



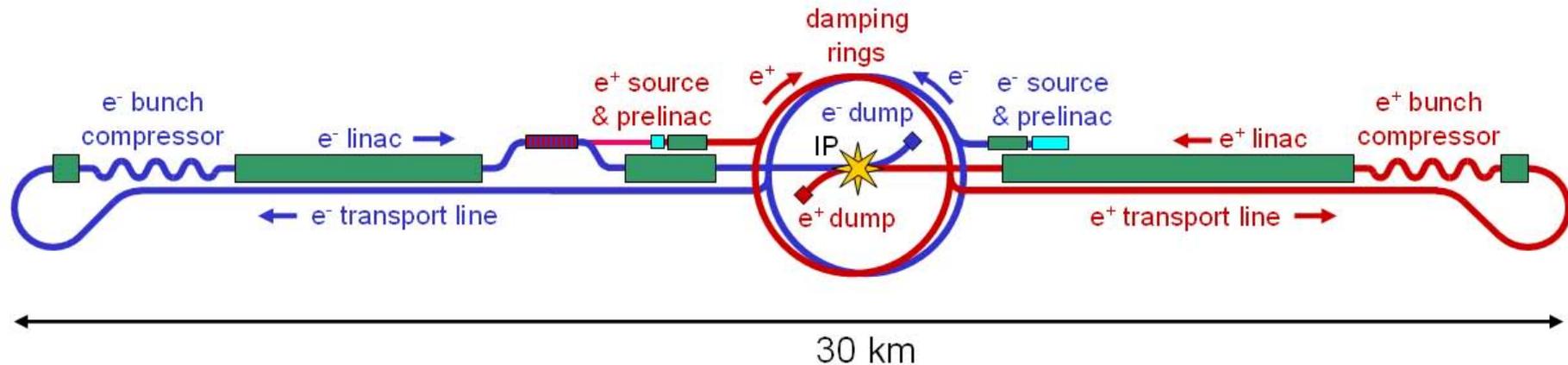
Critical R&D Issues for ILC Damping Rings and New Test Facilities

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ILC Key Parameters



Given the main linac parameters:

5 Hz repetition rate

1 ms RF pulse

9 mA average current during pulse

the ILC luminosity goal of $2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ will require:

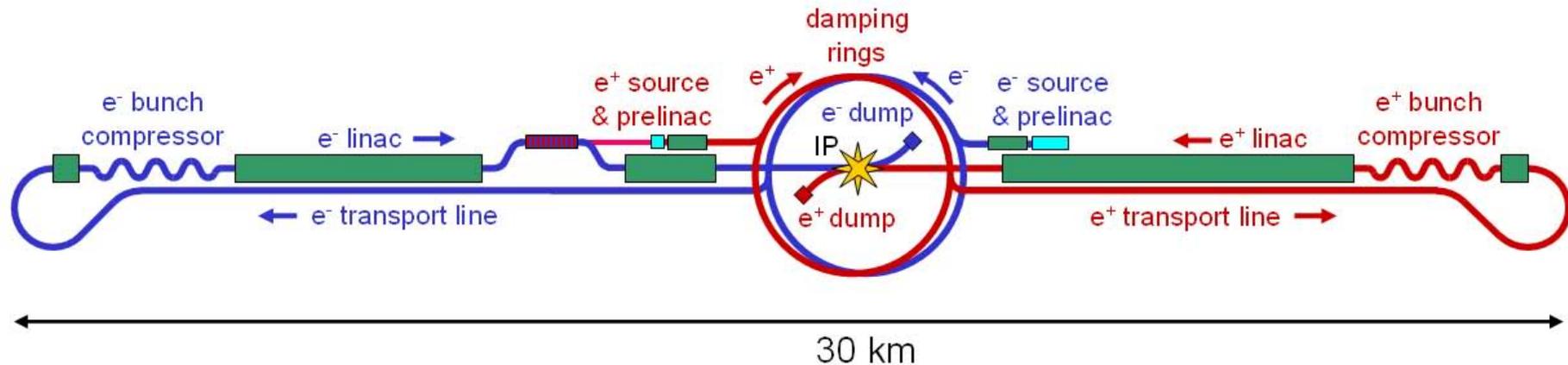
6000 bunches per pulse with 10^{10} particles per bunch

40 nm normalized vertical emittance at the IP

very high levels of beam stability (jitter < 10% of beam size)



Role of the Damping Rings



The positron source produces a beam with normalized emittances 0.01 m: the vertical emittance must be reduced more than five orders of magnitude.

To achieve this, we keep the beam in a storage ring with damping time ~ 25 ms, for 200 ms (between machine pulses).

A 1 ms beam has total length 300 km... this must be compressed to fit into a damping ring.

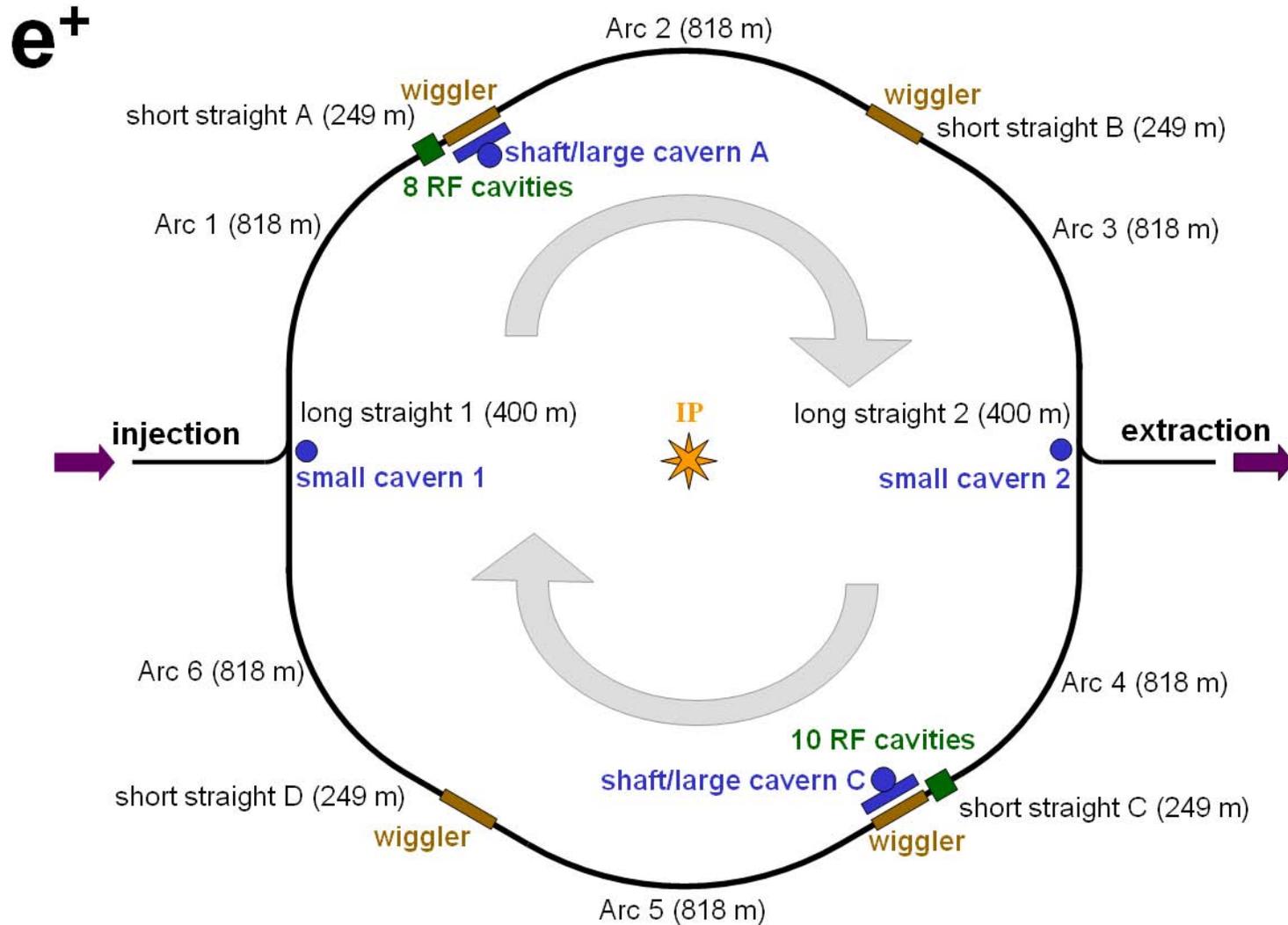


Damping Rings Configuration

- To keep the damping rings a practical size, we extract bunches individually, to "decompress" the bunch train from the damping rings into the main linac.
- This allows some flexibility in the damping rings configuration. After considering beam dynamics issues, capability of technical subsystems, and costs, the parameters for the present configuration are:
 - **circumference of between 6 and 7 km;**
 - **beam energy of 5 GeV;**
 - **one electron ring and one positron ring in a single tunnel centered on the interaction point.**
- Configuration choices are based on a trade-off between competing technical challenges and cost drivers.



Damping Rings "RDR" Layout





R&D Challenges

The main research and development challenges for the present configuration of the ILC damping rings include:

- **designing a lattice to accept a large beam from the positron source, with low sensitivity to errors;**
- **developing fast (single bunch) injection/extraction kickers;**
- **achieving a vertical emittance of 2 pm;**
- **keeping the chamber impedance low enough to avoid beam instabilities;**
- **characterizing and suppressing fast ion instability in the electron damping ring;**
- **characterizing and suppressing electron cloud effects in the positron damping ring.**



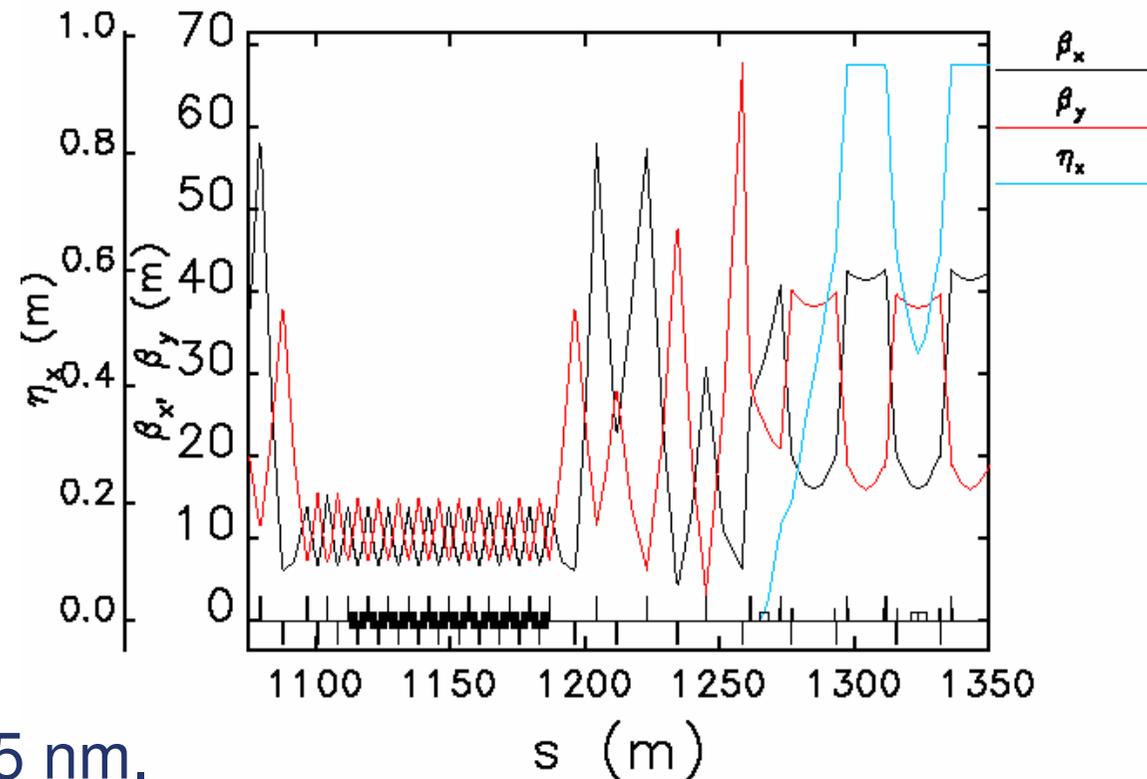
Lattice Design

The lattice is fundamental to the design work for the rings.

RDR design is based on arcs constructed from "theoretical minimum emittance" (TME) cells, with six long straights for damping wigglers, RF, injection and extraction etc.

Natural emittance is 0.5 nm.

Momentum compaction factor is 4×10^{-4} .

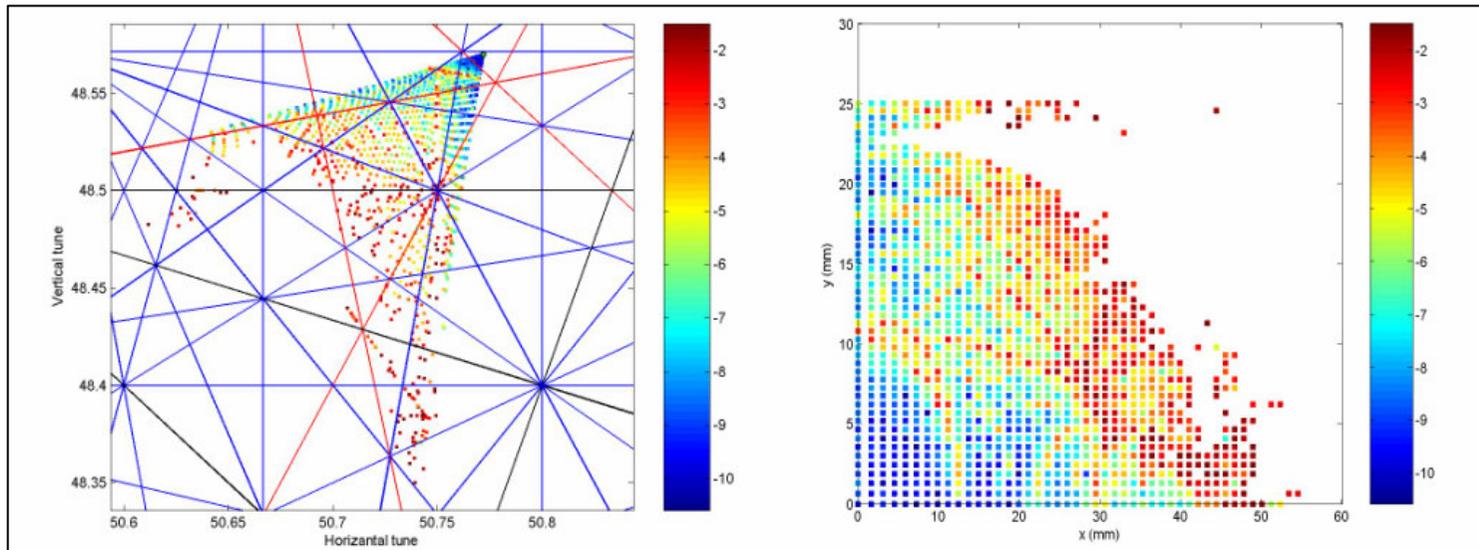


Aimin Xiao, Louis Emery (ANL)



Lattice Design

Achieving the necessary dynamic aperture to accept the large positron beam is a challenge in a very low emittance lattice.



Other concerns include sensitivity to magnet alignment and strength errors, numbers and parameters of magnets, etc. Features such as ability to tune the momentum compaction factor are highly desirable.

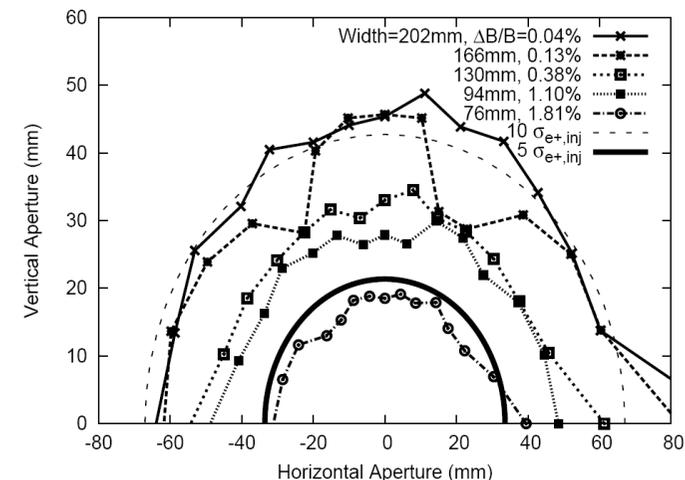
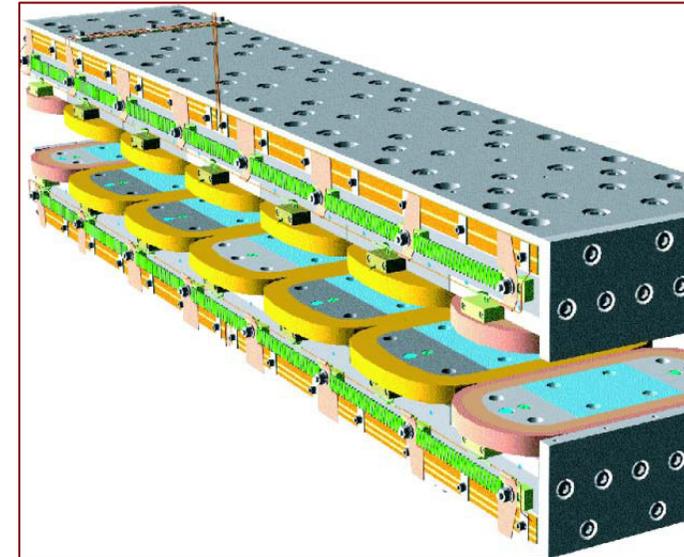
Yi-Peng Sun, Jie Gao (IHEP)



Damping Wigglers

Systematic nonlinear field components in the long (200 m) damping wigglers are a potential concern.

Tools have been developed (Dragt and Mitchell, and others) to allow accurate modeling of wiggler fields for particle tracking. Studies using designs based on the CESR-c superferric wigglers indicate that the field quality can be good enough not to impact the dynamic aperture.



J. Urban, G. Dugan, M. Palmer (Cornell)



Injection/Extraction Kickers

Compression of the full ILC bunch train (1 ms) to fit inside a 6 km damping ring will be achieved by extraction (and injection) of individual bunches.

Injection must be on-axis during normal operation.

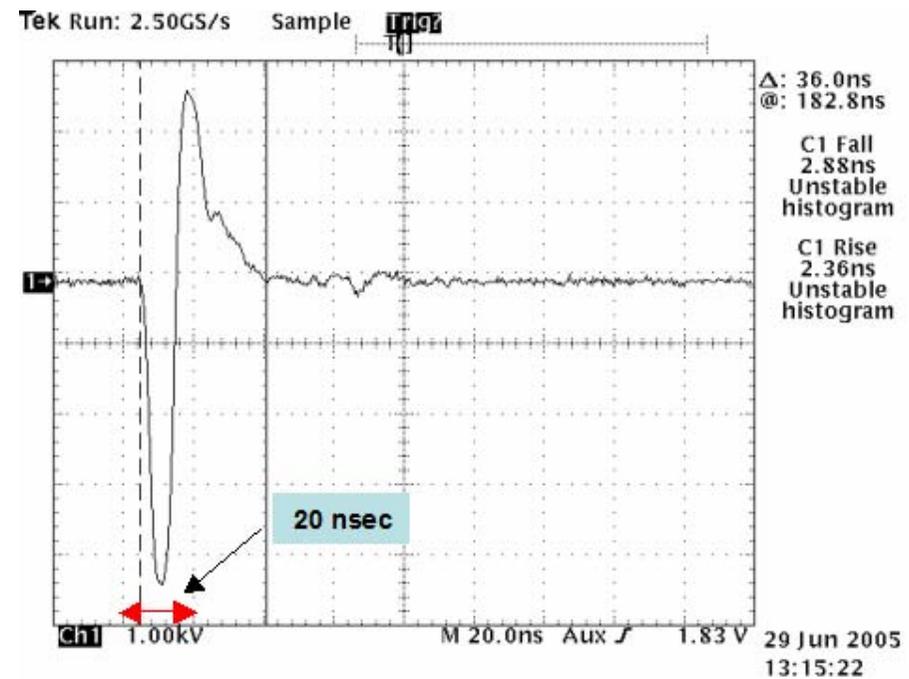
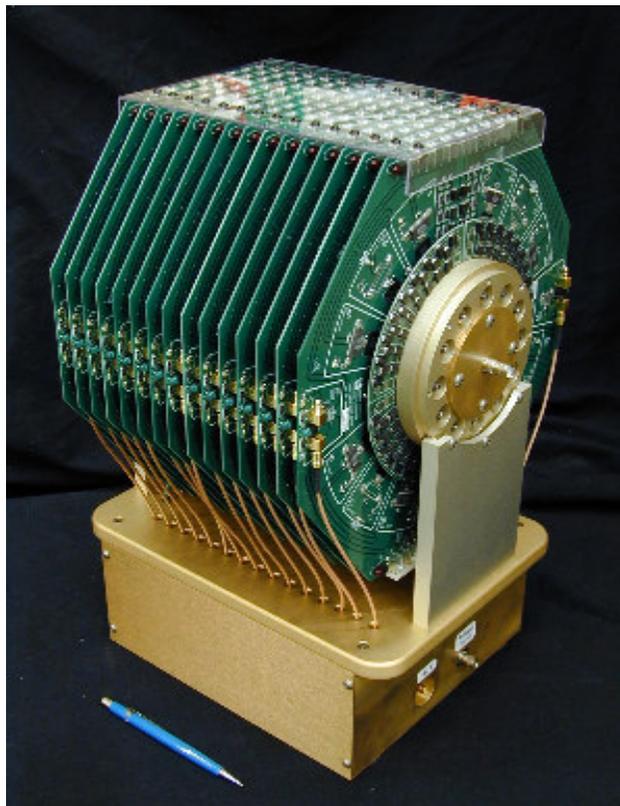
Ring circumference, beam size and stability criteria drive the specifications for the injection/extraction kickers:

- **kicker rise/fall time: 3 ns**
- **amplitude (for injected positrons): 130 kV-m**
- **"burst" frequency: 6 MHz**
- **burst length: 1 ms**
- **burst repetition rate: 5 Hz**
- **pulse-to-pulse stability: < 0.1%**



Injection/Extraction Kickers

High-availability MOSFET "Inductive Adder" pulser.

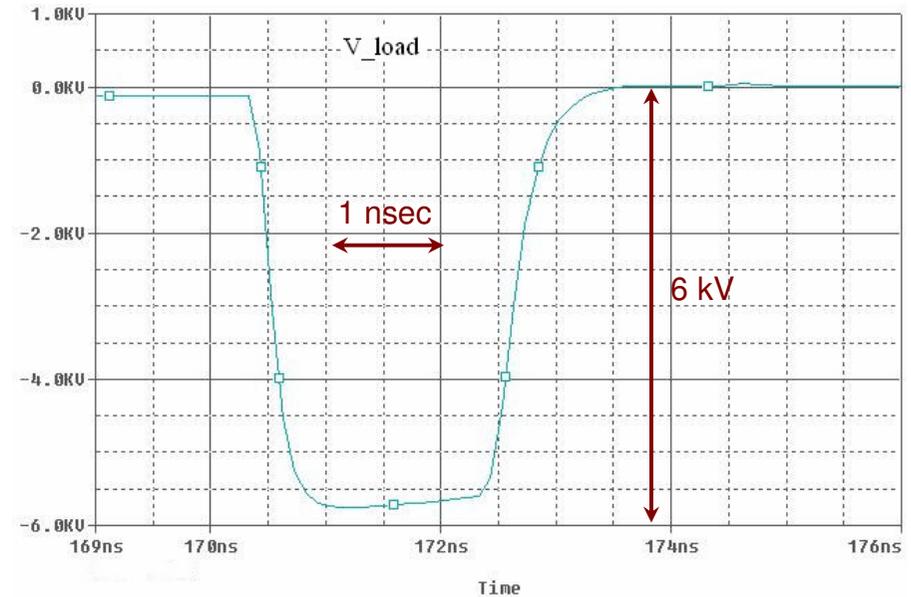
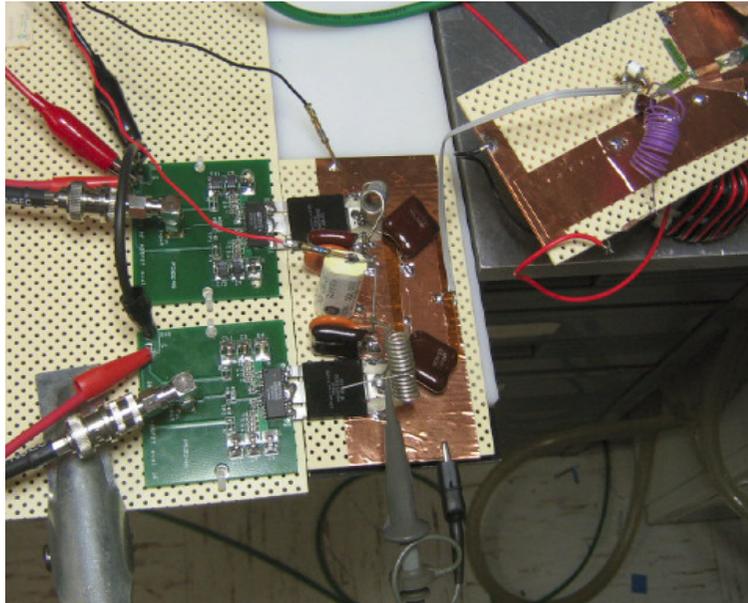


Ed Cook (LLNL)



Injection/Extraction Kickers

Delay Step Recovery Diode.



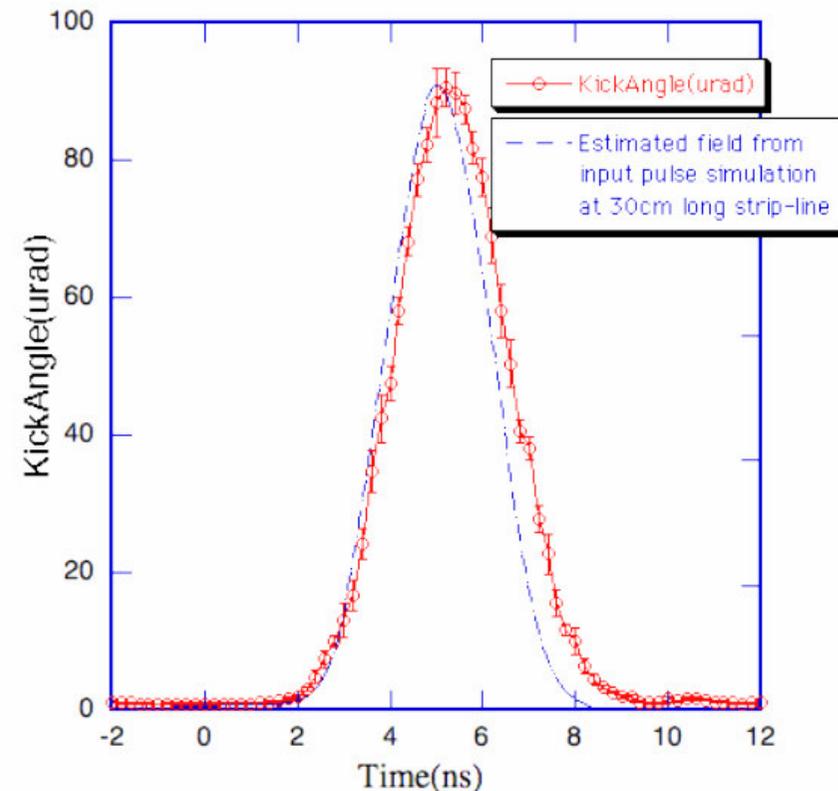
Anatoly Krasnykh (SLAC)



Injection/Extraction Kickers

Fast Ionization Dynistor: beam tests at KEK-ATF.

- Kicker amplitude is estimated from coherent motion induced on a bunch.
- Kicker pulse shape is measured by varying the timing between the pulse and the passage of the bunch.
- FID pulser is a commercial device with parameters approaching the ILC specifications.

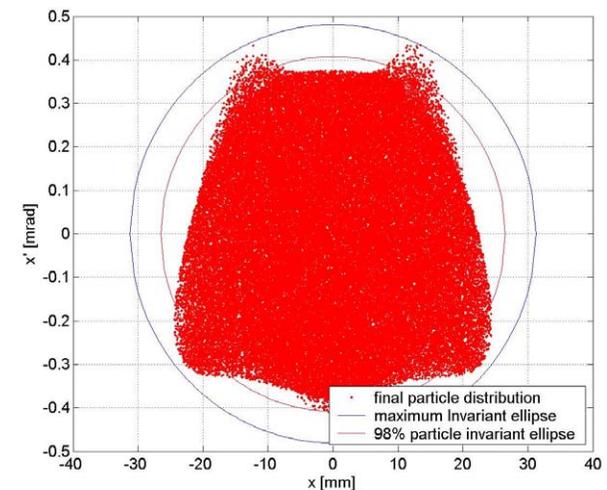
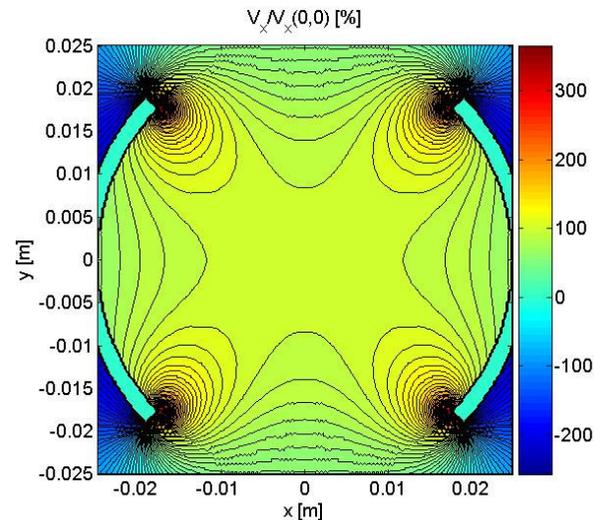
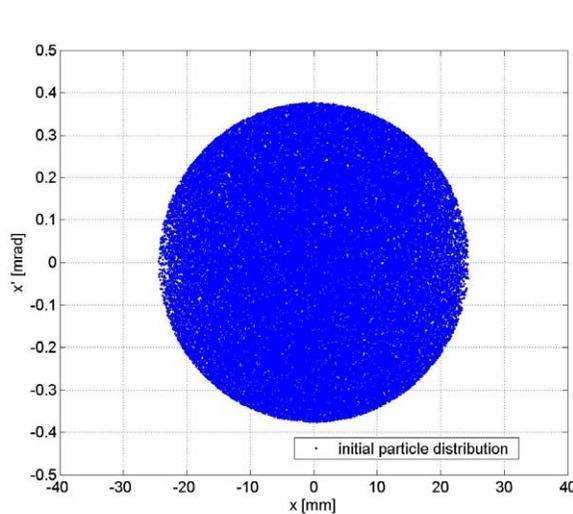


Takashi Naito et al (KEK); FID GmbH



Injection/Extraction Kickers

Kicker striplines must provide very good field quality to avoid distortion of injected phase space distribution.



David Alesini (LNF)



2 pm Vertical Emittance

- Luminosity depends directly on vertical emittance achieved at the interaction point: ILC specification is 40 nm (norm.).
- To allow for dilution effects between the damping ring and the IP, specified vertical emittance in the damping ring is 20 nm, or 2 pm geometric (at 5 GeV).
 - **Lowest achieved vertical emittance in any existing storage ring is 4.5 pm in KEK-ATF.**
- Fundamental limit (from vertical opening angle of synchrotron radiation) is of order 0.1 pm: practical limitations will be from steering and alignment errors.



2 pm Vertical Emittance

R&D goals include:

- demonstration of 2 pm emittance in an operating storage ring;
 - **develop an understanding of dominant sources of emittance generation and techniques to minimize them;**
 - **understand the requirements on the instrumentation and diagnostics for tuning and emittance measurement.**
- development of lattice design with acceptable sensitivities to steering and alignment errors;
- specification of technical subsystems to ensure capability for routine operation at ultra-low emittance;
 - **ground motion and magnet supports;**
 - **temperature stabilization;**
 - **diagnostics and correction schemes.**



2 pm Vertical Emittance

2 pm is the specified vertical emittance at full current. Collective effects (such as intrabeam scattering) tend to increase the emittance with bunch charge.

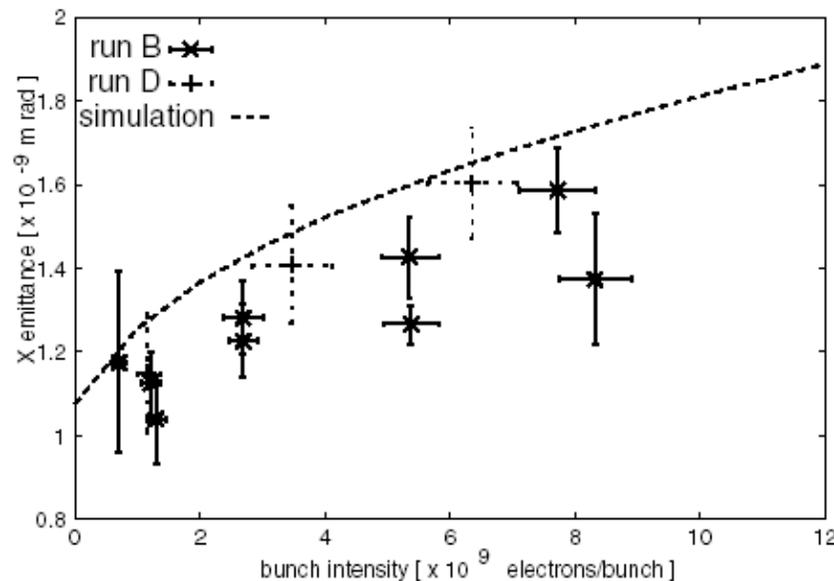


FIG. 3. Current dependence of the horizontal emittance: Data for the smallest emittance cases (runs B and D) are shown. The result of a SAD simulation for 0.4% coupling is superimposed.

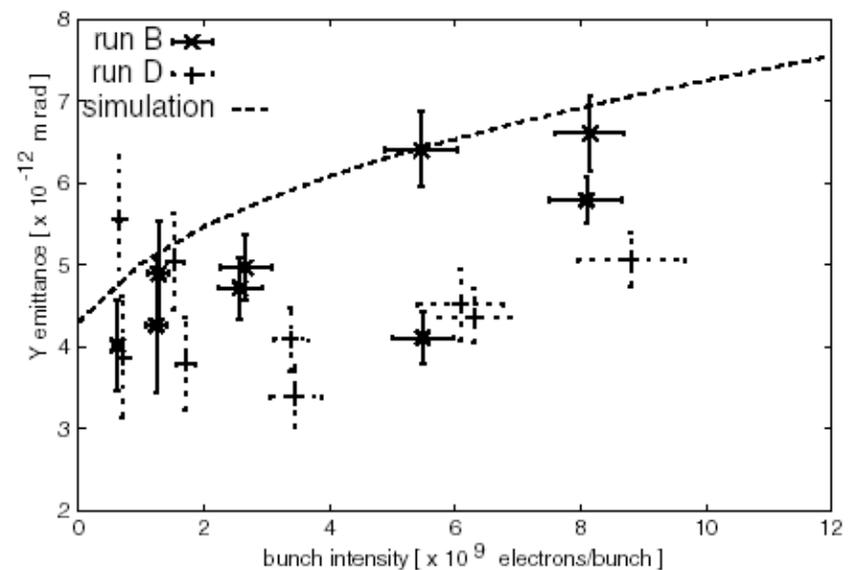


FIG. 2. Current dependence of the vertical emittance: Data for the smallest emittance cases (runs B and D) are shown. The result of a SAD simulation for 0.4% coupling is superimposed.

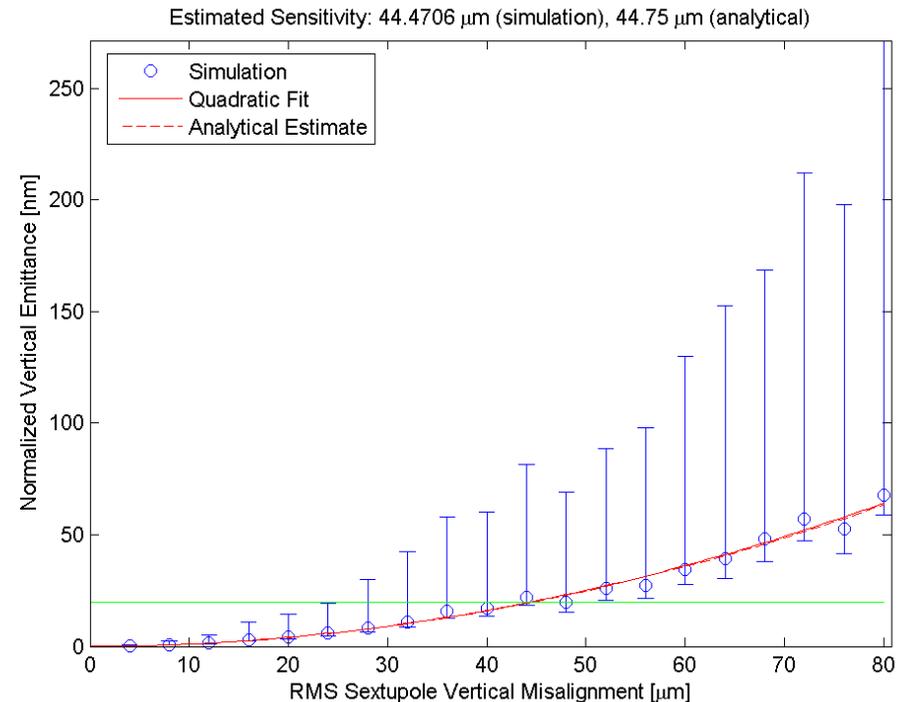
Y. Honda et al, Phys. Rev. Lett. 92, 054802-1 (2004)



2 pm Vertical Emittance

Simulation studies (backed up by experimental work at KEK-ATF) suggest that the damping rings will be sensitive to magnet motion at the level of tens of microns.

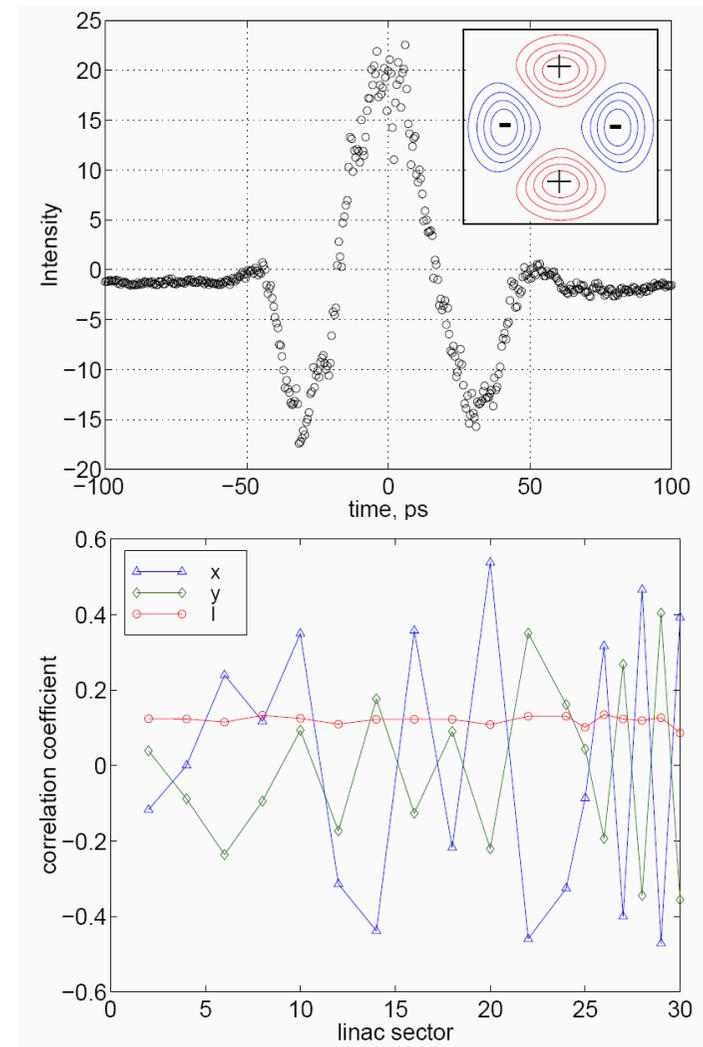
Studies of alignment sensitivities and tuning techniques allow estimates to be made of requirements for alignment and stability, diagnostics performance frequency of tuning, temperature stability, etc.





Vacuum Chamber Impedance

- Impedance of the vacuum chamber can drive various instabilities (microwave, transverse mode-coupling...)
- At the SLC it was found that even small variations in charge distribution in the damping rings (associated with impedance-driven instabilities) became amplified in downstream systems and made tuning and operation very difficult.



Boris Podobedov (BNL)



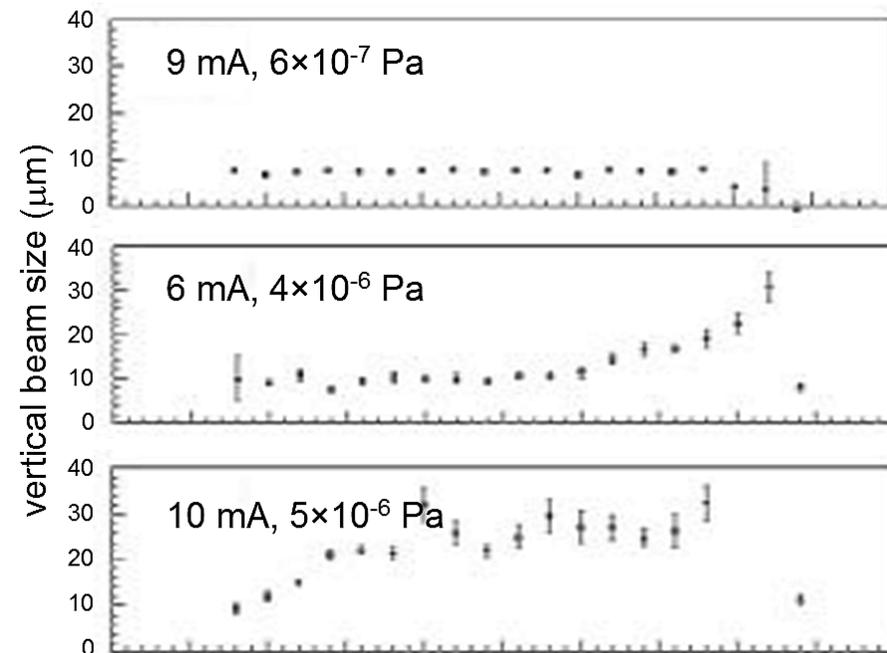
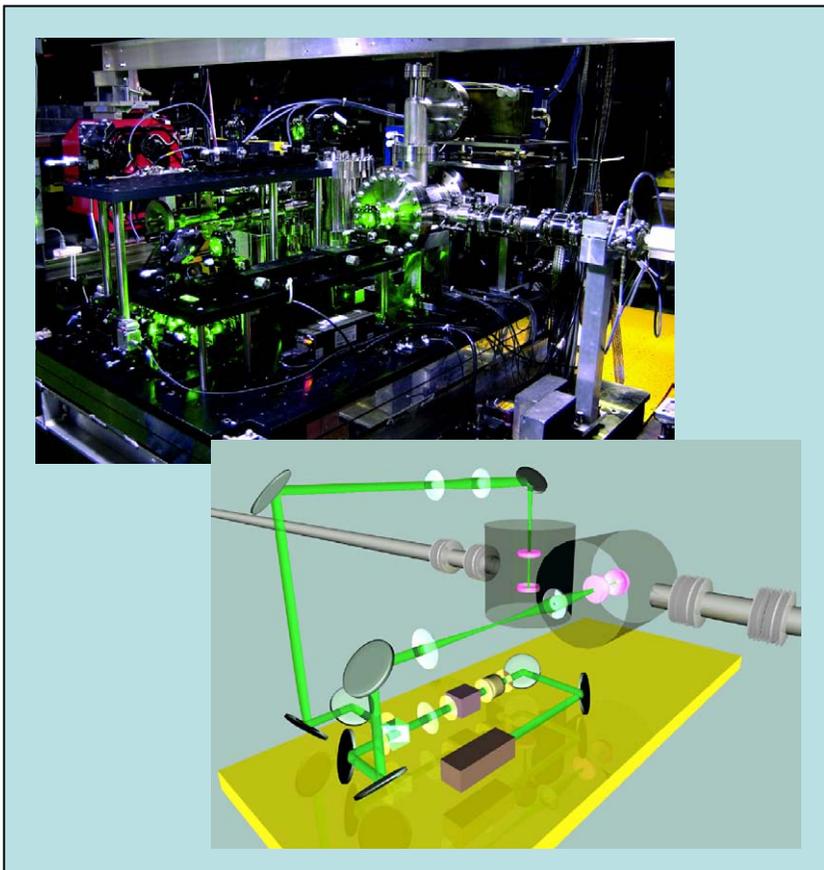
Vacuum Chamber Impedance

- The ILC damping rings will operate at lower bunch charges than the particle factories (e.g. KEKB, PEP-II) but could be significantly more sensitive to instabilities.
- Impedance is an issue for the parameter specifications and lattice design (bunch charge, bunch length, momentum compaction factor) and for the designs of the vacuum system and diagnostics.
- Preliminary impedance models are being constructed, based on scaling of components from existing machines.
- As detailed technical designs become available, the impedance model will be revised and updated, allowing more thorough studies of instabilities.



Fast Ion Instability

Ions accumulated in the passage of a small number of bunches can drive coherent motion of the following bunches.



*Vertical emittance growth in ATF dependent on vacuum pressure and bunch number, measured using a laser wire.
Yosuke Honda (KEK)*



Fast Ion Instability

- Observations of effects consistent with a fast ion instability (including emittance growth dependent on vacuum pressure) have been made at ALS, PLS and ATF.
- Quantitative data are still lacking. Further experiments are planned for the ATF in fall 2007.
- The R&D goals are:
 - **to validate the models;**
 - **to predict the impact of the fast ion instability on operation of the electron damping ring;**
 - **to set design specifications on ring design, vacuum pressure, feedback system etc., to mitigate any performance limitations from fast ion instability.**



Electron Cloud

- Simulation studies, using codes benchmarked against experimental data, suggest that electron cloud could be a serious issue for the positron damping ring.
- The B-factories operate at much higher currents, but:
 - **solenoid windings are needed to suppress electron cloud: this technique will not be effective in the damping wiggler in the ILC damping ring, where enough cloud could be generated to destabilize the beam;**
 - **the ILC damping rings are specified to provide beams with emittances two orders of magnitude lower than the B-factories: this makes the beam potentially more sensitive to lower cloud densities.**



Electron Cloud

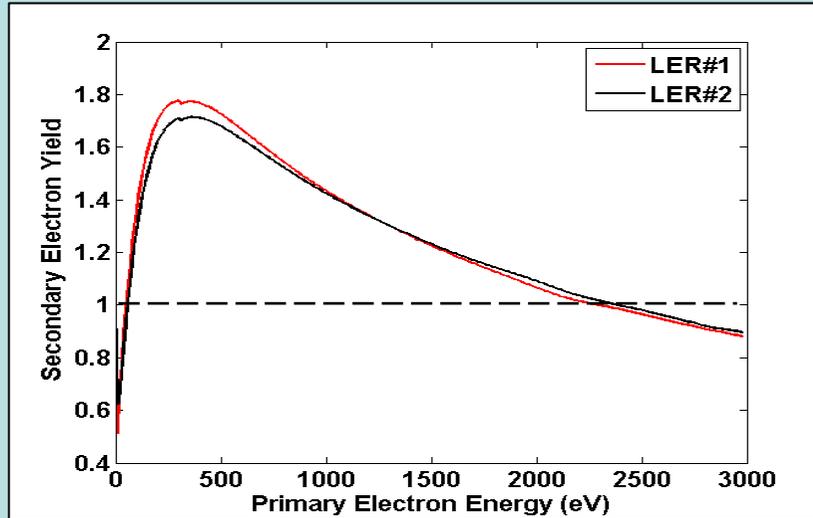
The electron cloud R&D goals for the damping rings are:

- **to collect experimental data** on electron cloud build-up and beam instabilities in a parameter regime relevant for the ILC damping rings;
- **to investigate the properties of a range of mitigation techniques** under operational conditions;
- **to determine the build-up of electron cloud and beam stability in the damping rings** under operational conditions with any of a variety of mitigation methods implemented;
- **to select a baseline mitigation technique**, design a vacuum system incorporating this technique, and **demonstrate effectiveness of the mitigation under relevant conditions.**

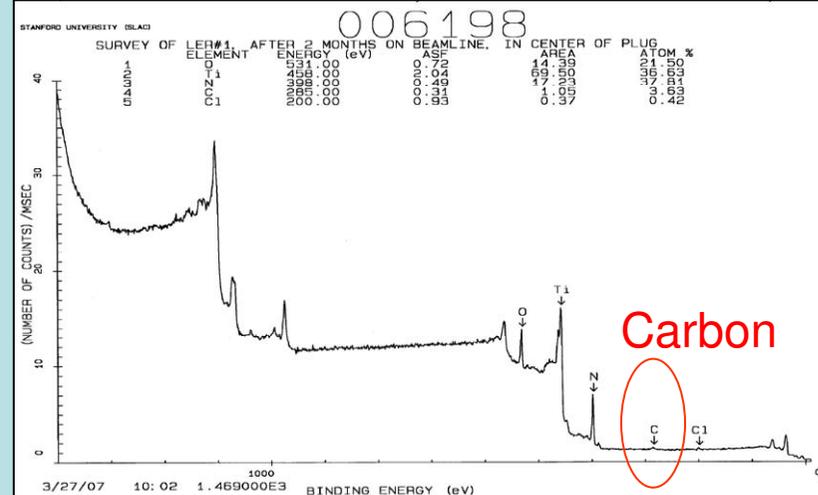
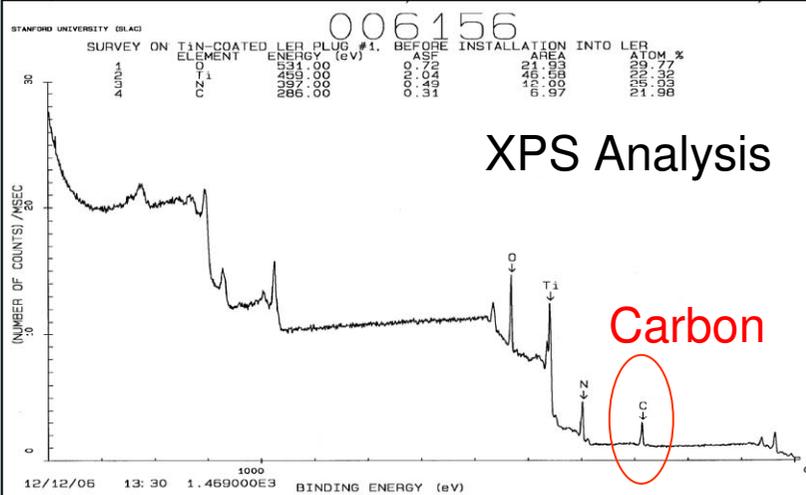
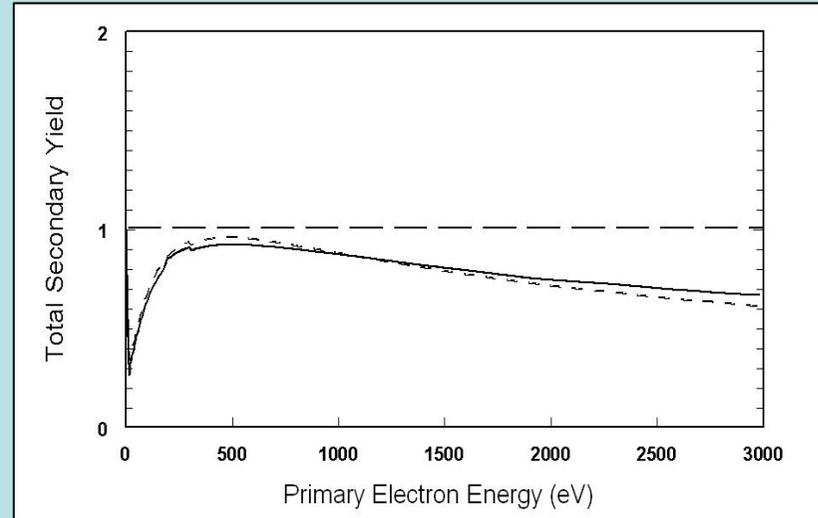


Tests of TiN Coating in PEP-II

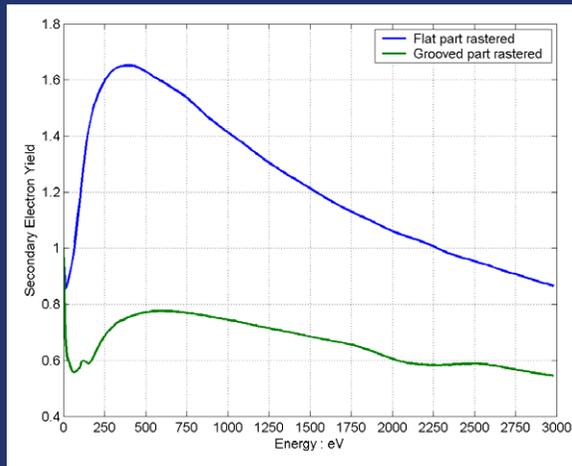
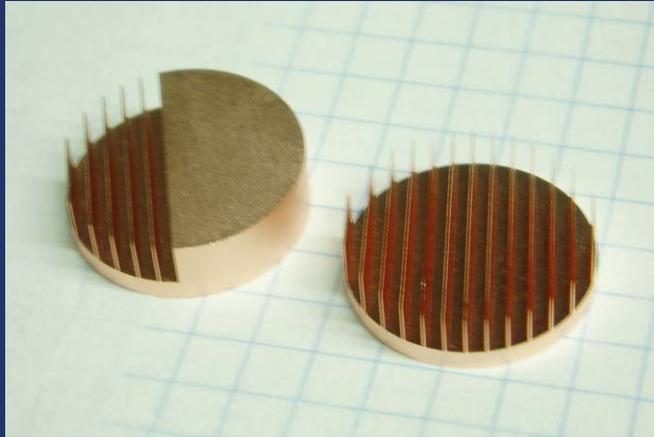
Before installation in LER



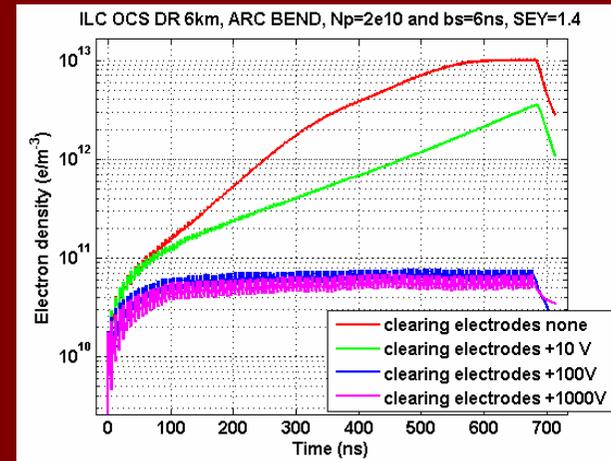
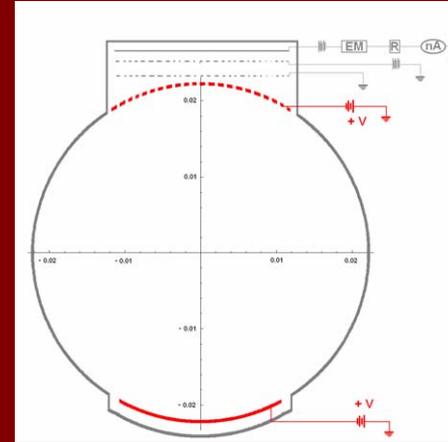
After 2 months exposure in LER



Grooved or finned surfaces



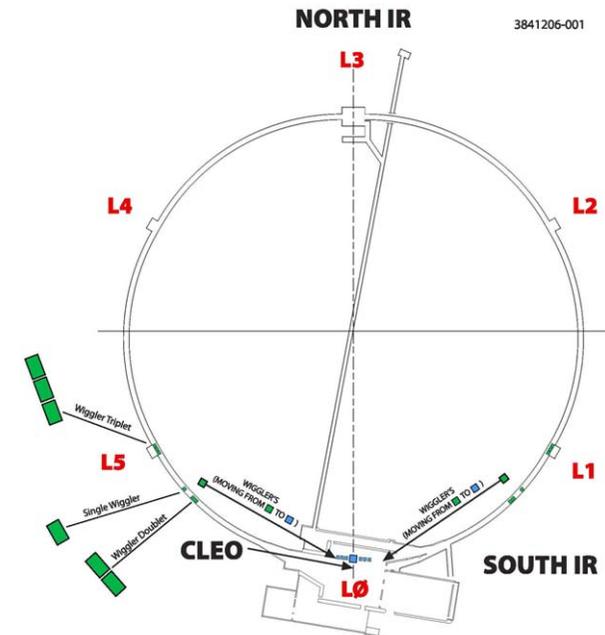
Clearing electrodes





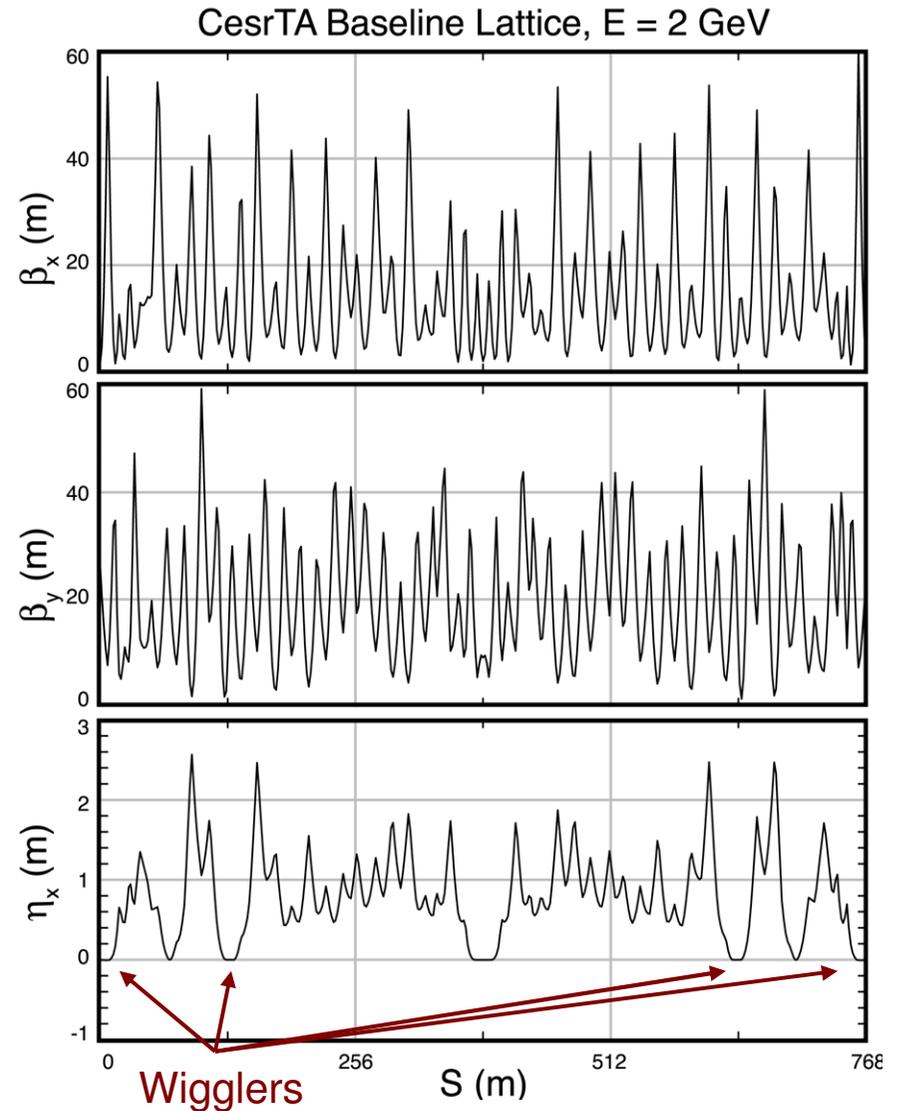
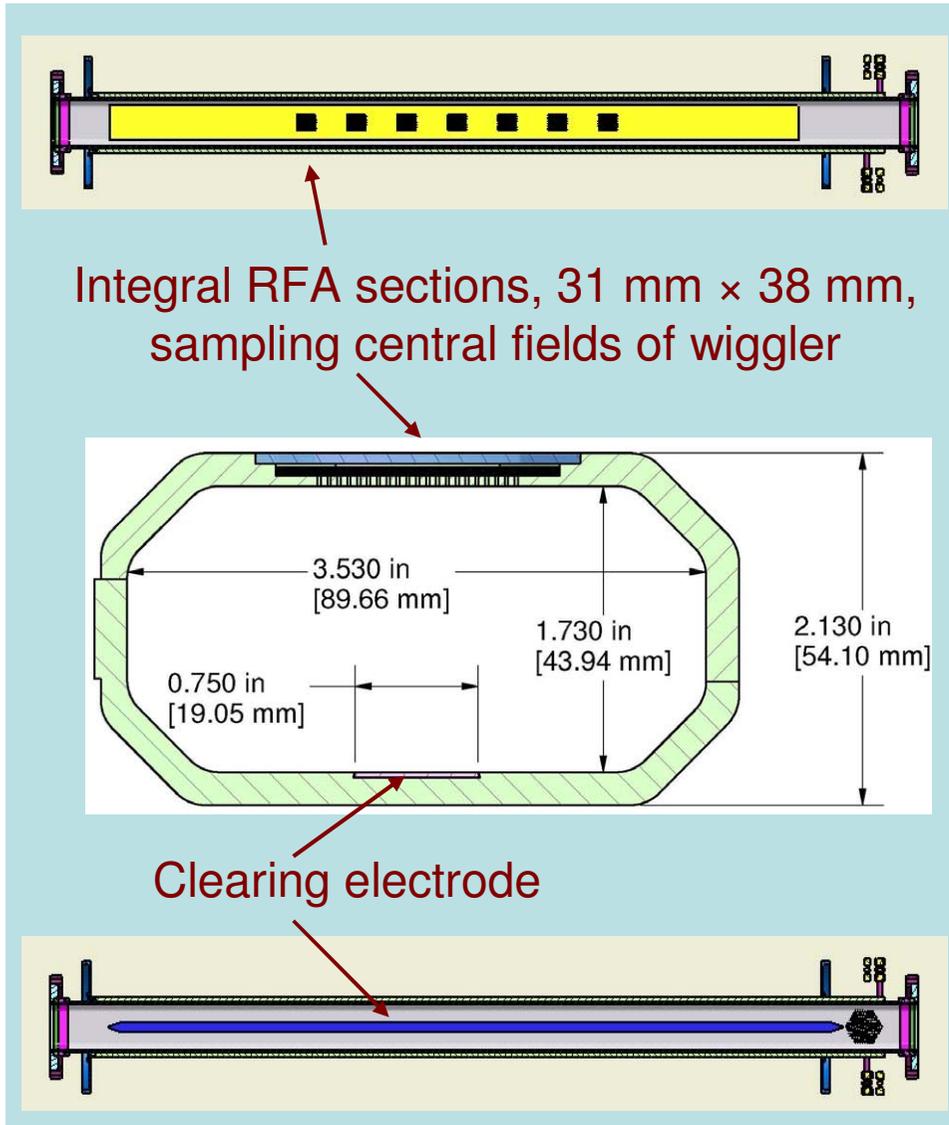
Test Facilities: CesrTA

- CESR-c is the only present storage ring where the radiation damping is dominated by wigglers.
- The specifications for the ILC damping ring wigglers are based on the CESR-c design.
- Relocation of the wigglers would allow low-emittance operation: "CesrTA".
- CesrTA would provide an ideal facility for damping rings studies, including low-emittance tuning, electron cloud studies, and development of instrumentation.
- *M. A. Palmer et al, "Plans for Utilizing CESR as a Test Accelerator for ILC Damping Rings R&D," PAC 2007 (MOOAKI01).*





Test Facilities: CsrTA





Test Facilities: KEKB

- The use of KEKB LER for electron cloud studies is being discussed. The goals would be:
 - **to achieve small horizontal and vertical emittances, comparable to those specified for the ILC damping rings;**
 - **to observe electron cloud instability with low emittance beams, and validate theories and simulations.**
- Low emittance would be achieved by reducing the beam energy from 3.5 GeV to 2.3 GeV.
- Dedicated use of LER for ILC studies will not be possible before integrated luminosity of KEKB reaches 1,000 fb⁻¹ (possibly by early 2009, depending on operating budget).
 - **Some limited time for ILC studies could be available before 2009...**
 - **...but would need separate funding, and must not interfere with normal operations.**

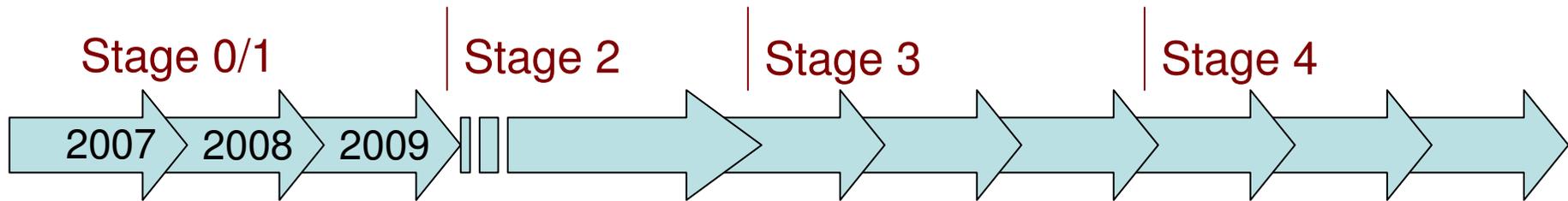


Test Facilities: KEKB

- Preliminary studies have explored possible optics, estimated IBS effects, and alignment sensitivity.
- Advantages of KEKB include:
 - **Similarity in parameters (circumference) to ILC DRs;**
 - **Machine is well understood from eight years of operation for Belle.**
 - **Solenoid windings allow control over electron cloud.**
- Potential disadvantages include:
 - **Difficulty of achieving ultra-low vertical emittance (ground motion; BPM performance; "surplus" components, etc.).**
 - **Lower beam energy leads to stronger instabilities.**
 - **Shortage of necessary instrumentation for measurements of ultra-low emittance beam.**



Test Facilities: HERA-DR



Ferdi Willeke has suggested a four stage approach to development of HERA into one of the damping rings for the ILC:

- **Stage 0:** HERA maintained as it is (approved, level of 4 FTE).
- **Stage 1:** Prepare the existing accelerator for its use as a damping ring.
- **Stage 2:** Demonstrate the most pressing accelerator physics issues of the damping rings using HERA, with moderate R&D investments.
- **Stage 3:** Modify HERA into one of the ILC damping rings, commission it, and demonstrate the required performance.
- **Stage 4:** Disassemble and reinstall the ring at the ILC site, recommission and operate it.



Test Facilities

operating

proposed

goal

	KEK ATF	CesrTA	KEKB LER	HERA-DR	ILC DR
Circumference	140 m	768 m	3 km	6.3 km	6.7 km
Beam energy	1.28 GeV	2.0 GeV	2.3 GeV	5 GeV	5 GeV
Natural emittance	1 nm	2.25 nm	1.5 nm	0.25 nm	0.5 nm
Vertical emittance	4.5 pm*	5 pm	1.5 – 15 pm	2 pm	2 pm
Length of wigglers	-	15.6 m	106 m	120 m	200 m
Wiggler peak field	-	2.1 T	0.51 T	0.8 T	1.6 T
Vertical damping time	28.5 ms	47 ms	100 ms	16 ms	25 ms
RF voltage	0.77 MV	8.5 MV	1.5 MV	40 MV	23 MV
Momentum compaction factor	2.1×10^{-3}	6.4×10^{-3}	2.4×10^{-4}	1.1×10^{-4}	4.2×10^{-4}
Synchrotron tune	0.0081	0.075	0.011	0.038	0.064
Natural bunch length	3 mm	9 mm	5 mm	3 mm	9 mm
Natural energy spread	5.5×10^{-4}	8.6×10^{-4}	4.8×10^{-4}	1.2×10^{-3}	1.3×10^{-3}

*Achieved at low current



Summary

- The present configuration for the ILC damping rings represents a trade-off between construction costs and technical R&D challenges.
- Six very high priority R&D issues have been identified:
 - **lattice design**
 - **injection/extraction kickers**
 - **ultralow-emittance tuning**
 - **impedance**
 - **fast ion instability**
 - **electron cloud**
- An active R&D programme is addressing each of the very high priority issues.
- The ATF has been an important and extremely successful test facility for damping rings R&D.
- Three new major damping rings test facilities have been proposed, which will provide opportunities for essential studies on electron cloud, low emittance tuning, and other issues.