17TH ADVANCED BEAM DYNAMICS WORKSHOP ON

FUTURE LIGHT SOURCES

Linear Theory of "Phased Longitudinal Acceleration Improved by Dispersion"

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Linear Theory of "Phased Longitudinal Acceleration Improved by Dispersion"

Linear transport matrices for longitudinal phase space:

$$\begin{bmatrix} 1 & 0 \\ \alpha & 1 \end{bmatrix} \begin{bmatrix} 1 & \delta \\ 0 & 1 \end{bmatrix} \begin{bmatrix} t \\ E \end{bmatrix} = \begin{bmatrix} t + \delta E \\ \alpha t + (1 + \alpha \delta) E \end{bmatrix},$$

phased acceleration	long. dispersion	initial coordinates	final coordinates

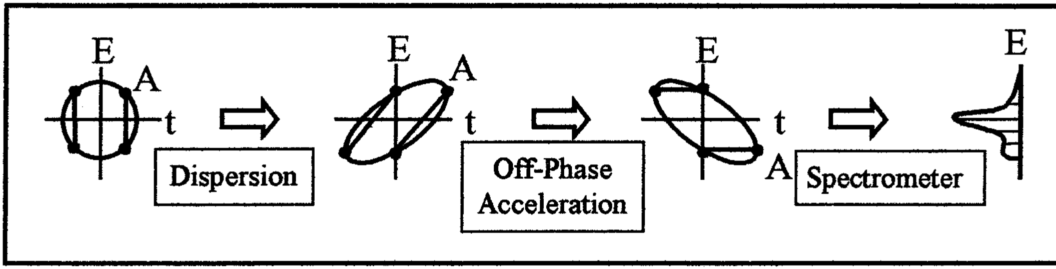
where $\alpha =$ keV/ps and $\delta =$ ps/keV.

Notice that, when $\alpha\delta = -1$, then $E_{final} = \alpha\, t_{initial}$.

Then the energy spectrometer measures the temporal profile of the initial bunch with resolution

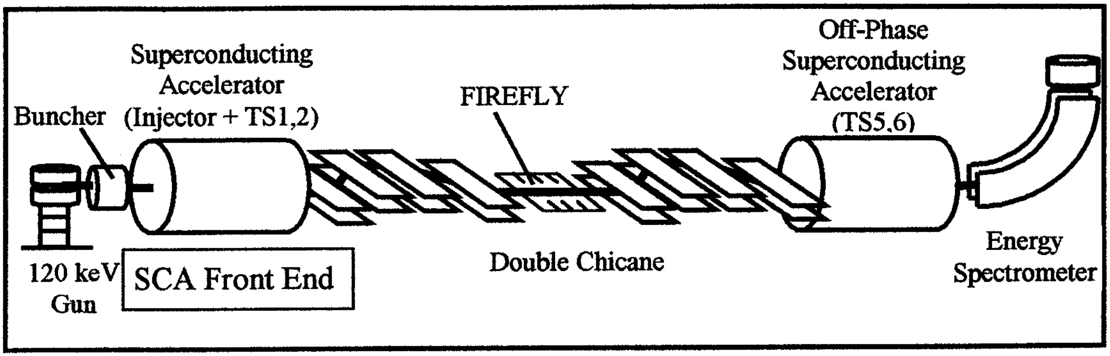
$$\Delta t = \Delta E_{spec} / \alpha.$$

Phase-Space Transformations



The linear transformation of phase space converts a temporal slice of the bunch, such as the segment containing point A, into a slice of the energy distribution which is imaged in the energy spectrometer. The stretching of the phase space in the dispersive section allows the phased acceleration to remove the initial energy spread from the slice.

The Superconducting Accelerator



Typical parameters for PLAID measurement:

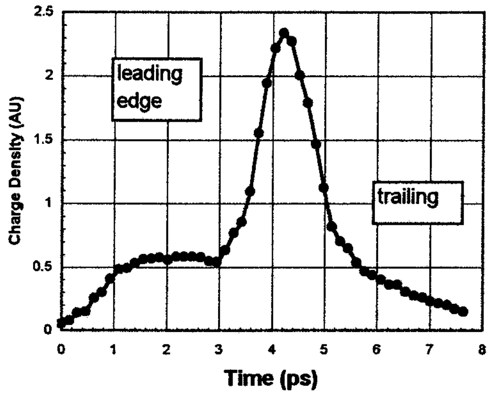
Beam energy:	19 MeV
Initial energy spread:	120 keV
Electrons per bunch:	4×10^7

Spectrometer resolution:	< 0.06%
(limited by transverse beam emittance)	
Phased acceleration ramp:	100 keV/ps
Chicane dispersion:	-0.010 ps/keV

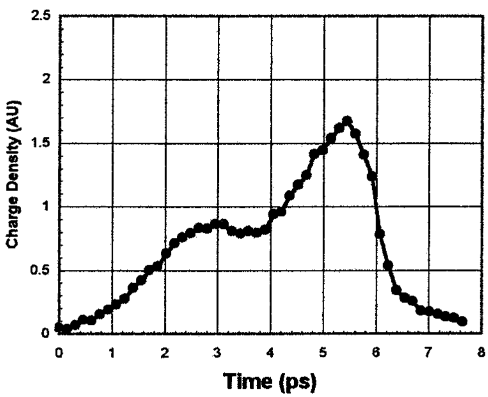
Best profile resolution so far: 120 femtoseconds

How to tailor your electron bunch profile

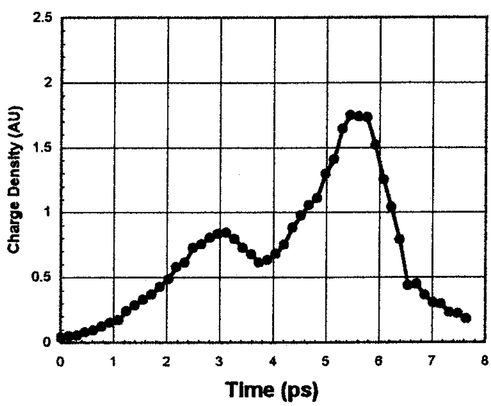
#1) Begin with a typical pulse for FEL operation



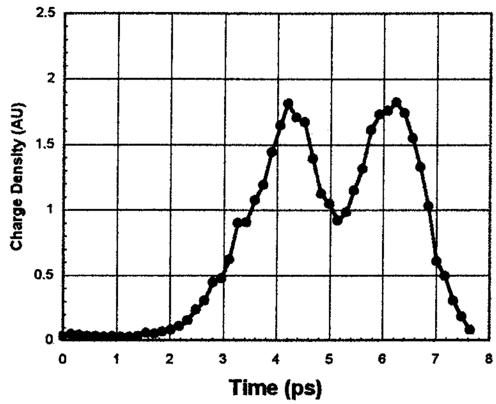
#2) Increase RF amplitude in pre-accelerator



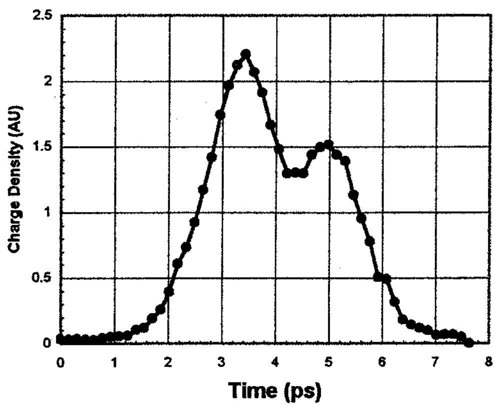
#3) Adjust Phase of RF Buncher



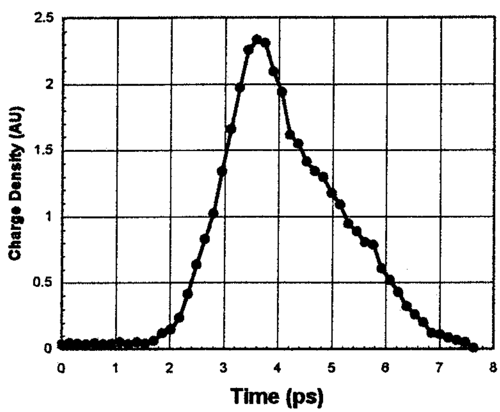
#4) Adjust phase of pre-accelerator to increase energy slew



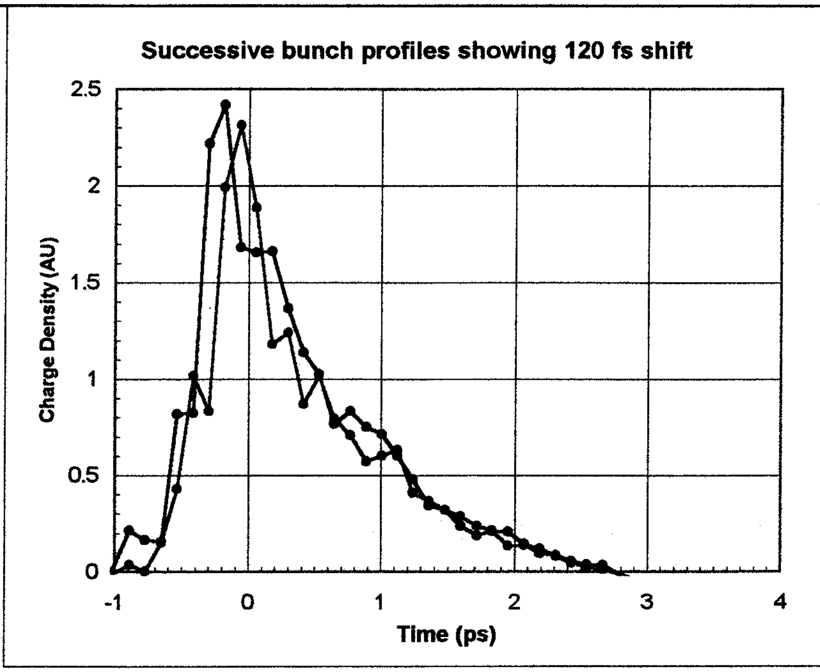
#5) Adjust pre-accelerator phase further to increase energy slew



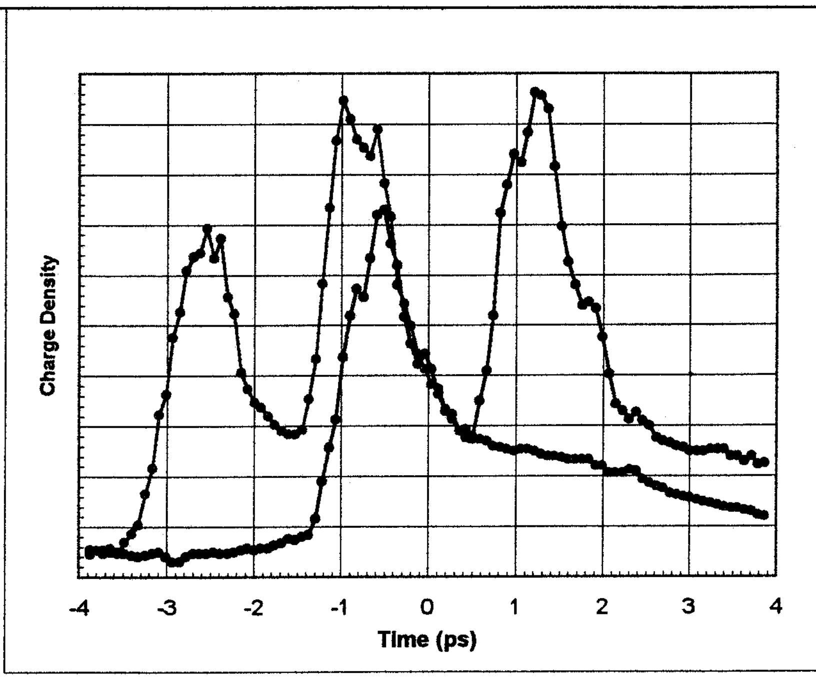
#6) Adjust pre-accelerator phase to increase energy slew again



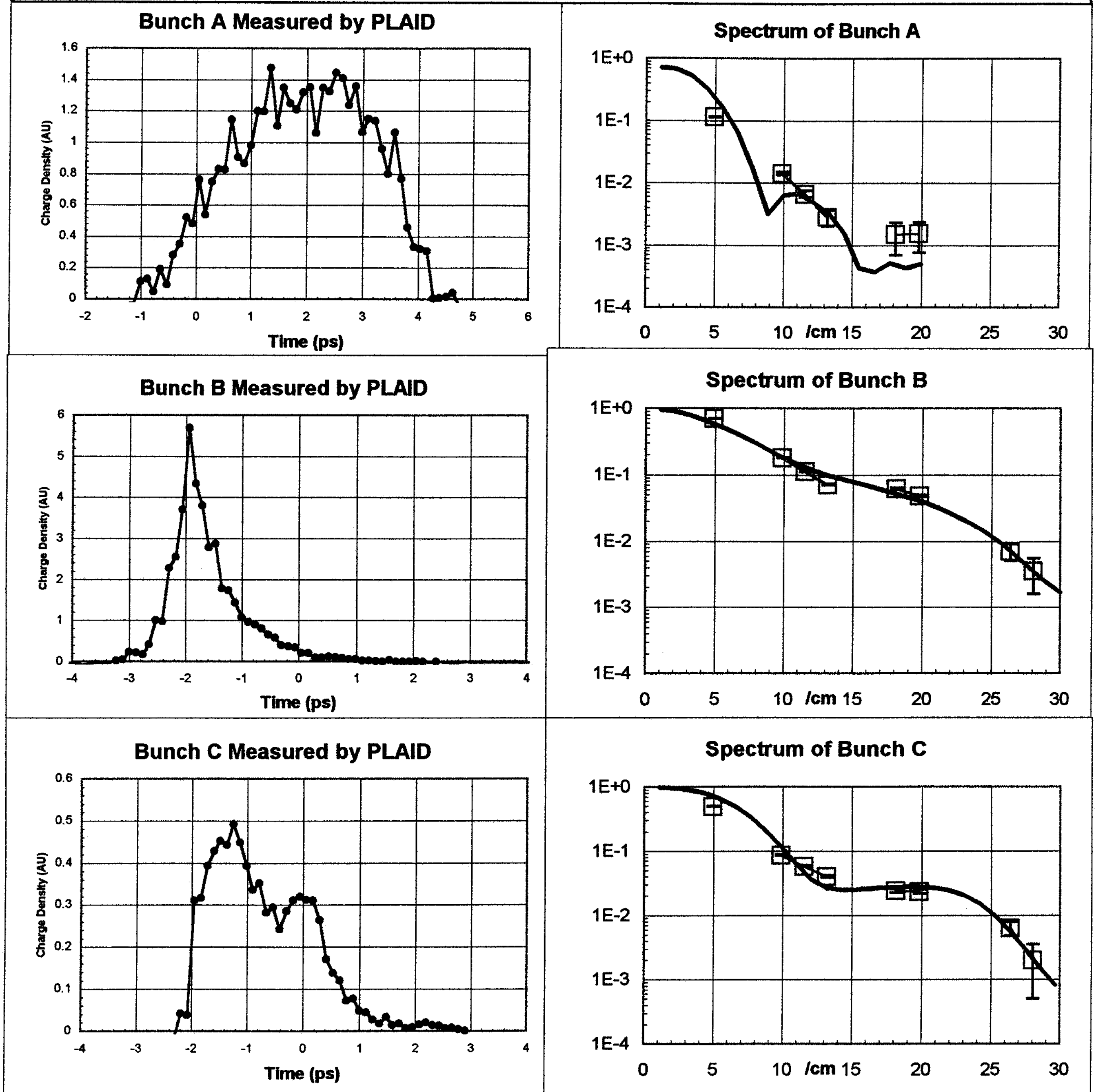
Best resolution achieved so far: 120 femtoseconds



Acceptance of the system: Here an electron bunch profile is scanned twice in the energy spectrometer, with a phase shift of 1.9 ps between scans.

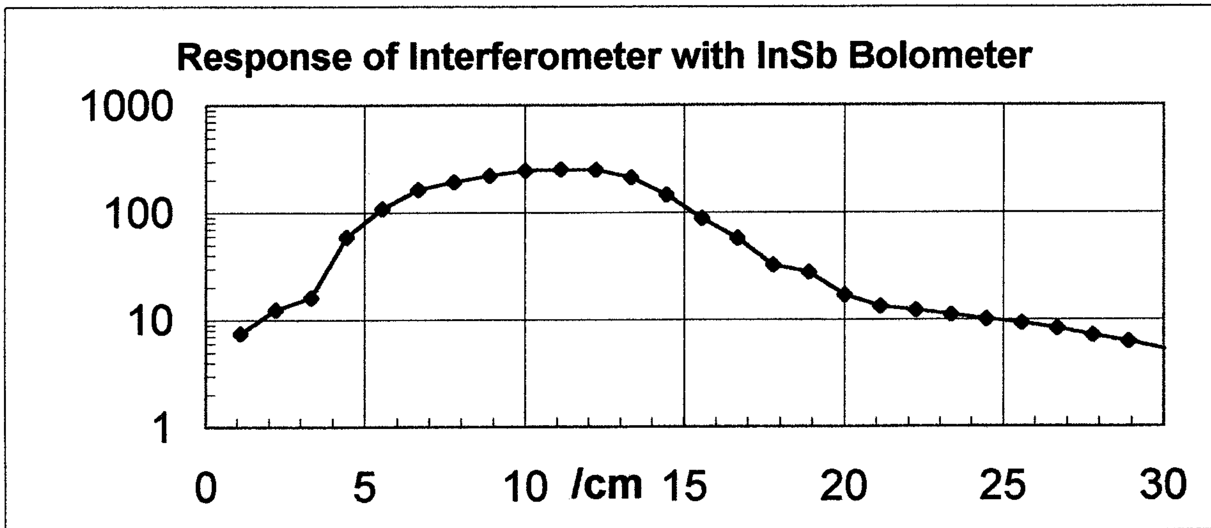


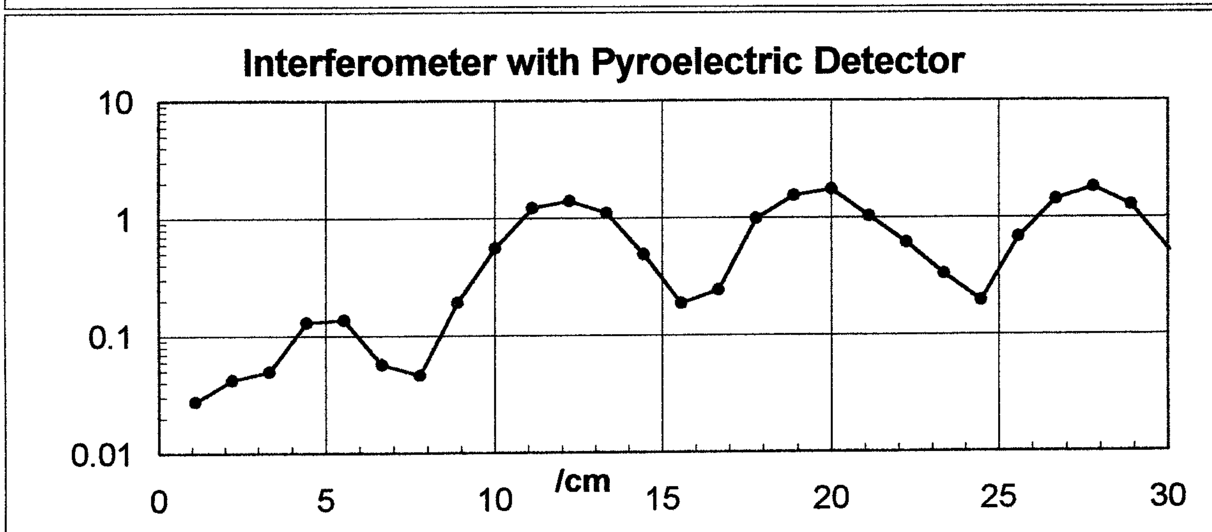
A comparison of the bunch Fourier power spectrum and the coherent transition radiation spectrum



The smooth curves at right are transforms of the bunches at left. The data points were measured with a pyroelectric detector.

Obtaining bunch shape from coherent transition or synchrotron radiation is difficult because of the large nonlinearity in submillimeter wave detectors and the optical system





Second Order Dispersive (Temporal) Effects

Beam to be Measured — (Z^0,γ^0) — Temporal Dispersion — (Z^1,γ^1) — 90 degree linac section $E=E_1\sin(\omega\tau)$ — (Z^2,γ^2) — Magnetic Spectrometer

γ_0

$Z^1=Z^0+D(\Delta\gamma/\gamma_0)$
$+D'(\Delta\gamma/\gamma_0)^2$

$\gamma^2=\gamma^1+S\Delta Z$
$S=(E_1/E_{beam})\omega/c$

$$\gamma^2/\gamma_0 = \gamma^0/\gamma_0(1+SD) + SZ^0 + SD'(\gamma^0/\gamma_0)^2$$

$(\Delta t)_{min} = (E_{beam}/E_1)(T/2\pi)[(\Delta\gamma/\gamma)^2_{spec} + (1+SD)^2(\Delta\gamma/\gamma)^2_{beam} + (SD')^2(\Delta\gamma/\gamma)^4_{beam}]^{1/2}$,
where T is the period of the 90 degree section.

Two cases are of particular interest:
a) SD = -1, providing the best resolution for a given S, and
b) D = 0 = D', the conventional case requiring no dispersive section

These lead to:
a) $(\Delta t)_{min} \sim \Delta t_{ideal}[1 + 2(\Delta\gamma/\gamma)^4_{beam}/(\Delta\gamma/\gamma)^2_{spec}]^{1/2}$
b) $(\Delta t)_{min} \sim \Delta t_{ideal}[1 + (\Delta\gamma/\gamma)^2_{beam}/(\Delta\gamma/\gamma)^2_{spec}]^{1/2}$,

where $\Delta t_{ideal} = (E_{beam}/E_1)(T/2\pi)(\Delta\gamma/\gamma)_{spec}$ and where D' has been assumed to be about 1.5 D, as is typical for a 4 magnet chicane.

Example: Assume a 10 GHz system, a 0.01% spectrometer, a 10 MeV slewing section and a 100 MeV beam. Then,
$\Delta t_{ideal} = (100/10)\,(10^{-10}/2\pi)\,(10^{-4}) \sim 16$ femtoseconds

With no temporally dispersive section this resolution can be obtained only if the beam energy spread is <0.01%. With the dispersive section, the energy spread can be as much as 1.0% and the temporal resolution will still be 30 fs. (Without the dispersive section the resolution of a 1% beam will only be 1.6 ps-a factor of ~50 degradation.) Note that in the present example D is a fairly modest 0.5 mm/%.

Discussion of PLAID–
“Phased Longitudinal Acceleration Improved by Dispersion”

- Longitudinal electron bunch profiles have been measured at the SCA with a resolution of 120 femtoseconds, a limit imposed by the transverse phase space of the beam.

- Newer accelerators with better transverse emittance might achieve 10-30 fs resolution with this technique.

- Applications include electron bunch-shape tailoring for FELs and other exotic light sources.

- This method supplements other longitudinal diagnostics such as coherent radiation spectra, and may serve as a substitute for or improvement over a streak camera in many instances.