Summary of system tests

R. Corsini, H. Hayano

14:00 - 15:30

Accelerator Common Topics - System Tests

Convener: Roberto Corsini, Hitoshi Hayano (KEK)

Location: Rio Grande A

14:00 **Overview of CLIC system tests** *20'*

Speaker: Roberto Corsini

Material: Slides

14:20 **Plans for the drive beam front-end and CLIC zero outlook** *20'*

Speaker: Steffen Doebert

Material: Slides

14:40 **9mA study progress at FLASH** *20'*

Speaker: Dr. Shinichiro Michizono (KEK)

Material: Slides

15:00 **STF status and future plan** *20'*

Speaker: Hitoshi Hayano (KEK)

Material: Slides

9 mA study at FLASH on Sep., 2012

Shin MICHIZONO (KEK)

Outline

I. Achievement before Sep.2012

II. Study items for ILC

III. Study plan

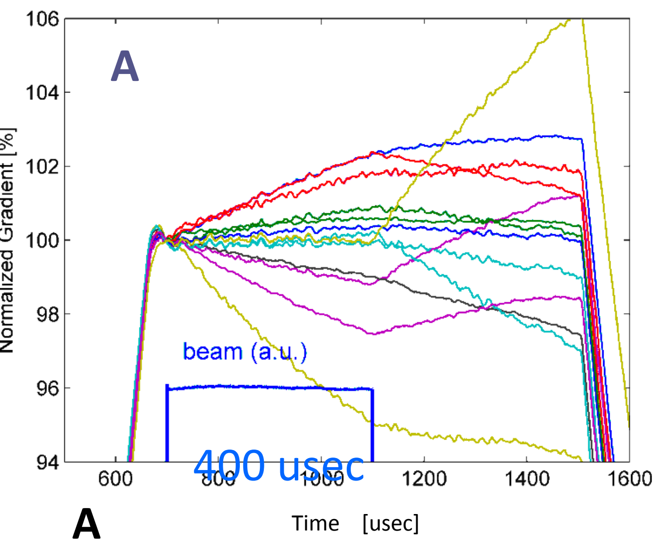
IV. Study results

- Gradient study for near quench limit operation
- Klystron output linearization
- RF operation near klystron saturation

V. Summary and future plan

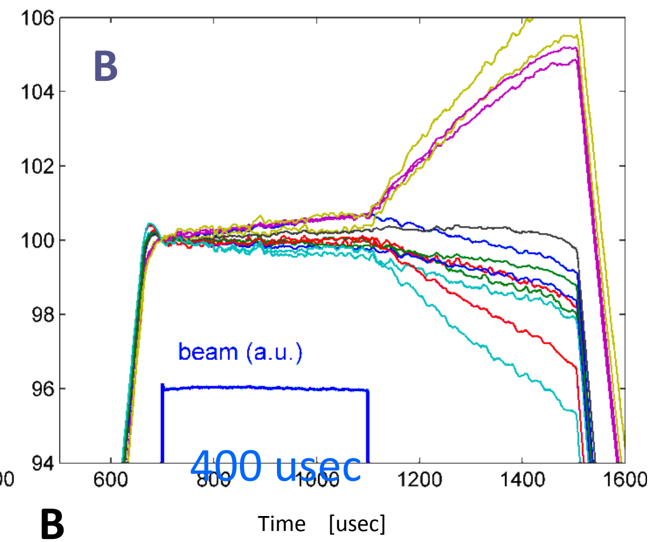
P_kQ_L control demonstration with 4.5mA beam loading

Results from FLASH 9mA study (Feb. 2012): I_{beam} = 4.5 mA



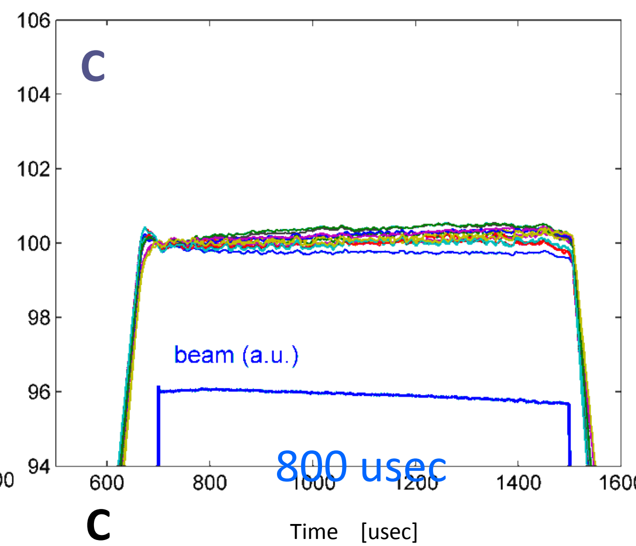
A

- short bunch train
- default Q_L = $3\text{x}10^6$



B

- short bunch train
- optimized Q_L



C

- long bunch train
- optimized Q_L

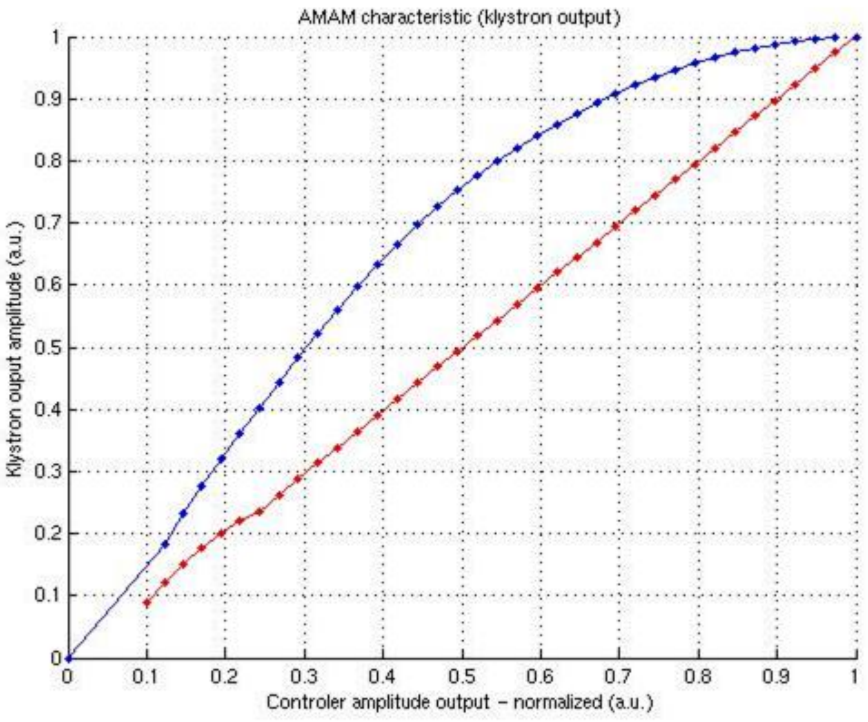
Results from FLASH 9mA study (Sep. 2012):

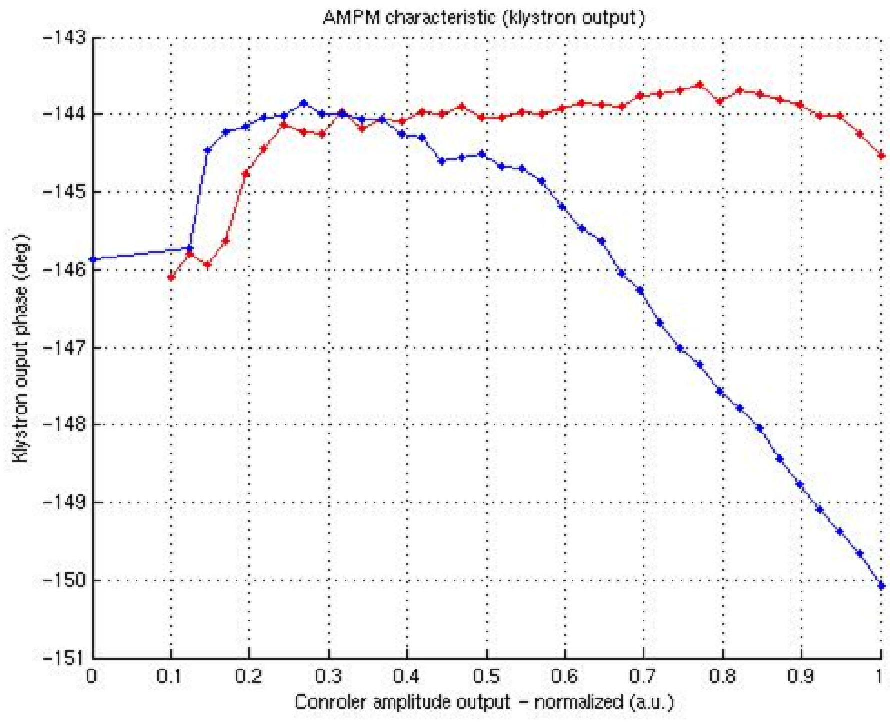
QL optimization algorithm now includes **exception handling** (Piezo, Ql,…)

Still not fully understood about optimization procedure **(next study)**:

Linearization of Klystron characteristics for FB control at saturation region

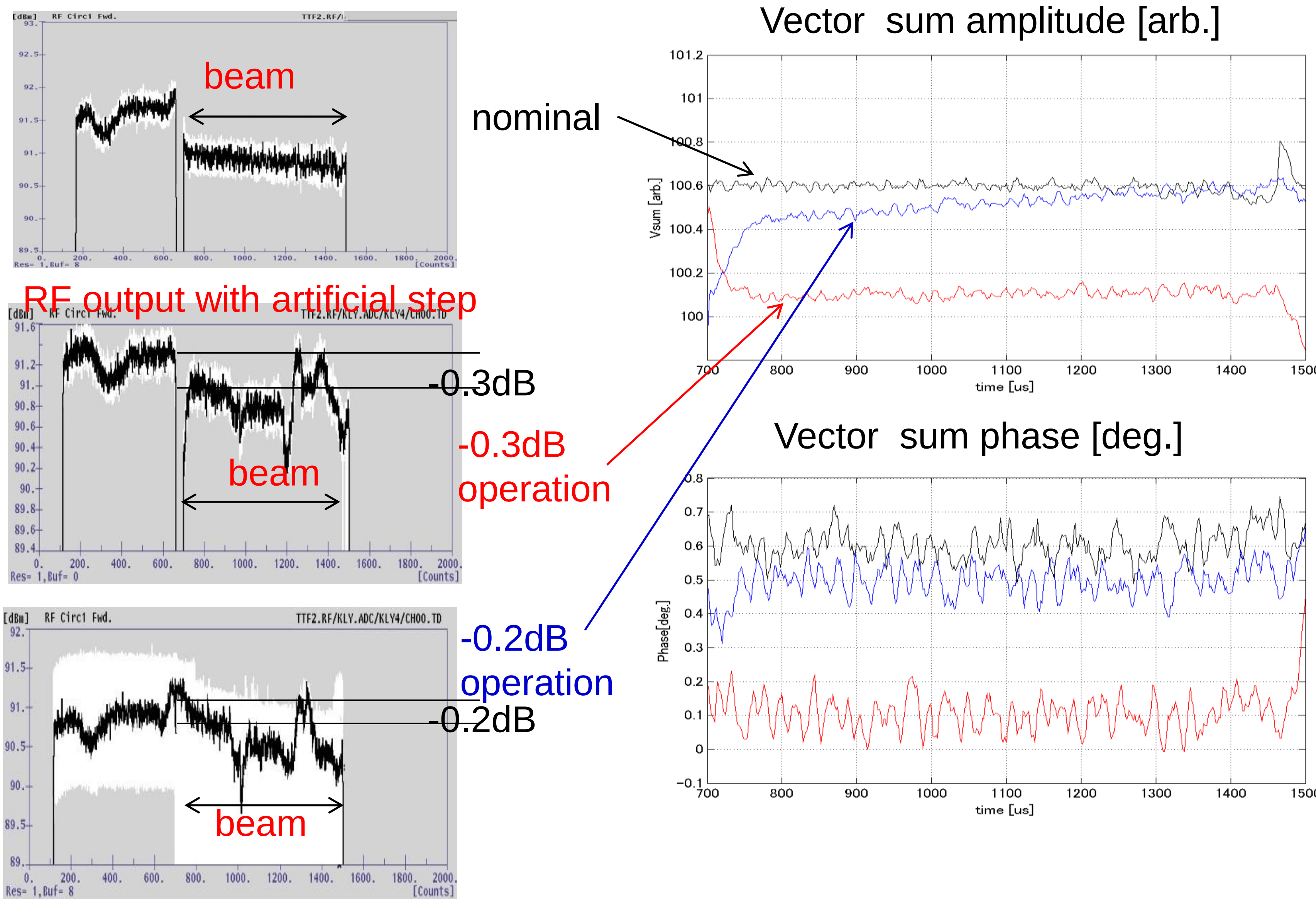
The results of linearization achieved during last high beam current studies at FLASH (RF station for accelerating modules ACC67 – 10 MW klystron) (red characteristics).





Proposed and implemented method allowed for klystron behavior linearization. Although some system weak points can be recognize (eq. poor phase detection for low signal levels) amplitude and phase characteristic correction can be considered as satisfactory.
The main benefit of constant gain maintenance can be clearly noticed especially for operation with wide working point range (eq. high feedback gain control).

FB control at klystron saturation region with intentional reduction of klystron HV, artificial RF amplitude steps



Summary and future plan

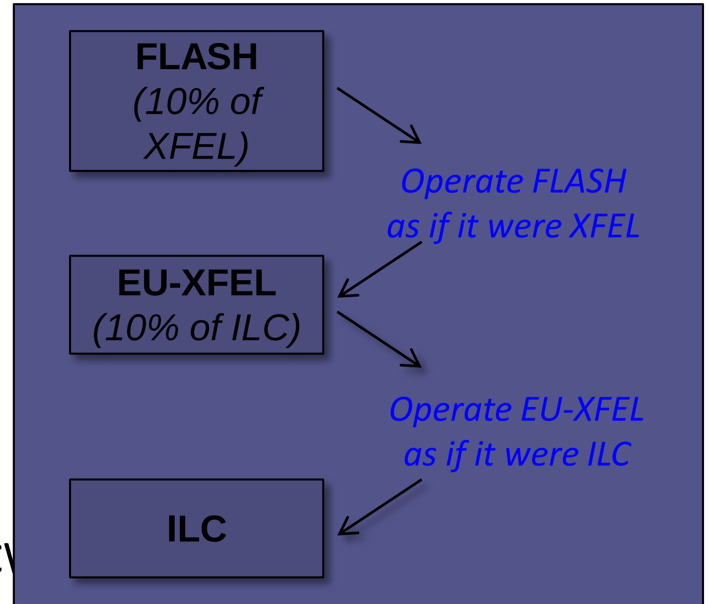
- Several studies have been carried out at FLASH for technical demonstration of ILC specification.
  - PkQl control (Ql adjustment) for near quench limit operation

  -> strategy for automation (reach near quench limit without exceeding etc.)
  - Klystron linearization and rf operation near saturation

  -> Beam energy stability, long term stability with flat beam current
  - High current beam loading with long bunch train.

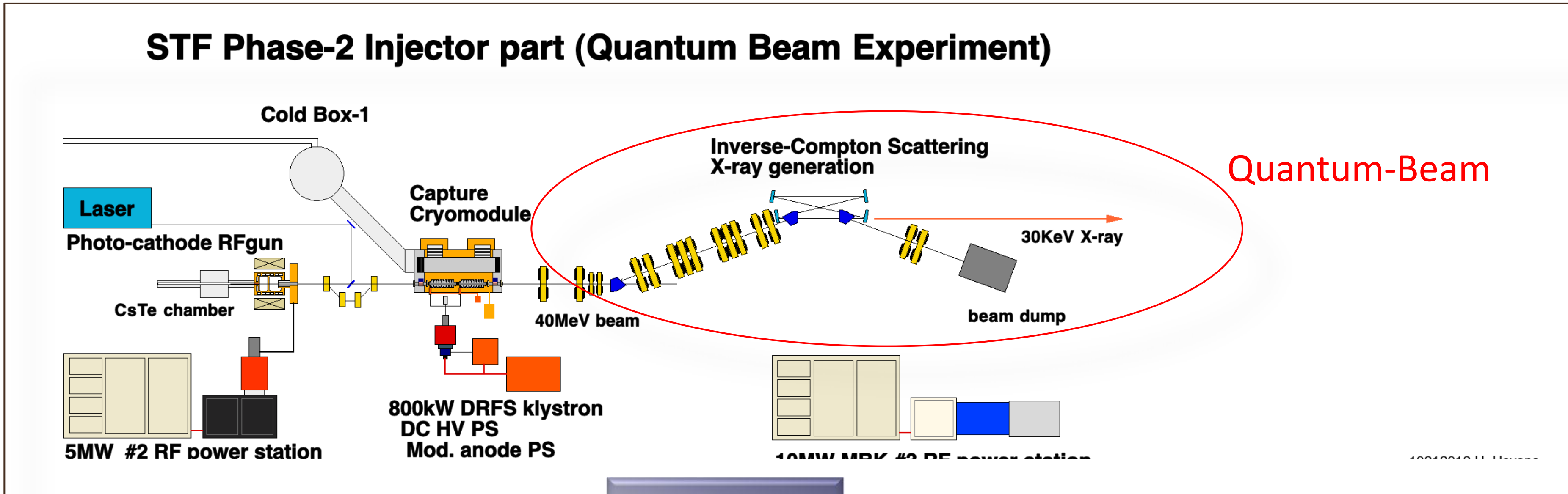
  -> High beam, high gradient, near klystron saturation study
- For the engineering phase (post TDR), we need to accumulate more experience for stable operation.
- XFEL and ILC have many common study items because of the similar beam parameters.

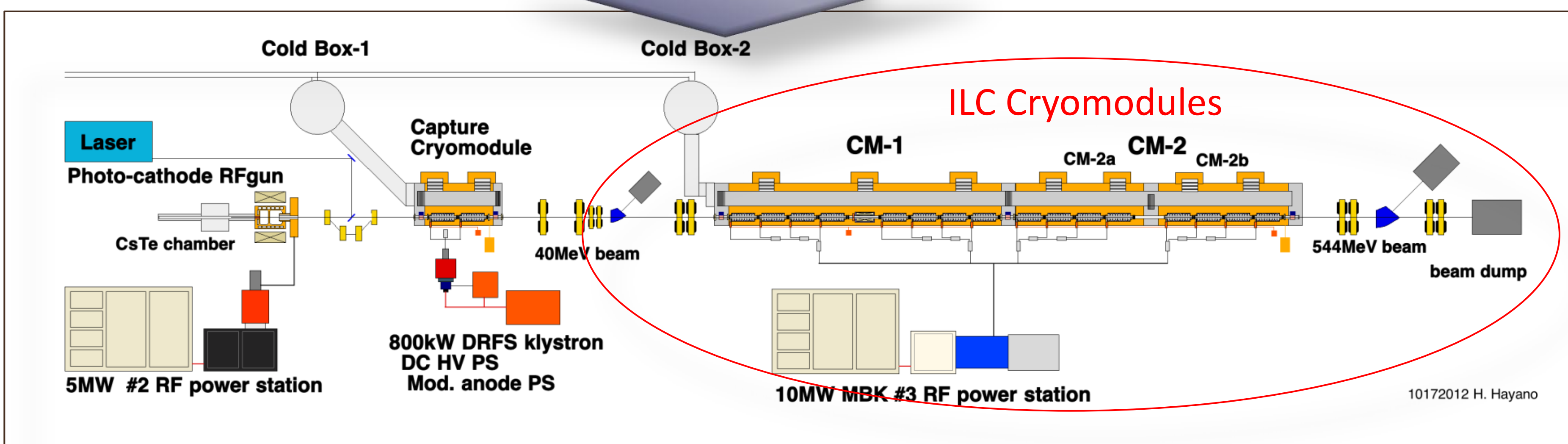
	EU-XFEL	ILC (250GeV)
Gradient	23.6 MV/m	31.5 MV/m +-20%
Bunch charge	1 nC	3.2 nC
Beam current	5 mA	5.8 mA
Energy stability	2.5MeVrms/20GeV (0.013%)	0.1% rms



Injector part as Quantum-beam-experiment is under operation in 2012, and then series of ILC cryomodules will be placed at downstream.

STF Accelerator Plan (2012- 2015)



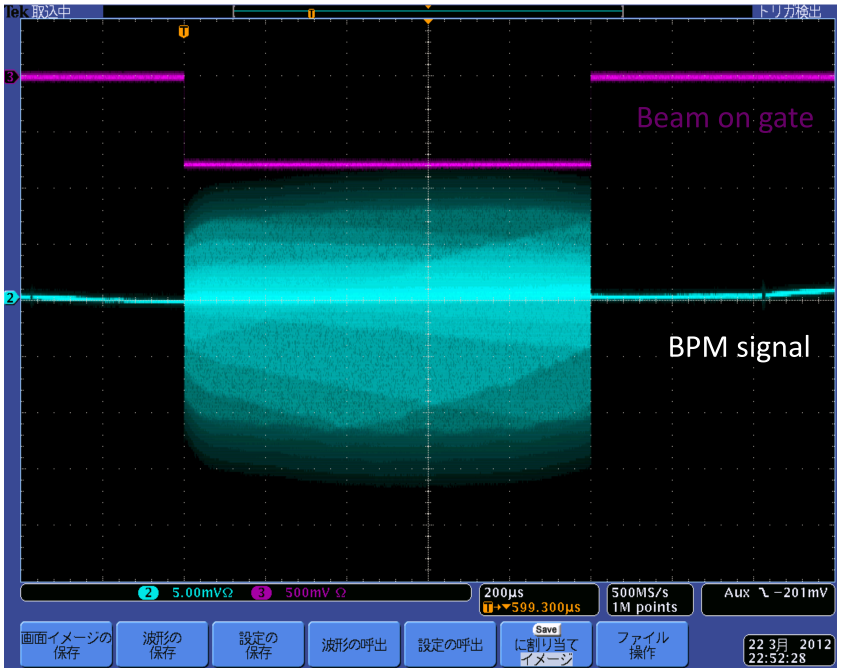


1ms bunch train with 2.5mA beam are successfully accelerated to 40MeV in Injector operation, 4 mirror laser accumulator is ready for X-ray generation experiment.

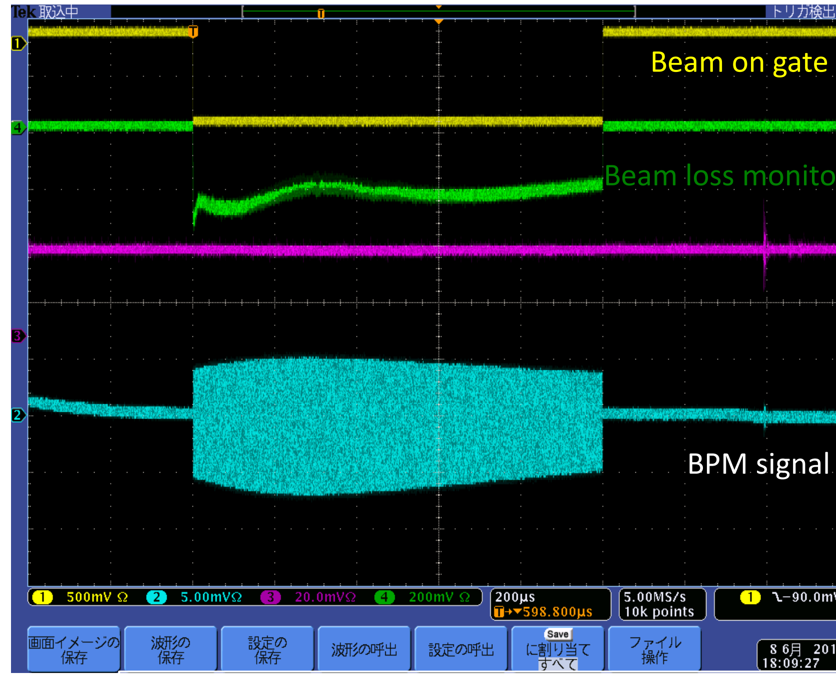
Achieved Long bunch train generation and acceleration

1ms bunch train extraction from RF-gun

Beam acceleration by Capture Cryomodule



1ms flat Beam extraction from RF-gun 1ms
(RF feedback ON) 03.22.2012



Beam acceleration with 1ms train (15pC/bunch)
(Gun/SCRF RF feedback ON) 06.08.2012

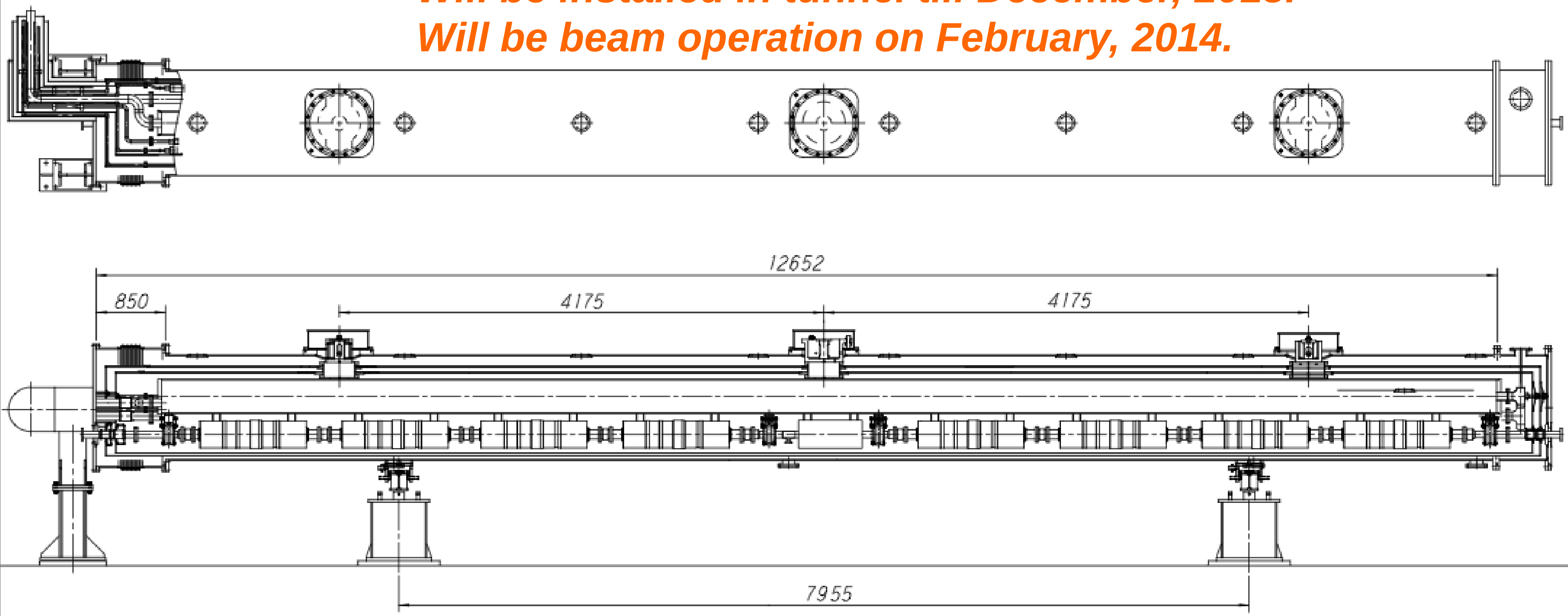
2.5mA

* ILC(TDR) : 5.8mA beam current, 0.727ms train length

ILC-type Cryomodule has started its construction. Cavities are all TDR qualification clear performance. It will be installed into STF accelerator in 2013. Series of cryomodules will come later, year by year.

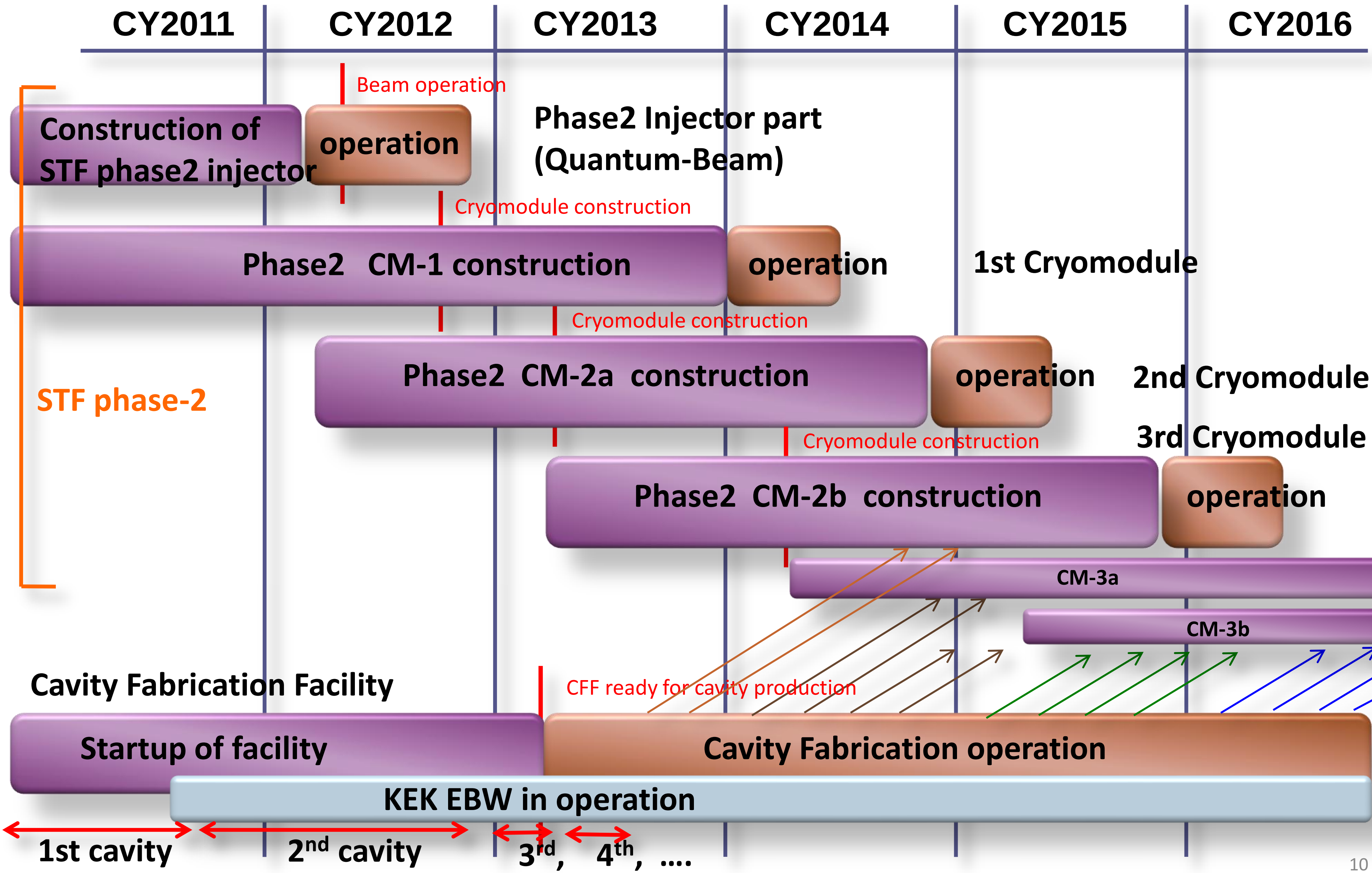
ILC design cryomodule : CM-1

The fabrication started in this month.
Will be completed till June, 2013.
Will be installed in tunnel till December, 2013.
Will be beam operation on February, 2014.



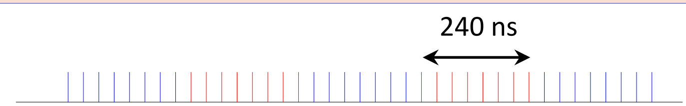
8 Cavities + dummy quad
4 cavities : slide-jack tuner in center
4 cavities : slide-jack tuner in end

STF future Plans



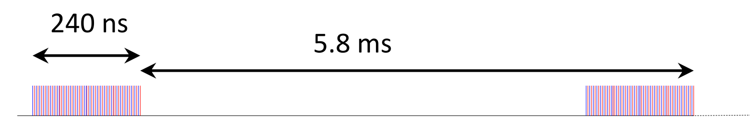
The ultimate CLIC system test

Drive beam time structure - initial

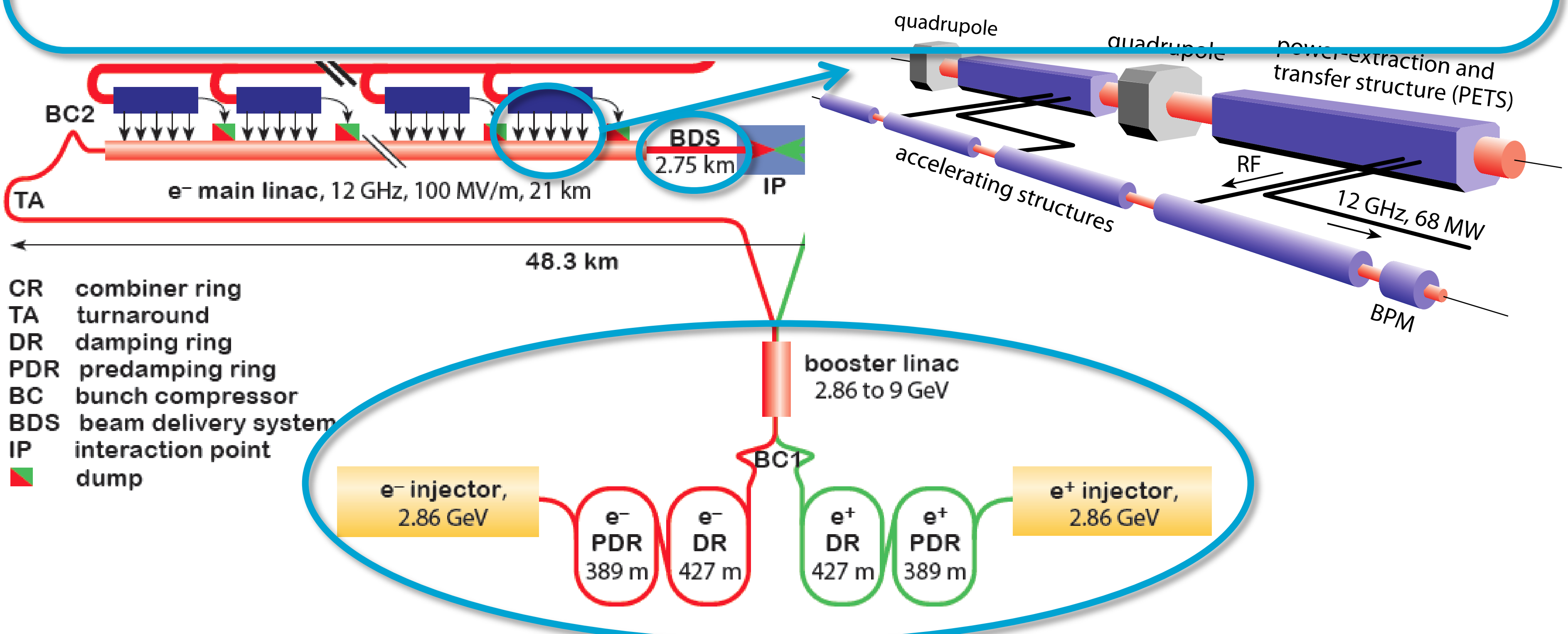


140 ms train length - 24 × 24 sub-pulses
4.2 A - 2.4 GeV – 60 cm between bunches

Drive beam time structure - final



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



Main Beam Generation Complex

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	

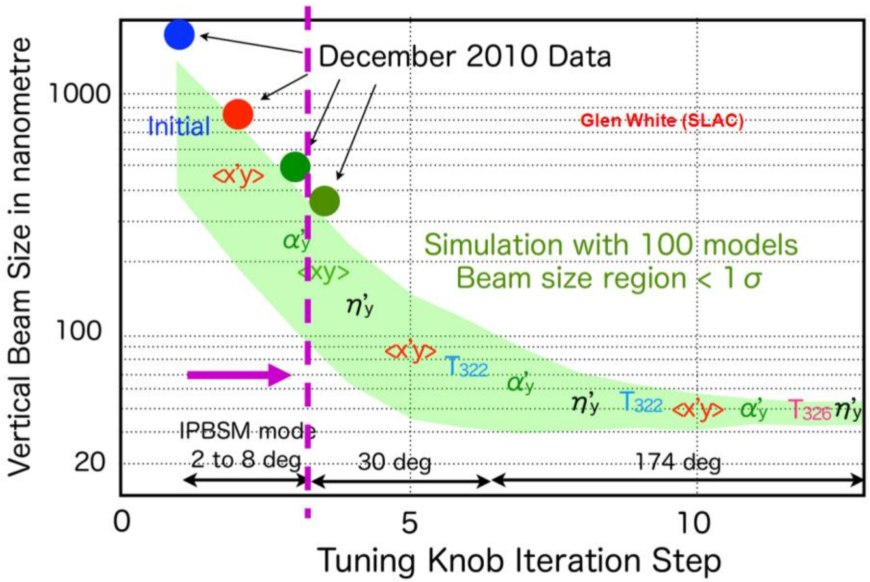
In general, most of detrimental effects **are equivalent or worse in CTF3** because of the low energy, however in CLIC the beam power is much larger (heating, activation, machine protection)

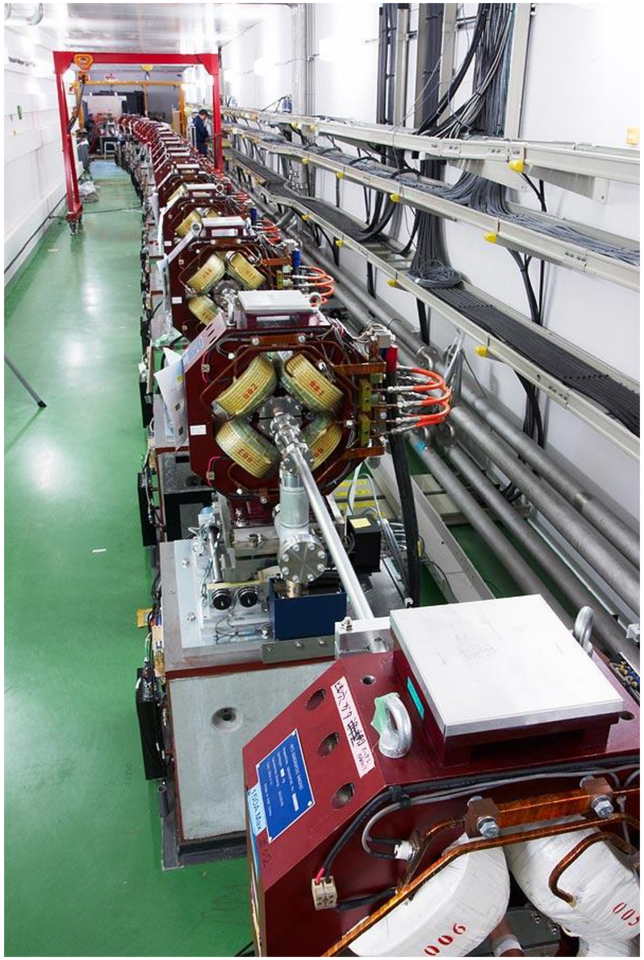
Needed tolerances on the final drive beam parameters (phase, current, energy stability...) are more stringent in CLIC – some ~~could be~~ **are being demonstrated** in CTF3 as well

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





Emittance Preservation – Main linac Beam-Based Alignment

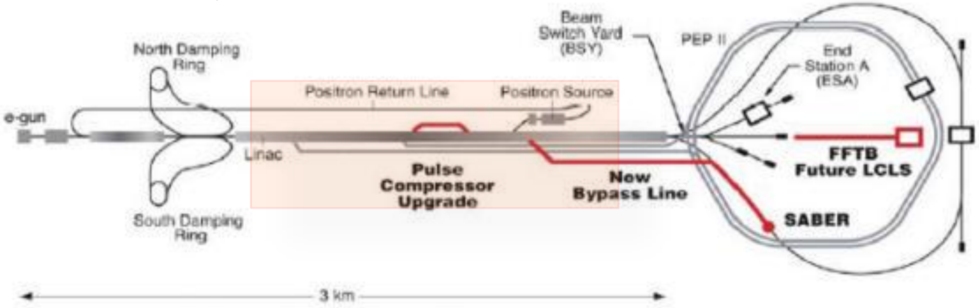
T501: FACET test-beam proposal to study advanced global correction schemes for future linear colliders.

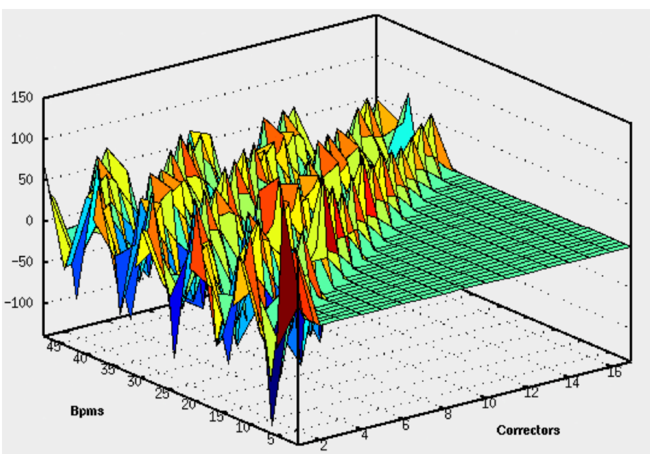
CERN-SLAC collaboration where algorithms developed at CERN are tested on the SLAC linac.

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.

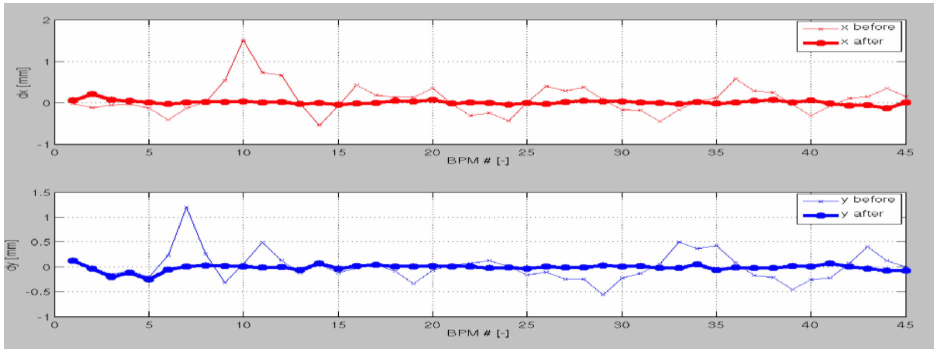
The section of the SLAC beamlines we work on



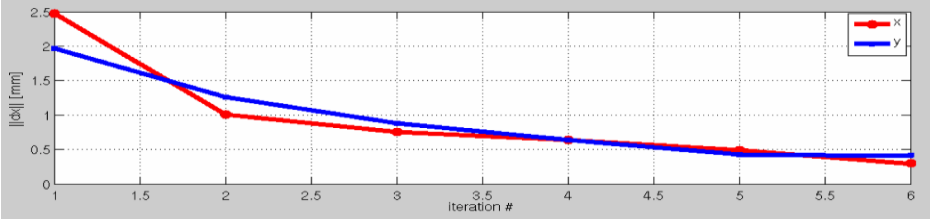


(Above) Measured Rx response matrix for the test-section of the linac (17 correctors, 48 BPMs)

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



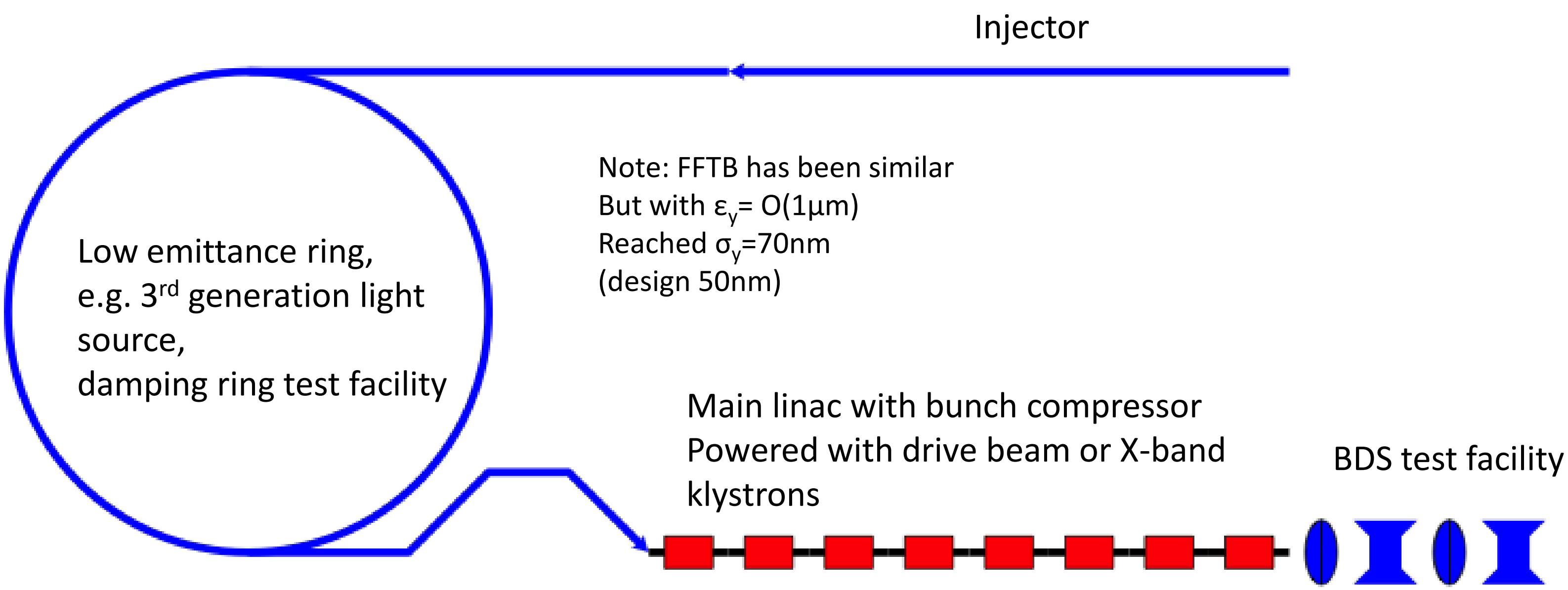
(above) Horizontal and Vertical trajectories before and after orbit correction



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

Dream test facility – emittance generation/preservation/beam delivery

Daniel Schulte, CLIC Collaboration Workshop, May 2012

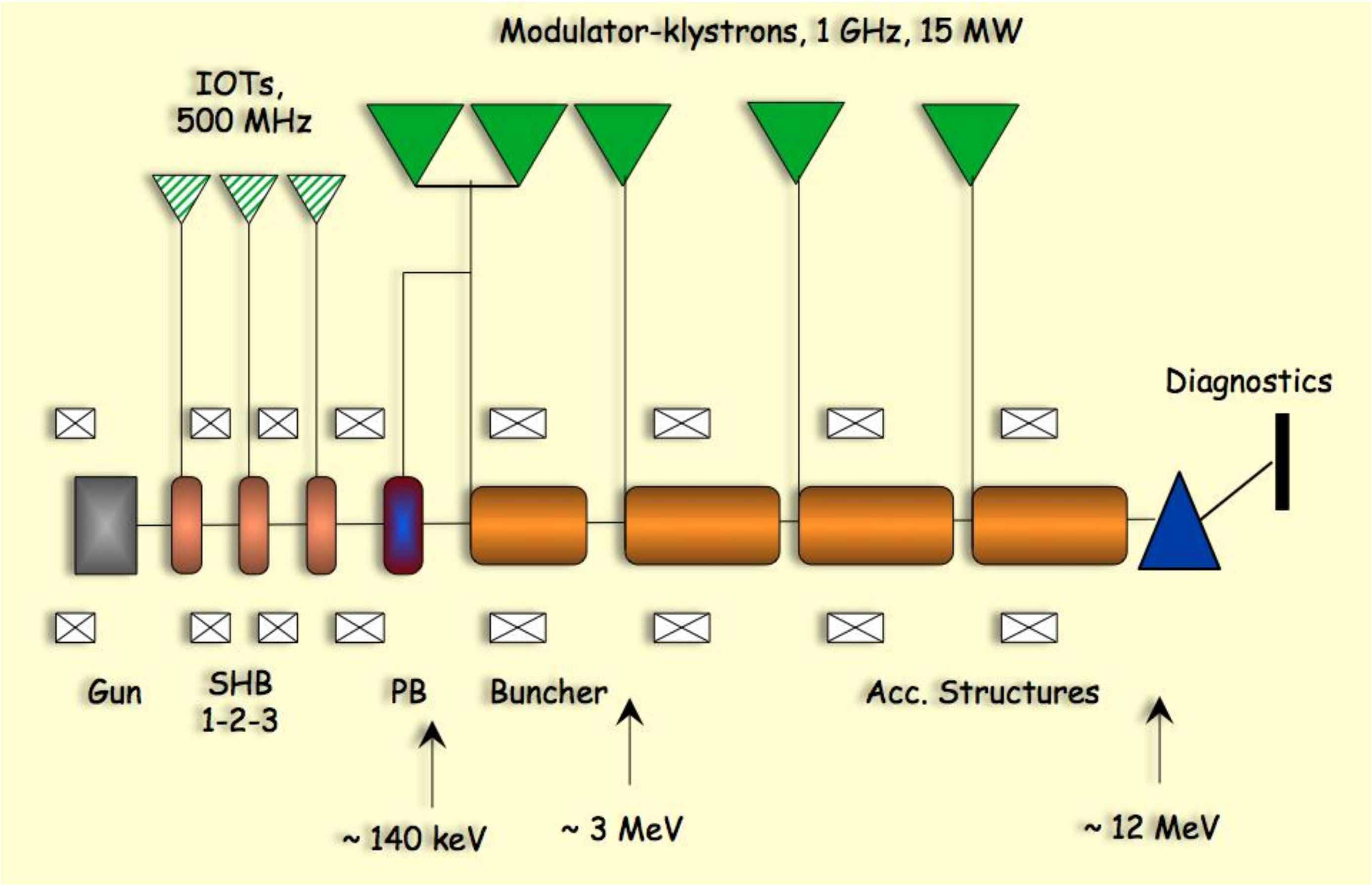


Example options: SPS as damping ring (combined with CLIC0?),
FACET with improved damping ring? ATF, PEP-II, ESRF, SLS, SPRING-8, …

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

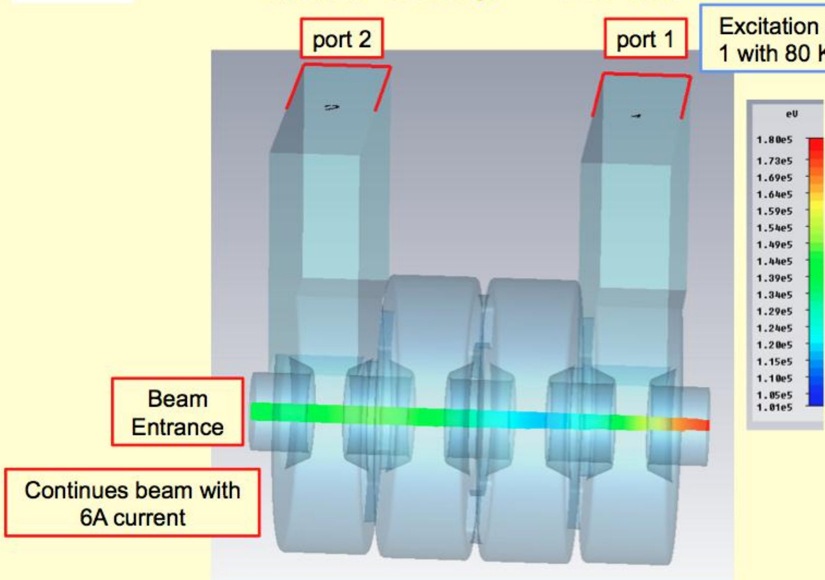
Maybe some benefit in using ring and linac together as light source or for other experiments, e.g. ATF3

CLIC DB front end, Post CDR Project

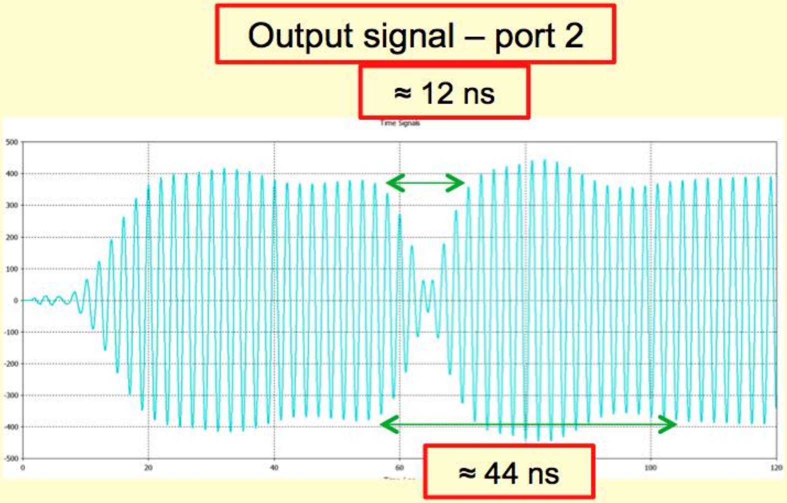


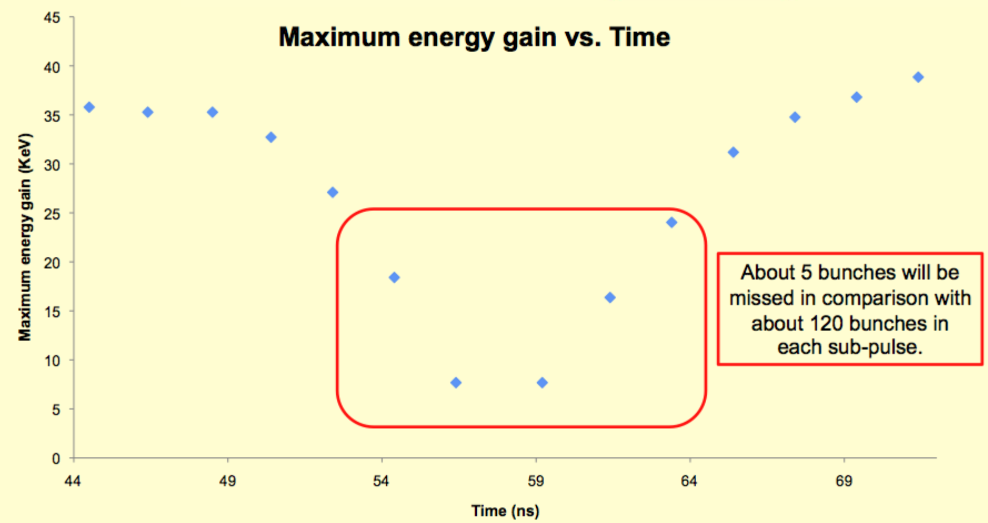
Gun, sub-harmonic bunching, bunching, three accelerating structures, 5 long pulse klystrons and modulators, diagnostics

Phase flipping simulation with beam - 10 ns



Hamed Shaker

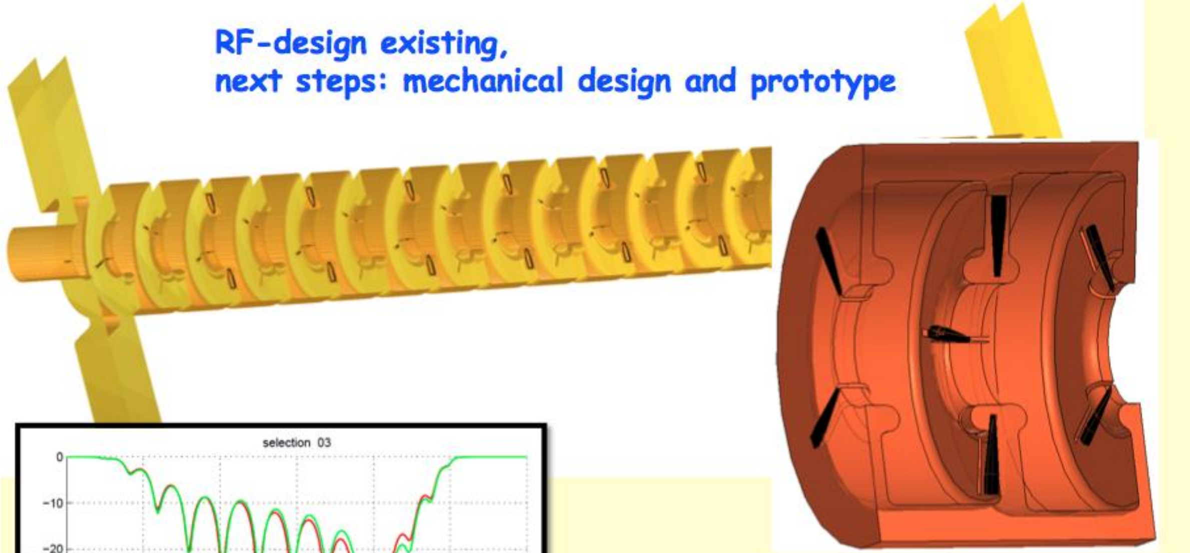


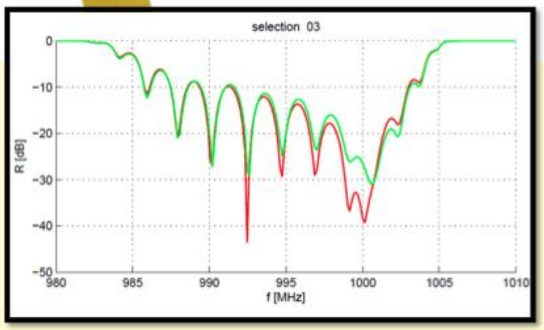


Sub-harmonic bunching system

RF-design existing,
next steps: mechanical design and prototype

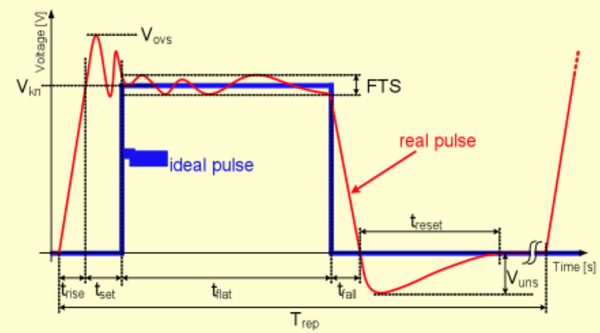
DB-accelerator structure





modulator specs

Modulator main specifications			
Pulse voltage	V_{kn}	150	kV
Pulse current	I_{kn}	160	A
Peak power	P_{out}	24	MW
Rise & fall times	t_{rise}	**3**	**μs**
Flat-top lenght	t_{flat}	140	μs
Repetition rate	Rep_r	50	Hz
Flat-top stability	FTS	0.85	%
Pulse reproducibility	**PPR**	**10**	**ppm**



~300MW required for klv. mod.

Pulse efficiency definition $$\eta_{pulse} = \frac{E_{ideal\_p}}{E_{real\_p}}$$

Approach:
Develop and explore with collaboration partners technologies to meet the ultimate specification for CLIC with the goal to have two working prototypes in 2015-2016.
First collaboration with ETH Zürich started, prototype in 2015

Klystron specifications

FREQ	Vklystron	Iklystron	V pulse width	RF pulse width	Peak RF Power	Repetition rate	Average Power	Gain	Efficiency	Waveguide
MHz	kV	A	μs	μs	MW	Hz	kW	dB	%	
1300	115	132	1700	1500	10	10	150	47	65	WR 650

TH1802, ILC MBK klystron

PARAMETER	VALUE	UNITS
RF Frequency	999.5	MHz
Bandwidth at -1dB	tbd	MHz
RF Power:		
Peak Power	$\geq$ 18	MW
Average Power	135	kW
RF Pulse width (at -3dB)	150	μs
HV pulse width (at full width half height)	165	μs
Repetition Rate	50	Hz
High Voltage applied to the cathode	tbd, 150 (max)	kV
Tolerable peak reverse voltage	tbd	kV
Efficiency at peak power	$\geq$ 65	%
RF gain at peak power	tbd, > 50 ?	dB
Perveance	tbd	$\mu A/V^{1.5}$
Stability of RF output signal		
0.5-1.0 of max. power and 0.75 -1.0 of max. cathode HV to be:		
RF input vs output phase jitter [*]	±0.5 (max)	RF deg
RF amplitude jitter	±1 (max)	%
Pulse failures (arcs etc.) during 14 hour continuous test period	$\leq$ 1	
Matching load, fundamental and 2nd harmonic	tbd	vswr
Radiation at 0.1m distance from klystron	$\leq$ 1	μSv/h
Output waveguide type	WR975	

FREQ	Vklystron	Iklystron	V pulse width	RF pulse width	Peak RF Power	Repetition rate	Average Power	Gain	Efficiency	Waveguide
MHz	kV	A	μs	μs	MW	Hz	kW	dB	%	
999.52				**150**	**15-20**	**50**	**113**		**70**	

What do we plan to do until 2016

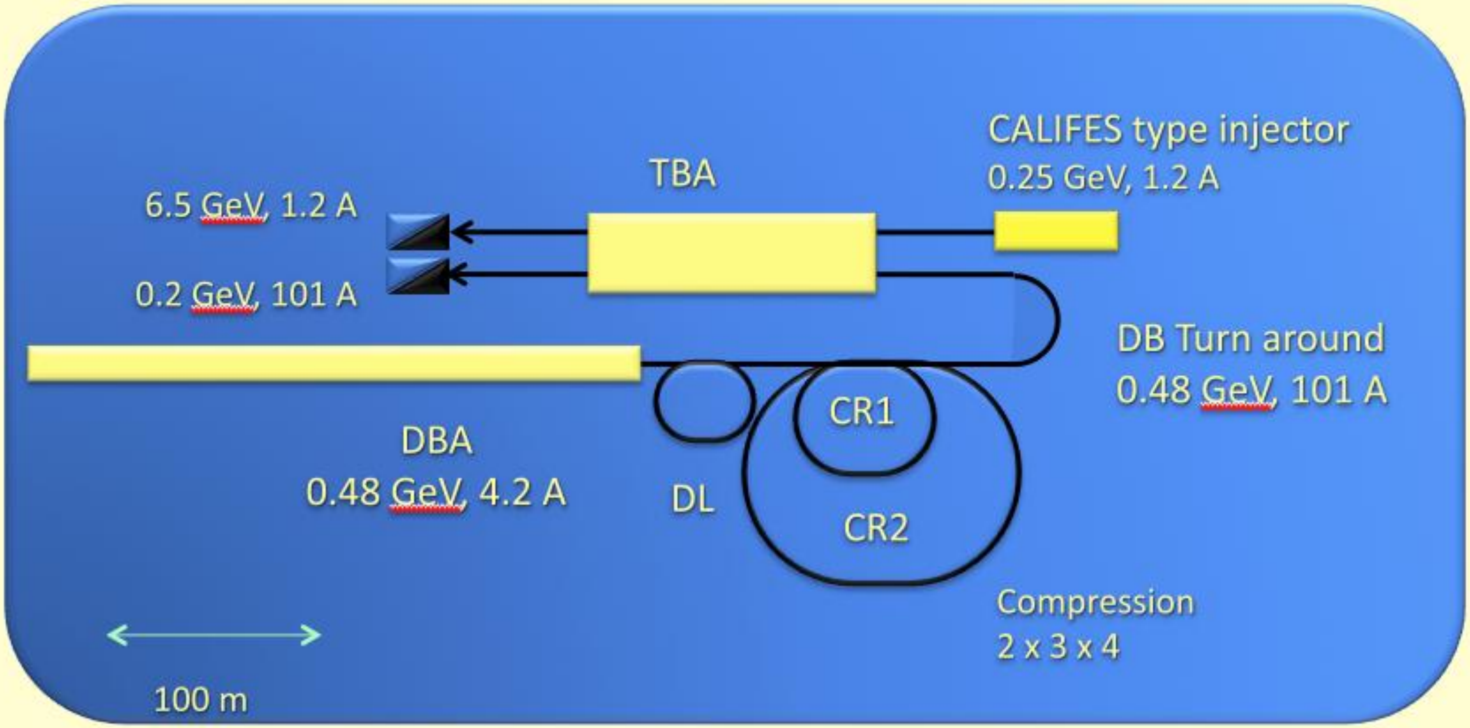
Optimistic and rough planning

Task	2012	2013	2014	2015	2016
Space needed		prepare gun test facility	prepare Klystron test sand	prepare injectot building	injector building
Gun	conceptunal design	design and construction	GUN test facility	GUN test facility	
SHB Buncher	design	fabrication	testing		
500 MHz power source	specification	purchase	testing		
Buncher	specification	design and purchase	reception, low power test	high power test	
1 GHz structure	specification	design and purchase	reception	low power test	high power test
Diagnostis	specification, purchase		IC in gun test		
LLRF		specification	fabrication+test	ready for klystron test	
1 GHz klystrons	tender	design at manufacturer	fabrication of prototype	Receive Klystron 1	Klystron 2
1 GHz Modulator	tender	R&D	R&D	Receive first MDK	MDK2
Injector integration, vacuum, controls, magnets, diagnostics	on hold	on hold	design		

Create a gun test facility to test the source
and a high power test stand to test the klystron, modulator and rf structures

Introduction to CLIC zero

20 % of the CLIC Drive Beam and 10 % of a CLIC decelerator



H. Braun, CLIC 2008 Workshop

Conclusions

- ILC now concentrating on SC linac operation.
- Good results with “ILC-like” beams reported from Flash and STF.
- EU-XFEL will provide a lot of operational experience.
- CTF3 has completed its initial program. Future program centered on Two-Beam modules tests.
- R&D on high average power drive beam generation to prepare technology and complement CTF3 results – drive beam front-end facility in preparation.
- Importance of system tests beyond main linac, for critical sub-system: BDS (ATF), damping ring, main beam generation.
- Integrated tests > “dream facilities”…