

Recent RD53B Test Results

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ATLAS | **BERKELEY LAB**
EXPERIMENT

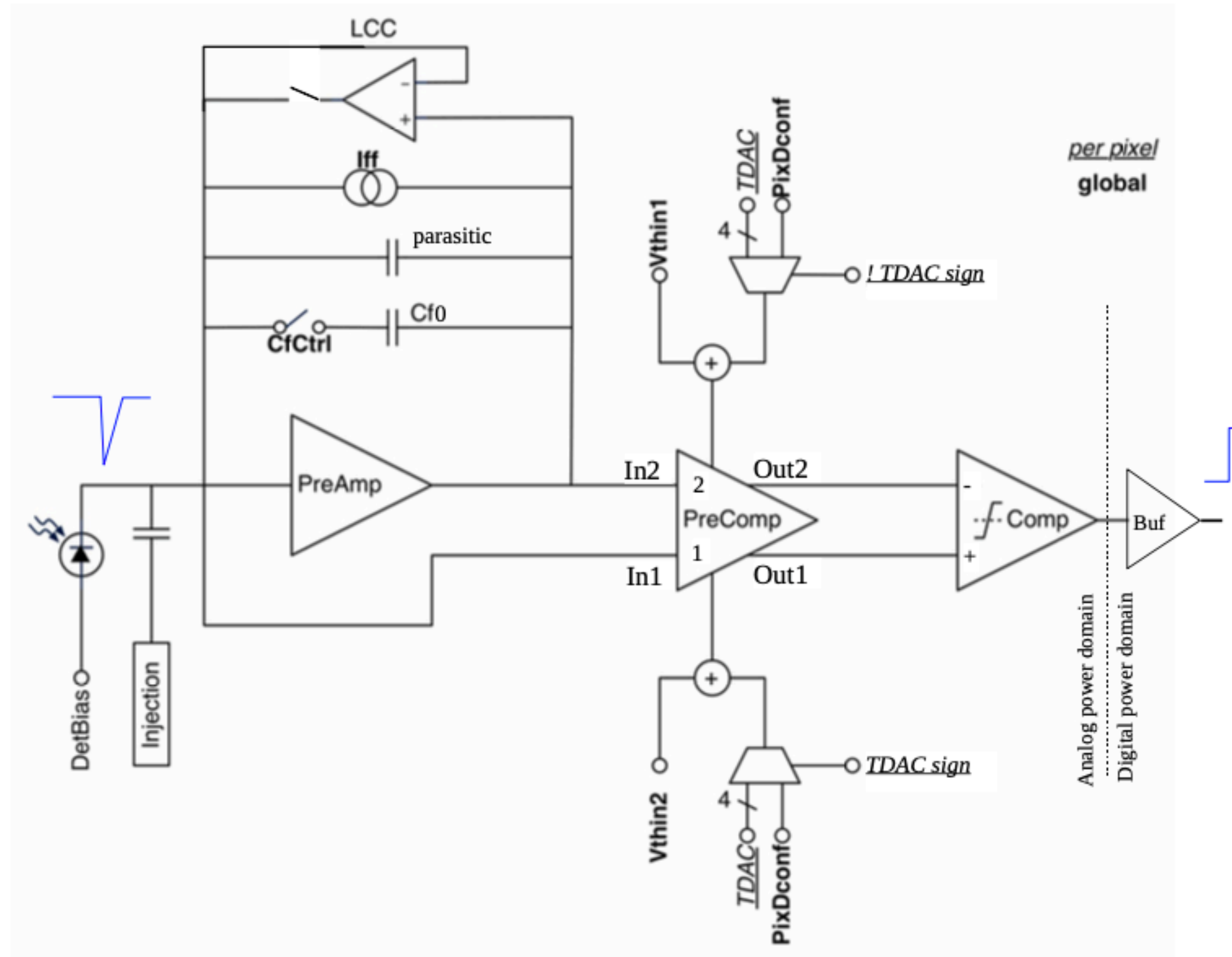


- RD53b Analog Frontend
- Recent Studies

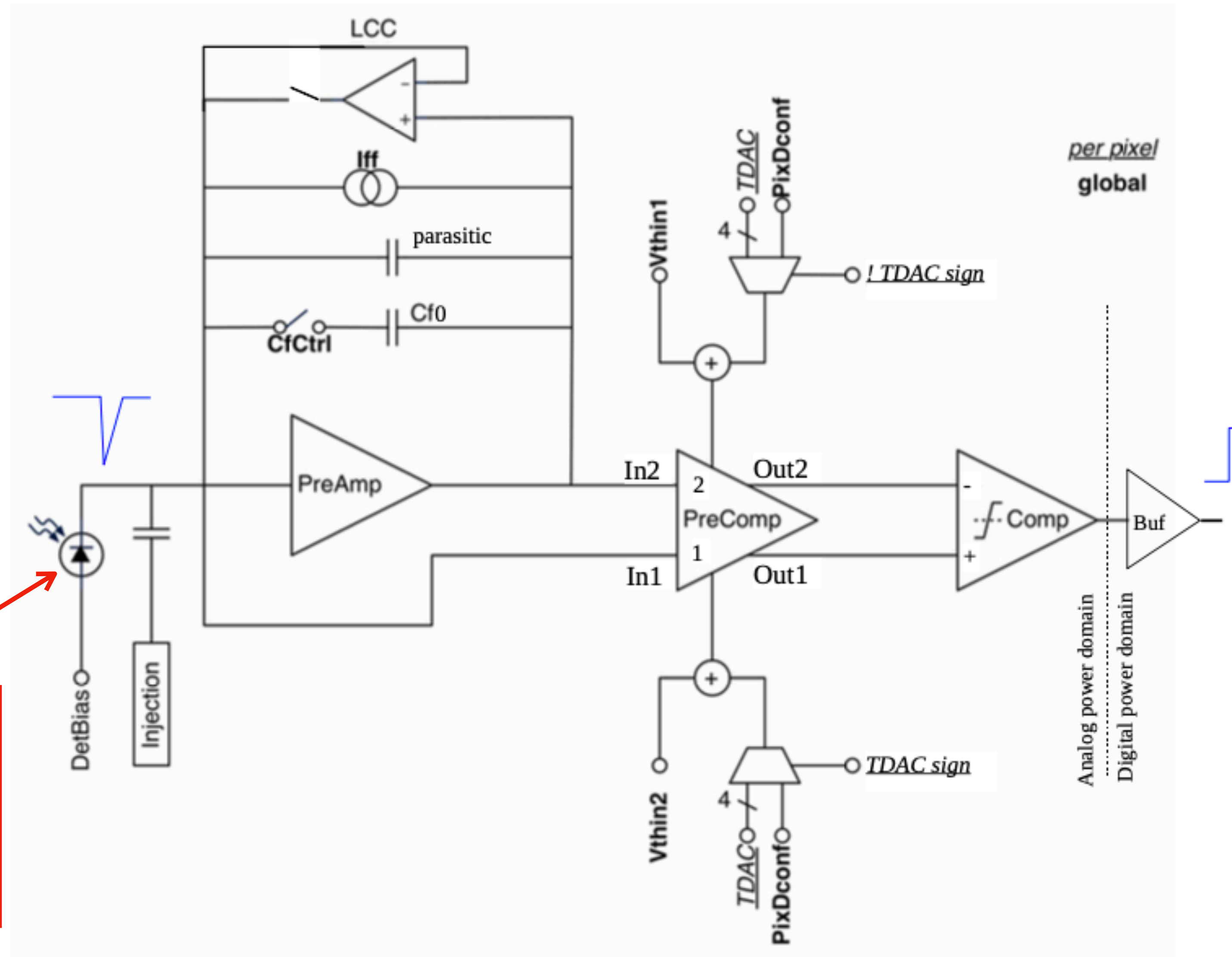
- The RD53B is the current front-end ASIC that we are working with for reading out the pixel detectors in the upgraded tracking detectors of ATLAS (ITk)
 - ITkPix*
 - The whole chip is a “frontend chip”, but composed logically of two domains: **analog** and **digital**
 - Referred to as the “analog front-end” / “digital front-end”
 - The analog front-end is responsible for **directly interfacing with the detector/sensing materials** to collect the signals of interest (e.g. current pulses) generated from passing particles or something else of interest
 - The digital front-end is responsible for interfacing with the analog front-end: digitizing the information contained therein and passing it along to the downstream data processing pipeline (serialization, storage, etc)
- ➔ **A lot of the recent studies done by LBL folks have been on studying and characterizing the analog front-end, so we’ll talk about this portion of the RD53B**

RD53b Analog Frontend

This is a high-level schematic of the analog front-end

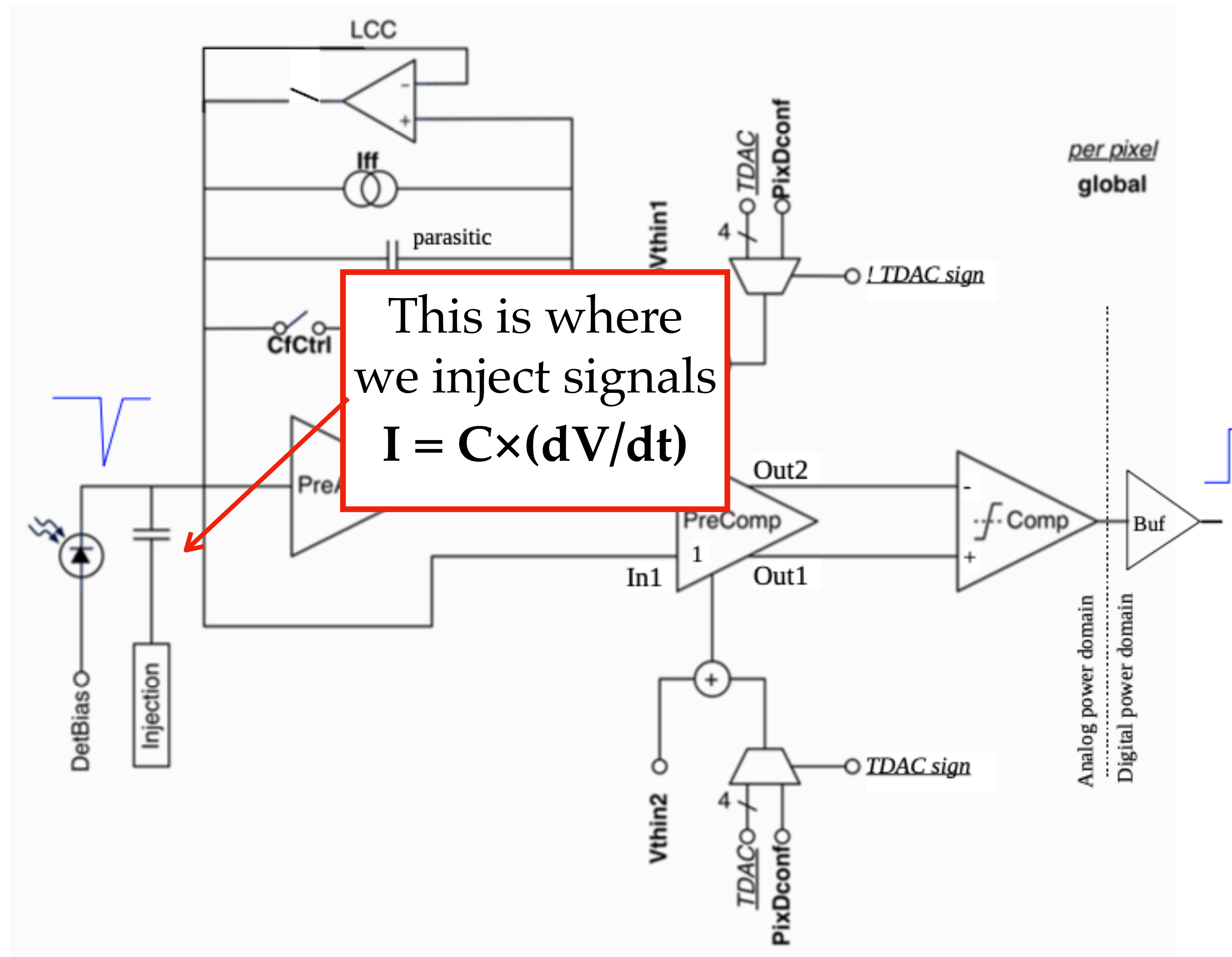


This is a high-level schematic of the analog front-end

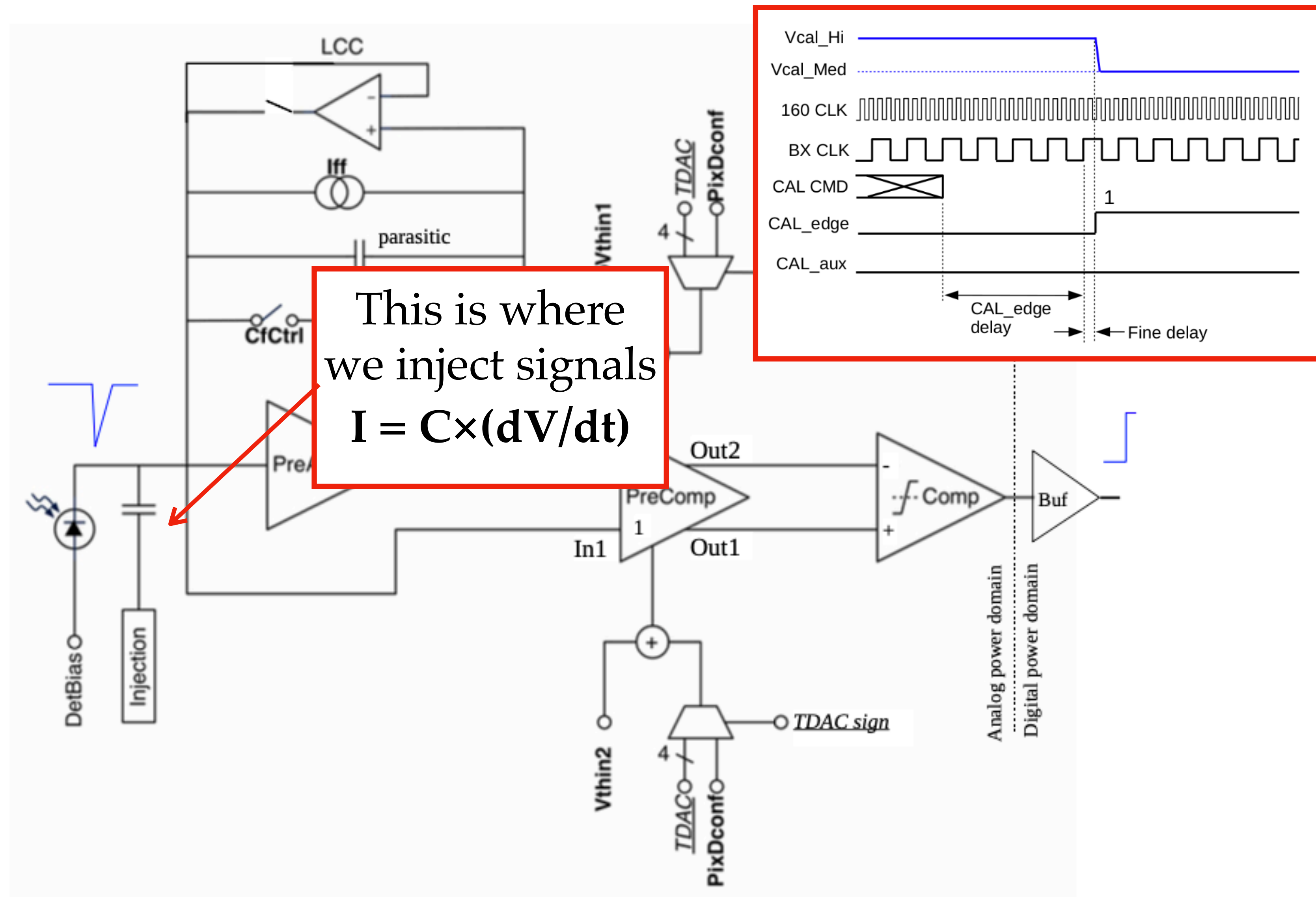


This is where the detector signals come in — they are negative current pulses

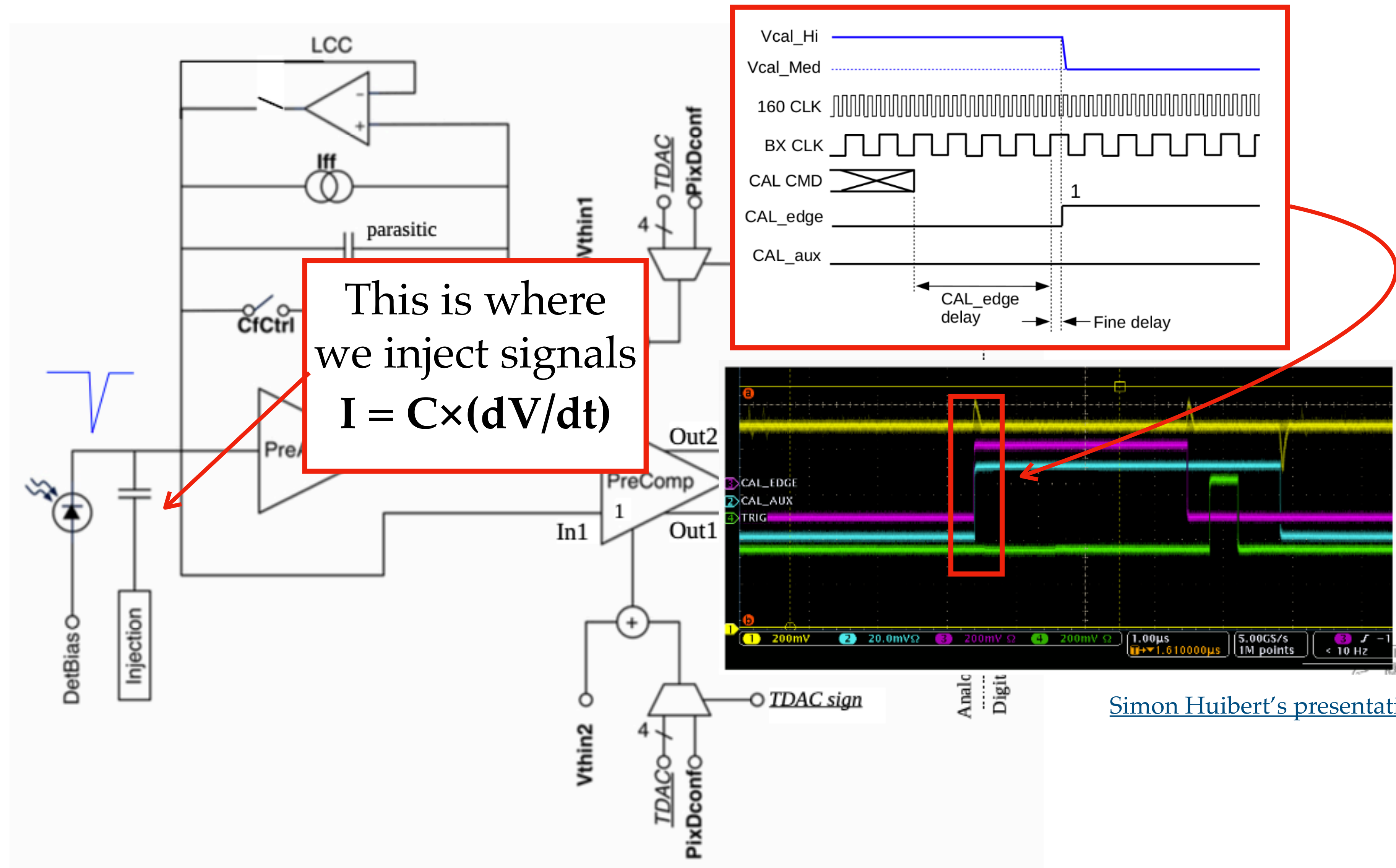
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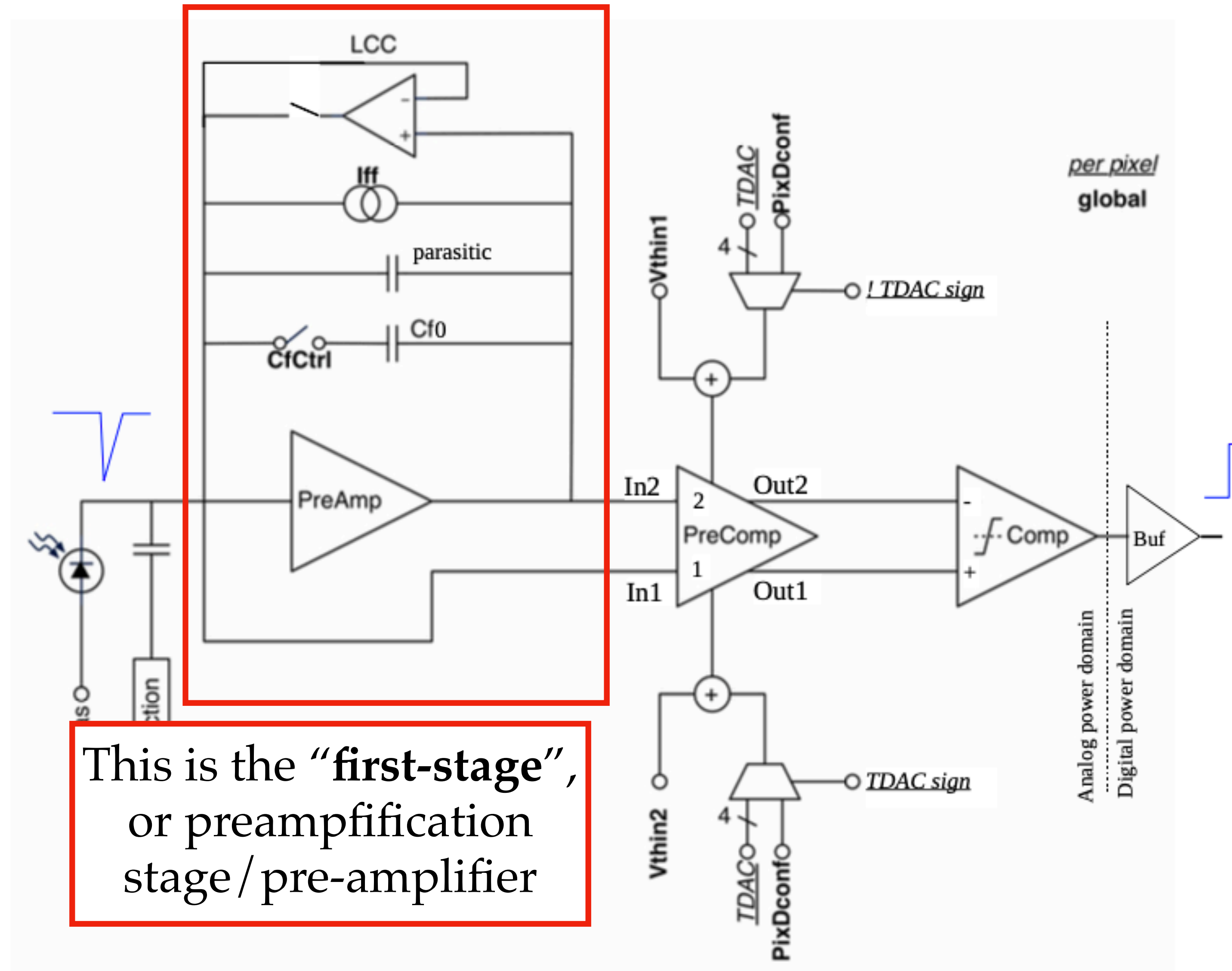
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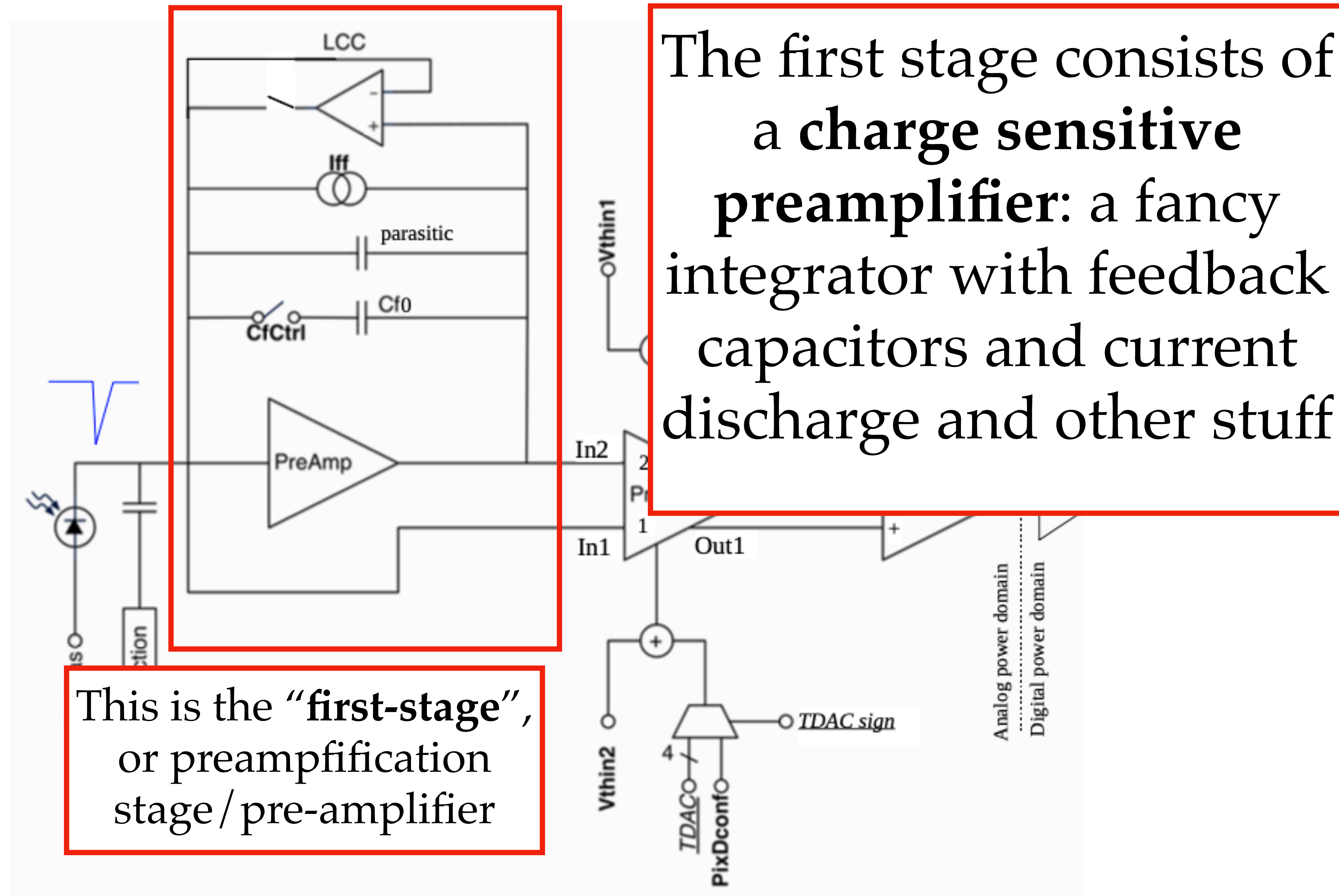
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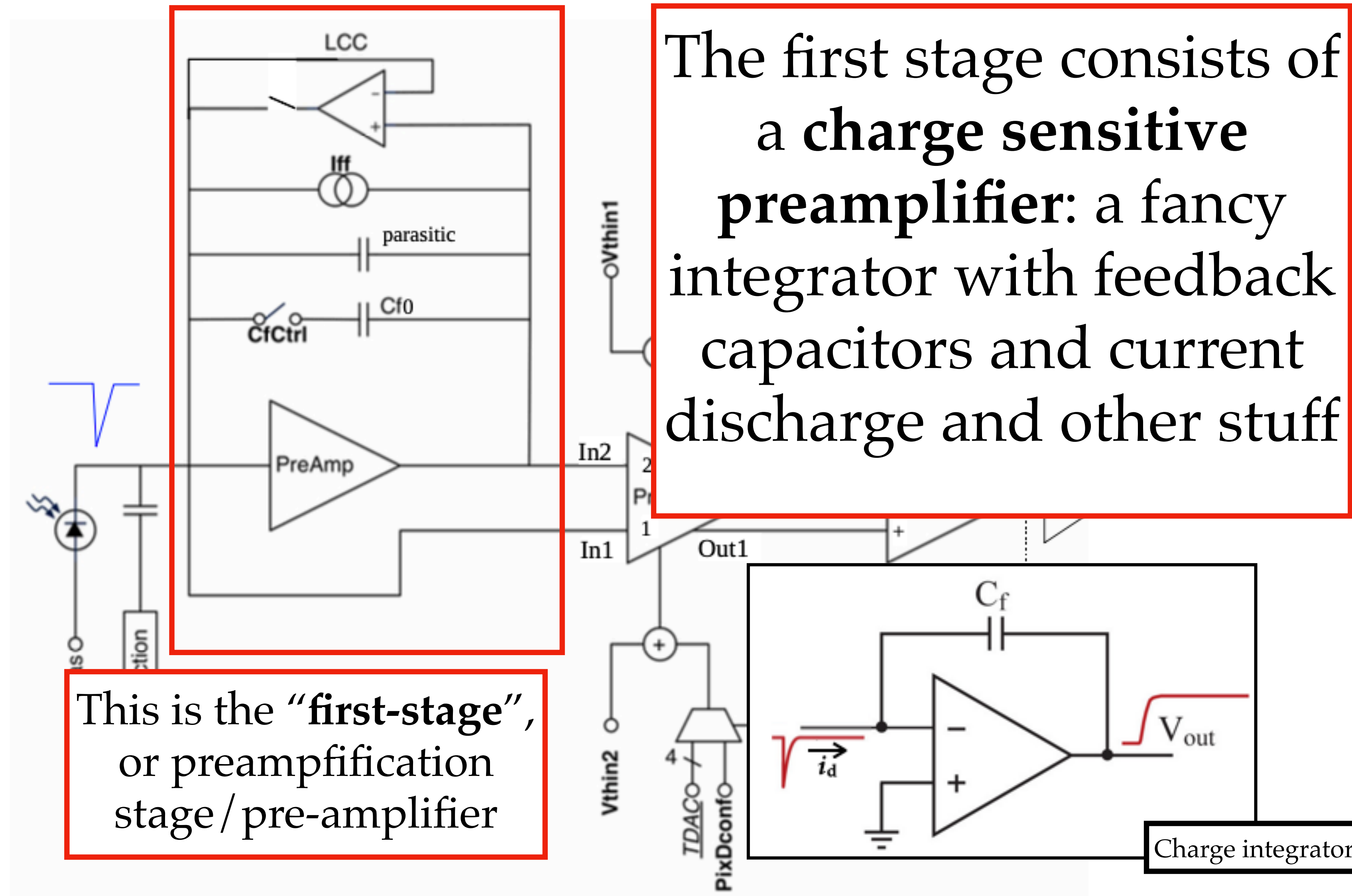
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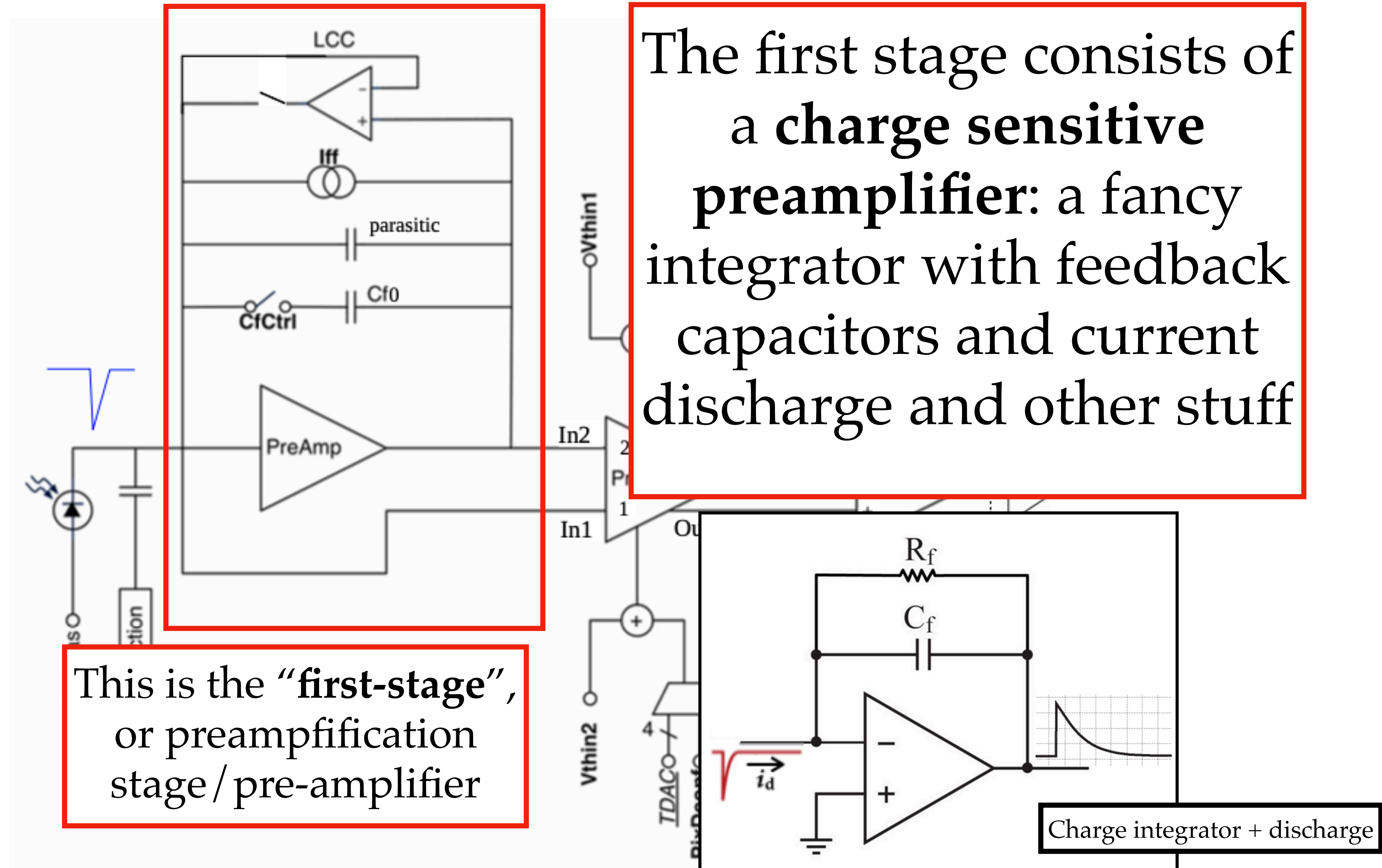


The first stage consists of a **charge sensitive preamplifier**: a fancy integrator with feedback capacitors and current discharge and other stuff

This is the “**first-stage**”, or preamplification stage / pre-amplifier

Charge integrator

This is a high-level schematic of the analog front-end

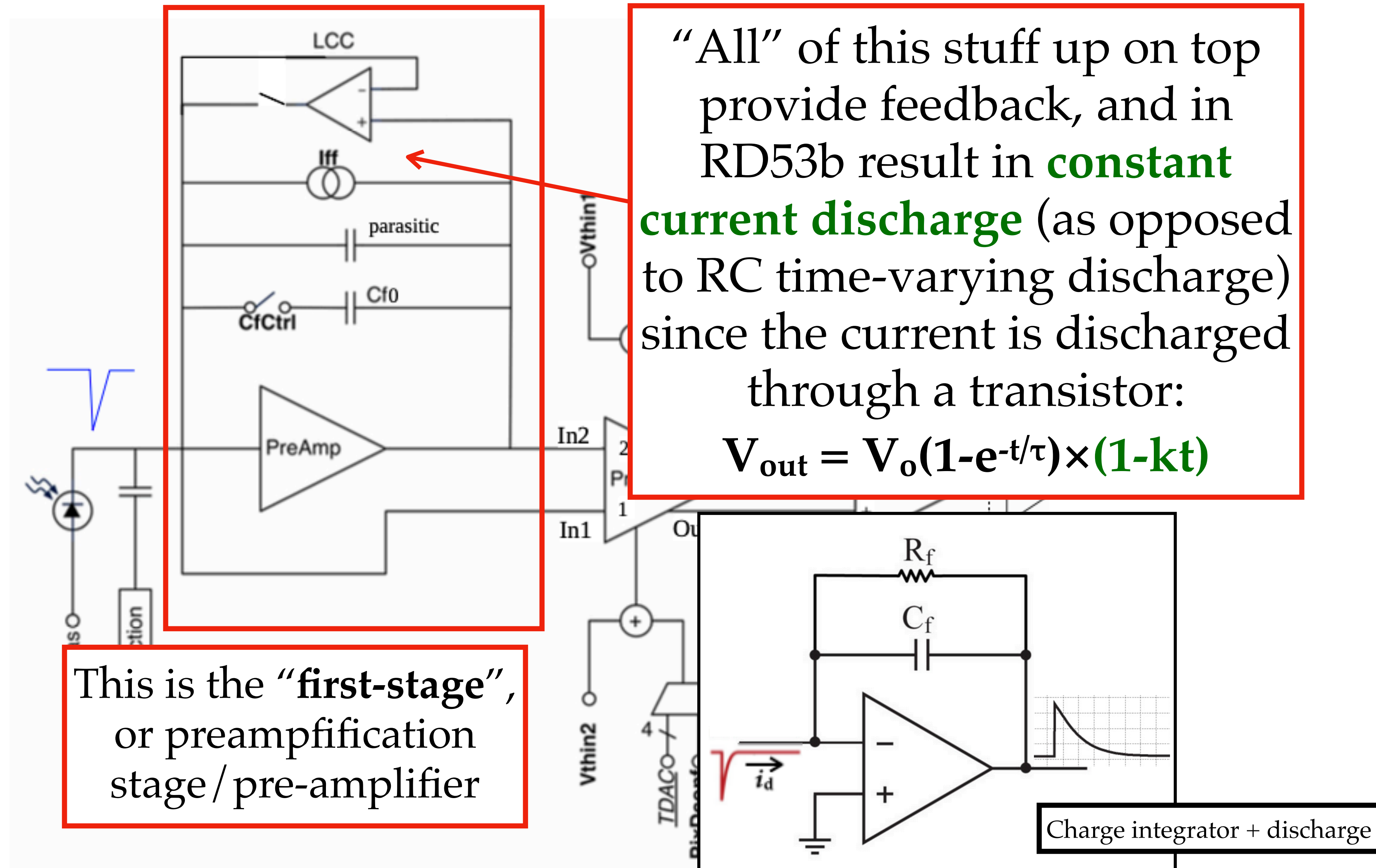


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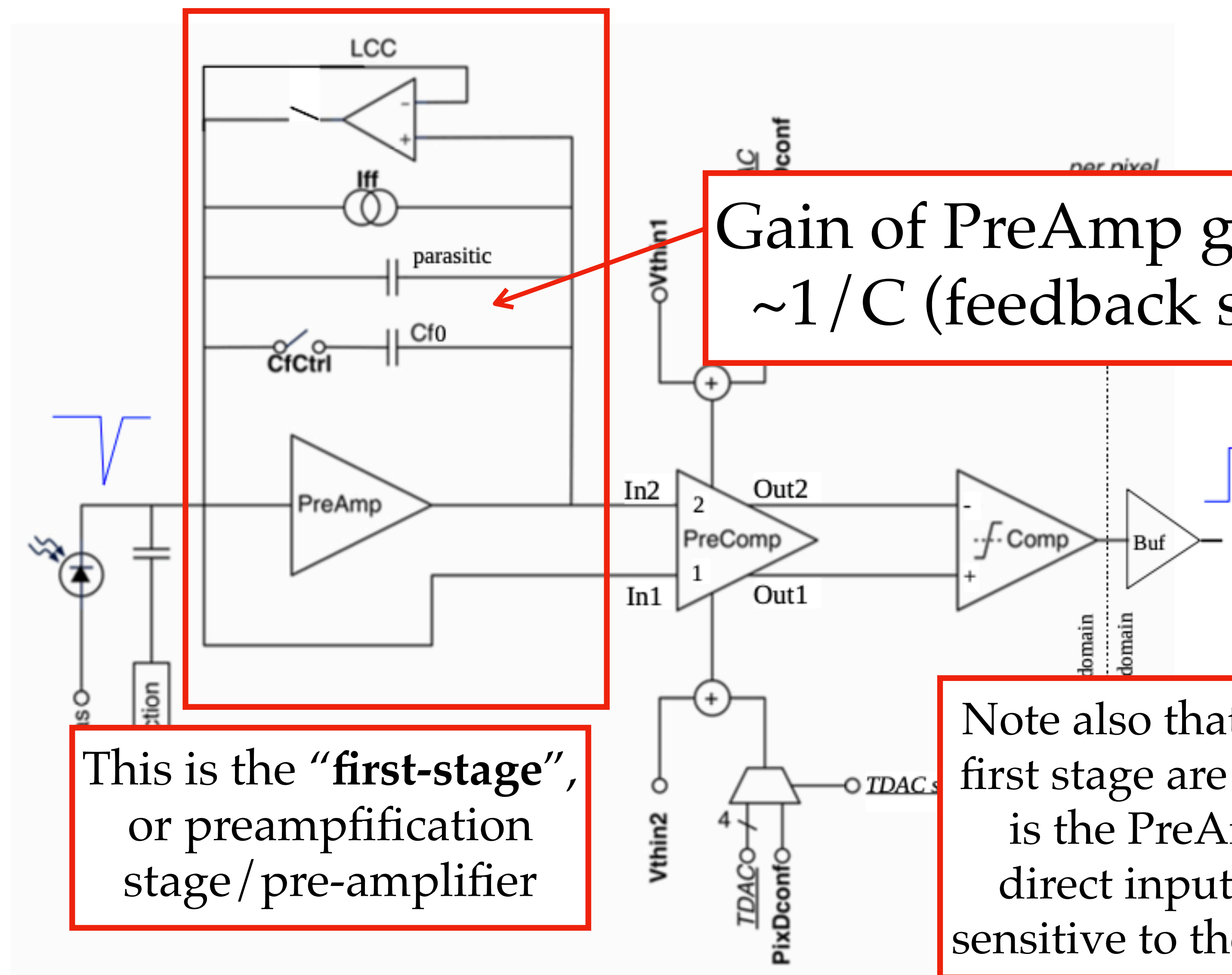
This is the “**first-stage**”, or preamplification stage / pre-amplifier

Charge integrator + discharge

This is a high-level schematic of the analog front-end



This is a high-level schematic of the analog front-end

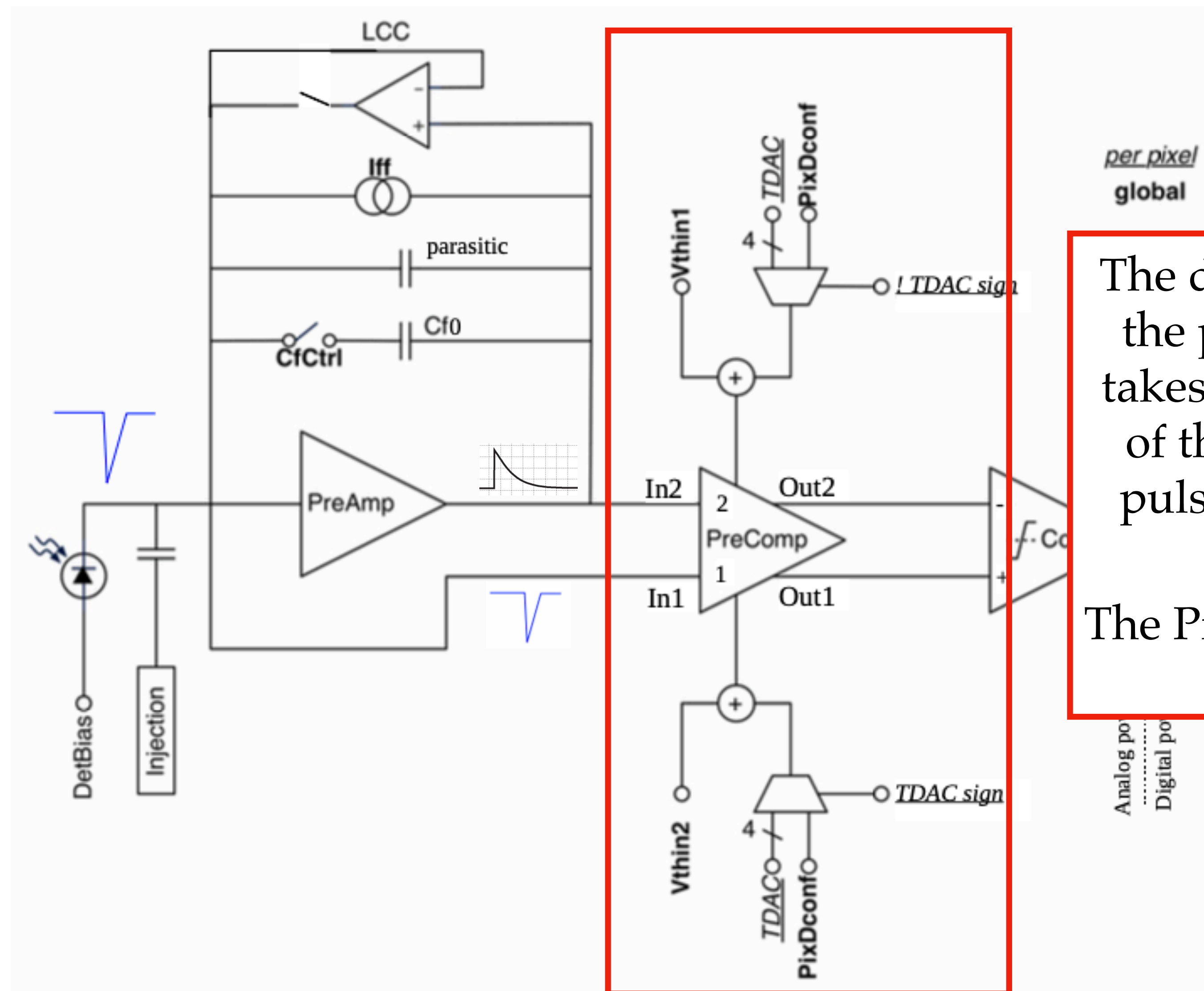


Gain of PreAmp given by $\sim 1 / C$ (feedback stages)

This is the “**first-stage**”, or preamplification stage / pre-amplifier

Note also that the + and - output of the first stage are treated differently: + side is the PreAmp output and - side is direct input of the front-end (and is sensitive to the PreAmp feedback stage)

This is a high-level schematic of the analog front-end

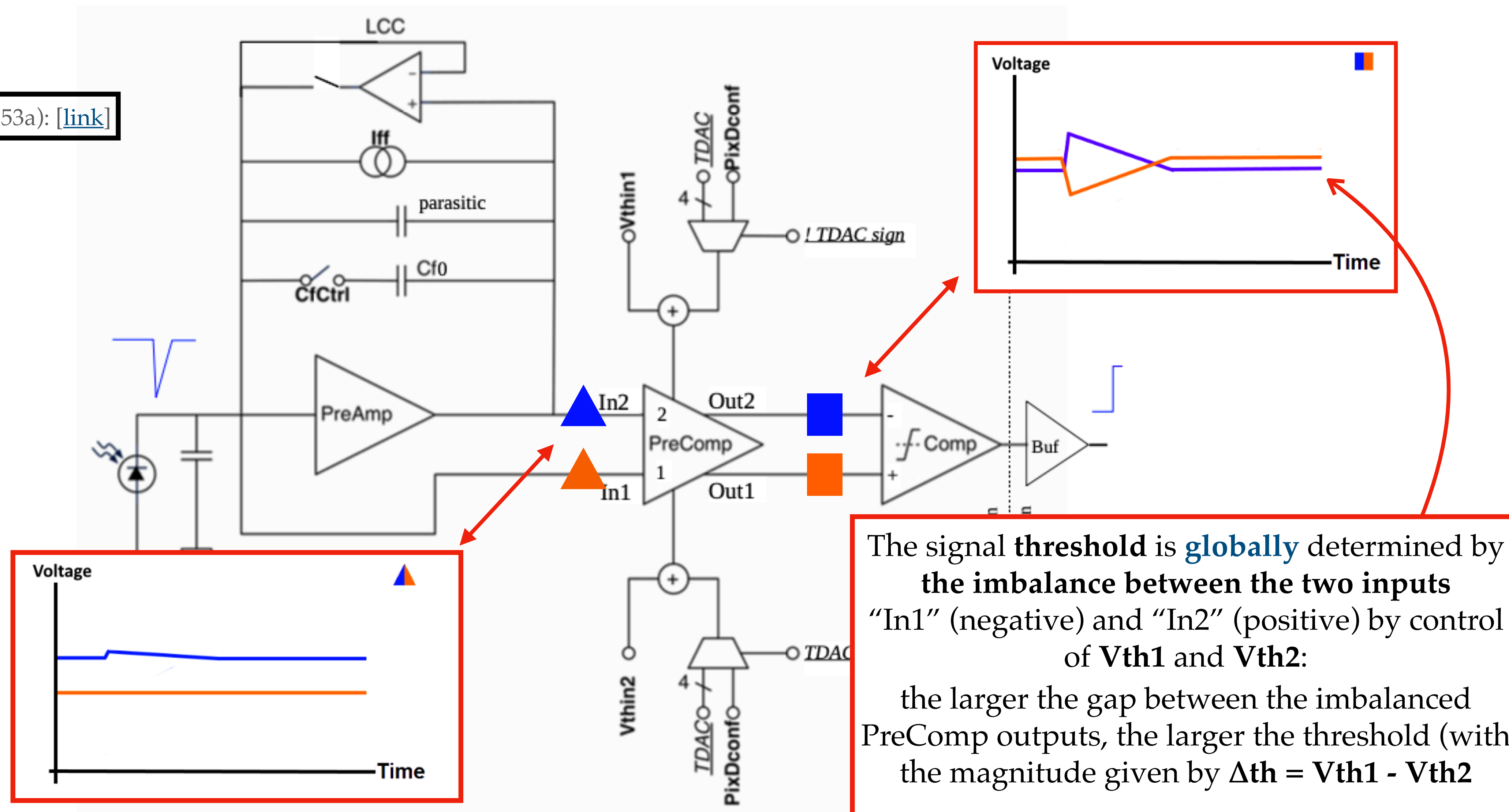


The differential second-stage consists of the pre-comparator (“PreComp”) and takes as input the positive-pulse output of the pre-amplifier and the negative pulse from the analog front-end input

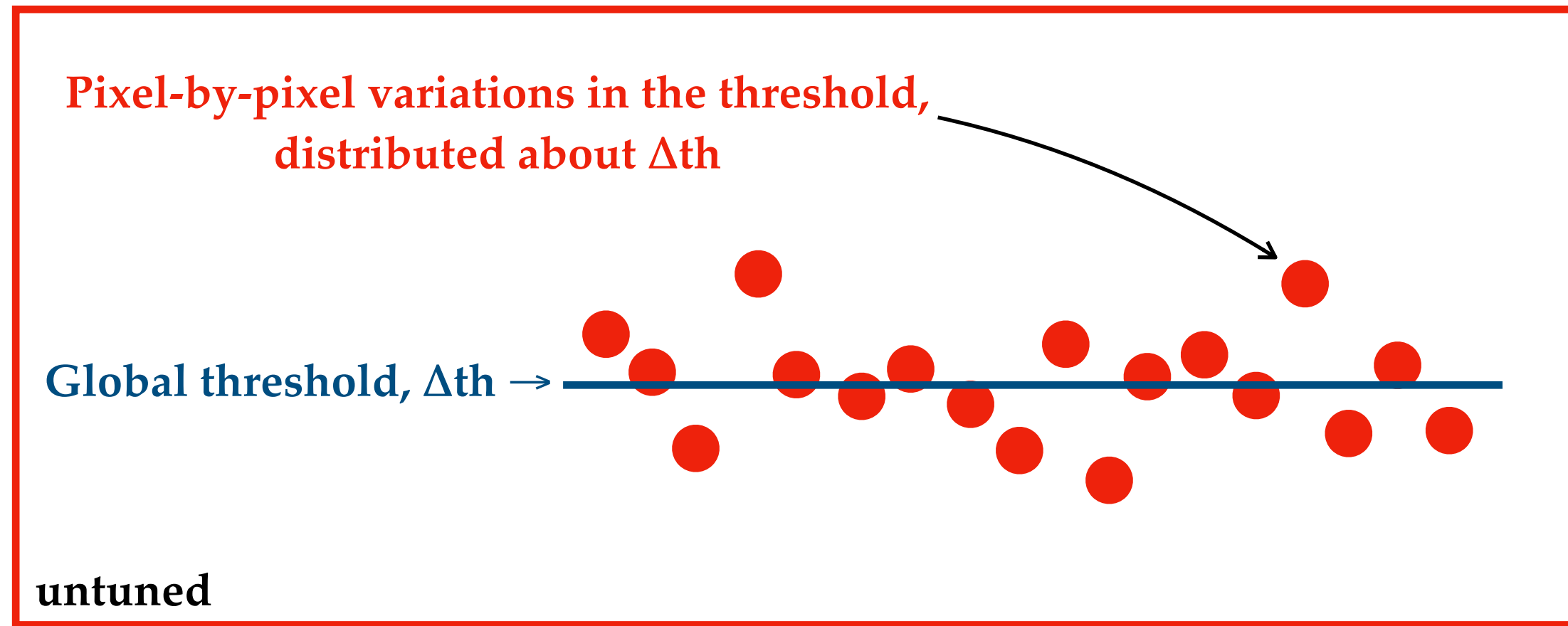
The PreComp introduces both a **gain** and a **threshold**

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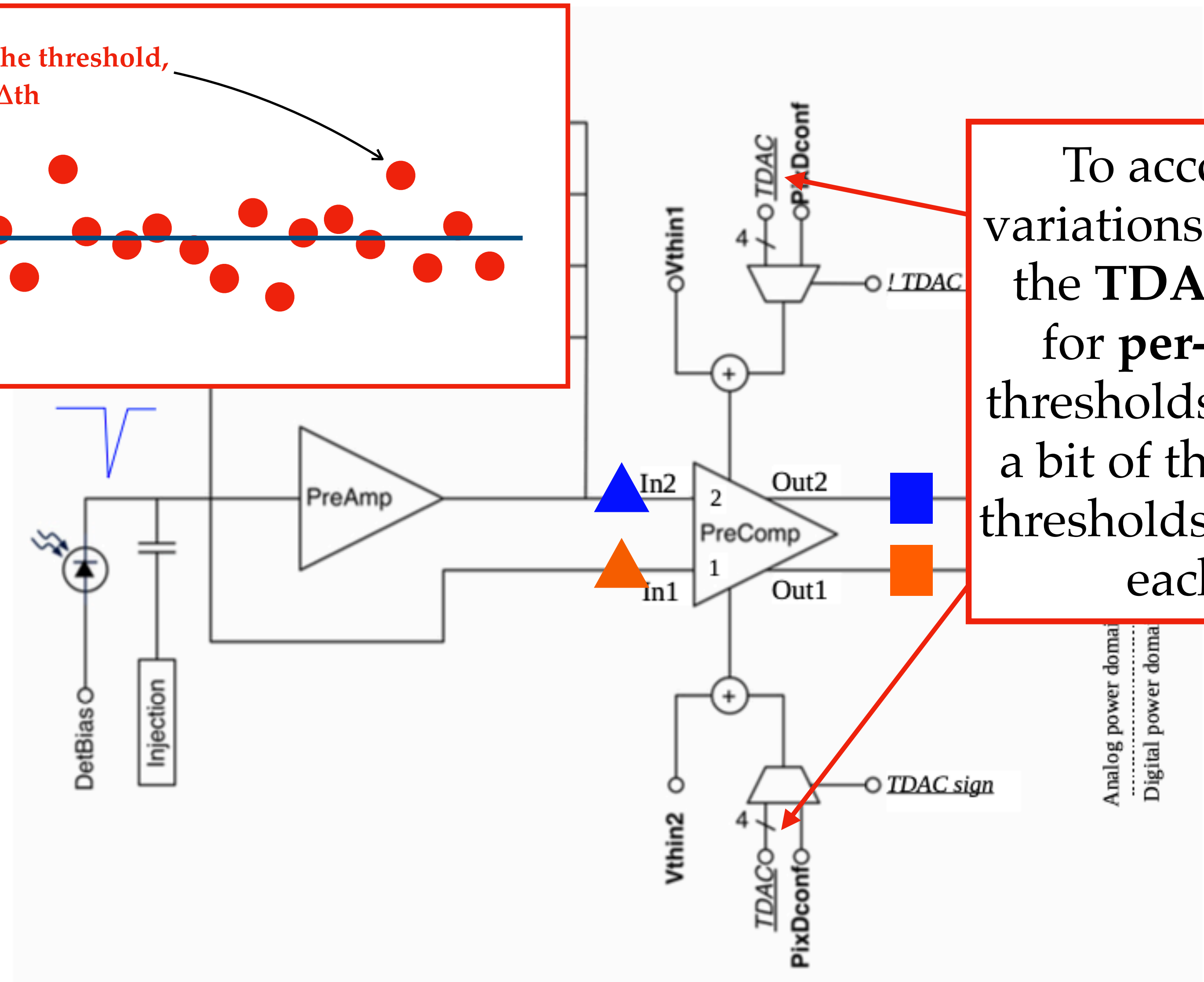
Nice reference (for RD53a): [\[link\]](#)



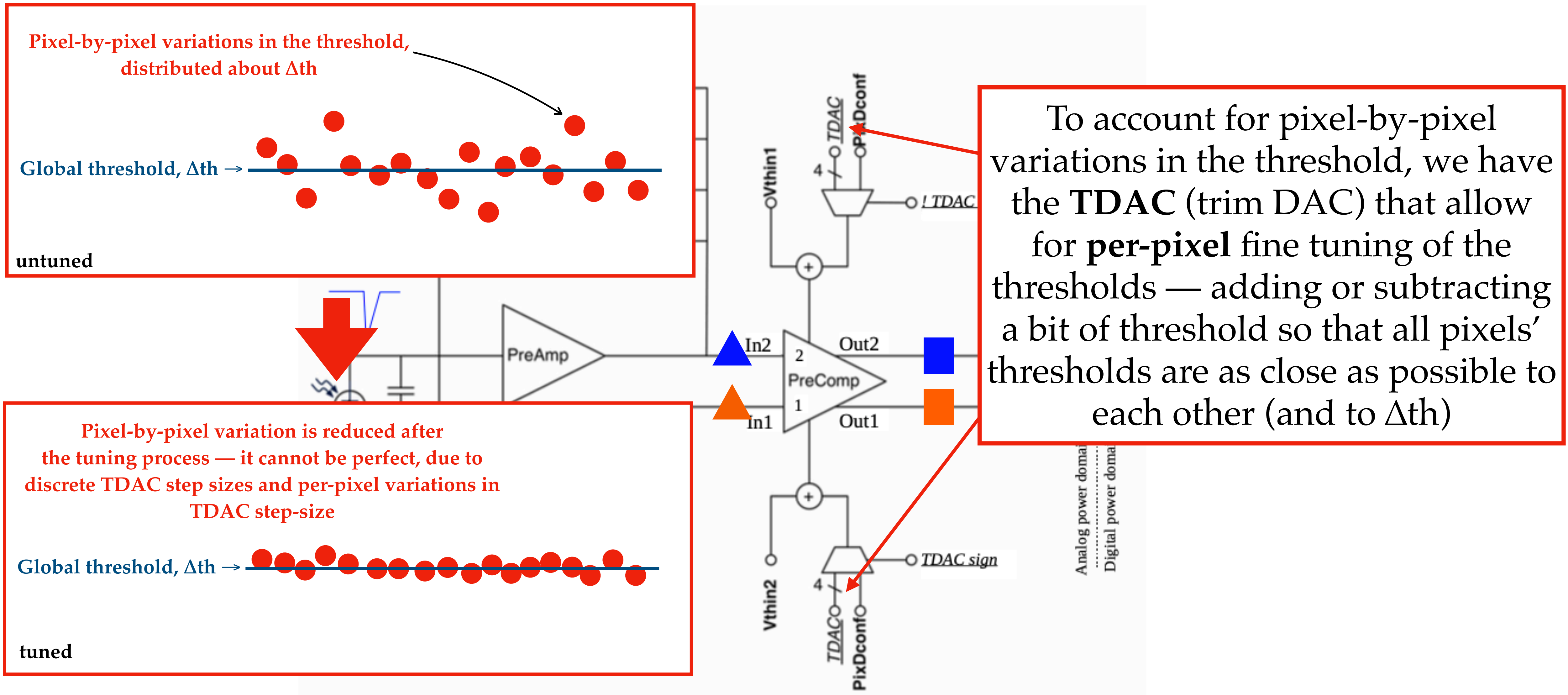
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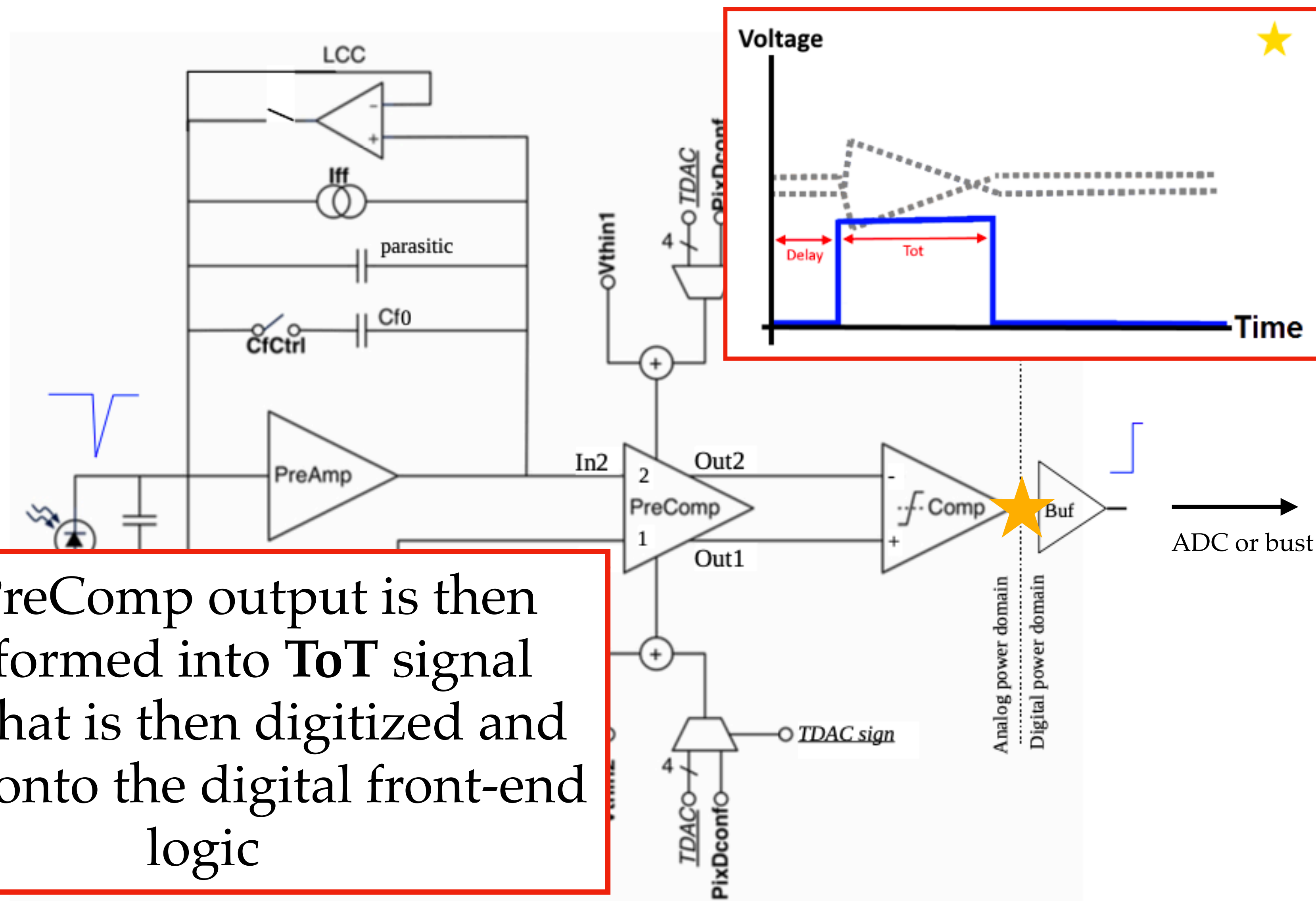
To account for pixel-by-pixel variations in the threshold, we have the **TDAC** (trim DAC) that allow for **per-pixel** fine tuning of the thresholds — adding or subtracting a bit of threshold so that all pixels' thresholds are as close as possible to each other (and to Δth)



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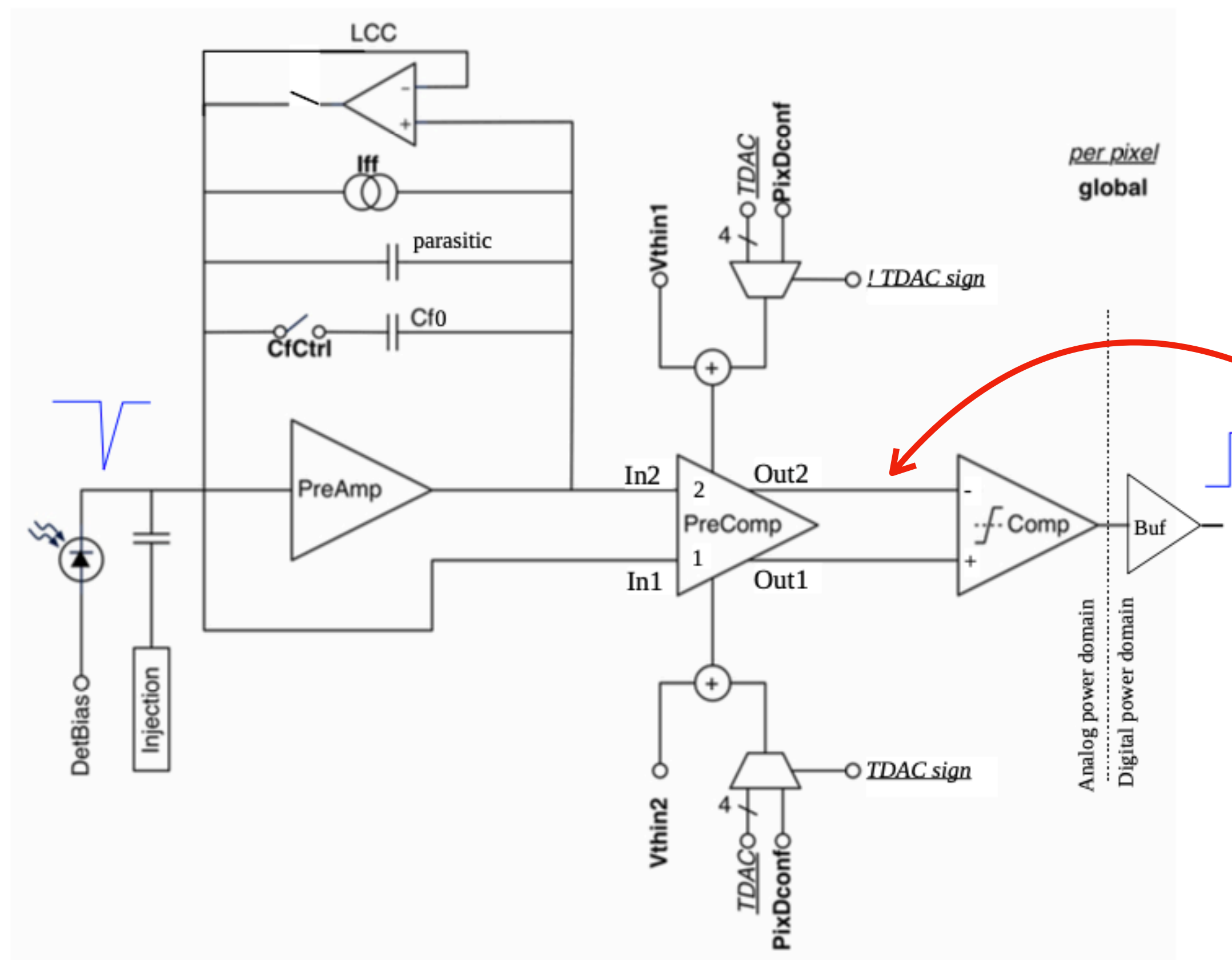


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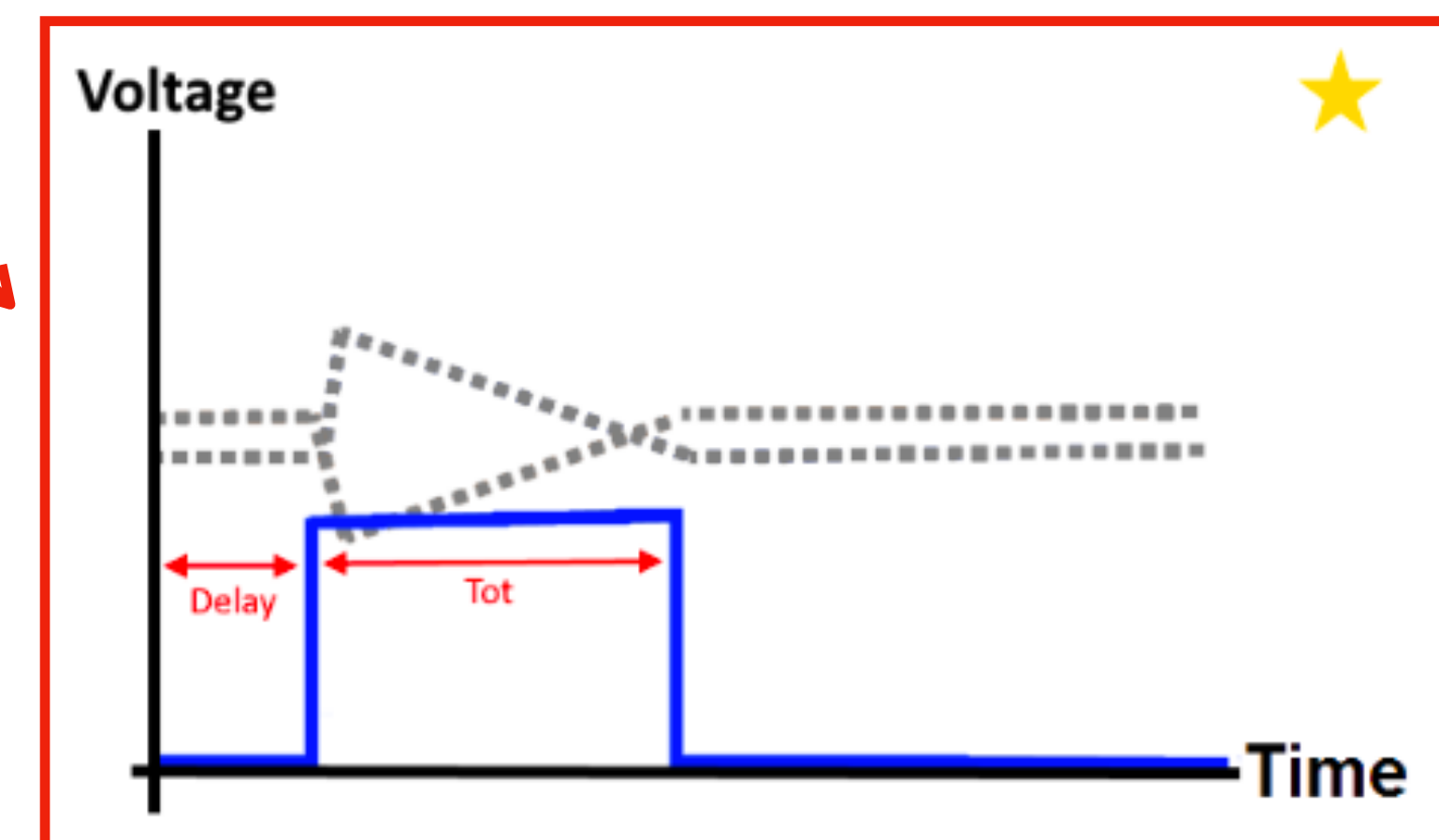


Recent & On-going Studies

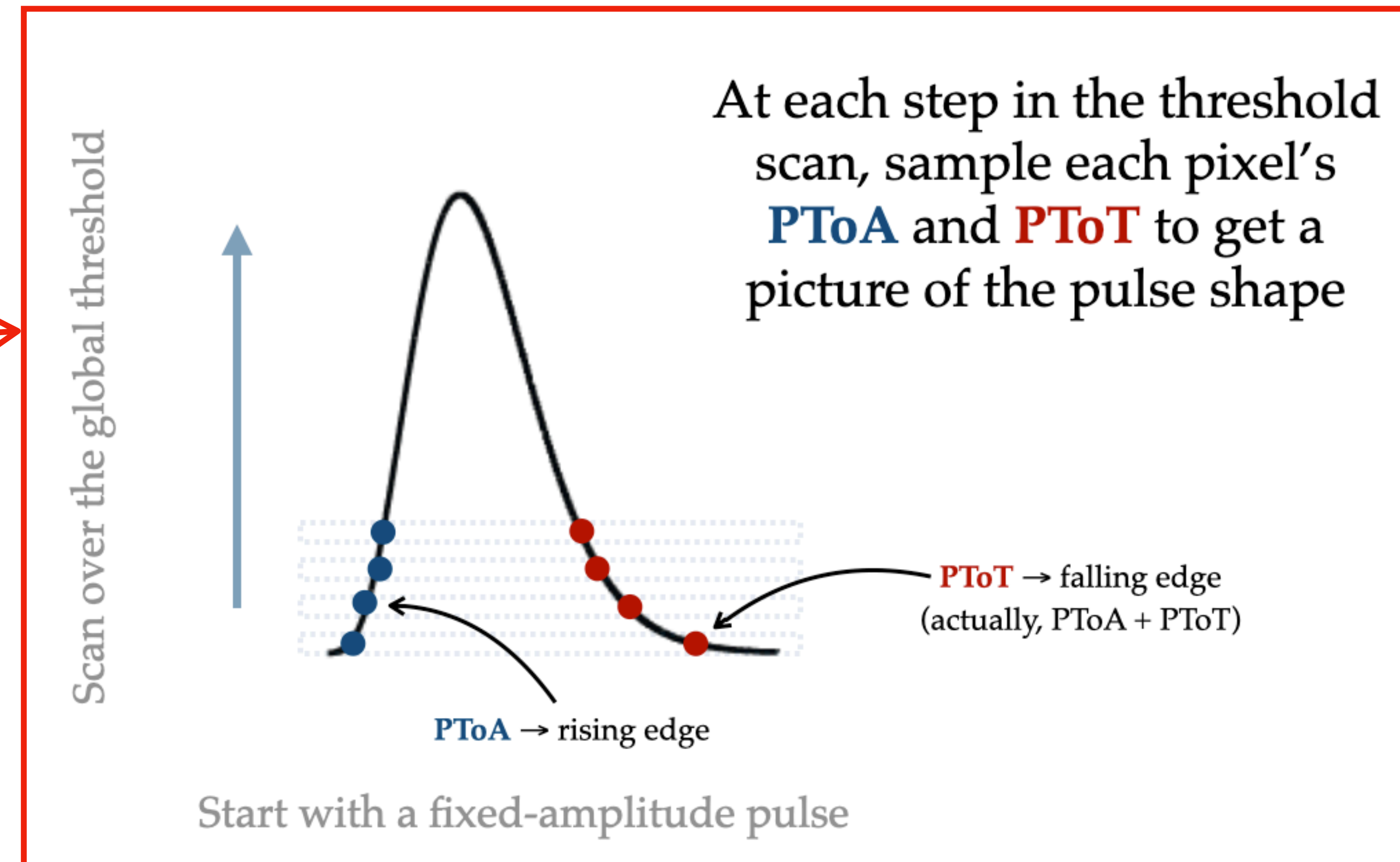
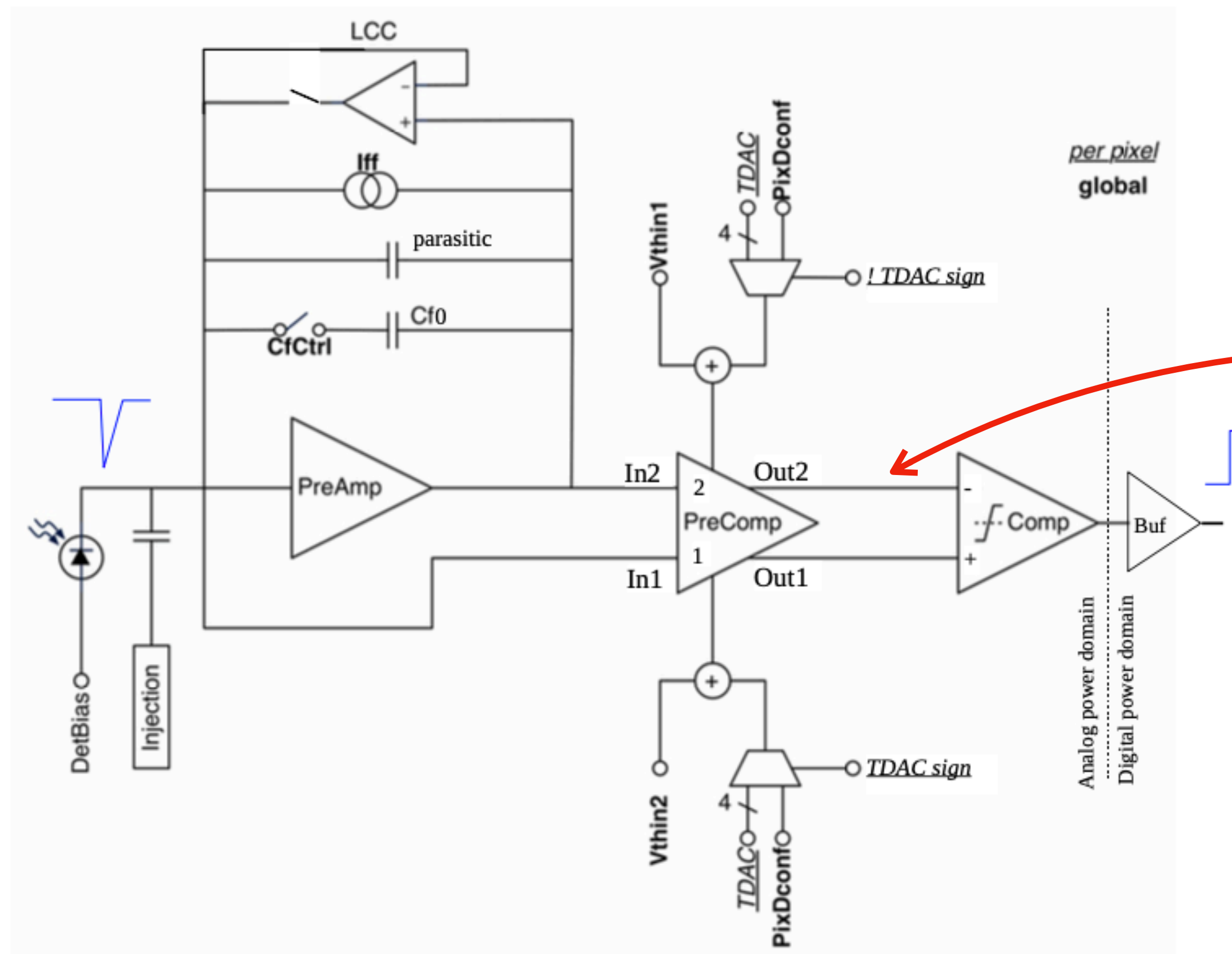
- There is no direct probe of the analog front-end output stages in the RD53B chip, as in the case of the RD53a chip
- At the very least, we can infer analog front-end output from the PreComp stage based on the precision (digitized) timing information that we read out from the digital front-end



Measurement of **Time of Arrival (ToA)** (~Delay in the picture below) and **Time over Threshold (ToT)** allows us to sample the rising and falling edges of the analog pulse shape at the PreComp output

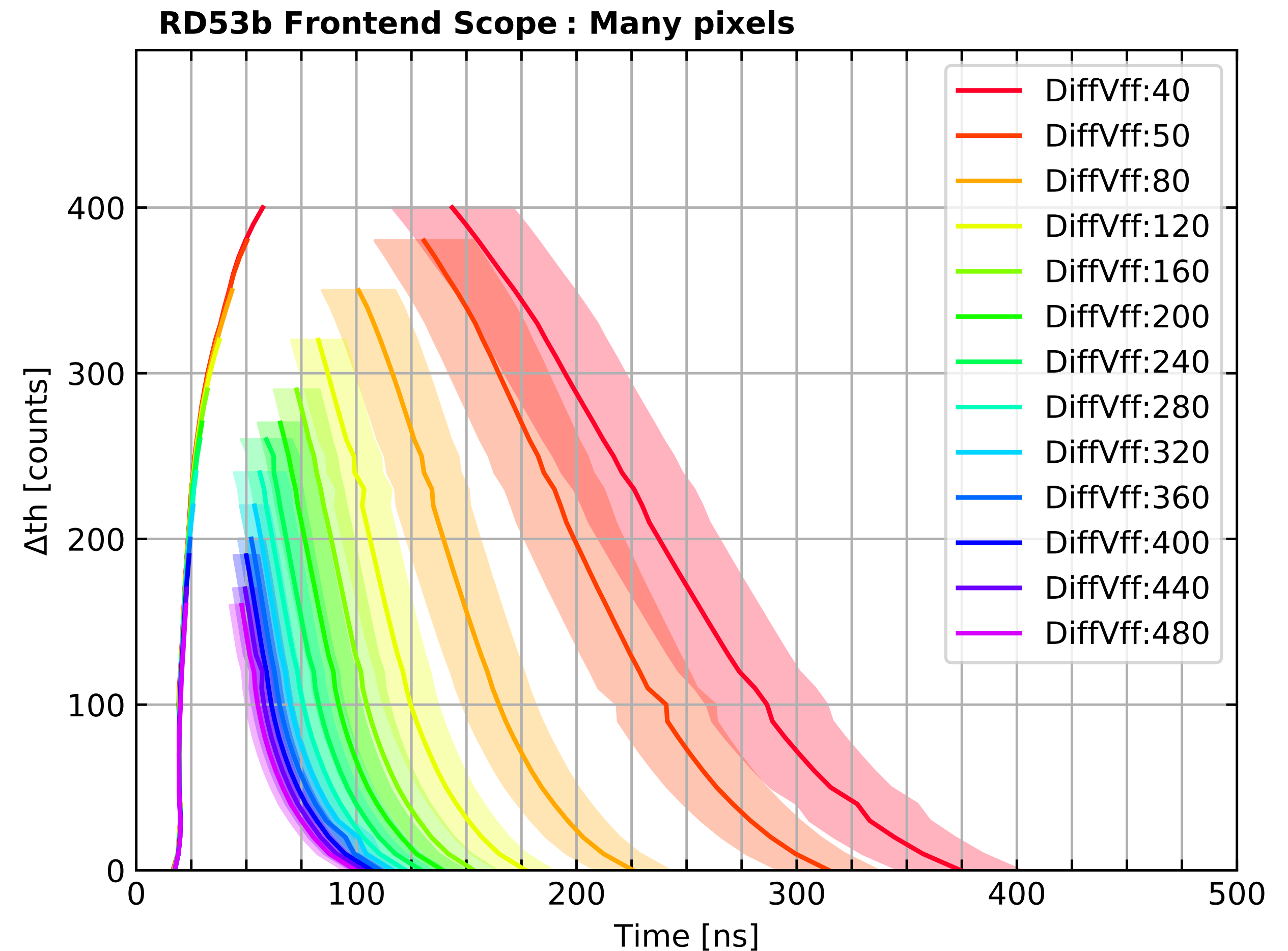
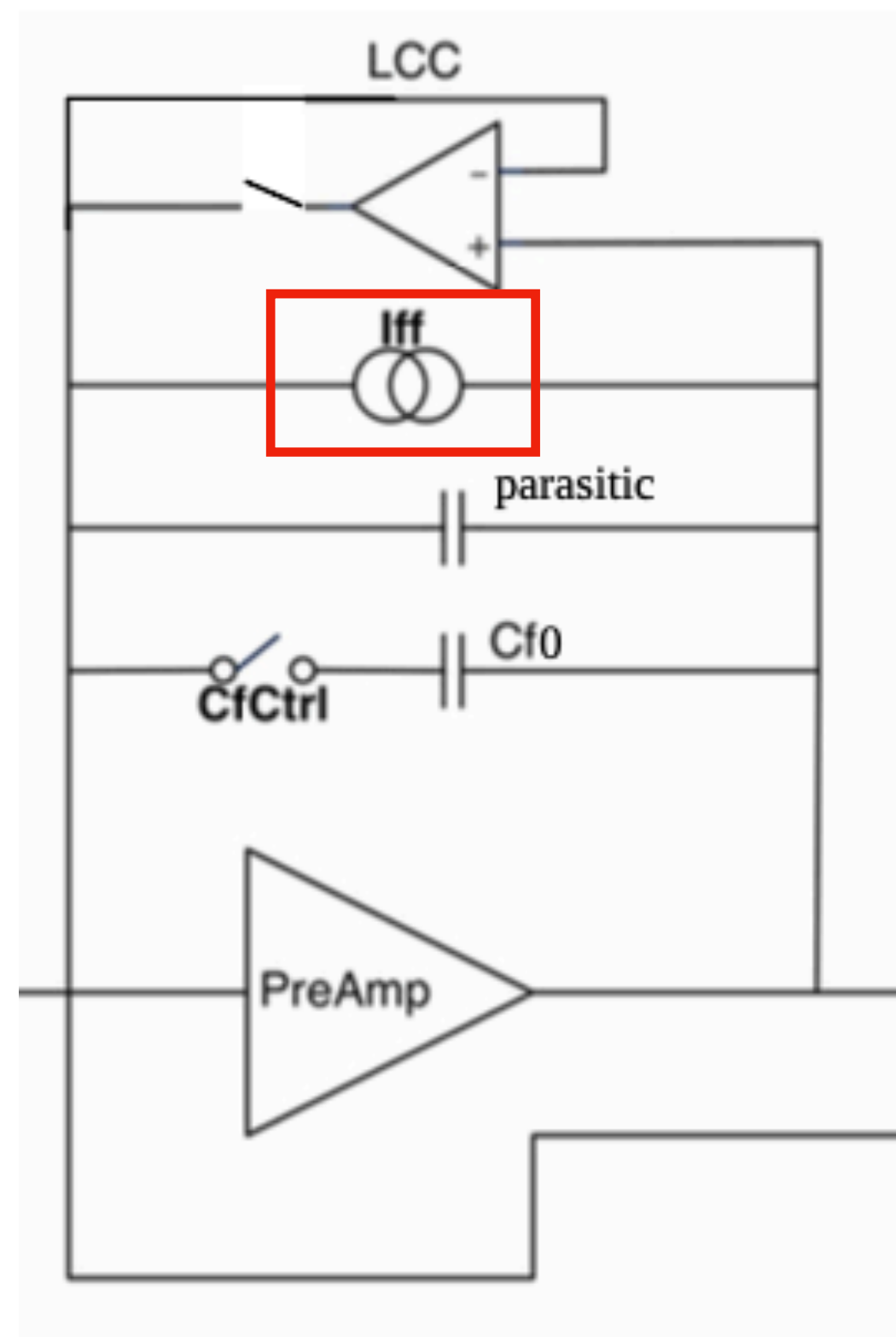


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Adjusting parameters of the analog front-end and measuring their impact on the analog front-end output

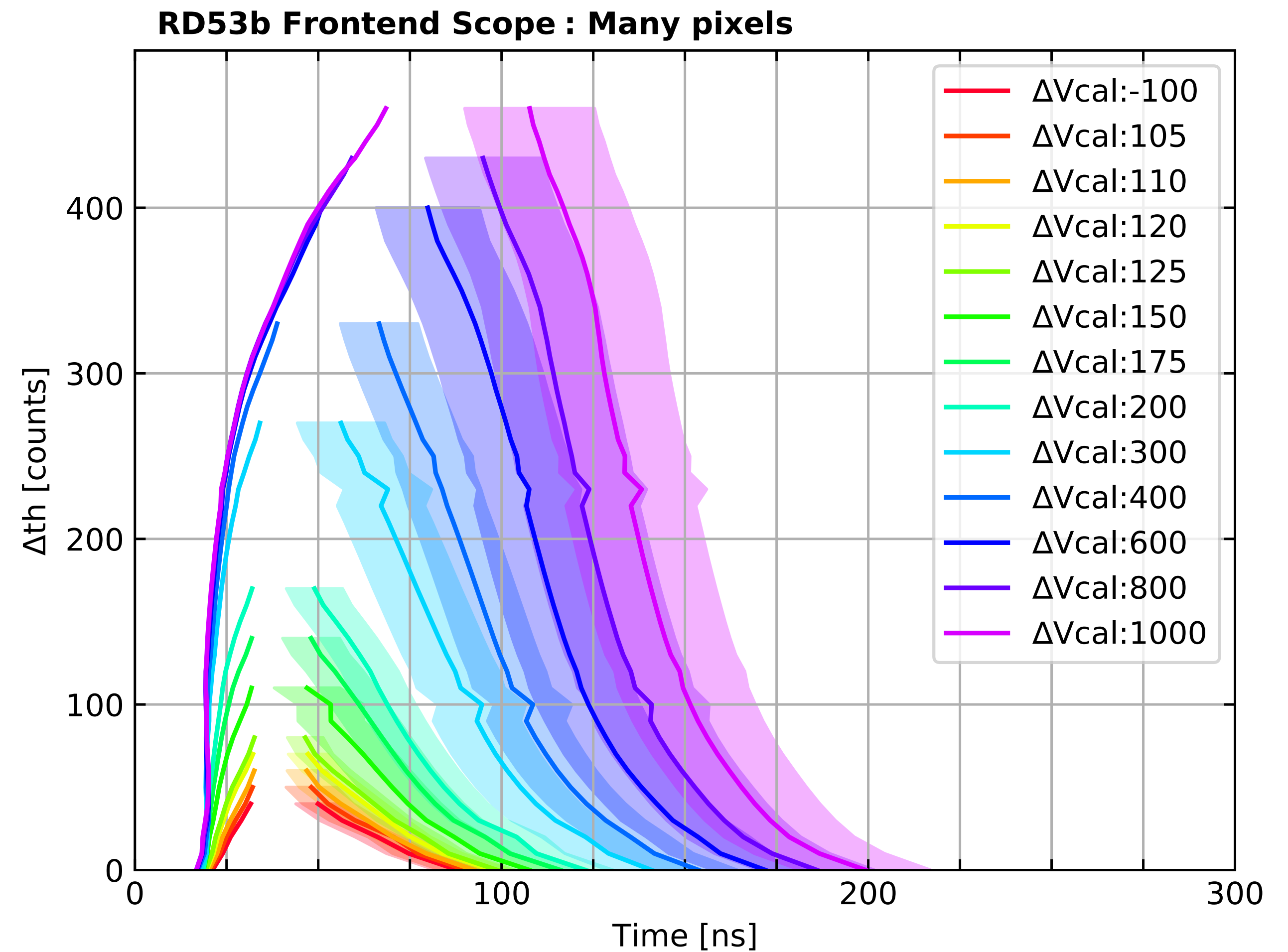
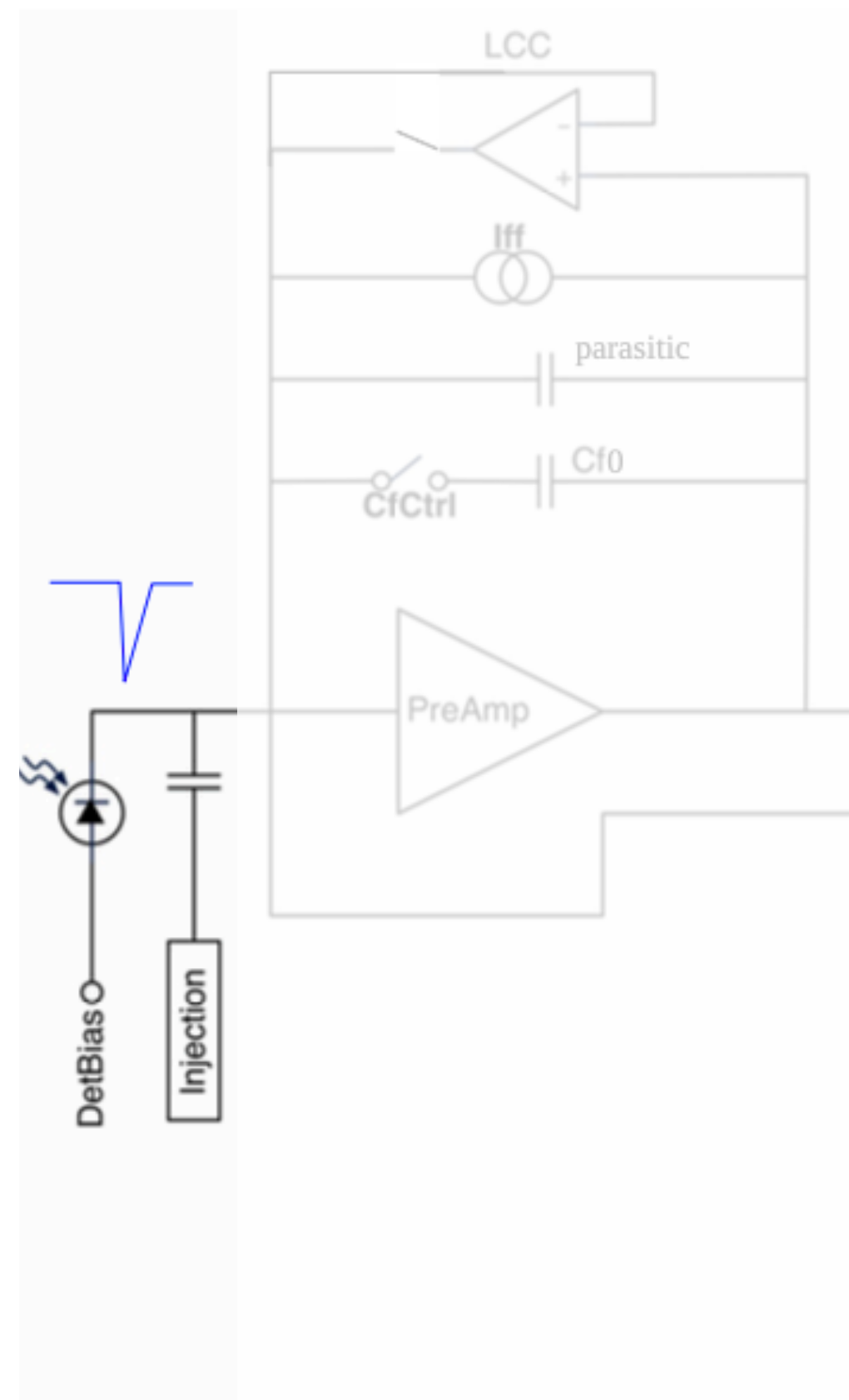
DiffVff controls the constant-current discharge in the feedback circuitry in the first stage of the analog frontend



As the discharge rate increases, the pulse width (ToT) decreases — but also the pulse amplitude (the discharge rate begins to overtake the charge-up rate)

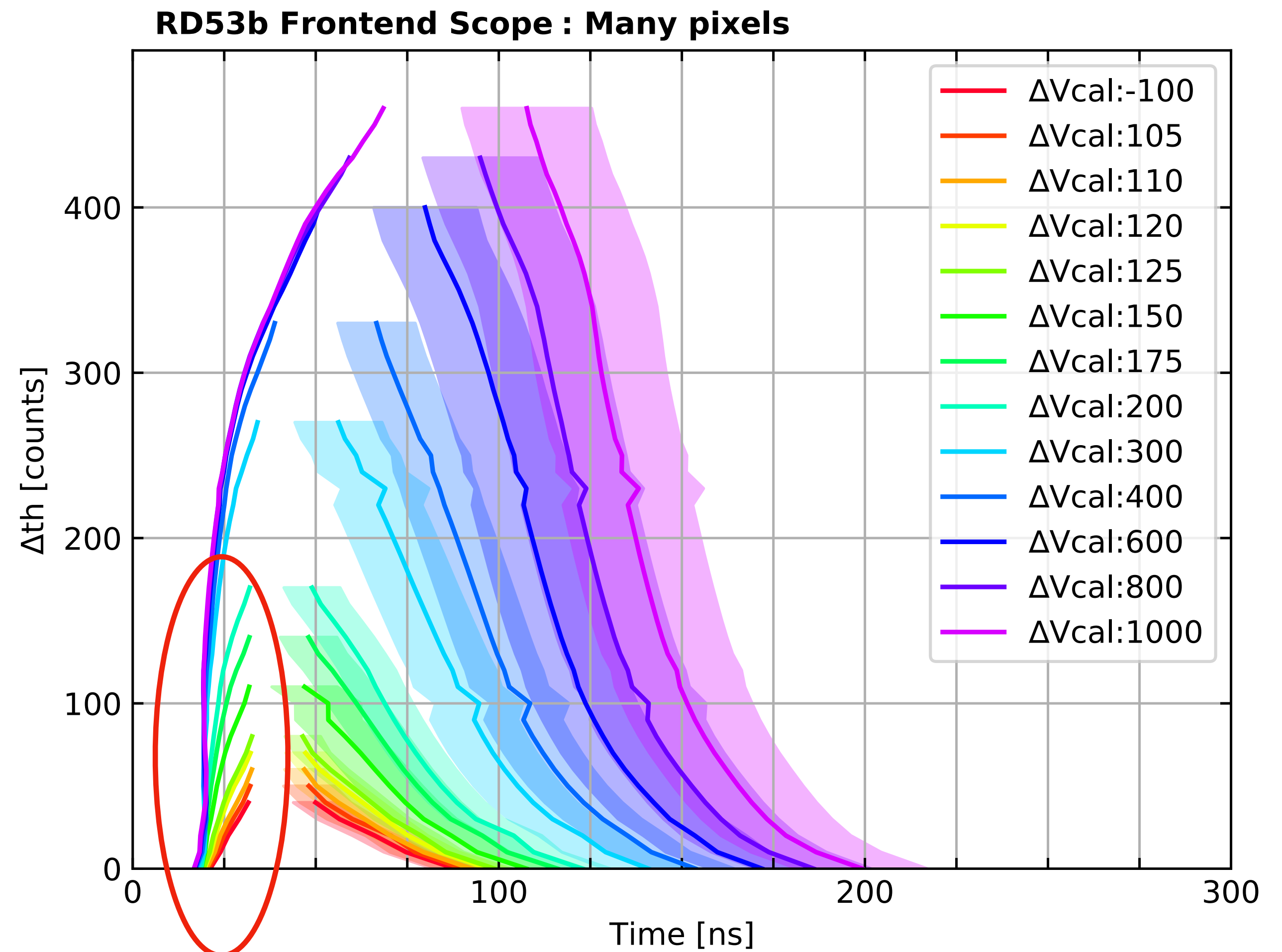
Adjusting parameters of the analog front-end and measuring their impact on the analog front-end output

ΔV_{cal} controls the amplitude of the injected pulse coming into the analog front-end



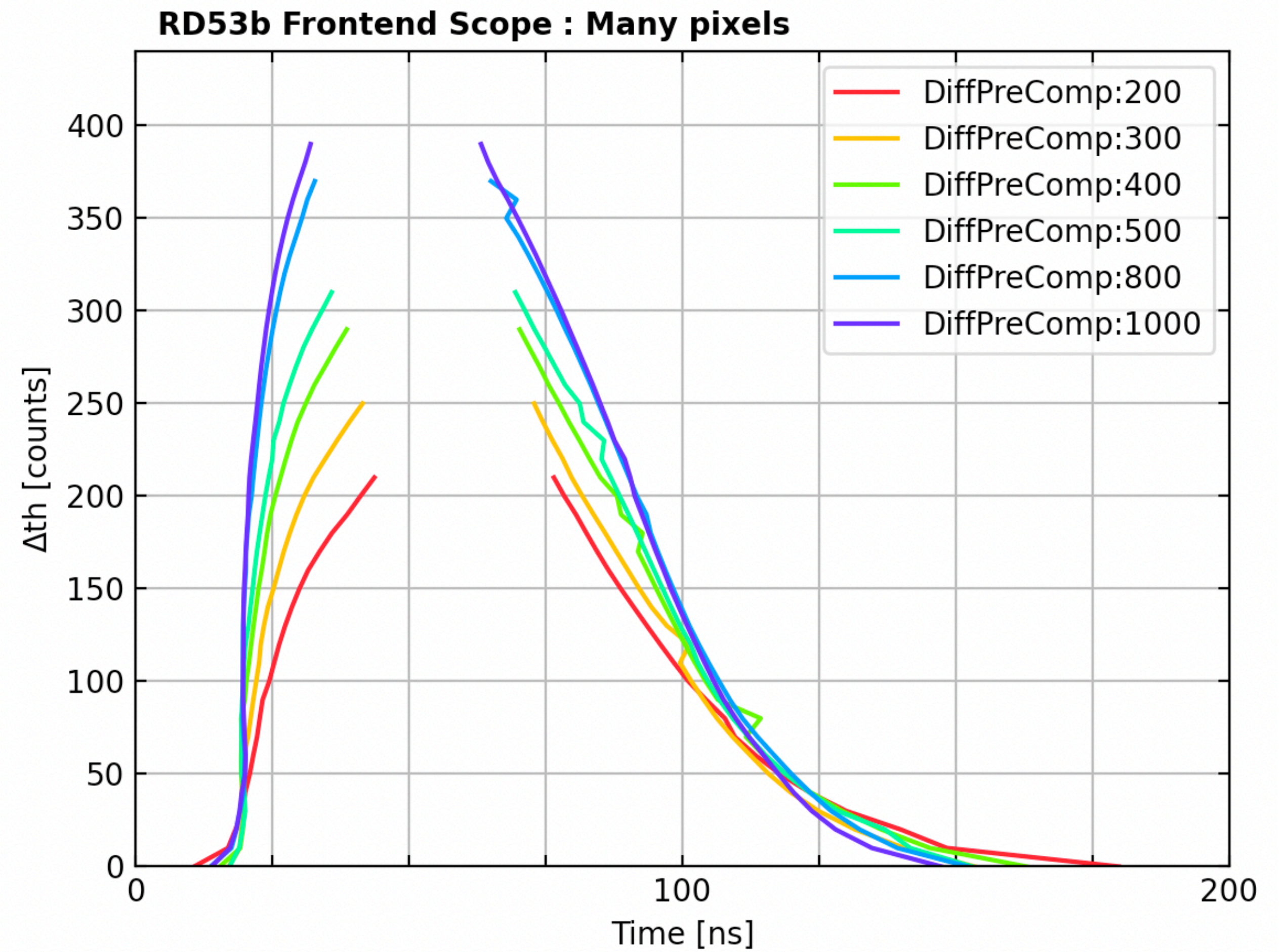
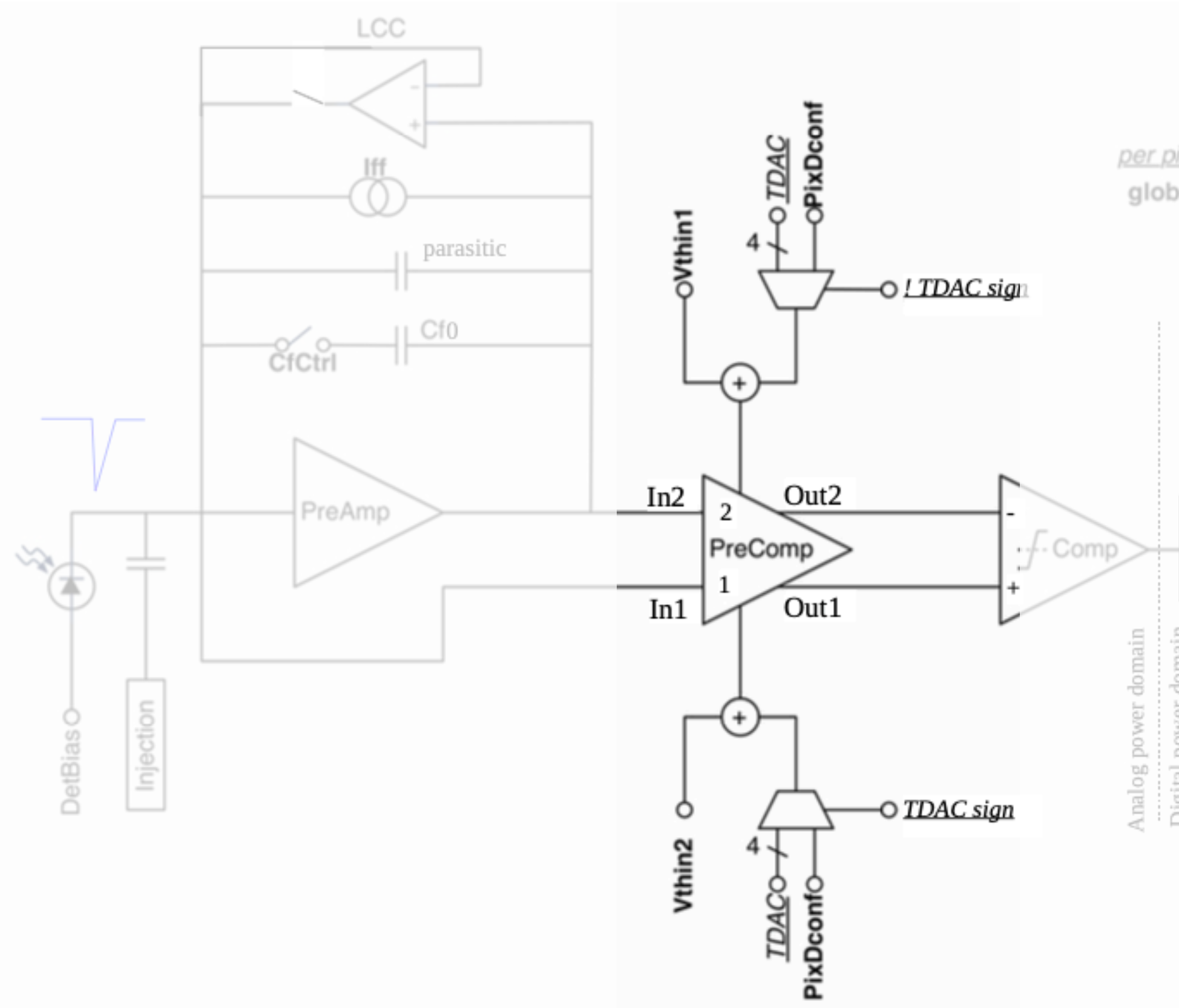
Adjusting parameters of the analog front-end and measuring their impact on the analog front-end output

One can see the effect of **timewalk**: a change in apparent signal arrival time (for signals injected at the same relative time) that depends on the signal amplitude — more on this later



Adjusting parameters of the analog front-end and measuring their impact on the analog front-end output

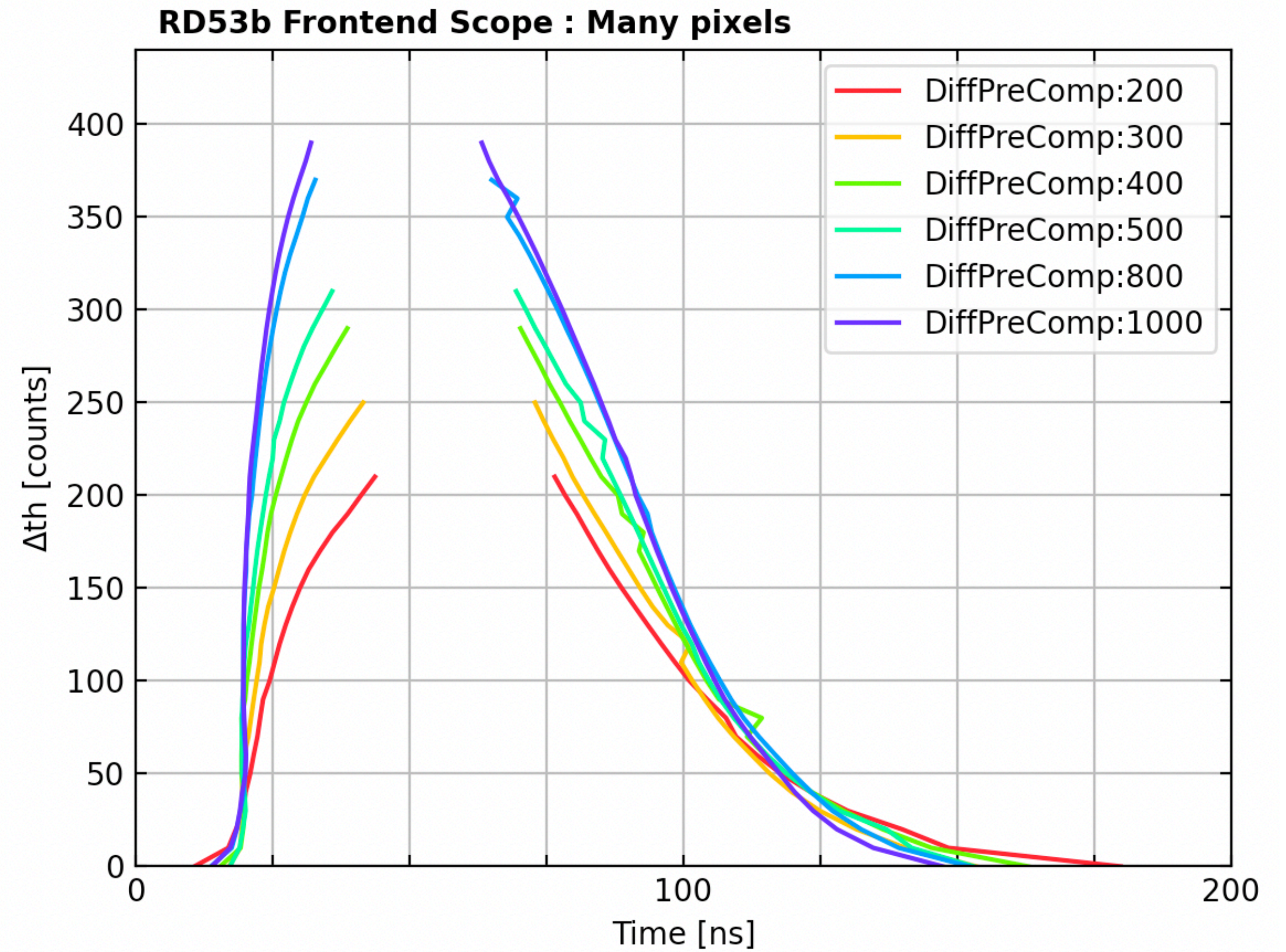
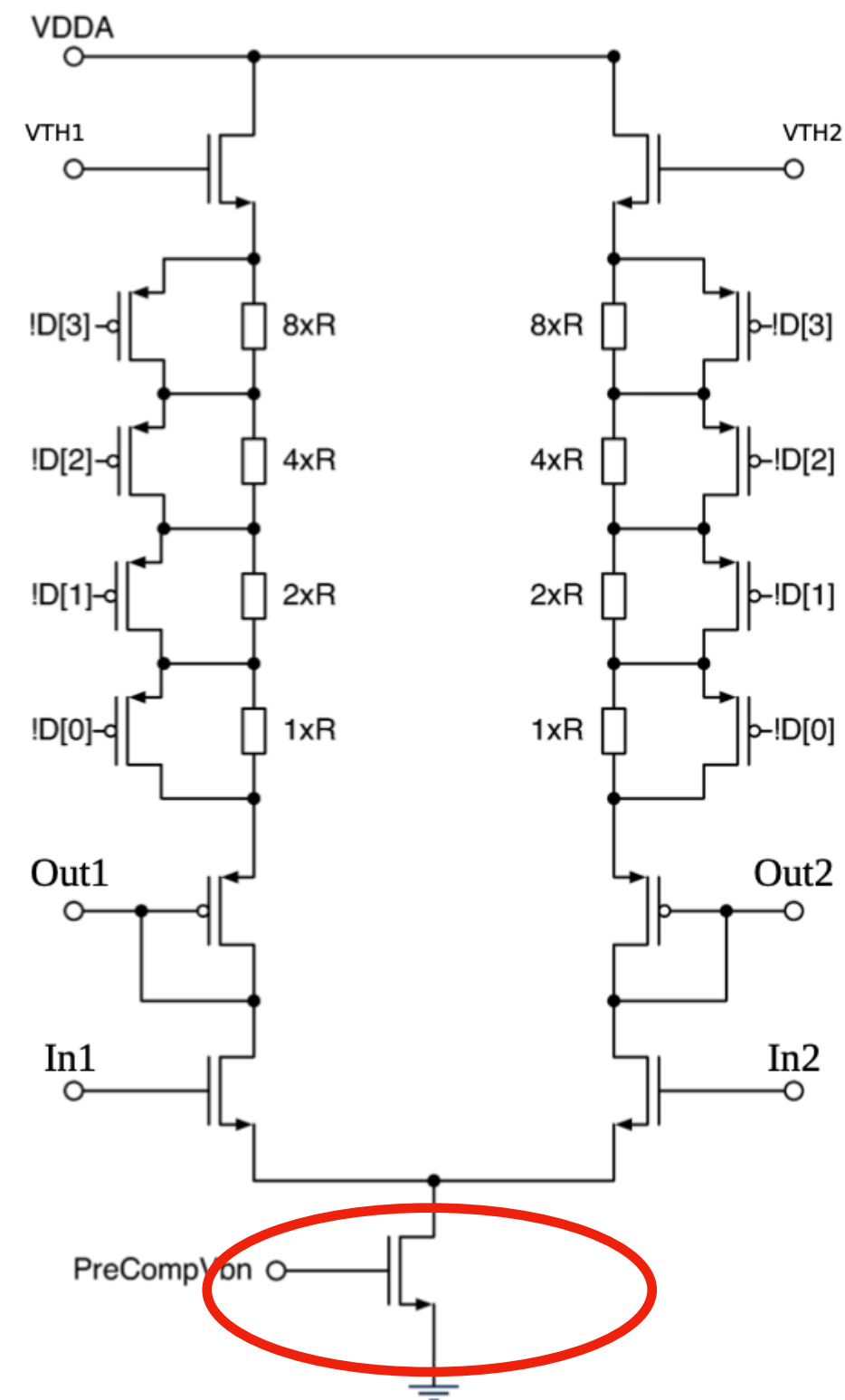
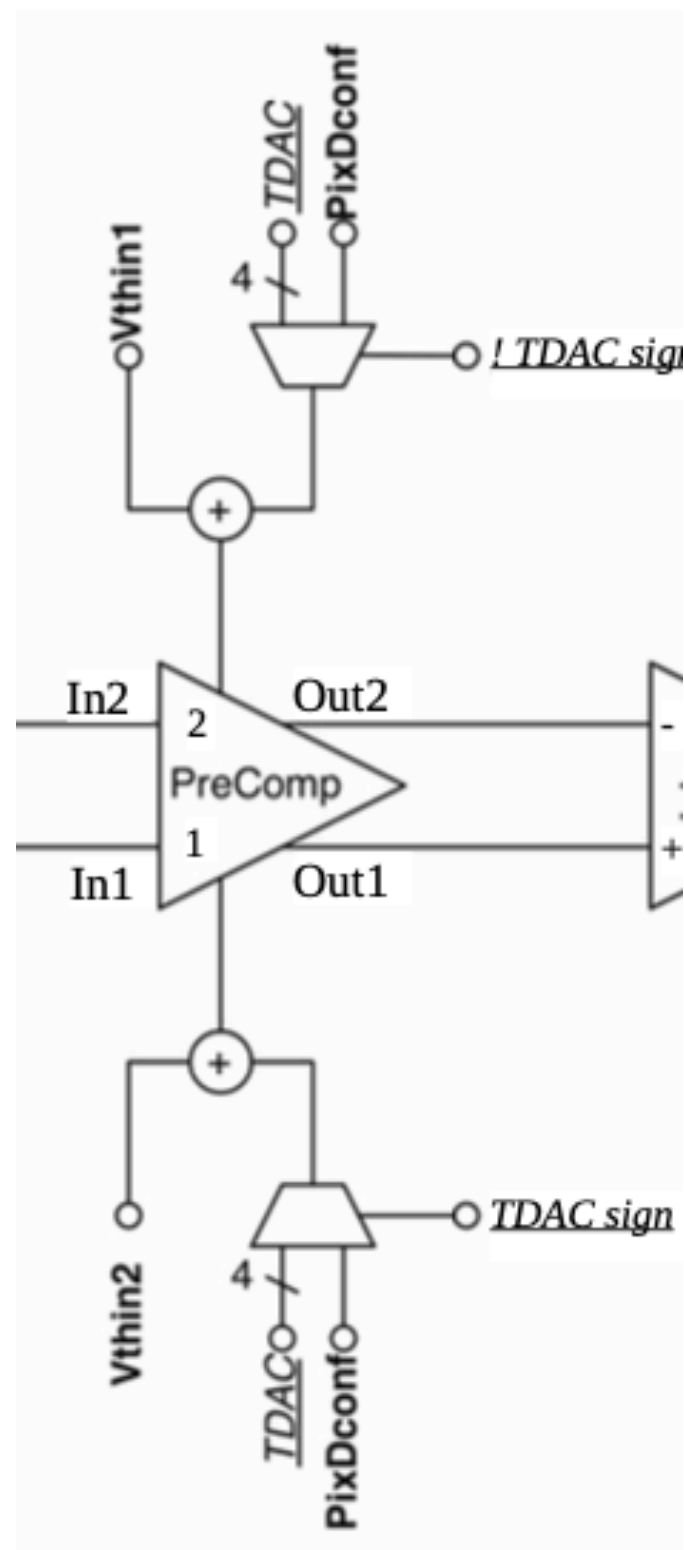
DiffPreComp controls the strength of the bias on the PreComp stage transistors



As we increase the PreComp bias, the rise time decreases (the rising edge slope increases)

Adjusting parameters of the analog front-end and measuring their impact on the analog front-end output

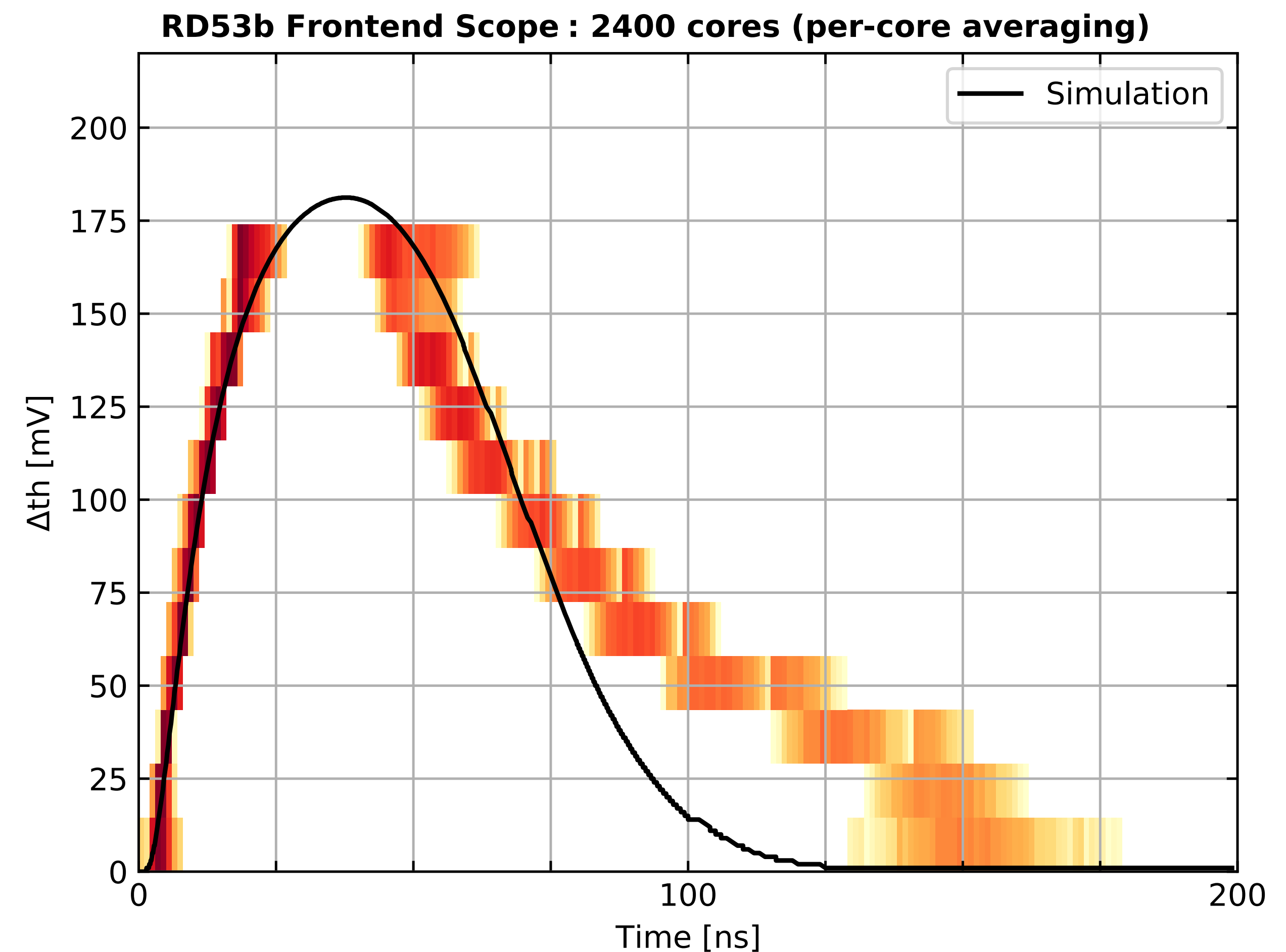
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We can also simulate the PreComp output and compare to the measured response of the analog front-end

- Here we show the pulse shapes with **per-core averaging**:
 - N pulse shapes for N cores, as the timing information for the 64 pixels in a given core are averaged together
 - Right now, trying to understand some differences between simulation and data:
 - Correspondence between the expected injection amplitude:
 - ➔ Simulation = 3000e (this corresponds to $\Delta V_{cal} \sim 320$ counts)
 - ➔ In the data (on the right), we have $\Delta V_{cal} = 218$ counts
 - Falling edge has clear shape differences
- ➔ These studies are developing now



- It is important to characterize the timing response of a front-end ASIC like RD53b
- Various working points / configurations of the analog front-end influence the timing response of the chip
- **Reminder:** Timewalk refers to an apparent difference in signal times that depends on the signal amplitude
 - Two signals enter your detector at the same time from the same BX crossing **in reality...**
 - But your front-end electronics response is such that one signal appears to have come later in time since its amplitude was smaller (vice versa)
 - **If the time walk is too large in your nominal operating configuration of the front-end chip, hits from one pp bunch-crossing could start being associated with pp bunch-crossings later in time**

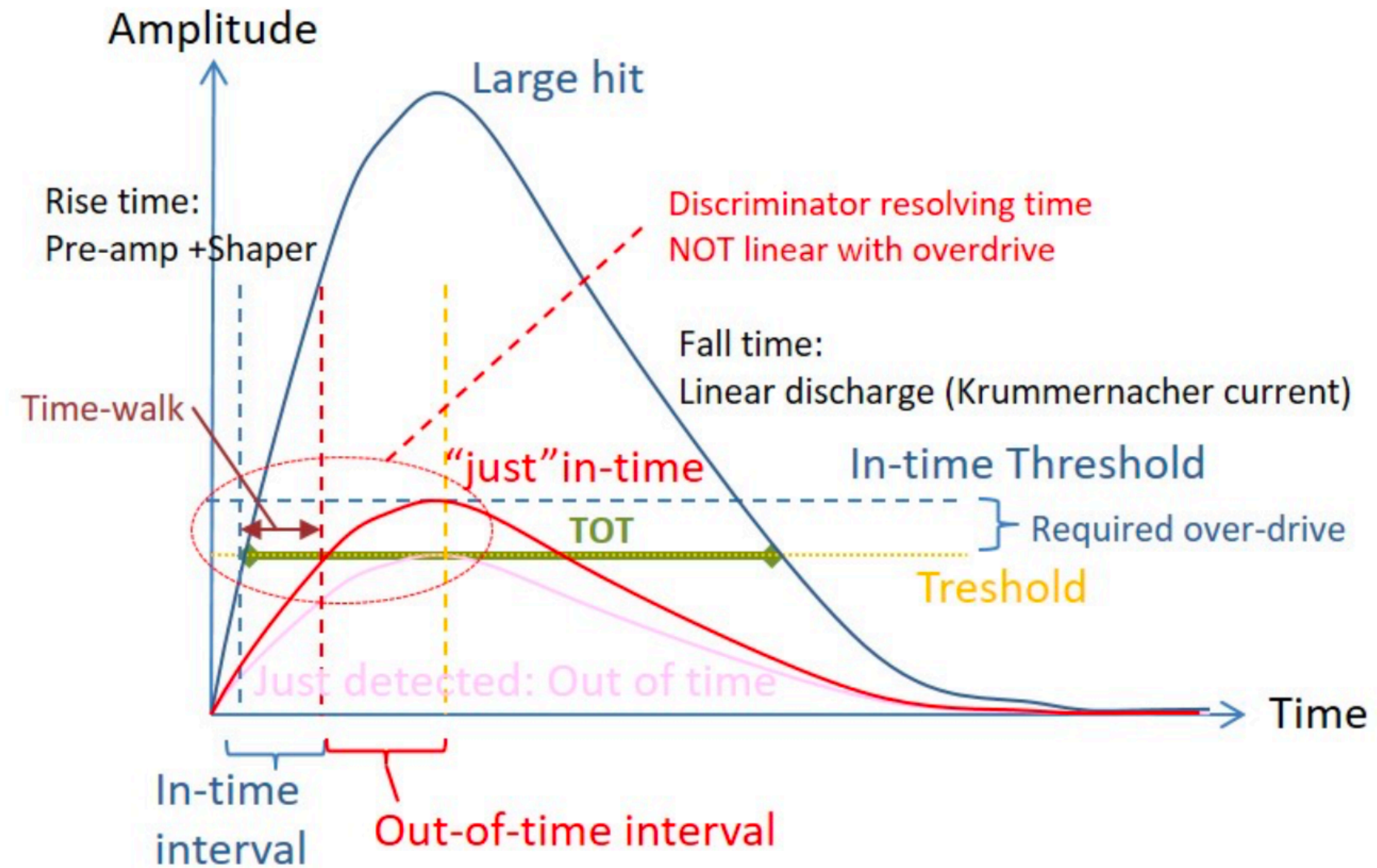
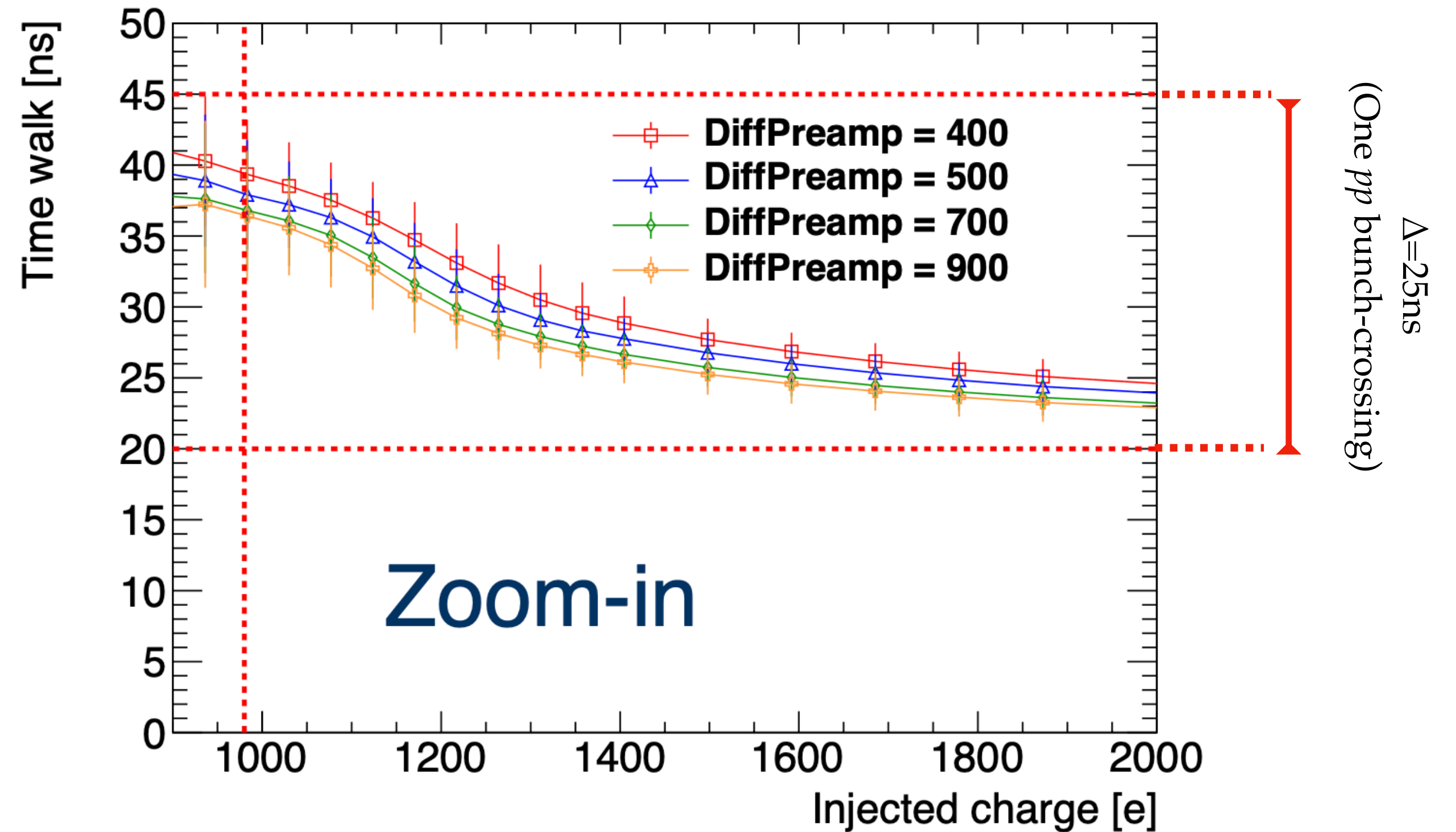
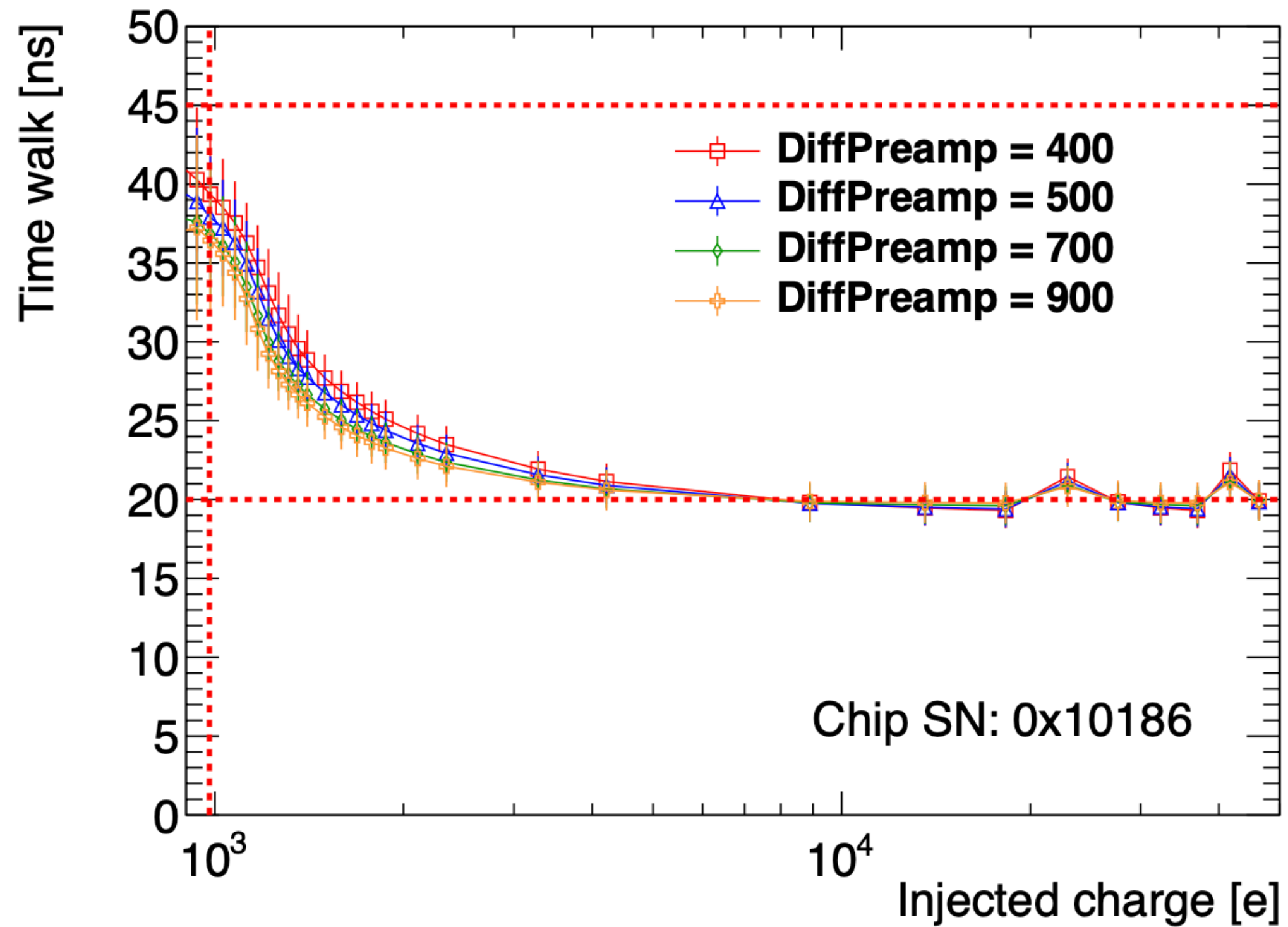


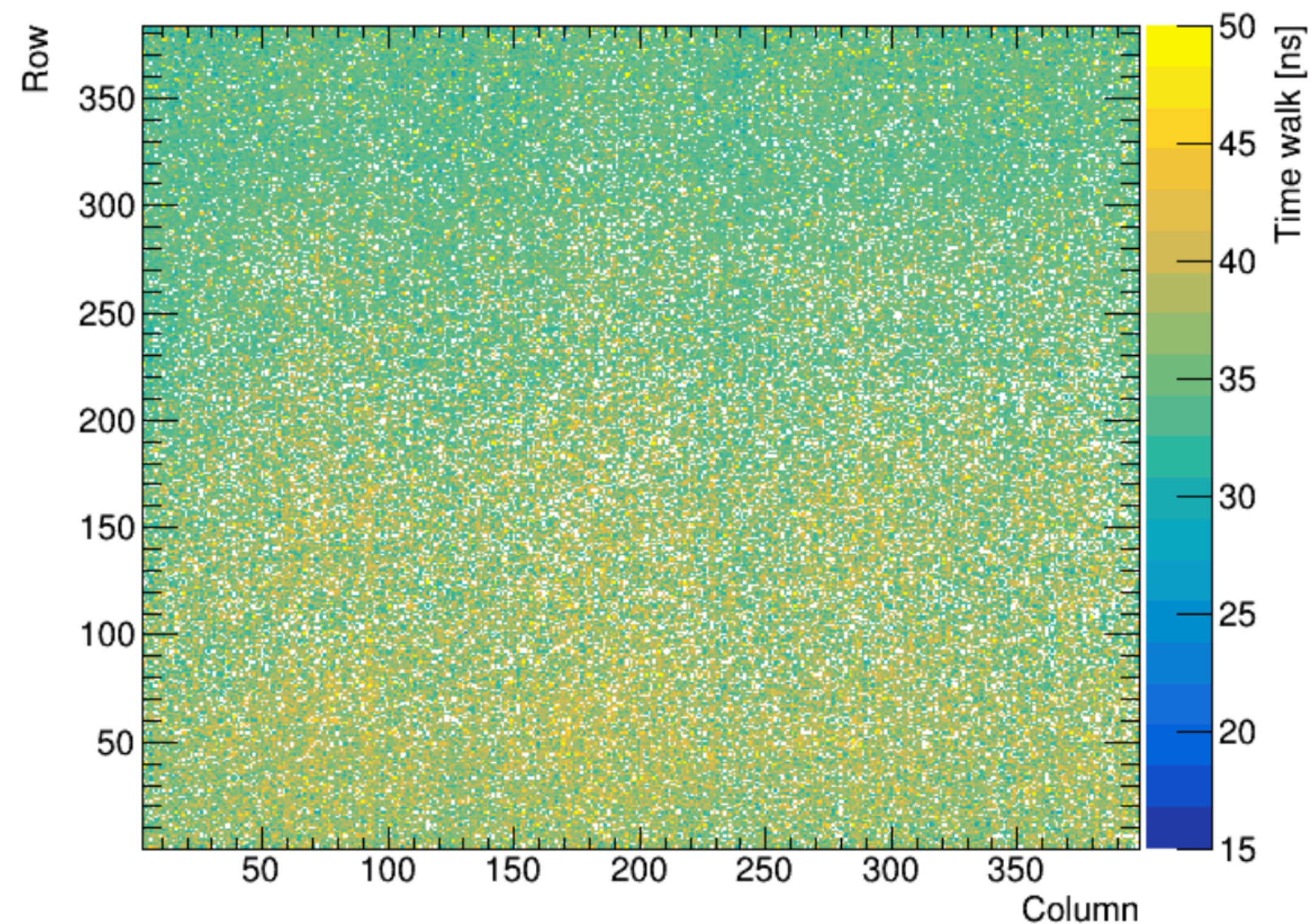
Figure from: <https://cds.cern.ch/record/2665301>

Timewalk measurements as a function of PreAmp bias

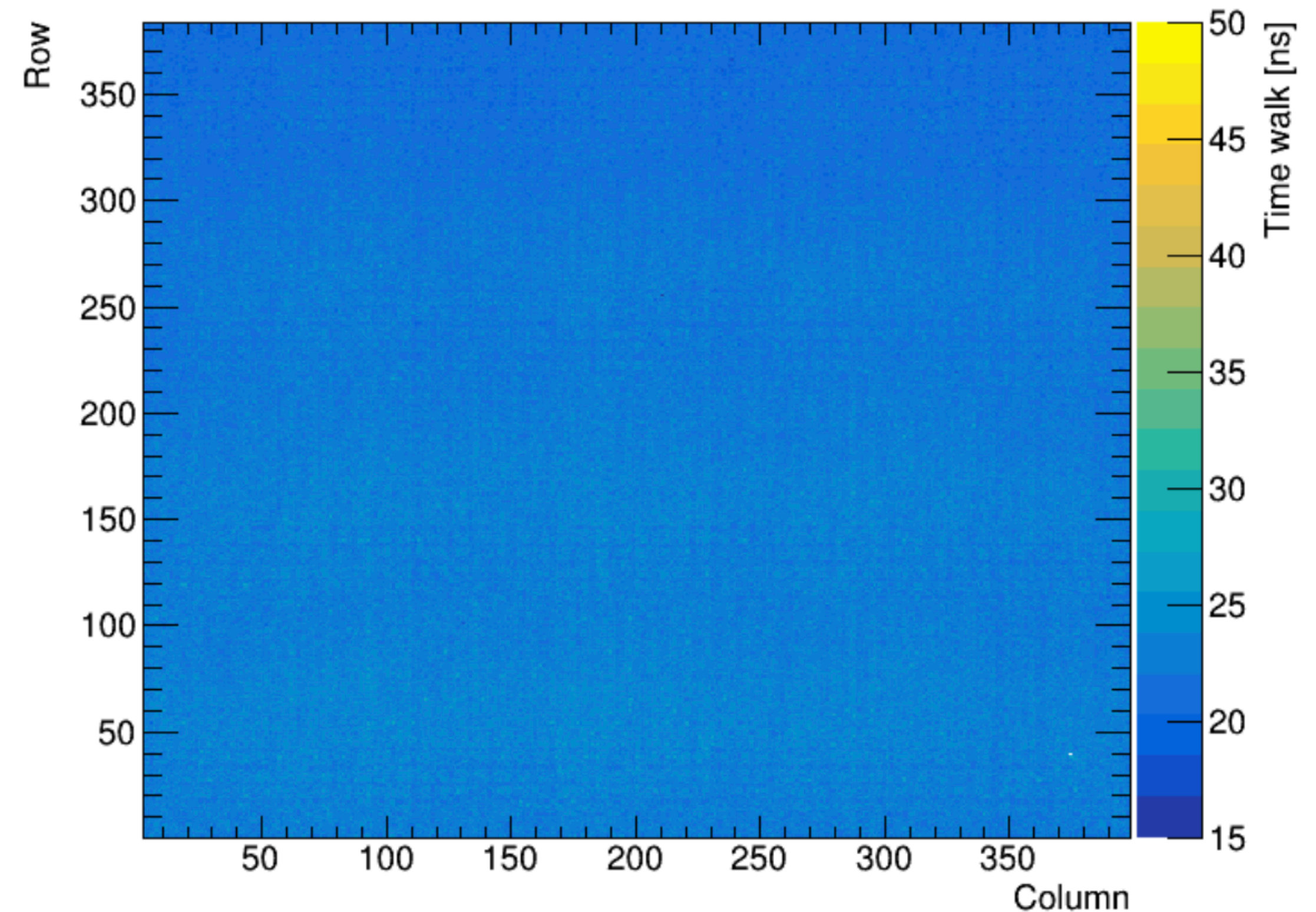


Tuned to a threshold of $1000e^-$

Timewalk maps (at PreAmp bias = 900), still tuned to a threshold of $1000e^-$

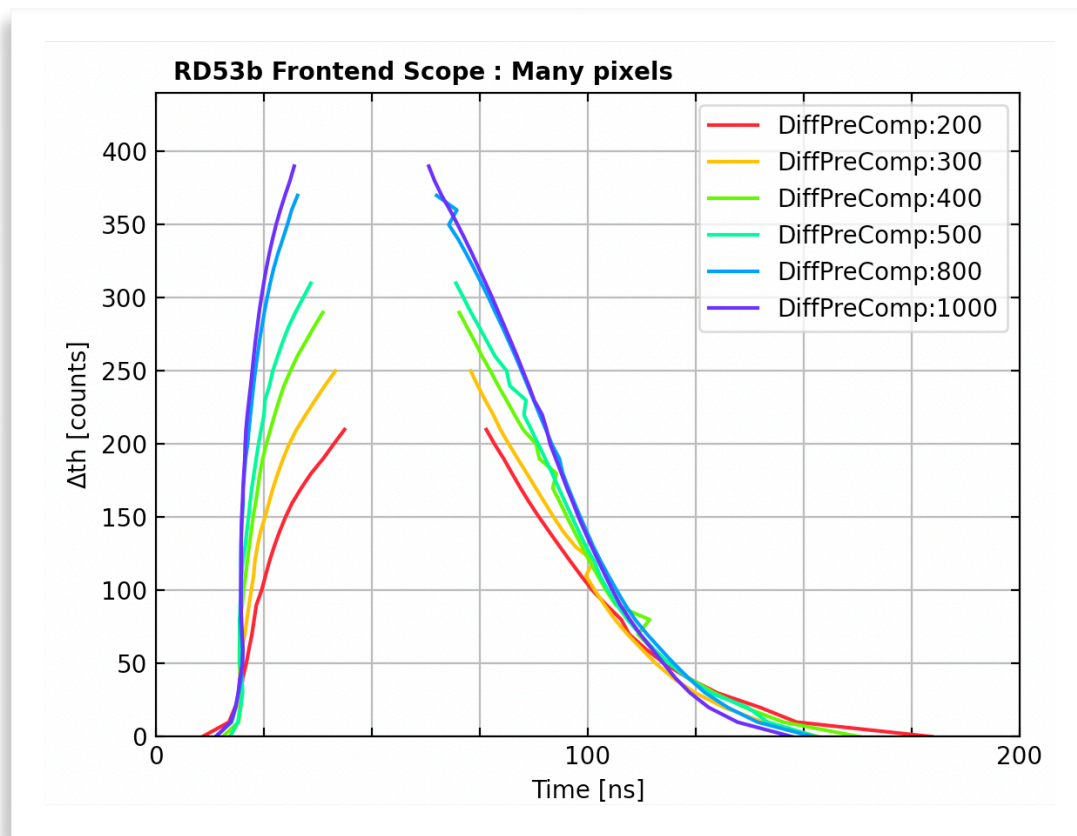
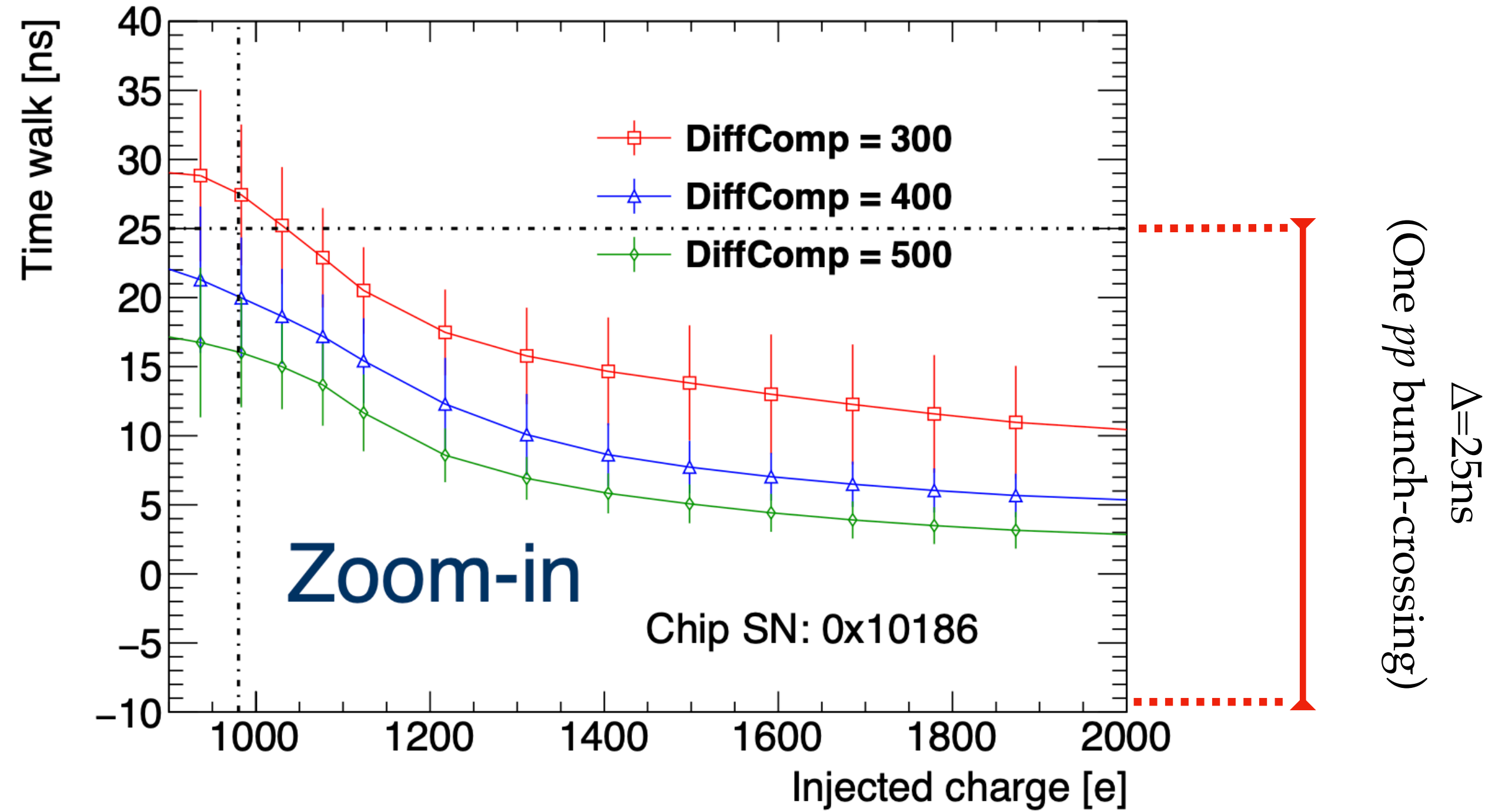
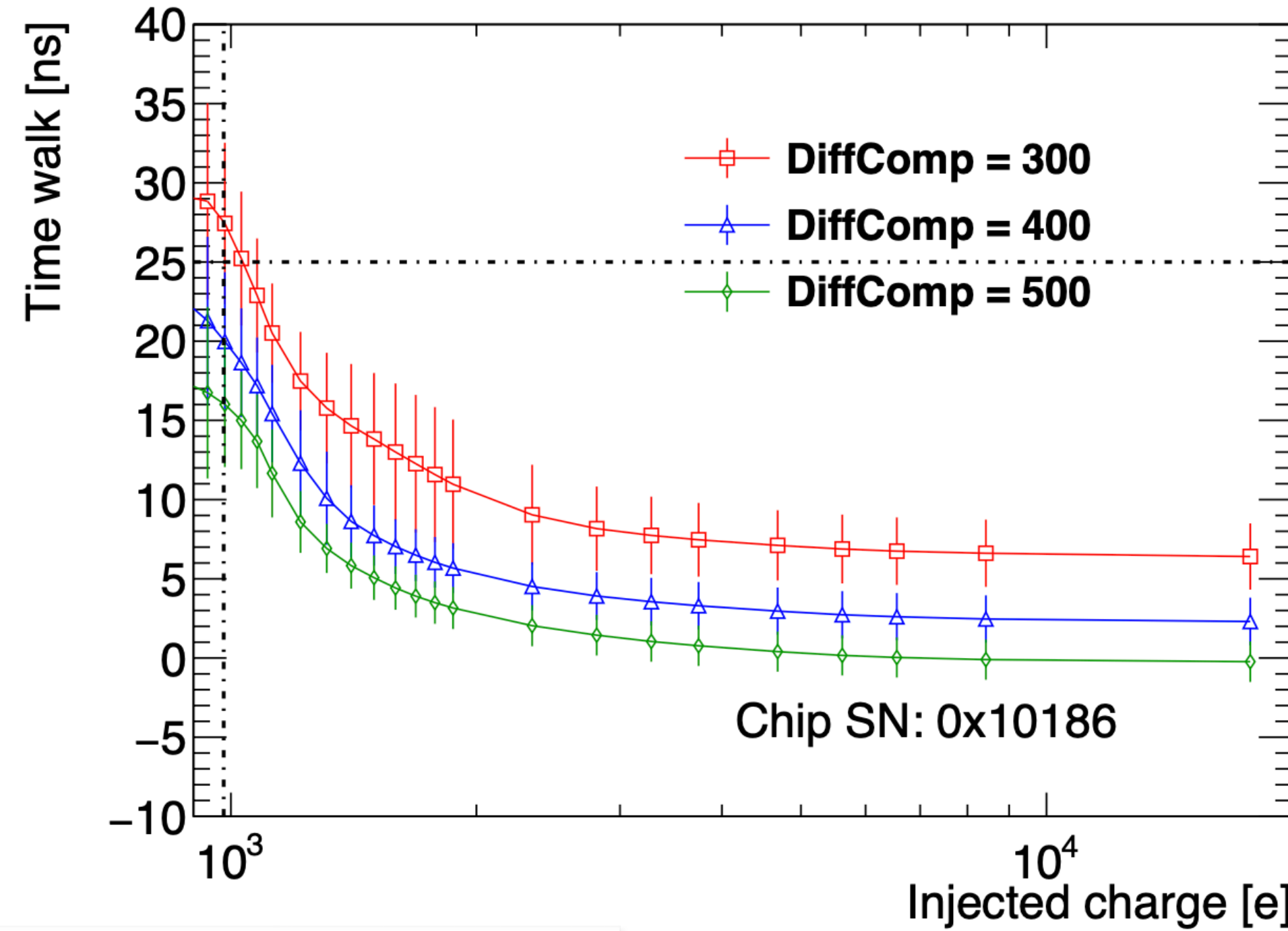


Injection = $980e^-$
(right at threshold)
Timewalk gets worse at the top
of the chip (bottom of the plot)



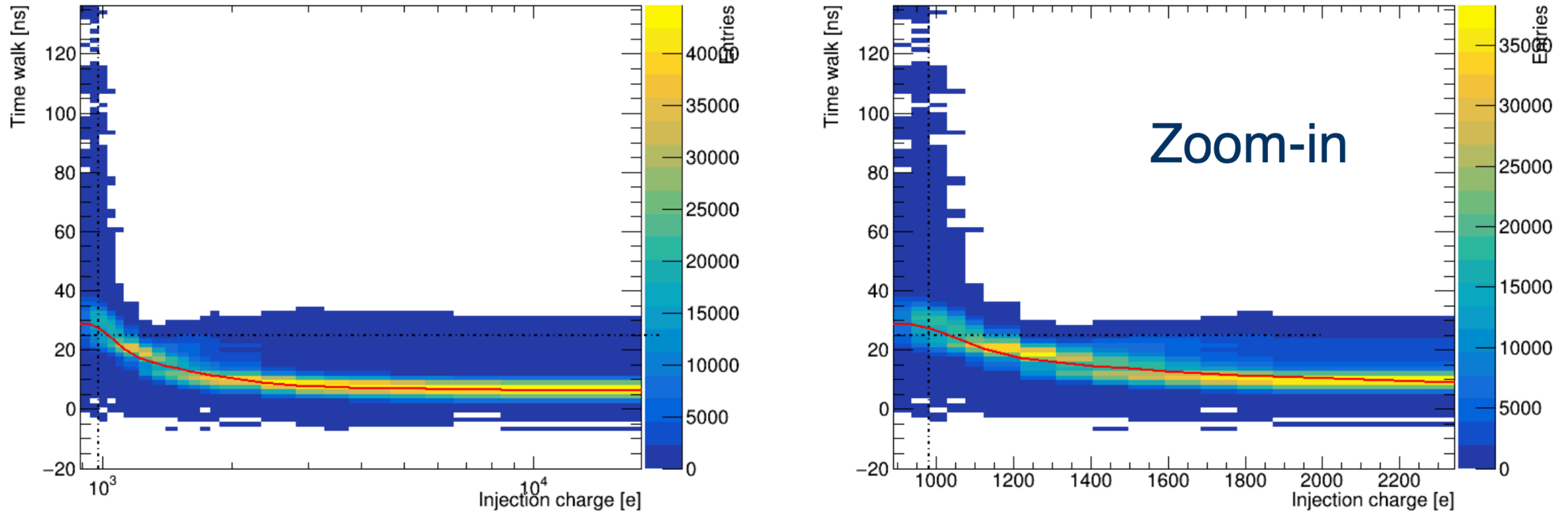
Injection = $2100e^-$:
Uniform timing response

Timewalk measurements as a function of PreComp bias



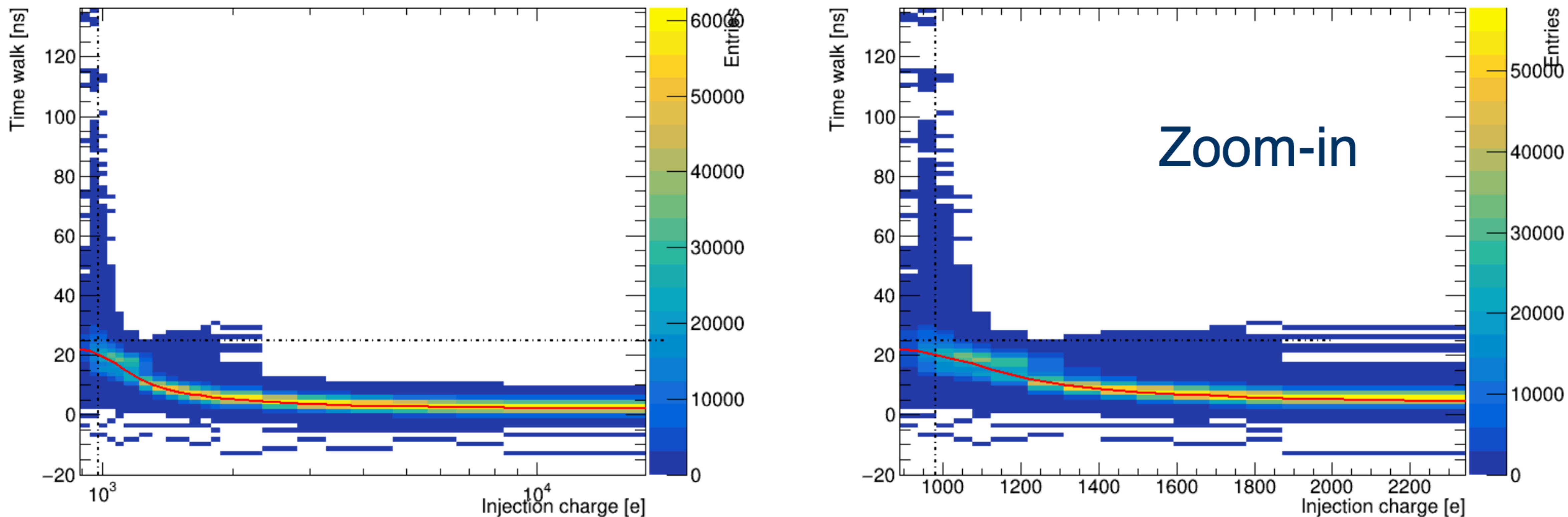
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Timewalk measurements as a function of PreComp bias



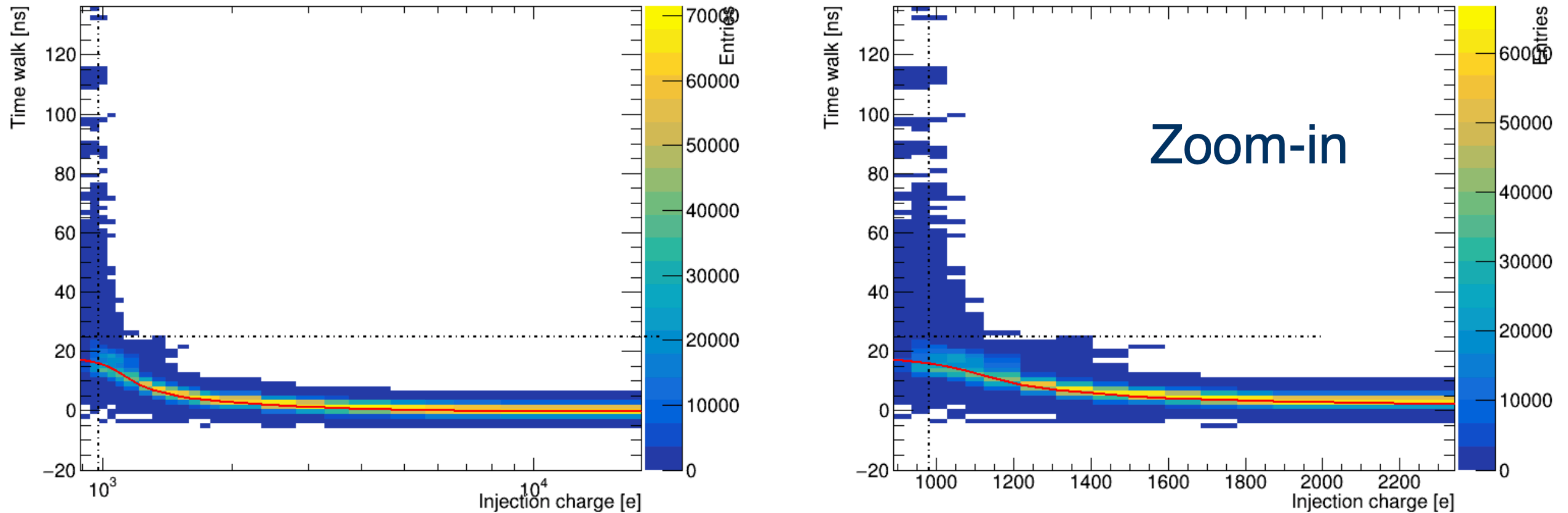
Showing the dispersion across many pixels
@DiffComp = 300

Timewalk measurements as a function of PreComp bias



Showing the dispersion across many pixels
@DiffComp = 400

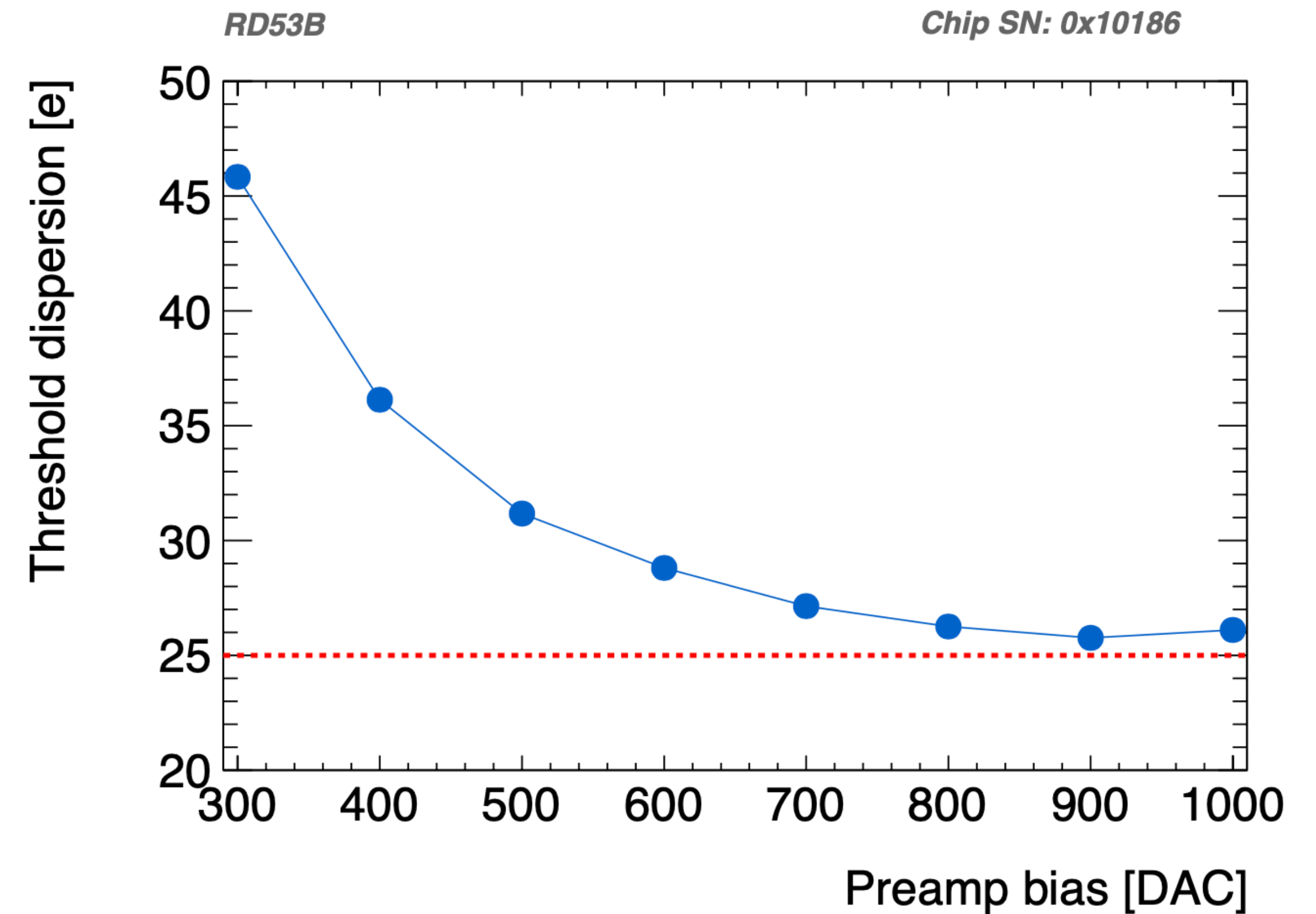
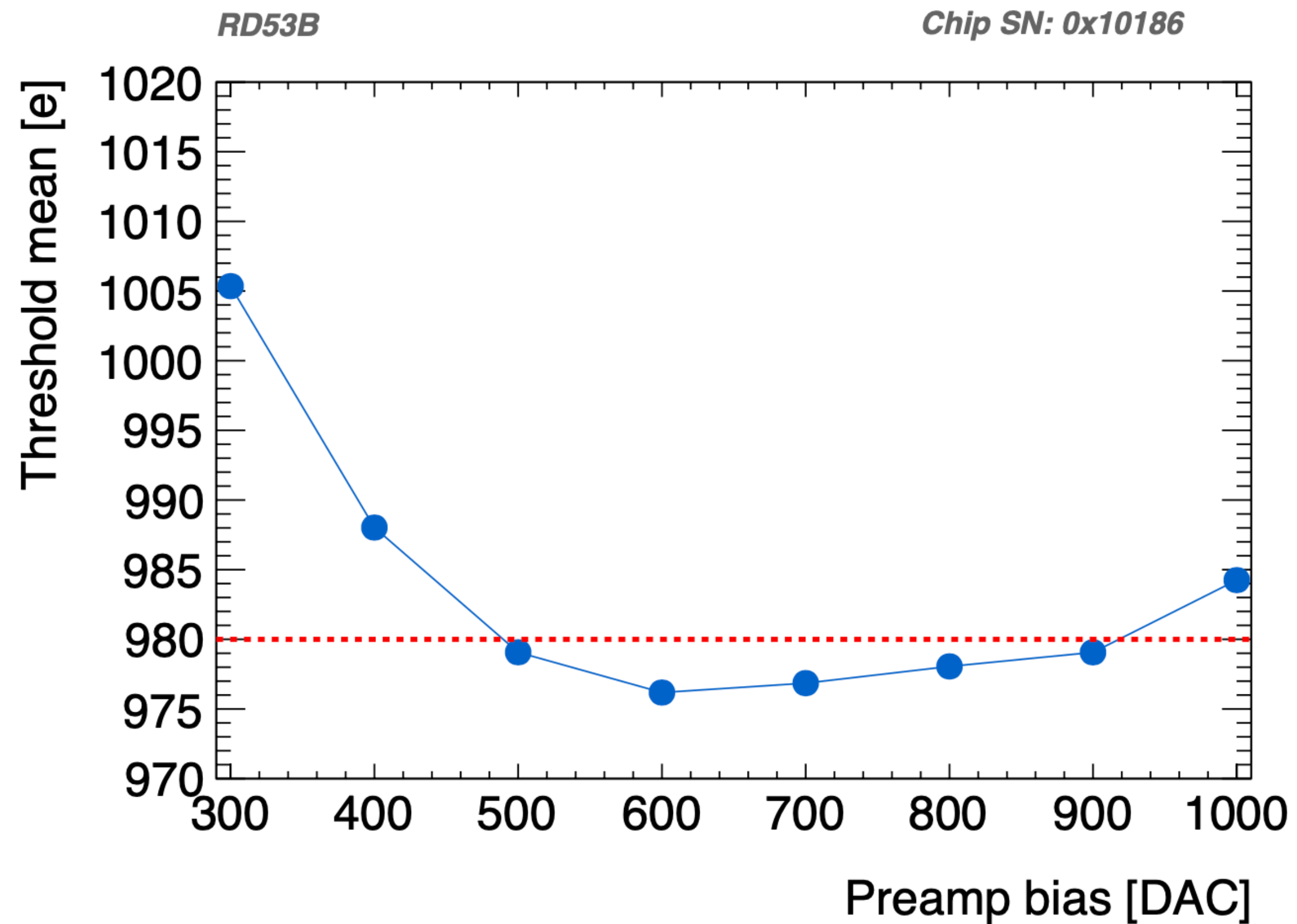
Timewalk measurements as a function of PreComp bias



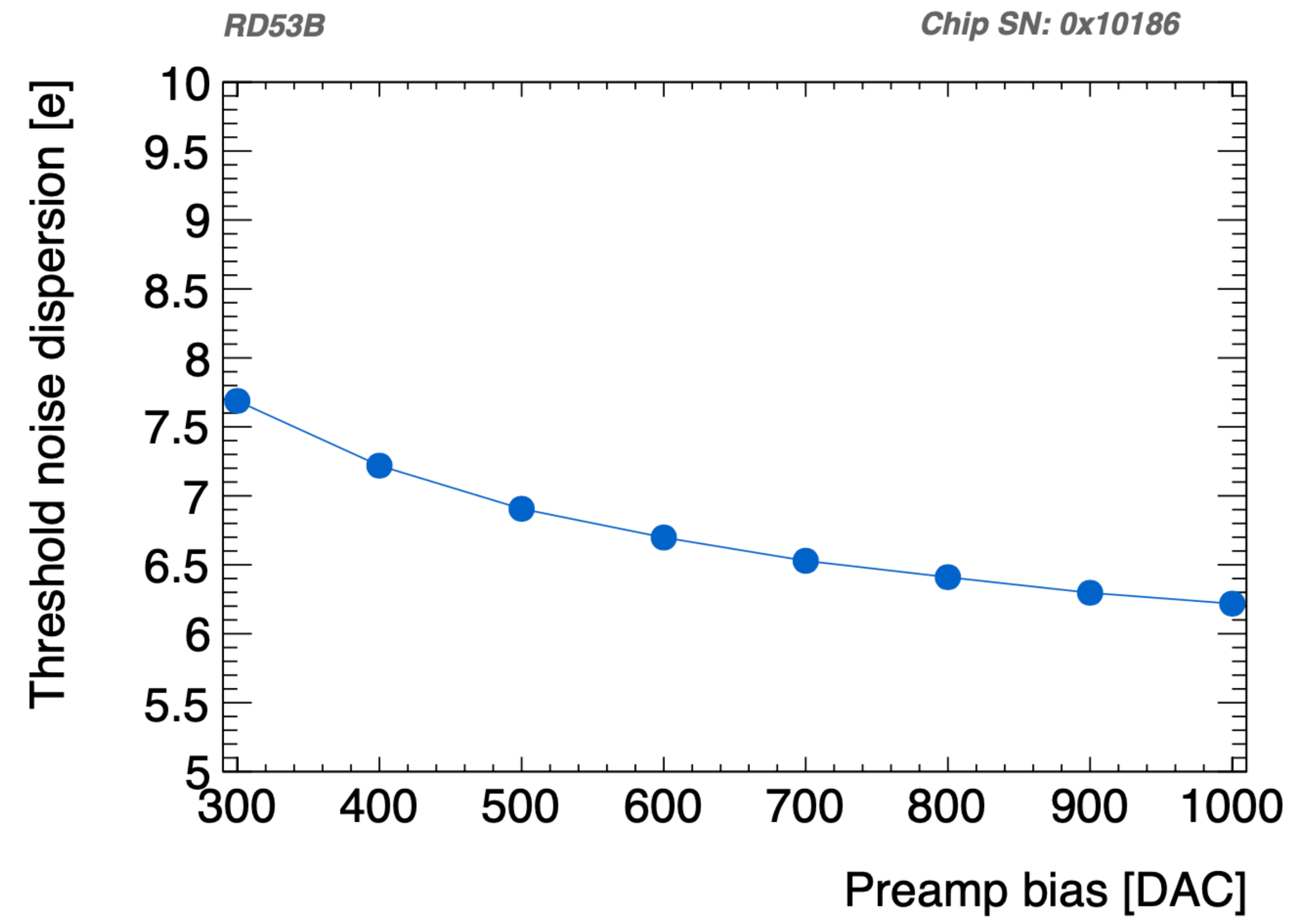
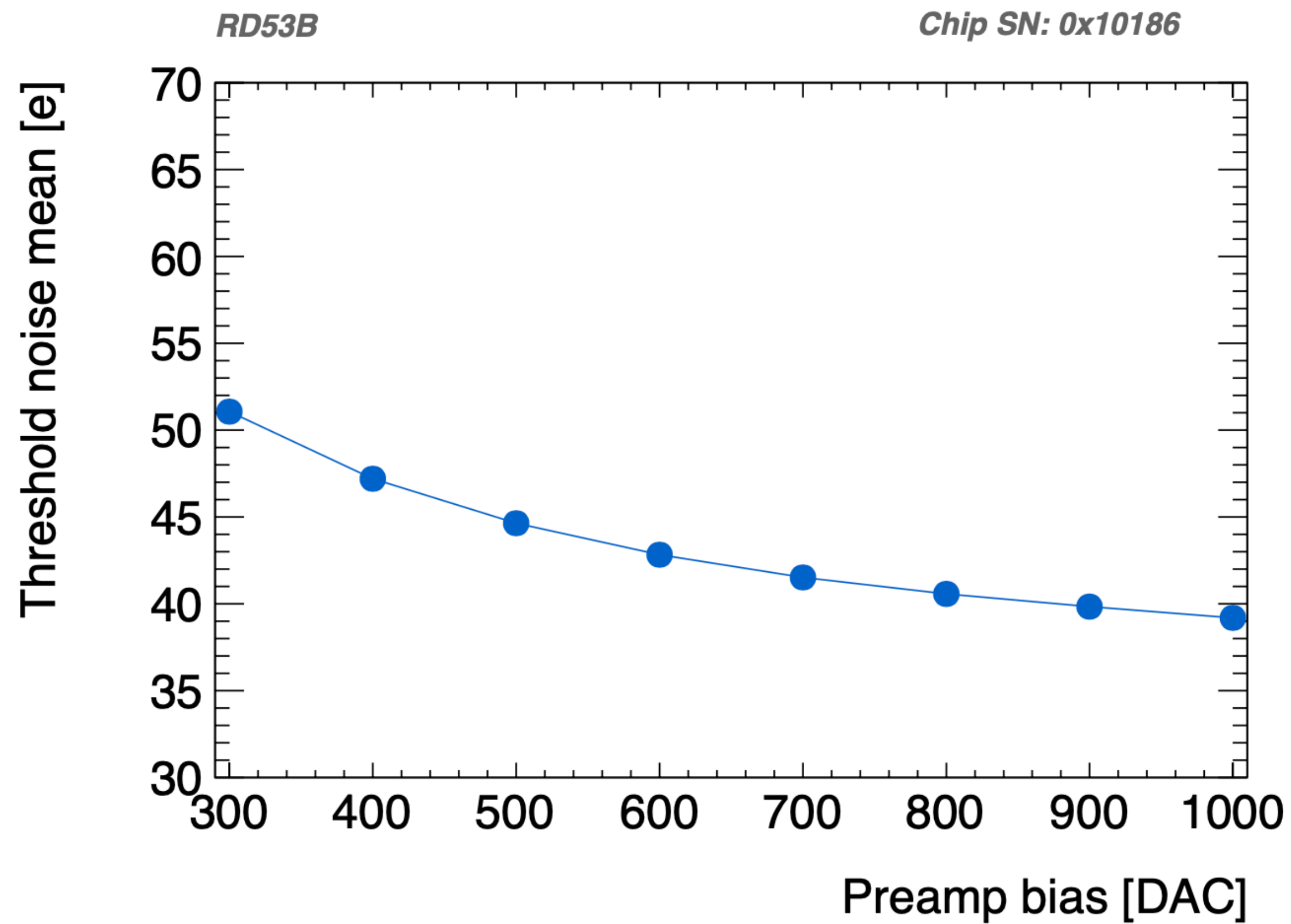
Showing the dispersion across many pixels
@DiffComp = 500

- The configuration of the analog front-end also influence the sensitivity to input signals by influencing the circuitry that controls the threshold adjustment and tuning

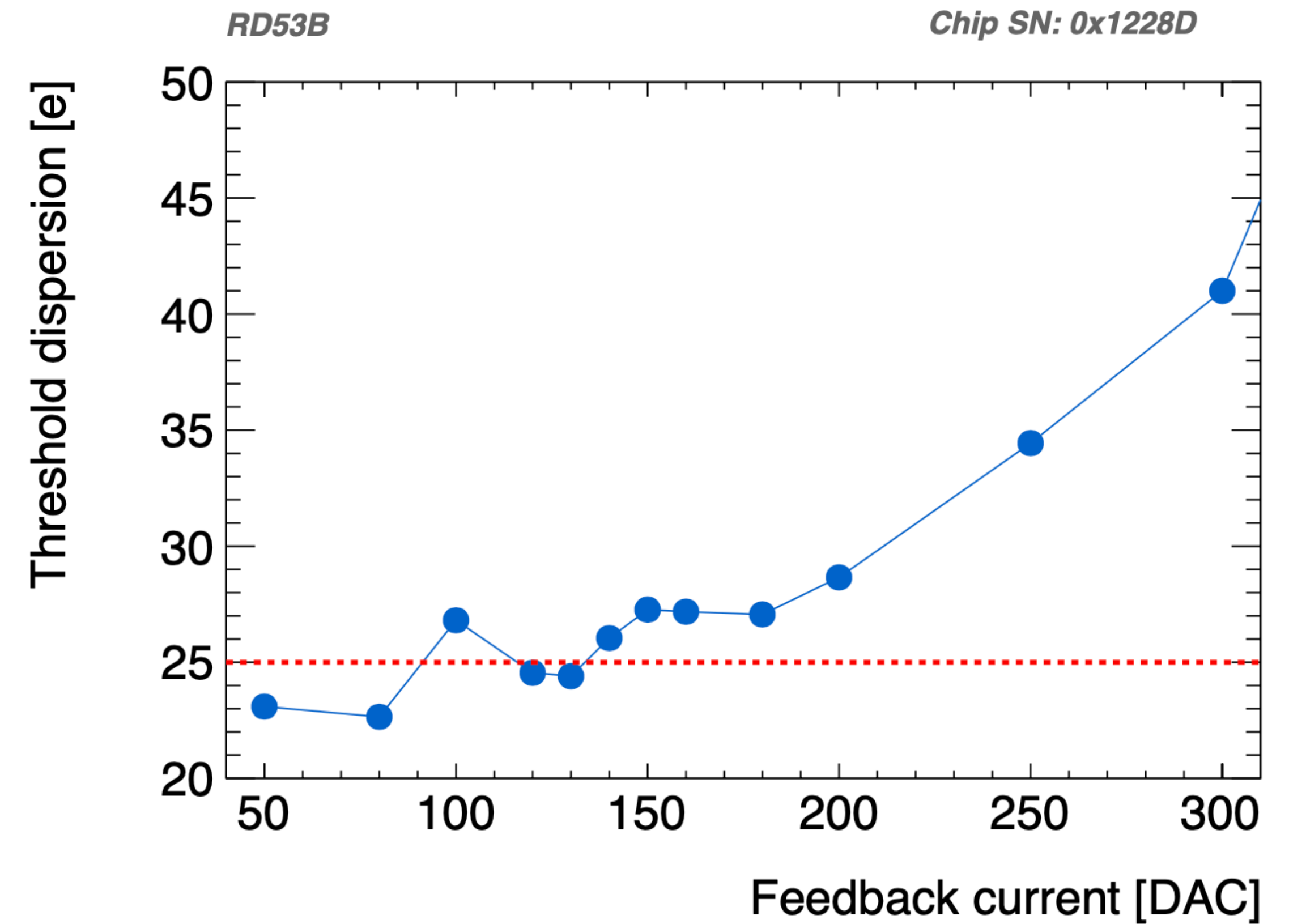
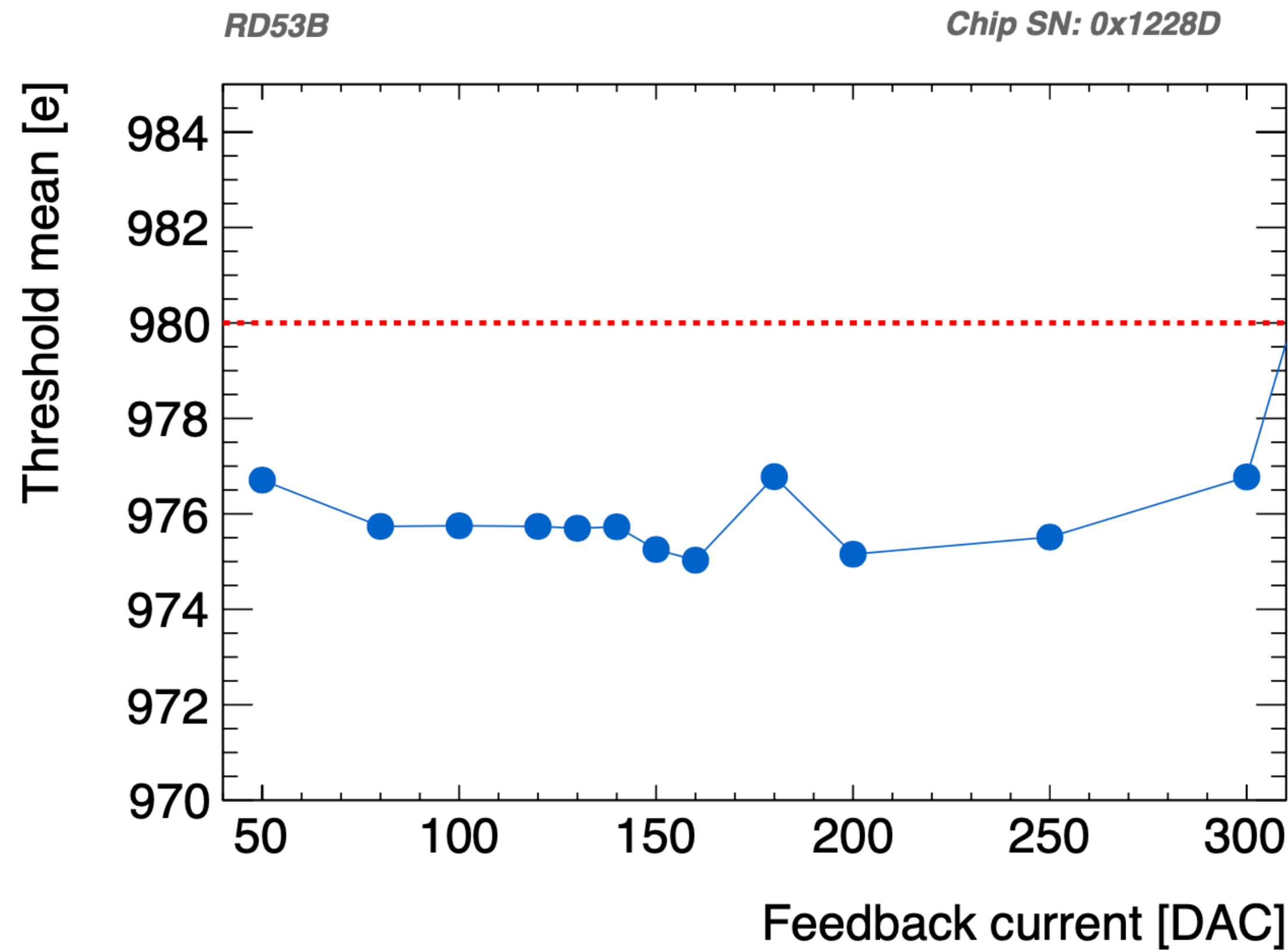
Threshold dispersion (variation in tuned threshold across pixels) decreases with PreAmp bias



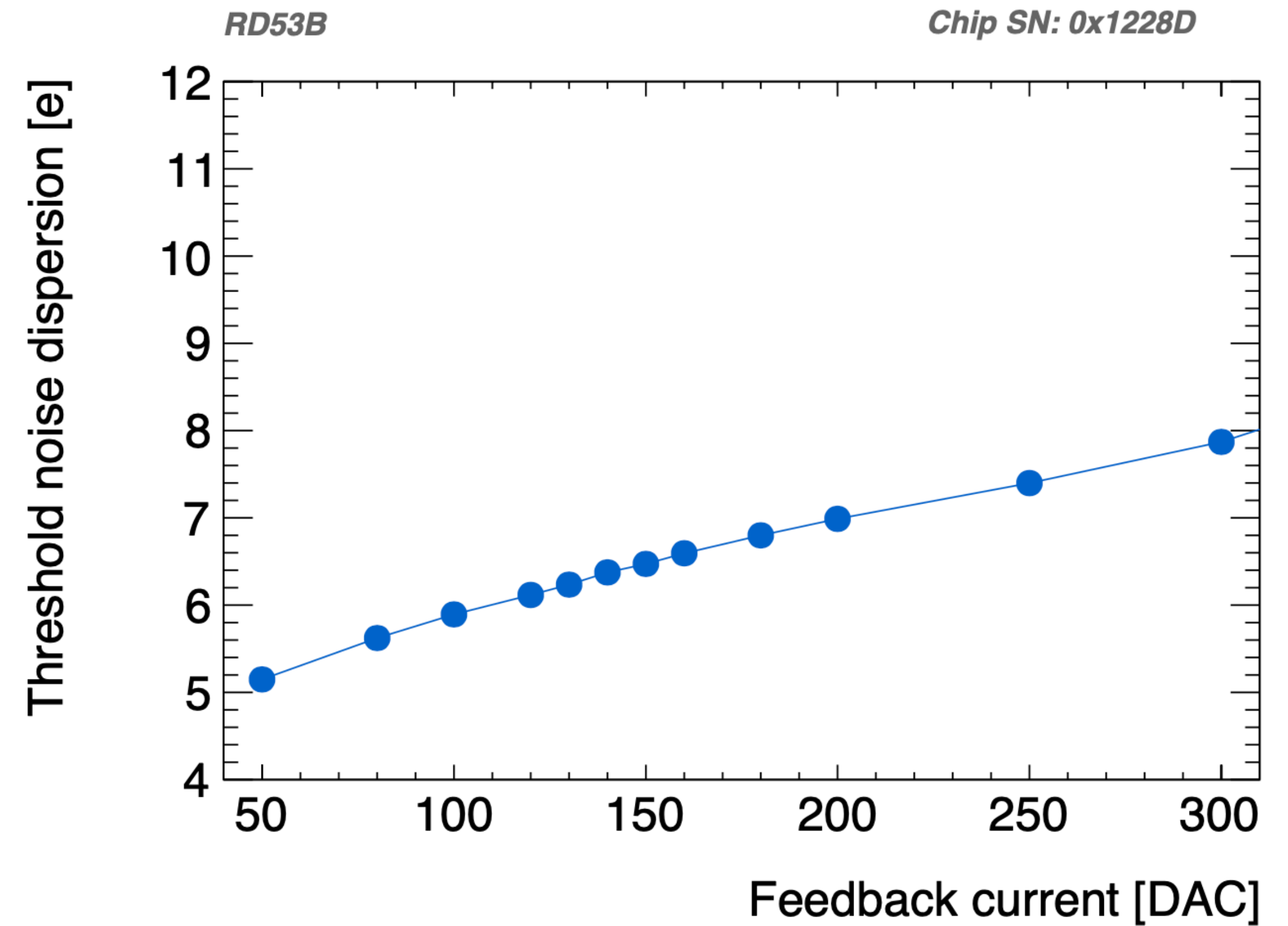
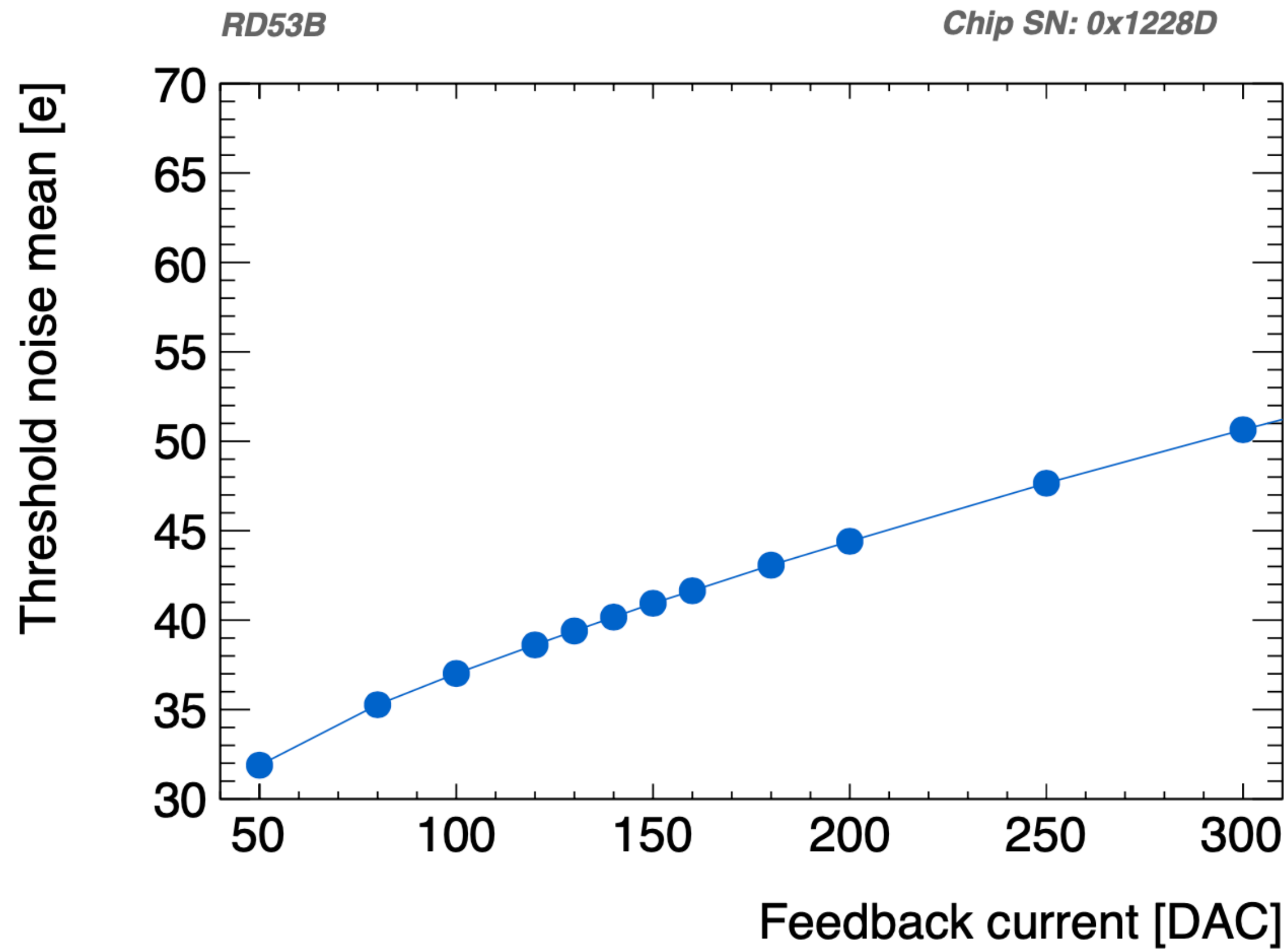
Pixel noise (variation in noise across pixels) decreases with PreAmp bias



Increasing DiffVff (faster discharge) increases tuned threshold dispersion

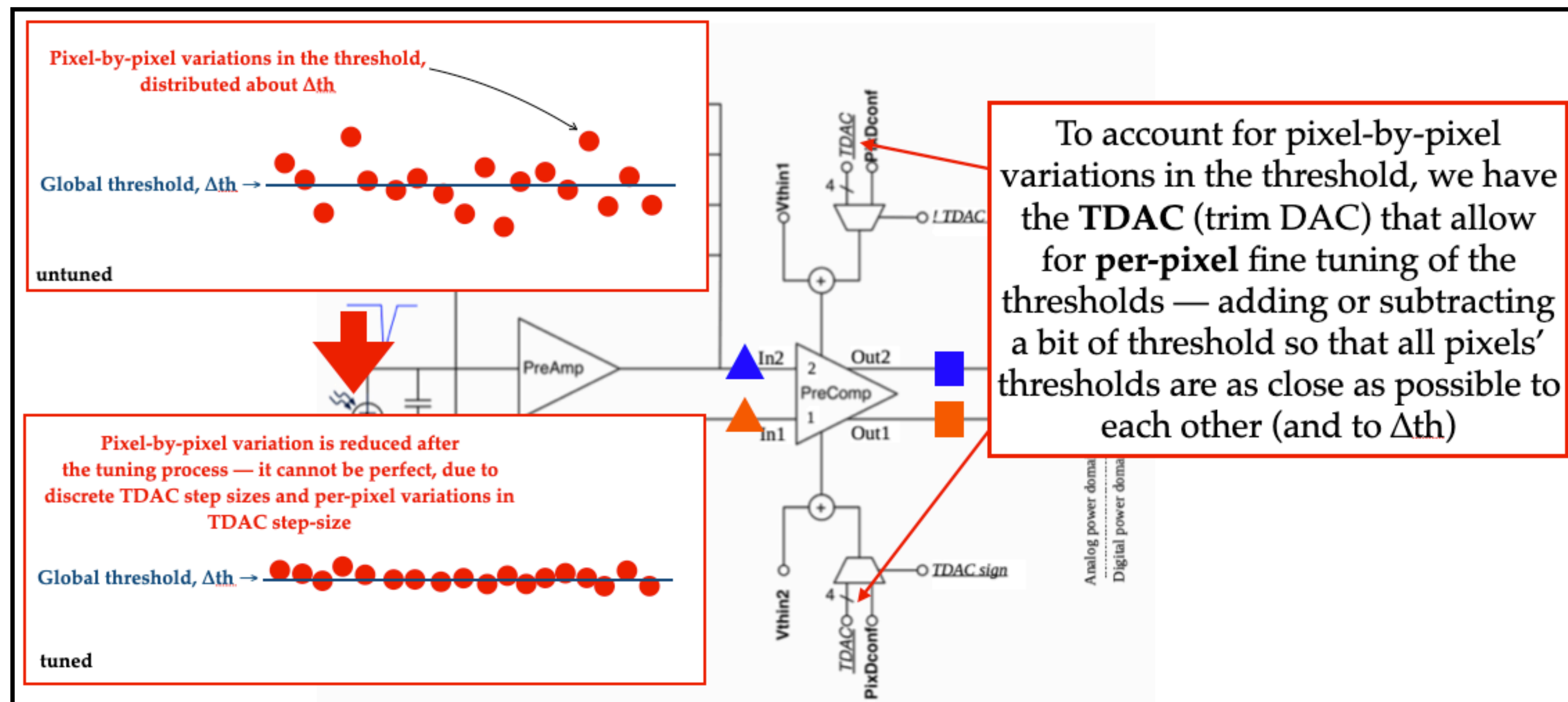


Increasing DiffVff (faster discharge) increases the noise

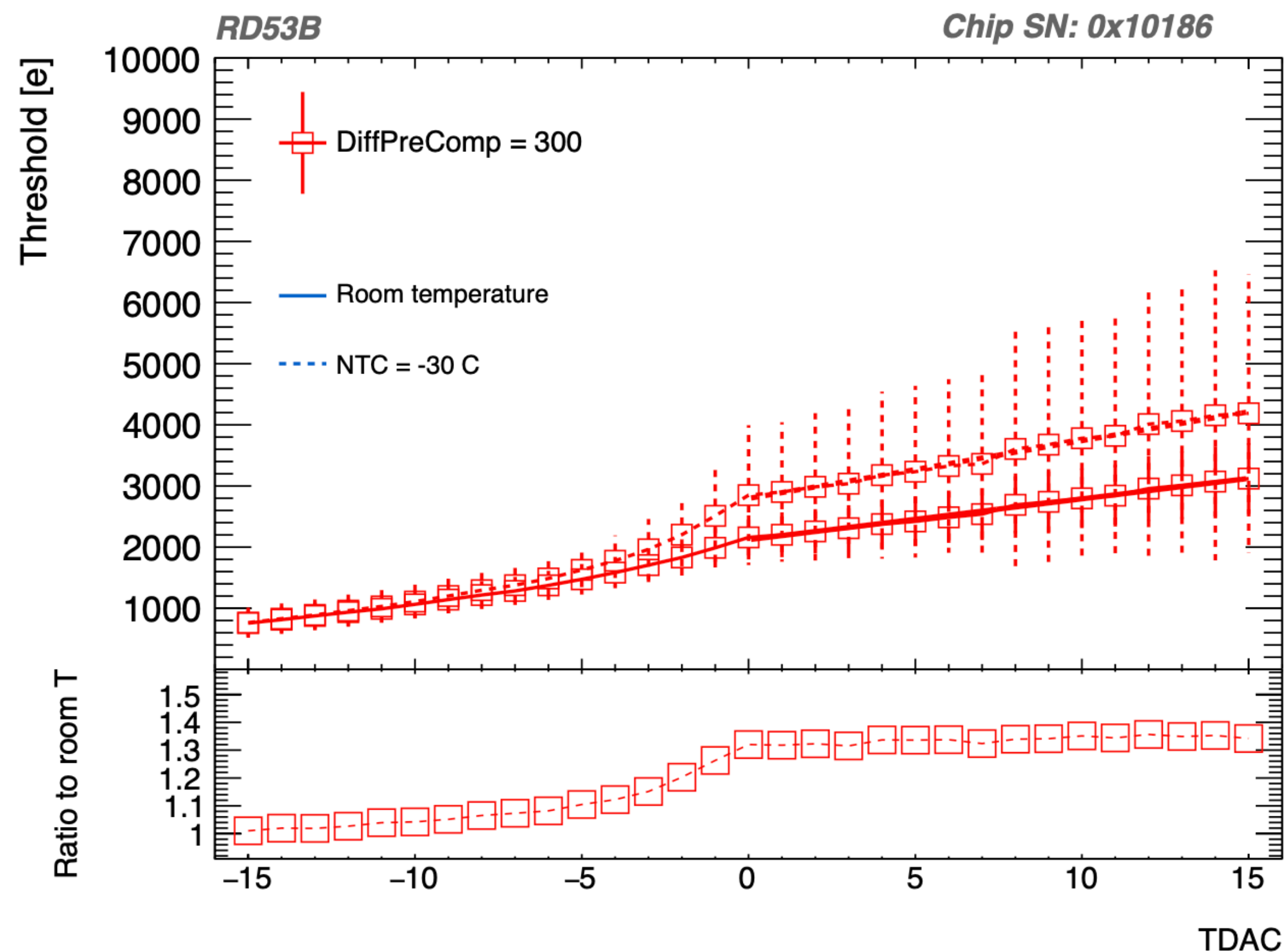


Another interesting effect is the difference in response between negative TDAC and positive TDAC

reminder



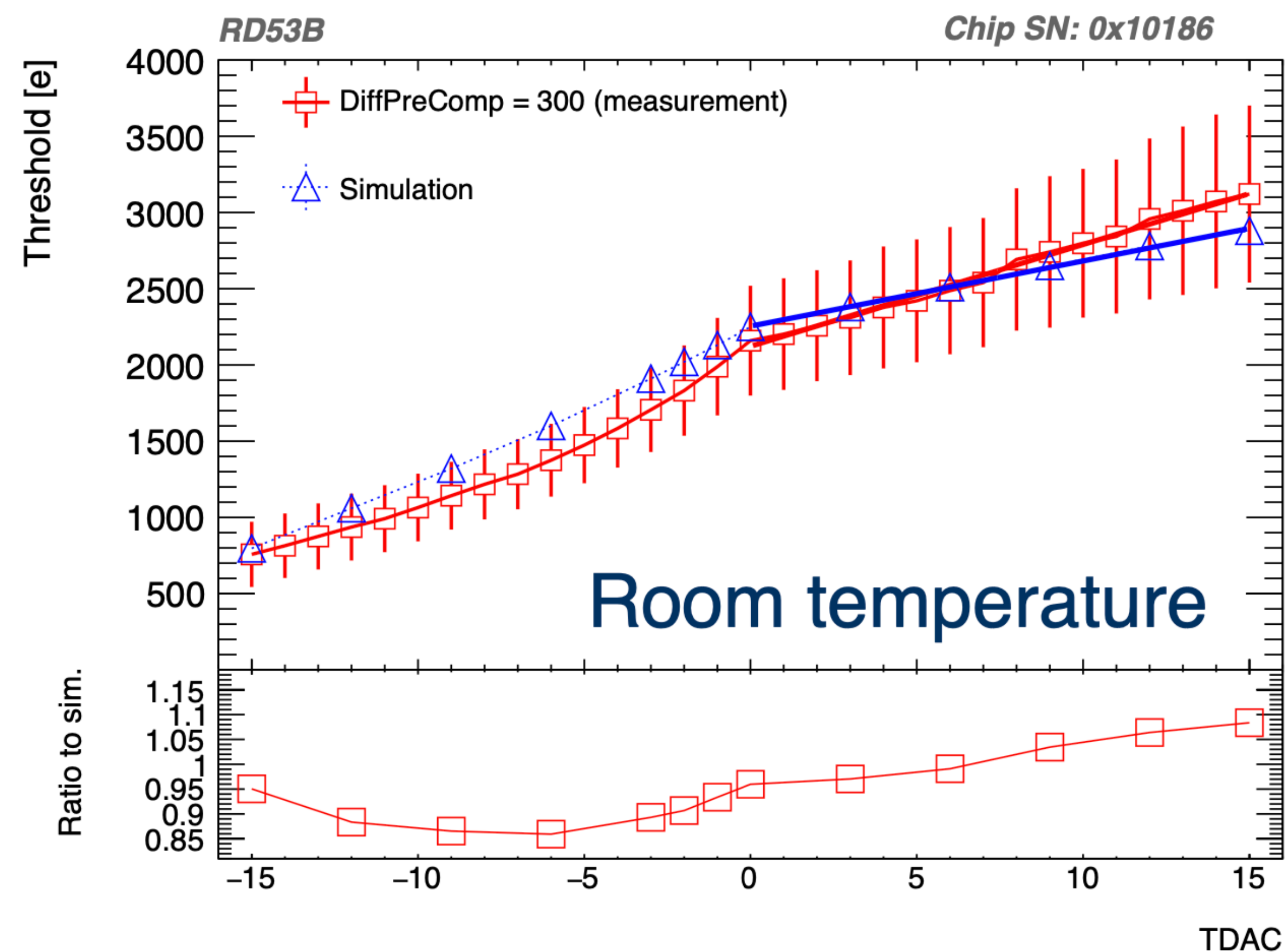
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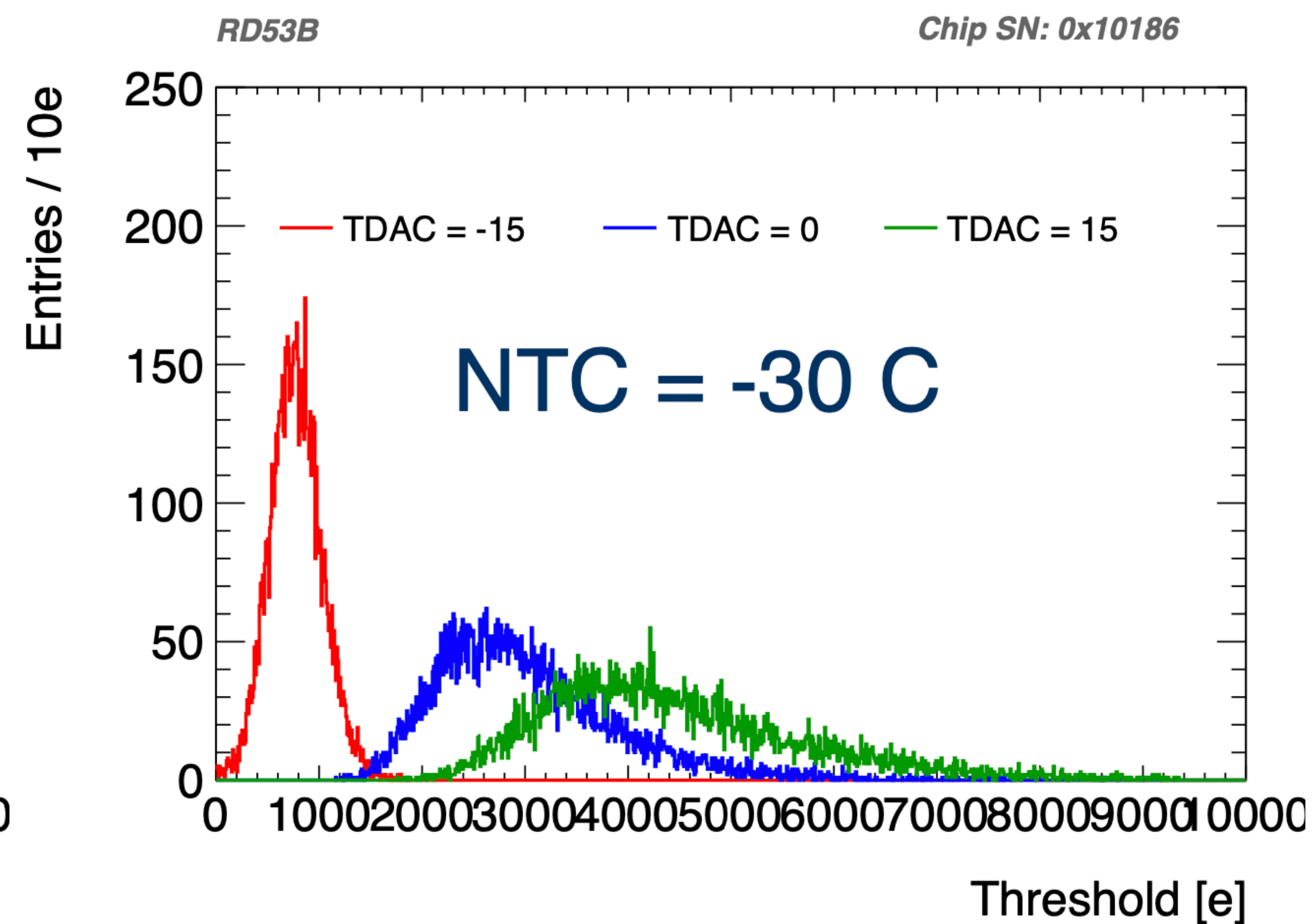
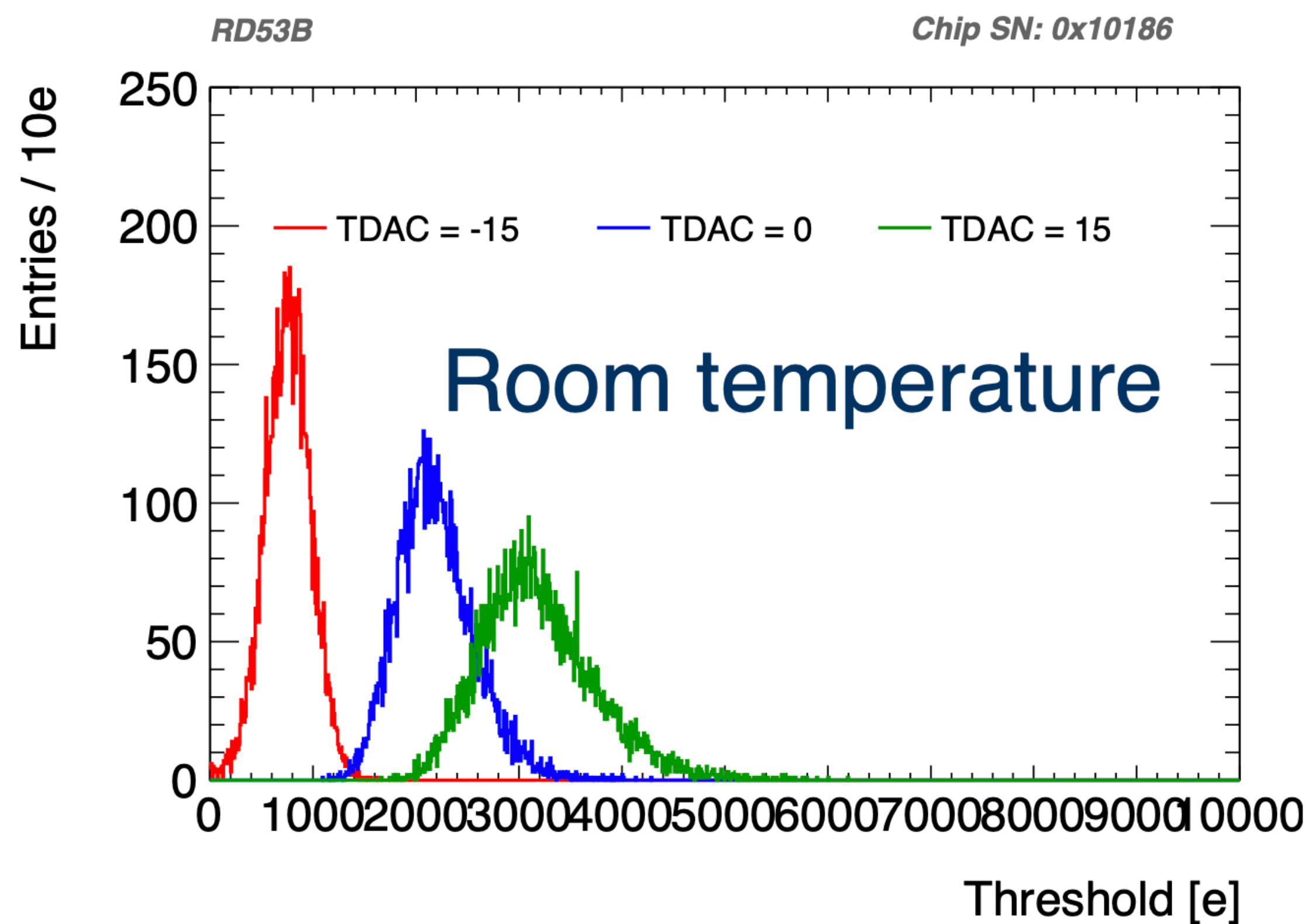
This shows that the amount by which a pixel's threshold is trimmed by varying its TDAC differs if we are trimming down vs trimming up — and there appears to be some dependence on temperature

Another interesting effect is the difference in response between negative TDAC and positive TDAC

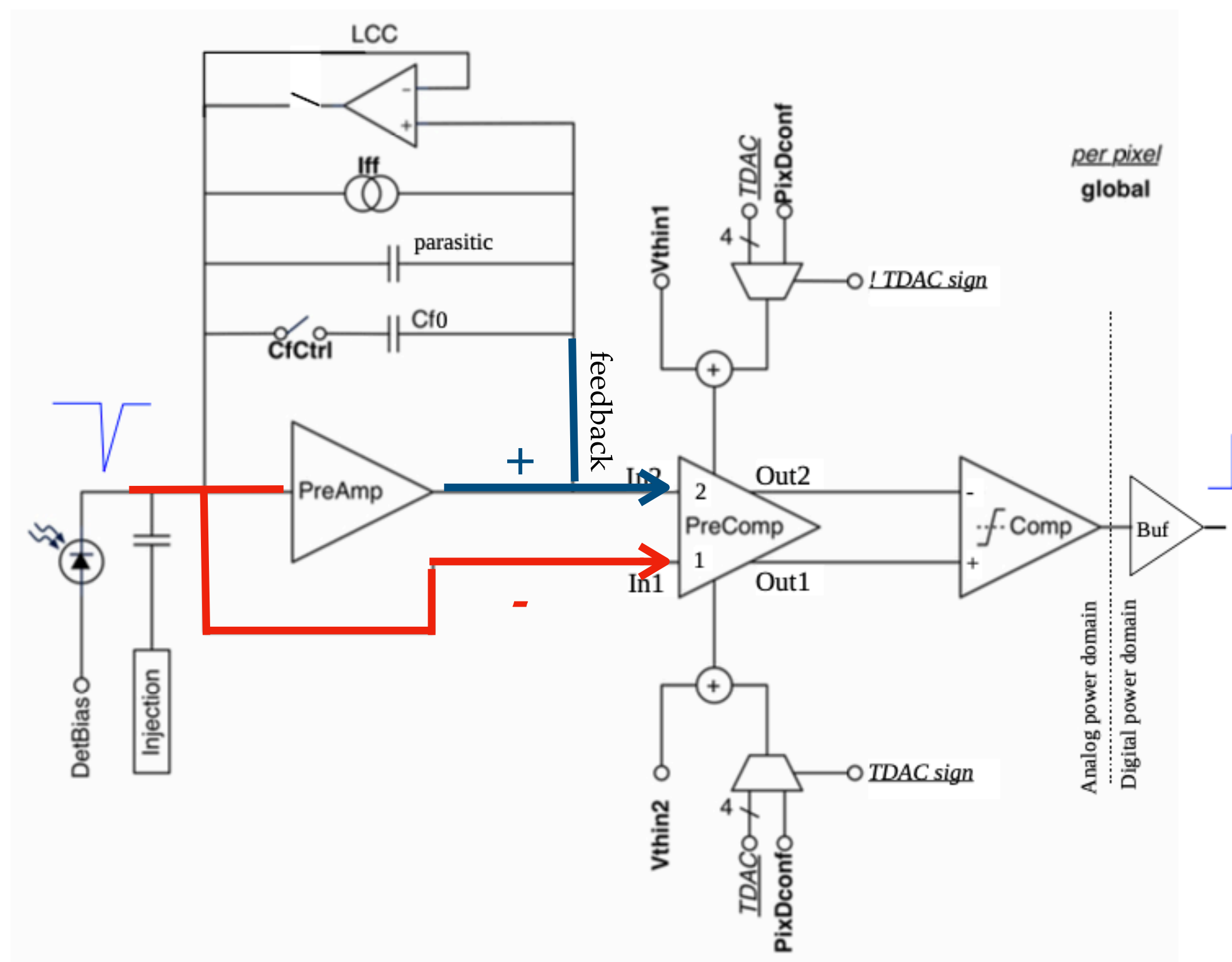
This negative vs positive TDAC difference is seen also in the simulation of the analog front-end



The overall (untuned) threshold dispersion varies quite a bit as a function of TDAC (and temperature)



The differences between the + and - TDAC is very much related to the internal circuitry of the analog front-end

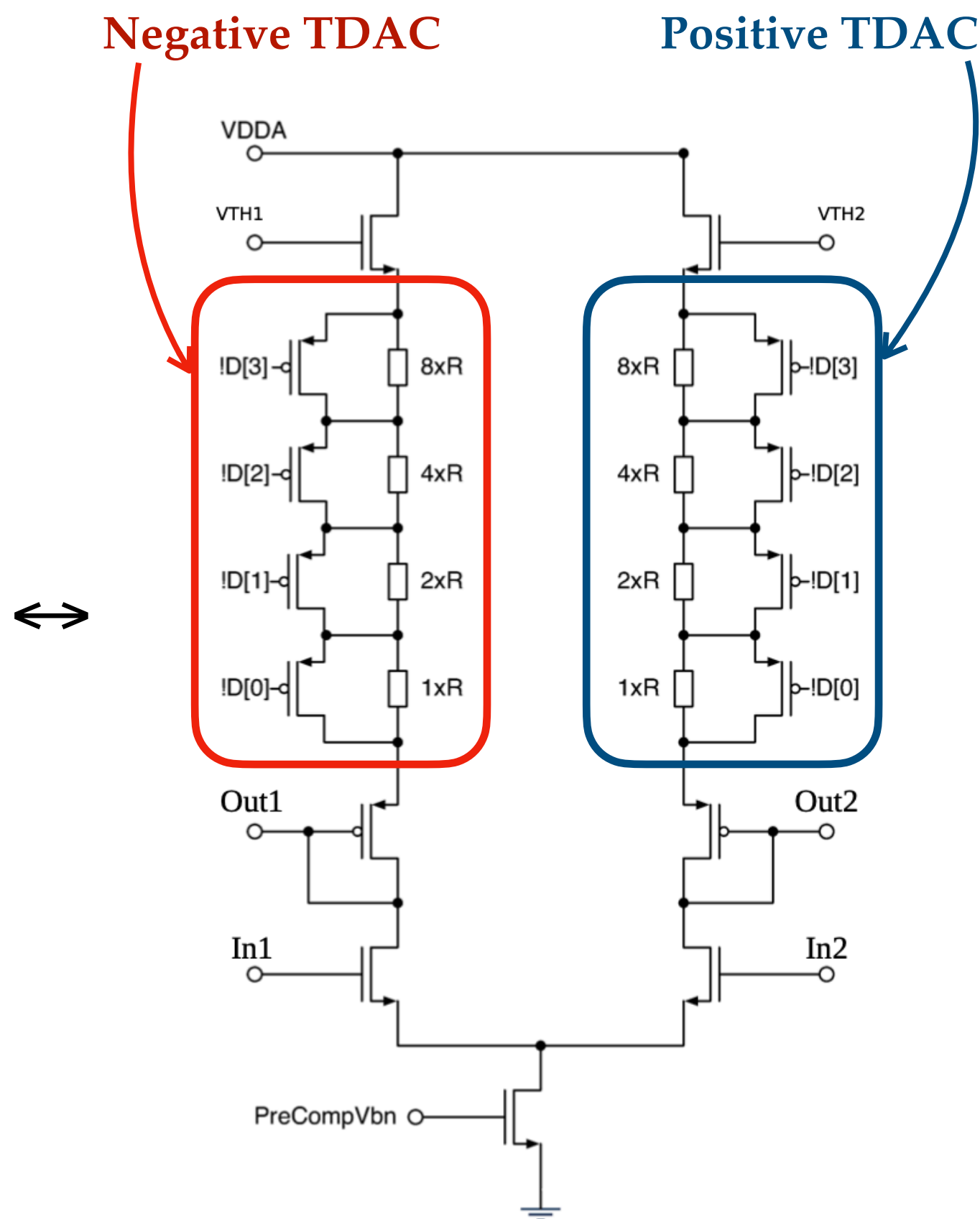
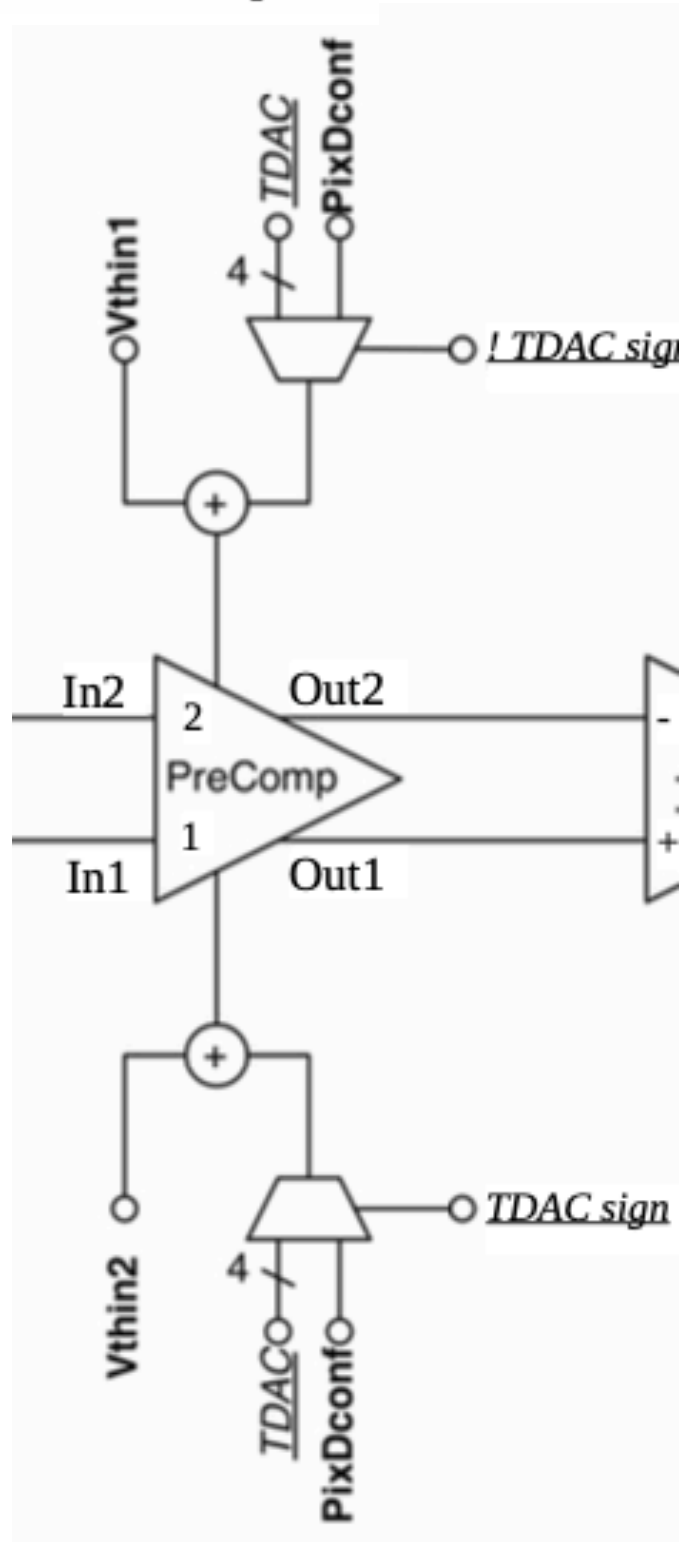
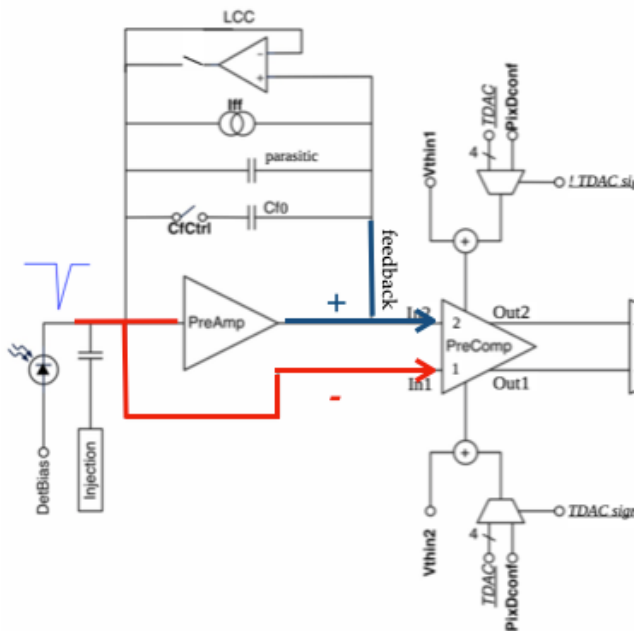


Reminder:

The + input to the PreComp is the output of the PreAmp stage

The - input to the PreComp is the input signal itself

The differences between the + and - TDAC is related to the internal circuitry of the analog front-end



And the circuitry that controls the + and - TDAC are applied to the + and - inputs *separately...*

The negative input side is also highly sensitive to the PreAmp output stages (directly coupled to feedback stages)...

Changes in the TDAC & threshold circuitry impact the feedback circuitry in the PreAmp stage...

→ Several on-going studies to further characterize this circuit