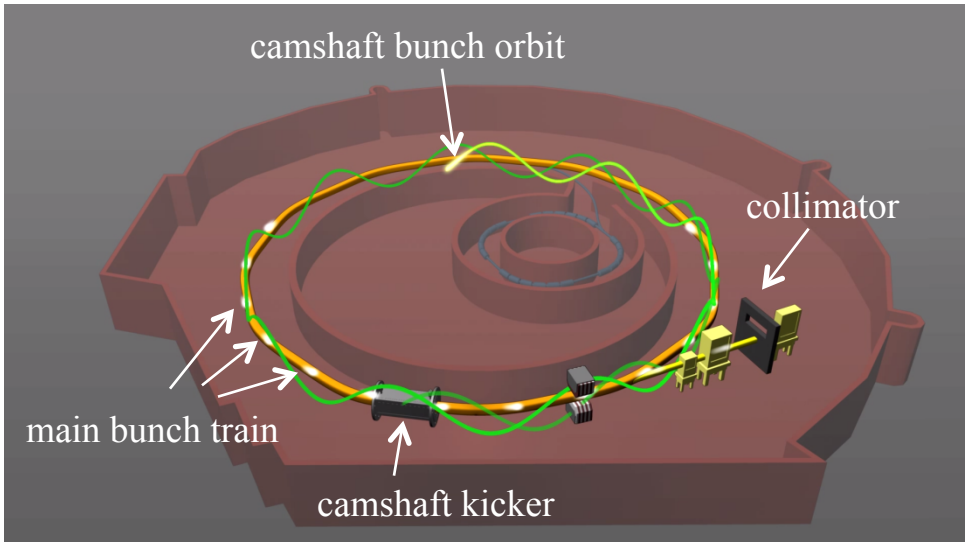
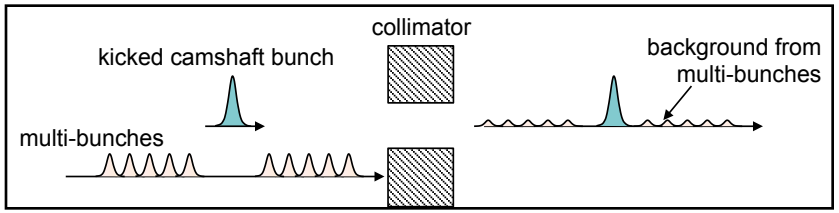
Pseudo-single-bunch operation with adjustable frequency

X-rays only when you want them

David Robin

Lawrence Berkeley Laboratory





Drastically improves signal-to-noise and reduces dose induced sample damage for laser pump-probe and time-of-flight experiments

Collaborators and information

Accelerator scientists and engineers

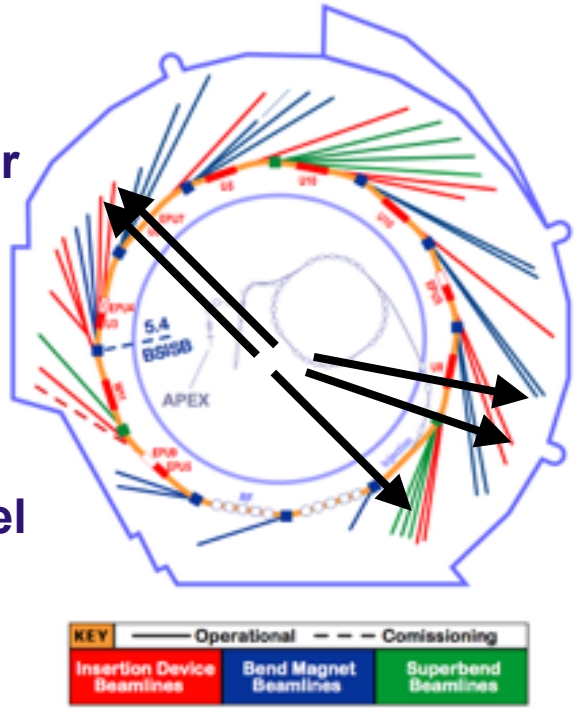
C. Sun, G. Portmann, S. Kwiatkowski, C. Steier and D. Robin

Beamline scientists

BL 6.0.1/6.0.2: M. Hertlein, A. Scholl, and T. E. Glover
BL 10.3.2: M. Marcus
BL 11.0.2: T. Tyliszczak
BL 12.3.2: M. Kunz

Applications

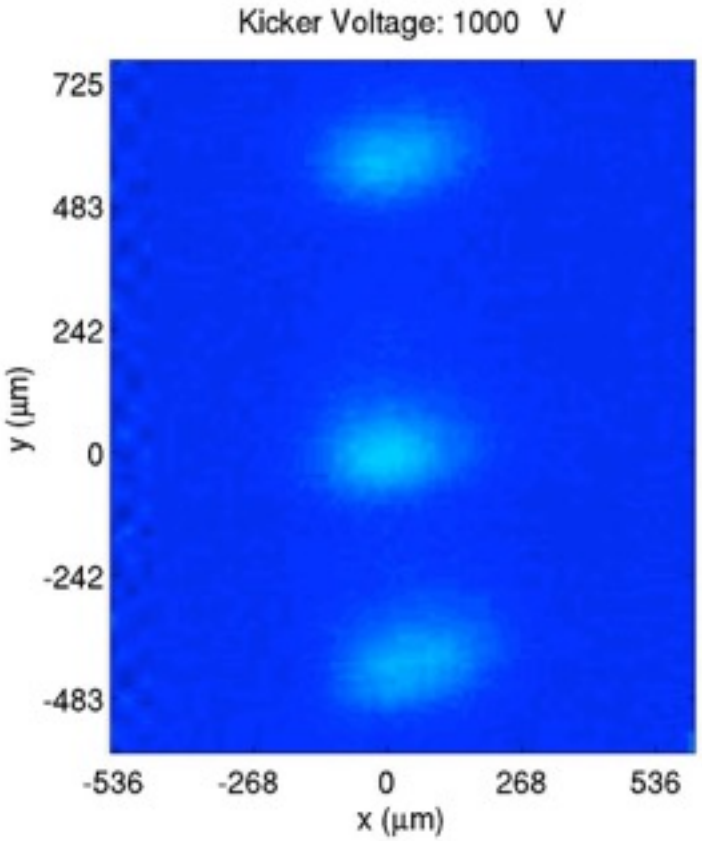
BL 6.0.2 Spin Crossover: A. Cordones and J.H. Lee
BL 6.0.2 Streak Camera: K. Engelhorn and B. Barbrel



Publications

1. Phys. Rev. Lett. 109, 264801 (2012)
2. Synch Rad. News. Vol. 26. No. 3 (2013)
3. *X-rays only when you want them: Optimized pump-probe experiments using pseudo-single-bunch operation*, to be published in Journal of Synchrotron Radiation

Outline

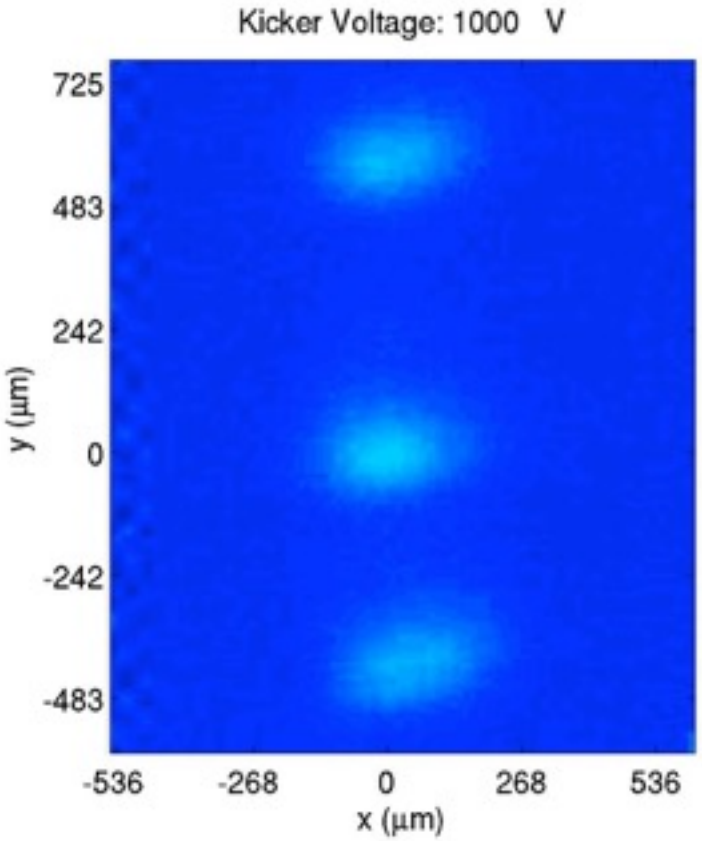


Motivation

What is Pseudo-single bunch (PSB)

Characterizing PSB at the ALS

Outline



Motivation

What is Pseudo-single bunch (PSB)

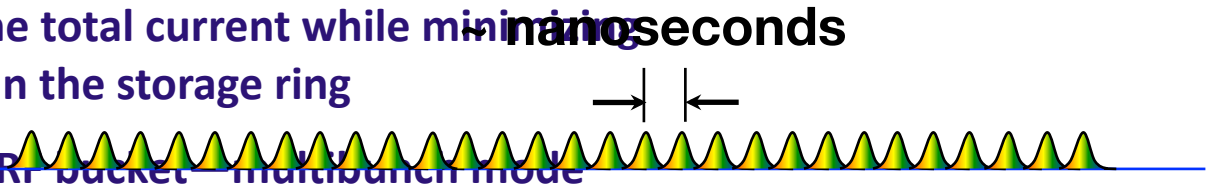
Characterizing PSB at the ALS

Two classes of beam experiments with conflicting requirements

High brightness/high flux experiments

Multi-bunch fill with large average current

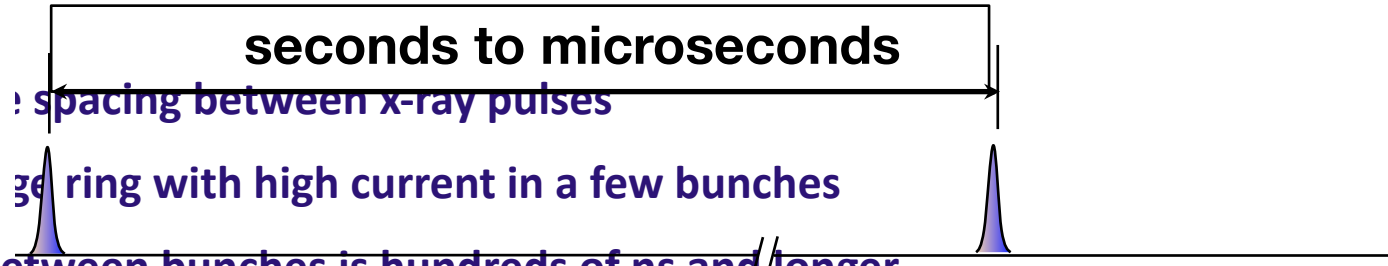
ze the total current while mini
nch in the storage ring
t of RF bucket – multibunch mode



The time spacing between each bunch is ~ns

Laser-pump x-ray probe and time-of-flight experiments

Few bunch fill with small average current

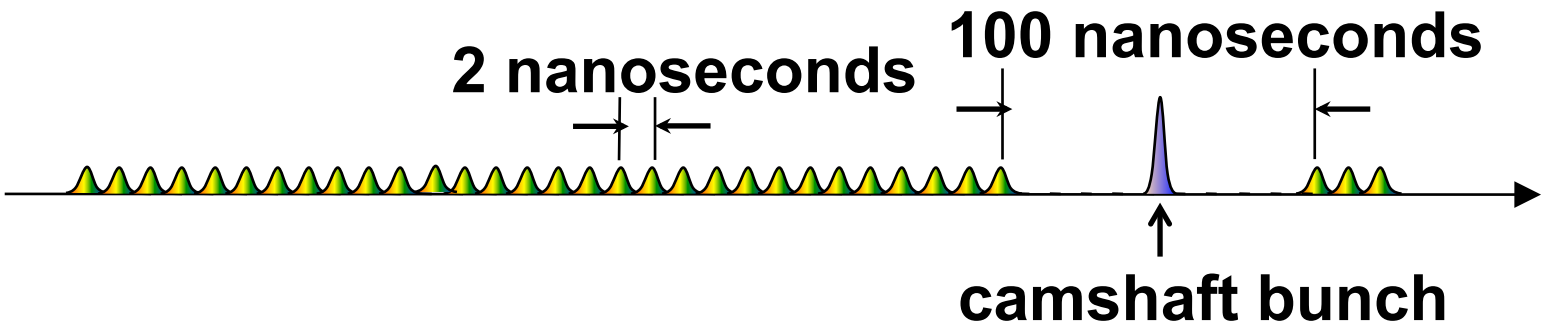


e spacing between x-ray pulses
ge ring with high current in a few bunches
The time spacing between bunches is hundreds of ns and longer

How can we satisfy both of these requirements simultaneously?

Start with a standard high-current multi-bunch camshaft mode

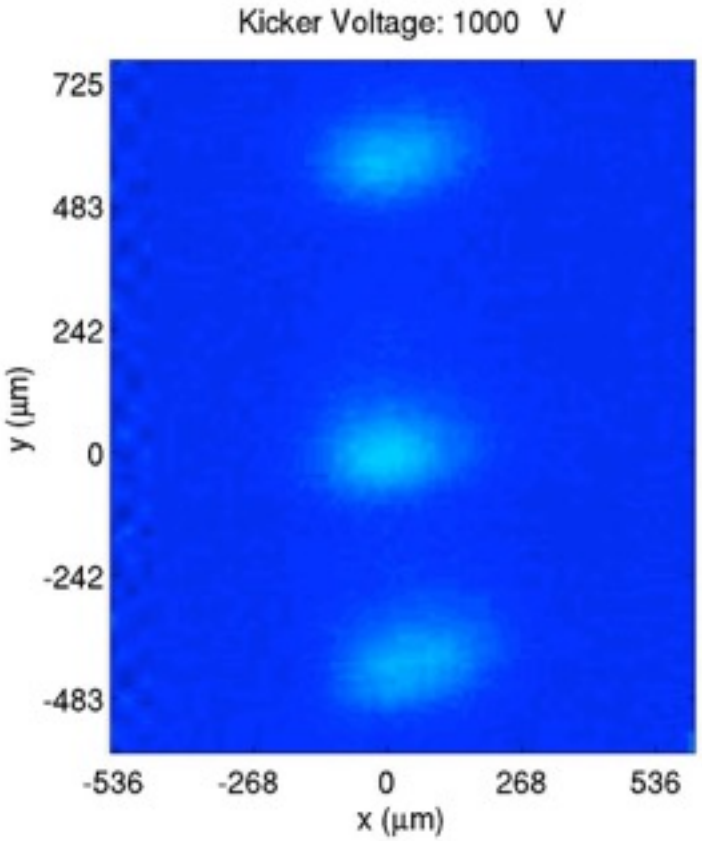
Multi-bunch with single camshaft bunch



How can one isolate the pulse from a single bunch?

Methods of isolating single pulses

Outline



Motivation

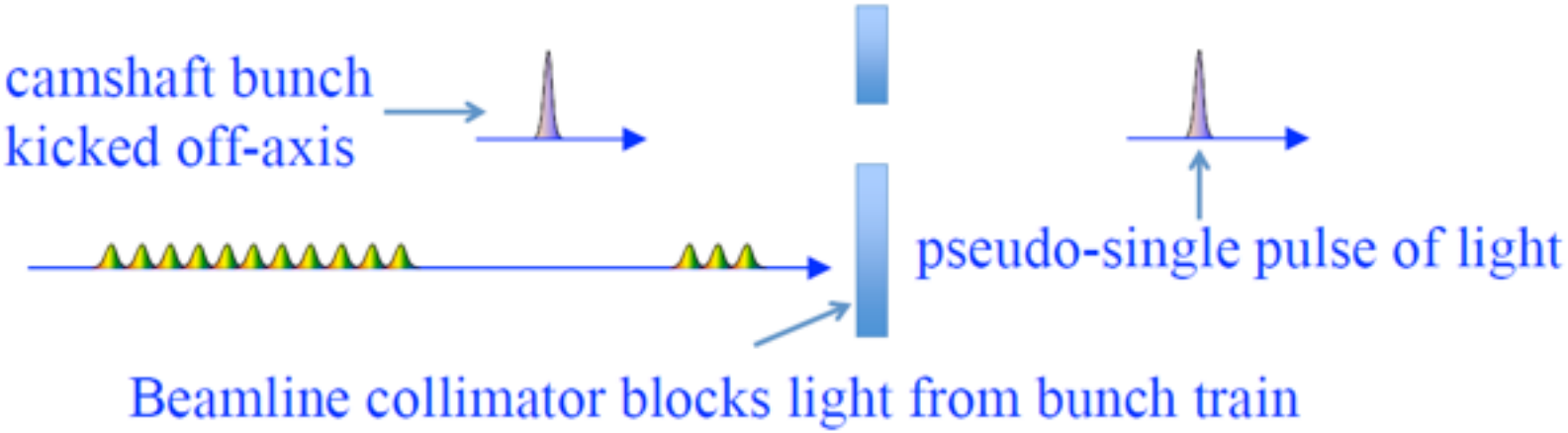
What is Pseudo-single bunch (PSB)

Characterizing PSB at the ALS

Pseudo Single Bunch Operation

What: An operational mode that enhances user capability for dynamics experiments during multi-bunch mode

Goal: Allow users to receive ***single x-ray pulses*** with ***adjustable repetition rate*** *from single shot up* to MHz ***while maintaining full beam for other beamlines***



Two modes for pseudo-single bunch operation

1. Original Pseudo single bunch operation mode provided a permanent orbit displacement and fixed frequency.

2. Newer Kick And Cancel (KAC) mode* allows beam-line users to receive a single pulse of x-rays with adjustable frequency from single-shot to 500 kHz, while maintaining full beam for other beamlines.

How: Adjusting ring tune and camshaft kicker frequency, we perturb the physical orbit of a bunch, and then bring it back within a few orbits

This is illustrated in the following animation.

http://als.lbl.gov/als_physics/csun/ALS_PseudoSingleBunch.mov

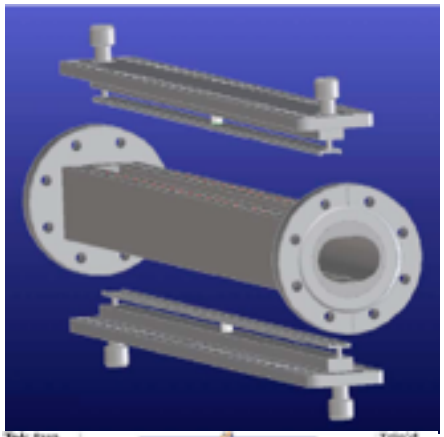
*Idea based on L. Blumberg, "VUV Wobbler", Brookhaven National Laboratory Memorandum, May 29, 1980

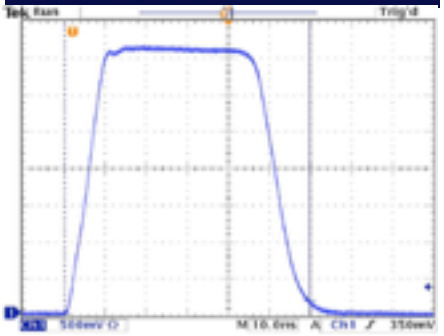
Camshaft kicker

Proceedings of EPAC 2006, Edinburgh, Scotland THPLS114

"CAMSHAFT" BUNCH KICKER DESIGN FOR THE ALS STORAGE RING*

S.Kwiatkowski, K. Baptiste, W. Barry, J. Julian, R. Low, D. Plate, G. Portman, D.Robin
LBNL, Berkeley, CA, 94720, USA

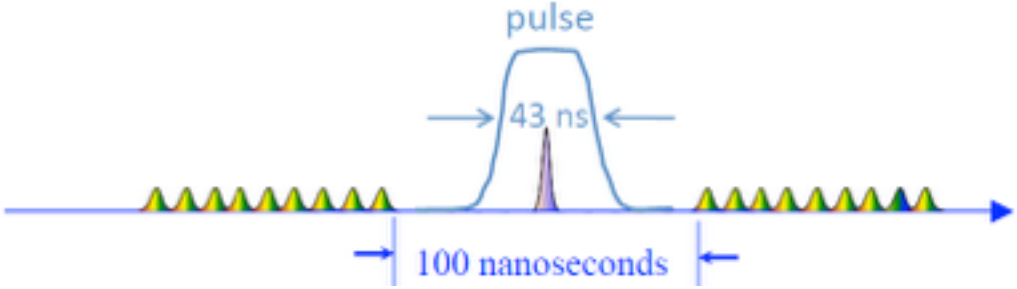




It is a stripline kicker

High repetition rate up to turn by turn (~1.5 MHz)

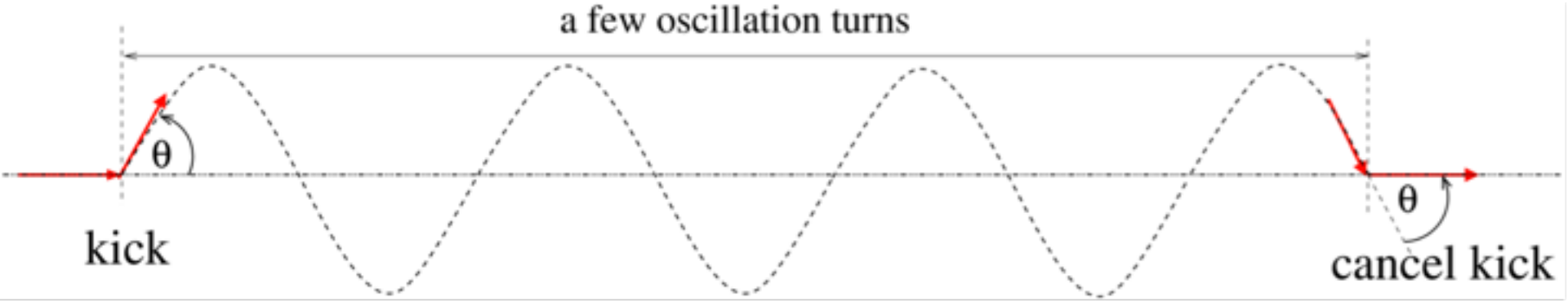
Short pulse duration (~43 ns) without kick the main bunch



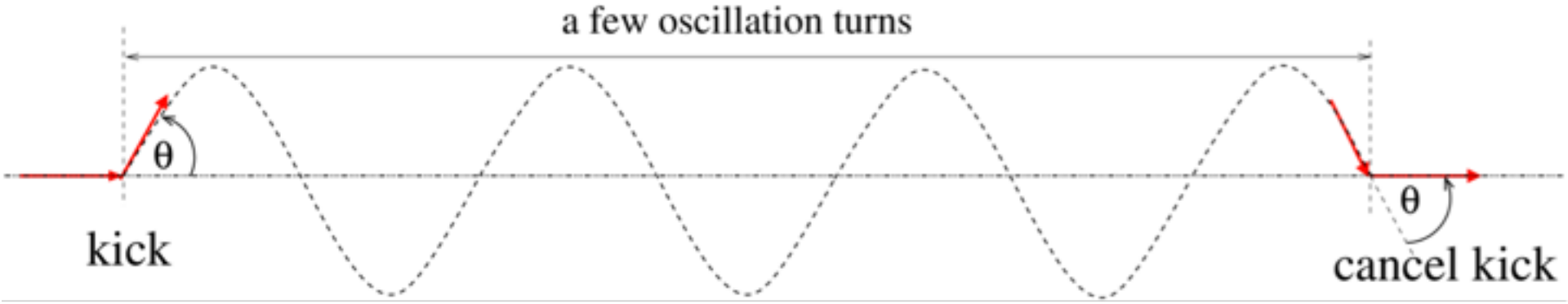
Cannot change kick strength and polarity in a fast way

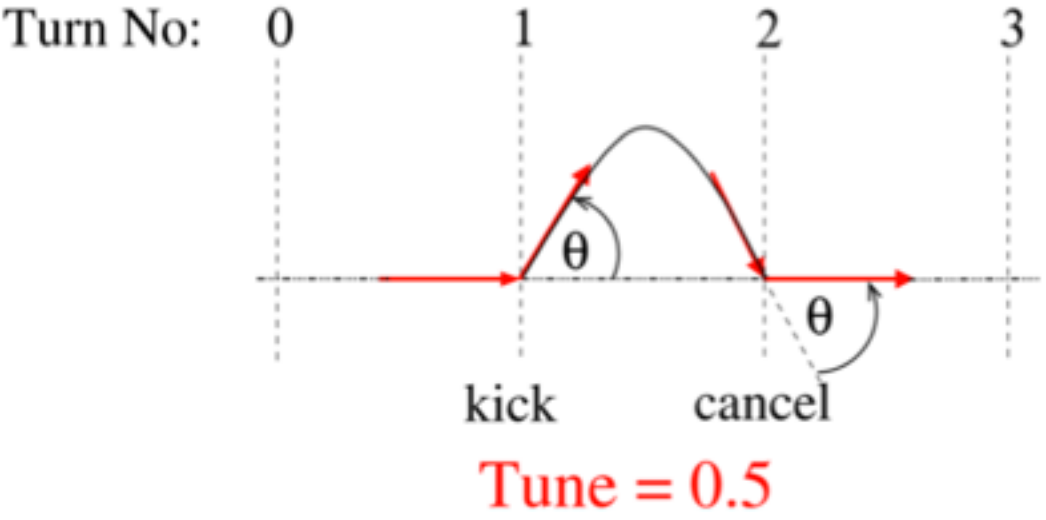
Flexible to change the pulse repetition rate and pattern

Kick-And-Cancel Mode



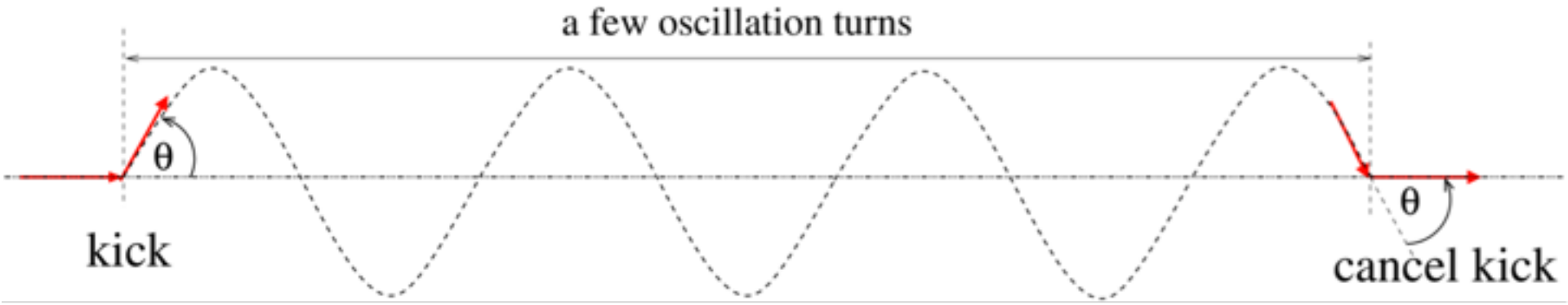
Kick-And-Cancel Mode

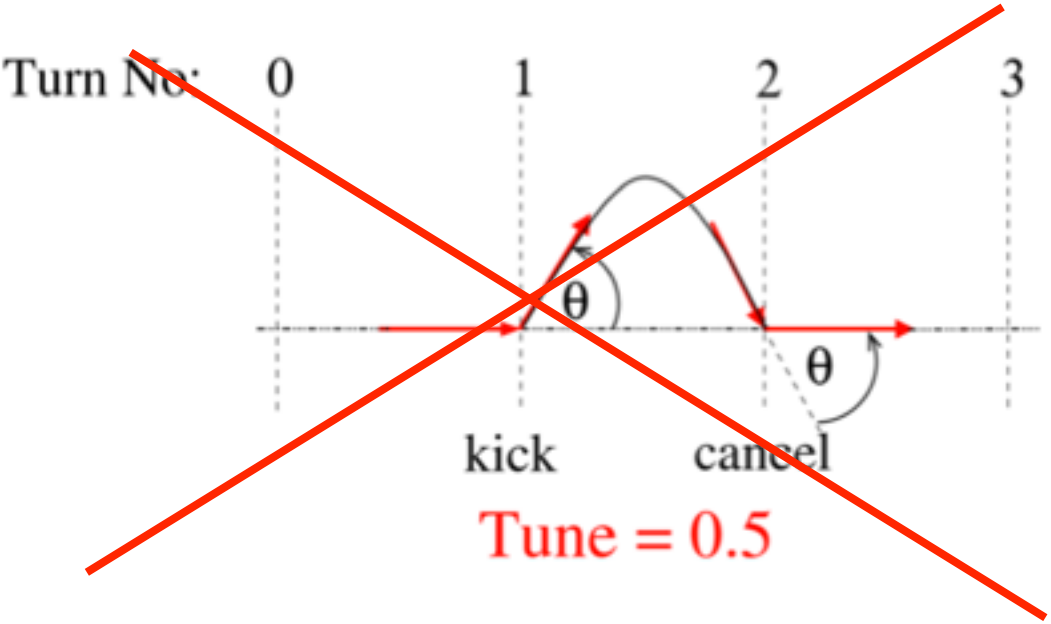




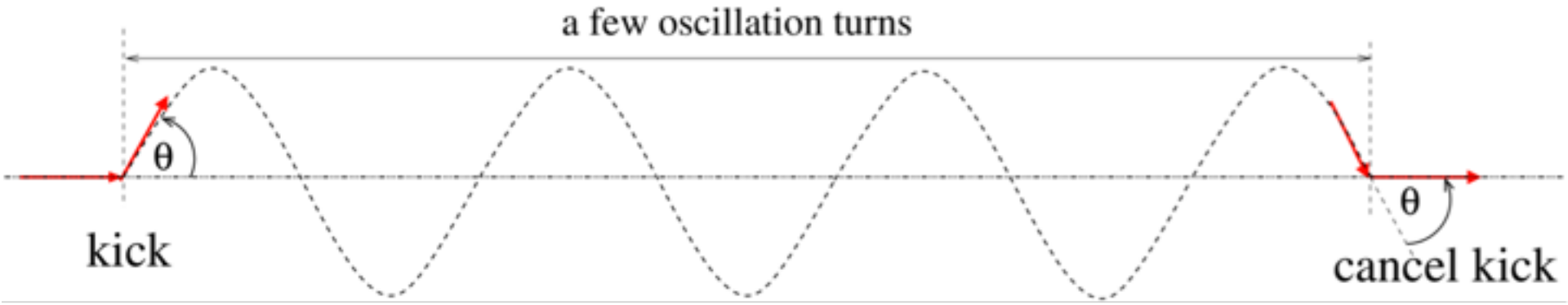
Tune = 0.5

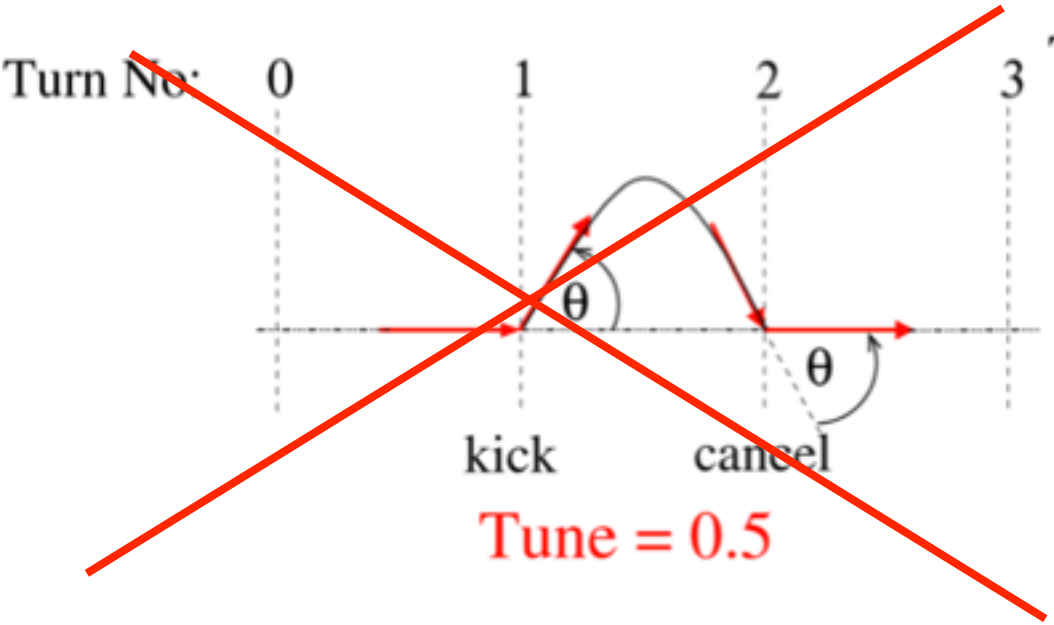
Kick-And-Cancel Mode

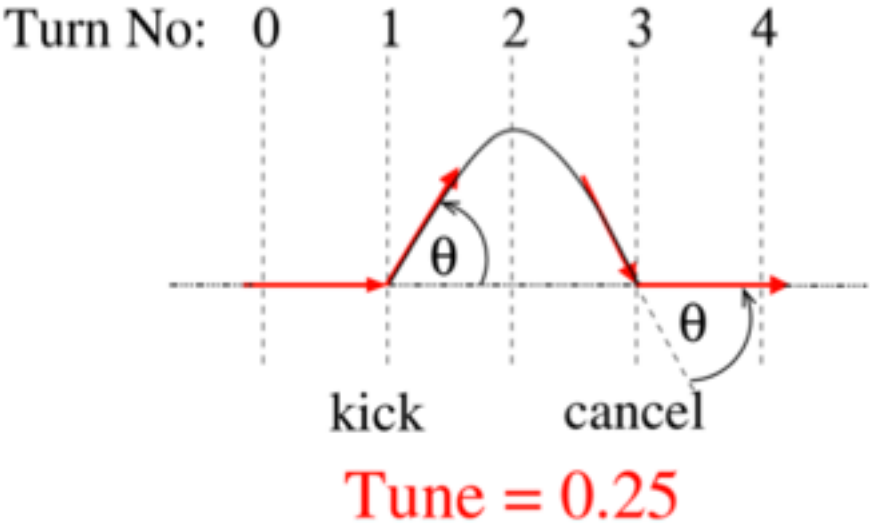




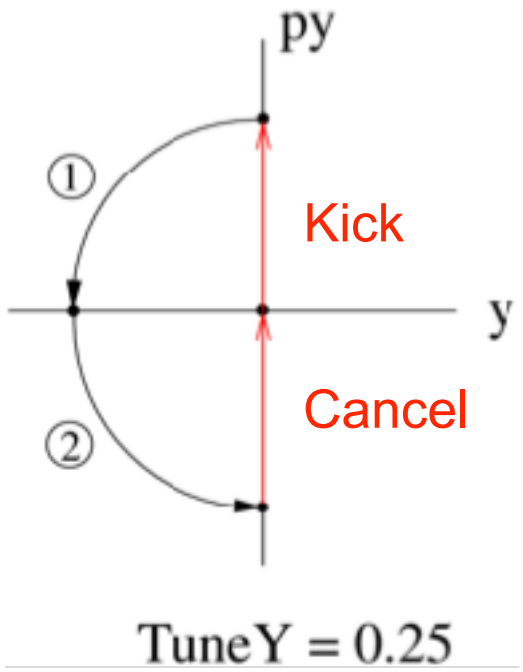
Kick-And-Cancel Mode



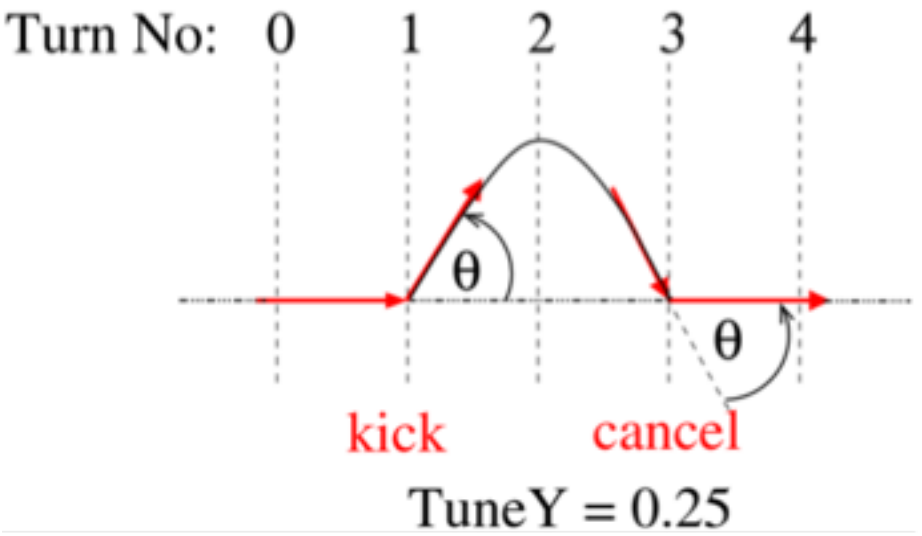




Phase and time space representations

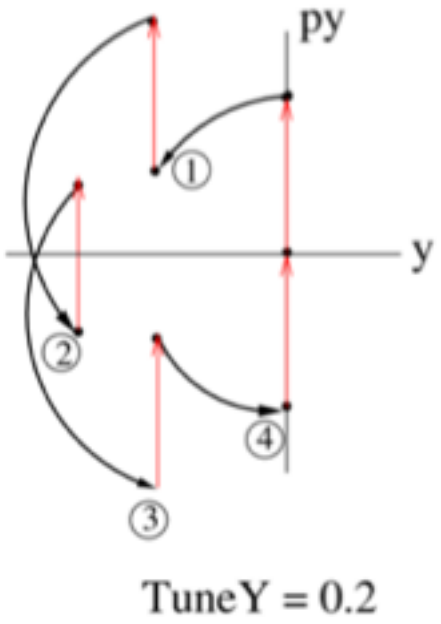


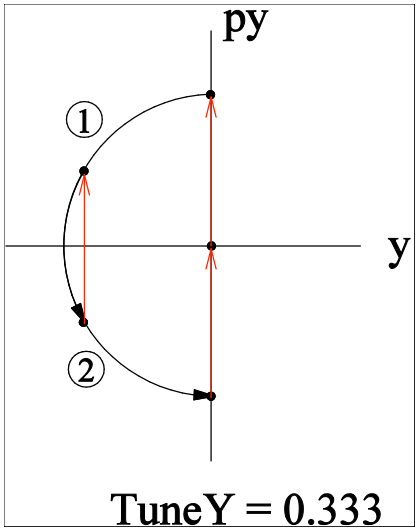
Phase Space

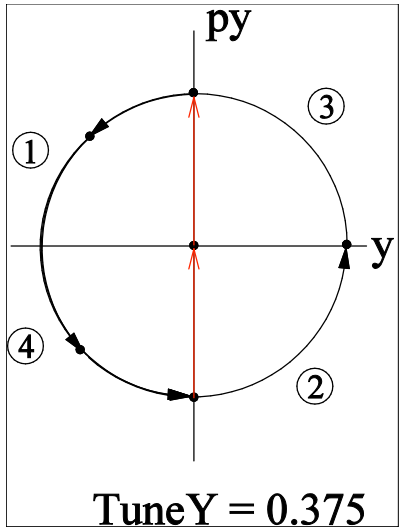


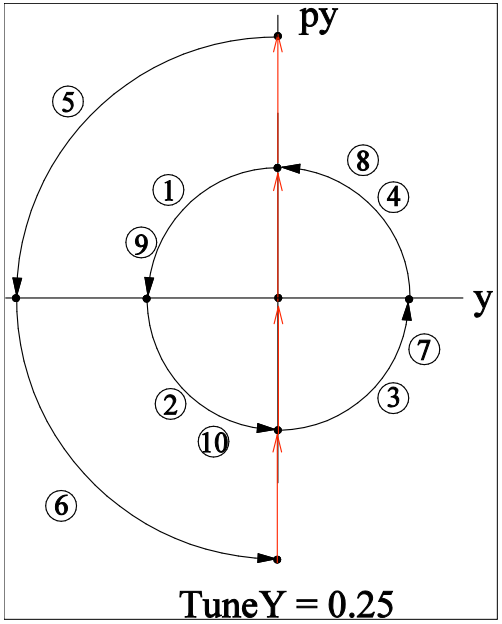
Time Space

Kick-and-cancel at other tunes





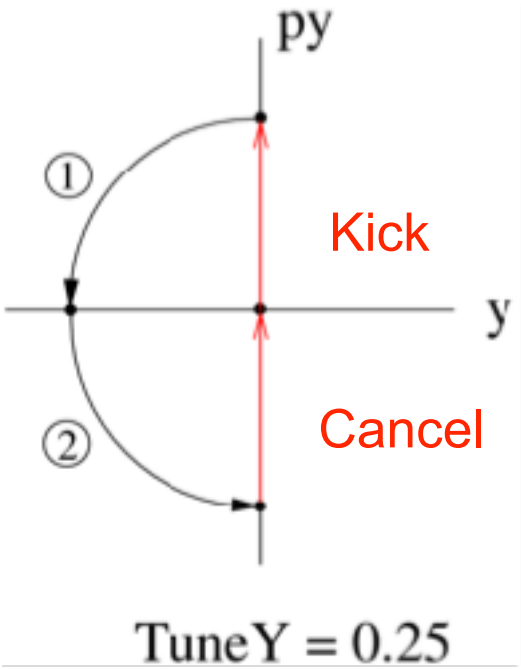




- >Thousand solutions have been found using 10 kicks and within 10 turns

Attractive features of using 0.25

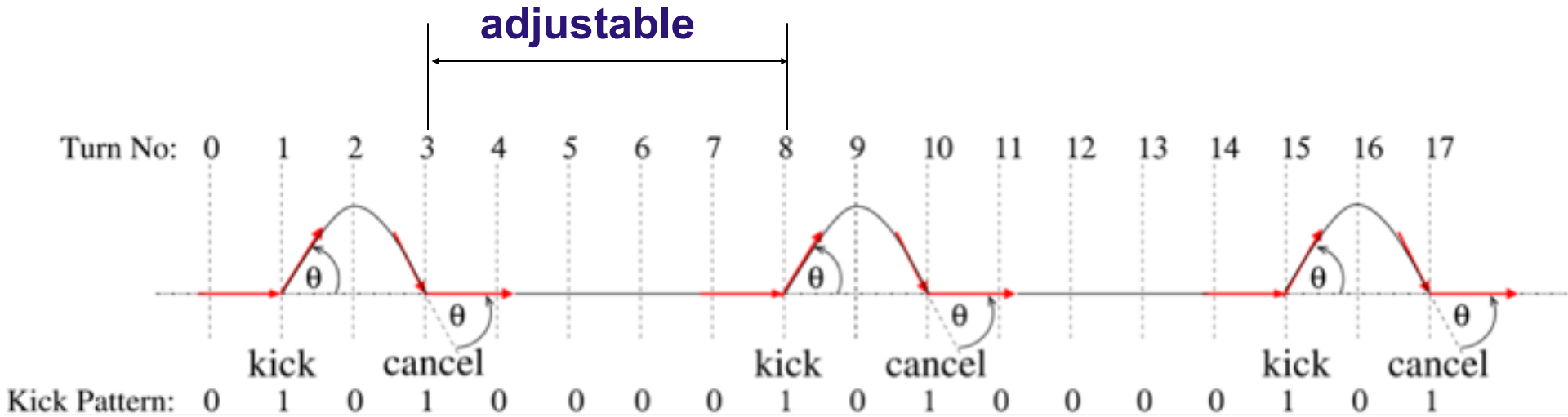
The most simple and practical solution is at tune 0.25:



- **Only need to fire kicker twice**
- **Only two offset-orbit oscillation turns**
- **The maximum-orbit-repetition-rate**
- **Minimizing residual motion and beam decoherence**

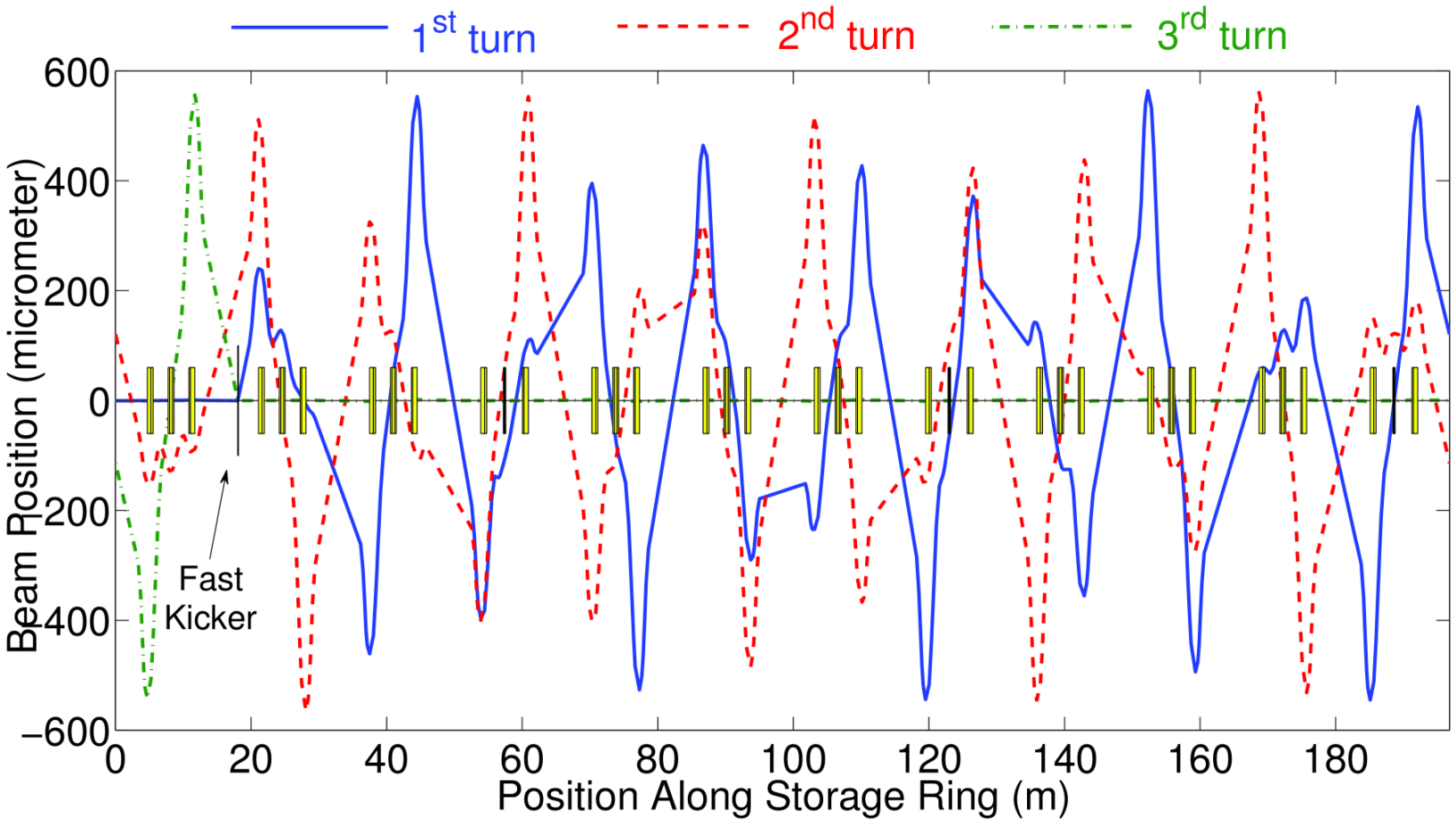
Can use KAC to adjust the frequency

Repeat this kick-and-cancel process, we can create pulses with an adjustable repetition rate.



After the cancel kick you can choose how long you want to wait to repeat this KAC process.

Orbit offset along the ALS ring



73 micron-rad vertical kick angle

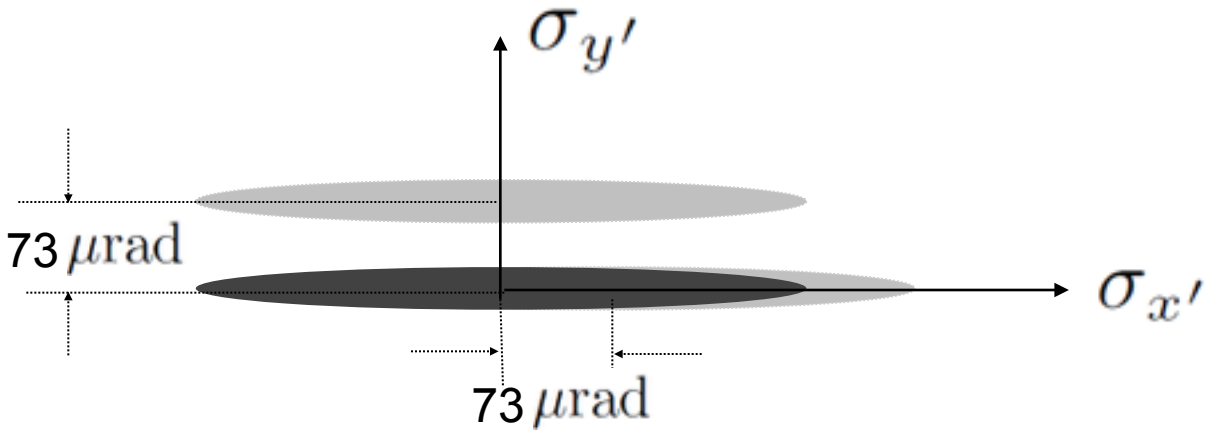
Why kick vertically instead of horizontally

The maximum kick angle provided by kicker is 73 μrad

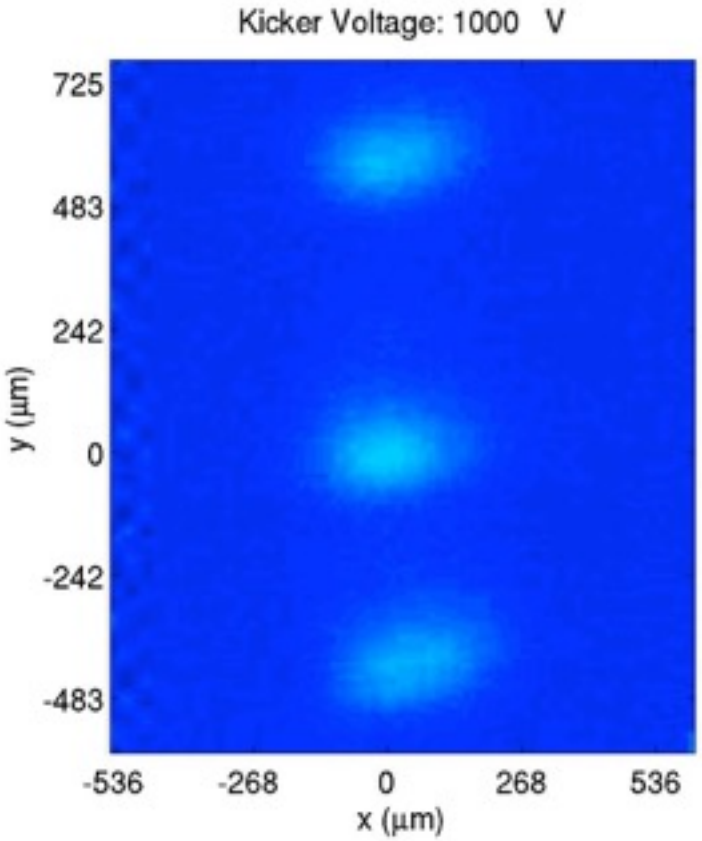
Beam size and divergence at the kicker location:

Horizontal Size, σ_x	303.1 μm	Vertical Size, σ_y	13.2 μm
Horizontal Divergence, $\sigma_{x'}$	21.2 μrad	Vertical Divergence, $\sigma_{y'}$	3.8 μrad

With the same kick angle, the vertical kick will give a larger number of sigma separation than the horizontal kick



Outline



Motivation

What is Pseudo-single bunch (PSB)

Characterizing PSB at the ALS

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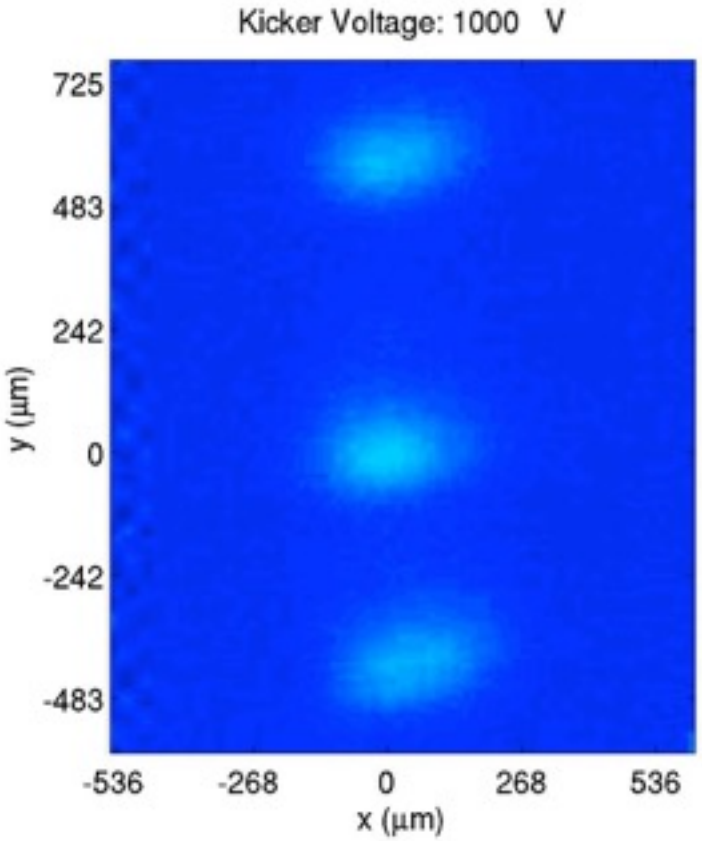

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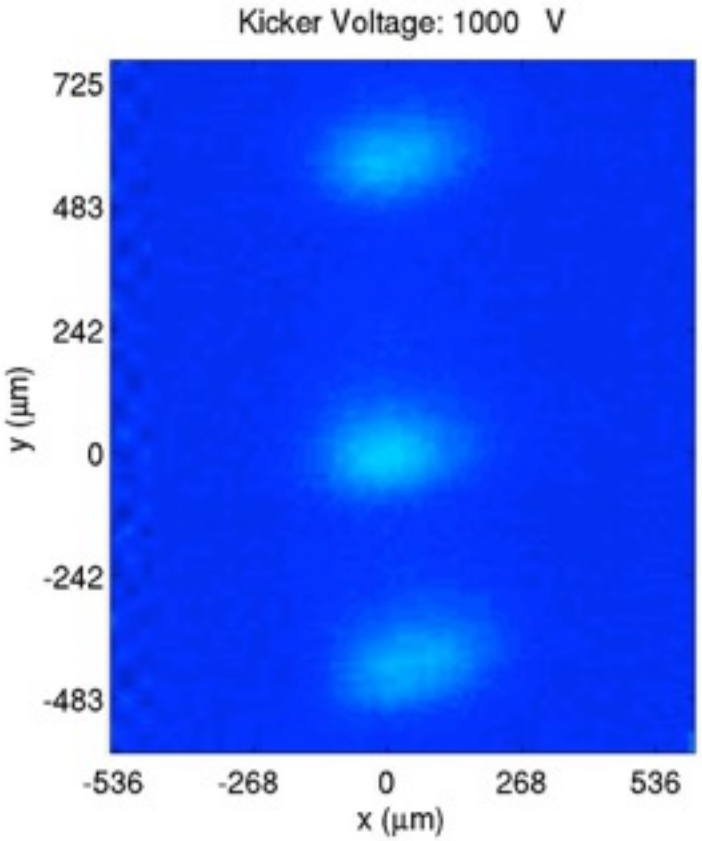
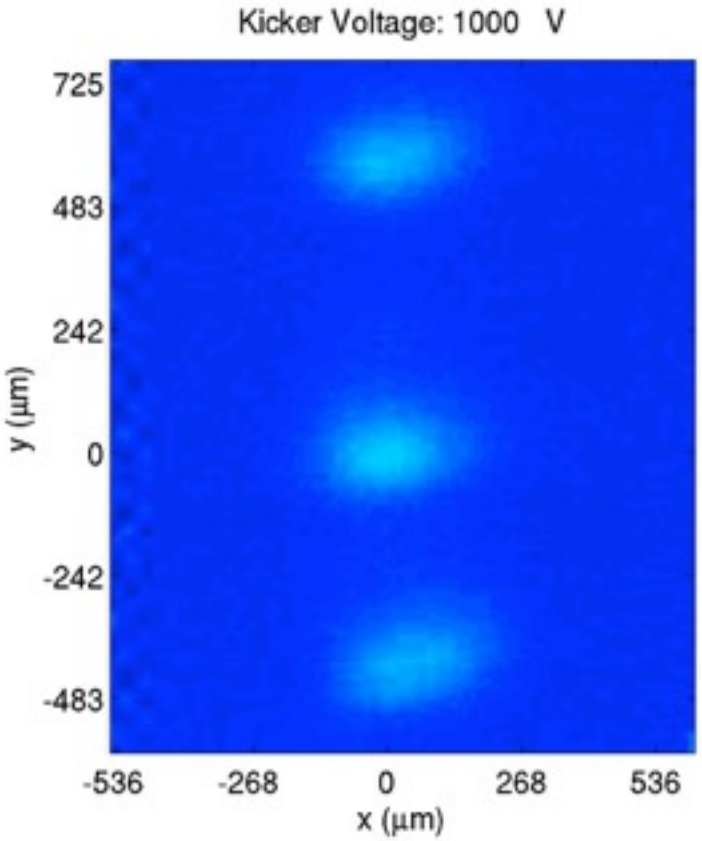


Characterizing PSB at the ALS

Single-Bunch Measurements

Multi-Bunch Measurements



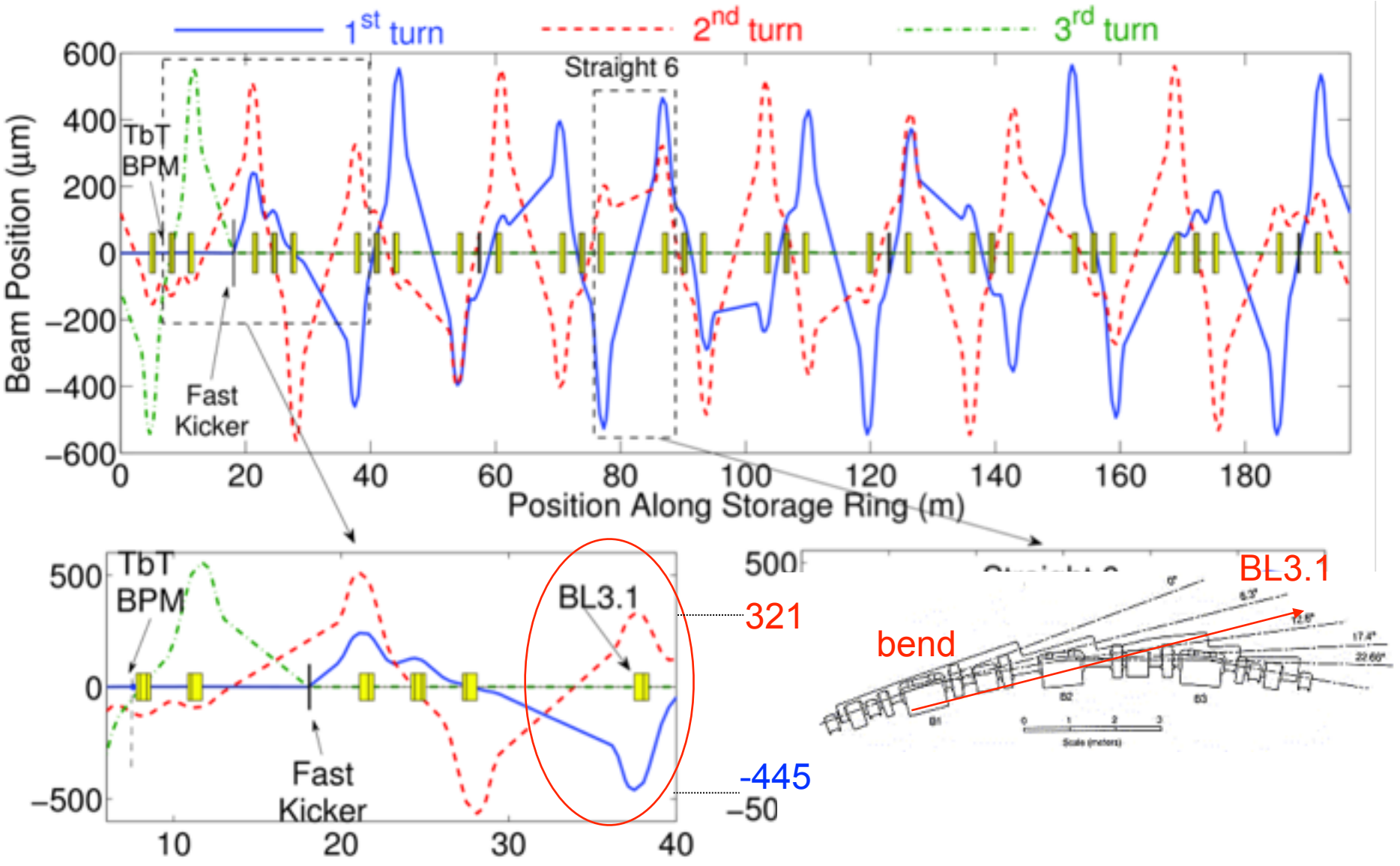
Characterizing PSB at the ALS

Single Bunch Measurements

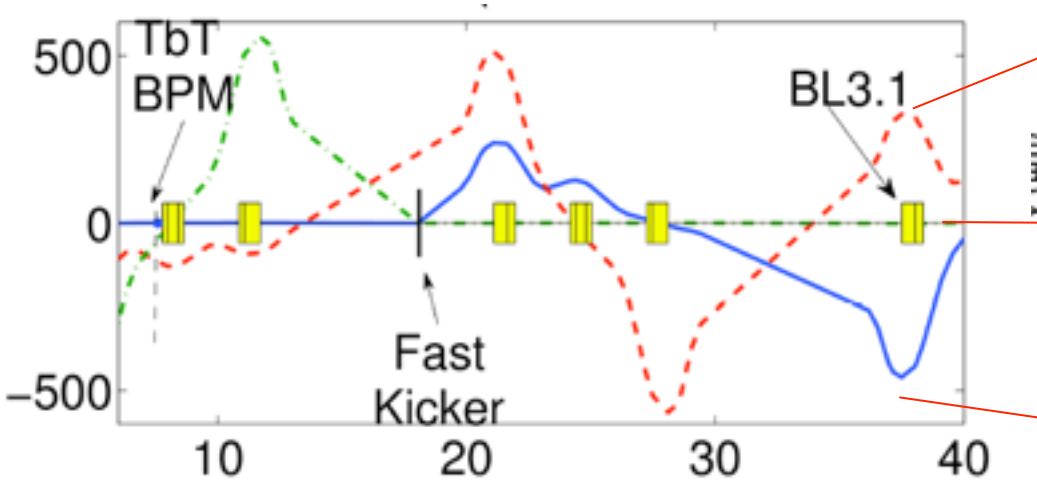
Measurement at diagnostic beamline

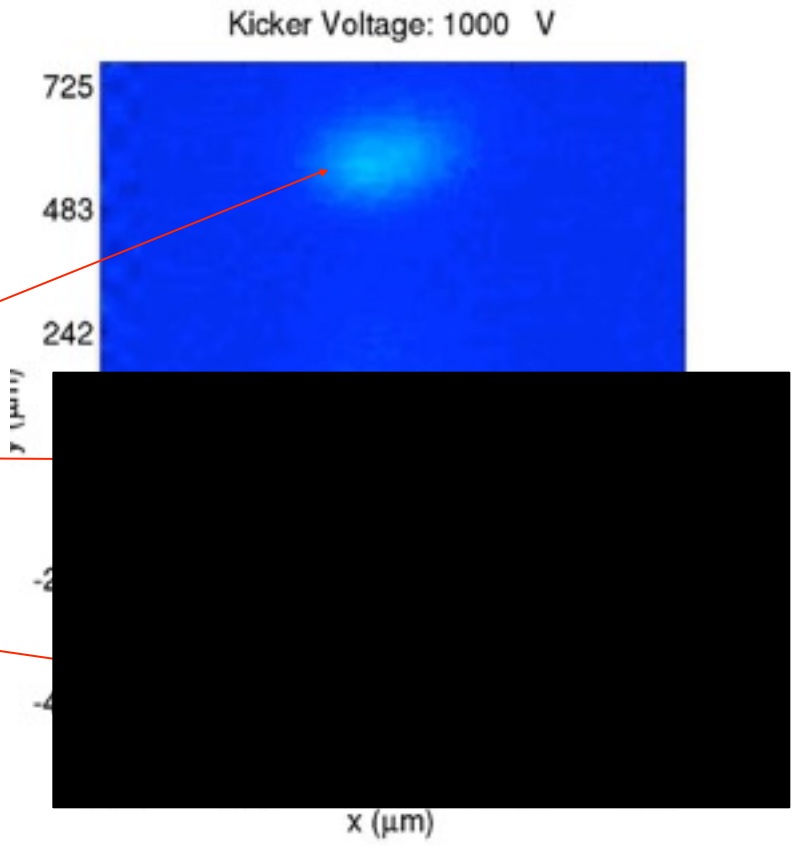
Turn-by-Turn (TbT) Beam Position Monitor (BPM)

Orbit at diagnostic BL3.1

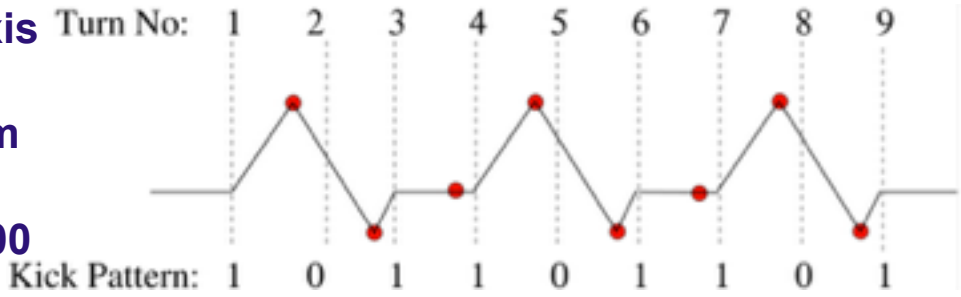


Orbit separation at diagnostic BL3.1@500kHz

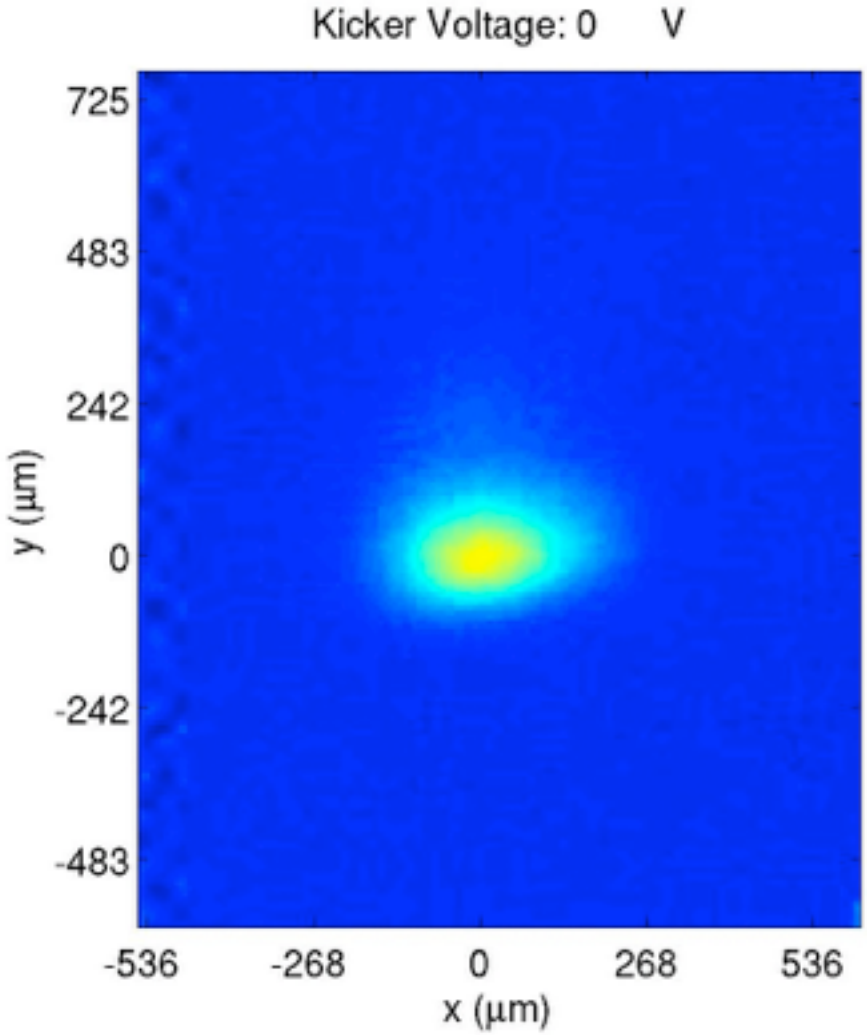




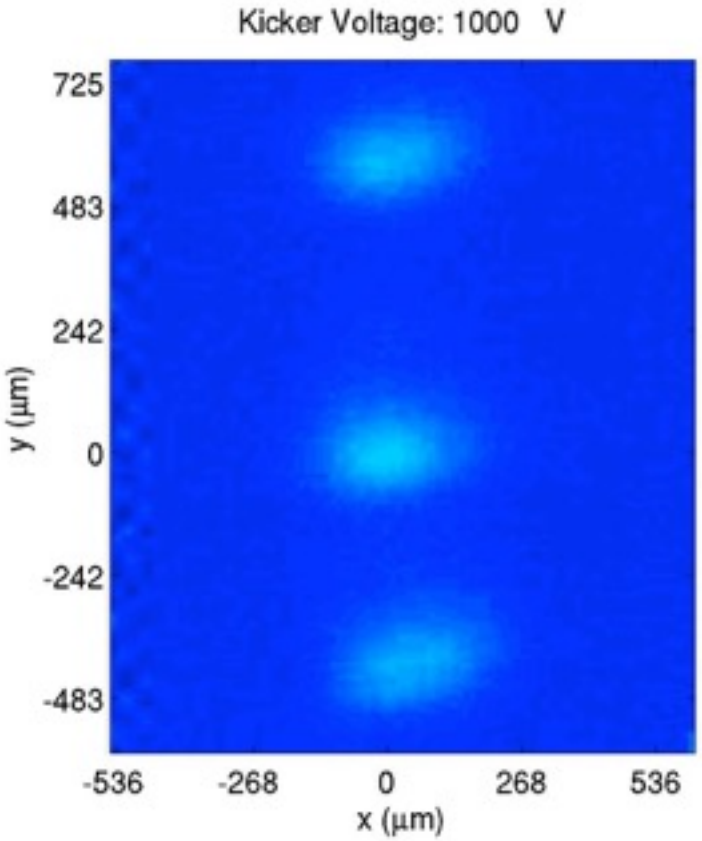
- One bunch filled in the ring
- Orbits are displaced on both sides of the axis on two separate turns
- Same current each turn due to the maximum kick frequency
- Repetition rate of orbit is up to maximum 500 kHz



Orbit Separation vs Kicker Voltage 500kHz



The orbit separation is increased as we increase the kicker voltage



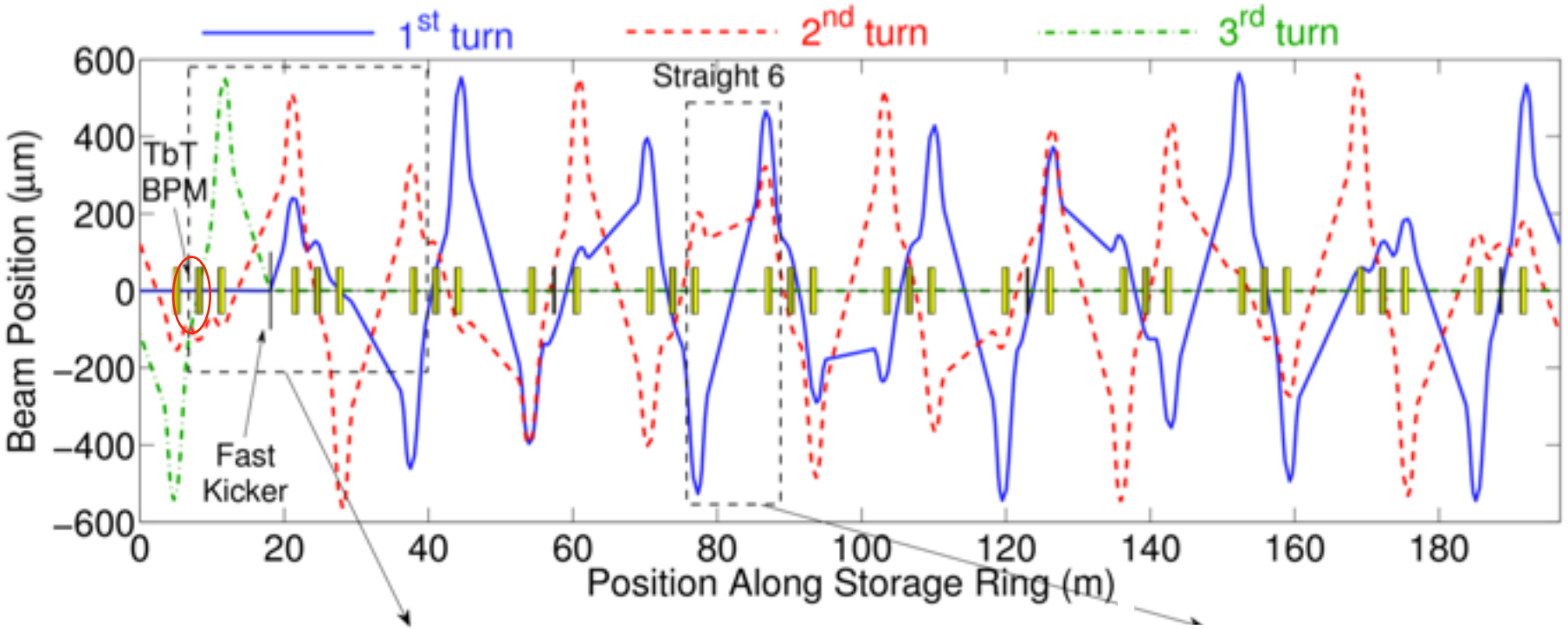
Experimental results

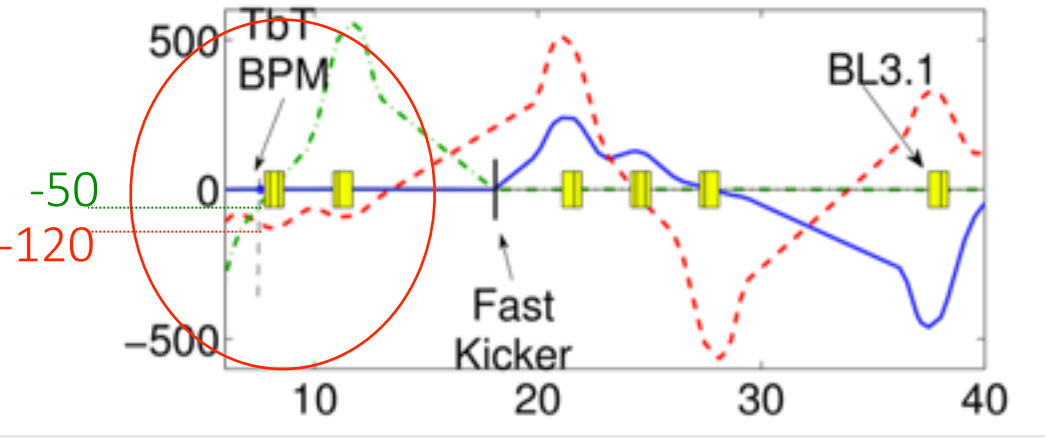
Single Bunch Measurements

Measurement at diagnostic beamline

Turn-by-Turn (TbT) Beam Position Monitor (BPM)

Simulated Orbit Offsets Along The Ring

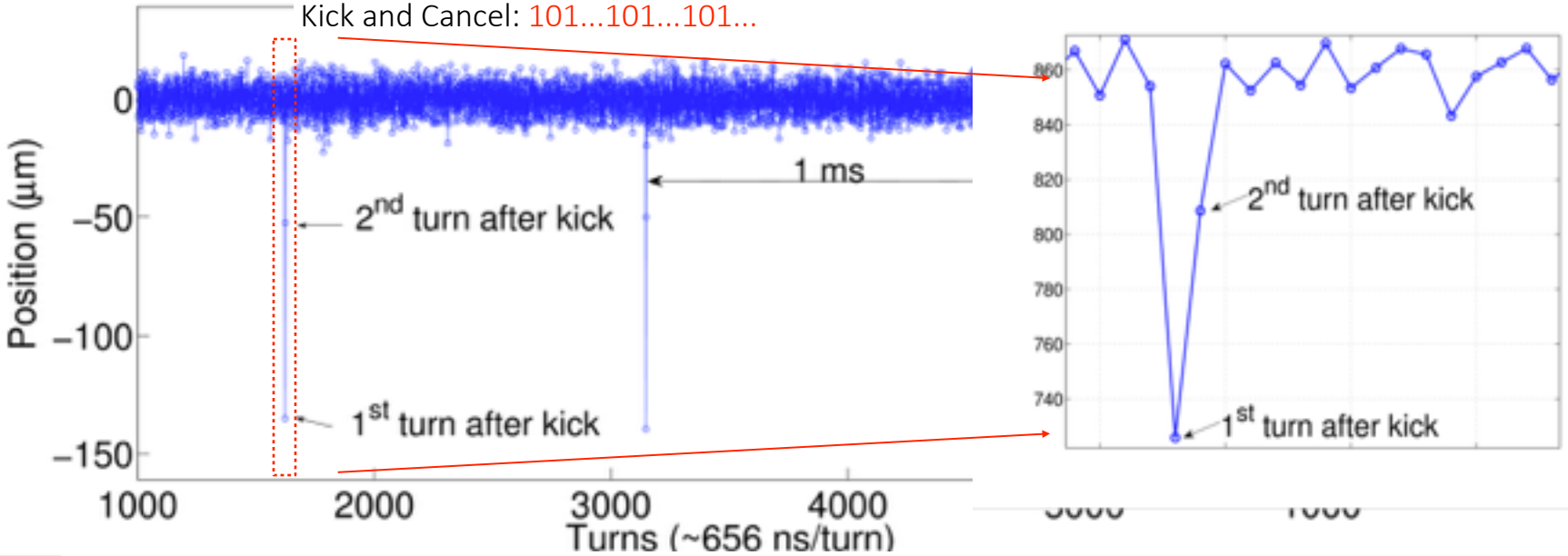




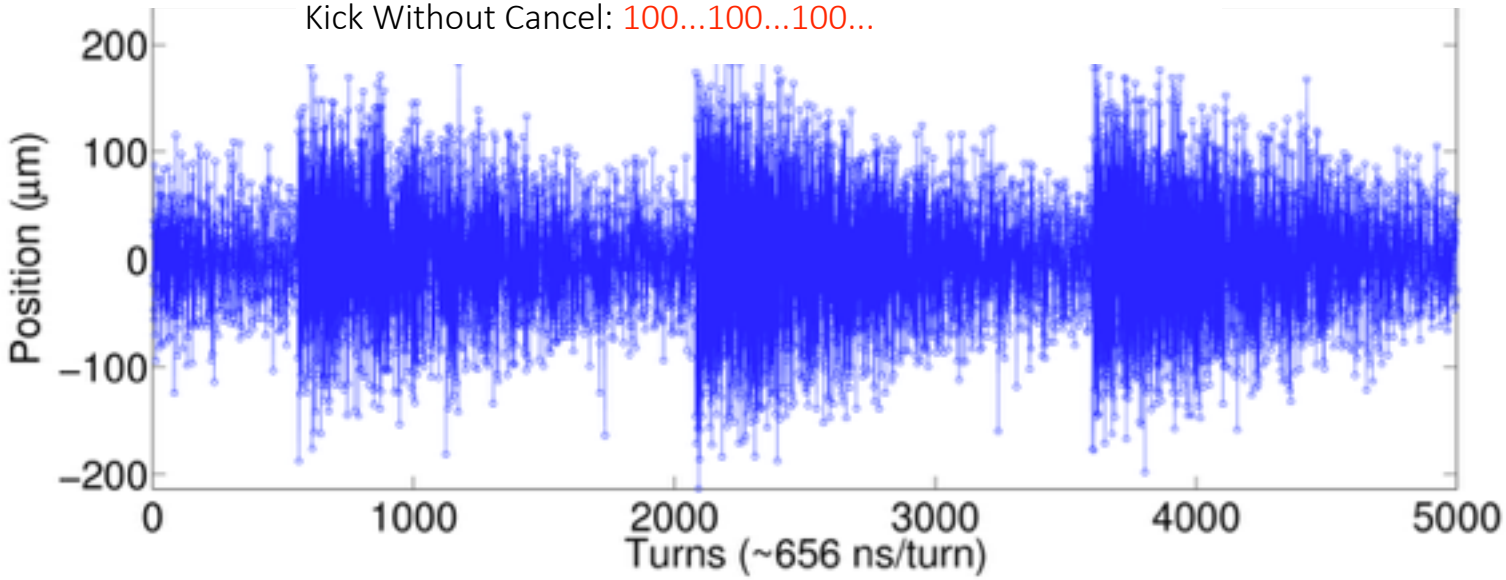
This Turn-by-Turn (TbT) beam position monitor (BPM) is located in Arc 1, right before the second bend.

It is a prototype of NSLS-II (the National Synchrotron Light Source II) BPM, developed and provided by the NSLS-II diagnostics beam.

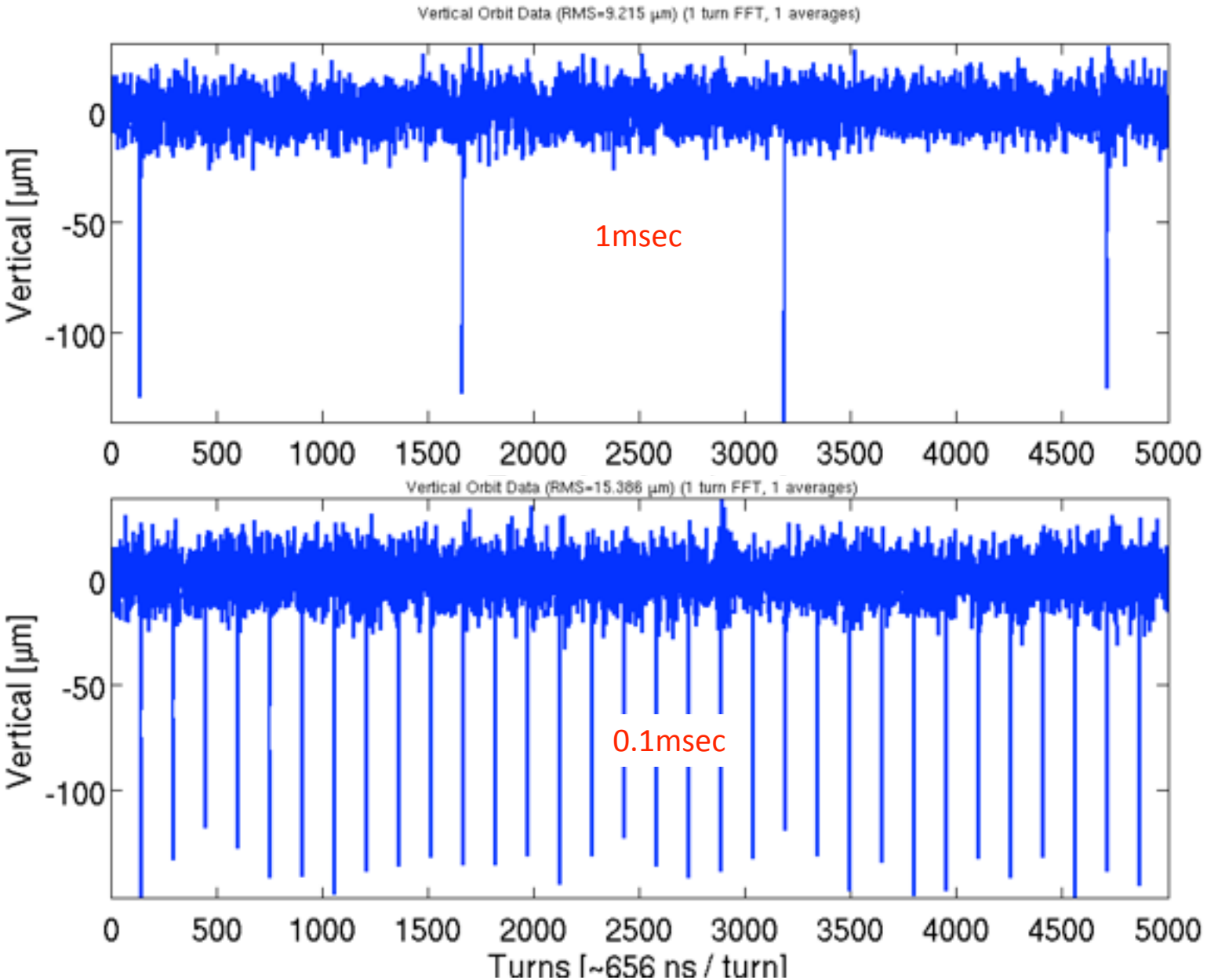
Turn-by-Turn BPM Signals



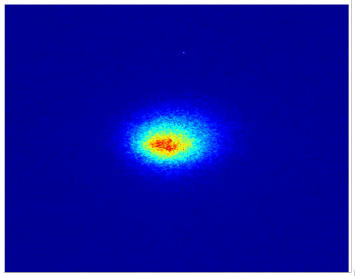
A 5 mA single camshaft bunch was filled in the storage ring.



BPM signal with adjustable freq

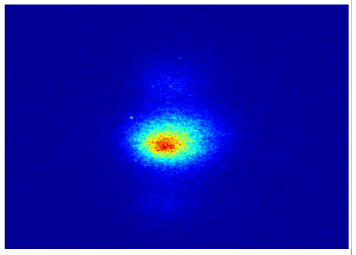


No kick

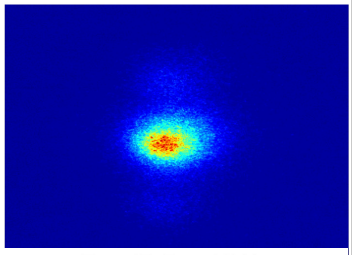


Measurement using the fast-gated camera, but in the integrating mode

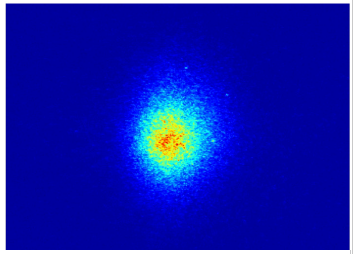
Turn:10, Freq:152kHz



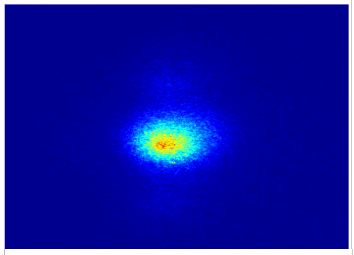
Turn:11, Freq:139kHz



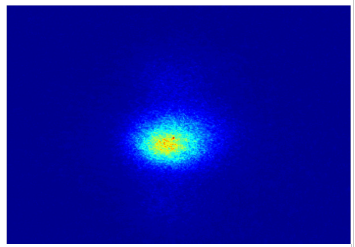
Turn:12, Freq:127kHz



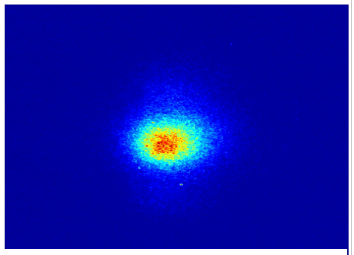
Turn:13, Freq:117kHz



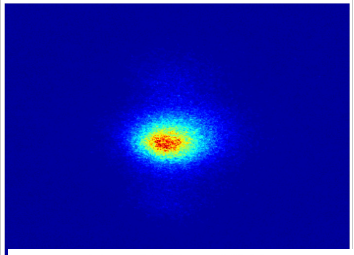
Turn:15, Freq:102kHz



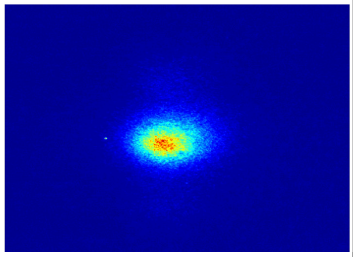
Turn:16, Freq:95kHz



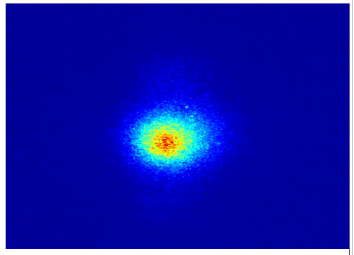
Turn:17, Freq:90kHz



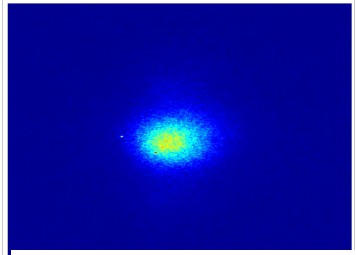
Turn:18, Freq:85kHz



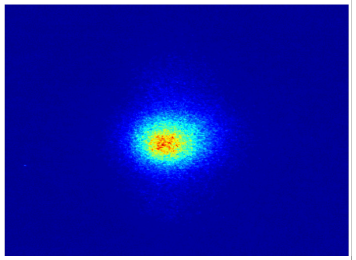
Turn:19, Freq:80kHz



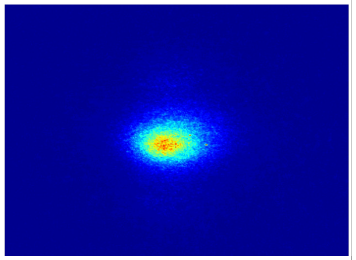
Turn:20, Freq:76kHz



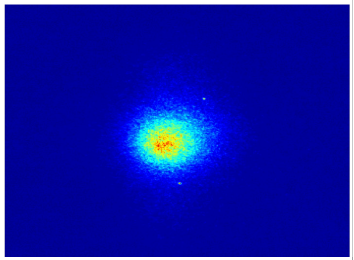
Turn:21, Freq:73kHz



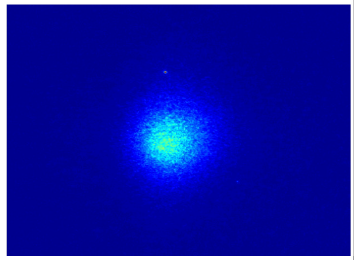
Turn:22, Freq:69kHz



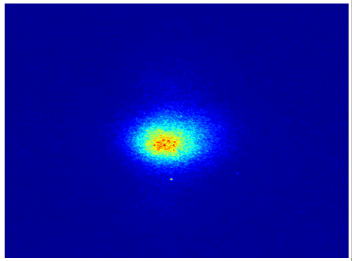
Turn:23, Freq:66kHz



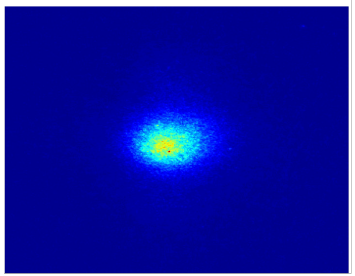
Turn:24, Freq:64kHz



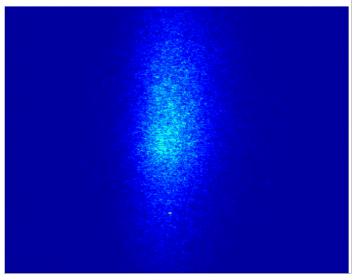
Turn:25, Freq:61kHz



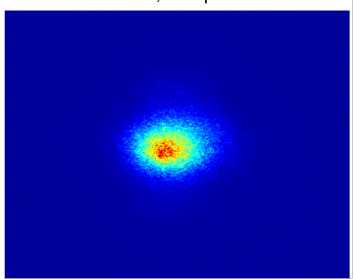
Turn:26, Freq:59kHz



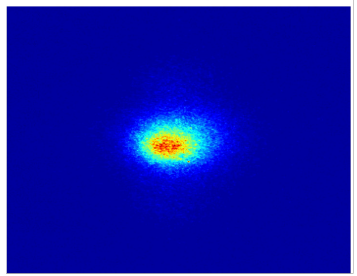
Turn:27, Freq:56kHz



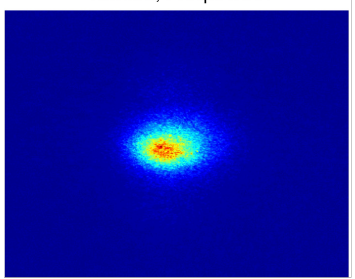
Turn:28, Freq:54kHz

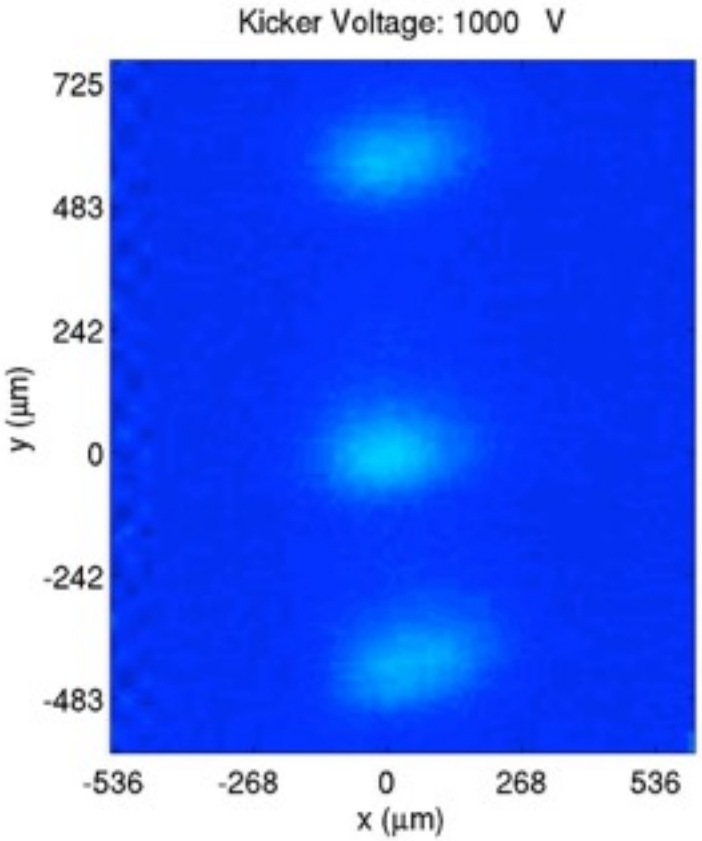


Turn:29, Freq:53kHz



Turn:30, Freq:51kHz





Experimental results

Single-Bunch Measurements

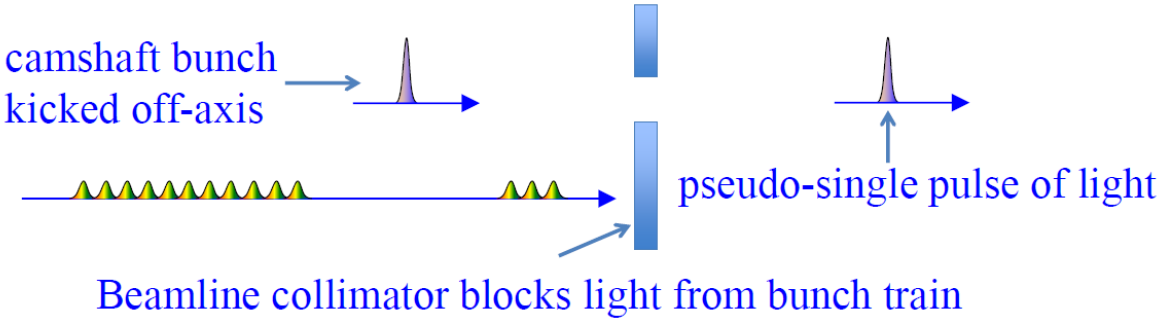
Multi-Bunch Measurements

Spatial Separation

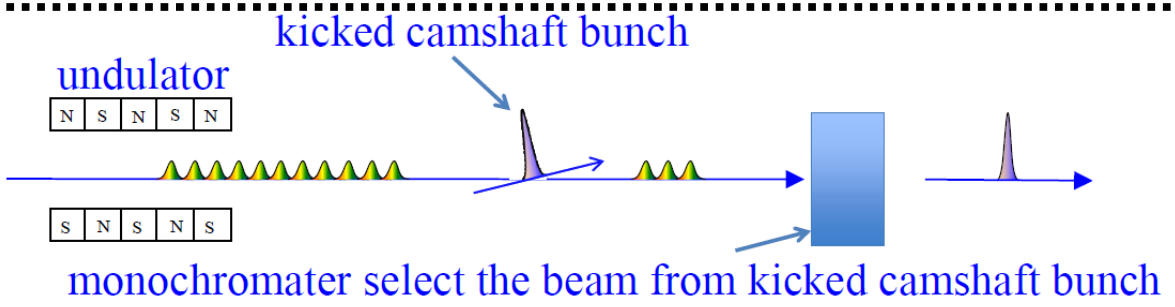
Angular Separation (*Backup slides*)

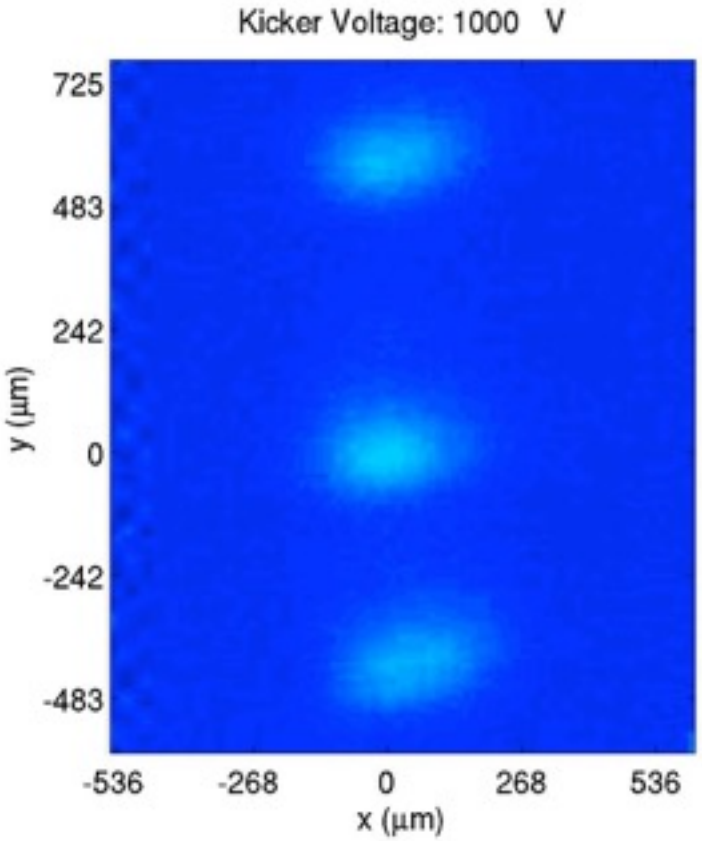
Methods of isolating single pulses

(b) Spatial separation using kicker & aperture



(c) Spectral separation using kicker & monochromator





Experimental results

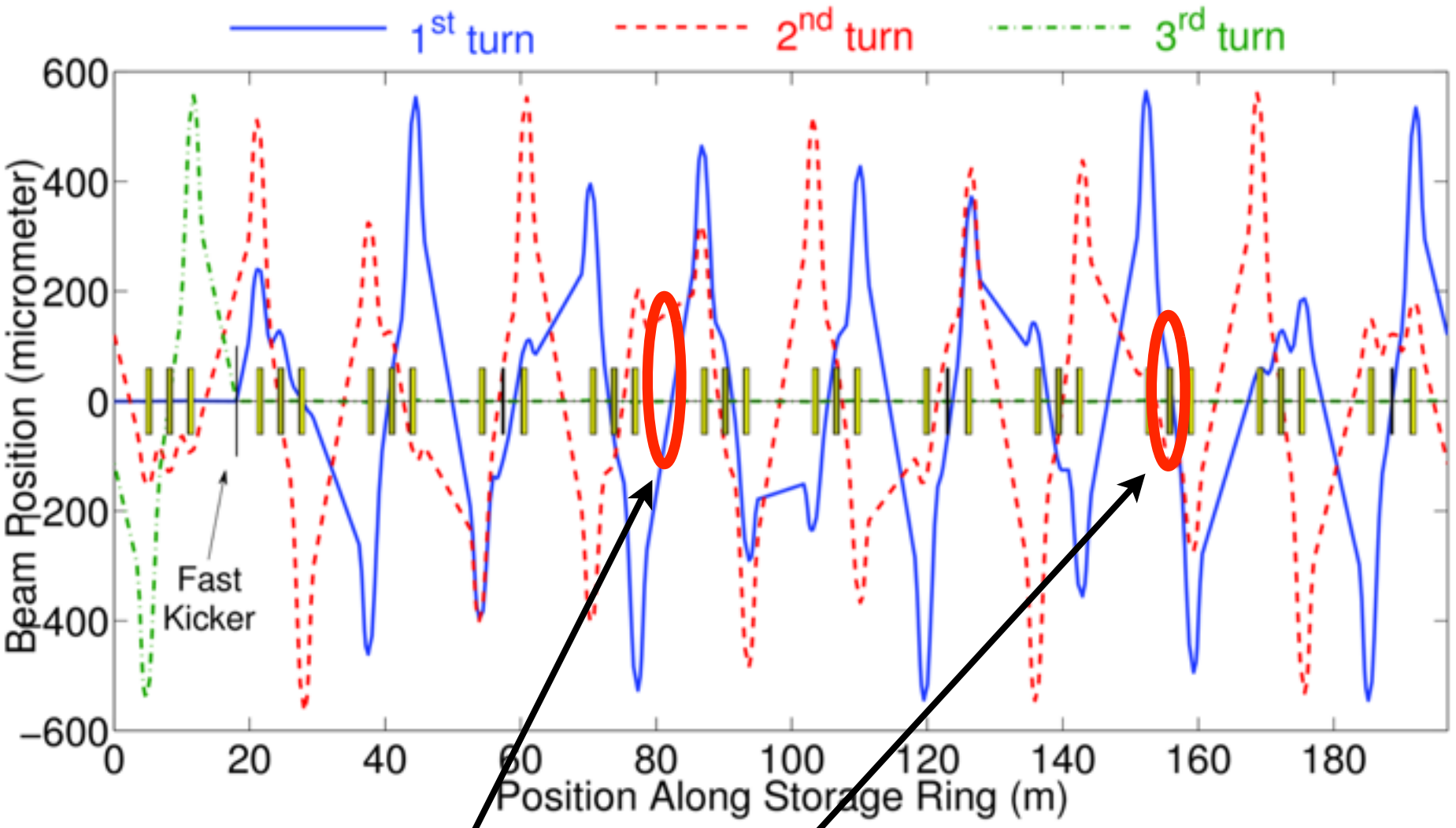
Single-Bunch Measurements

Multi-Bunch Measurements

Spatial Separation

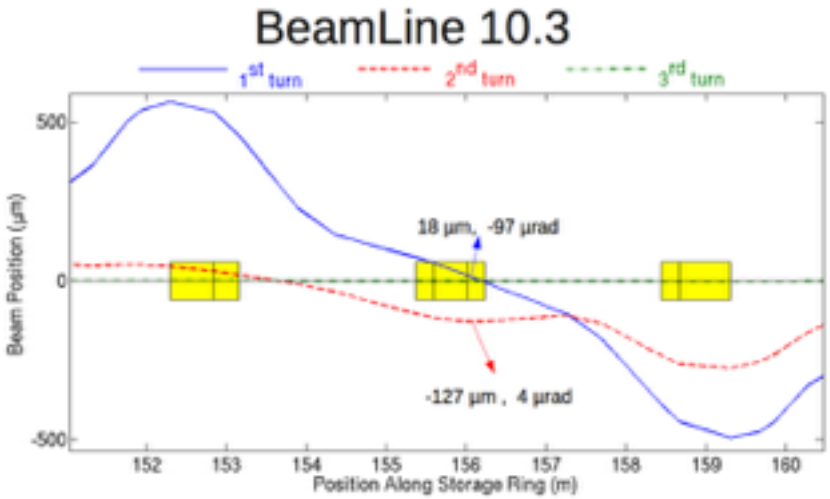
Angular Separation (*Backup Slides*)

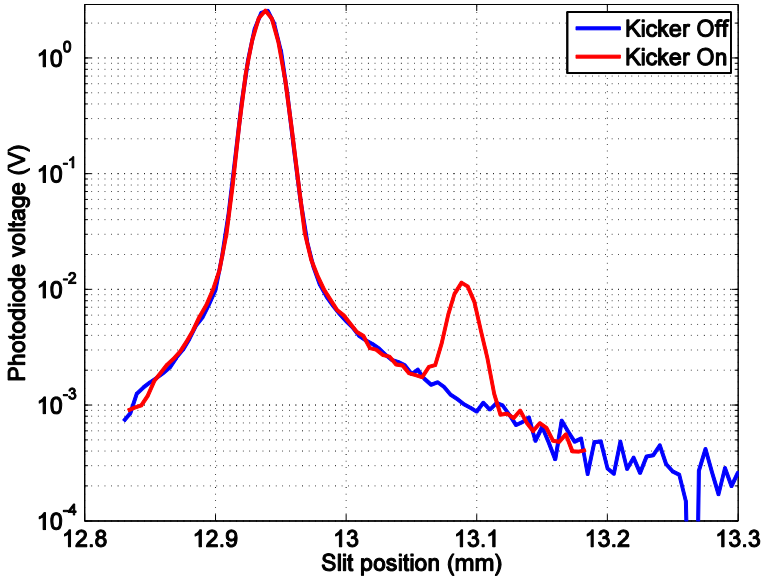
Experiments carried out at 3 beamlines



Dipole Beamline 10.3.2: PSB @ 500kHz

Measurement Condition
- multibunch beam has 350mA
- camshaft has 4mA but appears offset every 3rd turn.

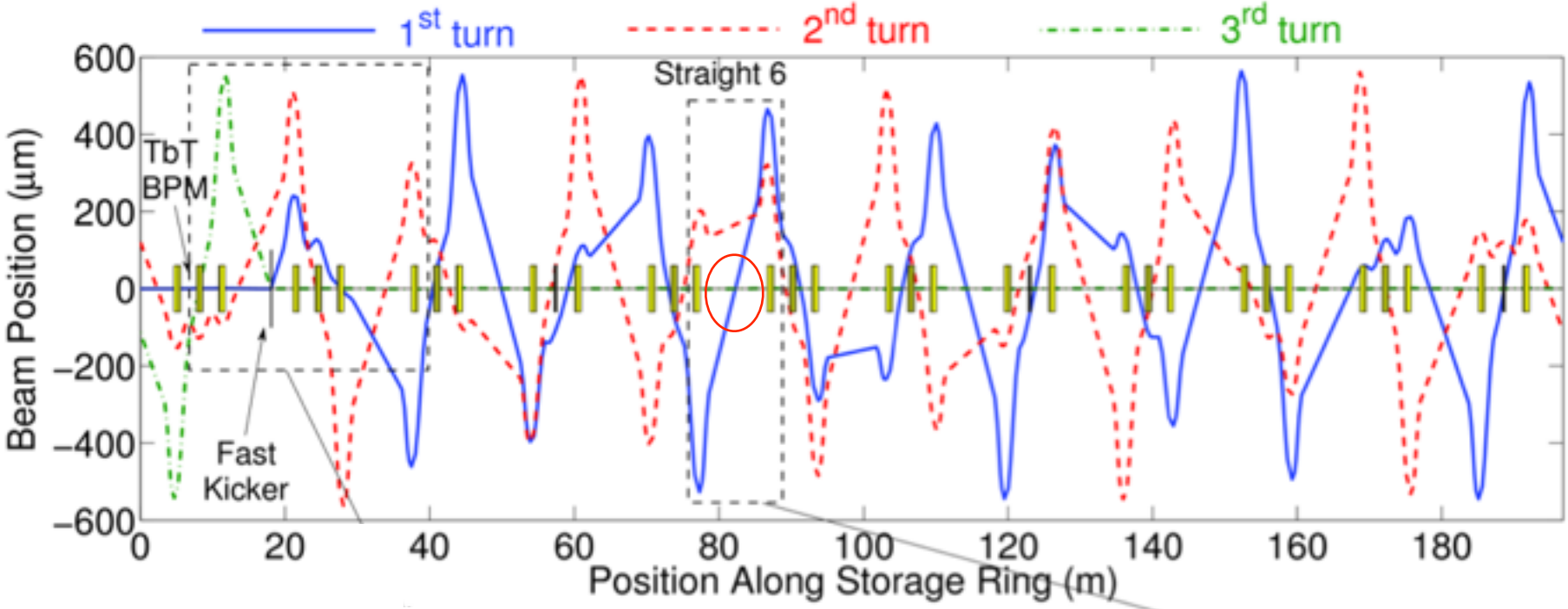


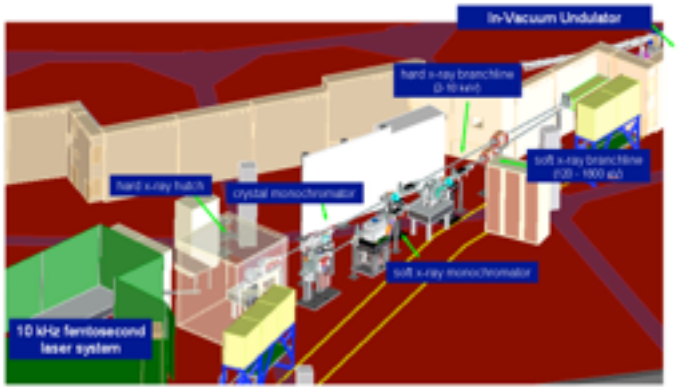


Without PSB: Signal-to-background is 1:260
With PSB: Signal-to-background is 11:1

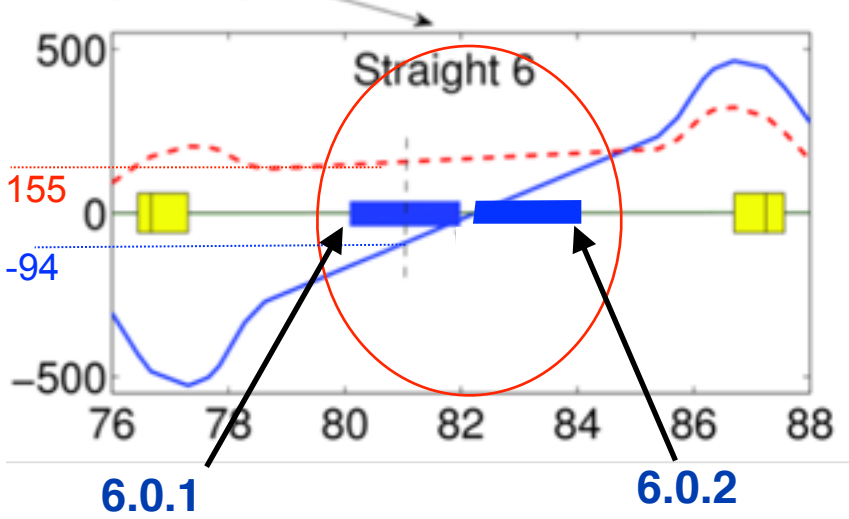
~3000 times suppression of unwanted x-rays using PSB-KAC

Insertion Device Beamlines: 6.0.1/6.0.2

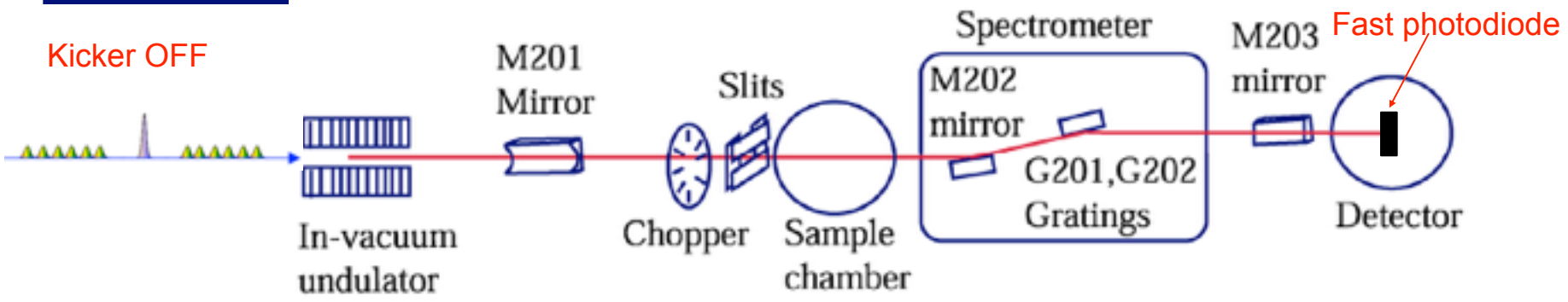




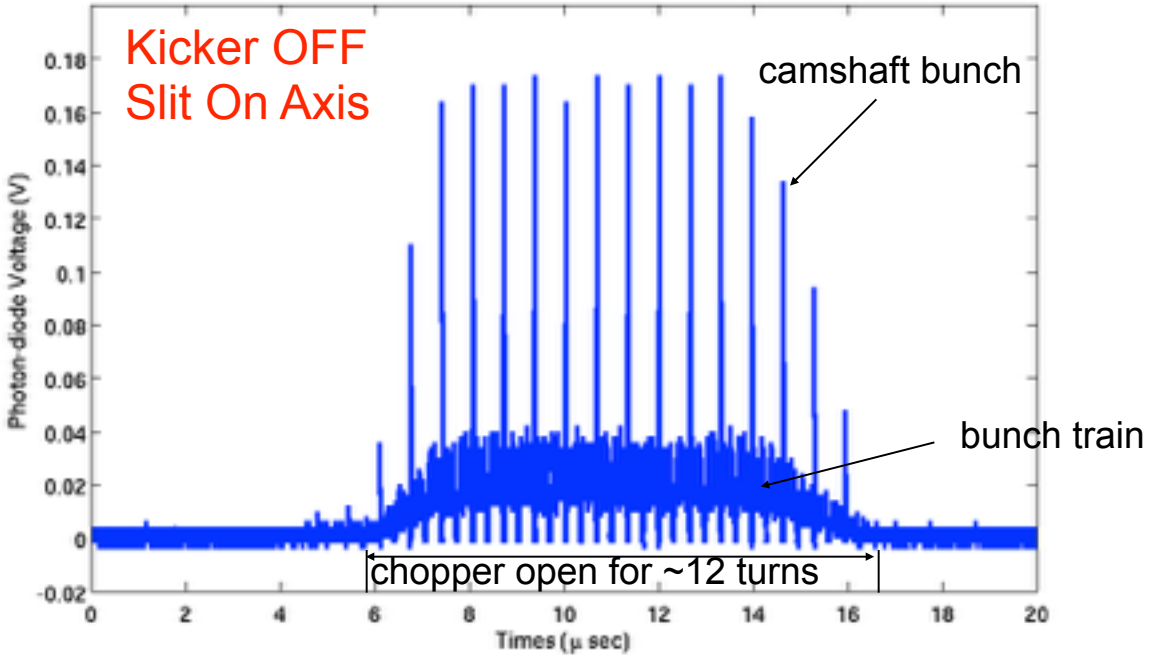
BL 6.0.1: Ultrafast / Femtosecond Dynamics Hard X Ray



Measurement at beamline 6.0.1

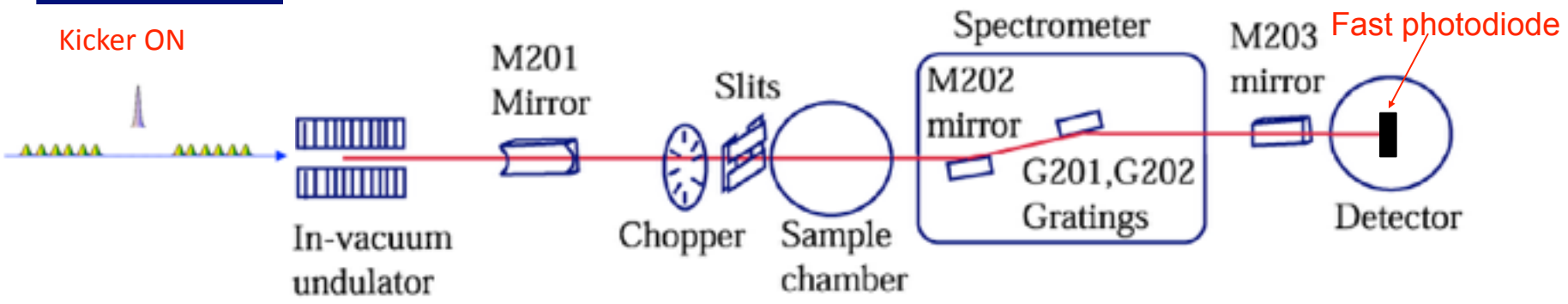


Ring filled to 52mA with multibunch and 3.7mA camshaft

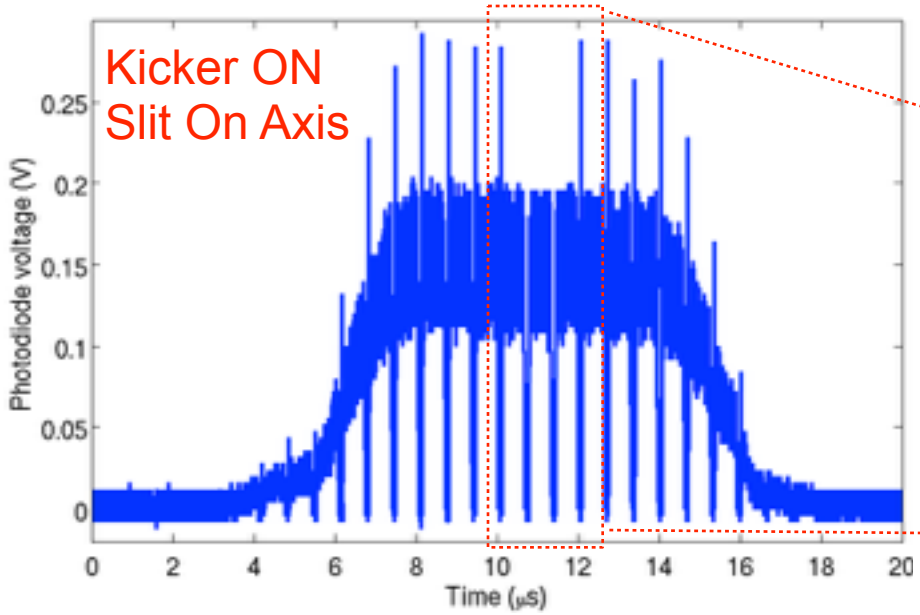


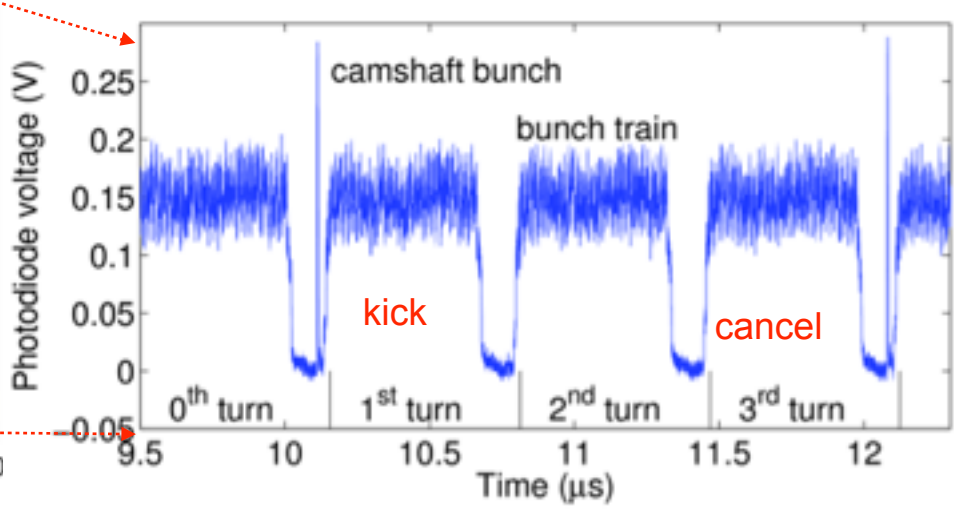
A typical x-ray pulses measured using gated photodiode

Measurement at beamline 6.0.1

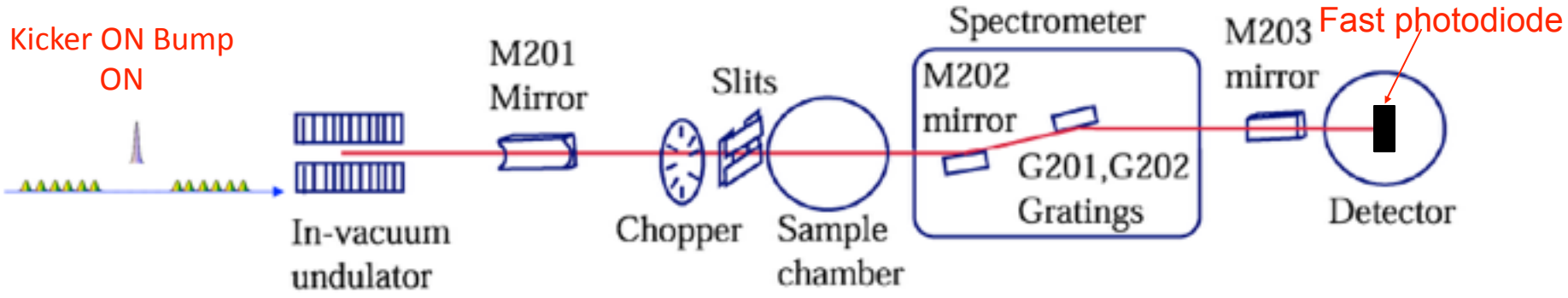


Ring filled to 276 mA with multibunch and 5 mA camshaft.

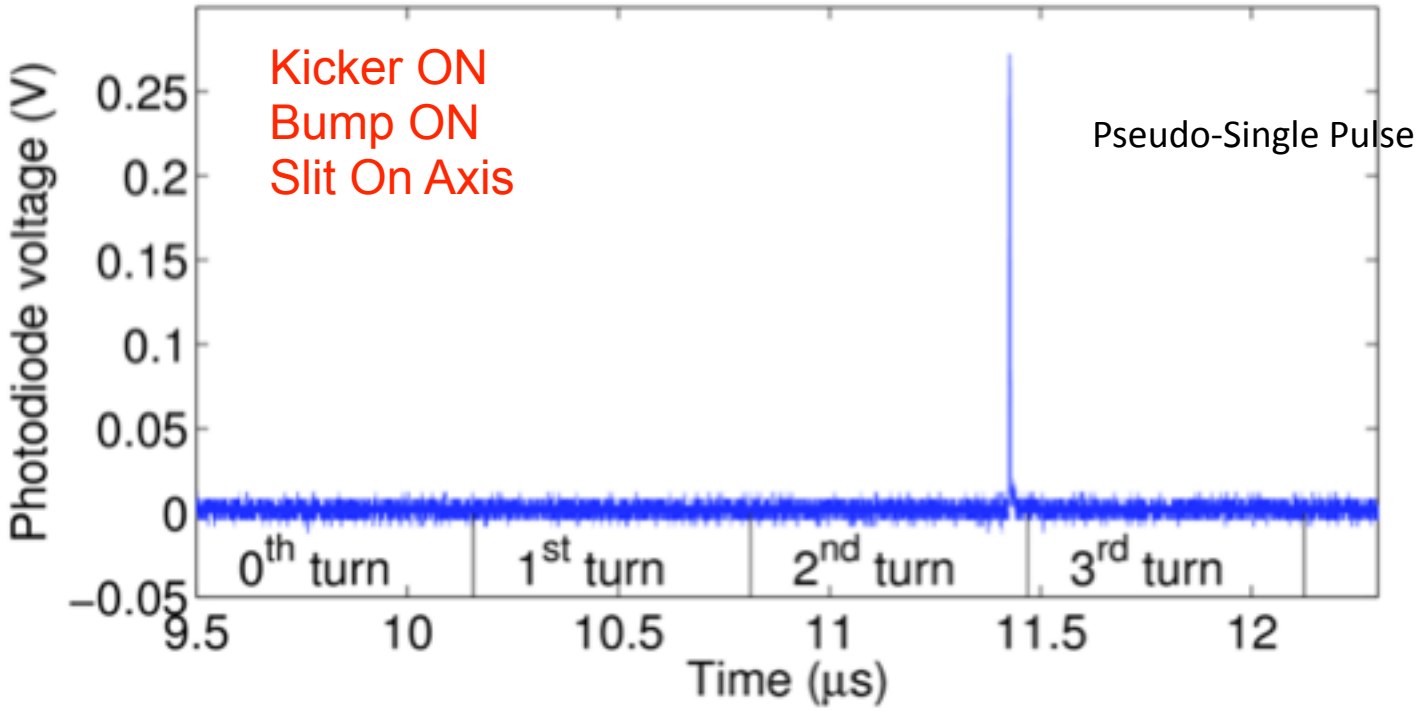




Measurement at beamline 6.0.1

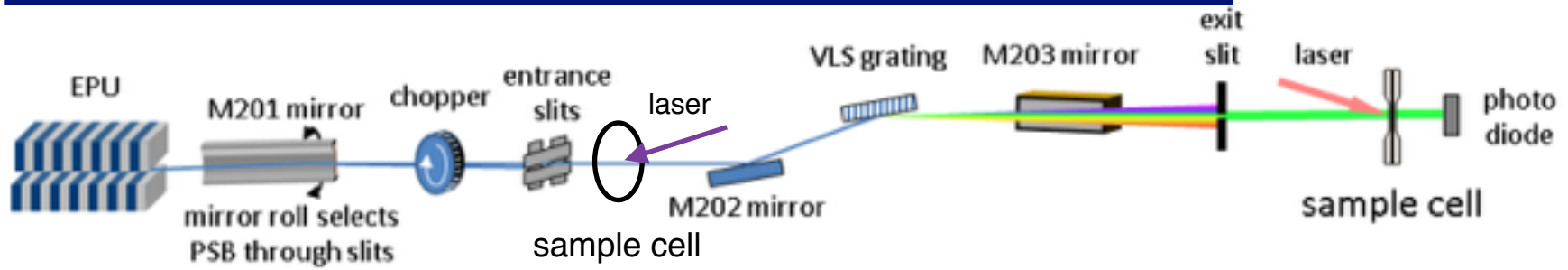


Ring filled to 276 mA with multibunch and 5 mA camshaft.



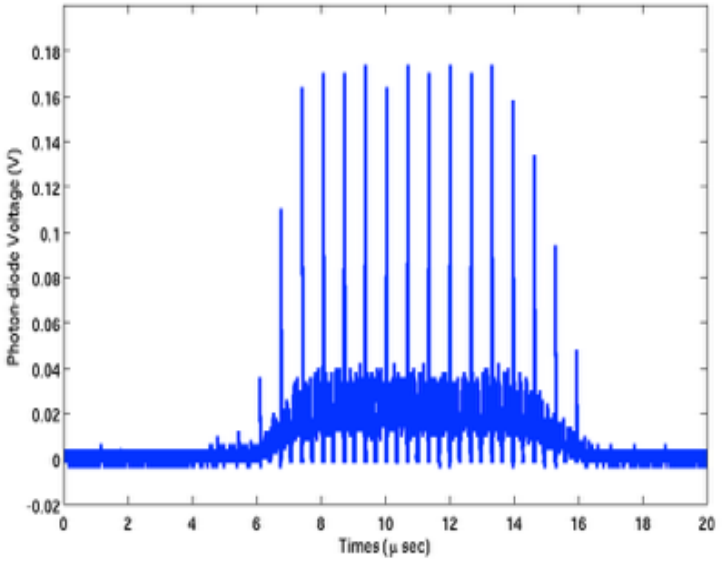
More than 1000 times suppression of unwanted x-rays using PSB-KAC

Issues of background on beam line 6.0.2



Mechanical chopper reduces the background by a factor of ~30

- **Still the chopper window is opened for 8 ms (12 turns)**
- **1199 out 1200 photons reaching the sample were not timed correctly with the laser pulse**



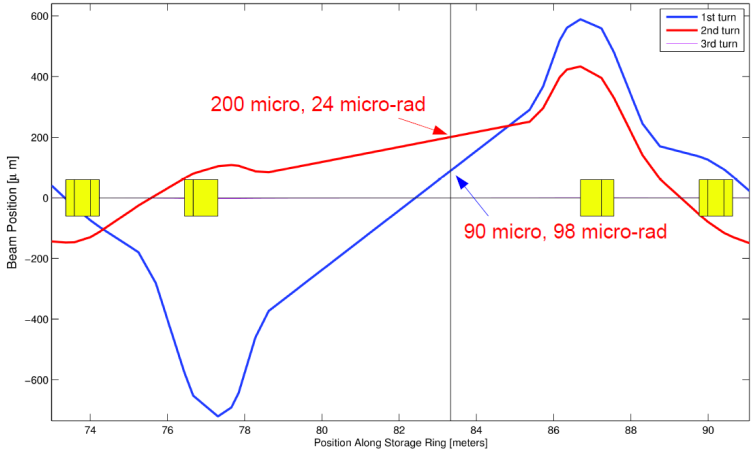
- **these "unwanted photons"**
  - **contribute to sample damage and**
  - **need to electronically rejected using a fast gated camera**

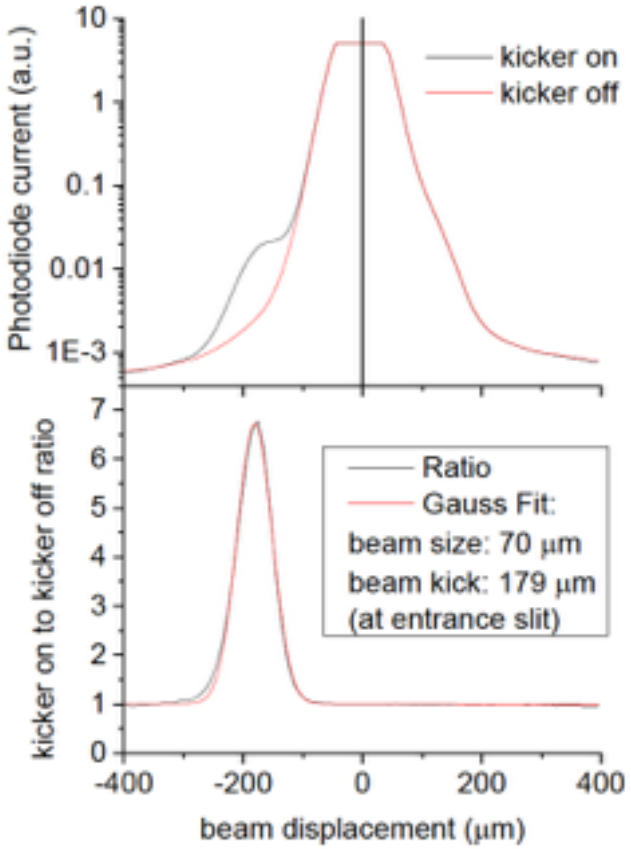
Beamline 6.0.2: PSB-KAC @ 4kHz with chopper

Measurement Condition (normal 500 mA)

- multibunch beam has 495 mA
- camshaft has 5mA
- chopper allows about 12 turns through

Beamline 6.0.2





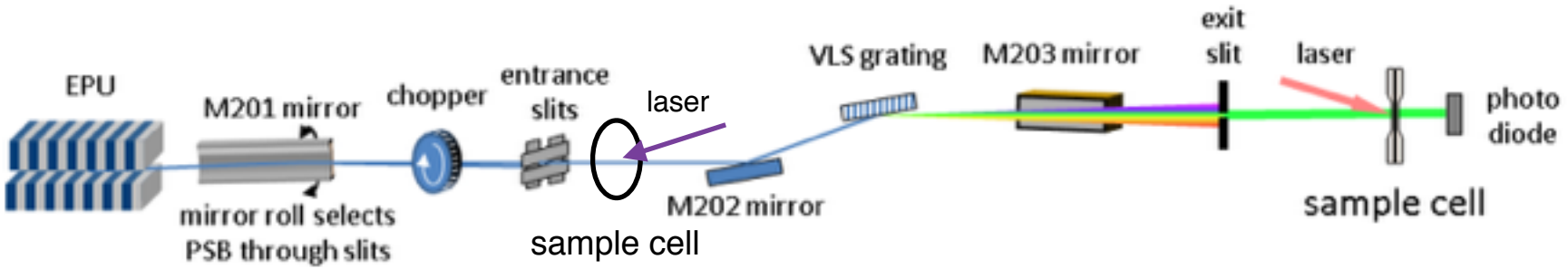
w/PSB-KAC: Signal-to-background is 1:1200
w/**PSB-KAC**: Signal-to-background is 7:1

~7000 times suppression of unwanted x-rays using PSB-KAC

Background suppression on 6.0.2

The mechanical chopper paired with PSB-KAC mode results in a total background suppression of more than 200,000

- **factor of ~30 from the chopper**
- **factor of ~7,000 from PSB-KAC**



Permitting low repetition rates and single shot experiments using integrating detectors

Attractive Features of PSB-KAC Mode

- Create isolated single pulses of light on demand
  - ✓ Reduce sample damage rate for timing experiments
  - ✓ Reduces signal to background and in some cases can allow the use of integrating detectors
- Compatible with multi-bunch operation
- Inexpensive and does not require a lot of real estate in the storage ring
- Can be used by multiple beam lines simultaneously (require coordination of the repetition rate)
- Complementary with other techniques such as choppers and perhaps VSR

Pseudo-single bunch is now in regular user operation at ALS

Acknowledgements

Like to thank Janos Kirz (former acting director of the ALS) and Kem Robinson (Engineering Division Director) for their support and funding.

THANKS FOR YOUR ATTENTION