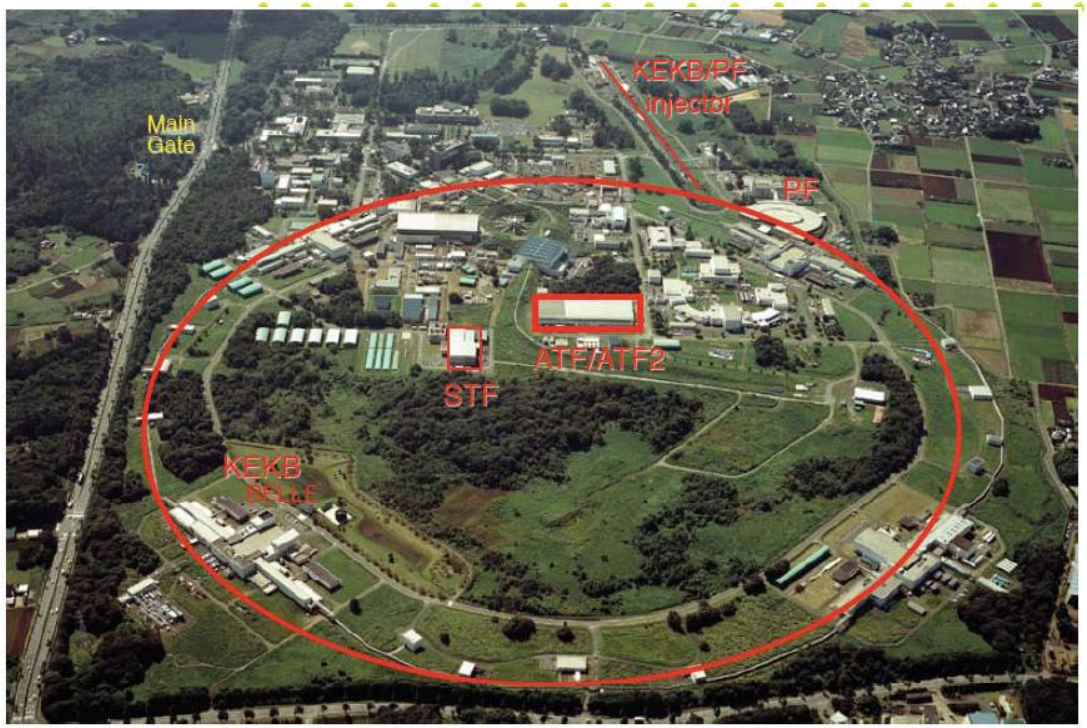
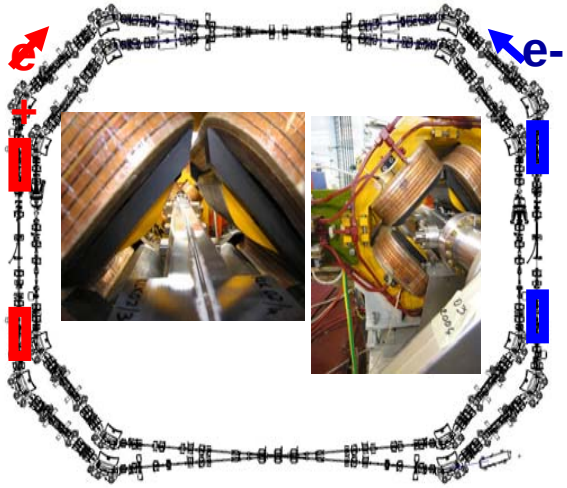
Final Focus and Damping Ring Test Facilities

ATF/ATF2 at KEK



CesrTA at Cornell University



DAΦNE rings at LNF

Presented by Junji Urakawa
KEK

ILC Damping Rings

1. Damping Ring Goals for the TDP
2. Fast Injection/Extraction Kickers R&D
3. CESR Reconfiguration for CesrTA
4. CesrTA - Low Emittance Tuning
5. Electron cloud simulation and benchmarking at CesrTA
6. Damping Rings Engineering Model

ATF/ATF2

ATF International Collaboration, Instrumentation R&D, low emittance tuning, fast ion instability study

ATF2 – model of ILC BDS, construction, Advanced beam instrumentation at ATF2, FD

DR Goals for the TDP: Test Facilities

- **CesrTA:** Electron cloud; ultra-low emittance.
  - **Validate modelling codes for cloud build-up and instabilities in a (low emittance) parameter regime relevant for the ILC damping rings.**
  - **Determine conditions necessary to avoid electron cloud limitations in the ILC damping rings.**
  - **Demonstrate sufficiently effective mitigation techniques.**
- **ATF:** Fast kickers; ultra-low emittance.
  - **Demonstrate reliable operation of fast extraction kickers meeting ILC damping ring specifications.**
  - **Demonstrate reliable operation of the damping ring with vertical emittance < 4 pm (if possible 1pm).**
- **DAΦNE:** Fast kickers; electron cloud.
  - **Demonstrate reliable operation with fast injection/extraction kickers.**
  - **If resources and schedule permit: collect data on cloud build-up and instabilities for code validation; investigate mitigation techniques.**

DR Goals for the TDP: Critical R&D

- **Electron cloud**
  - Model build-up and instabilities, and test mitigation techniques **(to be performed by a collaboration focused on CesrTA).**
- **Fast injection/extraction kickers**
  - Test commercial (FID) pulsers **(to be carried out at ATF and DAΦNE).**
  - Develop new technologies providing reliable performance at reduced cost **(SLAC, LLNL, and industry through SBIR funding).**
- **Ultra-low emittance tuning**
  - Develop and test a range of low-emittance tuning techniques **(collaborations focused on CesrTA and ATF).**
  - Gain experience and collect data **that will provide the basis for specifications on alignment, stabilisation and correction systems for the ILC damping rings.**

Damping Ring Goals for the TDP

- **Complete the design work** at the level needed to assess technical risks; evaluate costs; and identify opportunities for cost reduction.
  - Present (post-RDR) lattices provide a reasonable basis for studies of the damping rings themselves.
  - Need to develop lattice designs for injection/extraction lines.
- **Assess technical risks and develop a reliable cost estimate.**
  - Engineering model presently being developed will provide a basis for major risk and cost elements.
  - Present available effort is focused on the vacuum system: **this is a key subsystem in relation to technical risks (electron cloud, ion effects, impedance…) and significant costs (related through magnet apertures to power and cooling needs).**
  - Many other subsystems require further development for proper assessment of risks and costs: **magnets; power/cooling; controls…**

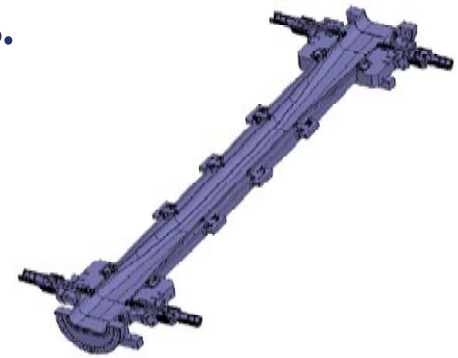
Fast Injection/Extraction Kickers

Specifications for fast high-power pulsers for ILC damping rings:

Pulse amplitude	7.5 kV	Assumes each pair of striplines is driven by a pair of pulsers.
Rise/fall time	3.08 ns	For bunch population 2.0×10^{10}.
	1.54 ns	For bunch populations $1.0\text{-}1.9\times10^{10}$.
Machine pulse repetition rate	5 Hz	
Intra-pulse (burst) repetition rate	5.4 MHz – 1.5 MHz	For bunch populations $1.0\text{-}2.0\times10^{10}$.
Pulse length	1 ms	
Pulse-pulse stability	<0.1%?	Needs further study to understand impact and possible mitigation of bunch-bunch horizontal jitter.

Fast Injection/Extraction Kickers

- Injection/extraction kickers in ILC damping rings will consist of a sequence of > 20 striplines, driven by fast, high-power pulsers.
- Striplines must meet specifications for:
  - aperture;
  - field quality;
  - beam impedance;
  - kicker rise/fall time (limits length of each pair of striplines).
- Fast high-power pulsers must meet specifications for:
  - pulse amplitude;
  - rise/fall time (<½ bunch spacing);
  - repetition rates (machine pulse and intra-pulse) and pulse length;
  - kicker pulse-to-pulse stability;
  - reliability.
- Striplines and pulsers both require R&D; but the pulsers are the more challenging.

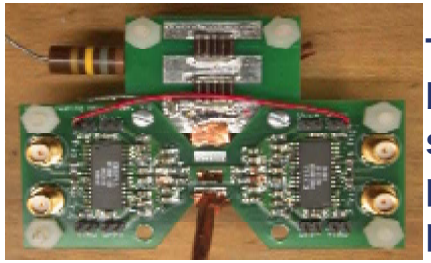


Tapered strip-line of INFN-LNF.

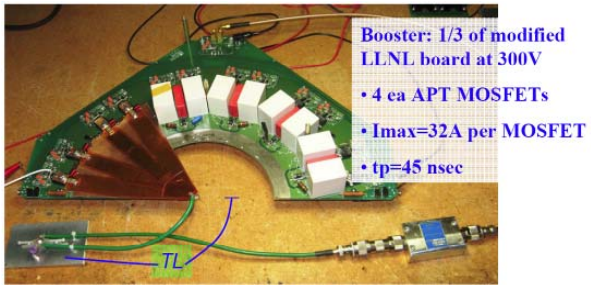
New pulser (FID)

Fast Kicker R&D Program

- There are presently four strands to the R&D program:
  - **SLAC/LLNL: Development of fast high-power pulsers based on MOSFET technology.**
  - **SLAC/DTI: Development of fast high-power pulsers based on DSRD (drift step recovery diode) technology.**
  - **INFN-LNF: Tests of fast kickers in DAΦNE.**
  - **KEK: Tests of fast kickers in the ATF.**
- Tests in DAΦNE and ATF are driven by machine upgrade plans (efficient beam injection for DAΦNE and 30~60 multi-bunch train to ATF2 beam line), but are directly relevant for the damping rings R&D program.
- So far, machine tests of fast kickers have relied on commercial (FID) pulser technology.



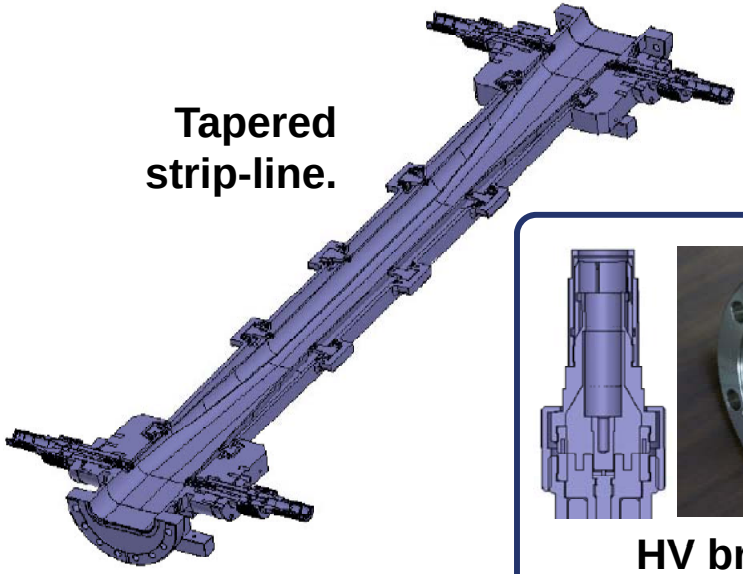
Tests of MOSFET-based pulser show promising performance.



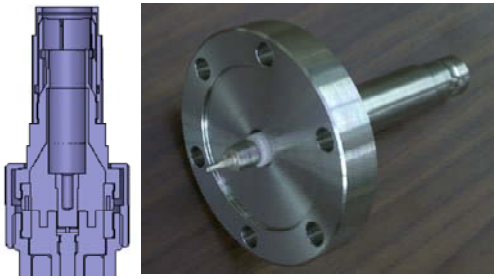
Tests of DSRD-based pulser using board based on LLNL design (for MOSFET inductive adder). Performance is limited by board design and components.

Fast Kicker R&D at DAΦNE

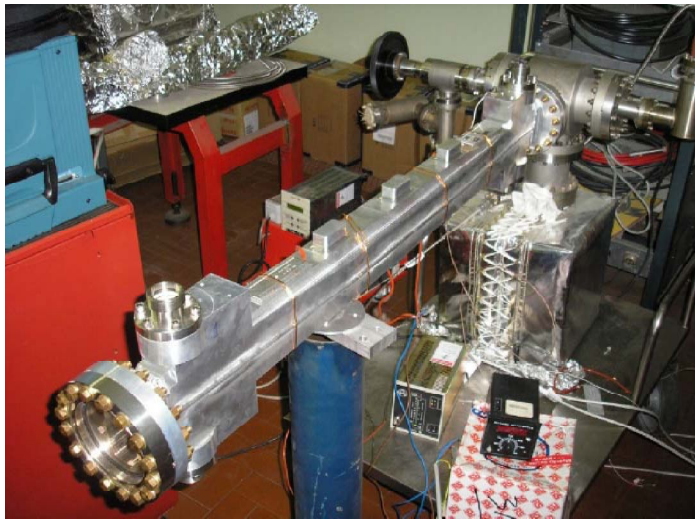
- **Program includes:**
  - **development of kicker strip-lines;**
    - **considering all relevant aspects, including field quality, beam coupling impedance, etc.**
  - **development of HV (50 kV) broad-band feed-throughs;**
  - **tests of FID fast pulsers.**
  - **Build a prototype kicker for ATF. Design is almost complete; goal is to complete fabrication by end 2008.**



Tapered strip-line.



HV broad-band feed-through.

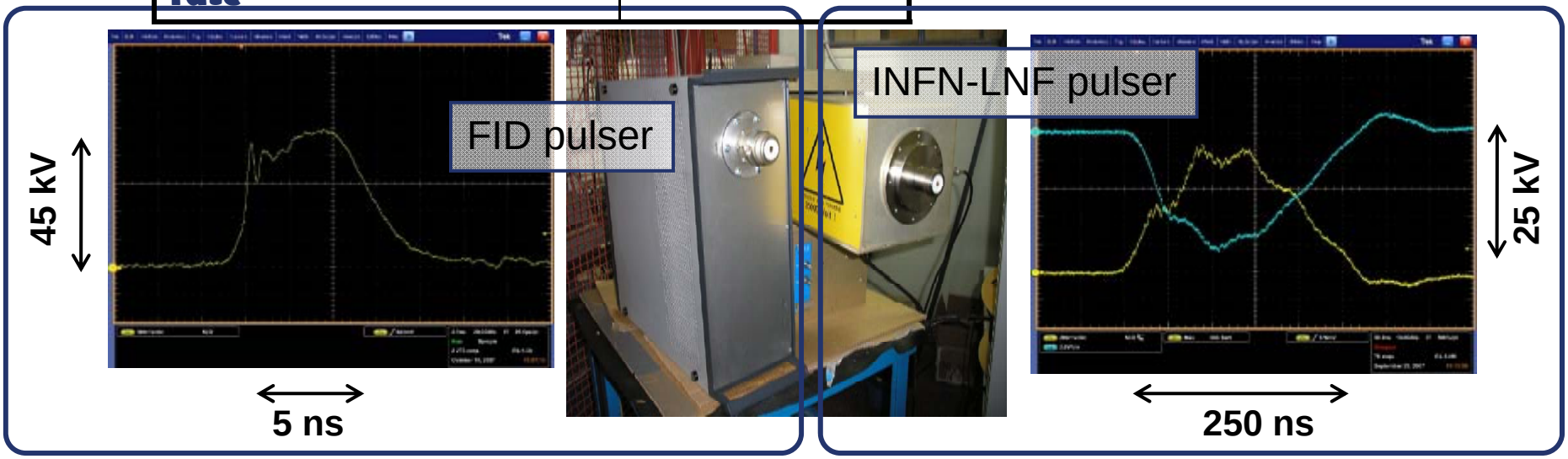


Chamber with kicker for tests with fast pulsers.

Fast Kicker R&D at DAΦNE

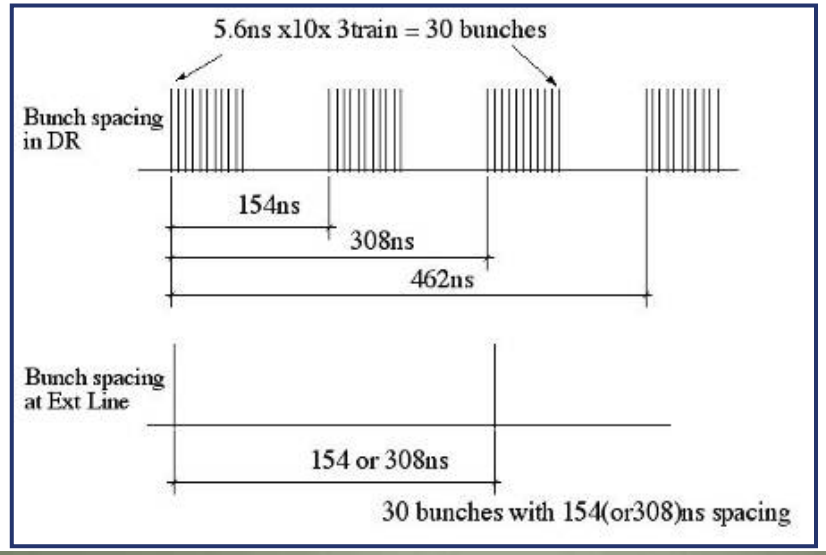
Beam energy	510 MeV
Deflection from kicker	5 mrad
Total deflecting voltage	2.5 MV
Total kicker length	90 cm approx.
Voltage per strip	45 kV
Input pulse length	5 ns approx.
Maximum repetition rate	10 Hz

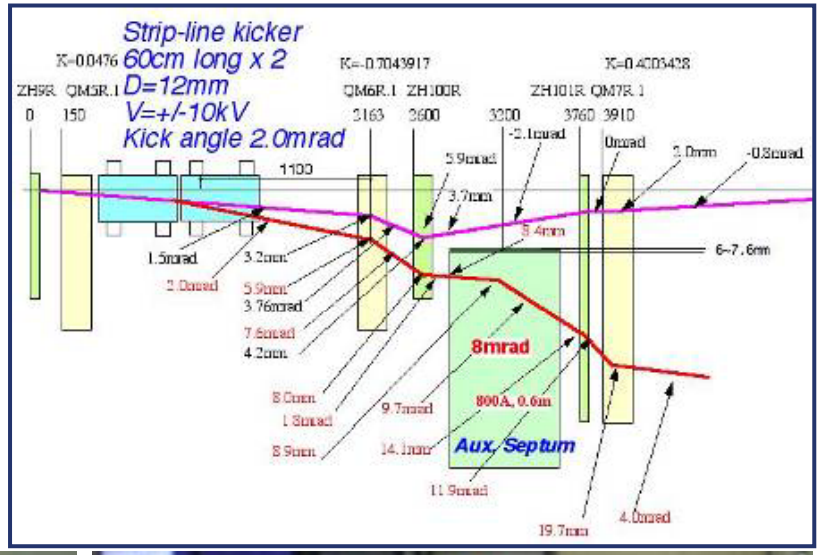
Old pulser (LNF)

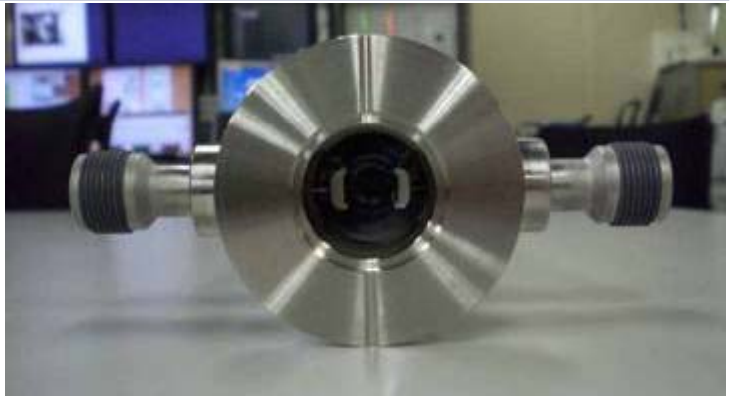


Fast Kicker R&D at ATF

- Goal is to provide bunch train with ILC-like time structure for ATF2, by extraction of individual bunches from train in ATF damping ring.
- Space limitations make it impractical to extract just by using a kicker: kicker pulse will be superimposed on a "slow" orbit bump.

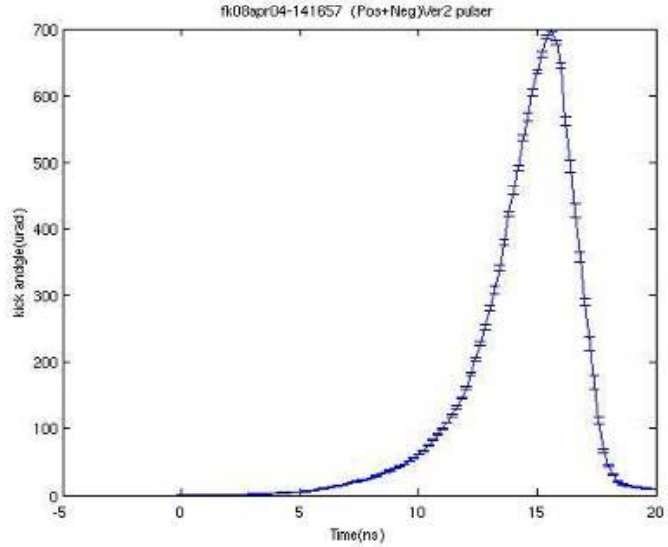




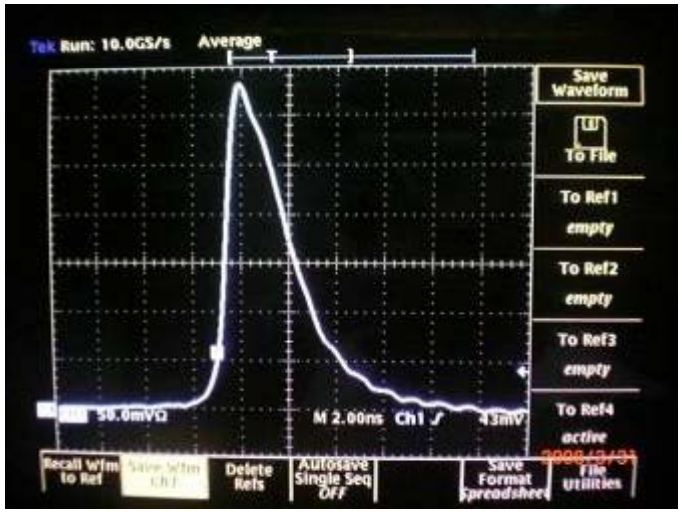


Fast Kicker R&D at ATF

- Right: Kicker pulse measured from bunch timing scan. Deflection amplitude is as expected from pulsers providing approximately ±10 kV.
- 0.44mrad kick by 30cm strip-line.



Pulser: FID FPG 10-6000KN

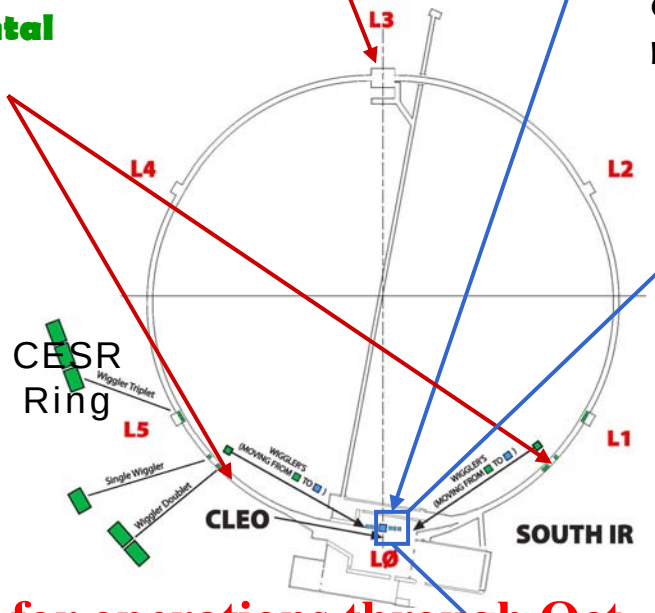


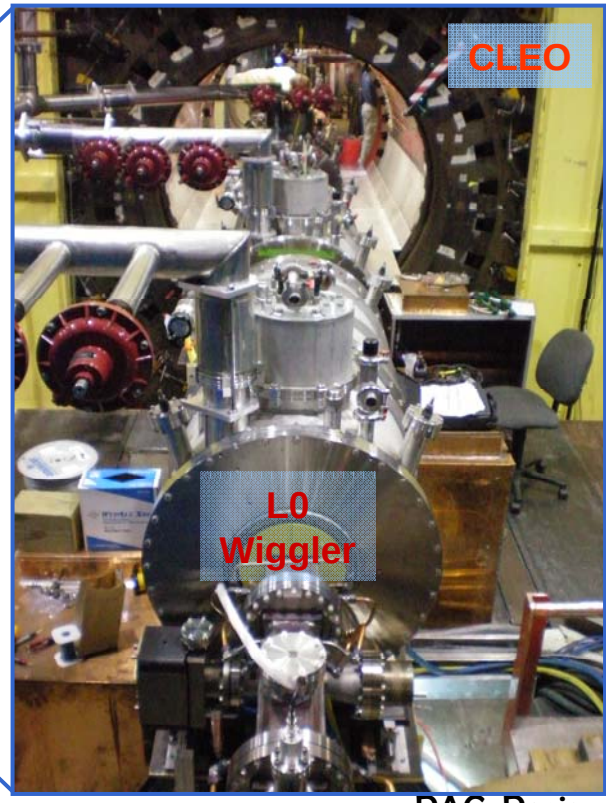
Maximum output voltage	**10 kV**
Rise time, 10 – 90%	**< 1 ns**
Rise time, 5 – 95%	**< 1.2 ns**
Pulse duration at 90% peak amplitude	**0.2 – 0.3 ns**
Pulse duration at 50% peak amplitude	**1.5 – 2.0 ns**
Output pulse amplitude stability	**< 0.7%**
Maximum pulse repetition frequency	**6.5 MHz**
Number of pulses per burst	**110 (max)**
Burst repetition frequency	**5 Hz**

Beam extraction test:January 2009

CESR Reconfiguration

- **Electron Cloud Diagnostics**
  - **L3 region prepped for arrival of PEP-II EC hardware including diagnostic chicane**
    - **Hardware being removed at SLAC**
    - **Delivery to Cornell in November**
  - **New EC experimental regions in arcs w/ locations for collaborator VCs**
  - **L0 region reconfigured as a wiggler straight**
    - **Instrumented with EC diagnostics**
    - **Wiggler chambers with retarding field analyzers (fabricated at LBNL) - scheduled for installation ~Oct 23rd**
    - **Chambers with EC mitigation (TiN coatings by SLAC)**





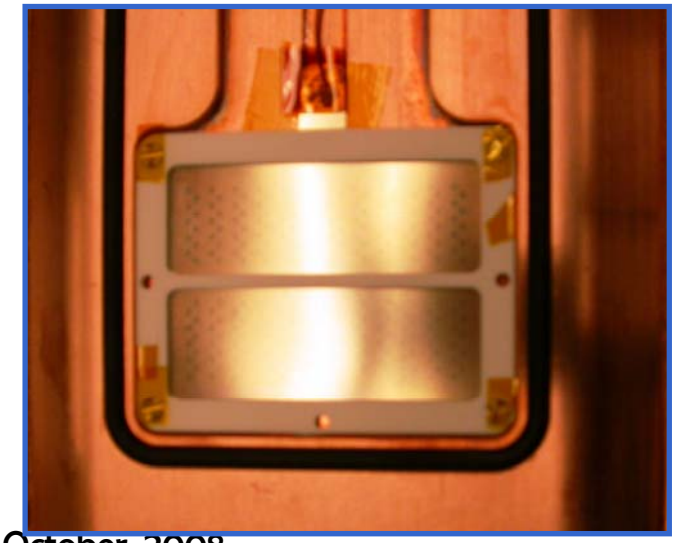
Re-commissioning for operations through Oct 27th

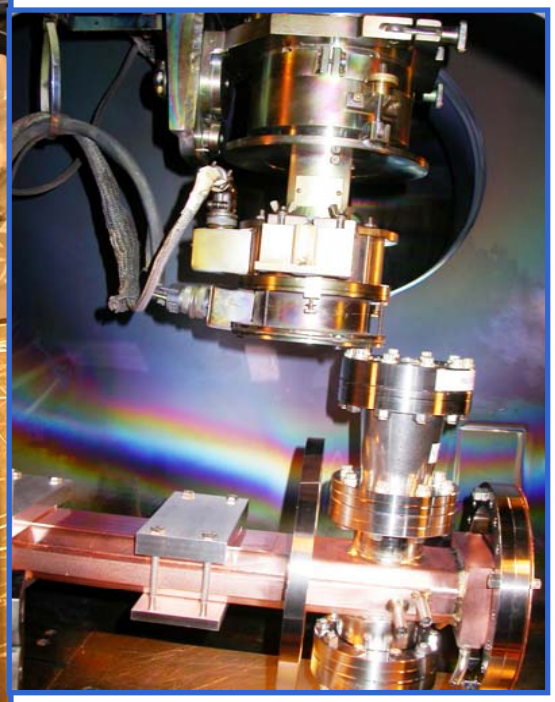
CesrTA dedicated experiments: Oct 27-Nov 10

Electron Cloud Experiments, Low Emittance Operation, X-ray Beam Size Monitor

Wiggler EC Diagnostics

- RFAs assembled and checked for both VCs
- E-beam welding
  - 1st VC complete
  - 2nd VC complete
- Installation into cryostats
- Installation into CESR ~Oct 23





CesrTA - Low Emittance Tuning

Optics will be commissioned during the October/November CesrTA run

Survey

- Complete network of survey monuments that permit more rapid and reliable survey have been installed around the CESR tunnel.
- Quadruple vertical offset is measured with 25μm precision.
- Magnet mounting fixtures that permit precision adjustment are installed on all quads

Alignment

- Allows beam-based identification of quad offsets and dipole rolls.

Analysis software

- Gain mapping
  - Software to fit the relative gains of the 4 BPM buttons to orbit data has been developed and tested.
- Orbit response matrix
  - Effectiveness of ORM has been limited by BPM resolution and irreproducibility and it will significantly improve with installation of new BPM electronics.

BPM upgrade

- Digital bunch by bunch/ turn by turn BPM electronics and infrastructure is ready for installation.

X-ray beam size monitor

- Measurement of the size of the positron beam with few micron resolution beginning in January 2009 run
- Single bunch/single pass measurement May-June 2009 run

EC Simulation Goals at CesrTA

- *Understand cloud buildup* in drift, quadrupole, dipole and wiggler sections of CesrTA, with different cloud suppression techniques.
- *Understand interaction of the cloud and the beam* in CesrTA, including instabilities and emittance growth.
- *Validate cloud buildup and cloud dynamics simulations using CesrTA data*, in order to develop confidence in the application of these simulations to predict cloud behavior in the ILC damping ring.
- *Demonstrate cloud suppression techniques* suitable for use in the ILC damping ring.

Simulations

- Tools:
  - Simulation codes: POSINST, ECLOUD, CLOUDLAND
  - Analytic and numerical estimates of response of beam to cloud
  - RFA response models
- Initial steps:
  1. benchmark simulation codes using simple cases relevant to CesrTA and ILCDR conditions
  2. simulate cloud buildup in RFA-instrumented chambers, and RFA instrumental response, to guide RFA experiments as probes of average cloud density.
  3. simulate ring-averaged cloud buildup and associated coherent tune shifts, to guide tune shift experiments as probes of cloud density and dynamics

Code benchmarking

- We have started a series of benchmarking runs to gain confidence that the code predictions can be made to agree, or the differences understood, under cloud development conditions similar to those of CesrTA and the ILC damping ring.
- The SEY models in ECLOUD, POSINST and CLOUDLAND have been carefully studied to understand the differences in the physics models, if any.

RFA measurements of electron currents

RFA measurements have been made at several drift regions and in a dipole, under a variety of conditions:

- Electrons and positrons
- 1.9 GeV and 5.3 GeV
- Various loading trains

Qualitative agreement with POSINST and ECLOUD.

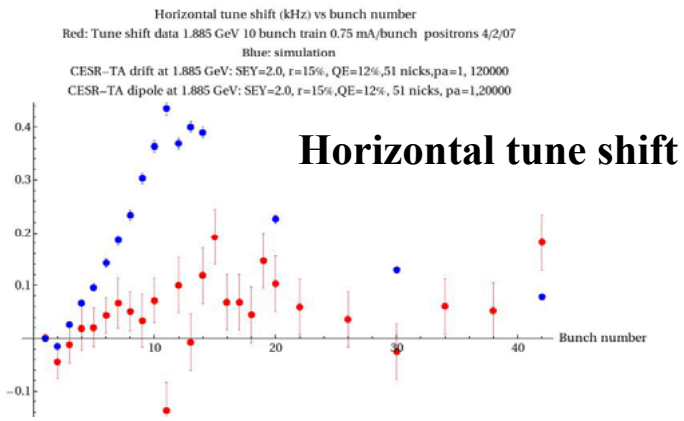
Simulation SEY models need further benchmarking.

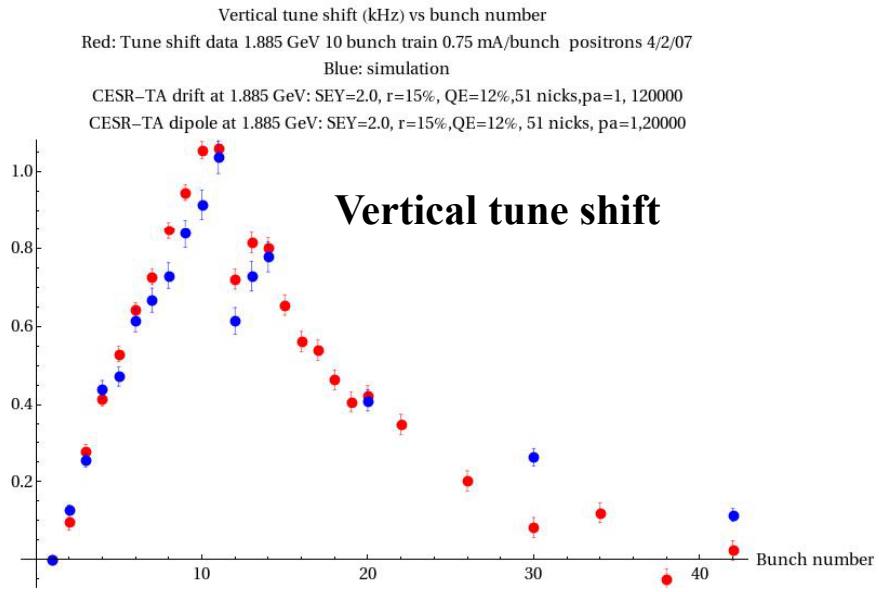
The devices measure the time-average electron current into the wall at the device location, as a function of energy (via grid bias).

Witness bunch measurements of coherent tune shift

- "Witness bunch" technique:
  - a train of "loading bunches" generates a cloud density around the ring
  - "witness bunches" are placed at variable times after the loading train, and the coherent tune of the witness bunch is measured. The coherent tune shift is a measure of the beam-averaged field gradient due to the cloud charge density at the time of the witness bunch.
- Coherent tune shift measurements (both vertical and horizontal tune) using the witness bunch technique have been done in a variety of conditions.
- We have also made measurements of the systematic variation of tune shift along a train vs. bunch current.

Comparison with data of 4/2/07 Coherent horizontal and vertical tune shifts at 1.9 GeV



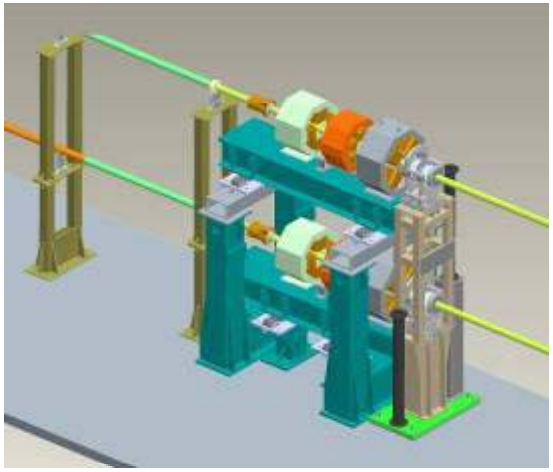


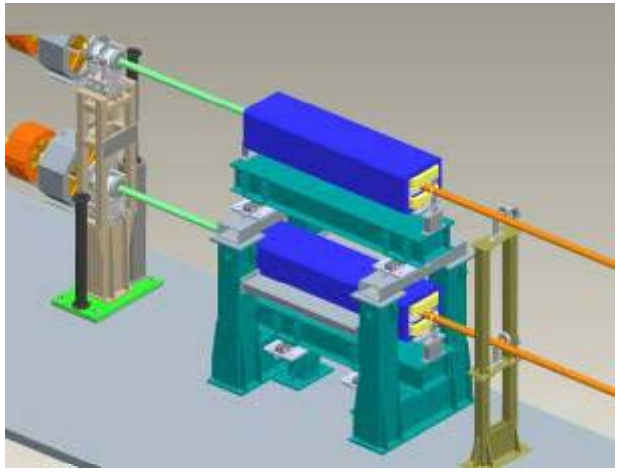
Future plans at CesrTA

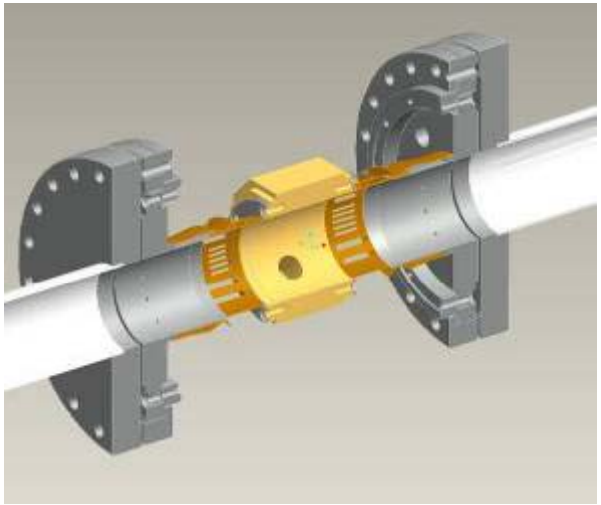
- We need to complete the code comparison (benchmarking) and fully understand the differences between the SEY models in ECLOUD, CLOUDLAND and POSINST.
- For RFA data, we need an improved model of the RFA response (in progress).
- For the tune shift data, we need to fully include dynamic effects in the calculations (requires integration of beam motion into the simulation codes).
- Measurements of cloud-induced incoherent emittance growth can be made using XBSM. We need to estimate this in a simulation.
- Measurements of instability thresholds, growth rates, mode spectrum can be made. We need supporting calculations.
- Dependence of cloud effects on beam as a function of energy, species, bunch population, bunch spacing, and emittance, in alliance with the simulation program, can provide a comprehensive validation of the codes.

Damping Rings Engineering Model

- Work is in progress to develop an engineering model for the damping rings based on the latest (6.4 km) lattice.
- The goals are:
  - **To develop the vacuum system in sufficient detail to allow reliable predictions to be made of electron cloud, ion effects, and other instabilities.**
  - **To evaluate options for magnet and BPM supports, and other issues associated with achieving and maintaining ultra-low emittance.**
  - **To provide a basis for an improved cost estimate, and evaluation of opportunities for cost reduction.**







John Lucas, Norbert Collomb (STFC Technology), Oleg Malyshev (STFC ASTeC)

ATF International Collaboration

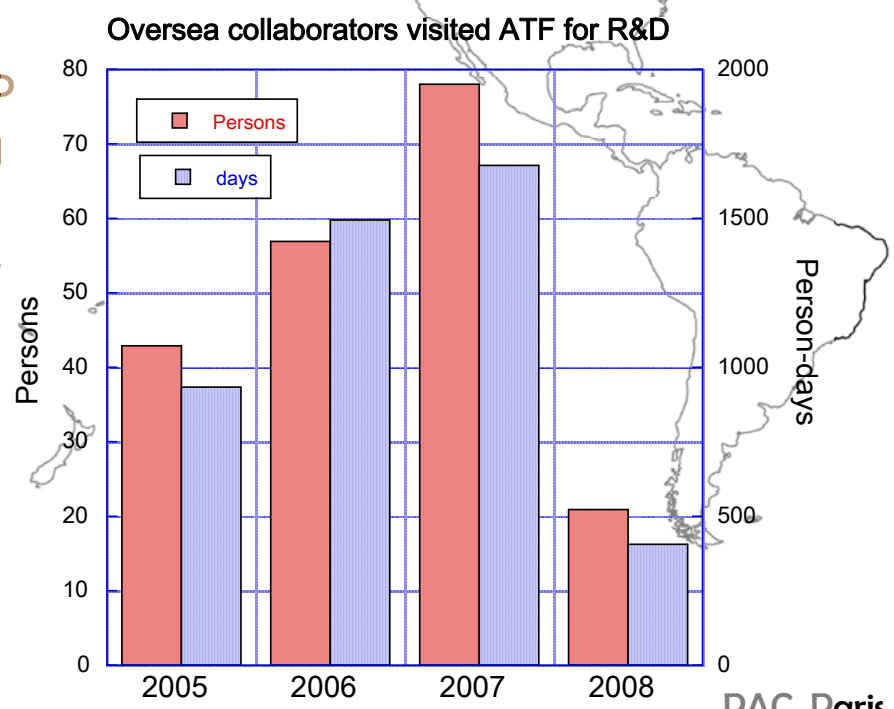
CERN
DESY
LAL, Orsay
Tomsk Polytechnic Univ.
INFN, Frascati
University College London
Oxford Univ.
Royal Holloway Univ.

KEK
Waseda U.
Nagoya U.
Tokyo U.
Kyoto U.
Hiroshima U.
PAL
IHEP
KNU

SLAC
LBNL
FNAL
Cornell Univ.
LLNL

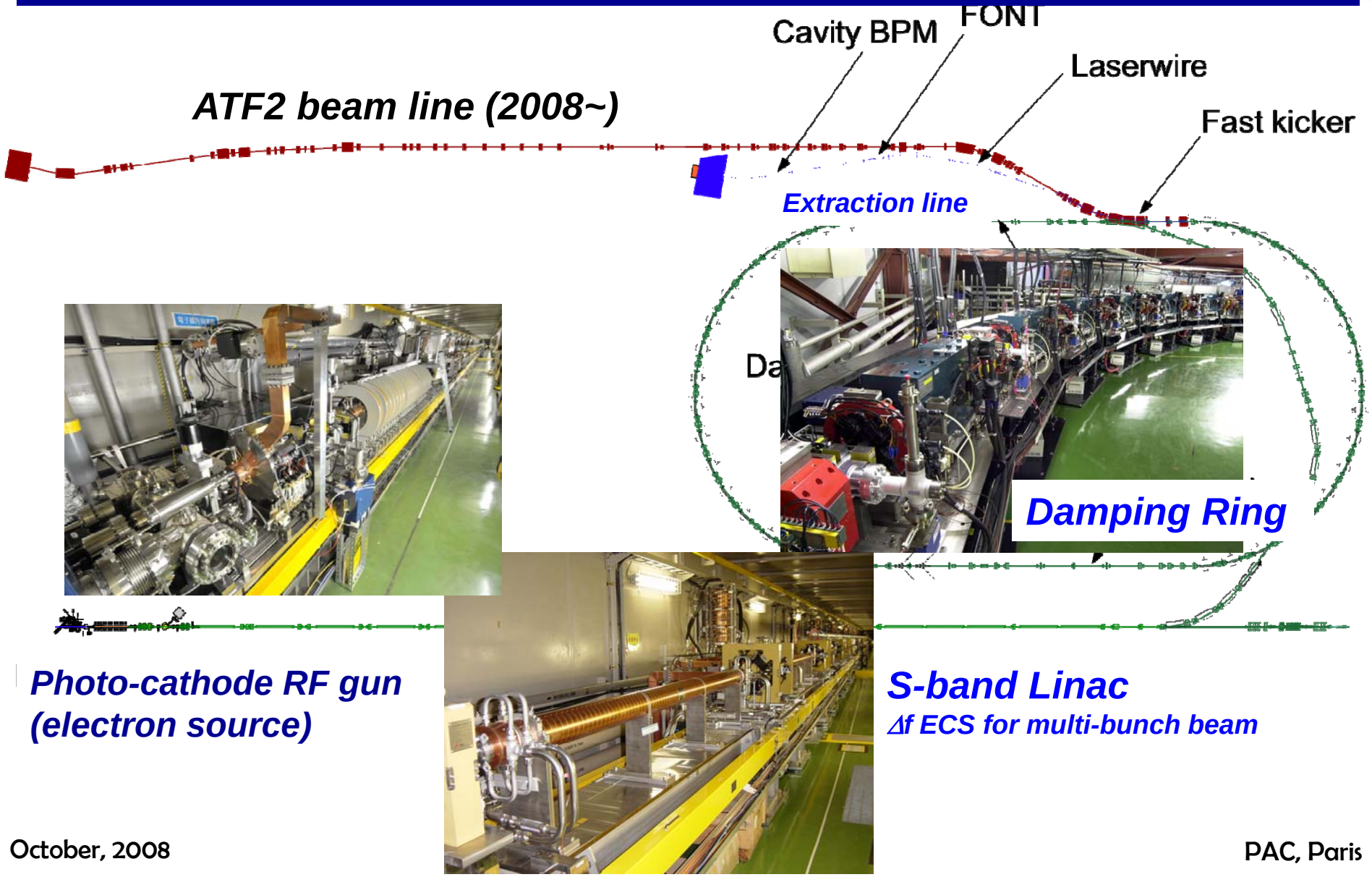
Oversea collaborators visited for R&D at ATF

23 Institutes,
~60 peoples,
~1500 people-days



Meeting for ATF operation

Accelerator Test Facility

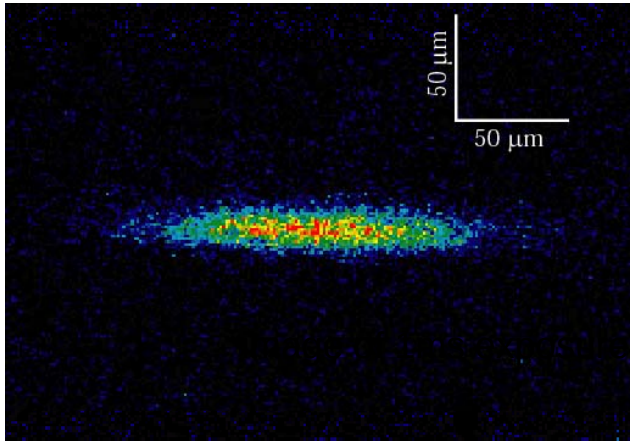


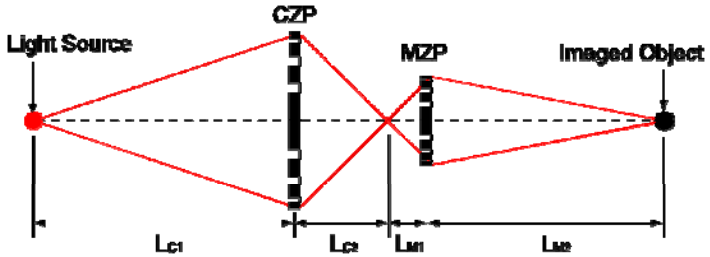
XSR beam-size monitor (Tokyo Univ., KEK)

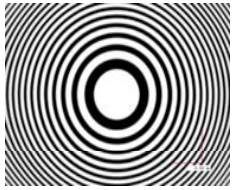
Real time beam monitor for ATF DR beam tuning

X-Ray Telescope using Zone Plate at 3.2keV
magnification : 20

- ***Non destructive measurement***
- ***High resolution (< 1μm)***
- ***2D direct imaging of the electron beam***
- ***Real time monitoring (< 1ms)***

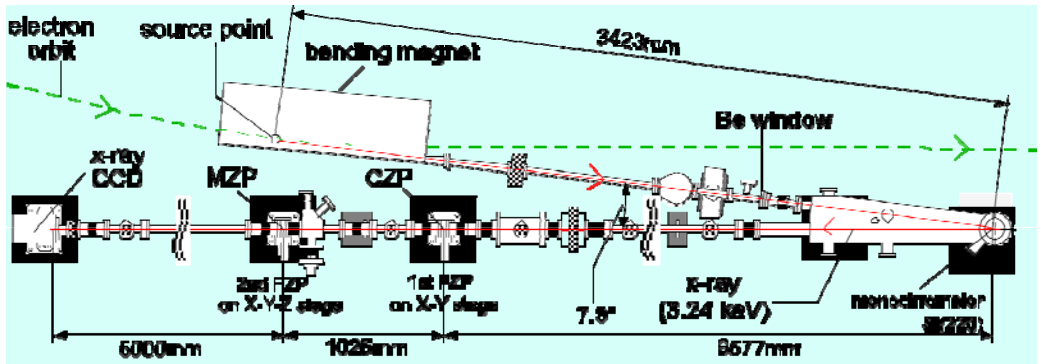






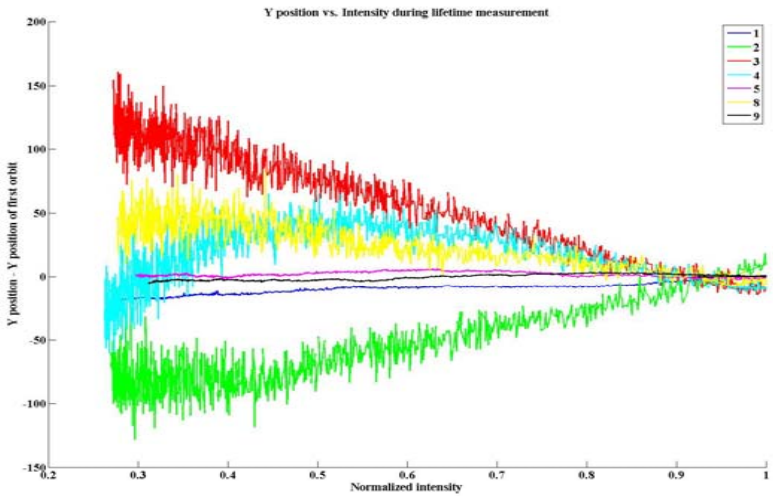
Zone plate

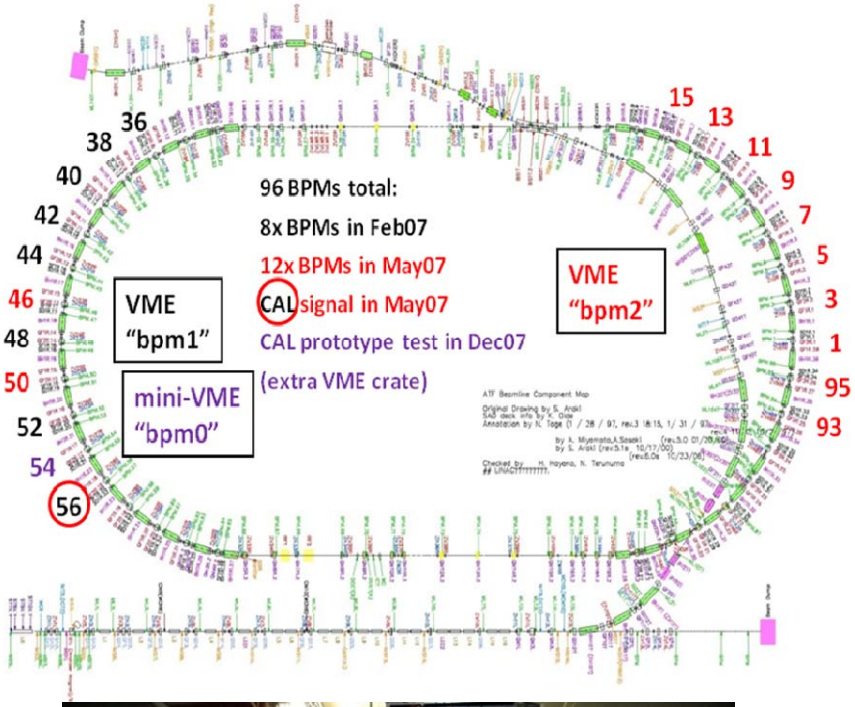
$\sigma_x = 48.2 \pm 0.5$ [μm]
$\sigma_y = 6.4 \pm 0.1$ [μm]

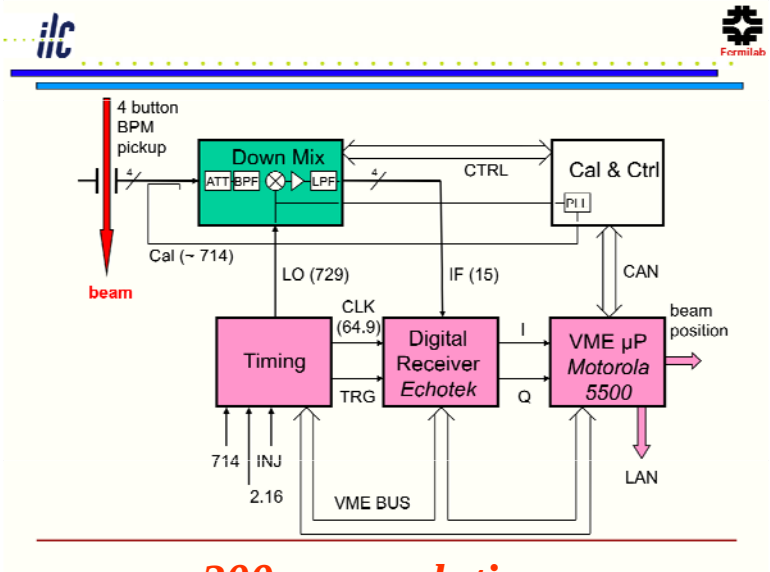


SR X-ray beam line

DR BPM upgrade (FNAL, SLAC, KEK)

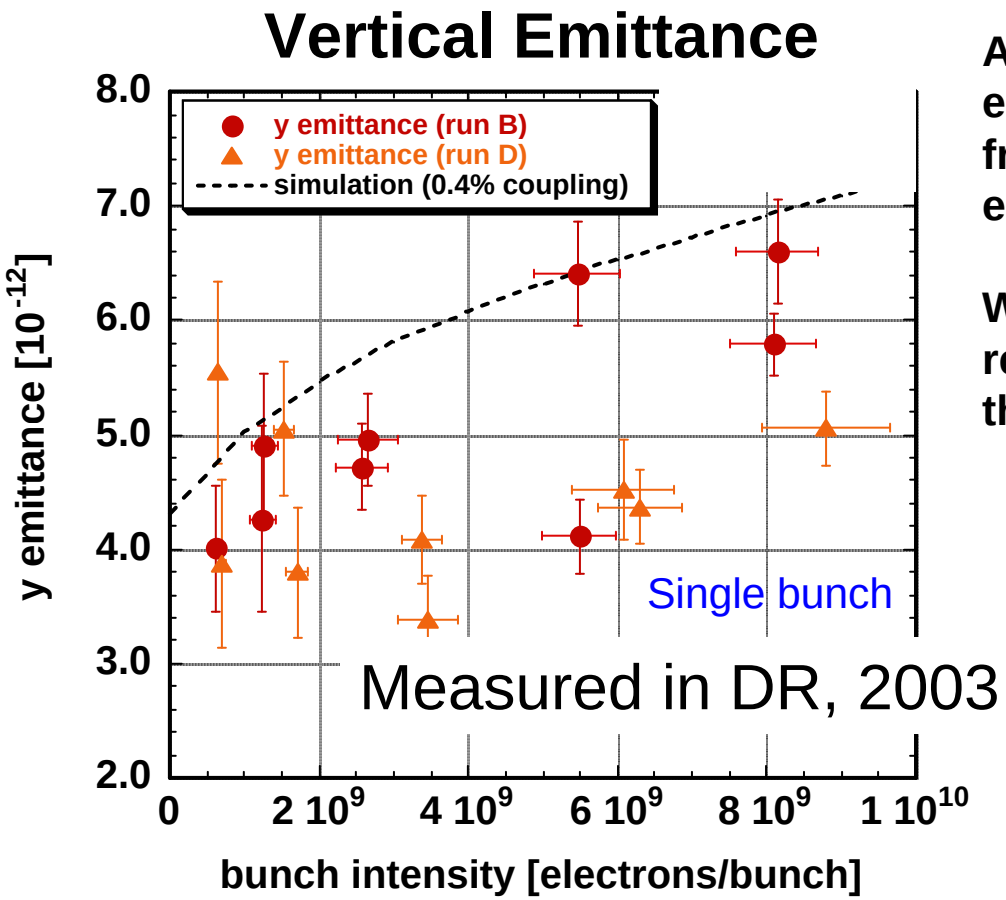






200nm resolution

Emittance tuning at ATF



ATF achieved about 4pm vertical emittance but we could not reproduce it from 2006 and the measured vertical emittance is about 20pm usually.

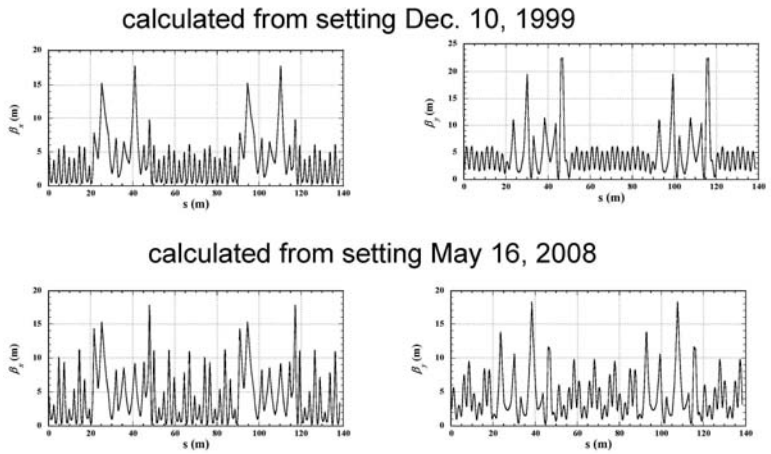
We checked the damping ring to find the reason and realigned all magnets of DR in this Fall.

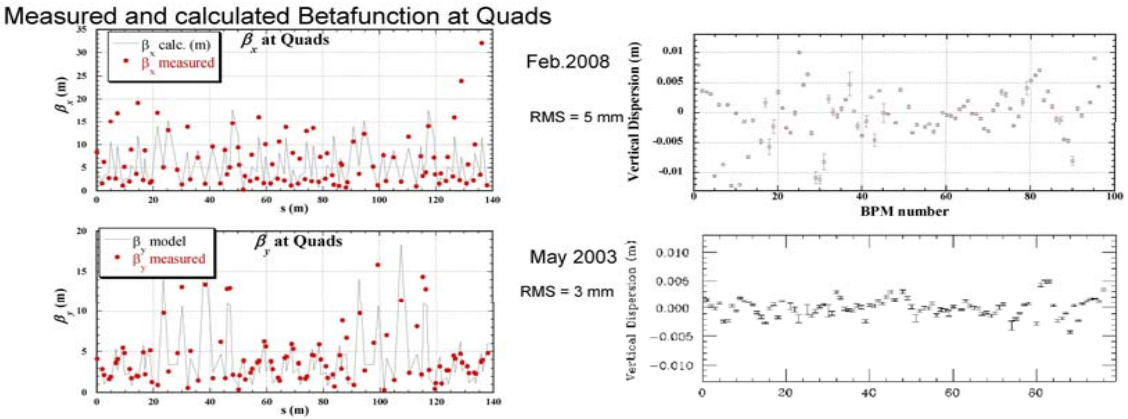
Necessary works

- **optics retuning**
- **beam based realignment**
- **BPM re-positioning**

Beam Optics deformation was checked.

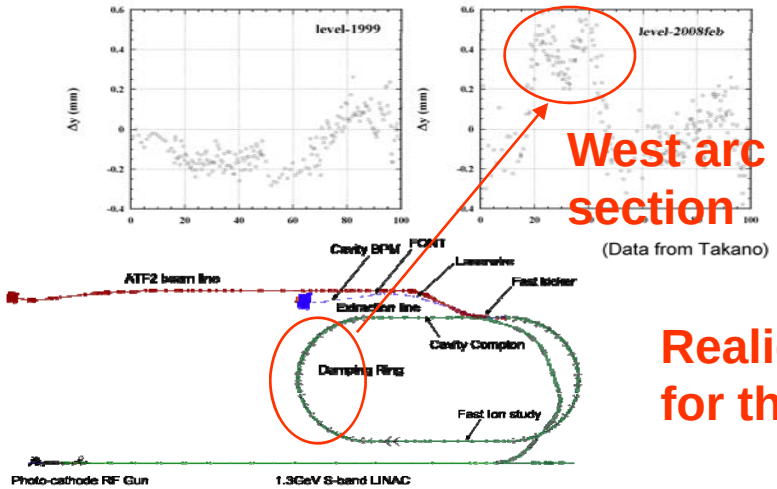
Optics retuning is necessary to recover ultra-low emittance.





Error of Beam Optics

Change of alignment

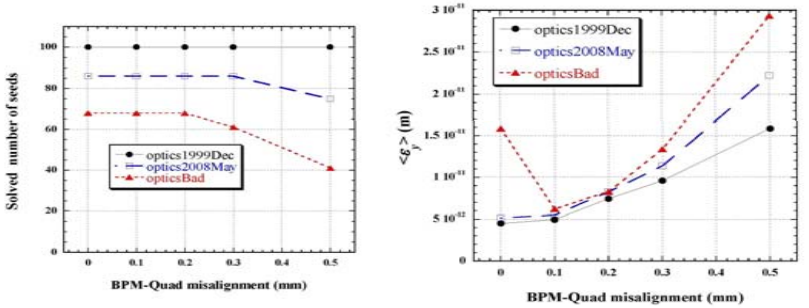


Change of magnets alignment without realignment during long period. Especially, west arc alignment was destroyed by ATF2 floor refurbishment.

Realignment will be finished in this Oct. for this autumn operation.

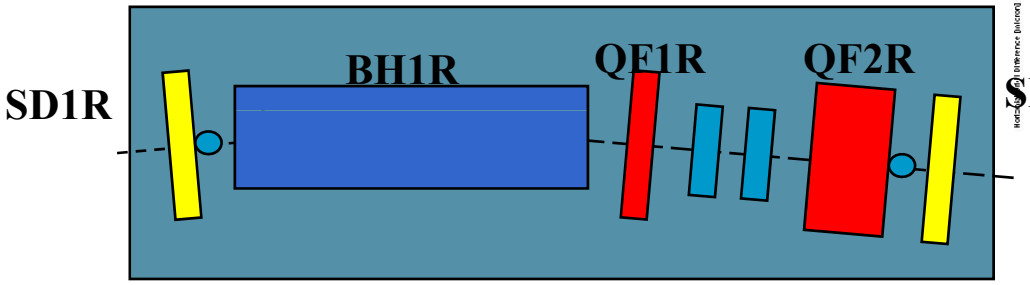
Effect of BPM alignment

Big difference more than 100μm between BPM center and quad center makes impossible to retune ultra-low emittance.



(simulated by K.Kubo)

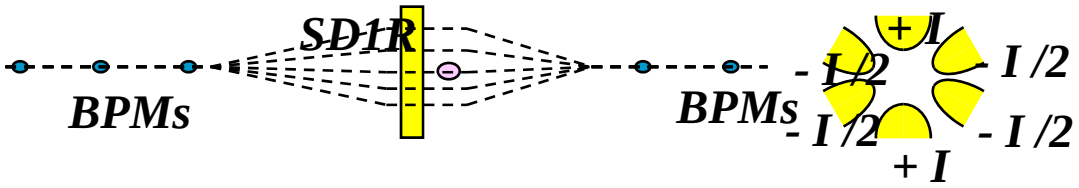
emittance growth due to the displacement between field center and BPM position

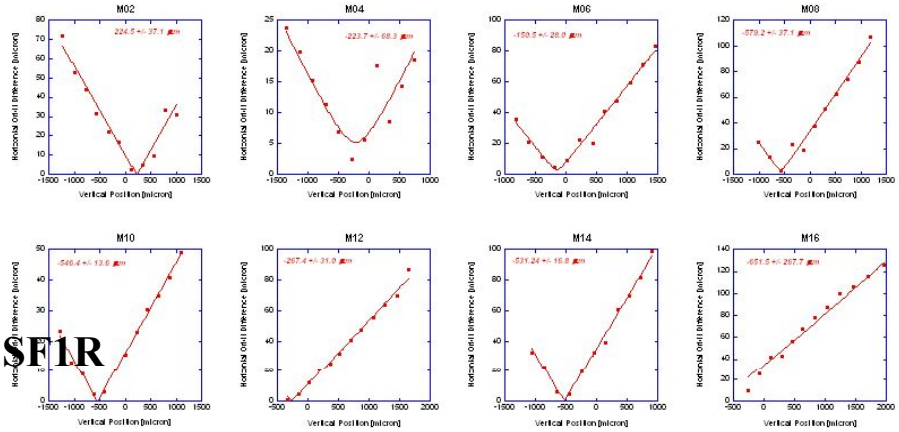


Magnet configuration of ATF DR normal cell

BBA (Beam Based Alignment)

Using trim Coil of sexta, displacement between BPM position and the field center of sexta was measured. BPM misalignment was measured with accuracy of about 30μm and we found big alignment error of about 500μm.

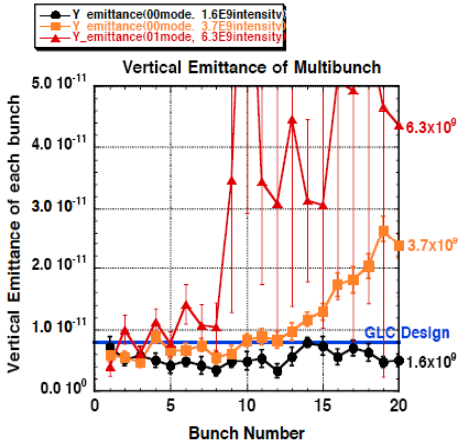


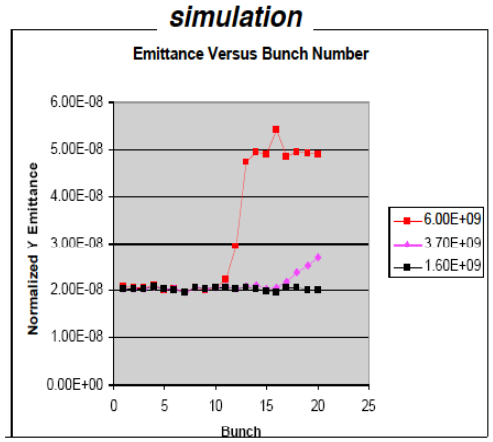


This measurement will be done from this autumn operation completely.

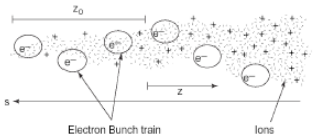
Fast Ion Instability observed at ATF in 2004

Preliminary result of Fast Ion Instability simulation





Behavior of Y emittance is very similar.



Schematic of the Fast-Beam Ion Instability

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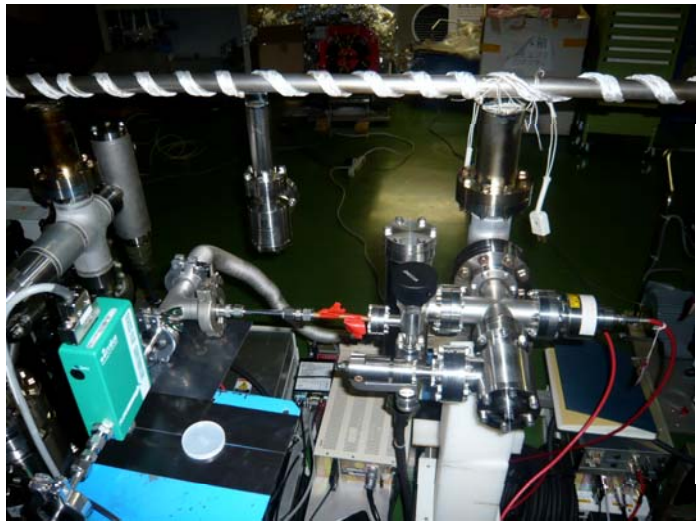
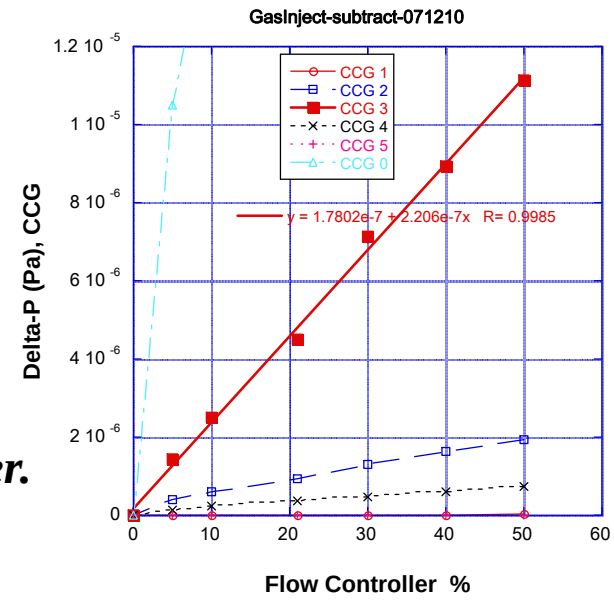
Assuming dipole oscillation

- *Continuous gas leak into the beam chamber.*
- *We can control the leak rate of N_2 gas.*
- *Pressure range: 10^{-7} Pa ~10^{-3} Pa.*

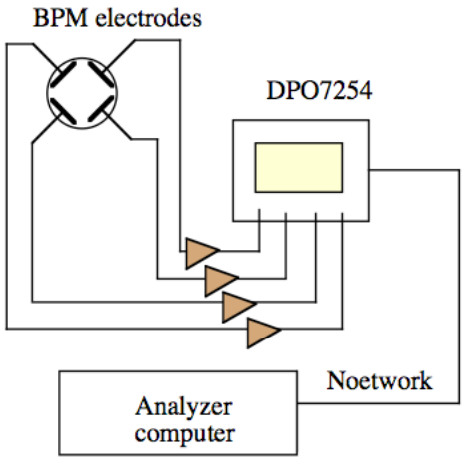
Pressure bump control in south straight section

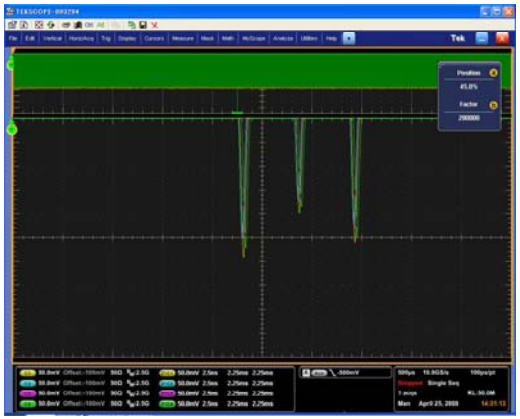




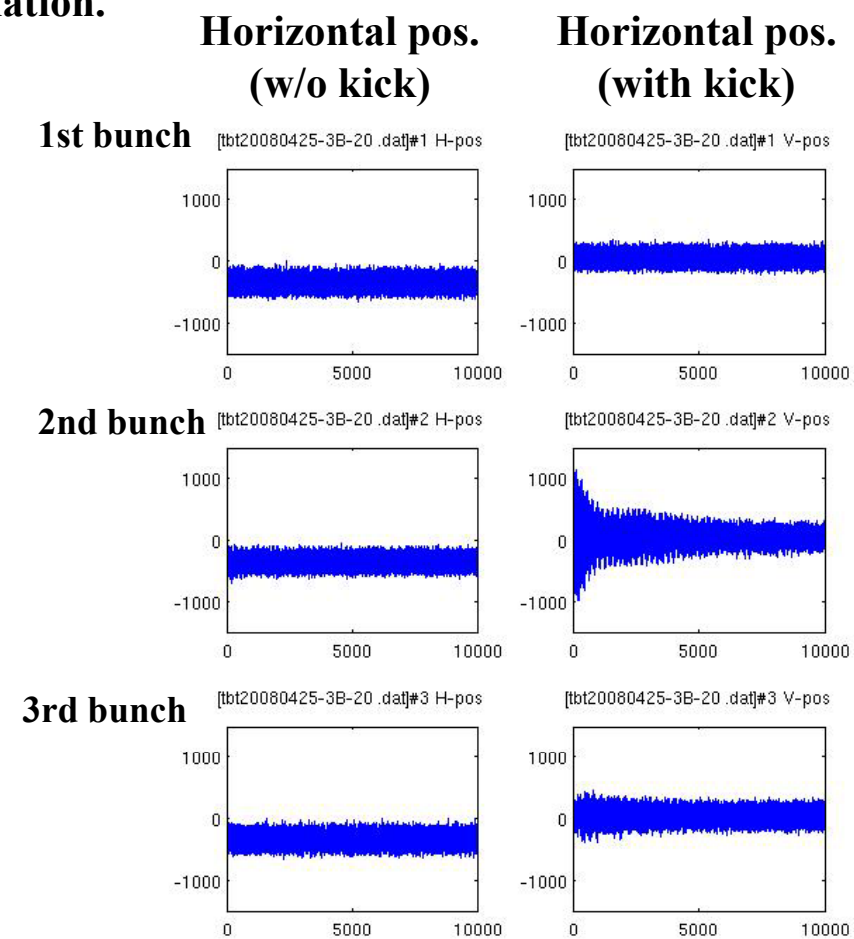
Measurement of beam position bunch by bunch

BPM signals are memorized into Oscilloscope (DPO7254, 0.1ns time resolution) during 10000 turns and we can observe beam oscillation.



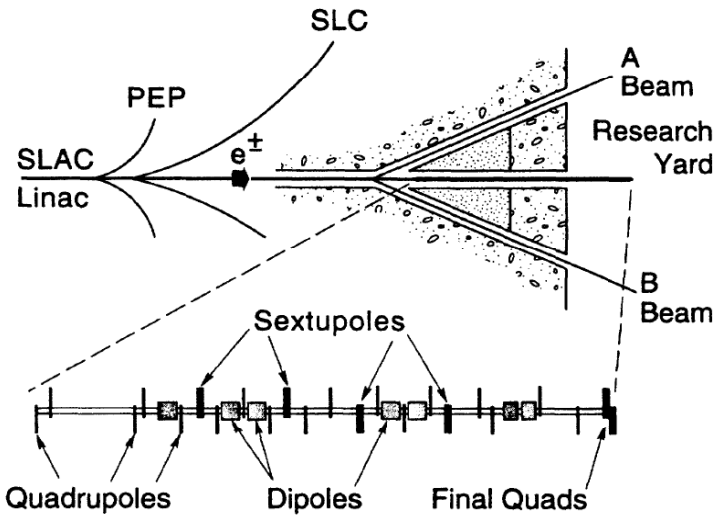


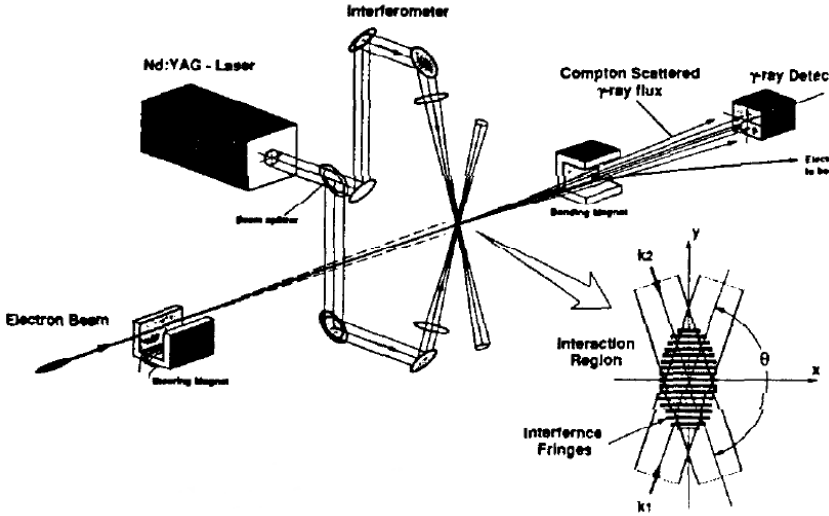
When we gave the dipole oscillation to second bunch, we observed no oscillation on 1st and 3rd bunches.



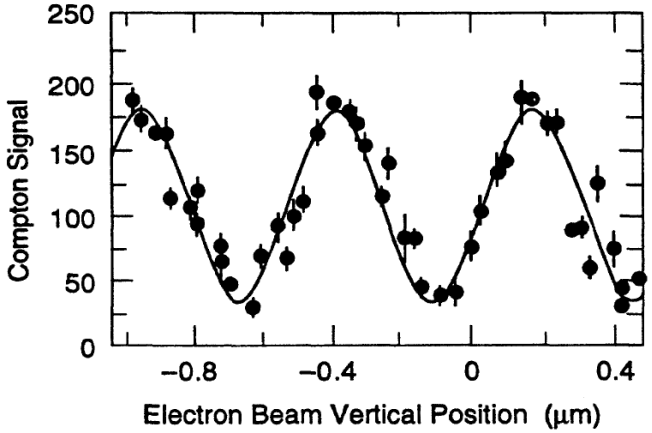
Three bunch signals from button electrode with 2.8ns bunch spacing.

Final Focus Test Beam – optics with traditional non-local chromaticity compensation

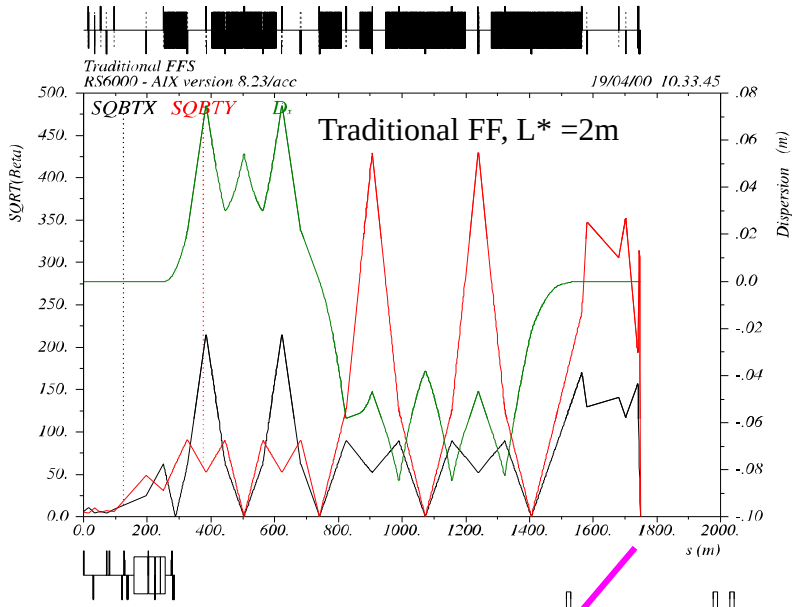


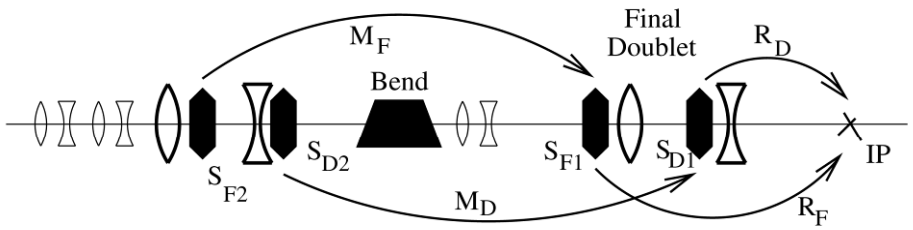


Achieved ~70nm vertical beam size

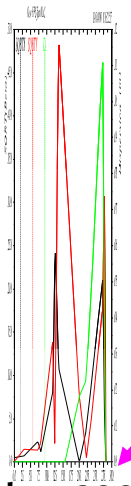


FF with local chromatic correction

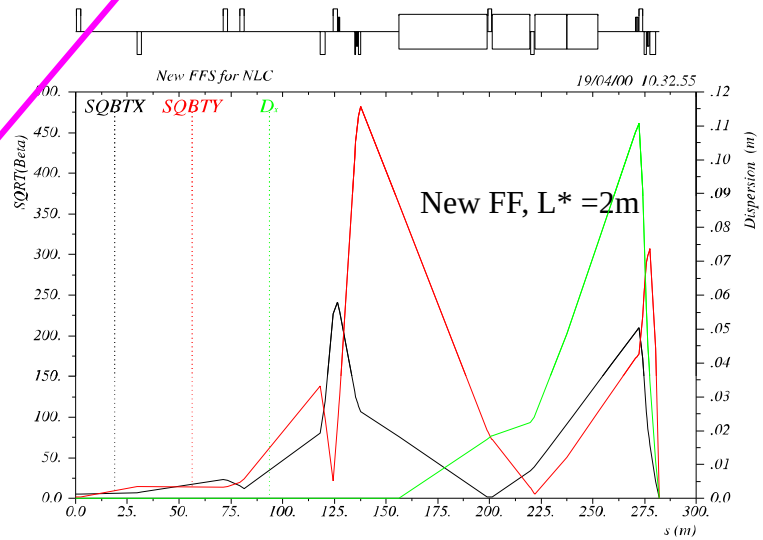




- Chromaticity is cancelled locally by two sextupoles interleaved with FD, a bend upstream generates dispersion across FD.
- 2nd order dispersion, geometric and higher order aberrations can be compensated and minimized.

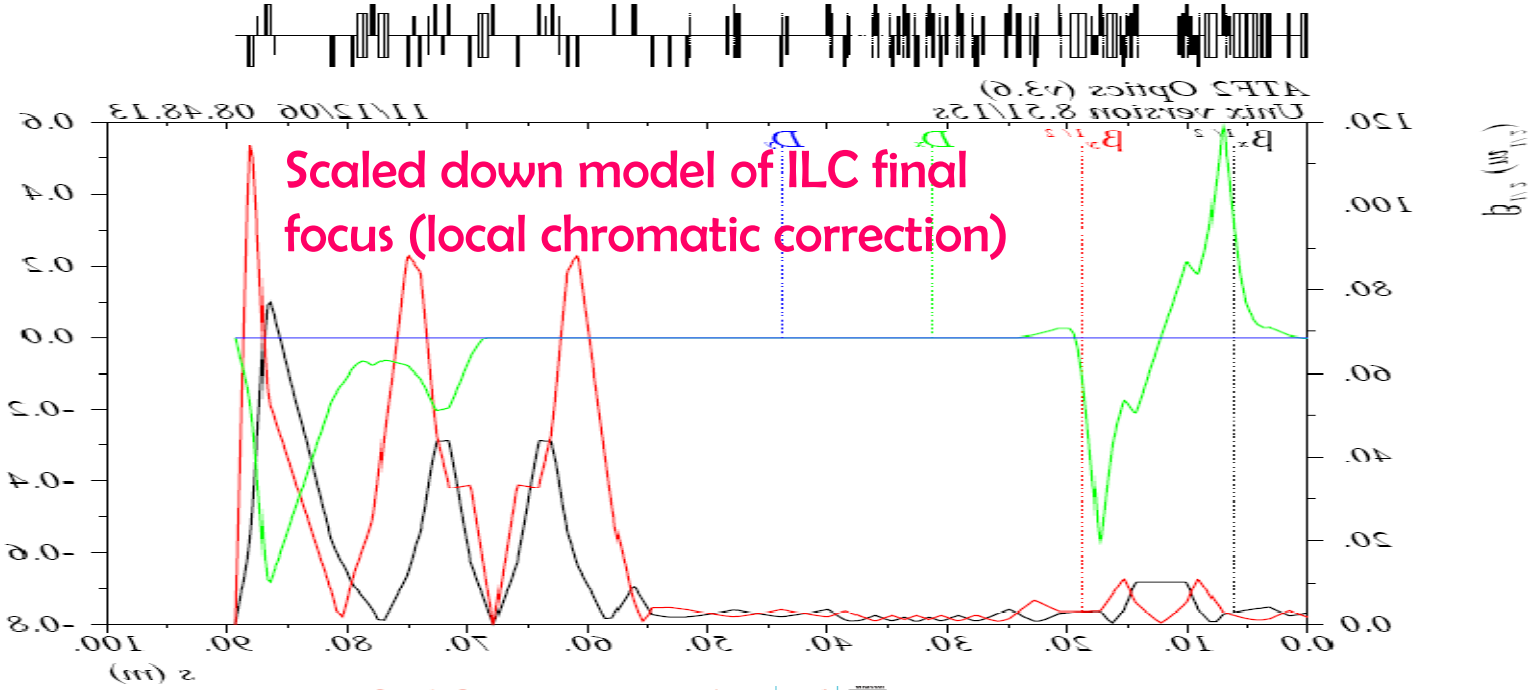


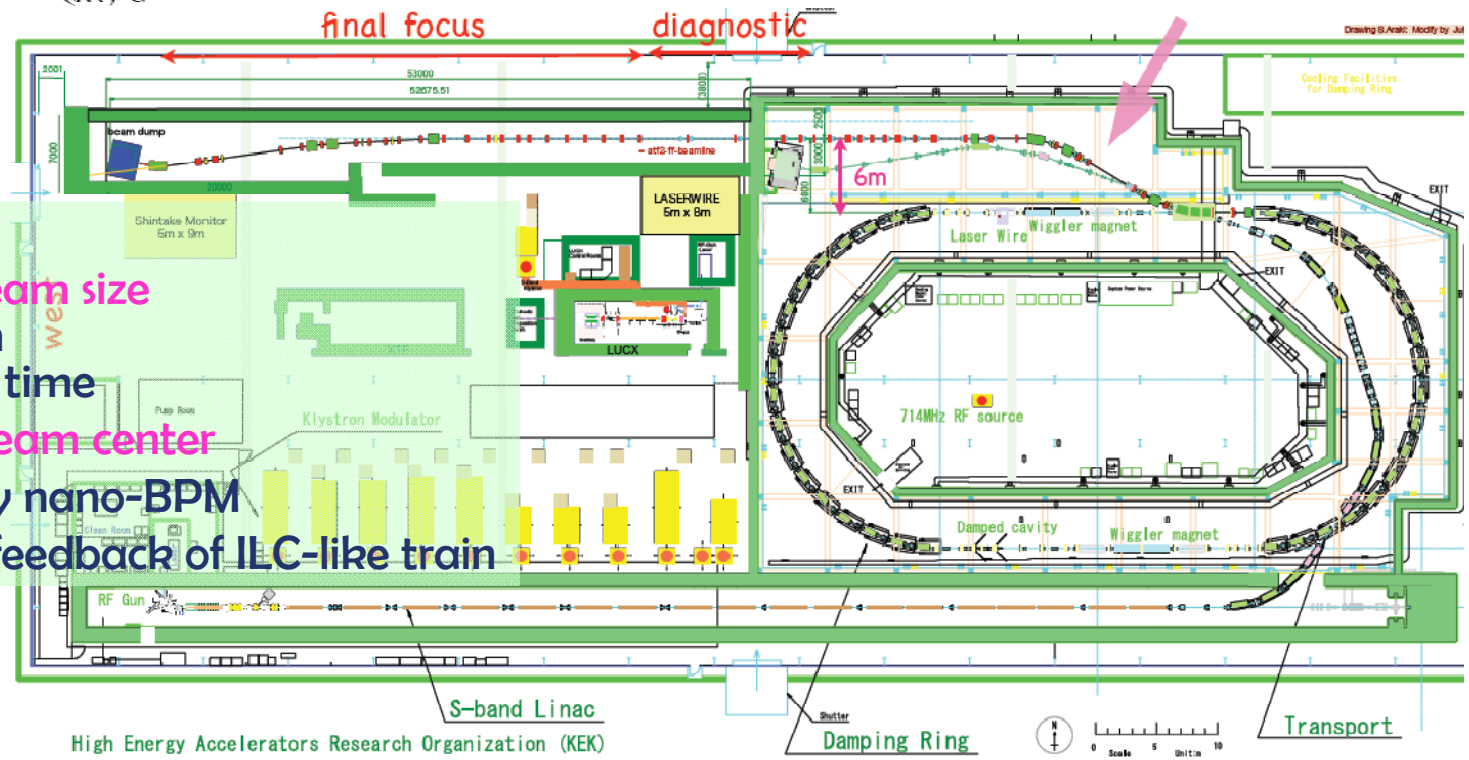
new FF



FF with local chromaticity compensation with the same performance can be ~300m long, i.e. 6 times shorter

ATF2 – model of ILC BDS



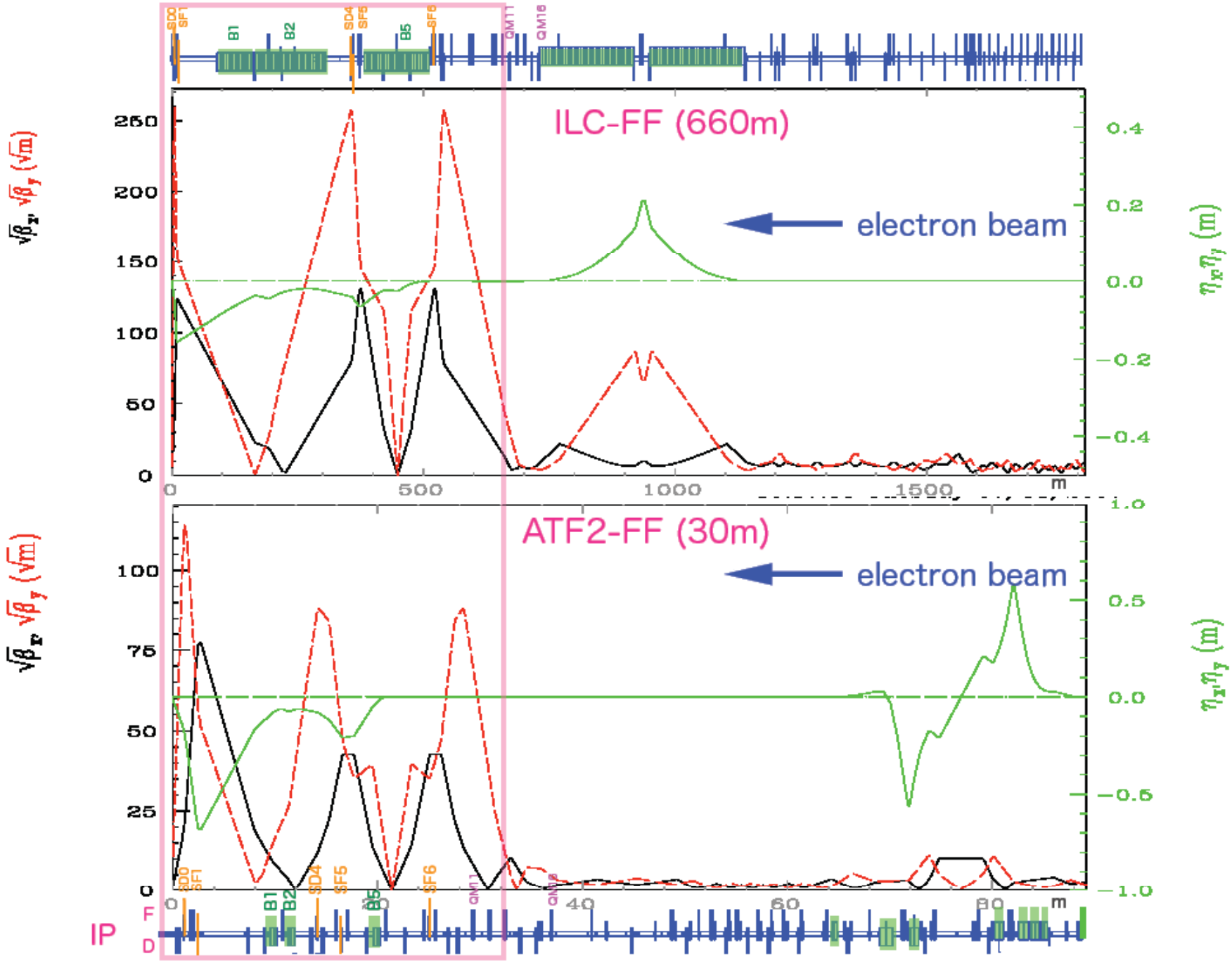


ATF2 goals

(A) Small nominal beam size
Obtain σ_y ~ 35nm
Maintain for long time

(B) Stabilization of beam center
Down to < 2nm by nano-BPM
Bunch-to-bunch feedback of ILC-like train

October, 2008


ILC-FF (660m)
electron beam
ATF2-FF (30m)
electron beam
IP
F
D
m

ATF2 construction in 2007-2008

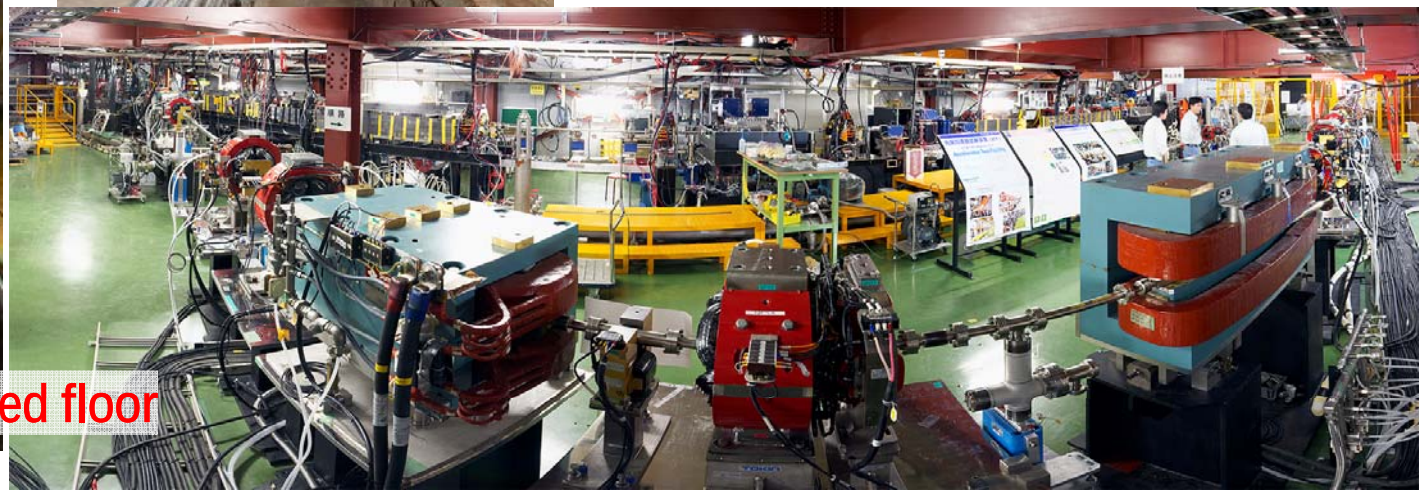
Assembly hall before construction

Assembly hall emptied for construction

Vacuum tube connected in Oct..

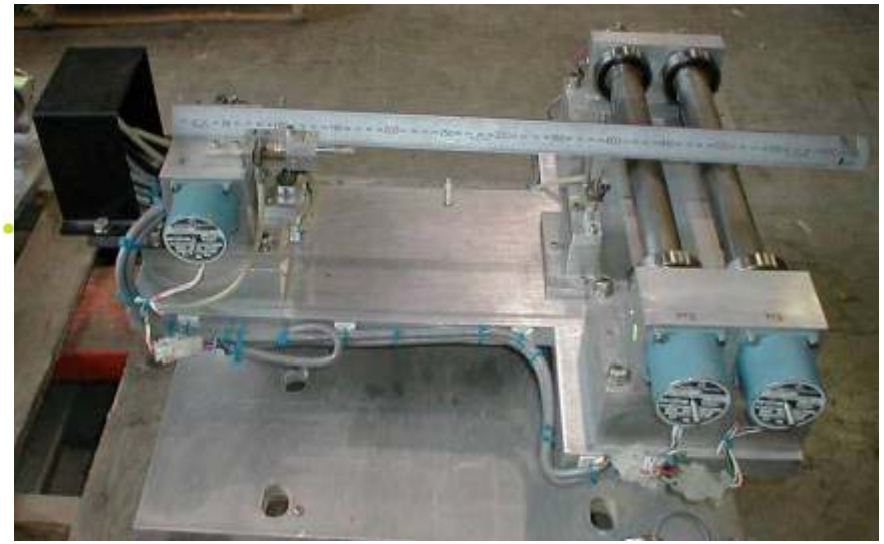
Construction of reinforced floor

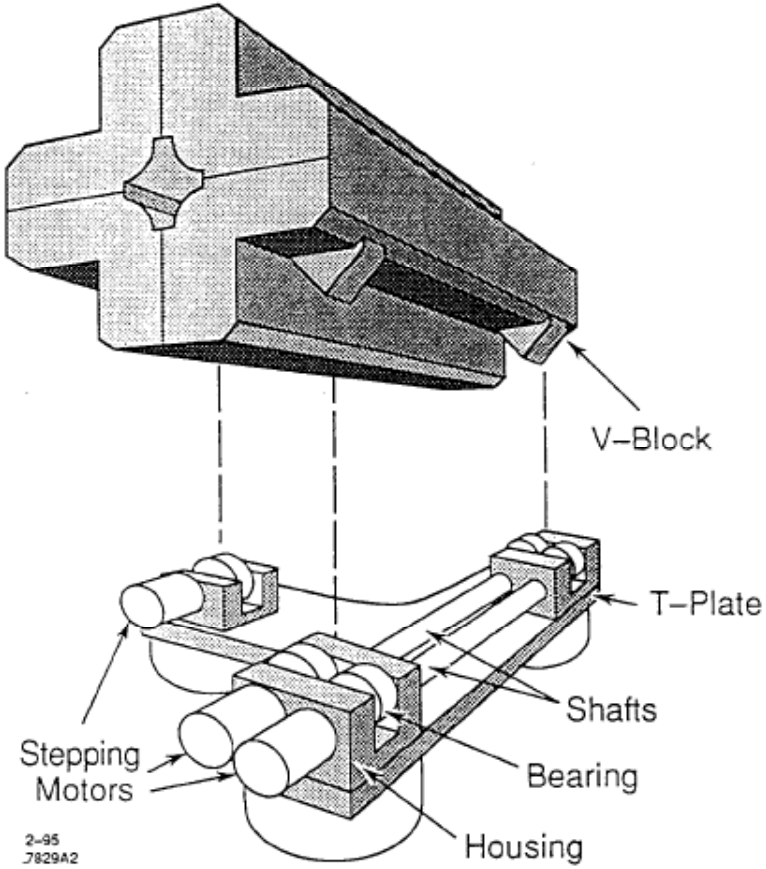
Construction of shielding



From extraction line to FF to be ready for Nov. beam commissioning

Beamline movers

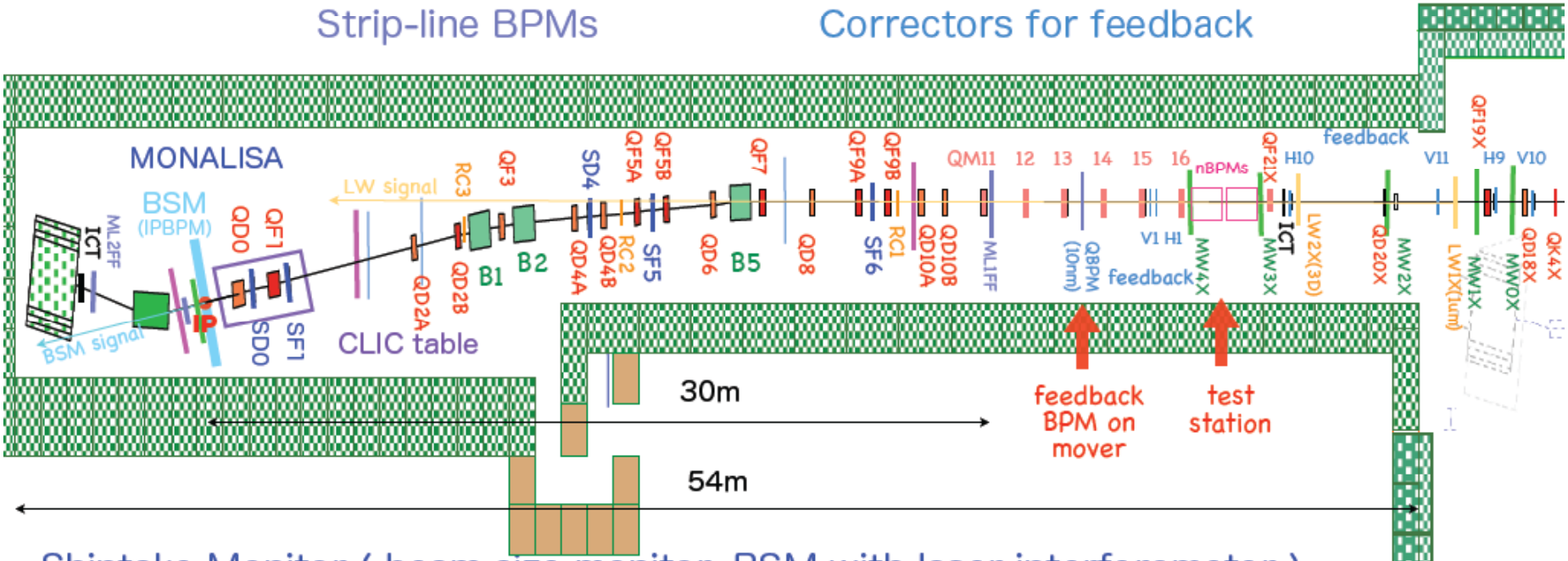




FFTB cam movers were refurbished and used for all magnets of ATF2 (except bends)

Advanced beam instrumentation and magnets at ATF2

- 22 Quadrupoles(Q), 5 Sextupoles(S), 3 Bends(B) in downstream of QM16
- All Q- and S-magnets have cavity-type beam position monitors(QBPM, 100nm).
- 3 Screen Monitors
- 5 Wire Scanners, Laserwires
- Strip-line BPMs
- Correctors for feedback

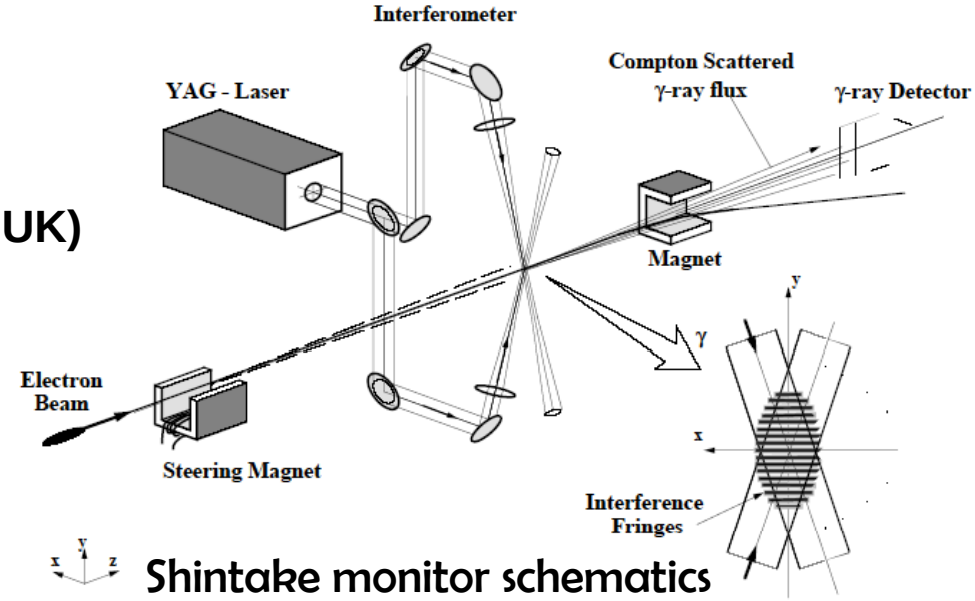


- Shintake Monitor (beam size monitor, BSM with laser interferometer)
- MONALISA (nanometer alignment monitor with laser interferometer)
- Laserwire (beam size monitor with laser beam for 1 μm beam size, 3 axies)
- IP intra-train feedback system with latency of less than 150ns (FONT)
- Magnet movers for Beam Based Alignment (BBA)
- High Available Power Supply (HA-PS) system for magnets

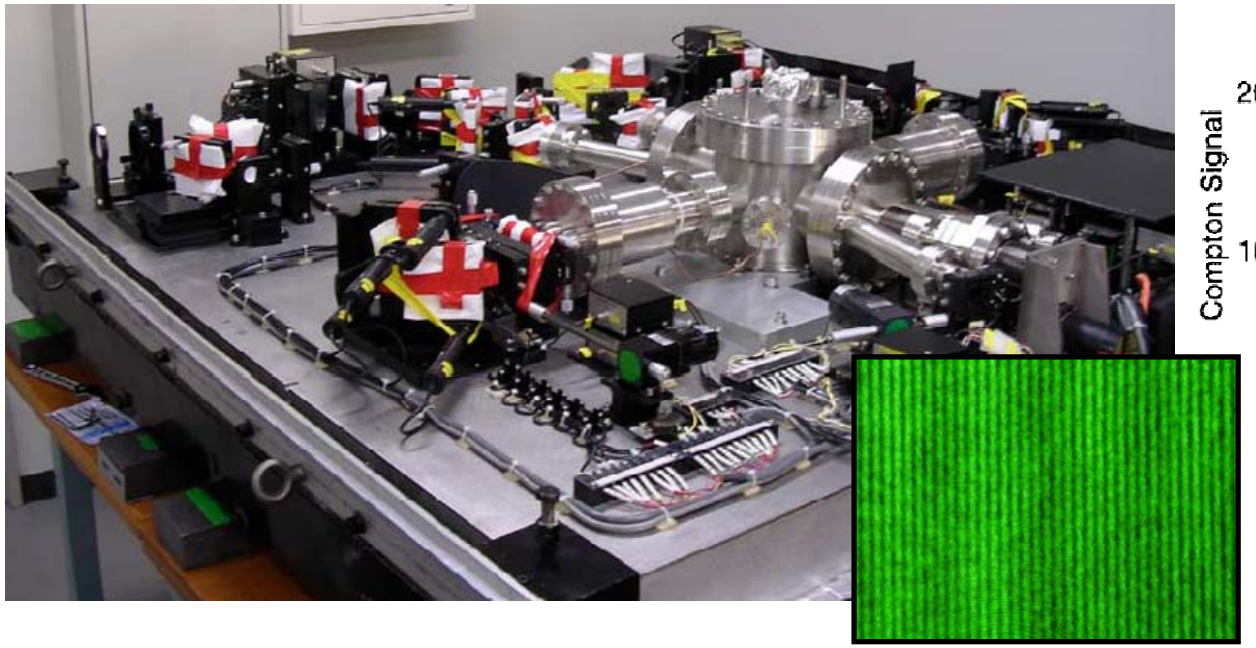
IP Beam Size monitor (BSM)

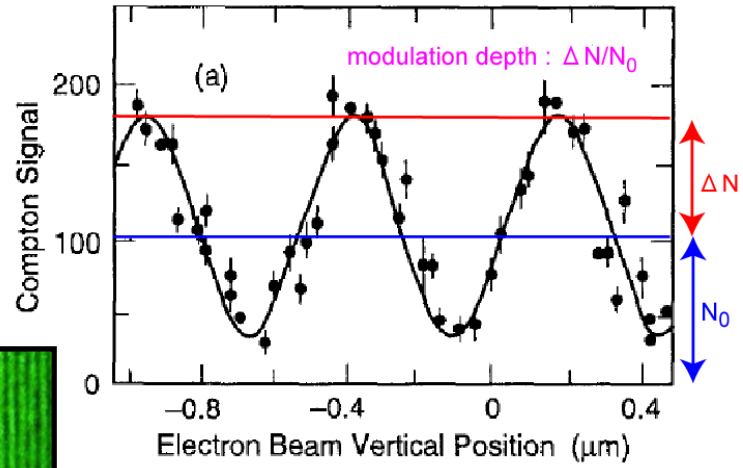
(Tokyo U./KEK, SLAC, UK)

- Significantly improved FFTB Shintake BSM
  - 1064nm=>532nm
  - σ_y: 35nm up to a few μm
  - phase scanning mode



Shintake monitor schematics

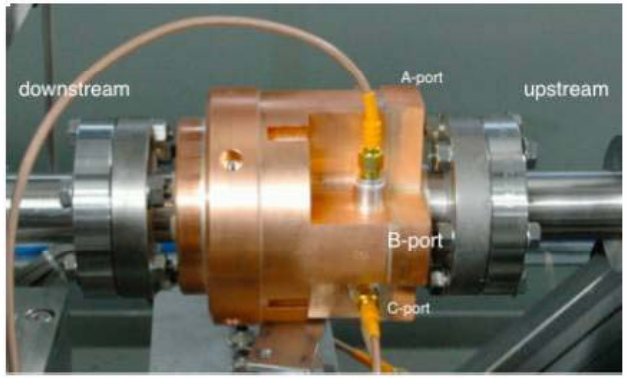




FFTB sample : σ_y = 70 nm

Cavity BPMs

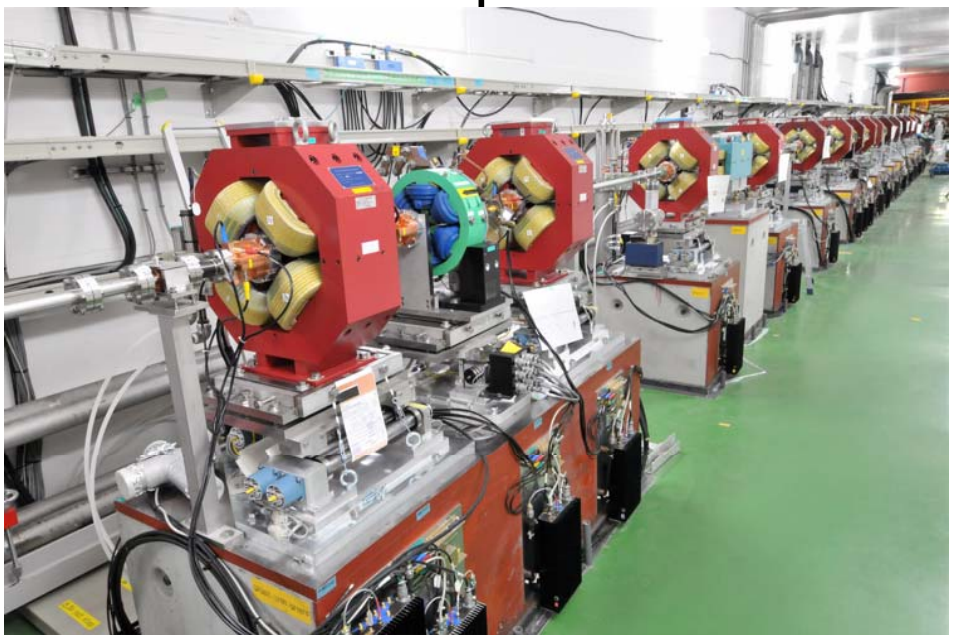
Cavity BPMs and front-end electronics modules will provide sub-micron resolution of beam position.



Cavity BPMs, for use with Q magnets with 100nm resolution (PAL, SLAC, KEK)

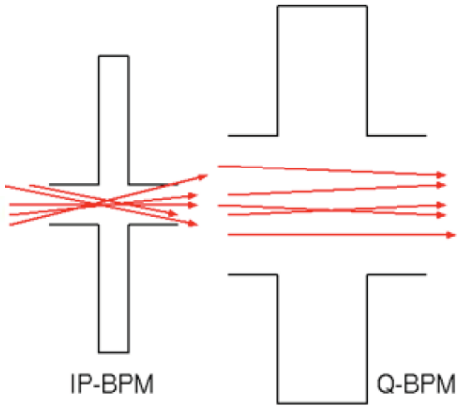
Prototype at PAL

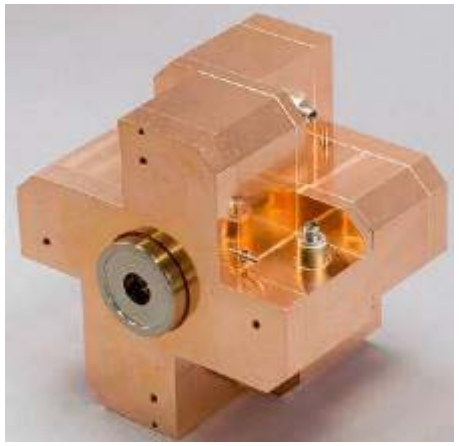
C-band dipole mode Reference cavity Downmix to ~25MHz Digitize at ~100Ms/s, ~14 bit. 100 nanometer resolution. Large dynamic range >500um



IP BPM

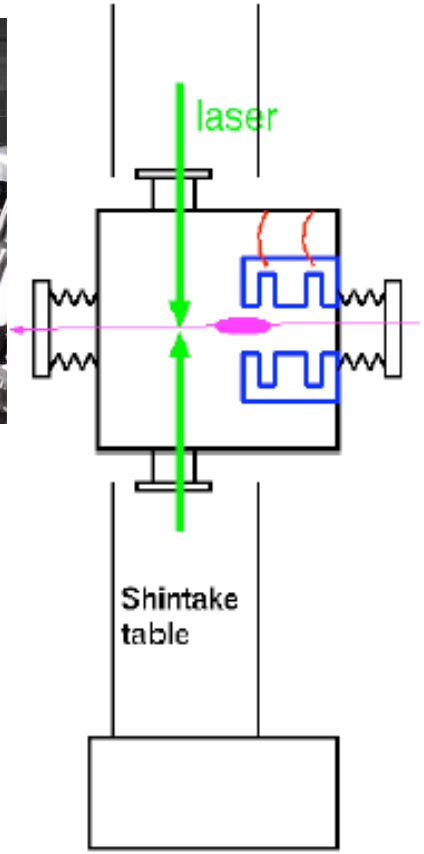
- Creates a reference at IP instead of opposite colliding beam
- => Need ~2nm resolution
- Challenge: ~100μrad angles at IP
- => Thin gap, small aperture, x-y separation



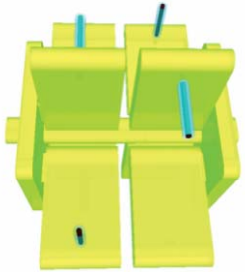


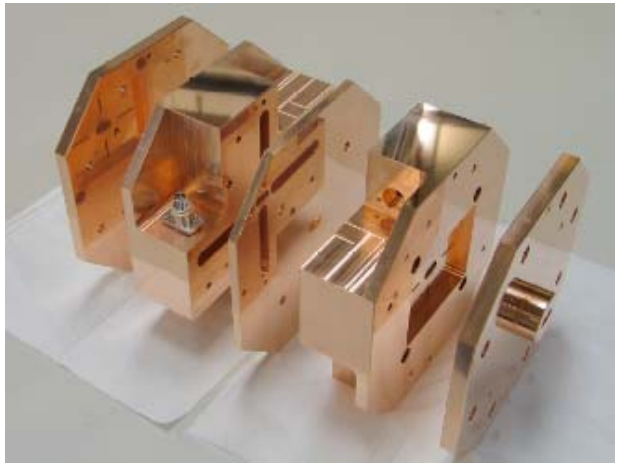
6.426 GHz (Y) and 5.712 GHz (X)

So far achieved resolution 8.7nm
dynamic range ~5 micron

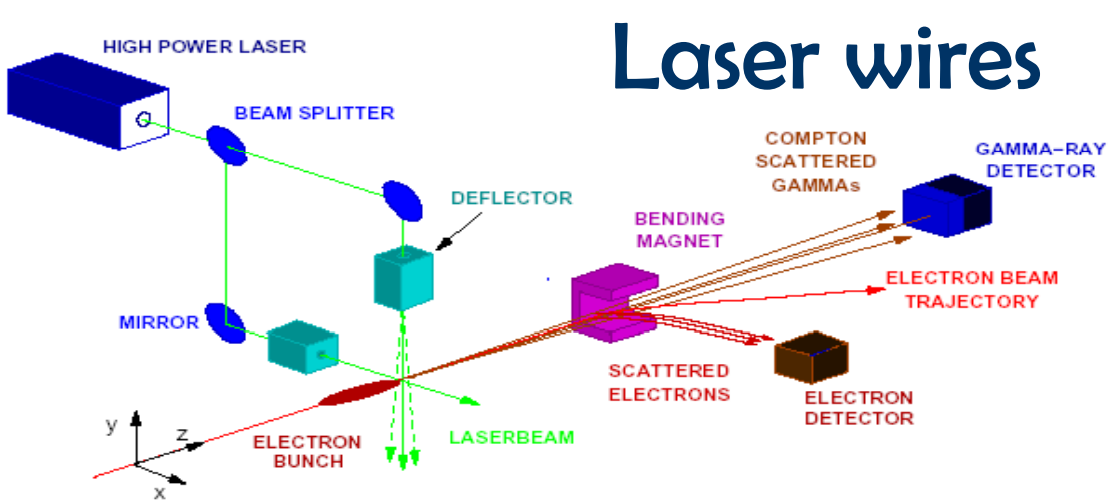


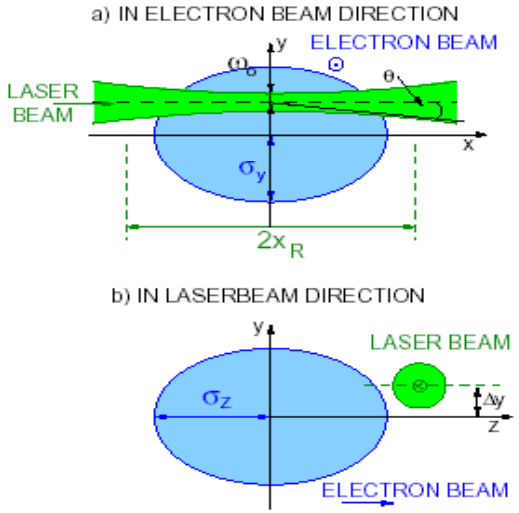
Target :
Cavity BPMs with 2nm resolution, for use at the IP (KEK)





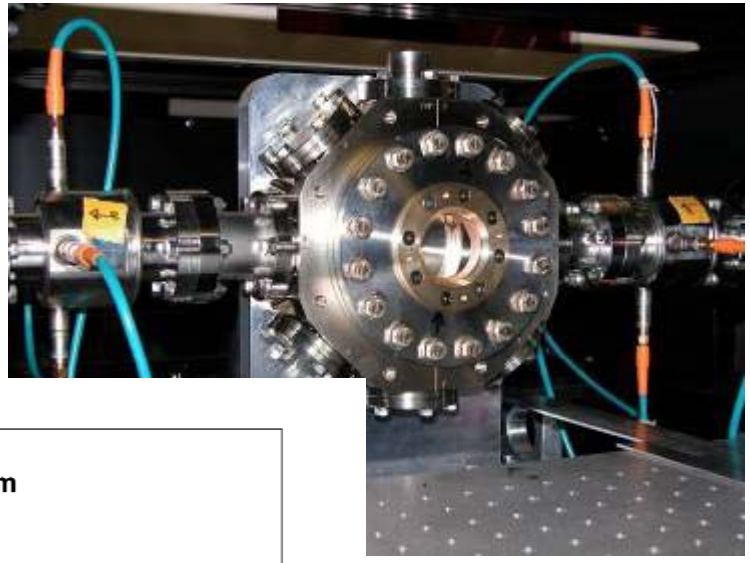
Laser wires

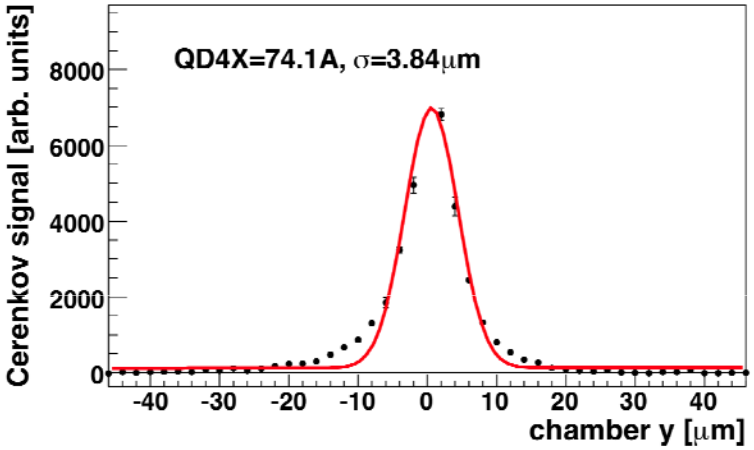




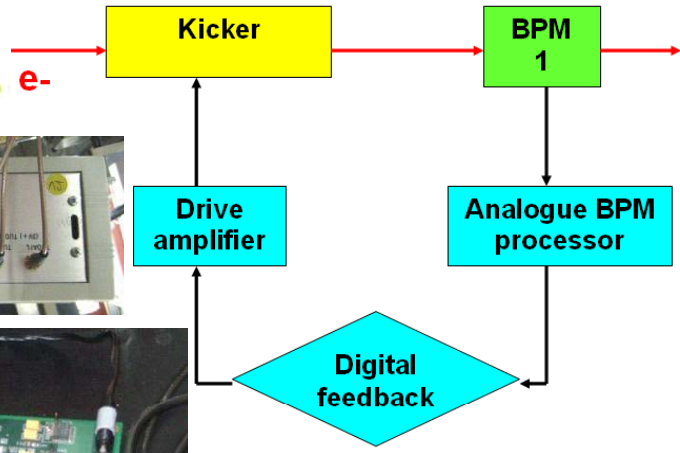
- Goal: non-destructive diagnostics for ILC
- (ATF2 to be tuned with carbon wires)
- Studies in ATF extraction line
- Aim to measure 1 μm spot beam
- Aim at 150ns intra-train scan
- To be located at ATF2 in a place with μm spot
- Presently achieved resolution ~3.0μm (limit by laser quality)

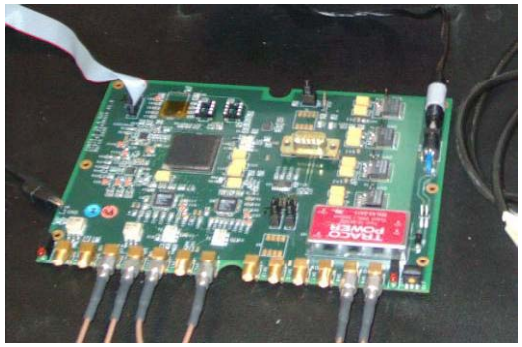
Laser wire chamber at ATF, Oxford and RHUL





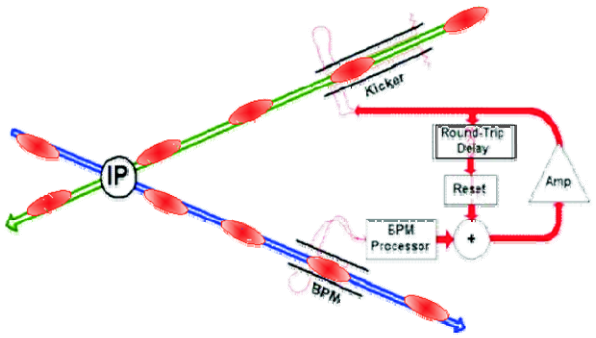
Fast feedback (FONT)

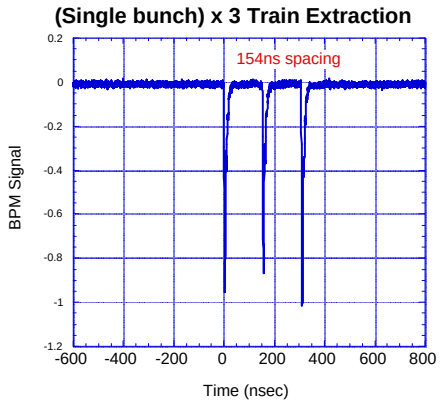




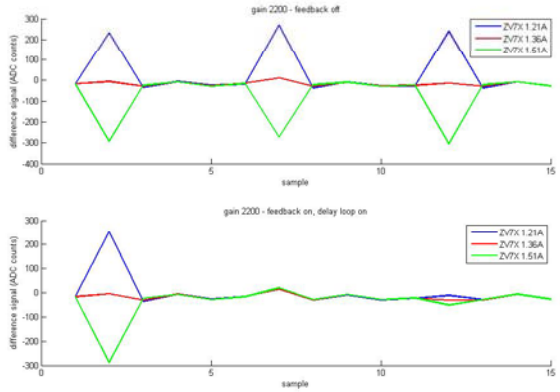
FONT – Feedback On Nanosecond Time scale Developments for ATF – digital, FONT4

- At ATF2, will have ~20 bunches spaced with150ns
- Feedback and feedforward will be used to straighten the train.
- FONT4: latency estimate
  - Irreducible latency: 14ns
  - Electronics latency: 118ns
  - Total latency: 132ns



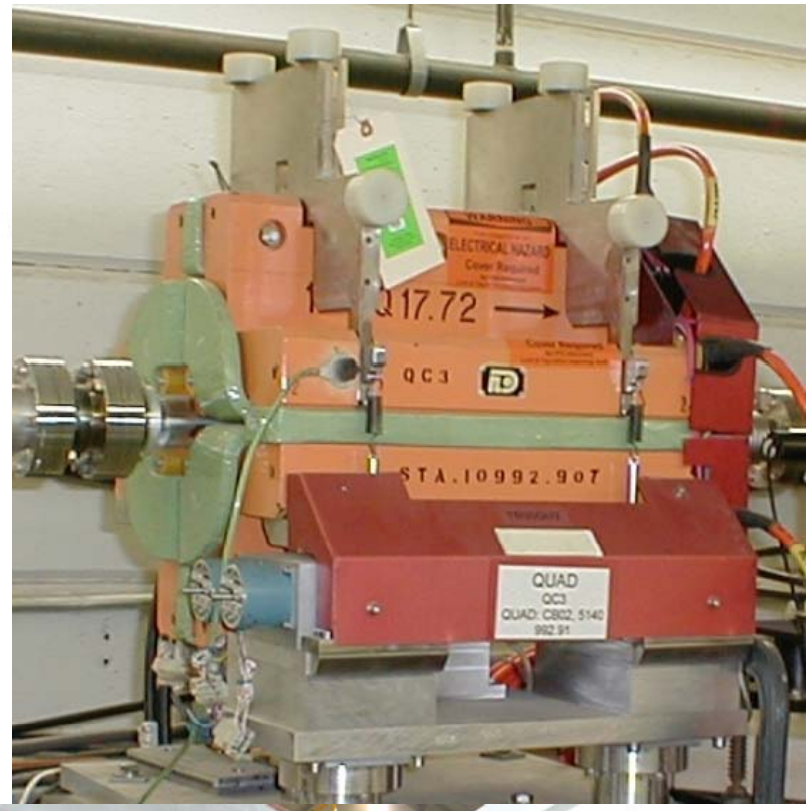


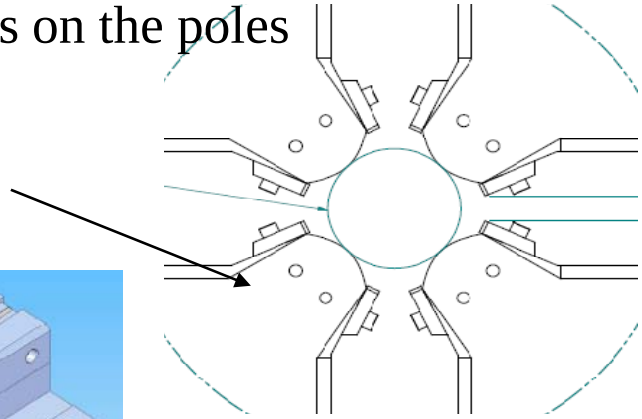
3 bunches, 154ns spacing

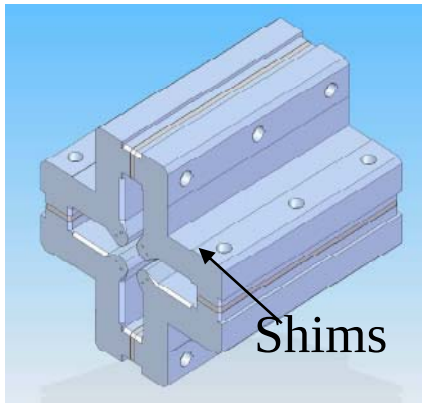


Final Doublet magnets

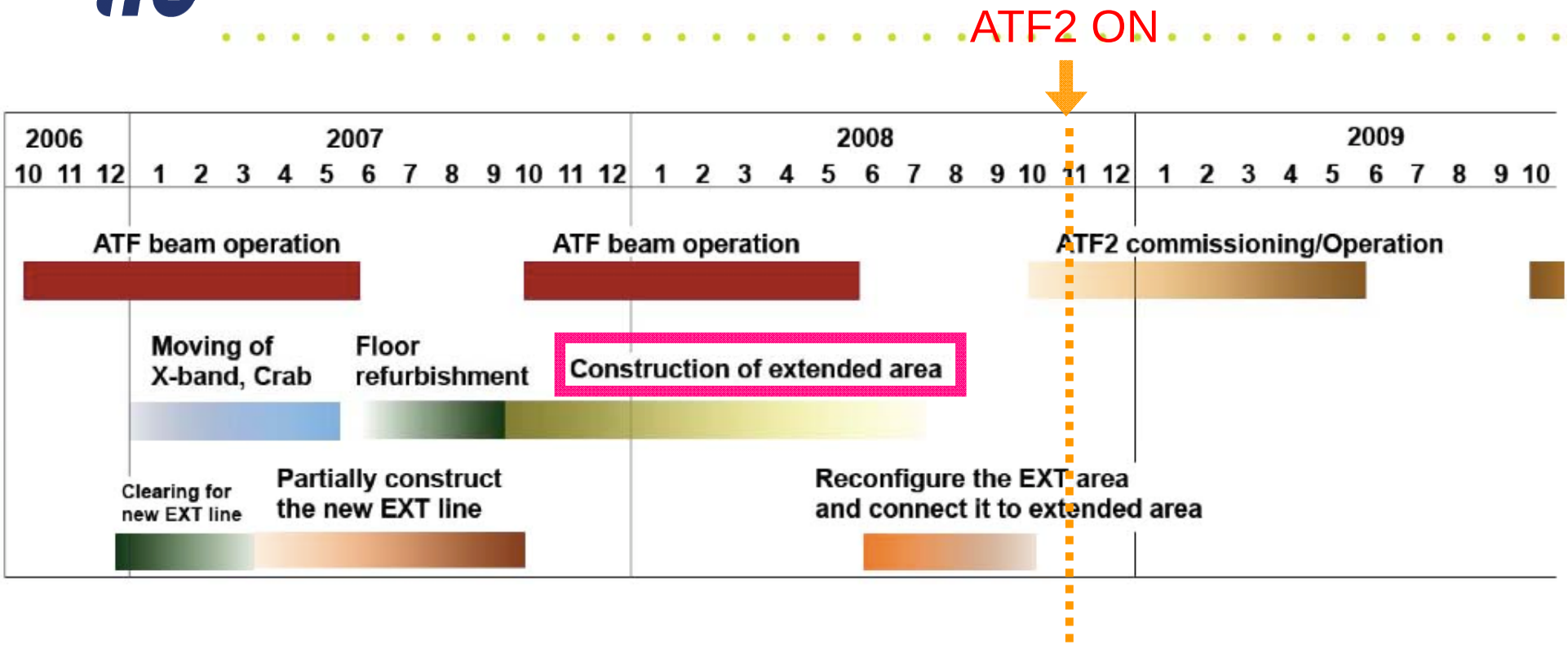
- FFTB quad was used to produce FD
- Aperture increased from 35mm to 50mm with shims at SLAC
- Shims on the poles to reduce 12th pole
- FD sextupoles are from used magnets too
- FD integration at LAPP, Annecy







ATF – beam operation schedule



Commissioning to start in November 2008

Summary

Test Facility	Deliverable	Date
Hardware development, Optics and stabilisation demonstrations:		
ATF	Demo. of reliable operation of fast kickers meeting the specifications for the ILC damping ring.	2010
	Generation of 1 pm-rad low emittance beam	2009
ATF2	Demo. of compact Final Focus optics (design demagnification, resulting in a nominal 35 nm beam size at focal point).	2010
	Demo. of prototype SC and PM final doublet magnets	2012
	Stabilisation of 35 nm beam over various time scales.	2012
Electron cloud mitigation studies:		
CESR-TA	Re-config. (re-build) of CESR as low-emittance e-cloud test facility. First meas. of e-cloud build-up using instrumented sections in dipoles and drifts sections (large emittance).	2008
	Achieve lower emittance beams. Meas. of e-cloud build up in wiggler chambers.	2009
	Characterisation of e-cloud build-up and instability thresholds as a func. of low vertical emittance (≤20 pm)	2010
DAΦNE	Fast kicker design and pulser reliability check	2010
	Characterisation of e-cloud build-up and instability thresholds	2010
SLAC/LLNL	Fast kicker pulser development	2010

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