CLIC RTML and ML overview

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Table of contents

- Introduction
- RTML overview
    - Ongoing studies
- ML overview
    - Ongoing studies
- Conclusions

Emittance budgets

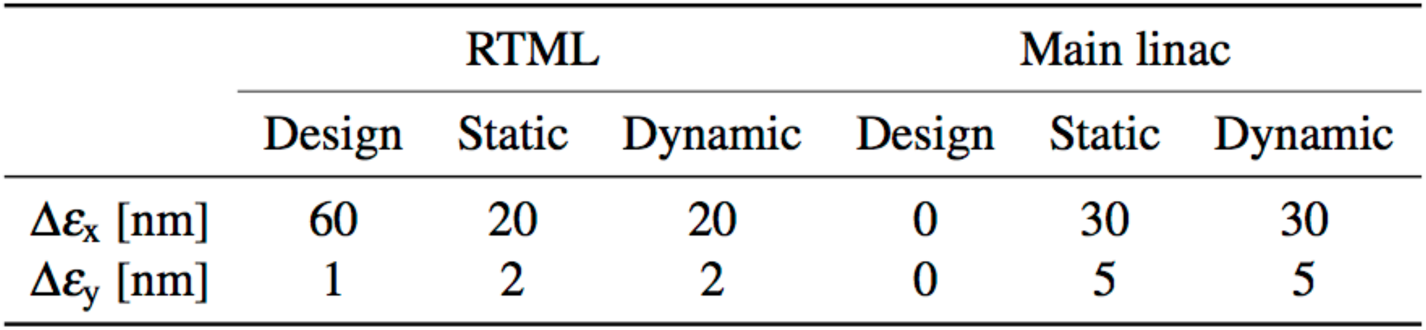
The CLIC luminosity target is $L_{0.01} = 2 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$.

To achieve this goal very small beam emittances are required. The damping rings will deliver emittances of **ε_x = 500 nm** horizontally and **ε_y = 5 nm** vertically.

During the transport of the beam from the damping rings to the BDS, the emittances increase due to:

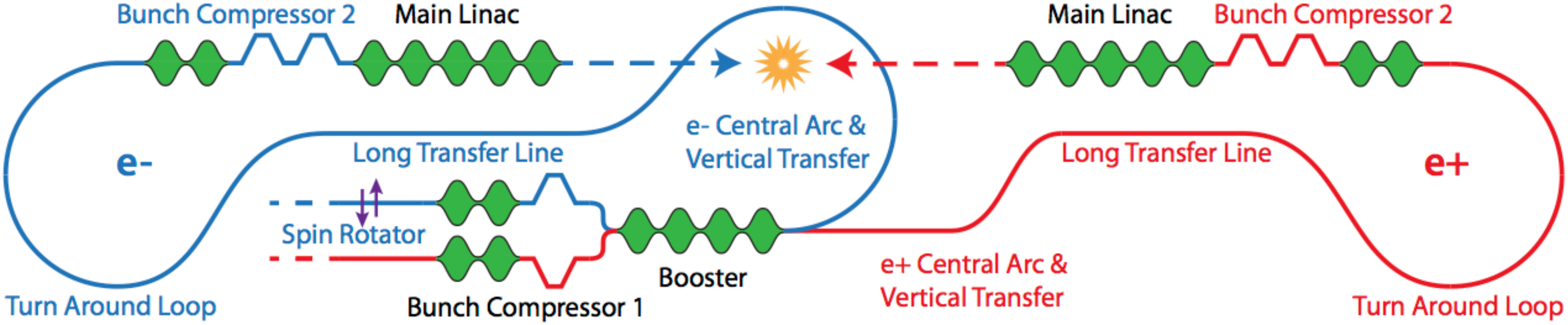
- effects from the lattice design, e.g., incoherent and coherent synchrotron radiation in the RTML
- effects from static imperfections, e.g., misalignment of the BPMs;
- effects from dynamic imperfections, e.g., quadrupole jitter

In order to limit the emittance to **$\varepsilon_x \leq$ 660 nm** and **$\varepsilon_y \leq$ 20 nm** at the entrance of the BDS, emittance growth budgets have been defined:



	RTML			Main linac		
	Design	Static	Dynamic	Design	Static	Dynamic
$\Delta\varepsilon_x$ [nm]	60	20	20	0	30	30
$\Delta\varepsilon_y$ [nm]	1	2	2	0	5	5

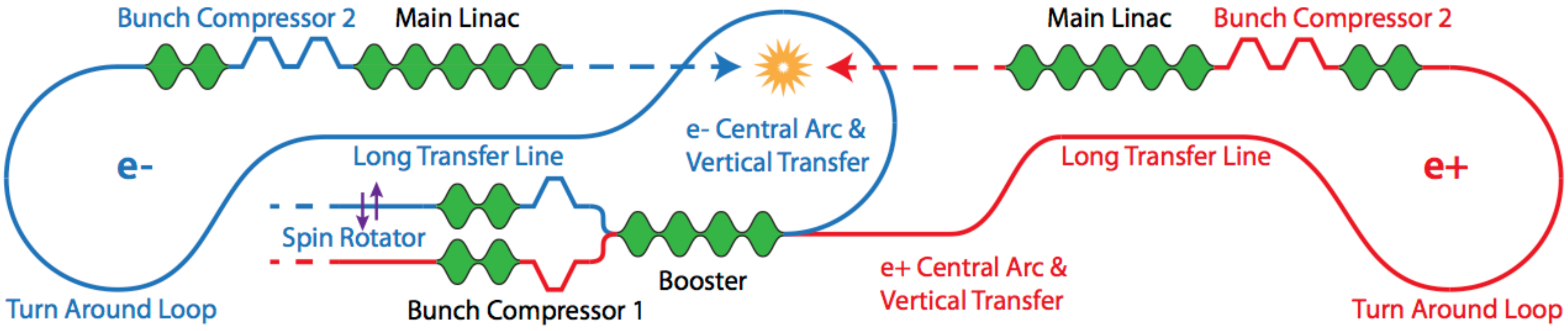
CLIC RTML



RTML includes several sub-systems:

- Spin-Rotator (e^- only) ; Bunch Compressor 1 ; Booster ; Central Arc & Vertical Transfer ; Long Transfer Line ; Turn Around Loop ; Bunch Compressor 2

CLIC RTML



Particle energy	E_0	2.86	GeV
Bunch charge	Q_0	0.65	nC
RMS bunch length	σ_s	1600	µm
RMS energy spread	σ_E / E_0	0.13	%
uncorr. energy spread	σ_E / E_0	0.13	%
Energy chirp	u	0	1/m
Normalized emittance	$\varepsilon_{n,x}$	500	nm rad
	$\varepsilon_{n,y}$	5	nm rad
Polarization	P	?	%
Phase offset 2GHz	$\Delta\phi$	0	deg

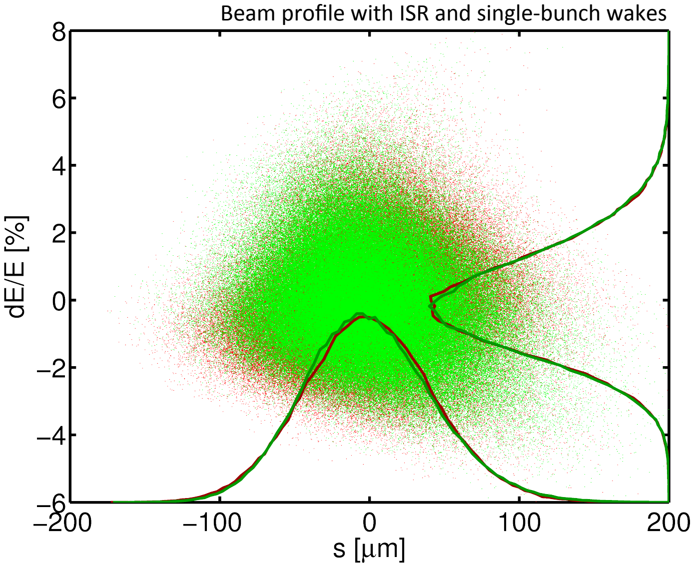
@ exit of damping rings

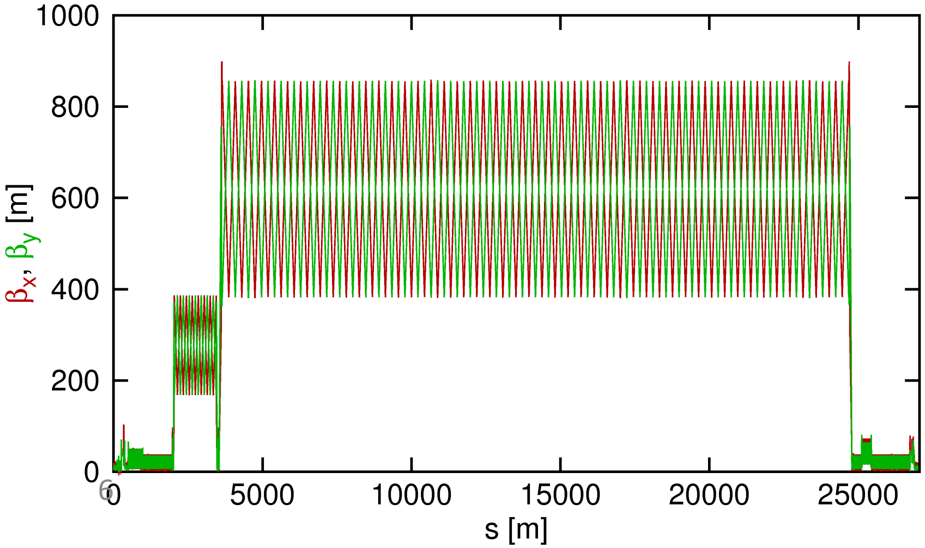
Particle energy	E_0	9	GeV
Bunch charge	Q_0	> 0.6	nC
RMS bunch length	σ_s	44	µm
RMS energy spread	σ_E / E_0	< 1.7	%
uncorr. energy spread	σ_E / E_0	< 1.7	%
Energy chirp	u	0	1/m
Normalized emittance	$\varepsilon_{n,x}$	< 600	nm rad
	$\varepsilon_{n,y}$	< 10	nm rad
Polarization	P	?	%
Phase offset 12 GHz	$\Delta\phi$	0	deg

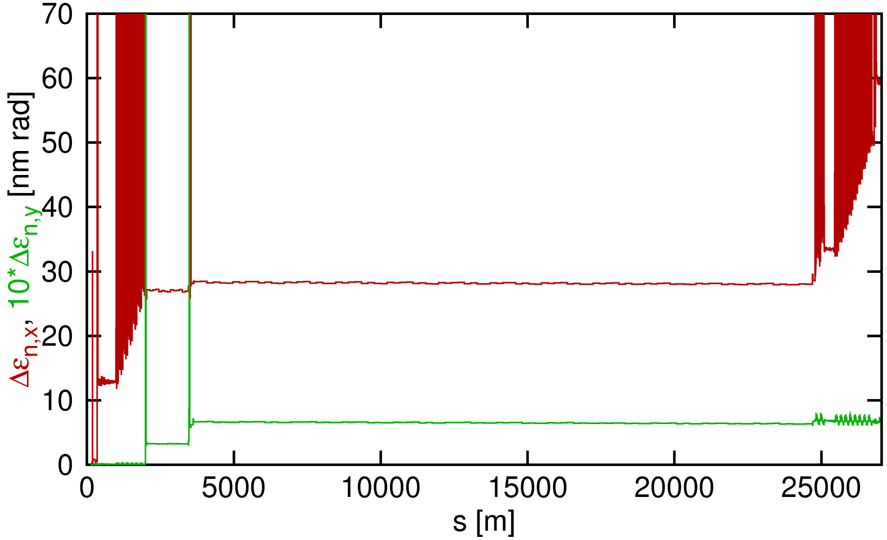
@ entrance of main linac

RTML Status

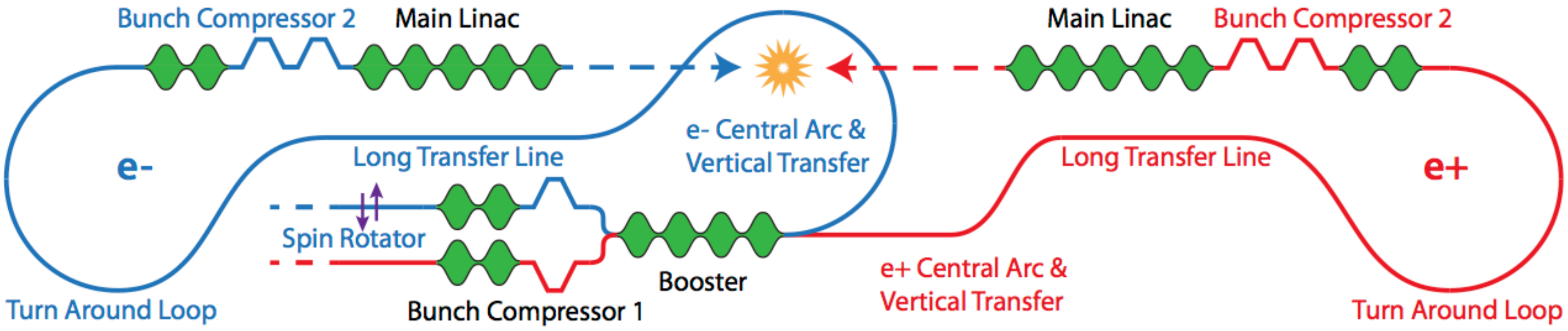
- A complete set of lattices exists
- ISR, CSR and short-range wakefields have been considered at design
- Design shows performance within the specifications
- Evaluations of misalignment tolerances have been performed in the return line and turn around loops:
  - micron range, tightest in turn around loops
  - DFS works for pre-alignment of ~100µm (sextupoles ~50µm)
- Design has been recently updated


Beam profile with ISR and single-bunch wakes

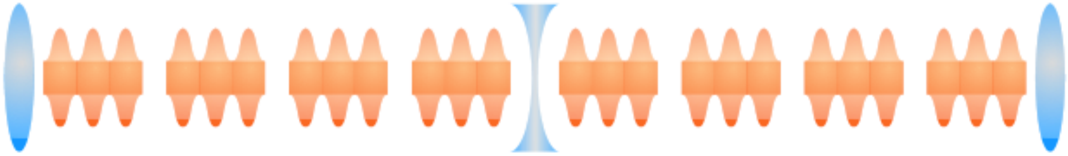




Layout: Booster Linac

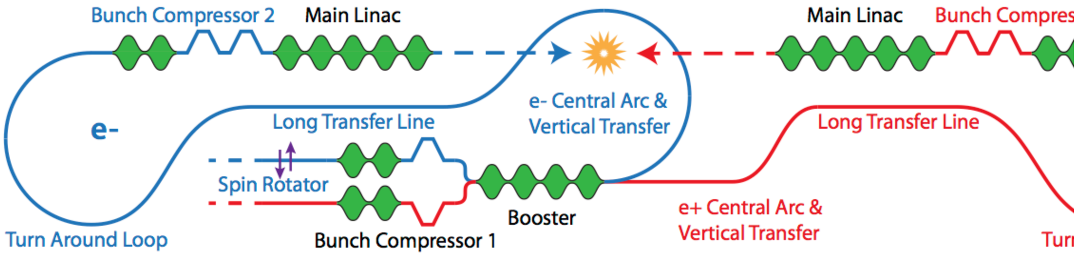


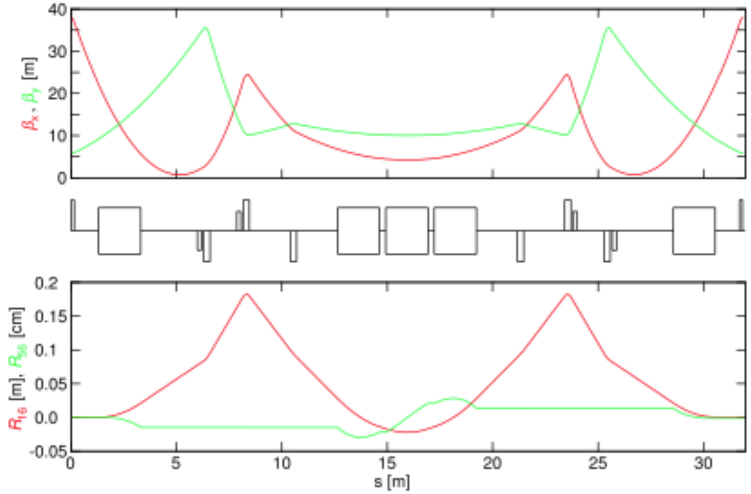
- Electrons and positrons share the same booster linac, from 2.86 to 9 GeV energy



6140 MV integrated voltage, 2 GHz frequency, 15 MV/m gradient, 410 m of cavities, 1.5 m cavity length, 274cavities embedded in a FODO lattice with 8 cavities per cell, total length 472 m.

Layout: Transfer Lines

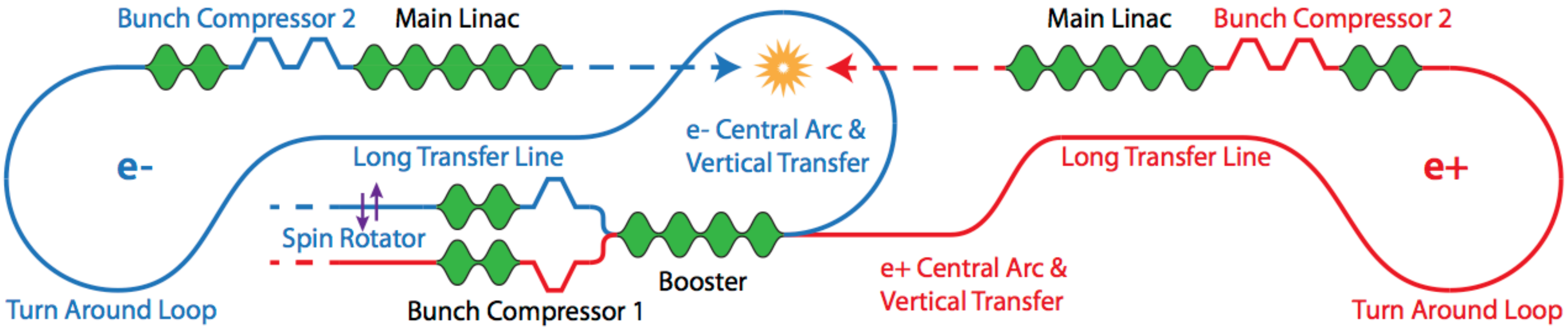




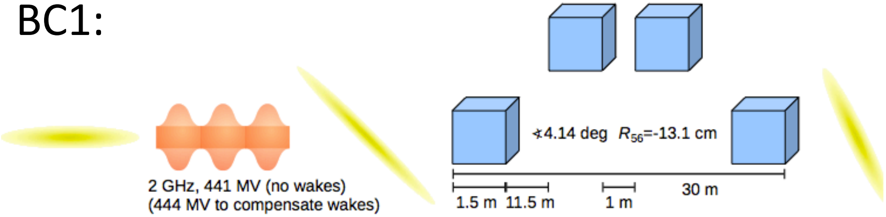
- Each RTML consists of about 26.3 km of beamlines: 21km for each transfer lines; 2km for each turn around loop
- The long transfer lines use a FODO lattice with 438m long cells for 9 GeV beam energy
- Fast ion beam instability, resistive wall wakes, stray fields

- TA uses a complex achromatic and isochronous lattice with strong quadrupoles and sextupoles: 2km long, 822 magnets
- TA is tuned to minimize emittance growth induced by ISR (CSR is sufficiently weak)
- The central electron arc uses the same lattice as the turn around loop. All other arcs are at least similar to the turn around loop.

Layout: Bunch Compressors



BC1:

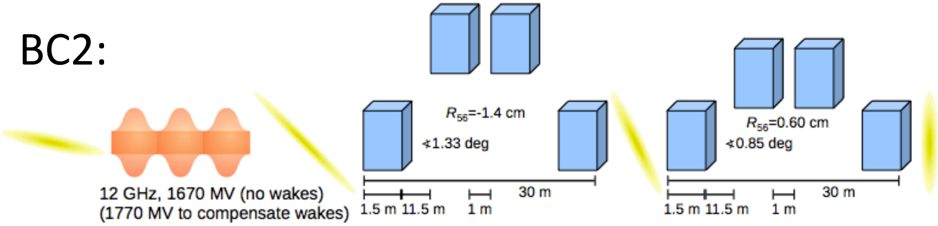


E_0	2.86	GeV
σ_s	1600	μm
$\sigma_{E,unc}/E_0$	0.13	%
$1/E_0\, dE/ds$	0	1/m
$\sigma_{E,tot}/E_0$	0.13	%

E_0	2.86	GeV
σ_s	1600	μm
$\sigma_{E,unc}/E_0$	0.13	%
$1/E_0\, dE/ds$	-6.45	1/m
$\sigma_{E,tot}/E_0$	1.04	%

E_0	2.86	GeV
σ_s	300	μm
$\sigma_{E,unc}/E_0$	0.69	%
$1/E_0\, dE/ds$	-25.8	1/m
$\sigma_{E,tot}/E_0$	1.04	%

BC2:



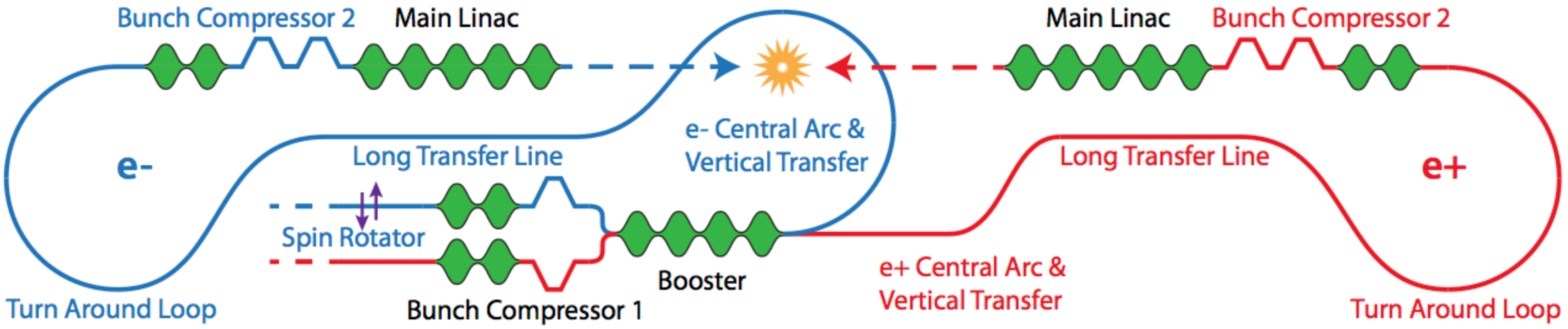
E_0	9	GeV
σ_s	300	μm
$\sigma_{E,unc}/E_0$	0.22	%
$1/E_0\, dE/ds$	-8.21	1/m
$\sigma_{E,tot}/E_0$	0.25	%

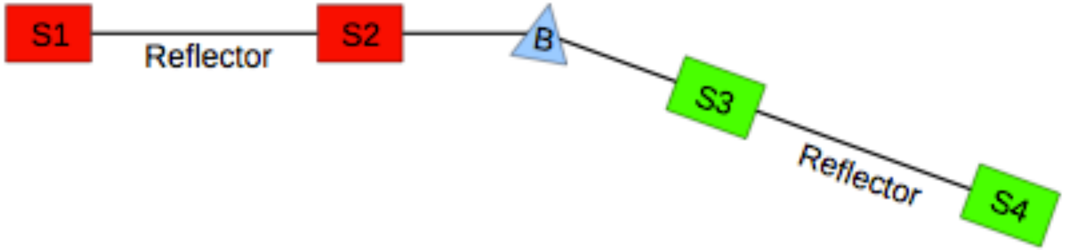
E_0	9	GeV
σ_s	300	μm
$\sigma_{E,unc}/E_0$	0.22	%
$1/E_0\, dE/ds$	-49.5	1/m
$\sigma_{E,tot}/E_0$	1.14	%

E_0	9	GeV
σ_s	100	μm
$\sigma_{E,unc}/E_0$	0.66	%
$1/E_0\, dE/ds$	-135	1/m
$\sigma_{E,tot}/E_0$	1.14	%

E_0	9	GeV
σ_s	44	μm
$\sigma_{E,unc}/E_0$	1.6	%
$1/E_0\, dE/ds$	0	1/m
$\sigma_{E,tot}/E_0$	1.6	%

Layout: Spin Rotator





total length ≈ 135 m

- To avoid spin dilution the spin vector is oriented in vertical direction in the damping rings

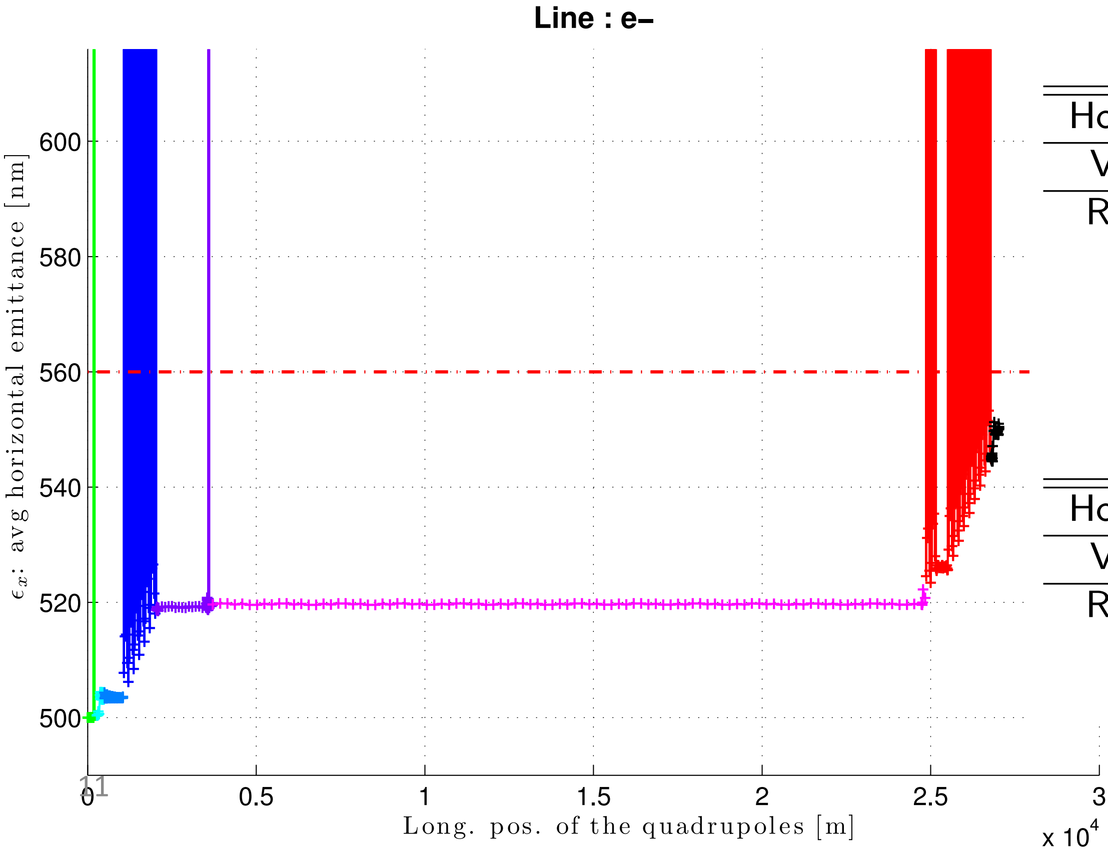
- Any orientation of the SR at IP should be possible

- Since injectors and main tunnel are parallel the electron spin rotator can be located in front of BC1. All bends after rotation are compensated (figure-eight movement) and energy spread will not induce any spin dilution (for the positrons, as the bends are not fully compensated (180 deg total bending), a 2% polarization loss would be induced)

CLIC RTML emittance budgets

	design	static	dynamic
$\Delta\epsilon_x$[nm]	60	20	20
$\Delta\epsilon_y$[nm]	1	2	2

e− line: horizontal emittance



Property	Symbol	Value	Unit
Horizontal emittance	ϵ_x	500	nm
Vertical emittance	ϵ_y	5	nm
RMS bunch length	σ_z	1600	μm

Table: @ exit of damping rings

↓ RTML

Property	Symbol	Value	Unit
Horizontal emittance	ϵ_x	<600	nm
Vertical emittance	ϵ_y	<10	nm
RMS bunch length	σ_z	44	μm

Table: @ entrance of main linac

Static alignment tolerances

- Acceptable static misalignments after beam-based alignment (BBA) to produce 1 nm emittance growth
- 1 um BPM resolution
- In progress work: fine tuning of the parameters will lead to improvement (*)

Subsystem	Tol. after 1:1 - $[\mu m]$	Tol. after DFS - $[\mu m]^\dagger$
BC1	17 (11)	55 (24)
BOO	29 (19)	45 (23)
CA	7 (5)	14 (7)
LTL	153 (88)	280 (150)
TAL	6 (4)	9 (5)
BC2	1.4 (0.8)	3.5 (2)

$\dagger$ *Average tolerance and percentile 90 in brackets.*

- In SR and LTL tols. seem slack $\lesssim 200\mu m$
- In BC1 and Booster, tols. seem moderate $\lesssim 50\mu m$
- In CA (VT), TAL and BC2, tols. seem tight $\lesssim 15\mu m$

(*) with 0.1 um resolution BPMs the tighter tolerances are relaxed by a factor ≈1.3.

RTML Post-CDR

RTML lattices have been updated:

- Pre-linac collimation system (see Rob's talk)
- Diagnostics has been improved: Emittance measurement stations have been added
- Beam-jitter Feed-forward (see Rob's talk)

Besides, a re-baselining process is in progress:

- the RF system seems an obvious candidate for cost-saving optimisations

CLIC Main Linac

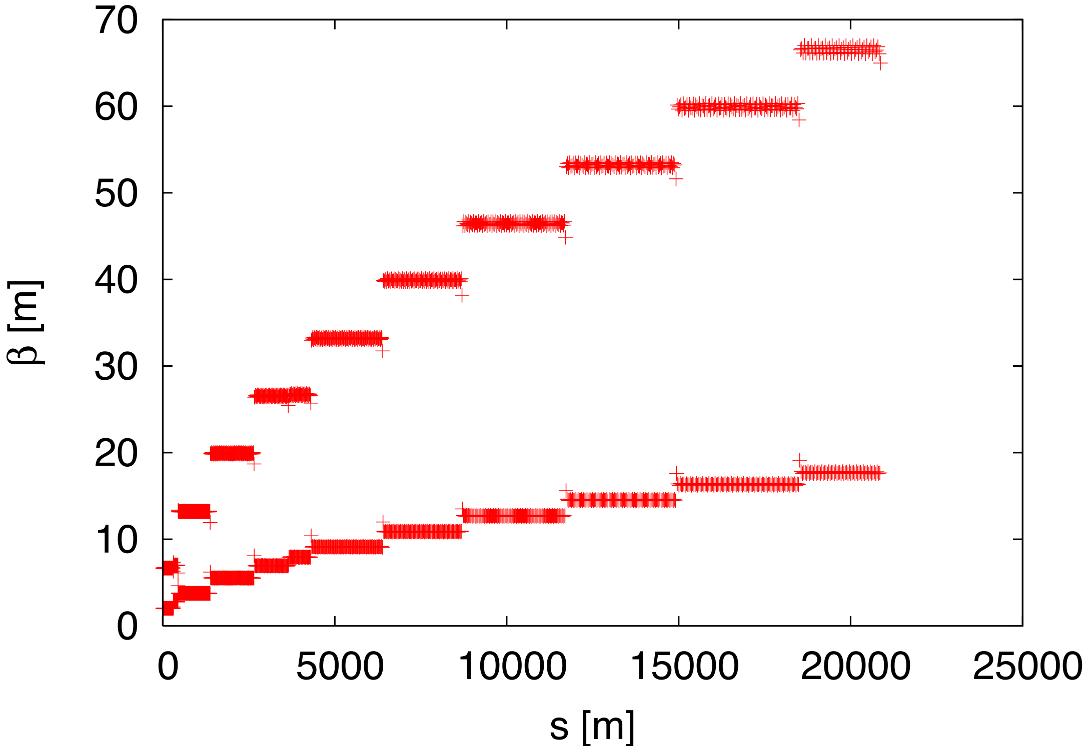
Linac design choices

- Requirements of beam-stability drive the choice of bunch parameters (charge, length, …)
- BNS damping at the beginning of the linac, and strong focusing, are used to compensate the effect of the transverse short-range wakes
- RF-phase offset toward the end of the linac is used for energy spread compensation

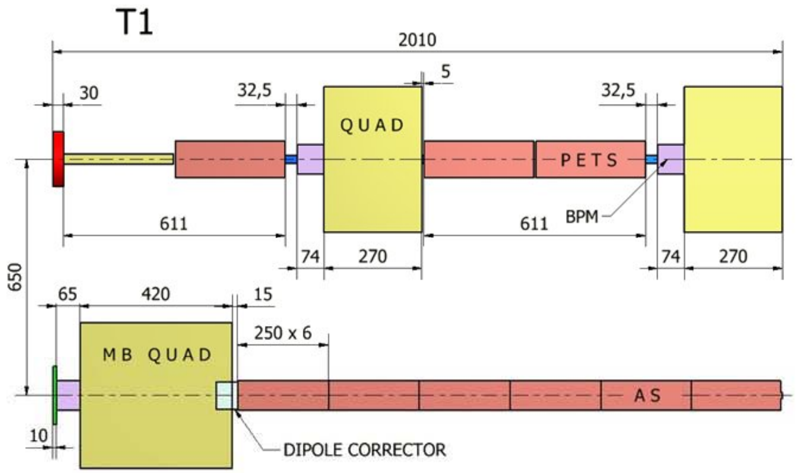
Main Linac Lattice

The RF phase offset chosen is 8◦ at the beginning and 30◦ at the end of the linac.

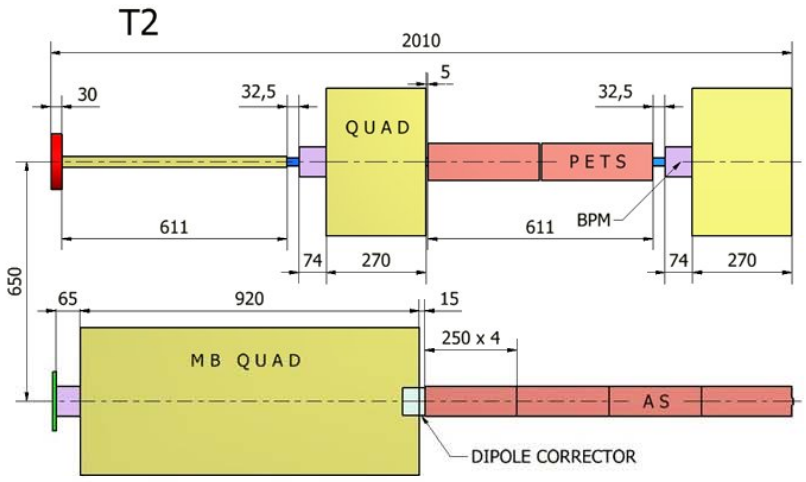
Beta-functions scale with sqrt(E)



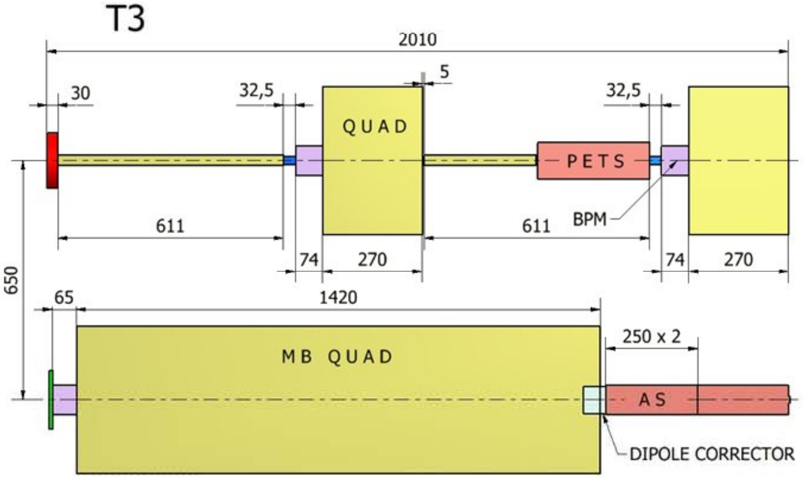
Two-Beam Modules



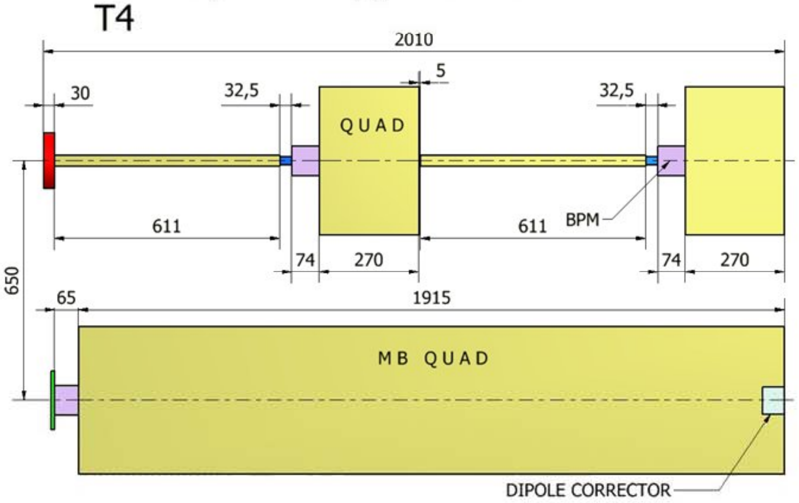
a) Type 1 module



b) Type 2 module

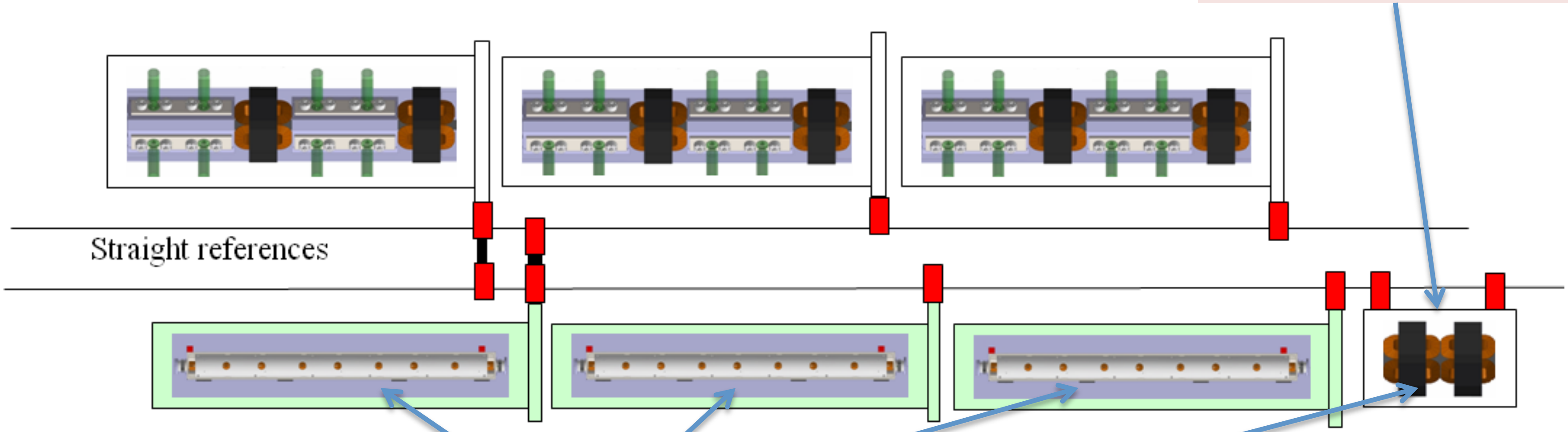


c) Type 3 module



d) Type 4 module

Main Linac Tolerances



Stabilise quadrupole
O(1nm) @ 1Hz

1) Pre-align BPMs+quads accuracy O(10µm)

2) Beam-based alignment

3) Use wakefield monitors accuracy O(3.5µm)

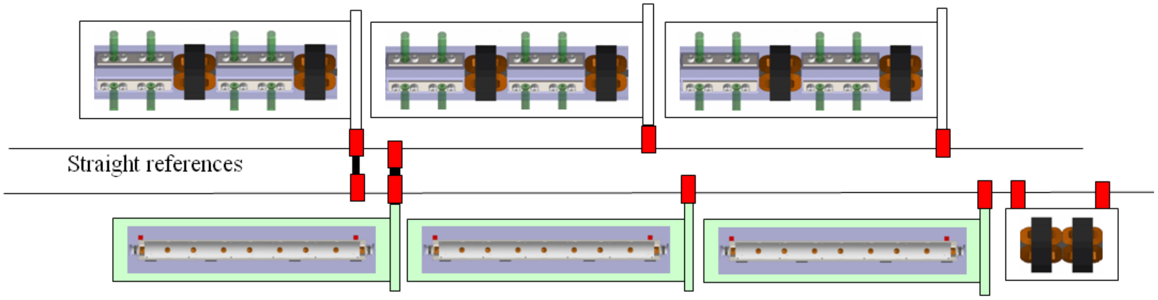
Tolerance for static imperfections in CLIC

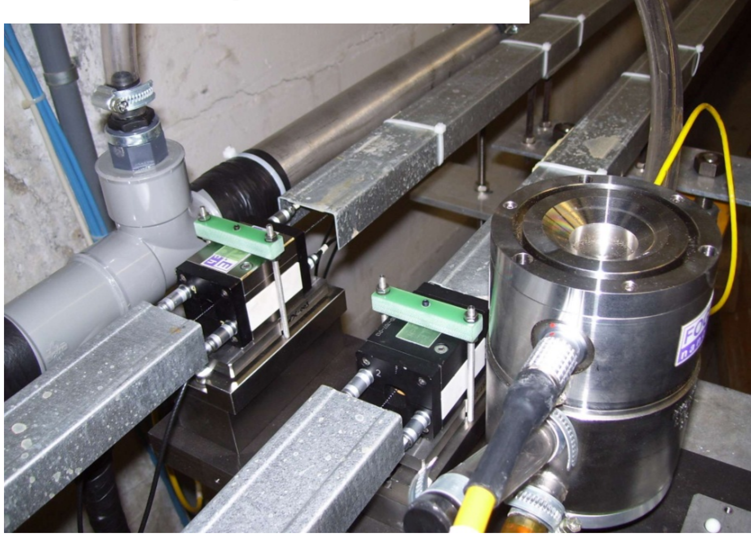
Error	CLIC	with respect to
Quad Offset	17 µm	girder/survey line
Quad roll	≤100 µrad	survey line
Girder Offset	9.4 µm	survey line
Girder tilt	9.4 µrad	survey line
Acc Structures Offset	5 µm	girder
Acc Structures tilt	200 µrad	girder
BPM Offset	14 µm	girder/survey line
BPM resolution	0.1 µm	BPM center
Wakefield monitor	3.5 µm	wake center

- In ILC the specifications have much larger values than in CLIC
  - More difficult alignment in super-conductive environment
  - Dedicated effort for CLIC is needed

- Wakefield monitors are used for BBA

Pre-alignment System

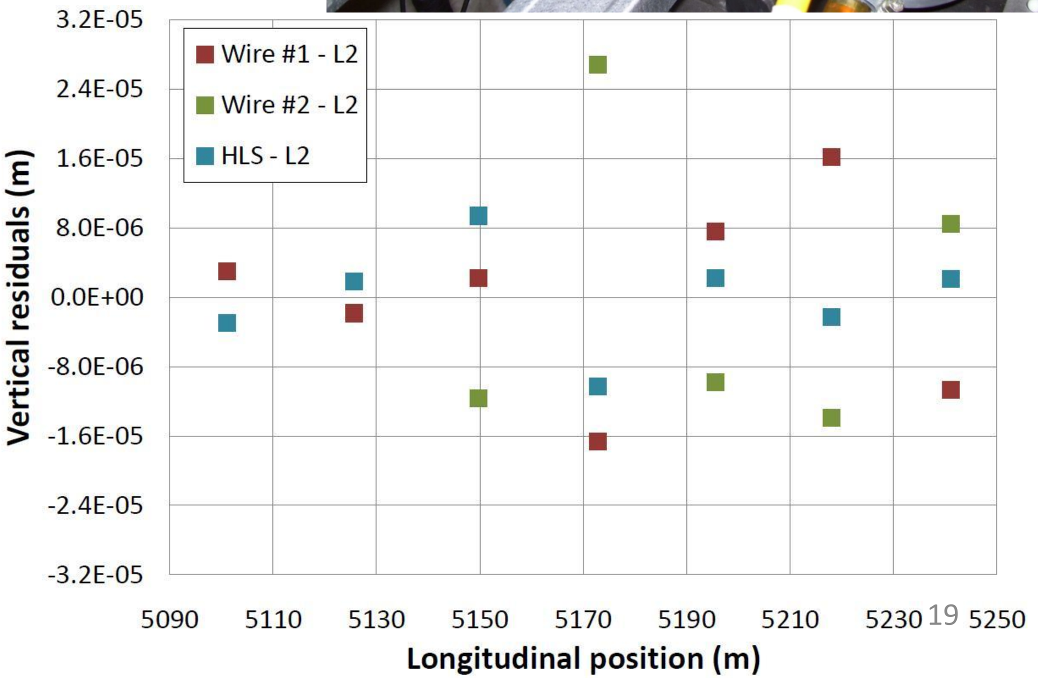




- Required accuracy of reference point is 10µm

- Test of prototype shows
  - vertical RMS error of 11µm
  - i.e. accuracy is approx. 13.5µm

- Improvement path identified



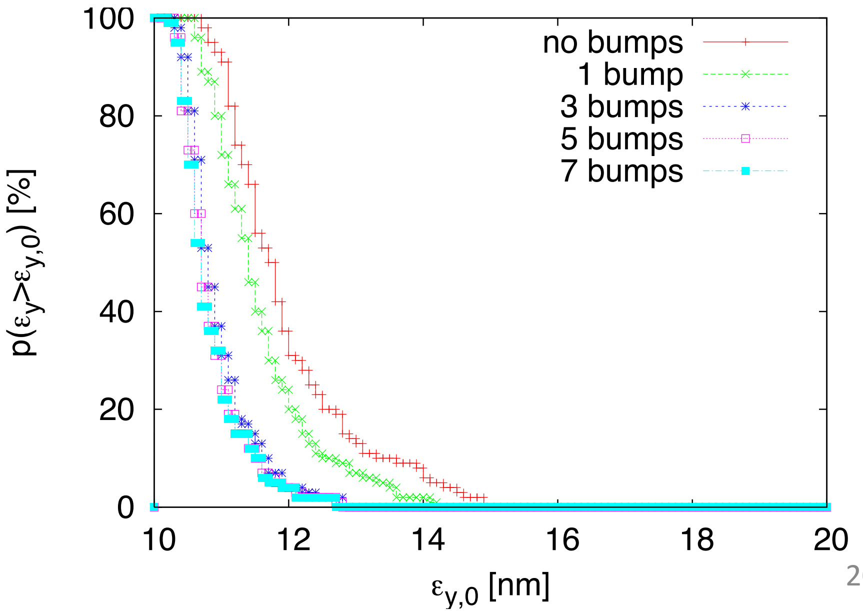
Emittance growth in the CLIC ML

Imperfection	With respect to	Value	Emittance growth
Wakefield monitor	wake center	3.5 µm	0.54 nm
Acc Structures tilt	girder	200 µrad	0.38 nm
BPM Offset	girder/survey line	14 µm	0.37 nm
Quad roll	longitudinal axis	100 µrad	0.12 nm
Articulation point offset	wire reference	12 µm	0.10 nm
BPM resolution	BPM center	0.1 µm	0.04 nm
Acc Structures Offset	girder	10 µm	0.03 nm
Girder end point	articulation point	5 µm	0.02 nm
		TOTAL	1.60 nm

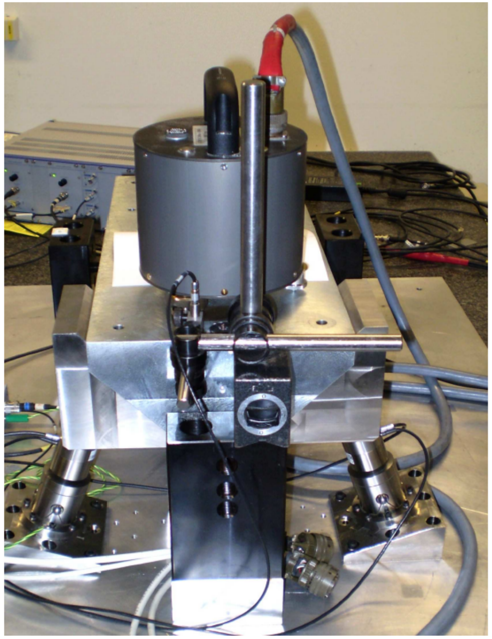
- We rely on Beam-Based Alignment
    - 1:1 ; DFS ; RF-Alignment ; (Bumps)

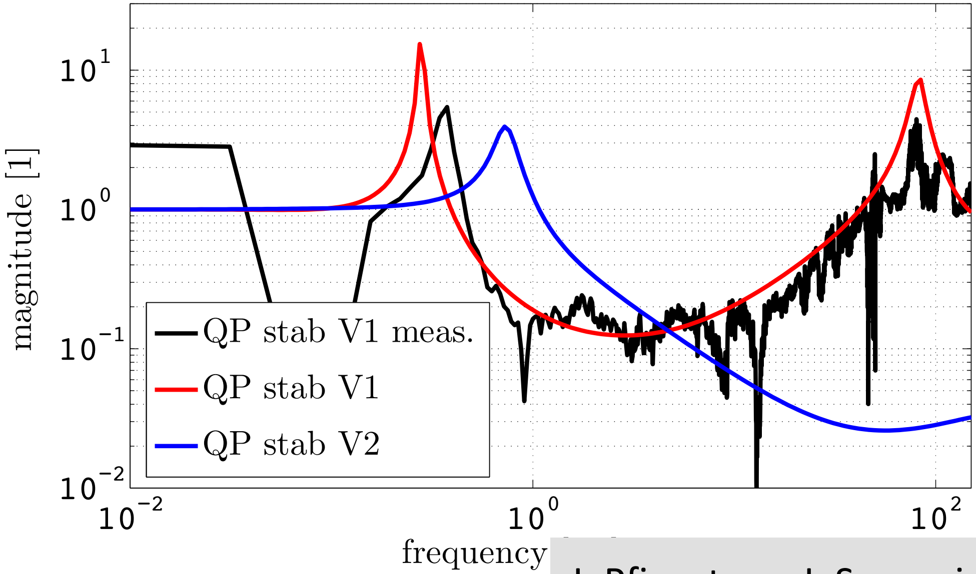
- Multi-bunch wakefield misalignments of 10 µm lead to 0.13 nm emittance growth

- Performance of local pre-alignment is acceptable

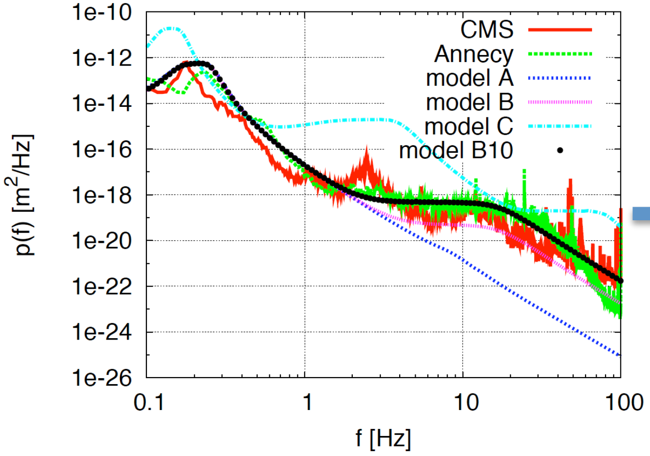


Active Stabilisation Results





J. Pfingstner, J. Snuverink et al.



Code

Machine model
Beam-based feedback

Luminosity achieved/lost

	B10
No stab.	53%/68%
Current stab.	~~108%/13%~~ 114%/7%
Future stab.	118%/3%

Close to/better than target

On-going studies

- Rebaselining for cost-savings
  - Developing a tool that allows to estimate the cost, based on lattice design performance / RF power considerations
- Advanced Feedback-loops with on-line DFS are being developed (see Juergen's talk)
- Experimental Tests of stabilisation
  - Synergy between beam-dynamics and alignment engineers
  - Stabilisation experiments at ATF2 (see ATF2 day tomorrow)
- Experimental Tests of Beam-Based Alignment
  - (see my talk on BBA @ FACET)

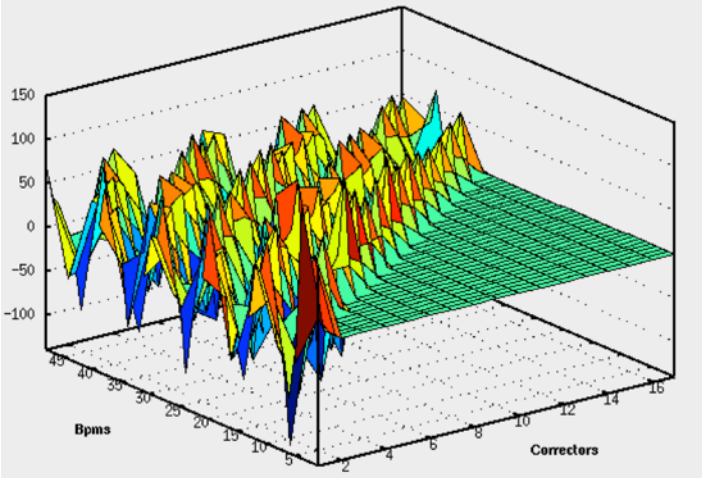
CERN BBA at SLAC

FACET test-beam proposal to study advanced global correction schemes for future linear colliders.

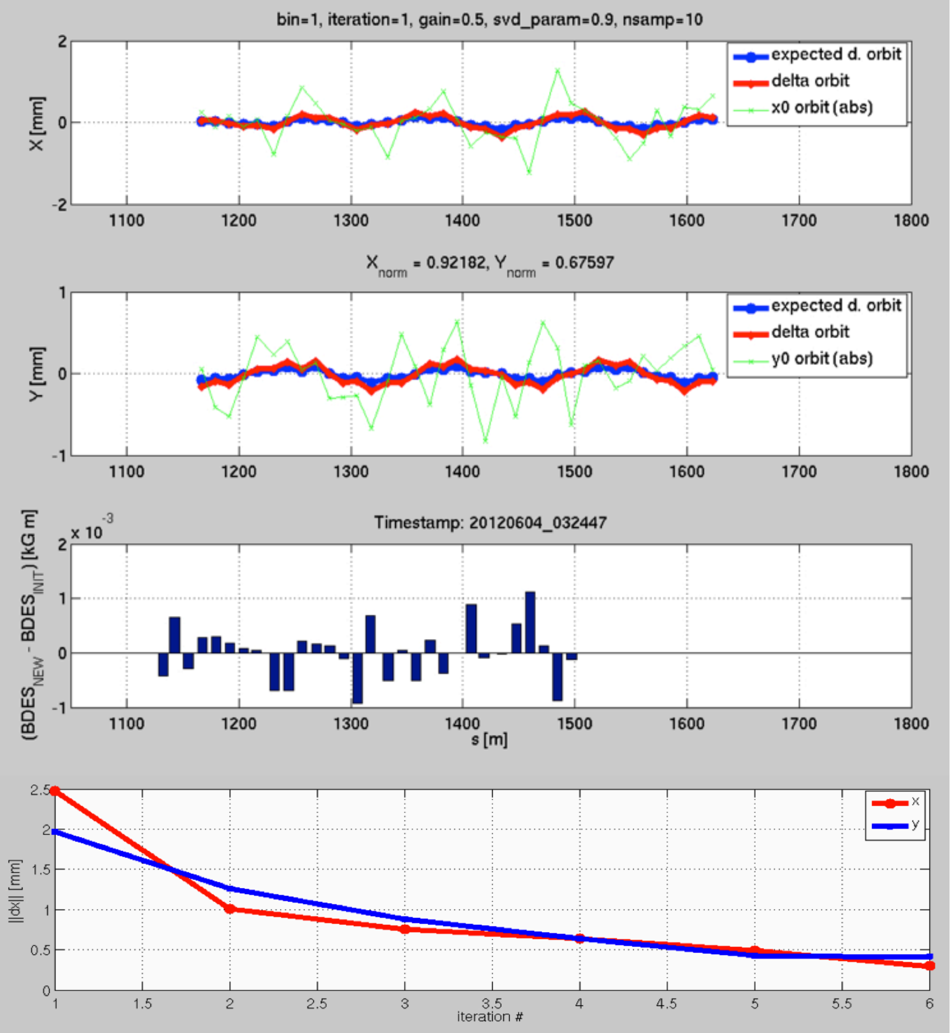
CERN-SLAC collaboration where algorithms developed at CERN are tested on the SLAC linac.

The study includes linac system identification, global orbit correction and global dispersion correction.

Successful system identification and global orbit correction has been demonstrated on a test-section of 500 m of the linac.



(Above) Identified Rx response matrix for the test-section of the linac (17 correctors, 48 BPMs)



Horizontal and Vertical Obrits

Convegence

(Above) Global orbit correction of test-section, with feed-forward to prevent the correction to affect FACET S20 experimental area.

A. Latina, J.Pfingstner, D. Schulte (CERN), E. Adli (SLAC)

Conclusions

CDR documents the baseline design, many studies have been carried out since then

In the RTML:
- The design has been completed with diagnostics, feed-forward loops to stabilise the beam, pre-linac collimation
- Optimisation of costs and performance for rebaselining is in progress

In the ML:
- Pre-Alignment and Stabilisation studies are progressing
- Experimental activities are ongoing (stabilisation at ATF2, BBA at FACET)

See Daniel’s talk for a comprehensive overview of all activities. See next talks for details on the mentioned studies.

Acknowledgements

These results have been obtained by the efforts of many people

Alignment and stabilization team:

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ILC International Collaborators:

- N. Solyak, K. Ranjan, K. Kubo, J. Smith, P. Tenenbaum, N. Walker, F. Poirier et al.