Design progress for the ILC Damping Rings

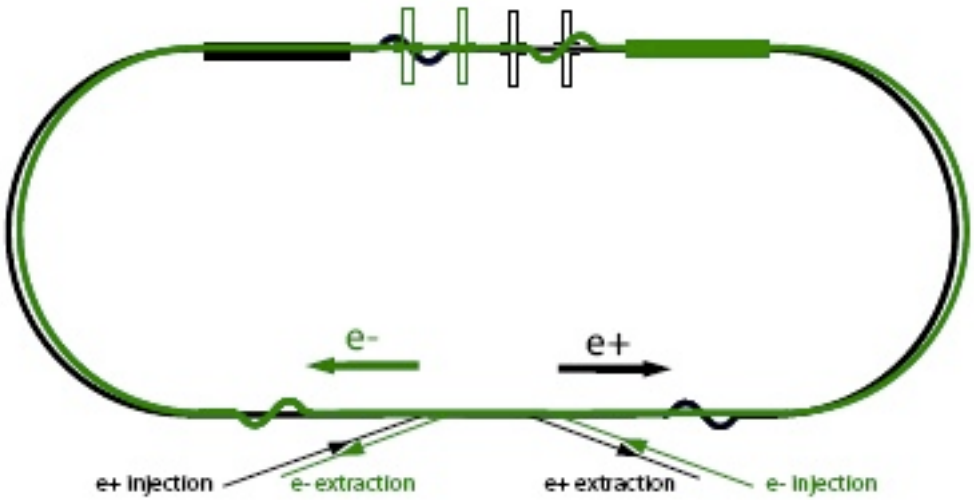
S. Guiducci, INFN-LNF

IWLC , Geneva 20 October 2010

Damping Ring Reference Design

DCO4 lattice

- 6.4 km circumference, 5 GeV
- Racetrack layout
- FODO cell arcs
- Flexibility in momentum compaction choice between 2.9 10^{-4} and 1.3 10^{-4}
- Single tunnel for injection and extraction beam lines can be used



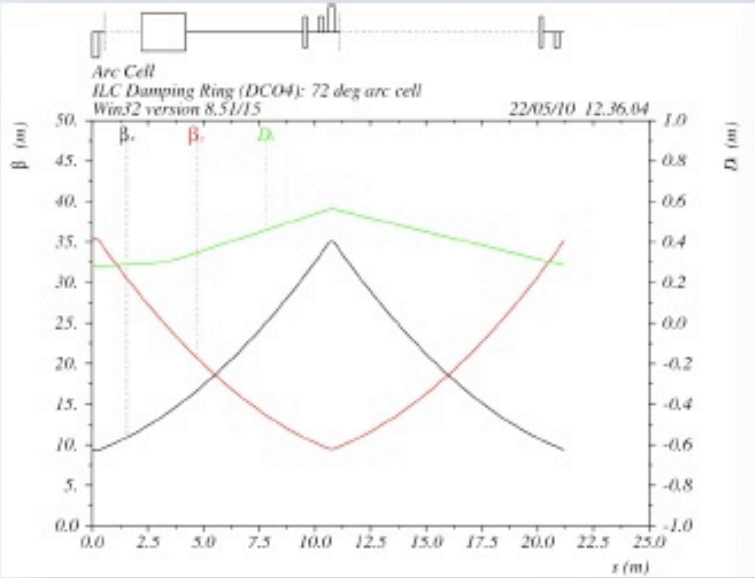
M. Korostelev, A. Wolski, "DCO4 LATTICE DESIGN FOR 6.4 KM ILC DAMPING RINGS", ILC-NOTE-2010-056

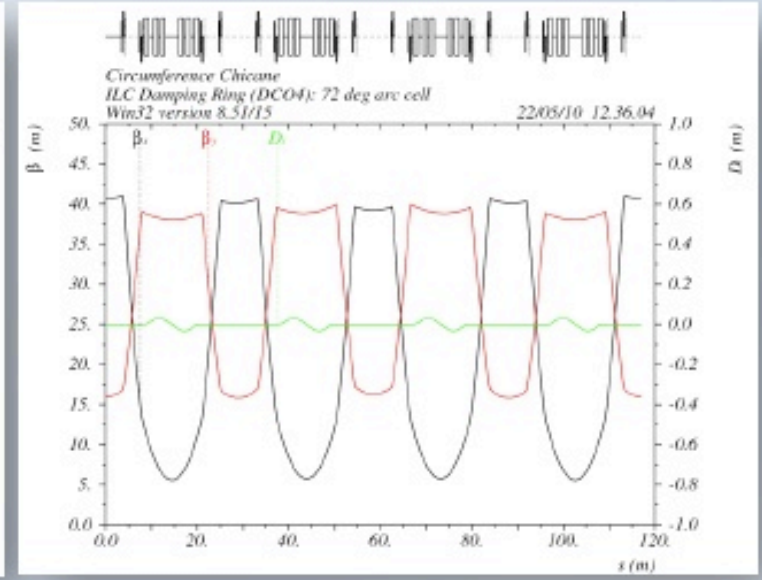
DCO4 DR Parameters

	DCO4 High Power 5Hz
Particle	e^+/e^-
Circumference (m)	6476
N bunches	2610
N part./bunch	2×10^{10}
Damping time τ_x (ms)	21
Emittance ε_x (nm)	0.44
Emittance ε_y (pm)	2
Energy loss/turn (MeV)	10.2
Energy spread	1.3×10^{-3}
Momentum compaction	1.6×10^{-4}
B wiggler (T)	1.6
Wiggler period (m)	0.4
Wiggler length (m)	2.45
Total wiggler length (m)	216
Number of wigglers	88
Bunch length (mm)	6
RF Voltage (MV)	21
Average current (A)	0.388
Beam Power (MW)	3.97
N. of RF cavities	16

Lattice Functions

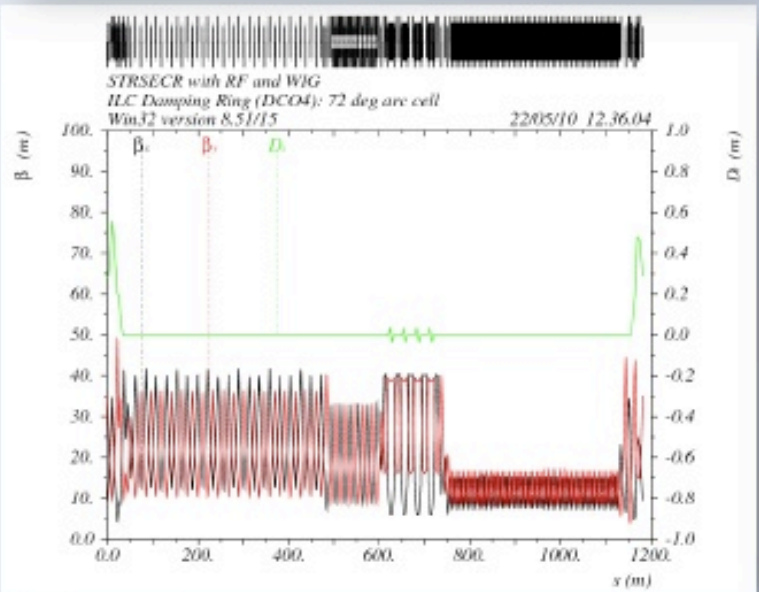
Arc Cell

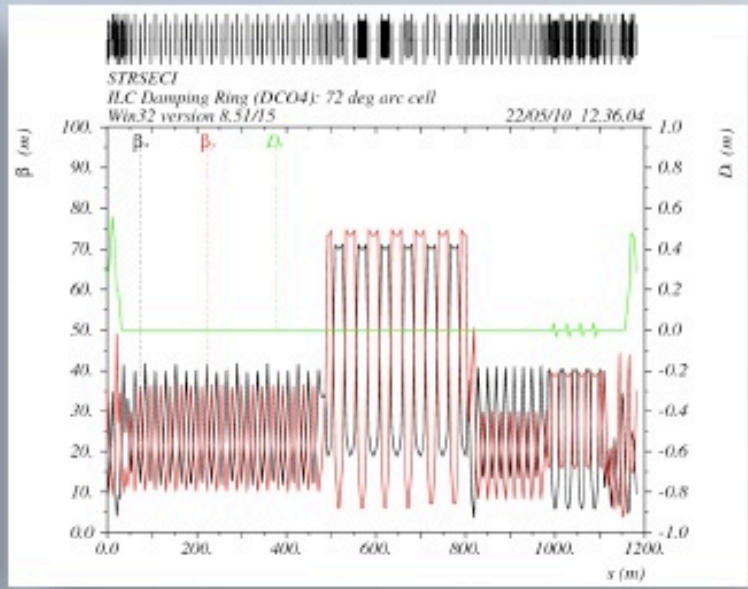




Chicane

Wiggler Straight

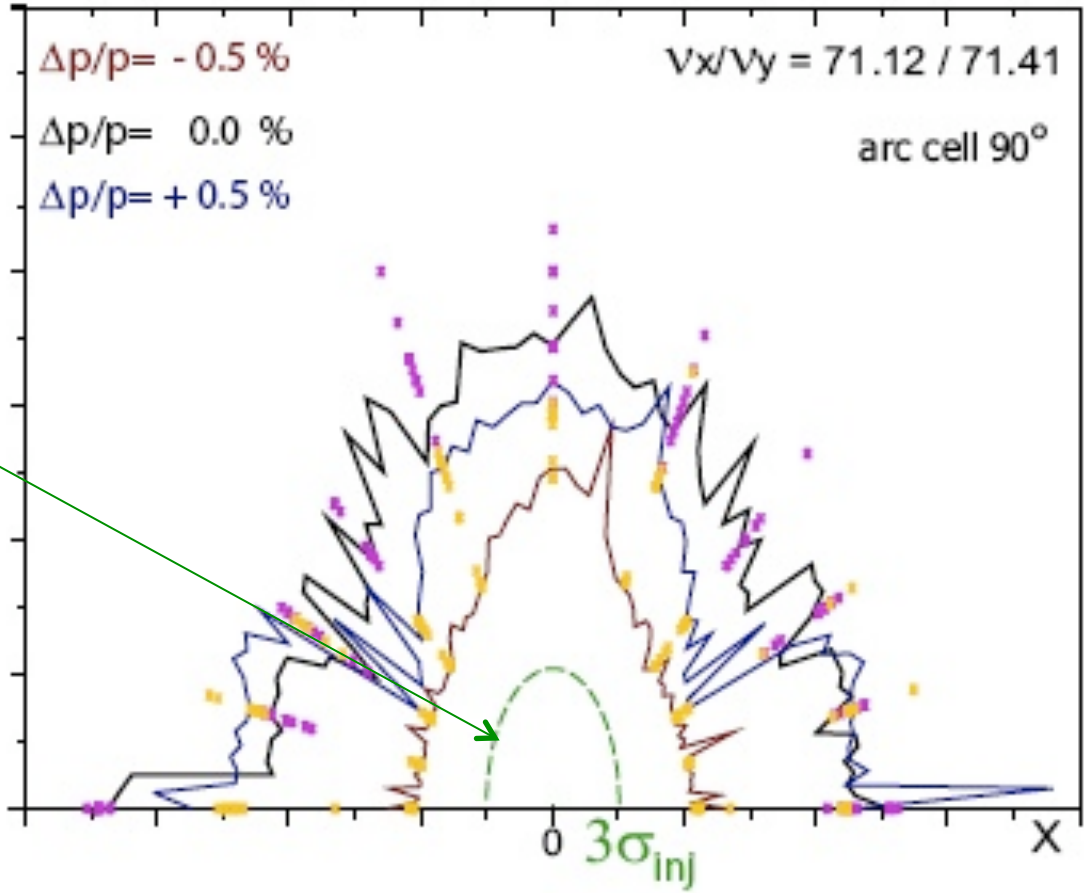




Injection/ Extraction Straight

Dynamic Aperture

Maximum betatron amplitude of injected e^+ beam

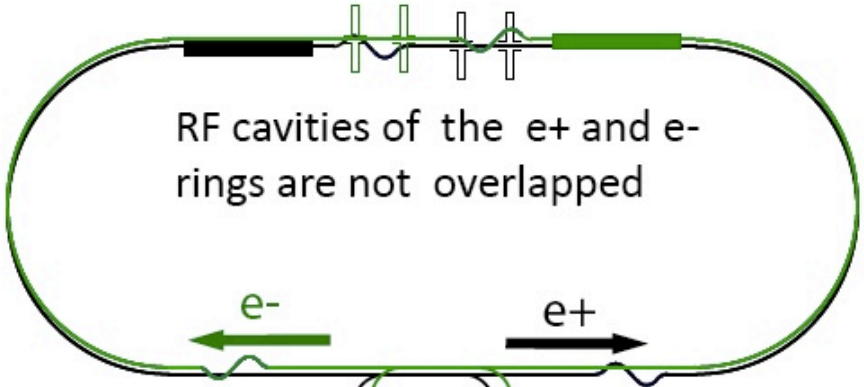


Solid lines correspond to DA without any lattice errors. Magenta and yellow points show the variations of the on-momentum and off-momentum *DA, respectively,* computed for ten seeds of random sextupole alignment errors with 80 *μm rms*

Positioning of the e+ and e- DR rings

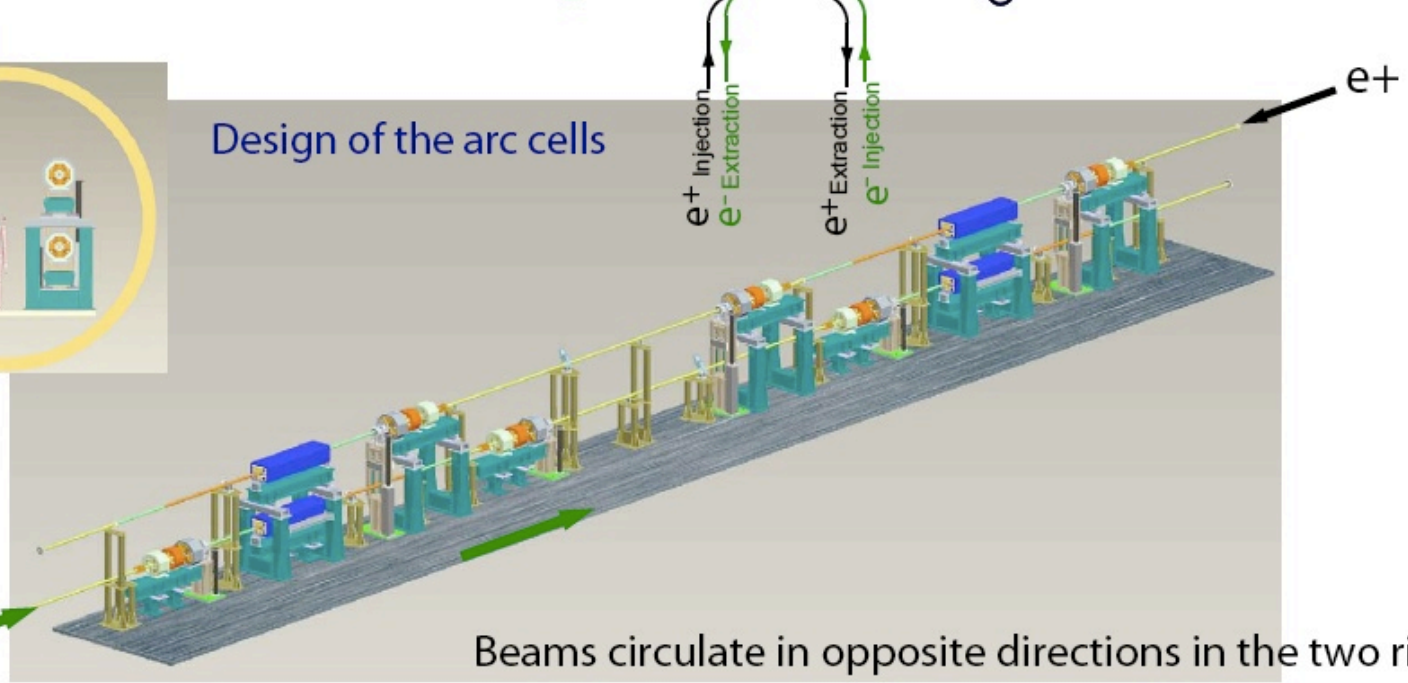
e- Damping Ring
e+ Damping Ring

The lattice of e- DR is identical to the lattice of the e+ DR.



Tunnel

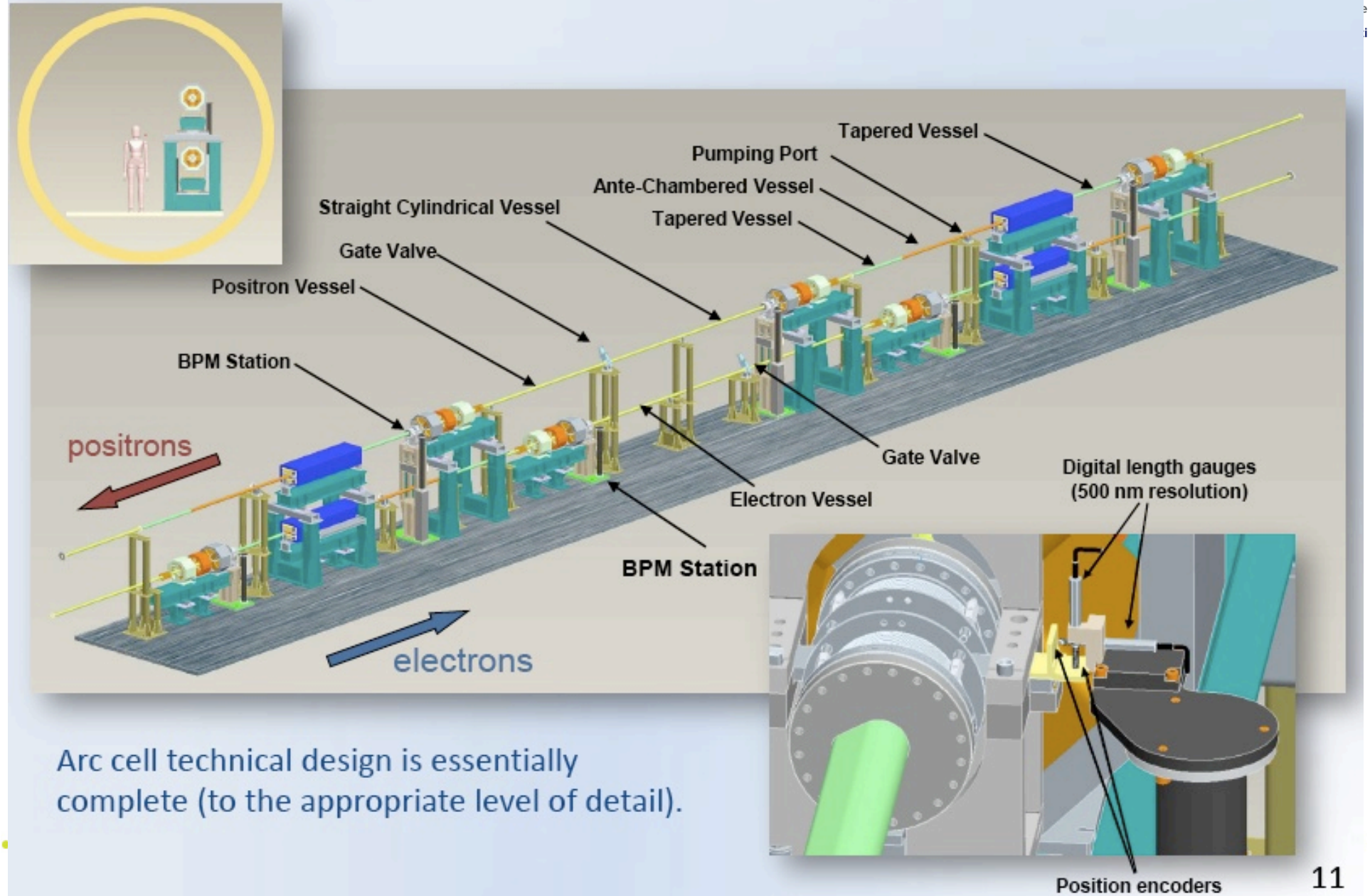
Design of the arc cells



Beams circulate in opposite directions in the two rings.

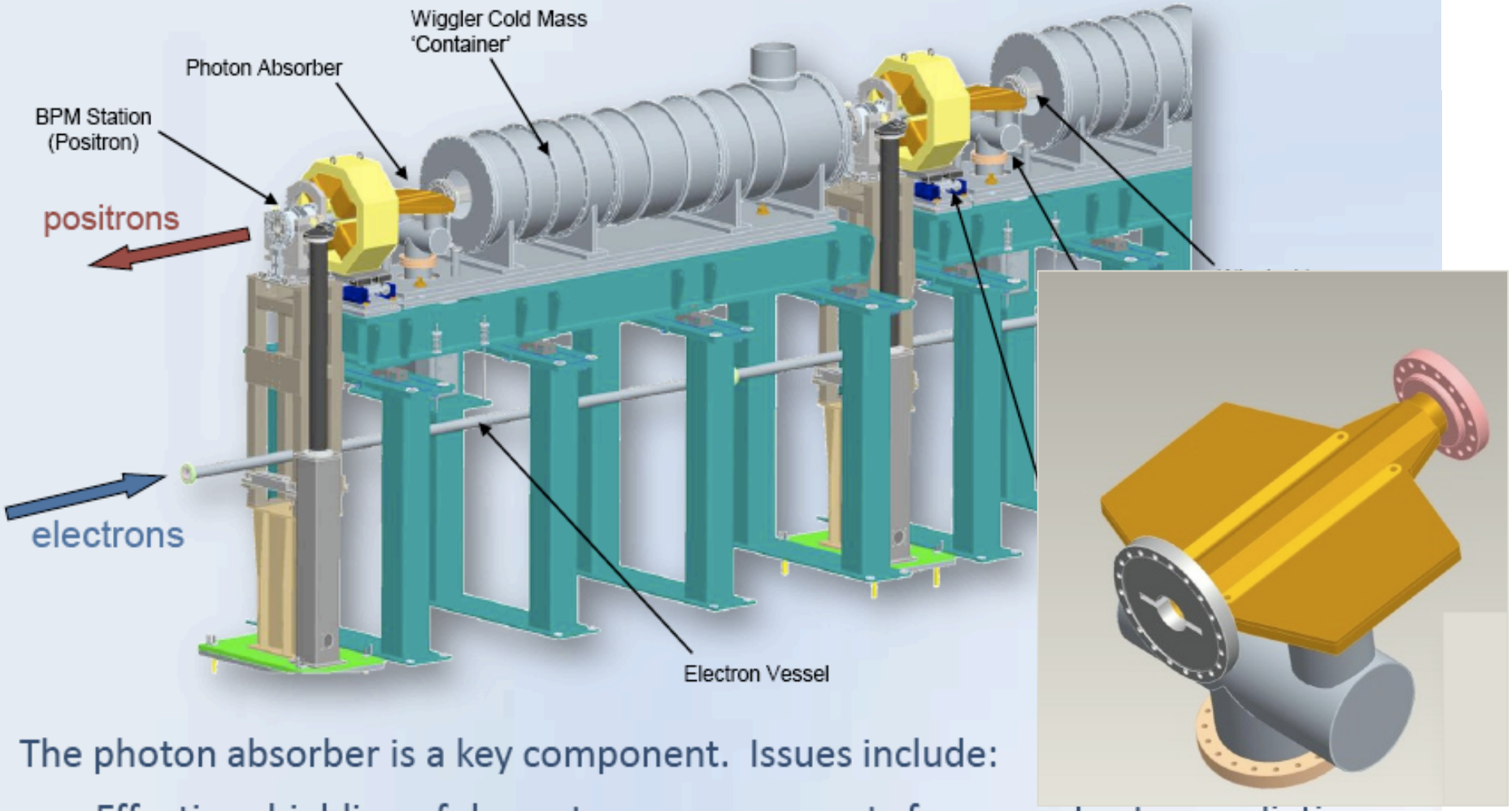
A. Wolski et al. **Damping Rings Design Work at the Cockcroft Institute,** ILC10 Beijing

Vacuum System Technical Design and Costing



Arc cell technical design is essentially complete (to the appropriate level of detail).

Wiggler Section



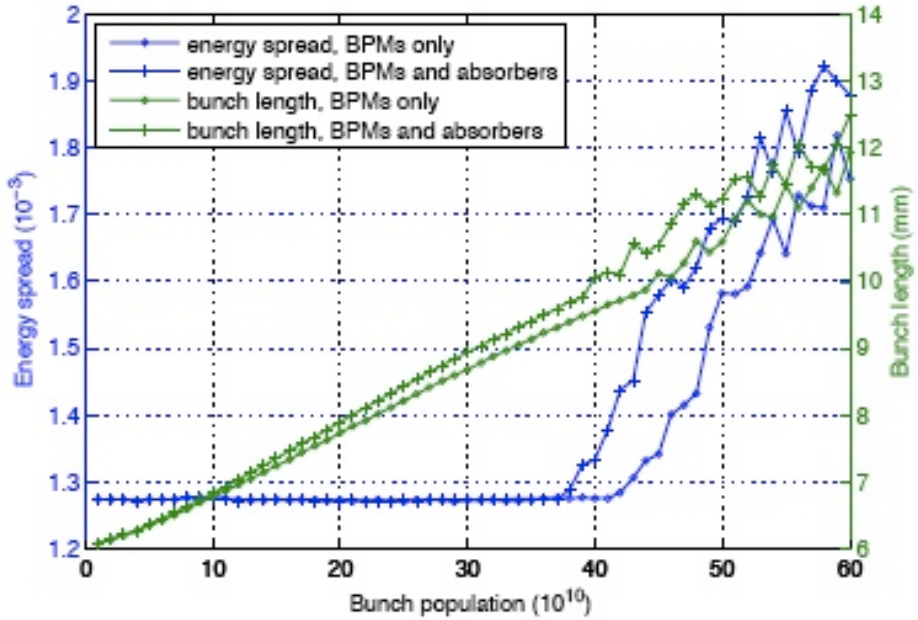
The photon absorber is a key component. Issues include:

- Effective shielding of downstream components from synchrotron radiation.
- Power loads (40 kW per wiggler) and cooling.
- Machine impedance.

SR POWER DISTRIBUTION ALONG WIGGLER SECTION OF ILC DR, K. Zolotarev, et al., IPAC10; **MECHANICAL AND VACUUM DESIGN OF THE WIGGLER SECTION OF THE ILC DAMPING RINGS,** O.B. Malyshev et al., IPAC10

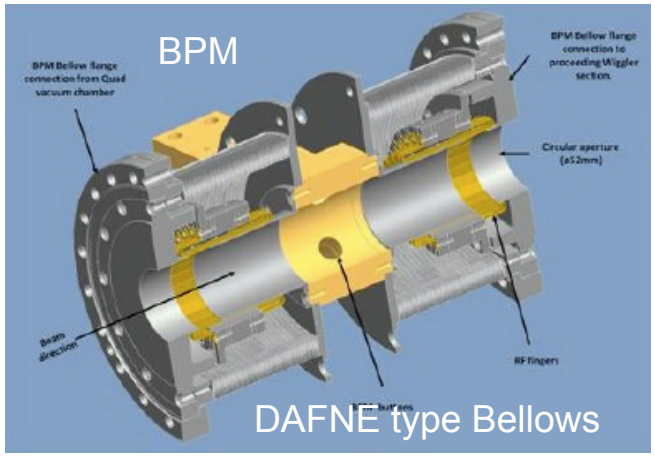
Impedance and single bunch instabilities

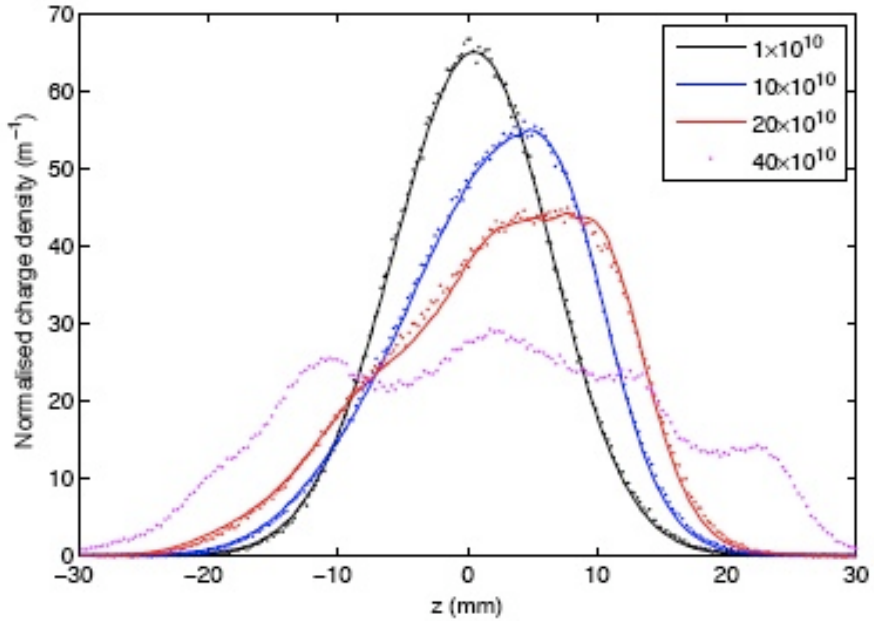
The wake functions from CST Particle Studio are used as input for the code. The evolution of the longitudinal phase space distribution is computed over 2,500 turns (~5 long. damping times) with 219 macroparticles per bunch.



Circles: 692 BPMs only
Crosses: 692 BPMs and 88 absorbers

Instability threshold ~40 10^{10} part/bunch
much larger than nominal bunch density 2 10^{10} part/bunch



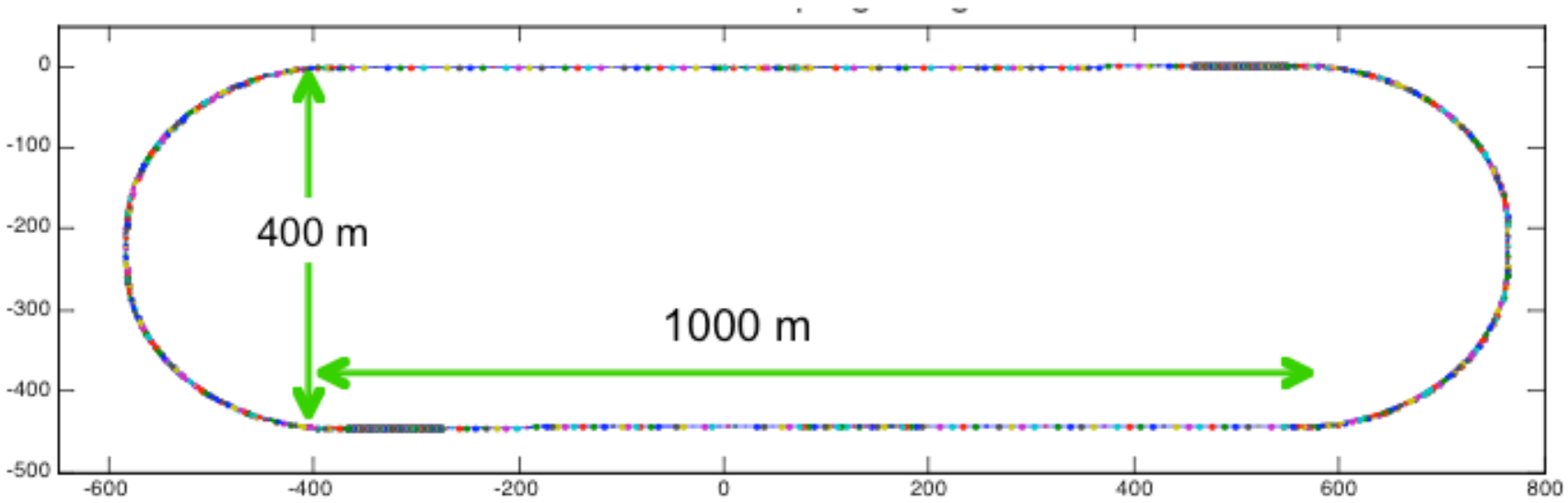


IMPEDANCE AND SINGLE-BUNCH INSTABILITIES IN THE ILC DAMPING RING*, M.Korostelev *et al. IPAC10*

Damping Ring SB2009 Design

- 3.2 km circumference, 5 GeV
- Same racetrack layout
- Similar straigth sections
- SuperB arc cells

DSB3 lattice



A LOW EMITTANCE LATTICE FOR THE ILC 3 KM DAMPING RING, S. Guiducci, M. E. Biagini, IPAC10

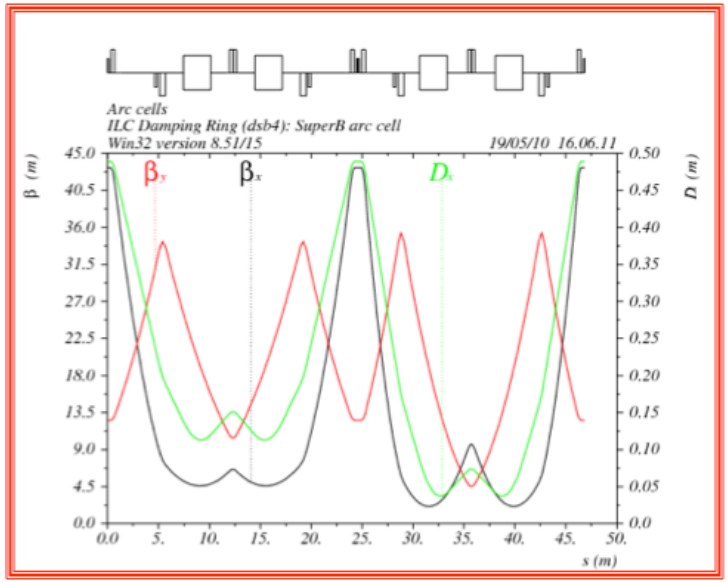
DR Parameters

Nominal: RDR High Power 2610 bunches
SB2009 Low Power 1305 bunches

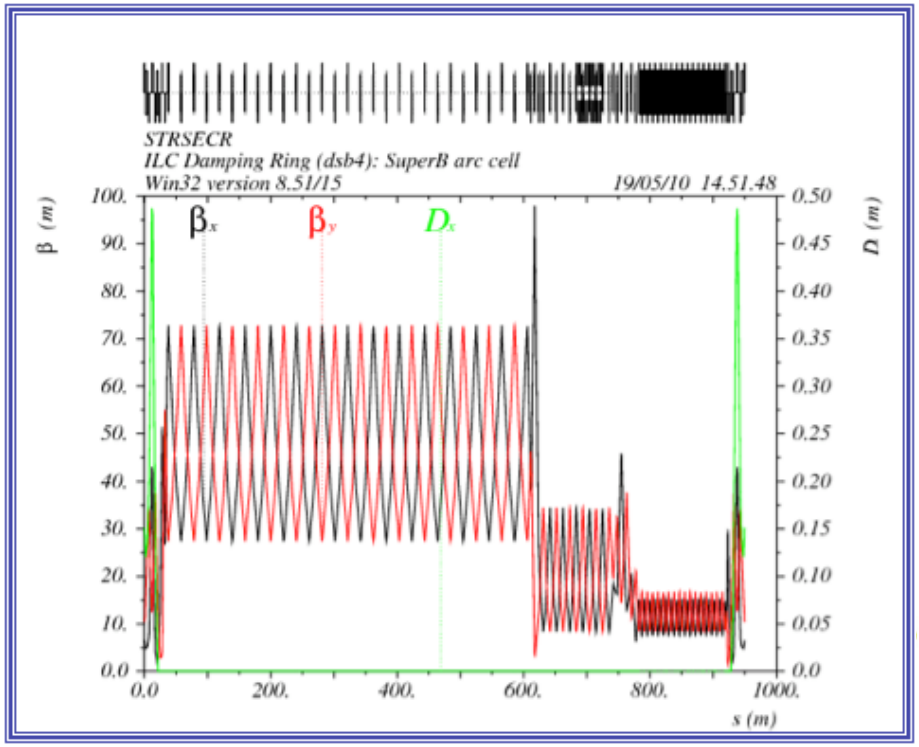
	DCO4 High Power 5Hz	SB2009 Low P. 5Hz
Particle	e^+/e^-	e^+/e^-
Circumference (m)	6476	3238
N bunches	2610	1305
N part./bunch	2×10^{10}	2×10^{10}
Damping time τ_x (ms)	21	24
Emittance ε_x (nm)	0.44	0.53
Emittance ε_y (pm)	2	2
Energy loss/turn (MeV)	10.2	4.5
Energy spread	1.3×10^{-3}	1.2×10^{-3}
Momentum compaction	1.6×10^{-4}	1.3×10^{-4}
B wiggler (T)	1.6	1.6
Wiggler period (m)	0.4	0.4
Wiggler length (m)	2.45	2.45
Total wiggler length (m)	216	78
Number of wigglers	88	32
Bunch length (mm)	6	6
RF Voltage (MV)	21	7.5

Lattice functions

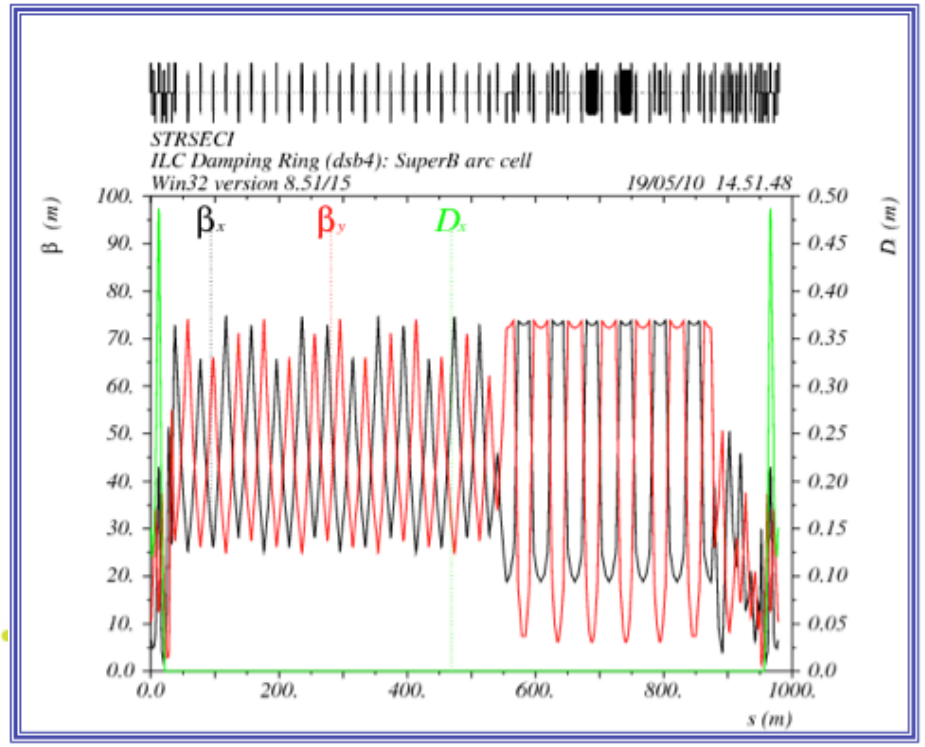
Arc cells



Wiggler straight

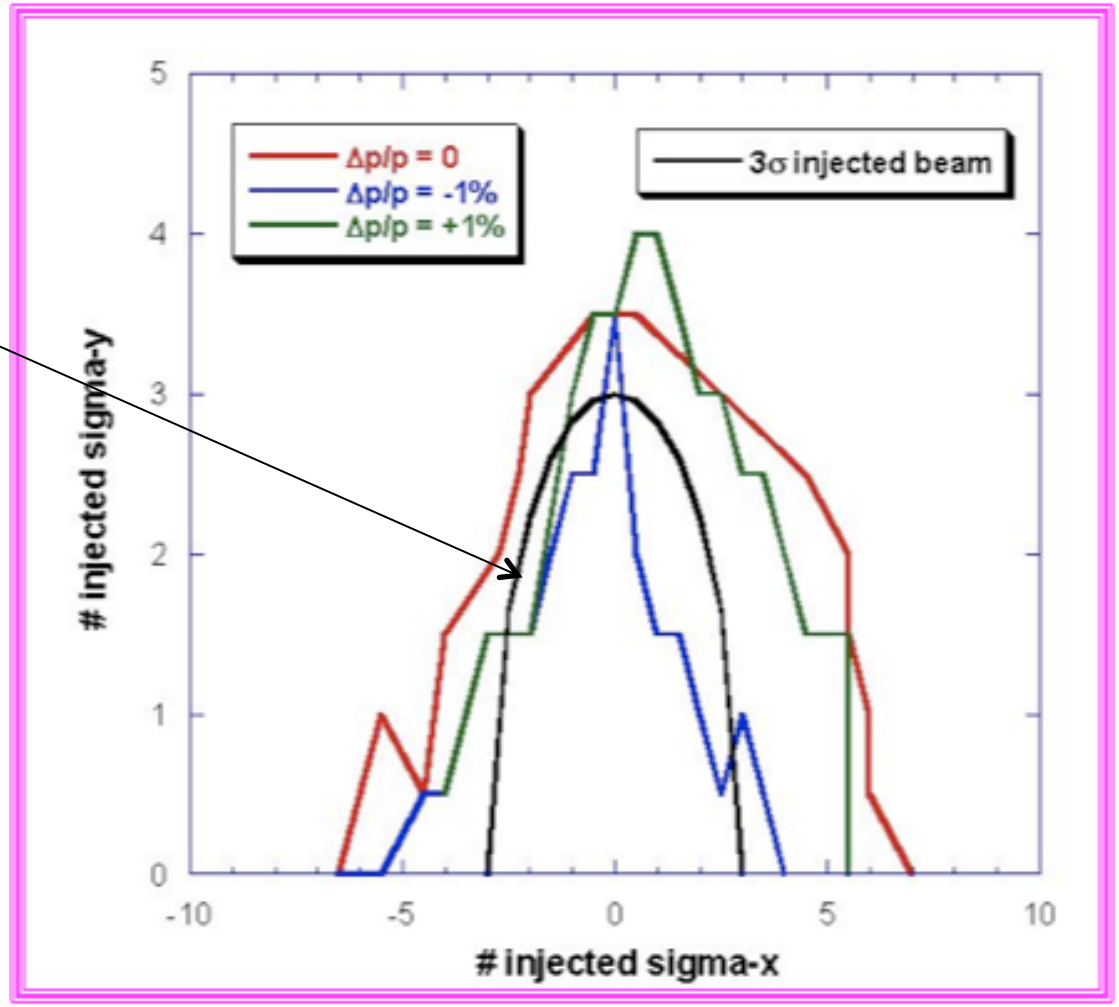


Injection straight

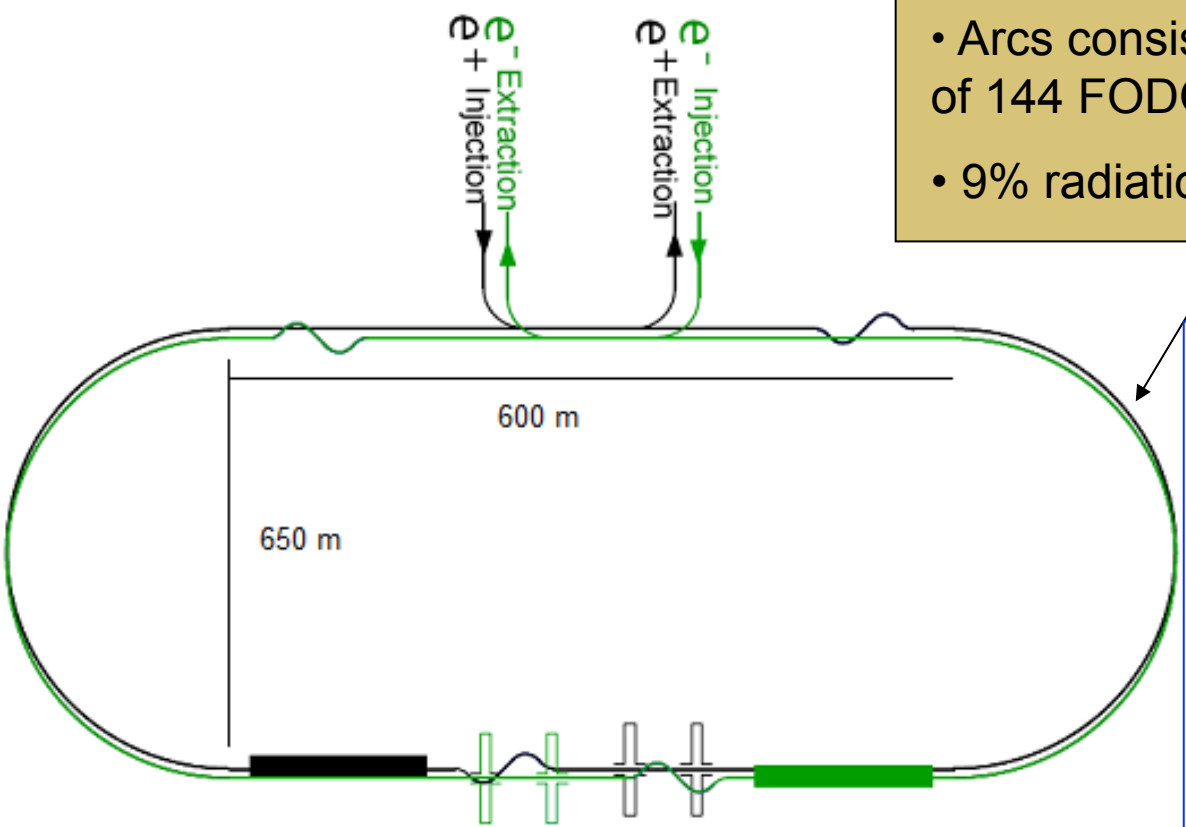


Dynamic Aperture

Maximum betatron amplitude of injected e^+ beam



FODO lattice for 3.2 km ring



- Arcs consist of a total of 144 FODO cells
- 9% radiation in arcs

Jie Gao, IHEP, WG2, Wednesday 11:15

Flexible but large momentum compaction

↓

high RF voltage
Improved DA

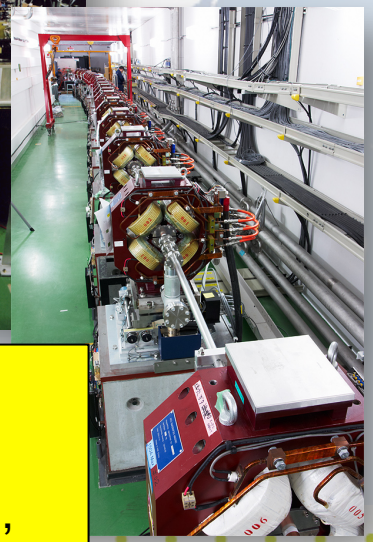
- Straights are similar to 6 km DCO4
- 91% radiation in straights

A NEW DESIGN FOR ILC 3.2 km DAMPING RING BASED ON FODO Cell, D. Wang, J. Gao and Y. Wang, IPAC10

Beam Test Facilities (non SCRF)

- **Two Large Scale Test Facilities for R&D:**
  - Damping Ring (ATF, CesrTA)
  - Beam Delivery System (Final Focus) (ATF2)

strong ILC-CLIC synergy



- ATF/ATF-2 (KEK)

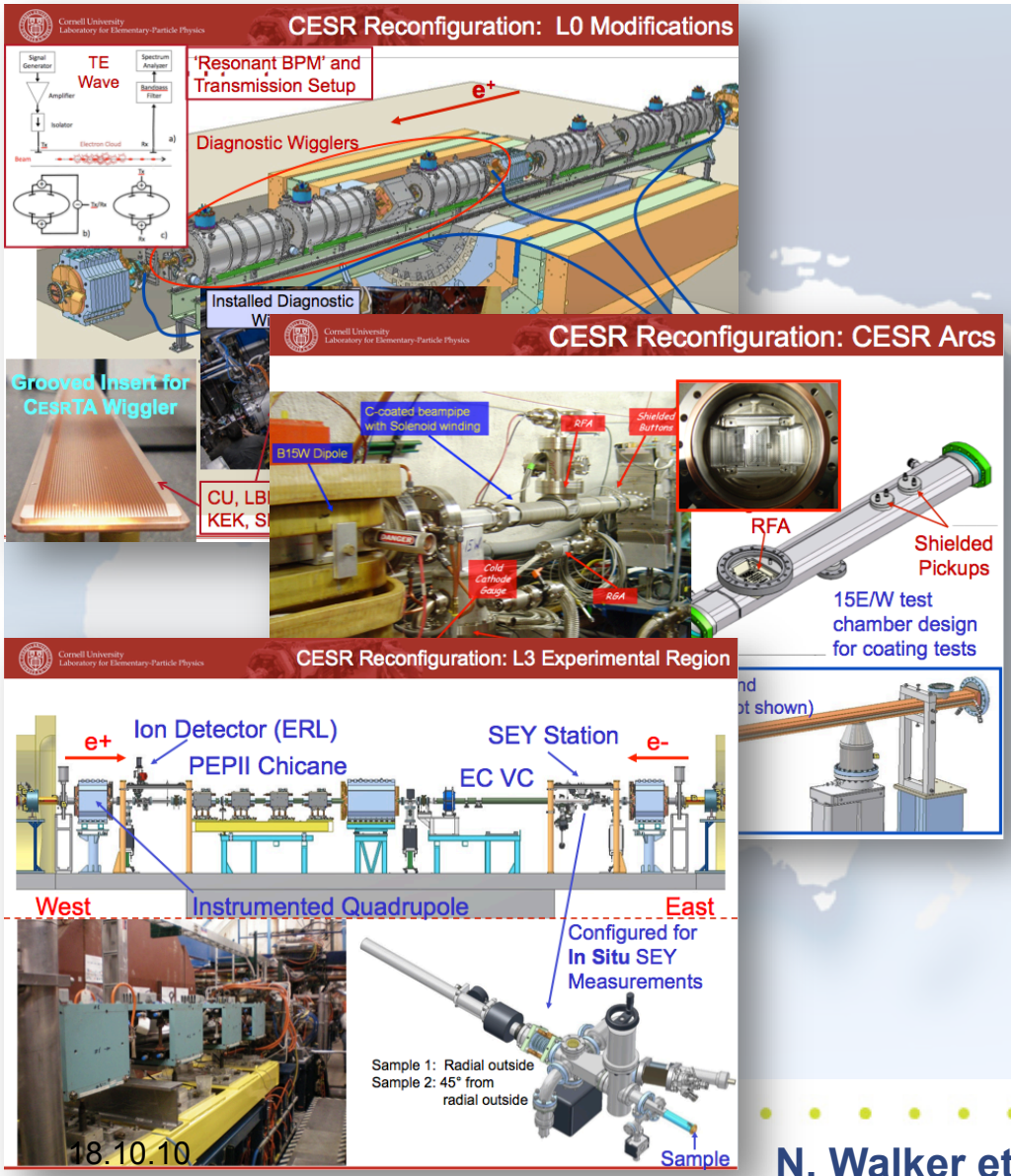
- CesrTA (Cornell)

T. Tauchi (*KEK*), Accel plenary, Tue 15:40
J. Urakawa (KEK), WG2, Wed 10:15

M. Palmer (*Cornell*), Accel plenary, Tue 16:30
J. Shanks, M. Billing (Cornell), WG2, Wed & Thu

N. Walker et al

CesrTA Programme (Collaboration)



- **Major Reconfiguration of CESR ring**
- **2 Year Programme**
  - Ending 2010 (i.e. now)
- **Principal goals**
  - Measure EC build-up in wigglers / arcs
  - Evaluate experimentally mitigating techniques
  - Develop (benchmark) models for EC-driven instabilities

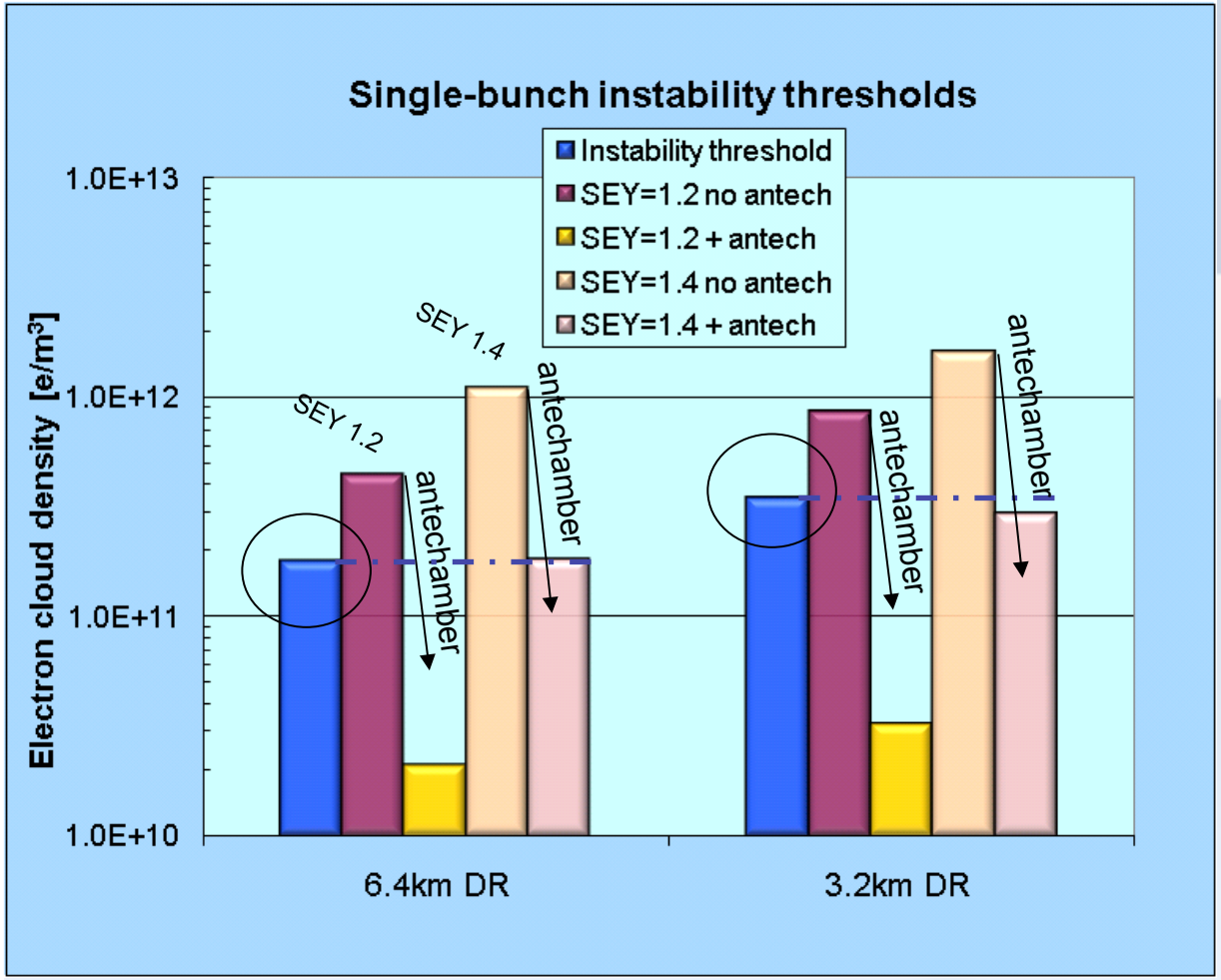
N. Walker et al

ECLOUD WG

- An ECLOUD Working Group has been setup, coordinated by Mauro Pivi
- Since 1 year, WG is meeting regularly and monthly via Webex
- WG Charge:
  - **Recommendation for a reduced Damping Ring Circumference (Given March 2010)**
  - **Recommendation for the baseline and alternate solutions for the electron cloud mitigation in various regions of the ILC Positron Damping Ring (by end 2010)**
  - **Characterization of electron cloud at different bunch spacing: 6ns (nominal) and 3ns (higher luminosity) (by end 2010)**

M. Pivi (*SLAC*), WG2, Thu 17:00

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

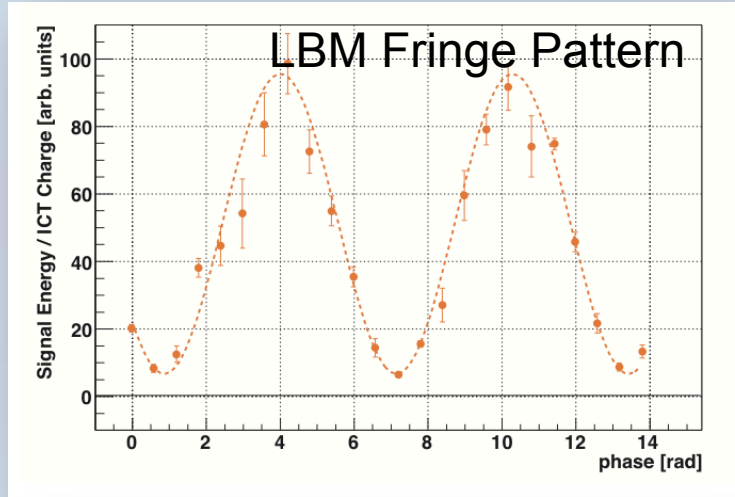
- Preliminary CESRTA results and simulations suggest the presence of *sub-threshold emittance growth*
  - Further investigation required
  - May require reduction in acceptable cloud density ⇨ reduction in safety margin
- An aggressive mitigation plan is required to obtain optimum performance from the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

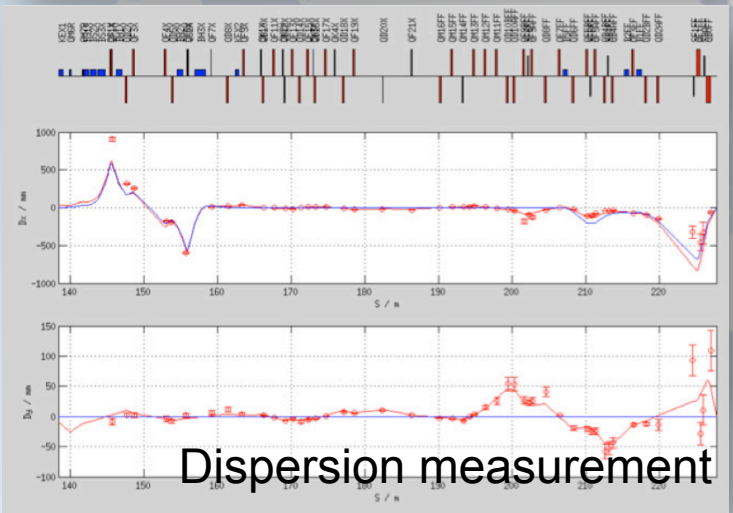
S. Guiducci, M. Palmer, M. Pivi, J. Urakawa on behalf of the ILC DR Electron Cloud Working Group

ECLOUD10, Cornell 8-12 October

- 61 talks, 59 participants
- Lot of progress in understanding and counteracting the e-cloud effects
- Large community and different type of accelerators involved, including lepton and hadron machines, colliders, and synchrotron light sources
- Impossible to mention all. CesrTA will be reported here. Just mention the SuperKEKB effort to build a new vacuum chamber equipped with the most effective e-cloud mitigations in order to achieve high positron currents and very low emittances. High synergy with Damping Rings.

ATF-2 (KEK)



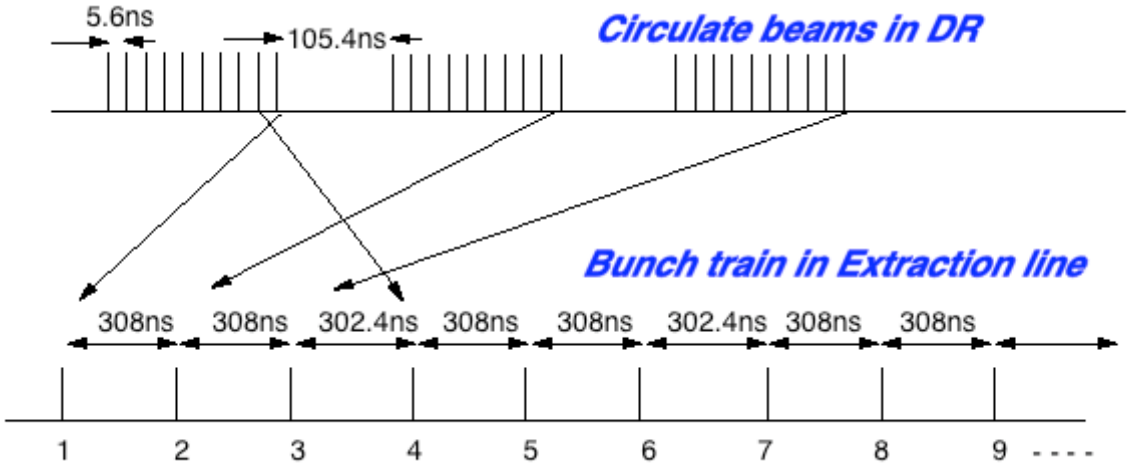


- **Shintake laser monitor (LBM)**
  - improved S/N
- **Significant progress on optics**
  - beam based alignment
  - tuning algorithms
  - optics modelling
- **2010/11 run just beginning**

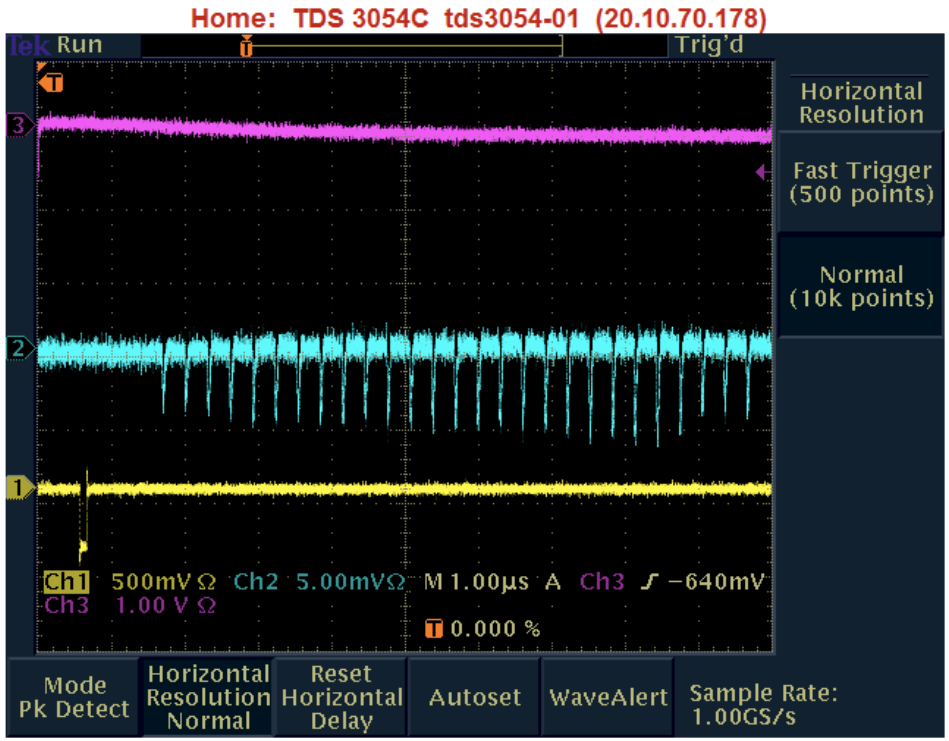
σ_y ~ 310 nm

[goal: 38 nm]

Multi-bunch beam extraction by the Fast kicker



- *Kick angle was stable as 4×10^{-4} < ILC requirement.*
- *Further improvements of the HV pulser should be done for multi-bunch extraction.*



in DR:

- 3 Trains,
- 9(max 10) bunches/train with 5.6 nsec spacing

Extracted:

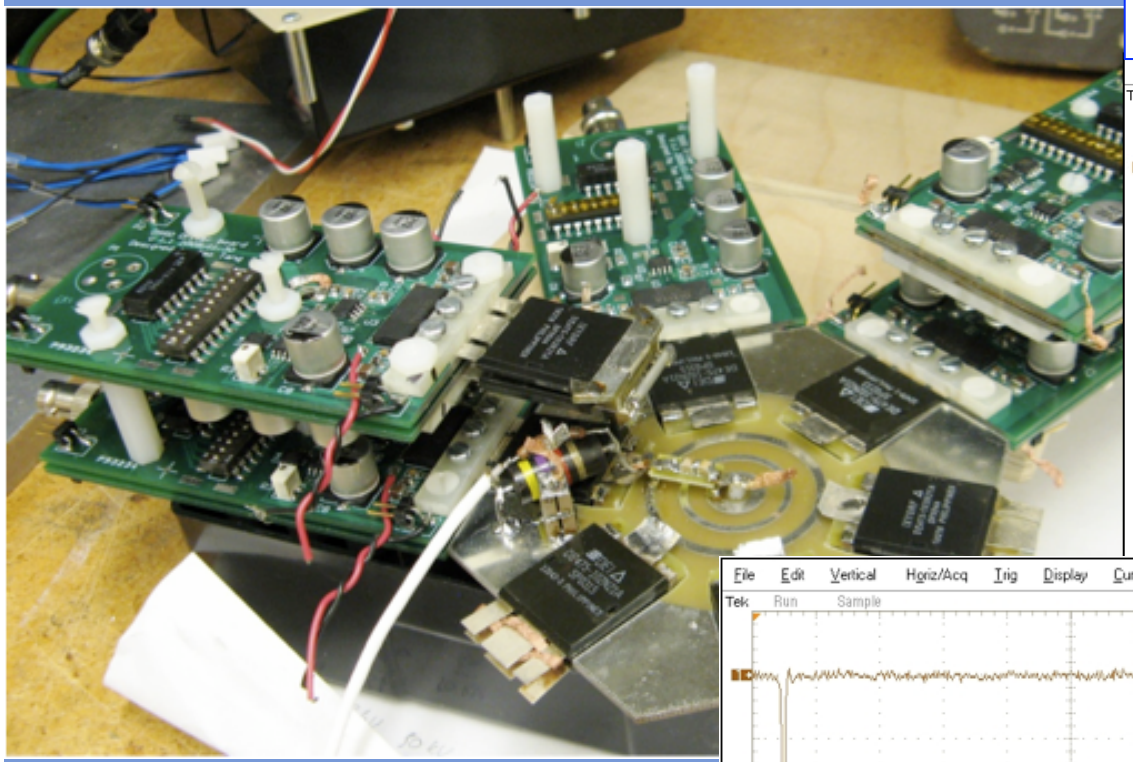
- 27(max 30) bunches with 308 ns spacing
- bunch-by-bunch profile follows that in the DR.
- bunches were extracted from the last bunch to the first bunch.

N. Terunuma (KEK), ILC2010, Beijing

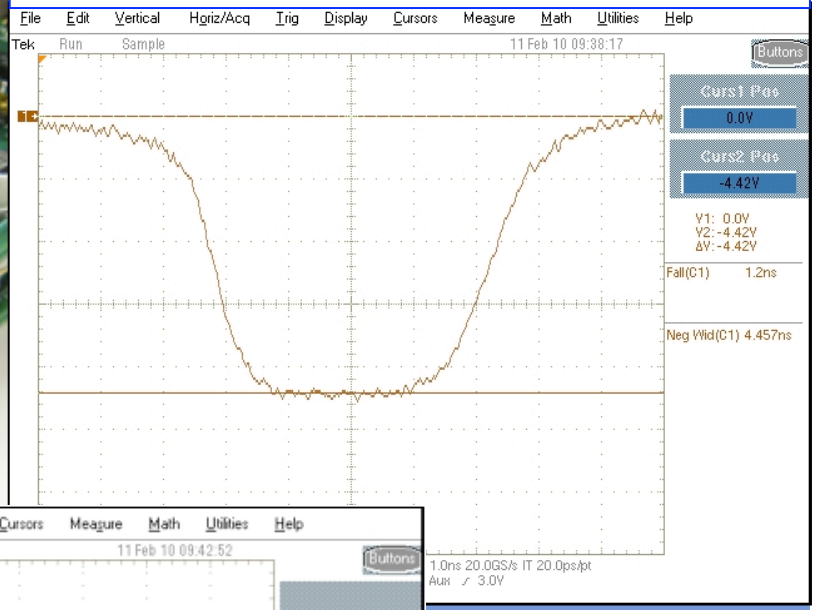
Updated results, T. Naito, WG2, Wed 14:30

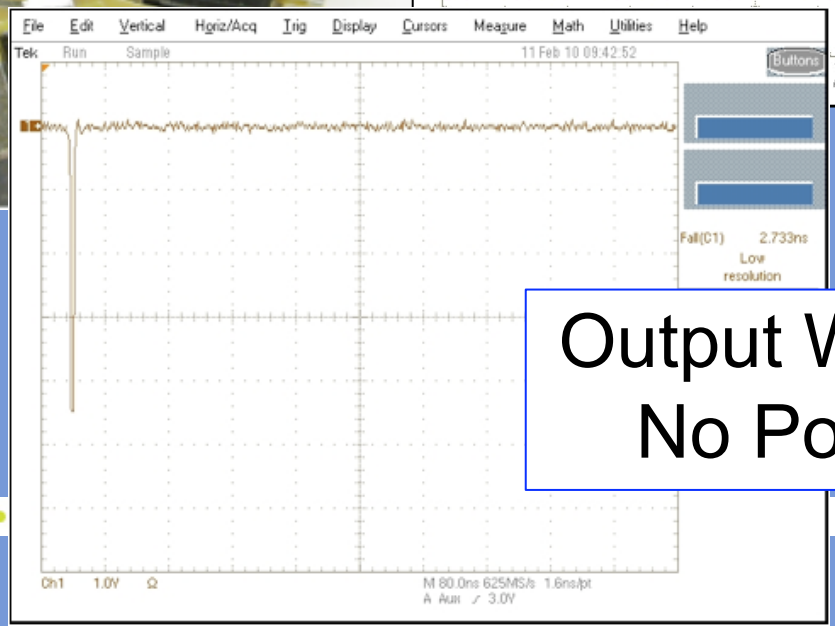
R&D on kicker pulser at SLAC

Partially Assembled DSRD Circuit



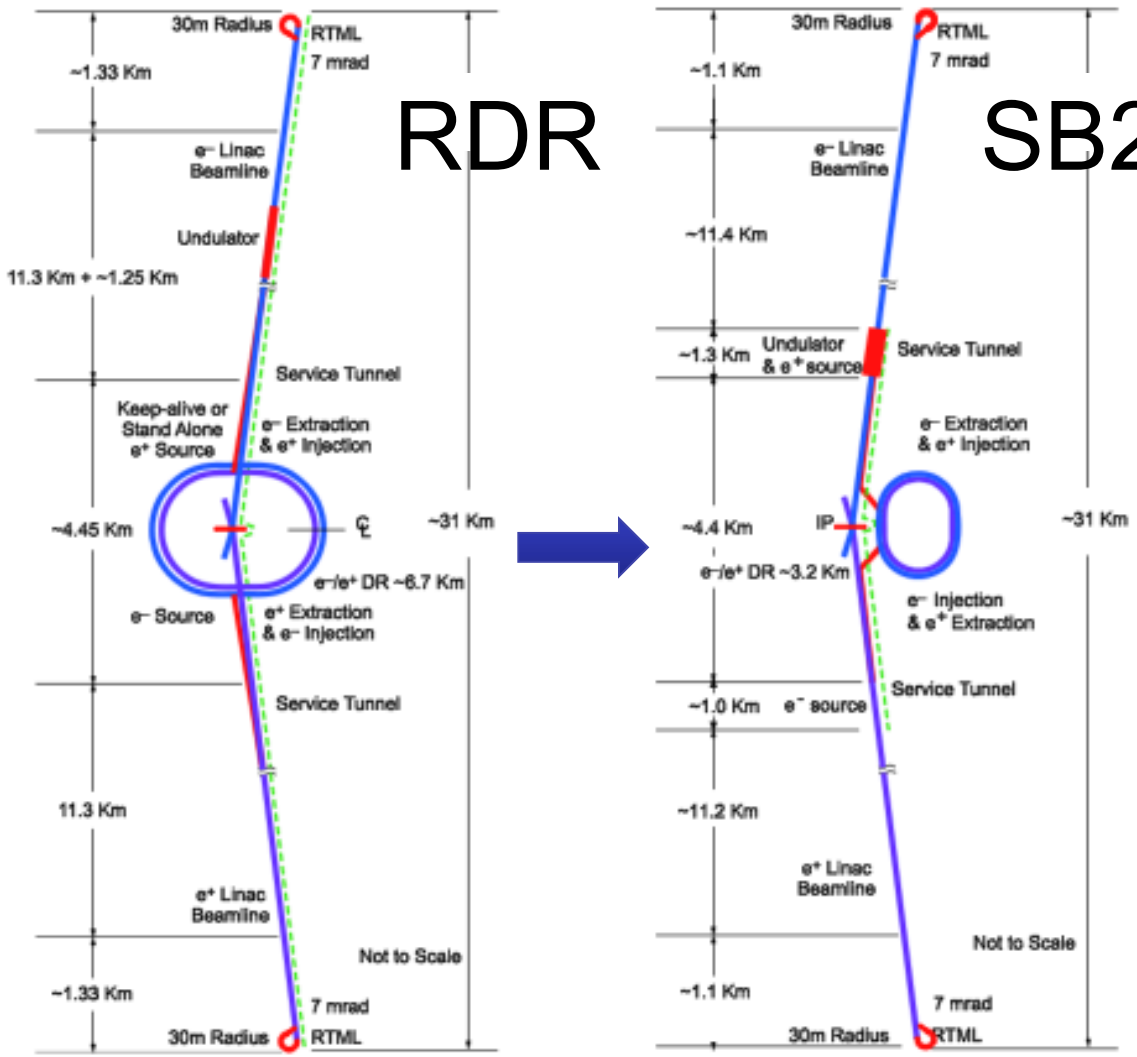
Reduced Width (2 ns) Output Waveform

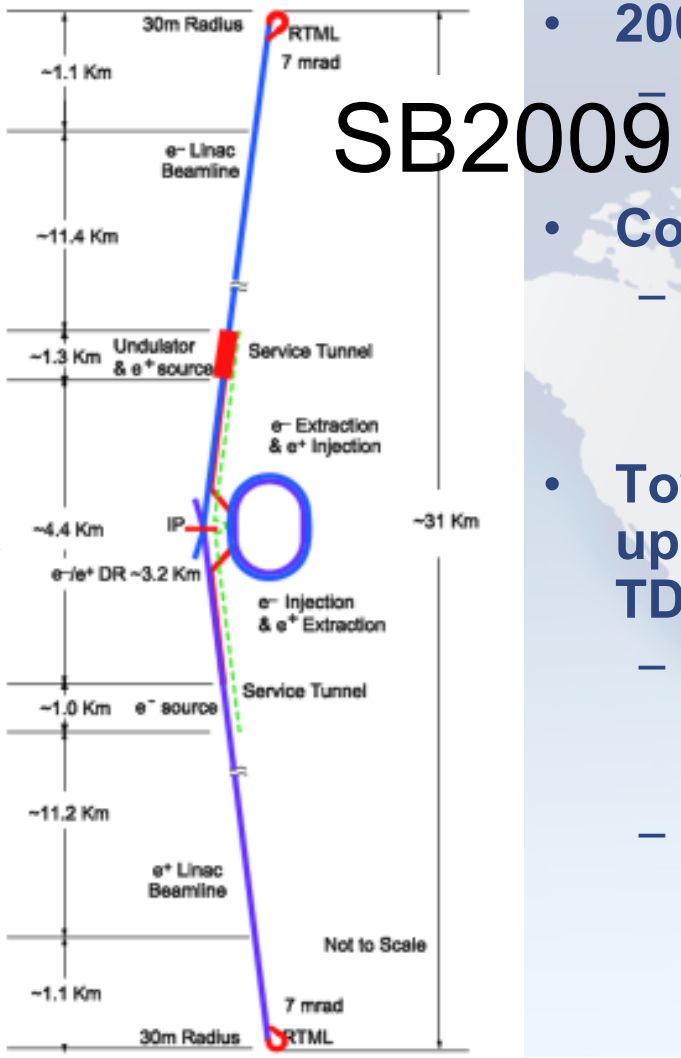




Output Waveform: No Post-pulse

Accelerator Design & Integration





- **2009 Design Studies**
  - on-going
- **Cost Constraint**
  - 'Global' Value Engineering
- **Towards an agreed-upon baseline for the TDR**
  - Top-Level Change Control Process (**TLCC**)
  - Communication with stakeholders (e.g. Physics & Detector groups)

TLCC Process

1. Accelerating Gradient
2. Single-tunnel (HLRF)
3. Low-Power Parameter
4. Positron source location

1st BAW
KEK 7-10th Sept. 2010
2nd BAW
SLAC 18-21st Jan. 2011

Issue Identification

- Planning
- Identify further studies
- Canvas input from stakeholders
- …

Baseline Assessment Workshops

- Face to face meetings
- Open to all stakeholders
- Plenary

Formal Director Approval

- Change evaluation panel
- Chaired by Director

This workshop critical important milestone for TLCC process

keywords: open, transparent

BAW-2 Themes

								upgrade
Centre-of-mass energy	E_{cm}	**GeV**	**200**	**230**	**250**	**350**	**500**	**1000**
Luminosity	L	$\times 10^{34}$ cm^{-2}s^{-2}	**0.5**	**0.5**	**0.7**	**0.8**	**1.5**	**2.8**
Luminosity (Travelling Focus)	L_{TF}	$\times 10^{34}$ cm^{-2}s^{-2}	**0.5**		**0.8**	**1.0**	**2.0**	
Number of bunches	n_b		1312	1312	1312	1312	1312	2625
Collision rate	f_{rep}	Hz	5	5	5	5	5	4
Electron linac rate	f_{linac}	Hz	10	10	10	5	5	4
Positron bunch population	N_+	$\times 10^{10}$	2	2	2	2	2	2

Low-power option (1312 bunches):
→ Smaller circumference damping ring (6.4 km → 3.2 km)

Low E_{cm} running luminosity improved (over original SB2009) with 10Hz alternative pulse operation mode for e+ production → const. charge:
→ Requires shorter damping time in DR
→ 50% duty cycle DR operation

DR Implications

1 TeV Upgrade:
→ assumes re-establishment of full RDR bunch number (2625)

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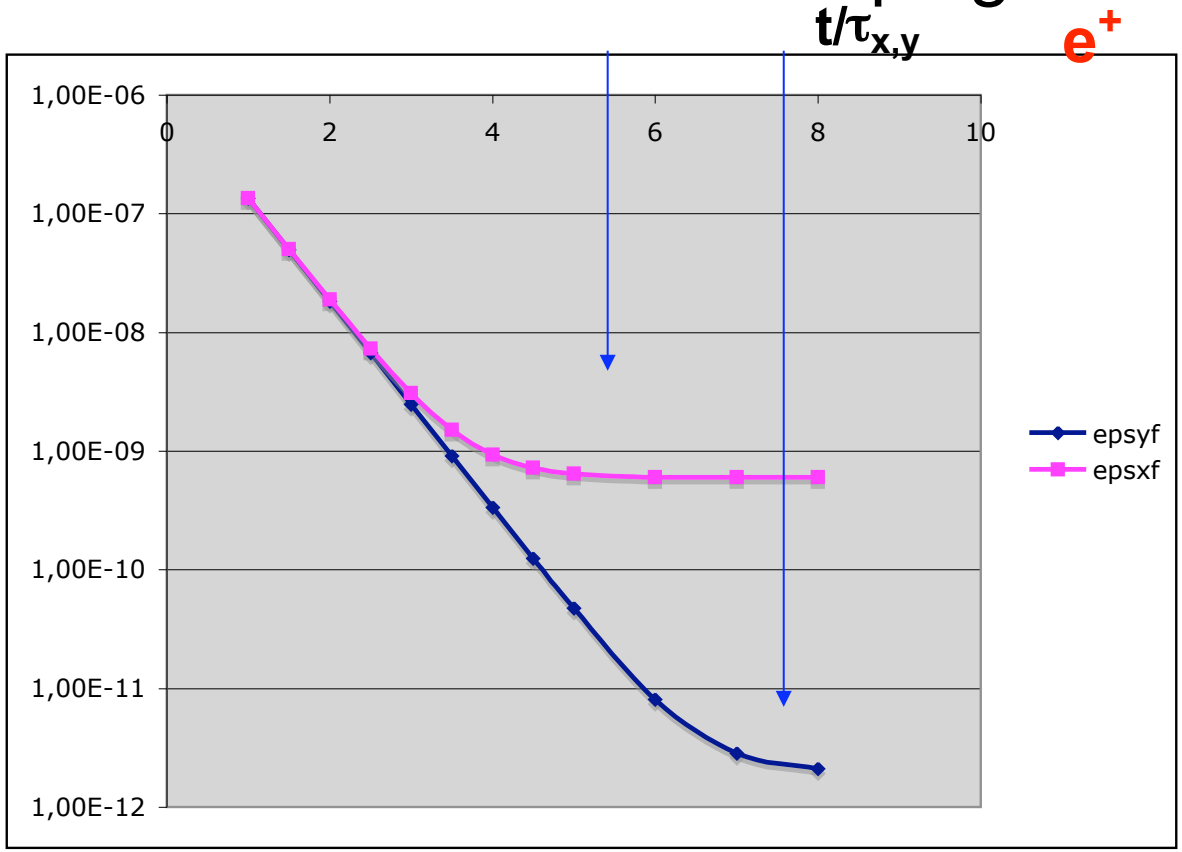
10 Hz Operation

Positron emittance damping



~8 damping times are needed for the vertical emittance

5 Hz ⇒ $\tau_{x,y} \leq 26$ ms

10 Hz ⇒ $\tau_{x,y} \leq 13$ ms

SB2009 - 3.2 km ring

DR Parameters for positron ring
Low power – 5 and 10 Hz operation

	5 Hz e^+	10 Hz e^+
Circumference (m)	3238	3238
Number of bunches	1305	1305
N part./bunch	2×10^{10}	2×10^{10}
Damping time τ_x (ms)	24	13
Emittance ε_x (nm)	0.53	0.57
Emittance ε_y (pm)	2	2
Energy loss/turn (MeV)	4.5	8.4
Energy spread	1.2×10^{-3}	1.5×10^{-3}
Bunch length (mm)	6	6
RF Voltage (MV)	7.5	13.4
Average current (A)	0.39	0.39
Beam Power (MW)	1.8	3.3
N. of RF cavities	6	12
B wiggler (T)	1.6	2.4
Wiggler period (m)	0.4	0.28
Wiggler length (m)	2.45	1.72
Total wiggler length (m)	78	75
Number of wigglers	32	44

8 damping times needed to reduce vertical e^+ emittance

5 Hz ⇒ $\tau_{x,y} \leq 26$ ms

10 Hz ⇒ $\tau_{x,y} \leq 13$ ms

Increase wiggler field

Reduce wiggler period

Double the number of RF cavities

DCO4 RF Parameters

	DCO4 High Power 5Hz	DCO4 High Power 10Hz	
Particle	e^+/e^-	e^+	e^-
Circumference (m)	6476	6476	6476
N bunches	2610	2610	2610
Damping time τ_x (ms)	21	13	18
Energy loss/turn (MeV)	10.2	16.6	12.0
RF Voltage (MV)	21	32	24
Average current (A)	0.388	0.388	0.388
Beam Power (MW)	3.97	6.42	4.66
N. of RF cavities	16	24	18
Voltage/cavity (MV)	1.31	1.33	1.33
Power/cavity (kW)	248	267	260
Klystron/ring	4	6	6
Power/klystron (kW)	992	1070	780

SB2009 RF Parameters

	SB2009 Low P. 5Hz	SB2009 High P. 5Hz	SB2009 Low Power 10Hz		SB2009 High Power 10Hz	
Particle	e^+/e^-	e^+/e^-	e^+	e^-	e^+	e^-
Circumference (m)	3238	3238	3238	3238	3238	3238
N bunches	1305	2610	1305	1305	2610	2610
Damp. time τ_x (ms)	24	24	13	18	13	18
En. loss/turn (MeV)	4.5	4.5	8.4	6.2	8.4	6.2
RF Voltage (MV)	7.5	7.5	13.4	10.4	13.4	10.4
Average curr. (A)	0.39	0.78	0.39	0.39	.78	.78
Beam Power (MW)	1.76	3.51	3.28	2.42	6.55	4.84
N. of RF cavities	6	12	9	9	18	15
Power/cavity (kW)	293	292	364	269	363	322
Voltage/cav. (MV)	1.25	0.63	1.5	1.16	0.74	0.70
Klystron/ring	2	4	3	3	6	5
Power/klystron (kW)	880	880	1093	807	1090	970

RF Parameters

Summary for 2 rings (e^+ and e^-)

	SB2009				DCO4	
	Low P. 5Hz	High P. 5Hz	Low P. 10Hz	High P. 10Hz	High P. 5Hz	High P. 10Hz
Circumf. (m)	3238	3238	3238	3238	6476	6476
N bunches	1305	2610	1305	2610	2610	2610
Damp. time τ_x (ms)	24	24	13/18	13/18	21	13/18
Num. of RF cavities (2 rings)	**12**	**24**	**18**	**33**	**32**	**42**
Power/cavity (kW)	**293**	**292**	**364/269**	**363/322**	**248**	**267/260**
Voltage/cavity (MV)	**1.25**	**0.63**	**1.5/1.16**	**0.74/070**	**1.31**	**1.33**
Tot. numb. of kly's	**4**	**8**	**6**	**11**	**8**	**12**

50% Duty Cycle

- e^- linac runs at 10 Hz alternating:
  - **1 pulse for positron production and injection into e^+ DR**
  - **1 pulse for collisions at 5 Hz**
- e^+ DR is empty half of the time (100 ms):
  - **Beam injected in ~1ms**
  - **Beam stored for 100 ms for damping**
  - **Beam extracted in ~1 ms**
- Main Concern:
  - **large beam loading variation in a very short time (1 ms)**
  - **implications on RF system and beam stability**
- WG2 RF Session, Wednesday 16:00: Discussion to get advice from RF experts in preparation of BAW2 meeting, SLAC 18-22 Jan 2011
  - **Feasible? Needs more R&D? Cost implications?**

Back-up

Alternate 10Hz Cycle DR RF Operation

- In consultation with Sergey Belomestnykh (Cornell)
- Normal Operations:
  - **Reactive beam loading is large**
  - **Cancelled by appropriate cavity de-tuning**
  - **Beam-loaded cavity then represents a matched load for the klystron**
- Issues
  - **With no beam, the cavity is detuned far from resonance**
  - **For DR parameters, ~365kW would be required to maintain the voltage in each cavity**
  - **This exceeds available power from klystron in our present specification**
- Potential Solutions
  - **Fast Frequency Tuner with either feedforward or feedback system ⇨ Tune cavity as beam is injected/ extracted**
    - Tristan utilizes a piezo tuner on their SCRF cavities
    - CESR cryomodules also equipped with piezos for microphonics (not enough range for large detuning)
    - Requires an R&D effort to implement for this application, but millisecond timescale seems quite reasonable.
  - **Fast Waveguide Tuner**
    - Under development at several laboratories, but not presently used in operations
    - Probably not sufficient by itself as ower requirements will still be high
    - May be useful in conjunction with a Fast Frequency Tuner (particularly if frequency tuner has limited range)
  - **Other?**
- Conclusion: Significant R&D will be required for the alternating 10Hz scenario ***OR*** a significant cost increase to deal with the additional power overhead