Design of **Phase Feed-Forward System in CTF3** and Performance of **Fast Beam Phase Monitors**

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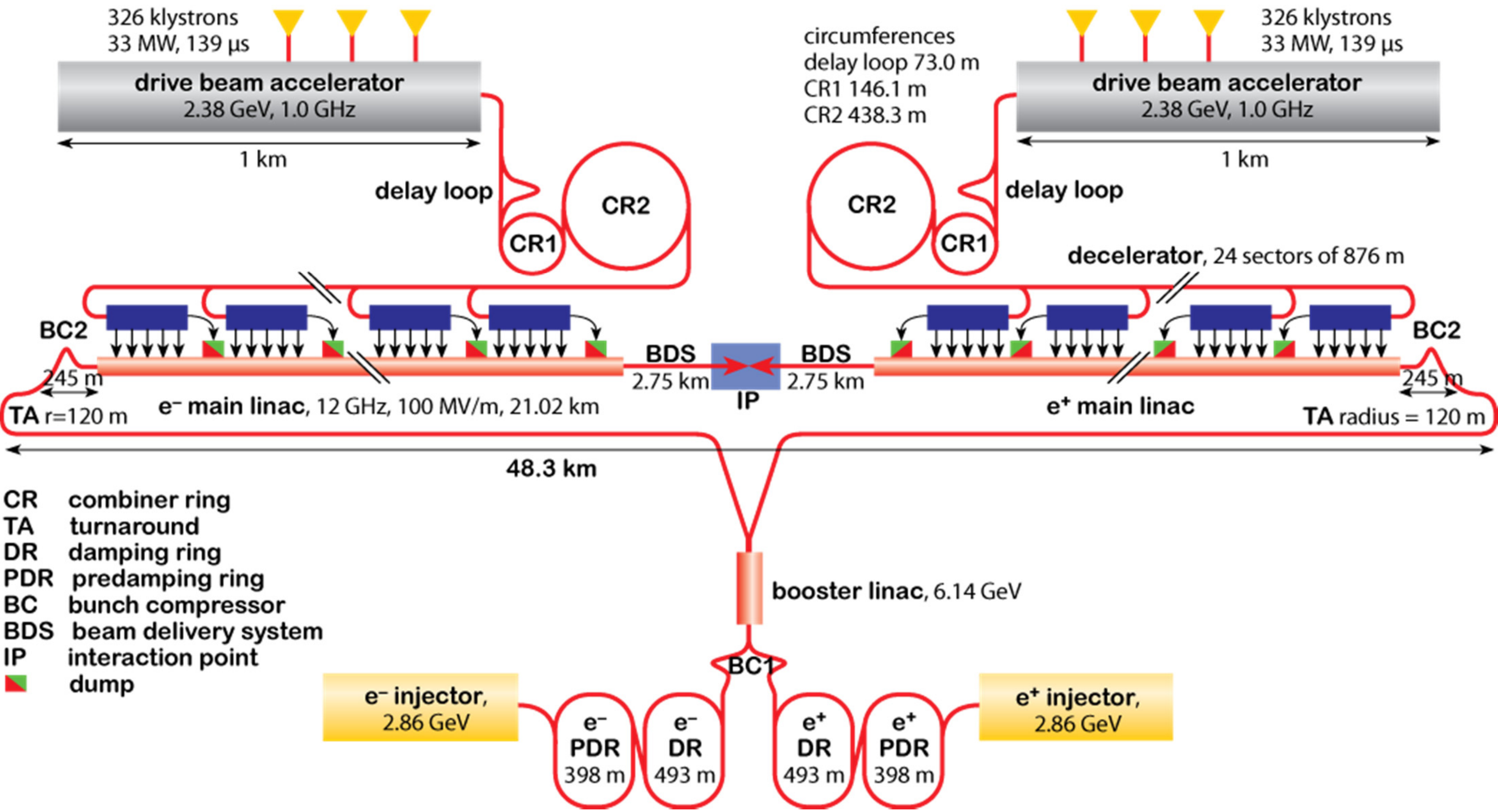
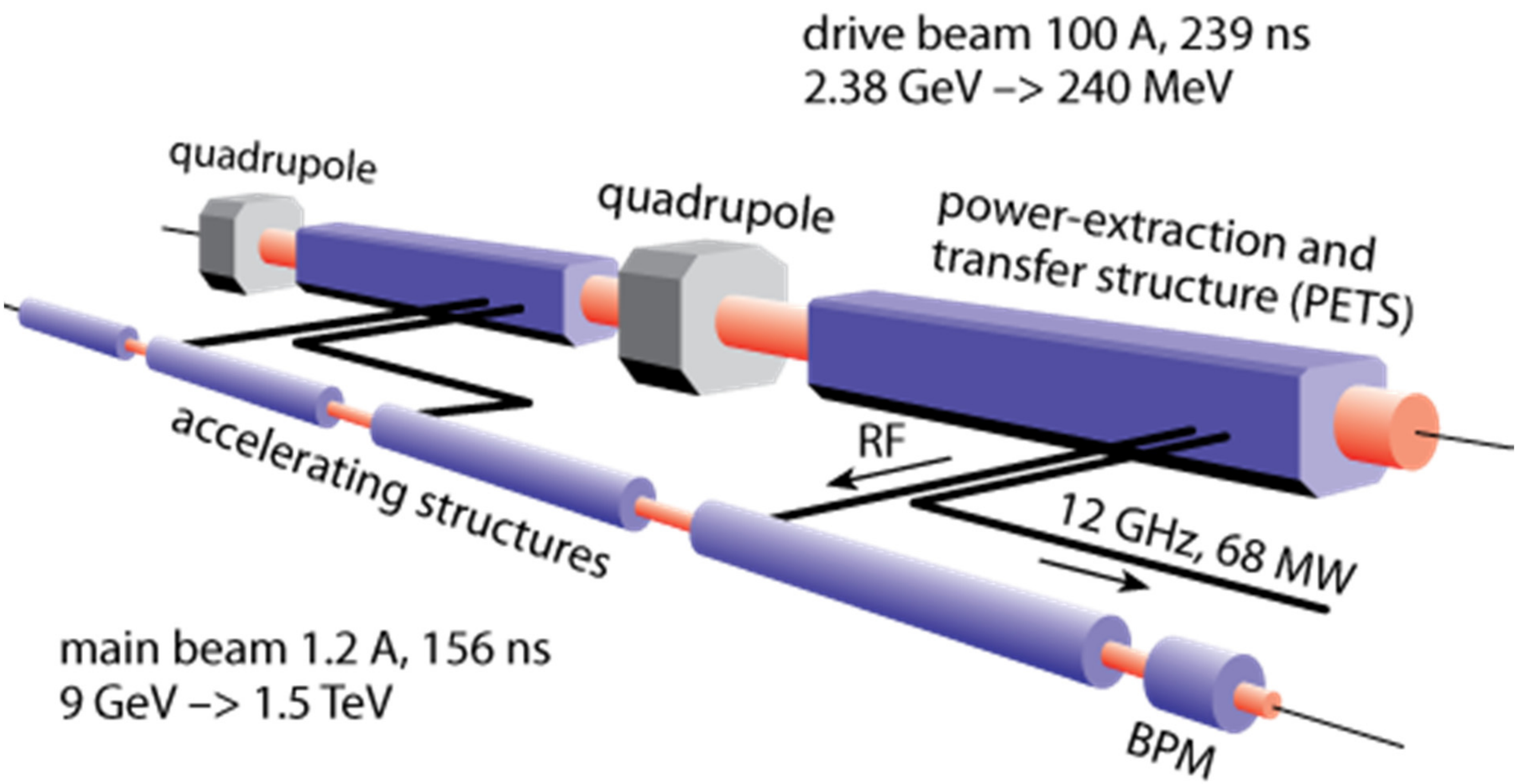
Compact Linear Collider aka CLIC



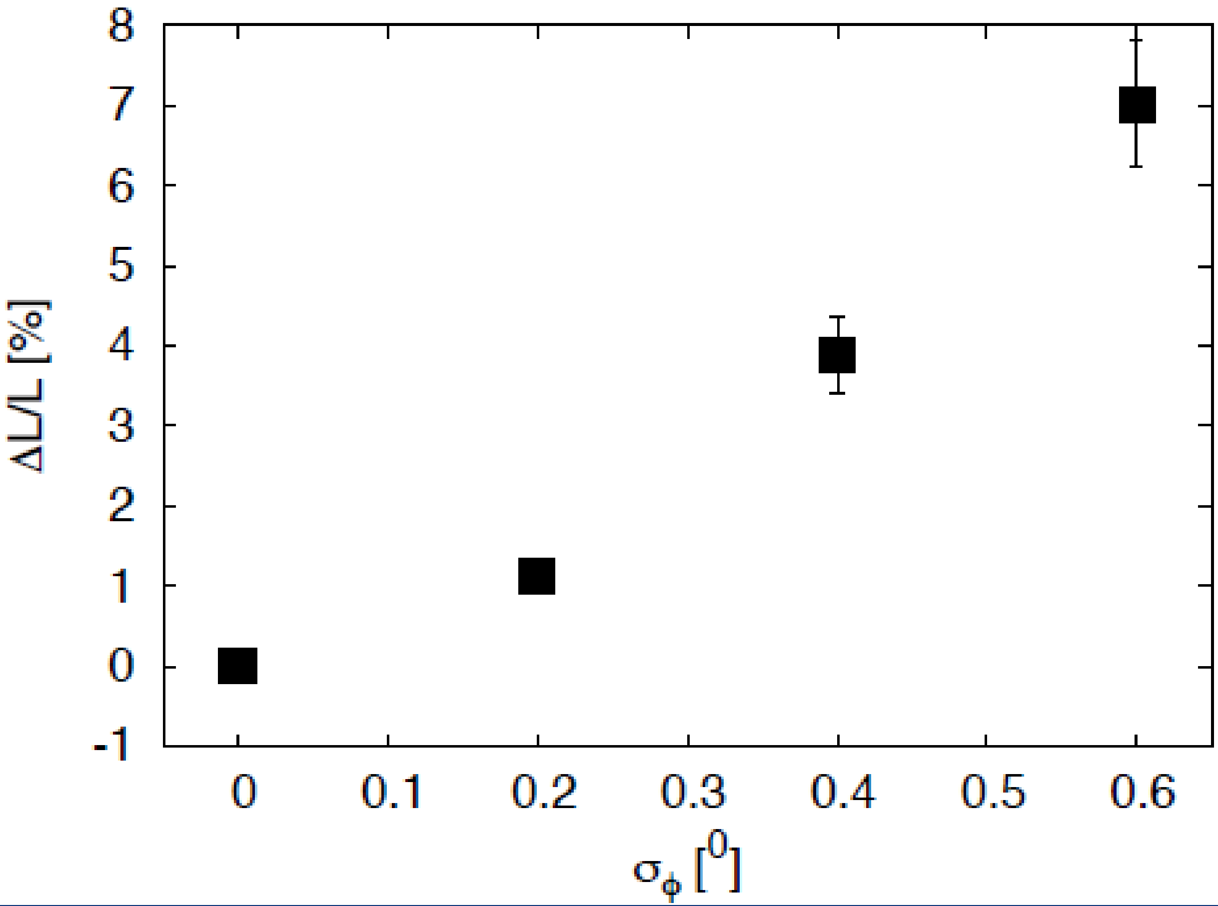
The Two Beam Acceleration



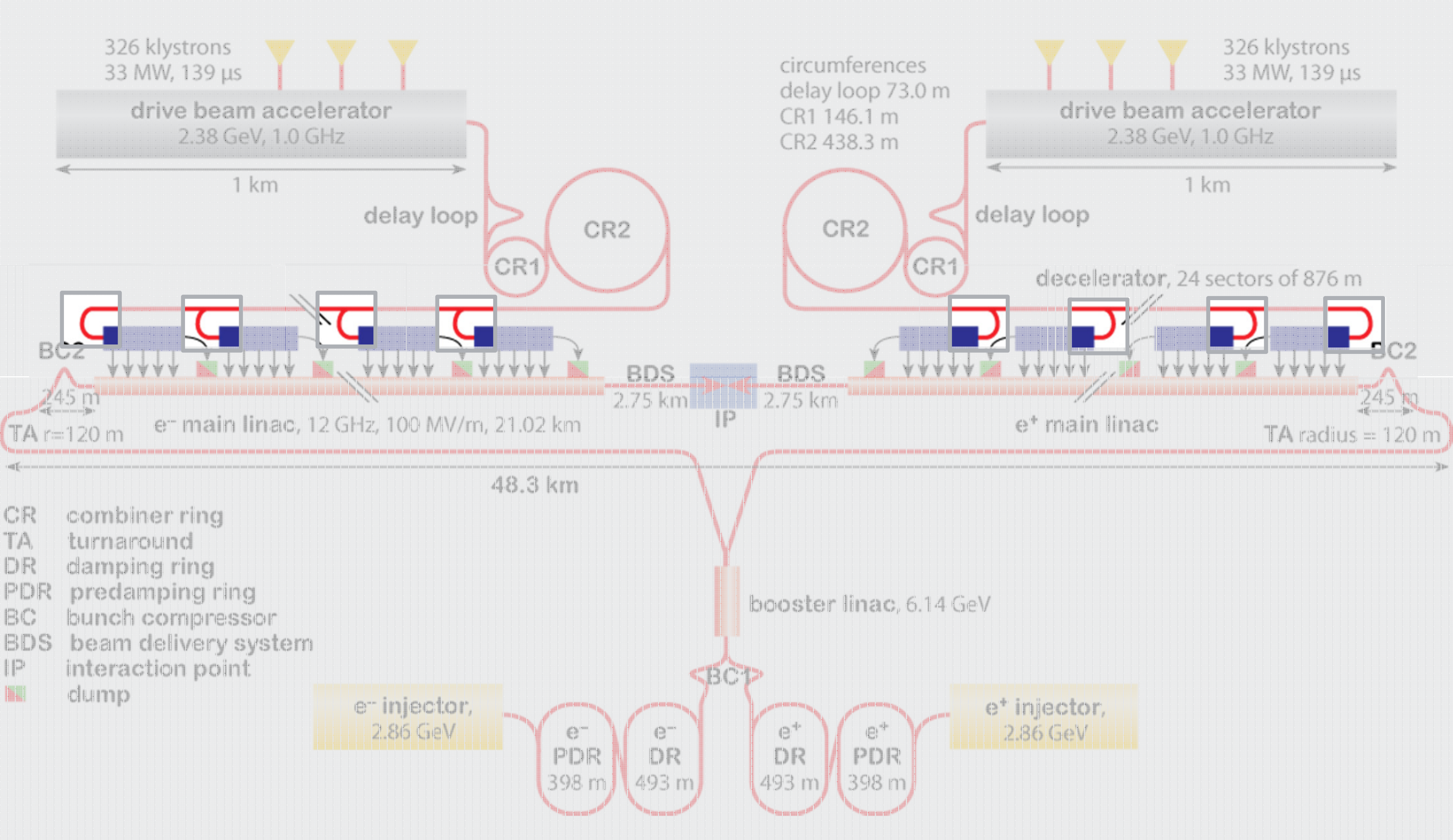
Phase Tolerance Between the two beams

- CLIC luminosity quickly drops if the RF phase jitters
- Expected (conservative) drive beam phase stability 2.5°@12GHz

→ **Must stabilize!**

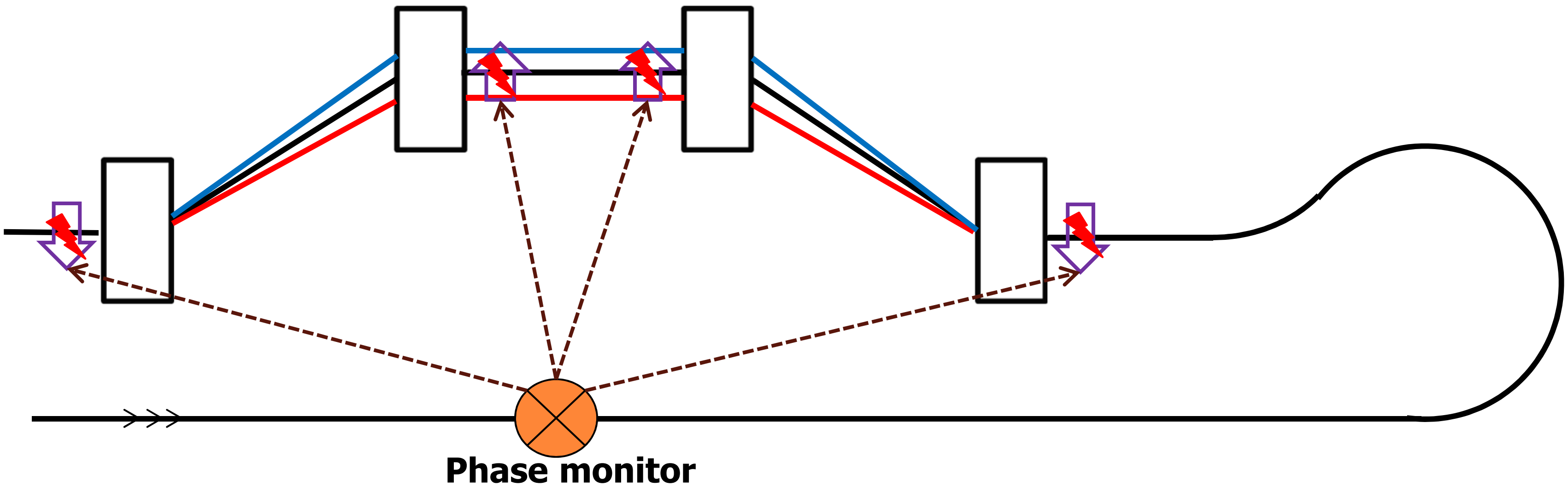


Phase stabilization in the Drive Beam Turn Arounds



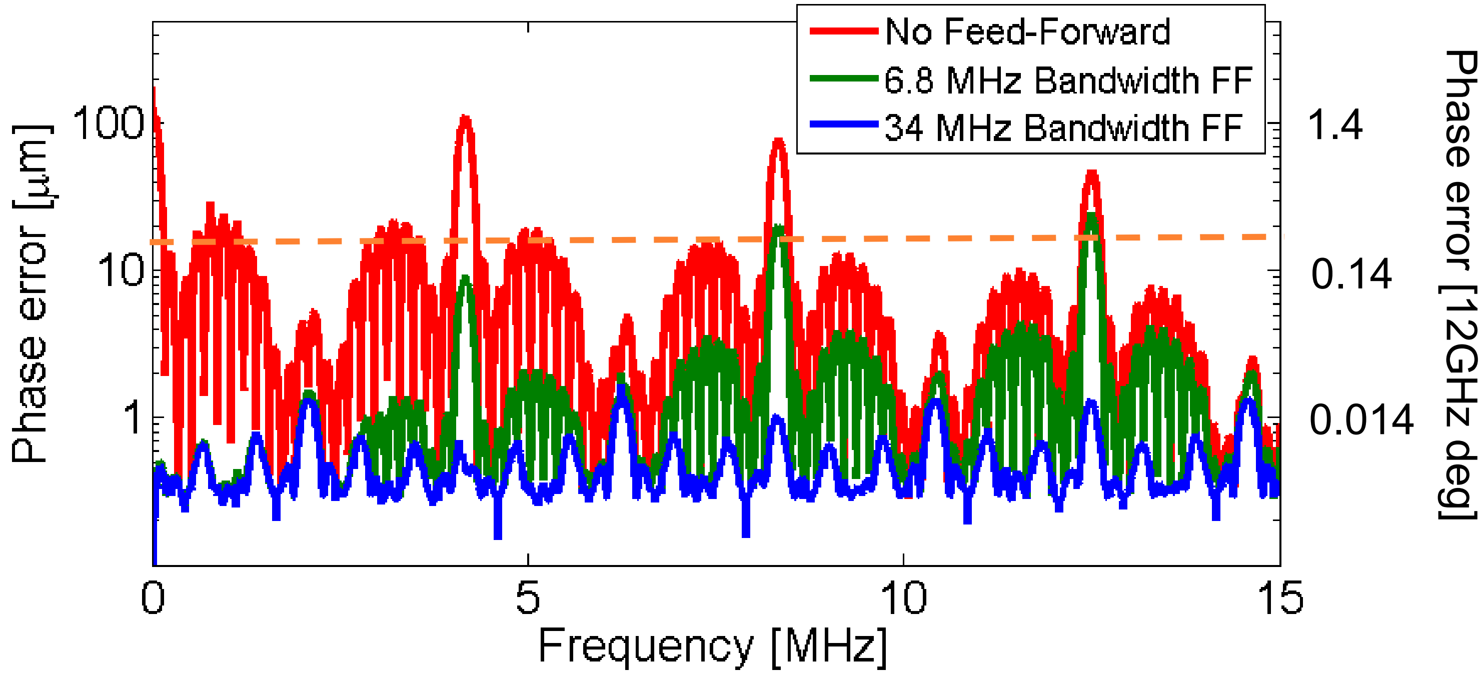
The CLIC Phase Stabilization Feed-Forward System

- It will increase the drive beam stability and correct phase variation along pulse to the required 0.2° at 12GHz
  - Measure phase offset before the turn around
  - Correct it after the turn around
- The current CLIC design based on a 4-bend chicane
  - Each bend is equipped with a fast kicker so that the time of flight though the chicane is variable, and thus the time of flight also



Challenge: Bandwidth and amplifier power

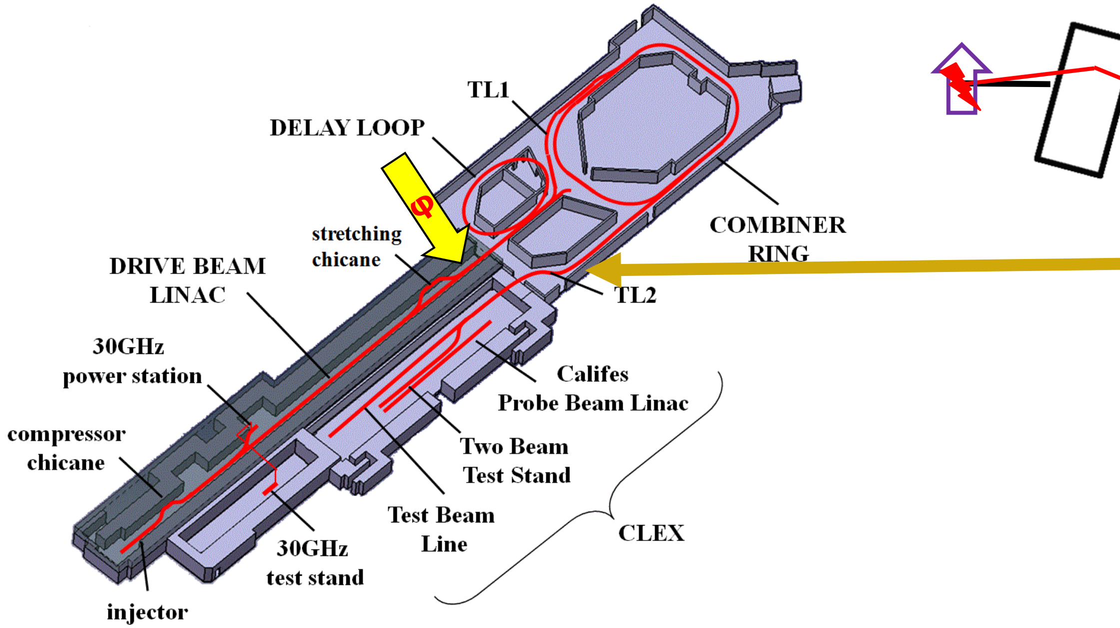
- Naturally, the bandwidth of the system is the key parameter

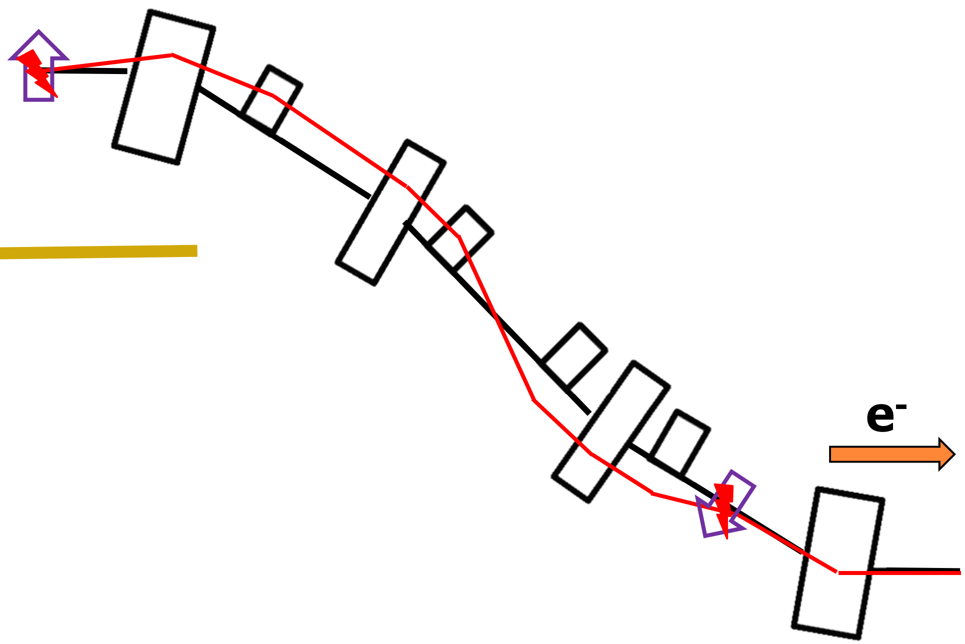


- And the amplifier power to deliver sufficient deflection angle for the 2.4 GeV beam **combined with the high bandwidth**

Phase Feed-Forward @ CTF3

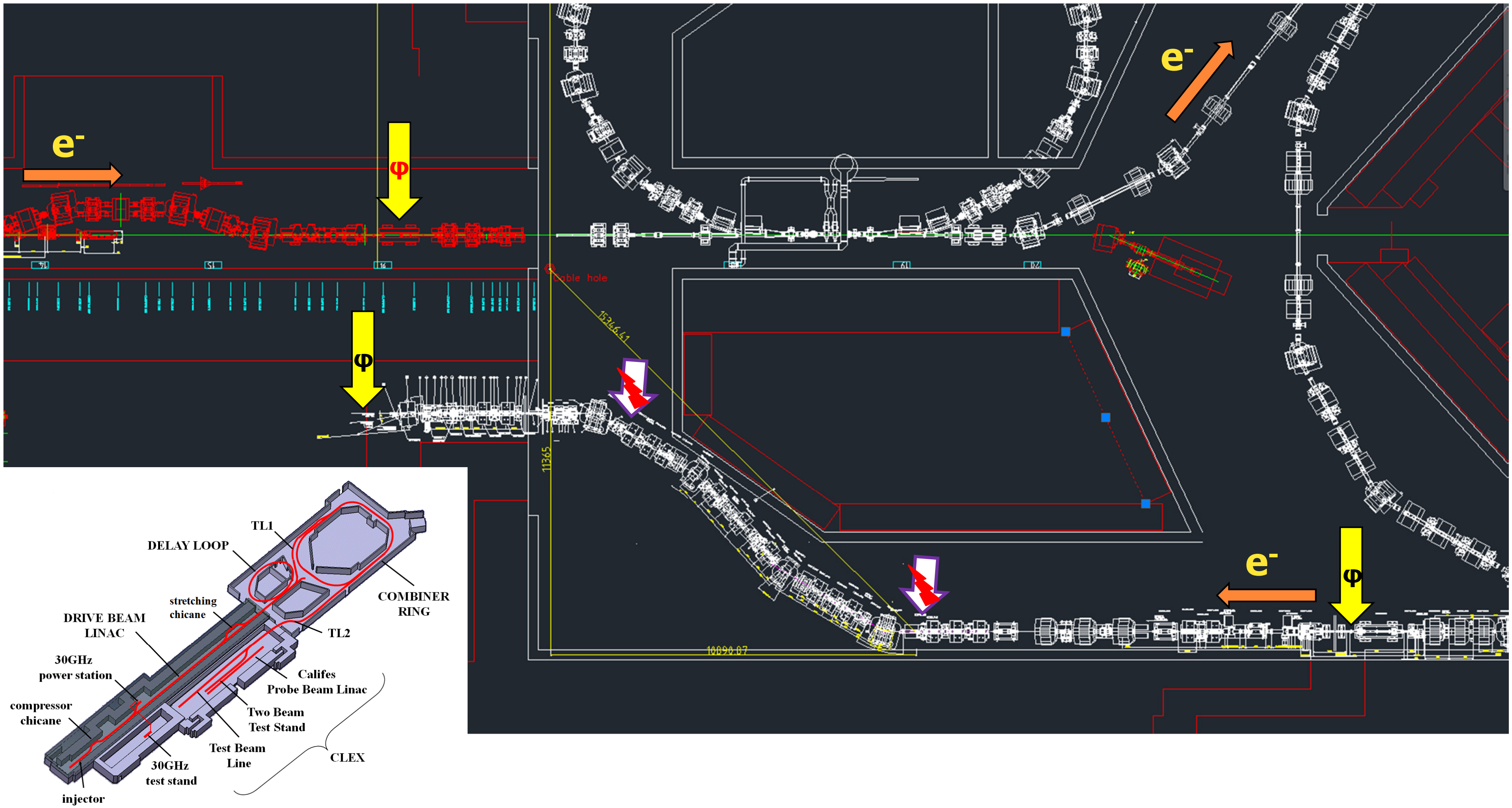
- A prototype system implementation in CTF3
  - Prove its feasibility
  - Test area for the R&D
  - Ultimate goal: phase stabilization to 0.2 deg @ 12 GHz
- Phase measured before the Delay Loop with a dedicated monitor
- Correction in the **dog-leg chicane** after Combiner Ring using 2 kickers
- Verification with 2 monitors installed just before and after the dogleg
- 280 ns latency





Phase Feed-Forward @ CTF3

- A more detailed technical view

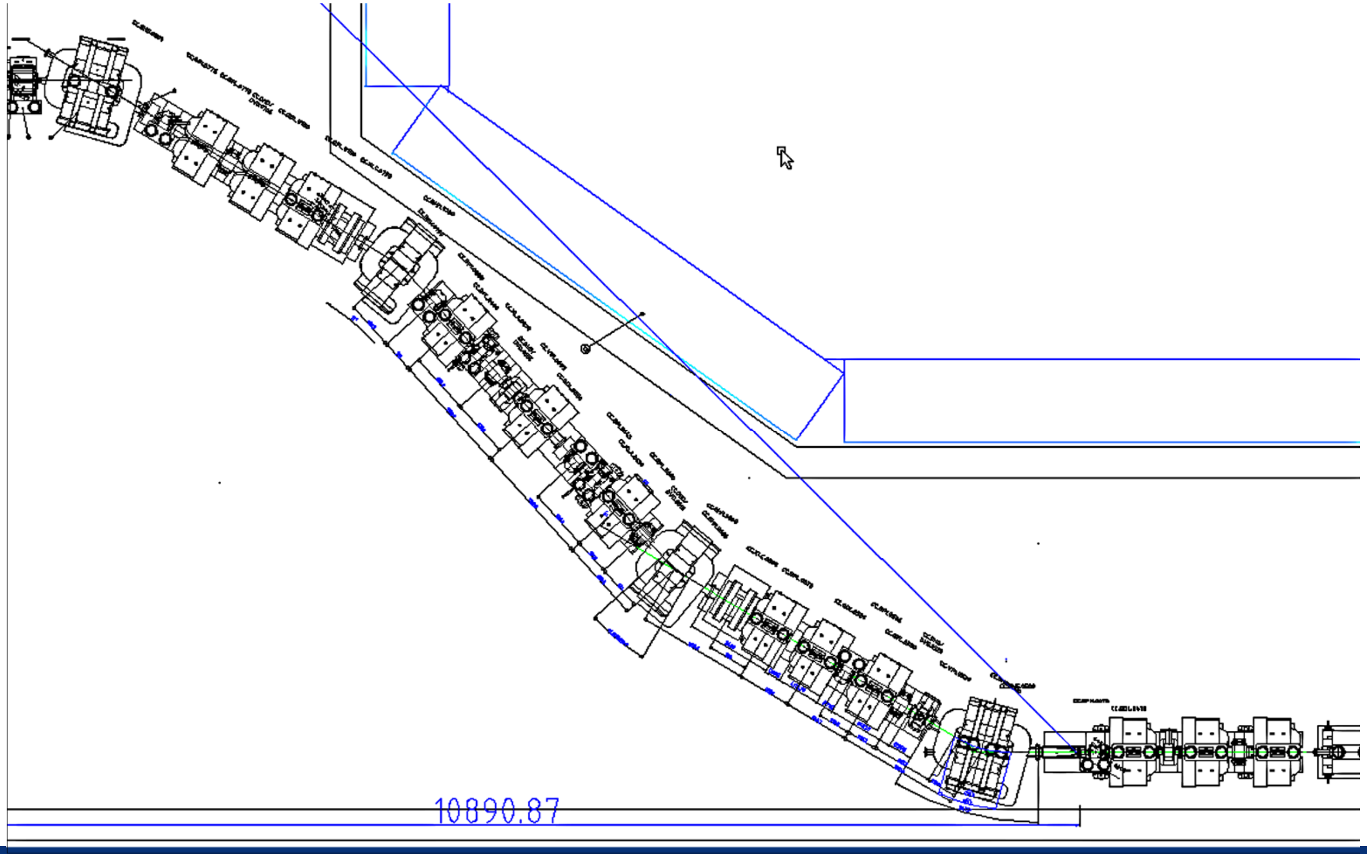


An Ideal Optics

- Large R_{52}, at least 1 m
  - Defines the phase range that can be corrected with a given kick
    - R_{52}=1 m implies 1 mm path length change for nominal 1 mrad kick
- $R_{12} = 0$ from kicker to kicker
  - Orbit does not move after the correction
- $R_{22} = 1$ (or -1) from kicker to kicker
  - Kicker amplitude is the same (-1 means reversed polarity)
- Dispersion amplitude below 2m
- No dispersion after the dogleg
  - Including the bumped orbits
- Smooth transverse optics
  - Max betas not too big and min ones not too small
- Small R_{56}, adjustable

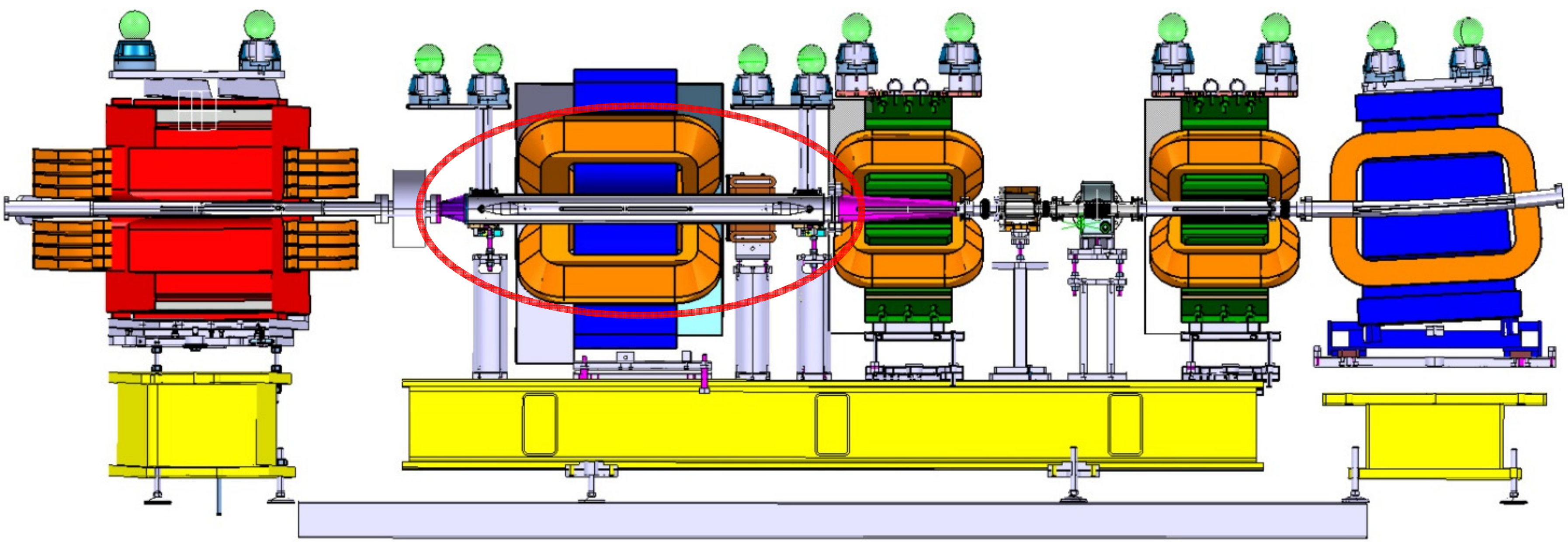
Chicane Layout

- A compromise was found between costly modifications and satisfactory performance
  - The correction chicane is implemented within an existing line
  - It is already densely packed → Kicker insertion tricky
  - For the system tests the resulting beam does not have to be perfect



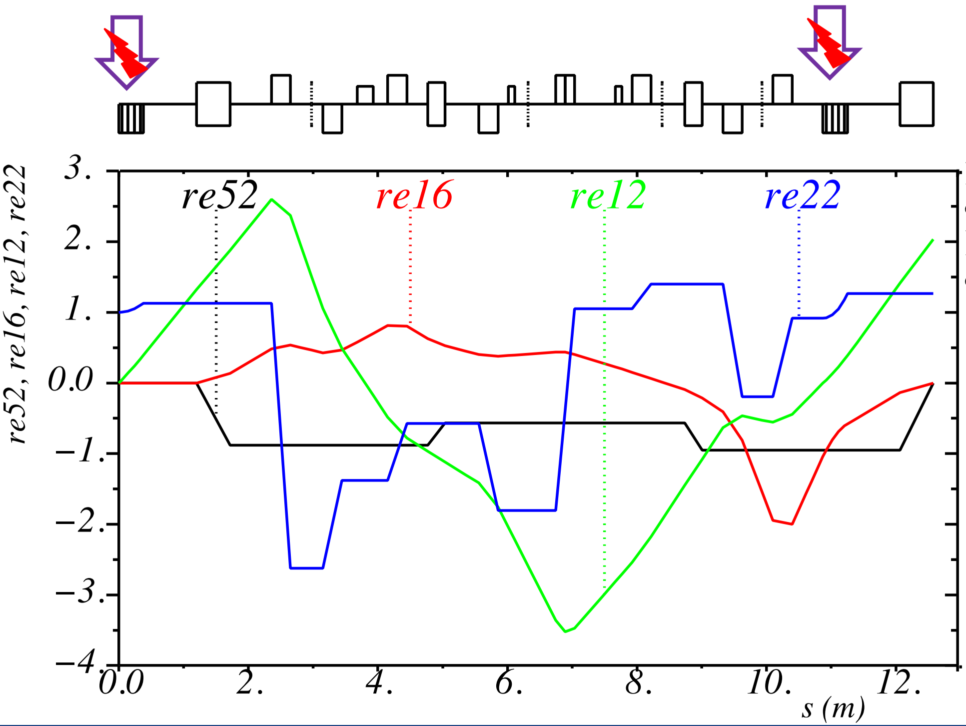
Integration of the kickers

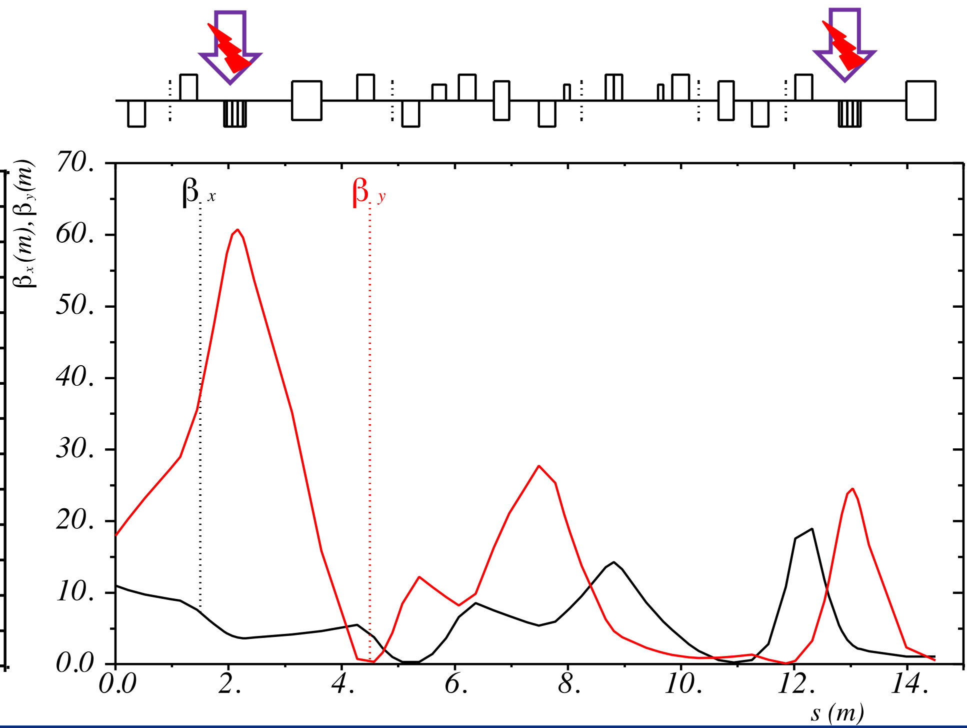
- A quadrupole and magnetic corrector around each kicker
  - The quadrupole is needed to preserve lattice functionality
  - The corrector:
    - will help in the commissioning
    - allows a slow feed-back to prevent phase drifts out of the kicker correction range



Optics

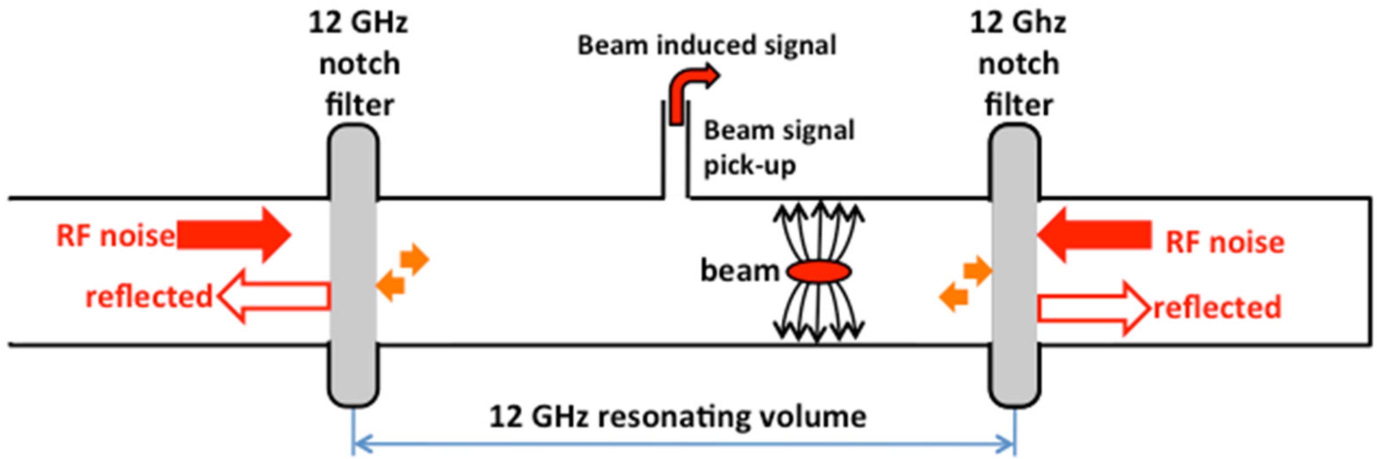
- R52=-1.05 ➔ Correction range +/- 15° @12GHz
- The orbit bump perfectly closed
- Dispersion closed
- Maximum dispersion amplitude 2.2 m
- Spurious dispersion ~15 cm at maximum kick

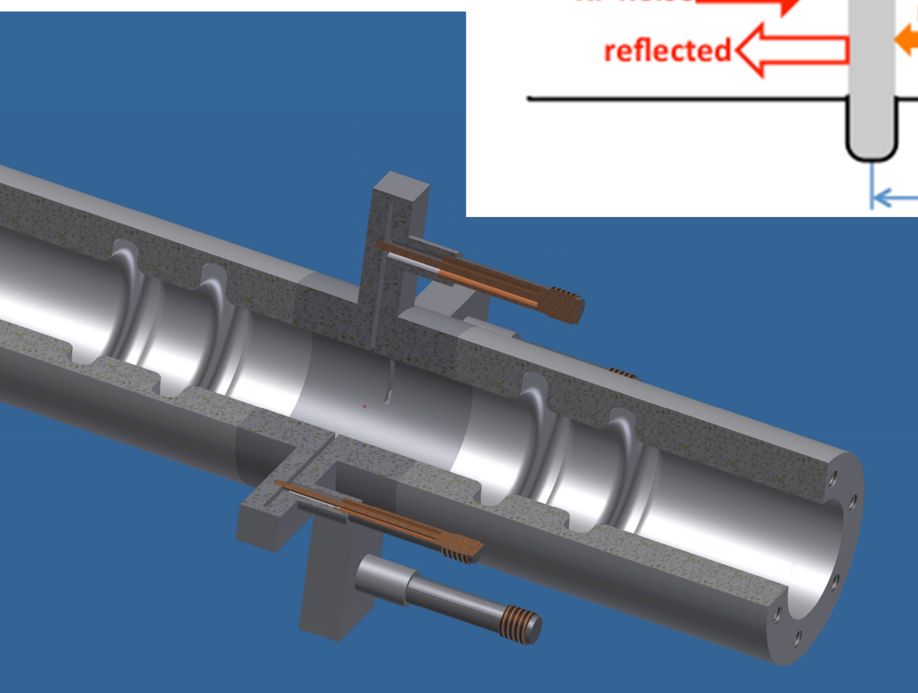


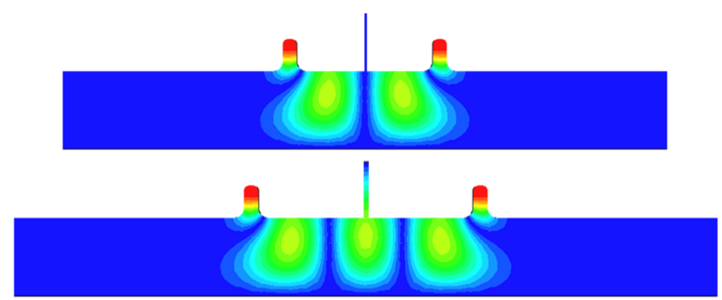


Phase Monitors
LNF/INFN Frascati

- 12 GHz RF pickups using a choke mode cavity
  - 30 MHz bandwidth
  - 0.2° at 12 GHz resolution





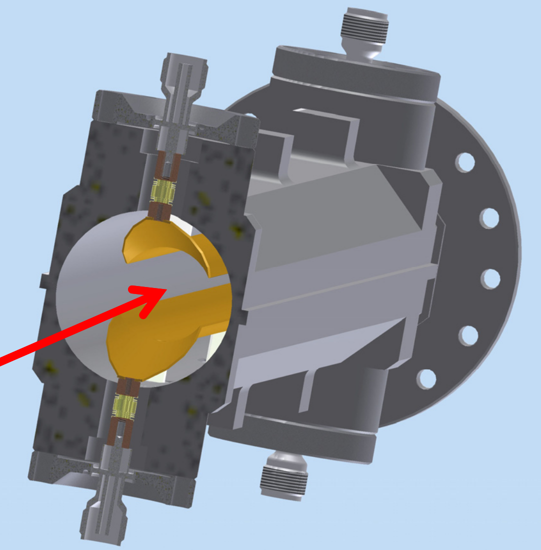


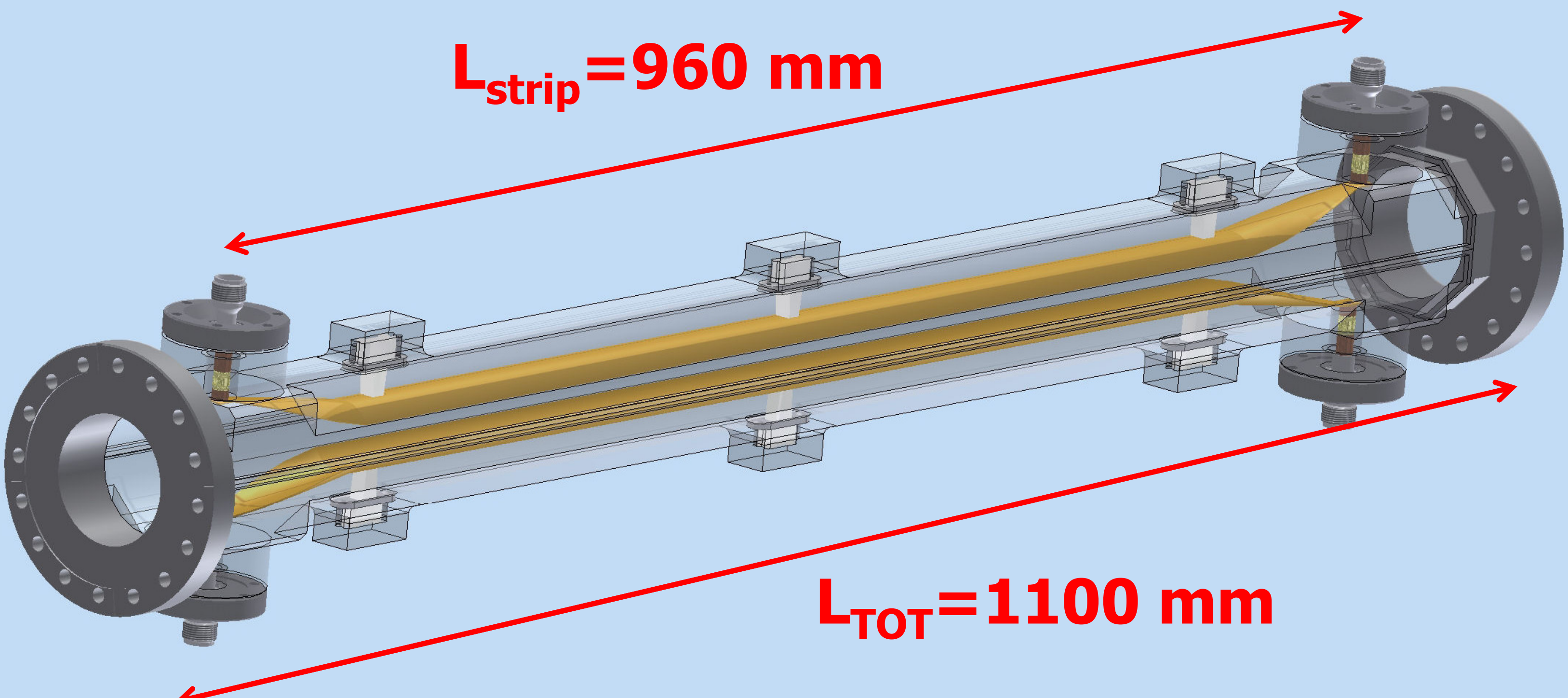
Kickers

LNF/INFN Frascati

- Strip-line kickers based on the Dafne design
- 1.1 kV for 1 mrad deflection @125 MeV
  - 100 Ω differential impedance
  - At least 50 kW drive needed

Strip-line Internal Diameter=40 mm





Amplifiers

John Adams Institute / Oxford University

- It is a major challenge: **Bandwidth and Power**
- Nominal peak power of 65 kW
- The target bandwidth is at least 50 MHz
  - But will be less for large changes in signal amplitude due to slew rate limitation
- Full performance guaranteed over a 280-420 ns range
  - 1.2 μs pulse duration for the full uncombined CTF3 beam possible with somewhat limited performance
- 4 parallel 18 kW modules
  - Each with its own power converter and output transformer
  - The output stage of the amplifier module made of two 1200 V SiC FETs driven by low voltage Si FETs
  - Droop in the output transformers limited to 10% over 1.2 μs
  - Each equipped with a separate drive and control module

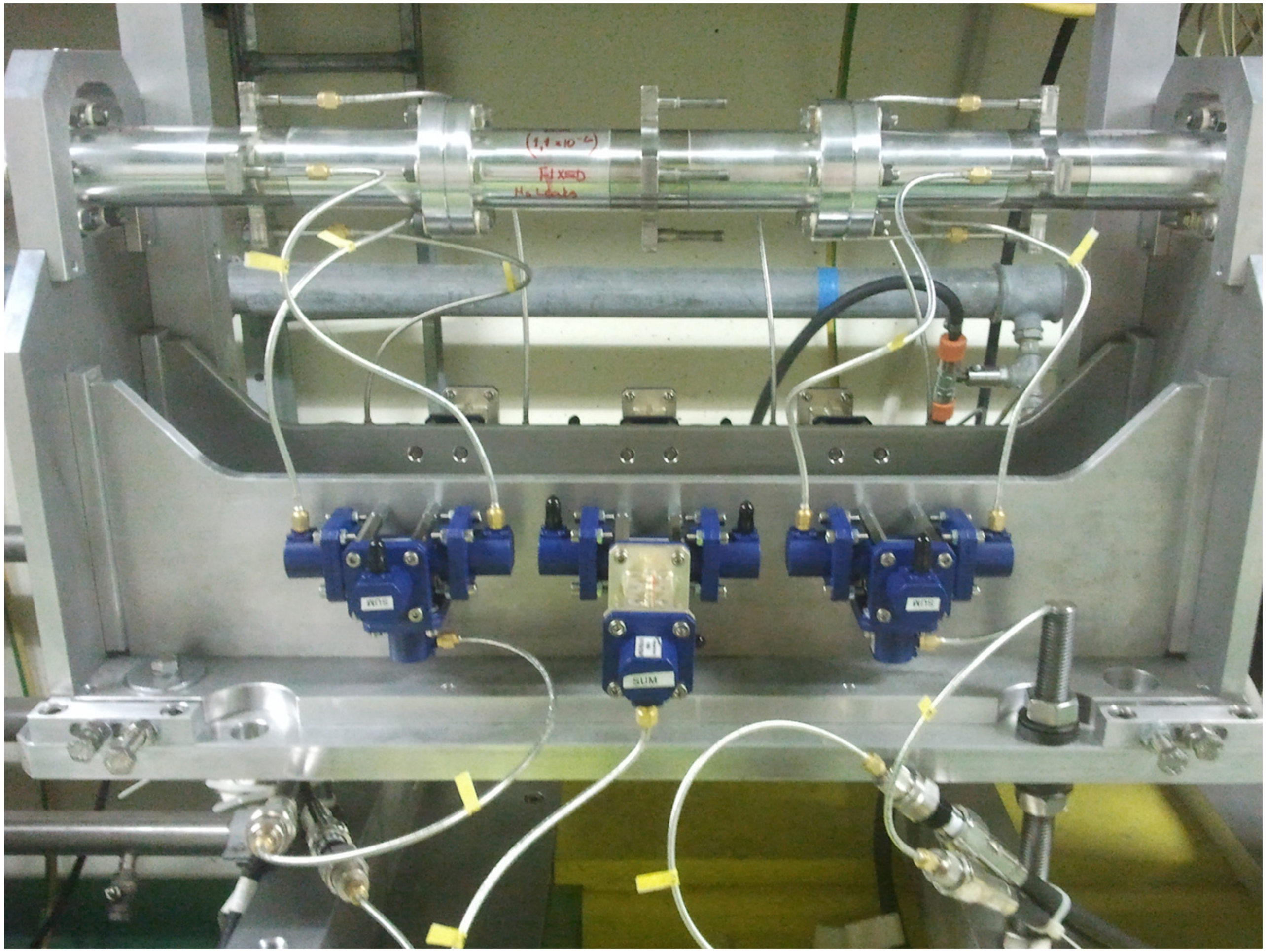
Feed-forward processor

John Adams Institute / Oxford University

- The brain of the system, will drive the kicker amplifiers
  - A custom digitiser and feed-forward controller based around a Xilinx Virtex-5 FPGA.
    - 9 analogue input channels, digitisation done using 14-bit 400 MS/s ADCs
    - 4 analogue output channels, using 14-bit 210 MHz DACs
  - The FPGA logic operations can be clocked in the range 200-400 MHz
    - External clock synchronized with CTF3 RF

- The feed-forward algorithm will allow for operation on both un-combined and combined beam.
  - For combined beam, measurements from corresponding sections of the different sub-pulses will be averaged together
    - This mimics the interleaving in the Delay Loop and Combiner Ring

Performance of **Fast Beam Phase Monitors**



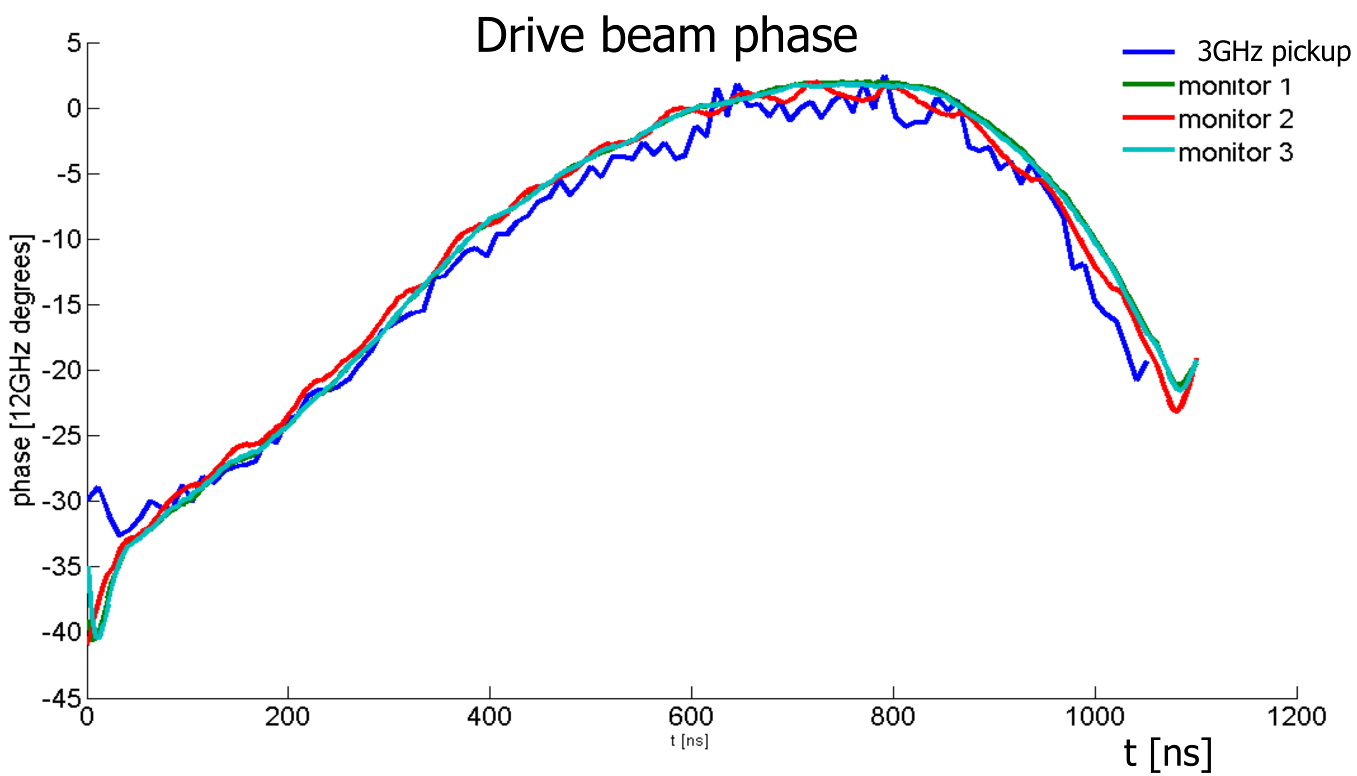
The 3 monitors installed in a string for their validation

Read-out electronics

- 2 horizontal or vertical ports are connected to a hybrid
  - To remove TE11 dipole mode
- The sum signal is mixed with a 12 GHz reference producing signal proportional to A $\sin(\phi)$
  - The mixer output is amplitude dependent
- The sum amplitude is also measured with a diode
  - To resolve "A" for a given beam
- The difference signal is also measured with a diode
  - It is proportional to the beam position offset
- Calibration using a synthetized signal with frequency close to the 12 GHz and with different amplitudes
  - In this way crosstalk and the all the calibration constants can be measured for the interesting range of amplitudes.

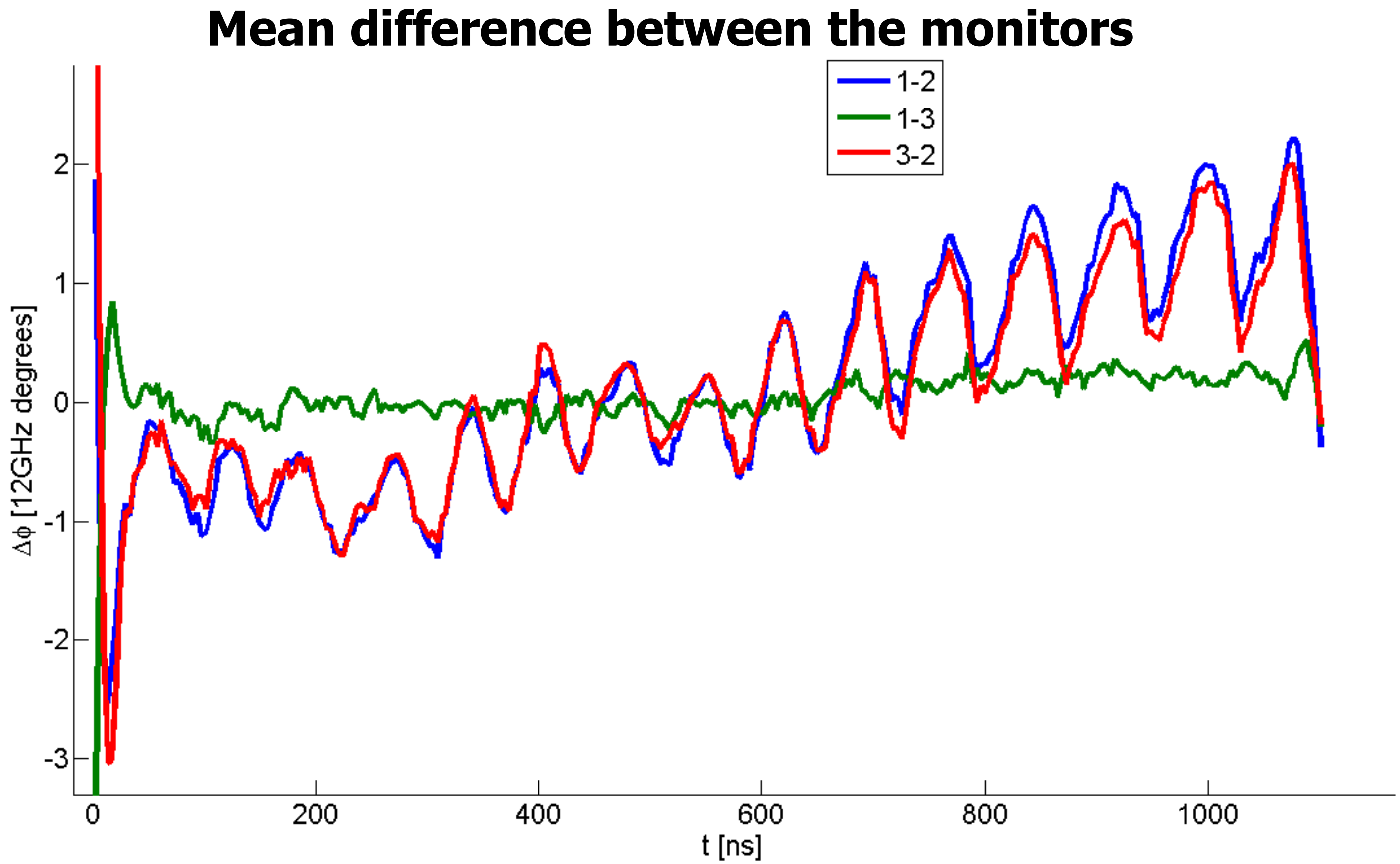
Resolution

- Electronics resolution at the moment is about 0.2 degree
  - Will be soon improved with better signal and ADC level matching
- The monitors agree between each other and a 3 GHz button pickup



Resolution

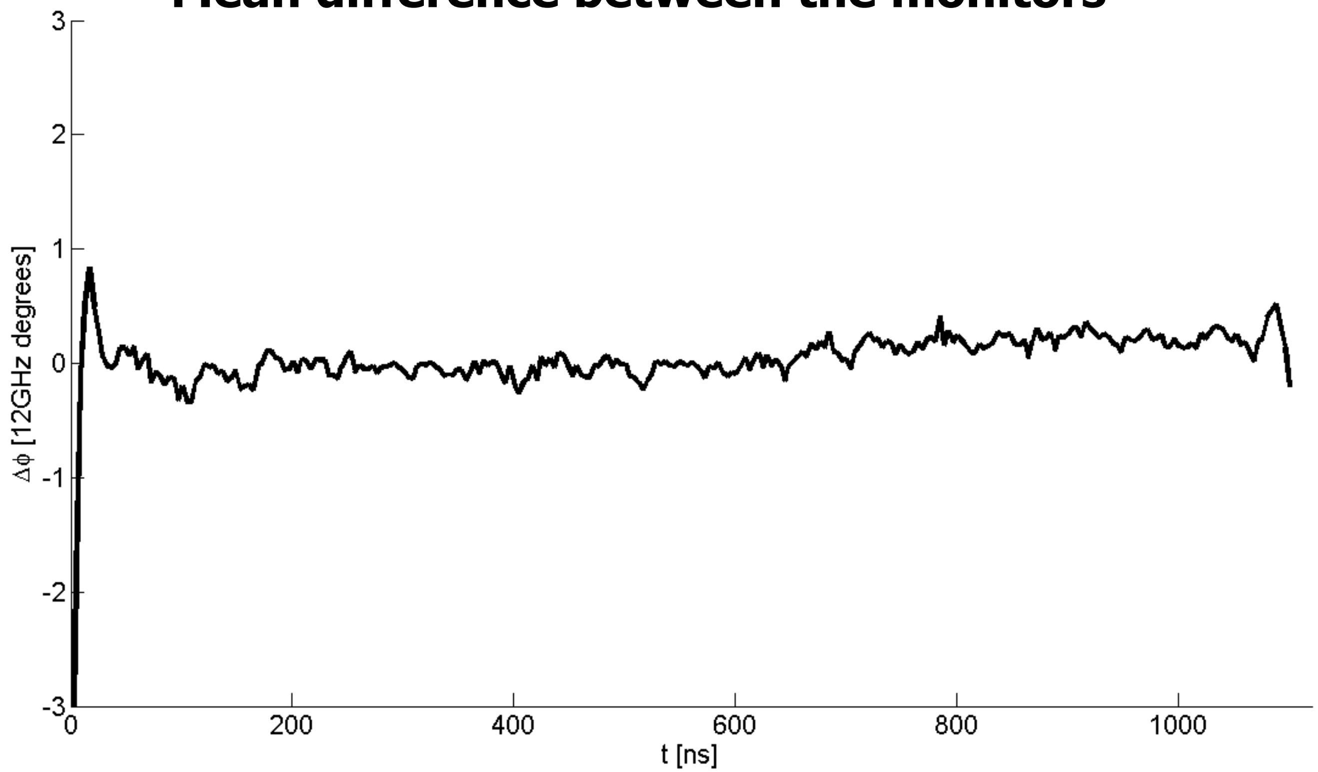
- However, monitor 2 performs not as good as 1 and 3
  - It was reported to have problems with the feed-through installation
  - It is discarded for the moment and will be repaired during shutdown



Resolution

- The monitors 1 and 3 agree within 0.3 degrees
- Standard deviation of the residuals is 0.33 degrees
- The resulting resolution is 0.23 degrees
  - ➔ resolution is dominated by the electronic noise of 0.2 degrees

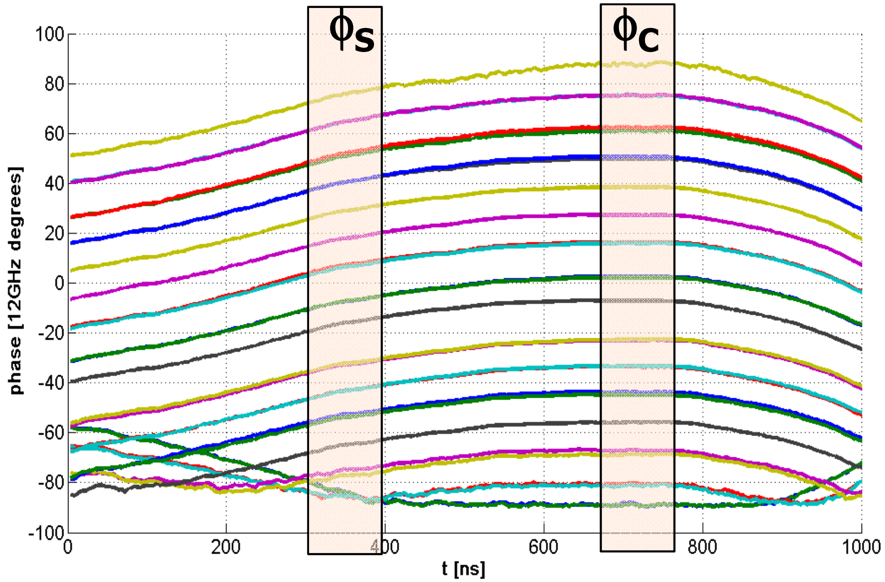
Mean difference between the monitors



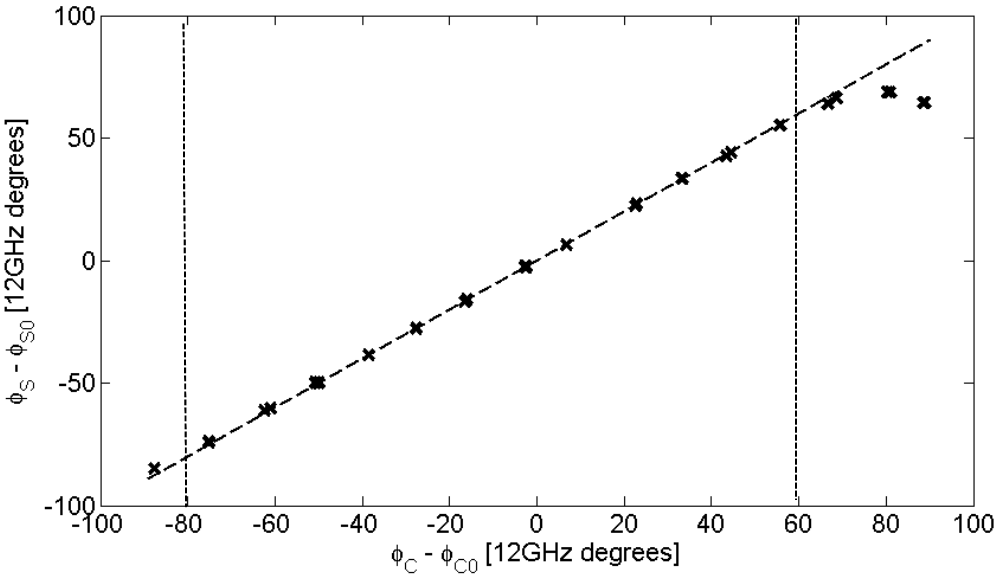
Linearity

- The CTF3 beam has inherent phase sag due to the RF pulse compression system
- We observed how the measured phase sag changes for different phases of the local oscillator
- To quantify the preservation of the shape difference at 2 locations ϕ_C and ϕ_S within traces is plotted

Measured beam phase for different LO phases

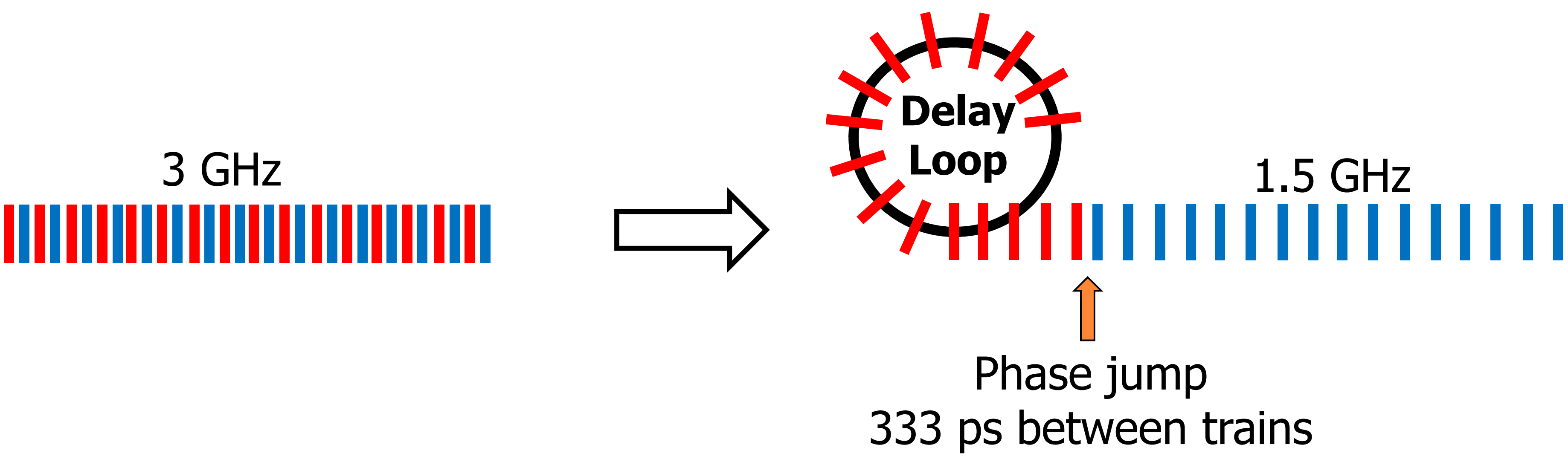


Linear within ±70°



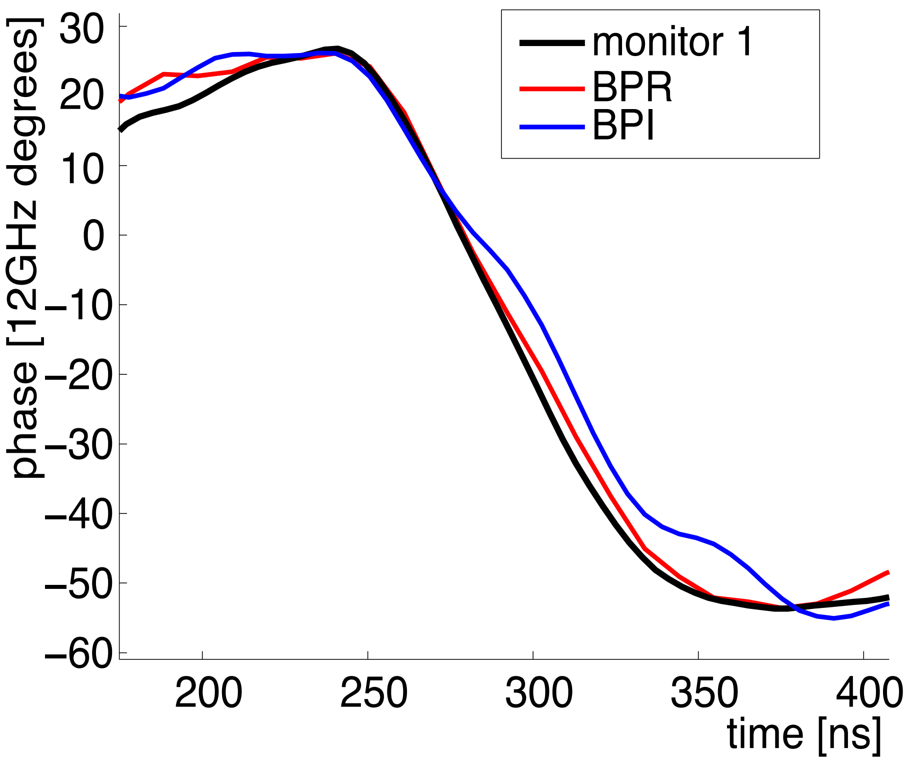
Bandwidth checks

- The monitors were designed for 30 MHz bandwidth
- The final bandwidth measurement will be done only when the monitors are installed at their positions downstream of the Delay Loop
  - The Delay Loop allows us creating a train with a sharp phase jump



Bandwidth checks

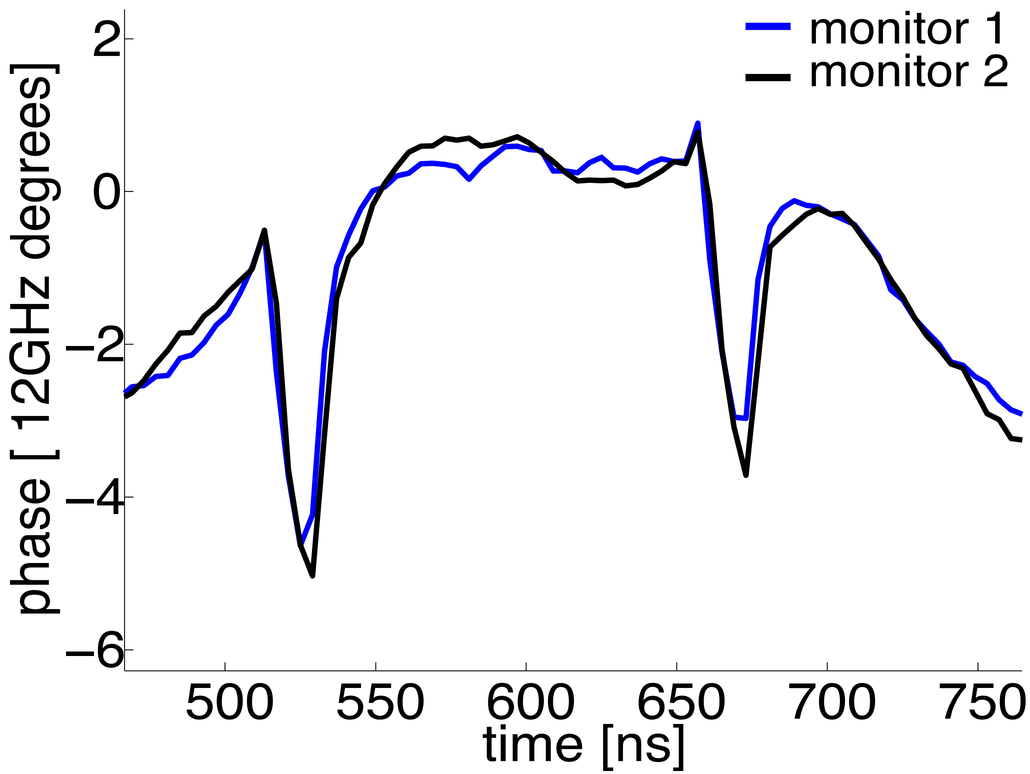
- A steep phase step was introduced
  - The RF pulse compression for the last station was programmed to deliver an amplitude step as sharp as possible
    - And hence the beam energy change
  - The Stretching chicane adjusted to R56=0.45 converted the energy change to the phase change
  - The steepness was verified using
    - A BPM (BPI) at a large dispersion location
    - A BPR - a 3GHz button phase pickup



- The bandwidth is at least 3.7 MHz

Bandwidth checks
The phase switches

- Measurement of phase switches in the sub-harmonic bunchers
  - 180° phase switches needed for recombination with the Delay Loop
- Imperfect switches create discontinuity in bunch phase
- The monitors measure a 30 ns effect that implies **10MHz** BW
  - There is no independent way in CTF3 to cross-check the phase change



Beam position dependence

- A beam position offset induces dipole mode TE_{11}
  - -25dB lower than the monopole mode
- If the hybrid is perfect, it shouldn't be present in the sum
  - Hybrids are never perfect
- Direct position scans show no statistically relevant effect
  - The beam was moved ±4 mm using 2 magnetic correctors installed just upstream of the monitors and a ballistic beam behind them was measured with 2 BPMs
- By measuring how the difference channel power changes with the beam position, we calculated the hybrid rejection level to -25dB
  - By symmetry, this must the same in the sum (phase) signal
  - We calculated the position-to-phase crosstalk to 0.16°/mm

Conclusion

- A prototype Phase Feed Forward system
  is in preparation in CTF3
- It will serve as an R&D and test area for the technology development
- The fast phase monitors are operational and perform accordingly to their specification

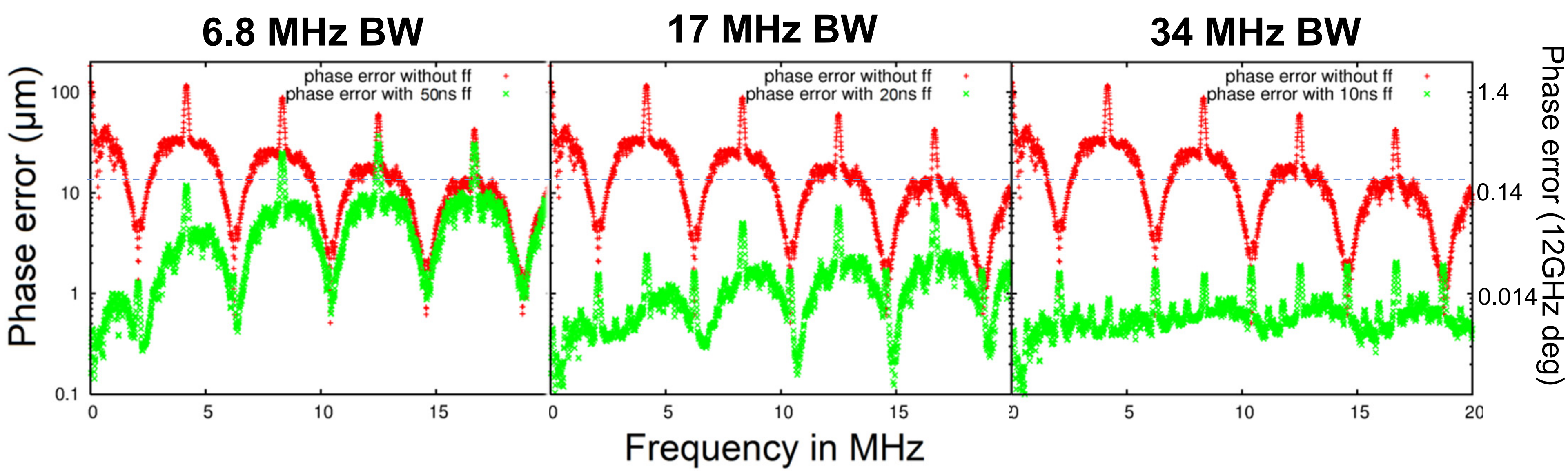
- The full system will be operational
  at the end of summer 2013

Backup slides

- Backup Slides

Challenge: Bandwidth and amplifier power

- Naturally, the bandwidth of the system is the key parameter



- The power of the amplifier to deliver sufficient deflection angle for the 2.4 GeV beam **combined with the high bandwidth**

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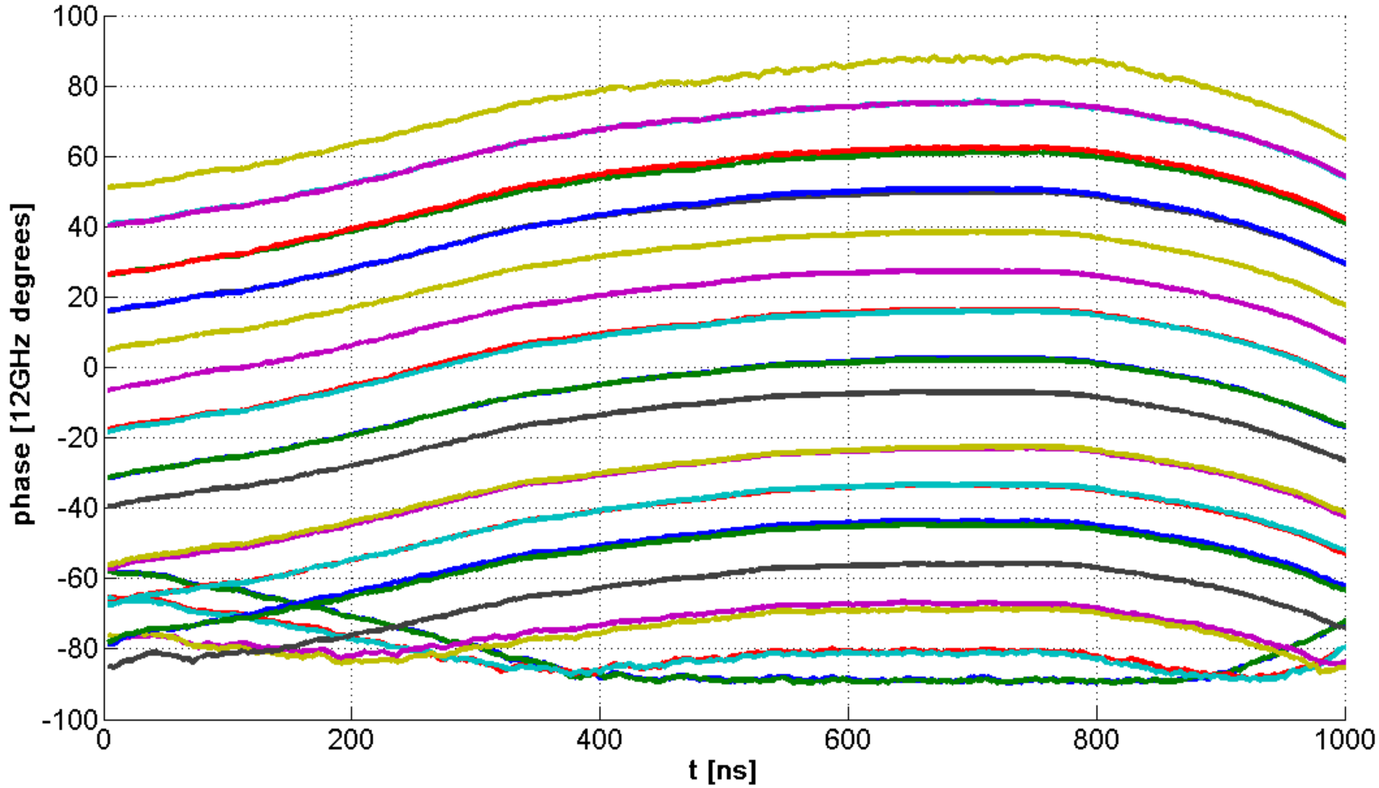
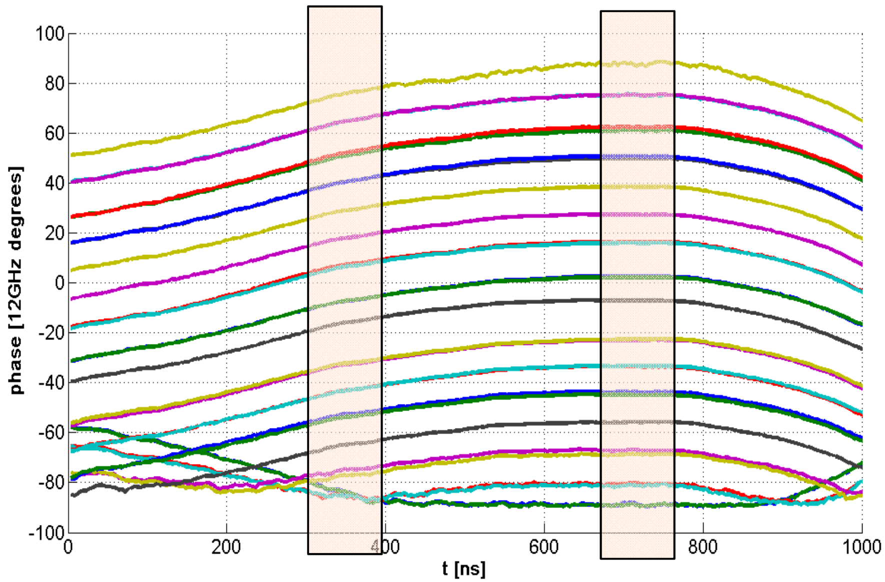
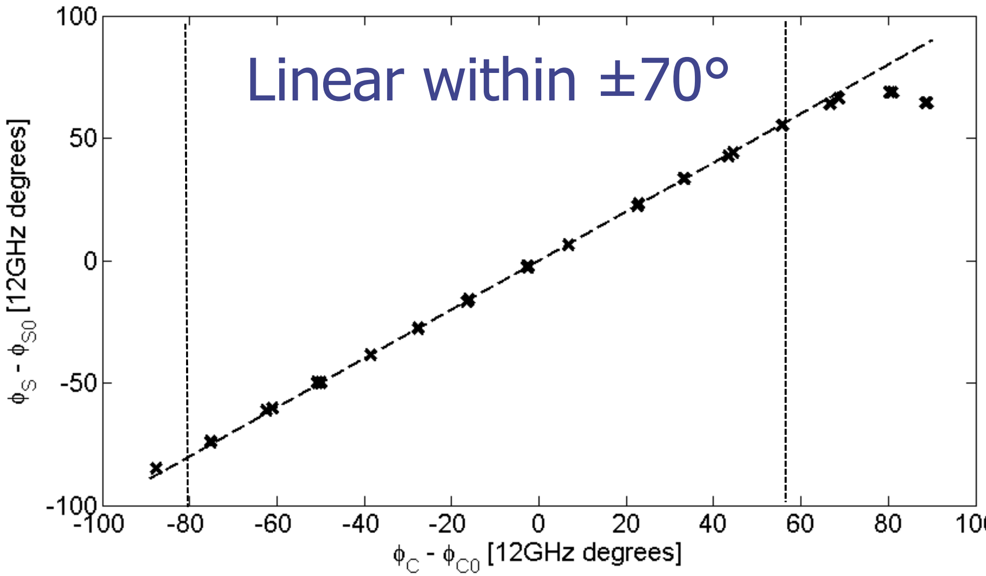


Linearity

- To quantify the preservation of the shape
  - 2 values at different locations within traces are taken, ϕ_C and ϕ_S
  - One trace is taken as a reference, corresponding phases ϕ_{C0} and ϕ_{S0}
  - For each trace, the difference to the corresponding point in the reference is calculated for





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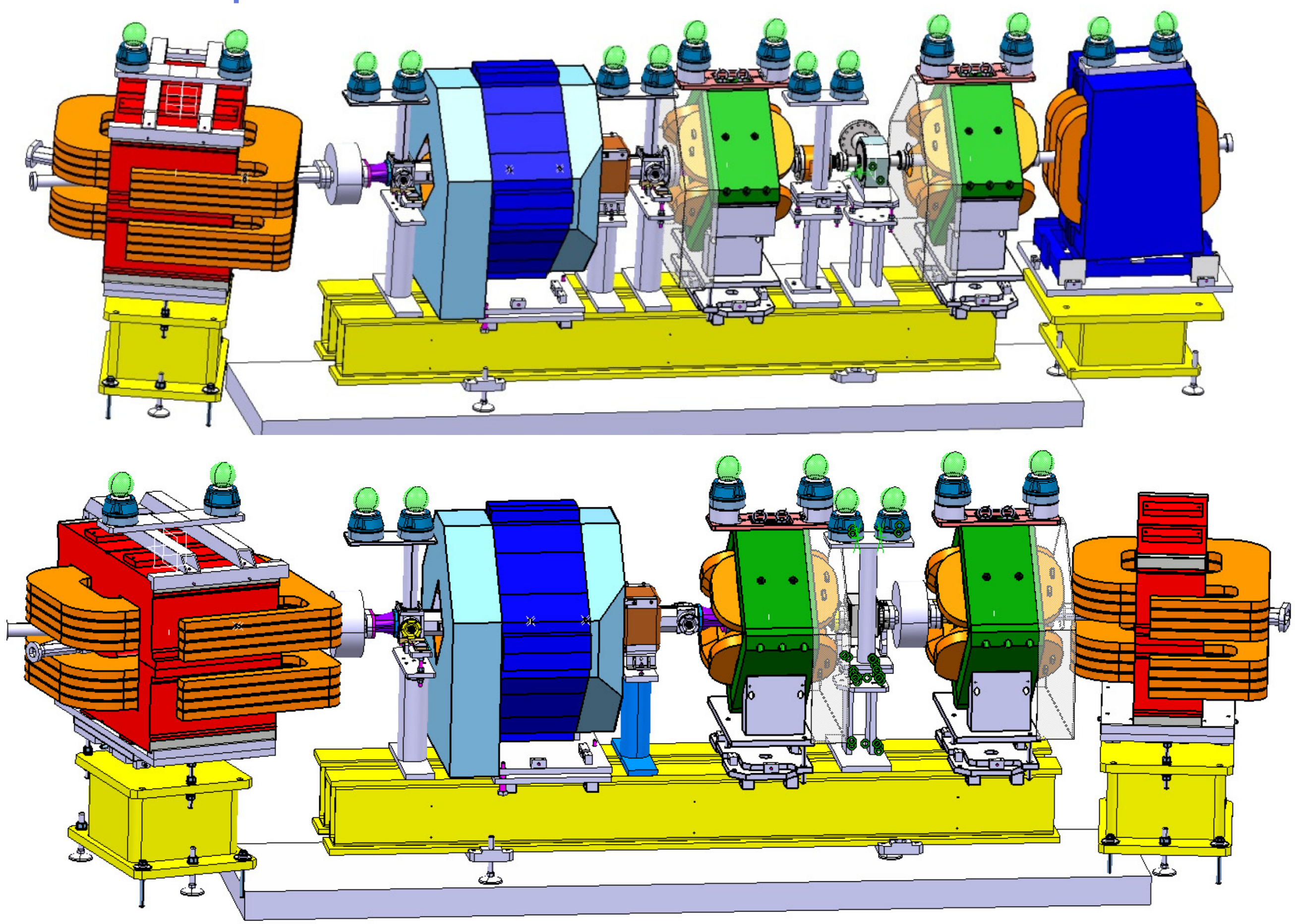
  - Corrector will help in the commissioning and allow implementation of a slow feed-back



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