MCP Signal Extraction and Timing Studies

Kurtis Nishimura
University of Hawaii
LAPPD Collaboration Meeting
June 11, 2010

Outline

- Studying algorithms to process pulses from MCP devices.
  - With the goal of finding an implementation that can be done quickly for on-line feature extraction with DSPs (as mentioned by Matt).
- Studies with:
  - Burle/Photonis Planacon (10 μm pore)
    - Timing w/ CFDs versus waveform sampling algorithms.
  - Hamamatsu SL10 (10 μm pore)
    - Software studies using high bandwidth oscilloscope data.

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High resolution photon timing with MCP-PMTs: a comparison of commercial constant fraction discriminator (CFD) with ASIC-based waveform digitizers TARGET and WaveCatcher.

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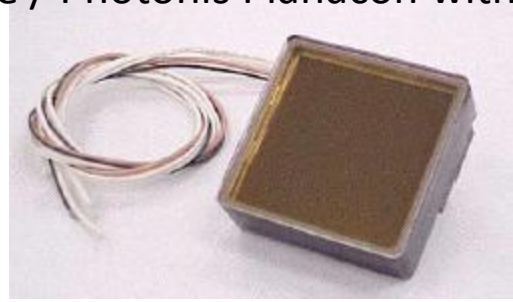
***To be submitted to NIM A**

➔Comparison btw Ortec CFD/TAC/ADC, and waveform digitizers (TARGET & WaveCatcher) (1 GHz bandwidth)

Burle / Photonis Planacon with 10 μm pore



N_{pe} ~ 30-50 for these tests.

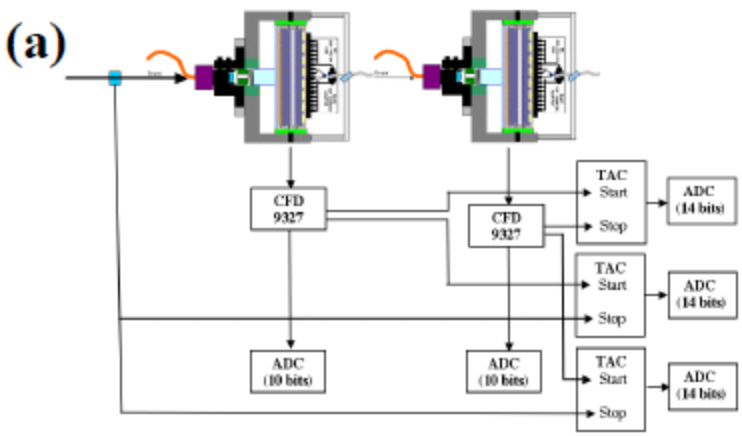
Parameter	Target	Wave Catcher
Number of channels	16	2
Resolution	9 bits	12 bits(board) >12.5 bits (chip)
Conversion time	<500□□s/32 samples	100 ns/one sample
Termination	90 Ω, 1kΩ, 10kΩ	>50 Ω (board) > 1 MΩ (chip)
Power consumption	<10 mW/ch.	<2.5 W (board) <300 mW(chip)
Sampling rate	1-2.5 GSa/s	0.4 to 3.2 GSa/s
Sampling bin in this test	~450 ps/bin	312.5 ps/bin
S/N ratio in this test *	~50-60	~450
Chip's front end BW in this test	~150 MHz	500 MHz
Storage depth (samples/channel)	4096.	256
Trigger rates	Up to 50 kHz	Up to 30 kHz
Encoding	Wilkinson	On board ADC
Cross-talk to nearest channel	~10% **	<0.5%
Readout time (ASIC->FPGA)	16 µs for 48/64 cells over 16 channels	~30 µs for 256 cells over the two channels
External interface	USB 2.0	USB 2.0

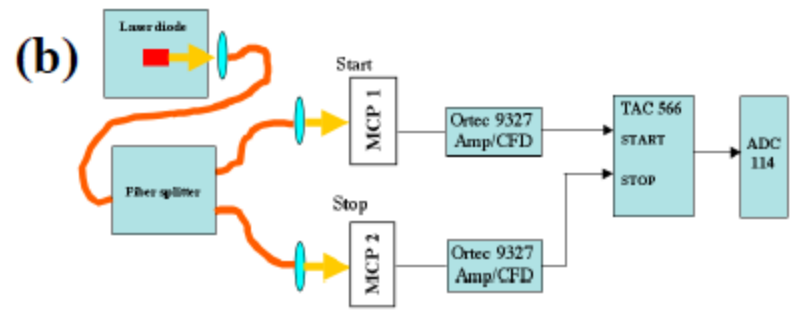
CFD Test Conditions

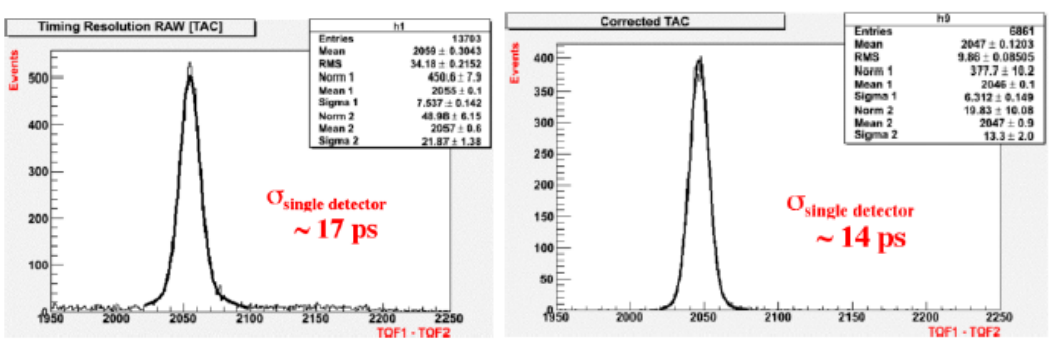
a) Fermilab test beam (120 GeV/c proton)

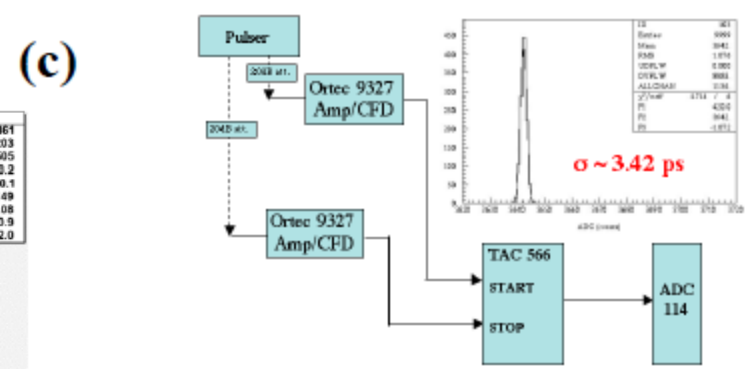
b) Laser test setup

c) Electronics calibration setup



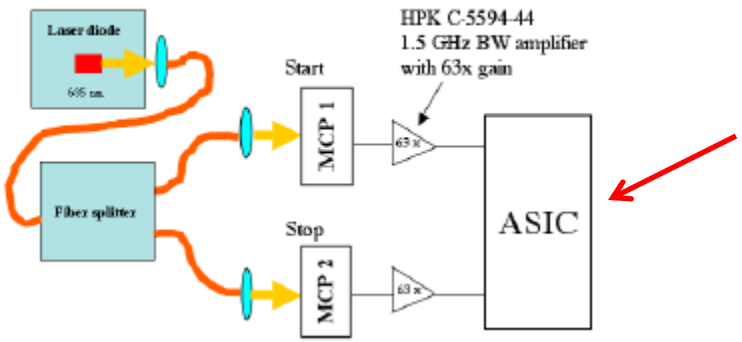




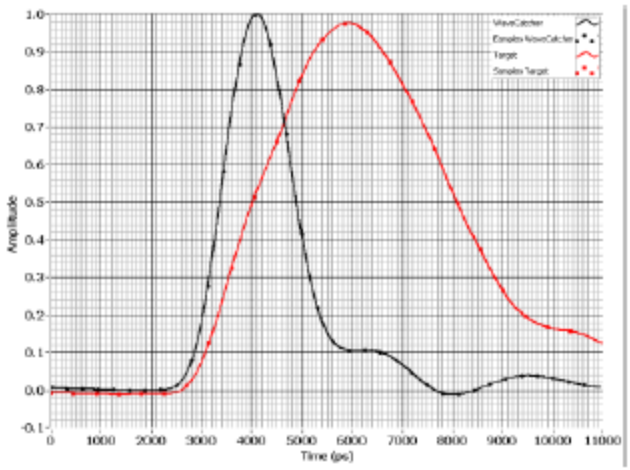


Test beam data raw (left) and time walk corrected (right). Laser results comparable.

ASIC Test Conditions



WaveCatcher
TARGET



Analysis is performed with two algorithms:

<u>Constant fraction algorithm</u>

Simple software implementation of a constant-fraction discriminator.

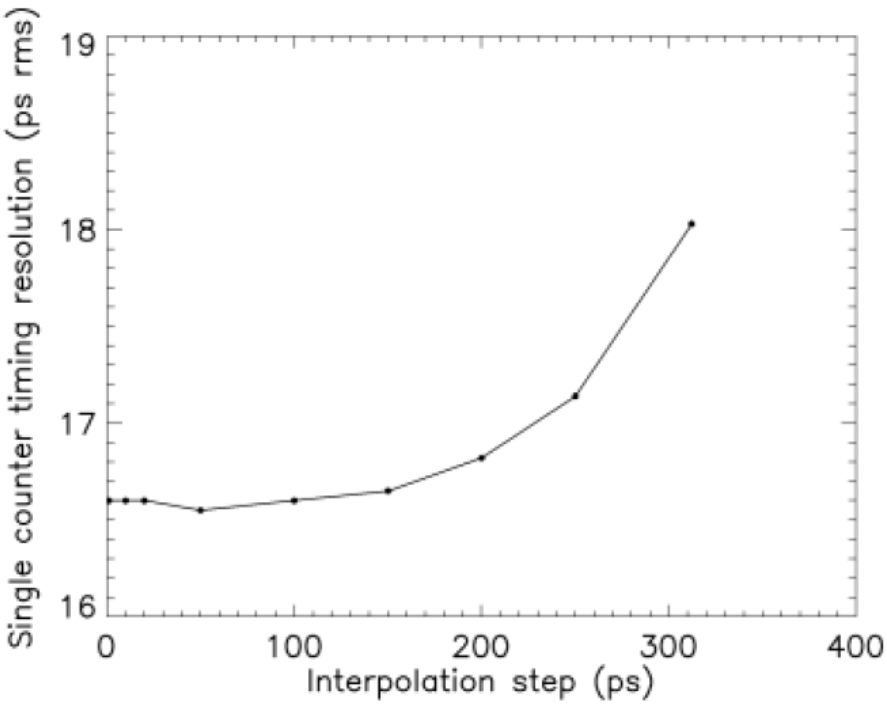
1) Find peak voltage.
2) Find the time to cross a fraction of the peak voltage.

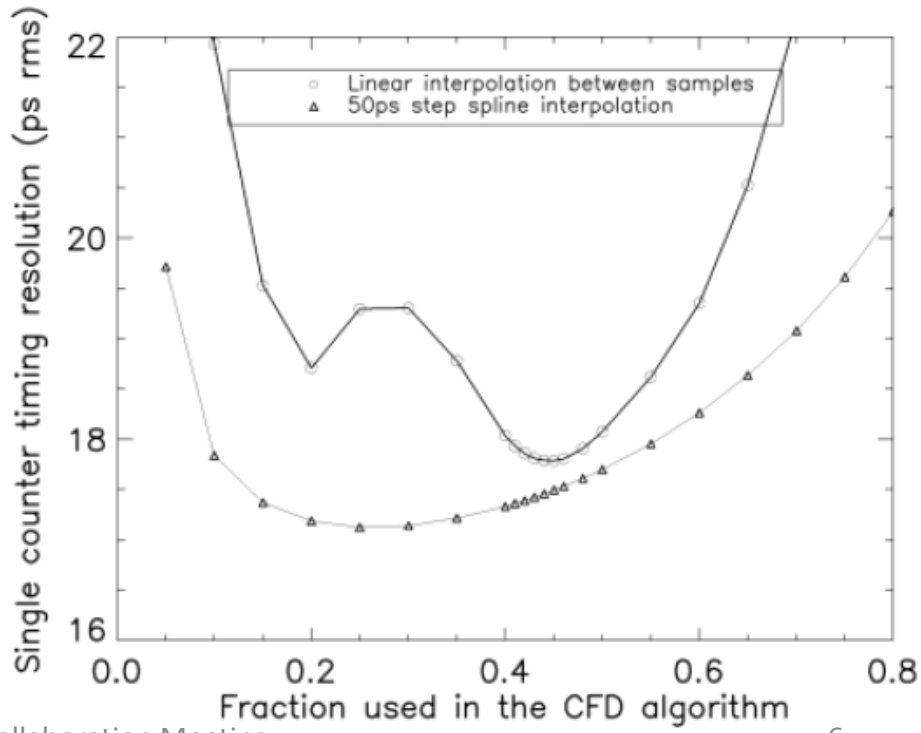
<u>χ^2 algorithm</u>

1) Take many waveforms to determine an average pulse profile
2) Scan the profile over varying delays until you find the lowest χ^2

Constant Fraction Algorithm

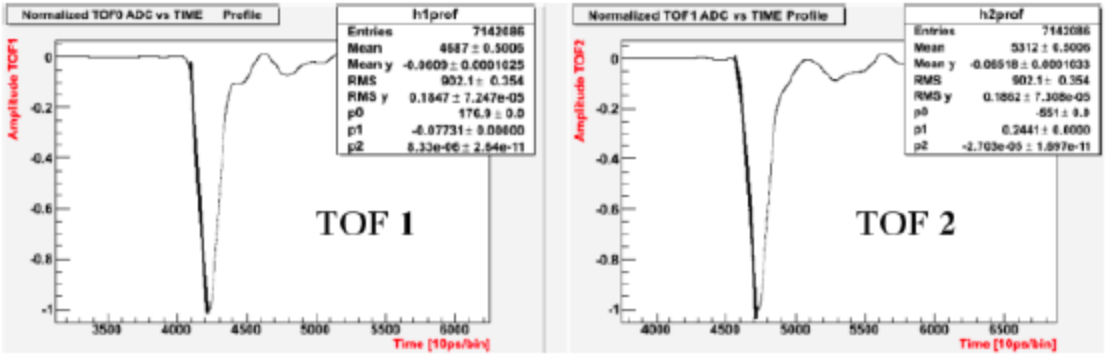
- Relatively simple, but still some knobs to tune…
  - Between waveform points, is it better to use linear interpolation or something else (e.g., spline).
  - Which fraction optimizes timing resolution?

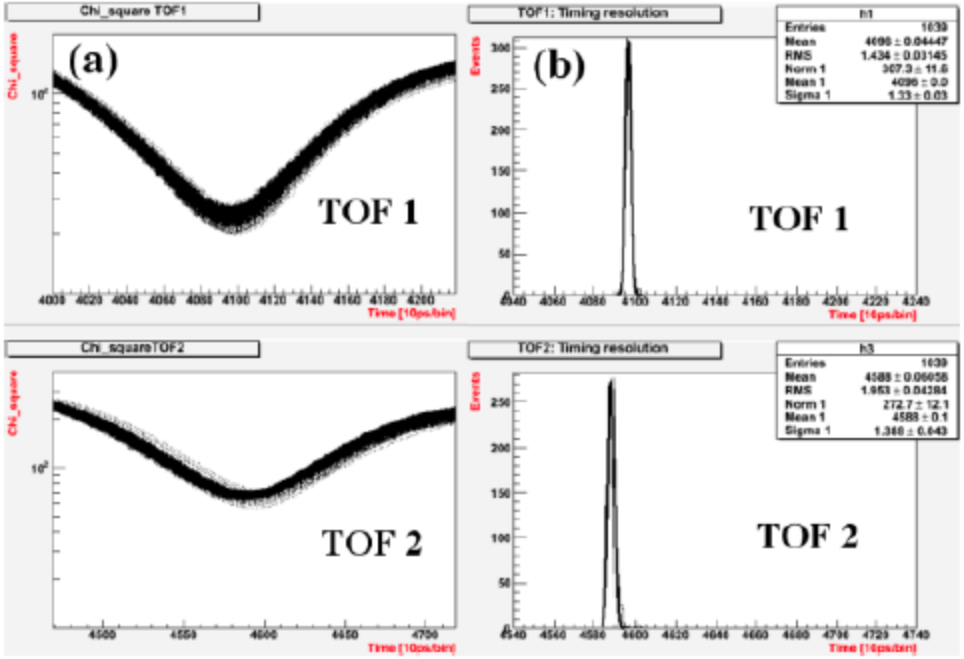




χ^2 Algorithm

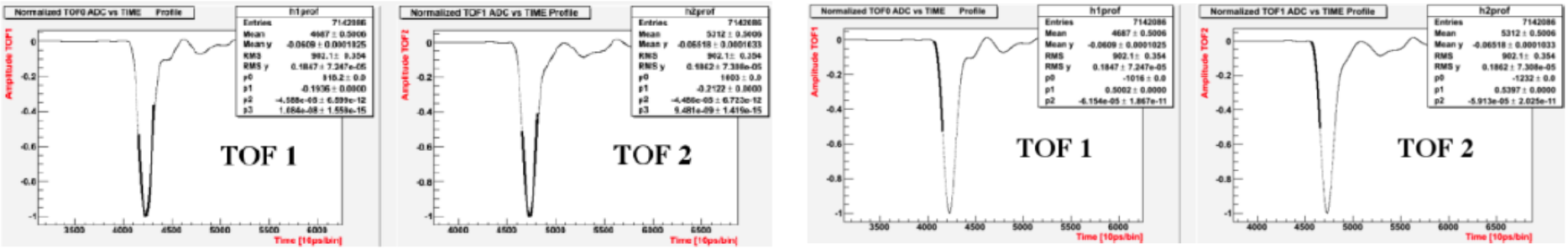
- More complicated…
  - Same interpolation questions as CFD algorithm.
  - How much (and what section) of the waveform should be included in the χ^2?
    - ➔Generally best results were obtained with a polynomial fit to the first part of the leading edge.

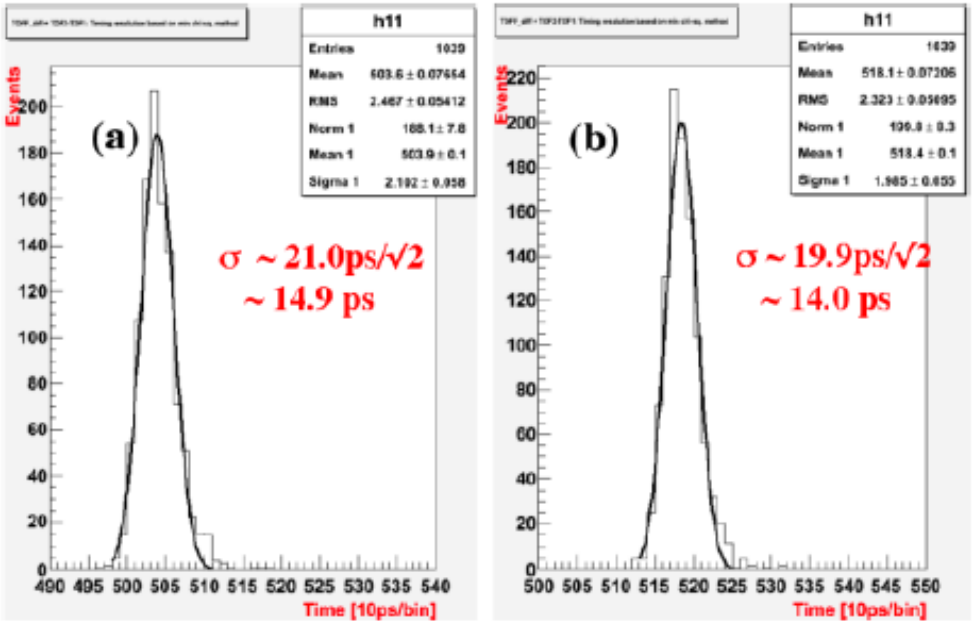




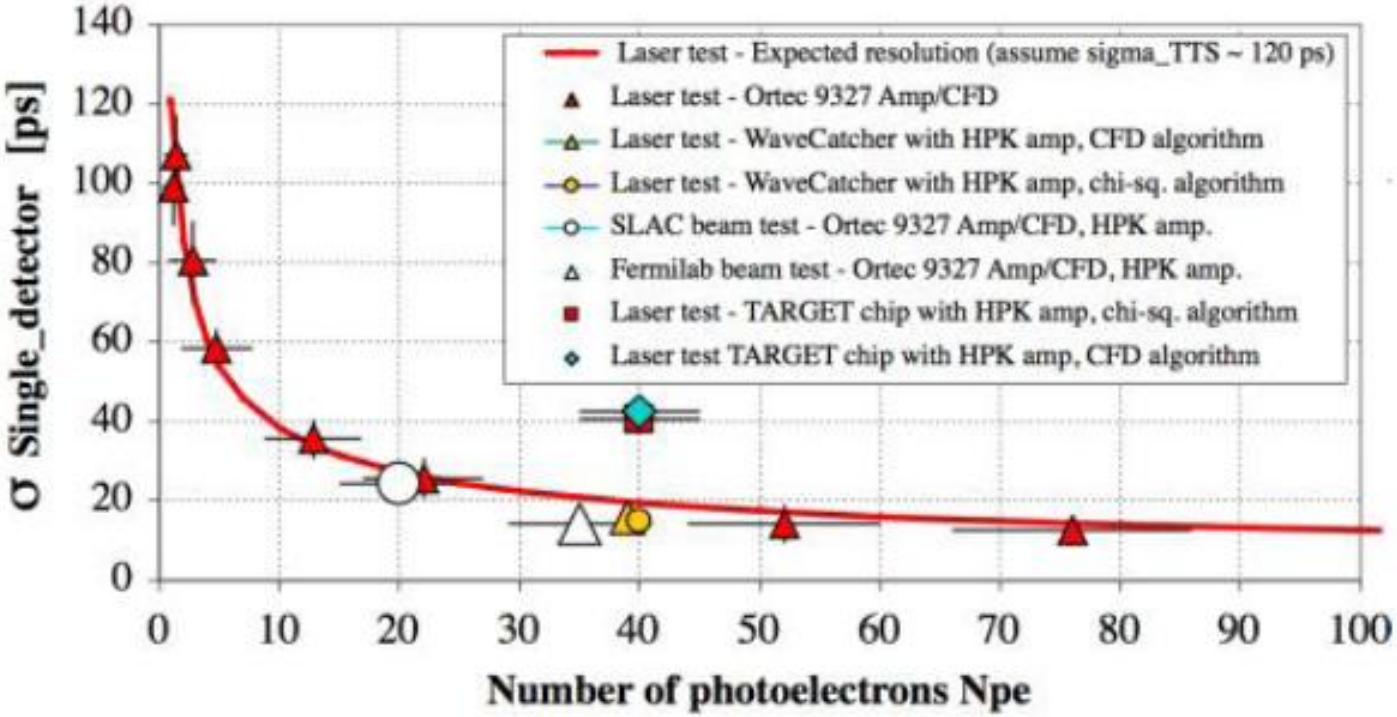
χ^2 Algorithm

- How much (and what section) of the waveform should be included in the χ^2?
  - Generally best results were obtained with a polynomial fit to the first part of the leading edge.





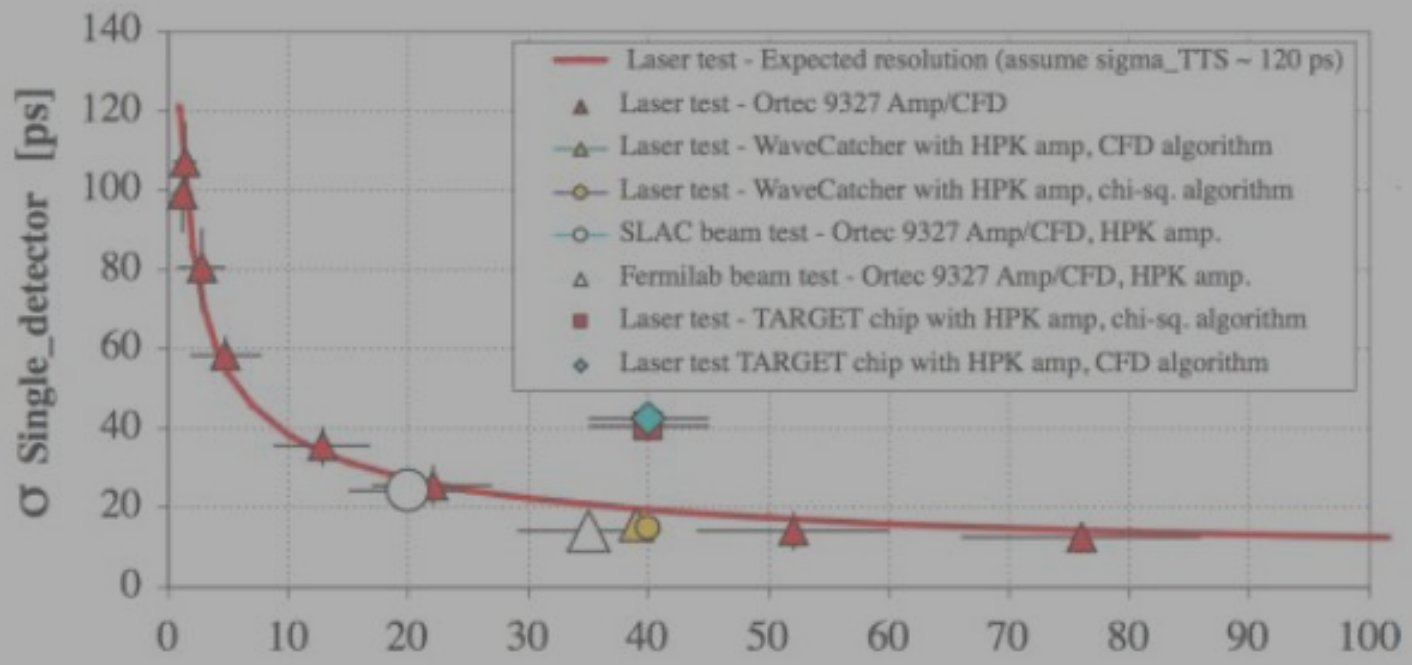
Timing Comparisons



➔Overall, results using χ^2 fitting are slightly better than those using a constant fraction algorithm, though there is significant added complexity.

➔Results with ASICs are competitive with hardware CFD as long as the analog bandwidth is high enough.

Timing Comparisons



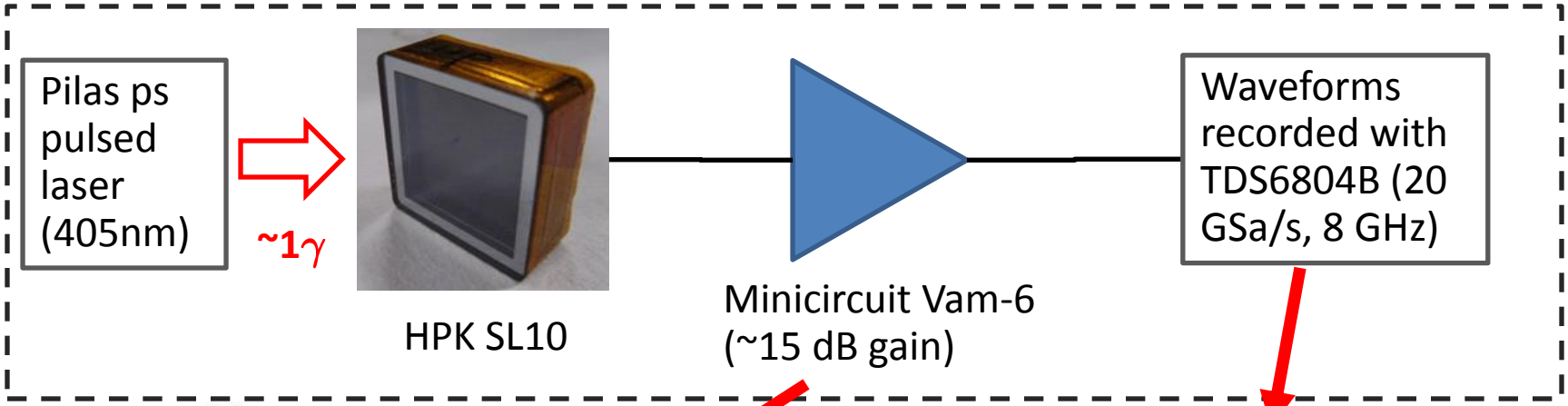
What about single photons?

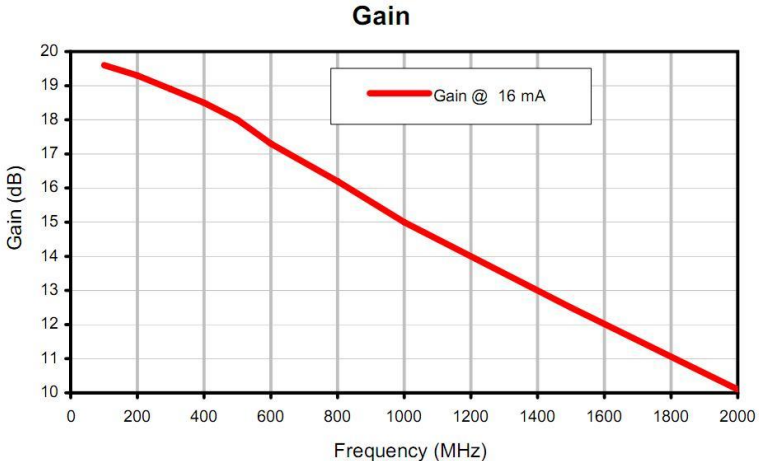
➔Overall, results using χ^2 fitting are slightly better than those using a constant fraction algorithm, though there is significant added complexity.

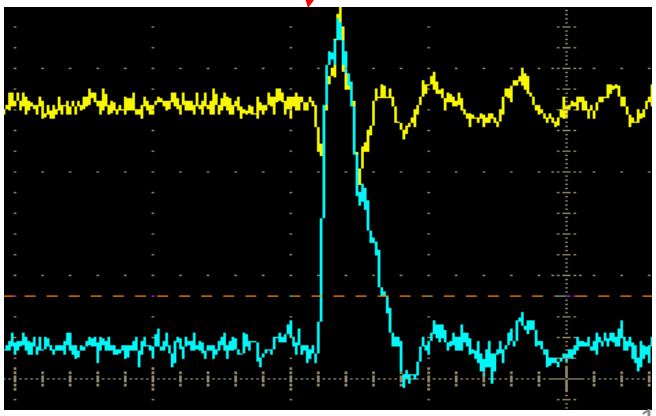
➔Results with ASICs are competitive with hardware CFD as long as the analog bandwidth is high enough.

Analysis of Fast PMT Pulses (**Single** γ)

- Timing studies also performed using the Hamamatsu SL10 w/ high bandwidth oscilloscope.
- Setup:

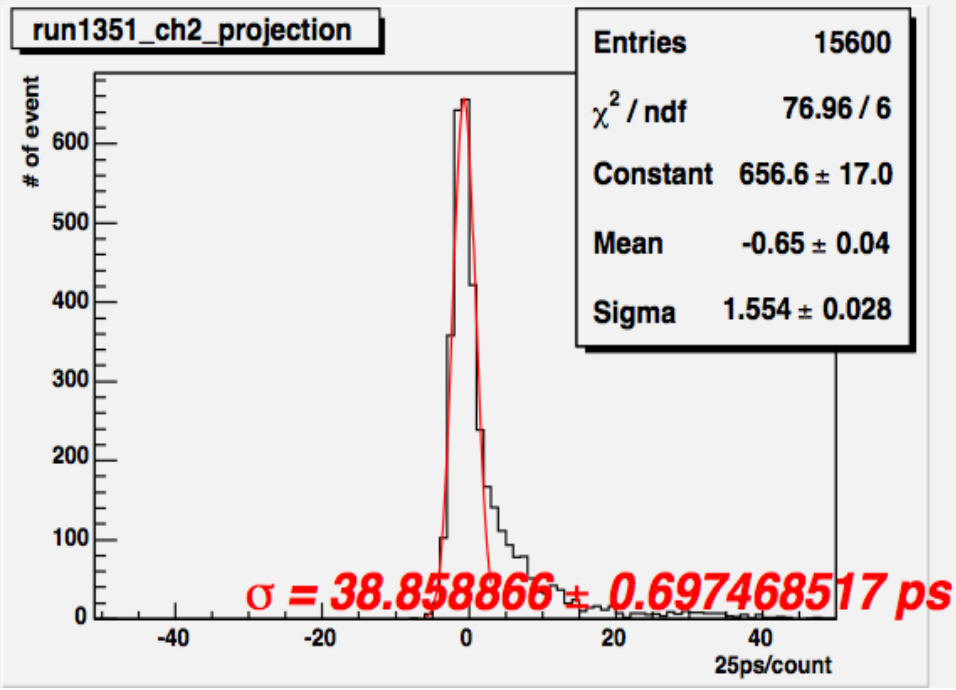




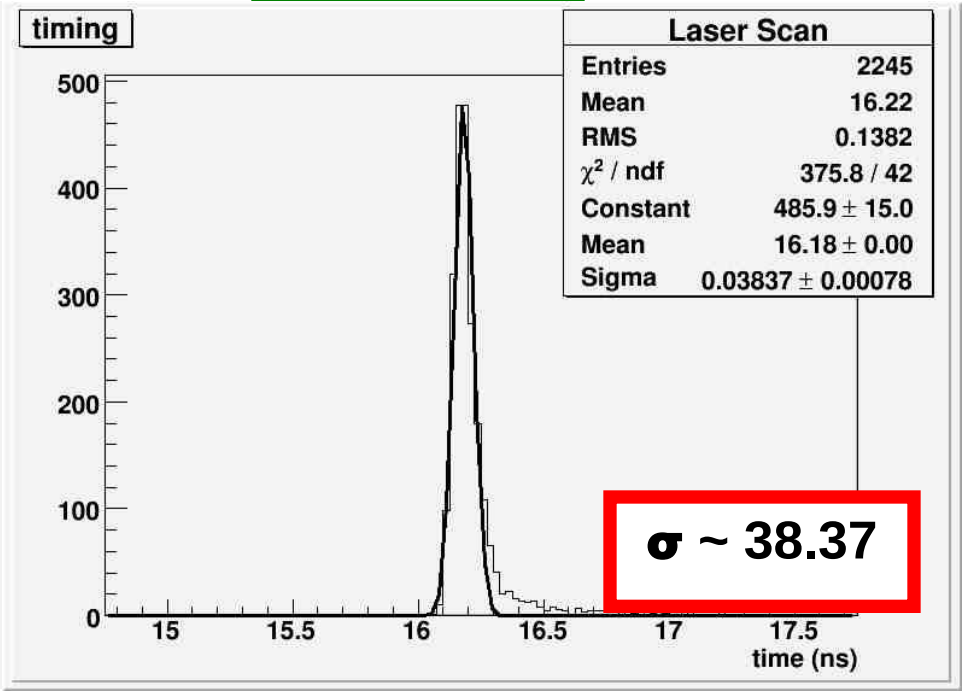


TDC Distributions (Single Photon Timing)

Nagoya



Hawai'i

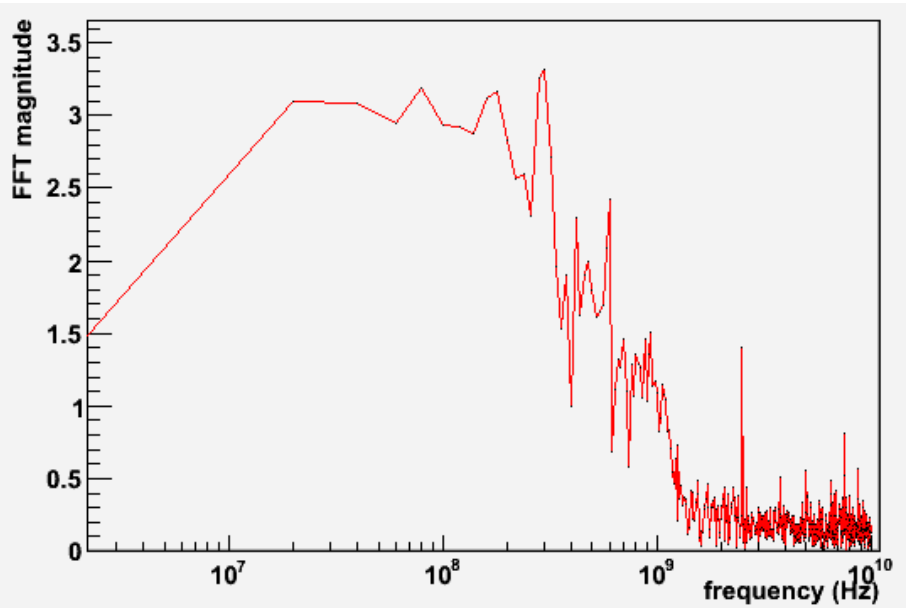


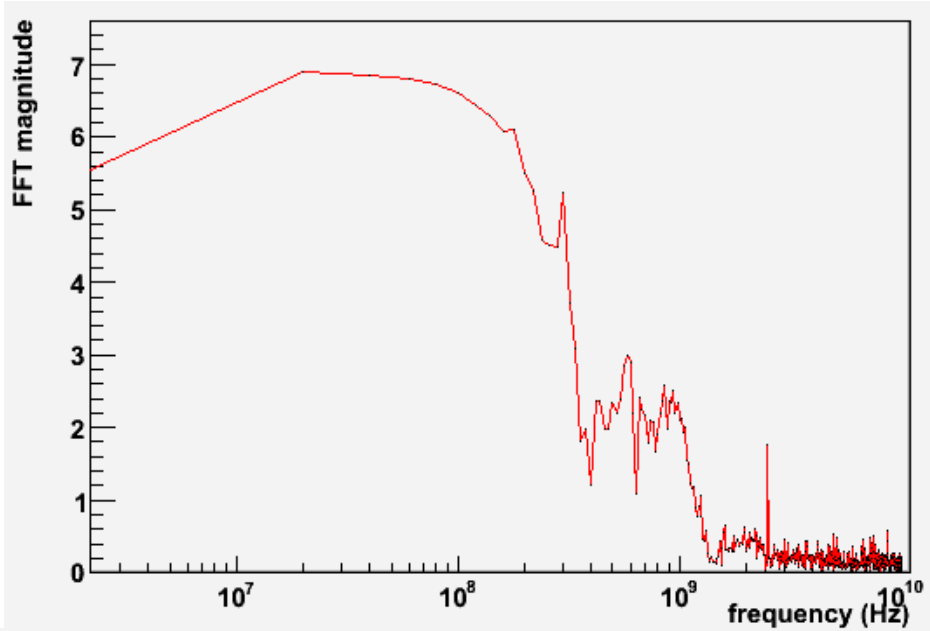
- Nagoya & Hawai'i measurement agree with each other
- Hawai'i has less of a tail in distribution
  - Less overall TDC RMS

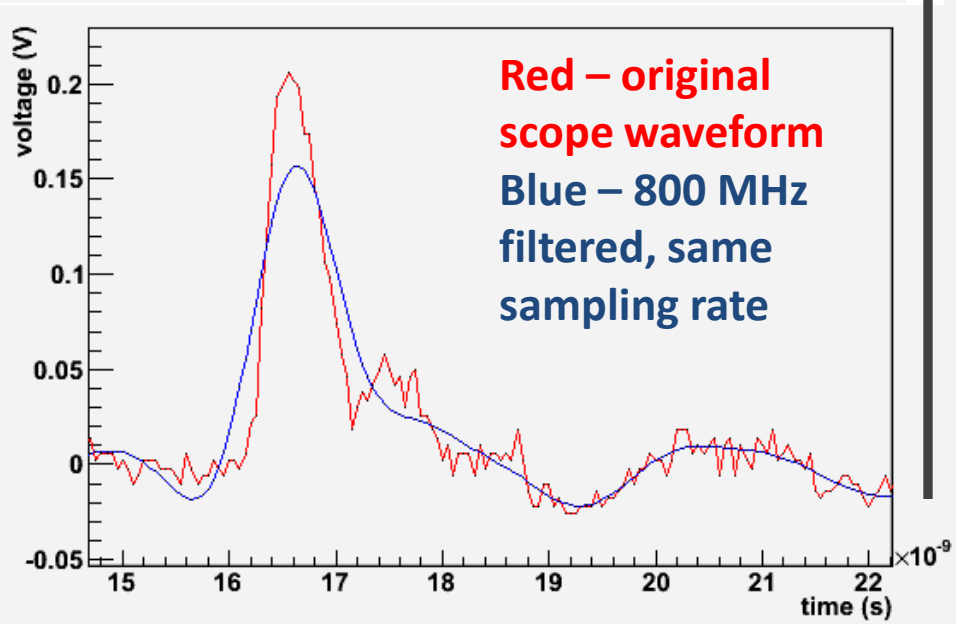
Updated Analysis

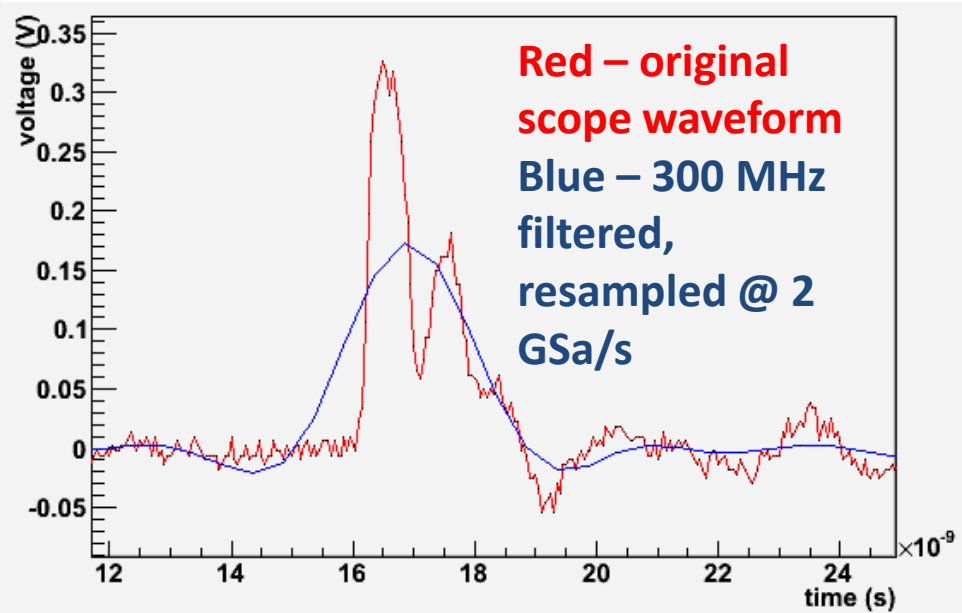
- Previous analysis used waveforms “as-is” from the scope.
- What happens if we have lower bandwidth and/or a lower sampling rate.
  - To test, for example, expected performance from a waveform digitizing ASIC.
- New analysis steps:
  1. Take FFT of the raw scope waveform
  2. Apply low pass filter with varying 3dB points to simulate bandwidth limitations.
     - In this analysis, we use a 4th order Butterworth filter, but we can explore others, for example simulated frequency response of a waveform digitizing ASIC.
  3. Transform back to the time domain
  4. Downsample to simulate lower sampling rate.
     - We take every N^{th} point, with initial offset randomly chosen from 0 to N-1. We can make this more sophisticated as well, but interesting to start.
  5. Perform timing measurement similar to before.
     - We find the time to reach 30% of the measured peak voltage.

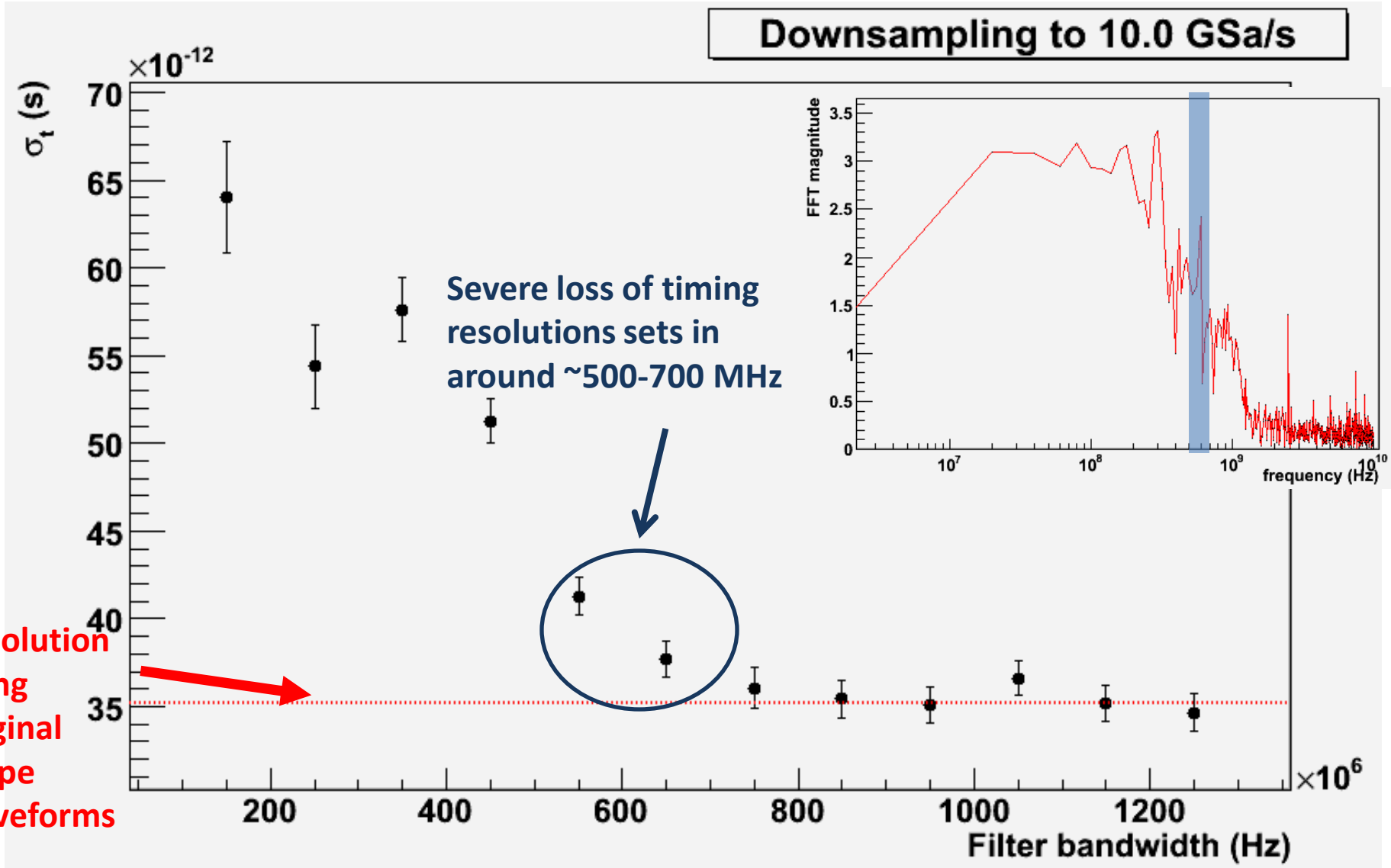
Sample Spectra, Waveforms



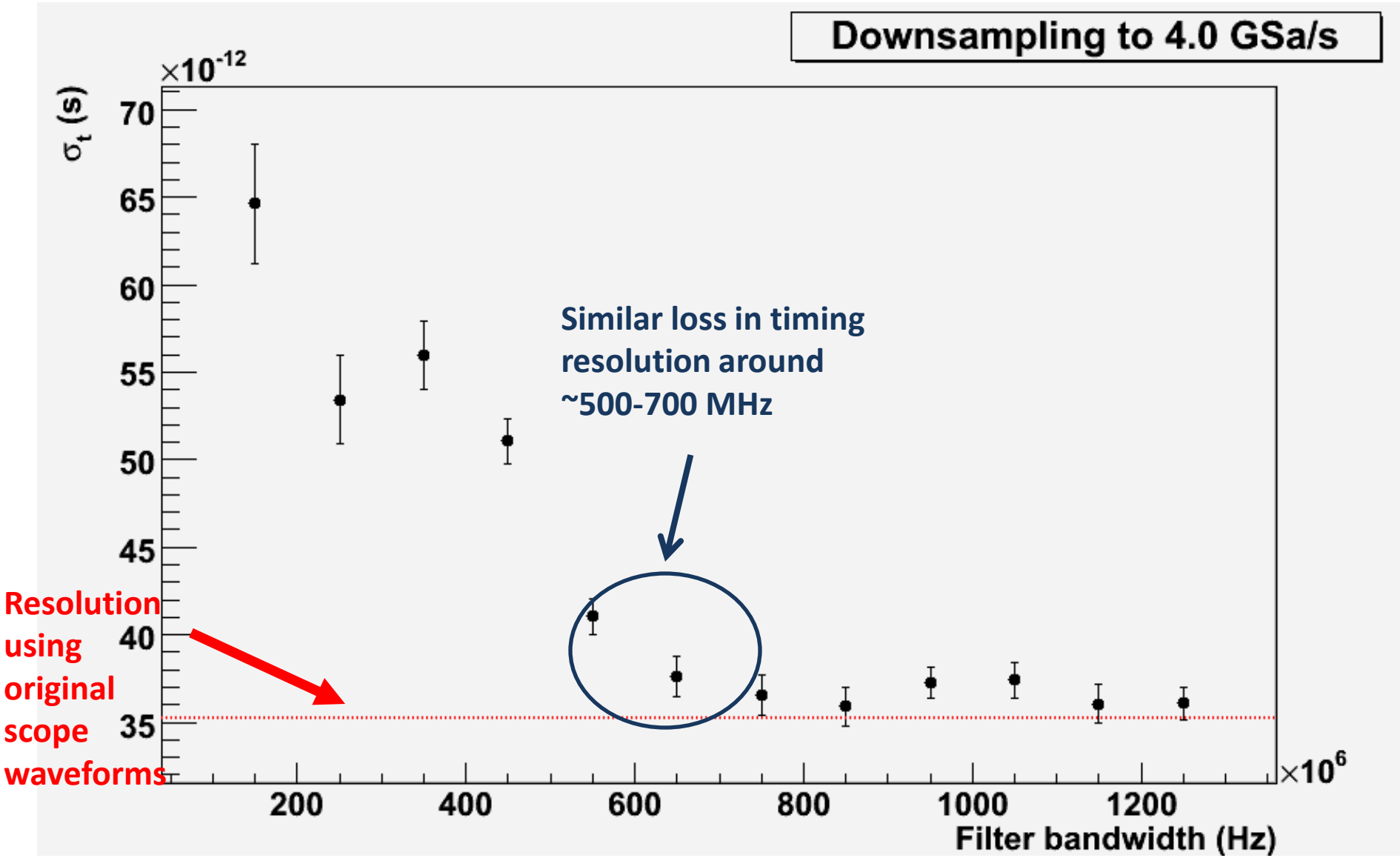


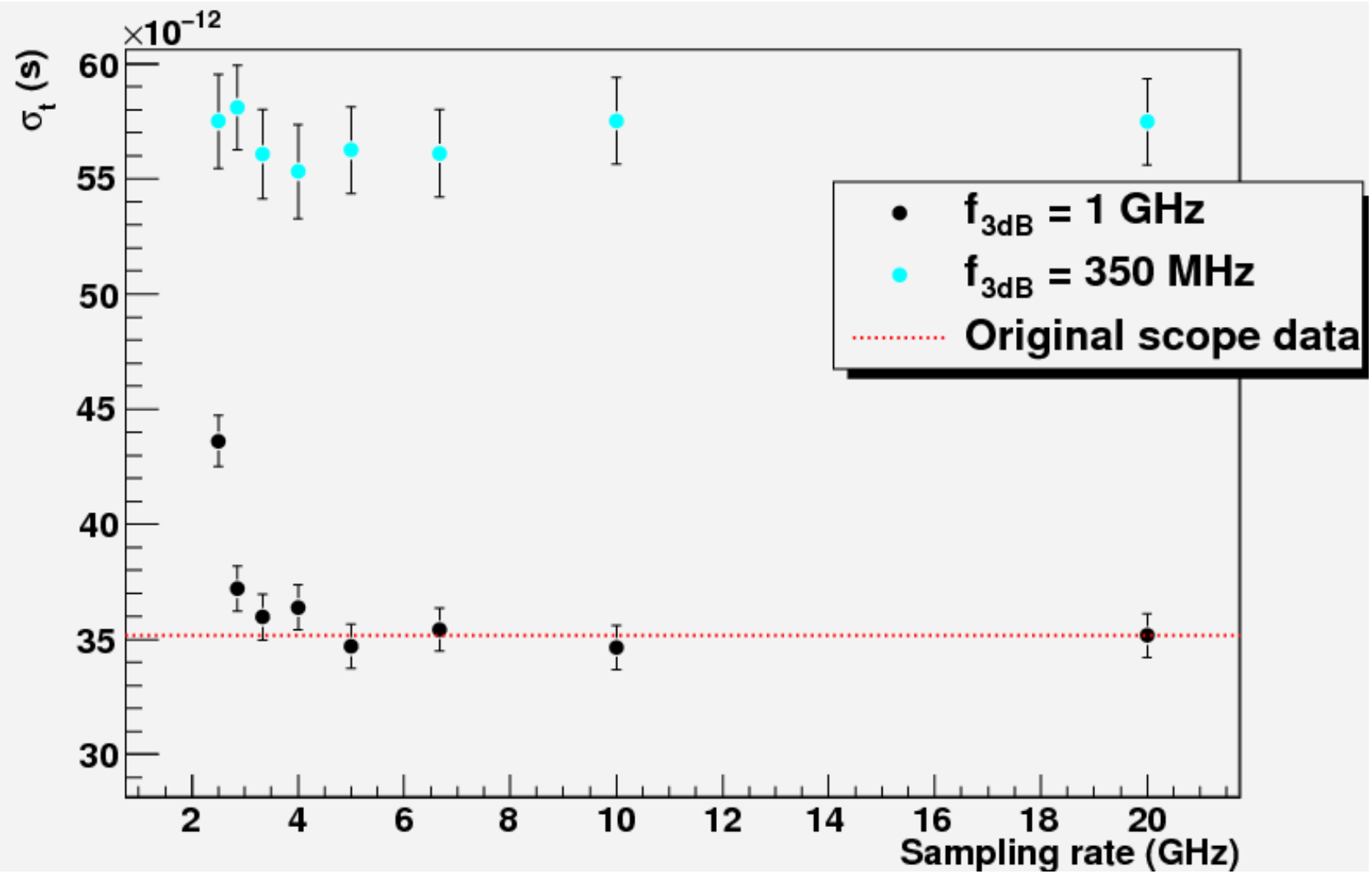






Resolution using original scope waveforms


Downsampling to 4.0 GSa/s
$\times 10^{-12}$
σ_t (s)
70
65
60
55
50
45
40
35
200
400
600
800
1000
1200
$\times 10^{6}$
Filter bandwidth (Hz)
Similar loss in timing resolution around ~500-700 MHz
Resolution using original scope waveforms

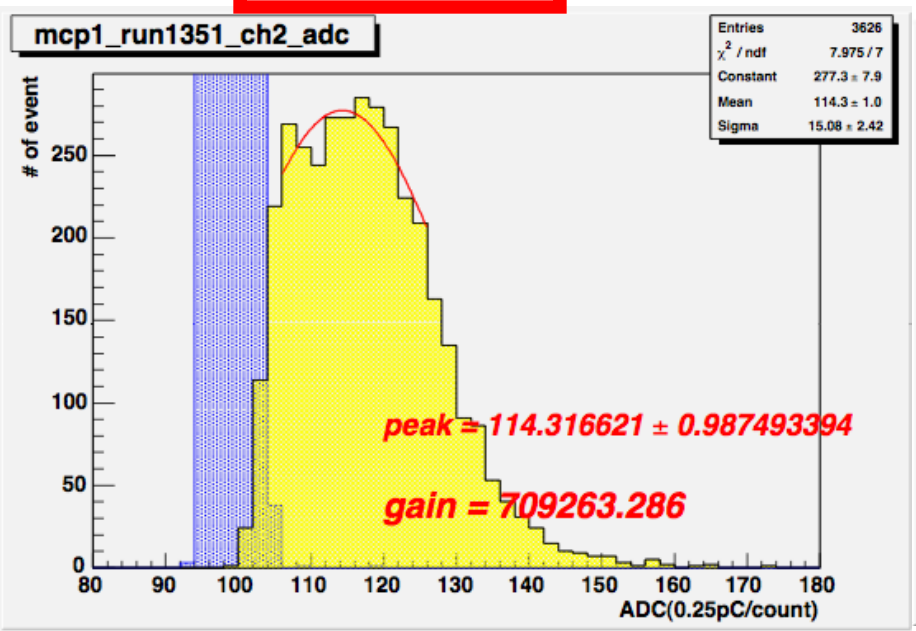

×10^-12
σt (s)
60
55
50
45
40
35
30
2
4
6
8
10
12
14
16
18
20
Sampling rate (GHz)
f3dB = 1 GHz
f3dB = 350 MHz
Original scope data

Conclusions

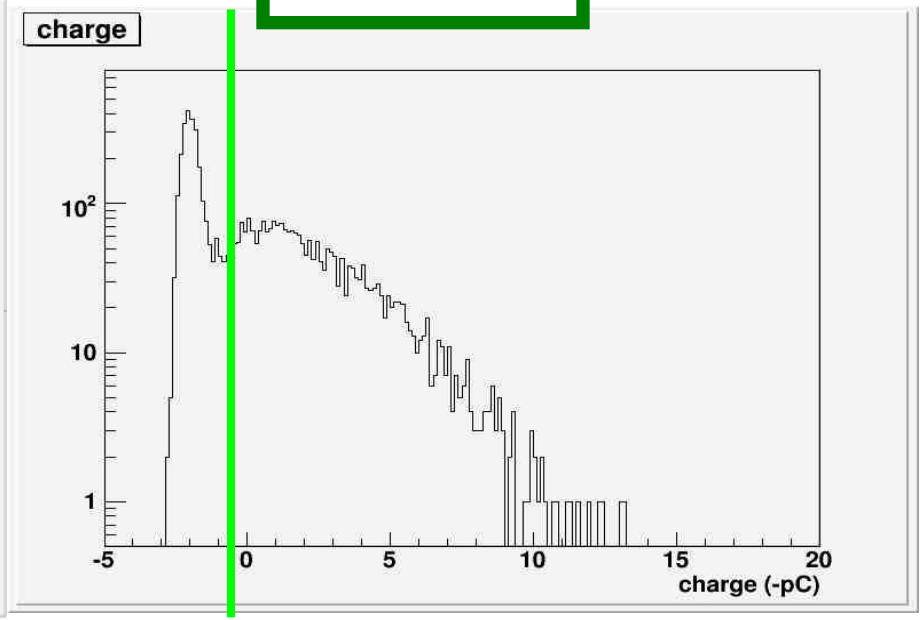
- Study is ongoing of various techniques for processing sampled waveform data, with focus on:
  - Simplicity / speed (as it needs to be done with on-line processing for many applications)
  - Performance (mainly in timing)
- So far, software CFD seems quite competitive with more complicated techniques.
- For future ASIC designs, it would be valuable to have a sample of data from the final device to determine what kind of bandwidths / sampling rates are necessary.

ADC Distributions

Nagoya



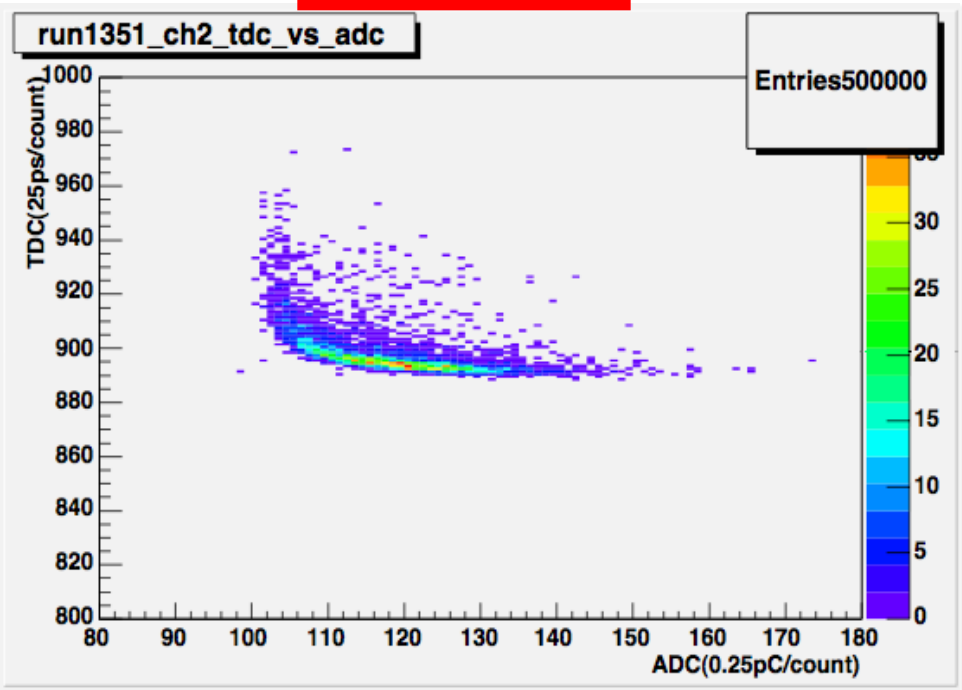
Hawai'i



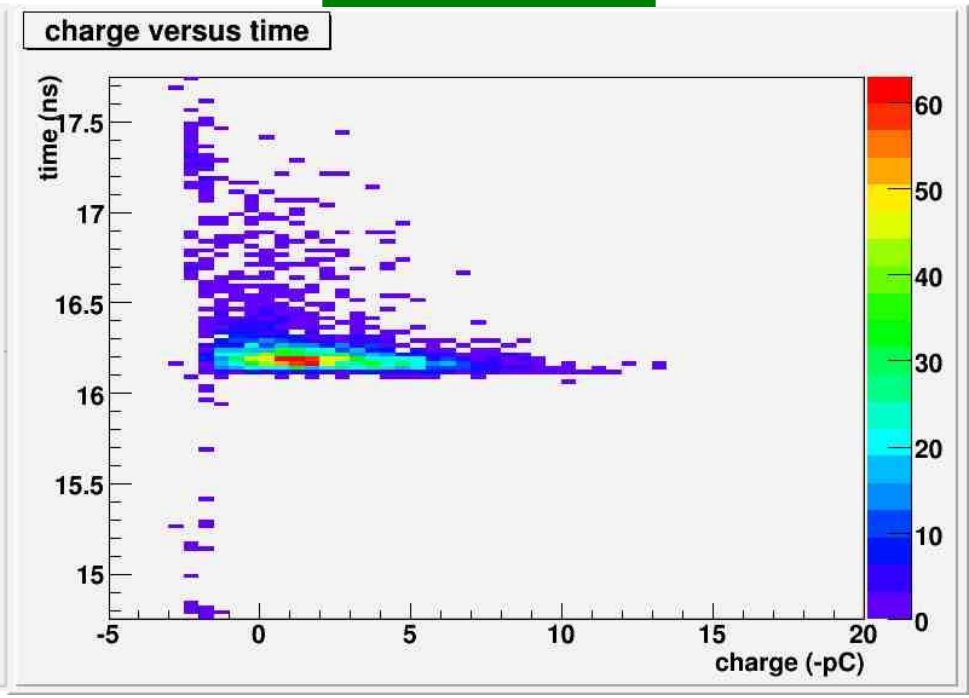
- Nagoya: larger gain for the external amplifier
- Hawai'i: recorded every waveform (even if no signal)

ADC vs TDC Distributions

Nagoya



Hawai'i



- Nagoya: time-walk correction performed
  - time is measured by CFD
- Hawai'i: no time-walk correction performed
  - time is measured by interpolating the leading edge threshold crossing using waveform data
  - Threshold set to 50% of the peak voltage for each event

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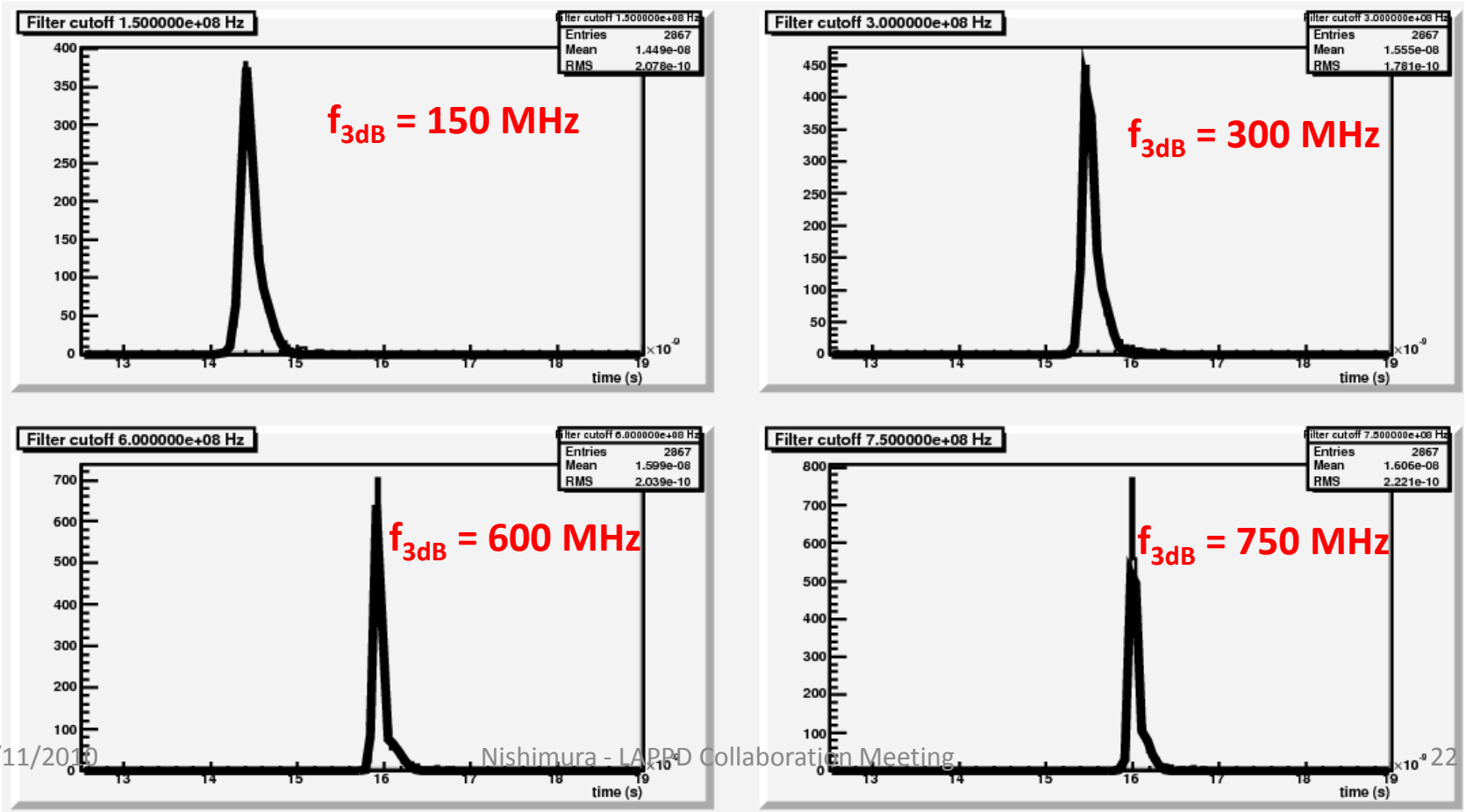
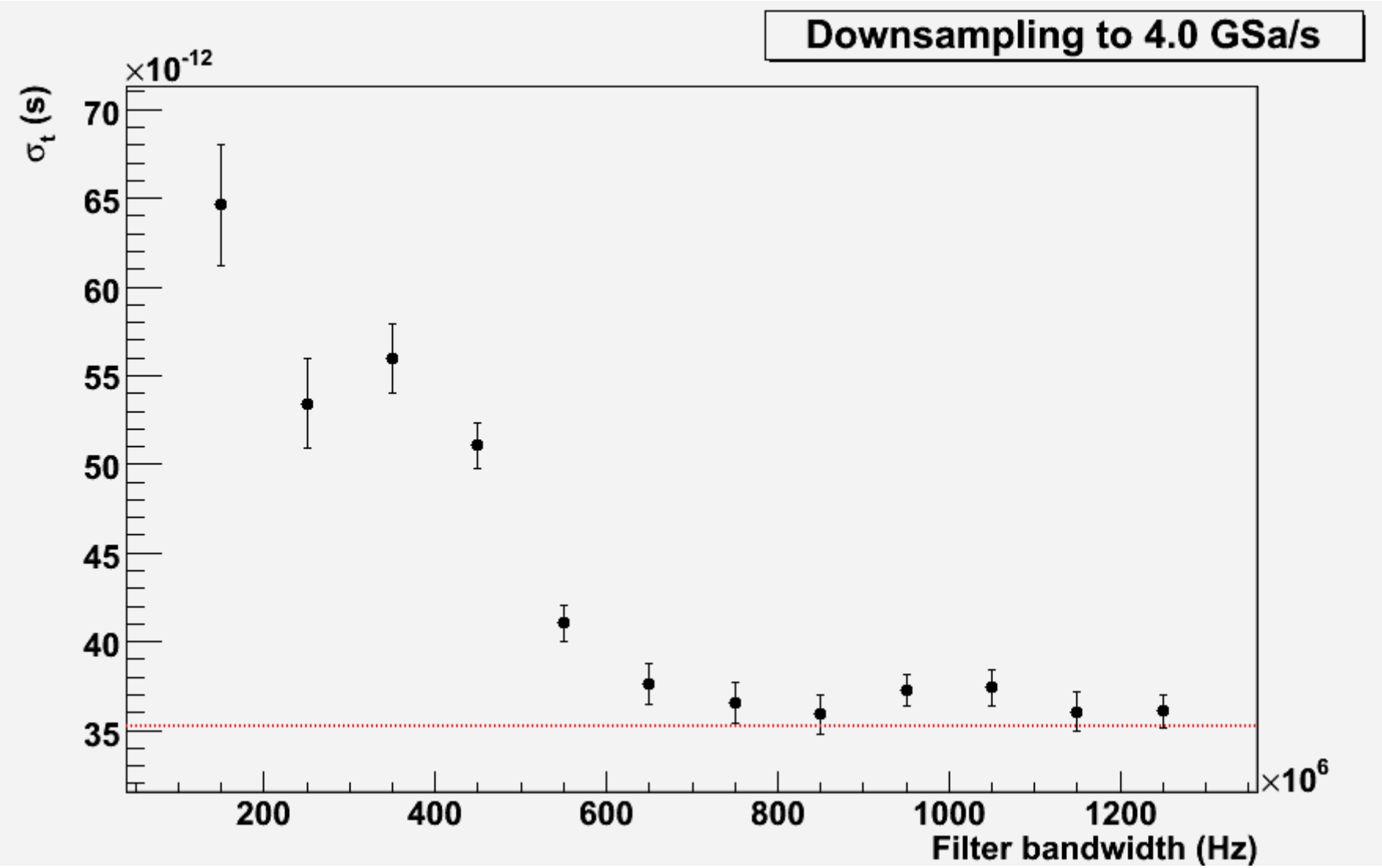
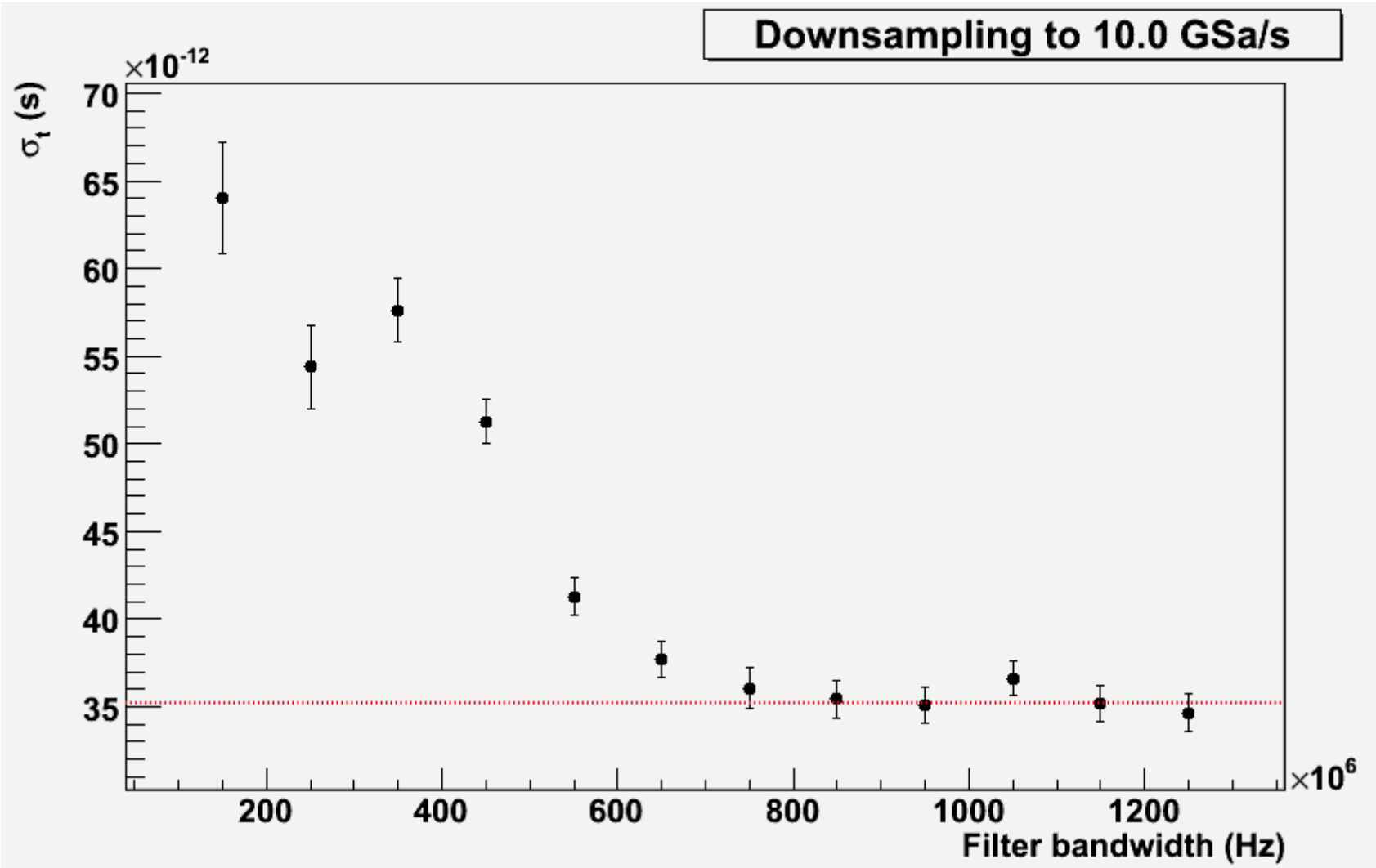
Single Photon Timing Resolutions

- Double Gaussian fits to the distribution of calculated times (using 30% of peak voltage method)
- Time resolution is σ of the narrow Gaussian.
- Example fits @ 10 GSa/s downsampling:




Downsampling to 4.0 GSa/s
×10^-12
σt (s)
70
65
60
55
50
45
40
35
200
400
600
800
1000
1200
×10^6
Filter bandwidth (Hz)


Downsampling to 10.0 GSa/s
×10^-12
σt (s)
70
65
60
55
50
45
40
35
200
400
600
800
1000
1200
×10^6
Filter bandwidth (Hz)