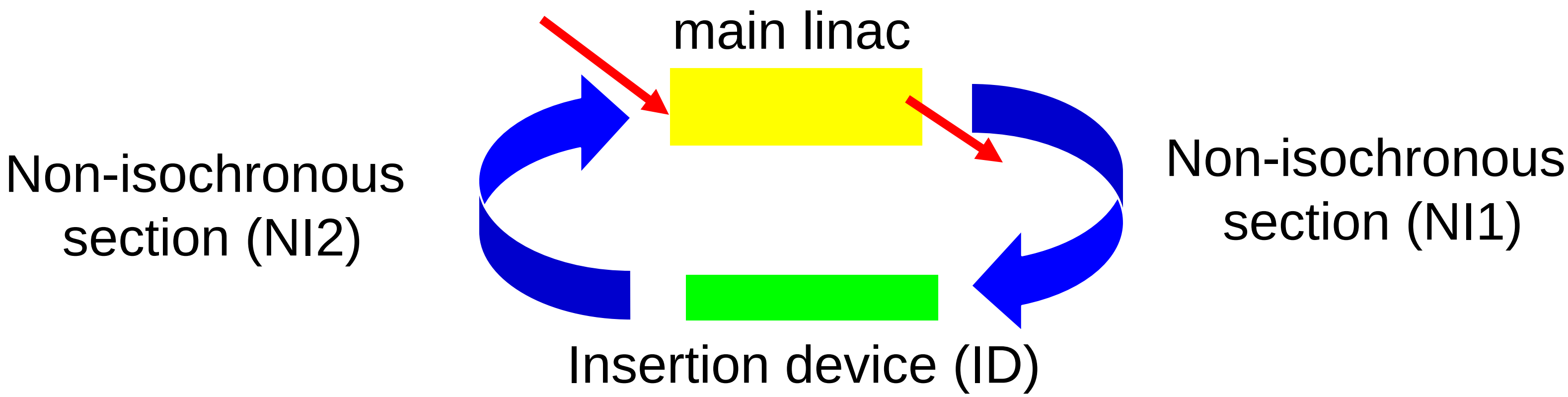
Longitudinal phase space manipulation at high and medium energy

- Generic energy recovery linac:



- Injector ⇨ main linac (accelerate beam) ⇨ NI1: prepare beam for ID requirement ⇨ NI2: re-inject beam into linac on decelerating phase

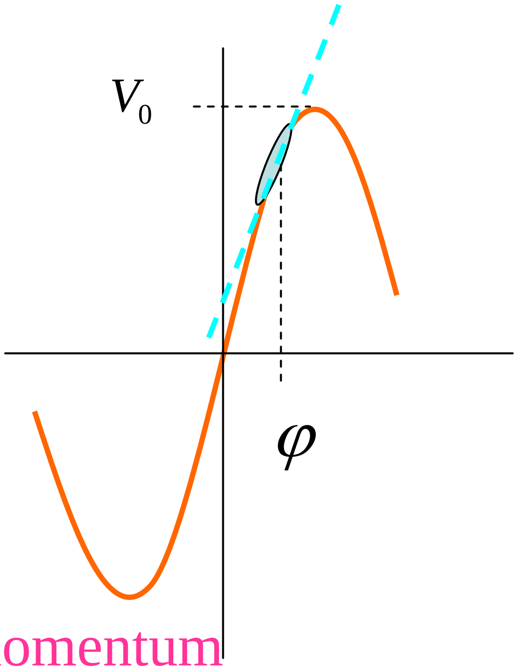
Linac to ID (linear theory)

- Energy time correlation:

$$E(z) = E_0 + eV_0 \cos(kz + \varphi)$$

$$\delta = \frac{eV_0}{E_0 + eV_0 \cos\varphi}\left[\cos(kz+\varphi) - \cos\varphi\right] = \kappa z + O(z^2)$$

chirp: $\kappa \equiv \frac{d\delta}{dz} = \frac{-keV_0}{E_0 + eV_0 \cos\varphi}\sin\varphi$



- Bunch compressor

1st order momentum compaction

$$z_f = z_i + R_{56}\delta_i$$

- Final bunch length and energy spread (1st order):

$$\sigma_{z,f} = \sqrt{(1+\kappa R_{56})^2 \sigma_{z,i}^2 + R_{56}^2 \sigma_{\delta,i}^2 E_0^2 / E^2}, \sigma_{\delta,f} = \sqrt{\kappa^2 \sigma_{z,i}^2 + \sigma_{\delta,i}^2 E_0^2 / E^2}$$

Min bunch length

getting very small at high energy!

Linac to ID (nonlinear effects)

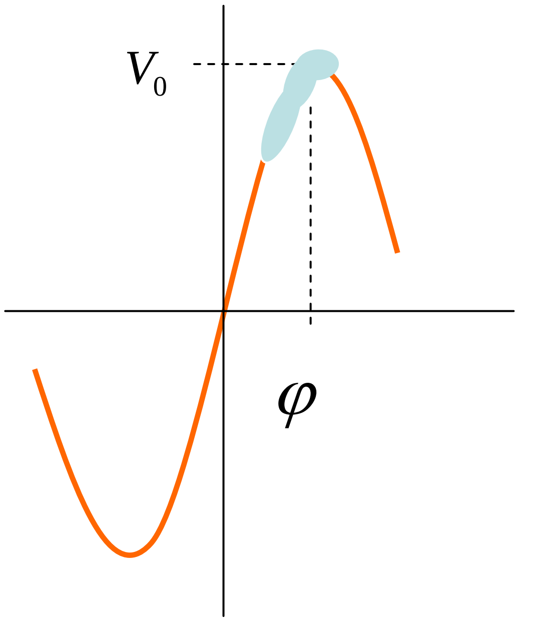
- Energy time correlation:

$$\delta = \kappa z + \mu z^2 + O(z^3)$$

- Bunch compressor

$$z_f = z_i + R_{56}\delta_i + T_{566}\delta_i^2$$

- Final bunch length is minimized if



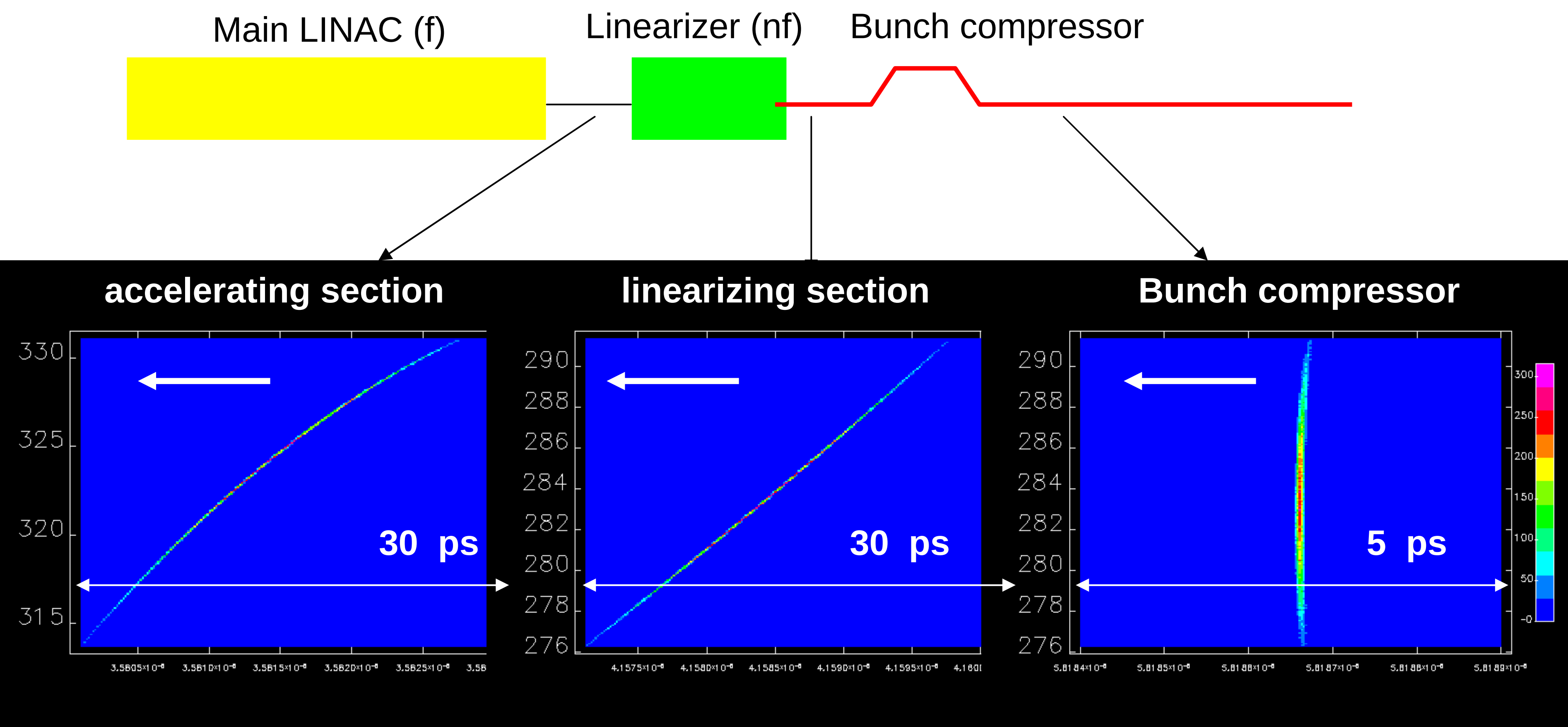
$$0 = z_i(1+\kappa R_{56}) + z_i^2(\mu R_{56} + \kappa^2 T_{566})$$

Limit achievable minimum Bunch length

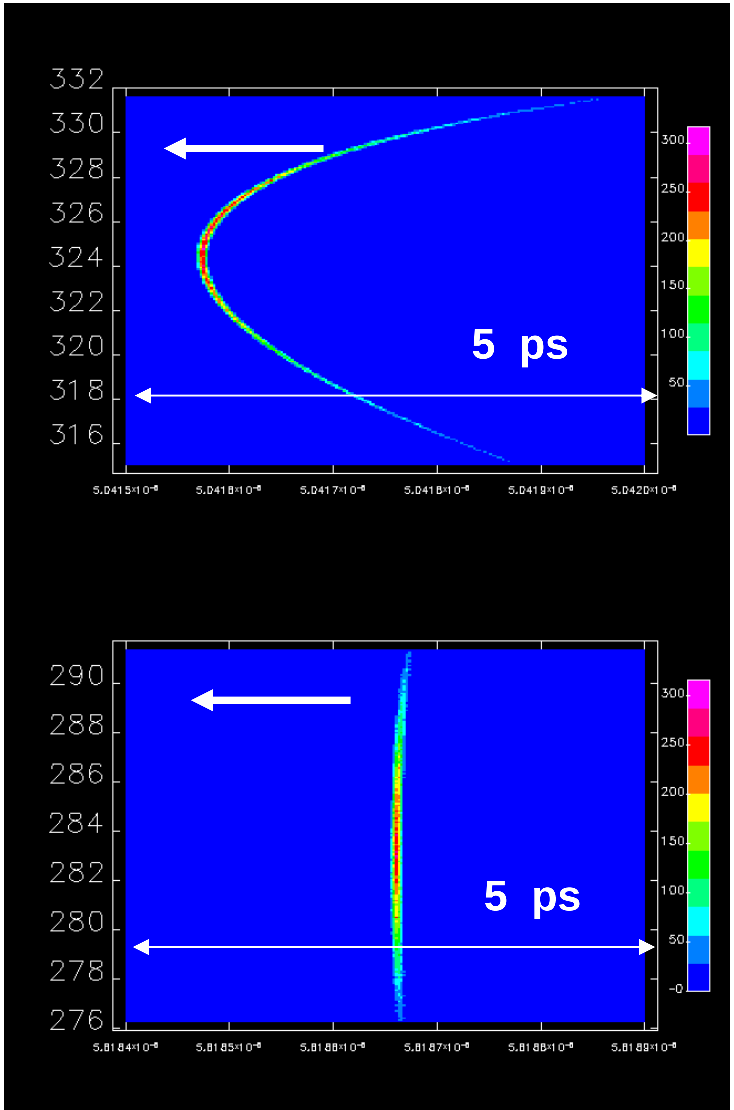
2nd order momentum compaction

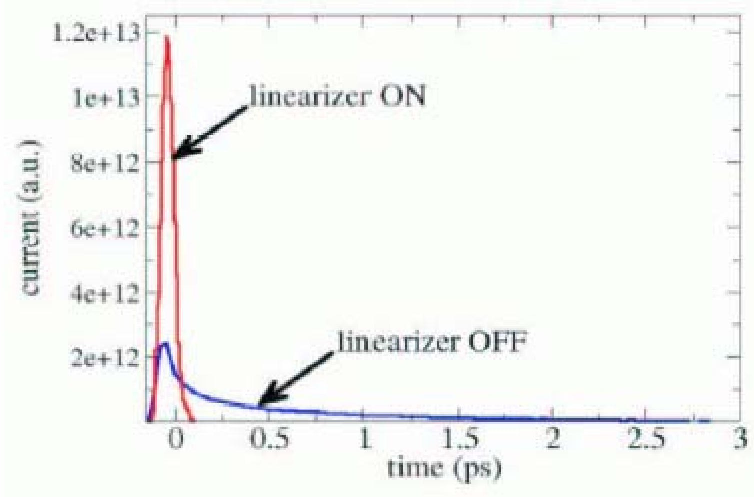
Higher order effects: pulse control

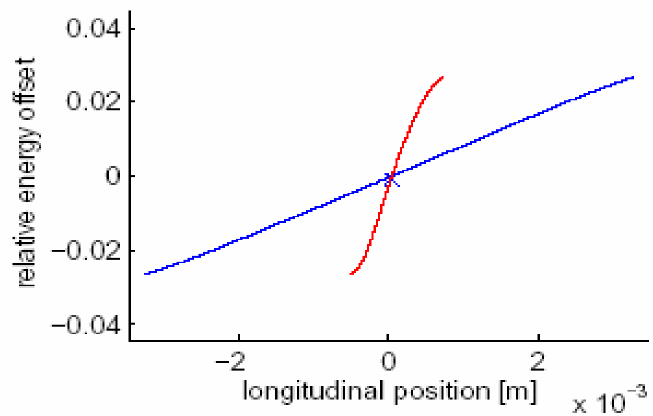
- Correction with higher harmonic rf-field provide two independent knobs (κ and μ parameters to minimize σ_z given R_{56} and T_{566}),
- sextupoles to some extent also provide these knobs



Higher order effects: pulse control

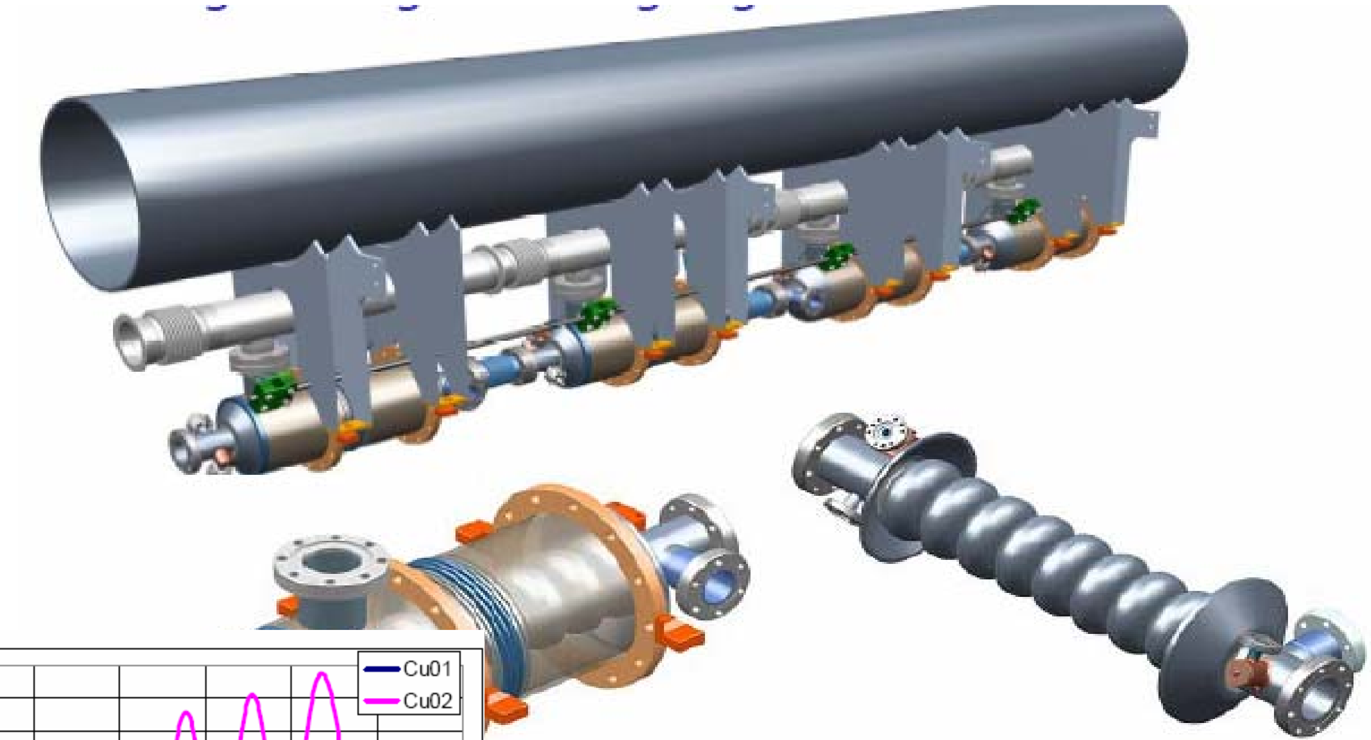


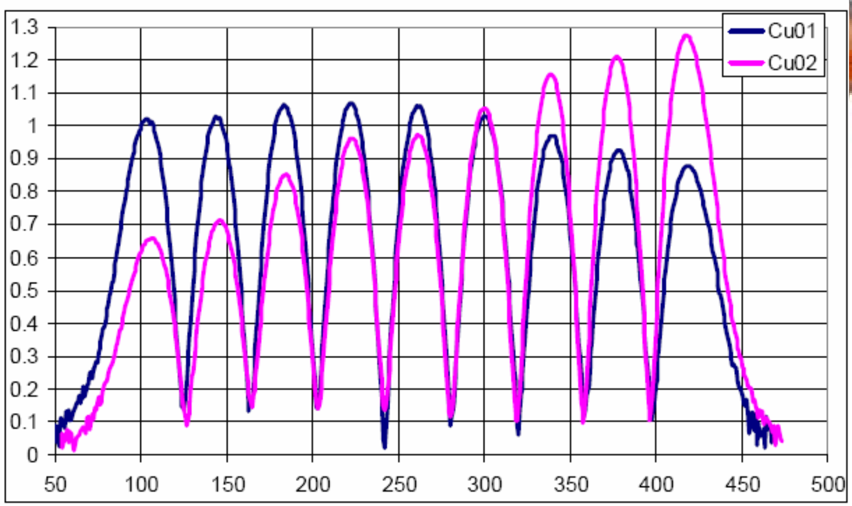




- A third harmonic (3.9 GHz) SCRF cavity is being built at FNAL (Solyak, LINAC 2004)

Higher order effects: 3.9 HZ harmonic cavity

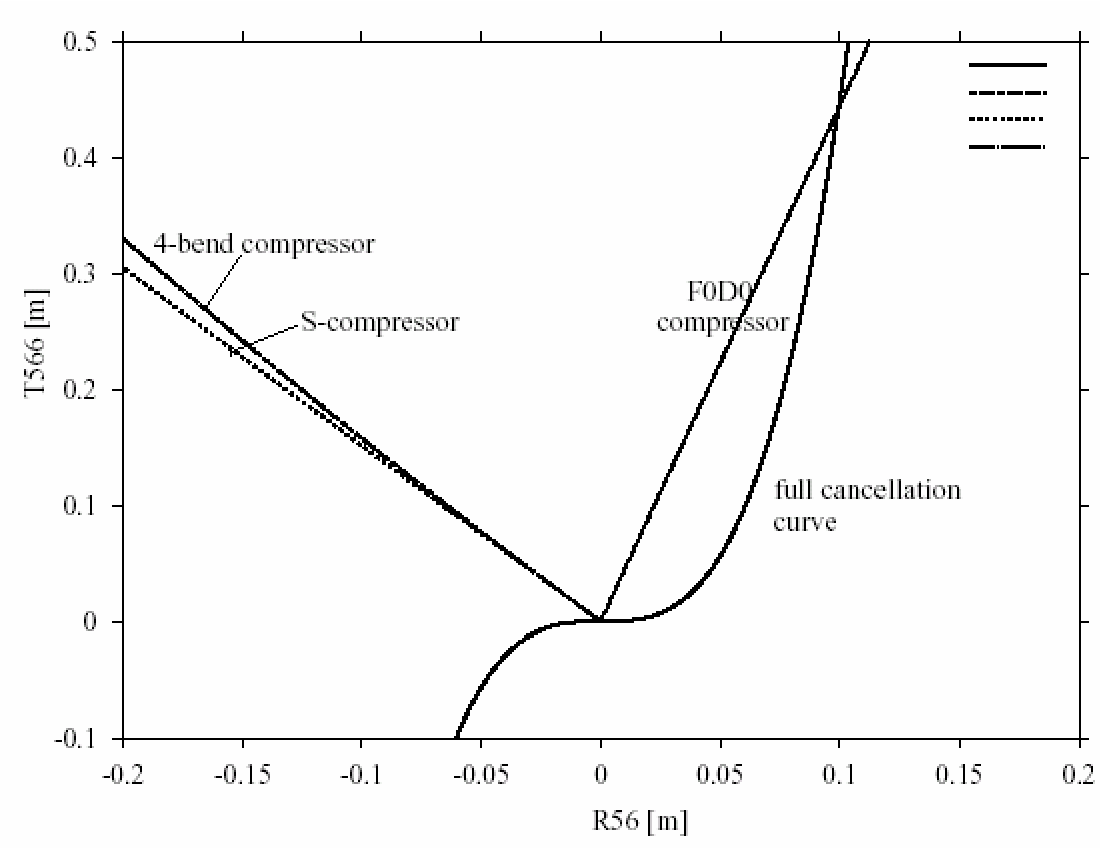




(Solyak, LINAC 2004)

Higher order effects: pulse control

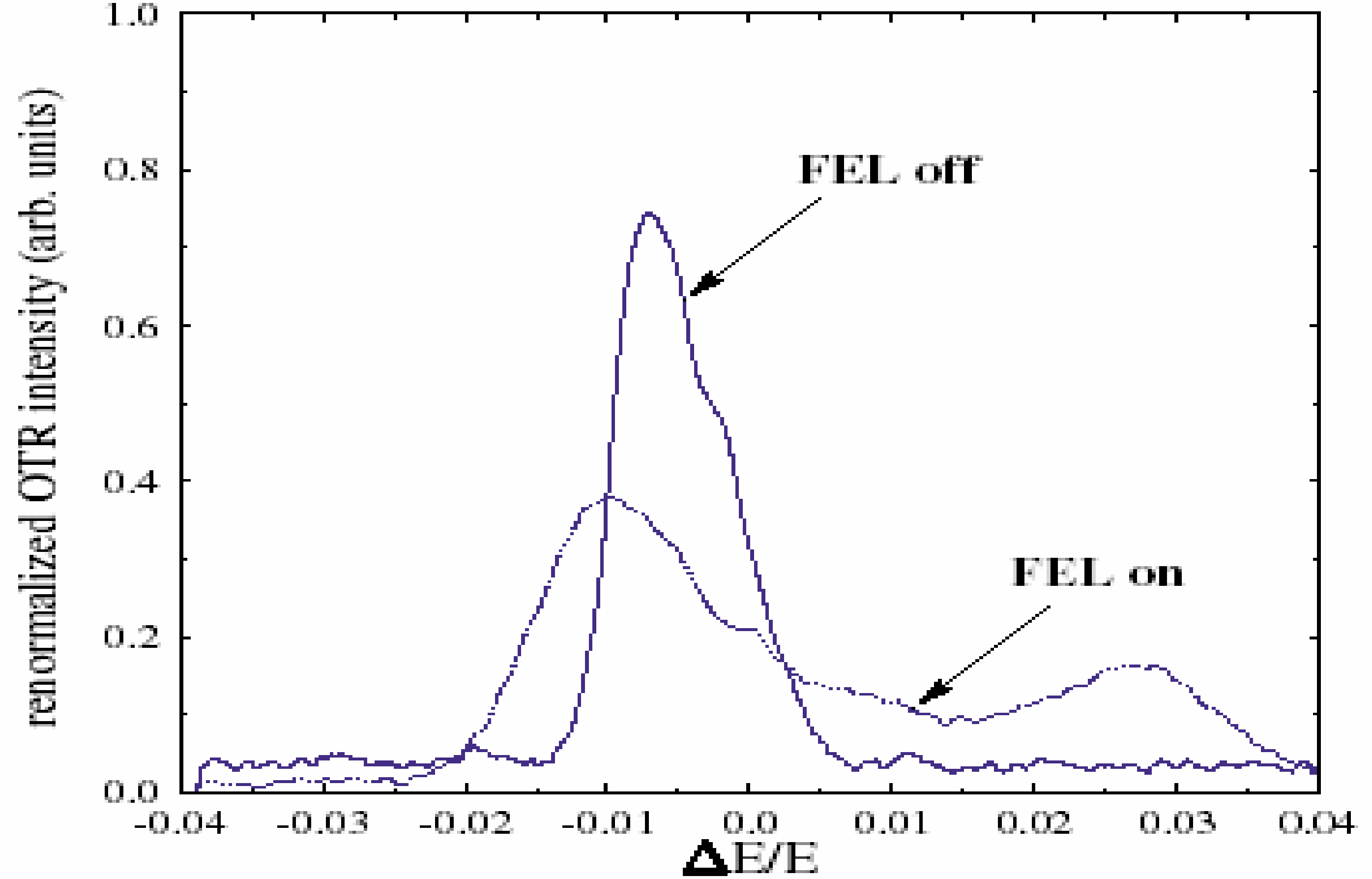
- Sextupoles, to some extent, also provide these knobs
- But coupling between longitudinal and transverse phase space is introduced



- Chicane
  $R_{56}<0$, $T_{566}>0$
- S-chicane
  $R_{56}<0$, $T_{566}>0$
- F0D0 arc
  $R_{56}>0$, $T_{566}>0$

Effect of FEL interaction

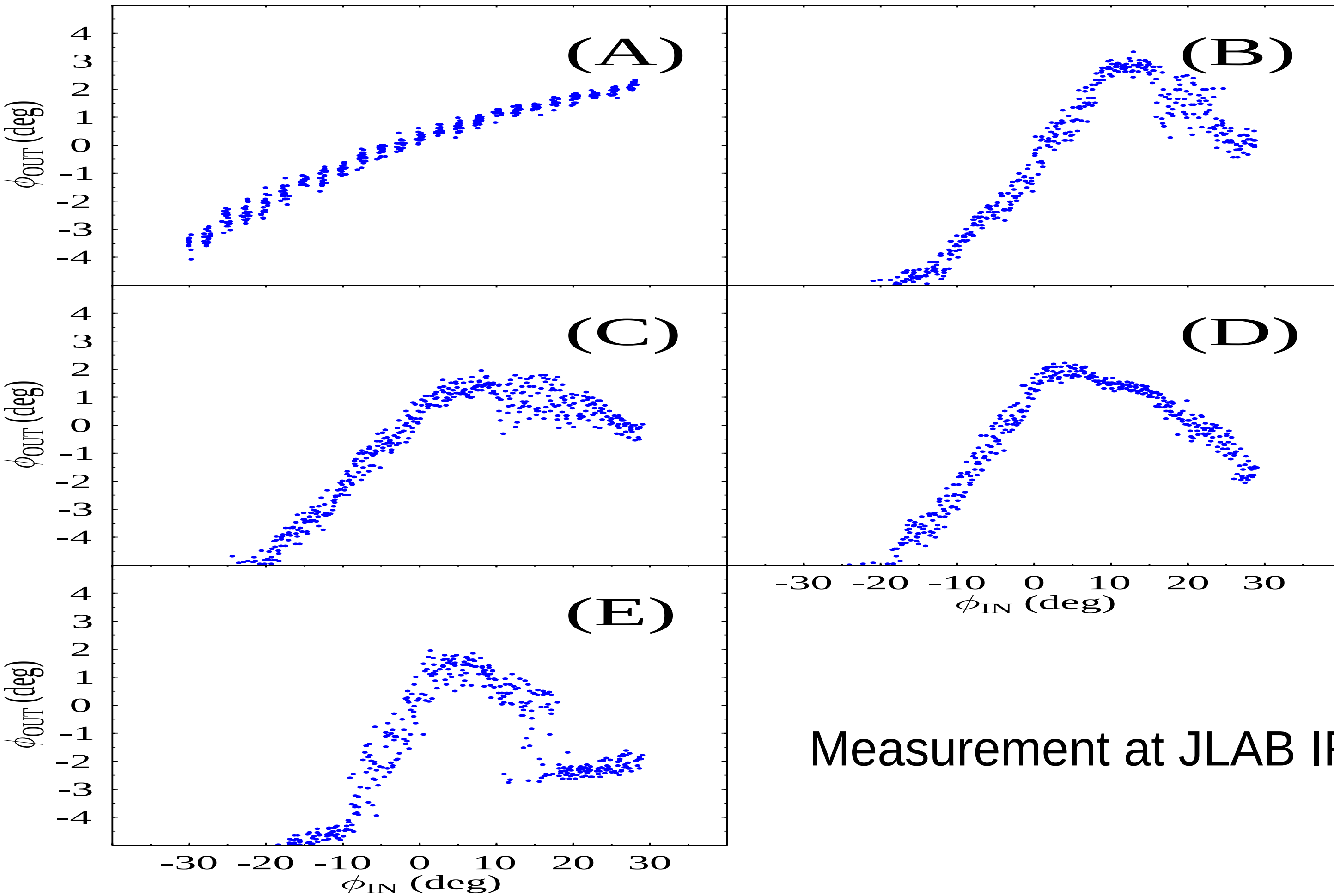
- Increase in uncorrelated momentum spread



Measurement at JLAB IR-DEMO

Effect of FEL interaction

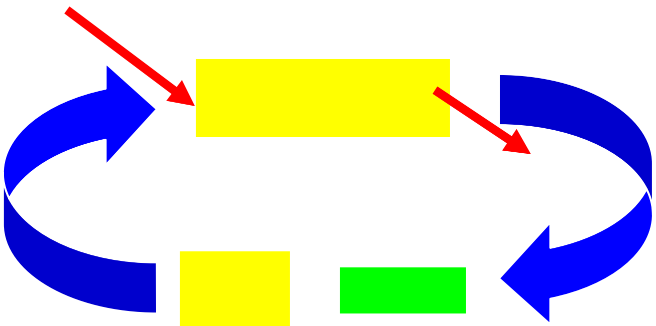
- Change in time-of-flight?



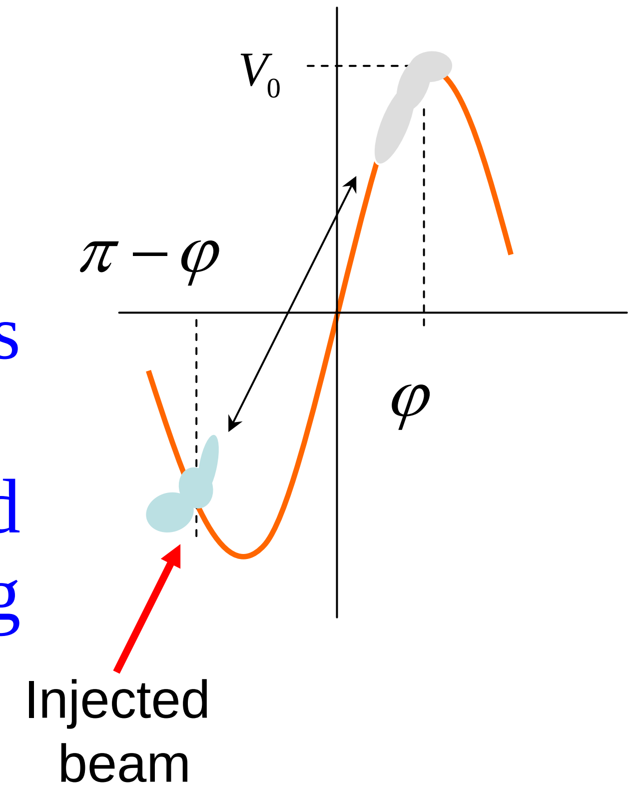
Measurement at JLAB IR-DEMO

Energy recovery

- Recirculation optics ⇨ match longitudinal phase space to slope of decelerating linac
- Need again to match slope and curvature

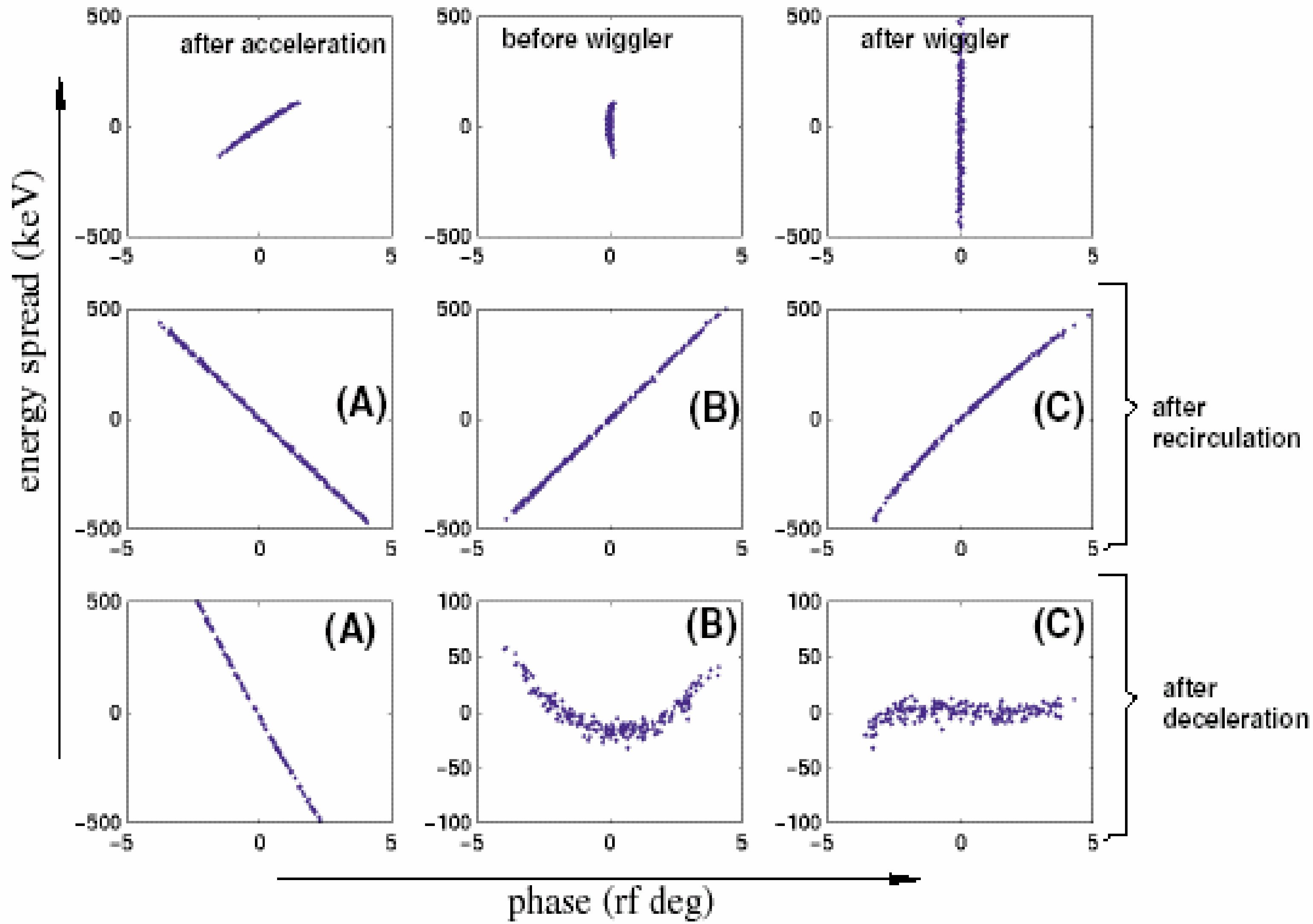


- Full recirculation loop is generally isochronous,
- Possible to use a dedicated cavity operated at zero crossing in the loop

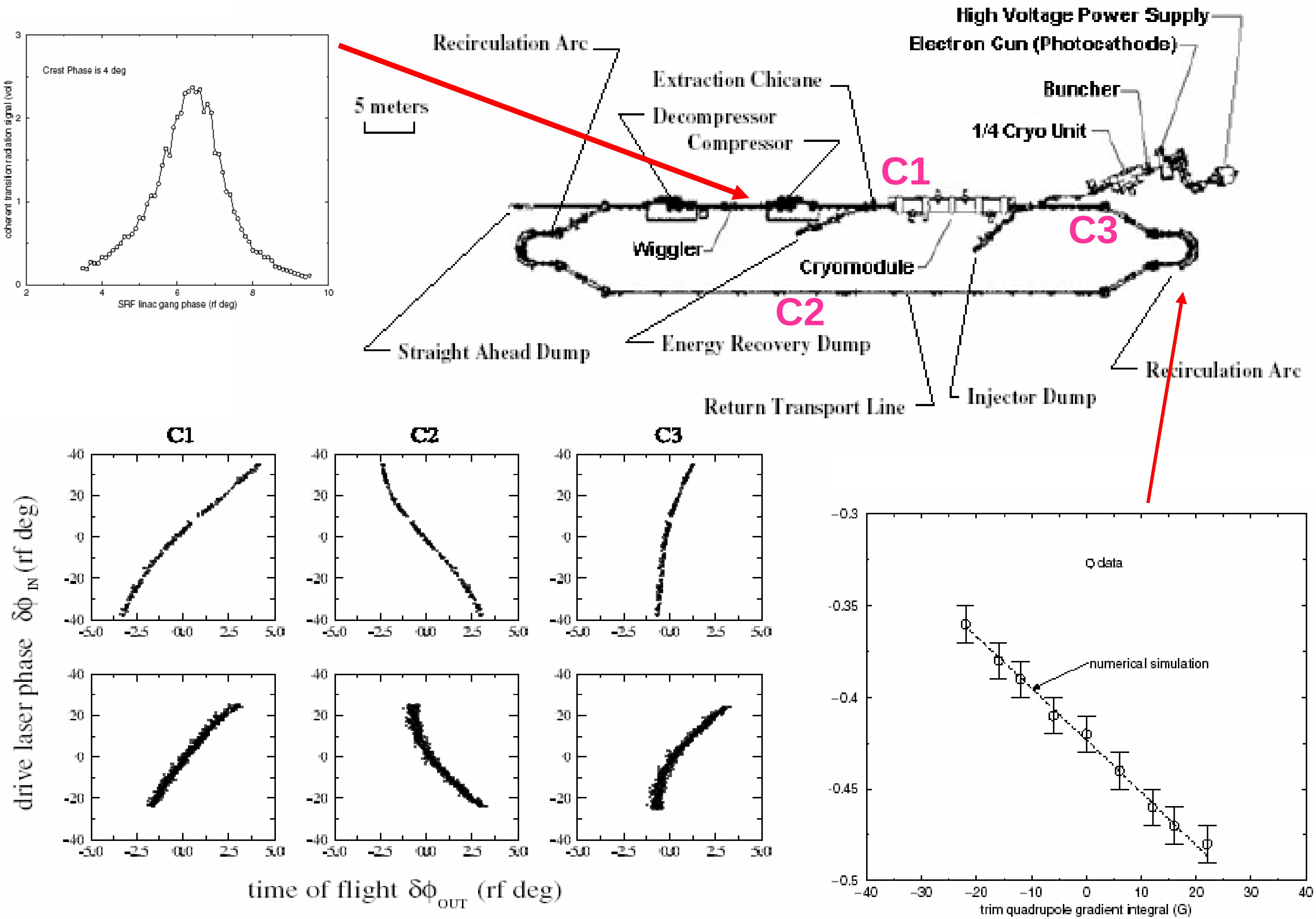


Energy recovery

- Recirculation optics ⇨ match longitudinal phase



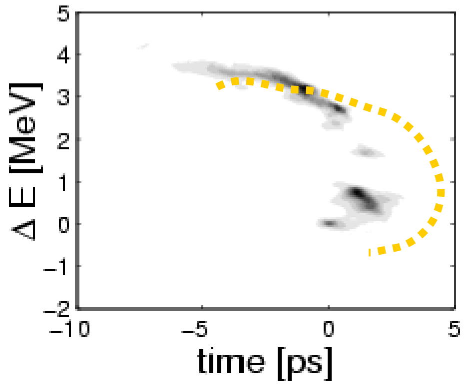
Example JLab IR-demo

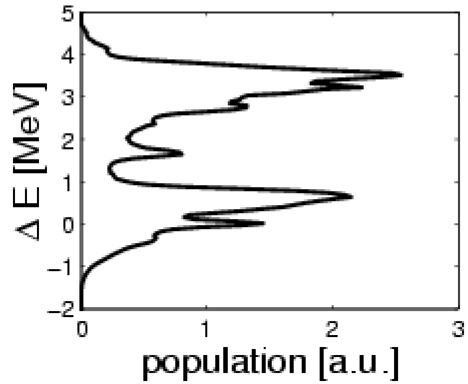


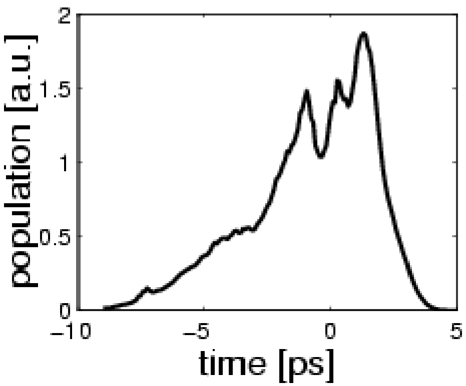
comments

- Don’t want to compress to hard

$$\sigma_{z,f} = \sqrt{(1+\kappa R_{56})^2 \sigma_{z,i}^2 + R_{56}^2 \sigma_{\delta,i}^2 E_0^2 / E^2}$$







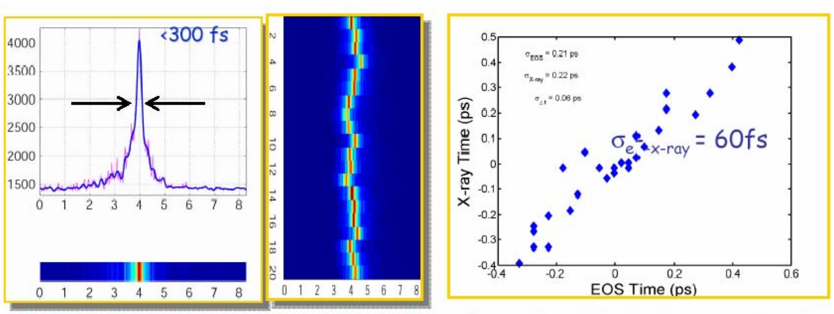
Measurement of longitudinal phase-space via tomo-graphic technique

(M. Huening, et al FEL’2000)

- Parasitic time of flight measurement using EO imaging?

Femtosecond x-ray stopwatch

A. Cavalieri, D. Fritz, S. Lee, P. Bucksbaum, D. Reis and SPPS Collaboration



Single-Shot Electron Beam Timing Jitter (20 timing measurement shots)

Strong Correlation between measured Electron Beam and X-ray beam timing