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Transient Short Pulse Generation Through Beam Manipulation

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SPX Workshop

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Introduction

- A few months after 2004 Strategic Planning meeting, we began to study alternate short x-ray pulse-generating schemes
- These alternate schemes are all transient (i.e. pulsed) and disrupt the entire ring
 - Characterized by beam manipulation to create short pulse
 - Emittance or bunch length eventually blows up
 - Relies on radiation damping to restore emittance, bunch length
 - Repetition rate limited to ~20-50 Hz (possibly 1 kHz)
- Potentially useful for beam & beamline diagnostics development, possibly experiments (only during machine intervention/studies)
- Transient schemes studied (2004-2006)
 - Synchrotron coupling (Guo et al.)
 - Pulsed rf phase modulation (Decker)
 - Quarter-integer betatron resonance (Borland, Guo)

Introduction (cont)

■ **Synchrobetatron coupling**

- Chirp is produced via a magnet kick rather than deflecting cavity
- Beam (y-t) tilt in ID, rather than (y'-t) as with deflecting cavity

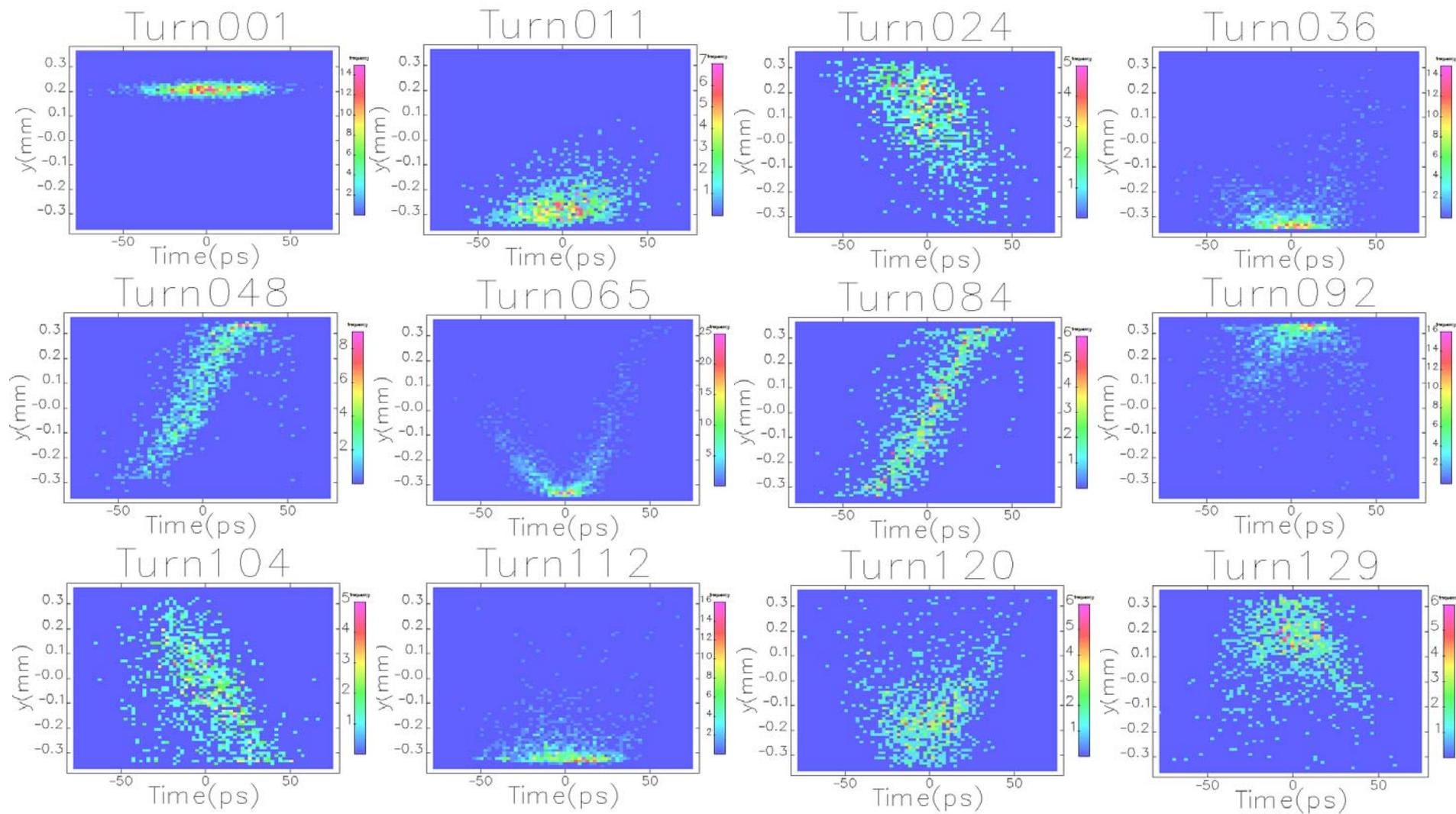
■ **Pulsed rf phase modulation**

- Bunch length actually compressed – no tilt
- Bunch shape oscillation at 2x synchrotron frequency

■ **Quarter-integer betatron resonance**

- Same chirp as deflecting cavity, only build-up over several turns using resonant excitation
- Drive at much lower power at 1 MV at a frequency ($8 \times \text{frf} + 0.25\text{frev}$)

Synchrotron coupling: simulation including chrom, QE, damping (y-t plots)



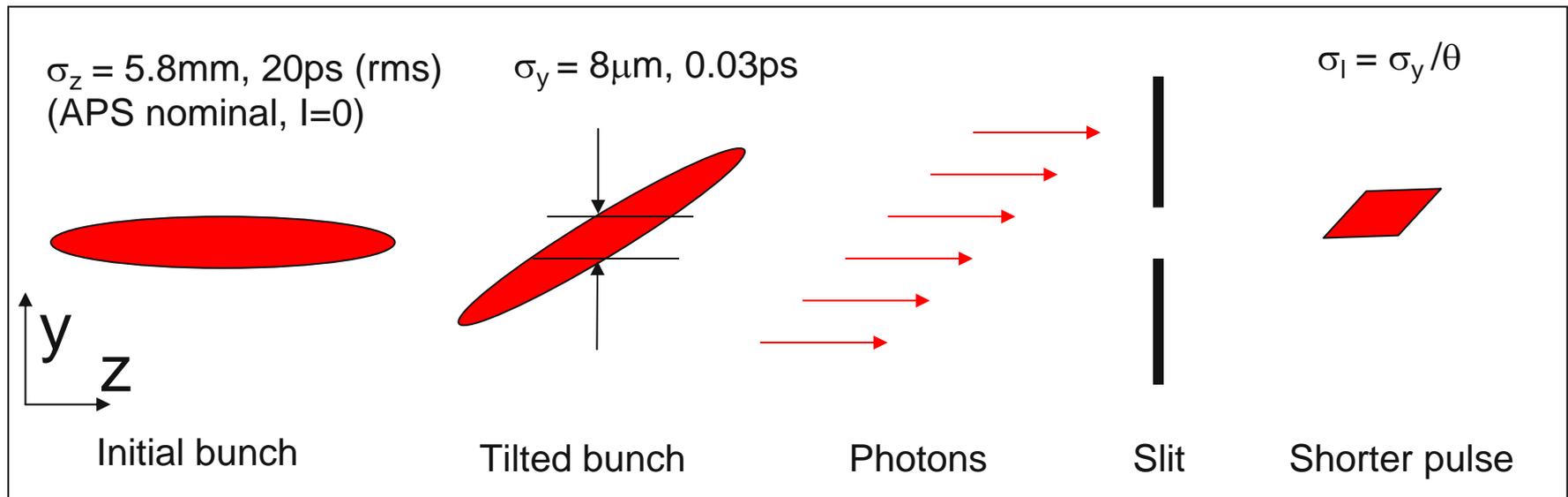
Short x-ray pulses from a chirped bunch

W. Guo, K. Harkay, B. Yang, M. Borland, V. Sajaev, Proc. 2005 PAC, 3898 (2005)

B.X. Yang, M. Borland, W. Guo, K. Harkay, V. Sajaev, Proc. 2005 PAC, 3694 (2005)

W. Guo, B. Yang, C.-x. Wang, K. Harkay, M. Borland, Phys. Rev. ST Accel. Beams 10, 020701 (2007)

W. Guo, M. Borland, K. Harkay, C.-x. Wang, B. Yang, Proc. 2007 PAC, 1133 (2007)

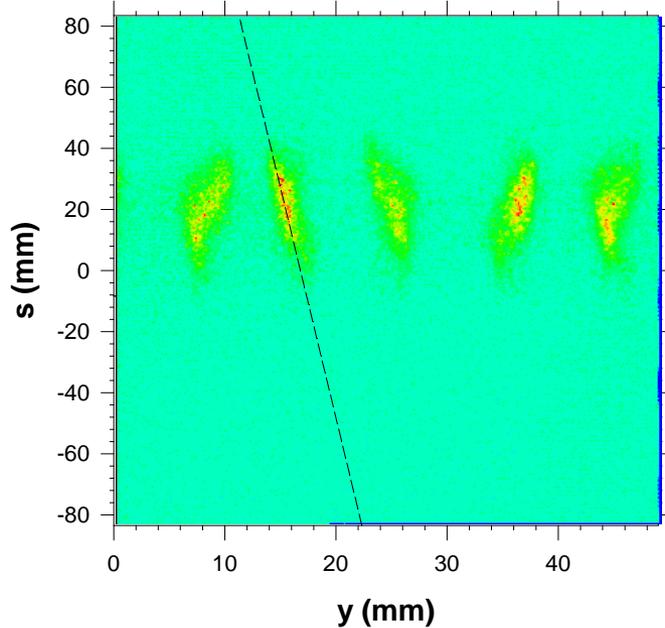


Cavity kick \rightarrow Betatron oscillation \rightarrow $\mathbf{A(z)} \sin(\nu_x \theta + \psi)$

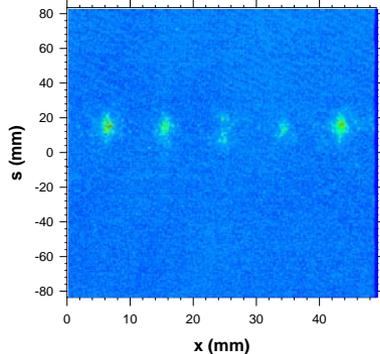
Magnet kick \rightarrow Synchrobetatron coupling \rightarrow $\mathbf{A} \sin(\nu_x \theta + \psi(\mathbf{z}))$

Generate tilted bunch using synchro-betatron coupling: Sector 35 tests (W. Guo, K. Harkay, B. Yang)

Streak camera image: 64 turns after kick



Streak camera image: 64th turn with slits



10-bunch
train

Nov 16, 2004 xxMV200systemV3.adl 00:57:23

S:VID3 Imaging System

Source: 2.29 ROI:

Frame Selection: View Image: 11

Original Histogram Background Subtracted First Field Even

X Pos: 0 256 480 256
Y Pos: 0 30 480 30
X Size: 0 20 480 20
Y Size: 0 179 480 179

Ext: 2 NoFrame 4 Frame # 2 Frame Delay 0
Ech. Trigger Continuous Profile Peak Profile Peak Threshold 7000 Y: 50000

Profiles/sec: 2 2 Missed Frames: 0

Monitor View: 2 2 Bisplay 0 Clear Scr
Live Normal Hide Plot OFF On
Freeze Unifreeze Polar Bal Text Off On

Configuration Save Camera Setup in Cal File 30-10-R3 pixrula camera

Analysis:

X Profile Peaks Y Profile Peaks

Adjacent Profile Average Baseline Baseline Results to Average (std. dev.)
Frames to integrate: 1 On Boxcar Width: 50 off of Size: 15 On Size: 300

X Profile Y Profile

Intensity Intensity
Position Position

X Axis: Cal EGU Pixels

Calibrated Table Index: 42 S35BM:STRK2 Zoom factor: 1.000 Calibration

	Raw Data	Fit Data	Average	STD	Raw Data	Fit Data	Average	STD
centroid:	0.859	4.350	1.335	1.26	-155.646	-155.863	-151.802	6.66
Sigma:	0.103	1.328	0.254	0.43	6.207	5.750	9.890	4.00
FWHM:	0.015	5.108	Units		10.060	13.501	Units	
FWTM:	0.303	0.792	XX		112.048	23.955	PS	
profile:	21	1287	509	394	38	29	43.722	21

Length of visible light pulse: 6 ps
(length limited by spatial resolution)

Effect of jitter, wakefields

GENERATING PICOSECOND X-RAY PULSES IN ... **W. Guo et al** Phys. Rev. ST Accel. Beams **10**, 020701 (2007)

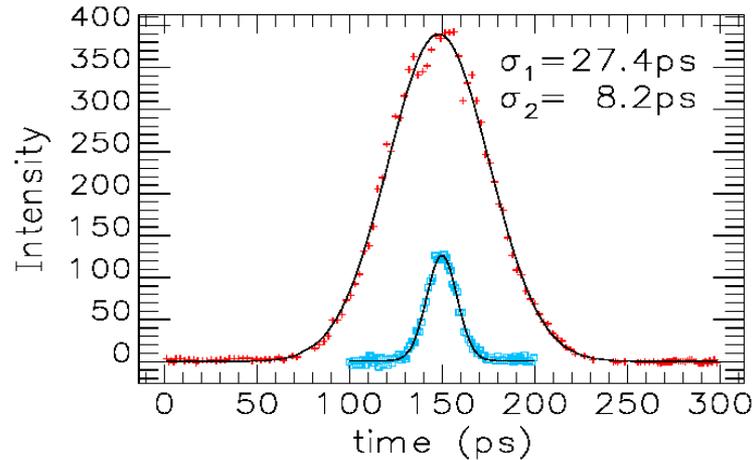


FIG. 7. (Color) The length of the long-time-overlapped pulses. Red crosses, without the slit; blue squares, with the slit.

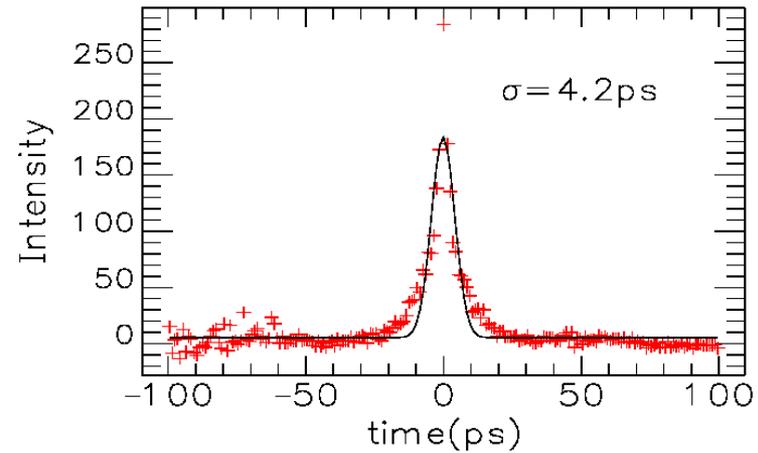
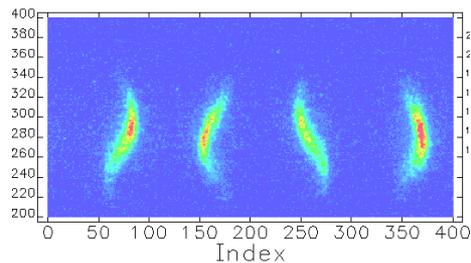
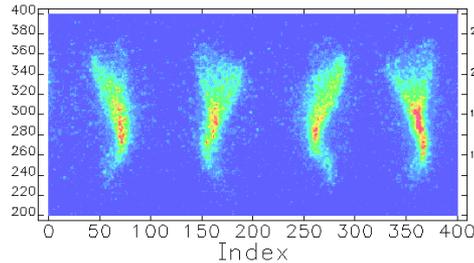


FIG. 8. (Color) The average length of the slitted pulse when the time jitter is removed.

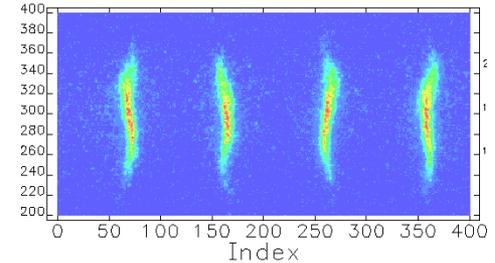
Wakefield effect. Kicker calibration is 0.36 mm peak beam orbit offset per kV kick.



10 bunches spaced $3 \lambda_{rf}$, 2.3 mA total intensity, 4 kV kick.



2.1 mA single bunch, 4 kV kick



2.1 mA single bunch, 2 kV kick

X-ray Beamline Experiment Demo

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

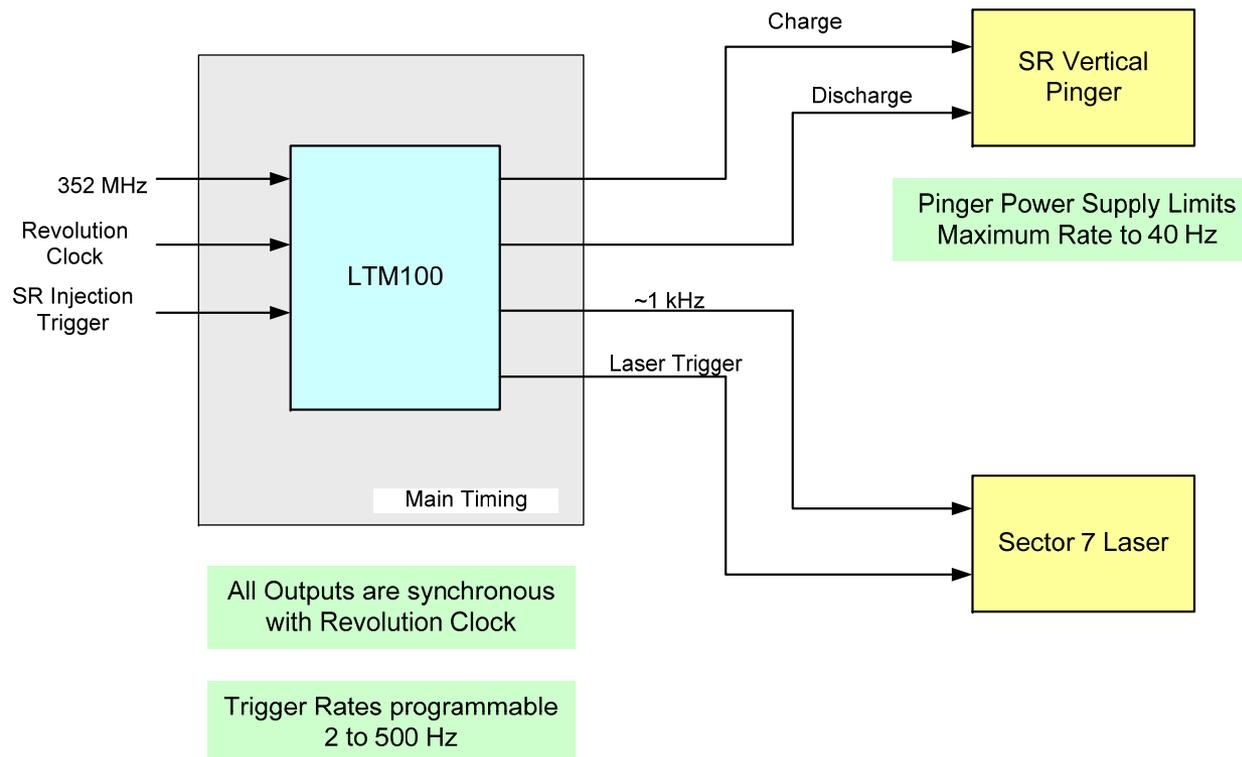
Structural molecular reorganization following photoinduced isomerization/dissociation can be studied on a finer timescale. **Transient pulse requires acquisition of entire x-ray absorption spectrum in a single shot.** Time resolution of ~5 ps is demo goal.

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

FY2006 LDRD addressed items 1&2 and separately, item 4

July 5, 2007 Test (Interim beamline test)

- S7 ID took beam for 4 hours with SR pinger running at 40 Hz
- Did not use Laser
- 1.7 mA pulse (low current), 2 kV kick
- 4 psec rms pulse (measured with S35 Streak Camera), 1.7 mA
- Successfully Imaged beam – Intensity is sufficient for experiments



Rf Phase Modulation Concept

- Separate the phases of the two rf stations until one sits on crest with the other at zero crossing. The on-crest system voltage must equal $U_0 = 5.37$ MV.
- AC modulation of the on-crest phase at twice the synchrotron frequency $2 \cdot f_s = 3.6$ kHz induces a shape oscillation.
- Minimum bunch length occurs twice each synchrotron period, decaying exponentially, but limited by quantum excitation (simulation).

Experiment: G. Decker, W. Guo, N. Sereno, K. Harkay, B. Yang, A. Lumpkin, D. Horan (Mar 2005)

G. Decker, M. Borland, D. Horan, A. Lumpkin, N. Sereno, B. Yang, S. Krinsky, Phys. Rev. ST Accel. Beams 9, 120702 (2006)

G. Decker, N. Sereno, Proc. 2005 PAC, 3247 (2005)

Streak camera image showing transient bunch compression
using rf phase modulation technique (4/21/05)

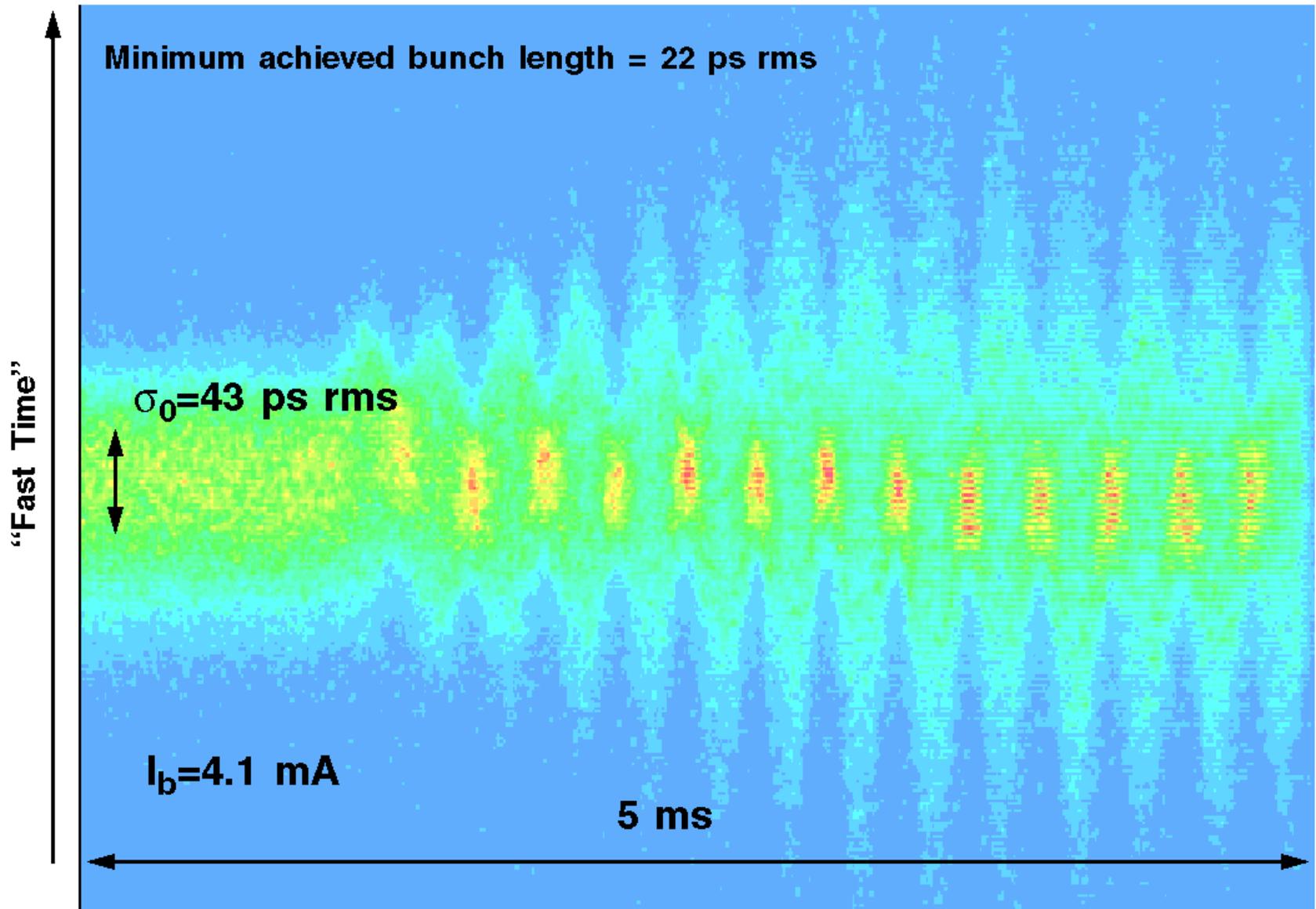
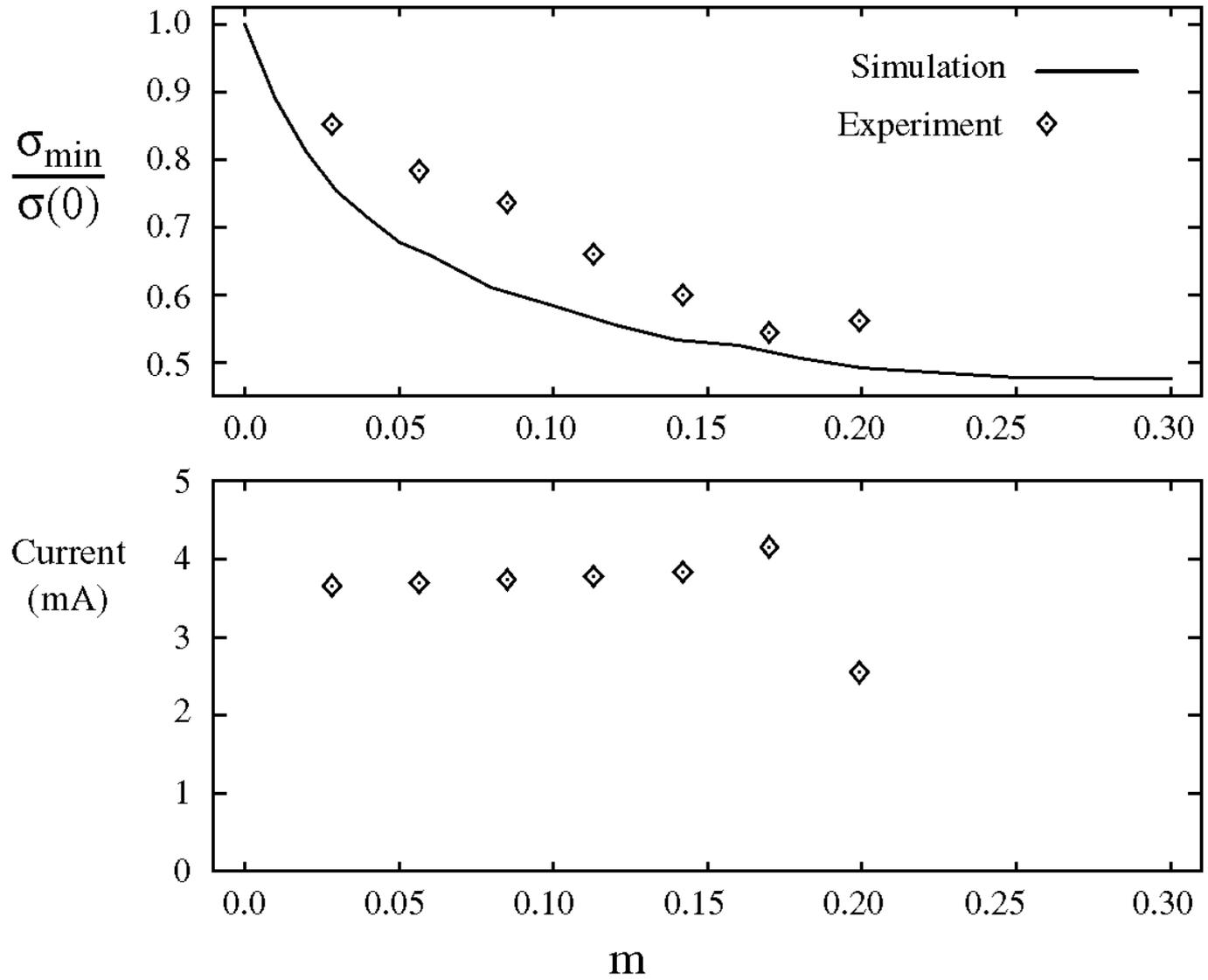


Figure courtesy G. Decker

Bunch Compression Efficiency



Phase Modulation Experiment Summary

- Nearly a factor of two compression achieved
- Simulation indicates a factor of three possible at 5 GeV
- True bunch compression - no fancy x-ray optics needed
- Partial time reversal possible, allowing duration $< \tau_{\epsilon}$
- All this, for less than \$5000

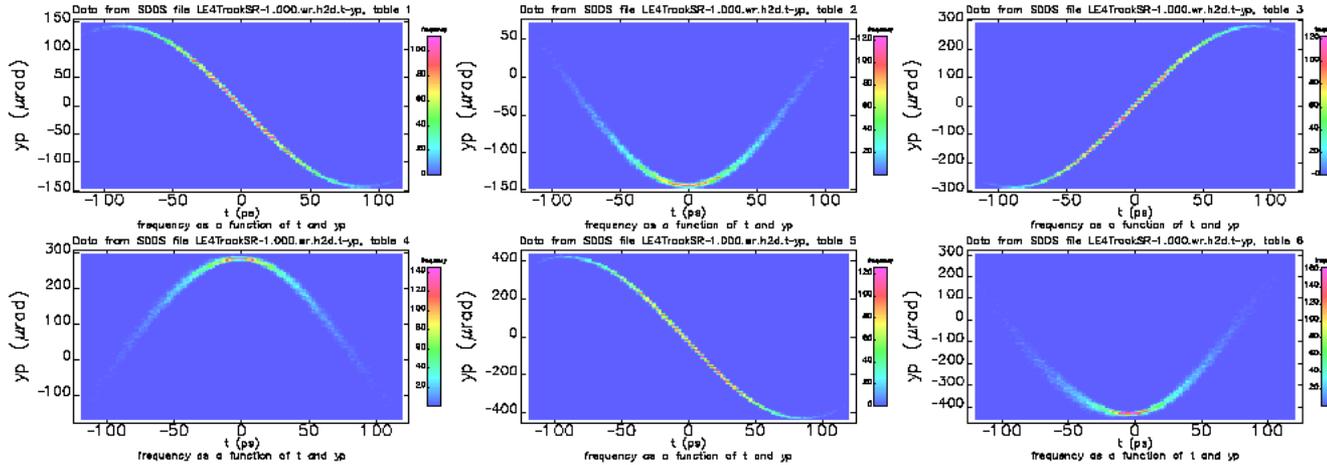
Quarter-integer resonance

- **Non-resonant RT deflecting cavity scheme requires several MV and several MW of power, requiring a klystron**
- **Driving the beam resonantly, i.e. at a fraction of the betatron frequency, would require far less power (few 100 kW)**
- **Idea is to build up chirp over several turns (with up to 1 MV), then turn drive off and let beam decay**
- **M. Borland initially studied integer resonance¹, then W. Guo suggested the quarter-integer resonance ($8 \times \text{frf} + 0.25\text{frev}$)**
- **Simulations² predict x-ray pulses down to a few ps**

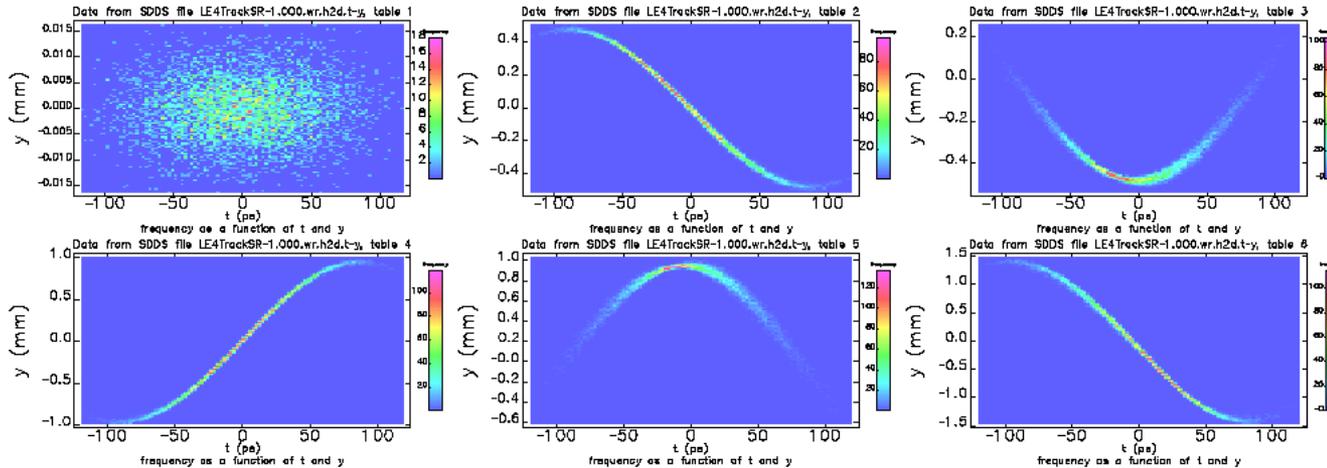
1. M. Borland, Technical Note OAG-TN-2005-021, Rev. 1 (Aug 23, 2005)
2. M. Borland, Technical Note OAG-TN-2005-023, Rev. 2 (Aug 23, 2005)

Simulation results

$y'-t$



$y-t$



Predicted performance

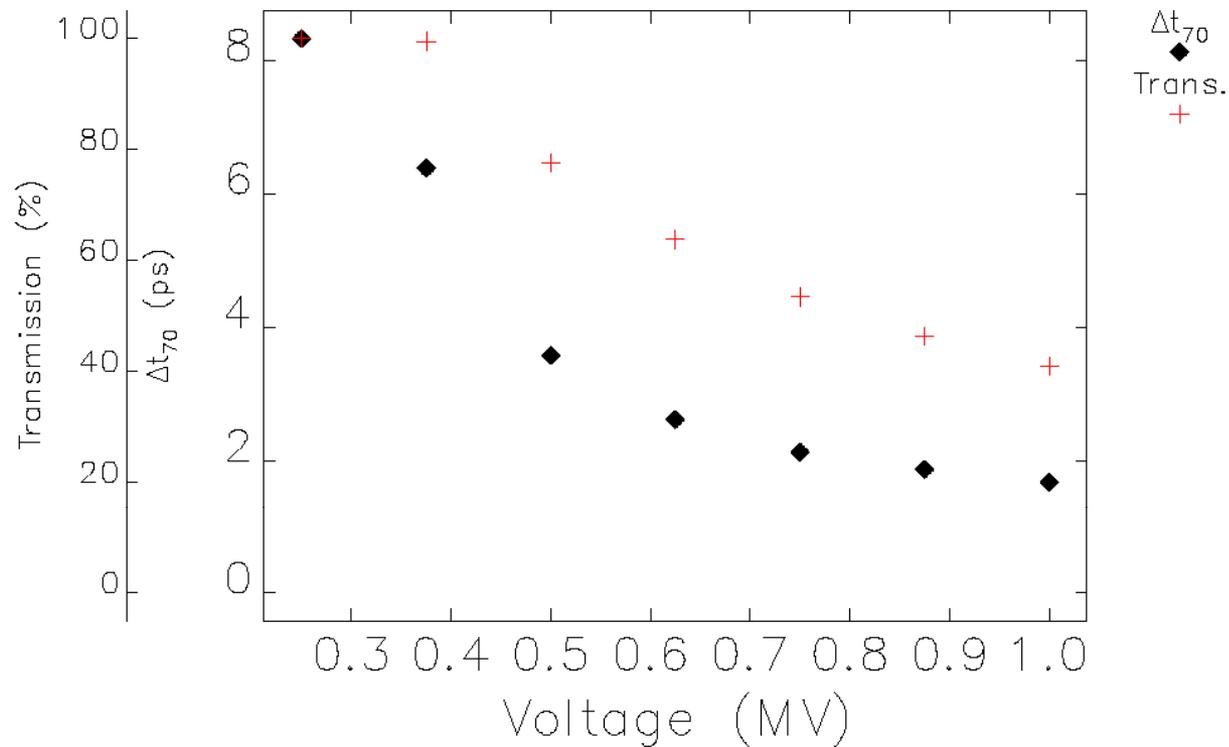


Figure 7: Minimum compressed x-ray pulse length and transmission through ± 5 mm slits as a function of deflecting voltage. For voltage above 0.6 MV, the dependence of pulse length on voltage is somewhat weak, so reducing the voltage if necessary due to aperture concerns should not compromise performance much.

Summary

	Pulse compression achieved	Repetition rate limit	Pro	Con
Synchro-betatron	3x (avg) 6.5x (w/o jitter)	~40 Hz (1 kHz w/ fast kickers)	Available h/w	Bunch current limited to few mA, sensitive to tune jitter & wakefields
Rf phase modulation	2x	~40 Hz	Available h/w, should allow ~50 mA	Limited pulse compression
Quarter-integer resonance	To be demo'd (simul. 50x)	~20 Hz	Same as RT deflecting cav	Needs h/w (cost TBD)

Acknowledgements

M. Borland, E. Cherbak, G. Decker, W. Guo, K. Harkay, D. Horan, R. Laird, F. Lenkszus, A. Lumpkin, A. Nassiri, N. Sereno, C.-x. Wang, Ju Wang

7ID: B. Adams, B. Kraessig, E. Landahl, E. Peterson, L. Young, others

Did not review operational short-pulse schemes implemented elsewhere:

- **Femtosing** (ALS, BESSY, SLS)
- **Low momentum compaction** (BESSY) [V. Sajaev, Technical Note ASD/APG/2005-02 (Jan 2005)]