The PDD ASIC: Highly Efficient Energy and Timing Extraction for High-Rate Applications

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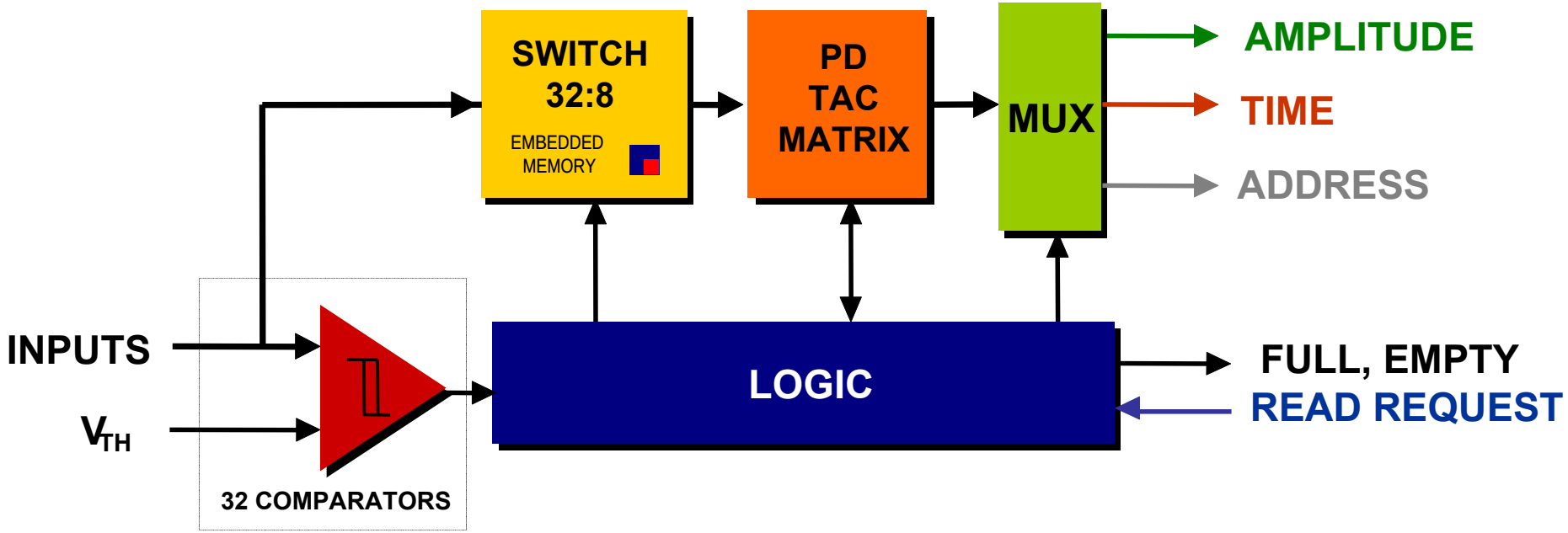
Outline

- The PDD architecture
- New features:
  - Simultaneous Events Catcher (SEC)
  - Pileup Discrimination and Rejection
- A modular test system
- Test results
  - SEC performances
  - High rate spectroscopy
  - A first example of pile-up rejection
- Future works and conclusions

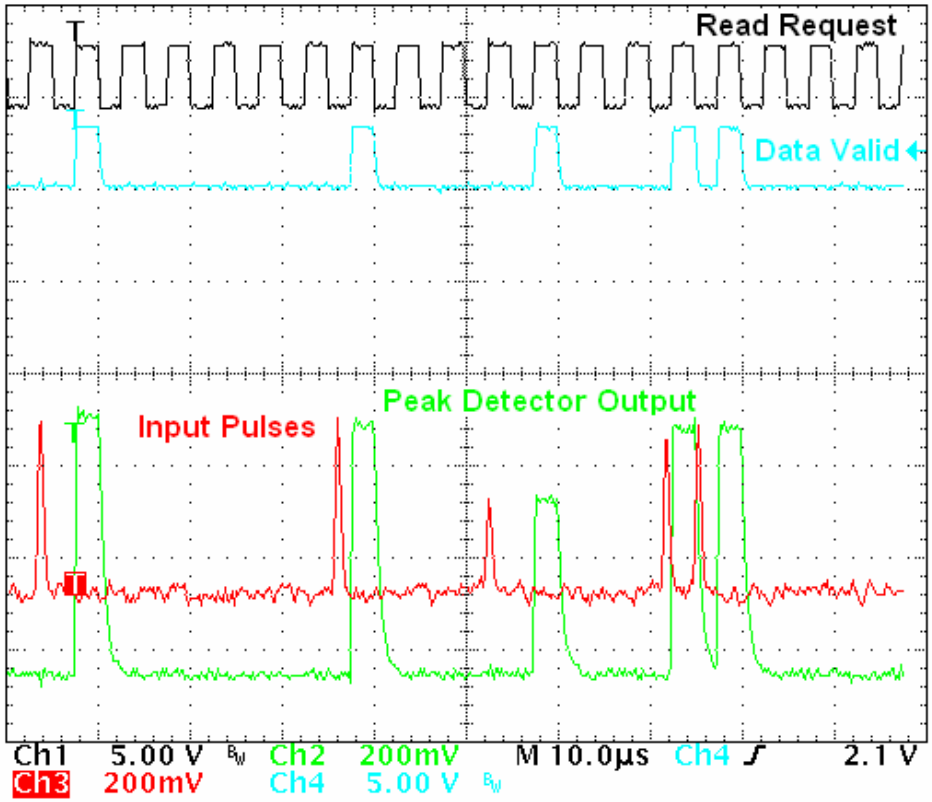
The Peak Detector Derandomizer ASIC Architecture

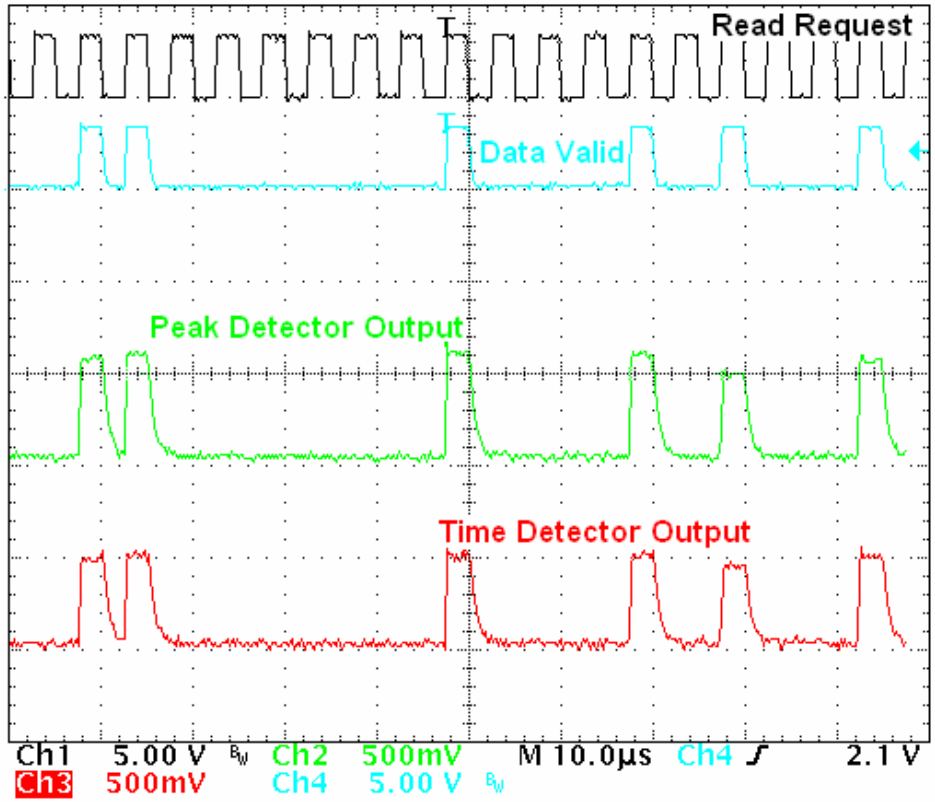


- New architecture for efficient readout of multichannel detectors
  - *Self-triggered and self-sparsifying*
  - *Simultaneous amplitude, time, and address measurement for 32 input channels*
  - *Set of 8 peak detectors act as derandomizing analog memory*
  - *Rate capability improvement over present architectures*
- Based on new 2-phase peak detector combined with Quad-mode TAC
  - *High absolute accuracy (0.2%) and linearity (0.05%), timing accuracy (5 ns)*
  - *Accepts pulses down to 30 ns peaking time, 1.6 MHz rate per channel*
  - *Low power (2 mW per channel)*

P. O'Connor, G. De Geronimo, A. Kandasamy, *Amplitude and time measurement ASIC with analog derandomization: first results*, IEEE Trans. Nucl. Sci. 50(4), pp. 892-897 (Aug. 2003).

PDD ASIC waveforms





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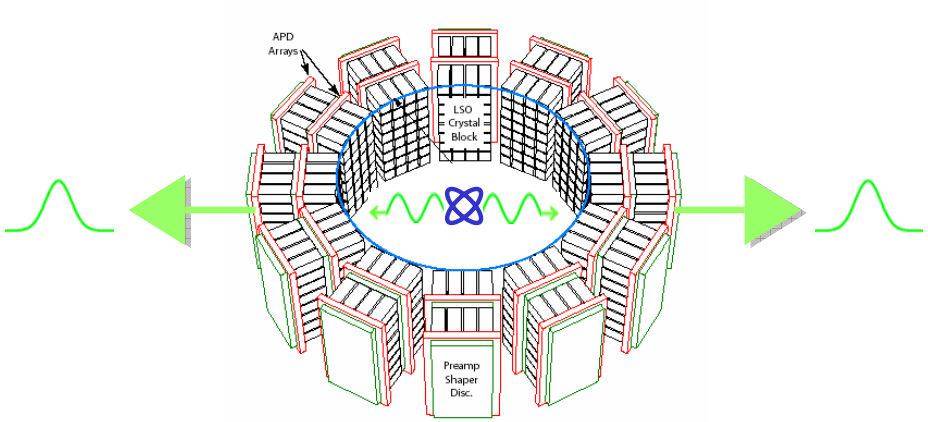
The PDD for Simultaneous Events

Simultaneous events = events that cross the threshold within a time window of about 10ns

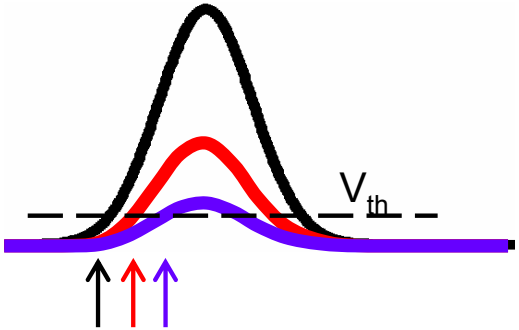
Coincident detection (e.g. PET)

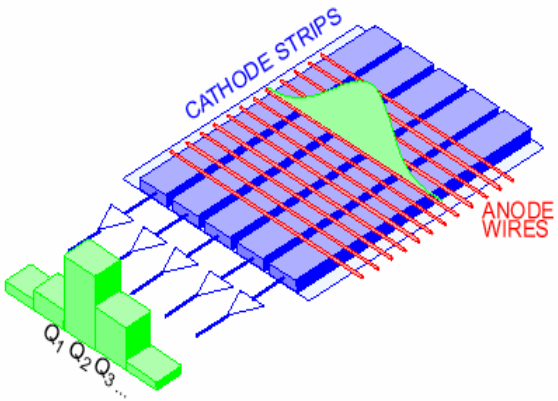
- similar amplitudes
- typically only two channels
- usually non-neighboring



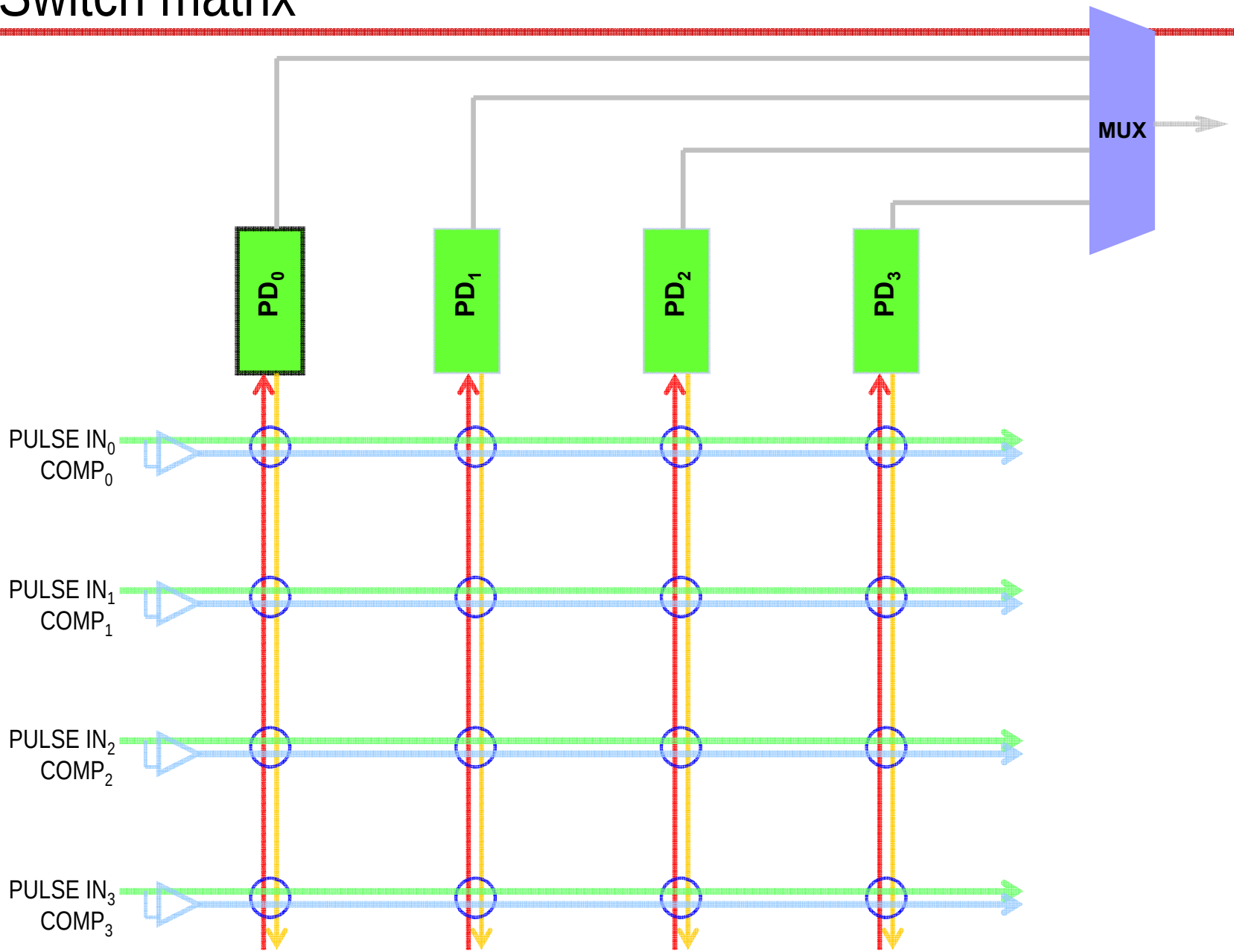
Charge-shared events (e.g. pad and strip MWPCs)

- occur in neighboring channels
- different amplitude (typically)
- more than 2 channels (often)





The Switch matrix



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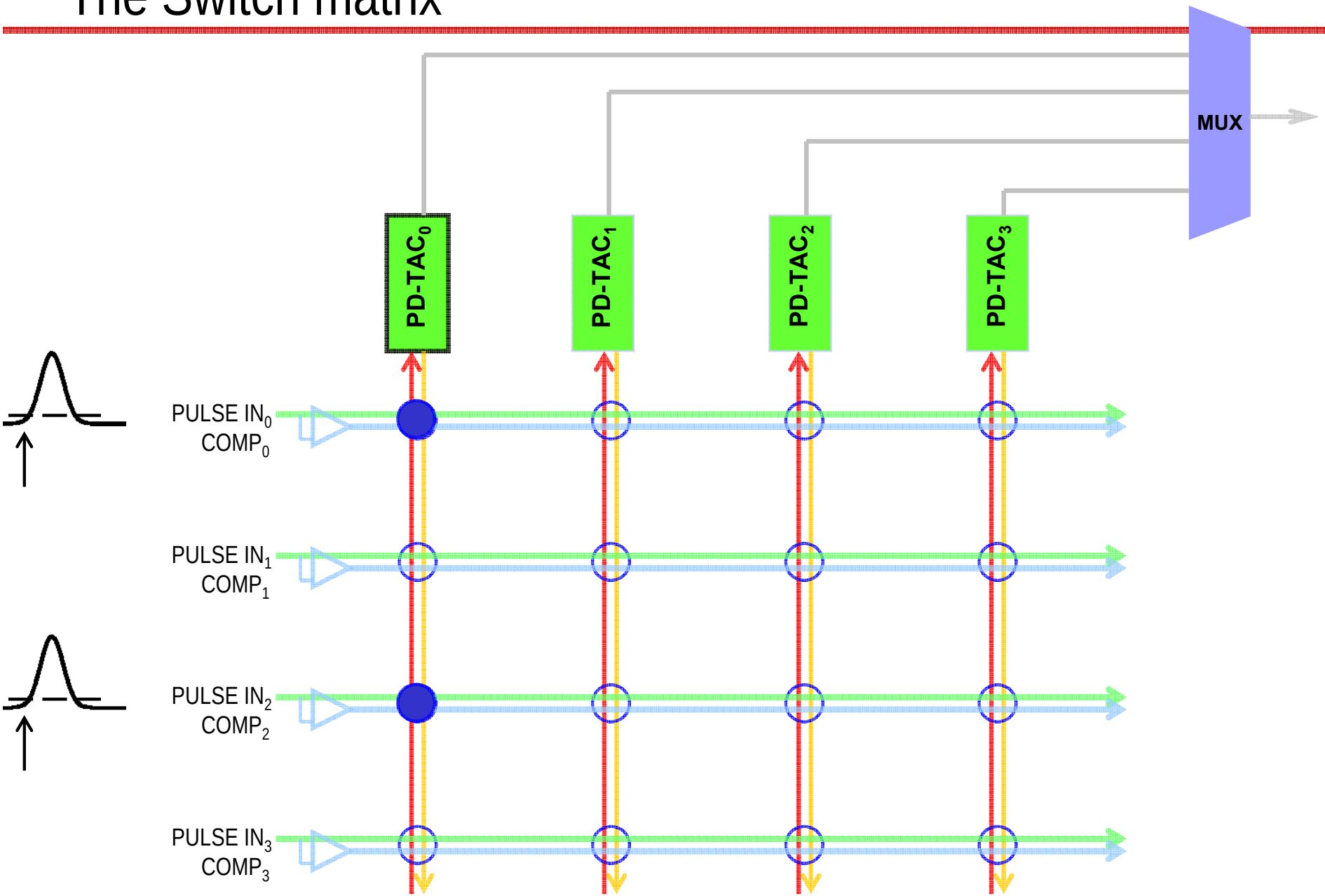

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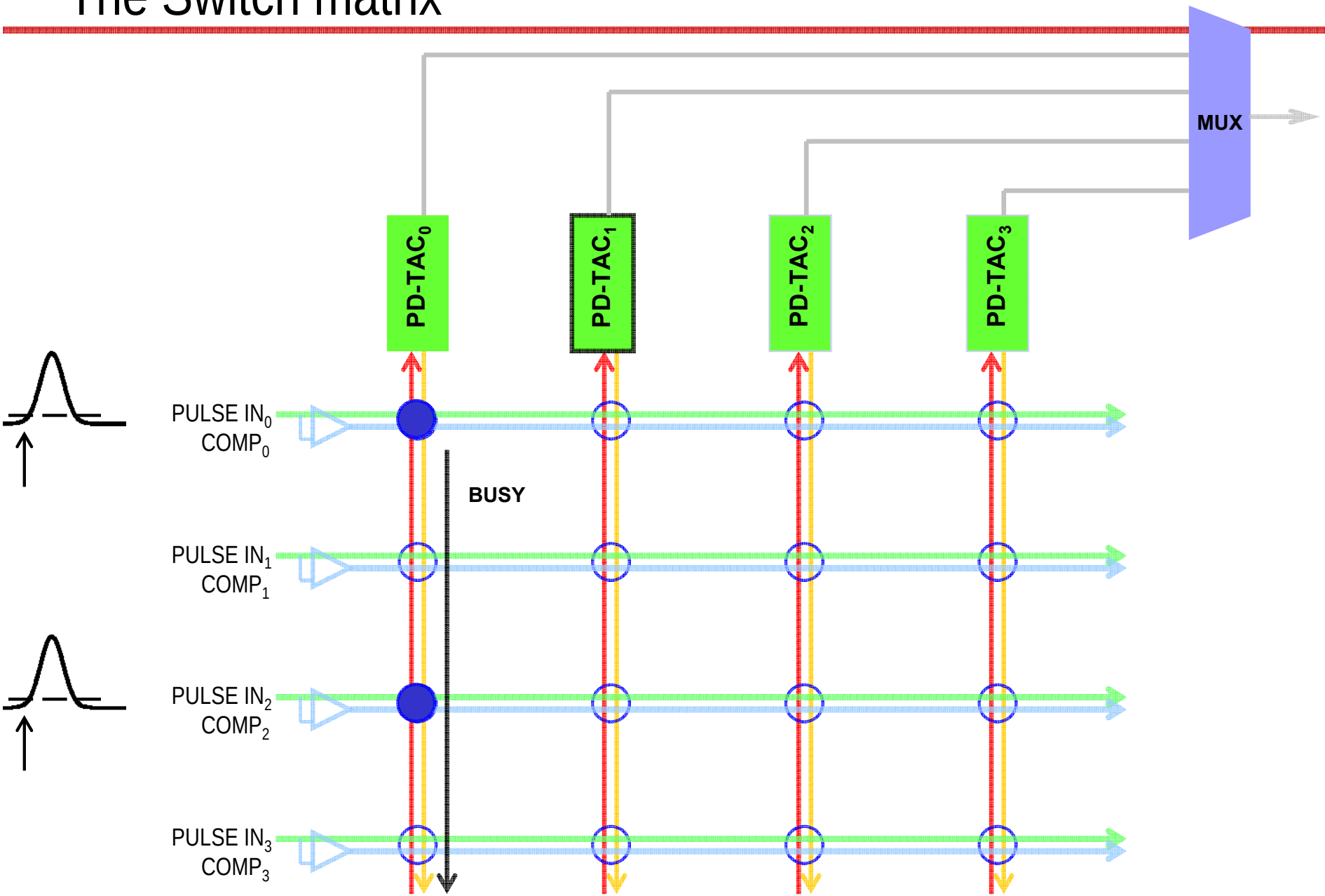

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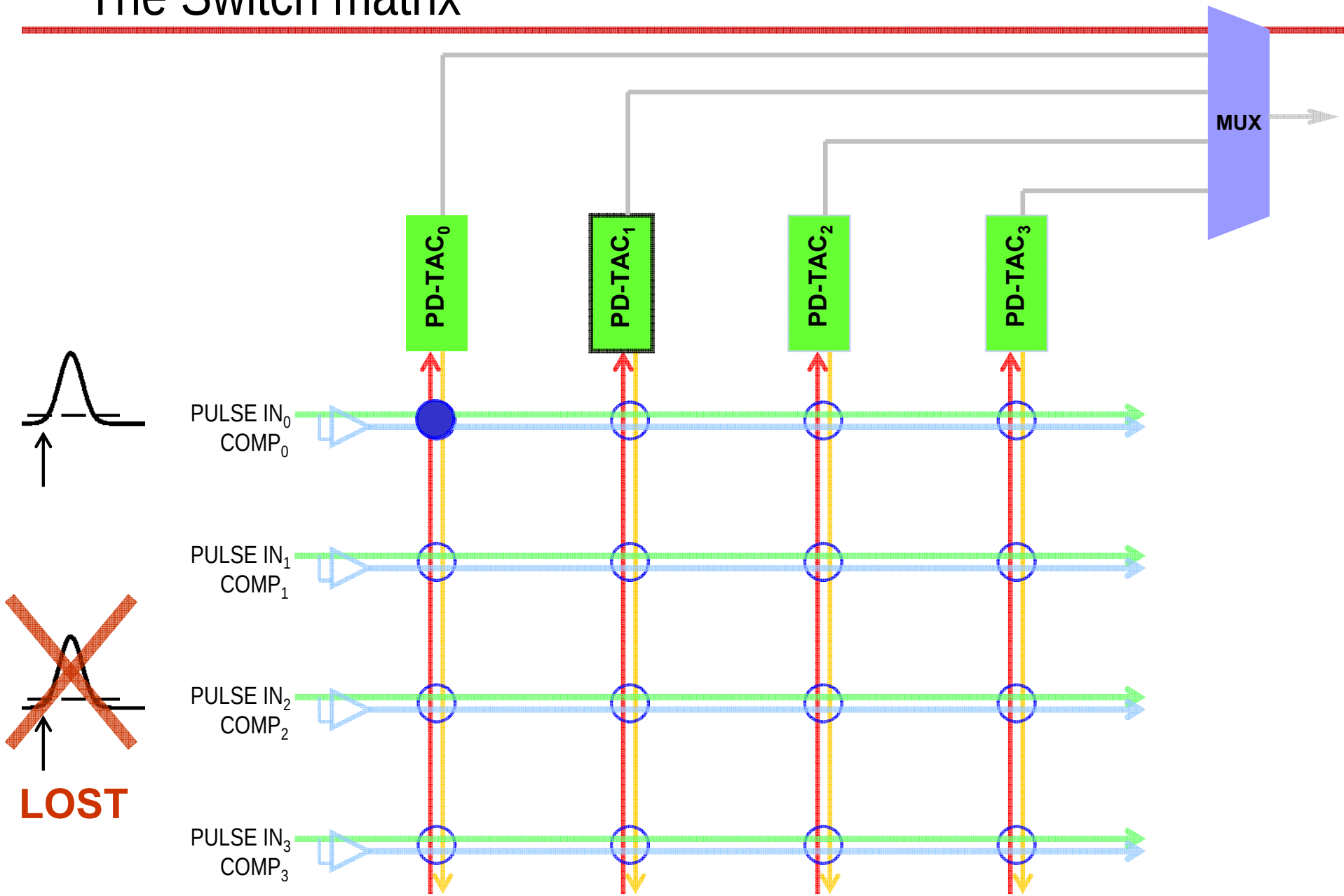
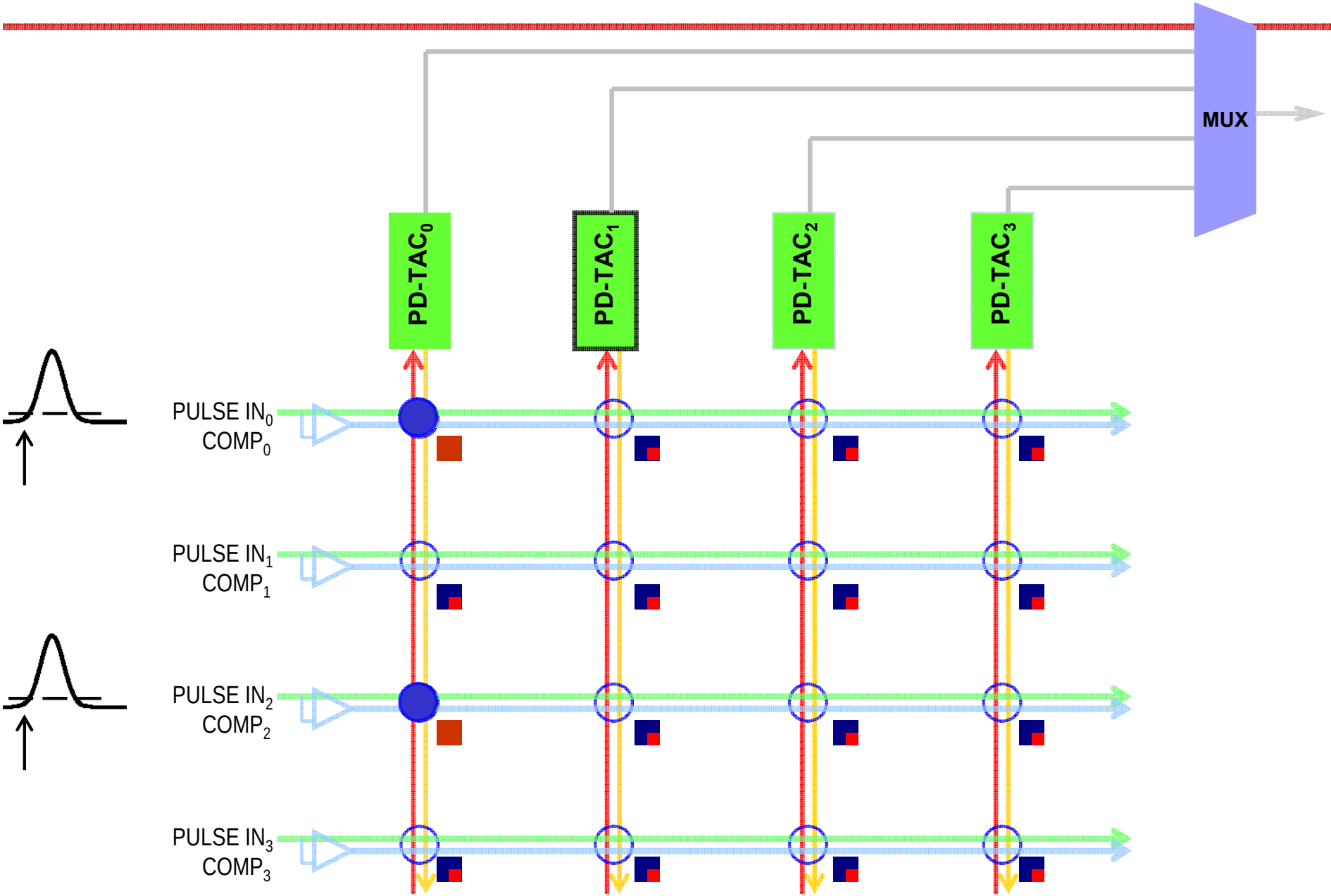


The Switch matrix + Simultaneous Events Catcher (SEC)



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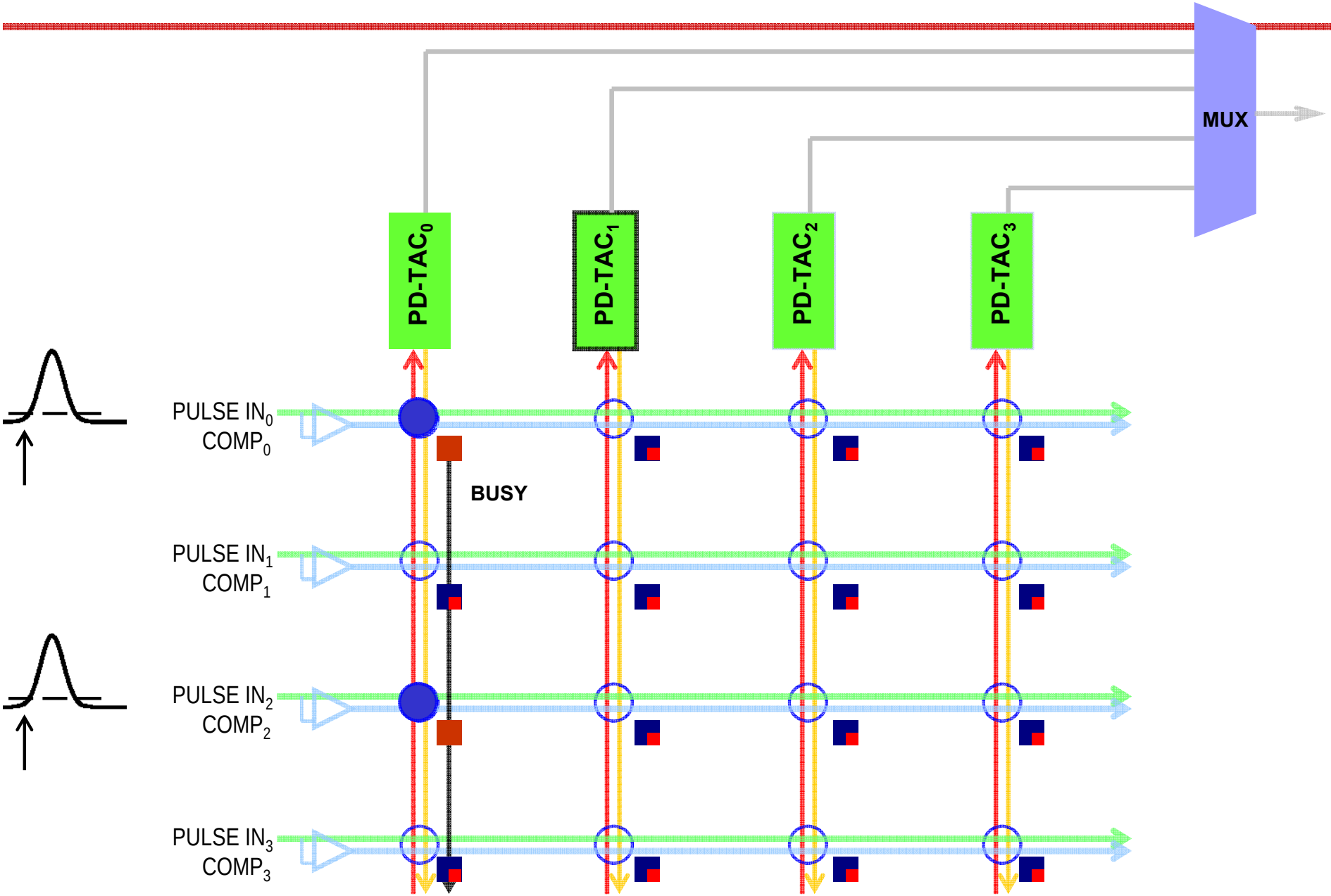

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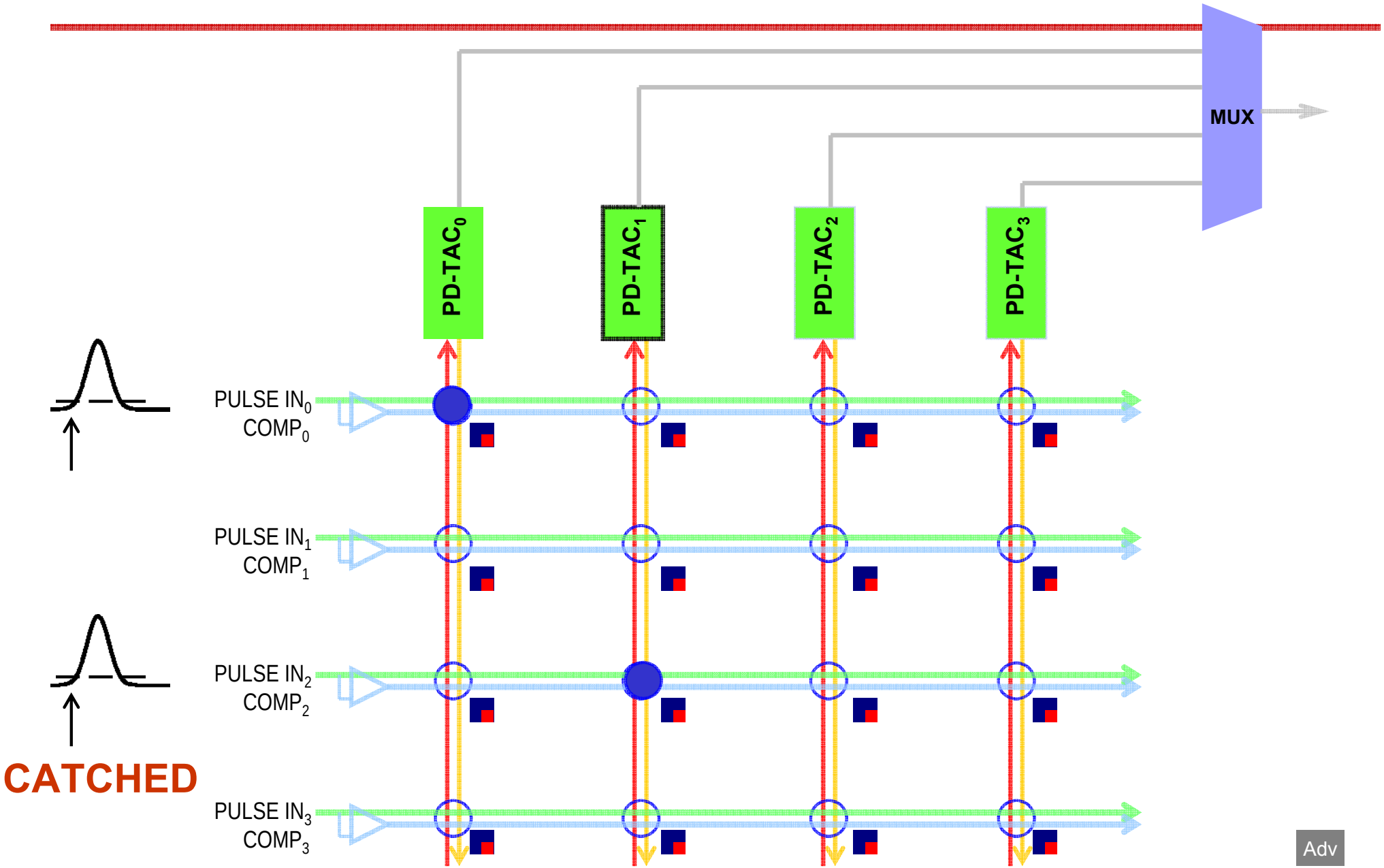

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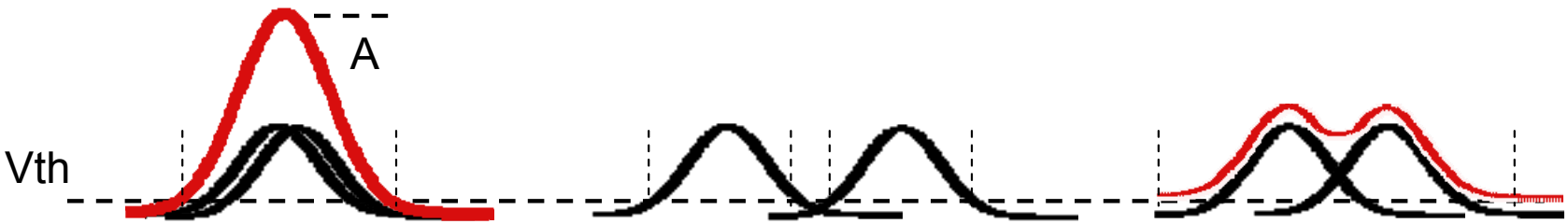
The PDD for High Rate

At High Rate the probability of piled up events increases

Is it possible to extract an information from the signals to properly identify and reject corrupted data?

Time-Over-Threshold

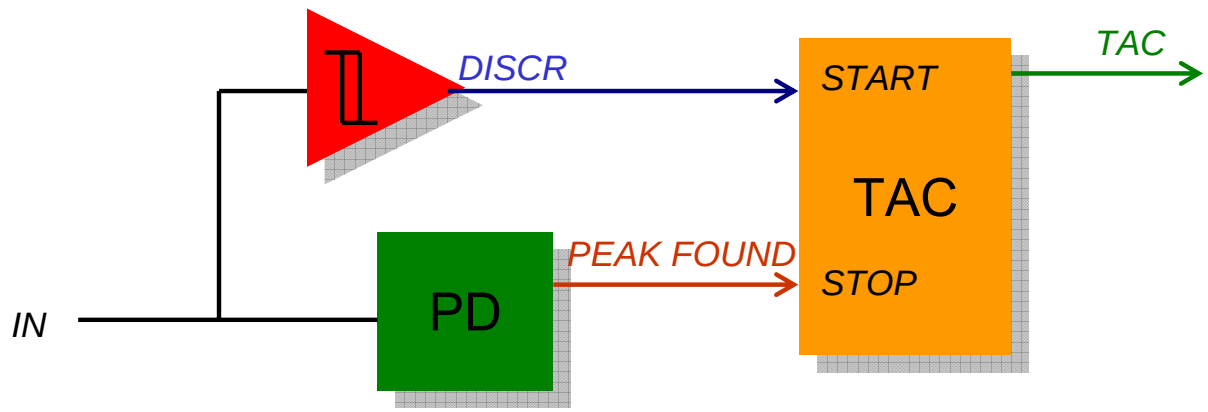


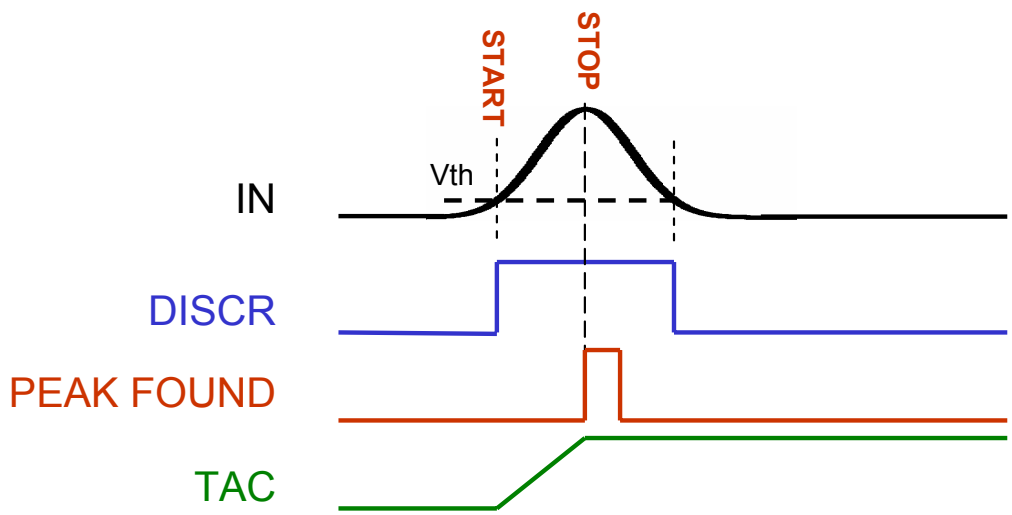
TOT > TOT(A) expected
Pulse to be rejected

TOT = TOT(A) expected
Pulses acceptable

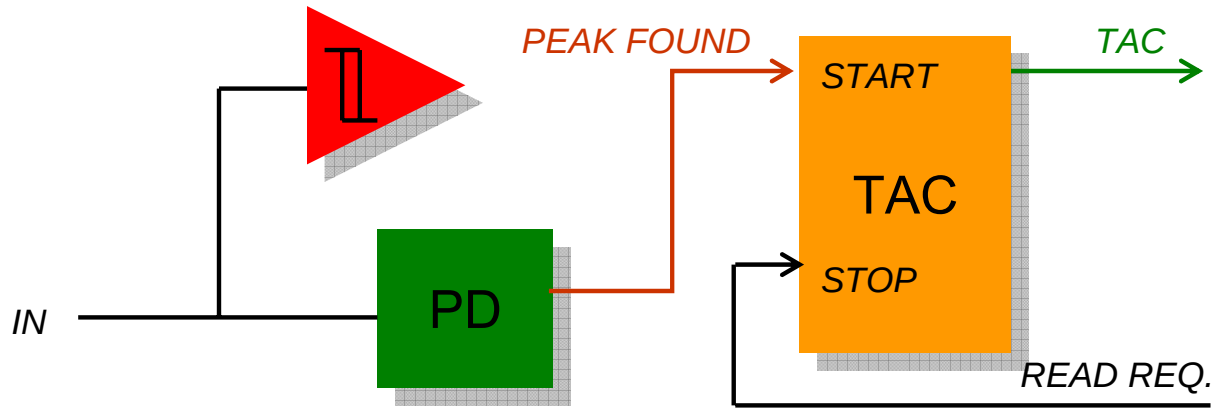
TOT > TOT(A) expected
Pulses acceptable
peaks are separate

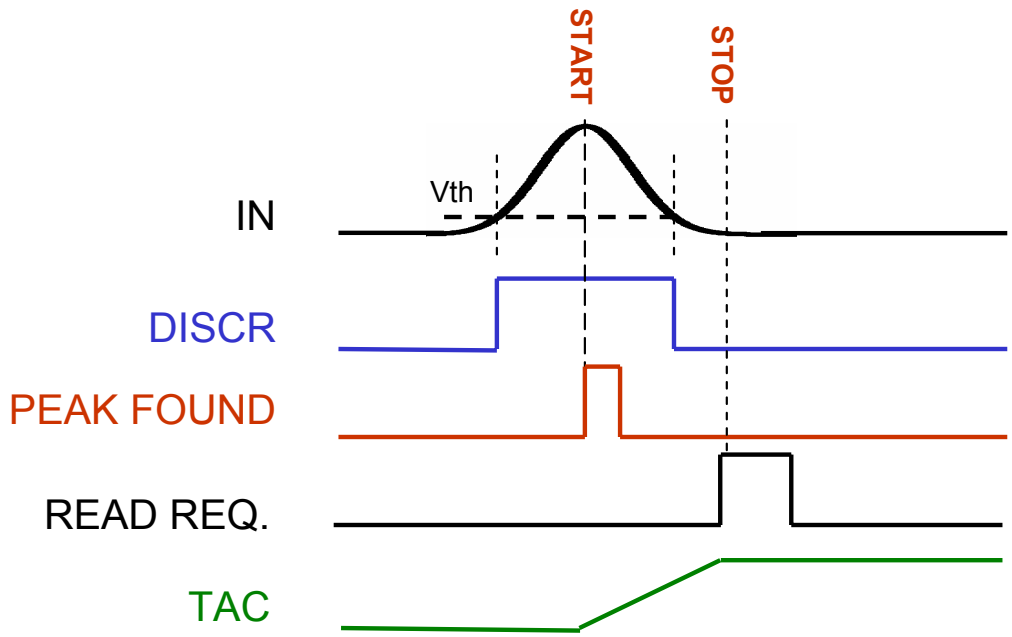
MODE 1 – Rise time mode



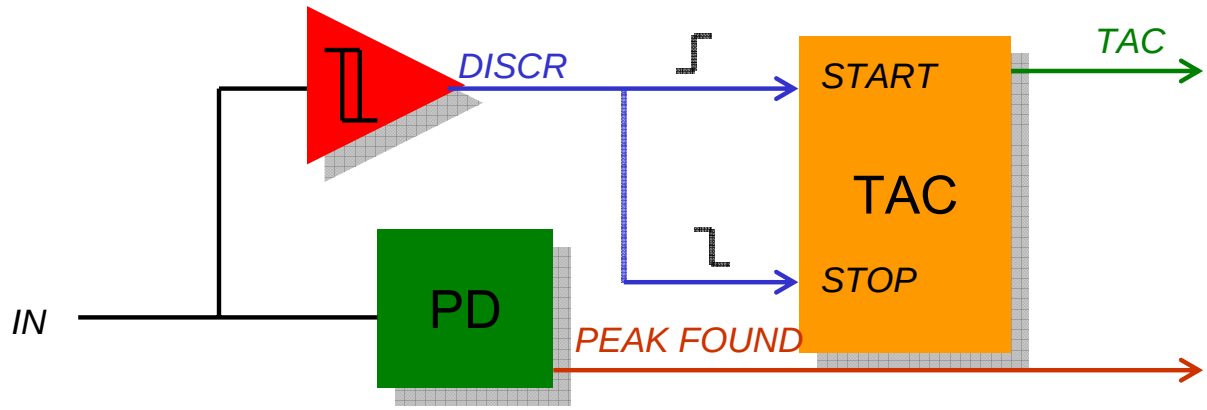


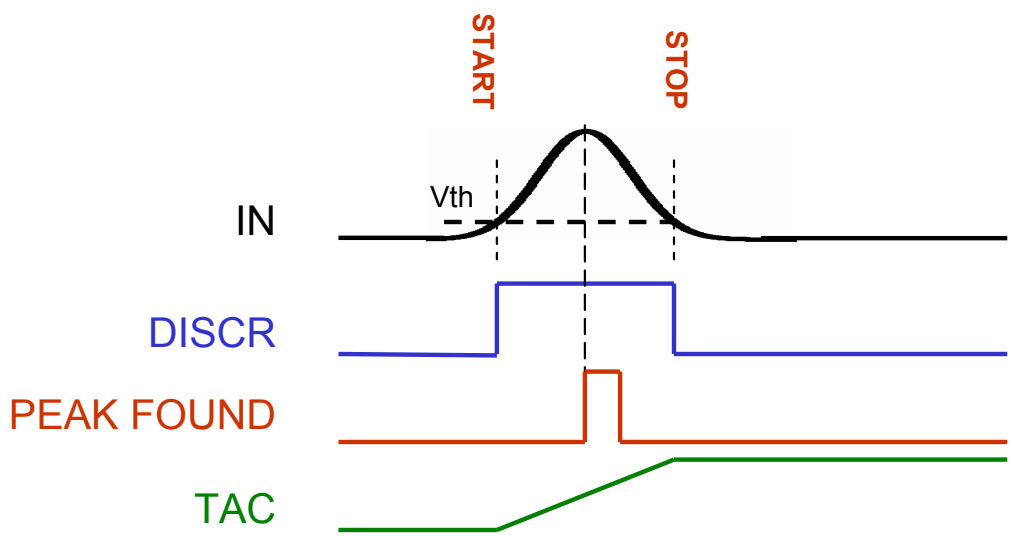
MODE 2 – Time of occurrence mode



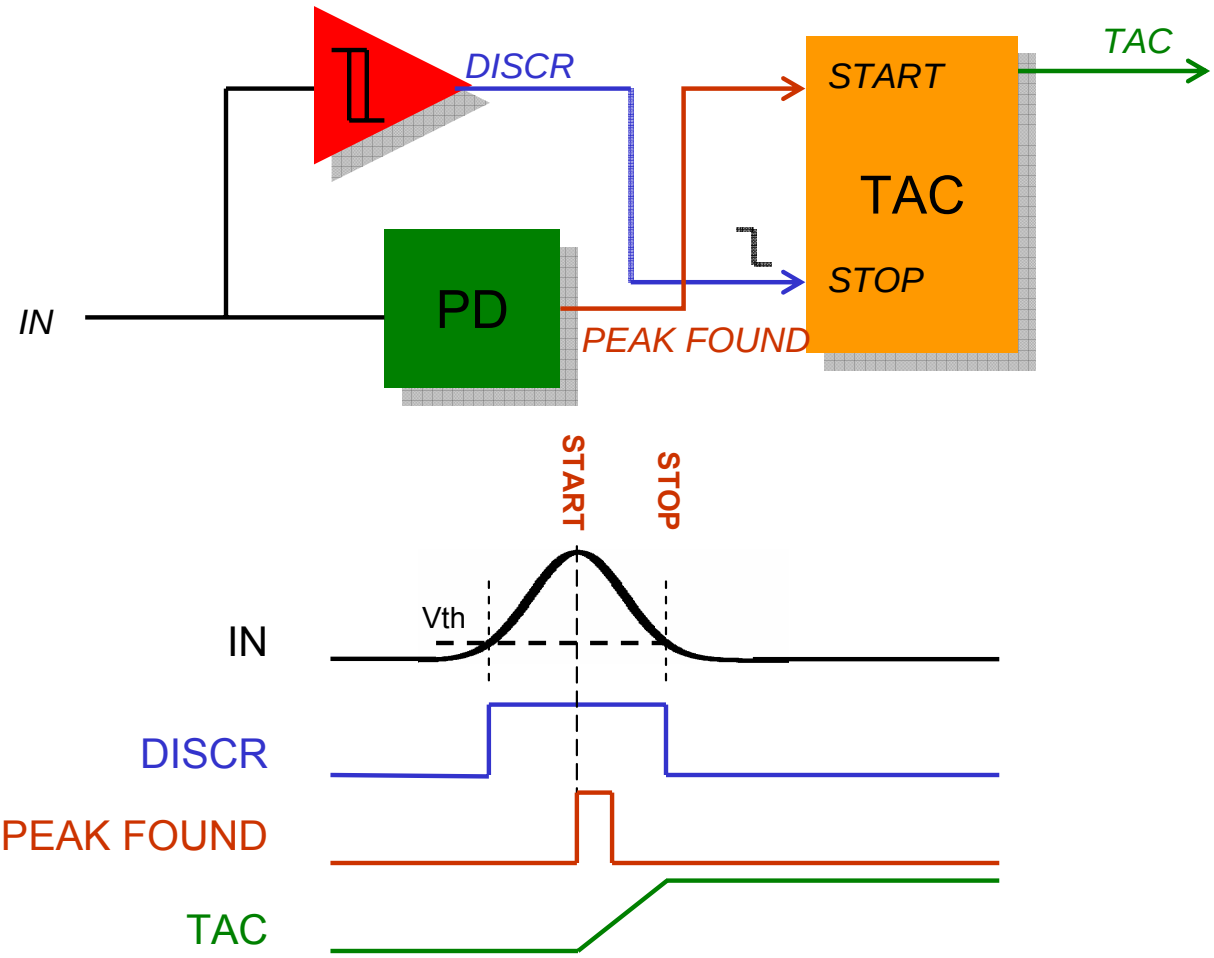


MODE 3 – Time Over Threshold (TOT) mode

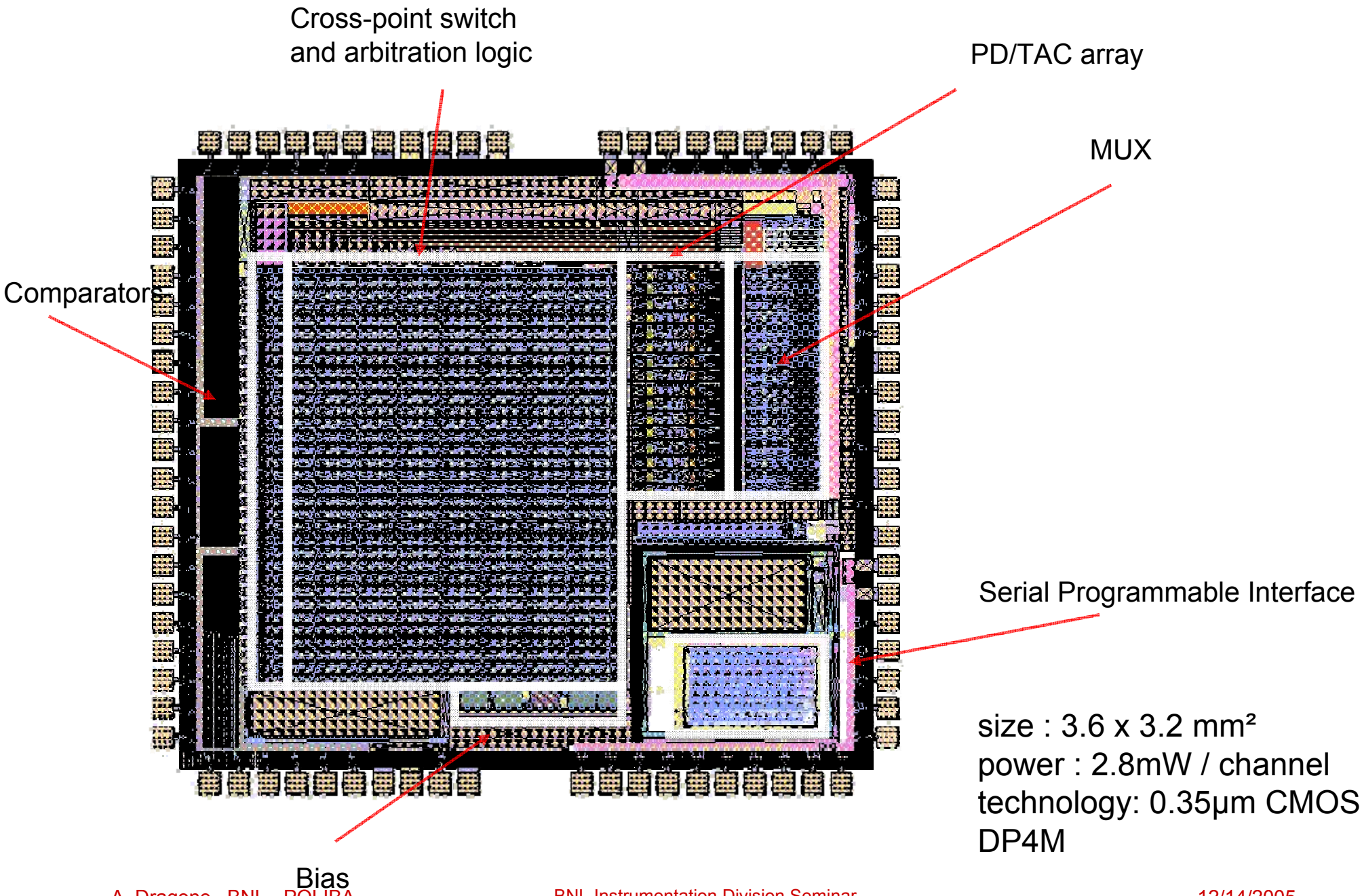




MODE 4 – Fall Time mode

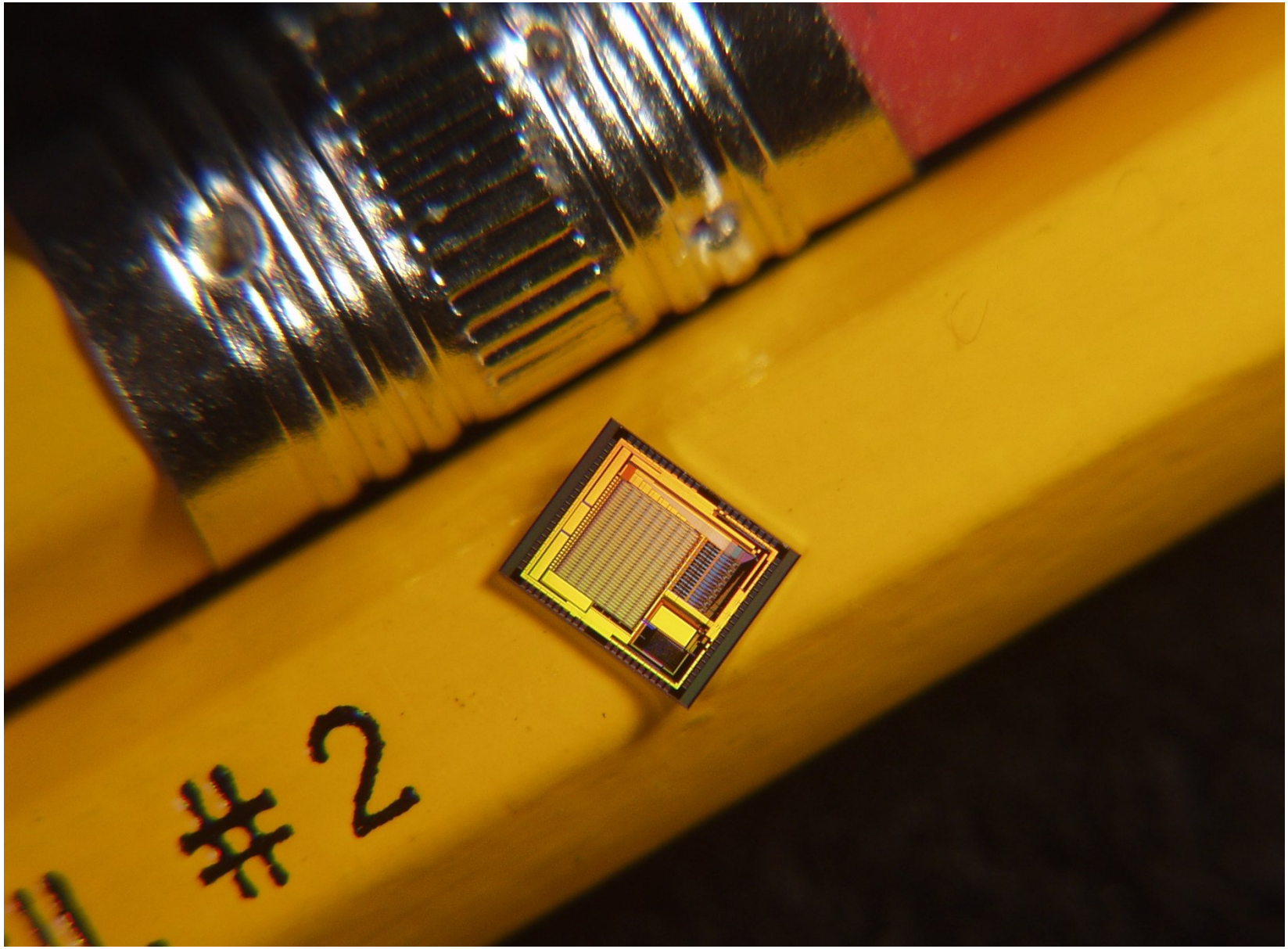


PDD Layout



size : 3.6 x 3.2 mm²
power : 2.8mW / channel
technology: 0.35µm CMOS DP4M

PDD die



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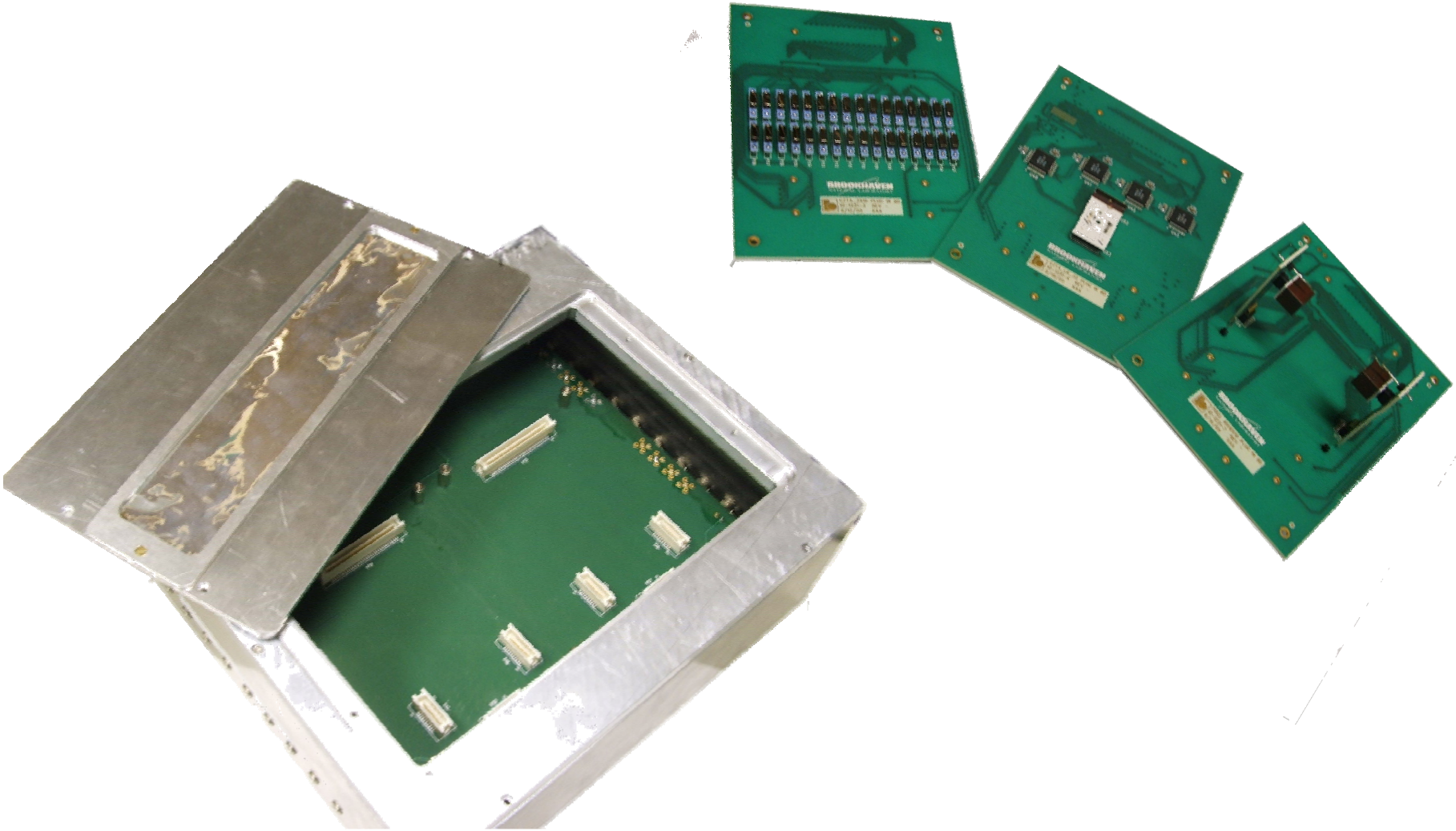
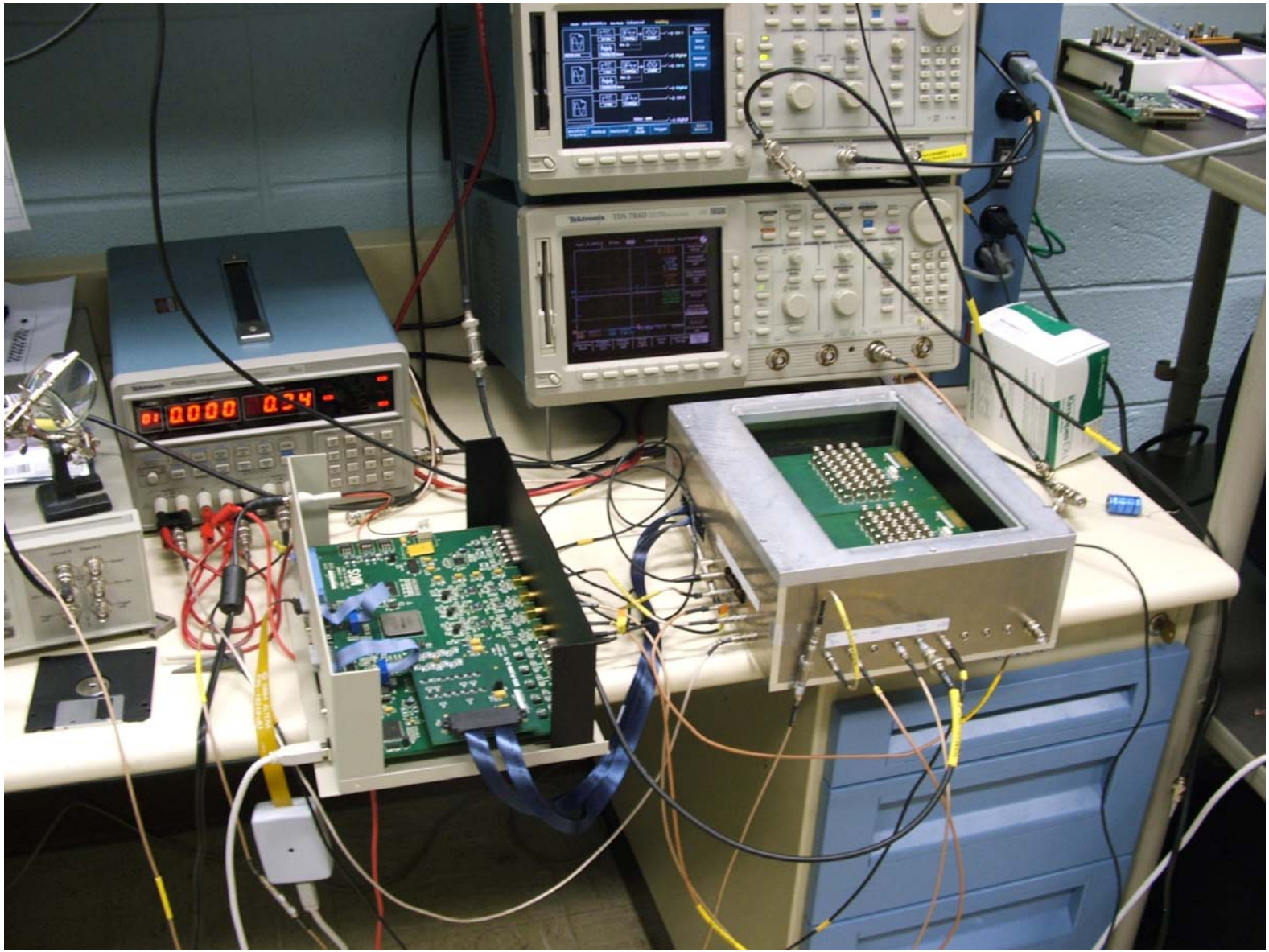
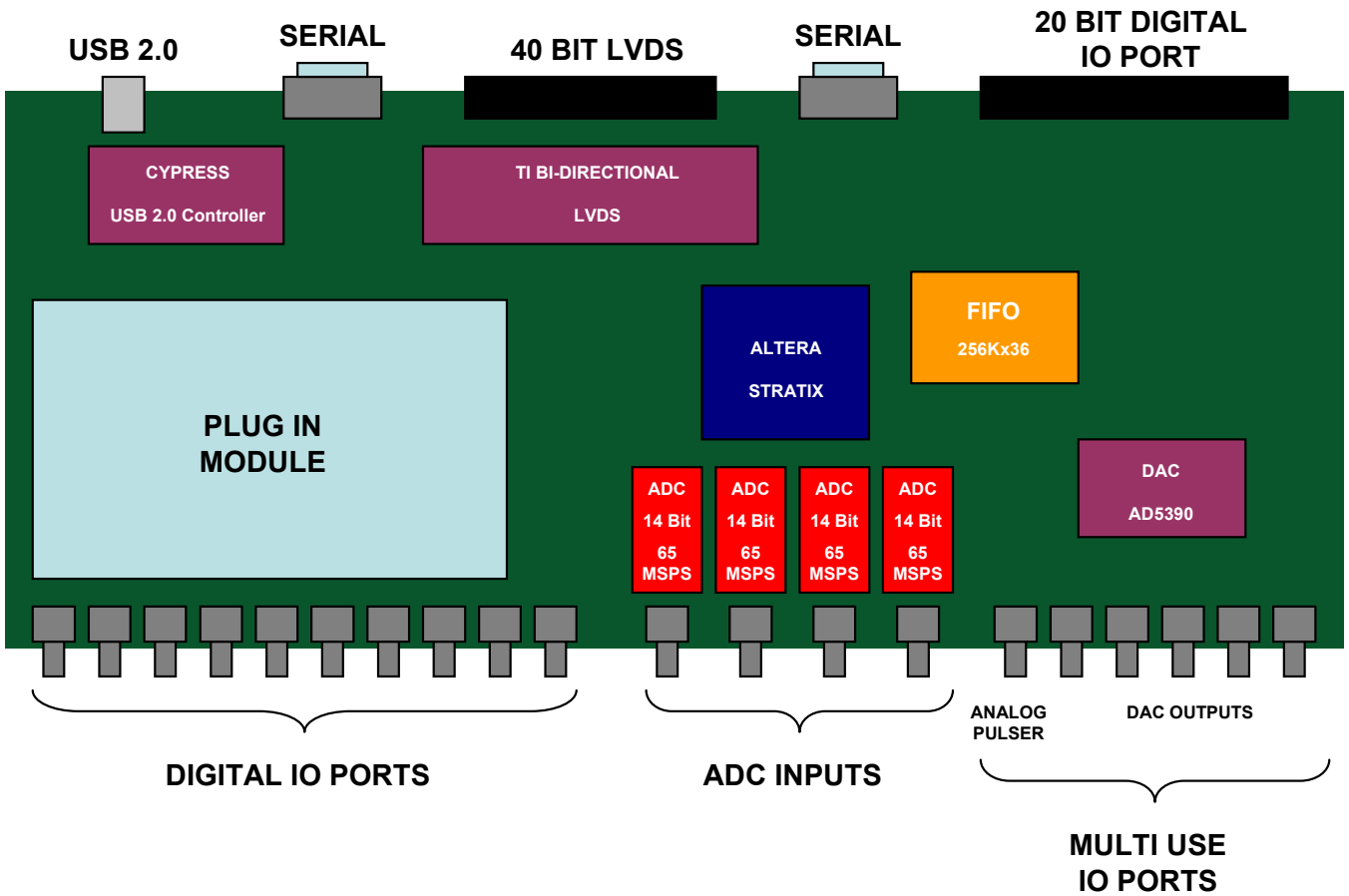
Test setup



Test setup



Multi Input Output data acquisition System (MIOS)



FEATURES

4 analog inputs, 14 bit, 65 Mb/s, simultaneous sampling ADCs

Analog input range

0 to 3.3V, LSB ~200 uV

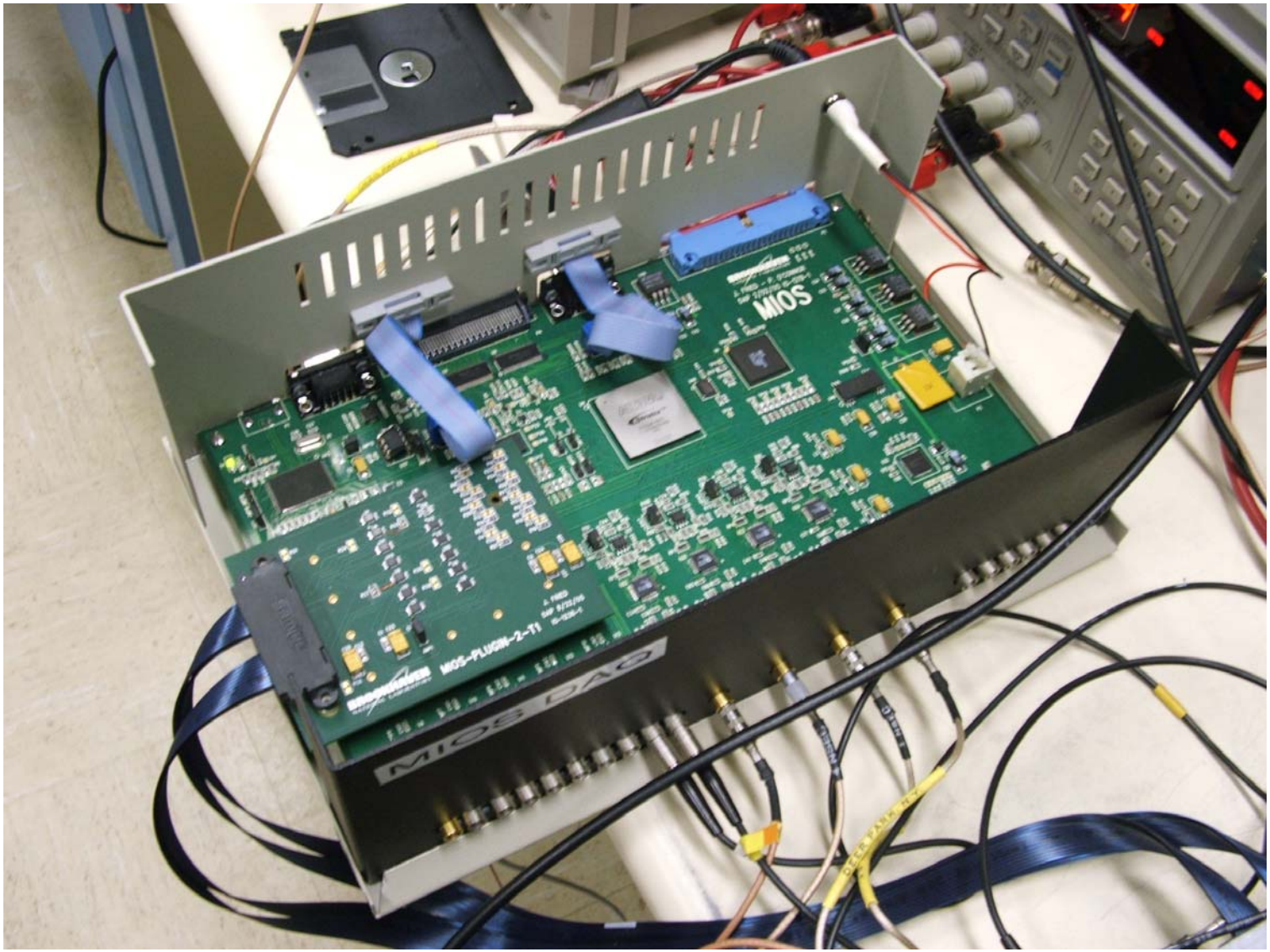
20 digital I/O

8 analog output DACs

USB + LVDS interface to PC

Measured data transfer rate to PC ≥ 24MHz

Test setup



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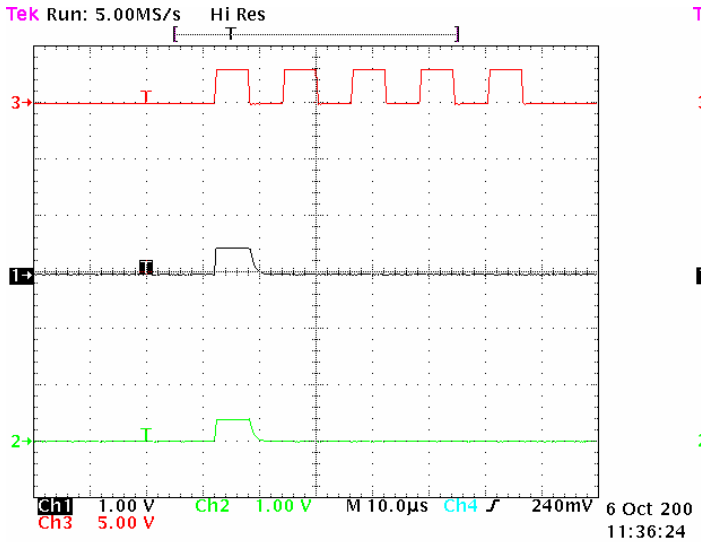
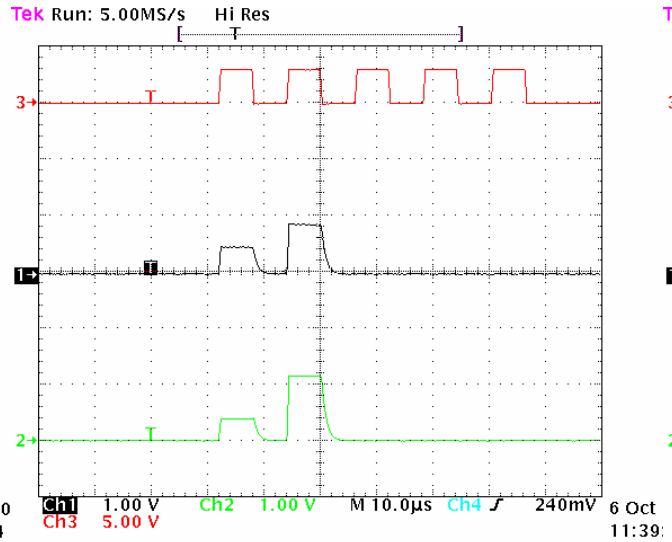
SE Catcher efficiency

Example of 3 simultaneous events

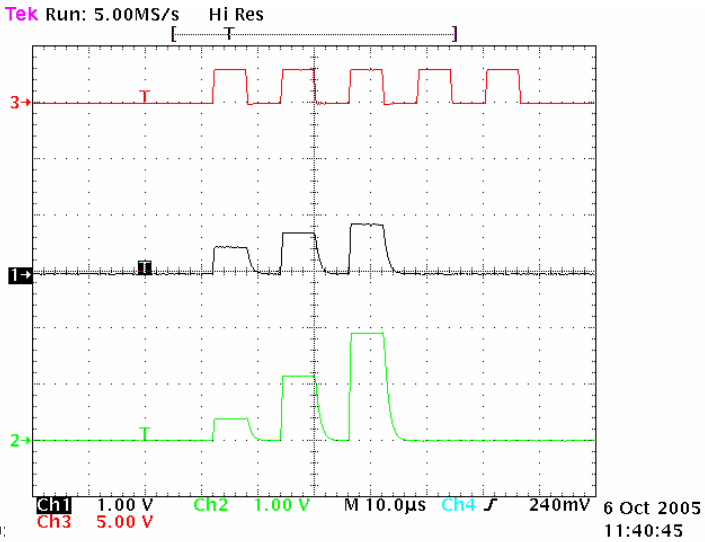
3 Triangular pulses with increasing amplitude and delay within 5ns were sent to Ch. 0, 2 and 4 respectively. Delays were adjusted in order to point out the efficiency of the SEC.



Catcher disabled



Catcher in normal mode

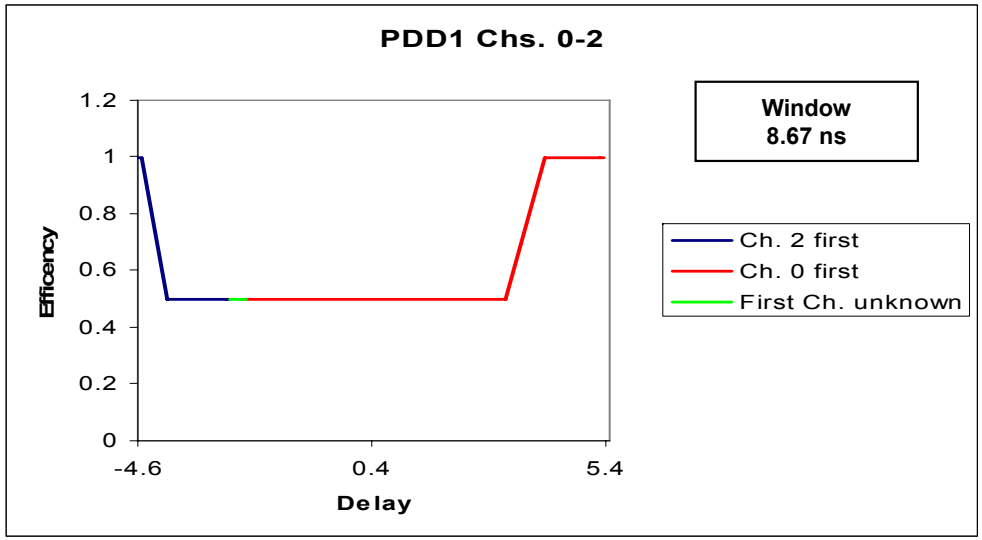


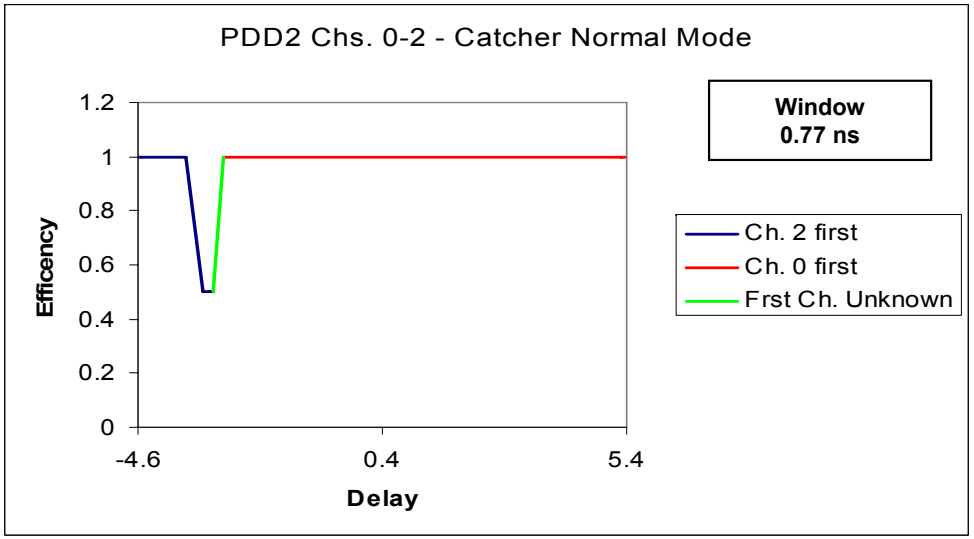
Catcher in enhanced mode

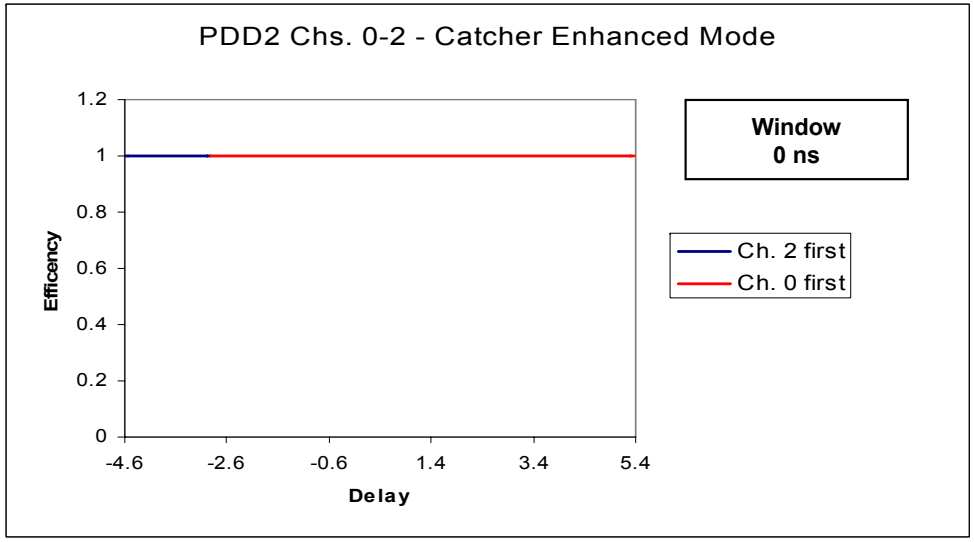
SE Catcher efficiency

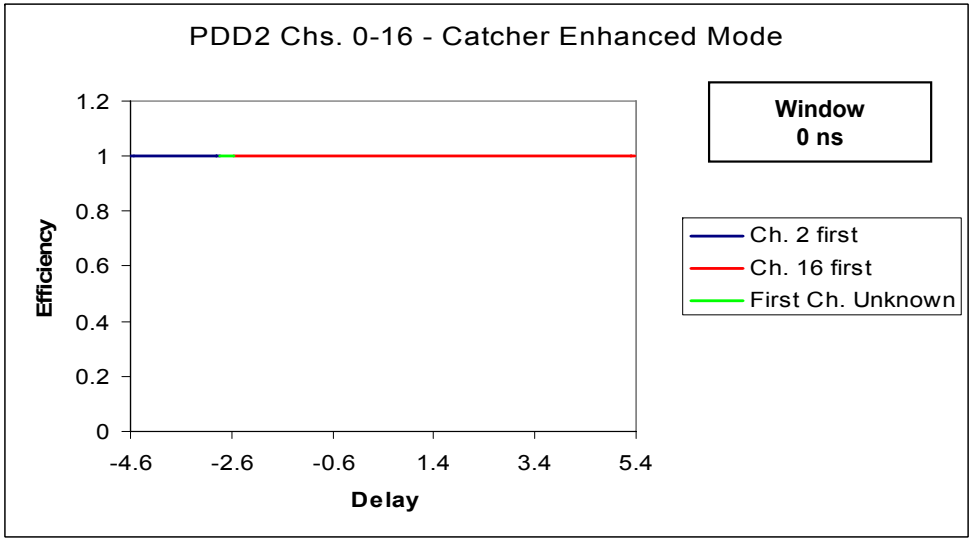
Test Conditions:

2 Asymmetric Triangular Pulses (500ns) of 1.8V and 2.4V respectively with an adjustable delay



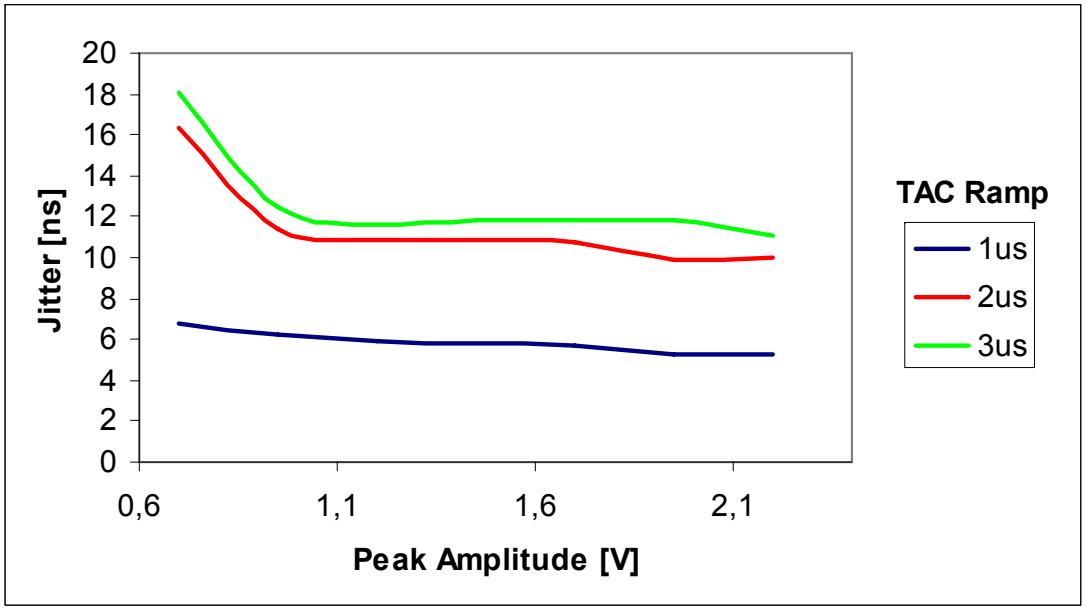






TAC jitter under Simultaneous Events Conditions

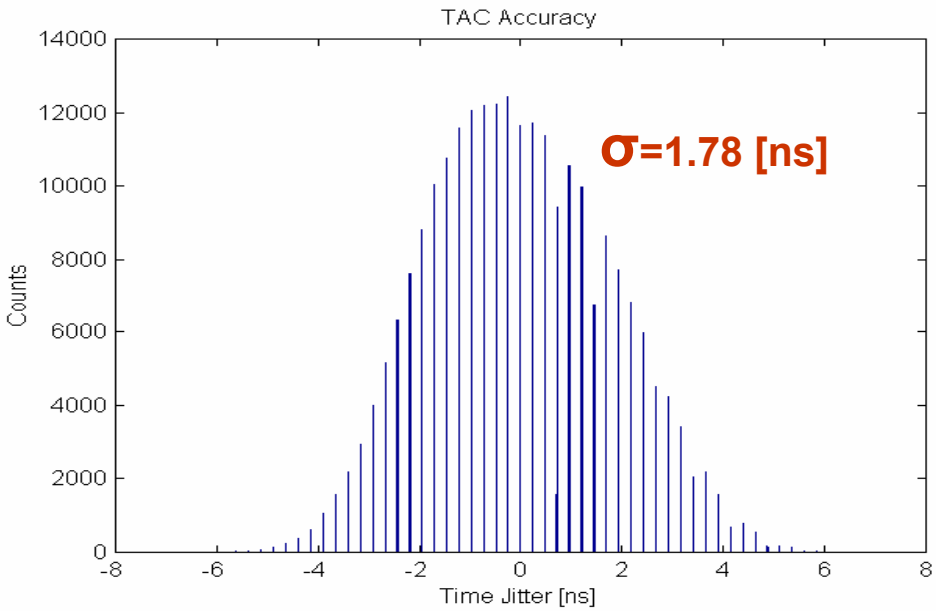
Repetitive measure of the time interval between to asymmetric triangular pulses with 5ns delay calculated as a difference between the time of occurrence of the pulses relative to the RR. The pulses are asynchronous with respect to the RR



The two major contributes to the jitter are noise and the non-linearity error of the TAC

INL r.m.s error for TAC with 1us slope is: INL r.m.s.= 3.6 [ns]

Repeating the measurement with 2.2V pulses synchronous with respect to the RR and with a slope of 1us:



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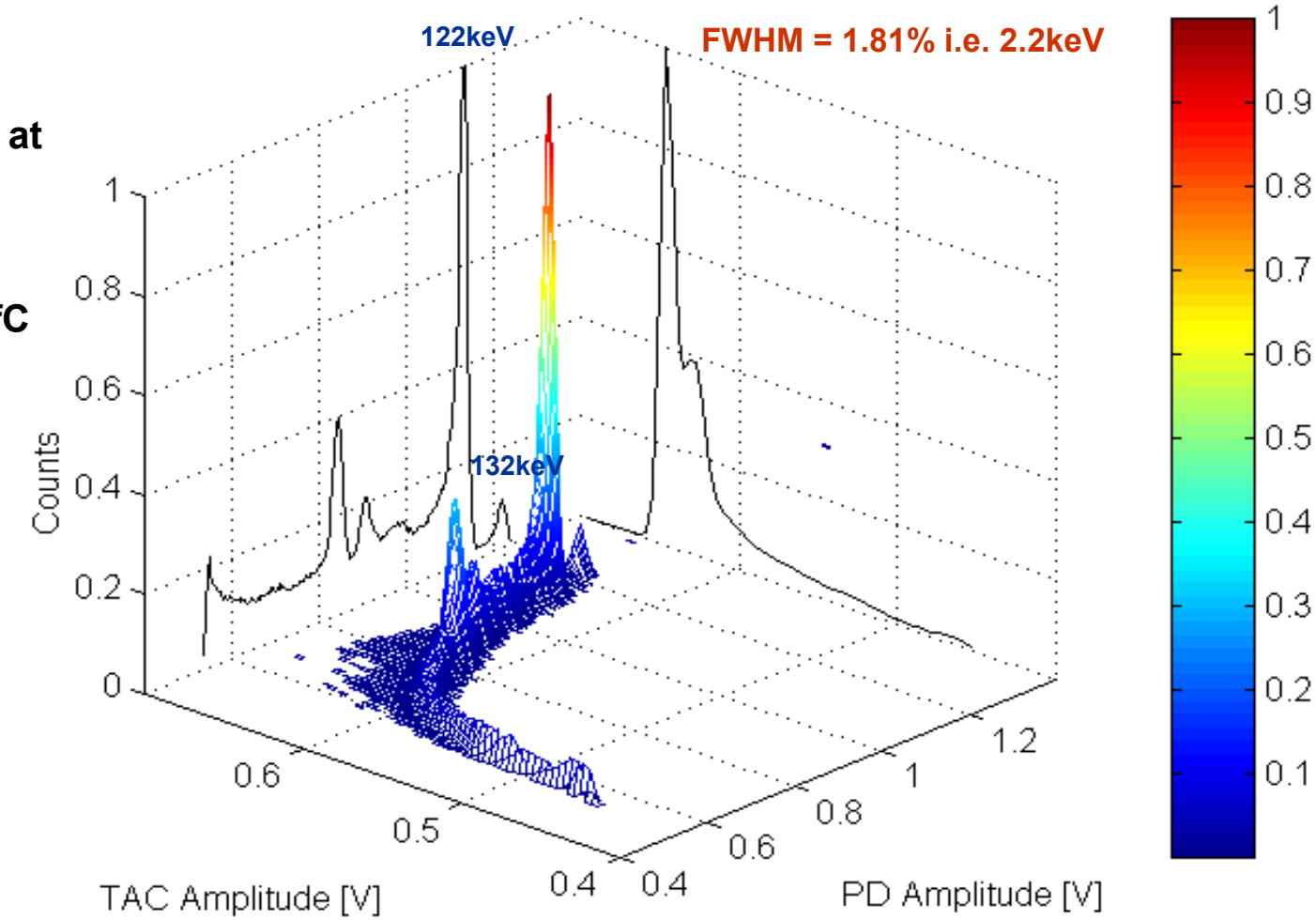
^{57}Co 3D Pulse Height Spectrum as a function of the Peaking Time

Single Channel Spectrum

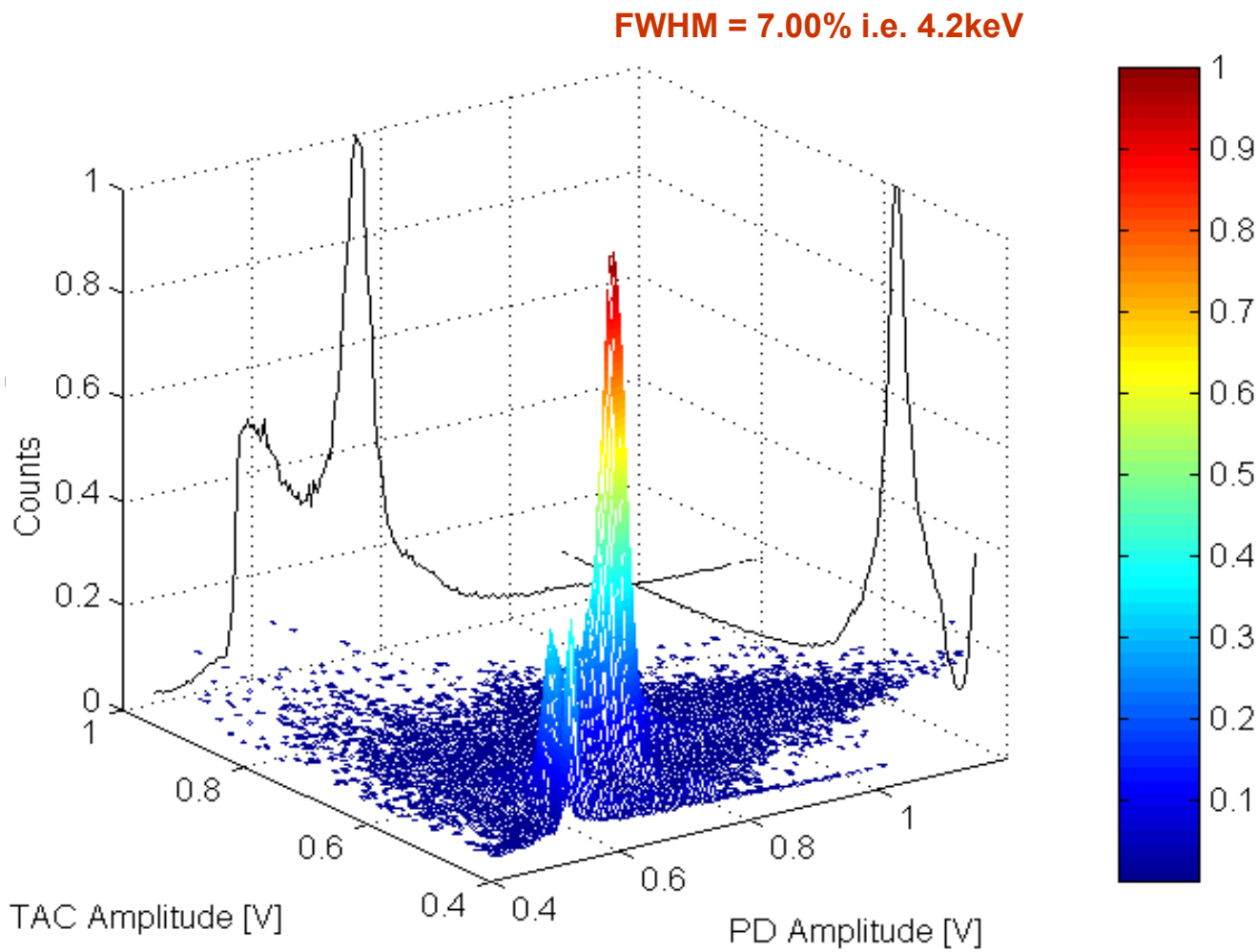
- **Detector: eV Products CZT Pixellated Linear Array of 32 elements 16x3x3 mm^3 biased at 900V**
- **Source: 25mCi ^{57}Co**
- **FE: tp = 400ns, gain=200mV/fC**
- **Event Rate: 8kCounts/s on a single pixel**



^{241}Am 3D Pulse Height Spectrum as a function of the Peaking Time

Cumulative Spectrum of 32 Channels

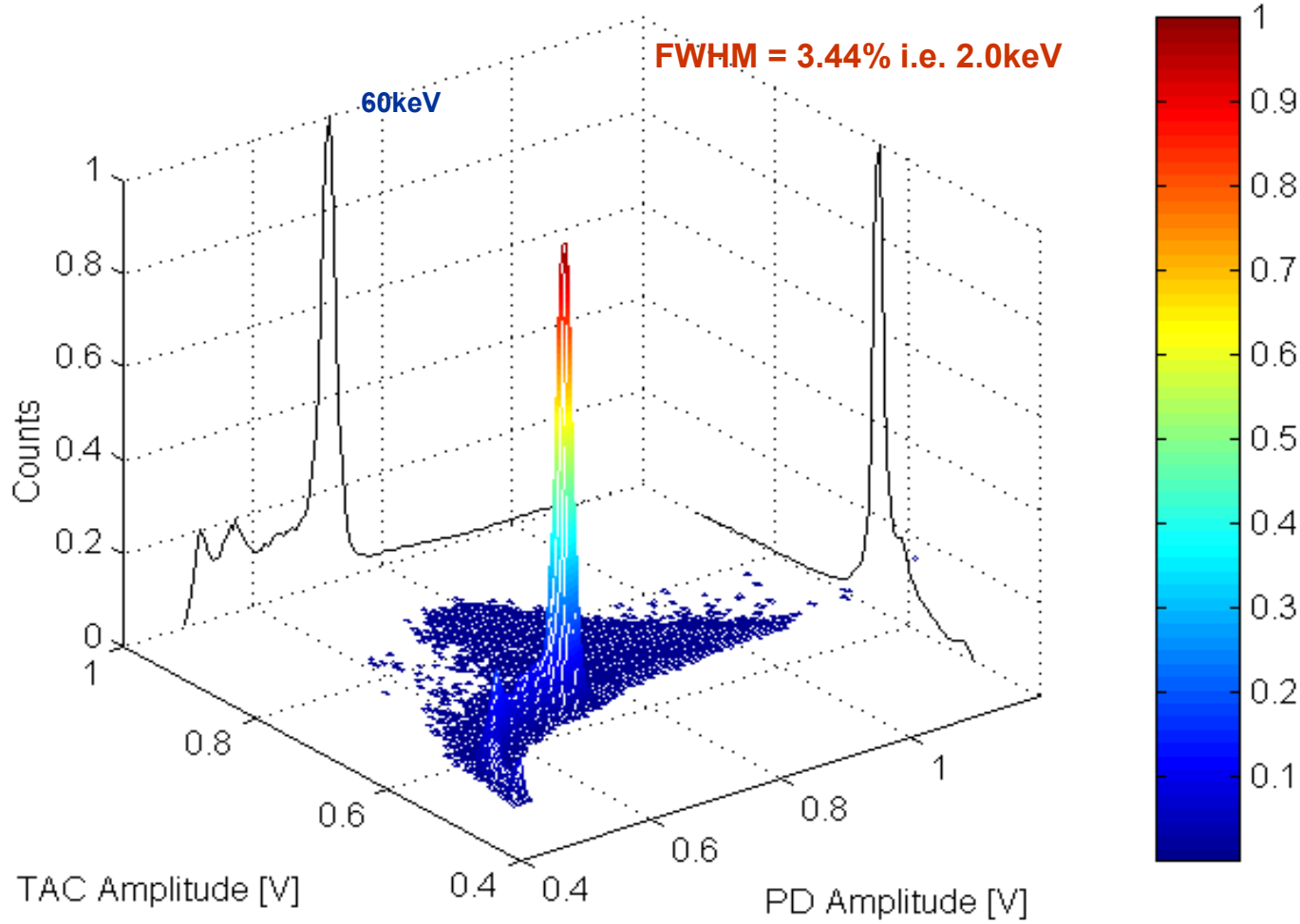
- **Detector: eV Products CZT Pixellated Linear Array of 32 elements 16x3x3 mm^3 biased at 900V**
- **Source: 2 x 8mCi ^{241}Am**
- **FE: t_p = 400ns, gain=200mV/fC**
- **Event Rate: 4.5MCounts/s overall**



^{241}Am 3D Pulse Height Spectrum as a function of the Peaking Time

Single Channel Spectrum

- **Detector: eV Products CZT Pixellated Linear Array of 32 elements 16x3x3 mm^3 biased at 900V**
- **Source: 2 x 8mCi ^{241}Am**
- **FE: tp = 400ns, gain=200mV/fC**
- **Event Rate: 4.5MCounts/s overall, 210kCounts/s on the single pixel**



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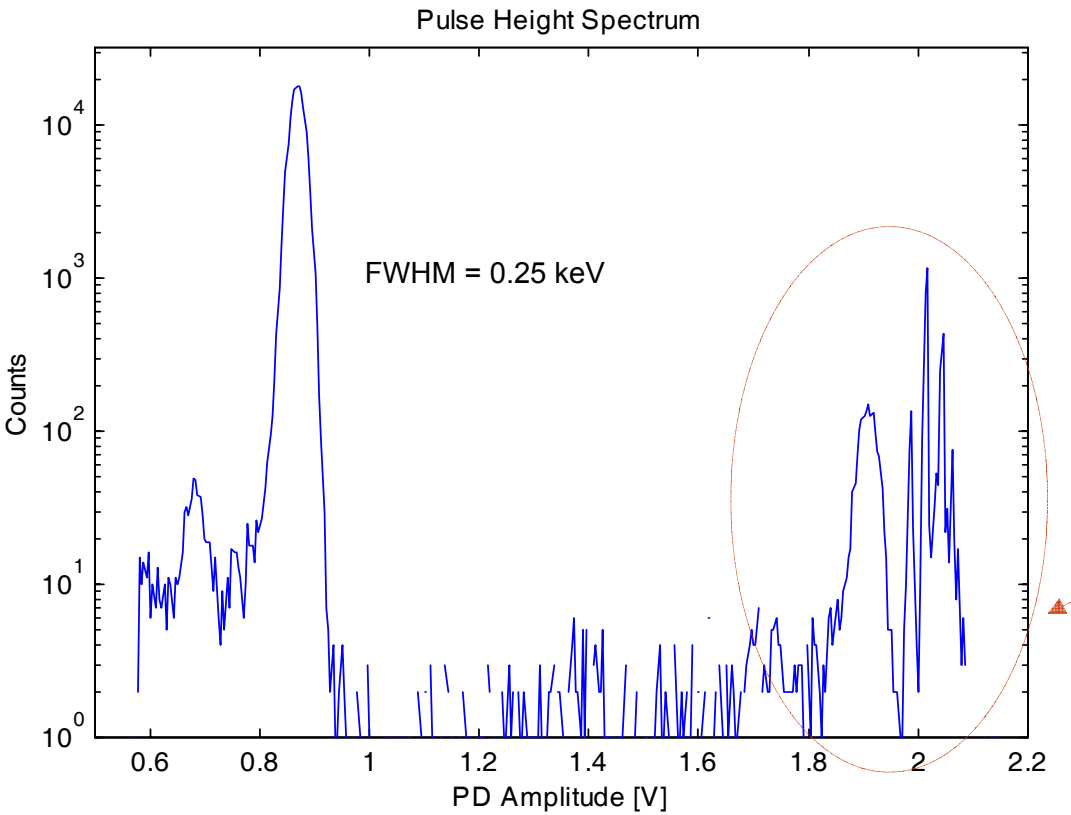
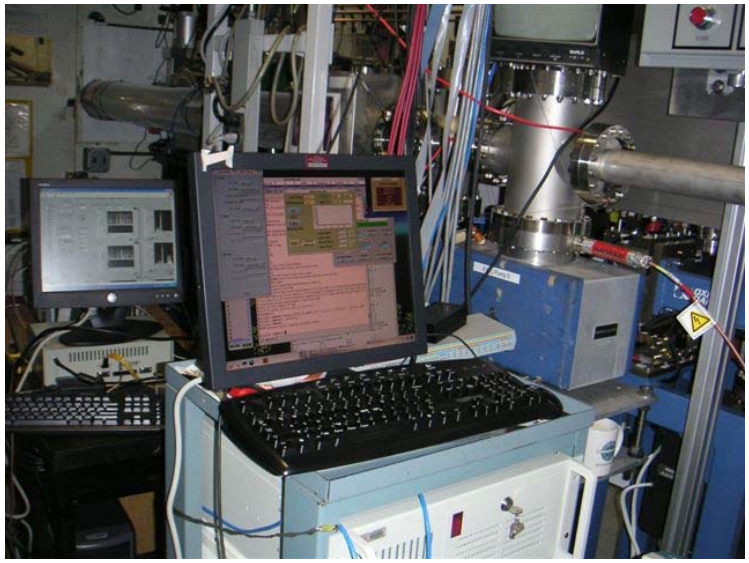
Time-Over-Threshold Measurement for pile-up rejection

Experiment Setup

- Array of 1mm x 1mm silicon diodes, built on a fully-depleted 400um high-resistivity wafer and cooled at ~ -54 ˚C
- 8keV X-ray monochromatic collimated 10umx10um beam from NSLS focused on the center of one pixel
- FE with 2us peaking time





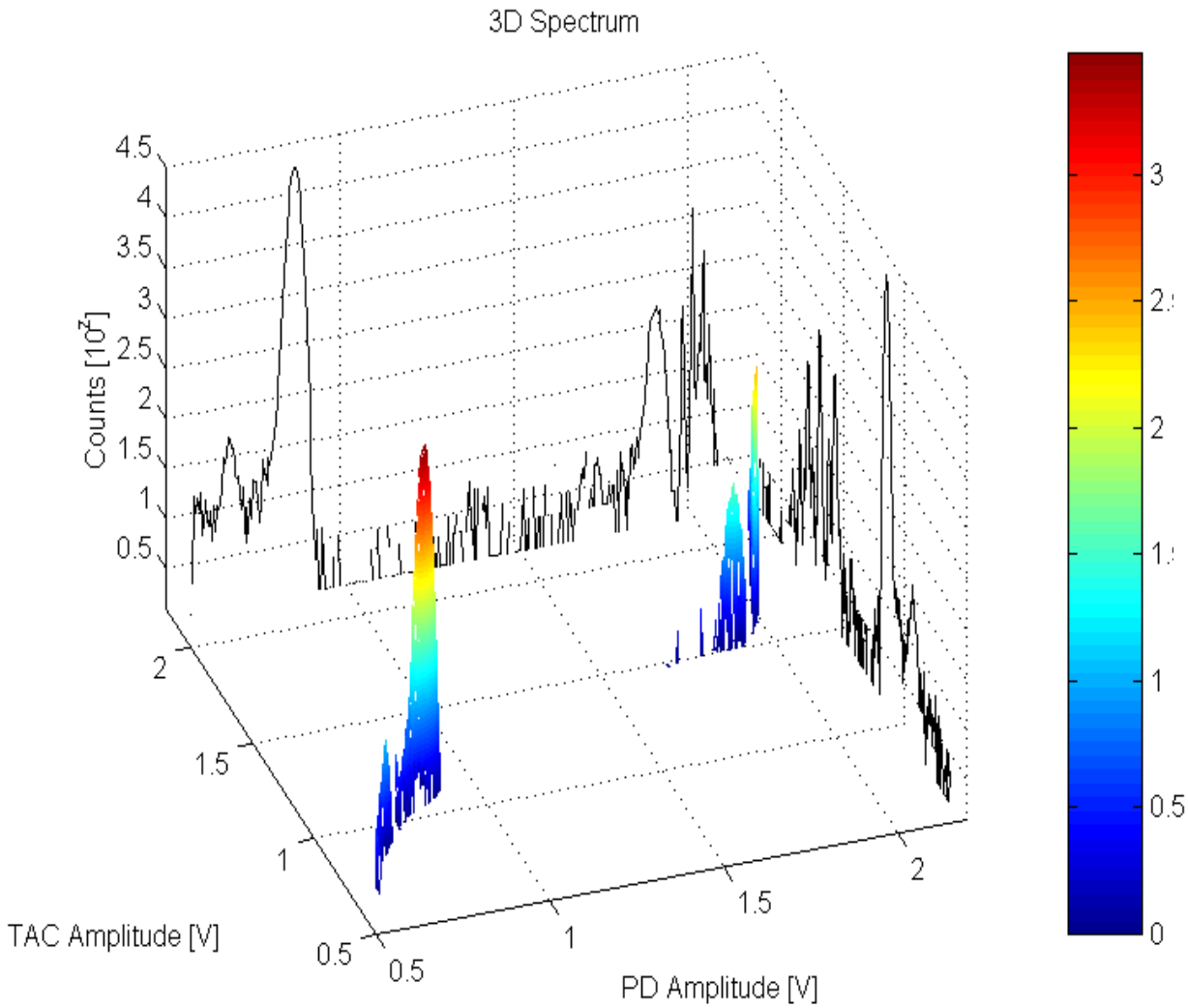
Pulse Height Spectrum when the events rate is equal to 400 Counts/s

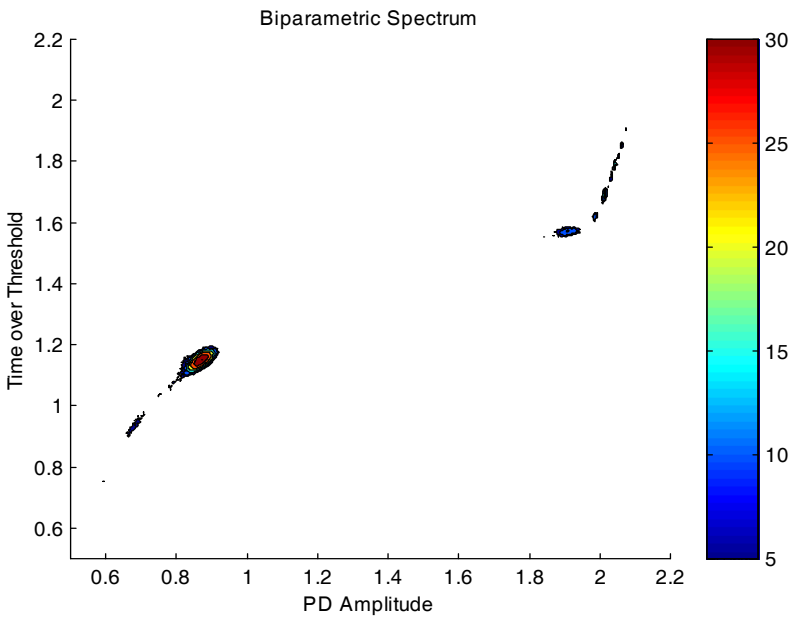
No pile up effects are visible

A 3rd order harmonic from the monochromator is present and saturates the FE

Time-Over-Threshold Measurement for pile-up rejection

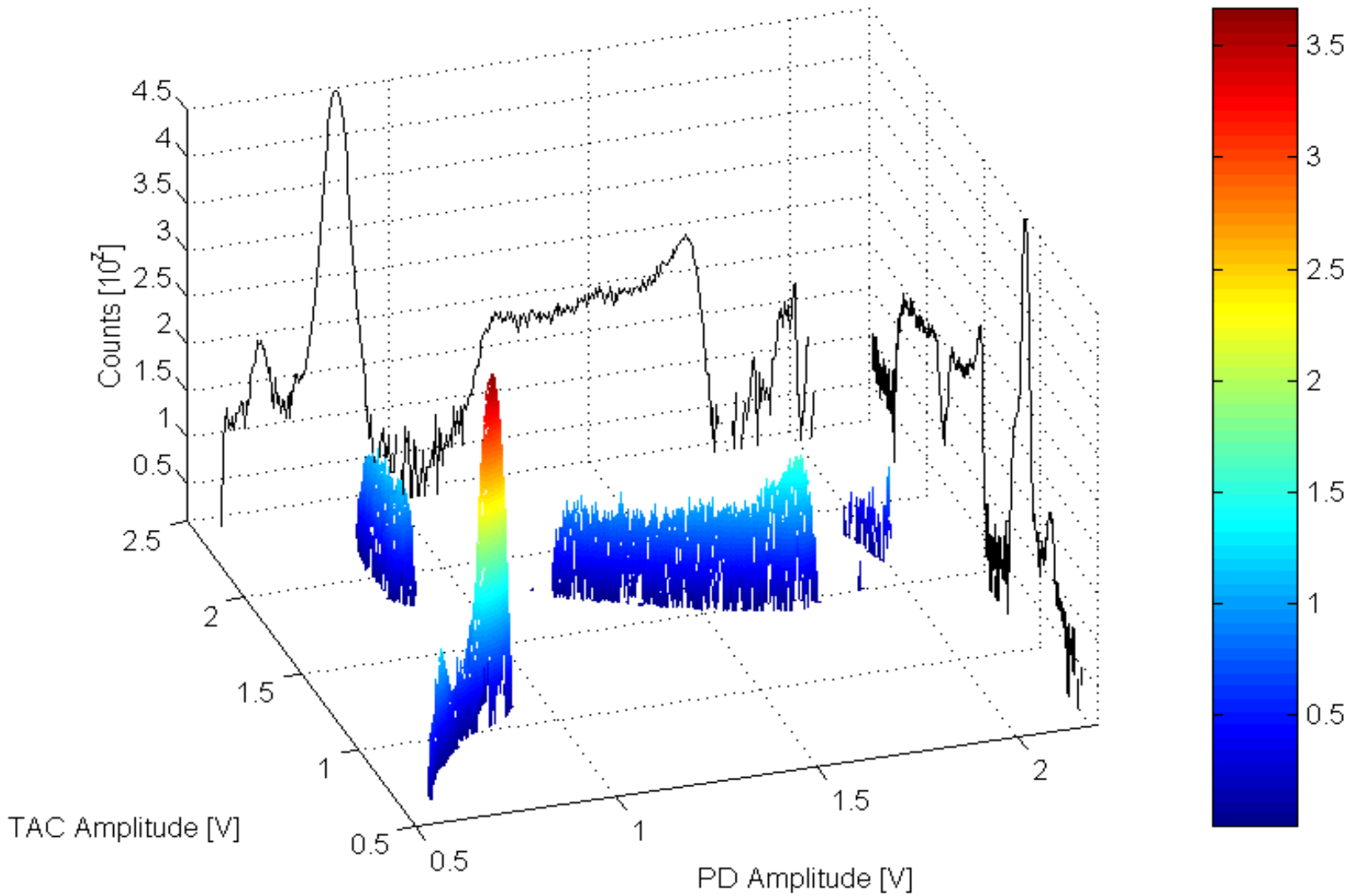
3D Pulse Height Spectrum as a function of the ToT





Time-Over-Threshold Measurement for pile-up rejection

3D Pulse Height Spectrum as a function of the ToT



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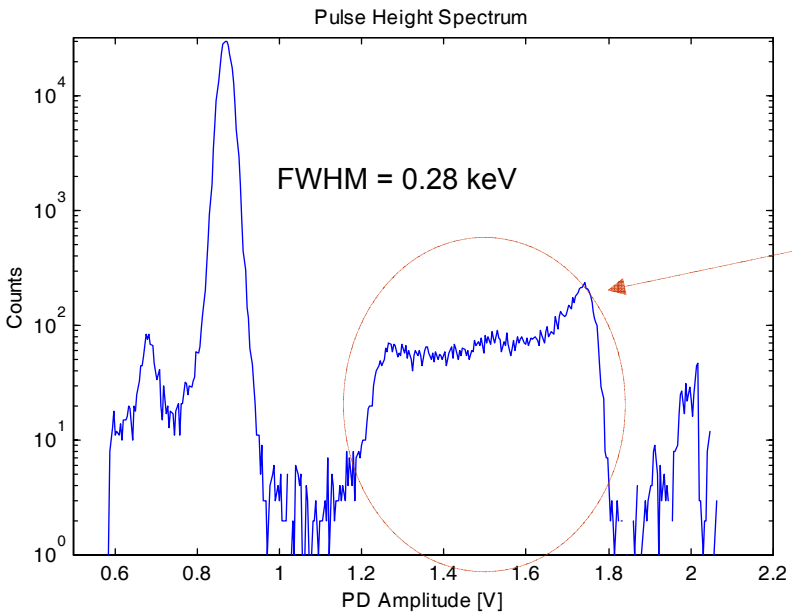
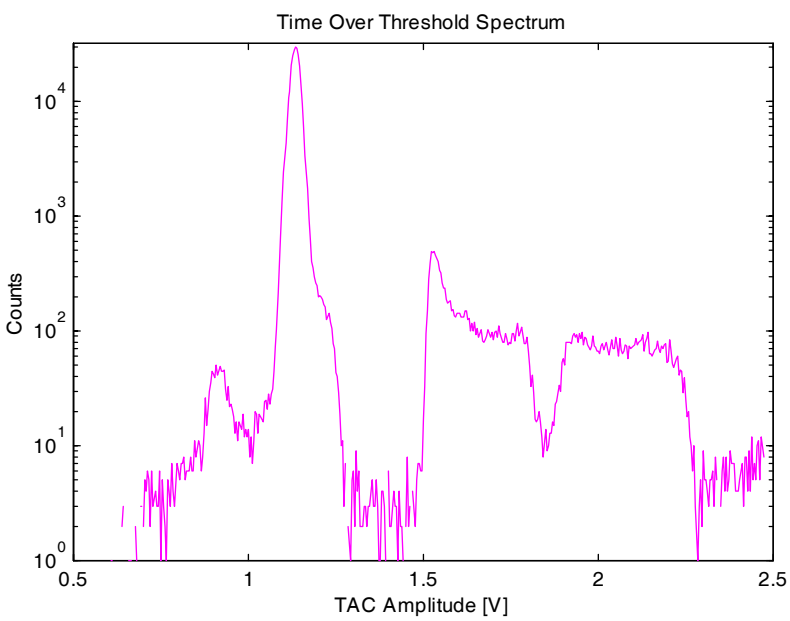
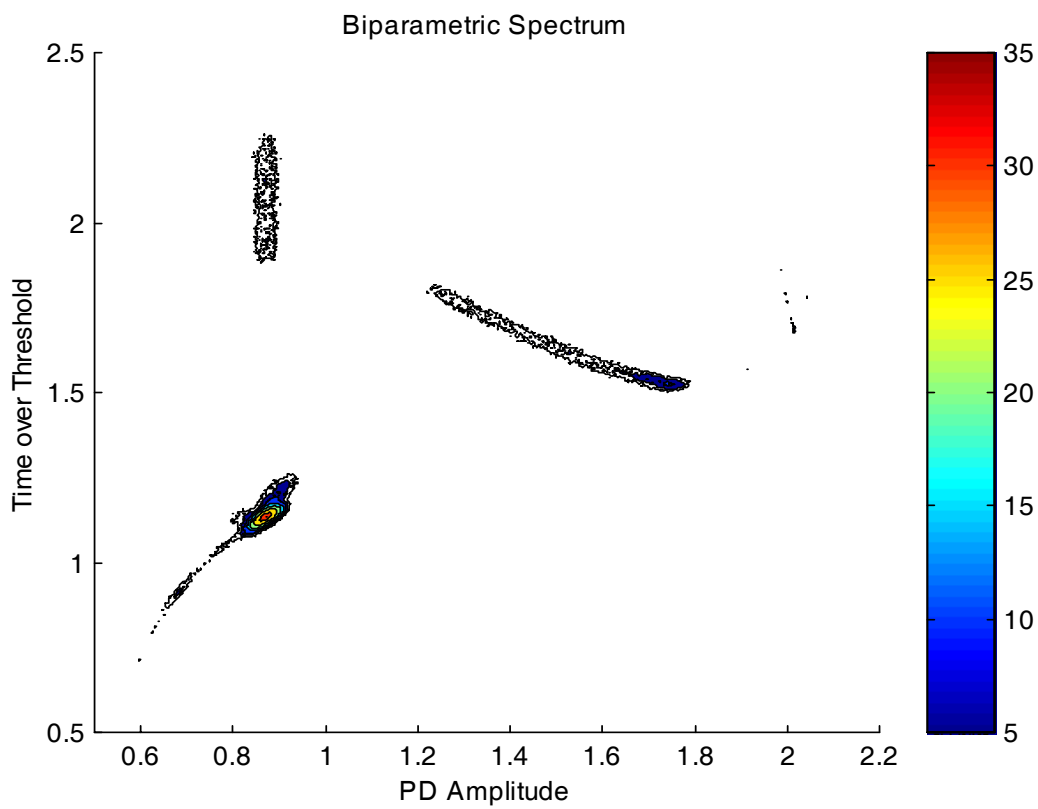




Pulse Height Spectrum when the events rate is equal to 22 kCounts/s

Pile up effects are visible

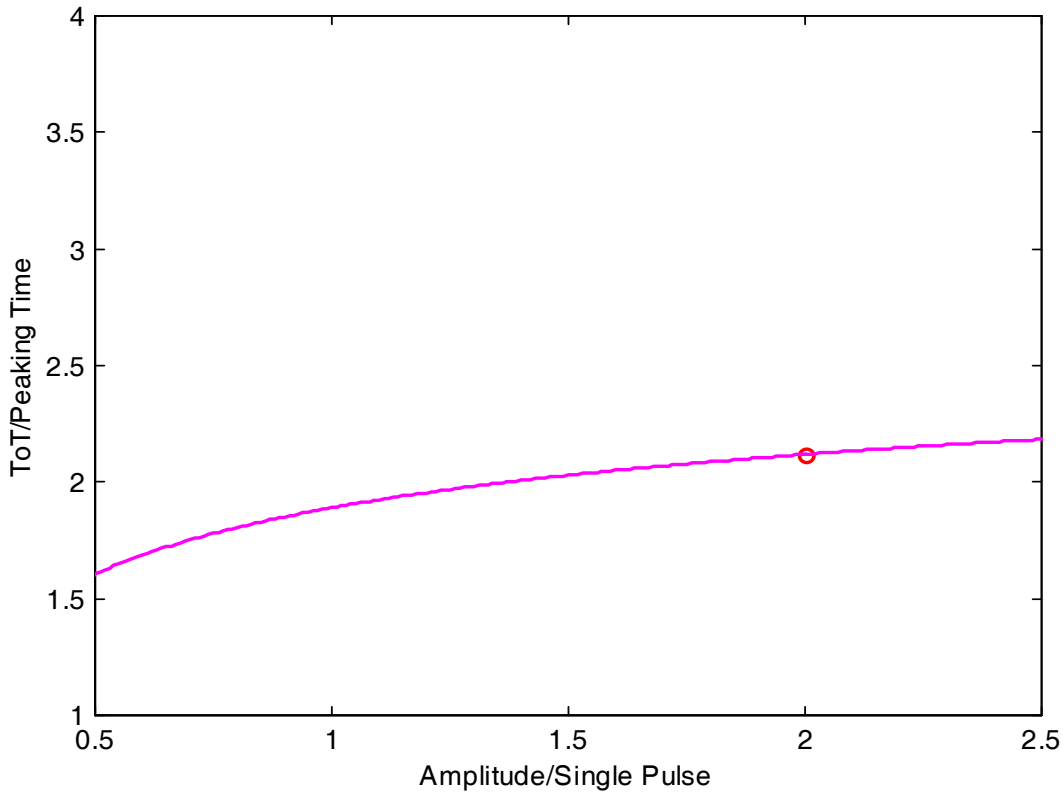
A 3rd order harmonic from the monochromator is still present.



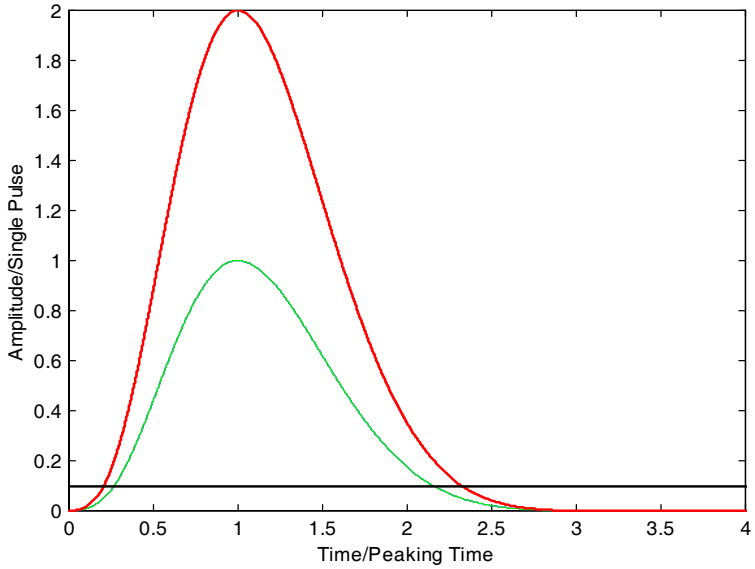
Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



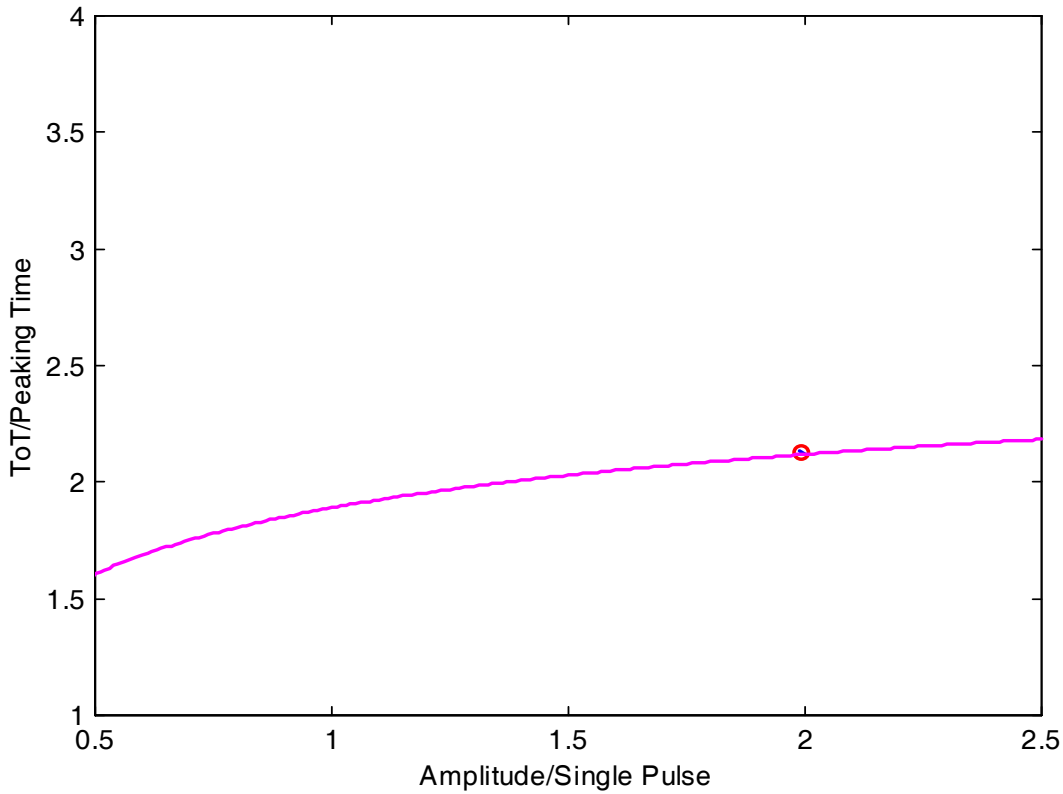
Delay = 0.0



Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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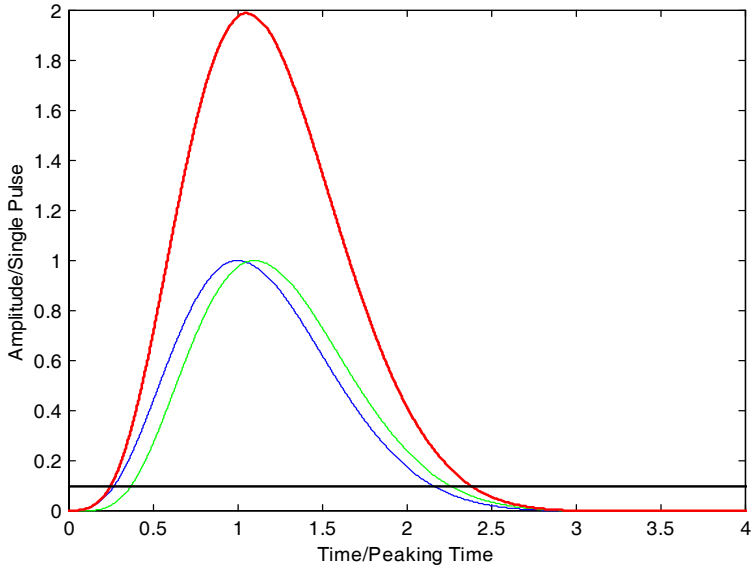
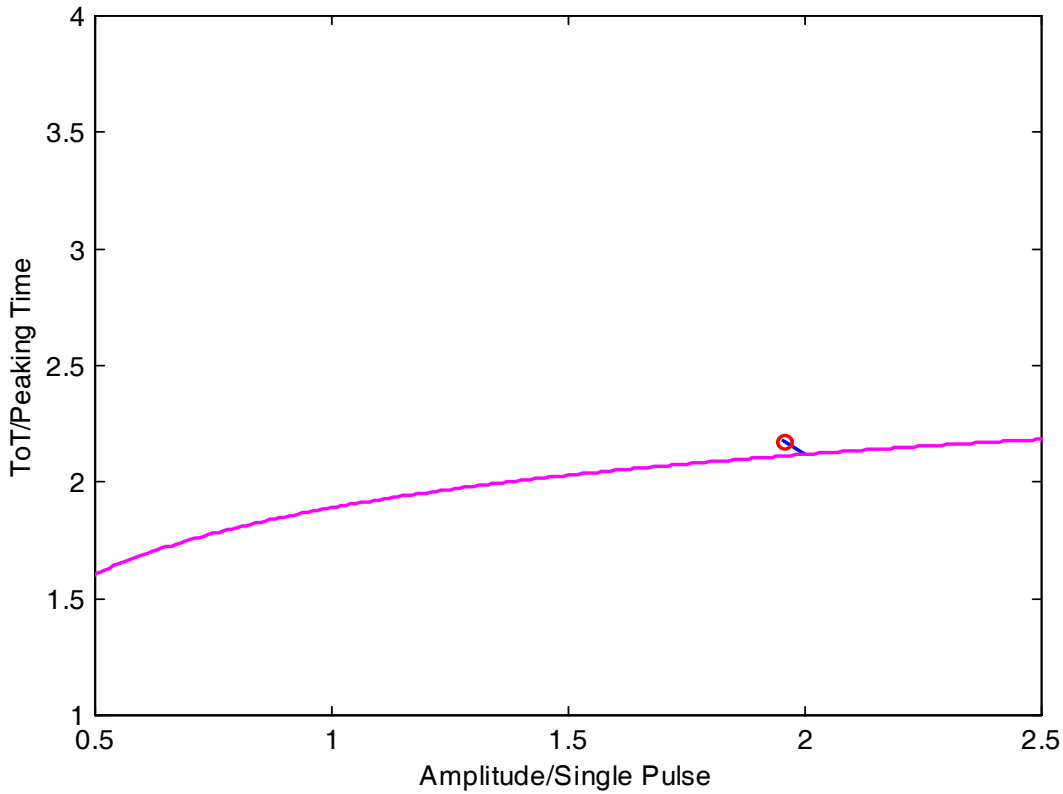


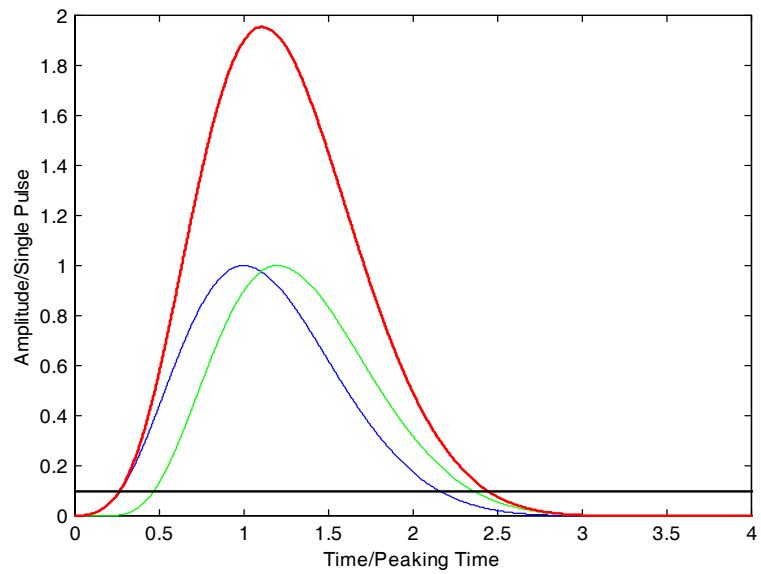
Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



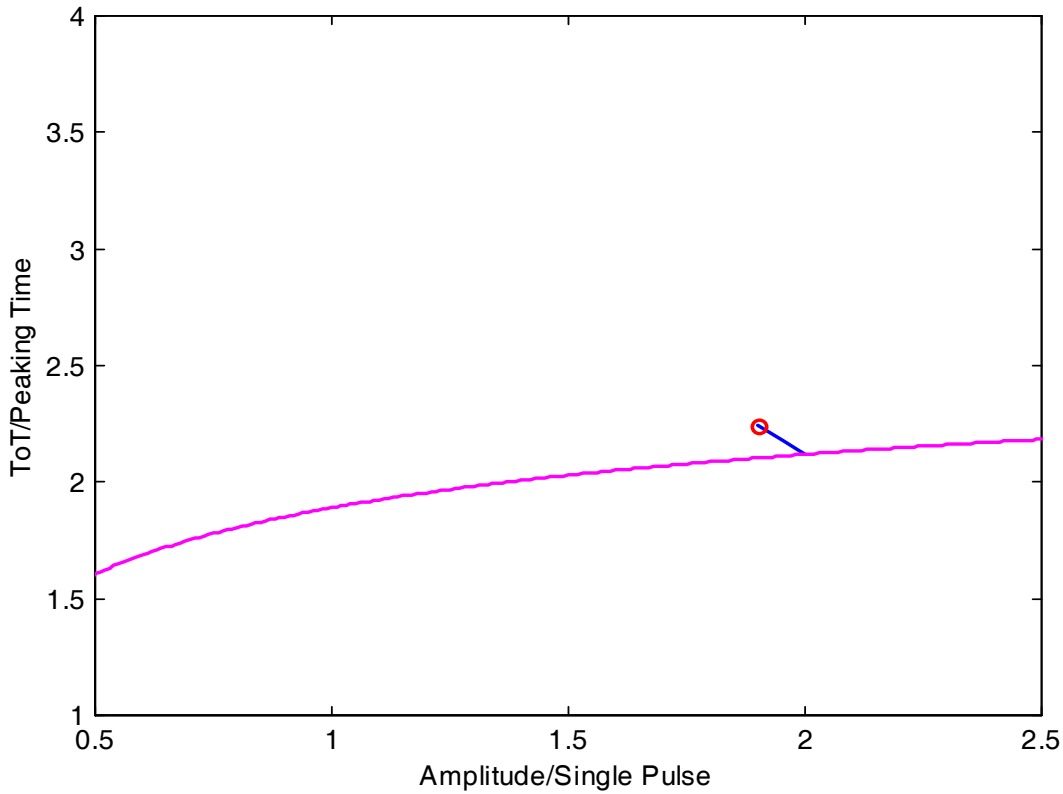
Delay = 0.2



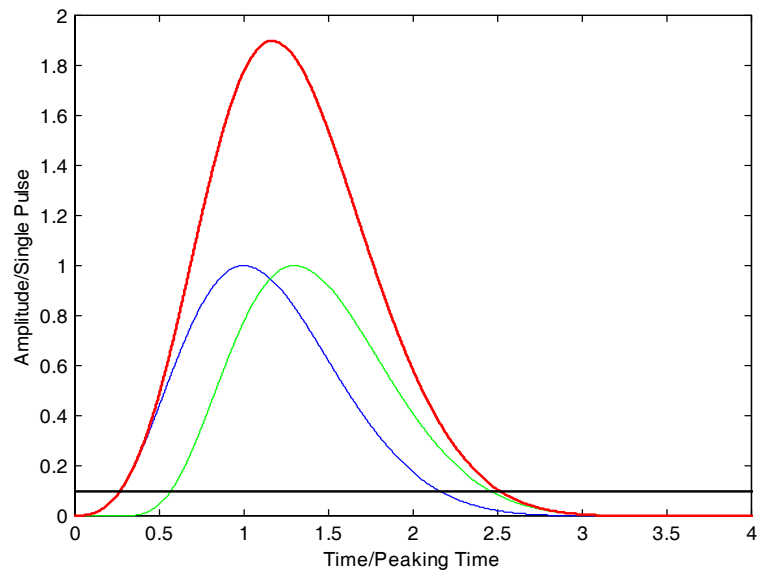
Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



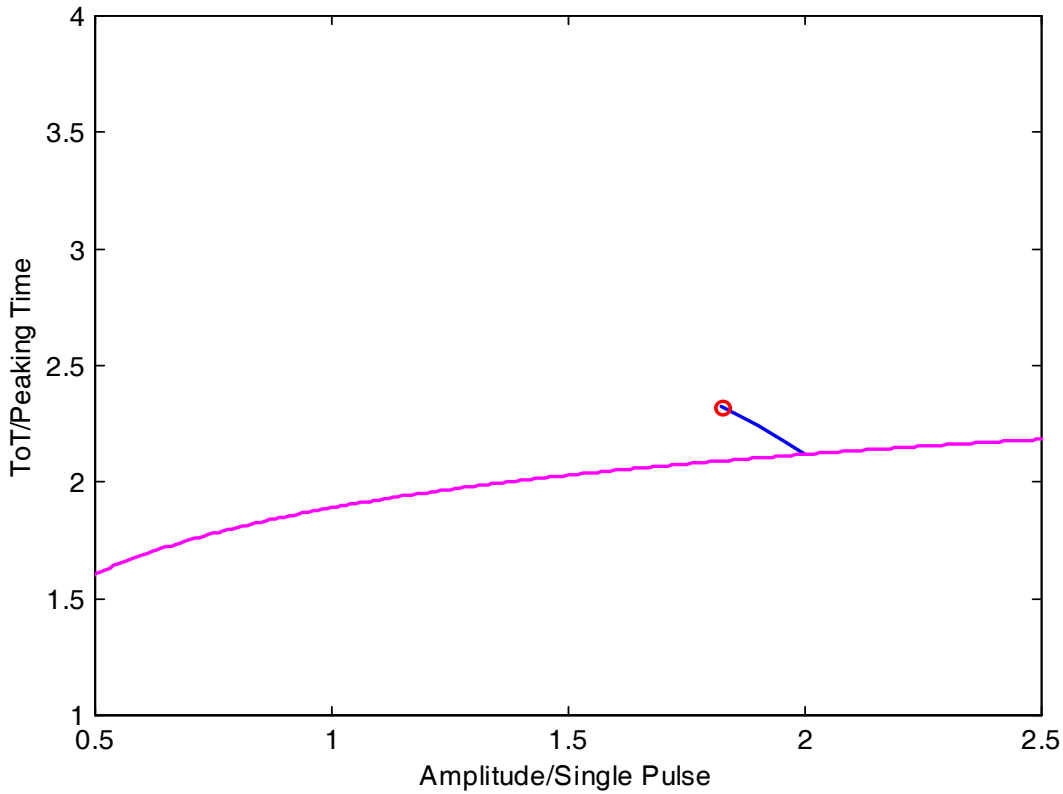
Delay = 0.3



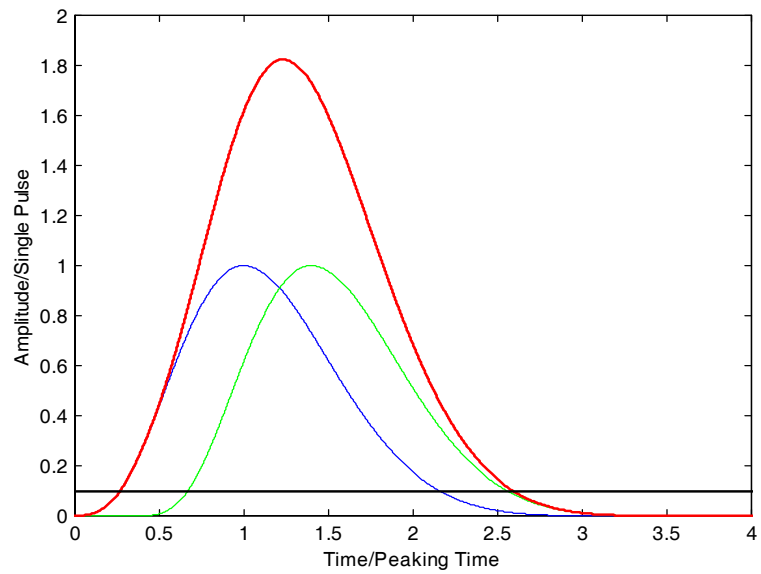
Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



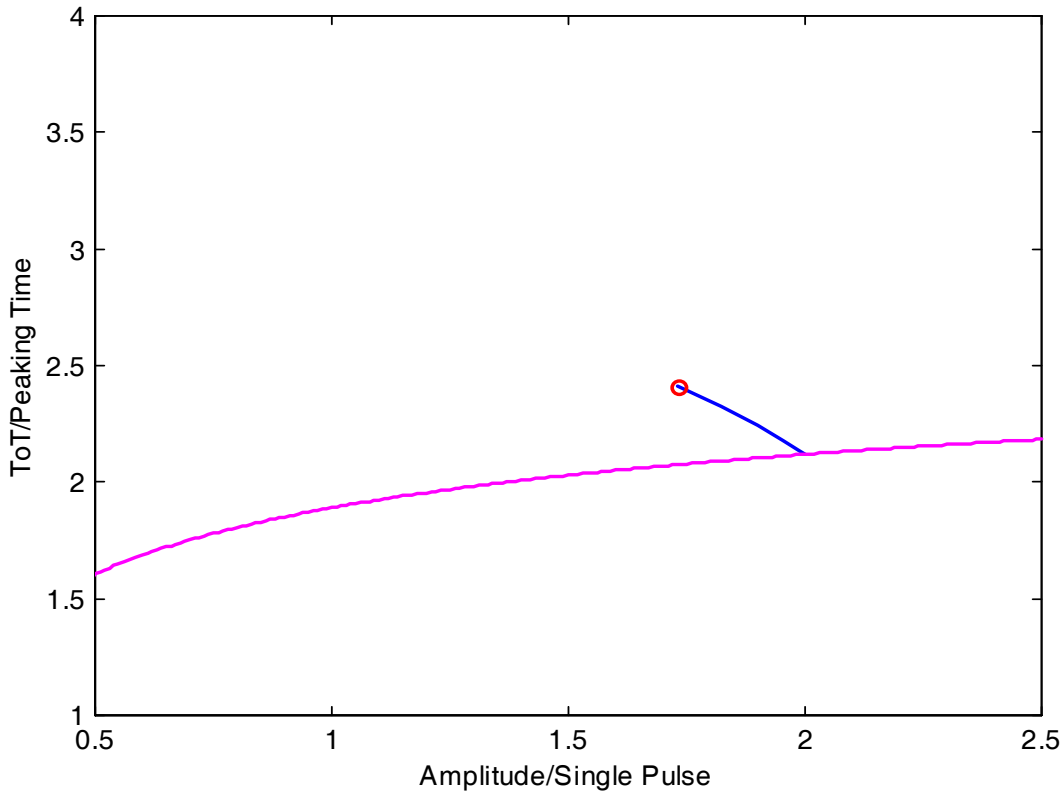
Delay = 0.4



Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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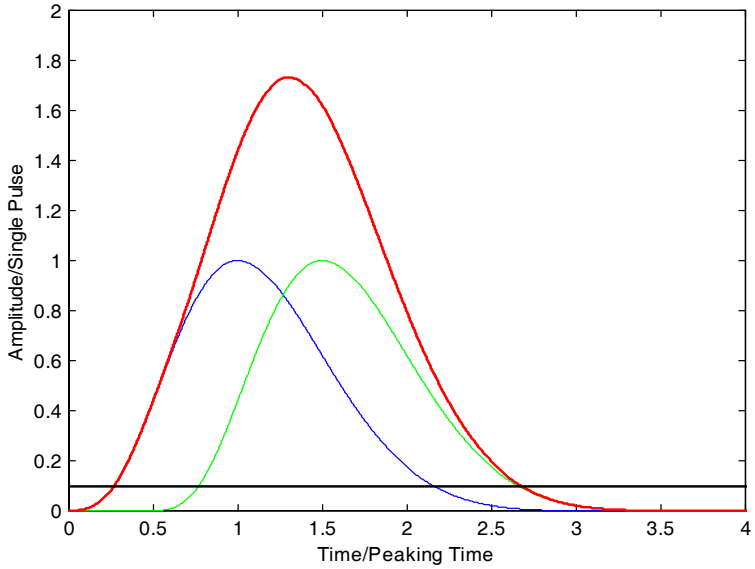
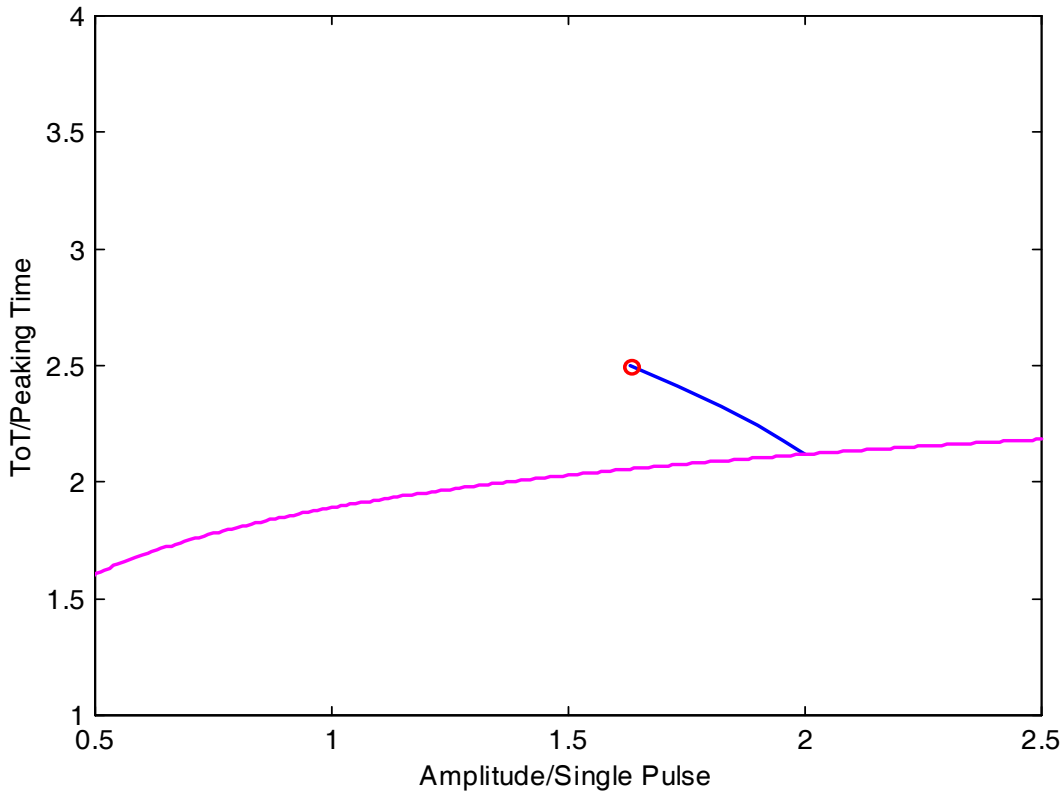


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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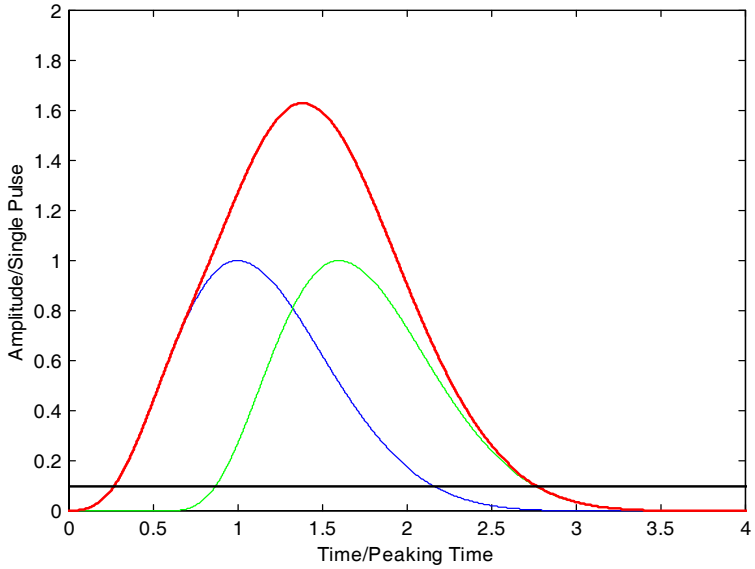
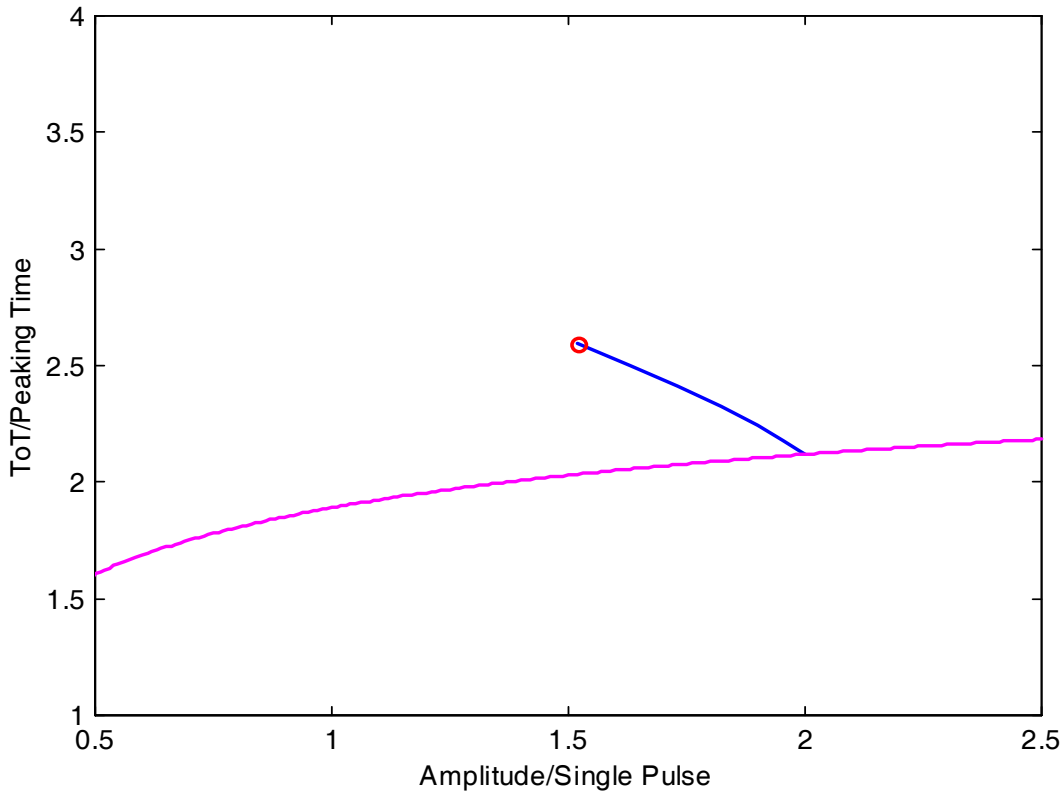


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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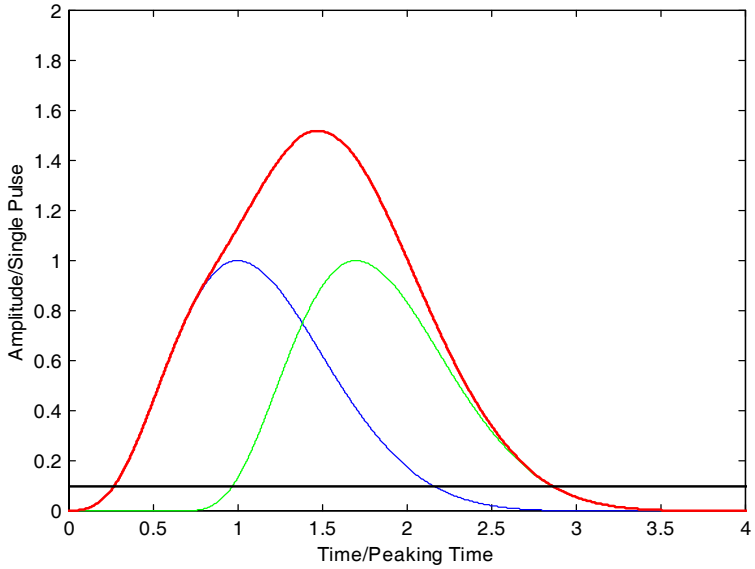
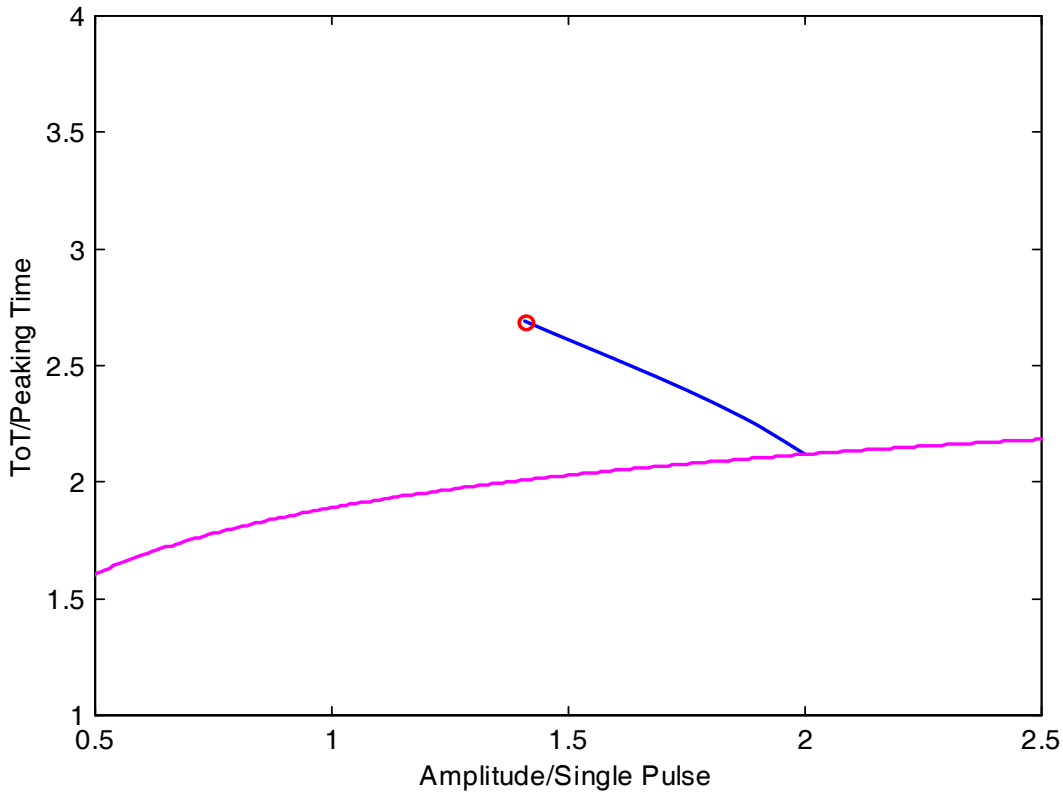


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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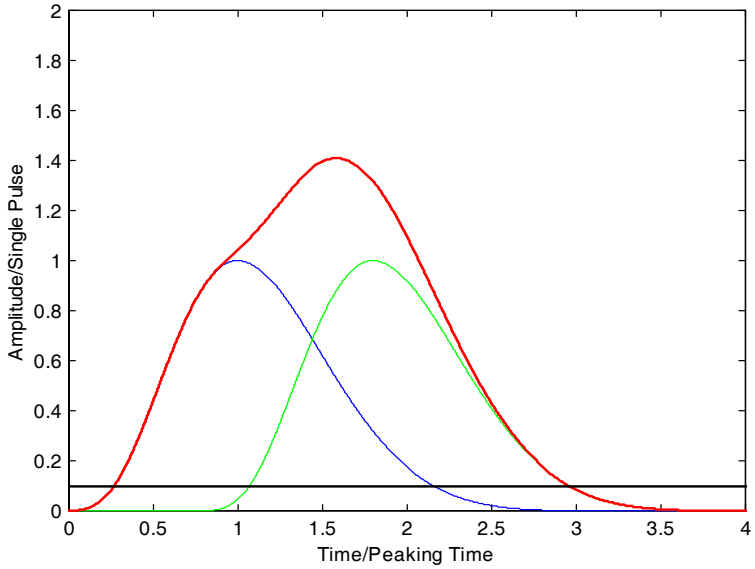
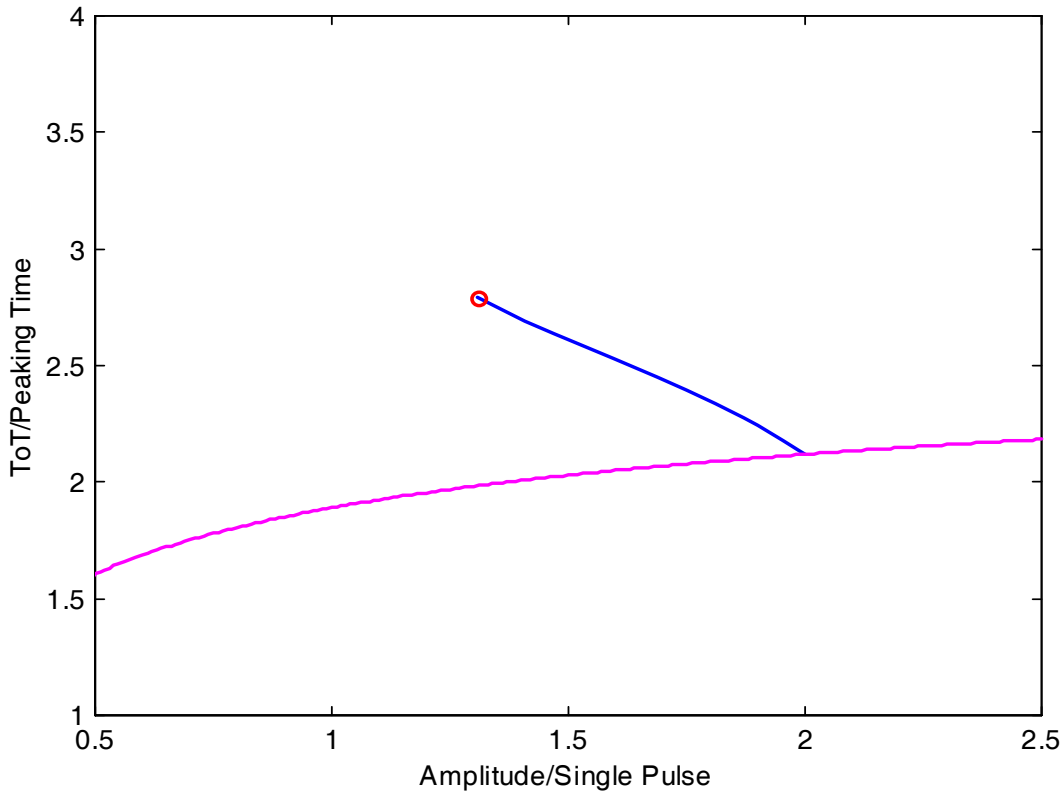


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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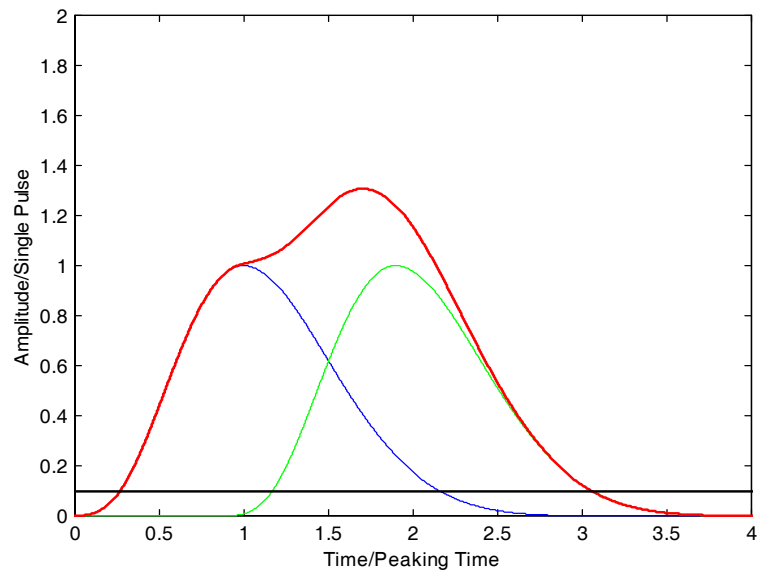
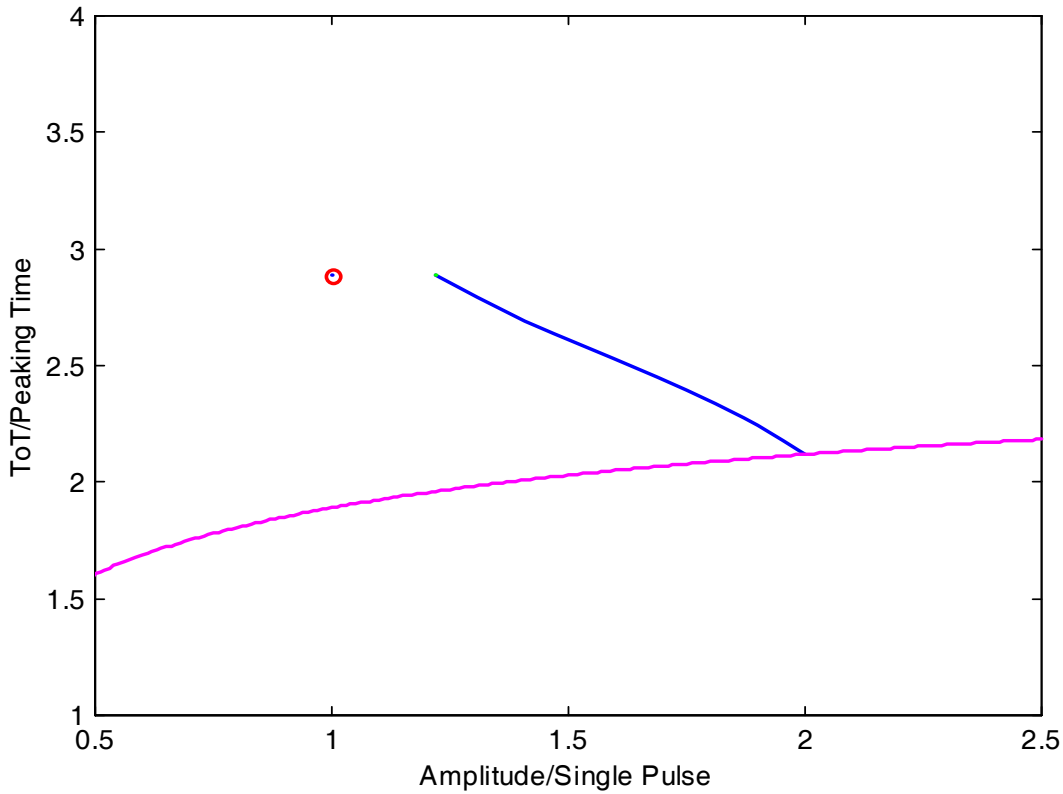


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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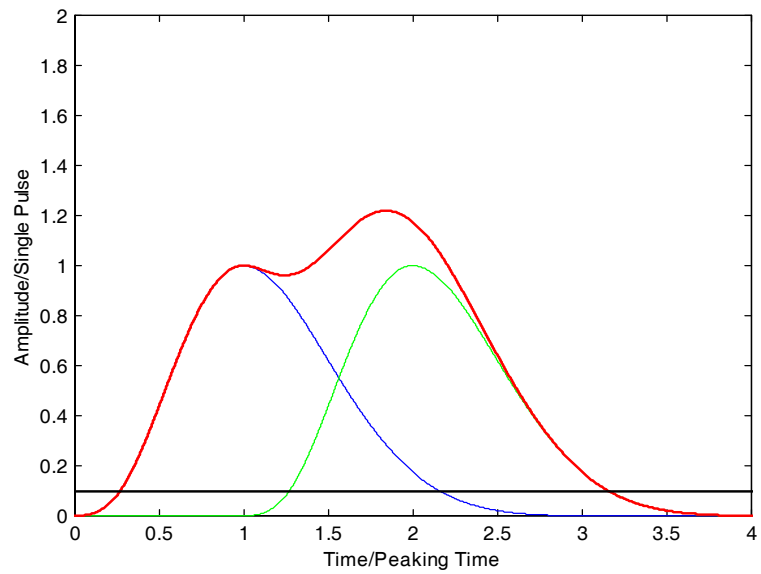
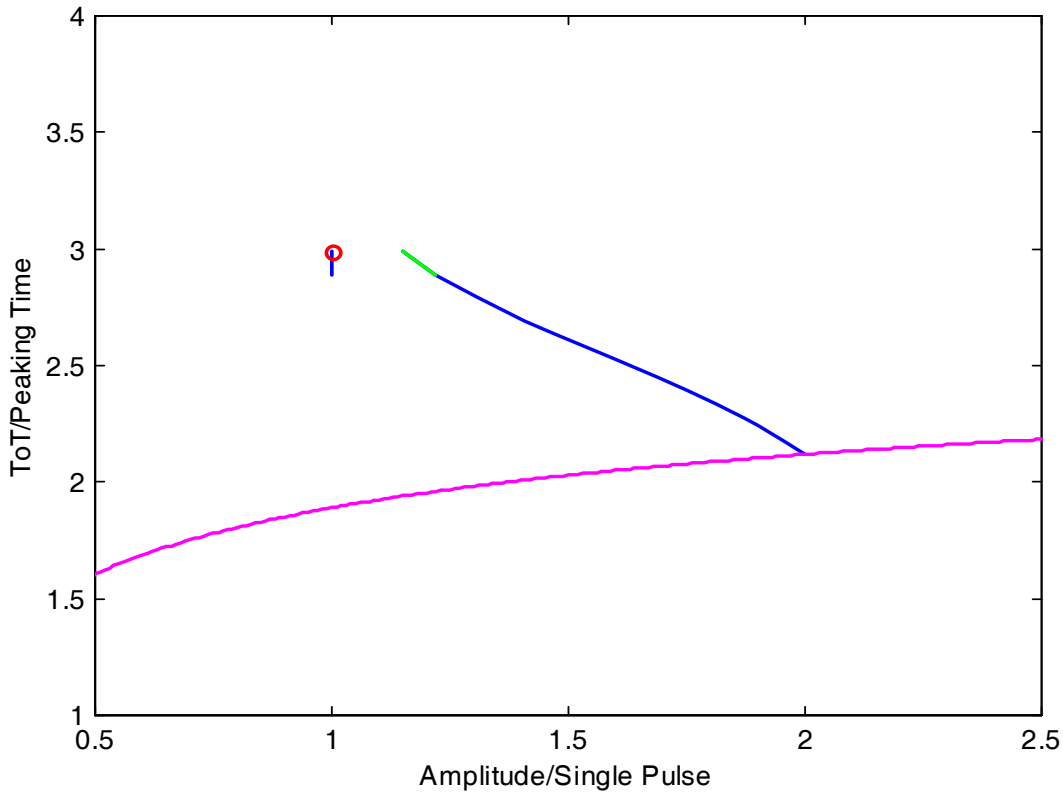


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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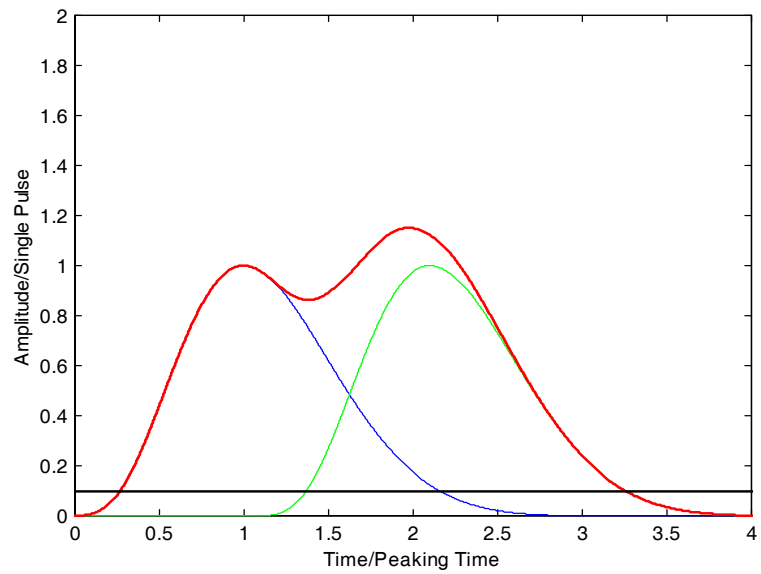
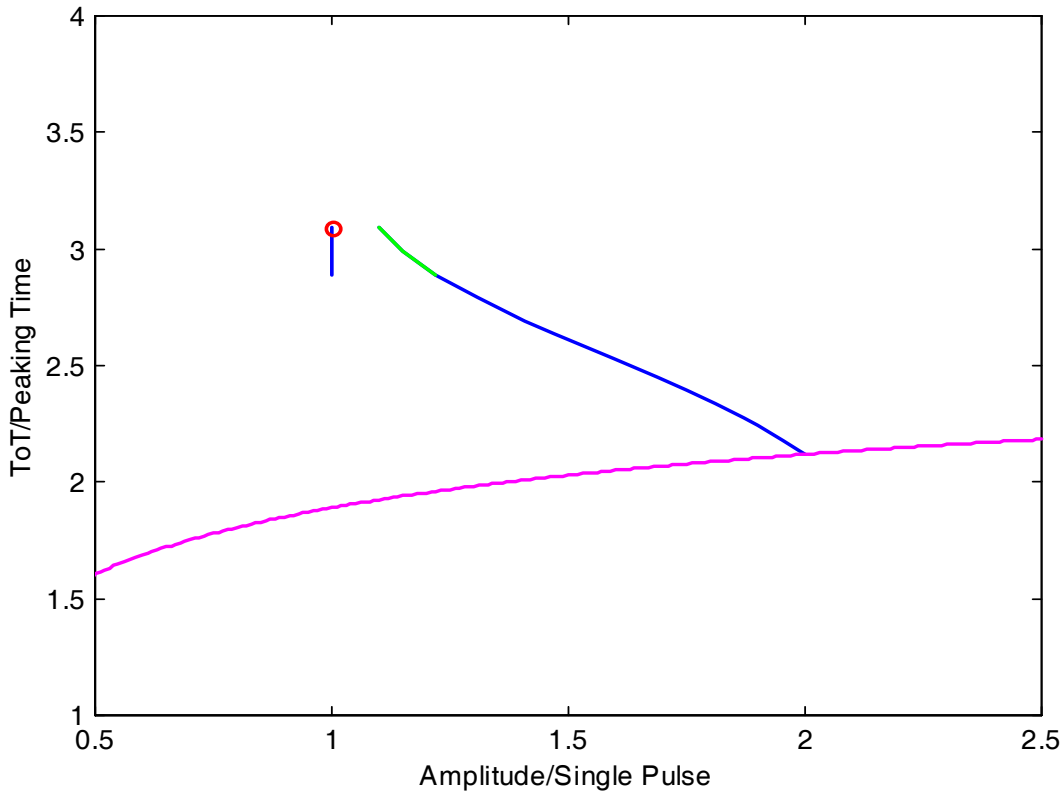


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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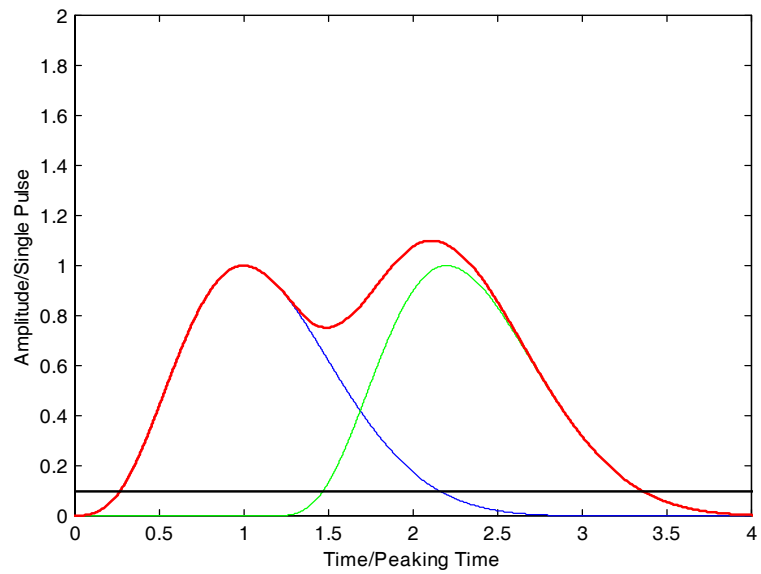
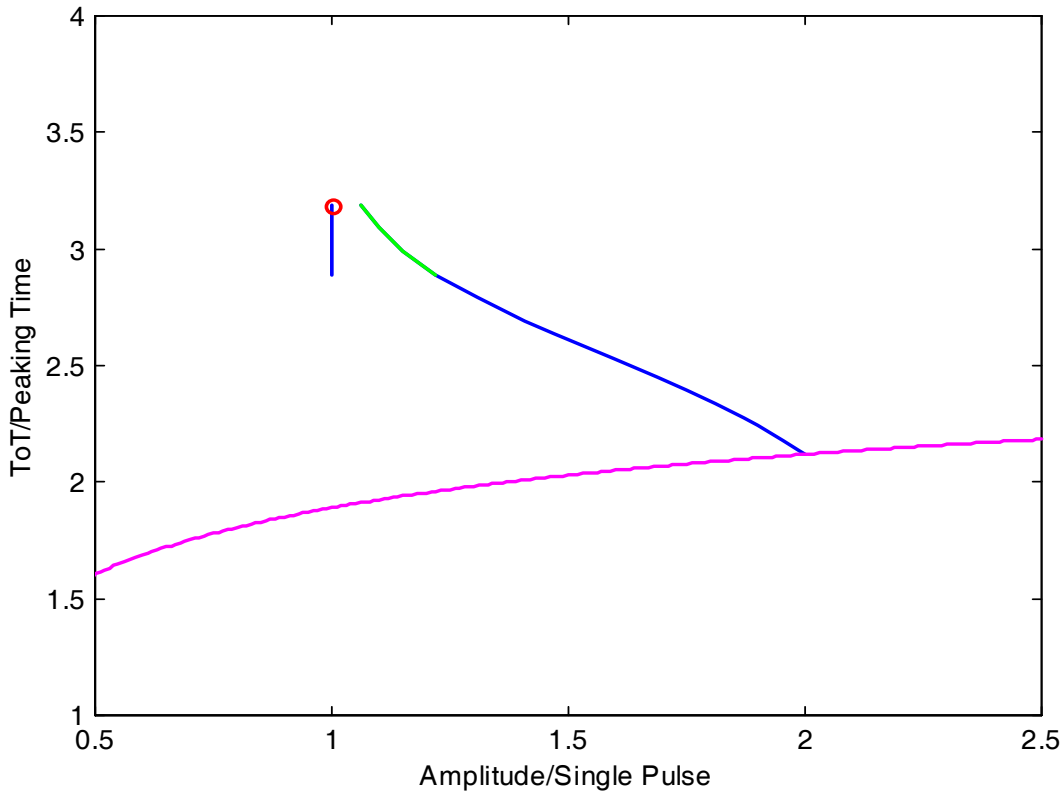


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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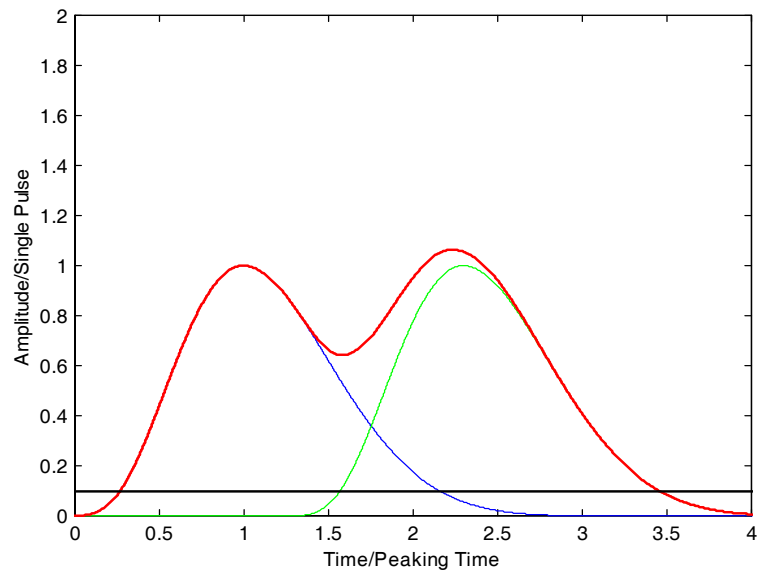
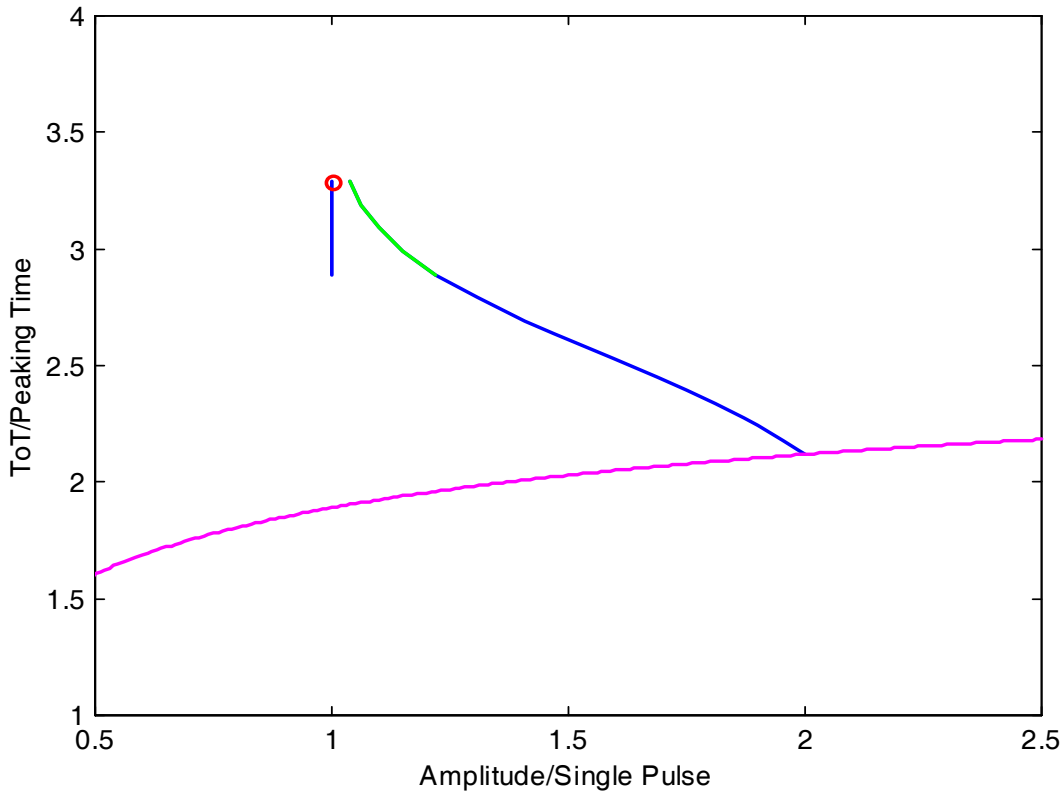


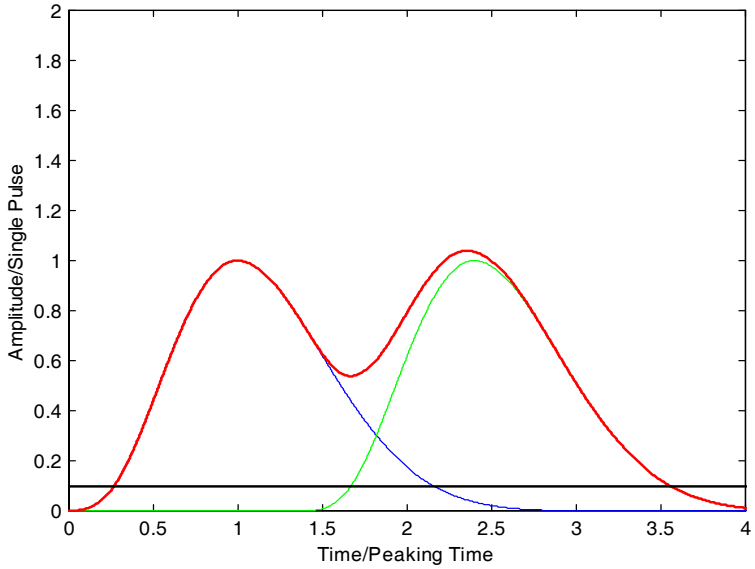
Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



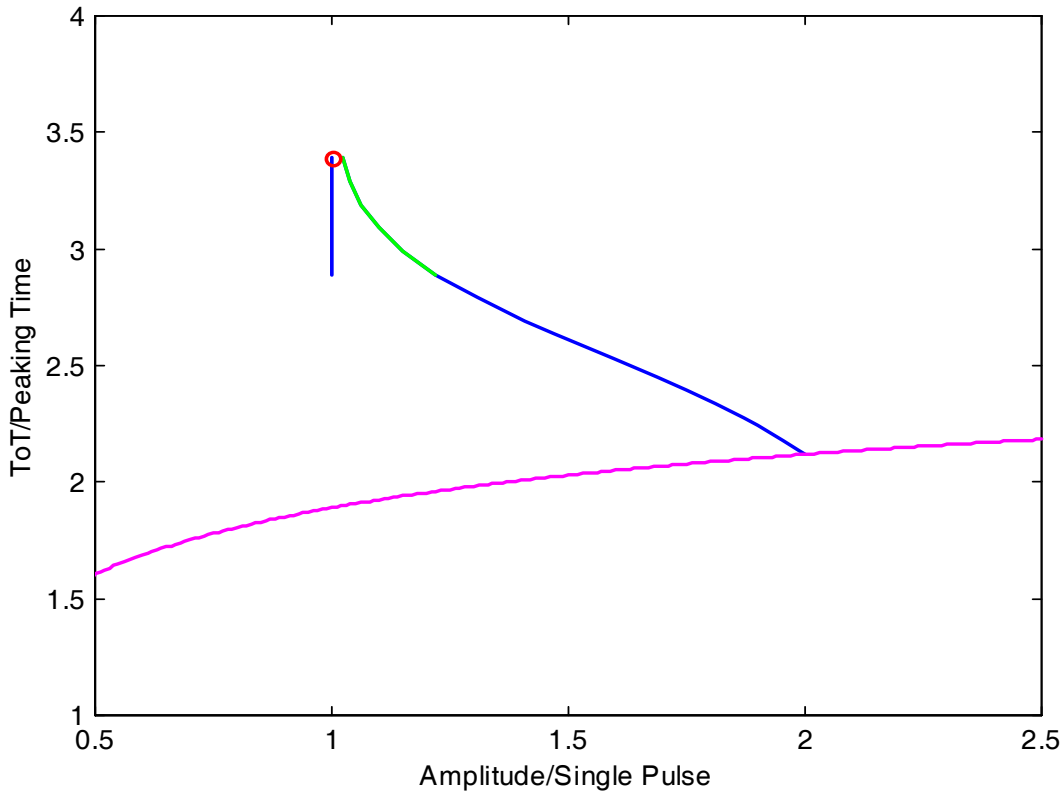
Delay = 1.4



Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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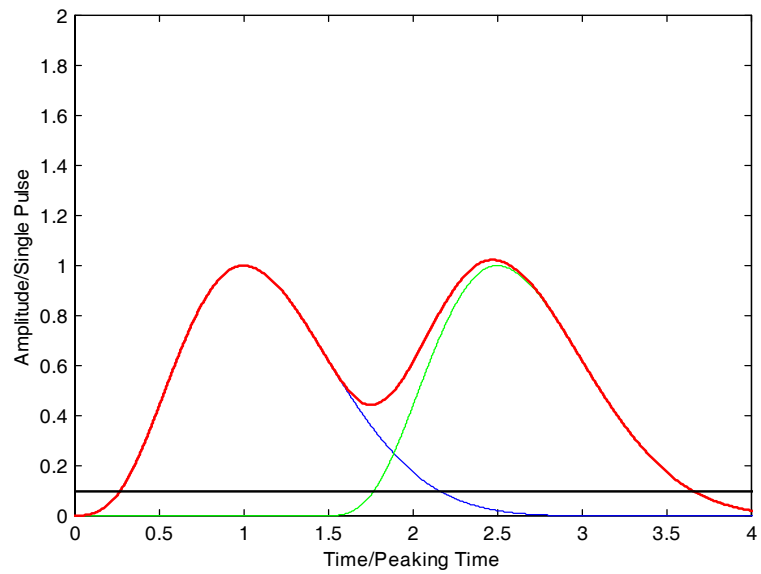
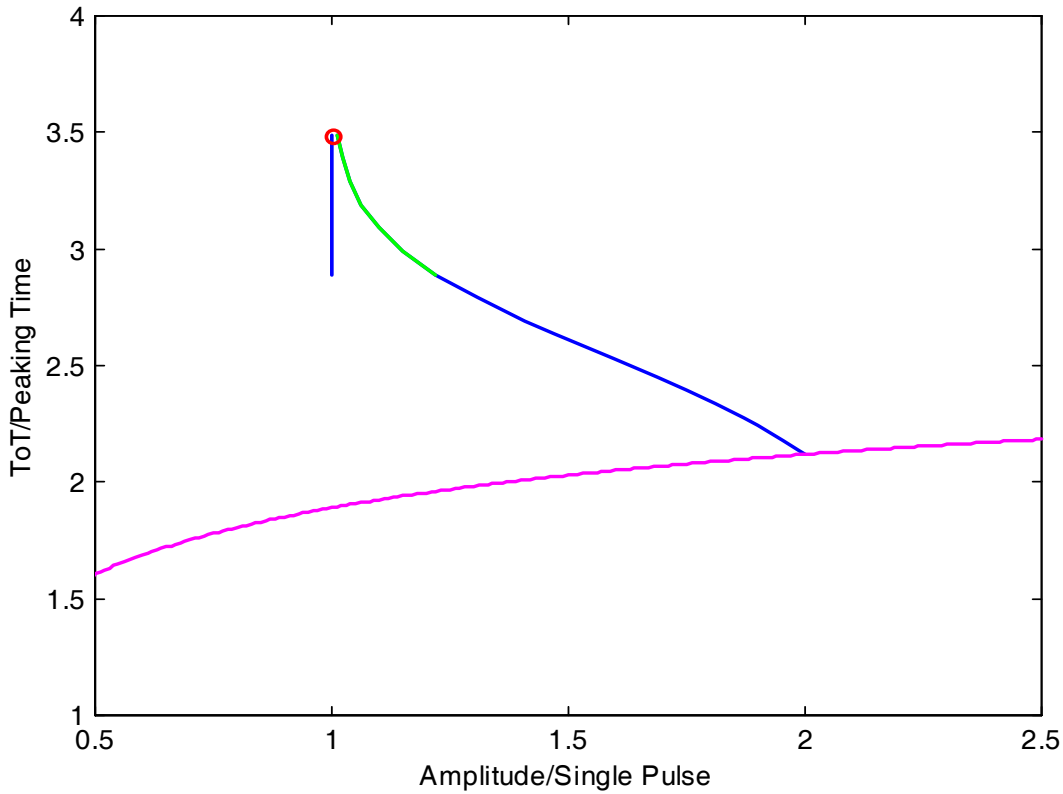


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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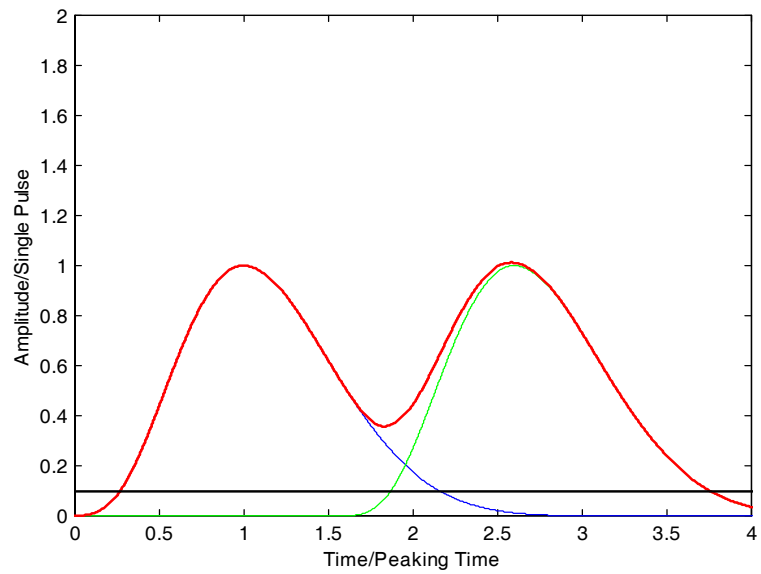
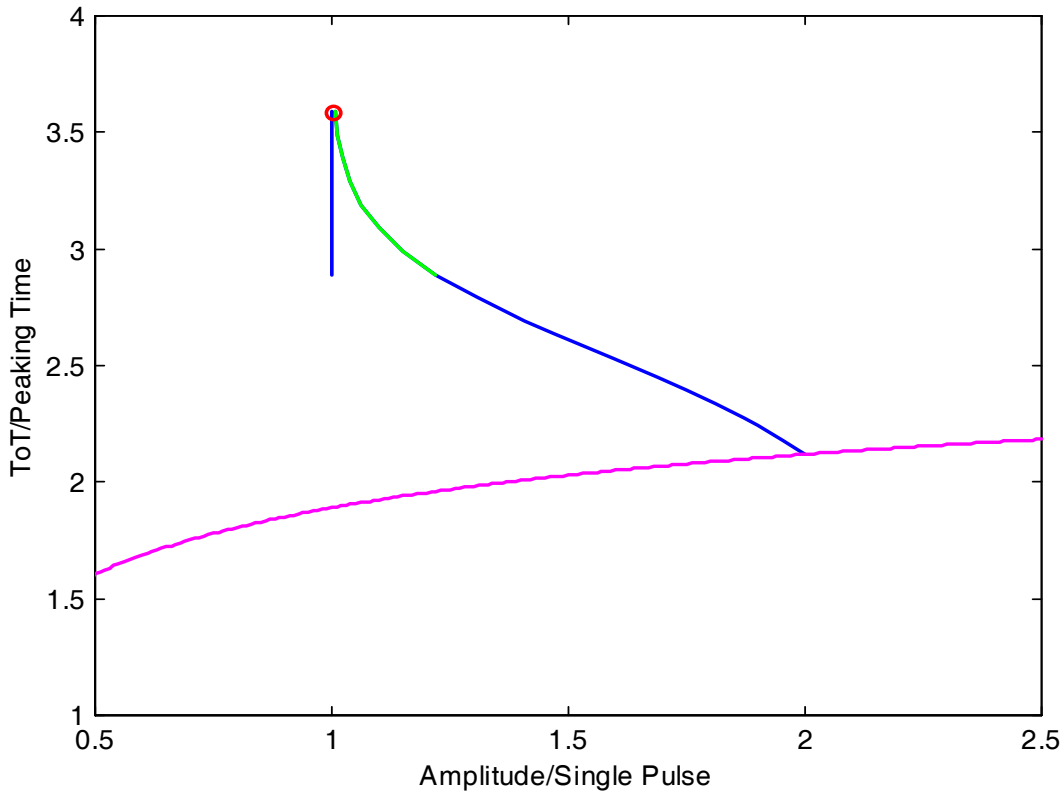


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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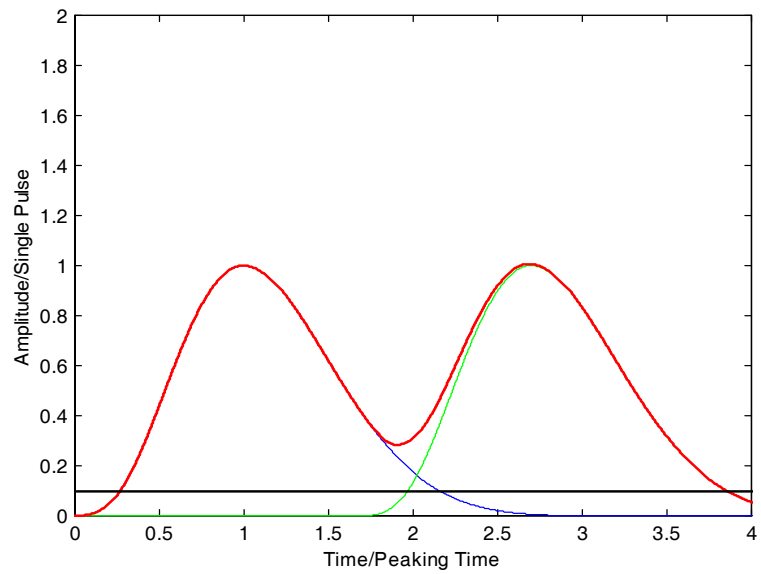
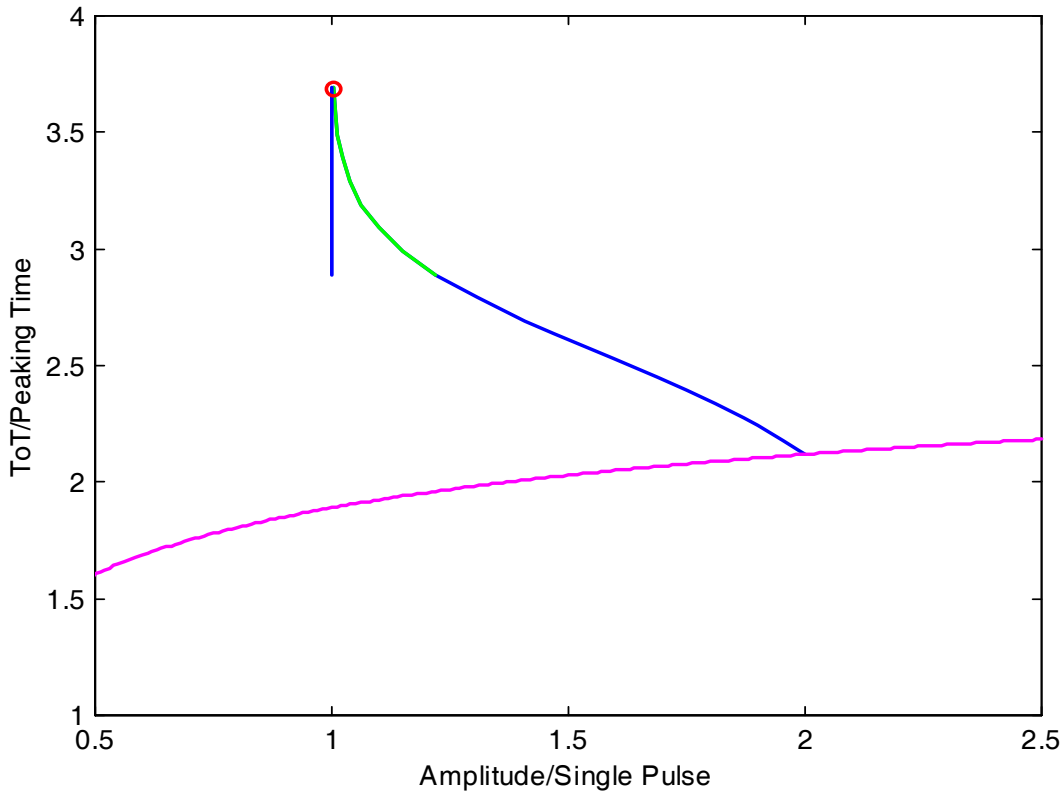


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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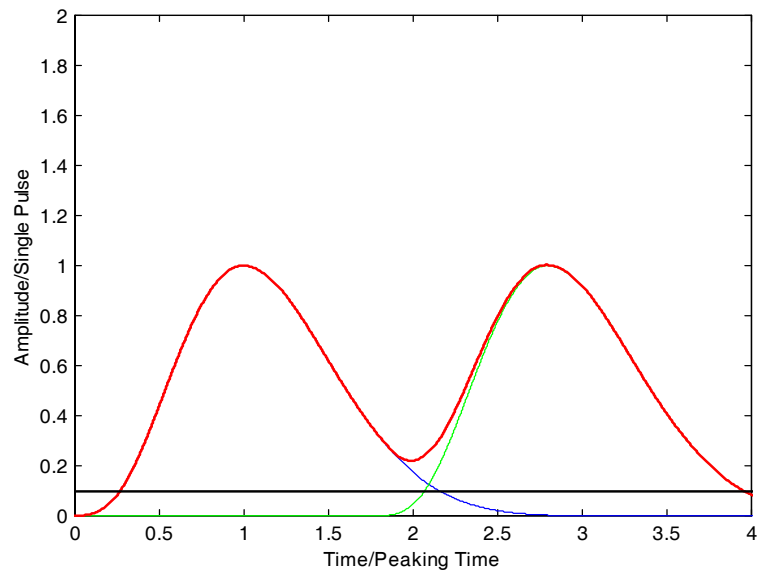
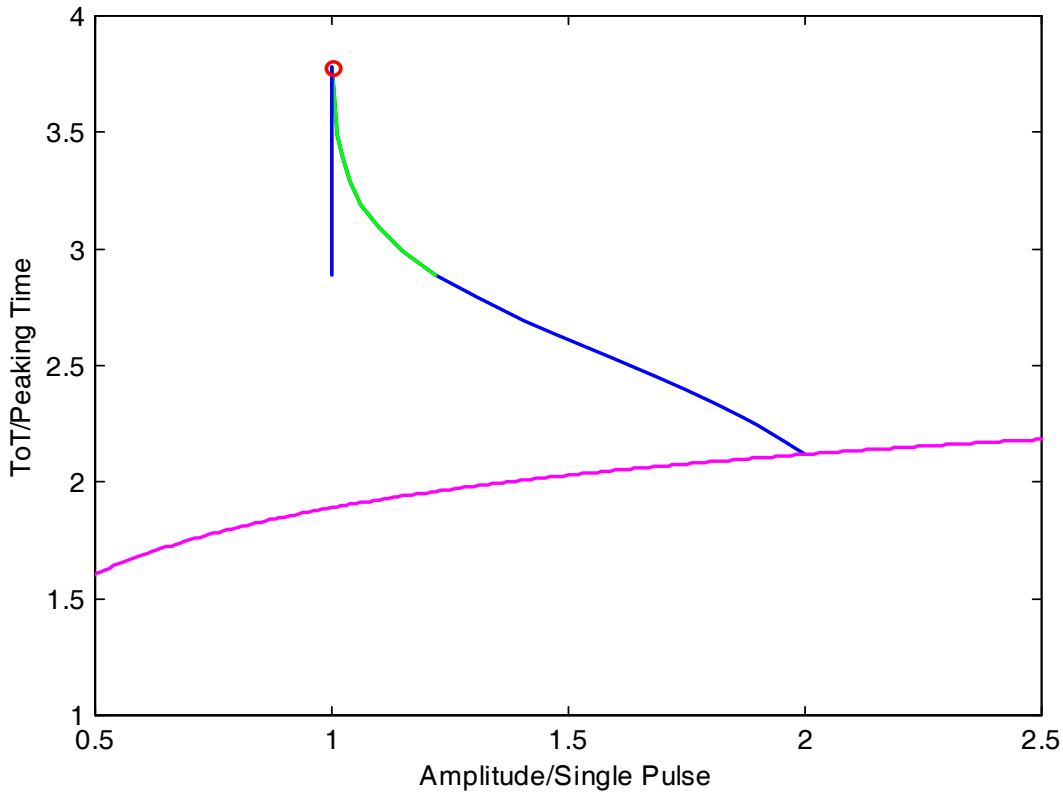


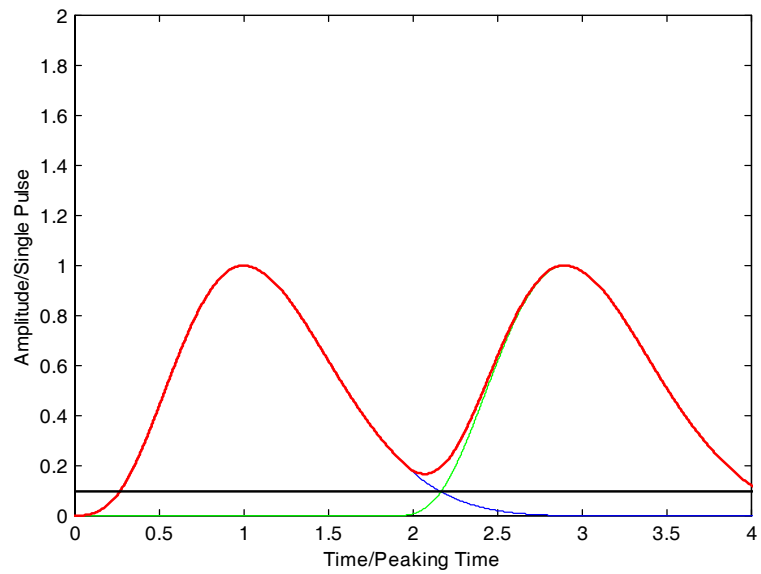
Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



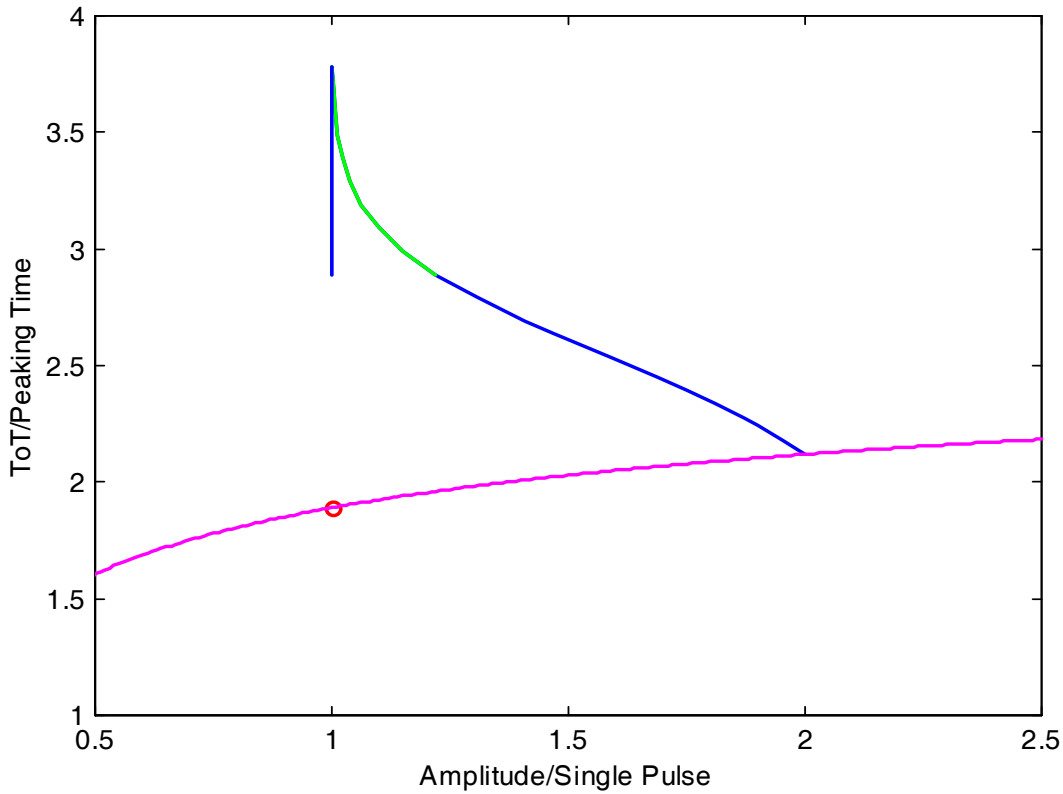
Delay = 1.9



Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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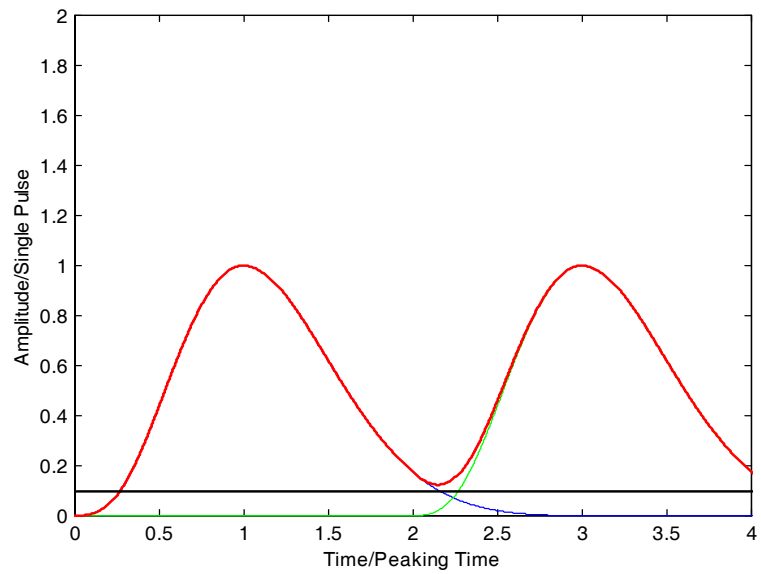
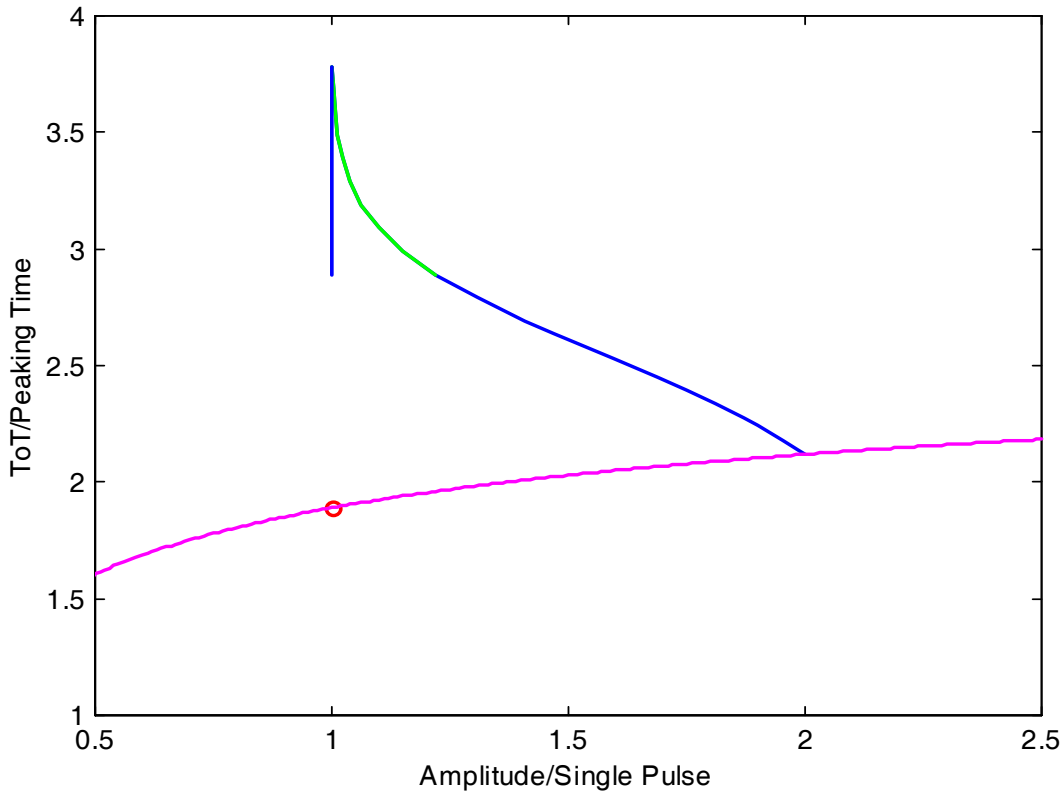


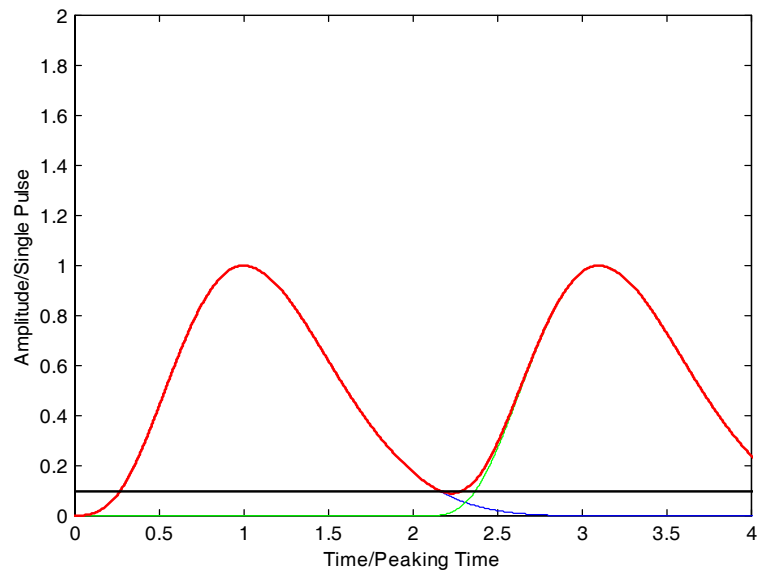
Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



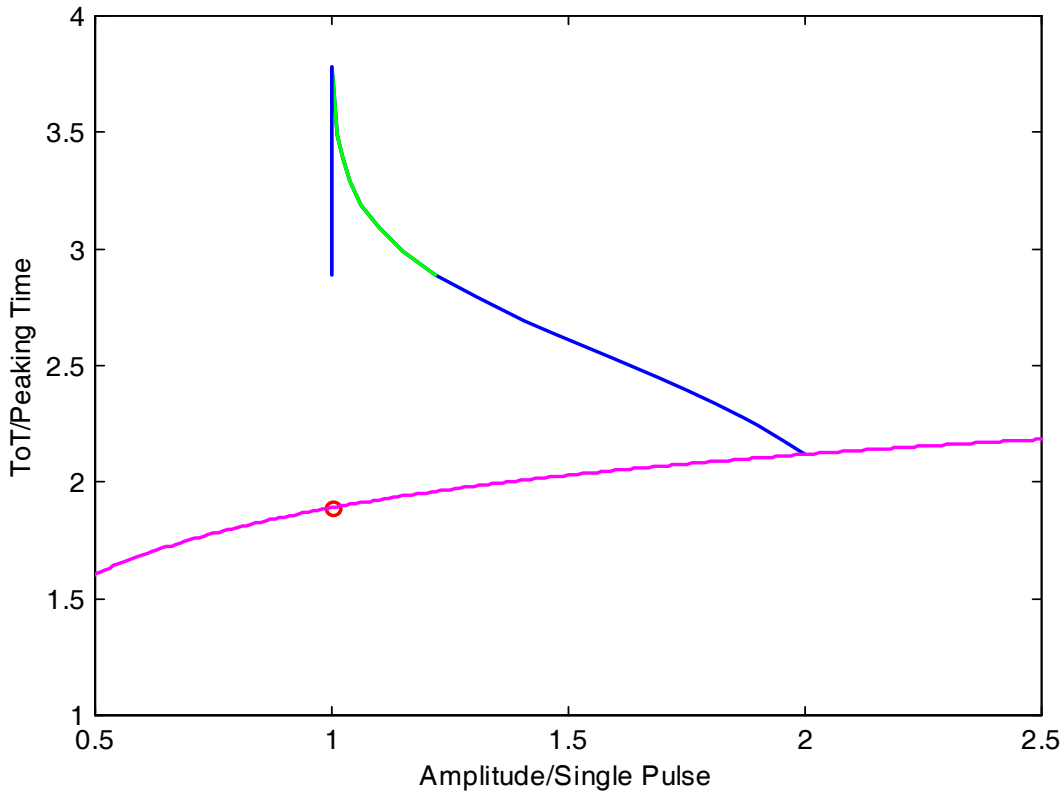
Delay = 2.1



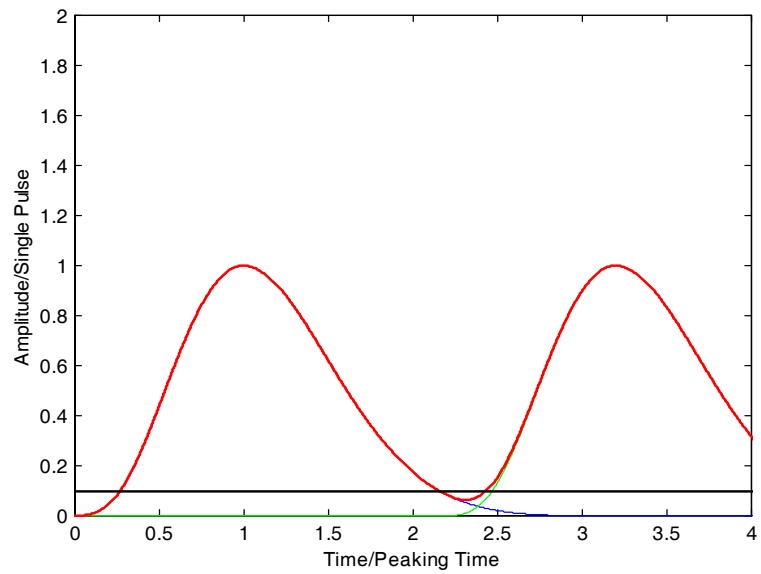
Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



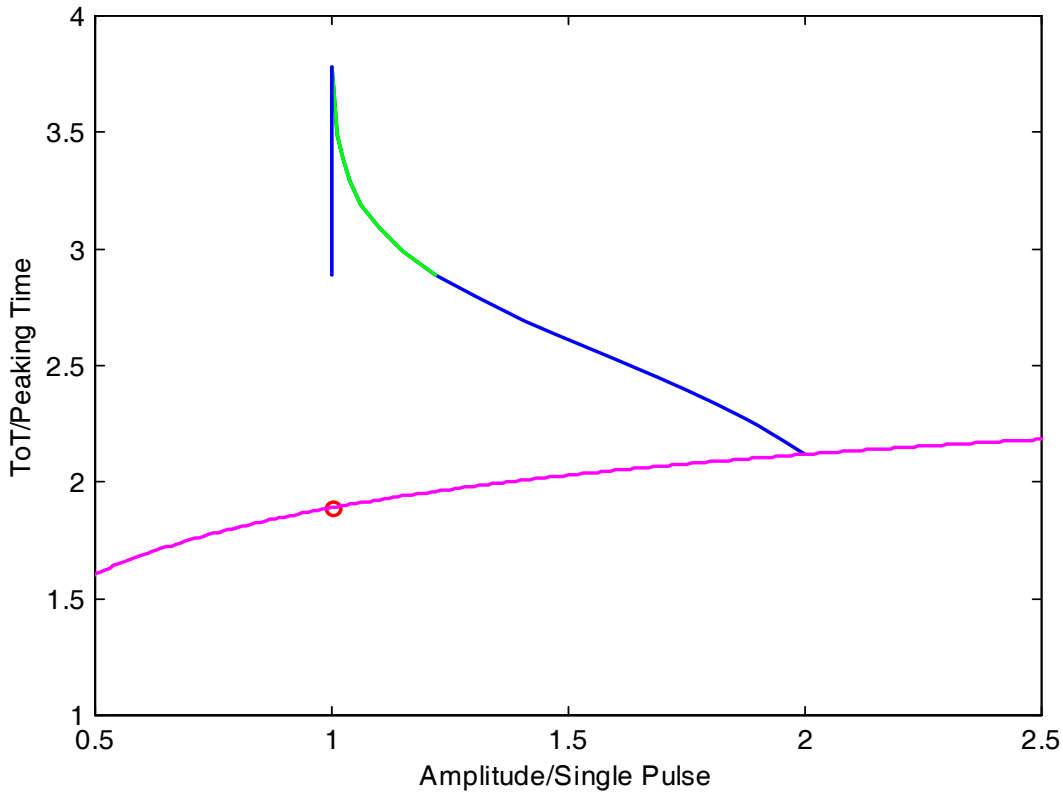
Delay = 2.2



Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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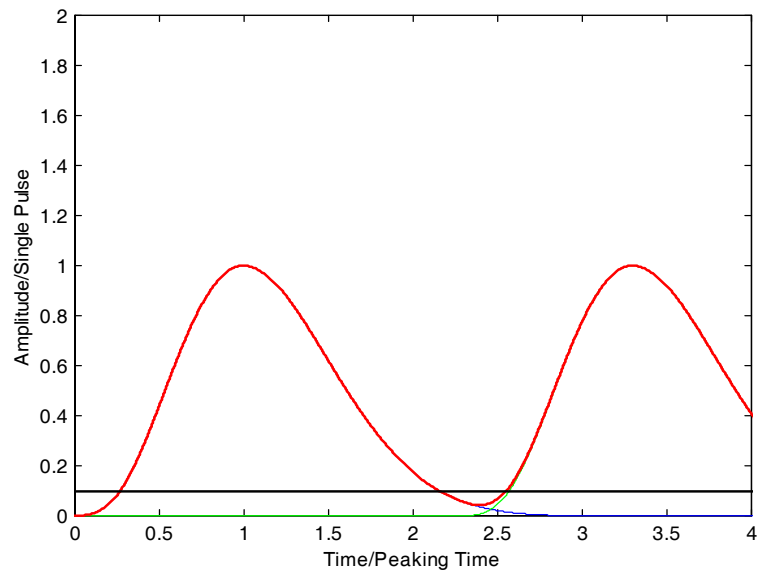
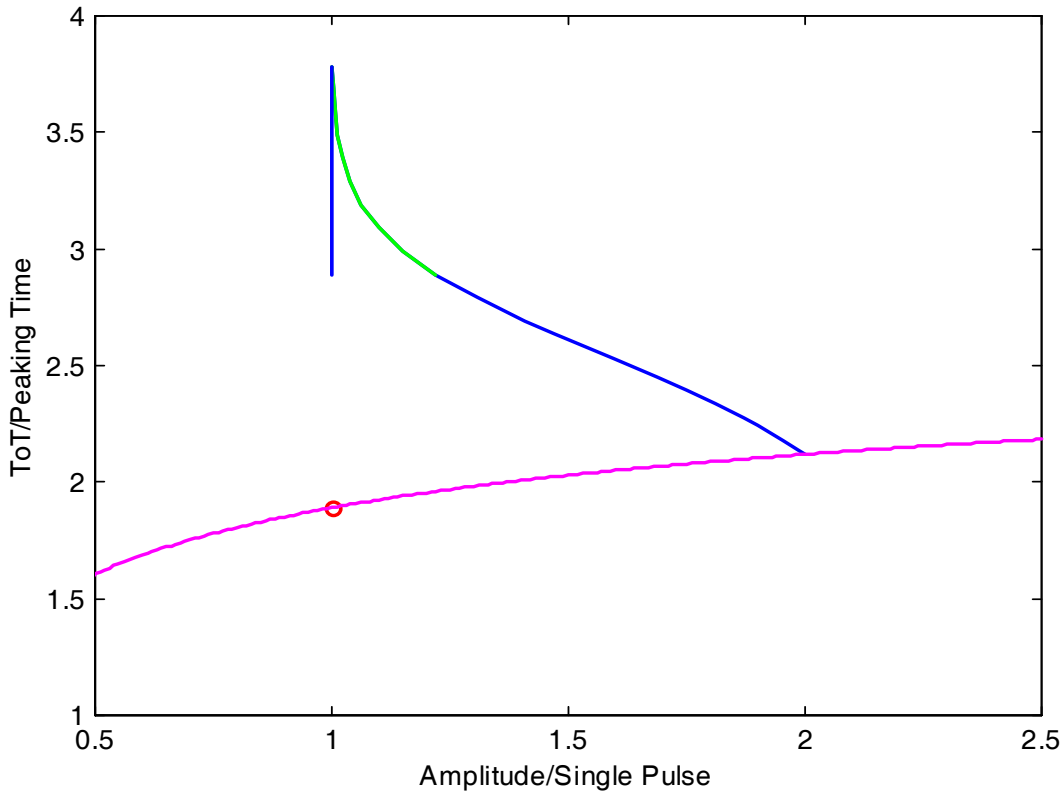


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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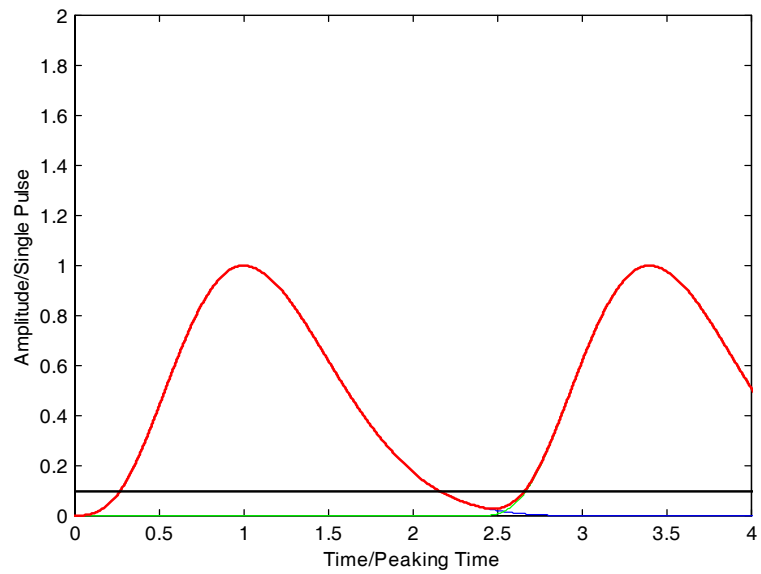
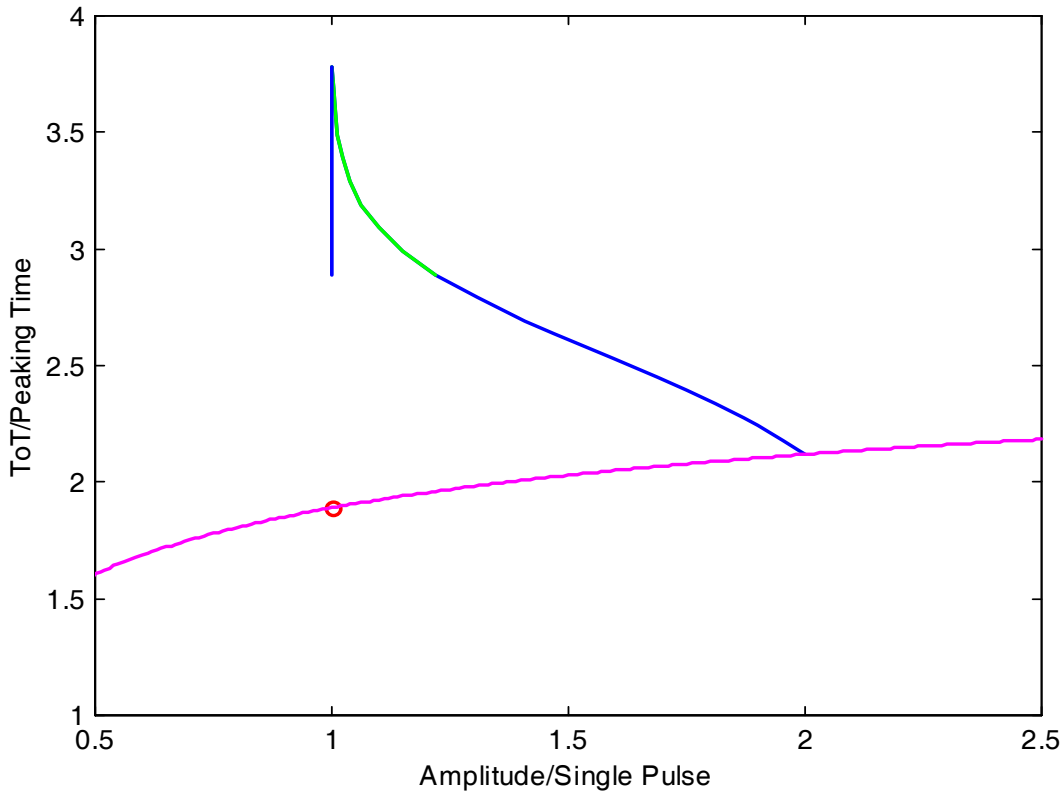


Time-Over-Threshold Measurement for pile-up rejection

ToT vs. Peak Amplitude Characteristic

for a pulse from a 5th order complex poles semi-Gaussian shaper



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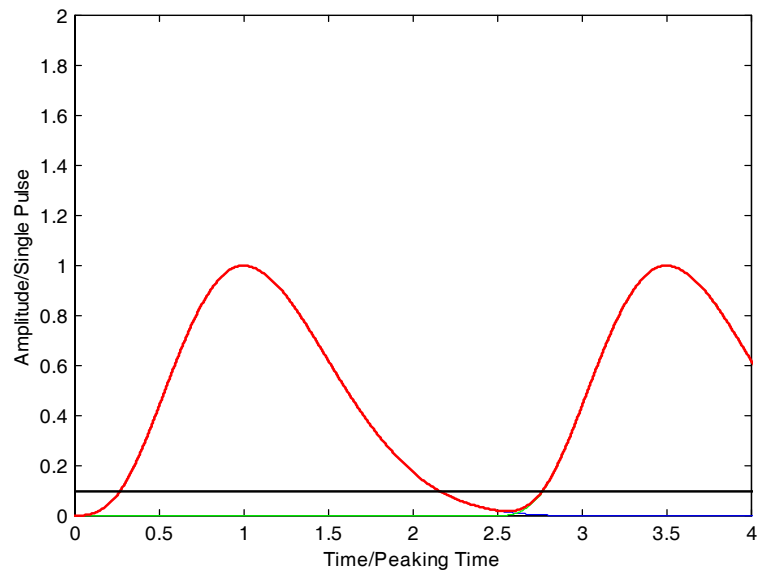
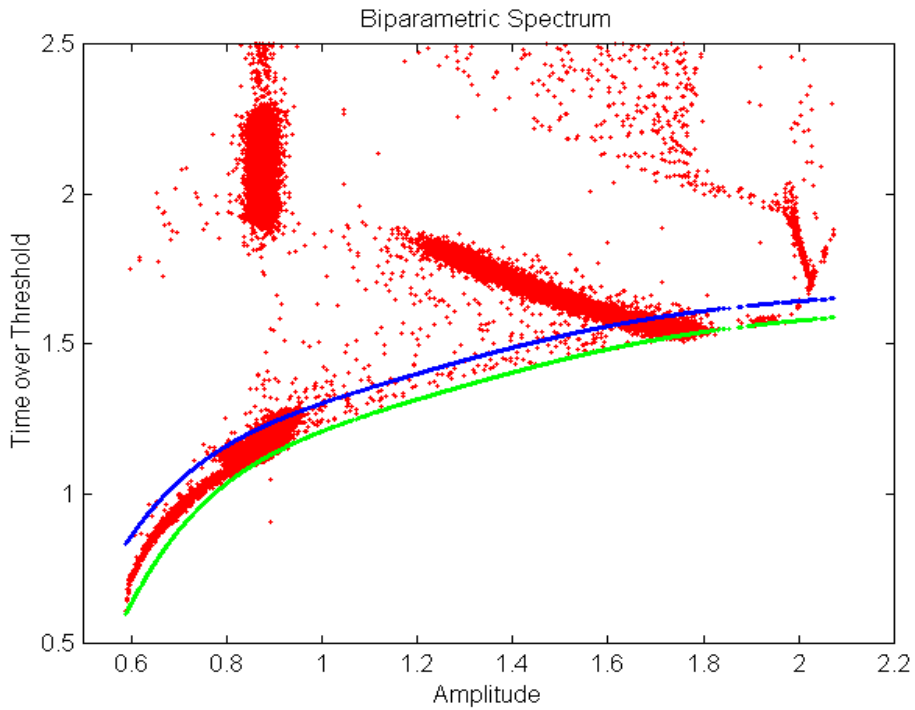
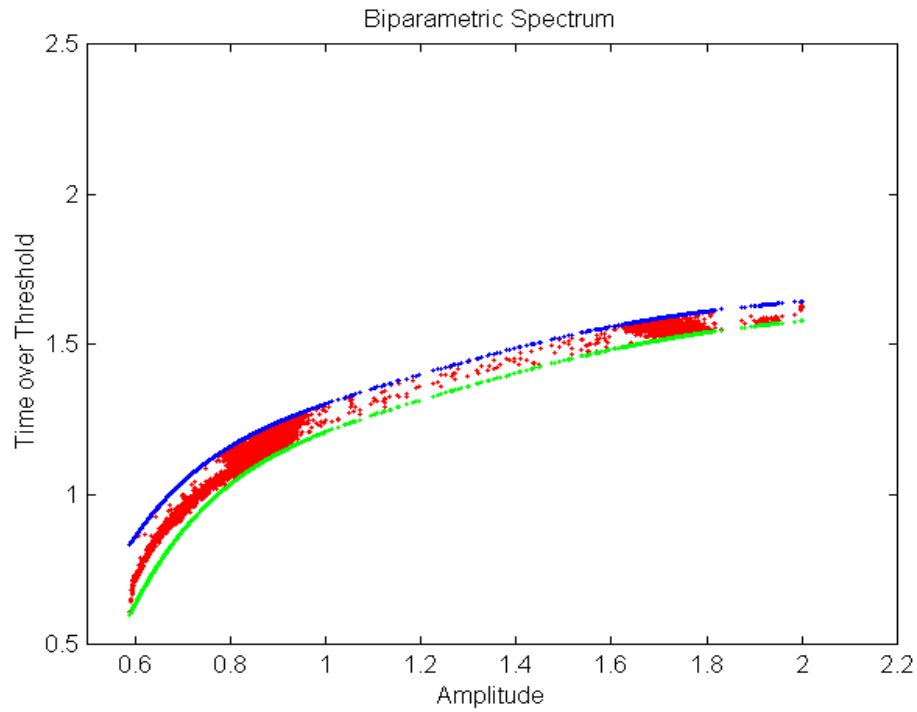


Time-Over-Threshold Measurement for pile-up rejection

The Pile-Up Rejection Algorithm

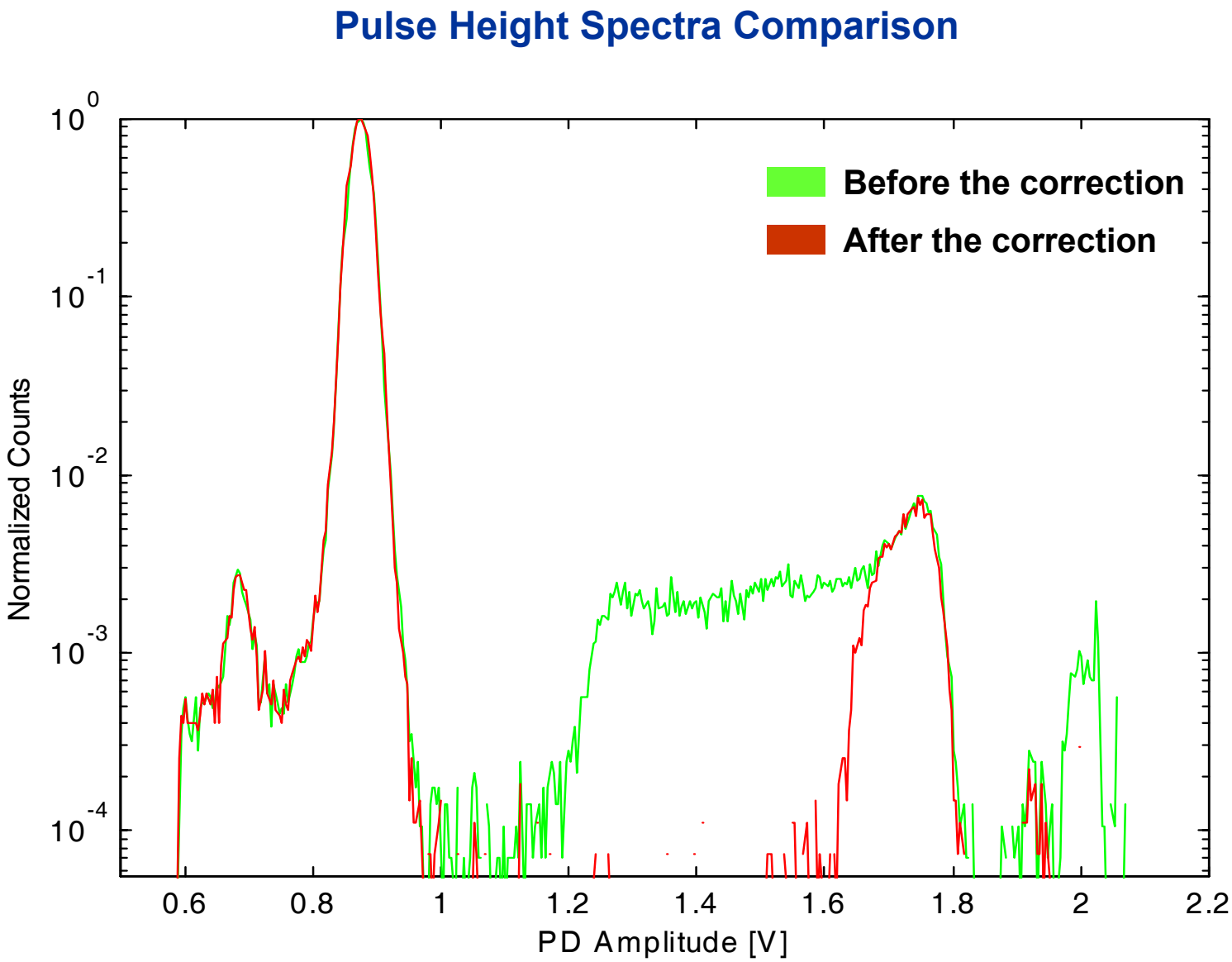


Before The Correction



After The Correction

Time-Over-Threshold Measurement for pile-up rejection



Outline

- The PDD architecture
- New features:
  - Simultaneous Events Catcher (SEC)
  - Pileup Discrimination and Rejection
- A modular test system
- Test results
  - SEC performances
  - High rate spectroscopy
  - A first example of pile-up rejection
- Future works and conclusions

Future works and Conclusions

- Extensive Characterization of the PDD for Spectroscopy under High Rate Conditions
- Improvements on the Pile-up Rejection Algorithm
- Split event reconstruction in pad/pixel detectors
- Coincidence Analysis for compact PET systems

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