Intra-Pulse Feedback at the NLC Interaction Point

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Snowmass 2001

Ground Motion at NLC IP

- Differential ground motion between opposing final lenses may be comparable to the beam sizes
- Several solutions possible:
  - Optical anchor stabilization
  - Inertial stabilization (geophone feedback)
  - Pulse-to-pulse beam-beam alignment feedback
- Can we use beam-beam deflection within the crossing time a single bunch train?

- There exists Intra-Pulse feedback along the linac to keep the bunchs in line along the train, not discussed here.

Integrated Ground Motion

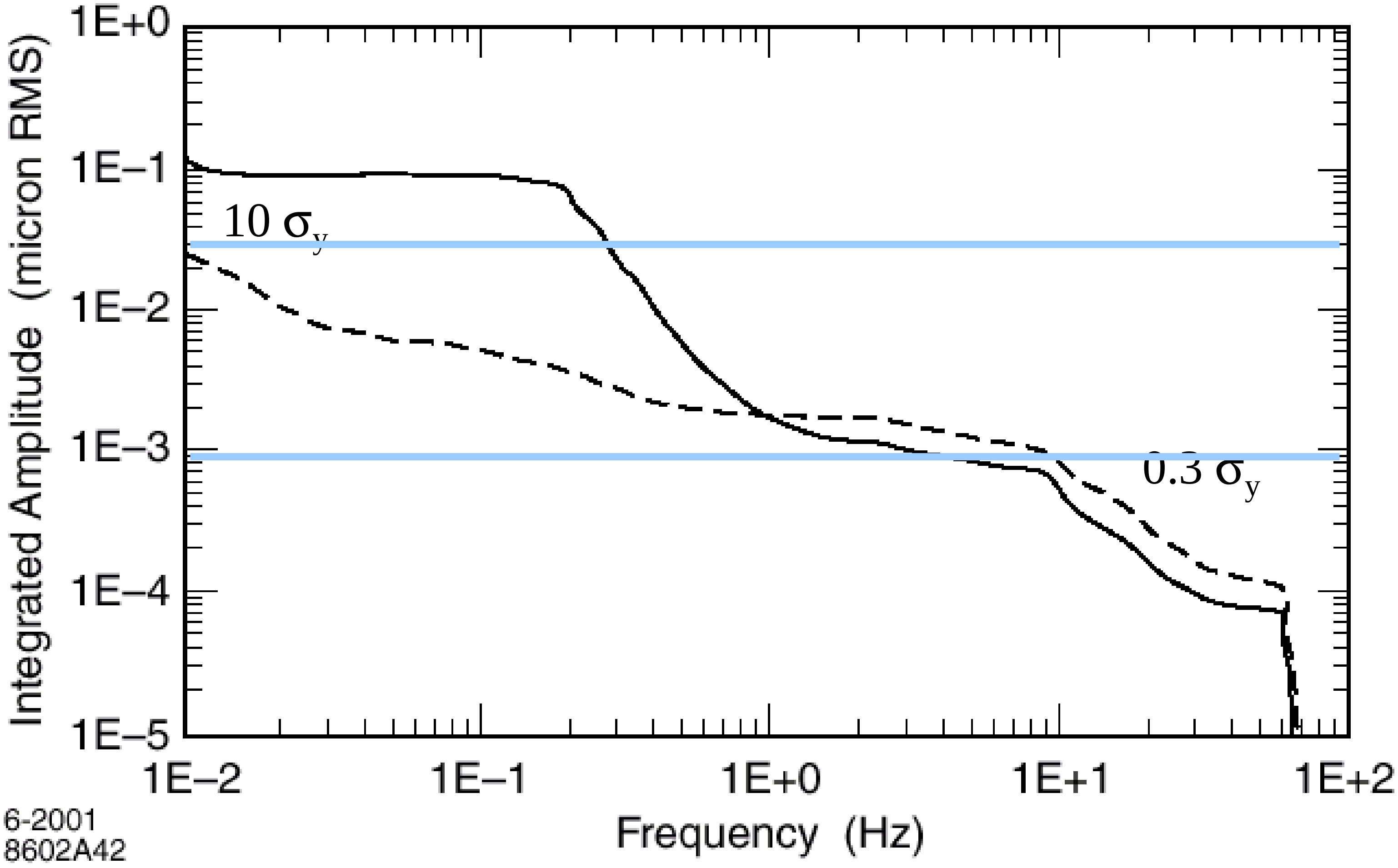


Figure 7.2: Integrated motion of the SLAC site, based on power spectral density measurement in Figure 7.1. Both the absolute motion at a single sensor (solid) and the difference in motions between two sensors separated by 100 m (dashed) are shown.

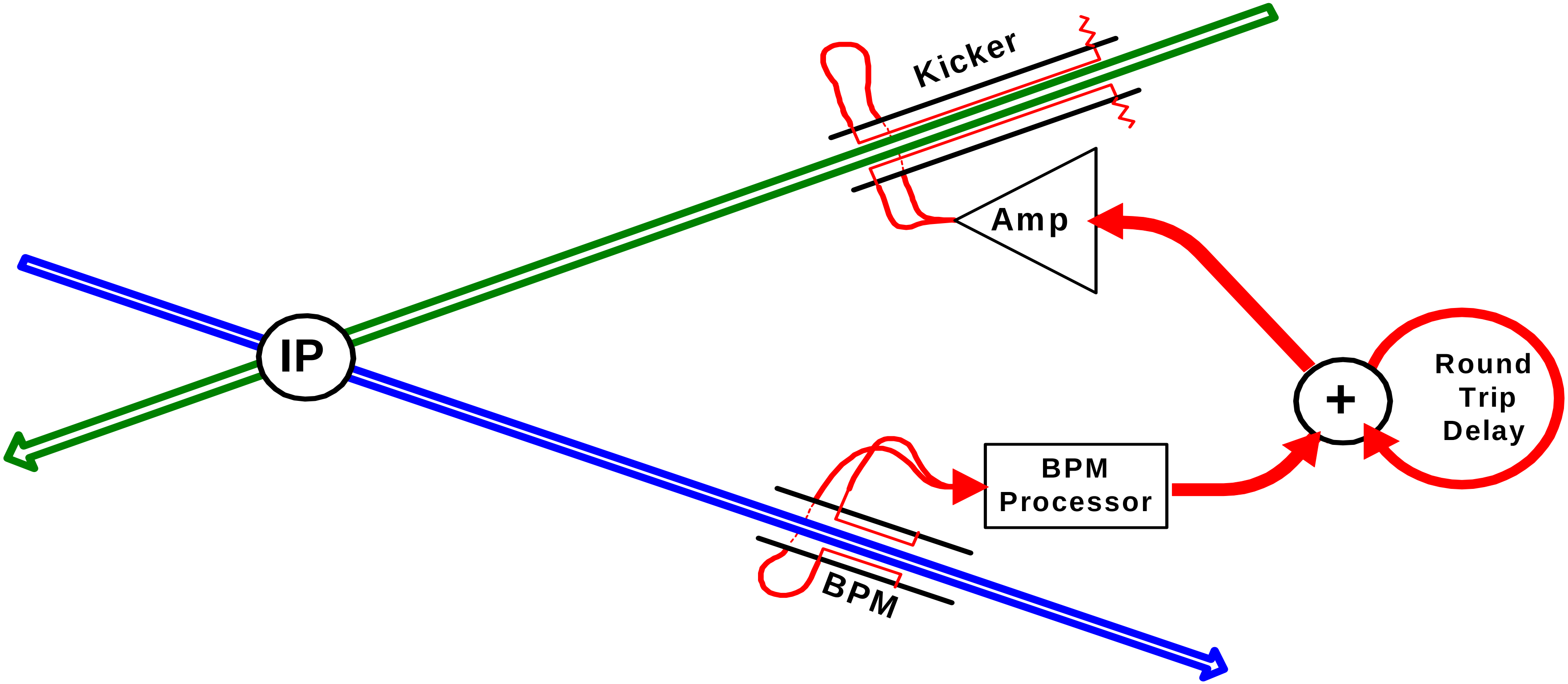
NLC Interaction Point Parameters

High E IP Parameters (2/00)		
	Stage 1	**Stage 2**
CMS Energy (GeV)	490	888
Luminosity (10^{33})	**22**	**34**
Repetition Rate (Hz)	120	120
Bunch Charge (10^{10})	**0.75**	**0.75**
Bunches/RF Pulse	190	190
Bunch Separation (ns)	1.4	1.4
Eff. Gradient (MV/m)	**50.2**	**50.2**
Injected $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ (10^{-8})	300 / 2	300 / 2
$\gamma\varepsilon_x$ at IP (10^{-8} m-rad)	360	360
$\gamma\varepsilon_y$ at IP (10^{-8} m-rad)	**3.5**	**3.5**
β_x / β_y at IP (mm)	8 / 0.10	10 / 0.12
σ_x / σ_y at IP (nm)	**245 / 2.7**	**200 / 2.2**
σ_z at IP (um)	110	110
Yave	0.11	0.26
Pinch Enhancement	1.43	1.49
Beamstrahlung δB (%)	4.6	8.8
Photons per e+/e-	1.17	1.33
Two Linac Length (km)	5.4	9.9

Beam-Beam Parameters

Parameter	**Value**	**Comments**
σ_y	2.65 nm	**(!)**
σ_x	245 nm	
σ_z	110 μm	
Disruption Parameter	14	
Deflection slope	25 μradian / nm	At origin
Displacement slope	100 μm/nm	At BPM

Intra-Pulse Feedback

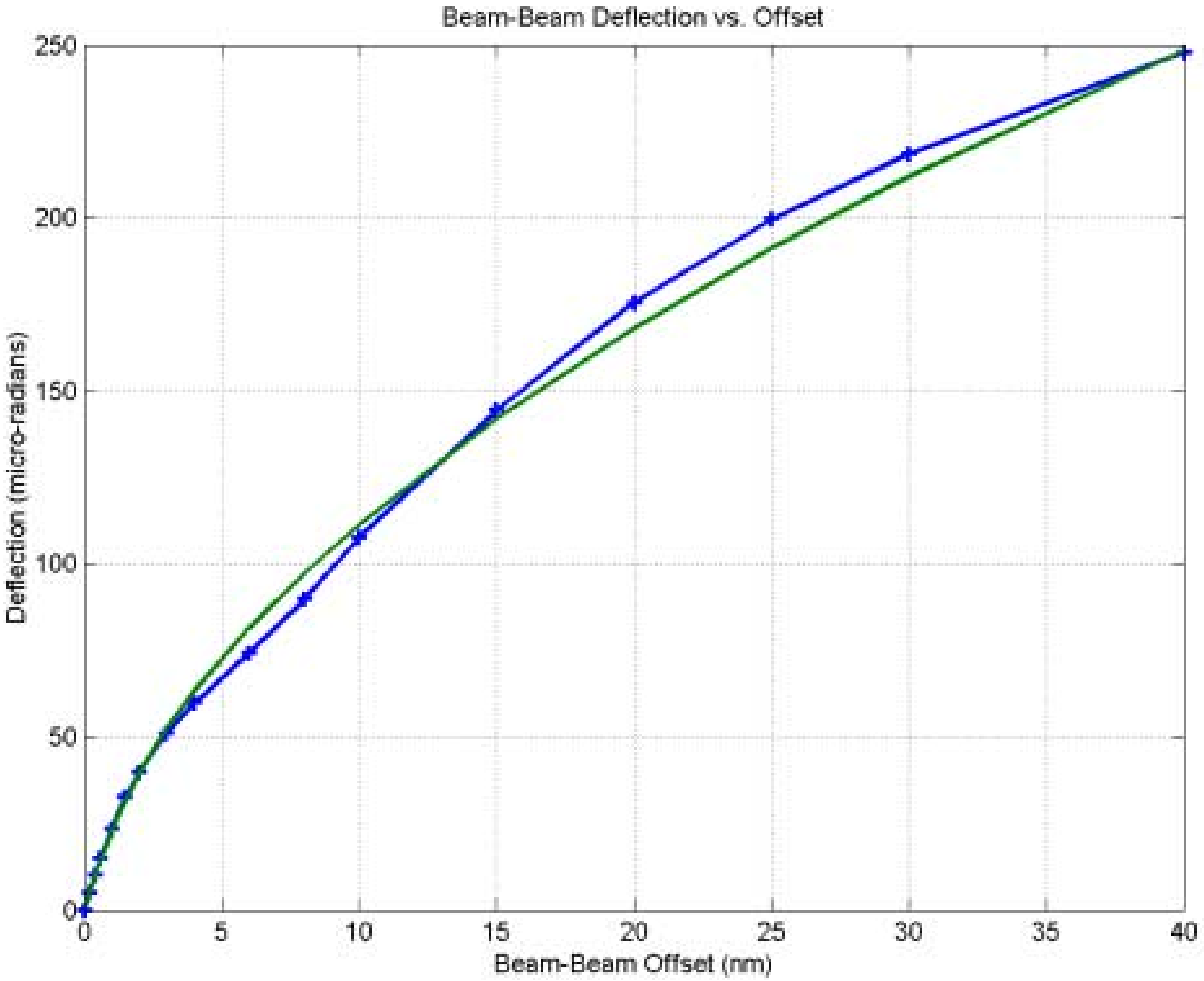


Intra-pulse Feedback

- Fix interaction point jitter within the crossing time of a single bunch train (266 ns)
- BPM measures beam-beam deflection on outgoing beam
  - Fast (few ns rise time)
  - Precise (micron resolution)
  - Close (~4 meters from IP?)
- Kicker steers incoming beam
  - Close to IP (~4 meters)
  - Close to BPM (minimal cable delay)
  - Fast rise-time amplifier
- Feedback algorithm is complicated by round-trip propagation delay to interaction point in the feedback loop.

Beam-Beam Deflection

"Guinea Pig" simulation provided by A. Seryi



-- simulation

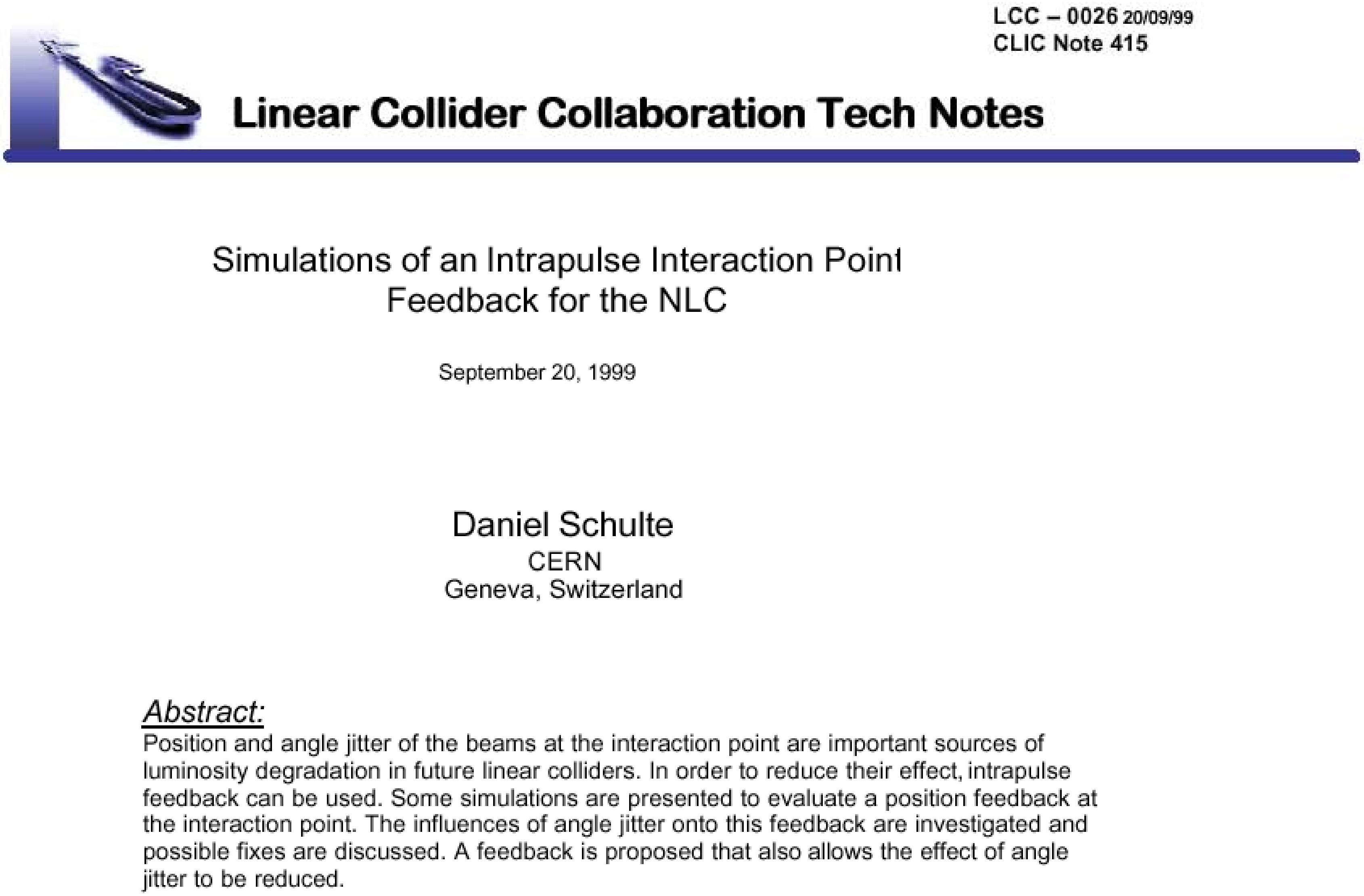
-- parameterization

Limits to Beam-Beam Feedback

- Must close loop fast
  - Propagation delays are painful
- Beam-Beam deflection is non-linear
- Feedback gain drops like 1/δ for large offsets
- Feedback converges too slowly beyond ~ 30 σ to make a recover luminosity
- May be able to fix misalignments of 100 nm with moderate kicker amplifiers
- Amplifier power
  - Goes like square of misalignment
  - Inverse square of kicker length, distance to IP

Conceptual Design

- Fast position monitor processor
  - < 3 ns analog response time
  - Conventional RF design
  - Commercial RF components
- Higher-order Feedback Regulator design
  - Faster convergence than first-order
  - Flexible
  - Easier to implement
- Example of a kicker
- System simulation in Matlab / Simulink



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Linear Collider Collaboration Tech Notes

Simulations of an Intrapulse Interaction Point Feedback for the NLC

September 20, 1999

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CERN
Geneva, Switzerland

Abstract:

Position and angle jitter of the beams at the interaction point are important sources of luminosity degradation in future linear colliders. In order to reduce their effect, intrapulse feedback can be used. Some simulations are presented to evaluate a position feedback at the interaction point. The influences of angle jitter onto this feedback are investigated and possible fixes are discussed. A feedback is proposed that also allows the effect of angle jitter to be reduced.

4 Correcting Offsets

The effect of the feedback on the relative beam positions is shown in Figure 6. An initial offset $\Delta_y = 2\sigma_y^*$ is corrected with three different gains. Here, the gain g is defined via the correction δ_y applied in between two bunches

$$\frac{\delta_y}{\sigma_y^*} = g\frac{\theta}{\sigma_{y'}^*}$$

As can be seen, the gain $g = 0.03$ achieves a smooth correction while $g = 0.06$ and $g = 0.09$ produce an overshoot. As is visible in the bottom part of the figure, the value of $g = 0.06$ is best (the total loss of luminosity is proportional to the area below the curves).

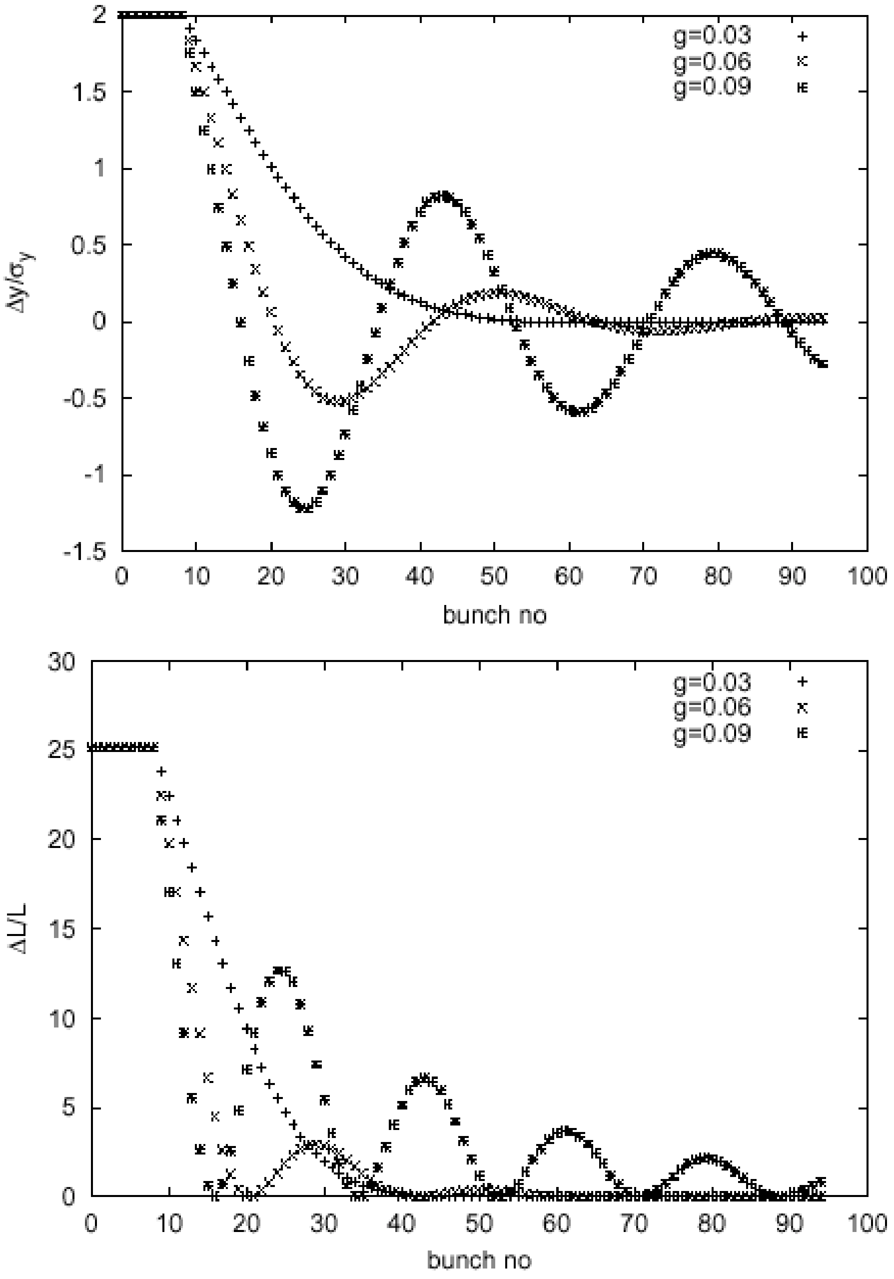
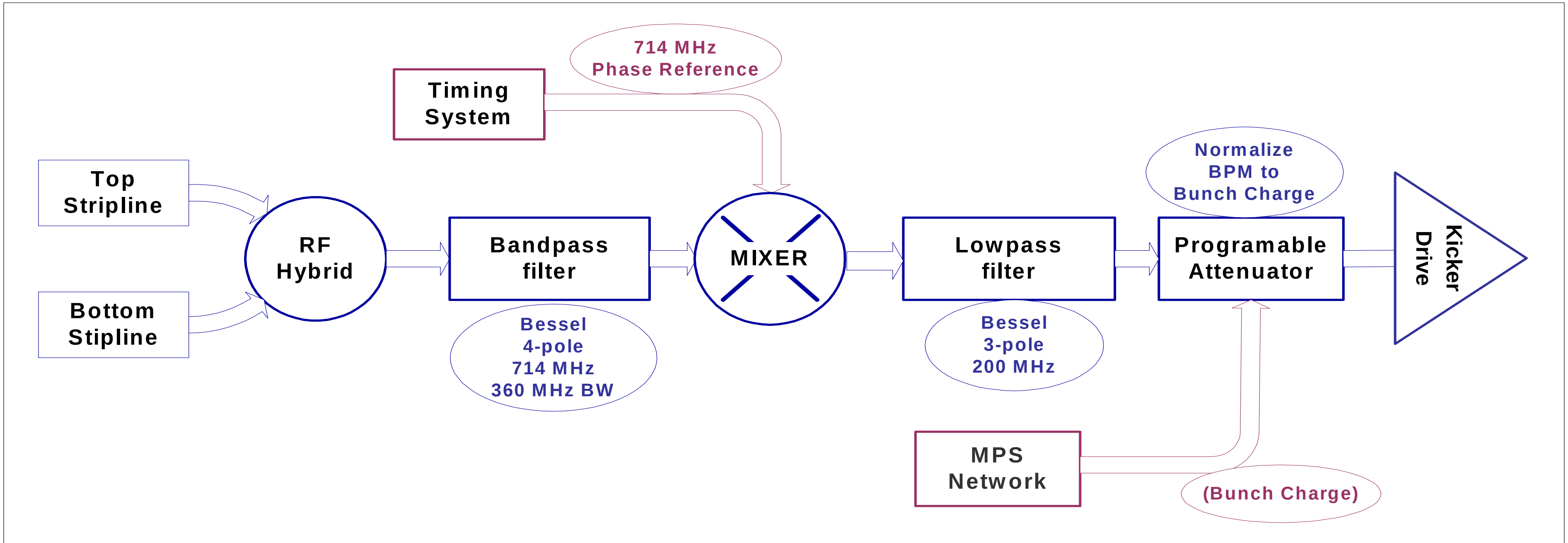


Figure 6: The effect of the feedback on the relative offsets of the two beams. Three different gain factors are shown.

Beam Position Monitor

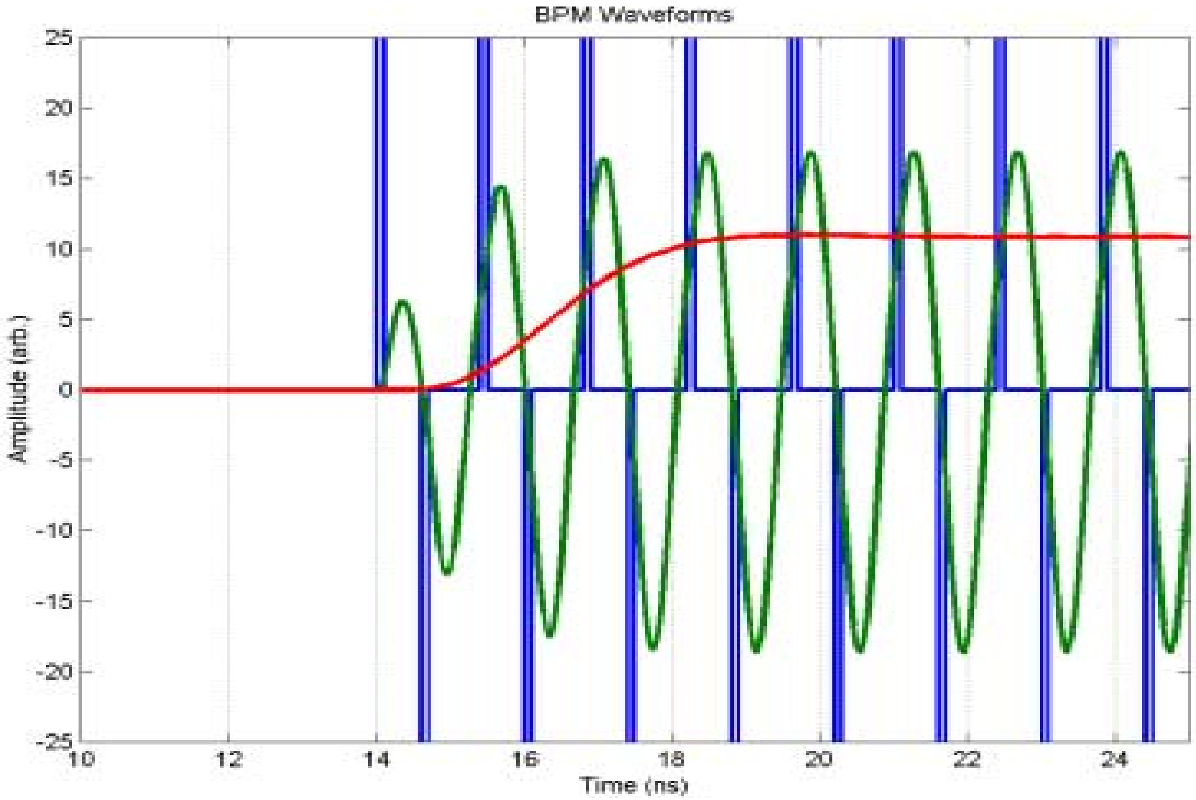
- BPM Pickup
  - 50 Ohm striplines
  - 1 cm radius
  - 10 cm long
  - 7% angular coverage
  - 4 m from IP
  - Must be careful of propagating RF from IP region
- BPM Processor
  - Fast, < 3 ns propagation delay (+ cable lengths)
  - Amplitude difference at 714 MHz
    - Downconvert to baseband
    - (need to phase BPM)
    - Wideband: 200 MHz at baseband
  - Modest resolution requirement
    - Need only $\sigma < 25\ \mu m$ rms at BPM
    - Johnson noise resolution limit ~ 50 nm (< 1pm beam-beam offset)
  - Must suppress interference
    - A secondary electron knocked off stripline makes apparent position shift of ~ 1 pm
    - An imbalance of 8×10^5 (10^{-4} of bunch) causes a 1 micron error

Fast BPM Processor



Fast BPM Processor Block Diagram

Simulated BPM Processor Signals



BPM Pickup (blue)
Bandpass filter (green)
and BPM analog output (red)

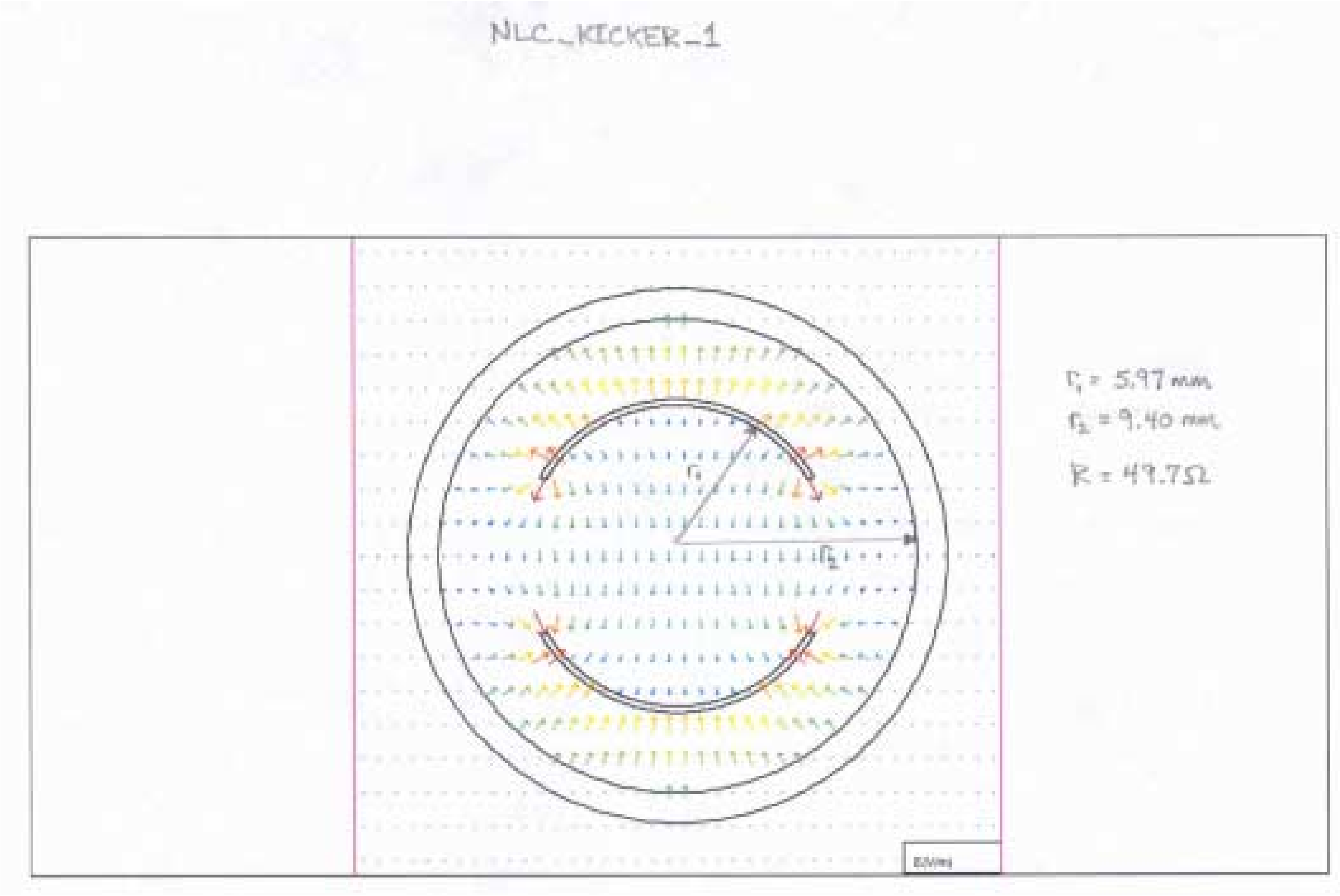
BPM Processor Parameters

First Filter (RF)	Second-order bandpass Center Frequency 714 MHz Bandwidth 360 MHz Second-order lowpass Bandwidth 1 GHz
Mixer	Double balanced GaAs diodes for rad-hardness Max. linear input: 300 mV RF bandwidth: 500 MHz – 900 MHz IF bandwidth: 200 MHz
Baseband Filter	Fourth- order Lowpass 200 MHz Bandwidth
Hybrid	Printed circuit

Stripline Kicker

- Baseband Stripline Kicker
  - Parallel plate approximation $\Theta = 2eVL/pwc$
    - (half the kick comes from electric field, half from magnetic)
  - 2 strips, each 75 cm long
  - 50 Ohm / strip
  - 6 mm half-gap
  - 4 m from IP
  - Deflection angle $\Theta = 1$ nr/volt
  - Displacement at IP $d = 4$ nm/volt
  - Approximately 1Volt drive kicks beam one sigma
  - 15 σ (40 nm) correction requires 2 Watts (peak) drive per strip
  - Drive amp needs bandwidth from 1 MHz to 100 MHz

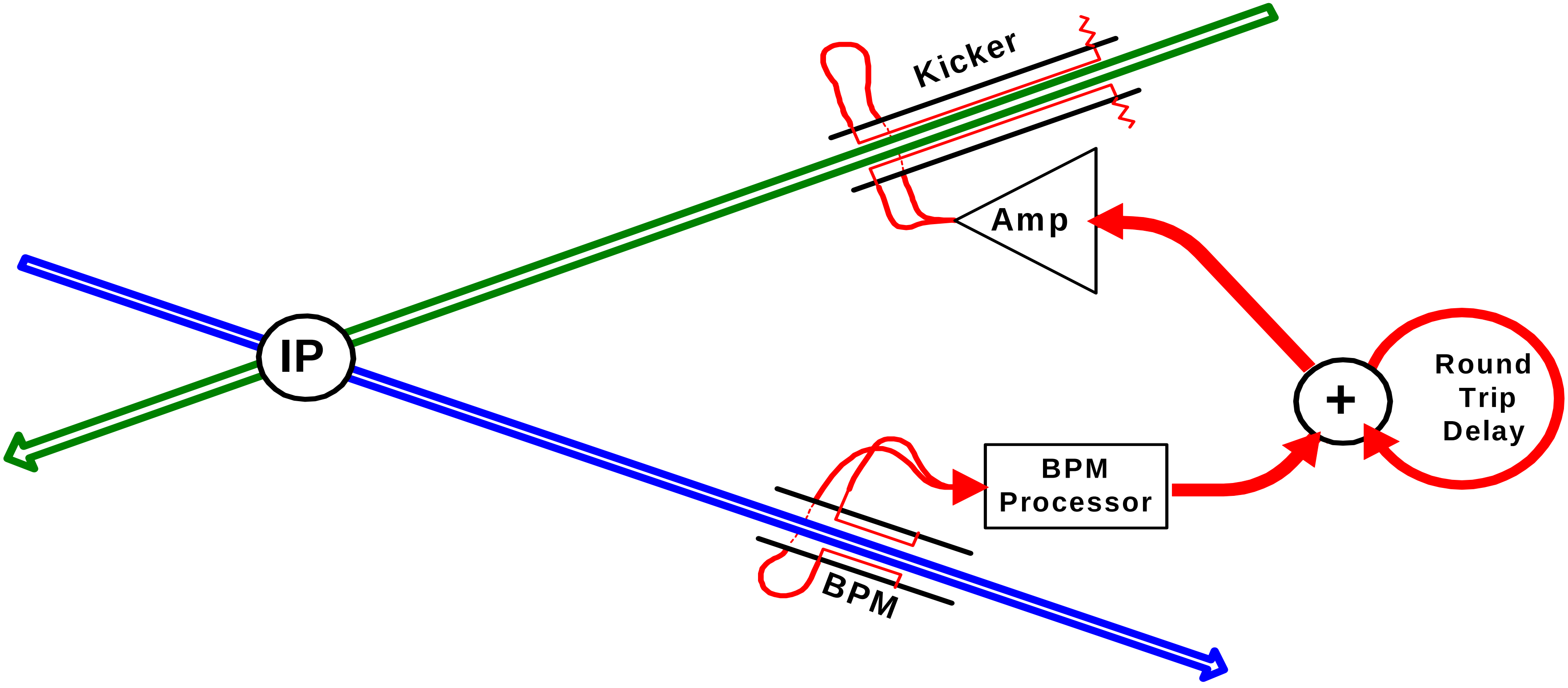
Example Kicker for IP Feedback



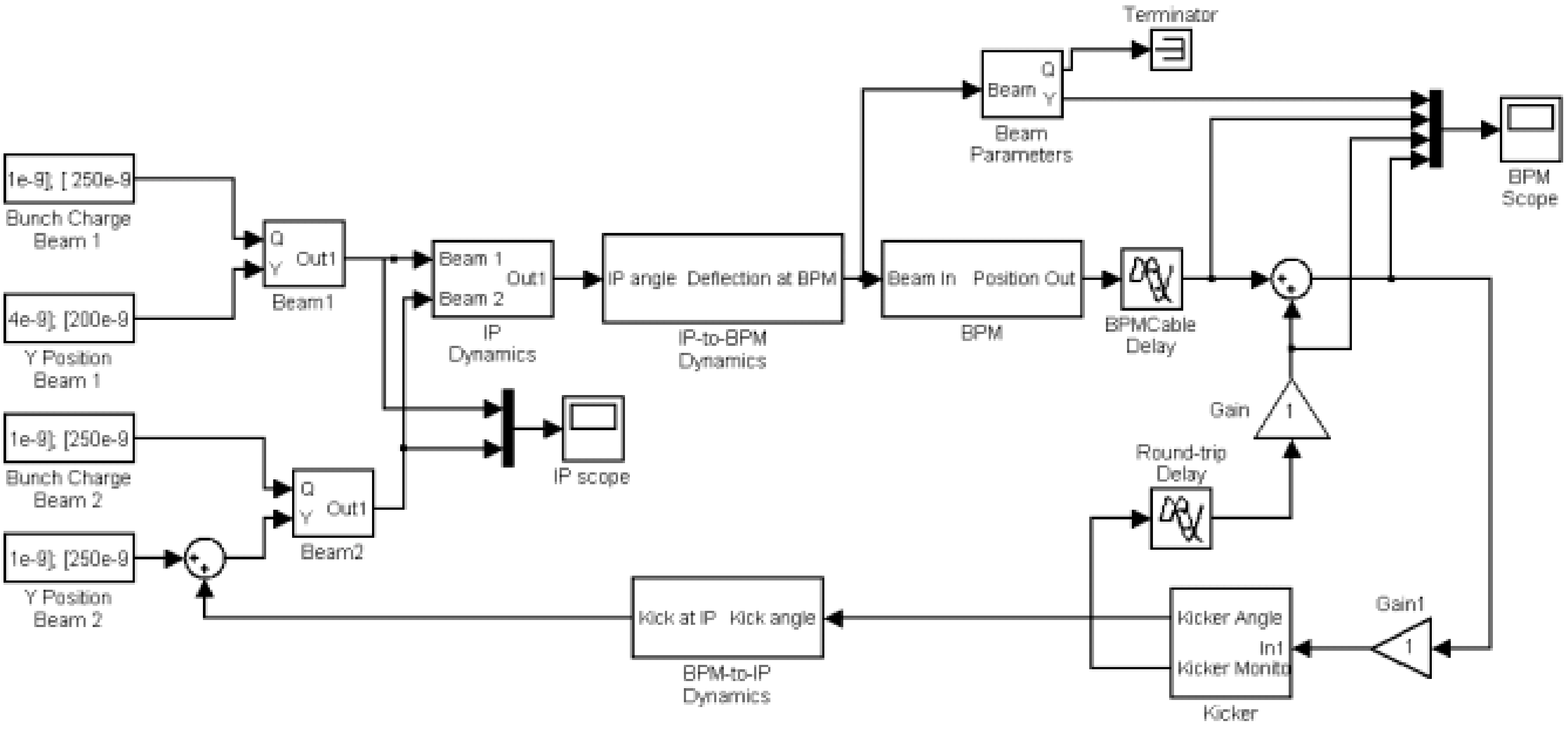
- Odd mode impedance is ~50 Ohms per strip
- 10% stronger than parallel plate kicker with same half-gap

Feedback Regulator

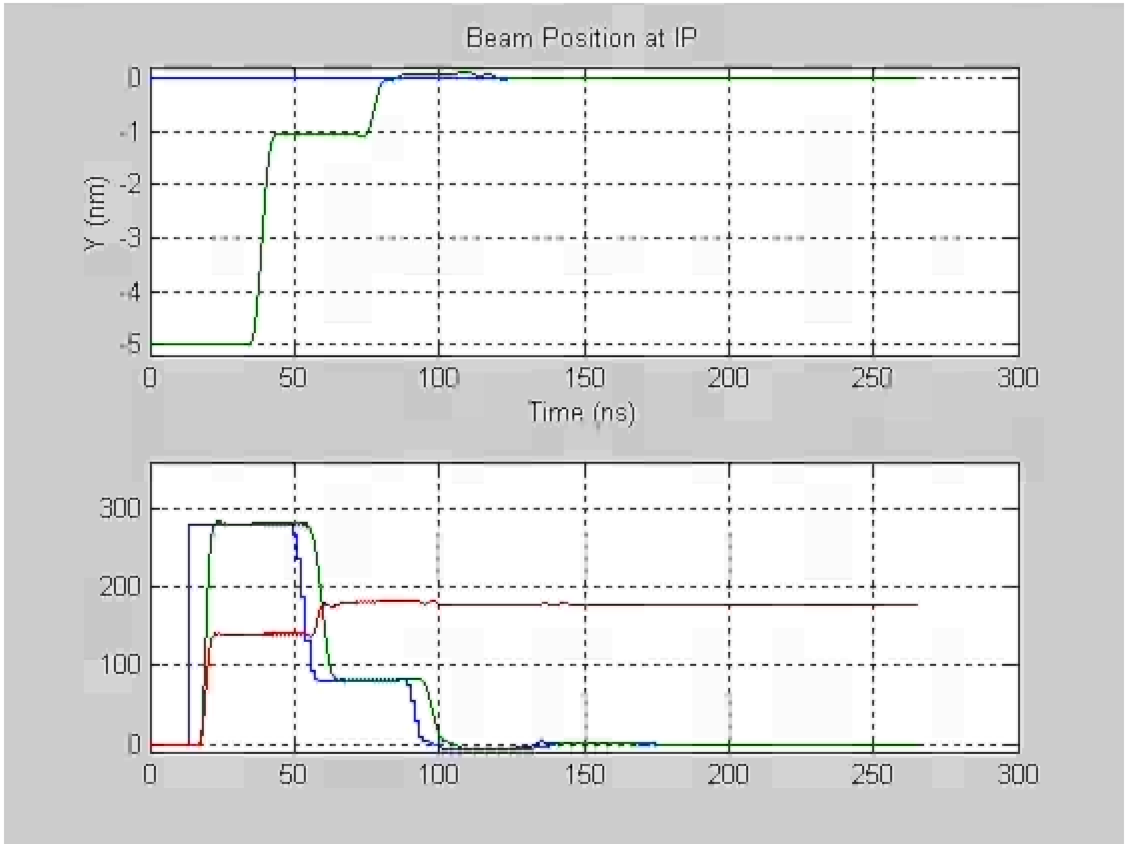
- Compensate for interaction-point round-trip propagation delay
- Use comb integrator
- Physical implementation: 27’ of coax (plus integrator reset)



System Block Diagram

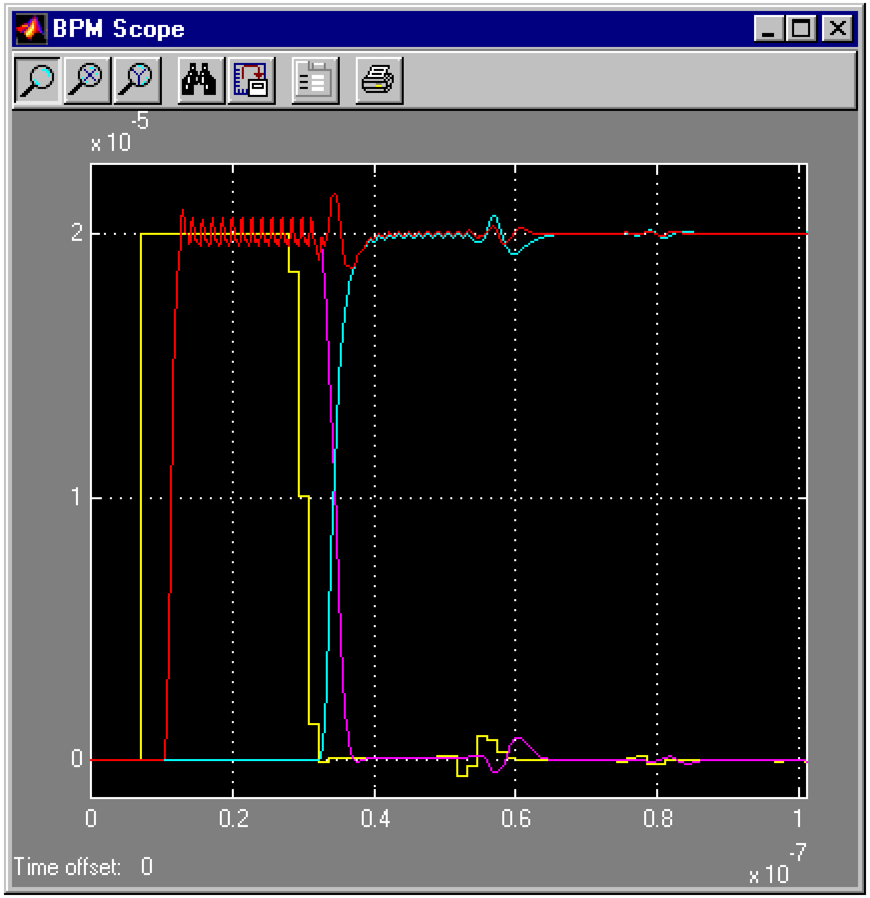


IP Feedback

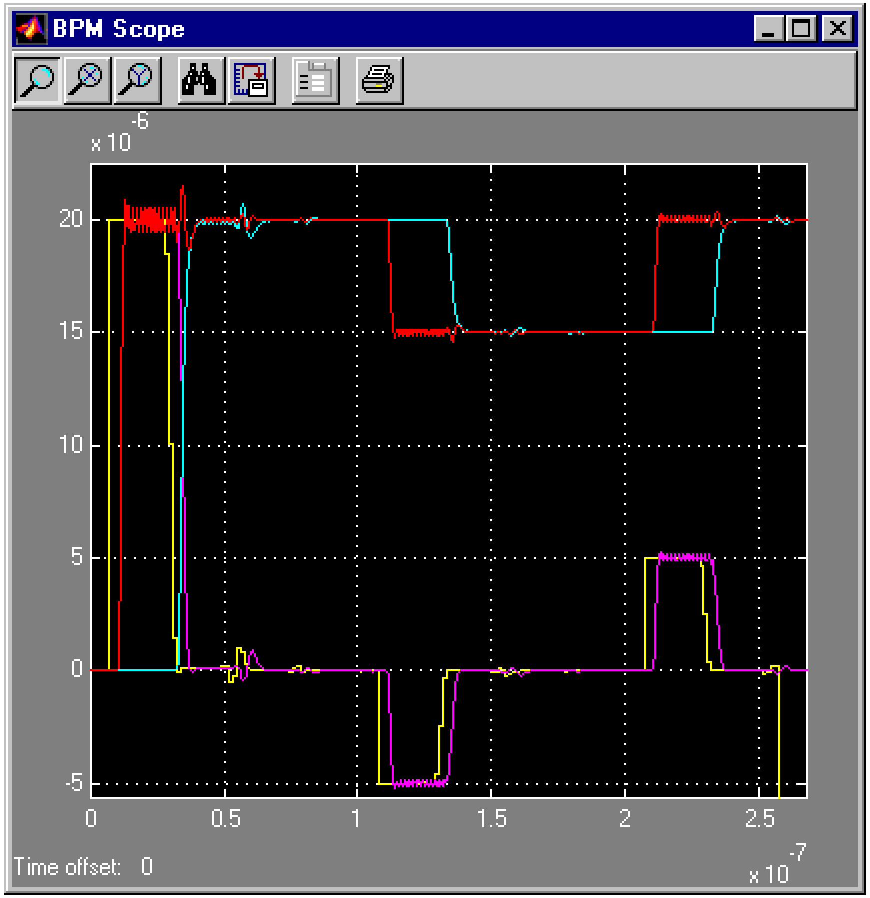

Beam Position at IP
Y (nm)
0
-1
-2
-3
-4
-5
0
50
100
150
200
250
300
Time (ns)
300
200
100
0
0
50
100
150
200
250
300

BPM Scope

Response at BPM



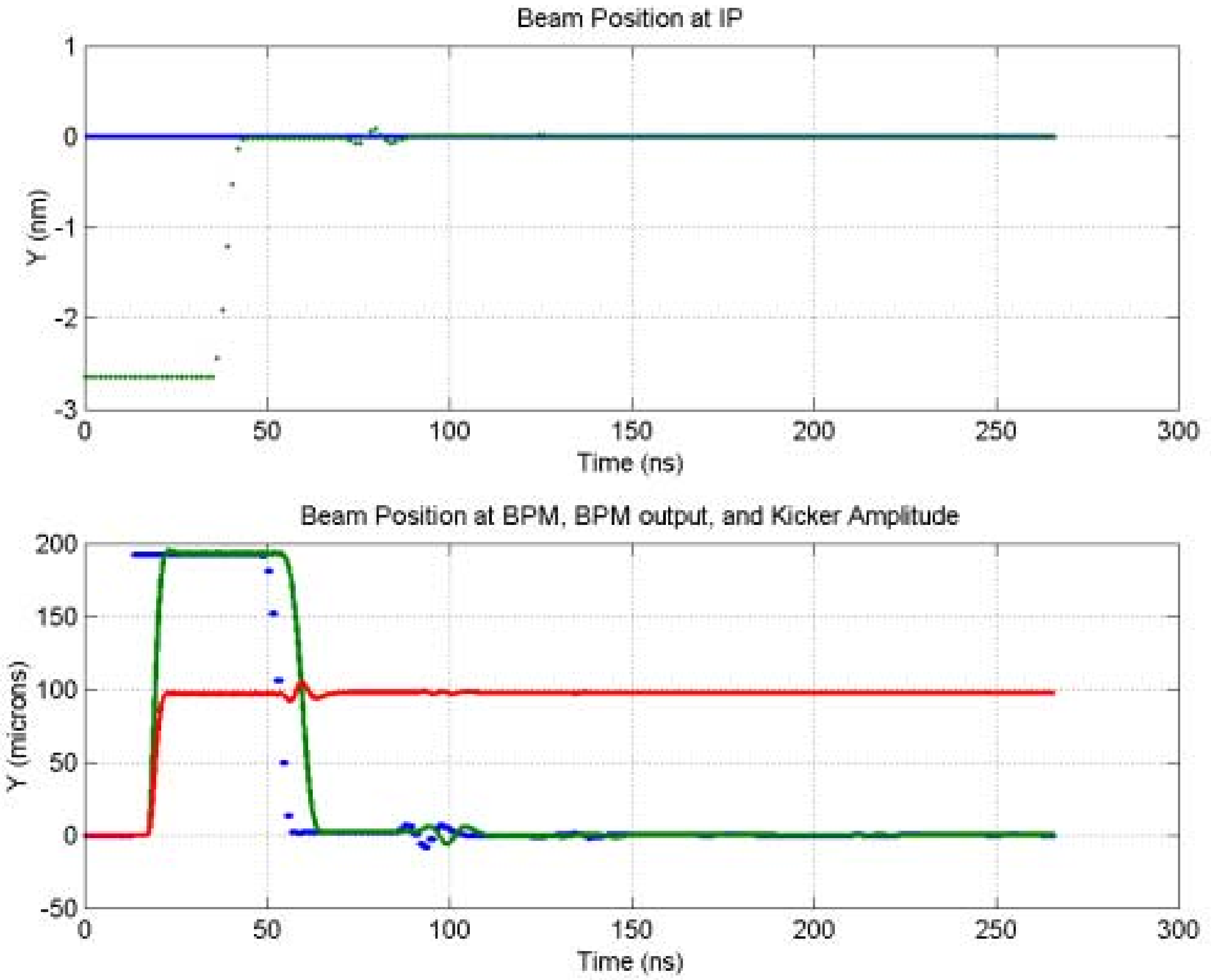
First 100 ns



Full bunch train

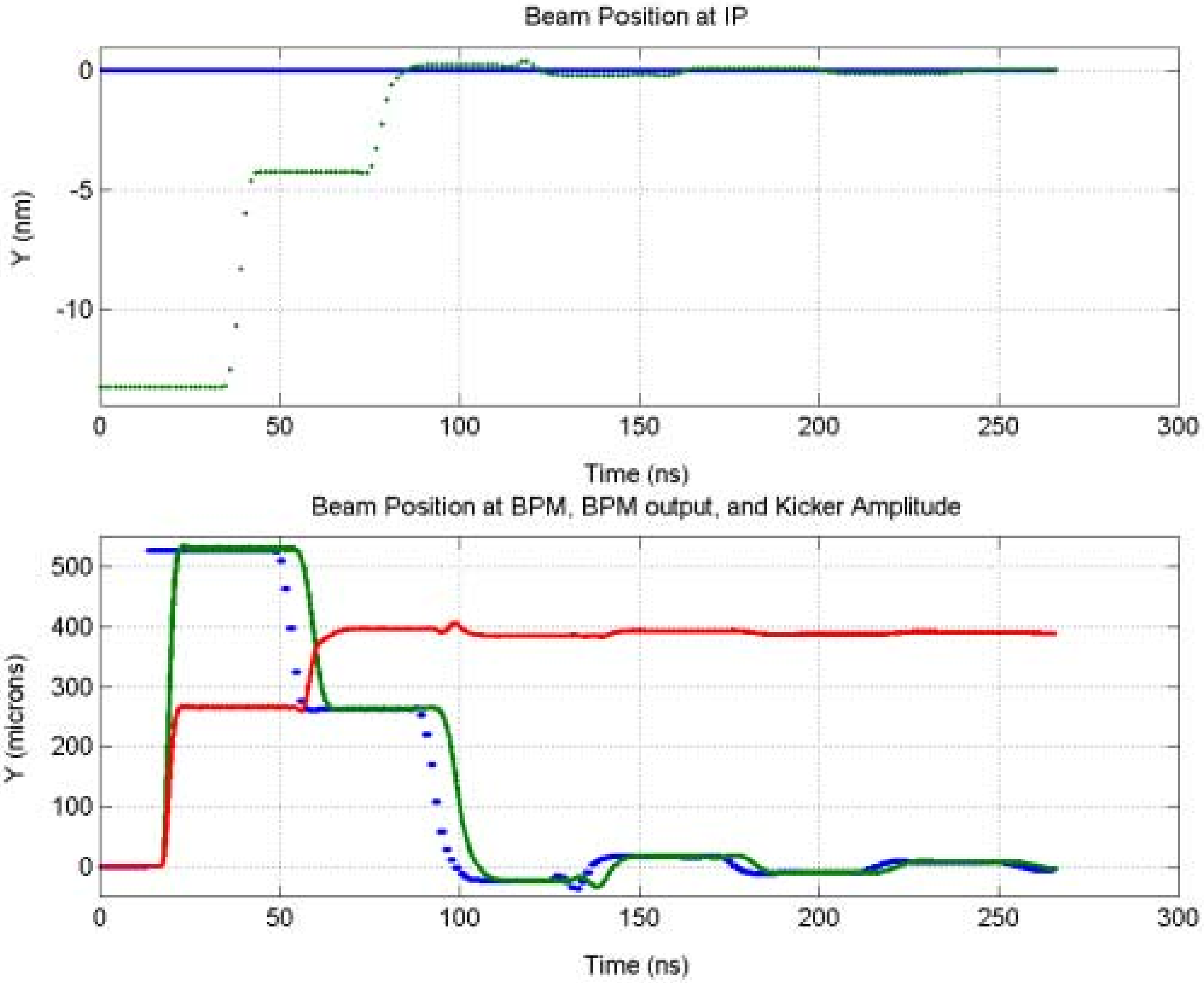
Small Signal Response

(1 σ initial offset)



Capture Transient

5 σ Initial Offset (13 nm)



Beam-Beam Deflection

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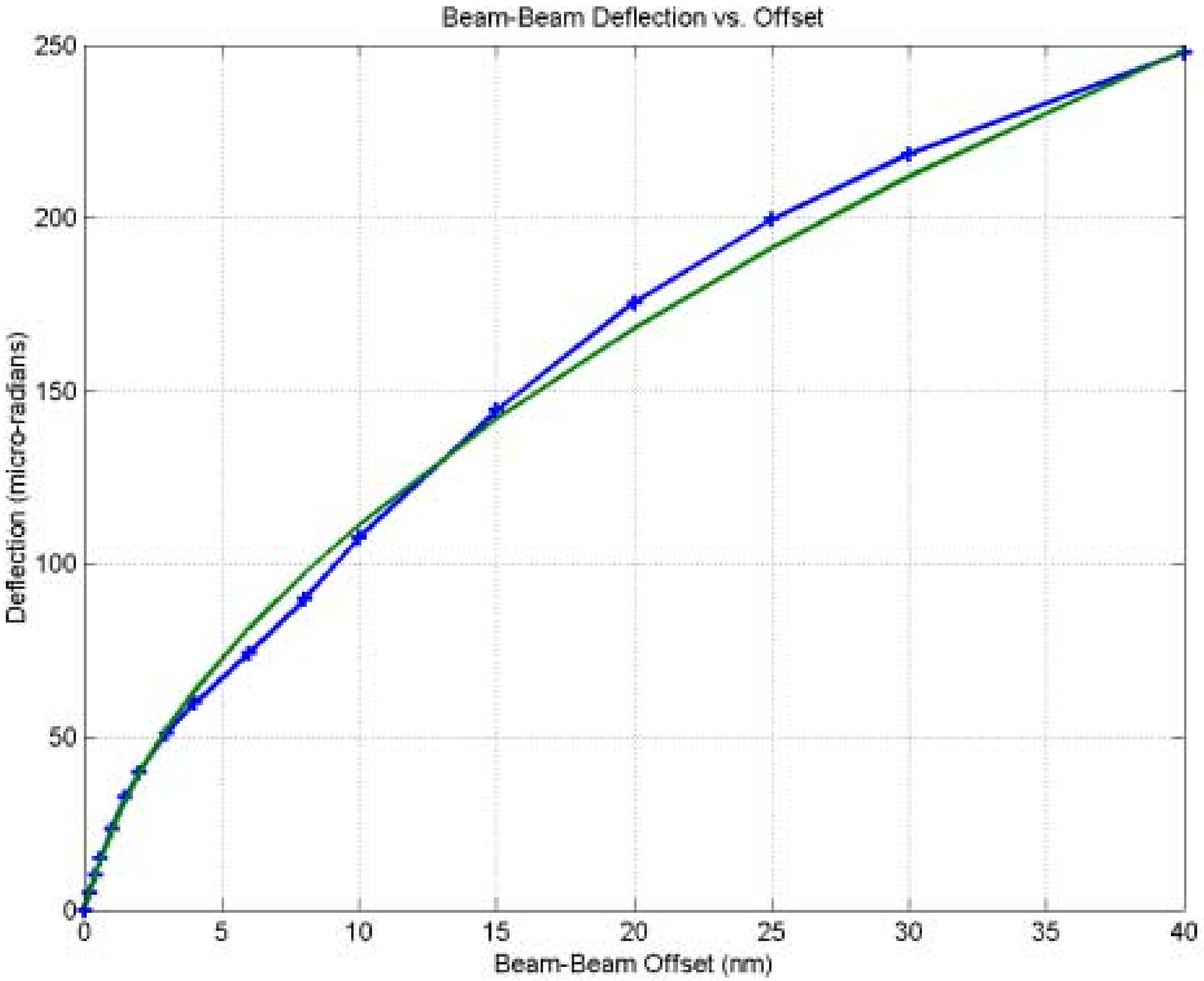
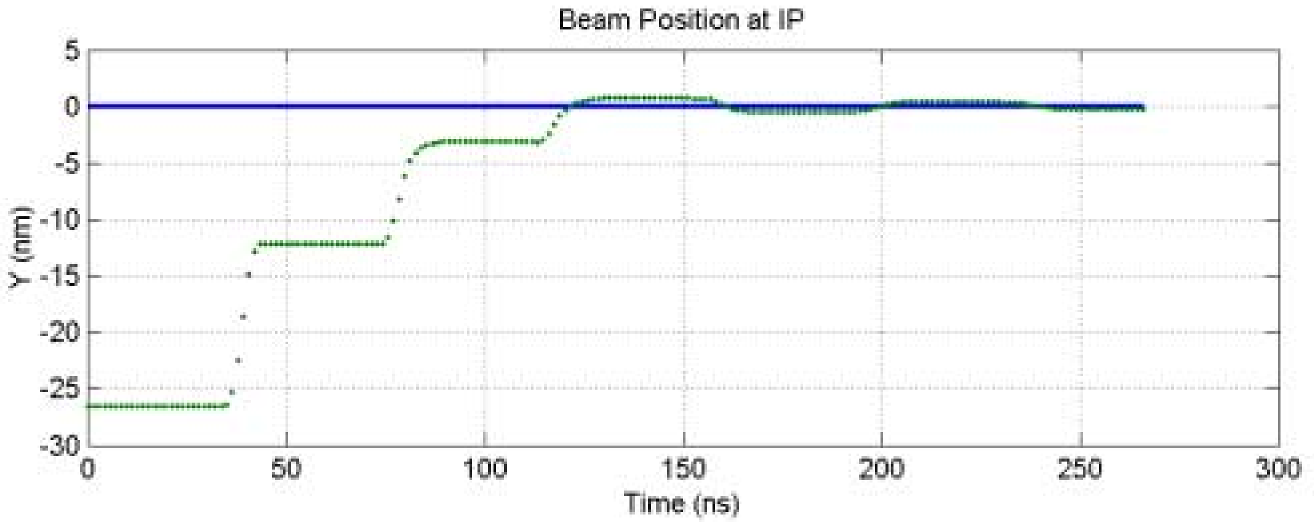


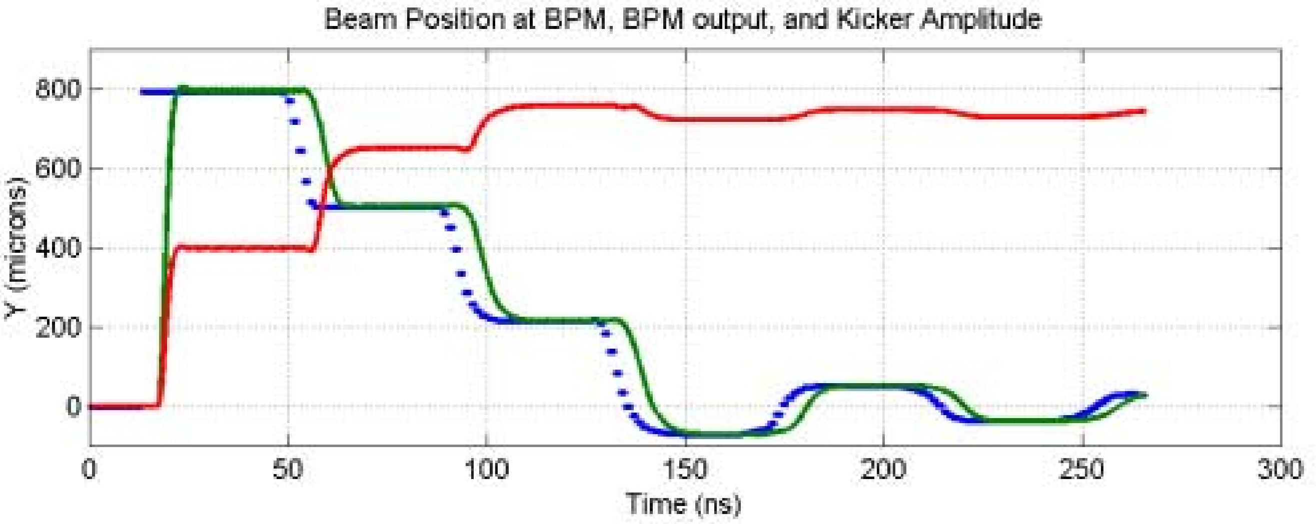
-- simulation

-- parameterization

Capture Transient

10 σ Initial Offset (27 nm)





R&D

- Understand, optimize parameter space
  - Phil Burrows and Oxford colleagues
- Prototype electronics / Beam Tests
  - Bench test
  - SLAC beam tests
  - KEK ATF(?)
- Investigate
  - Angle feedback
  - non-linear feedback
    - i.e. apply higher gain when way out
  - Adaptive feedback
    - Adjust gain to optimal for present jitter
  - Time-dependent gain
    - I.e. decrease gain along bunch train
  - Speed up round-trip time

Conclusions

- Works great (on my workstation)
- Stripline beam position monitor is conventional
- Processor can be conventional technology
  - Conventional BPM processor technology (PEP-II, most light sources)
  - Conventional RF components
  - Can be built from commercially available parts
    - Low cost
    - Hybrid, mixer, amplifier available off-the-shelf
    - Filters readily available
- Electronic propagation delay can be small
- An appropriate feedback regulator is proposed
  - looks great in simulation
- Kicker drive requirements are modest
- One of multiple tools to control IP motion & beam jitter