

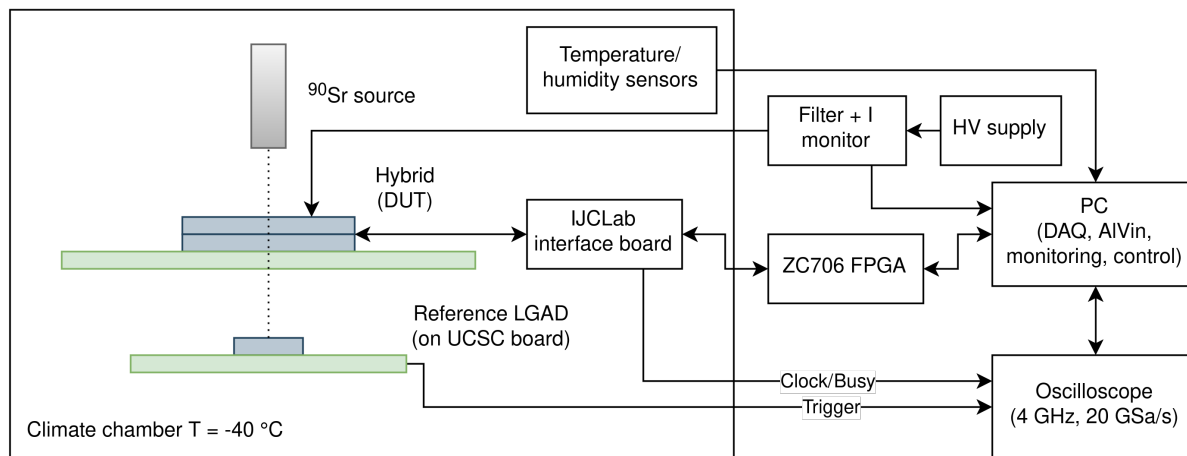
Irradiated hybrid timing performance measurements at JSI

HGTD irradiated hybrid ^{90}Sr timing measurements



Hybrid timing measurement setup at JSI

- Irradiated hybrids mounted on test boards
- Measurement using 2 plane configuration
 - Top plane is hybrid DUT
 - Bottom plane is reference LGAD sensor (calibrated using 3 plane method with two additional sensors - 36 ps)
 - Data readout with Alvin and 4 GHz 20 GSa/s oscilloscope (reference pulse and clock signals)



Monitoring during measurements

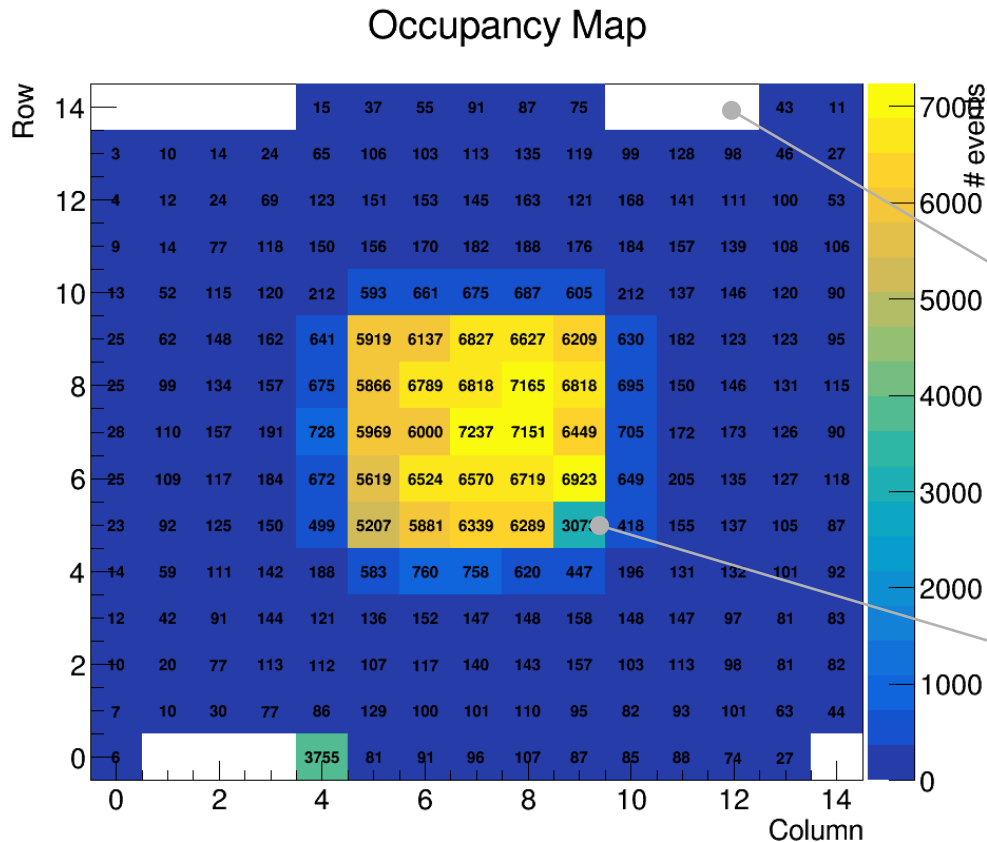


During measurements environmental data (3x Pt100 + temp./rh.) and sensor voltage/current are monitored.

Data capture and processing

- Data from FPGA is processed in chunks rather than performing ordinary source scan
 - This speeds up capture/transfer as invalid events (outside 0-127 ToA range are discarded before waveforms are downloaded from oscilloscope)
- Analysis performed on pixels with sufficient number of events
 - Using different ToA LSB processing methods (1LSB, 4LSB)
 - Perform time walk corrections
 - Timing resolution extracted using different fitting methods (full normal, limited normal, double sided crystal ball (normal with exponential tails))
 - Output in ROOT files

Test board cutout window limitations



- Due to test board PCB geometry only central 5x5 pixel area can be tested

Masked noisy pixels.

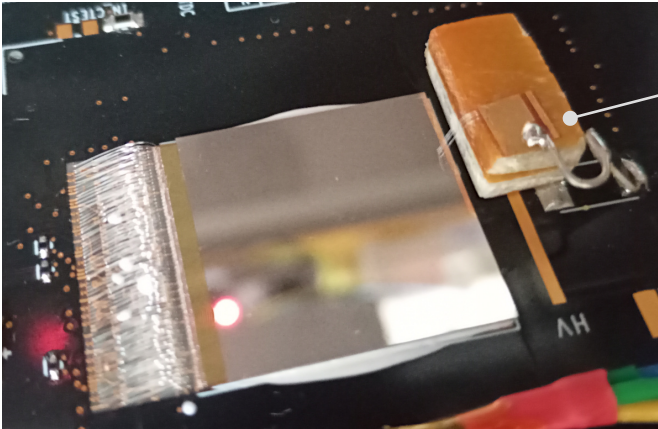
This pixel has less events than others due to thermal grease blob on the bottom side.

Measurement procedure

- Mount sample on test board (with HV bias modification to resolve ToA flatness issue)
- Mount test board inside measurement setup
- Test digital connectivity with ASIC
- Cool down climate chamber to operating temperature (-40 °C)
- Perform GDAC tune, 3 TDAC tunes and threshold scan to confirm tuning
 - If indications of noisy pixels are present, perform additional noise scan and use result to mask noisy pixels
- Tune ToT LSB to 1.0 (AlVIn)
- Tune ToA LSB to 20 ps
- Start source scan until ~5k/events pixel in central region (~16 h runtime)
- Extract timing information with analysis software

S12 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$, $U = 550 \text{ V}$

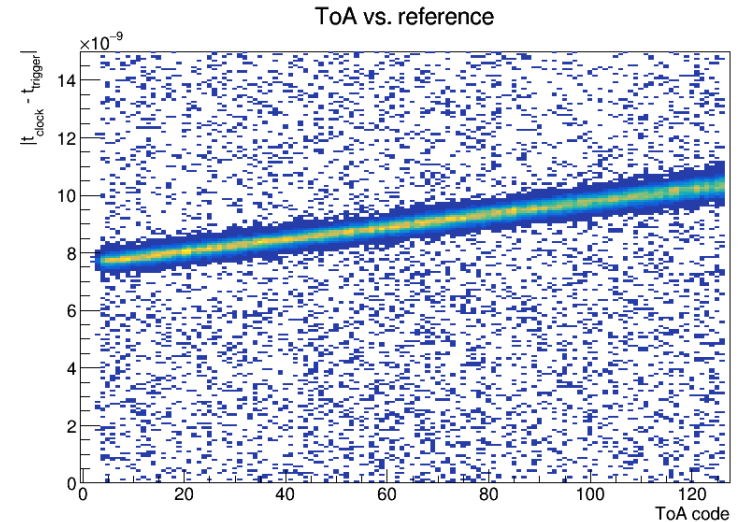
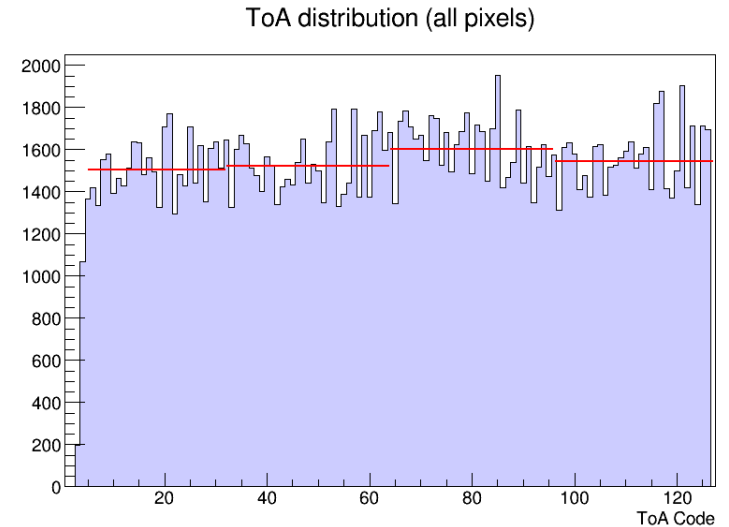
- Hybrid previously used in sparking tests
 - Subjected to harsh conditions and mishandling
- Developed some noisy pixels on edges that were masked during data taking
- Overall stable operation without any major issues
- Flat ToA distribution (HV bias modification fixed the issue)
- Good ToA correlation with trigger, minimum number of uncorrelated noisy events



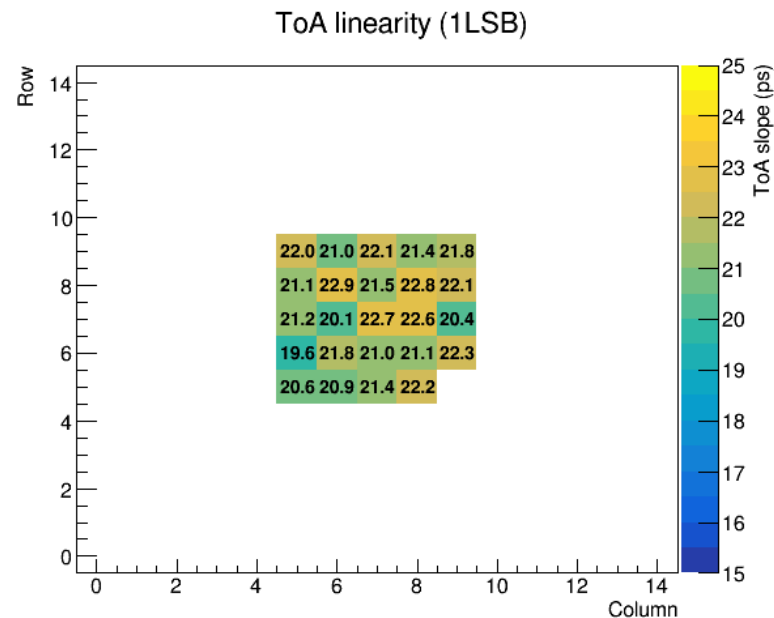
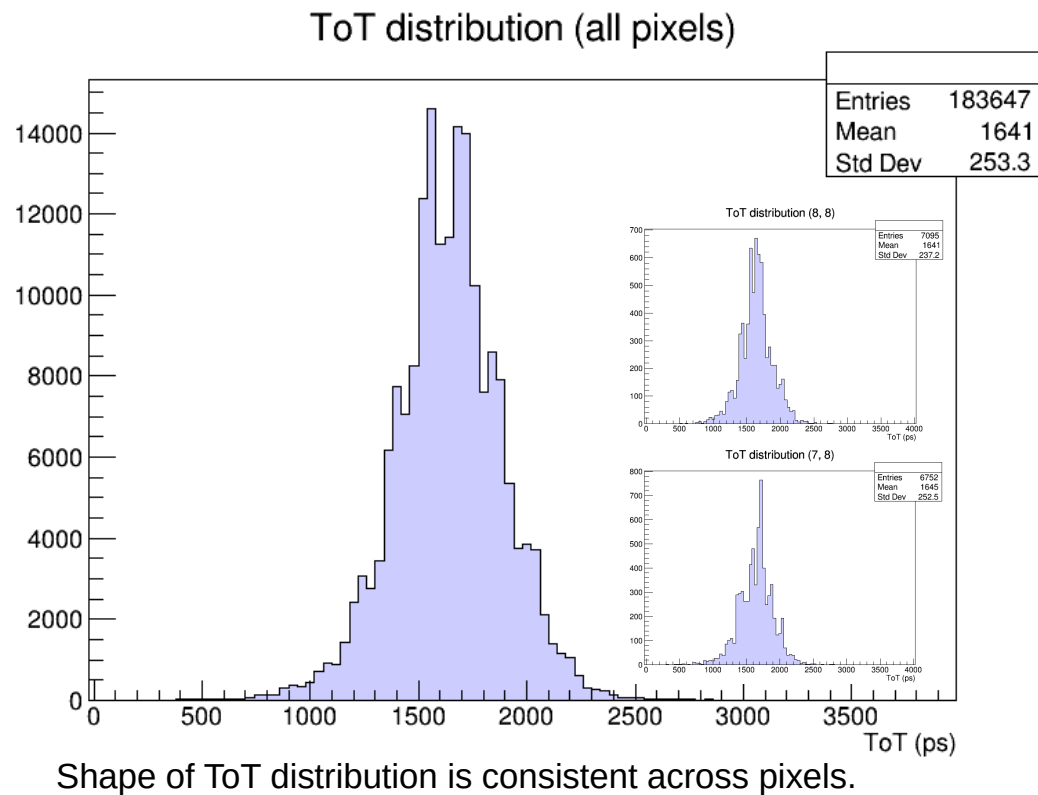
HV bias network
modification
to lower node capacitance.

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Hybrid timing measurements



S12 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ - ToT, ToA LSB

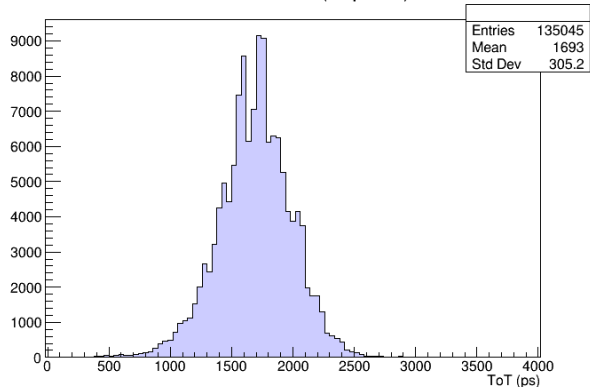


ToA LSB value extracted from data is somewhat on high side. Improvement of LSB values should be possible after additional tweaking.

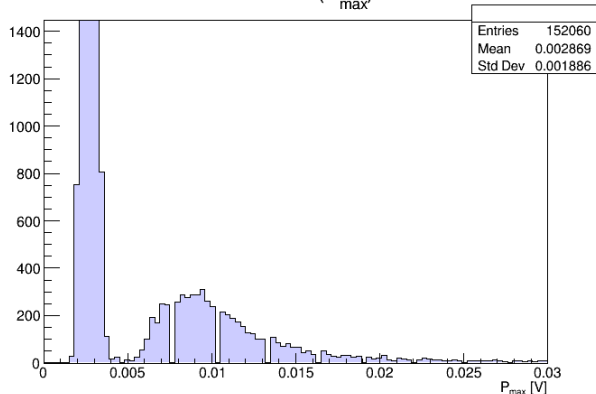
Shape of ToT distribution

Looking at another sample (S13, $2.5 \cdot 10^{15}$), S12 probe was not setup correctly!

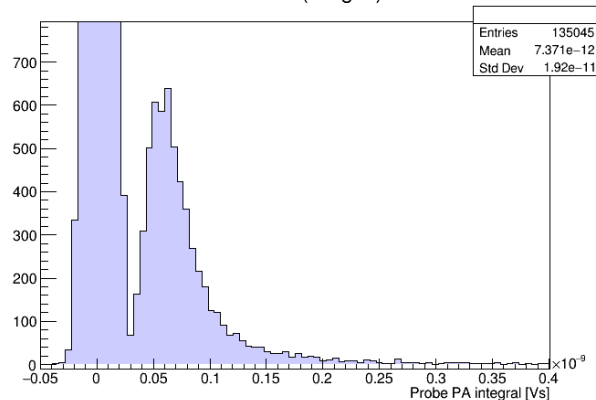
ToT distribution (all pixels)



Probe PA ($P_{\max}$)



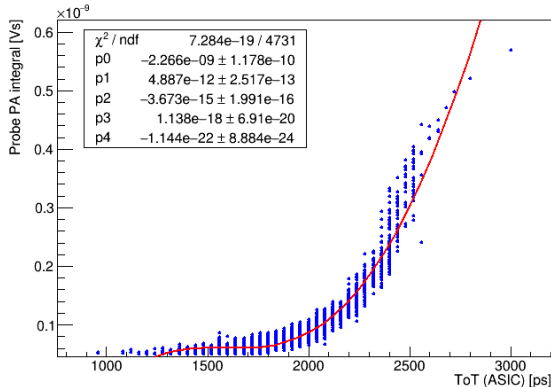
Probe PA (integral)



ToT distribution is not landau shaped -
ToT value is not proportional to $P_{\max}$ or charge!

$P_{\max}$ values measured on single
channel follow landau distribution.

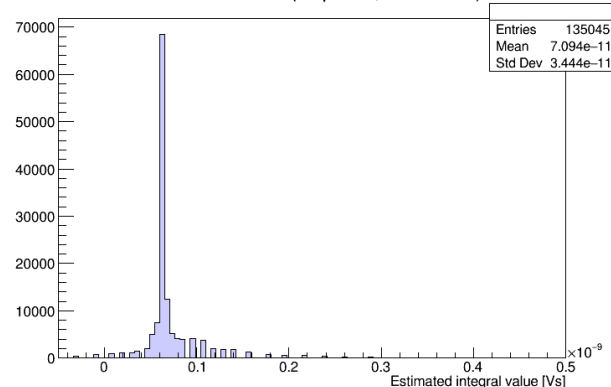
Probe PA vs. ToT correlation



Apply model to all ToT data

There is a clear relationship between
 $P_{\max}$ or integral and actual measured
quantity on analog waveform. Using
appropriate model it should be
possible to extract $P_{\max}$ or integral
distribution from ToT measurements.

ToT distribution (all pixels, calibrated)

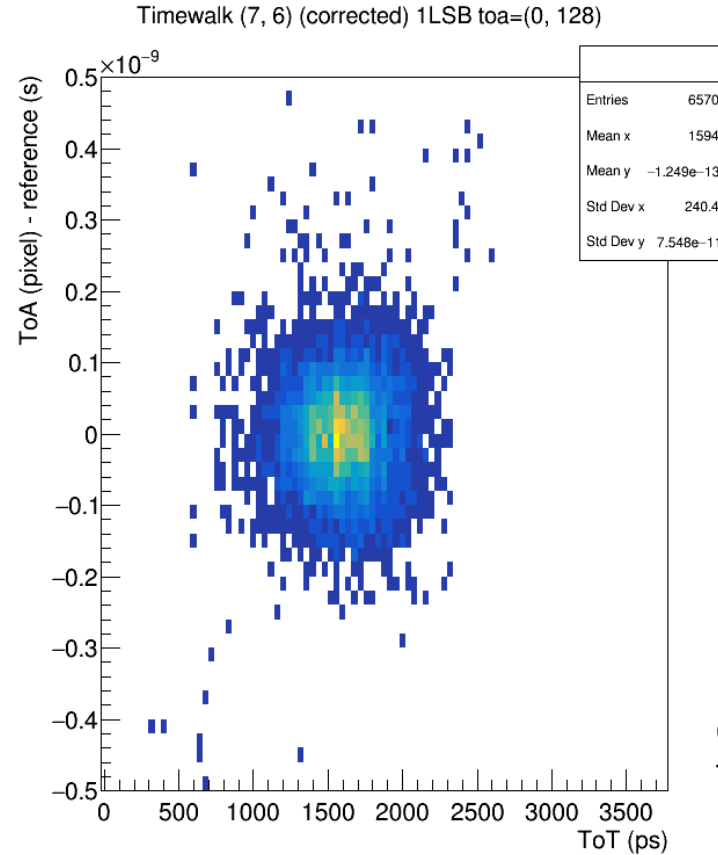
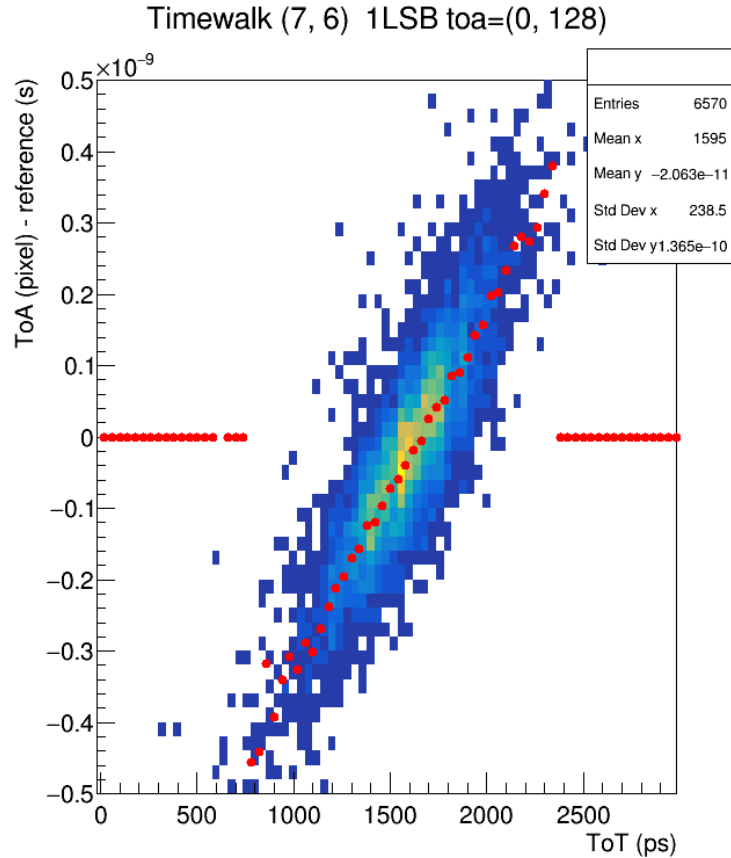


Applying even bad model reveals distribution shape.

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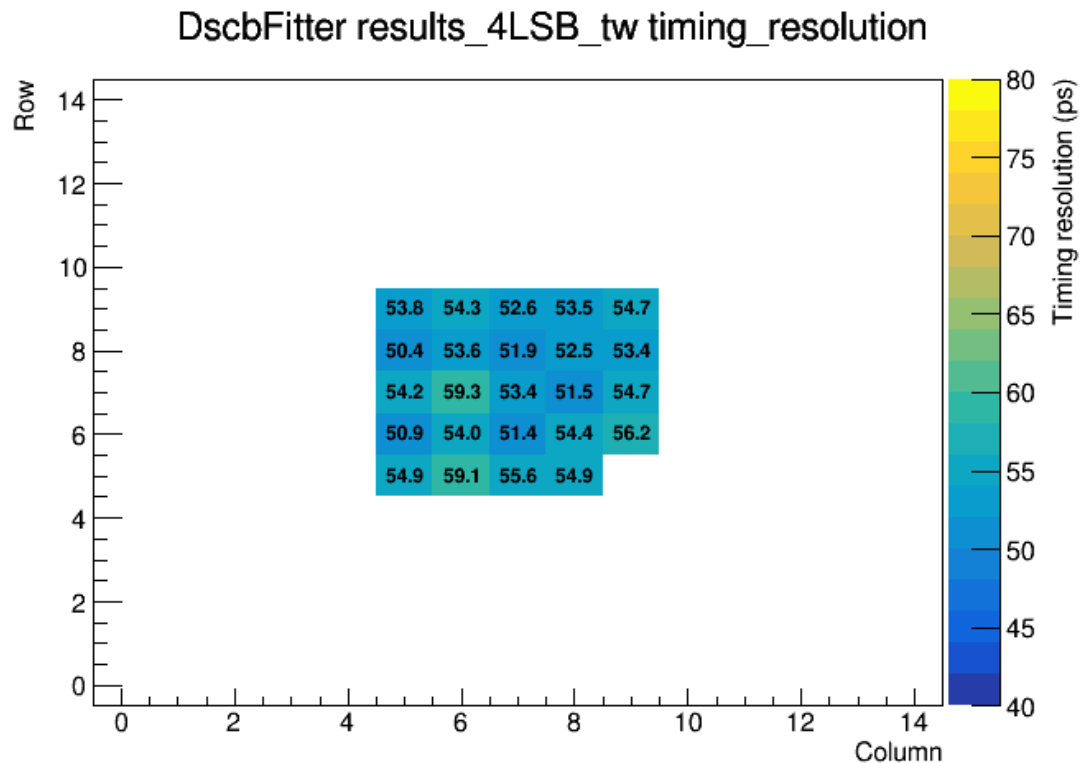
Hybrid timing measurements

S12 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ - time walk correction



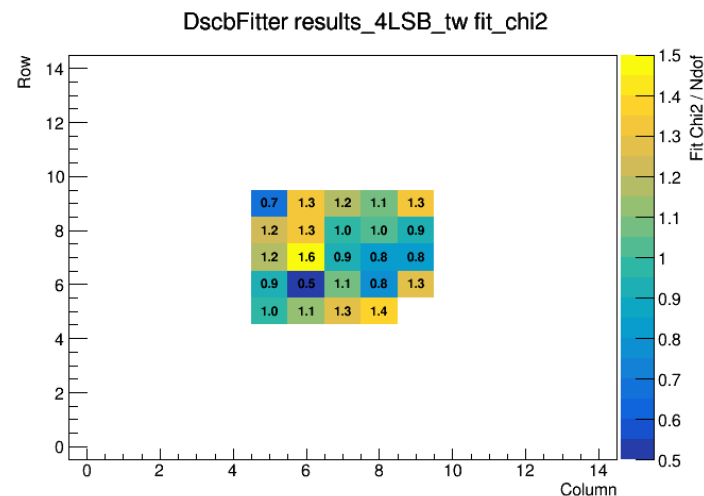
Dataset contains enough events to perform good time walk correction.

S12 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ - timing resolution



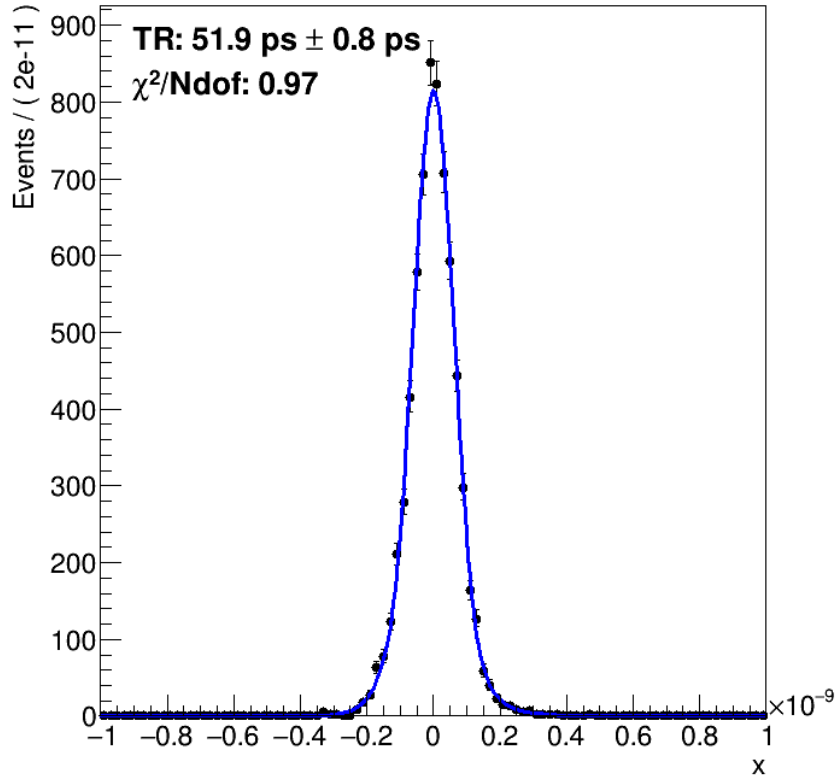
Resulting timing distributions are not normally distributed, fitting results give different values depending on selected method.

Overall DSCB method is most stable giving consistent results with Chi2/Ndof values close to 1.

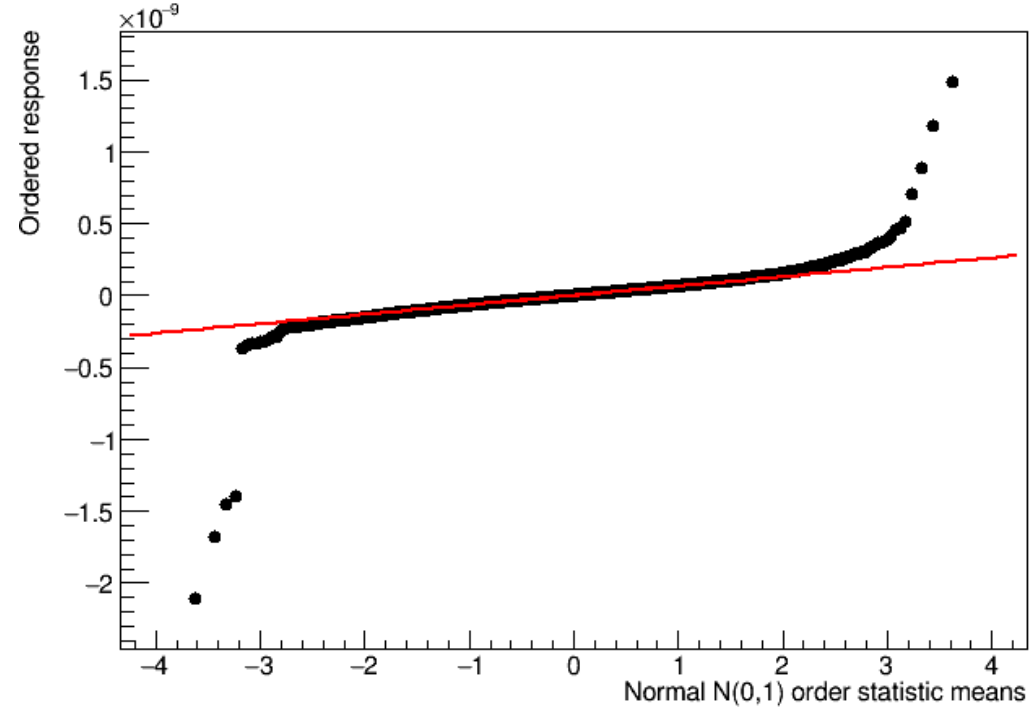


S12 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ - timing resolution (pixel example)

Pixel_7_8_4LSB_stacked_TW

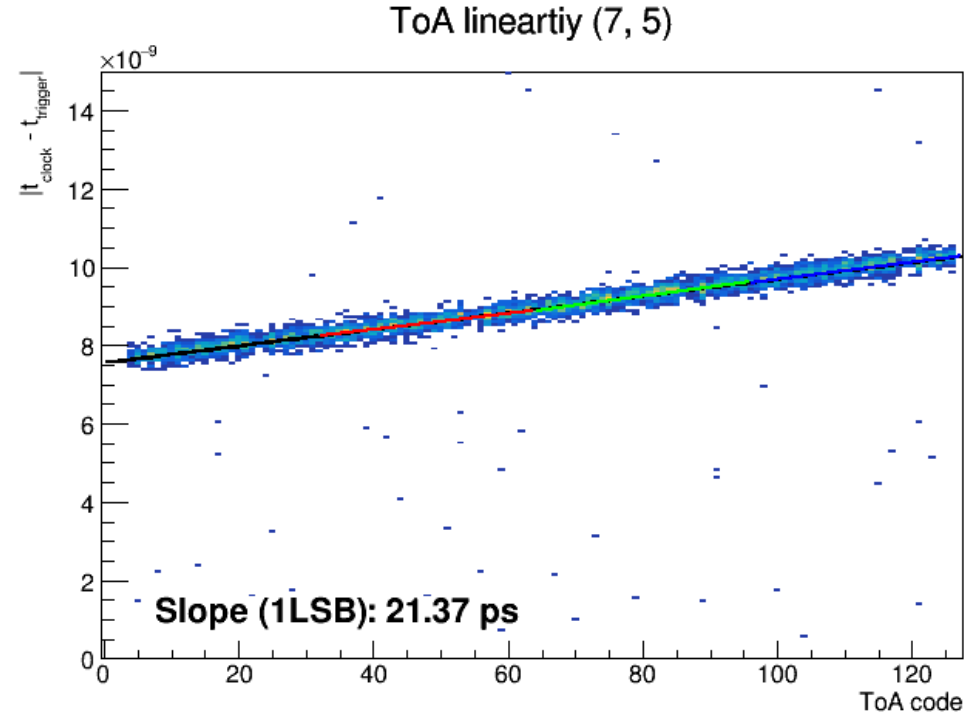
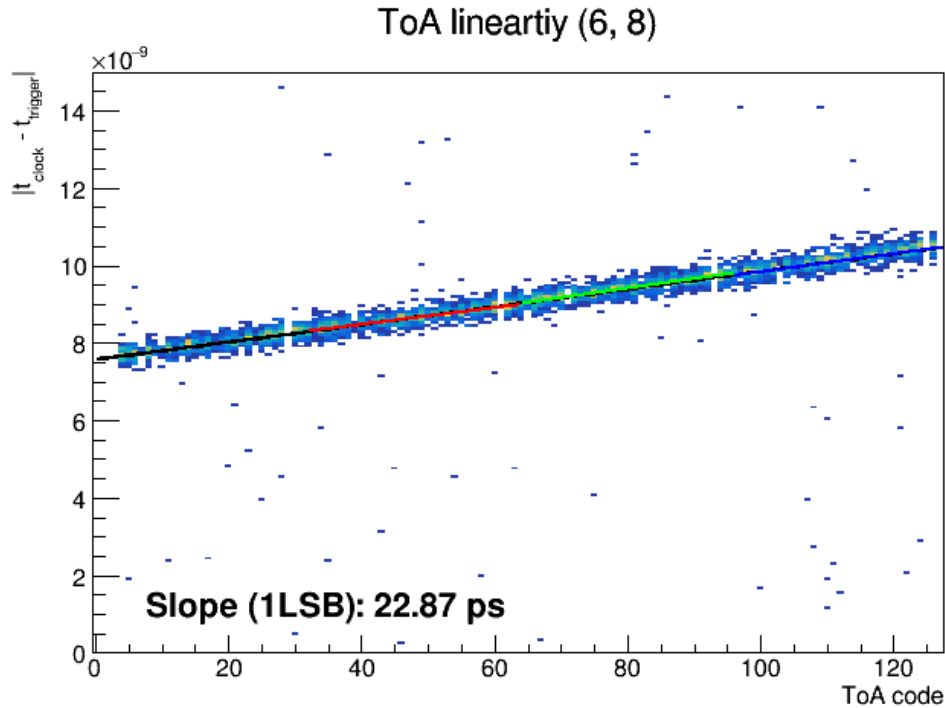


Q-Q (Pixel_7_8_4LSB_stacked) (TW corrected)



Q-Q plot reveals that distribution is normal around 1-2 σ from mean, while events in tails are following another distribution.

S12 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ - ToA observations



Some pixels have missing ToA codes (software bug or something else?)

S12 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ - timing method comparison

DSCB

Timing res.

53.8	54.3	52.6	53.5	54.7
50.4	53.6	51.9	52.5	53.4
54.2	59.3	53.4	51.5	54.7
50.9	54.0	51.4	54.4	56.2
54.9	59.1	55.6	54.9	

χ^2/Ndof

0.7	1.3	1.2	1.1	1.3
1.2	1.3	1.0	1.0	0.9
1.2	1.6	0.9	0.8	0.8
0.9	0.5	1.1	0.8	1.3
1.0	1.1	1.3	1.4	

Normal

Timing res.

59.1	60.9	58.8	58.2	58.6
57.4	59.9	57.8	58.5	60.1
61.6	61.5	58.8	57.4	60.5
60.6	59.4	56.8	60.2	59.5
60.6	62.3	60.9	60.5	

χ^2/Ndof

3.0	3.1	2.6	3.3	3.1
3.1	3.4	3.4	3.0	3.4
2.8	2.4	3.0	3.5	3.0
3.0	2.5	2.8	2.6	2.8
3.1	2.3	2.8	2.2	

Normal (with limits)

Timing res.

53.1	50.6	52.3	54.7	54.6
49.4	53.3	49.8	52.8	52.6
52.4	52.1	53.5	49.9	51.7
50.0	53.0	49.1	51.4	51.6
55.8	54.4	53.7	55.1	

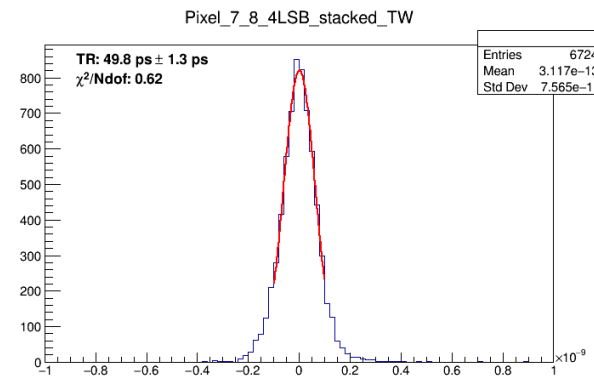
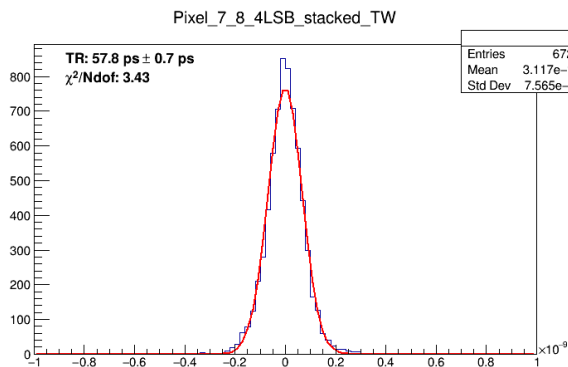
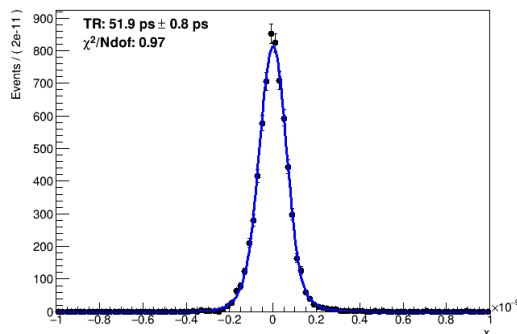
χ^2/Ndof

0.5	0.6	0.9	2.0	2.4
2.0	0.9	0.6	0.7	0.8
1.9	0.6	1.9	1.2	0.6
0.9	0.6	1.0	1.1	0.1
1.5	1.8	1.8	1.3	

Chi2 values relatively stable compared to other methods.

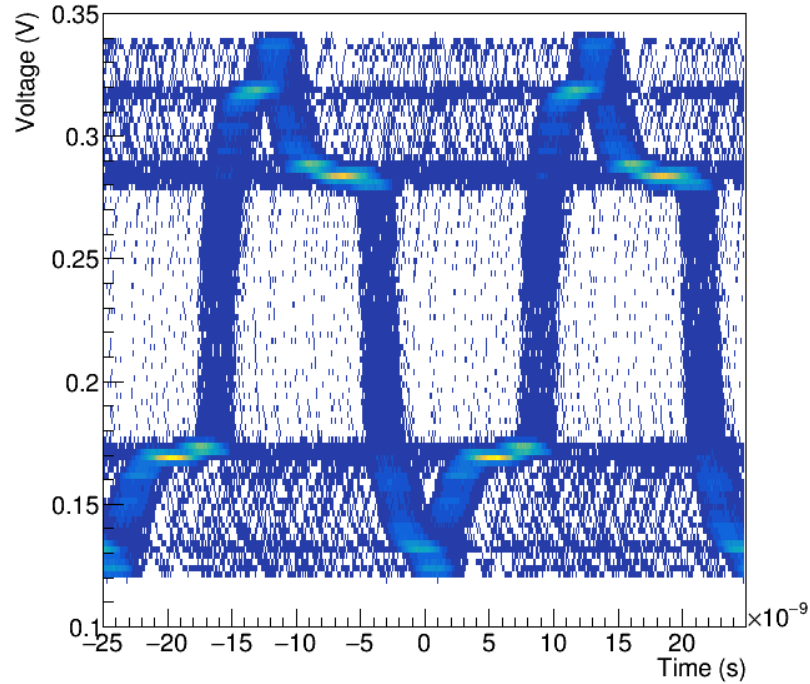
High chi2 indicates model is not representative (see Q-Q plot)

High chi2 variation dependent on manually selected parameters.

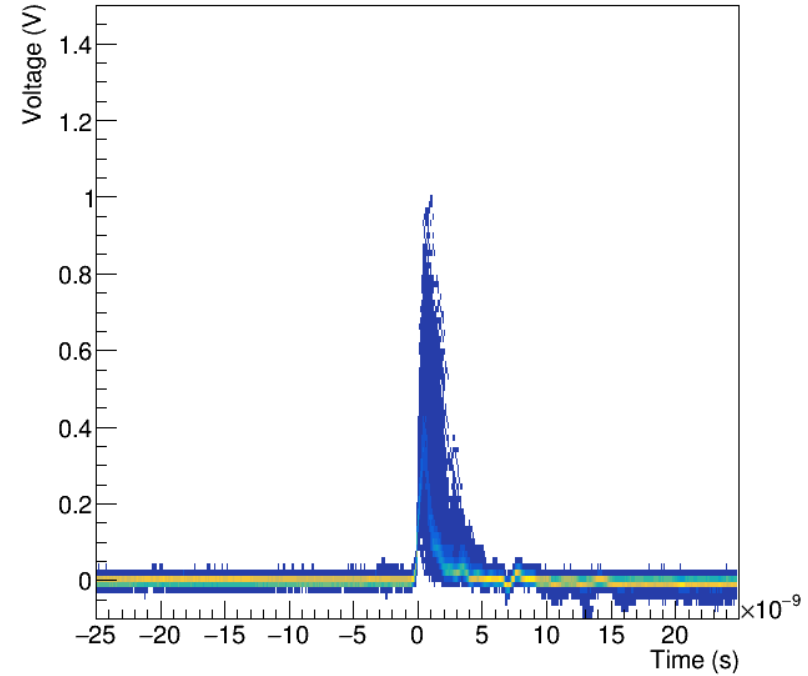


S12 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ - waveforms

Clock



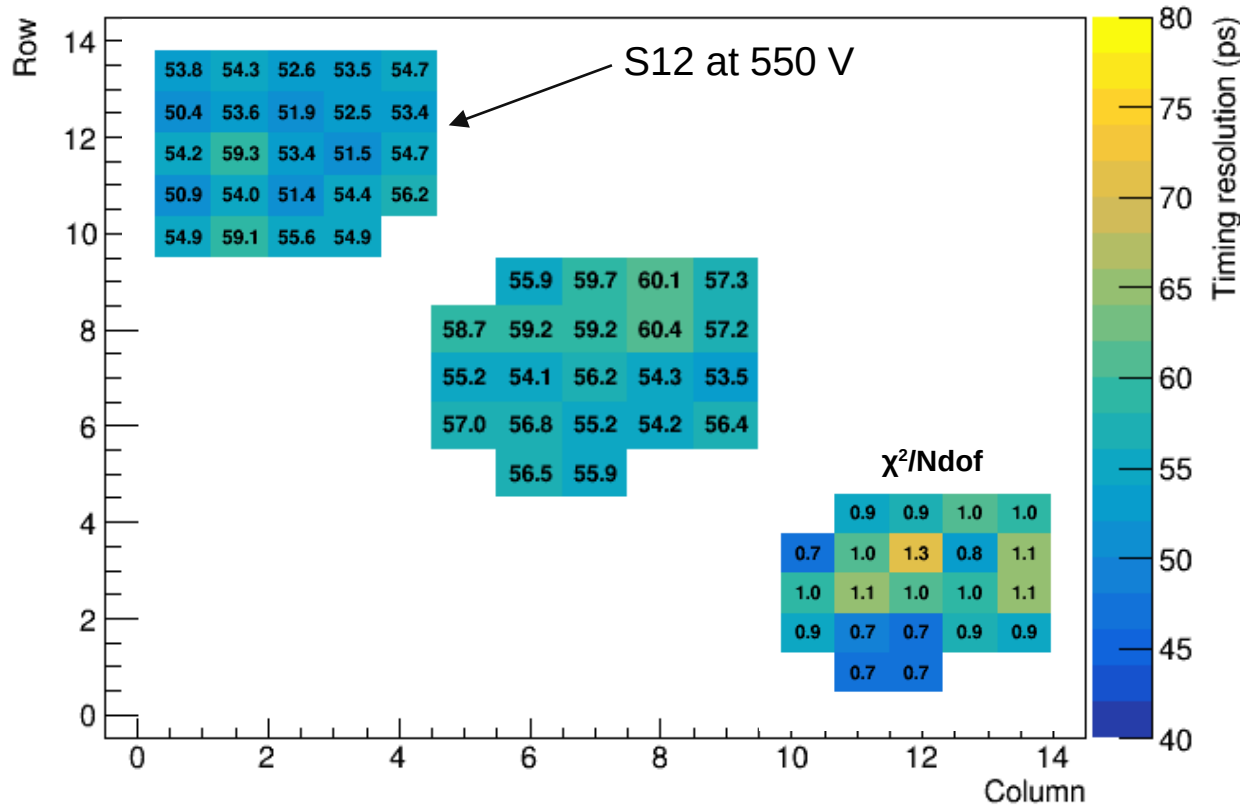
Trigger



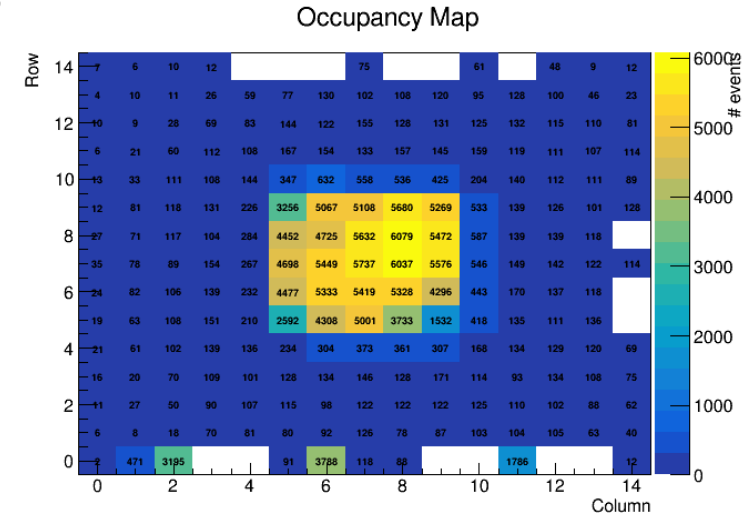
Some events are not well correlated
(random clock position relative to trigger;
expected within acquisition window -
majority of events)

S13 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$, $U = 530 \text{ V}$

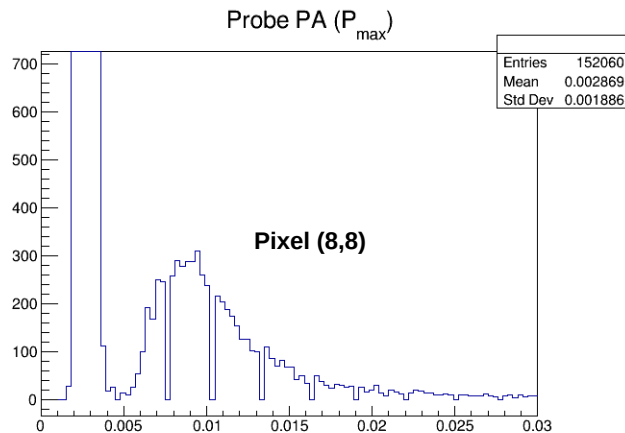
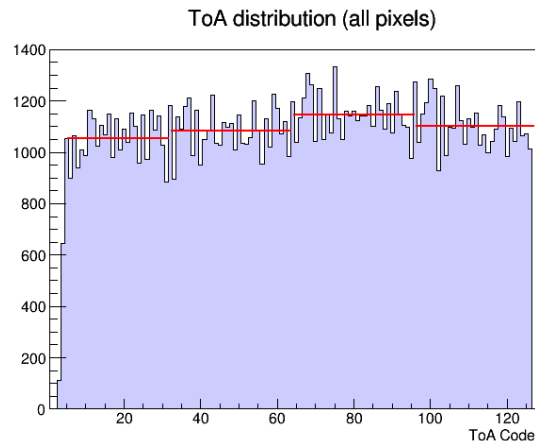
DscbFitter results_4LSB_tw timing_resolution



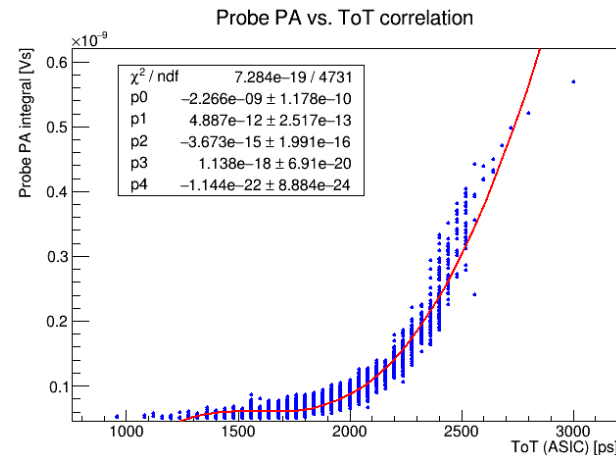
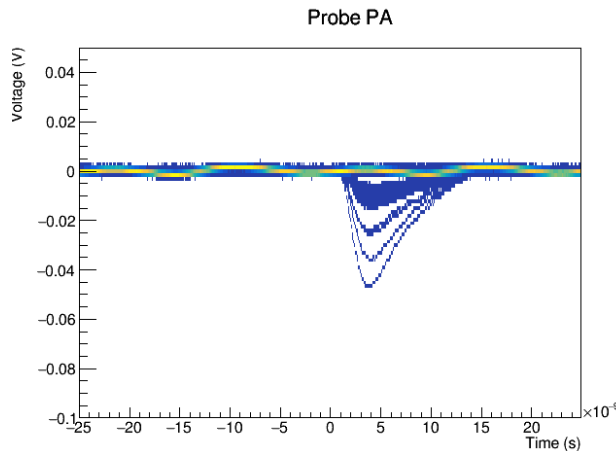
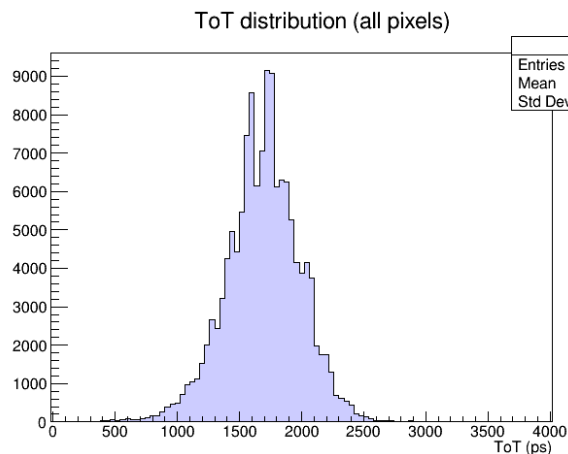
Second hybrid tested at a lower voltage (measured resolution is a somewhat higher compared to previous device)



S13 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$, $U = 530 \text{ V}$



Flat ToA distribution, peak values of analog waveforms on probe PA follow landau distribution

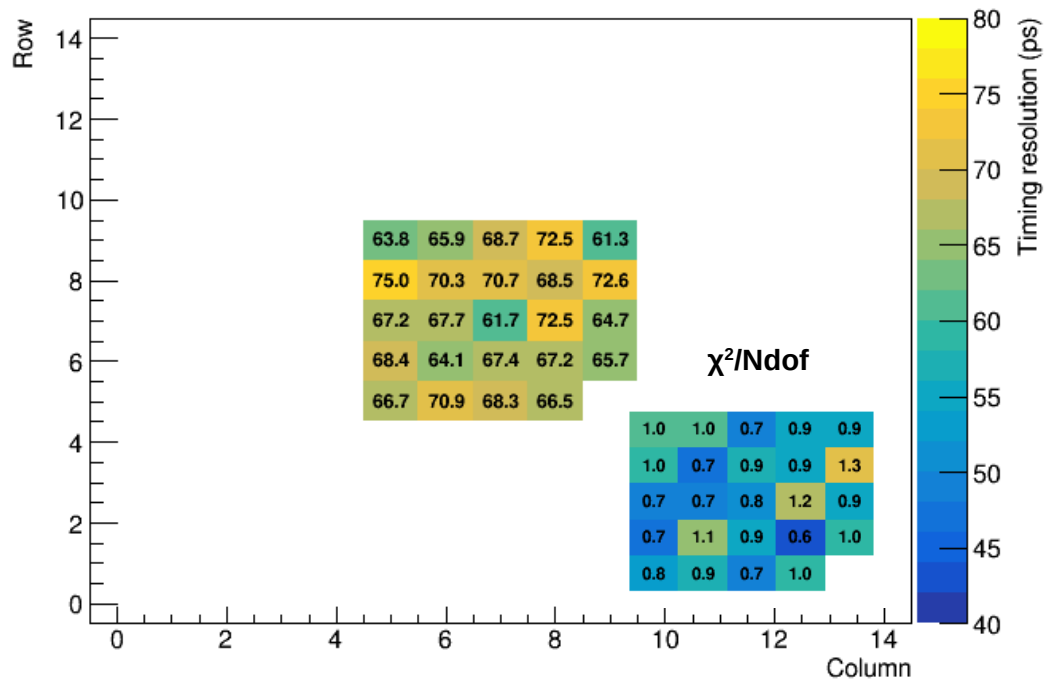


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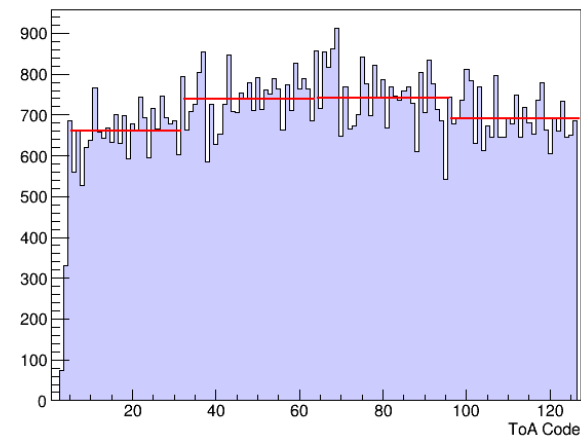
Hybrid timing measurements

S13 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$, $U = 400 \text{ V}$

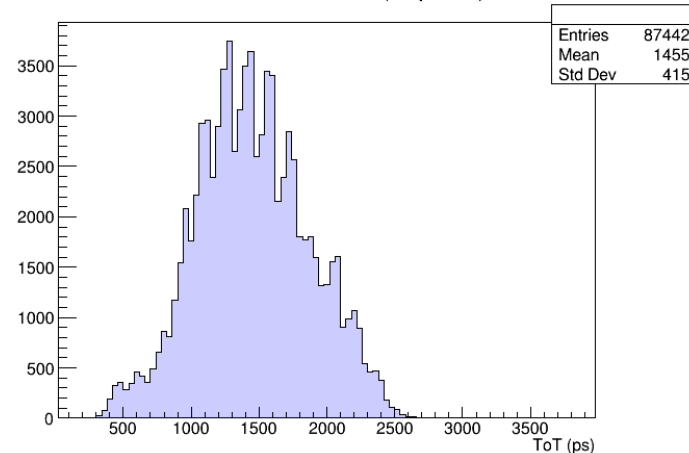
DscbFitter results_4LSB_tw timing_resolution



ToA distribution (all pixels)



ToT distribution (all pixels)



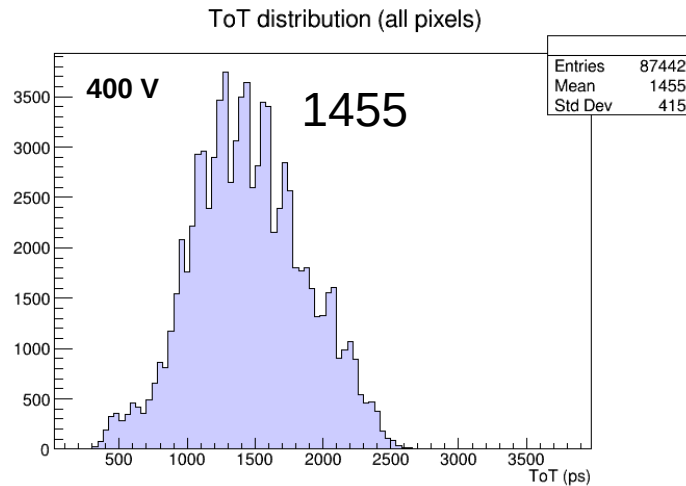
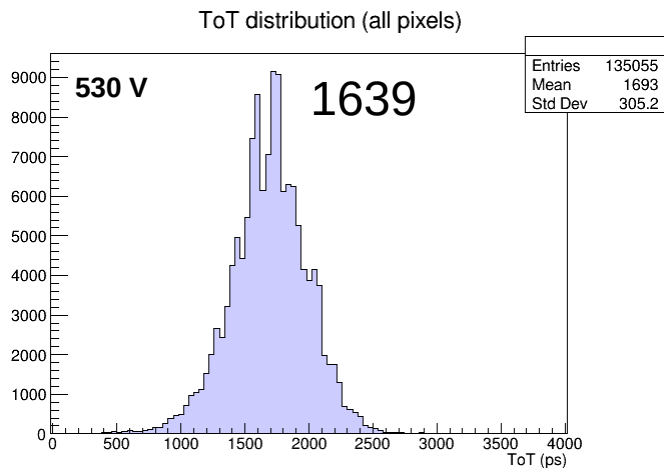
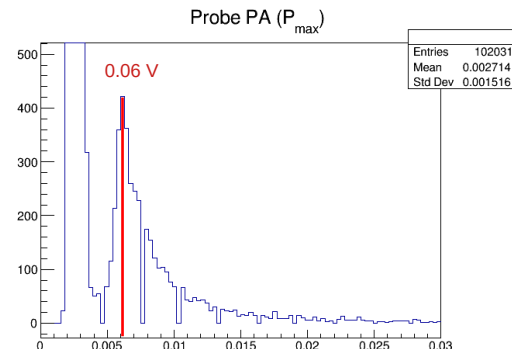
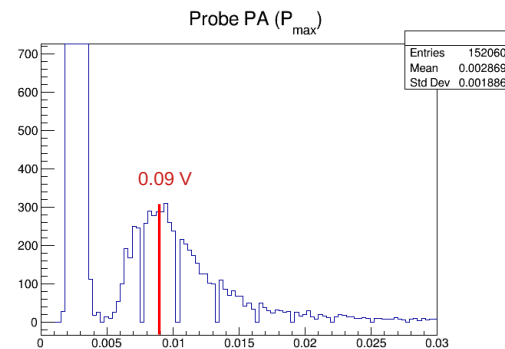
S13 - $2.5 \cdot 10^{15} \text{ n}_{\text{eq}}/\text{cm}^2$ comparison 530 V and 400 V

Timing 530 V

	55.9	59.7	60.1	57.3
58.7	59.2	59.2	60.4	57.2
55.2	54.1	56.2	54.3	53.5
57.0	56.8	55.2	54.2	56.4
	56.5	55.9		

Timing 400 V

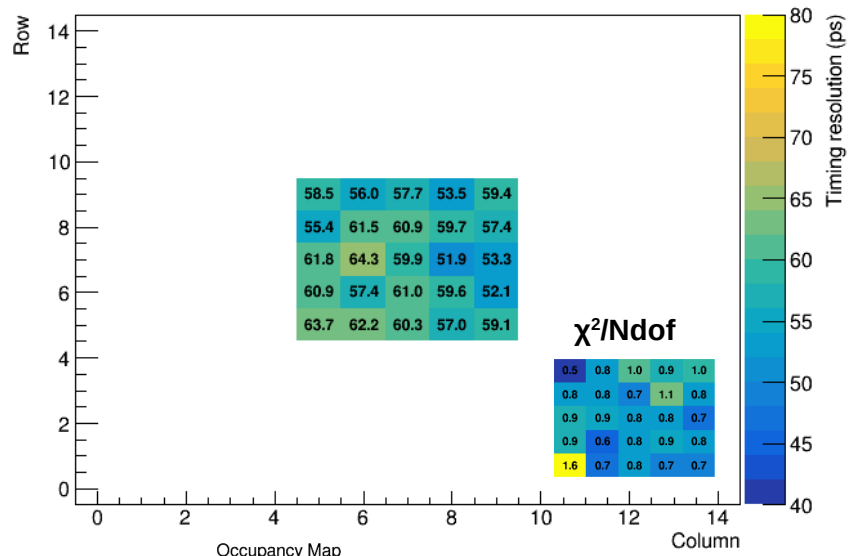
63.8	65.9	68.7	72.5	61.3
75.0	70.3	70.7	68.5	72.6
67.2	67.7	61.7	72.5	64.7
68.4	64.1	67.4	67.2	65.7
66.7	70.9	68.3	66.5	



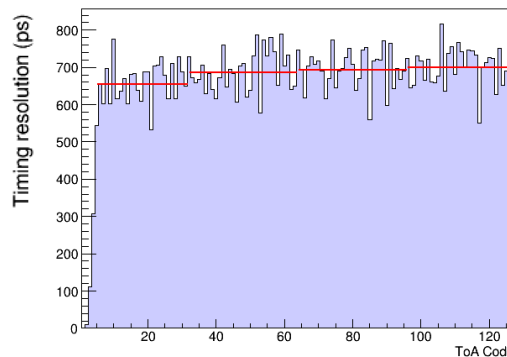
Hybrid timing measurements

Unirradiated reference at 95 V (-40 °C)

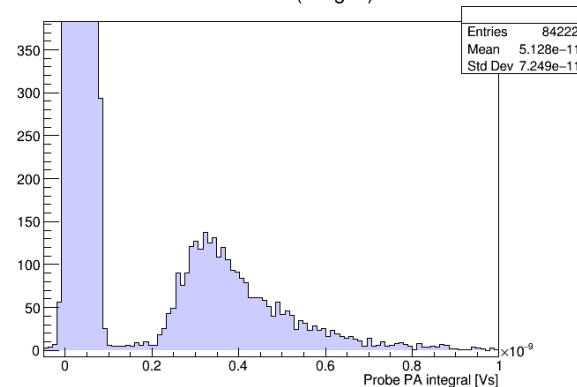
DscbFitter results_4LSB_tw timing_resolution



ToA distribution (all pixels)

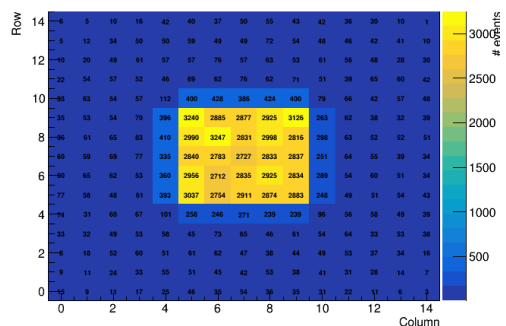


Probe PA (integral)

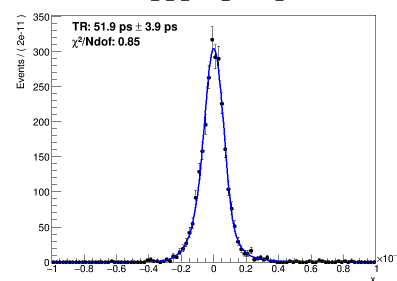


Timing resolution results are higher than expected (Temperature too low? Breakdown above 105 V).

Had some issues with reference LGAD, could not get past 95 V at -40 °C without breakdown occurring. Replaced with identical sensor that is able to go up to 155 V at -40 °C.



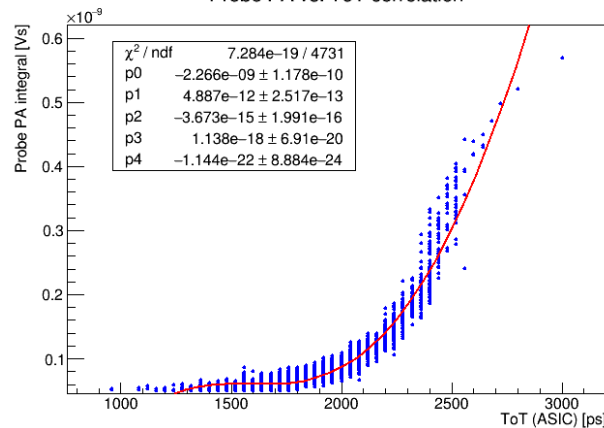
Pixel_8_7_4LSB_stacked_TW



Pulse shape evolution

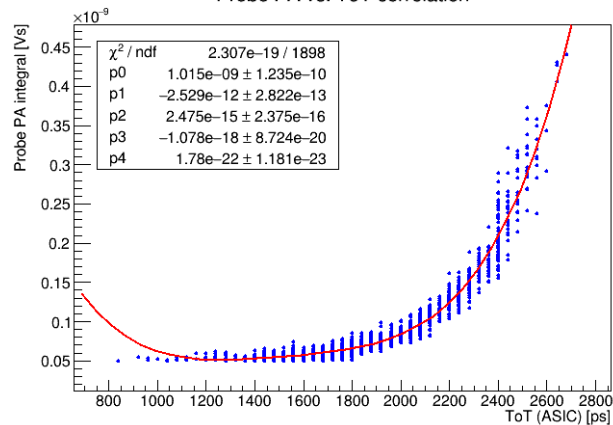
S13 530 V

Probe PA vs. ToT correlation



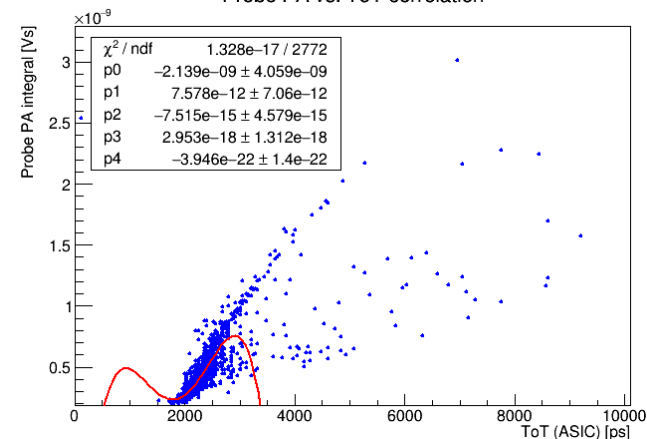
S13 400 V

Probe PA vs. ToT correlation

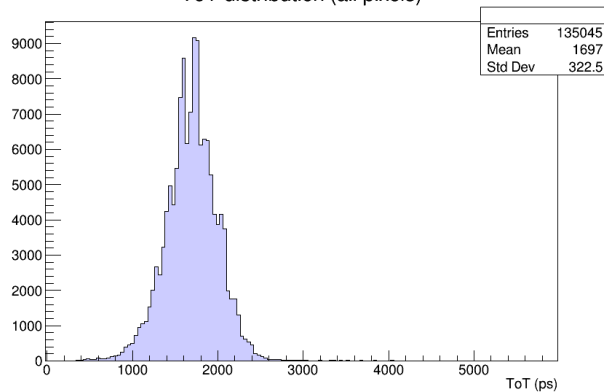


Reference 95 V

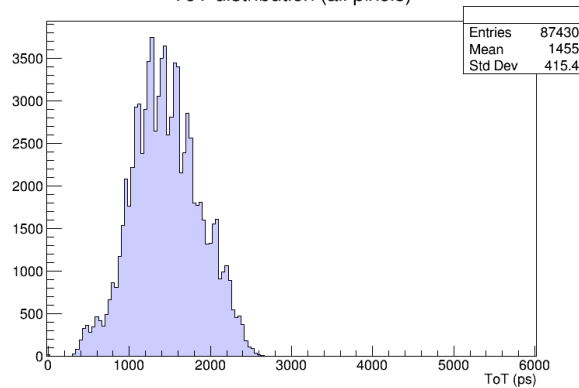
Probe PA vs. ToT correlation



ToT distribution (all pixels)



ToT distribution (all pixels)



ToT distribution (all pixels)

