Longitudinal Diagnostics Experimental Activities at the Advanced Light Source

S. De Santis

Topical Workshop on Longitudinal Profile Measurements

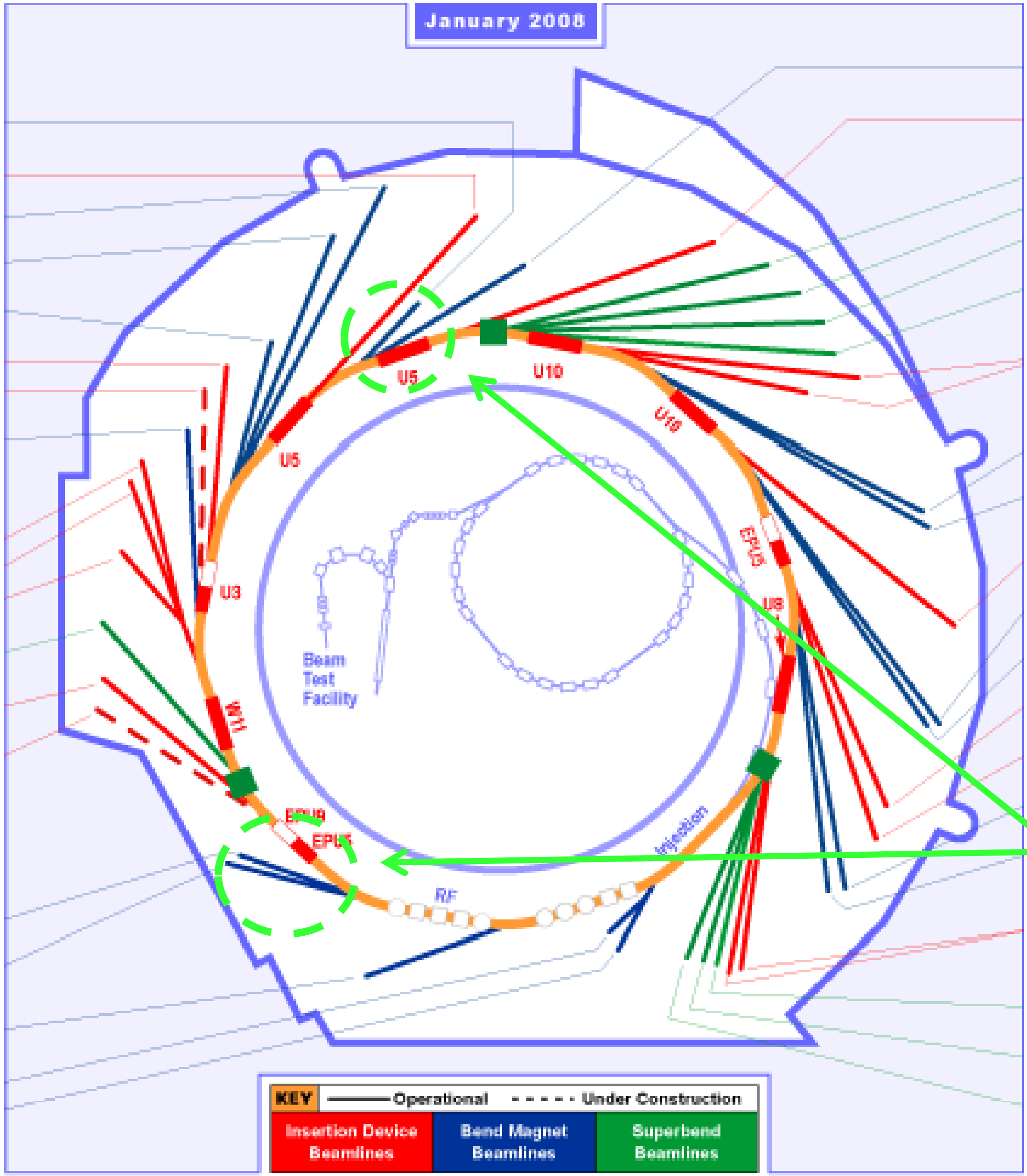
Summary

A light source is the ideal place for experimenting with synchrotron radiation based diagnostics.

- **Streak camera**
  - **Longitudinal dynamics at injection**
- **Non-linear laser mixing**
  - **Optical sampling scope (LARP)**
- **Gated microchannel plate**
  - **Abort gap monitor (LARP, Tevatron)**
- **Remote instrumentation – Fiberoptic based**
- **Beam timing monitor (EOM) – Wideband BPM**

J. Byrd, J.-F. Beche, M. Placidi, W. Turner, Y. Yin, M. Zolotorev

The Advanced Light Source



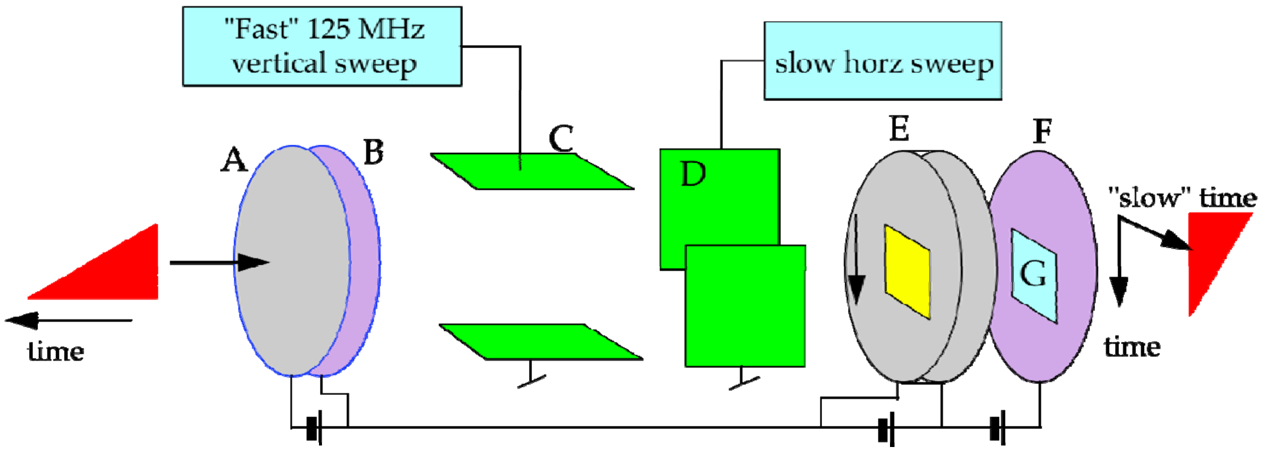
Machine Parameters

- Energy: 1.9 GeV (injection 1.5 GeV)
- Current: 200÷400 mA
- Number of bunches: up to 320
- RF frequency: 500 MHz
- Revolution frequency: 1.5 MHz
- Syncrotron frequency: 12 kHz
- Bunch length: ~30 ps

Two dedicated diagnostic beamlines (dipole radiation). IR to X-ray wavelengths.

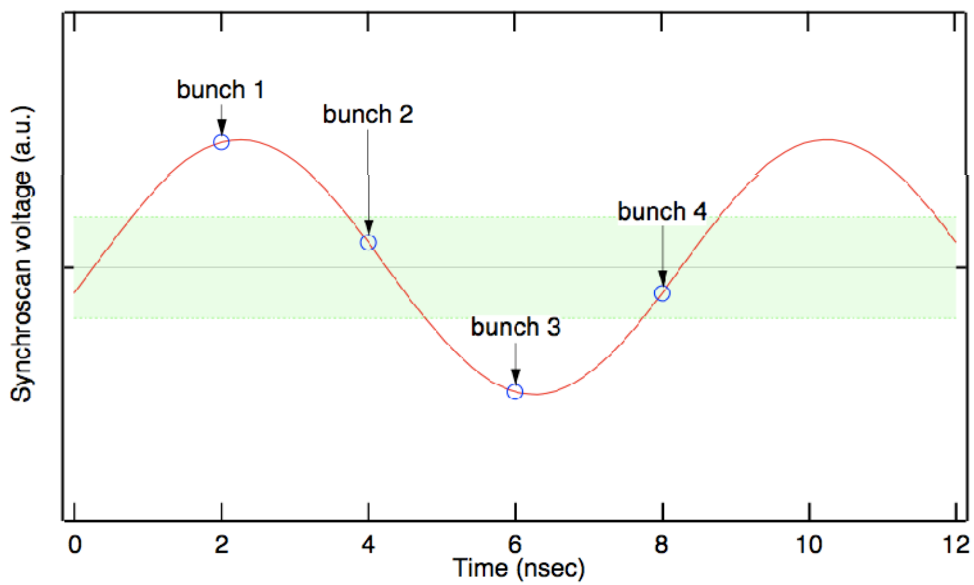
Streak Camera

Hamamatsu C5680



125 MHz synchroscan (=f_{RF}/4)

Only every other bunch is displayed



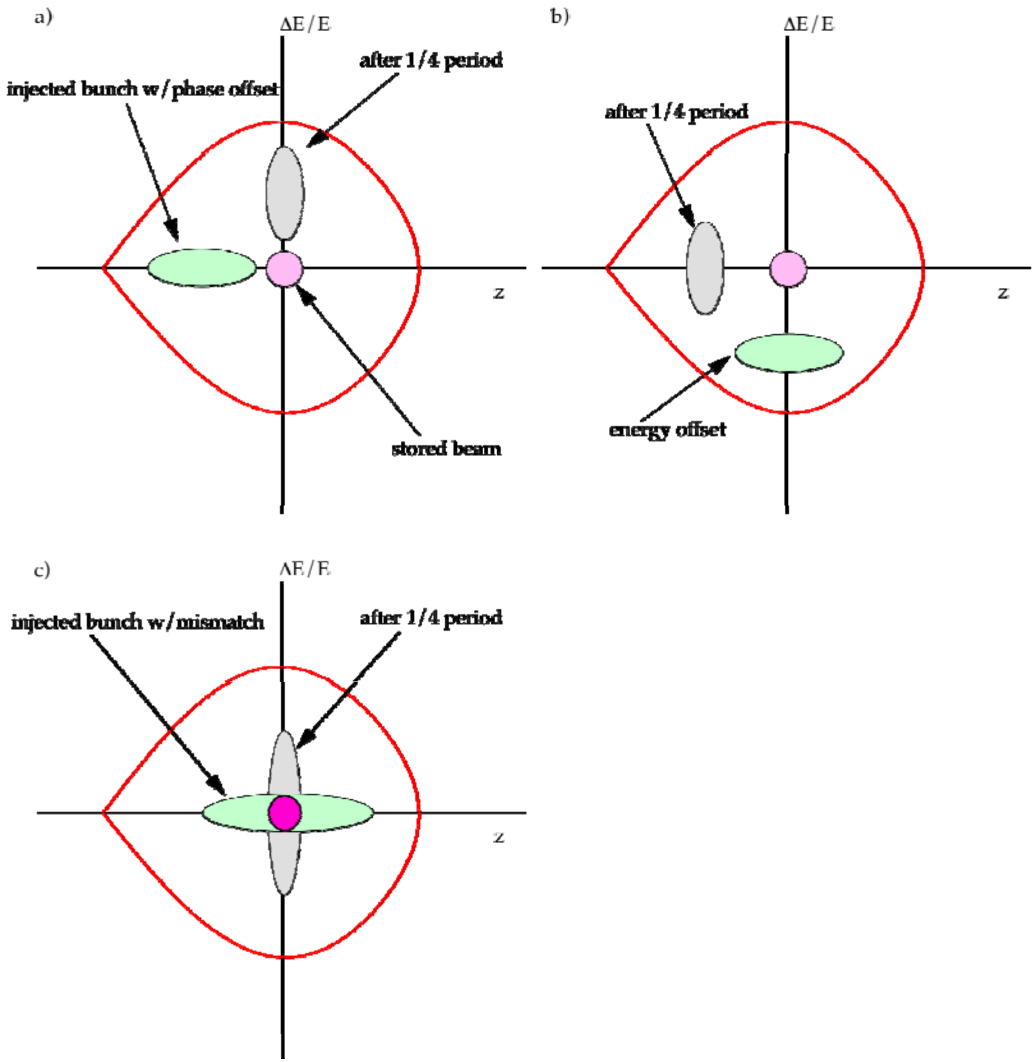
Injected bunch ≠ Stored bunch

- Injection errors
    - Phase offset
    - Energy offset

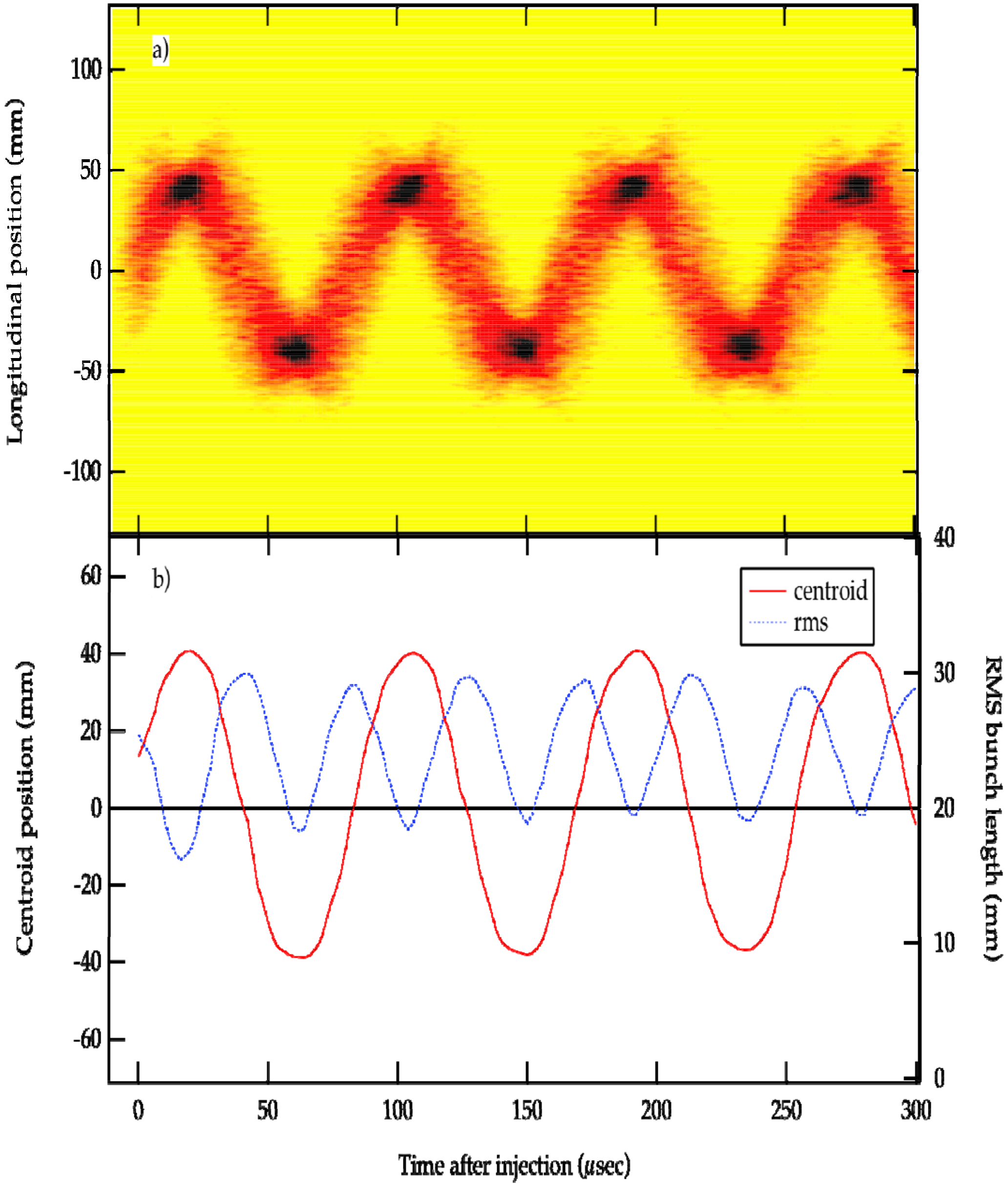
which are *almost* the same thing (energy becomes phase after a quarter of synchrotron period)

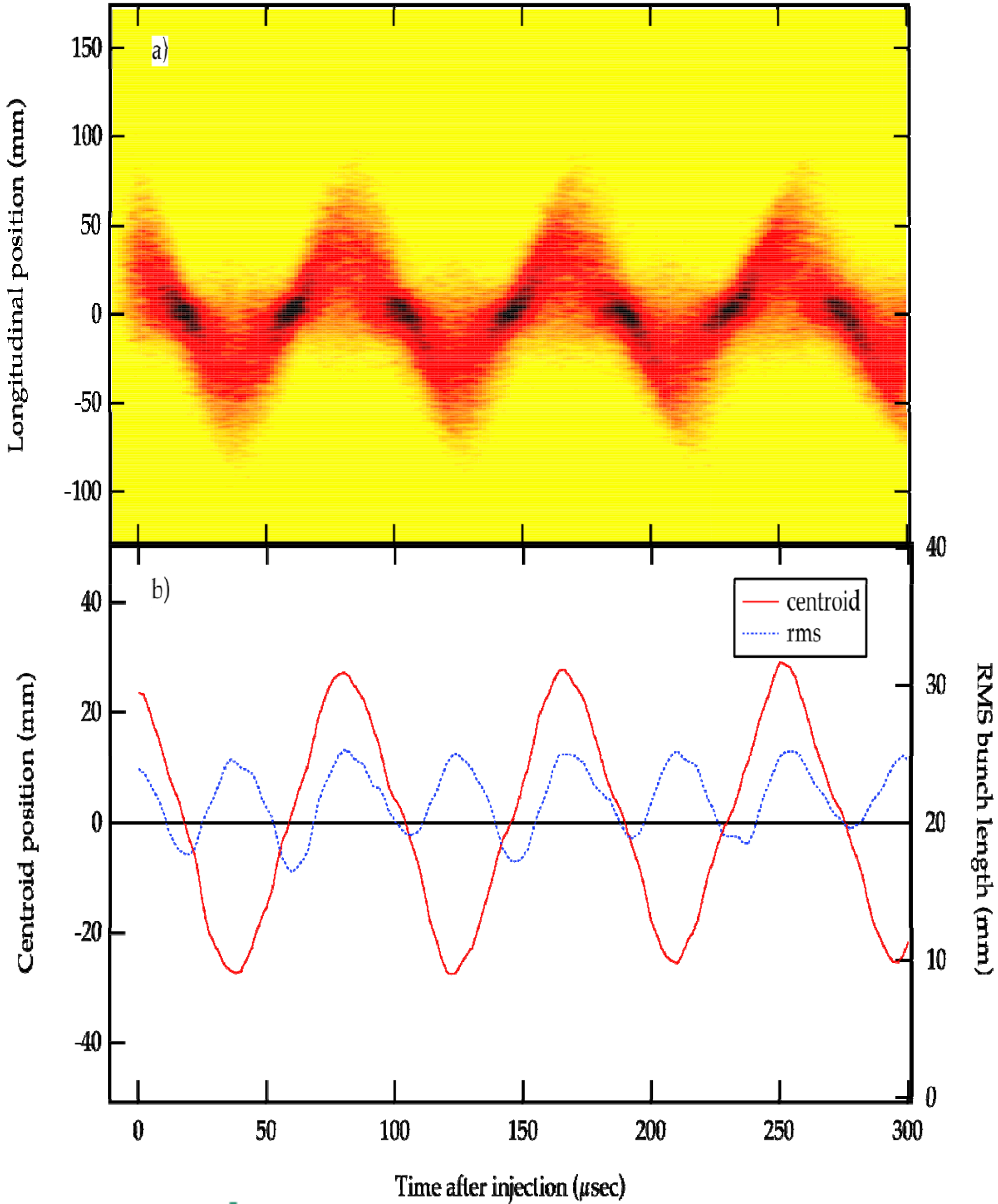
- Phase-space mismatch

Longitudinal phase space in the storage ring does not look anything like the longitudinal phase space in the booster+transfer line



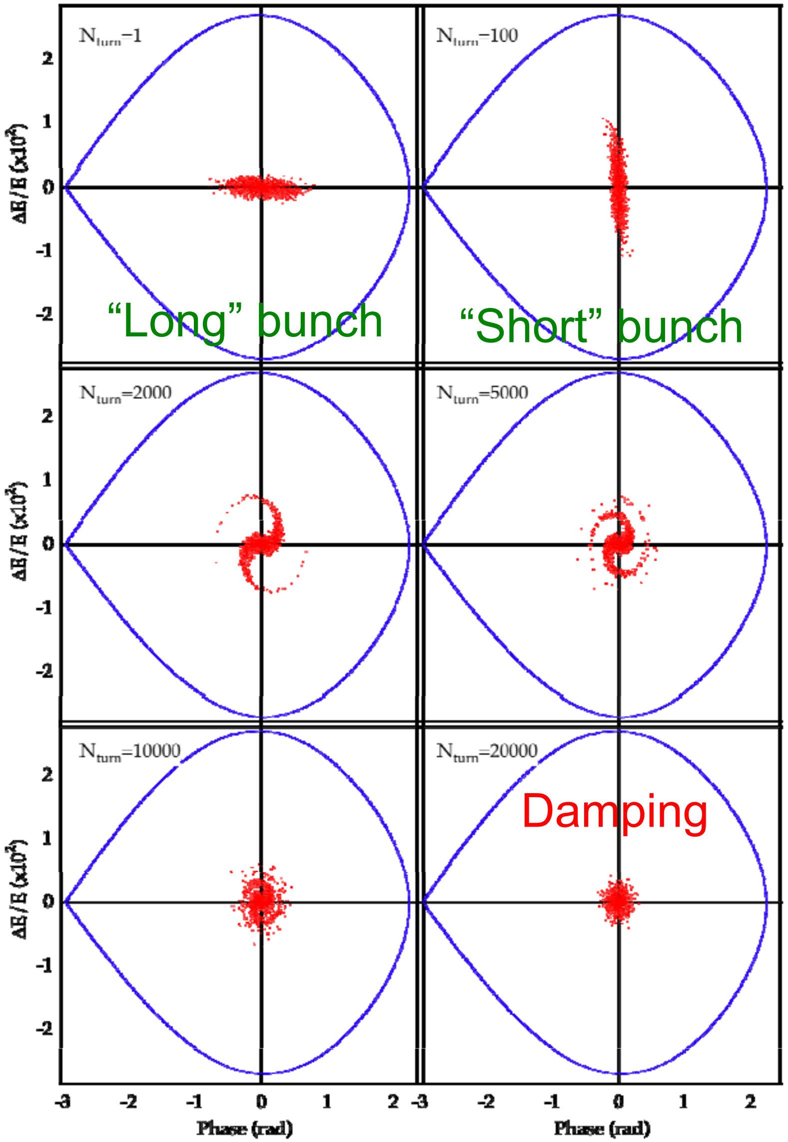
Injection Errors

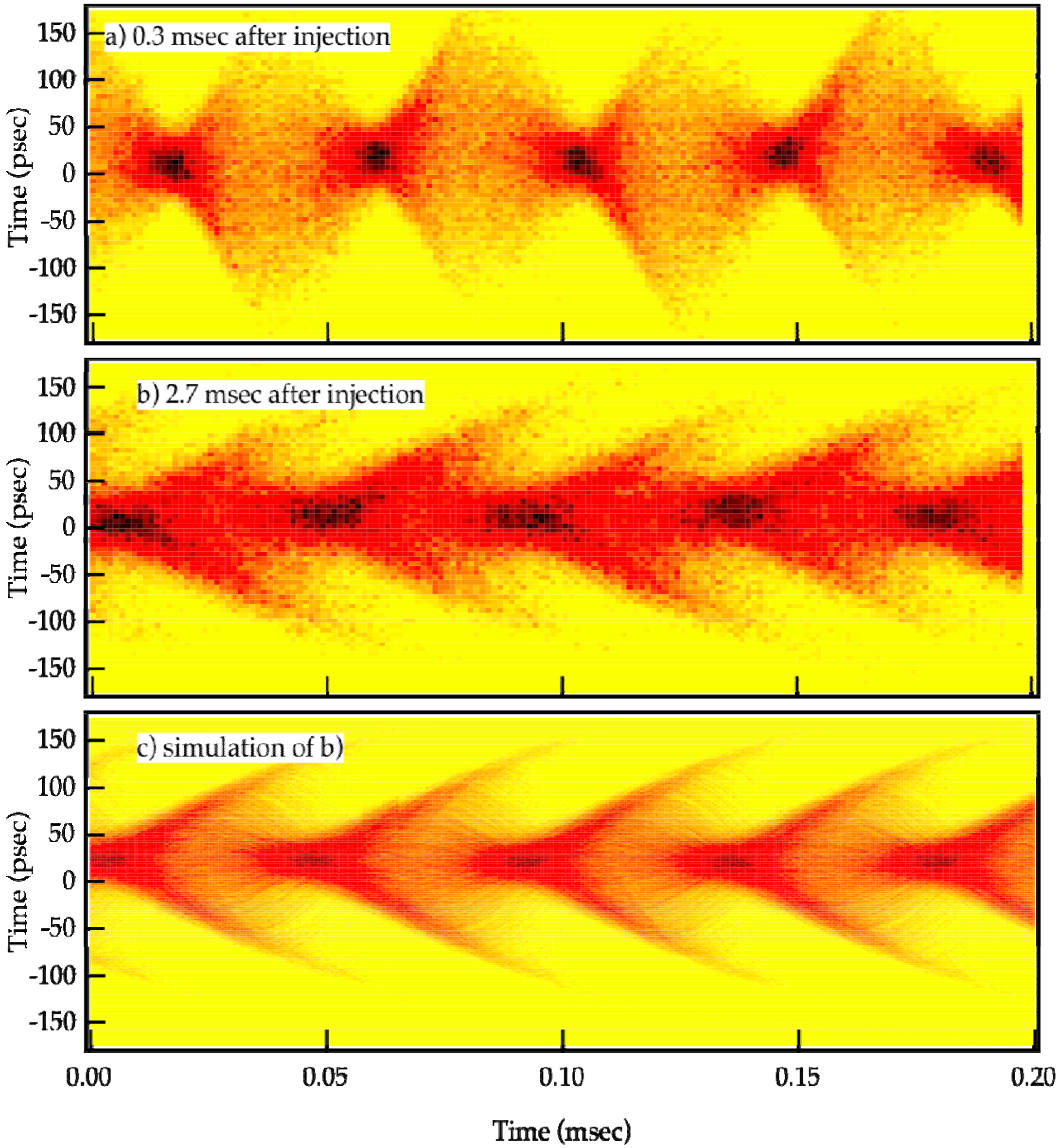




Phase-space Mismatch

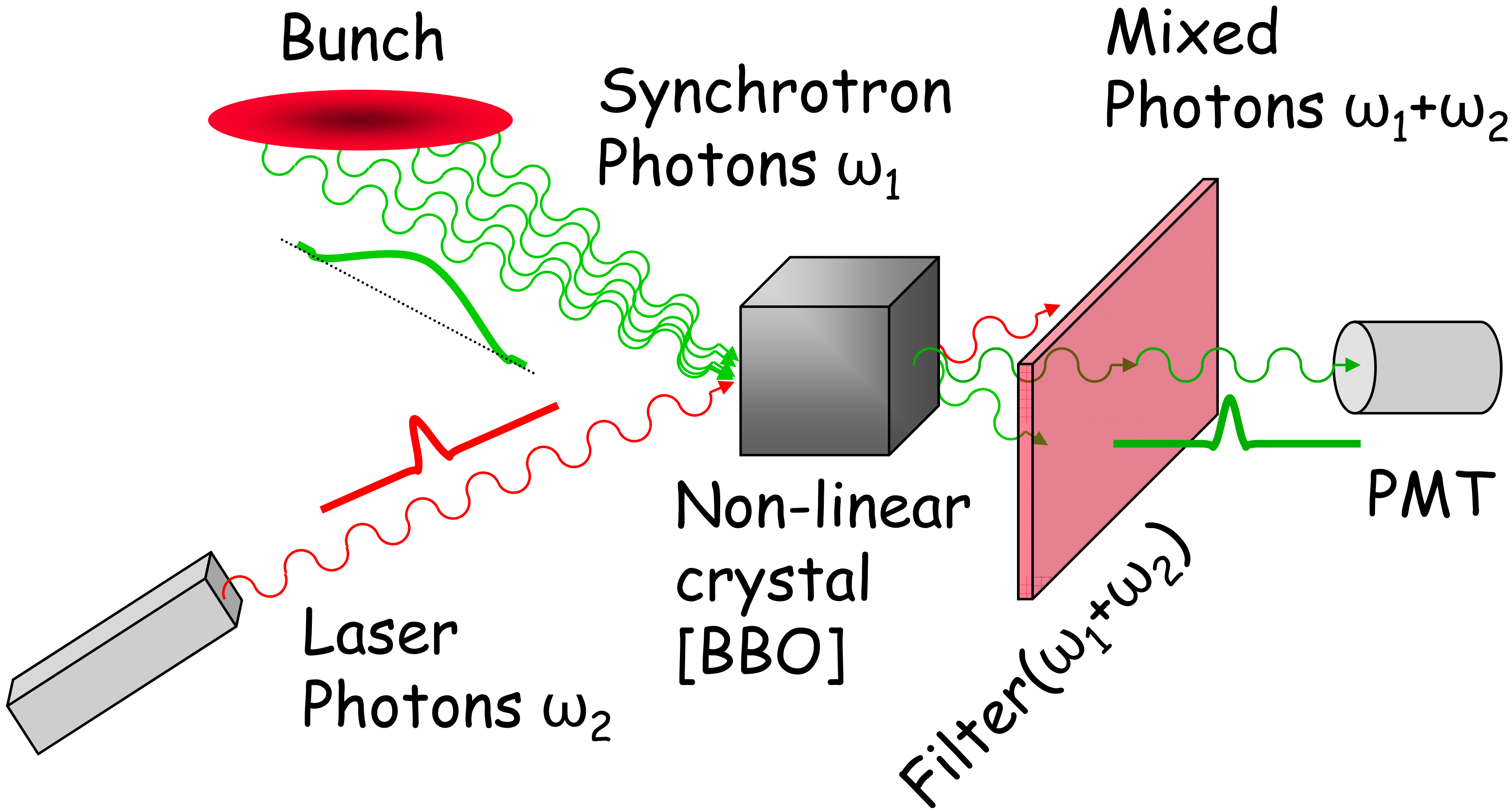
Filamentation





Optical Sampling Scope

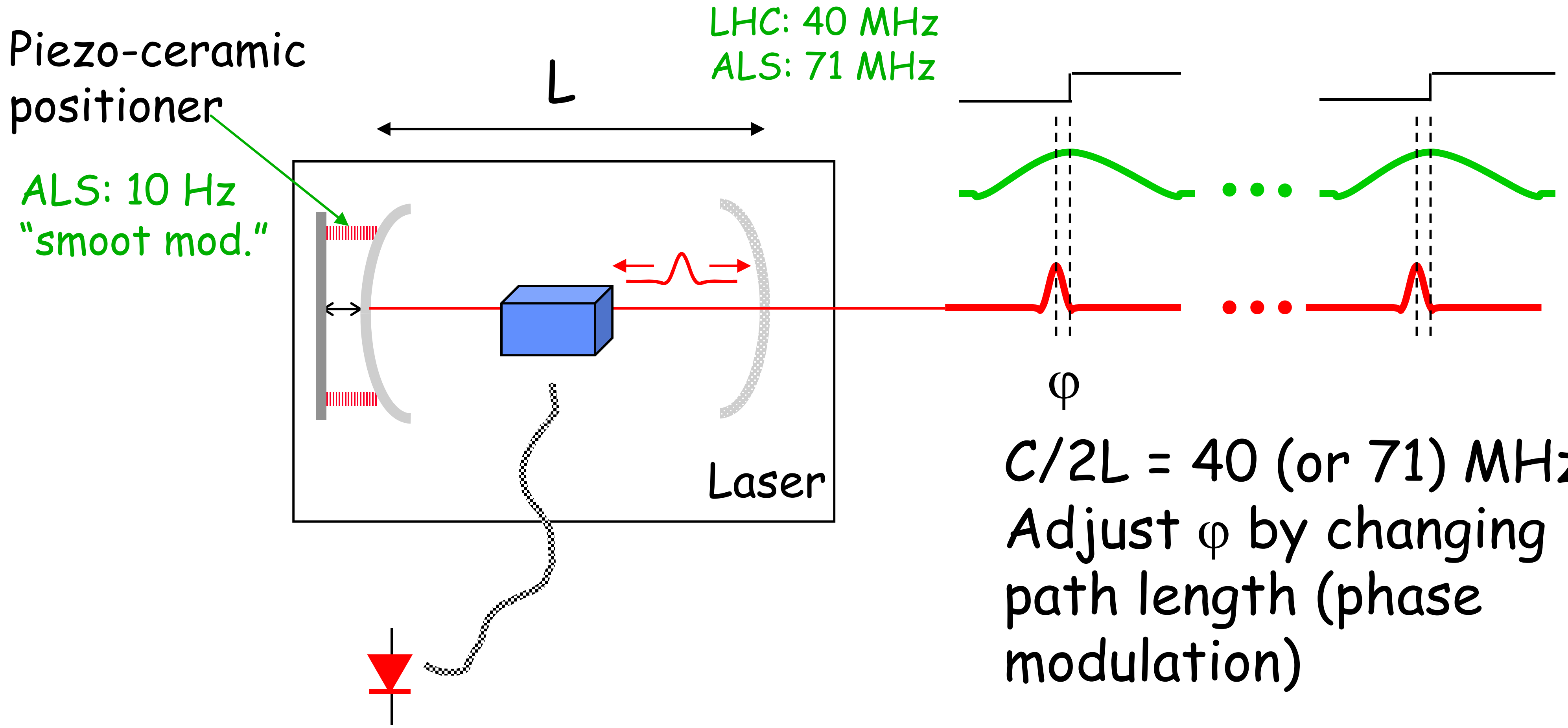
$\omega_1+\omega_2$ = visible wavelength



mode-locked Ti:Al_2O_3 laser

laser pulse length << bunch length

Scanning the Bunch



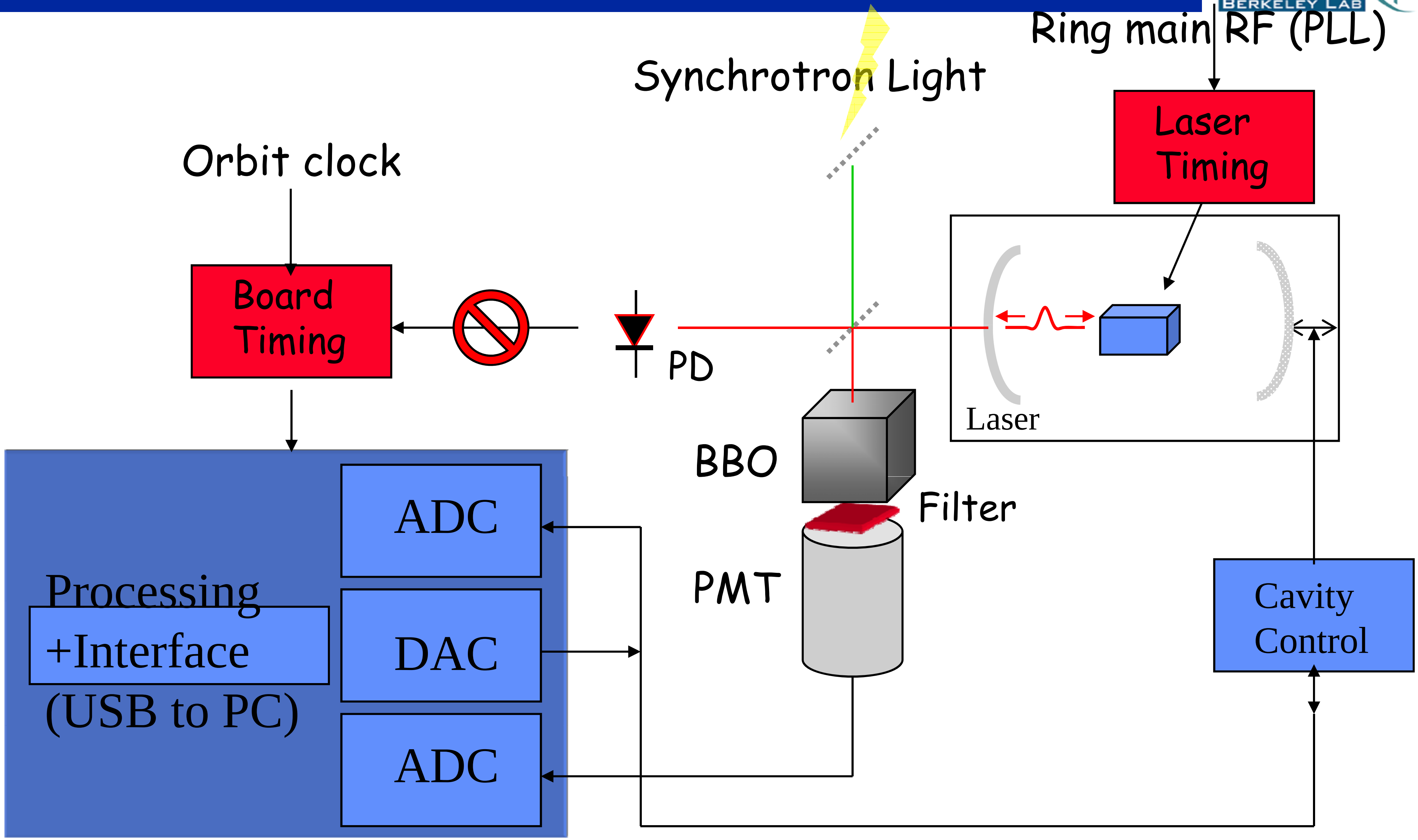
C/2L = 40 (or 71) MHz
Adjust φ by changing path length (phase modulation)

100-200 mW diode-pumped laser

LHC: 22 bins (std. mode)
ALS: 32 bins

ALS: 50 fs, LHC: 50 ps (10 W)

Schematic (timing)

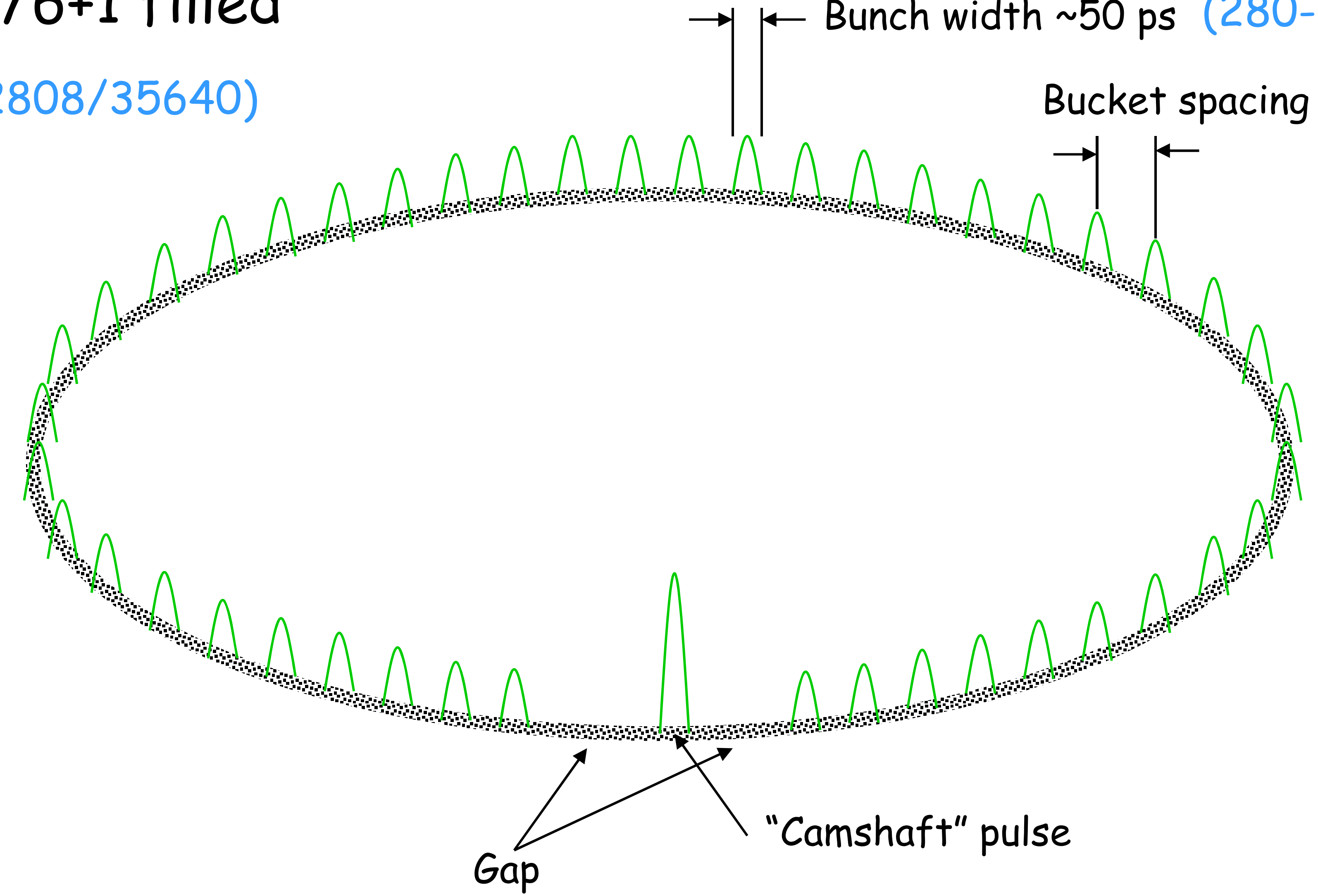


Tests at the ALS

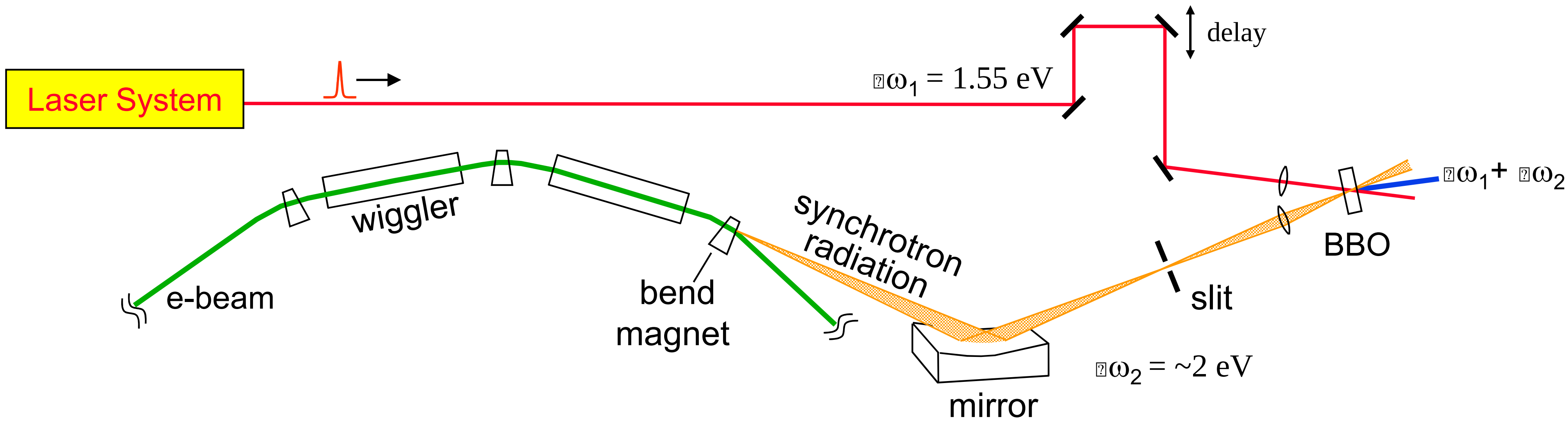
(LHC parameters)

328 RF buckets
276+1 filled

(2808/35640)



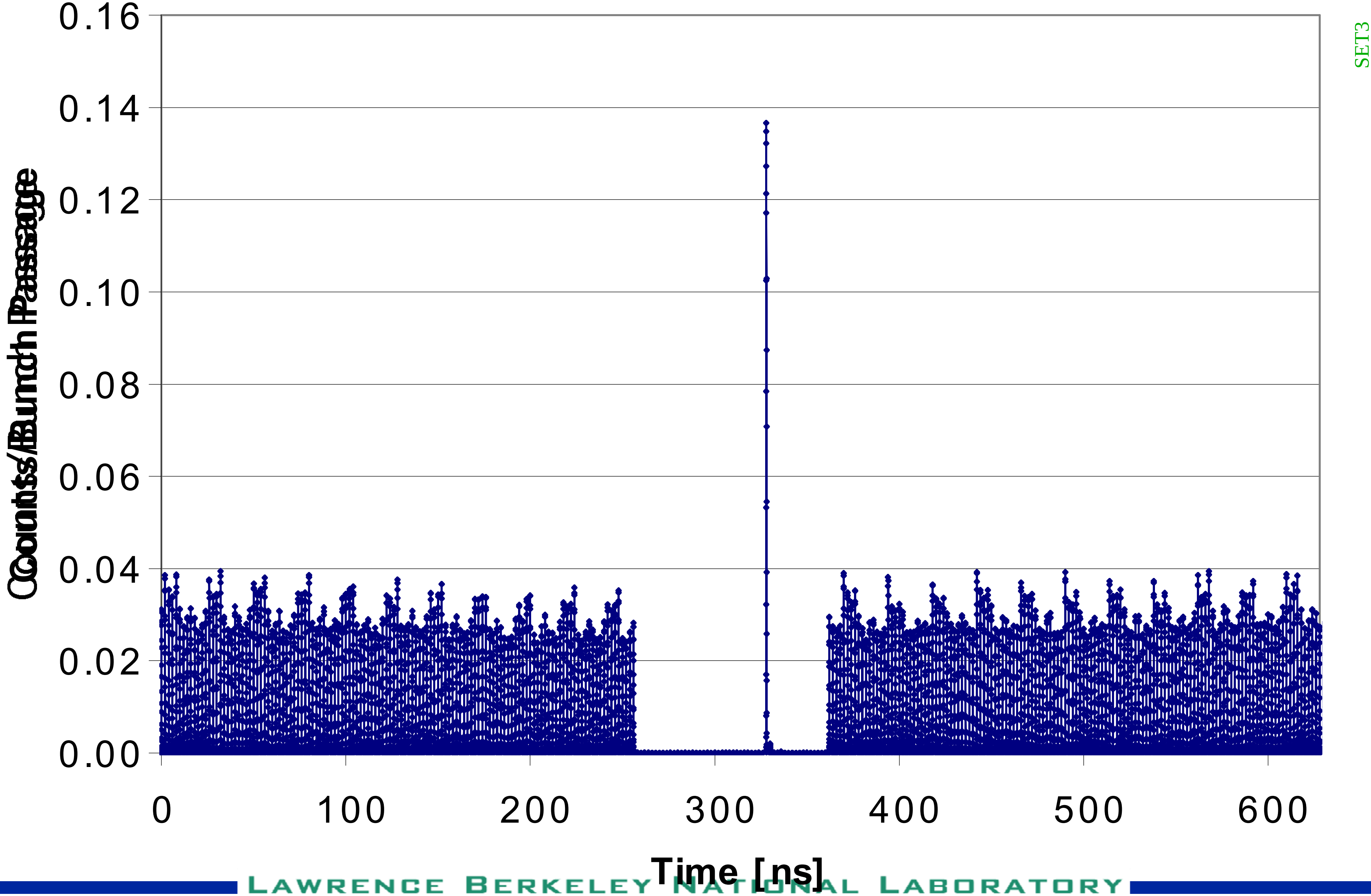
Optical layout at the ALS



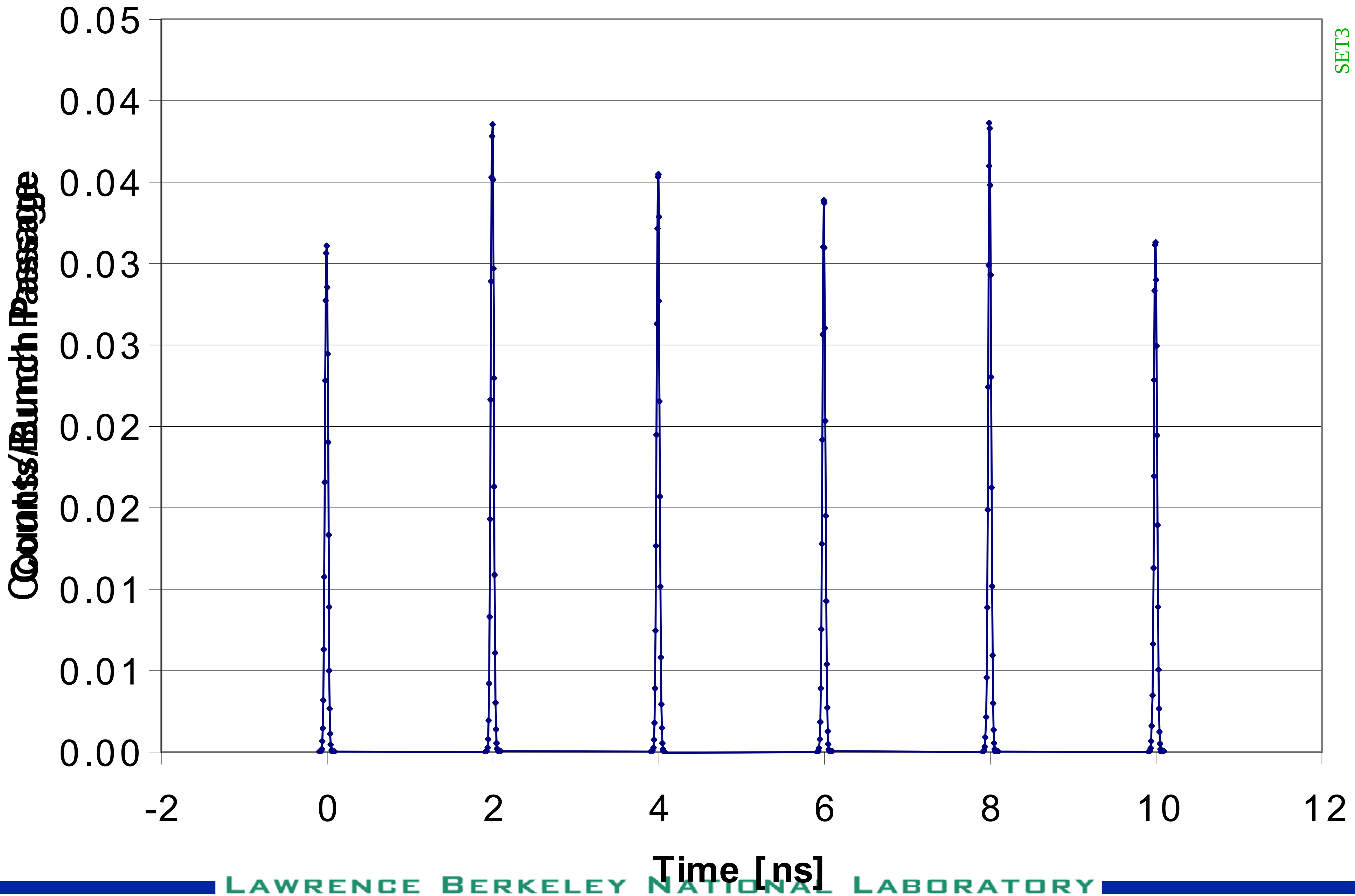
λ_L= 800 nm, λ_S= 638 nm ➡ λ_Σ=355 nm

Conversion efficiency is proportional to the laser power density and is optimized for $\lambda = \lambda_S$

ALS Bunch Profile in Time

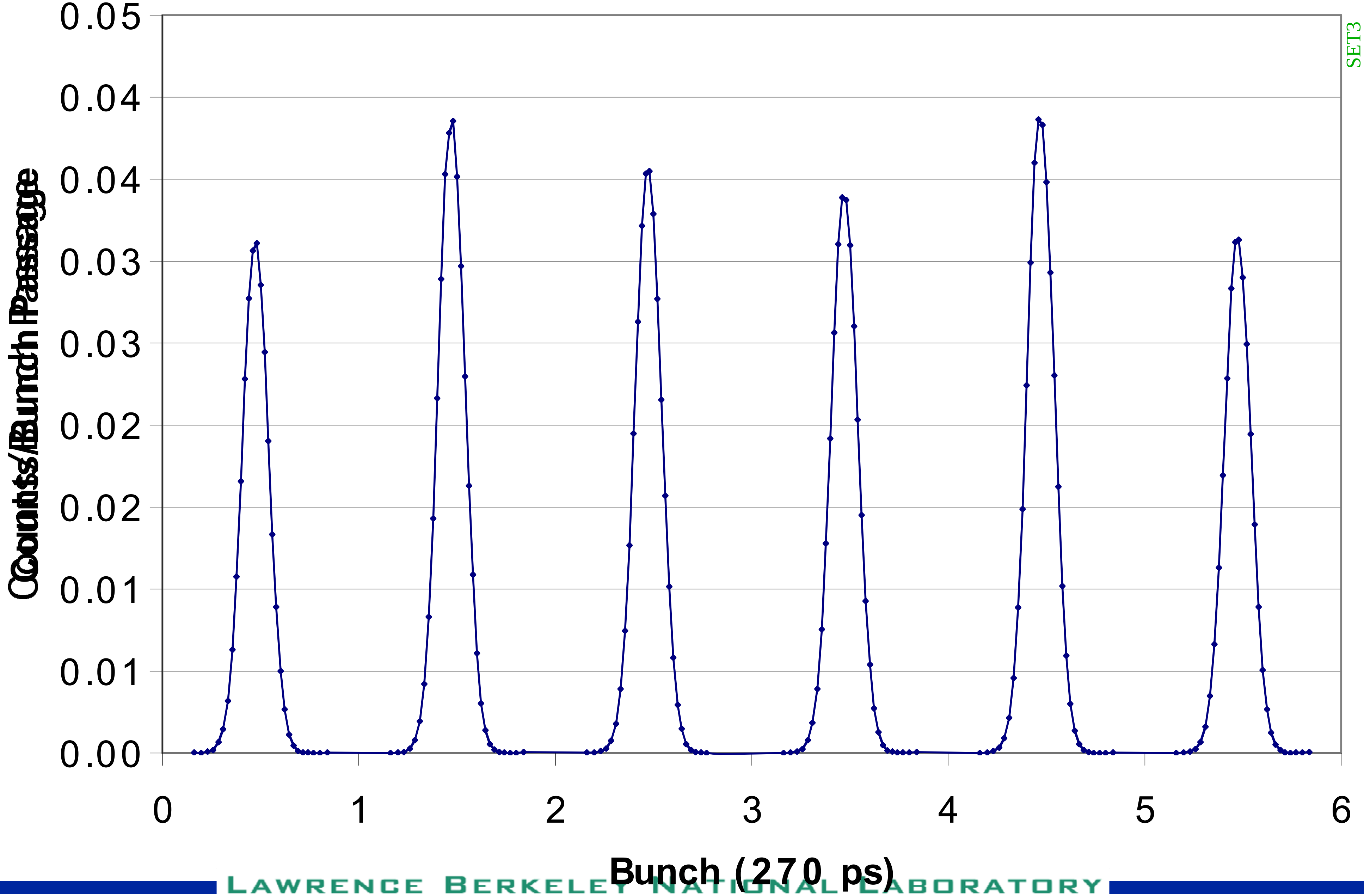


Zoom in...

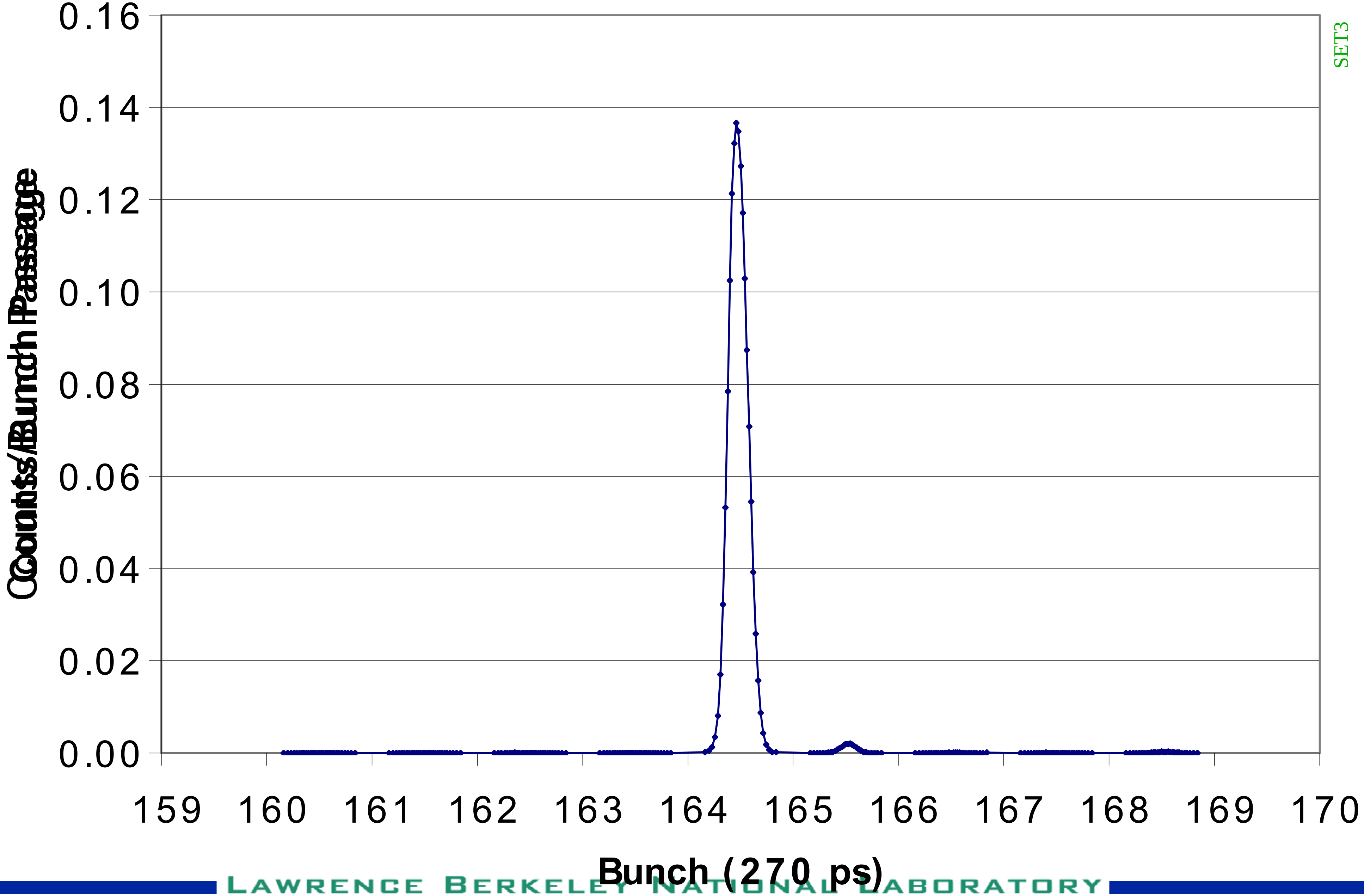


0.05
0.04
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
Counts/Bunch Passage
SET3
-2
0
2
4
6
8
10
12
Time [ns]

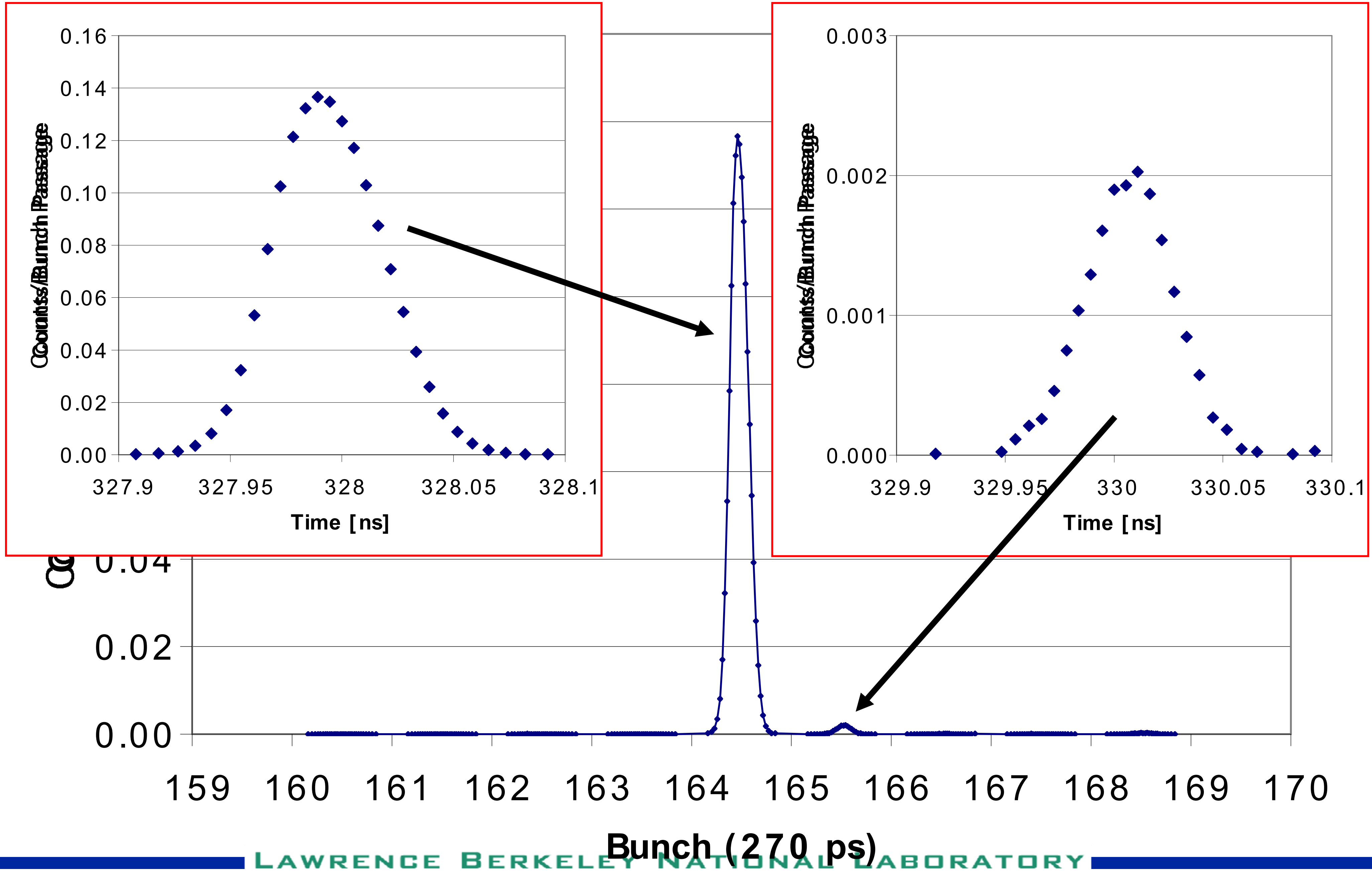
Compress Scale...



Large dynamic range

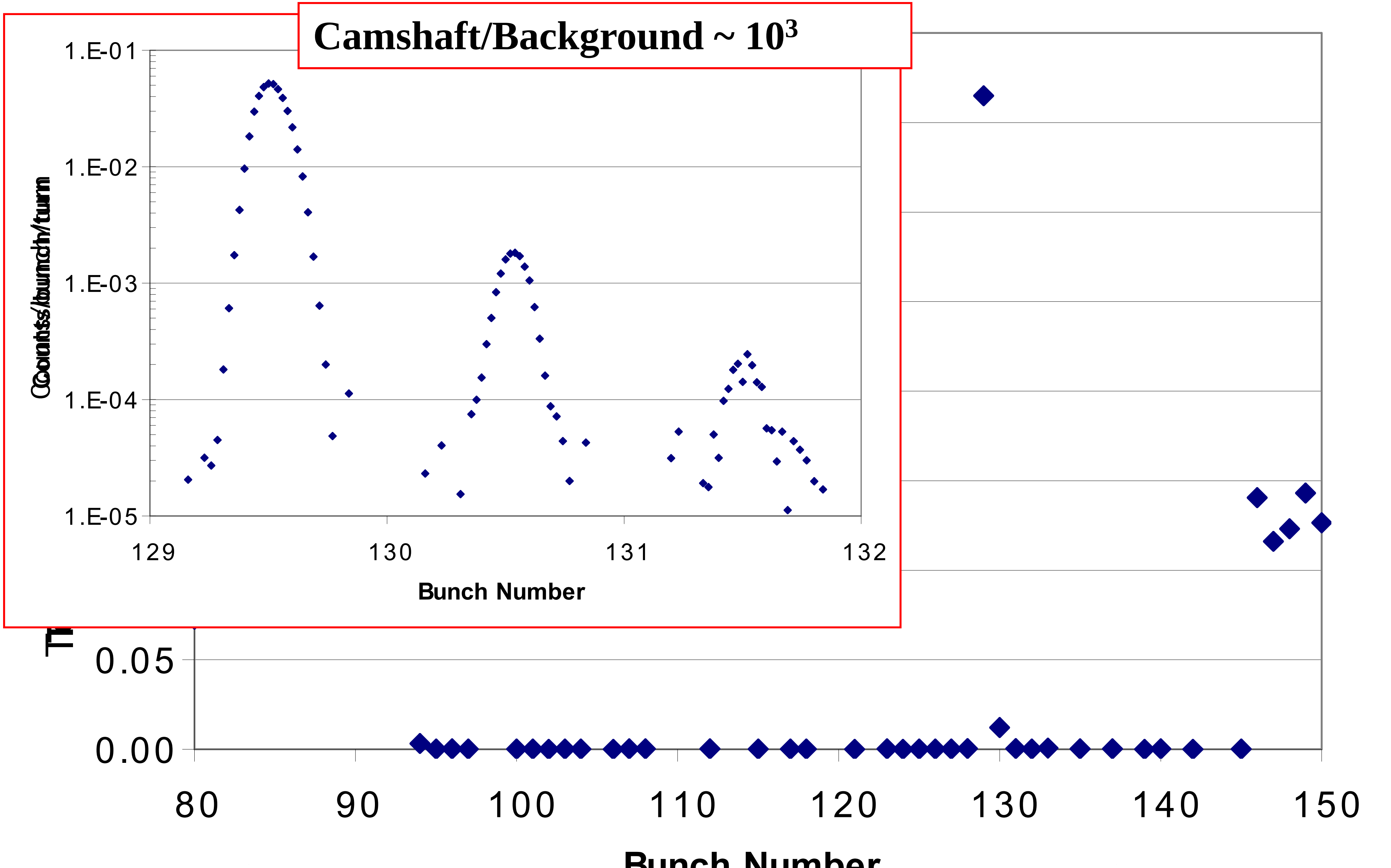


Details



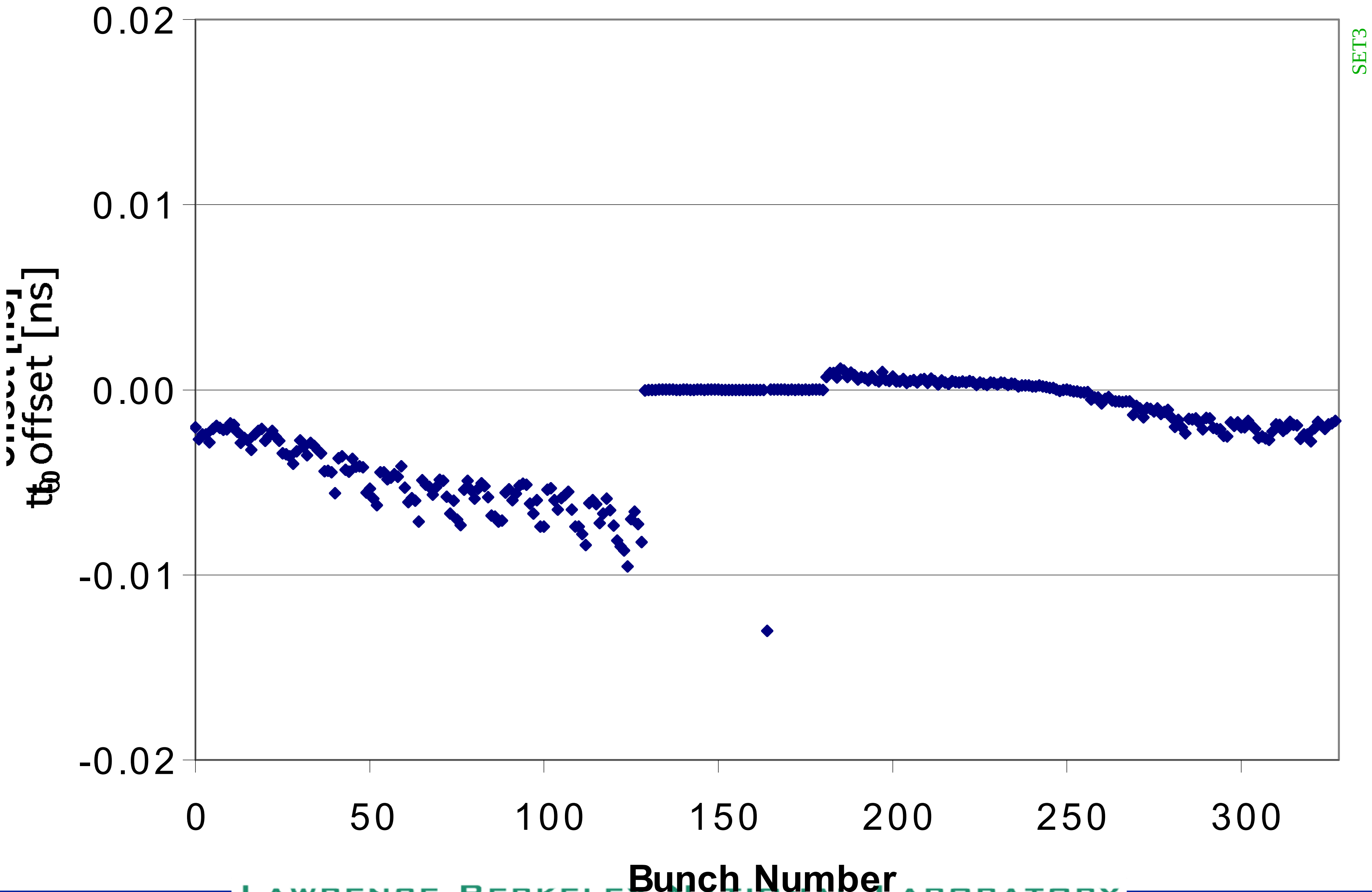
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Counts/Bunch Passage
327.9
327.95
328
328.05
328.1
Time [ns]
0.003
0.002
0.001
0.000
Counts/Bunch Passage
329.9
329.95
330
330.05
330.1
Time [ns]
0.04
0.02
0.00
159
160
161
162
163
164
165
166
167
168
169
170
Bunch (270 ps)

Background

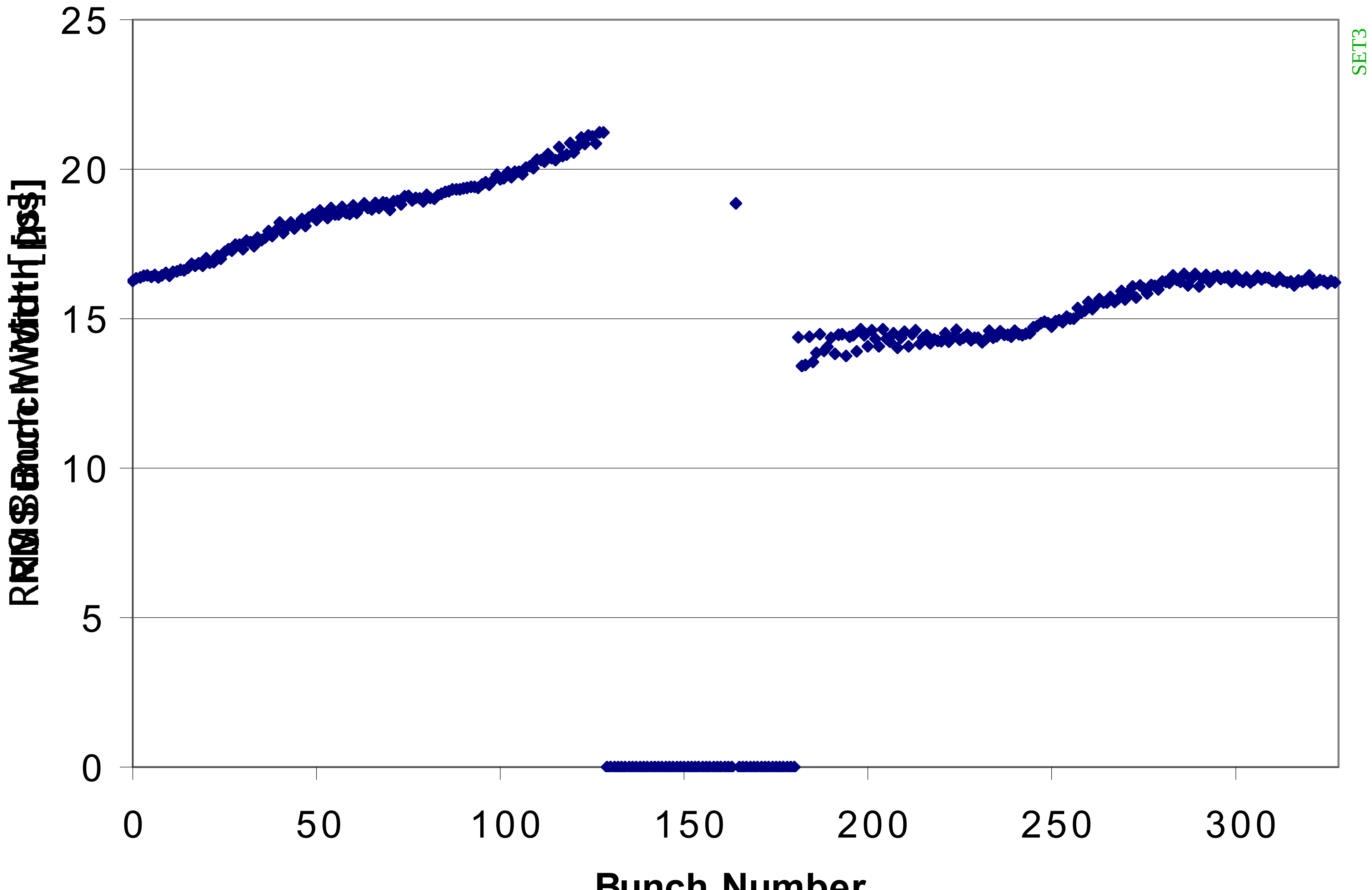


Camshaft/Background ~ 10^3
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
Counts/bunch/turn
129
130
131
132
Bunch Number
0.05
0.00
80
90
100
110
120
130
140
150
Bunch Number

Synchronous Phase Transients



Bunch Length



Challenge

Measuring very low charge densities over long portions of the ring, in the presence of very large beam signals.
And do it quick.

MCP-PMT for the AGM

Gate min. raise time: 1 ns

<2.5 ns RF bucket spacing; can gate out filled buckets

<<100 ns resolution

Gate voltage: 10 V

Low voltage switching required

Max gain: 10^6

< 10 dark counts/sec

High S/N

Max duty cycle: 1%

Max gate length: 10 μs

HAMAMATSU

GATEABLE MICROCHANNEL PLATE PHOTOMULTIPLIER TUBE (MCP-PMTs)
R5916U-50 SERIES

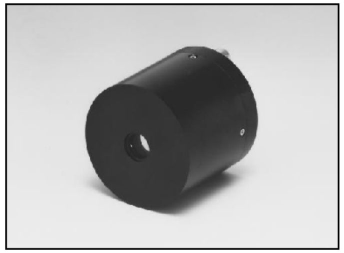
Featuring Fast Gating Function with Improved Time Response and Switching Ratio

FEATURES

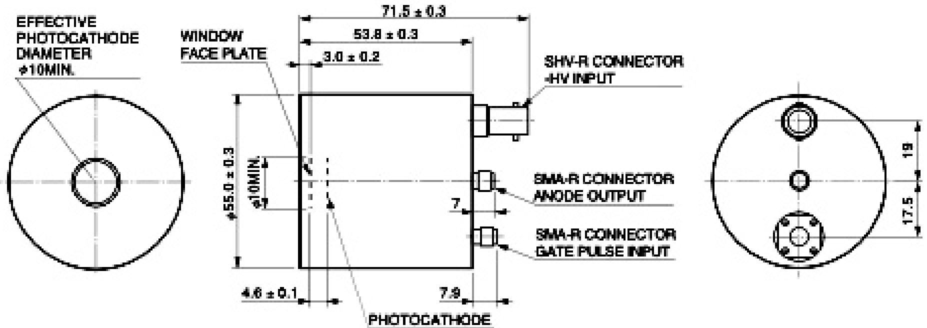
- High Speed Gating by Low Supply Voltage (+10V)
  - Gate Rise Time : 1 ns [1)]
  - Gate Width : 5 ns
- Fast Rise Time : 180 ps
  - Narrow TTS [2)] : 90 ps
- High Switching Ratio : 10^8 at 500 nm
- Low Switching Noise
- Low Dark Noise
- Variety of Photocathode Available

APPLICATIONS

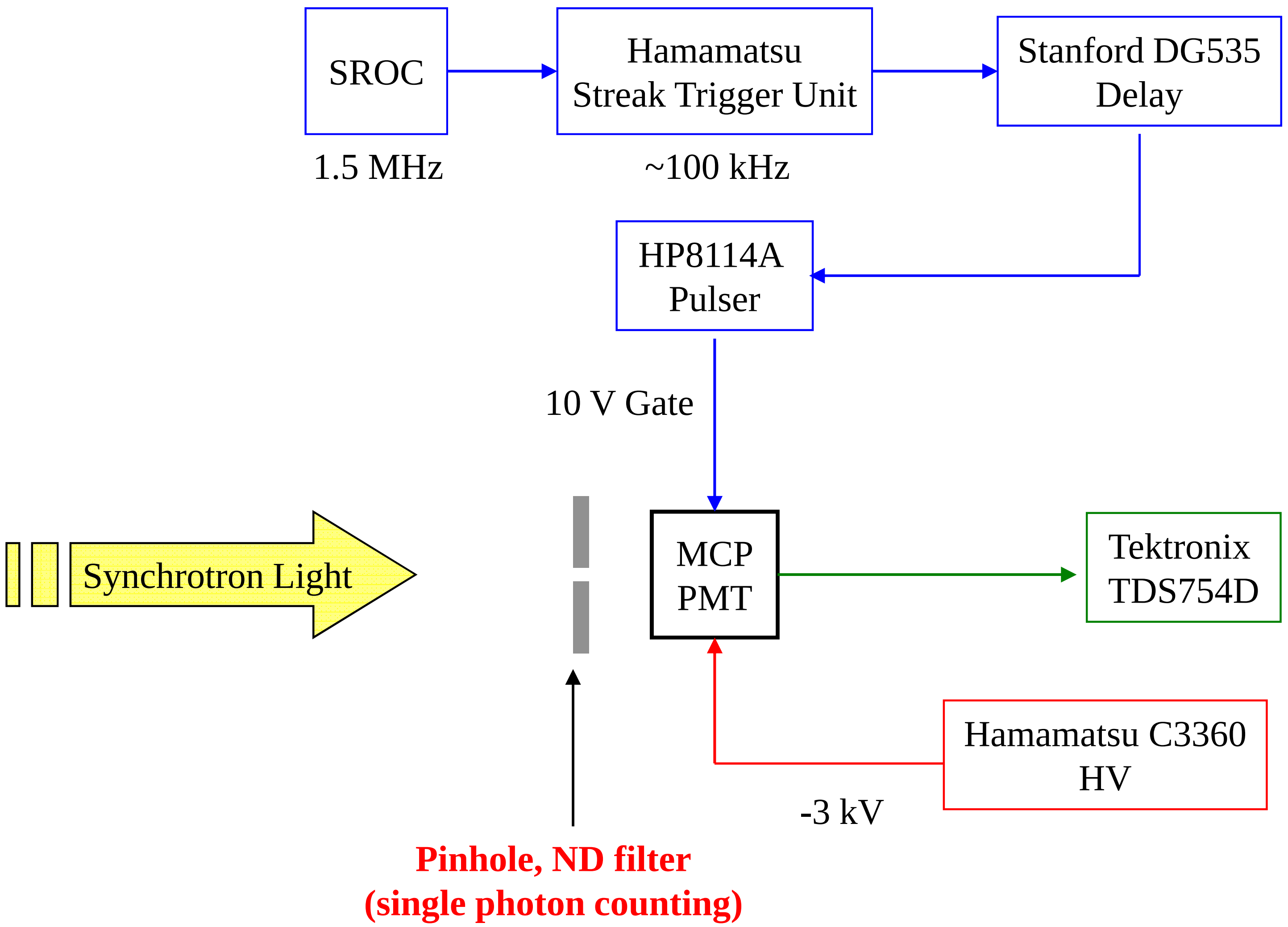
- Environmental monitoring
- Satellite laser ranging
- Fluorescence decay analysis



Dimensional Outline (Unit: mm)

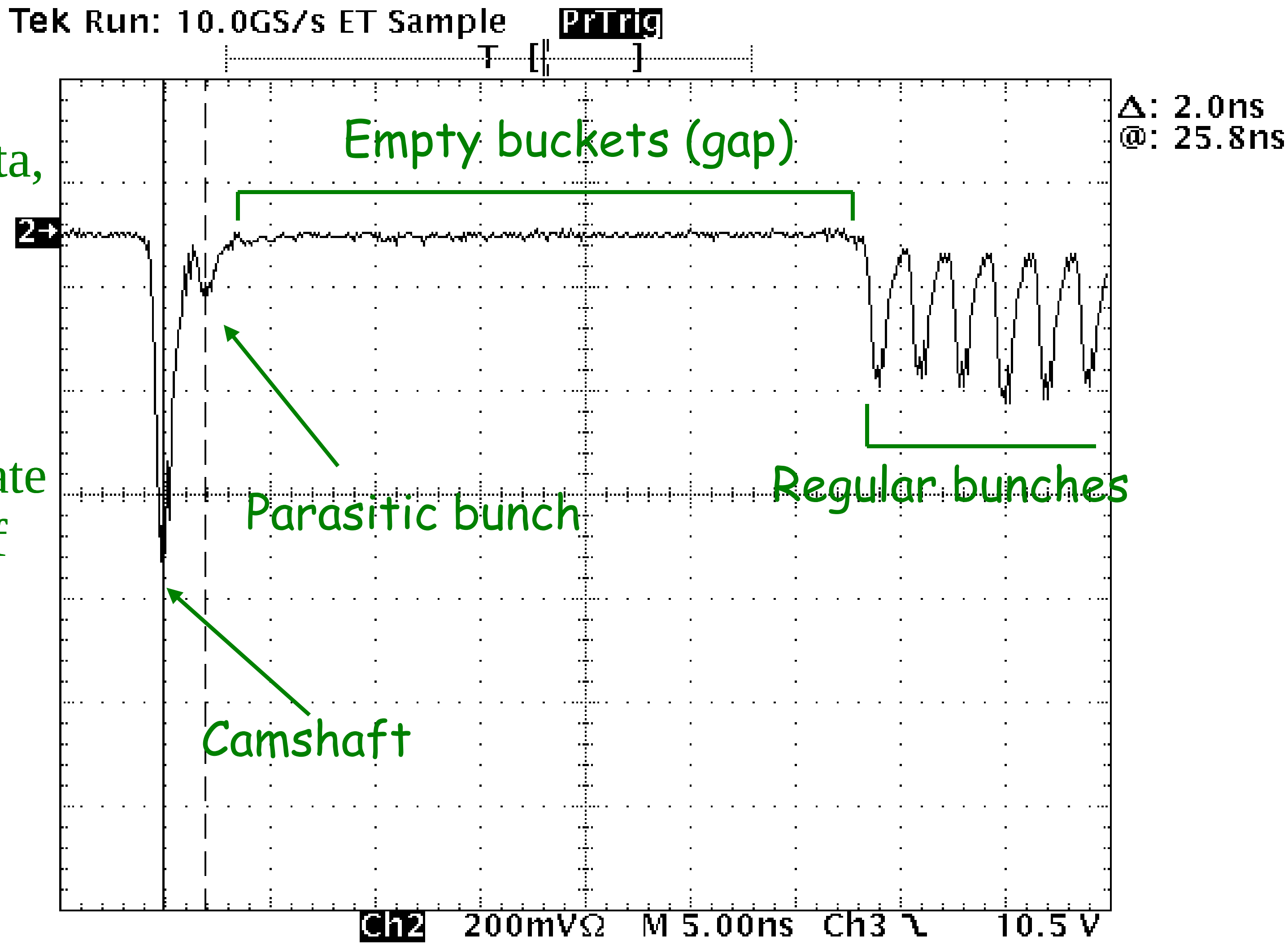


Experimental setup



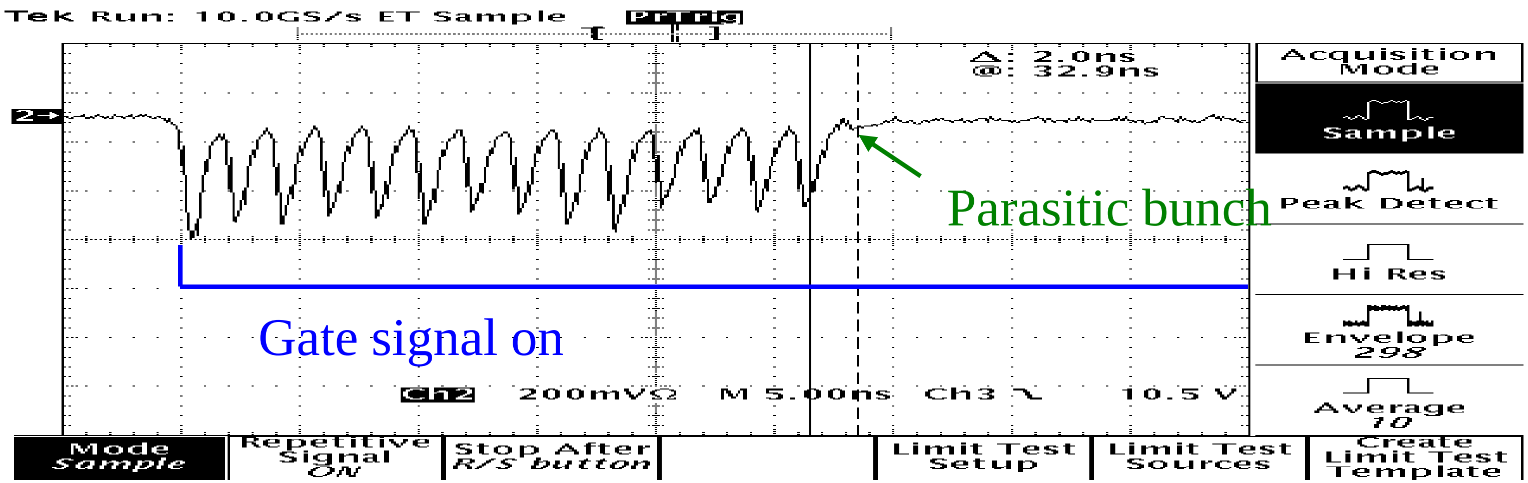
Experimental Data

No need to average data, at least at the ALS. Future experiments at the ALS will carefully evaluate the available photon flux and simulate the LHC parameters, if possible.

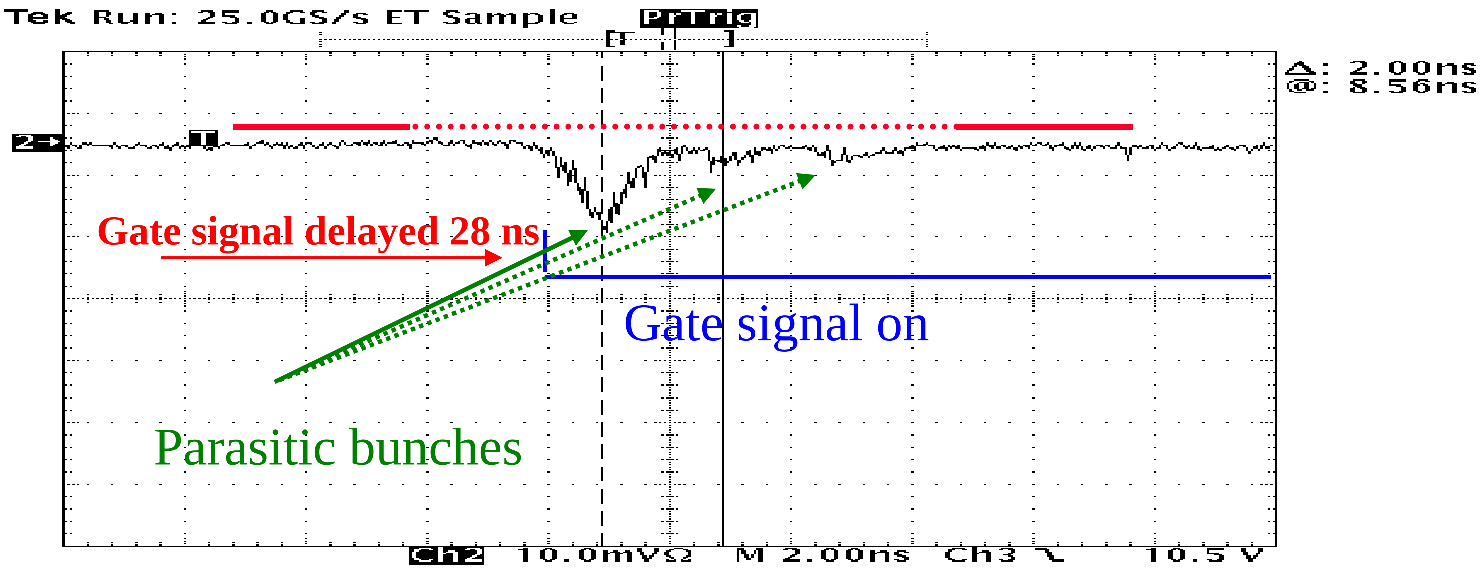


Some more interesting data

Photocatode recovery is not an issue

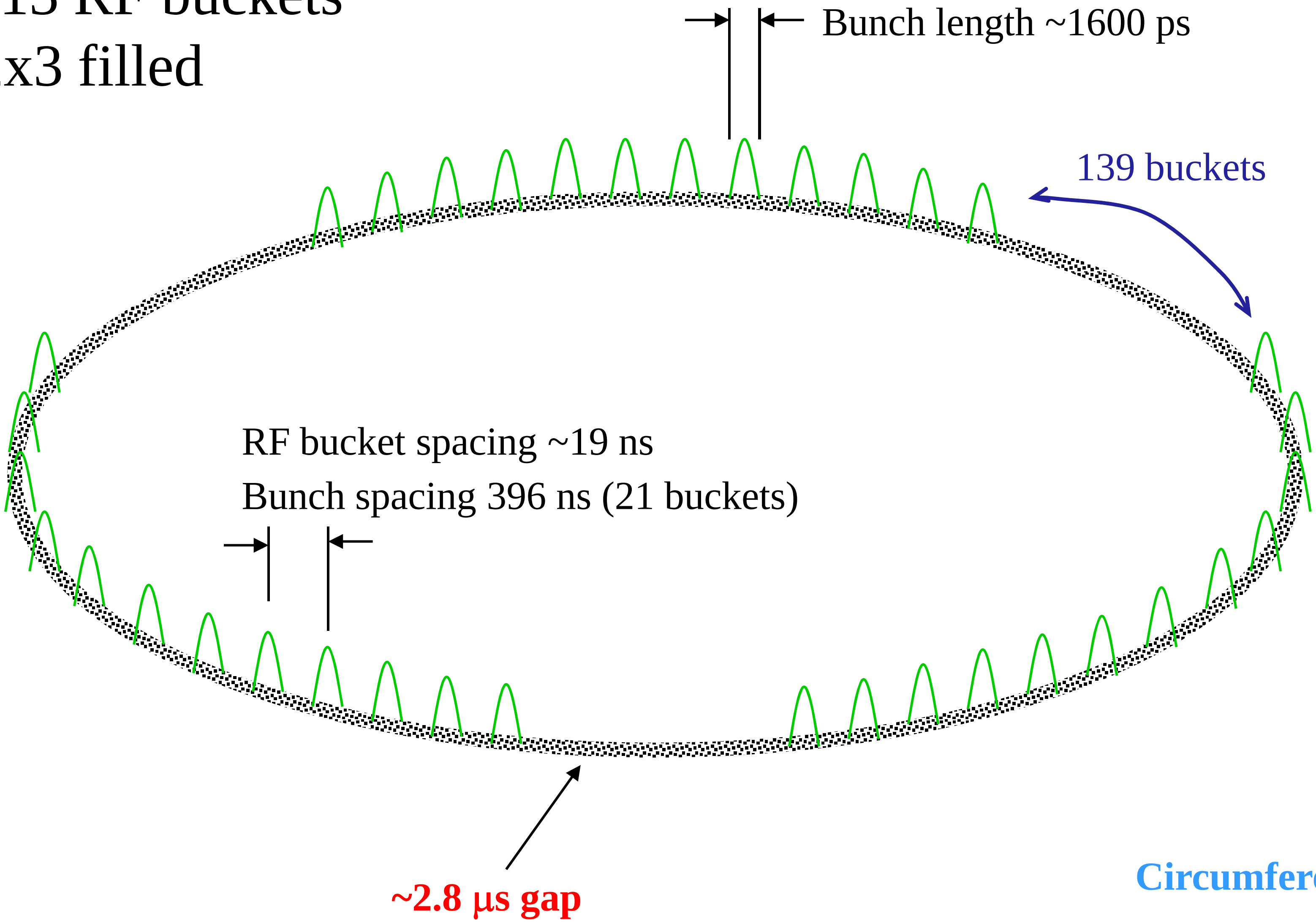


Compare zero level with gate on and off



Tests at the Tevatron

1113 RF buckets
12x3 filled

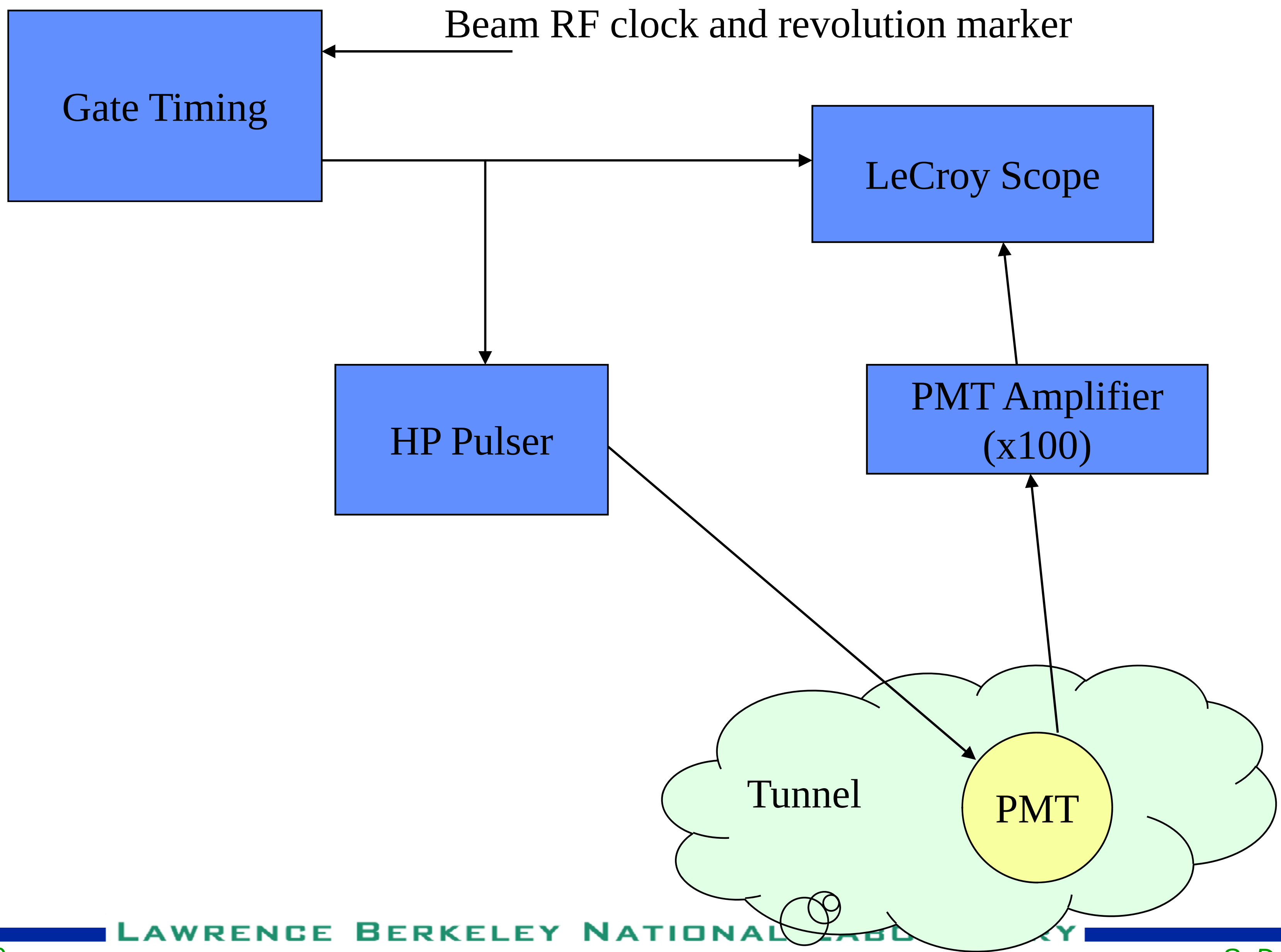


Circumference: 21 μs

Tests on the Tevatron

- - PMT is gated on for a period where we want to count photons
- - LeCroy scope tallies times of arrival of individual photons
- - Tevatron Electron Lens (TEL) produces gap in longitudinal distribution
- - Microbunches are visible in end of abort gap
  - Level of microbunches is ~10^7 particles / rf bucket
- - No structure visible in front half of abort gap
  - Pbars are injected in front half, so kicker cleans that part

PMT Photon Counting Setup

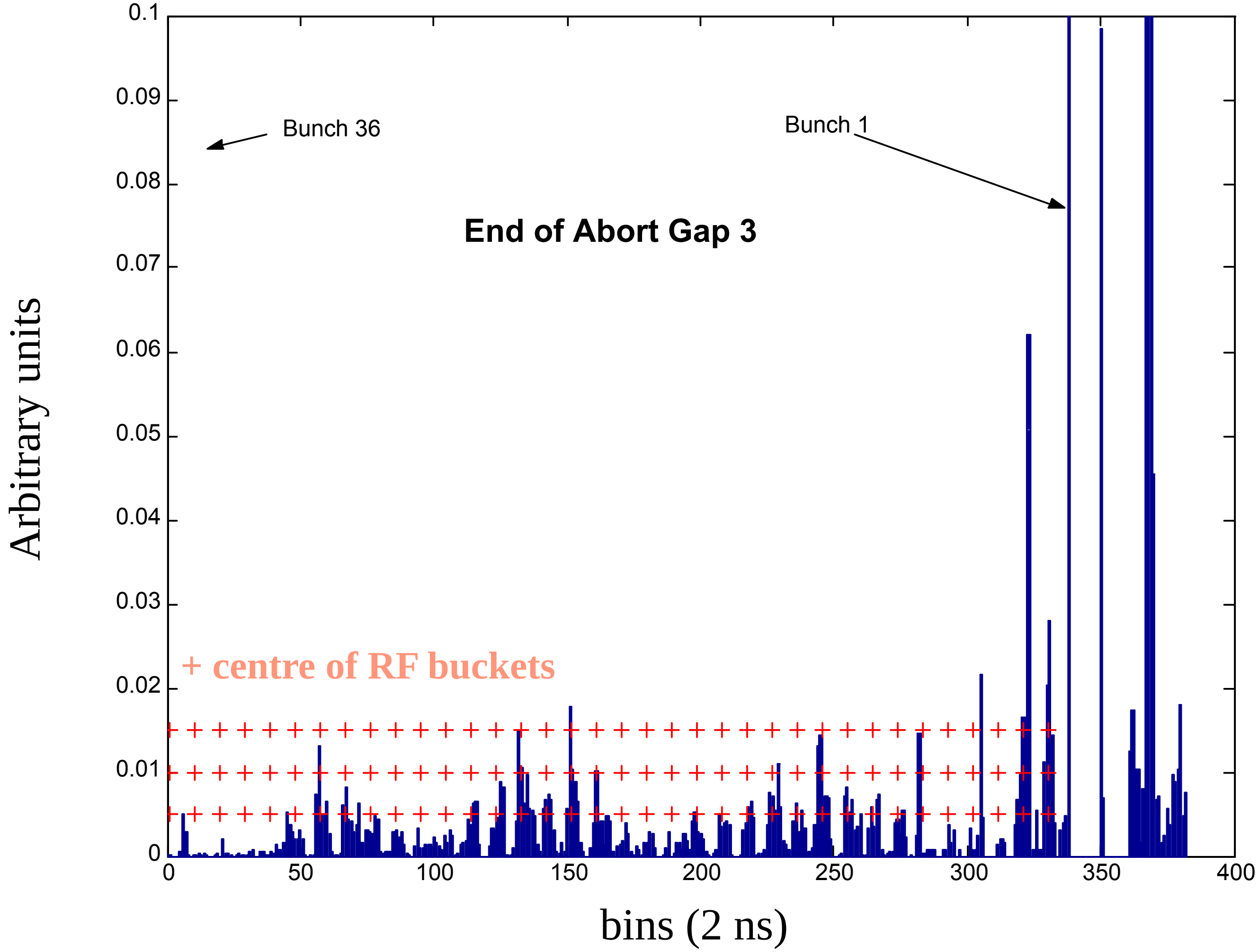


Single photon counting at the Tevatron

- 1 μs gate
- average of 3 gaps
- counts accumulated over 1000 turns

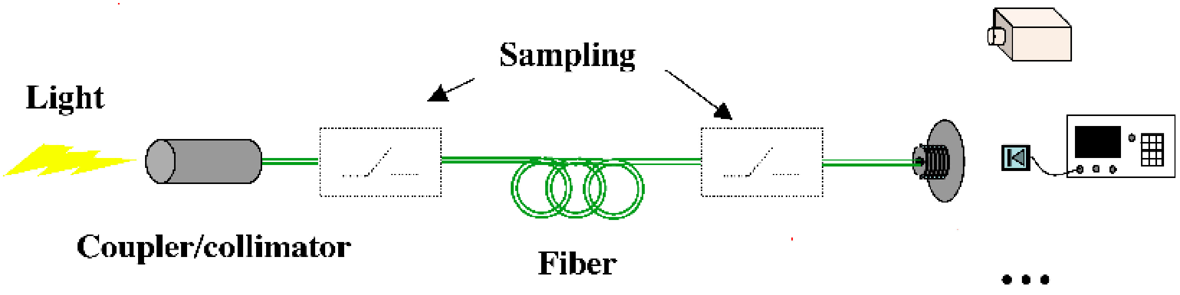
Microbunches are clearly visible

Bunch 36 is 2 μs to the left of this plot



Fiberoptic-based Remote Instrumentation

General Concept



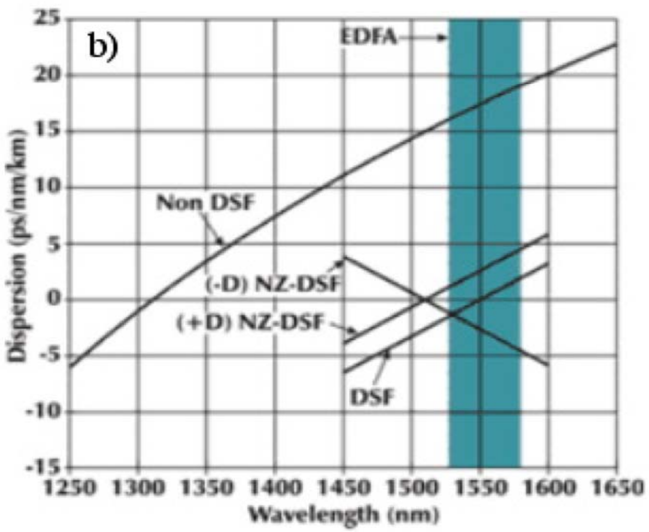
Bring synchrotron light at large distances away from the ring preserving its temporal properties.

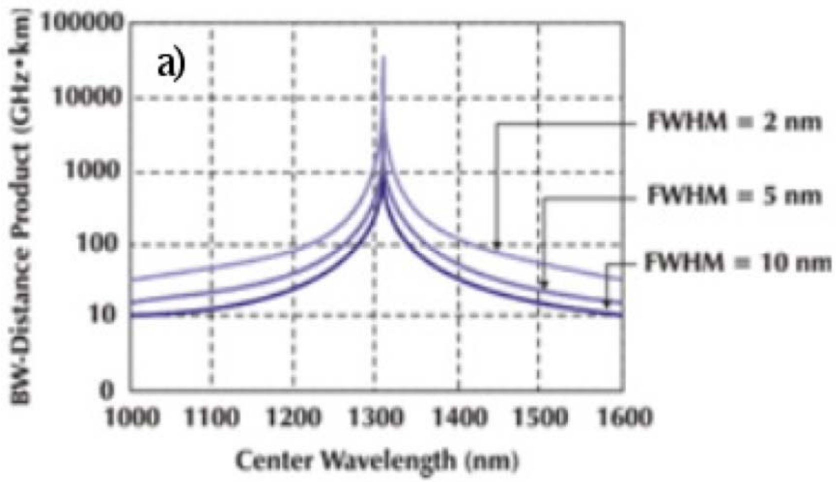
Optical fibers are inexpensive and allow easy integration of components developed for the much larger market of telecommunications

Problems: dispersion, insertion losses

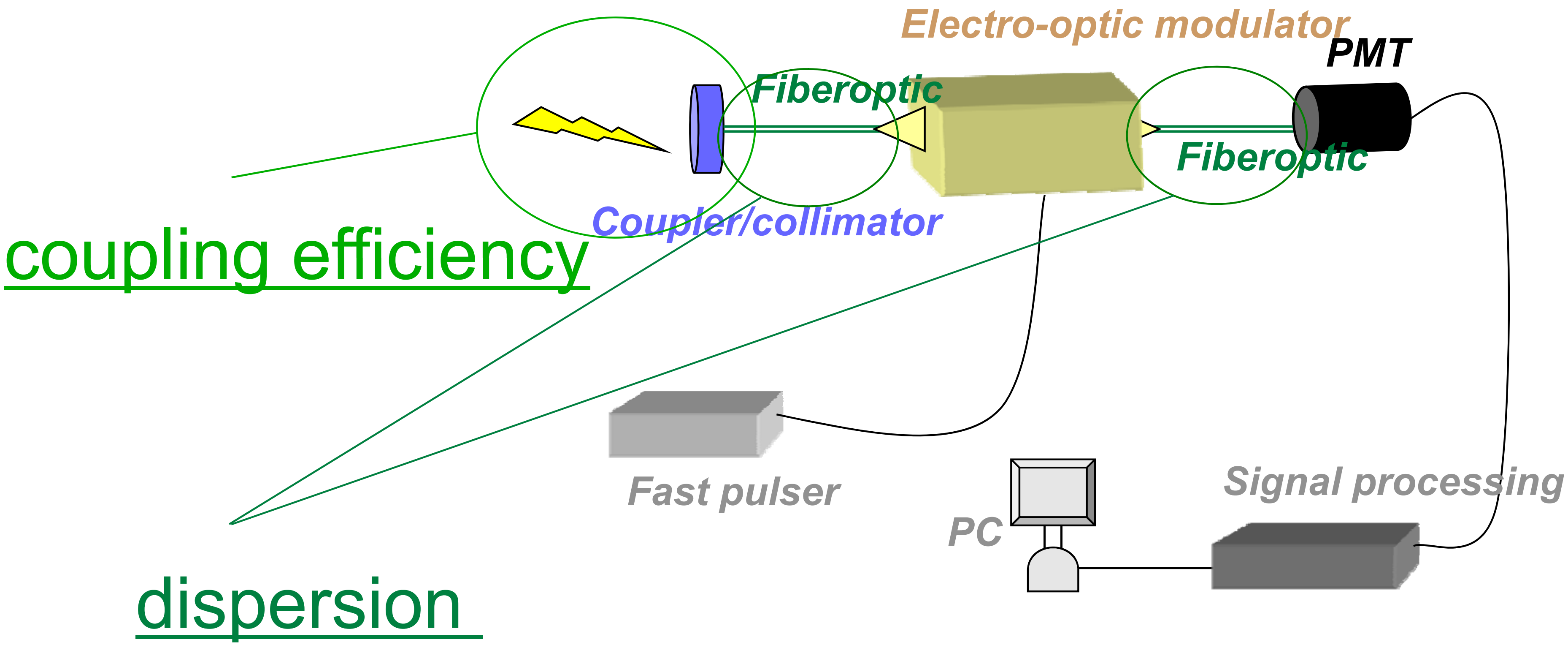
Choice of Optical Fiber

- Single-mode
  - Pros: lowest attenuation (1550 nm), zero dispersion (1310 nm), availability of dispersion compensating fibers.
  - Cons: small numerical aperture. High insertion losses when coupling to synchrotron radiation.
- Multimode
  - Pros: large numerical aperture, multimode matching
  - Cons: reduced bandwidth, higher losses





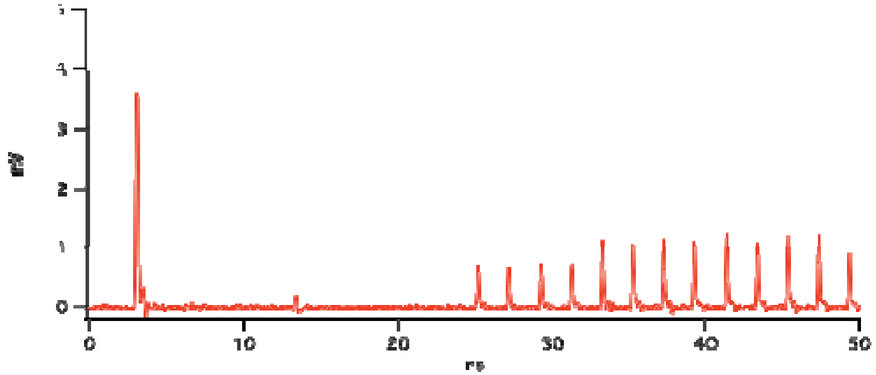
Application Example



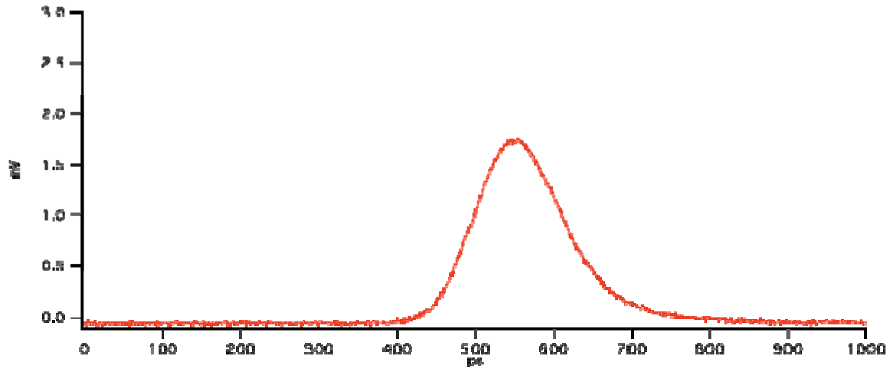
Commercially available electrooptic modulators ($LiNbO_3$): 40 GHz bandwidth, extintion ratio 25/30 dB, insertion loss <3 dB

Experimental Results

ALS gap w/ camshaft

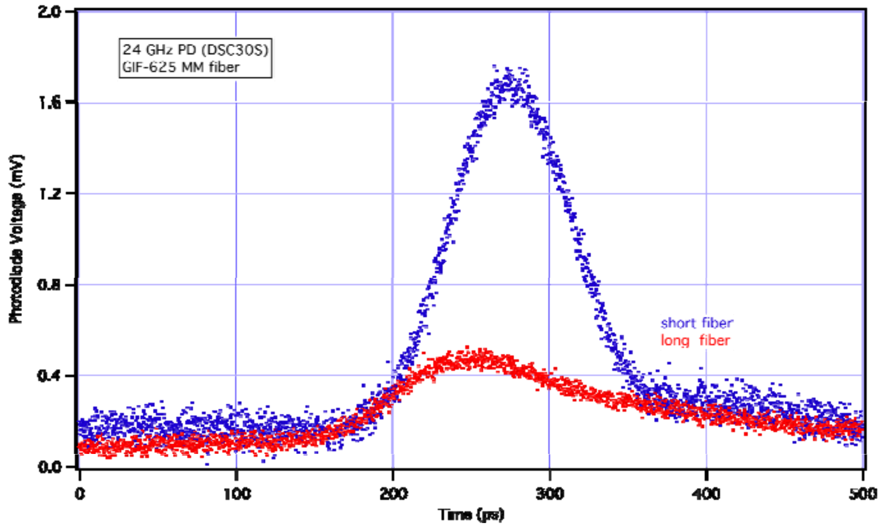


Single bunch (5 mA)



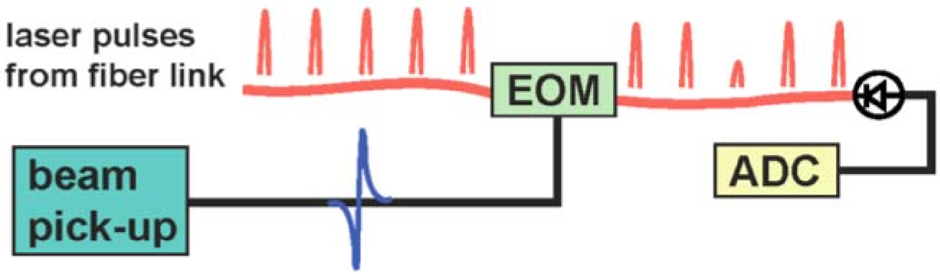
Single-mode fiber (100 ft.), InGaAs PIN photodiode (5 GHz). Overall coupling efficiency: ~50%.

Multimode fiber, 24 GHz photodiode
Short fiber vs. 100 m-long fiber

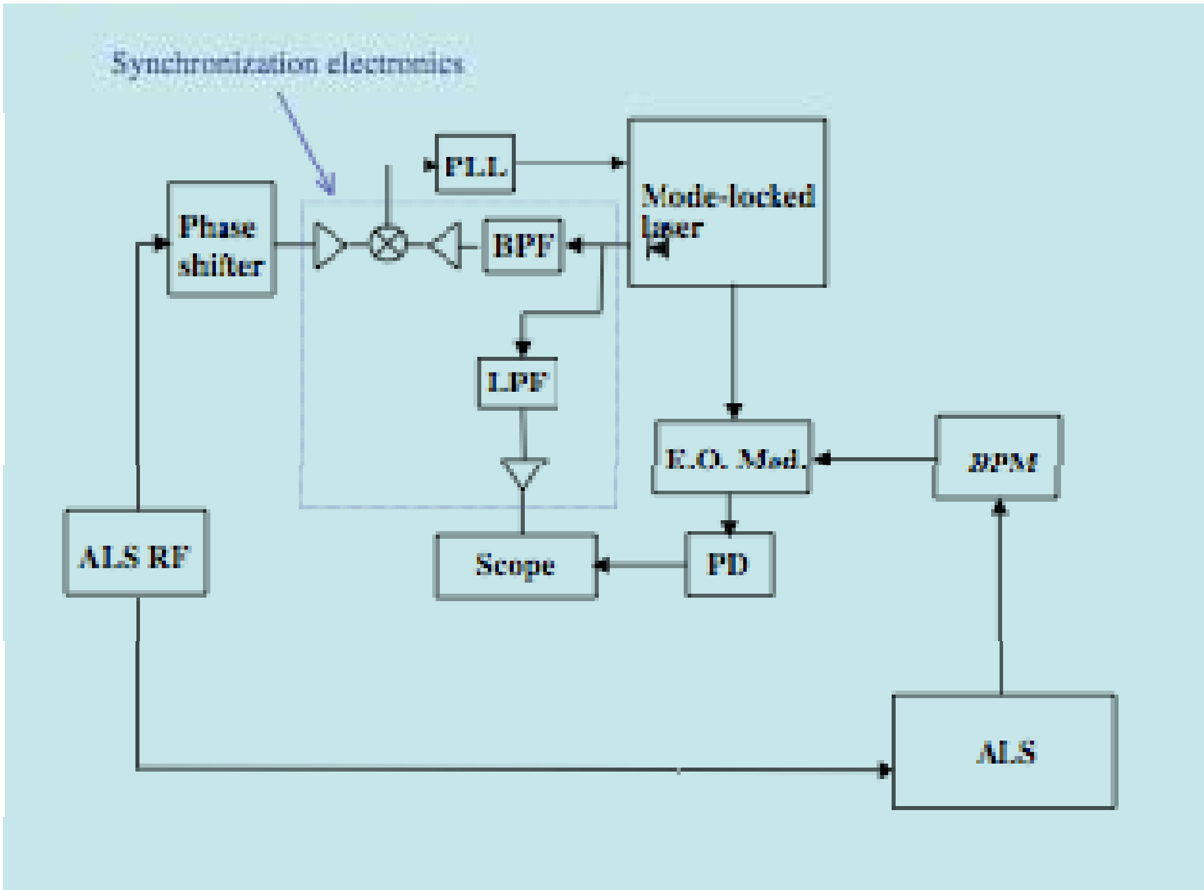


Beam Timing Monitor

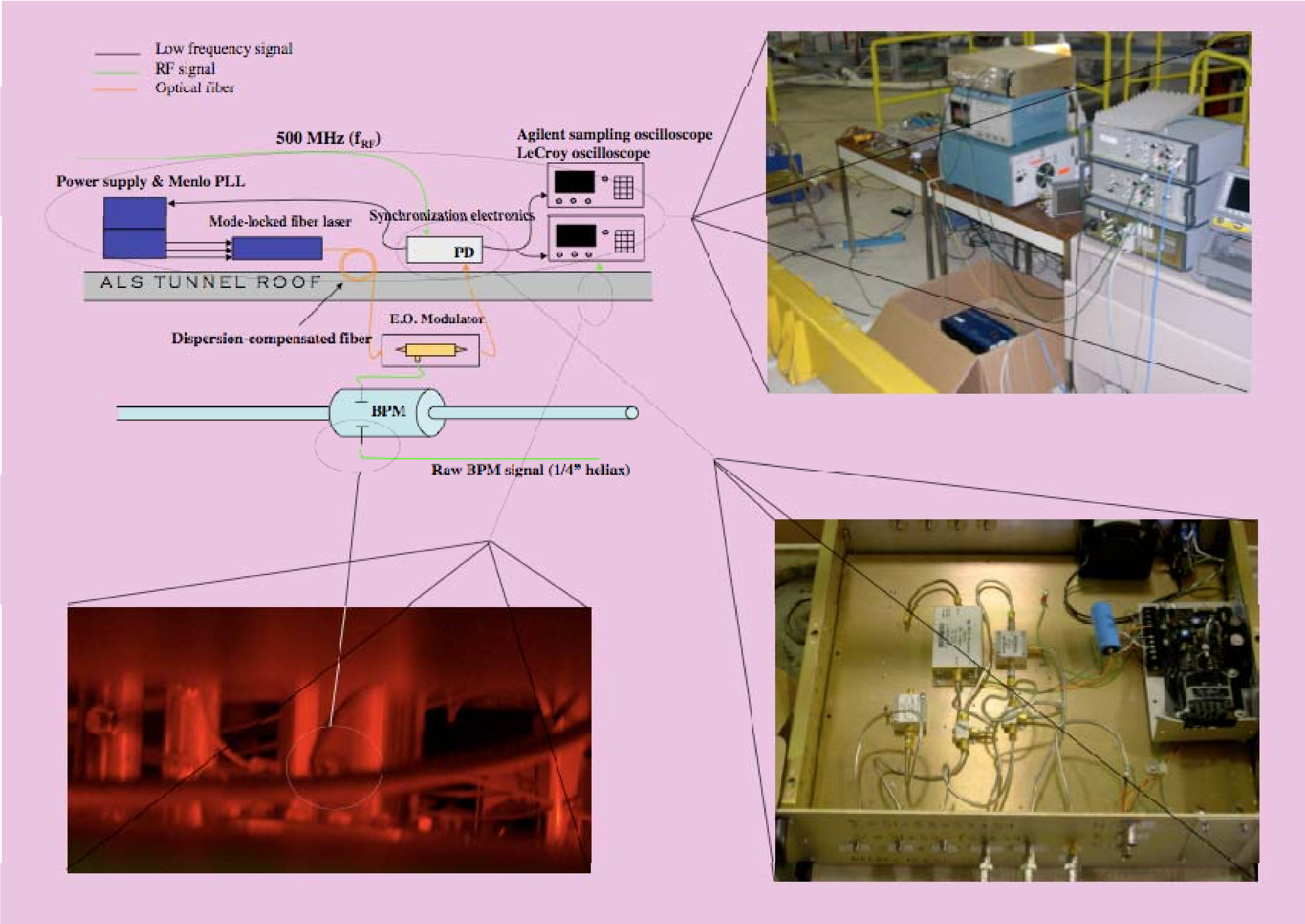
Original concept
F. Loehl



…and its LBNL implementation



Beam Timing Monitor – Wideband BPM



Initial Experimental Results