Report from Frascati ILCDR'07 meeting
(March 5~7, 2007, INFN)

Guoxing Xia
DESY
March 16, 2007

ILCDR'07 goals

About the meeting…

- ~30 attendees,
- ~25 talks
- Three very high priority issues were discussed (lattice design, low emittance tuning and ion effects)
- Successful meeting

ILCDR'07 goals…

I. Review the changes required to the present lattice design, and outline a plan leading to an "optimised" lattice for the EDR (including possible alternatives to the baseline).

II. Review the techniques presently used for low-emittance tuning.
Identify the strengths and weaknesses of the various techniques, and the requirements for lattice design, alignment, instrumentation etc.
Discuss possible alternative tuning procedures, and outline a plan leading to a demonstration of the required 2 pm vertical emittance.

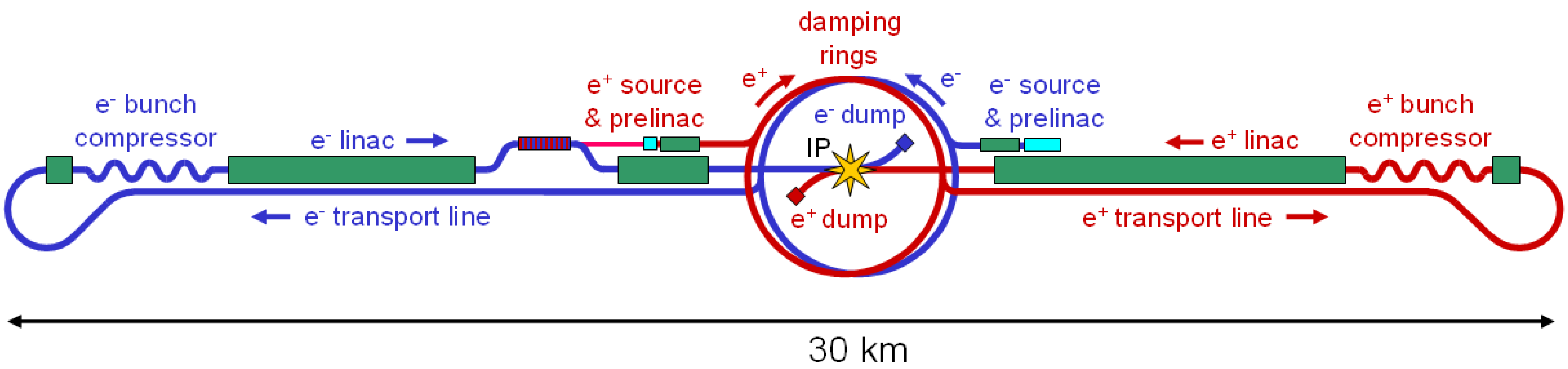
III. Discuss the present status of knowledge of ion effects, particularly fast ion instability in the regime of the ILC damping rings.
Specify the design requirements for avoiding performance limitations from ion effects in the ILC damping rings.
Describe the experimental studies required to validate predictions of ion effects in the ILC damping rings, and outline a plan for performing such studies.

Meeting agenda

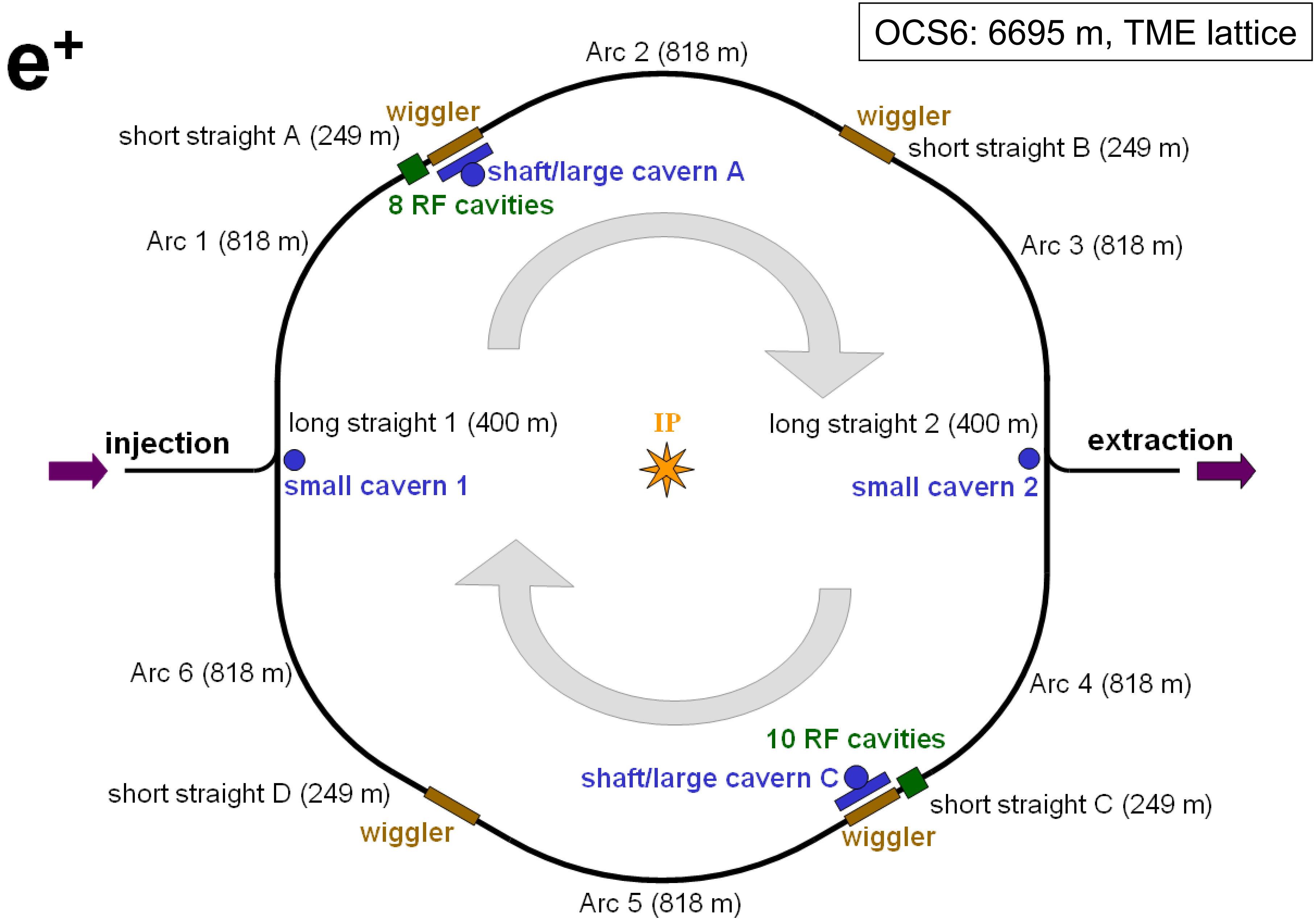
	Monday, 5 March		Tuesday, 6 March		Wednesday, 7 March
09:30	Introduction	Wolski		Emery 2	
10:00	Lattice Design	Sun ☎	Low Emittance Tuning	Sagan	Discussion/Summary Preps
10:30		Emery 1		Cai	
11:00	Coffee		Coffee		Coffee
11:30		Preger		Milardi	
12:00	Lattice Design	Palmer 1	Low Emittance Tuning	Kubo	Summaries
12:30		Bettoni		Jones	
13:00		Mitchell	Ion Effects	Xia	
13:30	Lunch		Lunch		Lunch/End
15:00		Naito		Lee	
15:30	Lattice Design	Rubin 1	Ion Effects	Rubin 2	
16:00		Biagini		Urakawa	
16:30	Coffee		Coffee		
17:00		Palmer 2		Drago	
17:30	Lattice Design		Ion Effects	Byrd/Venturini	
18:00		Reichel ☎		Wang ☎	
18:30	End		End		

20:00		Workshop Dinner	

The RDR configuration



- One electron and one positron ring in a shared tunnel around the Interaction Region.
- 5 GeV beam energy.
- "OCS6" lattice:
  - 6695 m circumference (harmonic number 14516).
  - 24 MV, 650 MHz RF (gives natural bunch length of 9 mm).
  - Momentum compaction factor 4.2×10^{-4}.


e+
OCS6: 6695 m, TME lattice
Arc 2 (818 m)
wiggler
short straight A (249 m)
wiggler
short straight B (249 m)
shaft/large cavern A
8 RF cavities
Arc 1 (818 m)
Arc 3 (818 m)
injection
long straight 1 (400 m)
IP
long straight 2 (400 m)
extraction
small cavern 1
small cavern 2
Arc 6 (818 m)
Arc 4 (818 m)
10 RF cavities
shaft/large cavern C
short straight D (249 m)
short straight C (249 m)
wiggler
wiggler
Arc 5 (818 m)

Evolution of the configuration and design

- Throughout 2006:
- Continuing studies, including more detailed cost estimates, led to a number of configuration and design changes:
  - 6695 m circumference (h = 14516) to satisfy timing constraints.
  - Eliminated second positron damping ring.
  - Reduced the number of straight sections from 8 to 6.
  - Co-located two damping rings in a single, central tunnel.
  - Reduced RF voltage by increasing natural bunch length to 9 mm.
- How do we optimize the lattice for good dynamical performance and low cost?
  - Beam dynamics considerations include:
    - Dynamic aperture
    - Sensitivity to errors; low-emittance tuning
    - Sensitivity to collective effects, including: impedance-driven instabilities, ion effects, electron cloud, intrabeam scattering, etc.
  - Affects choice of momentum compaction factor etc.

Highlights on lattice design

- Lattice Design Updates
  - FODO lattice from Y. Sun
    - Reduction in straights and magnets relative to OCS6
    - α_c in 2-6x10^{-4} range possible
  - TME lattice from L.Emery
    - Discussion momentum compaction adjustment
    - Chicane for circumference adjustment
  - FMA analysis on OCS6 and predessor from I. Reichel
    - Better operating points can be found

Wiggler updates

Permanent magnet hybrid update from M.Preger

Better field quality

Detailed evaluation and control of octupole contributions

Optimized superconducting wiggler from M. Palmer

Shorter period and higher field?

Cost reductions relative to RDR estimate

DAFNE wiggler optimization update from S. Bettoni

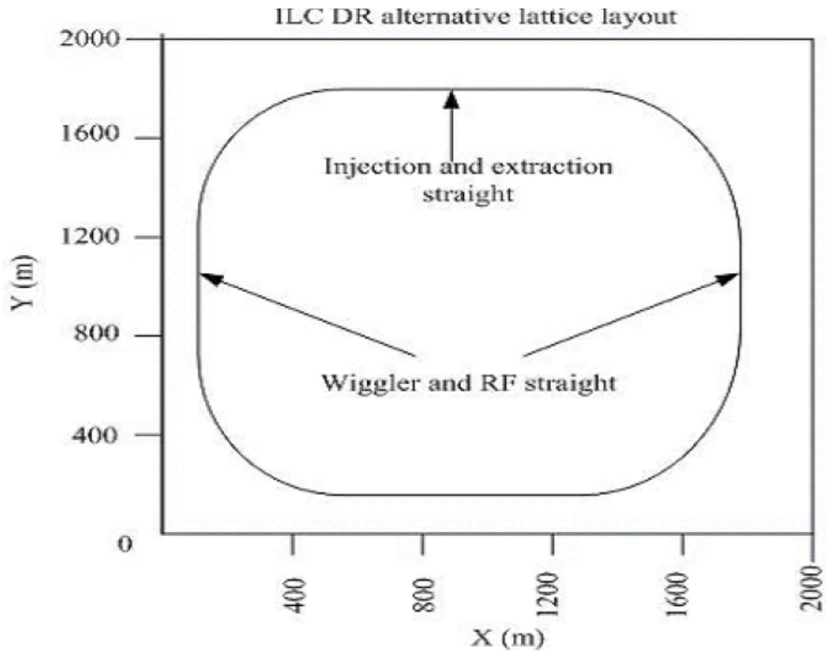
Significant parameter improvement shown

Others

ATF kicker update from T.Naito

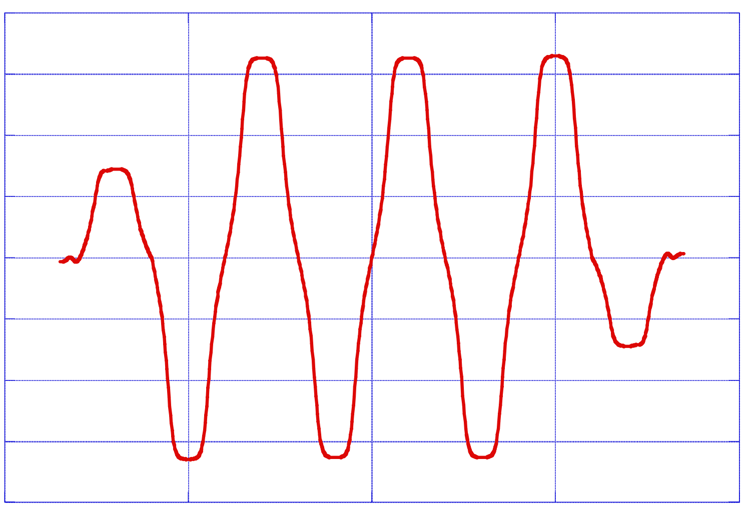
Alternative injection/extraction region design from D. Rubin

Y.Sun



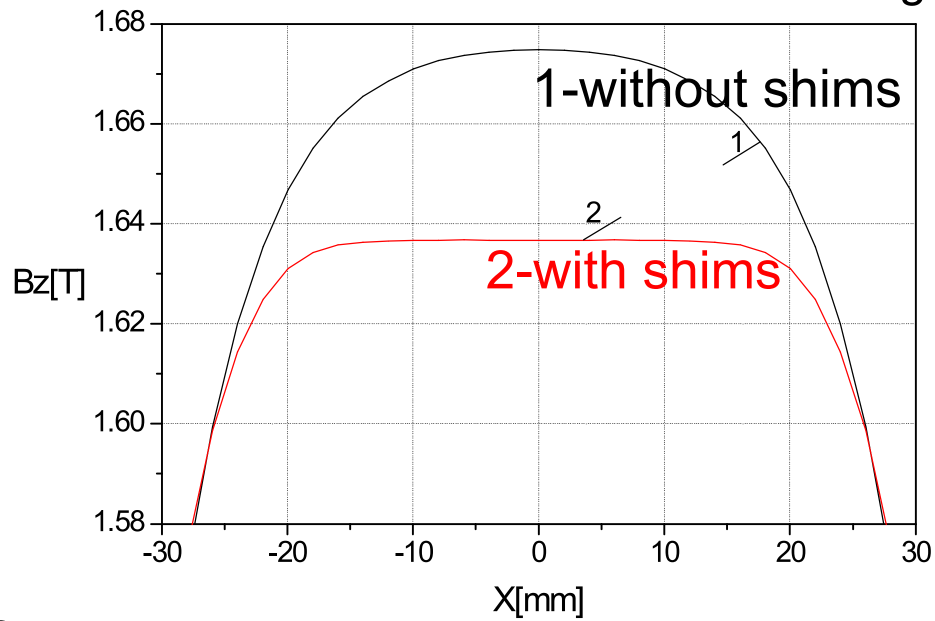
FODO DR layout for ILC

	OCS6	*FODO2*
Circumference [m]	6695	6695
Arc cell	TME	FODO
Phase advance of arc cell	90/90 (108/90)	72/72 (90/90)
Momentum compaction [10^{-4}]	4/2	4/2
Quadrupoles in all	**682**	**468**
Dipoles in all	114 × **6** m + 12 × **3** m	368 × **2** m
Sextupoles in all	**480**	**368**
Number of wiggler straights	**4**	**2**



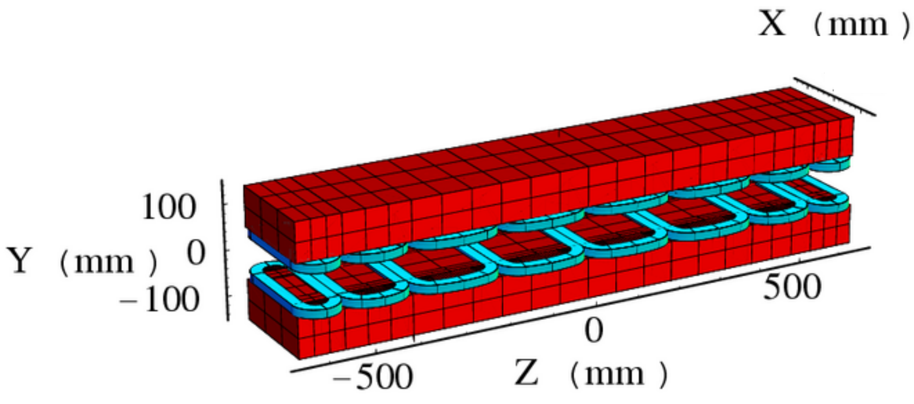
Vertical field component on wiggler axis

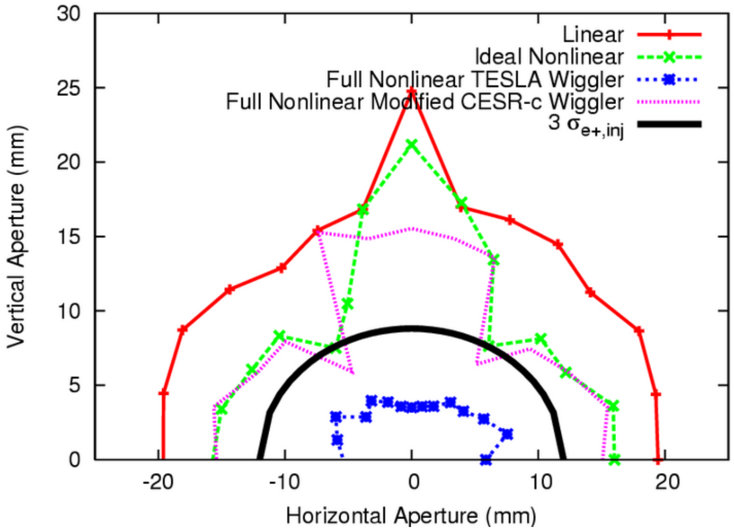
Miro Preger



Shimming results

(M. Palmer)



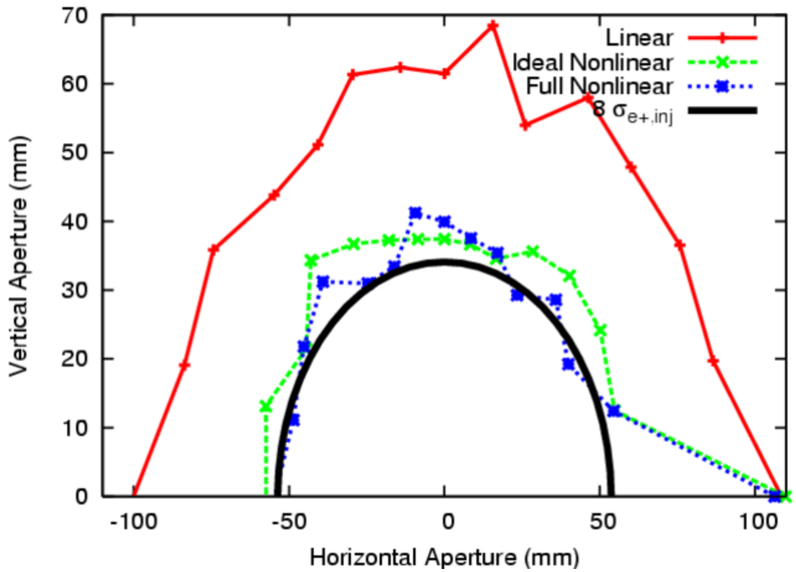


(Wiggler info)

https://wiki.lepp.cornell.edu/ilc/bin/view/Public/CesrTA/WigglerInfo

Superferric ILC-Optimized CESR-c Wiggler

12 poles
Period = 32 cm
Length = 1.68 m
By,peak = 1.95 T
Gap = 86 mm
Width = 238 mm
I = 141 A
tdamp = 26.4 ms
ex,rad = 0.56 nm·rad
sd = 0.13 %



Low emittance tuning

- The vertical emittance of 4.5 pm achieved in KEK-ATF is still the lowest that has been achieved anywhere.
- The ILC damping rings are specified for a vertical emittance < 2 pm… so there is still some way to go.
- Considerations and implications of low-emittance tuning:
  - The vertical emittance is an important performance metric for the damping rings; but the scaling of machine luminosity with extracted emittance is not very strong.
  - The "ease of achieving" 2 pm vertical emittance will depend on details of the lattice design: magnet strengths and locations, machine tunes, lattice functions, etc. How do we compare 2 pm in ATF, for example, with the goal of 2 pm in the ILC damping rings?
  - To what extent do we trust simulations? The real world has many aspects that simulations do not usually include, for example: BPM dependence on current, random failures of BPMs and correctors…
  - Low emittance tuning is coupled to lattice design (sensitivity to alignment errors) and to the vacuum system design (BPM performance).

Highlights on low emittance tuning

ANL aims to demonstrate $\varepsilon y/\varepsilon x \leq 1/400$

should give εy of 2 pm

Combination of orbit, vertical dispersion, coupling correction is needed

reaching $|Dy| \leq 2$ mm suffices at APS

use harmonic SK knobs for coupling control

Fast and reliable size measurement at 2 pm not easily done

- CESR-TA can test both e^- and e^+
- Measure coupling and phase by shaking beam at betatron tune
  - look at bpm response
  - get good correction of phases and coupling
- Proposed bpm upgrade will speed up measurement
- Challenge to measure the small beam size (laser wire; x-ray imager, very fast $\Rightarrow$ bunch-by-bunch)
- **New ATF bpms will allow progress toward getting 2 pm vertical emittance (bpms' tests are ongoing in ATF DR)**

permit better response matrix optics correction and BBA data

  - **use improved laser wire for measurements**
- **DAΦNE saw vertical beam size growth due to clearing electrode impedance**
  - **must test "cures" to make sure they are not severe**

Ion Effects

- •Effects consistent with the Fast Ion Instability have been observed in several storage rings (ALS, PLS, ATF, KEKB, ESRF, ATF etc)…
- •…but we cannot predict with confidence the impact of ion effects on the performance of the ILC electron damping ring.
  - What will be the residual gas pressure and composition in the vacuum chamber, as functions of time (conditioning) and position?
  - How will the beam interact with the ions? What will be the impact on performance of the damping rings under various conditions?
  - To avoid performance limitations from ion effects, what should be the specifications for:
    - the lattice (optics);
    - vacuum system;
    - bunch-by-bunch feedback system;
    - fill pattern (bunch charge, bunch spacing, and gaps).
  - There is a lack of quantitative data with which we can benchmark the simulation codes in the appropriate (low emittance) regime: further studies will be very important.

Linear theory of FII

Critical mass

$$A_{crit} = \frac{N_b L_{sep} r_p}{2\sigma_y(\sigma_x + \sigma_y)}$$

Incoherent tune shift

$$\Delta Q_{ion} \approx \frac{N_b n_b r_e C}{\pi\sqrt{(\gamma\varepsilon_x)(\gamma\varepsilon_y)}}\left(\frac{\sigma_{ion} p}{k_B T}\right)$$

The exponential vertical instability rise time

$$\tau_{FII} \approx \frac{\gamma\sigma_x\sigma_y}{N_b n_b c r_e \beta_y \sigma_{ion}}\left(\frac{k_B T}{p}\right)\sqrt{\frac{8}{\pi}}\left(\frac{\Delta f_i}{f_i}\right)$$

Estimation of FII in OCS6 DR

# of bunches	bunch spacing	bunch intensity	critical mass	incoh. tune shift at train end	exponential rise time at train end
2625	6 ns	2.0E10	5.4	0.0037	0.005 s
5534	3 ns	1.0E10	1.4	0.0039	0.004 s

Partial pressure of CO is 0.15nTorr; one long bunch train and 30% relative ion frequency spread are assumed here

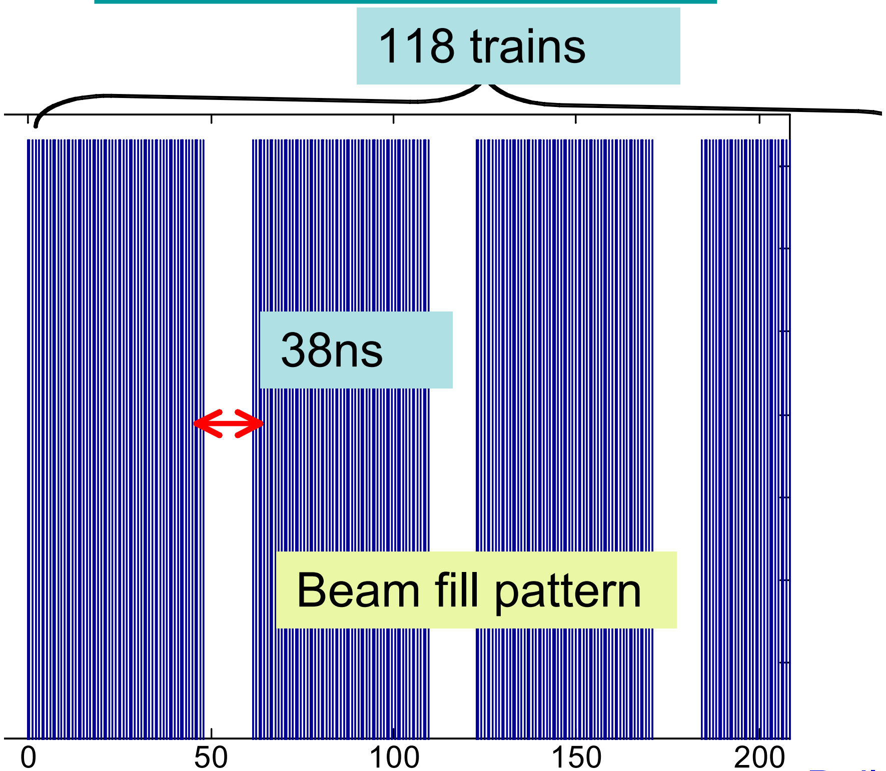
Cures of FII

- Traditional methods to clear ions from electron beam include electrostatic electrodes, beam shaking and gaps in the bunch trains
- Clearing electrodes may increase the chamber impedance
- Beam shaking requires dedicated device to drive the ions and beam and may cause coherent transverse instabilities
- Multi-train fill pattern with regular gaps is an efficient and simple way to remedy of FII
- Bunch by bunch feedback system

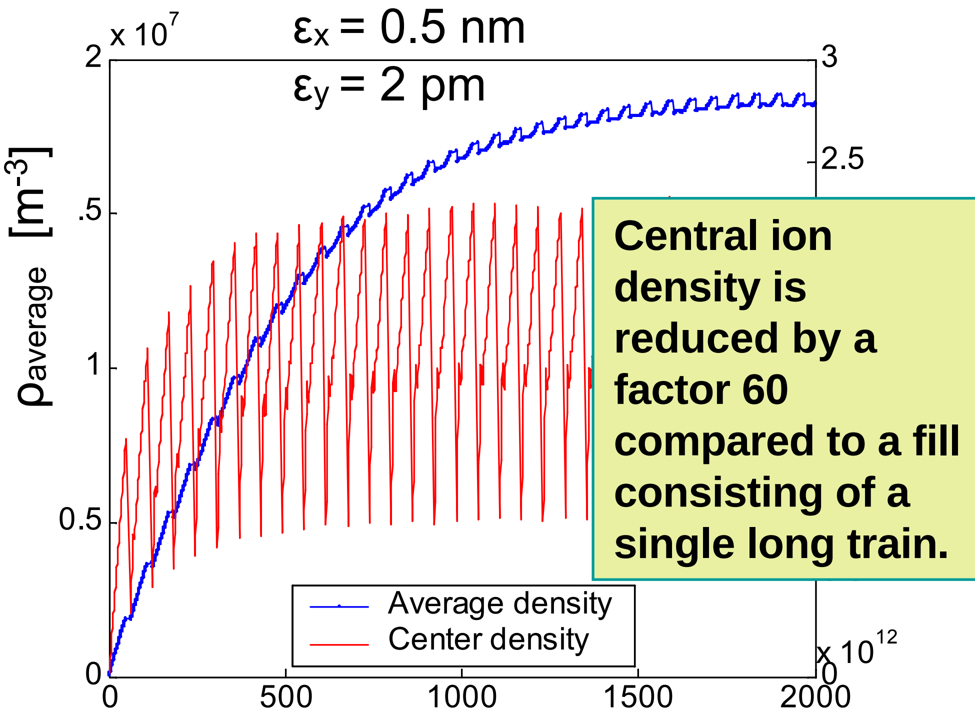
L. Wang

Mini-train effect

$$\mathrm{IRF} = \frac{1}{N_{train}} \frac{1}{1 - \exp(-\tau_{gap} / \tau_{ions})}$$



Simulation results on effect of train gaps for ILC DR



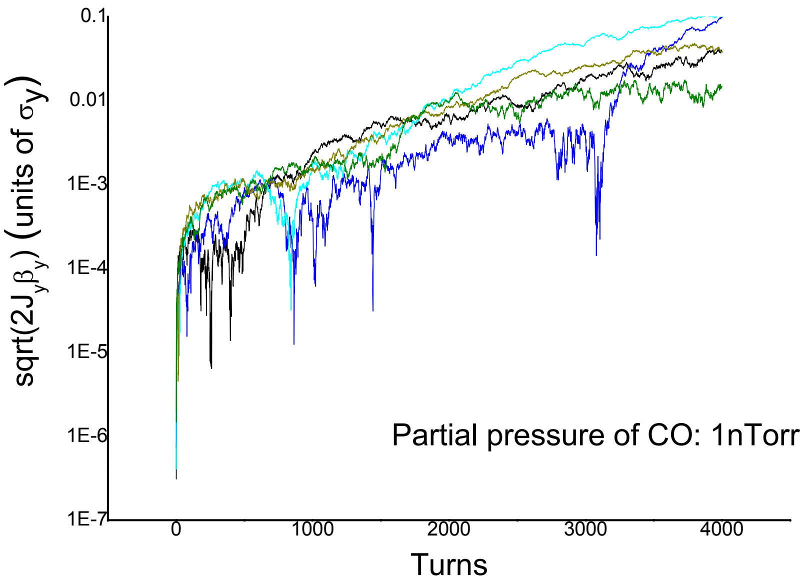
Central ion density is reduced by a factor 60 compared to a fill consisting of a single long train.

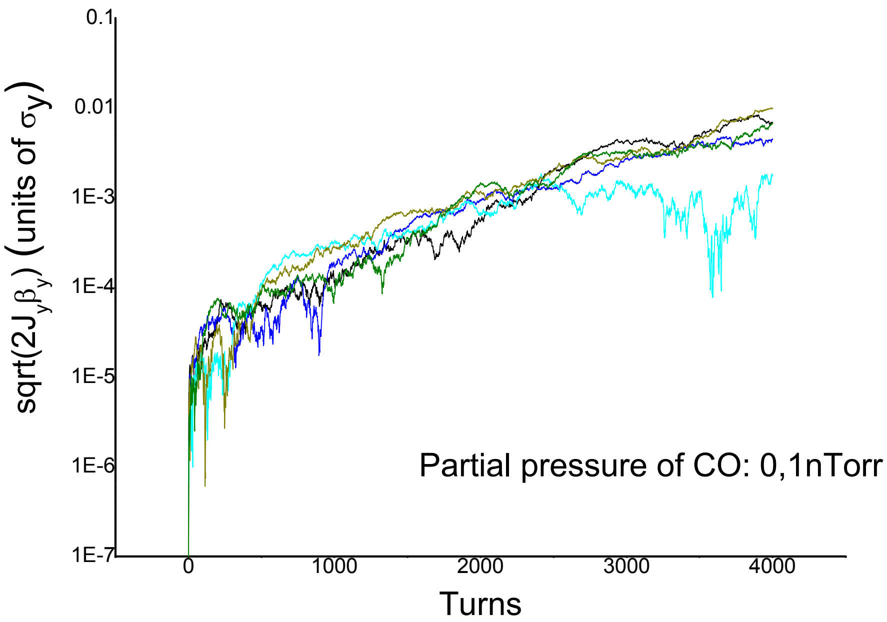
Build-up of CO+ ion cloud at extraction (with equilibrium emittance). The total number of bunches is 5782, P=1 nTorr. IRF=0.017 in this case!

G.Xia

Simulation of FII

Vertical oscillation





Oscillation amplitude in units of *σy* as a function of number of turns

Future R&D plan for FII

- A proposal has been submitted to TB of ATF international collaboration meeting
- A plan on experimental studies of FII in ATF DR is ongoing (see Junji's presentation)

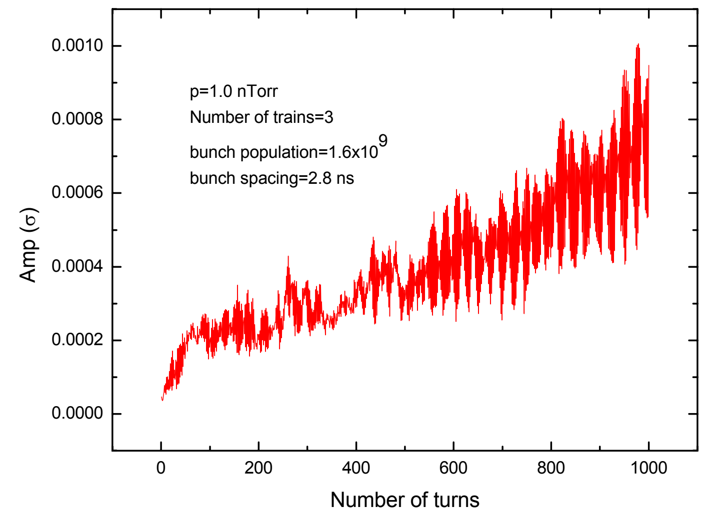
- Goals of FII experiment:
  - Distinguish the two ion effects: beam size blow-up and dipole instability.
  - Quantify the beam instability growth time, tune shift and vertical emittance growth. Based on the linear model, the growth rate is proportional to the ion density (the related parameters include gas species, vacuum pressure, average beam line density, emittance, betatron functions and beam fill pattern).
  - Flatness of beam and its effect on FII growth.
  - Provide enough experimental data to benchmark against simulation results.
  - Check effectiveness of feedback system to suppress the FII

G.Xia

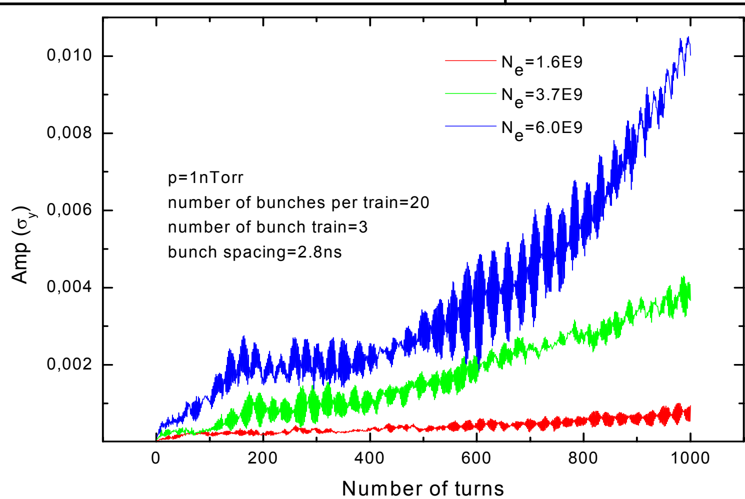
FII in ATFDR

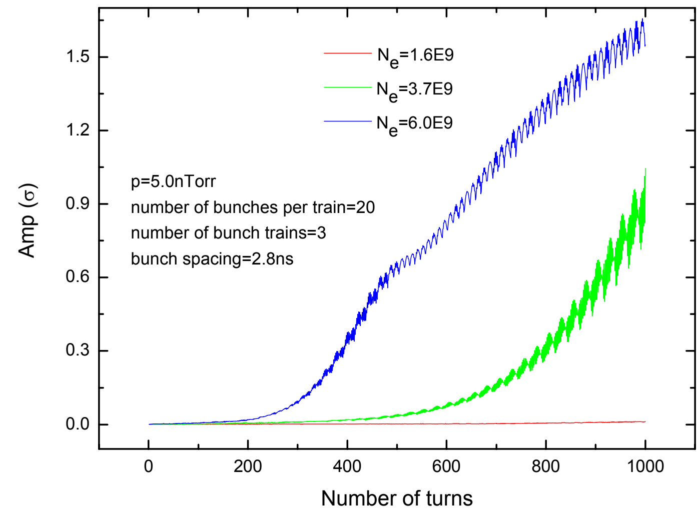
Parameters of ATF damping ring

Beam energy [GeV]	1.28
Circumference [m]	138.6
Harmonic number	330
Momentum compaction	2.14E-3
Bunch population [$\times 10^9$]	1.6, 3.7 and 6.0
Bunch length [mm]	6
Energy spread	0.06%
Horizontal emittance [mrad]	1.4E-9
Vertical emittance [mrad]	1.5E-11
Vacuum pressure [nTorr]	1 and 5



Fast beam ion insatbility in ATF Damping Ring





One long bunch train is used in simulation ! (The 60th bunch is recorded here)

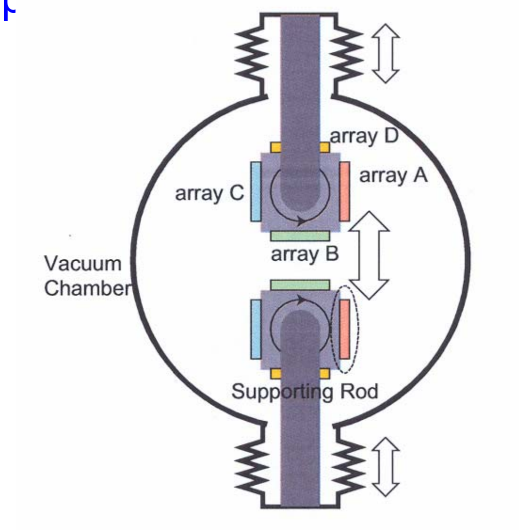
Beam centroid oscillation amplitude with respect to number of turns

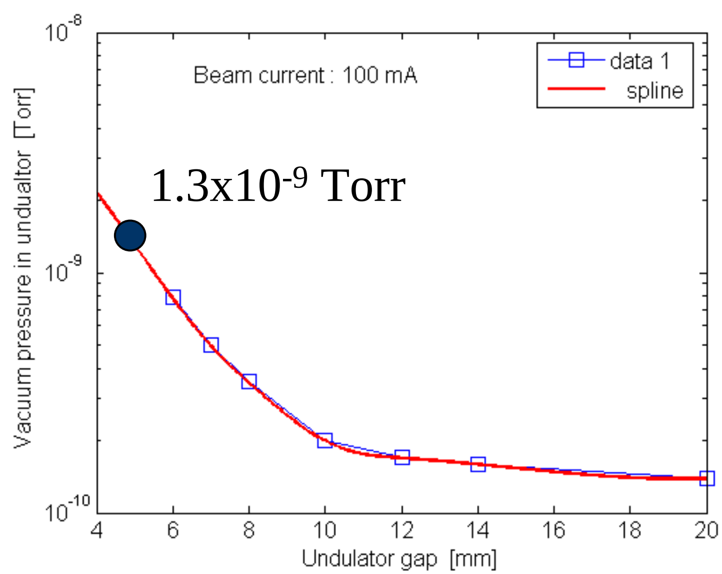
FII experiments in PLS

- Due to the revived interests in FII, we planned to do more experiments.
- PLS has a Revolver In-Vacuum X-ray UNdulator (RIVXUN). The minimum gap is 5 mm. The length is 1.2 m
- If the beam orbit is distorted when the RIVXUN gap is lowered, the vacuum pressure of the undulator area is increased up to one order of magnitude higher. (Undulator SR hits internal structure).
- It is possible to control the local pressure step by step

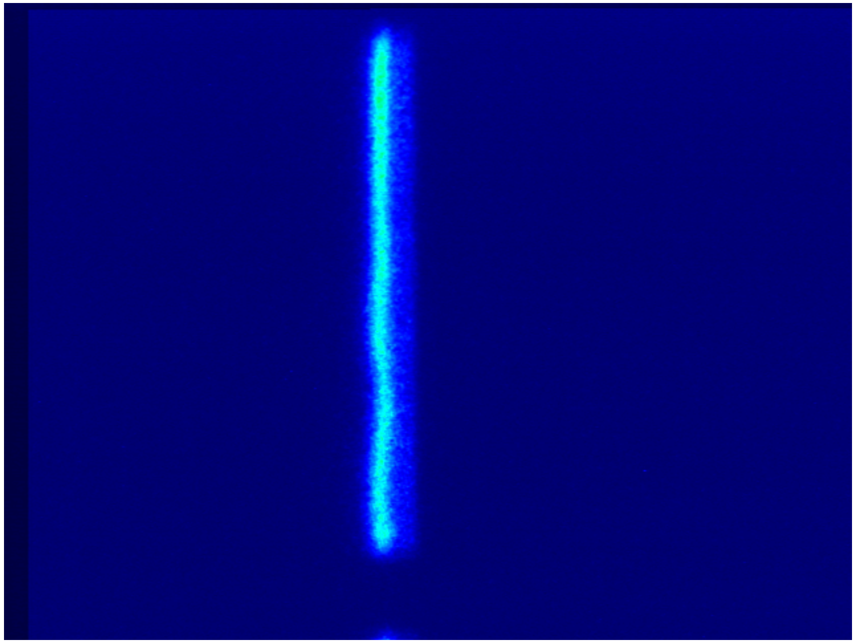
The Revolver vacuum pressure increased by 10 times when the gap was changed from 20mm to 6mm.

This local high vacuum pressure gives rise to FBII

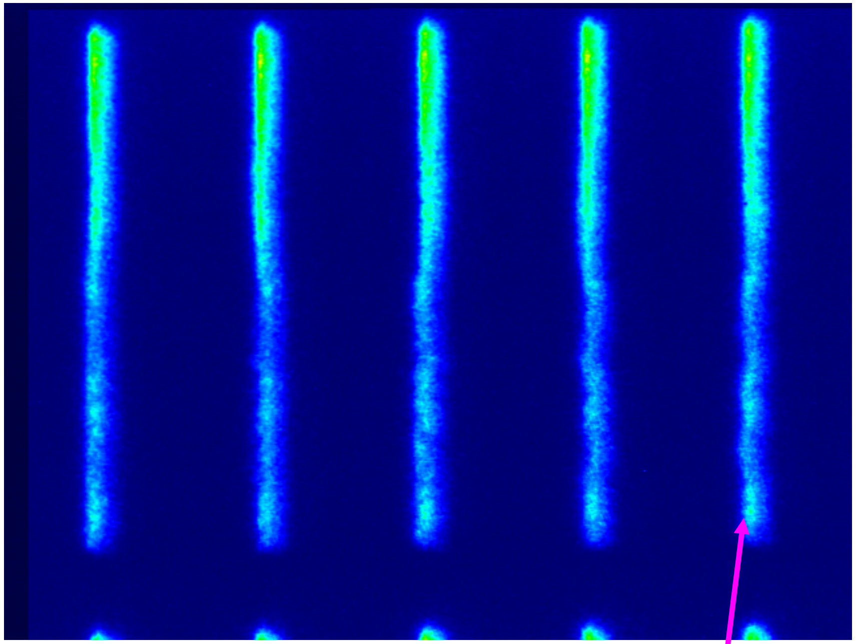




FII experiments in PLS



FBII at 6.4 mm Undulator Gap



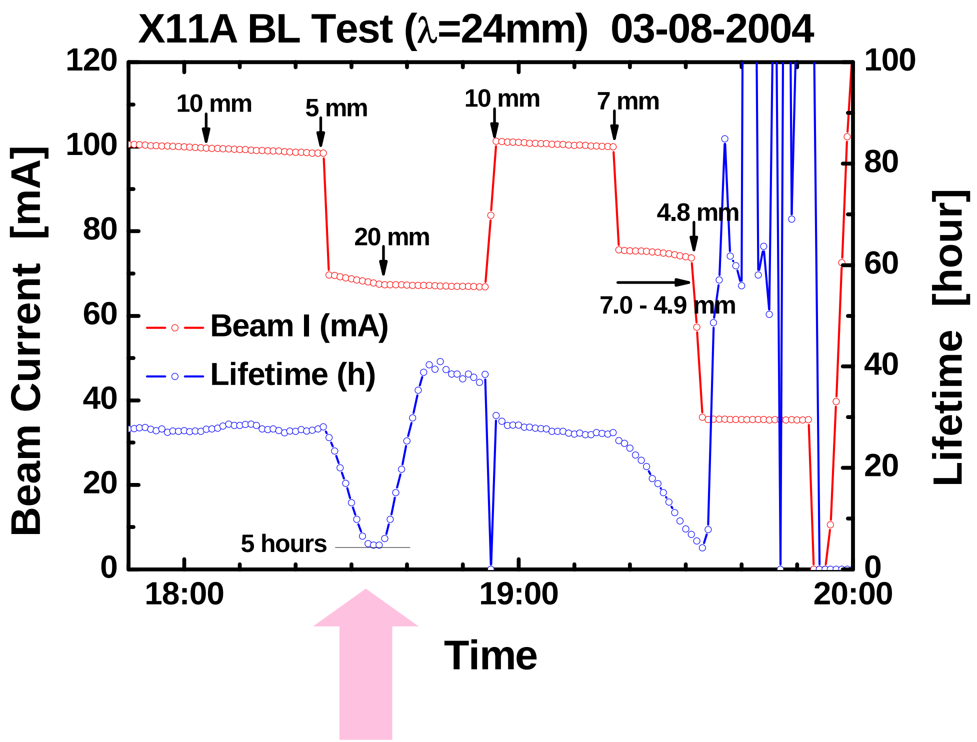
FBII at 5mm Undulator gap

Beam loss is mostly at the tail

The tail part of the bunch train is oscillating vertically.

Ion Instability during the undulator gap change

- Above gap 7mm, no instability and no lifetime change
- Below gap 6.4mm, transverse ion instability appeared and then beam loss occurred.



Beam loss occurred as well as lifetime decreased rapidly
~ 5 Hours Electron Beam Lifetime @ 5 mm Undulator Gap !

FII experiments in Cesr-TA

Cesr TA characteristics:

Flexible optics

- range of emittance, 2→ 200 nm
- positrons *and* electrons →

Flexible bunch spacings suitable for damping ring tests

Flexible energy range from 1.5 to 5.5 GeV

Instrumentation that provides for measurement of all dependencies

Beam parameters very similar to ILC damping ring.

Fast ion effects in CesrTA anticipated to be good indicator of fast ion effects in damping ring.

Cesr TA beam parameters

45 bunch train - 4ns spacing
σL ~9mm
2 e10 particles/bunch
Electrons or positrons
Pressure ~ 1nT

Linear FII theory estimation:

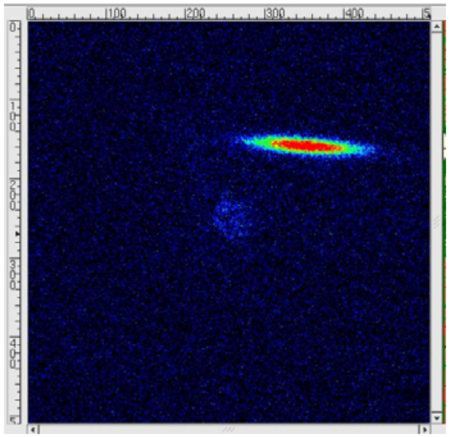
τmb ~ 1.2 turns
ΔQy ~ 0.04

Goals of the FII experiment in ATF

(according to two proposals from L. Wang, T. Raubenhimer and G. Xia, E. Elsen)

- Distinguish the two ion effects: beam size blow-up and dipole instability.
- Quantify the beam instability growth time and tune shift. The growth rate is related to the ion density (vacuum pressure, average beam line density, emittance, betatron function and so on).
- Quantify the bunch train gap effect
- Provide detailed data to benchmark simulations with experiment.

Fast ion instability studies at ATF (Feb, 2007)

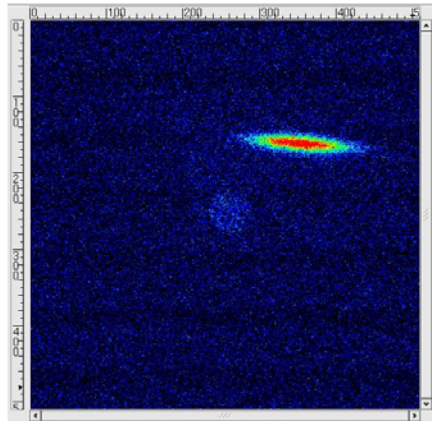


Single bunch/single train
2×10^{10} bunch/train

Ave: 2×10-7 Pa

X : 49.5±2.3 μm
Y : 8.1±0.7 μm

This profile was appeared on normal beam operation



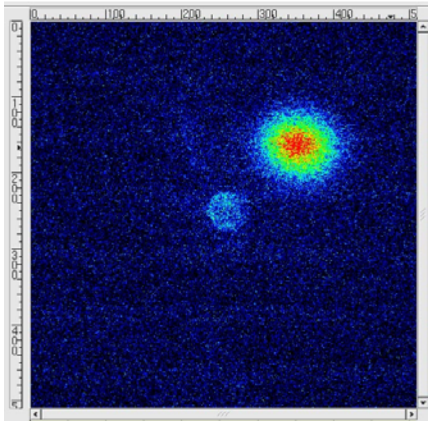
Single bunch/single train
2×1010 bunch/train

Ave: 2×10-6 Pa (Maybe)

X : 46.8±2.9 mm
Y : 8.4±0.8 mm

We have not found vertical beam size blow-up in this vacuum condition

Change 3train mode



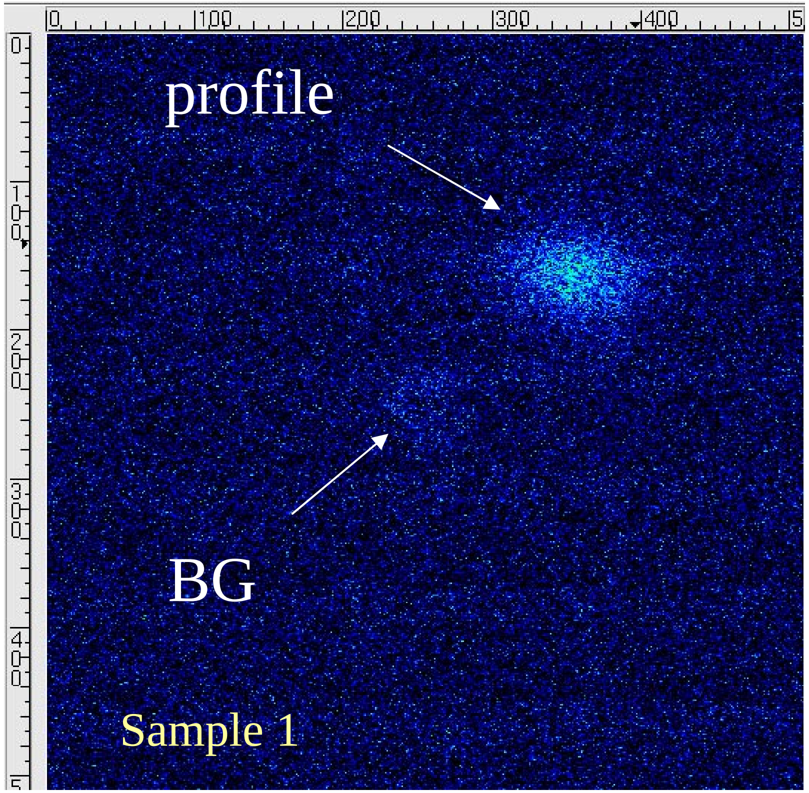
Vacuum : 1×10^{-5} Pa

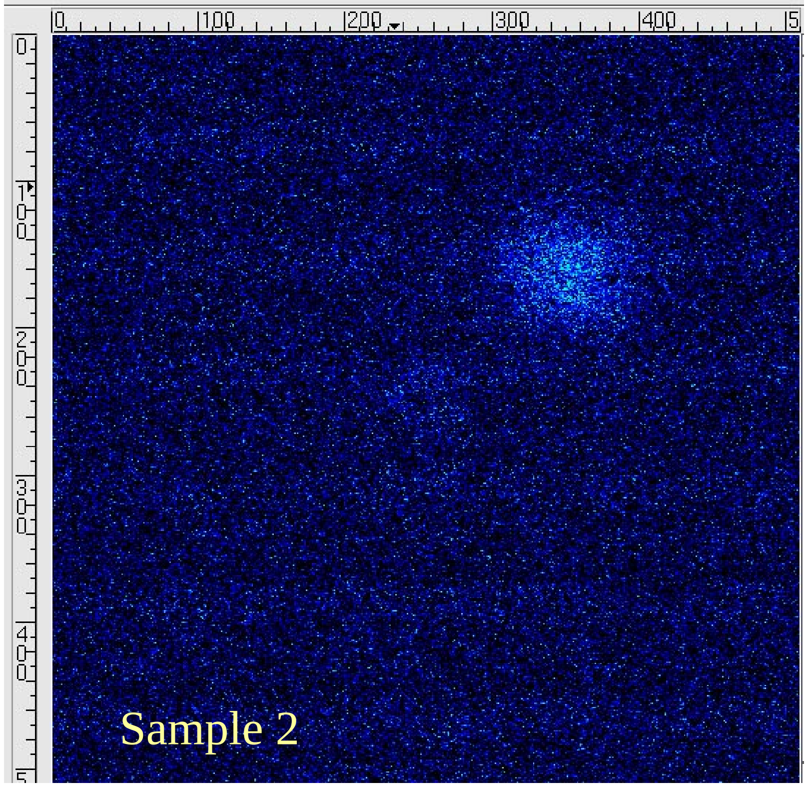
On a 3 train mode at 2×1010 /bunch, sudden large vertical beam blow-up was appeared. On XSR monitor, measured vertical beam size was not fixed on same sizes. We also see a vertical beam oscillation by turn-by-turn monitor.

J. Urakawa

Measured beam profile by XSR monitor on 3 train mode (2)

Vacuum : 2×10^{-6} Pa





On a 3 train mode at 2×10^9 /bunch (1/10 reduction than before), vertical beam blow up was also appeared. But this amplitude was reduced on XSR monitor. The measured beam sizes were 32.5±0.9 μm horizontally and 24.7±4.7 μm vertically. After changing single train, we did not find this vertical beam blow-up.

L. Wang

FII simulation in ILCDR

Effect of interaction points 1/2

Nb=5782, 1 IP

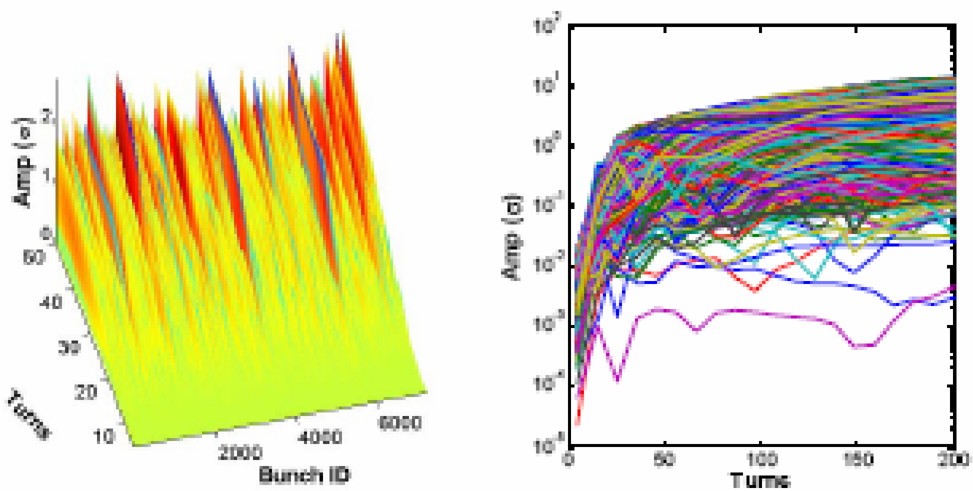
Average Co+ frequency fx/fy=12.36/ 53.97 [MHz]

Growth time in vertical =4turns

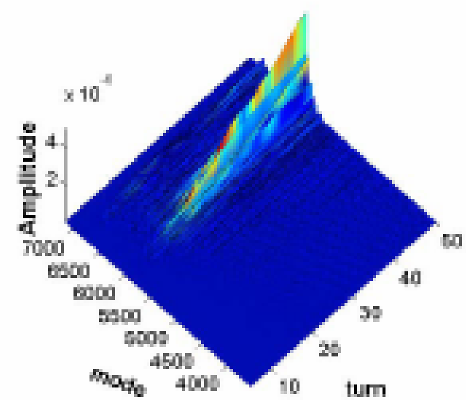
Growth time in horizontal =70turns

$$\frac{1}{\tau_e} \simeq \frac{c r_e \lambda_i \beta_y}{3\sqrt{2}\gamma\sigma_y\left(\sigma_x+\sigma_y\right)} \frac{1}{\left(\Delta\Omega_i\right)_{rms}}$$

Gennady Stupakov,et.al, KEK Proceedings 96-6, p. 243 (1996)



Bunch Vertical oscillation amplitude



Instability modes

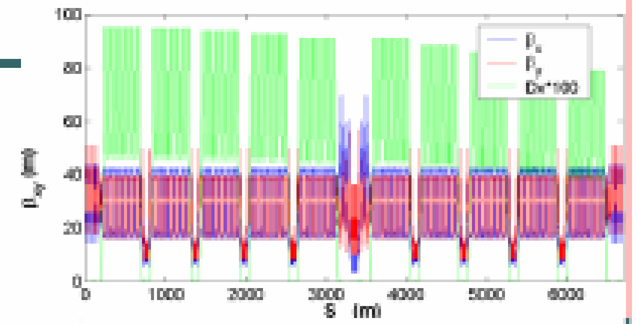
L. Wang

FII simulation in ILCDR

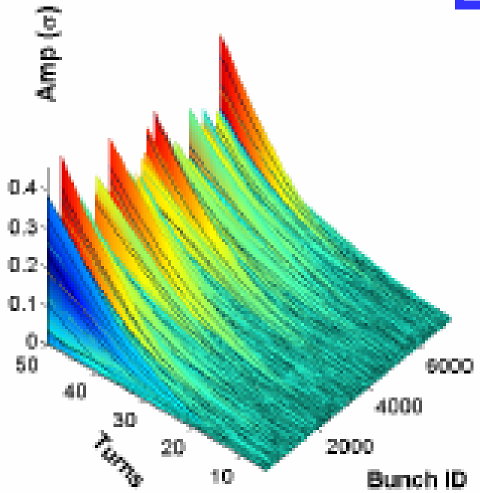
Effect of interaction points 2/2

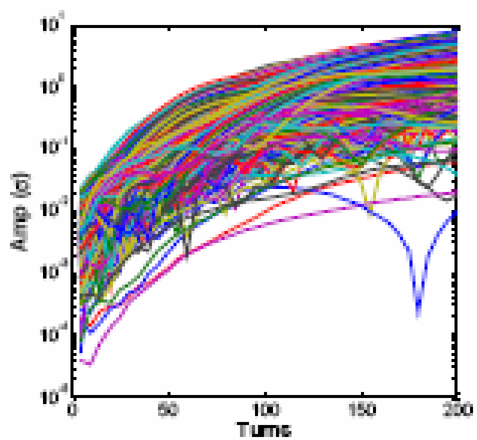
Nb=5782, N IPs

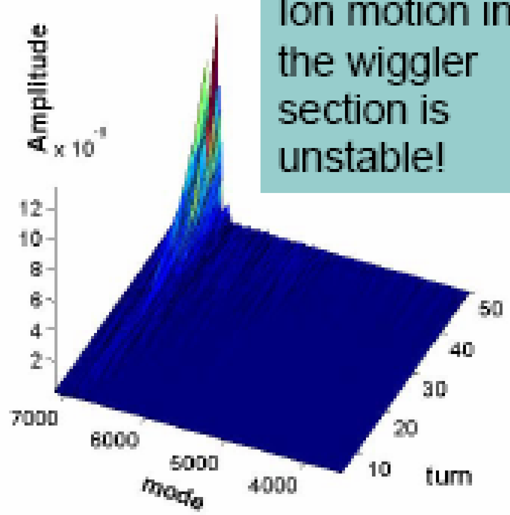
- Optics is included in the simulation
- Growth time in vertical Plane=13turns
- Simulation gives $(\Delta\Omega_i)_{rms} \approx 0.3$



Ion motion in the wiggler section is unstable!





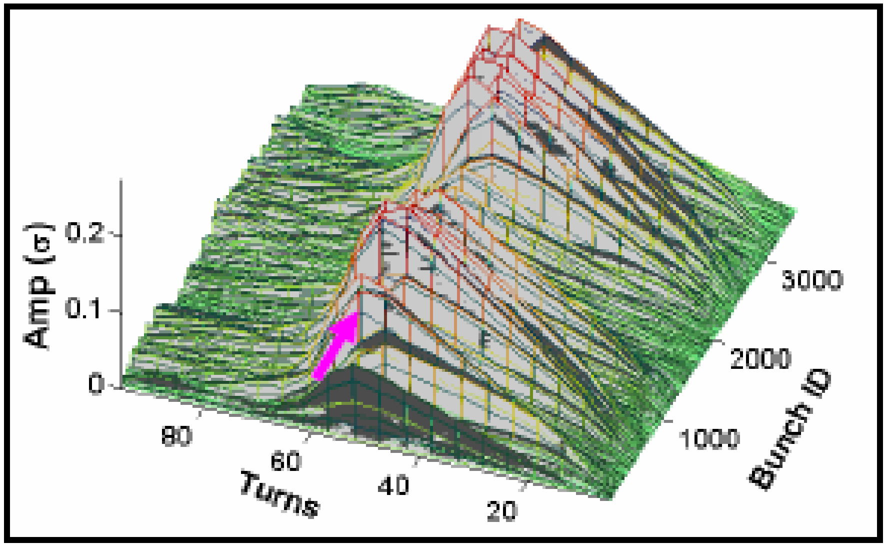


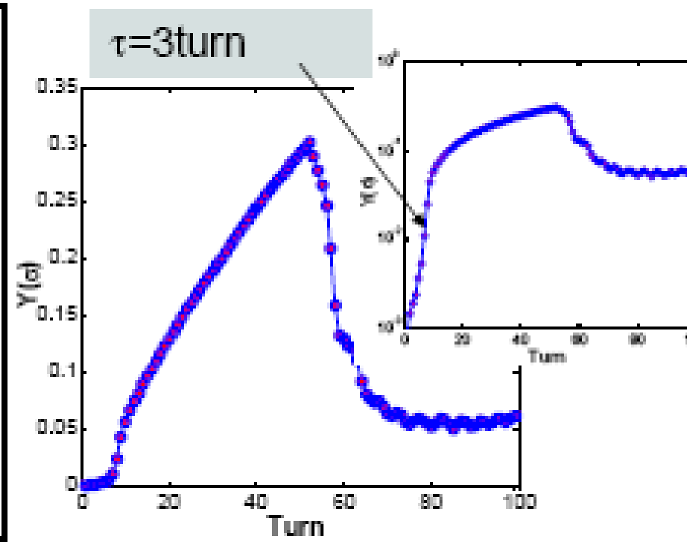
L. Wang

FII simulation in ILCDR

Can a slower feedback suppress the instability?

- A bunch-by-bunch feedback with a damping rate slower than the exponential growth rate may limit the oscillation amplitude in the exponential growth region (0.1~1sigma) by suppressing the linear oscillation.



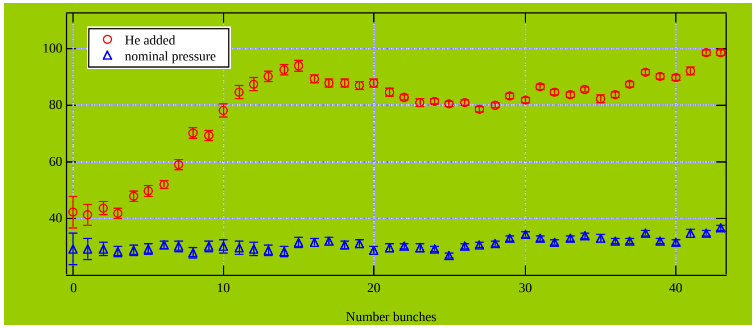


Feedback damping time 10 turn. It is turned on around 50th turn when the instability is already developed. (file:ocs_2767nb3devefdbk_amp)

J. Byrd

ALS experimental plan

- Demonstrate grow/damp technique under nominal conditions
  - evaluate resolution of turn-by-turn vertical motion
  - measure growth rates of conventional instabilities and optimize damping rate of TFB
- Re-establish low-emittance mode
  - record vertical beam size vs. emittance, bunch number, etc.
  - observe FBII via vertical spectrum and beam size
- establish conditions where TFB can control FBII; increase pressure if necessary
- measure FBII growth rates via grow/damp



Potential exists to characterize FBII in a situation which approaches ILC DR conditions

low vertical emittance

< 1 ntorr vacuum

Several experimental techniques available

beam size; time resolved via streak camera or gated CCD

turn-by-turn data analysis

sideband spectra

amplitude/phase shift along train

direct growth rate measurement via grow/damp to compare with simulation/theory

variable fill patterns

Summary

- Three very high priority issues were discussed in detail in Frascati meeting
- Still a lot of work to do in these three topics before we reach the EDR
- We are now calling for other critical issues to be stressed in the next DR meeting
- See more talks on the webpage: http://www.lnf.infn.it/conference/ilcdr07/prog.html

Thanks for your attention !