Longitudinal Studies of Ellipsoidal Bunches

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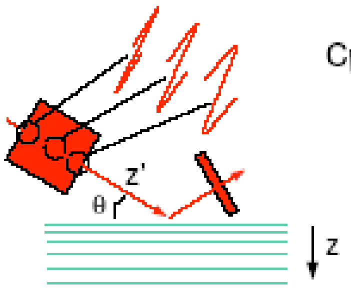
2005 Erice High Brightness Beams Workshop

Motivation: fully coherent x-rays exploit new science

Electron beam properties desired for seeded FELs

Longitudinal distributions for flat-top and ellipsoidal bunches

X-ray Pulse Shaping, 8 keV on Si (400)



$$Cp = \frac{1}{\omega}\frac{d\omega}{dz},$$

$$Cc = \frac{1}{a}\frac{da}{dz}$$

pulse chirp / crystal strain gradient matching:

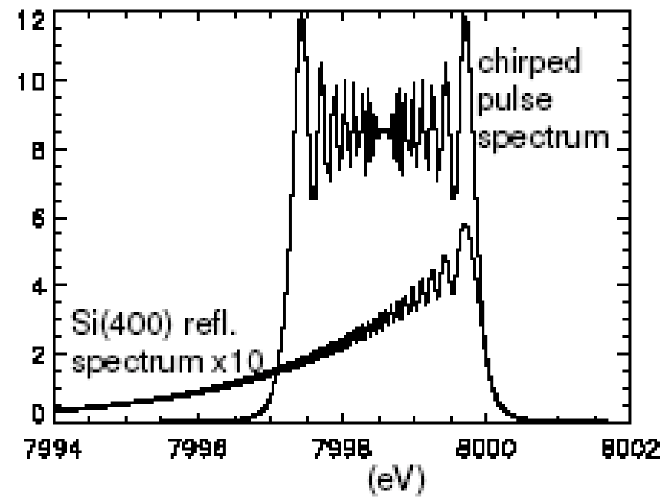
$$Cc = 2\ Cp\ \sin\theta$$

100 fs pulse, 2.85 eV chirp

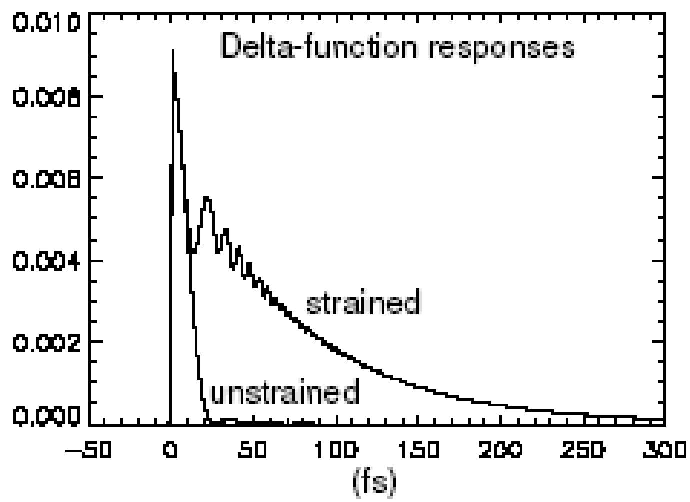
$Cp = 1.19 \times 10^{-5}$ /μm

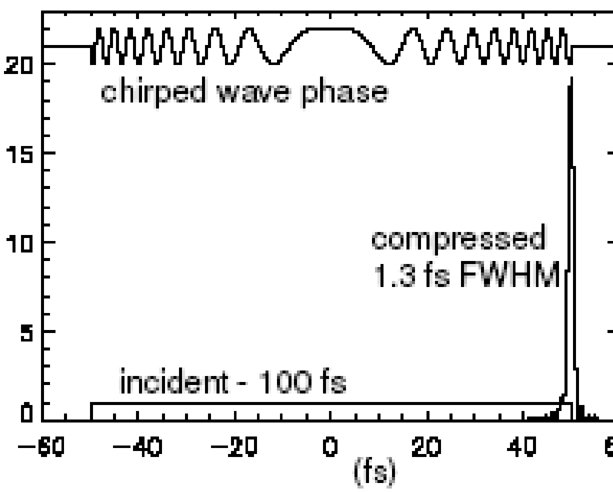
$Cc = 1.36 \times 10^{-5}$ /μm

$\theta = 34.8°$



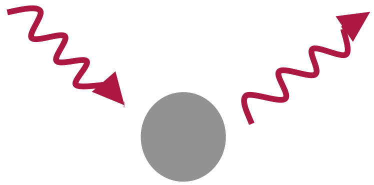
Collaboration of
Moncton (MIT)
Shastri (ANL)
Shargel (NYU)





Inelastic X-ray Scattering (IXS)

Photon-in – photon out



$q = k_i - k_f$

$\omega = \omega_i - \omega_f$

Probes charge-neutral excitations:

- Phonons, diffusive modes, orbitons, superconducting gaps…
- Excitons, plasmons, particle-hole creation, interband transitions…

•Experiment approved for FERMI@Trieste, collaboration of 8 institutions

Electron Beam Properties for Seeded FEL

Beam needs depend on application:

1) Sufficient flat-top to allow harmonic cascade FEL using fresh bunch method (including timing jitter)
2) Long x-ray pulses generating meV bandwidth
3) Low energy spread allowing many harmonic cascade stages

Electron beam parameters do not need to be extreme, but we always want constant values of current and energy spread

- Ideal beam has 1 kA, $\Delta E < 1$ keV, FWHM ~ 1 ps
- Current variations -> FEL optical phase shifts due to gain variations
- dE/E variations -> inconsistent bunching -> FEL optical phase shifts

Longitudinal Simulations

Recent work by Luiten *et al** on transverse properties of ellipsoidal distribution suggest examining distribution's longitudinal properties.

Simulations use Parmela to compare ellipsoidal with uniform flattop in S-band injector proposed for FERMI@Trieste project.

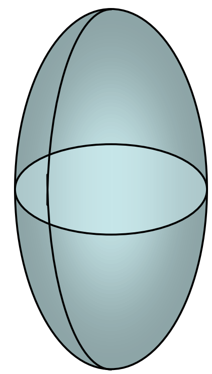
*PRL **93** 094802 (2004)

Parmela Photoinjector Simulations

S-band injector

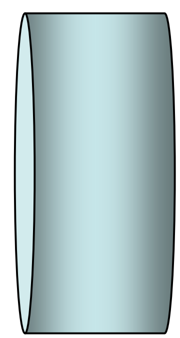
Compare ellipsoidal bunch with flattop.

RMS dimensions were set equal in each case



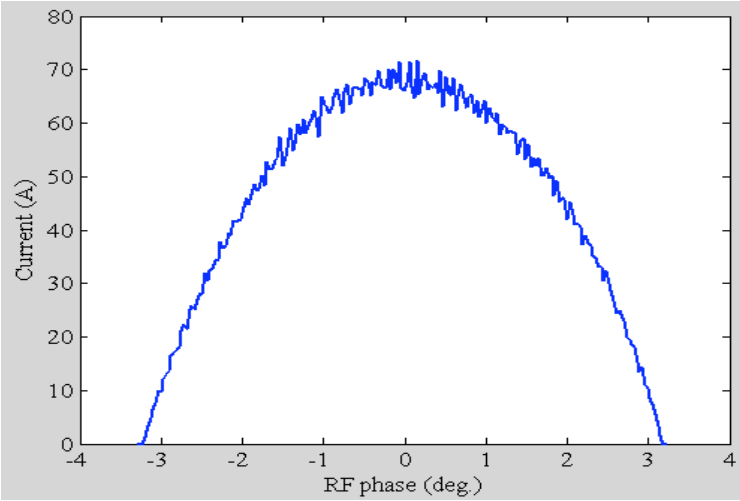
Ellipsoidal bunch

300 pC, ~1 mm radius, ~5 ps full width

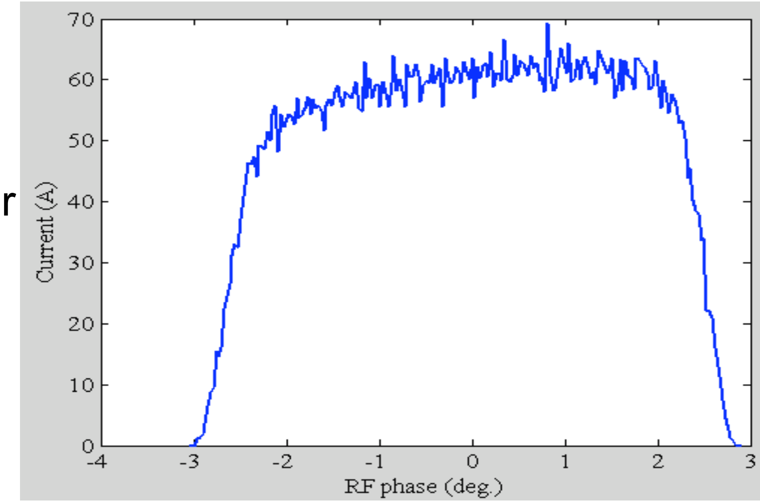


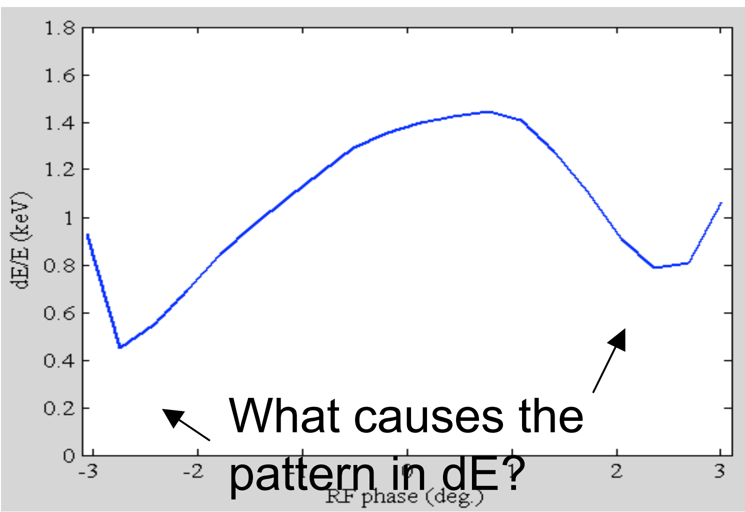
Flattop bunch

300 pC, ~1 mm radius, ~5 ps full width

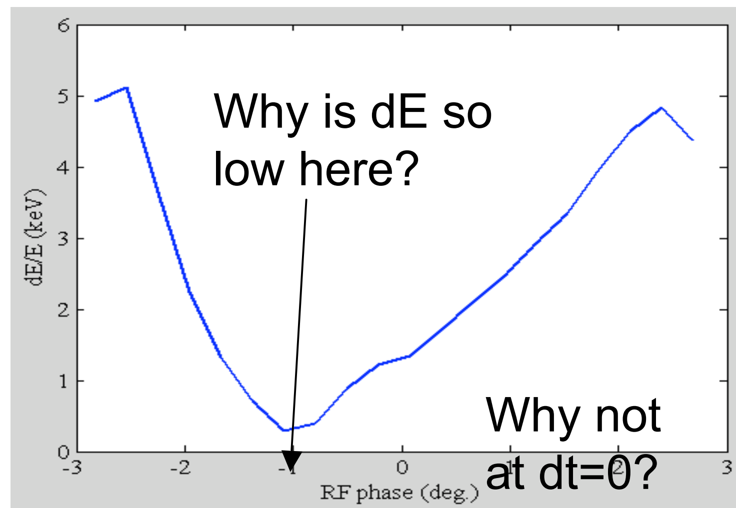


Current profiles for ellipsoid (left) and flattop (right).

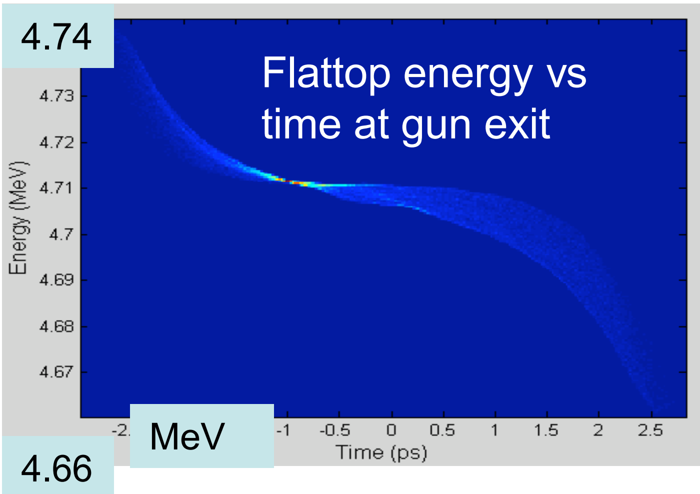


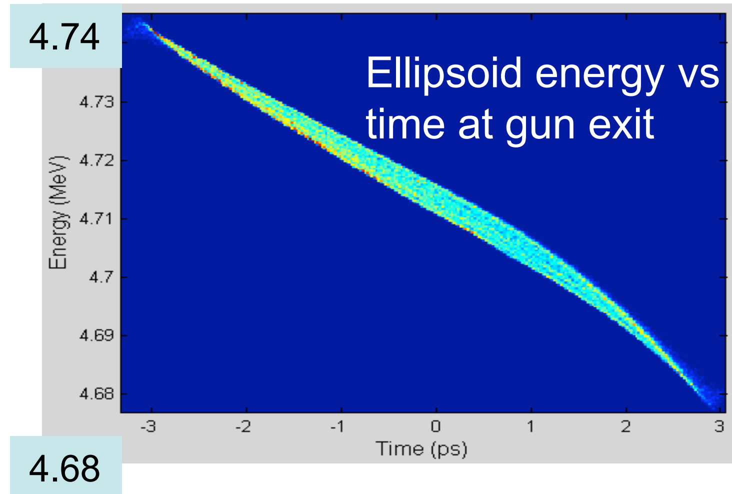


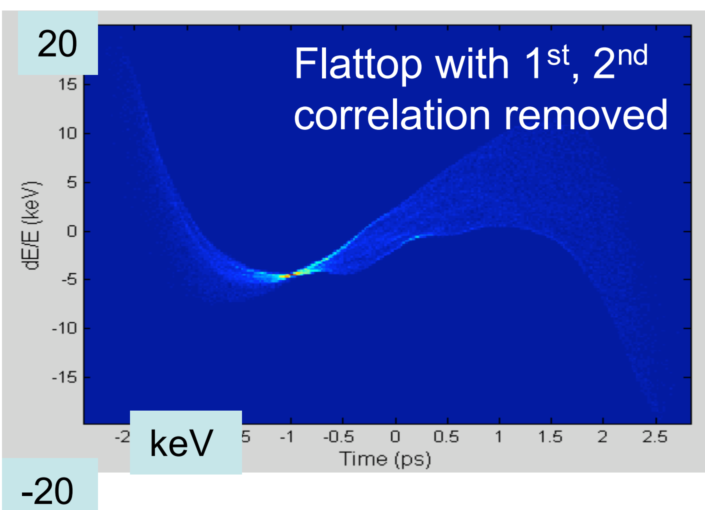
Energy spread for ellipsoid (left) and flattop (right).

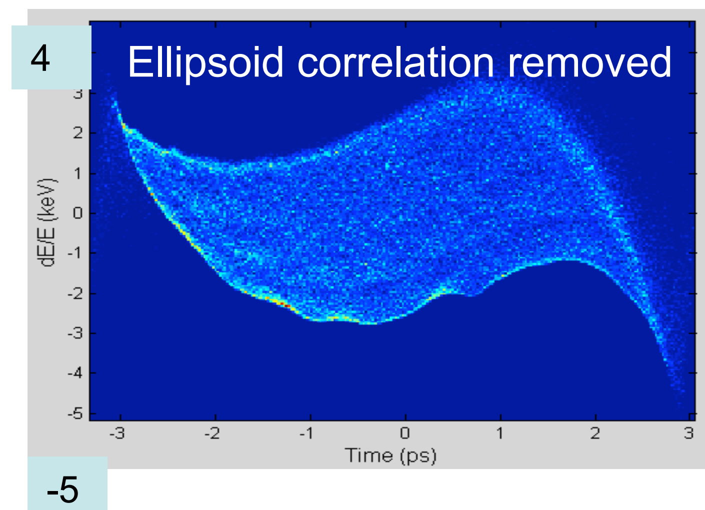


Longitudinal Phase Space Density

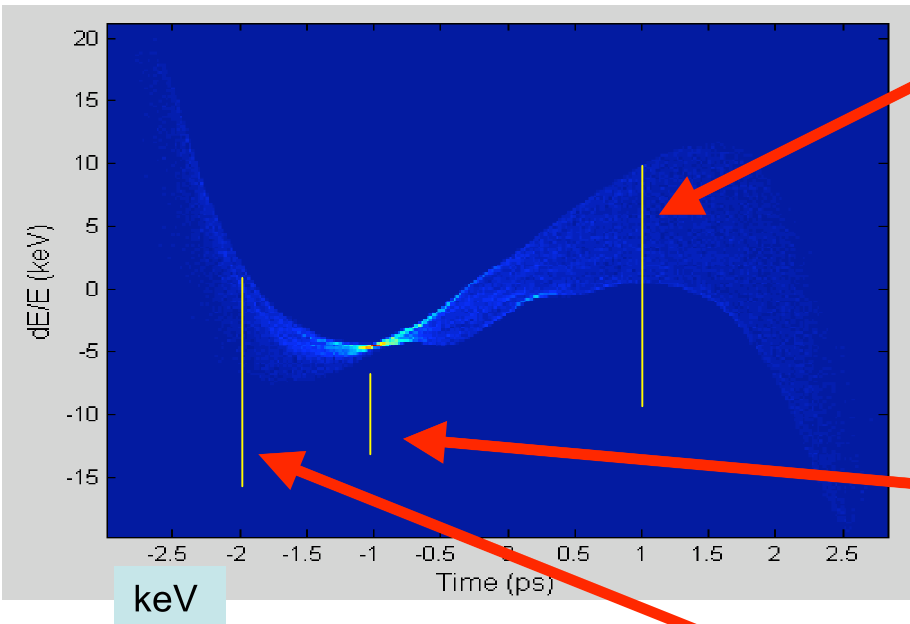


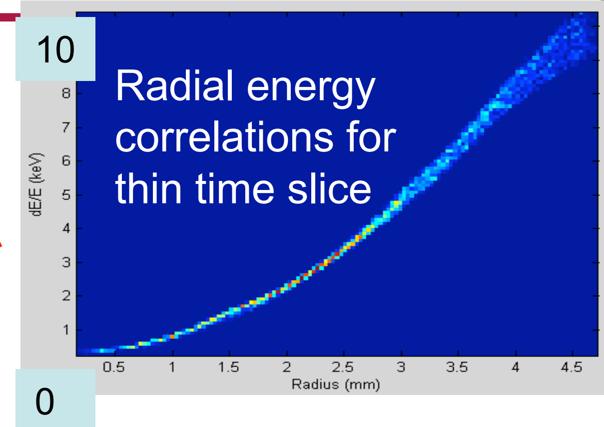


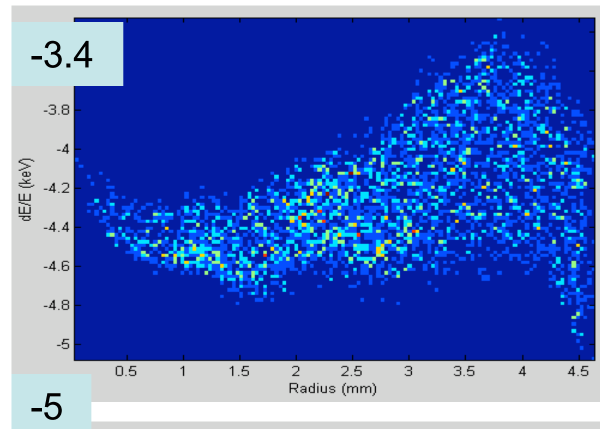


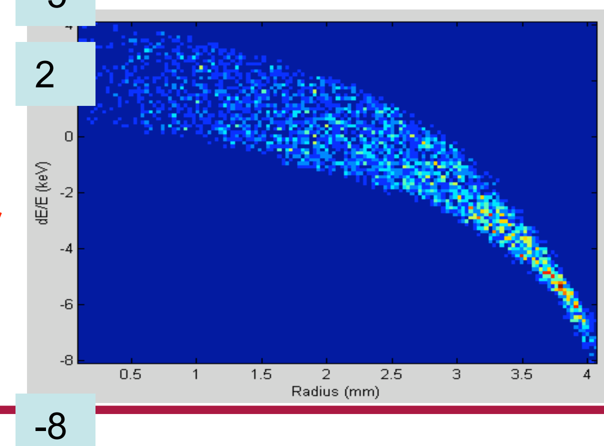


Radial energy correlation reverses slope from head to tail for flattop bunch



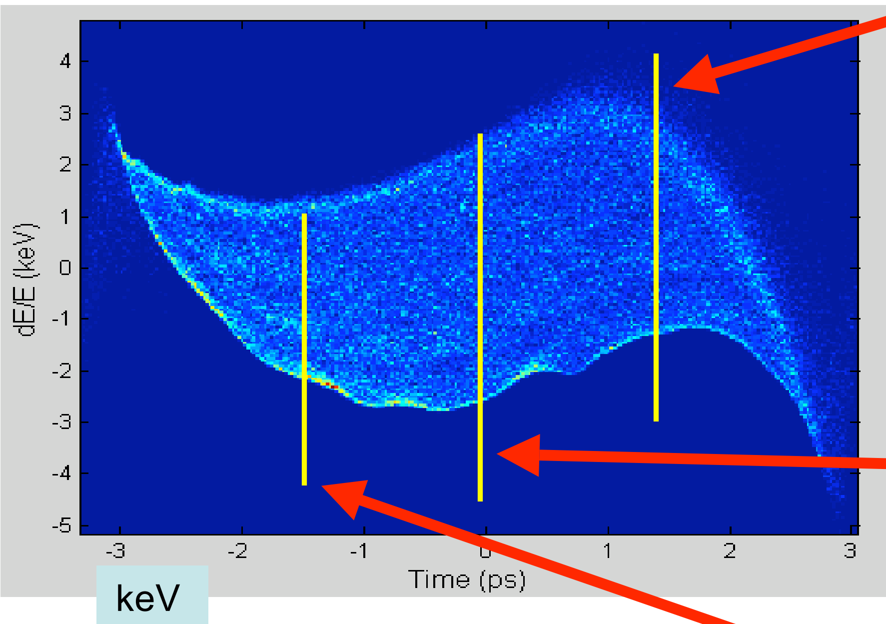


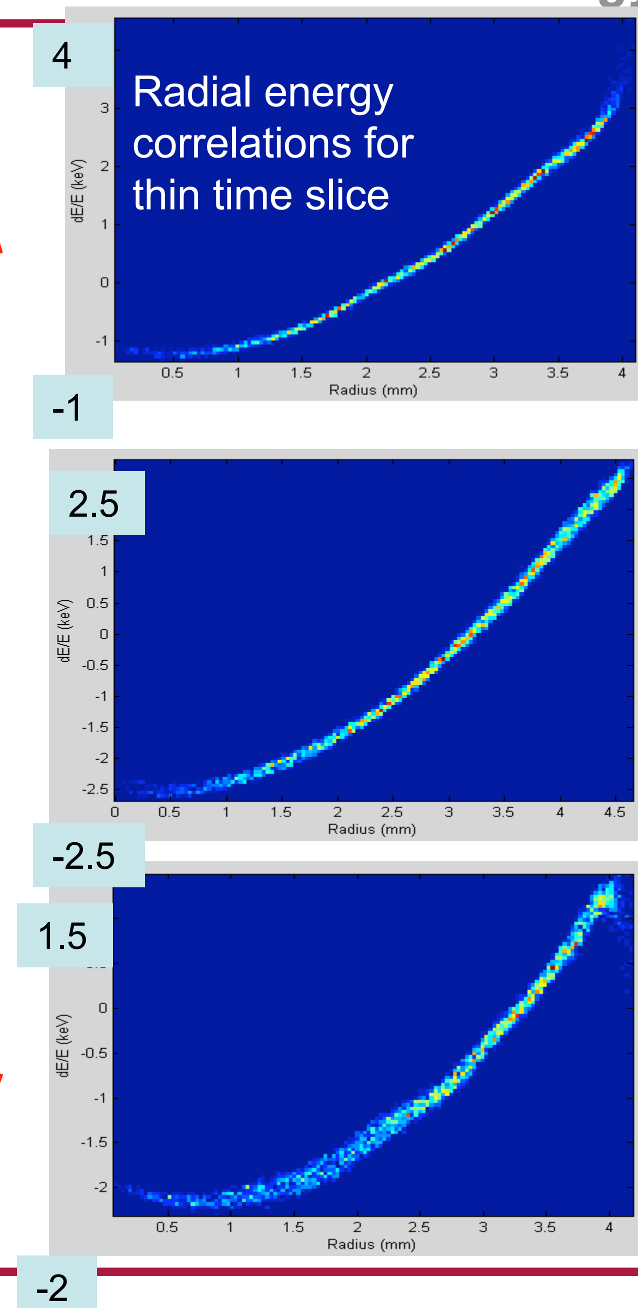




3 profiles show dE/E vs radius for the 3 short time slices above.

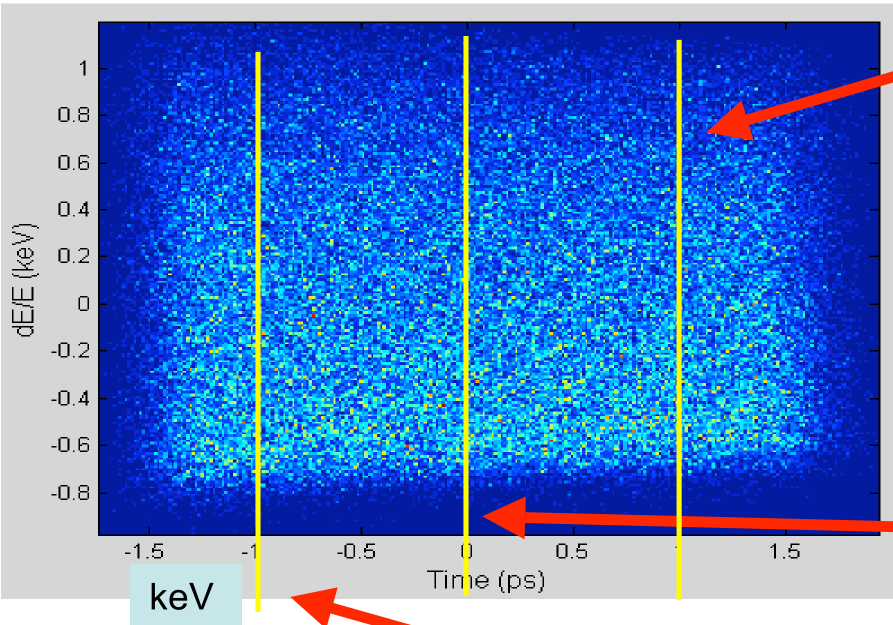
For ellipsoidal bunch, radial energy correlation is nearly constant.

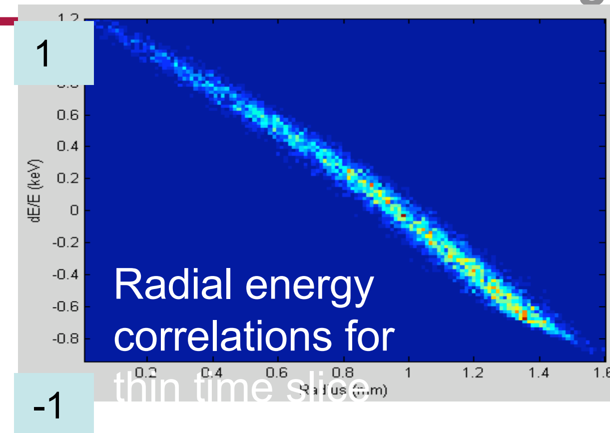


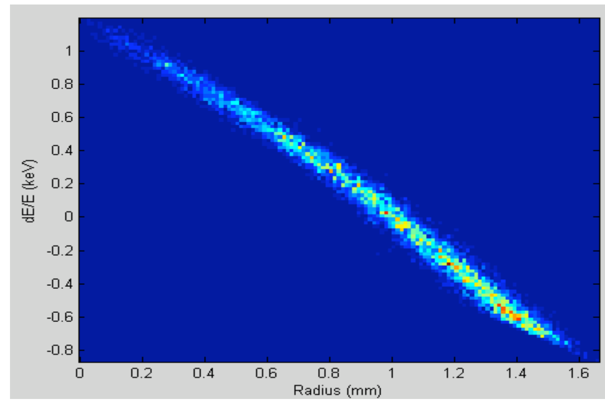


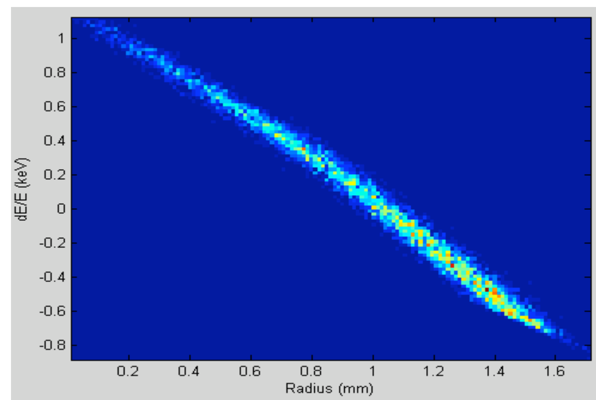
3 profiles show dE/E vs radius for the 3 short time slices above.

Space-charge turned off for flattop. RF Ez(r) responsible for radial correlation.

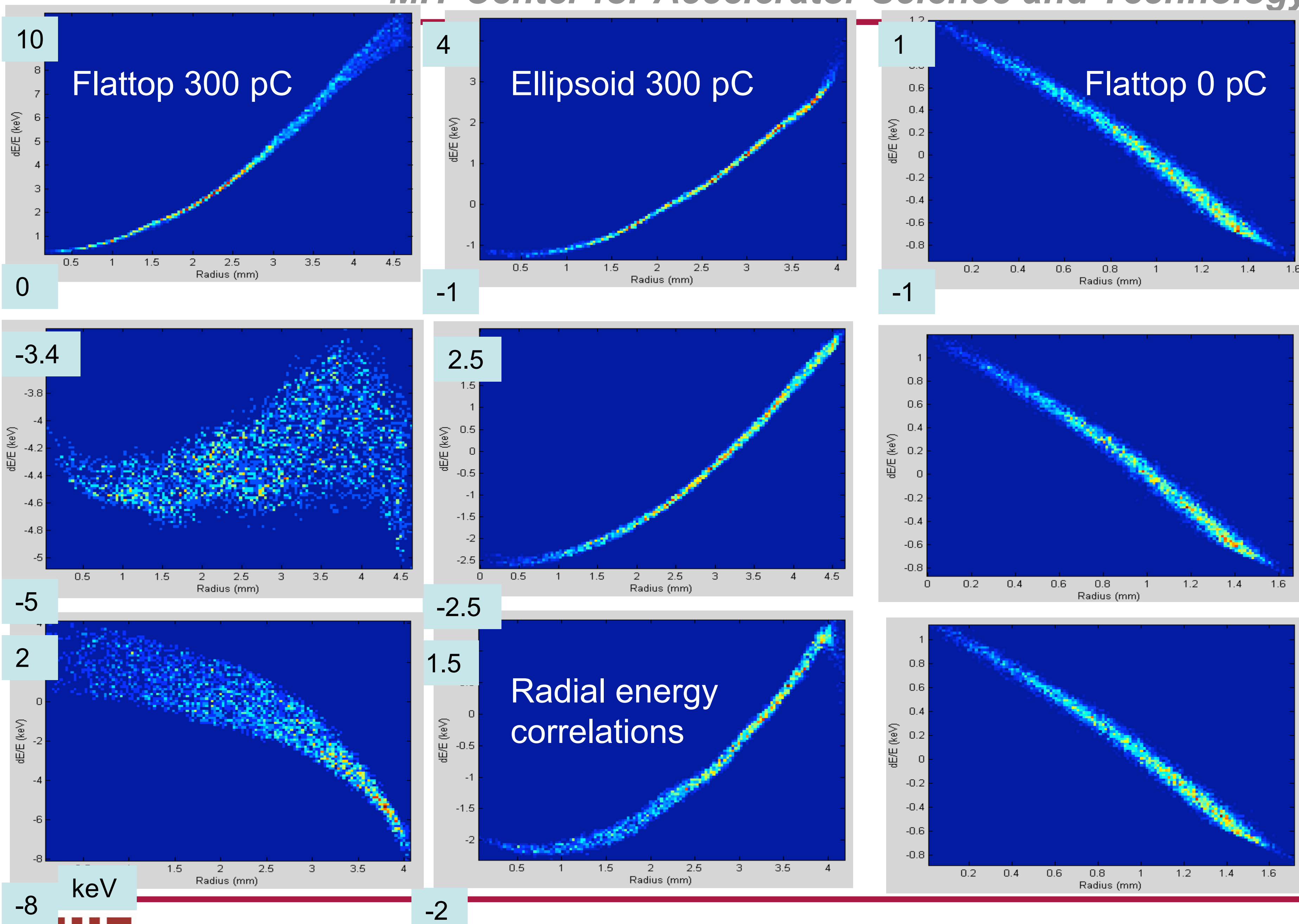






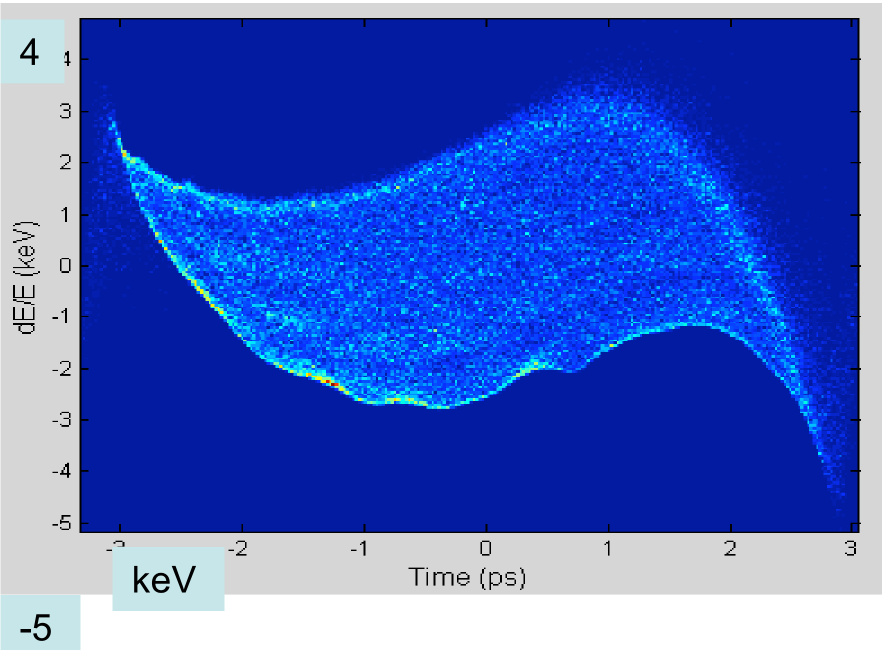


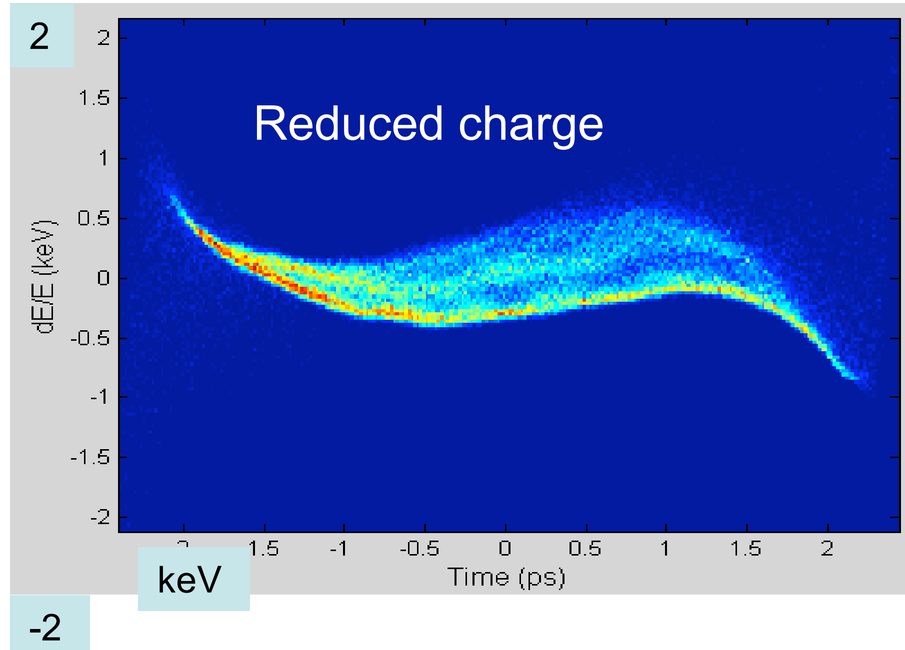
3 profiles show dE/E vs radius for the 3 short time slices above.



10
Flattop 300 pC
0
4
Ellipsoid 300 pC
-1
1
Flattop 0 pC
-1
-3.4
-5
2.5
-2.5
2
-8
keV
1.5
Radial energy correlations
-2
dE/E (keV)
Radius (mm)

Balancing RF radial correlation with Space Charge



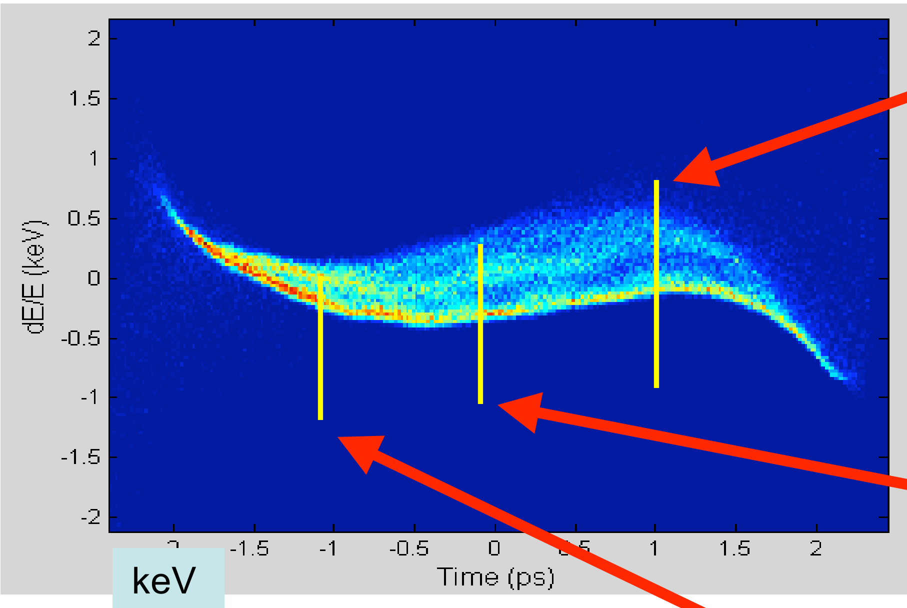


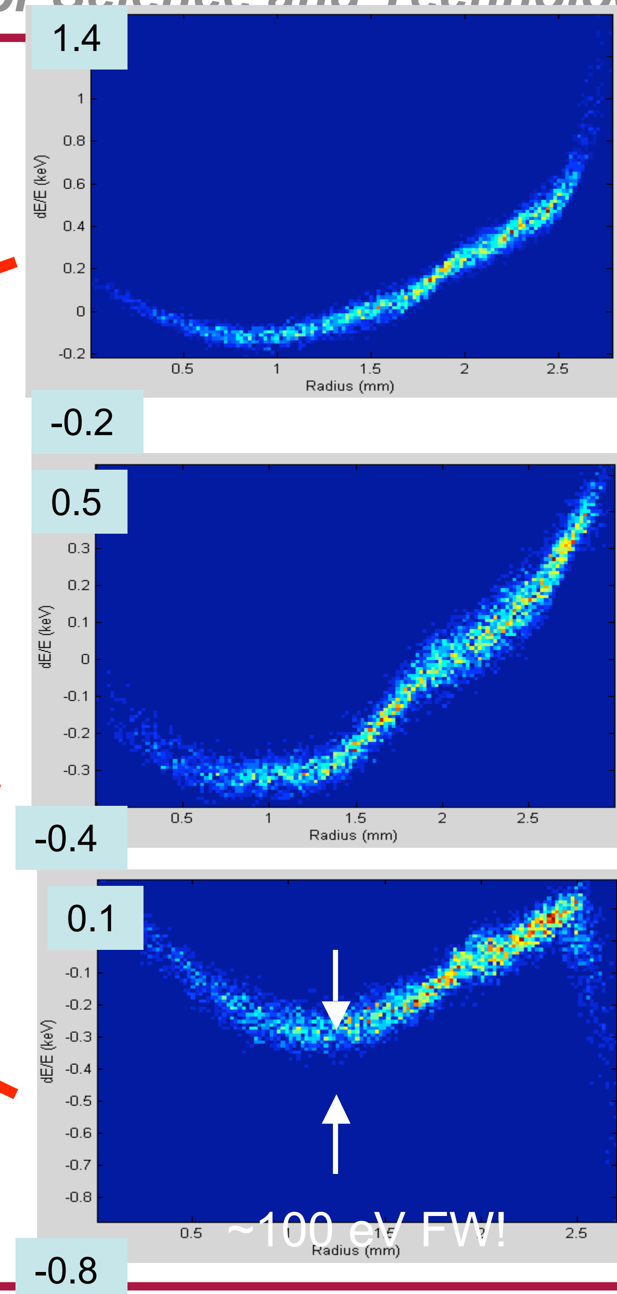
Energy vs time for 300 pC ellipsoidal bunch.

Energy vs time for 100 pC ellipsoidal bunch.

dE/E reduced factor of 6

Lower charge (100 pC) balances RF correlation with space charge. Generates ultra-low dE/E.





3 profiles show dE/E vs radius for the 3 short time slices above.

Summary

•Seeded FELs require constant current and energy spread for optimum performance.

•Ellipsoidal bunch distribution produces linear correlation of energy and time. Substantially improved over flat-top bunch.

•For thin time slices, all distributions show a strong correlation of energy with radius. Interesting new dynamics to study.

- RMS dE/E ~ 100 eV when radial correlation removed
- Slope of correlation due to radial variation of RF field is opposite to that of space charge for ellipsoidal bunch
- Slope of radial correlation for flattop bunch reverses sign from head to tail