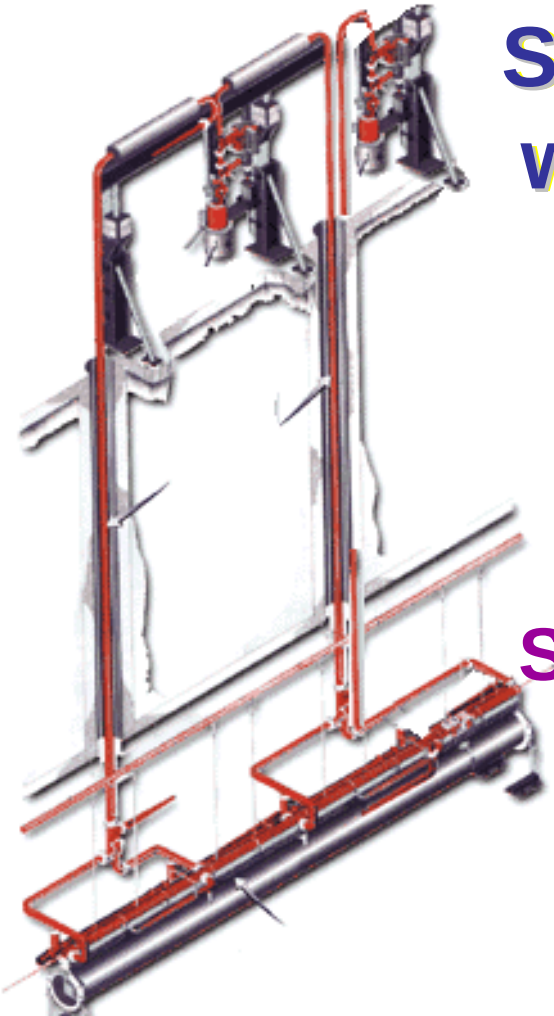
ERL 2005



Slice Parameter Measurements with RF Transverse Deflecting Cavities

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Issues

- Design parameters for RF power, length and wavelength for a specified resolution
- Measurement examples of longitudinal profile, slice emittance and slice energy spread
- Implementation and installation issues
- Modes of operation and triggering
- RF tolerance specifications
- Beam-based RF phase stabilization
- Calibration
- Image acquisition and controls integration

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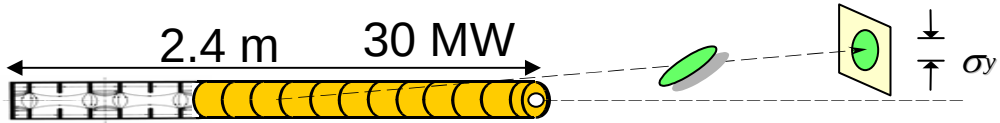
Bunch Length Measurements with the RF Transverse Deflecting Cavity

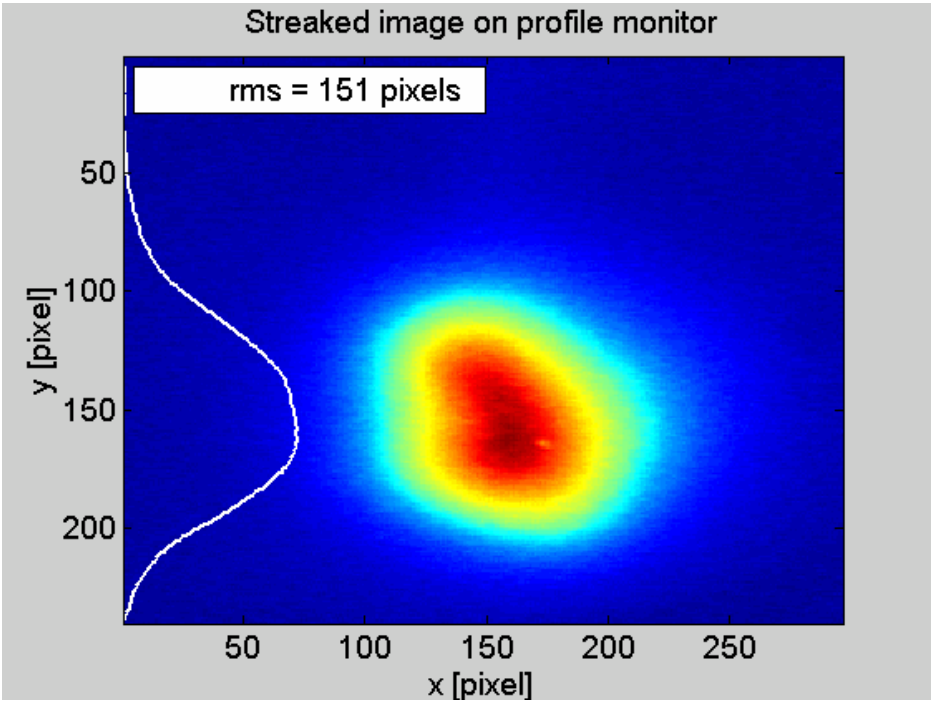


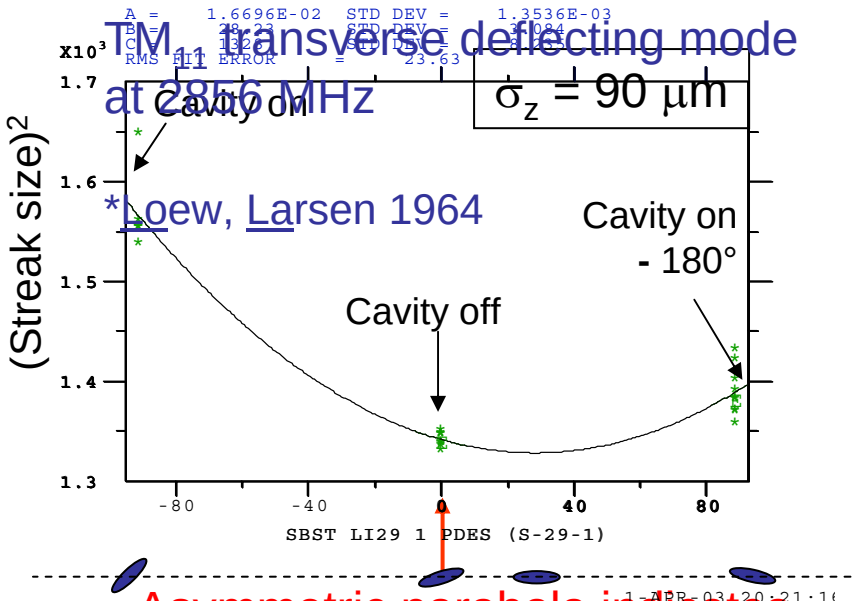
Bunch length reconstruction
Measure streak at 3 different phases

LoLa*

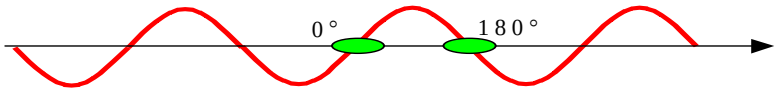
$$\sigma_y^2 = A\phi_{rf}^2 + B, \quad \sigma_z = \frac{\lambda_{rf}\sqrt{A}}{4C}$$

An S-band DLW structure with a TM_{11} transverse deflecting mode at 2856 MHz





*Loew, Larsen 1964



Asymmetric parabola indicates incoming tilt to beam

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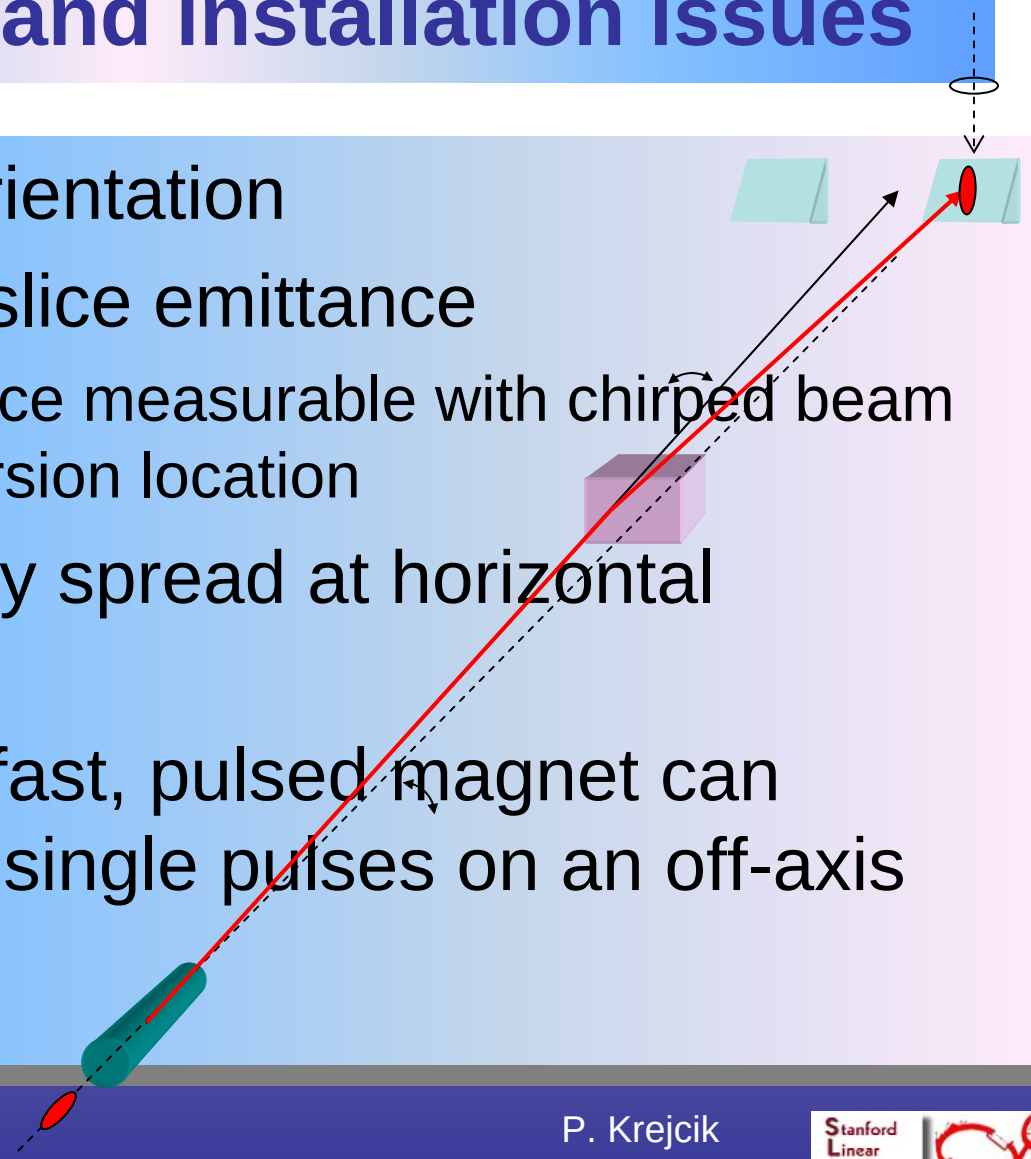
Implementation and installation issues

- Vertical deflection orientation
- Measure horizontal slice emittance
  - Vertical slice emittance measurable with chirped beam and horizontal dispersion location
- Measure slice energy spread at horizontal dispersion location
- In combination with fast, pulsed magnet can selectively measure single pulses on an off-axis screen



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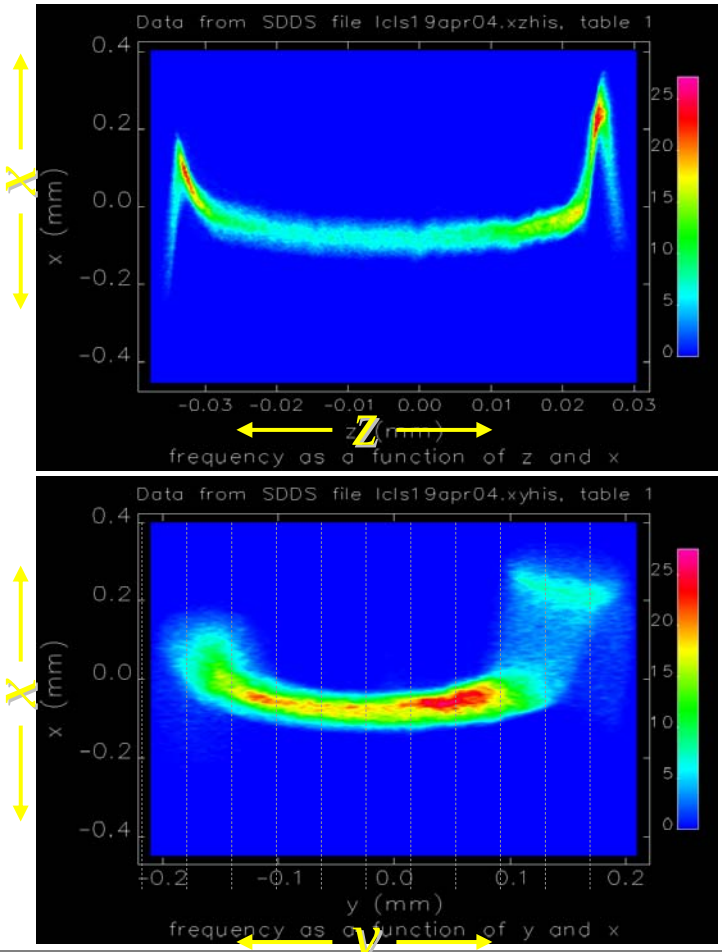
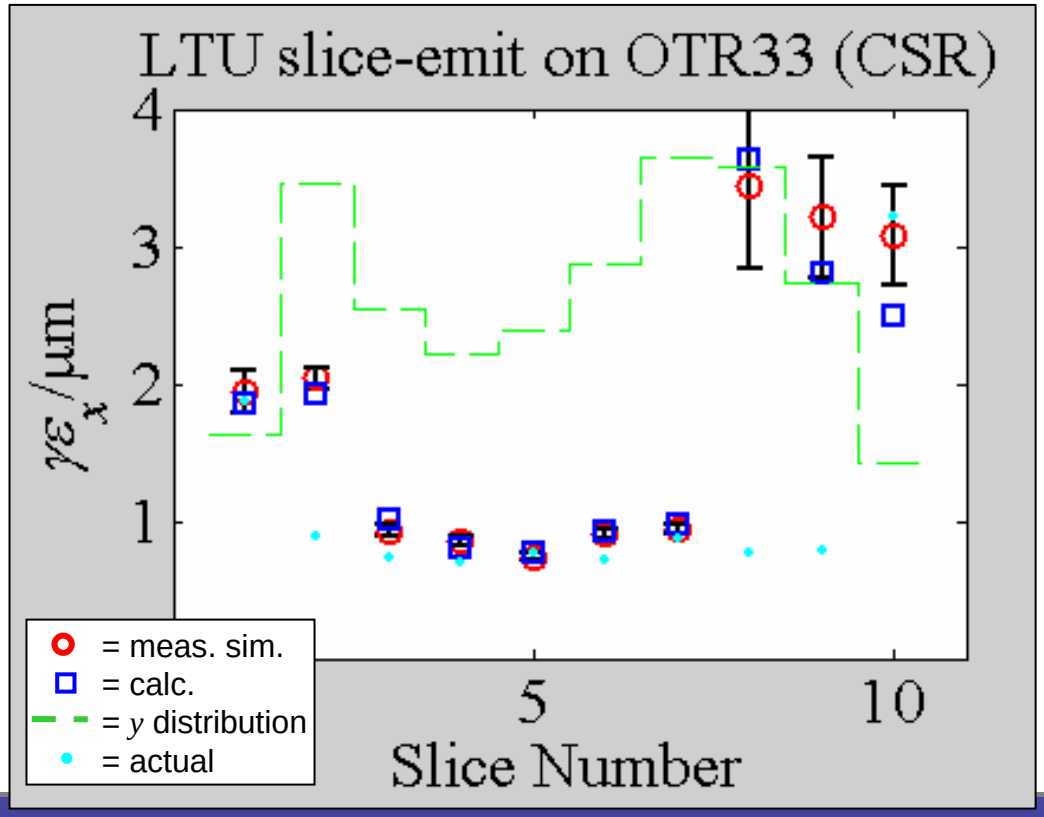
Slice-Emittance Measurements in LCLS

elegant simulation (M. Borland) courtesy P. Emma

3-screen method



LTU at 14 GeV with S-band RF-deflector at 24 MV



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Modes of operation and triggering

- Usually want it to be active on a small fraction of the bunches
- Normal conducting structure has a fill time of a few microseconds
  - For single pulse machines can intercept a single bunch
  - Otherwise in long pulse machines a bunch train will be deflected

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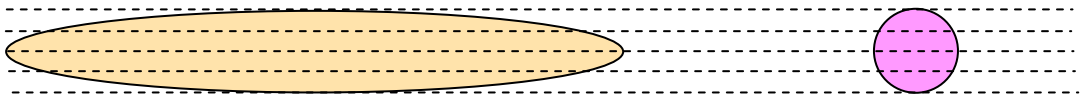
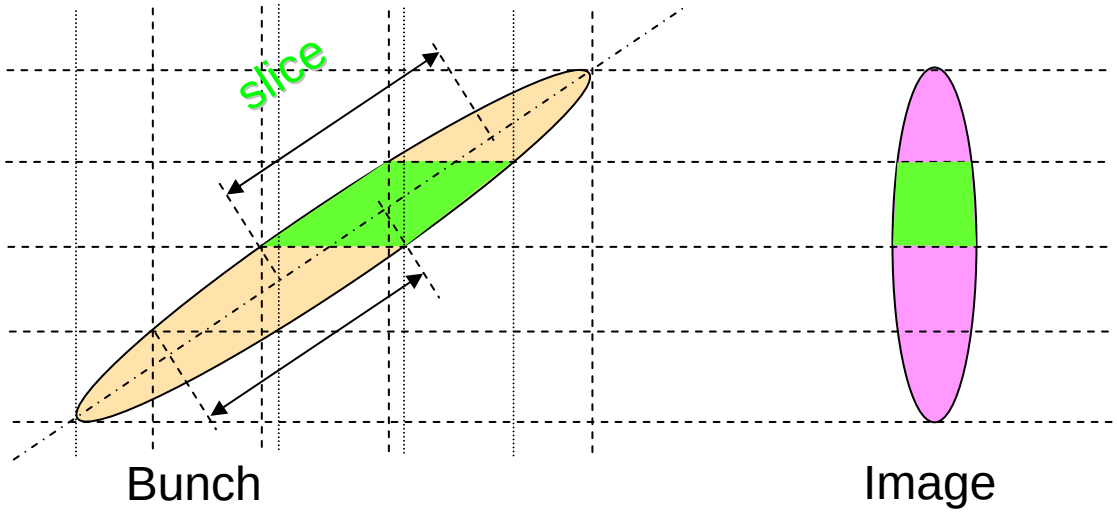
Slice resolution depends on TCAV amplitude

TCAV off



TCAV on



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Deflecting power and resolution

- For the SLAC S-band structure

$$V_0 \approx 1.6 L \sqrt{P_0} \left[MV/m/MW^{1/2} \right]$$

- Centroid deflection

$$\langle \Delta x \rangle = \frac{eV_0}{pc} \sqrt{\beta_d \beta_s} \sin \Delta\psi \sin \varphi$$

- Beam size

$$\sigma_x = \sqrt{\sigma_{x0}^2 + \sigma_z^2 \beta_d \beta_s \left(\frac{2\pi e V_0}{\lambda pc} \sin \Delta\psi \cos \varphi \right)^2}$$

- Requirement

$$|eV_0| \gtrsim \frac{\lambda}{\pi \sigma_z} \frac{1}{|\sin \Delta\psi \cos \varphi|} \sqrt{pc \cdot mc^2 \frac{\varepsilon_N}{\beta_d}}$$

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Typical operating parameters (LCLS)

RF deflector voltage	V_0	20	MV
RF deflector length	L	2.44	m
Peak input power	P_0	25	MW
RF deflector phase (crest at 90°)	φ	3.3	deg
Nominal beam size	σ_{x_0}	80	μm
Beam size with deflector on (two-phase mean)	σ_x	272	μm
Beta function at deflector	β_d	58	m
Beta function at screen	β_s	63	m
Betatron phase from deflector to screen	$\Delta\psi$	60	deg
Normalized rms emittance	ε_N	1	μm
Beam energy at deflector	E_d	5.4	GeV
Beam energy at screen	E_s	6.2	GeV

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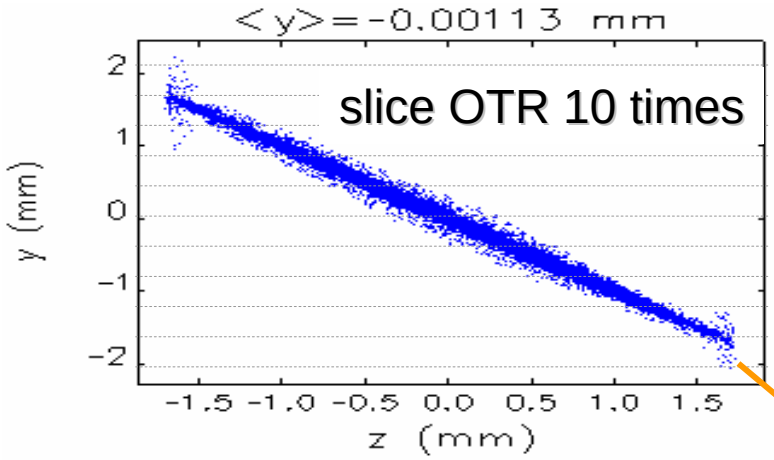
Slice-Emittance Measurement Simulation

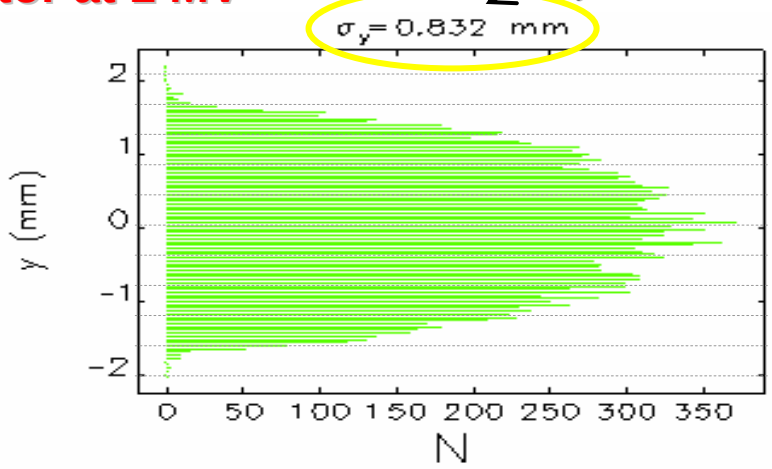
elegant simulation (M. Borland) courtesy P. Emma

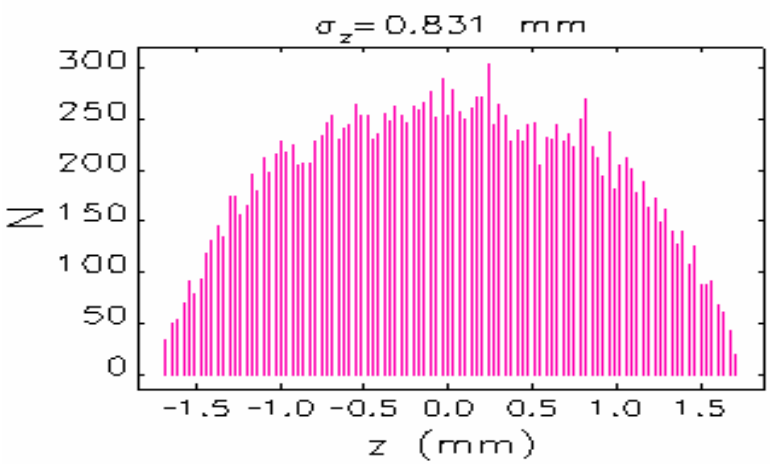
Quad can method:

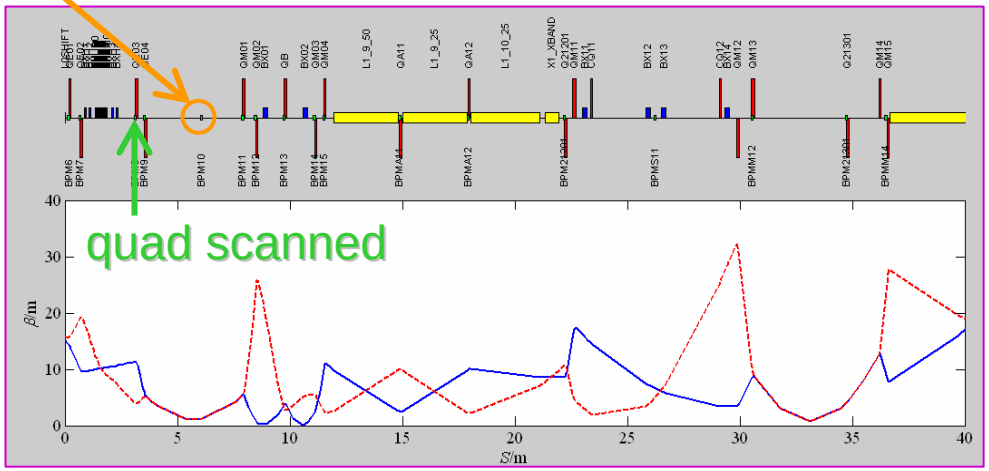
RF-deflector at 1 MV

$\sigma_y \approx$ bunch length









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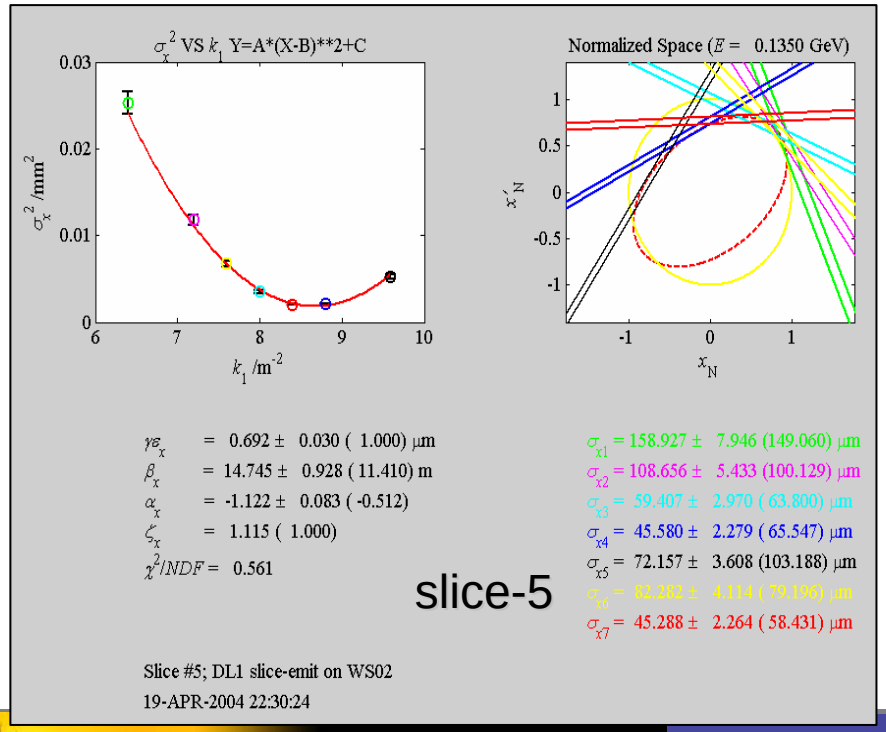
Slice-Emittance Measurement Simulation in the LCLS Injector

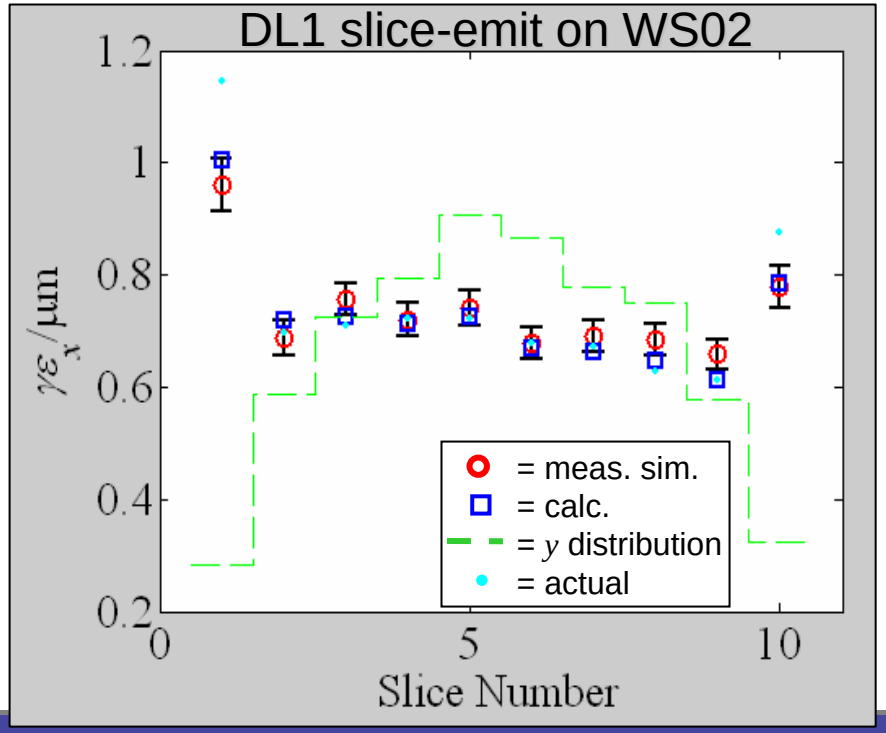
courtesy P. Emma

Injector at 135 MeV with S-band RF-deflector at 1 MV

(same SLAC slice-ε code used at BNL/SDL)

Slices have different emittance and phase space orientation





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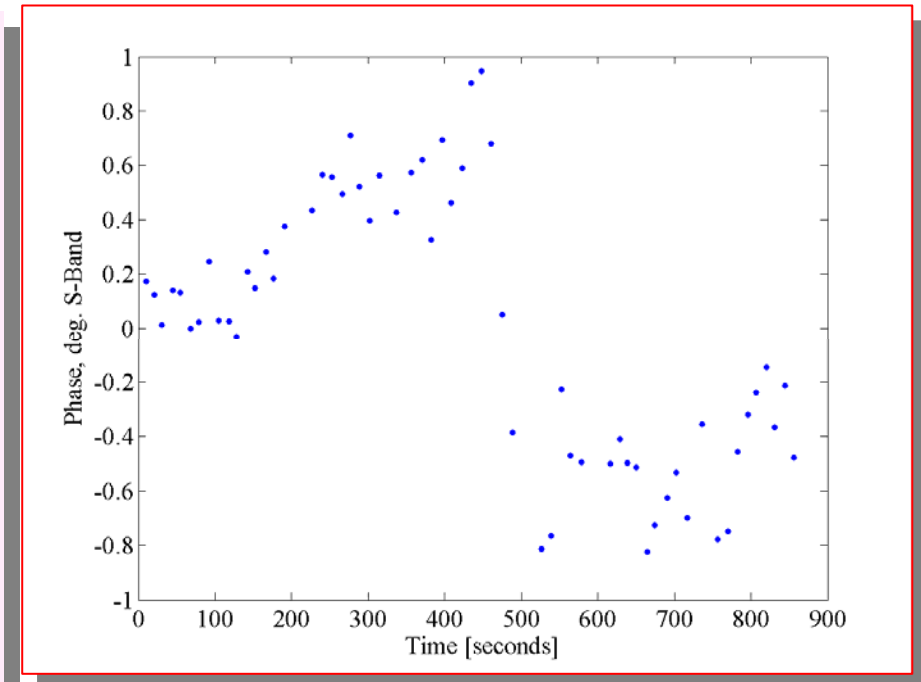
Invasiveness and RF tolerances

- Transverse aperture and screen size determine maximum usable beam deflection
- RF phase jitter causes position jitter
  - Acceptable if whole image is within field of view
- RF phase tolerance is about equal to the designed temporal resolution
  - e.g. if the beam is streaked sufficiently to resolve 10 fs, then the beam can't move by much more than 10 fs w.r.t. the TCAV RF phase



Phase deviations calculated from transverse kick measured by fitting BPM orbit downstream of cavity

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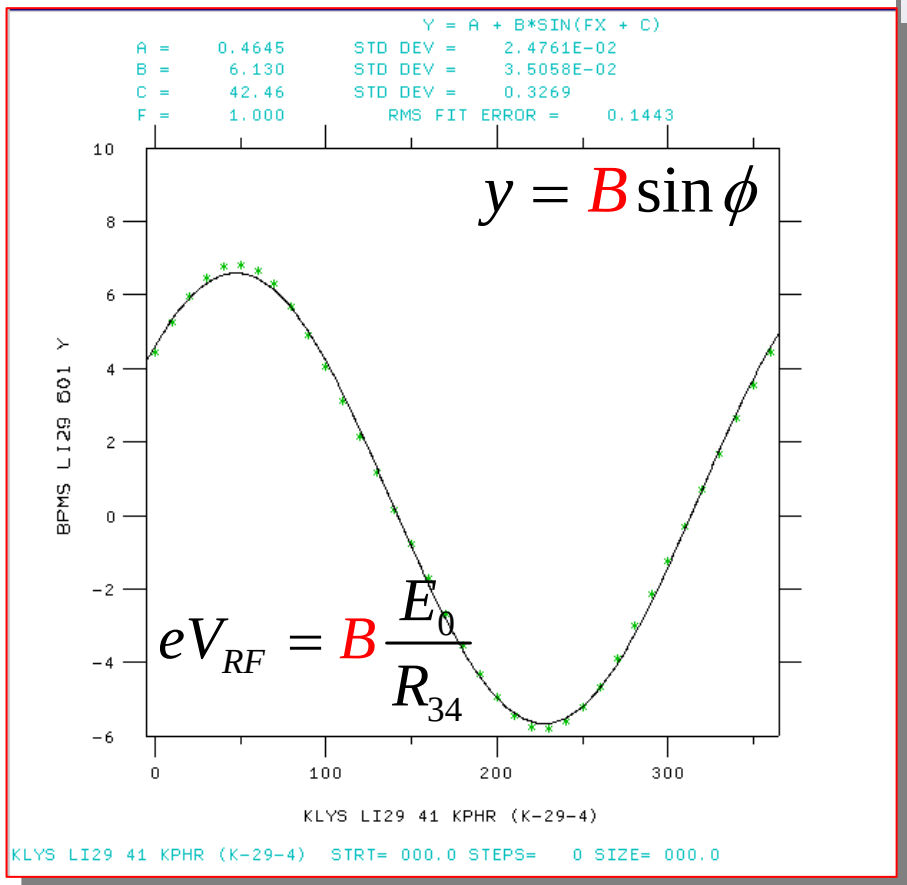
Beam-based RF phase stabilization

- At downstream BPM measure beam position versus phase of deflecting cavity
- "steering" feedback will recenter the beam using RF phase
- But change sign at other phase 0-crossing



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Controls integration

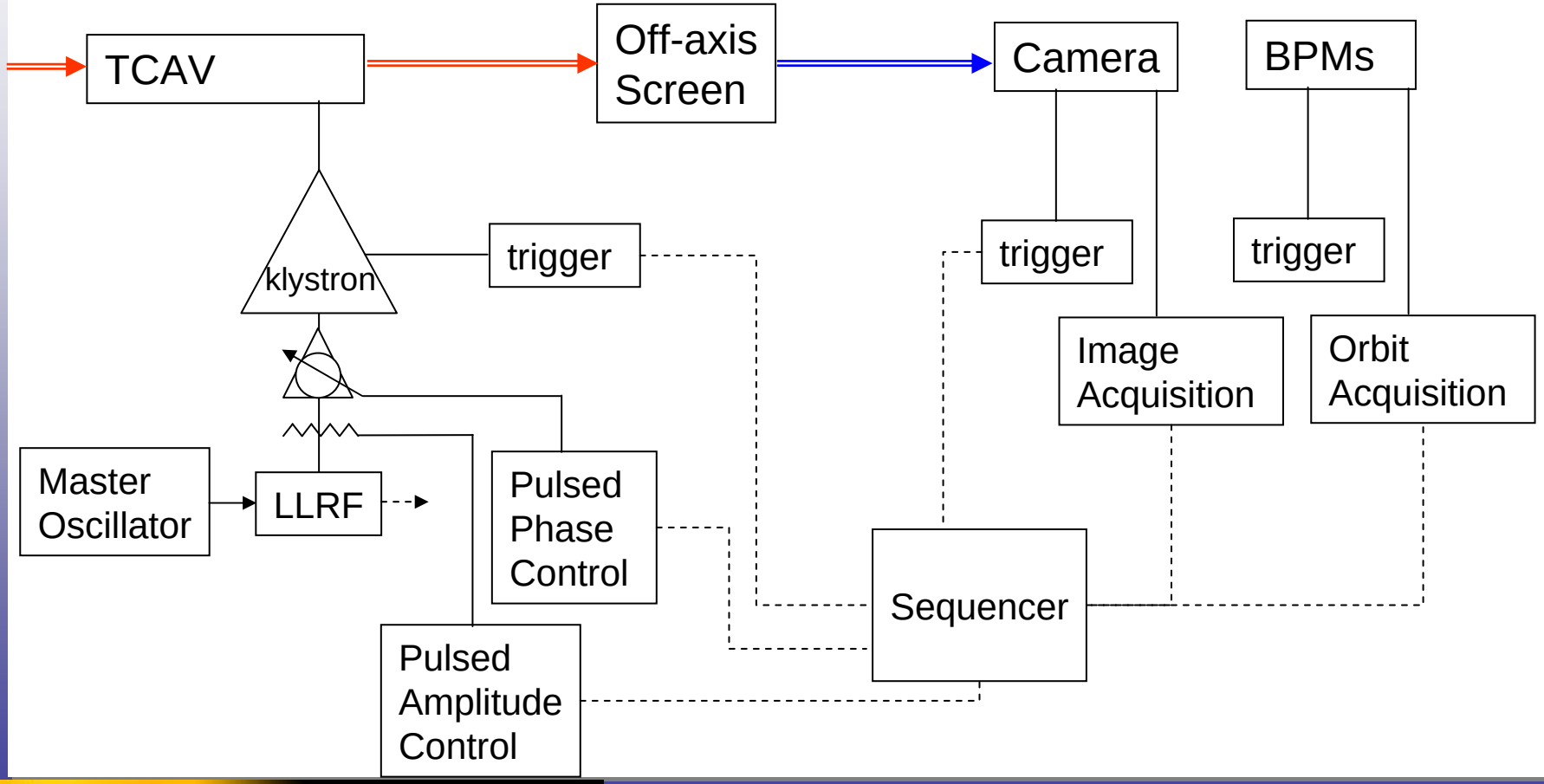

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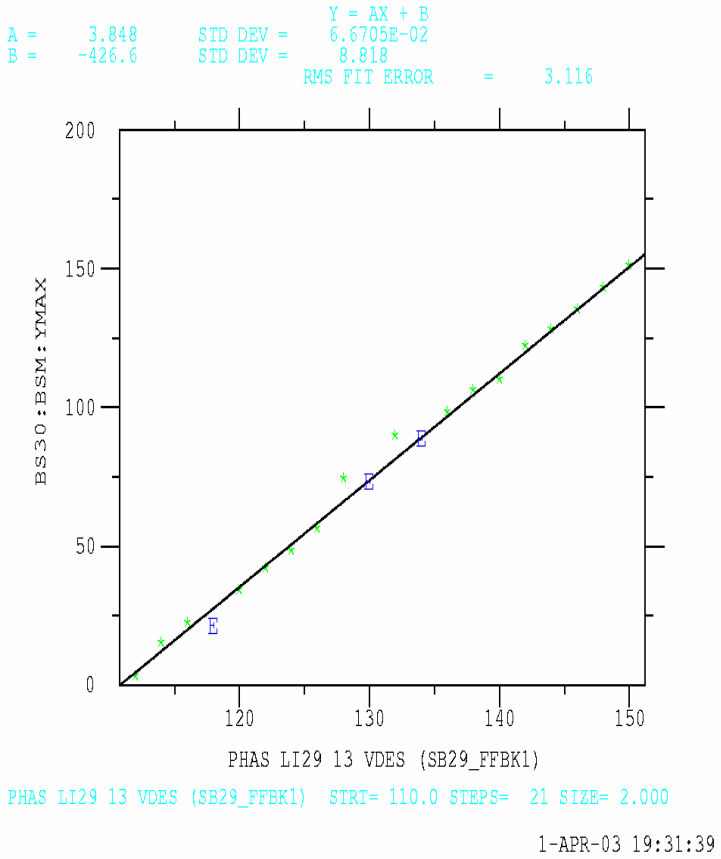
Image size calibration versus RF phase

- Plot centroid position in screen pixels versus phase of deflecting cavity
- Gives image size in longitudinal units
- Absolute calibration based on wavelength of S-band



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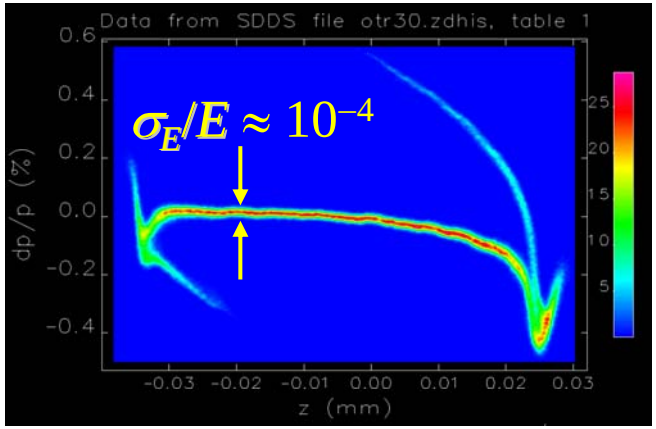
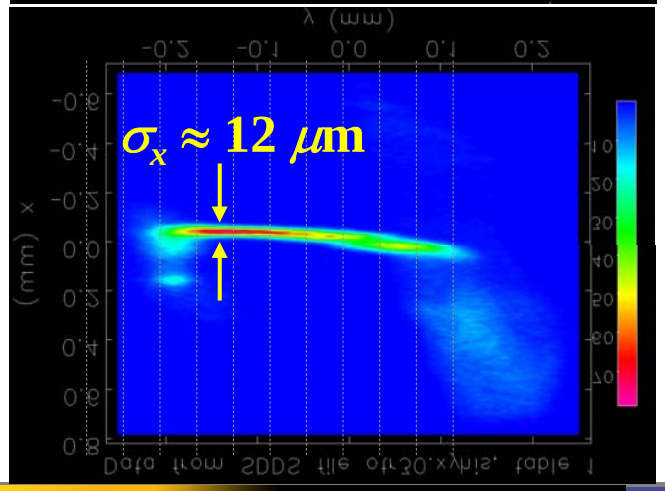
Slice Energy Spread Measurements in the LCLS

elegant simulation (M. Borland) courtesy P. Emma

Screen located at dispersive location, η_x=10 cm





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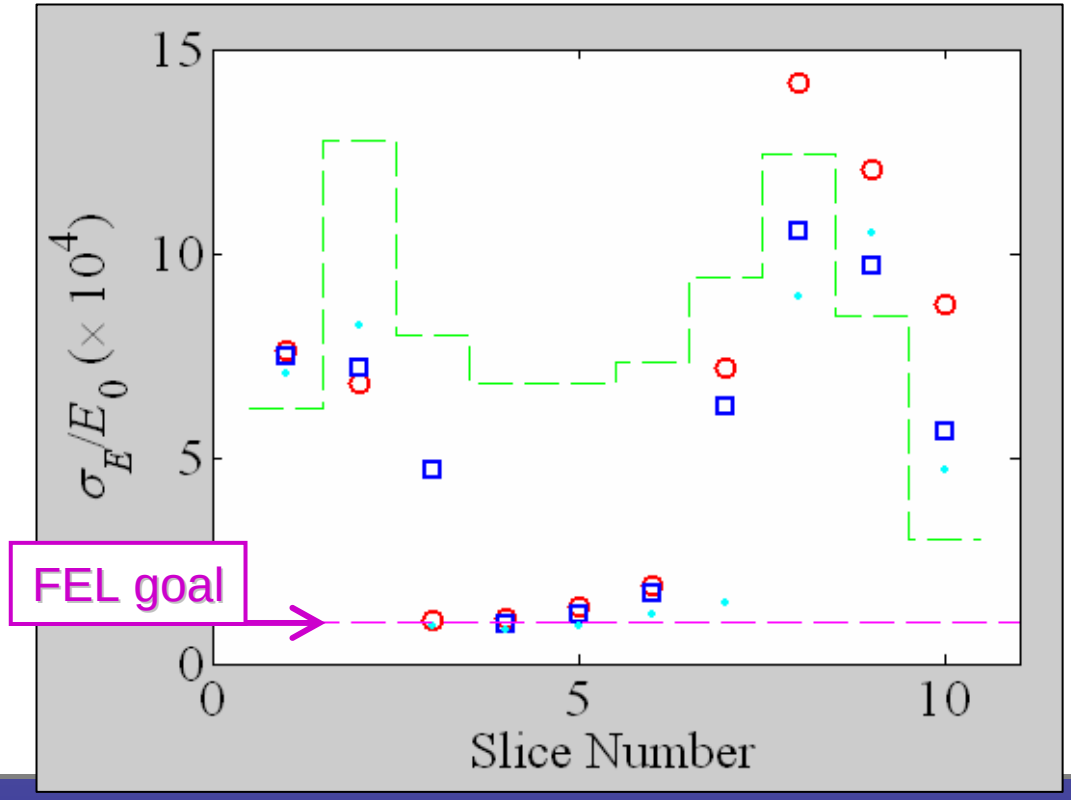

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