Main Linac Experimental Tests

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CLIC Collaboration meeting - May 9-11, 2012 - CERN

Motivation:
Main linac Beam-Based Alignment

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

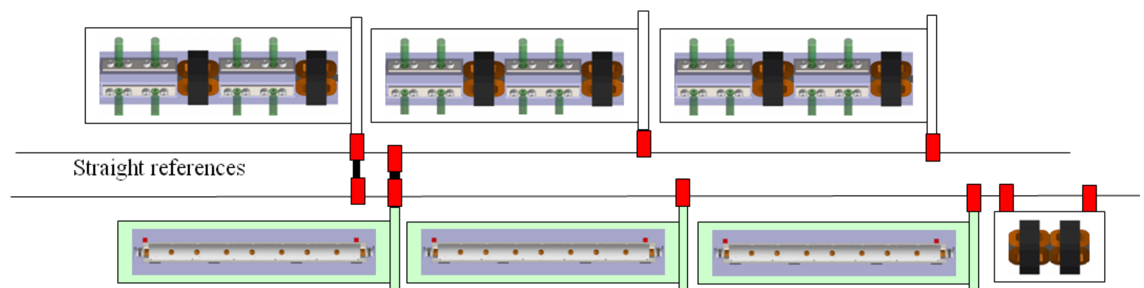
- Dispersion free steering
- aligns BPMs and quadrupoles

- Move girders onto the beam
- use wakemonitors
- removes wakefield effects

- Straight reference line defined by overlapping wires

- Girders are aligned to these wires

- Detailed work ongoing on module integration, mechanical alignment in module, wire system test, sensor cost reduction, use of laser system



CLIC Beam-based alignment strategy

- 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

Main Linac Considerations

Emittiance growth at 500GeV after DFS

Imperfection	With respect to	Value	$\Delta\varepsilon_y$ 1-2-1[nm]	$\Delta\varepsilon_y$ DFS [nm]	$\Delta\varepsilon_y$ RF [nm]
girder end point	articulation point	5 μm	0.62	0.62	0.02
roll	longitudinal axis	100 μrad	0.23	0.23	0.23
BPM offset	wire reference	14 μm	340.86	7.11	0.08
cavity offset	girder axis	14 μm	3.19	3.19	0.01
cavity tilt	girder axis	141 μrad	0.10	0.43	0.41
BPM resolution		0.1 μm	0.00	0.51	0.01
wake monitor	structure centre	3.5 μm	0.00	0.00	0.21
all			353.88	16.27	0.95

Main design issues

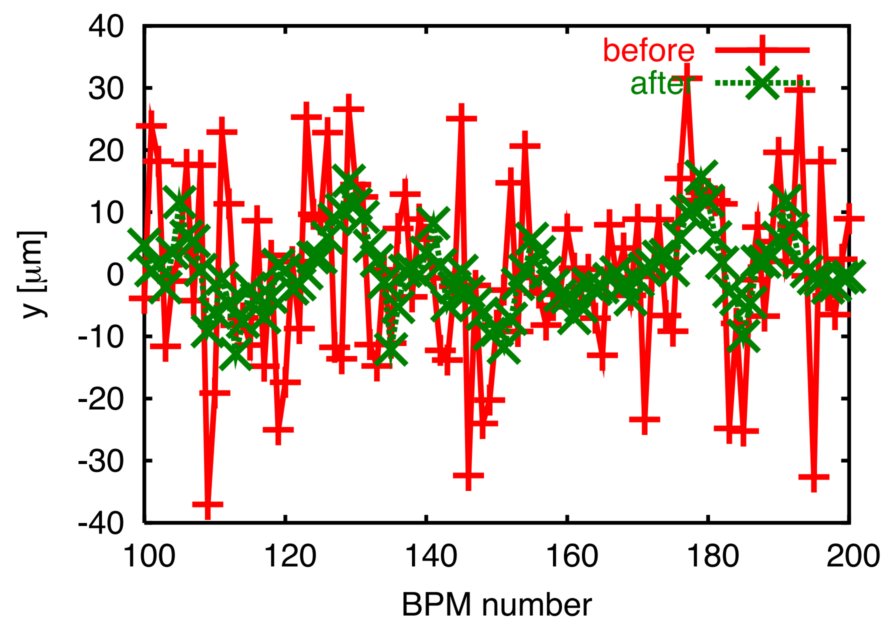
- Wakefields
- BPM alignment
- wake monitors
- structure tilt
- BPM resolution
- quadrupole roll
- quadrupole stability
- vacuum

- Design is OK
- Imperfection mitigation achieves target

- DFS has not been tested
- many effects were discovered during the studies, so maybe we miss one
- emittances are unprecedented in linacs (10nm vs. >1µm)

Dispersion-free steering

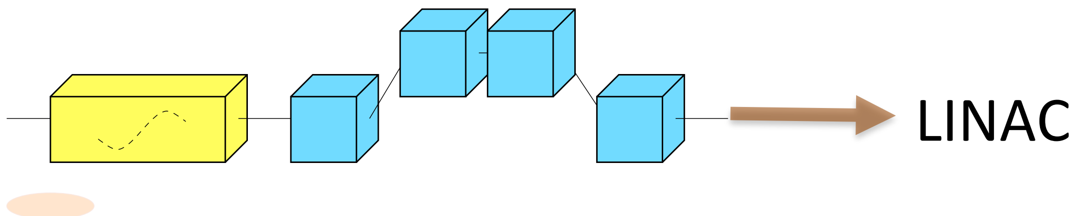
- Basic idea: use different beam energies to measure the dispersion and correct it
- CLIC:
  - Accelerate the beam with different gradients
  - Create initial energy difference using Bunch Compressor
  - (Alternative, in theory: scale the magnet focusing)
- Optimize trajectory and dispersion at the same time:

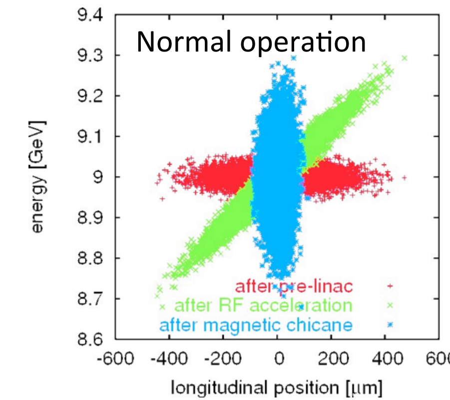


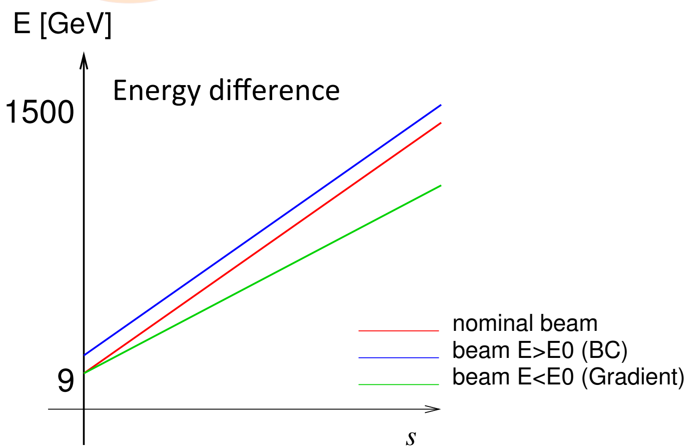
$$S = \sum_{i=1}^{n} \left(w_i (x_{i,1})^2 + \sum_{j=2}^{m} w_{i,j} (x_{i,1} - x_{i,j})^2 \right) + \sum_{k=1}^{l} w'_k (c_k)^2$$

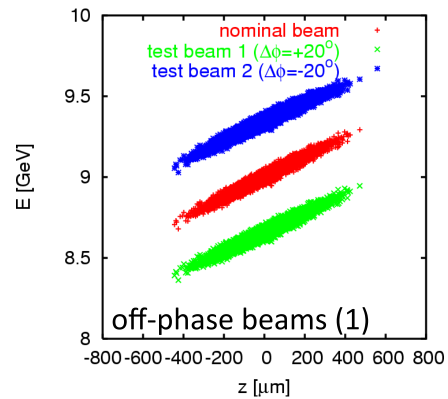
Bunch compressor for DFS

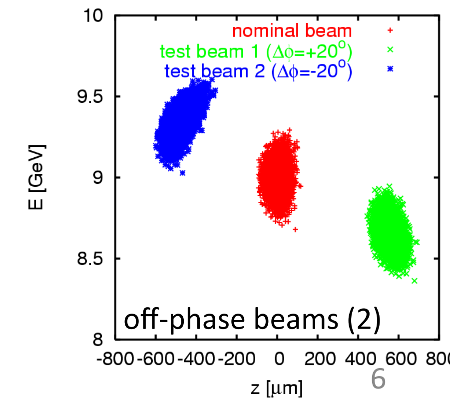
- Use BC2 to create the initial energy difference needed by DFS
- Introduce an offset in the RF-phase of the accelerating structures of the BC





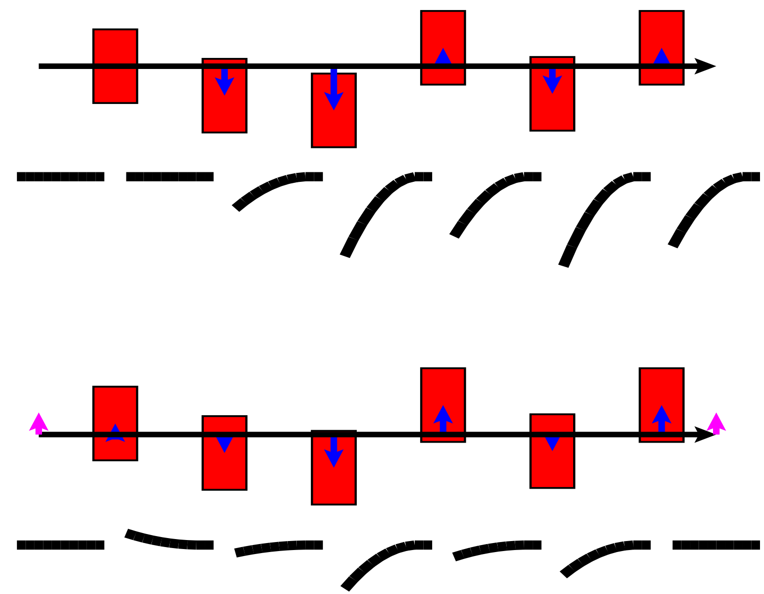






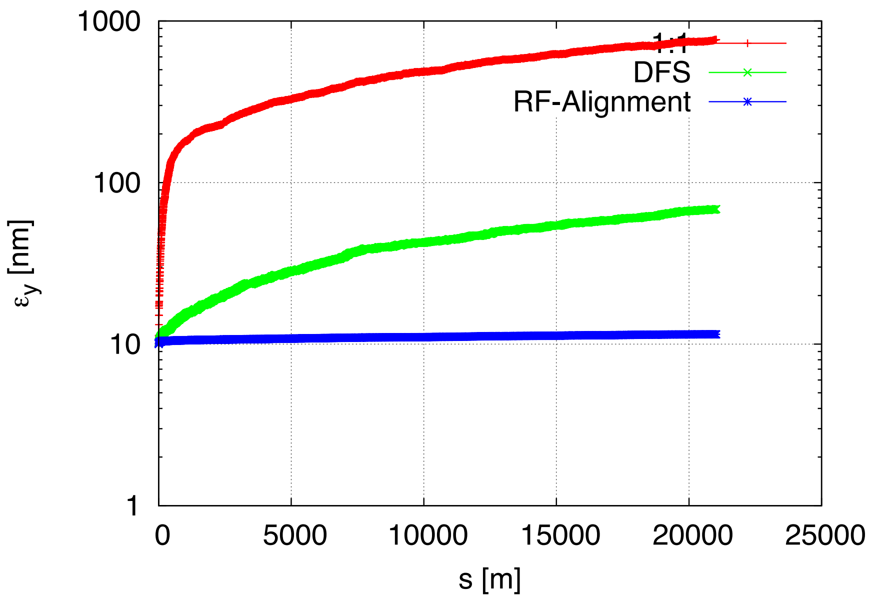
Beam-Based RF-Alignment

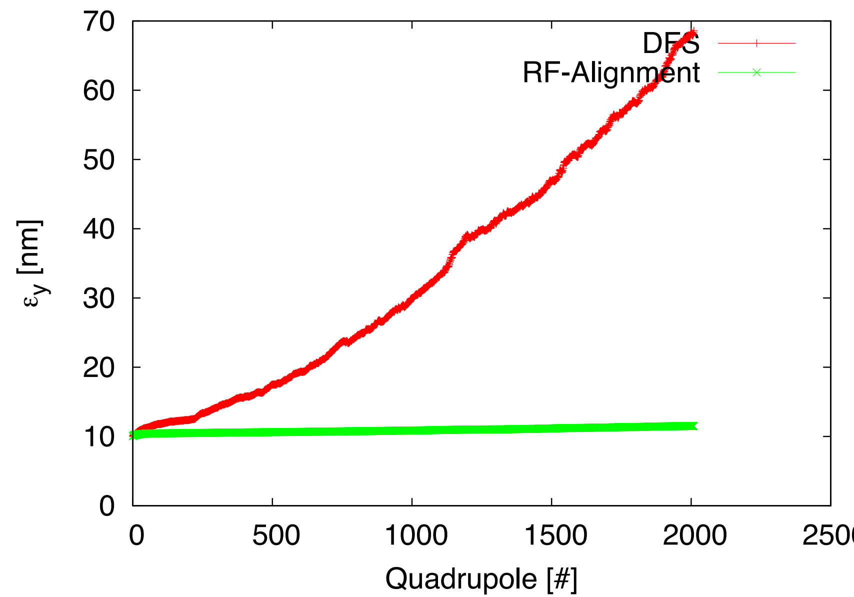
- RF-Alignment moves the girder to zero the average offset of the beam
- Each structure is equipped with a wakefield monitor, positioned with RMS error 5 µm
- Up to eight structures are on a movable girder
- The final mean offset is $\sigma_{wm} / \sqrt{n}$
- Simulations align each cavity individually



Growth along the ML

- Simulation for a CLIC 3 TeV Linac, 100 random seeds

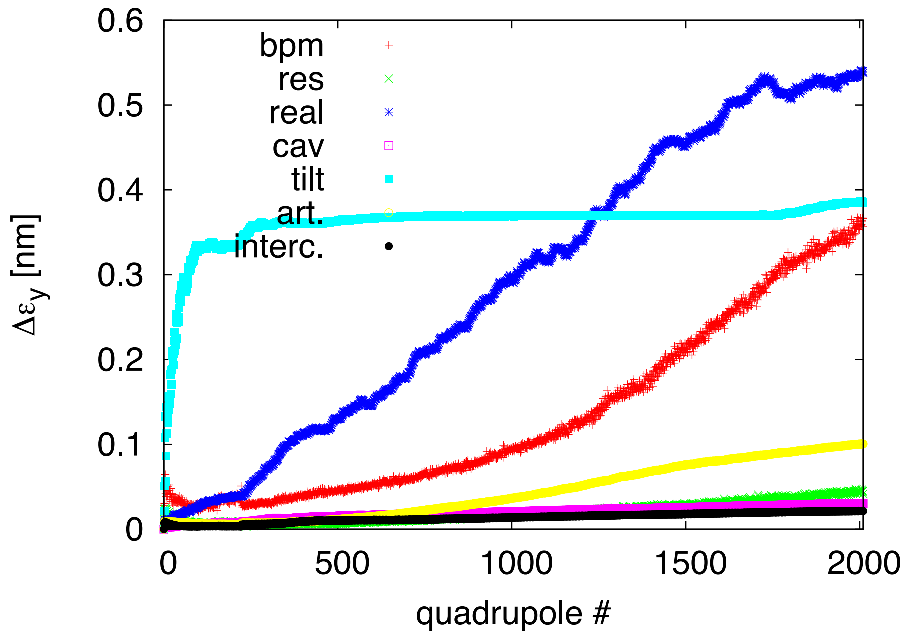




- Emittance preservation goal is achieved

Growth along the ML

- Emittance growth along the main linac due to the different imperfections
- The growth is mainly constant per cell
  - This follows from first principles applied during lattice design
  - Except for structure tilt, due to uncorrelated energy spread (flexible weights to be investigated)
- Some difference for BPMs
  - Due to secondary emittance growth



Experimental Validation

- Experimental validation with a real machine is important

- DFS has never been successfully tested
  - Previous attempts of DFS validation haven't given conclusive results (the reasons have been understood, the principle holds)

Double Challenge: BBA, and SYSID

- System Identification
  - Measures the model / response matrix
  - Good system identification is crucial for BBA
  - Requires a stable machine during measurement
  - Benefits from high BPM resolution
  - Time of convergence proportional to the number of correctors

- Beam-Based Alignment
  - Needs to be validated

Review of possible linac test facilities

Present time:

- SLC-FACET
- DESY's FLASH (small energy 1.6 GeV)
- SPring-8 (small energy, large emittance)

Future:

- Swiss FEL (better, has small emittance <0.6 um)
- DESY's XFEL (large emittance, 1.4 um)

SLAC Linac

https://slacspace.slac.stanford.edu/sites/ard/facet/sarec11/Documents/FACET-S20-beam-parameters.pdf

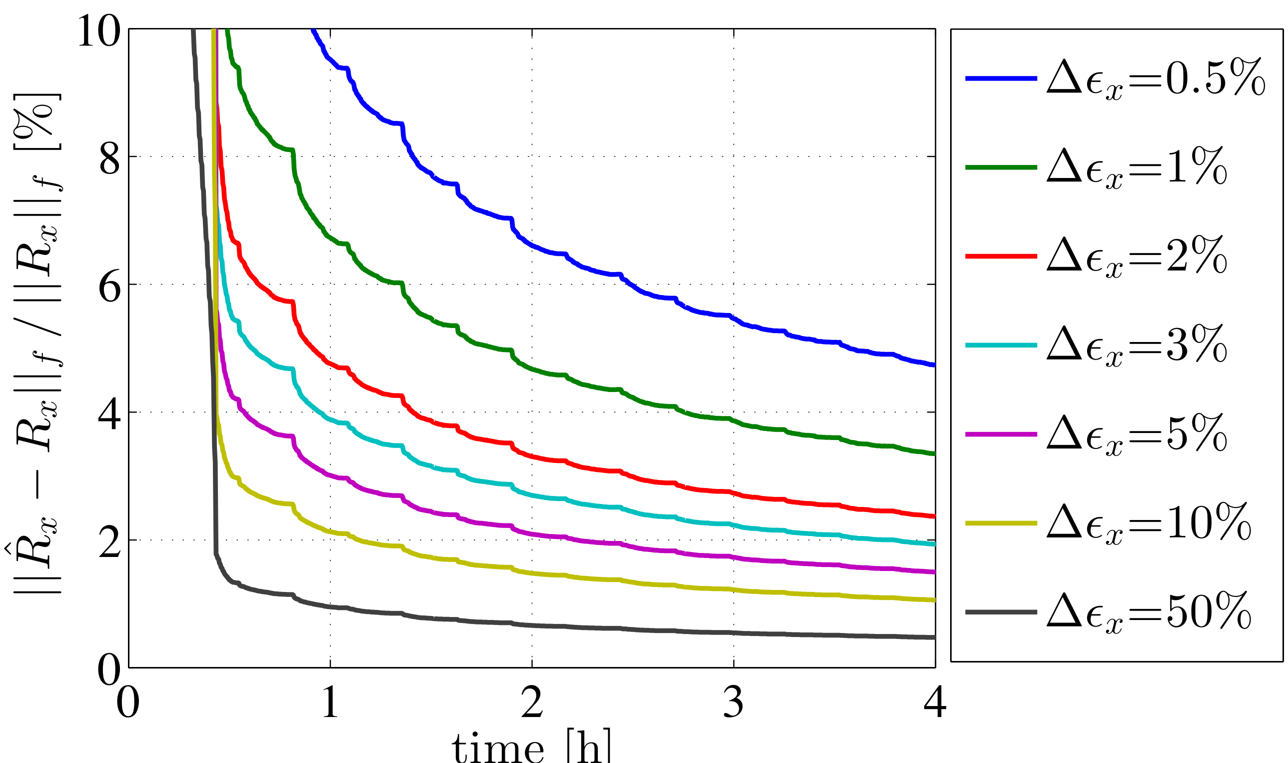
	Start	End	Remark
Energy [GeV]	1.19	23	
En. Spread RMS [%]	1.5	1.0	
Charge [nC]	3.2	3.2	
($\varepsilon_{N,x}$, $\varepsilon_{N,y}$) [μm×rad]	(30, 3)	(30, 3)	normalized emittance
(σ_x, σ_Y) [μm]	(250, 70)	(75, 25)	
σ_z [μm]	1500	100	
Rep. Rate [Hz]	-	1-30	
Length [km]	-	2	

Tests at SLC-FACET

- SLC is the only linac currently available with suitable parameters:
  - Still, large emittances: (30, 2.5) um rad, and large BPM resolution: 50 um (one-shot)
  - Good for testing SYSTEM IDENTIFICATION
  - Good for testing DFS
- Tests are on-going
- We need more beam-time

Simulation of System Identification at FACET

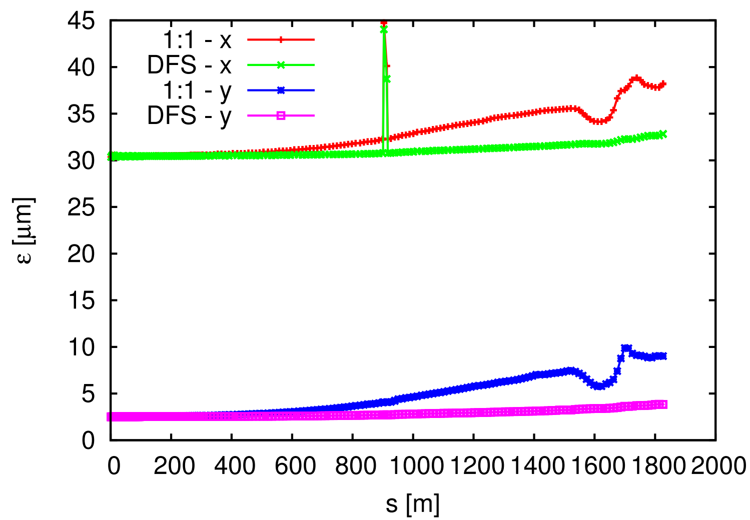
Assumed BPM resolution = 10 um (1 iteration: 15 seconds), 60% of the correctors



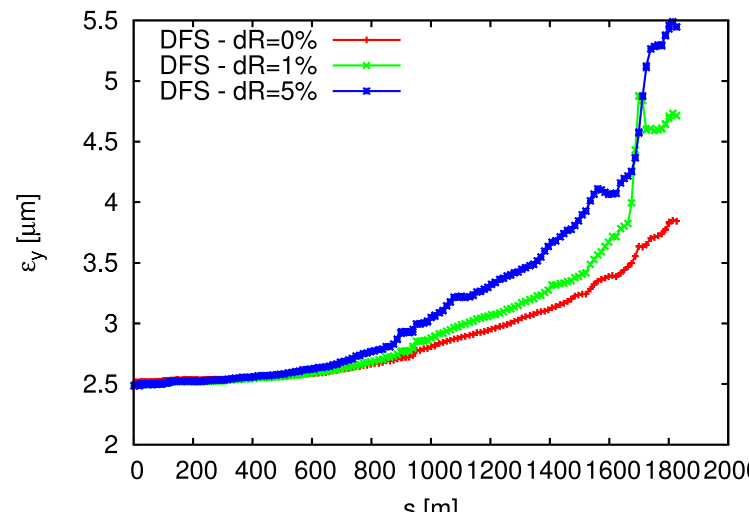
Simulation of BBA at FACET

- SLC beam parameters:
  - Emittances are : (30, 2.5) um
  - Bunch length is 1.5 mm, Simulated bpm resolution is 5 um
  - Energy goes from 1.19 to 23 GeV
- DFS possible using RF-phase offsets in some linac sectors

BBA at SLC



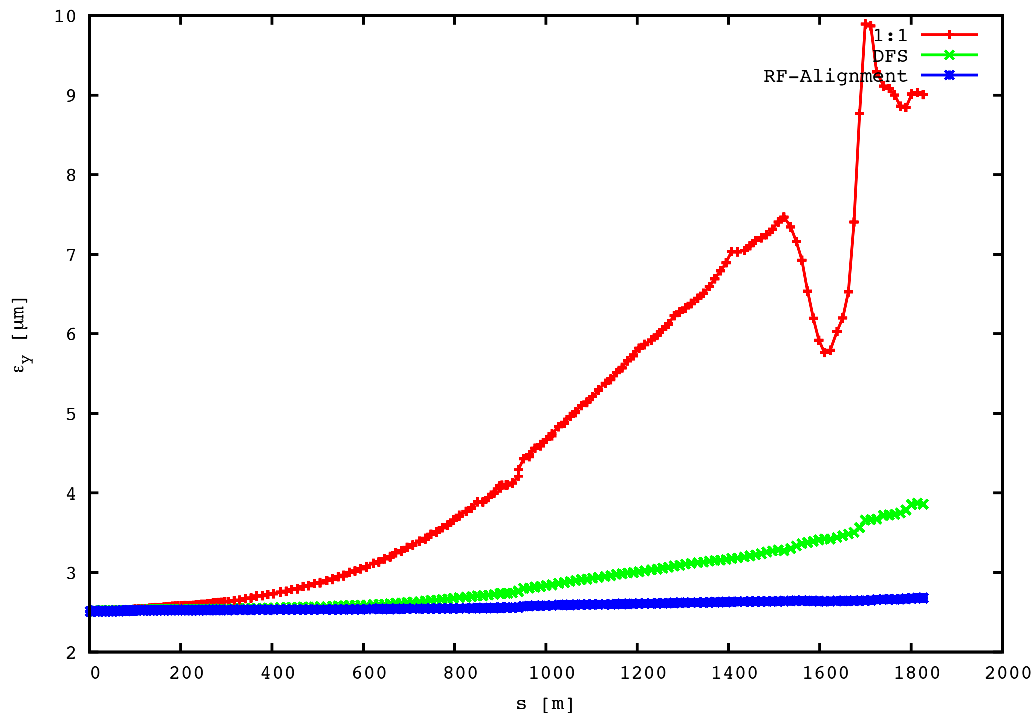
BBA with imperfect model (SYSID)



Final emittance growth after DFS is ~1.4 um (~60%)

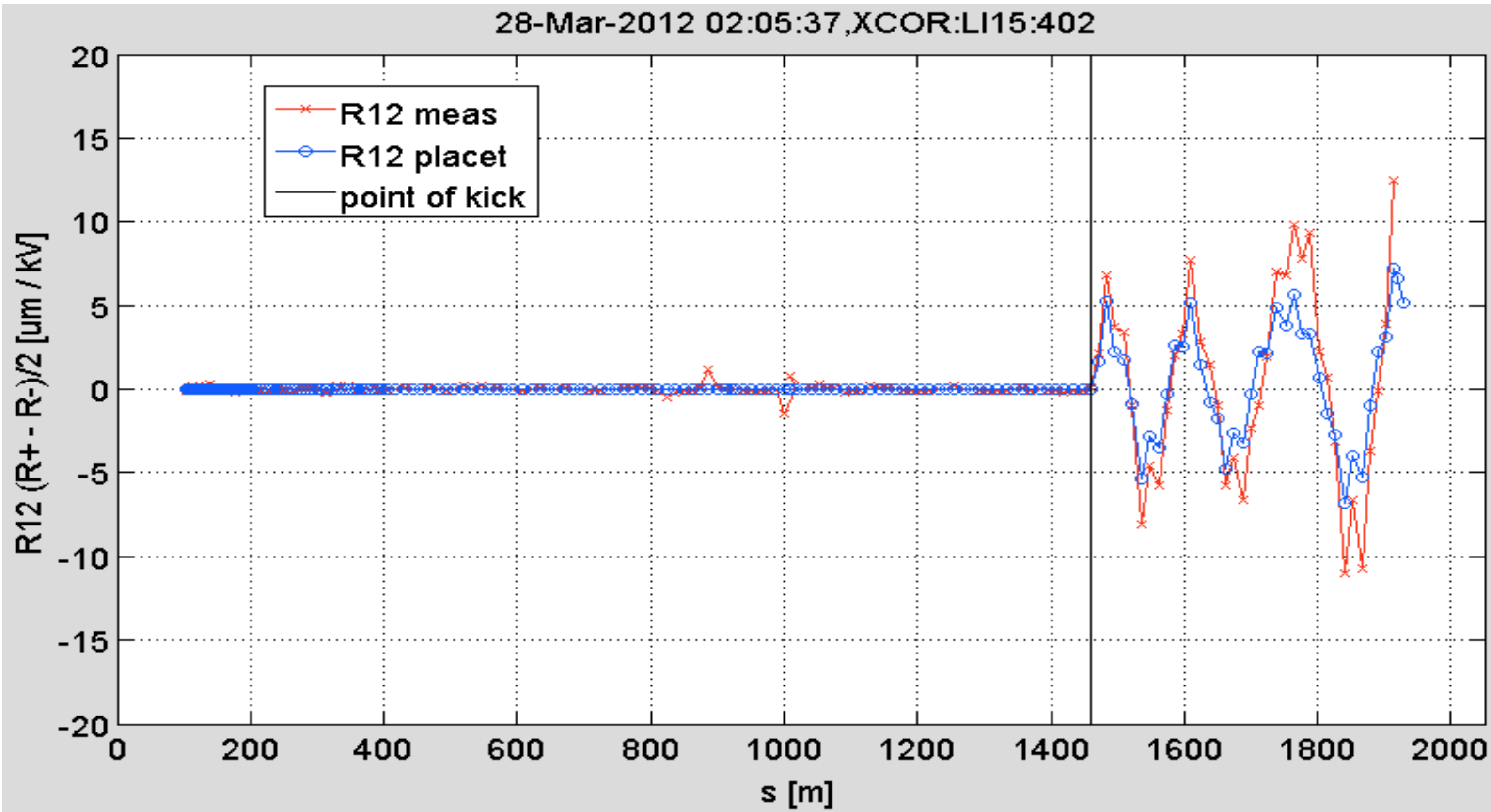
Simulation of RF-Alignment at SLC

We simulated RF-Alignment at SLC (where actually it cannot be applied). The simulations are the average of 100 random seeds.



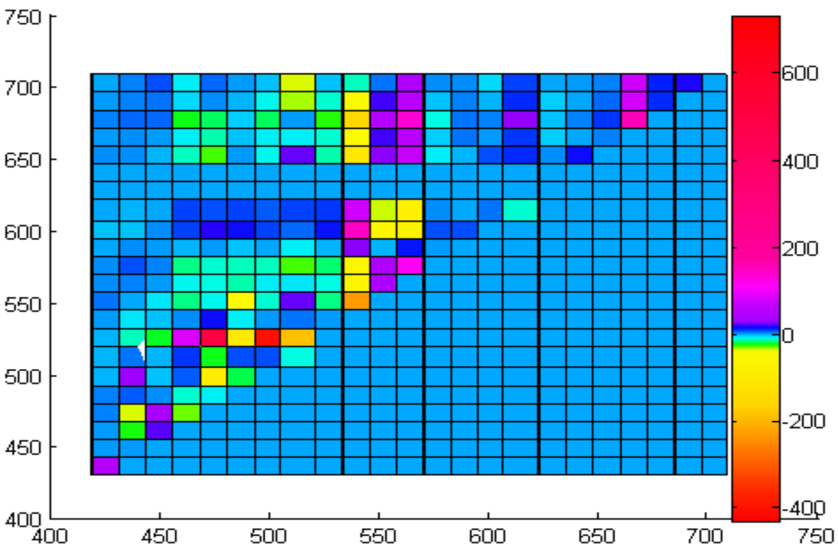
Emittance is recovered completely

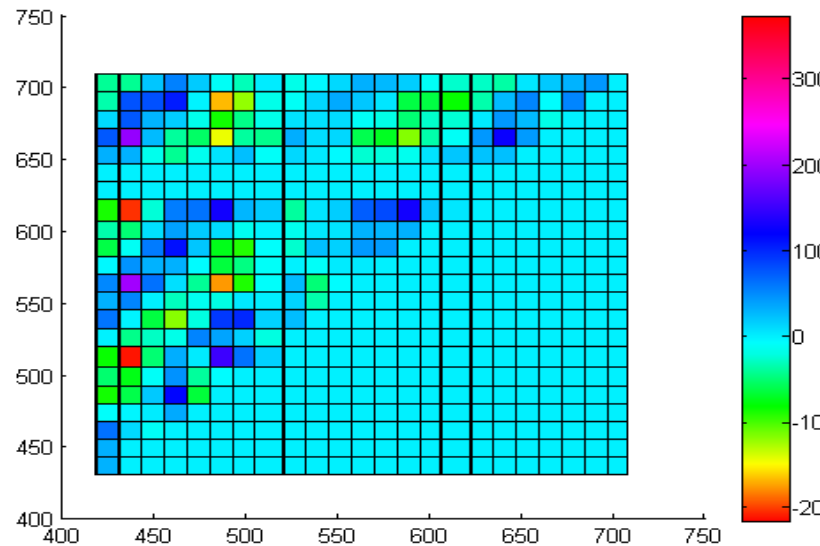
First Tests: Reconstructed R12's for COR:LI15:402



First Tests: System Identification

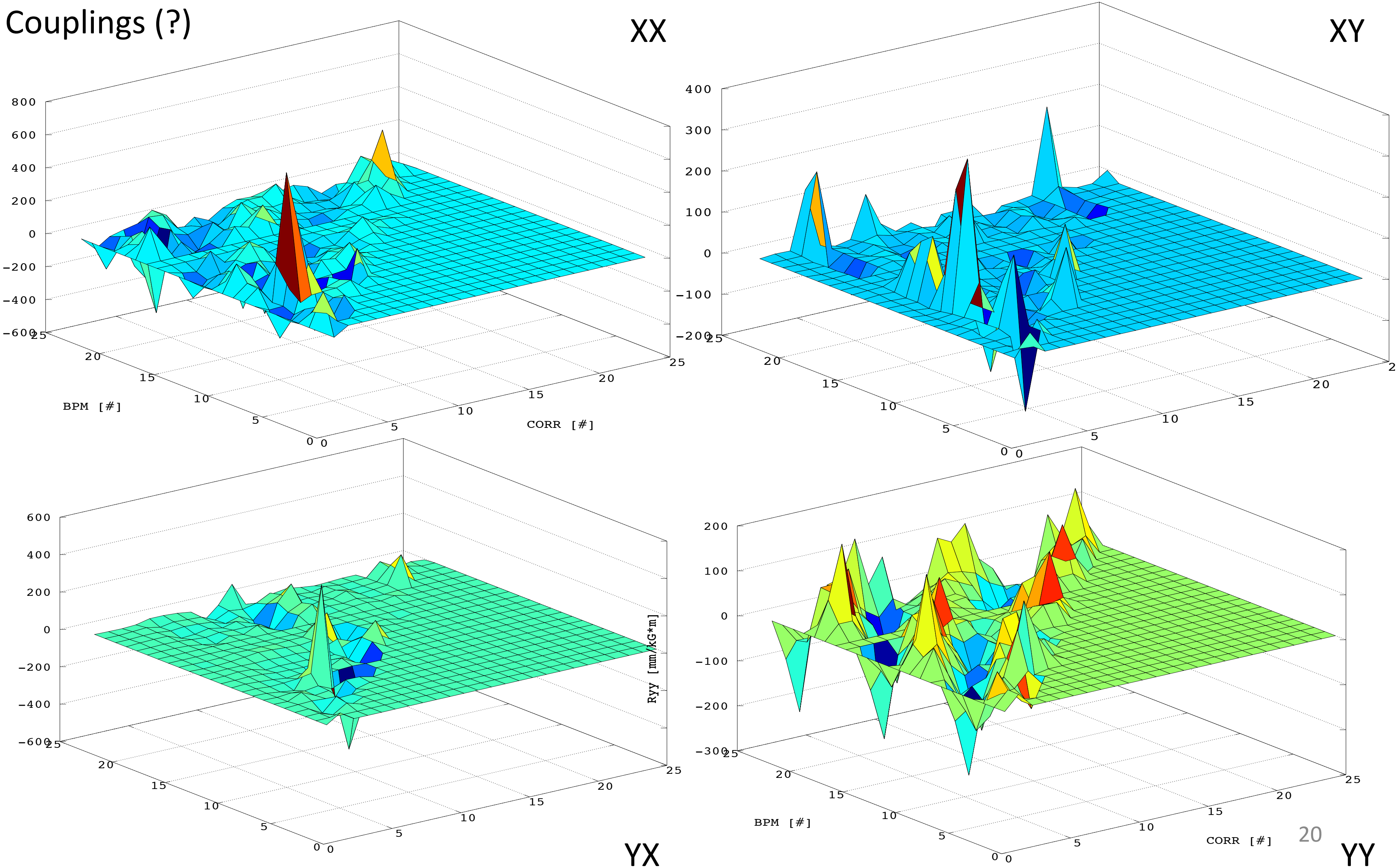
Reconstructed Response matrix for 400 m of linac





Two BPMS are not working.

Couplings (?)


XX
800
600
400
200
0
−200
−400
−600
BPM [#]
CORR [#]
XY
400
300
200
100
0
−100
−200
YX
YY
Ryy [mm/kG*m]
-300
0
5
10
15
20
25

FACET: Status and Plan

- Some tests of control and System Identification have been successful

- We need more beam-time to complete the experiment

- Simulations show that is not straight-forward:
  - Strong wakefields, larger BPM resolution

CLIC and SLC-FACET

CLIC:

- has different beam parameters: smaller emittances
- more advanced diagnostics: <1 um bpm resolution, WF-monitors
- more effective BBA: emittance growth ratio DFS/1:1 is ~15 (due to different optics, BNS damping, bunch compressor support)

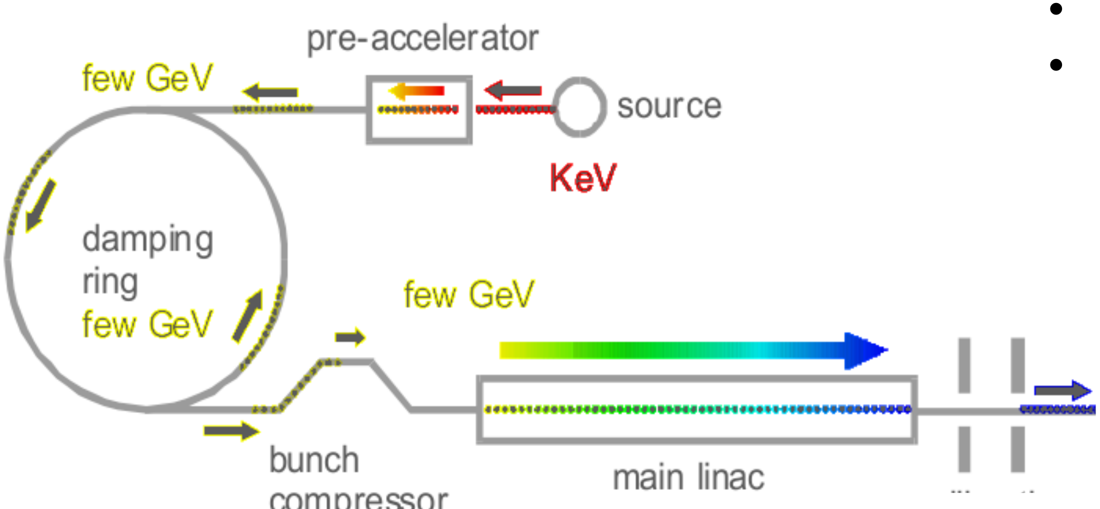
SLC: we have limited beam-time and depend on machine performance

Daniel's Idea for a Test Facility

Damping Ring + Bunch Compressor + Linac + Final Focus /
(alternatively: Light Source + XFEL)

Example parameters:

- 2GeV initial energy,
- 250μm bunch length,
- 0.8*3.7e9 particles



Options for the BC

- CLIC, BC1-like, 0.59 nC:
  - Bunch length: 1.5 mm -> 280 um
  - Energy: 2.86 GeV
  - RF: 2 GHz

- ILC-like, 3.2 nC:
  - BC1: 6-9 mm -> ~1 mm; BC2: ~1 mm -> 300 um
  - Energy: 5 -> 15 GeV
  - RF: 1.3 GHz

- ILC-SB2009: Single-Stage BC, 3.2 nC:
  - Bunch length: 6 mm -> 300 um
  - Energy: 5 GeV
  - RF: 1.3 GHz

Summary and Conclusions

- CLIC emittance preservation relies on beam-based alignment techniques and system identification: experimental validation is important

- An experimental program is foreseen for the next years, but limited by availability and performances of facilities

- Currently, on-going tests at FACET:
  - Great chance to prove SYSID and DFS
  - But it doesn't cover many CLIC specificities (nm emittances, RF-alignment, BC and ML chain for DFS)

CLIC main beam parameters

Parameter	Symbol	CLIC
centre of mass energy	E_{cm}	3000 GeV
luminosity	L	$5.9 \cdot 10^{34}$ cm^{-2}s^{-1}
luminosity in peak	$L_{0.01}$	$2 \cdot 10^{34}$ cm^{-2}s^{-1}
gradient	G	100 MV/m
charge per bunch	N	$3.72 \cdot 10^{9}$
bunch length	σ_z	44 μm
hotizontal emittance	ε_x	600 nm
vertical emittance	ε_y	100 nm
bunches per pulse	n_b	312
distance between bunches	d_b	0.5 ns
repetition frequency	f_r	50 Hz

Final emittance growth in the ML

imperfection	with respect to	symbol	value	emitt. growth
BPM offset	wire reference	σ_{BPM}	14 μm	$0.367\,\mathrm{nm}$
BPM resolution		σ_{res}	0.1 μm	$0.04\,\mathrm{nm}$
accelerating structure offset	girder axis	σ_4	10 μm	$0.03\,\mathrm{nm}$
accelerating structure tilt	girder axis	σ_t	200 μradian	$0.38\,\mathrm{nm}$
articulation point offset	wire reference	σ_5	12 μm	$0.1\,\mathrm{nm}$
girder end point	articulation point	σ_6	5 μm	$0.02\,\mathrm{nm}$
wake monitor	structure centre	σ_7	5 μm	$0.54\,\mathrm{nm}$
quadrupole roll	longitudinal axis	σ_r	100 μradian	$\approx 0.12\,\mathrm{nm}$

Emittance preservation goal is achieved

Potential main linac test facilities

Swiss FEL

http://www.psi.ch/swissfel/swissfel-accelerator

Electron accelerator consisting of a high-brightness electron gun, a booster, three sections of linear accelerator (linac) and two bunch compressors (BC).

Beam Parameters	Start	End	Remark	
Energy [GeV]	2.1	5.8		
En. Spread RMS [%]	0.016	0.006	350 keV	
Charge [nC]	0.2	0.2		
Peak Current [kA]	2.7	2.7		
($\varepsilon_{N,x}$, $\varepsilon_{N,y}$) [μm×rad]	(~0.6, ~0.6)	(~0.6, ~0.6)	normalized emittance	
σ_z [μm]	7500	7.5		
RF [GHz]	-	6	NC	
Length [km]	-	0.8		

DESY's FLASH

http://www.xfel.eu/sites/site_xfel-gmbh/content/e63594/e65073/e126274/e134426/13Feldhaus_StatusandExtensionofFLASH_eng.pdf

Possible long-term scenario for FLASH

	FLASH1	FLASH2	FLASH3
Energy (GeV)	0.7-1.6	0.7-1.6	0.7-1.6
Peak current (kA)	2.5	2.5	2.5
Charge (nC)	0.5	0.5	0.5
Normal. emittance (mm mrad)	1.0*	1.3	2.0
Energy spread (MeV)	0.2	0.5	1.0
Wavelength range @ 1.6 GeV	1.5 – 2	2.5-6.5	8-12
Undulator period (mm)	23	31.4	36
Minimum gap	10	9	9
Saturation length	<36	<30	<20
Total wavelength range**	1.5 – 10	2.5 – 40	8 – 80

DESY's XFEL Linac

http://xfel.desy.de/technical_information/electron_beam_parameter/

Main Linac Section 2/2

Beam Parameters	Start	End	Remark	
Energy [GeV]	2.5	20		
En. Spread RMS [%]	0.1	0.01	2.5 MeV	
Charge [nC]	1	1		
Peak Current [kA]	-	5×10^{-6}		
$(\varepsilon_{N,x}, \varepsilon_{N,y})$ [μm×rad]	(1.4, 1.4)	(1.4, 1.4)	normalized emittance	
σ_z [μm]	2×10^{3}	24		
Acc. Gradient [MV/m]	-	23.6	ILC/TESLA like cavities	
Length [km]	-	3.4		
Rep. Rate [Hz]	-	10		

SPring-8

http://epaper.kek.jp/l96/PAPERS/TUP44.PDF

Beam Parameters	Start	End	Remark	
Energy [GeV]	?	1.15		
En. Spread RMS [%]	1	0.45		
Charge [nC]	3	3		
$(\varepsilon_{N,x}, \varepsilon_{N,y})$ [μm×rad]	(100,100)	(100,100)	normalized emittance	
σ_z [μm]	2×10^3	24		
Energy stability RMS [%]	-	0.02		
Length [km]	0.140			

Grenoble - ESRF

Storage Ring: http://www.esrf.eu/Accelerators/Performance/Parameters

Energy	GeV	6.03
Maximum Current	mA	200
Horizontal Emittance	nm	4
Vertical Emittance (*minimum achieved)	nm	0.025 (0.010*)
Coupling (*minimum achieved)	%	0.6 (0.25*)
Revolution frequency	kHz	355
Number of bunches		1 to 992
Time between bunches	ns	2816 to 2.82