Damping ring experimental program

Yannis PAPAPHILIPPOUCERN

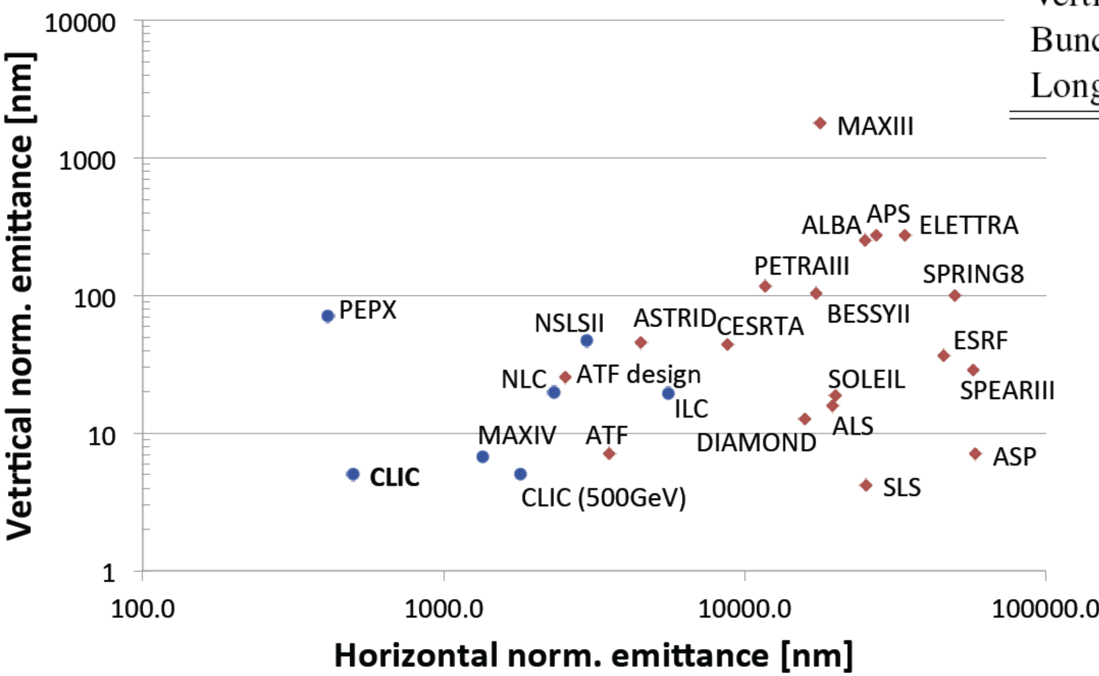
Special thanks to Hermann Schmickler

May 9th, 2012

CLIC DR parameters

- CLIC damping rings target ultra-low emittance in all 3 dimensions for relatively high bunch charge
- Dominated by collective effects (IBS, space-charge, e-cloud, FII, CSR,…)

Parameters	CLIC@3TeV
Energy [GeV]	2.86
Circumference [m]	427.5
Energy loss/turn [MeV]	4.0
RF voltage [MV]	5.1
Stationary phase [°]	51
Momentum compaction factor	1.3e-4
Damping time x/s [ms]	2/1
Number of dipoles/wigglers	100/52
Dipole/wiggler field [T]	1.0/2.5
Bend gradient [$1/m^2$]	-1.1
Bunch population [10^9]	4.1
Horizontal normalized emittance [nm.rad]	456
Vertical normalized emittance [nm.rad]	4.8
Bunch length [mm]	1.8
Longitudinal normalized emittance [keVm]	6.0

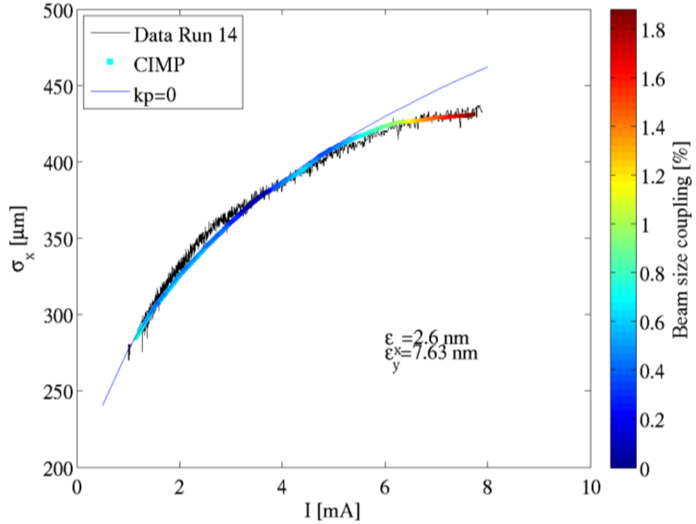


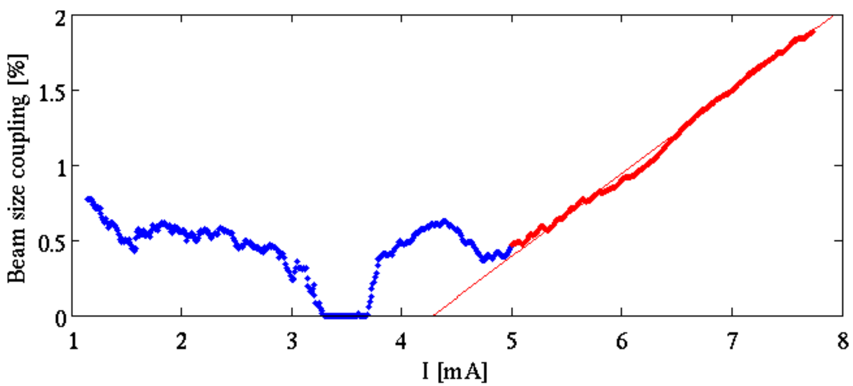
- Challenging technology (SC wigglers, Extraction kickers, RF system, Vacuum, Instrumentation, Feedback)

CLIC DR beam dynamics experiments

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

F. Antoniou





DR technology and experimental program

- Super-conducting wigglers
  - Demanding magnet technology combined with cryogenics and high heat load from synchrotron radiation (absorption)
- Prototype built in BINP, to be tested in ANKA (2013-2014)

- High frequency RF system
  - 1.5GHz RF system in combination with high power and transient beam loading
- Discussions with ALBA and SLAC (**HELP NEEDED**)

- Coatings, chamber design and ultra-low vacuum
  - Electron cloud mitigation, low-impedance, fast-ion instability
- Measurements at SPS, ESRF, CERTA, discussions with MAXlab

- Kicker technology
  - Extracted beam stability
- Stripline designed by Spanish industry, to be tested in ALBA, pulser in collaboration with SLAC, Full system test in ATF

- Diagnostics for low emittance
  - Profile monitors, feedback
- V-UV Profile Monitor (TIARA), initiated collaboration with ALBA

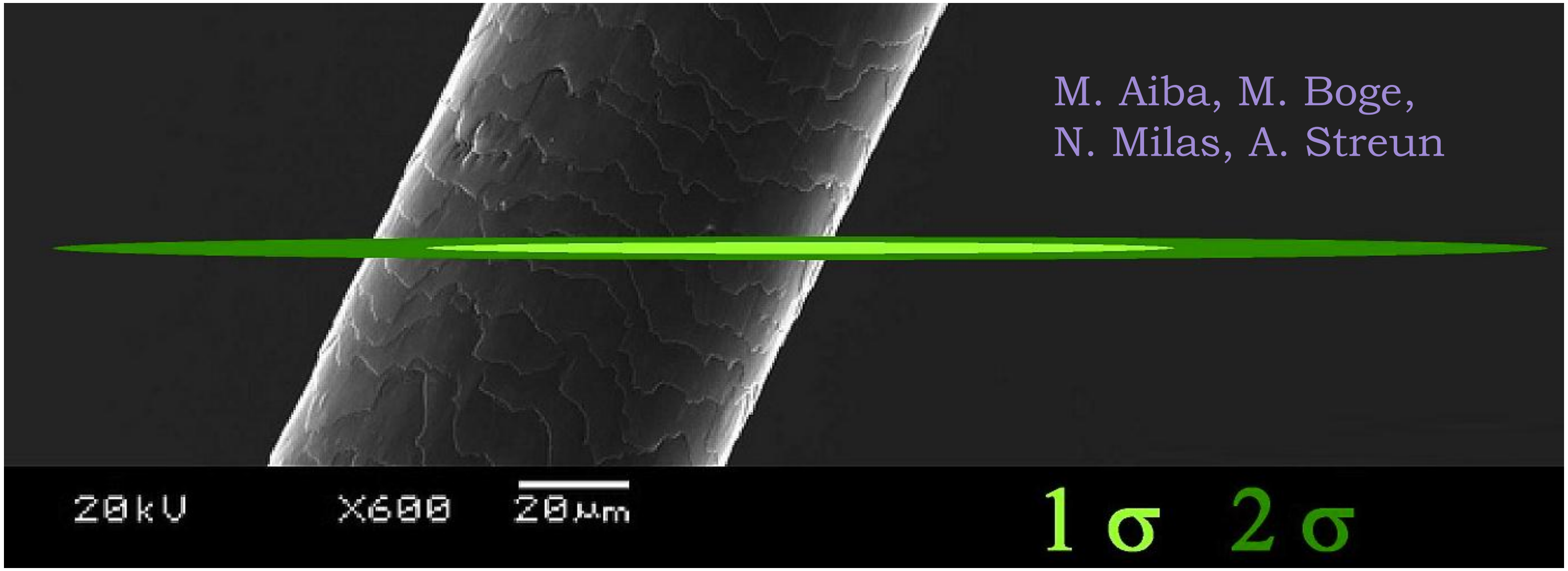
DR R&D

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-…	

WP6 - SVET

- SVET: “SLS Vertical Emittance Tuning”
- Objectives:
  - Allow the Swiss Light Source (SLS) to be used as an R&D Infrastructure
  - Demonstrate ultra-small vertical emittances as required for future Linear Collider Damping Rings (e.g. 5 nm normalized, <1 pm @ 2.86 GeV for CLIC)
  - Enable to extend tests to lower energies (IBS dominated regime).

Vertical emittance WORLD RECORD



- After re-alignment campaign of last autumn, series of MD shifts scheduled (end of 2011)
- Beam of 400 mA stored in top up mode
- Different methods of coupling suppression using 36 skew quadrupoles (combination of response matrix based correction and random walk optimisation)
- Performance of existing emittance monitor had to be further stretched to get beam profile data at a size of around 3-4µm
- Vertical emittance reduced to a minimum value of **0.9±0.4pm** (CLIC damping rings target vertical emittance) which is a **new world record**
- Work in progress for reproducibility of this result and understanding of systematic model errors

Low Emittance Rings' network

- Bring together scientific communities of **synchrotron light sources' storage rings, damping rings** and **lepton colliders** in order to communicate, identify and promote common work on topics affecting the design of low emittance lepton rings
- Initiated by a Low Emittance Ring workshop, 01/2010@CERN, see http://cern.ch/ler2010
- State of the art in design of accelerator systems especially in X-ray storage rings approaches the goals of damping rings for linear colliders and future B-factories' upgrade projects
- Common tasks identified including beam dynamics but also technology
- Second workshop in 10/2011 @ Heraklion acts as a catalyzer, see http://cern.ch/lowering2011
- Collaboration network enable scientific interaction and coordination for common design work including measurements and tests in existing facilities for achieving ultra-low emittance, high intensity beams with remarkable stability

Low-ε-Ring Coordination and Tasks

- Coordinators: Y. Papaphilippou (CERN), S. Guiducci (INFN-LNF), R. Bartolini (STFC-JAI-DIAMOND)
- Members: M. Biagini (INFN-LNF), M. Boege (PSI), R. Nagaoka (Soleil), H. Schmickler (CERN)
- Additional non-EU members: M. Palmer (Cornell), J. Urakawa (KEK)
  - Participants but not contractual partners

- Task 1: Low Emittance Ring Design (LERD)
  - Coordinator: M. Boege (PSI)
- Task 2: Beam INstabilities, Impedances and Vacuum (BINIV)
  - Coordinator: R. Nagaoka (SOLEIL)
- Task 3: Low Emittance Rings Technology (LERT)
  - Coordinator: H. Schmickler (CERN)
- Interest expressed by the 28 following institutes: ANKA-KIT, ANL, Australian Synchrotron, BESSY/HZM, BINP, BNL-NSLSII,CELLS-ALBA, CERN, Cockroft Ins, CIEMAT, Cornell Un., DESY, Elettra, ESRF, FNAL, IFIC-Valencia, INFN-LNF, JASRI/SPring-8, JAI-DIAMOND, KEK, LBNL, MAXLAB, NTUA, PSI-SLS, SLAC, SOLEIL, Un. Of Creta, Un. Of Thessaloniki.

Dream Damping Ring Test Facility

- Ring achieving lowest possible emittances in all three dimensions, in the range of few GeV
  - Vertical and longitudinal easier than horizontal
- Short bunch train structure similar to damping rings
  - Bunch spacing of 0.67ns (1.5GHz RF system) should be a good compromise
- Space for installing wigglers, kickers (and extraction line), vacuum test areas, RF, instrumentation
- Beam conditions for studying IBS, space-charge, low emittance tuning, e-cloud (positrons), fast ion instability, CSR…
  - High brightness single bunches/trains, small bunch length
- Available beam time for experimental tests

SPS

Evans and Schmidt, 1988

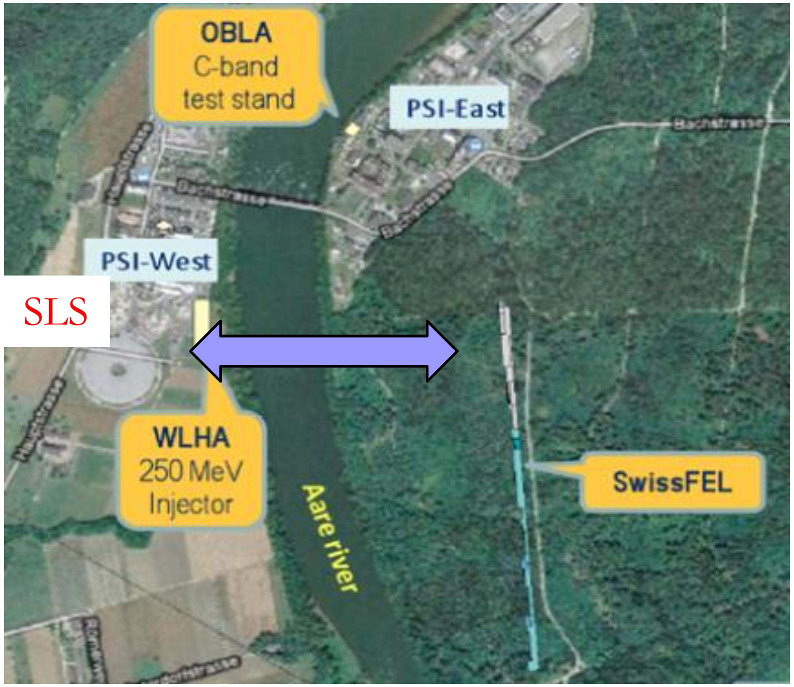
A	B	F	G	H	I
VARIABLES		*WITH WIGGLER*		Intrabeam scattering	
ETA	0.0018	brho	13.3424	ep	0.001637
VOLTS(V)	4.00E+07	wiggler deflection	0.00356	A	3.9E-06
Q VALUE	27	Bending radius	14.04463	k	0.005958
MOMENTUM COMPAC	0.0018	2*pi*rho^2	1239.369	a	0.003439
BETA (V/C)	1	F	0.005544	d	0.997034
ENERGY DPN JE	2	***Parameters With wiggler on***		lnc2a	8.492016
RADIAL DPN JX	1	Energy loss per turn	5.51E+06	Tx(sec)	1.37E+00
ENERGY(EV)	4.00E+09	Energy damping time	1.67E-02	Tz(sec)	1.23E+02
PARTICLES/BUNCH	5.00E+09	Horizontal damping time	3.34E-02		
HORIZONTAL BETA	40	Energy spread	9.11E-04		179.3655
VERTICAL BETA	40	Synchrotron Tune	0.168447		85.4419
HARMONIC NUMBER	10000	Bunch length sigma	1.07E-02		532.8773
BWIGGLER (TESLA)	0.95	Sigmasquared/beta	3.63E-10		27.19585
Pole Length	0.05	Normalised emittance	2.84E-06		179.3655
Total Wiggler Length	300	Norm long emit	7.64E-02		

- Already proposed as damping ring for CLIC and lately LHeC
- Low energies (4-10 GeV) in coasting mode
- Need wigglers (~300m) to get low horizontal emittance (3microns) and fast damping (a few tens of ms)
  - May gain by lattice modification
- RF system upgrade
  - Total voltage needed (Energy loss/turn of a few tens of MeV)
  - Different RF frequency (the higher the better)
- Need to revive lepton injector (now CTF) and transfer lines

Papaphilippou 2011

Parameter [unit]	High Rep-rate	Low Rep-rate
Energy [GeV]	10	7
Bunch population [10^9]	1.6	1.6
Bunch spacing [ns]	2.5	2.5
Number of bunches/train	9221	9221
Repetition rate [Hz]	100	10
Damping times trans./long. [ms]	2/1	20/10
Energy loss/turn [MeV]	230	16
Horizontal norm. emittance [μm]	20	100
Optics detuning factor	80	80
Dipole field [T]	1.8	1.8
Dipole length [m]	0.5	0.5
Wiggler field [T]	1.9	-
Wiggler period [cm]	5	-
Total wiggler length [m]	800	-
Dipole length [m]	0.5	0.5
Longitudinal norm. emittances [keV.m]	10	10
Momentum compaction factor	10^{-6}	10^{-6}
RF voltage [MV]	300	35
rms energy spread [%]	0.20	0.17
rms bunch length [mm]	5.2	8.8
average power [MW]	23.6	3.6

SLS

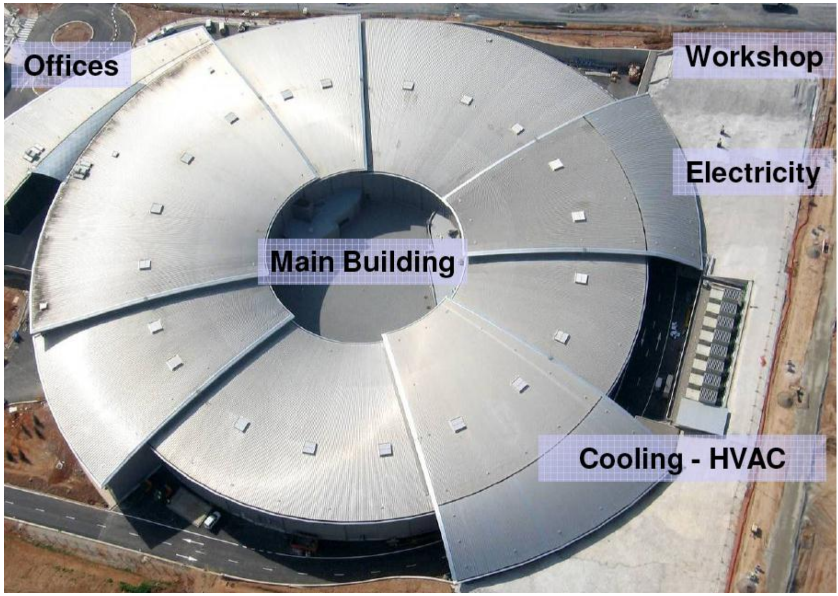


SLS Parameter	Value
Energy [GeV]	2.411
Circumference [m]	288
Energy loss/turn [MeV]	0.54
RF voltage [MV]	2.1
Mom. Comp. factor	$6.05e^{-4}$
Damping times h/v/l [ms]	8.59/8.55/4.26
Hor. emittance [nm rad]	5.6
Vert. emittance [pm rad]	0.9
Bunch length [mm]	3.8
Energy spread [%]	0.086

- Ultra-low emittances and ability to run at low energies
  - Horizontal norm. emittance of 26microns (2.4GeV) down to 5microns (1.6GeV)
  - Record vertical emittance of 0.9pm @ 2.4GeV (4.2nm normalized!!!). This is translated to 2.8nm normalized if established @ 1.6GeV
  - Bunch length of ~4mm, energy spread of 0.09% (long. norm. emittance of 7.9keV.m @ 2.4GeV)
- 1.5GHz, 3rd Harmonic cavity
- Proximity with Swiss FEL (can EAST meet WEST or 1 river to cross?)
- Very close to the dream test facility
  - BUT mainly a user facility

ALBA

- Recently commissioned
- Horizontal emittance of 4nm (23microns normalised, vertical not yet fully op
- Ability to run at lower energies (not demonstrated)
- RF system powered with IOTs
- 3rd harmonic cavity (1.5GHz)
- Super-conducting wiggler from BINP
- Some free straight sections for installing new equipment for tests
- Not yet fully booked by users but it will come

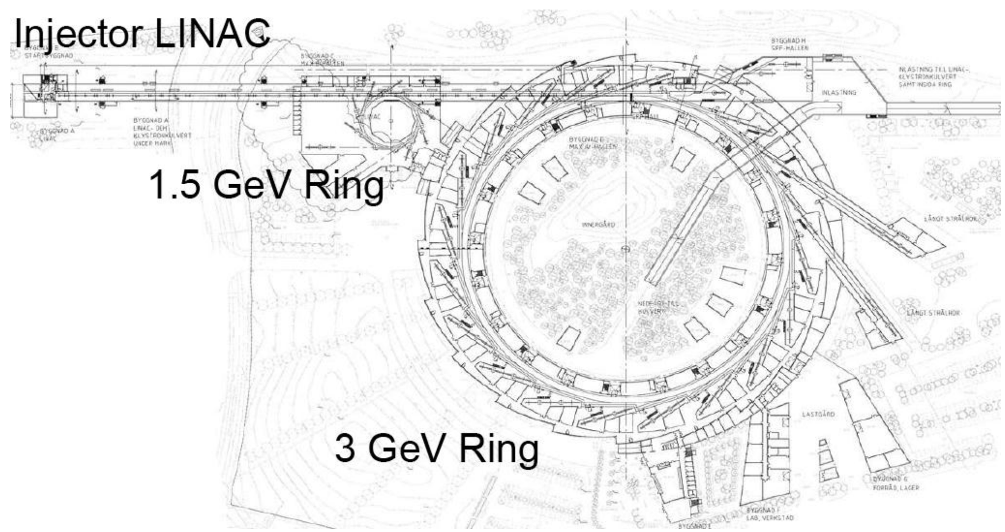


Electron beam energy	3.0 GeV
Storage Ring Circumference	268.8 m
Number of cells	16
Symmetry	4
Straight section lengths	4 x 8.0 m
	12 x 4.4 m
	8 x 2.6 m
Beam current	400 mA
Emittance	< 4 nm.rad
Lifetime	> 10 h

MAXIV

- Ultra-low horizontal emittance for 3GeV ring
  - 0.2nm @ 3GeV including IBS effect (1micron normalized) using high field (2.2T) PM wigglers
- A lot of fancy features
  - Compact magnets, multipole kicker, high-field wigglers, instrumentation
- 100MHz RF system
  - Long bunches of 50mm rms length using Landau cavity
- Commissioning of ring starts in 2015

Energy	3	1.5	GeV
Average Current	500	500	mA
Circumference	528	96	m
Horizontal Emittance	0.2 - 0.4	6	nm rad
# Straight Sections	20	12	
Length of Straight Section	4.8	3.5	m
Hor Beam Size	45	184	µm
Vert Beam Size	2	13	µm
Beam Lifetime	10	10	hours



ATF

IP parameter	nominal	04/2010	12/2010	02/2012
beam energy	1.3 GeV	1.3 GeV	1.3 GeV	1.3 GeV
ε_x	2 nm	1.7 nm	1.8-2.7 nm	1.84 nm
ε_y	12 pm	<10 pm	28-64 pm	15.6 pm
β_x*	4 mm	40 mm	10 mm	10 mm
β_y*	0.1 mm	1.0 mm	1.0 mm	0.3 mm
σ_x*	2.8 μm	10 μm	7.5 μm	4.3 μm
σ_y*	35 nm	900 nm	439 (247?) nm	165 (100?) nm

- Ideal for extraction kicker studies
  - Double kicker system
- Low vertical emittance <10pm
  - A lot of beam size instrumentation
- First IBS studies
- Discussions for ATF3 damping ring experimental program combined with FF studies

CESRTA

Lattice Parameters

Ultra low emittance baseline lattice

Energy [GeV]	2.085	5.0	5.0
No. Wigglers	12	0	6
Wiggler Field [T]	1.9	—	1.9
Q_x	14.57		
Q_y	9.62		
Q_z	0.075	0.043	0.043
V_{RF} [MV]	8.1	8	8
ε_x [nm-rad]	2.5	60	40
$\tau_{x,y}$ [ms]	57	30	20
α_p	6.76×10^{-3}	6.23×10^{-3}	6.23×10^{-3}
σ_l [mm]	9	9.4	15.6
σ_E/E [%]	0.81	0.58	0.93
t_b [ns]	≥4, steps of 2		

Range of optics implemented

Beam dynamics studies

Control γ flux in EC experimental regions

E[GeV]	Wigglers (1.9T/PM)	ε_x[nm]	
1.8	12/0	2.3	IBS Studies
2.085	12/0	2.5	IBS Studies
2.3	12/0	3.3	IBS Studies
3.0	6/0	10	
4.0	6 /0	23	
4.0	0 /0	42	
5.0	6/0	40	
5.0	0/0	60	
5.0	0/2	90	

- Huge effort for e-cloud evaluation and mitigation
  - Positrons and electrons, vacuum chamber test areas
- High-field wigglers
- Variable energy, low horizontal emittance

- Low Emittance Tuning
- IBS measurements
- Instrumentation for position, beam size, e-cloud
- Future running?

Linear Collider Test Accelerator / PEPII

	CesrTA	ILC	CLIC	LCTA/ PEP-II
Energy [GeV]	**2 - 5**	**5**	**2.86**	**2.86 - 5**
Circumference [m]	764	3200	493	2199
εx [nm-rad, 0 curr.]	2.5	0.6	0.07	0.3
εy [**pm**-rad, 0 curr.]	7	**2**	**0.9**	**0.9**
Beam Current [A]	0.06	0.4	0.35	0.5
Number of bunches	45	1300	312	1100
Bunch population	2×10^{10}	2×10^{10}	4.1×10^{9}	2×10^{10}
spacing, bs [ns]	4	6	0.5	6
σz [mm]	9	6	1.4	9
α	6.7×10^{-3}	3.3×10^{-4}	6×10^{-5}	-

LCTA - Extraction Line

IP Nominal parameters and LCTA/PEP-II extraction line parameters.

	ILC IP	CLIC IP	LCTA – EXT LINE
Energy, E0 [GeV]	250	1500	2.86
Norm. Emittance, $\gamma\varepsilon x$ [um]	10	0.66	2
Norm. Emittance, $\gamma\varepsilon y$ [um]	0.04	0.02	0.005
$\beta^{*}y$ [mm]	0.4	0.068	0.1
Vertical Beam Size [nm]	5.7	1	**9**
Bunch length [um]	300	44	9000

Factor 4 smaller than ATF2 goals

Conclusion

- A number of existing or future low emittance rings are approaching design goals of CLIC damping rings
- Some of them can be combined with a bunch c… test facility

May the dream come true

- Difficulty lies less on establishing an experimental program but more on the machine availability for running such experiments