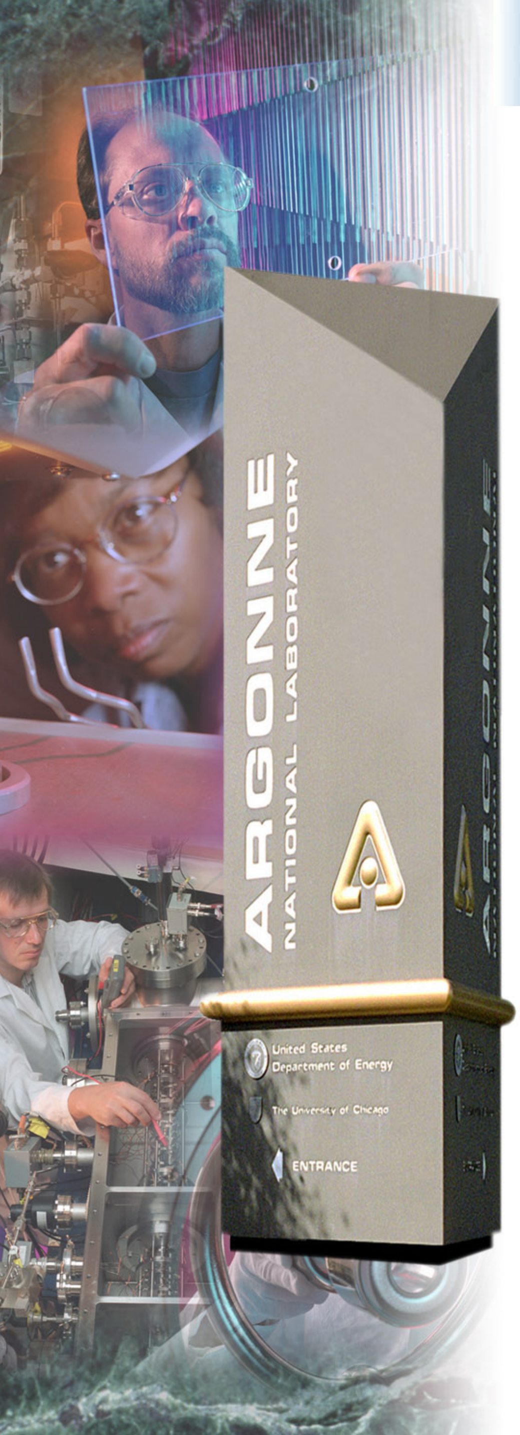

Short Pulse Generation Through Beam Manipulation

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Advanced Photon Source

ICFA mini-workshop on Frontiers of Short Bunches in Storage Rings (SBSR05)

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- Chun-xi Wang – beam dynamics
- Bingxin Yang – optical streak camera diagnostics
- Linda Young – ANL chemist, APS user (short-pulse demo exp.)

Outline

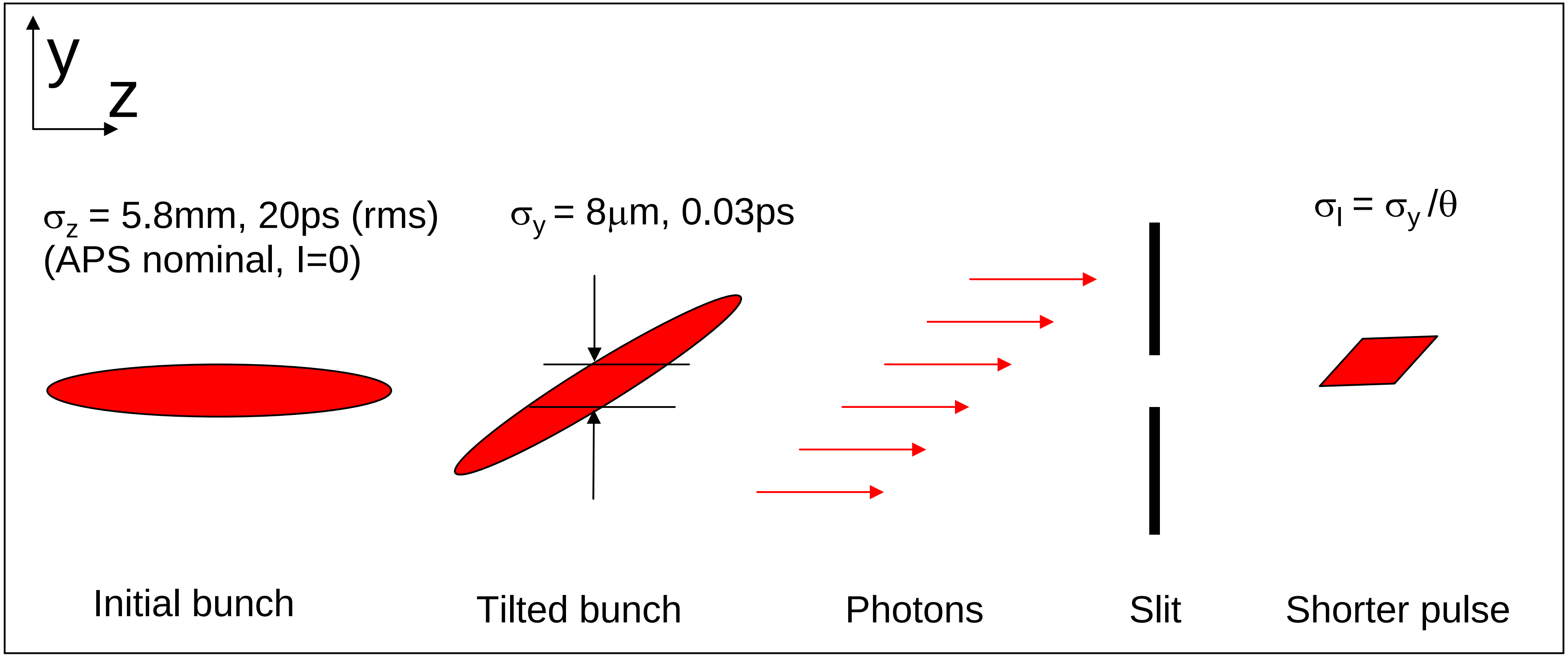
- Introduction
- Synchrobetatron coupling scheme
- Simulation vs. experimental results
- Short-pulse demonstration experiment
- Summary

Introduction

- Inspired by
  - Zholents' rf deflection method [1] for producing short x-ray pulses
  - Feasibility study at APS [2,3]
- Synchrobetatron coupling idea old [4], but Weiming Guo's idea to use it to "chirp" the bunch, like the rf deflection scheme, is new [5]

1. A. Zholents, P. Heimann, M. Zolotorev, J. Byrd, NIM A 425, 385 (1999).
2. K. Harkay et al., "Generation of Short X-Ray Pulses Using Crab Cavities at the Advanced Photon Source, " Proc. 2005 PAC.
3. M. Borland, Phys. Rev. ST Accel. Beams, 074001 (2005).
4. D. Edwards, R.P. Johnson, F. Willeke, Part. Accel., **19**, 145 (1986); R.E. Miller et al., SSC Report SSC-N-360 (1987); I.C. Hsu, Part. Accel., **34**, 43 (1990); S.Y. Lee, SSC Report SSC-N-749 (1991); J. Shi, S. Ohnuma, Proc. 1993 PAC, 3603 (1993); E. Kim, M. Yoon, Jpn. J. Appl. Phys., **40**, 4237 (2001).
5. W. Guo et al., "Generating ps x-ray pulses with beam manipulation in synchrotron light sources, " Proc. 2005 PAC; full paper in preparation.

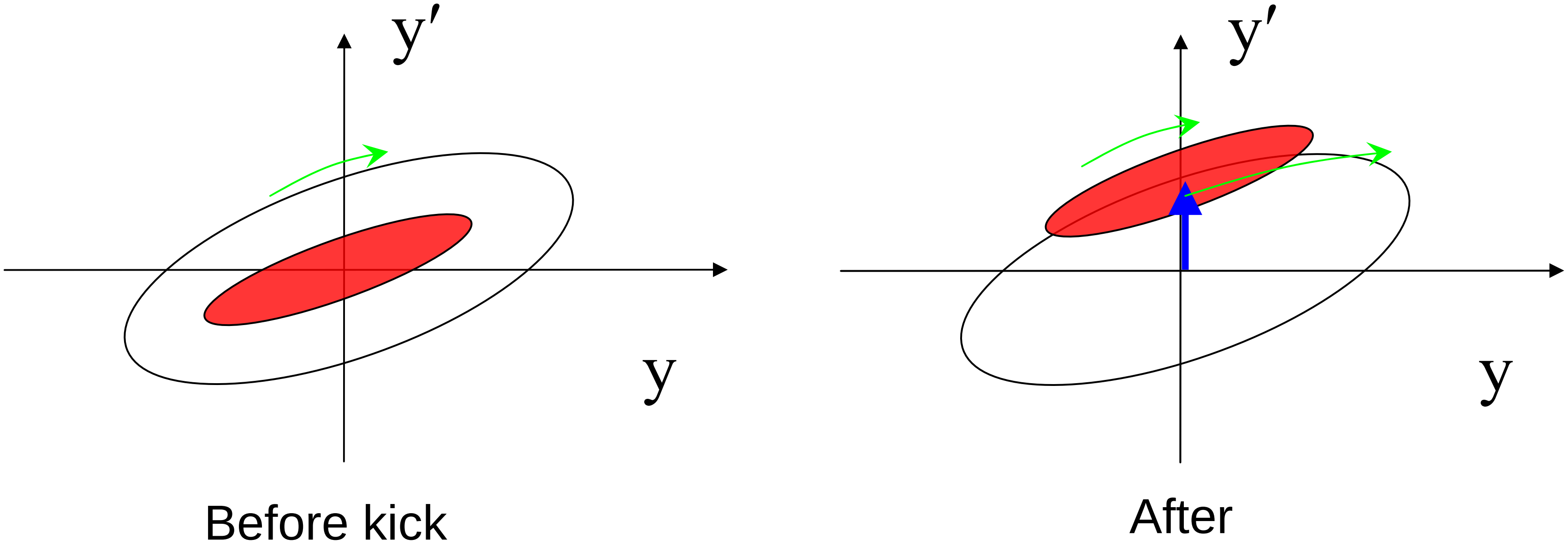
Short x-ray pulses from a chirped bunch



Cavity kick → Betatron oscillation → $A(z) \sin(\nu_x \theta + \psi)$

Magnet kick → Synchrobetatron coupling → $A \sin(\nu_x \theta + \psi(z))$

Particle Motion After a Vertical Kick



Betatron Oscillation

$$y = \sqrt{\beta(s)\beta(K)}\Theta \sin(\nu_y\theta + \Psi(s)) + \sqrt{\beta(s)\varepsilon_y} \sin(\nu_y\theta + \Psi(s) + \Psi_0)$$

Y-z correlation by synchrobetatron coupling

Vertical tune

$$\nu_y = \nu_0 + C_y\delta + \cdots$$

Phase advance due to chromaticity

$$\int C_y \delta d\theta = \frac{C_y}{h\alpha_c}\int \Delta\phi' d\theta = \frac{C_y}{h\alpha_c}(1-\cos\nu_s\theta)\Delta\phi + \frac{C_y}{\nu_s}\sin\nu_s\theta\delta$$

Betatron oscillation

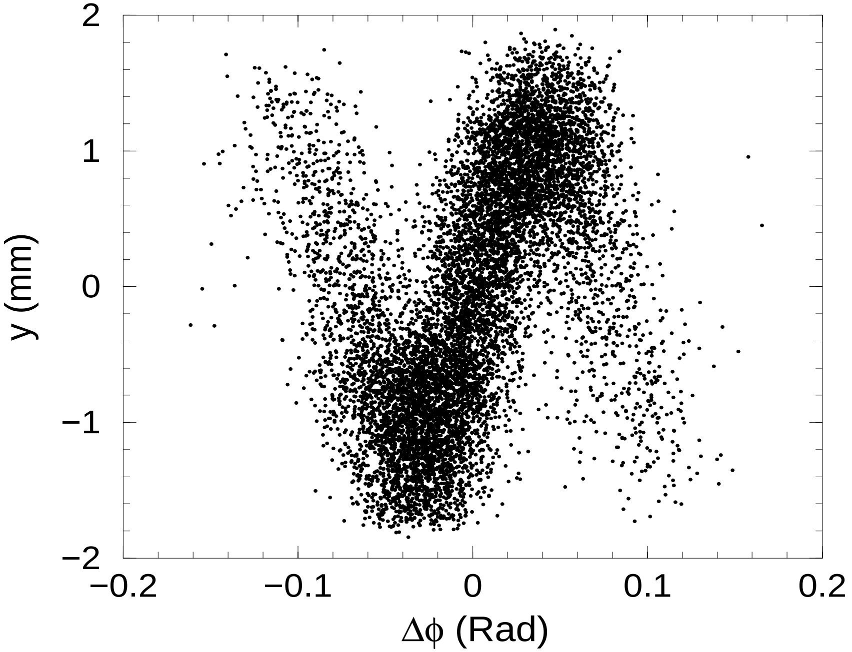
$$y = \sqrt{\beta(s)\beta(K)}\Theta\sin(\nu_{y,0}\theta + \frac{C_y}{h\alpha_c}(1-\cos\nu_s\theta)\Delta\phi + \frac{C_y}{\nu_s}\sin\nu_s\theta\delta + \Psi(s))$$

$$+\sqrt{\beta(s)\varepsilon_y}\sin(\nu_{y,0}\theta + \frac{C_y}{h\alpha_c}(1-\cos\nu_s\theta)\Delta\phi + \frac{C_y}{\nu_s}\sin\nu_s\theta\delta + \Psi(s) + \Psi_0)$$

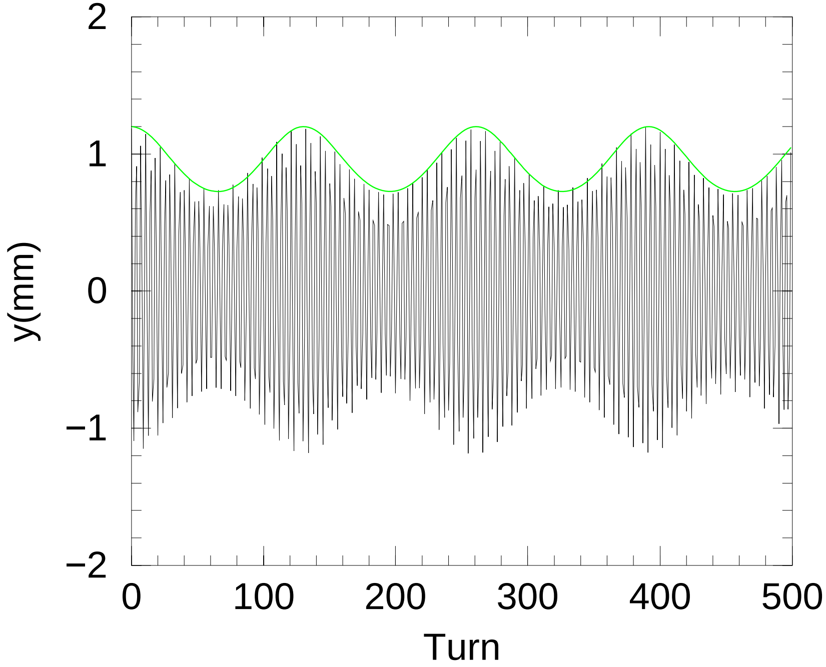
Average in one slice

$$\langle y(\delta,\Psi_0)\rangle(\Delta\phi) \propto \sin(\nu_{y,0}\theta + \frac{C_y}{h\alpha_c}(1-\cos\nu_s\theta)\Delta\phi + \Psi(s))$$

Simulation result with chrom. (no $\nu_y(y)$, QE, or damping)



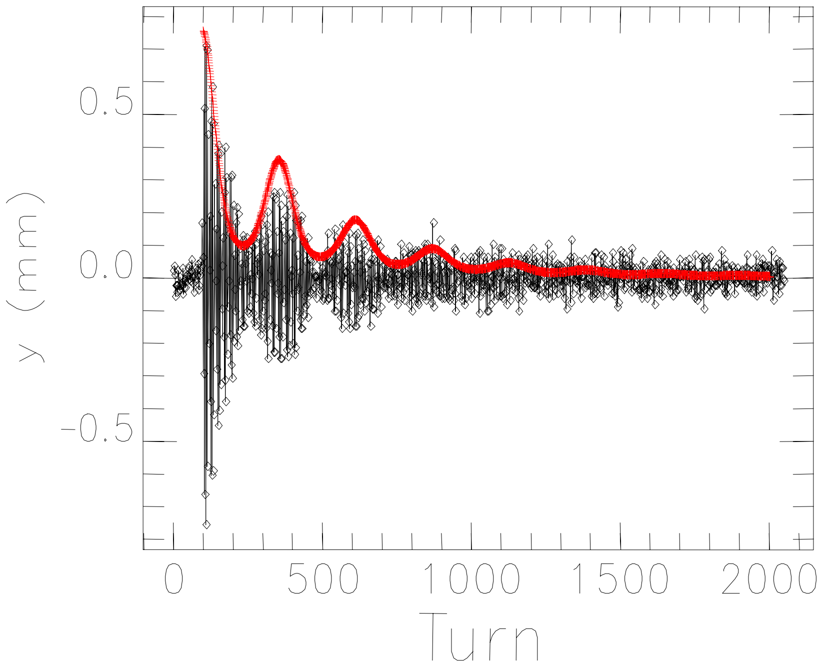
Bunch shape after ½ synchrotron period

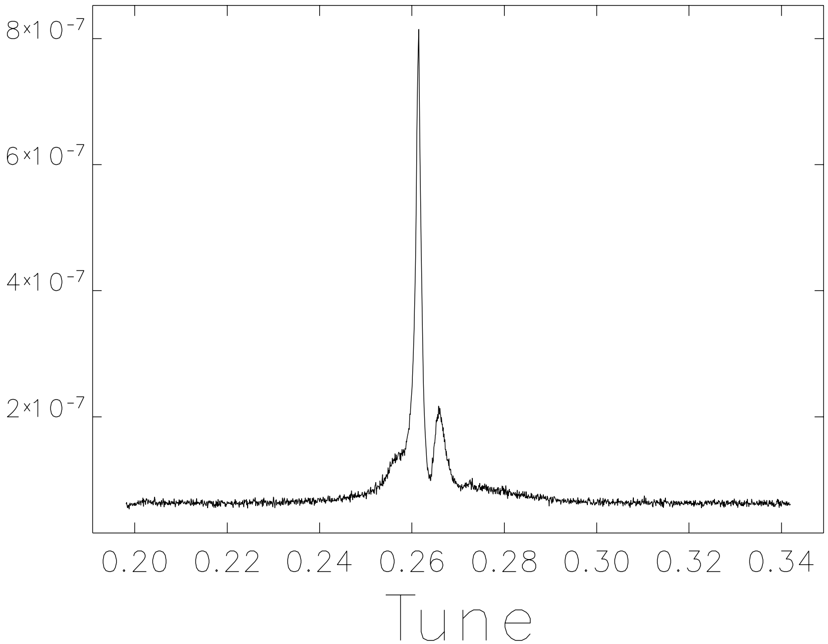


Centroid oscillation

- **Decoherence** is caused by **amplitude tune dependence, quantum excitation, transverse coupling, and wakefields**.
- Simulations carried out using one-turn map (Guo)

BPM signal envelop fit including decoherence

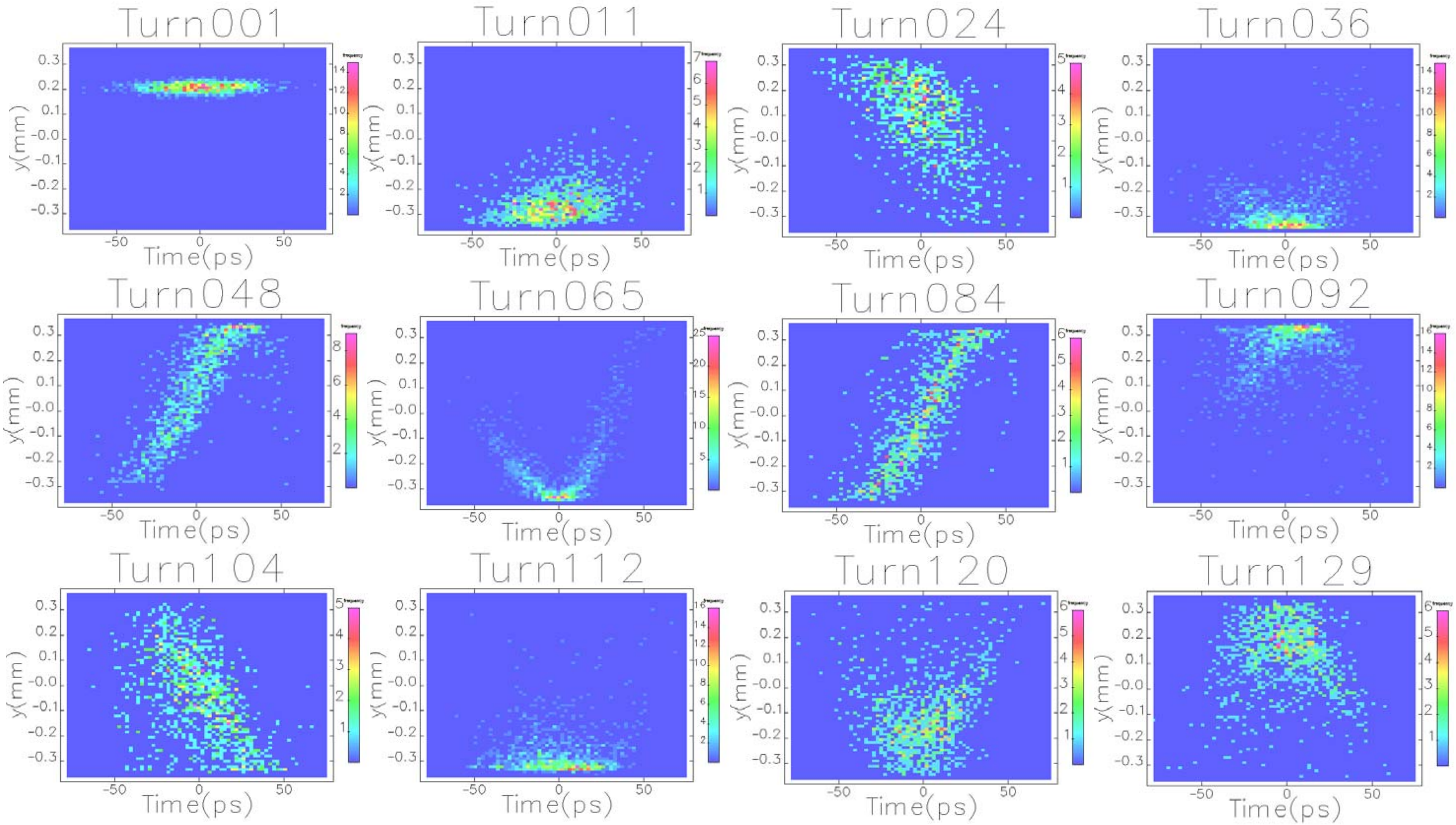




I=1.3mA, Cx=6.8, Cy=2.9, ν_s=0.0078, ν_m=0.004, k_1=2e-4, $k_2 \approx 0$

$$\langle y \rangle_{env} = \exp\left(-\left(\frac{C_y \sigma_\delta}{\nu_m} \right)^2 \left(1 - \cos \nu_m \theta \exp(-\alpha_l \theta)\right) - k_1 \theta - k_2 \theta^2 \right) \exp\left(-\frac{\theta}{\tau_y} \right)$$

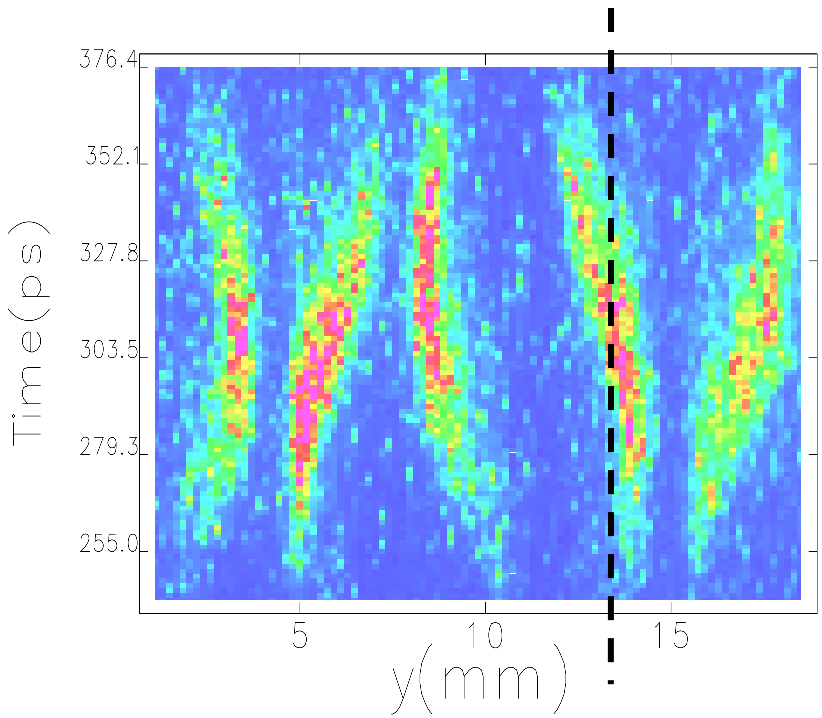
Simulation including chrom, QE, damping

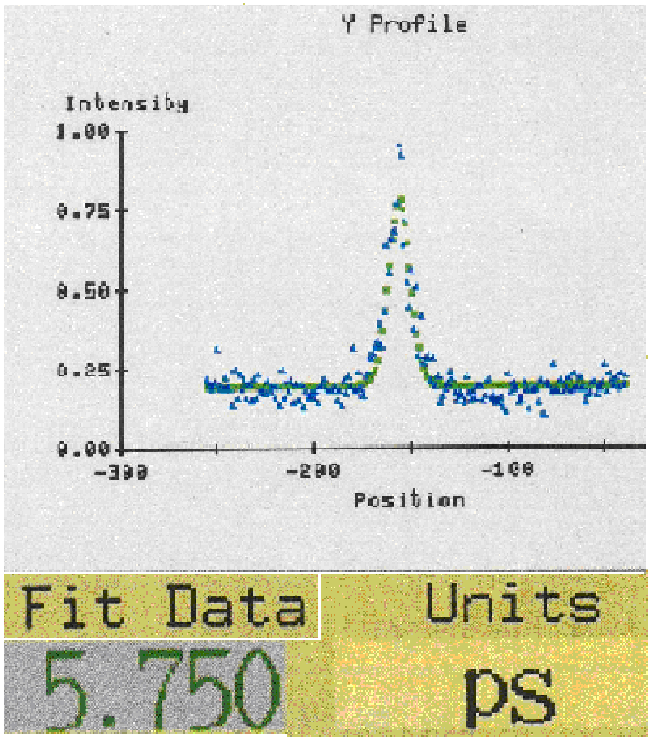


Experimental parameters for optical streak camera imaging (with B. Yang)

- C_y lowered to 4, C_x=6 nominal
- 2 mA in 10-bunch train (0.2 mA/bunch)
  - o single bunch current limit ~1.3 mA (c.f. 16 mA delivered to timing users in APS hybrid mode)
  - o tune jitter requires avg. over bunch train
- Kicker strength applied to the beam was 4kV, or 0.12 mr, corresponding to 0.5 mm in the straight sections
- Kicker frequency 2 Hz
- Streak camera set up to take images turn by turn, in (y,z) plane. Resolution y: 0.43 ps (0.13mm); z: 2.2 ps.
- Images acquired from 0 to 190 turns after kick, from which best turn to obtain shorter pulses was determined
- Effective slit width 100 μm

Streak Camera Measurement Results





Pixel size: 0.036mm × 1.2ps

Turn 83-87

Bunch length **31 ps**; slice length **5.75 ps rms**

Streak camera resolution and optical effects are not subtracted.

X-ray Beamline Experiment Demo

Carry out a demonstration short-pulse x-ray experiment on APS beamline (L. Young and colleagues)

Structural molecular reorganization following photoinduced isomerization/ dissociation can be studied on a finer timescale. Transient pulse requires acquisition of entire x-ray absorption spectrum in a single shot. Time resolution of ~5 ps is demo goal.

1. Improve synchronization between kicker, x-ray streak camera trigger, and pump laser
1. Improve kicker rep. rate, as necessary
2. Investigate tune jitter
3. Implement single-shot experimental method [Pettifer et al., Nature **435**, 78 (2005)]

Summary

- Guo's vertical kick approach based on synchrobetatron coupling demonstrated to produce transient short pulses
- Achieved photon pulse 5× shorter than electron bunch length in APS; hope to achieve up to a factor of 10.
- Advantages: available without major machine modifications, allows test of x-ray experimental methods, synchronization, and optics compression schemes in advance of operational system (based on rf deflection)
- Disadvantages: low rep. rate (max. ~20 Hz), low bunch current, sensitive to tune jitter
- X-ray demonstration experiment planned to be carried out this year
- Beam dynamics to be studied further: amplitude-dep. tune, turn number, longitudinal position, kicker strength and calibration, longitudinal tune, wakefield effects, minimum achievable pulse length