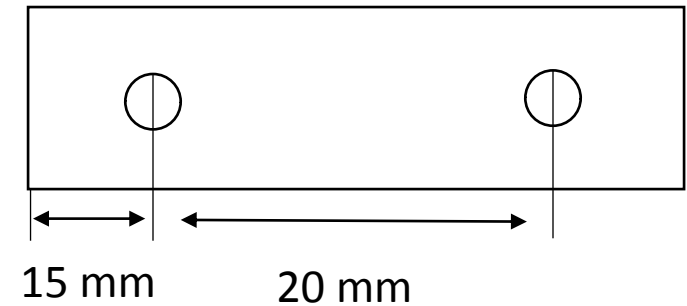
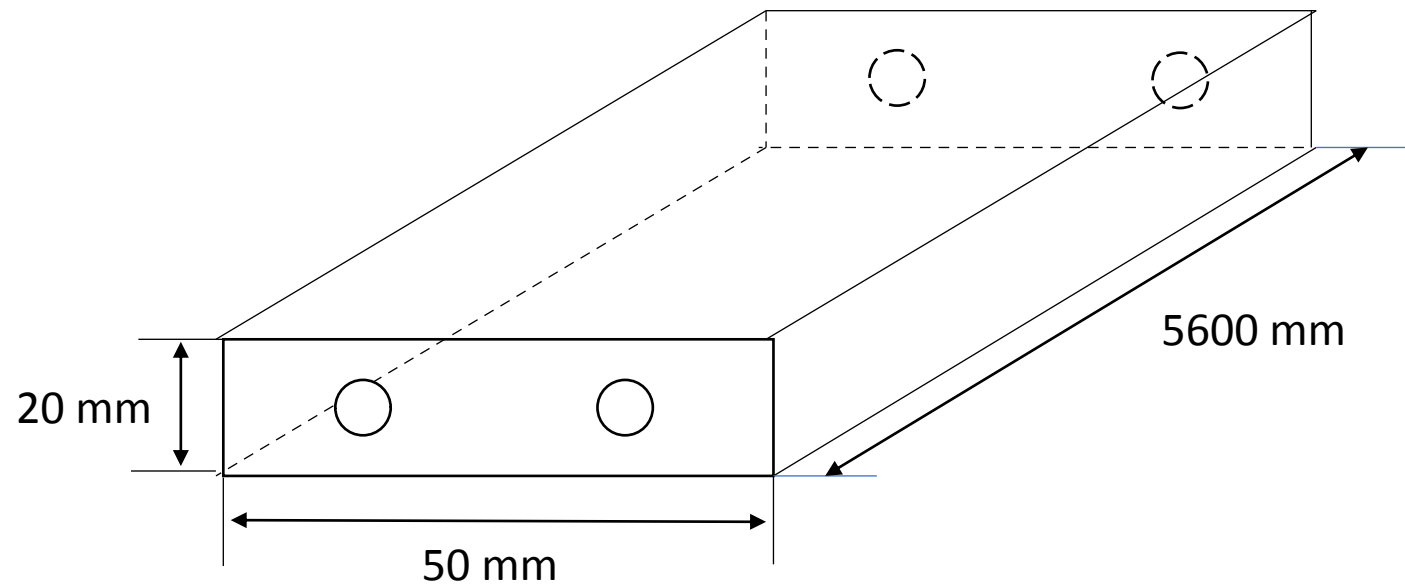


# Layout

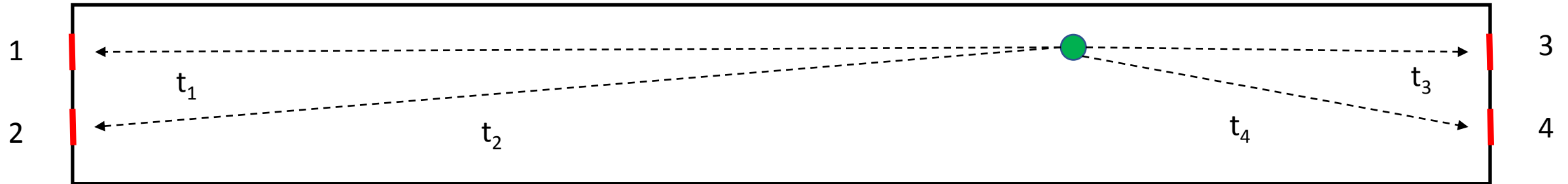


# Counters

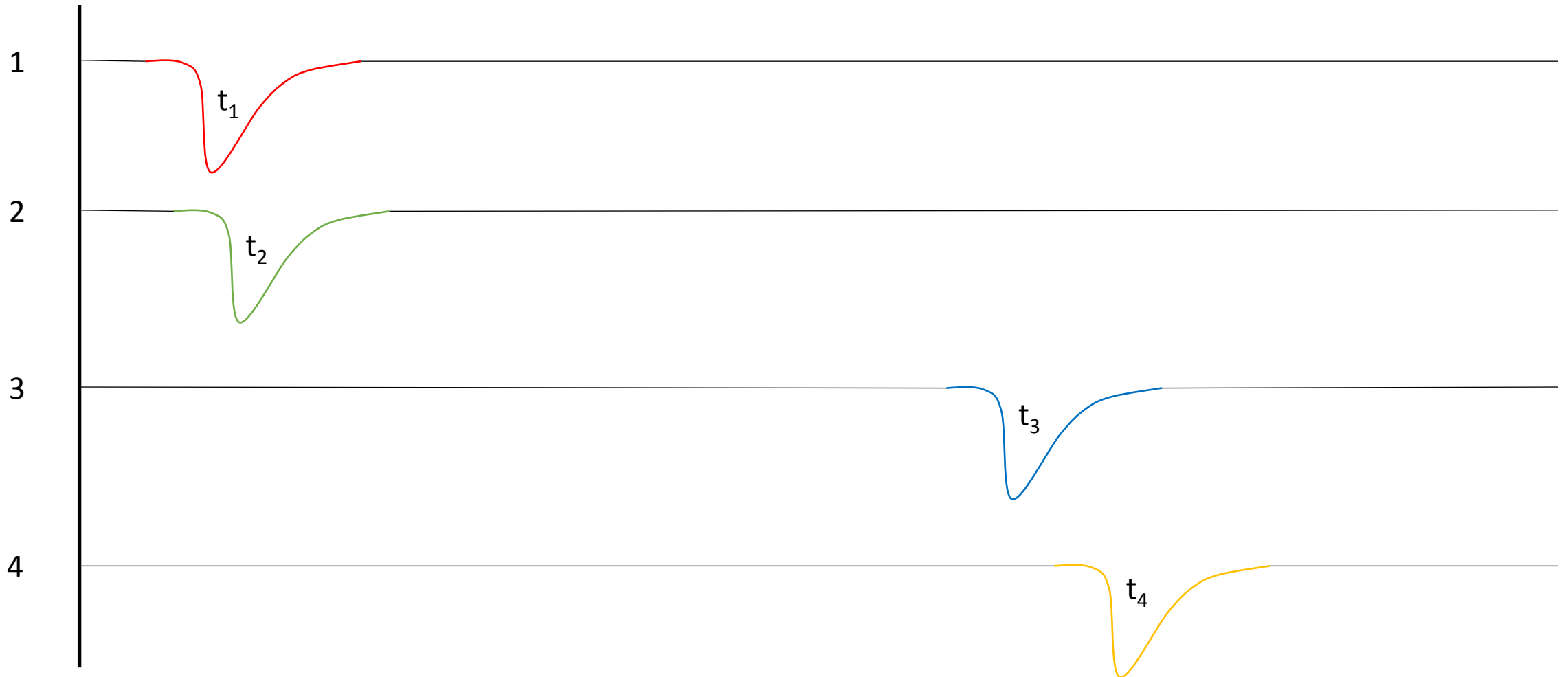
- 1,632 on CRV-T
- 4 fibers run through each
- Fibers connect to SiPMs



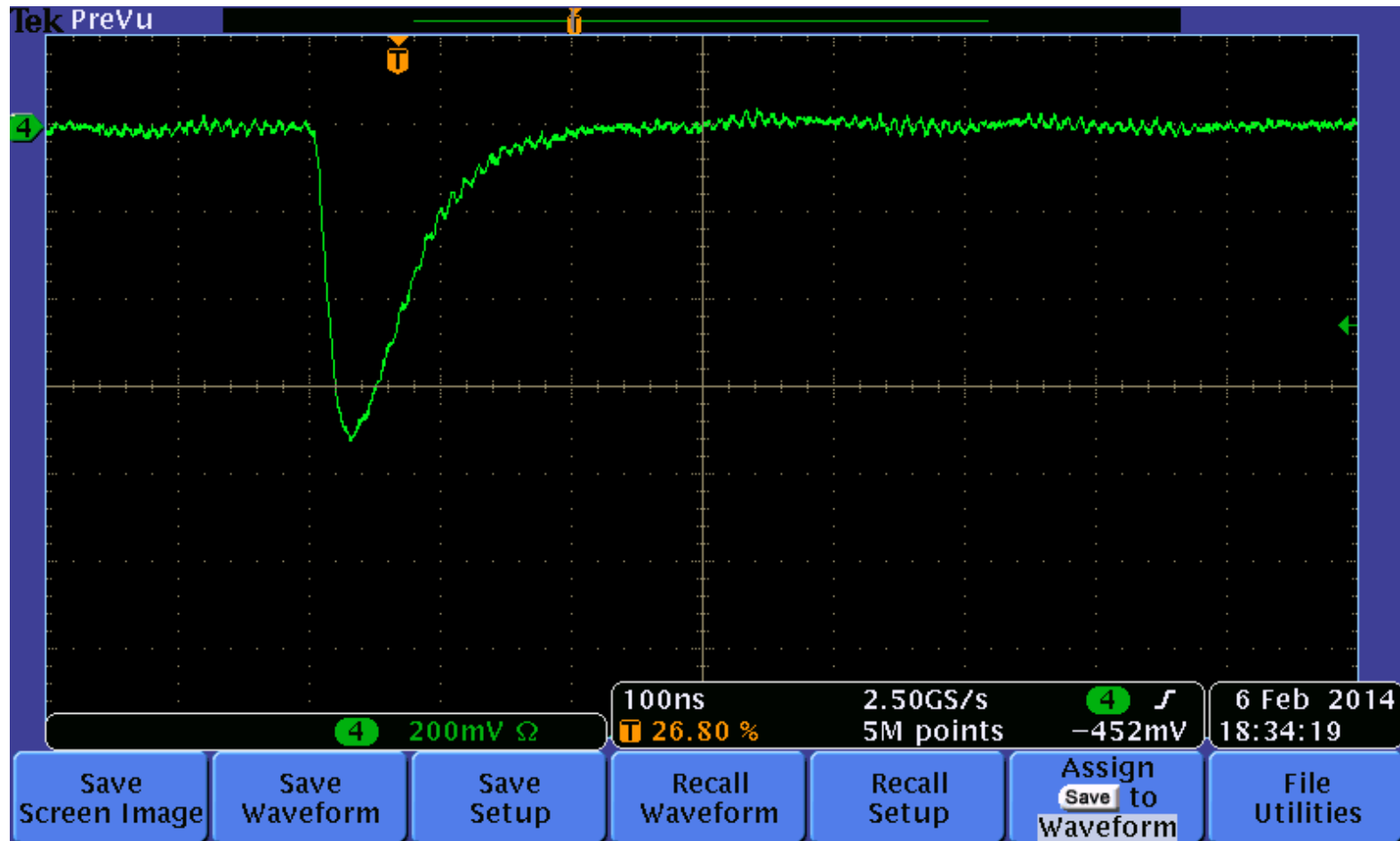
# Noise Problems



# Oscilloscope Readout (ideal world)



# Oscilloscope Readout (real world)



Timing error  $\approx \pm 300$  ps

# Method

- Shoot cosmic ray at specific point in counter
- Find theoretical time it takes to get to detector
- Introduce error to theoretical time to simulate measured time
- Try to get original position from simulated time using chi squared test

# Method

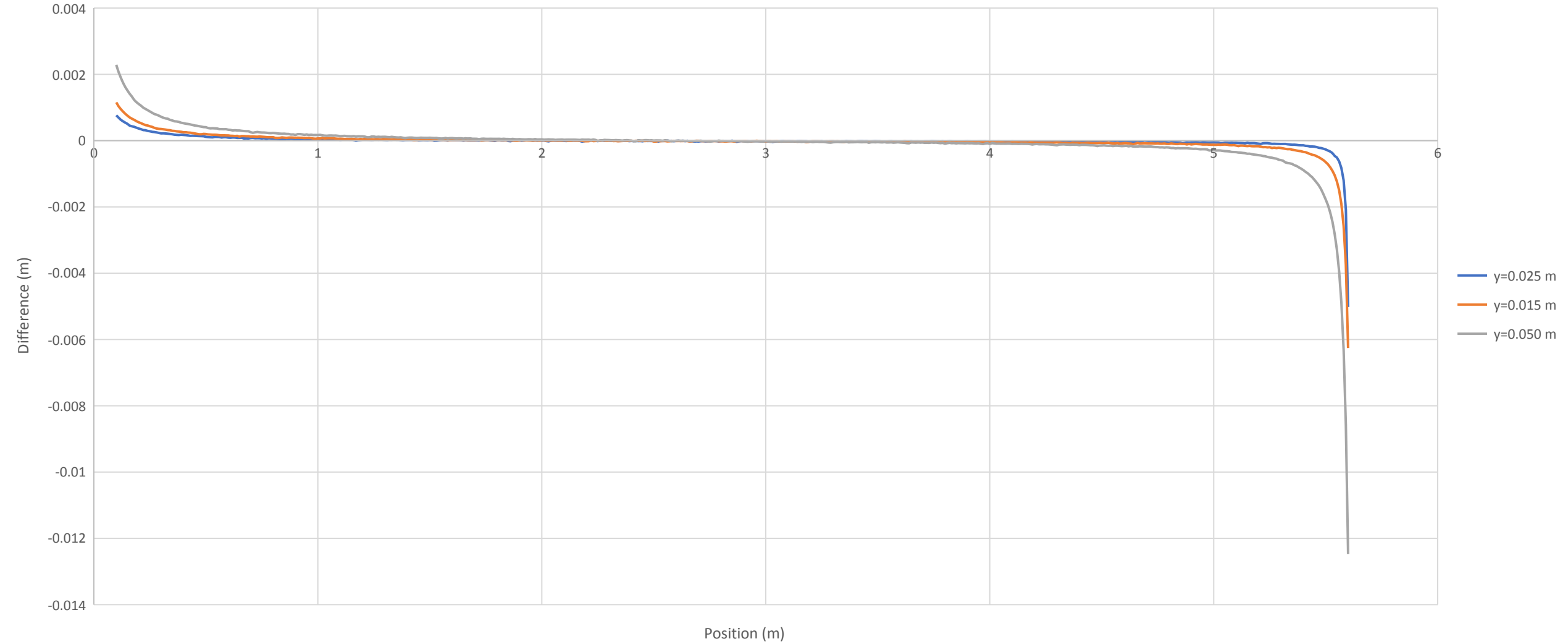
$$X^2 = \left[ \left(t_1 - \frac{z}{v}\right)^2 + \left(t_2 - \frac{z}{v}\right)^2 + \left(t_3 - \frac{L-z}{v}\right)^2 + \left(t_4 - \frac{L-z}{v}\right)^2 \right] \frac{v}{z}$$

$$\frac{\partial X^2}{\partial z} = 0$$

$$z^2 = \frac{2L^2 - 2Lt_3v - 2Lt_4v + t_1^2v^2 + t_2^2v^2 + t_3^2v^2 + t_4^2v^2}{4}$$

# Results

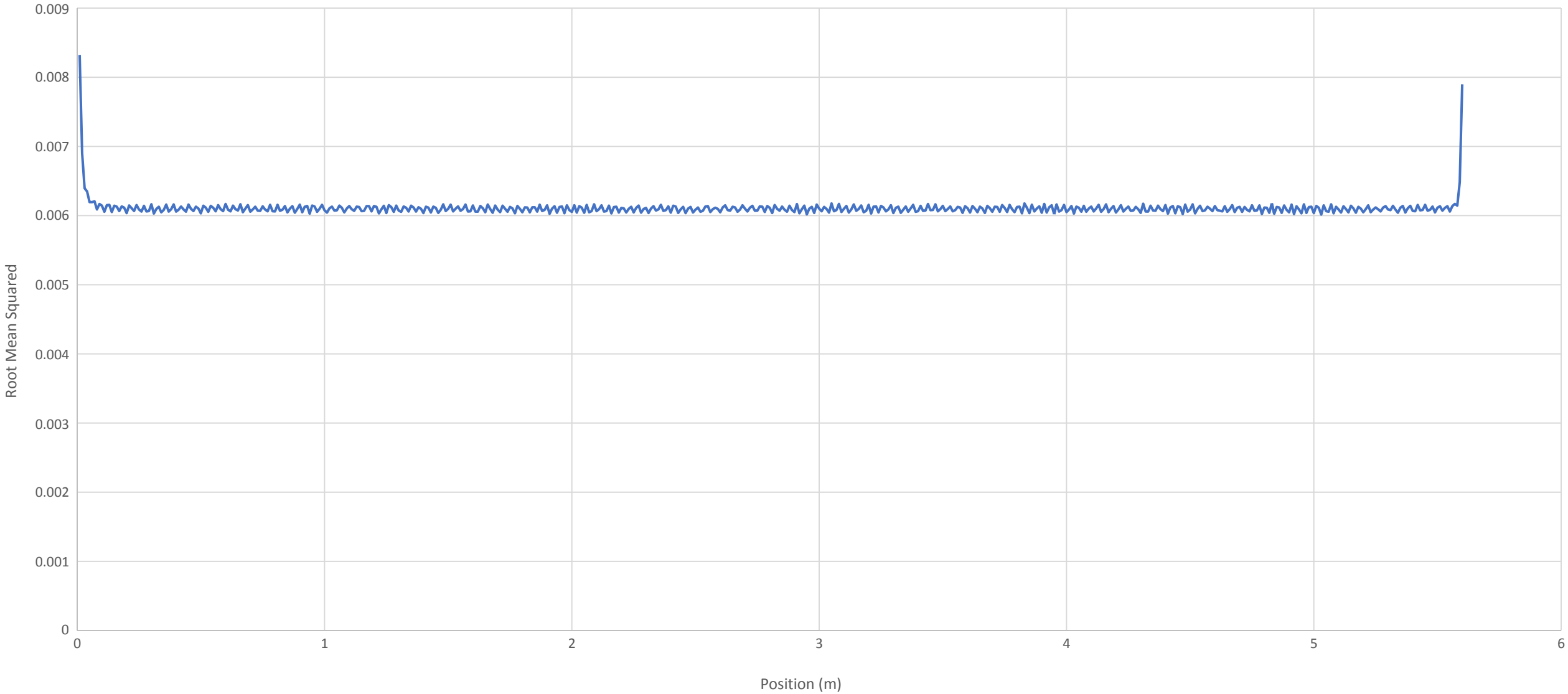
Average Difference vs. Position





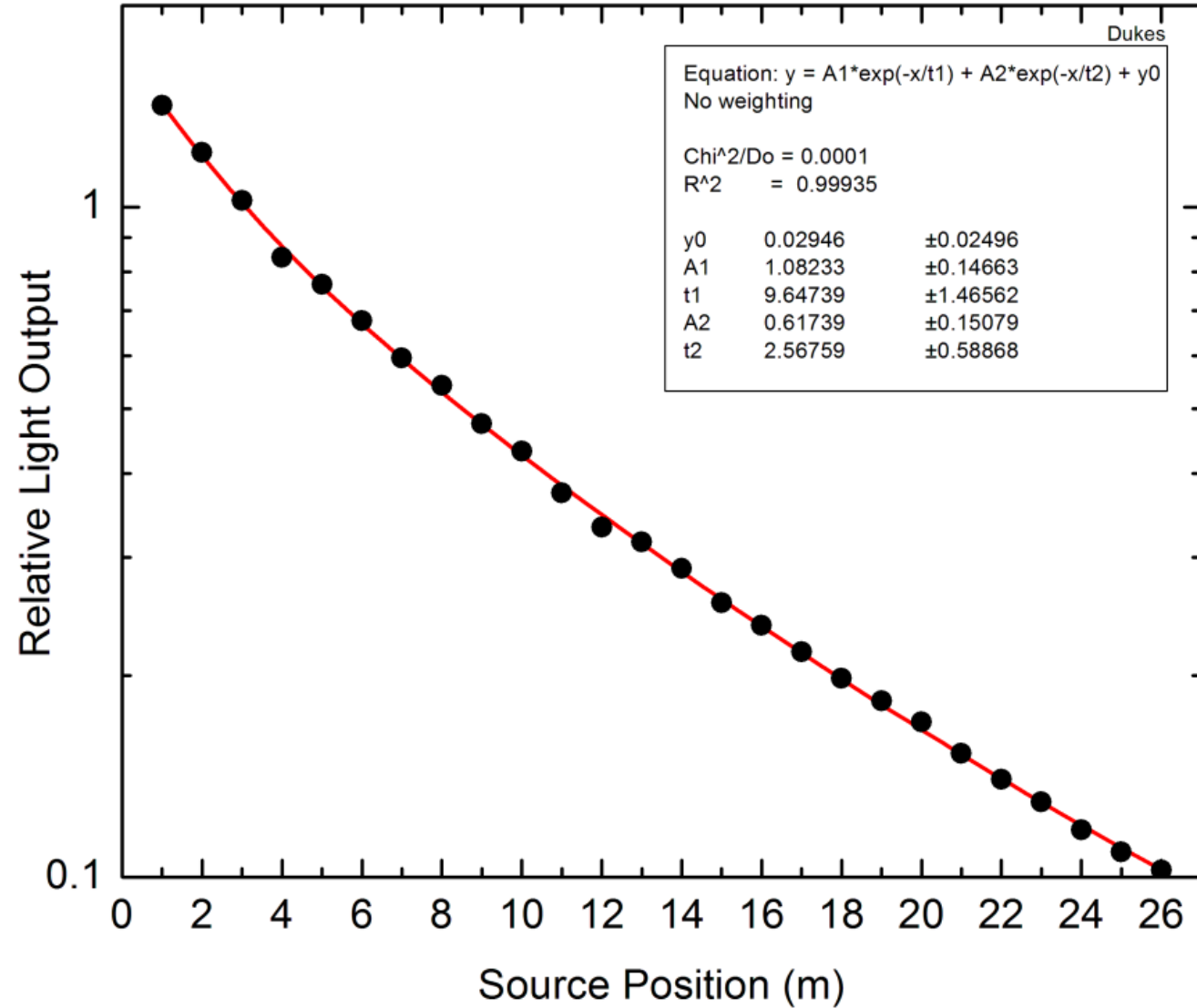
# Results

RMS vs Position



# Next Problem

- Attenuation
- Amplitudes

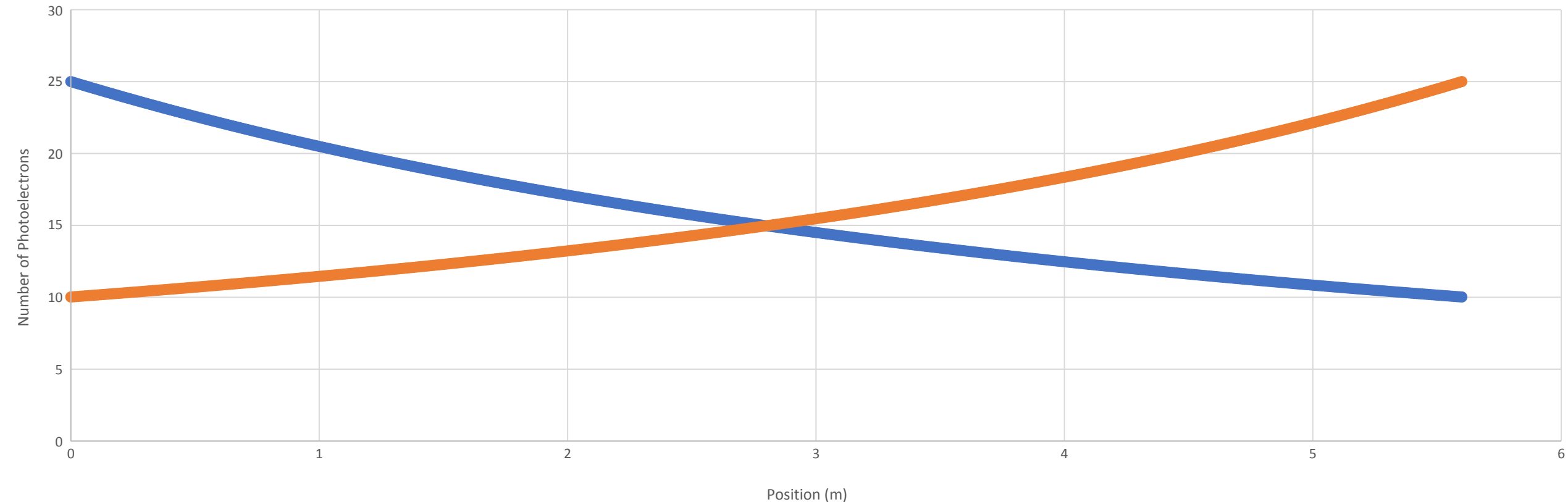


# Scenario

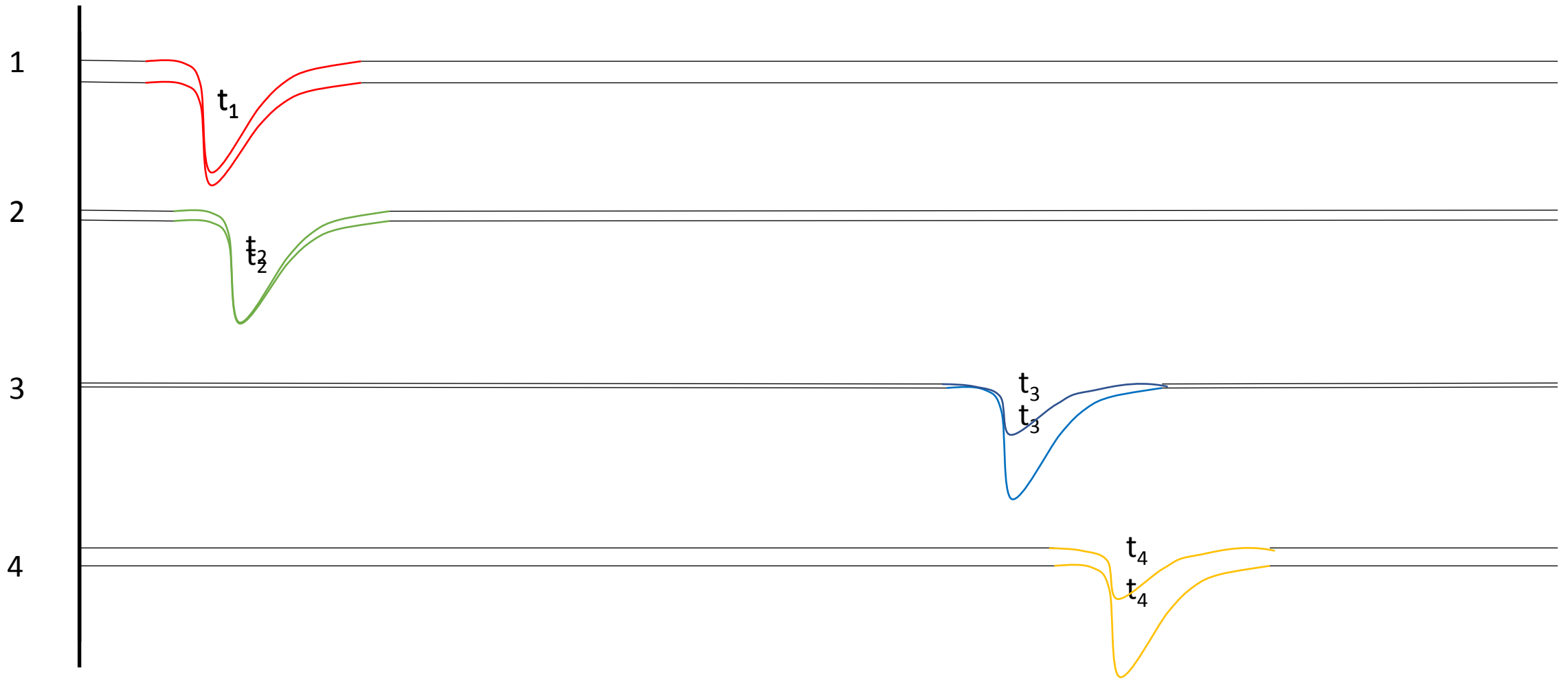
- When a cosmic ray hits the polystyrene 25 photoelectrons come out

Number of Photoelectrons vs. Position

● Number of PE to Counters 1 and 2 ● Number of PE to Counters 3 and 4

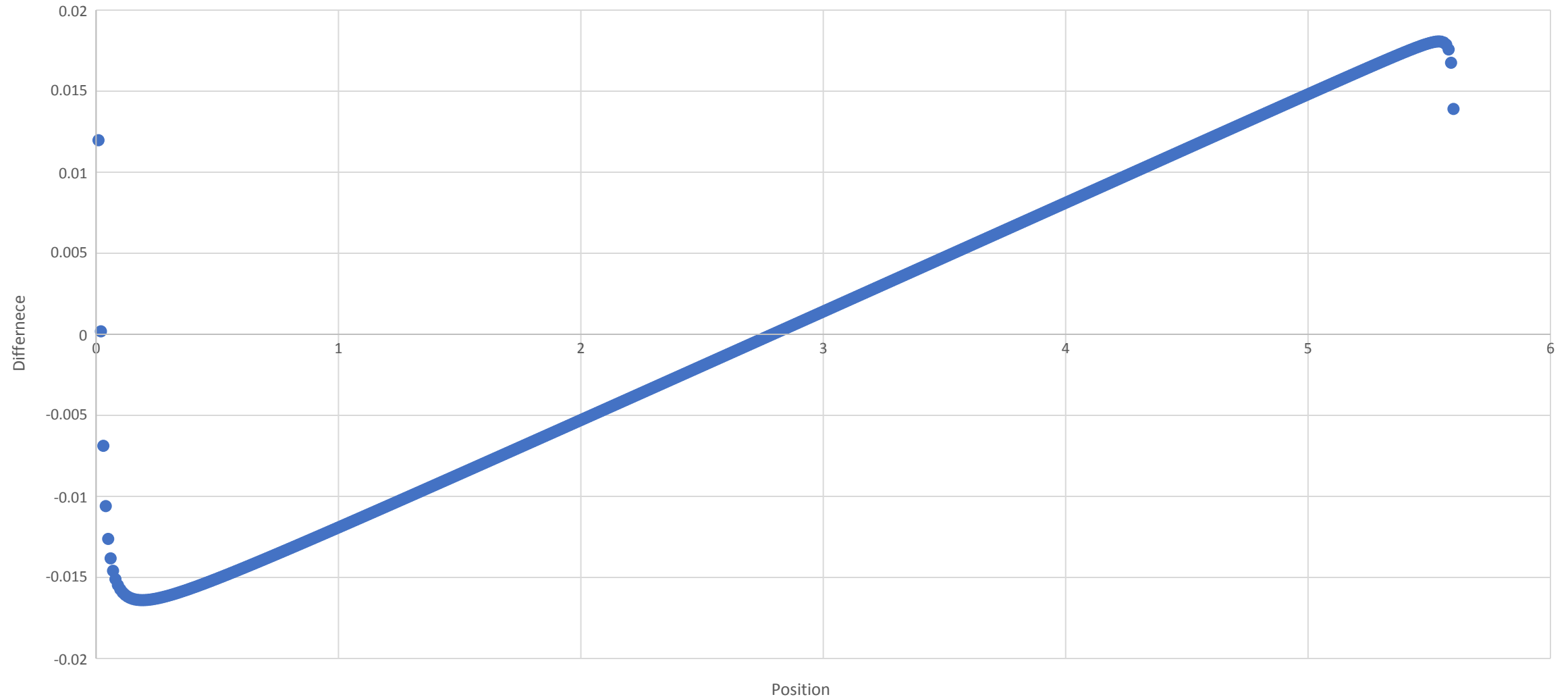


# Oscilloscope Readout



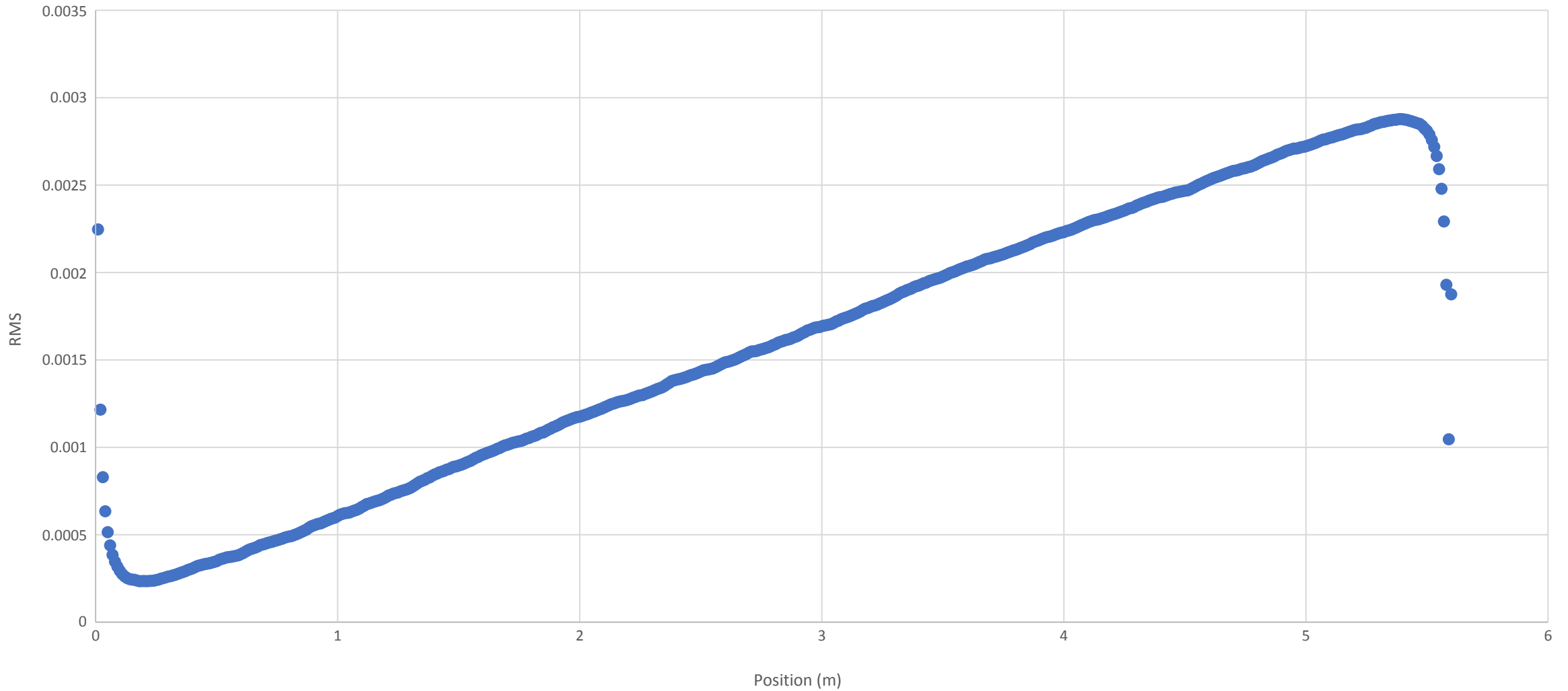
# Results

Difference vs Position



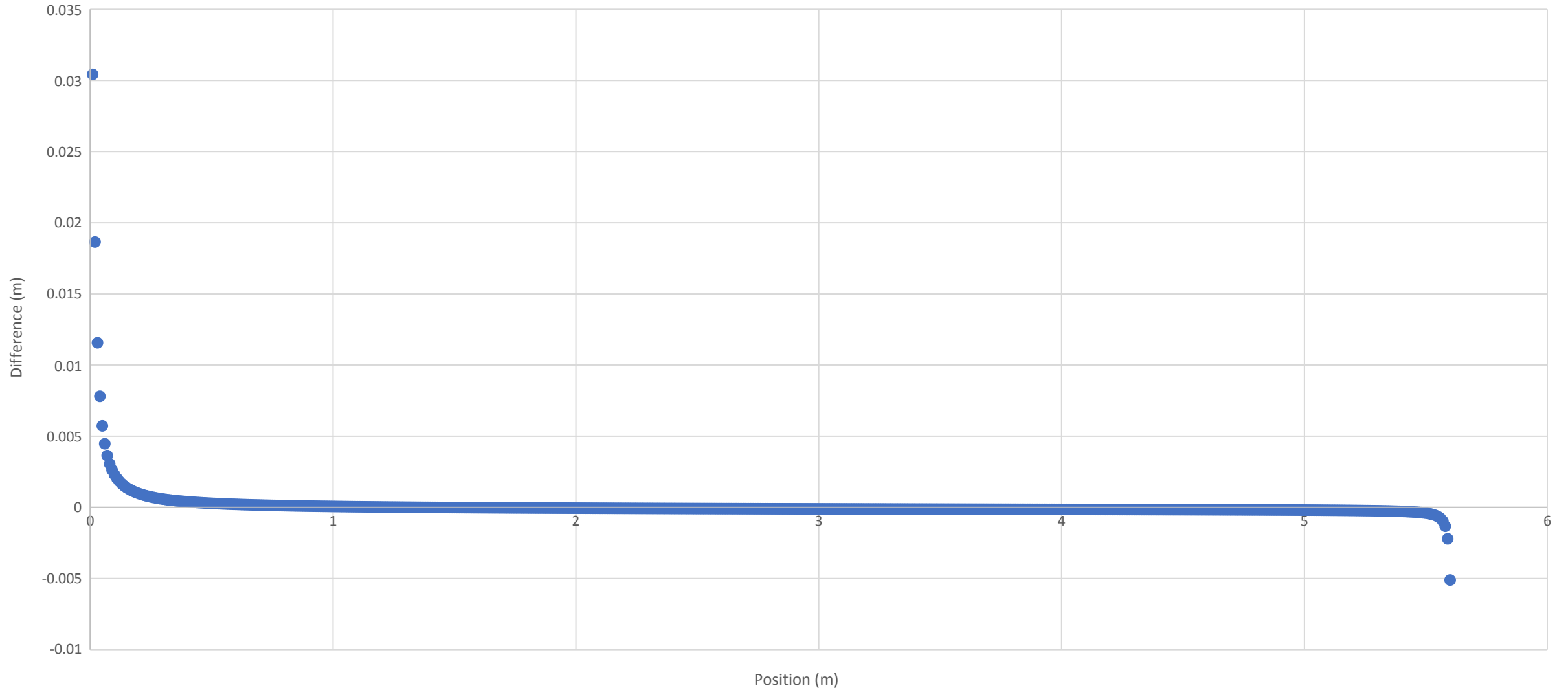
# Results

RMS vs Position



# Results

Difference vs Position



# Acknowledgements

- Big thanks to Glenn Horton-Smith and Tim Bolton for allowing me to work with them this Summer
- Thank you to the NSF for funding