

# A Fourier Series Kicker for the TESLA Damping Rings

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LCRD 2.22

# Introduction

- The TESLA damping ring fast kicker must inject/eject every  $n^{\text{th}}$  bunch, leaving adjacent bunches undisturbed.
- The minimum bunch separation inside the damping rings (which determines the size of the damping rings) is limited by the kicker design.
- We are investigating a “Fourier series kicker” in which a series of rf kicking cavities is used to create a kicking function with periodic zeroes and an occasional spike.

# Outline

## Overview

- TESLA damping rings and kickers
- how a “Fourier series kicker” might work

$p_T$  and  $dp_T/dt$

Flattening the kicker's  $dp_T/dt$

Some of the other points:

- finite separation of the kicker elements
- timing errors at injection/extraction

Conclusions

# Illinois participants in LCRD 2.22

Guy Bresler (REU student, from Princeton)

Keri Dixon (senior thesis student, from UIUC)

George Gollin (professor)

Mike Haney (engineer, runs HEP electronics group)

Tom Junk (professor)

We benefit from good advice from people at Fermilab and Cornell. In particular: Dave Finley, Vladimir Shiltsev, Gerry Dugan, and Joe Rogers.

# Overview: linac and damping ring beams

## Linac beam (TESLA TDR):

- 2820 bunches, 337 nsec spacing (~ **300** kilometers)
- Cool an entire pulse in the damping rings before linac injection

## Damping ring beam (TESLA TDR):

- 2820 bunches, ~20 nsec spacing (~ **17** kilometers)
- Eject every  $n^{\text{th}}$  bunch into linac (leave adjacent bunches undisturbed)

17 km damping ring circumference is set by the minimum bunch spacing in the damping ring: Kicker speed is the limiting factor.

# Overview: TESLA TDR fast kicker

Fast kicker specs (à la TDR):

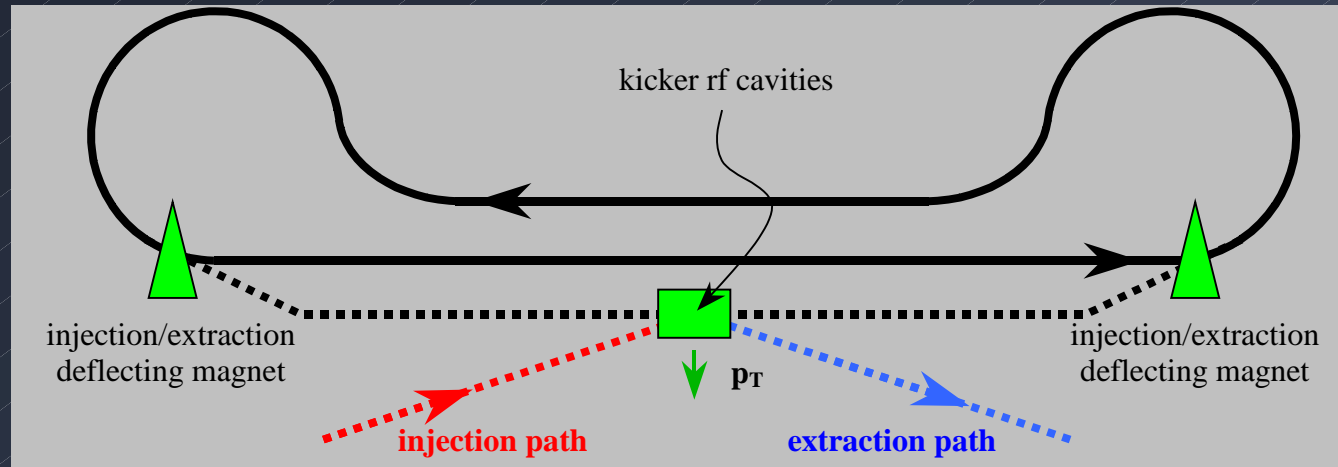
- $\int B dl = 100$  Gauss-meter = 3 MeV/c (= 30 MeV/m  $\times$  10 cm)
- stability/ripple/precision  $\sim .07$  Gauss-meter = 0.07

TDR design: bunch “collides” with electromagnetic pulses traveling in the opposite direction inside a series of traveling wave structures.

TDR Kicker element length  $\sim 50$  cm; impulse  $\sim 3$  Gauss-meter. (Need 20-40 elements.)

Structures dump each electromagnetic pulse into a load.

# Something new: a “Fourier series kicker”

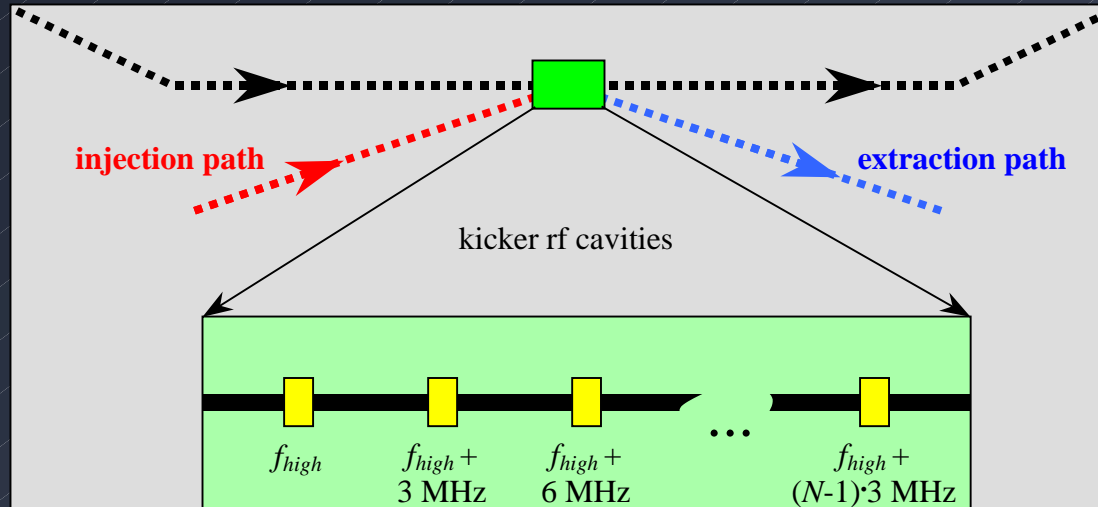


Fourier series kicker would be located in a bypass section.

While damping, beam follows the dog bone-shaped path (solid line).

During injection/extraction, deflectors route beam through bypass (straight) section. Bunches are kicked onto/off orbit by kicker.

# Fourier series kicker



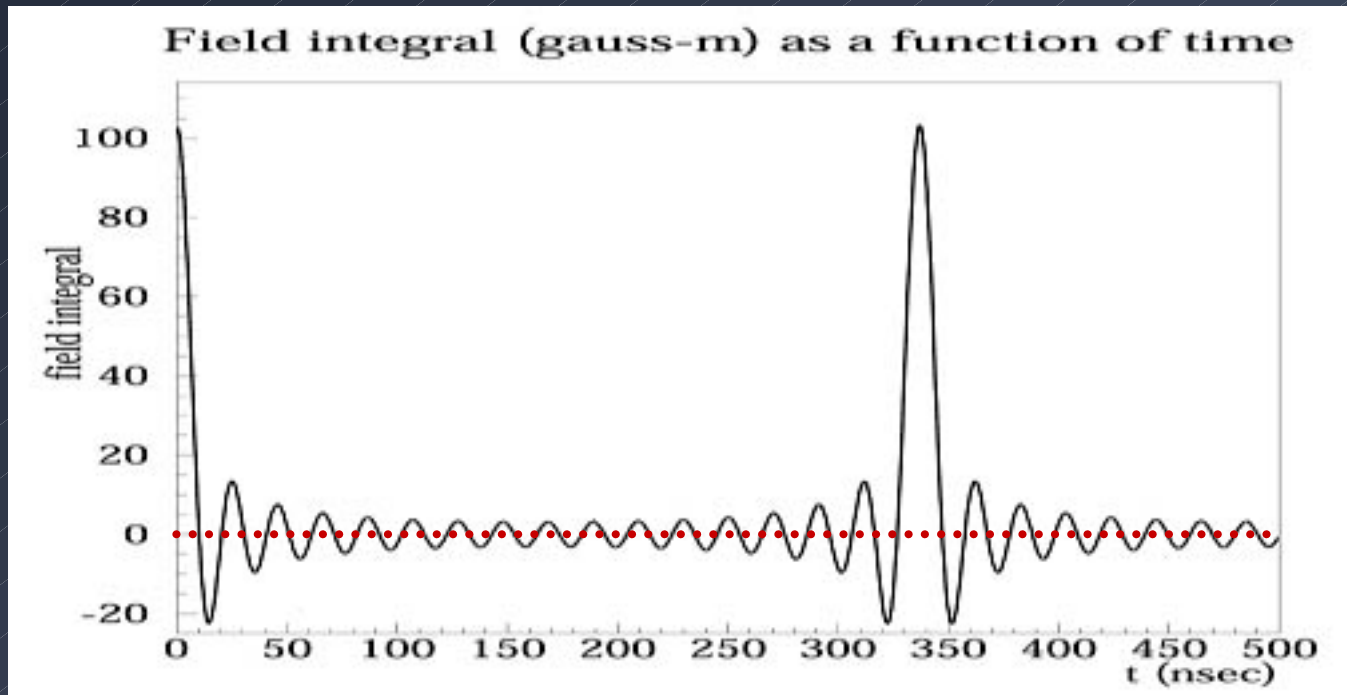
Kicker would be a series of  $N$  "rf cavities" oscillating at harmonics of the linac bunch frequency  $1/(337 \text{ nsec}) = 2.97 \text{ MHz}$ :

$$p_T = A \left[ \sum_{j=0}^{j=N_{cavities}-1} A_j \cos \left[ \left( \omega_{high} + j\omega_{low} \right) t \right] \right]; \quad \omega_{low} = \frac{2\pi}{337 \text{ ns}}$$

# Original idea

Run transverse kicking cavities at 3 MHz, 6 MHz, 9 MHz,...

Cavities oscillate in phase with equal amplitudes.

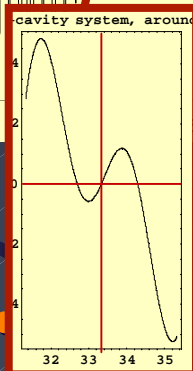
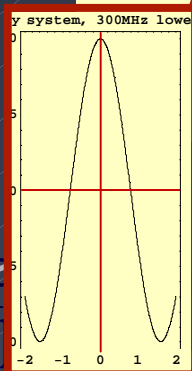
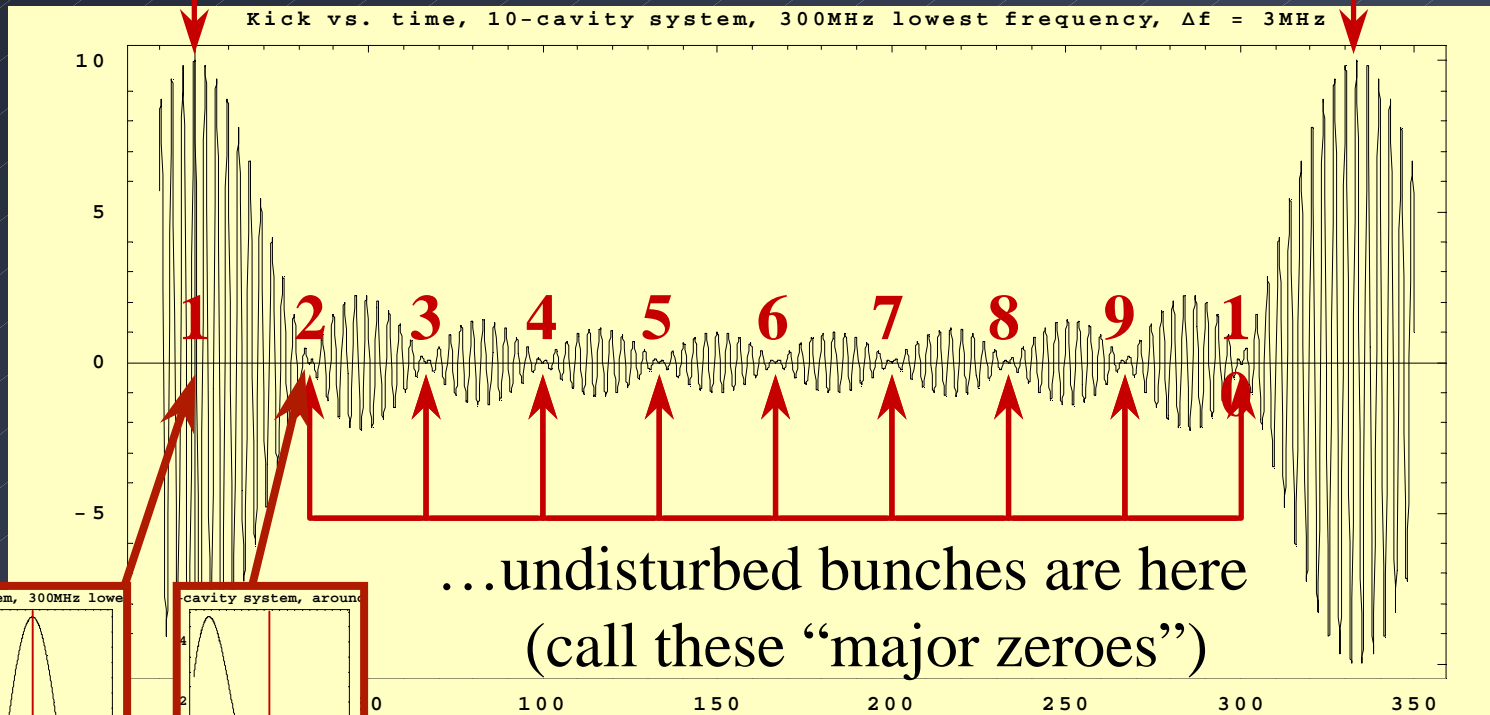


Problems: slope at zero-crossings might induce head-tail differences; LOTS of different cavity designs (one per frequency)

# Better idea: permits one (tunable) cavity design

Run transverse kicking cavities at much higher frequency; split the individual cavity frequencies by 3 MHz.

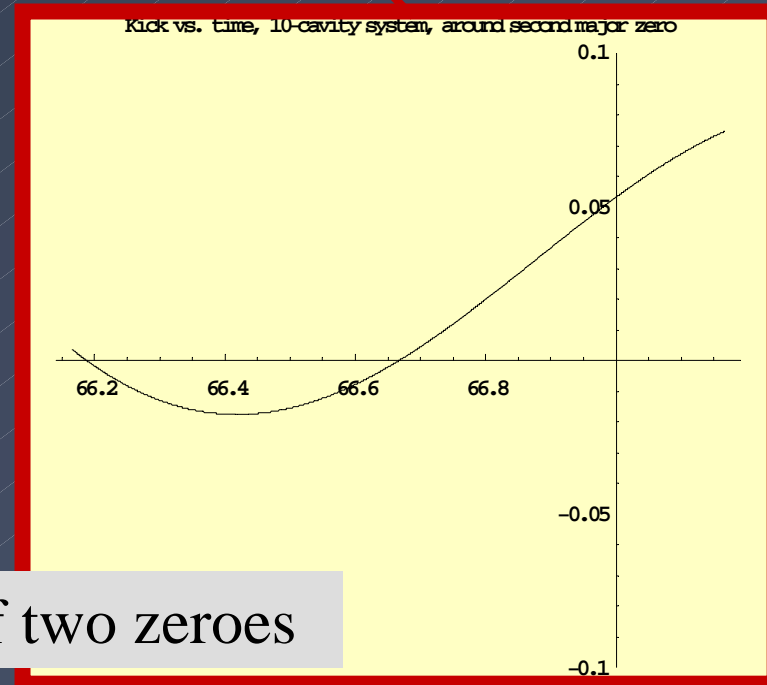
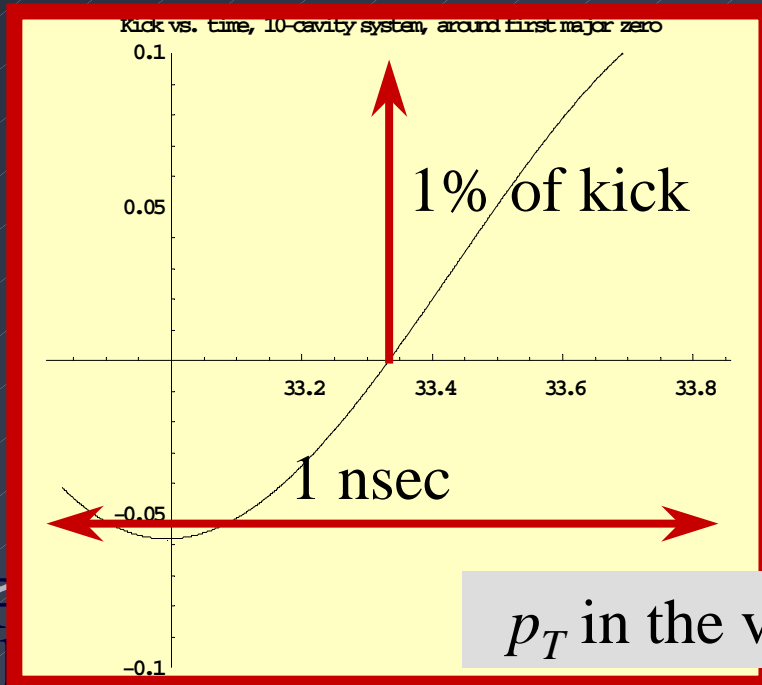
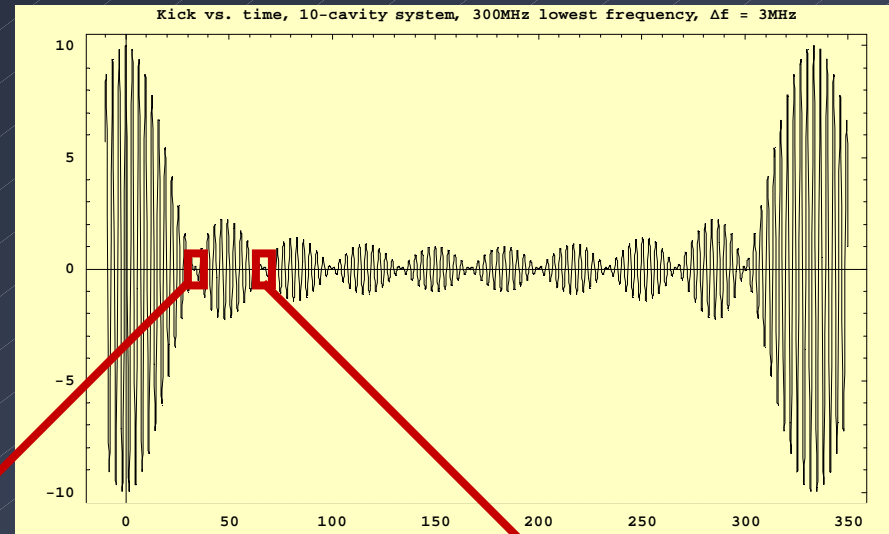
Kicked bunches are here



Still a problem: finite slope at zero-crossings.

# $dp_T/dt$ considerations

We'd like the slopes of the  $p_T$  curves when not-to-be-kicked bunches pass through the kicker to be as small as possible so that the head, center, and tail of a (20 ps rms) bunch will experience about the same field integral.

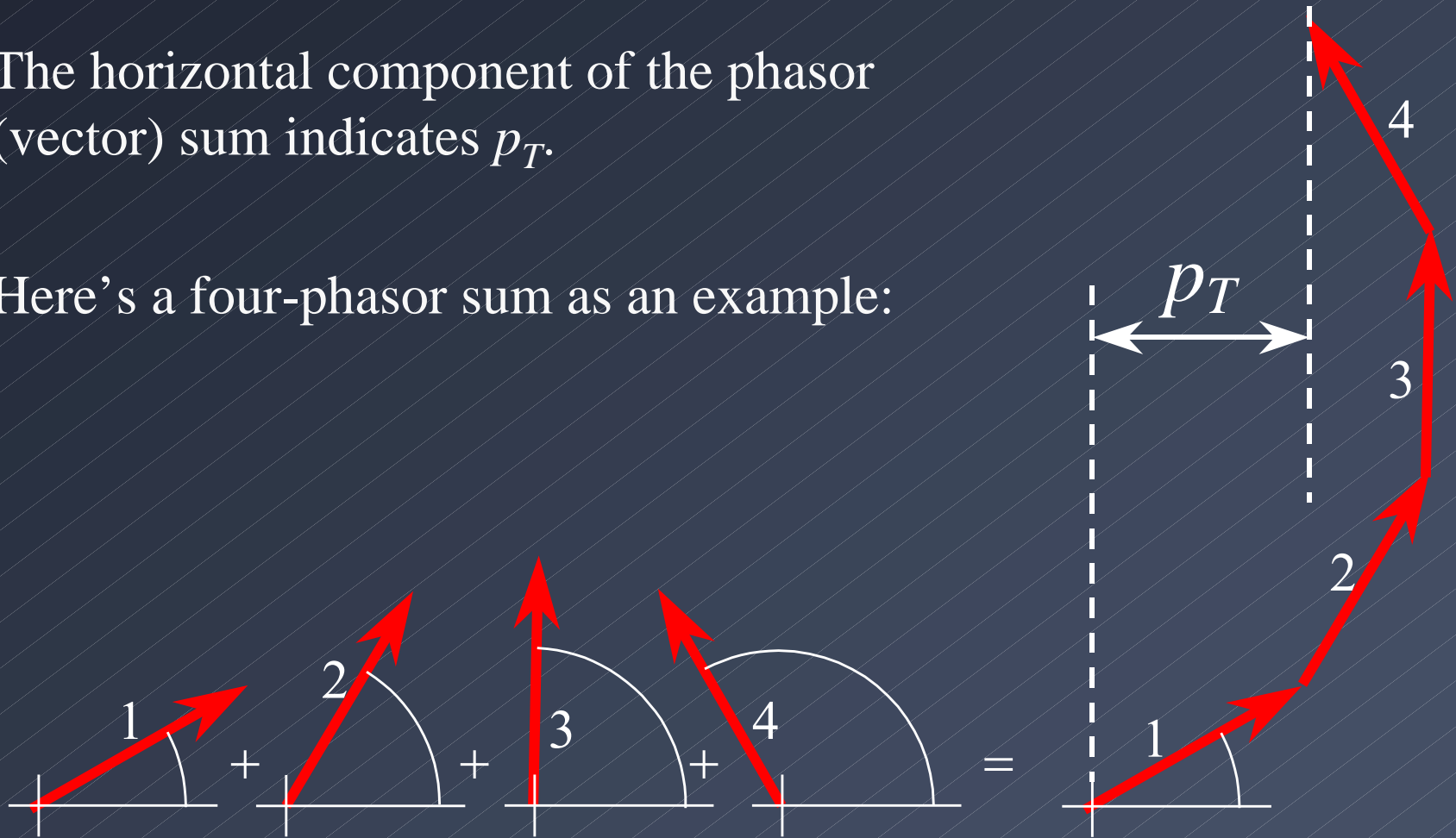


$p_T$  in the vicinity of two zeroes

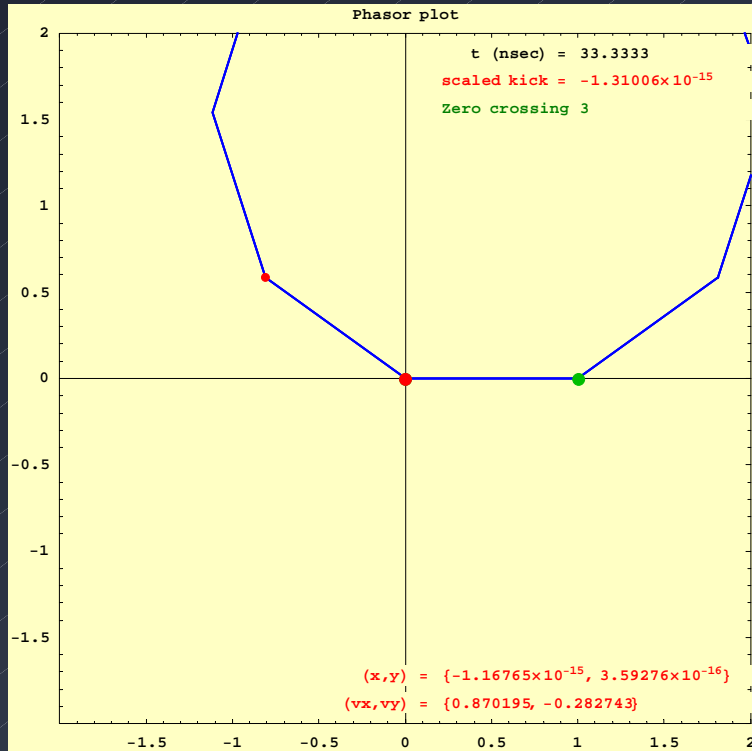
# Phasors: visualizing the $p_T$ kick

The horizontal component of the phasor (vector) sum indicates  $p_T$ .

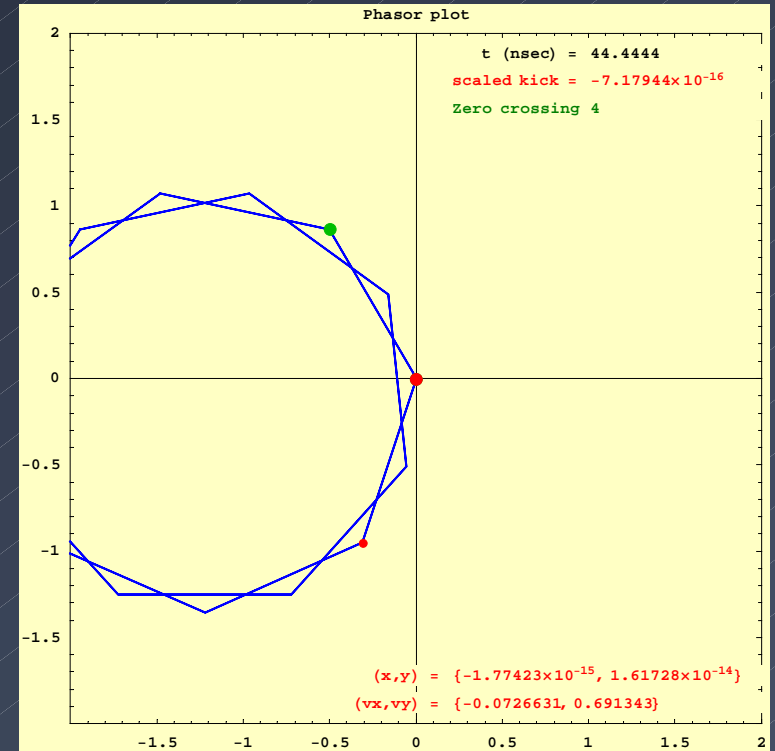
Here's a four-phasor sum as an example:



# Phasors when $p_T = 0$ (30 cavities)



zero #3



zero #4

# Flattening out $dp_T/dt$ at the zero-crossings

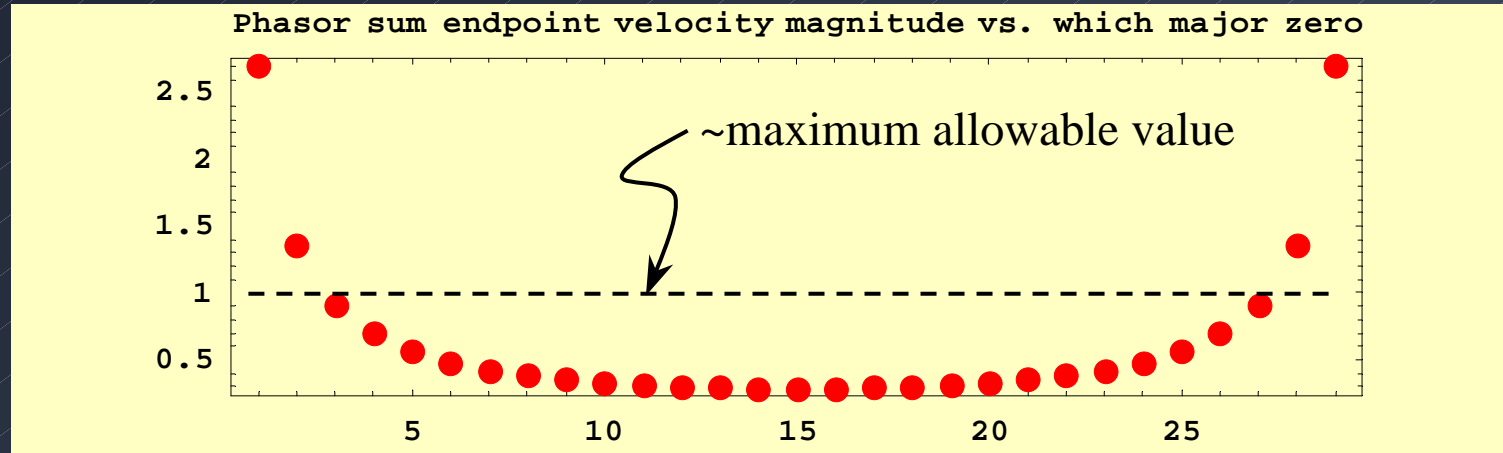
How large a value of  $dp_T/dt$  is acceptable?

- rms bunch length: 20 psec (6 mm)
- maximum allowable kick error:  $\sim .07\%$

$$\frac{.020 \text{ nsec} \cdot \frac{dp_T}{dt}}{p_T} < 0.07 \times 10^{-2}$$

A plot for a 30 cavities system is shown on the next slide.

# Flattening out $dp_T/dt$ at the zero-crossings



30-cavity system:  $p_T$  error vs. bunch number, one pass through the kicker.

Probably not good enough.

# More dramatic $dp_T/dt$ reduction...

...is possible with different amplitudes  $A_j$  in each of the cavities.

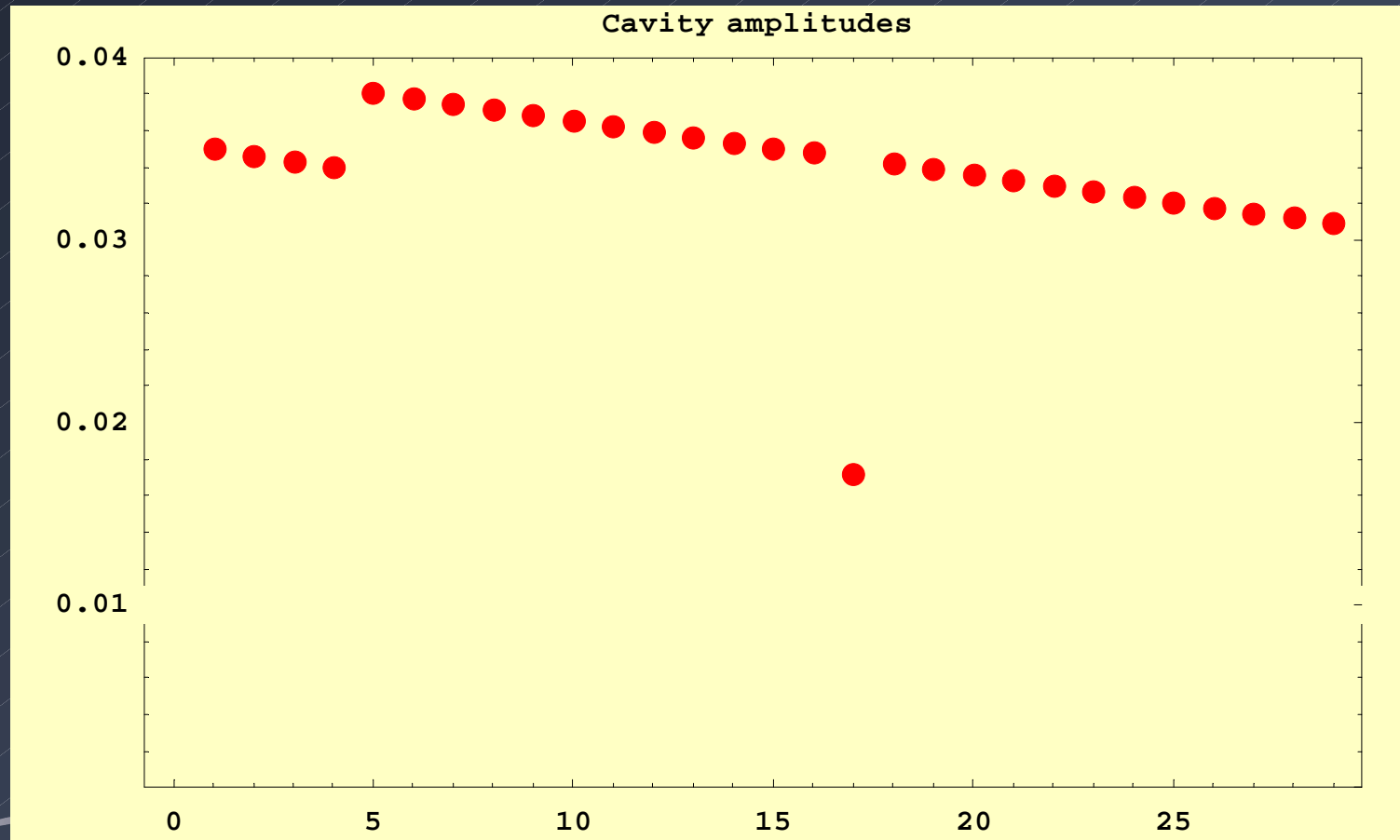
We (in particular Guy Bresler) figured this out last summer

Bresler's algorithm finds sets of amplitudes which have  $dp_T/dt = 0$  at evenly-spaced "major zeroes" in  $p_T$ .

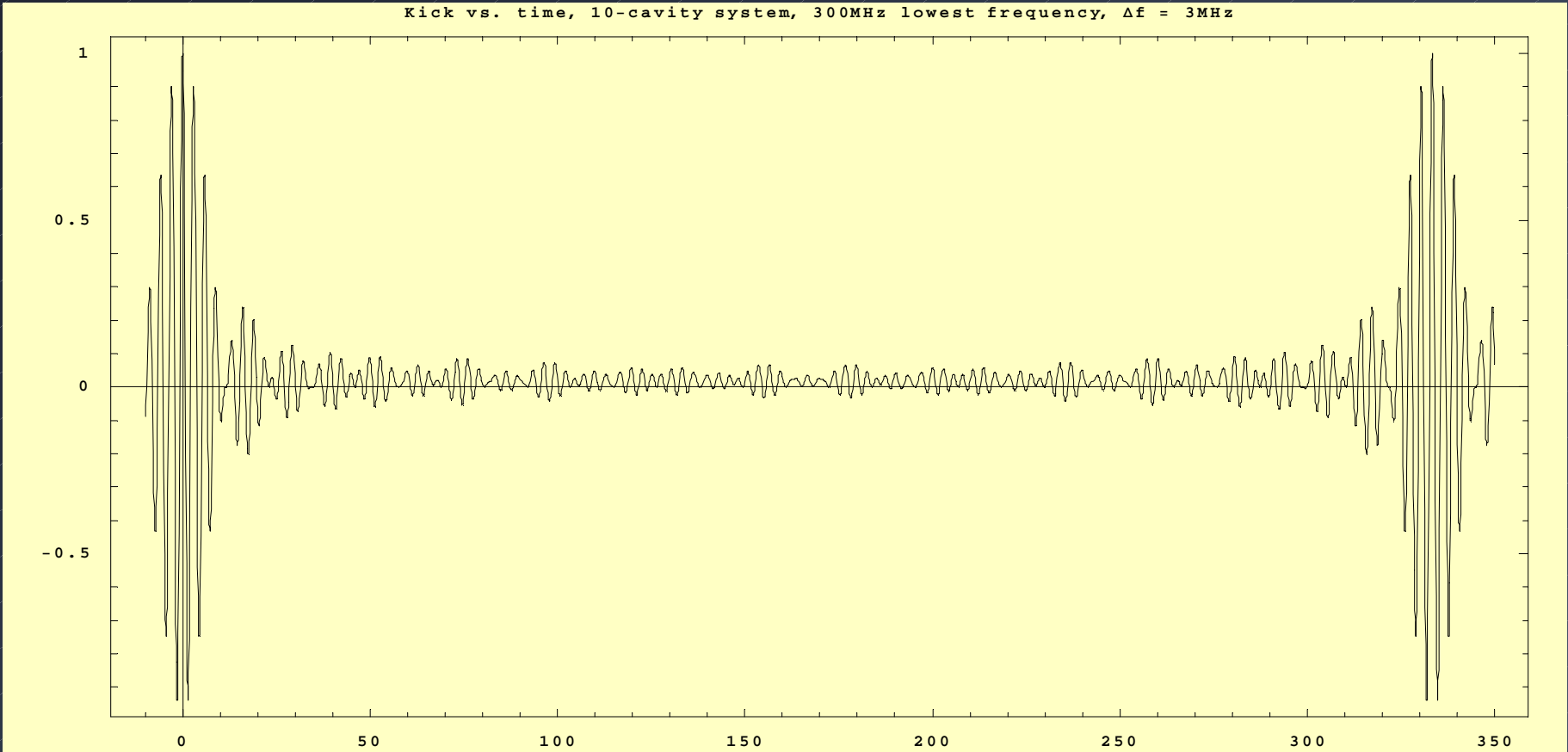
There are lots of different possible sets of amplitudes which will work.

# More dramatic $dp_T/dt$ reduction...

Here's one set for a 29-cavity system (which makes 28 zeroes in  $p_T$  and  $dp_T/dt$  in between kicks), with 300 MHz, 303 MHz,....:

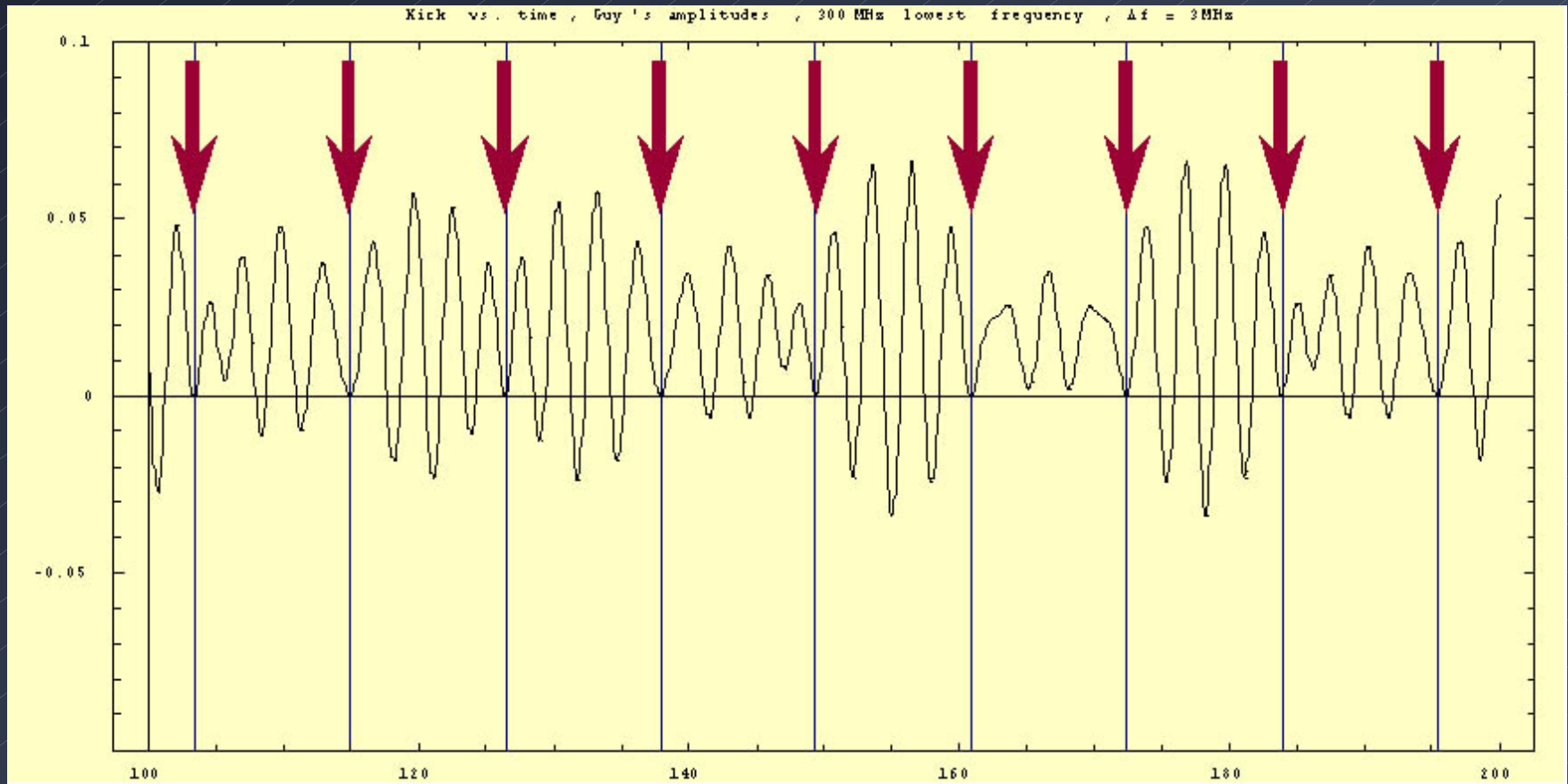


# Kick corresponding to those amplitudes



The “major zeroes” aren’t quite at the obvious symmetry points.

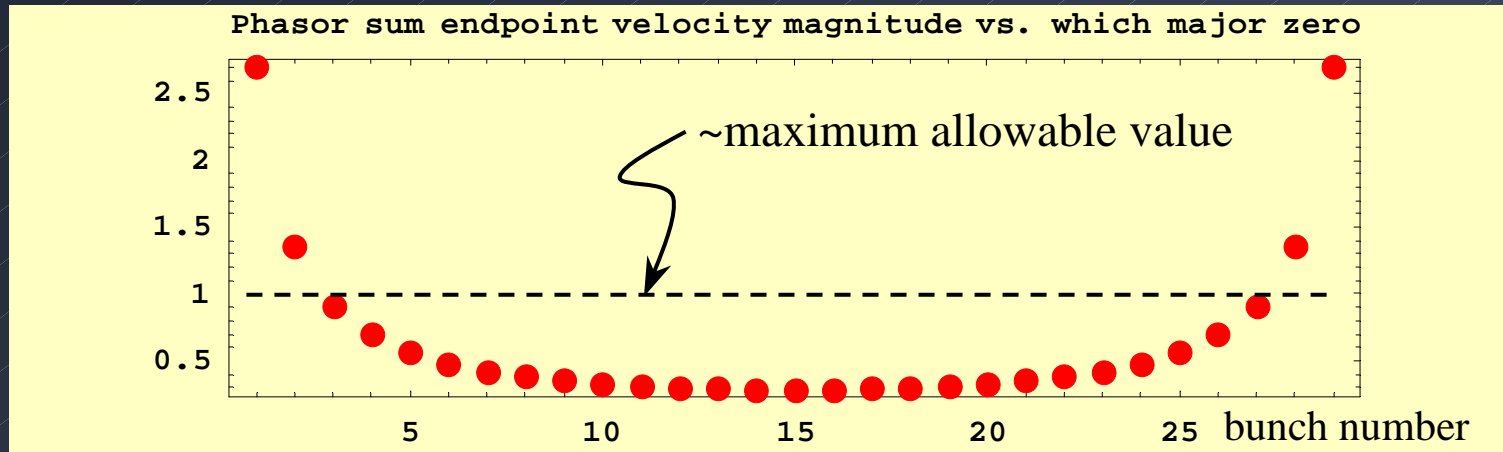
# Some of the zeroes...



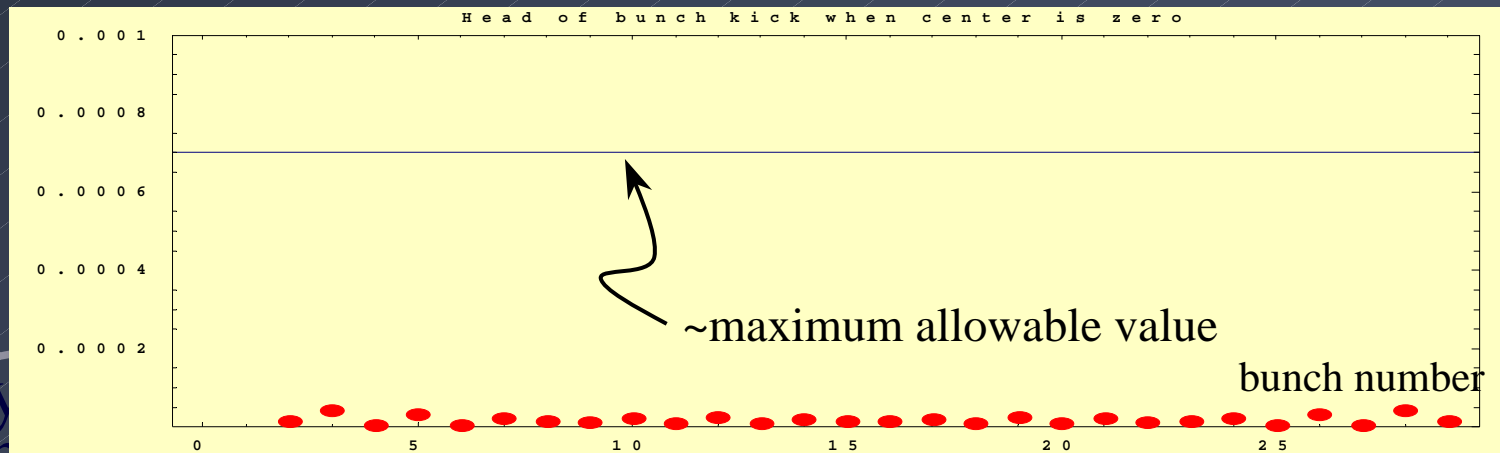
Note that they also satisfy  $dp_T/dt = 0$ .

# How well do we do with these amplitudes?

Old, equal-amplitudes scheme:



New, intelligently-selected-amplitudes scheme:



Wow!

# Multiple passes through the kicker

Previous plots were for a single pass through the kicker.

Most bunches make multiple passes through the kicker.

Modeling of effects associated with multiple passes must take into account damping ring's

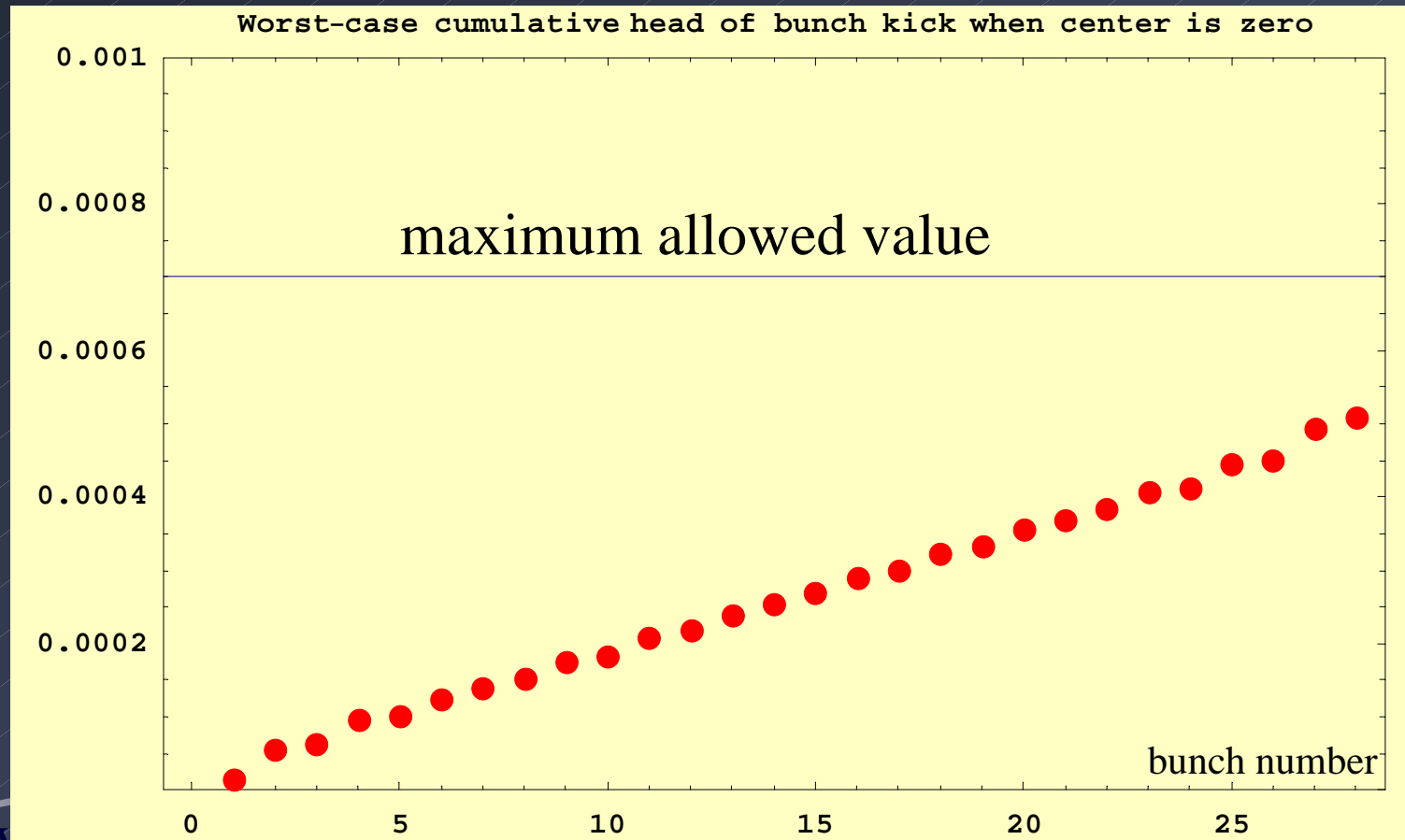
- synchrotron tune (0.10 in TESLA TDR)
- horizontal tune (72.28 in TESLA TDR)

We (in particular, Keri Dixon) worked on this last summer.

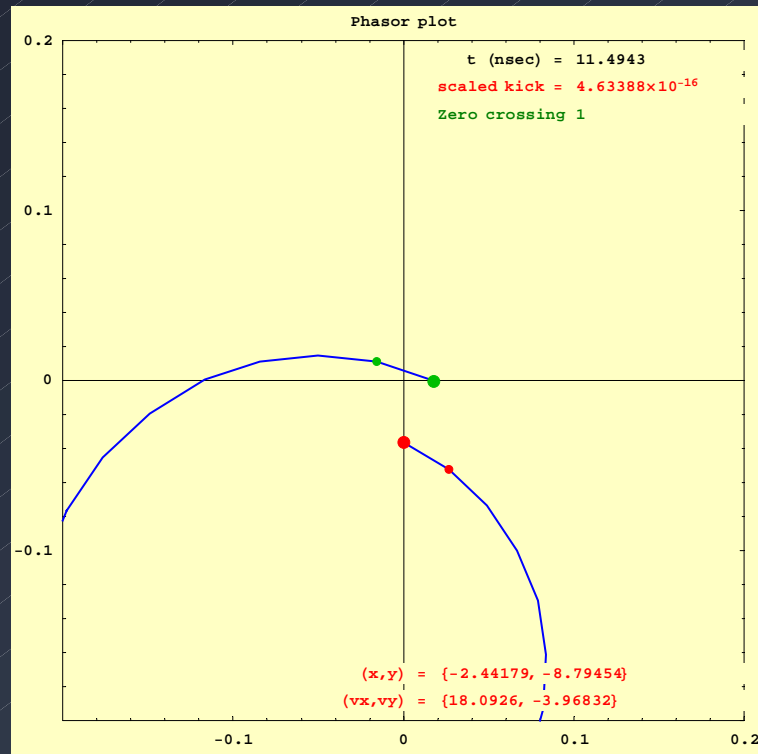
With equal-amplitude cavities some sort of compensating gizmo on the injection/extraction line (or immediately after the kicker) is probably necessary. However...

# Multiple passes through the kicker

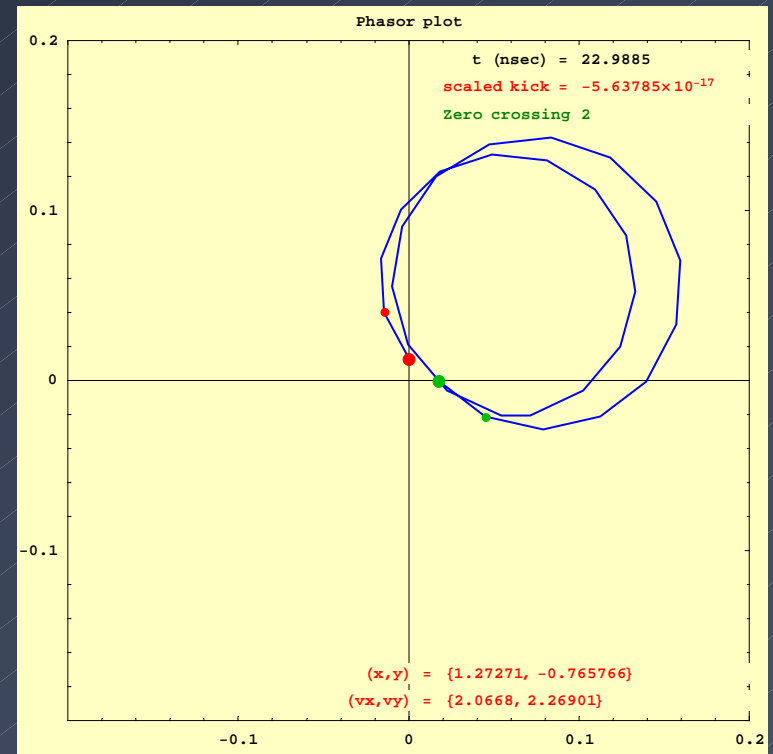
...selecting amplitudes to zero out  $p_T$  slopes fixes the problem! Here's a worst-case plot for 300 MHz,... (assumes tune effects always work against us).



# Phasors with amplitudes chosen to give $dp_T/dt = 0$ and $p_T = 0$ (29 cavities)



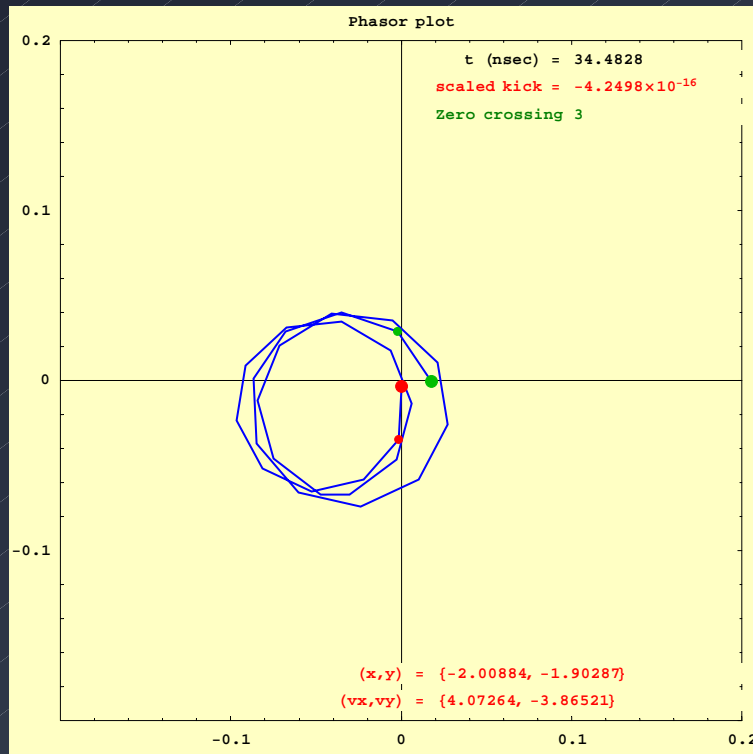
zero #1



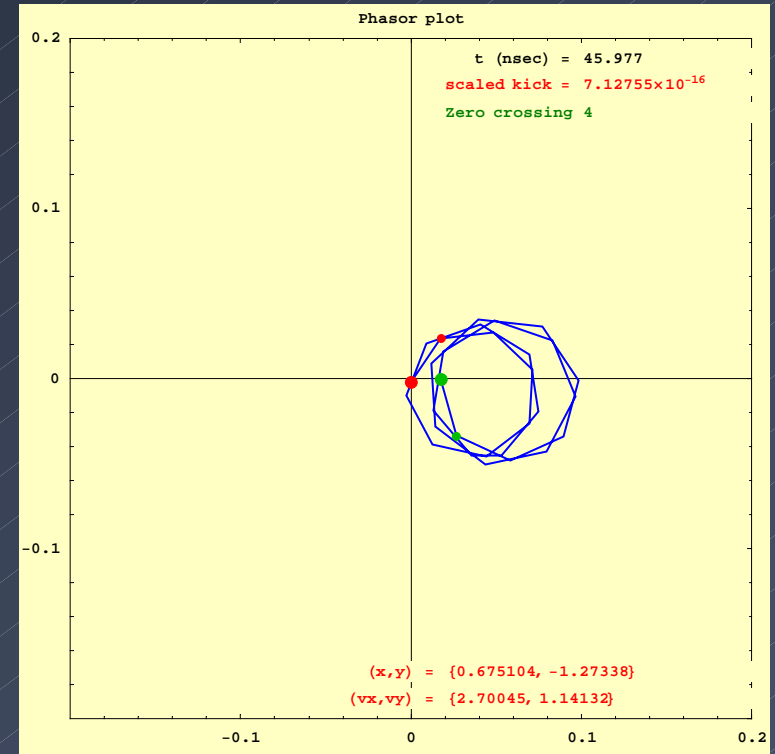
zero #2

The phasor sums show less geometrical symmetry. (Who cares?)

# Phasors with amplitudes chosen to give $dp_T/dt = 0$ and $p_T = 0$ (29 cavities)



zero #3



zero #4

etc.

# It looks promising.

Cavity amplitude stability and phase stability seem to be the next issue to investigate.

GG will spend a couple of days a week at Fermilab as a visiting scientist calendar year 2004 to work on Linear Collider issues, including kickers.

Stay tuned—

# Budget items

1. two undergraduates: full time during the summer, ~5-10 hours per week per student during the academic year, indirect costs.
  - ~ \$14k per year
2. PC's for students
  - ~ \$6k, first year only
3. small amount of travel

# Comments on doing this at a university

- Participation by talented undergraduate students makes LCRD 2.22 work as well as it does. The project is well-suited to undergraduate involvement.
- We get most of our work done during the summer: we're all free of academic constraints (teaching/taking courses). The schedule for evaluating our progress must take this into account.
- Last summer support for students came from (NSF-sponsored) REU program. We borrowed PC's from the UIUC Physics Department instructional resources pool. This summer we'd like to support them with grant money.

# Conclusions

- We haven't found any obvious show-stoppers yet.
- It seems likely that intelligent selection of cavity amplitudes will provide us with a useful way to null out some of the problems present in a more naïve scheme.
- We will begin studying issues relating to precision and stability later this winter...
- This is a lot of fun.