Damping Rings Towards Ultra-low Emittances

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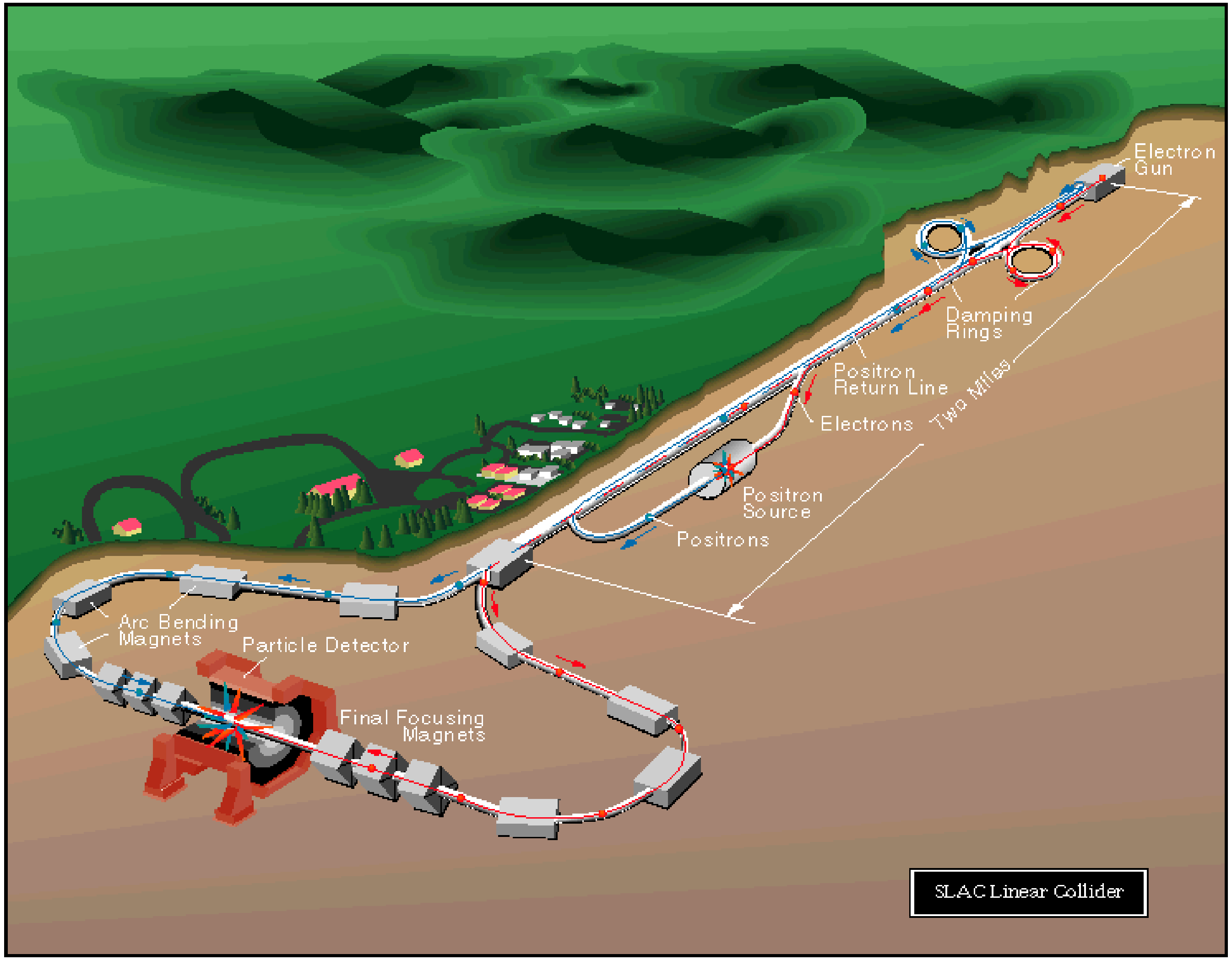
EPAC06

Edinburgh, 28 June 2006

Damping Rings (DR)

- DR are necessary to strongly reduce the beam emittance to achieve the small spot sizes required by high luminosity colliders
- SLC experience has demonstrated the importance of the DR in order to achieve the proper beam sizes and beam stability at the IP
- For ILC and CLIC projects DR are a crucial subsystem and a big effort has been put in design optimization

SLC Layout

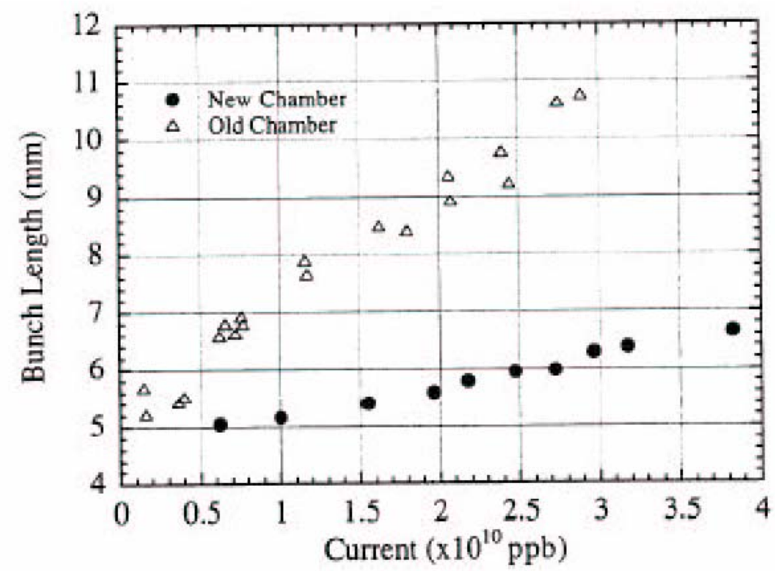


Electron Gun
Damping Rings
Positron Return Line
Electrons
Two Miles
Positron Source
Positrons
Arc Bending Magnets
Particle Detector
Final Focusing Magnets
SLAC Linear Collider

SLC DR Experience

- "Old" ring: threshold current for longitudinal microwave instability very low. Above threshold small pulse-to-pulse variation in bunch length and longitudinal phase of the extracted beam (saw-tooth instability) ⇒ almost impossible to operate the collider

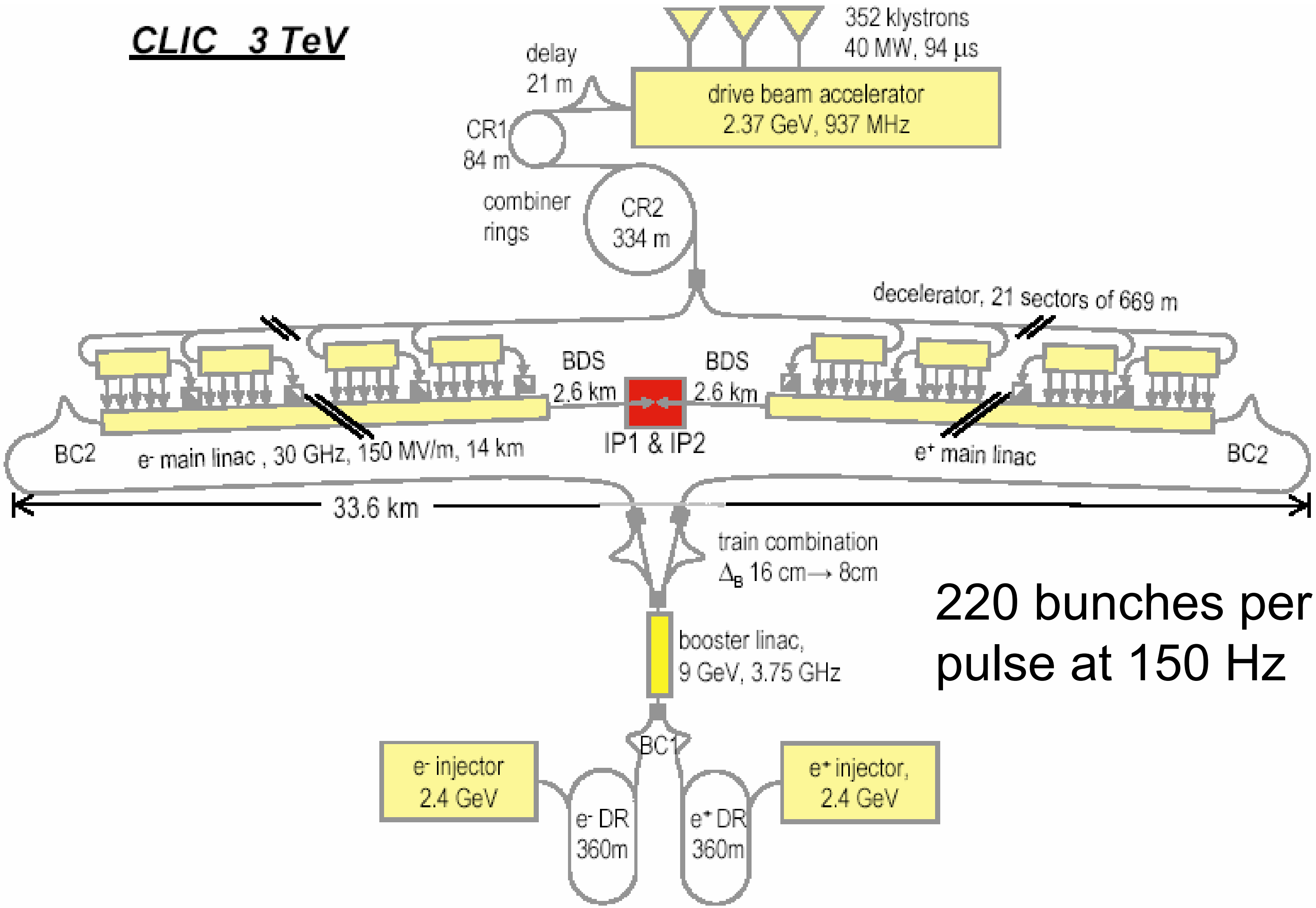
- "New" ring: new, low impedance vacuum chamber installed in '94 ⇒ bunch lengthening reduced but threshold also went down ("weak instability")
- Possible to routinely run DRs at more than twice the threshold, increasing the number of particles per bunch by a factor ~1.5 with respect to the old ring



SLC, ILC and CLIC DR Parameters

	SLC	ILC	CLIC
Energy (GeV)	1.19	5	2.4
C (m)	35	6695	360
N bunches	1	2767	1554
N part./bunch	$4\mathrm{x}10^{10}$	$2\mathrm{x}10^{10}$	$2\mathrm{x}10^{9}$
$\tau_{x,y}$ (ms)	3.5	25	2.8
$\gamma\varepsilon_x$ (nm)	$3\mathrm{x}10^{4}$	5600	550
$\gamma\varepsilon_y$ (nm)	$1.7\mathrm{x}10^{4}$	20	3.3
Mom. comp.	$1.5\mathrm{x}10^{-2}$	$4.1\mathrm{x}10^{-4}$	$0.81\mathrm{x}10^{-4}$
U_0 (MeV)	0.080	8.7	2.1
Energy spread	$0.77\mathrm{x}10^{-3}$	$1.29\mathrm{x}10^{-3}$	$1.26\mathrm{x}10^{-3}$
σ_l (mm)	5	6.0	1.55
RF volt.(MV)	0.8	46.6	2.4
RF freq.(MHz)	714	650	1875

CLIC layout



220 bunches per pulse at 150 Hz

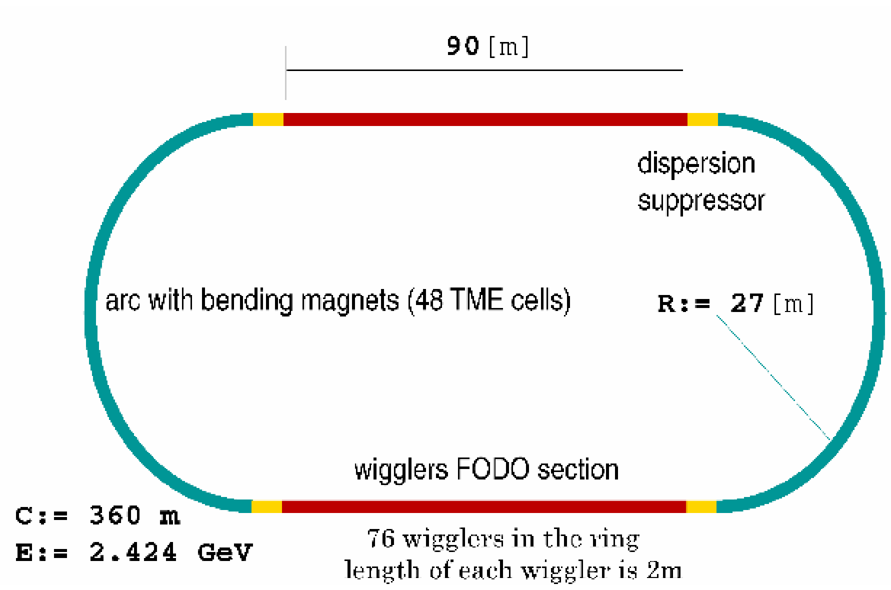
CLIC DR

- Ultra-low normalized equilibrium emittances

  $\gamma\varepsilon_y$ = 3.3 nm, $\gamma\varepsilon_x$ = 550 nm

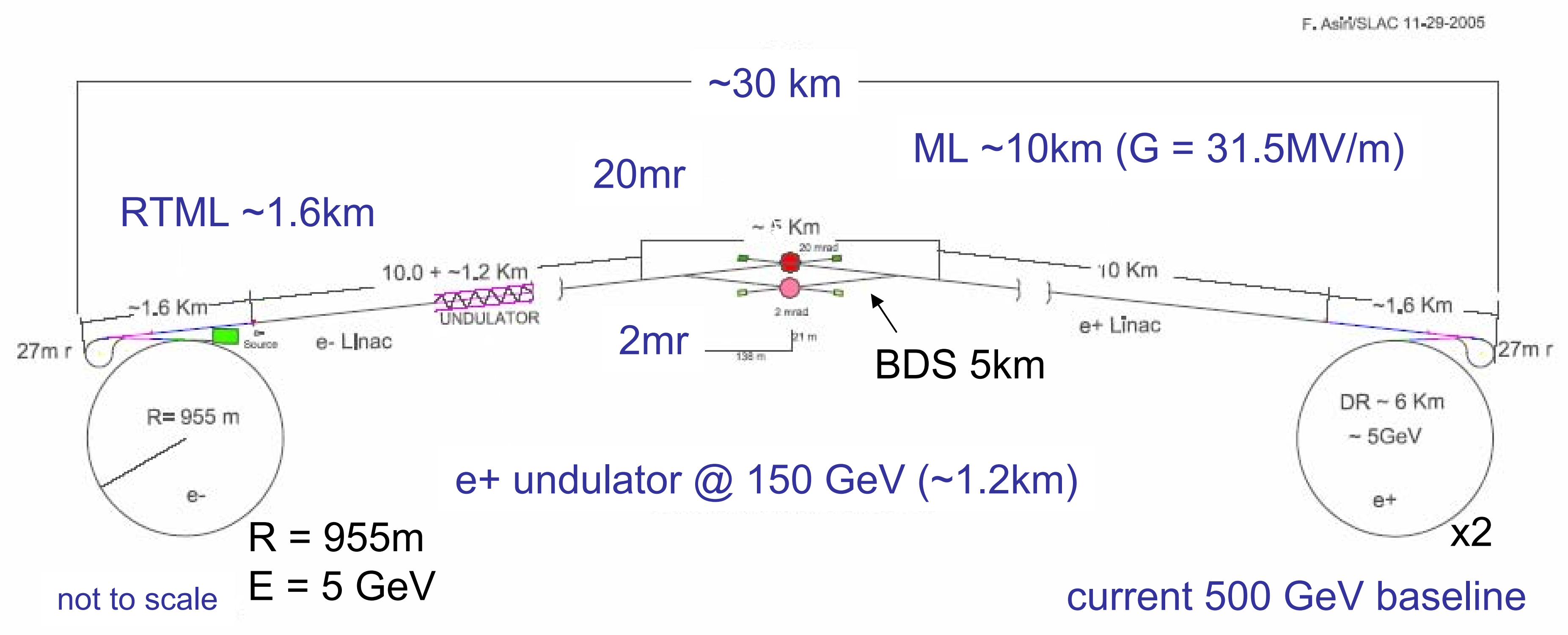
  $2.6 \cdot 10^9$ particles

  E = 2.4 GeV $\Rightarrow \varepsilon_y < 1$pm



- The dominant emittance growth mechanism is Intra-Beam Scattering (IBS).
- Intense synchrotron radiation damping from wigglers is required to counteract IBS effect

ILC Baseline Configuration



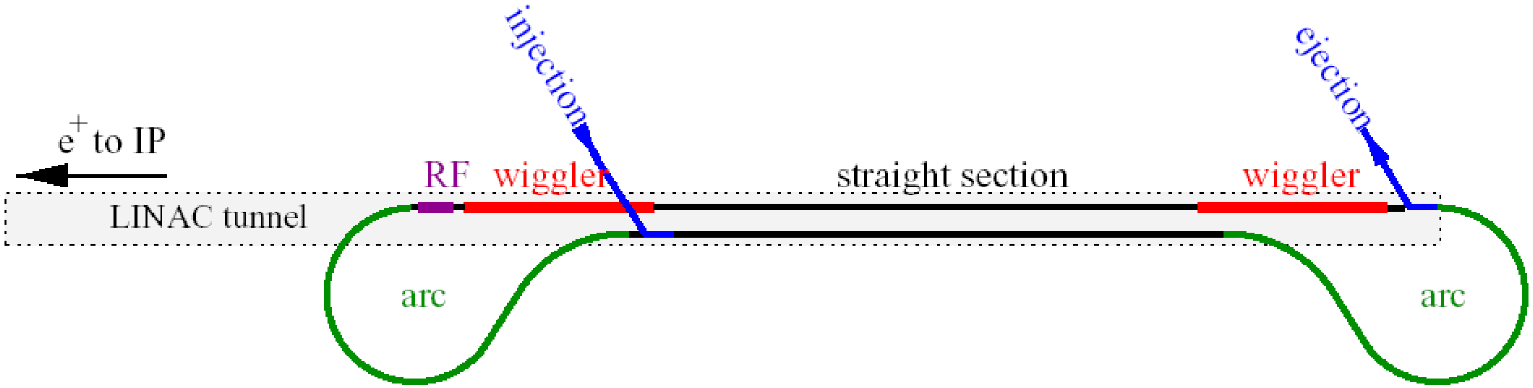
- General layout above was formally accepted as baseline at the Frascati GDE meeting

ILC DR

- Baseline Configuration Recommendation choice made at "ILCDR meeting" at CERN, November 2005
- Based on the work of ~50 researchers from America, Asia and Europe
- Reported in a detailed document (300 pages): A. Wolski, et al. "Configuration Studies and Recommendations for the ILC Damping Rings", LBNL-59449, February 2006

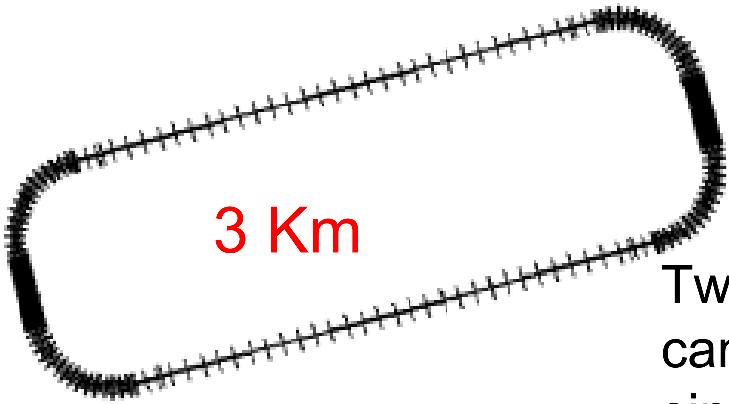
Circumference options

from TESLA dogbone 17 Km to 6 & 3 Km

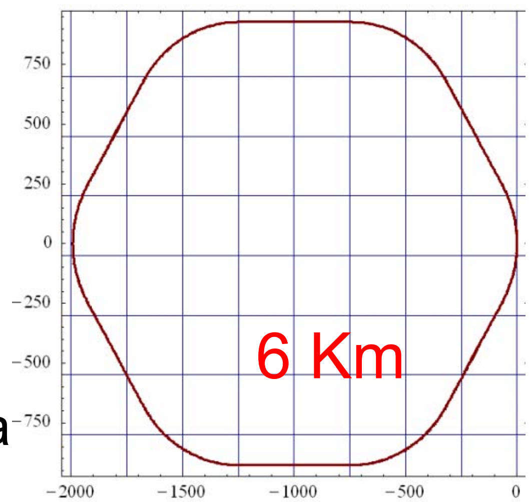


3 or 6 km rings can be built in independent tunnels

“dogbone” straight sections share linac tunnel



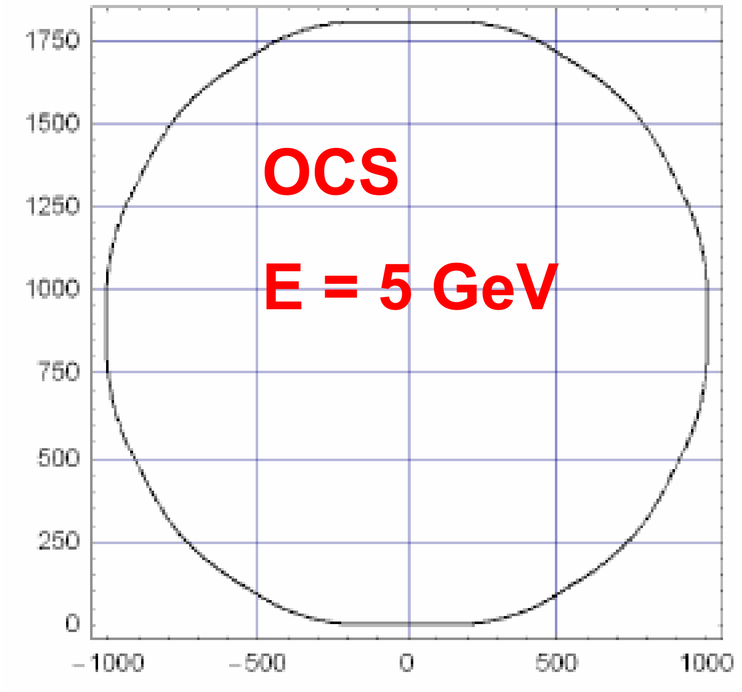
Two or more rings can be stacked in a single tunnel



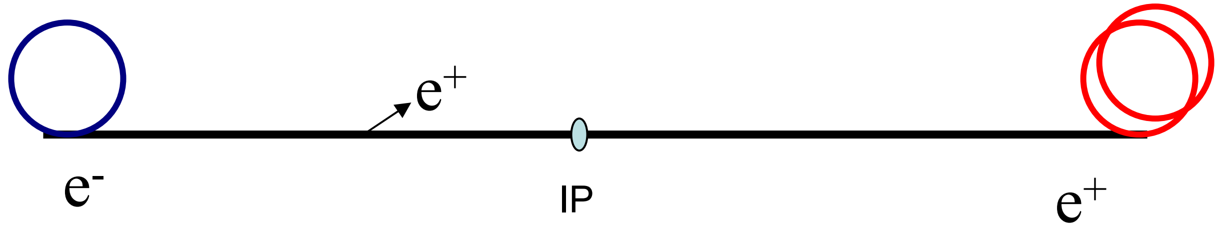
Baseline Configuration

Recommendation

- Positrons: **two** (roughly circular) rings of **~ 6 km** circumference
- Electrons: **one** ~6 km ring



- 2 tunnels at both linac ends
- e^+ rings vertically stacked in 1 tunnel

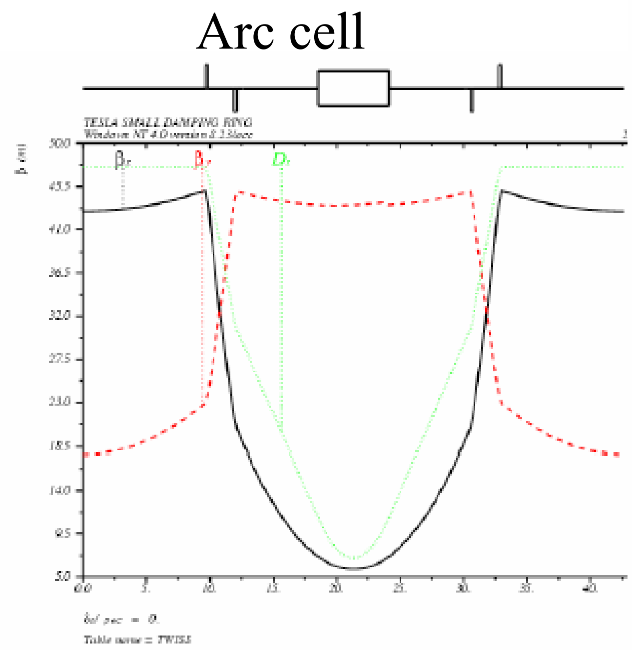


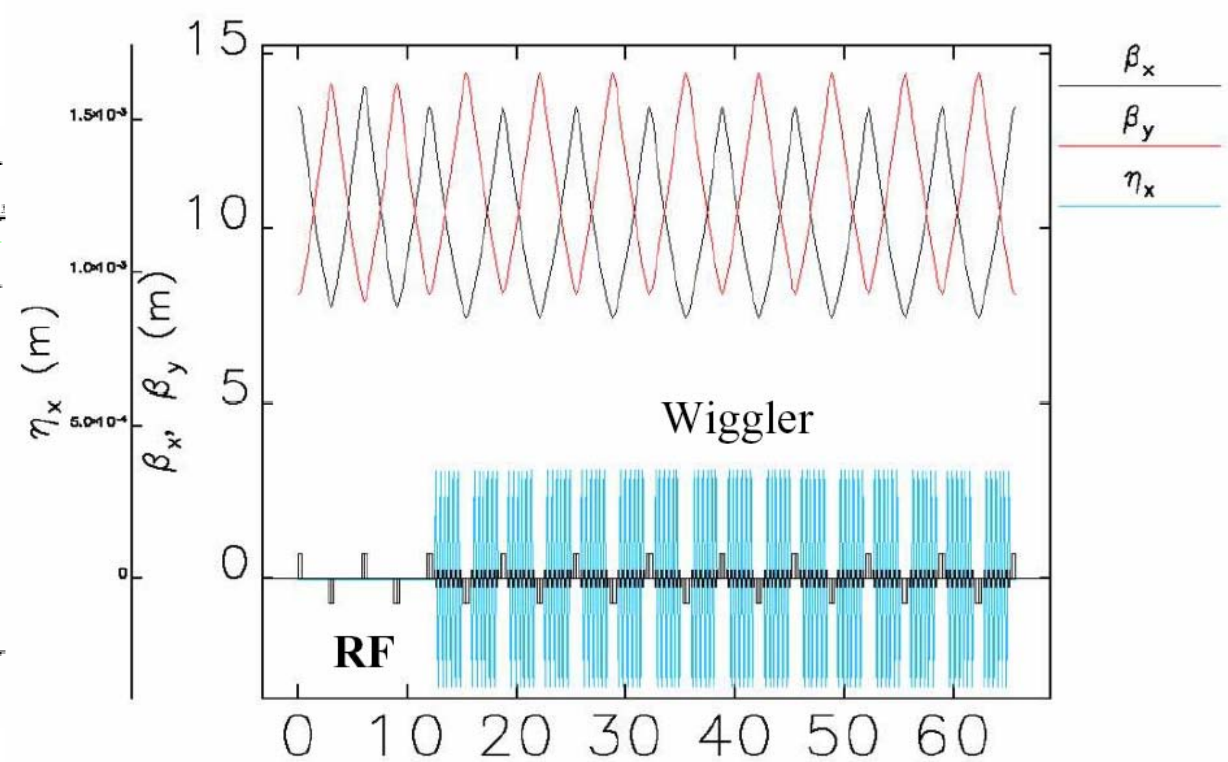
Issues for the circumference choice

- Acceptance
  - achieving a large acceptance is easier in a circular 6 km ring than in a dogbone ring.
- Collective effects
  - Electron-cloud effects make a single 6 km positron ring unattractive, unless significant progress can be made with mitigation techniques.
  - Space-charge effects will be less problematic in a 6 km than in a 17 km ring
  - The electron ring can consist of a single 6 km ring, assuming that the fill pattern allows a sufficient gap for clearing ions.
- Kickers
  - The injection/extraction kickers are more difficult in a shorter ring; at present the kickers for a 6 km ring are considered feasible even thought more R&D is required to fulfil all the specifications.

Lattice Description

- The ring is has 10-fold symmetry, with 10 long straight sections.
- 4 straight sections contain wigglers and RF cavities
- 2 accommodate injection/extraction lines and tune adjustment sections
- Each of the 10 arcs is made of 7 TME cells plus dispersion suppressor





A. Xiao, http://www.desy.de/~awolski/ILCDR/USTeleconference_files/2006-03-01/ILC1.pdf

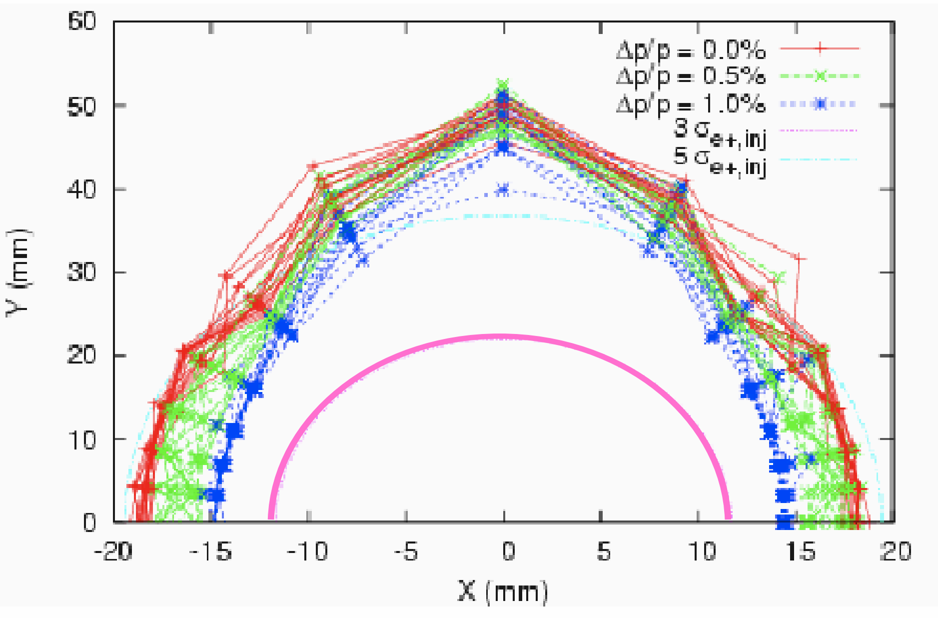
Acceptance

- A large acceptance is needed to inject the high emittance positron beam with high efficiency
- Extensive Dynamic Aperture (DA) studies on 7 reference lattices have been performed
- Calculations have been performed with different wiggler models and different codes, finding a good agreement
- OCS lattice achieves 100% injection efficiency
- Tracking studies were done to determine the effects of the physical aperture in the wiggler, which is expected to be the limiting aperture

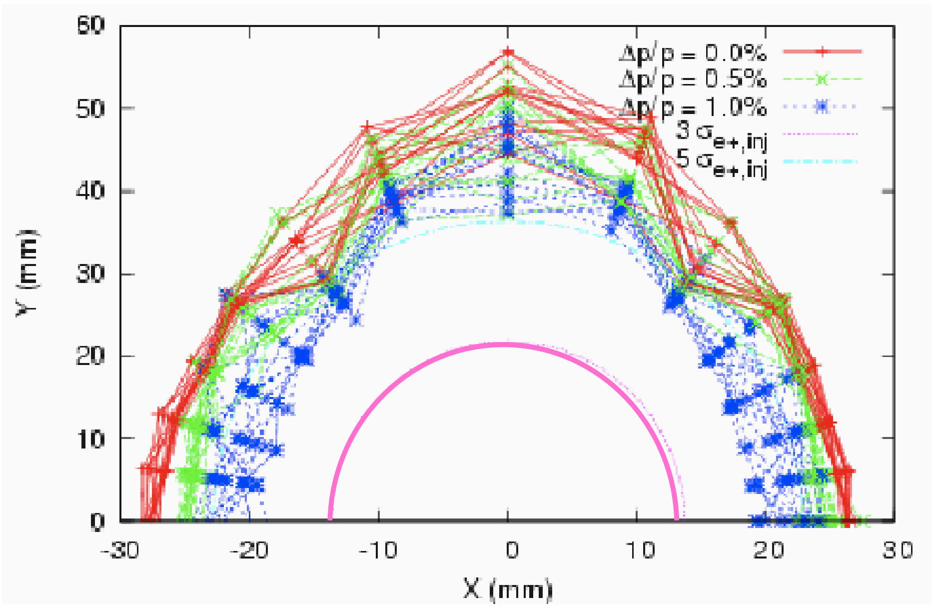
Dynamic aperture in the OCS lattice

Nominal injection requirement: 3 $\sigma_{e+,inj}$; $\Delta p/p<0.5\%$

Dynamic aperture with ideal nonlinear wiggler model and multipole errors.



Dynamic aperture with CESRc wiggler model and multipole errors.



Low emittance tuning

- Achievement of ultra low vertical emittance is one of the challenges of DR
- Very good alignement tolerances, low sensitivity to alignment errors, beam based alignment techniques, efficient coupling and dispersion correction algorithms, with high resolution BPMs are required
- Simulations show that, assuming KEK ATF ring alignment errors a design vertical emittance of 2 pm could be achieved in the OCS ring

MOPLS140 - J. Jones
MOPLS135 - M. Korostelev

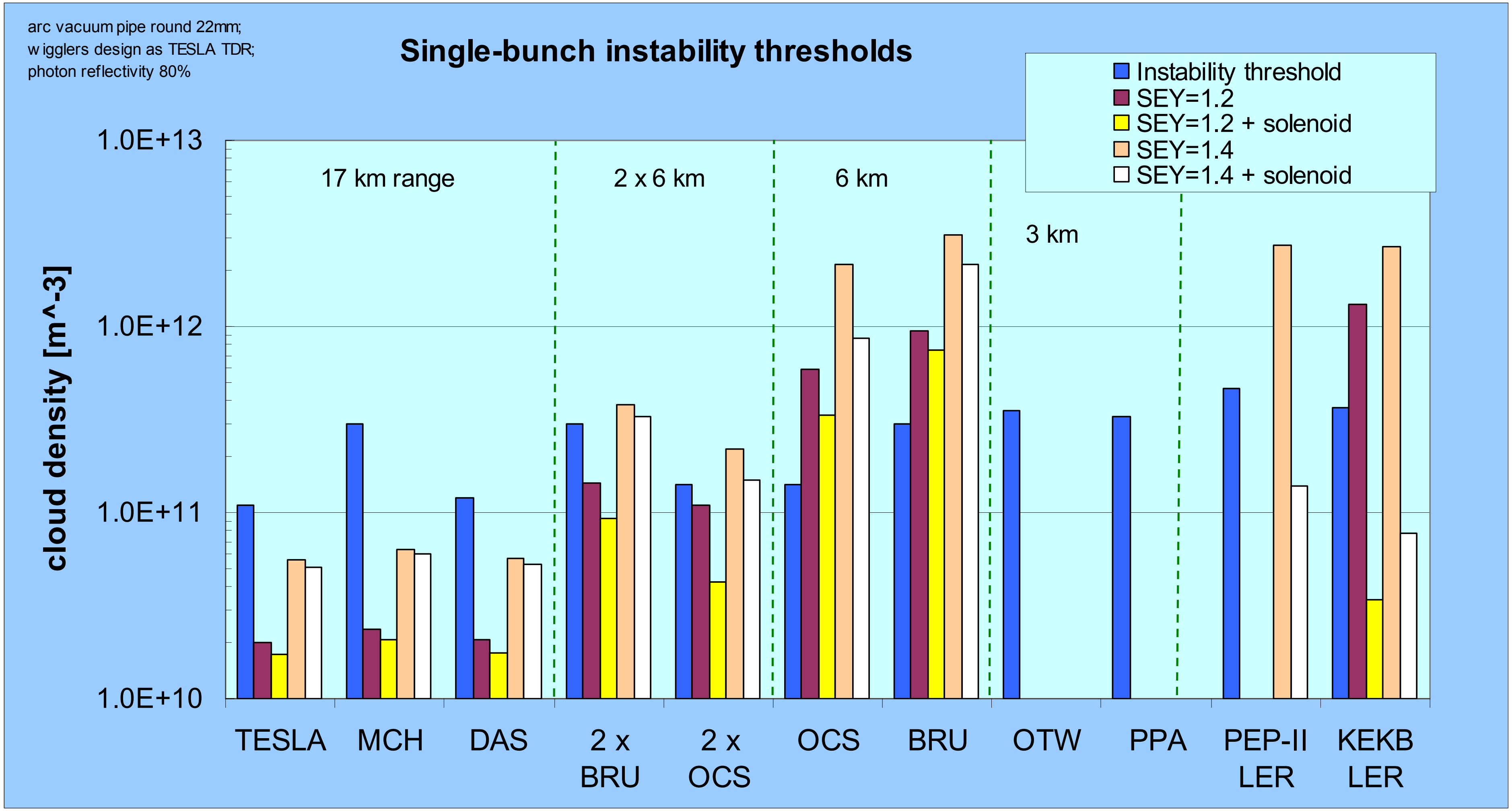
e-cloud in positron DR

- Causes:
  - Photoelectron build-up by electrons multipacting
  - Synchrotron radiation
  - Vacuum chamber geometry and material:
    - Secondary Electron Yield (SEY)
    - Reflectivity
- Effects:
  - Coupled bunch instability
  - Single bunch instability
  - Growth of beam size
- Cures:
  - Solenoid winding in straight sections
  - Transverse bunch-by-bunch feedback system
  - Low SEY vacuum chamber coating
  - Grooves in vacuum chamber
  - Antechamber
  - Clearing electrodes

e-cloud and DR design

- Build-up of the electron cloud is strongly dependent on the bunch separation
- Expected to be severe in dipole and wiggler regions
- Careful estimates of SEY threshold for build-up, and related single and coupled bunch instabilities, as a function of beam current and surface properties was made for a variety of optics designs
- Baseline Configuration currently specifies a pair of 6 km damping rings for the positron beam
- Highly desirable to find solutions to mitigate e-cloud in order to have a single 6 km ring

Single bunch instability threshold and simulated electron cloud build-up density



THPCH075 - M.T.F. Pivi et al.

Fast ion instability

- Due to high bunch density and short bunch spacing fast ion instabilities could be a serious problem for the electron DR
- Gaps in the bunch fill pattern can reduce the ion density by a factor 100 and even more
- Feedback system can suppress the instability even for a 3 ns bunch spacing if there is sufficient gap between trains

MOPLS133 - G. Xia et al.
MOPLS136 - F. Zimmerman et al.
WEPCH103 - L. Wang et al.
THPCH055 - E. Kim et al.

Remedy to suppress FII

Gaps between bunch trains

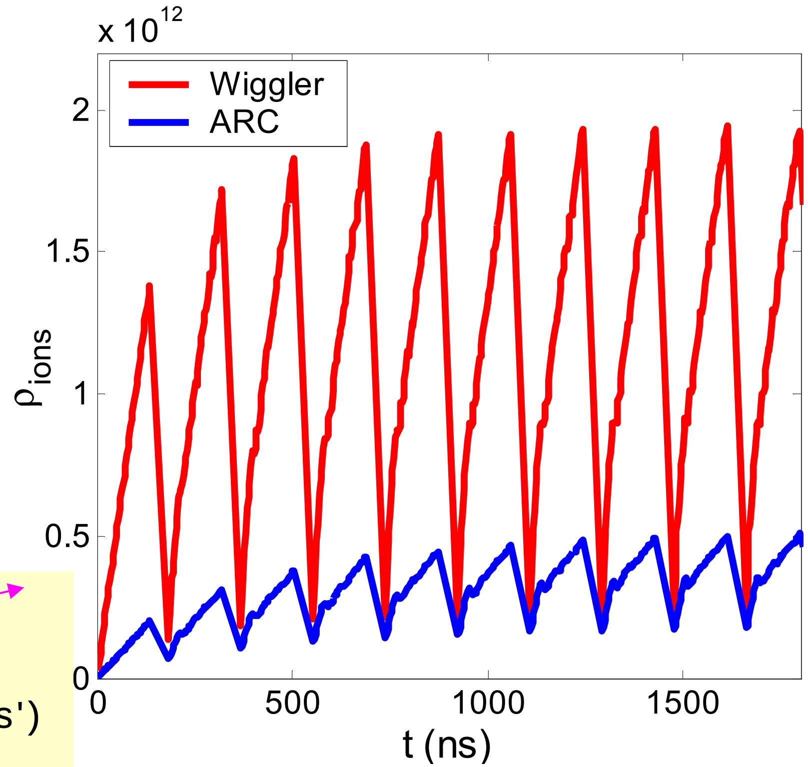
Gaps can reduce the ion density by a factor 100 and even more comparing without gaps fill pattern.

Ion reduction factor

$$IRF = \frac{Ion\_cloud_{\min i\_gaps}}{Ion\_cloud_{long\_train}}$$

$$= \frac{1}{N_{train}} \frac{1}{1-\exp(-\tau_{gap}/\tau_{ions})}$$

Low_Q fill pattern
Bunches per minitrain = 45
Gaps between minitrain = 49.23 ns (15 'missing bunches')
Number of bunch train=120
Particles per bunch = 1.04e10
Total number of bunches=5400



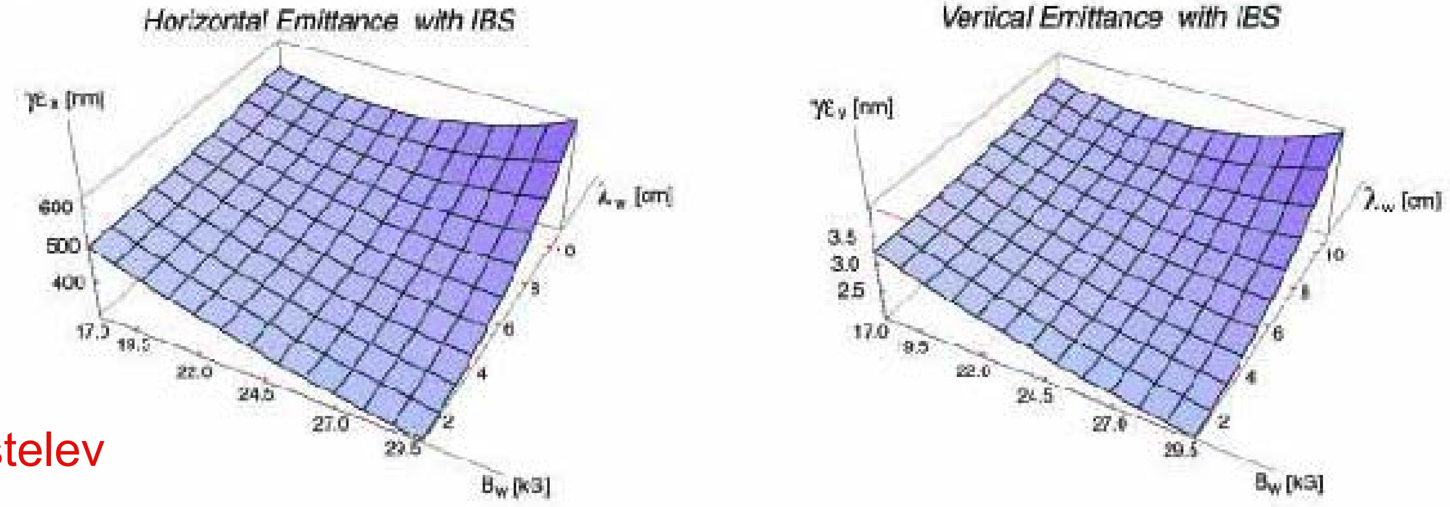
Ion density inside wiggler reduced by a factor of 100!

L.F. Wang and T. Raubenheimer (SLAC)

IntraBeam Scattering (IBS)

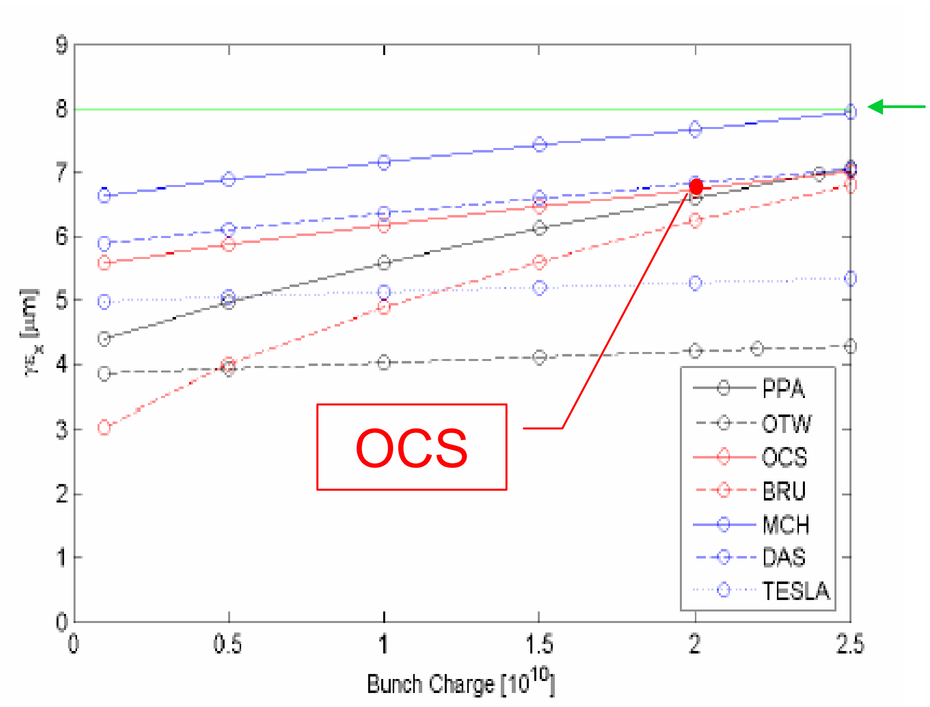
- In the CLIC DR the dominant emittance growth mechanism is IBS
- Intense synchrotron radiation damping from wigglers is required to counteract IBS effect

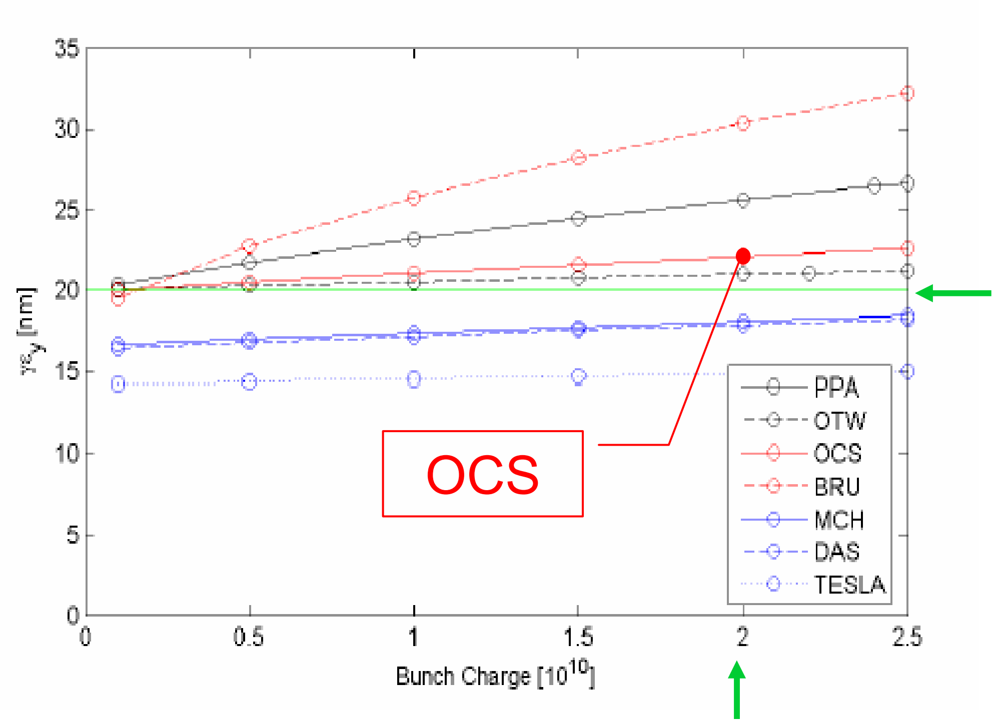
Normalized emittances with IBS of the CLIC DR as a function of wiggler period and wiggler peak field at betatron coupling 0.65%



M. Korostelev

Horizontal Emittance Growth From IBS in the ILC DR Reference Lattices





Design: $\gamma\varepsilon_x = 8\mu m$

$2x10^{10}$ part/bunch

Design: $\gamma\varepsilon_y = 20$ nm

$2x10^{10}$ part/bunch

All the lattices meet the specification on the horizontal emittance

OCS meets also the vertical emittance requirement

Injection

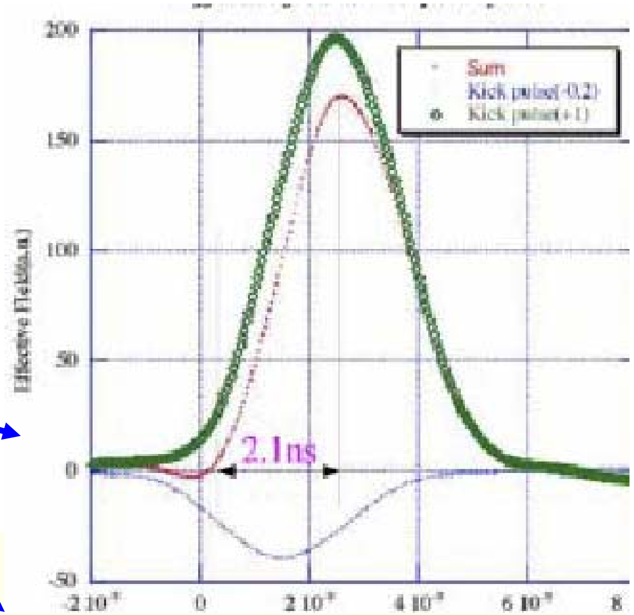
- Injection and extraction kickers are one of the most critical issues since the bunch distance and ring circumference are related to kicker pulse duration
- Stability of the beam position at the IP depends also on the kicker pulse stability
- R&D programs are in progress in laboratories worldwide both on fast pulsers and on stripline electrodes
- Requirements:
  - total pulse duration: < 12.4 ns for e^+, < 6.2 ns for e^-;
  - good uniformity;
  - low impedance;
  - 3 MHz for e+ (6 MHz for e-) repetition rate

THPCH148 - M. Palmer et al.

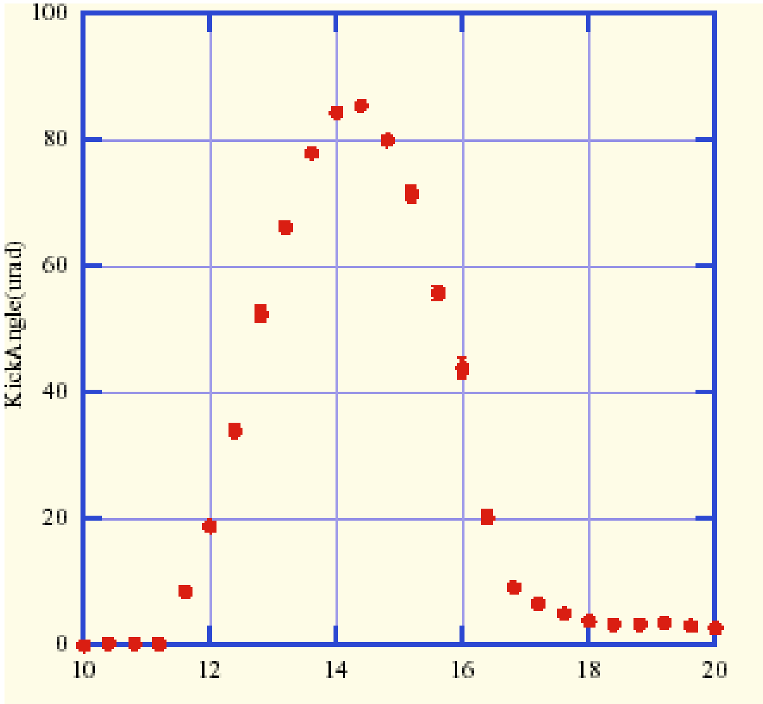
THPLS113 - S. De Santis et al.

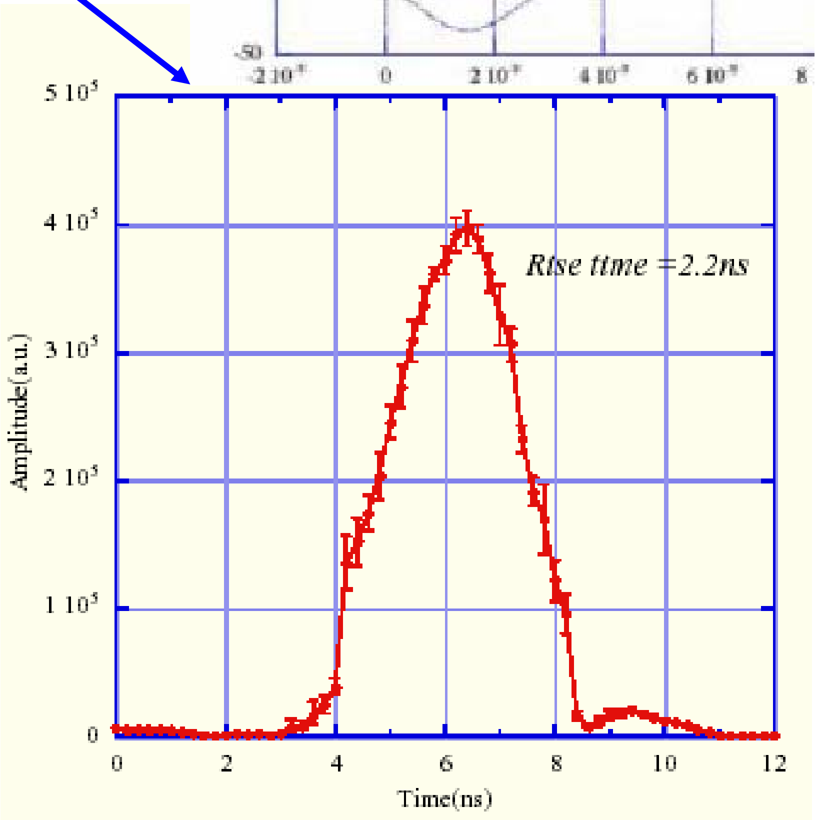
Kicker Tests at KEK-ATF

2 pulsers with opposite polarity
Rise time 2.2 ns



Single pulser rise time 3.2ns

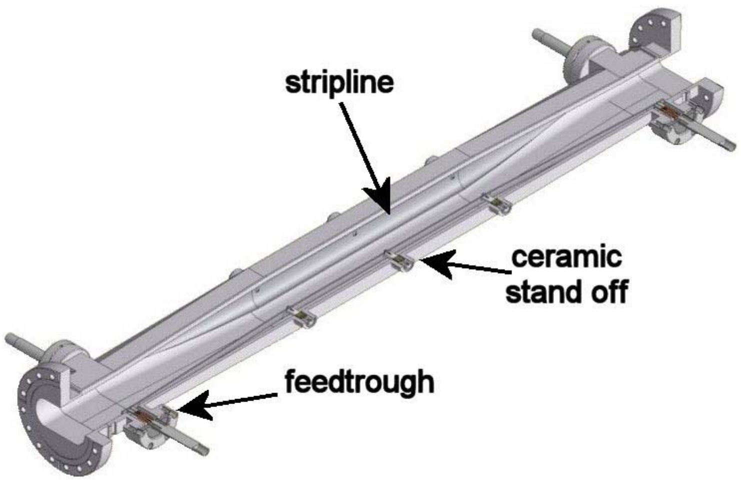




J. Urakawa, GDE meeting, Bangalore, March 2006

Fast kickers - LNF

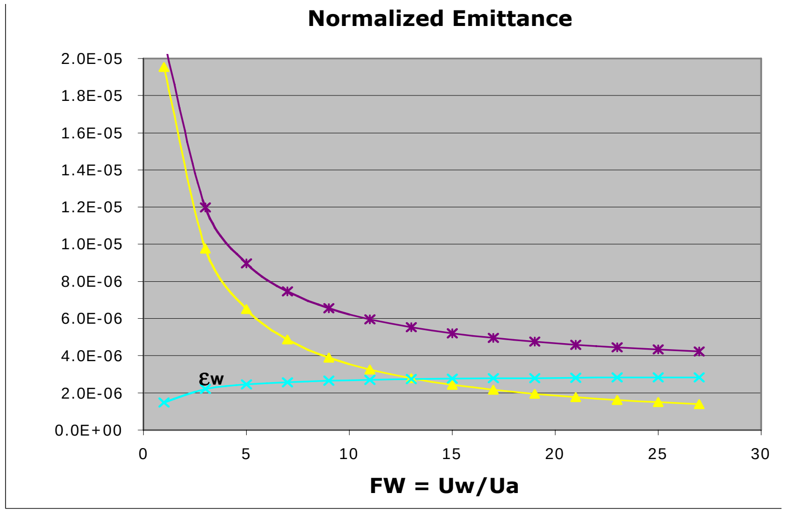
- Stripline kickers studied for the ILC positron DR will be used to upgrade the DAΦNE injection system
- Tapered to obtain good field uniformity and low beam impedance
- Rise/fall time < 6.2 ns
- Deflection 5 mrad at 0.5 GeV and 45 KV
- High voltage tests on prototype successfully done



TUPLS009 - D. Alesini et al.

Wigglers

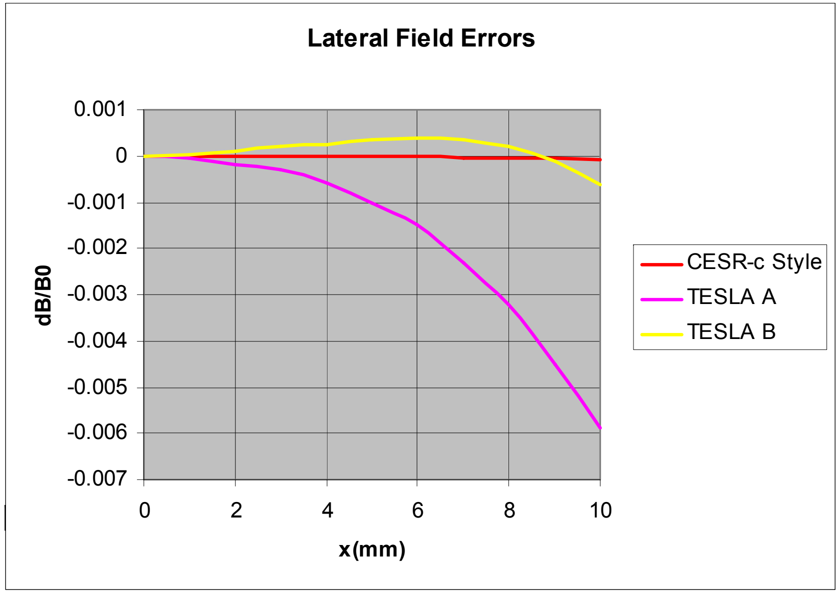
- Wigglers are necessary to reduce damping time, with a proper parameter choice they can reduce the beam emittance too
- Various wiggler designs (PM, SC, Hybrid…) have been studied worldwide
- Wiggler field nonlinearities can negatively affect dynamic aperture



ILC Wigglers

- High quality field and large physical aperture (at least 32 mm) are needed to achieve the necessary acceptance for the injected positron beam

B_{peak}	1.6 T
P	0.4 m
Total length	165 m
Radiated power	3.2 MW

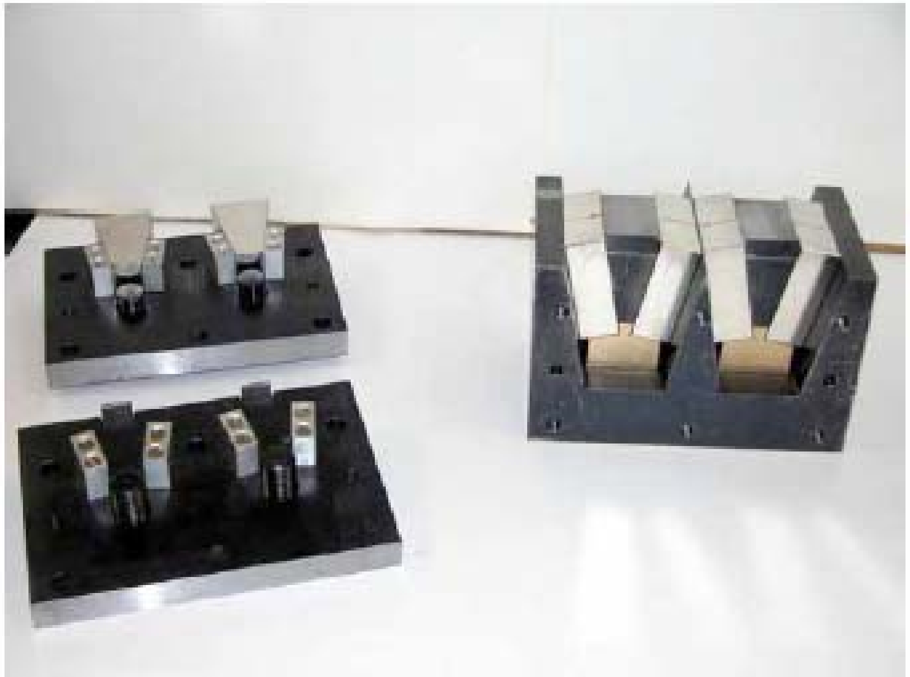


- Superferric CESR-c wiggler:
  - Large gap (50 mm vacuum chamber
  - $\Delta B/B \sim 7.7 \times 10^{-5}$ @ $\Delta x = 10$ mm
  - Nearly the same dynamic aperture as an ideal nonlinear wiggler (infinite pole with)

MOPLS141 - M. A. Palmer et al.

Wiggler technology for CLIC DR

Wiggler type	PM	SC
Period (cm)	10	5
Peak field (T)	1.7	2.5
Total length (m)	152	
$\gamma\varepsilon_x$ (nm)	540	383
$\gamma\varepsilon_y$ (nm)	3.4	2.4
Without IBS:		
$\gamma\varepsilon_x$ (nm) (w/o IBS)	131	88.5



PM wiggler prototype

Handling of synchrotron radiation heating requires special cares: periodic absorbers and long lumped absorbers at the end

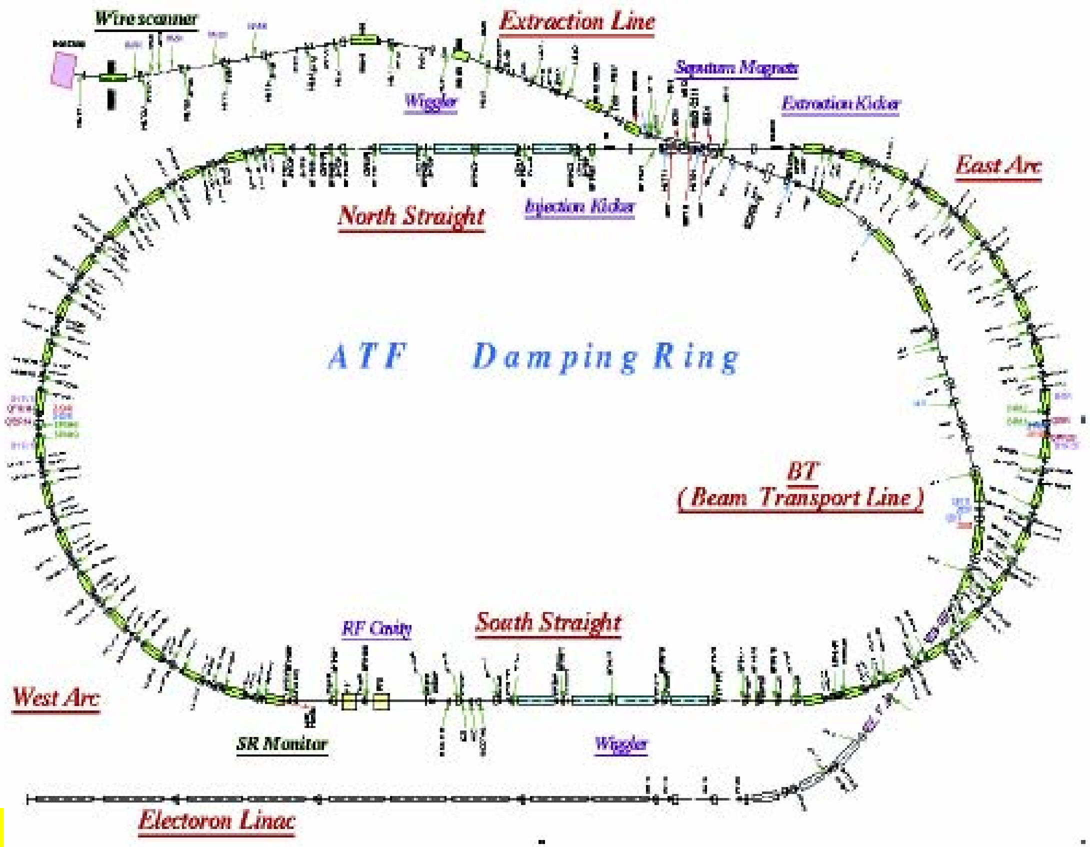
Feedbacks

- A digital feedback system of the type used at DAΦNE, PEP-II and KEKB is certainly recommended for the DR: in a digital system the feedback gain can be increased without increasing the noise
- A stripline electrode can be used as kicker in the transverse plane and an overdamped cavity (DAΦNE type) in the longitudinal plane
- The minimum feedback damping time measured at DAΦNE is 6 ms, corresponding to 20 turns
- Tests of an FPGA based feedback system were recently made by an international collaboration at KEKB and ATF

THPCH103 - D. Teytelman et al.

4 pm Vertical emittance demonstrated at ATF -Damping Ring Test Facility (KEK)

- $E = 1.28 GeV$
- $N = 2x10^{10}$ e/bunch
- 1 ~ 20 bunches
- $\varepsilon_{x/y}$ - 1.5nm/4pm
- 20 weeks/year
- 2 weeks/month



DR design ε_y: 2 pm

R&D in progress toward 1-2 pm emittance:

High resolution, low systematic errors, simple and fast calibration BPMs

New test facilities proposals

- CESRc has been proposed as DR test facility CesrTF. In 2008 it can be reconfigured to provide horizontal emittances in the few nanometer range, with 12 damping wigglers meeting DR requirements and the ability to operate with positrons or electrons
- The HERA electron ring, which ends operation mid 2007, matches almost perfectly the major DR design parameters; therefore it has been proposed to use it for the ILC DR

MOPLS141 - M. Palmer et al.

F. Willeke, http://events.lal.in2p3.fr/conferences/eaef/

R&D plans

- Based on the proposal of the research groups participating at the DR activities an R&D list has been compiled. It will be discussed at the next GDE meeting at Vancouver to specify a detailed R&D plan
- R&D list includes all the beam dynamics and technical issues that are relevant for the DR performance
- More than a dozen of Laboratories, universities and industries all over the world are involved
- Tests will be carried out at different operating machines: ATF (KEK), SPS (CERN), DAFNE (LNF), ALS (BNL), PEP-II (SLAC), KEKb, APS (ANL), CESR (Cornell)

Conclusions

- Lot of work was dedicated to beam dynamics studies and development of state of the art technology toward ultra-low emittance DR
- Beam tests have been done and others are planned at operating facilities to demonstrate performance
- This effort is made by a large number people on a worldwide scale, as shown by the large number of papers presented here, with authors from America, Asia, and Europe

Many thanks to all the contributors !