Peak-finding for Longitudinal Beam Halo Readout System

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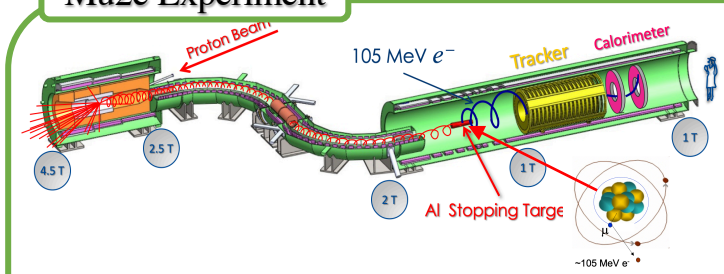
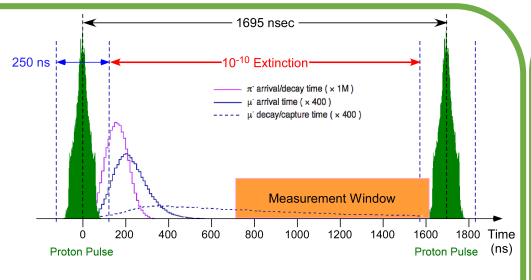
22nd IEEE Real Time Conference

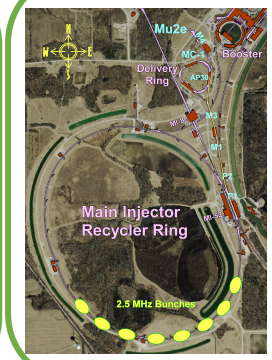
Mu2e Experiment

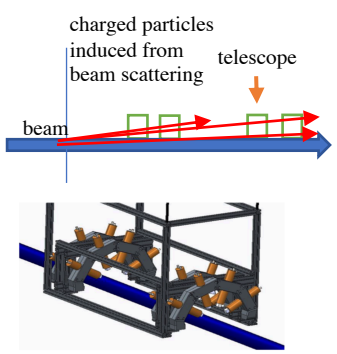




- Mu2e is an experiment at Fermilab that will search for the conversion of a muon to an electron that has been captured by an aluminum nucleus, with a 90% CL exclusion of 8 x 10^{-17}.
- The Mu2e Experiment requires the ratio of out-of-time protons to beam pulse protons to be less than 10^{-10}.

Precision Time Profile Monitor (PTPM) & Motivation



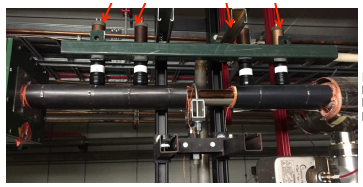


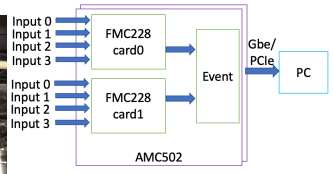
- 8 GeV proton beam from the Fermilab Booster Synchrotron is injected into the Recycler Ring.
- Proton beam is re-bunched to 8 bunches 2.5 MHz.
- 8 bunches are extracted to the Delivery Ring.
- From the Delivery Ring, the beam is resonantly extracted to Mu2e experiment via M4 beam line.
- PTPM was developed to study the longitudinal beam halo for the Mu2e experiment.
- PTPM has excellent time resolution compared to the nominal bunch length and a low background fake rate.
- PTPM need to monitor the beam data in long time (~ms).

Prototype & Readout System

- One arm of the PTPM (4 Cherenkov detectors) has been installed in the Recycler Ring.
- The PMT signal is read out by using a FMC228 card, an AMC502 is used to collect data from FMC228 card.
- The data will be sent to the data acquisition system via a gigabit ethernet or PCIe interface.

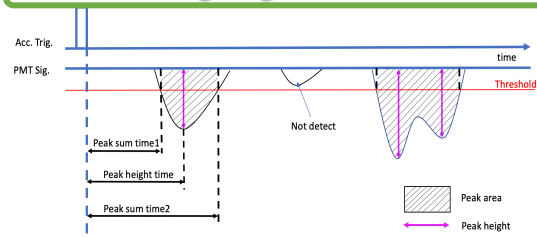
Quartz Cherenkov Detectors and PMTs



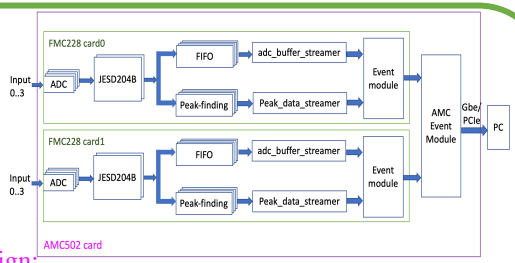


- Firmware Requirements:
  + Monitor the beam data in long time (~ ms).
  + Detect the particle hitting detector.
  + Distinguish two or more particles hitting detector close in time.
  + Send out long time peak data and short raw waveform length data.

Peak-finding Algorithm & Firmware Design



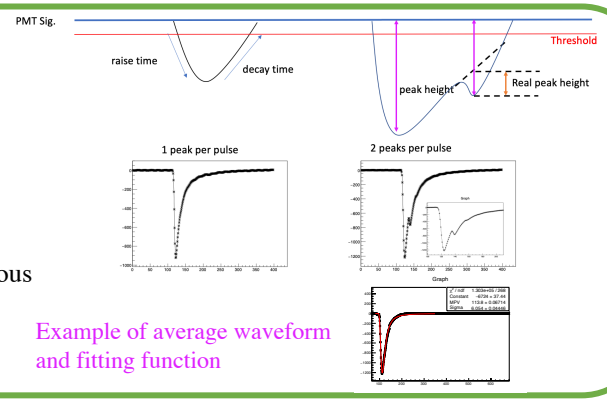
- Peak-finding algorithm:
  + Detect the peak in the pulse above the threshold.
  + Distinguish more than one peak in pulse.
  + Send out peak time, peak height and peak area.



- Firmware design:
  + The peak-finding algorithm is implemented as a peak-finding module on a Xilinx Kintex-7 FPGA on an AMC502 card.
  + The firmware sends out peak-finding data and raw waveform.
  + The firmware can send out data from multiple FMC228 cards.

Offline Analysis

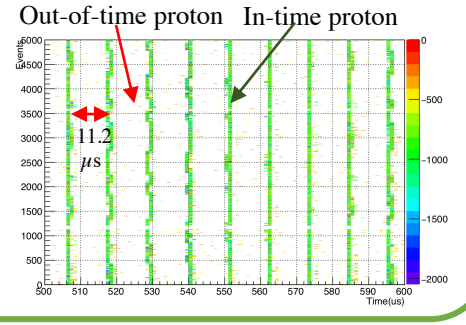
- Pulse pile-up:
  + On one pulse, maybe there are two or more peaks, such as two particles hitting detector close in time.
- Fake background:
  + Random particles hit the detector.
- Calculate real peak height to remove pulse pile-up:
  + Use the raw waveform to fit the peak shape pulse.
  + Use the fitting function to calculate the tail of previous peak and the real peak height signal of current peak.
- Take coincidence of four PMT signals in short time windows to reduce fake background.



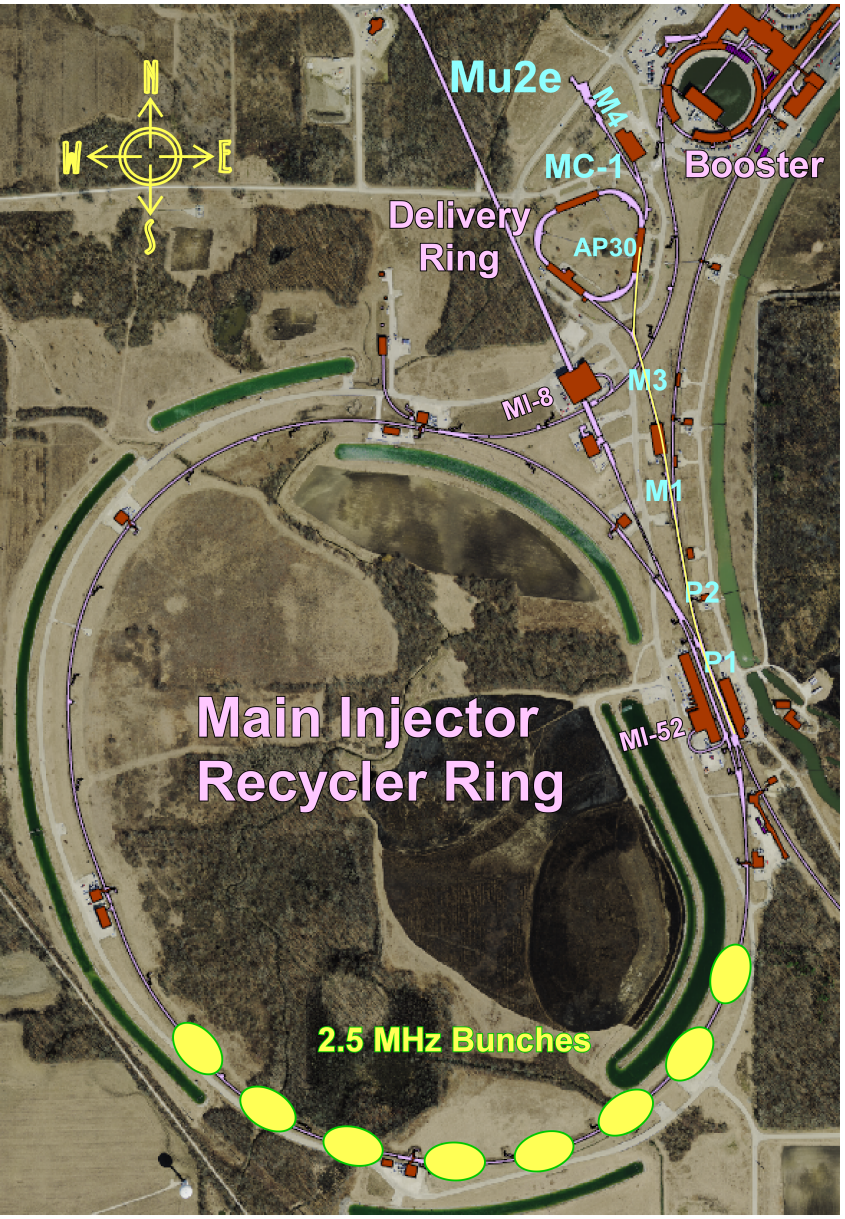
Example of average waveform and fitting function

Preliminary Results and Future Plan

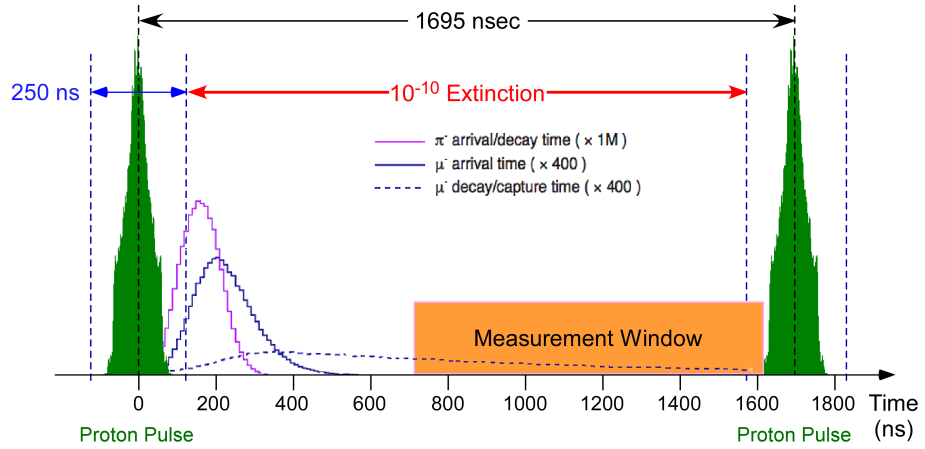
- The system is under test at the Fermilab Recycler Ring.
- The data is collected when the beam is sent to the Muon campus.
- The preliminary result confirm the system can monitor the beam in 100 ms windows, the right figure shows an example of in-time proton pulses separated by the 11.2 μs Main Injector period, as well as out-of-time protons.
- In future, the full monitor will be installed with 16 channels.
- Finally, the system will be moved to the Delivery Ring beam line for the Mu2e Experiment and it will provide fast feedback on the beam quality being delivered.



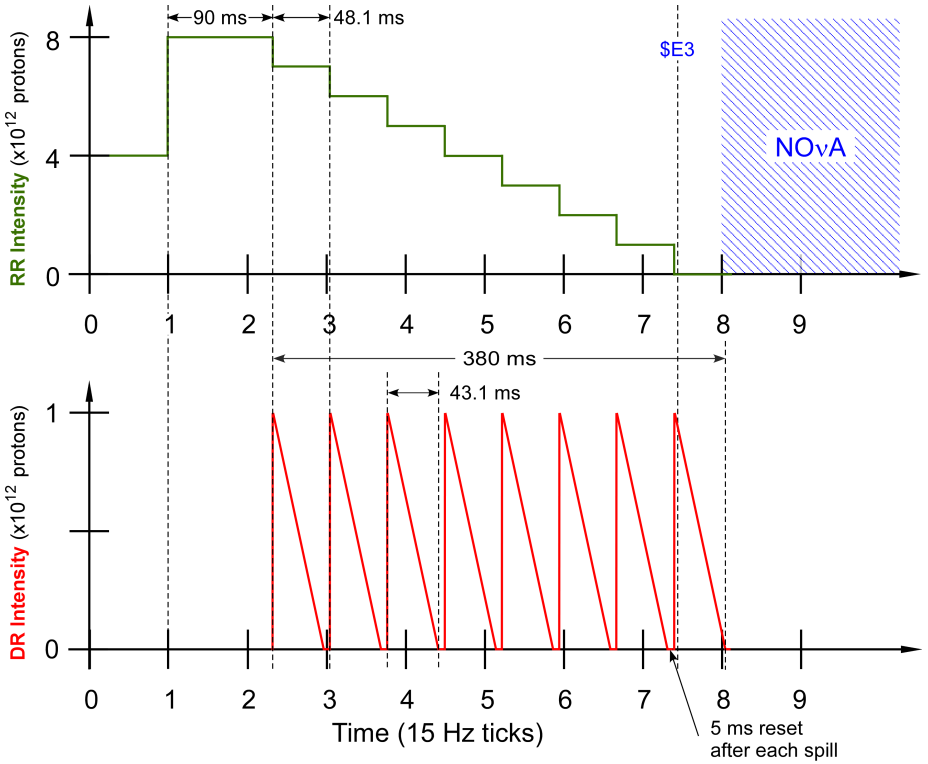
Backup



- An 8 GeV proton beam bunch from the Fermilab Booster is injected into the Recycler Ring
- A 2.5 MHz RF system re-bunches it to 8 bunches 2.5 MHz.
- These bunches are transferred one at a time to the Delivery Ring.
- From the Delivery ring, the beam is resonantly extracted.
- The 1.7 μs period of the Delivery Ring gives the beam the required Mu2e time structure.

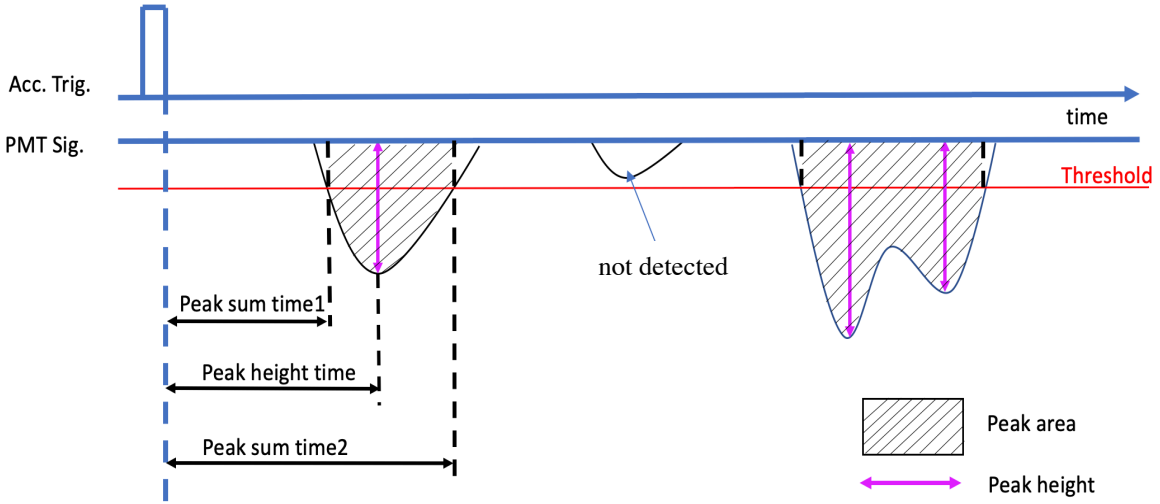


- The requirement for out-of-time beam for Mu2e will be achieved with a system of resonant dipoles and collimators; they will be configured such that only in-time beam is transmitted to the target.
- In order to achieve the requirements, the bunches formed in the Recycler Ring have out-of-time beam at the 10^{-5} fractional level or less.
- The PTPM is to measure out-of-time beam in the Recycler Ring to verify that it matches models.



- After 2nd proton batch injected into Recycler Ring, the proton beam is re-bunched in 90 ms.
- The resulting 8 bunches are slow extracted to Mu2e over an interval of 380ms.
- Each spill is 43 ms long with a 5 ms reset between spills.
- After the 8th spill the Recycler is used for NuMI/NOvA slip-stacking.

Firmware with Peak-finding



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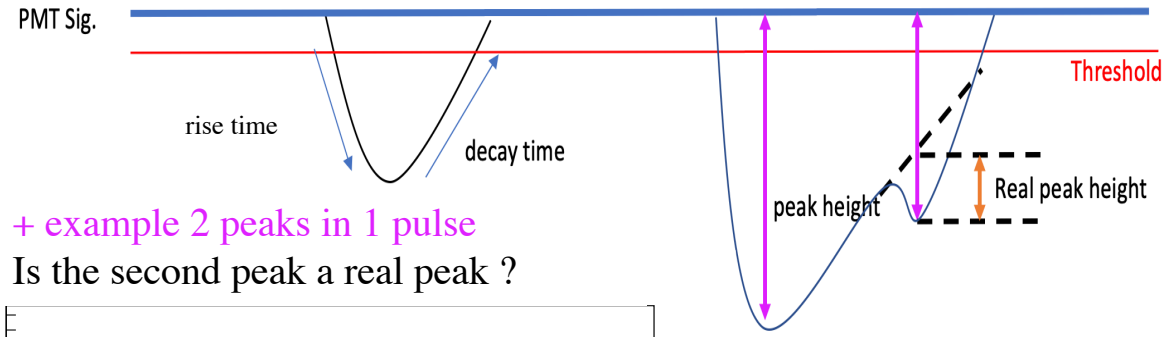
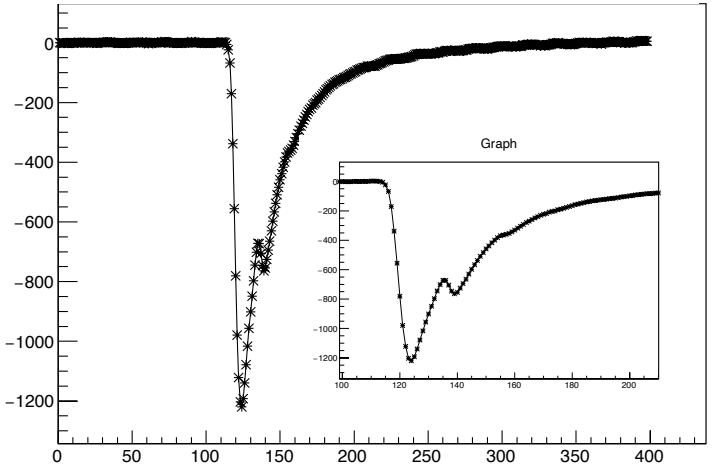
Offline analysis to reduce fake background

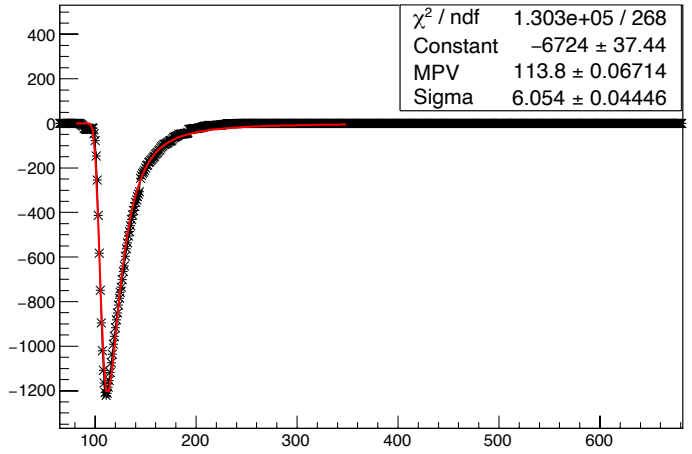


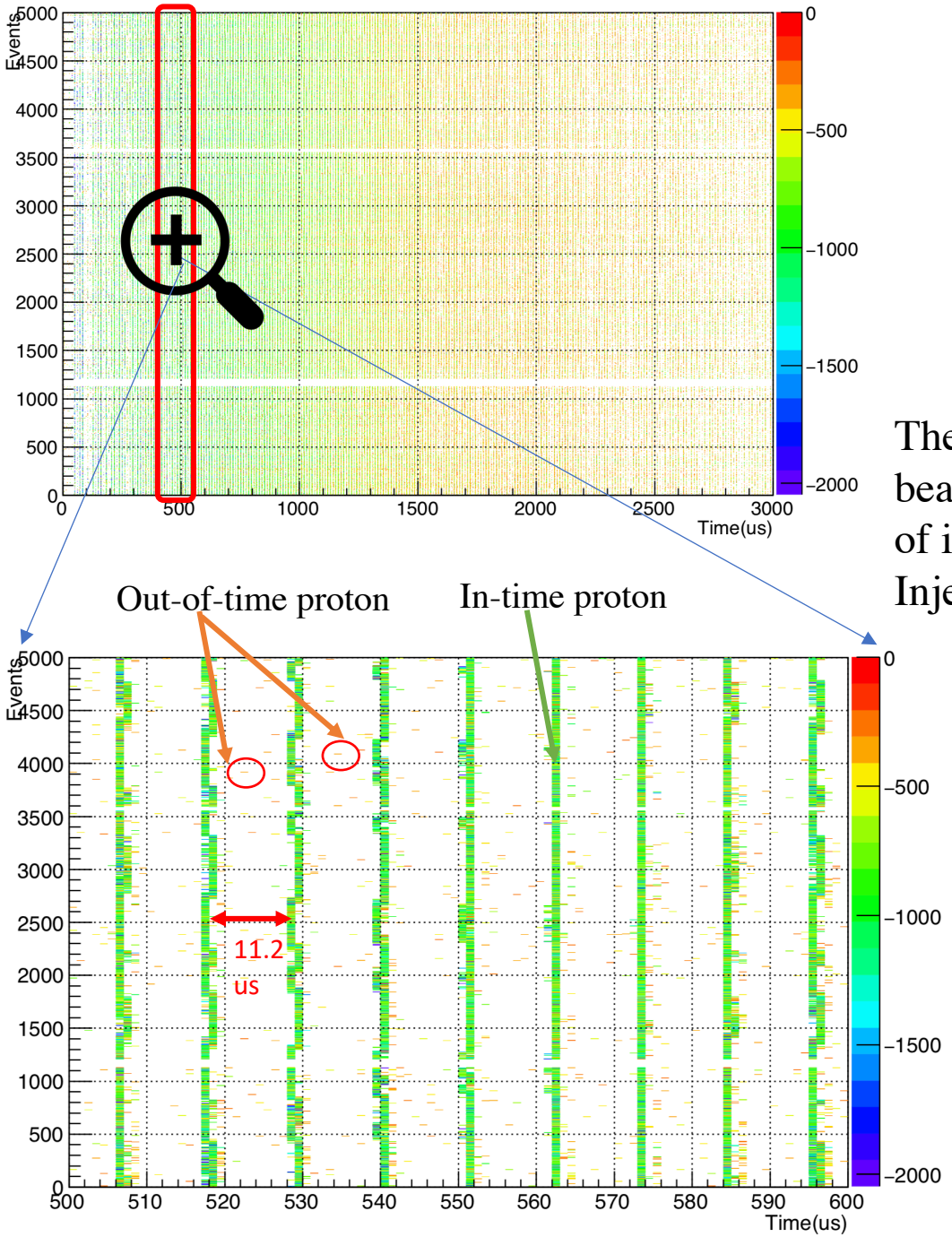
+ example 2 peaks in 1 pulse

Is the second peak a real peak ?



+ Average waveform and fitting function





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