Modeled pulse function for waveform analysis using DRS4

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SLAC
DRS4 digital evaluation board for timing studies in Fermilab Meson Test Beam and SiDet facilities

High-speed Digitization Readout of Silicon Photomultipliers for Time of Flight Positron Emission Tomography,


FERMILAB -TM-2487-PPD, February 2011
DRS4 Digital Oscilloscope Board

Sampling frequency: from 2 GSa/s to 5 GSa/s
4 channel, possibility of external trigger
USB interface, low energy consumption (power from USB)
Firmware improvements in v.3
Designed and manufactured in PSI (Zurich, Switzerland)
Apply DRS4 to improve time resolution

- TOF on Fermilab Meson Test Beam
- CMS Forward proton detector
- TOF PET applications

Fermilab MTBF 2010

- MCPPMT Photek 240: 14 ps
- Photek-SiPM: 24 ps
- ORTEC electronics ($3k/ch)

New approach:
SiPM + DRS4
Examples of the data: rise time varies from 2 ns to 50 ns
Test beam, Cherenkov, clipping capacitor 10 pF, 5 GSa/s
LSO crystal, $^{60}$Co source, 2 GSa/s
Some of methods which are currently in use

Different approaches:
- simulation of the Constant Fraction Discriminator
  - complicated procedure of parameter tuning
  - dependence of pulse height and sampling frequency
- Mean Pulse Model (use average of ~10k pulses as an template to fit the signal)
  - good performer but needs templates
- fit straight line to the leading edge
  - simple, but
  - the leading edge is far from the straight line
We model of SiPM as a charging/discharging capacitor

To take into account finite width of light pulse and clipping capacitor we parametrize the pulse function by two time constants: rise time $\tau_1$ and discharge time $\tau_2$:

$$p(t) = (1 - \exp(-t/\tau_1)) \cdot \exp(-t/\tau_2)$$

To describe LSO crystal data we convolute the pulse function with scintillator decay function $\exp(-t/T)$

To take into account signal jitter we convolute pulse function with Gaussian resolution function
Fit pulse function to the data

Needs reasonable initial value for free parameters

Two-stage fit procedure:
- fit the whole pulse to find position of the leading edge
- refit the leading edge region
Examples
Beam test data, STMicroelectronics SiPM, Cherenkov light, clipping capacitor 10 pF + amplifier
black line: global fit, red line: refit
(parameters which was fixed for refit have 0 error)
LSO crystals, $^{22}$Na source
Hamamatsu MPPC
clipping capacitor 10 pF + amplifier
black: global fit, red: refit
NB fluctuations on the tail

grsig_evt_7_ch_4 l=33.1 $\chi^2=1.6$

<table>
<thead>
<tr>
<th>$\chi^2$</th>
<th>130.4 / 18</th>
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<tbody>
<tr>
<td>$a_1$</td>
<td>-2048 ± 20.1</td>
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<td></td>
<td>32.36 ± 0.3077</td>
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STM SiPM, picosecond laser, low light

200 ns pulse, about 4 photoelectrons
Work, in progress. Some results.

Hamamatsu MPPC, $^{22}$Na, LSO
time resolution with skew correction

STM, no clipping, picosecond laser

Time resolution vs Npe
Summary

Pulse function approach seems promising for a wide range of applications.

Provides uniform description for different setups
- fast Cherenkov signal with 2 ns rise time
- LSO crystals with ~50 ns rise time
- SiPM and MCP PMT

Work in progress in preparation to coming beam test