New RF Structure Analysis Methods

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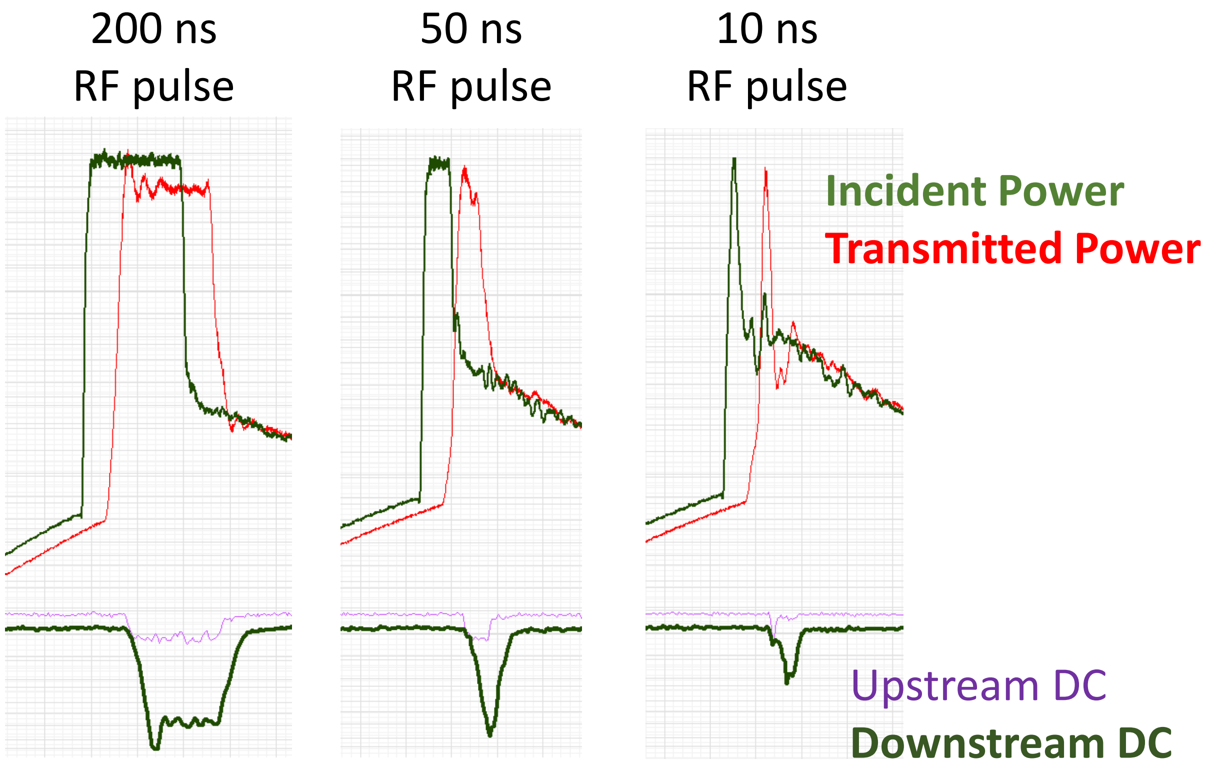
CLIC Workshop
22 January 2018

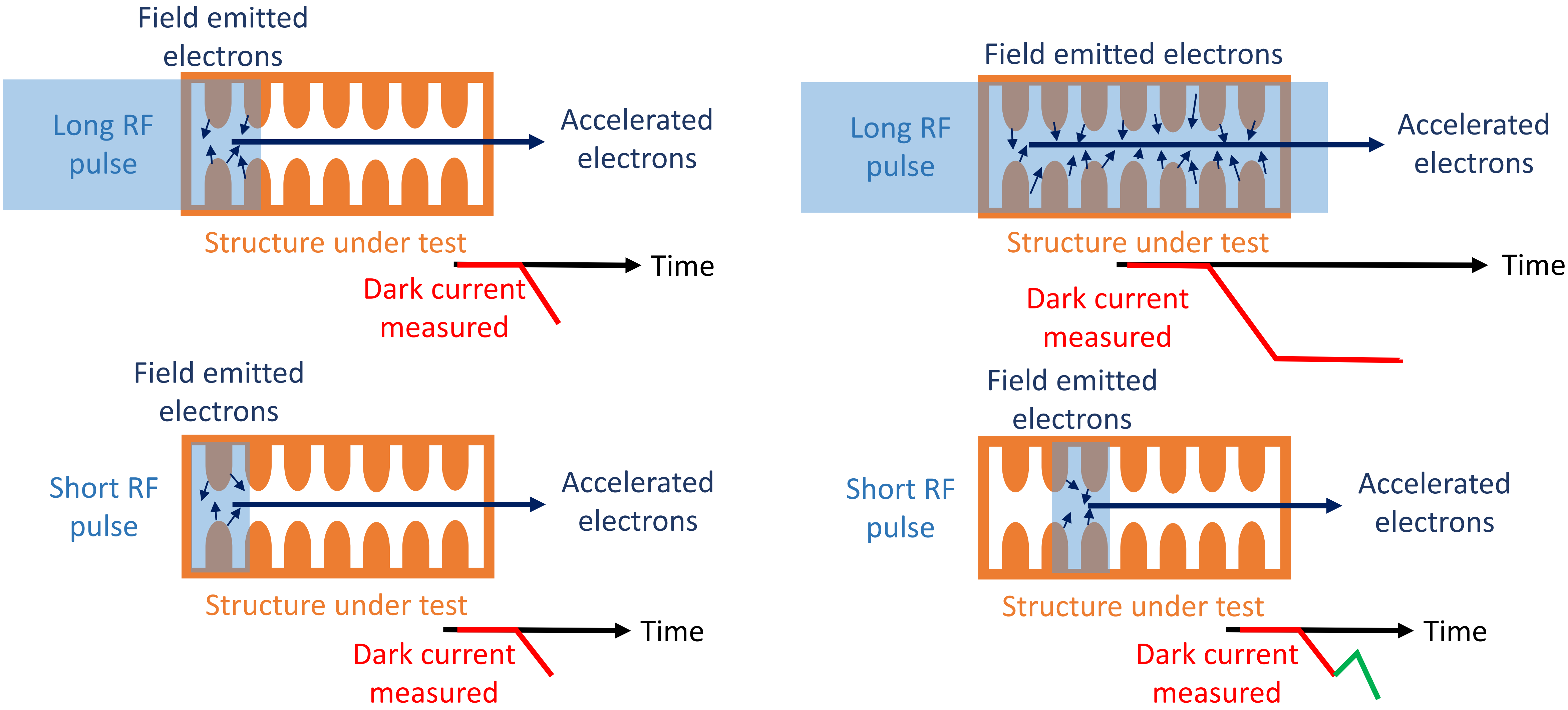
Field Emission Profile Measurements

Dark Current vs. RF Pulse Shape



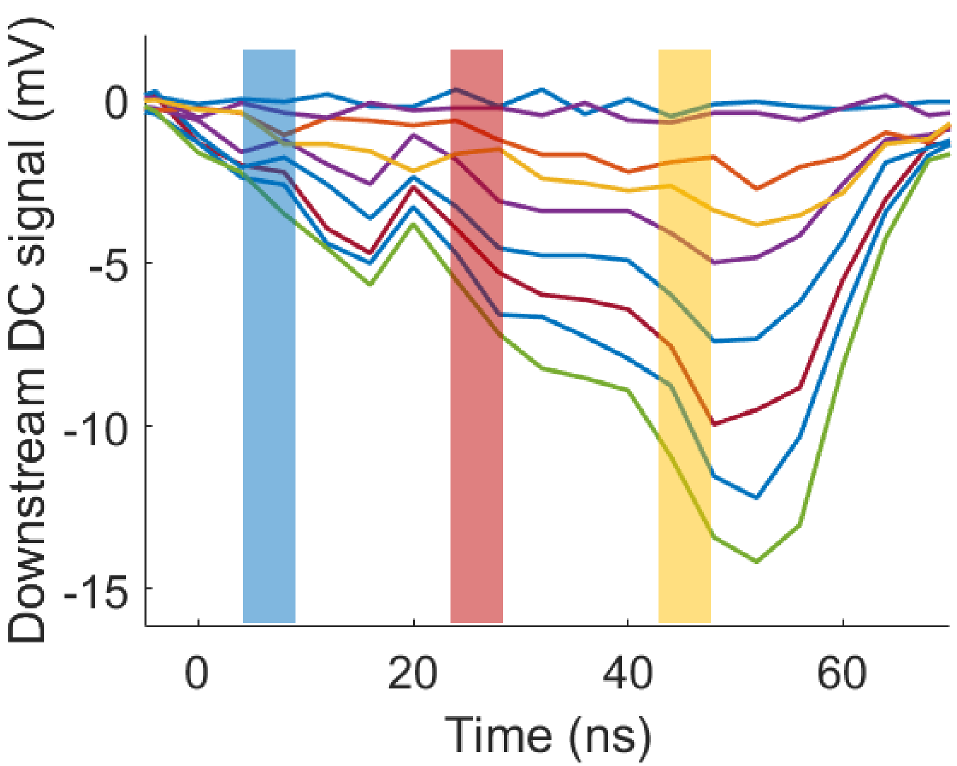
- Dark current measured rises and falls as structure fills and unfills – this could give useful information.
- Structures have low group velocity: 0.01…0.02 c.
- Emitted electrons can become relativistic within one cell.
- With long RF pulses, the entire structure emits electrons simultaneously.
- A very short pulse allows field emission to be probed in different parts of the structure.

Separating Parts of the Structure in Time

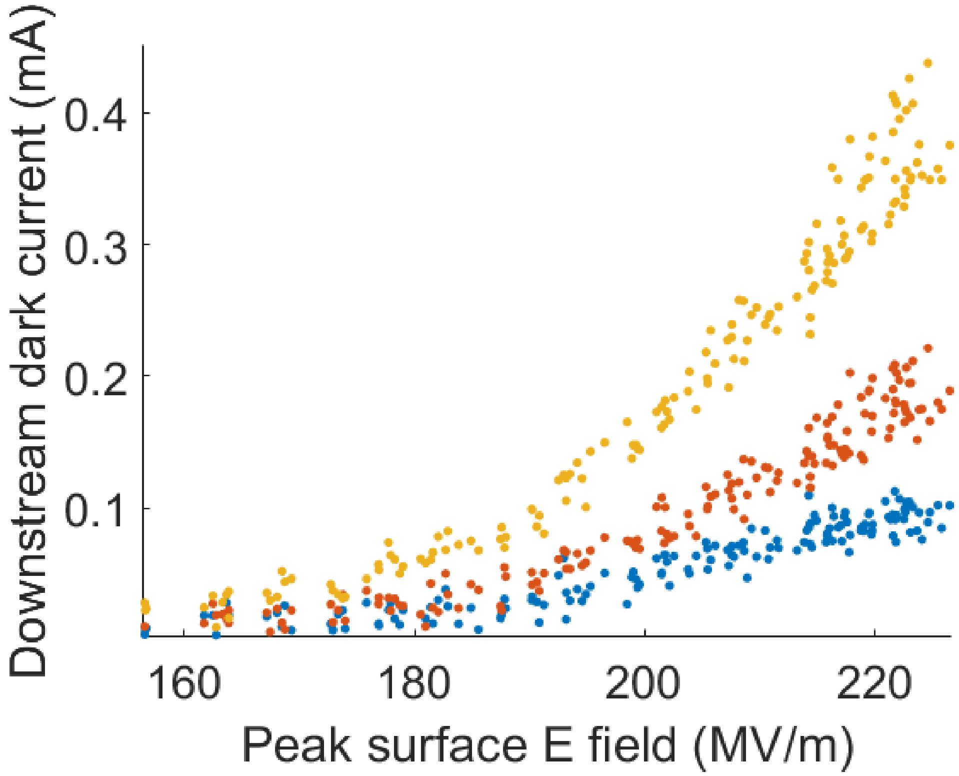


Mapping Field Emission

Dark current power scan with a 10 ns pulse length.

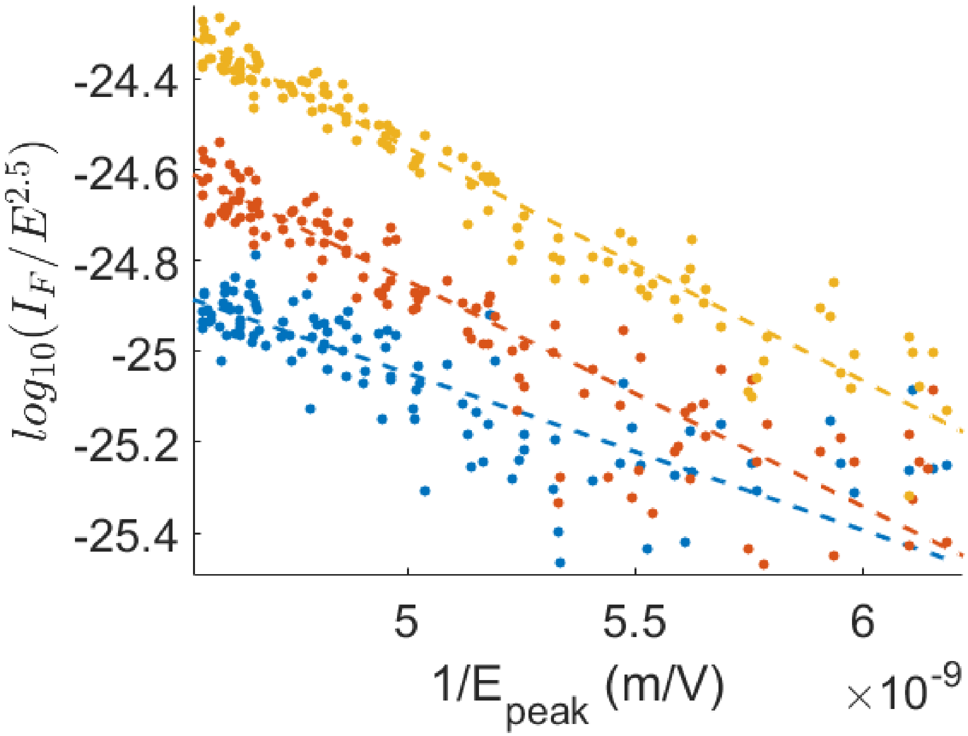


Dark current by sample as a function of surface E-field.



Mapping Field Emission

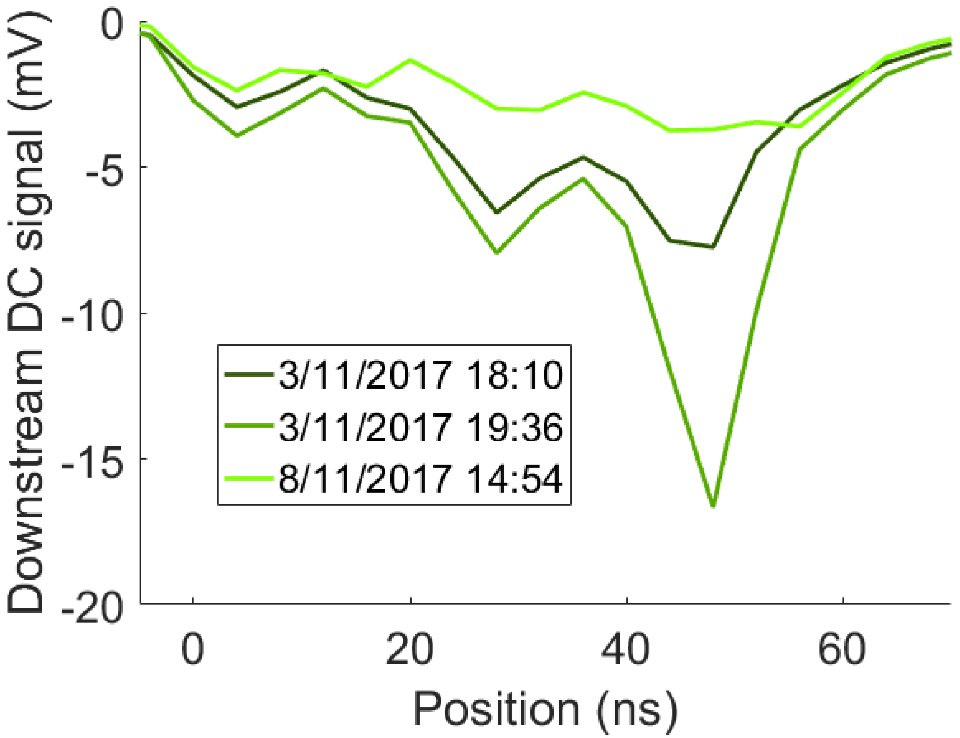
Fowler-Nordheim plot of dark current at each sample.



Fitted β value for each sample.

Behaviour Over Time

Dark current signal at E_{acc} = 100 MV/m on different days.



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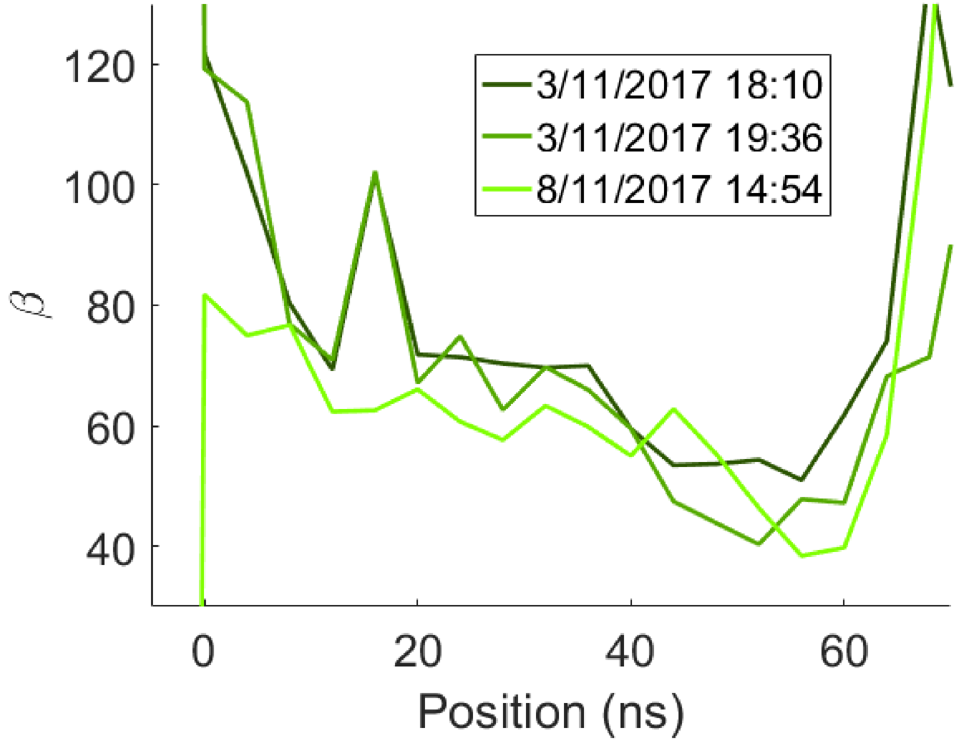

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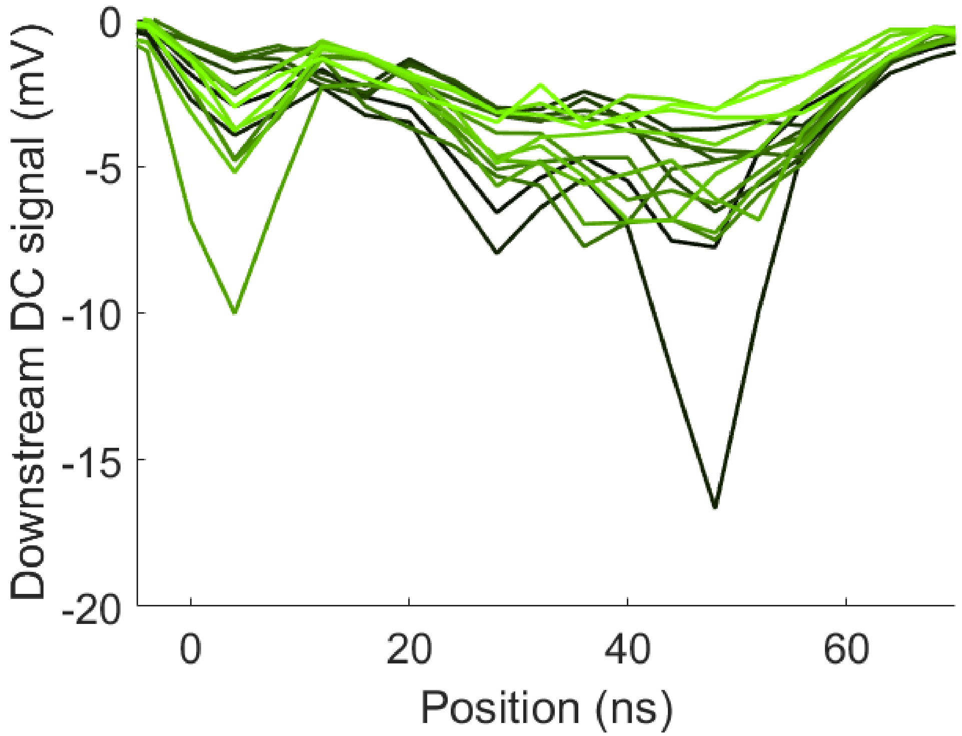

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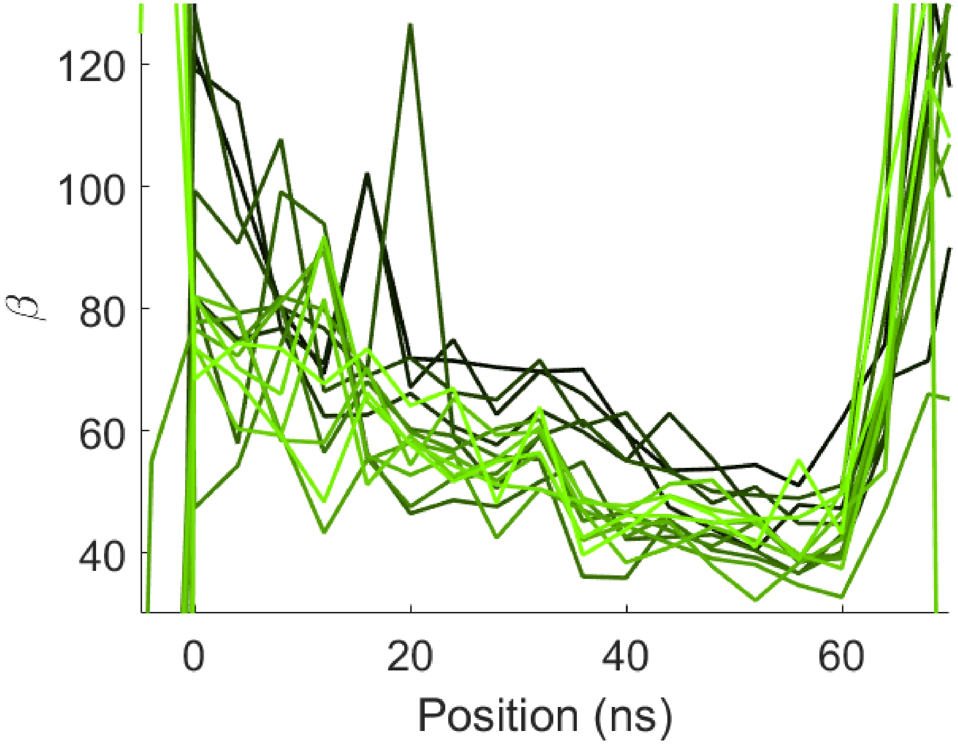
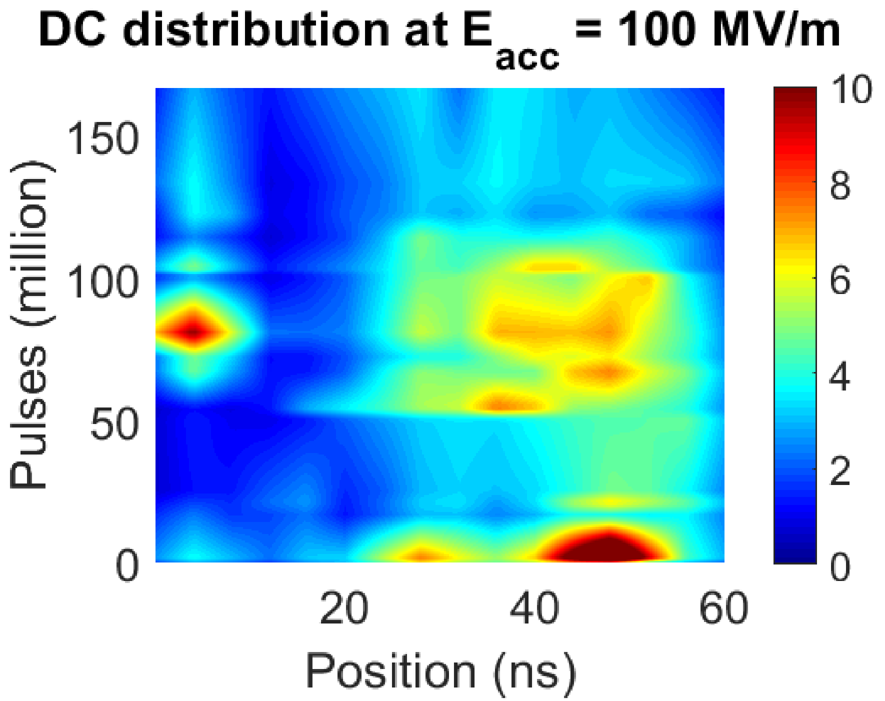
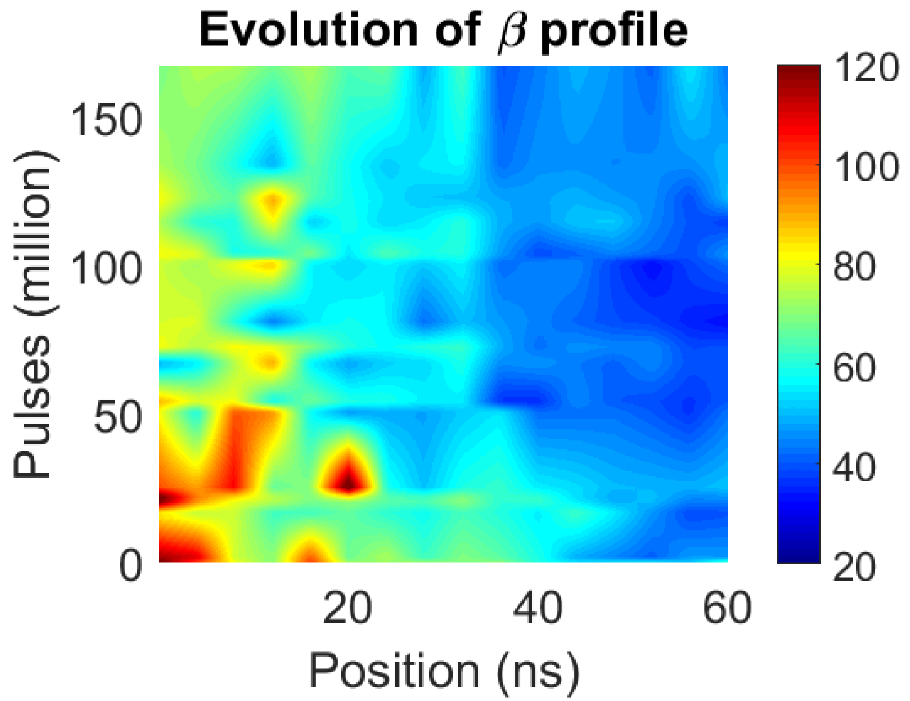
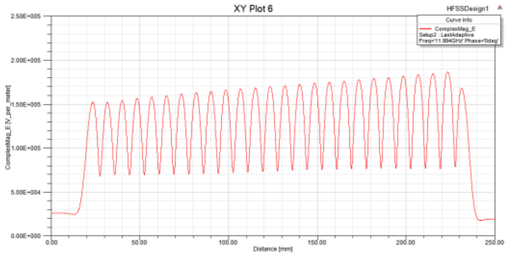
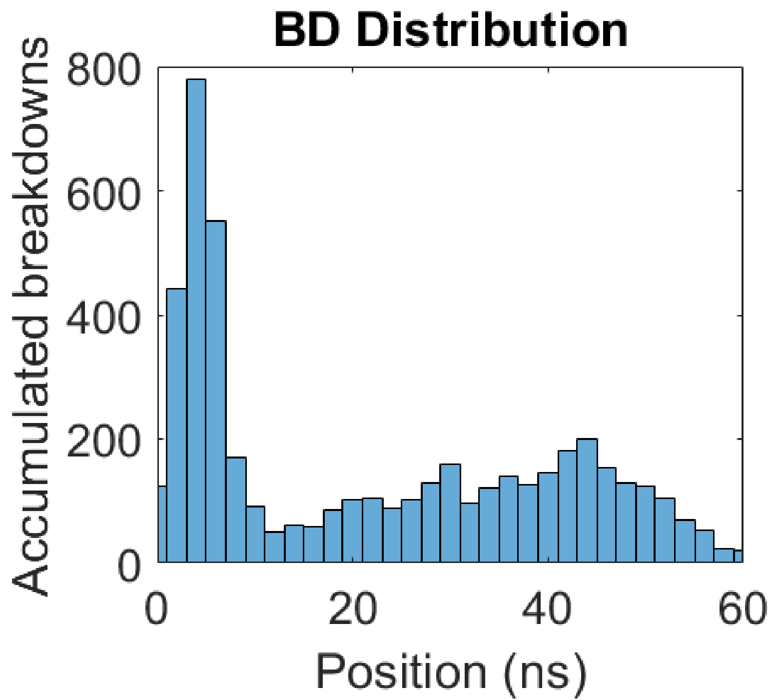


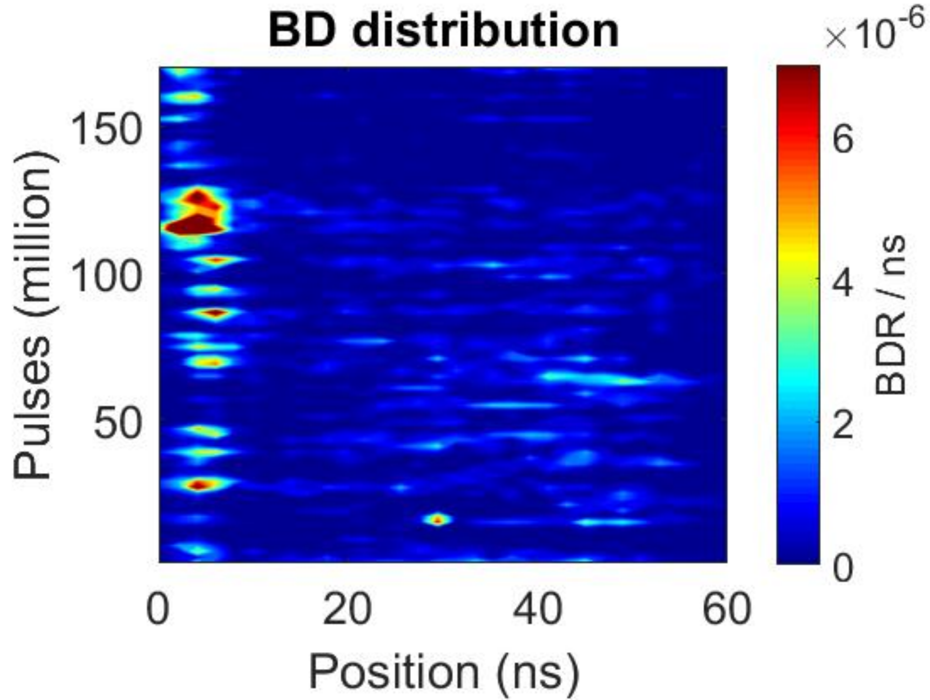




β value corrected for varying E-field along structure.



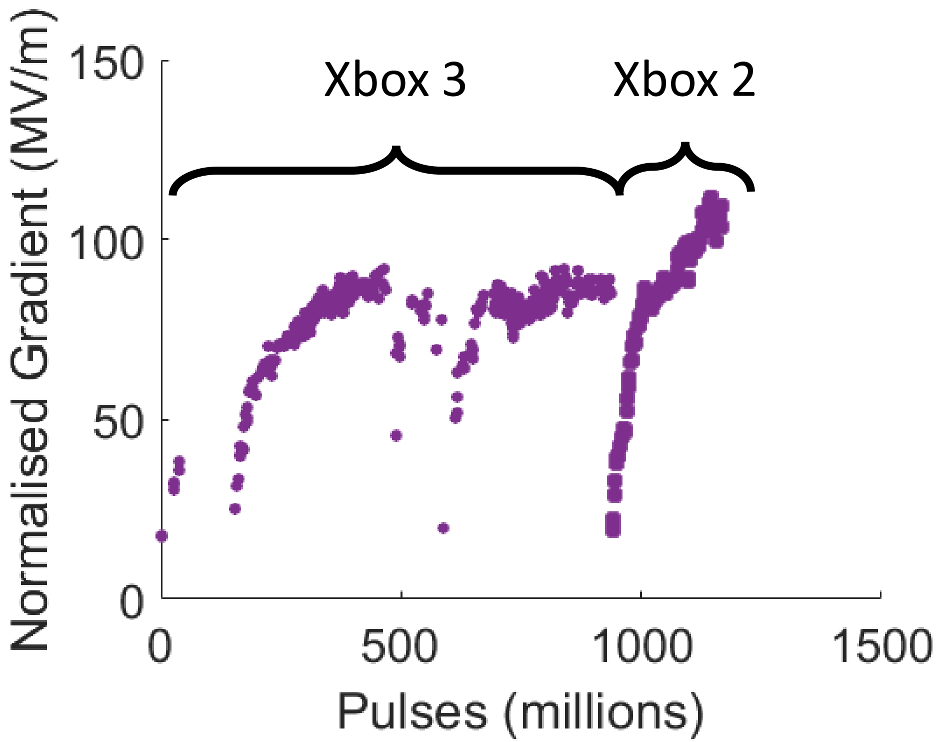




Further Work

- Measure full conditioning of a structure from start to finish – these measurements started after PSI structure moved to Xbox 2.
- Account for electron transport between field emission site and Faraday cup, dispersion, etc.
- Possibly measure radiation in addition to dark current.

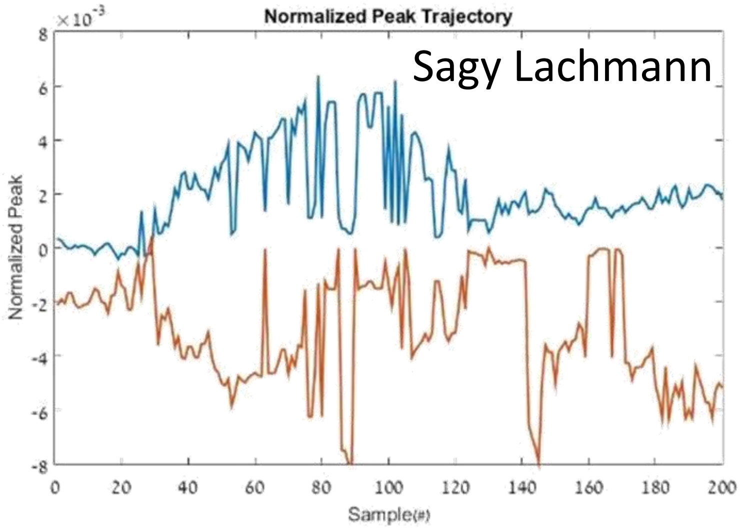
PSI1 structure conditioning curve.

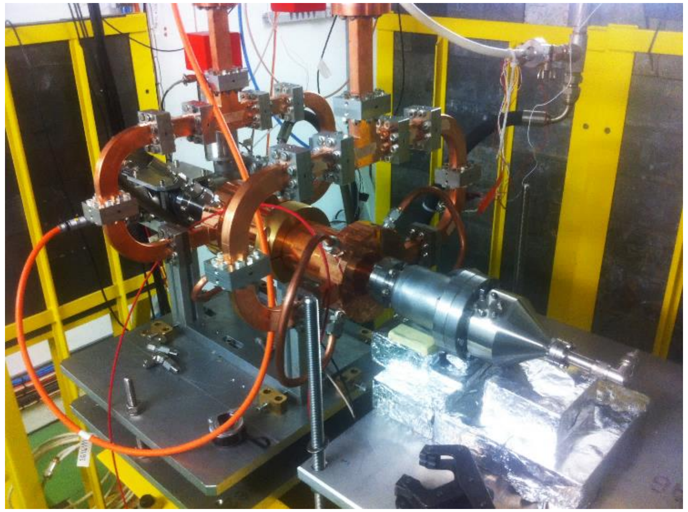


Dark Current Fluctuation Measurements

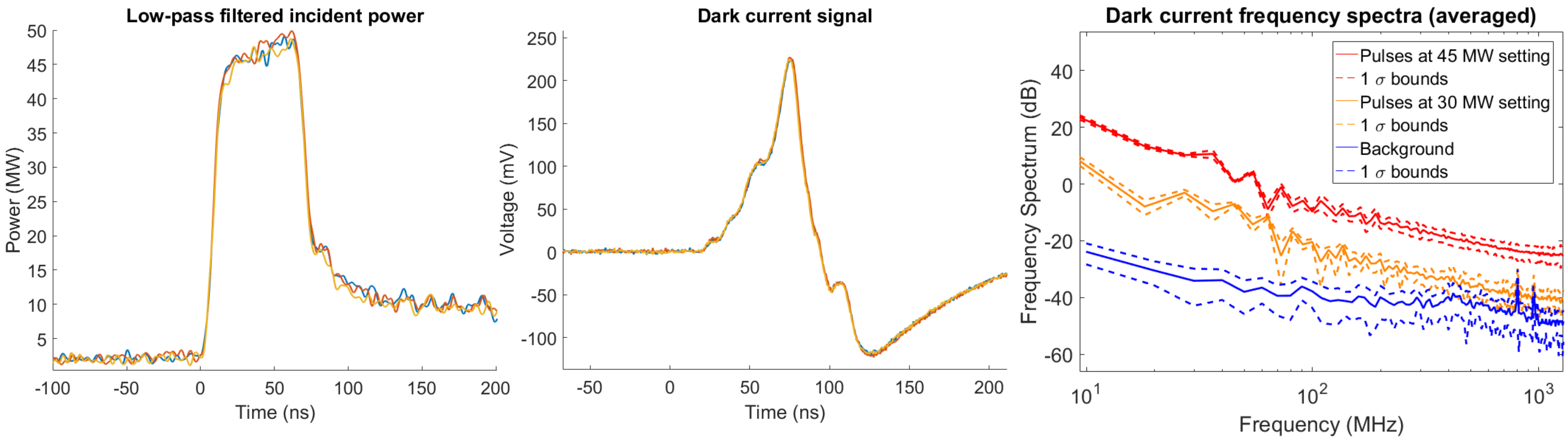
Dark Current Fluctuations in RF Structures

- Fluctuations in dark current observed in DC system – give insight into dislocation dynamics inside copper.
- Attempting to perform the same measurement in the RF structures.
- Previous measurements hindered by low bandwidth of Faraday cups and poor SNR.
- Signal improved by using better Faraday cup, and low-noise preamplifier.



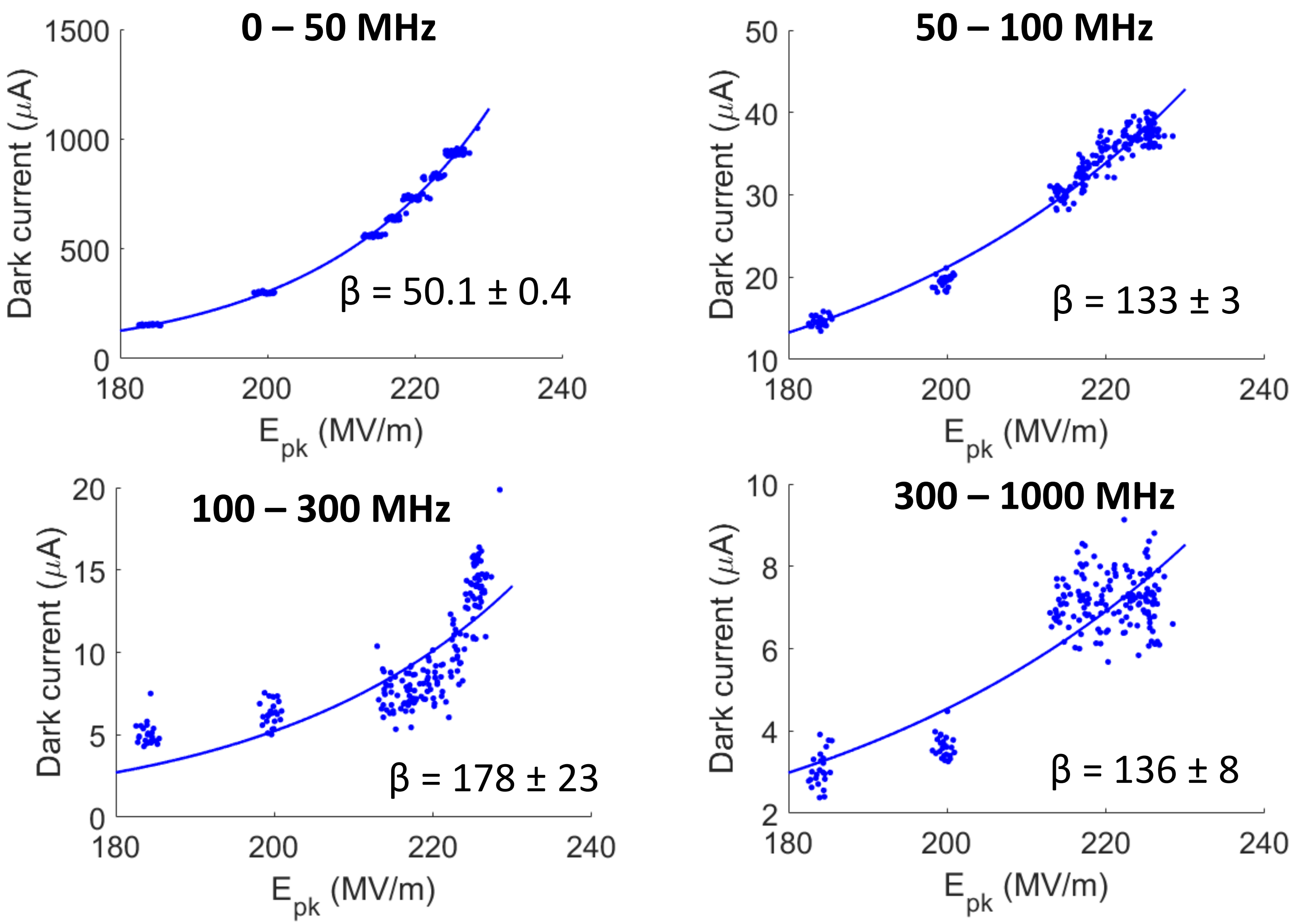


High Frequency Dark Current Measurements



Signal is inverted and high-pass filtered by amplifier. (Passband 20 MHz – 4 GHz)

Dependence on Power



Entire frequency spectrum varies exponentially with incident power, as expected for dark current phenomena.

i.e. The signal measured at high frequencies is not simply leakage from the high power RF.

Further Work

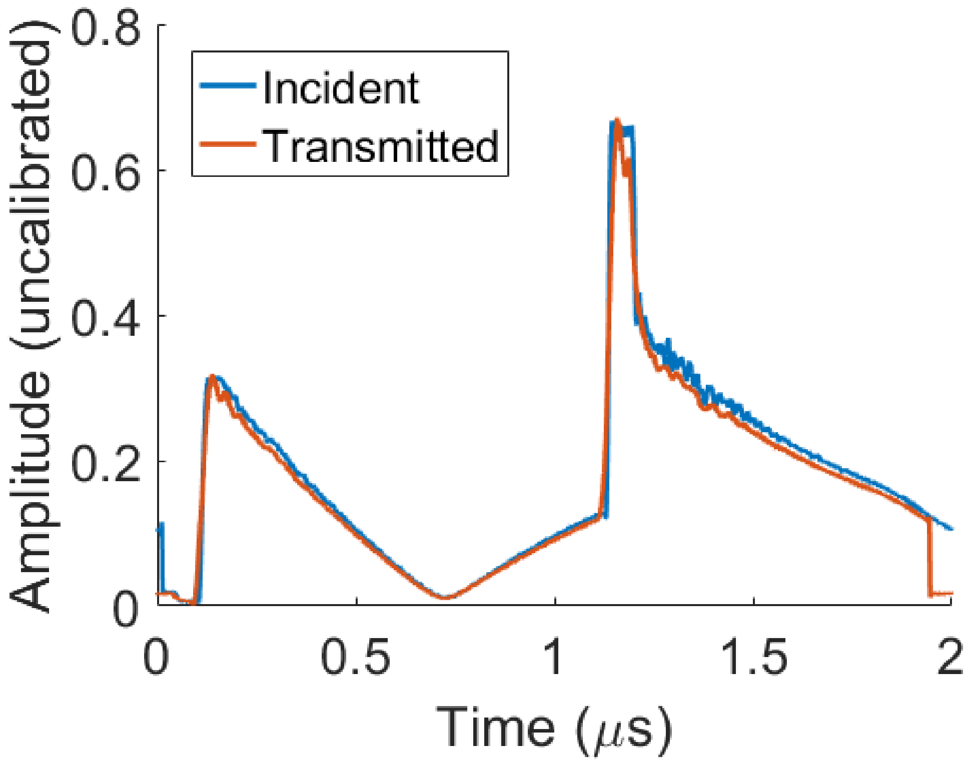
- Determine the cause of the measured dark current noise.
  - e.g. noise in RF pulse, shot noise due to quantisation of electrons.
  - structure + Faraday cup act like a diode: possible intermodulation effects.
  - or indeed surface fluctuations.
- Further improve bandwidth & signal-to-noise ratio.

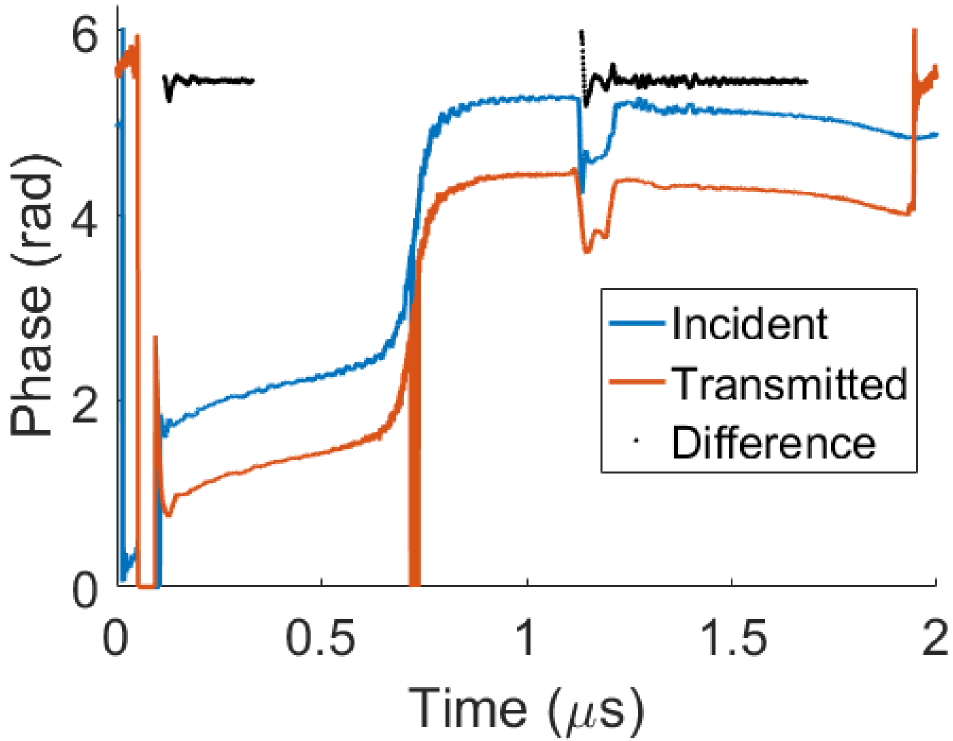
In-Situ Phase Measurements

Motivation

- Phase of acceleration is an important parameter to know.
- Temperature dependent effects in RF structures have been noticed.
- Need to begin properly measuring temperature and its effects.

Phase Measurement in High Power Testing

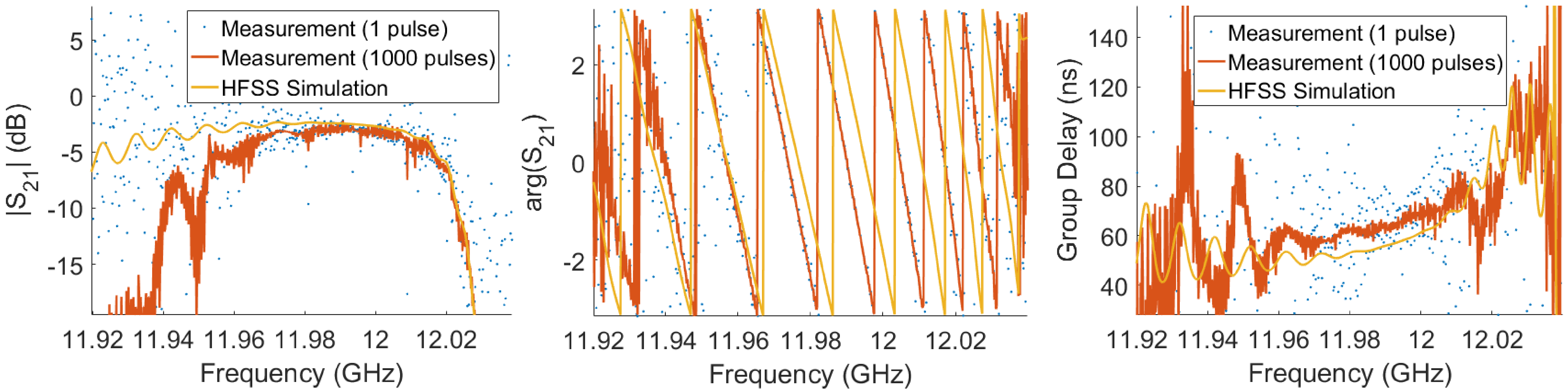




Signal edges aligned in time to compensate for time delay between incident and transmitted – important for short pulses.

Phase difference measured at times when amplitude is above a certain threshold.

Estimation of S-Parameters



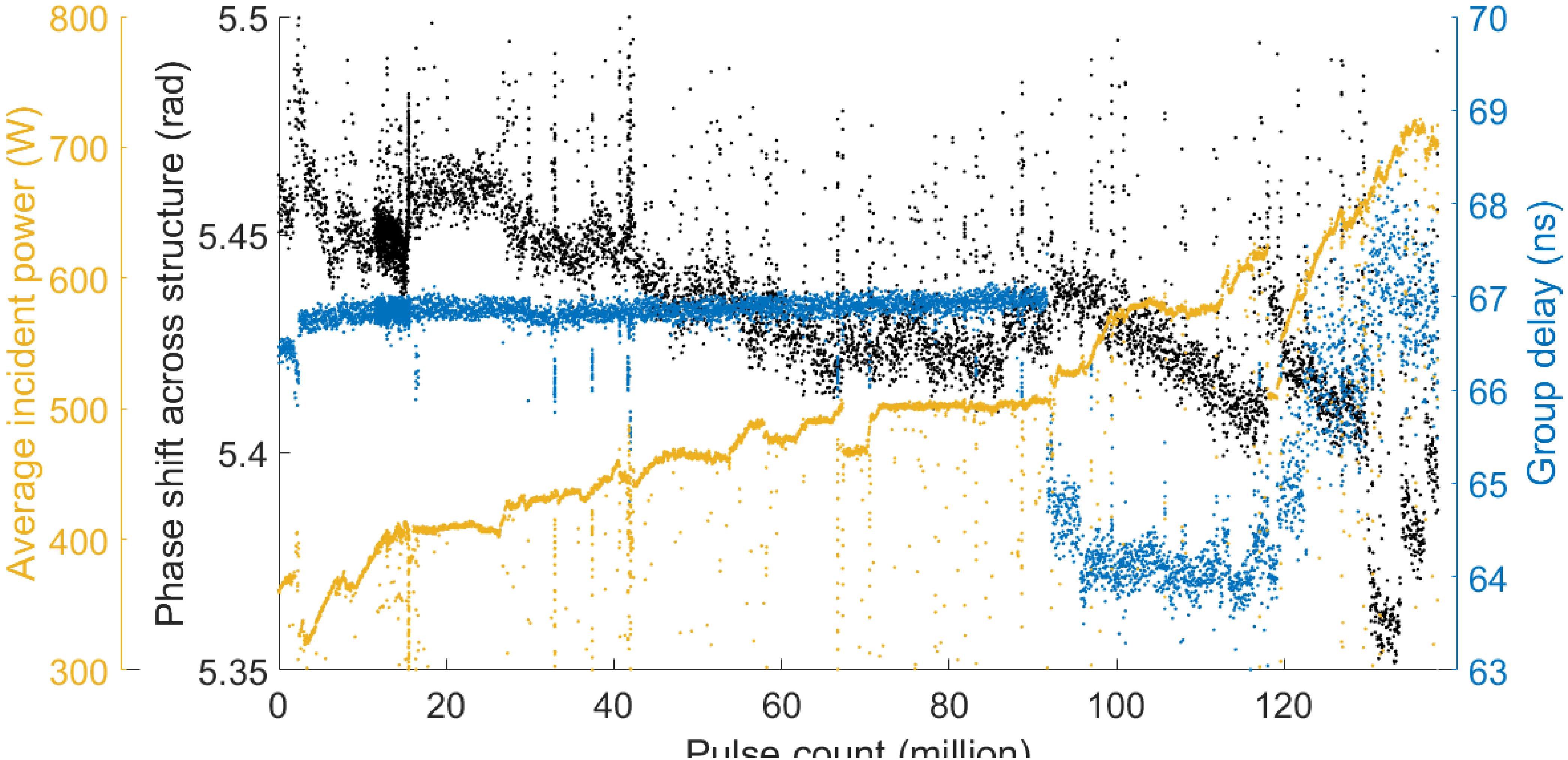
S-parameters and group delay could provide additional information.

Estimated by dividing the cross spectral density of the input and output by the power spectral density of the input. Excitation provided by normal RF pulses.

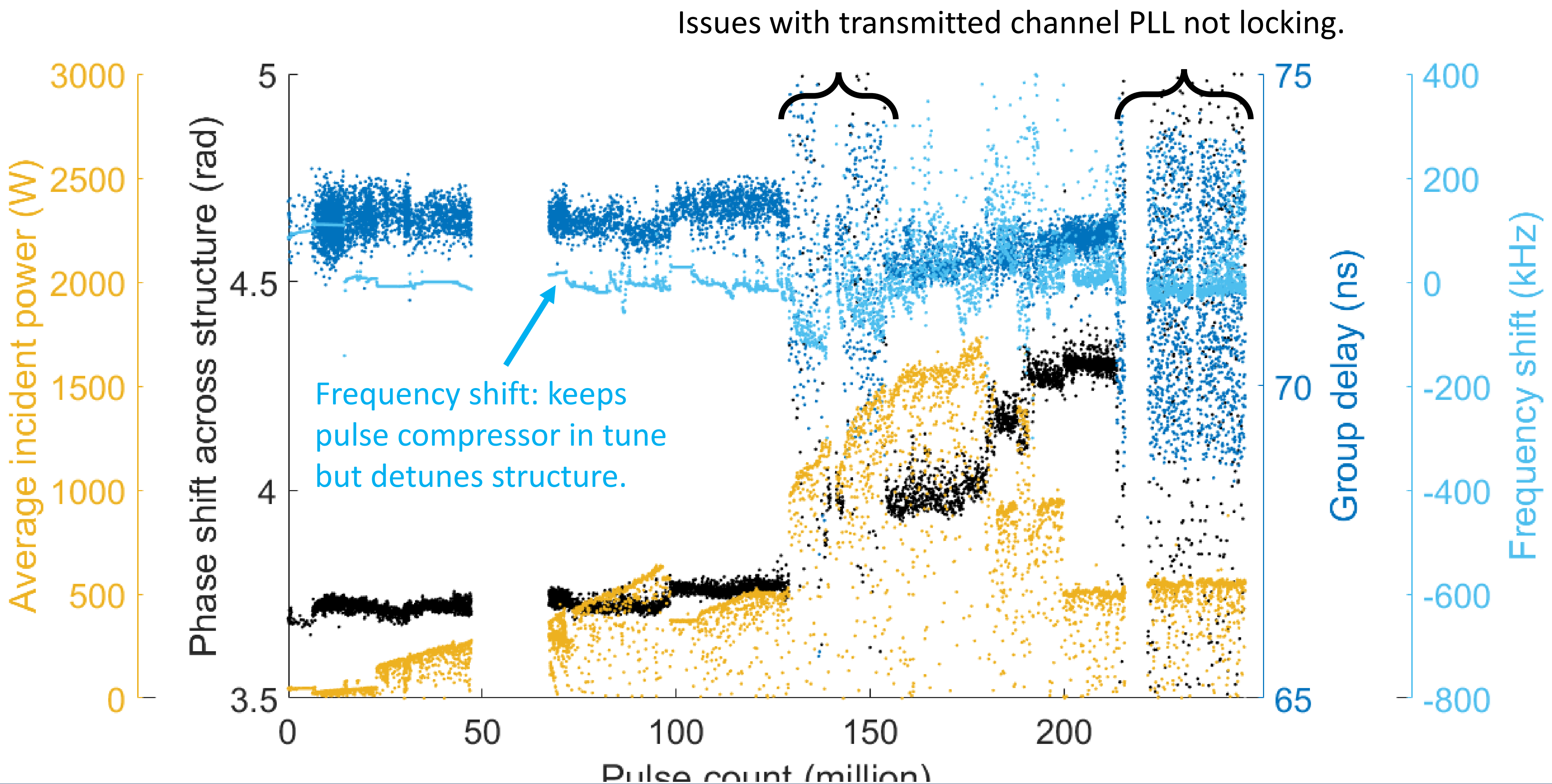
$$\widehat{S_{21}} = \frac{\langle FT[trans] \cdot FT[inc]^* \rangle}{\langle FT[inc] \cdot FT[inc]^* \rangle}$$

Data compared with the HFSS simulation used in the design of the structure.

Long Term Measurements: Xbox 2

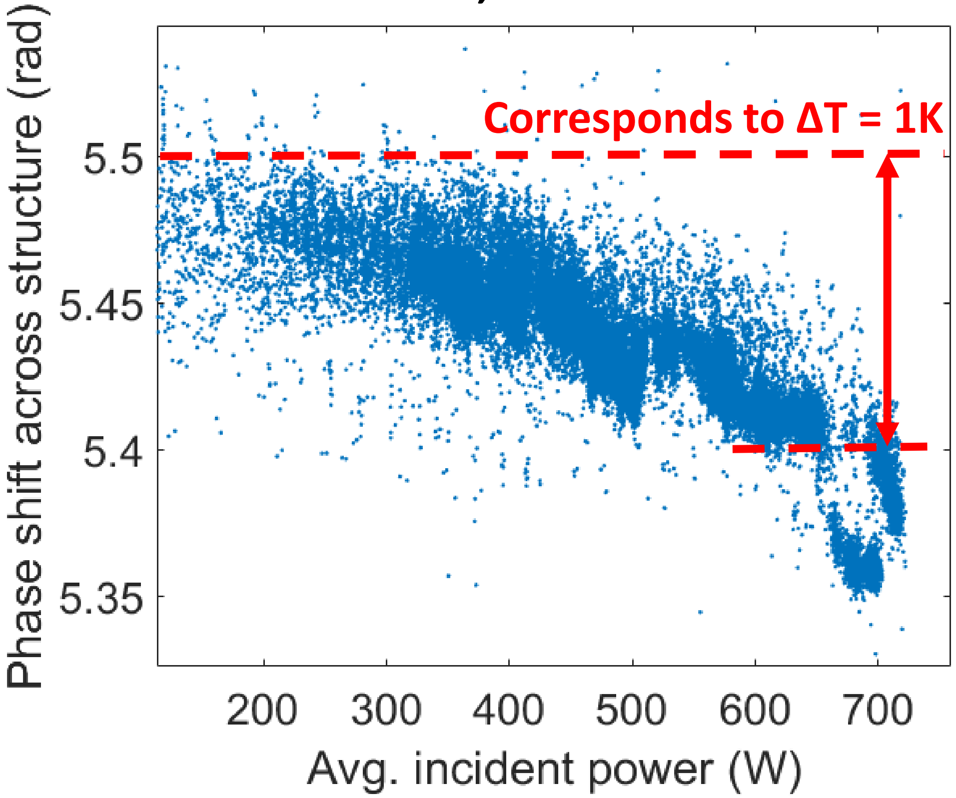


Long Term Measurements: Xbox 3C

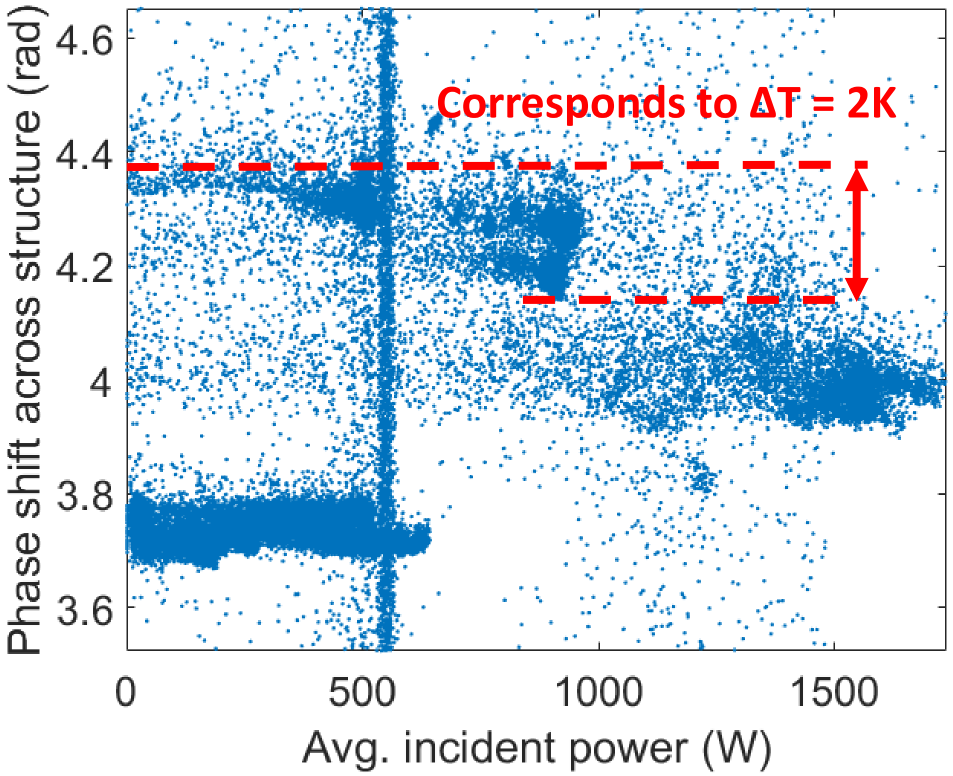


Correlation of Phase Shift to Incident Power

Xbox 2, PSI structure



Xbox 3C, SiC structure

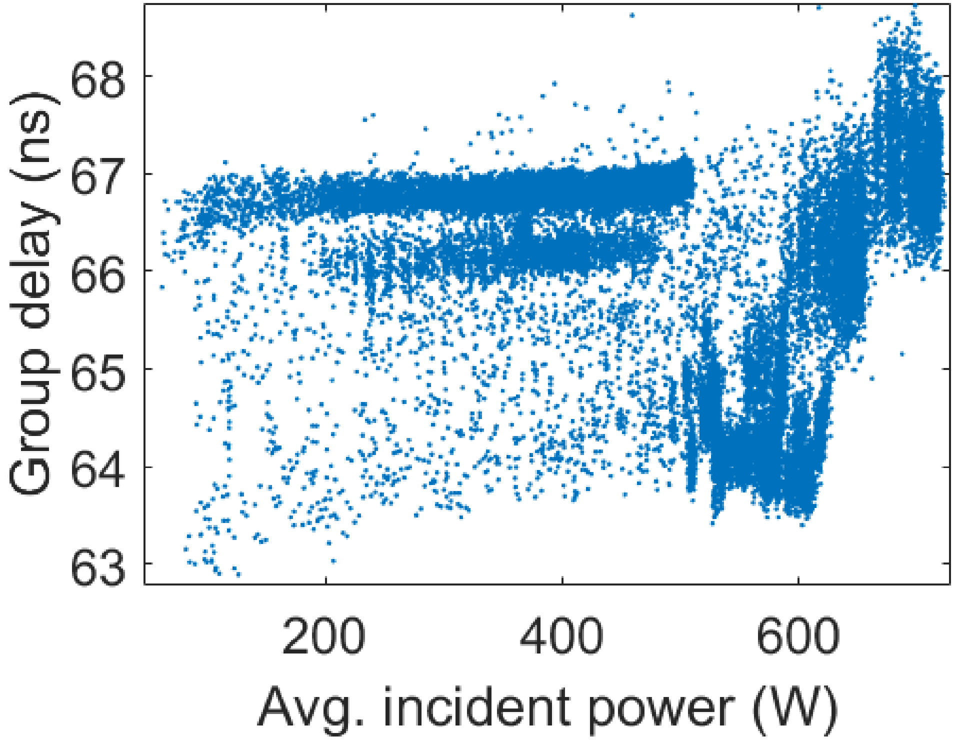


$$\frac{d\varphi}{dT} = -2\pi\alpha\tau_{group} f_0 \approx -0.1\, rad/K$$

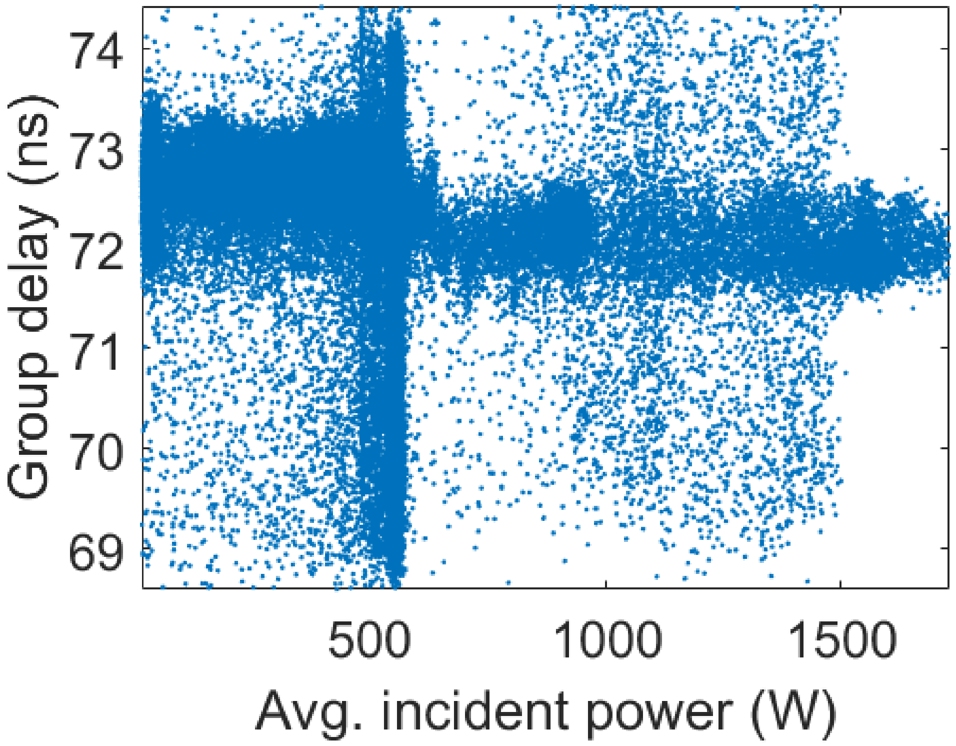
Phase value for SiC structure corrected for frequency shift using design group delay.

Correlation of Group Delay to Incident Power

Xbox 2, PSI structure



Xbox 3C, SiC structure



$$\frac{d\tau_{group}}{dT} \approx +0.1\, ns/K$$

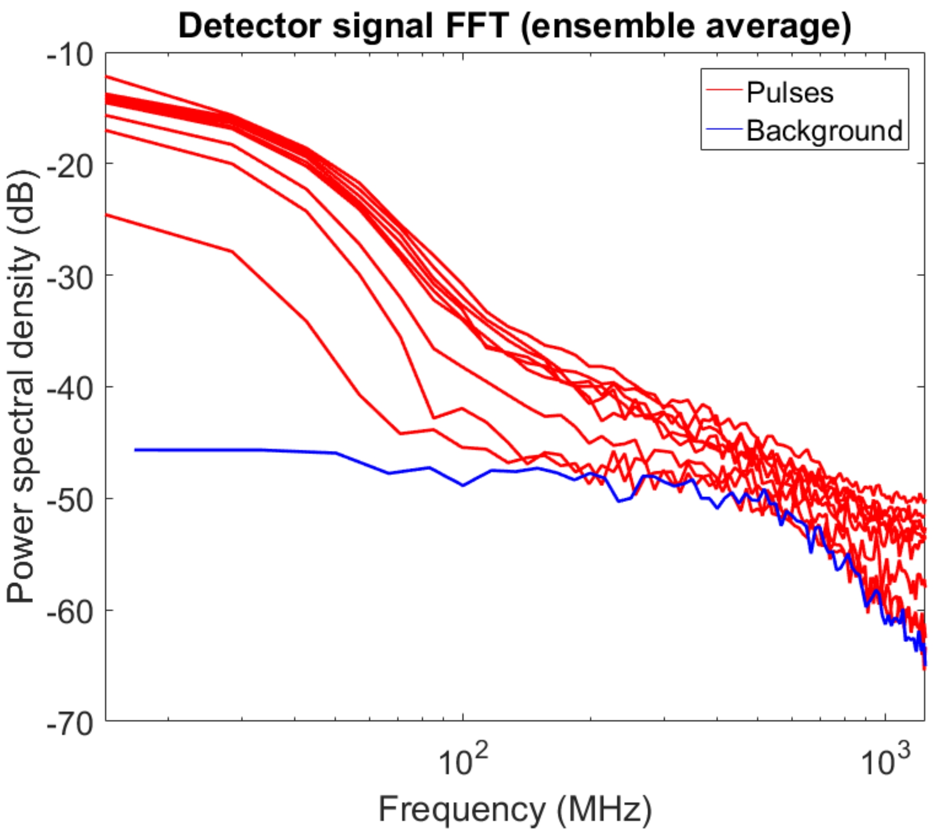
Further Work

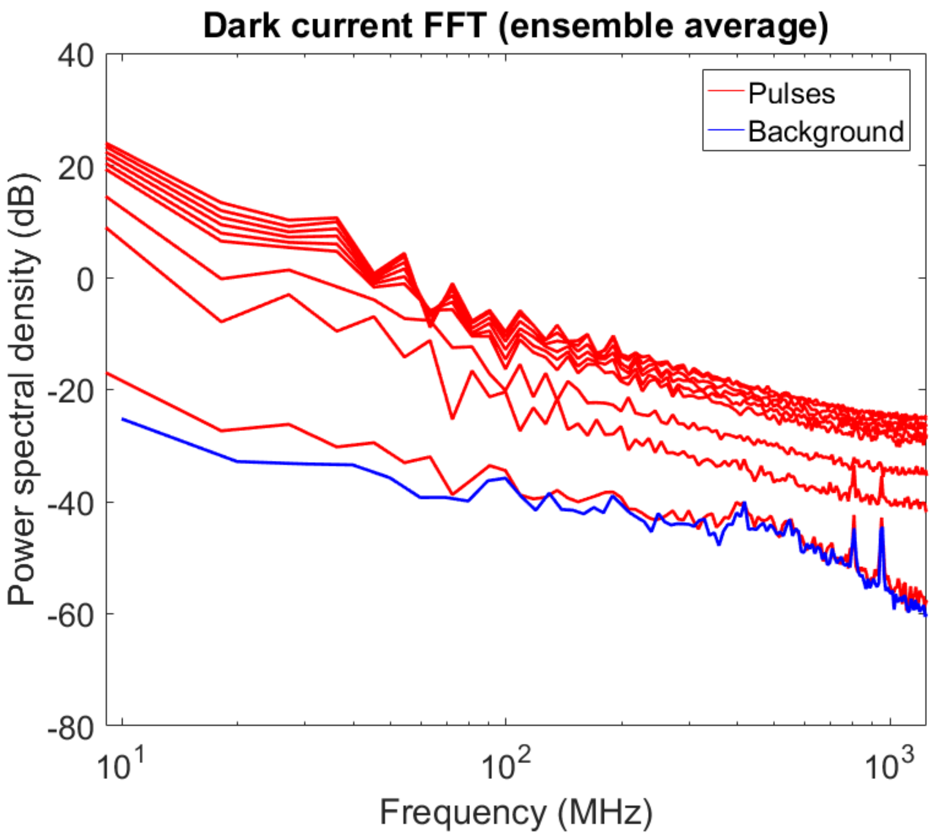
- There appears to be some measureable but very noisy signal.
- Improve phase and group delay signal quality: investigate both instrumentation and signal processing.
- Precise measurement of temperature and heat flow of structure.

Thank you!

Additional Slides

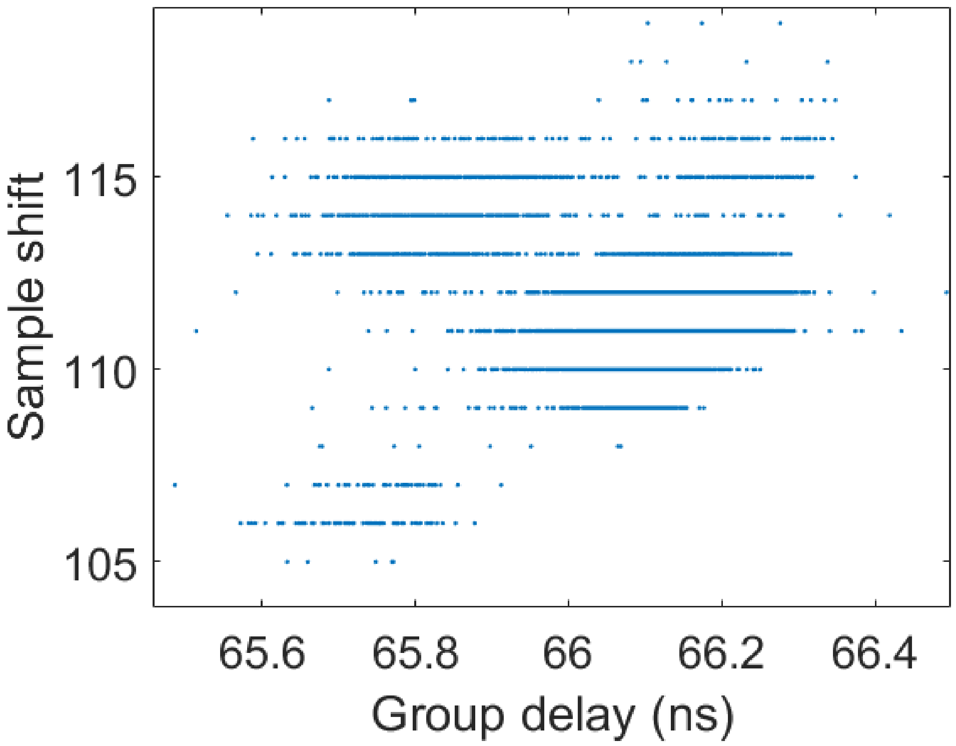
Dark Current vs. RF Noise



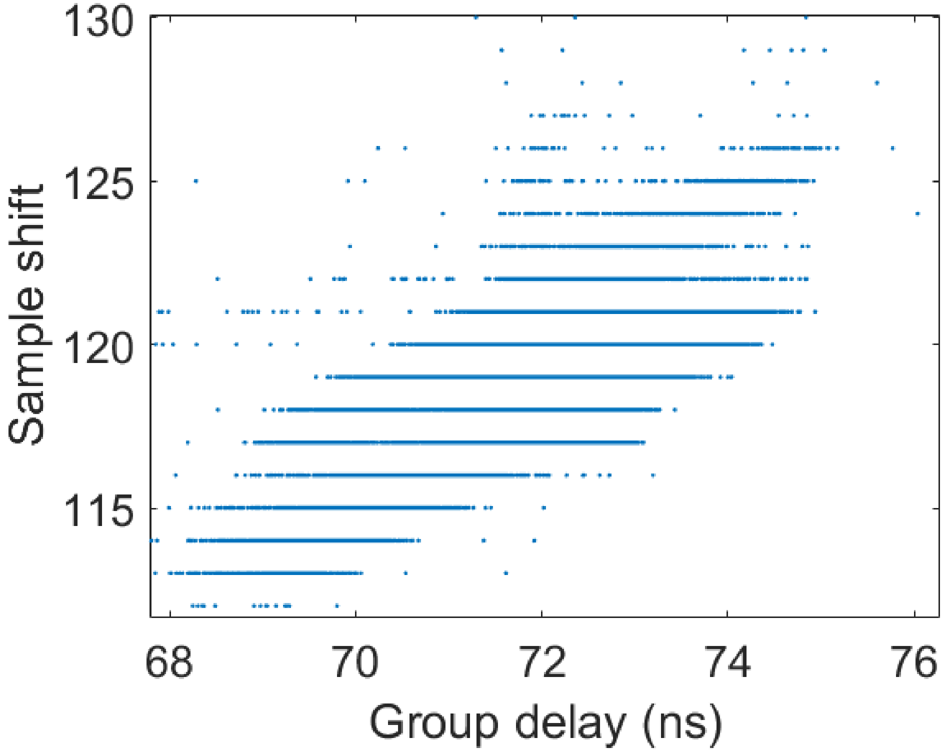


Sample Shifts in Signal Acquisition

Xbox 2, PSI structure



Xbox 3C, SiC structure



Comparison of Phase Measurement Methods