Pump-probe experiments with ps x-rays

Eric Landahl, XOR/TRR

1. Picosecond beamlines need flexibility
    a) Energy and energy bandwidth
    b) Fill pattern
2. Laser and laser synchronization must be part of the machine and beamline design
    a) Timing signal distribution
    b) Beamport for visible synchrotron light
3. Unique challenges undertaken by an enthusiastic and increasingly technically sophisticated User community
    a) Spatial and temporal laser pulseshaping
    b) Specialized x-ray techniques

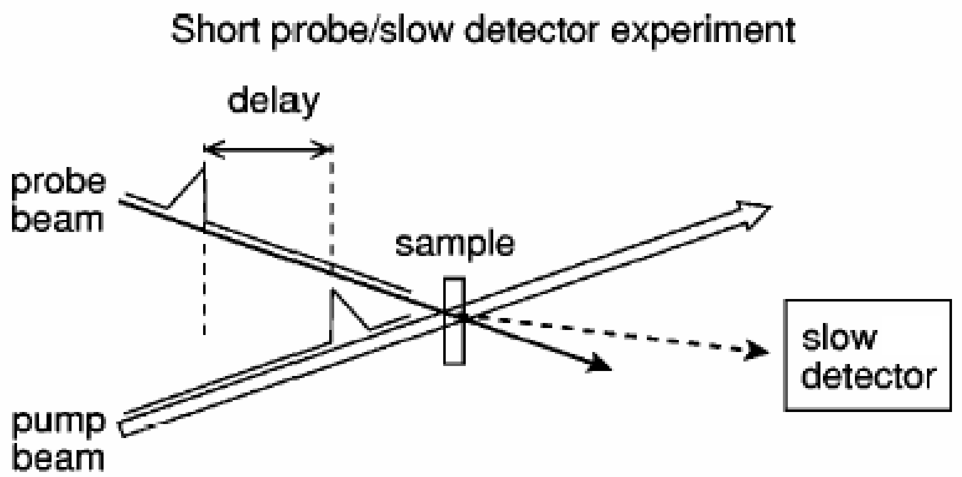
Incomplete Acknowledgements

- U.Michigan research groups (D. Reis, P. Bucksbaum, R. Merlin)
- SLAC (R. Akre, A. Cavalleri, J. Heritage)
- Sector 7 Staff (B. Adams, E. Dufresne)
- AOD Diagnostics (B. Yang)
- ASD Accelerator Physics (Y. Li)

Two types of pump/probe experiments

X-Ray

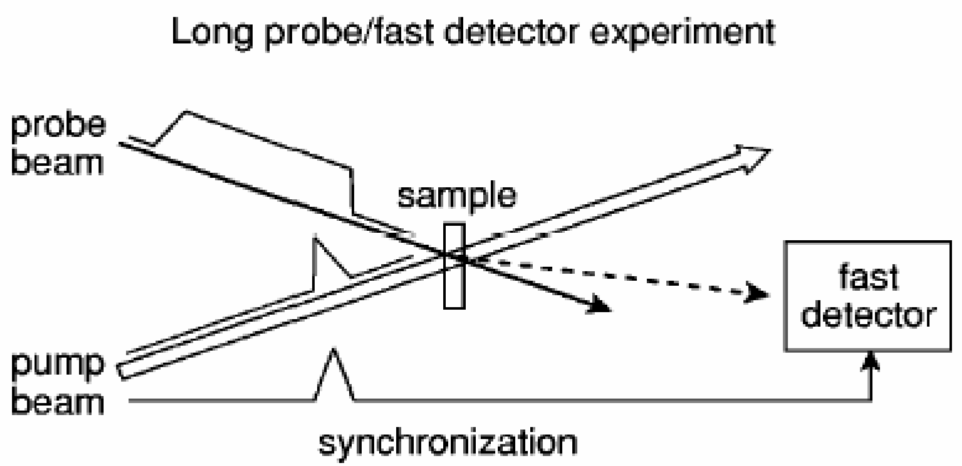
Laser



Time resolution limited by probe duration; X-ray chopper may be required which will be more difficult with larger vertical beam emittance

X-Ray

Laser

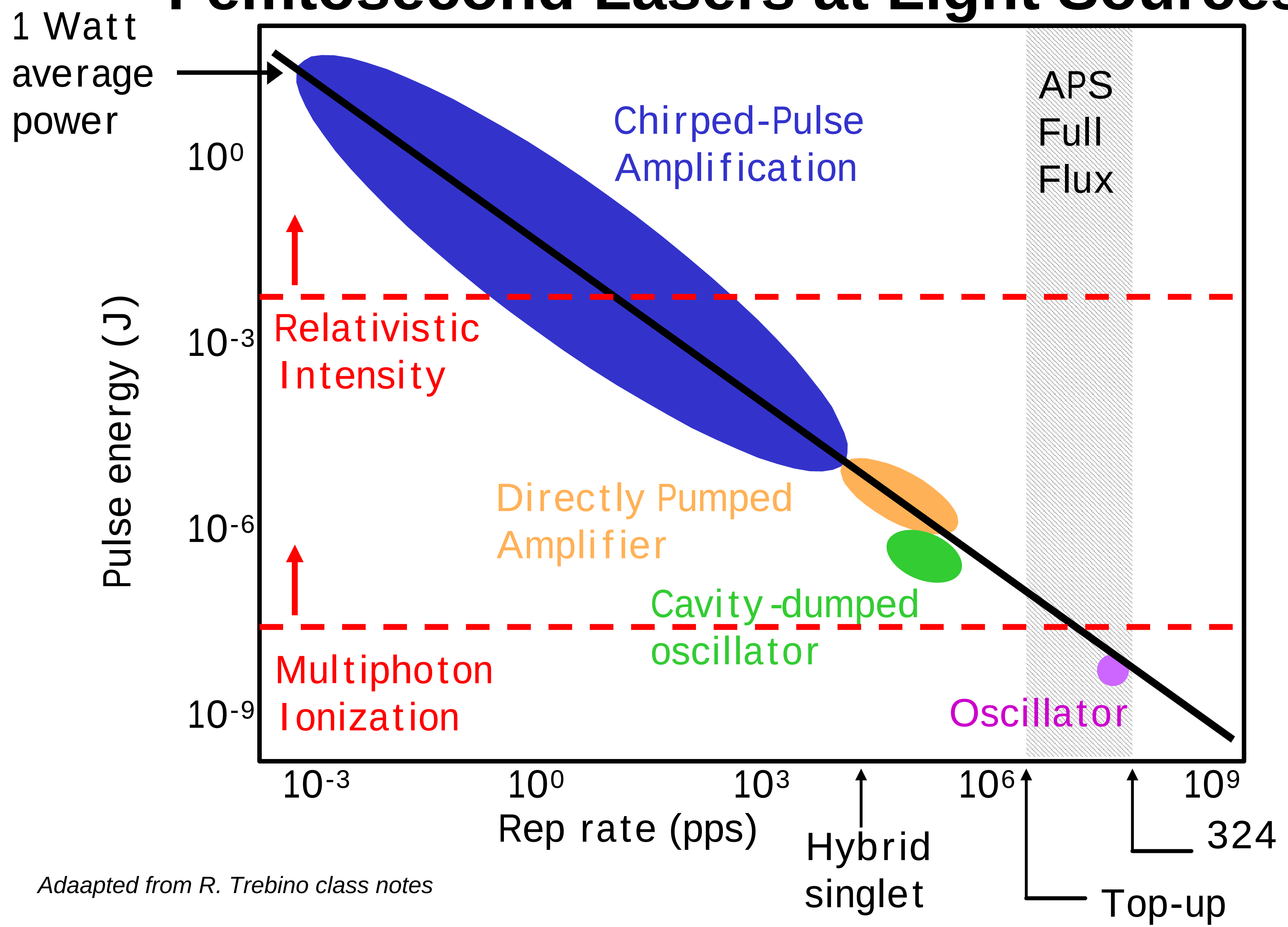


Time resolution limited by detector; poor sensitivity

Jitter is an issue with both types of experiment.

Rousse et al., RMP 73, 17 (2001).

Pulse energy vs. Repetition rate: Femtosecond Lasers at Light Sources



Adaapted from R. Trebino class notes

Battle to Become the Next-Generation X-ray Source

15 NOVEMBER 2002 VOL 298 SCIENCE

X-RAY VISIONS: TODAY'S SYNCHROTRONS AND BEYOND

Machine	Photons per pulse (0.1% BW)	Pulse length	Pulses per second	Estimated cost	# of beamlines
3rd-Generation Synchrotron	~~10^3–10^4~~ 10^5	~10–160 ps	5.4 million	>$1 billion	~100
Slicing Source	10^3–10^4	~100 fs	10–10,000	$5 million	1 or 2
Short-Pulse Photon Source	~~10^8~~ 10^5	~100 fs	10	$0.1 million to ?	1
Recirculating Linac	10^4–10^7	~100 fs	1000–10,000	$300 million to $500 million	~10
Free Electron Laser (LCLS)	10^{11}–10^{12}	~200 fs	60–360	$250 million	1+
APS RF Orbit Deflection	10^4 – 10^5	1-2 ps	6.5 million	--	2-6

ps = picoseconds, or 10^{-12} seconds

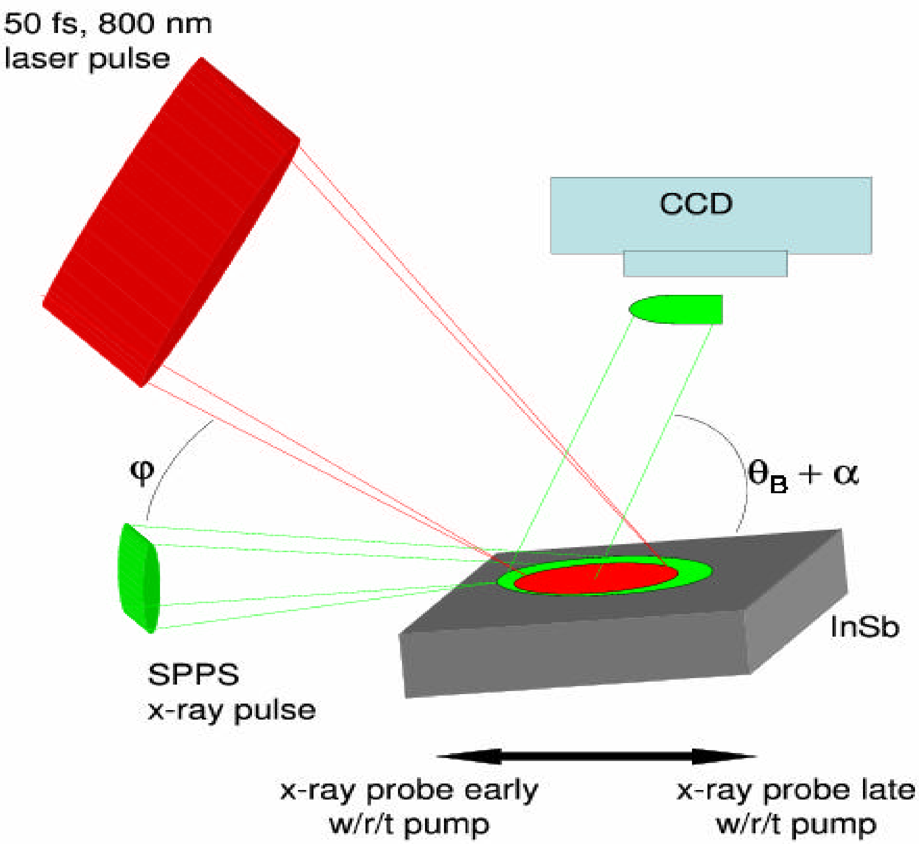
fs = femtoseconds, or 10^{-15} seconds

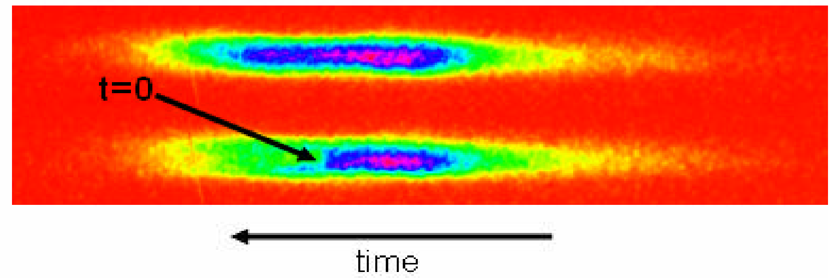
The real competition

Laser plasma	ID (3rd Generation)
• “Perfect” synchronization • <500 fs • Low flux • Low brightness (4π) • Limited tuning range • Limited pump-probe delay	• picosecond synchronization • 100 ps typical • High flux • High brightness • Tuneable • Arbitrary pump-probe delay

Courtesy D. Reis

Sub-picosecond structural phase transition

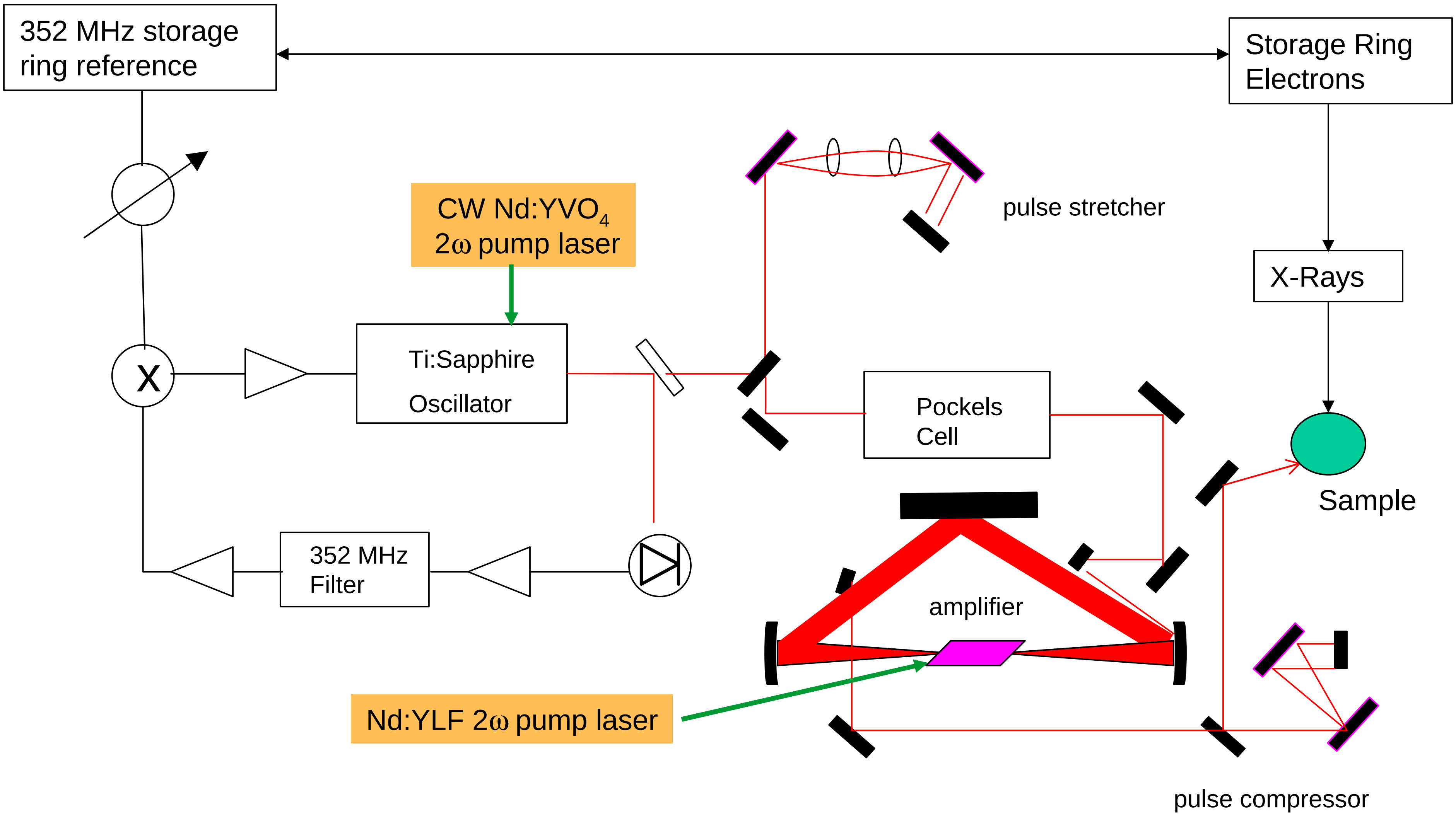




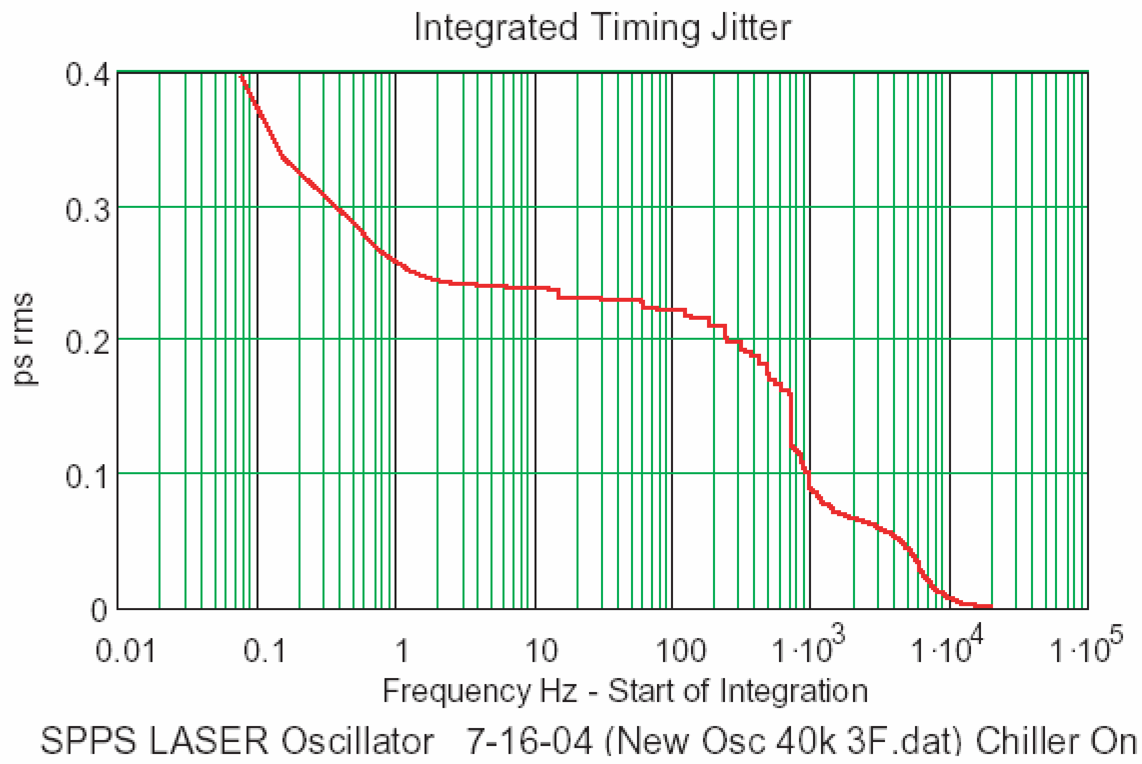
- For φ = 24 deg and x-rays grazing: ~18 fs/pixel
- Measures complete time history around t=0 in single shot

A. Lindenberg et al., SLAC

Sector 7 Ti:Sapphire CPA system



Femtosecond laser oscillators can be synchronized to stable rf to a few hundred fs

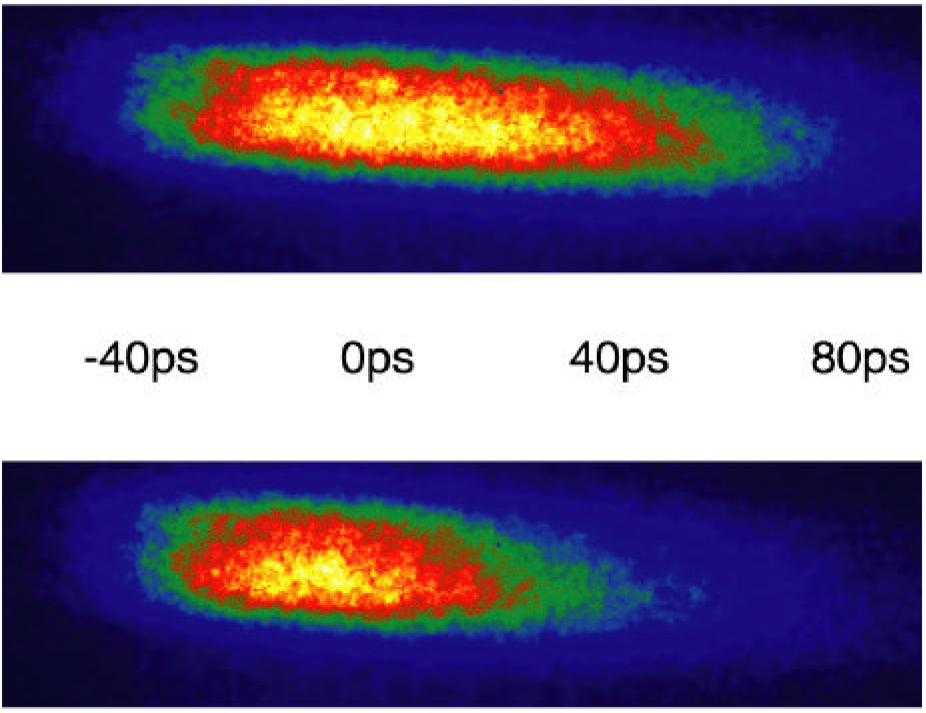


However accelerators are not “perfect” rf sources

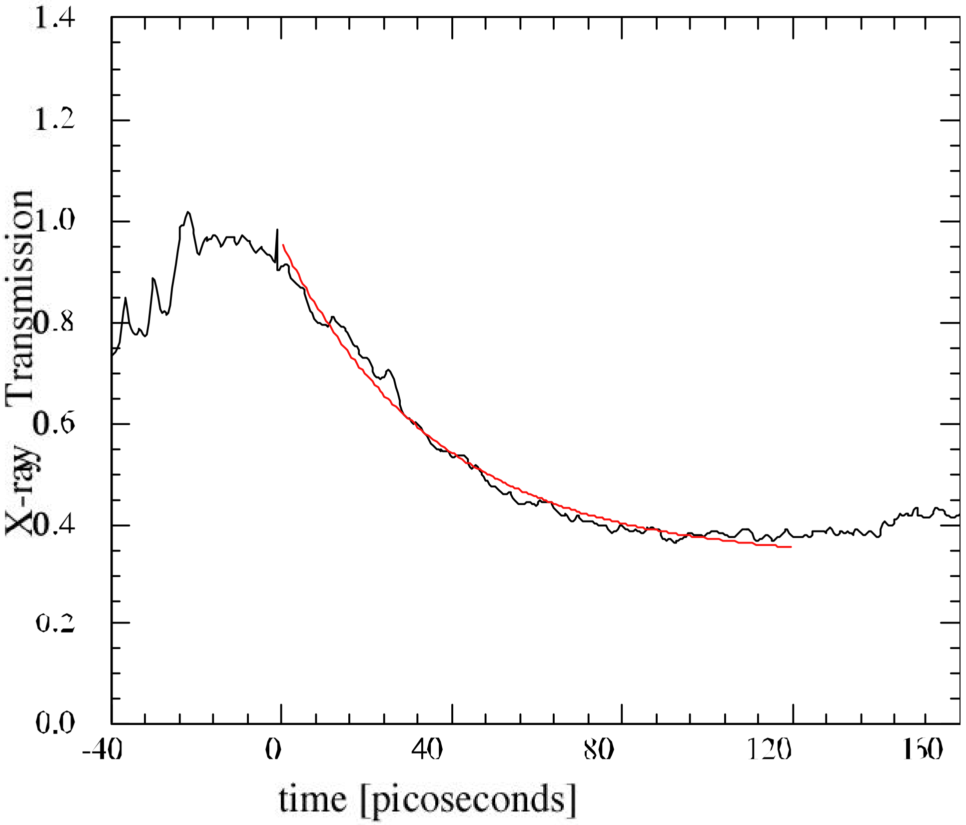
SPPS LASER Oscillator
0.5 degree phase error injected on reference RF

streak camera resolves transient switch

Laser off

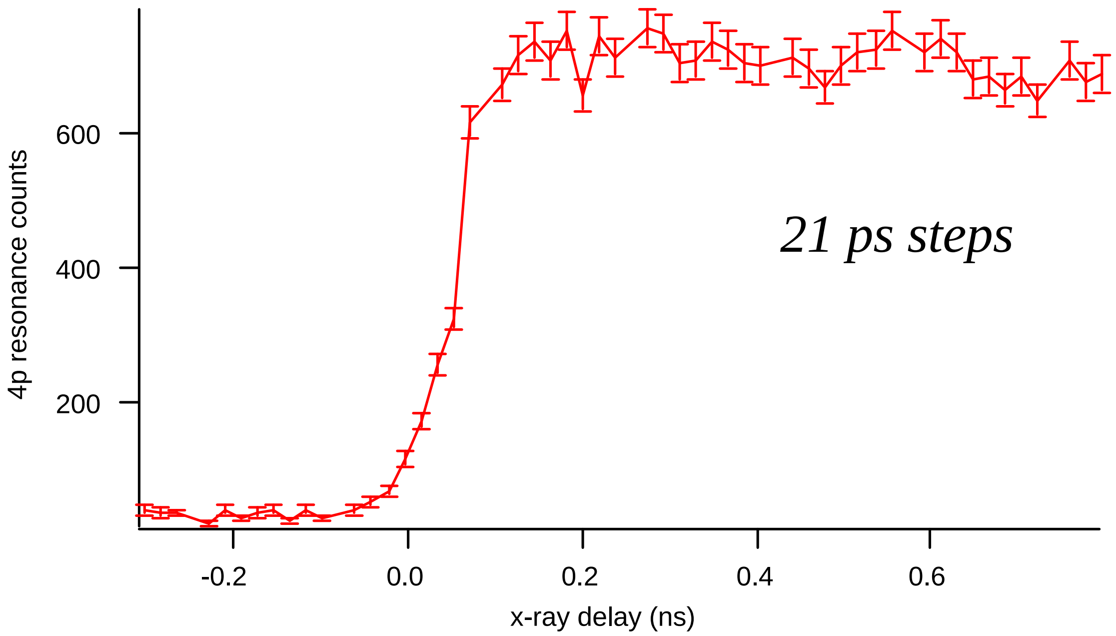


Laser on



~6 times the speed of sound: ambipolar diffusion.

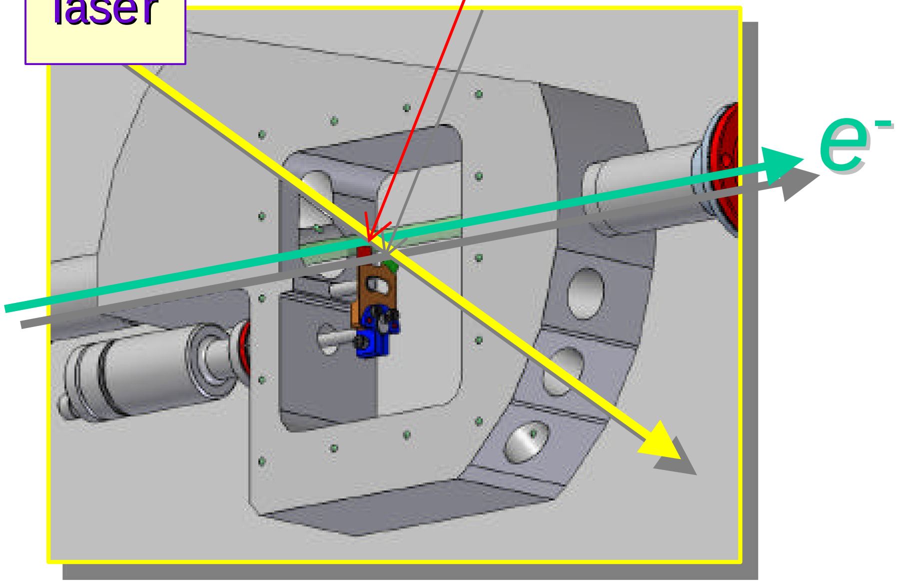
X-ray — laser cross-correlation



The prominent laser-induced 4p resonance enables a simple x-ray — laser cross-correlation measure of x-ray bunch length.

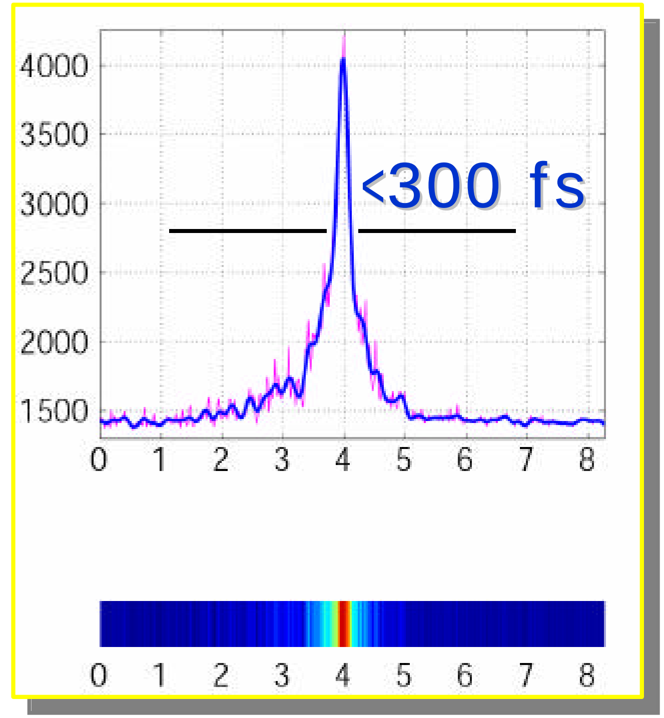
ANL AMO Group

Single-shot timing by electrooptic sampling

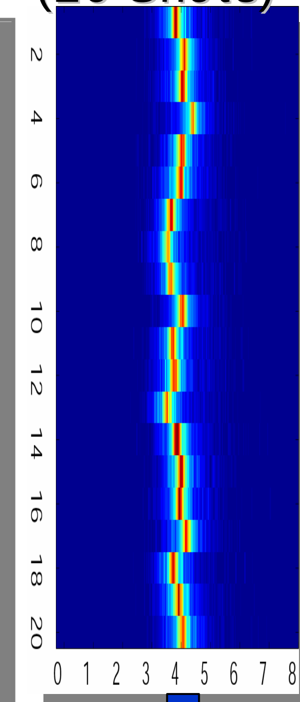


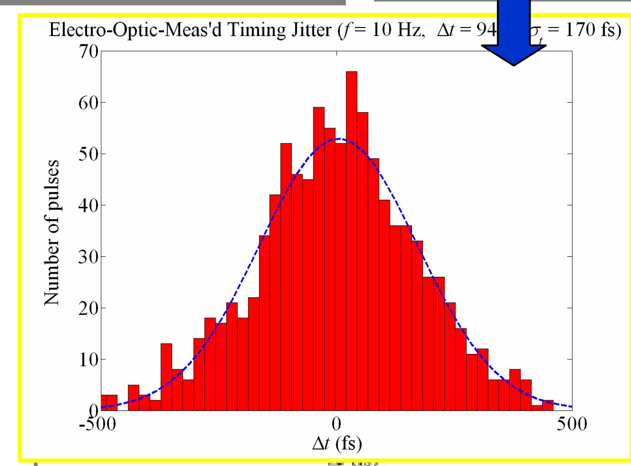
e^- temporal information is encoded on transverse profile of laser beam

Single-Shot



Timing Jitter (20 Shots)





Sub-Picosecond Pulse Source

Adrian Cavalieri et al., *U. Mich.*

Femtosecond lasers can be synchronized to within a pulse duration using optical techniques

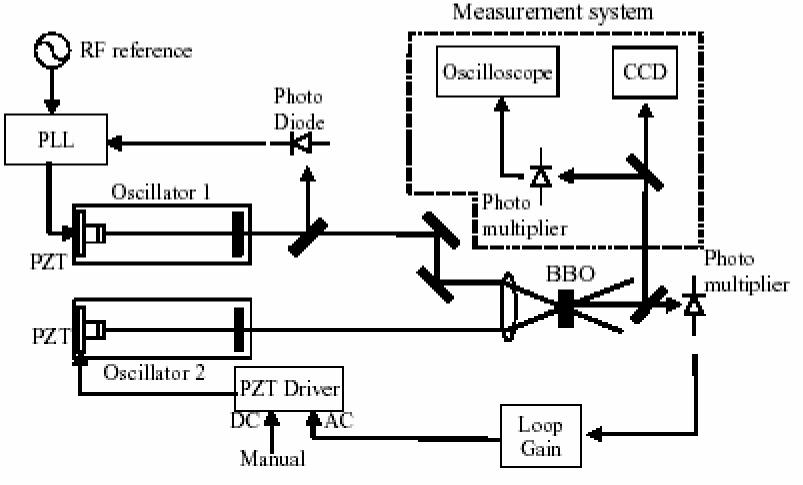
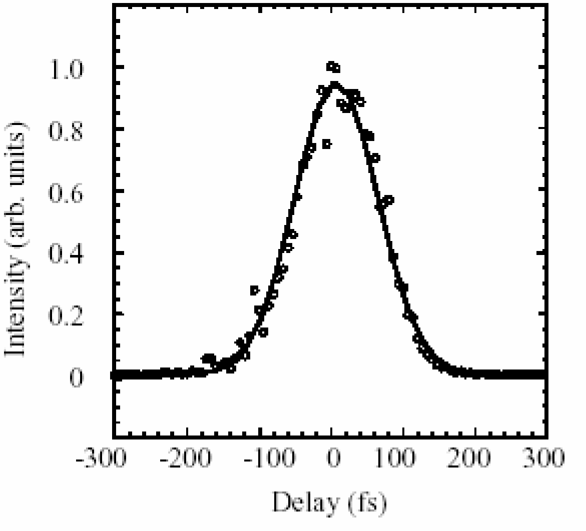


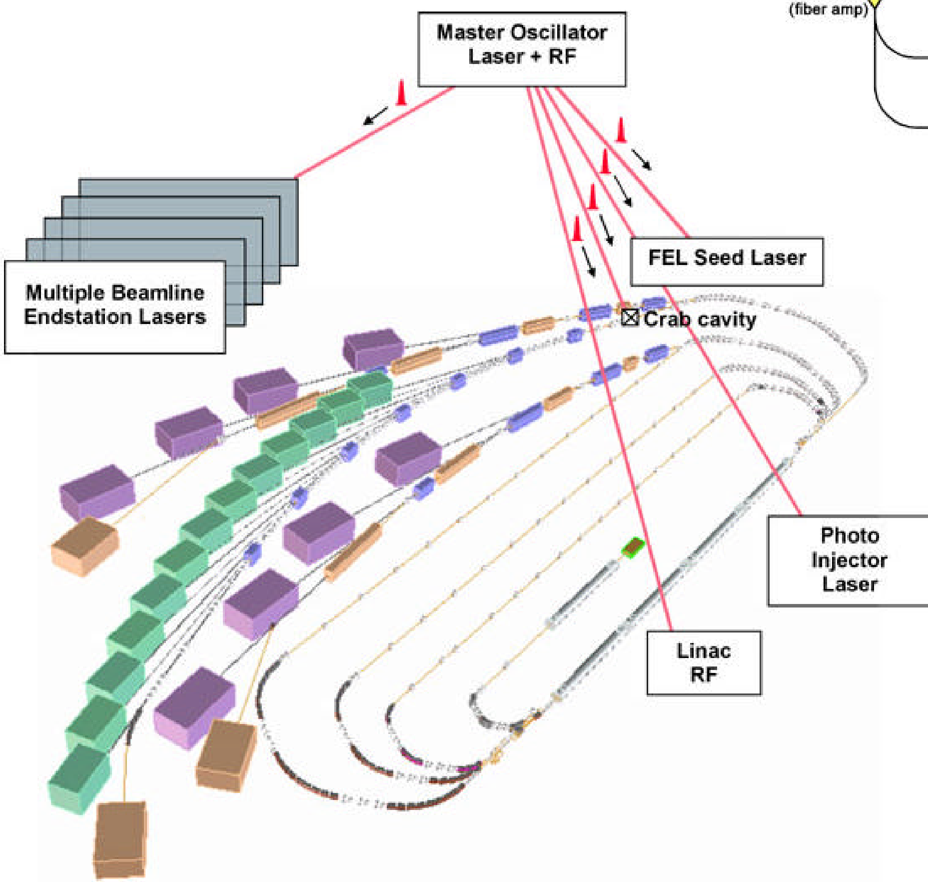
FIG. 5. Experimental set up for the synchronization of two mode locked oscillators.

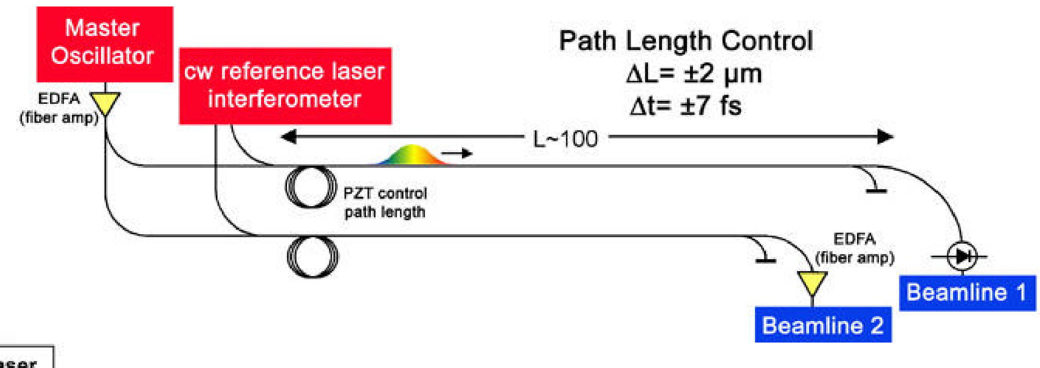


Kobayashi and Endo

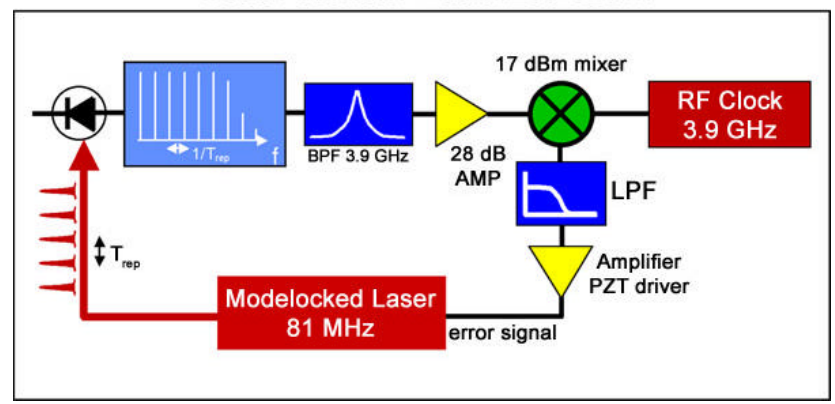
- This synchronization can be maintained throughout a laser amplifier system.
- Really hot new techniques can synchronize lasers to within an optical period (< 1 fs)!
- *We need this level of timing control to fully exploit the picosecond x-ray source*

LUX Timing Distribution Concept



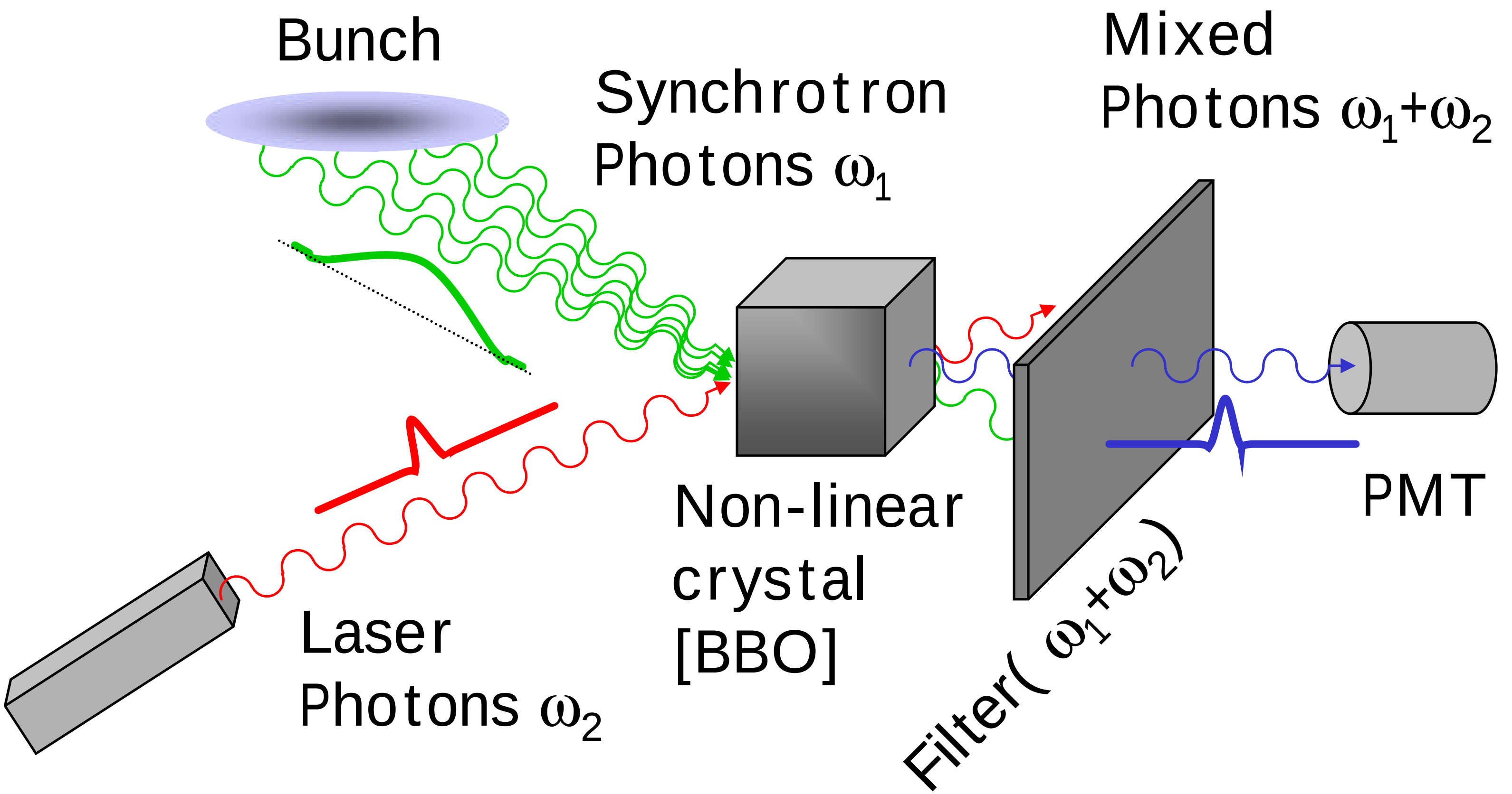


Master oscillator – stabilized laser/rf



An Optical Sampling Scope

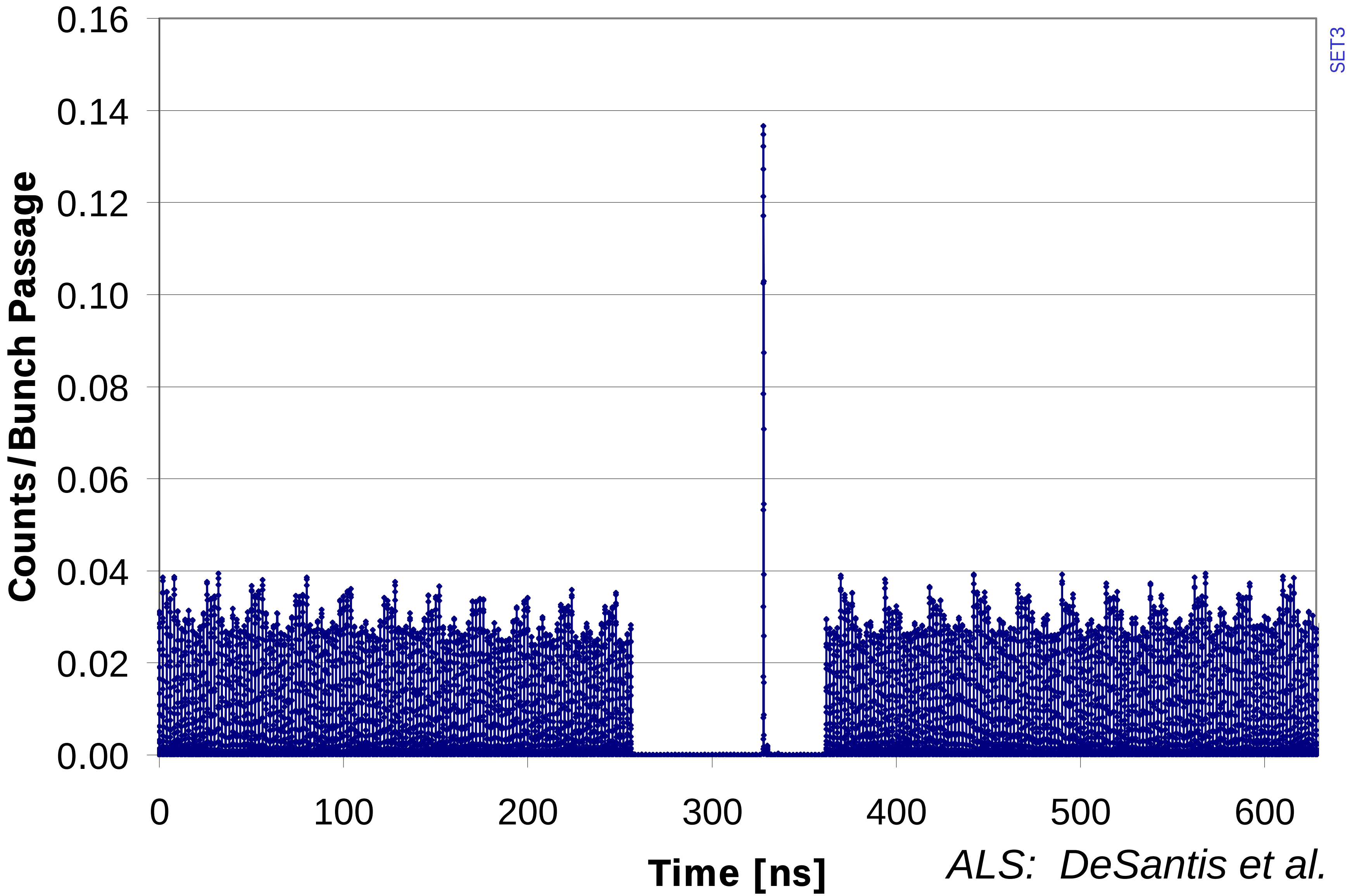
$\omega_1+\omega_2$ = visible wavelength



laser pulse length << bunch length

ALS: DeSantis et al.

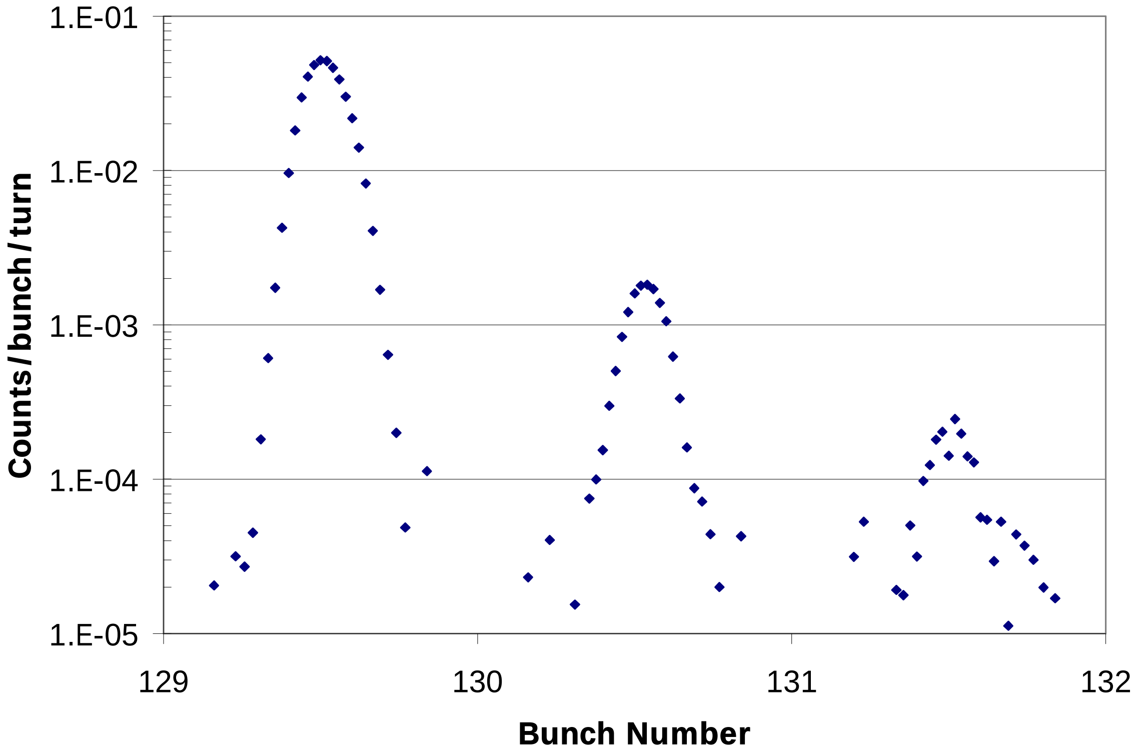
ALS Bunch Profile in Time



ALS: DeSantis et al.

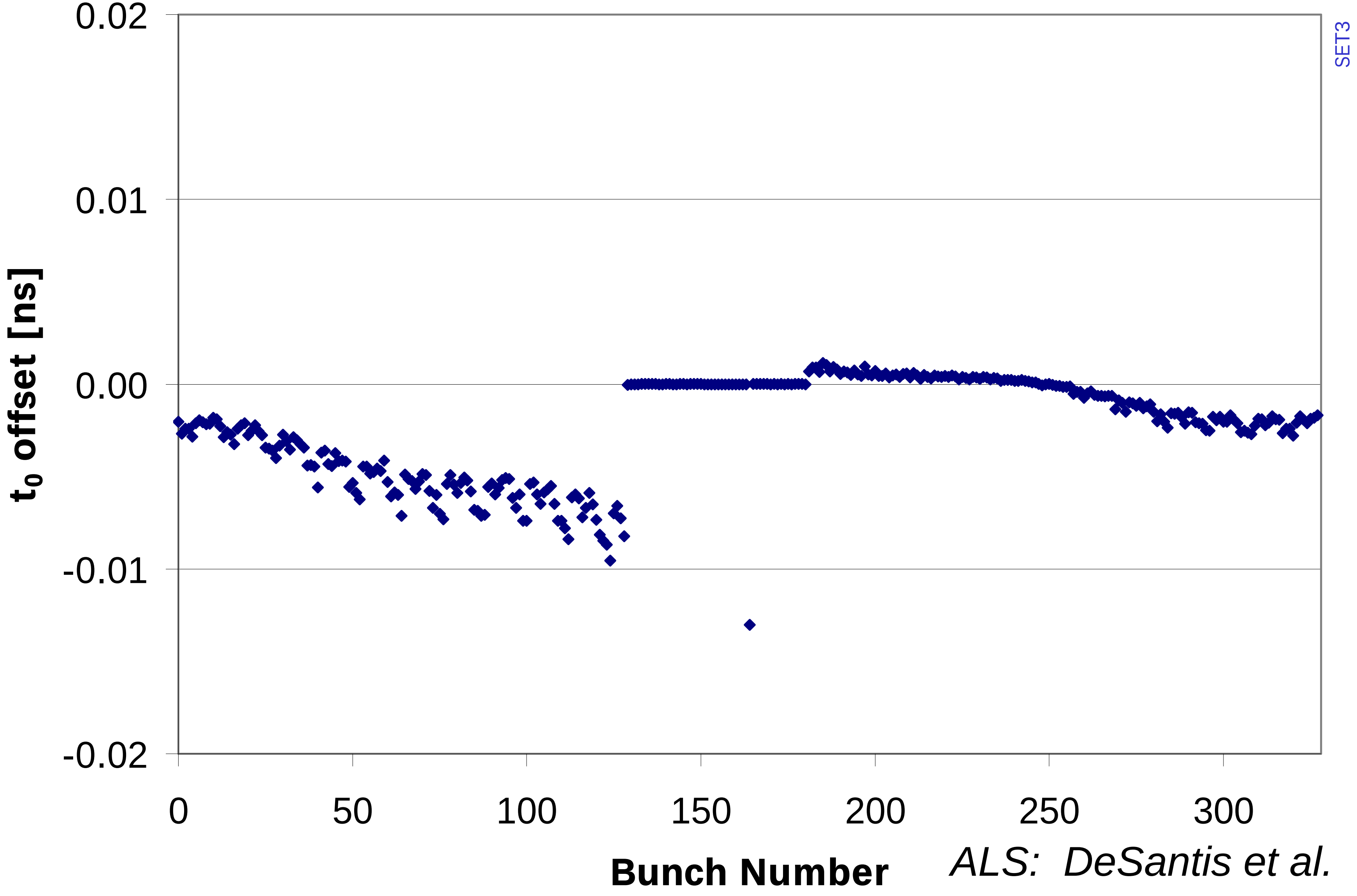
High Dynamic Range

Camshaft / Background ~ 10^3



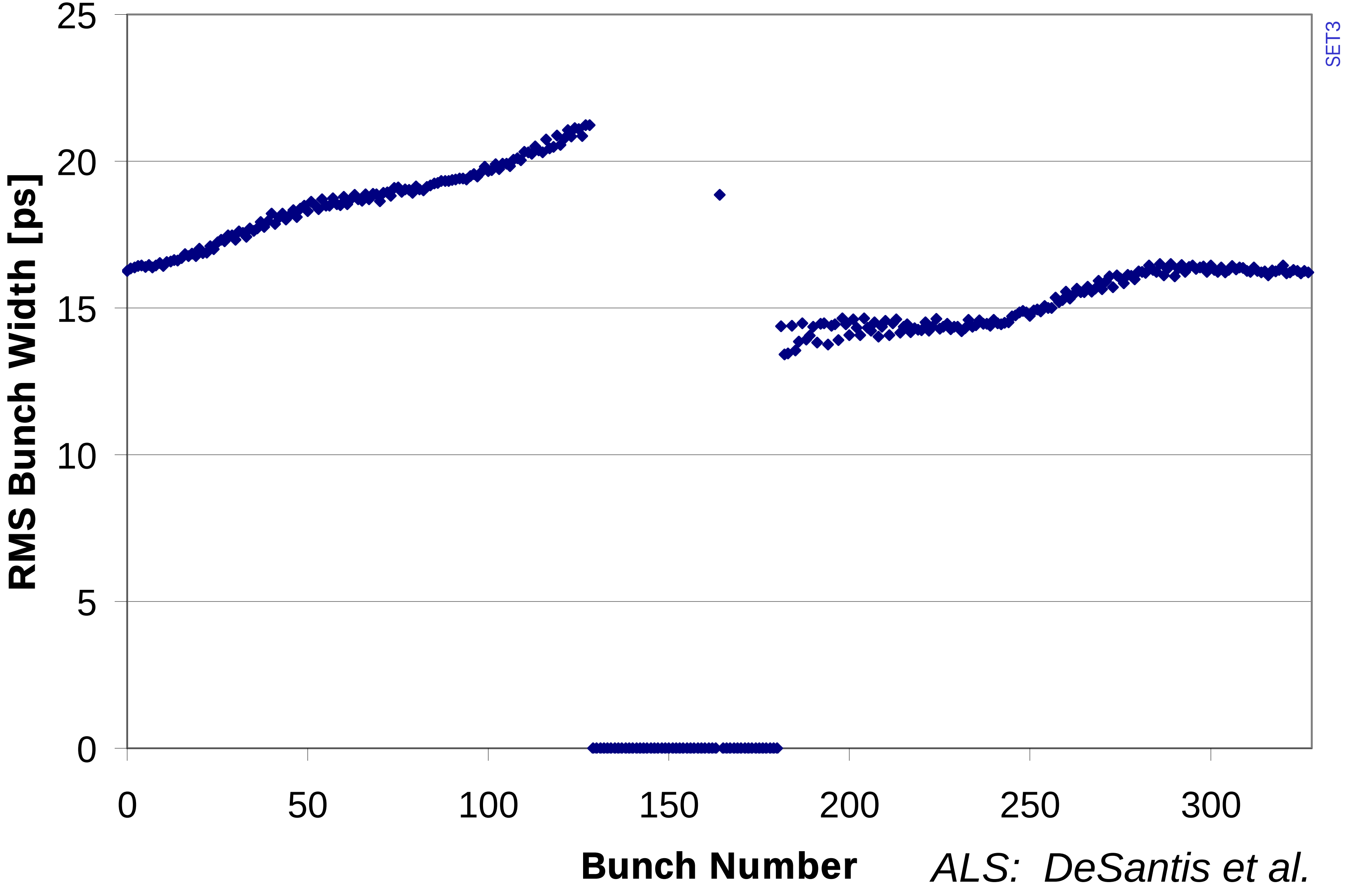
ALS: DeSantis et al.

Synchronous Phase Transients



ALS: DeSantis et al.

Bunch Length



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