Fourier series damping ring kicker for TESLA

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Introduction

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^{th} bunch into linac (leave adjacent bunches undisturbed)

Kicker speed determines minimum damping ring circumference.

We are investigating a “Fourier series kicker”: use a series of rf cavities to create a kicking function with periodic zeroes and an occasional spike. Perhaps closer bunches/smaller damping ring will be possible?

Participants

This project is part of the US university-based Linear Collider R&D effort (LCRD/UCLC)

Fermilab

Leo Bellantoni
David Finley
Chris Jensen
George Krafczyk
Shekhar Mishra
François Ostiguy
Vladimir Shiltsev

University of Illinois

Guy Bresler
Keri Dixon
George Gollin
Mike Haney
Tom Junk

Cornell University

Gerry Dugan
Joe Rogers
Dave Rubin

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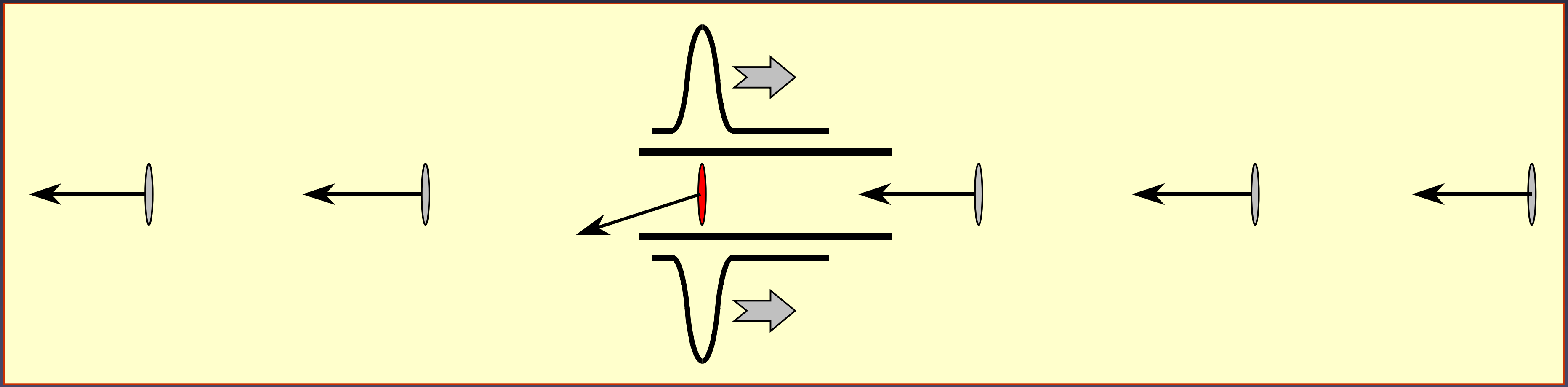
TESLA damping ring kicker *à la* TDR

TDR design: bunch "collides" with electromagnetic pulses traveling in the opposite direction inside a series of traveling wave structures. Hard to turn on/off fast enough.



Fast kicker specs (*à la* TDR):

- $\int B\,dl$ = 100 Gauss-meter = 3 MeV/*c* (= 30 MeV/m × 10 cm)
- stability/ripple/precision ~.07 Gauss-meter = 0.07%

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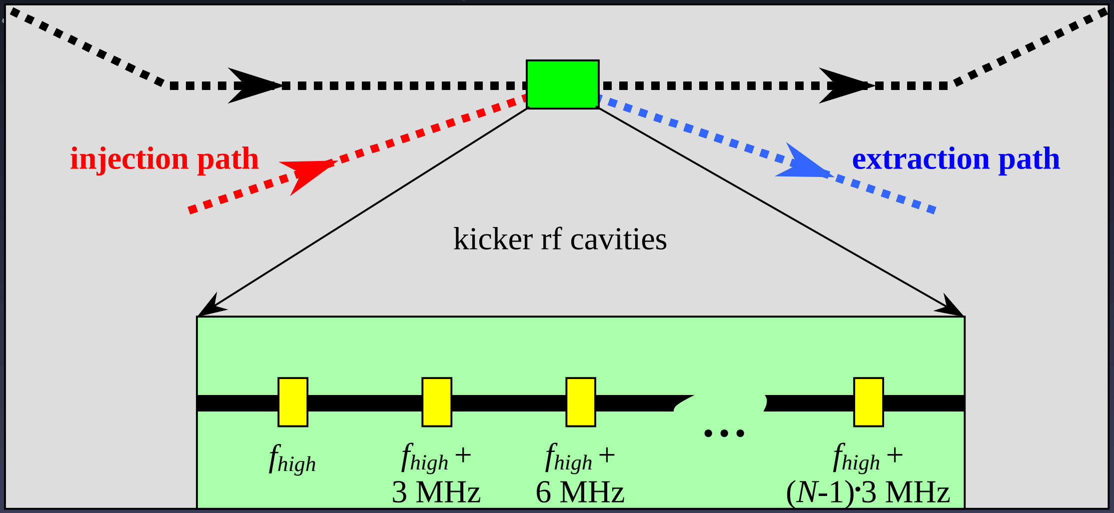
A different idea: "Fourier series kicker"



Kicker would be a series of *N* "rf cavities" oscillating at harmonics of the linac bunch frequency 1/(337 nsec) ≈ 3 MHz:

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

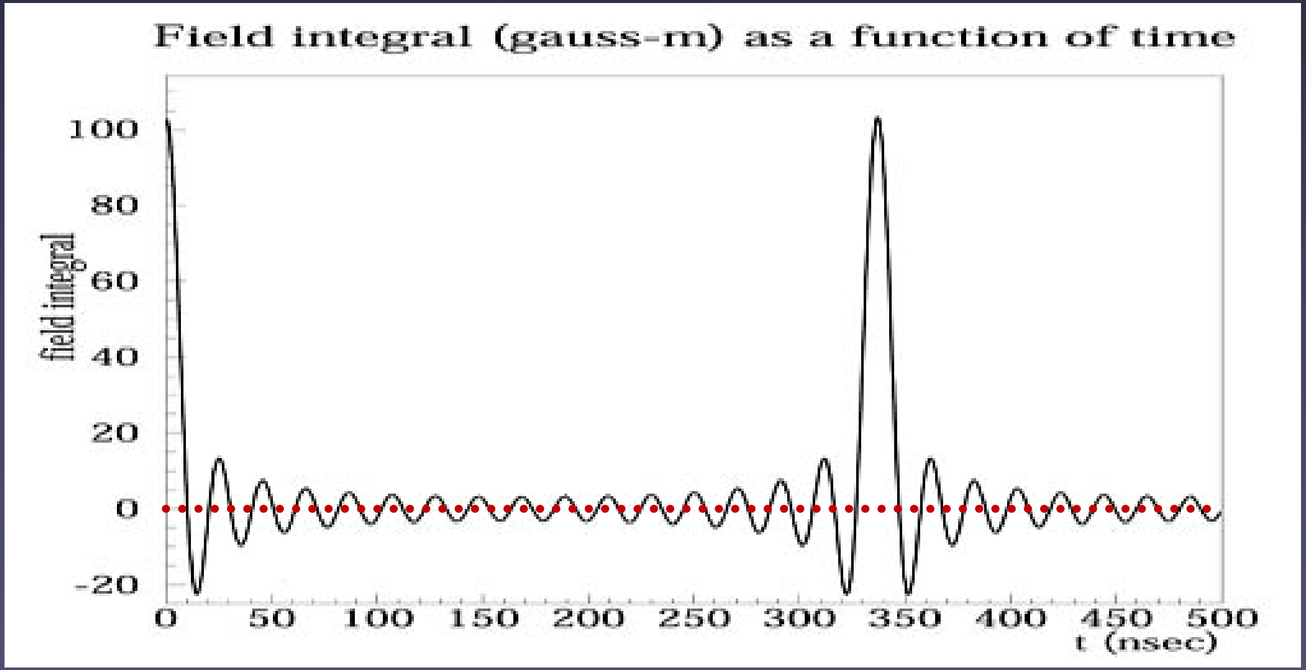
Version 1

Run transverse kicking cavities at 3 MHz, 6 MHz, 9 MHz,… in phase with equal amplitudes. Unkicked bunches traverse kicker when field integral sums to zero.

Problems with this:

• slope at zero-crossings might induce head-tail differences

• LOTS of different cavity designs (one per frequency)



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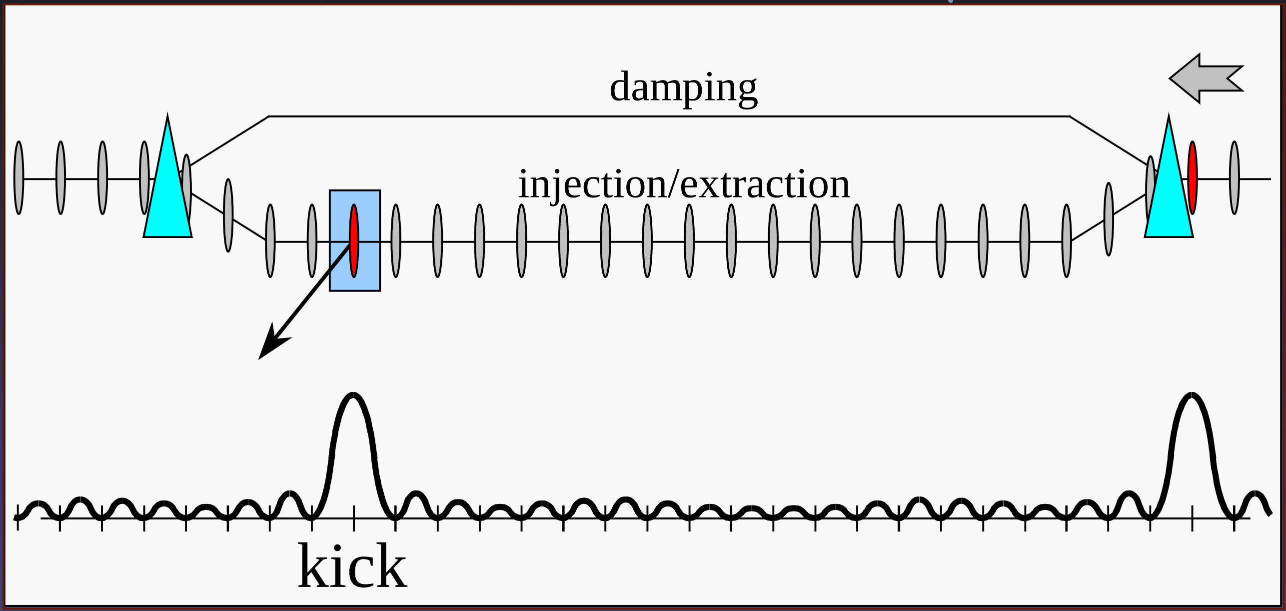
Damping ring operation with an FS kicker



Fourier series kicker would be located in a bypass section.

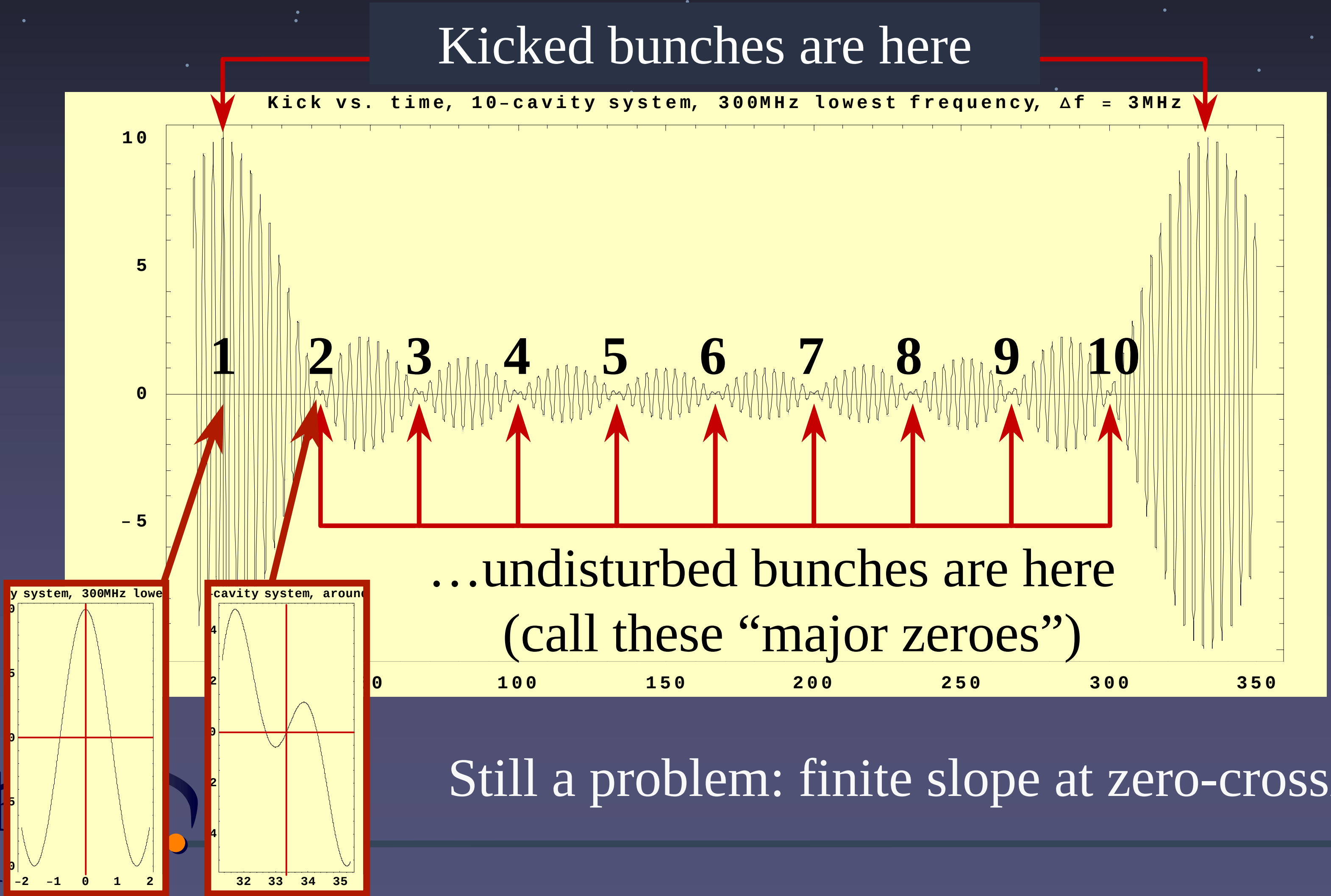
While damping, beam follows the upper path.

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

SCRF and transverse kick minimize beam-induced fields in cavities.

Better idea: permits one (tunable) cavity design

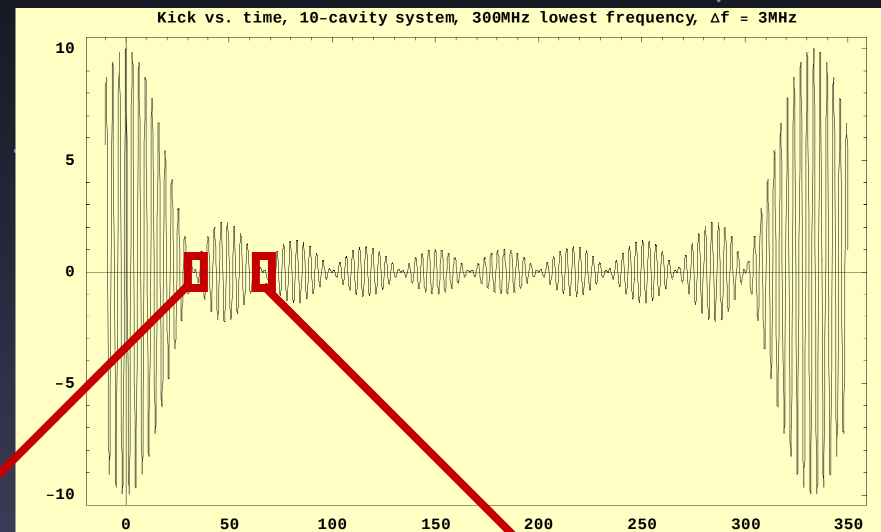
- Run transverse kicking cavities at much higher frequency; split the individual cavity frequencies by 3 MHz. (V. Shiltsev)

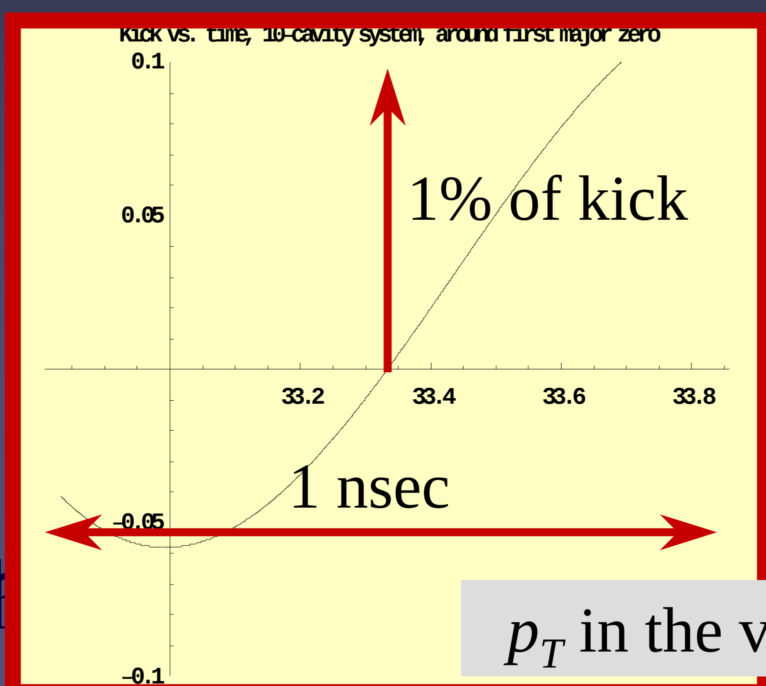


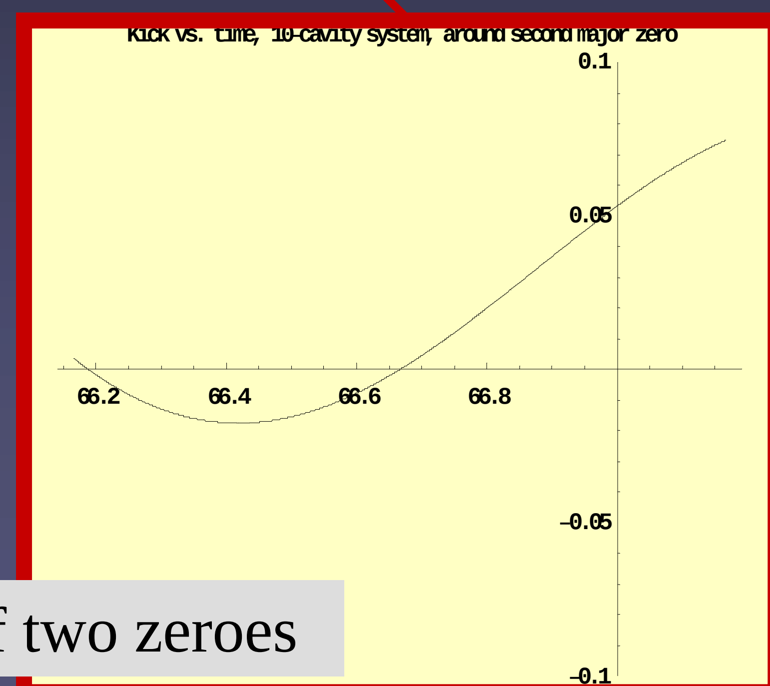
Still a problem: finite slope at zero-crossings.

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

More dramatic dp_T/dt reduction…

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

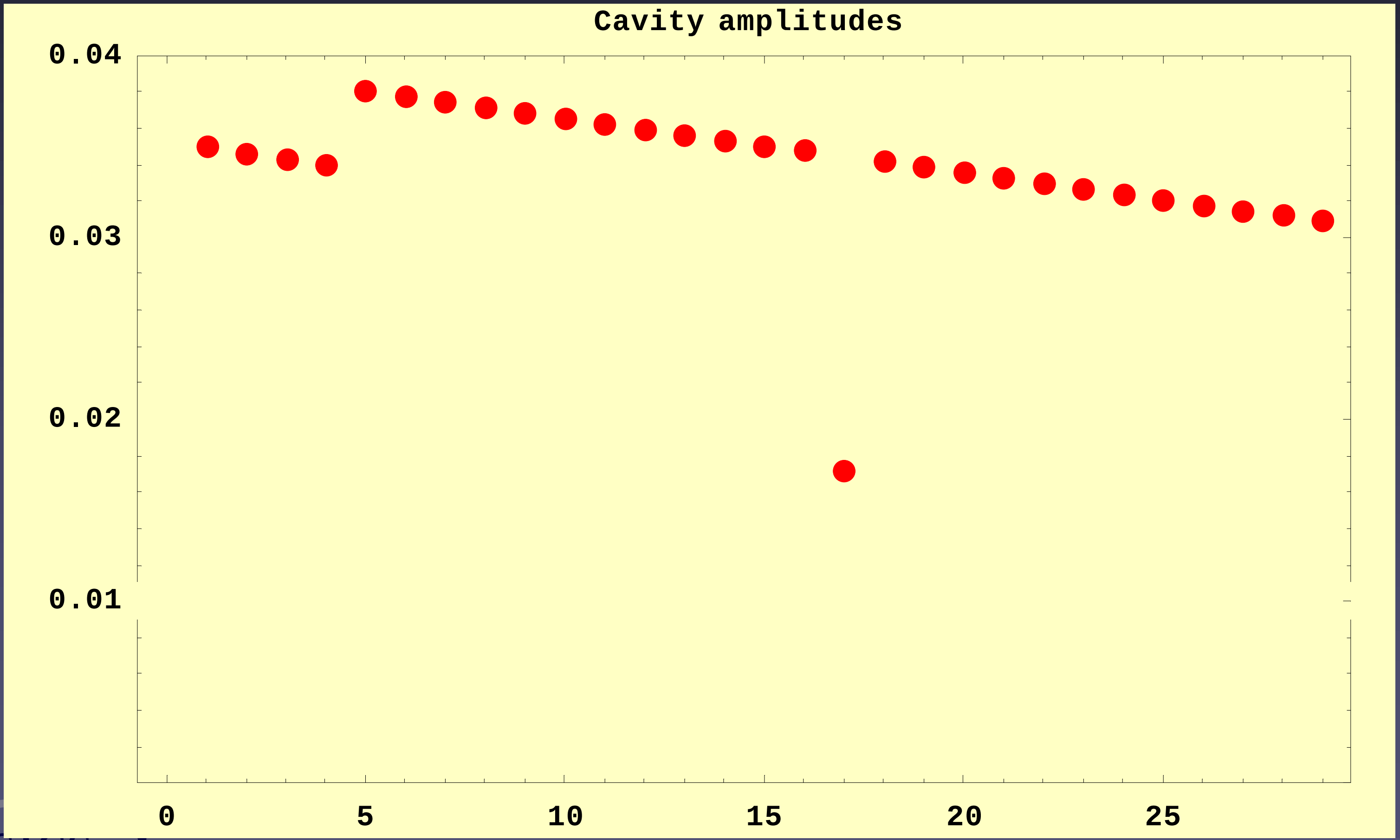
We (in particular Guy Bresler) figured this out last summer

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.

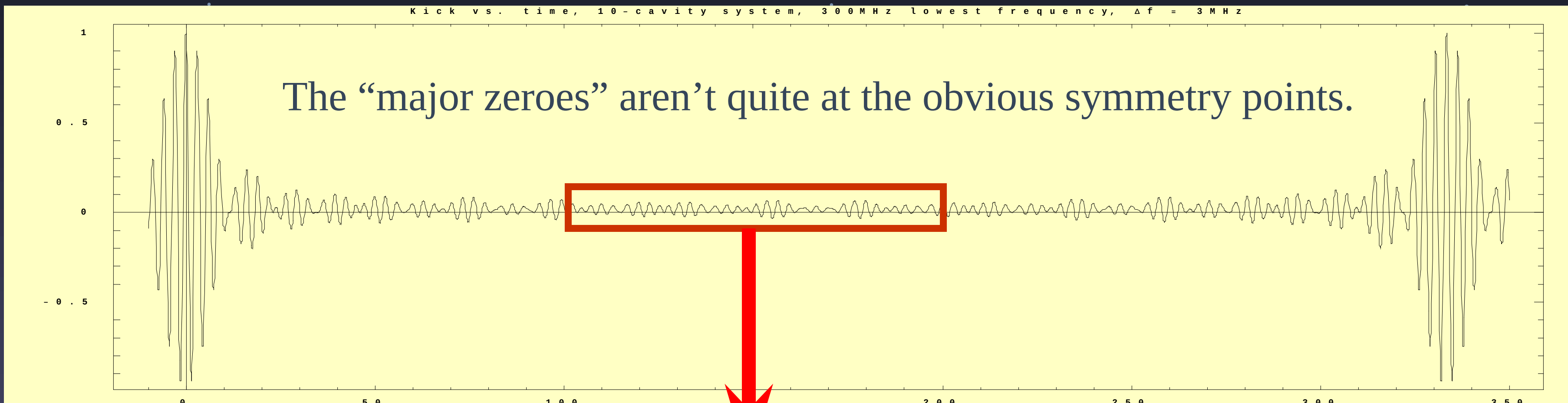
More dramatic dp_T/dt reduction…

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.



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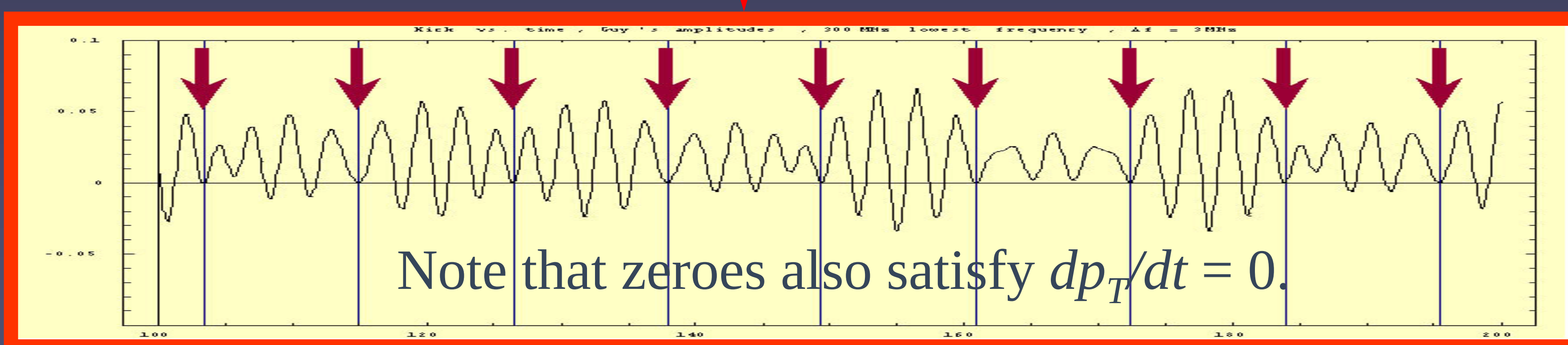
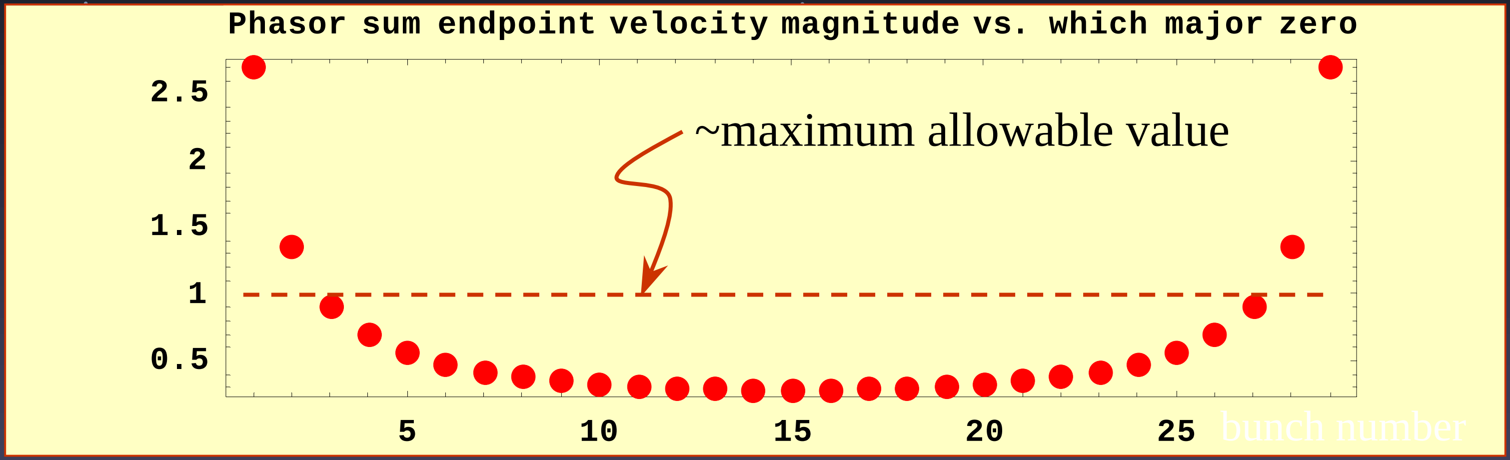


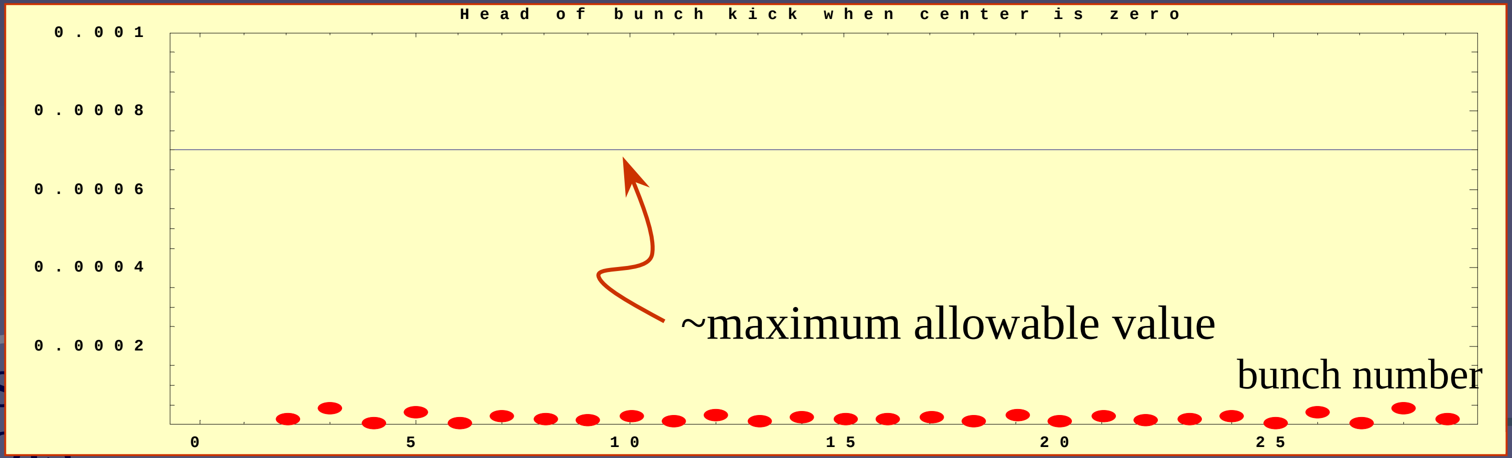
Note that zeroes also satisfy $dp_T/dt = 0$.

How well do we do with these amplitudes?

Old, equal-amplitudes scheme (head-to-tail, one orbit):



New, intelligently-selected-amplitudes scheme (head-to-tail, one orbit):



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

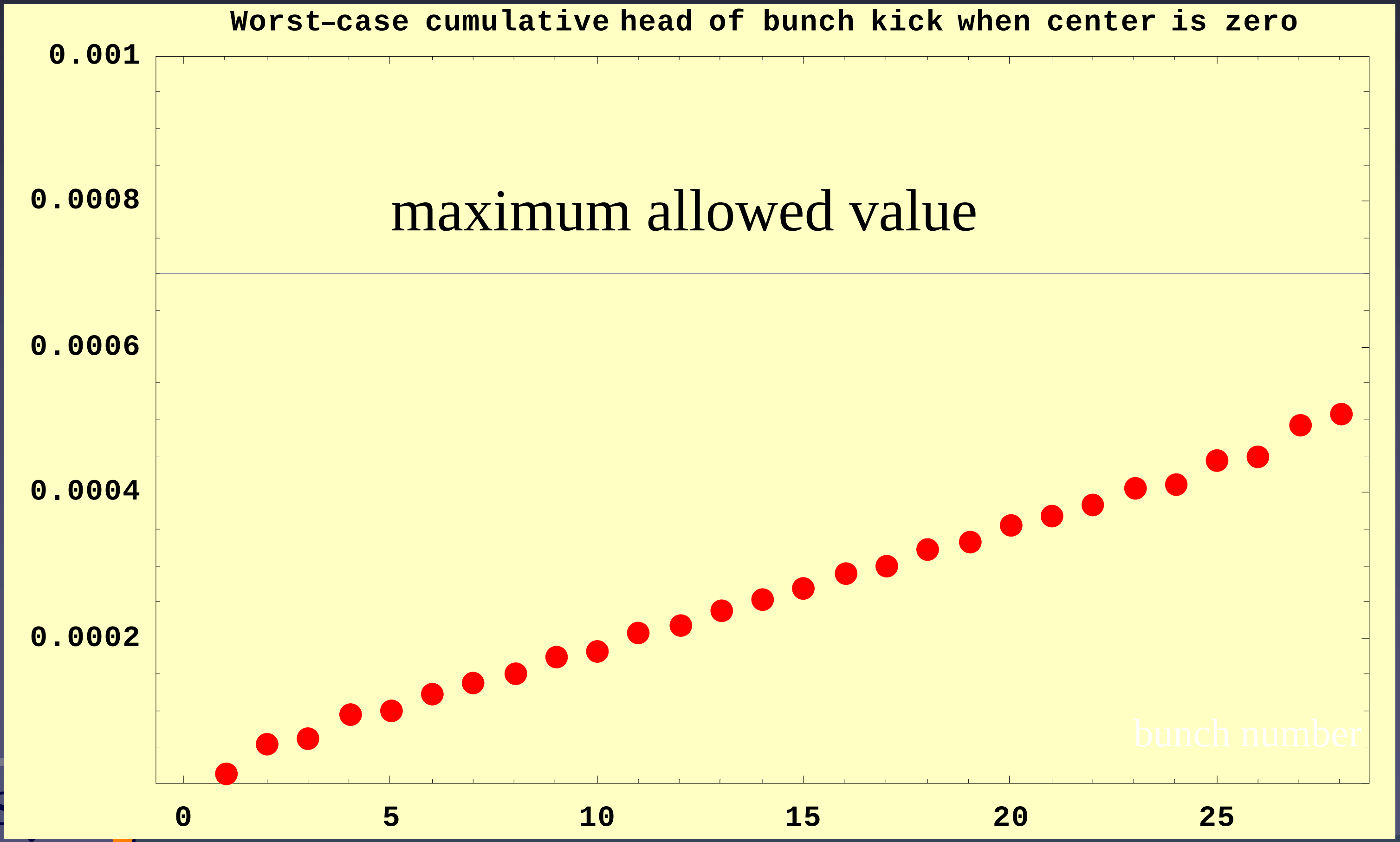
- synchrotron tune (0.10 in TESLA TDR)
- horizontal tune (72.28 in TESLA TDR)

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

Good news…

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).



Is there an even better way to do this?

In a Fourier series kicker, the beam sums the effects of the different (high-Q) cavities.

60 cavities would allow the damping ring to fit into the Tevatron (or HERA) tunnel.

That’s a lot of cavities to stabilize.

Is there a way to sum the different frequencies in a single cavity?

Yes, maybe…

Dumb, not so dumb, promising

Summing signals in a single cavity…

- dumb: build a 3MHz cavity and drive it so that multiple modes are populated. (cavity is huge, lots of modes to control…)

- not so dumb: use a high frequency cavity with low *Q* (so that it can support a wider range of frequencies), drive it with some kind of broadband signal. (large peak power needed, and we're back to the same problem)

- promising: launch different frequencies down a long (dispersive) waveguide to a low-Q cavity. Send the frequency with slowest group velocity first, fastest last. Signals arrive at cavity properly phased to make a short pulse.

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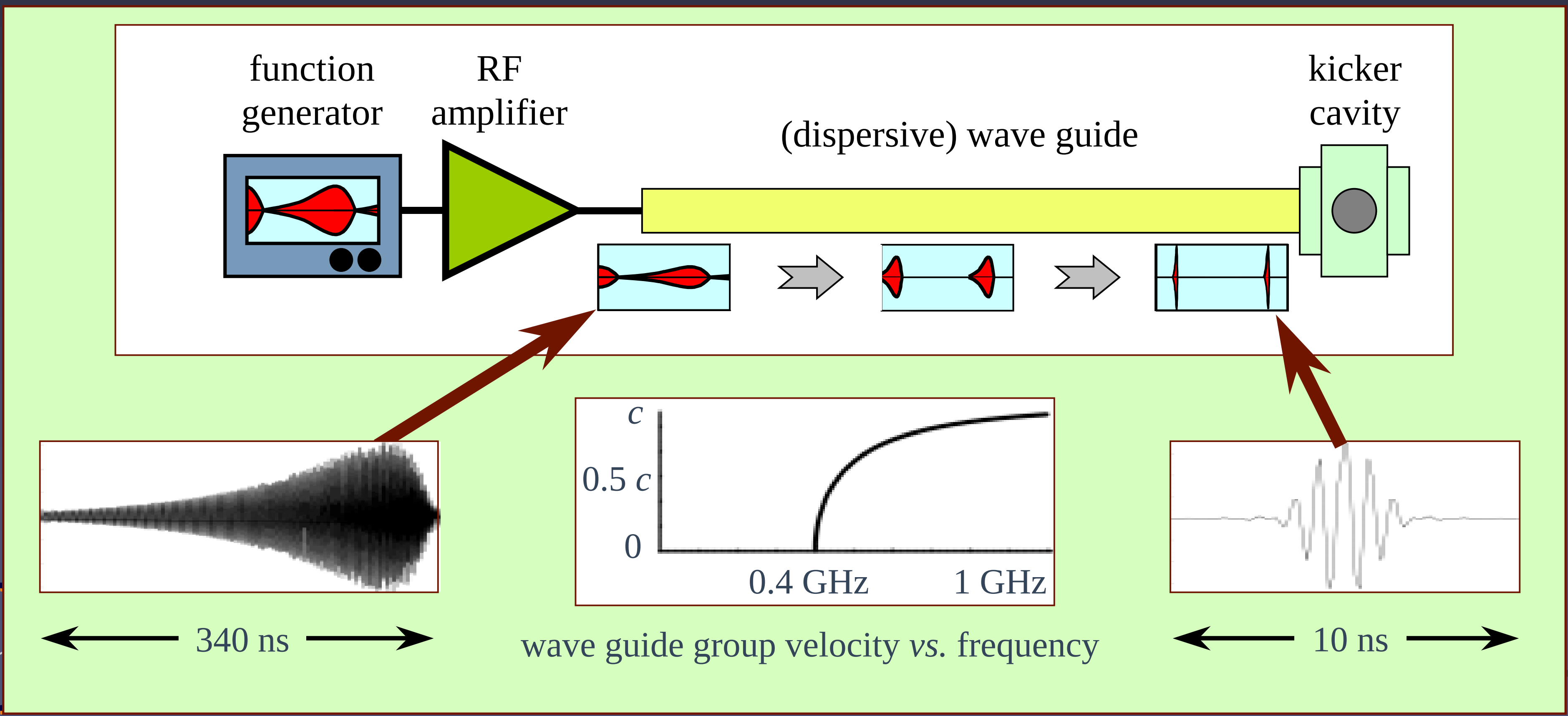
Chirped waveform pulse compression kicker
(Joe Rogers, Cornell)

Dispersive wave guide compresses chirped RF signal.

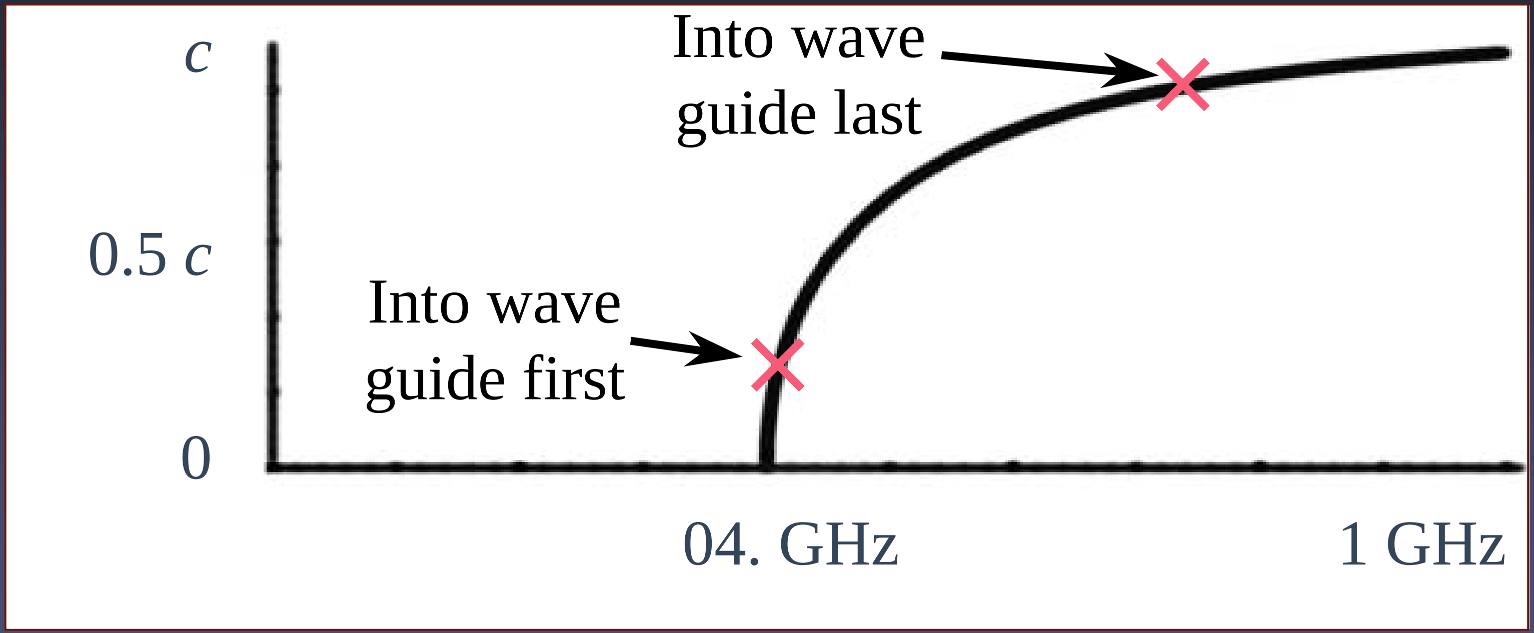
Commercial broadcast RF amplifier ~100kW, but compression generates large peak power for kicking pulse in low-Q cavity.



Group velocity vs. frequency

Dispersive wave guide compresses chirped RF signal.

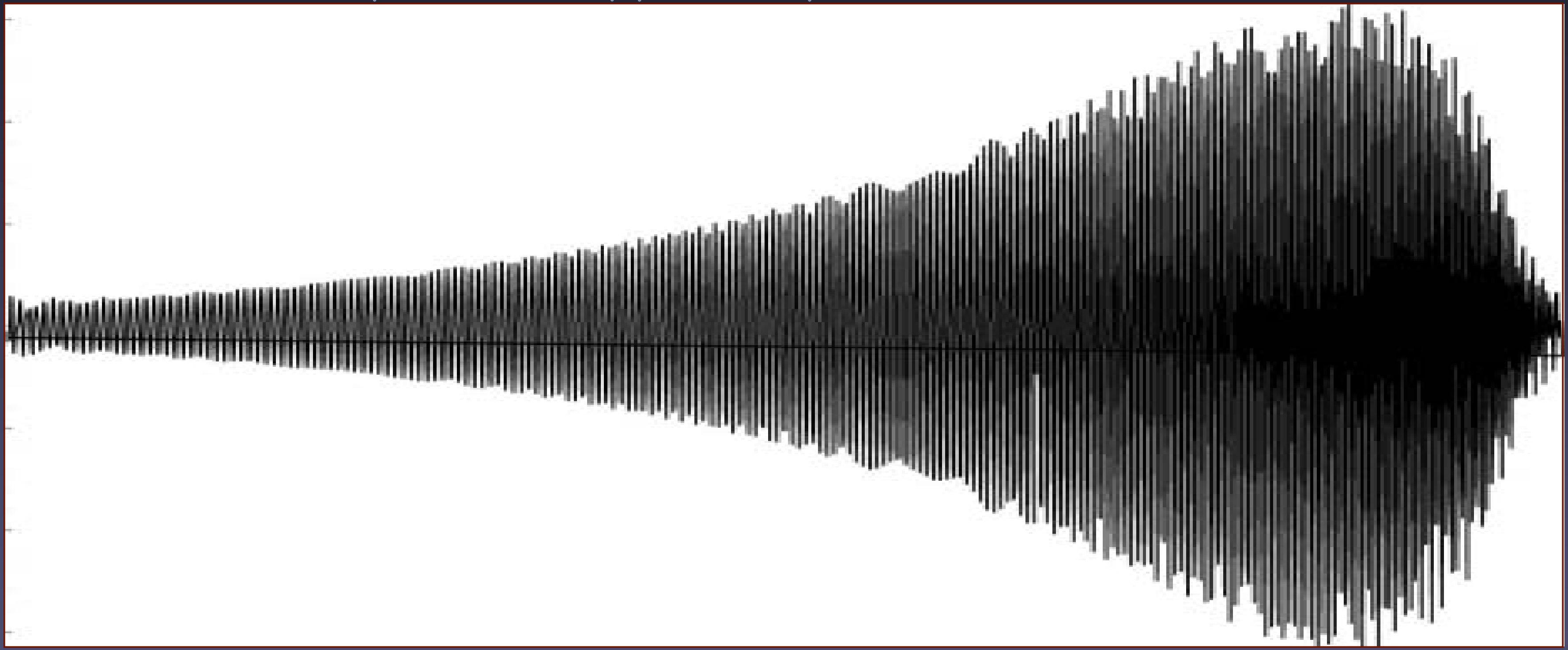
500 MHz signal travels more slowly than 1 GHz signal.



wave guide group velocity *vs.* frequency

Chirped signal into the wave guide…

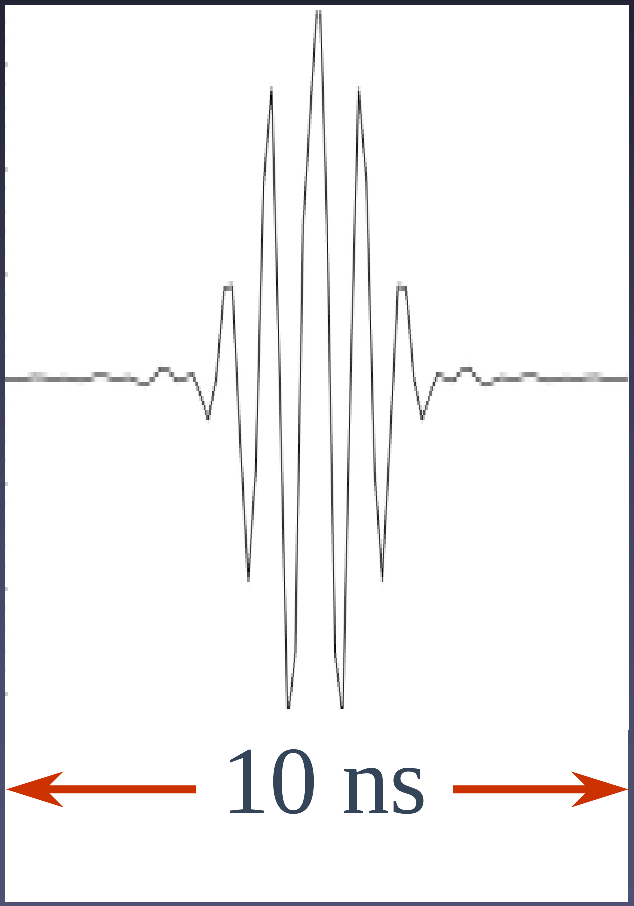
Wave guide input signal (not from actual measurements!):



340 ns

Signal at the far end of the wave guide…

Narrow!



Chirped waveform pulse compression kicker

Unlike Fourier series kicker, in which bunches “sum” the effects of different frequencies, this design uses the cavity to form the sum.

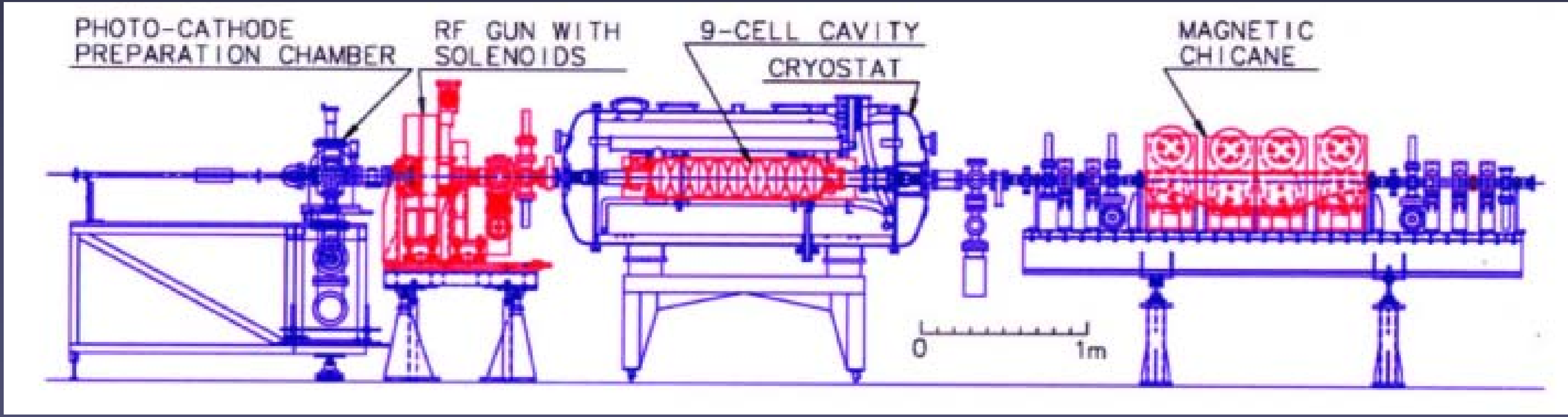
System is linear, so low-power tests can be used to evaluate concept. (Fermilab is interested in pursuing this.)

Programmable function generator can be reprogrammed to compensate for drifts and amplifier aging

Testing our kicker ideas

A0 photoinjector lab at Fermilab produces a relativistic (16 MeV now, 50 MeV in a few months), bunched low-emittance electron beam. (It's rather like a TESLA injector.)

This should be an excellent facility for kicker studies!



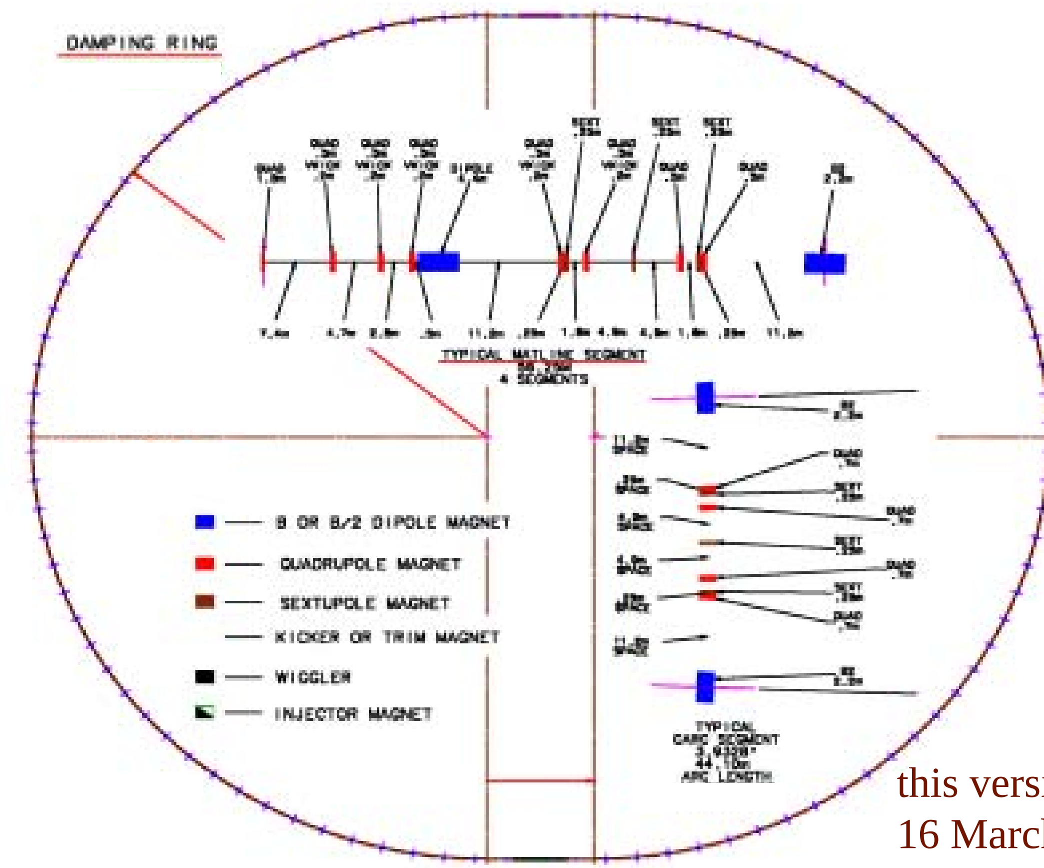
Small Damping Ring Lattice

What might a damping ring, small enough to fit into the Tevatron or HERA or tunnels, look like?

We had a small workshop in March at Fermilab to think about this.

Participants: ANL, LBNL, SLAC, Cornell, DESY, FNAL…

6 kms, 6 straight sections, 25 wigglers.



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Comparison of the two designs

Parameter	Small ring (e^+/e^-)	Dogbone (e^+/e^-)
Energy	5 GeV	5 GeV
Circumference	6.12 km	17 km
Horizontal emittance γe_x	8 mm·mr	8 mm·mr
Vertical emittance γe_y	0.02 mm·mr	0.02 mm·mr
Transverse damping time τ_d	28 ms / 44 ms	28 ms / 50 ms
Current	443 mA	160 mA
Energy loss/turn	7.3 MeV / 4.7 MeV	21 MeV / 12 MeV
Radiated power	3.25 MW / 2.1 MW	3.2 MW / 1.8 MW
Tunes Q_x, Q_y	62.95, 24.52	72.28, 44.18
Chromaticities ξ_x, ξ_y	-112, -64	-125, -68

Comments about damping rings

It will be interesting to see how various optimizations turn out if it is possible to remove the 20 ns minimum bunch spacing requirement.

A small damping ring could be built and tested before linac construction was complete. (Independent tunnels) This is an appealing idea! It could allow beam to be injected into the linac as soon as the main linac was under construction.

Exploration of technical issues associated with damping rings is becoming a major focus of LC activity at Fermilab.

Summary/conclusions

It is possible that alternative TESLA damping ring kicker designs will allow the construction of smaller rings.

Simulations are encouraging; we will begin testing some of these ideas over the next few months at Fermilab. Stay tuned!