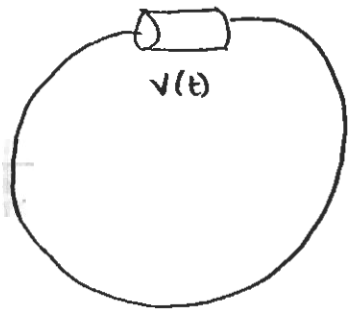
RF MANIPULATIONS IN SYNCHROTRONS

MJ3

SYNCHROTRON PRINCIPLE



$$V(t) = V \sin 2\pi f_{RF}(t - t_0)$$
$$= V \sin\phi$$

where $\phi = 2\pi h \frac{t}{T} + \phi_s$

"ideal" or "synchronous" particle: $t = T$ for one revolution

$\therefore \quad \phi = \phi_s + 2\pi h$, h = integer "harmonic number"

energy gain per turn: $\frac{dE_s}{dn} = eV \sin\phi_s$

$\phi_s = 0, \pi \longrightarrow$ no acceleration

otherwise, $\frac{dE}{dt} = f_0 \, eV \sin\phi_s$

slowly (adiabatically) move ϕ_s linearly from $\phi_s = 0$ (or π)

$$\Rightarrow \frac{dE}{dt} = f_0 \, eV \, \dot{\phi}_s t \qquad \dot{\phi}_s = \text{constant}$$

$$\Rightarrow E(t) = \underbrace{\tfrac{1}{2} f_0 \, eV \dot{\phi}_s t^2 + E(0)}_{\text{parabola}}$$

likewise, if raise $\vec{B}$ field parabolically, the corresponding ϕ_s will slide linearly; if raise $\vec{B}$ adiabatically, particle motion amplitude will be preserved.

<u>adiabatic</u>: parameter λ of the system is changed slowly w.r.t. period of oscillation

$$\frac{d\lambda}{dt} \Big/ \left(\lambda / T_s\right) \ll 1$$

(BASIC Program)

Let's talk about ...

a) cogging

i) transfers between synchrotrons

ii) p-$\bar{p}$ cogging in TEVATRON

b) slip stacking

c) bunch rotation

d) coalescing

e) barrier buckets

Cogging

essentially, phase slippage by changing relative momentum

i) transfers between synchrotrons

ex:

suppose $C_2 = 2C_1$; want to inject bunch in S_1 into particular bucket location in S_2

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

if $C_2 = 2C_1 \Leftrightarrow f_1 = 2f_2$, may never line up!

$\therefore$ make $\frac{\Delta T_1}{T_1} = \eta \frac{\Delta p}{p}$ such that after N turns,

$$N|\Delta T_1| = \frac{\Delta C_1}{v}$$

ii) $\bar{p}-p$ cogging in TEVATRON

RF layout @ Fϕ [see slide]

can adjust V, f_{RF} of cavities A, B $\rightarrow$ p, $\bar{p}$ separately

$\therefore$ adjust revolution time of p relative to $\bar{p}$, say

$$\Rightarrow \quad \frac{\Delta T}{T} = \eta \frac{\Delta p}{p} = -\frac{\Delta f_{RF}}{f_{RF}}$$

suppose want to "cog" by one bucket...

adjust Δf_{RF} which yields ΔT each turn; leave on for N turns

$$N = \frac{\text{time between buckets}}{\Delta T}$$

$$\Rightarrow \quad N = \frac{T/h}{\Delta T} = \frac{f_{RF}}{\Delta f_{RF}} \cdot \frac{1}{h} = \frac{f_0}{\Delta f_{RF}}$$

or, leave on for time $N \cdot T = \dfrac{f_0 T}{\Delta f_{RF}} = \dfrac{1}{\Delta f_{RF}}$

suppose $\Delta f_{RF} = 50\,\text{Hz} \rightarrow NT = 20$ msec to cog by 1 bucket

TEVATRON INJECTION [see slide]

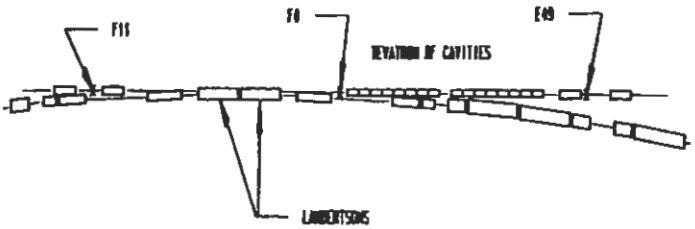


Figure 4: Plan view of F0 straight section.

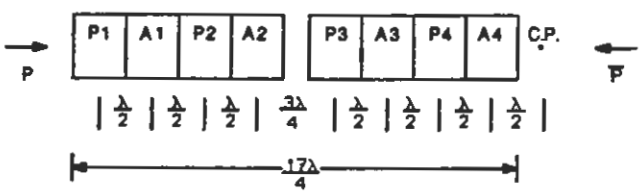


Figure 5: RF cavity placement at F0.

kickers are outside of the straight section proper; their location is not shown in the figure. The phase advance between septa anad kickers is more favorable with the septa located at the north end of F0.

To allow for independent high voltage control for the proton and antiproton beams, pairs of cavities need to be separated by an odd number of quarter RF wavelengths. Each cavity is one half wavelength long, so that the entire system of eight cavities requires 4.25 wavelengths, as depicted in Figure 5. In this figure, the pairs of cavities P1-P3 anad P2-P4 are used for proton acceleration, while A1-A3 and A2-A4 are used for antiproton acceleration. The center of cavity A4 is located one half wavelength from the proton-antiproton collision point.

The cavity phasing is shown in Figure 6. Here, the circled arrows indicate the direction of the cavity field when the synchronous particle is present. The upper portion of the figure illustrates a synchronous proton moving left to right, while the lower portion of the figure illustrates a synchronous antiproton moving

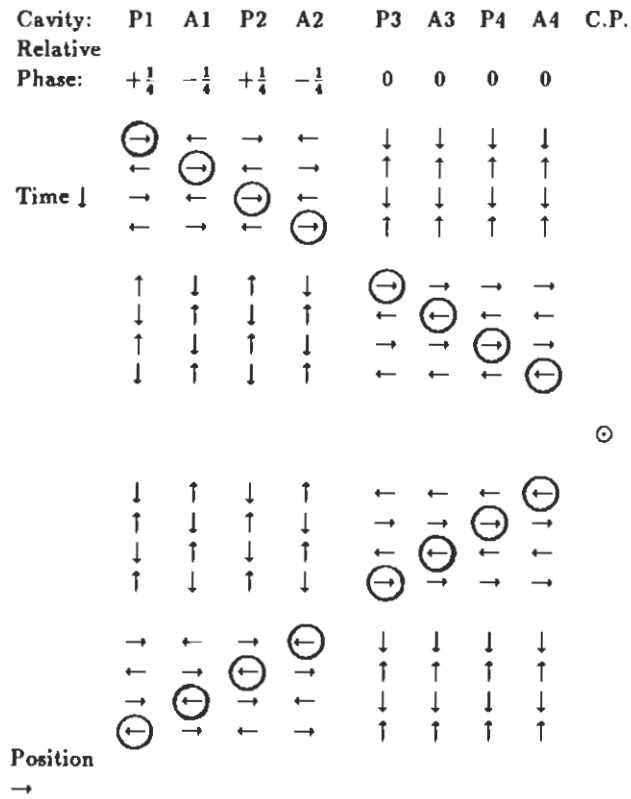


Figure 6: RF cavity phasor diagram.

right to left. If one of the cavities trips off, an increase or a reduction of the RF bucket area by roughly 10% will be seen by each beam. No RF phase offsets are induced by a tripped station.

5 Concluding Remarks

The purpose of this report is to present the current status of the design of a new bigh energy superconducting synchrotron for the Fermilab upgrade program. Much work is necessary to turu this preliminary version into a full design. The low-beta lattice shown in Figure 3 has an unacceptable high dispersion point just outside the interaction region that must be improved upon. The lattice design must also include a program for tuning the optics from injection to the final value of β^*. Realistic schemes for providing separated orbits for the proton and antiproton beams have not yet been investigated. Nevertheless, we think that we have demonstrated that there is latitude within the constraints imposed by a near-fixed geometry to improve the lattice design for this synchrotron.

References

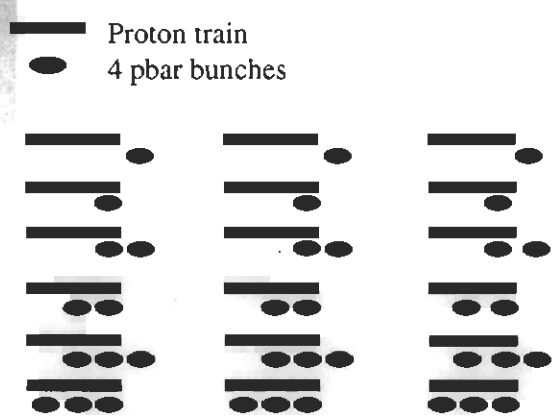
[1] A. A. Garren, M. J. Syphers, "1.8 TeV Tevatron Upgrade Lattices," these proceedings.

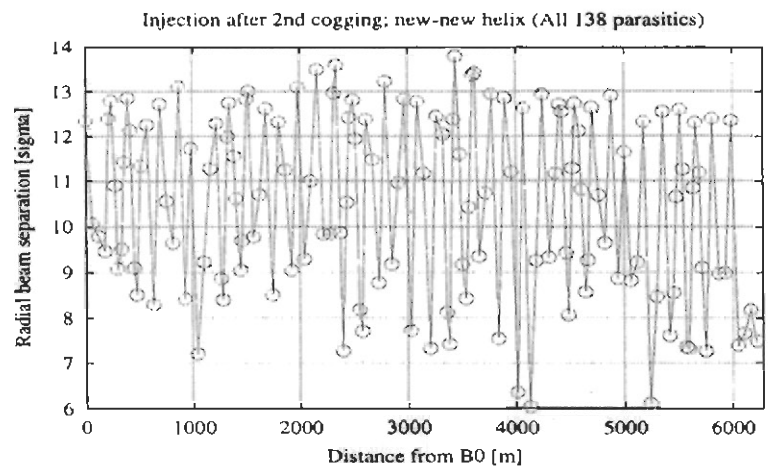
[2] M. Harrison, et al., "A High Field Dipole for the Tevatron Upgrade," these proceedings.

[3] S. Holmes, et al., "Upgrading the Fermilab Tevatron," these proceedings.

Cogging Stages

- Three cogging stages as inject antiprotons into Tevatron
- At each stage, lifetimes correlated with antiproton emittance, and depends upon bunch number
- **Dynamic aperture calculations** carried out
- Also observed:
  - Proton lifetime changes during antiproton injection; do the "weak" pbars influence the "strong" protons?





Slip stacking

essentially "cogging" during injection...

a) inject $\sim\frac{1}{2}$-circumference-worth into MI

b) accelerate slightly $\longrightarrow$ moves to different orbit, out
(uses RF system "A", say)

c) inject 2nd batch into MI in the remaining gap

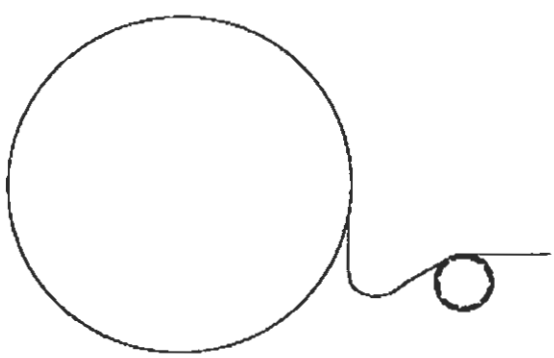
d) decelerate slightly $\longrightarrow$ moves orbit in, w/ system "B"

e) Δp on these 2 orbits $\longrightarrow$ $\Delta T/T = \eta\, \Delta p/p$ $\therefore$ will "slip" until they line up

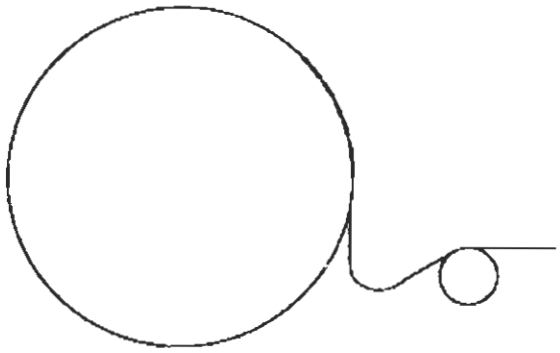
f) re-capture with higher voltage

[see slides from IK]

Slip Stacking cartoon (1)

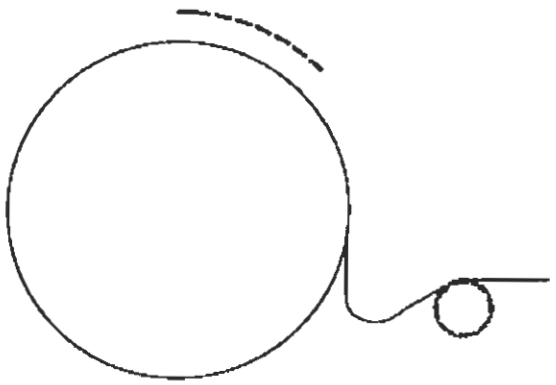


- First Booster Batch accelerated in Booster

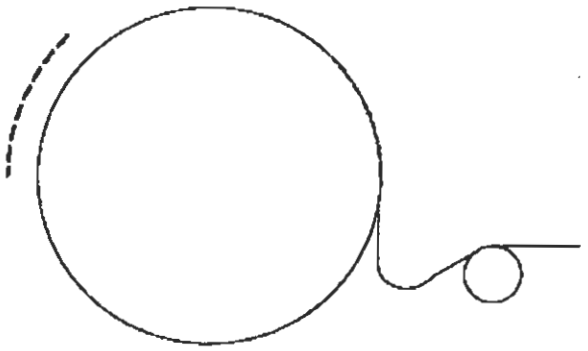


- First Booster Batch injected onto MI central orbit with RF system A

Slip Stacking Cartoon (2)

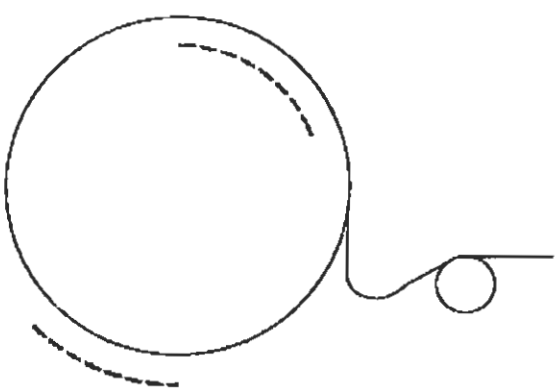


- First Booster Batch slightly accelerated in MI with RF System A
- Second Booster Batch accelerated in Booster

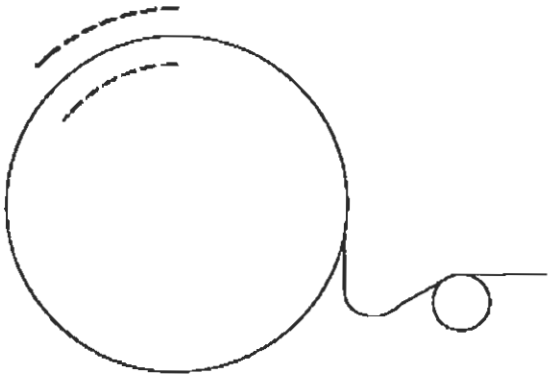


- Second Booster Batch injected onto MI central orbit with RF system B

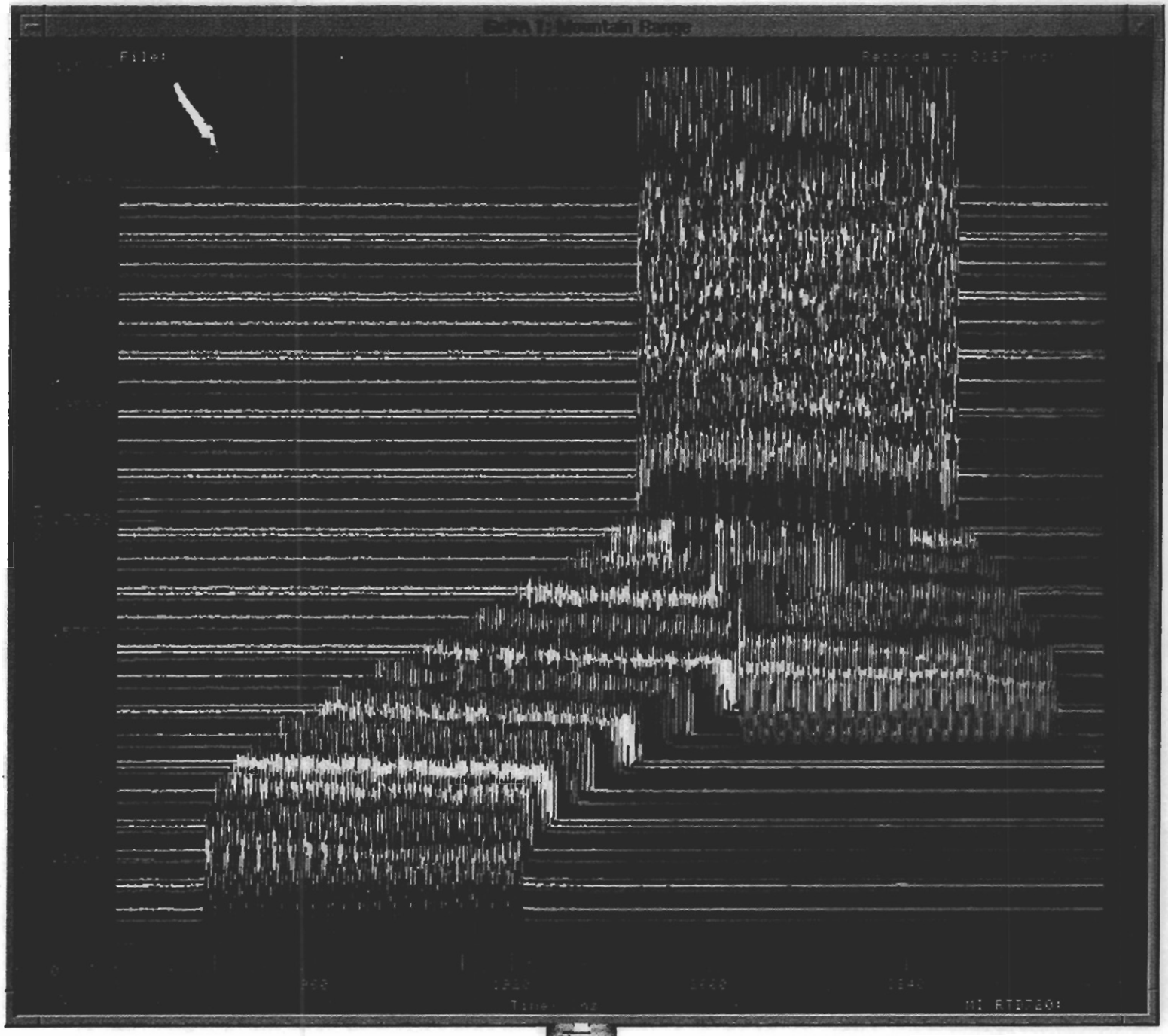
Slip Stacking Cartoon (3)



- Second Booster Batch slightly decelerated in MI with RF System B

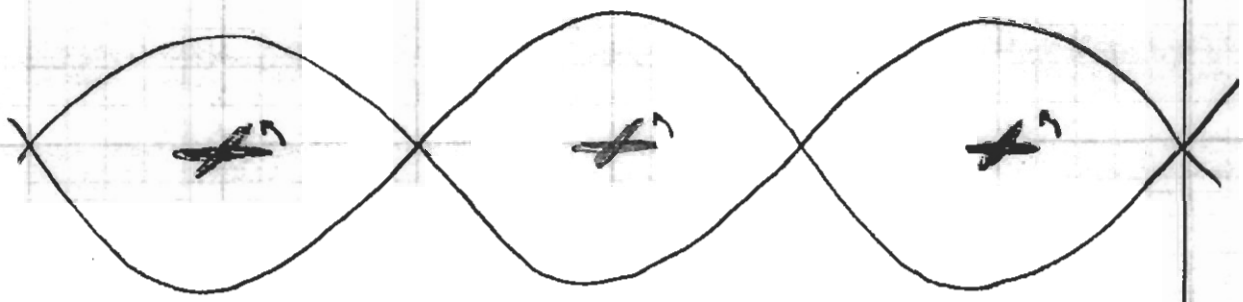


- Wait till batches line up and snap on RF system C while turning of RF systems A & B


ExPA 1: Mountain Range
File:
Time: ns
MI RTI720:
Close

bunch rotation

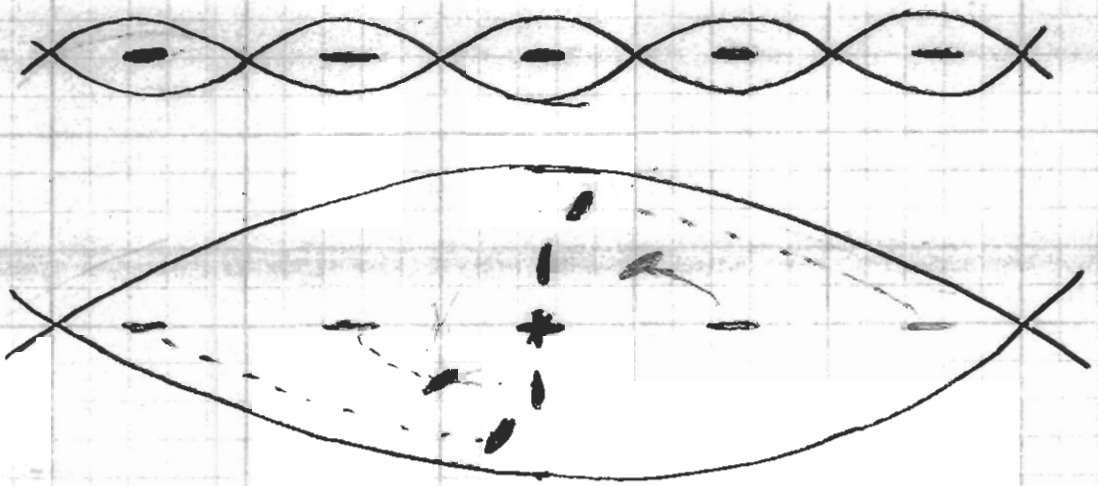
quickly raise voltage... bunches will rotate...

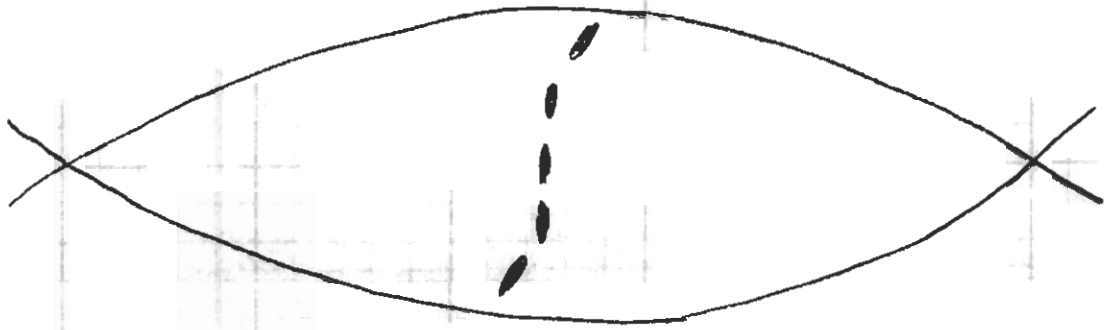


when rotated 90°, can capture with higher-harmonic RF system
or, for example, send to a target! ($\bar{p}$ source)

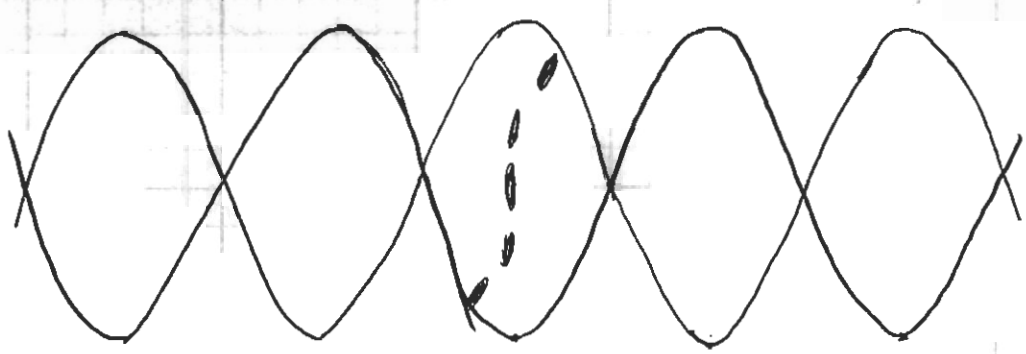
coalescing

similar, but also change RF frequency (harmonic)

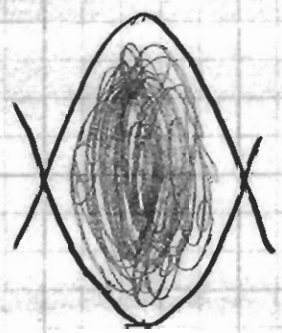




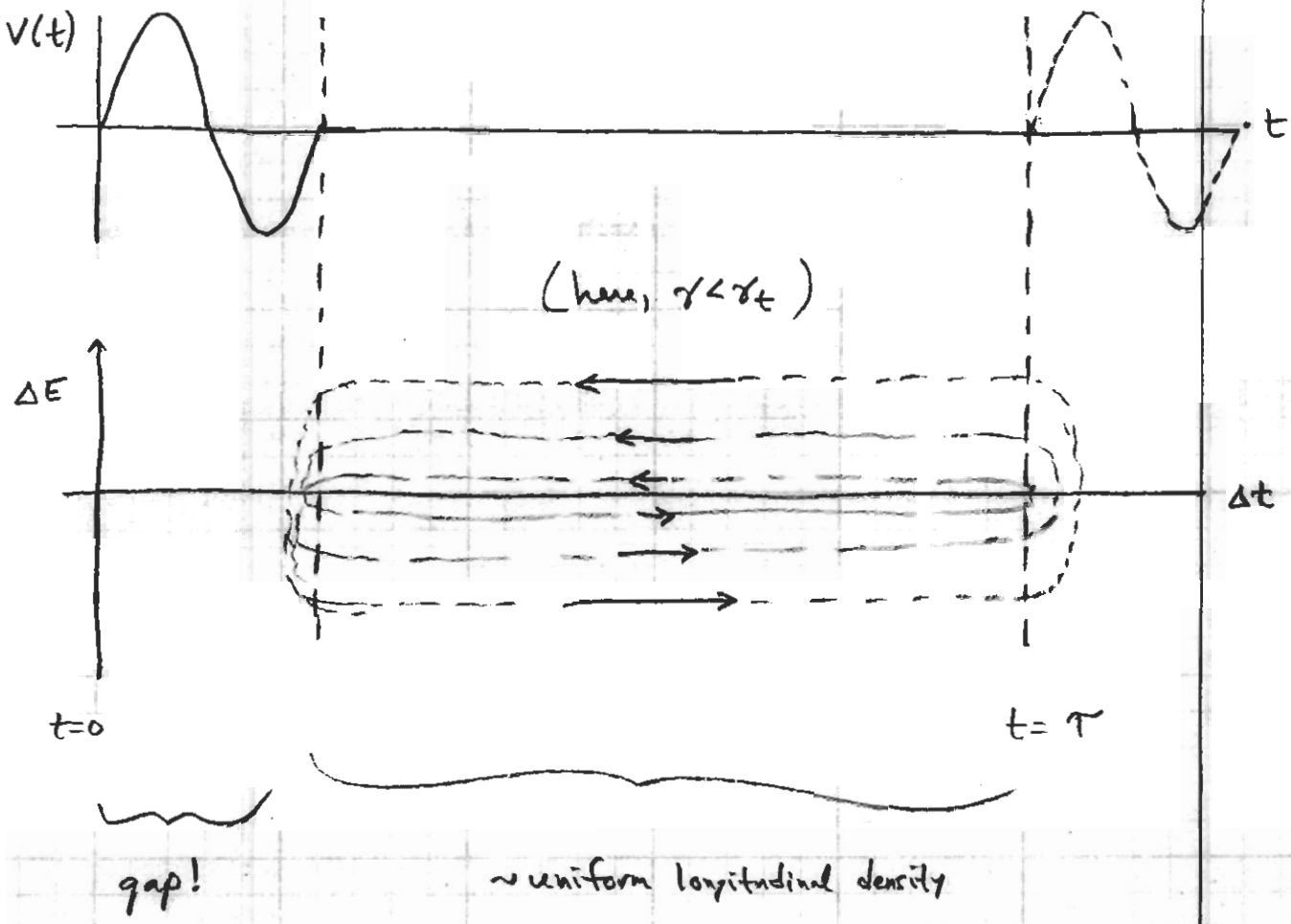
then, recapture w/ original harmonic system @ higher voltage



after dilution



barrier buckets



gap!

~ uniform longitudinal density