ATF2 Technical Review

KEK, April 3rd 2013

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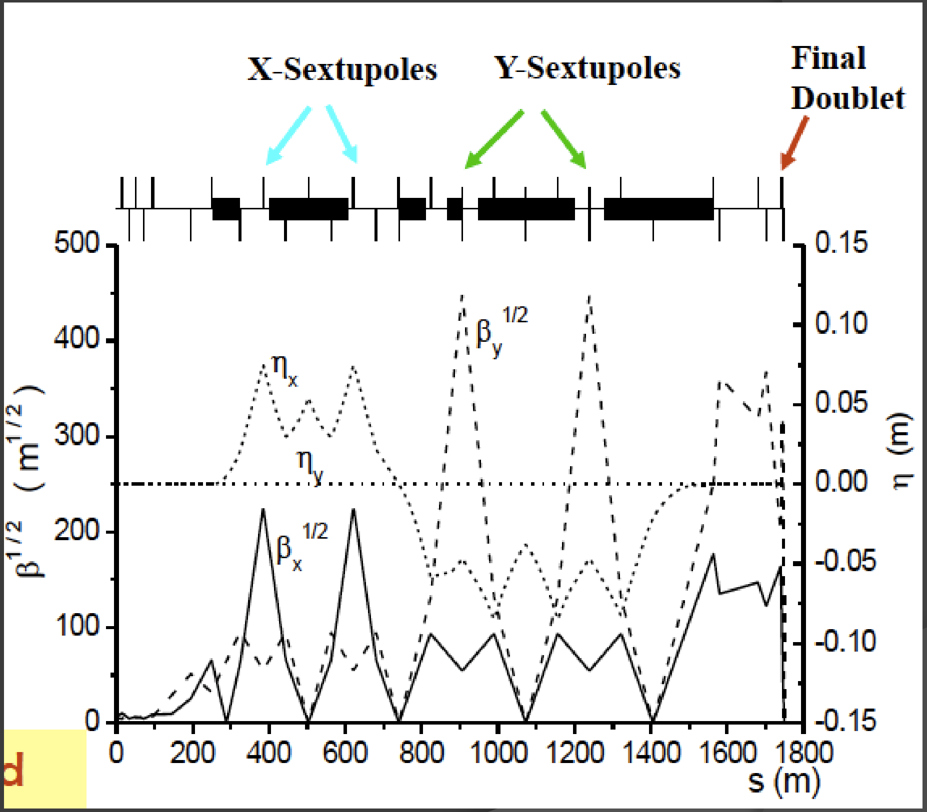
ILC FFS Optics Design and Beam Dynamics Verification by ATF2

Overview

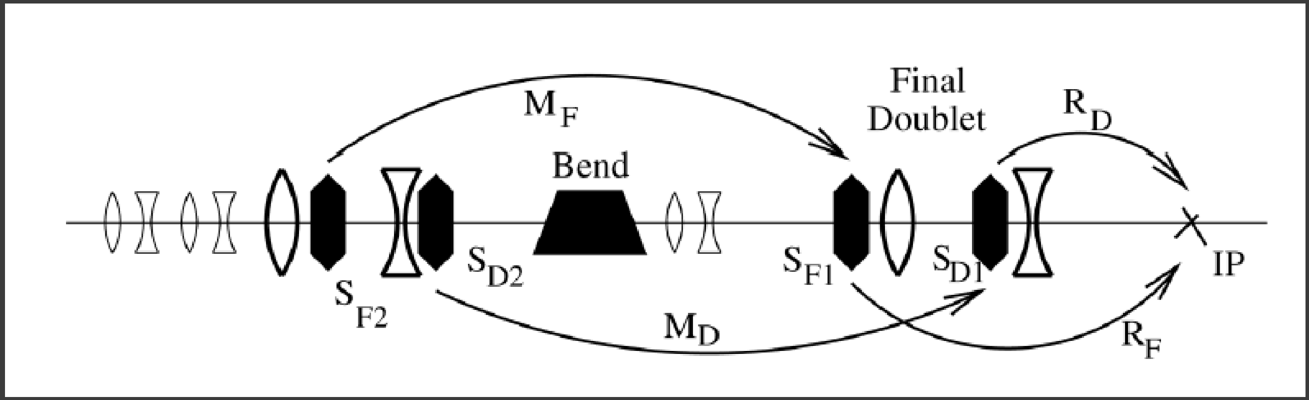
- FFS design for LC
- FFS design parameters
  - ILC, ATF2, FFTB, CLIC
- What are we testing at ATF2 and why?
- Simulation-based study of tuning process for ILC and ATF2
  - How to demonstrate capability of reaching ILC luminosity / ATF2 waist beam properties.
  - Using ATF2 results to verify this process.

“Traditional” FFS Design

- Non-local correction of FD chromaticity in dedicated upstream sections
- Pairs of sextupoles with –I transforms
- Tested at FFTB
- Some problems
  - Compensation of aberrations non-ideal as –I transform destroyed for off-energy particles
  - Large aberration generated in beam tails
  - Separated correction sections makes FFS very long

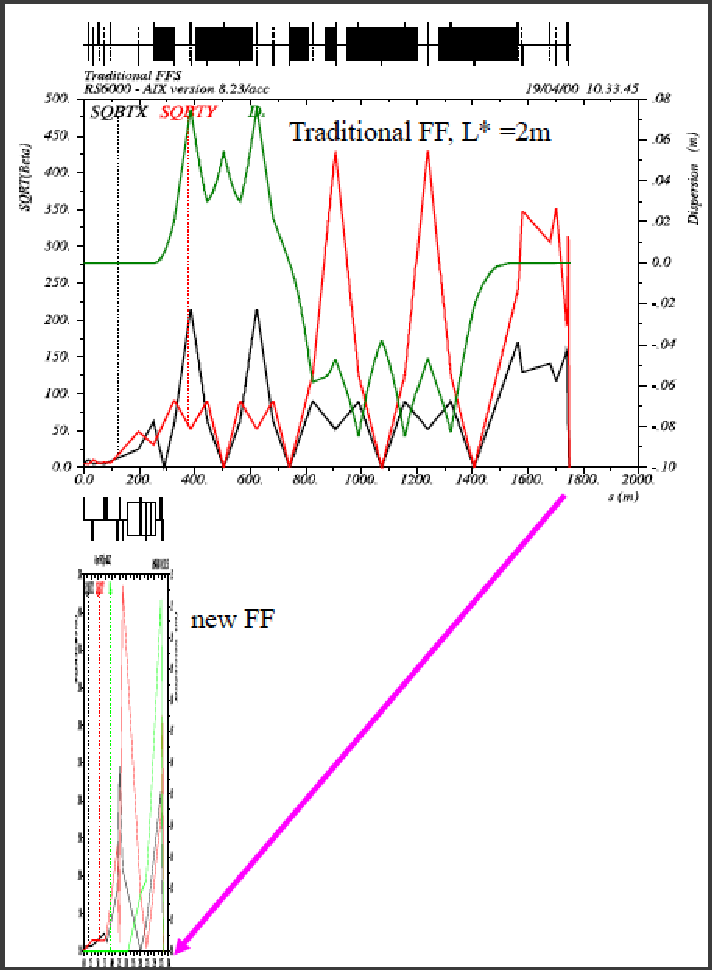


FFS with Local Chromatic Correction



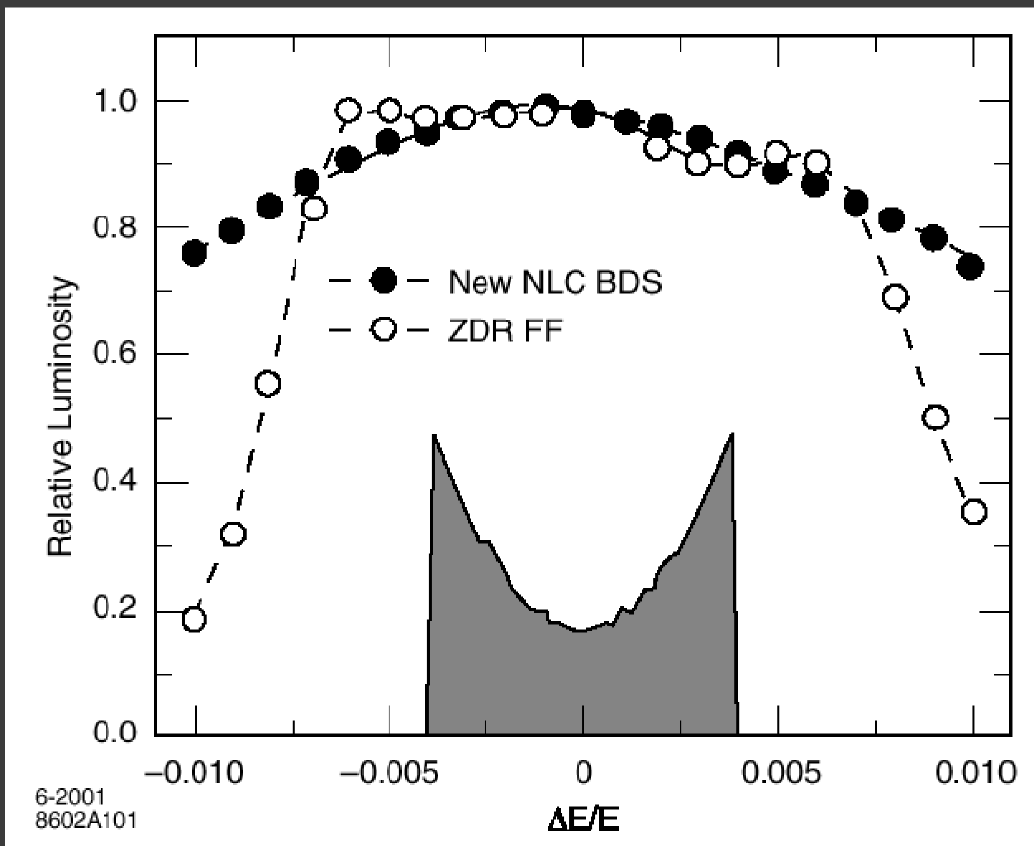
- Originally proposed by P. Raimondi & A. Seryi
- Correct chromaticity locally within final doublet using pairs of interleaved sextupoles
- Upstream bend magnet generates required horizontal dispersion
- Geometric aberrations cancelled with additional sextupoles placed upstream of bends in non-dispersive region.

Shorter FFS



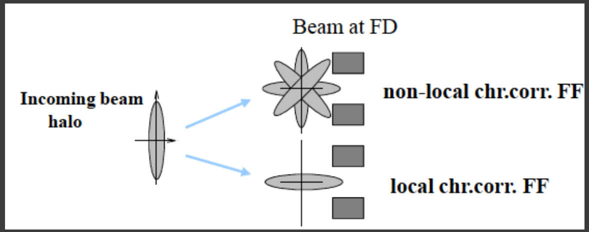
- Local scheme yields much shorter design
  - Cost savings
- NLC example shown here
  - 1800m -> 300m

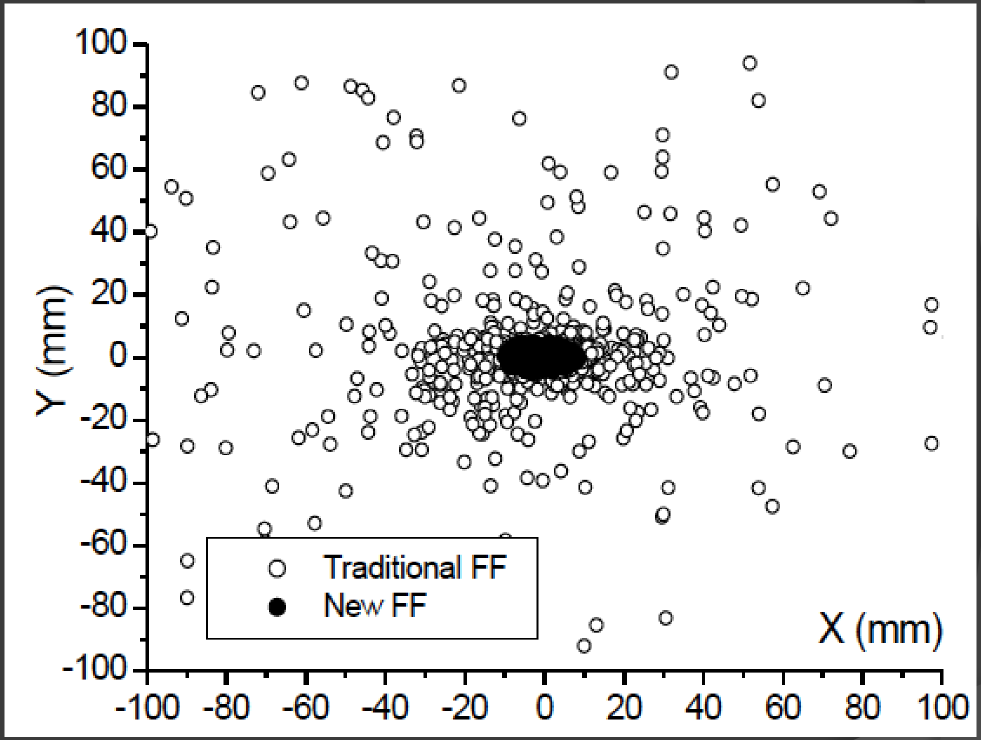
Improved IP Energy Bandwidth



- Energy bandwidth of local scheme can be better than non-local scheme
- NLC example shown

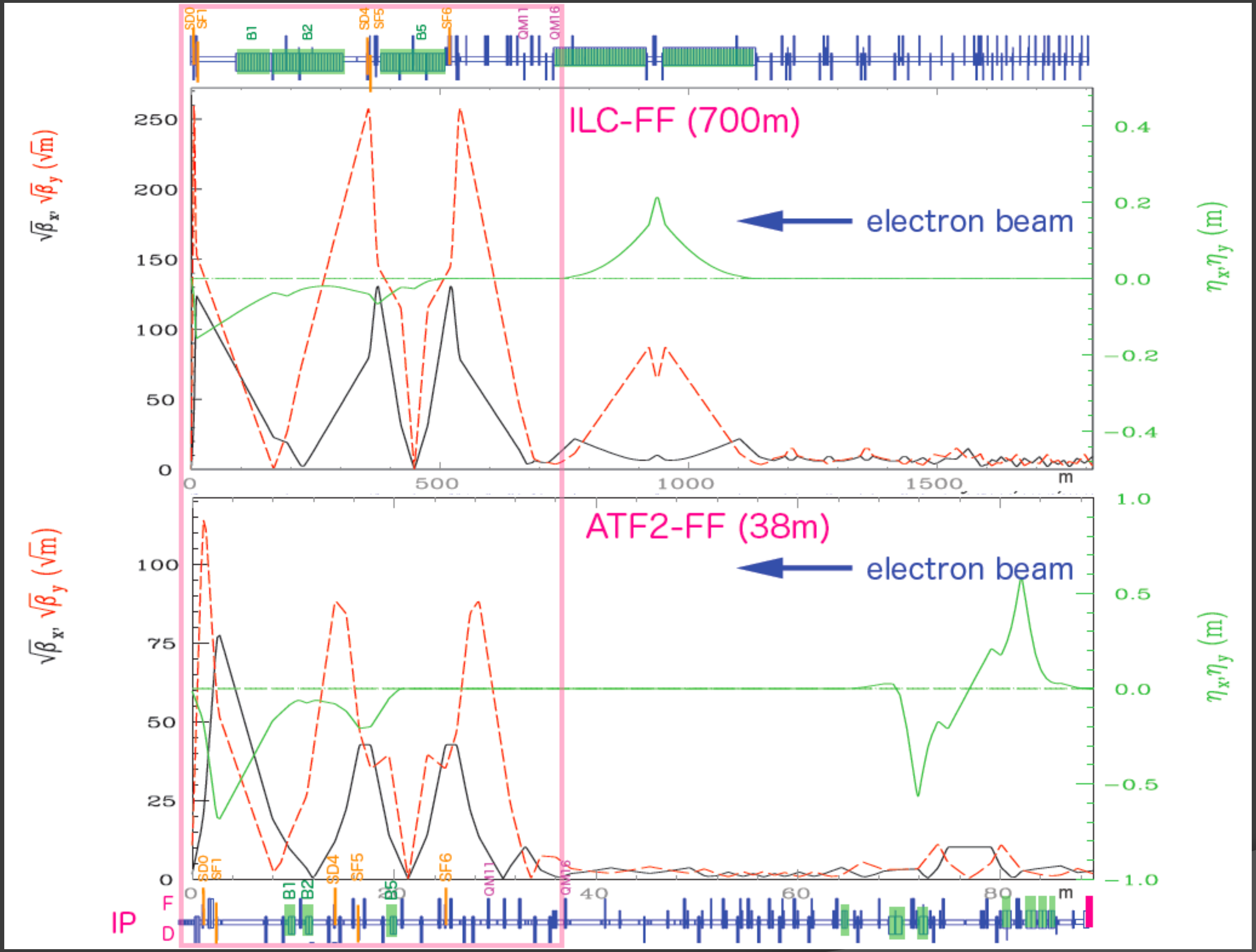
Aberration and Halo Generation





- FF with non-local chr. corr. generate beam tails due to aberrations + does not preserve betatron phase of halo particles
- FF with local chr. corr. has much less aberrations and it does not mix phases particles

Scale Test of ILC FFS Optics



- Scaled design of ILC local-chromaticity correction style optics.
- Same chromaticity as ILC optics.
- At lower beam energy, this corresponds to goal ~37nm IP vertical beam waist.

LC FFS Design Parameters

	ILC (TDR 500 GeV)	ATF2	FFTB	ATF2 (pushed)	CLIC (CDR 3 TeV)
L^* (m)	3.5 / 4.5 ^	1	0.4	1	3.5
ε_y (pm.rad)	0.07	12 (25*)	34	12	0.003
$\xi_y \sim (L^*/\beta^*_y)$	7,300/9,400 ^	10,000	4,000	33,000	50,000
σ_E	0.07/0.12 % +	0.1 %	0.3 %	0.1 %	0.3 %
$\Delta\sigma_y/\sigma_y \sim (\sigma_E.L^*/\beta^*_y)$	5/9 , 7/11 +,^	10	12	33	150
σ_y (nm)	5.9	37 (50*)	60	20	1
σ_y (nm) *Achieved*	---	73 +/- 5 *	77 +/- 7	---	---
β^*_x (mm)	11	4 (40*)	10	4 - 40	4
β^*_y (mm)	0.48	0.1	0.1	0.03	0.07

~ Tuning difficulty

compare with chromatically uncorrected ~450nm / 700nm

**Dec 2012*
+ [e+ / e-]
^ SiD / LCD

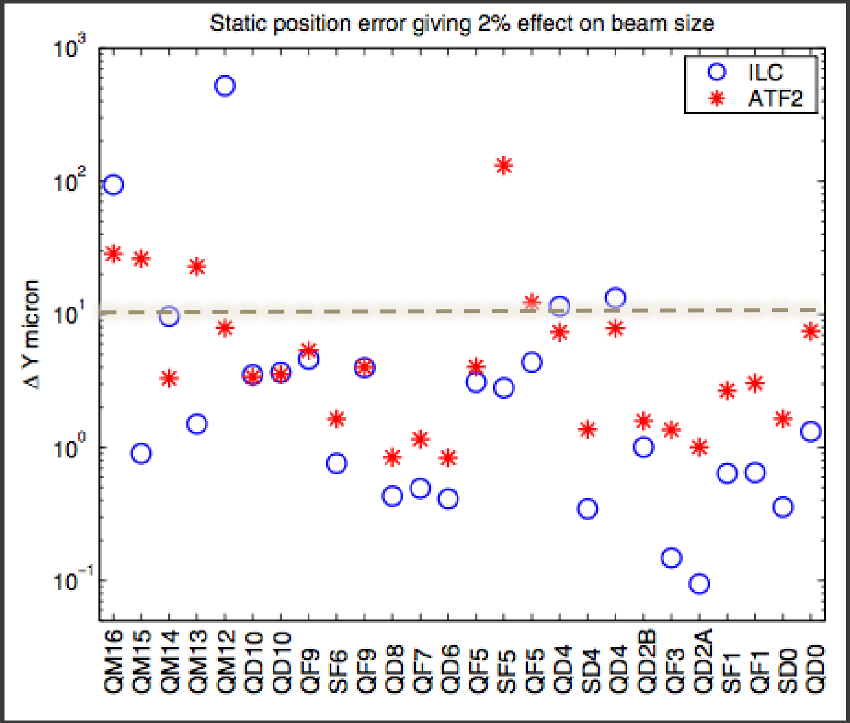
Why Test?

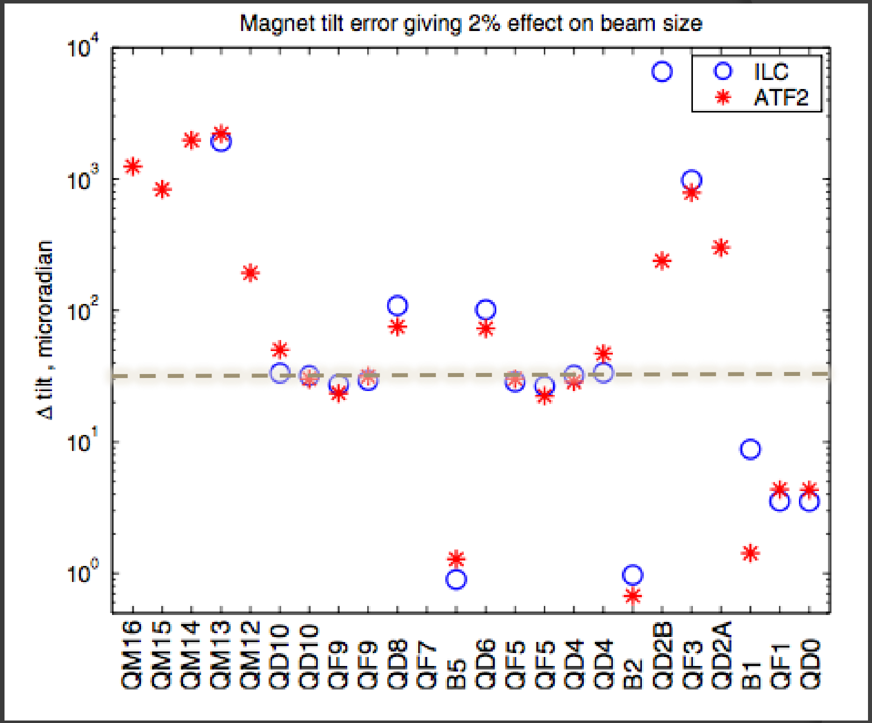
- Complicated "balancing of higher-order terms" in FFS design leads to very tight tolerances
  - Try to model effects where realistic error conditions destroy properties of FFS
  - Overcome these weaknesses by designing "tuning knobs" and simulate their effectiveness
  - ATF2 can validate this procedure by comparisons of accelerator tuning with expected results from simulations
- Once tuned, dynamics effects cause drifts on multiple timescales of IP beam size and position
  - Model all expected sources of dynamic drift and design countermeasures
  - Test in detailed simulations
  - ATF2 experience and implementation of dynamic drift countermeasures will validate simulations
- By validating simulations of magnitude, effect and mitigation of 'static' and 'dynamic' imperfections we will gain confidence in our ability to design and run similarly designed optics for future high-energy machines

‘Static’ Error Sources

- Installed positions
  - Horizontal / vertical / roll
  - Survey tolerances for ATF2 typically ~100um / 300urad
- Alignment
  - BPM -> magnet field centres
  - Installations for ATF2 10’s -> few-100 um
- Magnetic fields
  - Systematic and random integrated field strength deviations from model
  - Quality of fields – relative strengths of magnetic multipoles

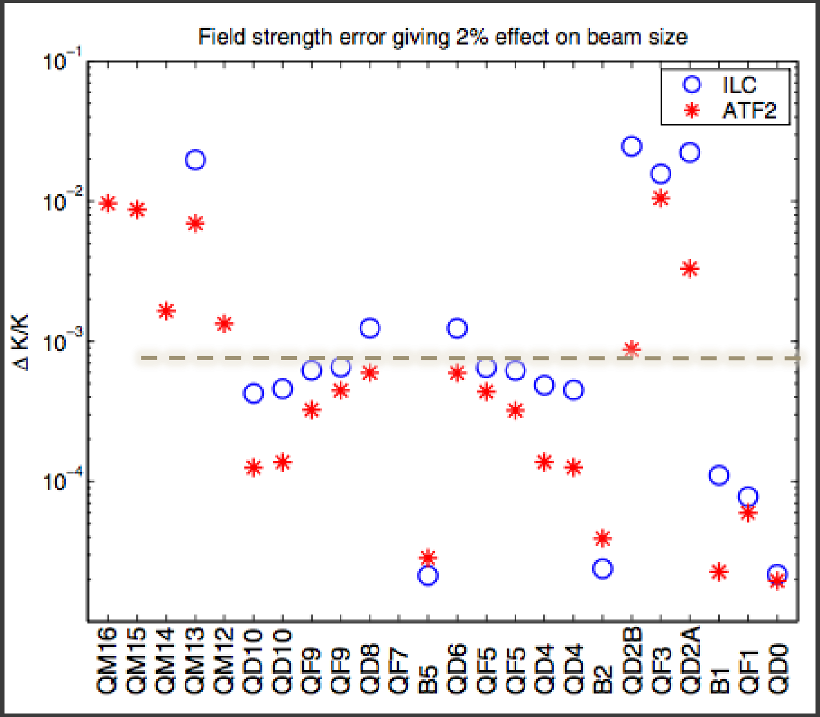
Tolerances on Placement Errors





- Like ILC (and CLIC), tolerances for many magnets much tighter than can be realised
- Need to rely on active tuning

Tolerances on Magnetic Field Errors



- Typical expectations of magnetic field accuracy 1e-3 – 1e-4
- Several magnets have much greater field accuracy requirements

FFS Tuning

- Have no expectations of producing or placing magnetic elements with these extremely tight tolerance requirements
- Instead, design “tuning knobs” to remove the aberrations at the IP that exceeding these tolerance requirements generates
- This generates a new set of “dynamic” tolerances for the optics design based on the ability for the designed tuning knobs’ ability to remove the expected aberrations
- Simulations including tuning knobs and all expected error sources must be run to asses the design of the FFS

Designing & Simulating FFS Tuning Procedure

- Specify full list of error sources
  - Use measurement data where available
- Generate multiple lattices with different error configurations from error list
  - MC simulations performed across, typically, 100 lattices
- Simulate initial steering/BBA/EXT coupling/EXT dispersion correction etc for each lattice seed
- Make a tuning knob to correct most common aberration from 100 seeds
- Apply this same knob to all 100 seeds
- Repeat last 2 steps until beam size converges

> - Simulations performed by multiple people using multiple simulation tools
>   - e.g. Lucretia, MAD, MADX, MAPCLASS, SAD, PLACET
> - Critical to avoid systematic errors creeping into simulations and for cross-checking. Very easy to make mistakes.

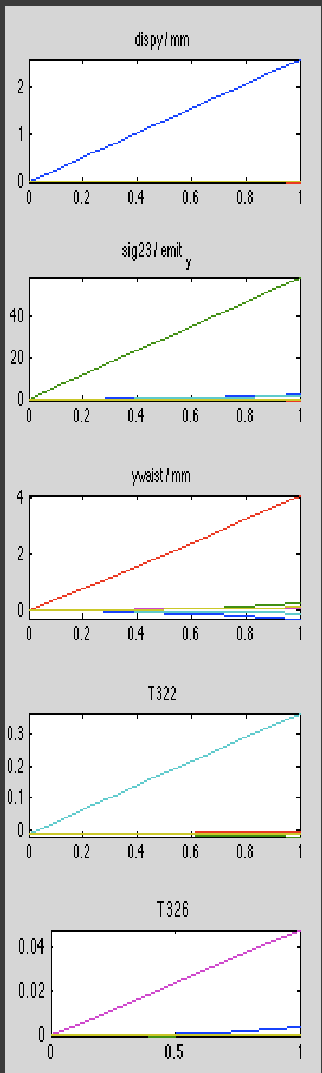
Aberrations @ IP (ATF2)

- Aberrations generated by lattice imperfections that need to be dynamically tuned are (in order of importance determined by simulation):
  - <x'y> coupling
  - Vertical waist offset
  - Vertical dispersion
  - Y22
  - Y26

These 2nd order terms also found to be important during ATF2 tuning experience

- In simulation, tuning of all aberrations by combinations of X/Y sextupole moves
- 4 skew-sextupoles added in 2012 in ATF2
  - Motivated by suspected larger than expected multipole components in some magnets.
  - Useful additional tool for orthogonal 2nd-order knobs, gives greater dynamic range to 1st-order knobs by sextupole moves
  - Worth considering for ILC…

ATF2 Tuning Knobs



Vertical Disperson

<x’y> coupling

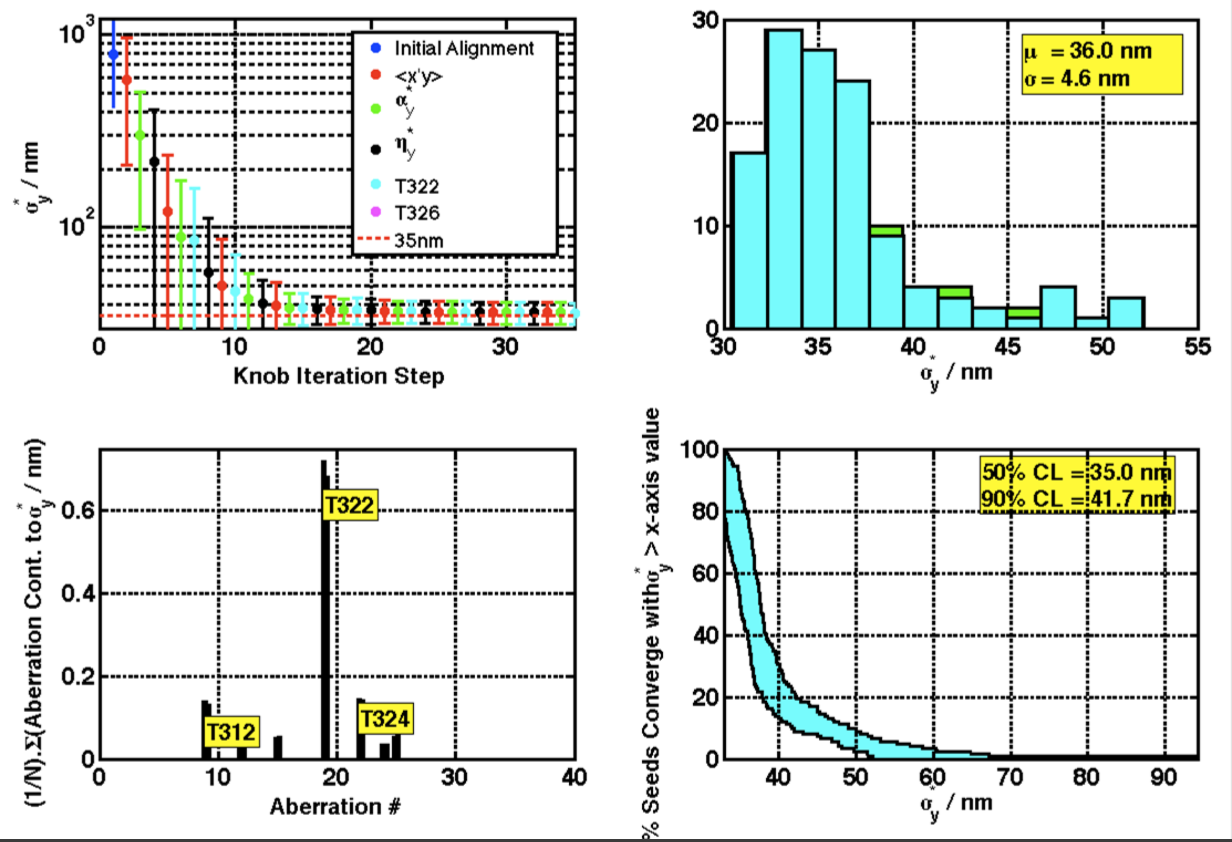
Vertical Waist

T322

T326

- Orthogonal knobs as shown developed using simulation framework
  - Also orthogonalise knobs to reduce horizontal dispersion and waist degradation
- Range of applicability of a given knob given by
  - Degree of contamination to other aberrations
  - Range of mover system
  - Degradation of orthogonality by lattice/alignment errors
- The range of aberration correction capability provides the true “dynamic” tolerances of a given lattice design

ATF2 Tuning Simulation



- Simulated tuning performance for a specific lattice design
- Lattice/tuning designs and simulations performed using different platforms by different groups for cross-checking
  - Lucretia, SAD, MADX (MAPCLASS), Placet

Tuning Performance Study with Different Optics

	BX1BY1	BX2.5BY1	BX10BY1
σ_y (50% CL) / nm (core size)	39.6	35.5	34.8
σ_y (90% CL) / nm (core size)	48.3	43.1	41.8
P(σ_y<37nm) / %	32	66	77
AGauss Spread (50%CL) / nm	6.8	4.0	2.7
AGauss Spread (90%CL) / nm	19.9	11.9	7.2
Convergence (lower better)	695	1183	992
Residual aberrations	T324 T326 T314	T324 <x'y> α_y	T322 T324 T312

- Tuning performance for different IP beta_x configs
- Pre-QF1FF replacement
- Motivated BX10BY1 optics due to tuning performance

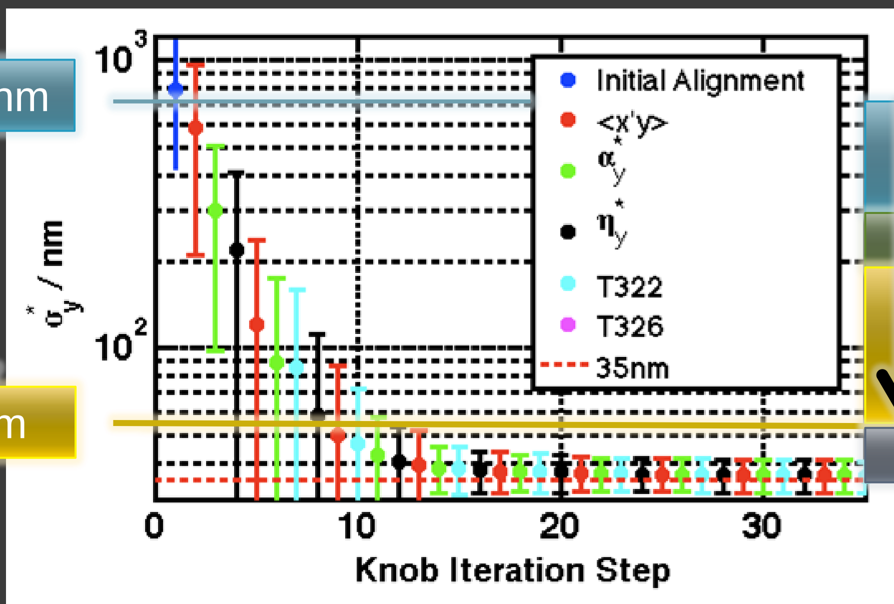
Dec 2012 Results

SIMULATION

Estimated Tuning Effects

750nm

60nm



Not required 2013
(bad sext coil or mag. material in skew-sext ??)

linear knobs ~400nm

~~**non-linear knobs ~100nm**~~

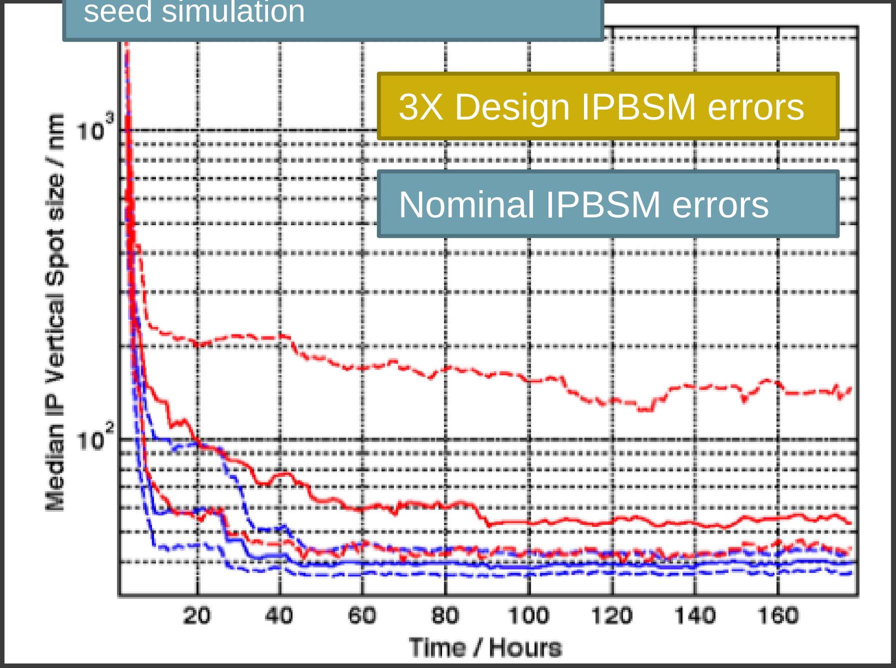
wakefield + steering effects ~150nm

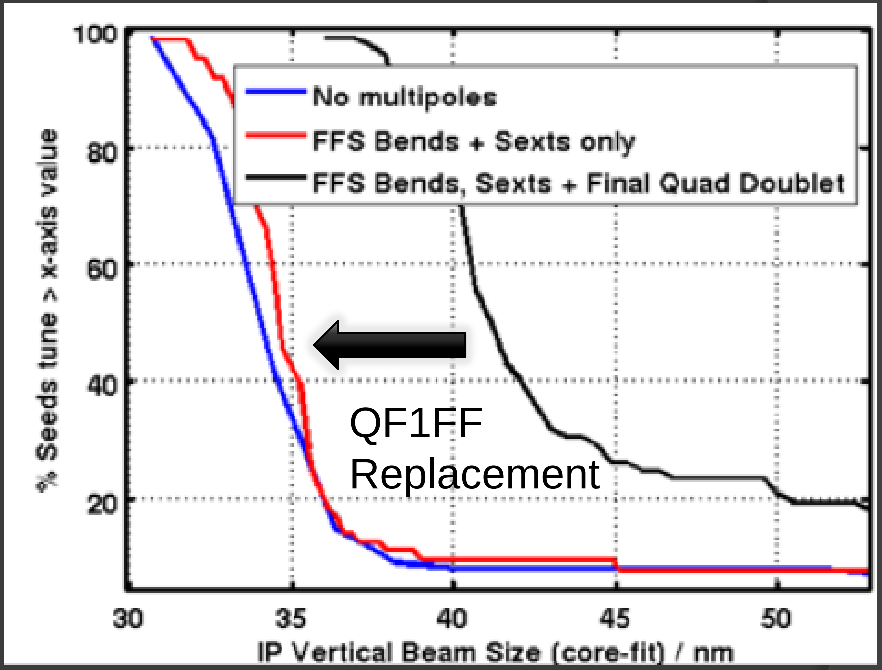
remaining 20nm to reach min beam size for measured emittance and IP beta

- Measured 73nm @ 25pm == 60nm @ 12pm (min 66nm == 53nm)
- Estimate effect of tuning knobs from corrections actually applied over ~3 week period
  - Corrections in this period not applied in an ideal way for this analysis
  - Re-asses after goal 1 achieved, then go back and tune in most efficient way possible

Simulated Long-Timescale Tuning at ATF2

Median, 10% and 90% CL vertical beam sizes at IP shown from 100-seed simulation





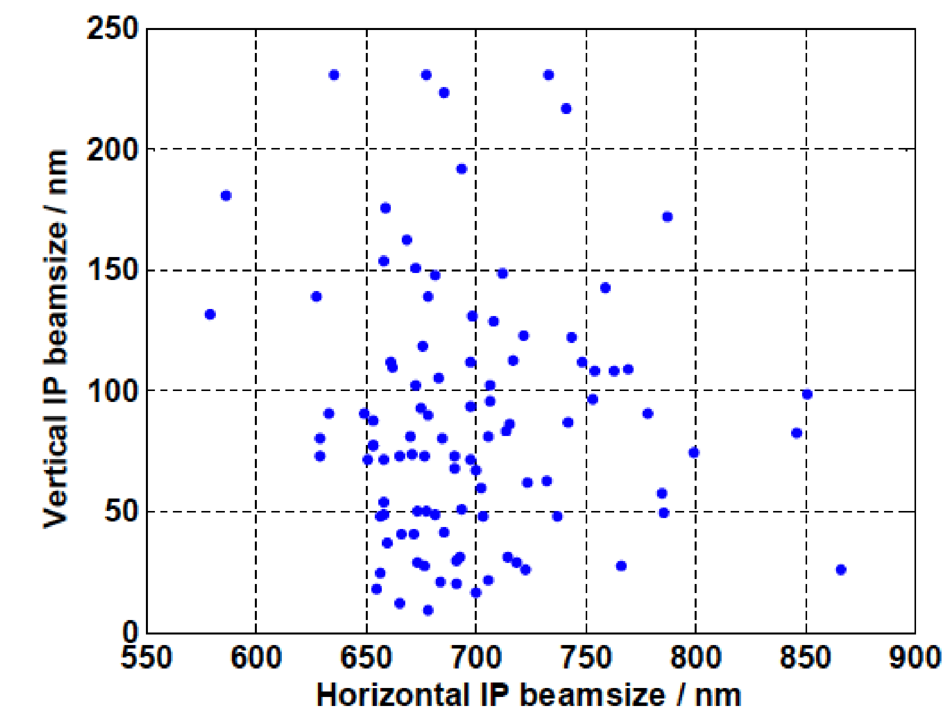
	20 mrad	10 mrad	1 mrad	< 100urad
σ_y (50% CL)	137 nm	90.0 nm	38.3 nm	34.8 nm
σ_y (90% CL)	190 nm	73.4 nm	47.6 nm	41.8 nm

- Tuning results with IPBSM rotation (including <xy> knob)

- Tuning performance over long timescale, including dynamic effects.
- RHS: best observed beam spot per seed over LHS time period.
- Results dependent on IPBSM performance

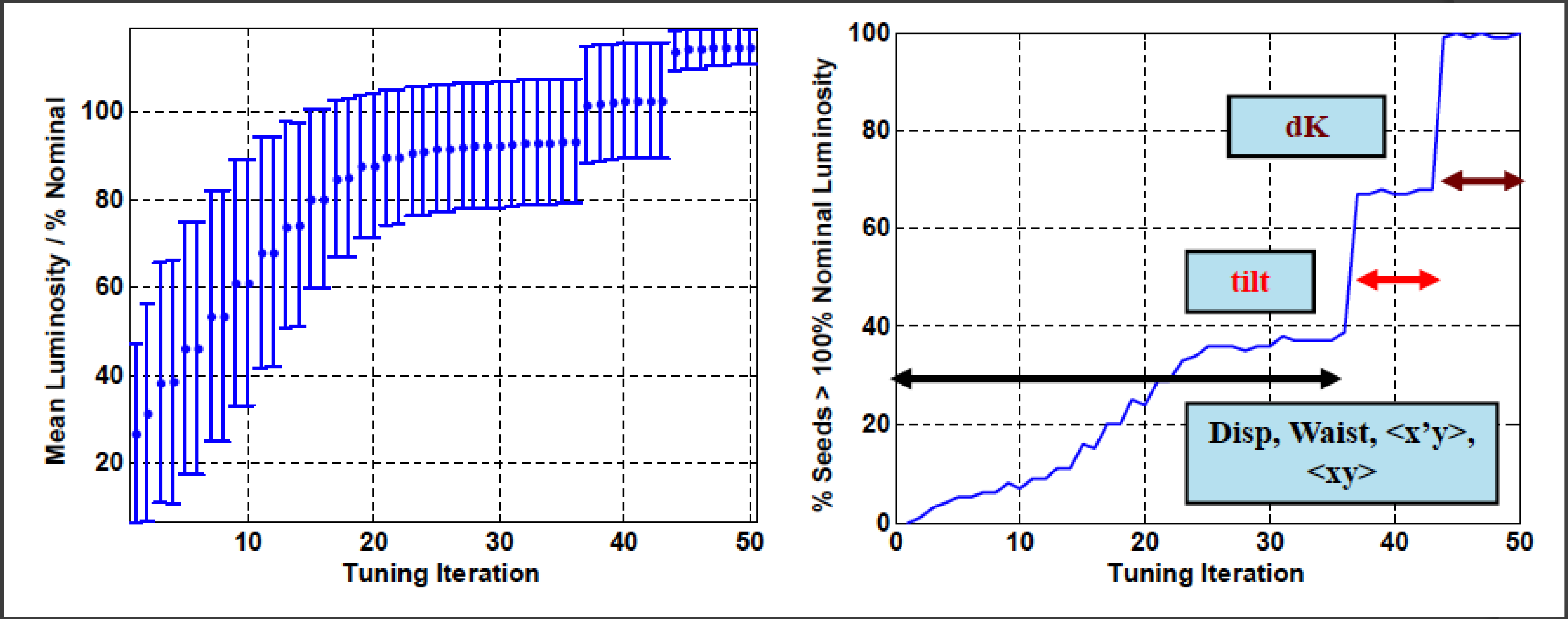
Initial Conditions, ILC BDS Simulation

- Initial conditions and preliminary tuning for ILC and ATF2 cases somewhat different.
- ILC
  - Assume significant tune-up in linac
  - More sophisticated BBA in BDS assumed based on DFS.
- ATF2
  - Added complications dealing with DR extraction system (more like ILC RTML)
  - Prefer steering to BPM centers due to wakefield issues.



- Initial beam sizes before final tuning in ILC simulation
- $\Delta\sigma_y/\sigma_y$ ~ 20 for average case
- Compare with 15 observed at ATF2

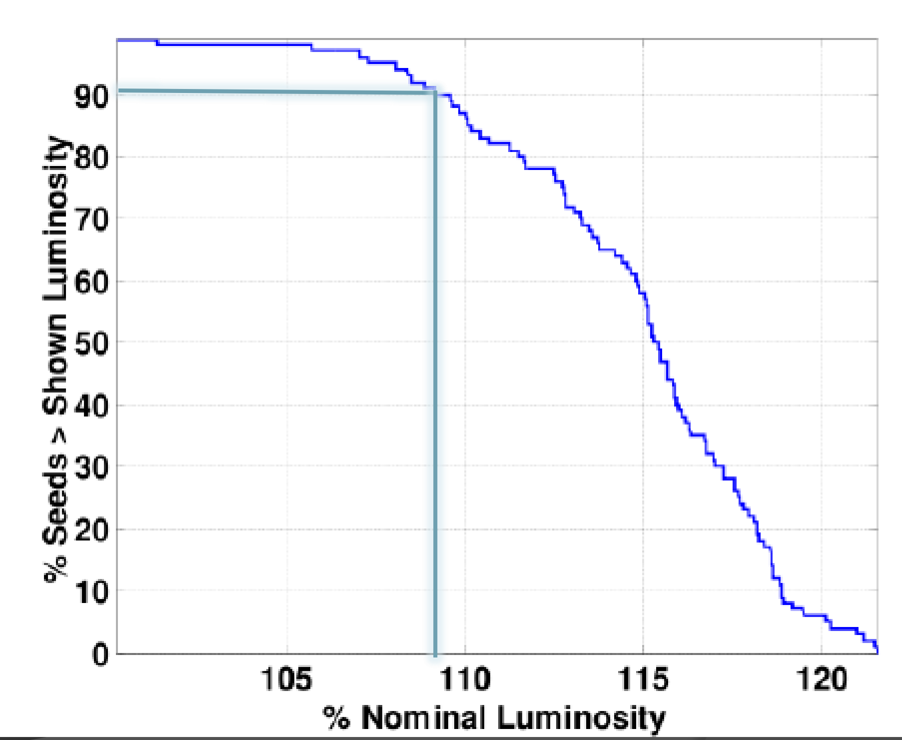
ILC BDS Tuning Simulation



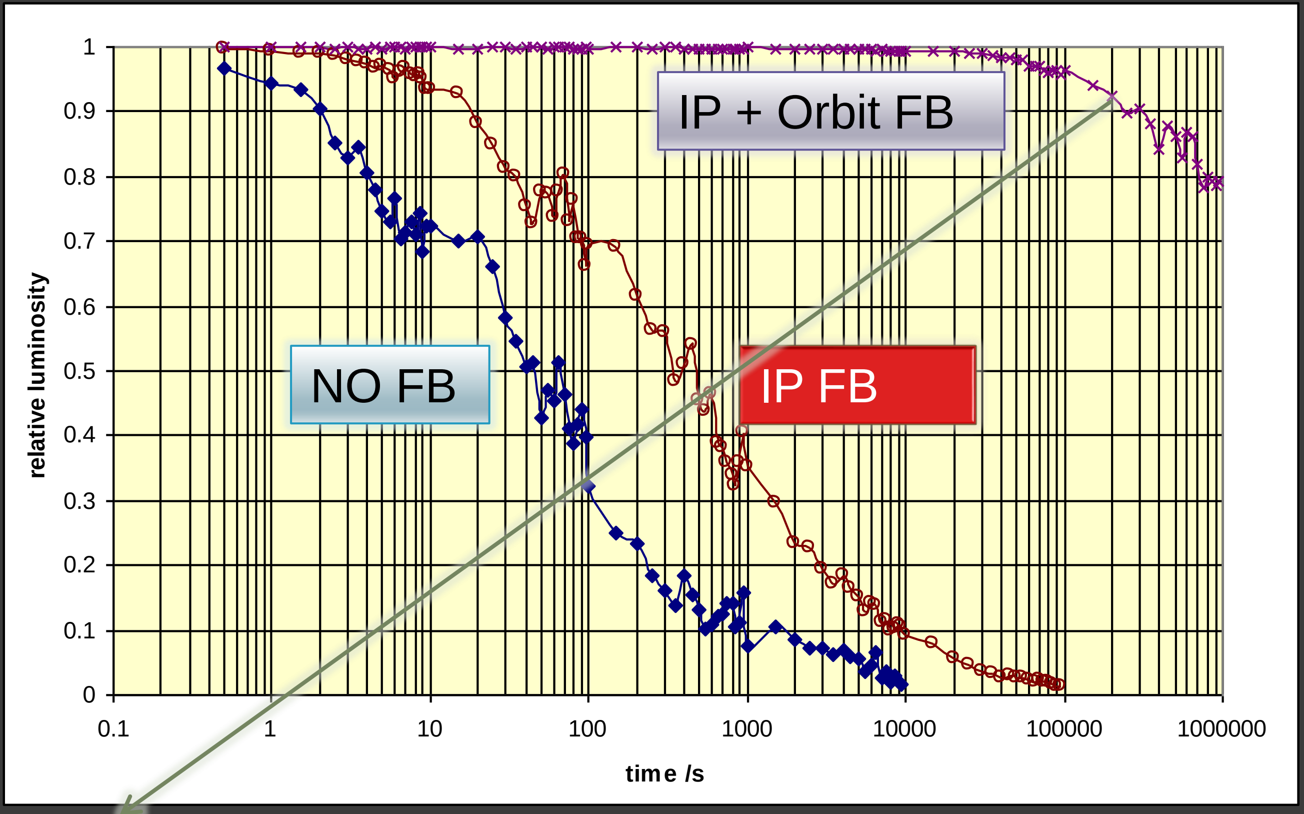
- Tuning simulation similar to ATF2
  - No specific 2nd-order knobs tried here though, could lead to improvements.
  - Includes dynamic effects (of slow-drift type corrections, not fast-feedback)

Demonstrating ILC Luminosity Performance with Simulations

- ILC RDR parameters
- Tuning procedure for BDS followed including consideration of dyamic effects due to ground motion + component jitter.
  - Include pulse-pulse feedback (cascaded linac + BDS)
  - Include 6nm BDS emittance overhead
- Need to add luminosity loss due inter-pulse dynamics including mitigation by intra-pulse feedback (2 loops in BDS at IP angle and position phases)
  - Worst-case (K-model GM, and TESLA-era linac HOM's) + **8%** lumi loss.
- Expect ~90% seeds to provide nominal luminosity



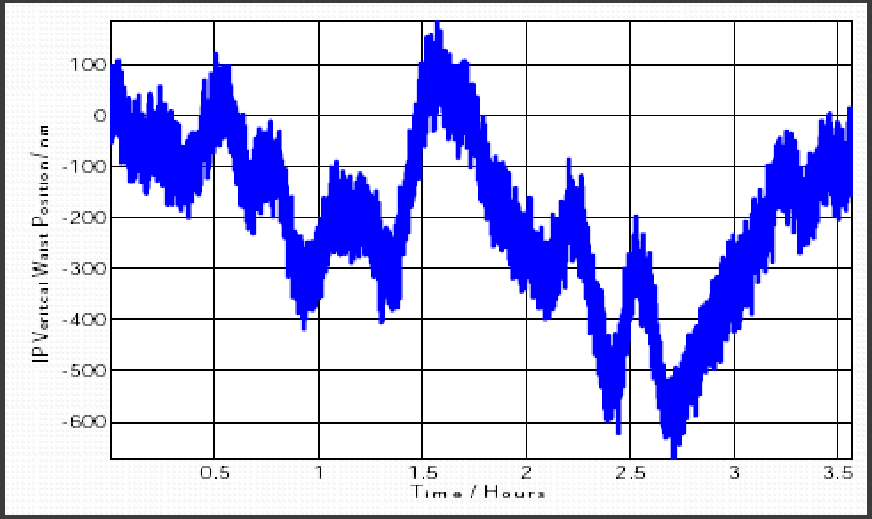
ILC Long-Term Luminosity Performance

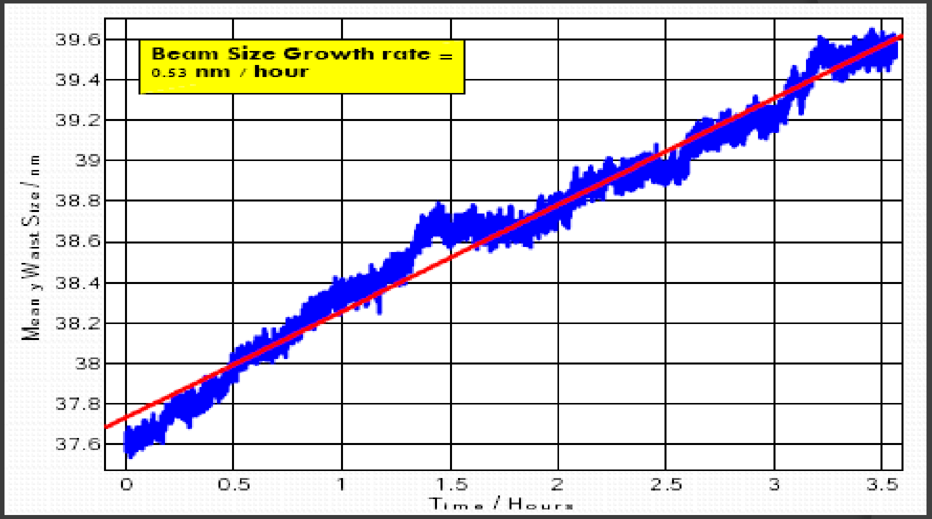


- Expect ~10% degradation in luminosity per week due to alignment drift
- Possible to test stability on this timescale @ ATF2 if DR extraction parameters can be kept stable

- Luminosity loss through fast motion of final doublets causing offset in beam collisions
  - Mitigated by MHz-scale intra-train feedback close to IP
- Emittance dilution due to orbit growth on longer timescales
  - Mitigated by distributed orbit feedback systems
- (Old simulation performed for TESLA)
  - (Walker/Wolski)

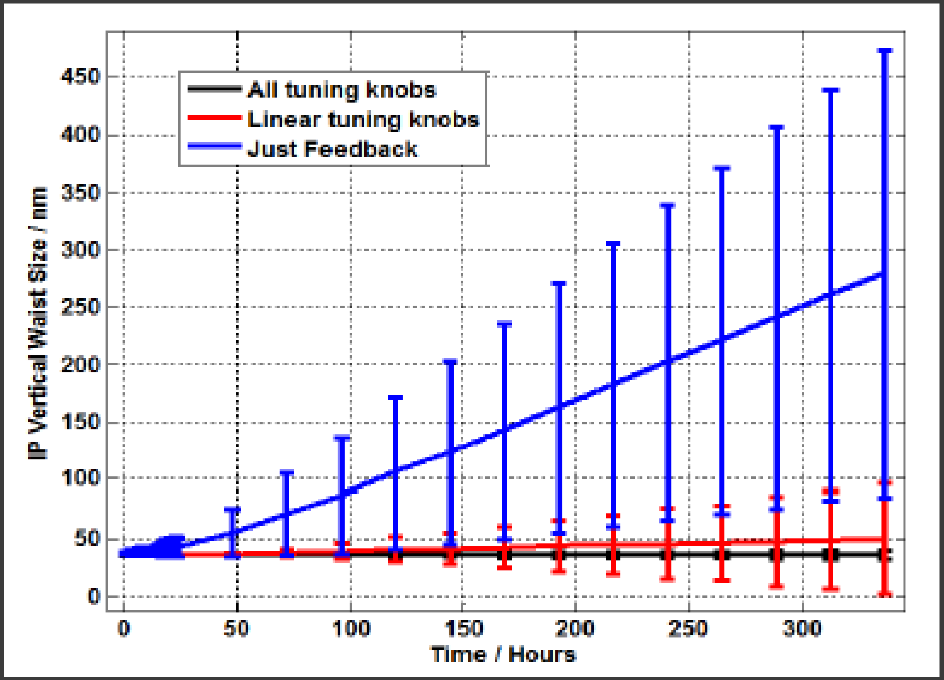
Dynamic Effects at ATF2





- Ground motion spectra taken at ATF2 site
- Relative vibration between final focus elements measured
- Expected effects modelled
- Maintain IP and orbit collisions through distributed feedbacks
  - High-precision cavity BPMs throughout lattice (~20-100 nm resolution demonstrated)
  - Ultra-high cavity BPM doublet near IP (5nm resolution demonstrated, goal 1-2 nm)

Long-Term Beam Size Stability at ATF2



- Feedback & Orbit control not enough for long term beam size stability
- Need to periodically tune using all available aberration correction knobs
- Concept of "tuning knob dither feedback"
- Understand timescale of running FFS system before full re-tuning necessary

Orbit Control in FFS @ ATF2

<100nm jitter measured

- FFS optics requirements lead to unusual situation for beam diagnostics
- All phase changes occur inside magnetic elements, only sample FD-phase
- 1 location for IP-phase sampling at IP vertical image point (waist) with small beam size
  - Critical for FFS feedback
  - Need high-performance BPM (on mover to help with limited dynamic range)

Summary

- ILC FFS sets unprecedented tolerances on optics
  - Overcome by designing static and dynamic tuning counter-measures
- MC simulations constructed to test ability of tuning process to deliver expected luminosity.
- By following simulation procedure for ATF2 and achieving aberration-removed design spot sizes we can verify the FFS design process and gain confidence in ability for ILC to deliver luminosity goals.
  - By investigating different IP beta optics, understand how FFS tuning difficulty varies with magnitude of FFS chromaticity.
- The tuning procedure is critically reliant upon the device by which you tune on
  - For ILC, the luminosity and pair monitors (also critically dependent upon understanding beam-beam physics).
  - For ATF2, the IPBSM
  - No expense should be spared on these systems!

Acknowledgements

- Thanks to various people I stole slides from (spread throughout history!)
- Many contributions to ATF2 simulations throughout LC & ATF2 collaboration, too many to represent here…