Bunch Manipulations in Synchrotrons

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- Cogging
- Slip Stacking
- Bunch Rotation
- Bunch Coalescing
- Barrier Buckets

Cogging

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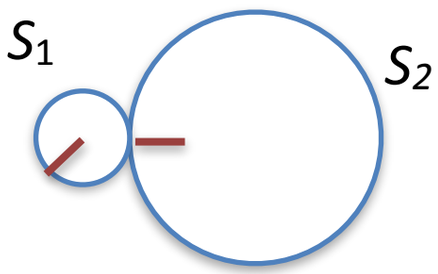
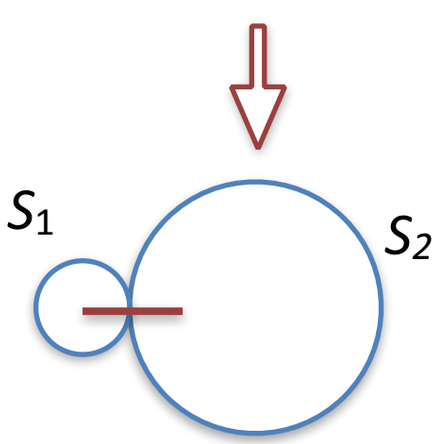
- Essentially, phase slippage by changing the relative momentum
- Ex: beam transfers between two synchrotrons





Suppose $C_2 = 2C_1$; want to inject bunch in synchrotron S_1 into a particular "bucket" location in synchrotron S_2

need to adjust the revolution frequency of one ring (pick S_1, say) until the two revolving "markers" line up

if $C_2 = 2C_1$ <<==>> $f_1 = 2f_2$, and may *never* line up!

So, make $\Delta\tau_1/\tau_1 = \eta\ \Delta p/p$ such that, after N turns,

$$N\ |\Delta\tau_1|\ =\ \Delta C_1/v$$

Cogging [2]

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$$\longrightarrow \qquad \frac{\Delta\tau}{\tau} = -\frac{\Delta f}{f} = -\frac{\Delta f_{\rm rf}}{f_{\rm rf}} = \eta\frac{\Delta p}{p}$$

Suppose want to "cog" beam by one RF bucket in S_1 … then $\Delta C_1 = C_1/h$

adjust $\Delta f_{\rm RF}$ which yields $\Delta\tau_1$ each turn; leave on for N turns; N = (time between buckets)/$\Delta\tau_1$

to cog by one bucket, $N\,|\Delta\tau_1| = 1/f_{\rm rf} \;\Rightarrow\; N\,(\tau_1\,\eta\,\Delta p/p) = 1/f_{\rm rf} \;\Rightarrow\; N\,\Delta p/p = 1/((\tau_1\eta h\, f_1)$

or, $N\,\Delta p/p = 1/(\eta h)$

Note: when generate an average $\Delta p/p$, the average horizontal displacement in the synchrotron at a particular position where there is ***dispersion*** will be $\Delta x = D\,\Delta p/p$.

Thus, $N\,\Delta x = D/(\eta h)$

Ex: Suppose we can accommodate radial motion on the scale of 10 mm where the dispersion function has value 2.5 m in a synchrotron with η = 0.05 and h=100. Then, to cog by one RF bucket would take N = (2.5 m / 0.01 m) / (0.05 * 100) = 50 revolutions.

Ex: Slip Stacking (ex: FNAL Main Injector)

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- Essentially "cogging" during injection
  - inject ~ 1/2-circumference-worth of beam
    - » accelerate slightly —> moves orbit outward
      - (use RF system "A", say)
  - inject 2nd batch into the ring, behind the first batch
    - » decelerate slightly —> moves orbit inward
      - (using RF system "B", say)
- Δp between these 2 orbits implies they will "slip" in time until they line up
- re-capture with a higher voltage RF in order to match the bucket shape to the beam emittance

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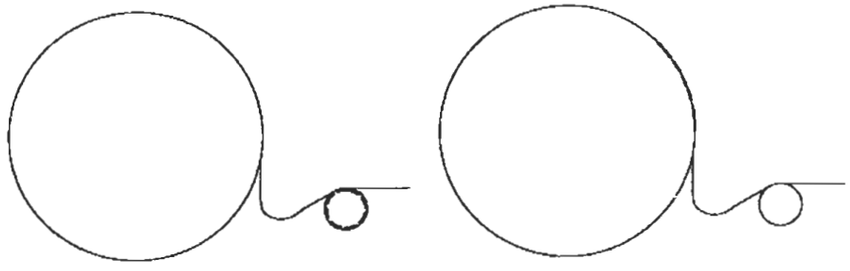
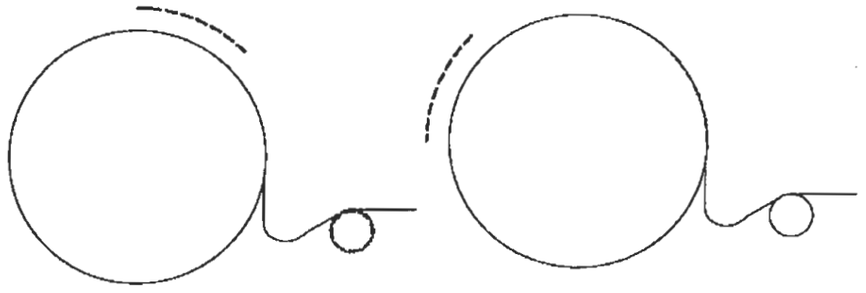
Slip Stacking cartoon (1)



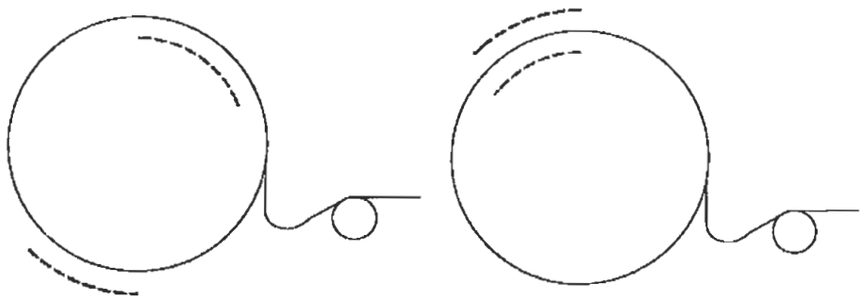
- First Booster Batch accelerated in Booster
- First Booster Batch injected onto MI central orbit with RF system A

Slip Stacking Cartoon (2)



- First Booster Batch slightly accelerated in MI with RF System A
- Second Booster Batch accelerated in Booster
- Second Booster Batch injected onto MI central orbit with RF system B

Slip Stacking Cartoon (3)



- Second Booster Batch slightly decelerated in MI with RF System B
- Wait till batches line up and snap on RF system C while turning of RF systems A & B

Protons on Target, I. Kourbanis

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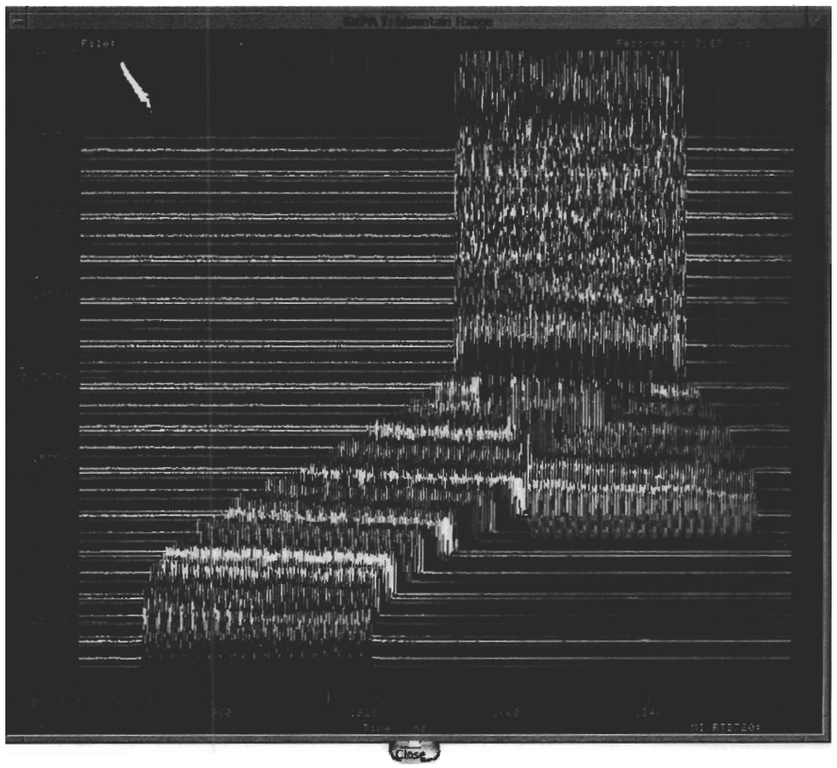

data

Bunch Rotation

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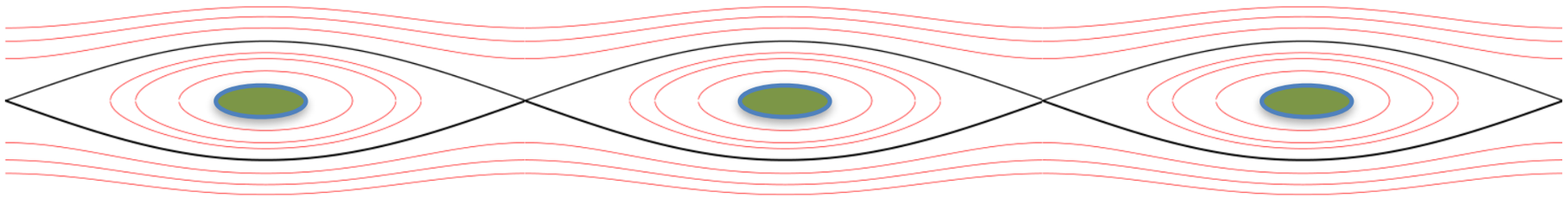
start:



Bunch Rotation

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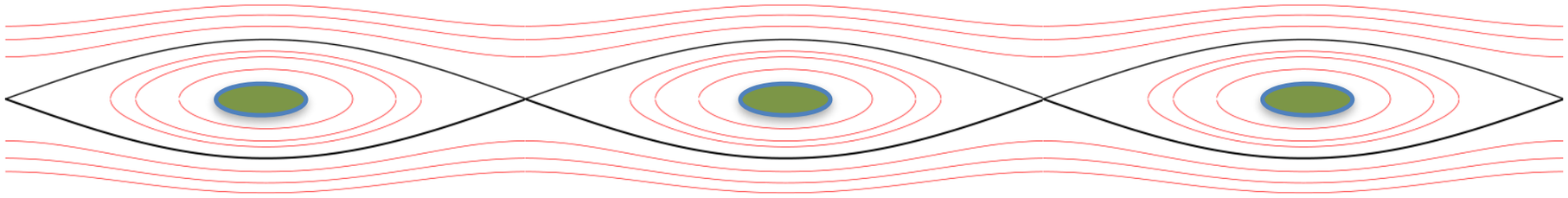
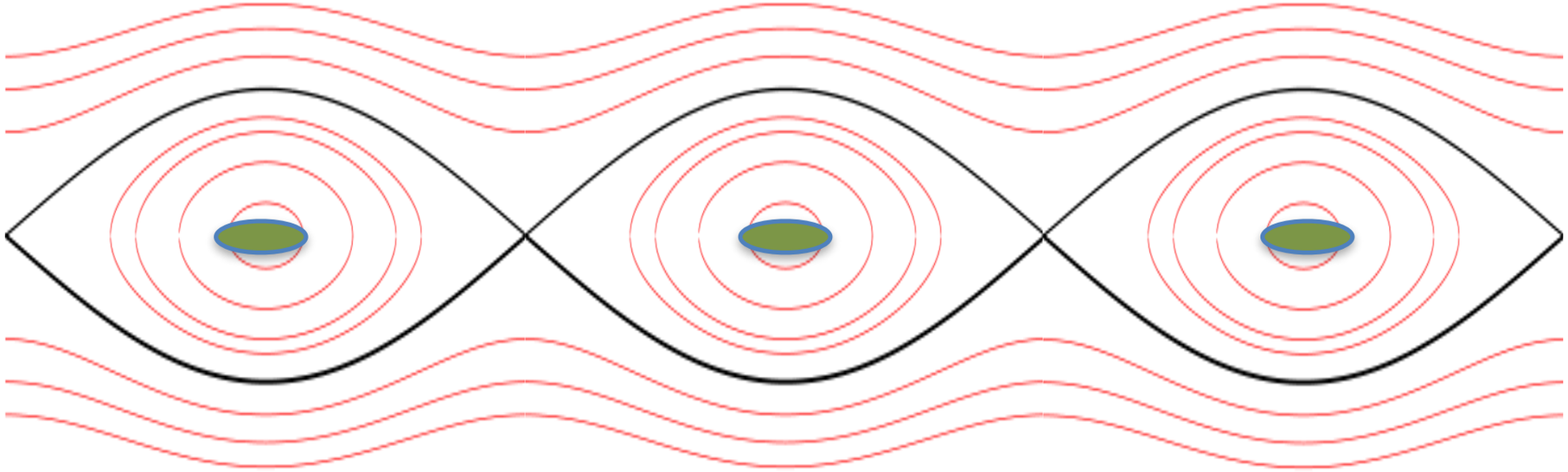


instantly raise RF voltage…

bunches will begin to rotate in phase space:



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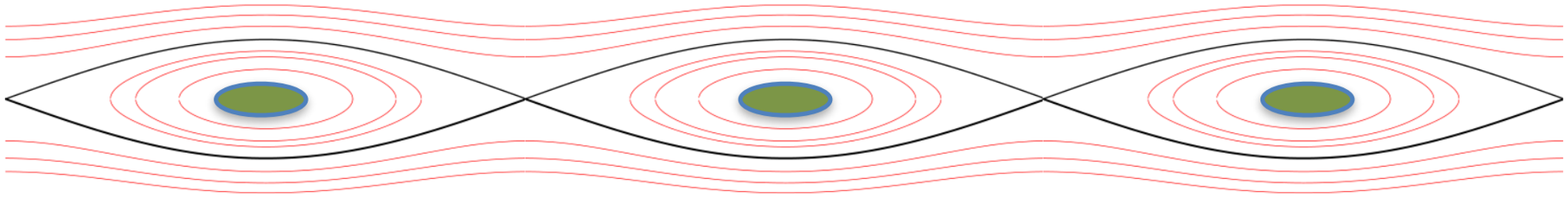

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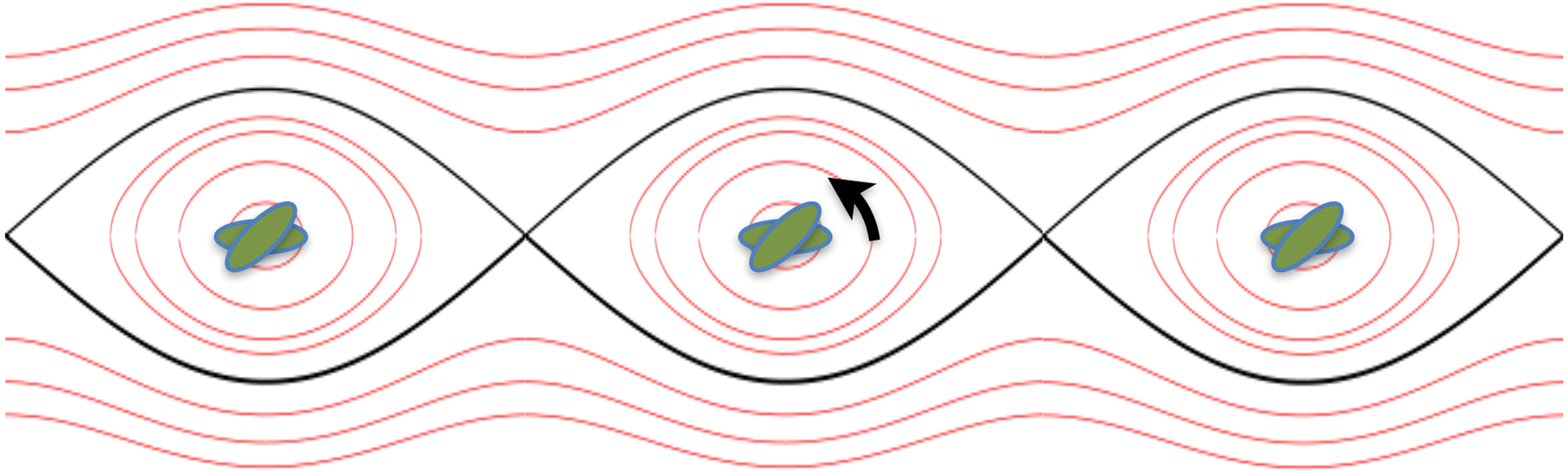

when rotated by 90^{o} can rapidly switch to a higher-harmonic RF system in order to maintain the shorter bunch length; *or*, for example, extract the beam and send to a target!

Bunch Coalescing

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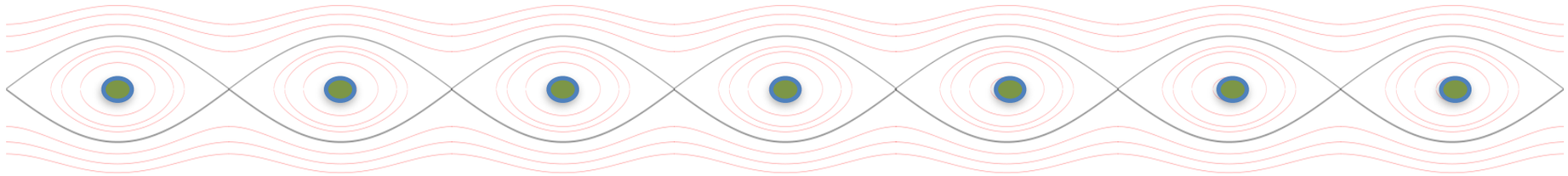
similar to bunch rotation, but also involves a change in RF frequency (harmonic)



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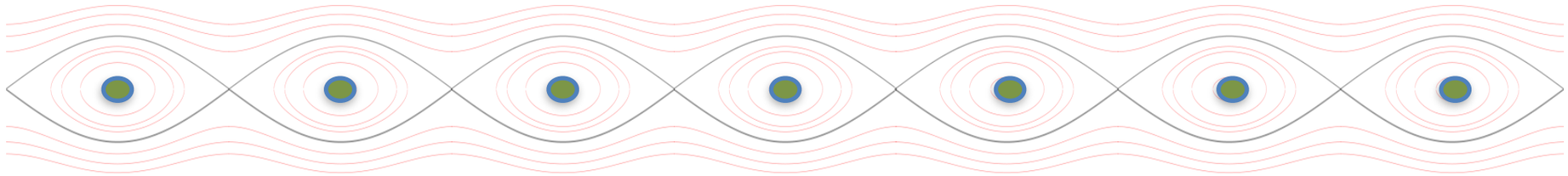
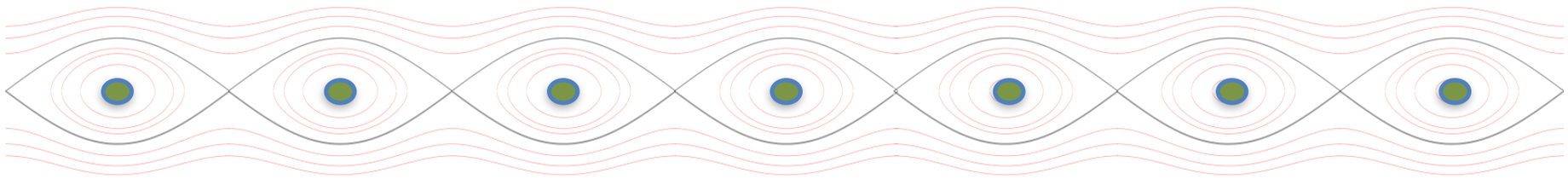


switch off high frequency, low voltage system,
switch on low frequency, high voltage system…



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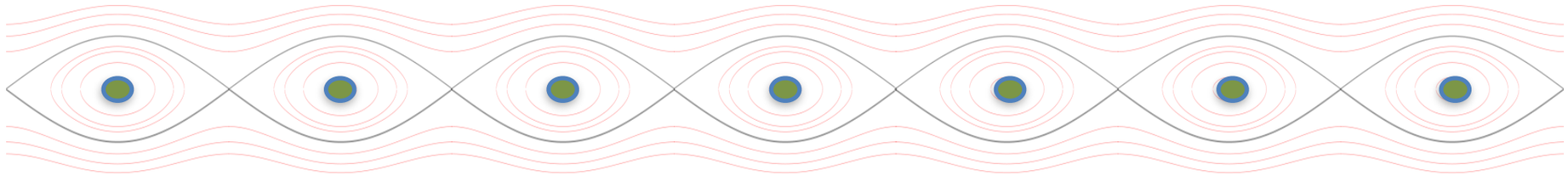

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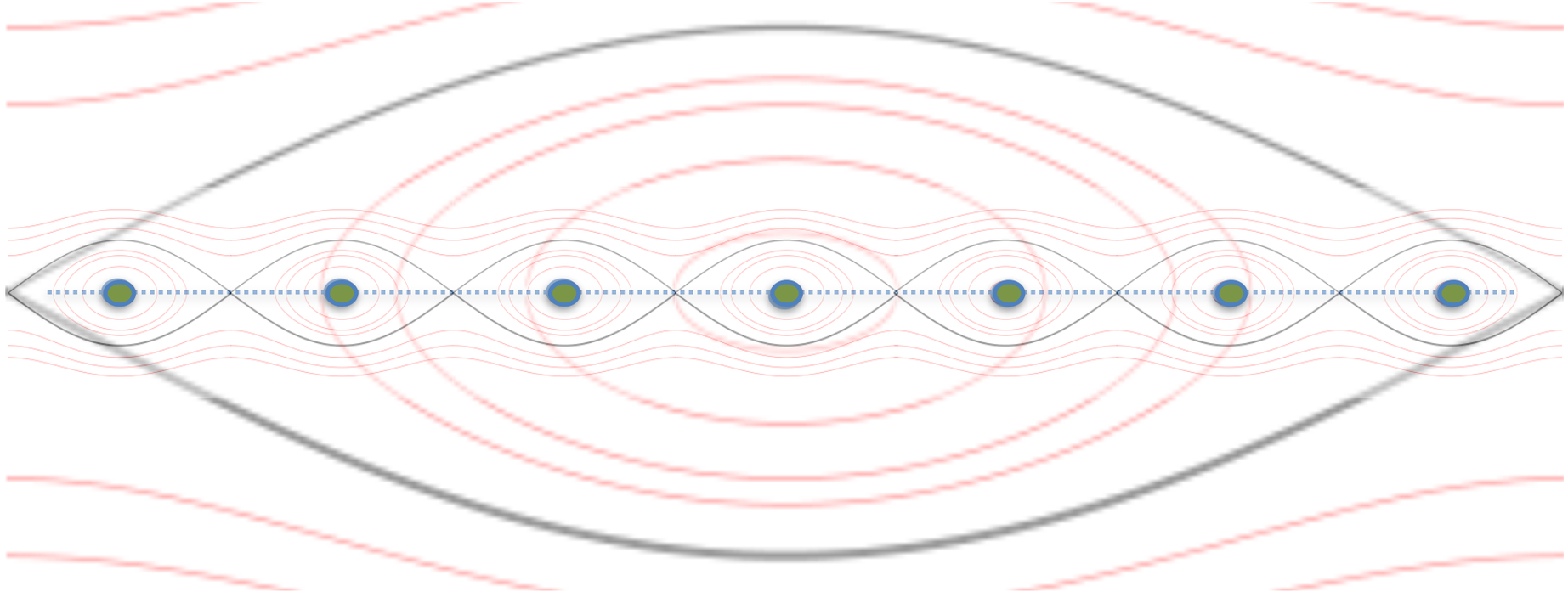

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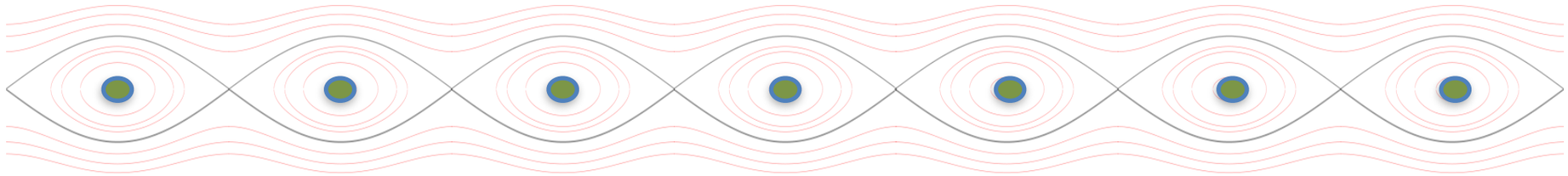

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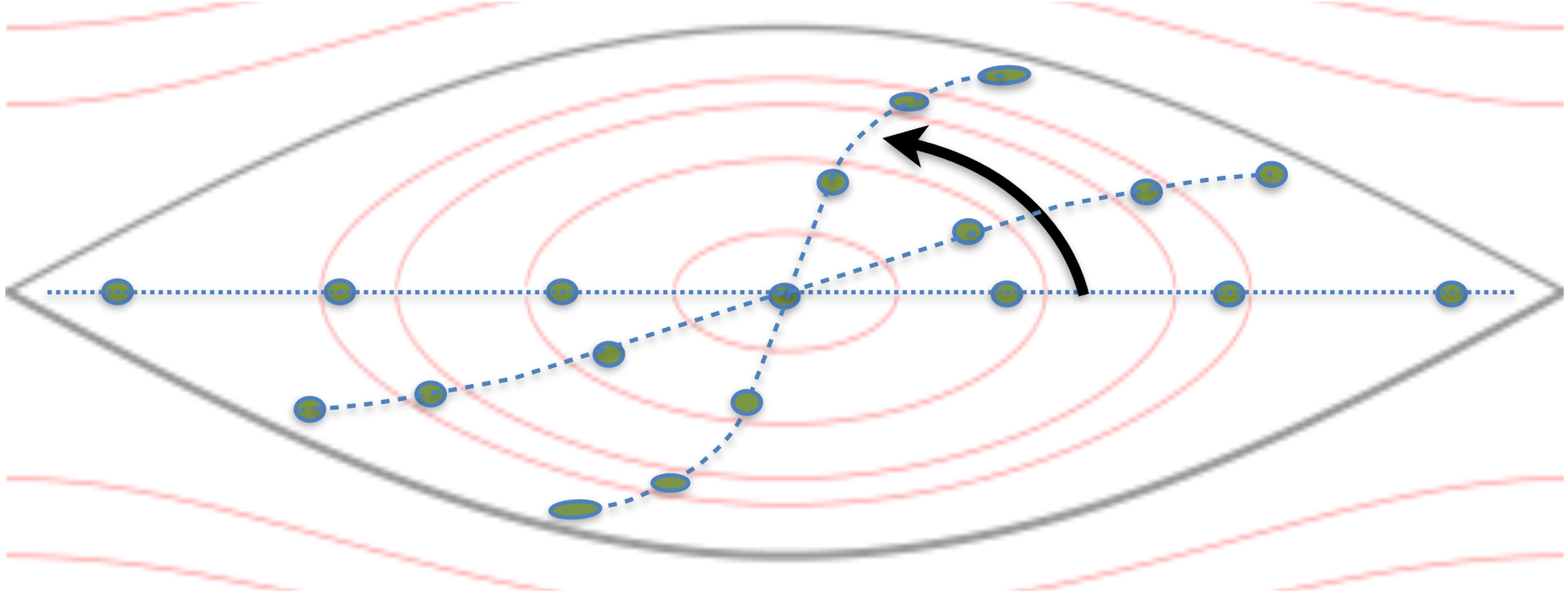

Bunch Coalescing [2]

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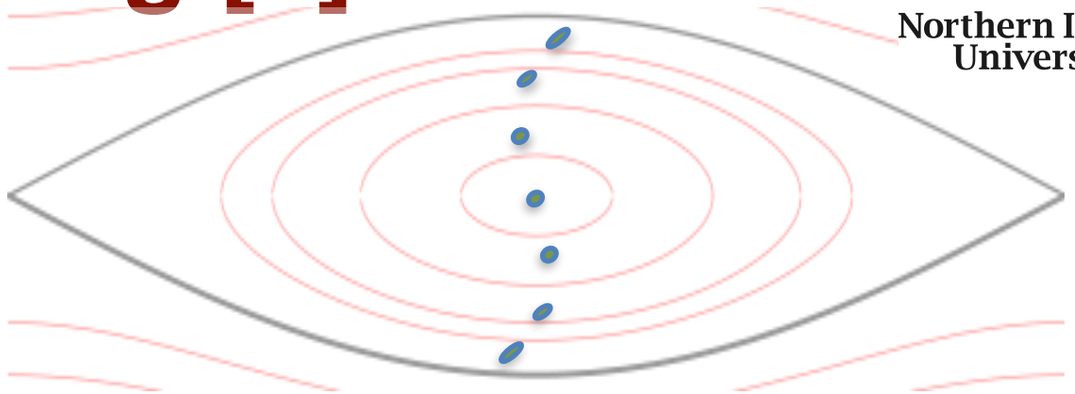
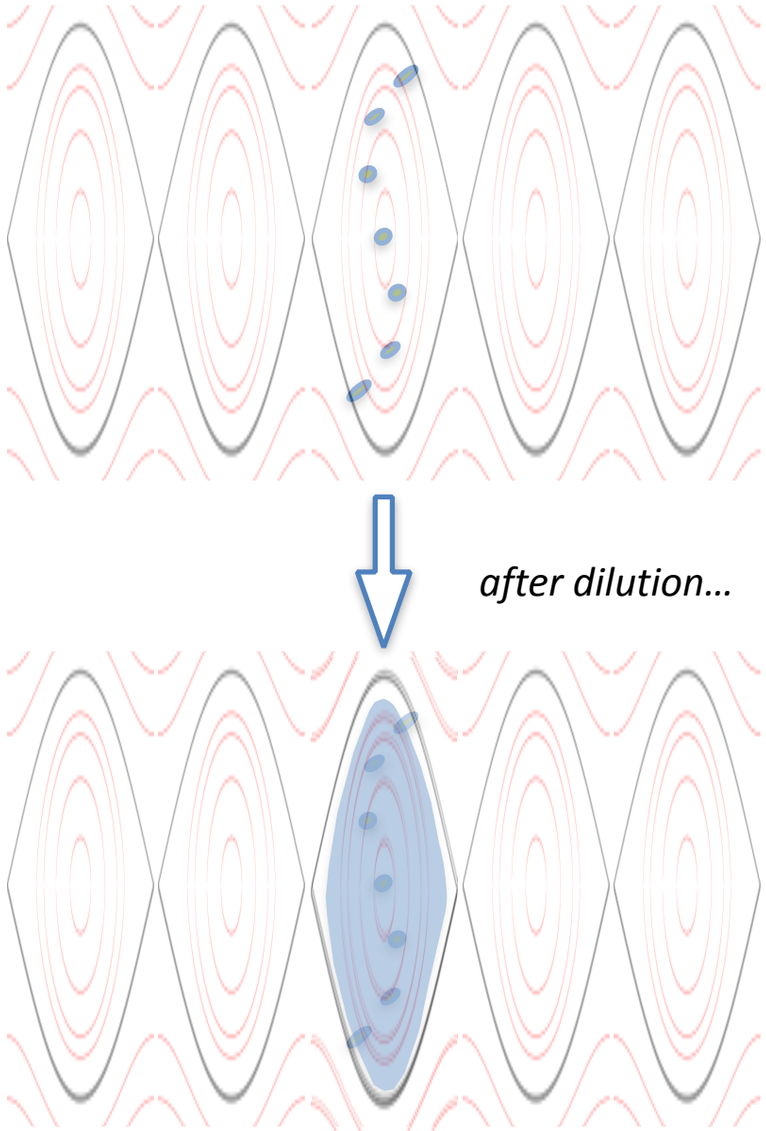
- Can use coalescing techniques to take bunched beam from one accelerator, make intense bunches, and inject into downstream accelerators to increase bunch intensities

- downside: increased longitudinal emittance



then, recapture with the original harmonic system @ higher voltage



Barrier Bucket(s)

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- Use a ***pulsed*** RF waveform to produce a "barrier" potential to contain (or exclude) beam in certain lengths of the circulating beam
- provides essentially DC beam, with a "gap" or gaps, which might be useful to provide time for kicker magnets to energize (injection, extraction) or for performing bunch compression to make room for incoming pulses of particles
- can adjust pulse separation, voltages adiabatically in order to control beam density, etc.