

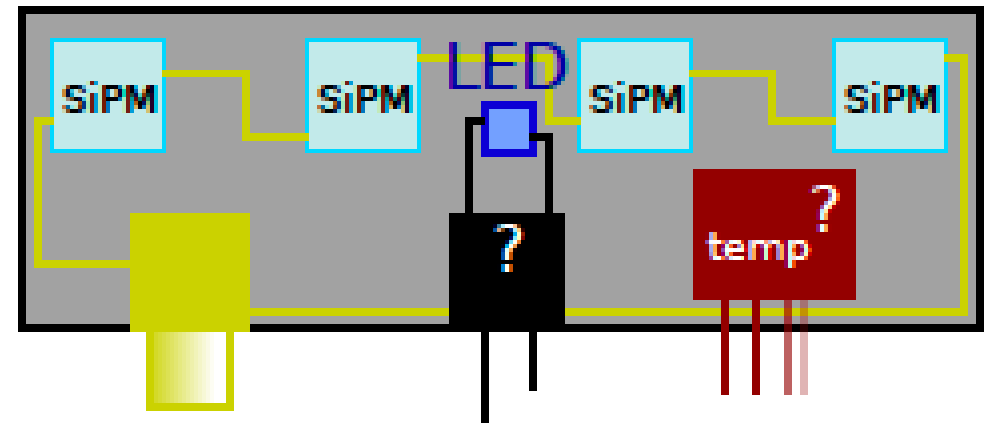
# Barrel TOF LED Calibration

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PANDA Collaboration Meeting, GSI Darmstadt, 5-9 march 2018

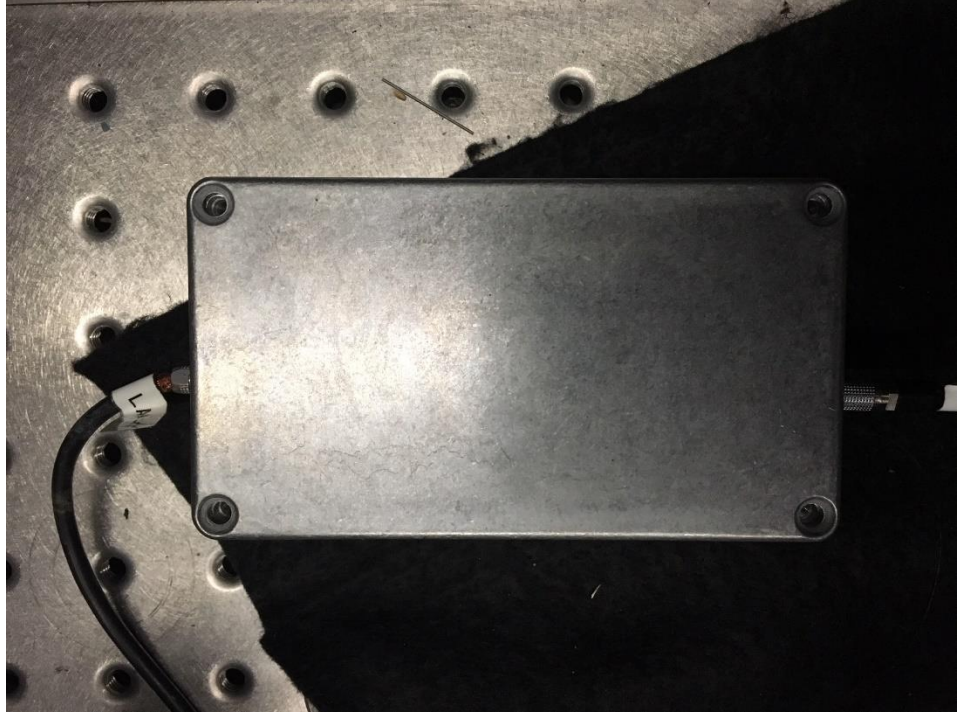
- Idea is to use blue LED to monitor the detector performances, in particular aging, and any other particular defects
- Project is to implement 1 (up to 3 if needed) SMD LED on the board between the SiPMs on both sides of the Scintillator
- Target is to reproduce as good as possible, in the first place, the amount of photons and time resolution of the detector (50ps)

	Color	Wavelength [nm]	Semiconductor material
	Infrared	$\lambda > 760$	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)
	Red	$610 < \lambda < 760$	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
	Orange	$590 < \lambda < 610$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
	Yellow	$570 < \lambda < 590$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
	Green	$500 < \lambda < 570$	<b>Traditional green:</b> Gallium(III) phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP) <b>Pure green:</b> Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN)
	Blue	$450 < \lambda < 500$	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate—under development
	Violet	$400 < \lambda < 450$	Indium gallium nitride (InGaN)
	Purple	multiple types	Dual blue/red LEDs, blue with red phosphor, or white with purple plastic
	Ultraviolet	$\lambda < 400$	Diamond (235 nm) Boron nitride (215 nm) Aluminium nitride (AlN) (210 nm) Aluminium gallium nitride (AlGaN) Aluminium gallium indium nitride (AlGaInN)—down to 210 nm
	Pink	multiple types	Blue with one or two phosphor layers: yellow with red, orange or pink phosphor added afterwards, or white with pink pigment or dye.
	White	Broad spectrum	Blue/UV diode with yellow phosphor

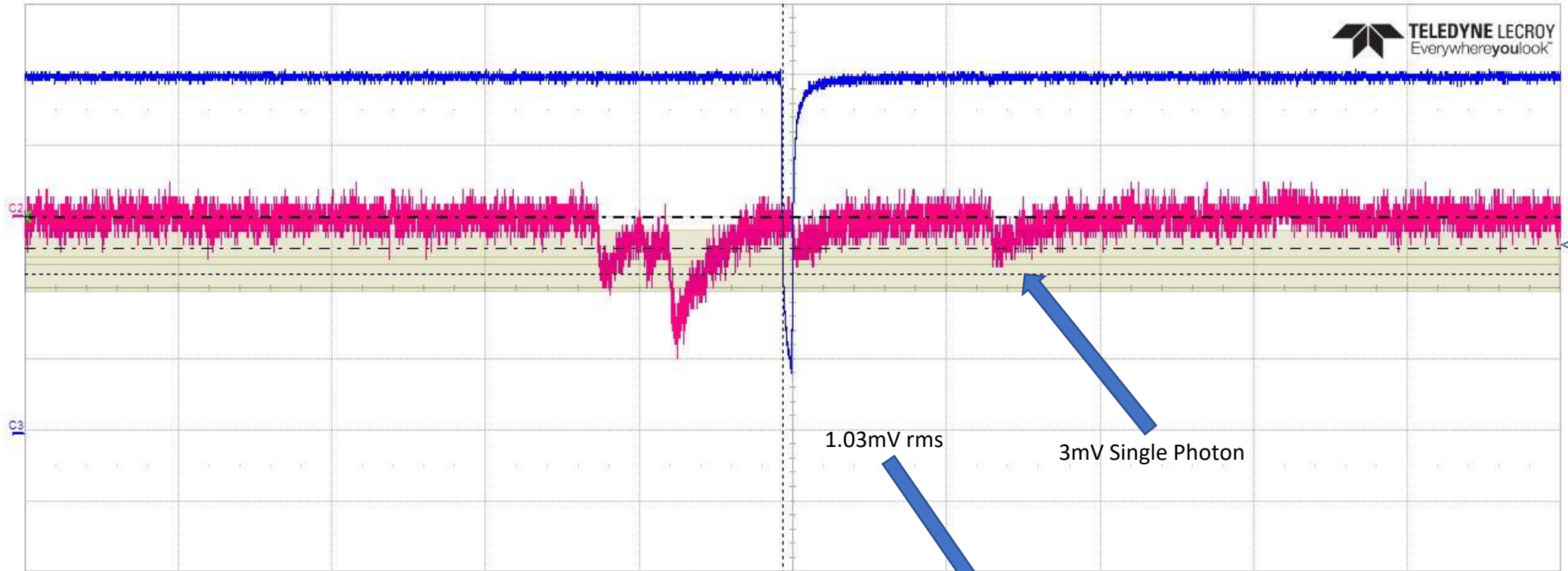


# Setup

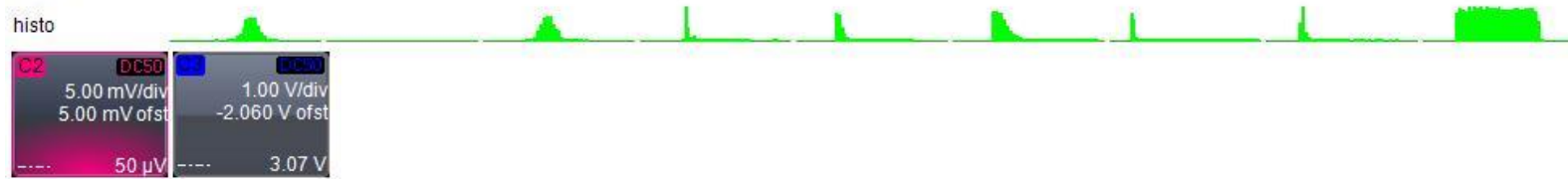
- Hamamatsu SiPM (100 $\mu$ m pitch)
- Blue Kingbright LED (GaN on SiC), Threshold at 3V
- PSI Preamplifier
- Hewlett Packard 8082A Pulse Generator
- LeCroy SDA 760Zi-A Oscilloscope



# Single Photon and Noise rms

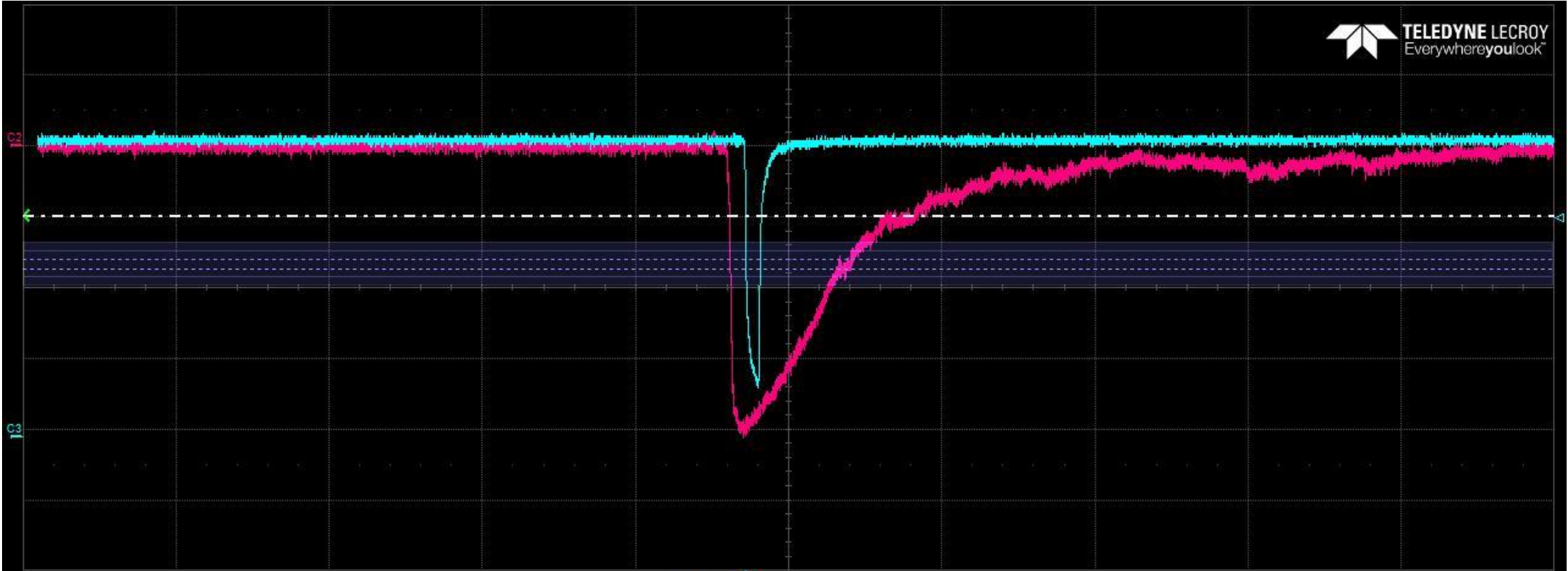


Measure	P1:widn(C3)	P2:freq(C3)	P3:ampl(C3)	P4:ampl(C2)	P5:fall(C2)	P6:rise(C2)	P7:widn(C2)	P8:rms(C2)	P9:dt@lv(C2,C3)	P10:rms(C2)	P11:(P1-P2)	P12:delay(C4)
value	6.9585 ns	---	4.25 V	12.03 mV	60.051 ns	51.237 ns	23.9733 ns	1.34 mV	73.1623 ns			
mean	6.93305 ns	---	4.27017 V	7.701 mV	139.1 ns	94.62 ns	785 ps	1.0292 mV	36.76 ns			
min	6.8171 ns	---	4.20 V	4.59 mV	113 ps	88 ps	81.0 ps	621 $\mu$ V	-18.4301 ns			
max	7.0122 ns	---	4.39 V	41.96 mV	993.842 ns	932.509 ns	102.1360 ns	6.99 mV	93.3594 ns			
sdev	26.05 ps	---	27.02 mV	3.899 mV	186.1 ns	95.48 ns	1.603 ns	714.5 $\mu$ V	31.69 ns			
num	1.449e+3	0	1.449e+3	1.449e+3	3.755e+3	3.699e+3	513.296e+3	1.449e+3	15.526e+3			
status	.R.	.A.	.R.	.R.	.R.	.R.	.R.	✓	✓			



C2 DC50 5.00 mV/div 5.00 mV ofst  
C3 1.00 V/div -2.060 V ofst  
--- 50  $\mu$ V --- 3.07 V

Timebase 0 ns Trigger C3 DC  
 100 ns/div Stop 2.66 V  
 20.0 kS 20 GS/s Measureme P



Measure	P1:widn(C3)	P2:freq(C3)	P3:ampl(C3)	P4:ampl(C2)	P5:fall(C2)	P6:rise(C2)	P7:wid@lv(C2)	P8:rms(C2)	P9:dt@lv(C2,C3)	P10:rms(C2)	P11:(P1-P2)	P12:delay(C4)
value	9.1264 ns	—	3.59 V	869 mV	4.259 ns	207.805 ns	227.1057 ns	183.8 mV	10.2307 ns			
mean	9.18018 ns	—	3.62671 V	850.01 mV	4.3517 ns	220.54 ns	256.65 ns	184.623 mV	9.9620 ns			
min	9.0675 ns	—	3.57 V	804 mV	3.570 ns	120.793 ns	23.4930 ns	158.5 mV	9.6133 ns			
max	9.2925 ns	—	3.70 V	887 mV	6.061 ns	395.642 ns	417.5454 ns	203.6 mV	10.2984 ns			
sdev	33.11 ps	—	21.66 mV	13.19 mV	270.9 ps	39.05 ns	48.01 ns	5.971 mV	115.2 ps			
num	1.145e+3	0	1.145e+3	1.145e+3	1.145e+3	1.145e+3	1.163e+3	1.145e+3	1.145e+3			
status	✘	⚠	✘	✘	✘	✘	✔	✔	✔			



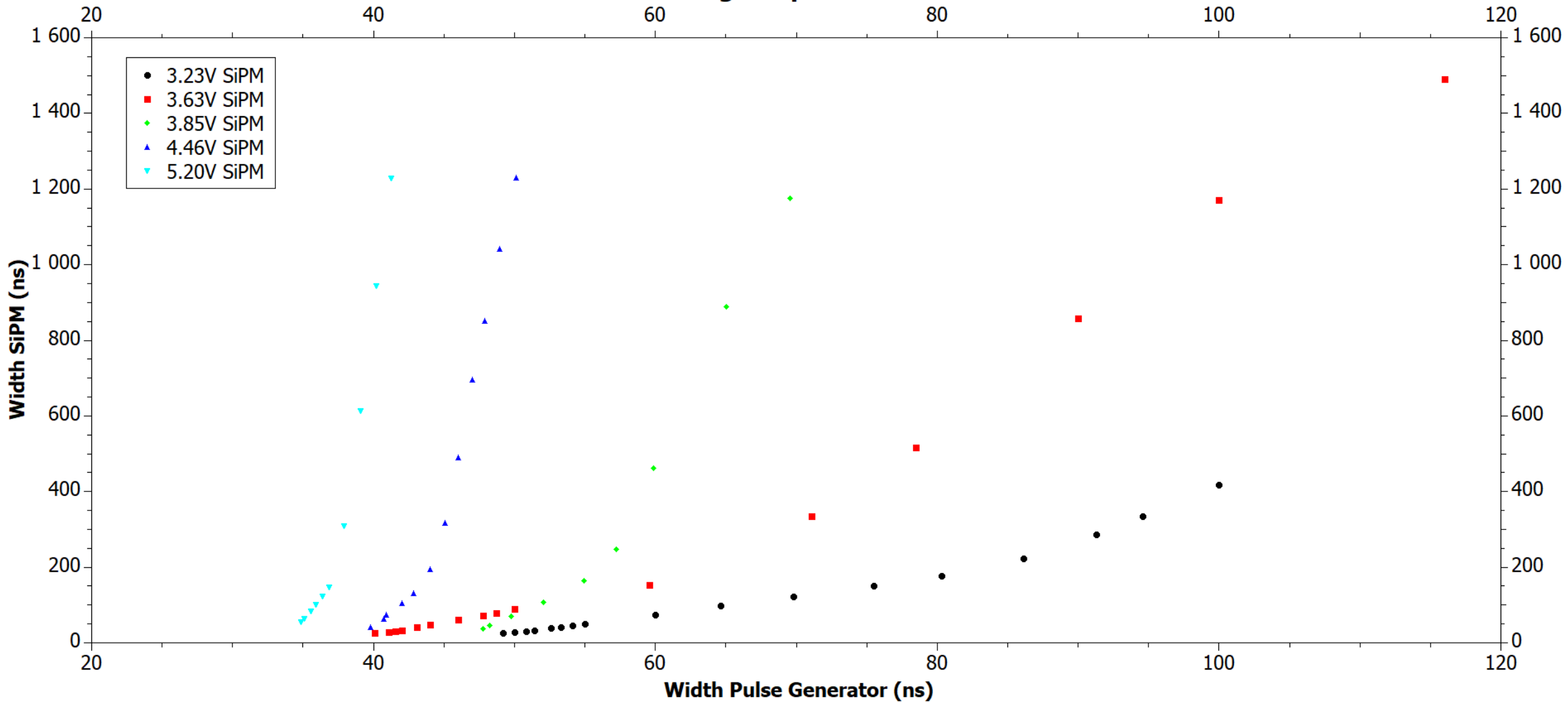
C2 DC50 200 mV/div 400.0 mV  
C3 DC50 1.00 V/div -2.100 V ofst  
 -196 mV 3.12 V

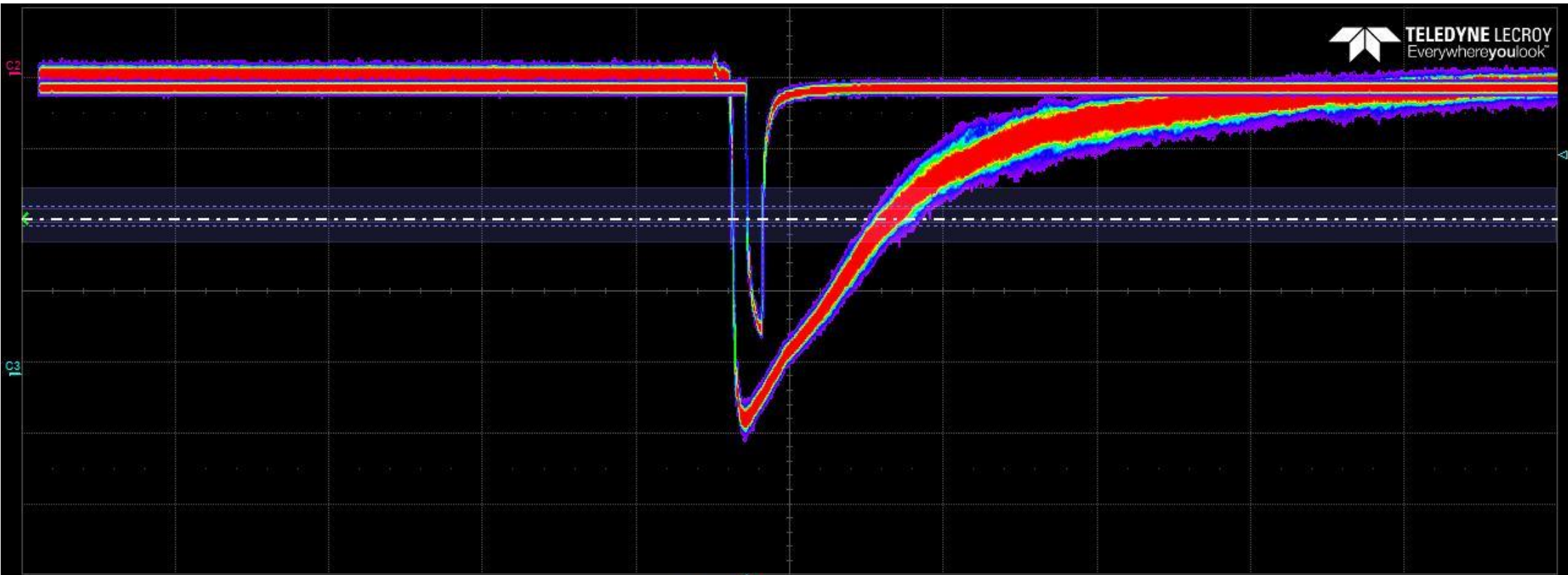
Timebase -28 ns 100 ns/div 20.0 kS 20 GS/s  
 Trigger C3 DC Normal 3.09 V  
 Measureme P

- SiPM signal much longer than the Input
- Need to test the SiPM with picosecond Laser to find out how long the LED actually emits photons
- Long and unstable Tail may be due to LED afterglow
- SiPM Amplitude highly dependent on Input Voltage and width



### Voltage Dependence





Measure	P1:widn(C3)	P2:freq(C3)	P3:ampl(C3)	P4:ampl(C2)	P5:fall(C2)	P6:rise(C2)	P7:wid@lv(C2)	P8:rms(C2)	P9:dt@lv(C2,C3)	P10:rms(C2)	P11:(P1-P2)	P12:delay(C4)
value	10.4433 ns	—	3.56 V	1.041 V	3.959 ns	298.188 ns	285.6048 ns	248.4 mV	9.5016 ns			
mean	10.46205 ns	—	3.57857 V	1.03431 V	4.3671 ns	276.66 ns	288.34 ns	248.605 mV	9.37599 ns			
min	10.3604 ns	—	3.52 V	988 mV	3.604 ns	177.633 ns	21.7982 ns	233.6 mV	9.1199 ns			
max	10.5620 ns	—	3.65 V	1.079 V	5.164 ns	415.318 ns	433.8973 ns	262.5 mV	9.6181 ns			
sdev	35.25 ps	—	21.46 mV	12.48 mV	246.8 ps	35.49 ns	43.94 ns	4.512 mV	81.24 ps			
num	683	0	683	683	683	683	691	683	683			
status	✘	⚠	✘	✘	✘	✘	✔	✔	✔			



**C2** DC50

200 mV/div  
610.0 mV

----- -406 mV

**C3** DC50

1.00 V/div  
-1.180 V ofst

----- 2.20 V

Timebase -28 ns

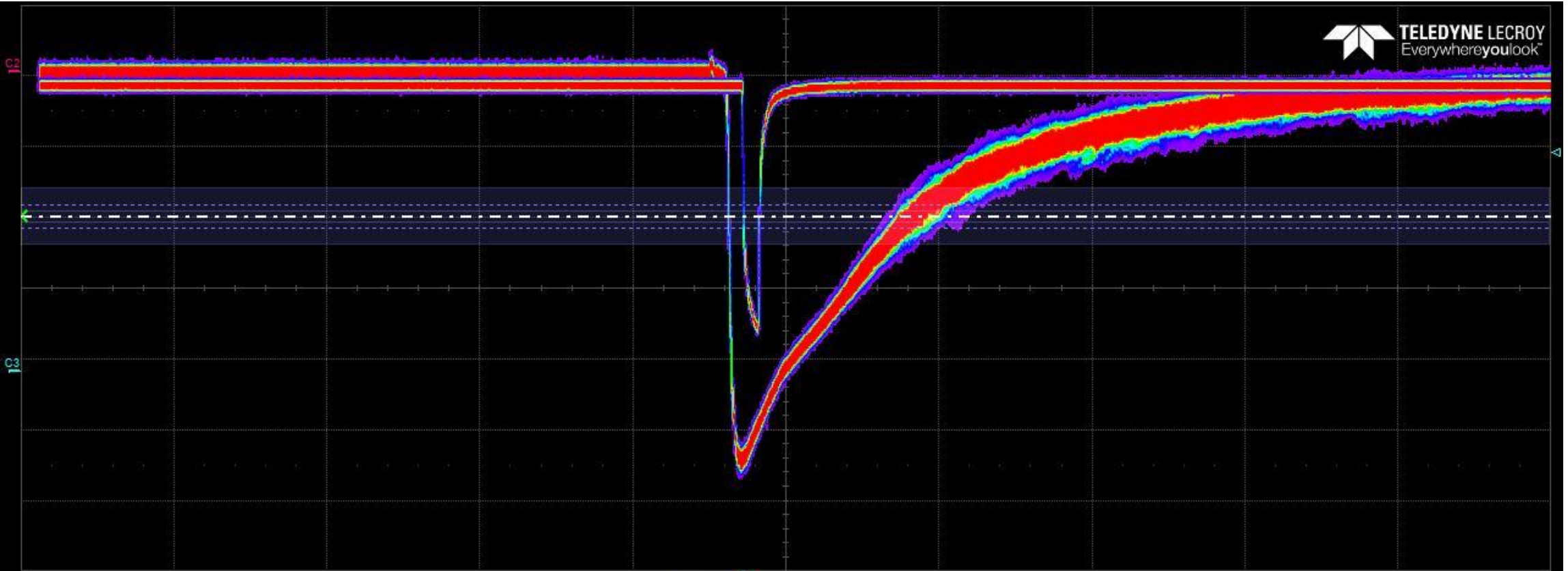
100 ns/div

20.0 kS 20 GS/s

Trigger **C3** DC

Normal 3.09 V

Measureme P



Measure	P1:widn(C3)	P2:freq(C3)	P3:ampl(C3)	P4:ampl(C2)	P5:fall(C2)	P6:rise(C2)	P7:wid@lv(C2)	P8:rms(C2)	P9:dt@lv(C2,C3)	P10:rms(C2)	P11:(P1-P2)	P12:delay(C4)
value	10.7096 ns	—	3.61 V	1.191 V	5.176 ns	351.488 ns	354.3085 ns	284.5 mV	9.5493 ns			
mean	10.70178 ns	—	3.58860 V	1.16002 V	4.8303 ns	305.38 ns	303.27 ns	281.712 mV	9.34953 ns			
min	10.5956 ns	—	3.54 V	1.127 V	4.221 ns	204.982 ns	18.8678 ns	270.2 mV	9.0245 ns			
max	10.8080 ns	—	3.67 V	1.197 V	5.566 ns	414.531 ns	406.8121 ns	293.8 mV	9.5917 ns			
sdev	35.94 ps	—	20.81 mV	12.03 mV	226.0 ps	34.85 ns	43.81 ns	3.920 mV	83.47 ps			
num	552	0	552	552	552	552	559	552	552			
status	✘	⚠	✘	✘	✘	✘	✔	✔	✔			

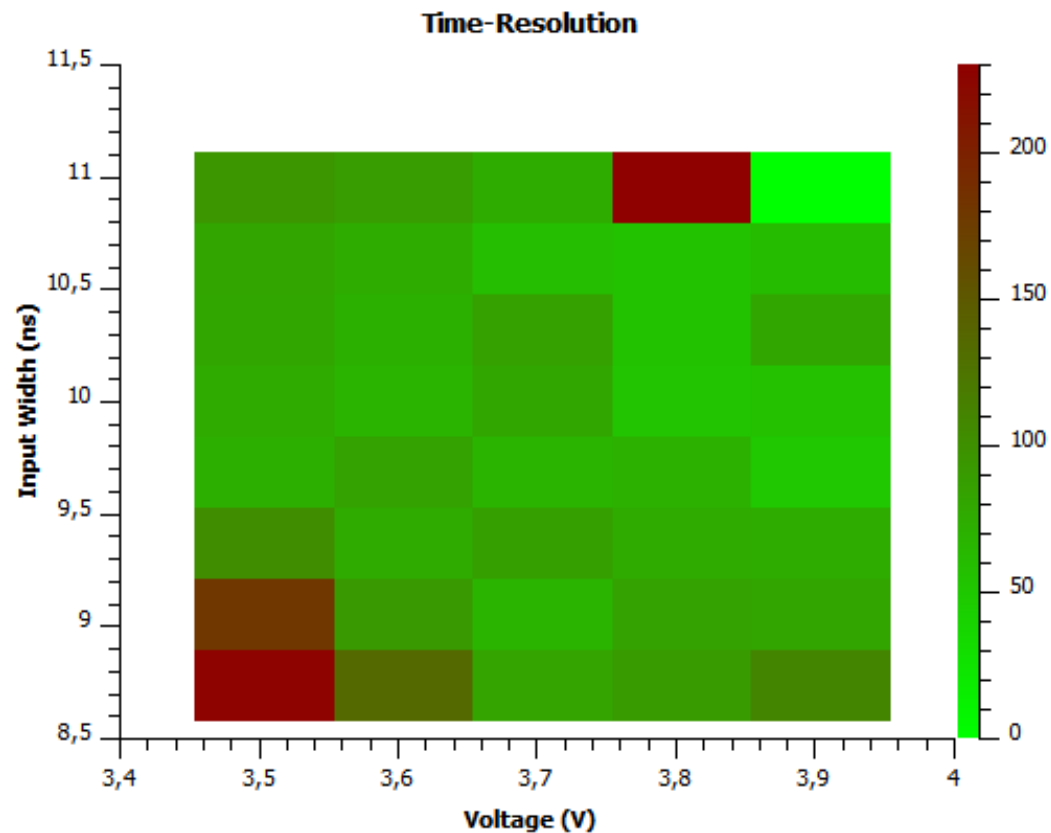


C2 DC50 200 mV/div 610.0 mV  
C3 DC50 1.00 V/div -1.180 V ofst  
---- -406 mV ---- 2.20 V

Timebase -28 ns  
 100 ns/div  
 20.0 kS 20 GS/s  
 Trigger C3 DC  
 Normal 3.09 V  
 Measureme P

# Time-Resolution distribution (3mm)

- Managed time-resolution down to 50ps (LED direct in front of SiPM)
- SiPM output voltage between 1.0V and 1.2V (330 to 400 photons)
- No such time-resolution for lower or higher output
  - Need to test SMD LED and take into consideration the use of 3 LEDs per side, if needed

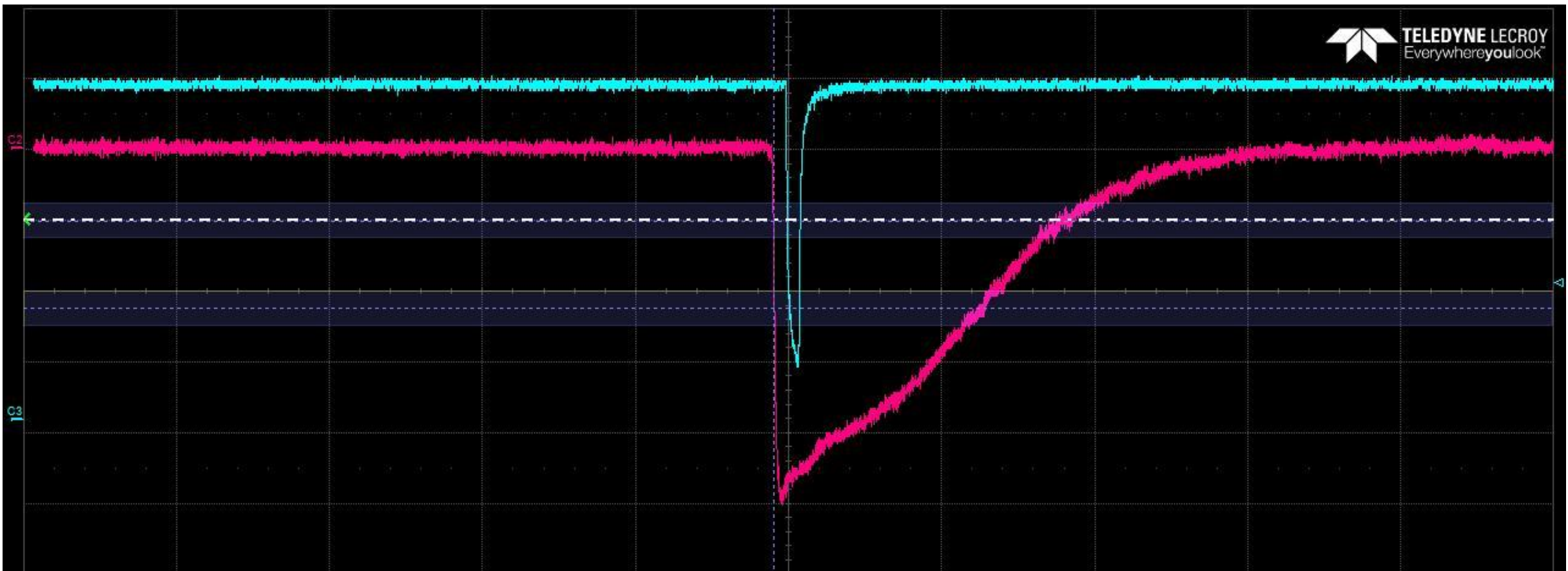


	3,504000000000	3,604000000000	3,704000000000	3,804000000000	3,904000000000
8,7400	228,0000000000...	135,0000000000...	82,0000000000...	90,0000000000...	110,0000000000...
9,0557	180,0000000000...	92,0000000000...	68,0000000000...	84,0000000000...	81,0000000000...
9,3714	102,7000000000...	76,0000000000...	87,0000000000...	76,0000000000...	75,0000000000...
9,6871	72,3000000000...	84,0000000000...	68,0000000000...	70,0000000000...	50,0000000000...
10,0028	75,6000000000...	67,5000000000...	80,0000000000...	54,0000000000...	56,0000000000...
10,3185	80,0000000000...	71,0000000000...	85,0000000000...	55,0000000000...	80,0000000000...
10,6342	81,0000000000...	74,0000000000...	59,0000000000...	55,0000000000...	60,0000000000...
10,9500	95,0000000000...	88,0000000000...	75,0000000000...	230,0000000000...	0,000000000000

- Time-resolution highly dependent on the 2 parameters
  - But: stable region around 3.8-3.9 V and 9.7-10.6 ns
- No SMD LED tested yet. (in the coming weeks)
- Addition of scintillator may give worst time-resolution.
- Project to automatize the process and get finer mesh and resolution

# Preliminary results with Scintillator

- Started last Friday with Scintillator and Board with 4 SiPMs glued on one side. Other side free: LED (3mm) aligned with the scintillator.
- 1.04V amplitude from SiPM (single photon not measured yet)
- At best, 81.24ps time-resolution
- Setup not optimal. But results highly motivating for the future.
  - Setup optimization can only increase the time-resolution
- What we previously thought might be afterglow disappeared.

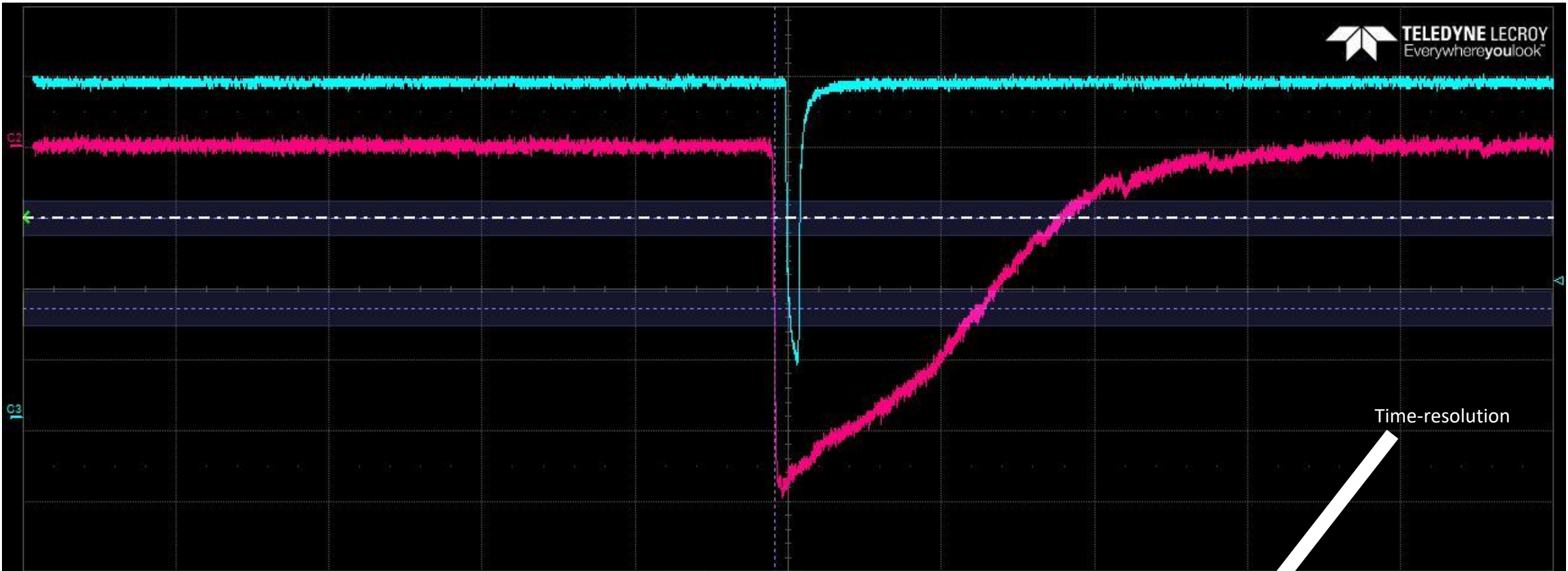


Measure	P1:widn(C3)	P2:freq(C3)	P3:ampl(C3)	P4:ampl(C2)	P5:fall(C2)	P6:rise(C2)	P7:wid@lv(C2)	P8:rms(C2)	P9:dt@lv(C2,C3)	P10:rms(C2)	P11:(P1-P2)	P12:delay(C4)
value	8.5887 ns	—	4.09 V	1.0430 V	3.302 ns	217.142 ns	235.1024 ns	285.8 mV	8.3240 ns			
mean	8.55591 ns	—	4.07969 V	1.03924 V	2.9209 ns	216.11 ns	236.28 ns	290.420 mV	8.25804 ns			
min	8.4598 ns	—	4.01 V	714.2 mV	1.459 ns	124.518 ns	16.5115 ns	274.1 mV	8.0043 ns			
max	8.6442 ns	—	4.17 V	1.1176 V	3.968 ns	262.591 ns	276.9914 ns	304.5 mV	8.5257 ns			
sdev	29.46 ps	—	24.43 mV	30.91 mV	255.9 ps	12.85 ns	14.56 ns	4.345 mV	83.06 ps			
num	1.249e+3	0	1.249e+3	1.249e+3	1.249e+3	1.249e+3	1.252e+3	1.249e+3	1.249e+3			
status	⌘	⚠	⌘	⌘	⌘	⌘	✓	✓	✓			
histo												

<b>C2</b>	DC50	<b>C3</b>	DC50
200 mV/div		1.00 V/div	
405.0 mV		-1.820 V ofst	
----	-201 mV	----	2.84 V

Timebase	0 ns	Trigger	C3 DC
	100 ns/div	Auto	1.92 V
20.0 kS	20 GS/s	Measureme	P

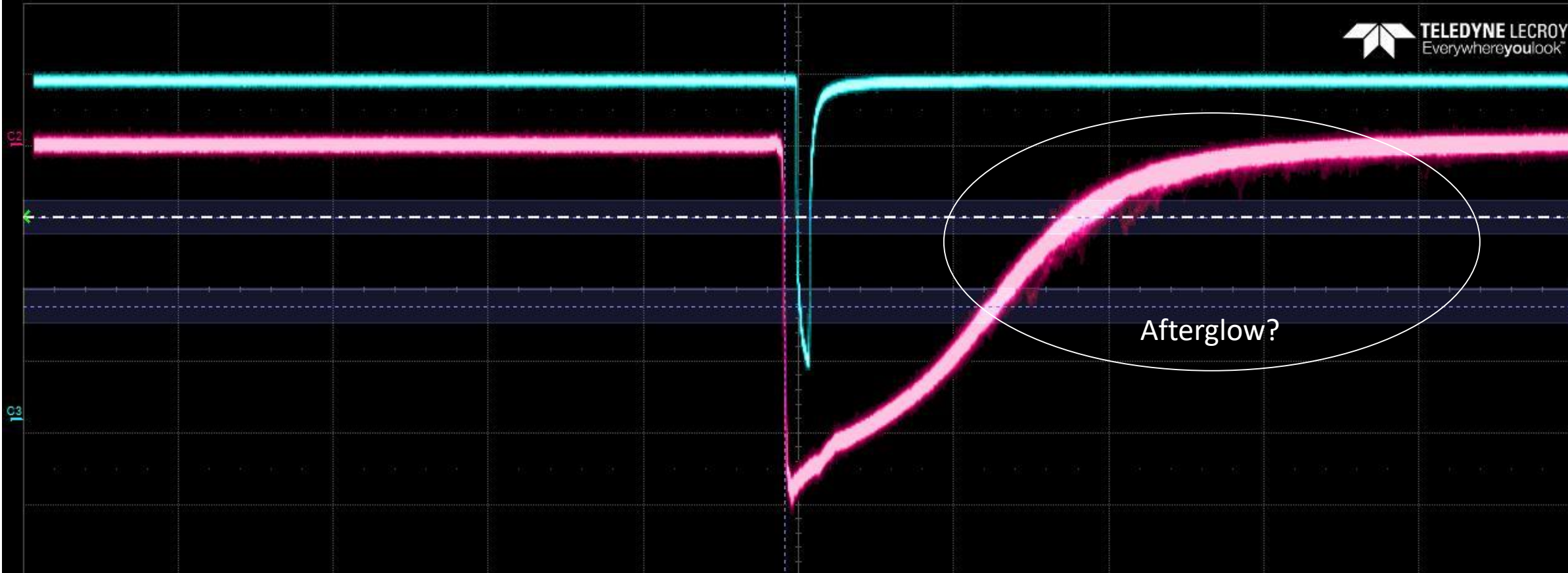




Measure	P1:widn(C3)	P2:freq(C3)	P3:ampl(C3)	P4:ampl(C2)	P5:fall(C2)	P6:rise(C2)	P7:wid@lv(C2)	P8:rms(C2)	P9:dt@lv(C2,C3)	P10:rise(C2)	P11:(P1-P2)	P12:delay(C4)
value	8.5806 ns	—	4.07 V	1.0249 V	2.530 ns	212.421 ns	233.6453 ns	287.3 mV	8.1311 ns			
mean	8.55595 ns	—	4.07995 V	1.03762 V	2.9135 ns	215.76 ns	236.18 ns	289.870 mV	8.25773 ns			
min	8.4598 ns	—	4.01 V	714.2 mV	1.459 ns	124.518 ns	16.5115 ns	272.7 mV	8.0043 ns			
max	8.6442 ns	—	4.17 V	1.1176 V	3.968 ns	262.591 ns	276.9914 ns	304.5 mV	8.5257 ns			
sdev	29.30 ps	—	24.12 mV	31.84 mV	255.5 ps	12.96 ns	13.76 ns	4.453 mV	81.30 ps			
num	1.579e+3	0	1.579e+3	1.579e+3	1.579e+3	1.579e+3	1.582e+3	1.579e+3	1.579e+3			
status	⌘	⚠	⌘	⌘	⌘	⌘	✓	✓	✓			
histo												

C2 DC50 200 mV/div 405.0 mV  
C3 DC50 1.00 V/div -1.820 V ofst  
--- -201 mV --- 2.84 V

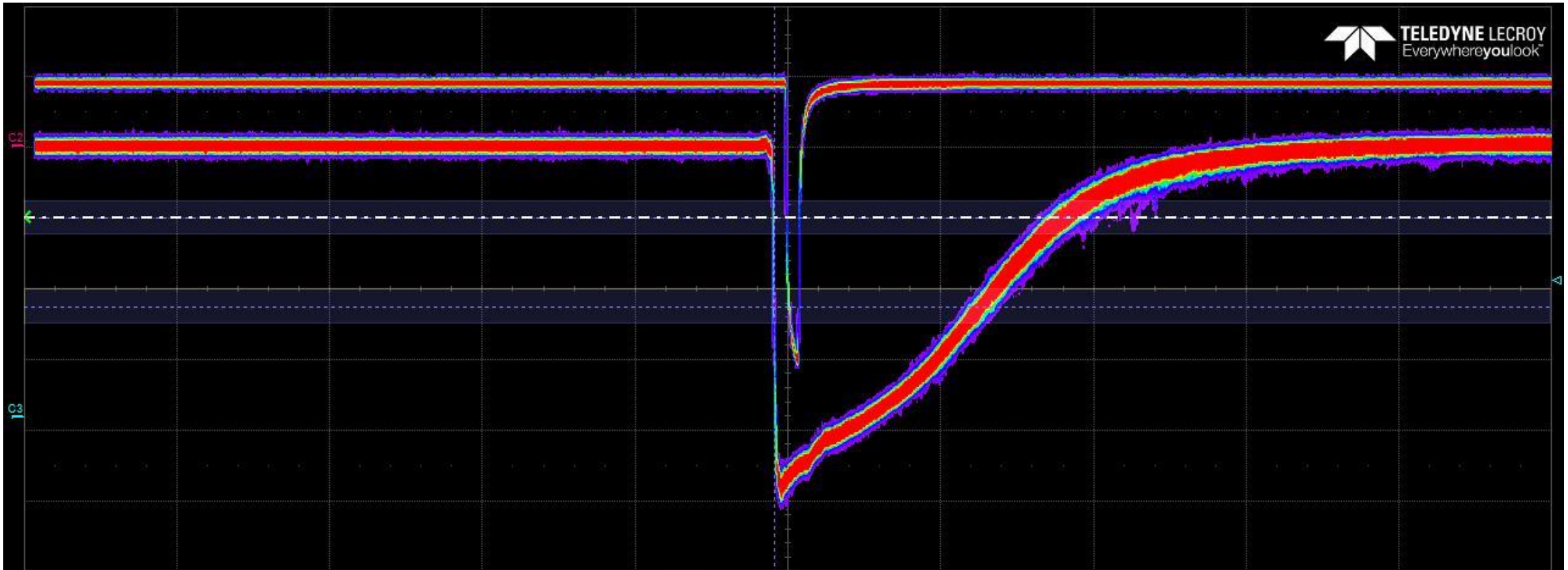
Timebase 0 ns 100 ns/div 20.0 kS  
 Trigger C3 DC Auto 1.92 V  
 Measureme P



Measure	P1:widn(C3)	P2:freq(C3)	P3:ampl(C3)	P4:ampl(C2)	P5:fall(C2)	P6:rise(C2)	P7:wid@lv(C2)	P8:rms(C2)	P9:dt@lv(C2,C3)	P10:rms(C2)	P11:(P1-P2)	P12:delay(C4)
value	8.5728 ns	—	4.05 V	1.0209 V	2.797 ns	212.048 ns	233.2810 ns	286.1 mV	8.1954 ns			
mean	8.55621 ns	—	4.08085 V	1.03412 V	2.9130 ns	215.13 ns	235.63 ns	288.619 mV	8.25509 ns			
min	8.4598 ns	—	4.01 V	714.2 mV	1.459 ns	124.518 ns	9.6761 ns	272.7 mV	8.0043 ns			
max	8.6442 ns	—	4.17 V	1.1176 V	4.287 ns	262.591 ns	276.9914 ns	304.5 mV	8.6105 ns			
sdev	29.10 ps	—	24.19 mV	30.32 mV	253.7 ps	12.52 ns	14.19 ns	4.750 mV	81.74 ps			
num	2.298e+3	0	2.298e+3	2.298e+3	2.298e+3	2.298e+3	2.303e+3	2.298e+3	2.298e+3			
status	✘	⚠	✘	✘	✘	✘	✔	✔	✔			
histo												

C2 DC50 200 mV/div 405.0 mV  
C3 DC50 1.00 V/div -1.820 V ofst  
--- -201 mV --- 2.84 V

Timebase 0 ns 100 ns/div 20.0 kS  
 Trigger C3 DC Auto 1.92 V Measureme P



Measure	P1:widn(C3)	P2:freq(C3)	P3:ampl(C3)	P4:ampl(C2)	P5:fall(C2)	P6:rise(C2)	P7:wid@lv(C2)	P8:rms(C2)	P9:dt@lv(C2,C3)	P10:rms(C2)	P11:(P1-P2)	P12:delay(C4)
value	8.5725 ns	—	4.08 V	1.0274 V	2.722 ns	218.343 ns	233.4951 ns	284.7 mV	8.2083 ns			
mean	8.55616 ns	—	4.08112 V	1.03380 V	2.9118 ns	215.06 ns	235.41 ns	288.499 mV	8.25458 ns			
min	8.4598 ns	—	4.01 V	714.2 mV	1.459 ns	124.518 ns	9.6761 ns	272.7 mV	8.0043 ns			
max	8.6442 ns	—	4.17 V	1.1176 V	4.287 ns	262.591 ns	276.9914 ns	304.5 mV	8.6105 ns			
sdev	29.17 ps	—	24.15 mV	30.37 mV	253.9 ps	12.52 ns	15.20 ns	4.737 mV	81.24 ps			
num	2.423e+3	0	2.423e+3	2.423e+3	2.423e+3	2.423e+3	2.430e+3	2.423e+3	2.423e+3			
status	⌘	⚠	⌘	⌘	⌘	⌘	✓	✓	✓			
histo												

**C2** DC50  
200 mV/div  
405.0 mV  
----- -201 mV

**C3** DC50  
1.00 V/div  
-1.820 V ofst  
----- 2.84 V

Timebase 0 ns  
100 ns/div  
20.0 kS

Trigger C3 DC  
Auto 1.92 V  
Measureme P

# Outlook

- Improve time-resolution with scintillator
- Understanding Afterglow and reduce this effect
- Test few SMD LED and compare: time-resolution, number of photons, afterglow, signal width.
- Drive LEDs with FPGA

Thank you for your attention!