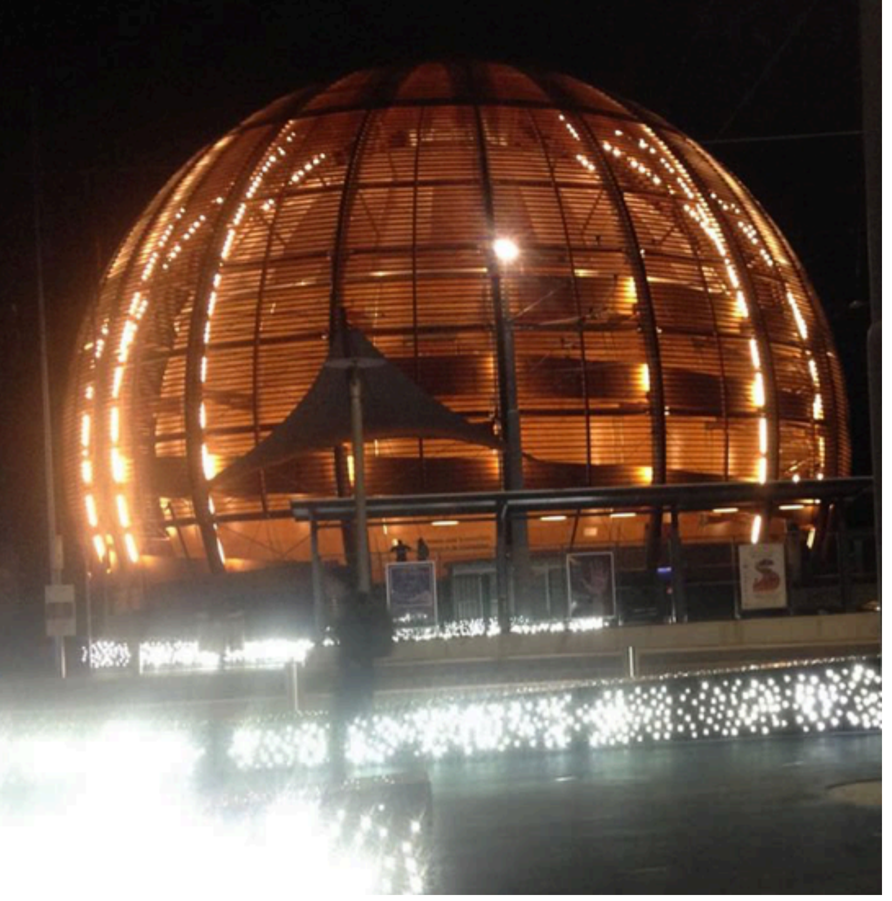


Working With Waveforms

In this talk we illustrate tools for digital signal processing through application in several recent publications

Sebastian White LIP-IDTM Sept. 13, 2023

Bibliography/ Topics

- High Gain (aka Deep Diffused) Avalanche Diodes

  “Deep diffused APDs for charged particle timing applications…..”, Vignali et al,NIM v 949, 162930 (Jan 2020)

- “PICOSEC” ~20 picosecond MPGD based MIP timing

  See Florian Brunbauer, these proceedings (and NIM articles referenced therein).

- Single Delay Line Shaping applied to SiPMs w 10’s of GHz Dark Count Rate

  S. White and A. Heering, “*Digitized waveform signal processing for fast timing: an application to SiPM timing in the presence of dark count noise*”, 2020 *JINST* **15** C04036

- Use of CADENCE based Xfer Func’s to mock up ASIC performance with beam data

  S. White, “Virtual ASICs with Real Data”, CPAD 2021, https://arxiv.org/pdf/1712.05256.pdf

- A new tool to mitigate time jitter from Dark Count noise

  “Signal processing to reduce dark noise impact in precision timing”, S. White: 2023 *JINST* 18 P07051

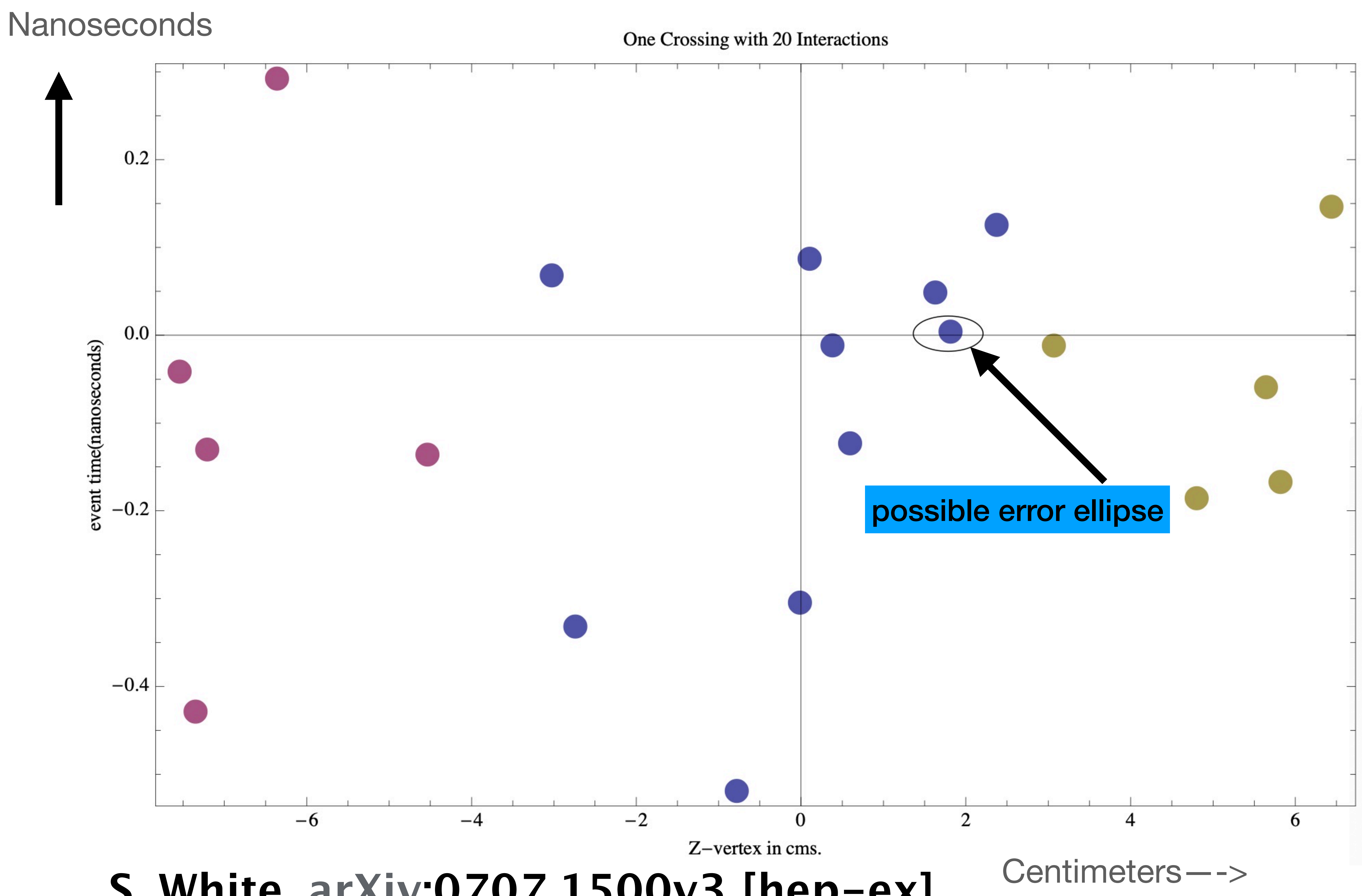
- Relating TOFHIR2C noise to effectiveness of above tool

  Work in progress…

In this talk we discuss all but 1st 2 topics

necessity= mother of invention….

- In 2011 I moved to CERN==> Crispin Williams' Lab
- Had written paper in 2007 advocating 4D vertexing for pileup mitigation
- => R&D on fast timing sensors



S. White, arXiv:0707.1500v3 [hep-ex]

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Projects

High Gain AD w. M.Moll, Princeton, Penn,RMD, LIP

PICOSEC MPGD from 2015 w. Saclay, GDD +++

Resources

FEE: help from P. Farthuoat, E. Griesmayer, Mitch Newcomer

DAQ: Lecroy very generous

+ prior work w. Wolfram-> “Mathematica for data”

Erich G. working on input protection

Lecroy down the road in Meyrin and very generous.
Former collaborator Al. Rothenberg wrote their software

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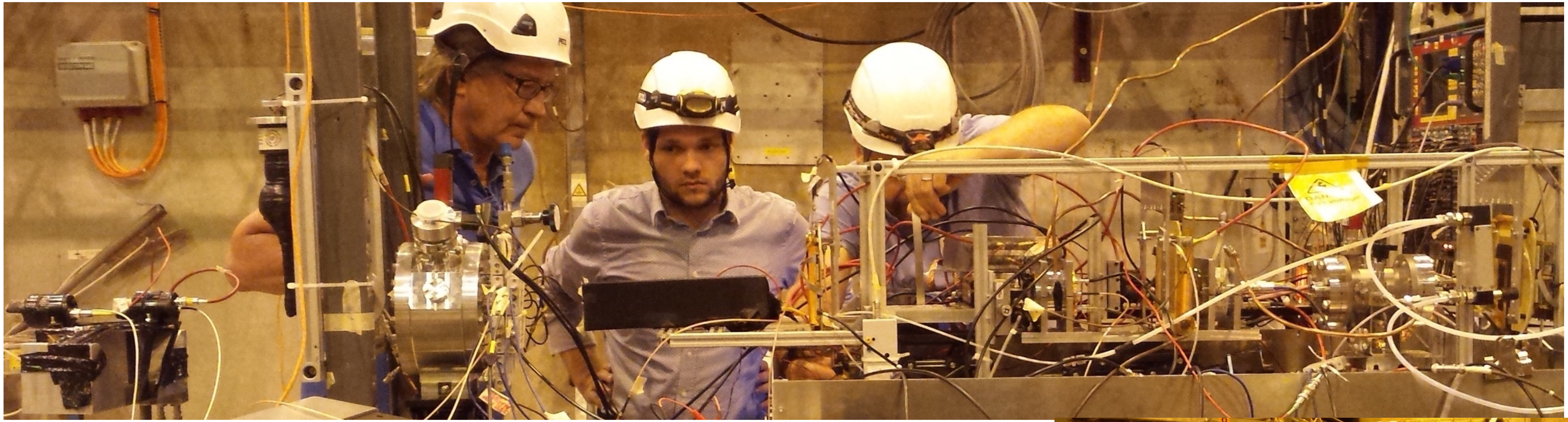
High Gain AD and PICOSEC shared resources: tracking, MCP-PMTs, and scopes



Typically all timing analysis from 1 to 2.5 GHz BW, 20 GSa/s or greater scopes.

Recently working w Eric Delagnes & Dominique Breton for PICOSEC.

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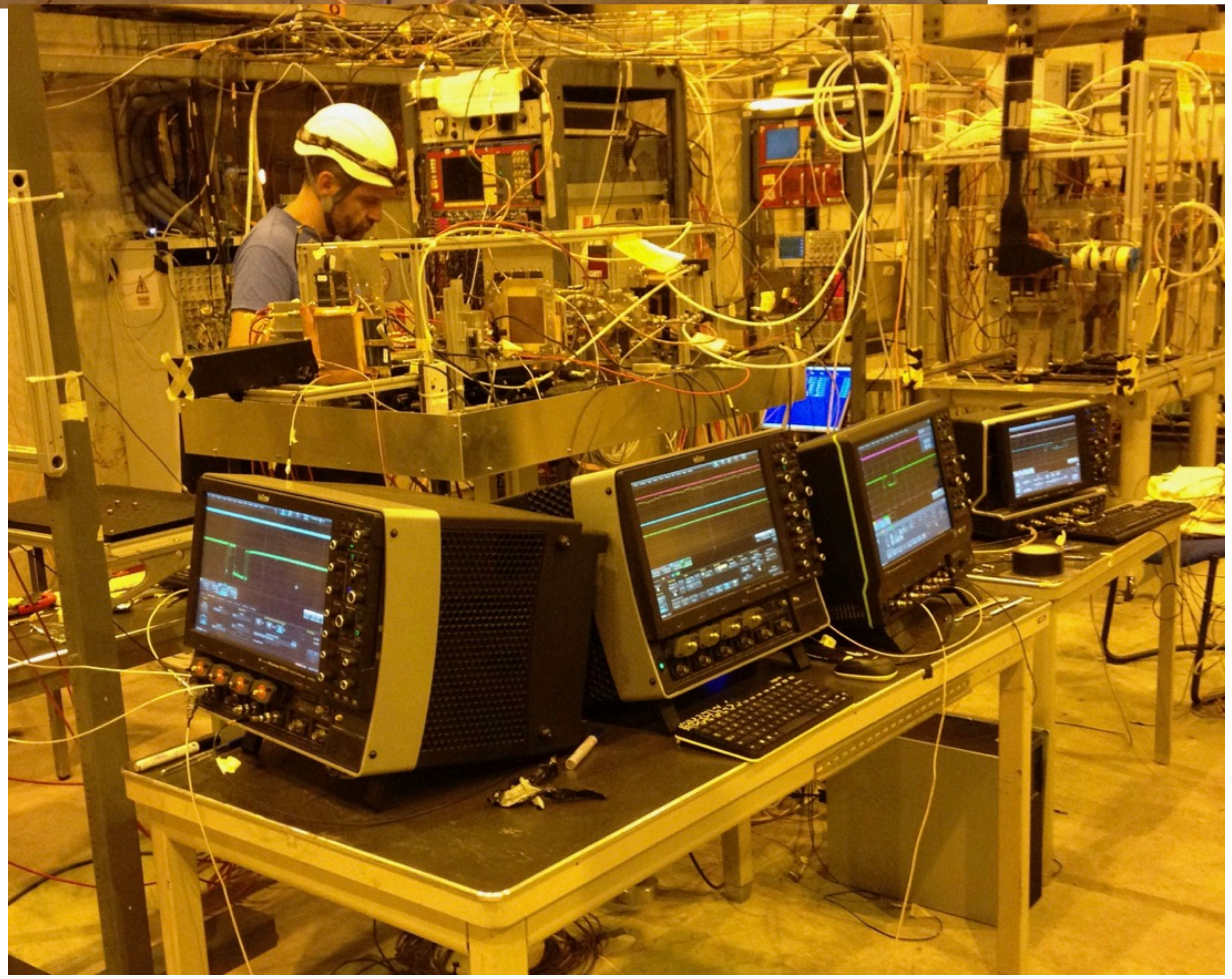
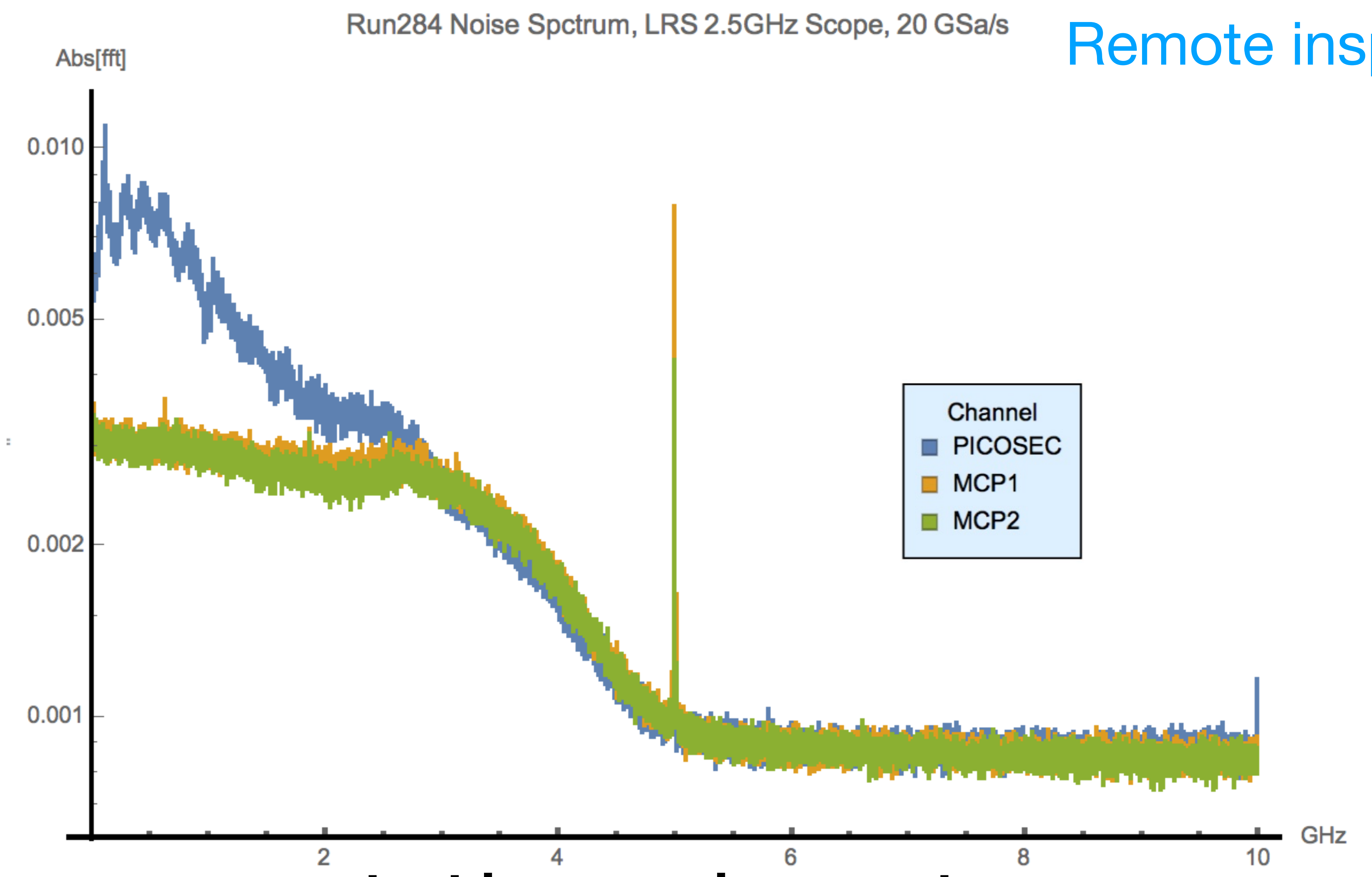
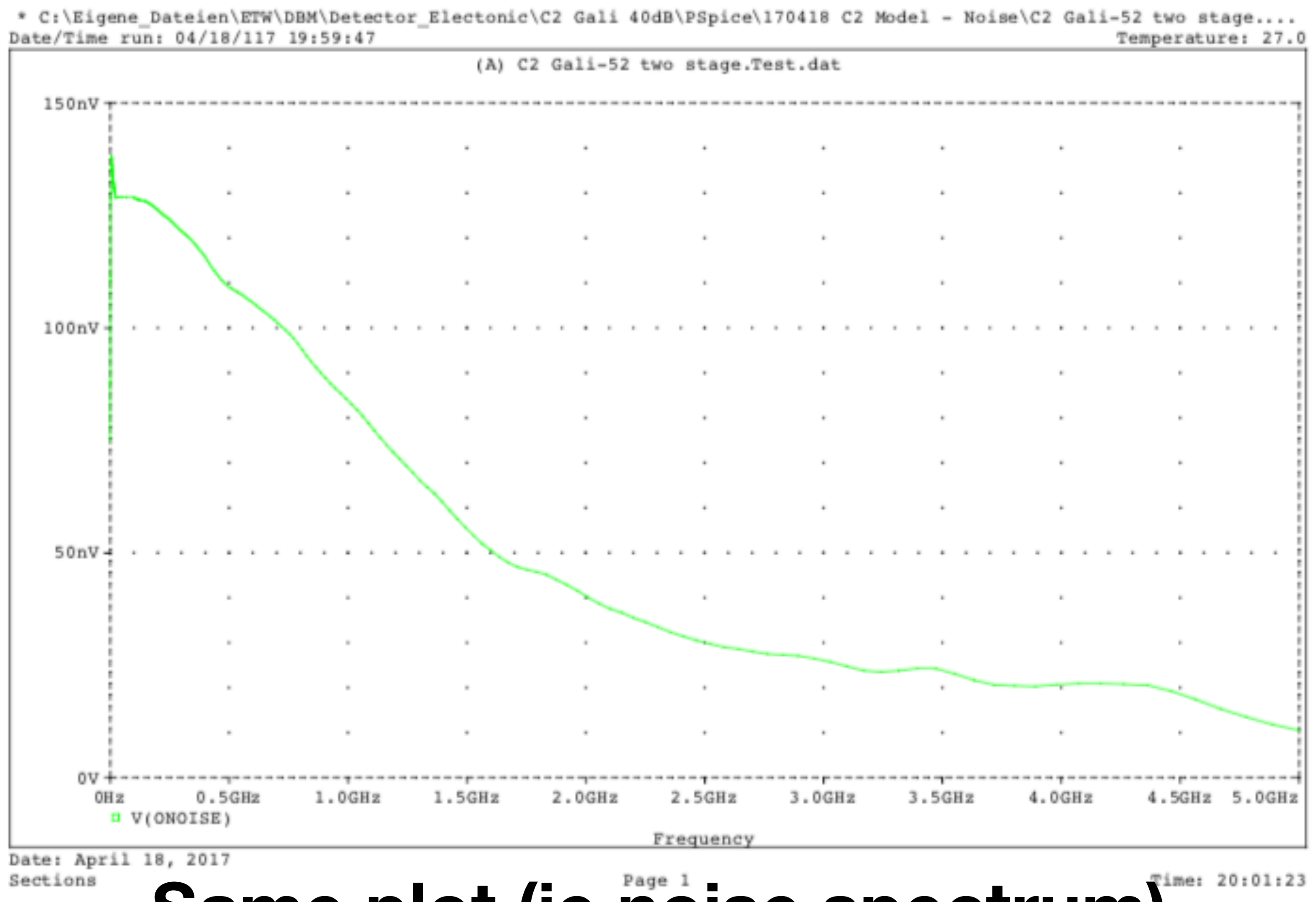


A Few applications: Discrete Fourier Transform-



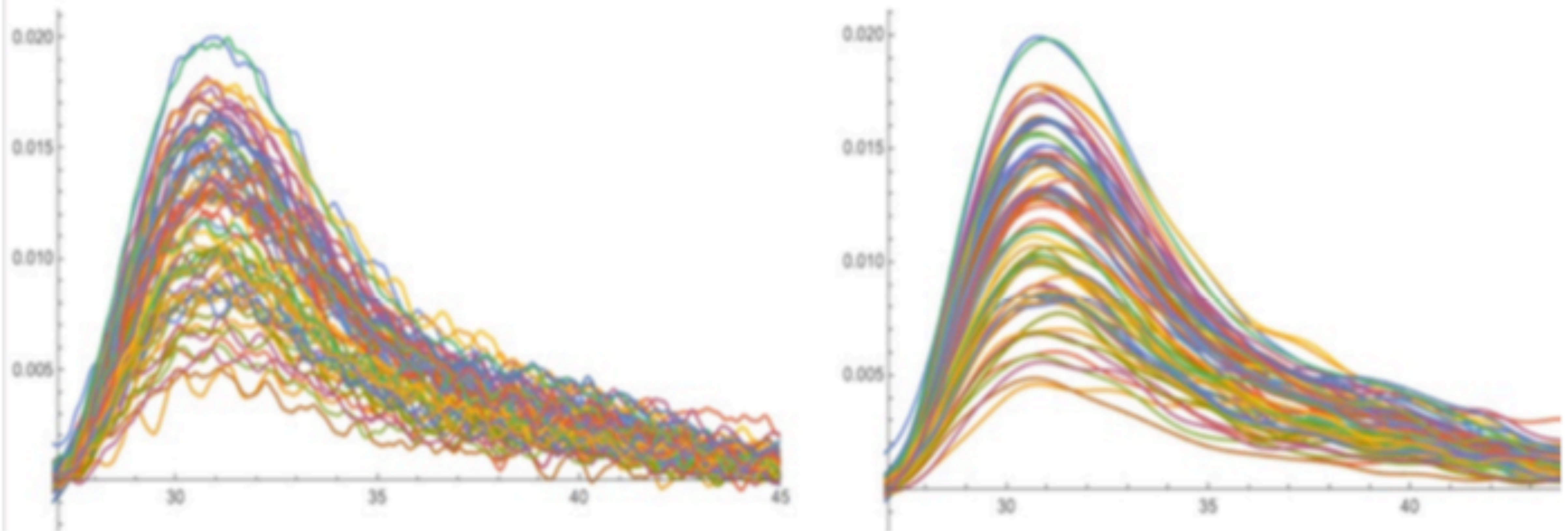
our test beam noise spectrum

Remote inspection of Noise Characteristics (CERN<-> CIVIDEC)



Same plot (ie noise spectrum)
verified by E. Griesmayer(Cividec)- SPICE

SiPM waveforms before/after Digital “Brick Wall Filter”



After the fact removal of pickup noise
from rf environment @ C. Joram lab at CERN
“brick wall filter”

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Signal Processing to deal w Pileup and Dark Count Noise

Lab Measurements of SiPM Time Resolution vs. Irradiation

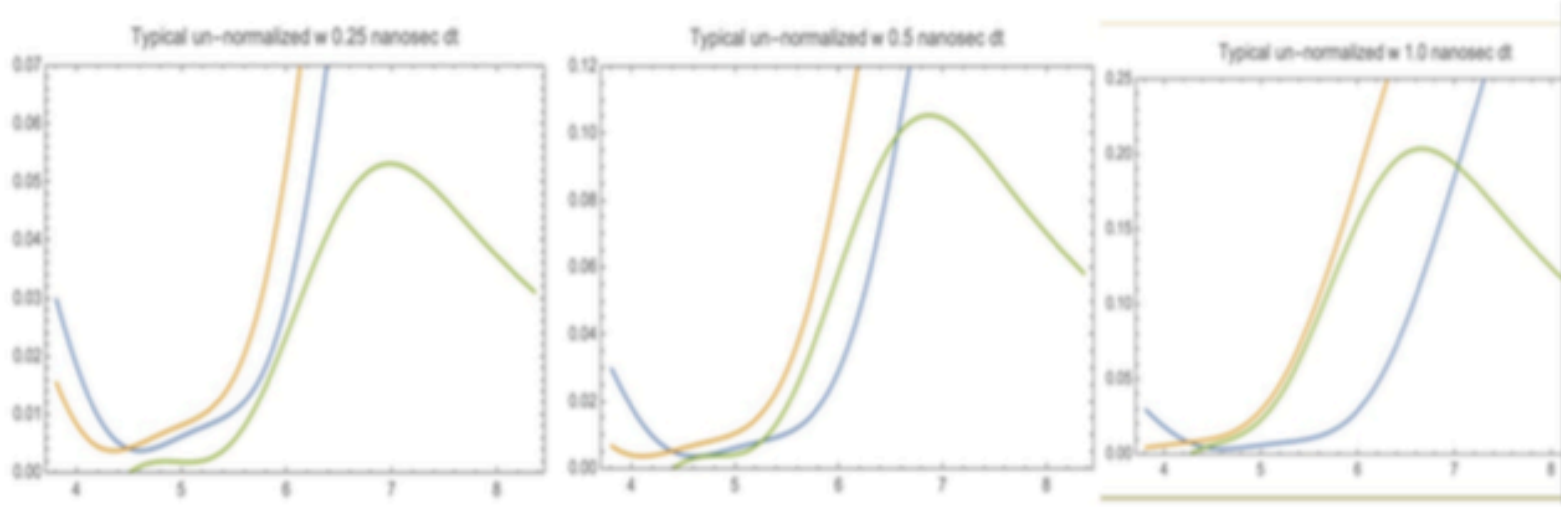
Sebastian White[a], Arjan Heering[b]

[a] *CERN/University of Virginia*
[b] *Notre Dame*

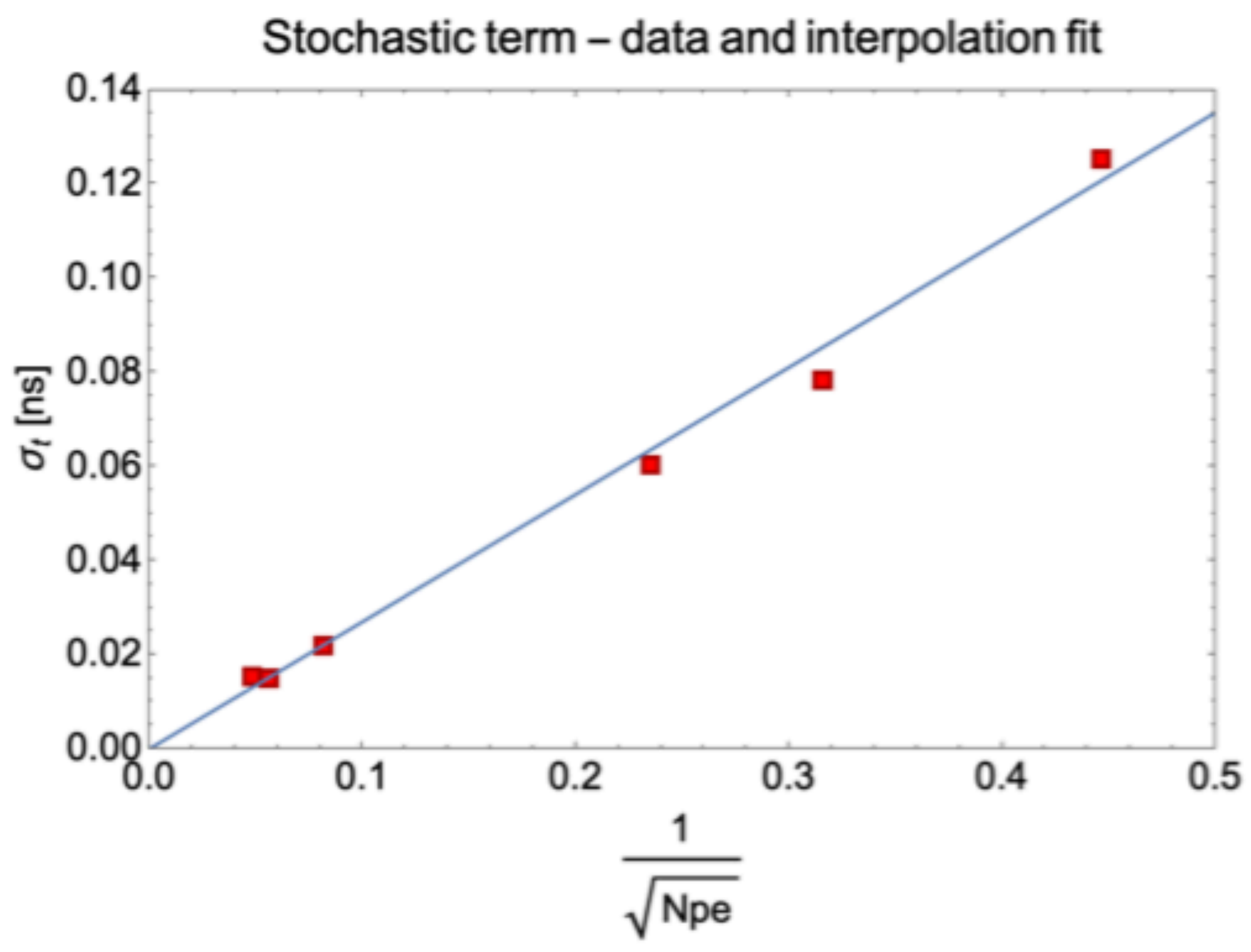
baseline restoration.
Signal processing algorithm, ie:

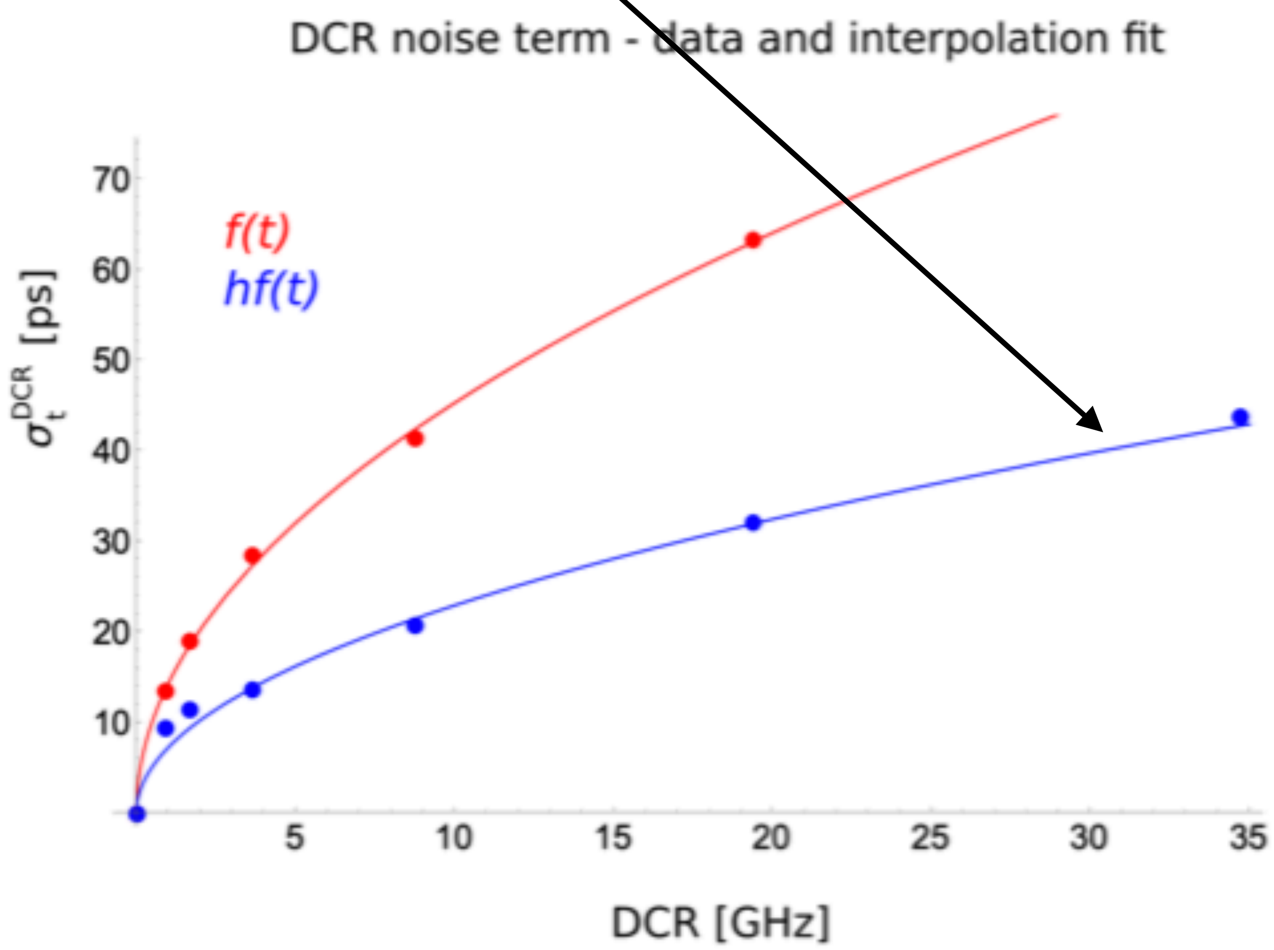
$$h\,f(t) = f(t) - f(t + \mathrm{d}t)$$

mitigates timing degradation
due to dark count noise



Examples of delay and subtract
for dt= 0.25, 0.5 , 1.0 nanosec





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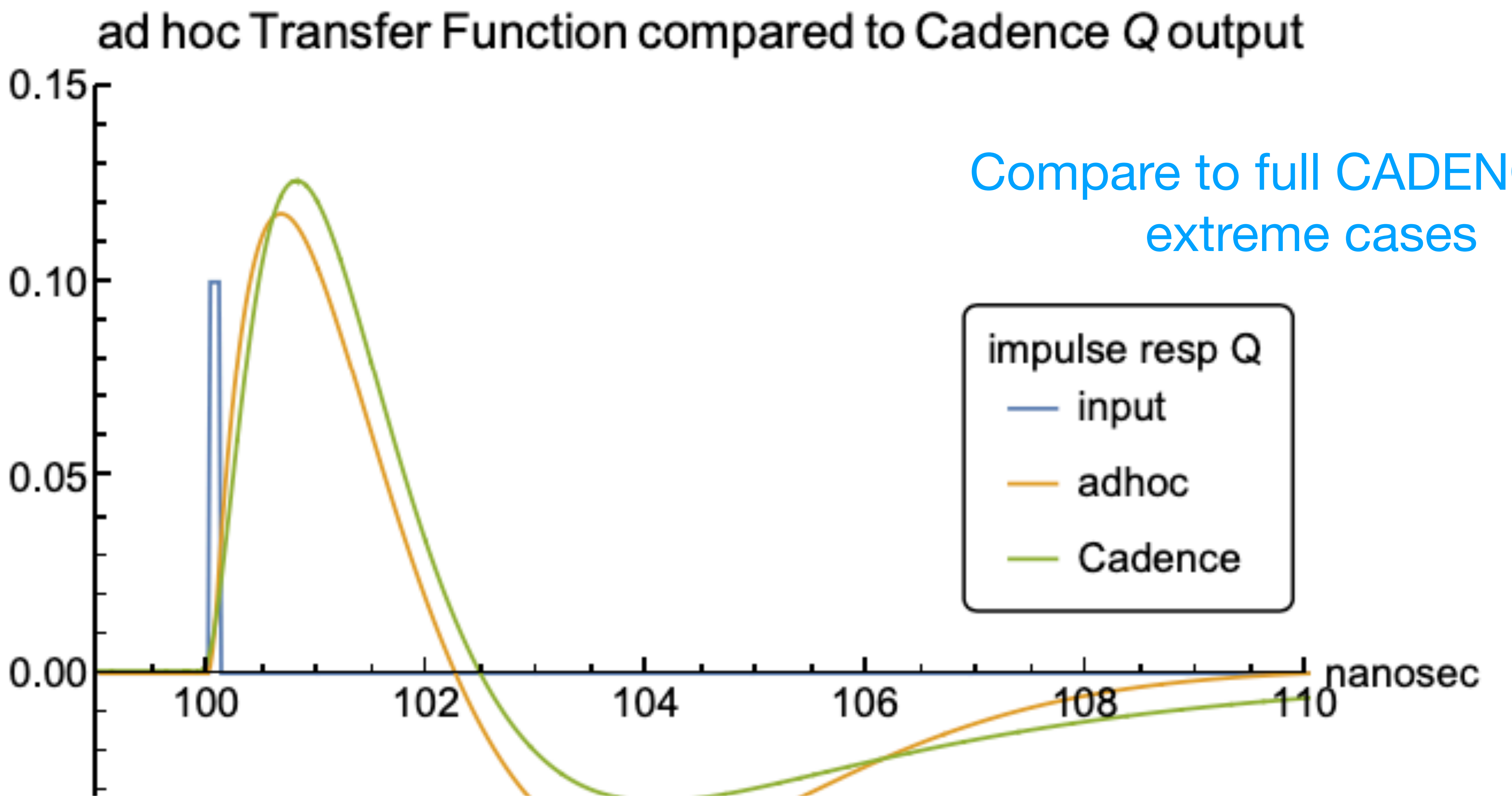
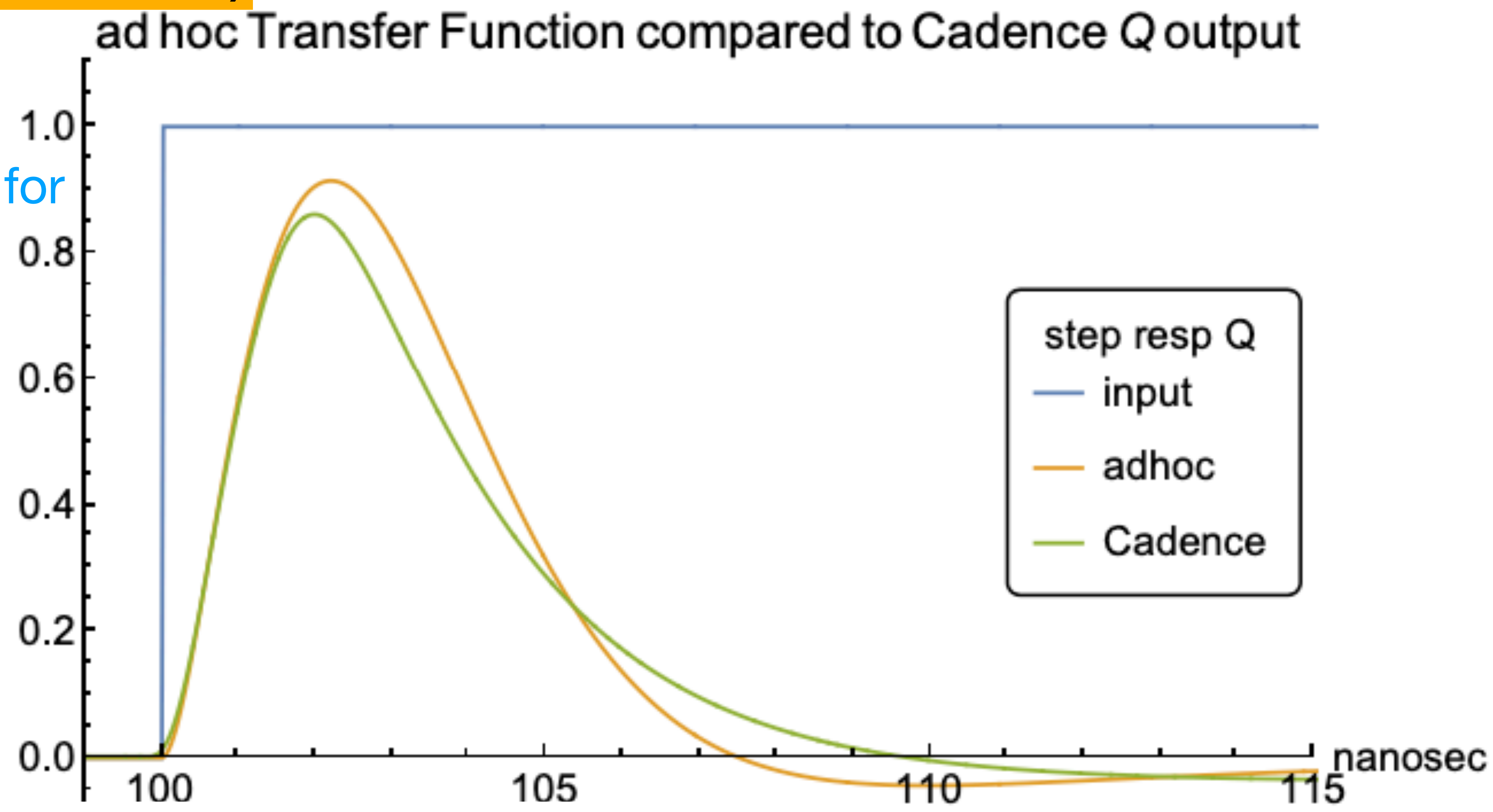
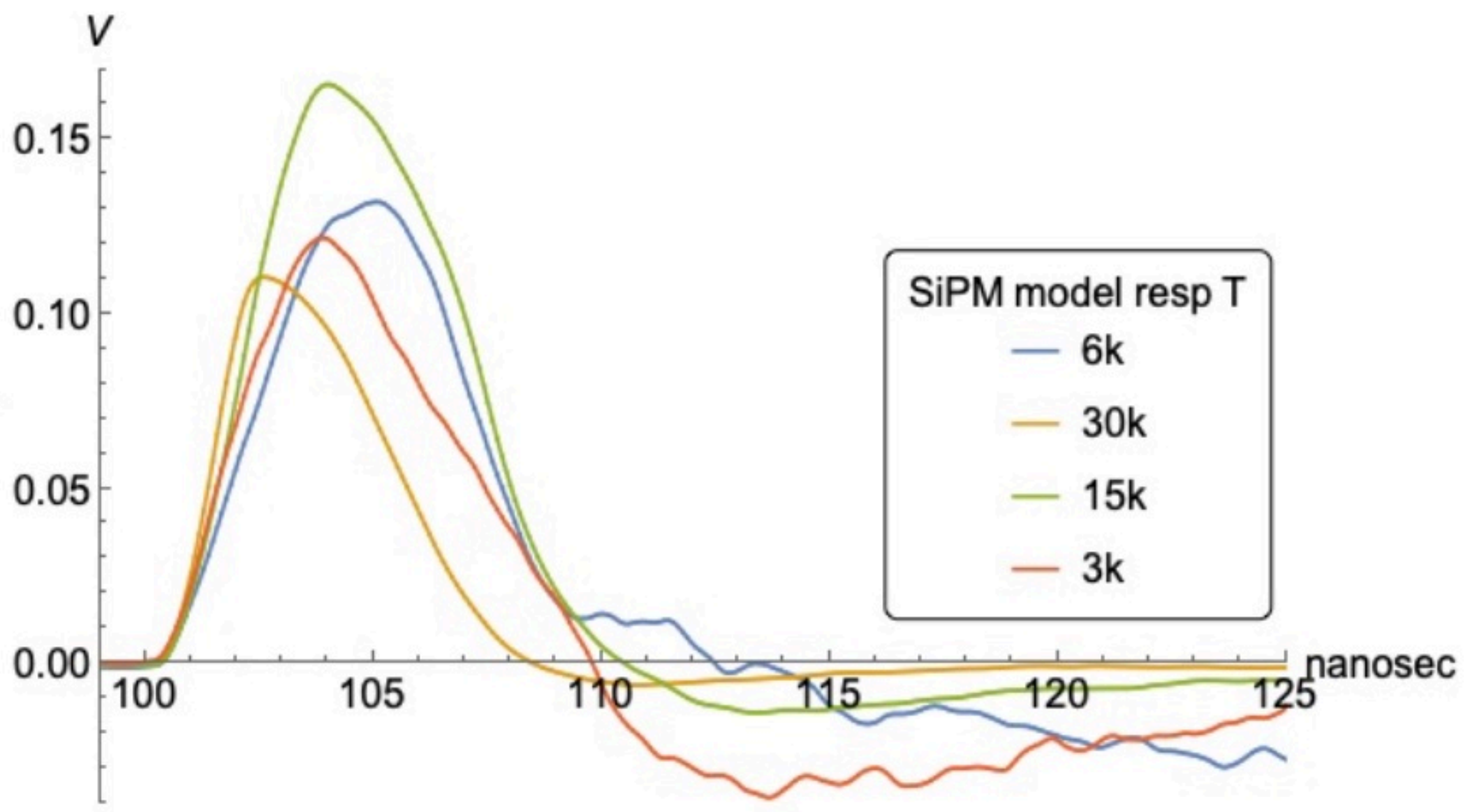
Probe CADENCE model to get “lightweight” code for xfer Functions

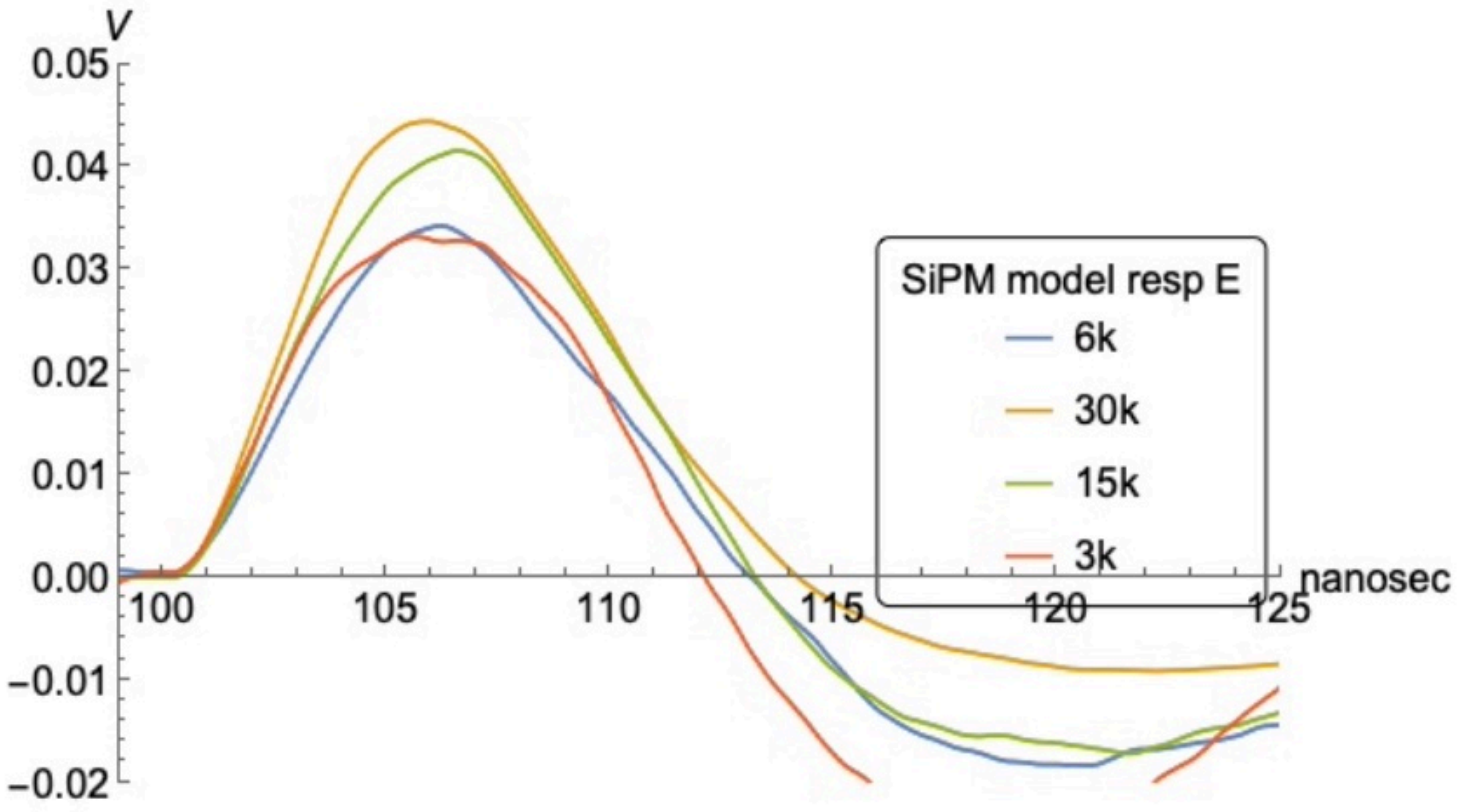
(to anticipate CMS BTL TOFHIR performance in beam)



Compare to full CADENCE for extreme cases

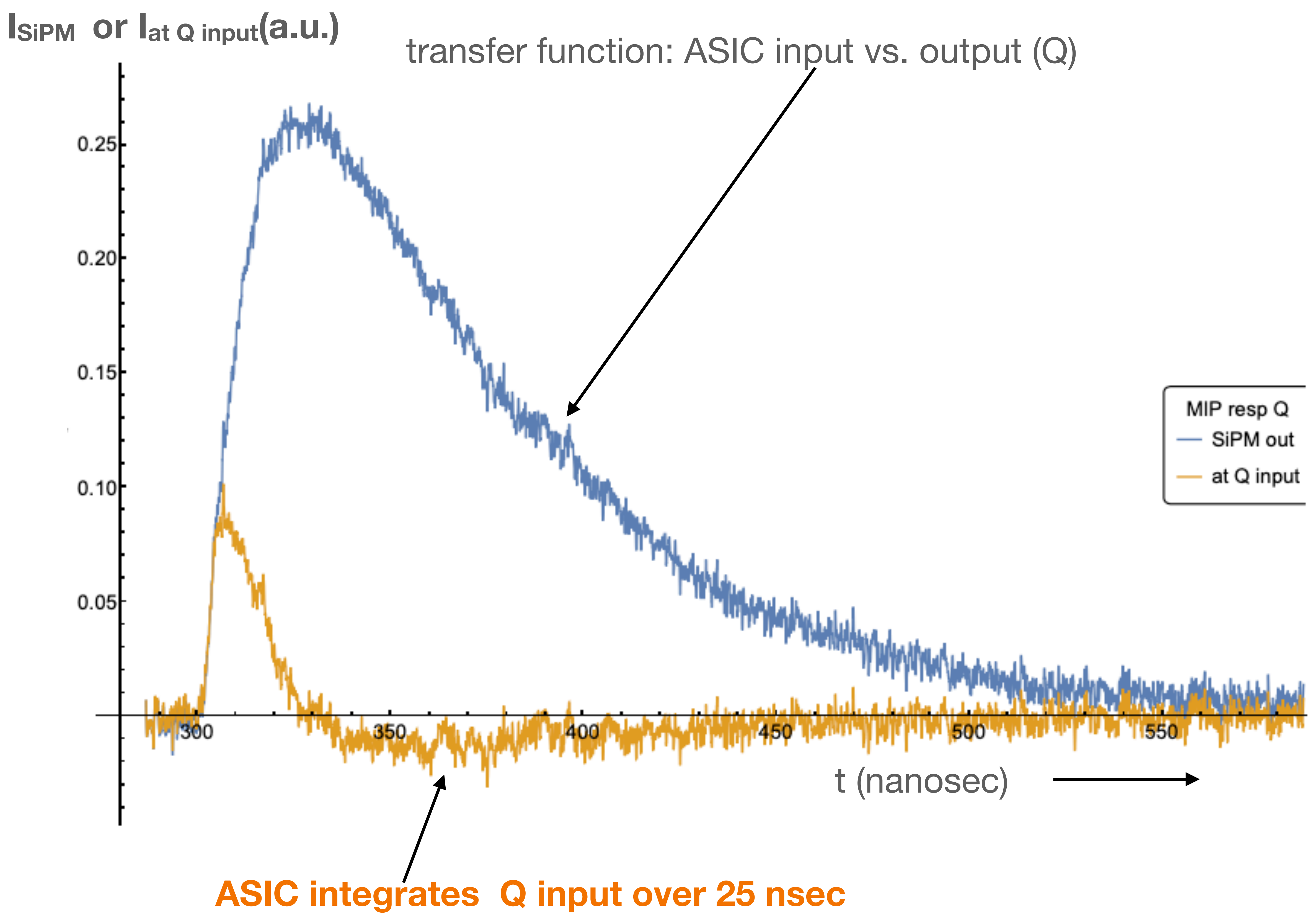


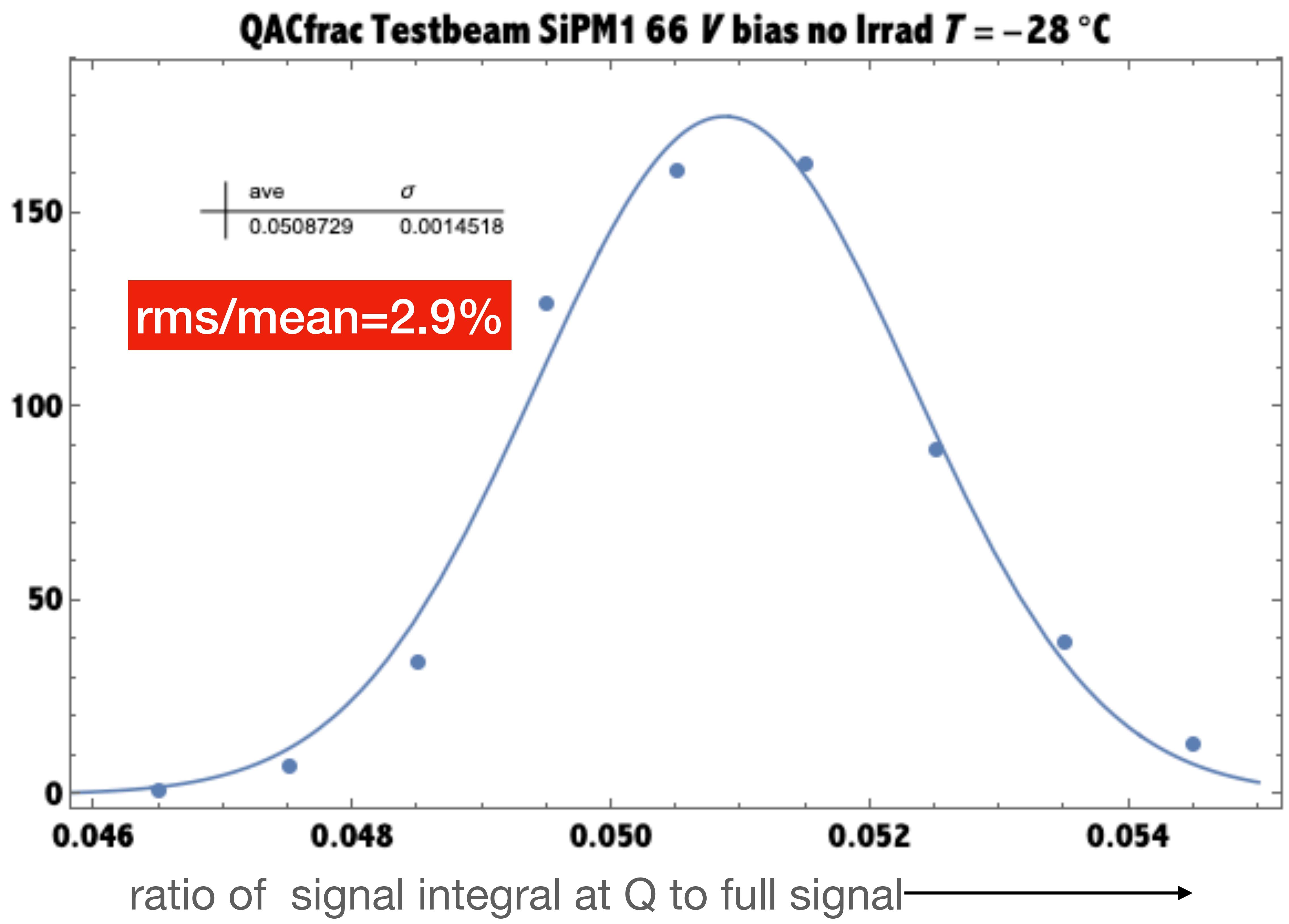




Probe nodes at Disc inputs to show circuit response linearity

Illustrative Application: How accurately does ASIC capture full Q?





Demonstrates that Q accuracy (for "Amplitude Walk Correction") of ~5% achieved for a real data set.

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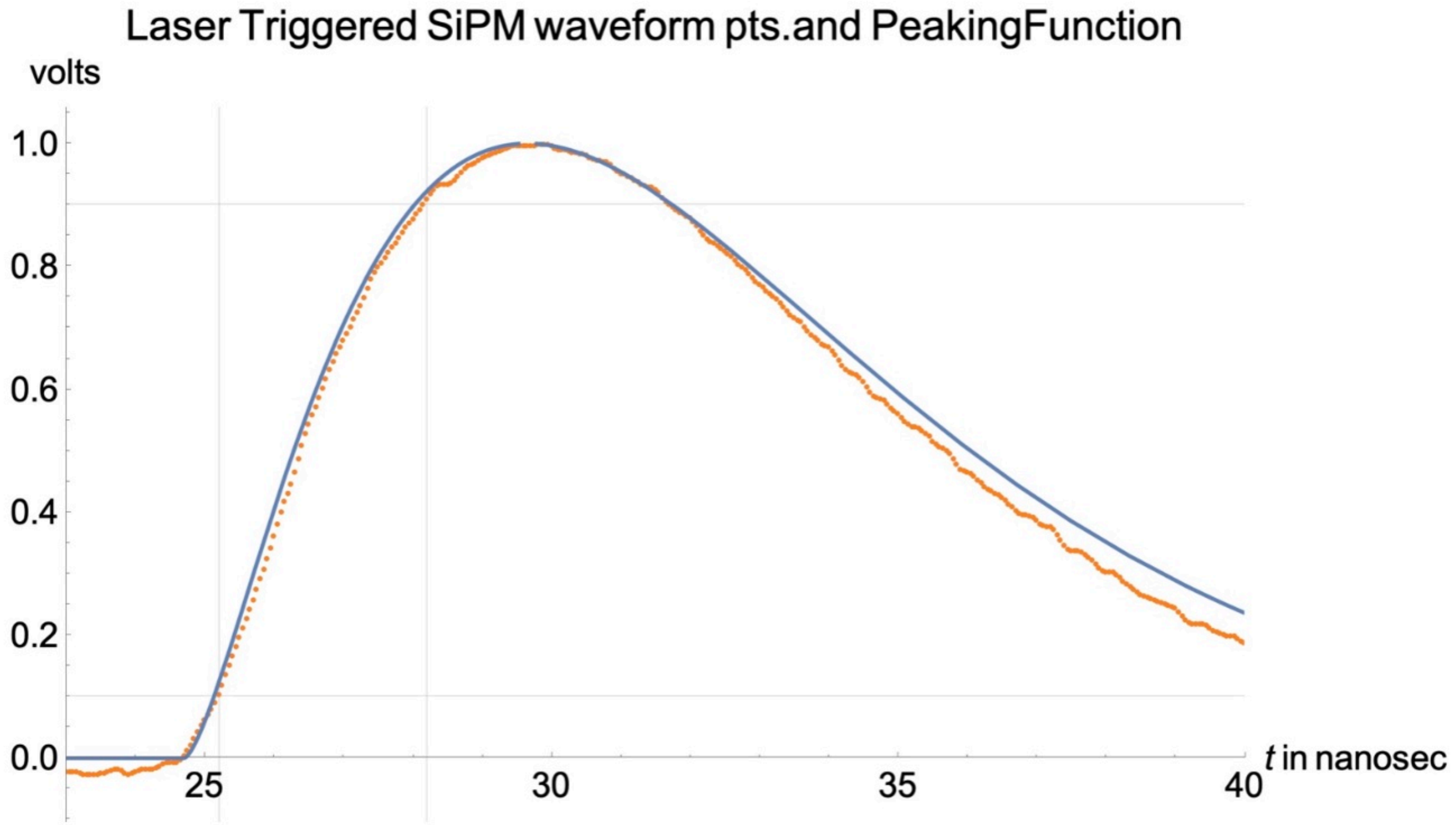
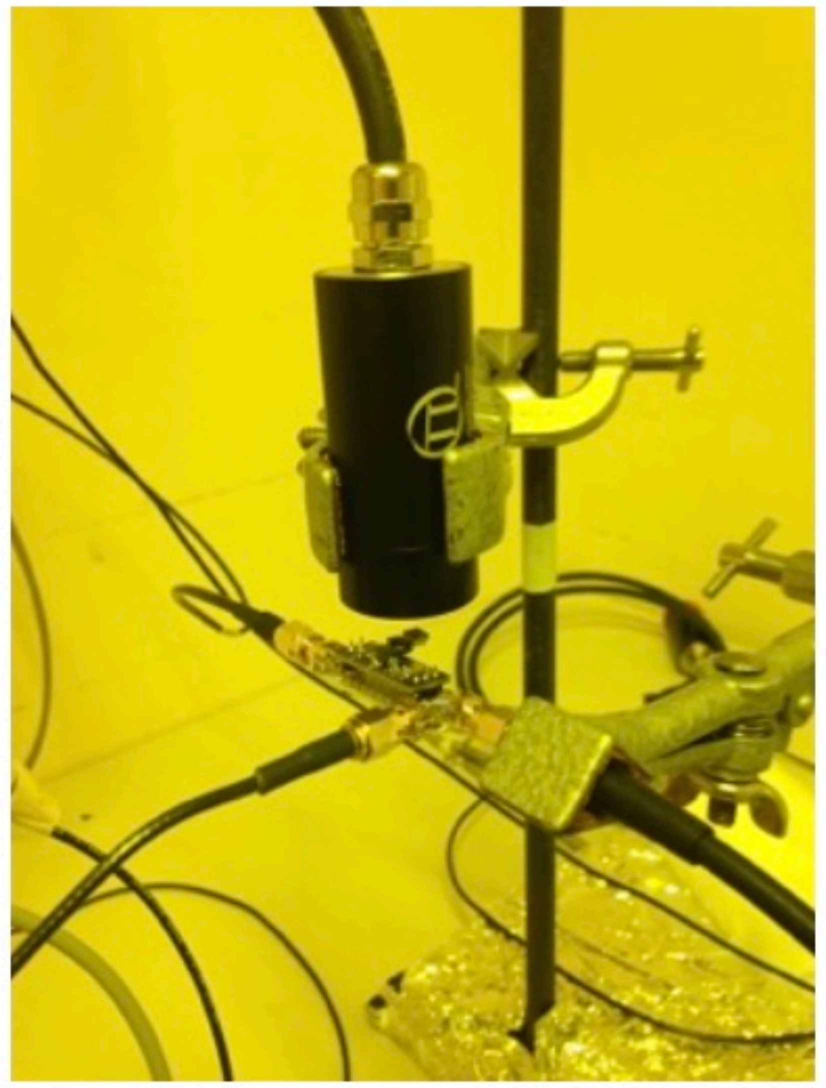
Now illustrate tool for DCR time jitter mitigation.

- We will find a timing correction from redundancy of slope and Q.
- Joram Lab laser data from earlier paper w A.Heering: start from models.





Solid Curve (signal model)—>

$$F[t] = A \times (\frac{t - t_0}{\tau})^n \times Exp[-\frac{(t - t_0)}{\tau}]$$

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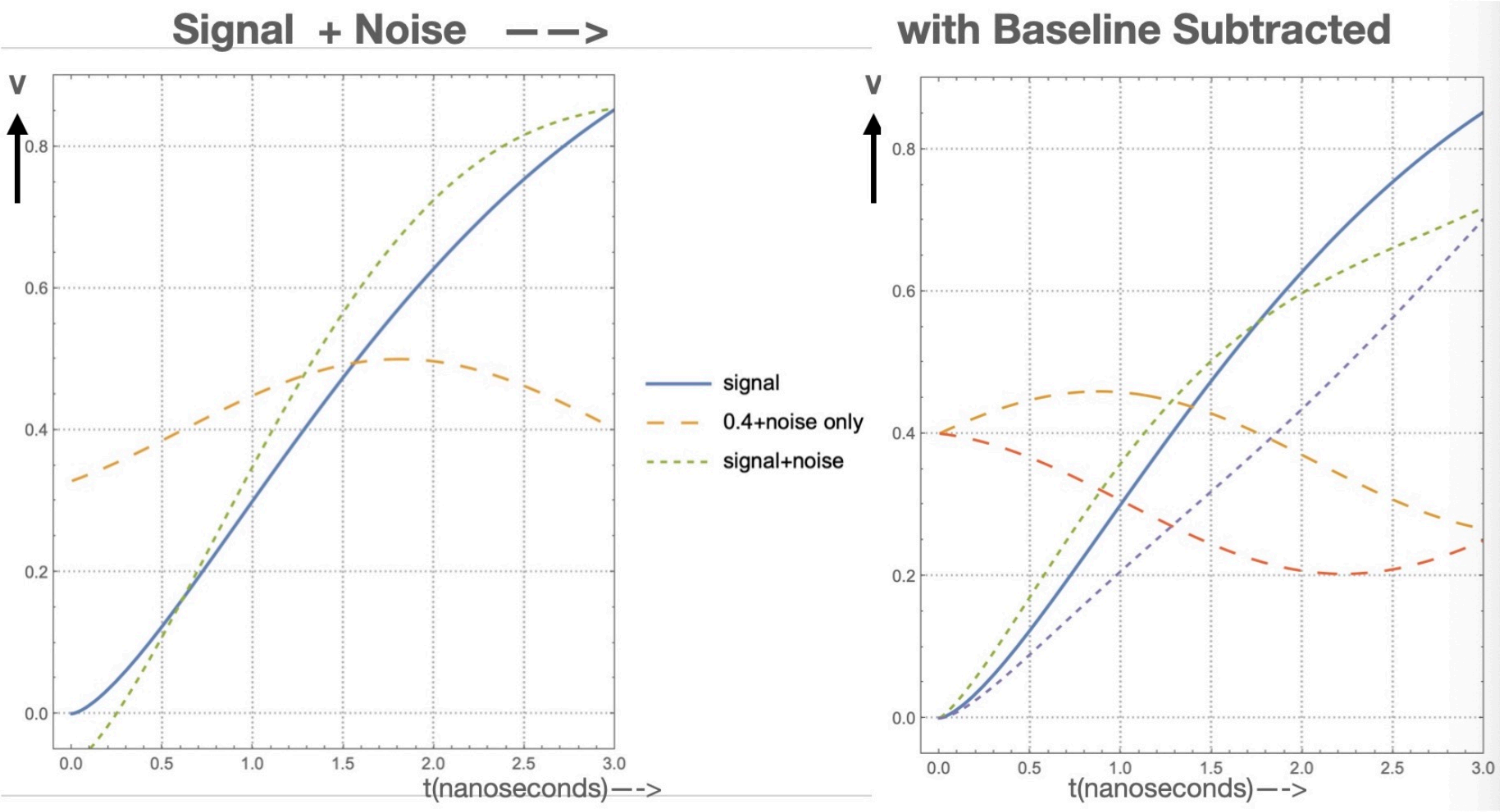
Key to dual threshold effectiveness-> baseline subtraction



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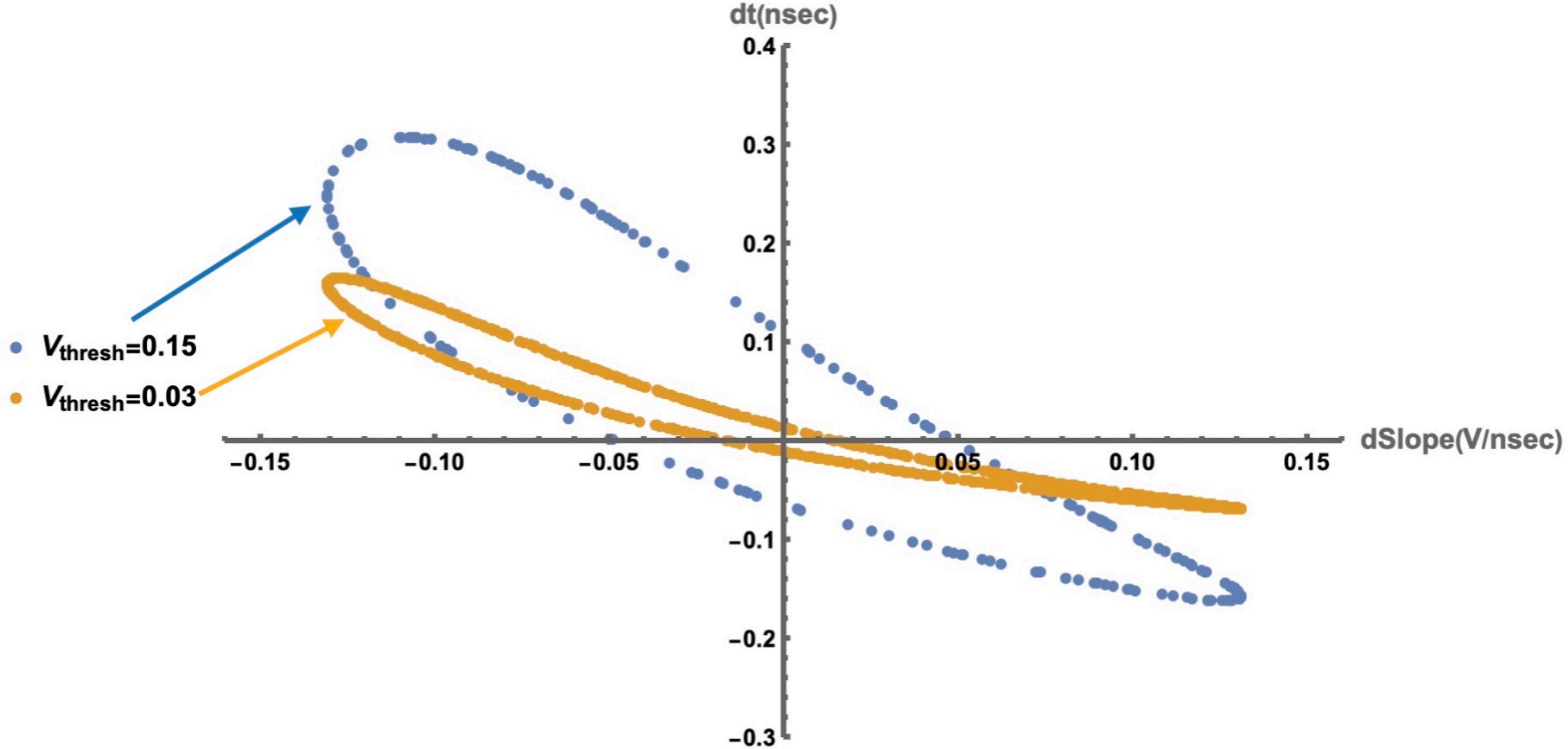
In simple model correlation persists up to high threshold



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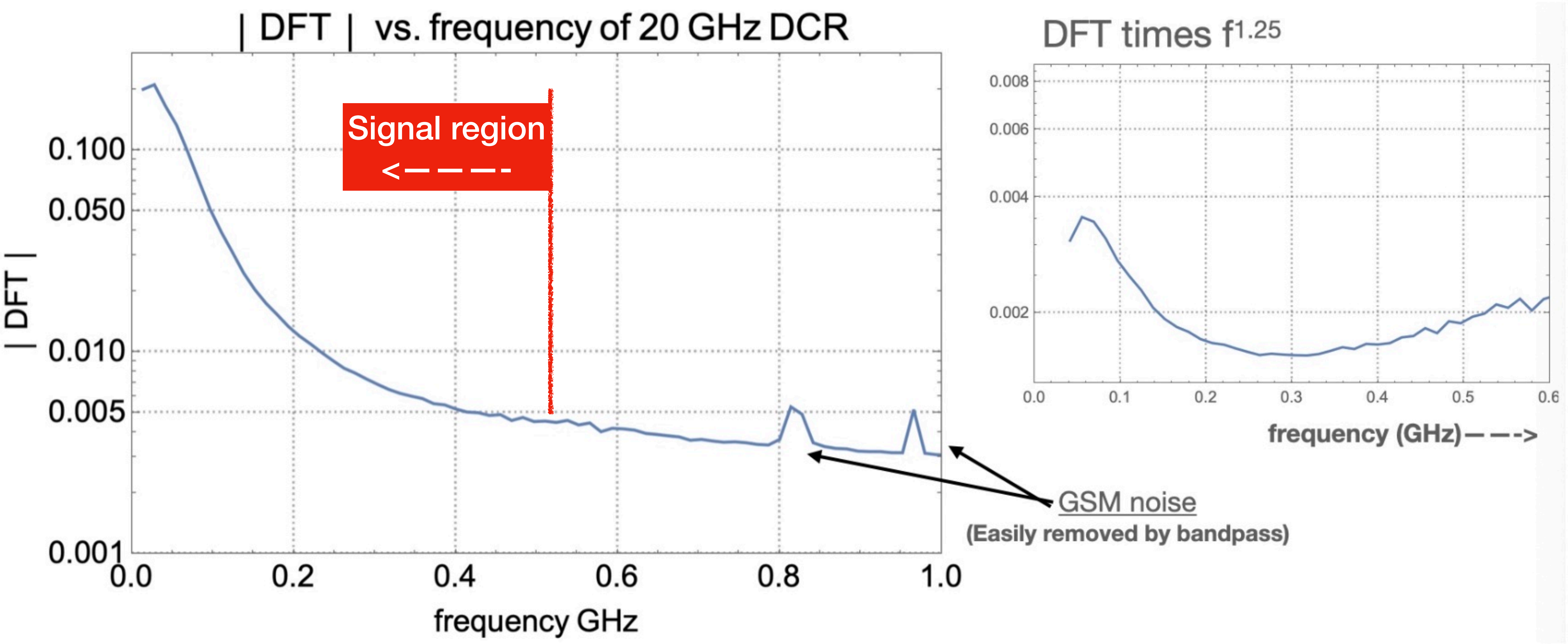
The noise spectrum+ external HF noise (above proper bandpass)



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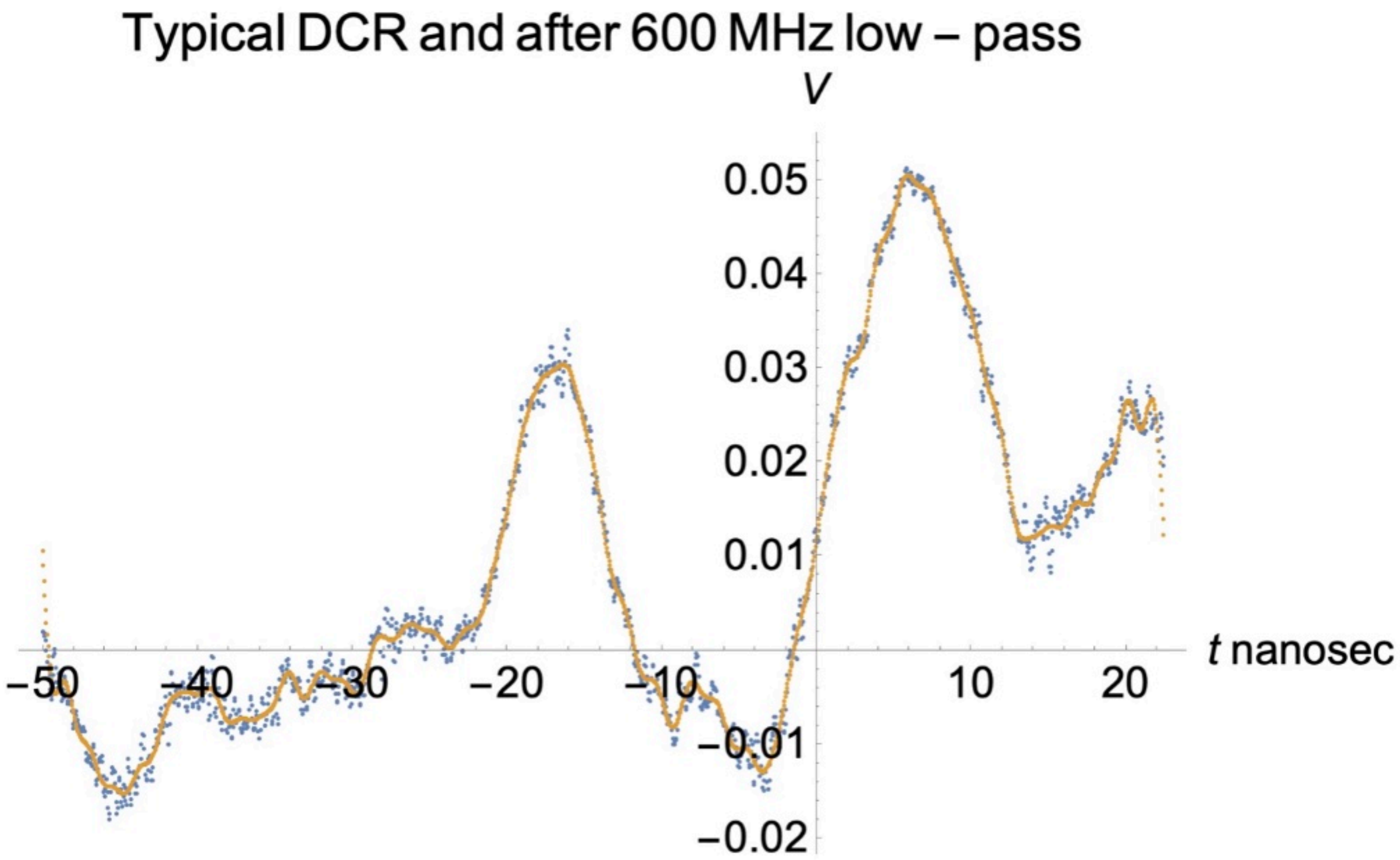
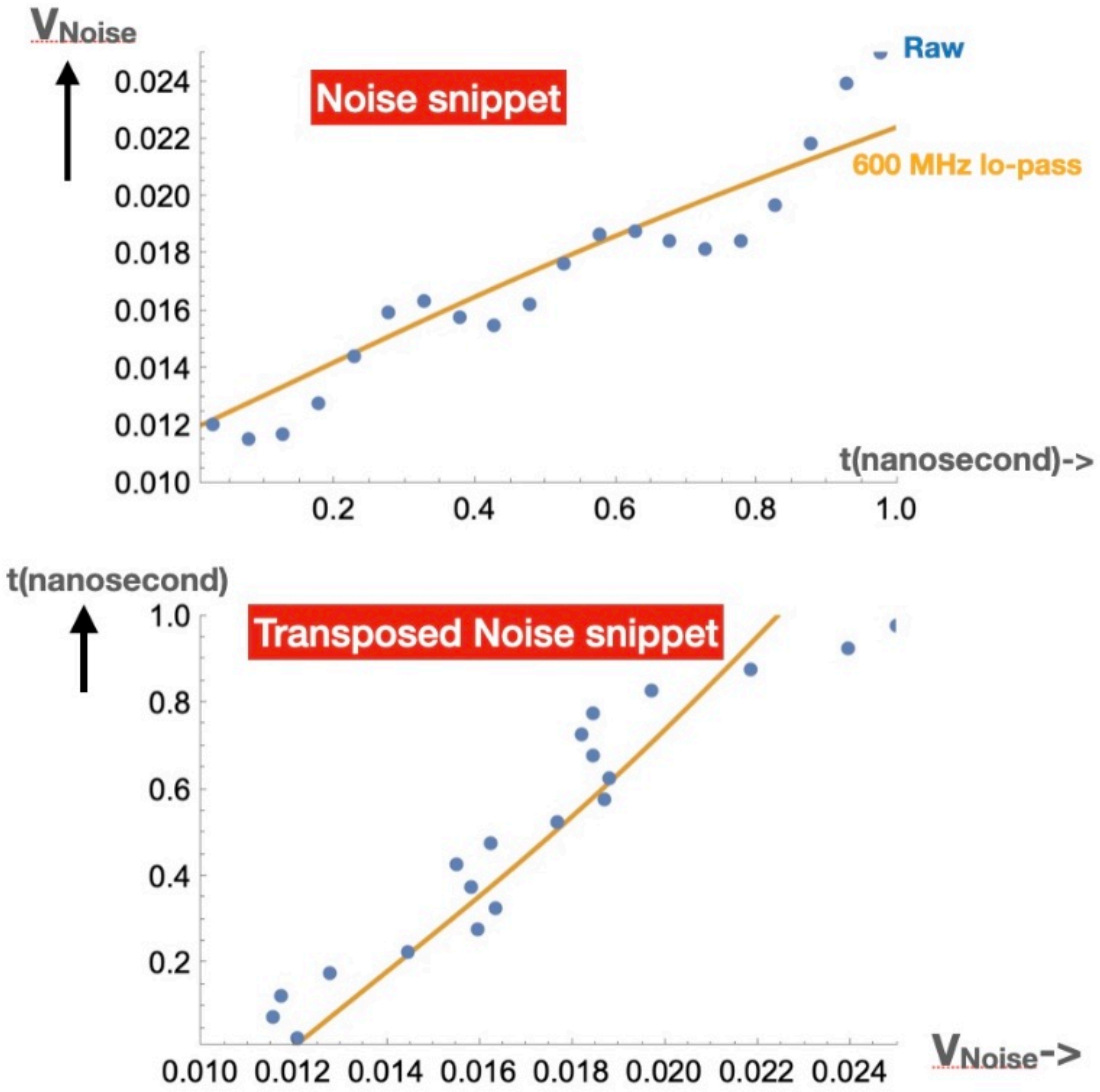
Even at low power HF noise has a big effect





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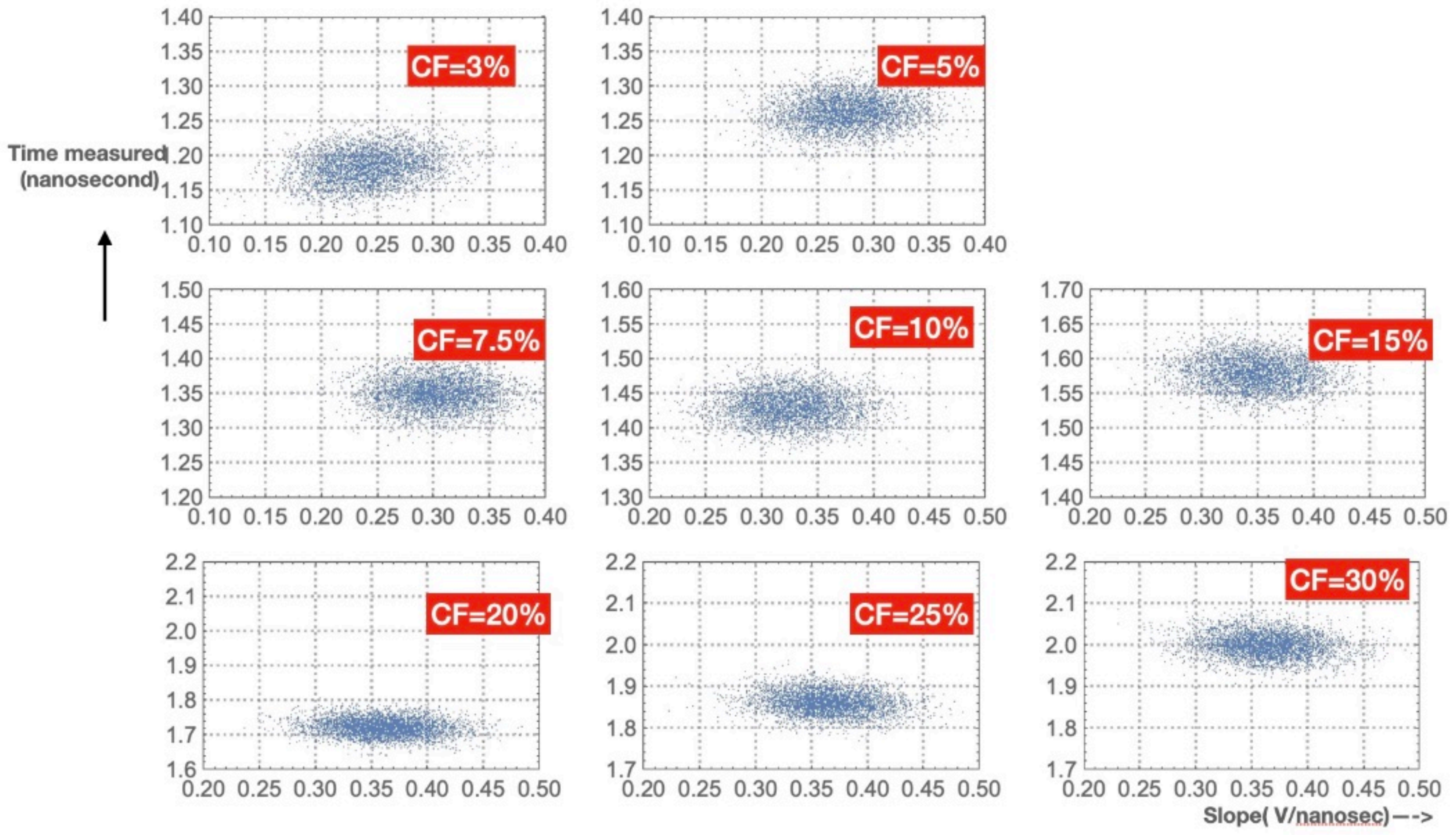
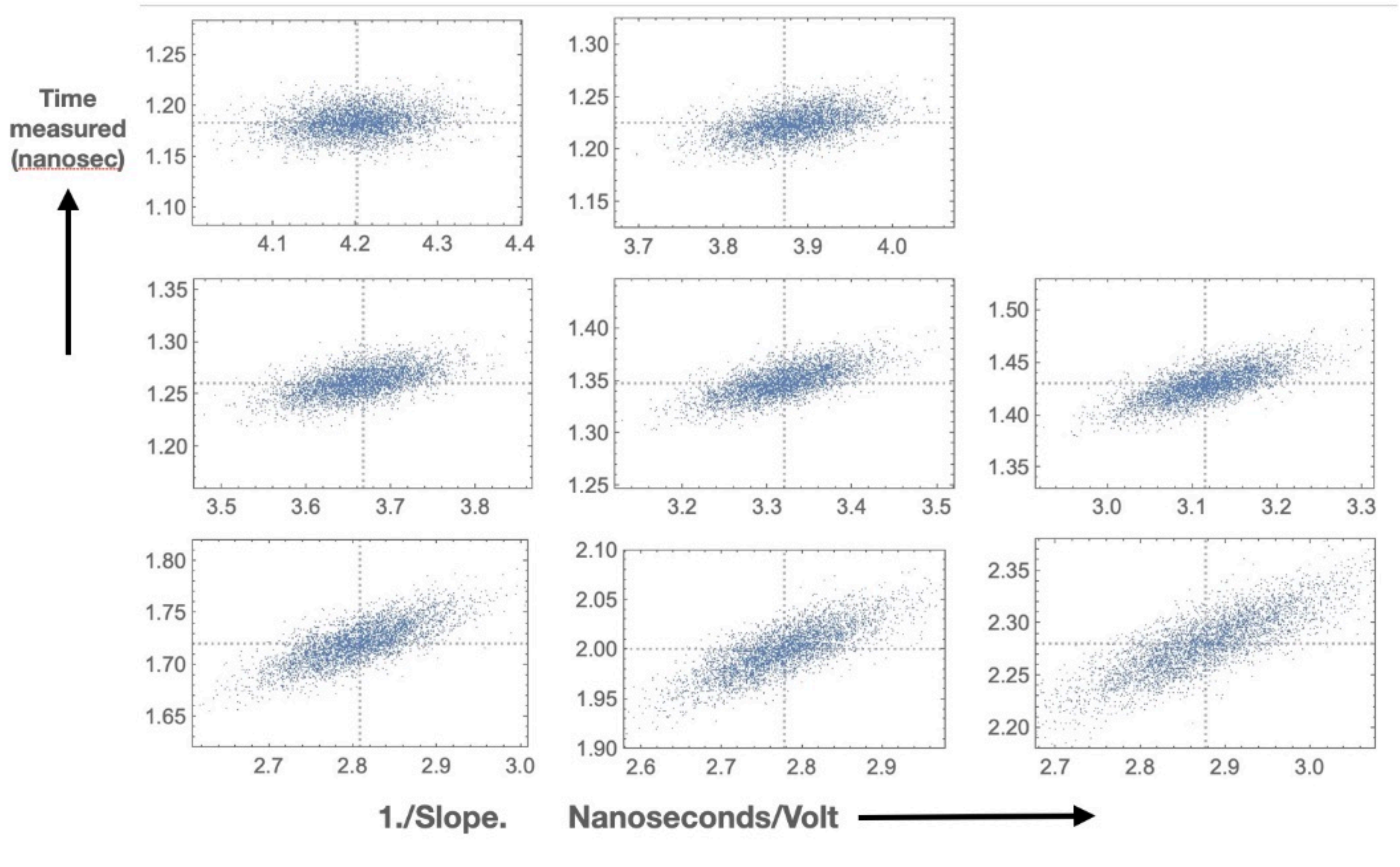
In our example it would short circuit timing mitigation:

Without 600 MHz low-pass filter



With 600 MHz low-pass filter



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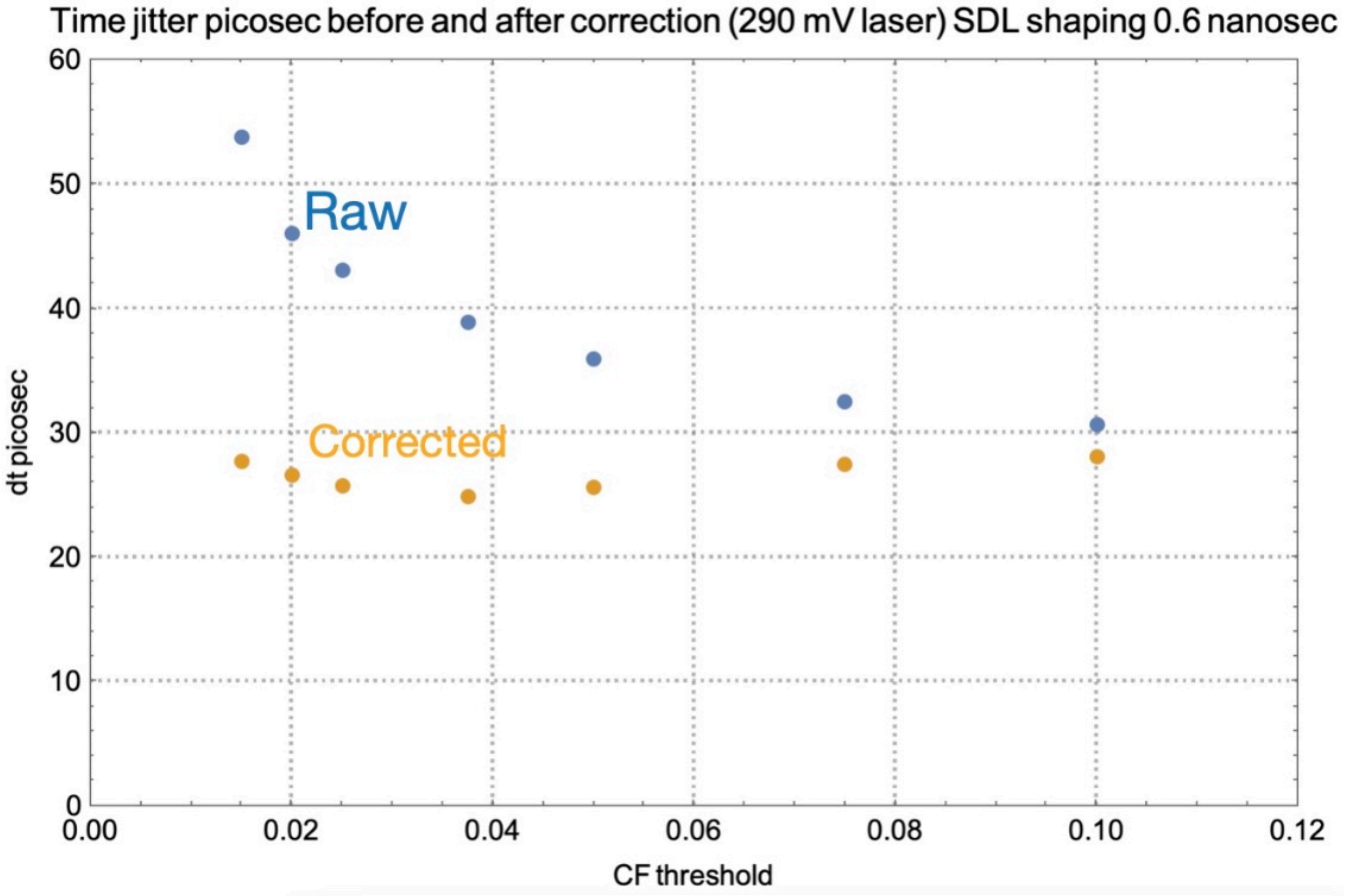
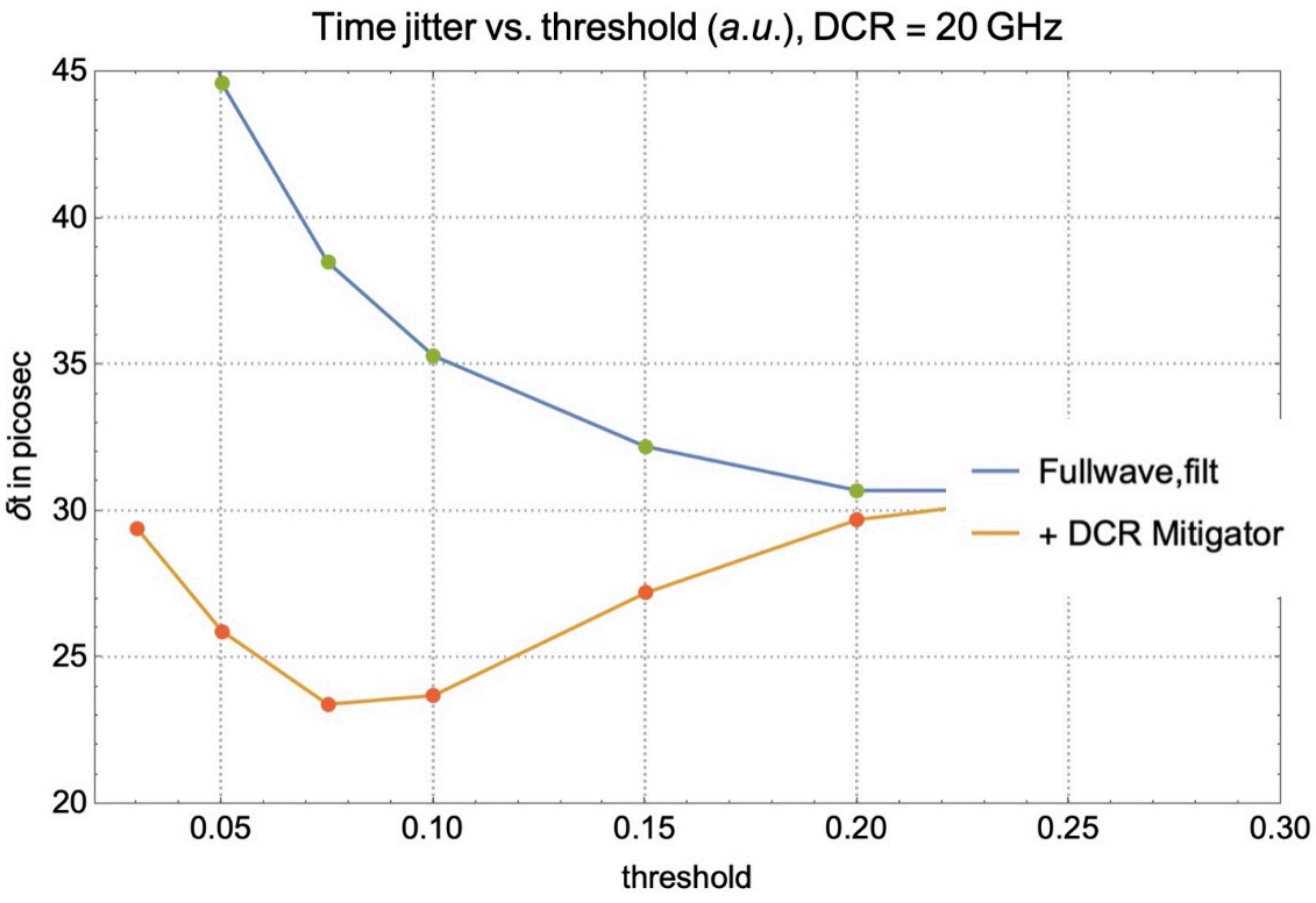
Does Delay Line Shaping (a la TOFHIR) reduce effectiveness? NO



Model Signal+Real Noise



Full Laser data+Real Noise

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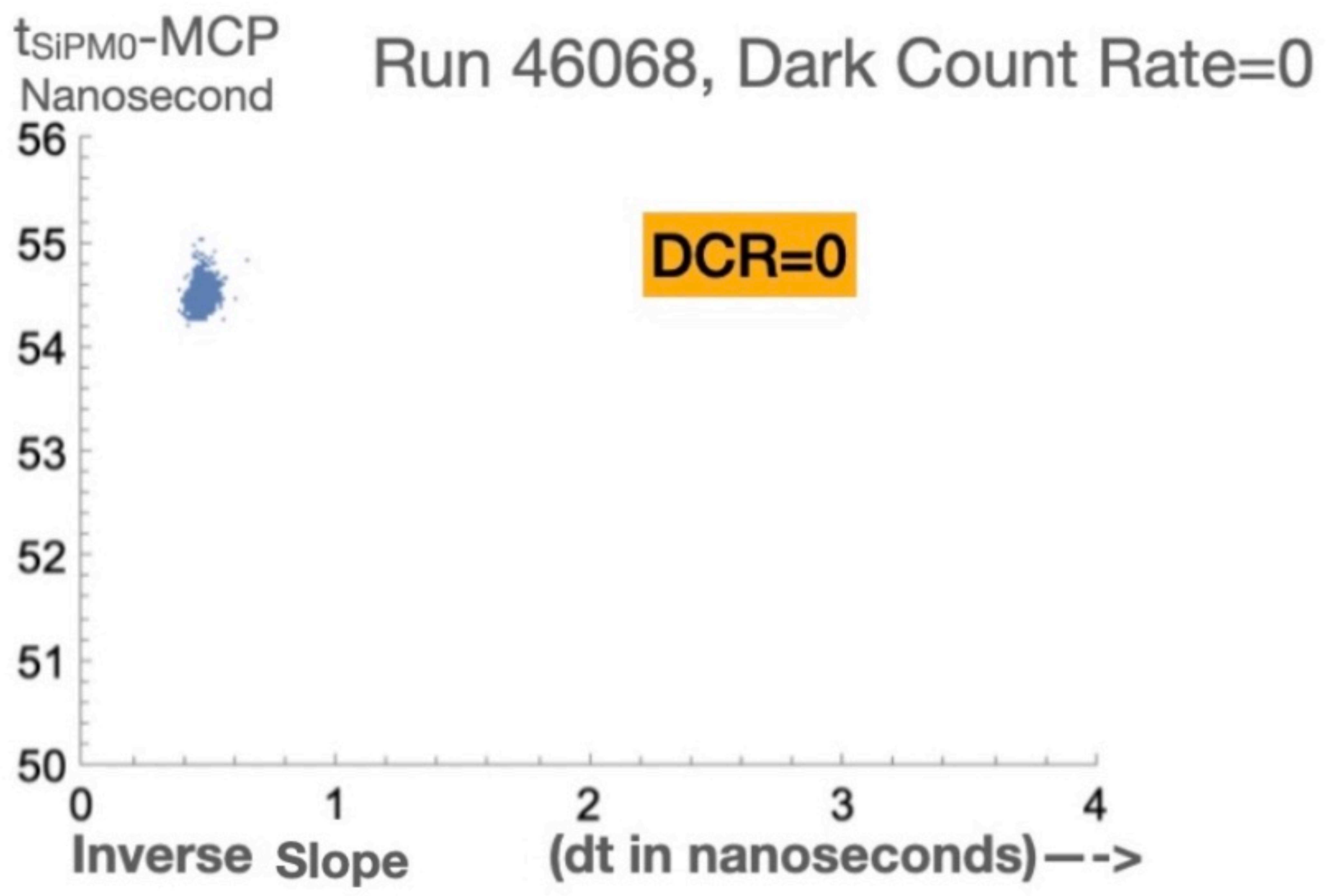
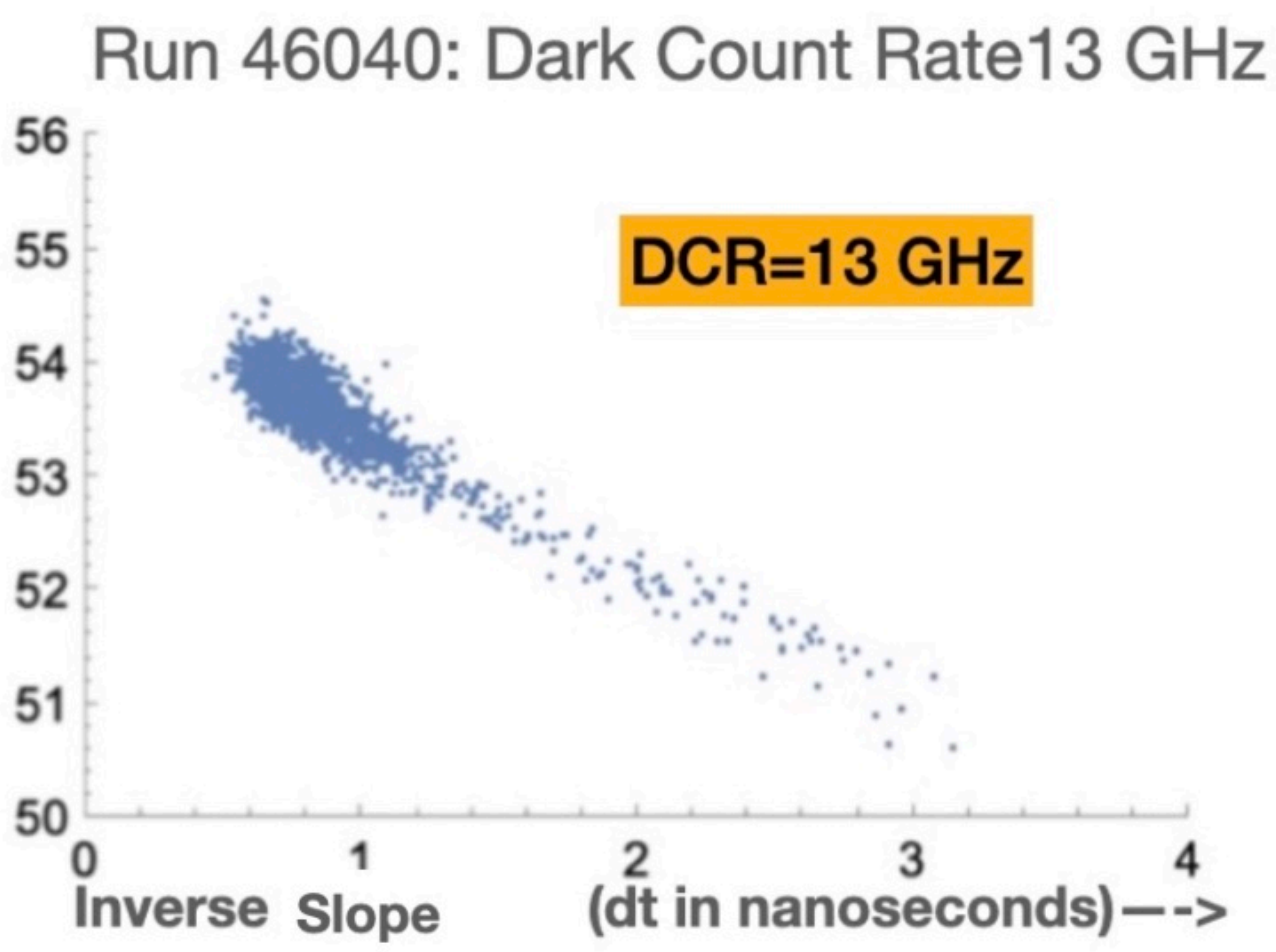
No less effective in LYSO/SiPM FNAL beam data than Laser





As we have seen before.

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Role of electronic noise in the workflow (in following-> impact in 2 steps).

Start from the usual steps in the workflow

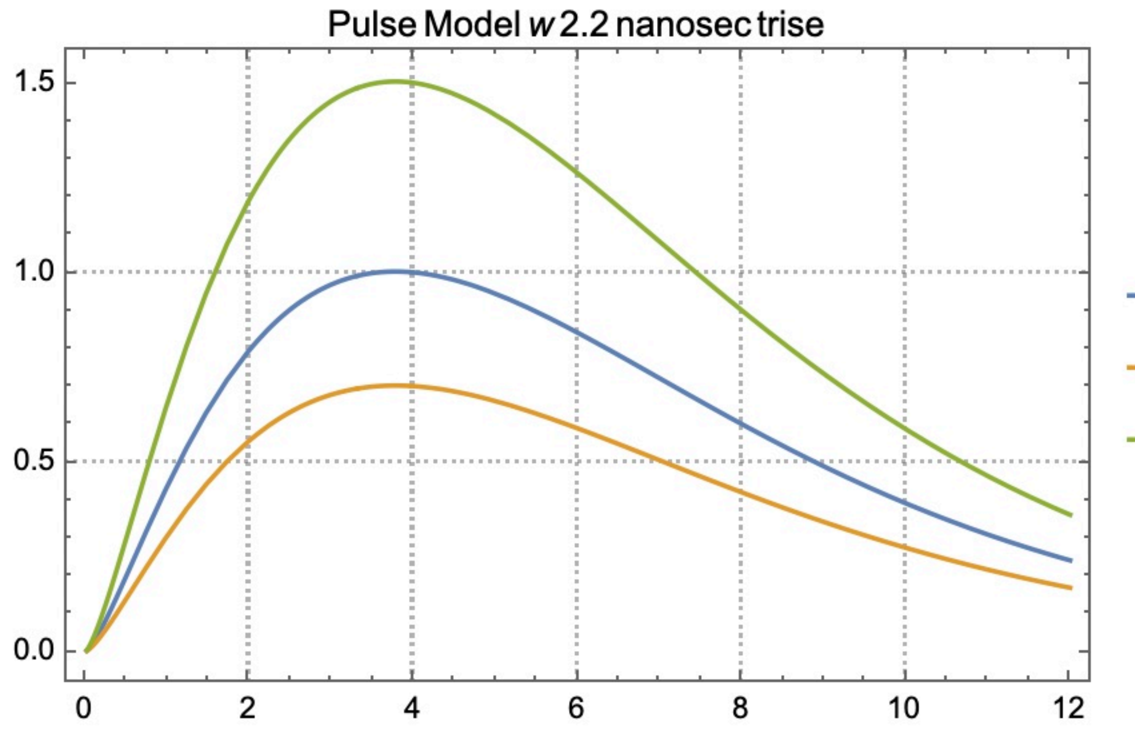
1) record time of threshold crossing (TOFHIR T1)

2) Apply a correction to T1 time to give "Time of Arrival (TOA)", using Q.

$$\rightarrow T_{ConstantFraction}=T1*f[Q]$$

- *This "Amplitude Walk Correction" is main correction to the TOA and f[Q] can, typically, just be derived from calibration data.*

  That is why CF rather than, ie, t_0.



- *Effective 'cause we spec'd Q error to be <5% (and this confirmed in lab).*
- *We could have, equivalently, used a measurement of $dV^{signal}/dt|_{@\,T1}$ to construct walk correction.*

  However precision of $dV^{signal}/dt|_{@\,T1}$ was not spec'd or measured (but discussed below).

3) at this point note contribution of electronic noise to the TOA. -> enters through usual jitter:

$$dT1 \sim V^{noise}_{rms}/(dV^{signal}/dt|_{@\,T1}) \qquad \textit{(from noise rms)}$$

And note that just rms noise that enters- not the noise power spectrum.

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Role of electronic noise in the workflow (in following-> impact in 2 steps).

Next we encounter DCR and ask if another correction analogous to "Amplitude walk correction" can be found

4)Using BTL data w. Scope DAQ we find a similar walk correction derived from noise slope

How well can we Measure slope with TOFHIR?
Now a clear Incentive!

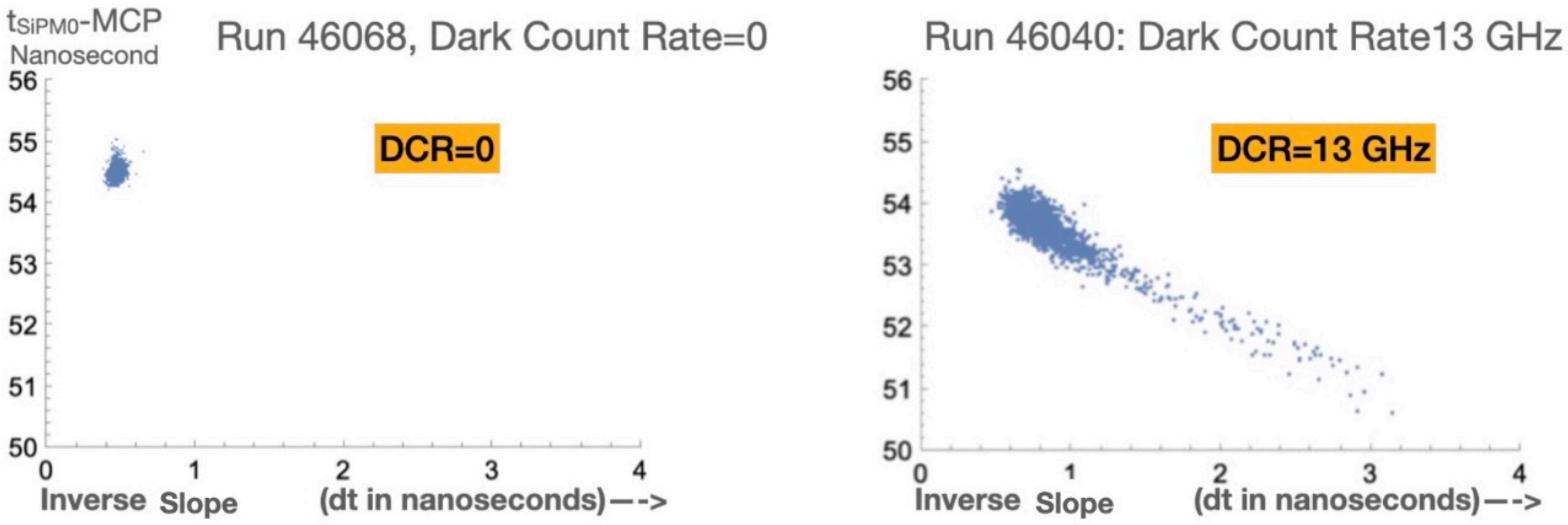

Figure 9. The same analysis was applied to testbeam data of a LYSO/SiPM model detector for the CMS Barrel Timing upgrade [3] in a 120 GeV proton beam at FNAL. The correlation between slope and time shift is seen clearly using highly radiation damaged SiPMs with DCR=13 GHz (right panel) whereas, as expected, time spread and slope spread were insignificant when using undamaged SiPMs (left panel).

- S. White, "Signal processing to reduce dark noise impact in precision timing", Journal of Instrumentation, Volume 18, July 2023, url = https://dx.doi.org/10.1088/1748-0221/18/07/P07051

Role of electronic noise in the workflow (in following-> impact in 2 steps).

How does electronic noise enter slope jitter?

4a) for data with given Q expect to see, on average, a signal slope of $<dV^{signal}/dt|_{@\,T1}.>$

4b) recall that in TOFHIR2C measurements actually on current but use V<->I(muAmps)

4c) How does noise enter slope measurement?

$$\text{“Slope”} \sim dV/dt|_{@\,T1} = dV^{signal}/dt|_{@\,T1} + dV^{noise}/dt|_{@\,T1}$$

(from noise slope-> frequency content important)

In what follows we will try to derive observed de-correlation in TOFHIR using what is known about TOFIR noise.

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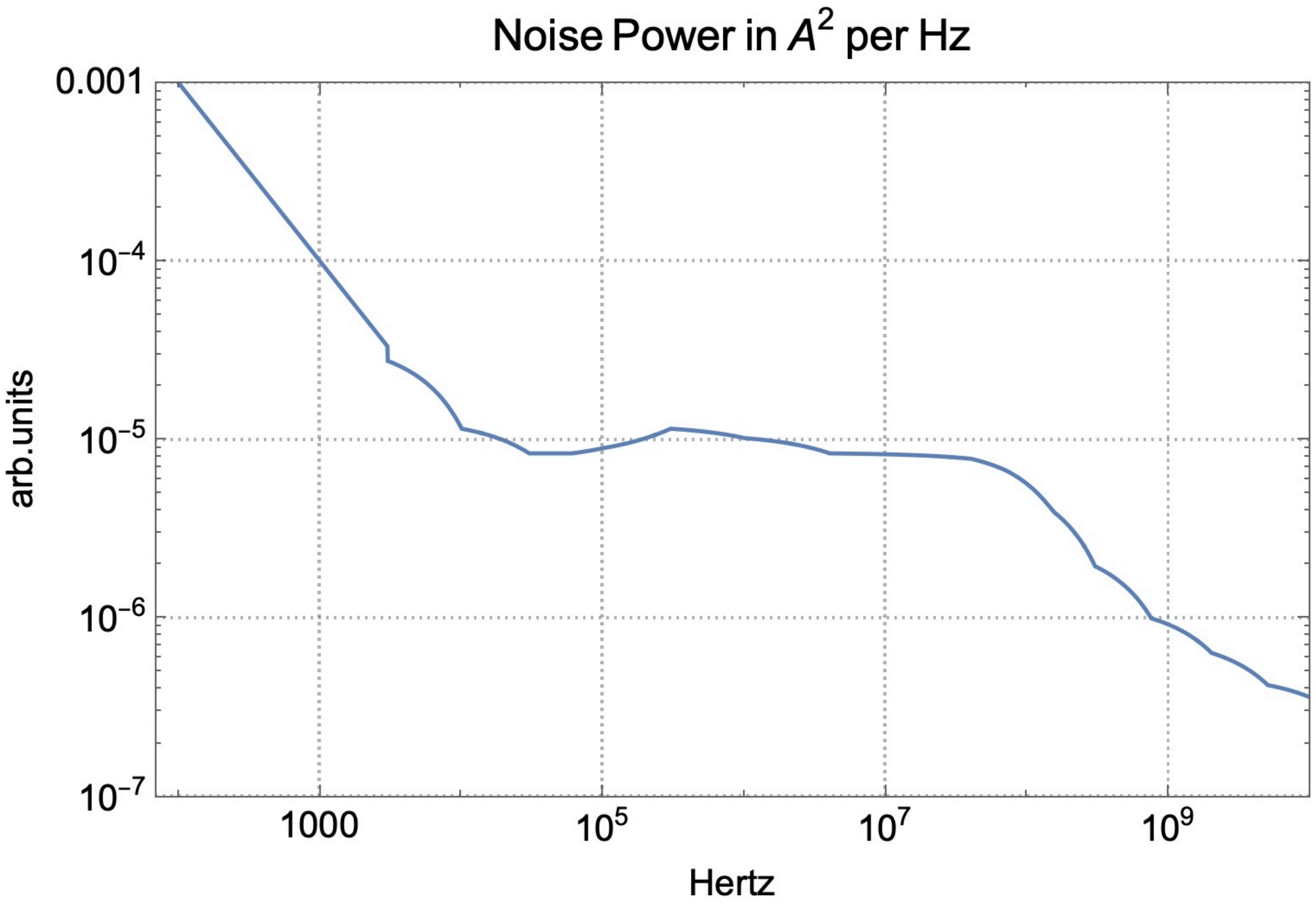
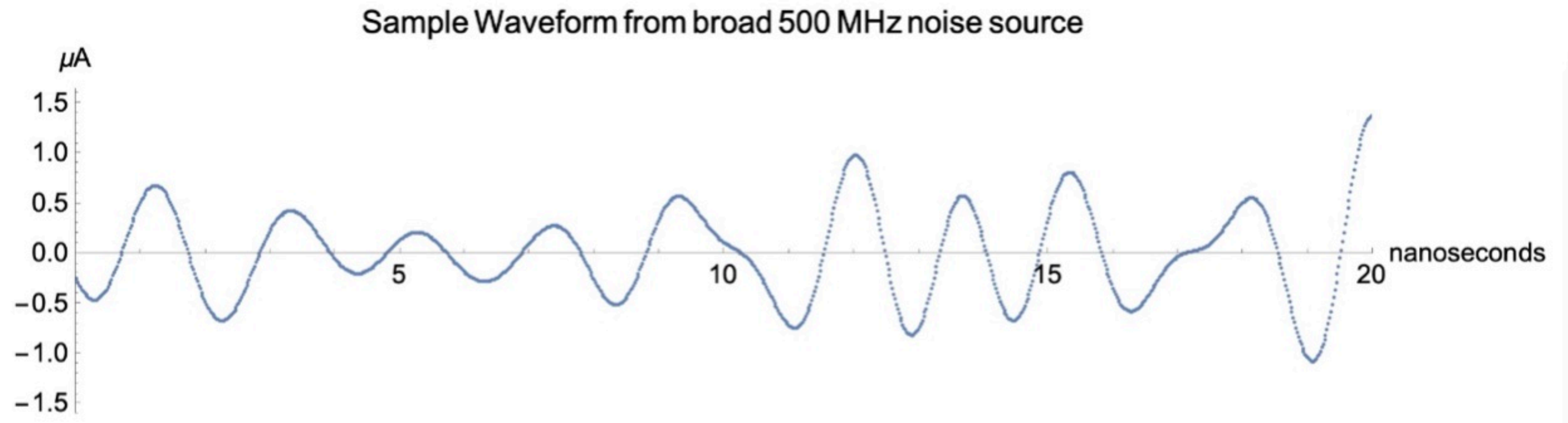
Calculating slope jitter due to noise:

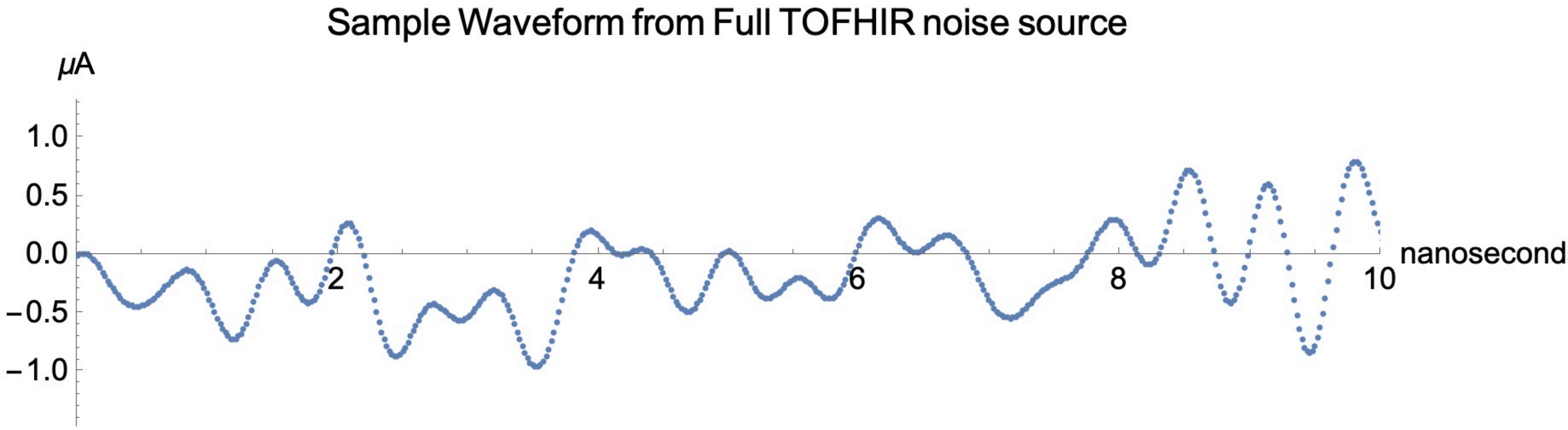
1)Overall (integrated over f) rms noise: various lab measurements-> ~ 0.4 microAmp. ->this provides normalization of power spectrum
2) Power spectrum: from xfer function to T1 discriminator input

Or directly from CADENCE calculation of power spectrum at T1 input

—>Construct random waveforms in time-domain Using Sqrt[PowerSpectrum] to generate Discrete FT







Summary

- Various lab and testbeam studies of Digitized waveforms have been a useful

complement to TOFHIR simulations with CADENCE and TOFHIR TB/Lab data.

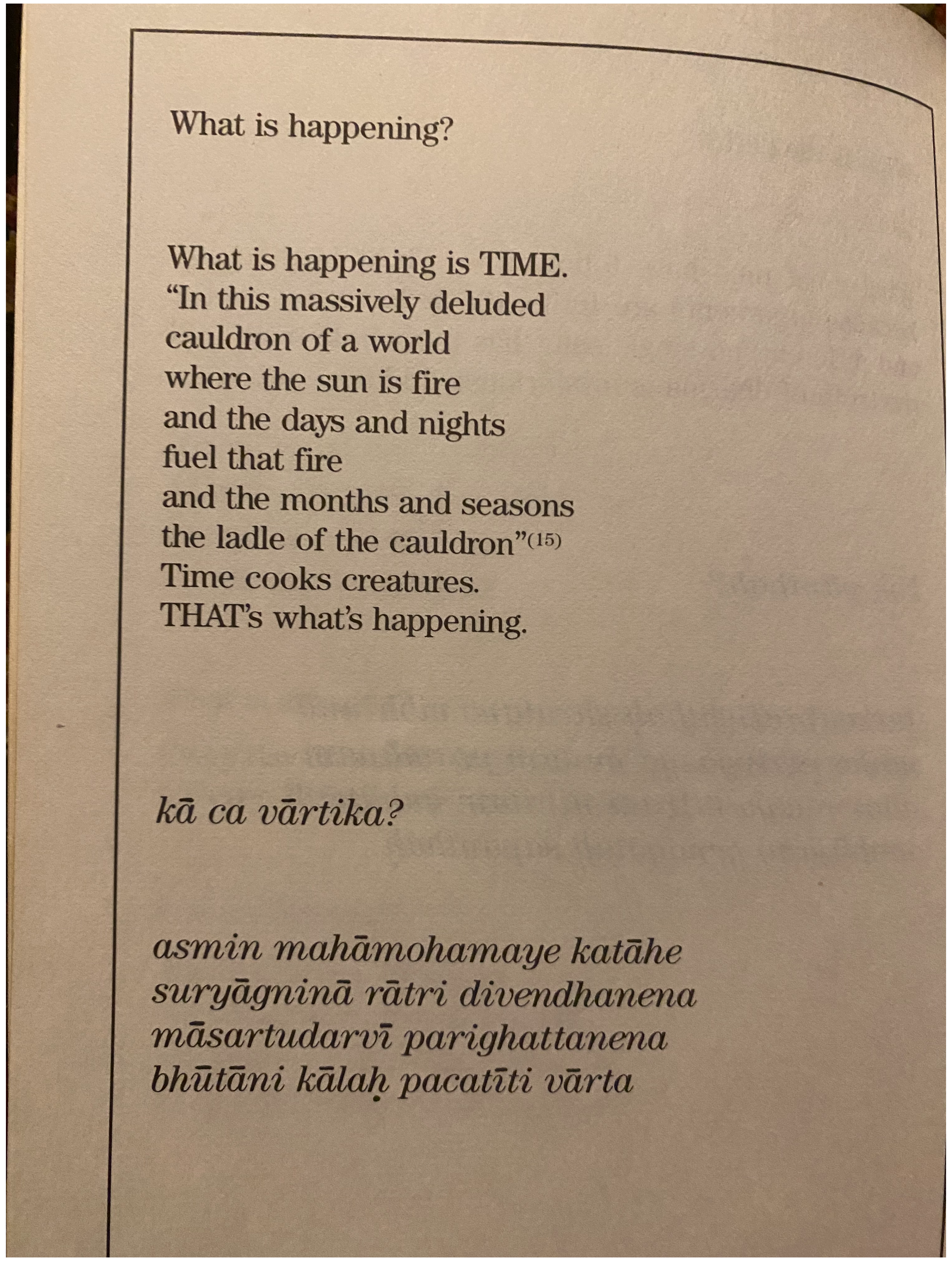
- Potential further improvement in time jitter @high DCR w. TOFHIR 2 thresholds.
- I presented tools to relate its effectiveness to understanding of internal noise.

Sanskrit equivalent of The Riddle of the Sphinx:

Riddle contest between a Yaksha and Yudhishthira

Q:What is happening?

A: What is happening is TIME.


What is happening?

What is happening is TIME.
"In this massively deluded
cauldron of a world
where the sun is fire
and the days and nights
fuel that fire
and the months and seasons
the ladle of the cauldron"(15)
Time cooks creatures.
THAT's what's happening.

kā ca vārtika?

asmin mahāmohamaye katāhe
suryāgninā rātri divendhanena
māsartudarvī parighattanena
bhūtāni kālaḥ pacatīti vārta

अस्मिन् महामोहमये कटाहे सूर्याग्निना रात्रिदिवेन्धनेन ।
मासर्तुदर्वीपरिघट्टनेन भूतानि कालः पचतीति वार्ता ॥ ९९

thanks to Milind Diwan for this reference

Sebastian White, LIP IDTM