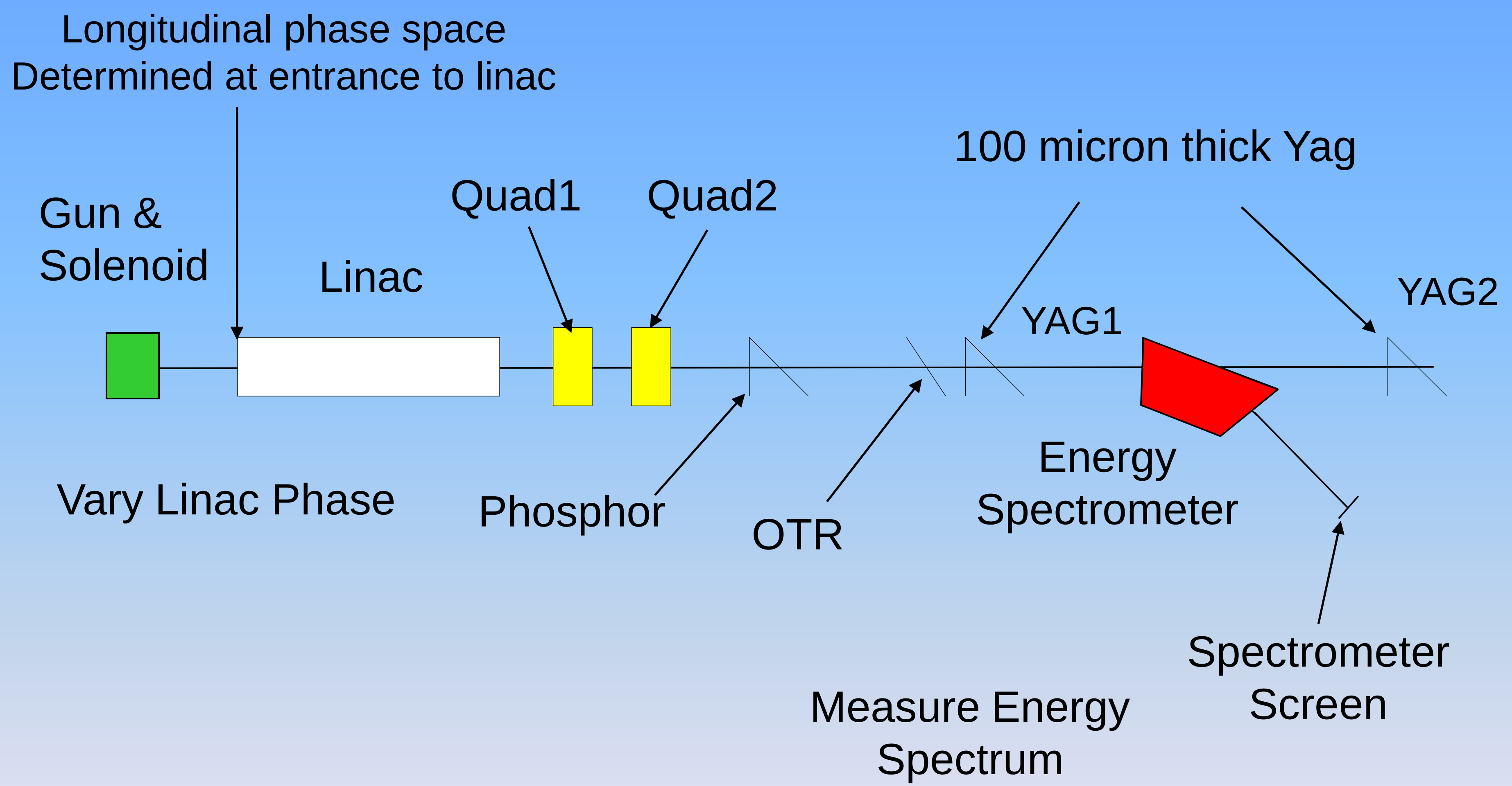
Lecture 10
Beam Diagnostics: Measuring the Longitudinal Phase Space Without a Transverse Cavity

•Description of the Experiment for measuring both the longitudinal and slice emittances
•Analysis technique of the data yields the longitudinal beam matrix and indicates a large correlated energy chirp out of the gun.
•A comparison of the measurements with simulations show the correlation comes from 0-π mode beating excited by the RF pulse.
•The technique of measuring the slice emittance by chirping the bunch energy combined with a quadrupole scan is described.

GTF Longitudinal Phase Space Measurements



GTF Diagnostics and Transport

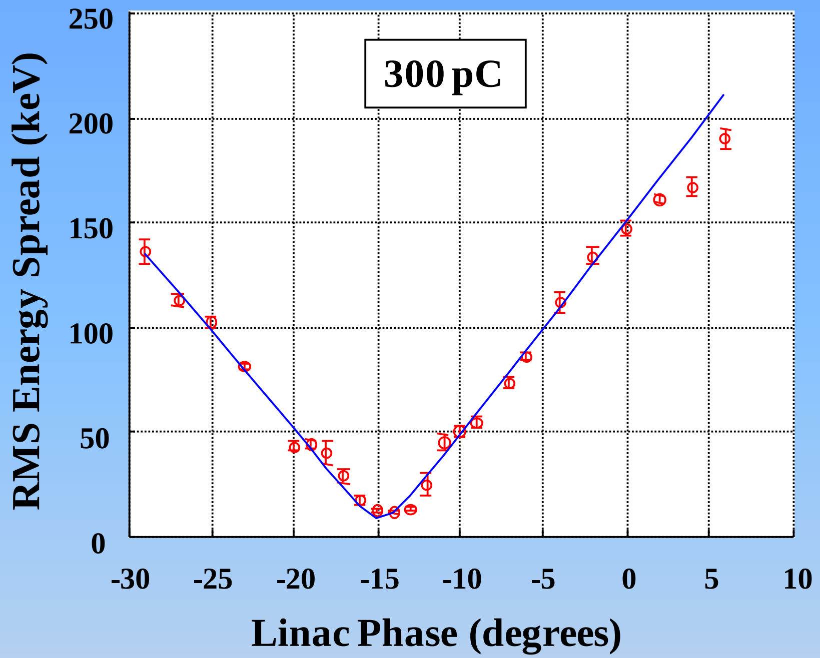
Analysis of Energy Spread vs. Linac Phase gives Longitudinal rms Parameters*

Symmetric longitudinal beam matrix:

$$\tau = \begin{pmatrix} \tau_{11} & \tau_{12} \\ \tau_{12} & \tau_{22} \end{pmatrix} \quad ; \quad \tau_{11} = \sigma^2_{t,\phi} \quad ; \quad \tau_{22} = \sigma^2_E$$

$$\tau(\text{spectrometer}) = R_{acc}\,\tau(\text{gun}+\text{drift})\,R^T_{acc}$$

$$R_{acc} = \begin{pmatrix} 1 & 0 \\ -E_{linac}\sin\phi_{linac} & 1 \end{pmatrix}$$



$$\tau(spectrometer) = \begin{pmatrix} \tau_{11} & \tau_{12} - \tau_{11}E_{linac}\sin\phi_{linac} \\ \tau_{12} - \tau_{11}E_{linac}\sin\phi_{linac} & \tau_{22} - E_{linac}\sin\phi_{linac}(2\tau_{12} - \tau_{11}E_{linac}\sin\phi_{linac}) \end{pmatrix}$$

$$\sigma_E(spectrometer) = \tau_{22} - E_{linac}\sin\phi_{linac}(2\tau_{12} - \tau_{11}E_{linac}\sin\phi_{linac})$$

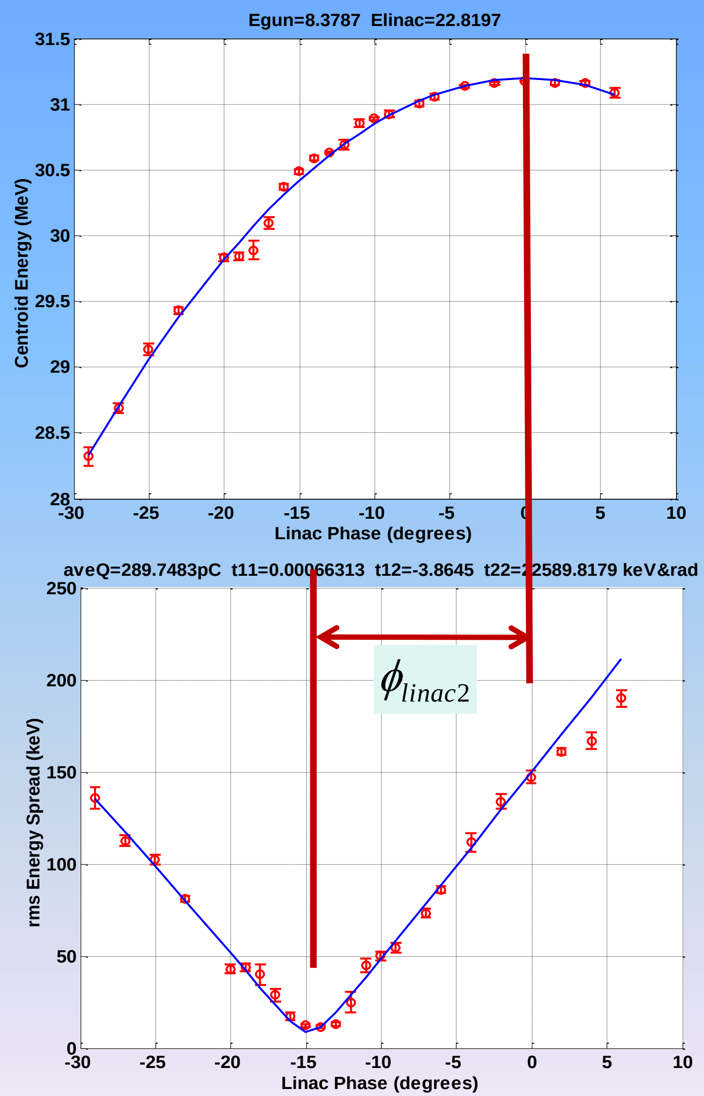
Find τ_{11}, τ_{12}, τ_{22} by fitting energy spread vs. linac phase

*D.H. Dowell et al., Nucl. Inst. Meth. A507(2003)331-334

Offset of Minimum Energy Spread from Maximum Energy Gain gives Chirp at Linac Entrance

Bunch energy vs. linac phase

Bunch energy spread vs. linac phase

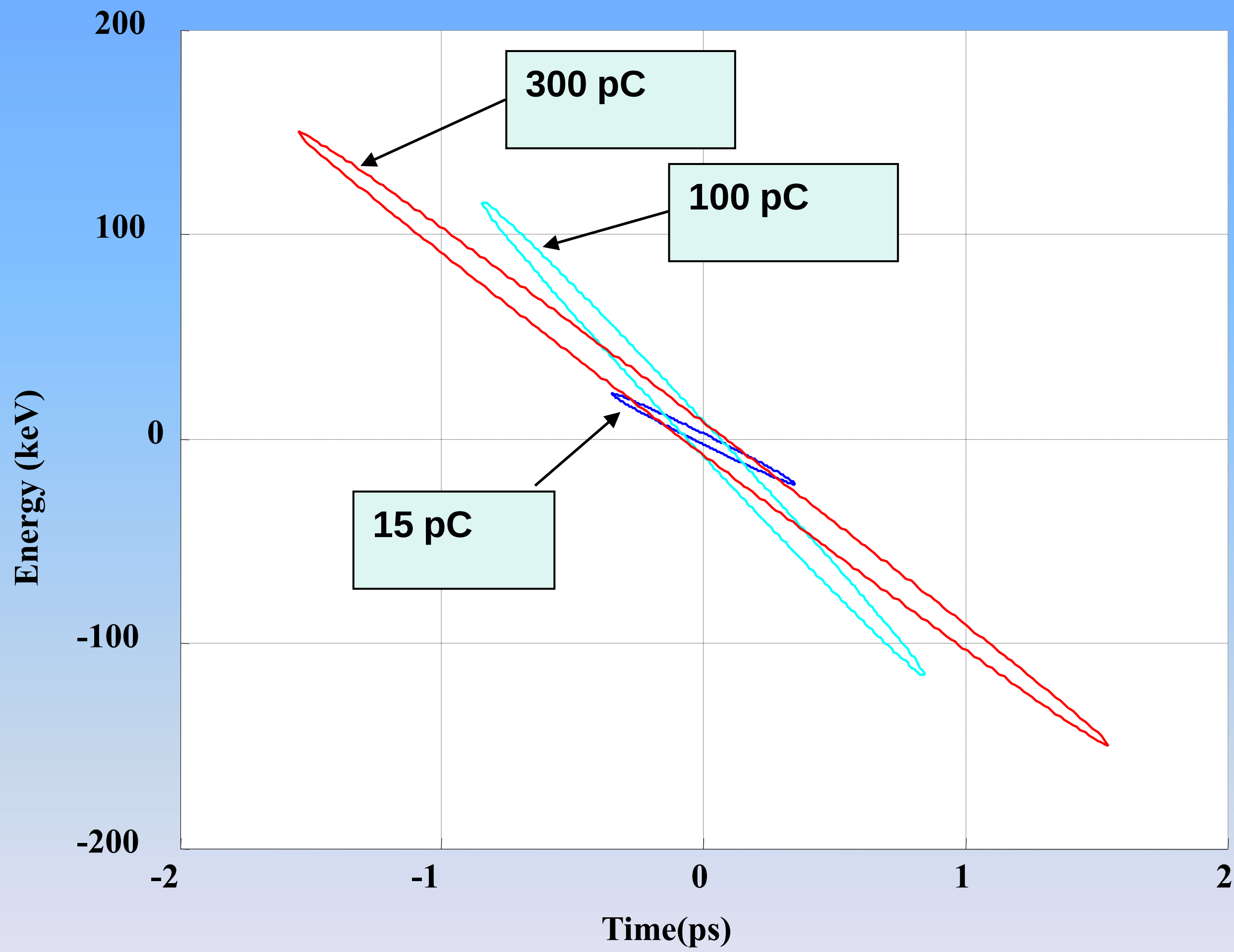


Energy Chirp, MeV/degRF:

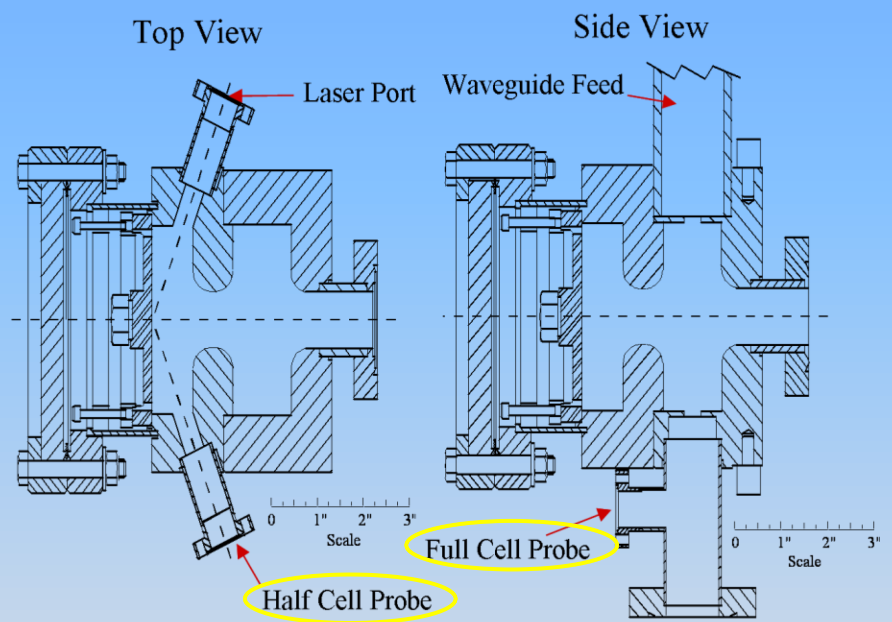
$$\left.\frac{\Delta E}{\Delta \phi}\right|_{\text{linac entrance}} = E_{linac} \sin \phi_{linac}$$

SLAC Gun Test Facility data

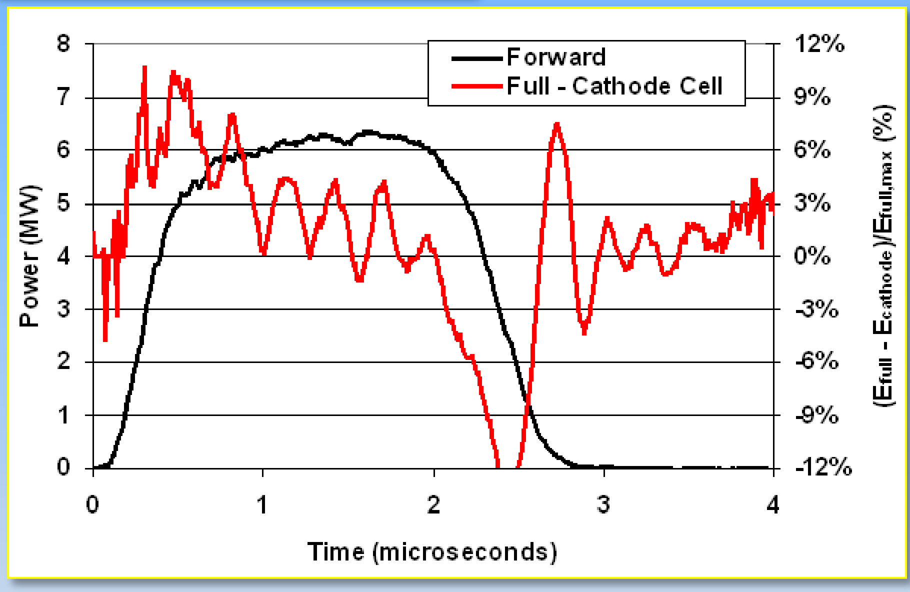
Result of Longitudinal Emittance Measurement



Gun probe signals show 0-π mode beating which can explain large correlated energy from gun

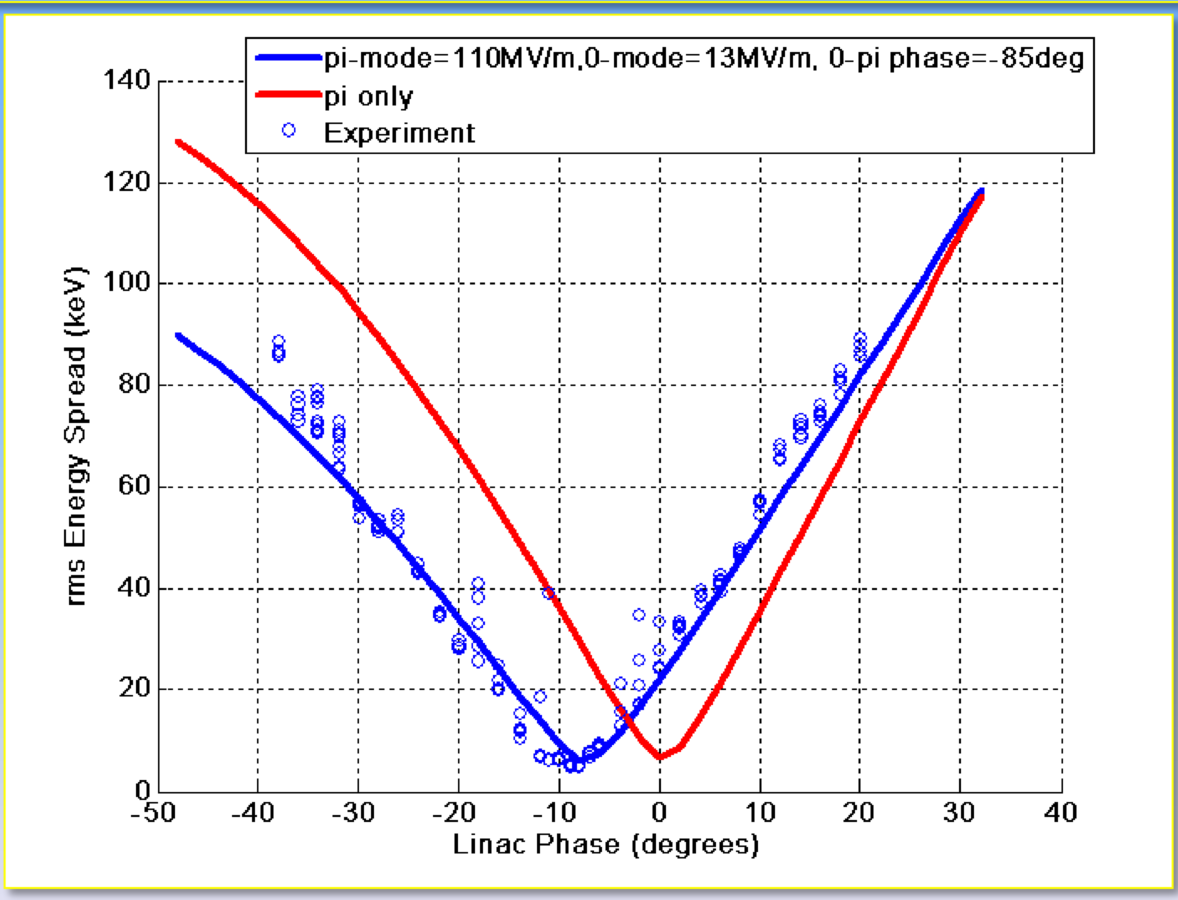


GTF gun RF probe signals

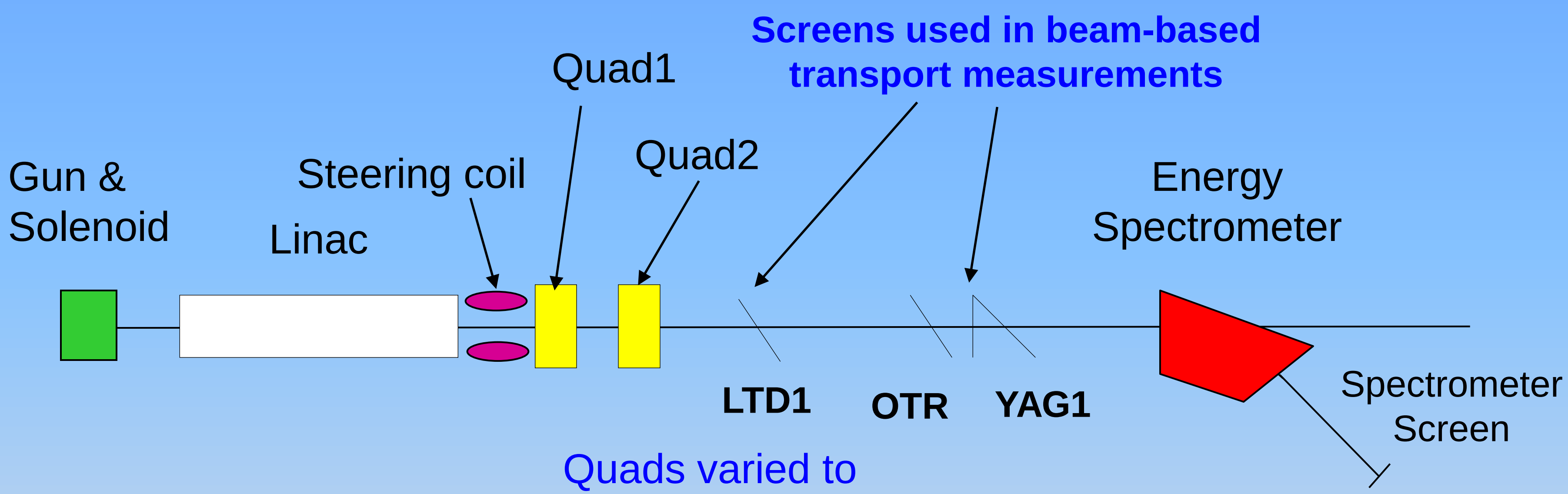


Comparison of Simulation and Measurements

RMS energy spread at 35 MeV vs. linac phase



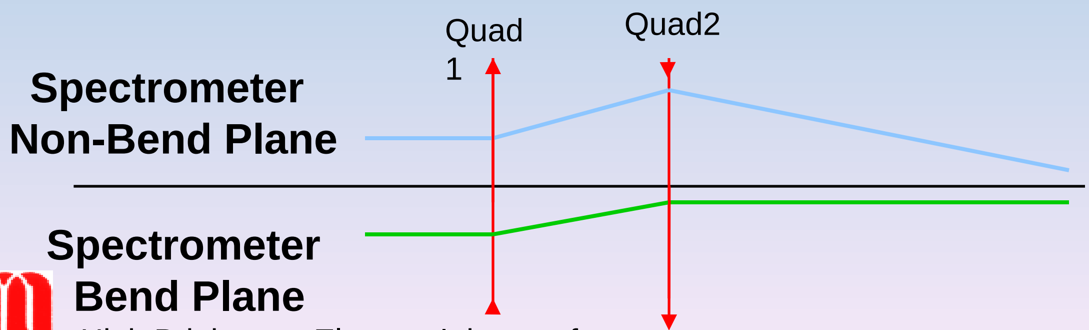
GTF Slice Emittance Experiment



Linac puts energy-chirp onto electron bunch

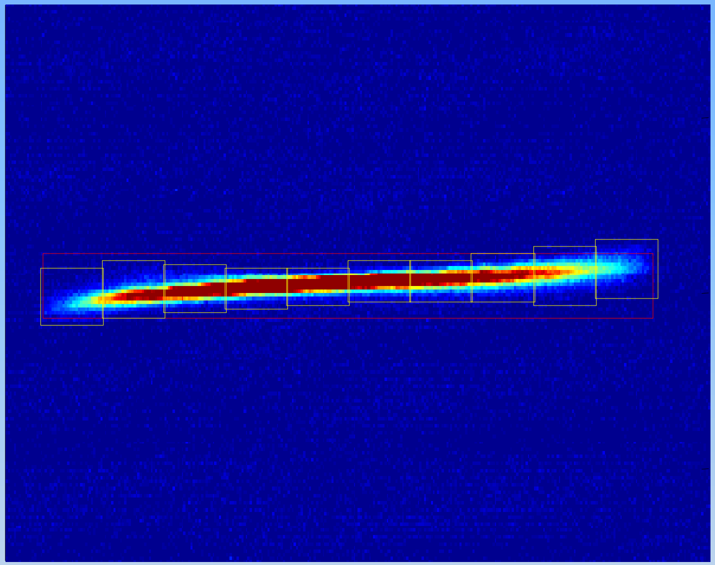
Quads varied to scan beam sizes at spectrometer screen

Measure energy-dispersed images vs. quad current.
Energy => Time
Transverse size => Emittance

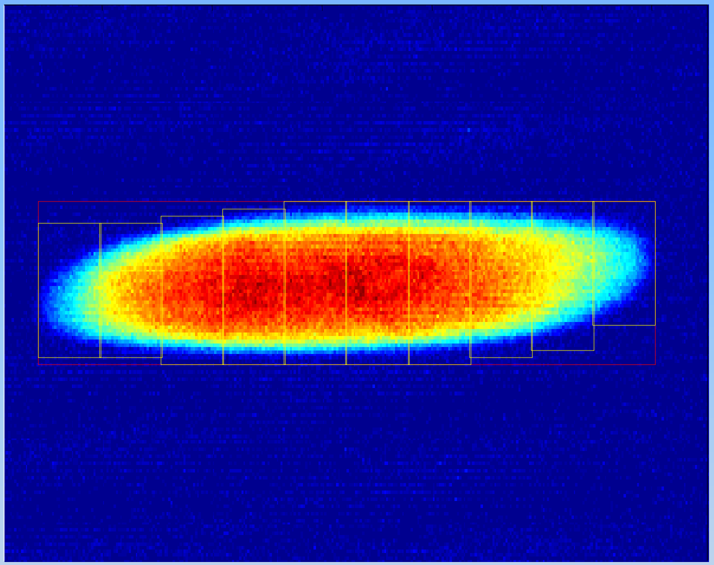


Chirped Bunch at 15 pC
For Two Quadrupole Strengths

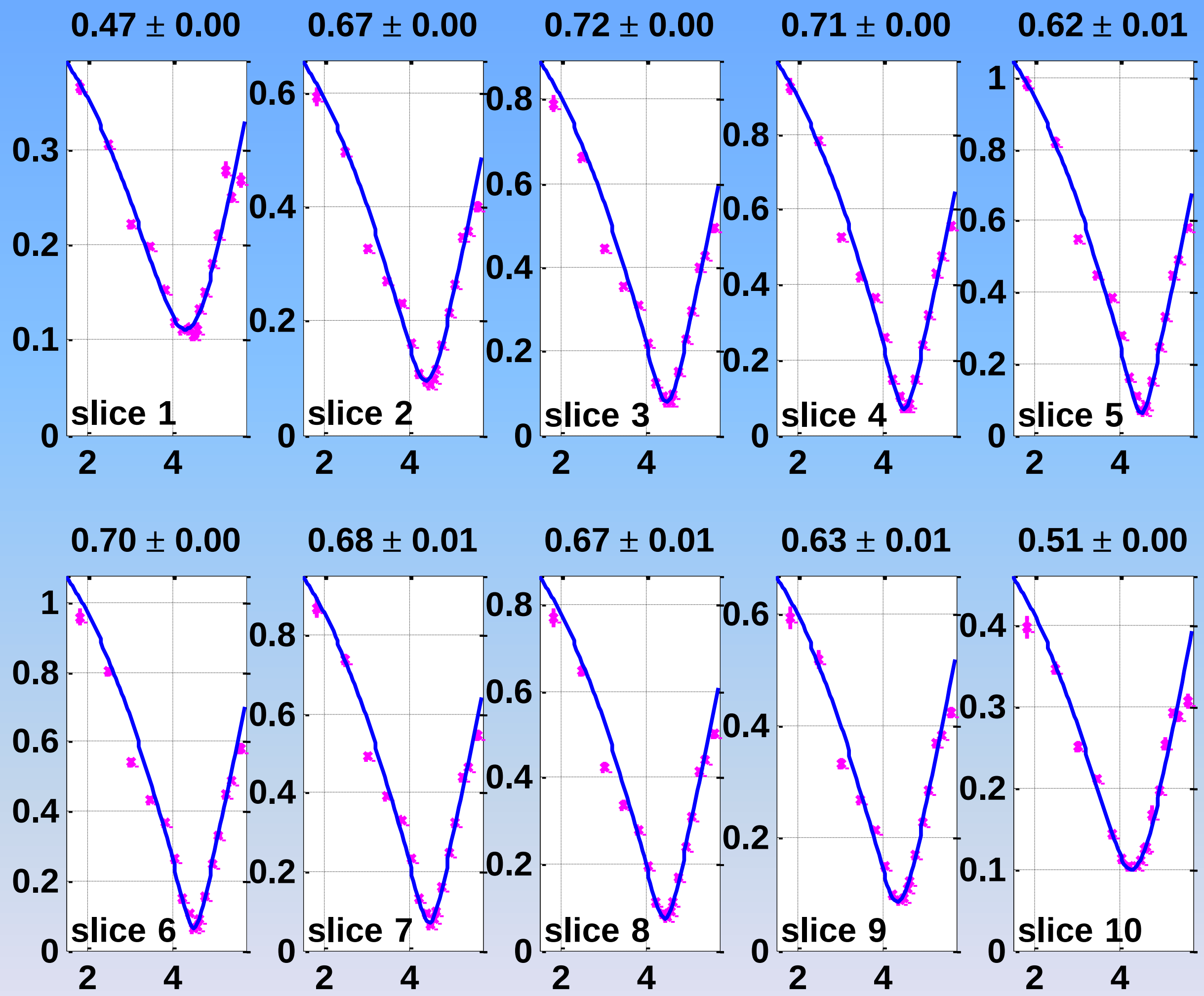
0906.tif (3.00 A) [70:346, 238:255] 277 X 18



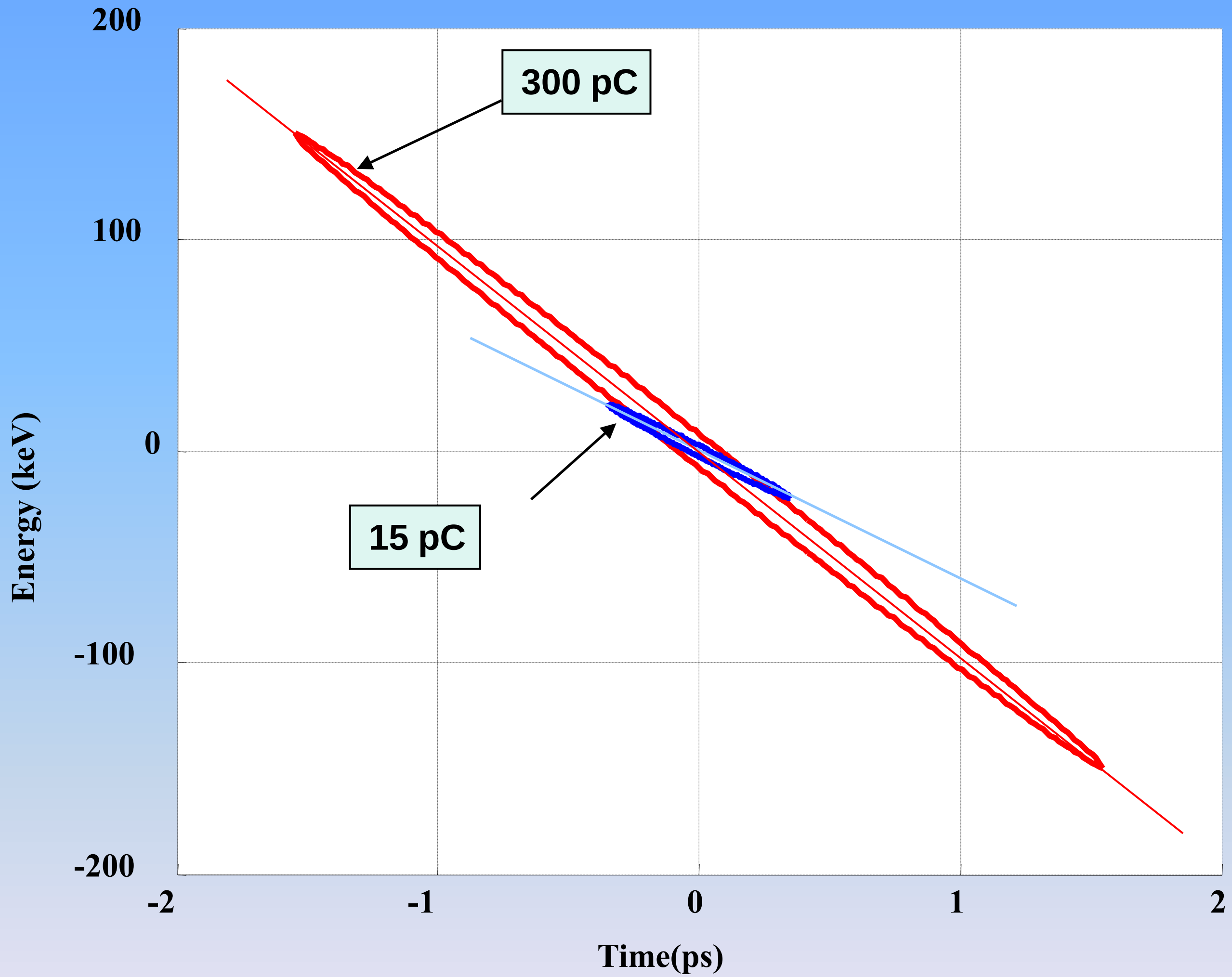
1402.tif (4.10 A) [70:349, 230:275] 280 X 46



15 pC slice fits, I-solenoid =104 amps

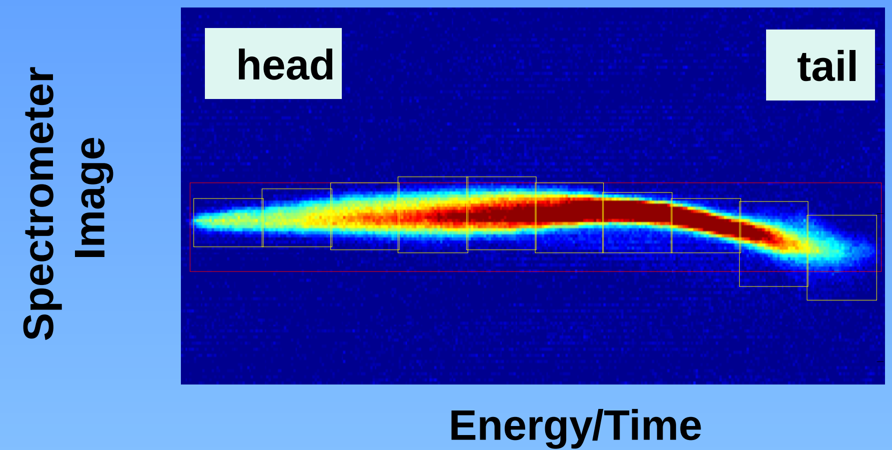


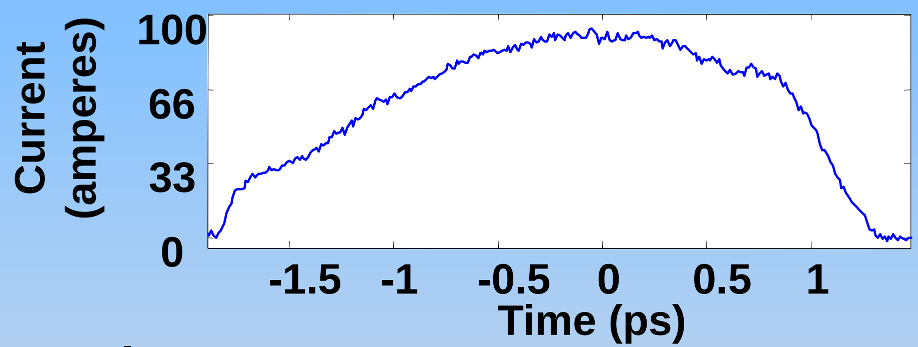
Conversion from Energy to Time Comes From Longitudinal Emittance Measurements



*Slice Analysis of 300 pC GTF Data**

Slice and projected emittances determined for 300 pC bunch charge. The slice time width is 330 fs. These data show an inverse relation between the best slice and projected emittances when optimizing with the solenoid. Therefore projected emittance measurements alone cannot give an optimized beam.





**D.H. Dowell et al., Nucl. Inst. Meth. A507(2003)335-338*

Lecture 10
Beam Diagnostics

•Described technique for measuring the longitudinal phase space and slice emittance without a transverse cavity.