Damping Rings and Ring Colliders

Introduction to Damping Rings

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Seventh International Accelerator School for Linear Colliders

Hosted by Raja Ramanna Centre for Advanced Technology

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Outline

- A3.1 - DR Basics: Introduction to Damping Rings
  - Role of the damping rings in the ILC accelerator complex
  - Review parameters and constraints of CLIC and ILC damping rings
  - Identify key challenges
- A3.2 - DR Basics: General Linear Beam Dynamics
  - Review the basic physics of storage rings including the linear beam dynamics
- A3.3 - LER Design: Radiation Damping and Equilibrium Emittance
  - Radiation Damping and Synchrotron Motion
  - Quantum Excitation and Equilibrium Emittance
  - Summary of Beam Parameters and Radiation Integrals
- A3.4 - LER Design: Damping Ring Lattices
  - ILC Damping Ring Design Optimization
  - The ILC DR Lattice, Parameters and Design Choices
  - CLIC Damping Ring Design Optimization
  - The CLIC DR Lattice, Parameters and Design Choices

These slides have been presented at the 2010 LC school by Mark Palmer with a few additions and updates by myself

Outline (contd)

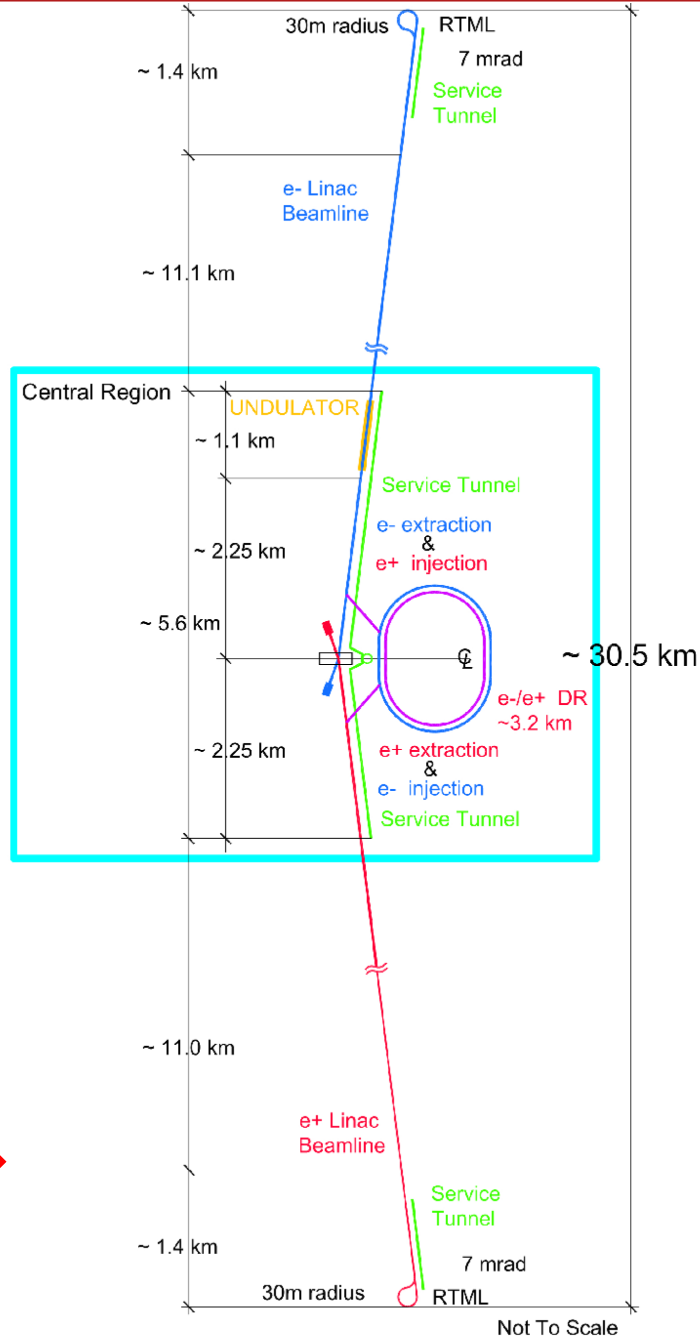
- A3.5 – DR Technical systems
  - Review technical challenges of ILC and CLIC DR
  - Vacuum system and e-cloud mitigations
  - Damping wigglers
  - Injection/extraction kickers
- A3.6 – Beam Dynamics
  - Overview of Impedance and Instability Issues
  - Review of Selected Collective Effects
- A3.7 – R&D Challenges and Test Facilities
  - CESR-TA
  - ATF
- A3.8 – Circular Colliders
  - Basics of circular colliders
  - Luminosity and tune shifts
  - Beam lifetimes
  - Challenges of future colliders

Role of the Damping Rings

The damping rings

- Accept e^+ and e^- beams with large transverse and longitudinal emittance and produce the ultra-low emittance beams necessary for high luminosity collisions at the IP
- Damp longitudinal and transverse jitter in the incoming beams to provide very stable beams for delivery to the IP
- Delay bunches from the source to allow feed-forward systems to compensate for pulse-to-pulse variations

ILC RDR Layout ⇨

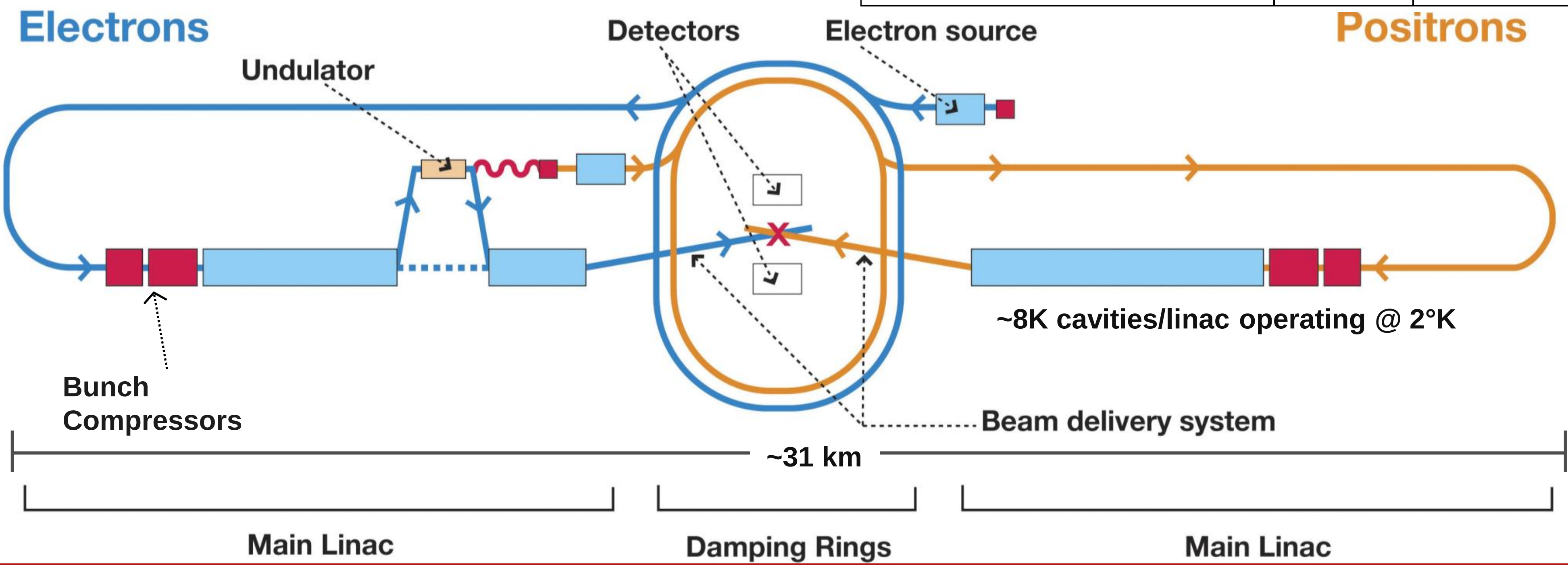


The ILC Reference Design

Machine Configuration

- Helical Undulator polarized e+ source
- Two ~6.5 km damping rings in a central complex
- RTML running length of linac
- 2 ×11.2 km Main Linac
- Single Beam Delivery System
- 2 Detectors in Push-Pull Configuration

Parameter	Unit	
Center-of-mass energy range	GeV	200 - 500
Peak luminosity[a)]	$cm^{-2}s^{-1}$	2×10^{34}
Average beam current in pulse	mA	9.0
Pulse rate	Hz	5.0
Pulse length (beam)	ms	~ 1
Number of bunches per pulse		1000 - 5400
Charge per bunch	nC	3.2
Accelerating gradient[a)]	MV/m	31.5
RF pulse length	ms	1.6
Beam power (per beam)[a)]	MW	10.8
Typical beam size at IP[a)] $(h \times v)$	nm	640×5.7
Total AC Power consumption[a)]	MW	230



DR Reference Design Parameters

By the end of the first 2 days of lectures, the goal is for each of you to be able to explain the reasons that the parameters in this table have the values that are specified. *Caveat: Some parameters have already been changed*

By the end of the DR lectures, you should be able to identify and explain why several of these parameters are *(or already have been)* candidates for further optimization.

So, let's begin our tour of ring dynamics and what these parameters mean…

Parameter	**Units**	**Value**
Energy	GeV	5.0
Circumference	km	6.695
Nominal # of bunches & particles/bunch		2625@2.0×10^{10}
Maximum # of bunches & particles/bunch		5534@1.0×10^{10}
Average current	A	0.4
Energy loss per turn	MeV	8.7
Beam power	MW	3.5
Nominal bunch current	mA	0.14
RF Frequency	MHz	650
Total RF voltage	MV	24
RF bucket height	%	1.5
Injected betatron amplitude, A_x+A_y	m·rad	0.09
Equilibrium normalized emittance, $\gamma\varepsilon_x$	μm·rad	5.0
Chromaticity, χ_x/χ_y		-63/-62
Partition numbers, J_x J_y J_z		0.9998 1.0000 2.0002
Harmonic number, h		14,516
Synchrotron tune, ν_s		0.067
Synchrotron frequency, f_s	kHz	3.0
Momentum compaction, α_c		4.2×10^{-4}
Horizontal/vertical betatron tunes, ν_x/ν_y		52.40/49.31
Bunch length, σ_z	mm	9.0
Momentum spread, σ_p/p		1.28×10^{-3}
Horizontal damping time, τ_x	ms	25.7
Longitudinal damping time, τ_z	ms	12.9

DR Reference Design Parameters

By the end of the first 2 days of lectures, the goal is for each of you to be able to explain the reasons that the parameters in this table have the values that are specified. *Caveat: Some parameters have already been changed*

By the end of the DR lectures, you should be able to identify and explain why several of these parameters are *(or already have been)* candidates for further optimization.

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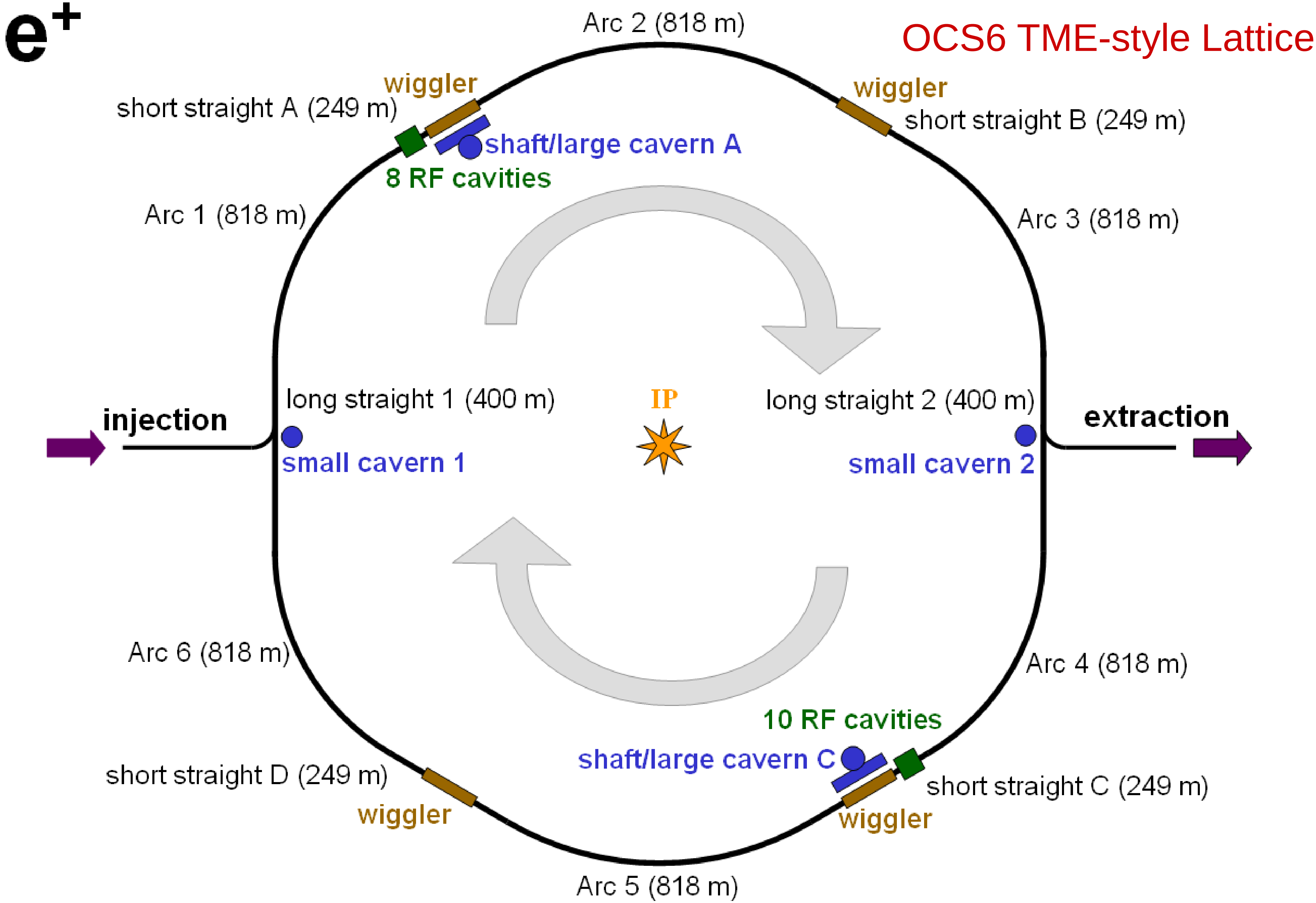
UPDATED
TDR Parameters - 2012

Parameter	5 Hz Mode Low Power	5 Hz Mode High Lumi
Circumference [km]	3.238	
Number of bunches	1312	2625
Particles per bunch [$\times 10^{10}$]	2	2
Maximum beam current [mA]	389	779
Transverse damping time τ_x, τ_y [ms]	23.95	
Longitudinal damping time τ_z [ms]	12.0	
Bunch length σ_z [mm]	6.02	
Energy spread σ_E/E [%]	0.11	
Momentum compaction factor α_p [$\times 10^{-4}$]	3.3	
Normalized horizontal emittance $\gamma\epsilon_x$[μm]	5.7	
Horizontal chromaticity ξ_x	−51.3	
Vertical chromaticity ξ_y	−43.3	
Wiggler Field [T]	1.51	
Number of Wigglers	54	
Energy loss/turn [MeV]	4.5	
RF Specifications:		
Frequency [MHz]	650	
Number of cavities	$10^{\dagger}$	12
Total voltage [MV]	14.0	
Voltage per cavity [MV]	1.40	1.17
RF synchronous phase [°]	18.5	
Power per RF coupler [kW]‡	176	294

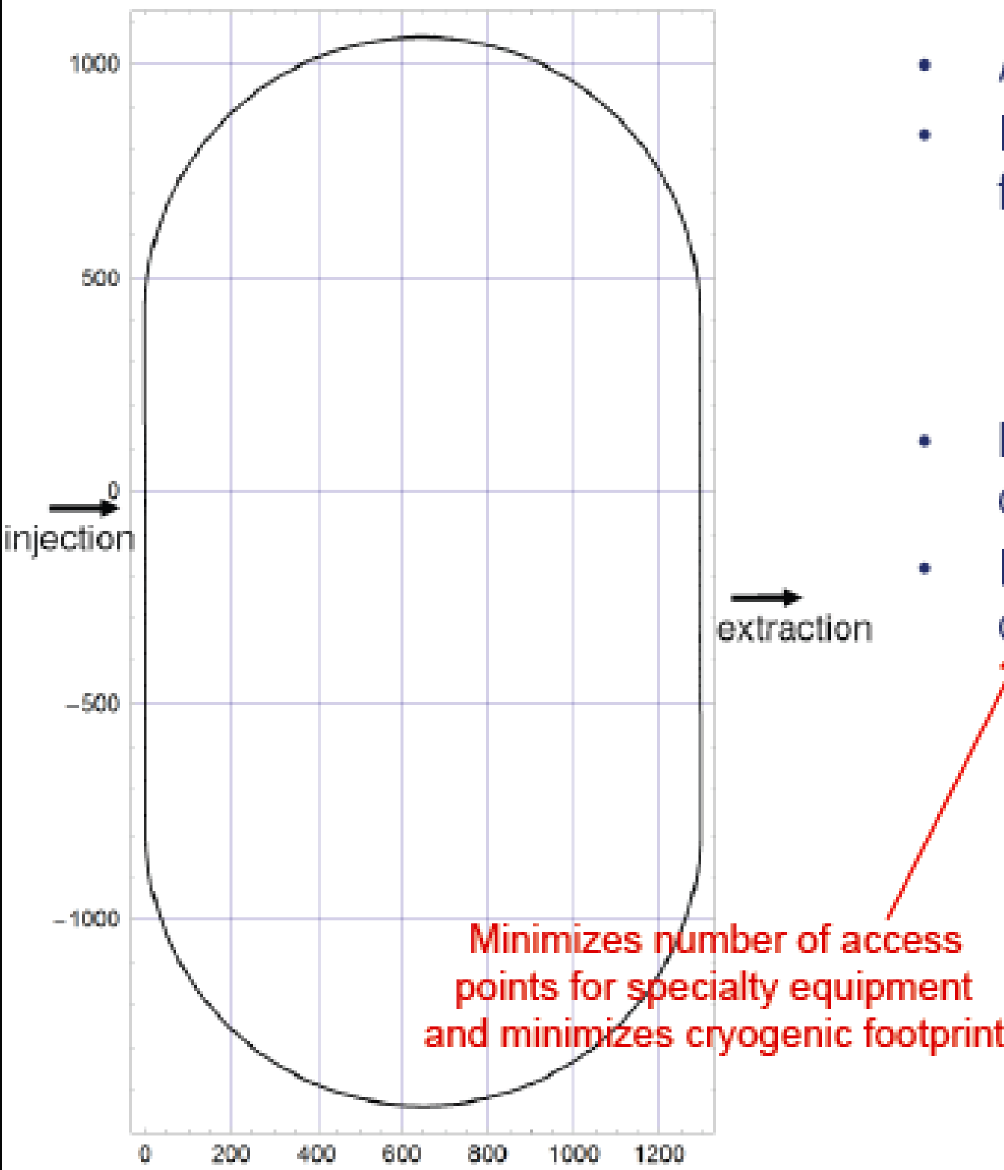
The RDR Damping Ring Layout



The DCO Lattice

Wolski, Korostelev

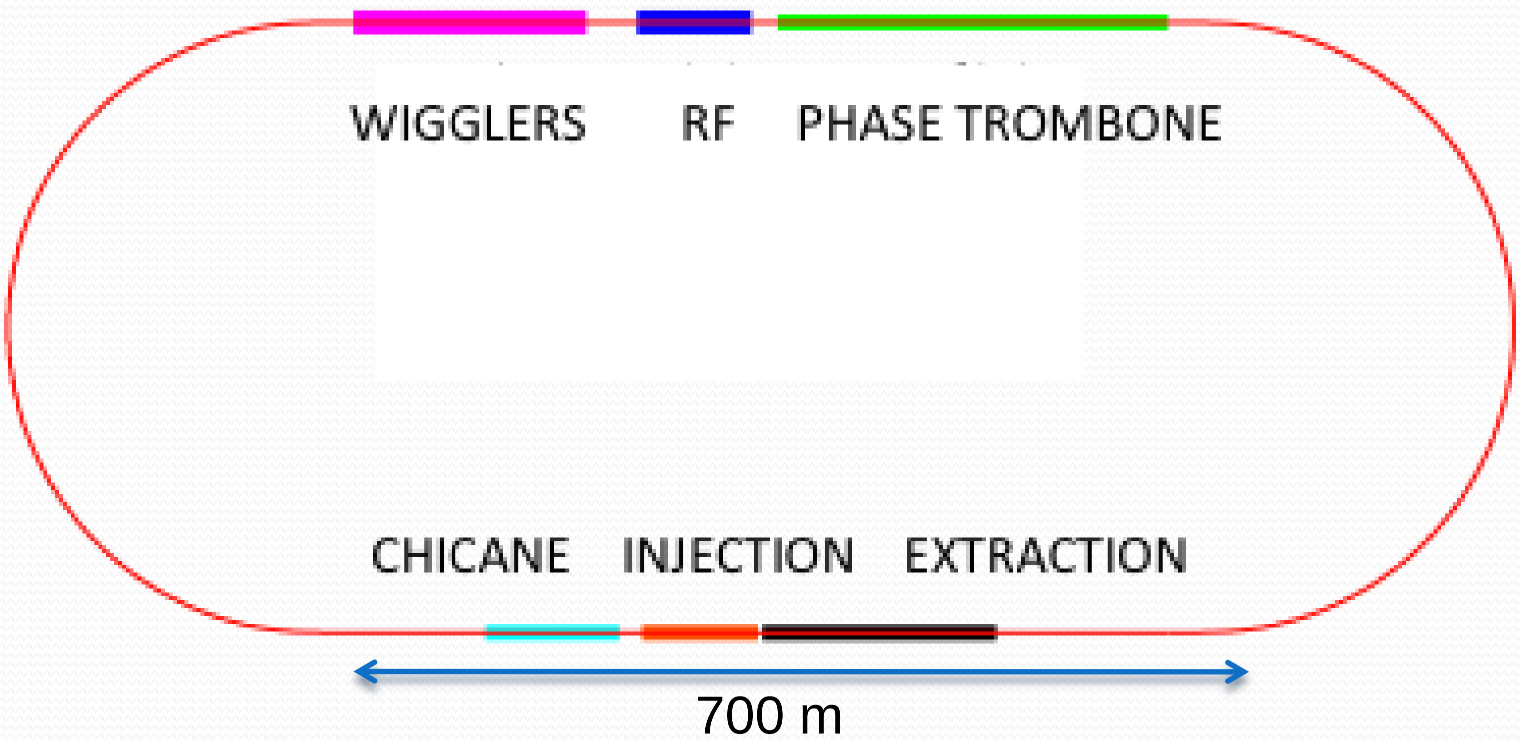
2008 Baseline Lattice - 6.5 km



- Arcs consist of a total of 192 FODO cells
- Flexibility in tuning momentum compaction factor, given by phase advance per arc cell:
  - **72° phase advance: α_p=2.8×10^{-4}**
  - **90° phase advance: α_p=1.7×10^{-4}**
  - **100° phase advance: α_p=1.3×10^{-4}**
- No changes in dipole strengths needed for different working points.
- Racetrack structure has two similar straights containing:
  - **injection and extraction in opposite straights**
  - **phase trombones**
  - **circumference chicanes**
  - **rf cavities**
  - **"doglegs" to separate wiggler from rf and other systems**
  - **wiggler**

The TDR Damping Ring Layout

DTC4 – TME style lattice
Circumference 3.2 km
Same layout as DCO lattice



ILC Damping Ring Design Inputs

A number of parameters in the previous table are (*essentially)* design *inputs* for the damping rings (or can be directly inferred from such inputs). The table below summarizes these critical interface issues. (⇨Updated TDR values)

We will examine these requirements from the perspective of the collision point first and then look at requirements coming from other sub-systems downstream and upstream of the DRs.

Particles per bunch	1×10^{10} - 2×10^{10}	Upper limit set by disruption at IP.
Max. Avg. current in main linac	~9 mA	Upper limit set by RF technology.
Machine repetition rate	5 Hz	Set by cryogenic cooling capacity. Partially determines required damping time.
Max. Linac RF pulse length	~1 ms	Upper limit set by RF technology.
Min. Particles per machine pulse	$\sim5.6\times10^{13}$	Lower limit set by luminosity goal.
Injected normalized emittance	0.01 m-rad (⇨0.008 m-rad)	Set by positron source. Partially determines required damping time.
Injected energy spread	±0.5% rad (⇨±0.75% rad)	Set by positron source.
Injected betatron amplitude (A_x+A_y)	0.09 m-rad (⇨0.07 m-rad)	Set by positron source.
Extracted normalized emittances	8 μm horizontally 20 nm vertically	Set by luminosity goal.
Max. Extracted bunch length	9 mm (⇨6 mm)	Upper limit set by bunch compressors.
Max. Extracted energy spread	0.15%	Upper limit set by bunch compressors.

Don't forget, however, that these parameters are the result of a great deal of back-and-forth negotiation between sub-systems and between accelerator and HEP physicists. Thus they represent a mix of technological limits and physics desires…

Downstream Requirements

The principle parameter driver is the production of luminosity at the collision point

$$\mathcal{L} = \frac{N^2 f_{coll}}{4\pi\sigma_x\sigma_y}\mathcal{H}_D$$

where

N is the number of particles per bunch (*assumed equal for all bunches*)

f_{coll} is the overall collision rate at the interaction point (IP)

σ_x and σ_y are the horizontal and vertical beam sizes (*assumed equal for all bunches*)

$\mathcal{H}_D$ is the luminosity enhancement factor

Ideally we want:

- High intensity bunches
- High repetition rate
- Small transverse beam sizes

Parameters at the Interaction Point

The parameters at the interaction point have been chosen to provide a nominal luminosity of 2×10^{34} cm^{-2}s^{-1}. With

- $N = 2\times10^{10}$ particles/bunch
- $\sigma_x \sim 640$ nm $\Leftrightarrow$ $\beta_x^* = 20$ mm, $\varepsilon_x = 20$ pm-rad
- $\sigma_y \sim 5.7$ nm $\Leftrightarrow$ $\beta_y^* = 0.4$ mm, $\varepsilon_y = 0.08$ pm-rad
- $\mathcal{H}_D \sim 1.7$

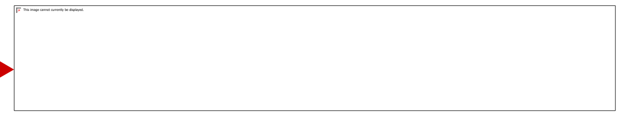
→

TDR UPDATE

- $\sigma_x \sim 474$ nm $\Leftrightarrow$ $\beta_x^* = 11$ mm, $\varepsilon_x = 20$ pm-rad
- $\sigma_y \sim 5.9$ nm $\Leftrightarrow$ $\beta_y^* = 0.48$ mm, $\varepsilon_y = 0.07$ pm-rad
- $\mathcal{H}_D \sim 2$

$$\mathcal{L} = \frac{N^2 f_{coll}}{4\pi\sigma_x\sigma_y}\mathcal{H}_D = \left(1.4\times10^{30}\, cm^{-2}\right)\times f_{coll}$$

→



In order to achieve the desired luminosity, an average collision rate of ~14kHz→9kHz is required (we will return to this parameter shortly). The beam sizes at the IP are determined by the strength of the final focus magnets and the emittance, phase space volume, of the incoming bunches.

A number of issues impact the choice of the final focus parameters. For example, the beam-beam interaction as two bunches pass through each other can enhance the luminosity, however, it also disrupts the bunches. If the beams are too badly disrupted, safely transporting them out of the detector to the beam dumps becomes quite difficult. Another effect is that of beamstrahlung which leads to significant energy losses by the particles in the bunches and can lead to unacceptable detector backgrounds. Thus the above parameter choices represent a complicated optimization.

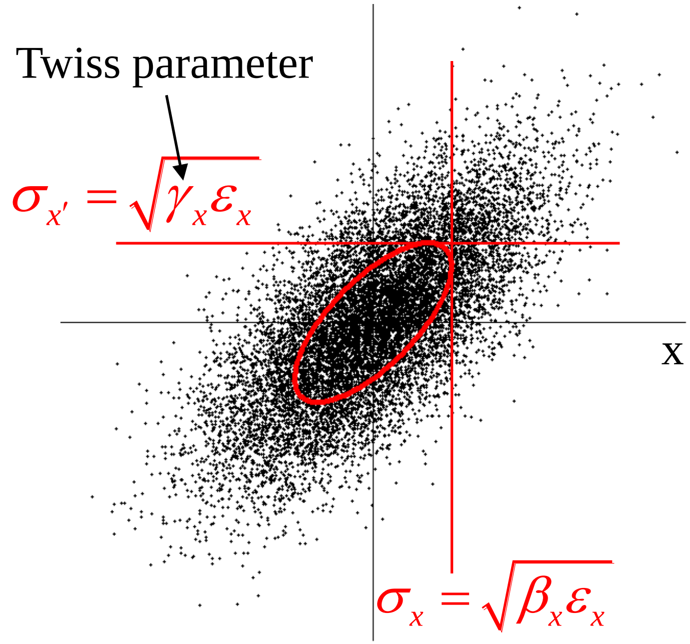
Emittance Transport from the DR to the IP

The geometric emittances required at the IP are:

$\varepsilon_x = 20$ pm-rad

$\varepsilon_y = 0.08$ pm-rad

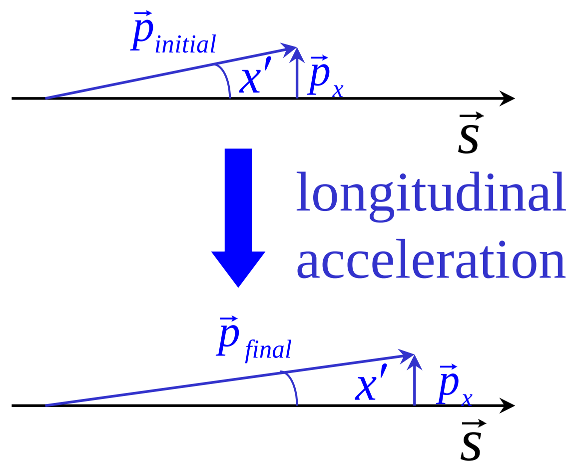
We need to use the relativistic invariant quantity, the *normalized emittance*, in order to project this to the requirements for the damping ring.



Note: We will take a more detailed look at emittance in the DR in tomorrow's lecture

Normalized Emittance:

Use of the conjugate phase-space coordinates (x, p_x) from the Hamiltonian instead of (x, x') gives:



$$p_x = px' = mc\beta\gamma x'$$

Thus we define the normalized emittance as

$\varepsilon_n = \beta\gamma\varepsilon_{geo} \approx \gamma\varepsilon_{geo}$ for a relativistic electron

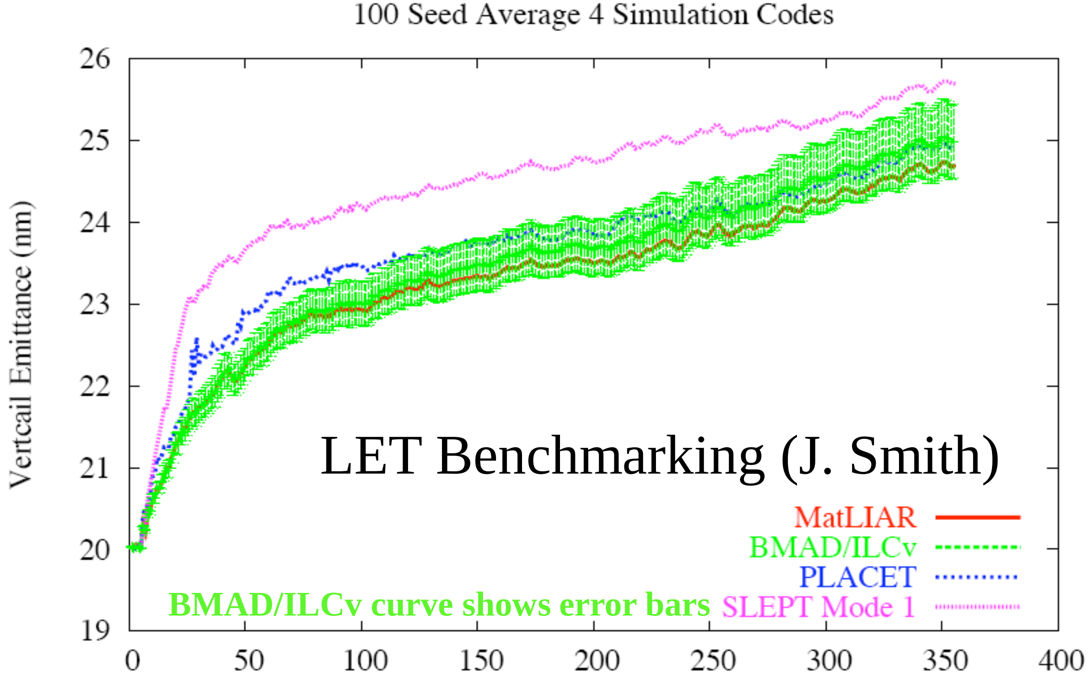
Emittance Transport from the DR to the IP

We can now infer the requirements for the equilibrium emittance requirements for the ILC DRs

	ε_{geo} @ IP (250 GeV)	ε_n @ IP	Equilibrium ε_n @ DR	Equilibrium ε_{geo} @ DR (5 GeV)
x	20 pm-rad	10 μm-rad	½ × (10 μm-rad)	0.5 nm
y	0.08 pm-rad	40 nm-rad	½ × (40 nm-rad)	2 pm

Allow for 100% vertical emittance growth downstream of DRs

DR extracted emittances must allow for downstream emittance growth during transport as well as for the finite damping time during the machine pulse cycle



ILC Main Linac (ML) Parameters

The bunch-train structure is largely determined by the design of the superconducting RF system of the main linac (ML)

Primary Limitation

- 1 ms (⇨0.7 ms) RF pulse
- 9 mA (⇨5.8 mA) average current in each pulse
- 5 Hz repetition rate

RF power system (1 ms RF pulse; average current in each pulse)

Cryogenic load (5 Hz repetition rate)

This leads to the nominal bunch train parameters:

n_b = 2625 (⇨1312) bunches per pulse

Δt_b ~ 380 ns (⇨554 ns) for uniform loading through pulse

The resulting collision rate at the IP is then

f_{coll} = 13.1 kHz (⇨7 kHz)

consistent with the target luminosity. The 5 Hz repetition rate places the primary constraint on the DR damping times. In order for the bunches in each pulse to experience 8 full damping cycles, a transverse damping time of ≤25 ms is required.

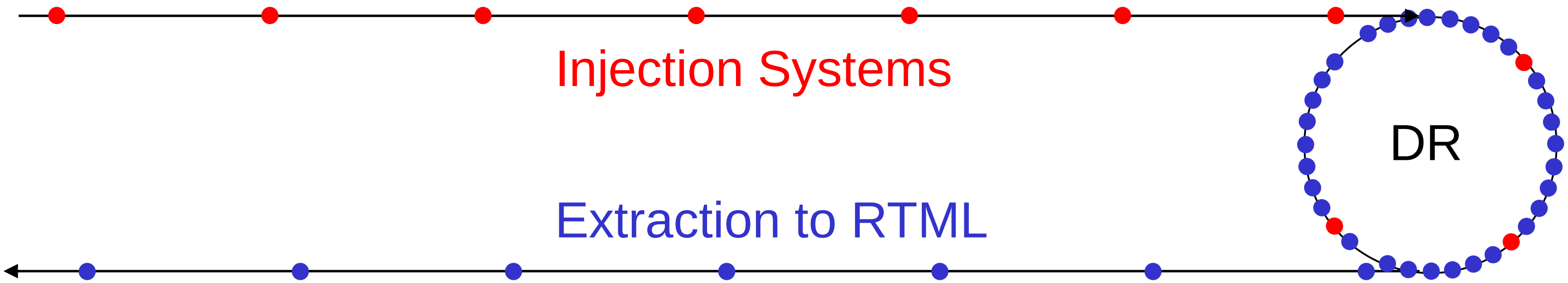
Baseline Bunch Train

From the discussion on the preceding page, we can now see the basic bunch train structure

- 1 msec pulse
- ~3000 uniformly spaced bunches (⇨1312)
- ~350 ns between bunches (⇨554 ns) (TDR ⇨ 220 km)

⇨ Train Length of □ 300km □ ML length > DR Circumference

Thus, the damping rings must act as a *reservoir* to store the full train. Because we cannot afford to build a 300+ km ring, we must *fold* the long bunch train into a much shorter ring ⇨ key trade-offs between bunch spacing and ring circumference.



Note that (for the RDR baseline) there will be significant overlap between the injection and extraction cycles:

- Structure of machine
- Maintain relatively constant beam loading

Bunch Compressors

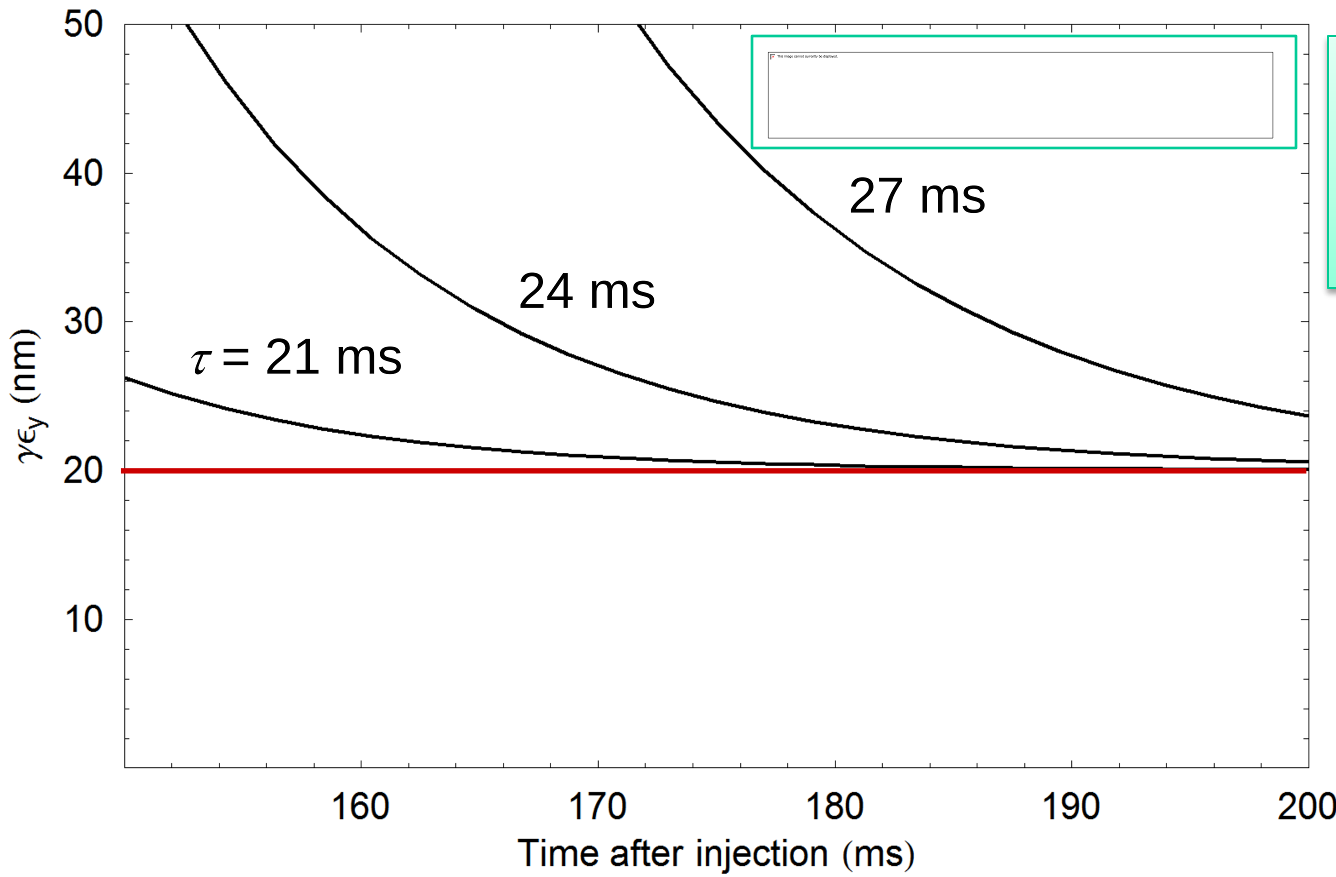
Shortly after extraction from the damping ring, the bunches will traverse the bunch compressors. These devices take the relatively long bunches of the damping rings ($\sigma_z \sim$ fraction of a centimeter) and manipulate the longitudinal phase space to provide bunches that are compatible with the very small focal point at the IP ($\sigma_z \sim$ 200-500 microns). Technical and cost limitations place serious constraints on how long the bunch from the DR can be and the maximum energy spread.

RDR DR Bunch length: 9 mm ⇨ 2-stage bunch compressor
Extracted energy spread within the bunch compressor acceptance

From the downstream point of view, lowering the bunch length to 6mm would allow the cheaper and simpler solution of using a single stage bunch compressor. From the DR point of view, shorter bunches require smaller values of the ring momentum compaction (impacts sensitivity to collective effects) or higher RF voltage (more RF units, hence greater cost).

Upstream Requirements

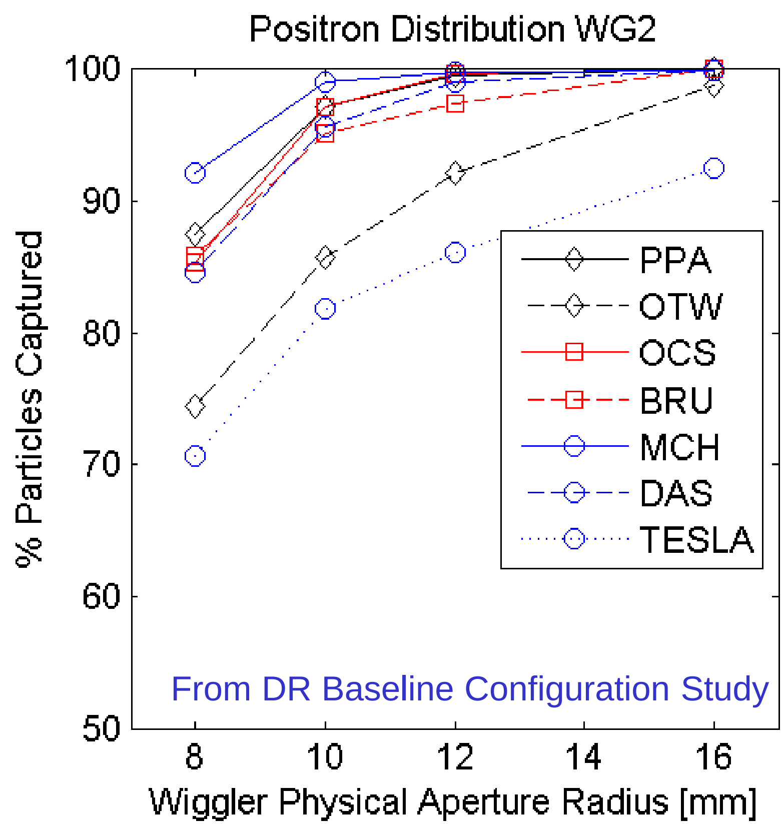
The key upstream requirement is the emittance of the beams produced by the injectors. Positron production via a heavy metal target results in much larger emittances due to scattering in the target for positrons than for electrons whose emittance can be controlled by the design of the injector gun and its cathode. The approach to the target extraction emittance is shown for various DR damping times assuming the target e^+ injected emittance ($\varepsilon_n = 0.01$ m-rad).



t/τ
200/27 = 7.4
200/24 = 8.3
200/21 = 9.5

Upstream Requirements

In addition to the need to damp the large emittance beams that are injected from the positron source, the injected beams are expected to have potentially large betatron amplitudes and energy errors. This requires that the acceptance of the damping ring to be sufficiently large to accommodate these oscillations immediately after injection. It places important constraints on the minimum aperture of the vacuum system and the minimum good field regions of all of the magnets (including the damping wigglers).



Particle capture rates assuming that the limiting physical aperture in the damping rings is due to the vacuum chambers in the wiggler regions. The choice of a superferric wiggler design, with large physical aperture, allows for a DR design with full acceptance.

Arriving at a design

We have now looked at several interface issues between the damping rings and the rest of the accelerator complex

- Train structure
- Equilibrium emittance requirements
- Bunch length requirements
- Acceptance of ring
- Timing structure

There are various choices that can be made to design a ring at this point

- The choices typically have a myriad of trade-offs
- Will look at a few examples to understand the design evaluations that are required
- Design choices must be carefully matched to likely paths of evolution of the overall machine design

Optimization Issues - I

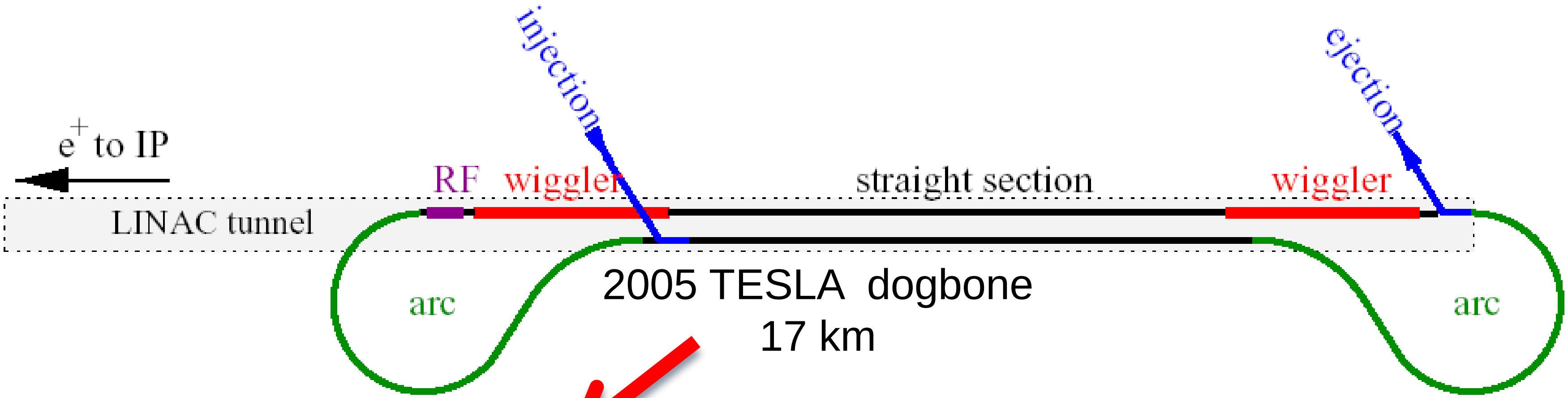
Optimization is complicated. Many decisions are tightly coupled and many trade-offs are required.

Example 1: Ring Circumference

- Large circumference ⇨ space charge effects are more severe
- If space charge effects are significant ⇨ a higher energy is desirable
- Higher energy ⇨ larger equilibrium emittance
- Control of equilibrium emittance ⇨ significant impacts on ring design

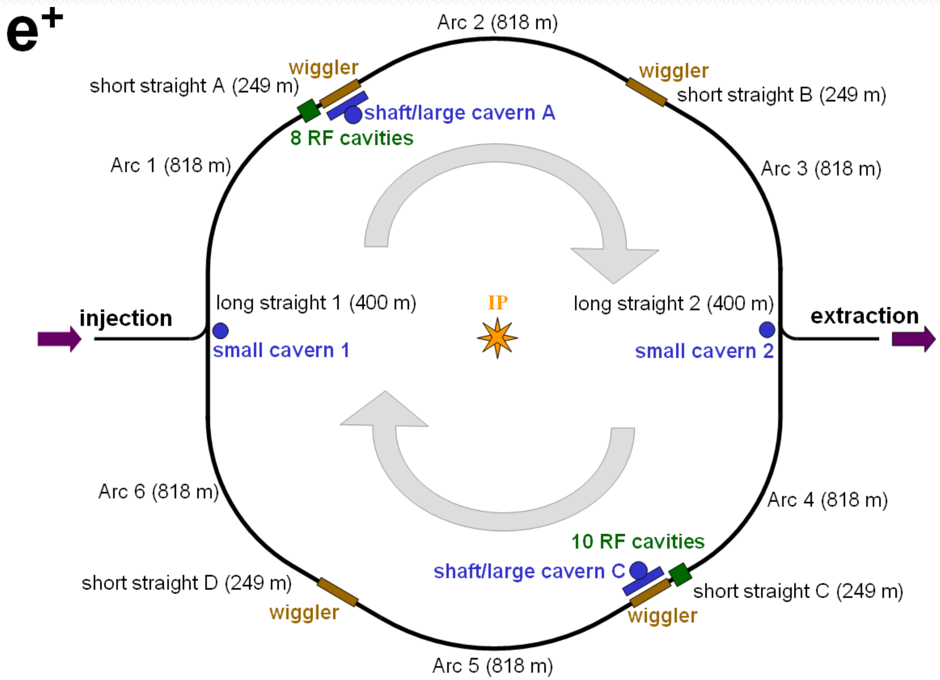
- Small circumference ⇨ fewer components and smaller tunnel so cheaper and potentially better net hardware reliability
- Small circumference ⇨ folding of linac bunch train into ring requires more closely spaced bunches
- Closely spaced bunches ⇨ more challenging bunch-by-bunch injection and extraction
- Closely spaced bunches ⇨ electron cloud and fast ion effects more severe

Lattice evolution

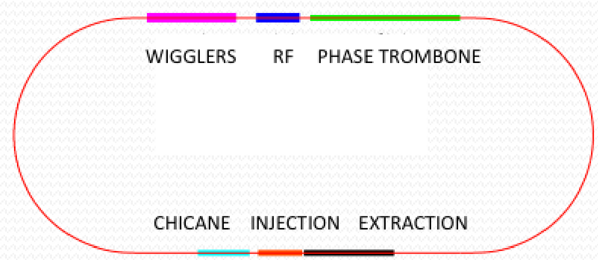


2005 TESLA dogbone
17 km

2007 RDR OCS6
6.5 km



2011 DTC04
3.2 km



Optimization Issues - II

Example 2: Beam Energy

- Higher energy ⇨ sensitivity to collective effects is lessened (beam instabilities, intrabeam scattering, space charge, etc)
- Higher energy ⇨ damping rates increase from the increased synchrotron radiation
- Higher energy ⇨ for a given normalized emittance from the sources, the beam is smaller due to adiabatic damping from the initial beam acceleration and the ring acceptance issues are eased

- Lower energy ⇨ in the limit of small enough bunch charge, this provides a smaller equilibrium emttance
- Lower energy ⇨ weaker magnets and lower field RF cavities to focus the beam, hence cheaper (and often more reliable) hardware

Optimization Issues - III

Example 3: Technical Contraints: High Voltage Kickers

- Wide kicker pulse ⇨ typically more stable, hence better for uniform injection/extraction
- Wide kicker pulse ⇨ requires a large ring circumference to allow bunch-by-bunch injection and extraction (bunch spacing)
- Wide kicker pulse ⇨ relatively fewer kicker structures (matched to pulse width) will be required in the ring (minimize impedance issues, improve reliability, minimize cost)
- Wide kicker pulse ⇨ works well in a scenario with full train injection/extraction

- Narrow kicker pulse ⇨ higher bandwidth requires careful impedance matching with kicker structure
- Narrow kicker pulse ⇨ many short kicker structures required (reliability and cost concerns)
- Narrow kicker pulse ⇨ high voltage pulses beyond state-of-the-art when the ILC RDR was published

Optimization Issues - IV

Example 4: Technical Constraints: Damping Wigglers

- Competing technologies:
  - Permanent magnet
  - Normal conducting electromagnet
  - Superconducting electromagnet
- Performance issues:
  - Aperture
  - Allowable field strength
  - Field quality
  - Sensitivity to radiation damage
  - Operating cost
- ILC design choice:

  Employ only a damping ring with no pre-damping ring
  - Places significant weight on aperture and field quality issues in order to handle the large input beams from the positron source

Optimization Issues - V

Example 5: Physics Requests

- Provide wider energy range for producing luminosity ⇨ for the ILC, this affects the positron production mode
- Positron production at fixed energy point in main linac ⇨ if want to explore a lower energy, need to produce positrons on one pulse and then change the acceleration in the ML for collisions on a separate pulse
- Two pulse configurations ⇨ positron damping ring only filled 50% of time
- 50% duty cycle ⇨ new RF system design
- 50% duty cycle ⇨ increase damping rate so that 5Hz pulses for collision can be maintained

- Lower positron production energy ⇨ poorer production and inability to achieve desired standard operating parameters
- Lower positron production energy ⇨ potentially unacceptable impact on the positron target design

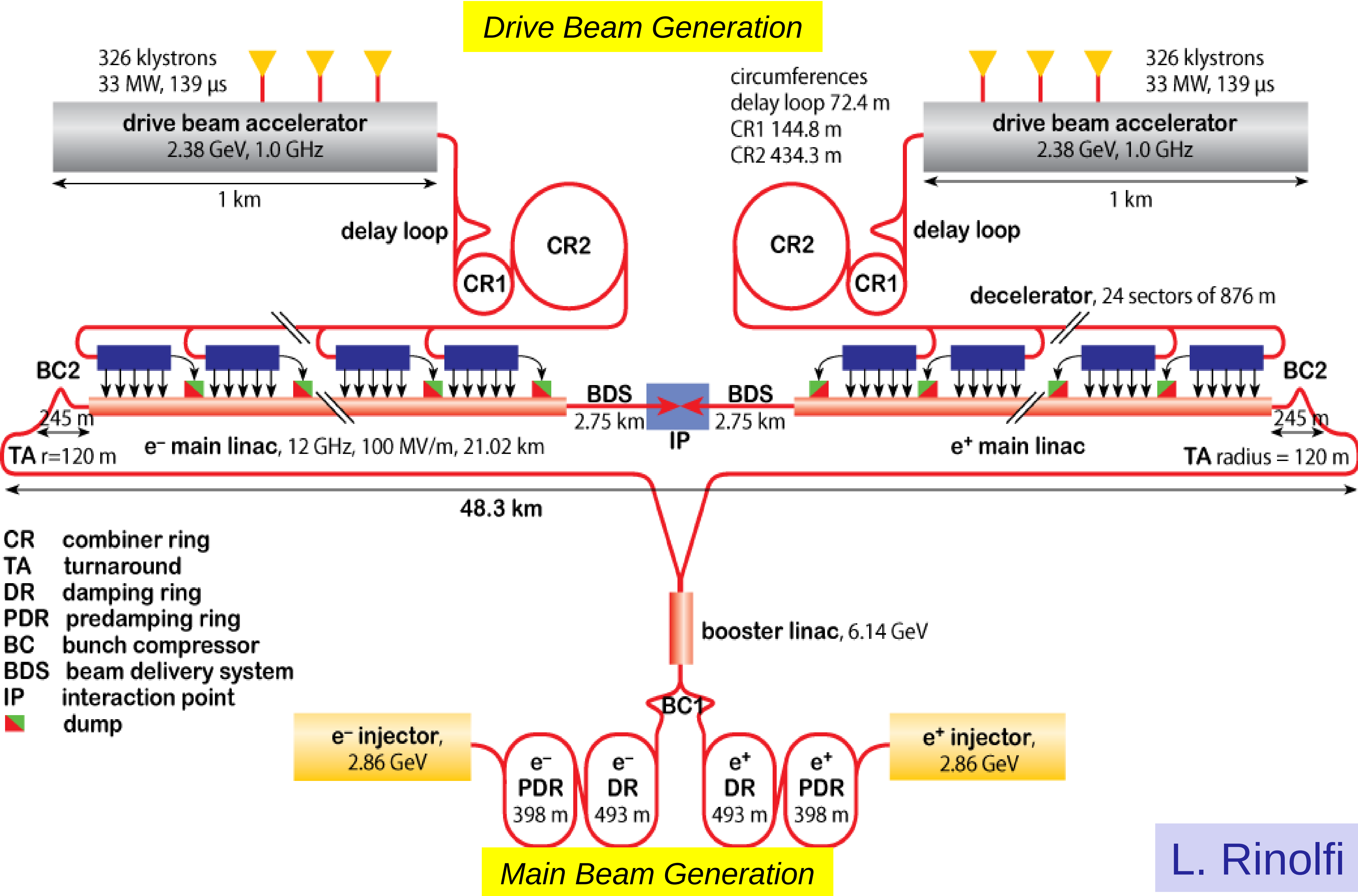
ILC DR Design

The ILC DR baseline configuration is able to meet the key design parameters required for the baseline design

- Validation of the various design choices continues
- Major limiting areas of operational concern identified for further R&D included
  - Achievement of 2pm vertical emittance
  - Electron Cloud effects
  - Fast Ion effects
  - Ability to stably inject and extract closely spaced bunches
- An aggressive R&D program has been underway for the past 2 years to try to address these issues
- The design continues to evolve as we iterate the overall ILC machine design to achieve maximum value…

Before going any further, however, let's look at the CLIC damping ring design…

General CLIC Layout for 3 TeV



L. Rinolfi

CLIC versus ILC parameters driving damping ring design

Parameters	Units	ILC	CLIC
Number of particles/bunch	10^9	20	4.1
Linac bunch spacing	ns	554	0.5
Number of bunches /train		1312	312
Repetition rate	Hz	5	50
Horizontal normalized emittance	nm	5500	500
Vertical normalized emittance		20	5
Longitudinal normalized emittance	keV m	33	6

Some ILC-CLIC Comparisons

Parameter	Units	ILC DR (RDR)	CLIC DR
Energy	GeV	5.0	2.86
Circumference	km	6.695	0.42056
Nominal # of bunches & particles/bunch		2625@2.0×10^{10}	312@0.41×10^{10}
Macropulse Repetition Rate	Hz	5	50
Average current	A	0.4	0.15
Energy loss per turn	MeV	8.7	4.2
RF Frequency	MHz	650	2000
Total RF voltage	MV	24	4.9
Equilibrium normalized emittance, $\gamma\varepsilon_x$	μm·rad	5.0	0.4
Natural Chromaticity, χ_x/χ_y		-63/-62	-168/-60
Momentum compaction, α_c		4.2×10^{-4}	8×10^{-5}
Bunch length, σ_z	mm	9.0	1.6
Momentum spread, σ_p/p		1.3×10^{-3}	1.4×10^{-3}
Horizontal damping time, τ_x	ms	25.7	1.9
Longitudinal damping time, τ_z	ms	12.9	0.96

Some ILC-CLIC Comparisons

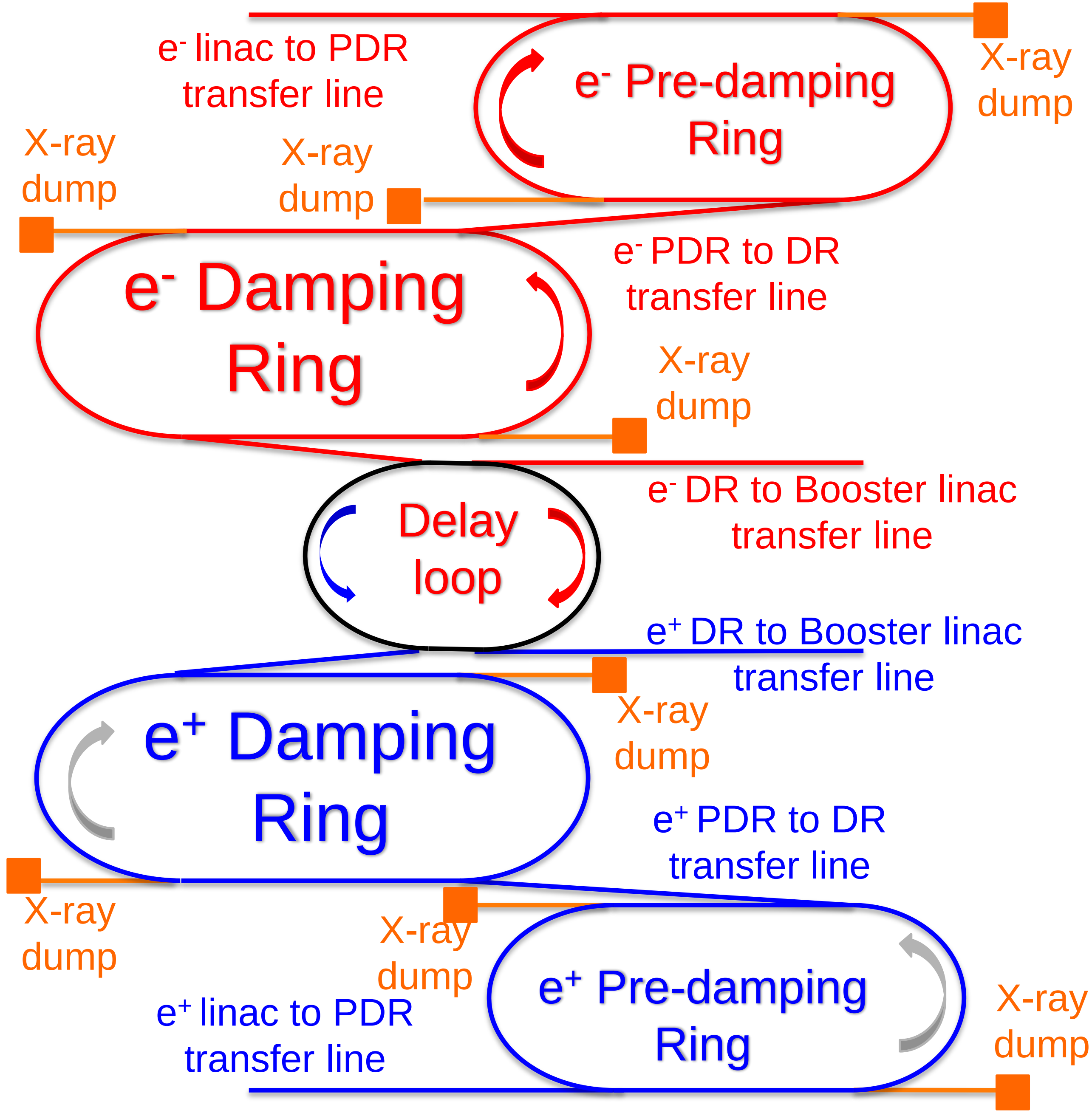
Parameter	Units	ILC DR (TDR)	CLIC DR (CDR)
Energy	GeV	5.0	2.86
Circumference	km	3.238	0.428
Nominal # of bunches & particles/bunch		$1312@2.0\times10^{10}$	$312@0.41\times10^{10}$
Macropulse Repetition Rate	Hz	5	50
Average current	A	0.4	0.15
Energy loss per turn	MeV	4.5	4.0
RF Frequency	MHz	650	2000 (1000)
Total RF voltage	MV	14	10
Equilibrium normalized emittance, $\gamma\varepsilon_x$	μm·rad	5.7	0.46
Natural Chromaticity, χ_x/χ_y		-51/-43	-115/-85
Momentum compaction, α_c		3.3×10^{-4}	1.3×10^{-4}
Bunch length, σ_z	mm	6.0	1.6 (1.8)
Momentum spread, σ_p/p		1.1×10^{-3}	1.0×10^{-3}
Horizontal damping time, τ_x	ms	24.0	2.0
Longitudinal damping time, τ_z	ms	12.0	1.0

Updated to 2012

CLIC DR Complex

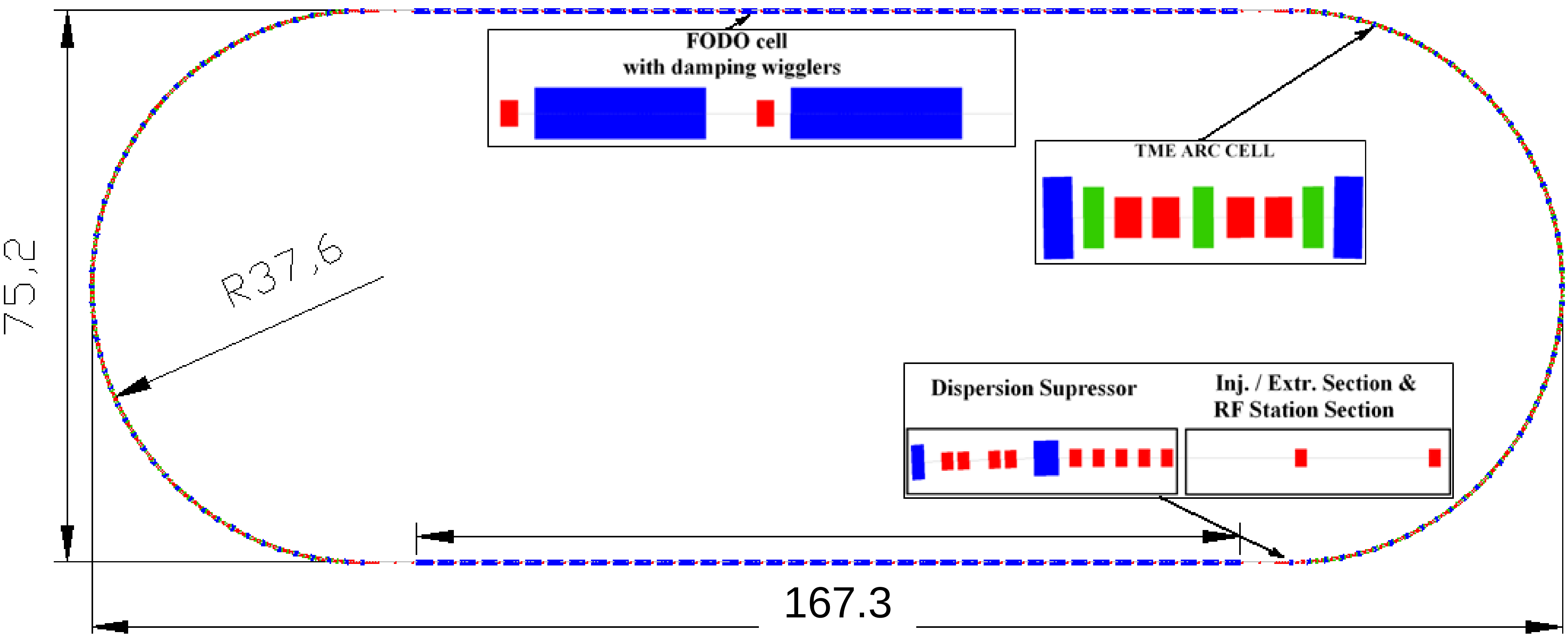
Normal conducting RF design in ML allows train-level injection/extraction instead of bunch-by-bunch

The use of pre-damping rings relaxes the dynamic aperture and energy acceptance requirements in the damping rings



CLIC DR Layout

S. Sinyatkin, et al., LER 2010



Racetrack shape with

- 96 TME arc cells (4 half cells for dispersion suppression)
- 26 Damping wiggler FODO cells in the long straight sections (LSS)
- Space reserved upstream in the LSS for injection/extraction elements and RF cavities

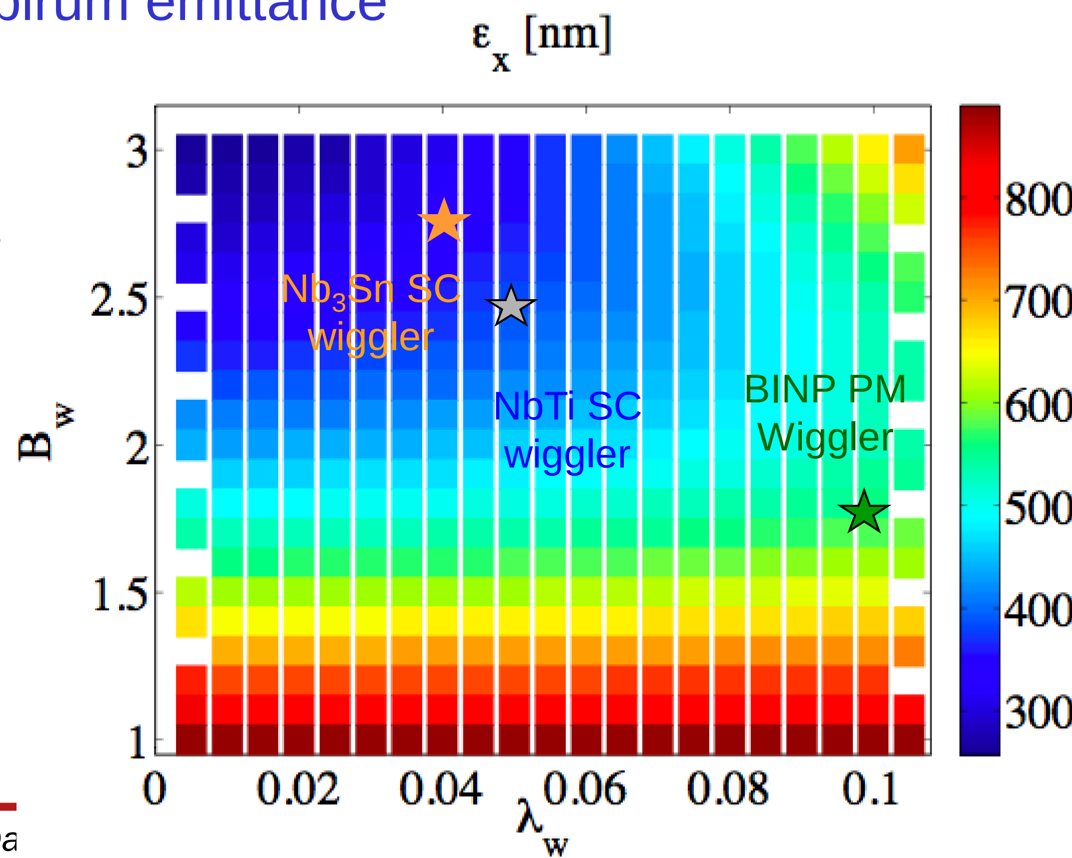
CLIC Damping Ring Challenges I

In the presence of the pre-damping rings, the major challenges for dynamic aperture and energy acceptance move upstream of the damping rings

Major issues for damping rings include:

- The repetition rate (50 Hz) requires very short damping times
- High charge density in each bunch means Intrabeam Scattering has a significant impact on the equilibirum emittance

⇨ Both of these issues drive the damping wiggler specifications to a very high field design which can only be achieved with superconducting technology



CLIC Damping Ring Challenges II

- Achieving the necessary equilibrium emittance requires careful lattice design
  - Target Emittance sensitive to:
    - IBS, which must be directly taken into account – it's not a small perturbation which is unlike any other rings of this type
    - E_{ring}
    - Achievable wiggler parameters
  - A very strongly focusing lattice requires particular care with:
    - Magnet strengths
    - Alignment tolerances

- Collective Instabilities
  - Electron Cloud in the positron ring
  - Fast Ion Instability in the electron ring
  - Space charge plays a major role in the energy and circumference choice

CLIC Damping Ring Challenges III

Repetition rate and bunch structure

- 0.5 ns bunch spacing to match main linac structure
- 2 GHz RF System – Examples of other rings:
  - SLAC-PEPII LER – 476 MHz
  - LBNL-ALS – 500 MHz
  - KEKB – 500 MHz SC
  - CESR – 500 MHz SC
  - KEK-ATF – 714 MHz
  - ILC DR – 650 MHz SC
  - CLIC DR – 2000 MHz
- Requires
  - New power source design
  - Demonstrated capability to handle high peak and average currents

CDR: 1 GHz RF option
DR bunch spacing 1 ns
To get 0.5 bunch spacing the trains have to be recombined in a delay loop downstream of the DRs with an RF deflector.

CLIC Damping Ring Challenges IV

With the extremely small beam sizes at the IP, exquisite pulse stability, O(10^{-4}) is required

- Similar to ILC DR
- However the pulser requirements, which must inject/extract the whole train in each pulse, is conceptually simpler
  - ILC DR pulse width ~6ns
  - CLIC DR pulse width ~160ns

So, while the design challenges involve many of the same issues for the ILC DR and the CLIC DR, the actual operating parameters give rise to distinctly different designs with different issues being the dominant ones.

In Summary

Requirements

- Number of bunches
- Number of particles/bunch
- Emittances ε_x, ε_y
- Damping times $\tau_{x,y}$
- Bunch length σ_l
- Energy spread σ_p
- Large acceptance for the injected positron beam

Design Choices

- Energy
- Circumference
- Momentum compaction
- Lattice
- Technical systems

Summary

At this point we have completed an overview of some of the key design issues for the CLIC and ILC damping rings

These rings offer a range of challenges both to the lattice designers as well as the technical designers who must come up with reliable implementations of hardware that meet the design specifications

I hope that you walk away from this portion of the lecture with an appreciation for how complicated trade-offs are required to meet aggressive physics specifications

In the next part of this lecture we will spend some time looking at the basic physics of storage rings in order to provide further insight into the details of such decisions

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