Final Focus Feedback

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Outline

The need for a Final Focus feedback

The Final Focus feedback system for the ILC

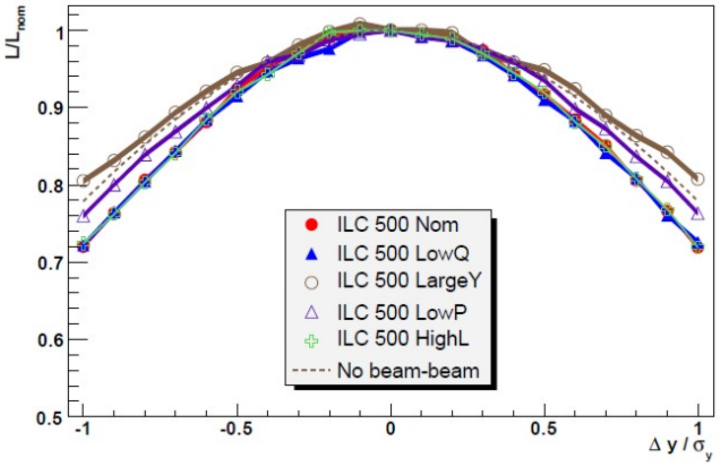
Considerations for C^3

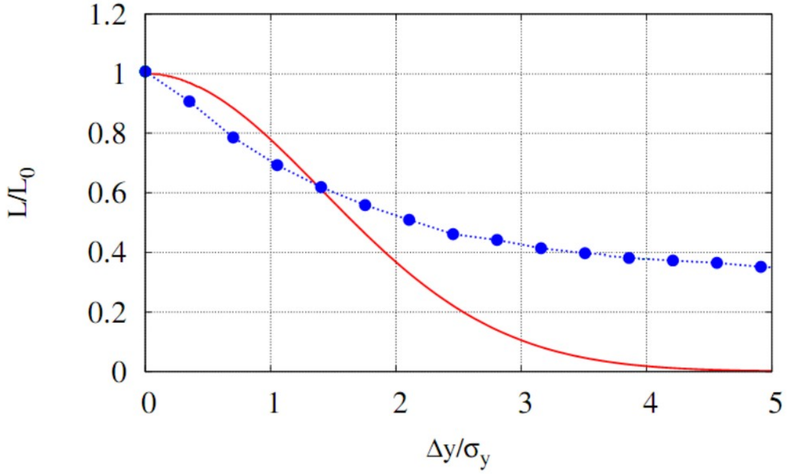
ILC: Luminosity at the interaction point

Much more important for a linear collider because beams do not circulate

Luminosity inversely proportional to product of horizontal and vertical beam size , but 'beamstrahlung' is inversely proportional to the sum → use flat beam with

Luminosity rapidly degrades as a function of the beam-beam offset



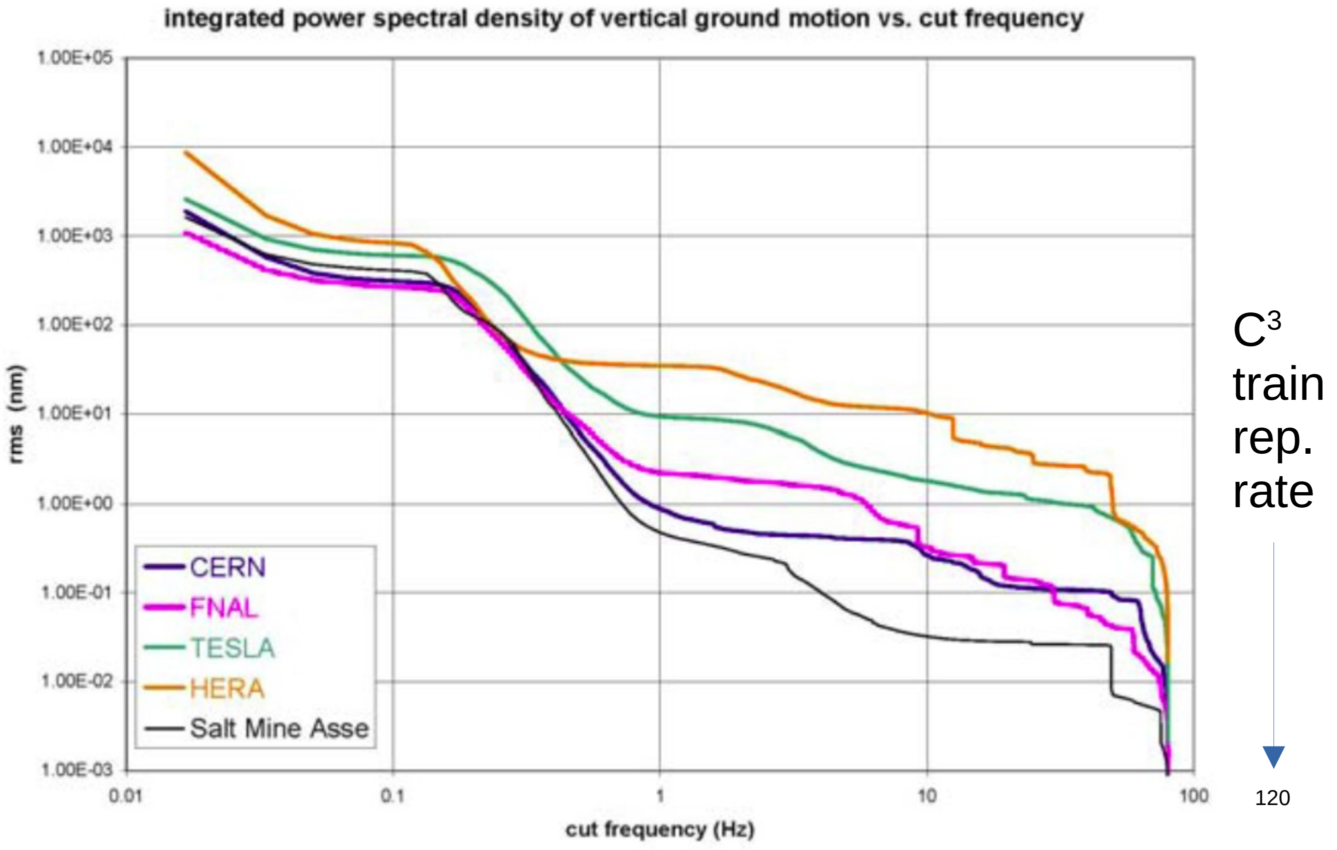


Ground motion

LC Vision → CERN is the relevant data set

On longer timescales (many C[3] trains), motion of the ground (and hence the accelerator components) is comparable to the beam size

Over 1 s (0.1 Hz), motion of about 1 nm can be expected

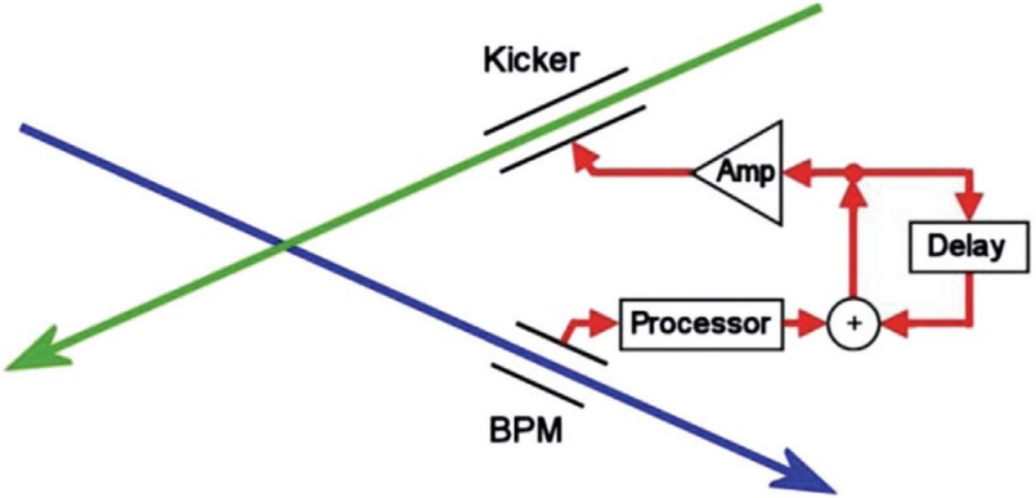


ILC: Final Focus feedback system

Last line of defence against relative beam misalignment

Measure (vertical) position of outgoing beam to infer the beam-beam deflection angle and hence the offset at the IP

Use fast amplifier and kicker to correct (vertical) position of incoming beam

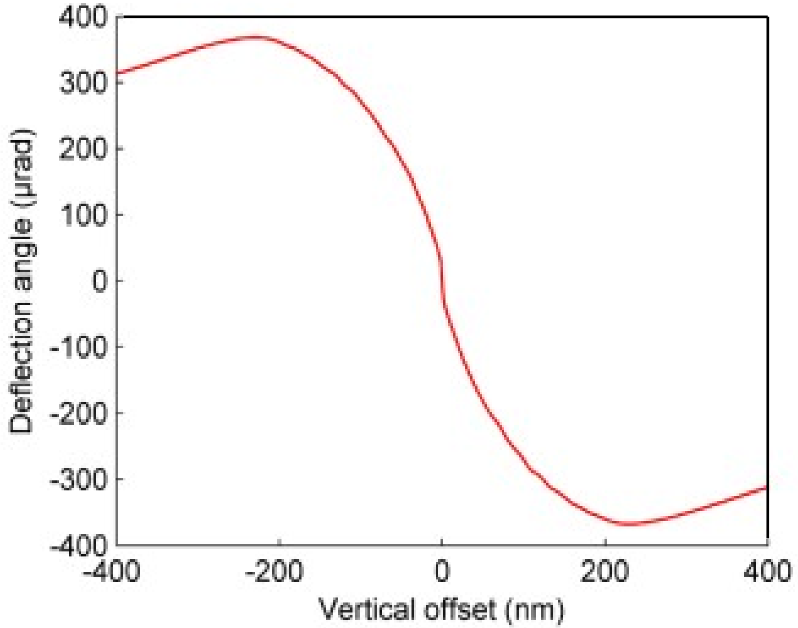


ILC: Operational range

A vertical offset at the IP causes a deflection that results in a much larger position offset downstream

The system is designed to compensate for a ±200 nm vertical offset at the IP – for a 250 GeV beam, this corresponds to a measured offset of up to ±1400 µm at the outgoing BPM

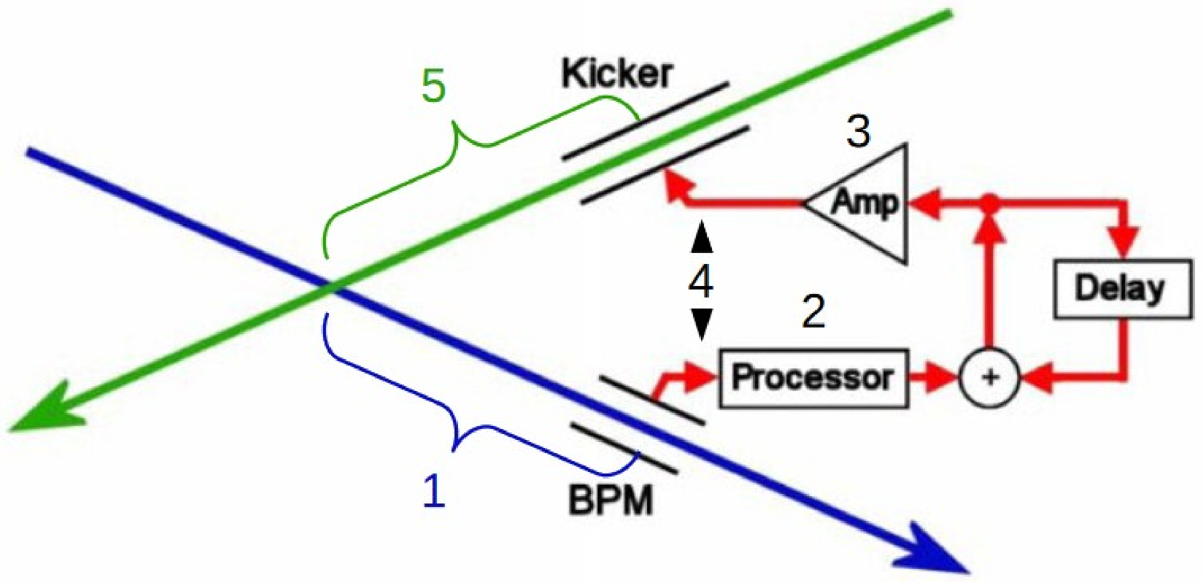
Correcting this requires the incoming beam to be deflected by ±60 nrad



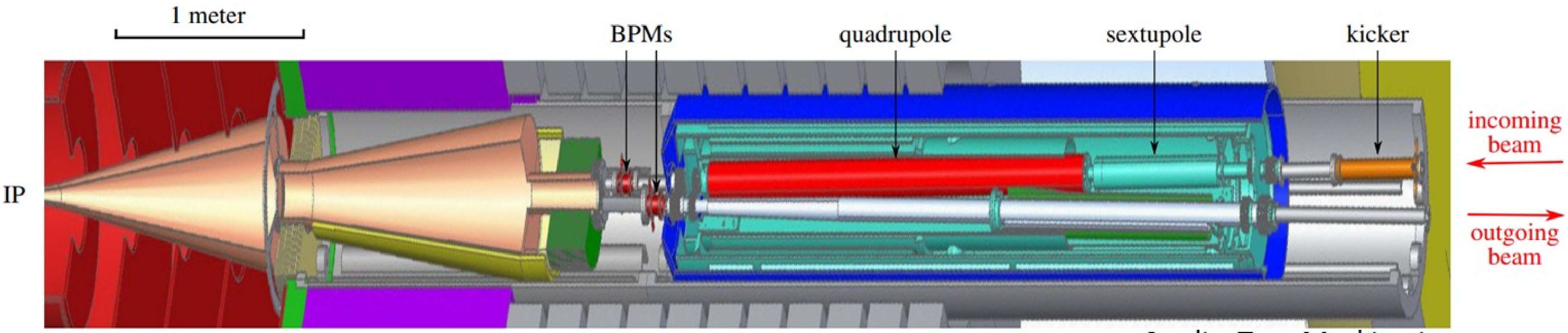
Latency

Bunch-by-bunch position correction latency

1. Beam flight time
   IP ► BPM
2. Signal processing,
   FB calculation
3. Amplifier & kicker
   response time
4. Cable delays
5. Beam flight time
   kicker ► IP



ILC: Feedback component locations



Credit: Tom Markiewicz

Considerations for C^3

"The C^3 can also reuse the final focus design of the ILC" quote from 2023 JINST 18 P07053

How does C^3 compare?

- Smaller beam size
- Much shorter bunch trains
- Much higher rep. rate
- Much shorter bunch spacing
- Lower bunch charge

Parameter	Symbol[unit]	NLC [3]	CLIC [21]	ILC-250 [22]	ILC-500 [22]	C^3-250 [6]	C^3-550 [6]
CM Energy	$\sqrt{s}$[GeV]	500	380	250	500	250	550
RMS bunch length	σ_z^*[µm]	150	70	300	300	100	100
Horizontal beta function at IP	β_x^* [mm]	10	8.2	13	22	12	12
Vertical beta function at IP	β_y^* [mm]	0.2	0.1	0.41	0.49	0.12	0.12
Normalized horizontal emittance at IP	ϵ_x^* [nm]	4000	950	5000	5000	900	900
Normalized vertical emittance at IP	ϵ_y^* [nm]	110	30	35	35	20	13
RMS horizontal beam size at IP	σ_x^* [nm]	286	149	516	474	210	142
RMS vertical beam size at IP	σ_y^* [nm]	6.7	2.9	7.7	5.9	3.1	1.7
Num. Bunches per Train	n_b	90	352	1312	1312	133	75
Train Rep. Rate	f_r [Hz]	180	50	5	5	120	120
Bunch Spacing	[ns]	1.4	0.5	554	554	5.26	3.5
Bunch Charge	Q[nC]	1.36	0.83	3.2	3.2	1	1
Bunch Population	$N_e[10^9$ particles]	8.49	5.18	20.0	20.0	6.24	6.24
Beam Power	P_{beam} [MW]	5.5	2.8	2.63	5.25	2	2.45
Final RMS energy spread	%	0.38	0.35	~ 0.1	~ 0.1	~ 0.1	~ 0.1
Crossing Angle	θ[rad]	0.020	0.0165	0.014	0.014	0.014	0.014
Crab Angle	θ[rad]	0.020/2	0.0165/2	0.014/2	0.014/2	0.014/2	0.014/2
Gradient	[MeV/m]	37	72	31.5	31.5	70	120
Effective Gradient	[MeV/m]	29	57	21	21	63	108
Shunt Impedance	[MΩ/m]	98	95			300	300
Effective Shunt Impedance	[MΩ/m]	50	39			300	300
Site Power	[MW]	121	168	125	173	~ 150	~ 175
Length	[km]	23.8	11.4	20.5	31	8	8
L^*	[m]	2	6	4.1	4.1	4.3	4.3

Impact on feedback

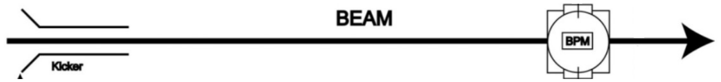
Smaller beam → tighter tolerances on position offset

Shorter bunch spacing → not possible to correct on a bunch-to-bunch basis

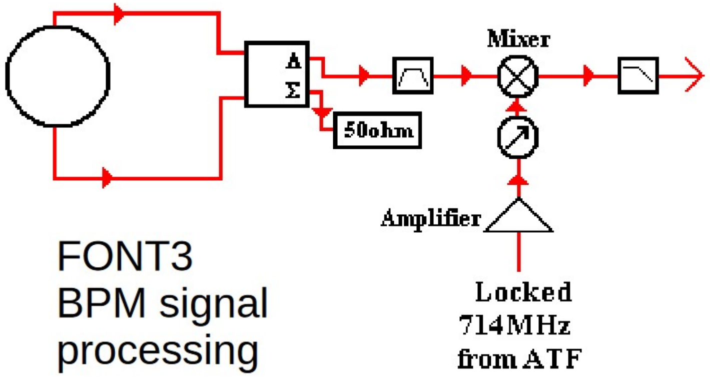
Lower charge → smaller deflection angles at the IP, worse resolution of BPM

Candidate system

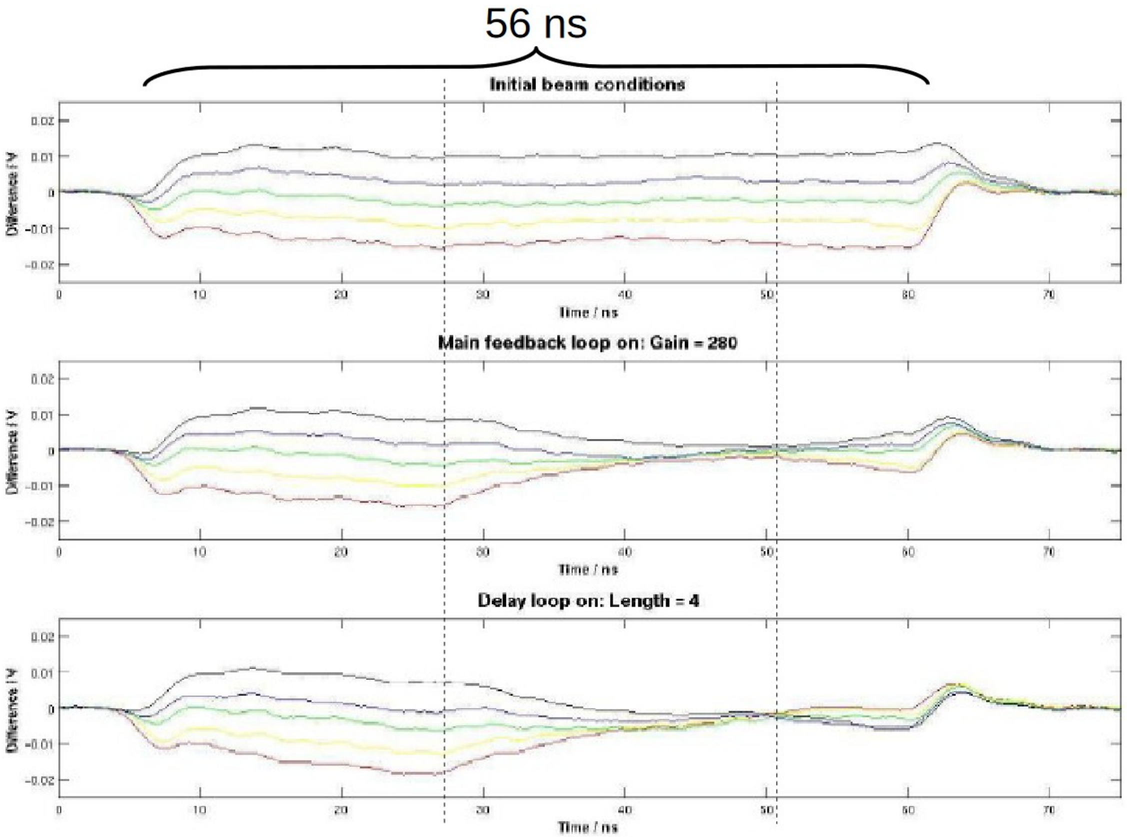
- FONT3: KEK ATF



- EPAC'06: Achieved latency = 23 ns



FONT3
BPM signal
processing



Latency considerations

23 ns latency with a 5.26 ns (3.5 ns) bunch spacing → correction after 5 (7) bunches

133 (75) bunches per train → uncorrected beam 3.8% (9.3%) of the time

Effect on luminosity depends on the beam motion model studied

Feedback performance

Results here are for a system using the FONT5 digital feedback processor but the other components (BPM, kicker) are the same

Latency much higher for FONT5 as it was aimed at ILC-like trains

TABLE IV. Comparison of the IP feedback performance required at the ILC with that achieved by the FONT feedback system at ATF.

		ILC	ATF
Energy per beam	GeV	250	1.3
IP feedback latency	ns	554	148
BPM dynamic range	μm	±1400	±1500
BPM resolution	μm	~1	~1
Beam angle correction range	nrad	~ ± 60	~ ± 180[a]

[a]Scaled by the ATF/ILC beam energy ratio.

Conclusion

From the viewpoint of final focus feedback, C^3 represents a more challenging case than ILC due to the smaller beam and shorter bunch spacing

An analogue system like FONT3 would be appropriate

Credits

Credit for this work belongs to the FONT team over the years:

Robert Apsimon, Neven Blaskevic Kraljevic, Ryan Bodenstein, Talitha Bromwich, Philip Burrows, Glenn Christian, Christine Clarke, Ben Constance, Michael Davis, Tony Hartin, Young Im Kim, Simon Jolly, Steve Molloy, Gavin Neson, Colin Perry, Rebecca Ramjiawan, Javier Resta Lopez, Jack Roberts, Christina Swinson