Longitudinal Density Monitor

LDM Techniques using synchrotron radiation

Non-linear mixing of SR with short-pulse laser light

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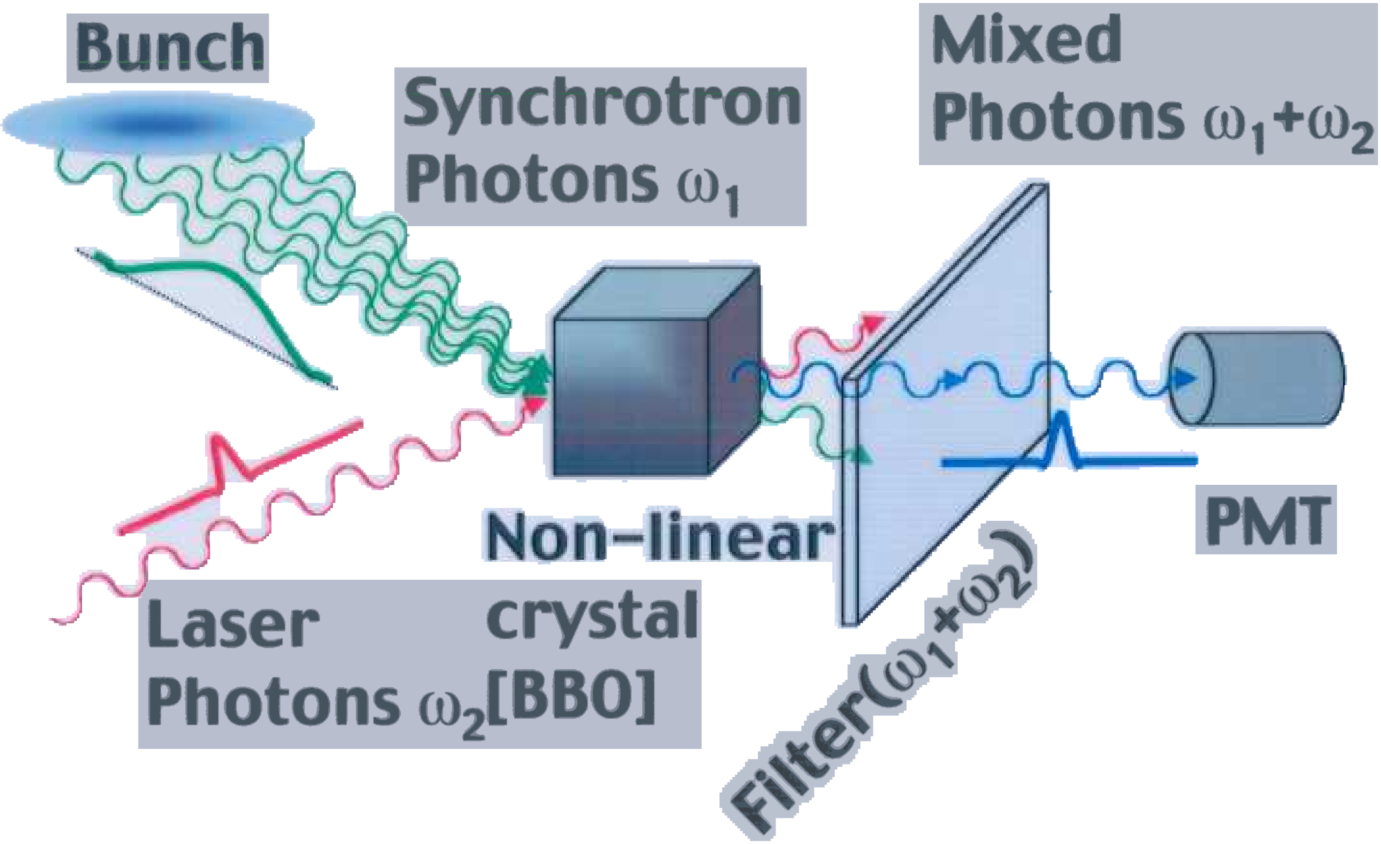
Concept



Bunch
Synchrotron Photons ω1
Mixed Photons ω1+ω2
Non-linear crystal [BBO]
Laser Photons ω2
Filter(ω1+ω2)
PMT

Frequency up conversion

$$P_{i3} = \chi^{(1)}_{ik} E_{k3} + \chi^{(2)}_{ilm} E_{l1} E_{m2}$$

$$\omega_3 = \omega_1 + \omega_2$$

$$\chi^{(2)} \approx 1/E_{atomic}$$

$$E_{atomic} \approx 10 \text{ V/Å} = 10^{11} \text{V/m}$$

For example for BBO crystal ($B_aB_2O_4$) $\chi^{(2)} \approx 2$ pm/V

Conversion efficiency for moderate laser intensities is strongly dependent on phase matching

ase matching condition

$= \omega_1 + \omega_2$

$= K_1 + K_2$

$_3)\omega_3 = n(\omega_1)\,\omega_1 + n(\omega_2)\,\omega_2$

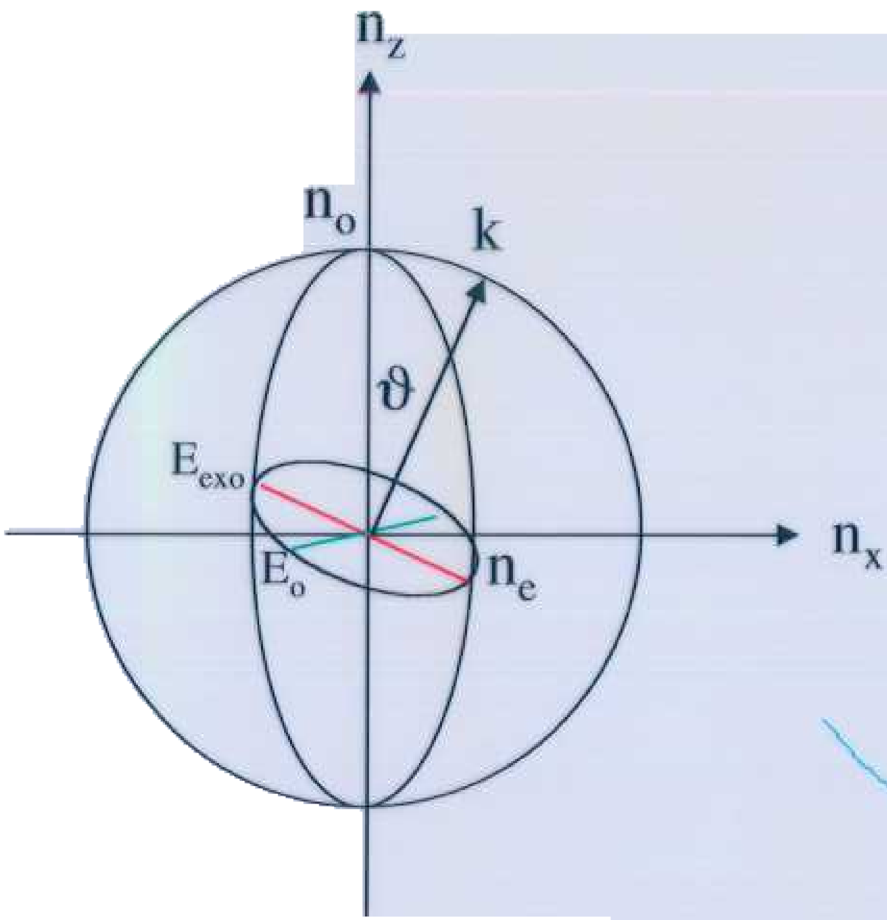
$$\eta \approx \frac{\sin^2\left[\frac{l\,\Delta k}{2}\right]}{\left(\frac{\Delta k\, l_o}{2}\right)^2}$$

rotron light conversion efficiency

$$\int \eta\,(k - k_{match})\,\frac{dk}{k_{match}} \qquad \frac{1}{l_o^2} = \frac{8\pi P_L \chi^2_{eff} k_1 k_2}{c\, n_1 n_2 n_3}$$

For a given crystal type and wavelength and under optimal focusing this depends only on laser pulse power, is independent of crystal thickness

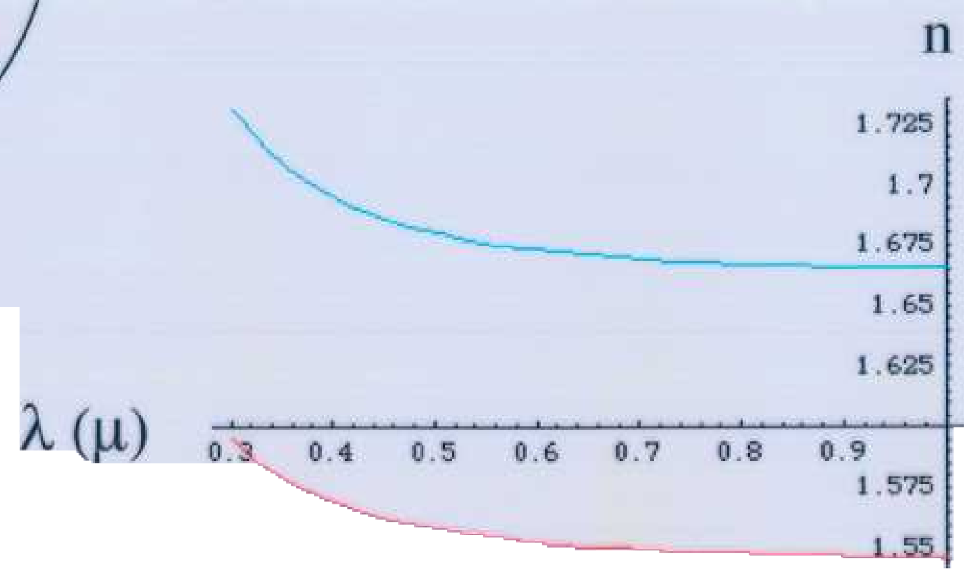
O crystal, Laser 1nJ 50fs 800nm, synchrotron light 630nm es conversion efficiency 10^{-3}



$$n^2 = n_o^2$$

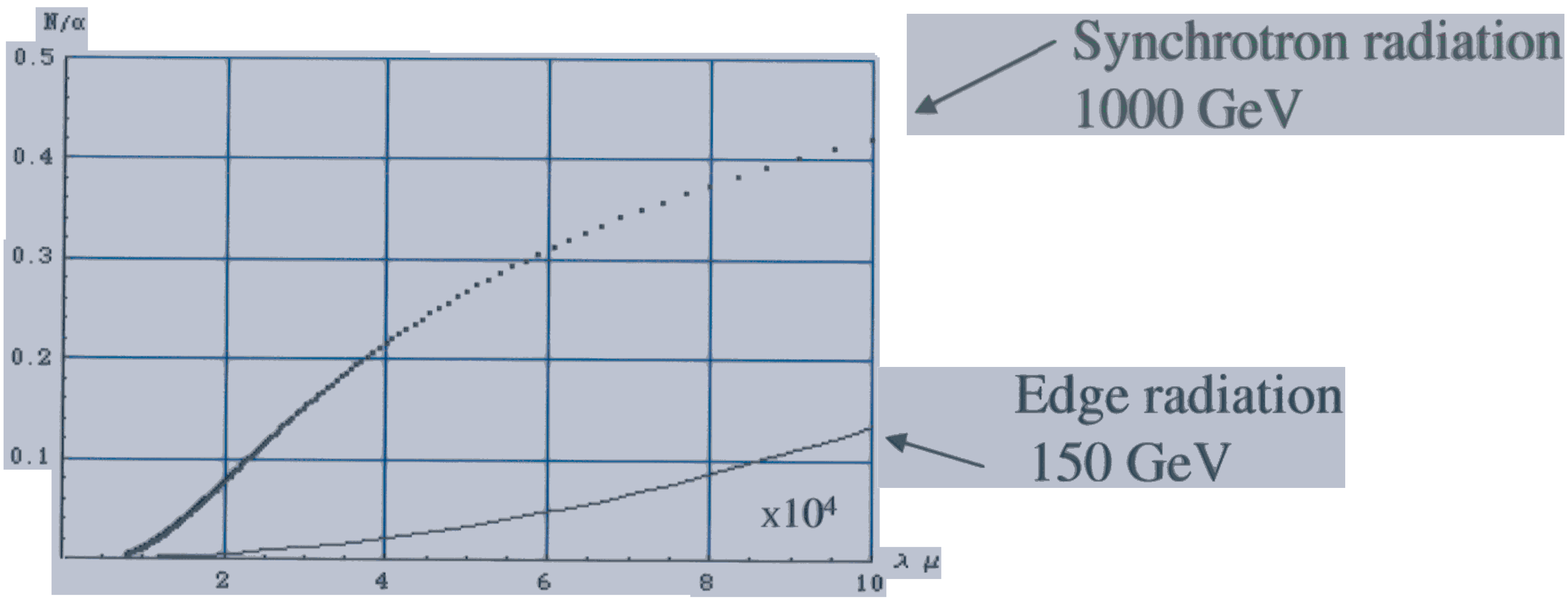
$$\frac{n_z^2}{n_o^2} + \frac{n_x^2 + n_y^2}{n_e^{\,2}} = 1$$

$$\frac{1}{n^2} = \frac{\mathrm{Cos}[\theta]^2}{n_o^{\,2}} + \frac{\mathrm{Sin}[\theta]^2}{n_e^{\,2}}$$

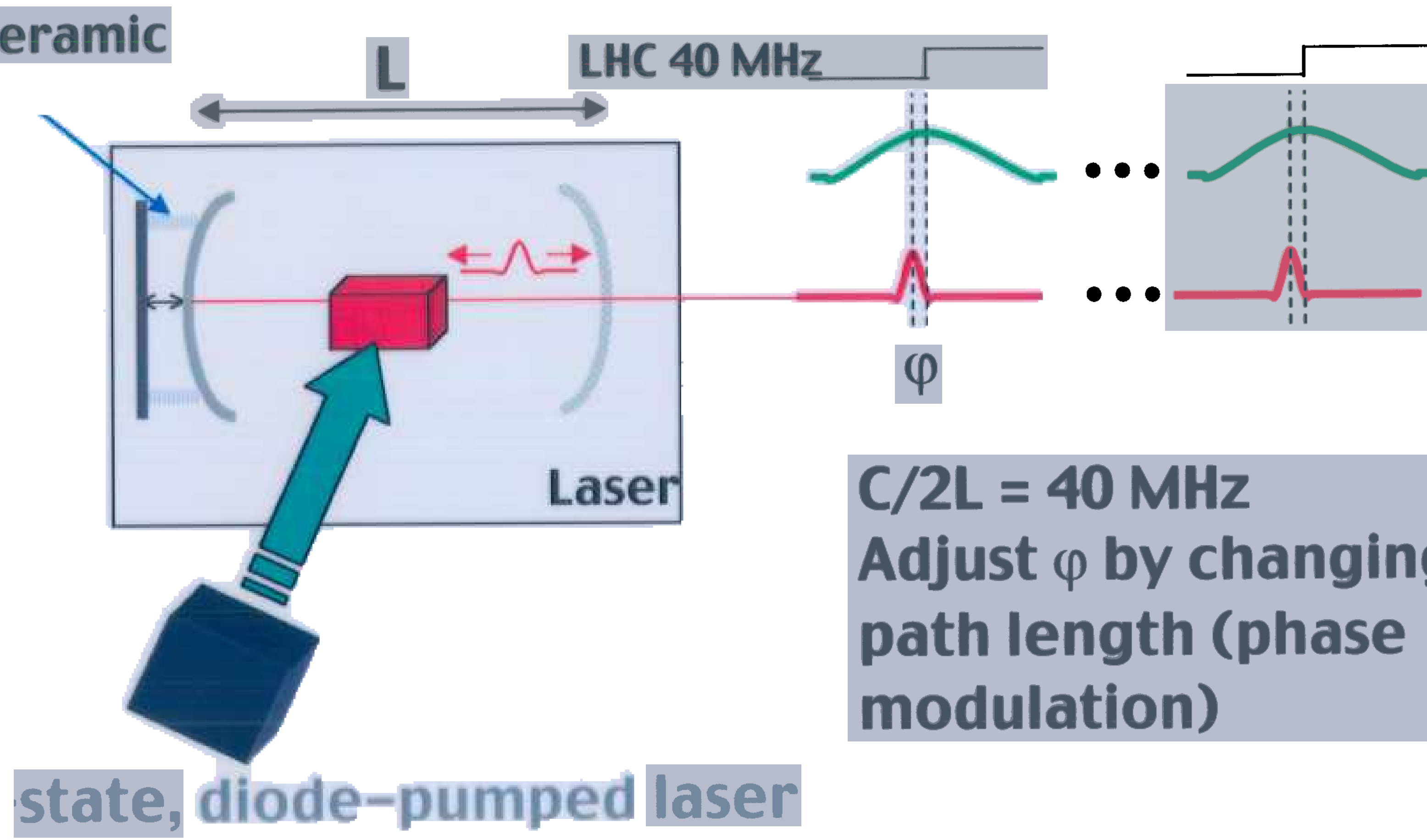


Synchrotron radiation for Tevatron (1000 Gev)

Edge radiation for Tevatron (150 Gev)



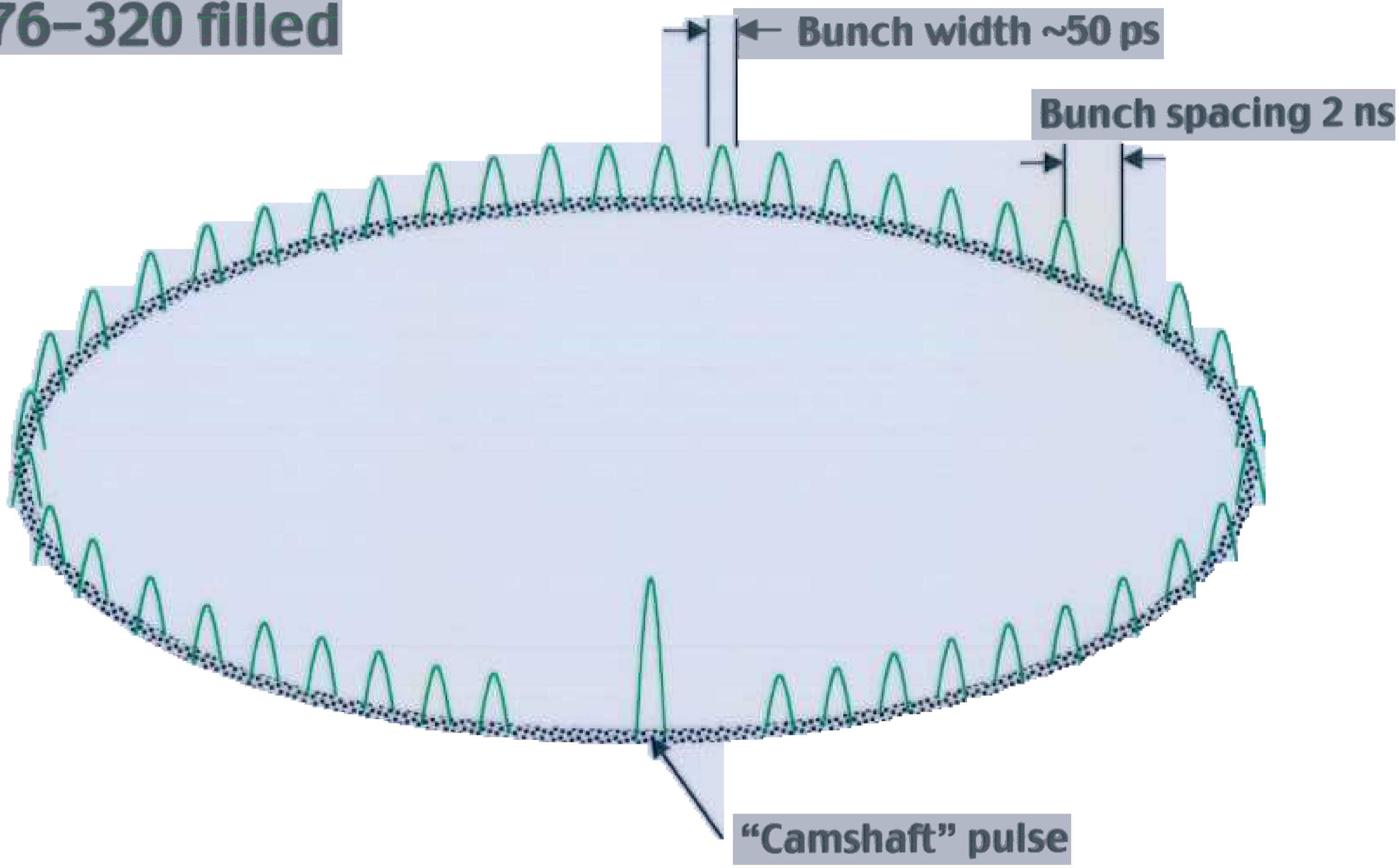
Scanning the Bunch



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

Test at the ALS

328 slots
276–320 filled



Setup

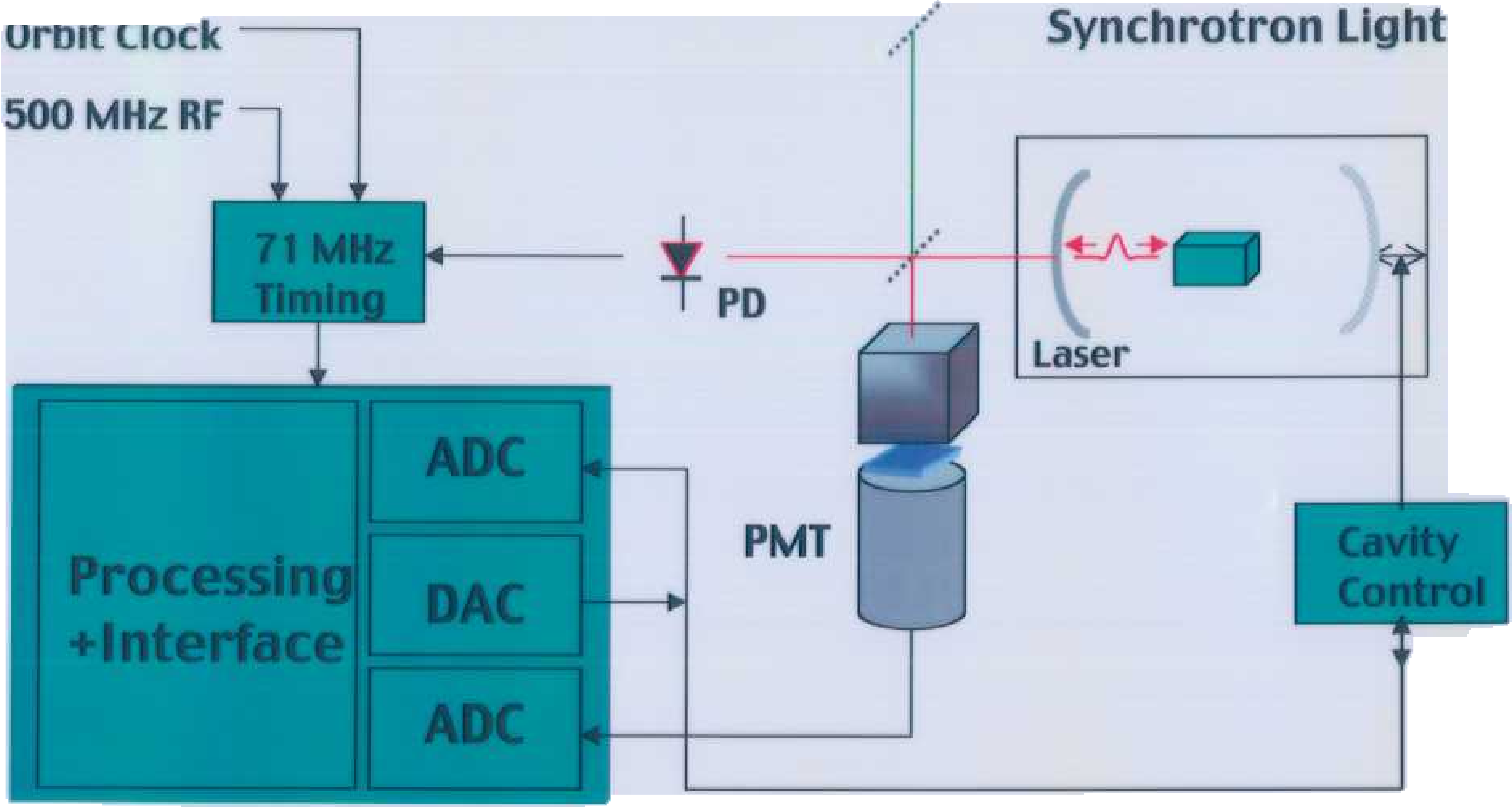
- In Beamline 5.3.1 using existing fs laser
- Laser repetition frequency is 71 MHz (1/7 ALS frequency)
- Scan bunches in groups of 7, then shift 1 bunch (0, 7, 14...; 1, 8, 15...; ... ; 6, 13, 20...)

Electronics, DAQ + Software

- Histograms the signal form each bunch
- Drives mirror with programmable displacement
- Profiles the mirror displacement (for bin position in time)

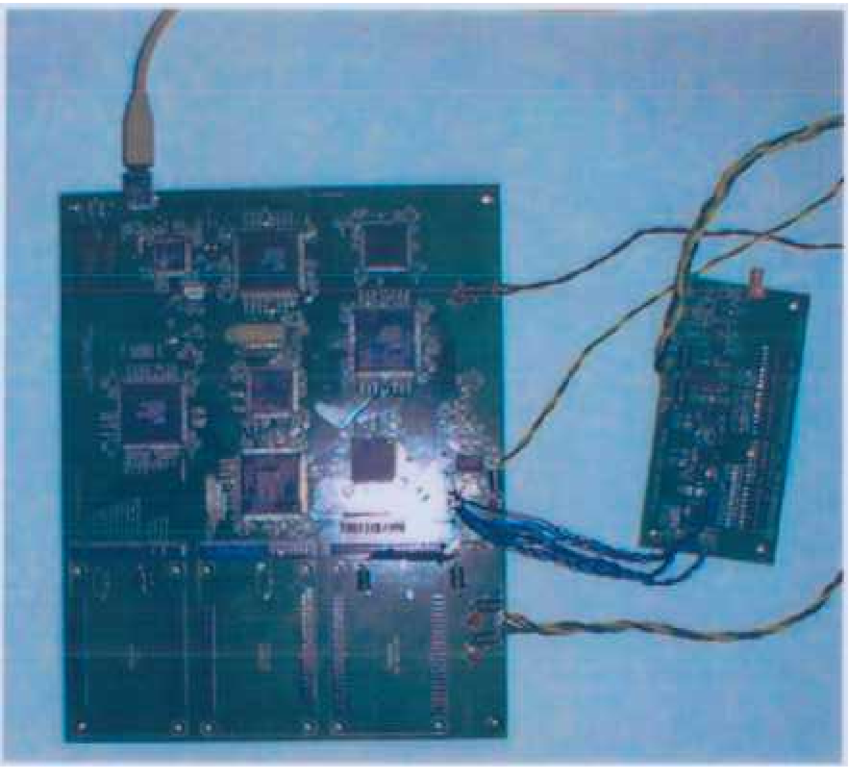
Some results from the first run – just to give a flavor of what is possible ...

Schematic



Orbit Clock
500 MHz RF
71 MHz Timing
PD
Synchrotron Light
Laser
PMT
ADC
DAC
ADC
Processing +Interface
Cavity Control

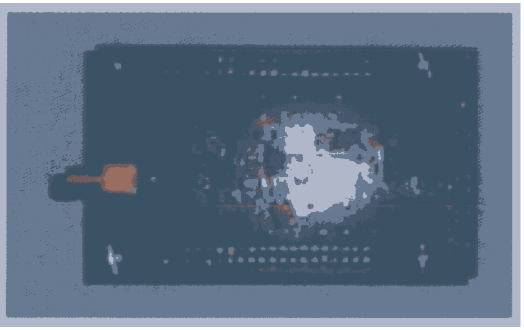
Electronics – I.



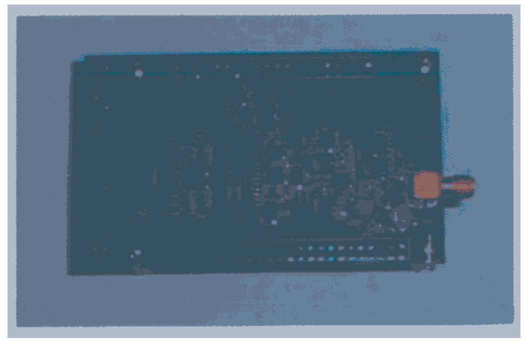
Mother Board with 71MHz clock board

USB Control and histogram/average is fully operational

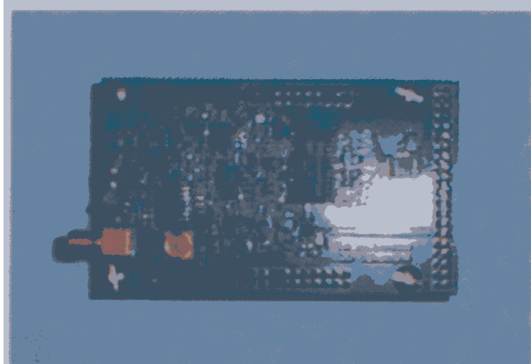
Electronics – II.



DAC Analog board for laser phase offset modulation



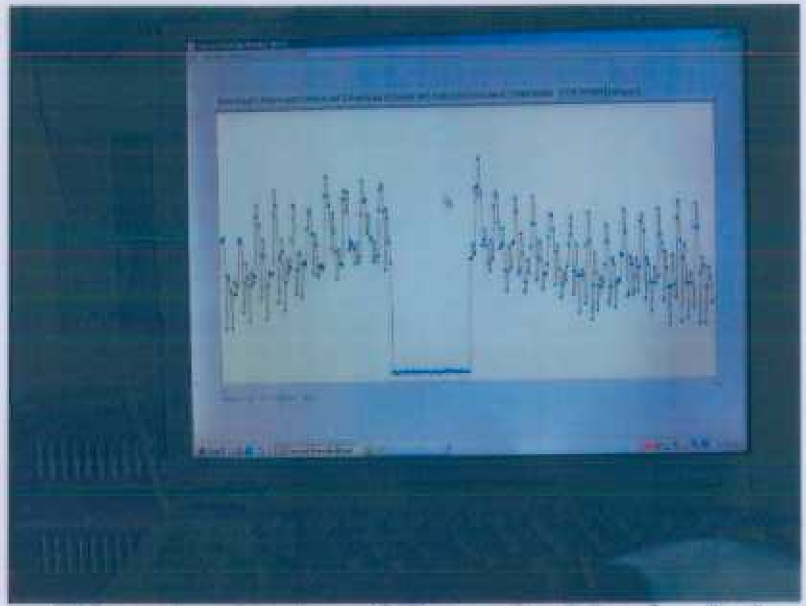
Actual Laser phase offset digitization board



Track and Hold board with self trigger for PMT pulse detection (only one bit is used in photon counting mode)

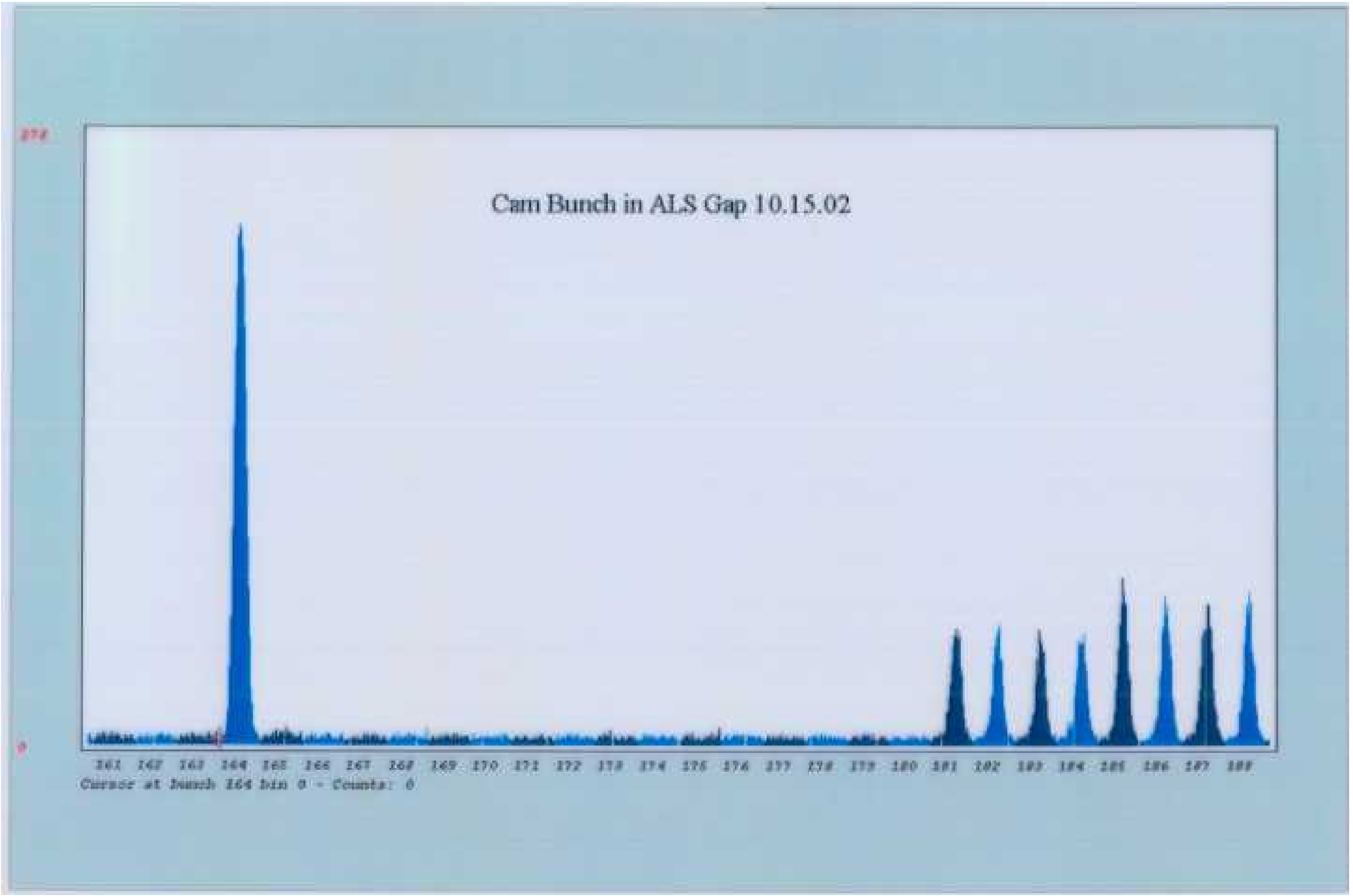
Experiment Setup

Electronics Setup



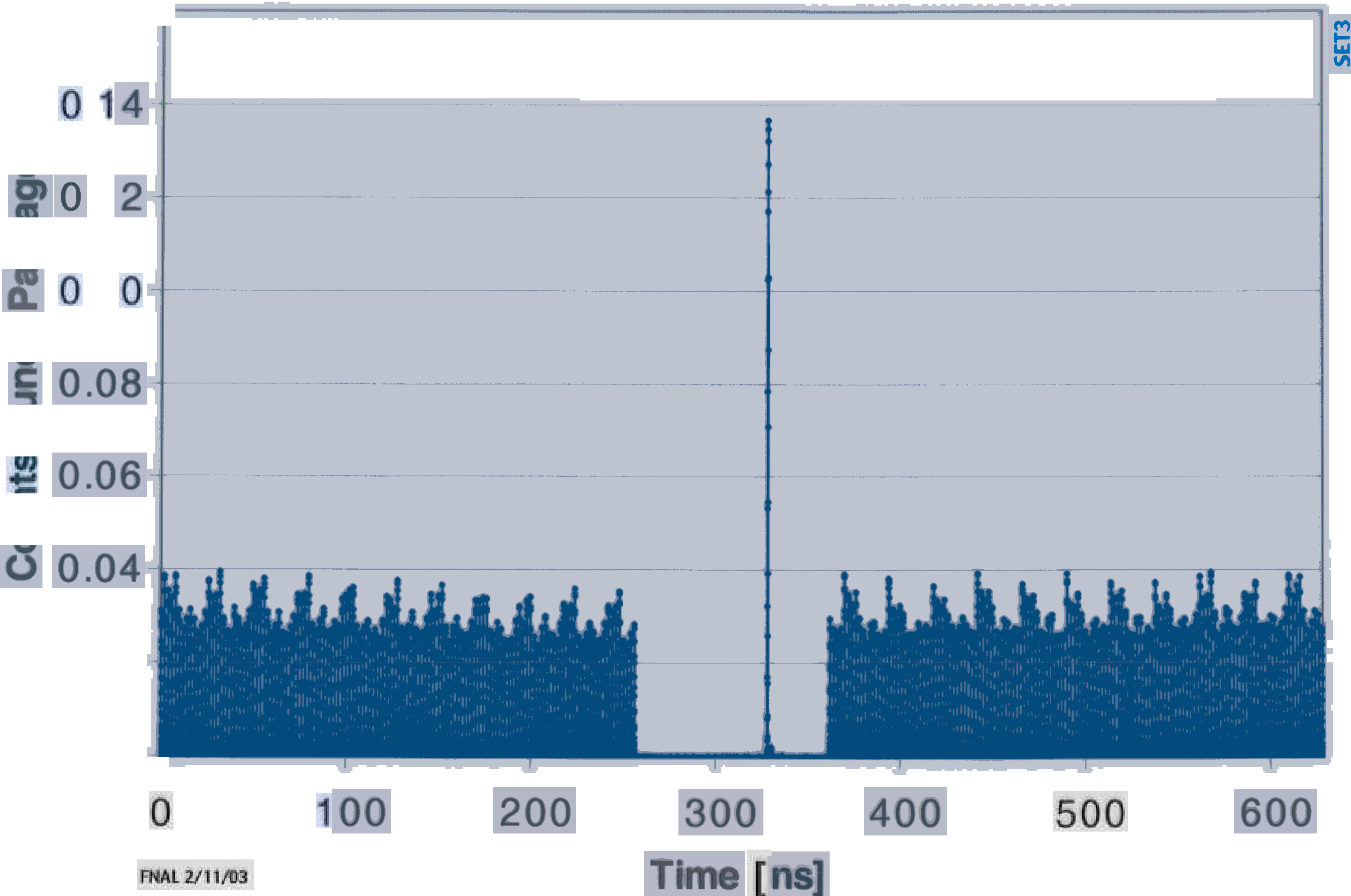
First data (Peak Height distribution)

Online Results



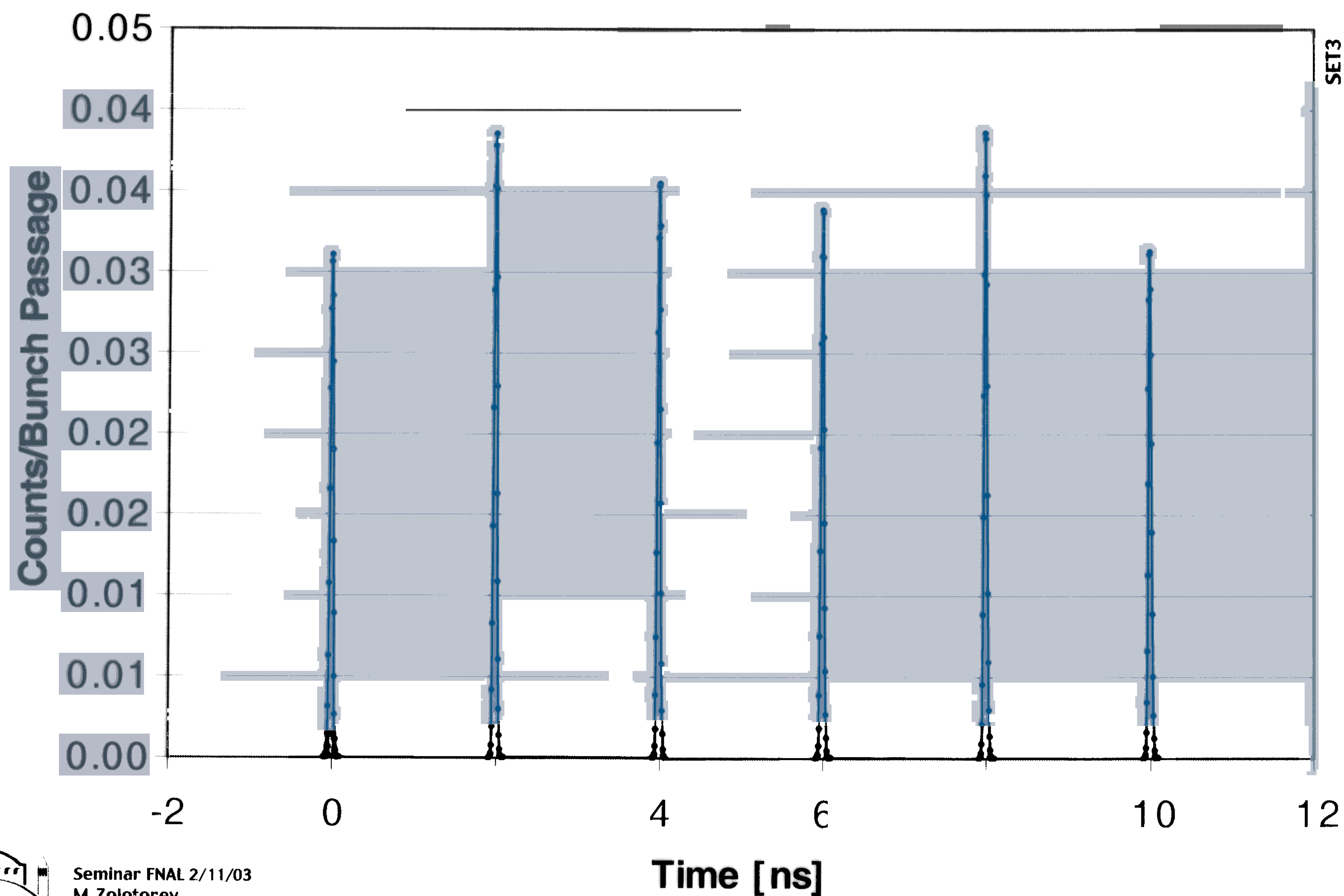
Cam Bunch followed by a gap and then the standard bunches.

ALS Bunch Profile in Time



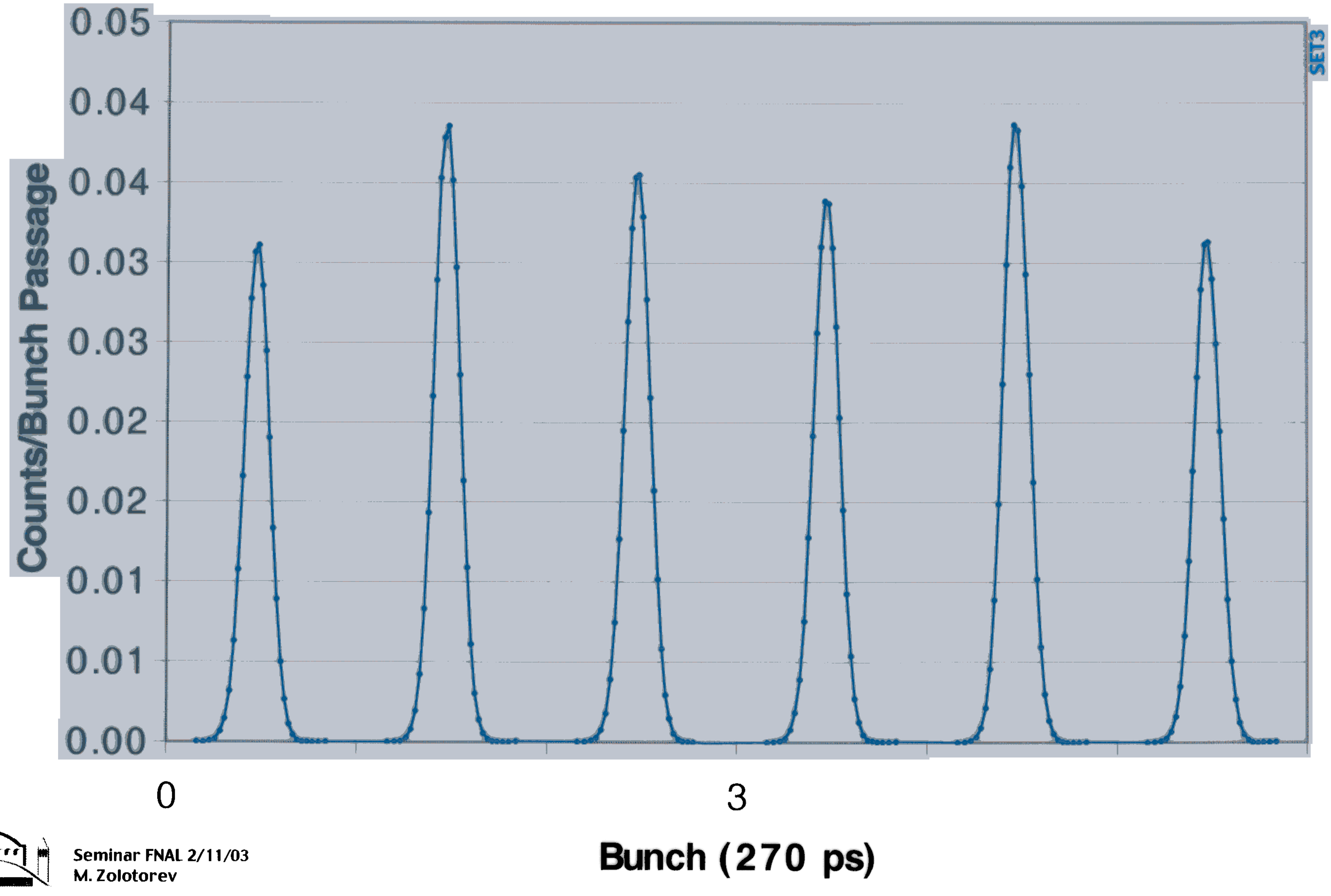
FNAL 2/11/03

Zoom in...

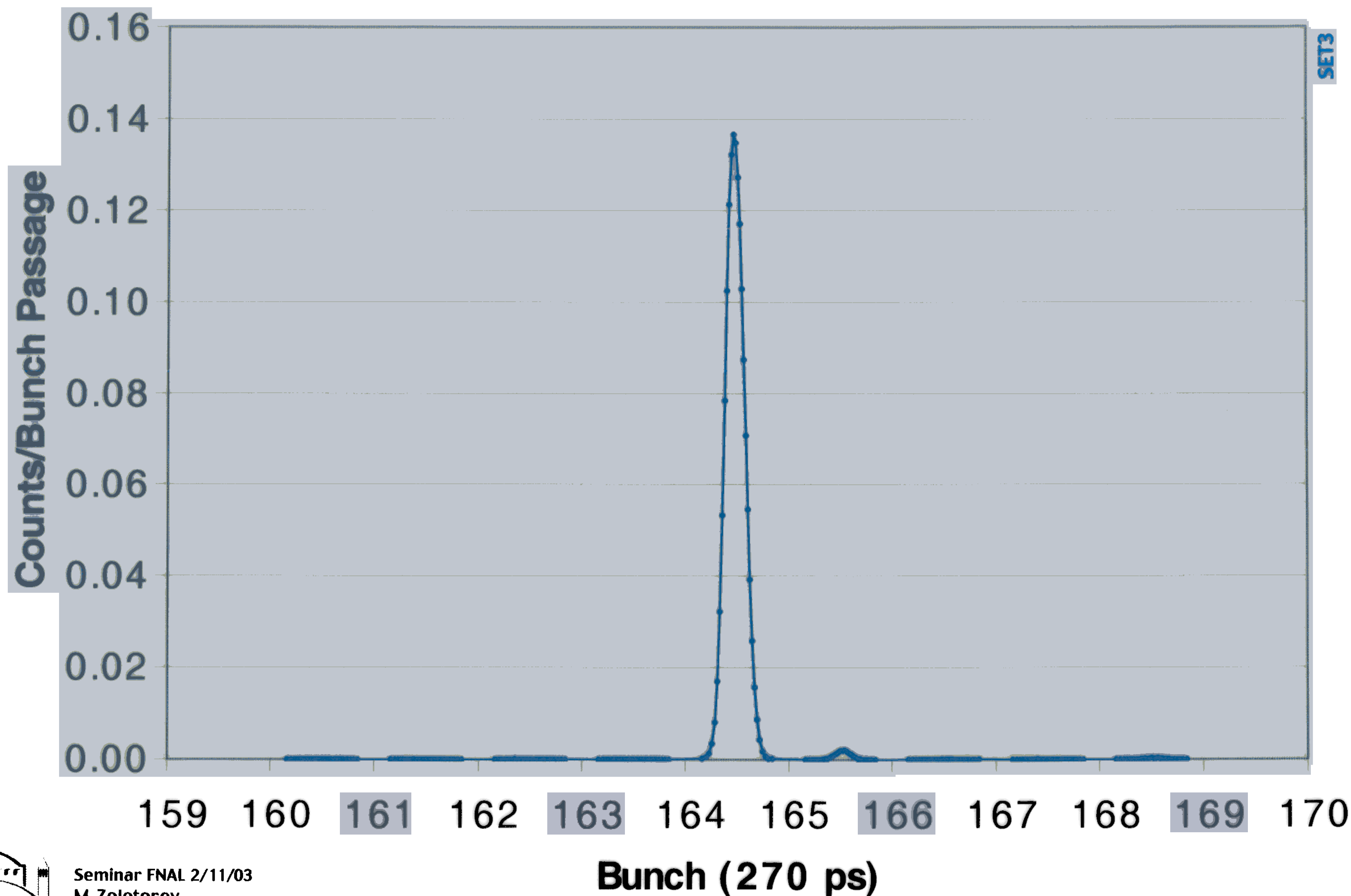


Counts/Bunch Passage
0.05
0.04
0.04
0.03
0.03
0.02
0.02
0.01
0.01
0.00
-2
0
4
6
10
12
Time [ns]
SET3

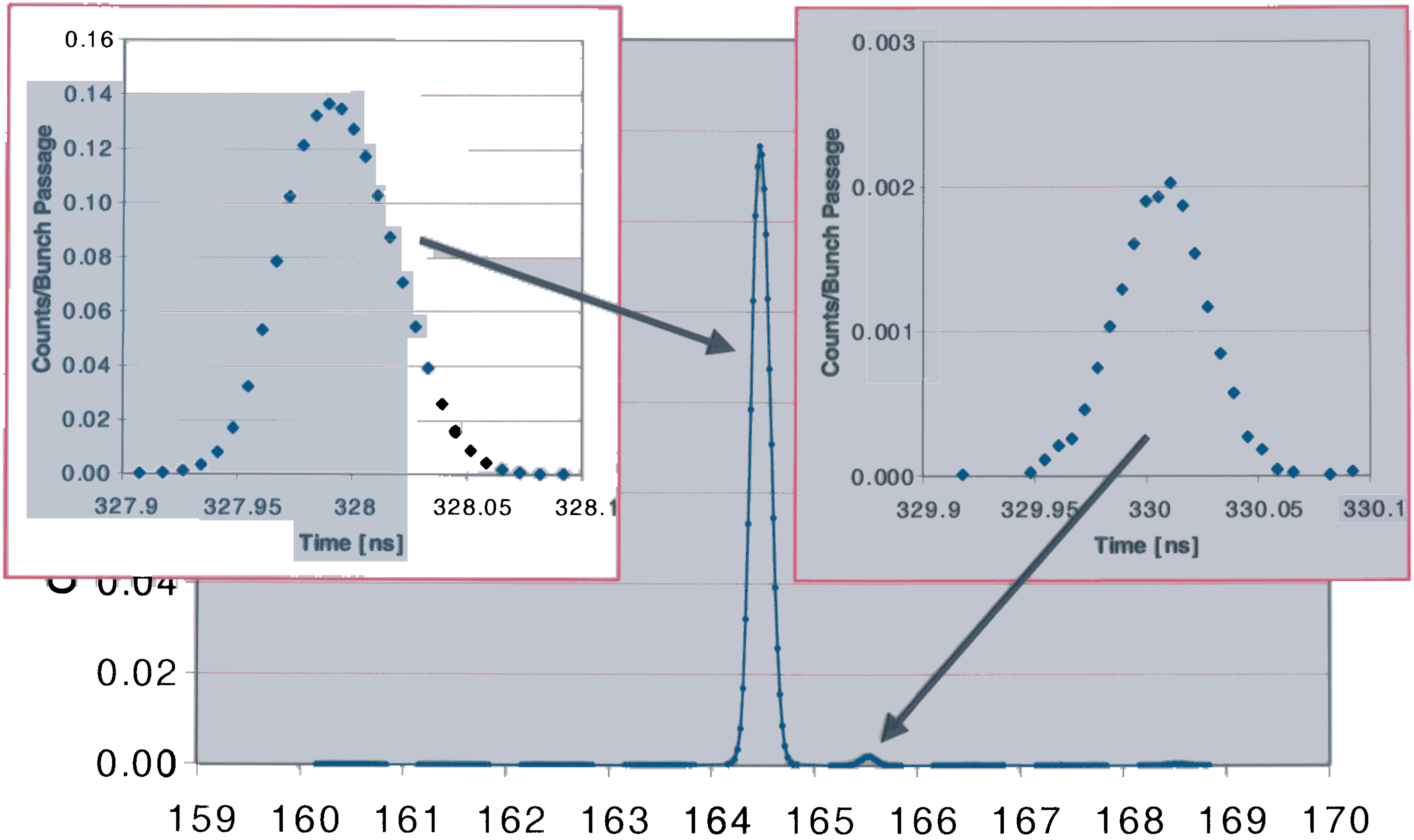
Compress Scale...



Camshaft Bunch

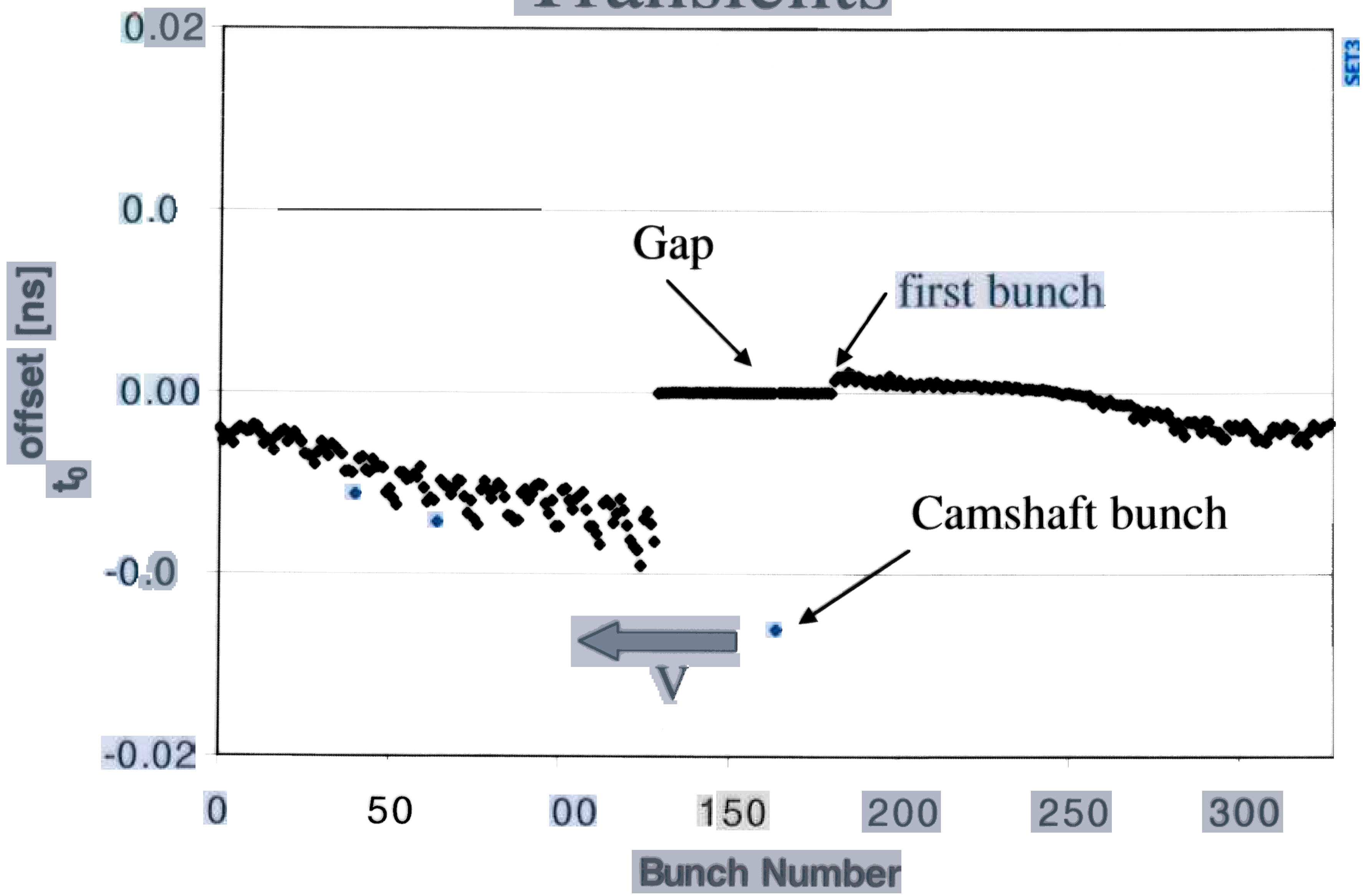


Details

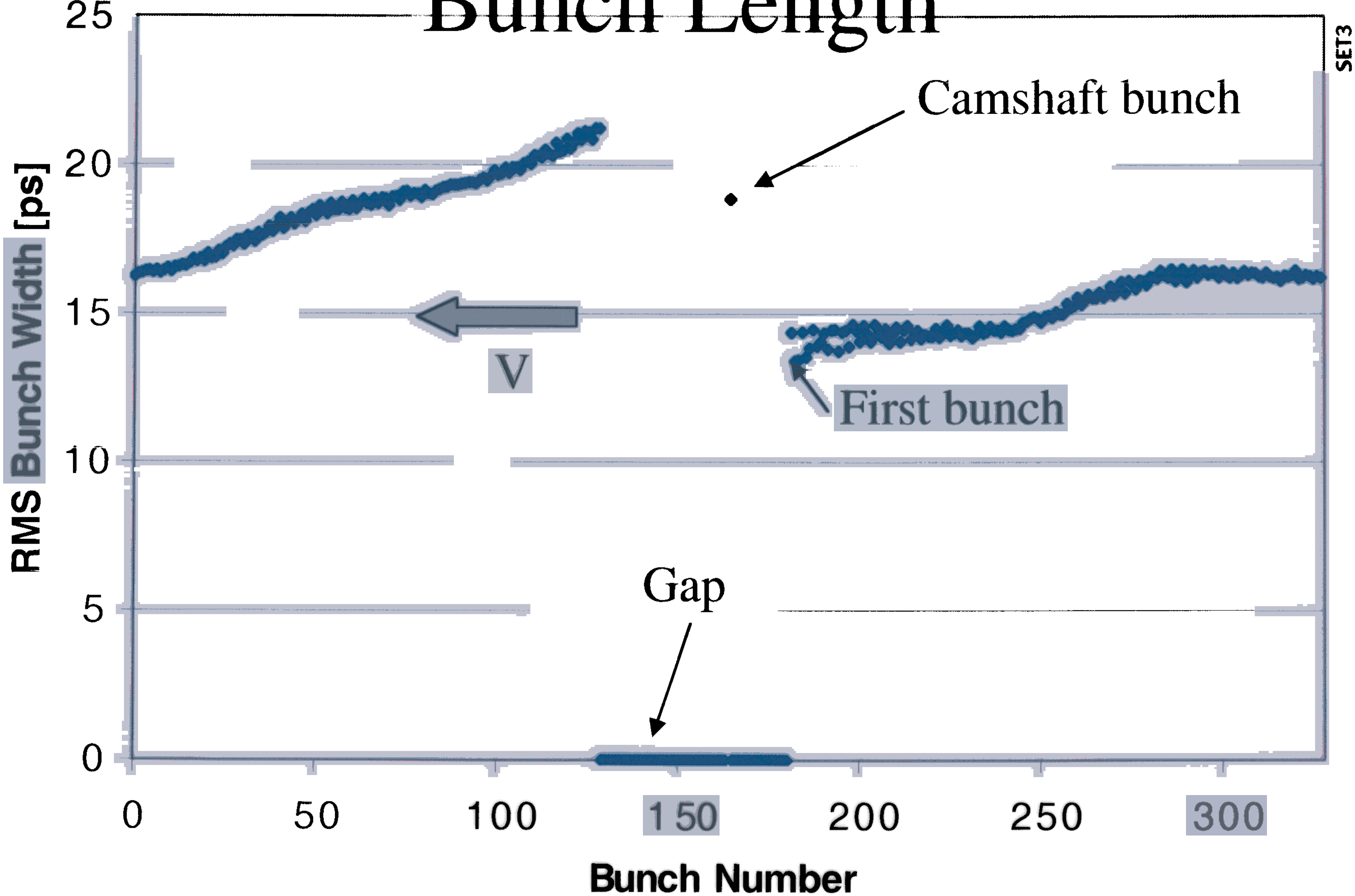


Counts/Bunch Passage
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
327.9
327.95
328
328.05
328.1
Time [ns]
Counts/Bunch Passage
0.003
0.002
0.001
0.000
329.9
329.95
330
330.05
330.1
Time [ns]
0.04
0.02
0.00
159 160 161 162 163 164 165 166 167 168 169 170
Bunch (270 ps)

Synchronous Phase Transients

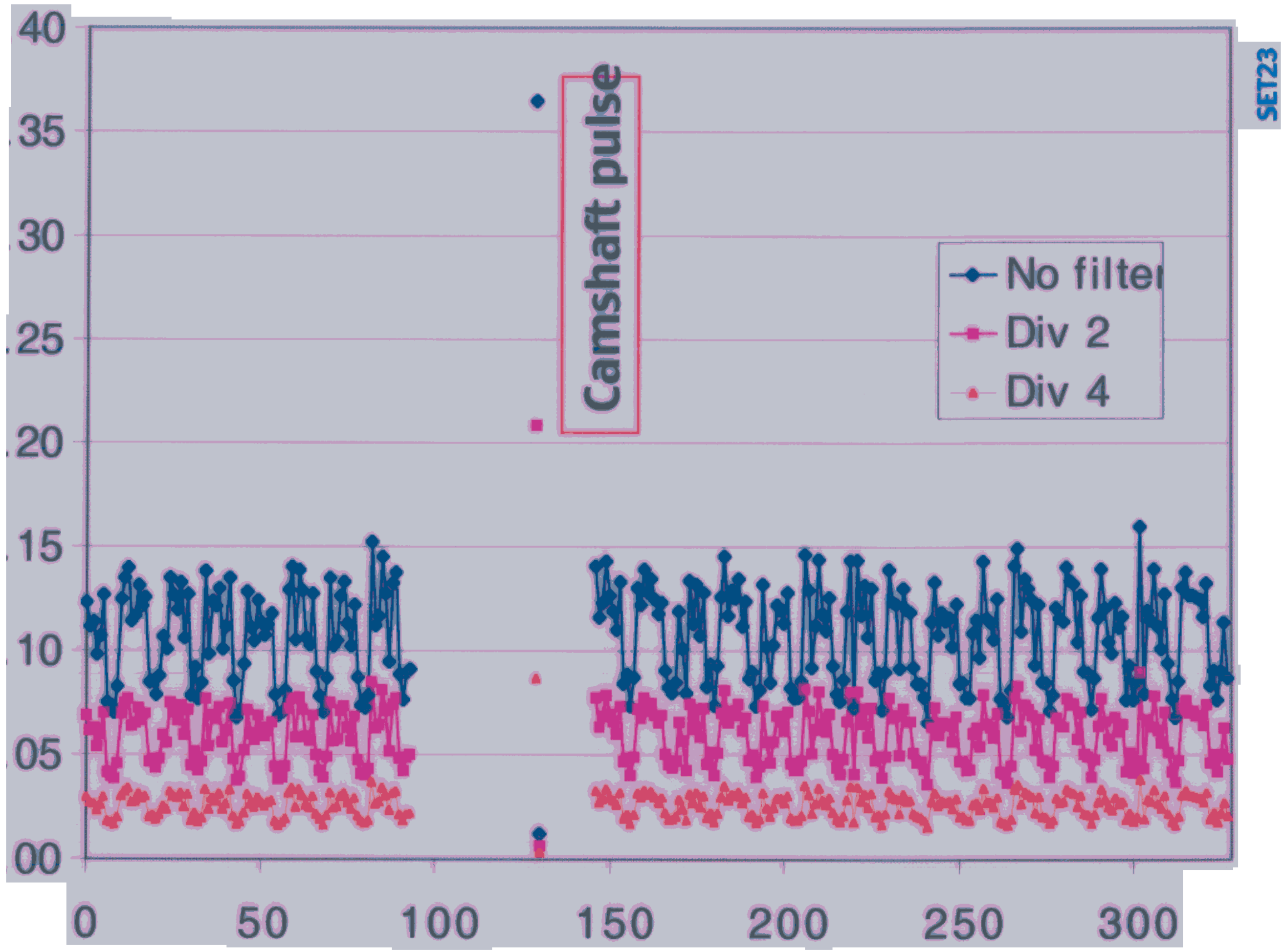


Bunch Length

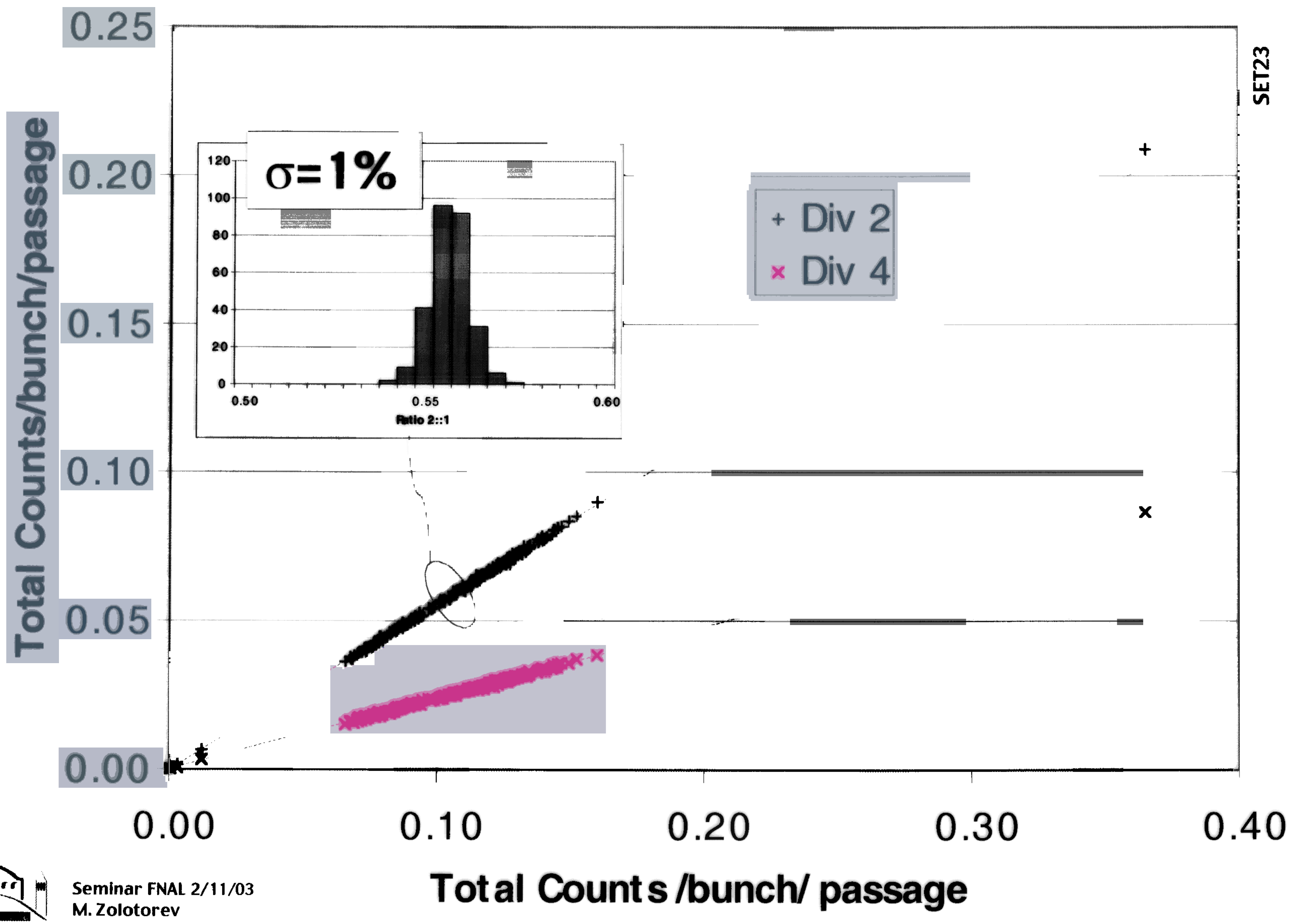


Linearity...

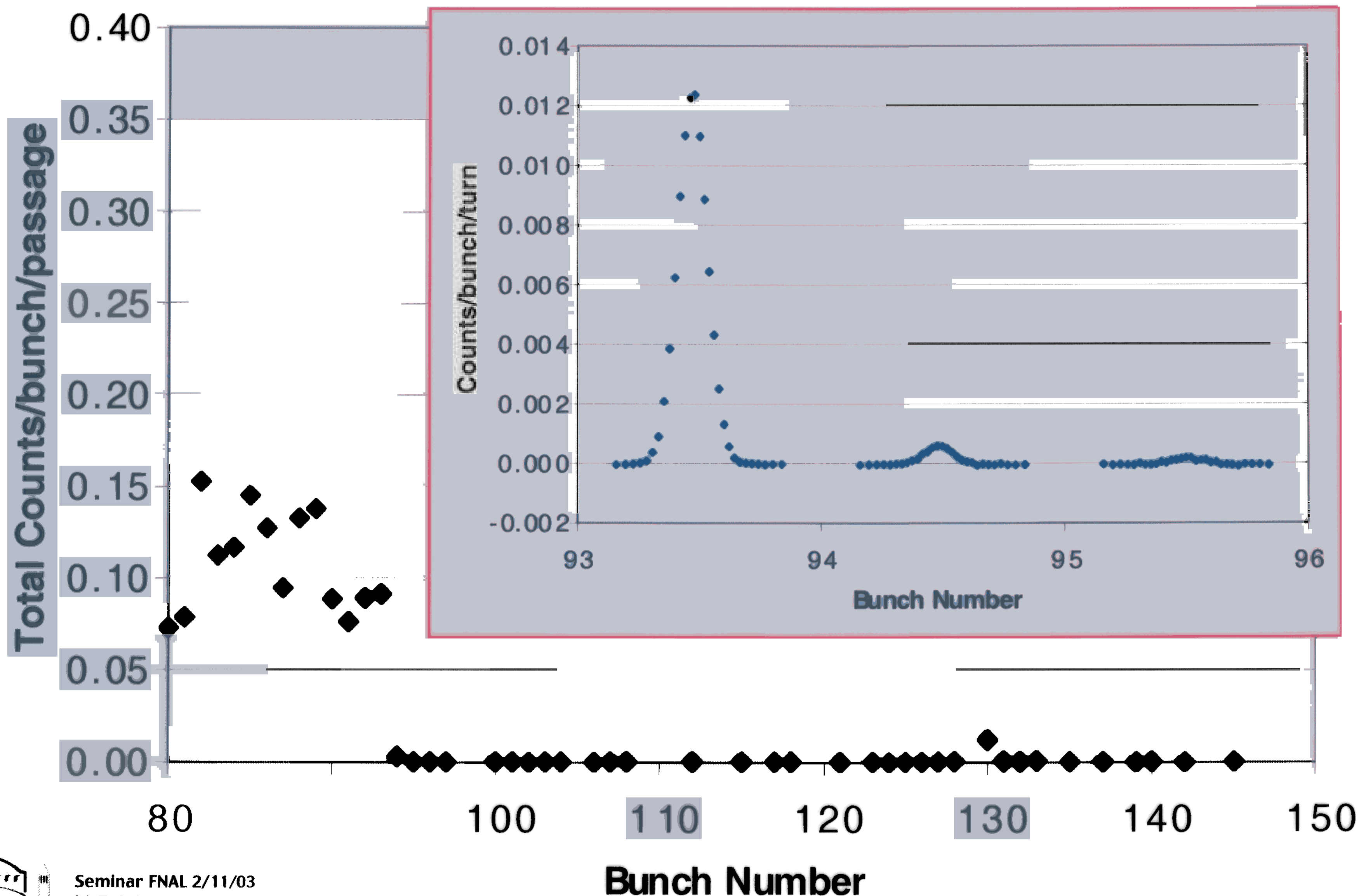
3 runs – same fill conditions, but put filters in front of PM



Response is quite linear

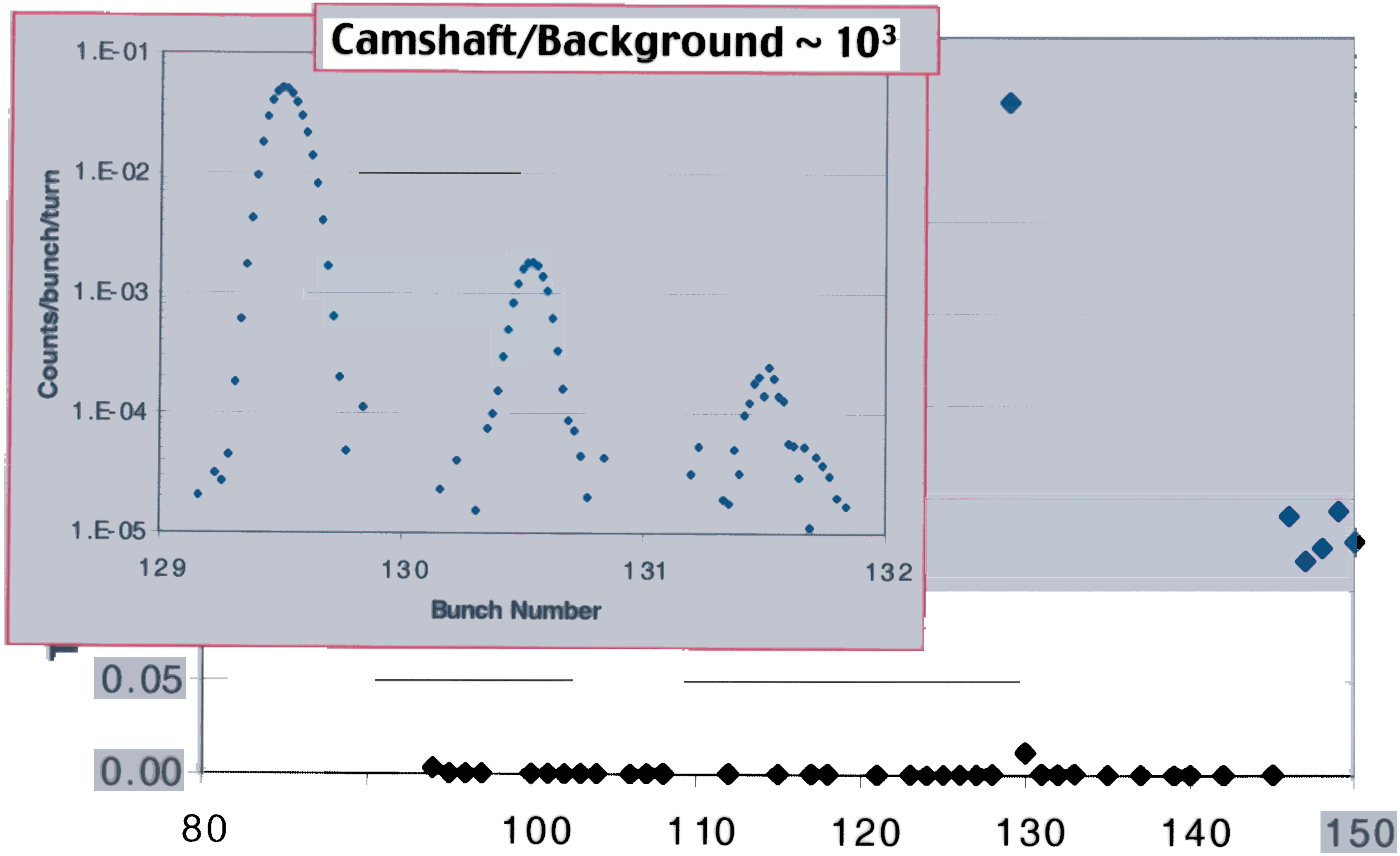


Zoom – I.



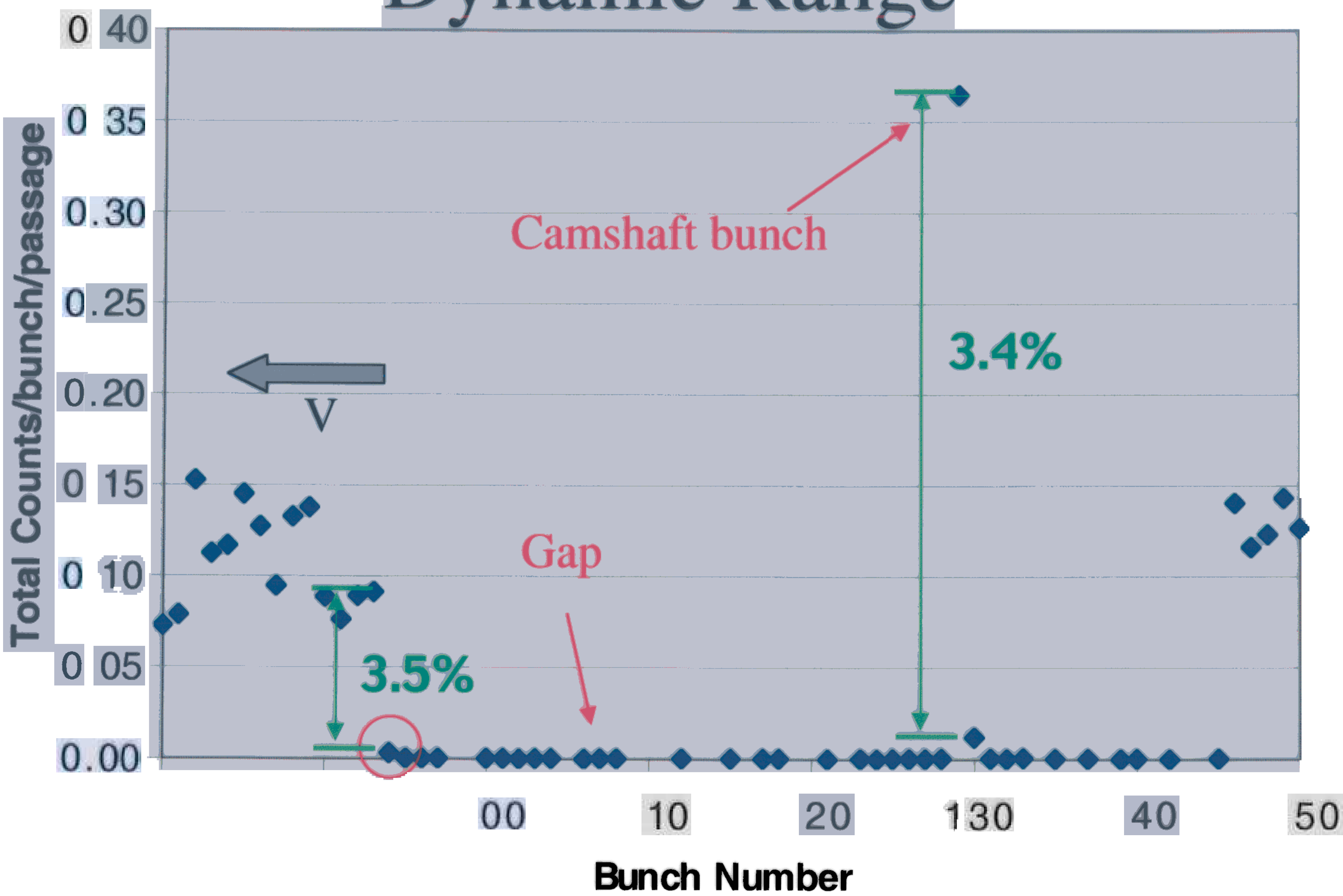
Total Counts/bunch/passage
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
80
100
110
120
130
140
150
Bunch Number
Counts/bunch/turn
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
93
94
95
96
Bunch Number

Zoom – II.



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

Interesting Detail Demonstrates Dynamic Range



Laser for Tevatron, RHIC and LHC

concept

- 10W laser
- 1064 nm
- ≥7 ps pulse width
  120 MHz

crystal in cavity will improves efficiency

NEW! Product introduction at CLEO 2000

Modelocked IR VIS UV

Multi-Watt picosecond Lasers

IR – multi-Watt infrared picosecond Nd:vanadate lasers

IC-LASER ps Nd:vanadate models: IC-3000 ps Nd:VAN: >3 W; IC-8000 ps Nd:VAN: >8 W; IC-10000 ps Nd:VAN: >10 W

Technical Data	IC-3000 ps Nd:VAN	IC-8000 ps Nd:VAN	IC-10000 ps Nd:VAN
Average output power	>3 W	>8 W	>10 W
Wavelength		1064 nm	
Output stability typical		<1% rms (24 h)	
Pulse width (FWHM), typical		7 ps	
Pulse repetition rate	68-500 MHz	68-120 MHz	68-120 MHz
Beam quality		fundamental mode; $M^2 \leq 1.2$	
Polarization		p	
Power Supply		100 VAC – 240 VAC 50 or 60 Hz	
Laser head size		430 x 200 x 75 mm (l x w x h)	
Beam height		50.8 mm (2 in)	
Controller size		430 x 200 x 88 mm (l x w x h)	

VIS – multi-Watt 532-nm picosecond Nd:vanadate lasers

IC-LASER ps frequency-doubled models: IC-532-1000 ps Nd:VAN: >1 W; IC-532-3000 ps Nd:VAN: >3 W

UV – modelocked UV lasers at 355 nm

IC-LASER ps frequency-tripled models: IC-355-500 ps Nd:VAN: >0.5 W; higher powers on request

Technical Data	IC-532-1000 ps Nd:VAN	IC-532-3000 ps Nd:VAN	IC-355-500 ps Nd:VAN
Average output power	>1 W	>3 W	>0.5 W
Wavelength	532 nm	532 nm	355 nm
Output stability typical		<1% rms	
Pulse width (FWHM), typical		~6 ps	
Pulse repetition rate		~80 MHz	
Beam quality		fundamental mode, $M^2 \leq 1.2$	
Polarization	s	s	p
Power Supply		100 VAC – 240 VAC 50 or 60 Hz	
Laser head size		530 x 200 x 75 mm (l x w x h)	
Beam height		50.8 mm (2 in.)	
Controller size		270 x 200 x 88 mm (l x w x h)	

High Q Laser Production GmbH
Kästle Park, 2nd Floor
Kaiser-Franz-Josef-Strasse 61
A-6845 Hohenems/Austria
T +43 (0) 55 76 / 43 0 40
F +43 (0) 55 76 / 43 0 50
E sales@highQlaser.com
www.highQlaser.com

HIGH Q LASER

For 10^{10} p/cm

$\lambda = 4\ \mu$ $\lambda_{up} = 0.8\ \mu$

Ga As photocathode tube Q.E. ≈50%

	1000 GeV	150 GeV
N_{up}	800	0.01
T(1%)	10 ms	20 min

All-in-One Tool

- Do not require visible light
- Can work from 150 – 1000 GeV

  Very wide dynamic range
- Online bunch length

  Intensity – including intensity in gaps (making it easy to diagnose unfilled buckets)
- Phase transients
- Fast: the results shown were accumulated in seconds–minutes

Preliminary Budgetary Estimate
One Longitudinal Density System

		$183k
	$100k	
sy	$ 38k	
-Physics	$ 55k	
·Materials		$127k
	$ 75k	
-Optical comp.	$ 12k	
-PMT, PDs	$ 10k	
onics	$ 30k	
·Total (include ovhd)		$310k
		~6 mo.

Max,

attached is the slide Bill and I prepared for the cost estimate of the LDM for FNAL.Given the assumptions are very rough and we did it very quickly,

I suspect this is -0, +30% accurate!! The slide shows no contingency, and I think 25% would be appropriate.

Once we talk more with FNAL and have a better understanding of what we need to do, this can be refined and the error bars reduced.

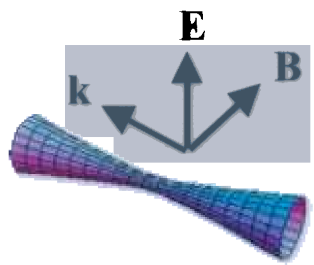
Let me know if you have questions.

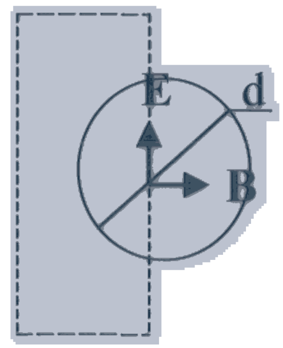
Alex

Light Fluctuation and Longitudinal Density Monitor

Catravas, P.
Sajaev, V.
Stupakov, G.
Zolotorev, M.

Diffraction and Coherence





$$\oint \vec{E}\, d\vec{l} = \frac{\partial}{c\,\partial t}\int \vec{B}\, d\vec{A}$$

$$E\, d \approx B\, k\, d^2\, \theta_{dif}$$

$$\theta_{dif} \approx \frac{1}{k\, d}$$

Transverse coherence

$$d_{\perp} = \frac{1}{k\,\theta}$$

Longitudinal coherence $$l_{\parallel} = \frac{c}{\Delta\omega}$$

Volume of coherence $$V_c = d_{\perp}^2\, l_{\parallel}$$

Degeneracy parameter == number of photons in volume of coherence

Degeneracy parameter

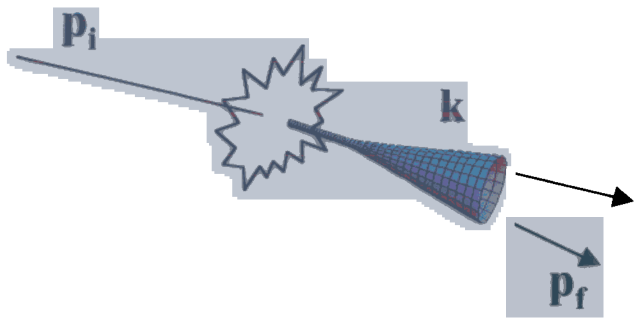
When degeneracy parameter is much greater than 1
The radiated field can be treated classically

rmal source $\dfrac{1}{\mathrm{Exp}[h\nu/kT]-1} \approx 1$

nchrotron radiation $\approx \alpha N \lambda / c\tau \approx 10^4$

3 Laser $\approx 10^{15}$

Superposition and radiation of beam



$$E_s(t, r) = \sum e_s\left(t - \tau_i, \vec{r} - \vec{r}_i\right)$$

$$E_s\left(\omega, \vec{k}\right) = e_s\left(\omega, \vec{k}\right) \sum e^{i \vec{k} \vec{r}_i - i \omega \tau_i}$$

If $k a \theta \ll 1$ $\quad a \ll d_c$

$$E_s(\omega, \theta) = e_s(\omega, \theta) \sum e^{-i \omega \tau_i} = e_s(\omega, \theta) \quad (\omega)$$

Incoherent radiation $\omega \tau_b \gg 1$

amplitude $E_s(\omega, \theta) \sim N^{1/2}$

intensity $\sim |Es(\omega, \theta)|^2 \sim N$

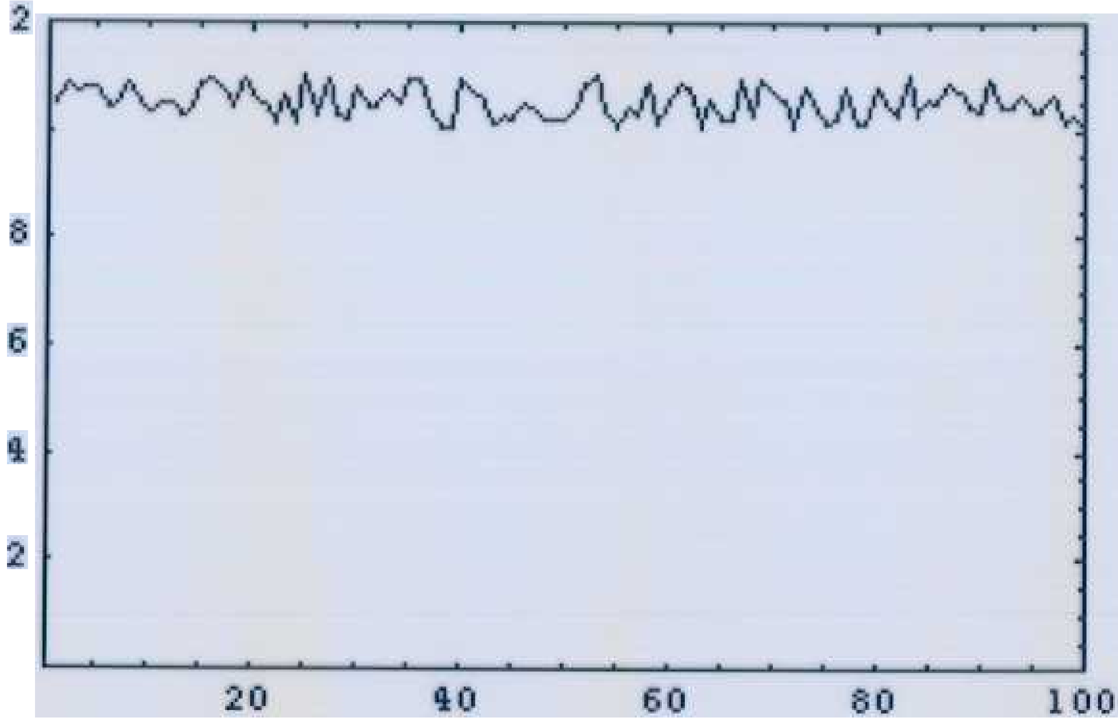
Coherent radiation $\omega \tau_b \ll 1$

amplitude $E_s(\omega, \theta) \sim N$

intensity $\sim |Es(\omega, \theta)|^2 \sim N^2$

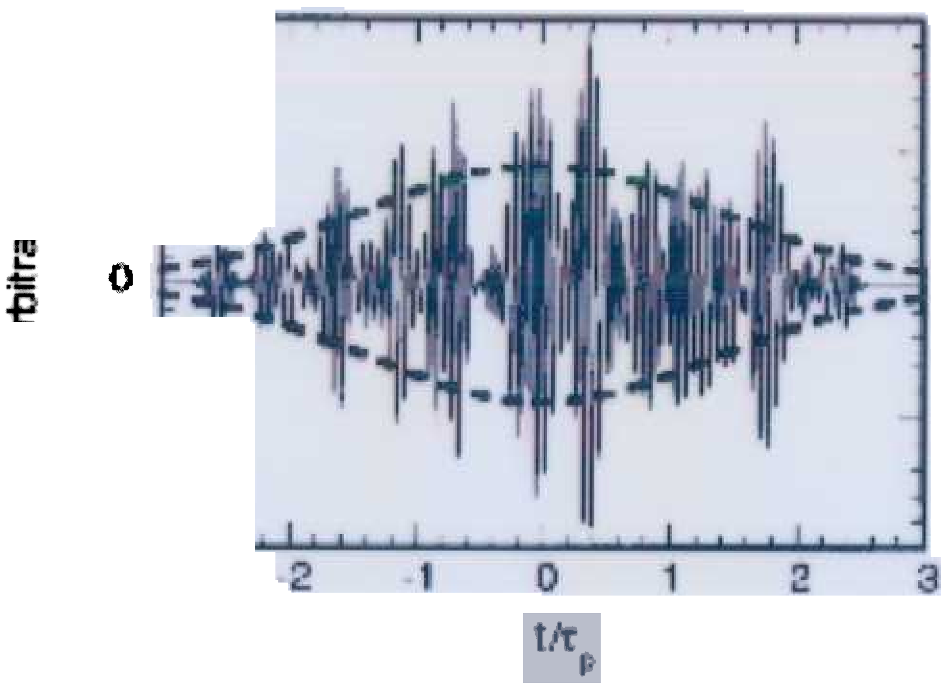
DC current can not radiate!

Incoherent Radiation by definition can come only from fluctuation (Noise) in beam density



Can information about longitudinal charge distribution be extracted from the incoherent radiation

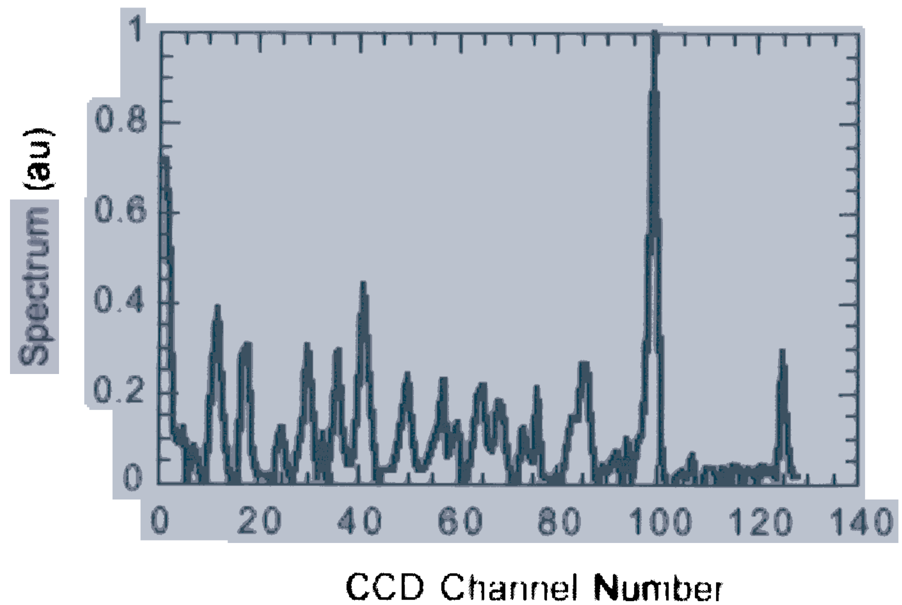
Time Domain



Time domain picture of incoherent radiation from Gaussian longitudinal charge distribution after filter with $\omega/\Delta\omega = 10$ and $\tau \approx 10/\Delta\omega$

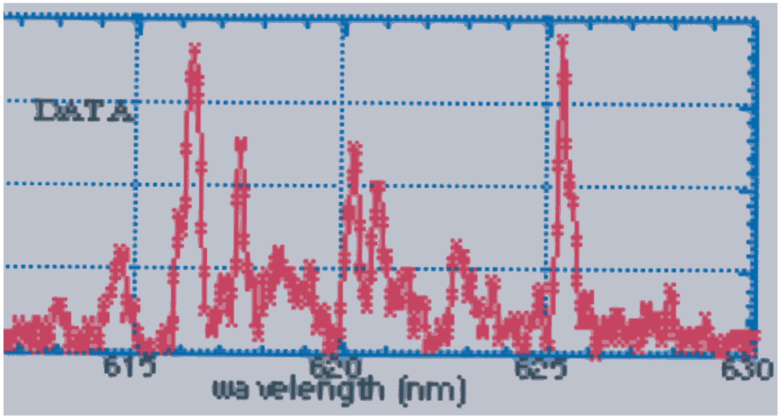
Pulse to pulse fluctuation in intensity under these conditions will be roughly $1/\sqrt{M}$,where M is the number of groups. In this case $M \approx 10$ and the fluctuation will be 30%. This does not depend on the number of electrons if the degeneracy parameter is large. For a known filter bandwidth and measured fluctuation the pulse length can be recovered.

Frequency Domain

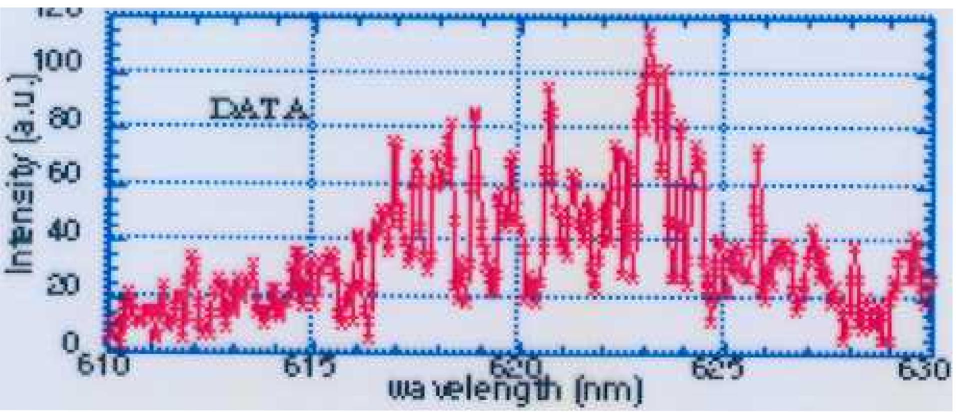


Spectral fluctuations: narrow spikes with width $1/\tau_b$.

ability distribution for spikes

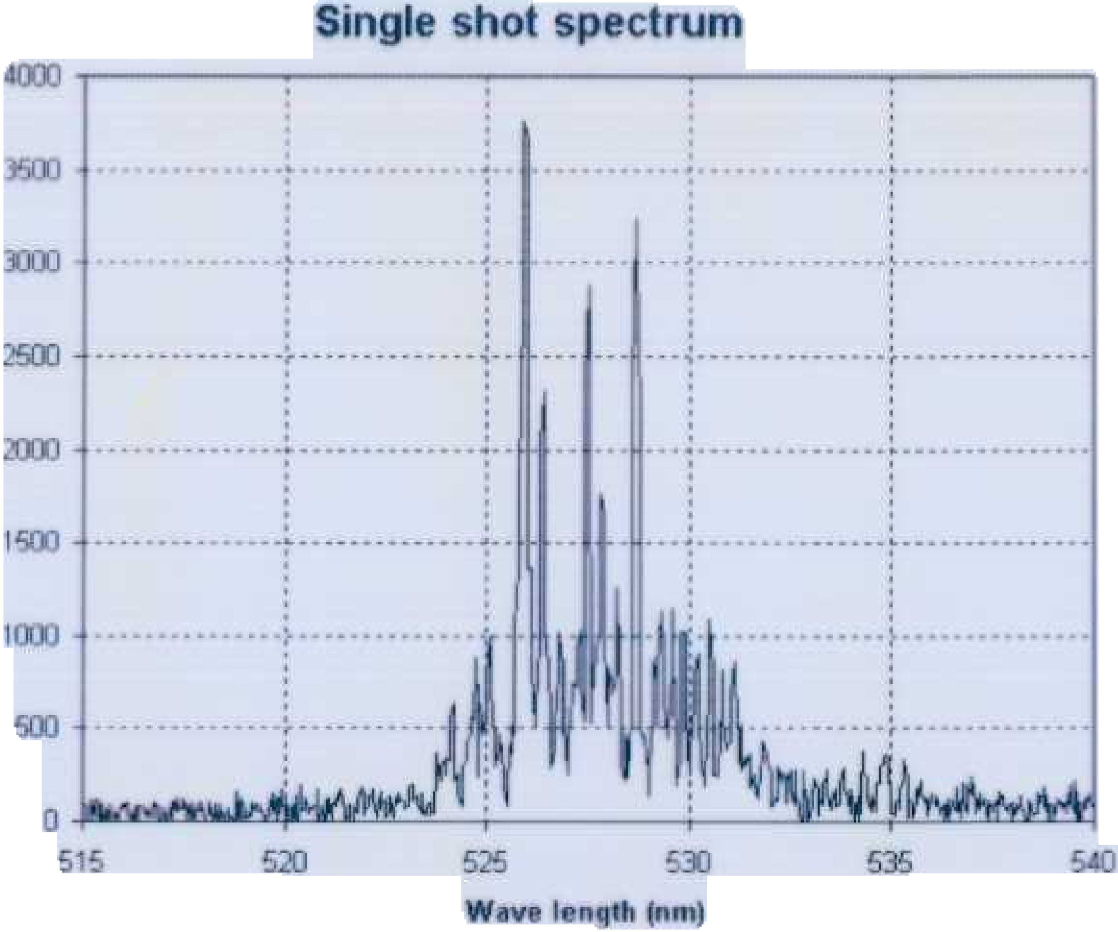


For beam size smaller than transverse coherence size and/or resolution of spectrometer $\Delta\omega < 1/\tau_b$, follows the Poisson distribution

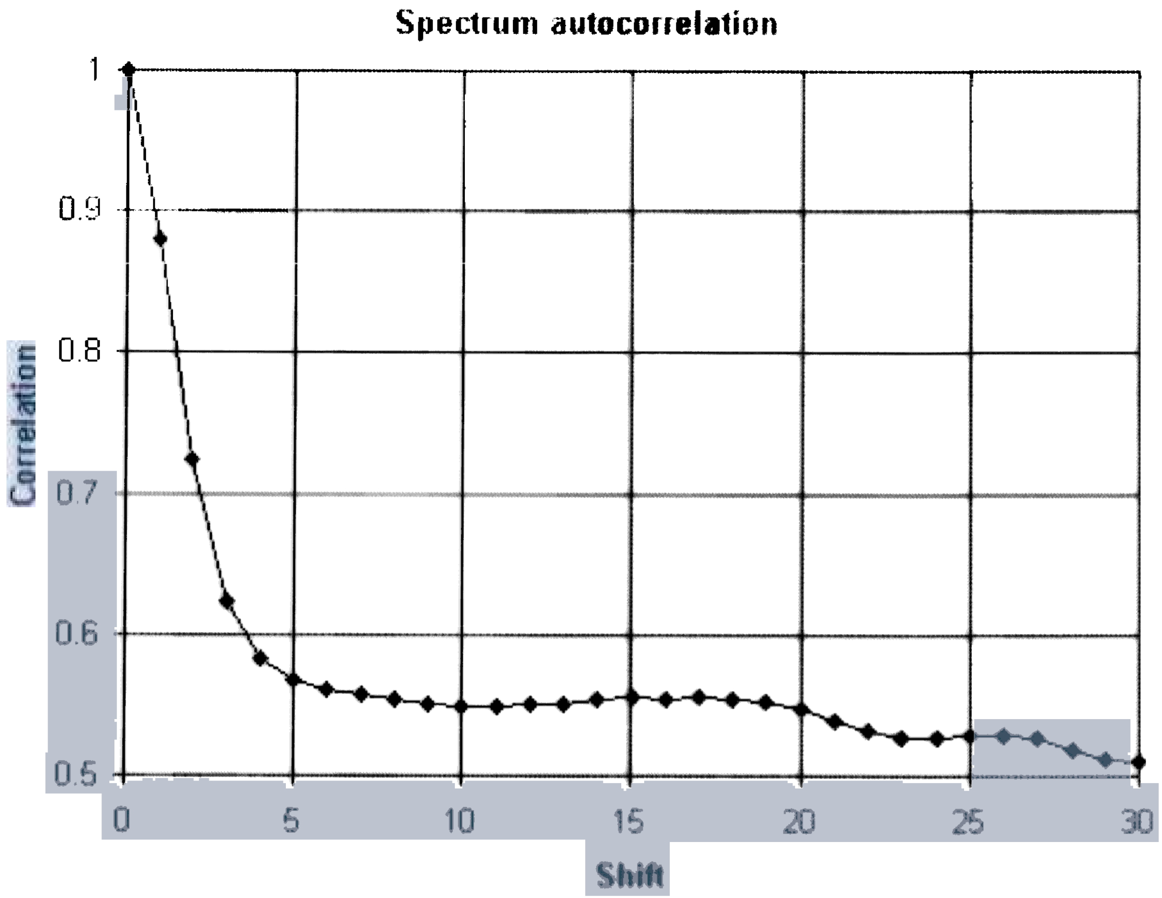


For beam size larger than transverse coherence size and/or resolution of spectrometer $\Delta\omega > 1/\tau_b$, follows the Gamma distribution

Experimental data taken at Brookhaven National Lab



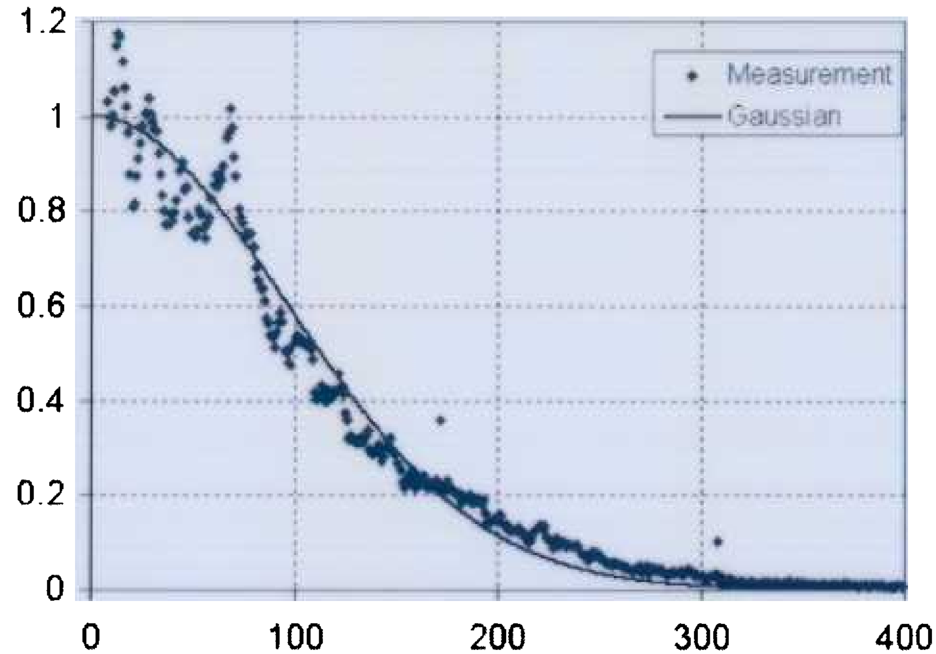
Experimental data taken at Argon National Lab



For no pedistal autocorrelation should go to .5
Spectral width of the spike can be seen to be ~ 2 pixels of ccd
for this experiment this corresponds to 1/2 ps.

Fourier transform of spectral auto-correlation function gives convolution function of particle charge density

Convolution of particle density



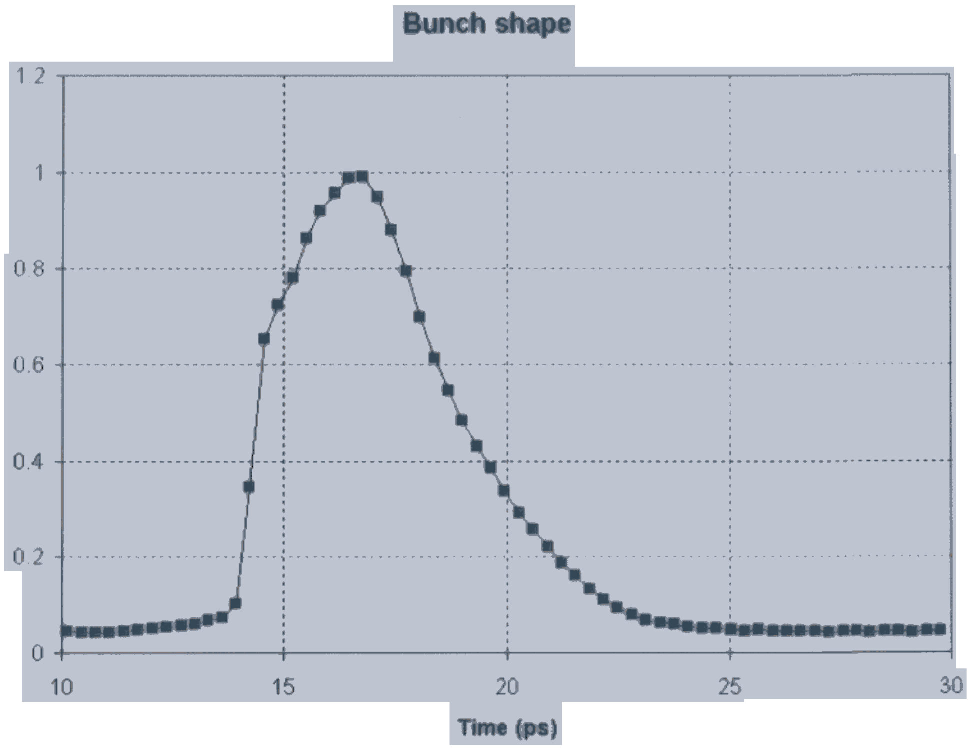
Knowledge of the convolution function does not allow a unique restoration of I(t).

One can try to recover I(t) using the suggestion of Lai and Sievers Micro Bunches Workshop AIP Conf Proc 367 1995

$$S(\omega) = \rho(\omega) e^{i\psi(\omega)} .$$

$$\psi_m(\omega) + \psi_{Blaschke}(\omega) = -\frac{2\omega}{\pi} P\int_0^\infty dx \frac{\ln \rho(x)}{x^2 - \omega^2} + \sum \arg\left(\frac{\omega - \omega_j}{\omega - \omega_j^*}\right)$$

$$\psi_m(\omega) = -\frac{2\omega}{\pi} P\int_0^\infty dx \frac{\ln[\rho(x)/\rho(\omega)]}{x^2 - \omega^2}$$



Bunch shape recovered using this technique, averaged over 100 pulses. (Sajaev, V proceedings of EPAC 2000)