



Amplitude Walk in Fast Timing: The role of Dual thresholds



Calibration of few $\times 10^5$ channel timing arrays @ HL-LHC

—> Unprecedented complexity:

- **Beam “spot” is not a spot, assumptions about tracking & P.I.D., etc**

—> Incentive for “self-calibrating” timing channel

- **== only data from channel itself (thr1,thr2,Q) used for calibration**

2 papers: <https://arxiv.org/abs/2405.08191>. and. <https://arxiv.org/abs/2507.07127> -> JINST

Sebastian White, October 7, 2025

CPAD 2025 at Penn

Outline

- HL-LHC timing
- “Pulse slope at threshold” central role in walk correction
- Case of a linear system
 - Linear= Pulse shape scales with Q
- The CMS Barrel Timing Layer(BTL) upgrade
- Laser Study shows utility of Slope in BTL Walk calibration
- Use of calibration data set for Day-1 walk corrections

Primary Criterion for Timing Upgrades @HL-LHC

Mitigate pileup induced backgrounds by enhancing vertexing w time-of-interaction

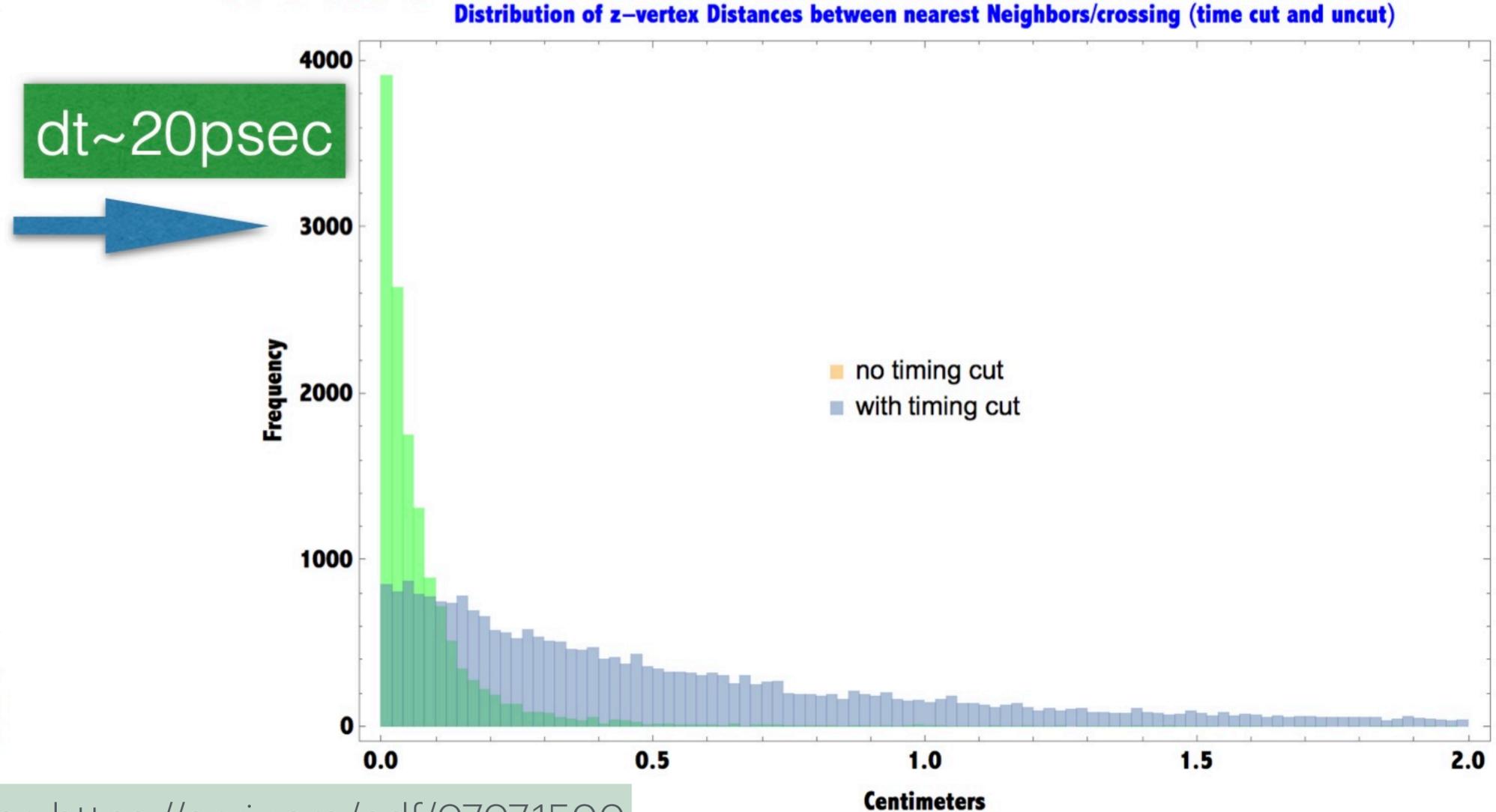
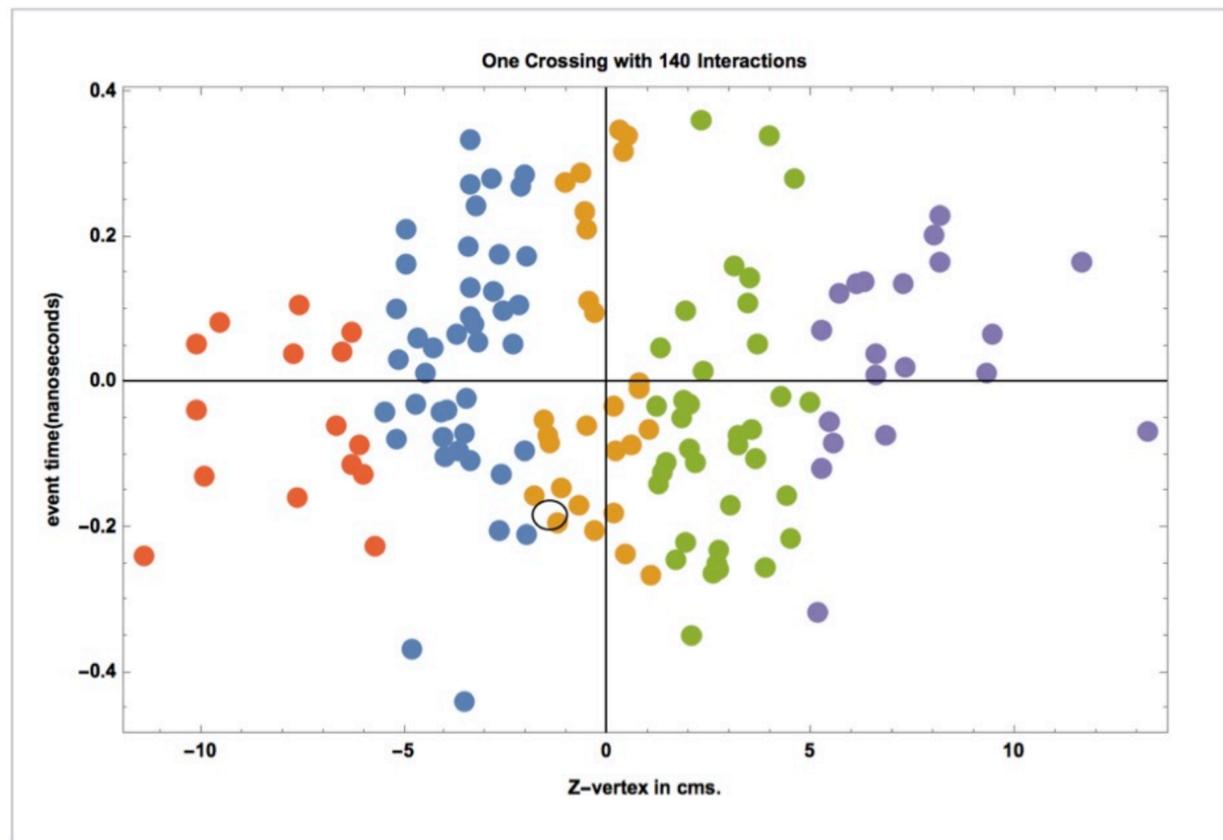


Fig.1. Simulation of the space(z-vertex) and time distribution of interactions within a single bunch crossing in CMS at a pileup of 140 events- using LHC design book for crossing angle, emittance, etc. Typically events are distributed with an rms-in time- of 170 picoseconds, independent of vertex position.

Not CMS-From my 2007 paper: <https://arxiv.org/pdf/0707.1500>

A very busy environment for use of beam events to do calibrations.
Yes for tracking time offsets but ~300k channels of walk corrections questionable.
See ALICE Run-2 experience

Amplitude Walk Basics:

Naive model:

Linear leading edge

Def'n: 1) time at threshold (t_{thr})

=time@thresh (ie t_Q)

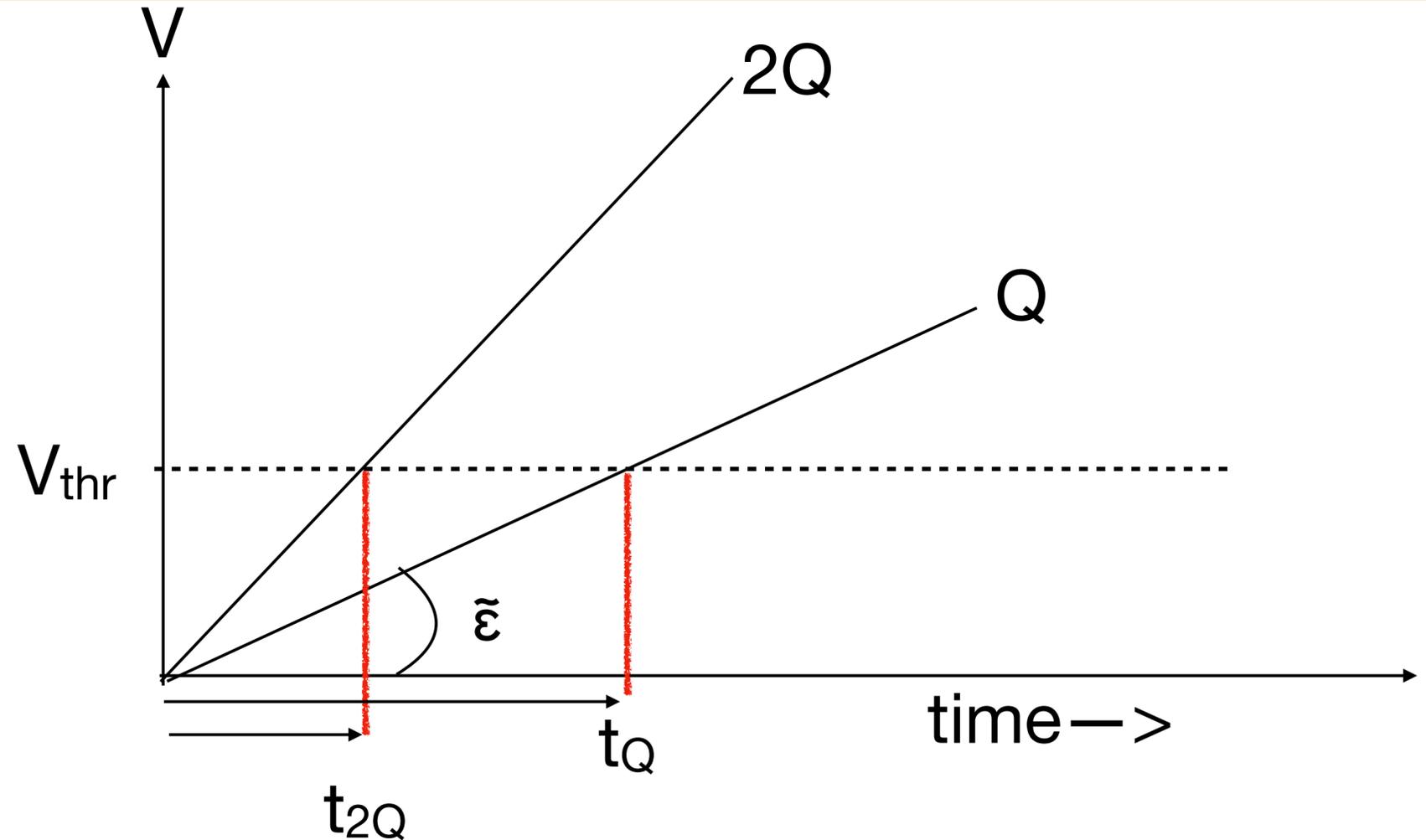
2) Slope(Q) = $\tan[\tilde{\epsilon}] \propto Q$

$\Rightarrow V_{thr}/t_{thr} = \text{Slope}$

$\Rightarrow t_{thr} = V_{thr} \times \text{Slope}^{-1}$

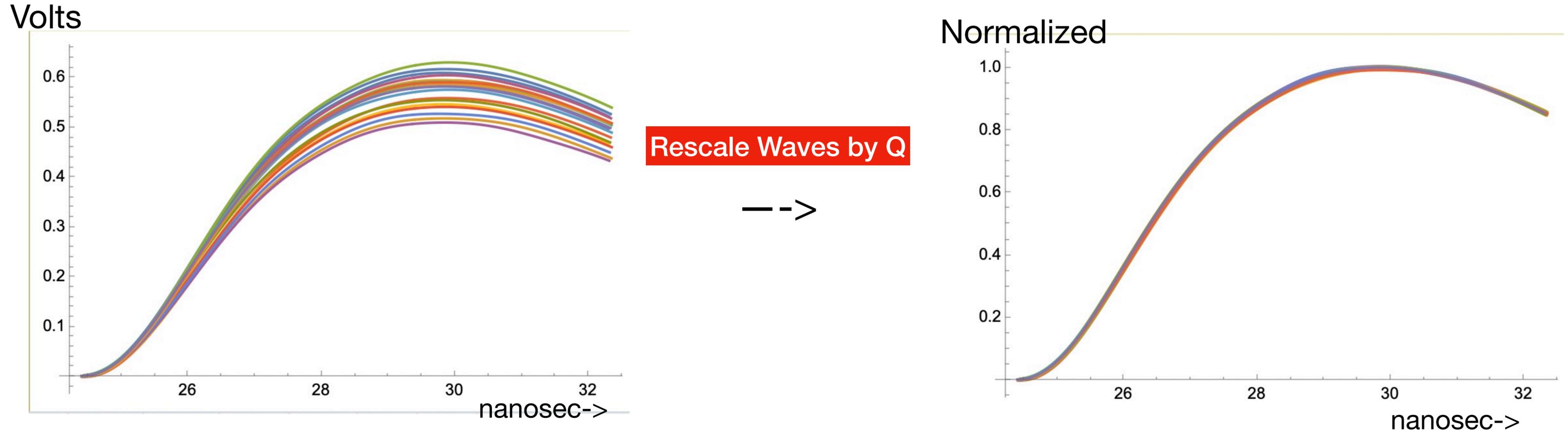
3) Amplitude Walk Coefficient (AWC)

==coefficient of Slope^{-1}



Q: $t_0 = t_{thr} - V_{thr} \times \text{Slope}(Q)^{-1}$
2Q: $t_0 = t_{thr} - V_{thr} \times \text{Slope}(2Q)^{-1}$
In naive case: $\text{AWC} = V_{thr}$

Let's consider "ideal" treatment- if we had full waveform to work with:

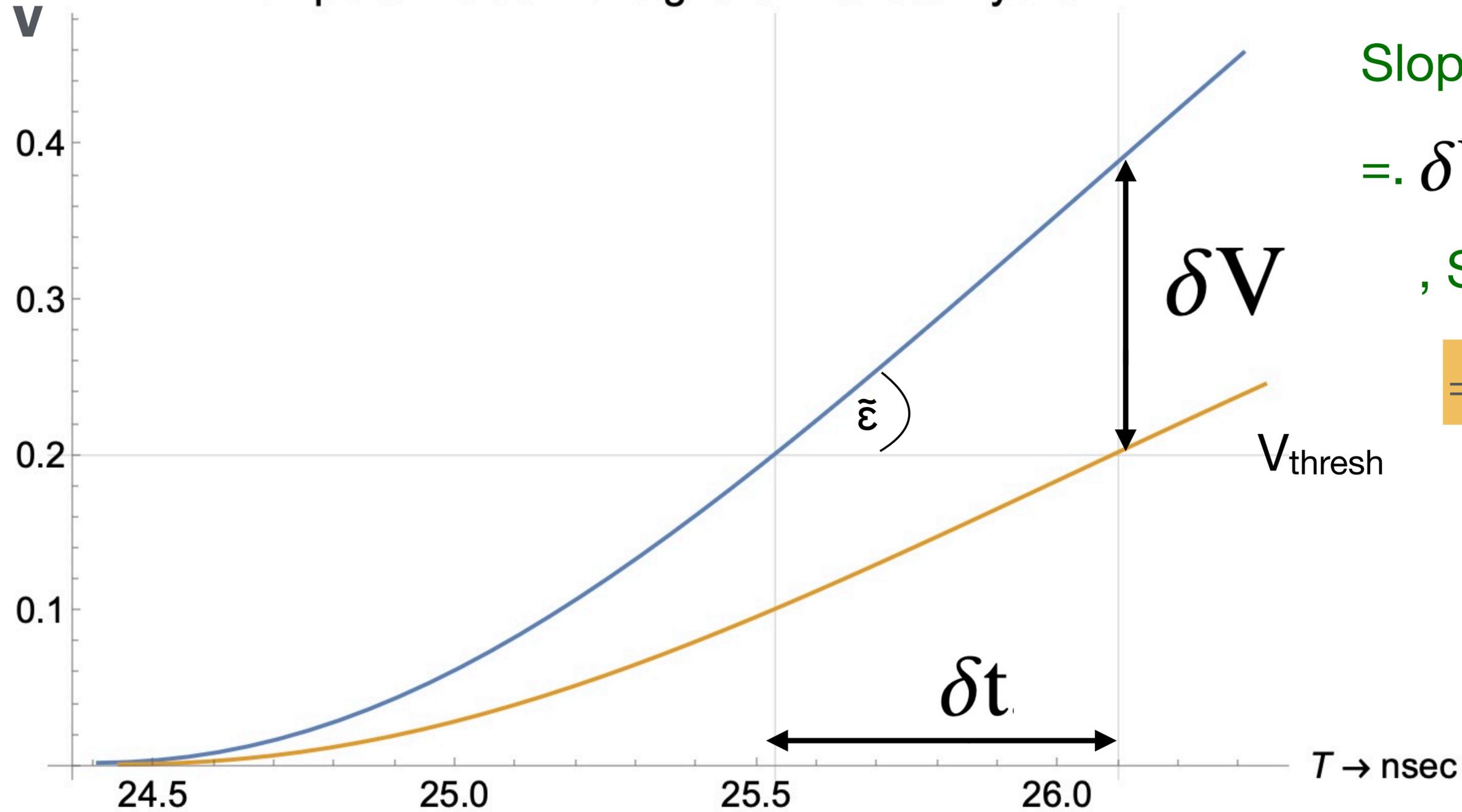


In Right plot we time at, say, 20% of peak and have "ideal time measure"(C.F.)

But we don't need full waveform. Can do the same from t_1 and dV/dt (at t_1).

Walk correction given by slope of Template since $\delta V = (Q_{\text{template}} / Q - 1) * V_{\text{thresh}}$

Template in blue with signal of interest in yellow



$$\text{Slope}(Q_{\text{template}}) = \text{Tan}[\tilde{\epsilon}]$$

$$= \delta V / \delta t$$

, Solve for δt

=> perfect CF timing

See: <https://arxiv.org/pdf/2405.08191>

Extension to system w/o linear scaling feature

Previous example demonstrates that, in many cases, no need for “brute force” walk

CMS Barrel Timing Layer(BTL) Upgrade ASIC=TOFHIR2C

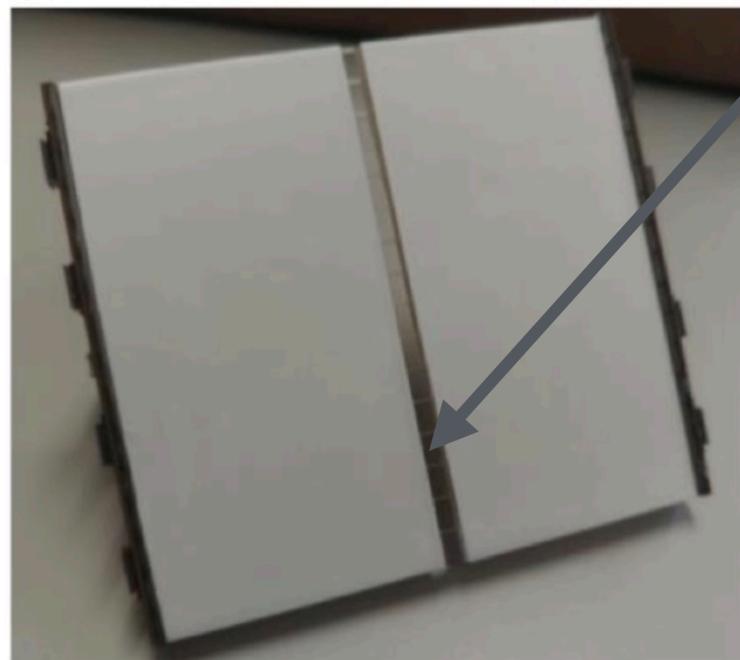
- Severe pileup and rad. Induced Dark Count Rate
 - Mitigated w. Single Delay Line Shaping
 - Readout 2 timing Discriminators (“thr₁”, “thr₂”) and QDC (“Q”)
 - QDC resolution <3%, “Slope at threshold” from $T(\text{thr}_2) - T(\text{thr}_1)$

Walk Calibration for BTL proposed in following

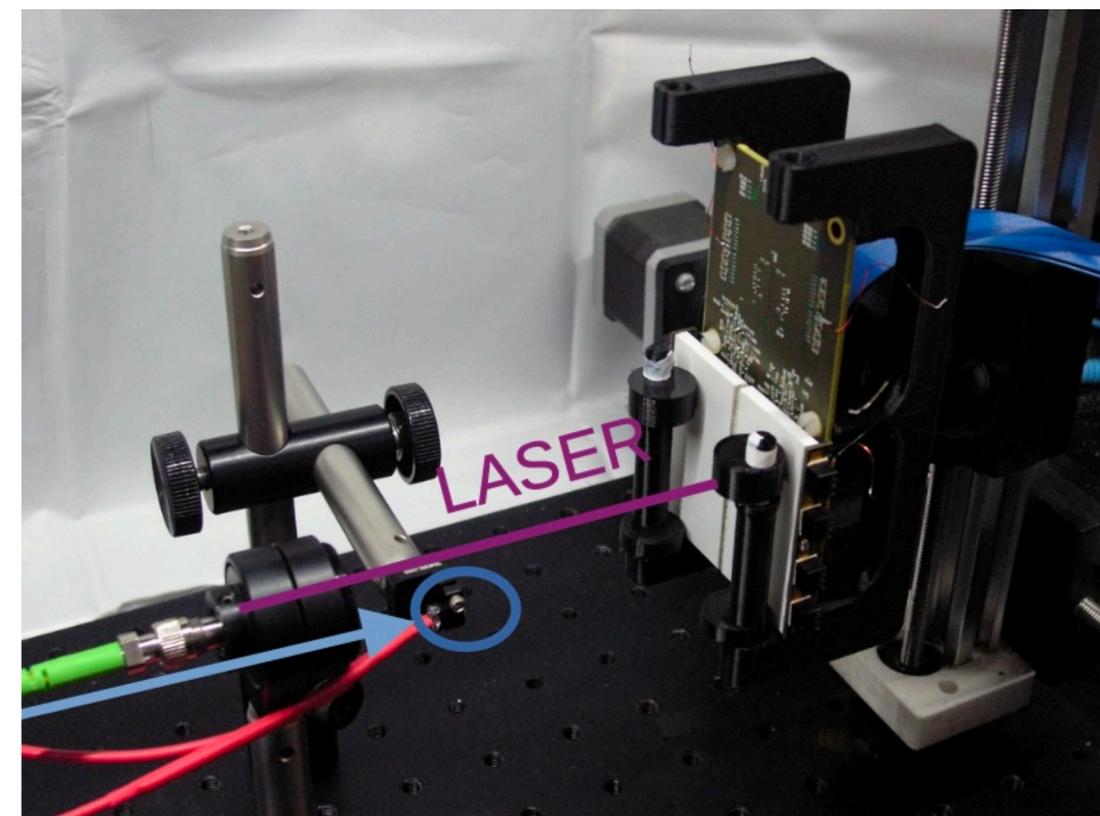
BTL components

~10.4k modules cover CMS barrel to $|\eta| < 1.48$

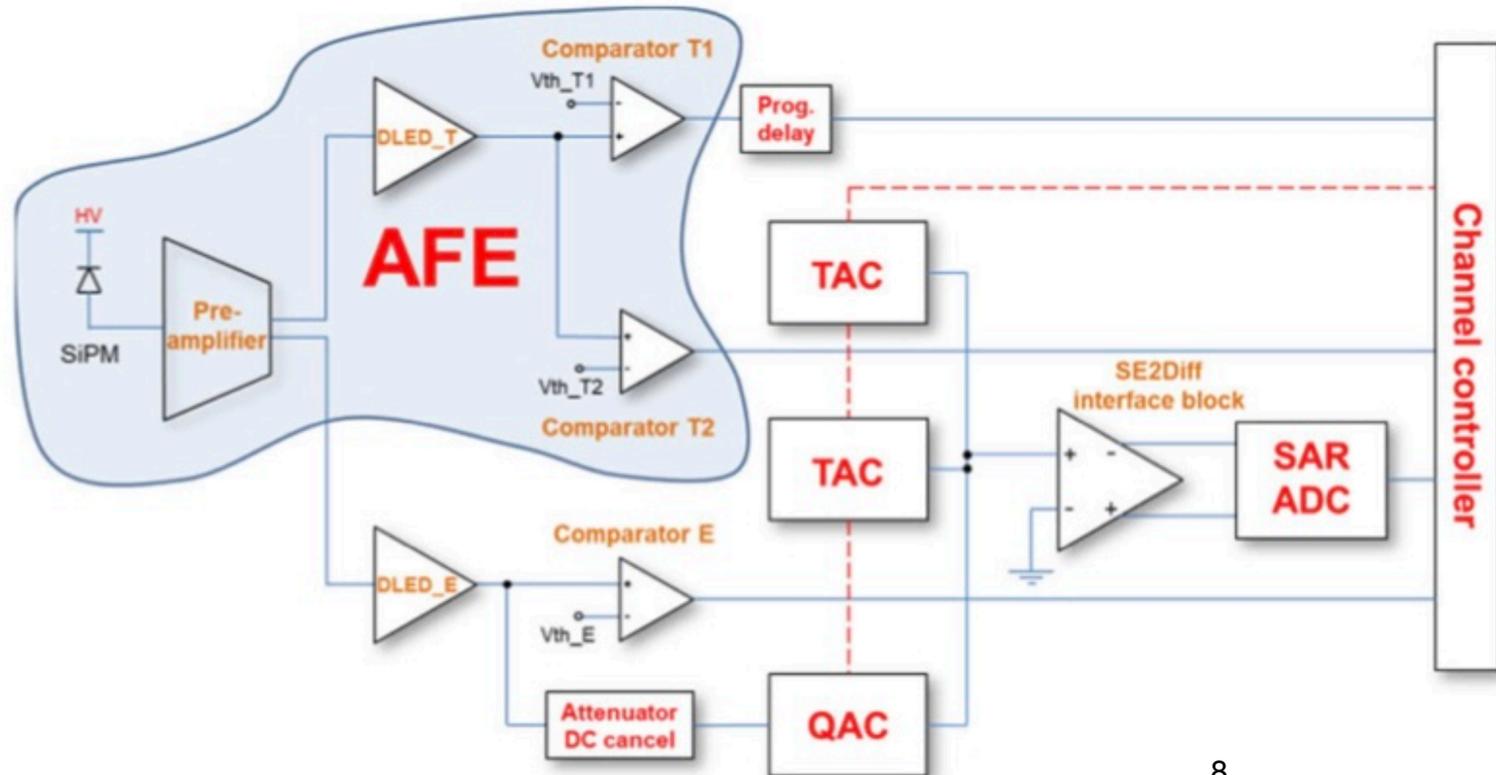
16 bar module
LYSO:Ce Scint
32 SiPM's



Wrapping removed
Allows UV laser input

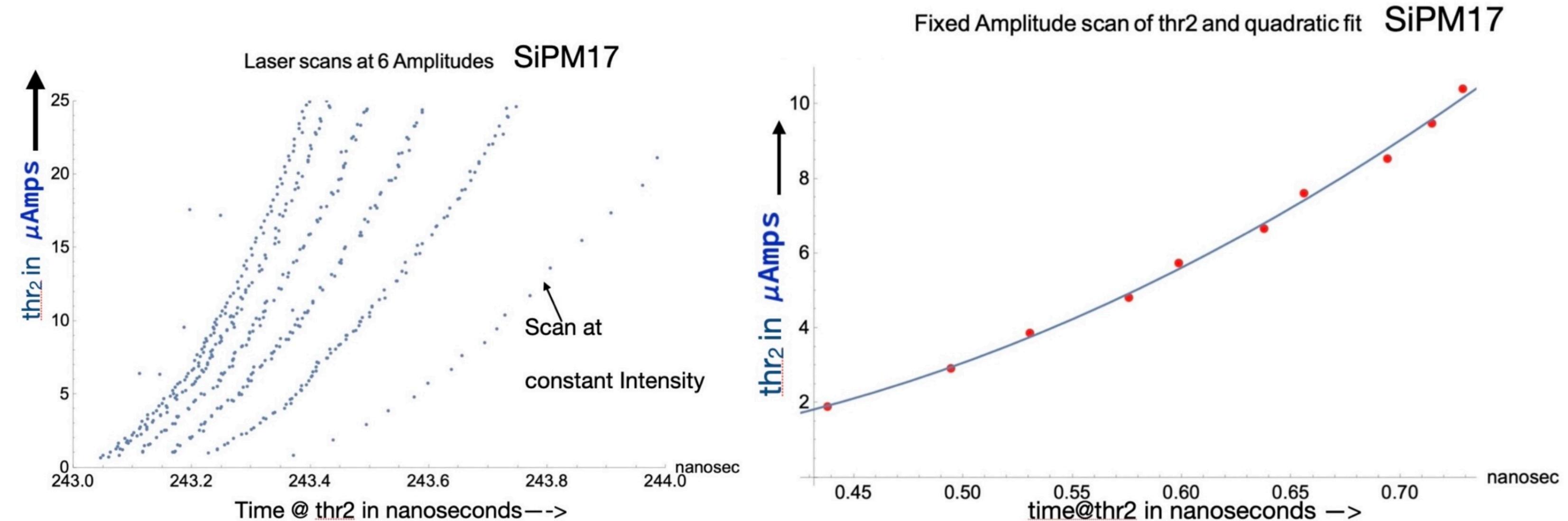


32 channel
TOFHIR ASIC



Pulsed UV laser data
Variable amplitude
Used for following
Slides

Typical Data set for one channel (SiPM17)

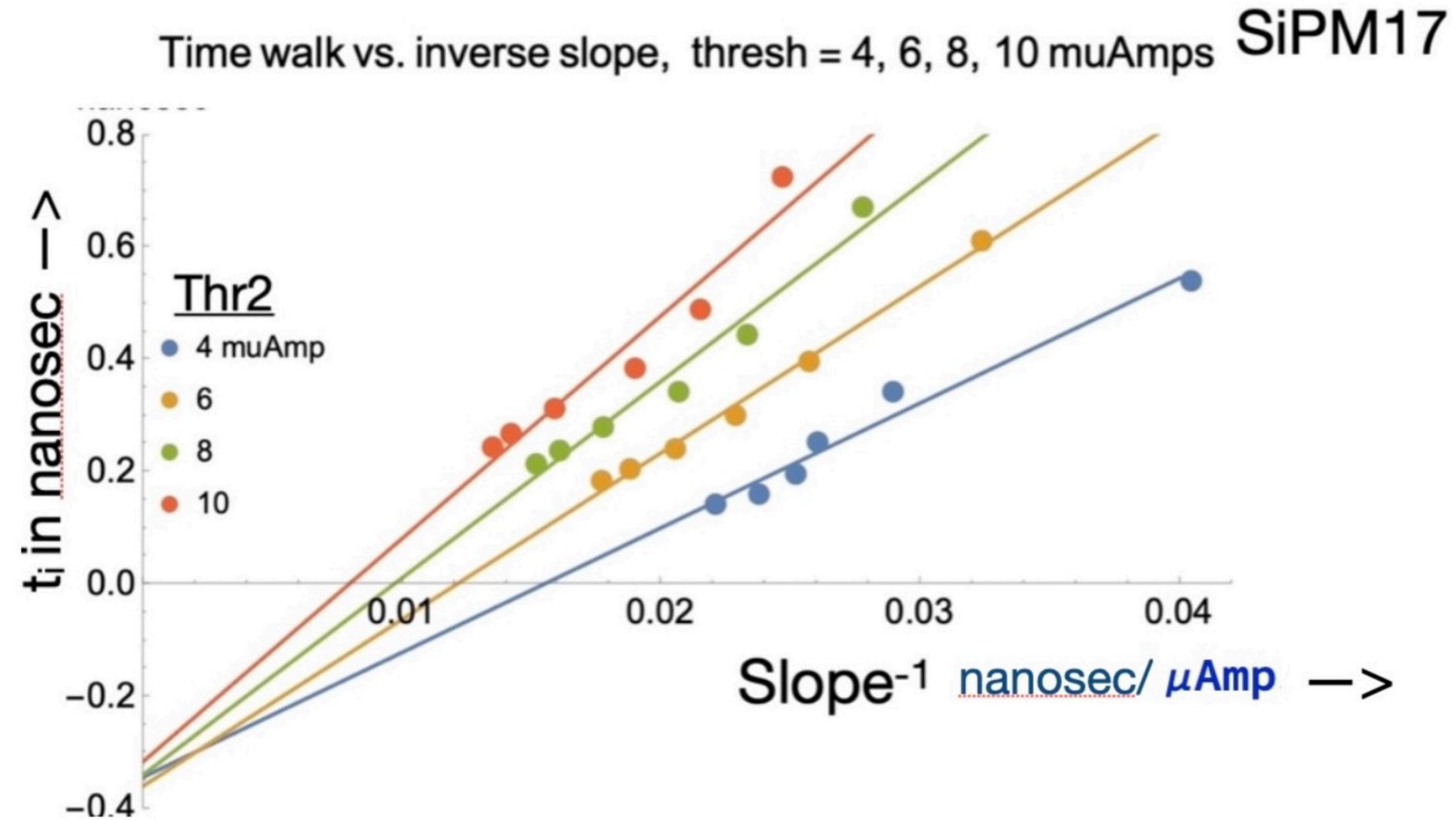


- Each point ~ 100 's of laser shots, Nominal thr₁ ~ 3.75 μAmps
- Time scale fixed phase to laser. \rightarrow — leading edge vs $Q_{1,2,3..6}$

From Quad fits->time walk vs Slope⁻¹ ->AWC* for 6 Amplitudes

AWC* =Amplitude Walk Coefficient

- AWC is a constant for fixed thr2
- The points are 6 different laser intensities.
intensities.
- For each threshold they fall on a line of time walk vs. inv. Slope.



Conclusion: Laser Studies show consistently that Slope⁻¹—> time walk in linear expression.

Next: 1) How to obtain Slope from Q?

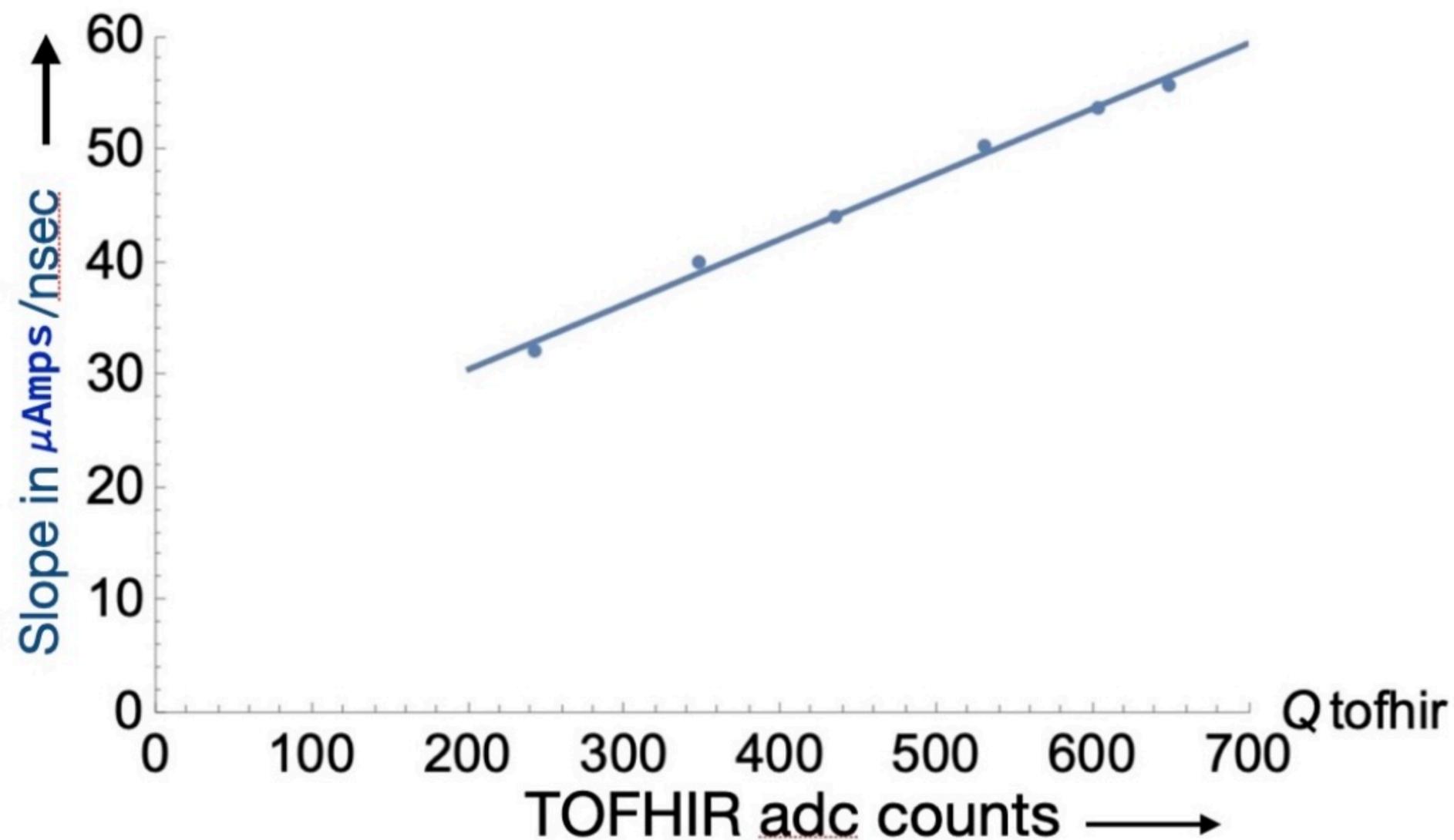
2) How to obtain AWC for all channels (ie without laser data)?

Since Q (measured to ~3%) is superior to Slope accuracy->LUT

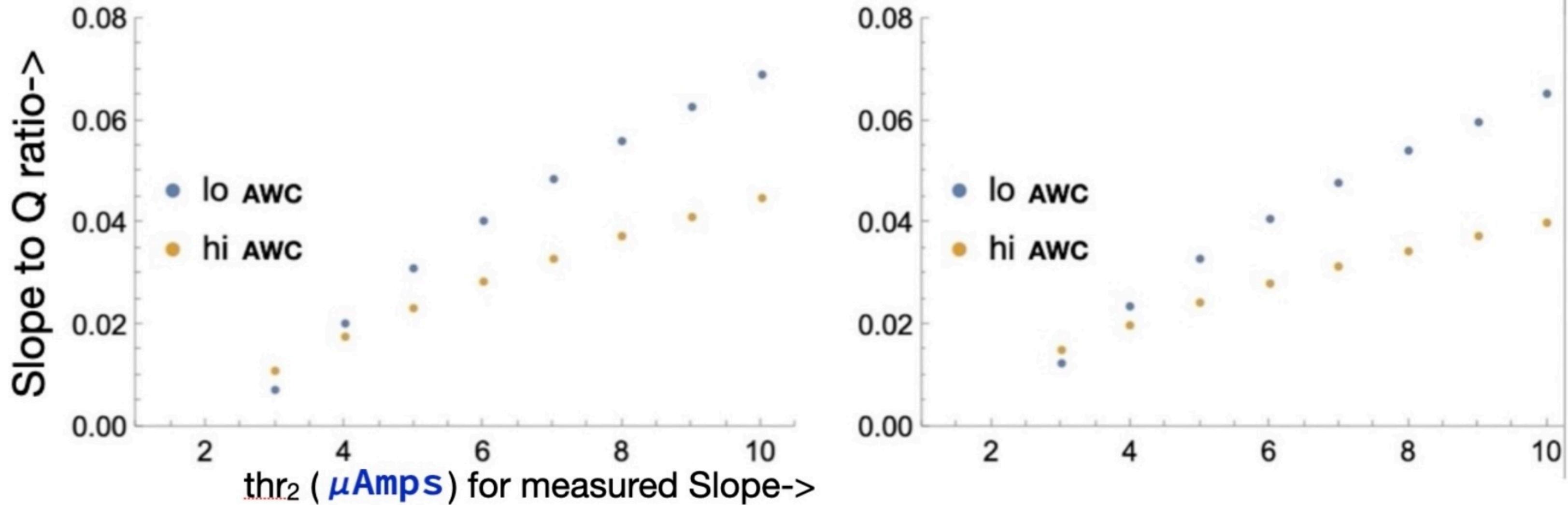
Day-1 min-bias sample
-> high statistics standalone
-> Look up Table for Slope from Q

Lab data show small variation in AWC
Correctable from variations
In this plot

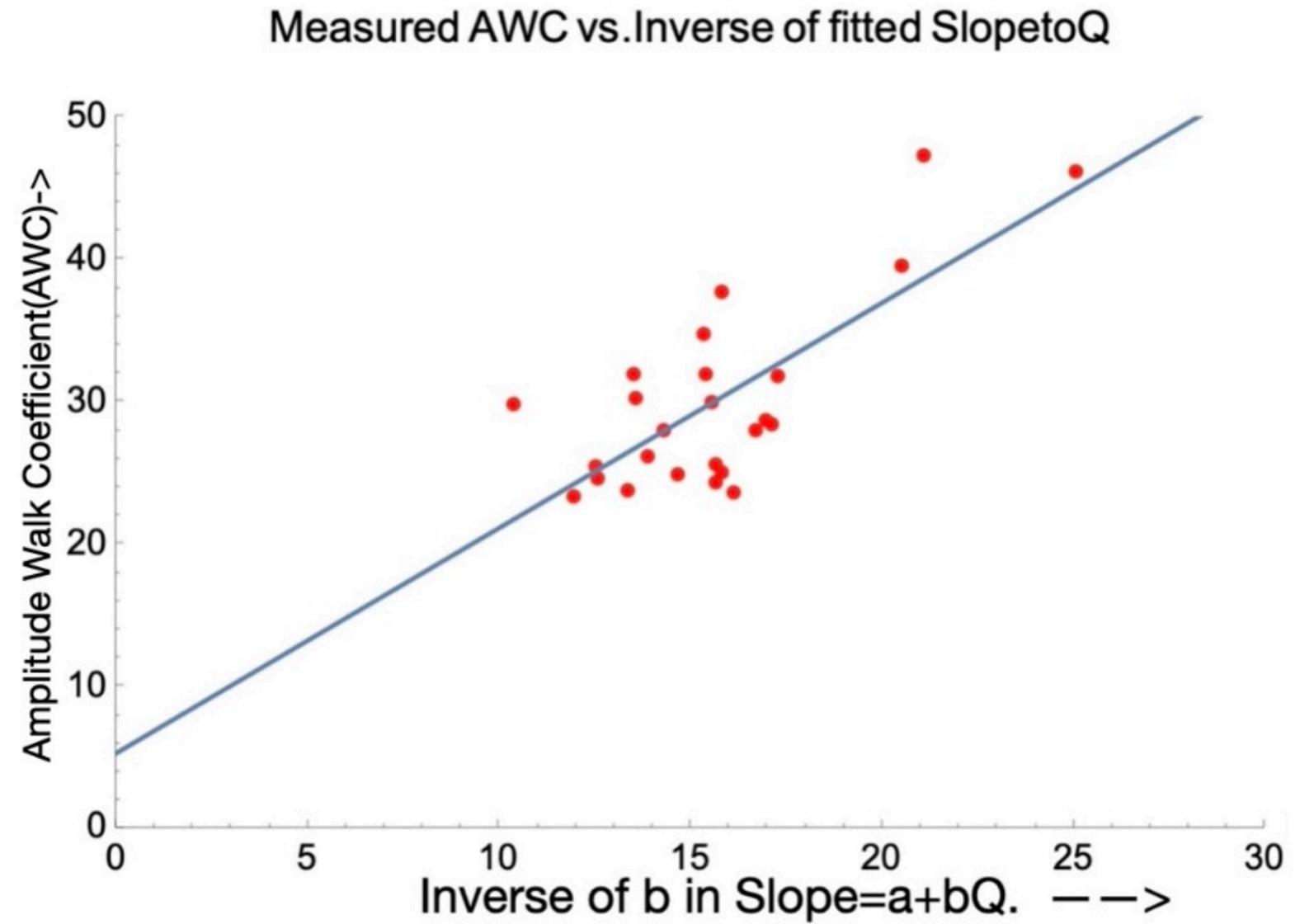
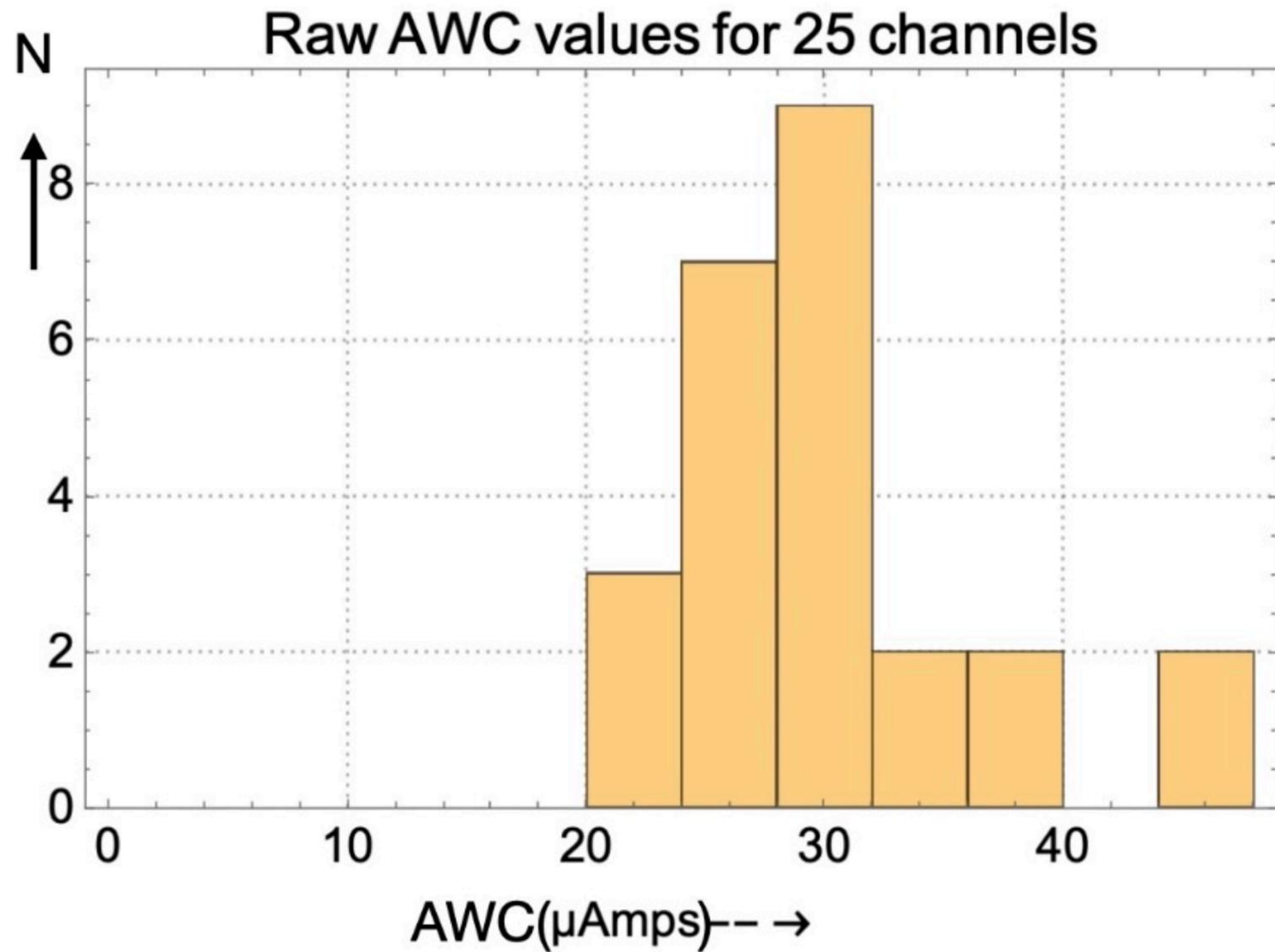
ch 17 Slope vs Q, thr = 6 muAmp



Variation in AWC is anti-correlated with Slope to Q Ratio



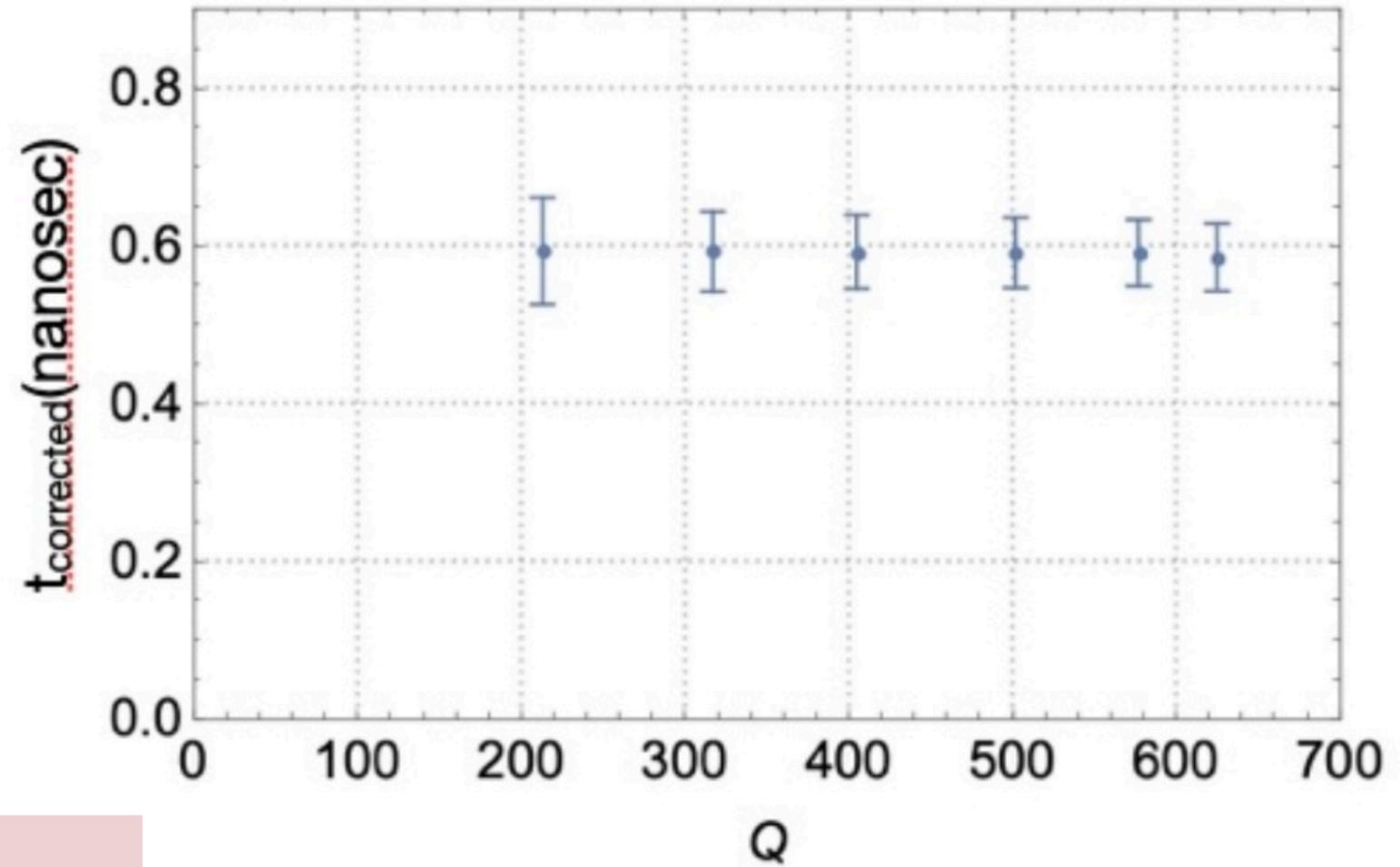
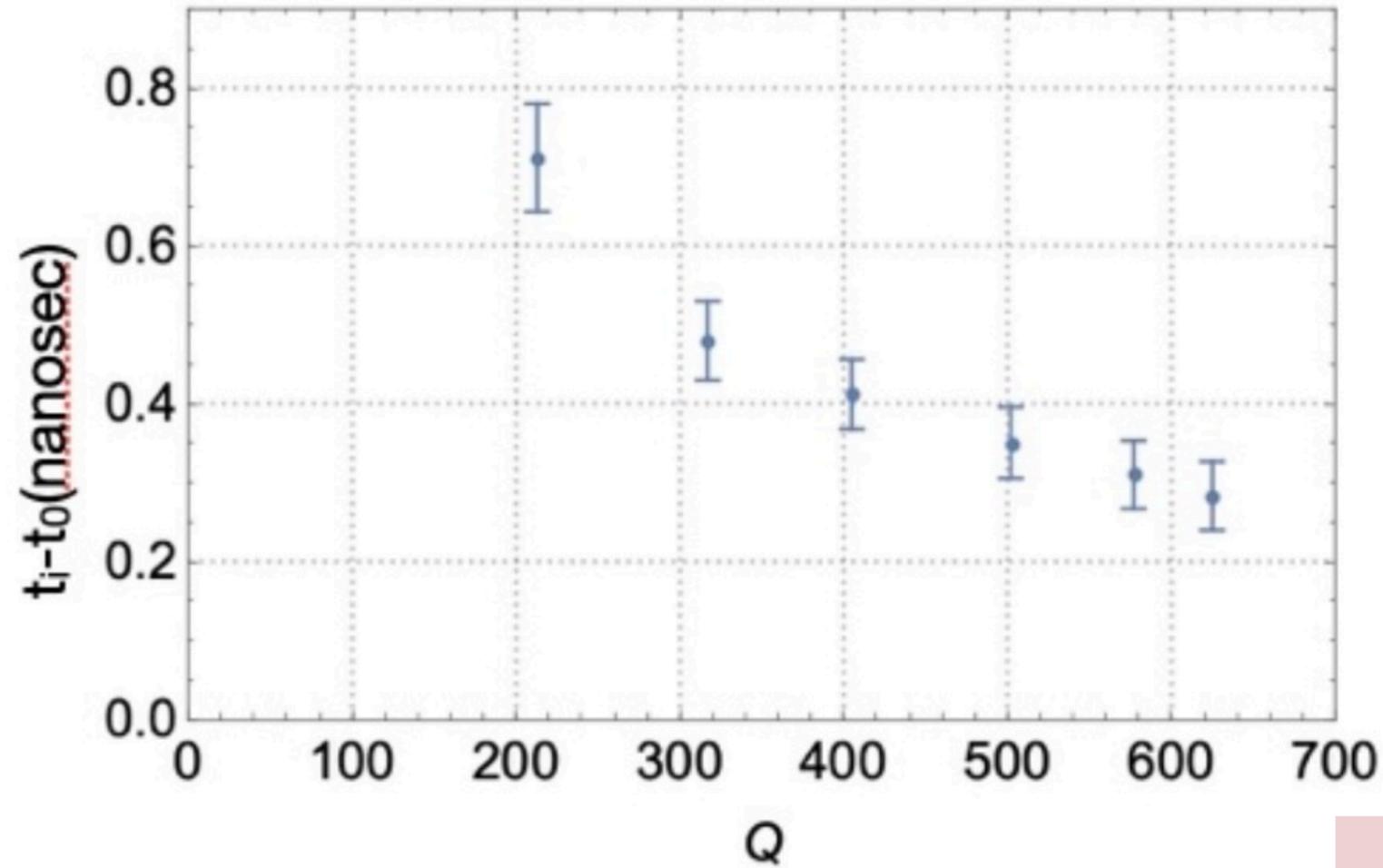
Summary of Laser measurements on 25 channels



Correlation (RH plot) reduces spread in calibration coefficients to ~13%

Does this eliminate Amplitude walk?

SiPM channel 31 Before and after AWC



Yes !

Summary and Next Steps

- **Can we eliminate “brute force” method for calibrating 330k channels of timing?**
- **We have shown examples demonstrating a “rational” solution.**
- **Simple linear dependence of Time walk = Coeff x Slope⁻¹ seems to hold.**
- **To be shown that Coeff’s accurate enough for Day-1 calibration.**
- **This advocates for inclusion of dual thresholds in future timing ASICs.**
- **September ‘25 CMS testbeam will increase sample significantly.**