Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Damping Rings – Part 3

FIFTH INTERNATIONAL ACCELERATOR SCHOOL FOR LINEAR COLLIDERS

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Lecture A3, Part 3 – Damping Ring Technical Systems

A. Systems Overview

B. Review of Selected Systems for ILC and CLIC

C. R&D Challenges

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Damping Ring Lectures

Lecture A3, Part 1 – Damping Ring Basics

- Introduction to Damping Rings
- General Linear Beam Dynamics

Lecture A3, Part 2 – Low Emittance Ring Design

- Radiation Damping and Equilibrium Emittance
- Damping Ring Lattices

Lecture A3, Part 3 – Damping Ring Technical Systems

- Systems Overview
- Review of Selected Systems for ILC and CLIC
- R&D Challenges

Lecture A3, Part 4 – Beam Dynamics

- Overview of Impedance and Instability Issues
- Review of Selected Collective Effects
- R&D Challenges

Damping Rings – Part 3

Our objectives for today's lecture are to:

Briefly review the range of technical systems required for a damping ring;

Identify key challenges for the CLIC and ILC designs

Review selected technical items

Review key aspects of the technical R&D program intended to let us converge on an optimized design for the ILC damping rings during the ILC Technical Design Phase. Much of the research is synergistic with the needs for the CLIC damping rings.

Damping Ring Technical Systems

The primary damping ring technical systems are:

- Vacuum System
- Magnets and Power Supplies
- Damping Wigglers
- Injection/Extraction System including Fast Kickers
- RF System
- Instrumentation
- Feedback System
- Supports and Alignment System

We will focus on the requirements and R&D on the items shown in red as part of this lecture

For the ILC DR, there are important interface issues with the conventional facilities and cryogenics groups. For example, temperature stability is critical to maintaining the magnet alignment requirements for stable operations. Particular engineering challenges arise in the wiggler region where the cooling system (not to mention the vacuum system) must handle the bulk of the ~3.5 MW/ring of beam radiation which is produced.

Technical Challenges

Technical Area	CLIC DR	ILC DR
Vacuum	EC Mitigations, FII, photon absorbers	EC Mitigations, FII, photon absorbers
Magnets and PS	-	-
Damping Wigglers	High Field	Aperture and Field Quality
Injection/Extraction	Stable Kickers	Fast Kickers
RF System	2 GHz	
Instrumentation	General	Bunch-by-bunch issues
Feedback	-	-
Supports and Alignment	-	-

- indicates that issues are probably within the current state-of-the-art capabilities

Vacuum System

The ILC DR vacuum system requirements are most closely related to the requirements for colliding beam storage rings and synchrotron light sources.

Vacuum Specifications:

- Arc Cells: <0.5 nTorr CO-equivalent
- Wiggler Cells: <2 nTorr CO-equivalent
- Straight Sections: <0.1 nTorr CO-equivalent

Recall that:
1 atm = 760 Torr
= 760 mm Hg

CO-equivalent pressure of gas species i is defined as: $P_i = P_{CO}\frac{\sigma_i}{\sigma_{CO}}$
where the σ_i are the scattering cross sections.

These requirements are driven, in particular, by the need to suppress the Fast Ion Instability in the electron DR (we will discuss the FII later in this lecture series).

Special Requirements for the Vacuum System

The overall vacuum system design offers one of the most critical issues for the ILC DR. Many (*most*) critical systems interface to the vacuum system, thus presenting special challenges. Some examples are*:*

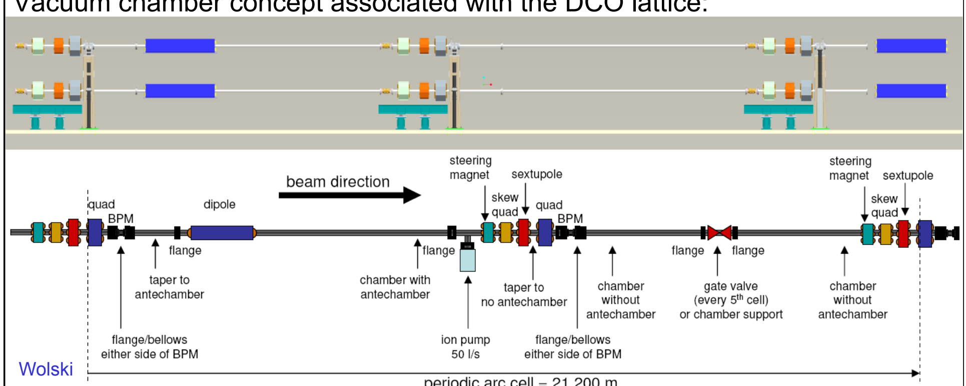
- Support for beam instrumentation and diagnostics must be incorporated. In the case of items like the beam position monitors, tight alignment tolerances to the quadrupoles must be accommodated while also dealing with potentially significant heat loads.
- Specialty hardware to mitigate specific beam dynamics effects such as the electron cloud must be added.
- Since the damping rings are a many-pass device, particular attention must be paid to developing a design that minimizes the beam impedance. The above specialty items quite often have adverse impact on the overall impedance of the vacuum system and thus require great care in their design and implementation.
- Furthermore since the key feature of damping rings is to produce large amounts of power as synchrotron radiation, the vacuum system must be able to locally handle high density power loads.
- Finally, the mechanical design must be compatible with the magnets that will be mounted around the chambers

DCO Arc Cell

In order to achieve the necessary vacuum, distributed pumping capacity via the use of Non-Evaporable Getter (NEG) coatings such as TiZrV.

- This requires that we be able to bake the vacuum chambers throughout the ring.
- A potential advantage of NEG coatings in the positron ring is that, in addition to providing pumping capability, these coatings also suppress secondary emission of electrons.

Vacuum chamber concept associated with the DCO lattice:



DCO Arc Cell

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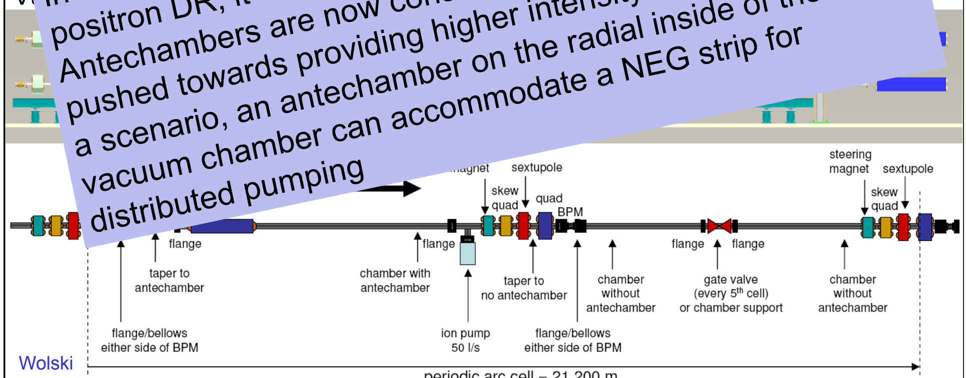
- This requires that we be able to bake the vacuum c… ring.
- A potential advantage of NEG coat… to providing pumping ca… on of electr…

V…

In the recent evaluation of electron cloud effects for the positron DR, it was determined that we would alter this plan. Antechambers are now considered a necessity as we are pushed towards providing higher intensity beams. In such a scenario, an antechamber on the radial inside of the vacuum chamber can accommodate a NEG strip for distributed pumping

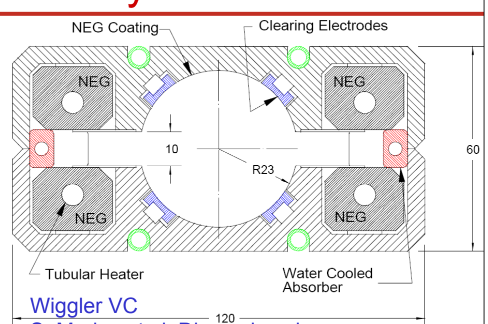


Wolski

ILC DR Vacuum System

The vacuum chambers in the wiggler regions must:

- Handle the power from the wiggler synchrotron radiation fan: ~40 kW/wiggler
- Provide pumping for photo-desorbed gases
- Suppress the electron cloud



Wiggler VC
S. Marks, et al. Dimensions in mm

Proposed vacuum chamber styles, pumping methods and EC mitigation methods:

Region	Vacuum Chamber Style	Pumping Methods	EC Mitigation
Arcs	Antechamber	NEG Strip + Sputter Ion Pumps (SIPs)	Grooves with TiN
Generic Straight Sections	Tube	??? + SIPs	Solenoids in drifts
Wiggler Straight Sections	Antechamber	NEG Strips	Clearing electrodes

ILC DR Wigglers

The damping ring wigglers are the first technical area that we will explore in somewhat greater detail.

Damping wigglers have been used in a number of rings to control the emittance of the machine. The first wiggler-dominated ring was the CESR-c ring which was used to study charm physics in conjunction with the CLEO-c detector from 2003 until early 2008.

From our discussion yesterday, the ring emittance in the presence of wigglers can be written as:

$$\varepsilon_0 = \frac{\varepsilon_{dip}}{1+F} + \frac{\varepsilon_{wig} F}{1+F} \quad \text{where} \quad F = \frac{U_{wig}}{U_{dip}}$$

In a wiggler-dominated ring, the location of the wigglers determines what that emittance may be. Clearly, if the wigglers are located in zero dispersion regions, the wiggler contribution to the emittance can be made quite small. On the other hand, by placing the wigglers in regions with dispersion, the emittance of the ring can be controlled by tailoring the dispersion function at the wiggler locations.

Emittance in a Wiggler-Dominated Ring

The emittance in a wiggler dominated ring can be written as:

$$\varepsilon_x = C_q \frac{\gamma^2 \left\langle \frac{\mathcal{H}}{\rho^3} \right\rangle}{J_x \left\langle \frac{1}{\rho^2} \right\rangle} = C_q \frac{\gamma^2 I_{5wig}}{J_x I_{2wig}}, \qquad C_q = 3.8319 \times 10^{-13} m$$

where J_x is the damping partition number and the radiation integrals are evaluated in the wiggler. If the wiggler are located in zero dispersion regions, it can be shown that the wiggler-dominated emittance is given by:

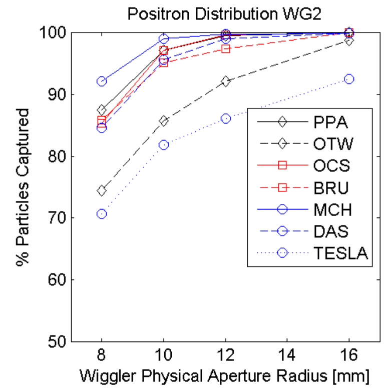
$$\varepsilon_x \approx C_q \frac{\gamma^2}{J_x} \frac{8\langle \beta_x \rangle}{15\pi k_p^2 \rho_w^3}$$

This will be the topic of one of today's problems.

Damping Wiggler Technical Criteria

Damping wigglers must satisfy a number of key criteria. In addition to providing the synchrotron radiation necessary to shorten the damping times and lower the emittance, they must:

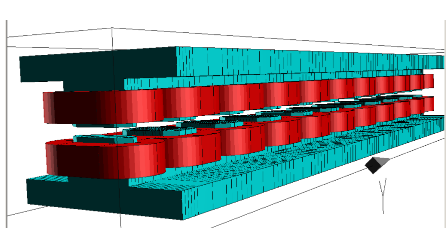
- provide sufficient aperture to allow efficient injection of positron beams which are injected with significant betatron amplitude;
- operate reliably over the long-term in an environment with large amounts of synchrotron radiation;
- have sufficient field quality such that the dynamic aperture of the ring is not compromised;
- be economical both for construction and during operation.



Three distinct wiggler technologies have been evaluated for use in the ILC DR: Normal conducting electromagnetic, permanent magnet hybrid, and superferric designs.

Normal Conducting Wigglers

Normal conducting wigglers have been used in a number of rings to provide additional damping. This is a proven technology with moderate construction costs, good resistance to radiation damage, and proven reliability. However, the large length of wiggler required for the damping rings means that operational costs will be quite high. It is also challenging to provide the desired vertical aperture without significantly increasing the power requirements.

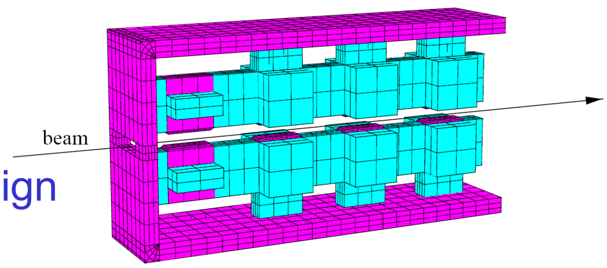


ATF Damping Wiggler

Permanent Magnet Hybrids

Permanent magnet hybrids use iron poles in conjunction with PM material to provide the field. The great advantage of a PM-based wiggler is that it is a passive device and requires no power. On the other hand, this solution requires a large amount of magnetic material in order to achieve the large physical aperture which is desired for the ILC DR wiggler. The design also requires careful pole tip shimming in order to avoid adverse impact on the DR dynamic aperture. Finally, the PM material is sensitive to radiation losses and could degrade over time.

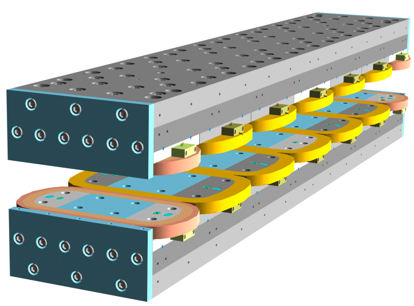
TESLA TDR Design



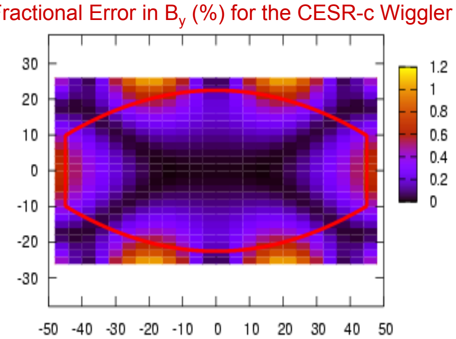
Superferric Wigglers

The CESR-c wiggler design was developed to provide damping in the CESR storage ring. They are a high field (2.1 T) design.

- Operating energy: 5.29 GeV for colliding beam operations at the ψ(4s) resonance ⇨ operation in the1.8-2.5 GeV range to study charm and tau physics.
- Colliding beam operations at CESR utilized counter-rotating beams in a single vacuum chamber with electrostatic separation ⇨ very good transverse field quality required



Fractional Error in B_y (%) for the CESR-c Wiggler



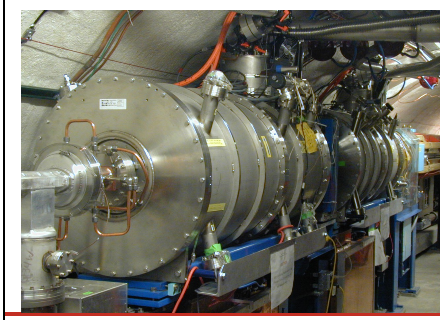
Superferric Wigglers

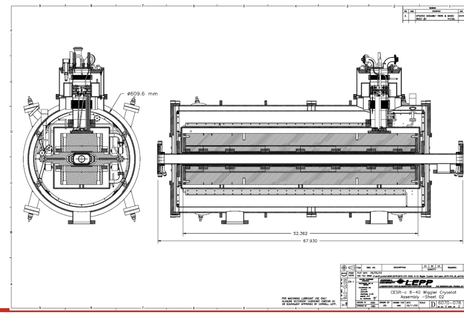
The advantages of the CESR-c design are:

- a proven high field wiggler
- extremely good field quality
- thus meets both the ILC DR field and field quality needs

Nevertheless, the superconducting design adds complexity:

- Cryogenics: cryostat adds to construction costs, cryogenics support needed for operation. Care must be taken to minimize radiation losses into cold mass.
- Vacuum chamber becomes trapped in cryostat





Wiggler Comparison

	TESLA	CESR-c	Modified CESR-c
Period	400 mm	400 mm	400 mm
$B_{y,peak}$	1.67 T	2.1 T	**1.67 T**
Gap	25 mm	76 mm	76 mm
Width	60 mm	238 mm	238 mm
Poles	14	8	**14**
Periods	7	4	**7**
Length	2.5 m	1.3 m	2.5 m

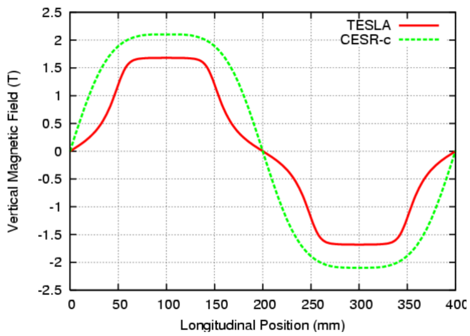
Wiggler Comparison

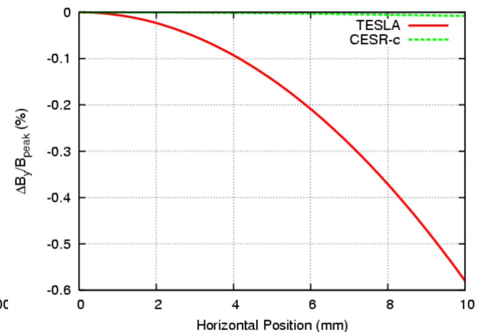
TESLA Wiggler

Hybrid permanent magnet
NdFeB with iron poles
$\Delta B_y/B_{peak}$ (x=10mm) = $5.7*10^{-3}$

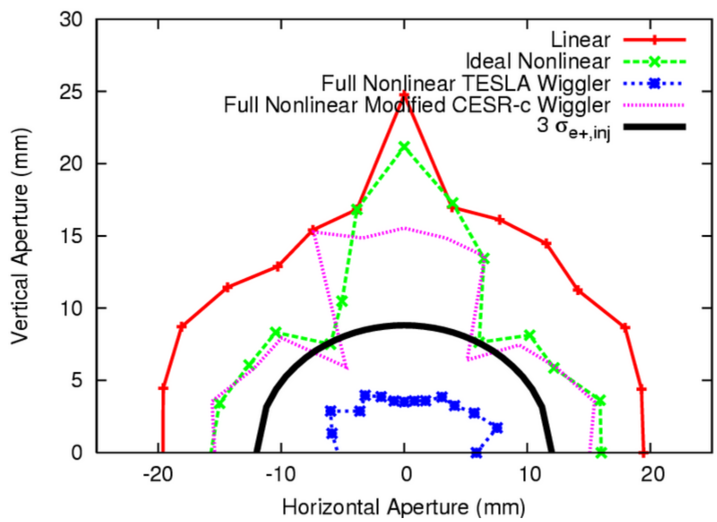
CESR-c Wiggler

Superferric magnet
NbTi coils with iron poles
$\Delta B_y/B_{peak}$ (x=10mm) = $7.7*10^{-5}$



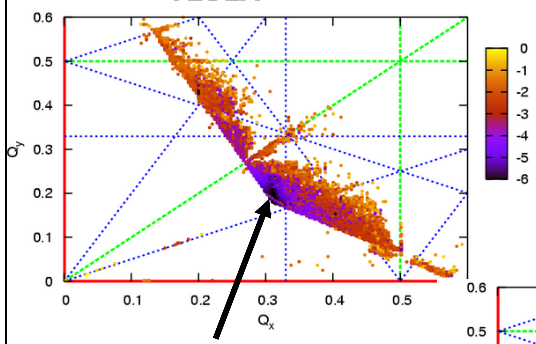


Dynamic Aperture



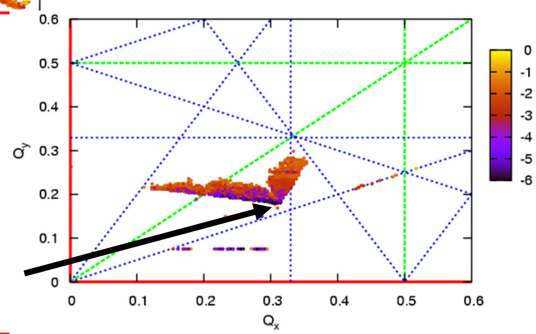
Frequency Map Analysis

TESLA



$$color = \log\left(\sqrt{\Delta Q_x^{\ 2} + \Delta Q_y^{\ 2}}\right)$$

Modified CESR-c Wiggler



Wiggler Optimization

Let's return to the expression for the wiggler emittance:

$$\varepsilon_x \approx C_q \frac{\gamma^2}{J_x} \frac{8\langle\beta_x\rangle}{15\pi k_p^2 \rho_w^3}$$

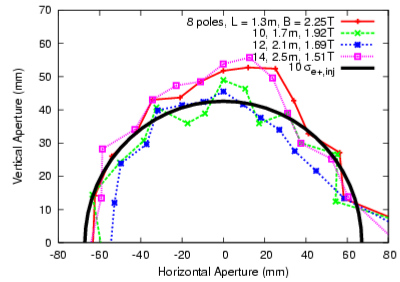
The wiggler contribution to the emittance can be lowered by:

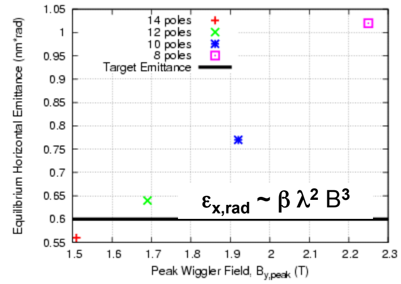
- Reducing the beta function in the wiggler
- Employing a shorter period
- Employing lower peak field

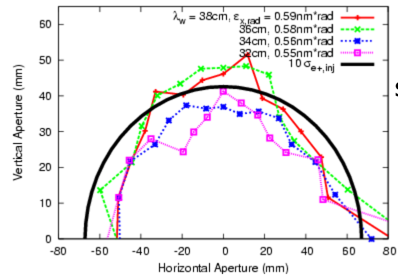
There are both positive and negative impacts:

- This will impact the energy spread – must take care to not exceed the energy acceptance of the downstream bunch compressors
- Shorter wigglers offers greater opportunity to handle synchrotron radiation outside the wiggler, hence minimizing radiation and heat load issues.
- Larger vertical gap allows more flexible access for vacuum chamber inside the cryostat in the superferric design

Optimizations







Fewer poles require higher fields which raises the emittance, a shorter period can counteract this with minimal DA degradation.

Optimize with:

12 poles and period = 32 cm

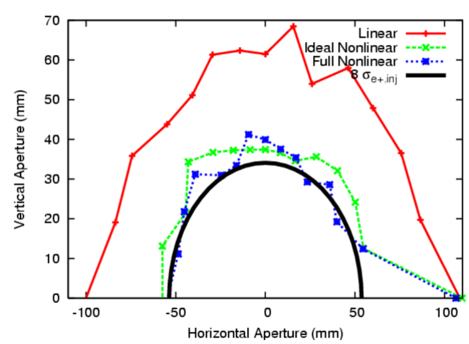
vs

14 poles and period = 40 cm

Parameters for an Optimized Wiggler

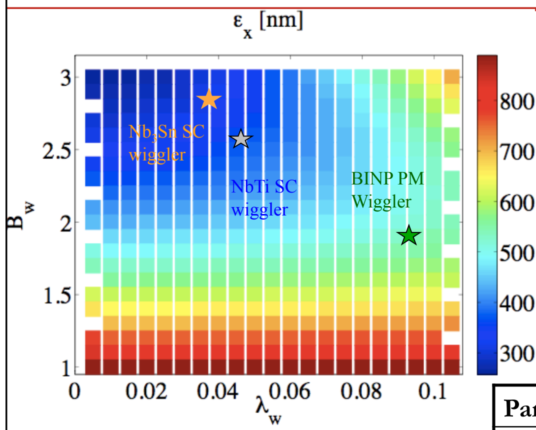
Superferric ILC-Optimized CESR-c Wiggler

- 12 poles
- Period = 32 cm
- Length = 1.68 m
- $B_{y,peak}$ = 1.95 T
- Gap = 86 mm
- Width = 238 mm
- I = 141 A
- τ_{damp} = 26.4 ms
- $\varepsilon_{x,rad}$ = 0.56 nm·rad
- σ_δ = 0.13 %



Optimized superferric design offers significant cost savings while still meeting all key design specifications

Emittance with Wigglers and IBS



Stronger wiggler fields and shorter wavelengths necessary to reach target emittance due to strong IBS effect

Current density can be increased by switch to Nb_3Sn

Nb_3Sn can sustain higher heat load (potentially 10 times higher than NbTi)

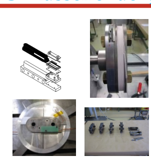
Parameters	BINP	CERN
B_{peak} [T]	2.5	2.8
λ_W [mm]	50	40
Beam aperture full gap [mm]	13	
Conductor type	NbTi	Nb_3Sn
Operating temperature [K]	4.2	

Y. Papaphilippou

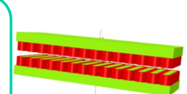
Nb_3Sn Technology

D. Schoerling, S. Russenchuck, et al.

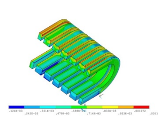
First Tests Short Model
- Conceptual Design for Short Model (Design Office Support needed!)
- 5 Test Coils for Insulation and Heat Treatment tests
- One Vertical Racetrack Coil ready to be tested
- Horizontal racetrack coil planned to wind
- 2-period wiggler in mirror and full configuration (planned)



Small Prototype
- Modules, Design and Test
- Joint Testing
- Field Quality Measurements at CASPER at ANKA

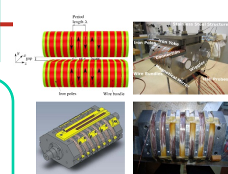


Full-Scale Prototype
- Full Scale Nb_3Sn Prototype with cryogenics to be tested at ANKA
- Design and manufacturing at CERN but with synergies from Nb-Ti wiggler!



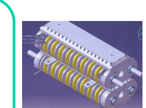
Nb-Ti Technology

First Tests Short Model
- Conceptual Design for Short Model
- 2-Period Short Model, successful tested at CERN in mirror configuration
- Short Model at BINP successful tested



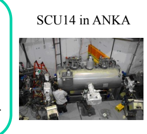
CDR

Small Prototype
- Modules, Design and Test
- Joint Testing
- Field Quality Measurements at CASPER at ANKA



Full-Scale Prototype
- Full Scale Nb-Ti Prototype with cryogenics to be tested within the collaboration framework with ANKA, Karlsruhe, Germany
- Design: Collaboration of ANKA, BINP and CERN.
- Manufacturing at BINP

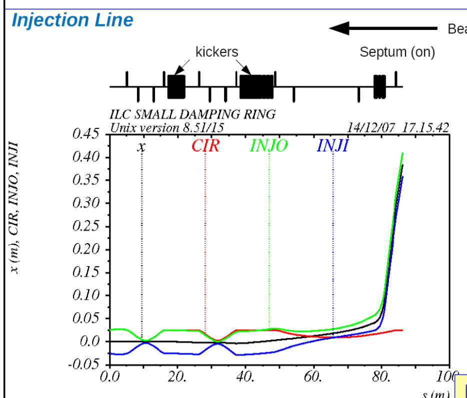
SCU14 in ANKA

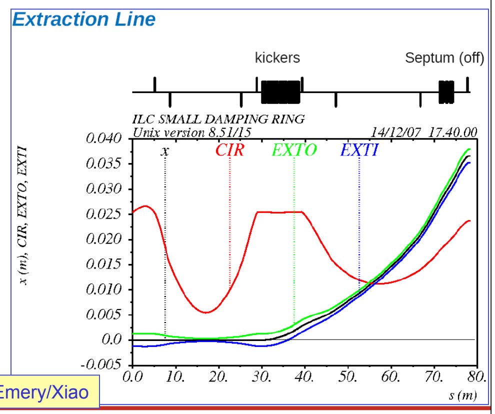


TDR

Injection and Extraction Systems

The injection and extraction scheme in the ILC damping rings is quite challenging. Bunches must be injected and extracted individually without affecting the neighboring bunches.

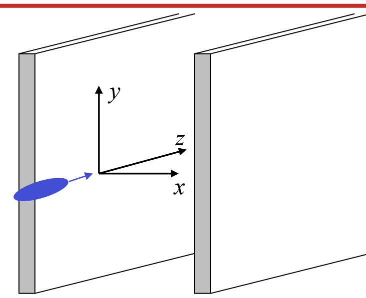




Emery/Xiao

Stripline Kickers

In order to elucidate the operation of stripline kickers, we consider the simplified geometry of 2 planar configured to provide kicks in the horizontal plane with nominally infinite extent in the vertical…



A voltage pulse applied to one end of the electrodes will produce a traveling wave with

$$E_x = E_0 e^{i(kz-\omega t)} \quad \text{and} \quad B_y = \frac{E_0}{c} e^{i(kz-\omega t)}$$

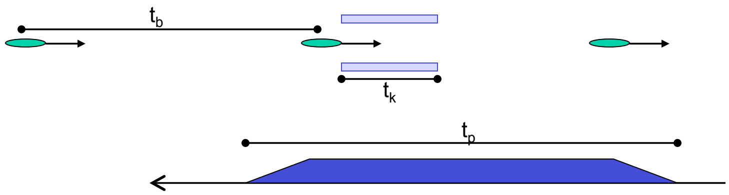
An electron moving in the $+z$ direction with velocity βc will experience a force:

$$F_x = q\left(E_x - v_z B_y\right) = q\left(1-\beta\right) E_0 e^{-(1-\beta)\omega t}$$

For $\beta \sim 1$, the forces will cancel when the particle travels with the pulse but will add when the particle travels oppositely to the pulse.

Structure Filling and Kick

Top View



We want to consider the above geometry of the kicker structure. The timing constraint on the length of the kicker structure, pulse, and bunch spacing can be written as: $t_p \le 2(t_b - t_k)$

This condition ensures that the pulse does not affect either the bunches ahead/behind the bunch being kicked. For a bunch spacing of 3.1 ns and a kicker length of 30 cm, this corresponds to a limit on the pulse width of ~4.2 ns.

Next we will consider the impulse imparted to the bunch assuming that the bunch passes through the stripline structure when completely filled.

Stripline Kick

Assuming that:

- the stripline structure has length L
- a parallel plate model with separation d between the electrodes
- the structure is filled (ie, in the flat top of the pulse) for the duration of the bunch passage

we can write the kick that is imparted to the bunch as:

$$\Delta\theta = \frac{F_x L}{p_0 d} = 2\frac{eVL}{E_0 d}$$

where p_0 and E_0 are the nominal particle momentum and energy. This form can be generalized to: $\Delta\theta = 2g\frac{eVL}{E_0 d}$

where g is a geometric factor representing other stripline configurations than our parallel plate case. For parallel plates with finite width, w: $g = \tanh\left(\frac{\pi w}{d}\right)$

Stripline Kick

The input assumptions for the kick required to bring the bunch near enough the septum for extraction are:

- A displacement of ~30mm from center is required
- The distance between the kickers (modeled as a single unit) and septum is on the order of 10s of meters (we will use 50)

$$\Delta\theta \approx \frac{0.03}{50} = 0.6\,mrad$$

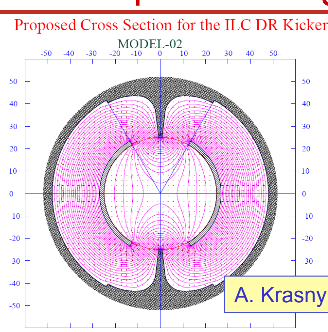
Let's take: $d = 20\,mm$ $\quad g = 0.7$

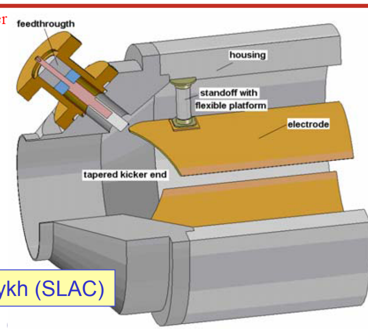
⇨ $$VL = 43\,kV - meters$$

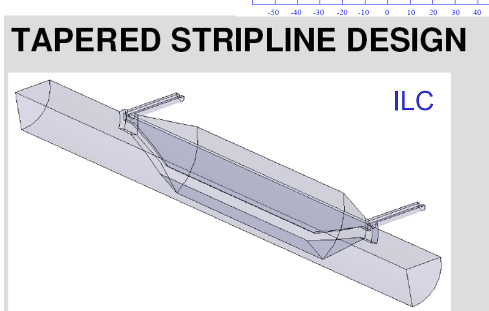
If the highest voltage pulsers available can provide 5-10 kV with the necessary rise and fall times, this immediately implies that we will need of order tens of pulsers and striplines to successfully inject or extract DR beams one bunch at a time.

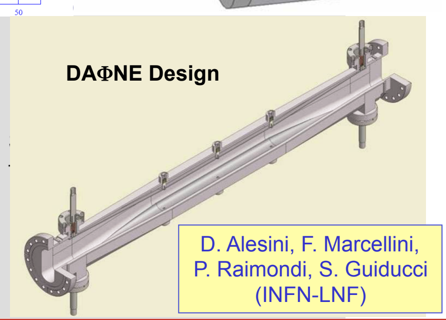
Stripline Designs

Work is underway to provide stripline kickers with the necessary field quality and suitable feedthroughs for the fast high voltage pulses required









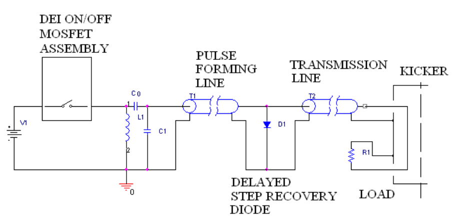
Fast Pulser Specifications

The resulting fast pulser specifications are shown in the table on the right. These parameters are somewhat beyond the current state of the art, but a major R&D effort is approaching these values.

Peak Voltage	10 kV
Rise Time	~1 ns
Fall Time	~1 ns
Flat Top	~2 ns
Amplitude Stability	0.1%
Burst Rate	6 MHz
Pulse Train Length	1 ms
Average Pulse Rate	30 kHz
Pulse Train Length	1 ms

Drift Step Recovery Diode (DSRD) R&D

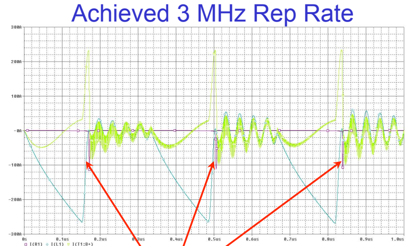
A. Krasnykh (SLAC)

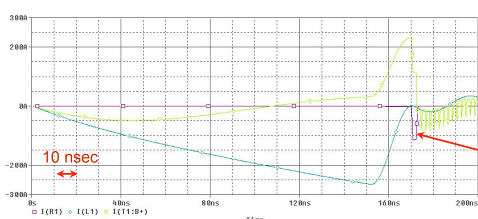


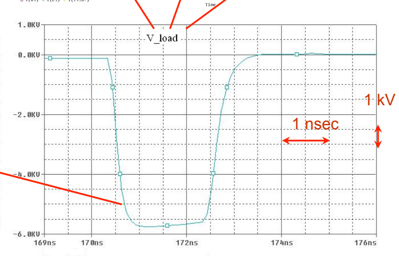
L=40 nH, C_o=30 nF, C_1=1.5 nF,

t_{on}=150 nsec, t = 1 nsec

Achieved 3 MHz Rep Rate





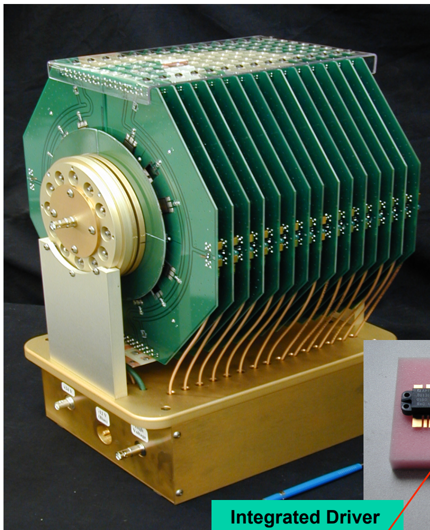


Currents vs. time for one cycle

~6kV Output Voltage, Residual Voltage is ~ 2%

Inductive Adder (IA) Prototype

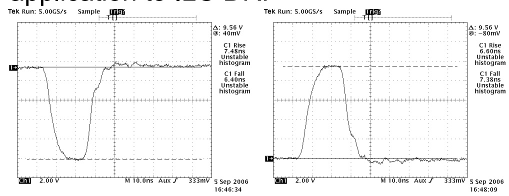
Utilizes MOSFET devices



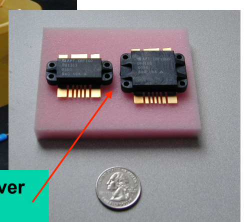
E. Cook (LLNL)

Integrated Driver & Power MOSFET

Intrinsic speed is too slow for direct application to ILC DR:



±9.6 kV pulses
7 ns rise and fall times

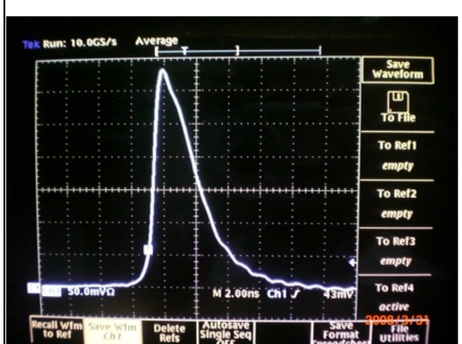


However, a hybrid Inductive Adder-DSRD device where this is the pumping stage for the DSRD is being pursued

Fast Ionization Device (FID) R&D

Tests at ATF with device targeting ±10 kV operation (T. Naito)

Pulse source(FID FPG 10-6000KN)



Specification

Maximum output voltage + 10 kV
- 10 kV
Rise time @ 10-90% level - < 1 ns
Rise time @ 5-95% level - < 1,2 ns
Pulse duration @ 90% - 0,2-0,3 ns
Pulse duration @ 50% - 1,5-2 ns
Output pulse amplitude stability - 0,5-0,7%
Maximum PRF in burst - 6,5 MHz
Number of pulses in burst - up to 110
PRF of bursts - up to 5 Hz

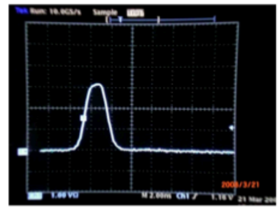
Fast Kicker Tests at ATF

T. Naito
IWLC2010

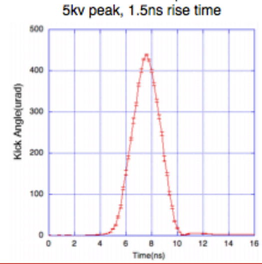
Single unit test

(To confirm 3ns of the rise time of the strip-line kicker)

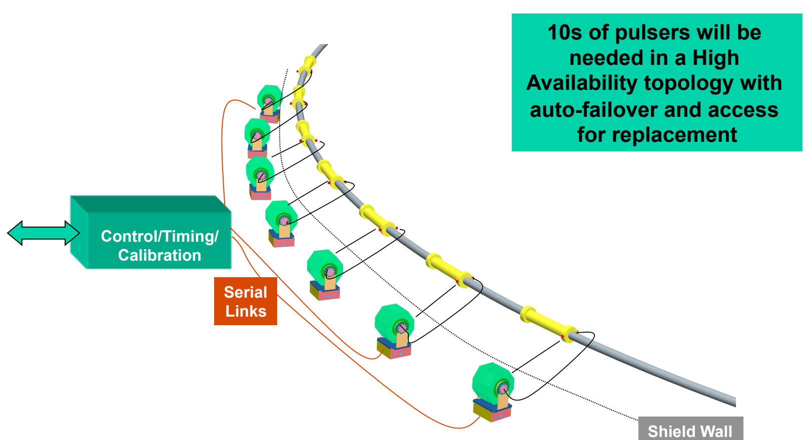
- *The time response of the kick field is strongly depends on the waveform of the drive pulse and the length of the strip-line electrode.*
- *FID pulser have 1.5ns rise time, 5kV peak voltage, 3MHz and 3000 burst pulse.*
- *The time response was tested when the drive pulse was applied to the 30 cm long strip-line electrode.*
- *The time response of the strip-line kicker was measured by measuring the betatron amplitude in ATF-DR. The measured rise time was 3ns, which meets the ILC requirement.*



Waveform of FID pulsr
5kv peak, 1.5ns rise time



System Topology



C. Brooksby BN/LLNL

Fast Kicker Summary

At present, the fast kicker R&D program appears to be converging towards viable solutions for bunch trains with spacings as small as 3ns. The overall system stability requirements for the ILC and CLIC kicker systems are very similar. Both groups plan to collaborate on further R&D in this area.

Instrumentation and Diagnostics

In order to provide reliable ultra-low emittance beams to the downstream portions of the ILC accelerator complex, the damping rings require high quality instrumentation and diagnostics.

- A high resolution (micron-level) beam position monitor system with turn-by-turn capability and very good stability
- Devices to characterize a range of beam instabilities

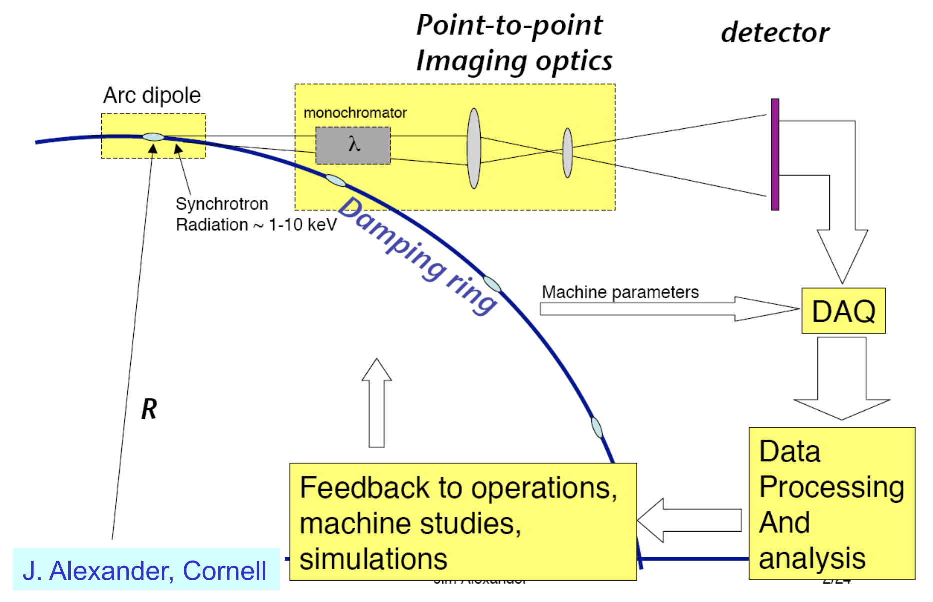
One particular device that is presently under development is a fast beam size monitor with resolution <10 μm and fast response. This device should be capable of:

- Resolving individual bunches
- An integration time scale sufficient to monitor the emittance damping process (single pass measurement capability is desirable)

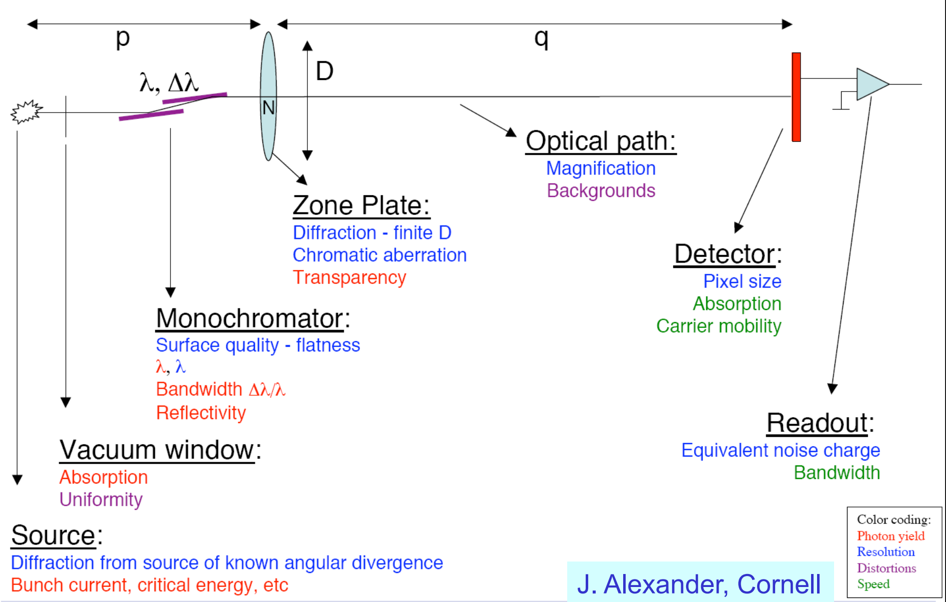
Such a device will aid in:

- emittance tuning
- verification the performance of the emittance damping in the ring
- understanding instability conditions during the short machine cycle

Fast X-ray Monitor Concept



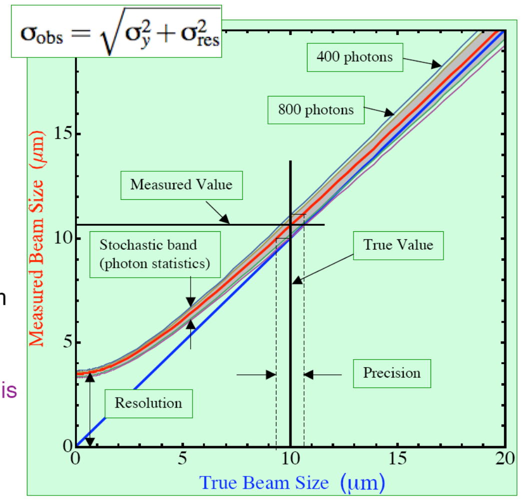
System Design Issues



Resolution and Precision Issues

Sidebar: Resolution, Precision, and Photon Statistics

- Optical transfer function is characterized by a resolution (point spread function). This is a *fixed property* of the optical system.
  For CESRTA design, it is 2-3μm. (Figure at right assumes 3.5 μm)
- Photon statistics (and electronic noise, if applicable) fluctuate from snapshot to snapshot.
- The *measurement precision* of this system is determined by the stochastic element, not the fixed correction*.



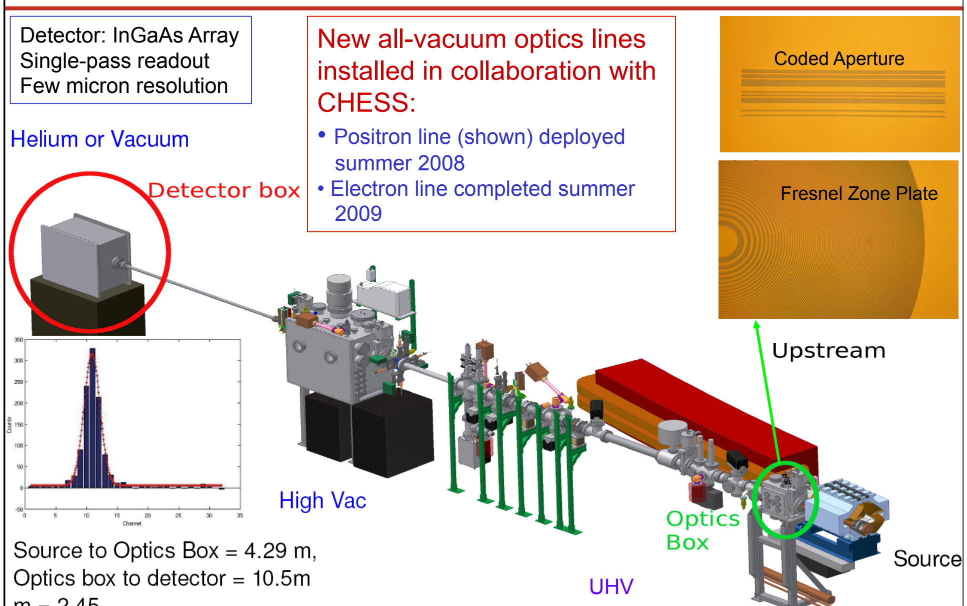
J. Alexander, Cornell

* Residual uncertainty in the optical resolution will appear as a systematic error

CESR Reconfiguration: X-Ray Lines

Detector: InGaAs Array
Single-pass readout
Few micron resolution

New all-vacuum optics lines installed in collaboration with CHESS:
- Positron line (shown) deployed summer 2008
- Electron line completed summer 2009



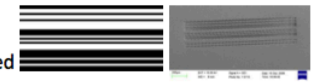
Source to Optics Box = 4.29 m,
Optics box to detector = 10.5m
m = 2.45

Coded Aperture for Single-Pass Measurements

Coded Aperture Imaging

Technique developed by x-ray astronomers using a mask to modulate incoming light. Resulting image must be deconvolved through mask response (including diffraction and spectral width) to reconstruct object. Open aperture of 50% gives high flux throughput for bunch-by-bunch measurements. Heat-sensitive and flux-limiting monochromator not needed.

We need such a wide aperture, wide spectrum technique for shot-by-shot (single bunch, single turn) measurements.



Uniformly Redundant Array (URA) for x-ray imaging being used at CesrTA. Pseudo-random pattern gives relatively flat spatial frequency response.

Source distribution:

$$\begin{bmatrix} A_\sigma \\ A_\pi \end{bmatrix} = \frac{\sqrt{3}}{2\pi}\gamma\frac{\omega}{\omega_c}(1+X^2)(-i)\begin{bmatrix} K_{2/3}(\eta) \\ \frac{iX}{\sqrt{1+X^2}}K_{1/3}(\eta)\end{bmatrix},$$

where

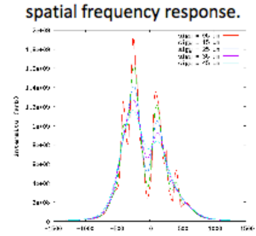
$$X = \gamma\psi,$$

$$\eta = \frac{1}{2}\frac{\omega}{\omega_c}(1+X^2)^{3/2},$$

+

Kirchhoff integral over mask (+ detector response)
→ Detected pattern:

$$A_{\sigma,\pi}(y_d) = \frac{iA_{\sigma,\pi}(\text{source})}{\lambda}\int_{\text{mask}}\frac{t(y_m)}{r_1 r_2}e^{i\frac{2\pi}{\lambda}(r_1+r_2)} \times\left(\frac{\cos\theta_1+\cos\theta_2}{2}\right)dy_m,$$



Simulated detector response for various beam sizes at CesrTA

J. Flanagan

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Application of Turn-by-Turn Imaging

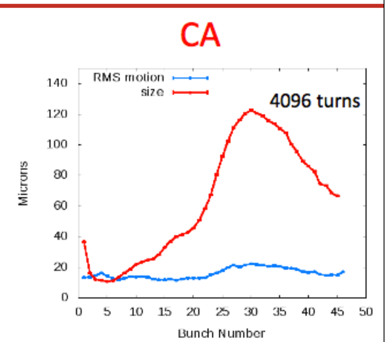
Results of turn-by-turn imaging of a 45 bunch train of positrons in CesrTA. ~2×10^{10} particles/bunch with 14ns bunch-spacing

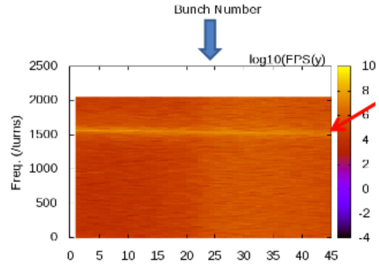
Data was acquired for each bunch on the same set of 4096 turns

Bunches in the train show the onset of a head-tail instability shortly after bunch 20.

Bottom plot shows the bunch-by-bunch vertical tune

If this can be developed into a "production" device, it will be of great use in monitoring the interleaved bunches in the ILC DR





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Summary

In the first section of this lecture we have highlighted several technical challenges for the ILC Damping Ring design. They range from serious R&D issues such as the fast kickers to technical optimization issues that can seriously impact the cost and/or performance capability of critical systems.

During the next lecture, we will look at several beam dynamics issues that affect ring design. Along with the major technical challenges, these physics issues are what drive the ongoing R&D program for the ILC damping rings. At present, the three most critical R&D challenges for the ILC damping rings are:

- Fast pulser design
- Electron cloud instability
- Fast ion instability