SPEAR3 short pulse development

J. Safranek for the SSRL accelerator physics group*

Outline:

- Timing mode fill patterns
- Short bunches
  - Low alpha
    - Bunch length vs. single bunch current
    - Operational issues
  - Injecting short pulses

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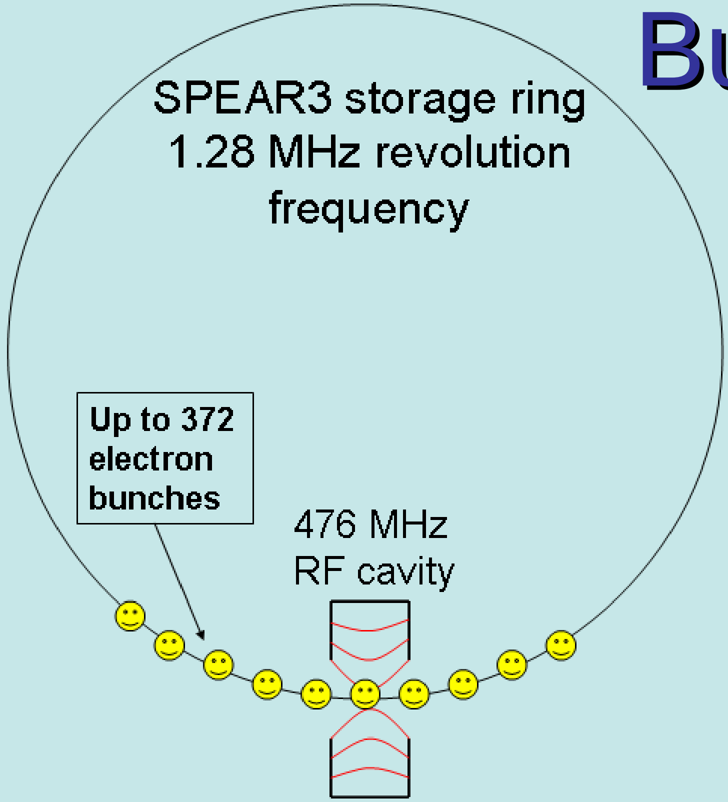
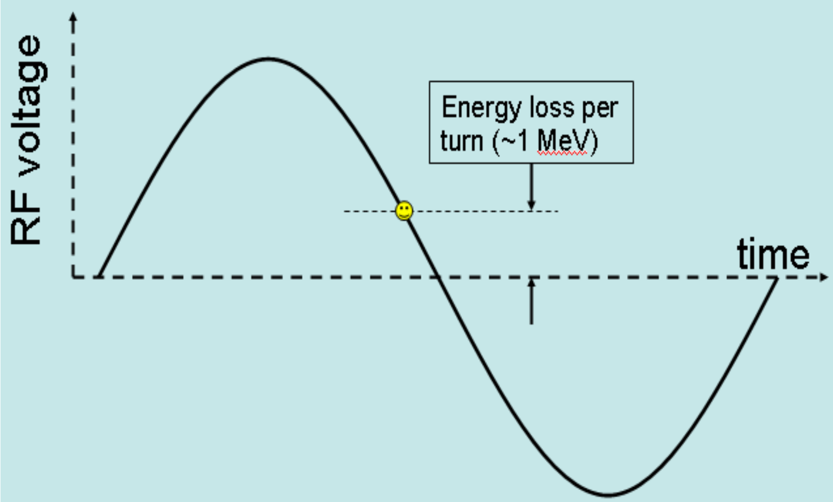
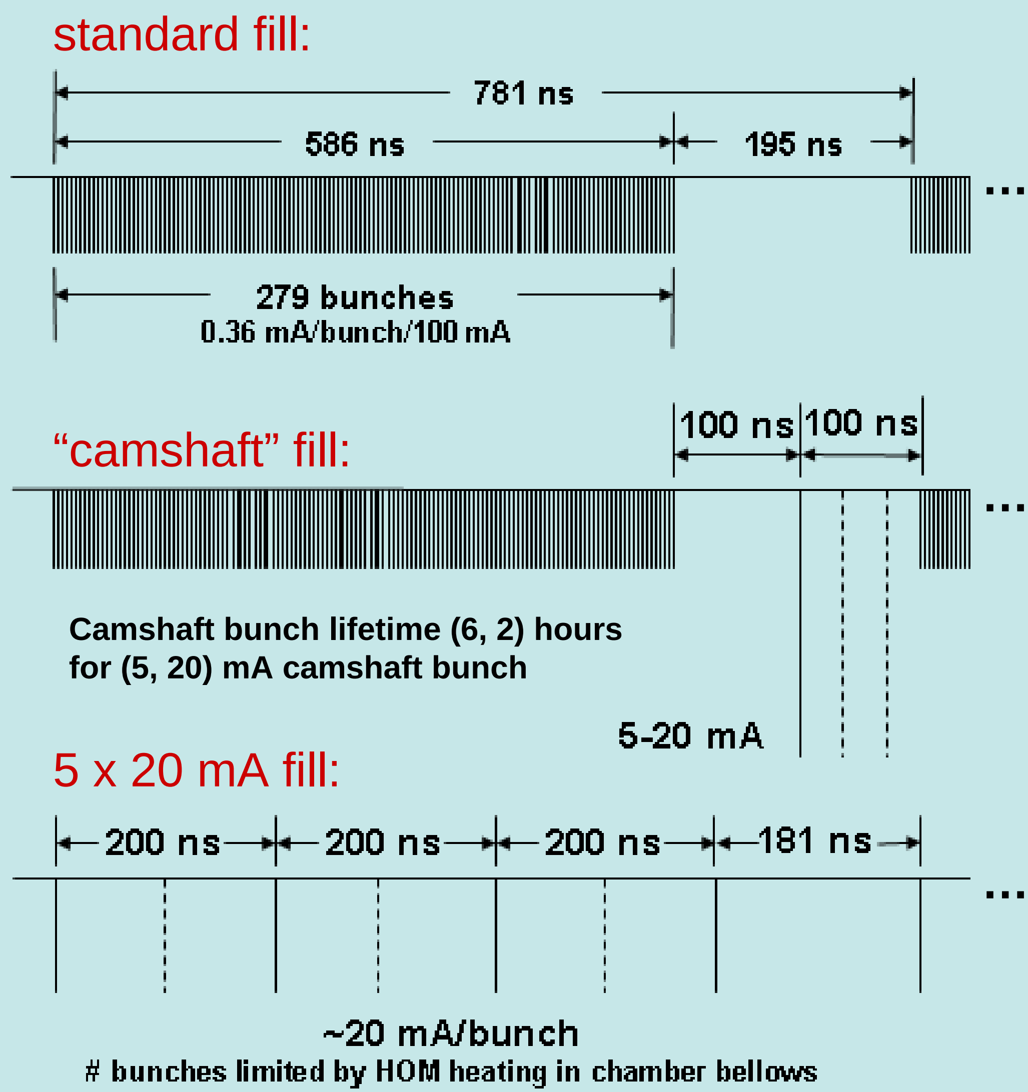
Bunch structure in SPEAR







Lifetime ~2 hours without increasing vertical beam size.

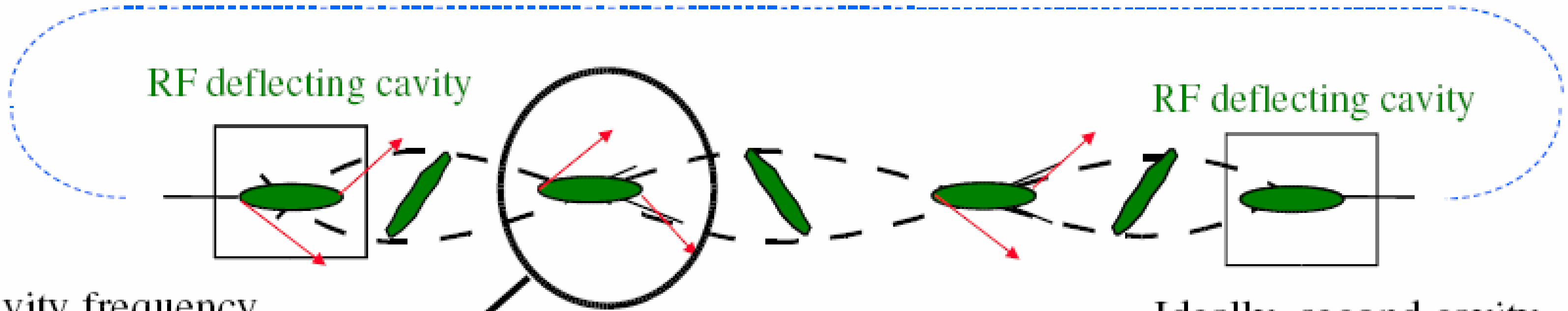
Short Bunch Implementation Schemes

(nominal SPEAR bunch length = 17 psec rms)

- Equilibrium schemes
  - o Low momentum compaction (low-α) lattice
    - < 1 – 6 ps rms, low current
    - emittance increase to 45 nm-rad
    - many beam lines served, inexpensive
  - o Harmonic cavity
    - ~10 ps possible
    - many beam lines served, expensive
  - o Superconducting crab cavities (Zholents)
    - ~0.6 ps rms,
    - very few beam lines served, expensive
- Non-equilibrium schemes
  - o Normal conducting crab cavities
    - ~1.5 psec rms,
    - 120 to 1000 Hz rep. rate
  - o Injected beam mode
    - inject and store short bunch for many turns, dump and re-inject
    - < 1 ps @ 1.28 MHz burst, 0.1-1 nC/bunch, serving all beam lines
    - expensive (short bunch injector, on-axis injection)

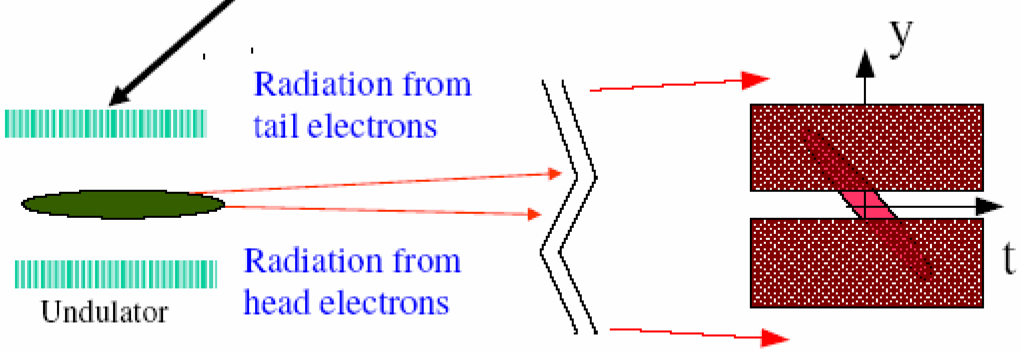
6: Zholents' Transverse Rf Chirp Concept

(Adapted from A. Zholents' August 30, 2004 presentation at APS Strategic Planning Meeting.)



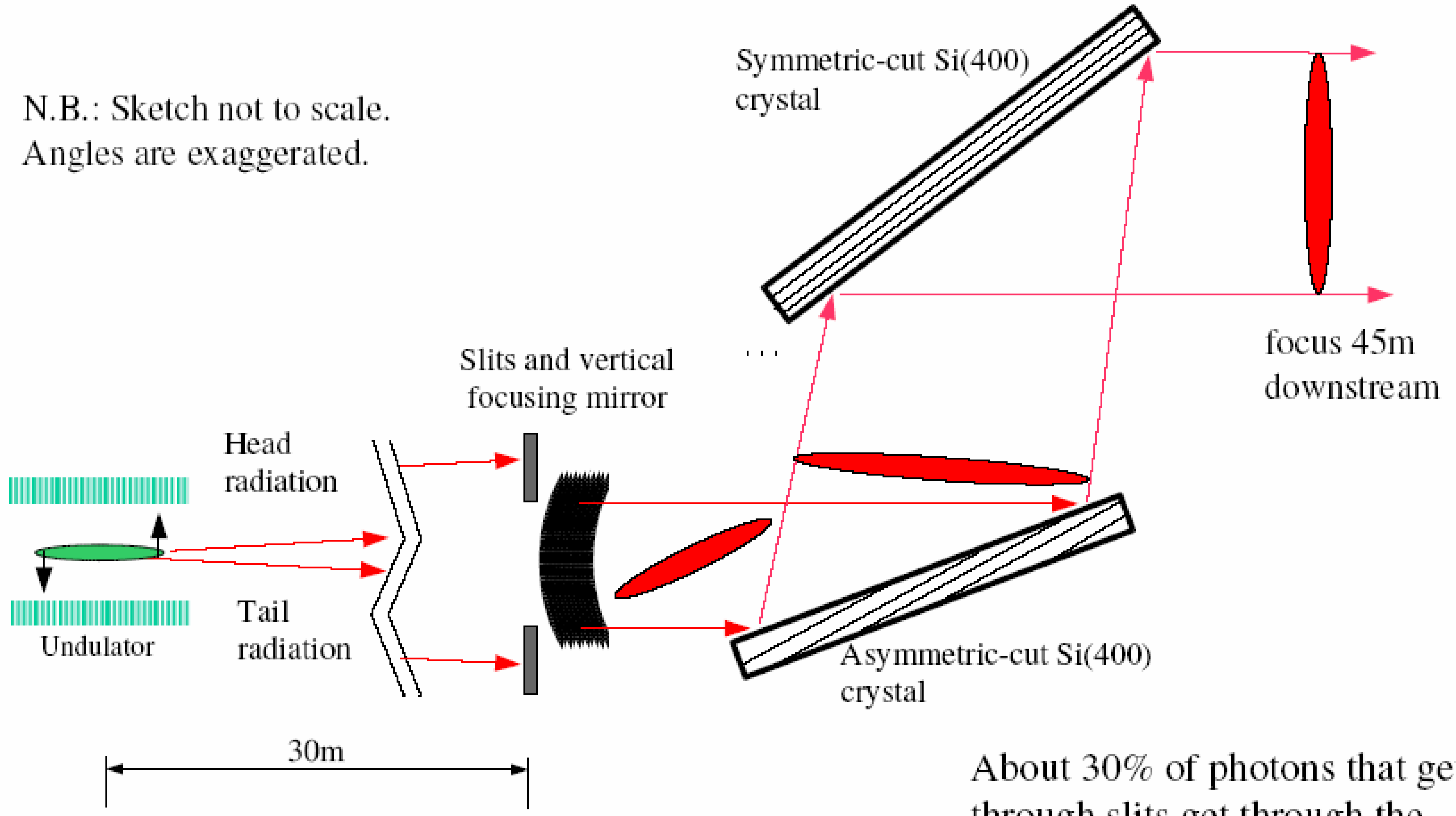
Cavity frequency is harmonic *h* of ring rf frequency

Ideally, second cavity exactly cancels effect of first



Pulse can be sliced or compressed with asymmetric cut crystal

6: APS Optics Concept for 10 kV

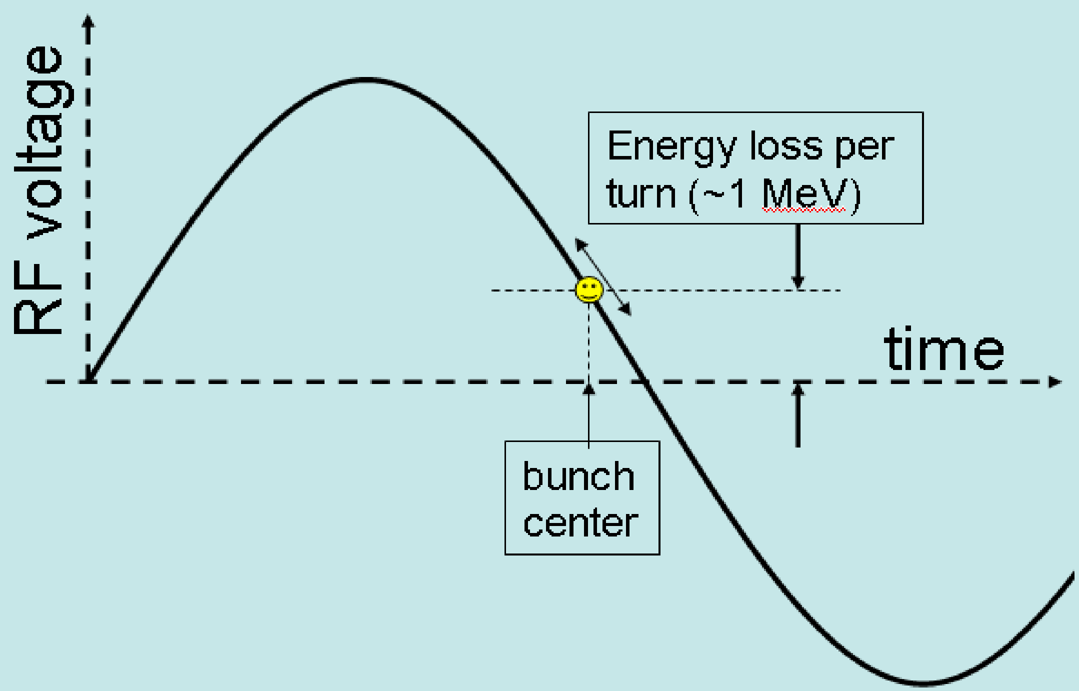


About 30% of photons that get through slits get through the compression optics.

After S. Shastri, APS

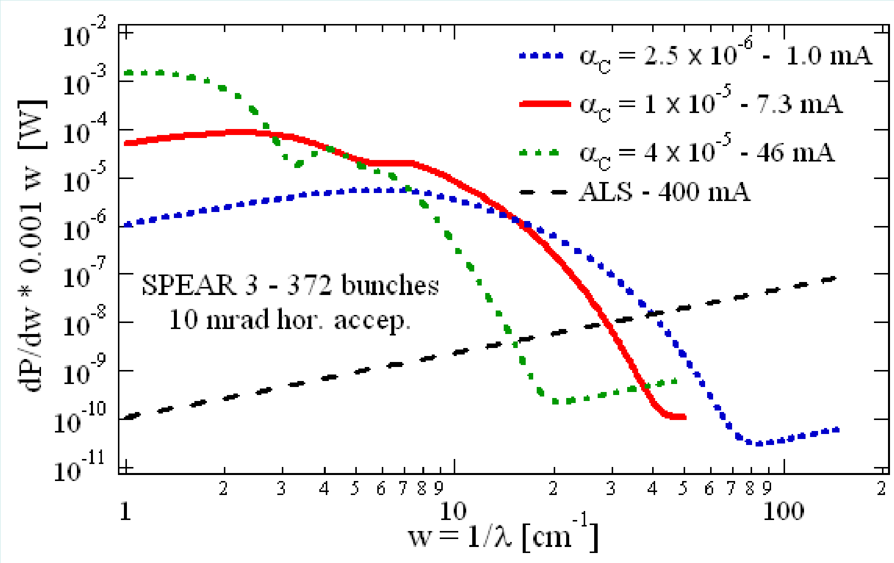
Equilibrium bunch length vs. α_c

- Bunch length (σ_z) depends on RF voltage (V_{RF}) electron energy spread (σ_E), and momentum compaction (α_c):
  - $\sigma_z \propto \sqrt{\alpha_c / V_{RF}}\ \sigma_E$
  - Increasing V_{RF} is expensive; σ_E is ~fixed by synchrotron radiation.
- Momentum compaction:
  - α_c is the change in ring circumference, L, with electron energy
  - electrons oscillate about the bunch center in energy and time.
  - The amplitude of the oscillations in time (and thus σ_z) depends on α_c.

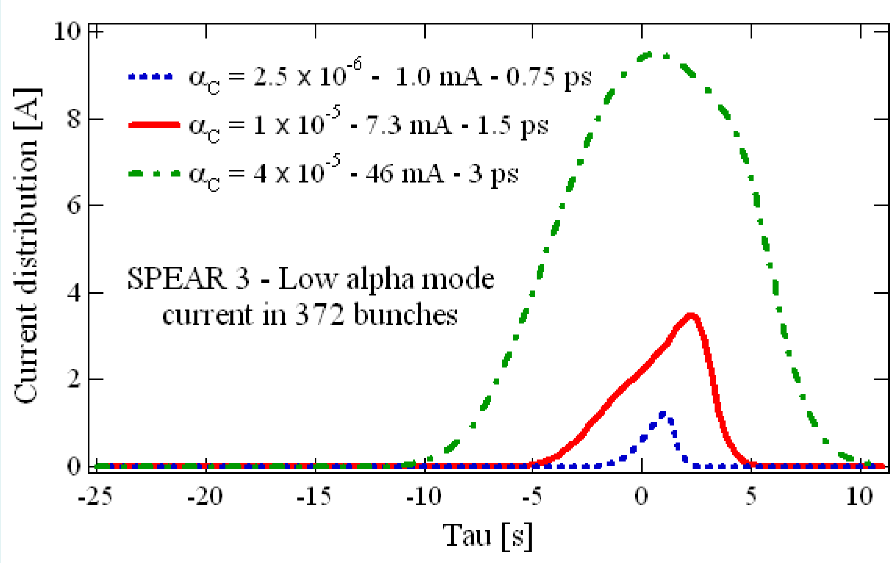


Coherent Synchrotron Radiation (THz)

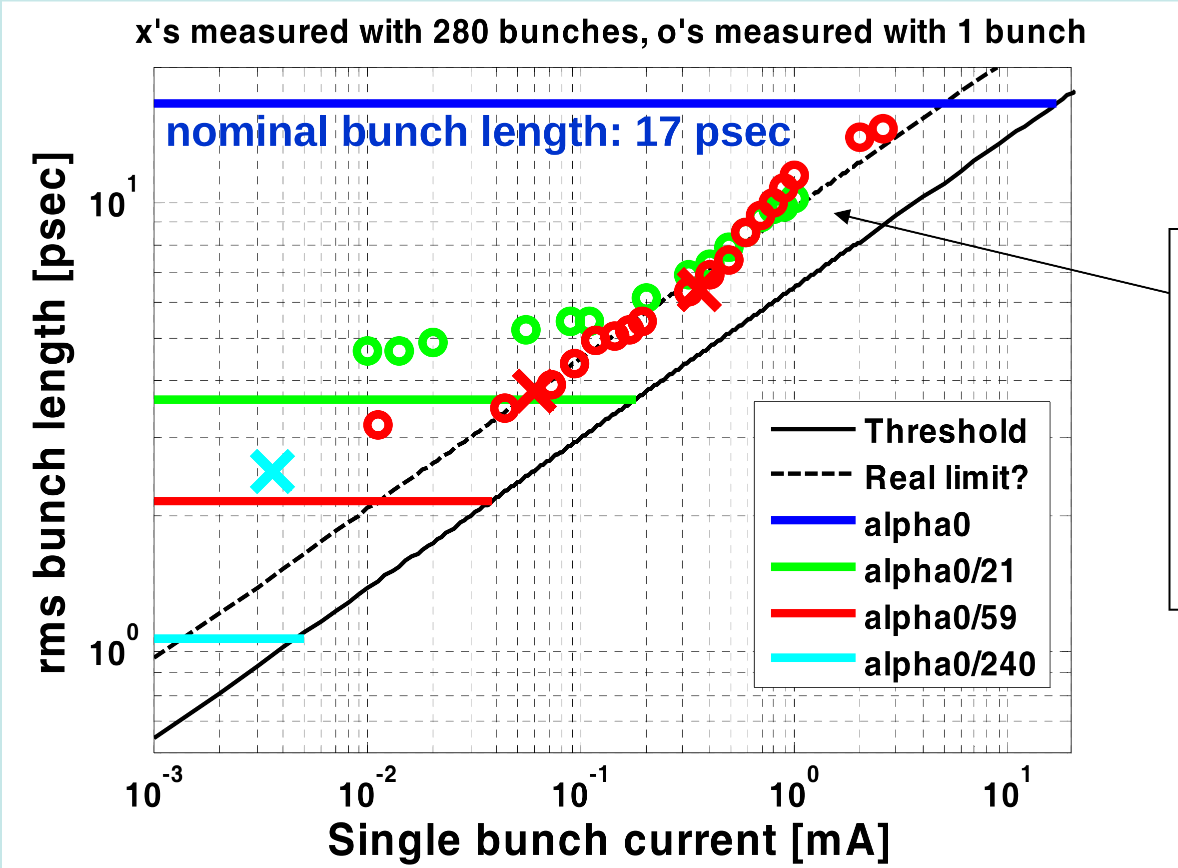
- For wavelengths $\lambda > \sigma_z$ bunch radiates coherently, P ~ N_{e-}^2.
- CSR from tail of bunch acts on head of bunch, distorting bunch shape.
- Bunch distortion extends frequency range of CSR, generating further bunch distortion.
- This feedback drives beam unstable, lengthening the bunch at higher bunch currents.
- CSR instability determines bunch length above instability threshold.
  – $\sigma_z \propto \sqrt{\alpha_c / V_{RF}}\ \sigma_E$ only at low bunch current
- CSR photon beamlines developed at BESSY-II.



Simulations by F. Sannibale, LBNL



SPEAR3 measured bunch length vs. current



CSR microbunch instability threshold defines bunch length for large bunch current.

Theory: Stupakov and Heifets, PRST-AB, May, 2002.

- Small-α, minimum bunch length:

$$\sigma_{\min}[\text{psec}] \approx 9.7 * I_{bunch}^{1/3}[mA]$$

I_{total} [mA]	100	17	0.28	0.028
I_{bunch} [μA]	357	61	1	0.1
$\sigma_{\min}$ [psec]	6.9	3.8	1.0	0.45

$I_{\text{total}} = 280 * I_{\text{bunch}}$

Low alpha at BESSY-II

- CSR μ-bunch instability threshold defines bunch length vs. current*:

$$\left(\frac{\sigma}{\sigma_1}\right)^4 = \left(\frac{\alpha}{\alpha_0}\right)^2 + \left(\frac{I_{bunch}}{I_1}\right)^{\frac{3}{2}}$$

- For small α, minimum bunch length:

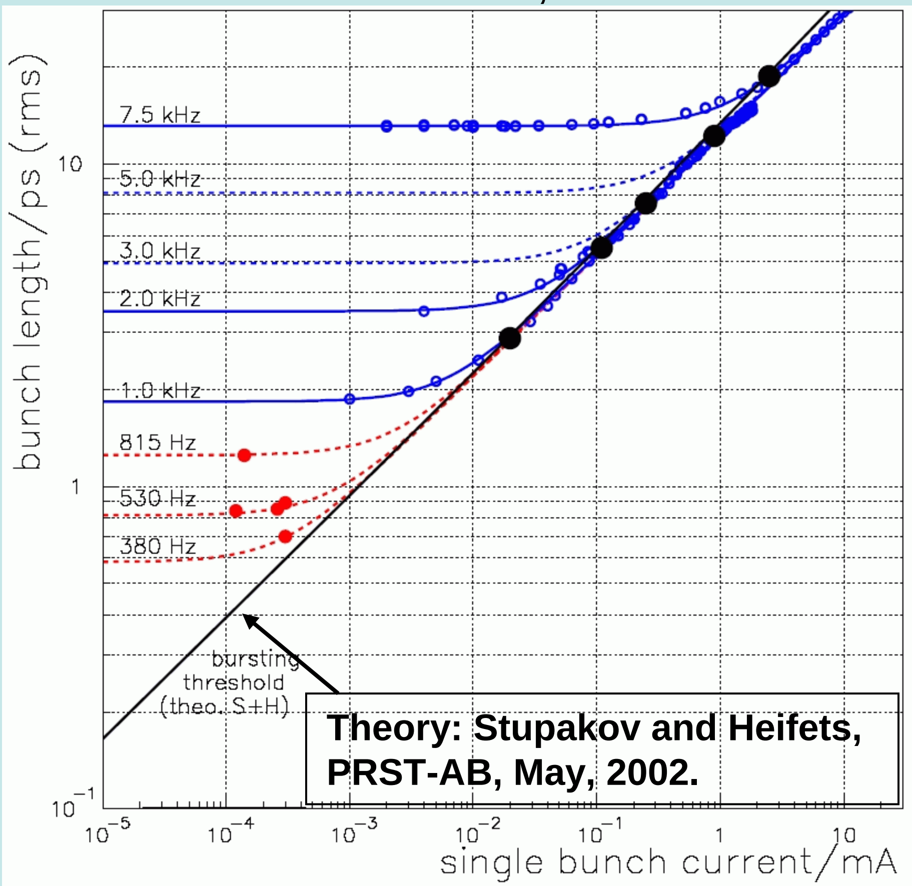
$$\sigma_{\min} \propto I_{bunch}^{3/8}$$

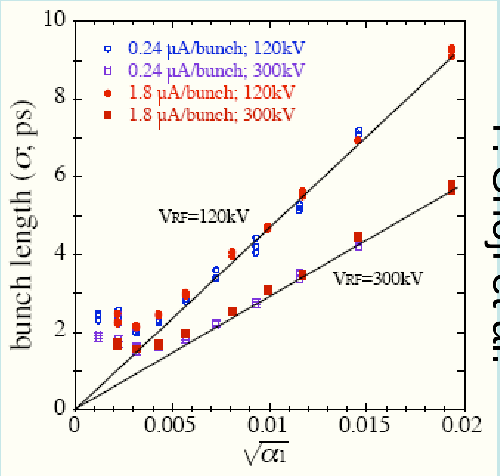
BESSY-II bunch lengths:

I_{bunch} [μA]	357	61	1	0.1
$\sigma_{\min}$ [psec]	8.4	4.3	1	0.4

- Similar results in Japan, NewSUBARU

Feikes et al., EPAC2004





Y. Shoji et al.

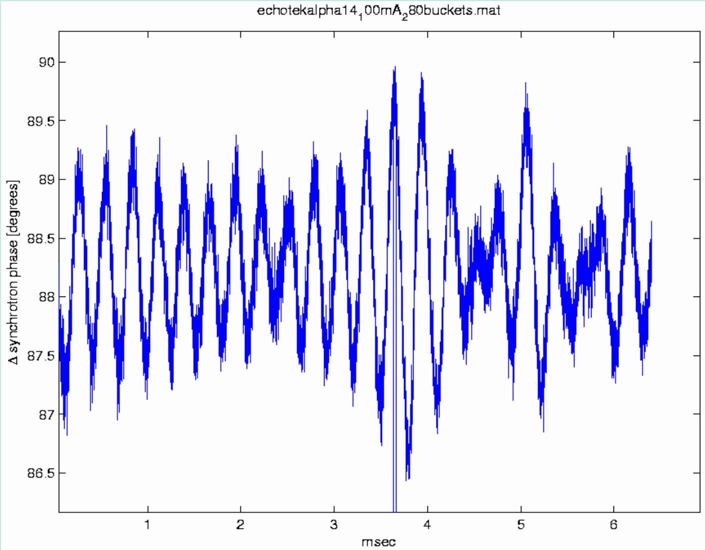
Low-α operational considerations

- Optics modification increases beam size
- Longitudinally stable
  - For small α_c, dynamics depends on higher-order terms
  - SPEAR3 naturally has α_{c2}, α_{c3} for longitudinal stability.
  - (Not so at ALS.)
  - Can reduce α_c by 1000 or more
- No multi-bunch instabilities.
- Reasonable lifetime, 13 hours at 100 mA (x4 less than standard optics)
- Injection more challenging, lower injection rates
- Work ongoing to reduce ~1 psec rms oscillations driven by RF.

Lattice	ε_x (nm)	σ_x ID (μm)
nominal	18	435
low-α	45	750

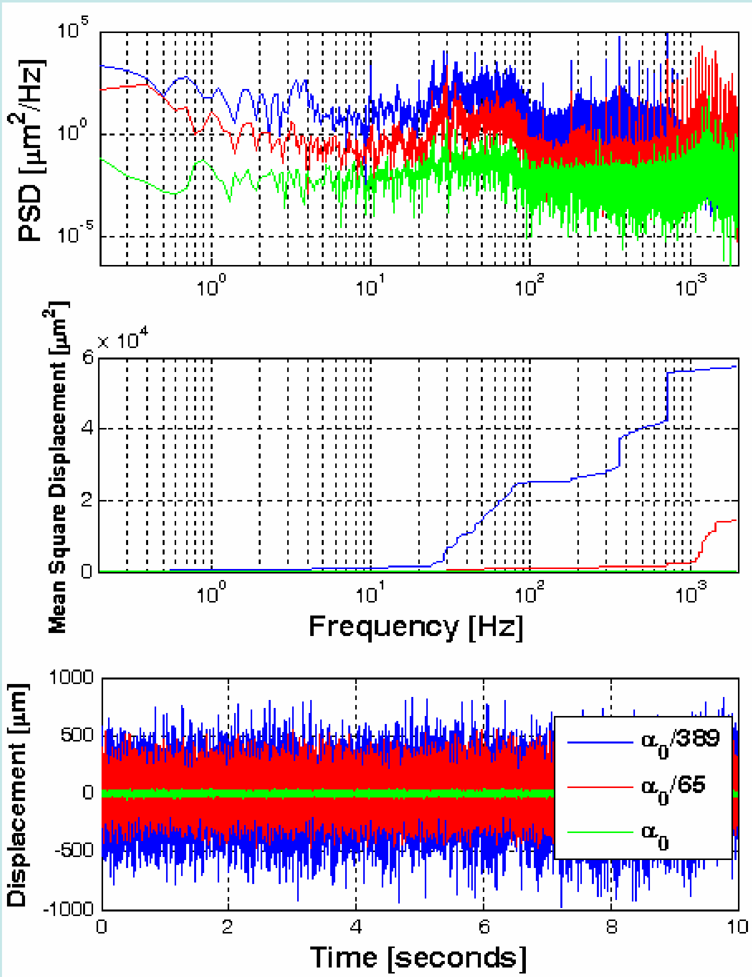
$$\frac{\Delta L}{L} = \alpha_c \frac{\Delta p}{p} + \alpha_{c2}\left(\frac{\Delta p}{p}\right)^2 + \alpha_{c3}\left(\frac{\Delta p}{p}\right)^3$$

Stability requirement: $3\alpha_1\alpha_3 - \alpha_2^2 > 0$

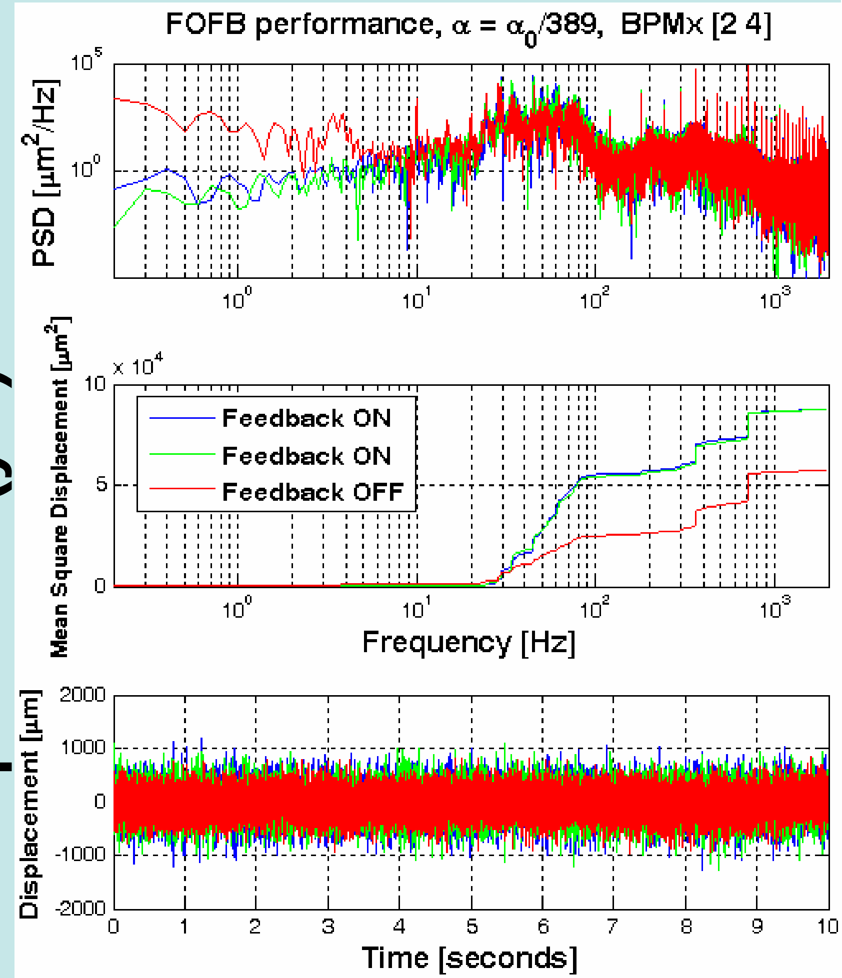


Orbit stability in low α

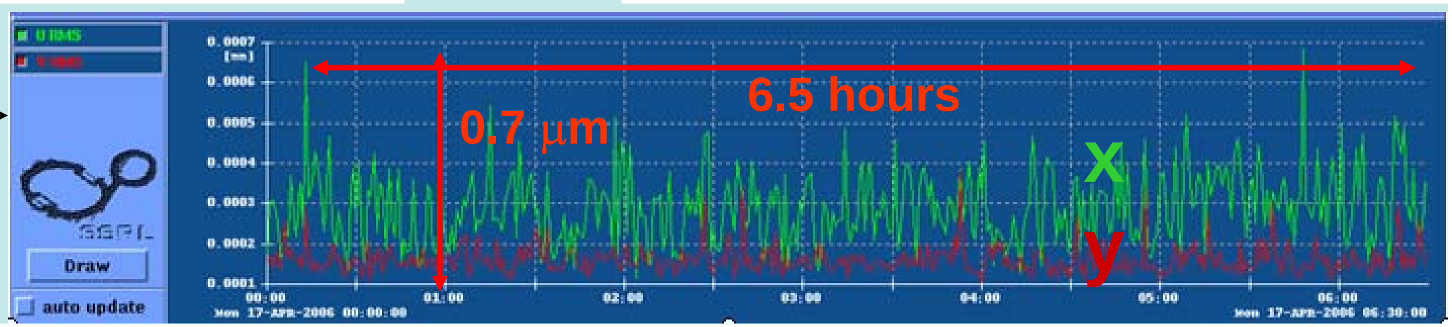
Large x-orbit variations ~η (no feedback)



Feedback doesn't fix high frequencies (yet)



Feedback fixes slow x motion

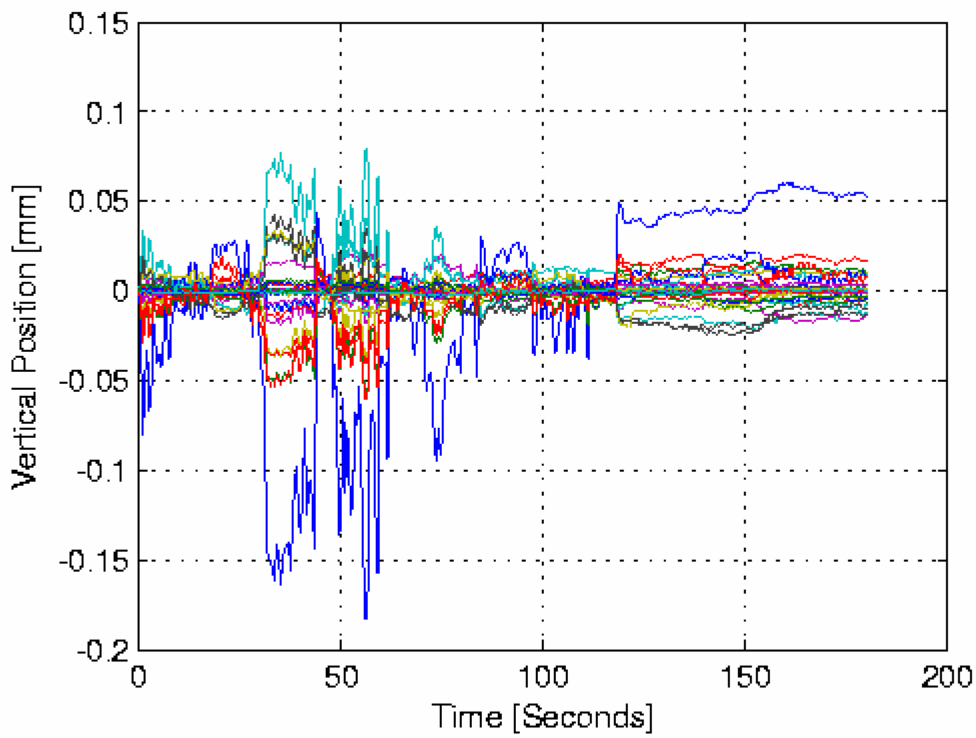


BPM performance at low current

- Beam position monitors noisy on west side of ring (BL1,2,11) at low current.
- RF (476 MHz) getting into BPM electronics.
- On east side, BPM noise ~1μm at 0.3 mA.

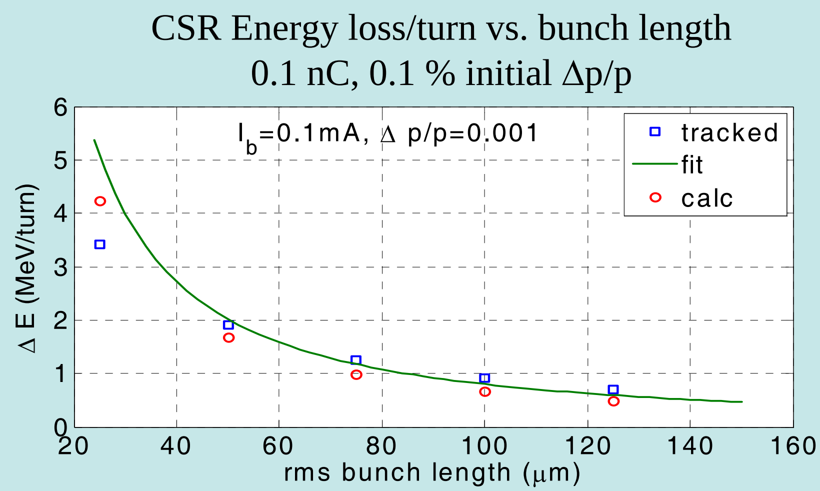
BPM performance, west side:

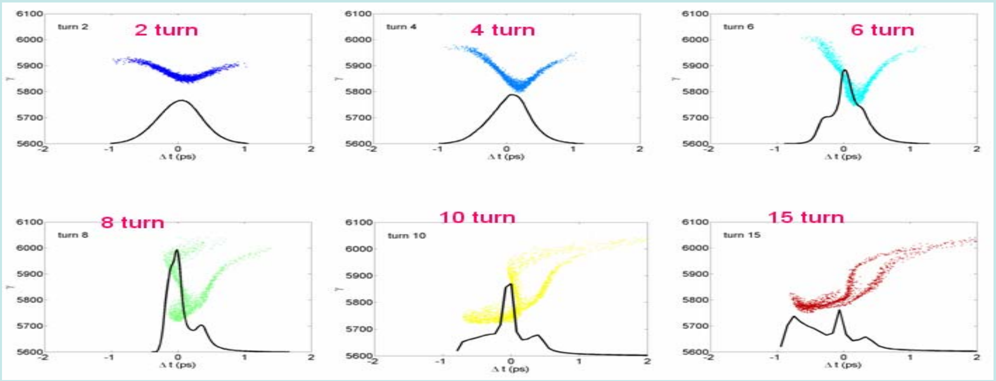
Stored current	BPM noise level (~peak)
0.3 mA	1000 μm
1.2 mA	200 μm
5 mA	40 μm



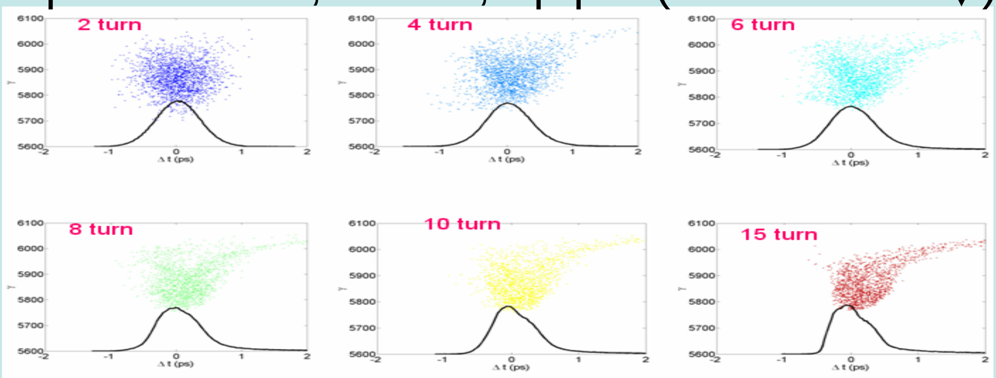
Injected Beam Mode

- Inject short pulses into SPEAR (from SLAC linac?) & circulate until bunch length degrades.
- Desired: 1 psec FWHM, 1 nC, 50-100 turns.
- Simulations show:
  - 1 psec FWHM, 0.8 nC, 15 turns
  - Requires ~6 MV RF for CSR losses … $$.
- Measurements at NewSUBARU
  - 1 GeV ring at Spring-8
  - 6 psec FWHM, 0.02 nC lasted 50 turns





1 psec FWHM; 0.8 nC; Δp/p = (0.1% ↑ 1.0% ↓)



Tracking by X. Huang

Conclusions

- Low alpha lattice is ~ready to go
  - 7 psec rms at 100 mA; 1 psec at 0.3 mA
  - Could be CSR source as well
- Injected beam study ongoing.
- Plan to investigate crab cavity further.
- We're open to suggestions.