Damping Rings and Ring Colliders
Damping Ring R&D Challanges

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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
- A3.2 - DR Basics: General Linear Beam Dynamics
- A3.3 - LER Design: Radiation Damping and Equilibrium Emittance
- A3.4 - LER Design: Damping Ring Lattices
- A3.5 – DR Technical systems
- A3.6 – Beam Dynamics
- A3.7 – R&D Challenges and Test Facilities
  - CESR-TA
  - ATF
  - Other R&D Efforts
- A3.8 – Circular Colliders

These slides have been presented at the 2010 LC school by Mark Palmer

ILC Damping Rings R&D Program

The ILC R&D program identified 4 key areas for work during part I (2008-2010) of the Technical Design Phase

- Understanding the electron cloud in the ILC DR parameter regime and developing methods to suppress it
- Ensuring that the fast ion instability can be controlled in the electron damping ring
- Developing fast injection/extraction kickers
- Demonstration of ultralow vertical emittance operation ($\varepsilon_y = 2\ pm$)
  This has now been demonstrated at light sources $\Rightarrow \varepsilon_y = 1\ pm$

Two dedicated test facilities were identified for this effort:

- CESRTA at Cornell (+ collaborators)
- ATF at KEK (+ collaborators)

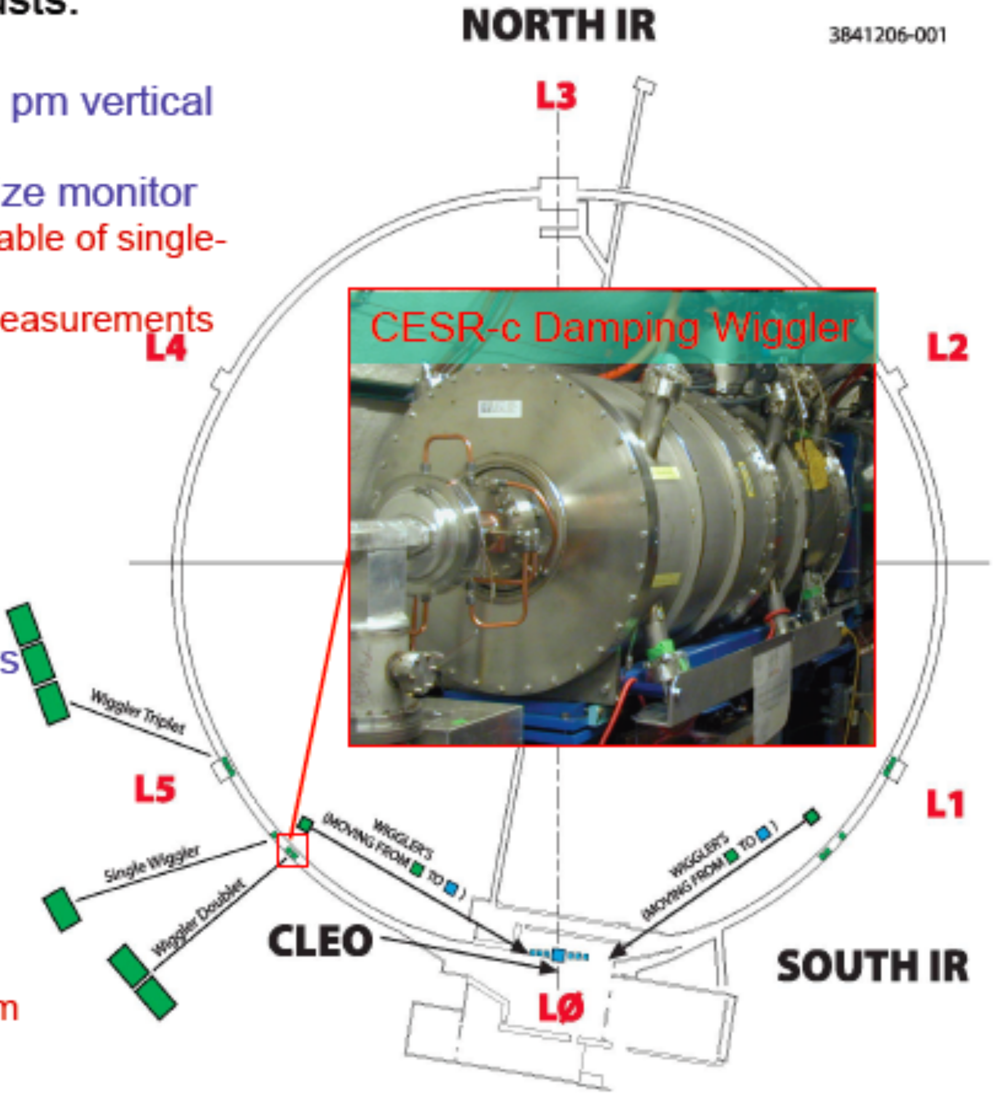
Contributors from institutions world-wide

- Simulation and Experiment
- EC Mitigation Methods
- Low Emittance Tuning
- Design Work

CESRTA Program

2.5 Year R&D Program with 3 major thrusts:

- ✔ – Electron cloud studies
- ✔ – Low emittance program (target of 20 pm vertical emittance)
- ✔ – Development of a fast X-ray beam size monitor
  - Target bunch-by-bunch monitor capable of single-pass measurements for ILC DR
  - Resolution for ultra-low emittance measurements



CesrTA Configuration:

- – 12 damping wigglers located in zero dispersion regions for ultra low emittance operation (move 6 wigglers from machine arcs to L0)
- – Diagnostic vacuum chambers with EC suppression methods
- – Designated sections available for installation of test devices
- – Precision instrumentation
  - Multi-bunch turn-by-turn BPM system
  - Fast X-ray beam profile monitors
- – 4 ns bunch train operation

CesrTA Parameters

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 photon flux in EC experimental regions

E[GeV]	Wigglers (1.9T/PM)	ε_x[nm]
1.8*	12/0	2.3
2.085	12/0	2.5
2.3	12/0	3.3
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

IBS Studies (1.8, 2.085, 2.3 GeV)

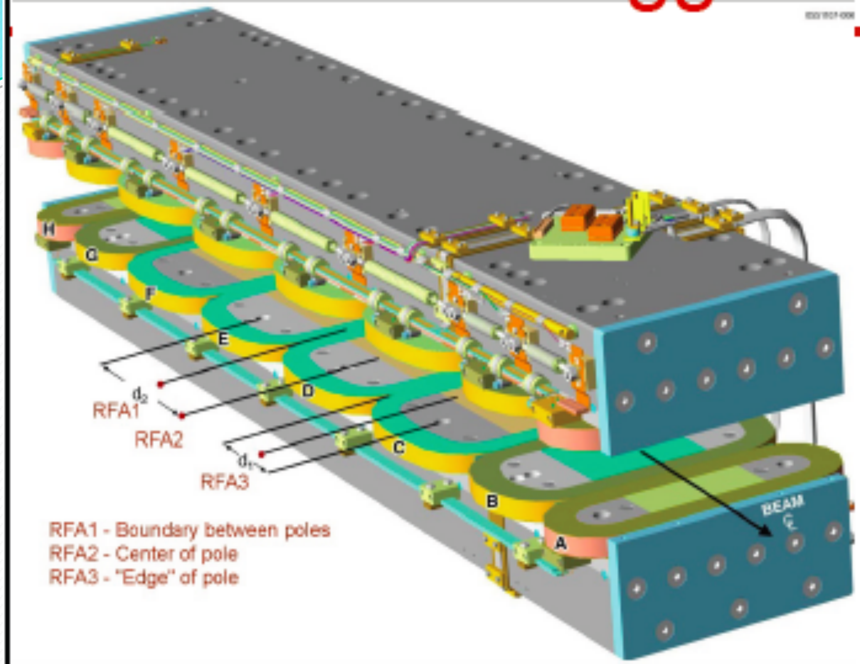
* Orbit/phase/coupling correction and injection but no ramp and recovery. In all other optics there has been at least one ramp and iteration on injection tuning and phase/coupling correction

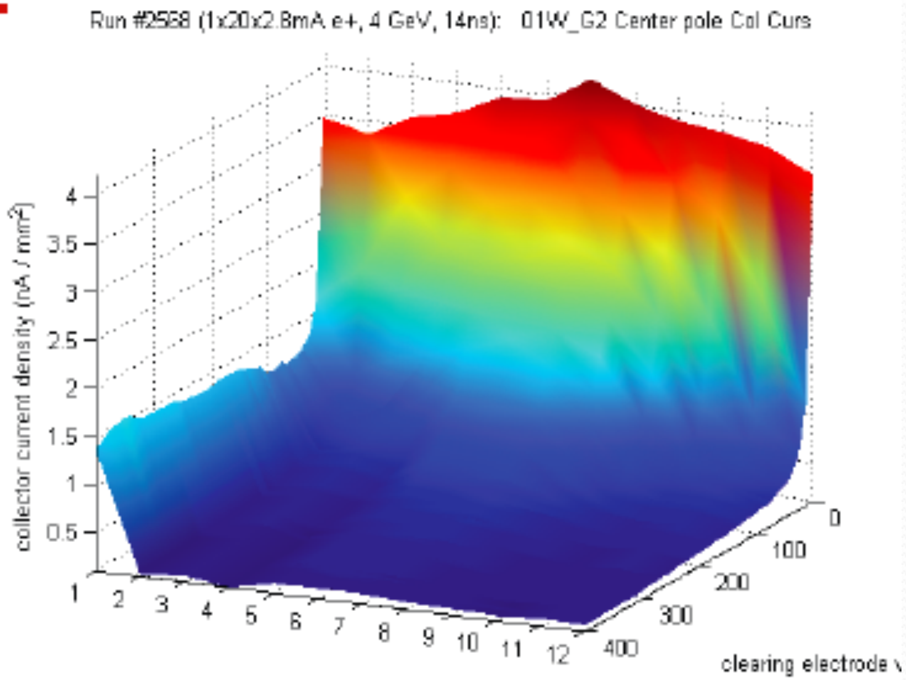
Mitigation Tests

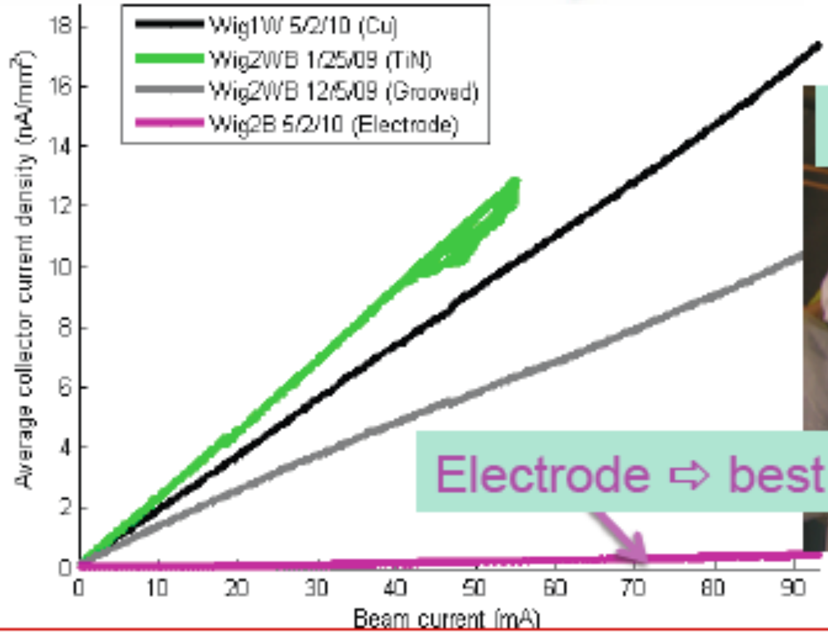
	Drift	Quad	Dipole	Wiggler	VC Fab
Al	✓	✓	✓		CU, SLAC
Cu	✓			✓	CU, KEK, LBNL, SLAC
TiN on Al	✓	✓	✓		CU, SLAC
TiN on Cu	✓			✓	CU, KEK, LBNL, SLAC
Amorphous C on Al	✓				CERN, CU
NEG on SS	✓				CU
Solenoid Windings	✓				CU
Fins w/TiN on Al	✓				SLAC
Triangular Grooves on Cu				✓	CU, KEK, LBNL, SLAC
Triangular Grooves w/TiN on Al			✓		CU, SLAC
Triangular Grooves w/TiN on Cu				✓ (planned)	CU, KEK, LBNL, SLAC
Clearing Electrode				✓	CU, KEK, LBNL, SLAC

✓ = chamber(s) deployed ✓ = planned

Wiggler Observations





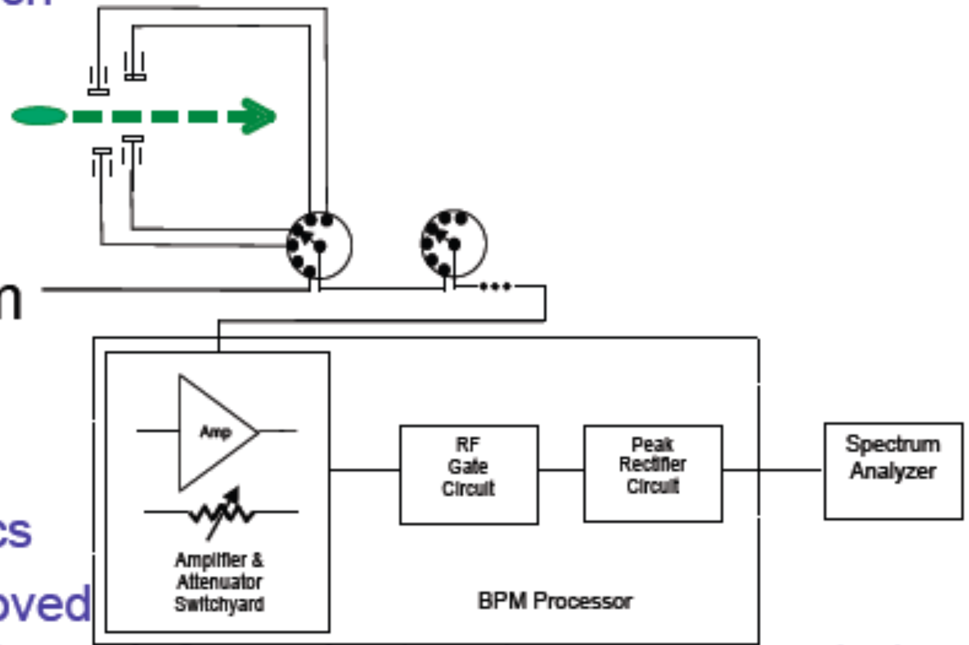


Measurement Technique for EC-induced Beam Dynamics

Frequency spectra of individual bunches from single button BPM routed to spectrum analyzer (10 s averaging)

- Sensitive to both V and H motion
- Signal is gated on a single bunch

Machine conditions (e.g. bunch currents, magnet & feedback settings) recorded before and after each spectrum

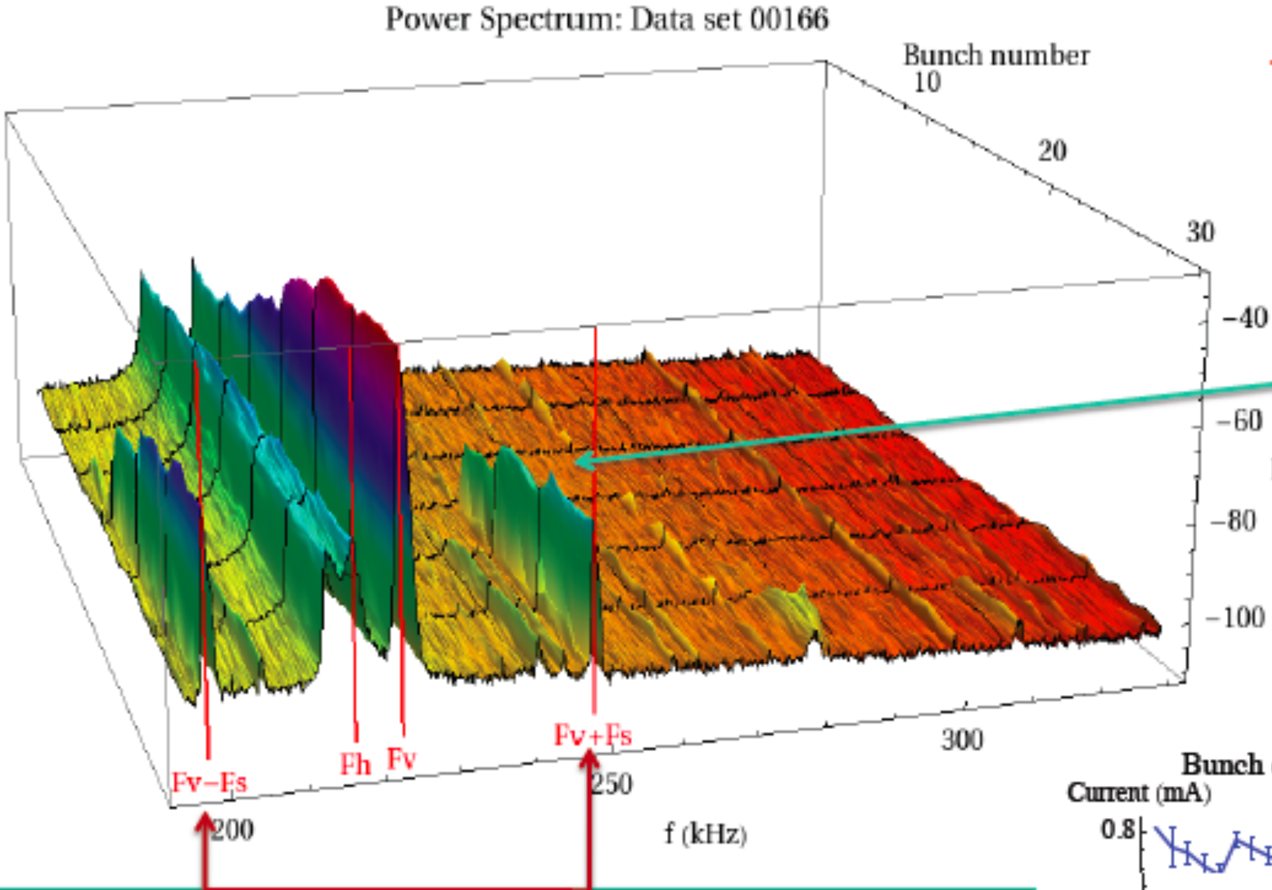


Systematic checks:

- Ruled out inter-modulation distortion in the BPM electronics
- Betatron and head-tail lines moved as expected when vertical, horizontal, & synchrotron tunes were varied.

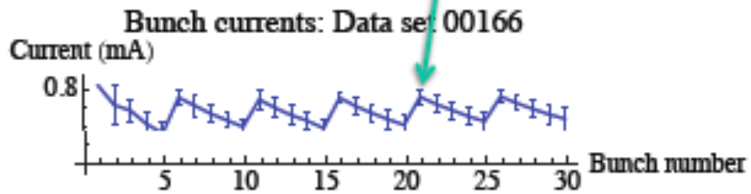
Conditions: 2.1 GeV, ε_H=2.6 nm, ε_V=20 pm, α_P=6.8x10^{-3}, σ_Z=10.8 mm, Q_H,Q_V,Q_S=14.57, 9.6, 0.065 30-45 bunch trains: 0.5-1 mA (0.8-1.6x10^{10})

Bunch-by-Bunch Power Spectrum



This is a representative example of the bunch-by-bunch power spectrum

Scallops in the power spectra are due to topping off the bunch currents



Synchro-betatron sidebands off the vertical tune are a signature of a head-tail instability. Onset around bunch 15 is consistent with this being an EC-induced instability.

(H,V) chrom = (1.33,1.155)
0.74 mA/bunch ⇨ 1.2×10^{10}

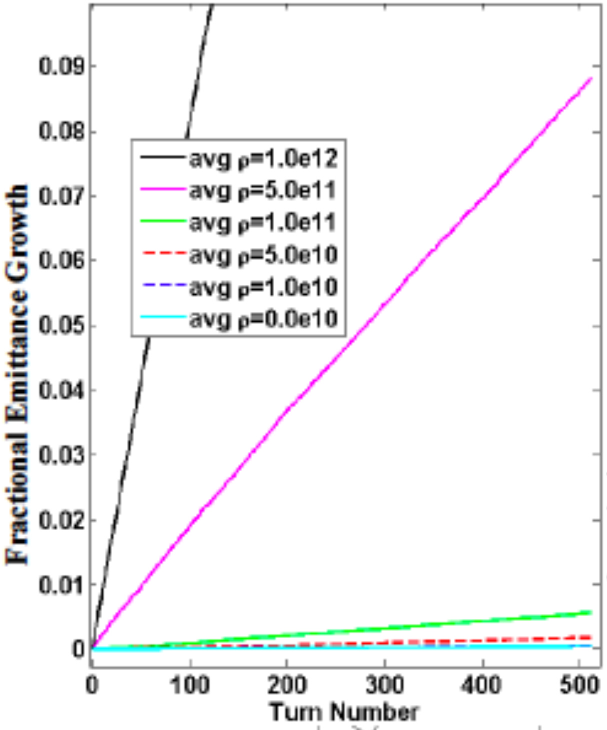
Simulation of Incoherent ε_y Growth & Instabilities

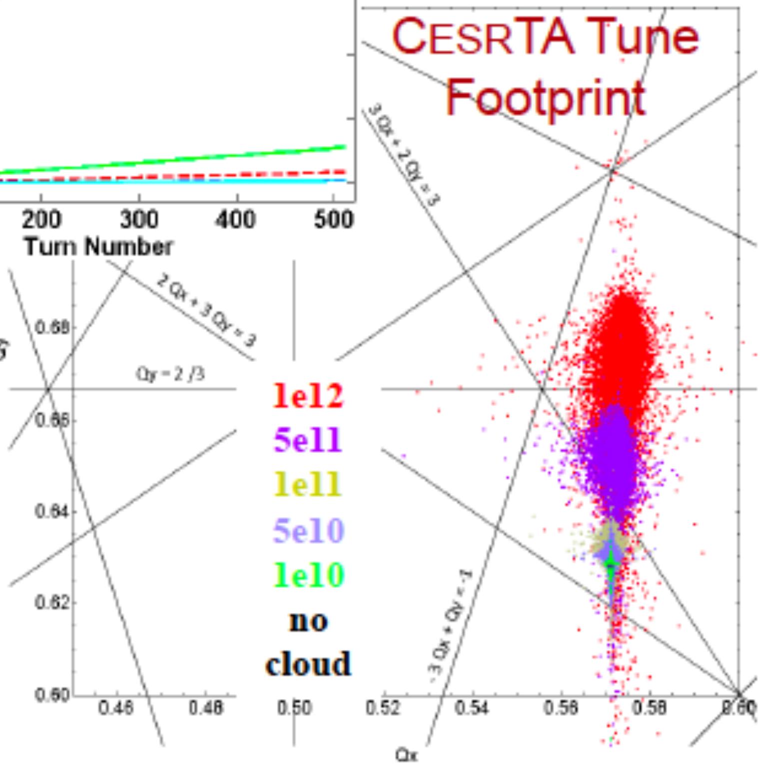
CMAD simulation (Pivi, Sonnad)

CMAD: tracking and e-cloud beam instability parallel code (M.Pivi SLAC)

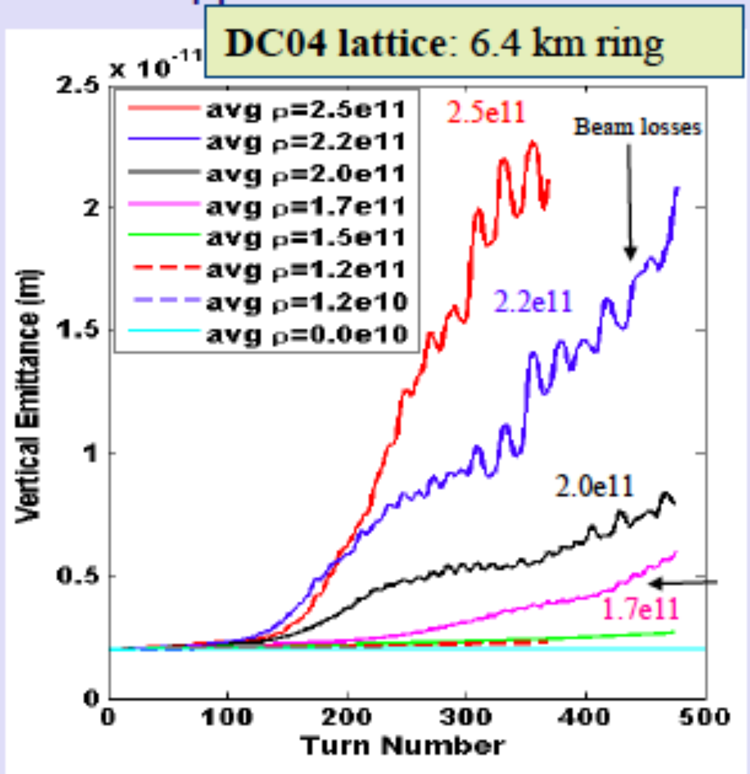
– Distribute EC in every magnetic element of ring: ~1,000 elements including drift, dipoles, quad, sext, etc.

– Apply beam-cloud IP in every element

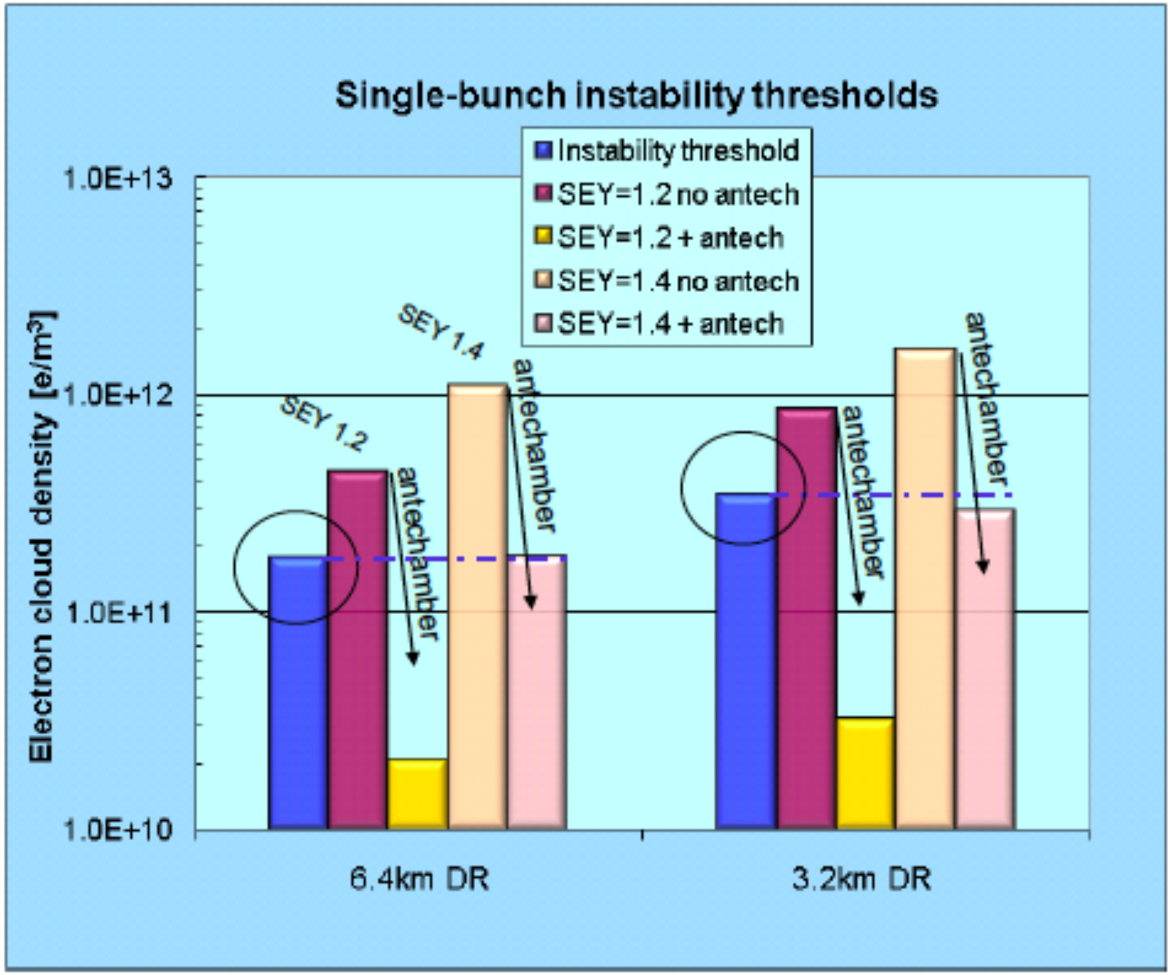




Application to ILC DR



Comparison of 6.4 and 3.2 km DR Options



Summer 2010 Evaluation

- Comparison of Single Bunch EC Instability Thresholds for:
  - 6.4km ring with 2600 bunches
  - 3.2km ring with 1300 bunches
  - ⇨ same average current
- Both ring configurations exhibit similar performance

⇨ 3.2km ring (*low current option*) is an **acceptable** baseline design choice

S. Guiducci, M. Palmer, M. Pivi, J. Urakawa on behalf of the ILC DR Electron Cloud Working Group

EC Working Group Baseline Mitigation Plan

Mitigation Evaluation conducted at satellite meeting of ECLOUD`10 (October 13, 2010, Cornell University)

EC Working Group Baseline Mitigation Recommendation

	Drift*	Dipole	Wiggler	Quadrupole*
Baseline Mitigation I	TiN Coating	Grooves with TiN coating	Clearing Electrodes	TiN Coating
Baseline Mitigation II	Solenoid Windings	Antechamber	Antechamber	
Alternate Mitigation	NEG Coating	TiN Coating	Grooves with TiN Coating	Clearing Electrodes or Grooves

*Drift and Quadrupole chambers in arc and wiggler regions will incorporate antechambers

- Preliminary CesrTA results and simulations suggest the presence of *sub-threshold emittance growth*
  - Further investigation required
  - May require reduction in acceptable cloud density ⇨ reduction in safety margin
- An aggressive mitigation plan is required to obtain optimum performance from the 3.2km positron damping ring and to pursue the high current option

S. Guiducci, M. Palmer, M. Pivi, J. Urakawa on behalf of the ILC DR Electron Cloud Working Group

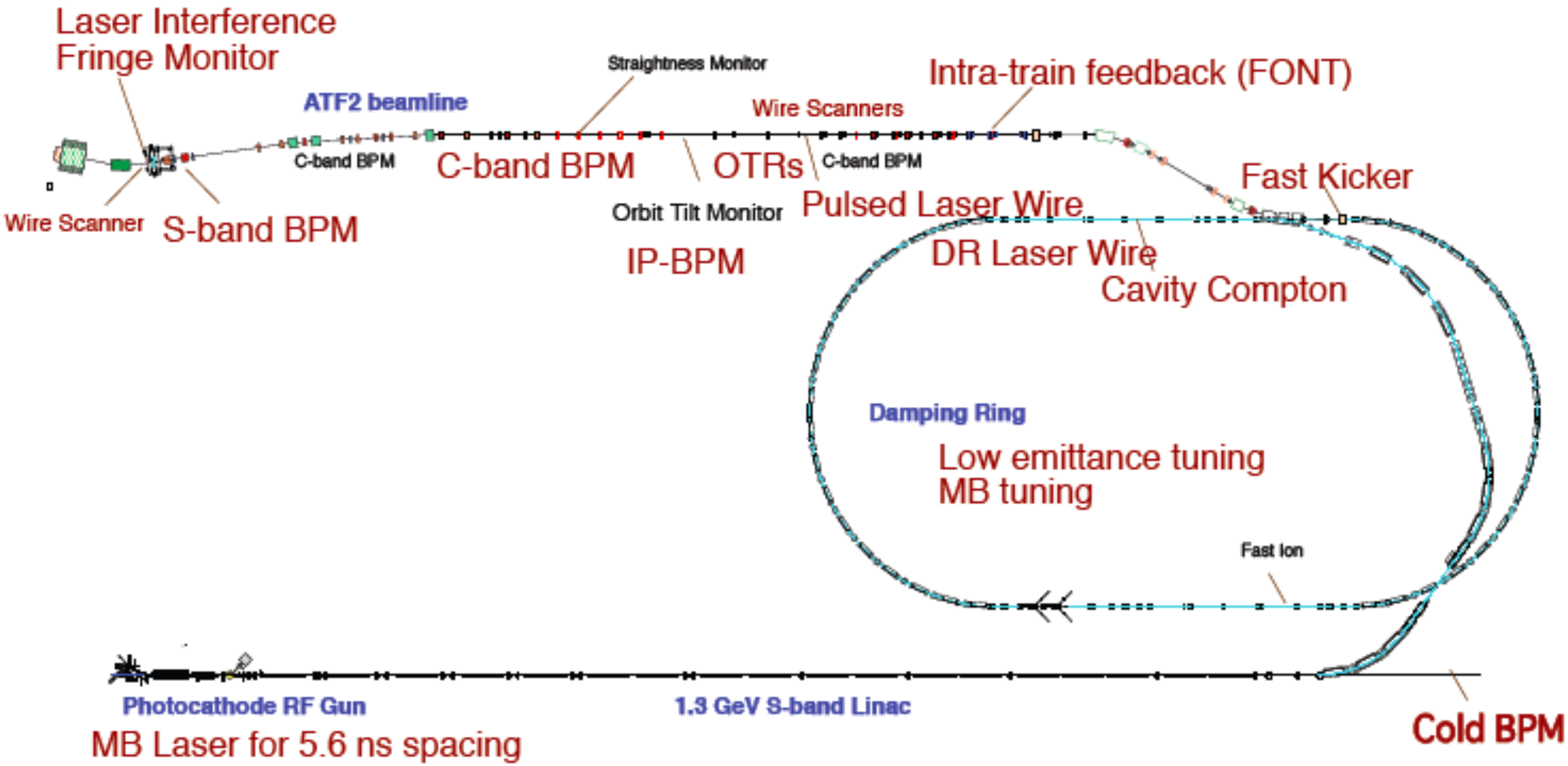
KEK-ATF and ATF2

ATF: 1.28 GeV

Bunch structure: 1-20 bunches/train, 2×10^{10} e/bunch (up to 3 trains)

Targeting 1 pm vertical emittance in damping ring

Now supporting Beam Delivery System R&D through the ATF2 beamline

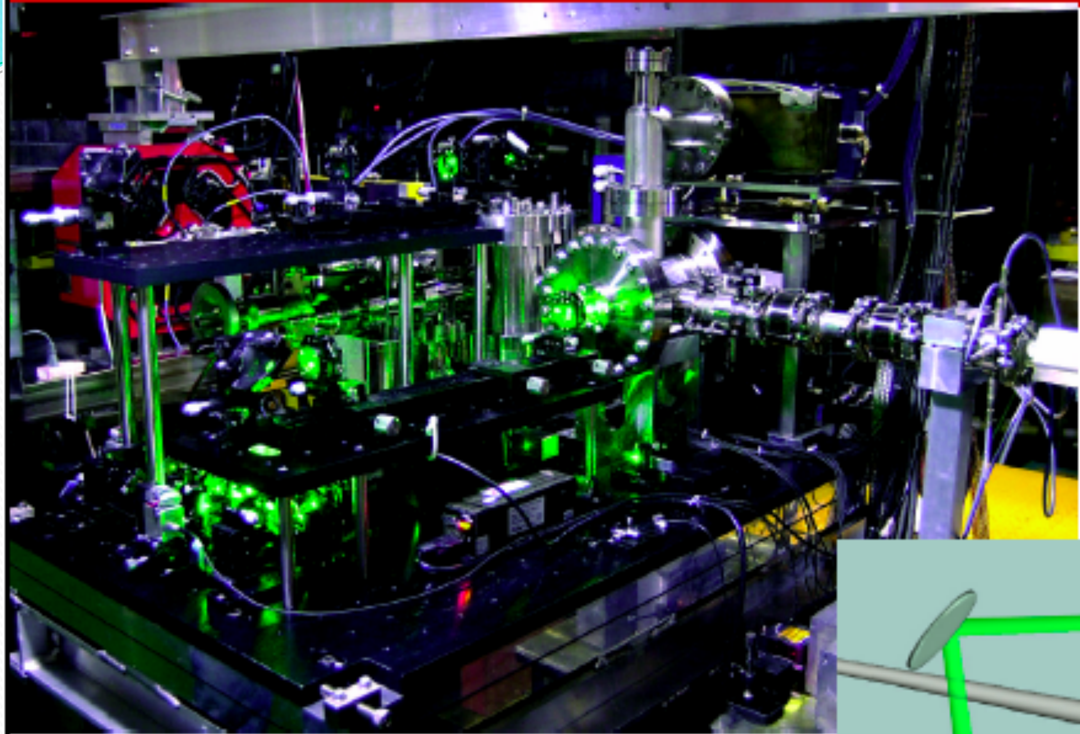


ATF

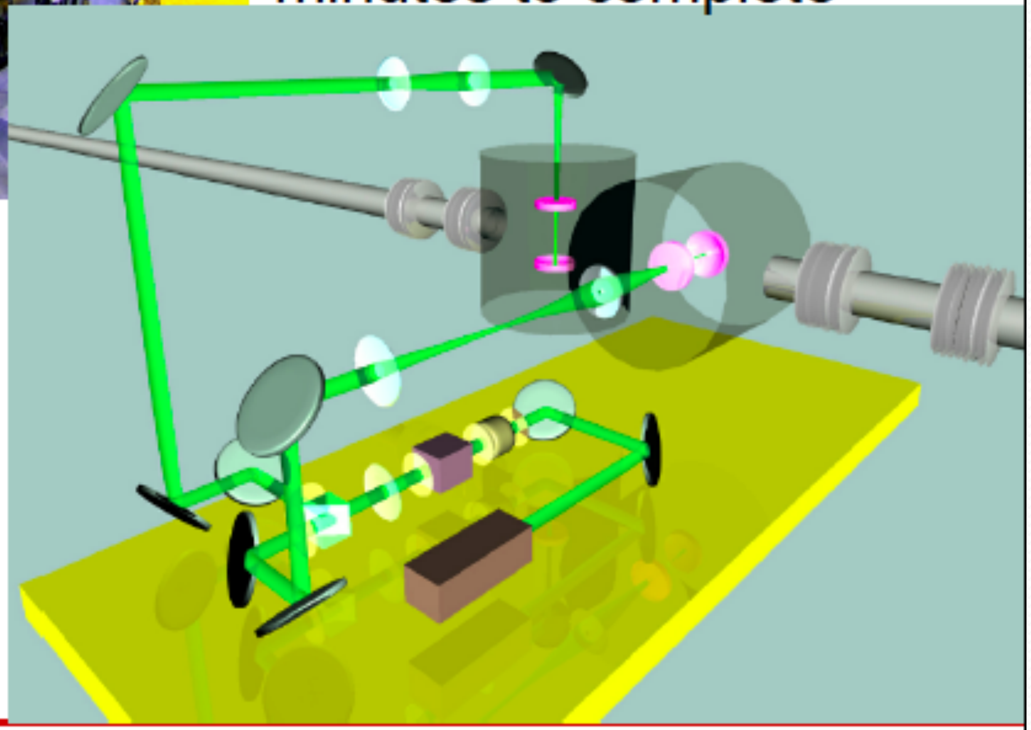
The ATF Damping Ring program has supported a wide range of important research for many years:

- Intrabeam Scattering Studies
- Studies of the Fast Ion Effect as shown earlier in this lecture
- Fast Kicker Studies
- Instrumentation Development of many types
  - Laser Wire
  - OTR
  - ODR
  - High Resolution X-ray Monitor
  - And others
- FONT Feedback System Development
- Compton Scattering experiment
- Etc

Laser wire beam size monitor: KEK-ATF



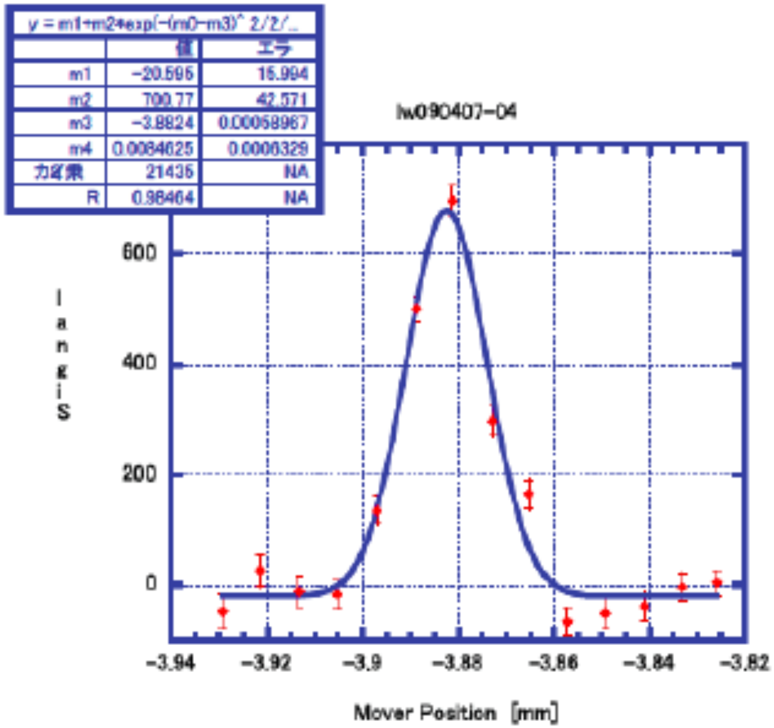
Measure rate of scattered photons as laser beam scanned through e^- beam
Measurement can be gated for individual bunches, but typically takes several minutes to complete

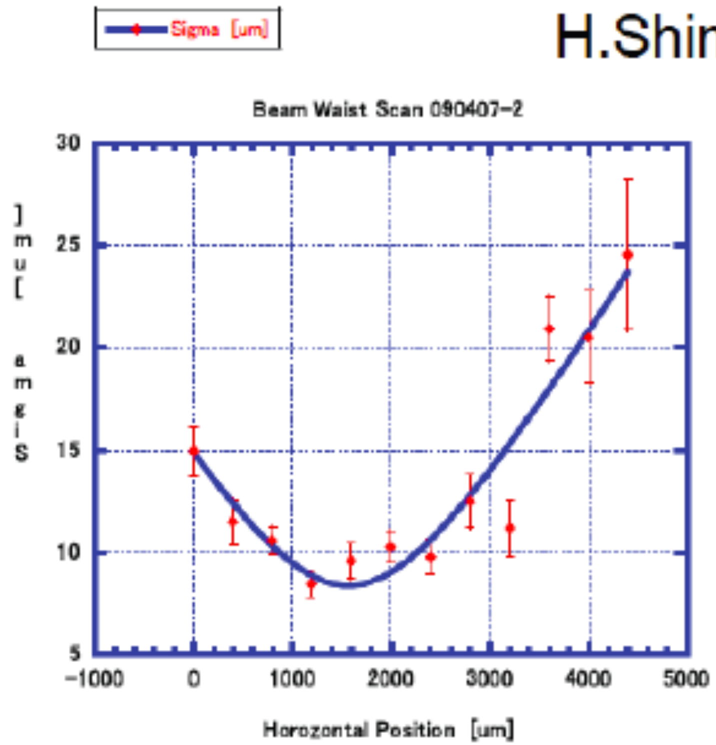


High Resolution Beam Size Measurements

Laser Wire Measurement

H.Shimizu





Minimum size measured=8.46um
Measured Laser waist=5.96um
→ e beam size=~6um

Scanning in horizontal position
Fitting with

$$\begin{aligned}\sigma_{Obs.}^2 &= \sigma_e^2 + \sigma_{LW}^2 \\ &= \sigma_e^2 + \frac{\lambda}{4\pi} z_0 \left\{1 + \frac{(z-c)^2}{z_0^2}\right\}\end{aligned}$$

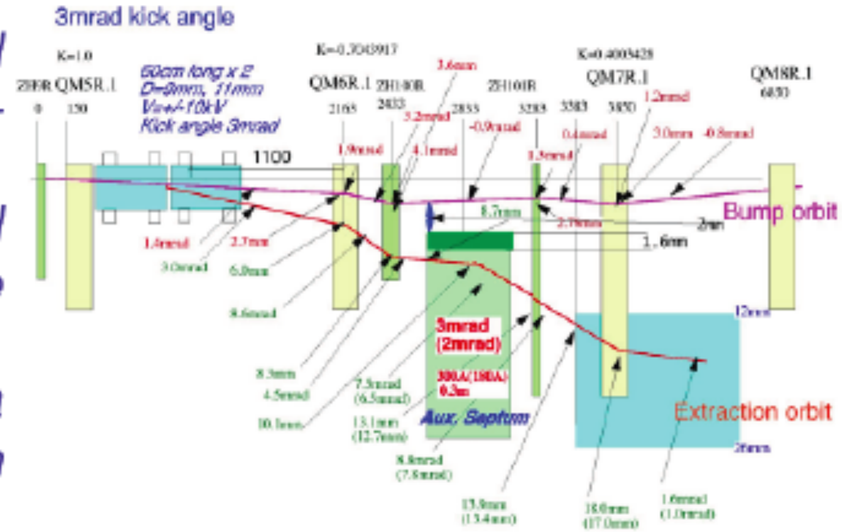
e beam size=6.41±1.07um

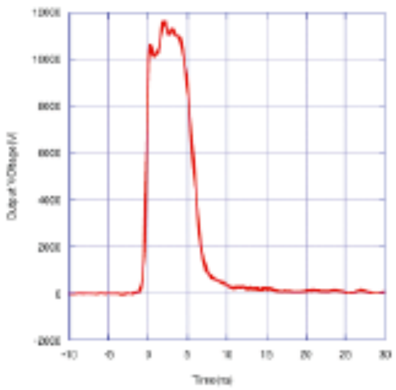
Assuming β_y~5m, ε_y=~7pm

ATF Kicker Extraction Test Setup

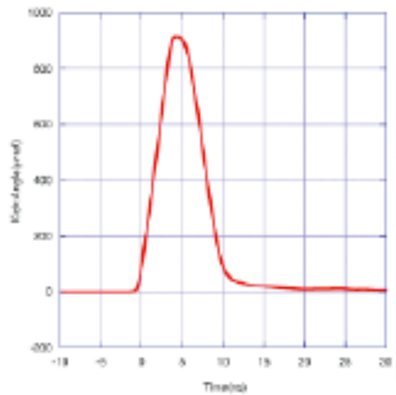
T. Naito

- *The beam extraction test was proposed to confirm the performance of the strip-line kicker.*
- *The pulsed magnet kicker was replaced to two units of 60cm long strip-line kicker.*
- *To help the lack of the kick angle, a local bump orbit and an auxiliary septum is used.*

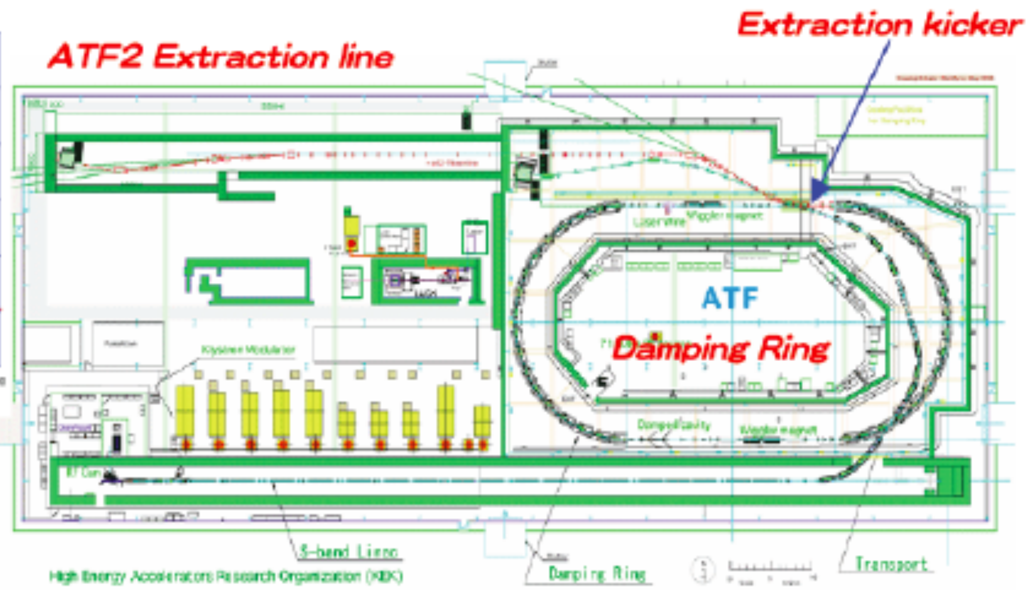




Kicker pulse



Kicker field



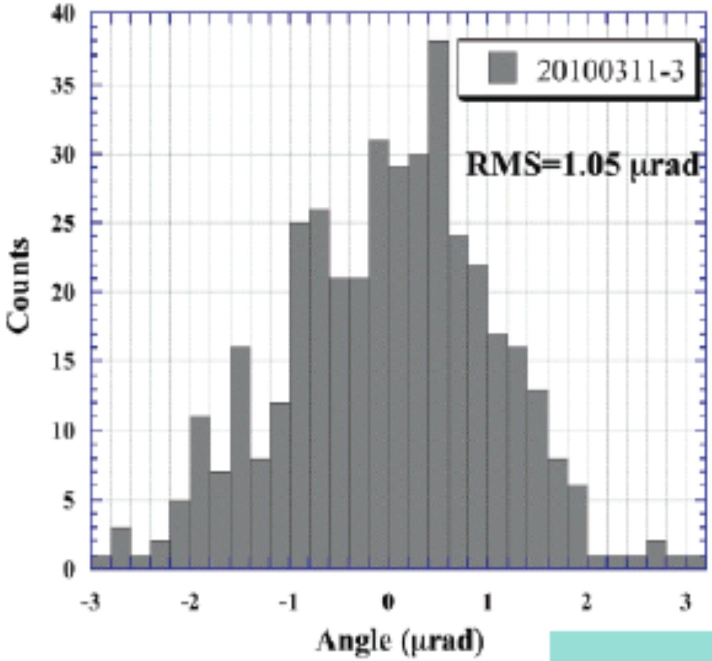
ATF Kicker Extraction Test – First Results

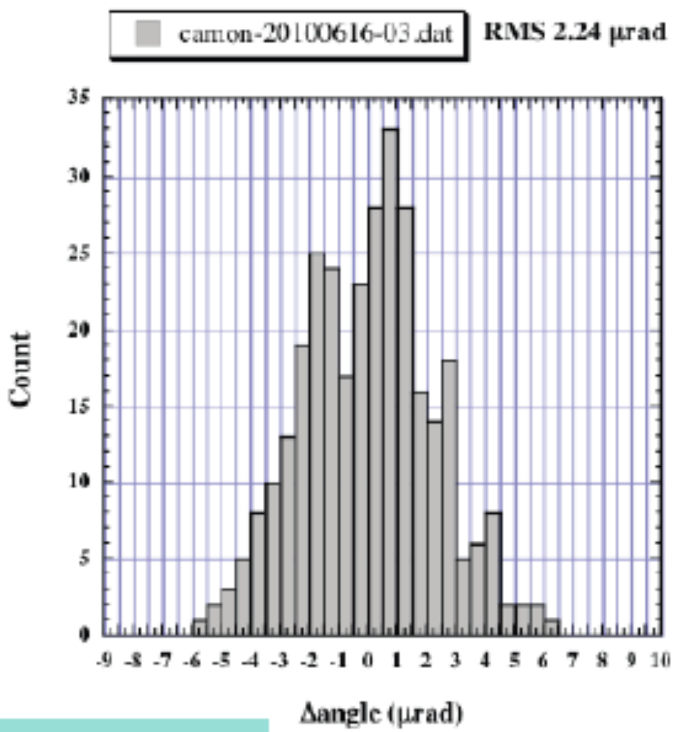
Distribution of fitted angle at EXT entrance

(single bunch)

Jitter 1.05e-6/3e-3=3.5e-4

Jitter 2.24e-6/3e-3=7.4e-4

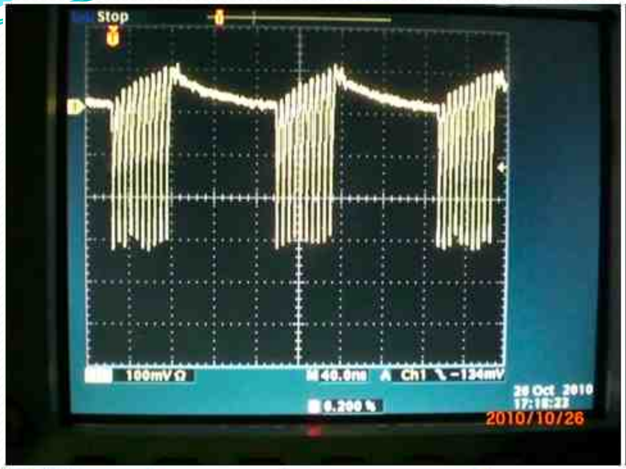


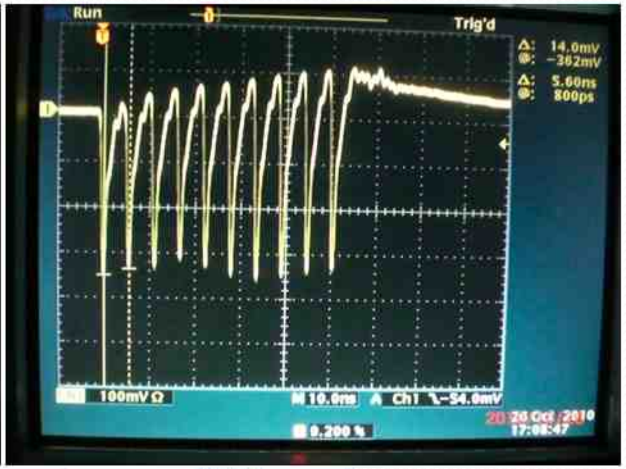


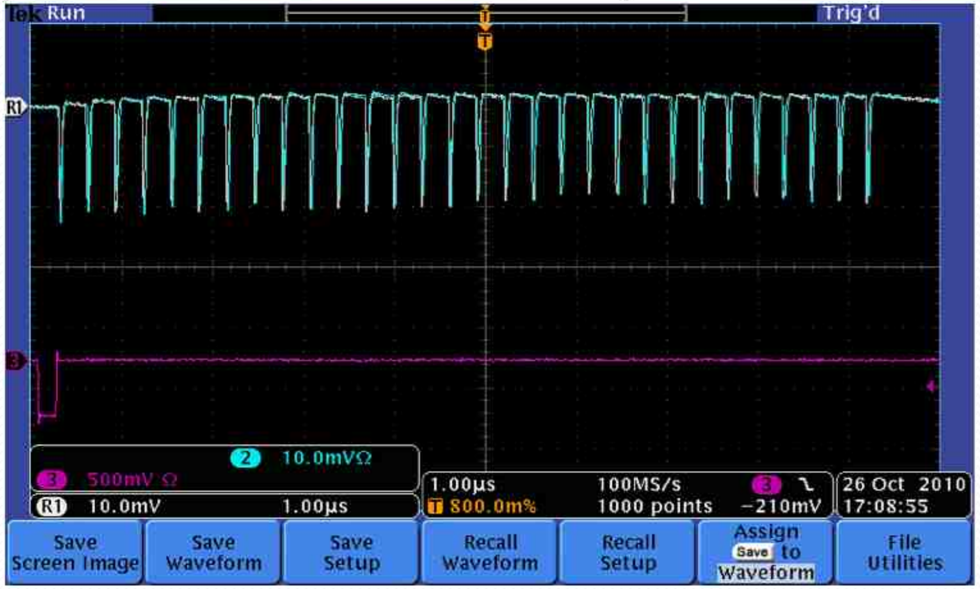
K.Kubo

Very Promising!

ATF damping ring – bunch by bunch extraction





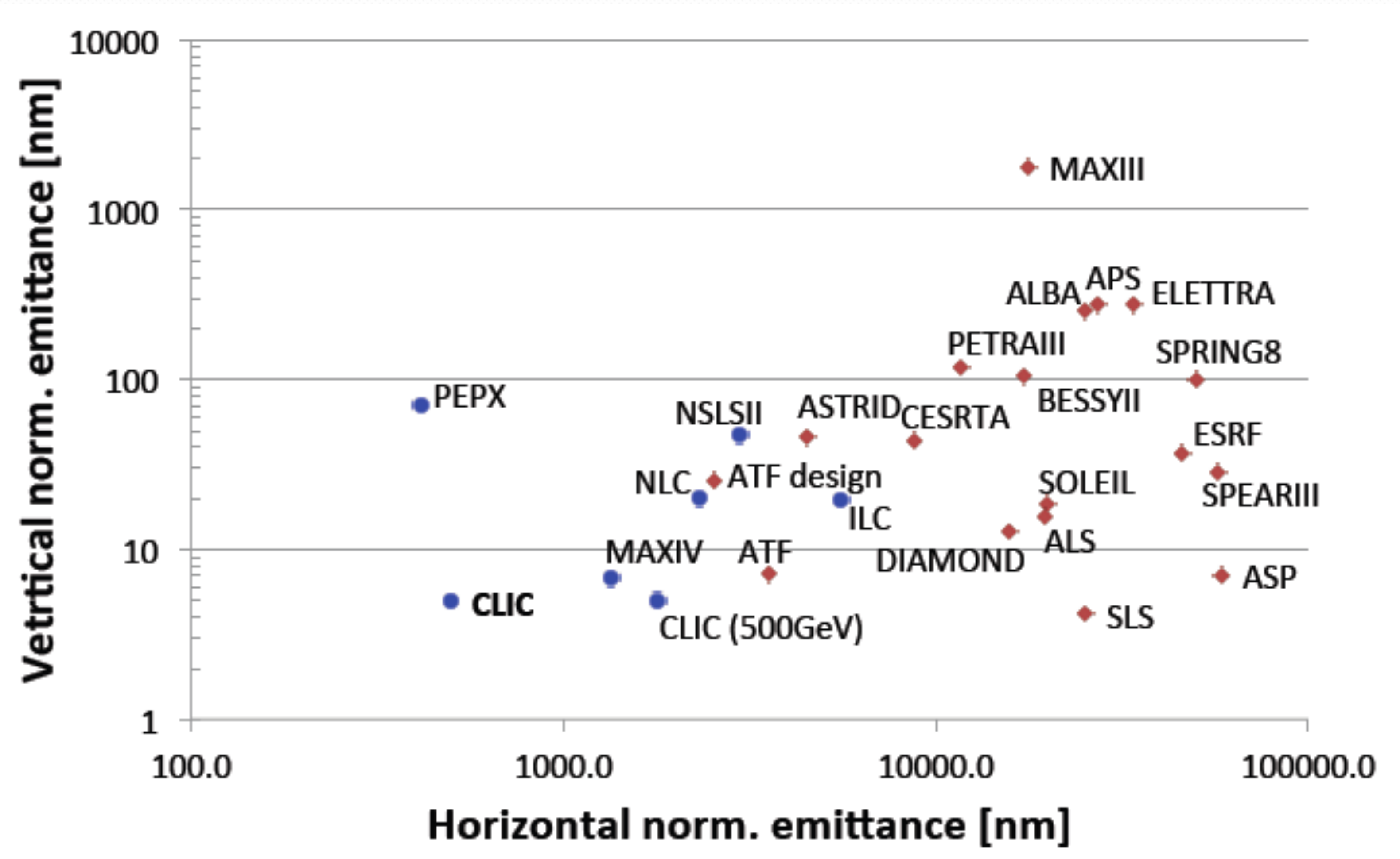


Strip line length	30 cm
Electrode gap	9 ÷ 11 mm
Peak Voltage	10 KV
Rise time	1.5 ns
Rep rate	3.3 MHz
Kick angle @1.3 GeV	3 mrad
rms angle jitter	~ 10^{-3}

Top: 3 trains of 10 bunches in DR with 5.6ns spacing
Bottom: 30 bunches extracted with 308-ns spacing

T. Naito, et al.,PhysRevSTAB. 14.051002, (2011)

Achievement of ultra-low vertical emittance



Low-emittance rings in operation (red) and in the design phase (blue)

ICFA Beam Dynamics Mini Workshop on Low Emittance Rings 2011

- The goal of the workshop is to bring together experts from the scientific communities working on low emittance lepton rings. This includes:
  - Damping rings,
  - Test facilities for linear colliders,
  - B-factories,
  - Synchrotron radiation storage rings
- Sessions include:
  - Low emittance optics design and tuning
  - Collective effects and beam instabilities
  - Low emittance ring technology
- This workshop specifically targets the strengthening of interactions within the low emittance ring community by forming a LOWεRING collaboration network

Initiated by the joint CLIC/ILC working group on damping rings

http://lowering2011.web.cern.ch/lowering2011/

Low Emittance Tuning (LET) in ILC DR

- An emittance-tuning procedure developed at CESRTA has been used to compensate for misalignments and field errors in the DR design
- The procedure has three basic steps:
  1. Measure and correct the closed orbit errors using all BPMs and all dipole correctors;
  2. Measure betatron phase and coupling by resonant excitation and correct errors, using all quadrupoles and skew-quadrupole correctors;
  3. Repeat measurement of orbit and coupling, and measure dispersion and then fit simultaneously using vertical dipole correctors and skew quadrupoles.
- The tuning algorithm depends for its effectiveness on the accuracy of the beam position monitors
- The tuning procedure consistently achieves the geometric vertical emittance of 2 pm rad

Low Emittance Tuning (LET) in ILC DR

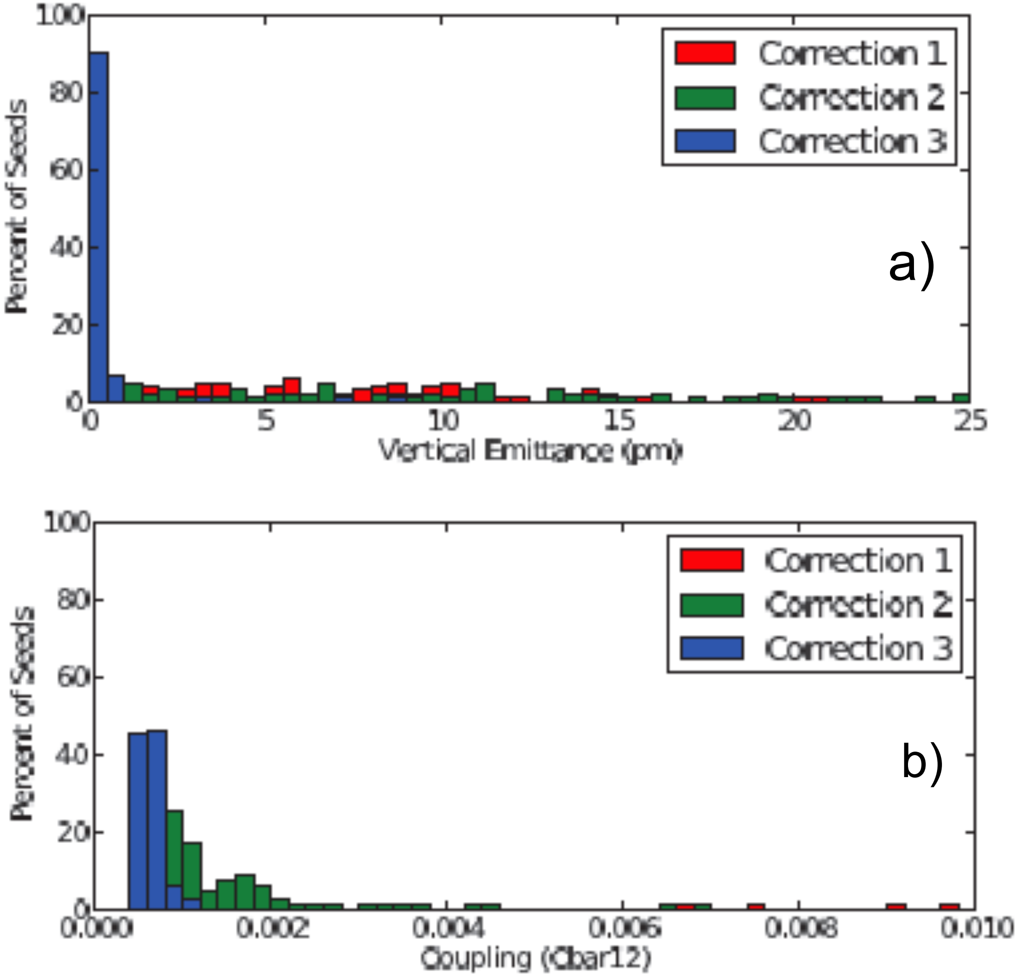


Table 6.3. BPM and magnet alignment tolerances.

Parameter	RMS
BPM Differential resolution†	2 µm
BPM Absolute resolution	100 µm
BPM Tilt	10 mrad
BPM differential button gain	1%
Quad & Sextupole Offset (H&V)	50 µm
Quadrupole Tilt	100 µrad
Dipole Roll	100 µrad
Wiggler vertical Offset	200 µm
Wiggler - Roll	200 µrad

† Reproducibility of single pass measurement

J. P. Shanks, IPAC12

Histogram of the a) vertical emittance and b) rms coupling (C12) at the conclusion of each step in the low-emittance tuning procedure for 100 lattices with randomly chosen misalignments and multipole errors.

Conclusion to the Damping Ring Lectures

Thank you all for your attention

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