Accelerator Instrumentation RD

Monday, July 14, 2003

Marc Ross

Linear Collider RD

- Most RD funds address the most serious cost driver – *energy*
- The most serious impact of the late technology choice is the failure to adequately address *luminosity* RD issues

Limiting LC technology:

- (not including physics of beams)
- gradient & RF power & associated diagnostics
- Low power µwave circuitry
- Lasers
- Positioning/alignment/vibration stabilization
- mm wave & FIR diagnostics
- Data flow – control system
- Radiation effects
- Vacuum
- Feedback
- Engineering – fabrication, packaging, testing

energy (gradient & RF power & associated diagnostics; Low power µwave circuitry)

luminosity (Low power µwave circuitry through Feedback)

R&D Challenges

1. *Precision microwave*
2. IR final doublet girder (~ internal to detector)
3. Beam size from optical transition/diffraction radiation
4. Bunch length
5. Storage ring instabilities – electron cloud
   – surface physics
6. Radiation modeling
7. Permanent Magnets
8. RF breakdown
9. *Control system*

From the April 2002 LCRD kickoff meeting

Cost drivers (%)

- Warm
  - Inj 15
  - ML 54
  - BD 8
  - Ctrl 4
  - Other 18
- ML
  - EDI 14
  - ***RF source/dist 40***
  - Girder 18
  - Civil 18
  - Other 10

- Cold
  - Inj 23*
  - ML 49
  - BD 8
  - Ctrl 3
  - Other 18
- ML
  - EDI 13
  - ***Cryo 38***
  - RF 19
  - Civil 12
  - Other 16

unofficial, ~*personal*, estimates

Risk/cost Drivers (1)

- Risk can be assessed many ways according to different metrics→
  - Example:
    - *Availability simulation assessment of risk*
    - Cold linac – cryomodule
    - The risk is: availability of the cryomodule, especially active components within it
      - All will agree that careful engineering is needed to mitigate risk and make sure that the:
      - Cavity tuners
      - Piezo tuners
      - Coupler interlocks
      - Cold 'moving parts'
  - Are as reliable and as reasonable as possible
  - and that failures are 'soft'

Availability simulation

- What happens when...
- a cryomodule component fails?
  - many cryomodule components are needed for stabilization systems/protection systems
    - first order effect may be negligible...
  - depends on the intrinsic stability
  - depends on the variability of beam parameters
  - *how well integrated are the cryo RF controls?*
    - *(example of TTF, JLAB)*

Risk/cost Drivers (2)

- Both warm and cold:
- Linac *emittance propagation* – spurious dispersion is extremely important for both
  - (perhaps single most important effect)
  - impact of BPM performance
  - impact of mis-alignment
  - impact of tuning time
- Additional beam size instrumentation within the linac
  - is there a need for instrumentation within the cold systems?
  - (*not* the TDR paradigm)
- What about the 'cold' BPM's? → how reliable are they?

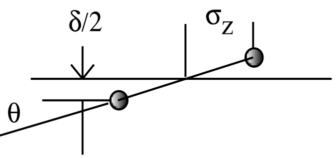
RD

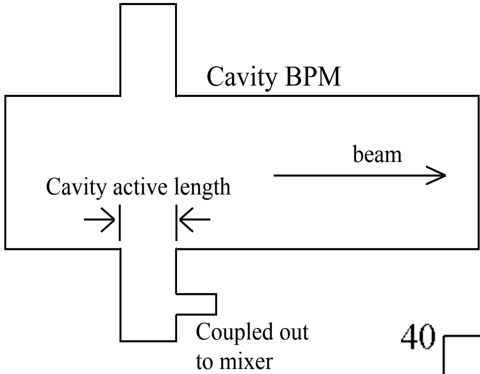
- *Most emittance dilution begins with a simple linear correlation*
- can catch and correct
  - beam position monitors
  - beam correlation monitors
- *Longitudinal phase space usually involved*
  - difficult to image directly

- Controls/electronics can have large leverage on cost
  - national labs now substantially lag in this technology
  - integration

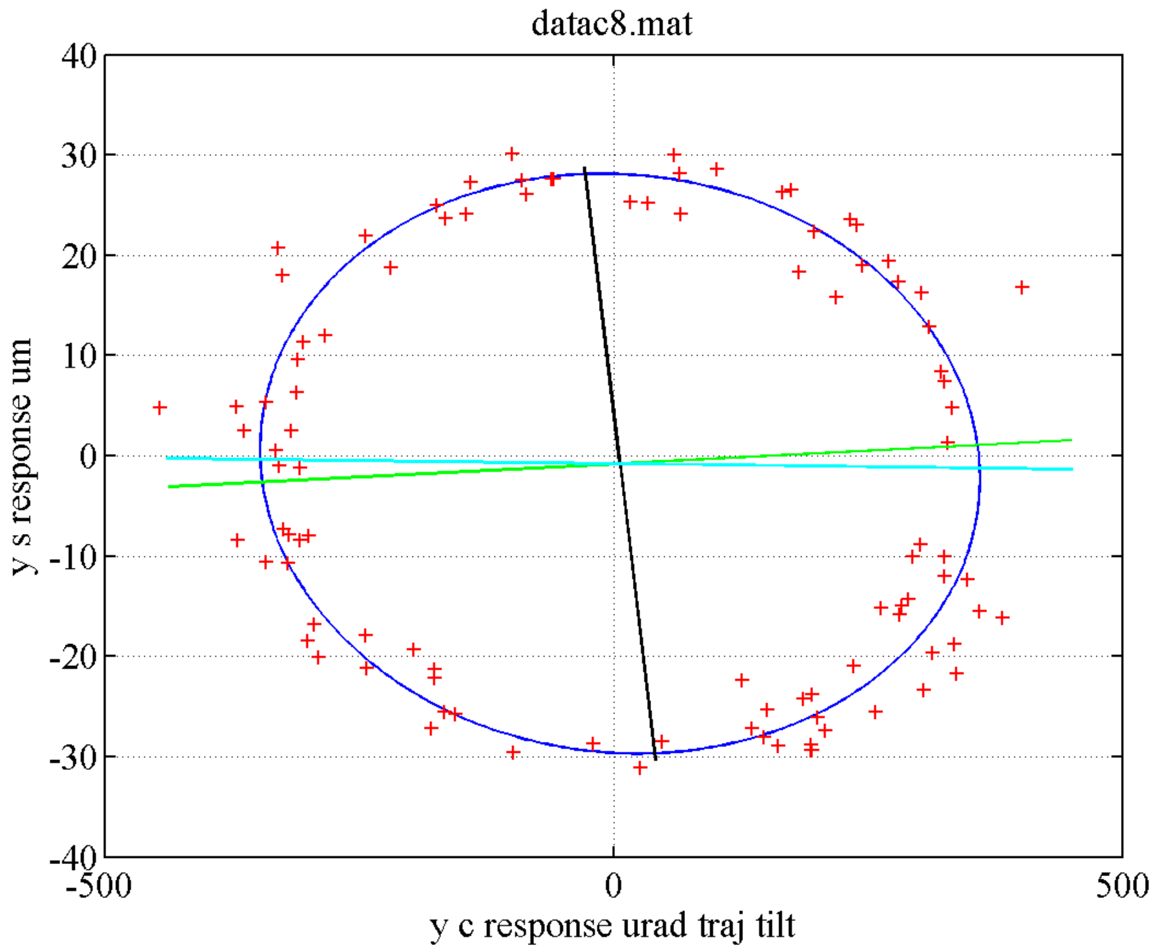
Three examples:

- correlation monitors
  - *recent results*
- *Multi-bunch* behavior of uwave cavity BPM’s
  - crude estimates/interesting pathologies
- longitudinal phase space
  - *recent results*
  - extremely short bunches/bunch shaping





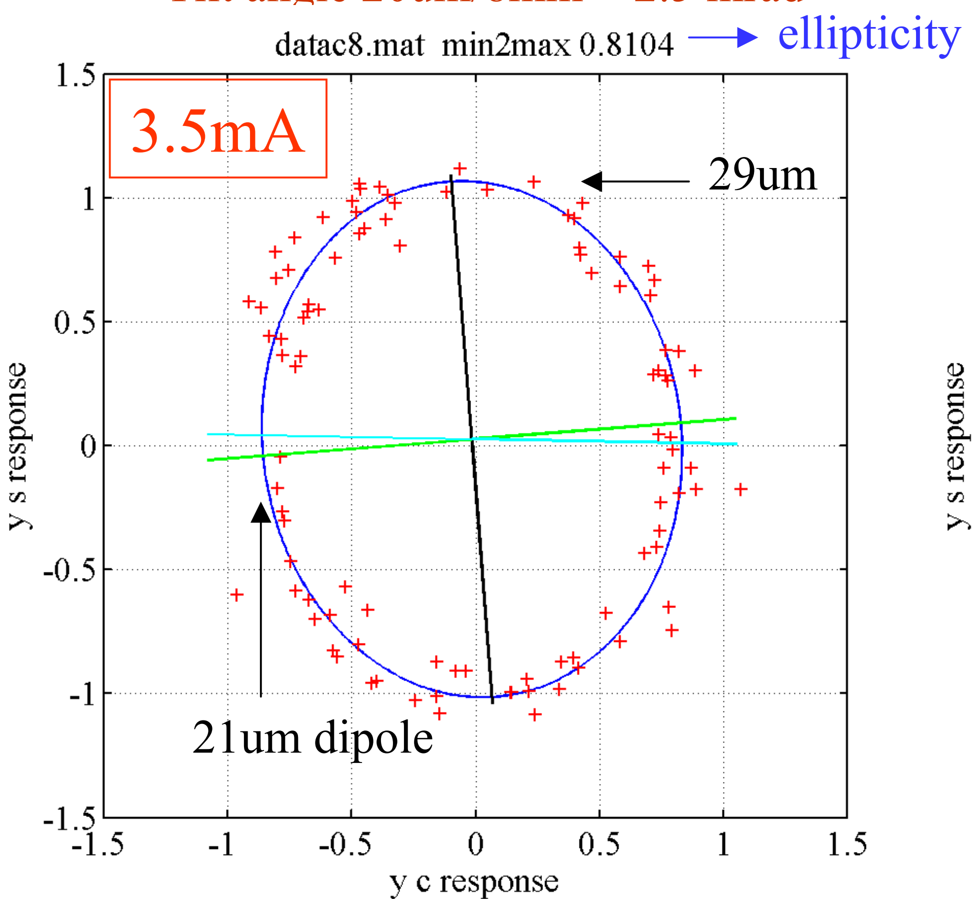
Correlation monitor: Deflection cavity/detector BPM

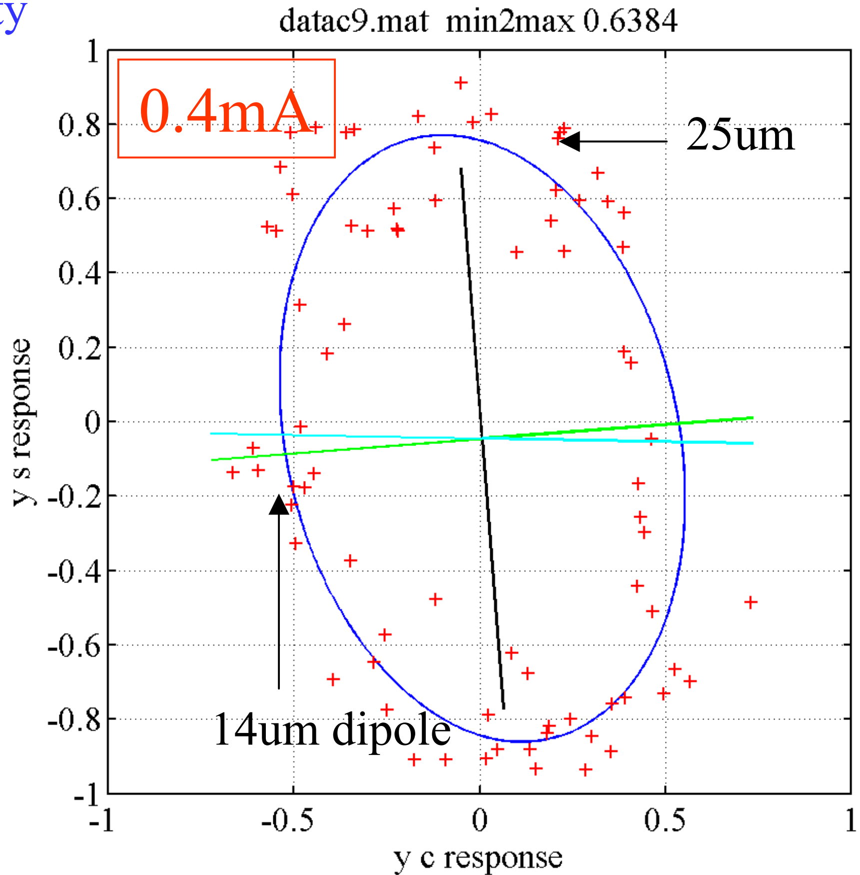


- I/Q cavity response with deflection cavity at full voltage
- Axes show directions of pure displacement (black) and pure angle (bluish) (green is 90 from pure displacement)
  - Tilter motion is not quite orthogonal
- Ellipticity is the ellipse aspect ratio
- This plot shows equivalent 'angle trajectory'

Comparison – 3.5 and .4 mA

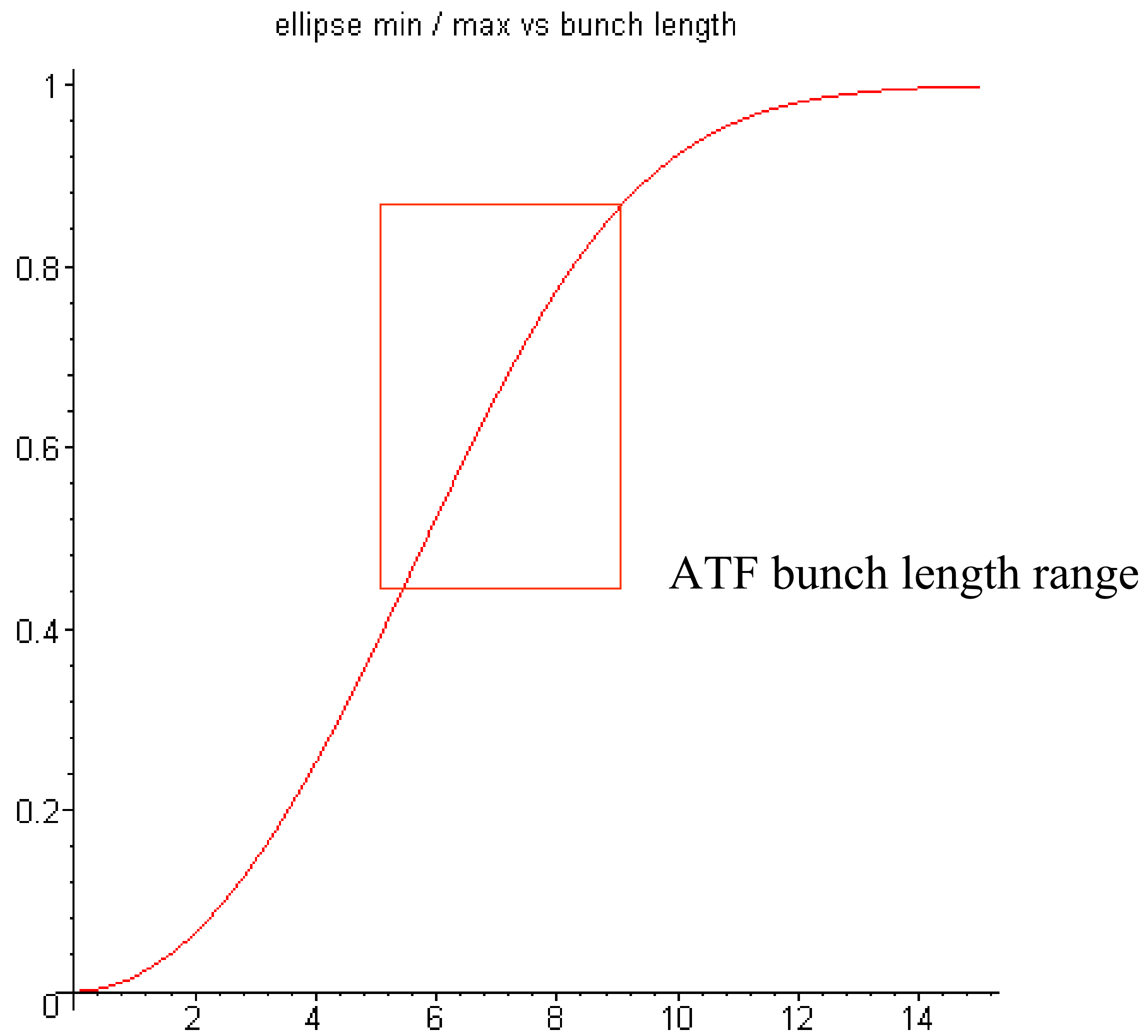
- Effective beam tilt scale 'full width dipole projection' is 0.9 of displacement for 8 mm bunch (scales with bunch length)
- See 29 um peak to peak kick at full I and 20 um projected dipole at monitor
  - Good vertical streak of 7 um beam!
  - Tilt angle 20um/8mm = 2.5 mrad





Estimate of bunch length from ellipticity

- Ellipse min/max vs bunch length (mm) for C-band
- Only length scale used is RF wavelength



Summary of bunch length measurements

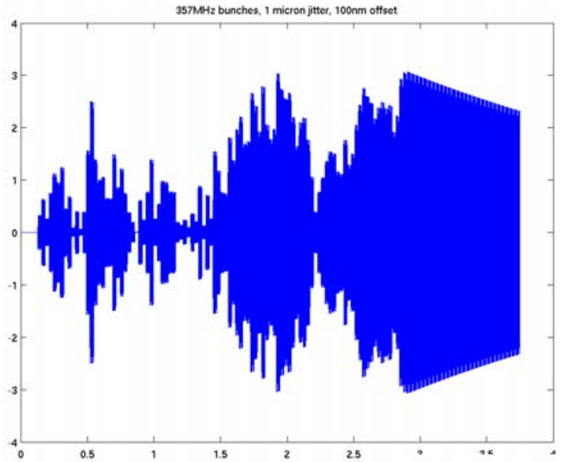
Data file	Condition	ellipticity	bunch length (mm)	ATF-01-01
datac8	nominal I= 3.5mA	0.81	8.5	9.0
datac9	0.39 mA	0.64	6.9	6.3
datac10	1.7 mA	0.74	7.7	7.5
datac11	.465 mA	0.61	6.6	6.8
datac12	0.3mA Vc 150 KV	0.79	8.3	8.8

- First bunch length measurement made entirely using RF cavities
- Beam/monitor jitter ~ 1 um (very stable over hours!)

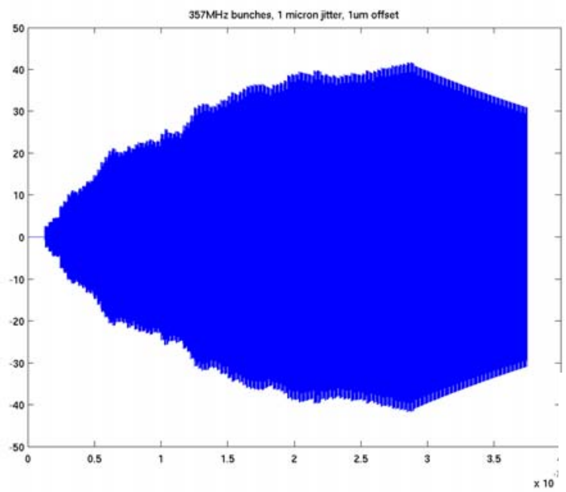
High Bandwidth Cavity BPMs for Multibunch

- Can imagine building a low Q cavity.
  - Strong coupling difficult
  - Fundamental mode overlap problem increases.
- Can look at signals from standard cavity BPM with higher bandwidth electronics.
- Integration time of 3ns vs ~300ns causes a loss of X10 (?) in resolution.
- Since bunches add coherently, *train* offsets or tilts can generate very large signals.

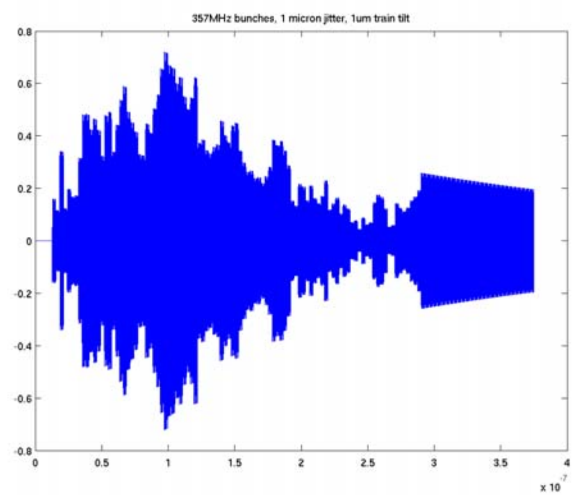
Simulated Multibunch Signals



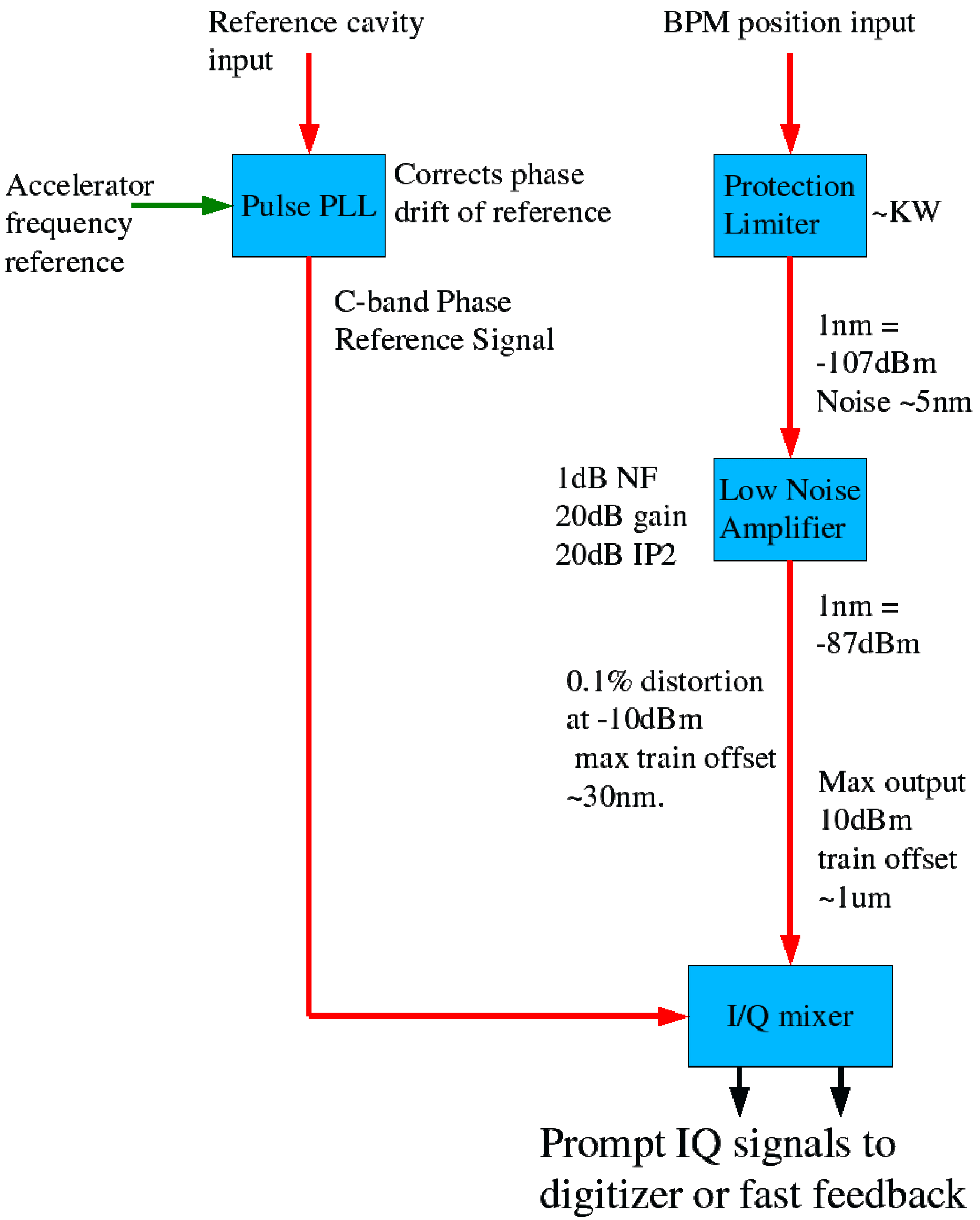
1um bunch noise
100nm train offset



1um bunch noise
1um train offset



1um bunch noise
1um train tilt



With C-band cavity, 357MHz, Best "conventional" electronics:

~5nm resolution, 1um maximum train offset

With 30GHz cavities, resolution ~1nm, but maximum train offset ~200nm

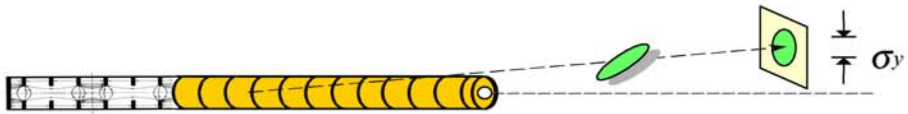
Phase space diagnostics based on deflecting/ *'crab'* RF

- Opens up new level of beam control and monitoring
  - active projects at SLAC (SPPS) & DESY (TTF2)

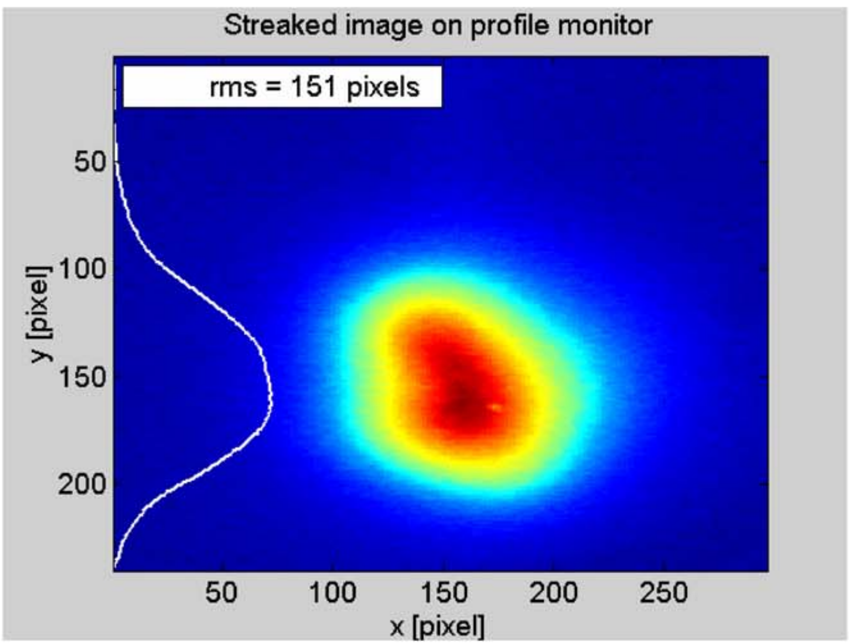
- Extensive use planned for FEL's, where short bunches critical

- Needed for finite crossing angle machines – big impact on *L*
- Needed to *correct* in addition to diagnose

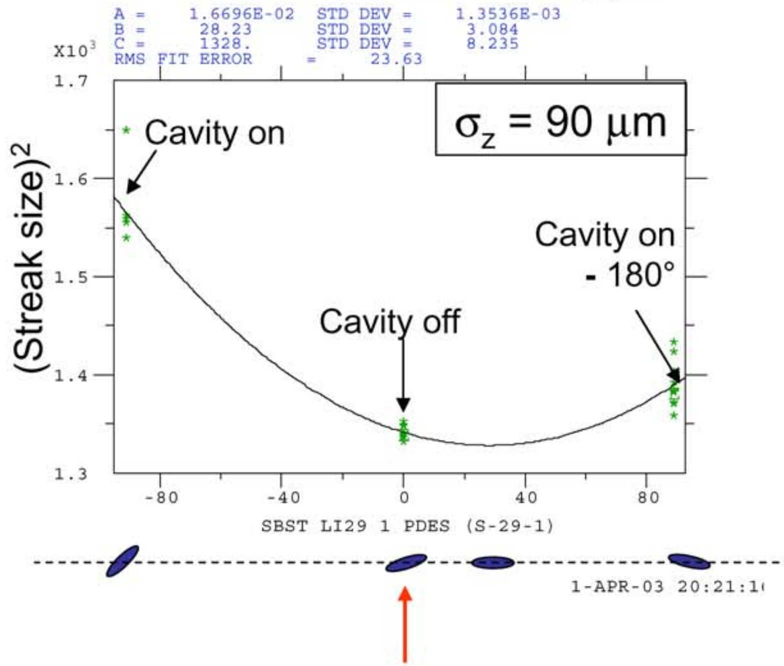
Bunch Length Measurements with the RF Transverse Deflecting Cavity

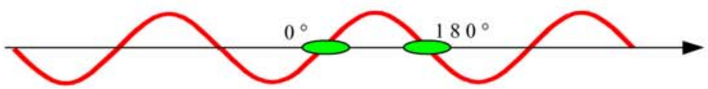


Bunch length reconstruction
Measure streak at 3 different phases



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

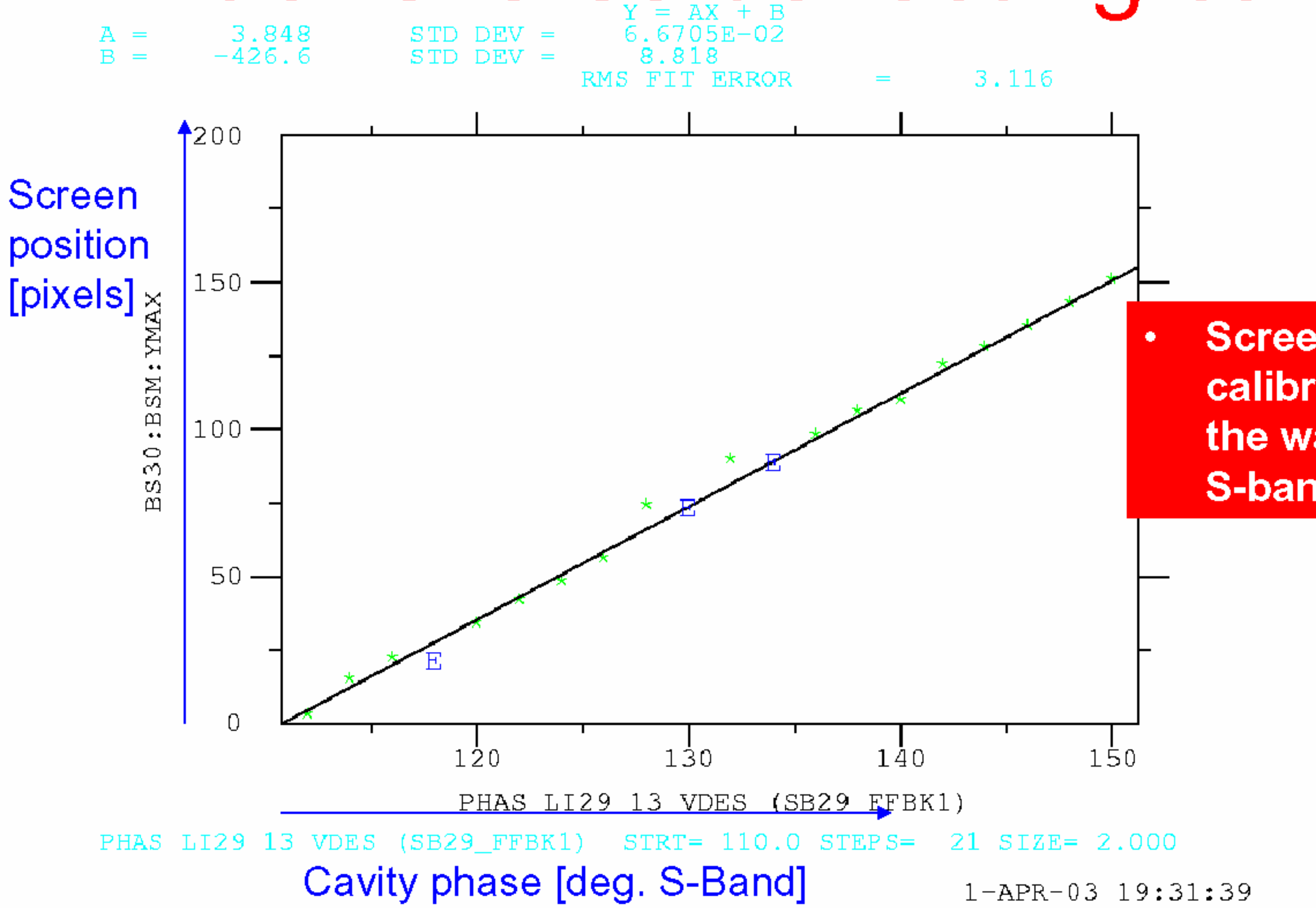




Asymmetric parabola indicates incoming tilt to beam

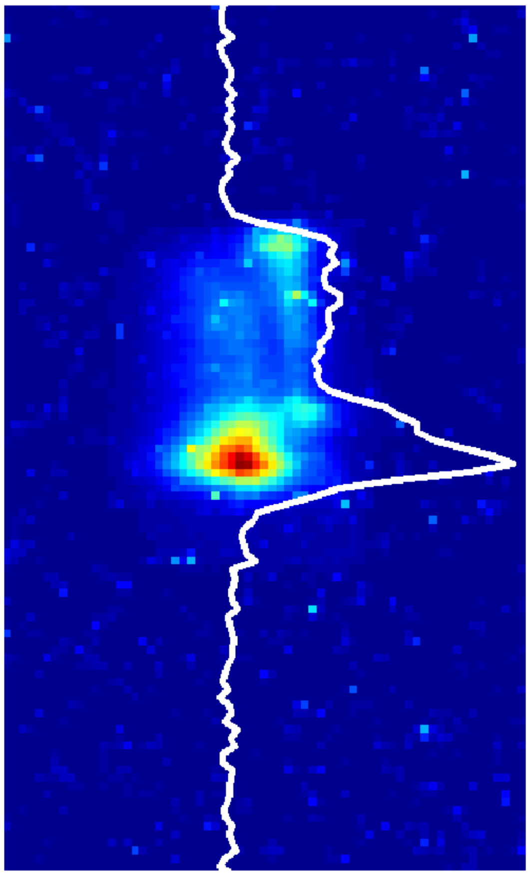
Krejcik/Emma - LCLS

Calibration scan for RF transverse deflecting cavity

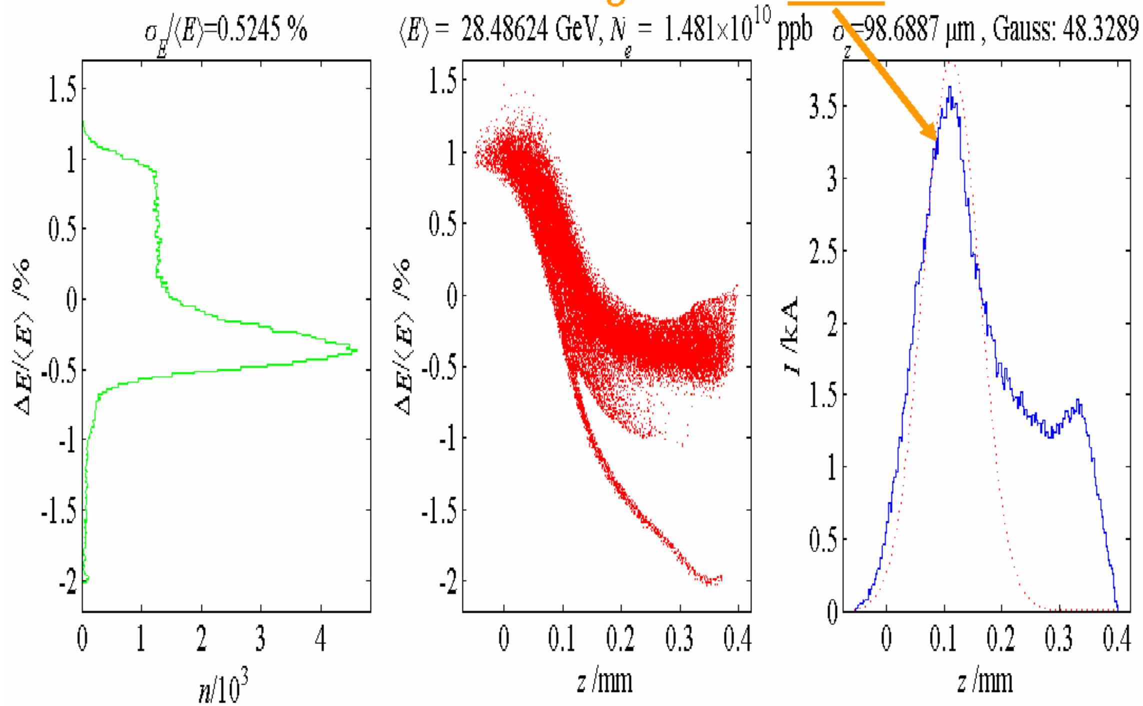


- Screen pixels are calibrated in units of the wavelength of the S-band RF

Measured and predicted energy spread of a compressed bunch



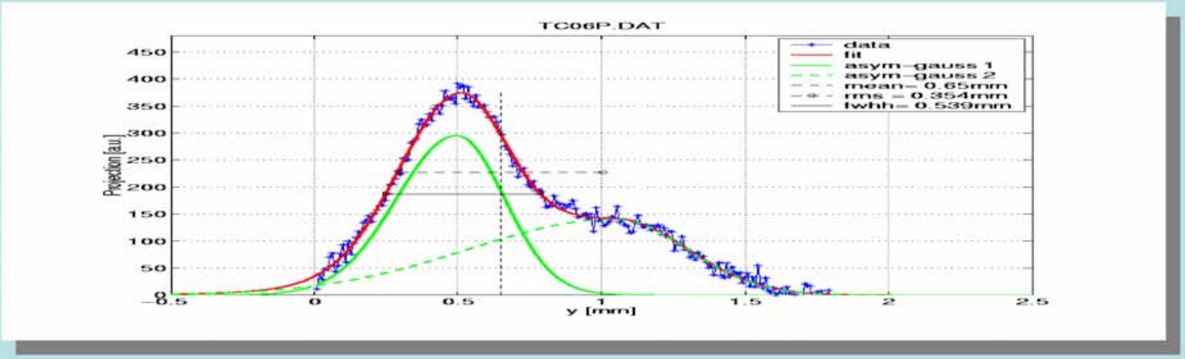
Special setup to give 100 µm bunch length with more charge at the head of the bunch

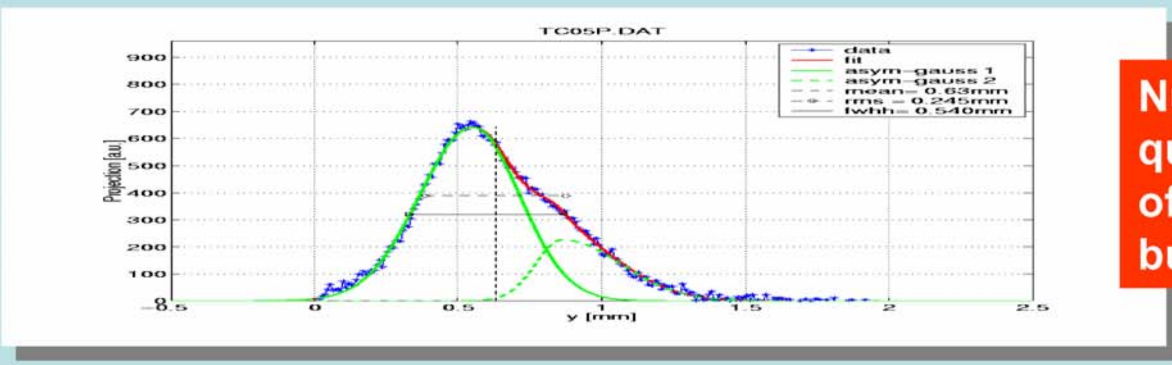


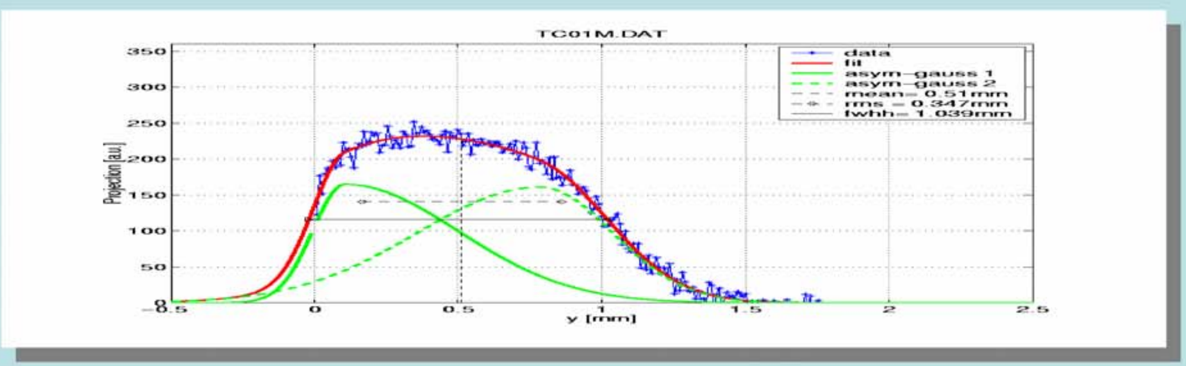
Measured at end of linac

Krejcik/Emma - LCLS

Examples of fitting two asymmetric Gaussians to the bunch profile



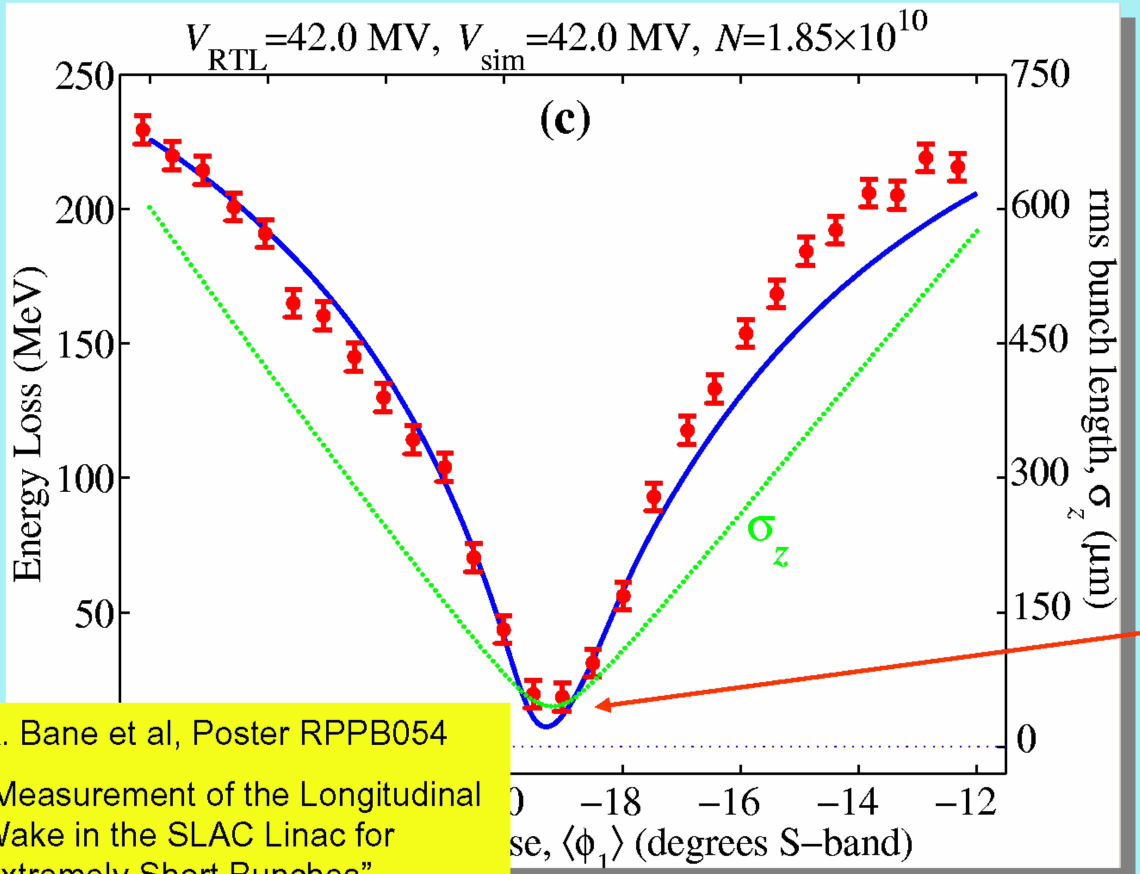




Numerically quantifying the width of non-Gaussian bunch profiles

H. Schlarb

Relative bunch length measurement based on wakefield energy loss scan



Energy change measured at the end of the linac

as a function of the linac phase (chirp) upstream of the compressor chicane

Shortest bunch has greatest energy loss

Predicted wakeloss___

For bunch length σ_z __

K. Bane et al, Poster RPPB054

"Measurement of the Longitudinal Wake in the SLAC Linac for Extremely Short Bunches"

HEP must aggressively attack *Controls/Instrumentation* issues

- System challenges are clearly greater for HEP machines
- Look at the shift SLAC.DESY.KEK accelerator groups away from HEP toward nuclear/synchrotron radiation/FEL physics and technology
  - very active growth field
- Many accelerator designers have no intrinsic connection with HEP