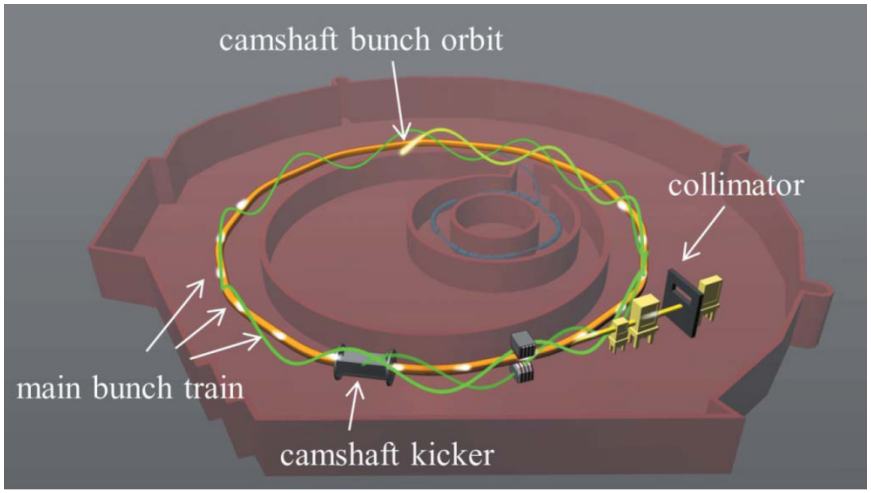
Realization of Pseudo Single Bunch Operation With Adjustable Frequency



Changchun Sun, David Robin, Christoph Steier
Greg Portmann,Marcus Hertlein,Mathew Marcus
May, 6th 2015

Advance Light Source (ALS)
Accelerator Accelerator Technology and Applied Physics Division (ATAP)
Lawrence Berkeley National Laborator (LBNL)

- *A new operational mode at the ALS that provides full timing and repetition rate control for single X-ray pulses while being fully transparent to other users of synchrotron radiation.*
- *It drastically improves signal-to-noise ratio and reduces sample damage rate for laser pump-probe and time-of-flight experiments.*

Outline

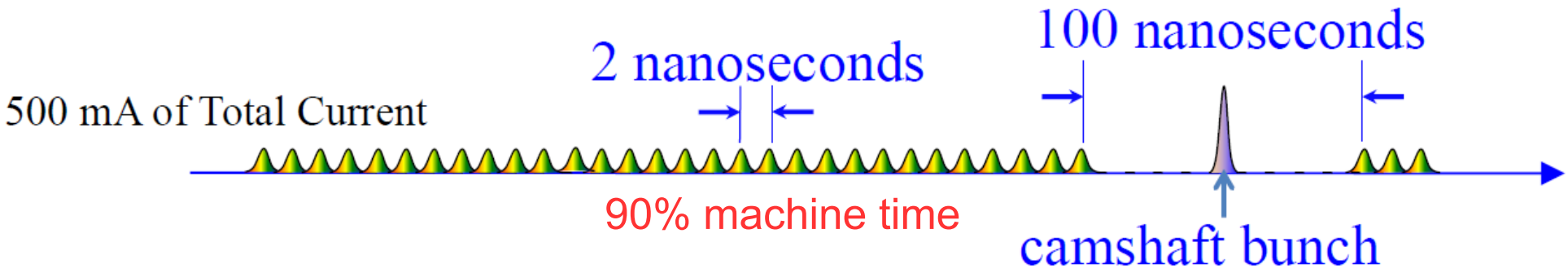
- Motivation
- Working Principle
  - What is Pseudo Single Bunch (PSB)?
  - What is Kick-And-Cancel (KAC) scheme?
  - Closed orbit and resonance condition of KAC
- Measurements
  - Camera measurements at diagnostic BL3.1
  - Turn-by-Turn (TbT) Beam Position Monitor (BPM)
  - X-ray pulse measurements with BL6.0.1 (single bunch)
  - X-ray pulse measurement at BL 10.3 (multi-bunch)
- Conclusions

Two classes of beam users with conflicting requirements

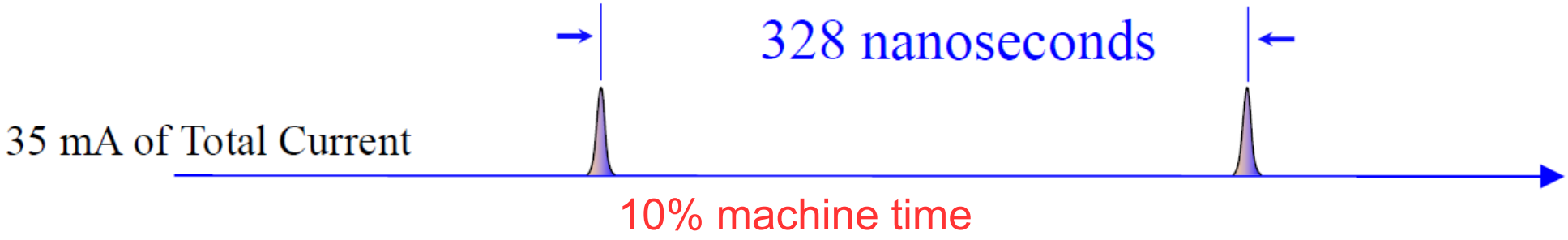
- High brightness/high flux experiments
  - Require to maximize the total current while minimizing the current per bunch in the storage ring
  - Require filling most of RF bucket—multibunch mode
  - The time spacing between each bunch is ~ns
- Time-of-flight/timing experiments
  - Require longer time spacing between x-ray pulses
  - Require to fill storage ring with high current in a few bunches
  - The time spacing between bunches is about few hundred ns

Two operational modes at ALS

Multi-Bunch with Single Camshaft Mode For High Flux Experiments



Two-Bunch Mode For Timing Experiments

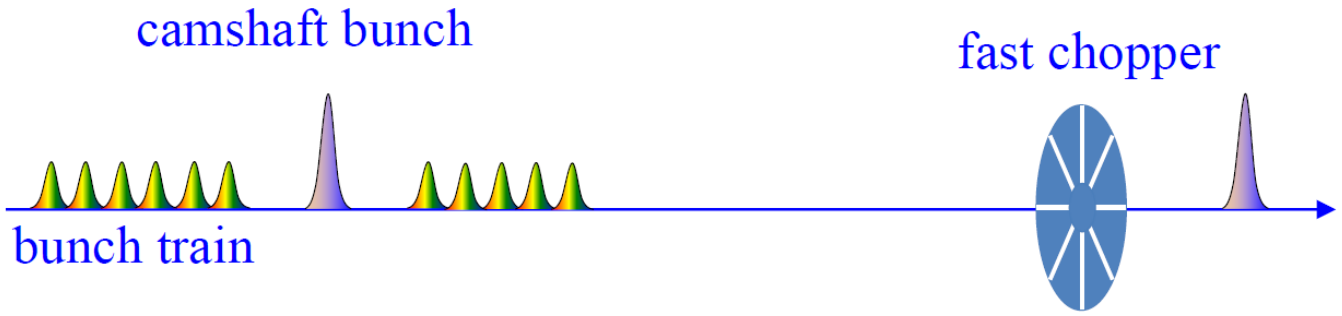


Can we satisfy both beam users at the same time?

If we can isolate the single camshaft bunch from the main bunch train, the timing experiment can use the light from isolated single bunch, and high flux experiment use the light from main bunch train.

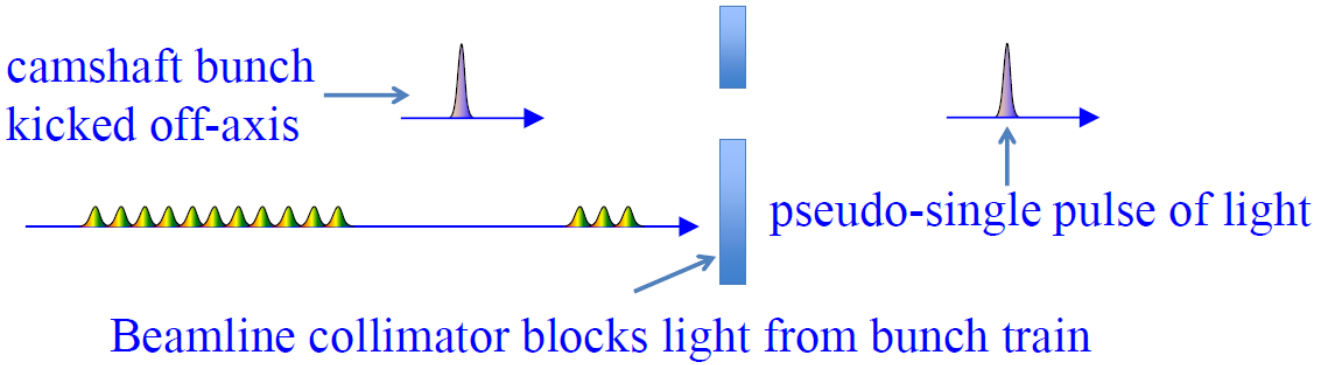
Methods of isolating single bunches

(a) Temporal separation using chopper



Possible for a large ring with kilometer circumference, not achievable for ALS

(b) Spatial separation using kicker & aperture



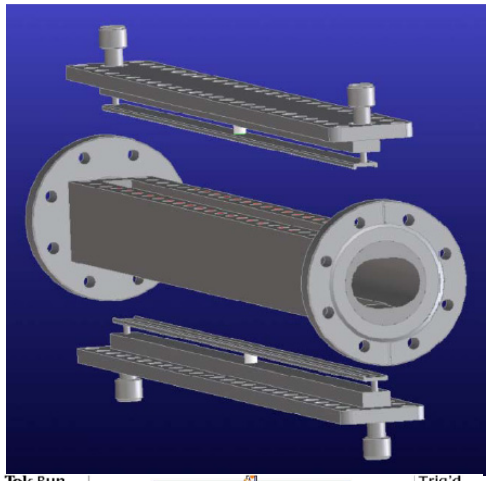
Camshaft kicker

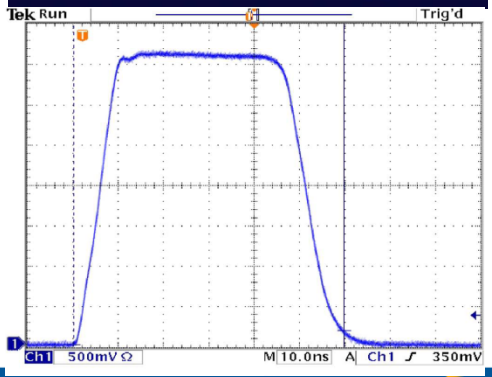
Proceedings of EPAC 2006, Edinburgh, Scotland THPLS114

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

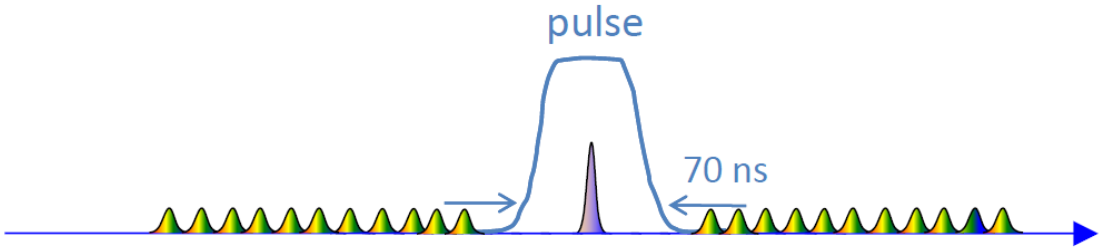
S.Kwiatkowski, K. Baptiste, W. Barry, J. Julian, R. Low, D. Plate, G. Portman, D.Robin
LBNL, Berkeley, CA, 94720, USA

* Kem Robinson for financial support for building the kicker.





- It is a stripline kicker
- High repetition rate up to turn by turn (~1.5 MHz)
- Short pulse duration (FW ~70 ns) without kicking the main bunch



- Cannot change kick strength and polarity in a fast way
- Flexible to change the pulse repetition rate and pattern

Two schemes to displace bunch

1. Closed-Orbit-Distortion (COD) scheme

- The bunch is permanently put on a different orbit
- Continue kicking every *n* turns to maintain the separation
- Orbit retraces itself every n turns (the pulse repetition rate is fixed, given by 1.5MHz/*n*)

2. Kick-And-Cancel (KAC) scheme

- The bunch is temporarily put on a different orbit
- Kick the bunch off axis, and then kick it back in next few turns.
- Pulse repetition rate is adjustable

Kick-And-Cancel (KAC) scheme

Goal:

Allow beam-line users to receive a single pulse of x-rays with adjustable frequency from Hz to MHz, while maintaining full beam for other beamlines.

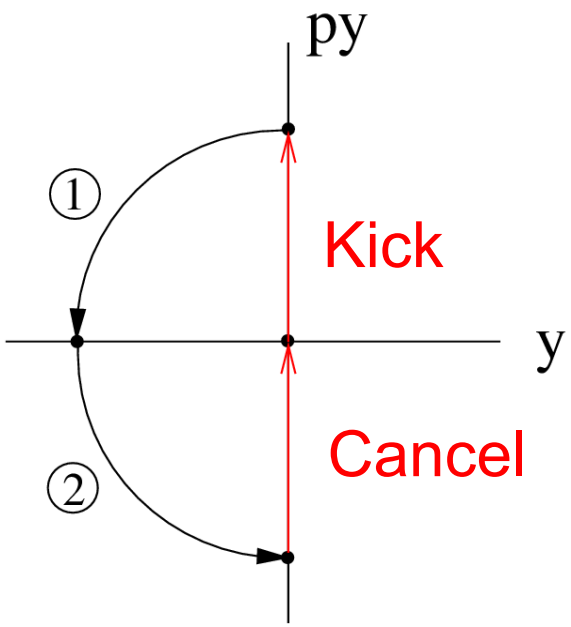
How:

By adjusting the ring tune and the camshaft kicker kick pattern, we can distort the orbit of the bunch and then correct it back within a few turns.

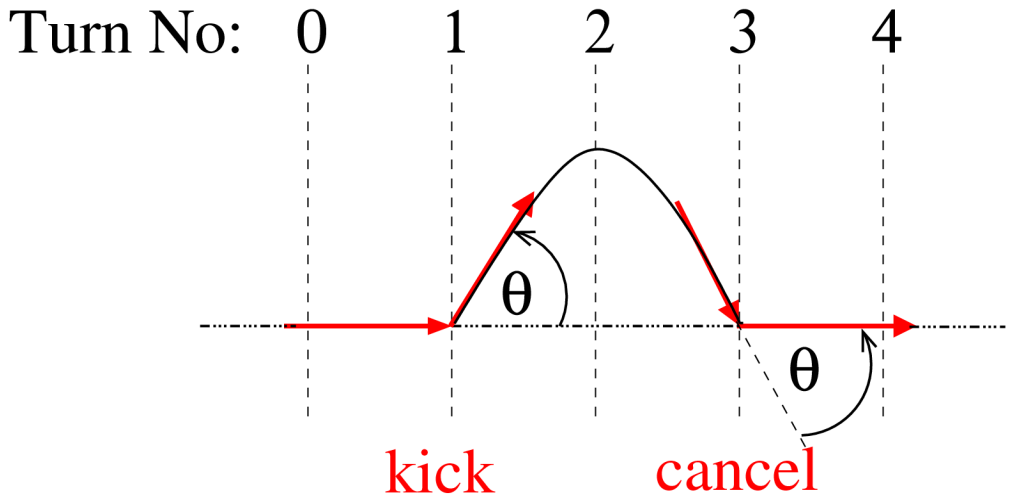
KAC scheme is illustrated in the following animation:

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

Kick-And-Cancel (KAC) scheme at Tune of 0.25

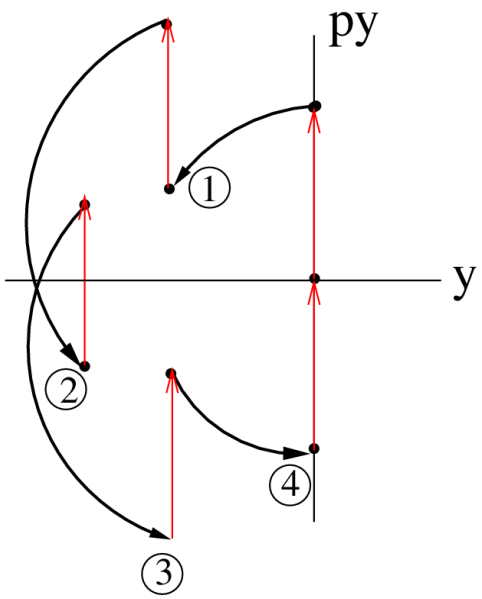


TuneY = 0.25

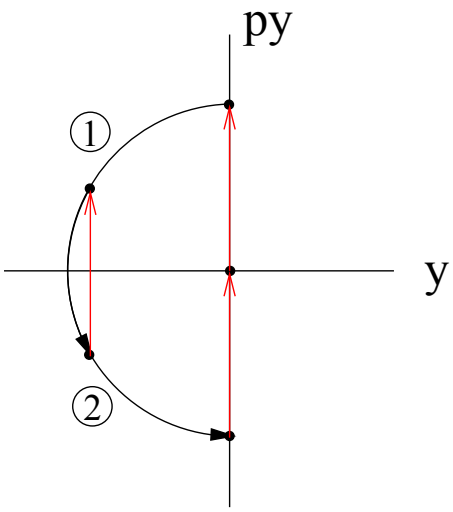


TuneY = 0.25

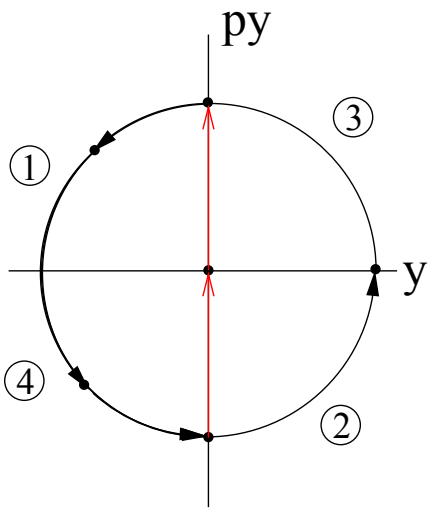
KAC scheme at other tunes



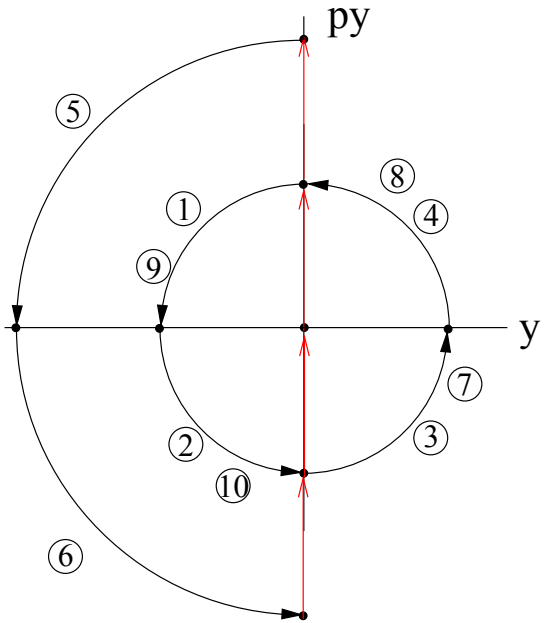
TuneY = 0.2



TuneY = 0.333



TuneY = 0.375

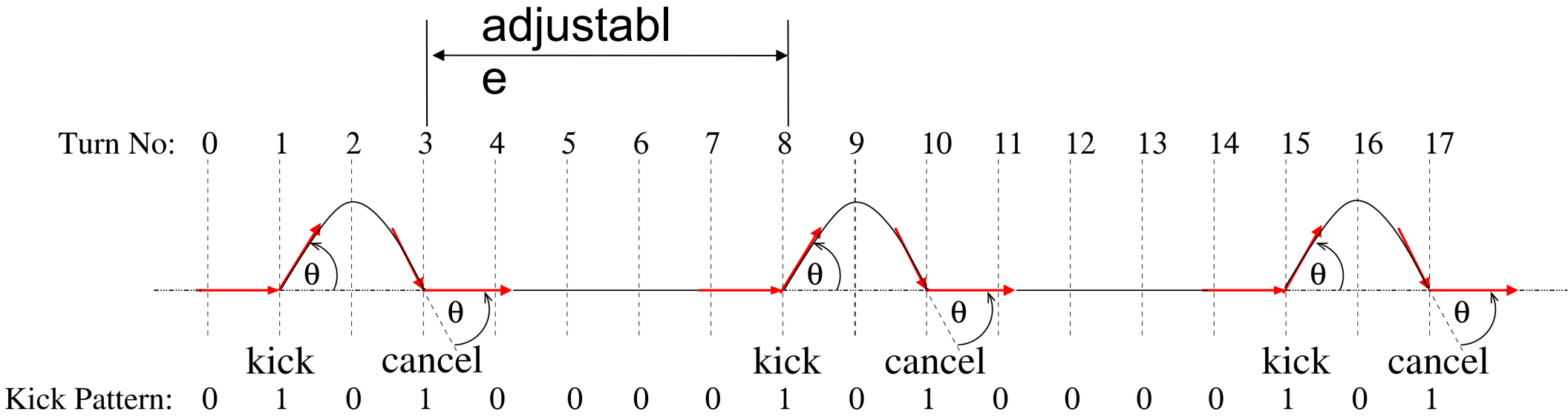


TuneY = 0.25

- Thousand solutions have been found.

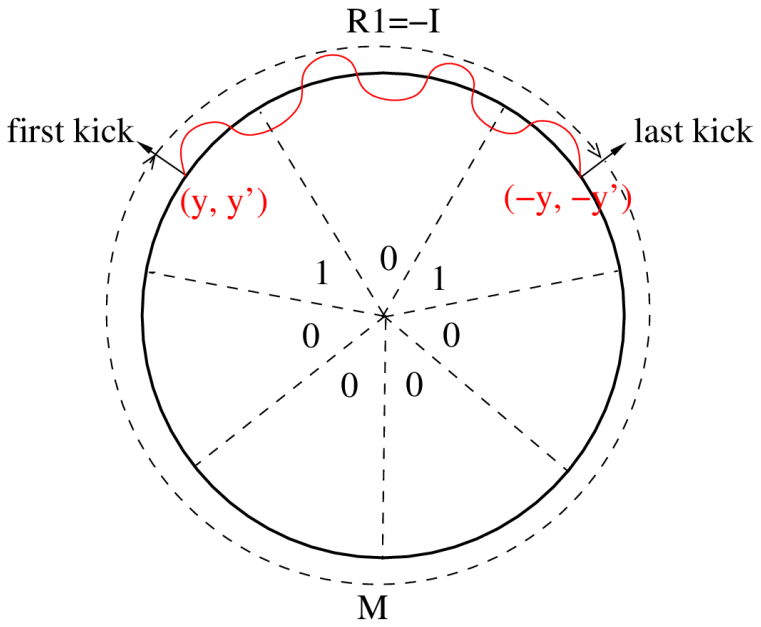
Kick-and-Cancel mode with adjustable frequency

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.

Closed orbit and resonance for KAC



The KAC beam orbit is a stable Closed-orbit distortion.

Closed orbit condition:

$$\begin{pmatrix} y \\ y' \end{pmatrix} = (\mathbf{M}) \times \begin{pmatrix} -y \\ -y' \end{pmatrix}$$

Two solutions:

1. M is -I, the total number of ring is a multiple of 4 --->(y,y') = any values Avoid
2. Otherwise, (y,y') = (0,0) -----> The orbit is a KAC closed orbit. OK

In general, we need to avoid the following resonance for a stable KAC operation:

$$m_x(\mathrm{N}\nu_\mathrm{x}) + \mathrm{m_y}(\mathrm{N}\nu_\mathrm{y}) = \mathrm{n}$$

Tunes of multi-turn ring

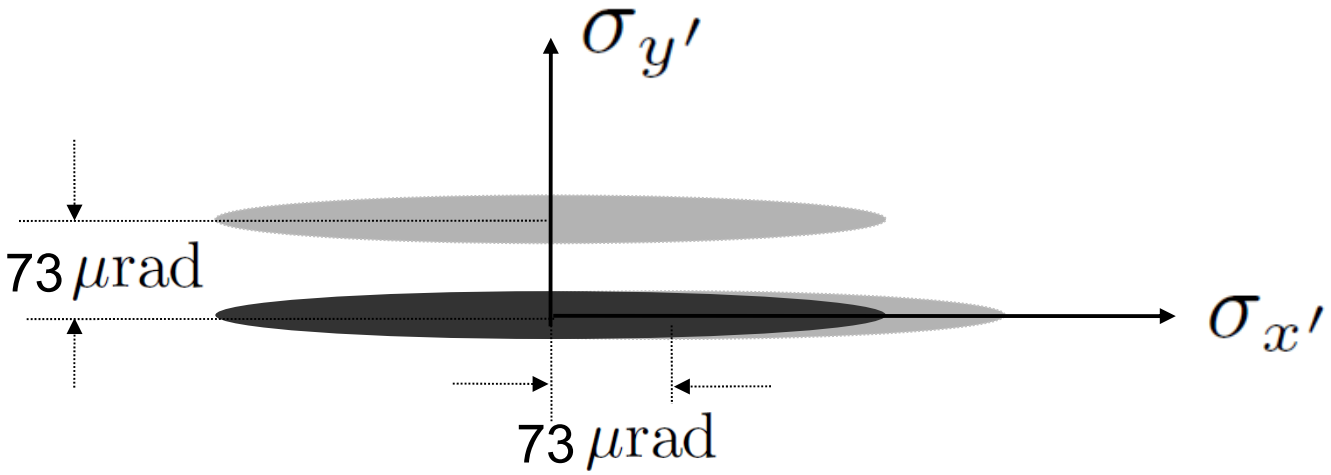
Why vertical kick instead of horizontal kick?

The maximum kick angle provided by kicker is $73\,\mu\text{rad}$

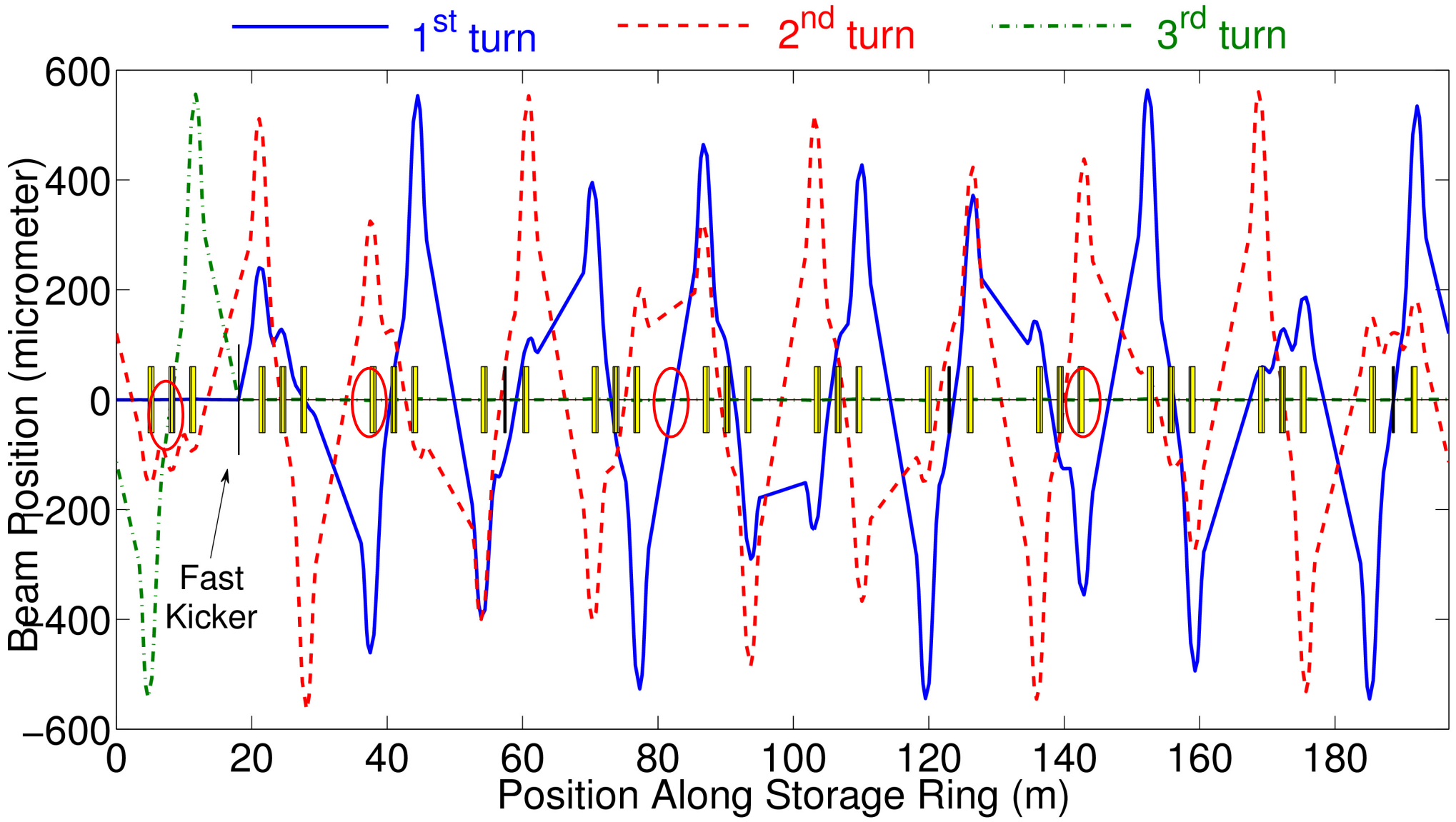
Beam size and divergence at the kicker location:

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

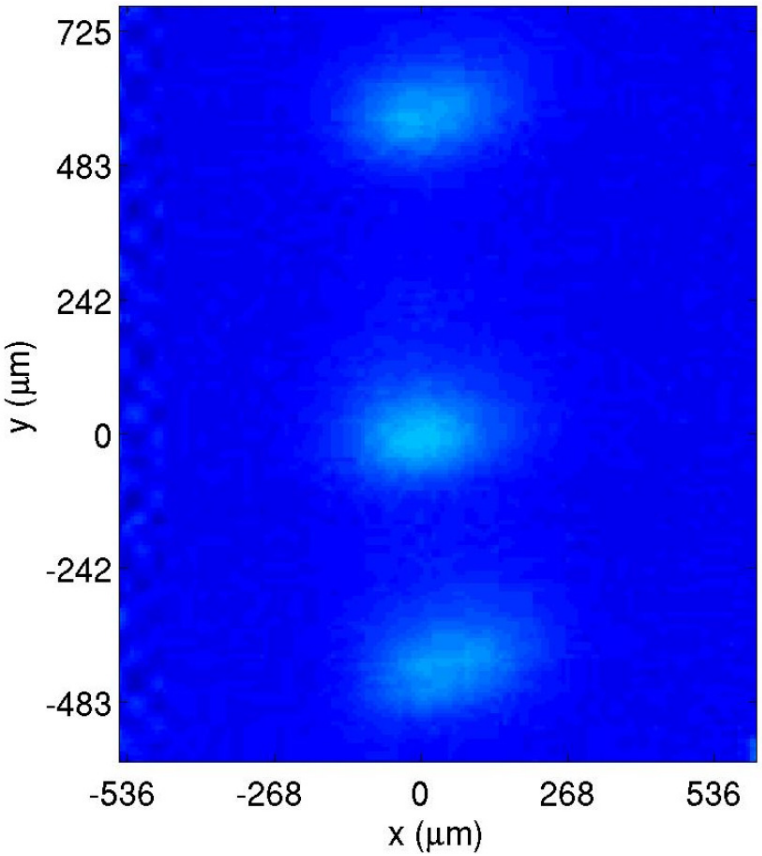


Simulated orbit offset along the ALS ring



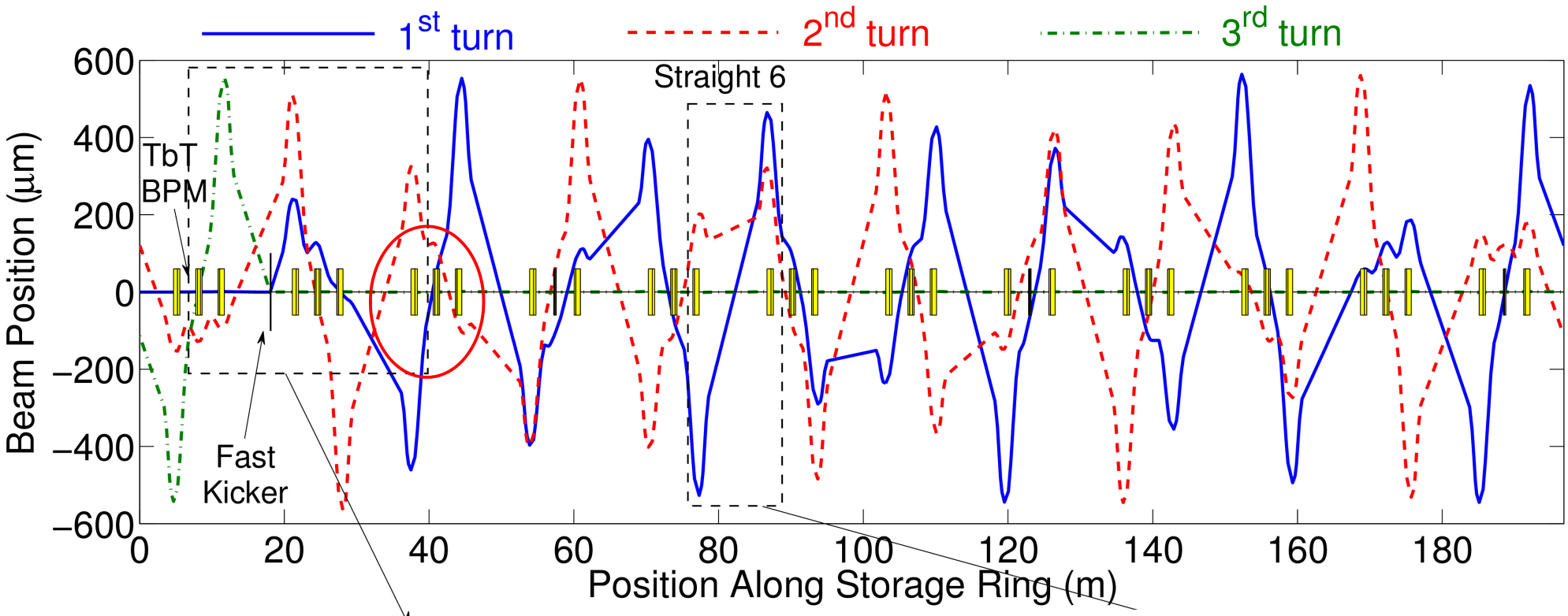
73 urad kick angle

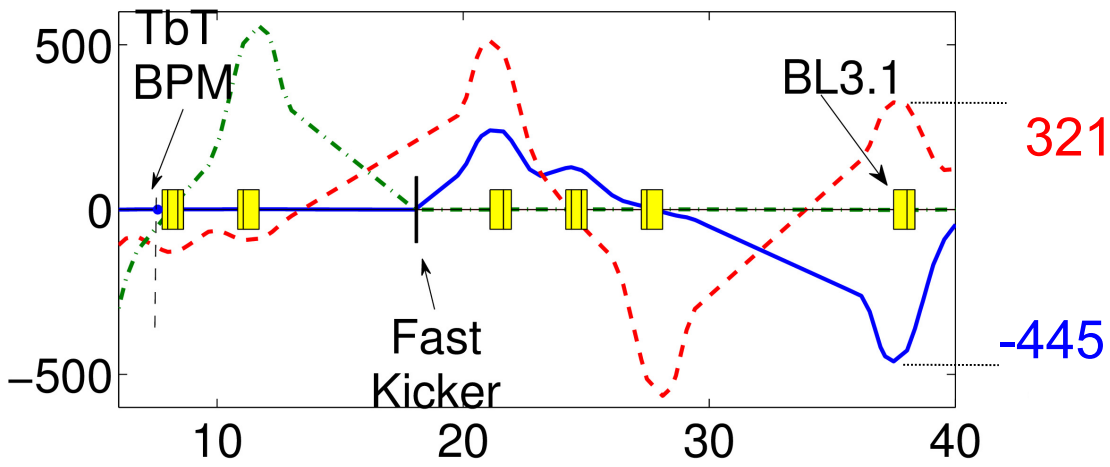
Part II: Measurements



1) Measurement at diagnostic BL3.1
2) Measurement using Turn-by-Turn (TbT) BPM
3) X-ray pulse measurement with BL6.0.1
4) X-ray pulse measurement with BL10.2

Orbit at diagnostic BL3.1



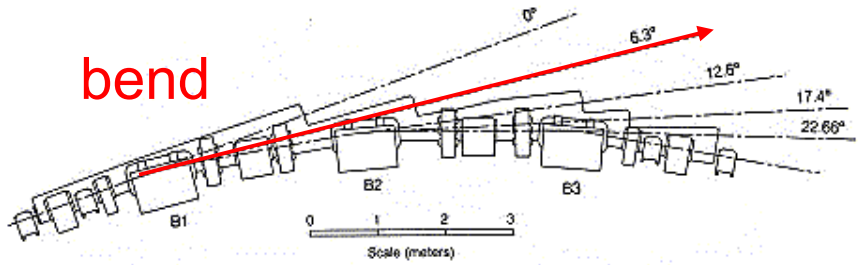


321

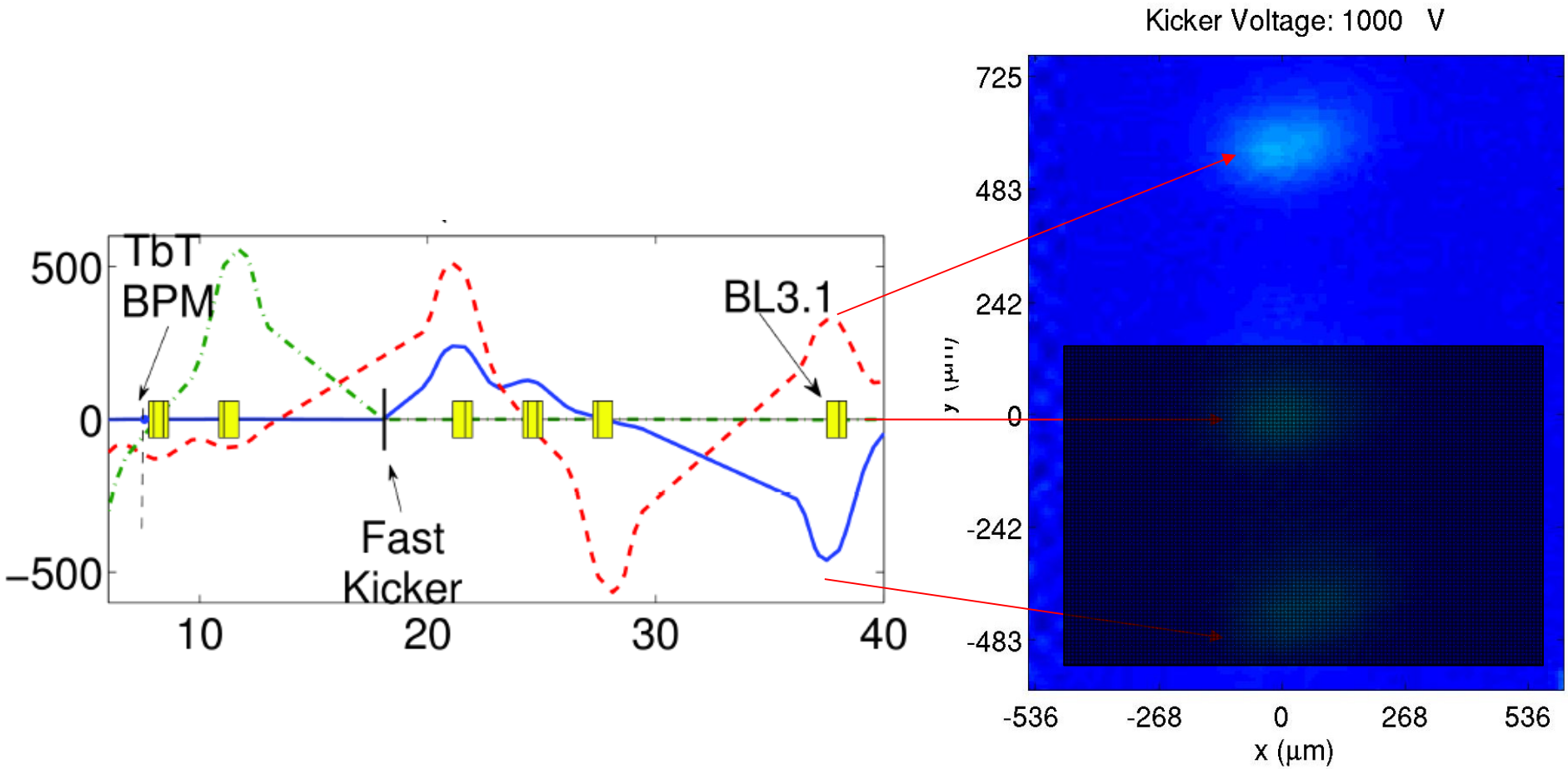
-445

BL3.1

bend

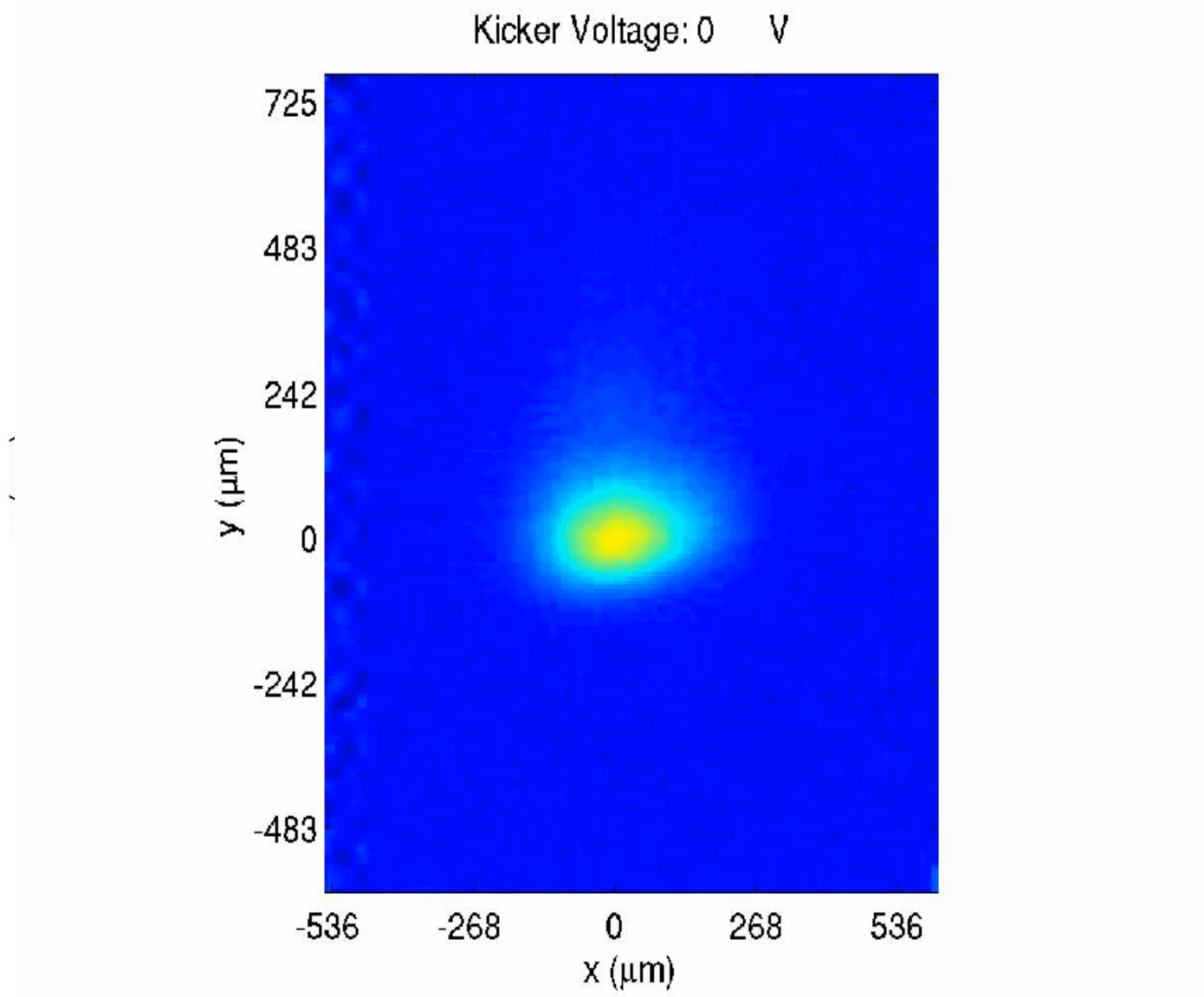


Orbit separation at diagnostic BL3.1



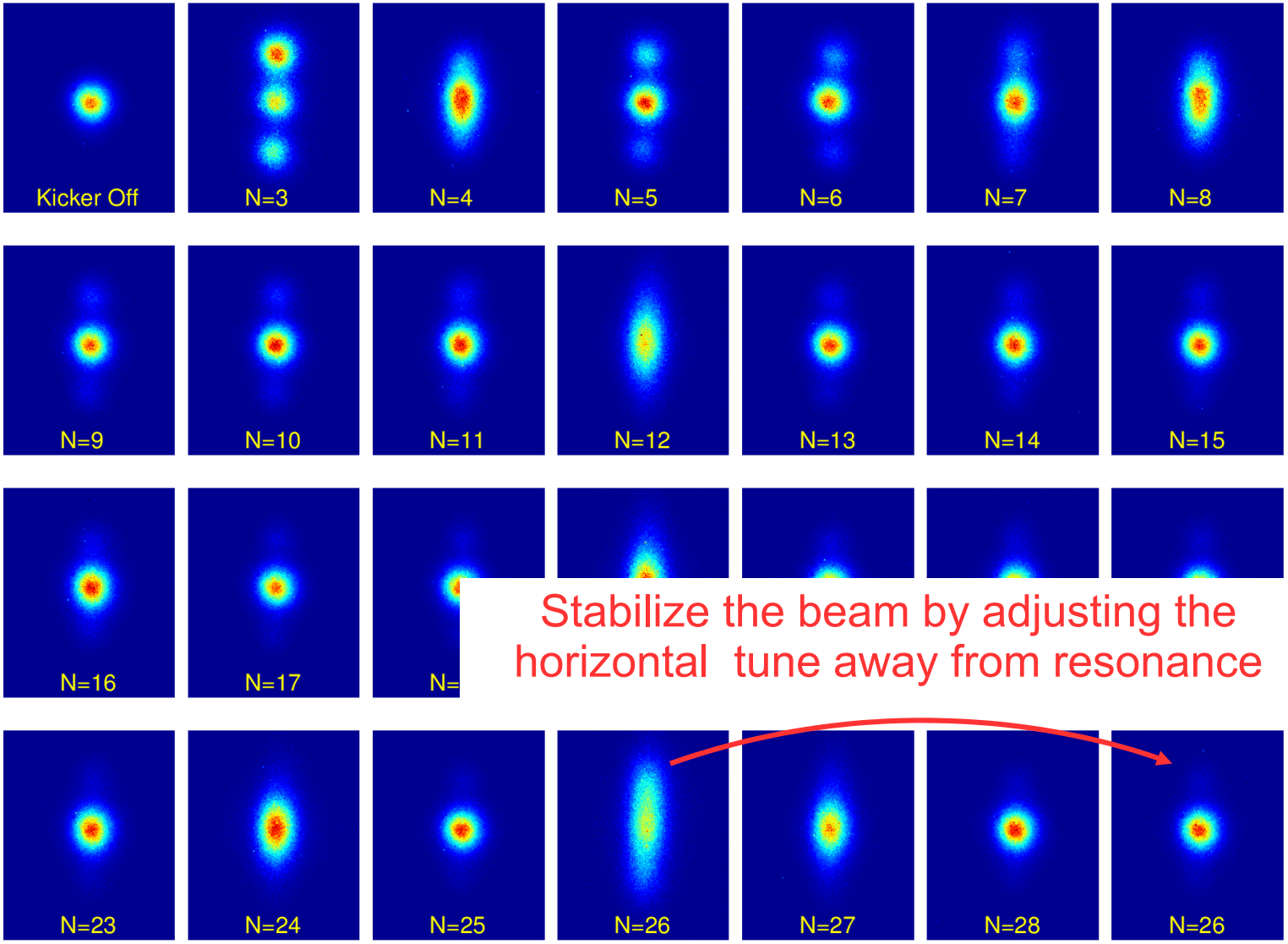
- One bunch filled in the ring
- Orbits are displaced on both sides of the axis
- Maximum KAC frequency 500 kHz,one third of the ring revolution freq
- Each beam spot repeats every third turn

Orbit separation vs kick amplitude



The orbit separation is increased as we increase the kick amplitude

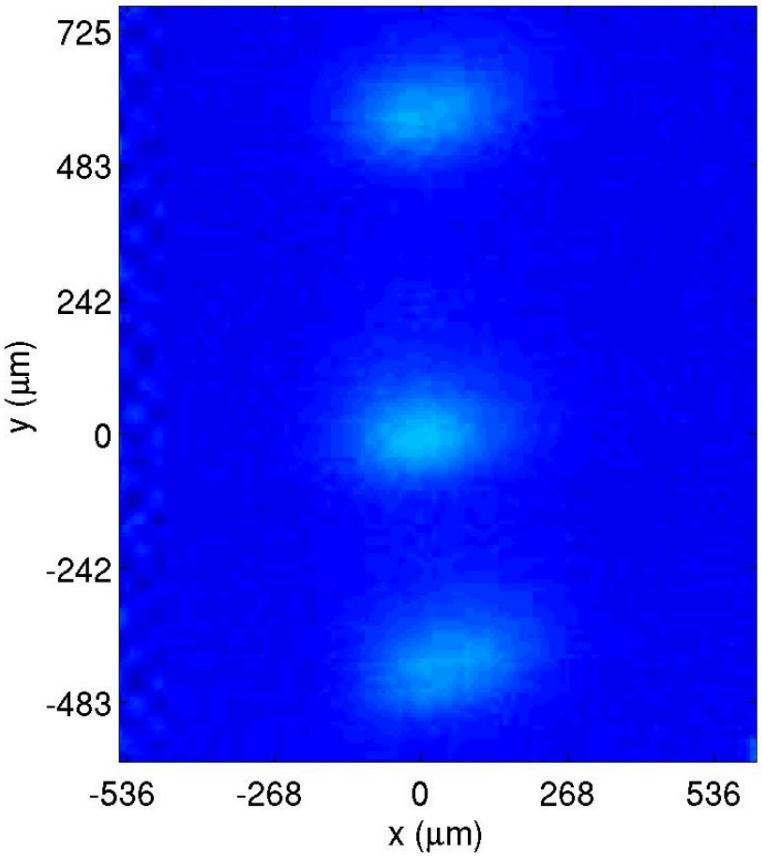
Beam images at difference KAC frequency



Beams are stable at most of the KAC frequency, but unstable when approach some resonance.

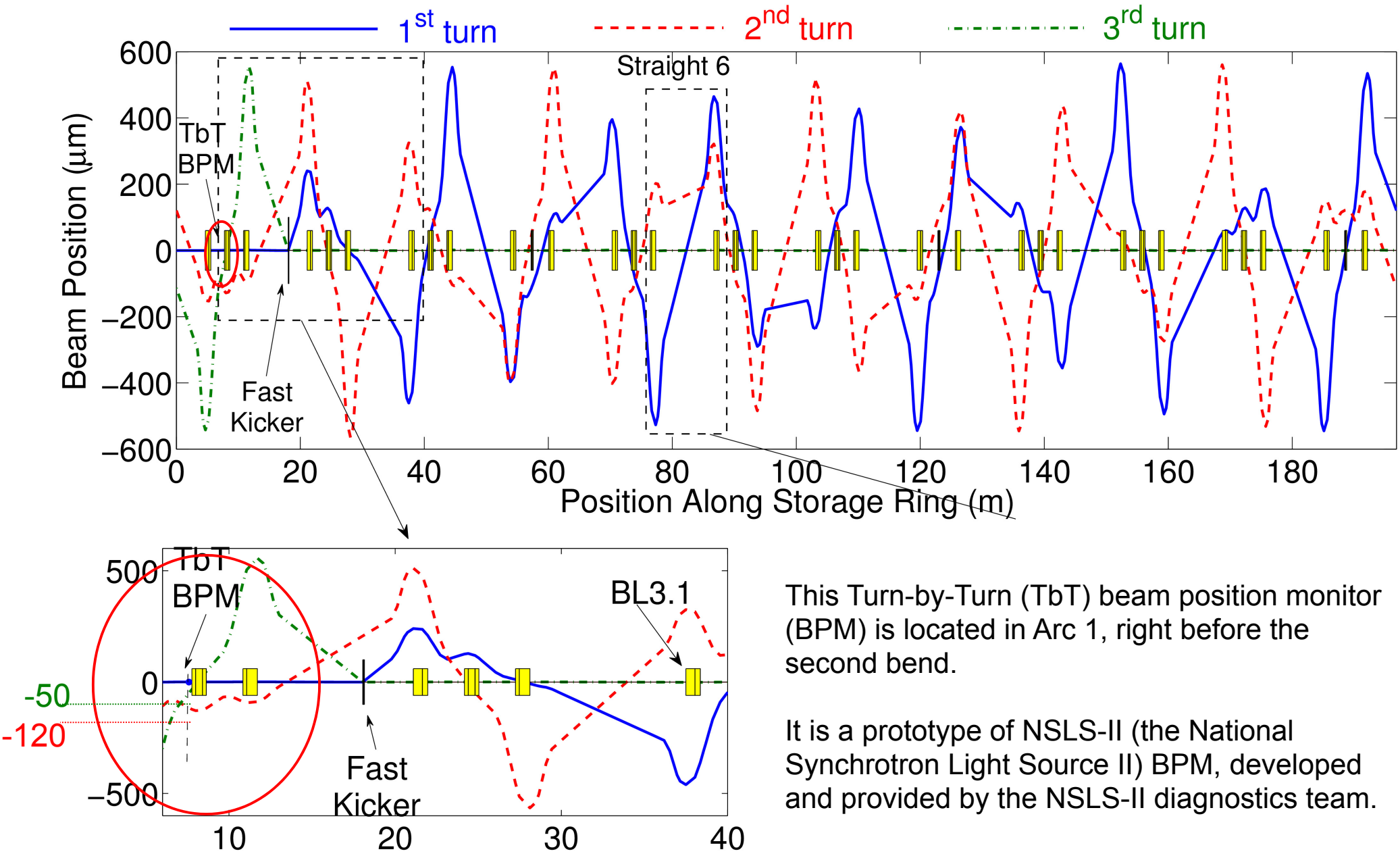
$$m_x(\mathrm{N}\nu_\mathrm{x}) + \mathrm{m_y}(\mathrm{N}\nu_\mathrm{y}) = \mathrm{n}$$

Part II: Measurements



1) Measurement at diagnostic BL3.1
2) Measurement using Turn-by-Turn (TbT) BPM
3) X-ray pulse measurement with BL6.0.1
4) X-ray pulse measurement with BL10.3

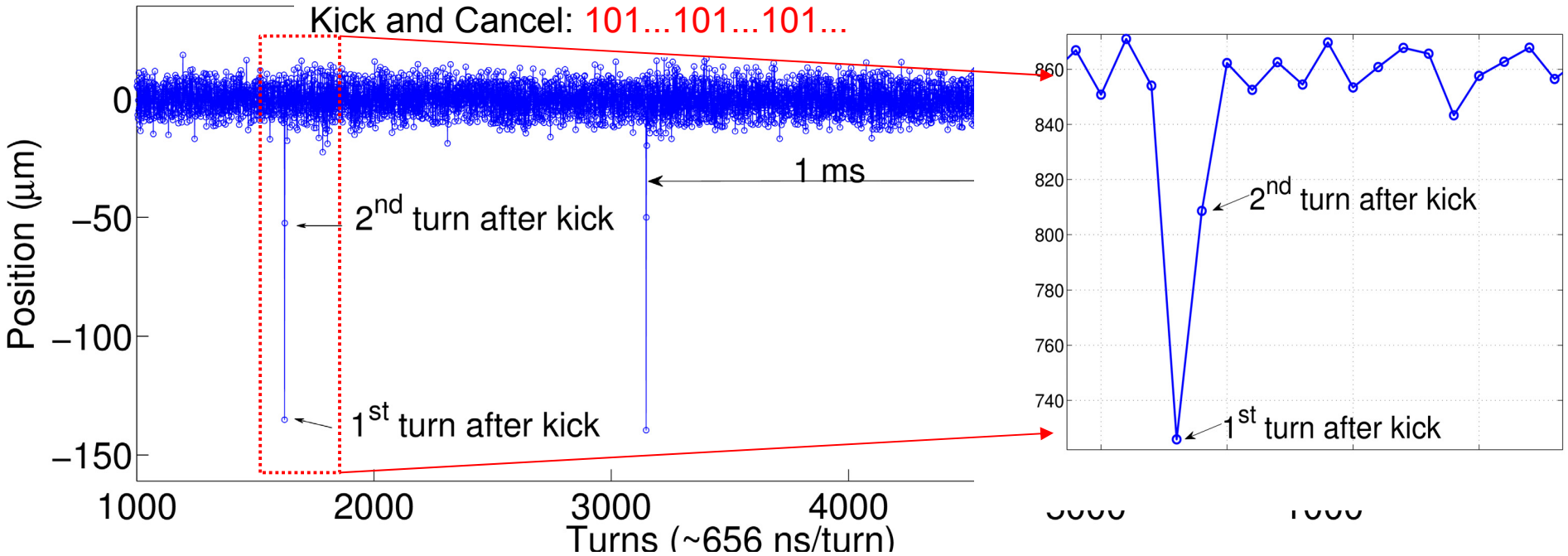
Orbit at TbT BPM location



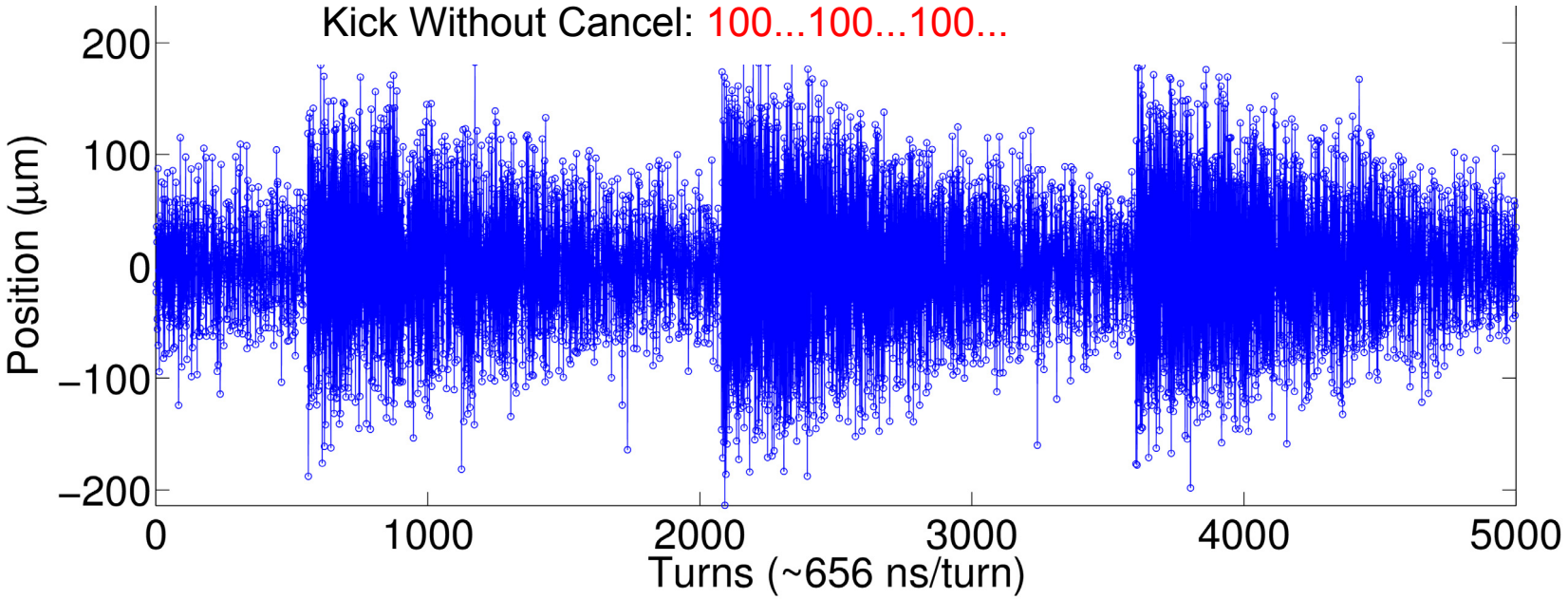
This Turn-by-Turn (TbT) beam position monitor (BPM) is located in Arc 1, right before the second bend.

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

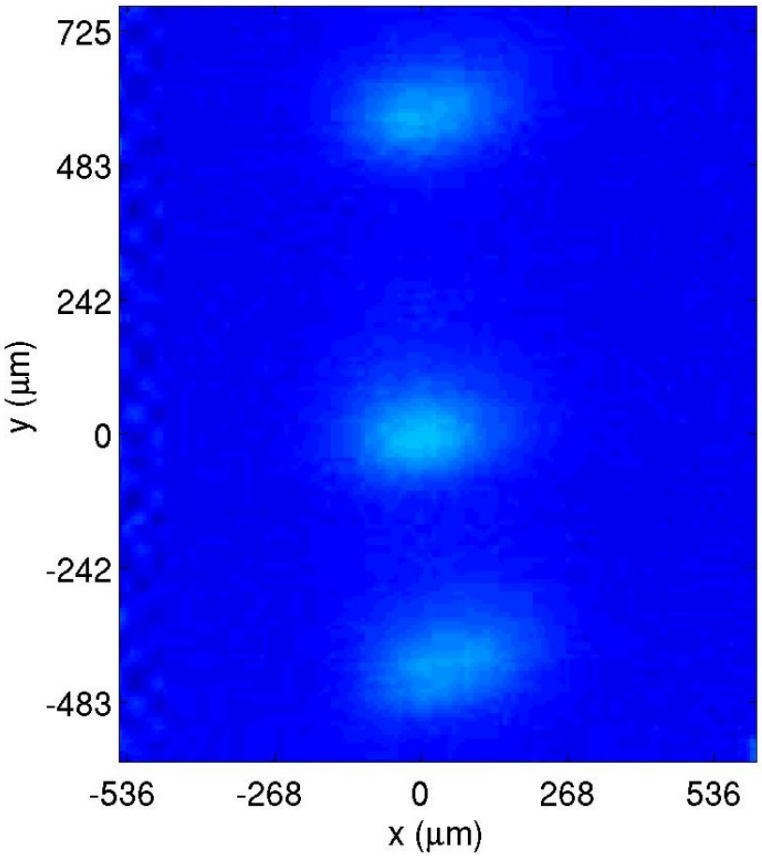
Turn-by-Turn BPM signals



A 10 mA two consecutive bunches was filled in the storage ring.



Part II: Measurements



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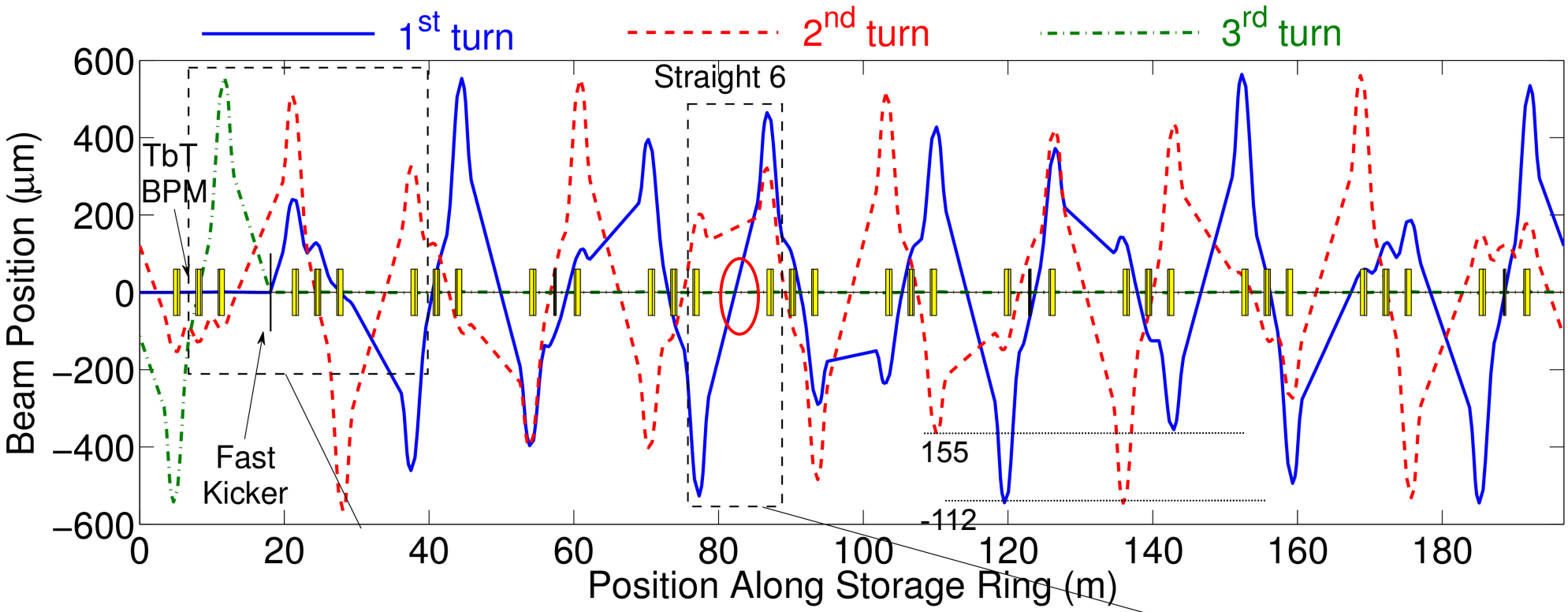
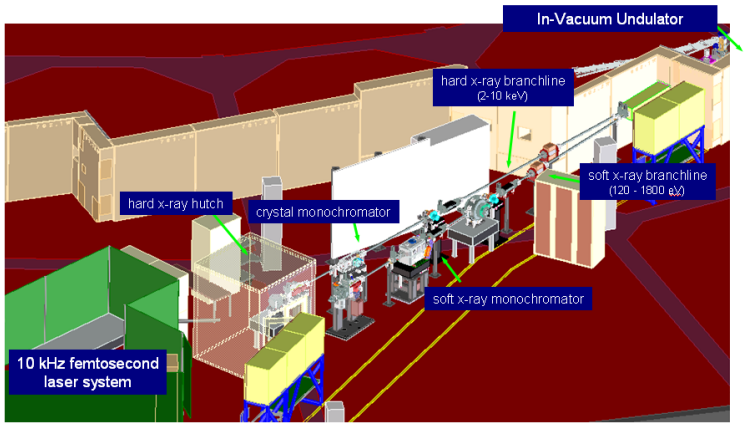
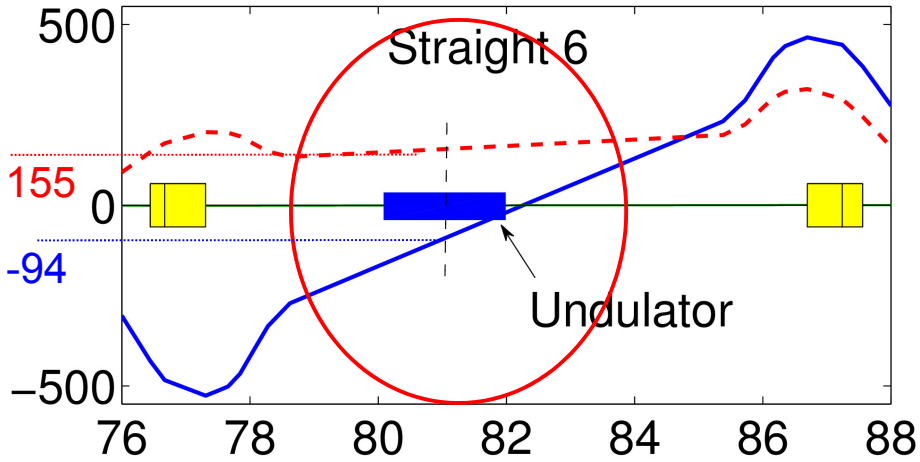
3) X-ray pulse measurement with BL6.0.1
4)X-ray pulse measurement with BL10.3

Orbit at beamline 6.0.1

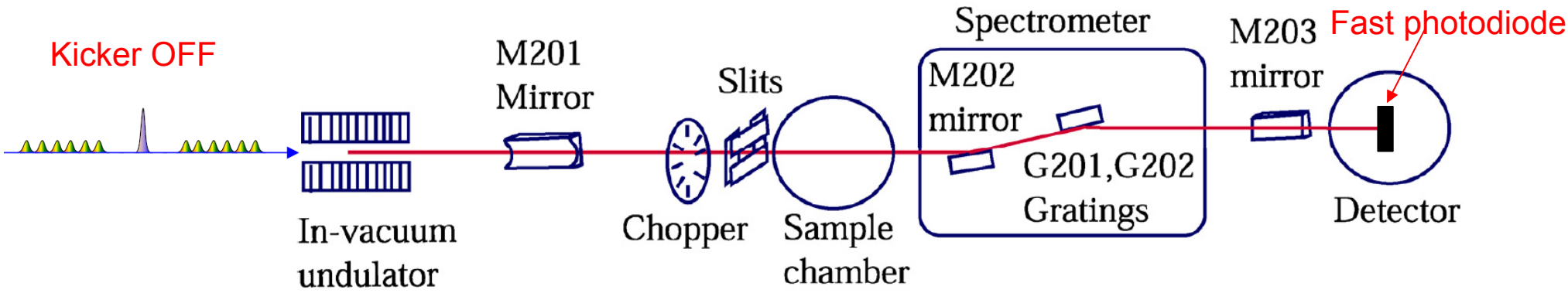




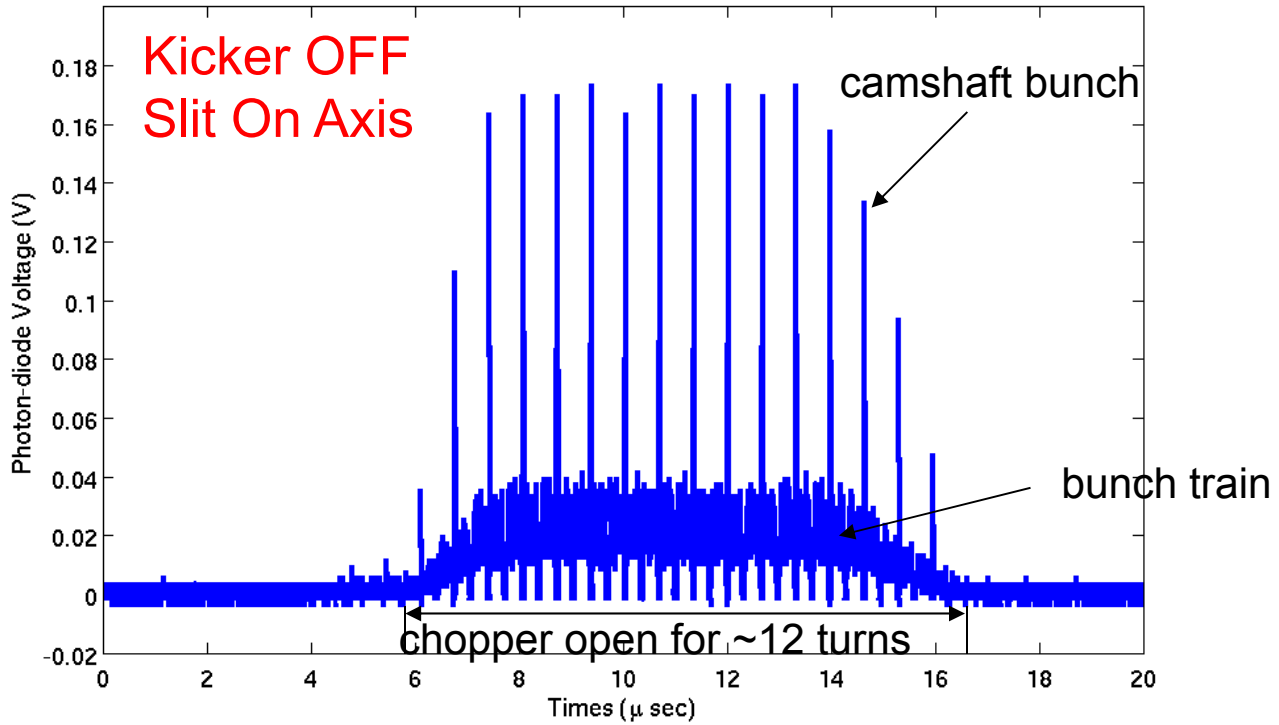


BL 6.0.1: Ultrafast / Femtosecond Dynamics Hard X Ray

Measurement at beamline 6.0.1

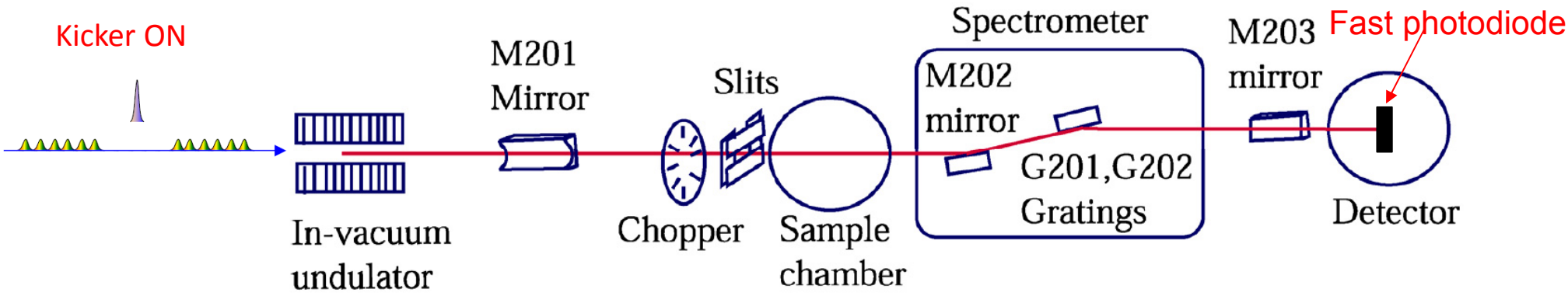


Ring filled to 52mA with multibunch and 3.7mA camshaft

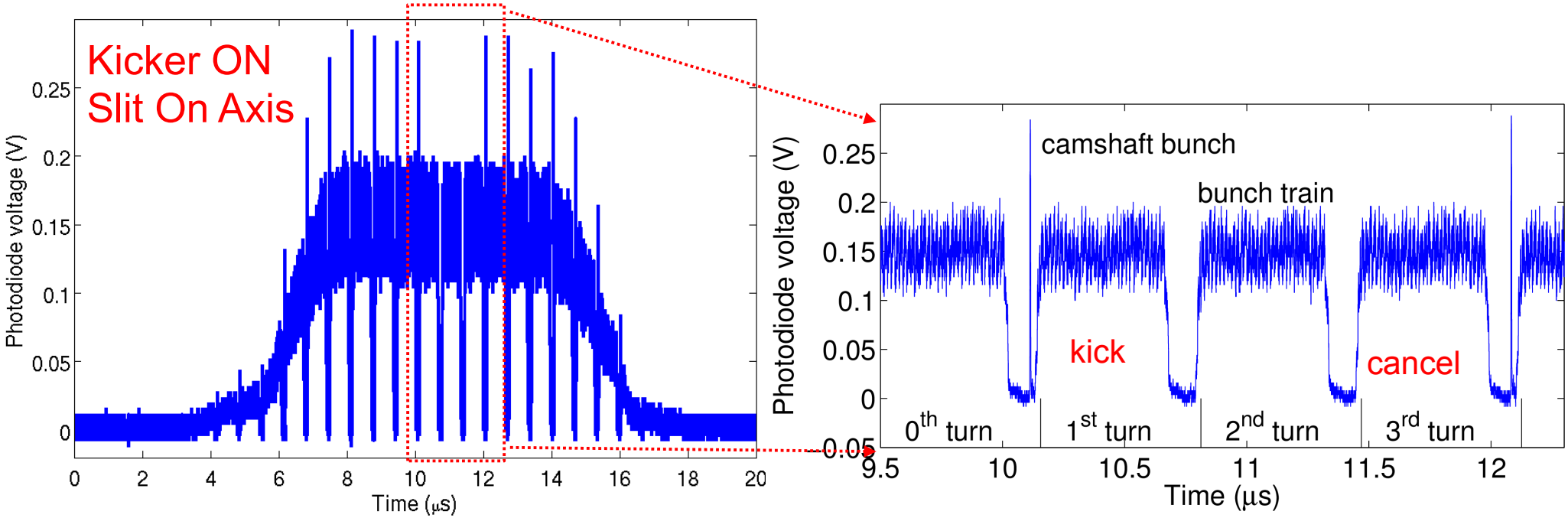


A typical x-ray pulses measured using gated photodiode

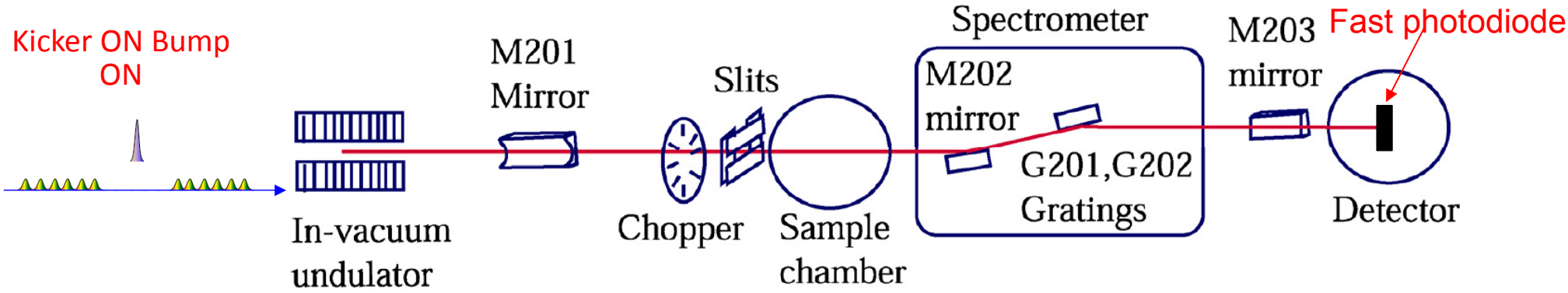
Measurement at beamline 6.0.1



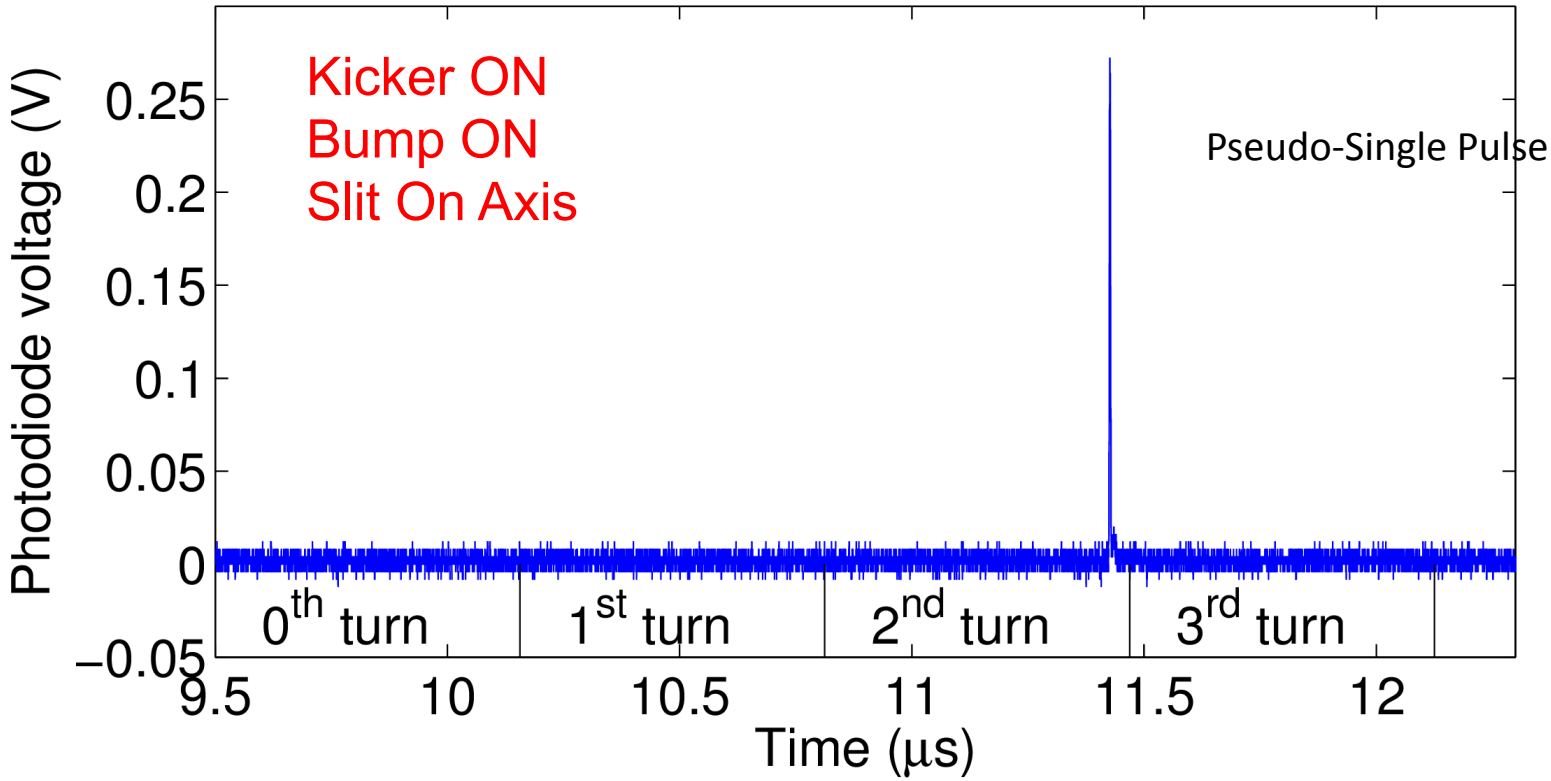
Ring filled to 276 mA with multibunch and 5 mA camshaft.



Measurement at beamline 6.0.1

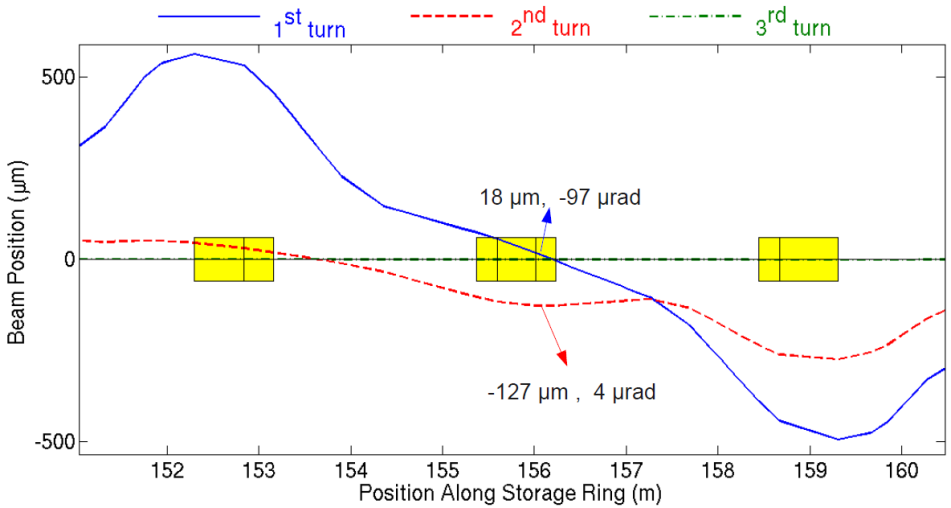


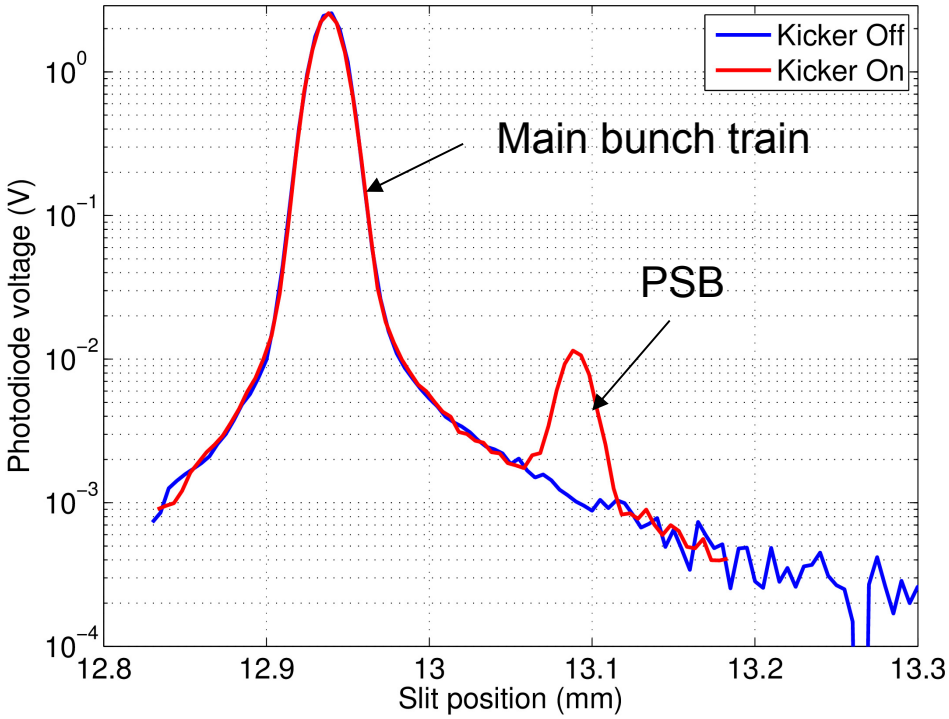
Ring filled to 276 mA with multibunch and 5 mA camshaft.



Measurement at beamline 10.3

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

Attractive features of PSB-KAC mode

- Create a single pulses of light on demand
  - Allow it to be matched with the user experiment timing
  - Reduce sample damage rate and signal to background ratio
  - Allow the use of integrating detectors
- Compatible with multi-bunch operation
- Inexpensive and does not require a lot of space in the ring
- Can be used by multiple beam lines simultaneously

PSB-KAC has been in regular user operation at ALS since 2013.

Acknowledgments

- ALS Accelerator Physics Group Members and Janos Kirz
- BL6.1.2, Peter Fischer and Mi-Young Im
- BL6.0.1, Marcus Hertlein, Andreas Scholl and Amy Cordones-Hahn
- BL10.3.2, Mathew Marcus
- BL11.0.2, Tolek Tyliszczak
- BL12.3.2, Martin Kunz
- SLAC, Jeff Corbett and Kai Tian

Thank you!