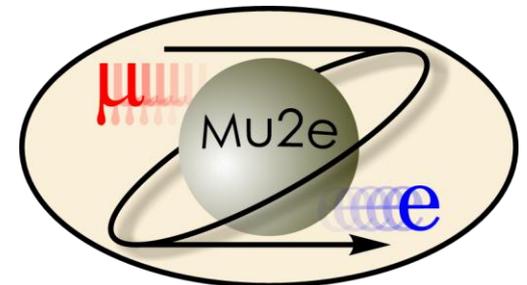


Straw Time Division, a Case Study on ADCs, and the Mu2e Toolkit

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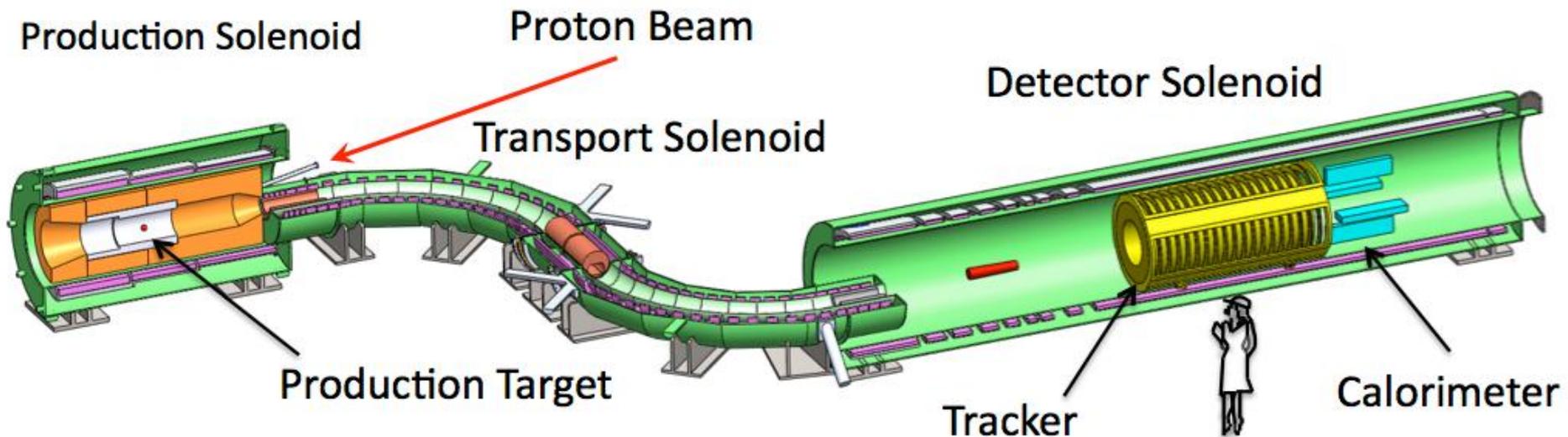


Outline

- Mu2e and straws
- Time division
- ADC Simulations
- Mu2e Toolkit

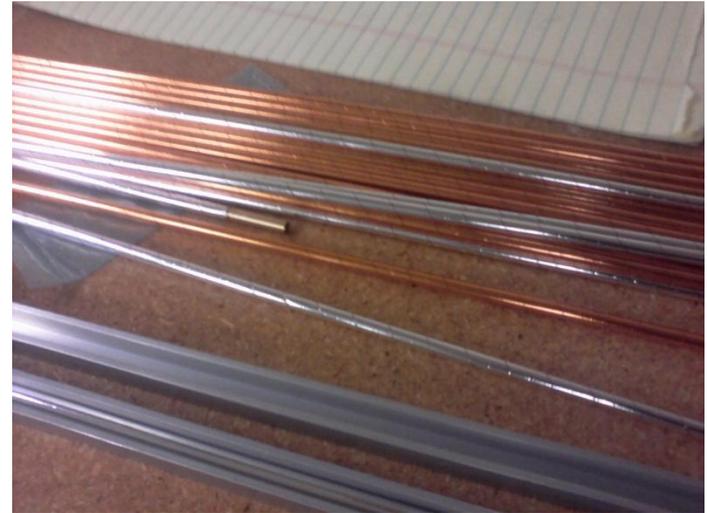
Mu2e

- Muons most often decay into an electron and two neutrinos: muon neutrino and electron-antineutrino
- Mu2e is searching for a muon that will decay directly into an electron at 105 MeV
- Employs the use of drift chambers to track the particles trajectory



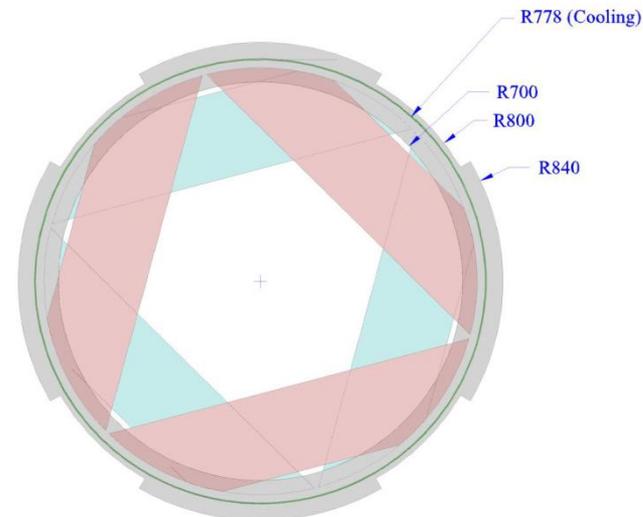
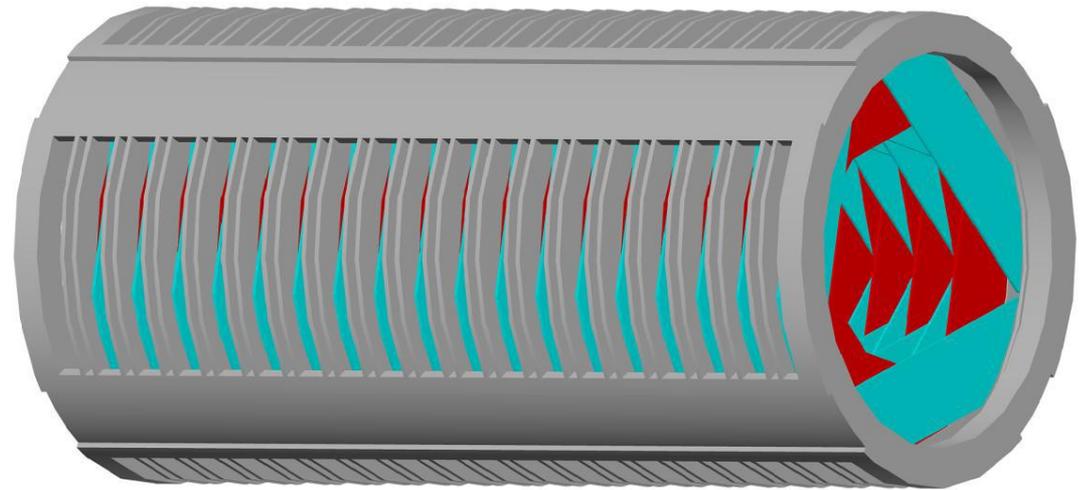
Straws

- Mu2e employs the use of drift chambers, referred to as straws, to track the trajectory and mass of particles
- These straws are made out of Mylar®, have a radius of 2.5mm, vary in length from 334mm to 1174mm, have a 25 μ m sense wire at \sim 1500V, and are filled with gas at 80% Argon 20% CO₂
- Particle hits the straws, ionizes the gas inside, electrons bump into molecules, they ionize as well which causes an avalanche effect, and the electrons get pulled towards a high voltage wire in the middle of the straw where the signal gets picked up by a pre-amplifier circuit



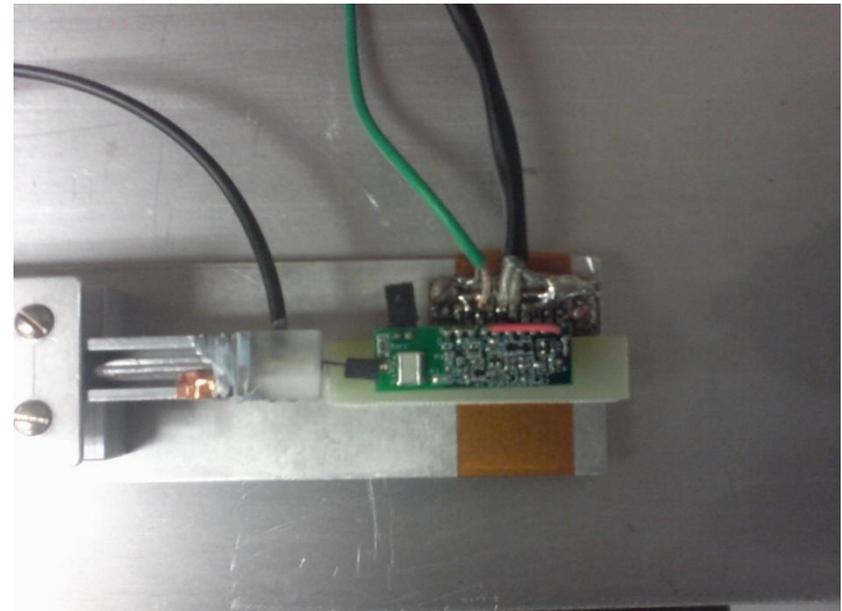
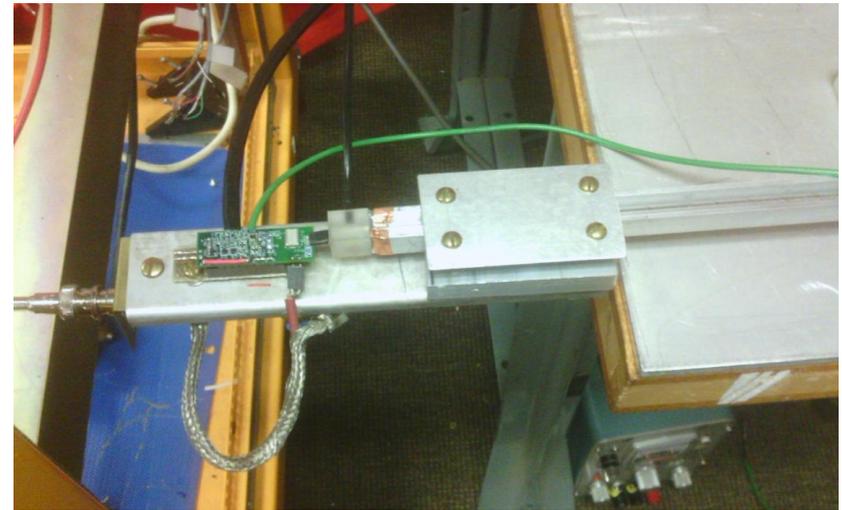
The Tracker

- Cylinder structure
- Contains ring sections holding the straws
- Entire tracker contains 21,600 straws



Time Divison

- At each end of the straw is a preamp circuit
- Signal reaches preamp, you calculate the difference in time of arrival, and you get a position at which the particle entered



Time Division

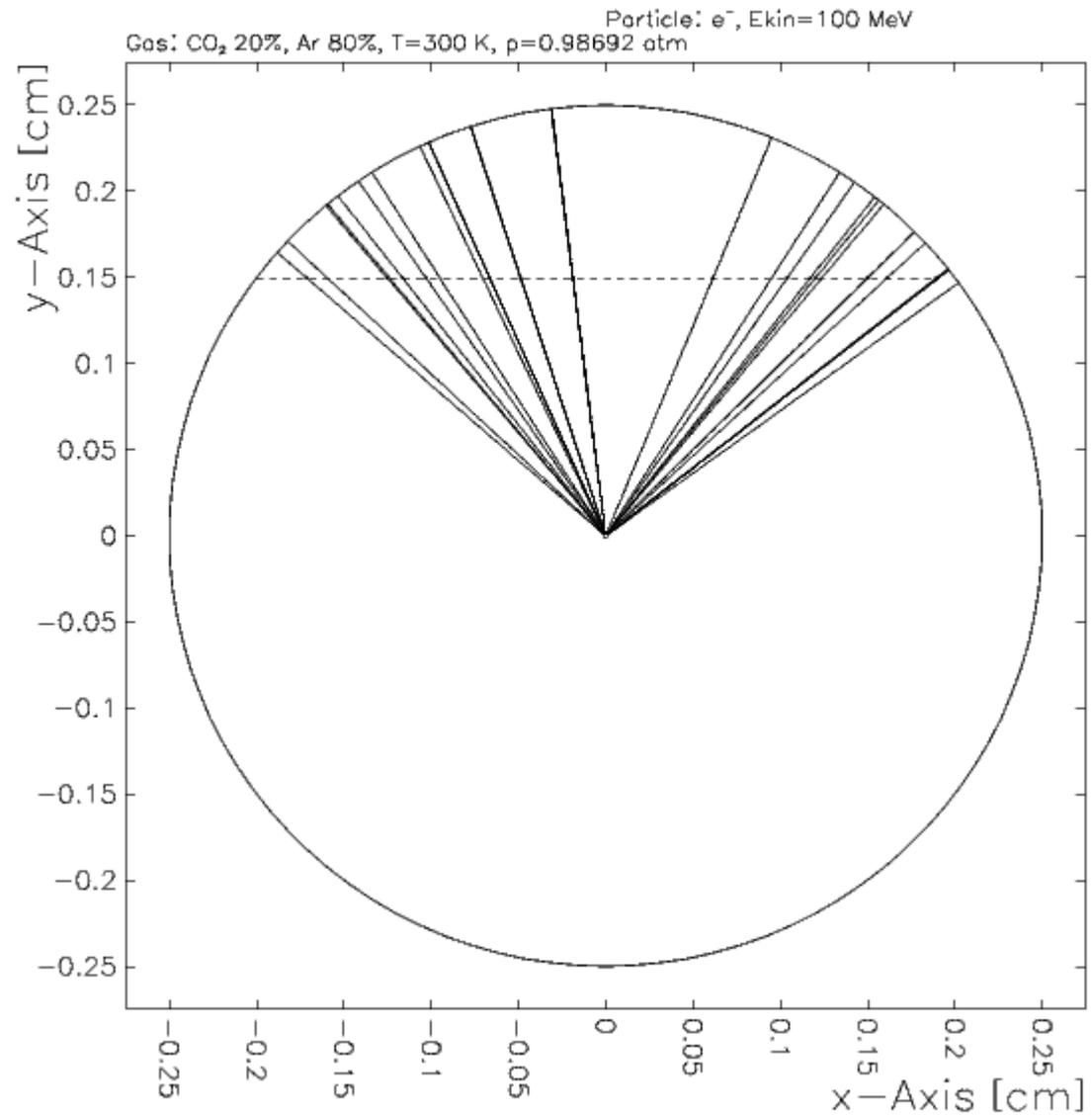
- Not a perfect world, noise affects the time division measurements
- Don't account for noise, you get inaccurate positions of particles
- Needed to generate data to recreate these conditions to properly analyze

Approach

- Garfield, an open source program from CERN, simulates two and three dimensional drift chambers
- Simulated a 2D drift chamber with a gas concentration of 80% argon and 20% CO₂
- Analyzed the data in ROOT, an open source data analysis program from CERN

Garfield

Track, clusters and drift lines



Approach

- In ROOT, the signal is passed through a low-pass filter to smooth out the signal
- Low-pass filter can be set to whatever frequencies the user needs
- In my analysis, I used 100MHz and 200MHz low-pass filters

Approach

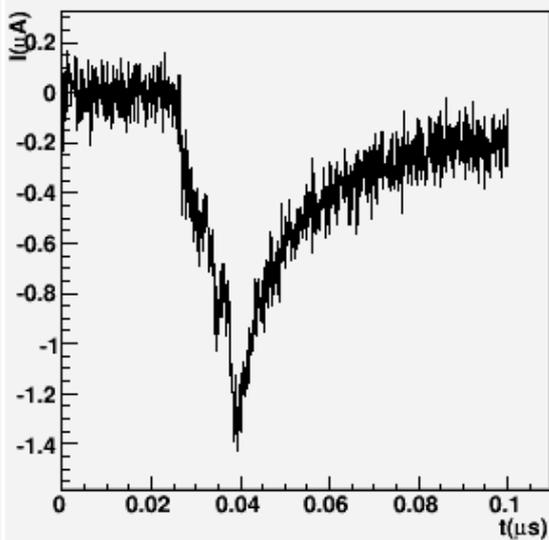
- Garfield doesn't simulate thermal noise which needs to be taken into account
- The high voltage wire used has a resistance of 300Ω
- In ROOT, we calculated the noise current based on the bandwidth, resistance, and temperature of the system
- $T = 300\text{K}$
- $f = [\text{user defined in program}]$
- $R = 300$

$$i_n = \sqrt{\frac{4k_B T \Delta f}{R}}$$

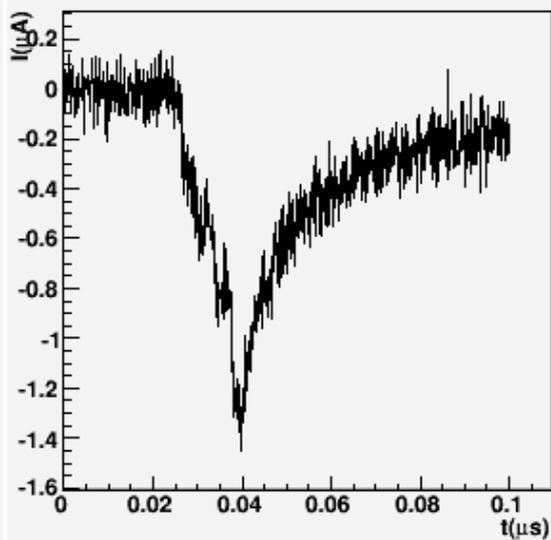
Approach

- Simulated 20,000 signals for electrons and gammas
- Electrons at 100MeV, Gammas at 6 KeV
- Why are gammas involved?
 - Gammas are used for calibrating the straws in physical experiments
- Created graphs and histograms of results
- Histograms:
 - Plotted the maximum current produced
 - Plotted Δt

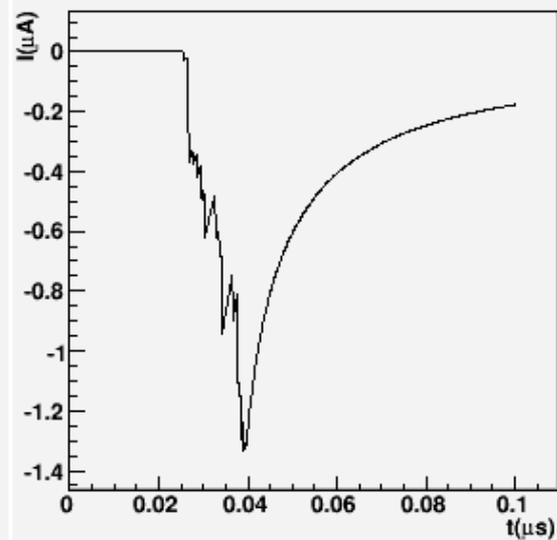
Initial Signal



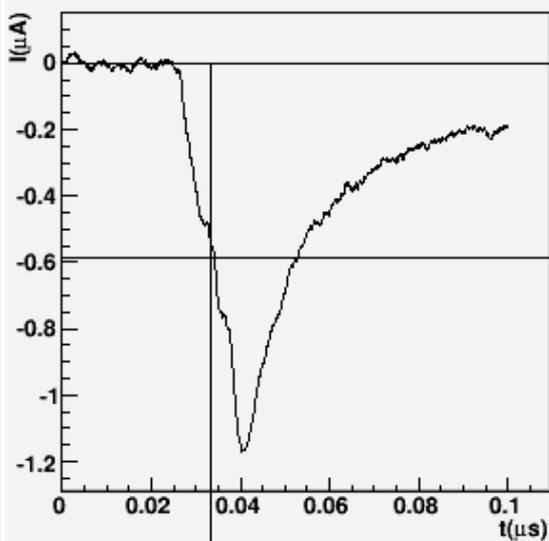
Initial Signal 2



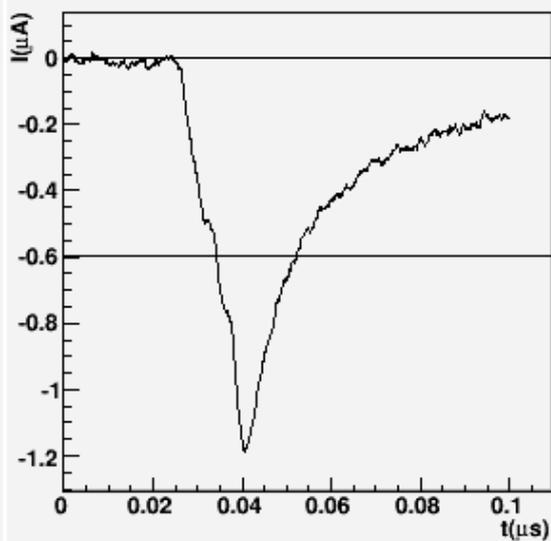
Initial Signal, No noise



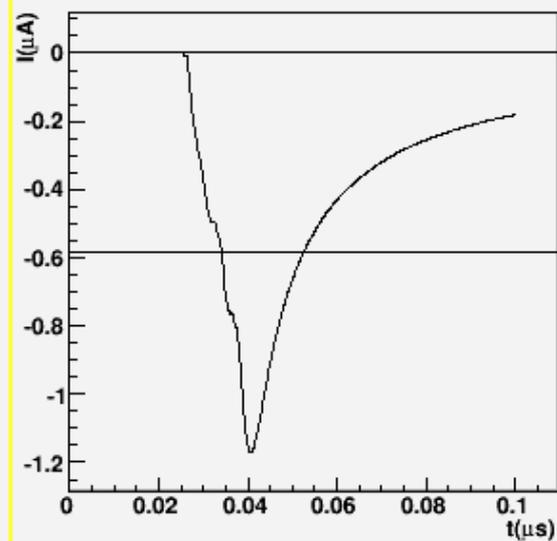
Lowpass on signal 1



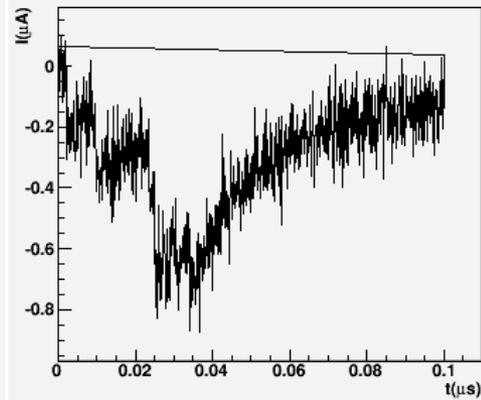
Lowpass on signal 2



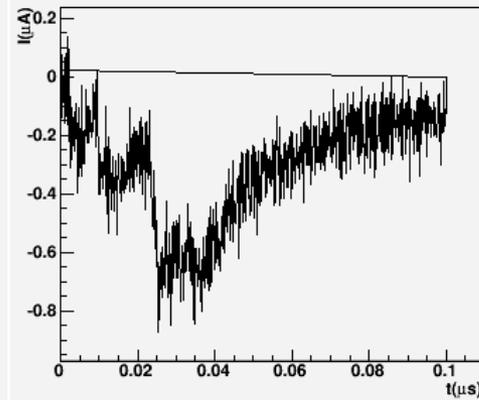
Lowpass on signal



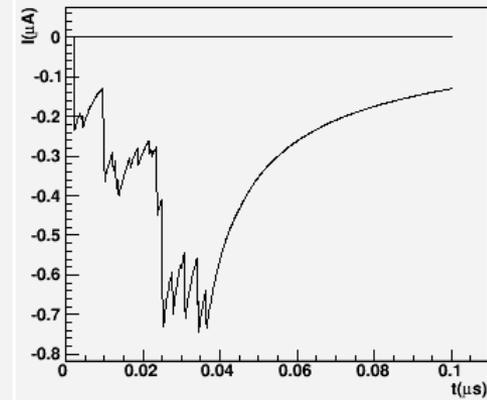
Initial Signal



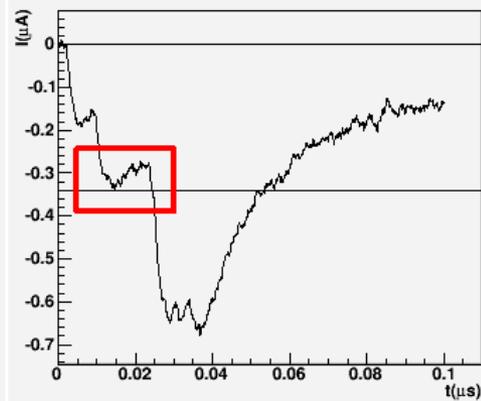
Initial Signal 2



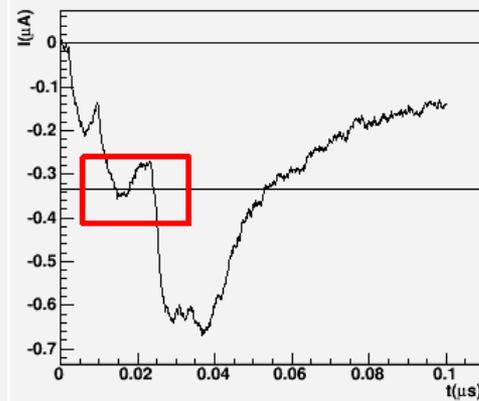
Initial Signal, No noise



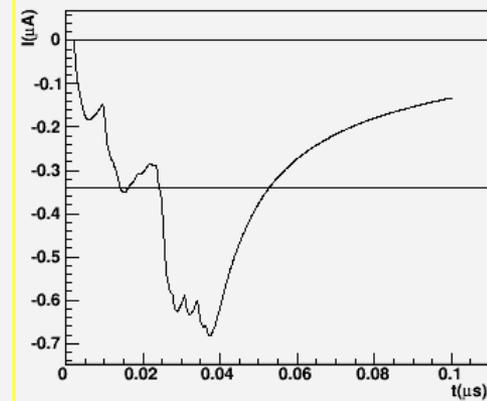
Lowpass on signal 1



Lowpass on signal 2



Lowpass on signal



```
shaboinkin@shaboinkin-N61Jq: ~/root/tutorials/plot/
```

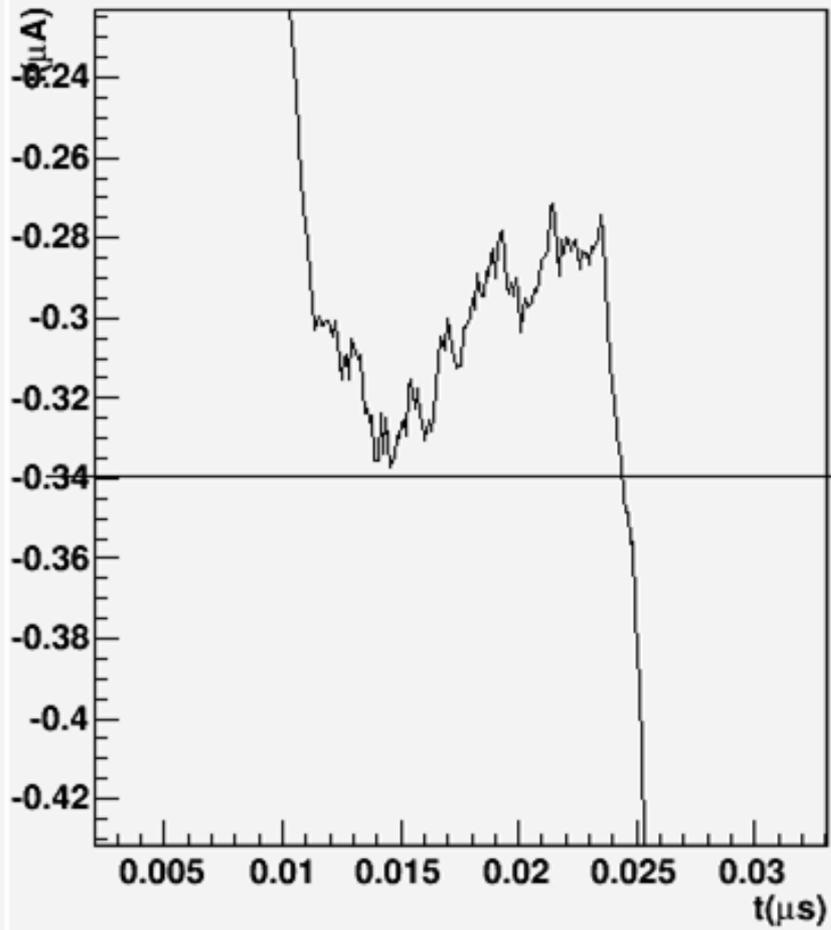
```
File Edit View Search Terminal Help
```

```
Threshold set at: -0.339227 uA on signal 1
Threshold set at: -0.334521 uA on signal 2
Threshold set at: -0.340616 uA on signal 3 [no noise]
```

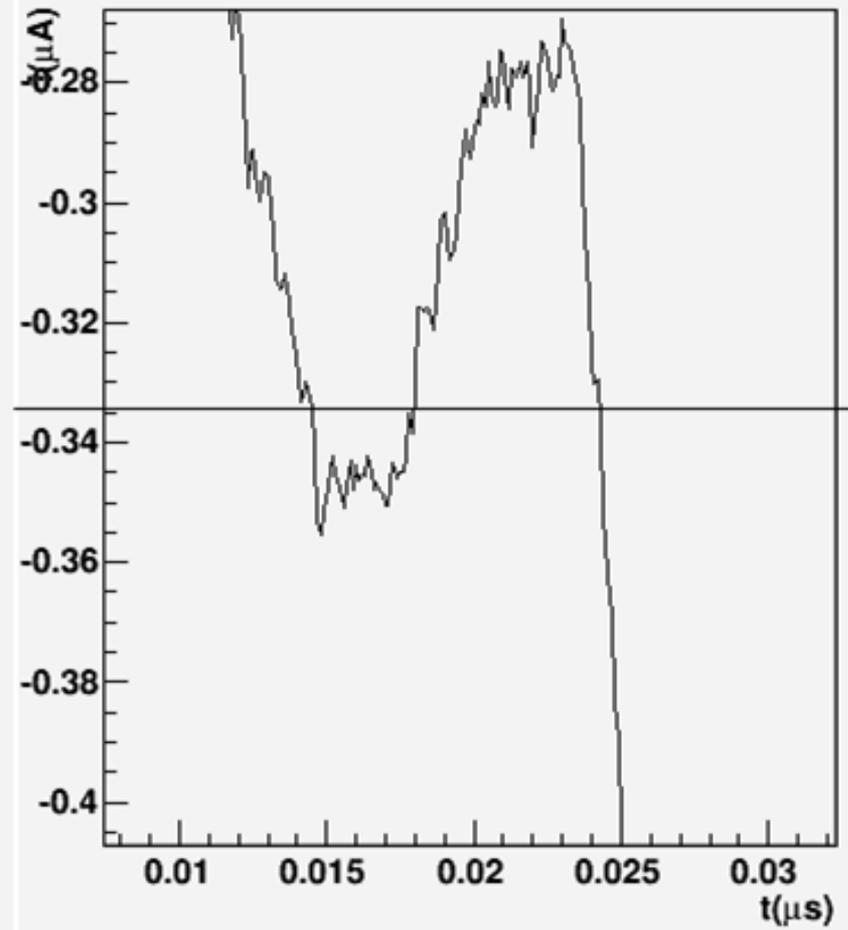
```
Signal 1 crosses at 24.4ns
Signal 2 crosses at 14.6ns
Difference in time: 9800ps
```

```
---Both signals crossed the threshold---
```

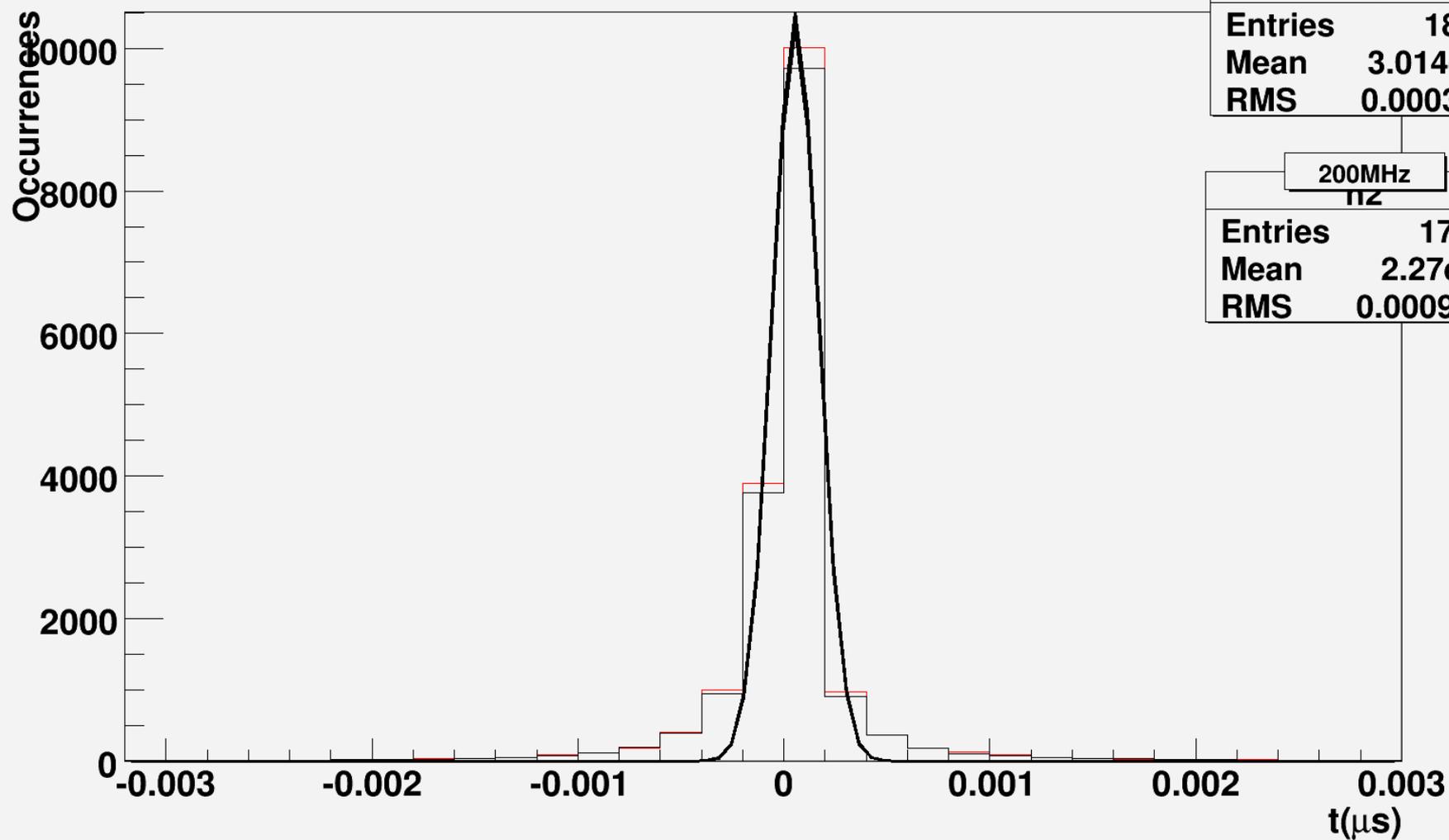
Lowpass on signal 1



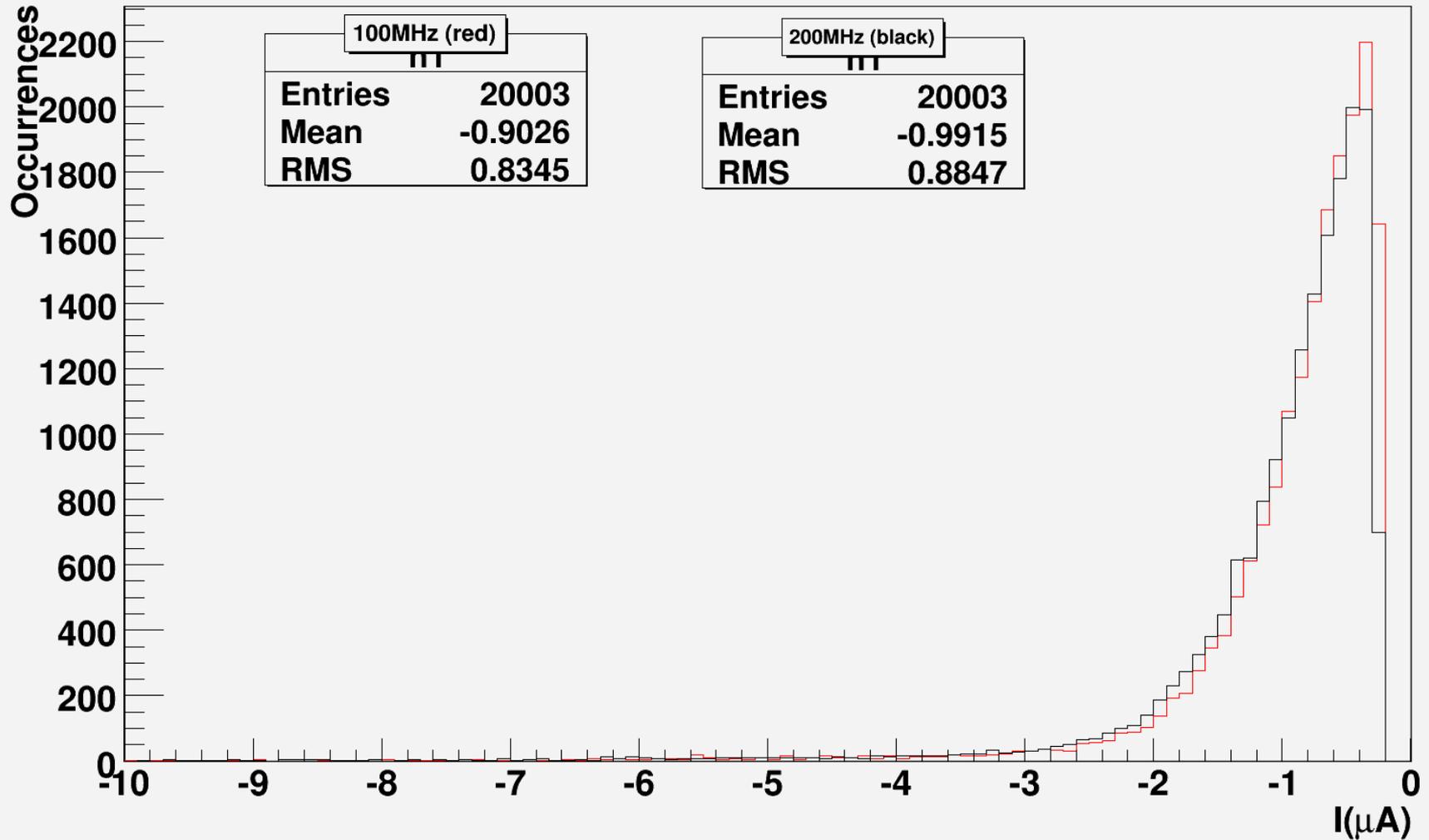
Lowpass on signal 2



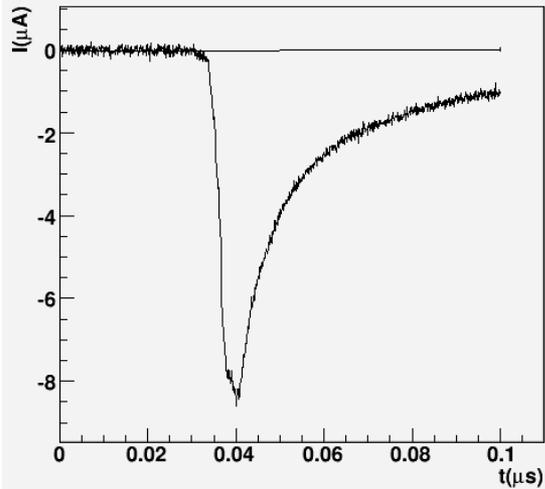
Time distribution: Electrons on 100MHz lowpass
and 200MHz lowpass (in black)



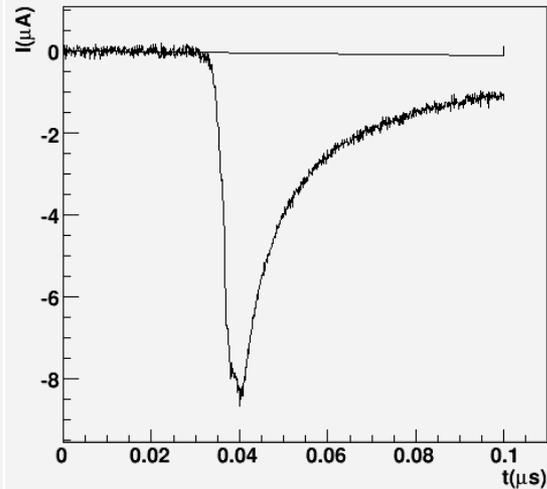
Maximum current: Electrons on 100MHz lowpass
and 200MHz lowpass



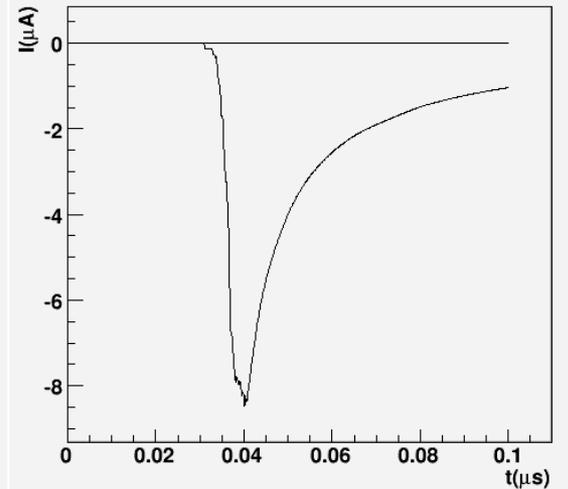
Initial Signal



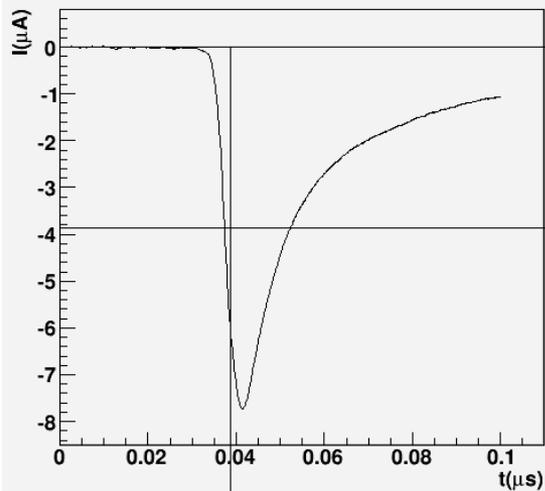
Initial Signal 2



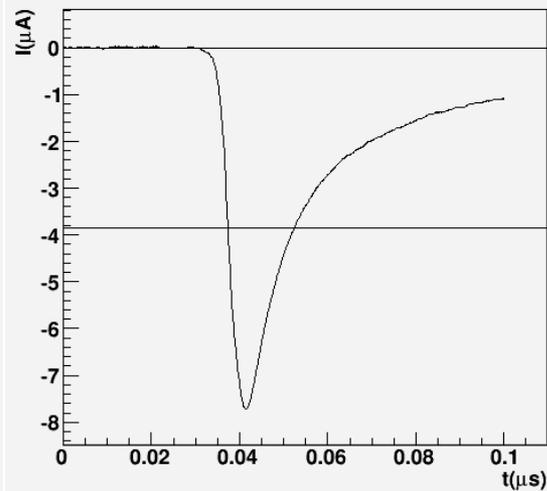
Initial Signal, No noise



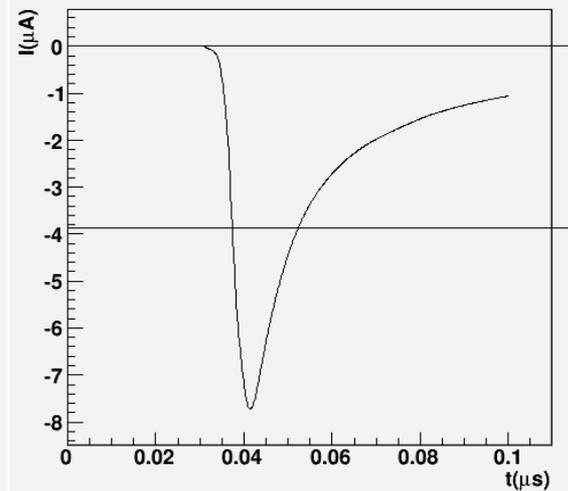
Lowpass on signal 1



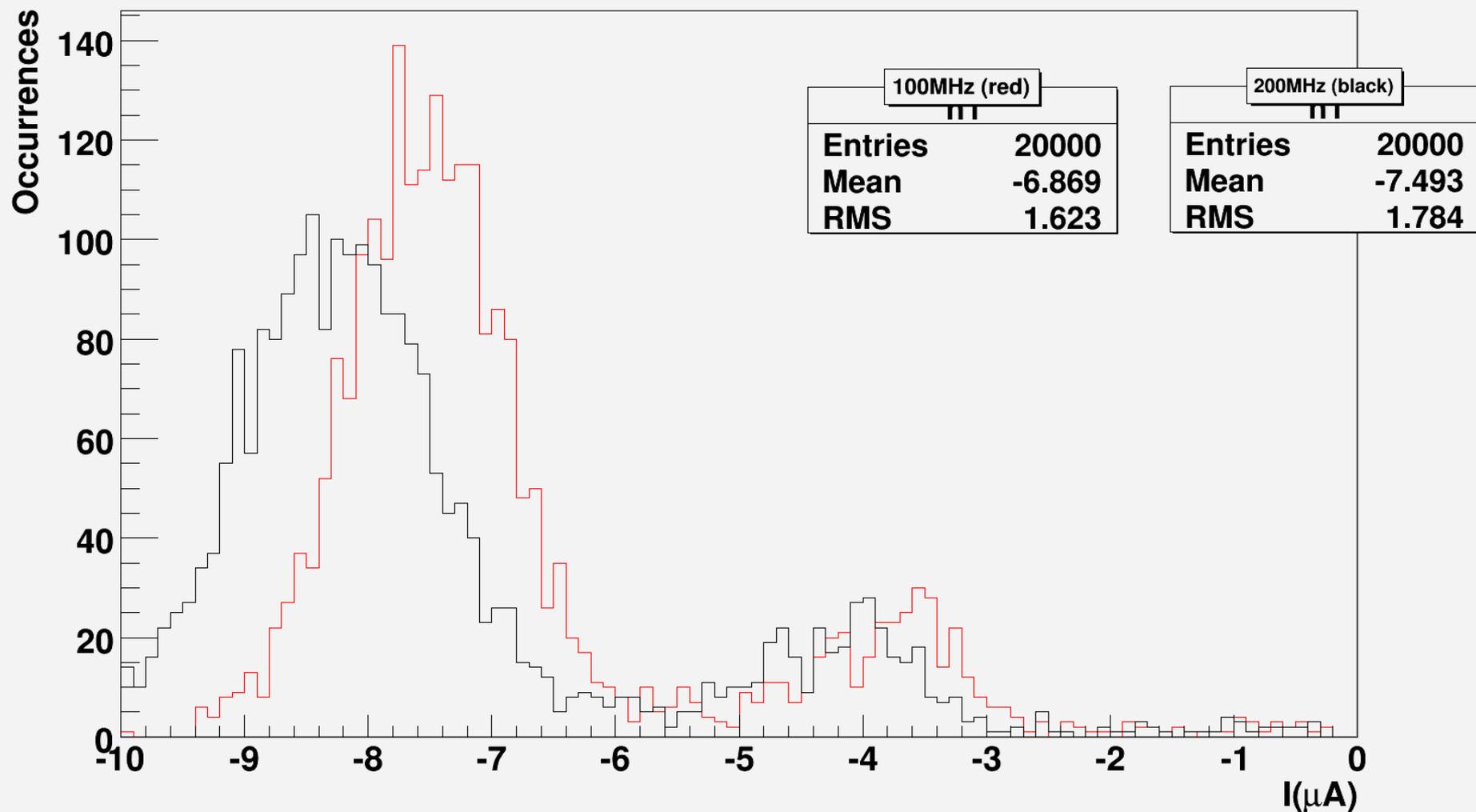
Lowpass on signal 2



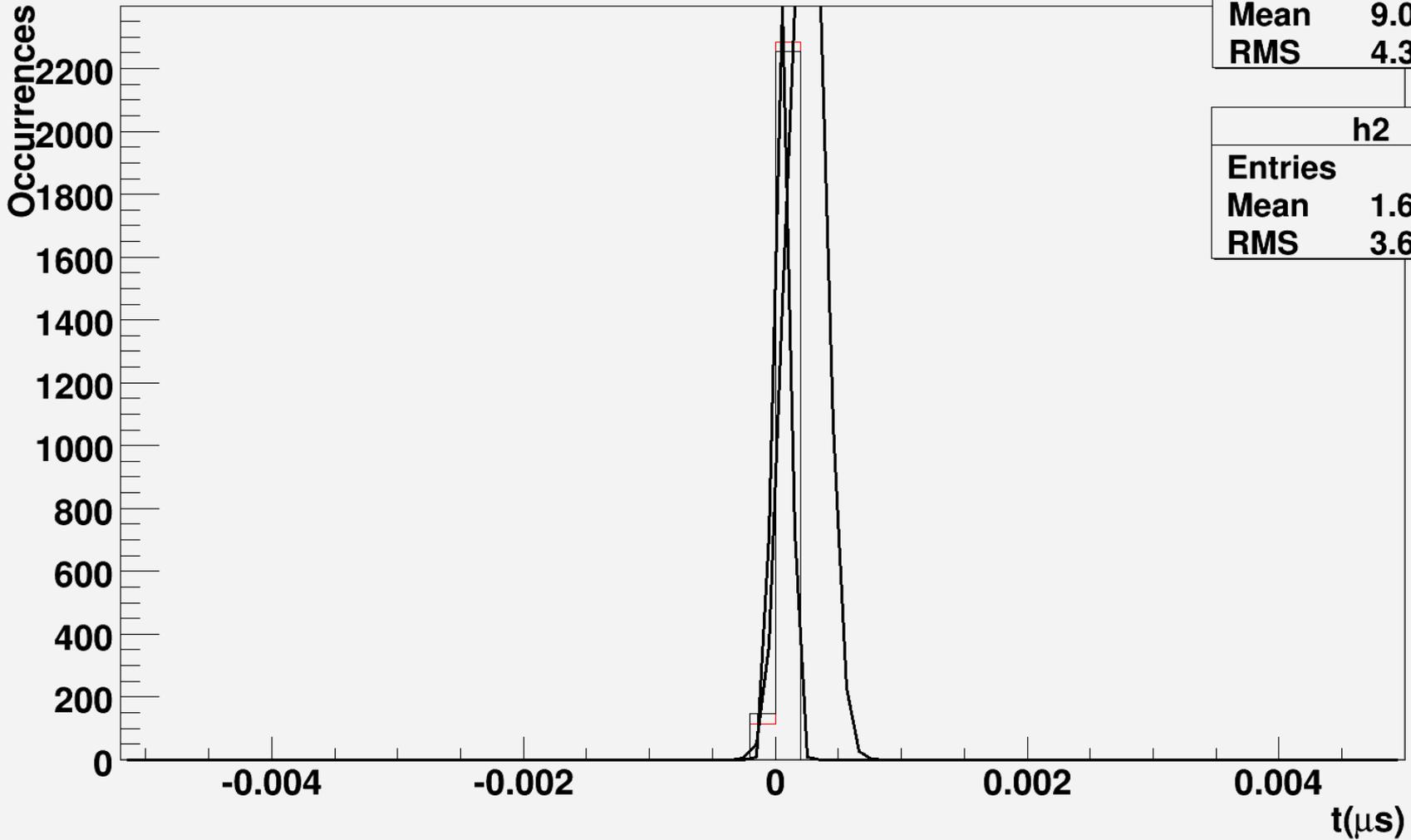
Lowpass on signal



Maximum current: Gammas on 100MHz lowpass



Time distribution: Gammas on 100MHz lowpass
and on 200MHz



h2	
Entries	2400
Mean	9.025e-05
RMS	4.345e-05

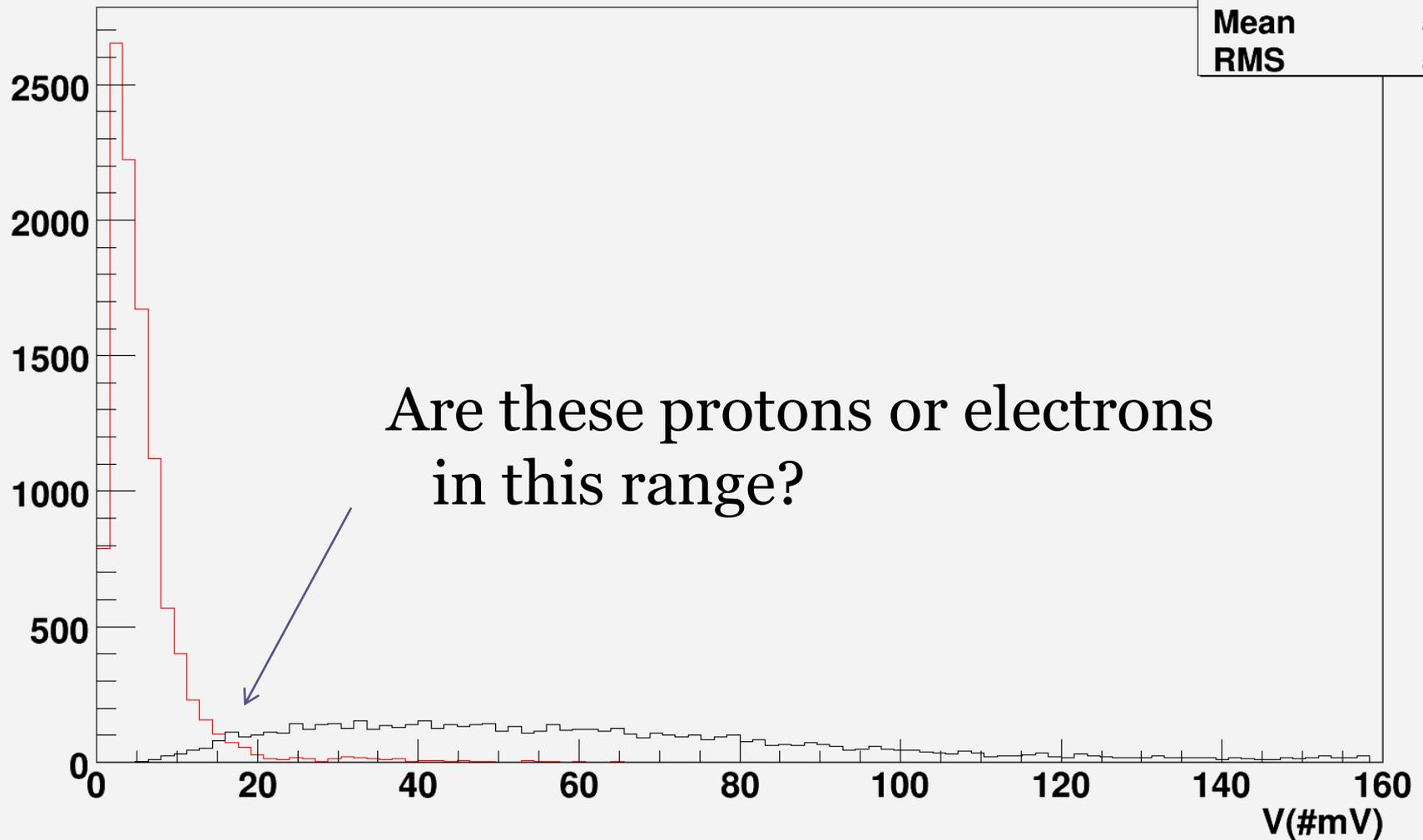
h2	
Entries	2400
Mean	1.667e-07
RMS	3.674e-05

Case study on Analog-to-digital converters and maximum signal distribution

- Maximum signal distributions on electrons and protons show a small overlap
- Can lead to uncertainty distinguishing electron signals and proton signals apart

Maximum voltage for electrons
and protons

h1	
Entries	10266
Mean	5.704
RMS	5.556

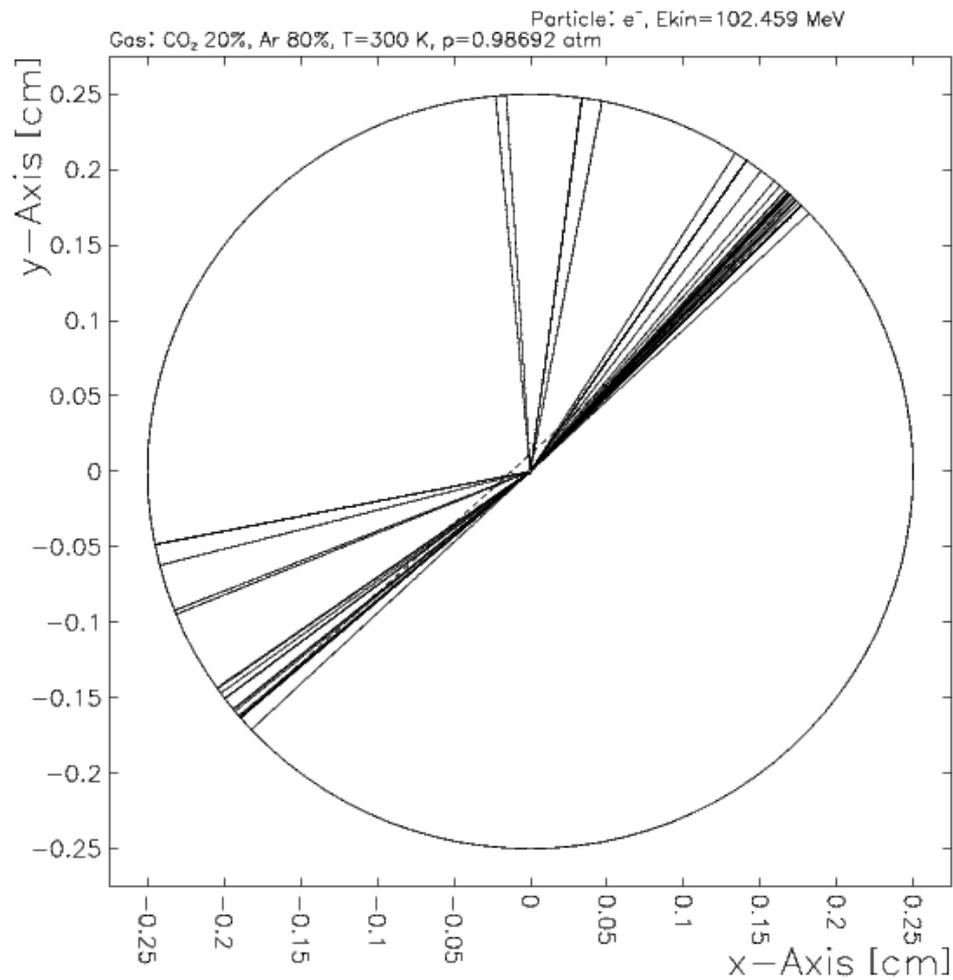


New Data Set

- Simulating a 3D drift chamber
- Data set contains x, y, and z coordinates of entry and exit of particles along with its energy
- File is read in line by line and modifies the Garfield source file to generate a simulation for each different coordinate set
- 10,278 electrons signals
- 6,835 protons signals
- Garfield data was passed into the pre-amp circuit through ngpisce

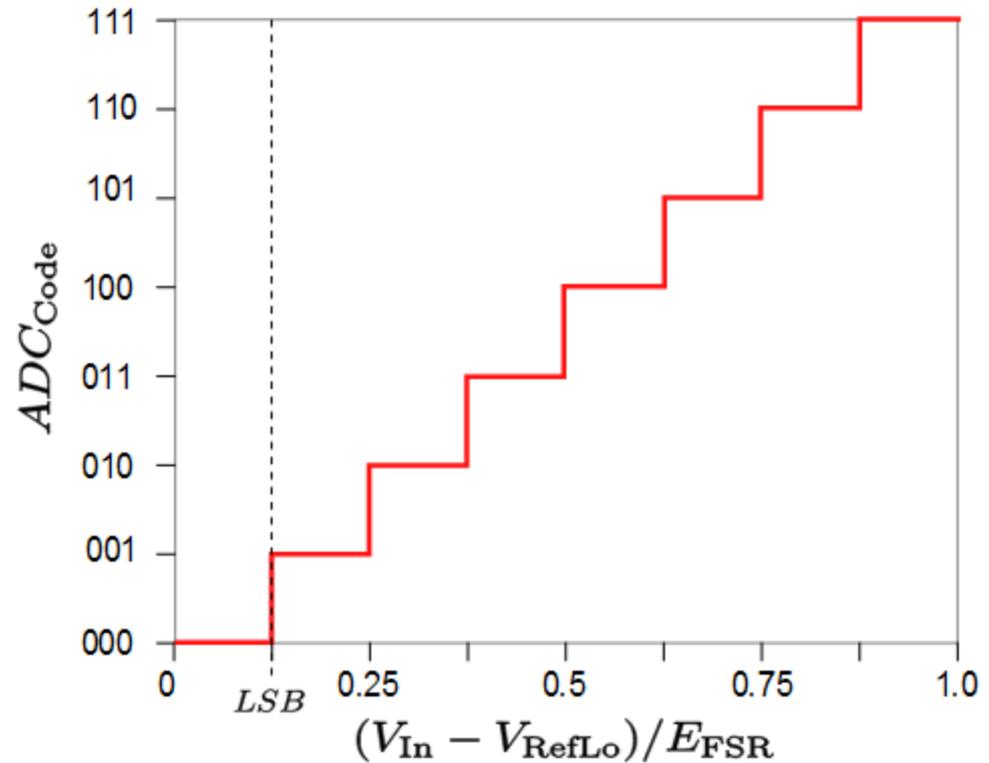
3D Drift Chamber

Track, clusters and drift lines



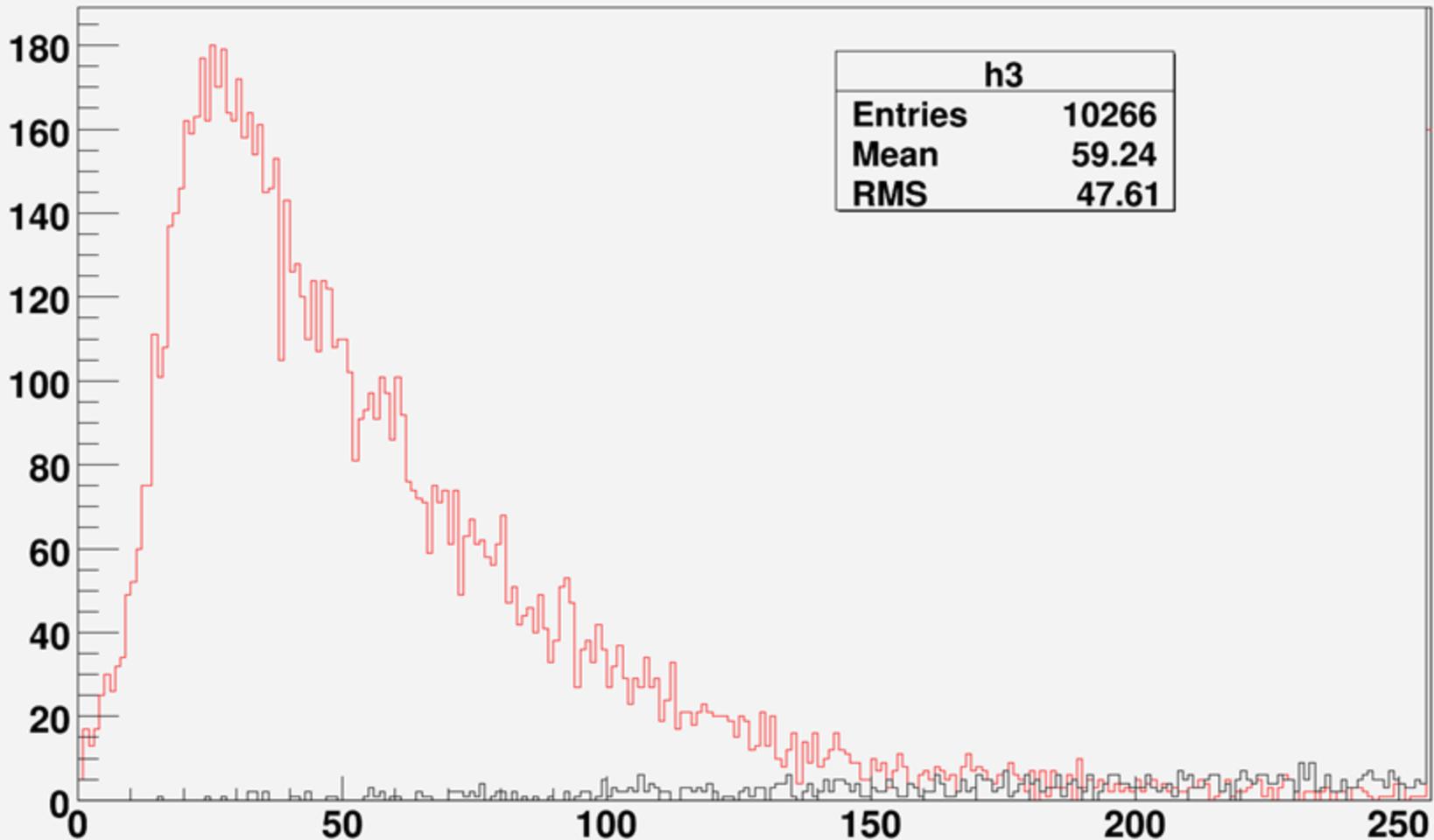
ADC Simulations

- Speed
 - 50MHz
 - 100Mhz
- Bits
 - 4bit
 - 8bit



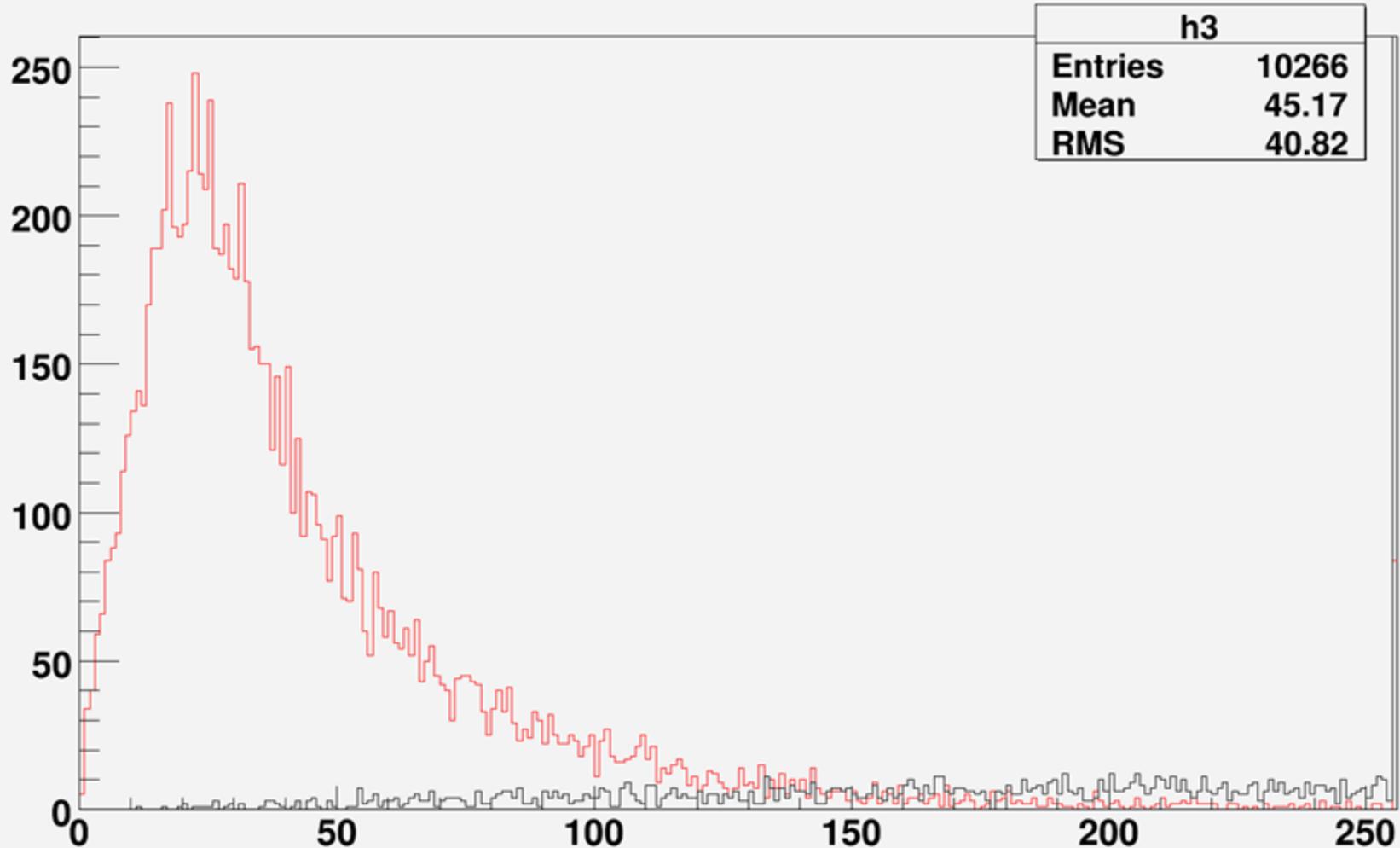
The Good: 100MHz 8bit ADC

Discretized max for electrons value on 100mhz 8bit ADC
with protons (in black)



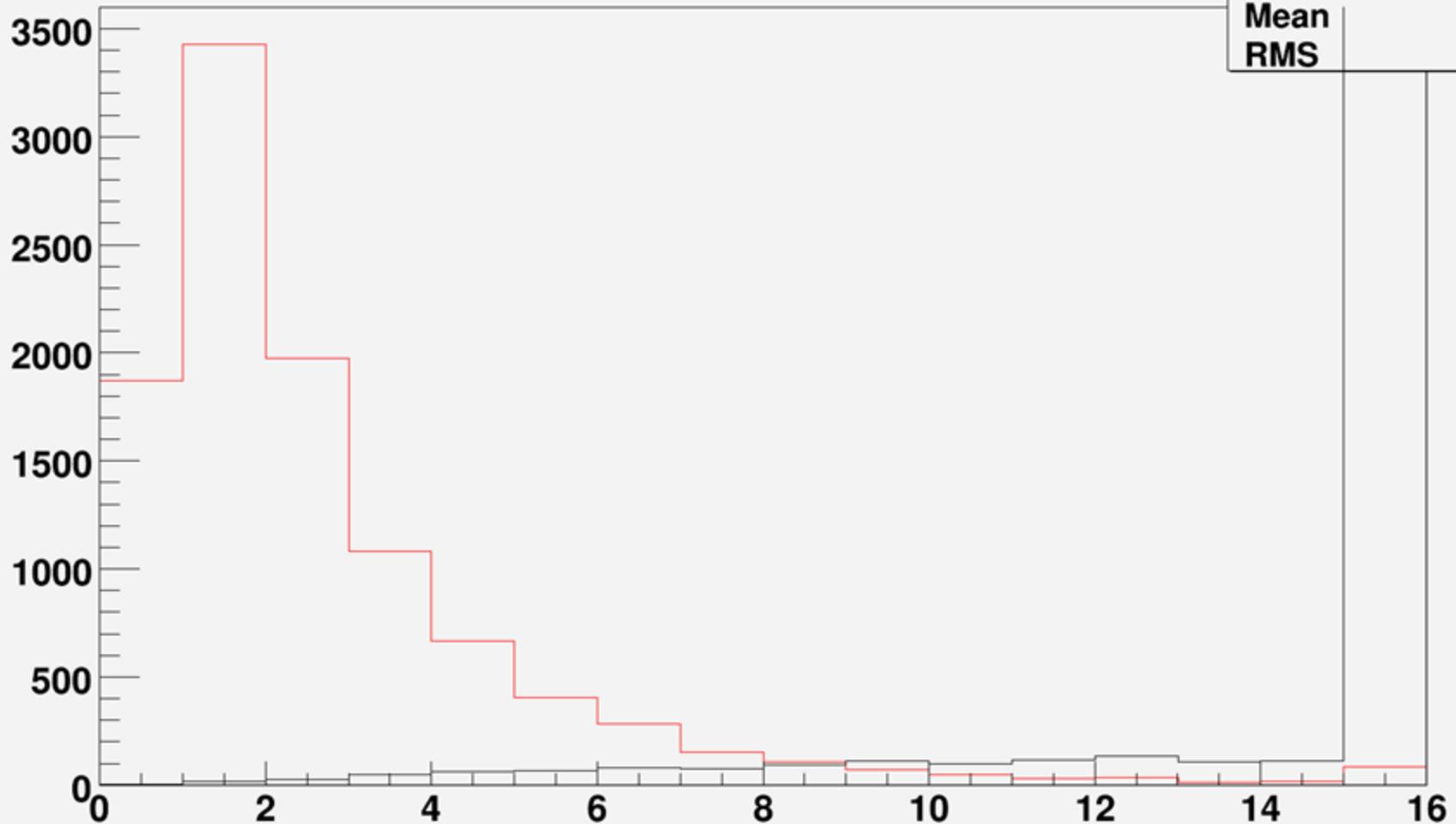
The Bad: 50MHz 8bit ADC

Discretized max for electrons value on 50mhz 8bit ADC
and protons



The ugly: 50MHz 4bit ADC

Discretized max for electrons value on 50mhz 4bit ADC
with protons



h3

Entries	10266
Mean	2.19
RMS	2.434

Results of ADC

ADC Type	Bin	5% cutoff	Rejection of Protons
100MHz 8bit	157	4.97%	96.95%
	156	5.08%	96.96%
50MHz 8bit	125	4.96%	95.10%
	1254	5.08%	95.18%
100MHz 4bit	11	4.12%	96.39%
	10	5.17%	97.08
50MHz 4bit	9	3.97%	94.28%

Mu2e Toolkit

- Needed to streamline the process of data analysis
- Initial process:
 - Change garfield source file if you want to generate different signals with different parameters, open terminal, go to location of file, run garfield, wait, split of garfield data file into individual signals for ngspice, format each individual signal to a format ngspice can read, start ngspice, process every signal, combine all files produced by ngspice to a single file, move file to ROOT, and run
- Has to be a better way...

Mu2e Toolkit

- Solution?
 - Create a script that does everything for you
- All the user has to do is make sure their data file is in the same folder as the script, launch it through the terminal, enter in 2 options, and wait for data to be generated
- 2 options
 - How many processes to run?
 - What signal do you want to process?

Summary

- Time division shows that noise will threaten an accurate reconstruction of the particles trajectory.
 - Applying a 200MHz lowpass filter appears to help with the time division measurements and output signals closer to their original maximum currents
- ADC Case study shows a faster ADC with 8bits will provide a better resolution with a higher rejection rate of protons
- Bash scripting = scary

Acknowledgements

- Vadium Rusu for dealing with all of my questions and not so efficient coding
- Asset Mukherjee for providing a C program for formatting files
- Dr. Davenport
- SIST Committee
- Fellow SIST Interns