Overview of CLIC system tests

R. Corsini for CLIC Collaboration

OUTLINE:

- Why & how do we need system tests?
- CLIC peculiarities - CTF3 as a system test
- Other ongoing system tests
- Future plans/needs

Why do we need system tests?

Linear colliders rely on complex technical systems, composed of many individual components.

Often, only an integrated test is able to assess the soundness of a system as a whole. The need for (and the goals of) system tests naturally evolve during the evolution of the study:

- Ensure feasibility, initial risk reduction
- Quantify and/or predict performance
- Assess cost
- Re-optimize design for cost, performance and risk. Converge on technical design.
- Prepare industrialization

System tests issues

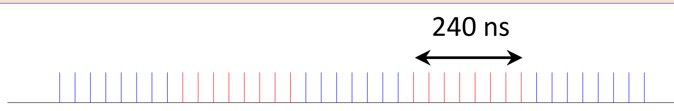
Definition & scope: it's not always clear what a "system" is. The linear collider may indeed be thought as a huge, single system – where to stop?
What is a meaningful sub-system to be tested? How to define boundaries? What about cross-talk between systems?

Problem of scale/completeness: a system test is most of the time a scaled/simplified version of the final system. What is a reasonable scaling down? Should all details be included? How to define goals? How to scale up the experimental results?

Other issues: What to measure? Beam tests are always needed? How representative a "probe beam" should be? …

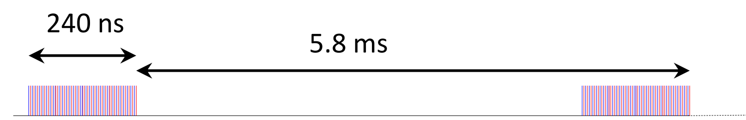
The ultimate CLIC system test

Drive beam time structure - initial

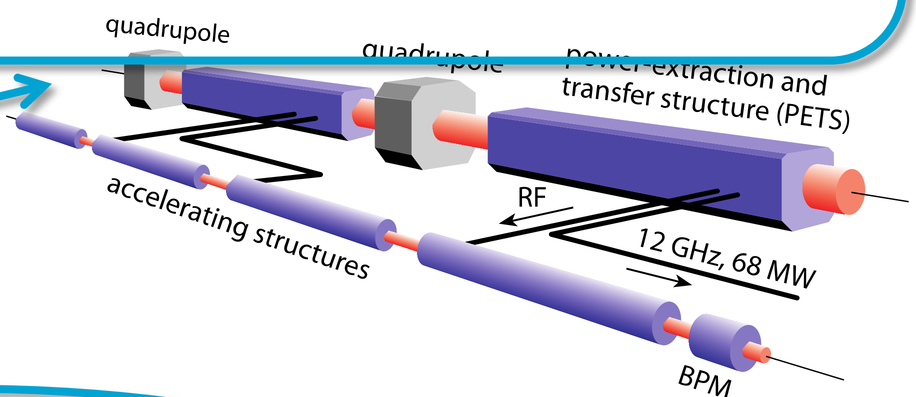


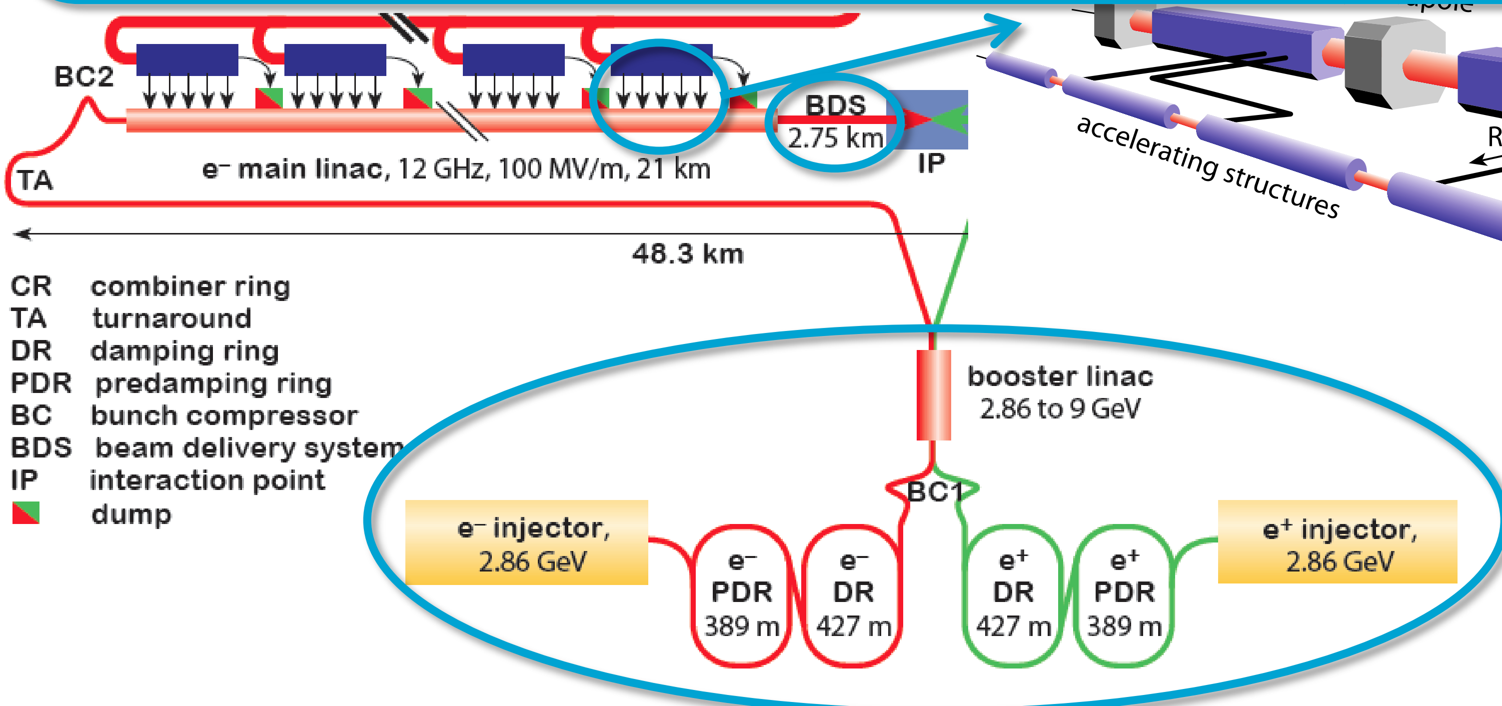
140 ms train length - 24 × 24 sub-pulses
4.2 A - 2.4 GeV – 60 cm between bunches

Drive beam time structure - final



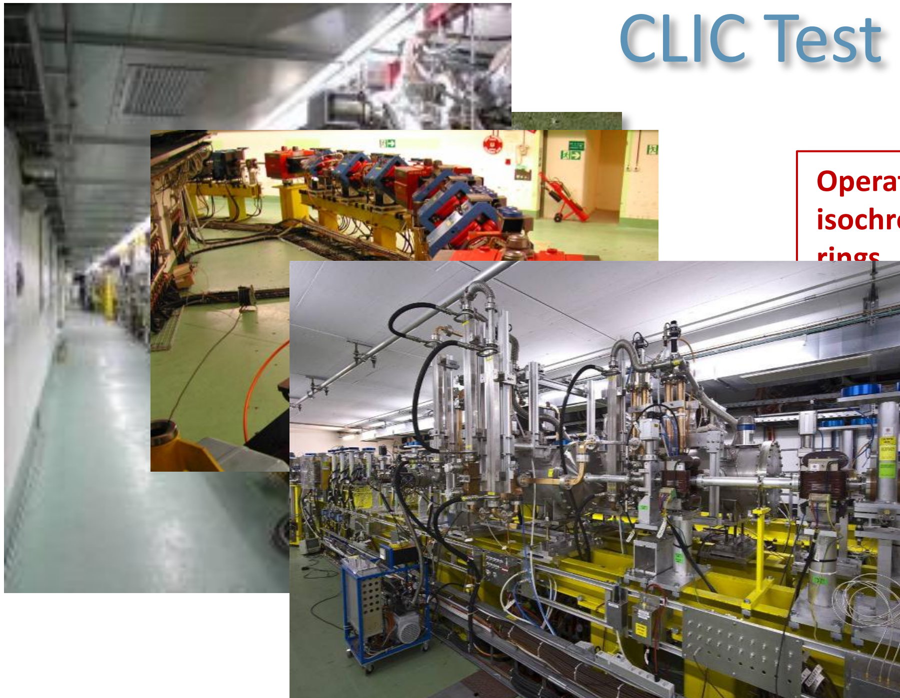
24 pulses – **101 A** – 2.5 cm between bunches



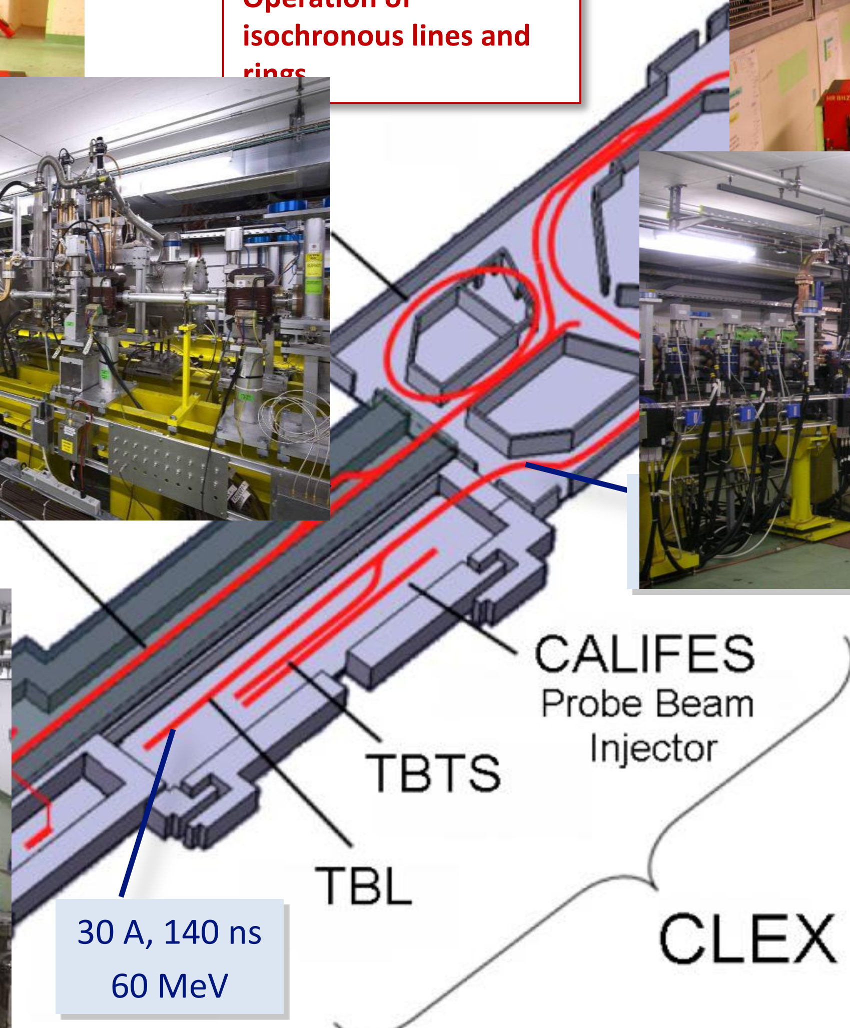


Main Beam Generation Complex

CLIC Test Facility (CTF3)



Operation of isochronous lines and rings



and current multiplication by RF deflectors

High current, full

30 A, 140 ns
60 MeV

12 GHz power generation by drive beam deceleration

High-gradient two-beam acceleration

What do we learn in CTF3, relevant for the CLIC RF power source ?

A non-exhaustive list ☺ easier ☹ more difficult

System	quantity/issue	CTF3	CLIC
Injector/linac	bunch charge	2-3 nC	6.7 nC
	current	3.5 - 4.5 A	4.2 A
	pulse length	1.4 μs	140 μs
	phase coding	same	
	frequency	3 GHz	1 GHz
	transverse stability	about the same - CTF3 ``too stable´´	
Delay loop/ring	final current	28 A	100 A
	beam energy	125 MeV	2.4 GeV
	combination	2 - 4	2 - 3, 4
	CSR, wakes	worse in CTF3 (lower energy)	
	Deflector instability	about the same	
Power production (PETS)	Aperture	23 mm	23 mm
	Length	≈ 1 m	23 cm
	Power	> 135 MW	135 MW
	Pulse length	140 ns (260 ns with recirculation)	240 ns
Decelerator	Fractional loss	50 %	90%
	Final energy	60 MeV	240 MeV
	wakes, stability	somehow ``masked´´ in CTF3	
	beam envelope	much larger in CTF3	

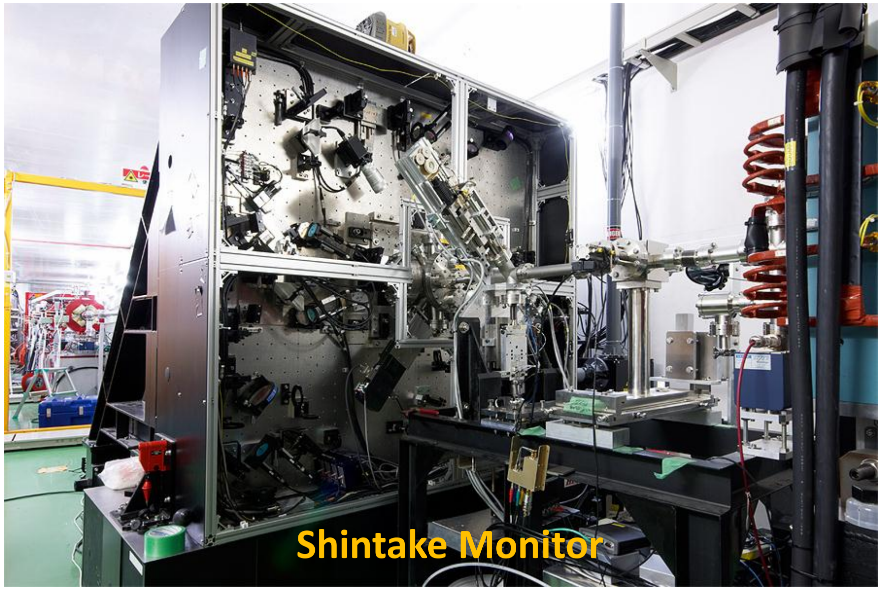
In general, most of detrimental effects **are equivalent or worse in CTF3** because of the low energy, however in CLIC the beam power is much larger (heating, activation, machine protection)

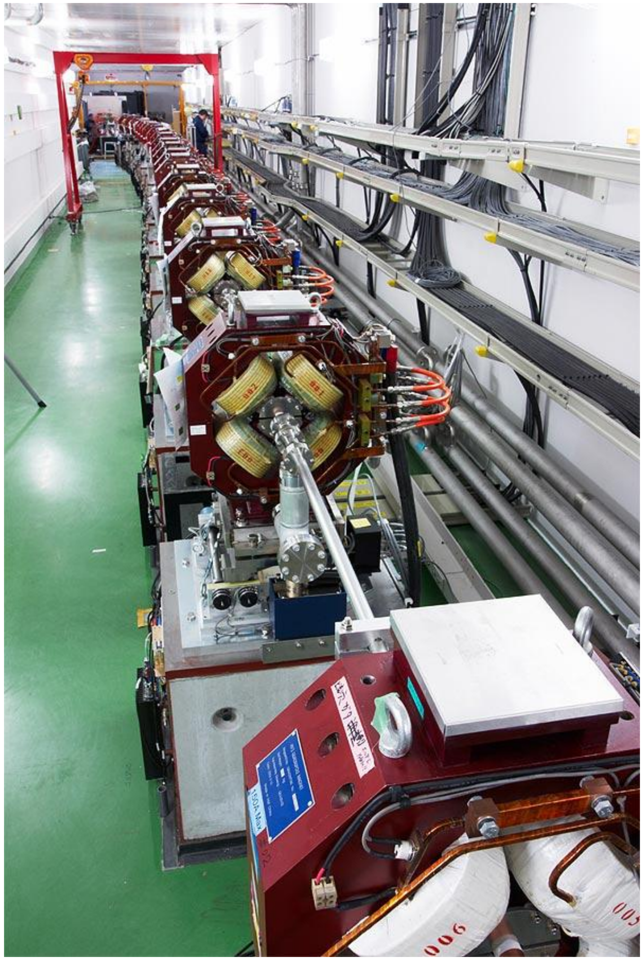
Needed tolerances on the final drive beam parameters (phase, current, energy stability...) are more stringent in CLIC – some ~~could be~~ **are being demonstrated** in CTF3 as well

Beam Delivery System (ATF 2)

Parameters	ATF2	ILC	CLIC
Beam Energy [GeV]	1.3	250	1500
L* [m]	1	3.5 - 4.5	3.5
$\gamma\varepsilon_{x/y}$ [m.rad]	5E-6 / 3E-8	1E-5 / 4E-8	6.6E-7 / 2E-8
IP $\beta_{x/y}$ [mm]	4 / 0.1	21 / 0.4	6.9 / 0.07
IP η' [rad]	0.14	0.0094	0.00144
δ_E [%]	~ 0.1	~ 0.1	~ 0.3
Chromaticity ~ β / L*	~ 1E4	~ 1E4	~ 5E4
Number of bunches	1-3 (goal 1)	~ 3000	312
Number of bunches	3-30 (goal 2)	~ 3000	312
Bunch population	1-2E10	2E10	3.7E9
IP σ_y [nm]	37	5.7	0.7

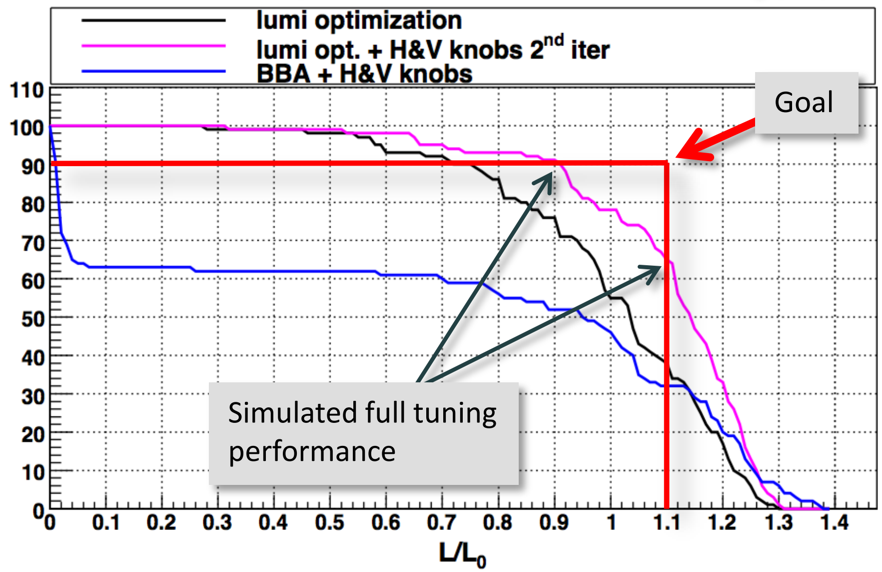
Philippe Bambade, CLIC Collaboration Workshop, May 2012

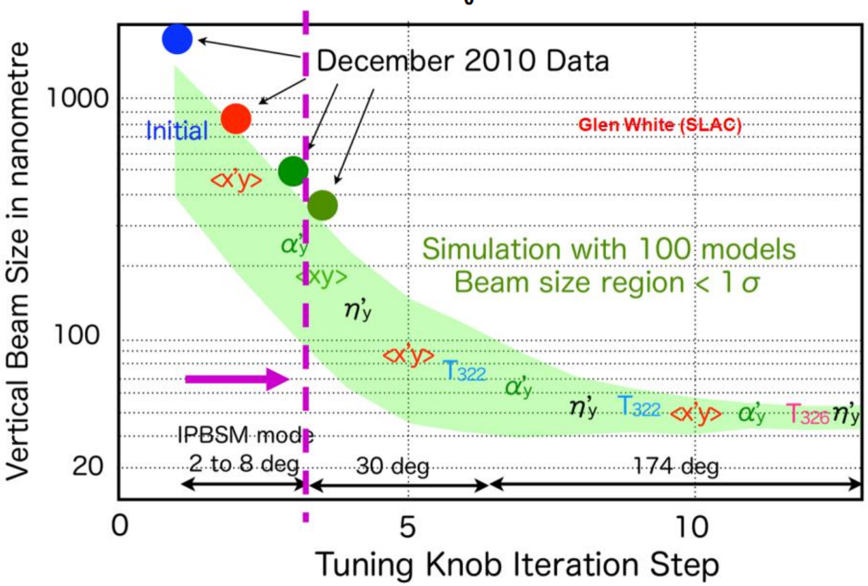


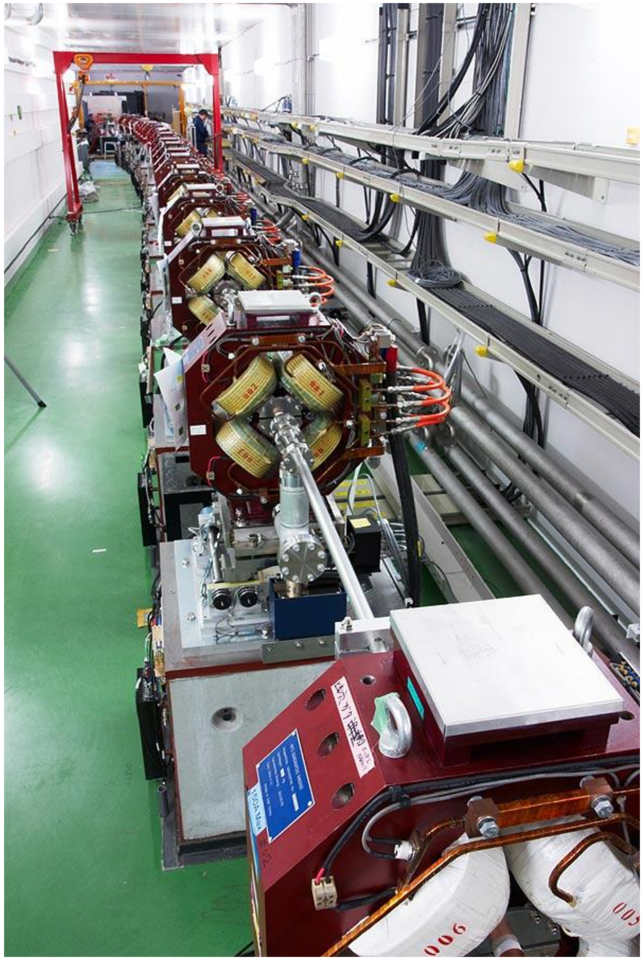


Beam Delivery System (ATF 2)

Probability to achieve more than L/L_0 [%]





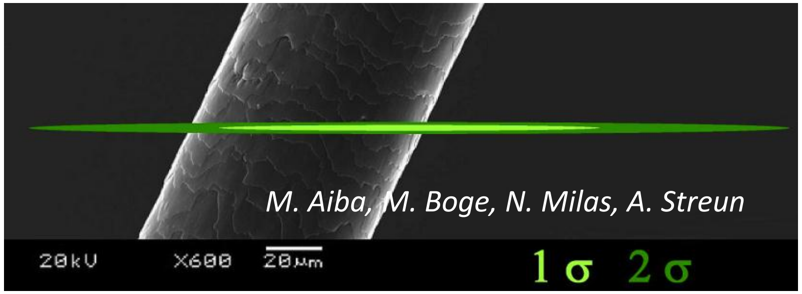


Damping Ring

Yannis Papaphilippou, CLIC Collaboration Workshop, May 2012

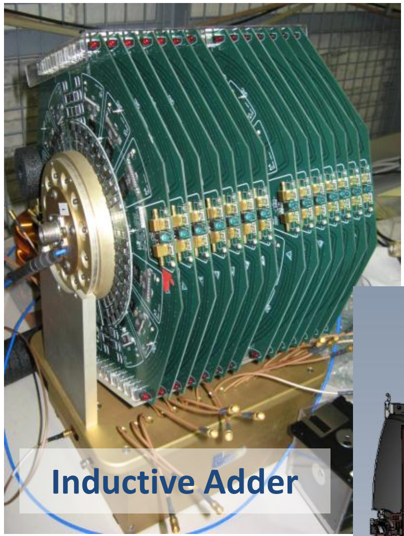
DR beam dynamics studies

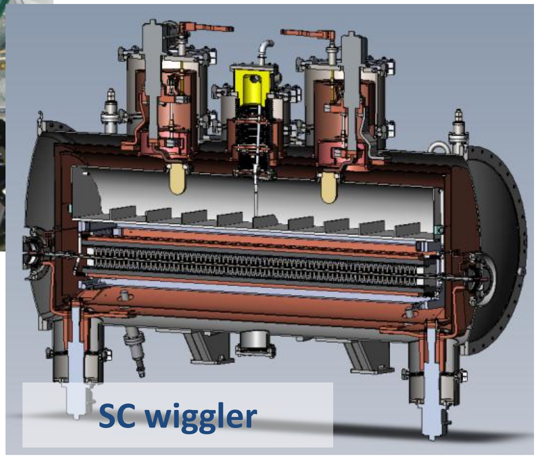
- Low Emittance Tuning (SLS, Australian Synchrotron)
- IBS (CESRTA, SLS)
- E-cloud (CESRTA)
- CSR (ANKA, ATF)
- Optics, non-linear correction (DIAMOND, SOLEIL)
- Fast Ion Instability (SOLEIL)
- Instabilities (SLS)



DR technical systems R&D

- Super-conducting wigglers (BINP, tested in ANKA)
- High frequency RF system (ALBA and SLAC)
- Coatings, chamber design and ultra-low vacuum (SPS, ESRF, CERTA, MAXlab)
- Kicker technology (Spanish industry, ALBA, SLAC, test in ATF)
- Diagnostics for low emittance (V-UV Profile Monitor - TIARA)





Damping Ring

Area	Scope	Institutes	Period	Contract
Optics and non-linear dynamics	Methods and diagnostics for linear and non-linear correction	JAI	2011-2013	MOU
Vertical emittance minimization	Beam dynamics and technology (alignment, instrumentation) for reaching sub-pm vertical emittance	SLS, MAXlab, INFN/LNF	2011-2013	EU/TIARA
		ACAS	2010-2012	MOU
		JAI	2011-2013	MOU
Intrabeam Scattering	Experiments for theory/code benchmarking	CESR/TA, SLS	2010-…	ILC/CLIC collaboration, LER network
E-cloud	Experiments for instability and mitigation			
Fast Ion Instability	Experiments for theory/code benchmarking, feedback tests	SOLEIL, ATF	2011-…	LER network
Super-conducting Wiggler	Prototype development and beam tests	KIT, BINP	2011-2013	MOU, K-contract
Fast kicker development	Conceptual design, prototyping and beam measurements (double kicker)	IFIC Valencia, ALBA, ATF	2011-2013	Spanish industry program
RF design	RF prototype and beam tests (including LLRF)	ALBA, SLAC	2011-…	LER network
Vacuum technology	Desorption tests of coated chambers in a beam line	ESRF, MAXIV	2011-…	

Yannis Papaphilippou, CLIC Collaboration Workshop, May 2012

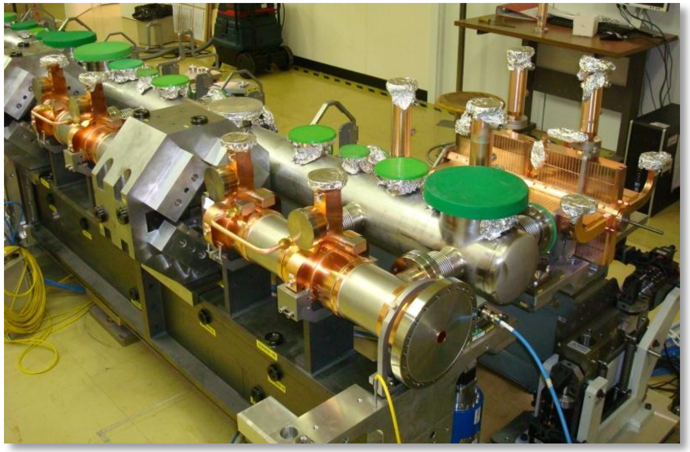
Two-Beam Modules

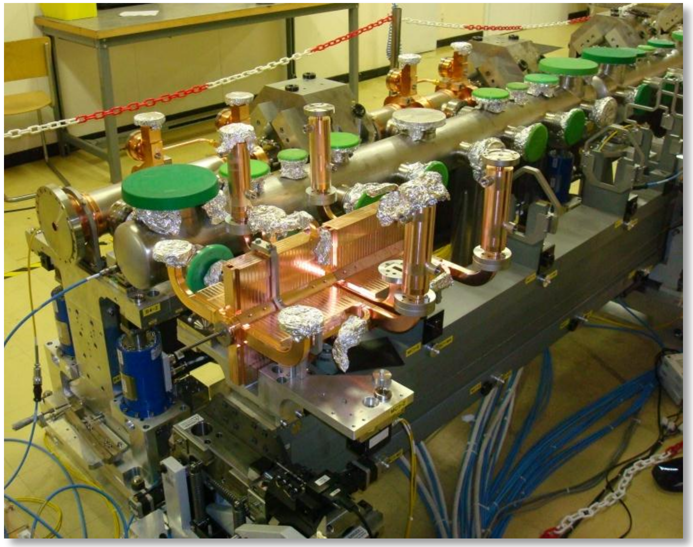
Ongoing: Fabrication of 4 modules to be mechanically tested in laboratory

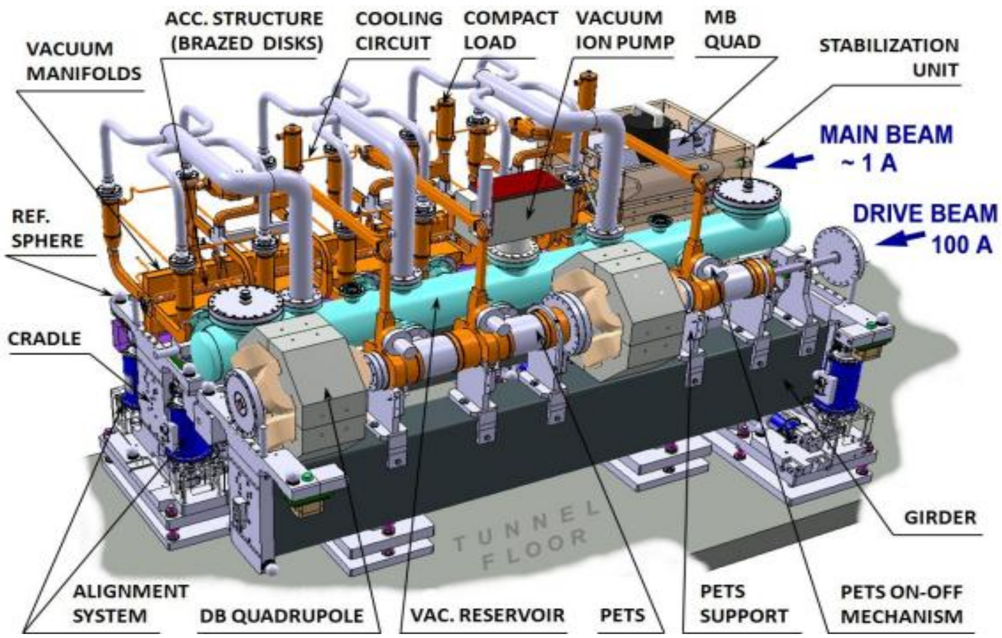
Next Step: Installation and test of full-fledged Two-Beam Modules in CLEX

First module in development, installation end 2013

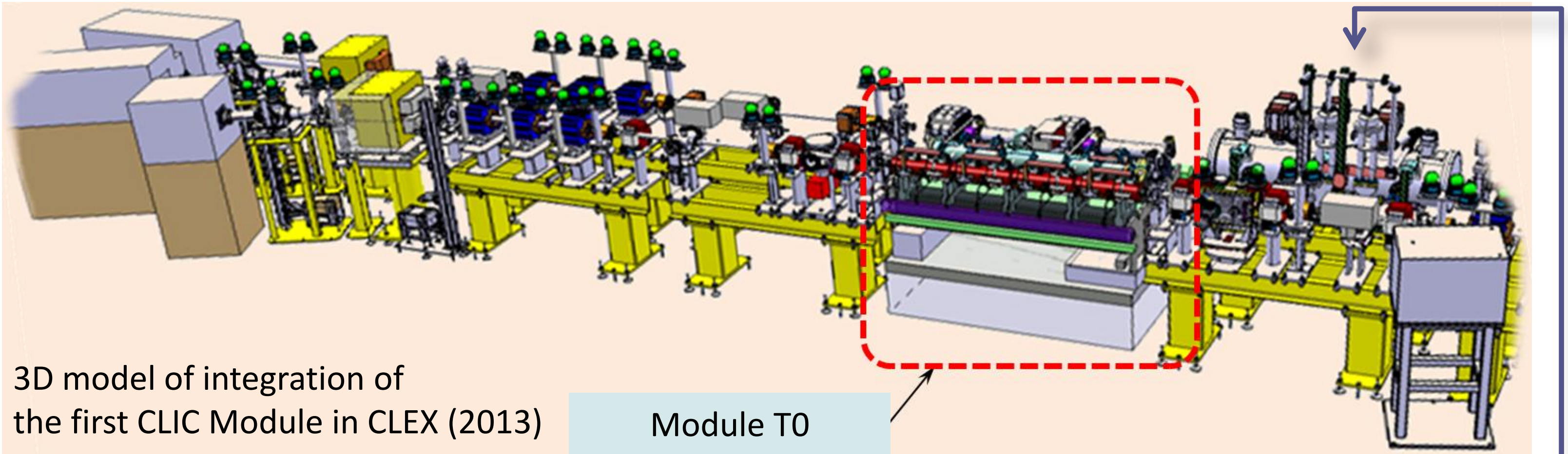
Three modules in 2014-2016







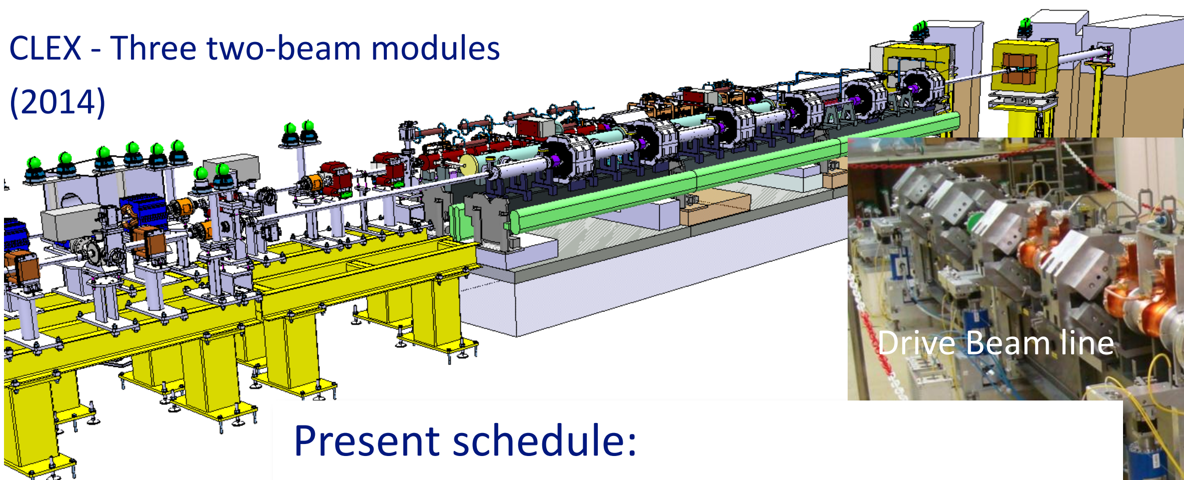
Two-Beam Modules

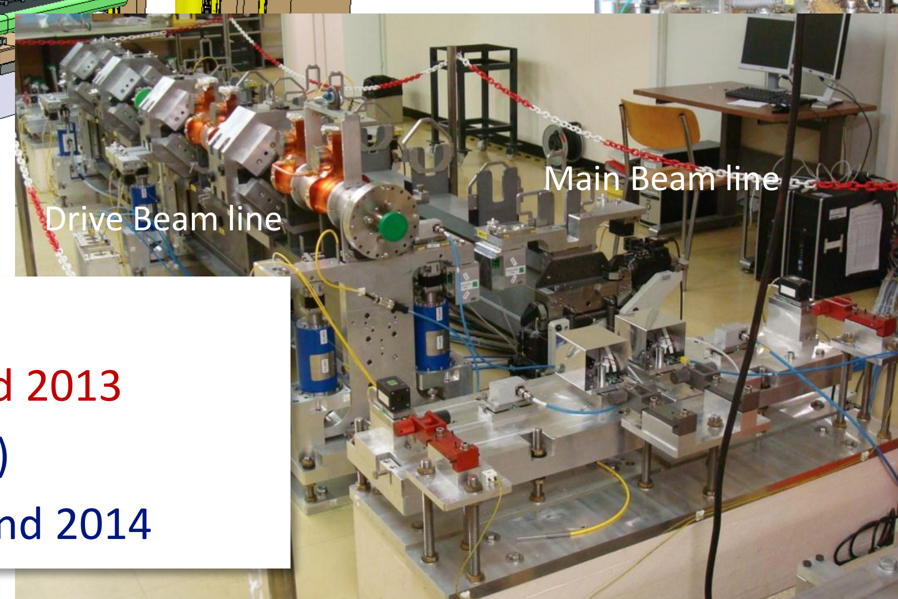


3D model of integration of
the first CLIC Module in CLEX (2013)

TBTS PETS tank

CLEX - Three two-beam modules
(2014)





Present schedule:

First module installation end 2013

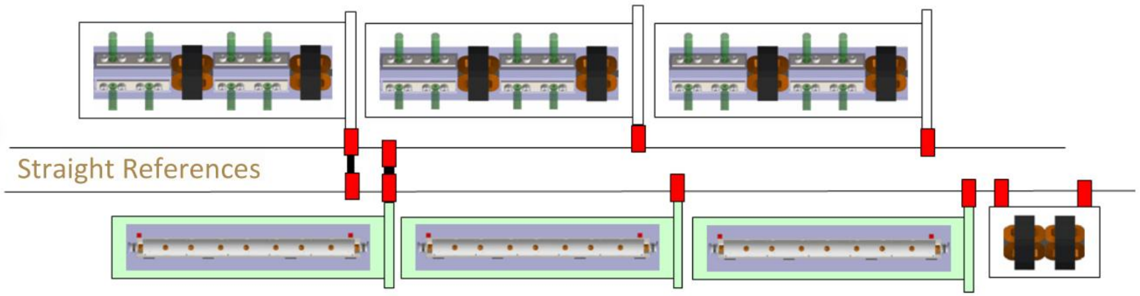
(At least one year of testing)

Module string installation end 2014

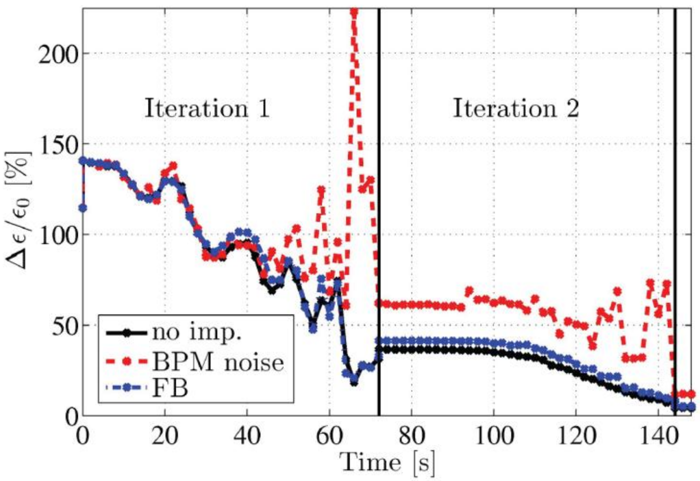
Emittance Preservation – Main linac Beam-Based Alignment

Andrea Latina, CLIC Collaboration Workshop, May 2012

- Pre-alignment O(10um)
- with wire system
- detailed model in simulations



- 1:1 correction
  - Makes beam pass the main linac
- Dispersion free steering
  - Removes dispersion, align BPMs and quadrupoles
  - Will use the the BC and reduced gradient in the linac to create the energy difference
- RF-Alignment
  - Removes residual wakefield and dispersive effects
  - Relies on wake field monitors in the accelerating structures and girder movers



Emittance Preservation – Main linac Beam-Based Alignment

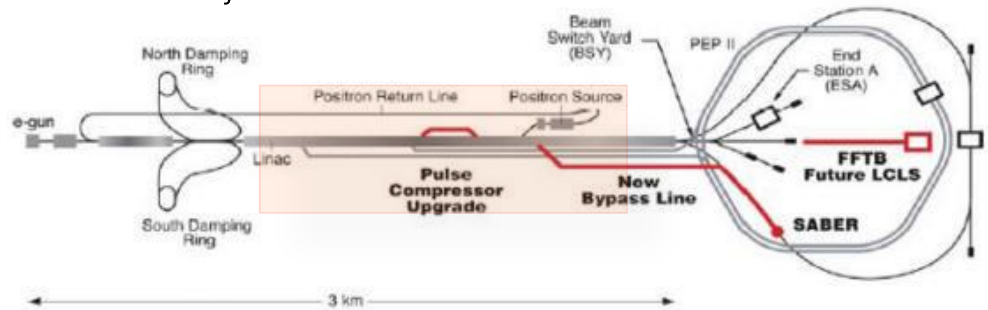
T501: FACET test-beam proposal to study advanced global correction schemes for future linear colliders.

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

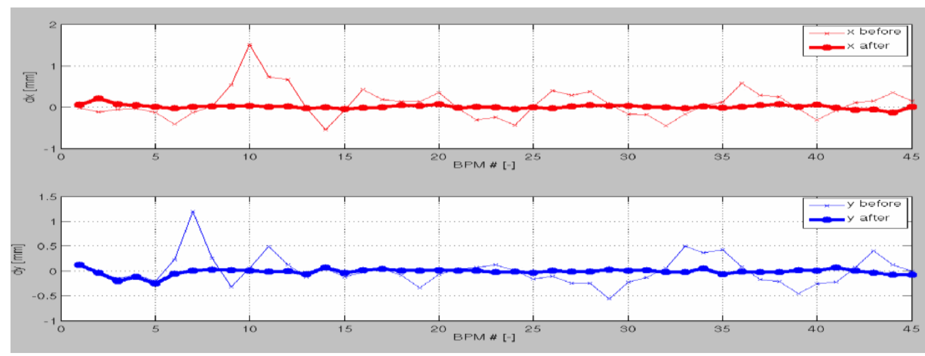
The study includes linac system identification, global orbit correction and global dispersion correction.

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

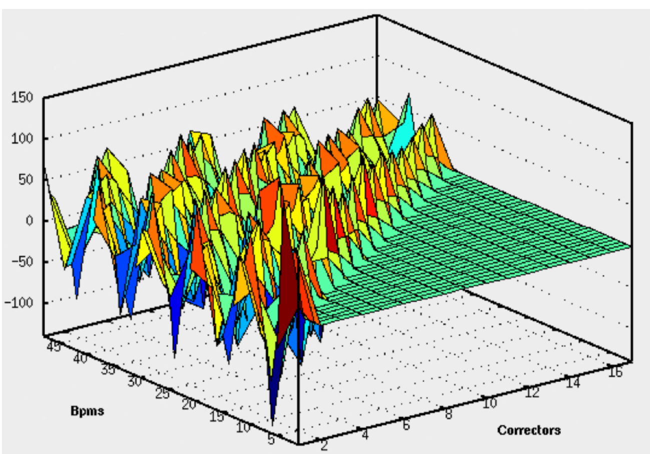
The section of the SLAC beamlines we work on



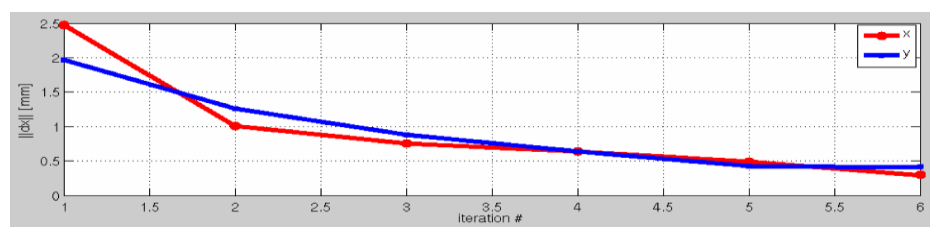
RESULT: Example of global orbit correction of a test-section of the SLC linac:



(above) Horizontal and Vertical trajectories before and after orbit correction



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



(above) Iterations of orbit correction: convergence of the algorithm

Some CLIC Drive Beam requirements

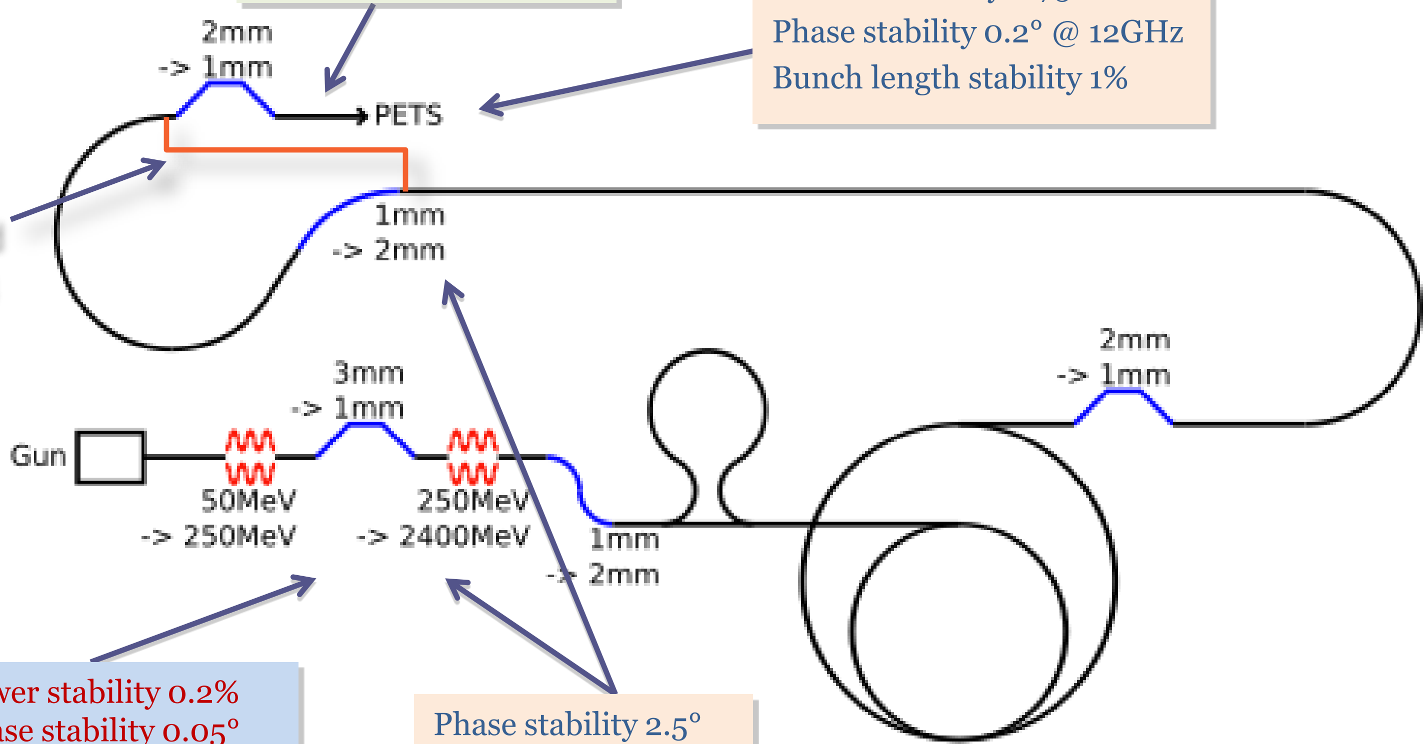
Tests in CTF3

Emittance $\varepsilon_{x,y} \leq 150\mu m$
Transverse jitter $\leq 0.3\sigma$

Tests in CTF3

Current stability $0.75 \cdot 10^{-3}$
Phase stability 0.2° @ 12GHz
Bunch length stability 1%

Feed-forward tests in CTF3



RF power stability 0.2%
RF phase stability 0.05°
Current stability 0.1%

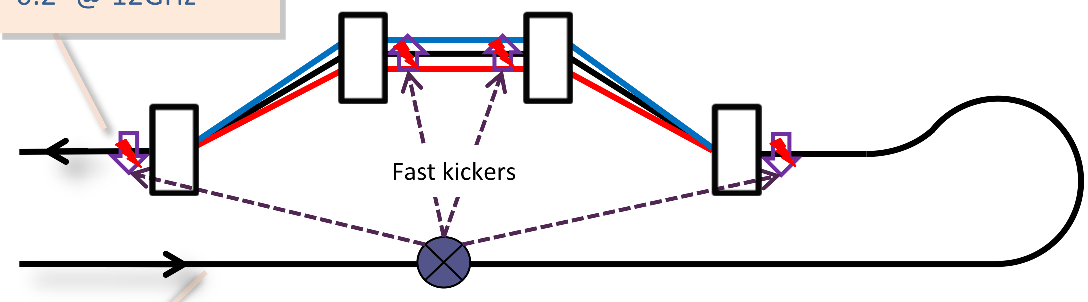
Phase stability 2.5°
@ 12GHz
0.2° @ 1GHz

Verified in CTF3

Tests in CTF3

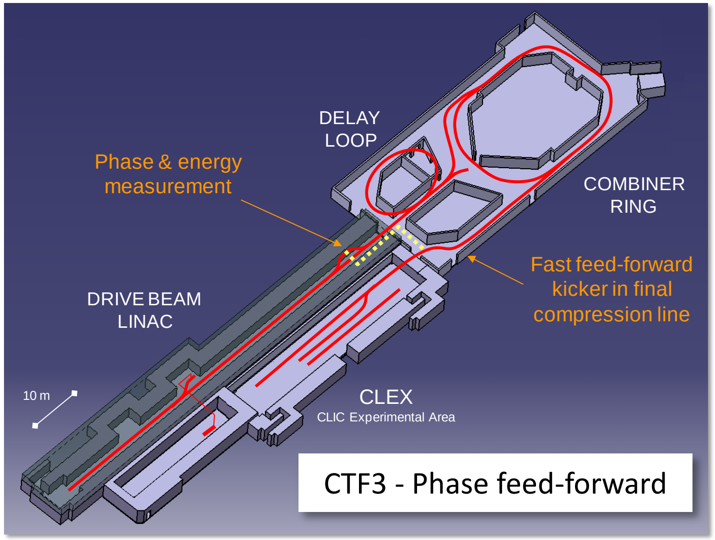
Drive Beam phase feed-forward tests

Phase stability
0.2° @ 12GHz



CLIC drive beam phase feed-forward concept

Phase stability 2.5° @ 12GHz
0.2° @ 1GHz



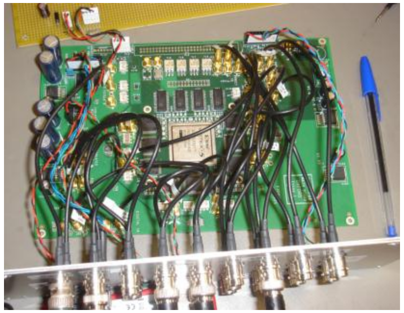
Not just a single experiment – series of related studies:

- Measure phase and energy jitter, identify sources, devise & implement cures, extrapolate to CLIC
- Show principle of CLIC fast feed-forward

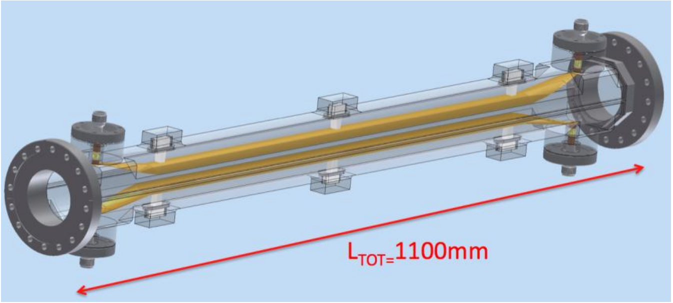
Close link to collaborating partners:

- INFN-LNF: Phase monitors, stripline kickers
- Oxford University/JAI: feedback electronics, amplifiers

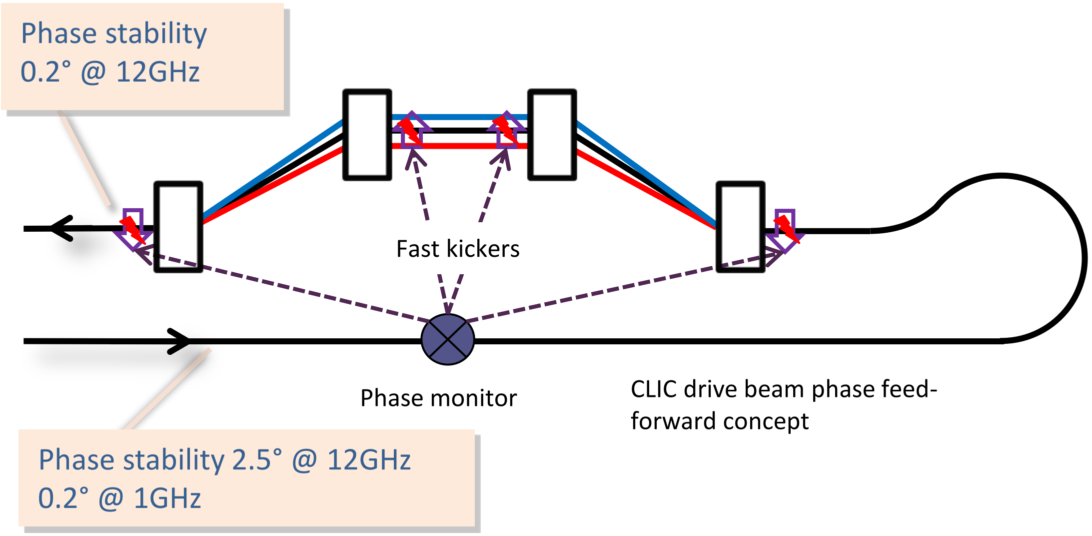
FONT5 board (Oxford)



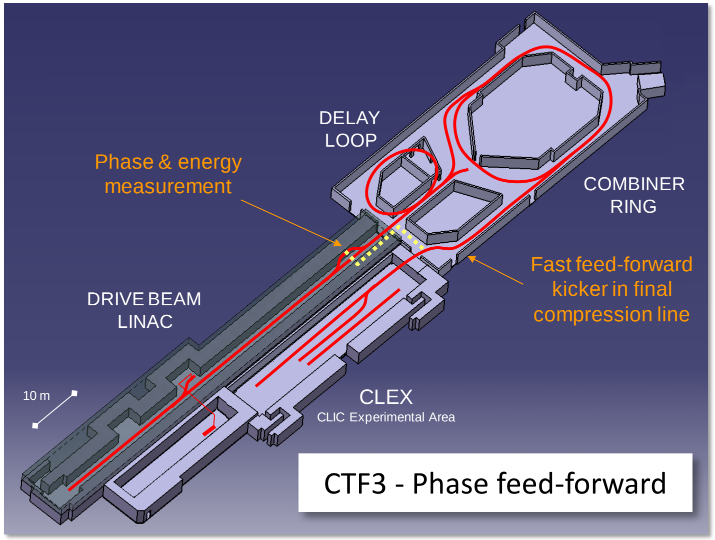
Stripline kicker (INFN-LNF)



Drive Beam phase feed-forward tests



CLIC drive beam phase feed-forward concept



CTF3 - Phase feed-forward

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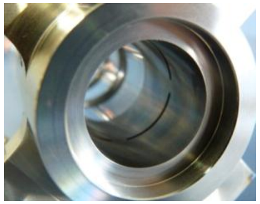
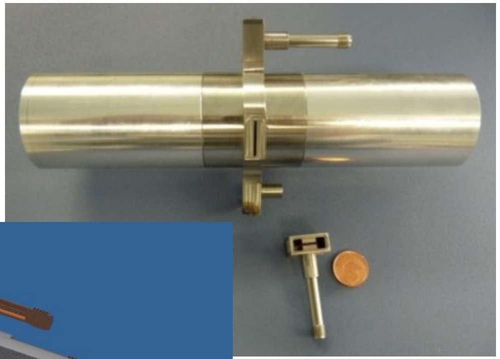
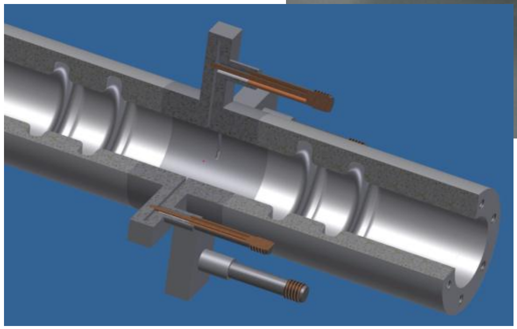


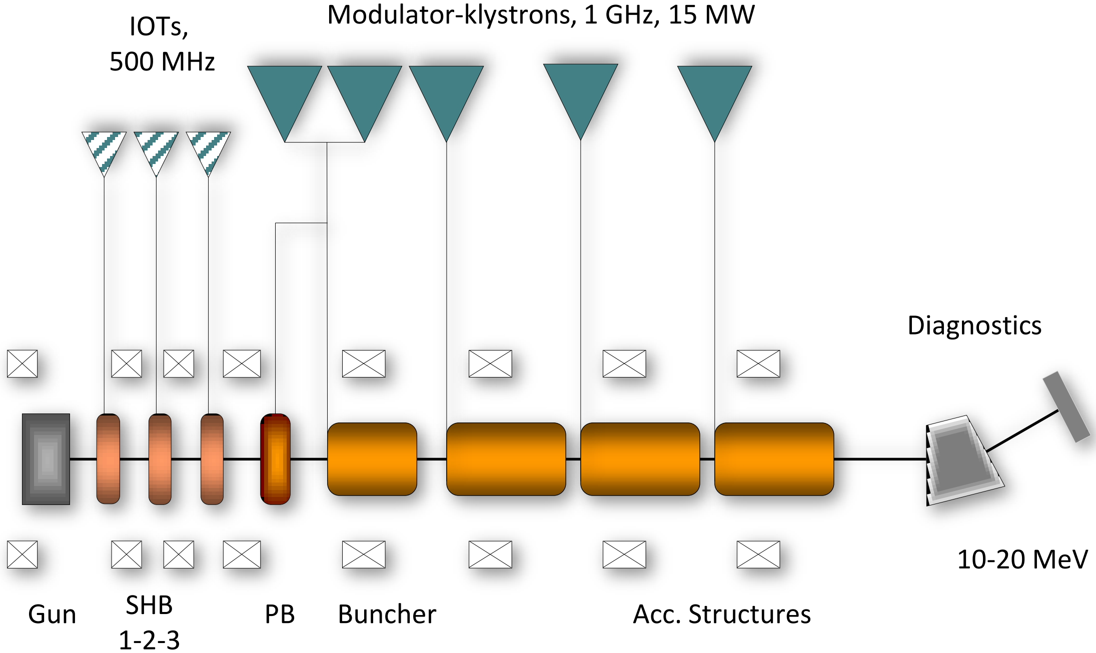


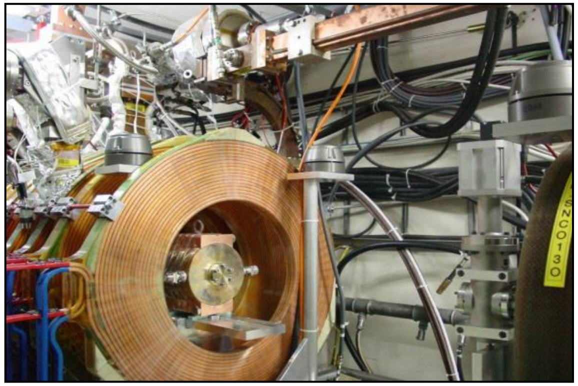


Phase monitor (INF-LNF, EuCARD)

Phase monitor prototypes installed. Test starting in 1-2 weeks

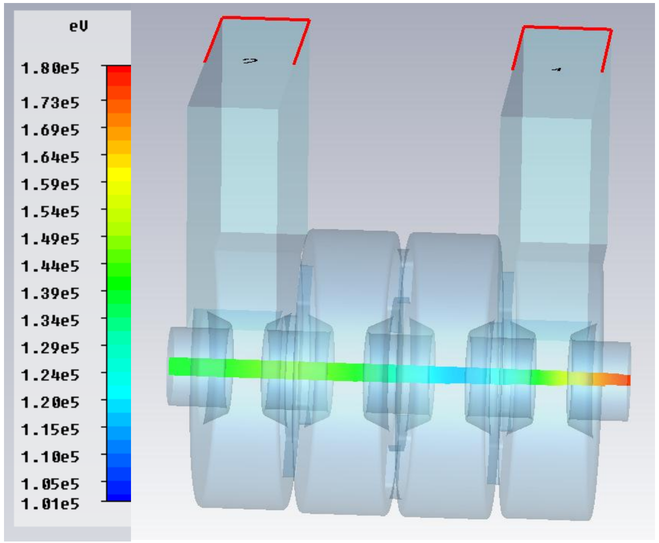
Drive Beam Front-End





CTF3 Injector

Sub-Harmonic Buncher RF design



Build and commission Drive Beam front-end with nominal CLIC parameters

- Essential R&D to assess drive beam injector (critical for performance)
- Develop RF unit for the drive beam linac (critical for cost/efficiency)
- Preparation for full CLIC Zero facility

Drive Beam Front-End issues

- Develop and demonstrate Drive Beam Accelerator RF unit at full pulse length:
  High efficiency klystron @ 1 GHz
  High efficiency and stable modulator
  Fully loaded, HOM damped 1 GHz accelerating structure (validate technology)

- Electron source technology R&D:
  Cathode and HV pulser. Life time, reliability, routine operation.

- Performance of drive beam front-end: beam quality and stability with long pulse:
  Current stability ~ 0.1%
  Beam phase stability
  Emittance and energy and position jitter
  Phase coding at 1 GHz

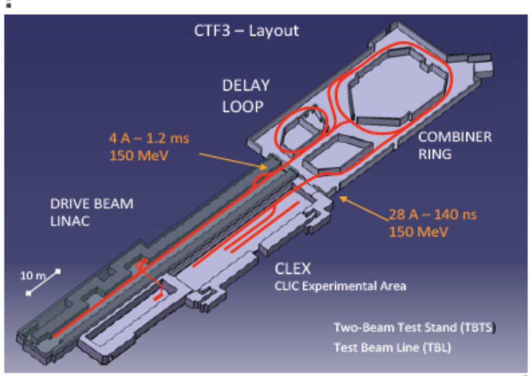
- Develop diagnostics suitable for long pulse and machine protection.

- DB front-end will be suitable for CLIC zero and CLIC

CLIC project time-line

2012-16 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.



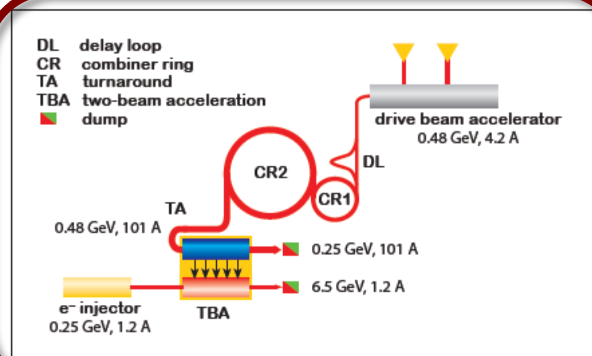
2016-17 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects), take decisions about next project(s) at the Energy Frontier.

2017-22 Preparation Phase

Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

Prepare detailed Technical Proposals for the detector-systems.



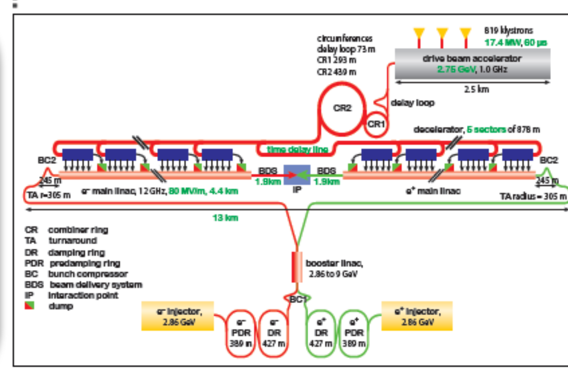
2022-23 Construction Start

Ready for full construction and main tunnel excavation.

2023-2030 Construction Phase

Stage 1 construction of a 500 GeV CLIC, in parallel with detector construction.

Preparation for implementation of further stages.

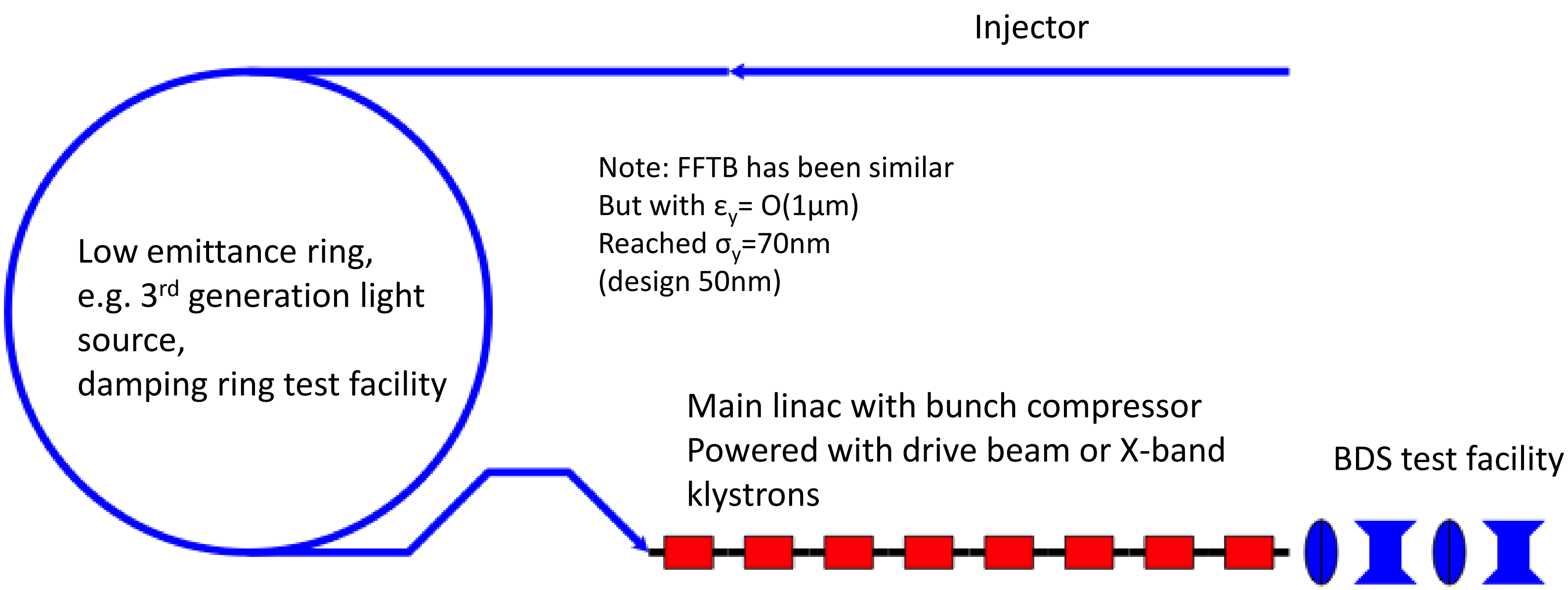


2030 Commissioning

From 2030, becoming ready for data-taking as the LHC programme reaches completion.

Dream test facility – emittance generation/preservation/beam delivery

Daniel Schulte, CLIC Collaboration Workshop, May 2012



Example options: SPS as damping ring (combined with CLIC0?),
FACET with improved damping ring? ATF, PEP-II, ESRF, SLS, SPRING-8, …

Bypassing the damping ring, one can use the linac as a 4th generation light source

Maybe some benefit in using ring and linac together as light source or for other experiments, e.g. ATF3

Example Parameters

Daniel Schulte, CLIC Collaboration Workshop, May 2012

- 3TeV structure, 108 quadrupoles, 324 super-structures, 2GeV initial energy, 250μm bunch length, 0.8*3.7e9 particles
  - Amplification of jitter emittance -> 4.7
  - 3.5um cavity scatter -> 0.14nm
  - 14um BPM scatter -> 14nm
  - Could use other structures and adjust bunch charge

- A power unit consists of
  - A pair of 50MW X-band klystrons with pulse length 1.6us
  - A pulse compressor with compression factor 6 -> 244ns +
  - Power gain is about 4.2
  - Splitter into three superstructures (6 structures)
  - i.e. 70MW/structure

- Significant cost could be reduced by
  - Not power all structures
  - Using different structures
  - Contribution from user community

CLIC Zero

CLIC Zero

(almost)
full-scale
DB Generation
Complex

- Beam driven processing/qualifying facility for X-band structures/modules
- Significant size series production of cost and performance critical hardware – drives industrialization needed for CLIC
- Demonstrate nominal drive beam generation (full combination, full pulse length) & two-beam acceleration/deceleration over a significant distance
- Most hardware re-usable for CLIC
- Other possible uses (outside the CLIC scope) presently being investigated