Status of the CLIC Phase Feedforward Prototype at CTF3

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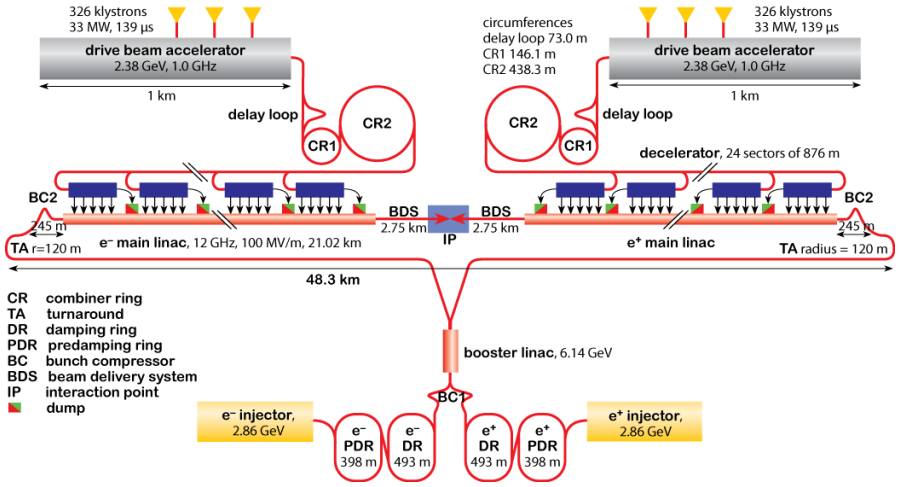
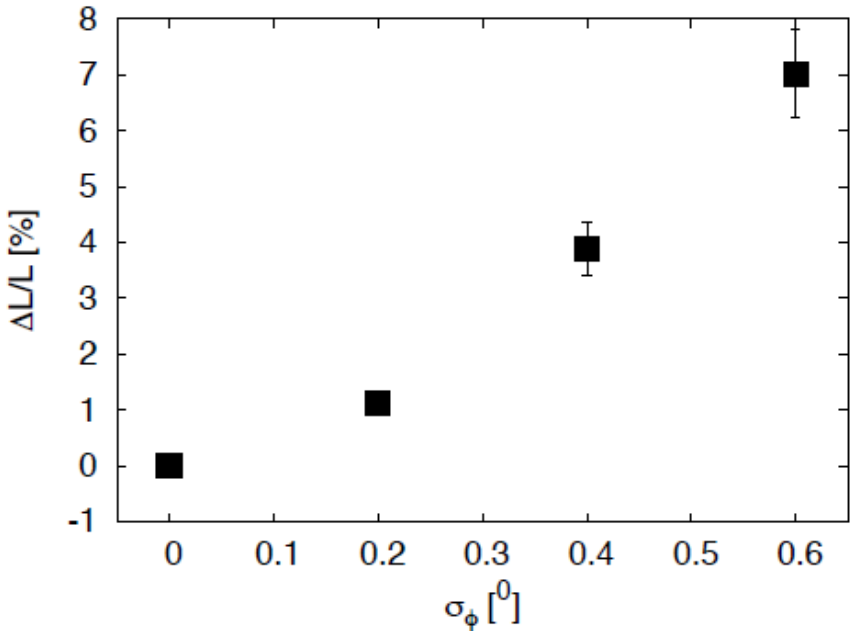
Overview

- Motivation for a phase feedforward system at CLIC.
- Design of the phase feedforward prototype at CTF3.
- Phase feedforward hardware (phase monitors, kickers, amplifiers and digital processor).
- Optics for the phase feedforward system.
- Results from slow phase feedback tests.

Motivation for Phase Feedforward



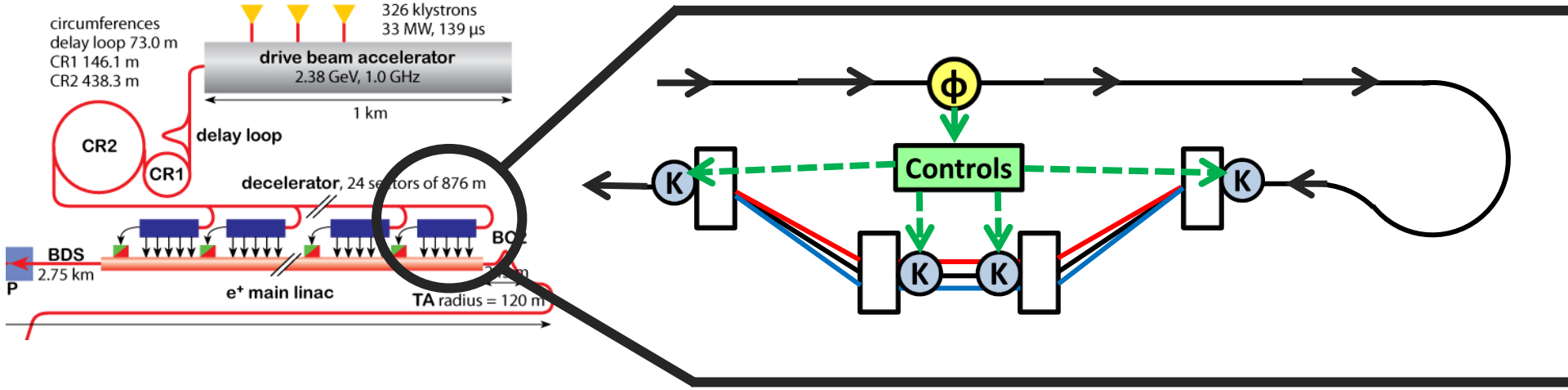


- CLIC luminosity quickly drops if the RF phase jitters.
- Expected drive beam phase stability: 2.5 degrees of 12GHz (drive beam bunch frequency).
- Required drive beam phase stability: <0.2 degrees of 12GHz.

CLIC Phase Feedforward Scheme

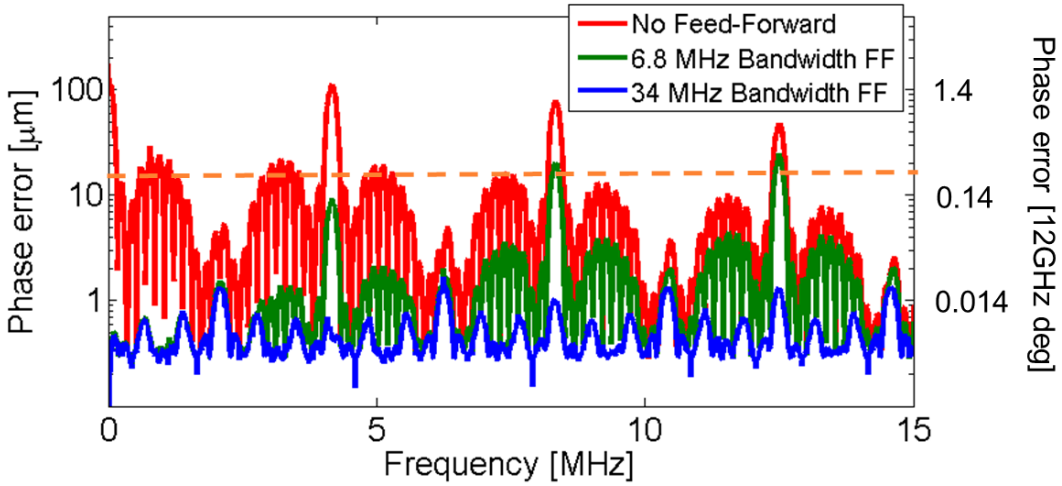
- 4 bend C-shaped chicane after each turnaround prior to drive beam power extraction.
- Measure phase prior to each turnaround.
- Correct the phase by kicking the beam on to shorter/longer trajectories through the chicane.

- Feedforward – correct same “bunch” that was originally measured (system latency < beam time of flight through turnaround).



Phase Feedforward Challenges

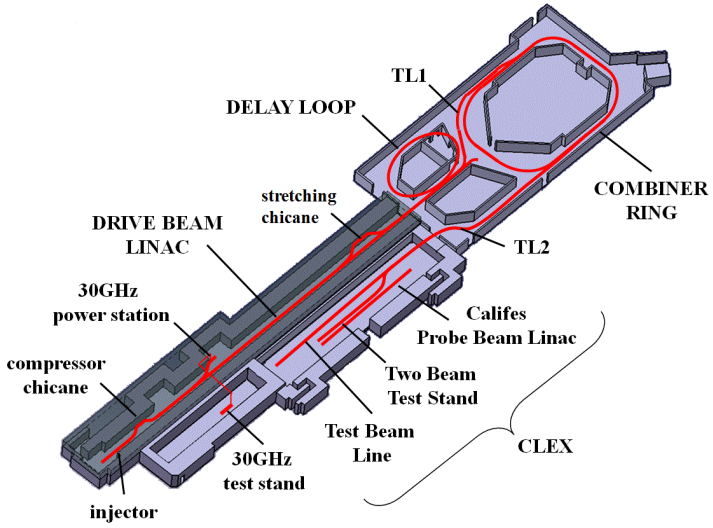
- Major hardware challenge: bandwidth, power, resolution and latency of the components.
- CLIC CDR (optimal target):
  - Correction: 50 MHz bandwidth, 0.2 degrees of 12 GHz resolution
  - Monitors: 100 MHz bandwidth, 0.1 degrees of 12 GHz resolution.
  - Amplifier: 70 MHz bandwidth, 500 kW peak power.
  - Each Kicker: 500 kW peak power for 375 μrad kick.
- Prototype in the final stages of installation at the CLIC test facility CTF3 at CERN to prove feasibility.

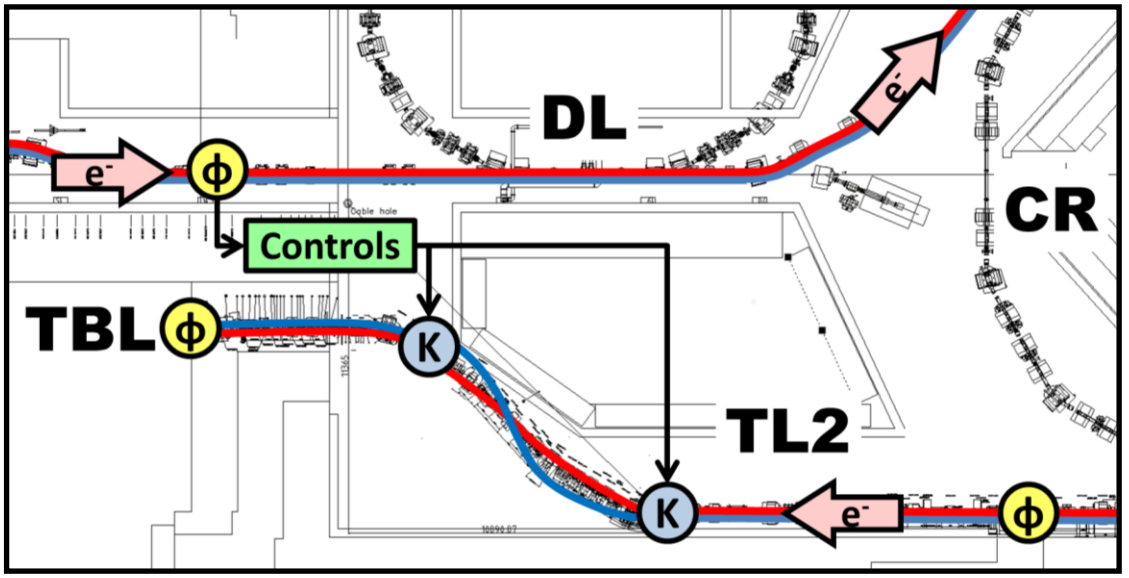


Phase Feedforward Prototype at CTF3

- Correction in the pre-existing four bend dog leg chicane in TL2.
  - 3 phase monitors (INFN Frascati)
  - 2 kickers (INFN Frascati)
  - Amplifiers
  - Digital processor (JAI Oxford)

- Current status: all hardware tested, phase feedforward tests to commence soon.



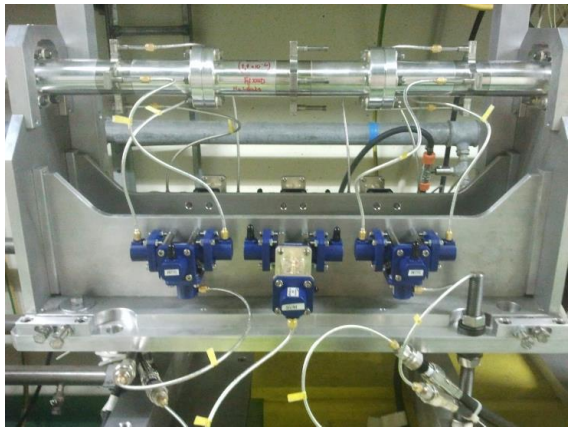


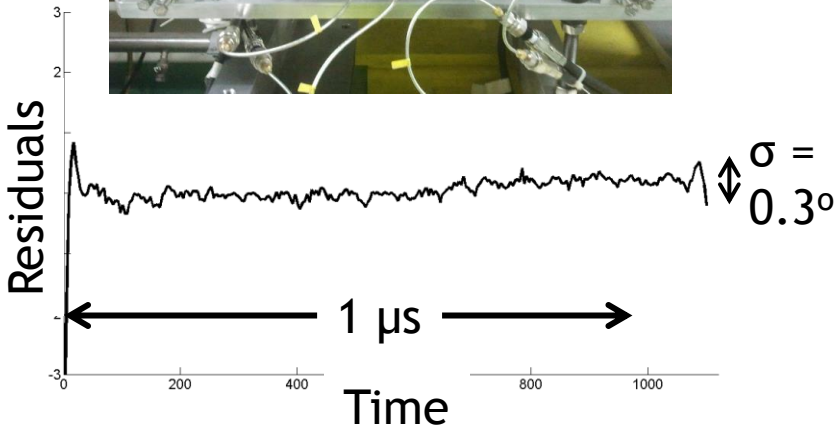
Phase Monitors (INFN Frascati)

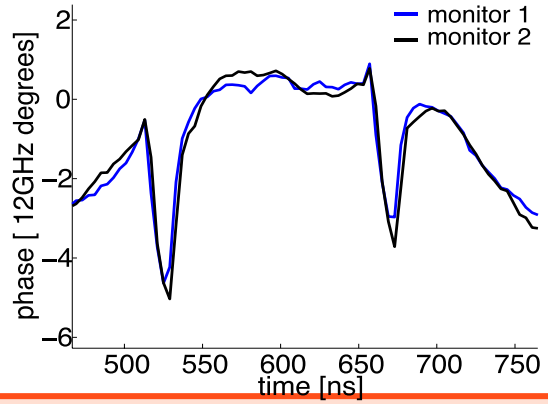
- 12 GHz RF pickups using a choke mode cavity.
- Output RF mixed with 12 GHz reference LO.

- Three monitors installed late 2012 but two damaged.
  - Showed 0.2° of 12 GHz resolution, linearity within ±70°, bandwidth of at least 10 MHz.
  - See Skowronski, WEOBB203, IPAC13 for details.

- Two new monitors with revised design installed last month.
  - First data taken last week, initial results look promising.





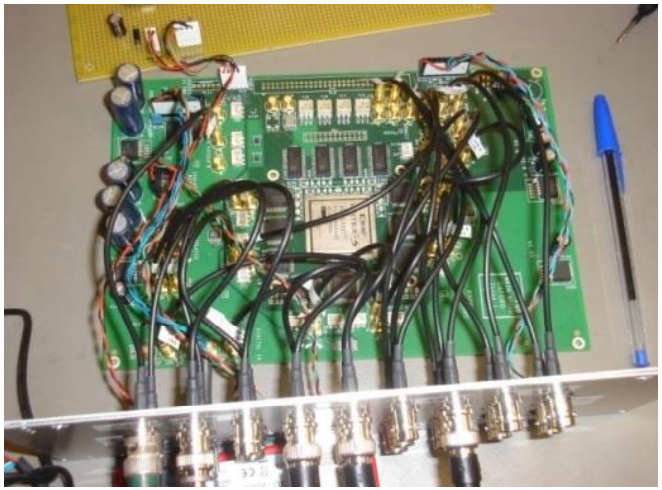


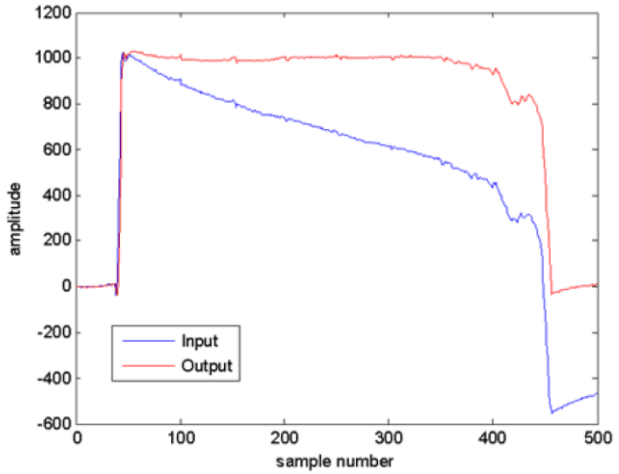
Digital Processor (JAI, Oxford University)

- The brain of the system: Digitises the phase monitor signals, calculates the necessary correction and drives the kicker amplifiers.

- A custom digitiser and feed-forward controller based around a Xilinx Virtex-5 FPGA.
  - 9 analogue input channels.
  - Digitisation using 14-bit 400 MS/s ADCs.
  - 4 analogue output channels, using 14-bit 210 MHz DACs.

- Successful tests of digitising phase monitor signals and driving the amplifiers.
  - Implemented IIR filter to correct droop in ADC response due to AC coupling of the input transformers.

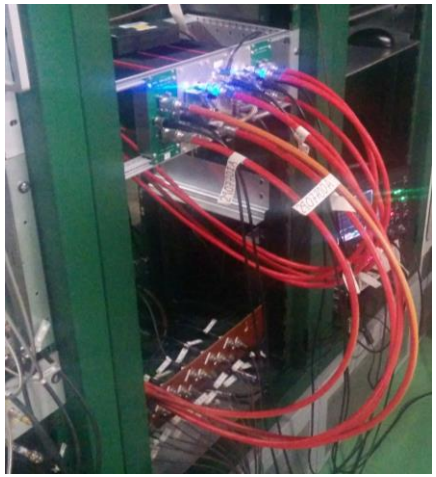




Amplifiers (JAI, Oxford University)

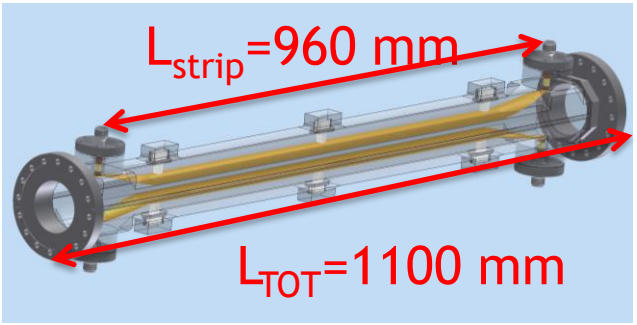
- 1.2 kV Cree SiC FETs driven by LV IxysRF Si FETs
- Nominal 18 kW output power per module (~65 kW combined)
- Output bandwidth: > 50 MHz (60 MHz expected), although slew-rate limited (reduced bandwidth for large change in output)

- First two modules (one per kicker) available in June for initial tests.
  - 345 V output.
  - Design output of each module 600 V (additional FETs will be added to reach design output).
  - Full 1.2 kV from four modules (per kicker) combined.



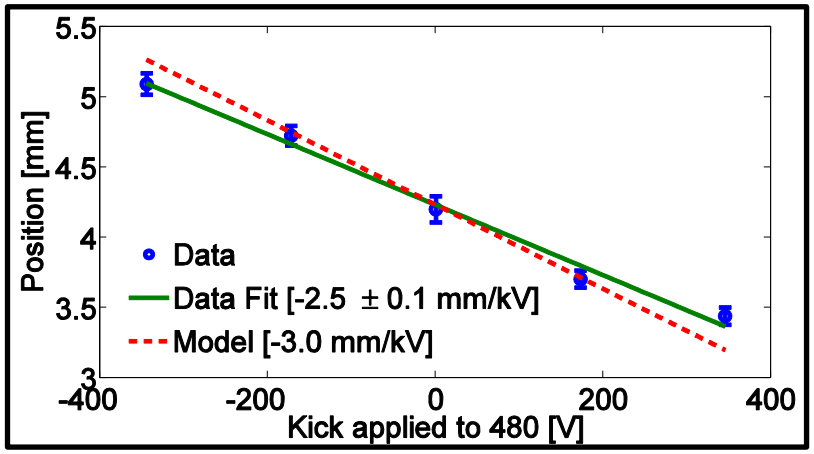
Kickers (INFN Frascati)

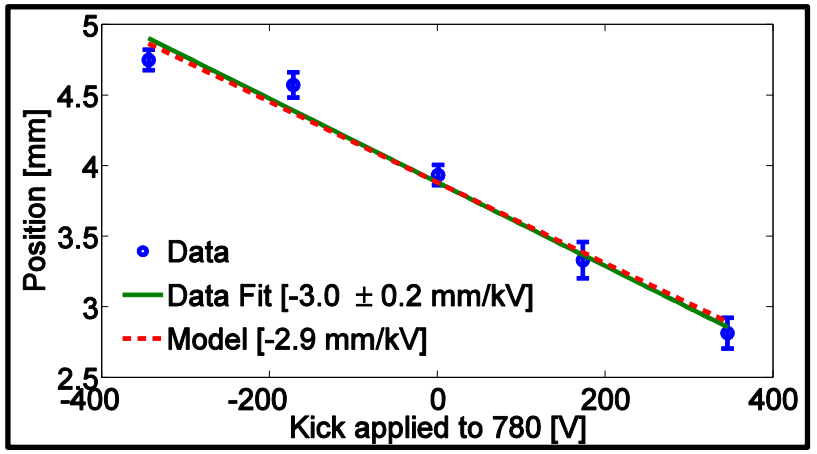
- Strip-line kickers based on the DAFNE design.
- Strip length 960 mm, aperture 20 mm.



- 1.1 kV for 1 mrad deflection at 125 MeV.
  - At least 50 kW drive needed

- The kickers have been integrated in to the TL2 chicane.
- Kickers powered with amplifier for first time in June.

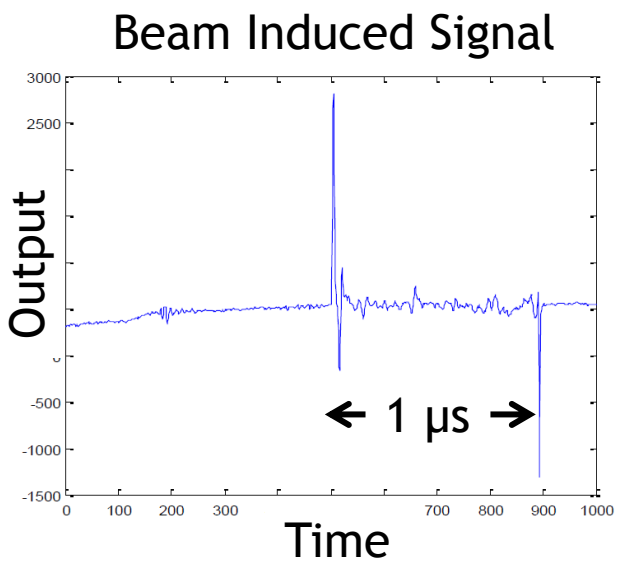




Latency

- Beam time of flight (first phase monitor to first kicker): **380 ns**.
- Kicker cable lengths: ~40 m or **210 ns** (at 0.67c)
- Remaining budget: **170 ns**.

- Original latency estimates:
  - Phase monitors (cables + electronics): 50 ns
  - Digital processor: ~70 ns
  - Amplifier: ~35 ns
  - Total: **155 ns**



- Comparison of timing between beam induced signal from the kickers and the amplifier drive signal, a latency deficit of around **8 ns** was identified.

- Kicker cables (for first kicker) now rerouted shortened by ~6 m or **~30 ns**.

Optics Requirements

- The lattice of the pre-existing TL2 chicane had to be rearranged to accommodate the phase feedforward kickers.
- In addition, the phase feedforward system places new optics constraints.

- **R_{52}** defines the maximum phase correction possible: R_{52} = 1 m means a 1 mrad kick gives a 1 mm path length change (~15° of 12 GHz).
- Compromise: Large R_{52} vs. Small **Dispersion**.

R12 = 0: Orbit after correction unchanged

|R22| = 1: Kick amplitudes equal.

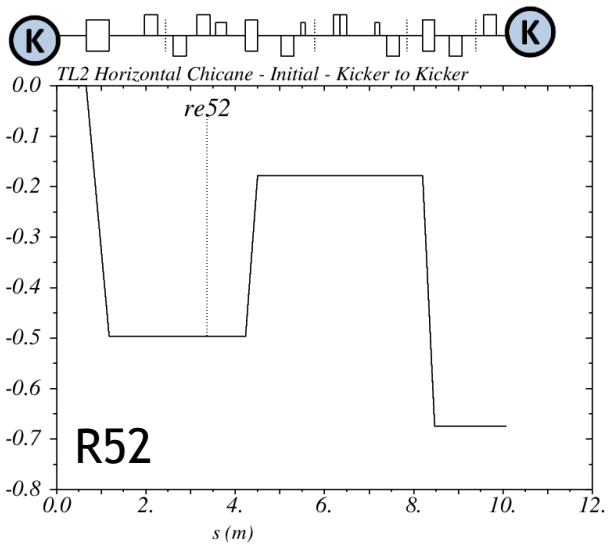
NOMINAL

- Dispersion amplitude below 2m.
- Dispersion closed at chicane exit.
- Smooth transverse optics.
- Small R_{56}, adjustable.

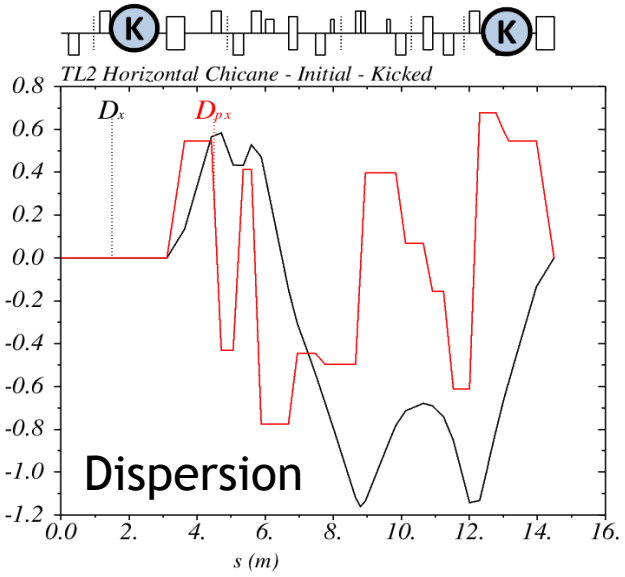
PHASE FEEDFORWARD

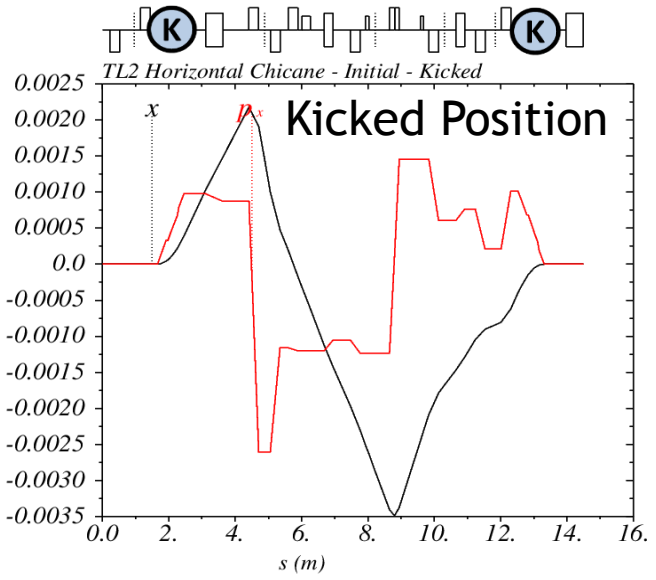
- **R_{52} as large as possible.**
- **R_{12} = 0 from kicker to kicker.**
- **$|R_{22}|$ = 1 from kicker to kicker.**

Proposed Optics



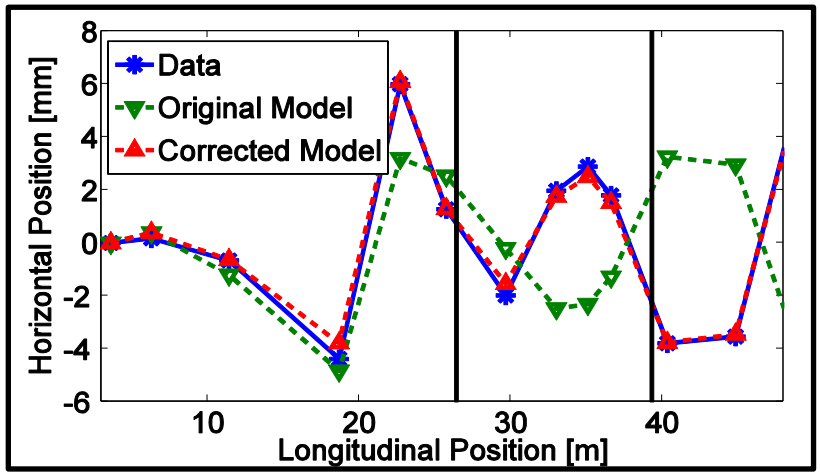
- R52 = -0.7 (10 degree correction range).
- Orbit bump closed for kicked orbits.
- Maximum dispersion 1.2m.
- Betas below 35m.





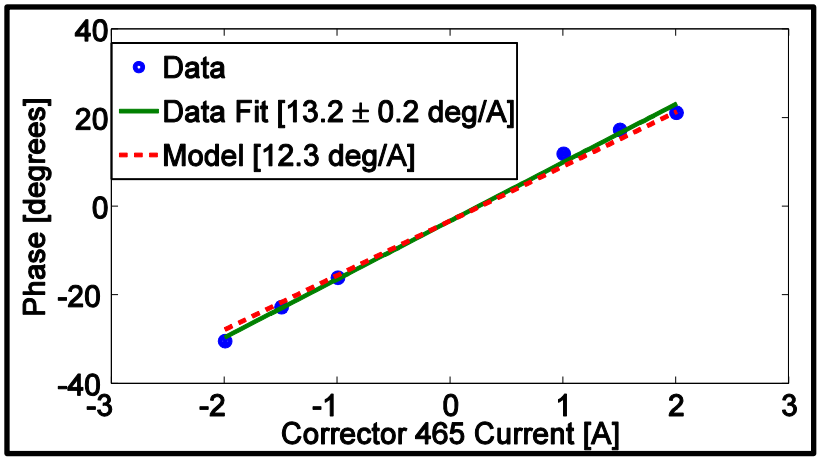
Model Corrections

- Transmission could not be achieved with nominal optics from MADX model.
- Took extensive set of response matrix measurements to identify errors in the model.
- Two major changes:
  - Error of 7% in strength of one type of quadrupole.
  - Large errors in dipole focusing effects.
- Corrected model: mean position offset reduced from 3.0 $\pm$ 0.7 mm to 0.2 $\pm$ 0.1 mm.

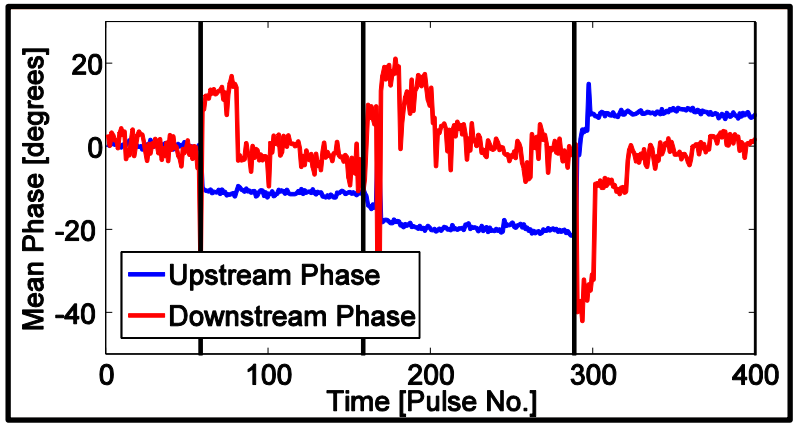


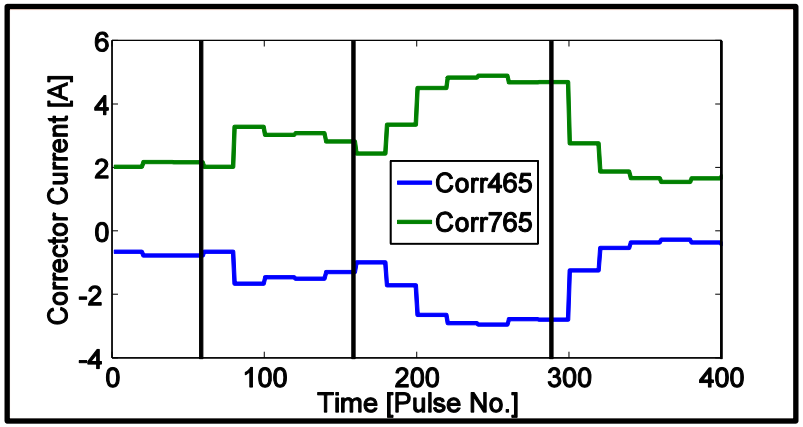
Slow Phase Feedback

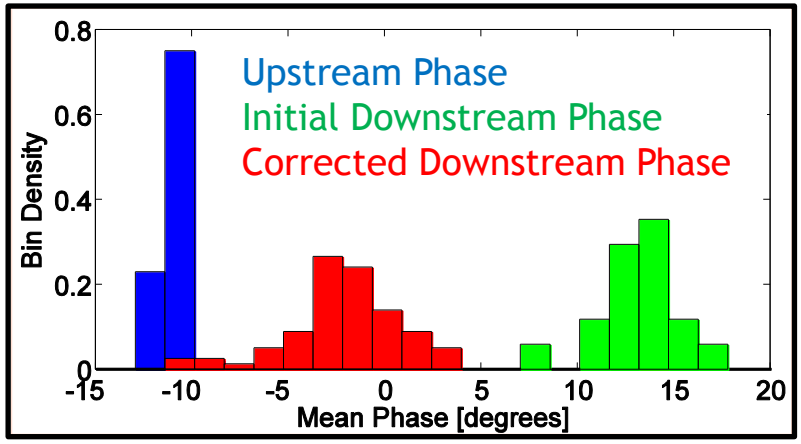
- A slow phase feedback will be used at CTF3 to prevent slow drifts outside the limited (10 degree) range of the feedforward system.
- It works in the same way as the feedforward system but uses two magnetic correctors installed in the chicane instead of the feedforward kickers.
- Slow feedback tests in June verified the performance of the optics and the ability to shift the phase in the TL2 chicane.



Slow Phase Feedback







Pulse No. 63 to 158

- Phase of beam shifted in steps of 10 degrees.
- Phase after chicane (downstream monitor) is brought back to nominal after the (20 pulse) averaging time of the slow feedback.
- Mean downstream phase offset of $13.0^\circ \pm 2.0^\circ$ reduced to $-0.2^\circ \pm 0.8^\circ$

Summary

- CLIC requires a high bandwidth phase feedforward system to reduce the drive beam phase jitter by an order of magnitude, down to below 0.2 degrees of 12 GHz.

- A prototype of the system is in the final stages of commissioning:
  - Verified 0.2 degree resolution of phase monitors.
  - First stage (345 V) amplifier tested. Upgraded (600 V) amplifier will soon be available prior to the ultimate 1.2 kV design amplifier.
  - Rectified major errors in the MADX model of the correction chicane.
  - Beam response to feedforward kickers in agreement with the MADX model.
  - Slow feedback tests demonstrate the ability to correct the phase in the chicane.

- Phase feedforward tests will commence very soon!