



CLIC Drive Beam Phase Stabilisation

Alexander Gerbershagen

Doctoral thesis for:

University of Oxford, FONT group

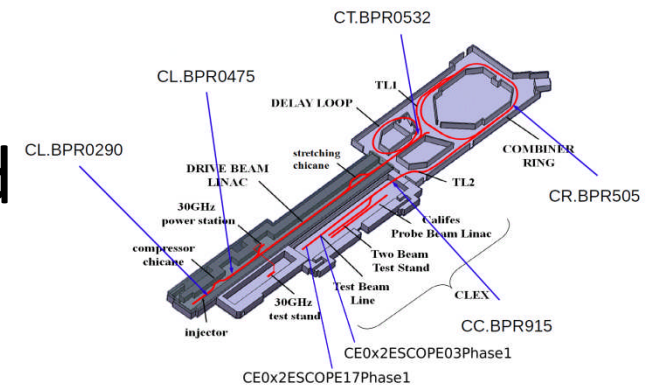
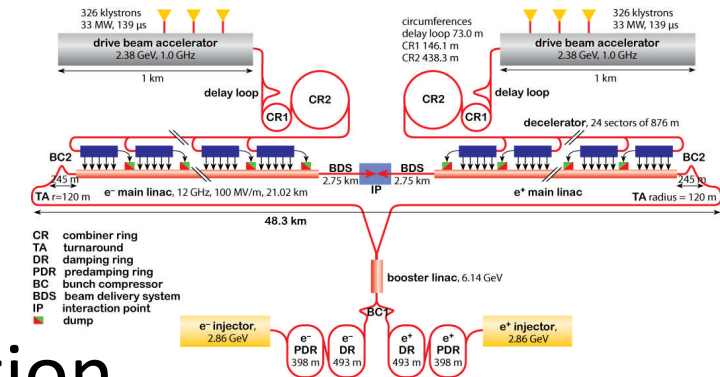
CERN, BE-ABP-CC3 group



Content



- CLIC overview
- CLIC stability simulations
 - Error Tolerances
 - Analysis of error propagation
 - Stabilisation via a feed-forward
- CTF3 measurements
 - Simulation of feed-forward system prototype

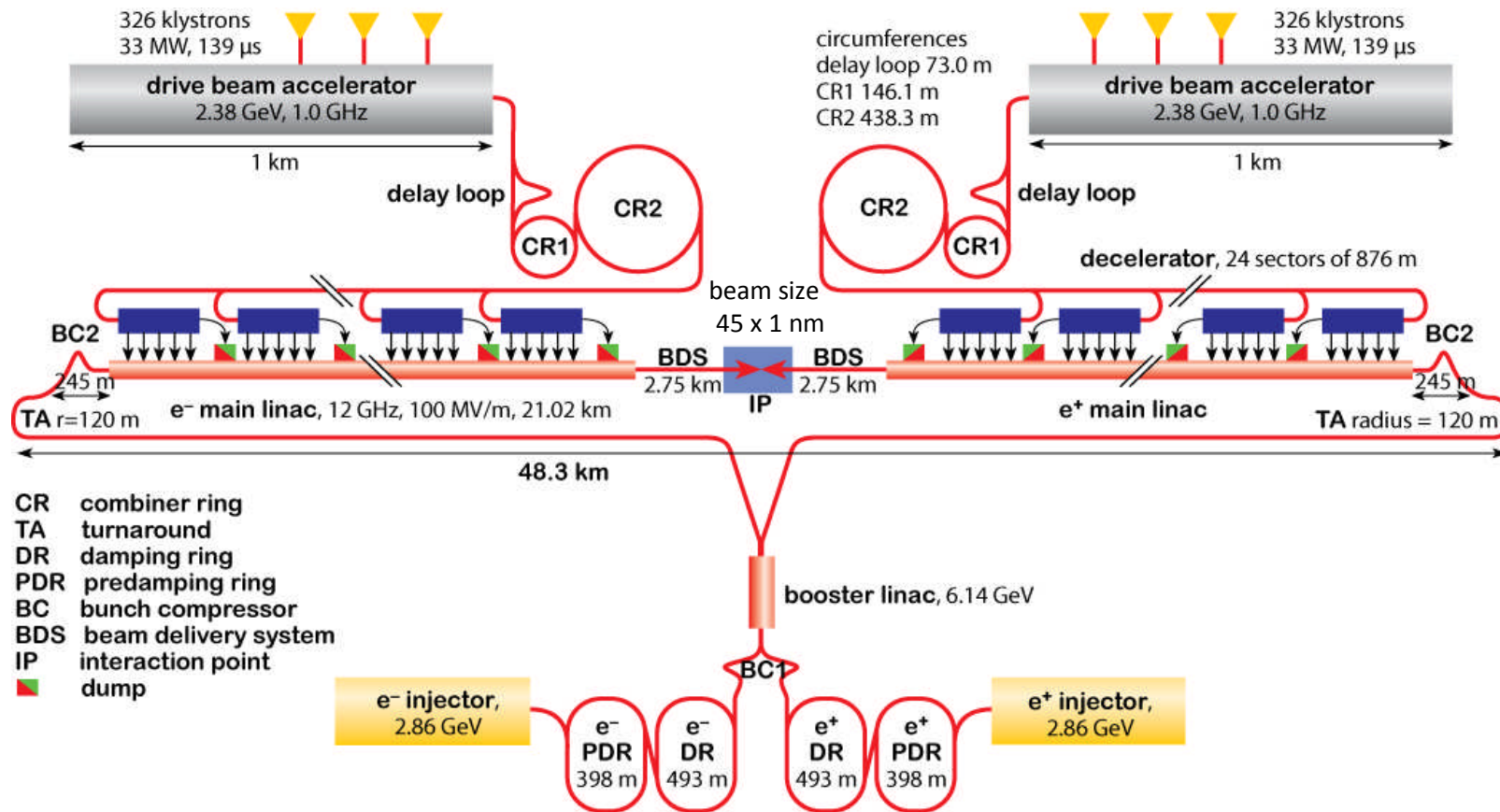




Phase stability simulations for CLIC

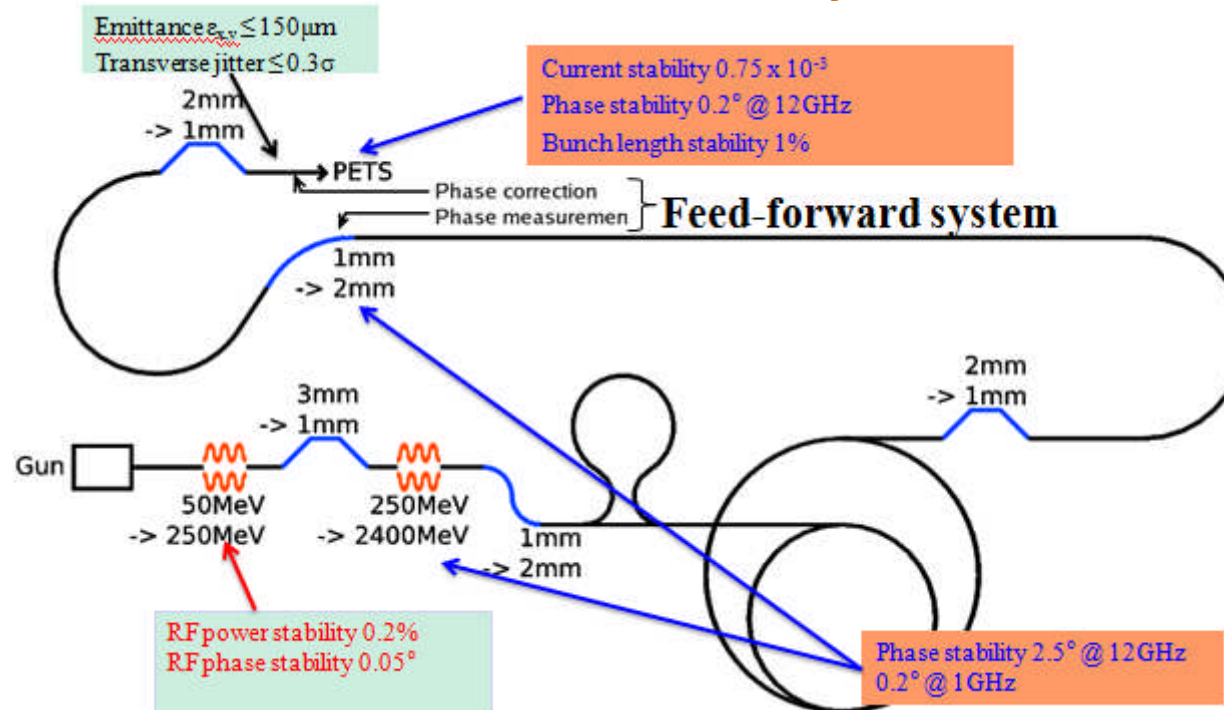


CLIC Layout at 3 TeV - Overview



“[...] Key studies will address stability and alignment, timing and phasing [...]”
– CLIC CDR (Executive Summary: work-packages 2012–2016)

Drive Beam Tolerances and Error Analysis



Plot: D. Schulte

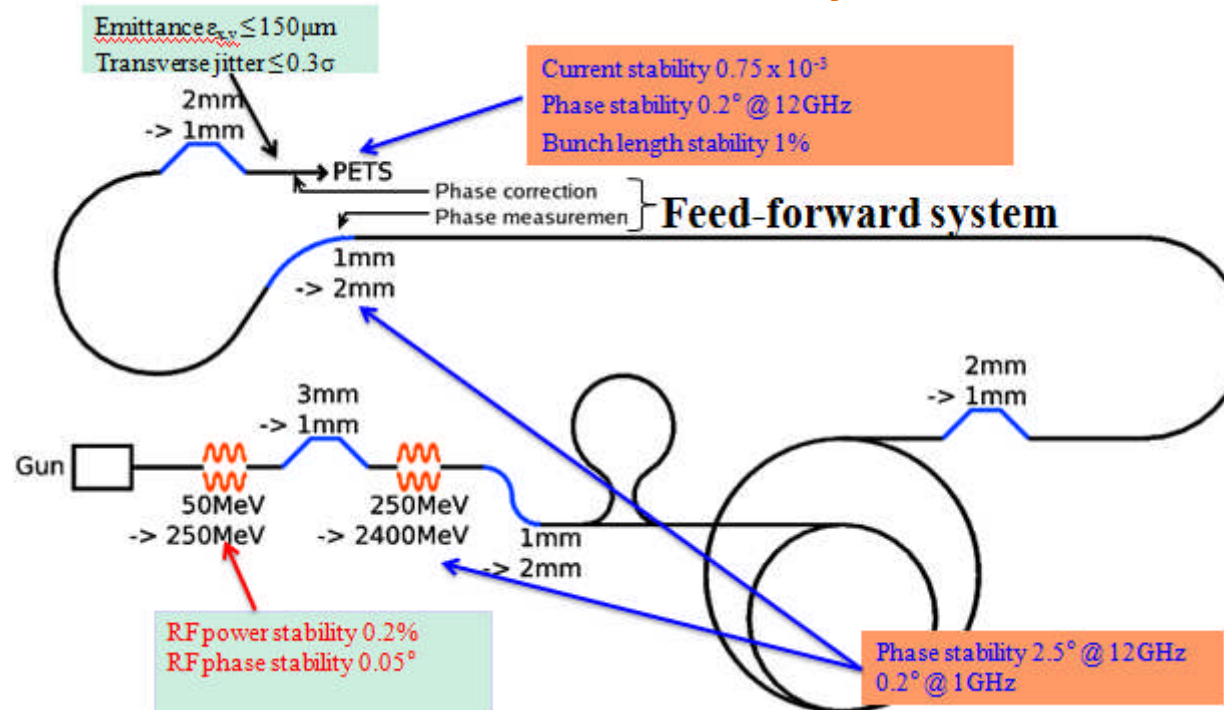
Step 1: Analyse the error, consider four Drive Beam sections:

1. Drive Beam accelerator
2. Compressor chicane
3. Recombination scheme
4. PETS & Main Linac

Step 2: Correct the error with a feed-forward system



Drive Beam Tolerances and Error Analysis



Plot: D. Schulte

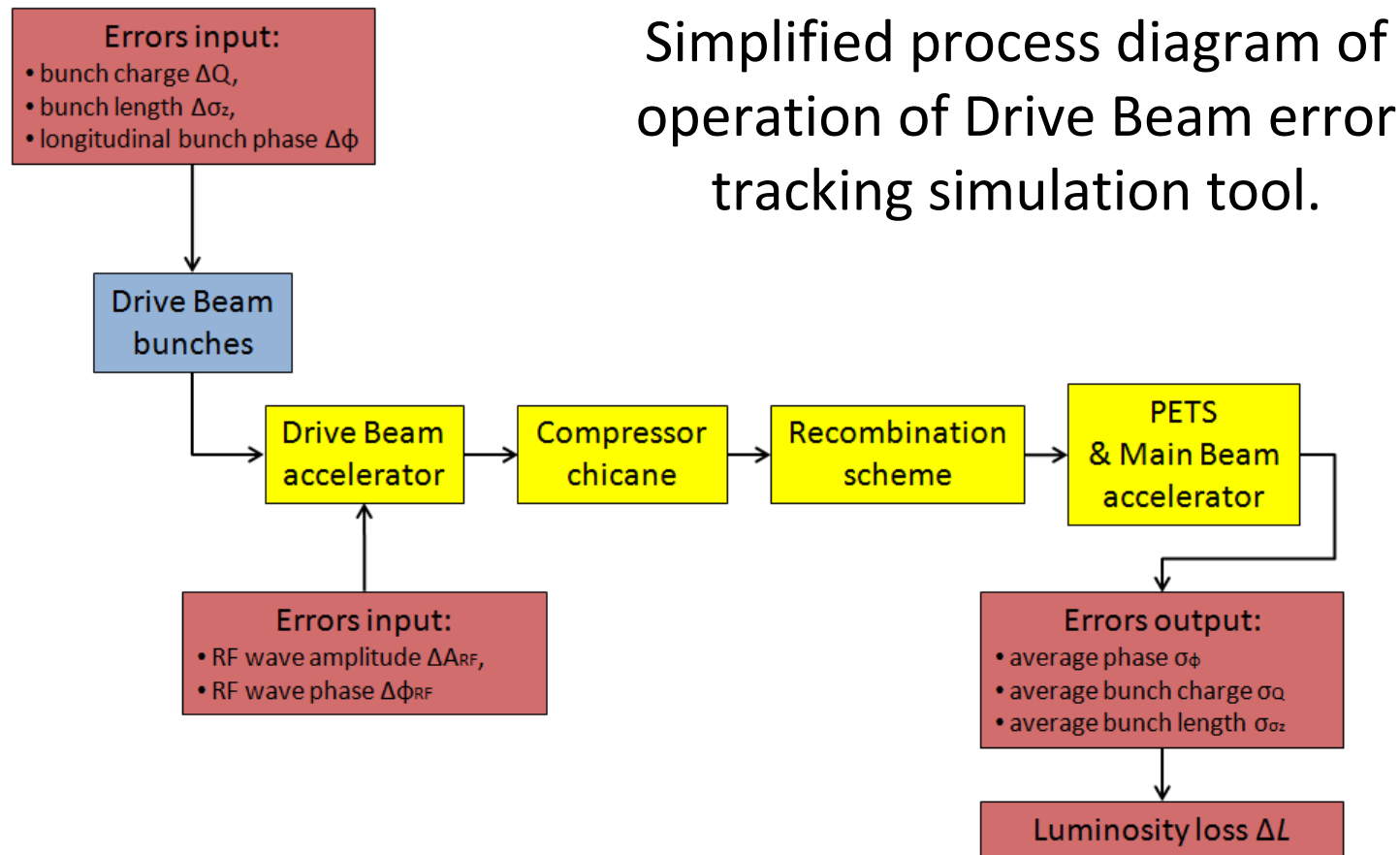
Step 1: Analyse the error, consider four Drive Beam sections:

1. Drive Beam accelerator
2. Compressor chicane
3. Recombination scheme
4. PETS & Main Linac

Step 2: Correct the error with a feed-forward system



Error propagation analysis Simulation tool



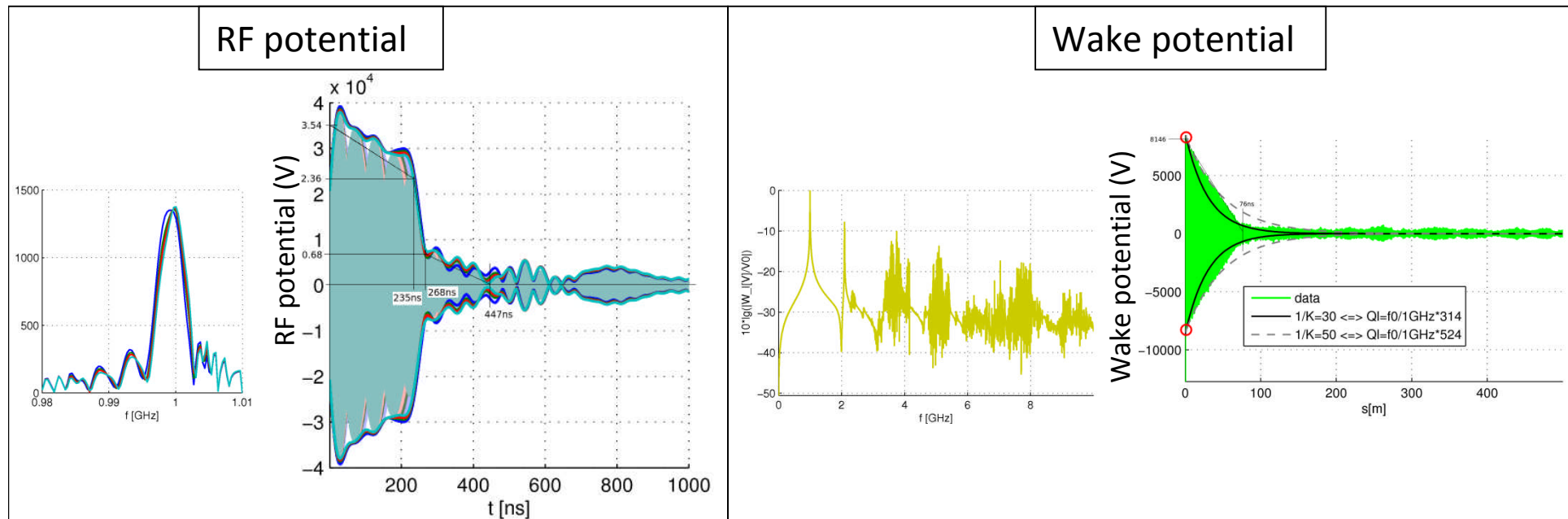


Analysing the errors (1/4)

Drive Beam accelerator



- RF amplitude and phase errors lead to beam energy errors
- Drive Beam bunch charge errors cause beam loading error in the accelerator leading to beam energy error



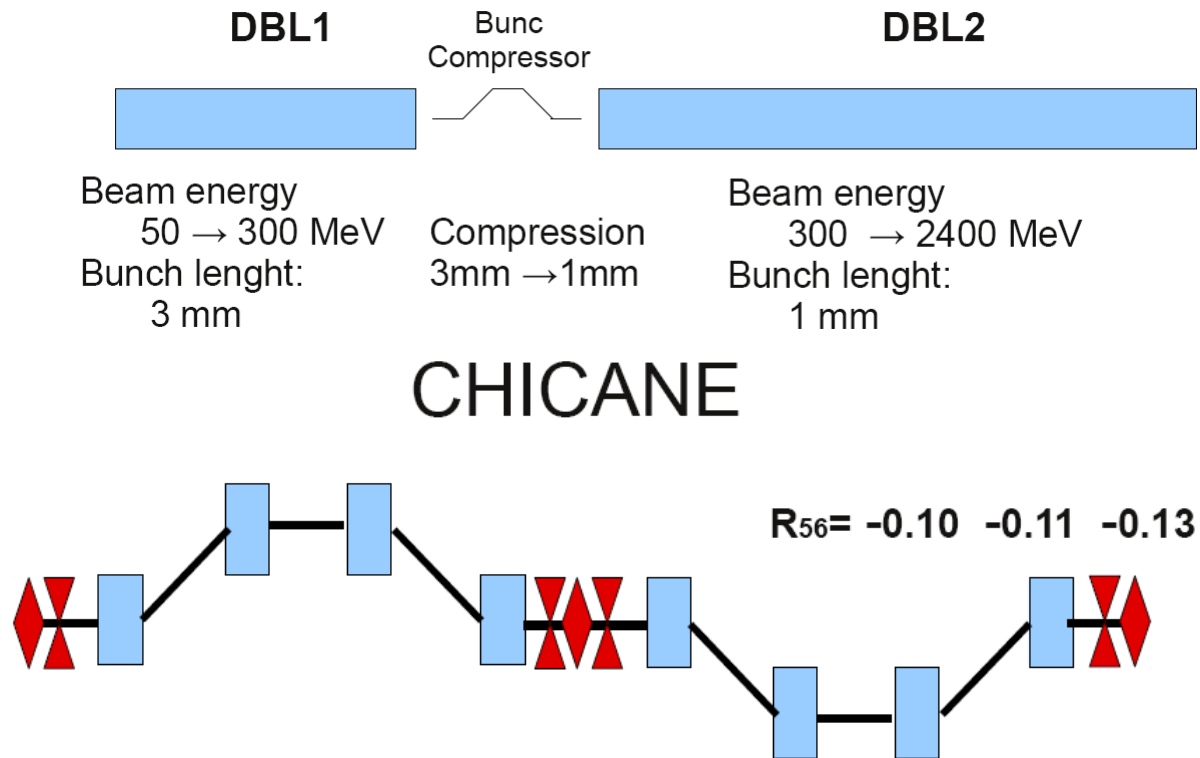
- Calculated in frequency domain, then fft to time domain
- Higher order resonances included in wake fields calculation
- 3 points per sinus wave, hence strong beating in RF potential

Simulations: R. Wegner



Analysing the errors (2/4)

Compressor chicane

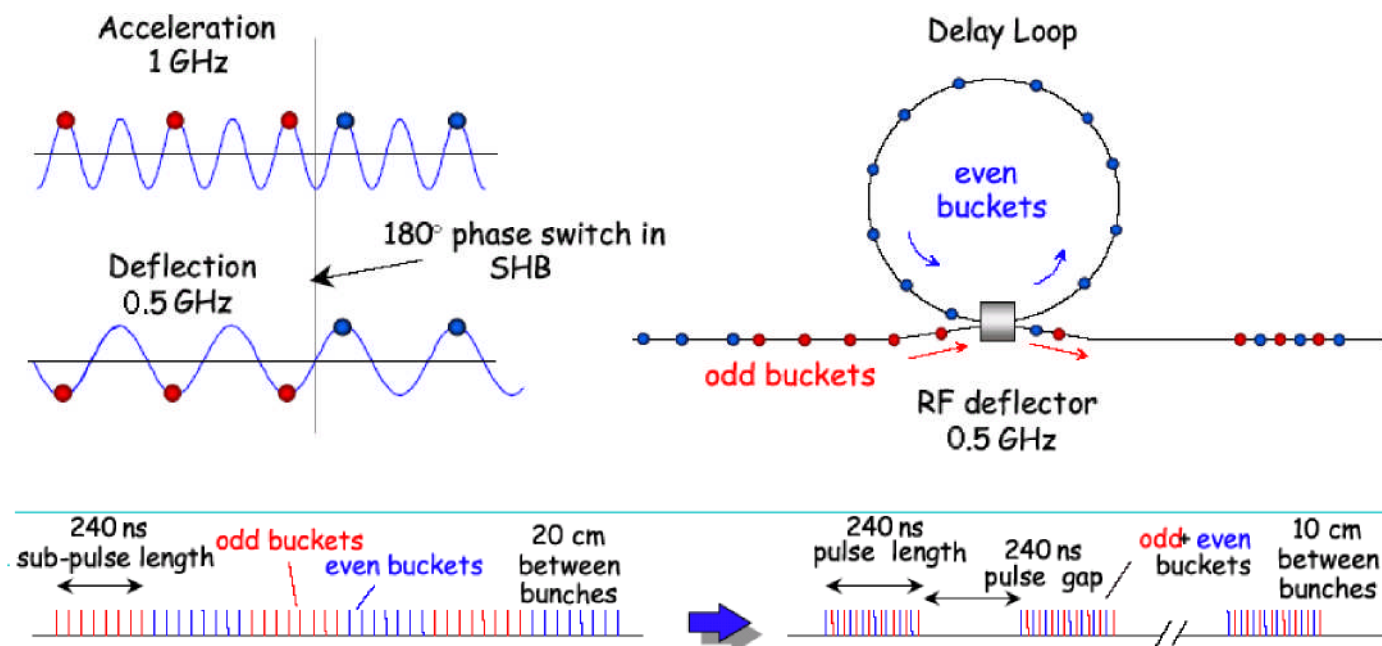


Simulations: A. Aksoy

Best stability is provided by chicane with $R_{56} = -0.1m$

Analysing the errors (3/4)

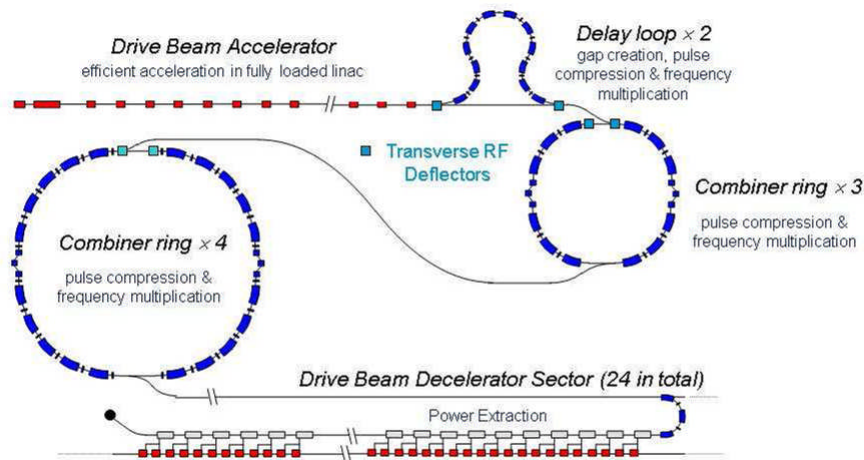
Recombination scheme



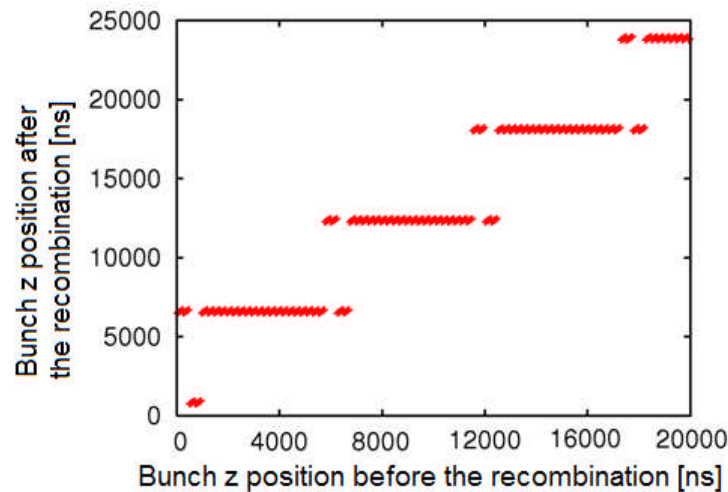
- Bunch frequency is 0.5 GHz
- 240 ns long trains have a relative phase-shift of 180°
- Acceleration at 1 GHz is equal for all trains
- RF deflector at the delay loop operates at 0.5 GHz and distinguishes between the 'even' and the 'odd' trains

Analysing the errors (3/4)

Recombination scheme



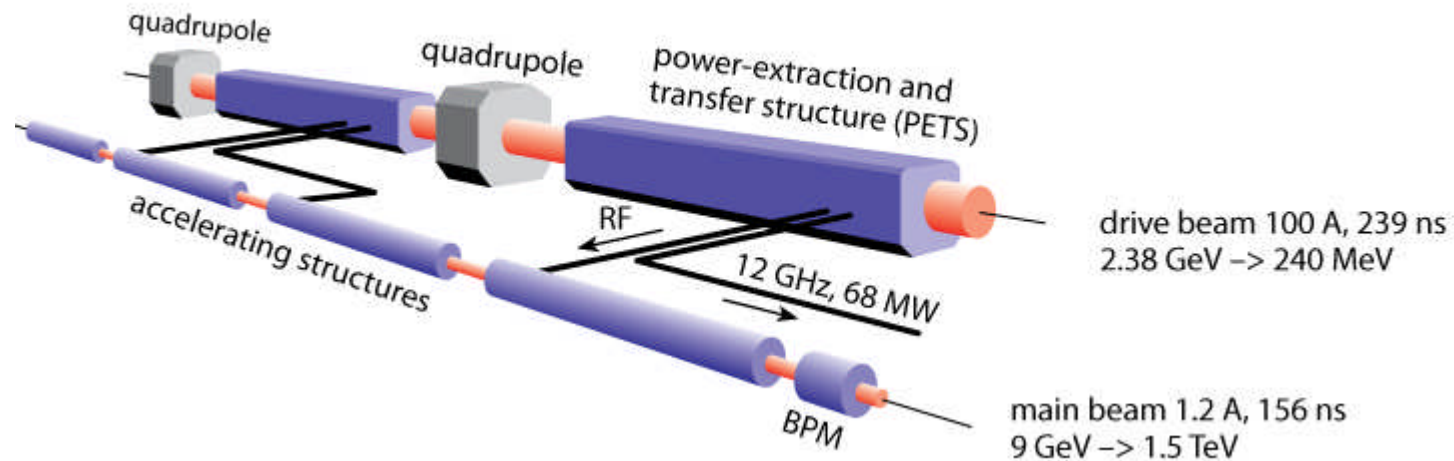
Beam has a recombination factor 24,
changing bunch frequency from 0.5 to 12GHz



Recombination in the first combiner ring is non-trivial, since the design allows to accommodate longer trains for the lower energy operation modes

Analysing the errors (4/4)

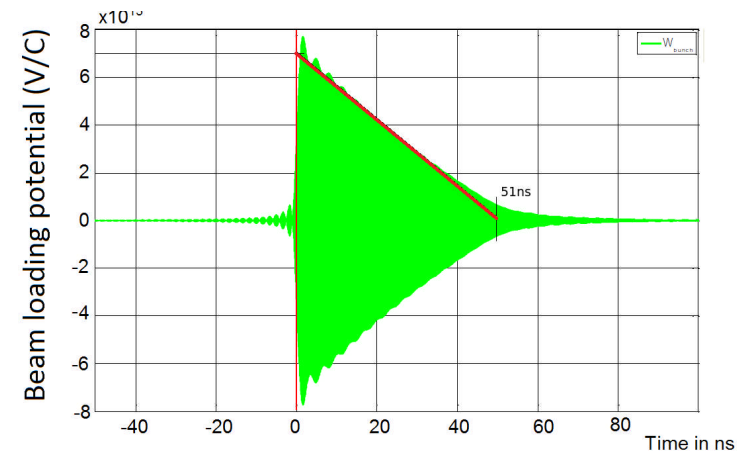
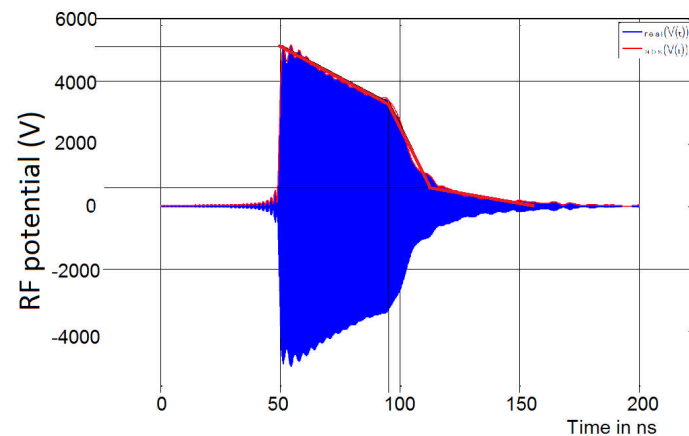
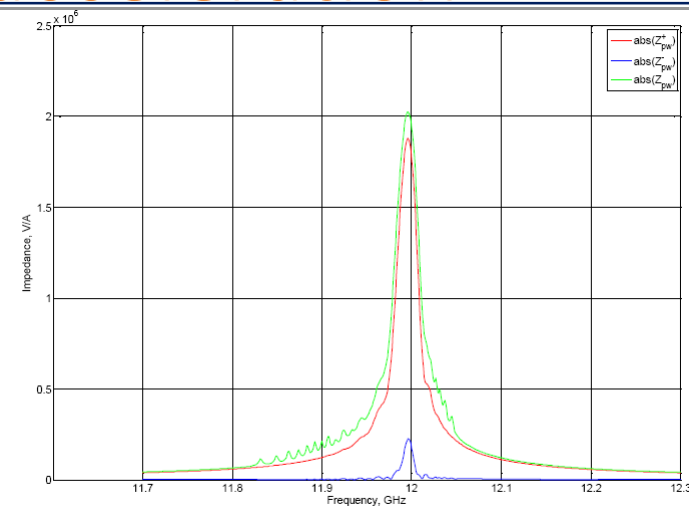
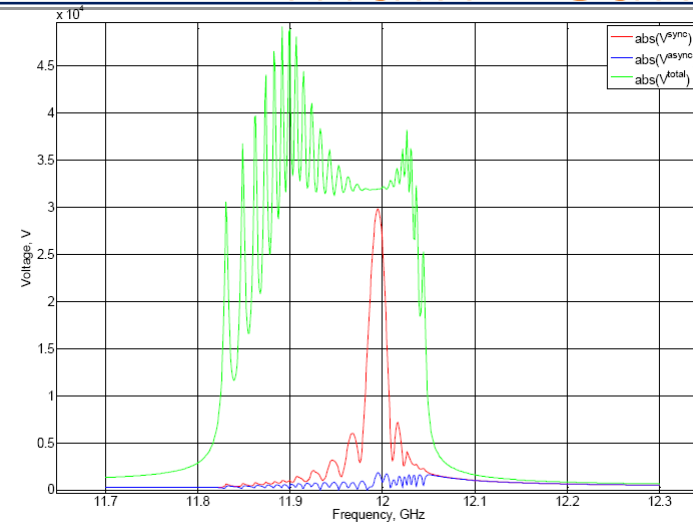
Main Beam acceleration



Analyze the impact
of the Drive Beam errors
on the Main Beam energy

Analysing the errors (4/4)

Main Beam acceleration



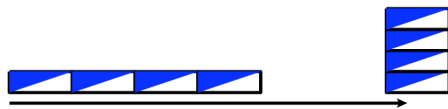
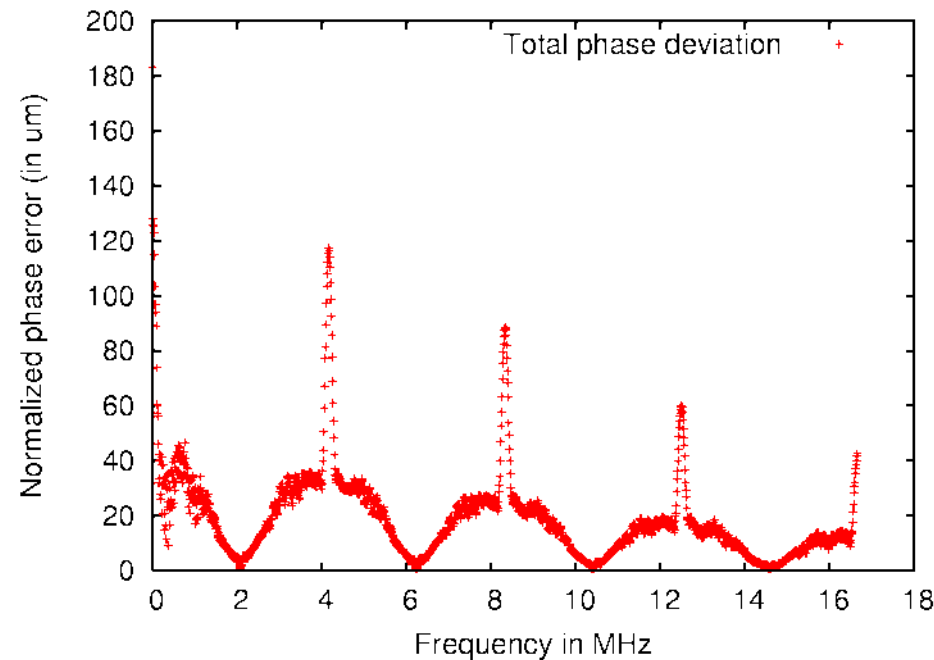
- Interval 11.7 GHz – 12.3 GHz
- Calculate in frequency domain, then fft

Simulations: O. Kononenko



Analysing the errors

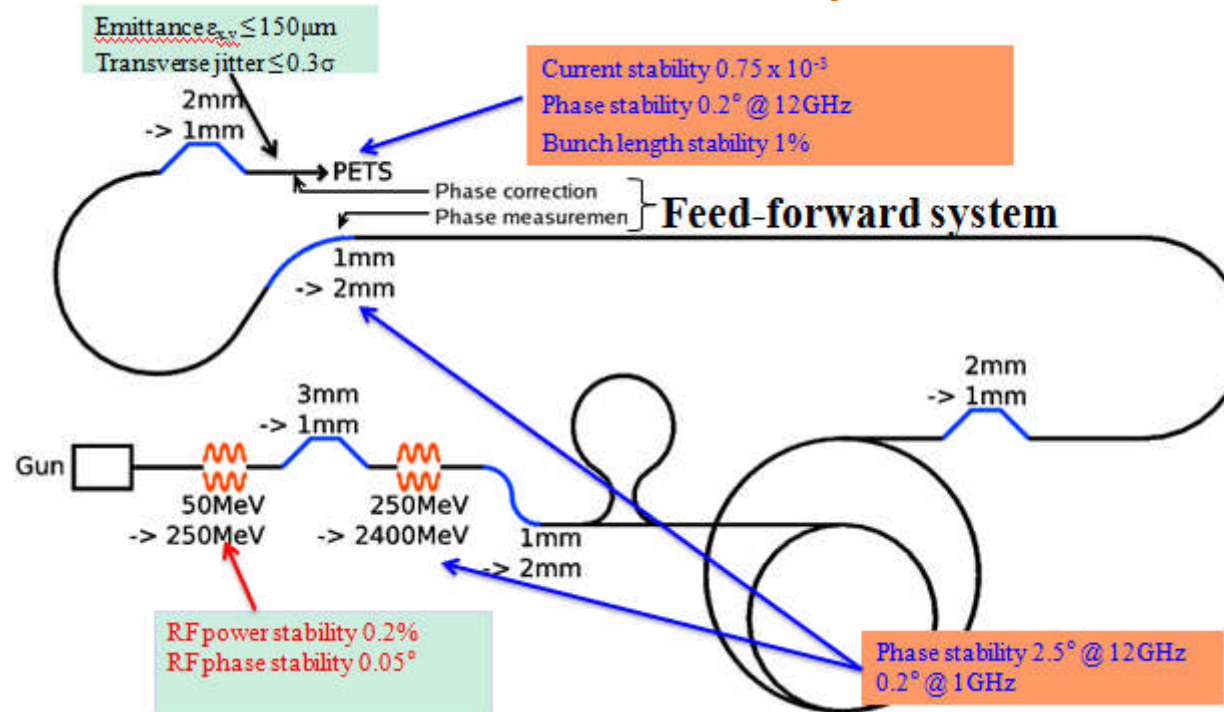
Phase error as function of frequency



When trains recombine,
their errors overlap

- Strong filtering by the in combination scheme
- Peaks from errors resonant with 240 ns long trains
- Suppression of peaks by drive beam accelerating structures
- Suppression of high frequencies by convoluting the signal with main beam accelerating structure RF filling

Drive Beam Tolerances and Error Analysis

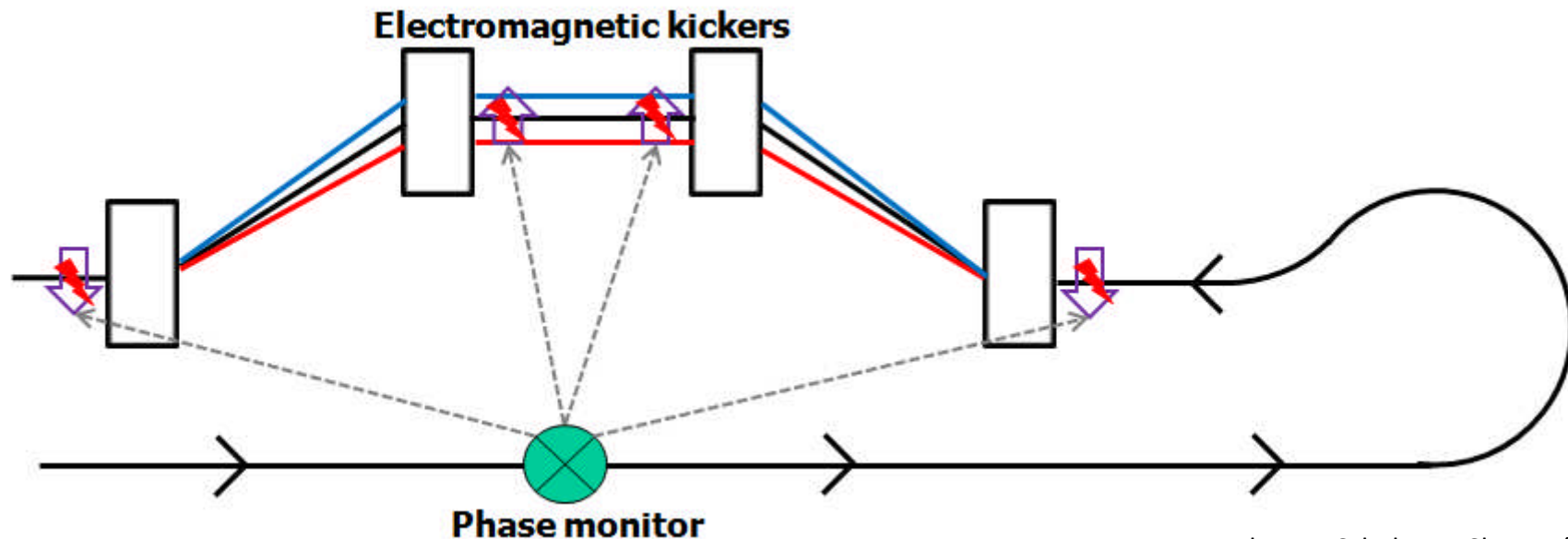


Plot: D. Schulte

Step 1: Analyse the error, consider four Drive Beam sections:

1. Drive Beam accelerator
2. Compressor chicane
3. Recombination scheme
4. PETS & Main Linac

Step 2: Correct the error with a feed-forward system

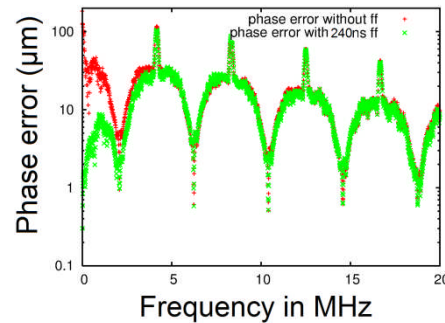


Plot: D. Schulte, P. Skowroński

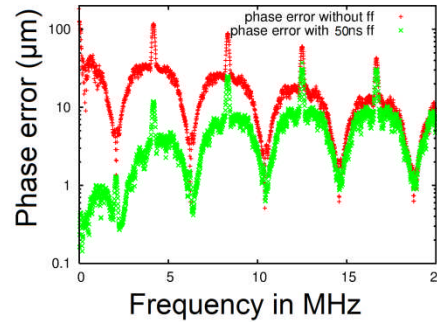
- Measure the longitudinal phase error before the turnaround
- Send the signal to the chicane before the beam arrives
- Chicane changes path length of the beam
 \Rightarrow One can modify longitudinal position of the bunches

Feed-forward amplifier rise time

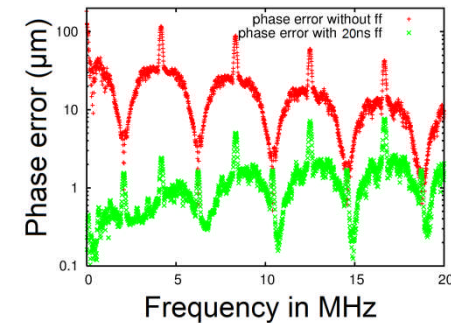
240ns



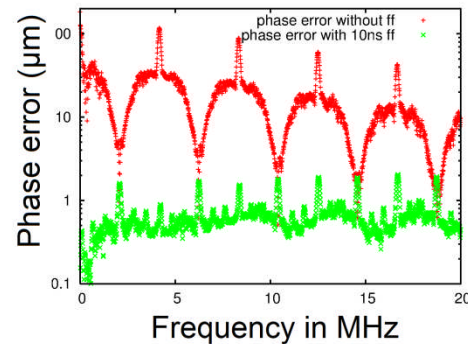
50ns



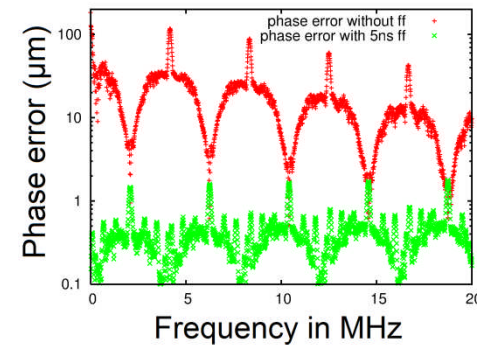
20ns



10ns



5ns



Lower amplifier rise time (= higher bandwidth)
allows more efficient correction



Feed-forward for different types of noise

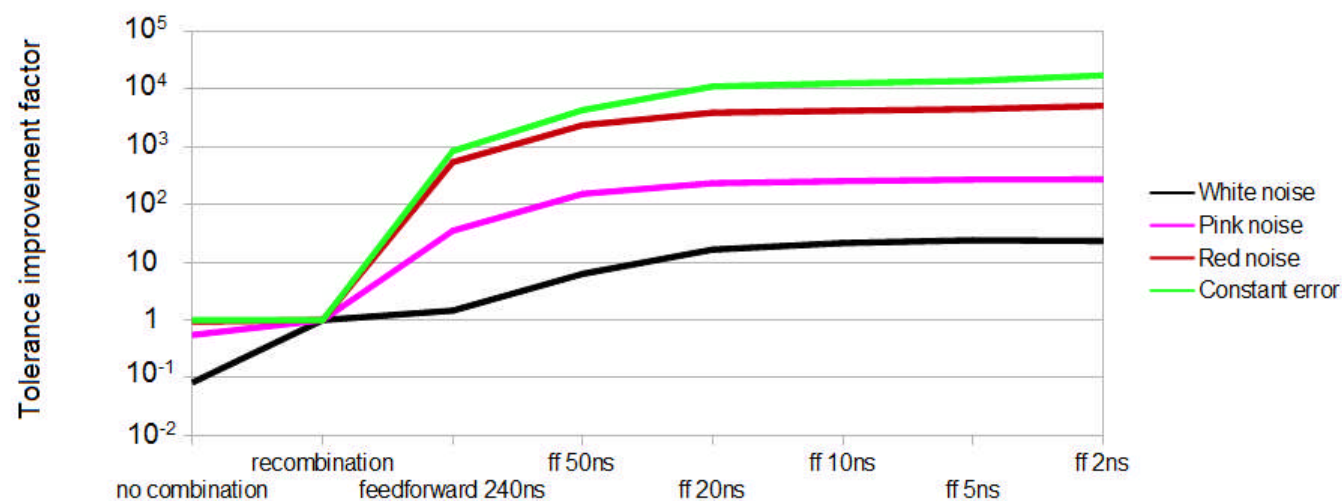
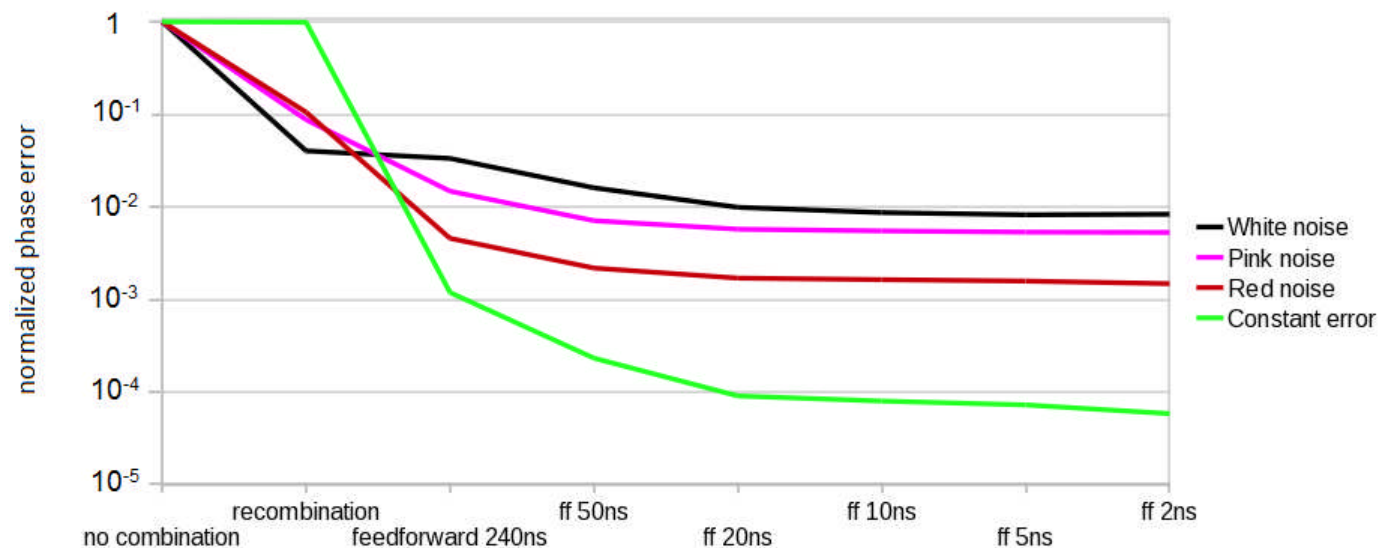


Reduction of
phase error amplitude

$$A = \sqrt{\int_{50\text{Hz}}^{20\text{MHz}} a^2(f)P(f)df}$$

Improvement of
phase tolerances

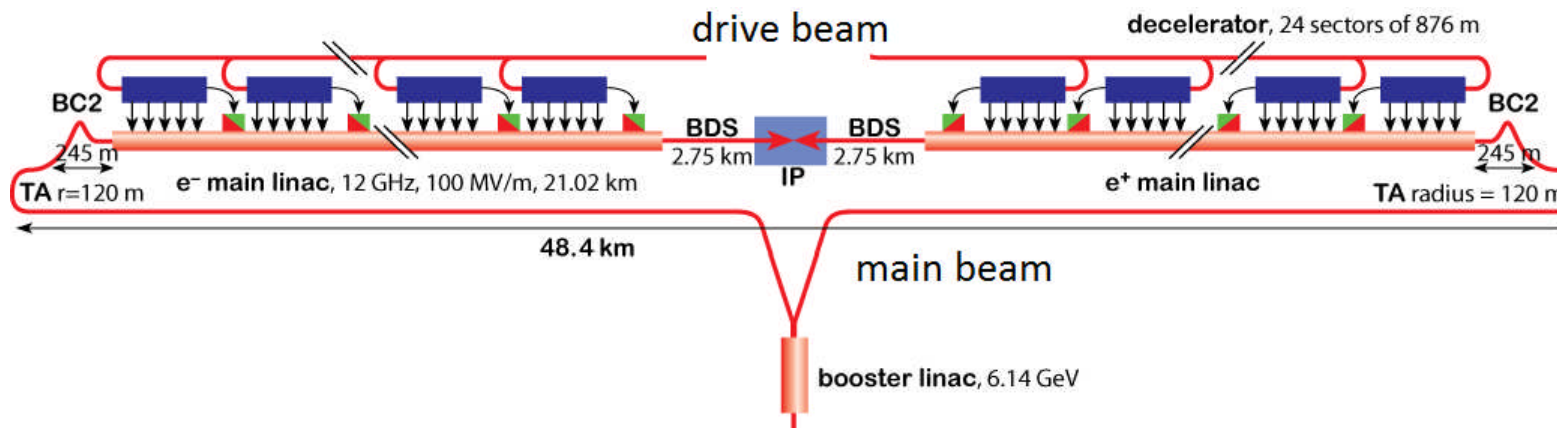
$$t = \frac{1}{A}$$



CLIC Drive Beam Phase Stabilisation



Synchronisation requirements along CLIC



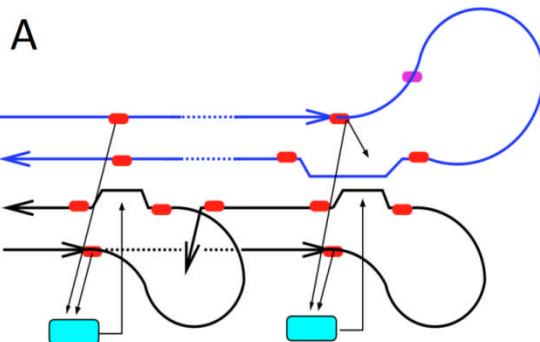
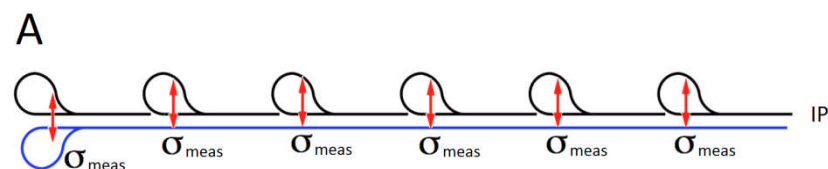
1% luminosity loss at CLIC would result from:

- 0.2 deg @ 12 GHz error in the relative Drive Beam - Main Beam phase
- 0.6 deg @ 12 GHz error between the two Main Beams phases at the IP

⇒ The signal of the nominal phase must be distributed along almost 50 km long CLIC collider

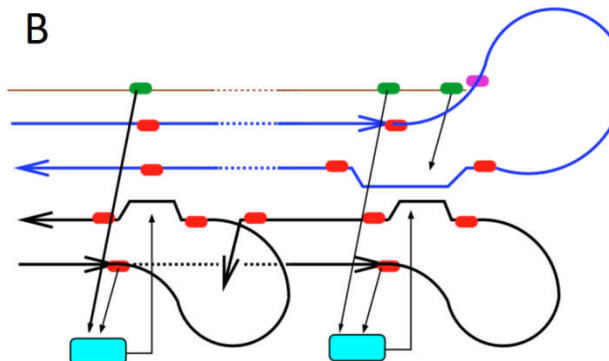
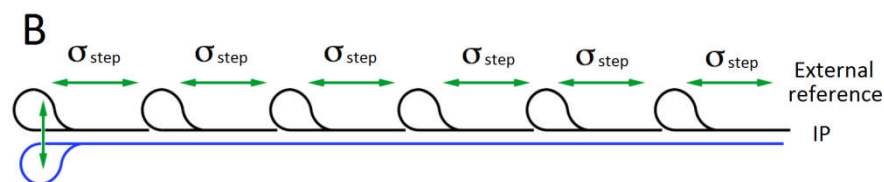
Phase signal distribution - two approaches:

A). Drive Beams alignment on the outgoing Main Beams.



Advantage:
No distribution
system noise.

B). Master clock near the IP defines the nominal phase.



Advantage:
Better alignment
between the two
Main Beams.

$\Delta L < 1\%$ requires $\sigma_{\text{step}} < 3.34 \mu\text{m}$
 $\Delta L < 0.1\%$ requires $\sigma_{\text{step}} < 1.06 \mu\text{m}$

Plot: D. Schulte



Summary of the CLIC Drive Beam stabilisation studies



- To achieve the required beam spot size of the Main Beam, the Drive Beam must be stabilised to a high degree
- Stabilisation of the longitudinal phase can be performed via
 - Error filtering by recombination scheme for high frequencies
 - Peaks at $n \times 4.17$ MHz remain unfiltered
 - Low frequencies remain unfiltered
 - Feed-forward system with a chicane and a high bandwidth amplifier for lower frequencies
 - Required improvement of RMS error by factor 12 is possible with 17.5 MHz amplifier
 - Distributed timing system can be implemented, stability specification would be $1.06 \mu\text{m}$ average error per decelerator segment

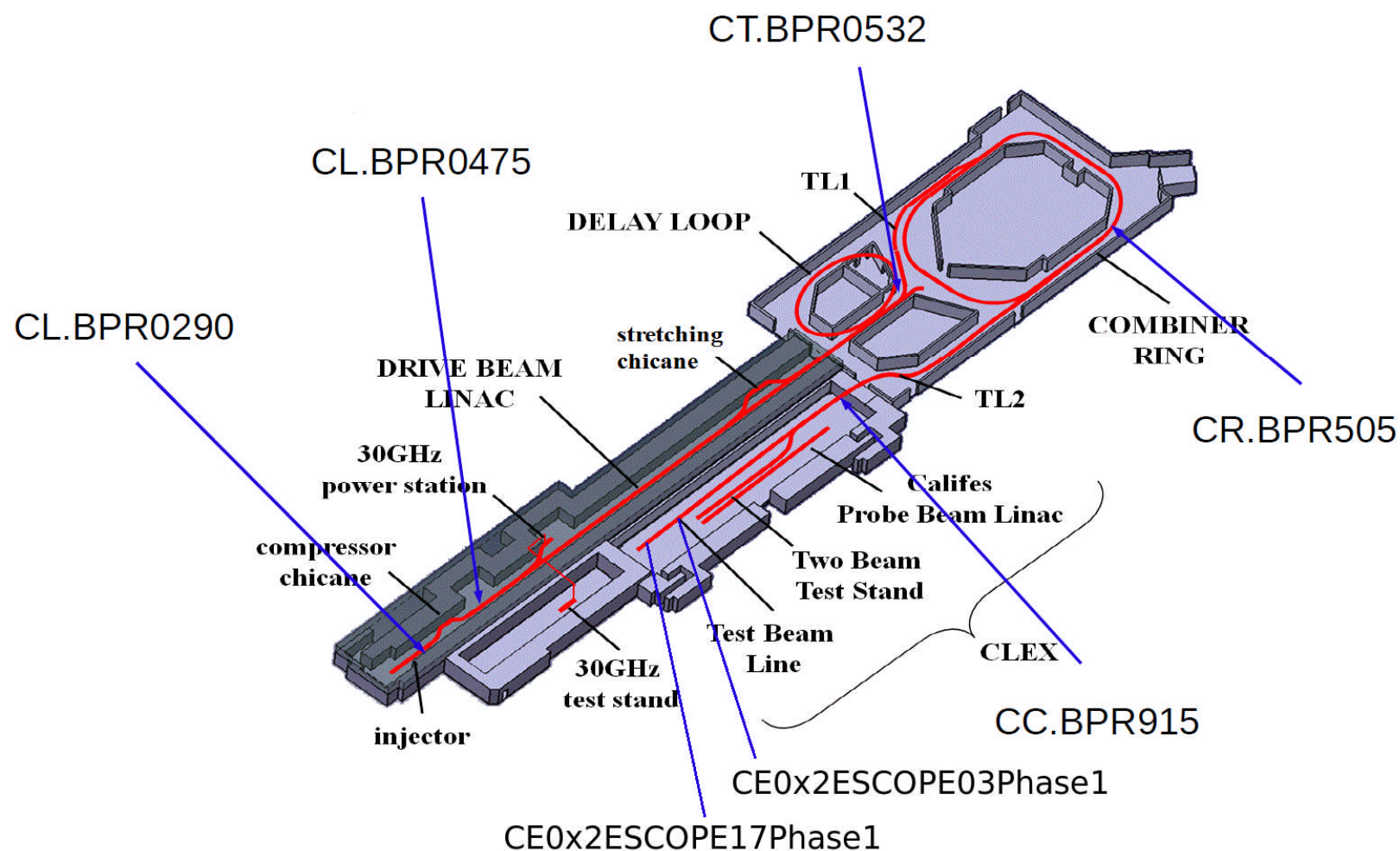


Phase stability measurement and simulations for CTF3



CTF3 phase measurements

Position of phase monitors





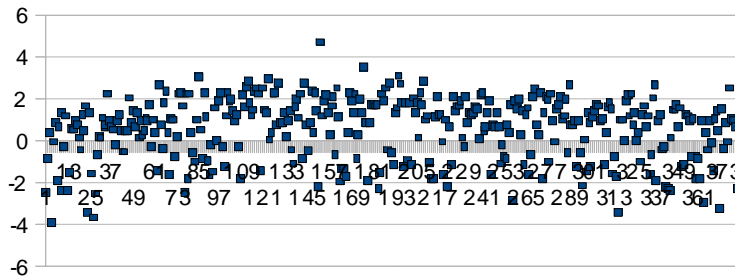
CTF3 phase measurements

average pulse phase



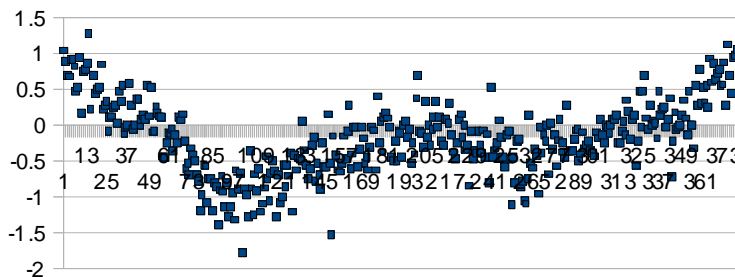
CL290

STD = 1.45
deg@12GHz



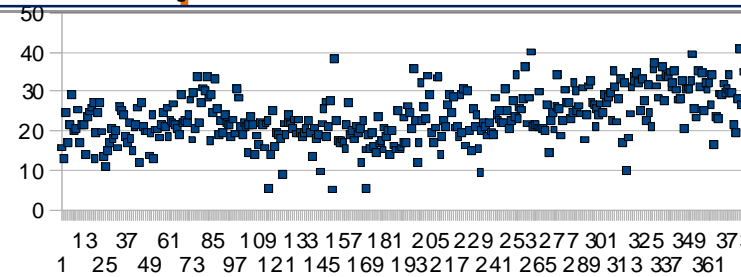
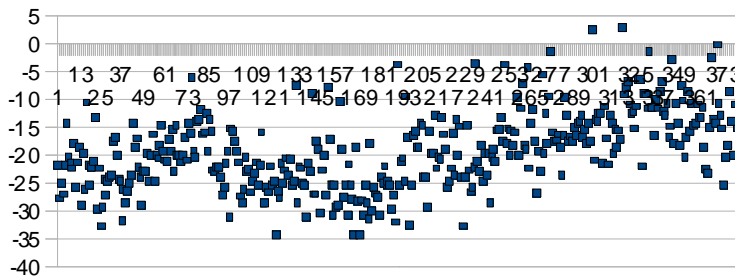
CL475

STD = 0.52
deg@12GHz



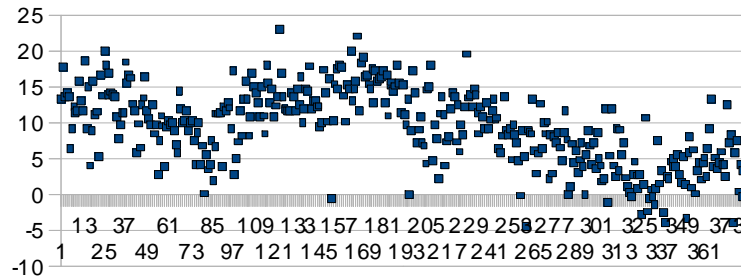
CT

STD = 6.77
deg@12GHz



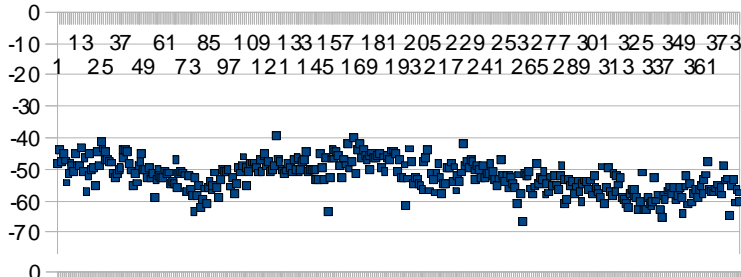
CR

STD = 6.31
deg@12GHz



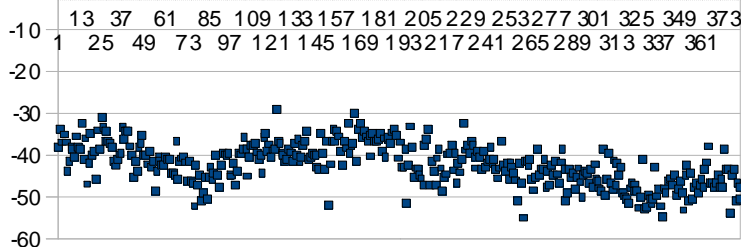
CC

STD = 5.25
deg@12GHz



CE03

STD = 5.0
deg@12GHz

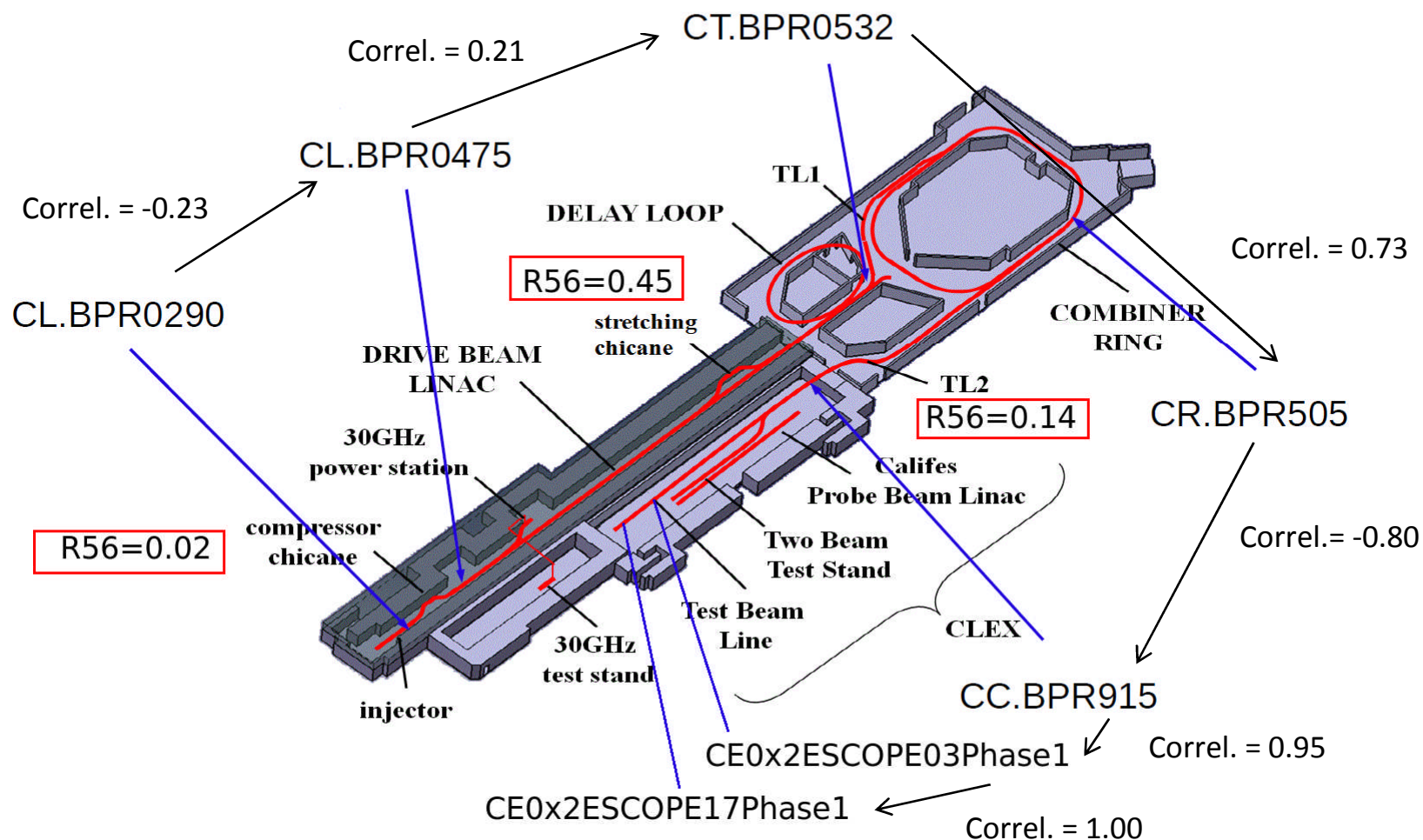


CE17

STD = 4.9
deg@12GHz

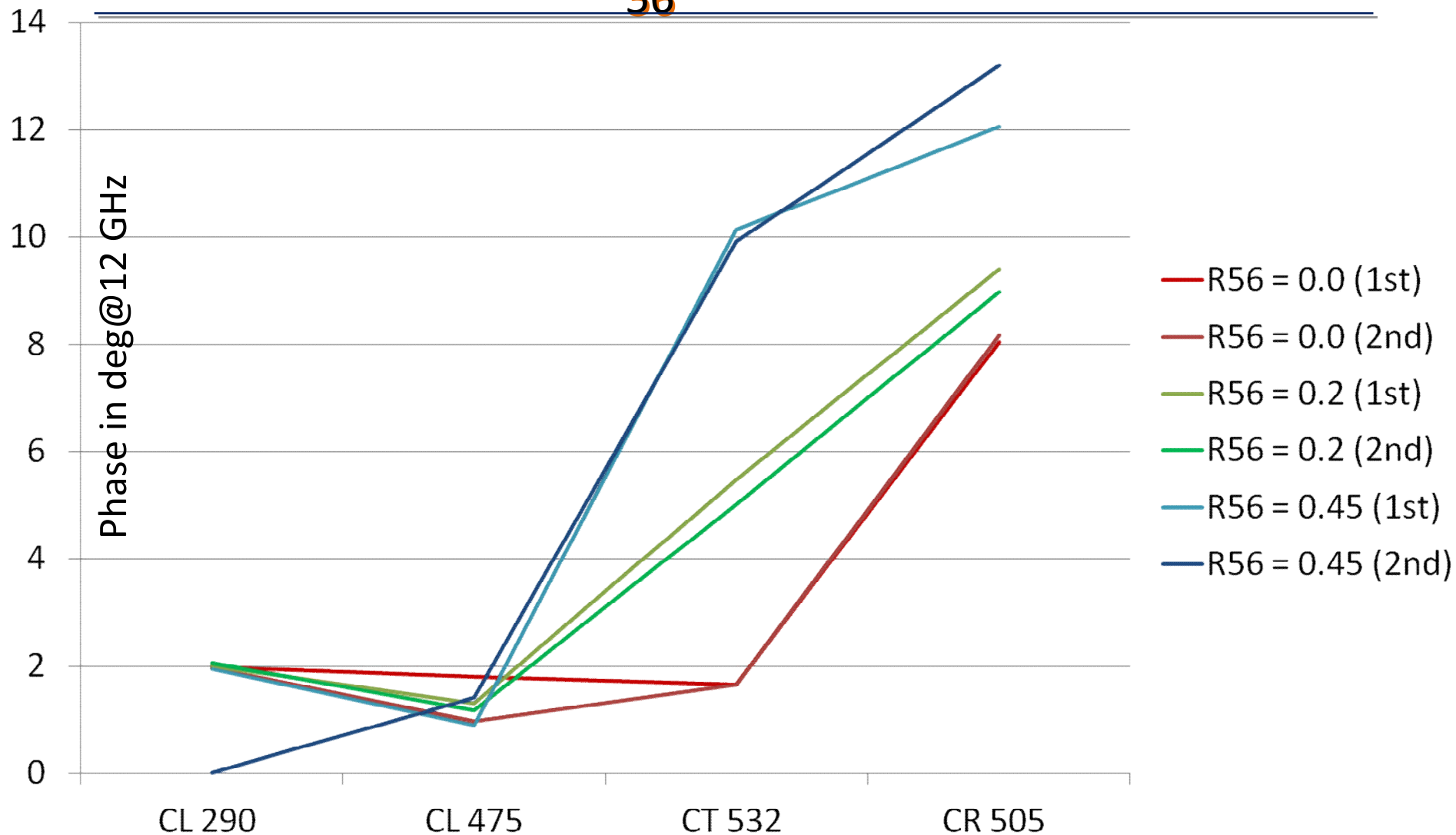


CTF3 phase measurements with different R_{56} values of the chicane





CTF3 phase measurements with different R_{56} values of the chicane





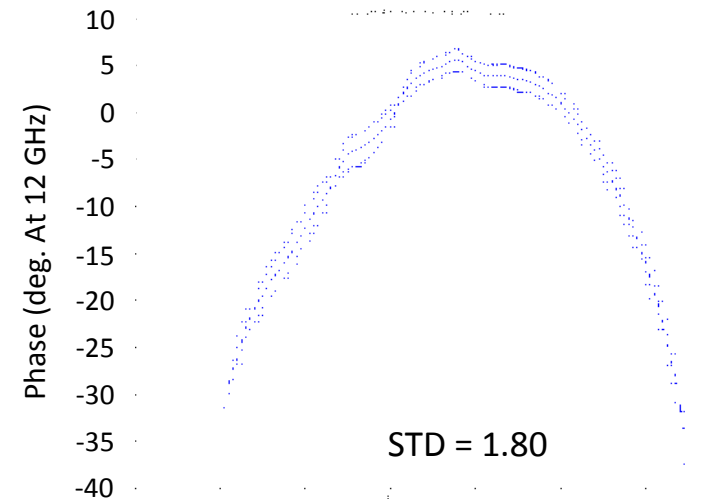
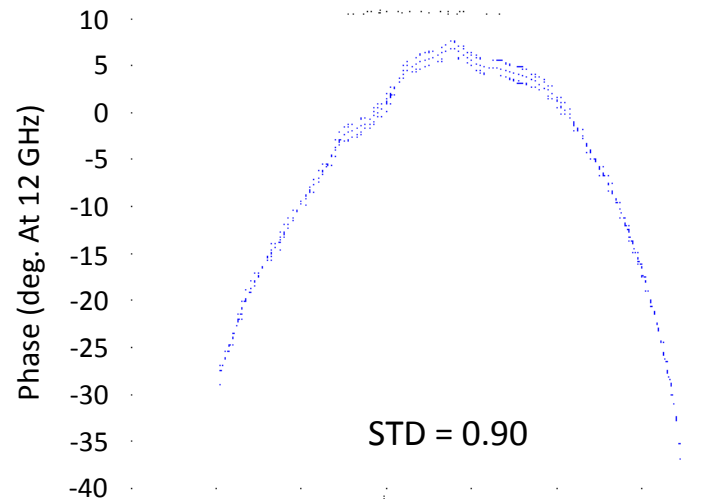
CTF3 phase measurements with different R_{56} values of the chicane



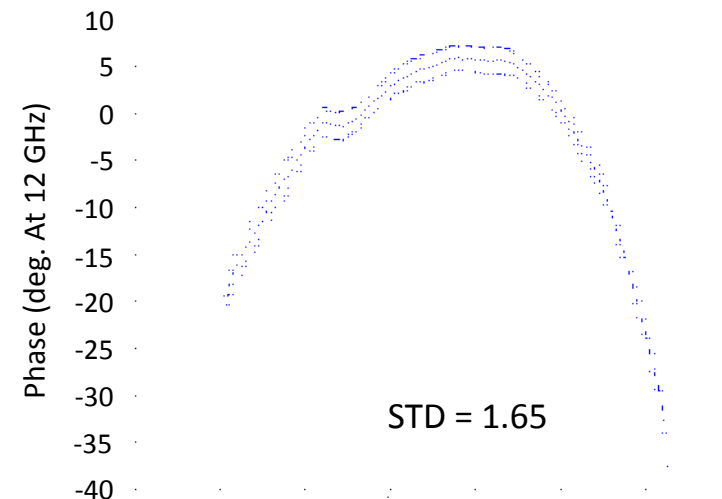
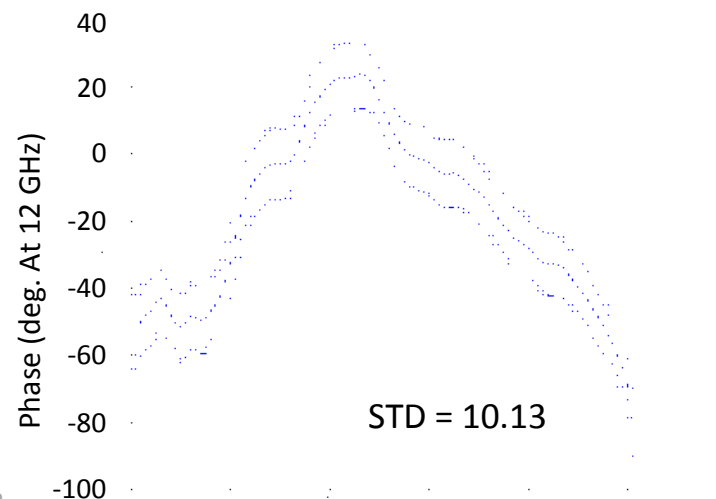
$R_{56} = 0.45$

$R_{56} = 0.0$

Monitor
CL 475



Monitor
CT 532



02/08/2013

Measurement: E. Ikarios



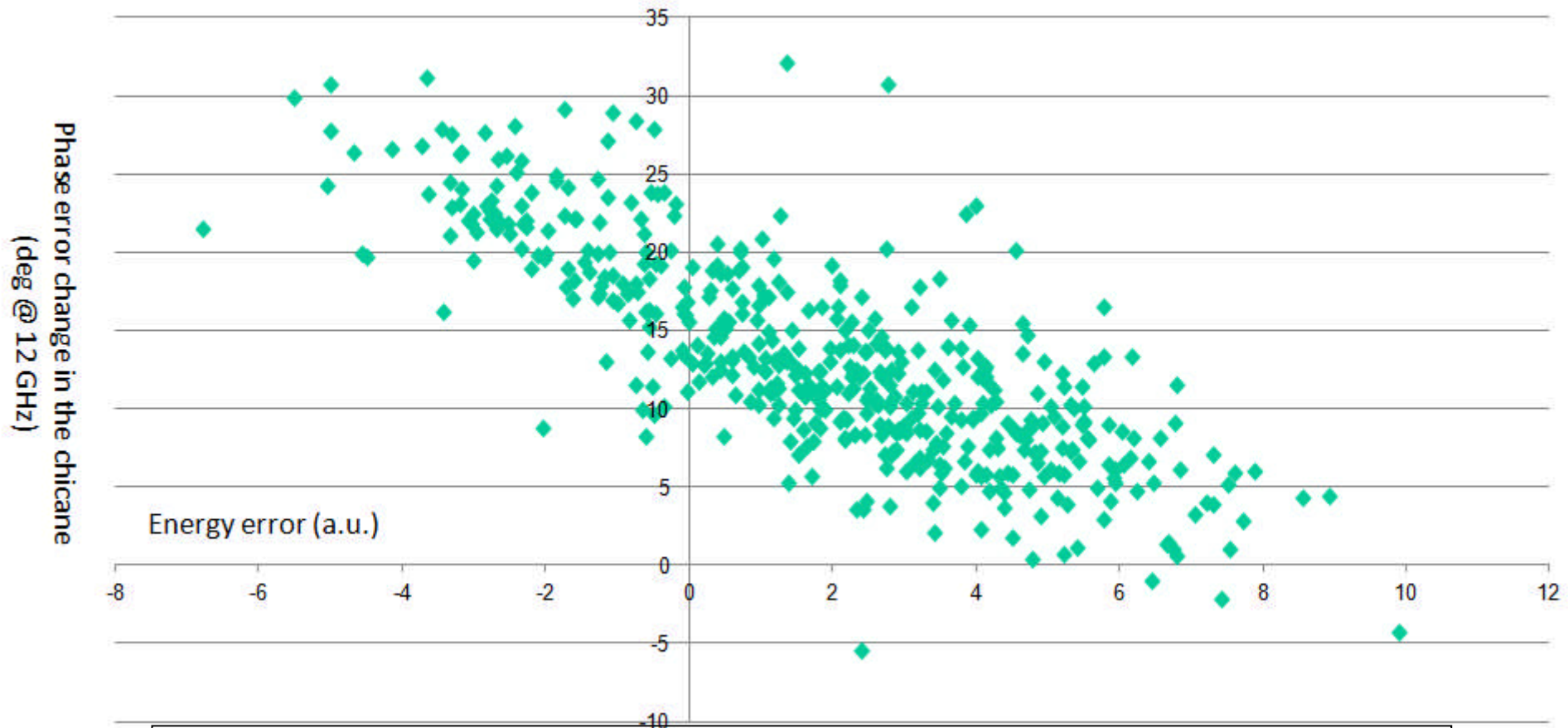
CTF3 measurements with $R_{56} = 0.45$

Phase change in the chicane vs. energy



Dispersive energy measurement in TL1 (BPI0608 monitor)

Correlation constant = **-0.79**



=> Large portion of additional phase error is caused by the beam energy error

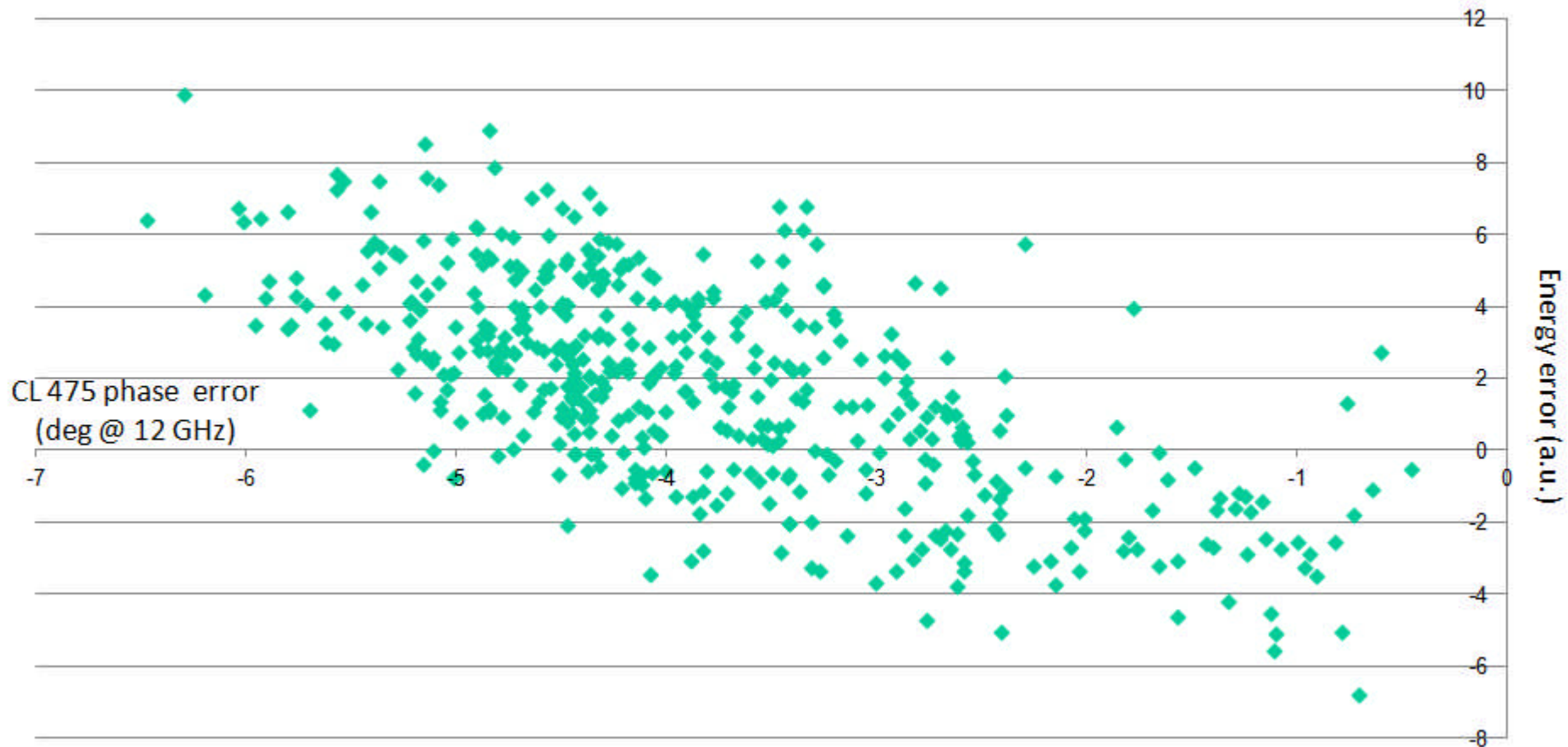


CTF3 measurements with $R_{56} = 0.45$

Beam energy vs. beam phase in linac



Correlation constant = **-0.66**



=> Energy error is partially caused by the beam phase error in the Drive Beam linac

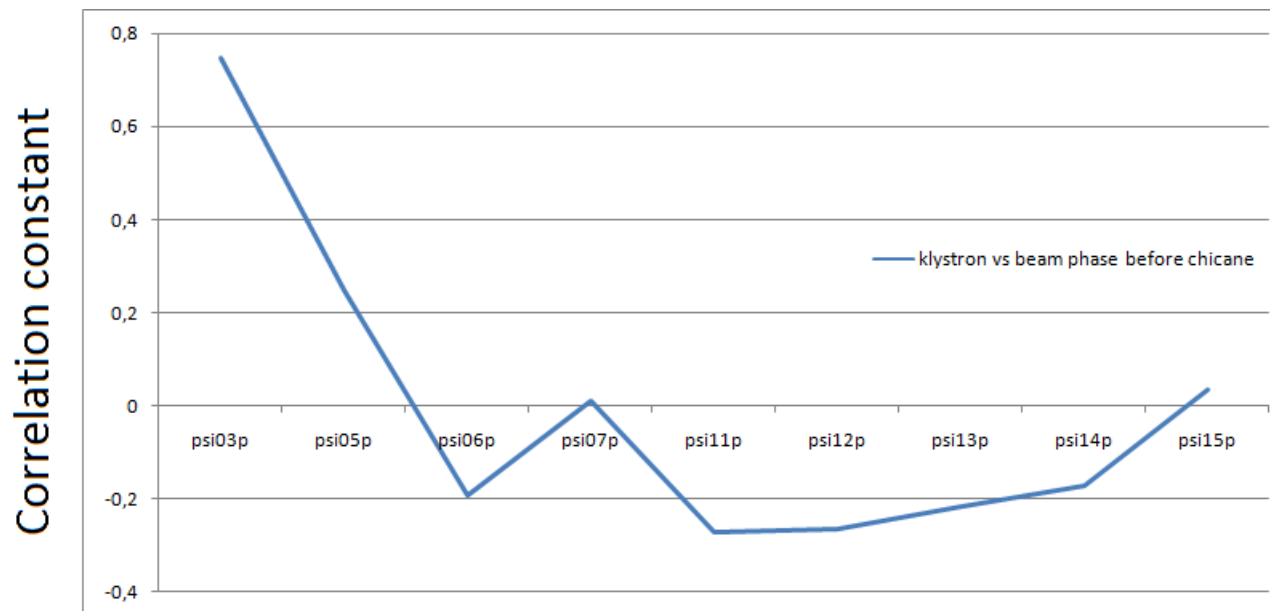


CTF3 measurements with $R_{56} = 0.45$

Klystron phase



Correlation of the beam phase error in linac with the phase of each individual klystron



- Standard deviation of klystron phase errors is comparable
- Correlation between any two klystrons is < 0.3

Klystron number

=> Phase error in the linac is partially caused by the phase error of first two klystrons



CTF3 measurements with $R_{56} = 0.45$

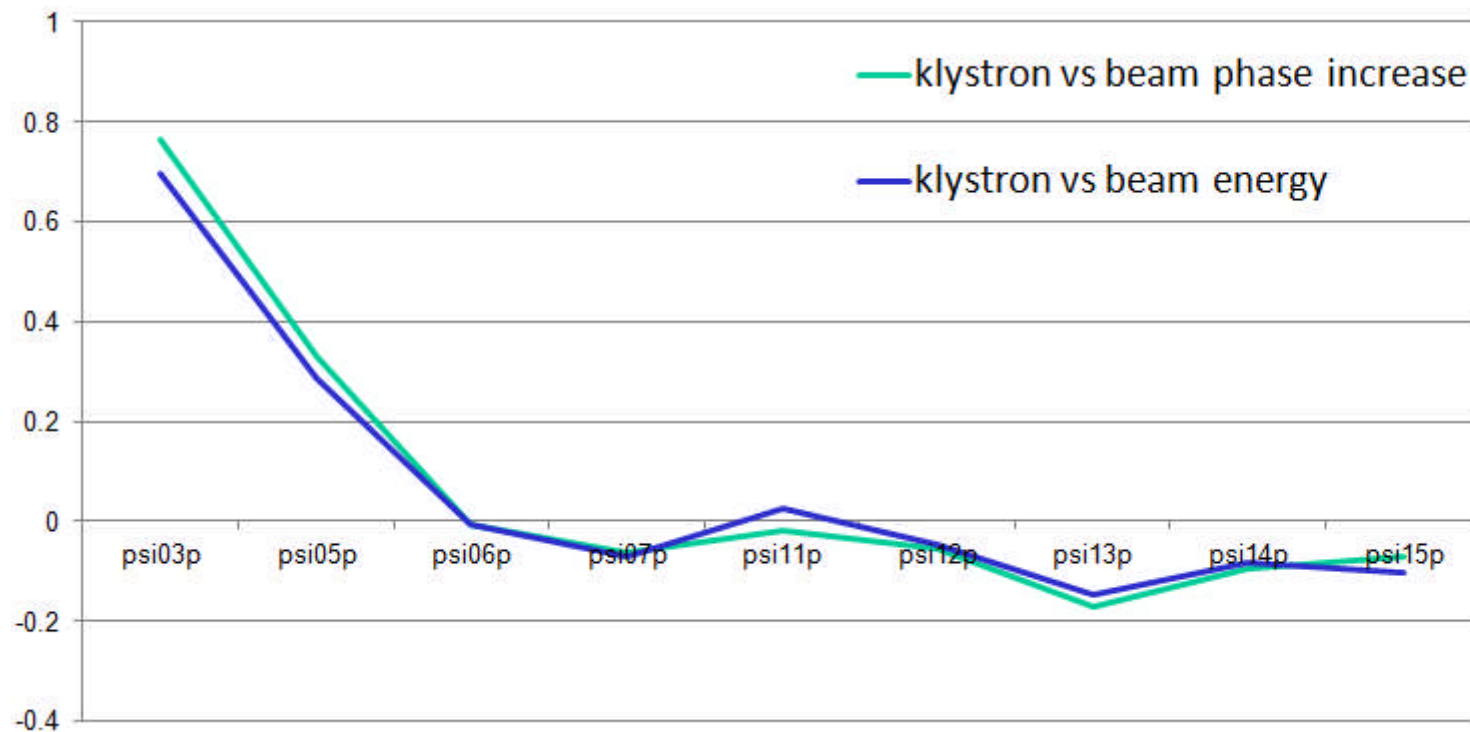
Klystron phase



Assumed chain of error transfer:

klystron phase error \rightarrow beam phase error in linac \rightarrow beam energy error \rightarrow additional beam phase error in the chicane

Correlation of the additional beam phase error in the chicane and the beam energy with the phase of each individual klystron

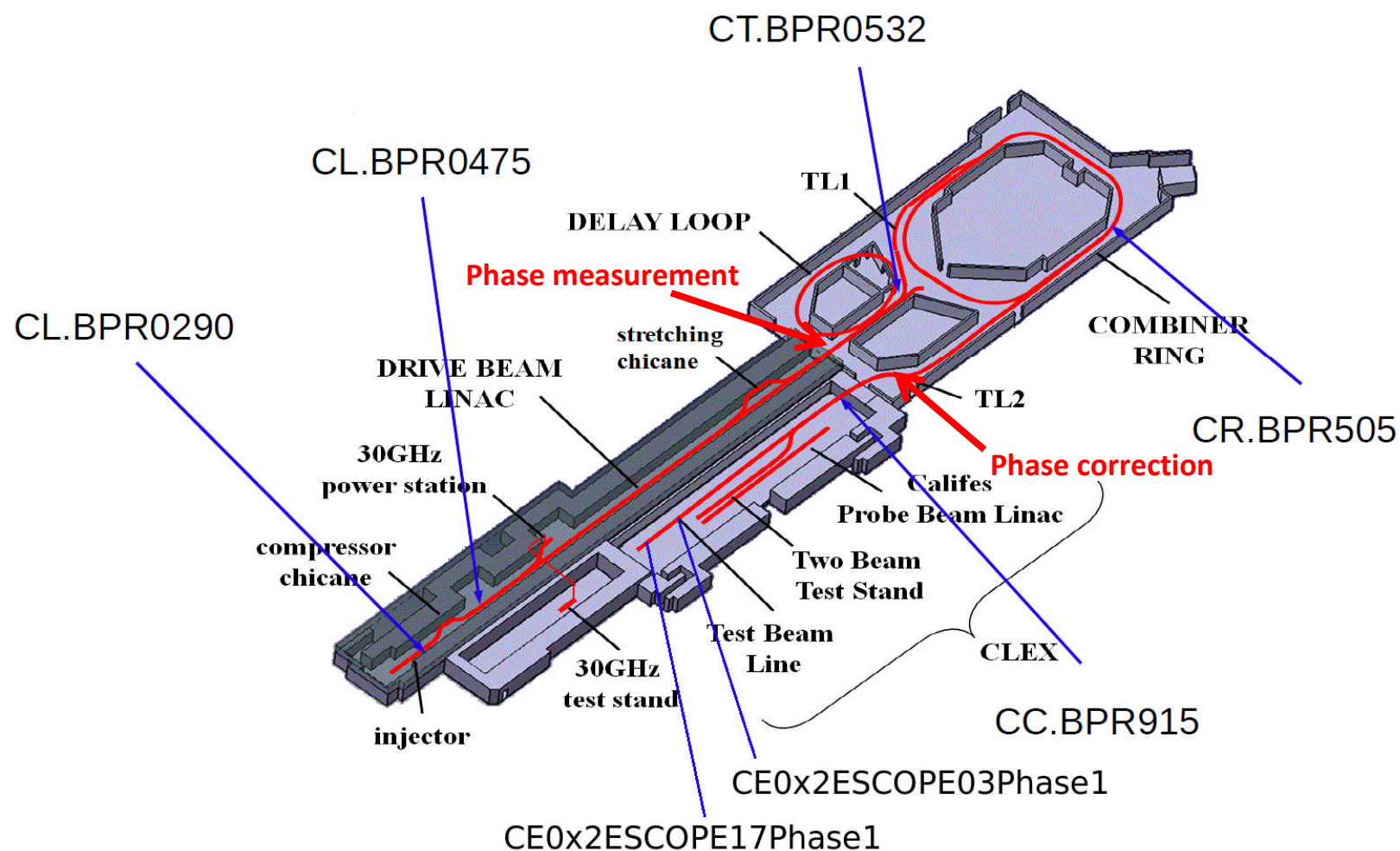


- Standard deviation of klystron phase errors is comparable
- Correlation between any two klystrons is < 0.3

Klystron number



CTF3 phase feed-forward prototype





Simulation of phase feed-forward prototype performance



Figure of merit - standard deviation of the bunch phase:

$$\sigma = \sqrt{\frac{1}{m \cdot n} \sum_m \sum_n (\varphi_{mn})^2}$$

with m being number of train, n being number of bunch in the train

Calculate feed-forward with

$$\varphi_{mn,ff} = \varphi_{mn} - \frac{1}{b} \sum_{i=n-b/2}^{n+b/2} a \cdot \varphi_{mi}$$

Where b is time of 20 ns
corresponding to 50 MHz amplifier
bandwidth,
 a is correction amplification
 $a = 0.85 \times \sigma(TL2) / \sigma(TL1) = 0.5$

Monitor position and feed-forward type	σ in deg at 12 GHz
TL1	39.48
TL2 without feed-forward	23.30
TL2 with 1-to-1 feed-forward	23.66
TL2 with 1-to-0.5 feed-forward	13.51
TL2 with 1-to-0.5 feed-forward with 17° maximal correction	14.75

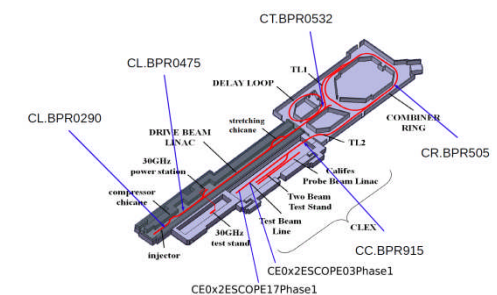
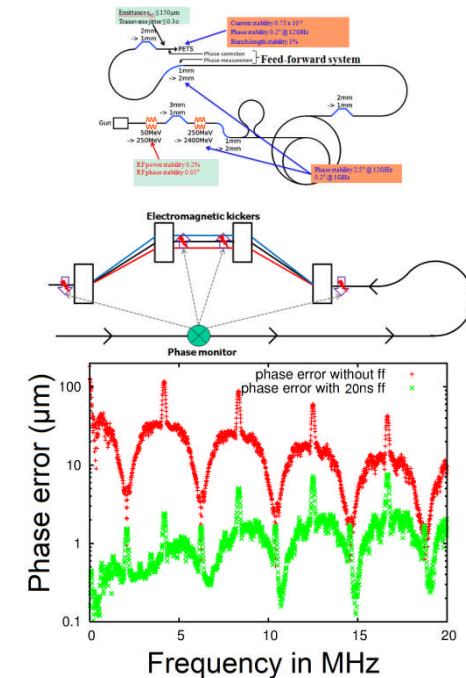
=> Correction will produce a measurable effect



Summary



- CLIC must be stabilised to a very high degree
 - Stabilisation of the Drive Beam phase is planned to be performed via a feed-forward system
 - Simulations show that the proposed feed-forward system is feasible
 - Amplifier must have a bandwidth > 17.5 MHz
 - Distribution system error must be $< 1.06 \mu\text{m}$ per decelerator
 - CTF3 phase error after the stretching chicane is caused by
 - the beam phase error in the linac and
 - the klystron phase error
 - Feed-forward system prototype will produce a measurable effect at CTF3 and will be tested in 2013.
- Specifications:
- 50 MHz amplifier bandwidth
 - 17° at 12 GHz maximal correction





Thank you very much for your attention!

Questions?

Backup Slides

Analysing the errors: Combiner Ring 1

