Broadcom SiPMs and PT*30 OPC

APEX Working Meeting
Sep 7, 2023

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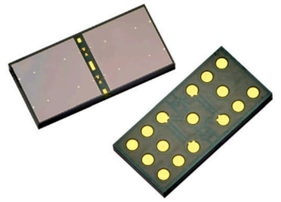
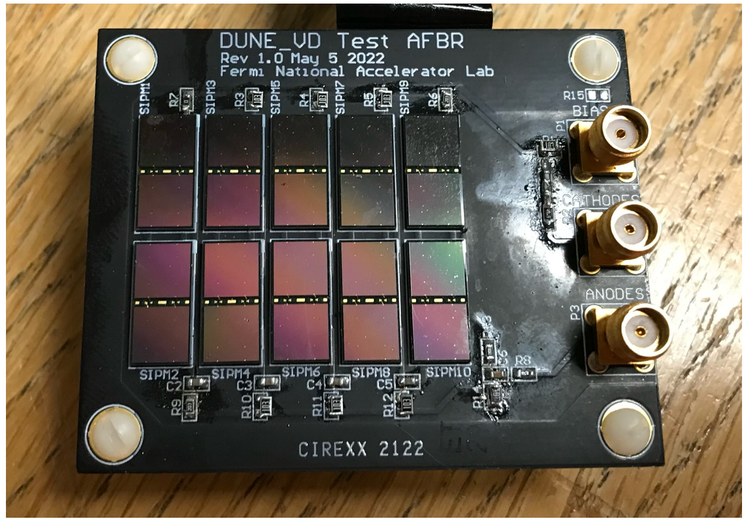
Broadcom SiPMs

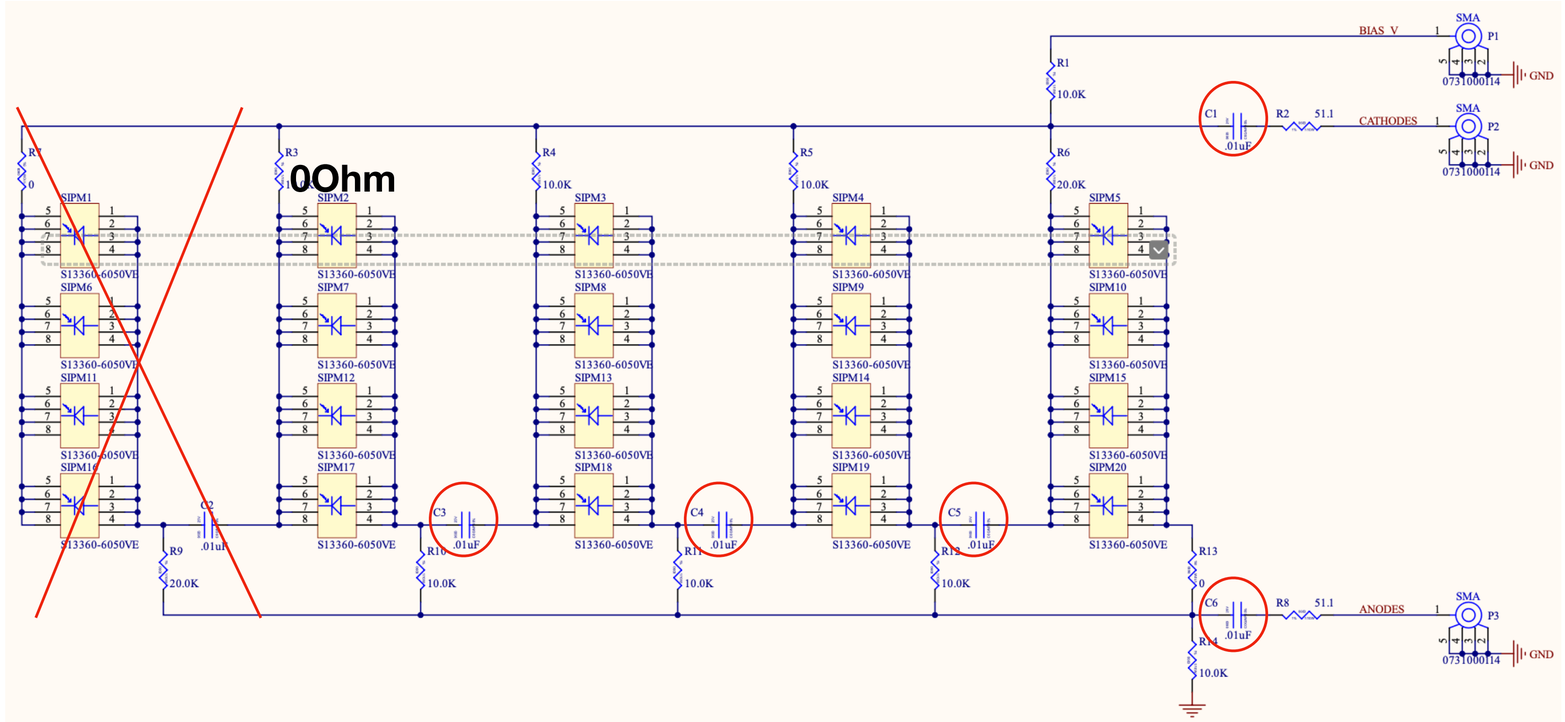
AFBR-S4N66P024M
2×1 NUV-MT Silicon Photomultiplier Array



- Broadcom 2x1 unit ($50/unit), 10 units grouped in parallel
  - V_{bd} = 27V (LN2), data sheet uses 12V above breakdown
  - Manufacturer claims 63% QE @~420nm, this is ~30% higher than HPK/FBK @ VD



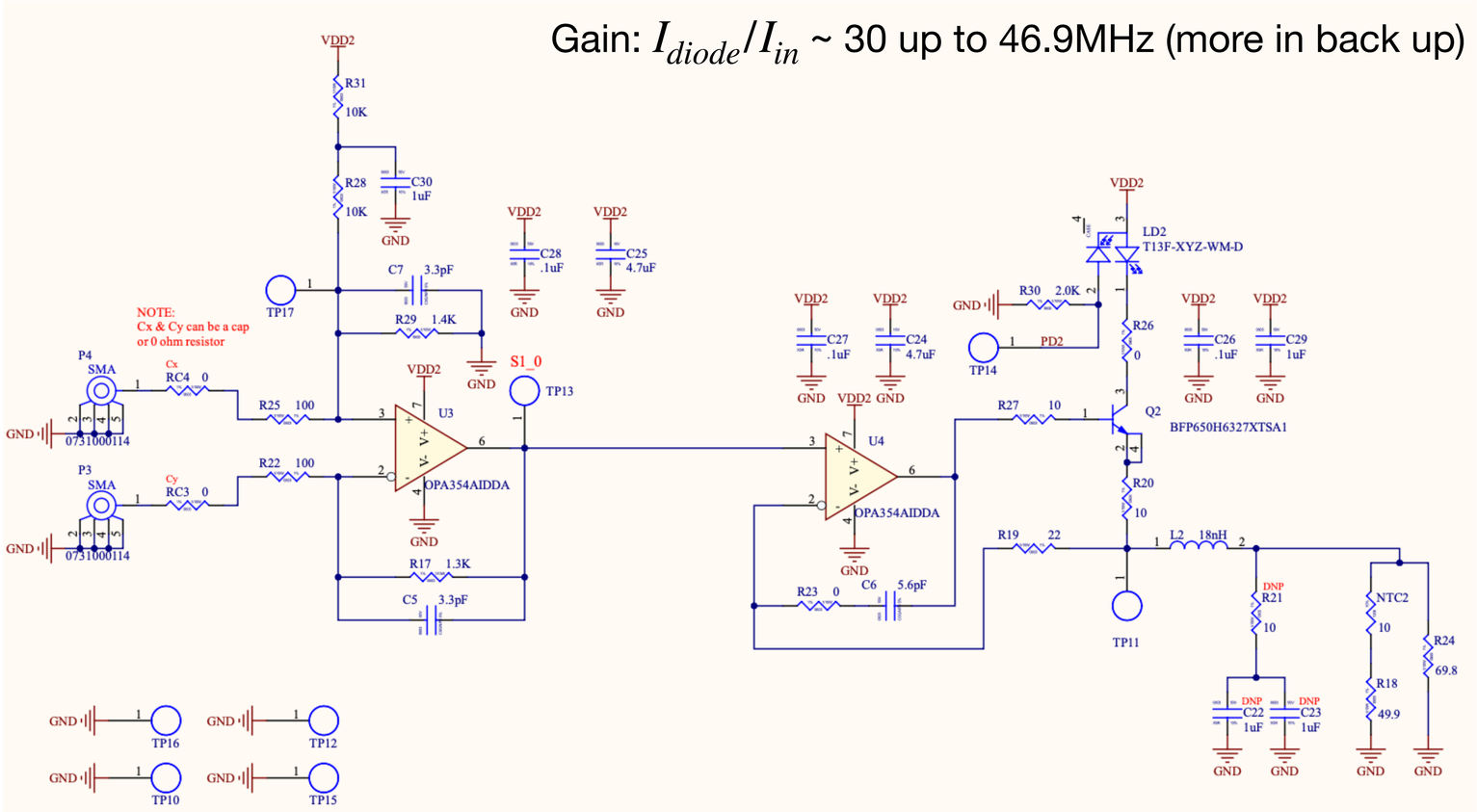
Broadcom 2x1 array board and schematic



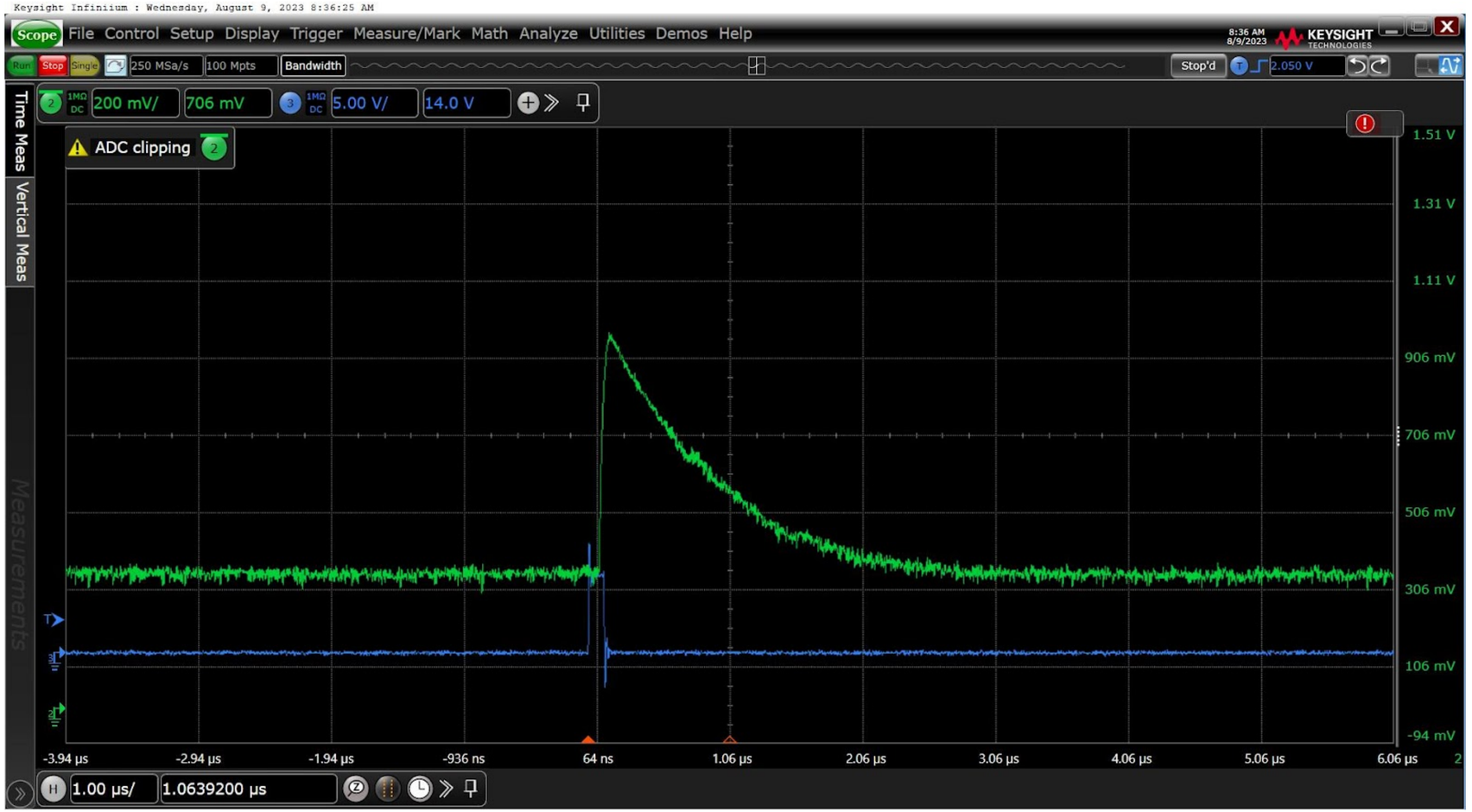
C1 - C6 changed to 22nF (solve undershoot)
R7 removed (broken pad), associated SiPM column also removed

Readout

- Readout with Alan's Argon_Simpx3 v1 channel2 (at warm)
  - Designed for VD, uses VD style laser diode and Koheron



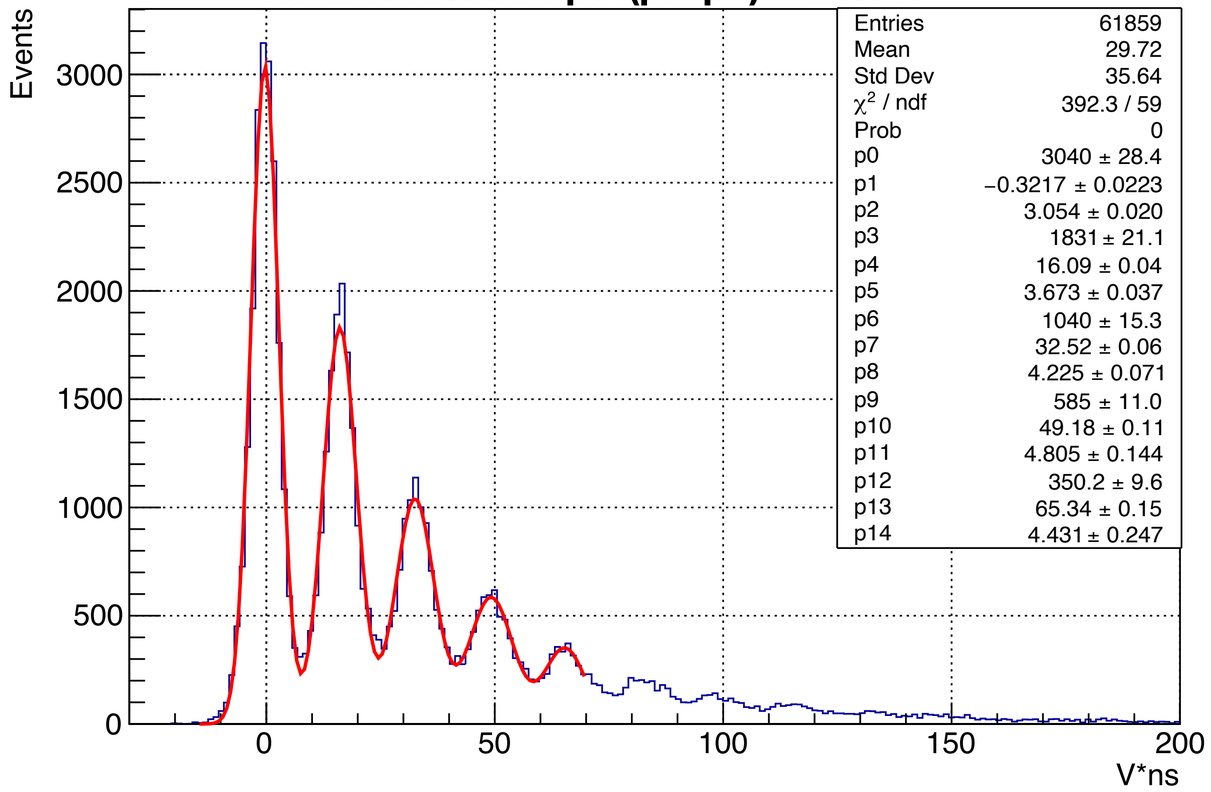
Signal Waveform



Decay time ~1.5 μs

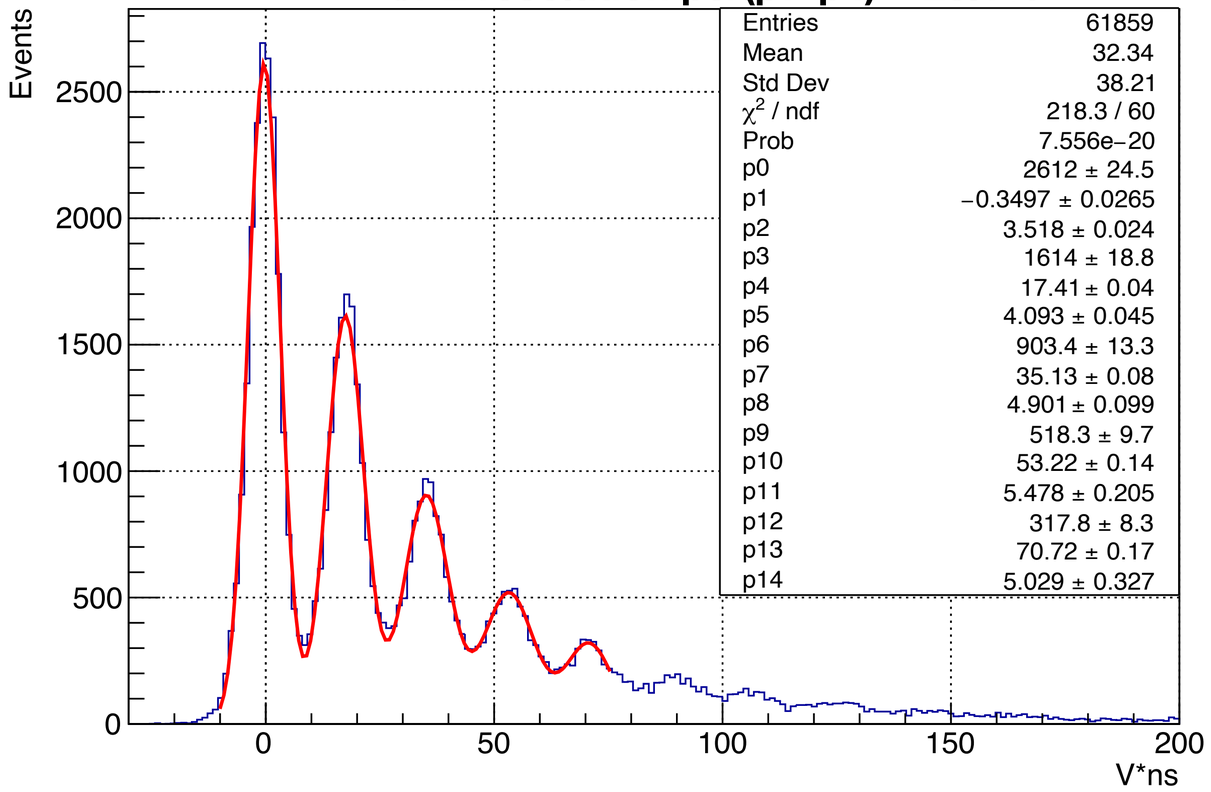
Broadcom 39V Bias from Keithley LED 4.9

SNR (p4-p1)/p2 = 5.37
SPE resolution p5/(p7-p4) = 22.3%



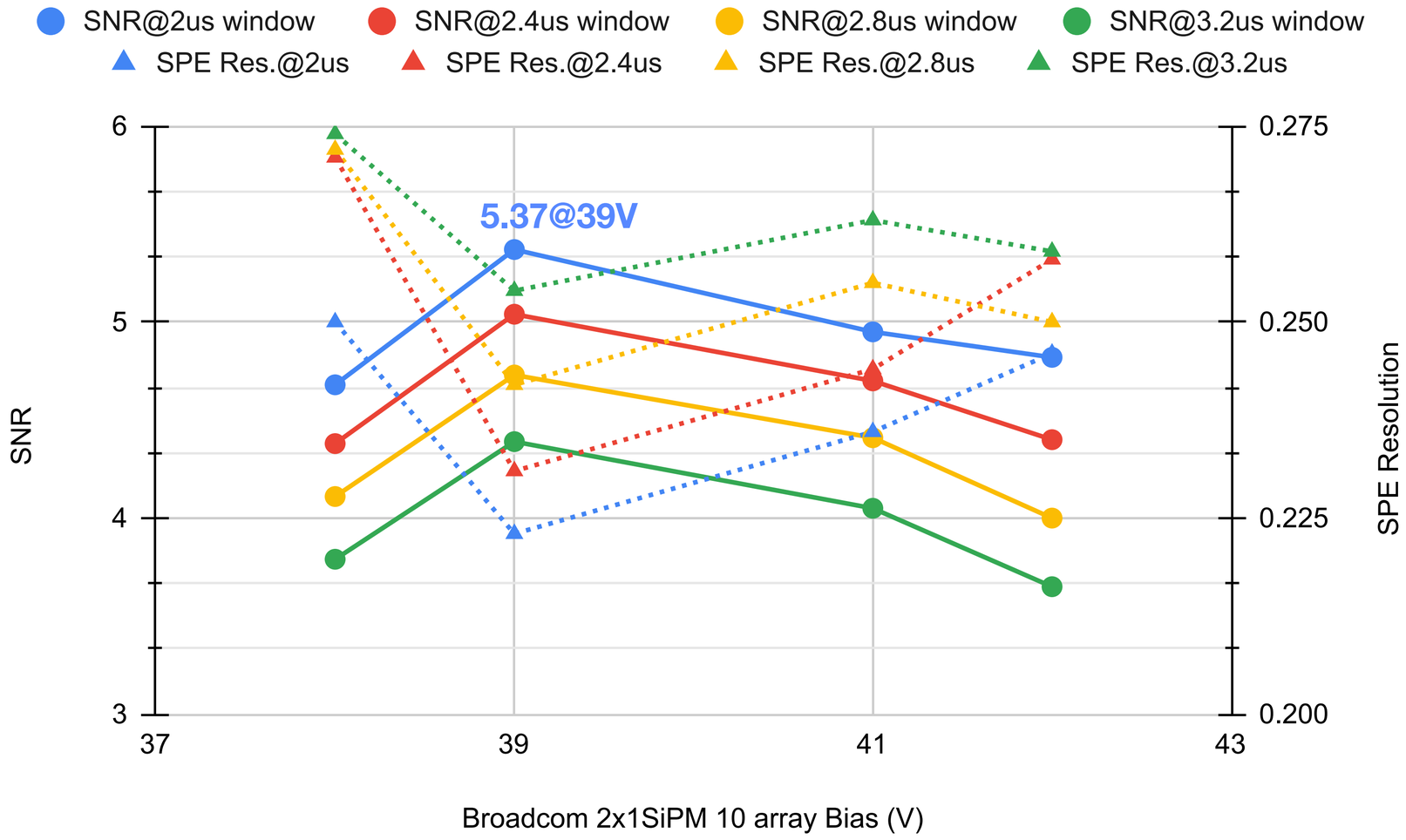
500x4ns integration time, trig offset 32x4ns

SNR (p4-p1)/p2 = 5.04
SPE resolution p5/(p7-p4) = 23.1%



600x4ns integration time, trig offset 32x4ns

Signal-noise-ratio Summary Plot

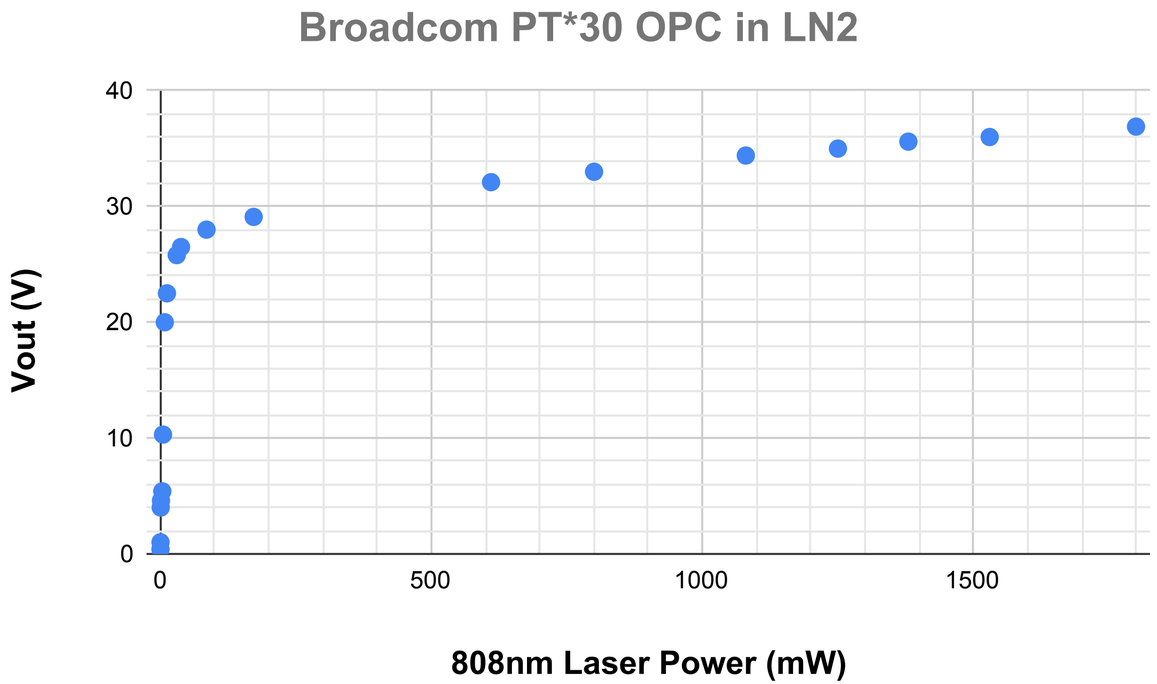


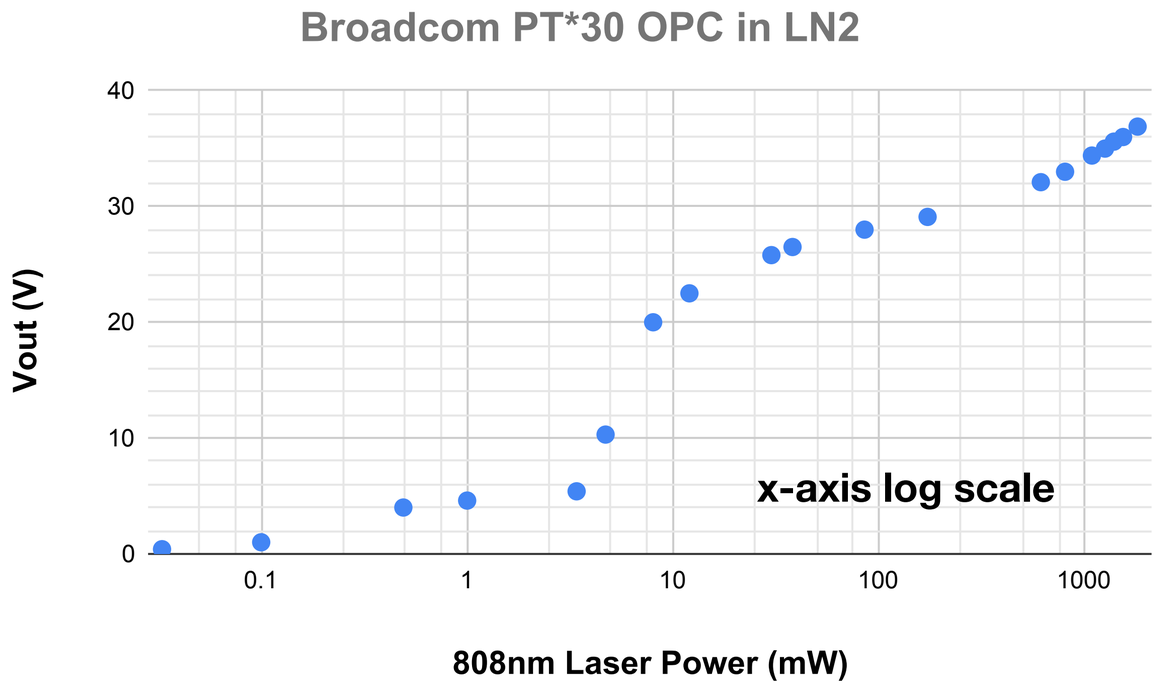
SNR Comparable to VD SiPMs

Detailed fit plots in back up

SiPM Bias from PoF

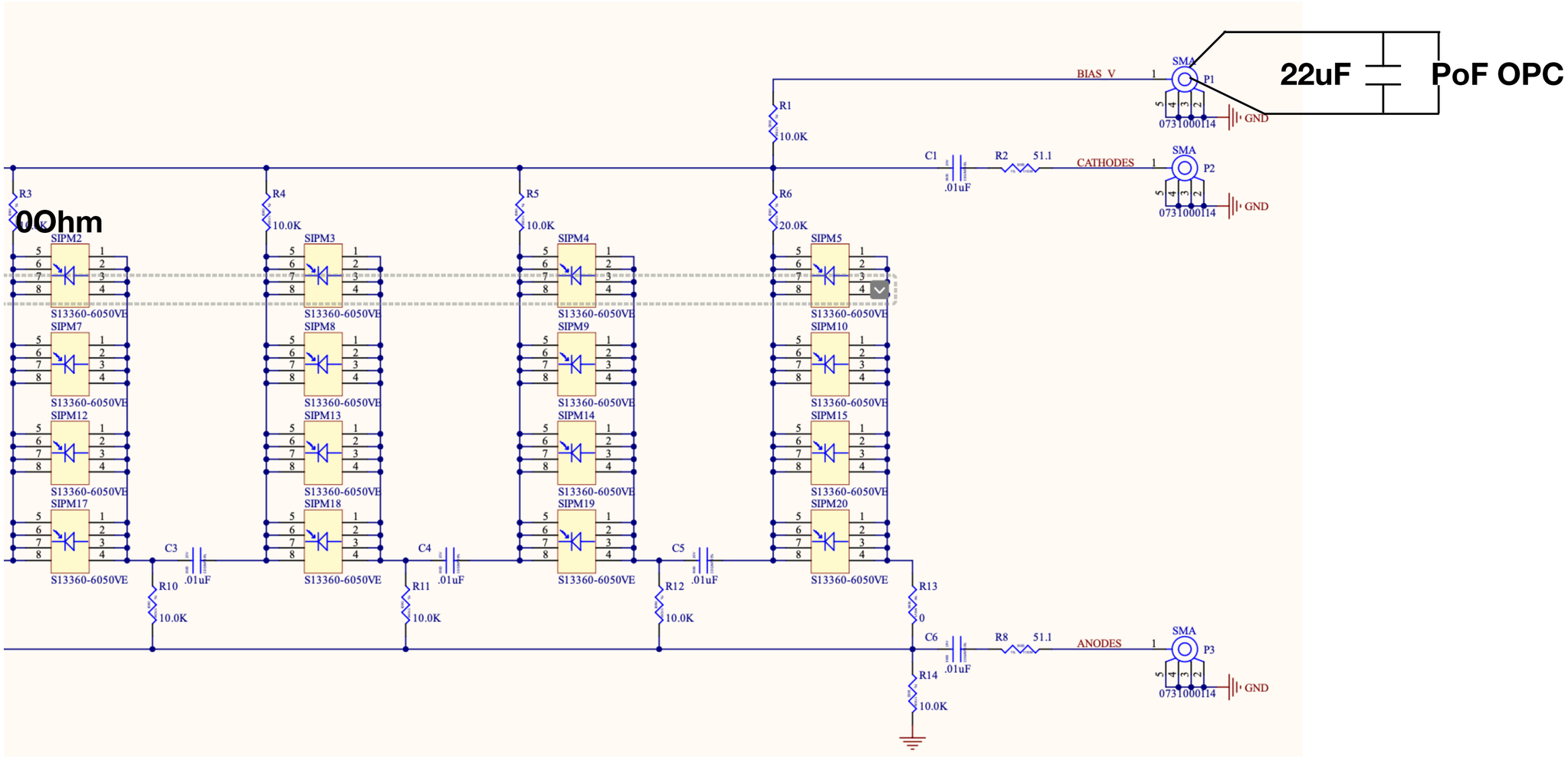
- Expect dedicated SiPM bias from PoF (instead of LDO+DC-DC step up) should improve noise
- PoF PT*30 OPC unit can provide bias up to 36.9V and tunable!



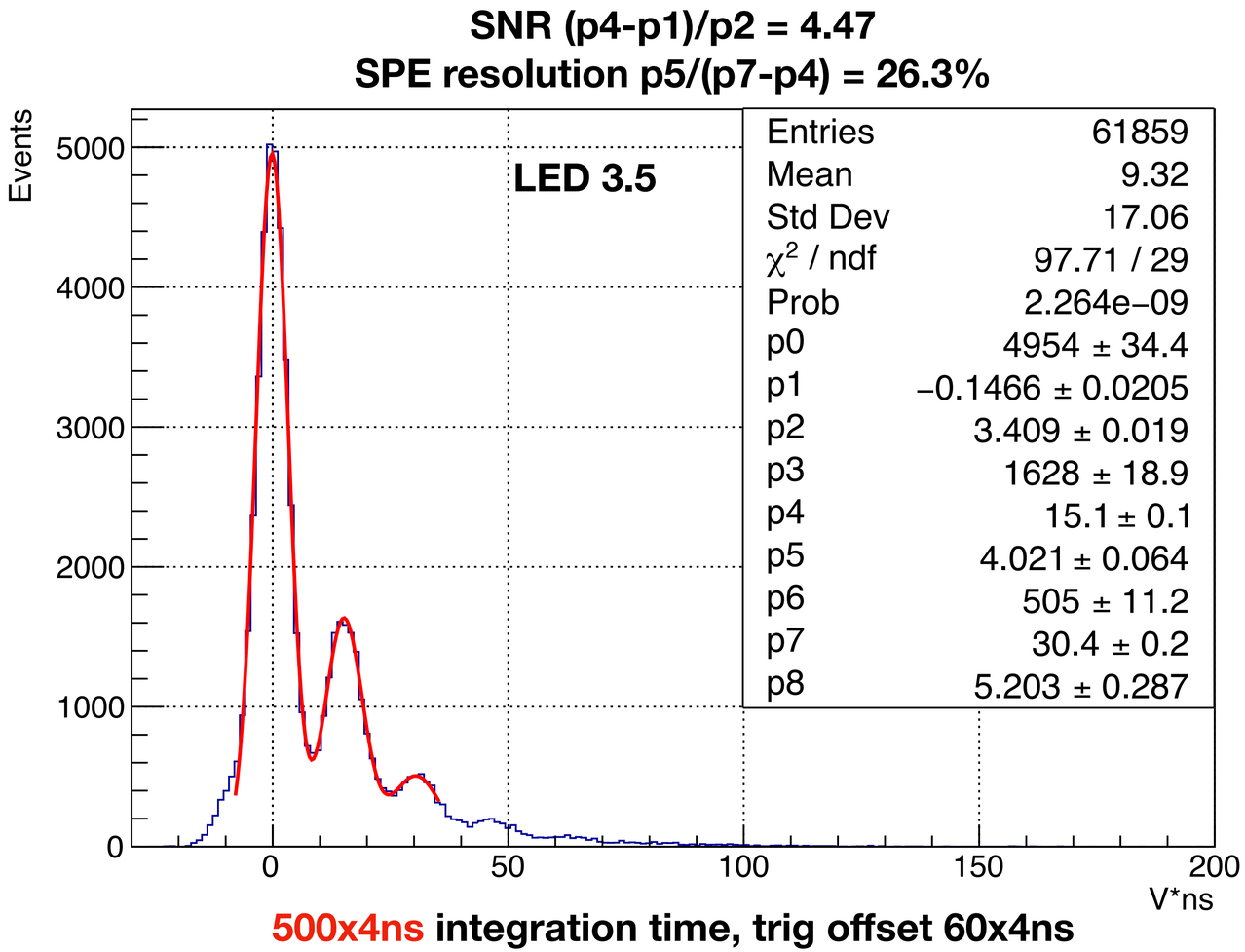


SiPM Bias from PoF

- 22uF cap across PoF to enable stable bias, otherwise bias drops when SiPM detects O(100kHz) pulse



Broadcom SiPM Biased at 36.9V from PoF



Summary

- Preliminary tests show Broadcom SiPMs performance comparable to HPK/FBK SiPMs used in VD
  - Tested Broadcom SiPMs in LN2 with one VD-style readout electronics: decay time ~ 1.5 μs
  - Observed best SNR is 5.37 @ bias 39V in LN2, with a 2us-long charge integration window

- Demonstrated PoF can provide SiPM bias
  - A new PoF PT*30 OPC unit in LN2 can output bias up to 36.9V (same end-to-end VD PoF set up)
  - Provide bias for Broadcom SiPM: observe a SNR of 4.47 @36.9V
  - Expect noise performance to improve compared to VD readout where SiPM bias is from PoF-LDO-DCDC step up chain

A Few Items to Discuss

- Need shorter SiPM decay time? (now τ ~1.5 μs, integration window up to 3.2 μs)

- OPC units need to have more dynamic range: 36-45V?
  - With as low as possible input laser power
    - Reference: VD per XA has 160SiPMs, DCDC: 30mA@6V, i.e. 180mW (~360mW laser power)
  - Need to demonstrate one OPC unit can reliably provide bias to more SiPMs (i.e., multiple APEX PD modules)

- Although adding 22uF cap across OPC makes bias more stable, still observe some minor shifts when use very large LED pulses
  - In reality maybe less a concern as we probably don't have high frequency large signals
  - 22uF cryogenic certified not available: several smaller cryo-certified caps in parallel

Back up

Broadcom SiPMs

AFBR-S4N66P024M

2×1 NUV-MT Silicon Photomultiplier Array

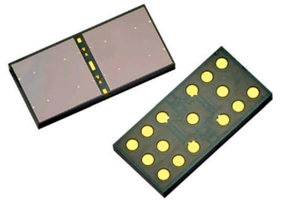


Figure 6: PDE vs. Wavelength at 12V OV

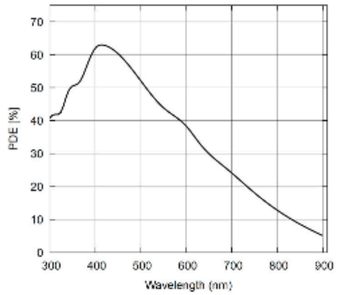


Figure 7: PDE vs. OV at 420 nm

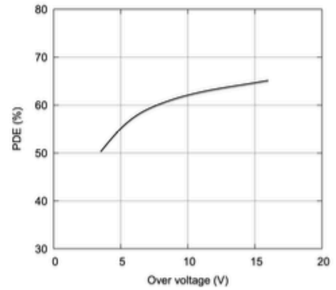


Figure 8: Reverse IV Curve in Dark Conditions

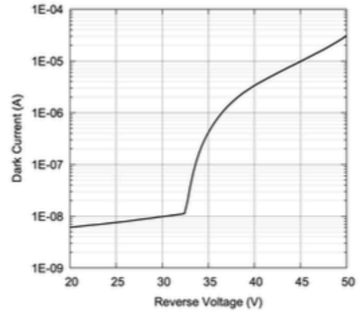


Figure 9: Dark Count Rate vs. Overvoltage

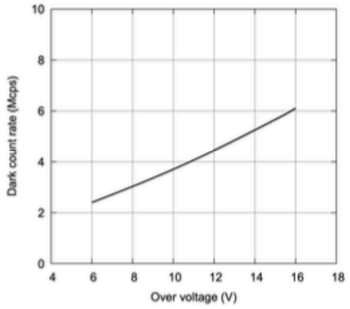


Figure 10: Gain vs. Overvoltage

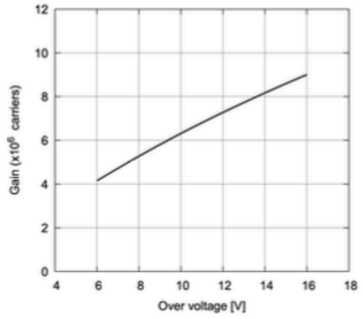


Figure 11: Total Correlated Noise vs. Overvoltage

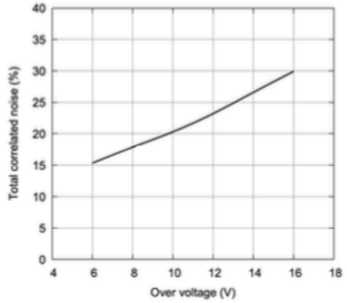
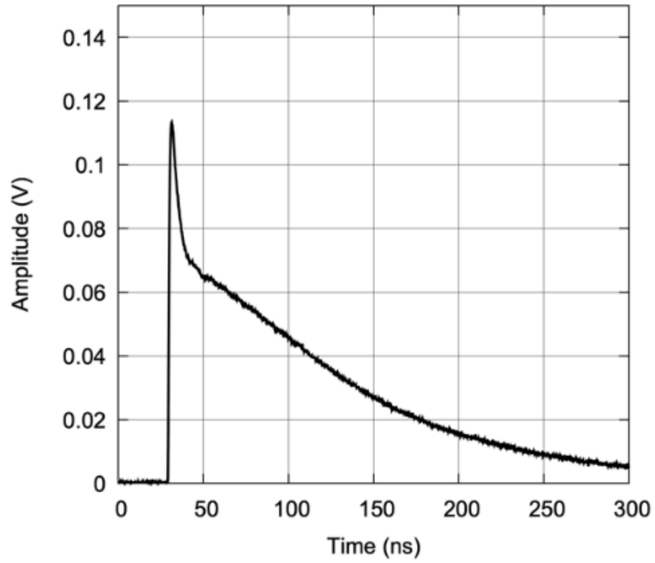
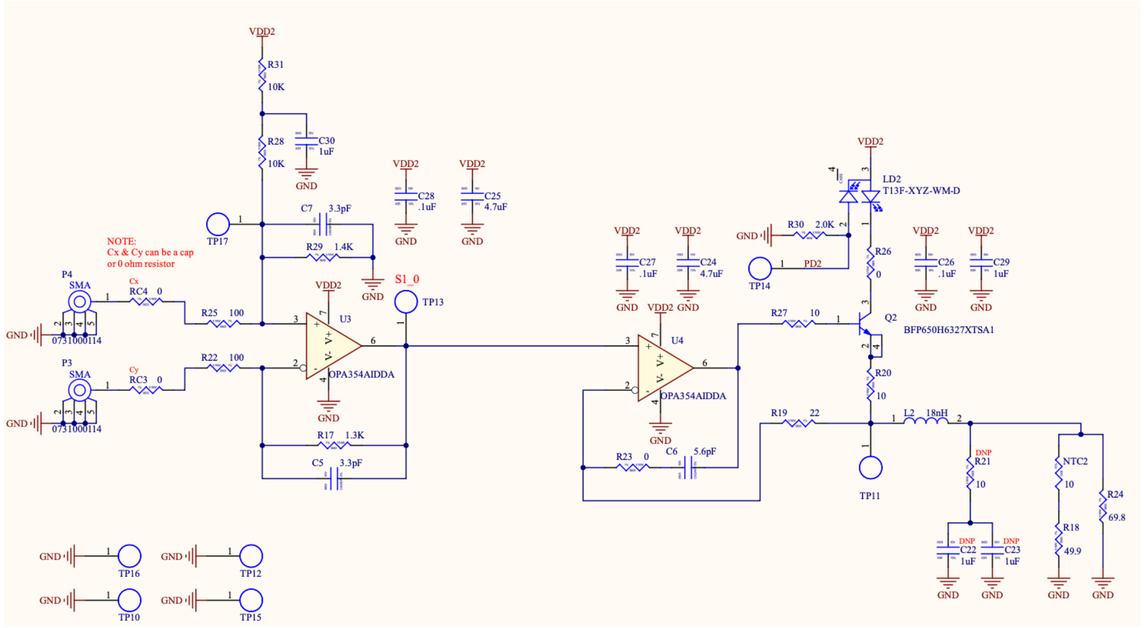


Figure 12: Typical Pulse Waveform in Response of a Picosecond Laser-Pulse on a Load Impedance of 25Ω and Applied Bias of 12V above Breakdown

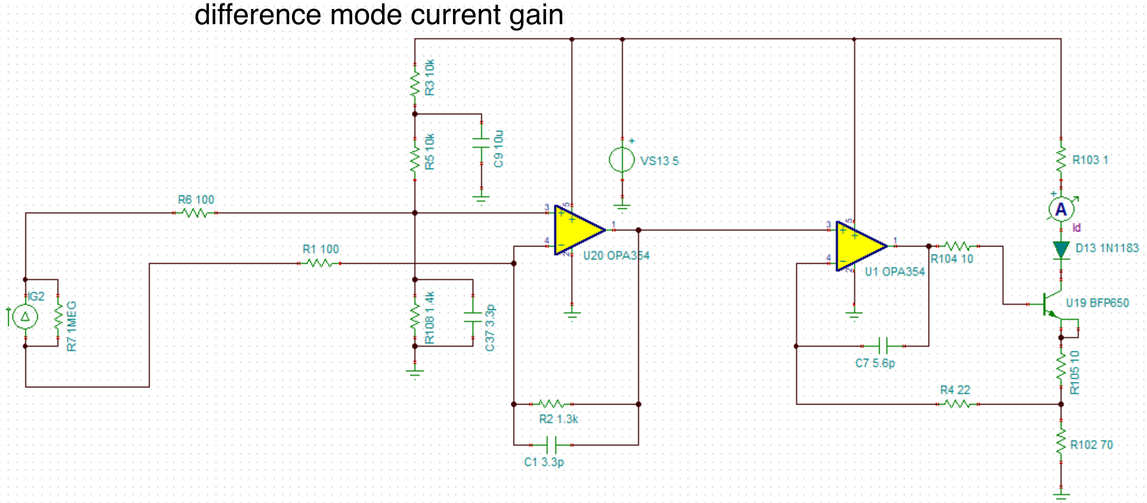


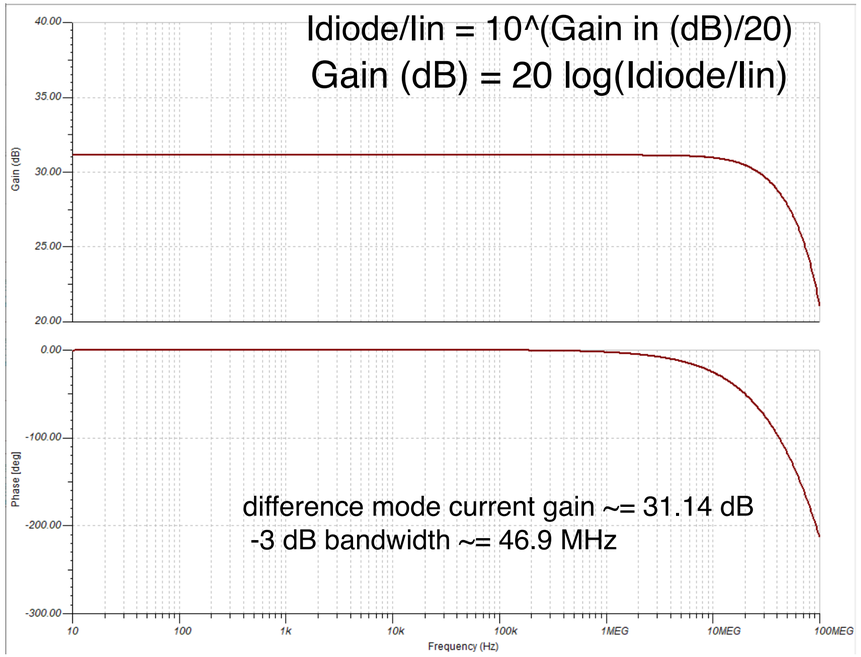
Readout Spice Simulation from Alan

- Readout with Argon_Simpx3 v1 channel2 (at warm)
  - With VD style laser diode and Koheron



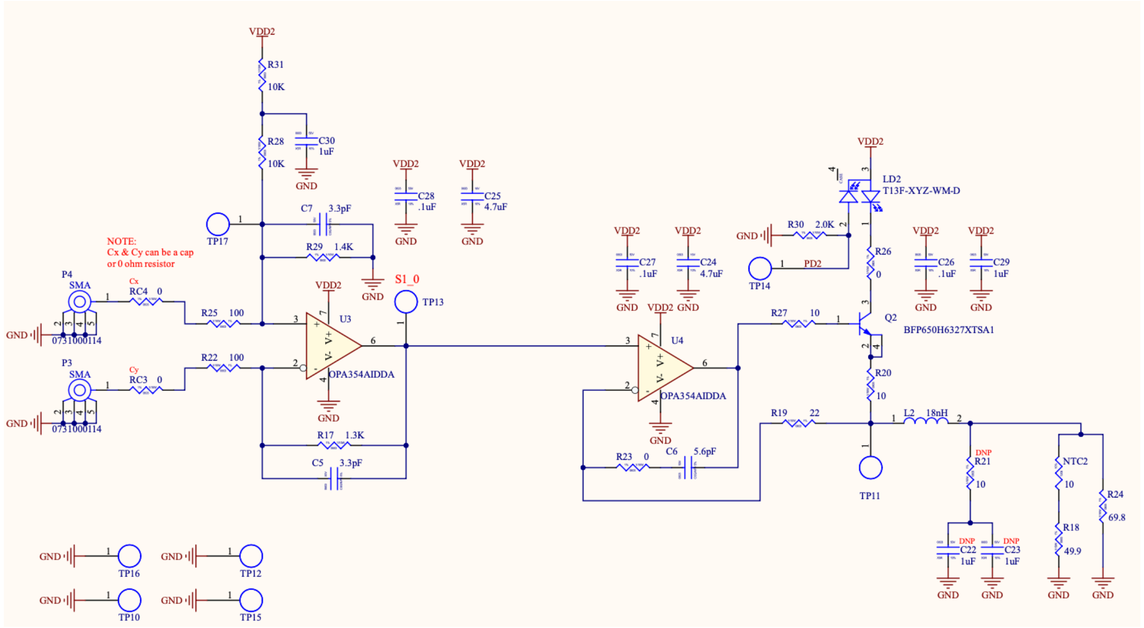
Diode current response to difference current mode excitation:
difference mode current gain



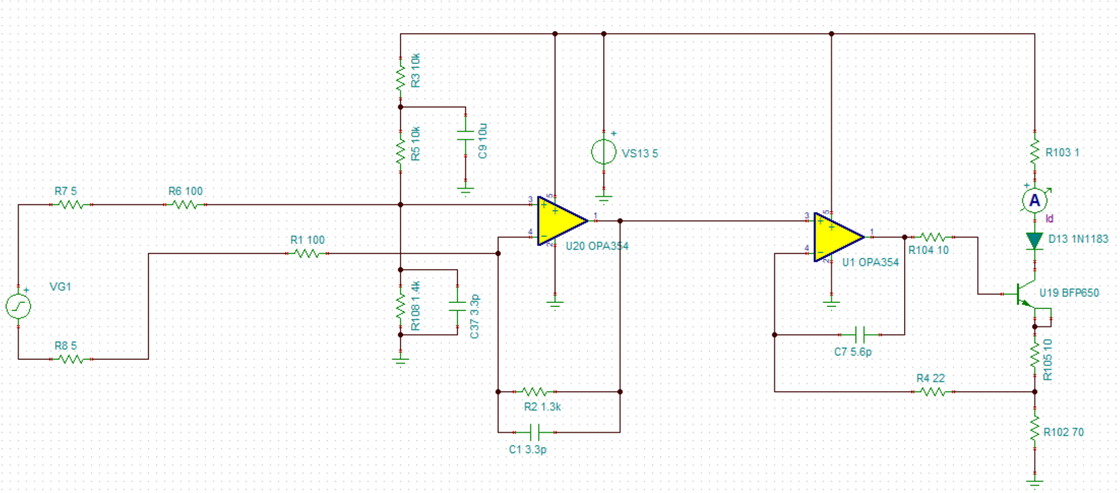


Readout Spice Simulation from Alan

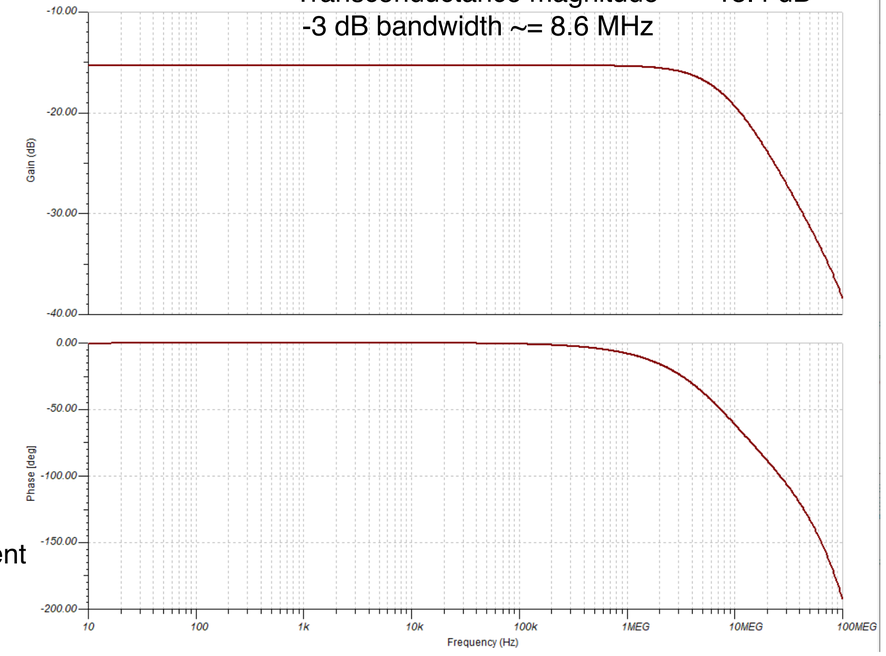
- Readout with Argon_Simpx3 v1 channel2 (at warm)
  - With VD style laser diode and Koheron



Diode current response to difference voltage mode excitation: difference mode transconductance



Transconductance magnitude ~= -15.4 dB
-3 dB bandwidth ~= 8.6 MHz

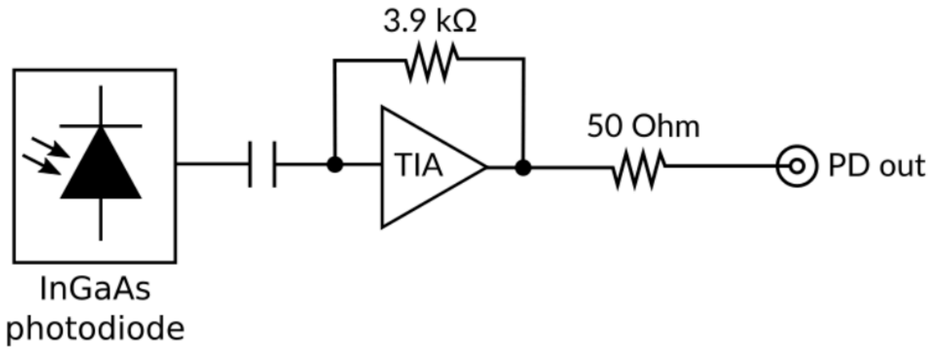


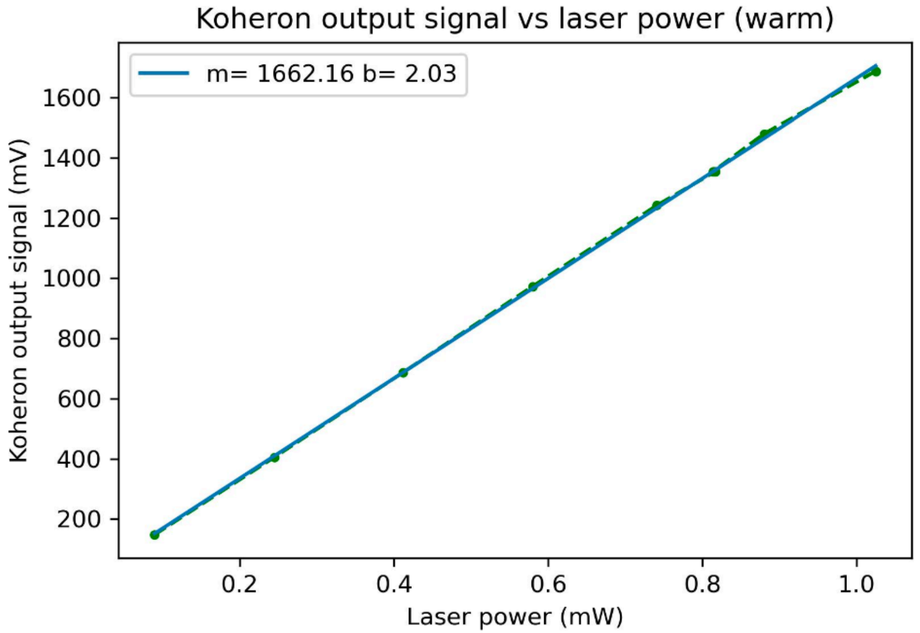
20mV input —> 3.4mA diode output current

Signal over fiber

Koheron PD100 low noise photodiode

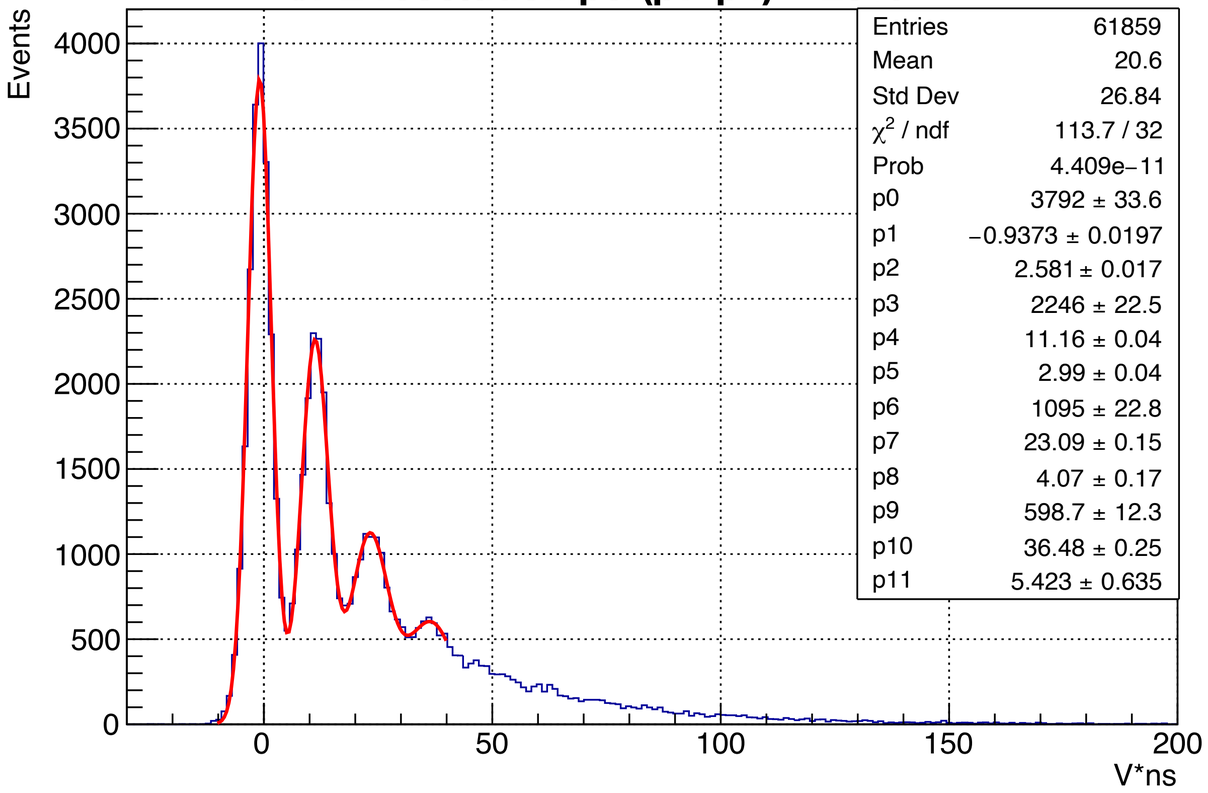
- single channel commercial solution - found early 2021
- Indium gallium arsenide (InGaAs) photodiode
- DC-coupled
- 0.9 A/W - 3.9 kV/A amplification
- 600 µW maximum input at 100 MHz
- ± 6V bias, ~40mA





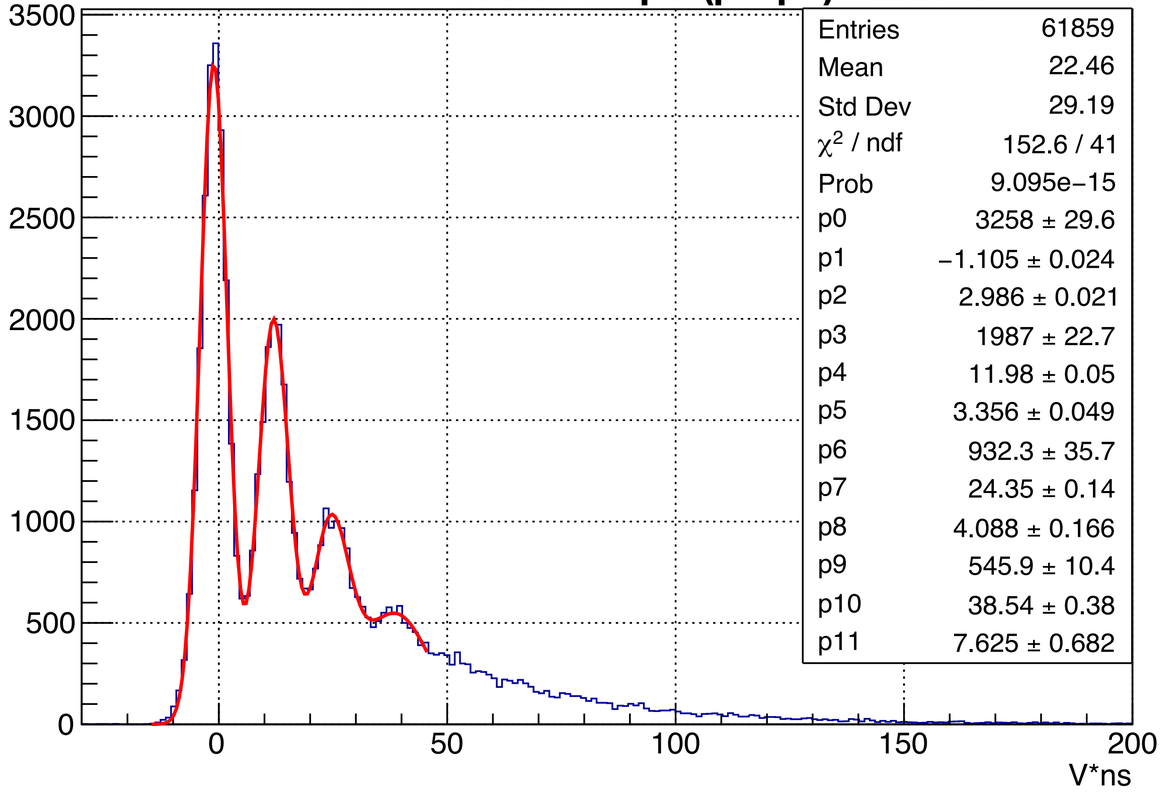
Broadcom 38V Bias from Keithley LED 4.9

SNR (p4-p1)/p2 = 4.68
SPE resolution p5/(p7-p4) = 25%



500x4ns integration time, trig offset 120x4ns

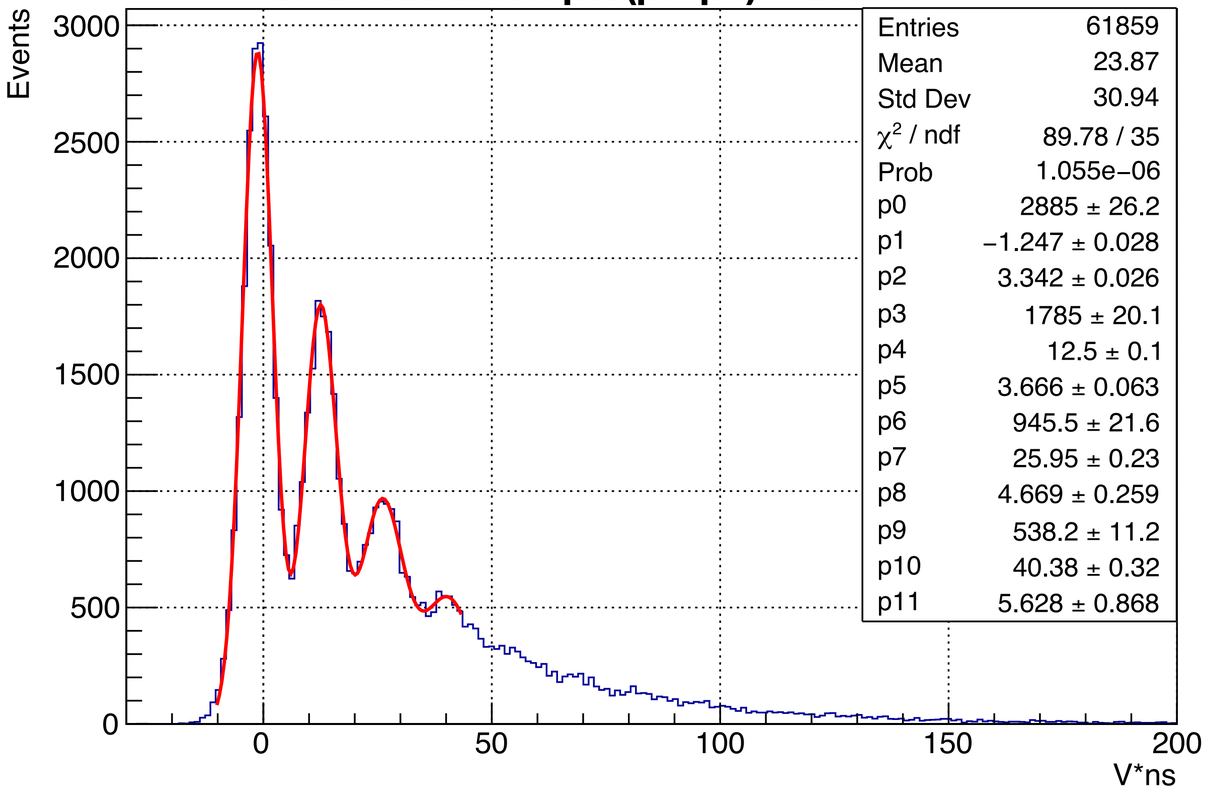
SNR (p4-p1)/p2 = 4.38
SPE resolution p5/(p7-p4) =27.1%



600x4ns integration time, trig offset 120x4ns

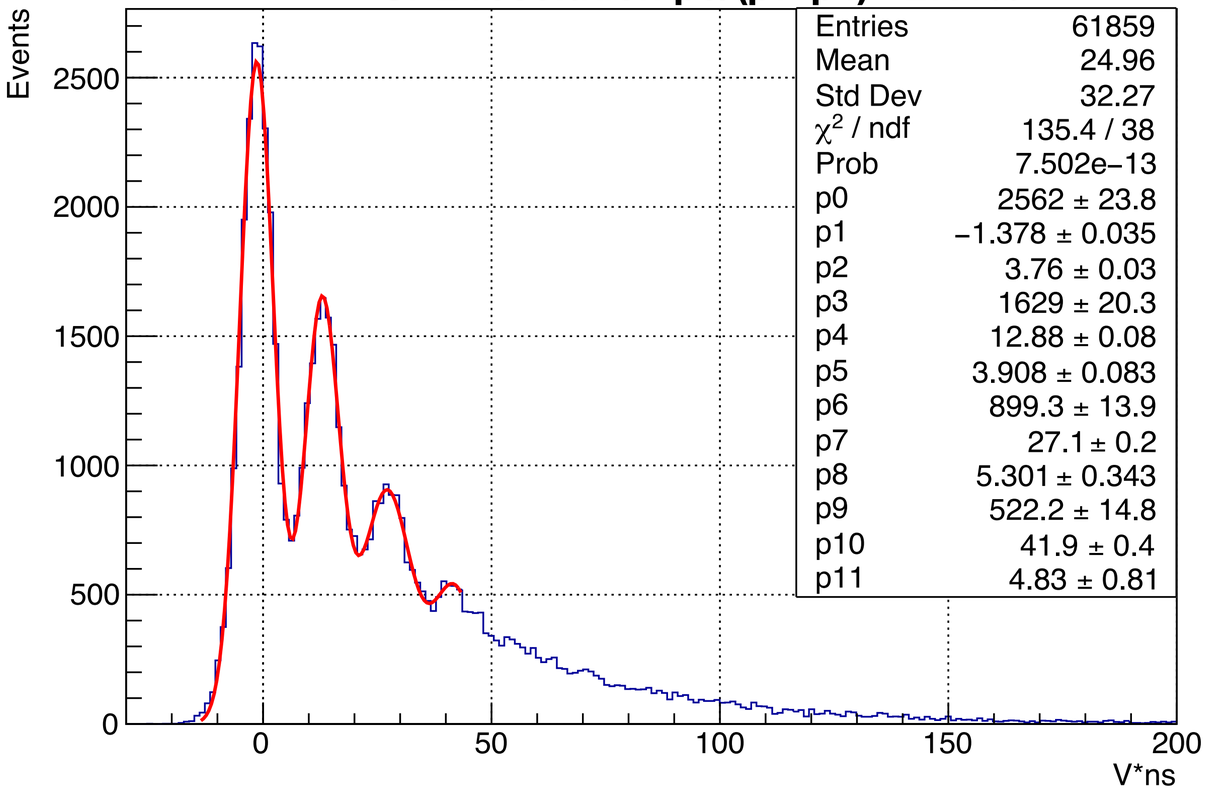
Broadcom 38V Bias from Keithley LED 4.9

SNR (p4-p1)/p2 = 4.11
SPE resolution p5/(p7-p4) = 27.2%



700x4ns integration time, trig offset 120x4ns

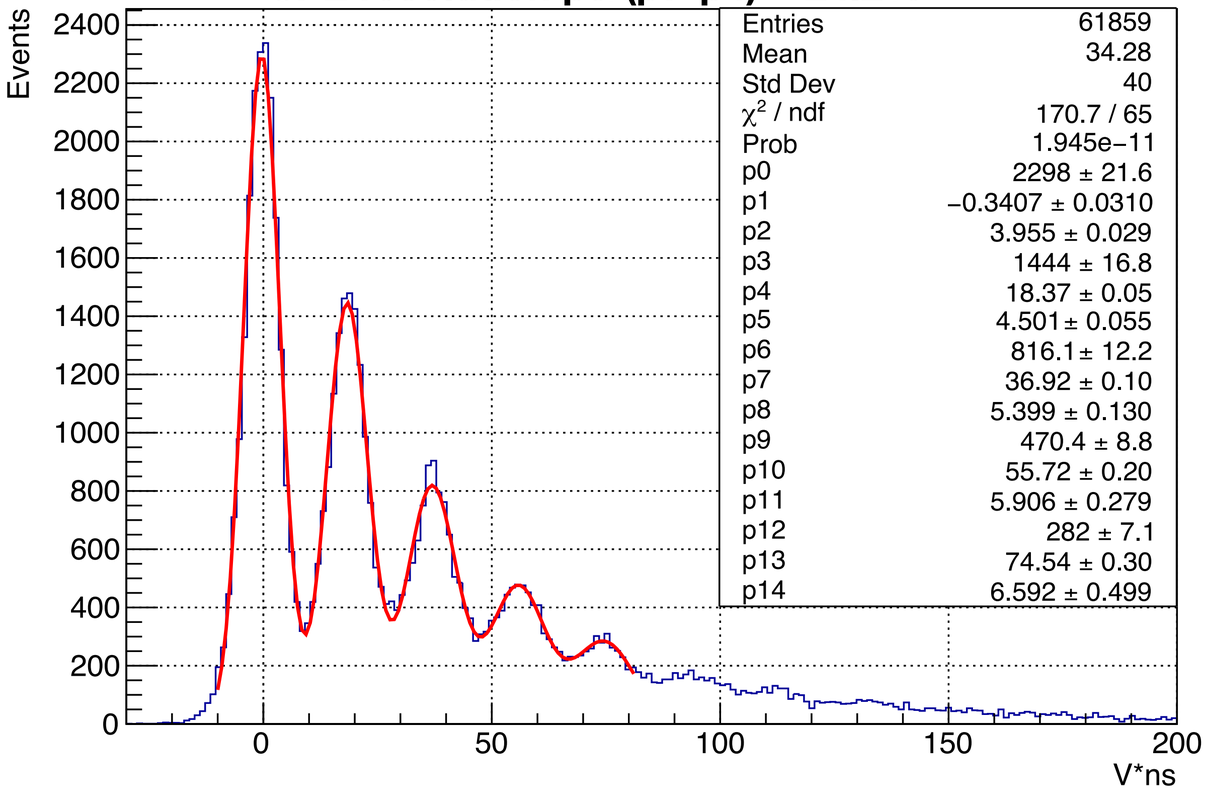
SNR (p4-p1)/p2 = 3.79
SPE resolution p5/(p7-p4) =27.4%



800x4ns integration time, trig offset 120x4ns

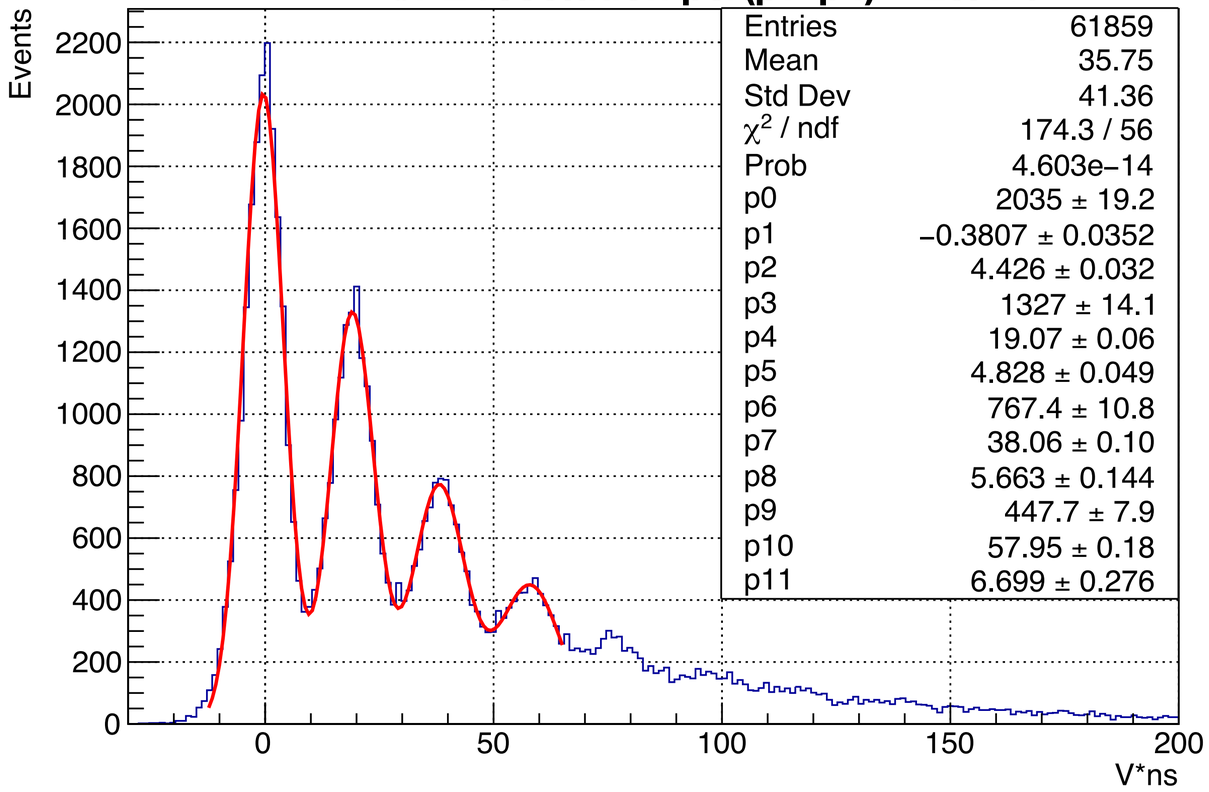
Broadcom 39V Bias from Keithley LED 4.9

SNR (p4-p1)/p2 = 4.73
SPE resolution p5/(p7-p4) = 24.2%



700x4ns integration time, trig offset 32x4ns

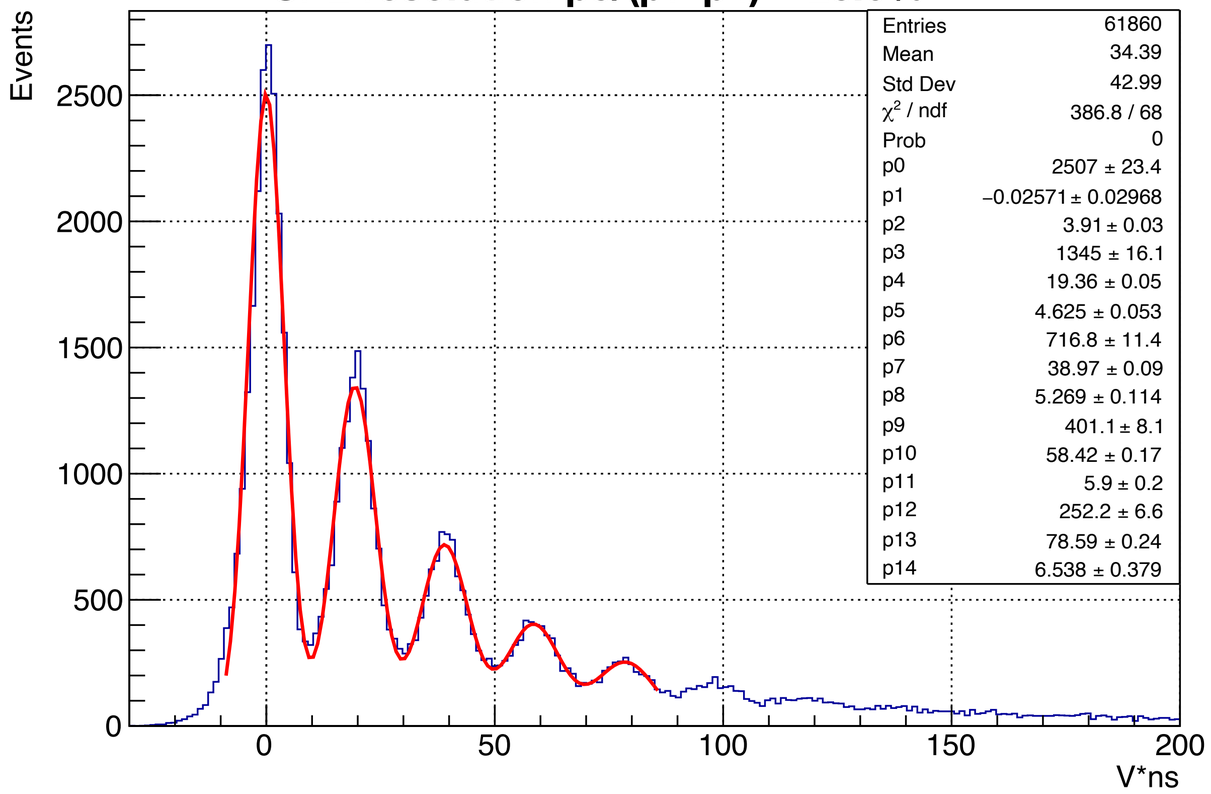
SNR (p4-p1)/p2 = 4.39
SPE resolution p5/(p7-p4) = 25.4%



800x4ns integration time, trig offset 32x4ns

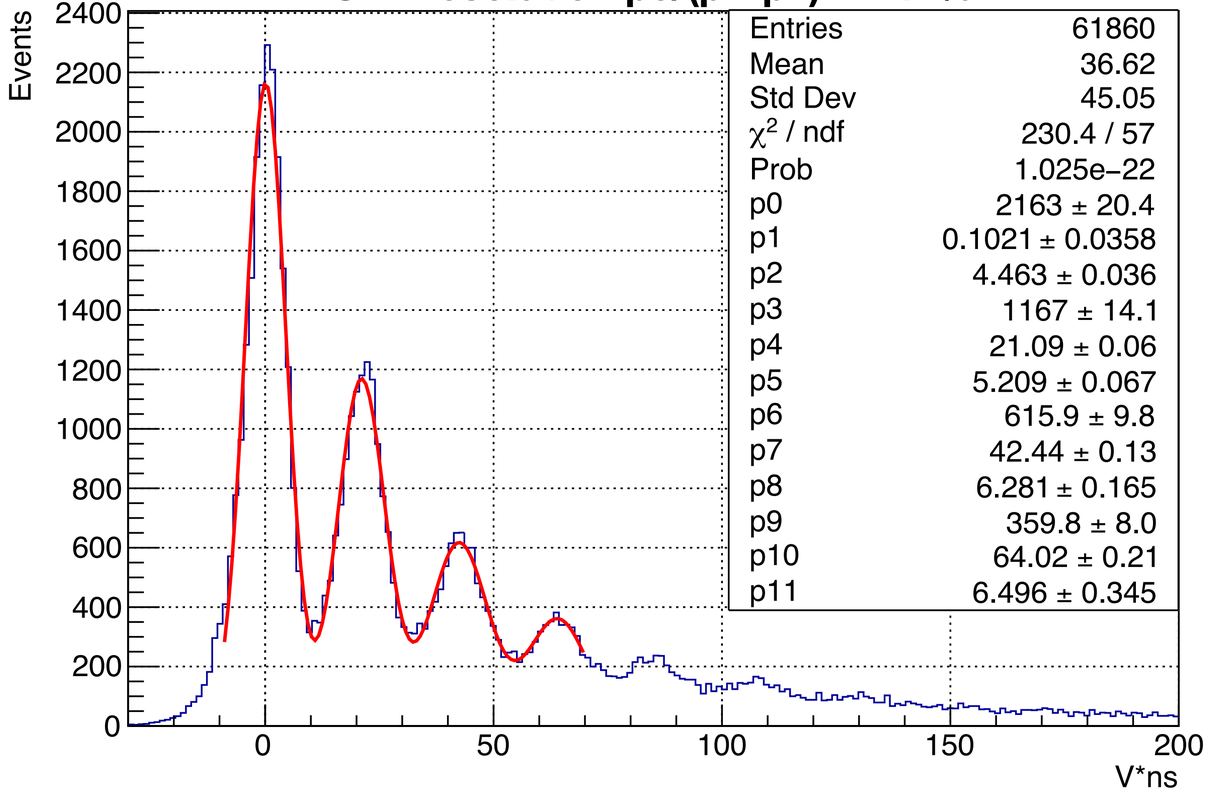
Broadcom 41V Bias from Keithley LED 4.9

SNR (p4-p1)/p2 = 4.95
SPE resolution p5/(p7-p4) = 23.6%



500x4ns integration time, trig offset -17x4ns

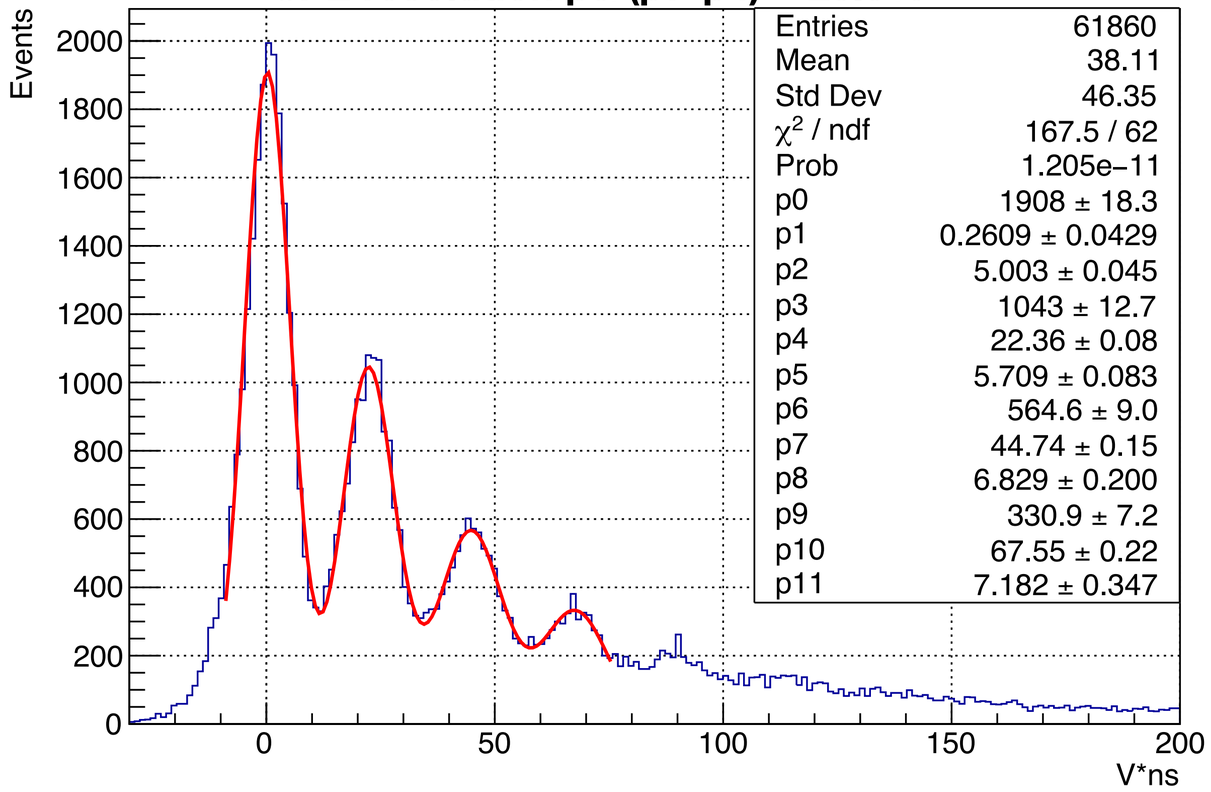
SNR (p4-p1)/p2 = 4.7
SPE resolution p5/(p7-p4) =24.4%



600x4ns integration time, trig offset -17x4ns

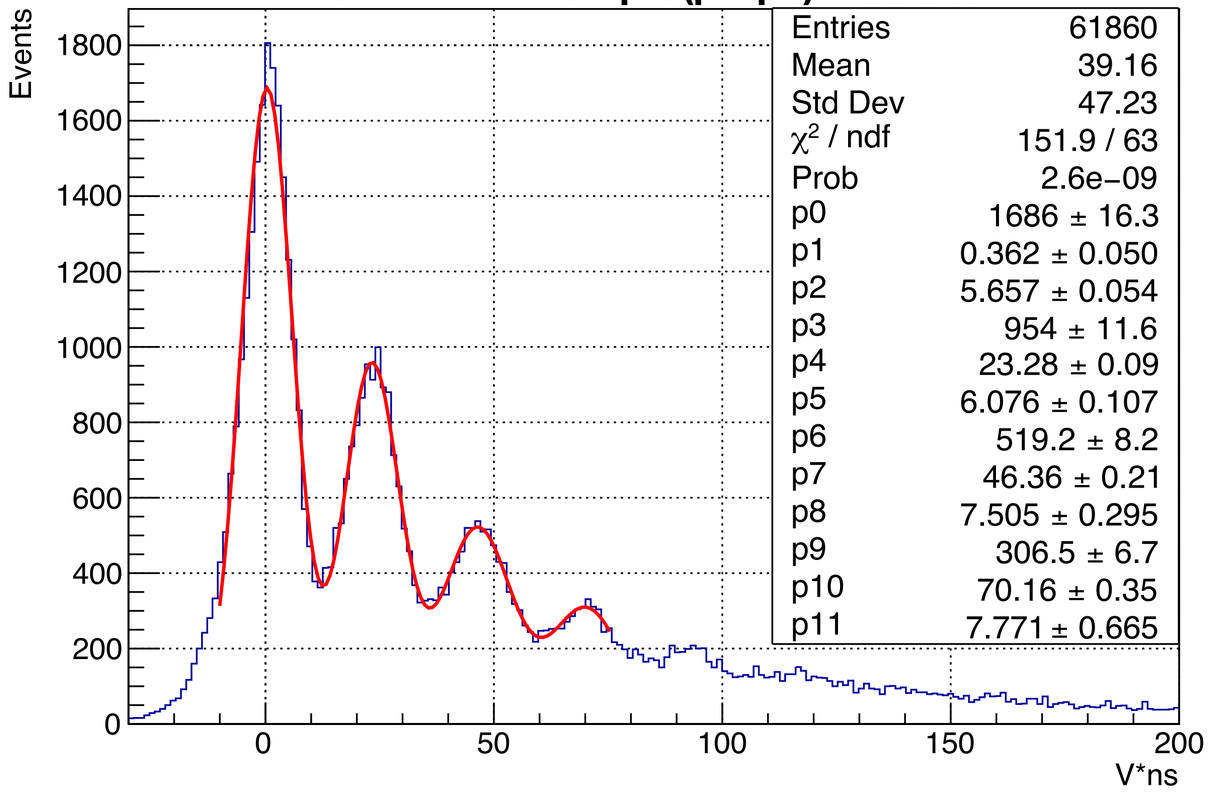
Broadcom 41V Bias from Keithley LED 4.9

SNR (p4-p1)/p2 = 4.41
SPE resolution p5/(p7-p4) = 25.5%



700x4ns integration time, trig offset -17x4ns

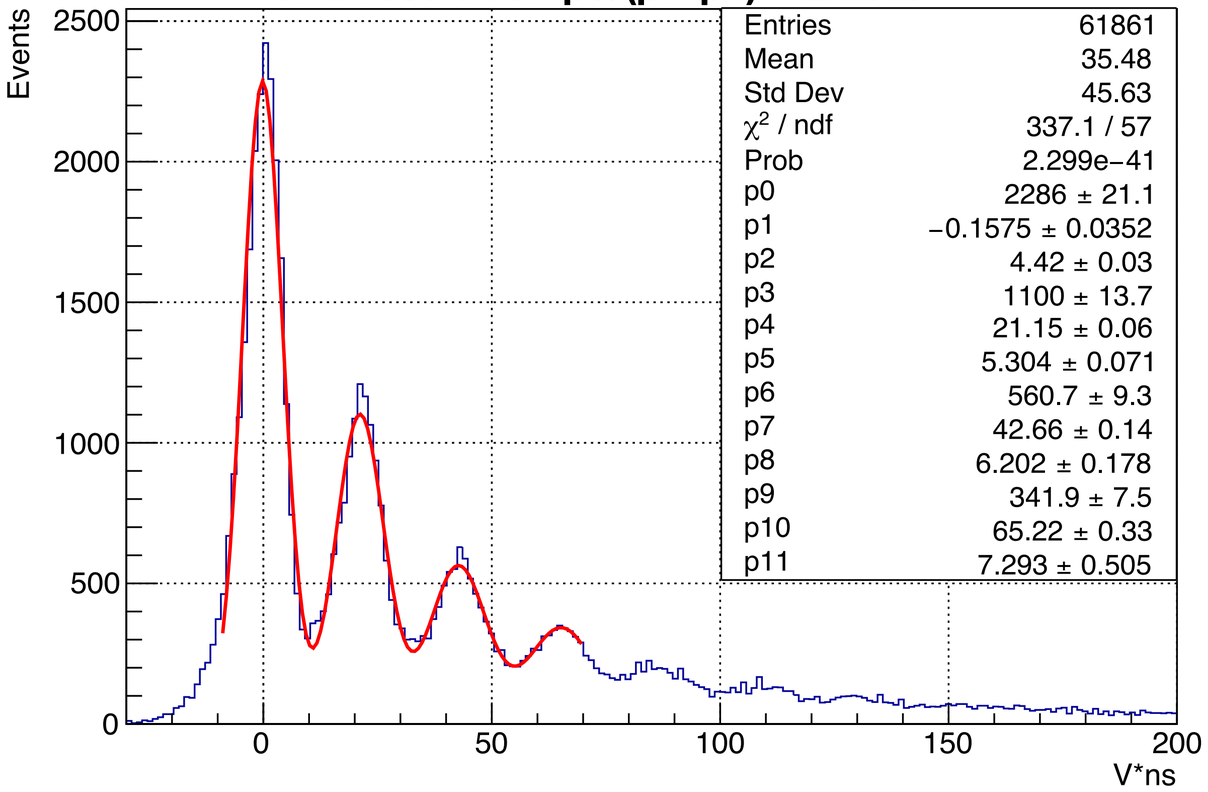
SNR (p4-p1)/p2 = 4.05
SPE resolution p5/(p7-p4) = 26.3%



800x4ns integration time, trig offset 32x4ns

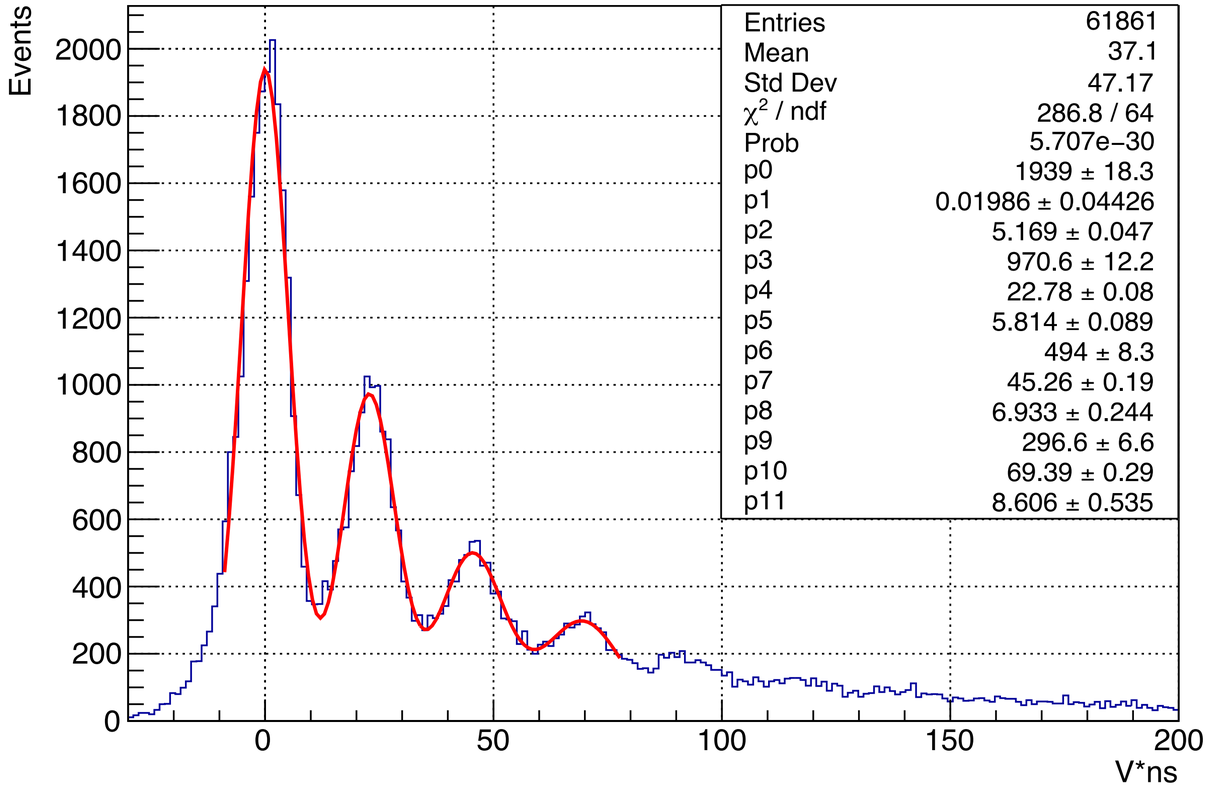
Broadcom 42V Bias from Keithley LED 4.9

SNR (p4-p1)/p2 = 4.82
SPE resolution p5/(p7-p4) = 24.6%



500x4ns integration time, trig offset 39x4ns

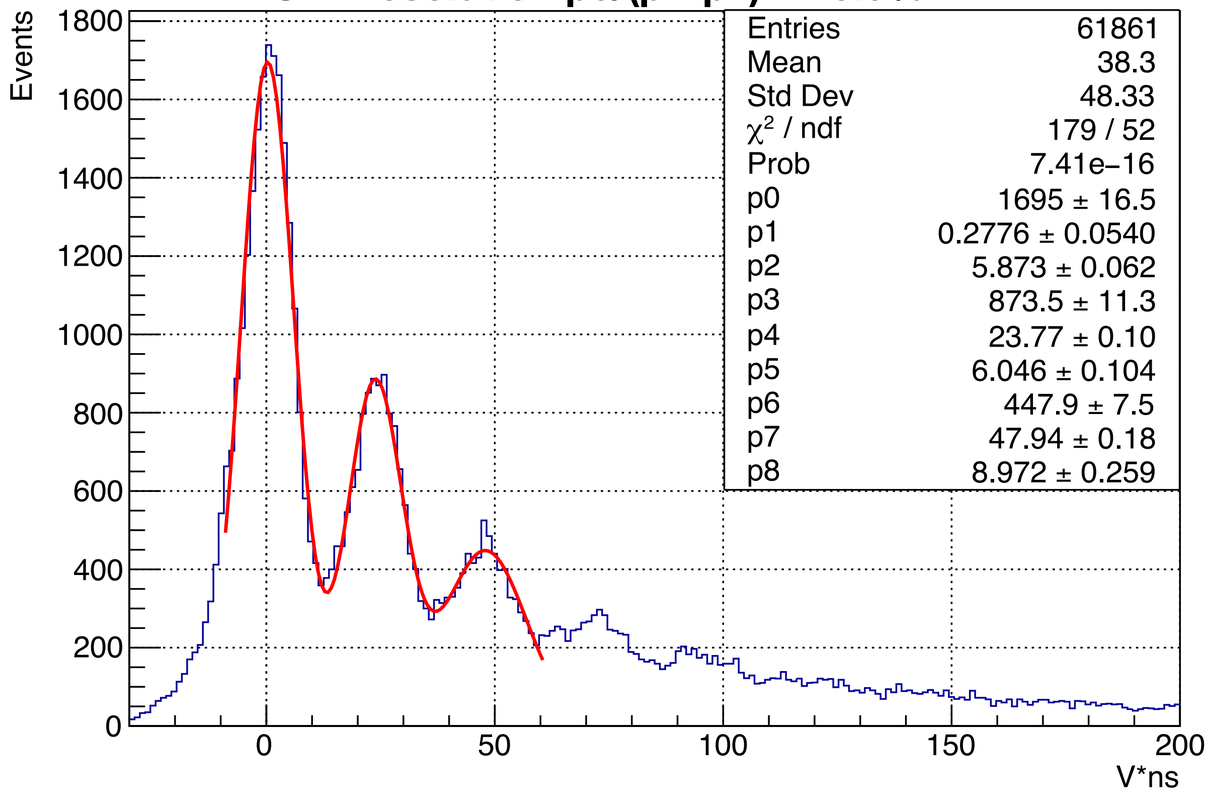
SNR p4/p2 = 4.4
SPE resolution p5/(p7-p4) =25.8%



600x4ns integration time, trig offset 39x4ns

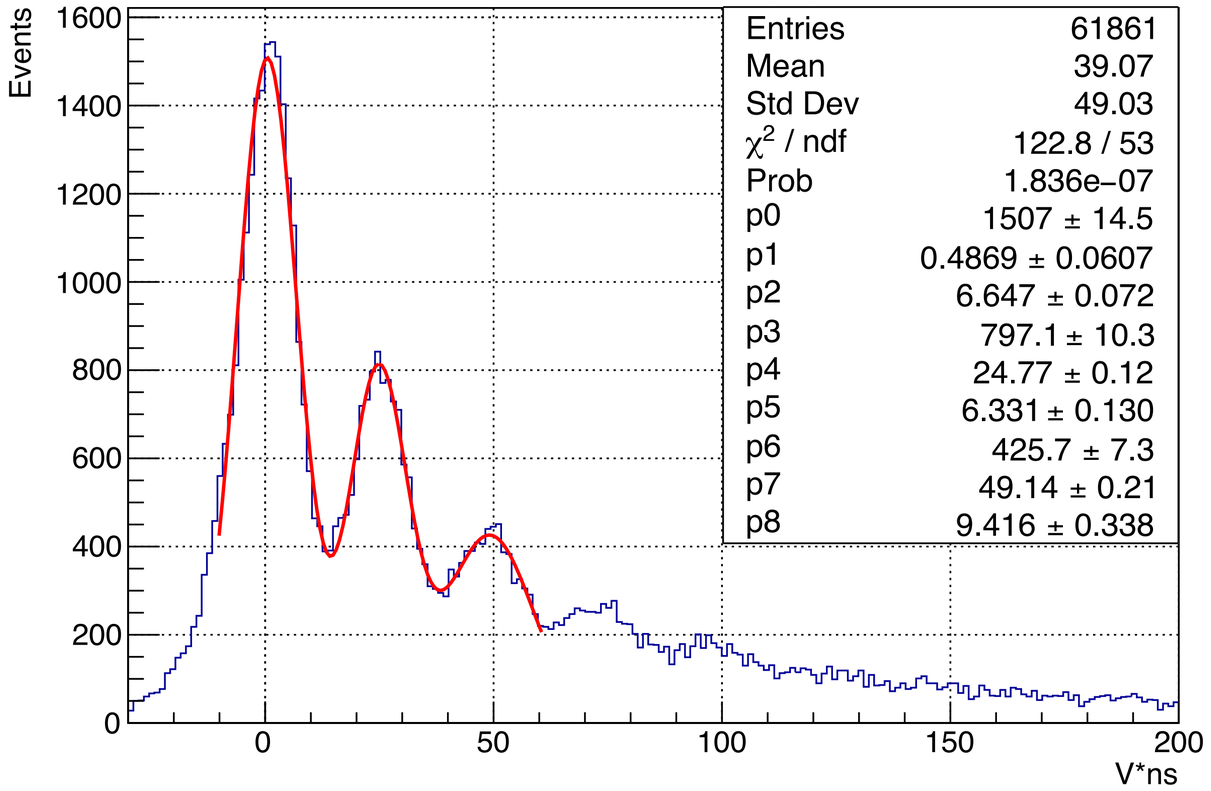
Broadcom 42V Bias from Keithley LED 4.9

SNR (p4-p1)/p2 = 4
SPE resolution p5/(p7-p4) = 25.0%



700x4ns integration time, trig offset 39x4ns

SNR (p4-p1)/p2 = 3.65
SPE resolution p5/(p7-p4) =25.9%

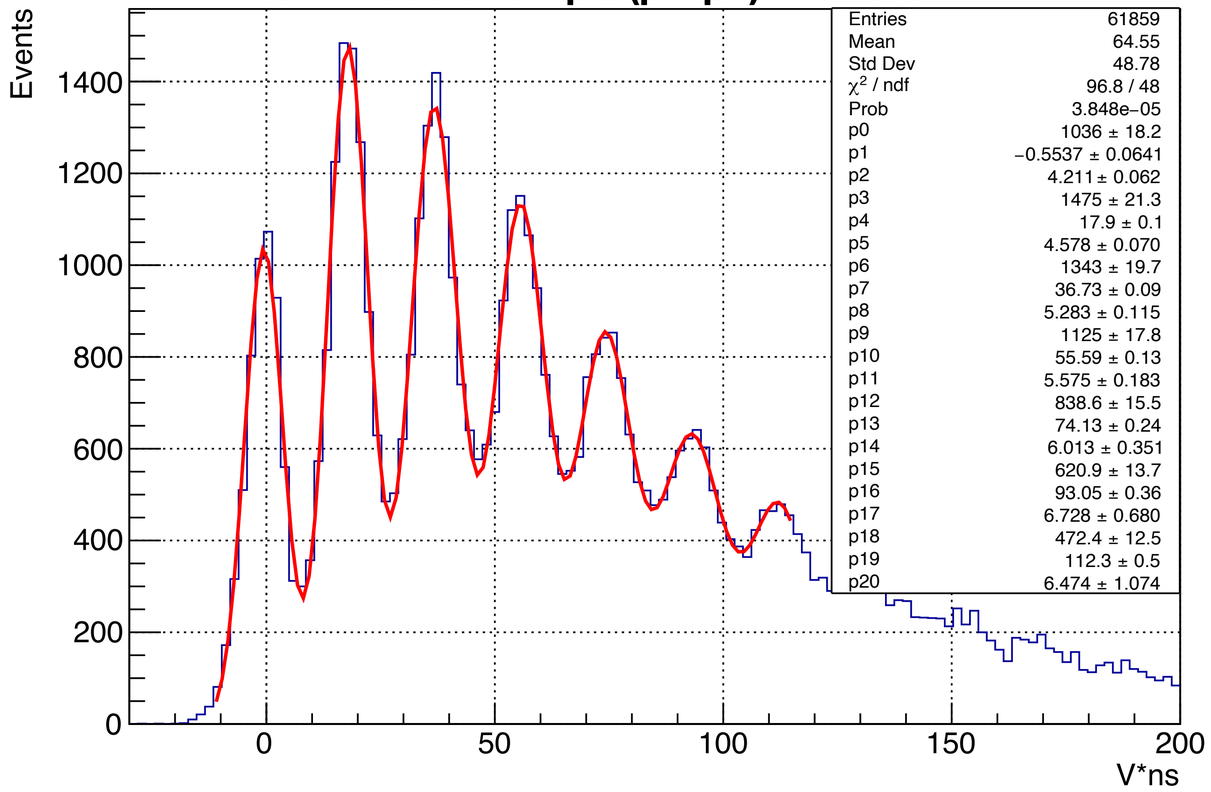


800x4ns integration time, trig offset 39x4ns

Broadcom 40V Bias from Keithley LED 4.9

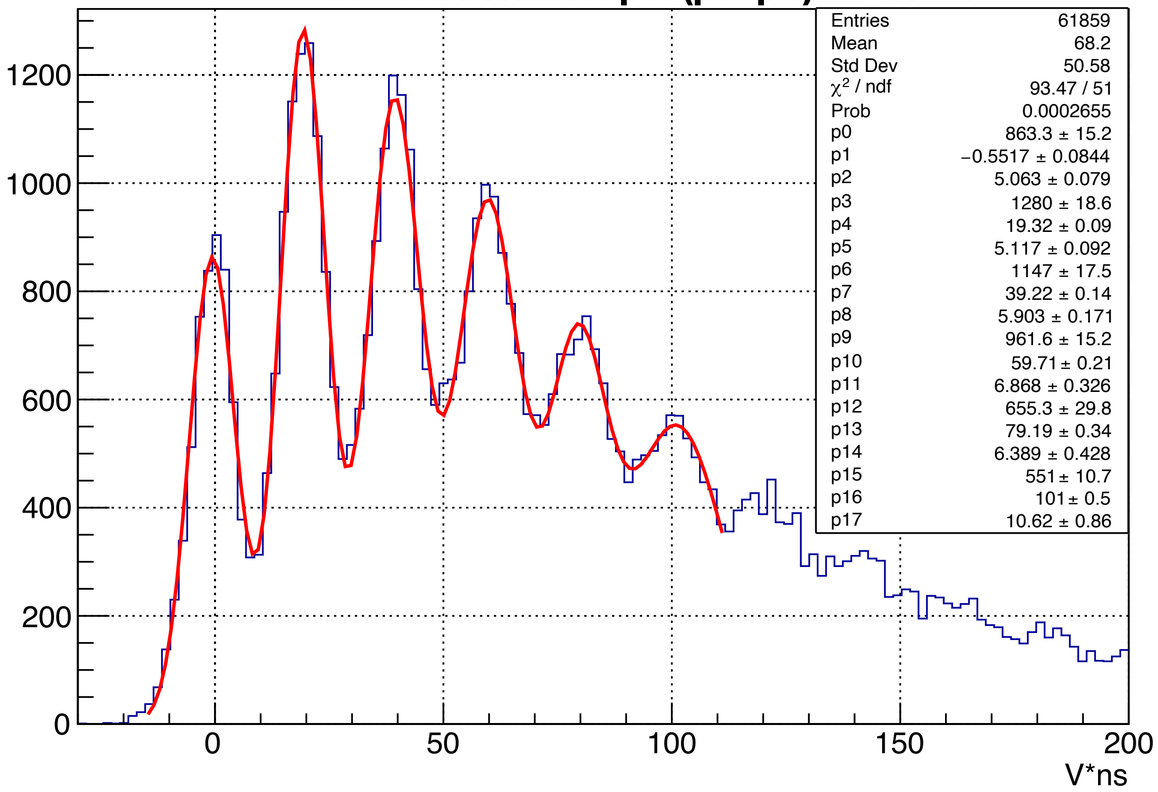
This dataset seems not LED 4p9

SNR (p4-p1)/p2 = 4.38
SPE resolution p5/(p7-p4) = 24.3%



500x4ns integration time, trig offset 40x4ns

SNR (p4-p1)/p2 = 3.92
SPE resolution p5/(p7-p4) = 25.7%

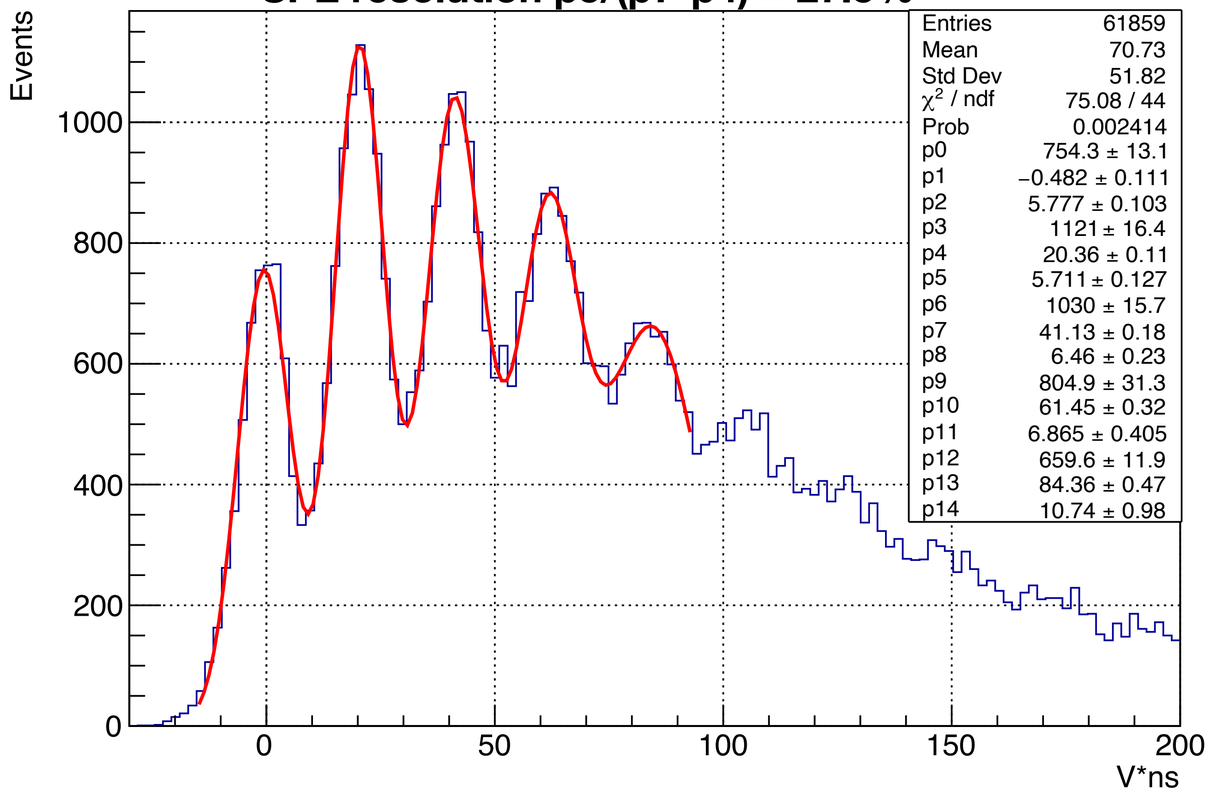


600x4ns integration time, trig offset 40x4ns

Broadcom 40V Bias from Keithley LED 4.9

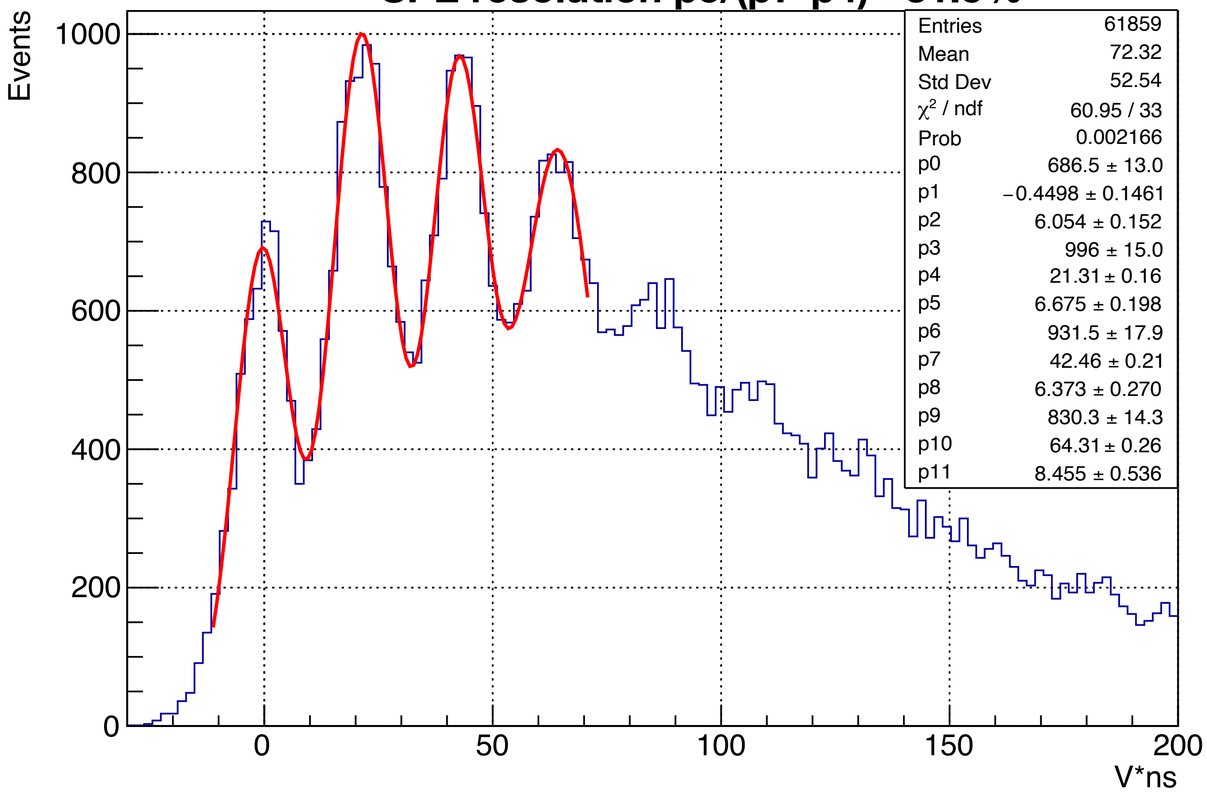
This dataset seems not LED 4p9

SNR (p4-p1)/p2 = 3.6
SPE resolution p5/(p7-p4) = 27.5%



700x4ns integration time, trig offset 40x4ns

SNR (p4-p1)/p2 = 3.59
SPE resolution p5/(p7-p4) =31.5%



800x4ns integration time, trig offset 40x4ns