Measurement of Tune Shift with Amplitude from BPM Data with a Single Kicker Pulse

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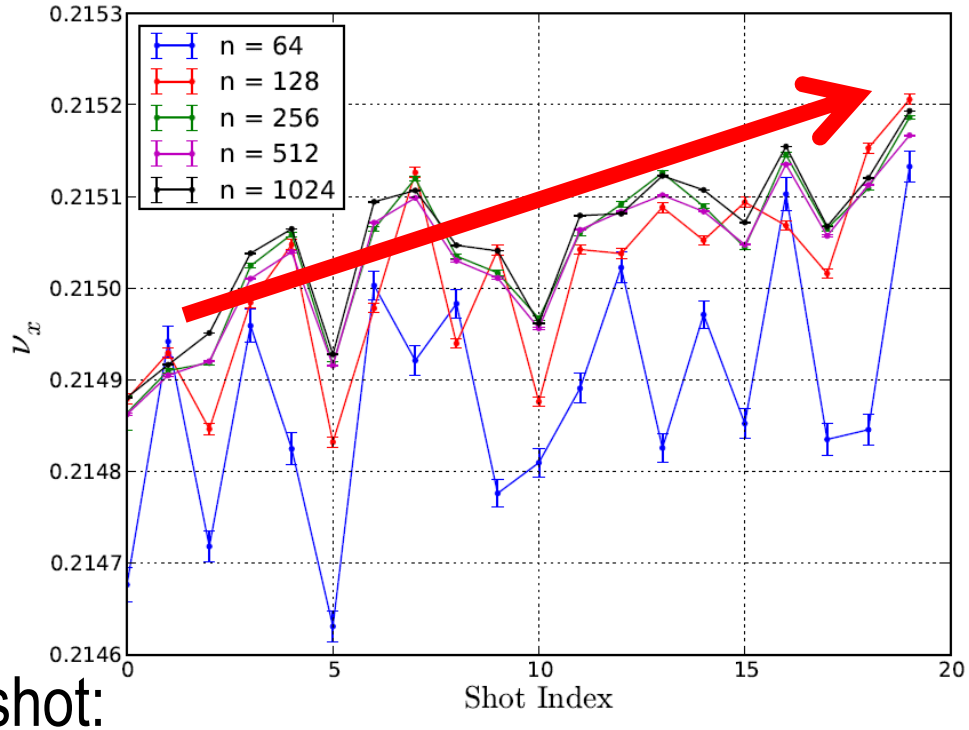
Outline

- Motivation for single-shot tune-shift-with-amplitude (TSwA) measurements
- Setups for single-shot TSwA measurements
- Unique NSLS-II BPM capability: Gated turn-by-turn BPM data that resolve groups of bunches within a turn
- Experimental results
- Other potential uses
- Conclusions and future plans

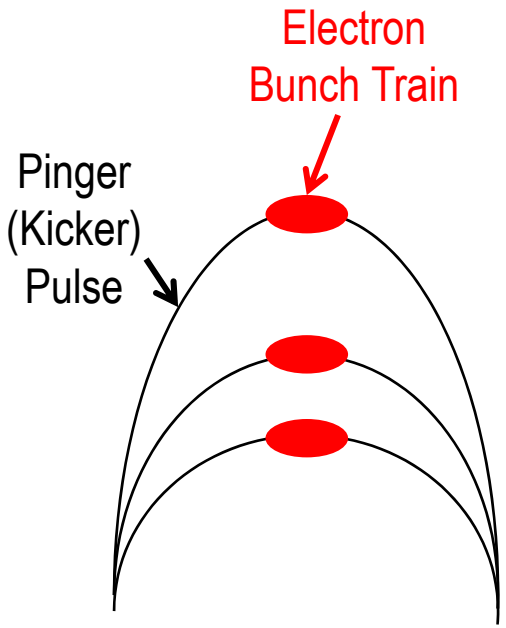
Motivation: Tune Jitter & Drift

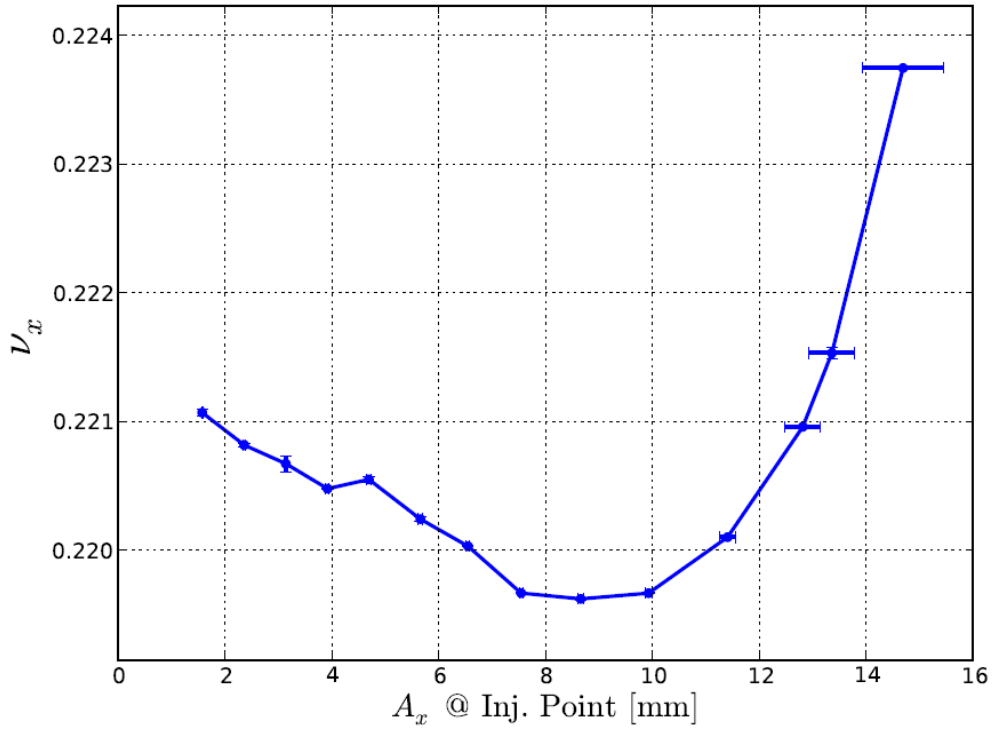
- Short-term jitter on the order of 10^{-4}
  - Acquired 20 TbT shots (~1000 turns for each shot; took 3.5 minutes for 20 shots)
  - Estimate average and RMS tune from 180 BPMs for each shot:
    - Error within a single-shot is very small (~ $0.008\ N^{-3/2}$, e.g., ~10^{-6} for N=300)
  - For >256 turns used: short-term tune fluctuation range ($\Delta\nu_x$=3×10^{-4}, $\Delta\nu_y$=1.5×10^{-4})
    - Even 10% kicker strength error should only induce <10^{-5} tune change
- Long-term upward tune drifting is also visible

$\Delta\nu_x$= 3×10^{-4}



Multi-Shot Experimental Data Corrupted or Not?





- Machine drift? Or real signature of nonlinear lattice properties?
  - Note tune error bar for each point is very small
- Not sure? Repeat measurements to be confident
- Single-shot measurement will rule out machine drift. Can we?

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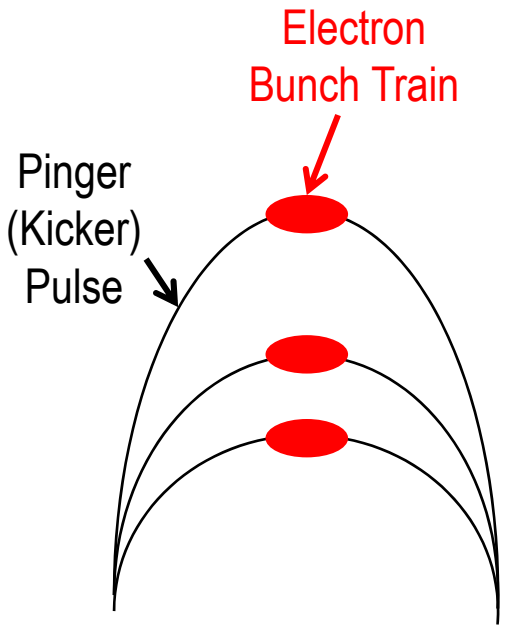

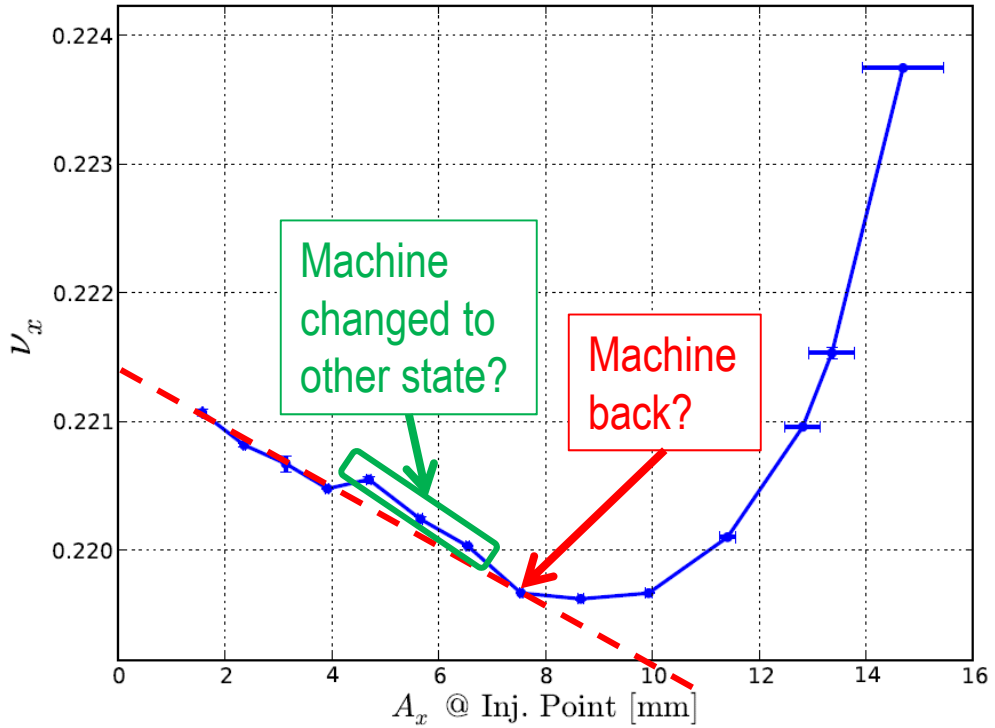

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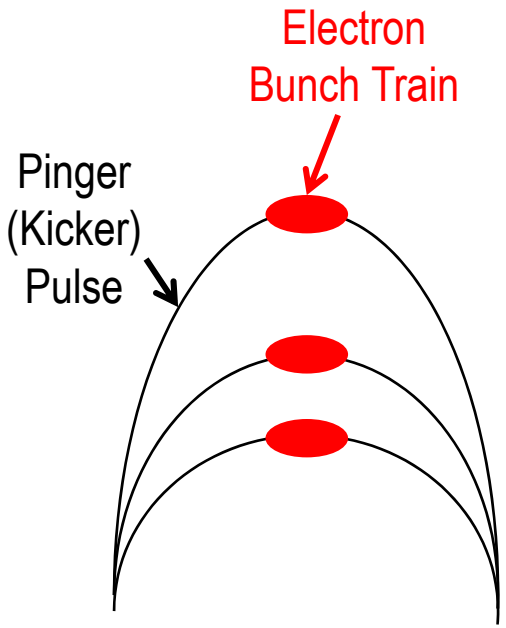

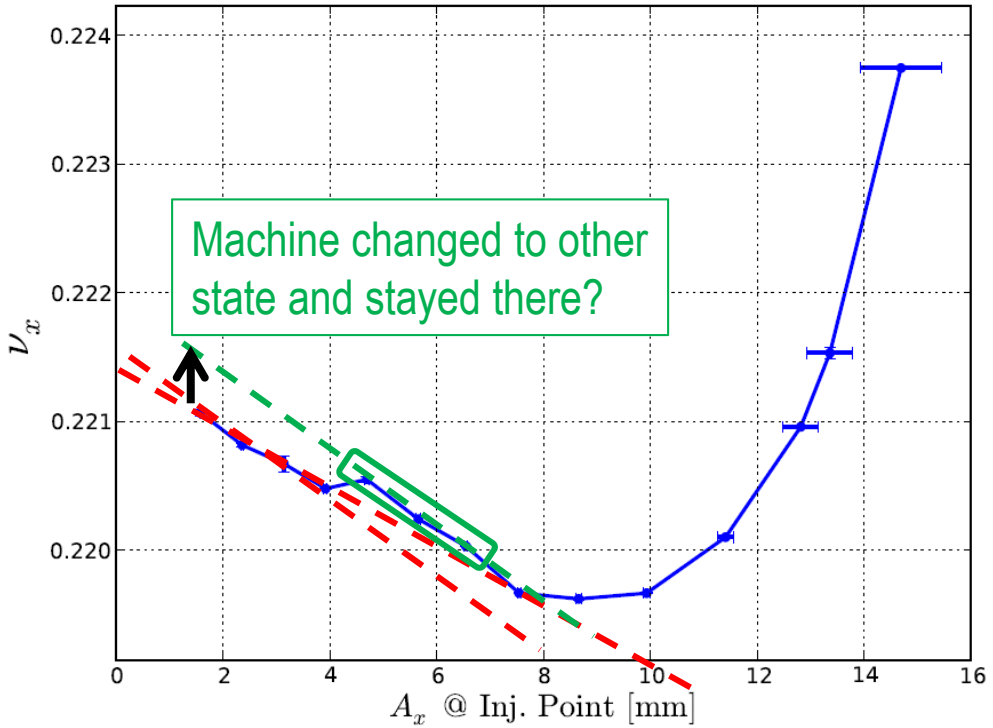

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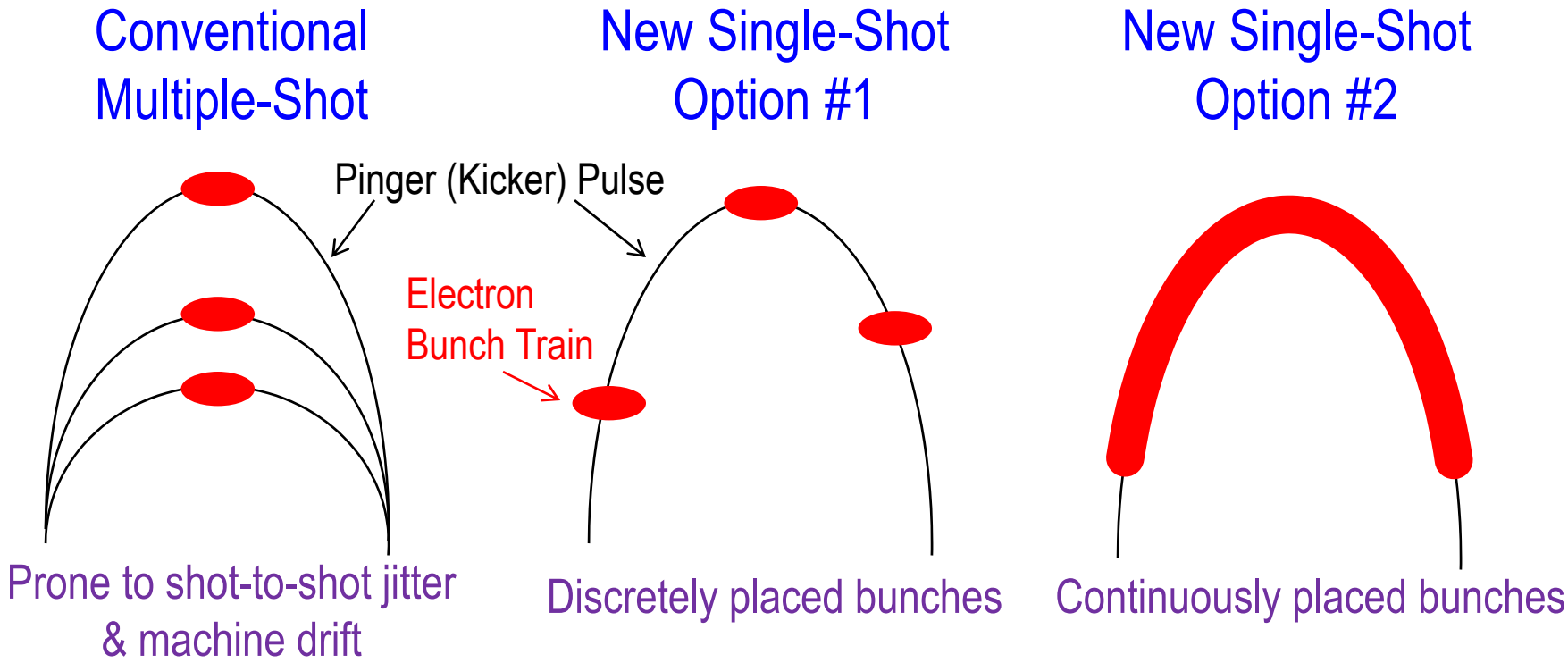
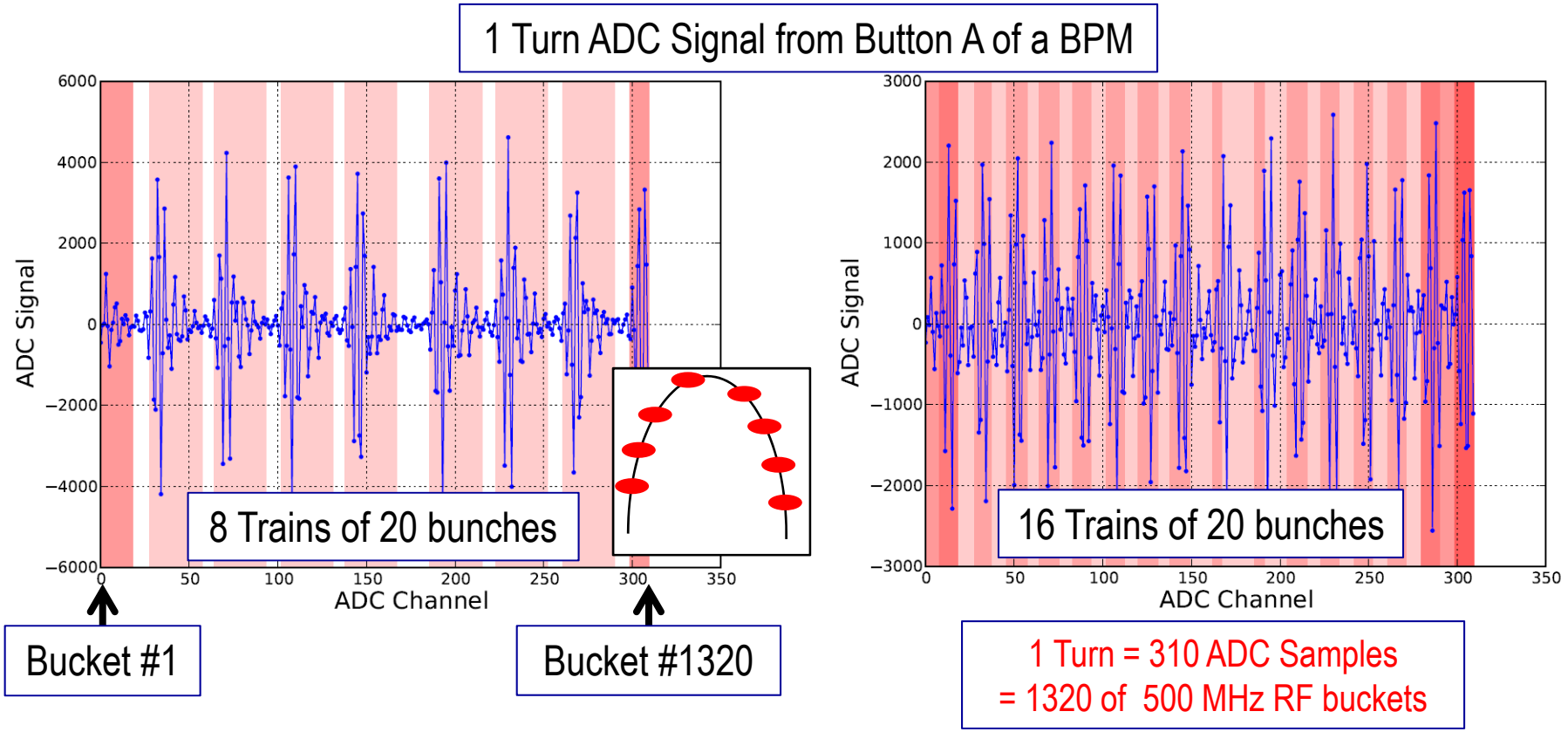
How to Measure Tune Shift with Amplitude



- Place trains of bunches in a ring with or without gaps to sample different amplitudes with a single pulse of a kicker
- Now we need to obtain TbT data for each train kicked with different amplitude
- RF BPMs at NSLS-II required to have turn-by-turn (TbT) capability only, NOT bunch-by-bunch (BxB) => We can now resolve better than TbT, though not quite BxB!

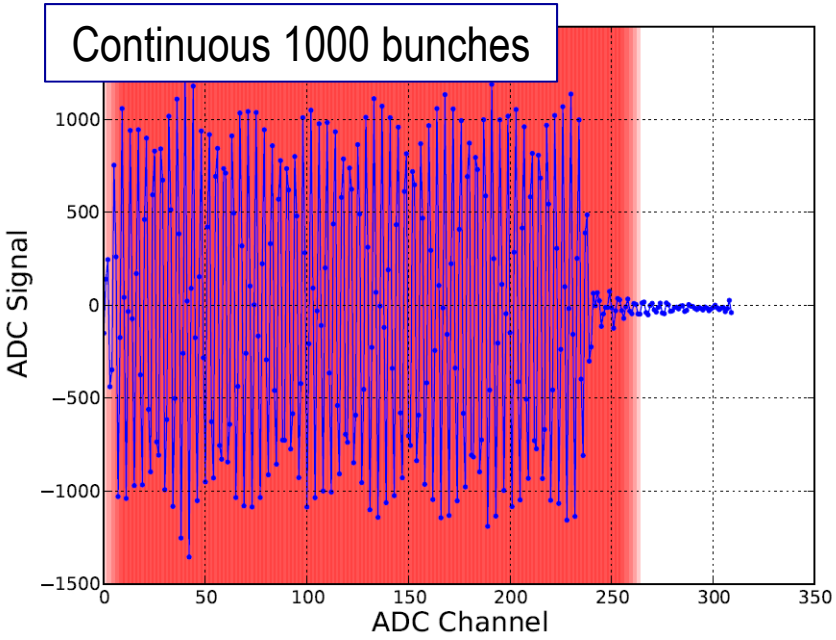
Gated Turn-by-Turn (TbT) Data: Resolving Bunches within a Turn

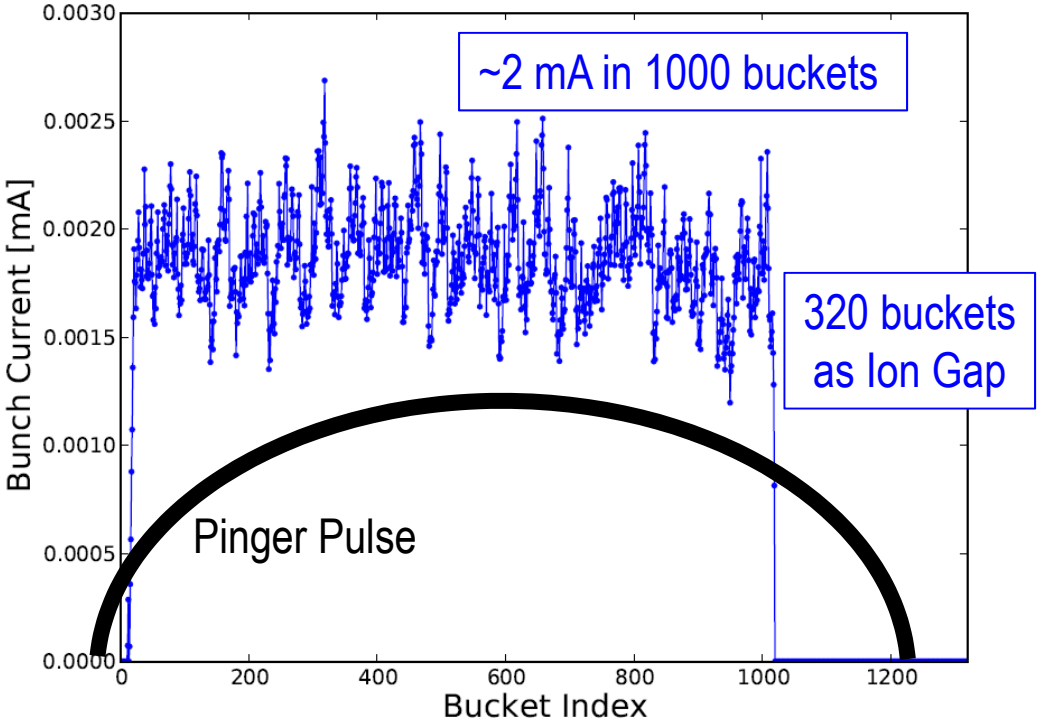


- Process all 310 ADC channels => X, Y, Σ TbT data for all bunches in the ring
- Process only a gated section of ADC channels => X, Y, Σ TbT data for the train of bunches in the gated buckets of the ring
- We can resolve up to 8 trains without overlapping of gating boxcar windows

*See B. Podobedov et al., IPAC2016 WEOBB01 and IBIC2016 proceedings for more explanation and applications on this new BPM capability

Single-Shot Measurement Setup (Continuous Train)





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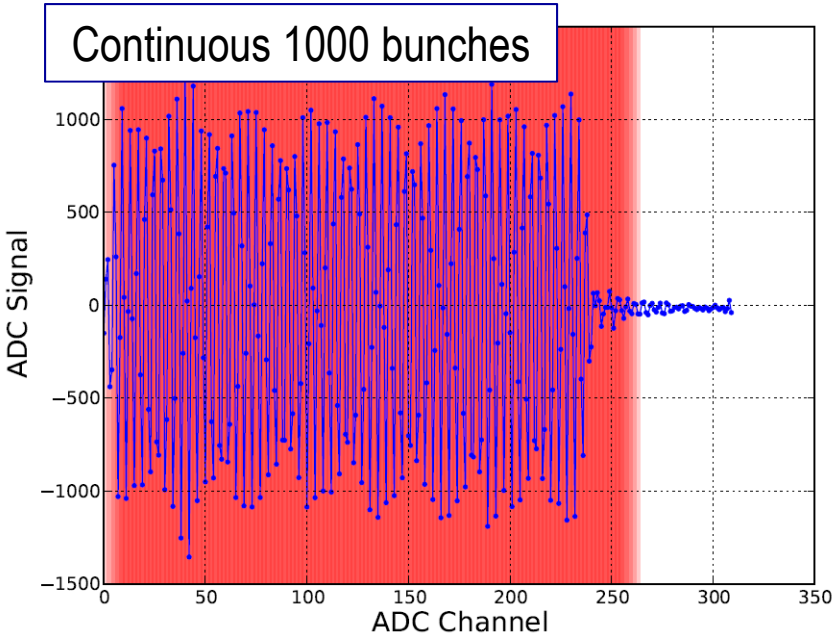

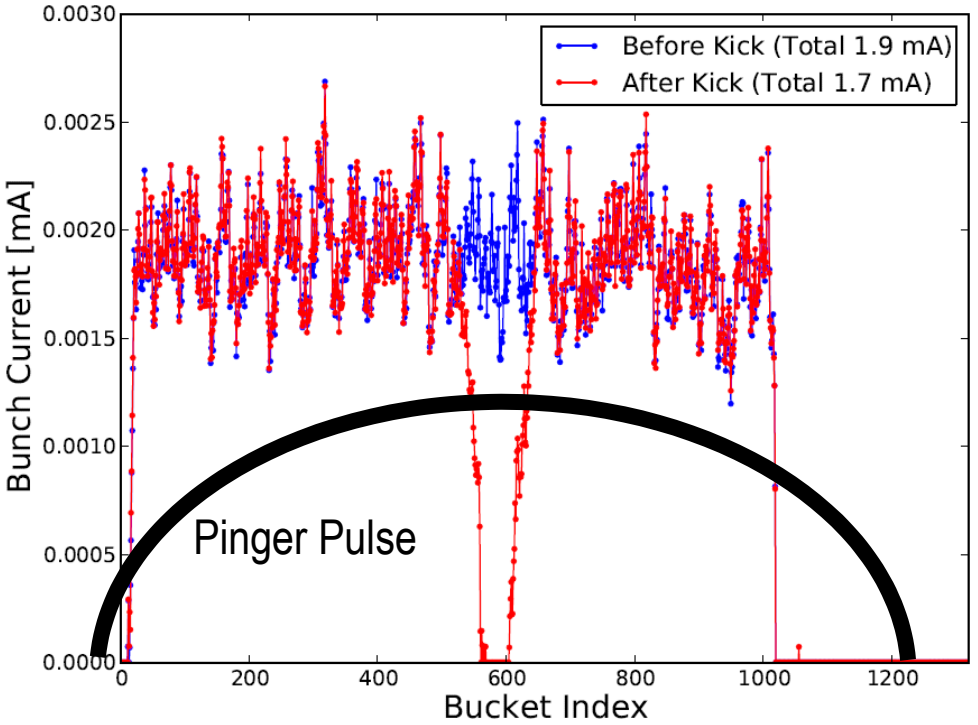

- Single-shot 1-D dynamic aperture (DA) measurement!
- Gated TbT data show different amplitudes.

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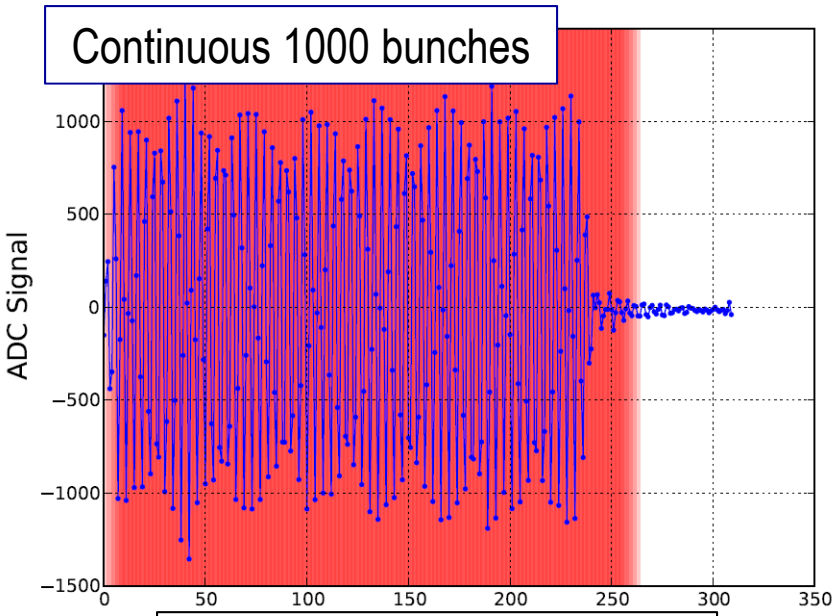

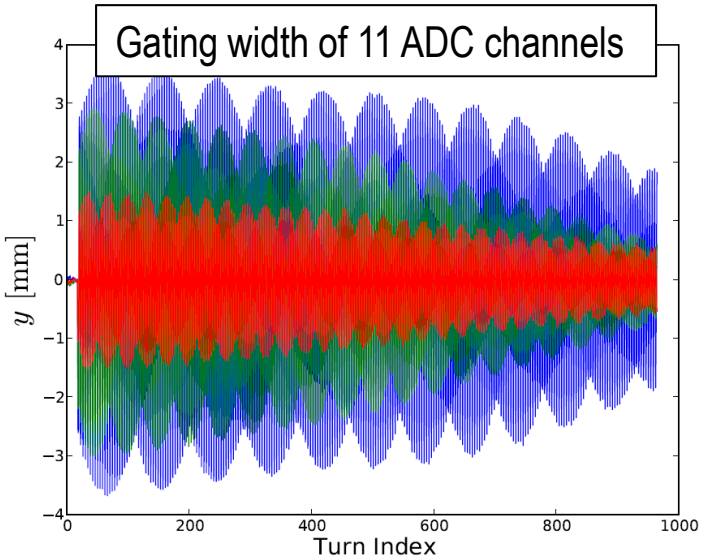

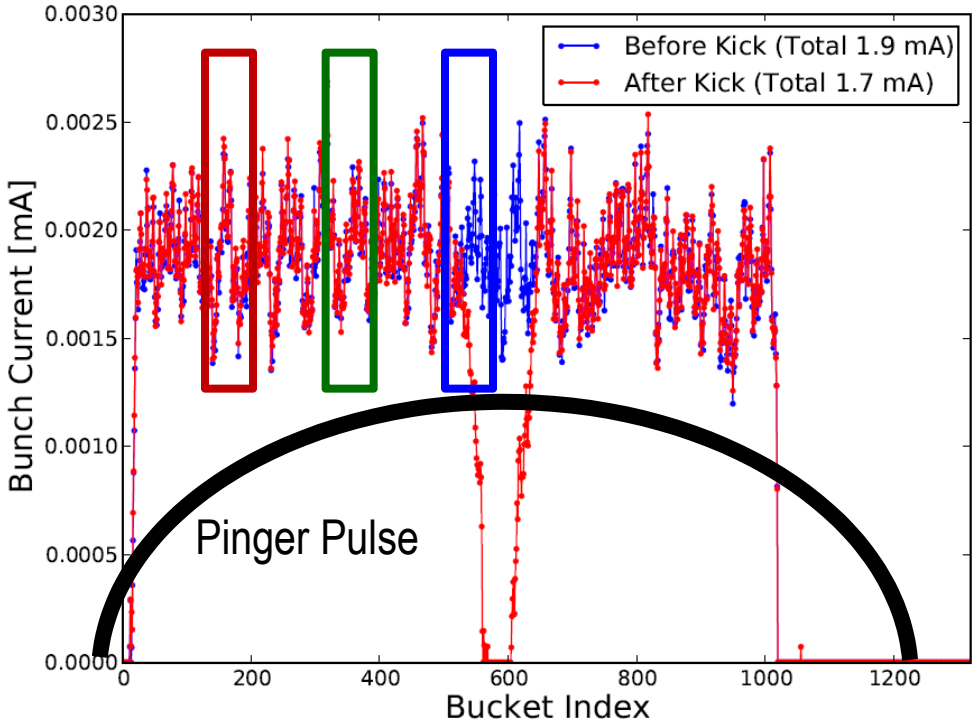

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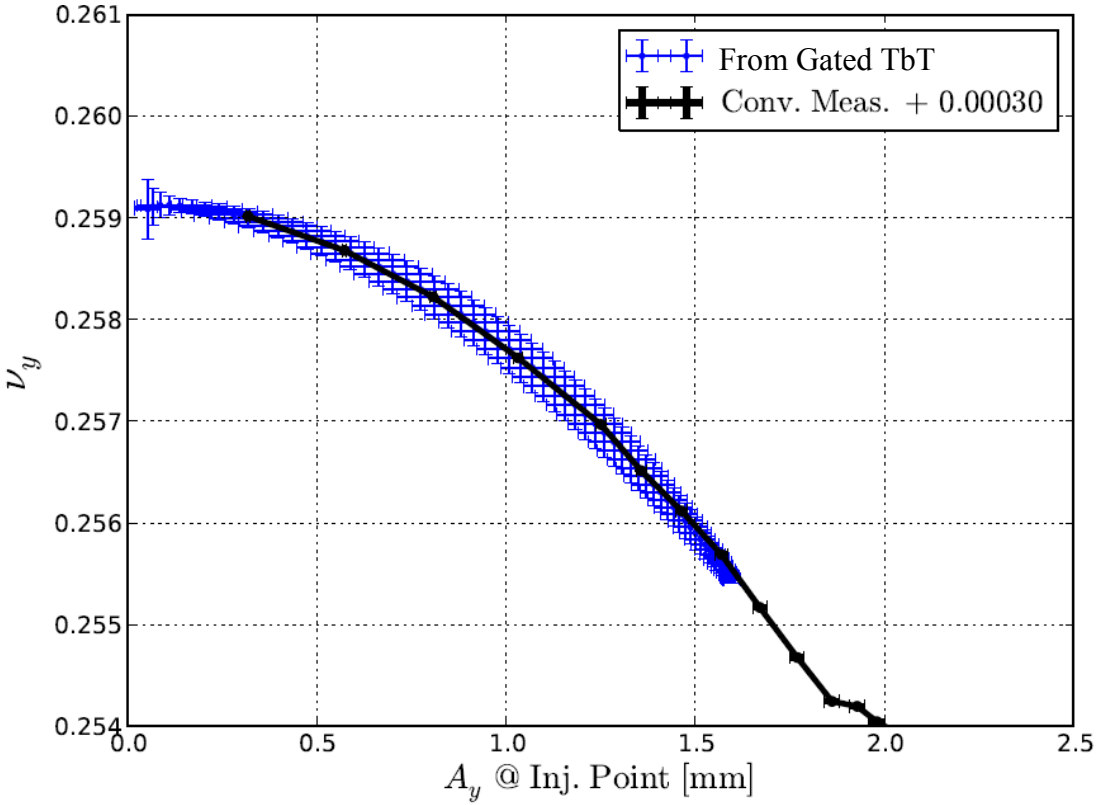
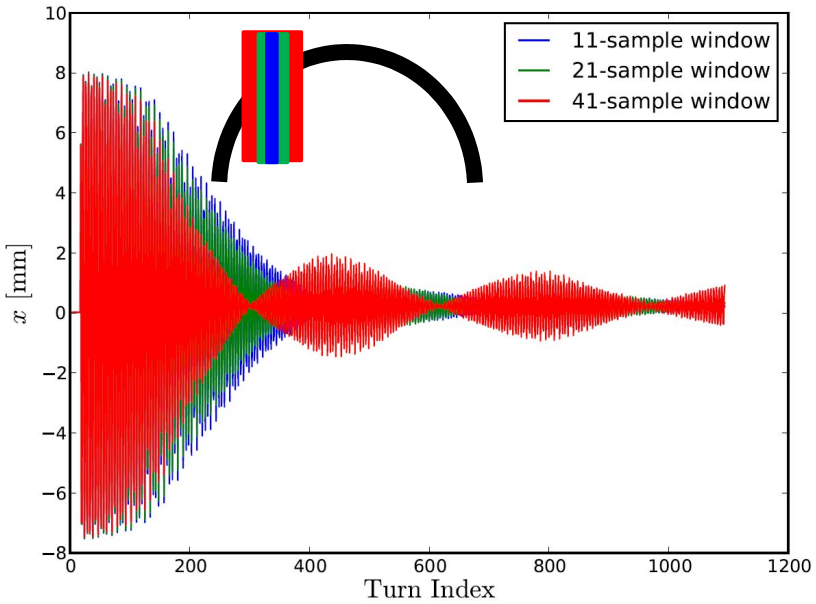
Single-Shot TSwA from Gated TbT (Cont. Train)



- Tune-shift-with-amplitude (TSwA) curve from "Gated TbT" (blue) very smooth and continuous
- "Gated" TSwA agrees well with the "conventional" multi-shot TSwA (black)
- "Gated" TSwA has much larger error bars both in tune and in amplitude, compared to "conventional" TSwA
  - Tune error from "conventional" method on the order of 10^{-6} (N=256) vs. 10^{-4} for "gated".

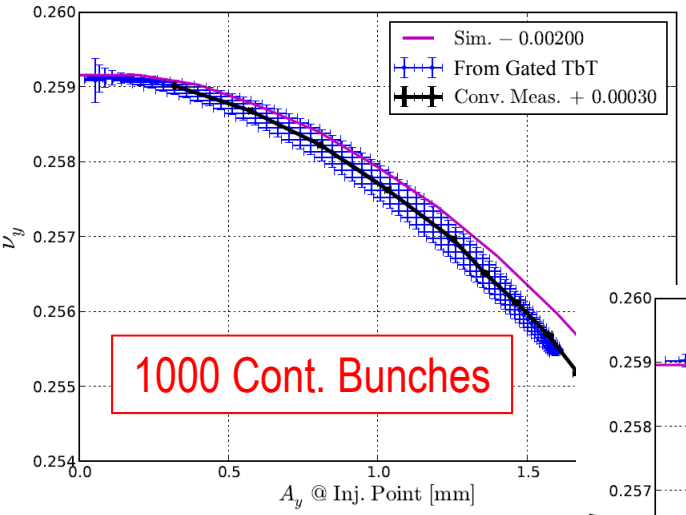
Why Large Error Bars?

- Signal leakage from adjacent bunches (kicked w/ different amplitudes) suspected to be corrupting position estimates => large error bars for tune and amplitude
  - Error bars shrink near the pinger pulse top

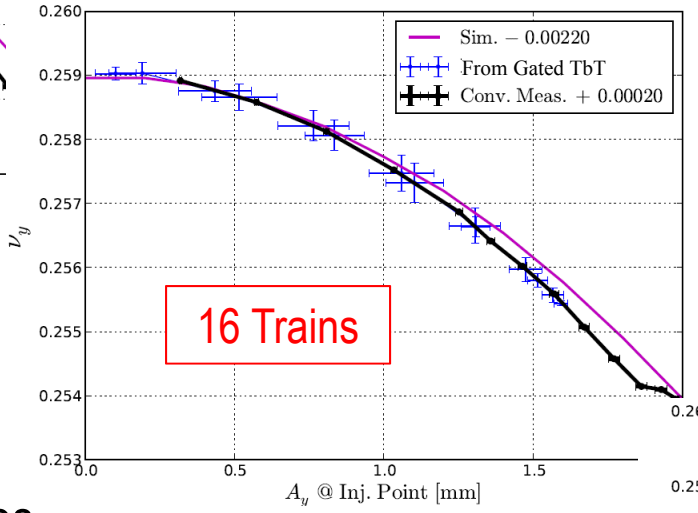


- Gated TbT signal decoheres faster if ADC window is widened due to signal leakage from adjacent bunches kicked w/ different amplitudes

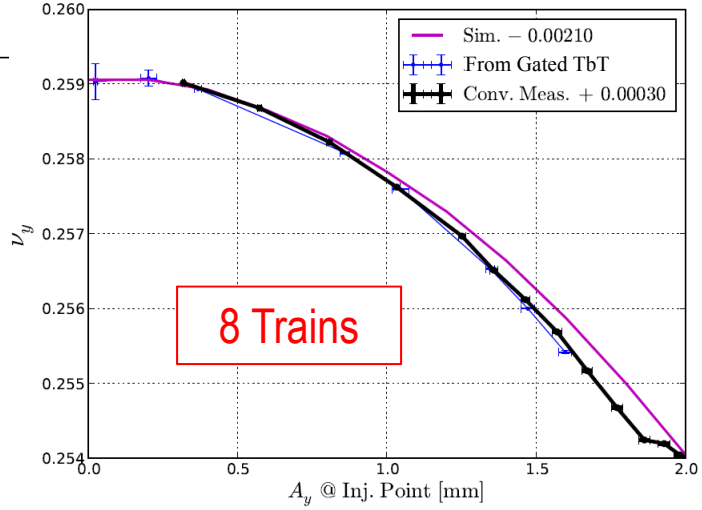
Solution #1: Give Bunches More Space



- Measured vertical TSwA fairly close to simulated TSwA (from TRACY particle tracking)!



Each train consists of 20 continuous bunches



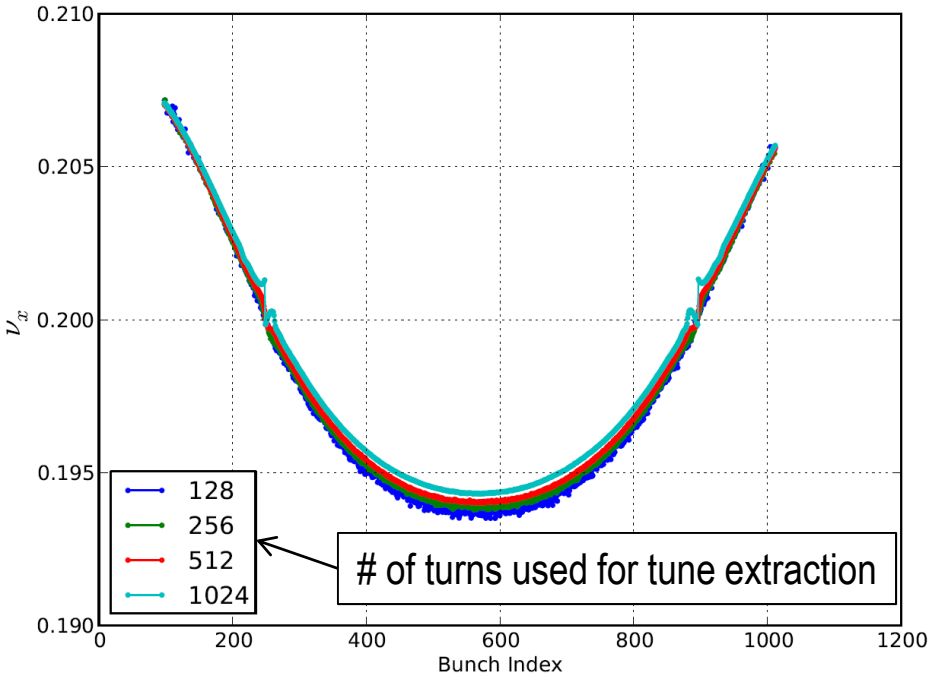
- 1000 Continuous Bunches
  - Large error bars for both tune and amplitude
- 16 Trains
  - Large error bars comparable to 1000-bunch case
- 8 Trains
  - Small error bars comparable to conventional measurement

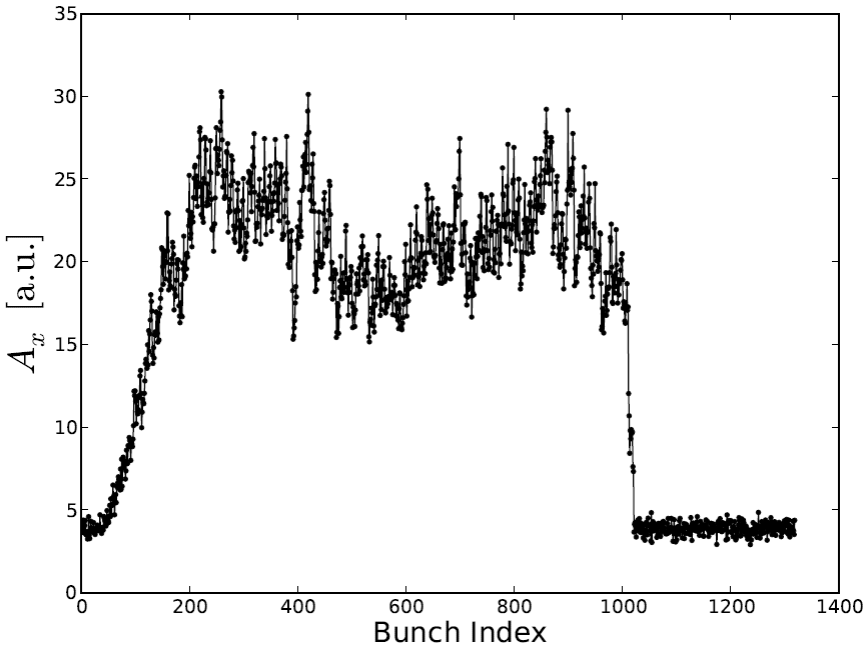
Solution #2: Use BxB Feedback System

- NSLS-II uses a commercial bunch-by-bunch (BxB) feedback system
  - Feedback function is NOT used for this study, but the system is used as a diagnostic to extract BxB TbT data

- BxB Pros:
  - Can provide true bunch-by-bunch position information
  - Tune measurement precision on the order of 10^{-5}
- BxB Cons:
  - Only single BPM available:
    - cannot utilize power of statistics to get averaged value or estimate error bar
    - No *s*-dependent information (e.g., beta function around the ring), though irrelevant for single-shot TSwA measurements
  - Lower BPM positional resolution (due to higher BW)
  - Need calibration to estimate absolute oscillation amplitude

Tune & Amplitude from BxB TbT





- Obtained very smooth and symmetric (due to symmetric pinger pulse shape) tune shift curve vs. bunch index
- Obtained amplitude vs. bunch index, however, does not resemble pulse shape
  - BxB alone cannot estimate absolute amplitude at the moment
    - position information is intermingled with sum information
    - potentially nonlinear response for large amplitude
  - Use amplitude estimated from gated TbT data

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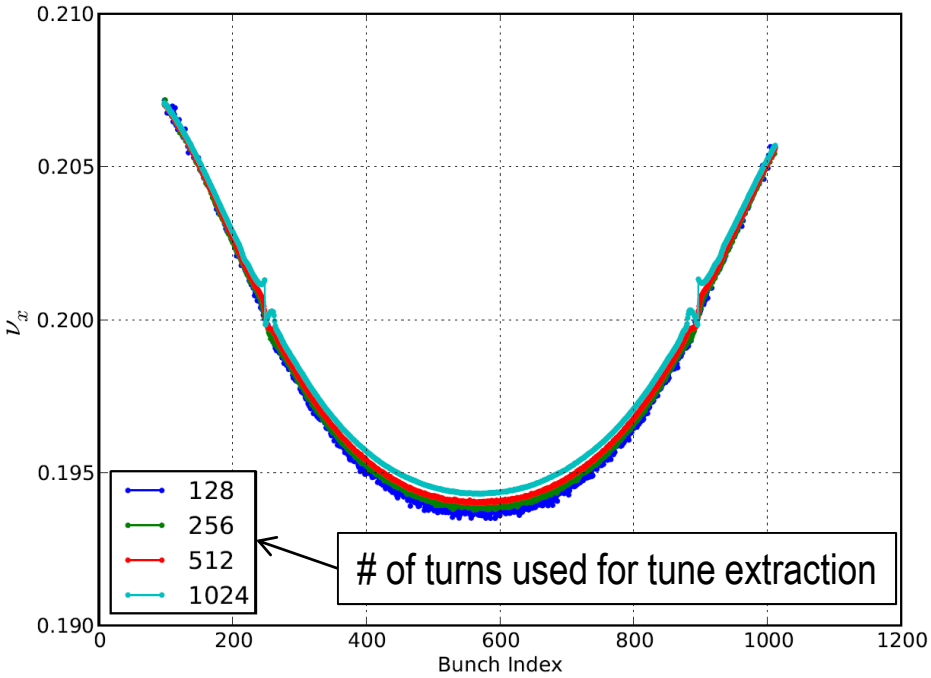

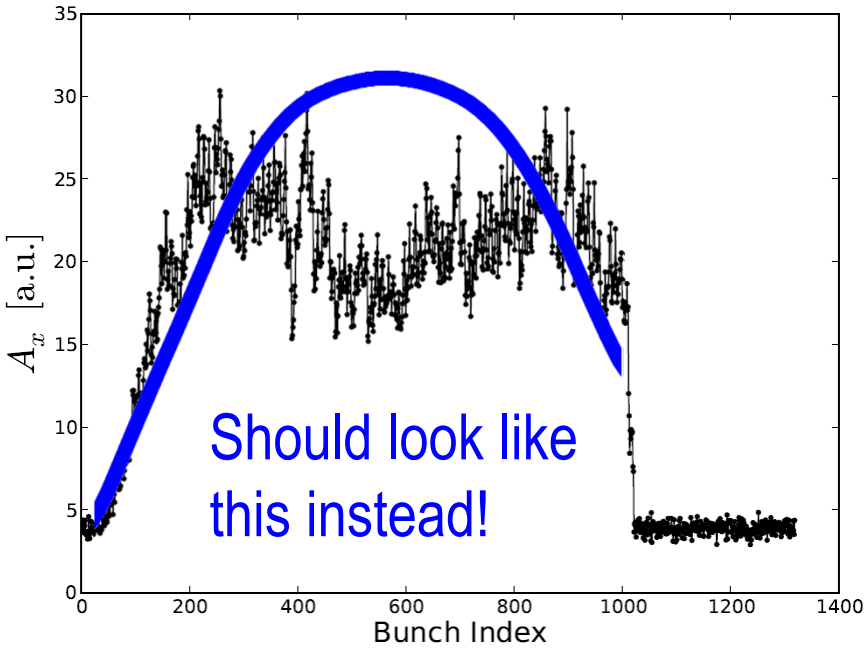

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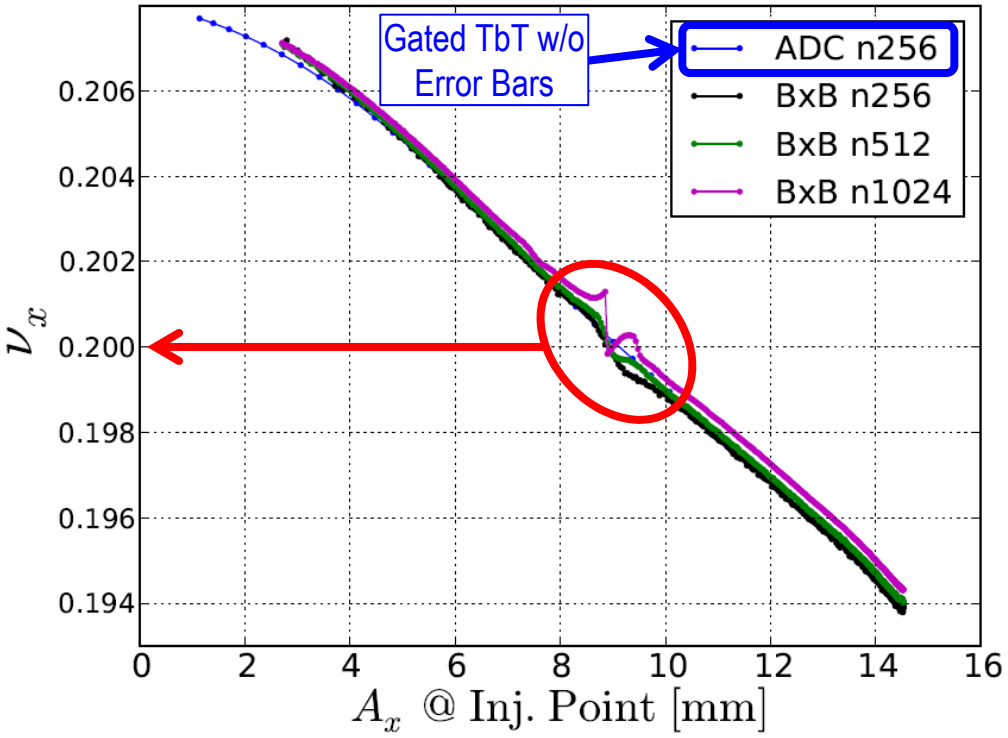
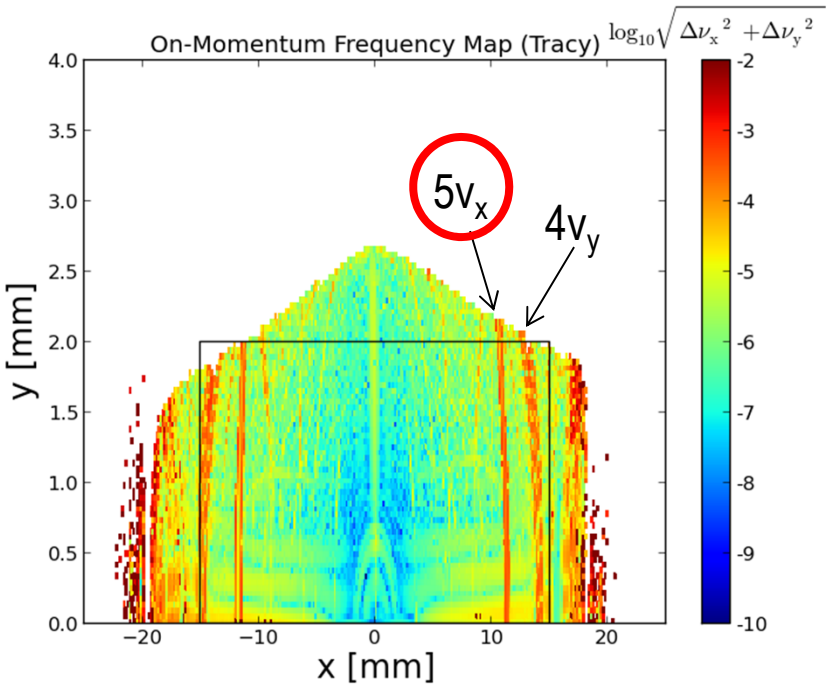
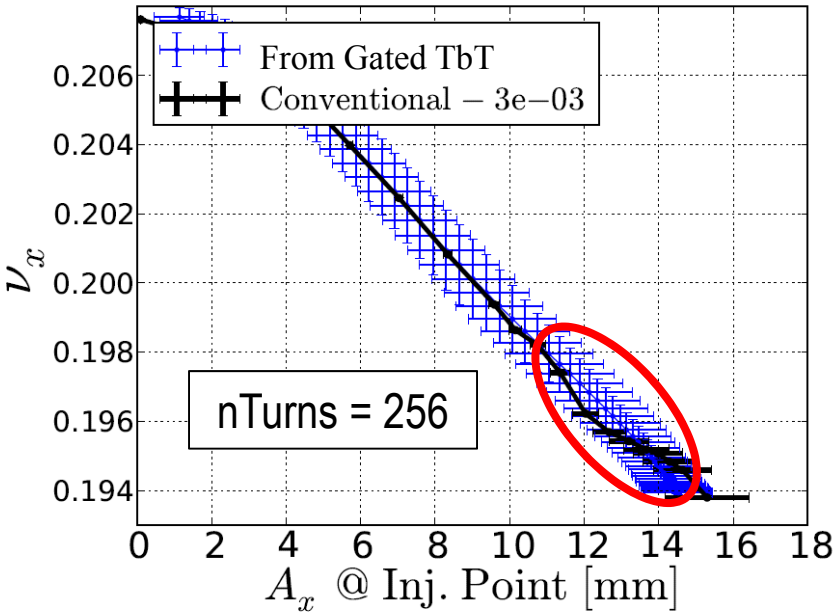
Combining Gated TbT & BxB TbT

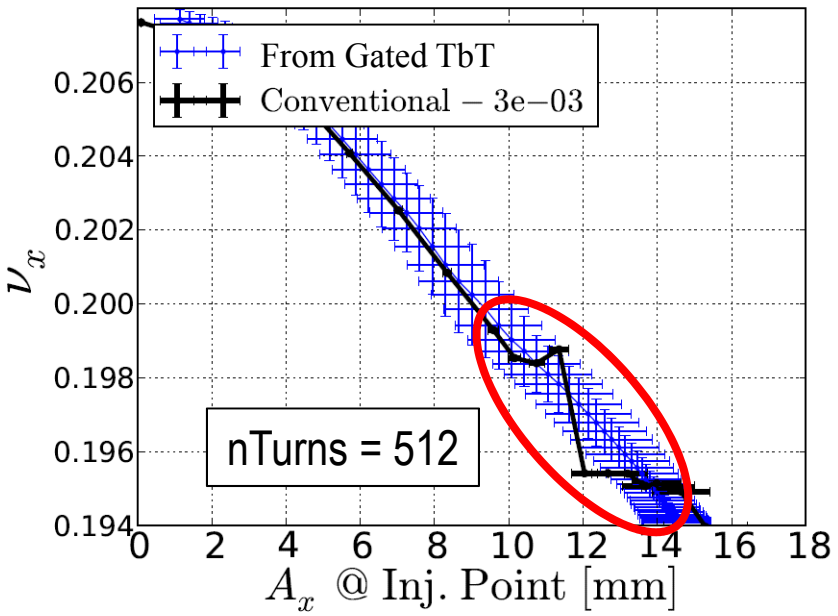




- "BxB" TSwA curve and "Gated" TSwA curve agree well
  - "Gated" TSwA has large error bars, but mean curve (avg. over BPMs) agrees well w/ "BxB" TSwA
- Distortion around ν_x = 0.2 ($5\,\nu_x$ resonance) from BxB (more pronounced with more number of turns used for tune extraction)
  - No distortion seen in "Gated" TSwA curve probably due to adjacent-bunch signal smearing
- Simulated frequency map analysis (w/ engineering tolerance) predicted this resonance!

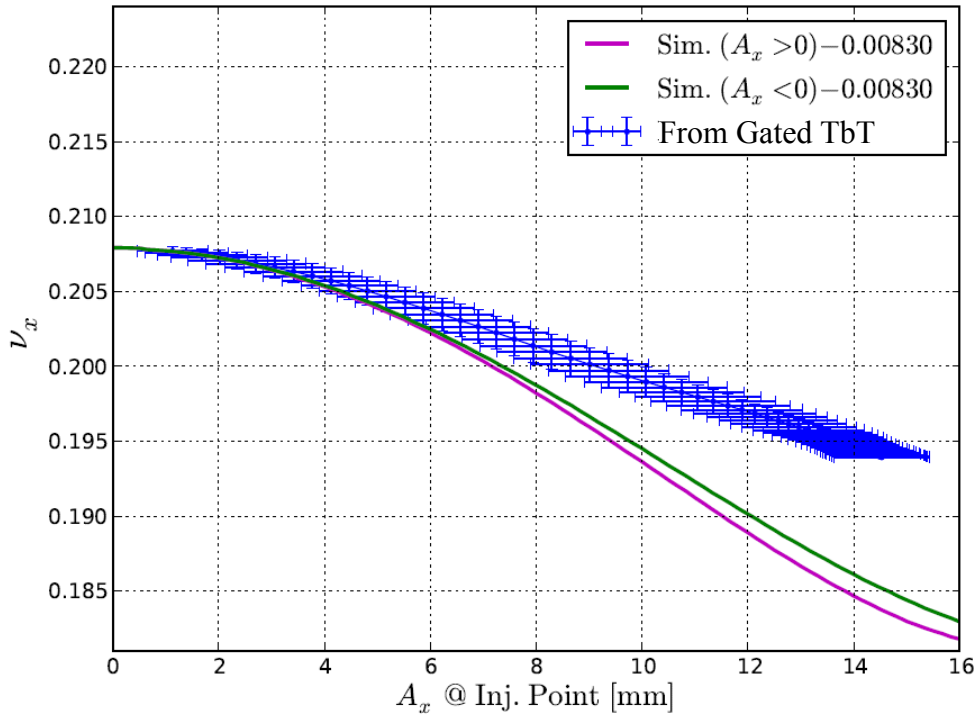
Advantage over Multi-Shot Technique





- Conventional multiple-shot TSwA also shows this resonance.
- We would have wondered whether this distortion is due to machine drift or not… but we now know for sure it's resonance due to single-shot BxB TSwA measurement!
- What we do not know for sure yet is…

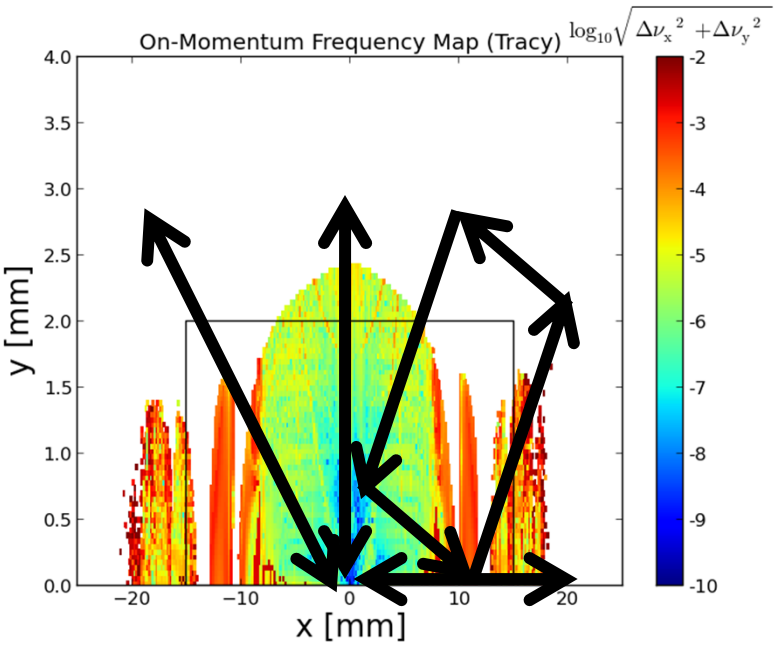
Horizontal TSwA: Experiment vs. Simulation

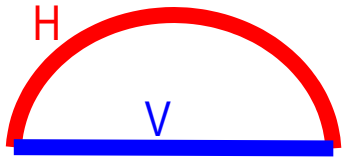


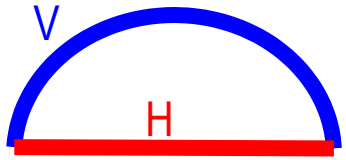
- Why the experimental curve for horizontal tune shift with amplitude is far from the simulated curves?

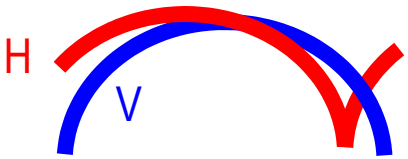
Other Potential Uses

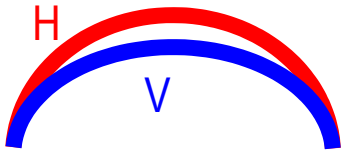
- Single-shot multi-amplitude phase space plot
- Simultaneous *s*-dependent linear and nonlinear lattice characterization
- Hi-resolution 1-D TSwA & Dynamic Aperture (DA) measurement
  - Less likely to miss dead zones and probe beyond first dead zone
- Faster frequency map & 2-D dynamic aperture (DA) measurement
  - Single-shot TSwA curve gives one radial line
- Semi-2D frequency map or DA measurement by shifting relative timing between horizontal & vertical pinger pulses











Conclusions and Future Plans

- Single-shot measurements of tune shift with amplitude (TSwA) have been demonstrated experimentally using “gated” TbT (recently added capability of NSLS-II RF BPMs) alone or combined with bunch-by-bunch (BxB) TbT from BxB feedback system.
- The single-shot method eliminates the possibility of machine drift / jitter corrupting tune shift measurements.
- Accuracy of this “gated” TbT technique is limited by timing alignment of different BPMs. This will be further investigated for improvement.
- Calibration of pinger vs. kick amplitude will be performed so that BxB TbT alone can produce TSwA curves.
- With this reliable new TSwA measurement technique, we are ready to characterize nonlinear lattice properties and determine the sources of observed discrepancies between simulation and experiment.

Acknowledgments

- We would like to thank all the colleagues at NSLS-II who helped us enable Gated BPM capability. Special thanks go to **Kiman Ha**, **Joe Mead**, **Om Singh**, and **Kurt Vetter** (now at ORNL) for their crucial contributions.
- We would like to also thank Dmitry Teytelman (Dimtel Inc.) for his assistance on BxB feedback system.