ILC & ATF2 Tuning Simulations, ATF2 Tuning Experience

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CERN ILC/CLIC/ATF2 FFS Tuning Meeting

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Summary

- ILC BDS tuning simulations summary.
- ATF2 EXT & FFS tuning simulations summary.
- Experimental experience tuning ATF2 EXT & FFS so far.

ILC BDS Tuning Simulations

- Demonstrate can tune-up ILC BDS from expected post initial survey conditions to nominal luminosity.
  - Magnet – BPM alignment.
  - Beam-Based alignment using magnet movers.
  - Luminosity tuning using Sextupole multi-knobs.
  - Single-sided fully dynamic simulation
    - A.S. Liar GM model 'B' + 5Hz feedback + 25nm RMS magnet jitter
  - 2-sided 'static' simulation.

Simulation Model

- Use Matlab + Lucretia.
- Beam model:
  - ILC RDR lattice
  - Single bunch tracking, 80,000 macro-particles.
  - Single ray used where possible.
  - Beam-beam physics with GUINEA-PIG (beam-beam kick, pair creation & lumi calculation).
- 5-Hz Feedback:
  - 5 x- and y- sextupole BPMs + 6 correctors.
  - ~50-pulse convergence gain.
- Initial beam:
  - Beam enters BDS on-axis with 10um/34nm horizontal/vertical normalised emittances (6nm vertical emittance-growth budget).

Error Parameters

Initial Quad, Sext, Oct x/y transverse alignment	**200 um**
Quad, Sext, Oct roll alignment	**300 urad**
Initial BPM-magnet field center alignment	**30 um**
dB/B for Quad, Sext, Octs (RMS)	**1e-4**
Mover resolution (x & y)	**50 nm**
BPM resolutions (Quads)	**1 um**
BPM resolutions (Sexts)	**100 nm**
Power supply resolution	**14 - bit**
FCMS: Assembly alignment	**200 um / 300urad**
FCMS: Relative internal magnet alignment	**10um / 100 urad**
FCMS: BPM-magnet initial alignment (i.e. BPM-FCMS Sext field centers)	**30 um**
FCMS: Oct – Sext co-wound field center relative offsets and rotations	**10um / 100urad**
Corrector magnet field stability (x & y)	**0.1 %**
Luminosity (pairs measurement or x/y IP sigma measurements)	**1 % (ATF2 SM ~5%)**

Alignment and Tuning Steps

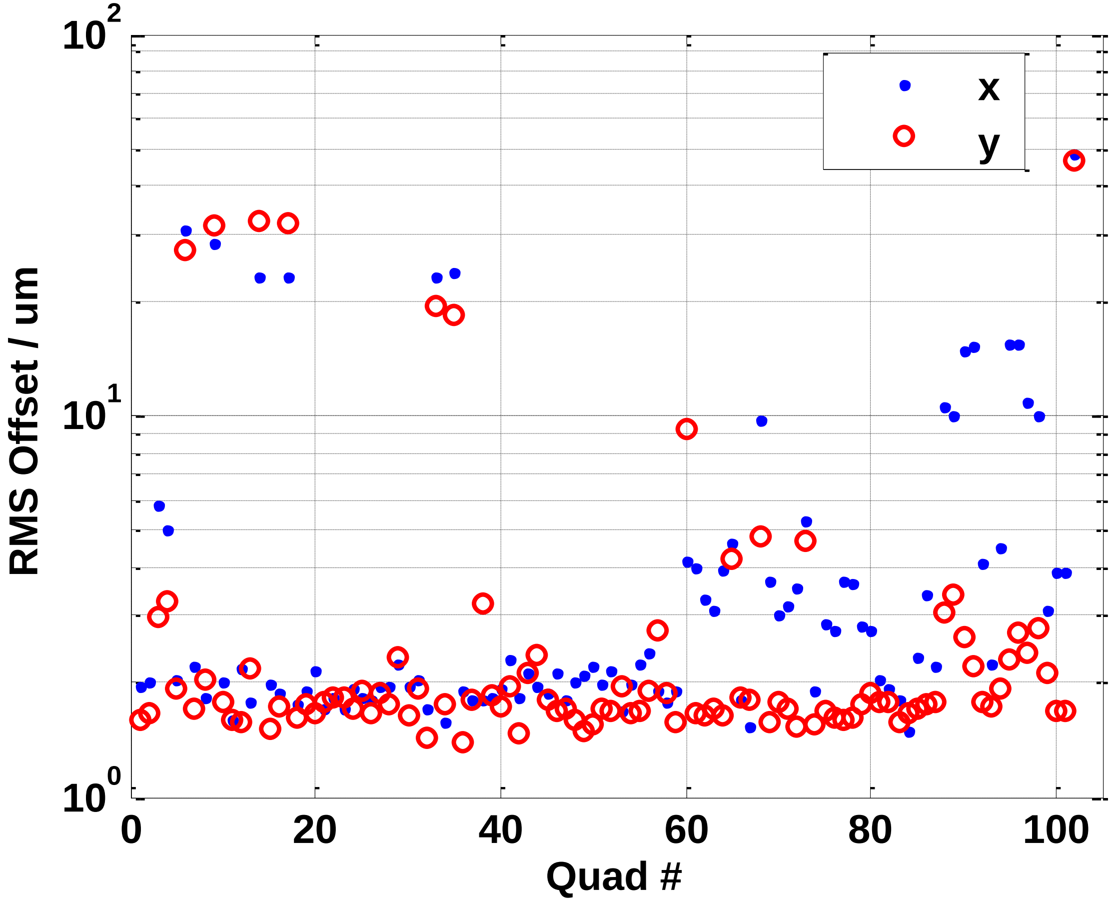
- Switch off Sextupoles and Octupoles.
- Perform initial BBA using Quad movers and BPMs -> beam through to IP.
- Quadrupole BPM alignment.
- Perform Quadrupole BBA (DFS).
- Align Sextupole BPMs.
- Move FCMS to minimize FCMS BPM readings.
- Align tail-folding Octupole BPMs.
- Activate and align sextupole and octupole magnets.
- Rotate whole BDS about first quadrupole to pass beam through nominal IP position.
- Apply sextupole multiknobs to tune-out IP aberrations and maximise luminosity.
- 5-Hz feedback system used throughout to maintain orbit whilst tuning.

Quadrupole BPM Alignment

- Nulling Quad-Shunting technique:
  - To get BPM-Quad offsets, use downstream 10 Quad BPMs for each Quad being aligned (using ext. line BPMs for last few Quads).
  - Quad dK 100-80 %, use change in downstream BPM readouts to get Quad offset.
  - Move Quad and repeat until detect zero-crossing.
  - For offset measurement, use fit to downstream BPM readings based on model transfer functions:

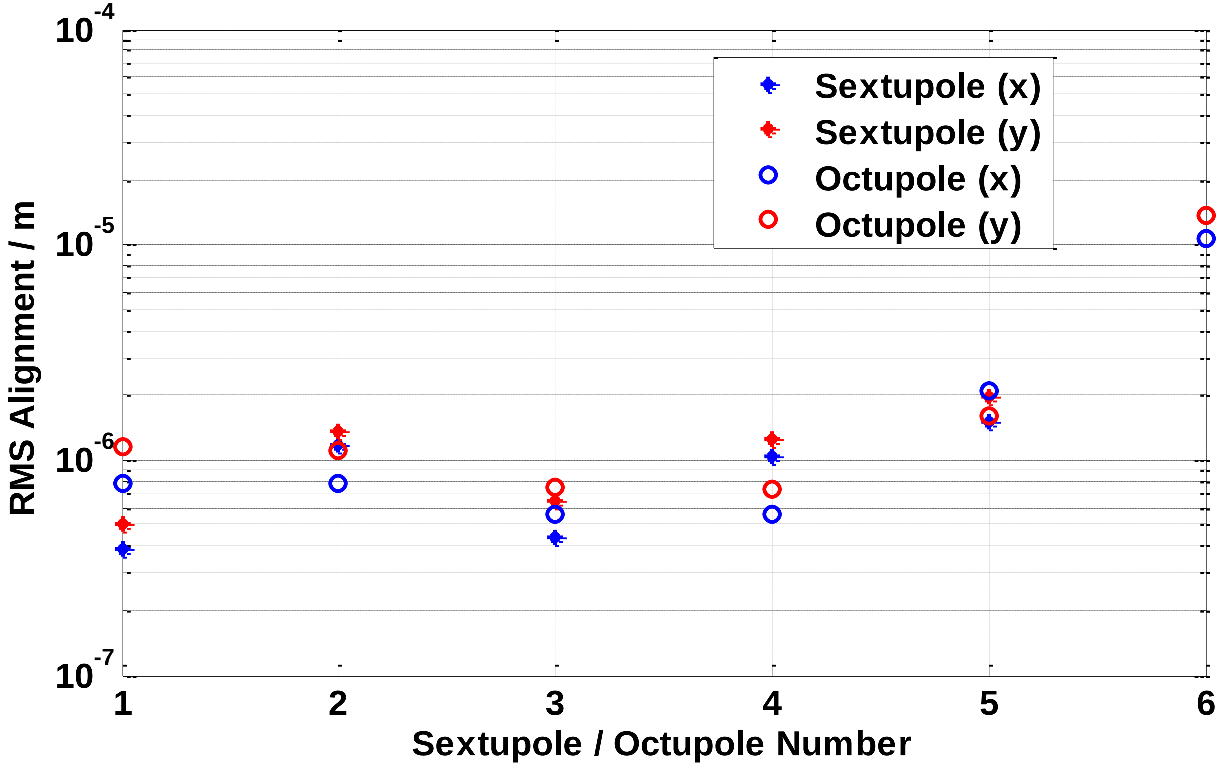
$$x_{Quad} = \Delta x_{BPM} / (\Delta R_Q(1,1) * R(1,1) + \Delta R_Q(2,1) * R(1,2))$$

Alignment Results



- RMS BPM-Quadrupole field center alignments (100 seeds).

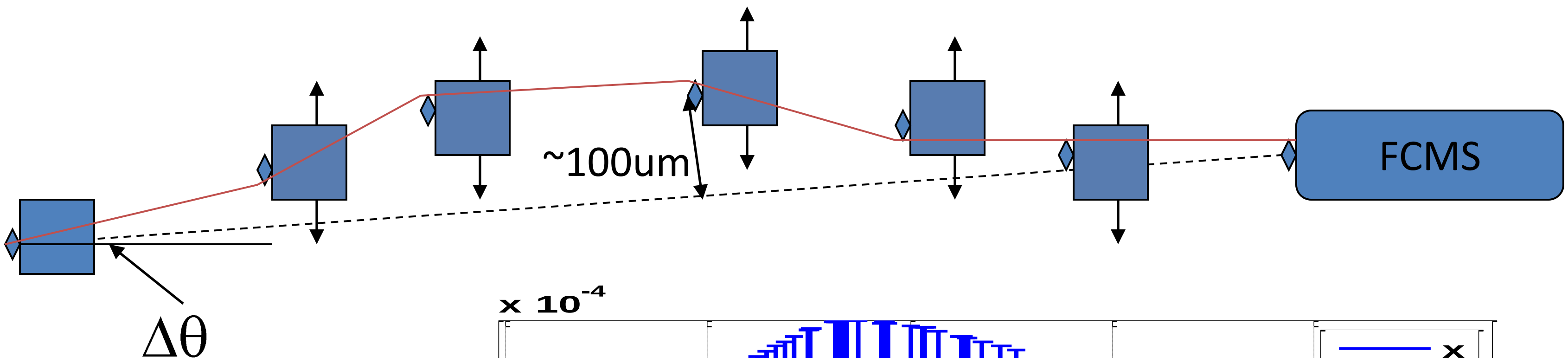
Sextupole/Octupole BPM Alignment



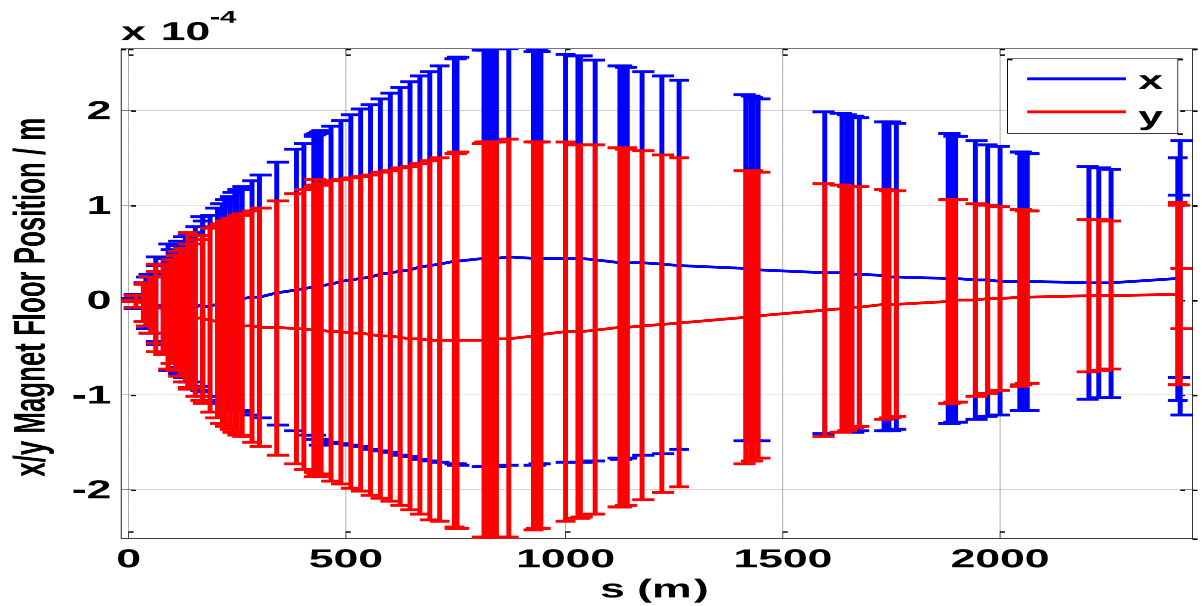
- Use x-, y-movers on magnets and fit 2nd, 3rd order polynomials to downstream BPM responses.
- Alignment is where 1st, 2nd derivative is 0 from fits.
- 6^{th} Octupole can only be aligned by increasing its field strength by a factor of 10, so is left with the initial alignment in the simulation.

Beam-Based Alignment of Quads

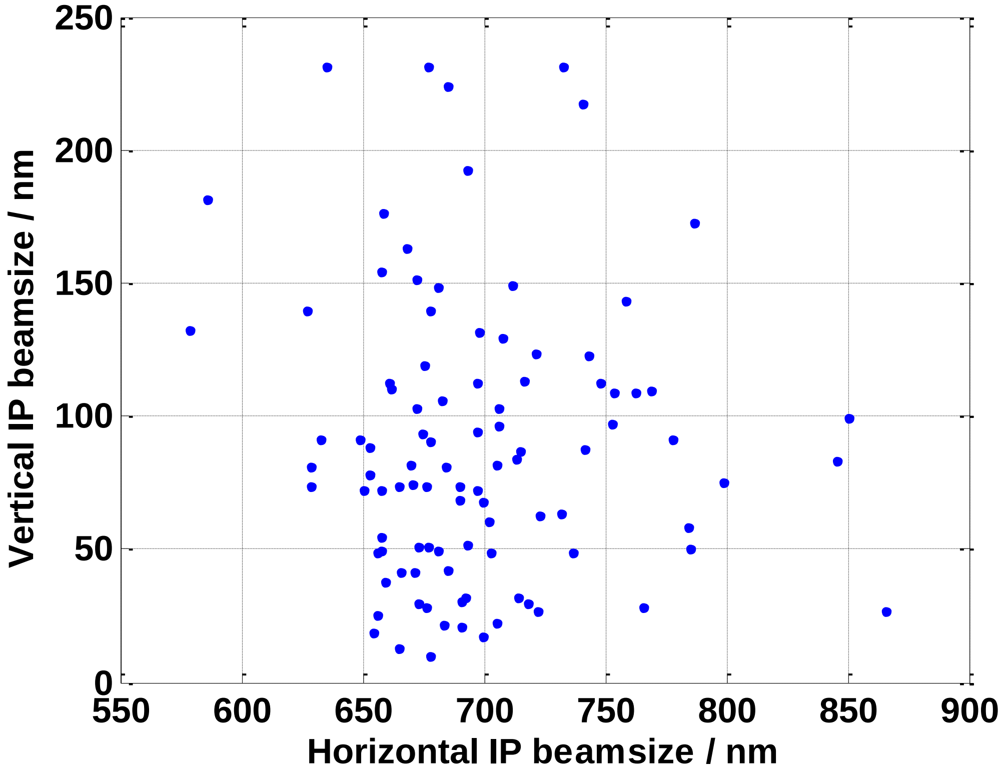
- Use mover minimisation and DFS constraints to limit the mover motion.
- Weights used in minimisation algorithm constrain how far movers move, this trades-off final mover positions against accuracy of BPM orbit.



- Results simulation.
- RMS Quad floor positions shown (100 seeds).



Beam Conditions Post-BBA



- IP beamsizes (100 seeds) after BPM alignment and BBA.
- Significant aberrations present at IP- coupling, dispersion, waist + higher order terms.
- Use sextupole multi-knobs to tune these out and arrive at nominal ILC luminosity parameters.

Sextupole Multi-Knobs

- Deliberately offsetting the beam orbit using the first 3 FFS sextupoles in an orthogonal way provides tuning knobs for dispersion and waist-shift at the IP through: $\Delta s_{x,y} \sim \Delta x . K_2^s L \beta_{x,y}^s \beta_{x,y}^* \cos(2.\mu)$

$$\Delta \eta_{x,y}^* \sim \Delta(x,y). K_2^s L \eta_{x,y}^s \sqrt{\beta_{x,y}^s \beta_{x,y}^*} \sin(\mu)$$

Orthogonal knobs are computed by inverting the sextupole move -> IP aberration matrix formed by scanning the sextupoles in turn and measuring the IP terms.

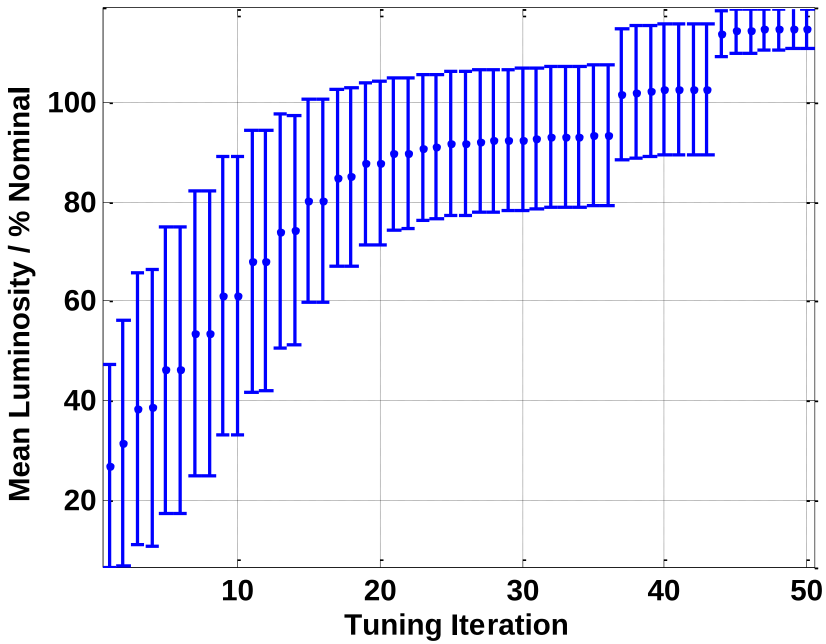
The dominant IP coupling term <x’y> is tuned-out using SQ3FF.

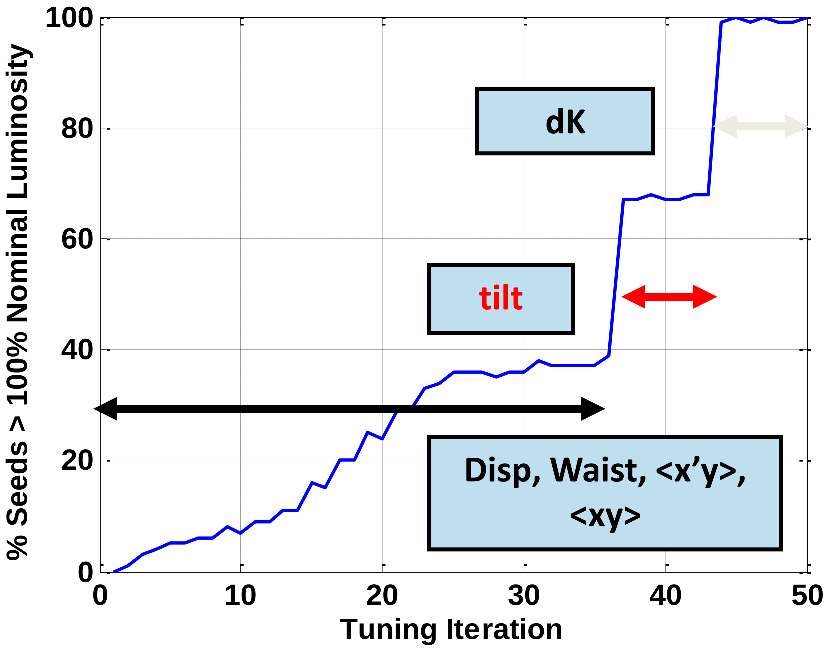
The 4 skew quads in the BDS coupling correction system are iteratively scanned to remove any <xy>.

Higher-Order Sextupole Multi-Knobs

- Due to sextupole tilt and strength errors, and due to non-linear fields as the beam passes off-center in the sextupoles, higher-order aberrations also exist at the IP.
- These are corrected for by iterating through sextupoles 1-3 using the tilt dof. on the movers to maximise luminosity after the linear knobs have converged.
- The strengths of the 5 sextupoles are also scanned.

Application of Multi-Knobs

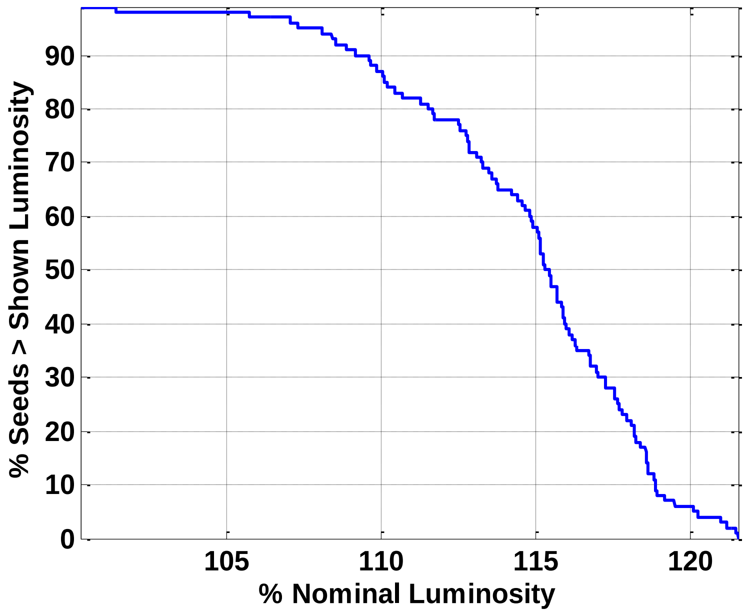




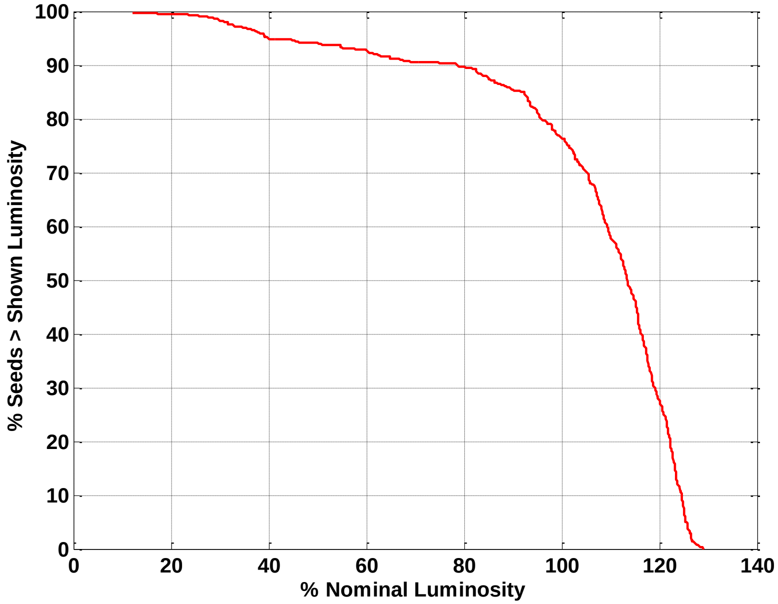
- Single-sided simulation (100 seeds).
- The linear sextupole knobs are applied until convergence, then the sextupole tilts and strengths are tuned on.

Achieved Luminosity

Single-Sided Sim

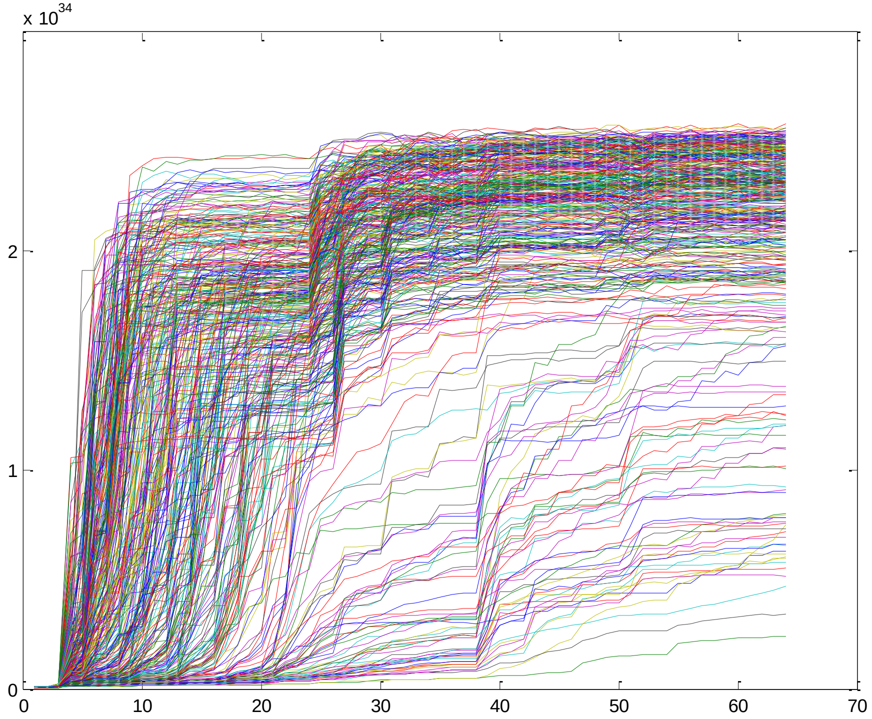


2-Sided Sim



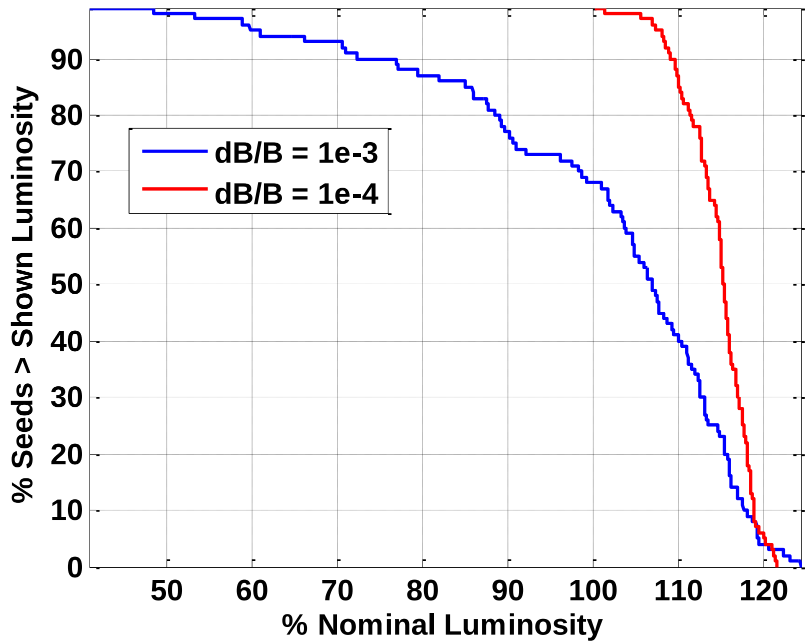
- Median lumi overhead ~15% in both cases
- When simulating both sides 25% of seeds fail to meet design luminosity.

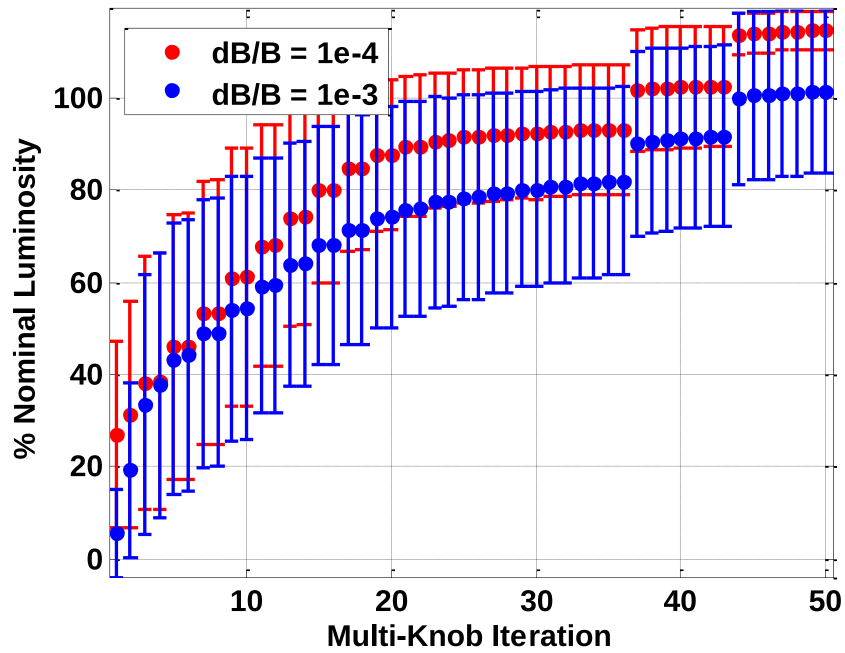
2-beam Simulation



- Some seeds slower to converge in 2-sided simulation case. (450 seeds simulated).
- In 2 beam-simulation:
  - Rotate 2 beamlines to bring beams into collision
  - Added tuning iterations – perform a tuning scan on e-, then e+ beam – in 1-beam simulation, effectively colliding beam with self-here against a larger beam-effects pair stats.

Magnet Strength Error Comparison





- Comparison of results with relative absolute RMS errors on all magnets of 1e-3 and 1e-4.

ILC Simulation Work to do

- Implement new 2009 ILC lattice
  - Low P parameter configuration
  - Tighter IP focusing, higher chromaticity
  - Expect tuning to be more difficult
- Start with 2-side sim
  - Make sure give enough sim time for convergence to be seen
- Examine slowest seeds in details to try and understand primary aspects effecting performance.

ATF2 Tuning Simulations

- Define realistic starting conditions (100 seeds)
- Standard installation errors + EXT BBA, disp corr, coupling corr, FFS BBA
- Study performance of IP tuning on 100 seeds including dynamic errors.
- Check h/w limits not exceeded at any point.
- Study effect of dynamic errors on tuned machine.

Errors

The reference ground motion model for ATF based on measured GM spectra on the DR (also available as a standalone Matlab routine- to be provided here shortly).

Error Parameter	Error magnitude
x/y/z Post-Survey	200 um
Roll Post-Survey	300 urad
BPM - Magnet field center alignment (initial install) (x & y)	30 um
BPM - Magnet alignment (post-BBA, if BBA not simulated) (x & y)	10 um
Relative Magnetic field strength (dB/B) (systematic)	1e-4
Relative Magnetic field strength (dB/B) (random)	1e-4
Magnet mover step-size (x & y / roll)	300 nm / 600 nrad
Magnet mover LVDT-based trim tolerance (x & y / roll)	1 um / 2 urad
C/S - band BPM nominal resolution (x & y)	100 nm
Stripline BPM nominal resolution (x & y)	10 um
IP BPM nominal resolution (x & y)	2 nm
IP Carbon wirescanner vertical beam size resolution	2 um
IP BSM (Shintake Monitor) vertical beam size resolution	use attached data
EXT magnet power-supply resolution	11-bit
FFS magnet power-suppy resolution	20-bit
Pulse - pulse random magnetic component jitter	10 nm
Pulse - pulse relative energy jitter (dE/E)	1e-4
Pulse - pulse ring extraction jitter (x, x', y, y')	0.1 sigma
Corrector magnet pulse-pulse relative field jitter	1e-4

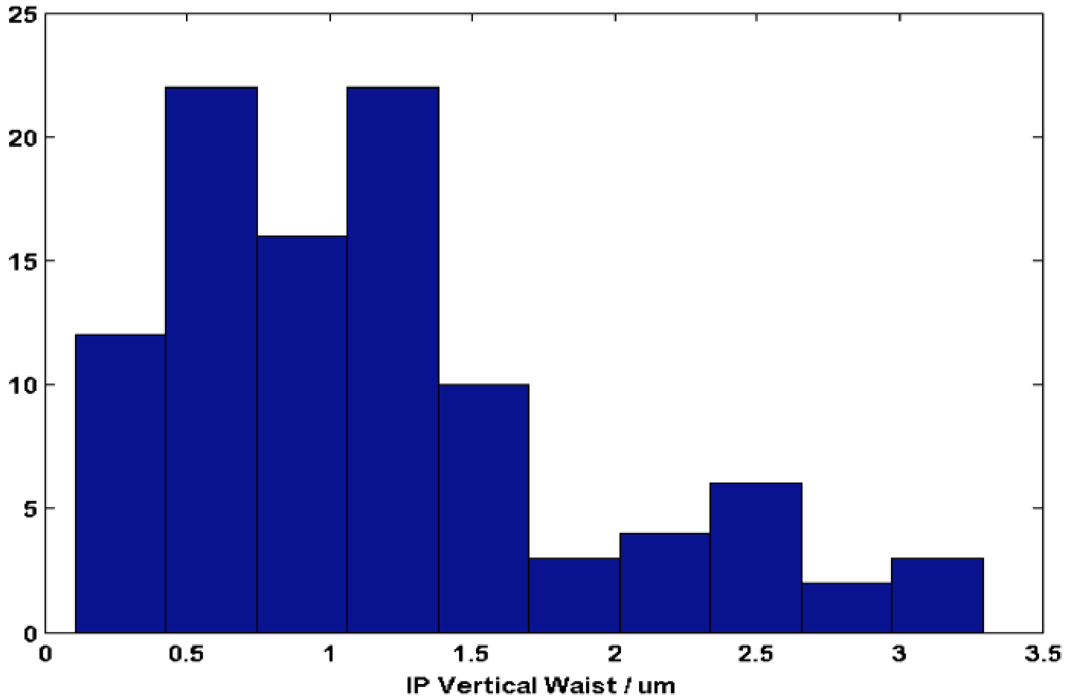
Done

- Error list on wiki
- Also GM- ATF fitted Model
- Also include measured multipoles for final doublet, sextupoles and FFS bends.

Simulated Tuning Process

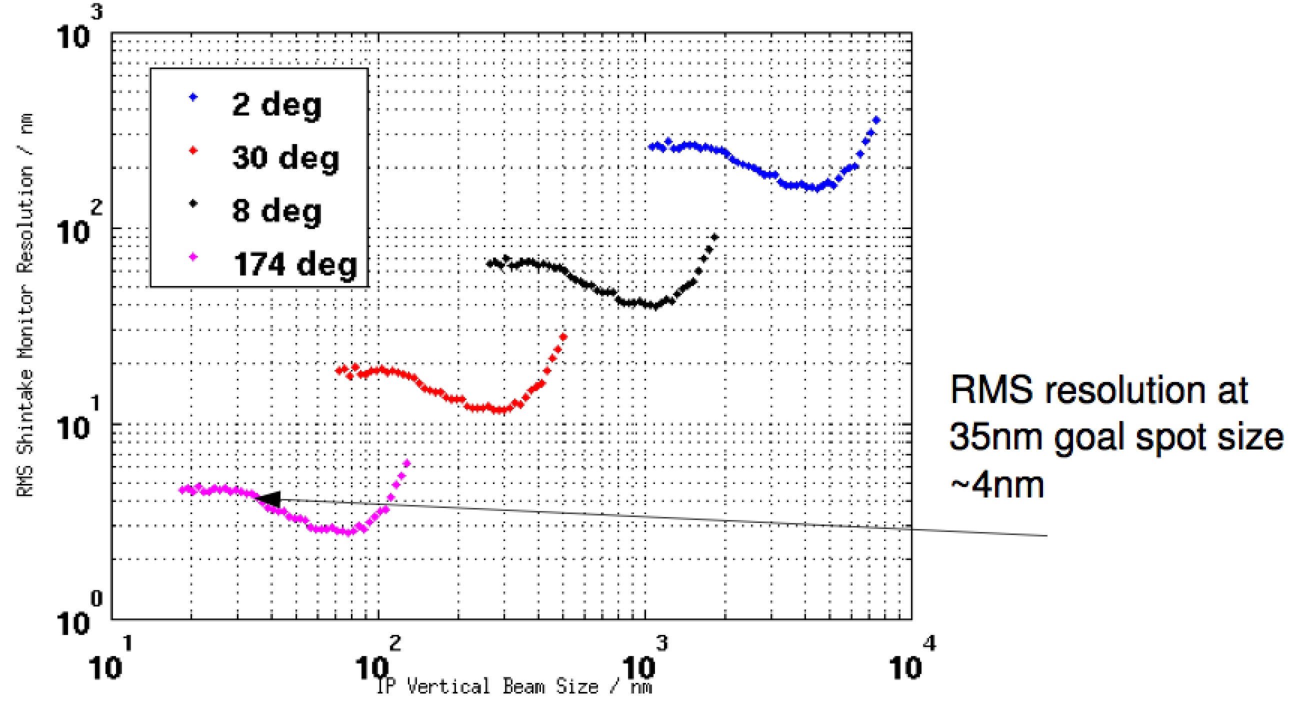
- Use EXT correctors + BPMs (EXT FB) to get orbit through EXT.
- Use FFS FB to get beam through FFS.
- Correct Dy/Dy' in EXT using skew-quad sum knob.
- Correct coupling in EXT using coupling correction system.
- Use FFS FB for launch into FFS.
- FFS Quad BPM alignment using quad shunting with movers.
- FFS Quad mover-based BBA.
- FFS Sext BPM alignment using Sext movers and IP BPM.
- Sextupole mover tuning knobs to get final spot size
  - Vertical IP dispersion and Waist
  - <x'y> coupling
  - Higher order terms collectively through Sext rolls + dK.
- Also use EXT skew-quads to tune other coupling terms.
- No attempt to model EXT BBA yet (assume 10um RMS bpm-magnet center offset)
- No attempt to model any lattice matching (Ring - EXT)

Beamsize After BBA



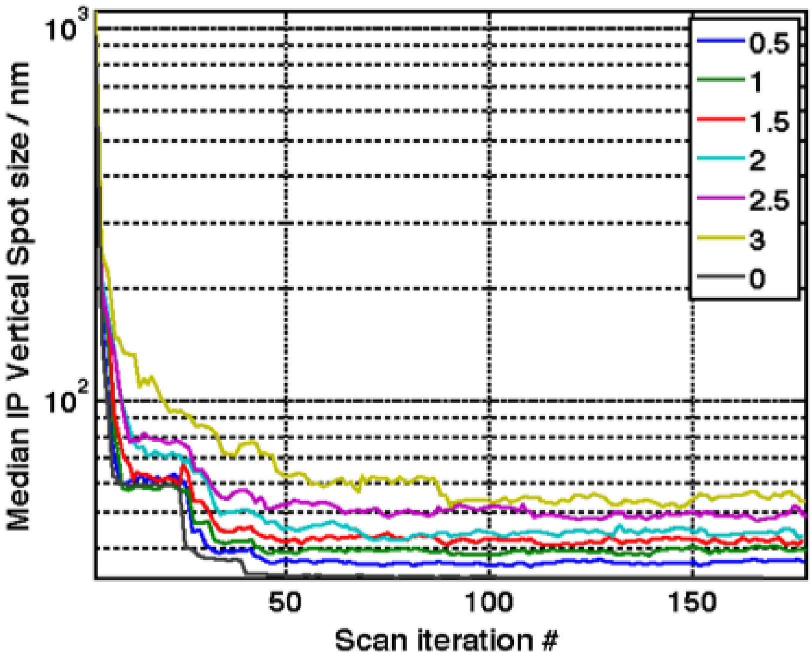
- IP waist size before sextupole FFS tuning knobs applied (100 seeds).

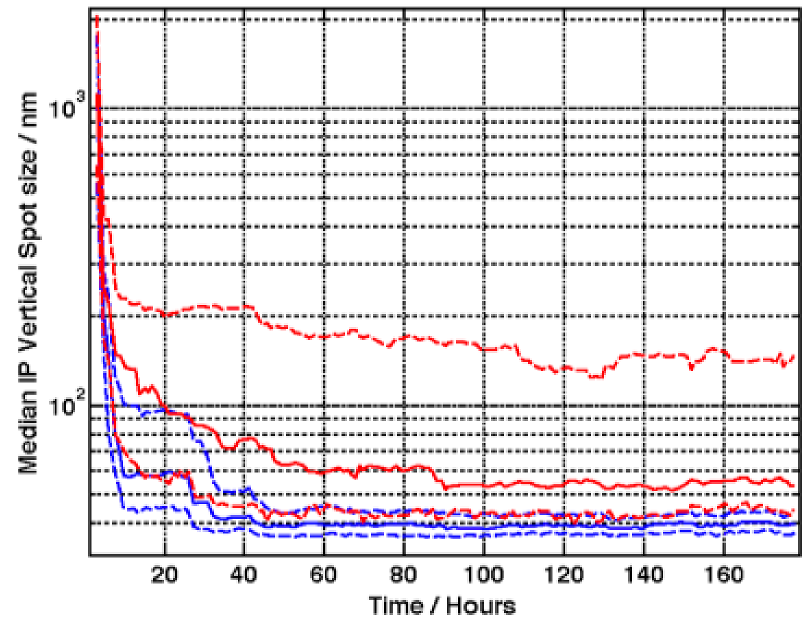
IPBSM Resolution



- In results shown, scale above data by: 0.5, 1, 1.5, 2, 2.5, 3

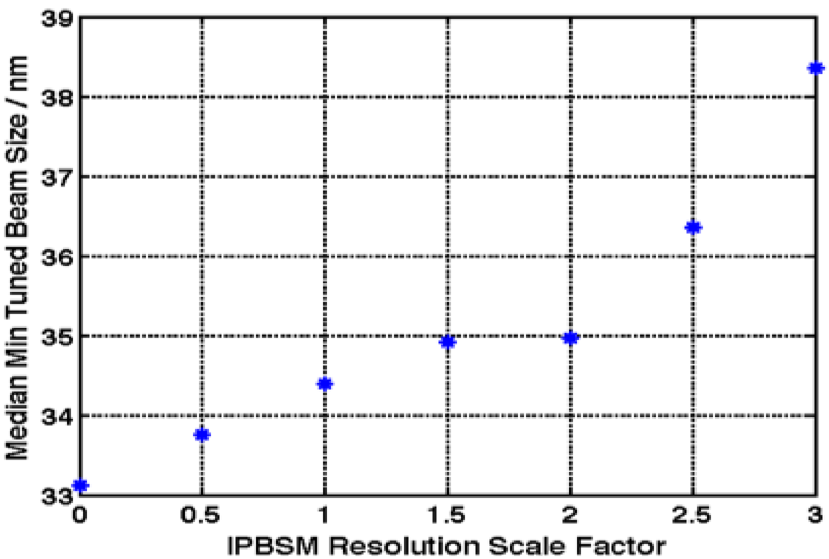
Median Tuned Spot Size

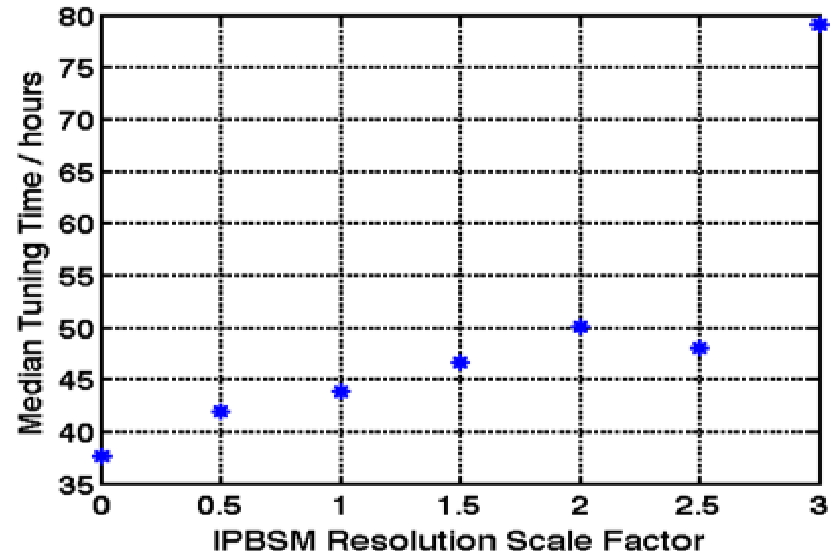




- From 100 simulated seeds - median IP beam size at each scan iteration point (left plot).
- The right plot shows 50% (median), 25% and 75% C.L. for the cases of scale factor 1 (blue points) and scale factor 3 (red points).

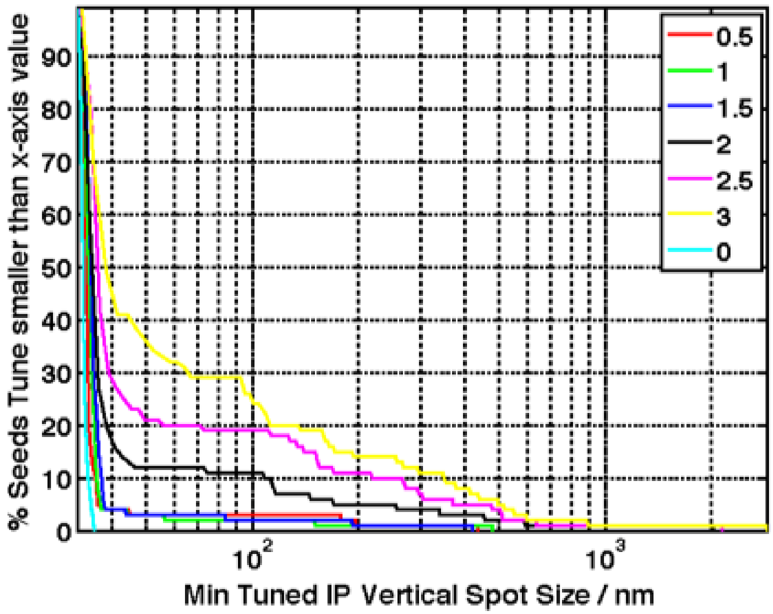
Median Tuning Performance

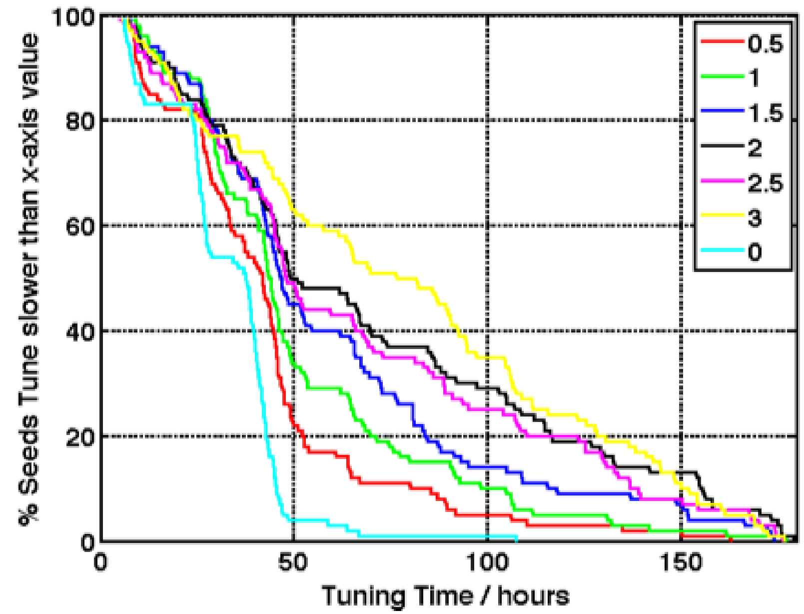




- Median min tuned beam size and time to tune to within 10% min beam size from 100-seed simulation with varying IPBSM resolution scale factor.

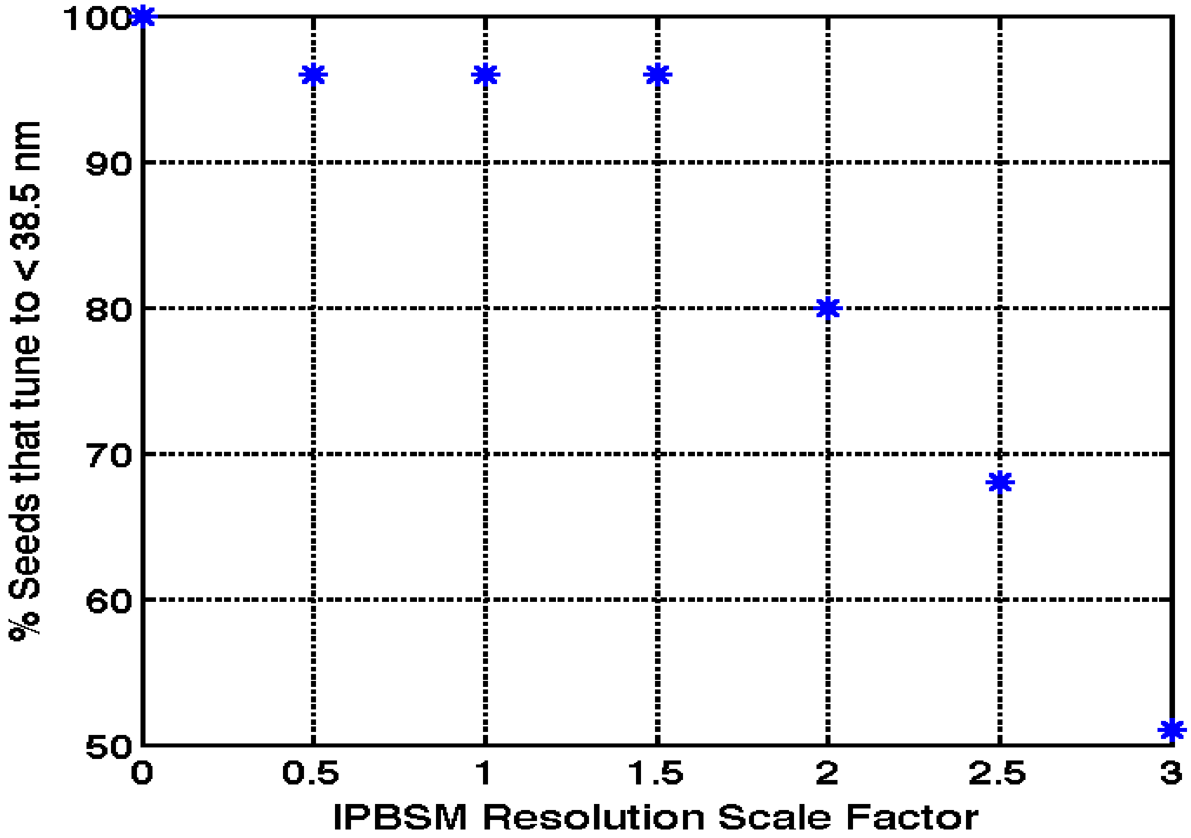
Tuning Results





- Results of 100 simulated seeds for different IPBSM resolution scale factors.

Success Expectation



- % Seeds that tune to better than 10% above nominal IP Spot Size

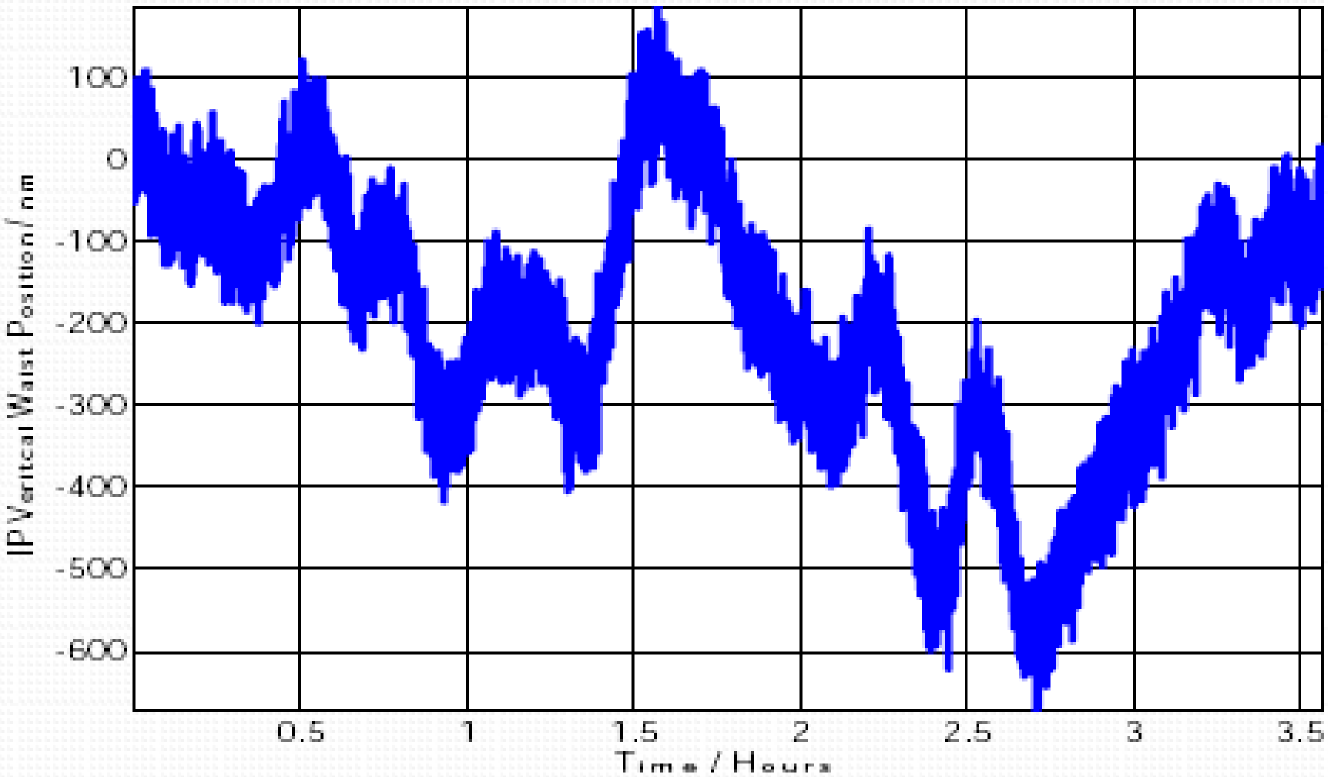
Post-tuning jitter effects on IP beamsize

- Just keep beam orbit with FFS feedback devices
- Need to periodically scan all sextupole knobs to restore optimal beam size

'Nominal' Jitter Parameters

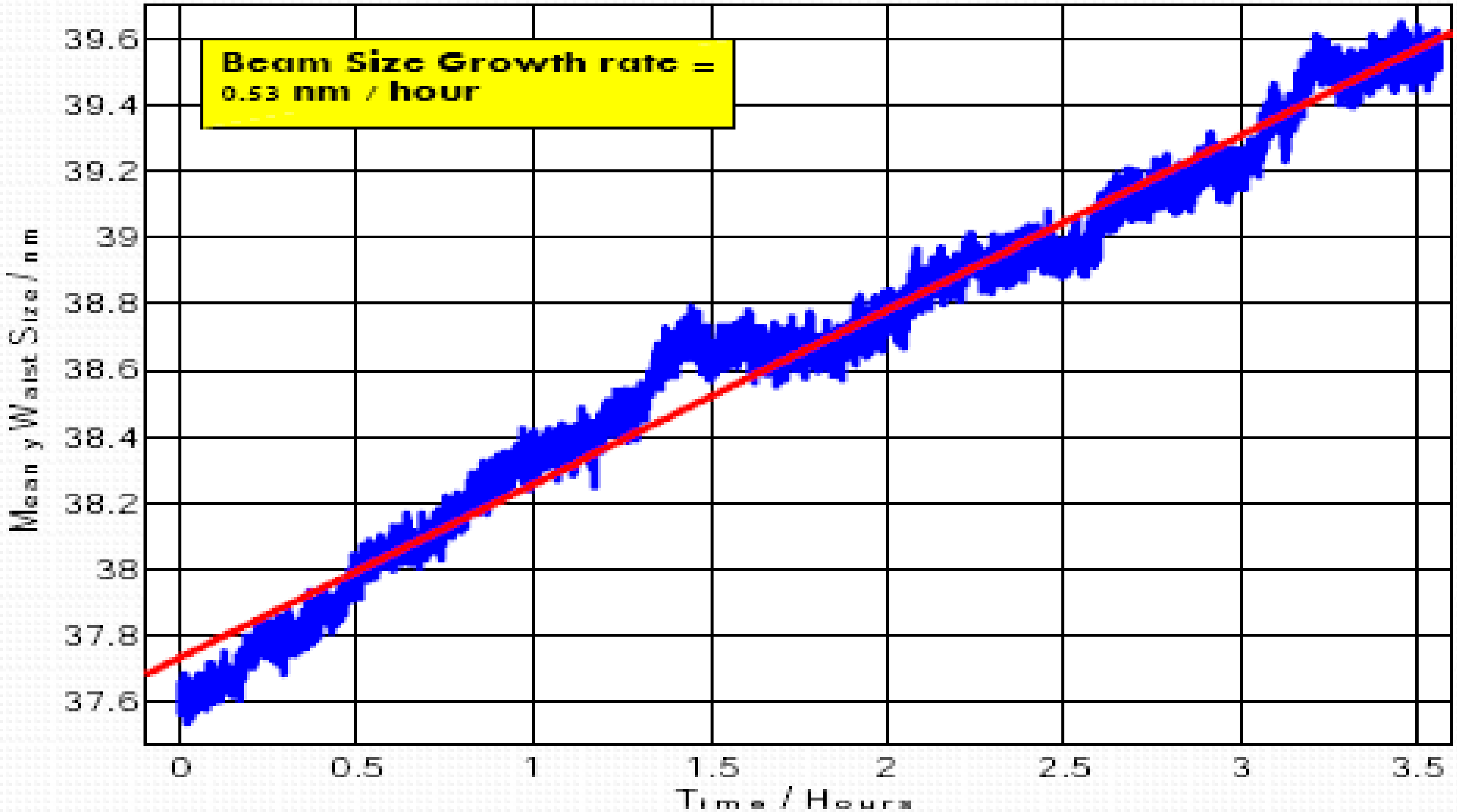
- 0.1 sigma x,x',y,y' RMS ring extraction jitter
  - 13 um/2.8 urad (x/x') 0.6 um/0.4 urad (y/y')
- 1e-4 dE/E error
- 10 nm magnet vibration
- 1e-4 strength errors pulse-pulse on corrector magnets
- 100 nm BPM resolution
- ATF fitted GM model
- Simulation performed with 100 random seeds

IP Motion



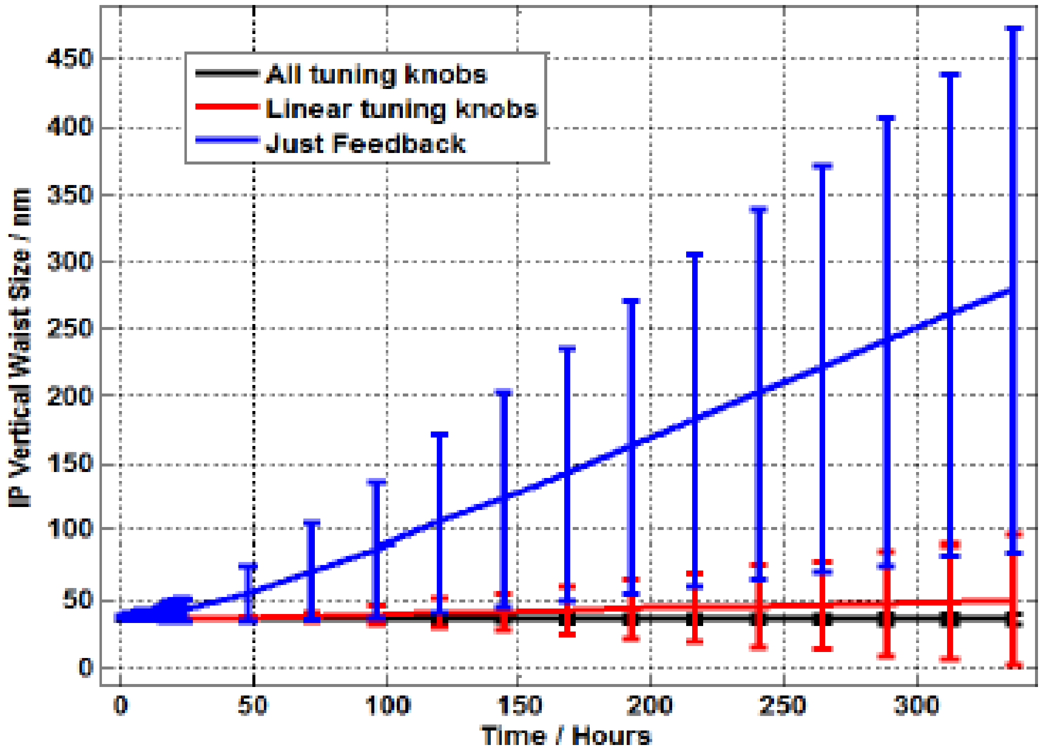
- 20,000 pulses @ 1.56 Hz (1 seed)
- IP vertical position drifts around on scales of a few 100 nm an hour.
- Slow enough that this can be 'de-trended' using Shintake Monitor as IP position monitor.

Beam Size Growth



- With feedbacks on, y beam size at IP as a function of time
- Mean of 100 seeds shown
- Growth rate ~ 0.5 nm per hour

Long – Timescale Performance



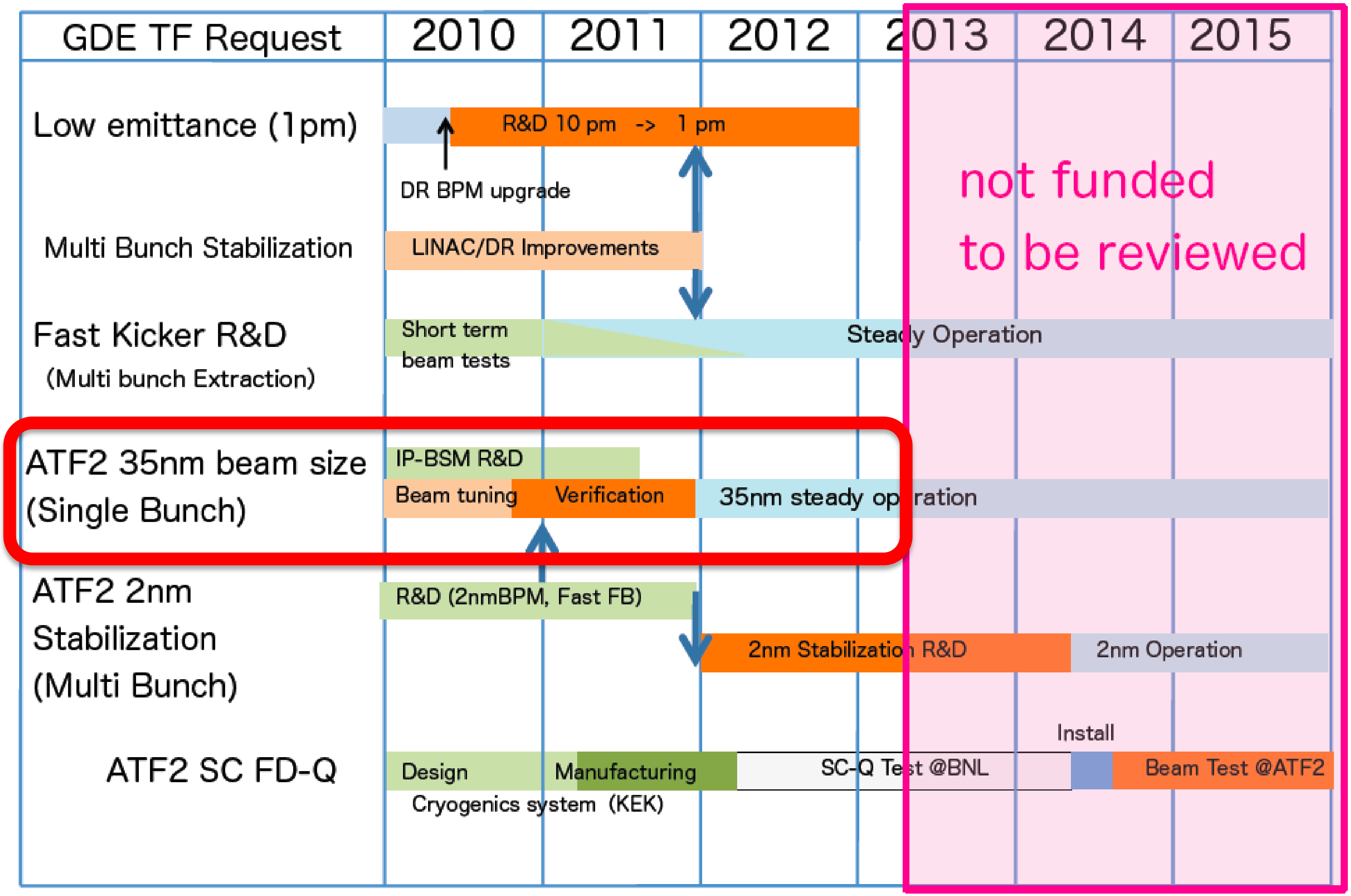
At each point, none, linear (waist, dispersion and coupling) and full tuning knobs (include sextupole strength and tilt scans) applied. For blue, red and black respectively.

- Vertical IP beam size over 2 week period
- Mean and +/- 1 sigma RMS from 100 seeds shown at each point

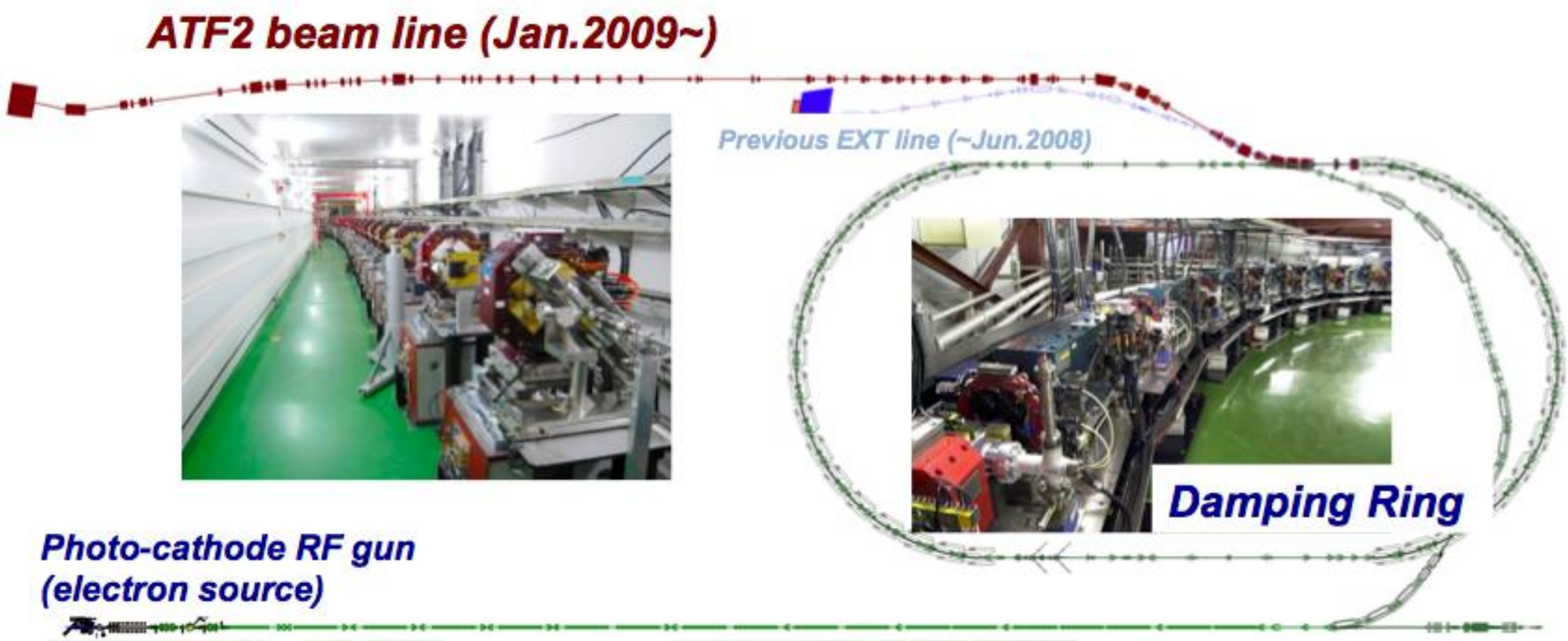
ATF2 Project Goals

- Experimental verification of the ILC FFS scheme
  - Development of beam tuning procedures
  - Goal A: focus vertical spot at IP to ~37nm (single bunch)
  - Goal B: maintain IP vertical position with few-nm precision (multi-bunch)
- Development of ILC instrumentation
  - BPMs, movers, Fast feedback (FONT), Laserwire,
  - beam size monitor, HA-PS, fast pulser, SC-FD etc.
  - *See talk by N. Terunuma this afternoon*
- Education of young generation for future linear colliders
  - Active participation of graduate students and post-docs.

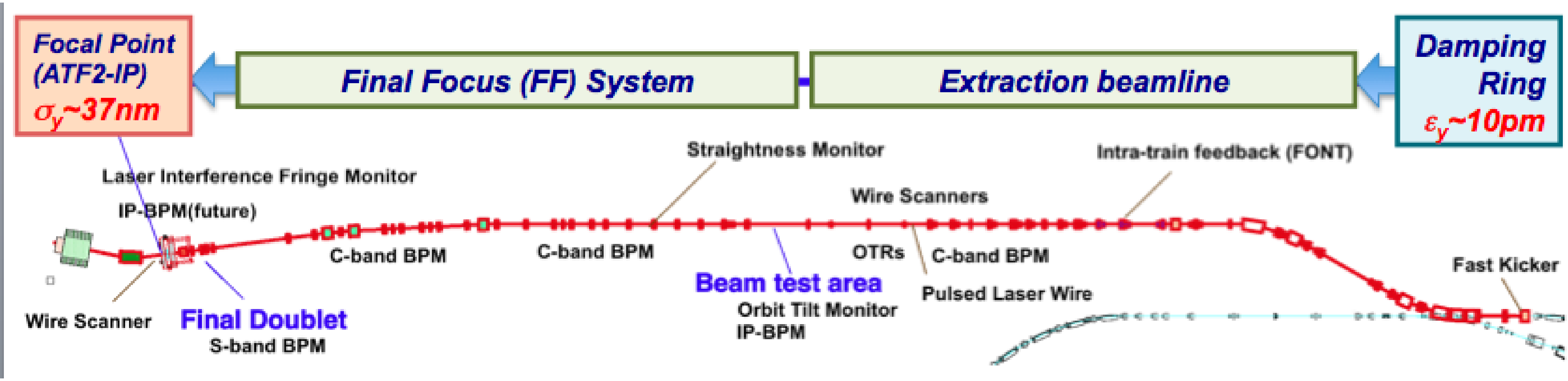
ATF Schedule



ATF2 Facility Layout



ATF2 Facility Layout



Final Focus System (FFS)

•Scale test of ILC FFS optics

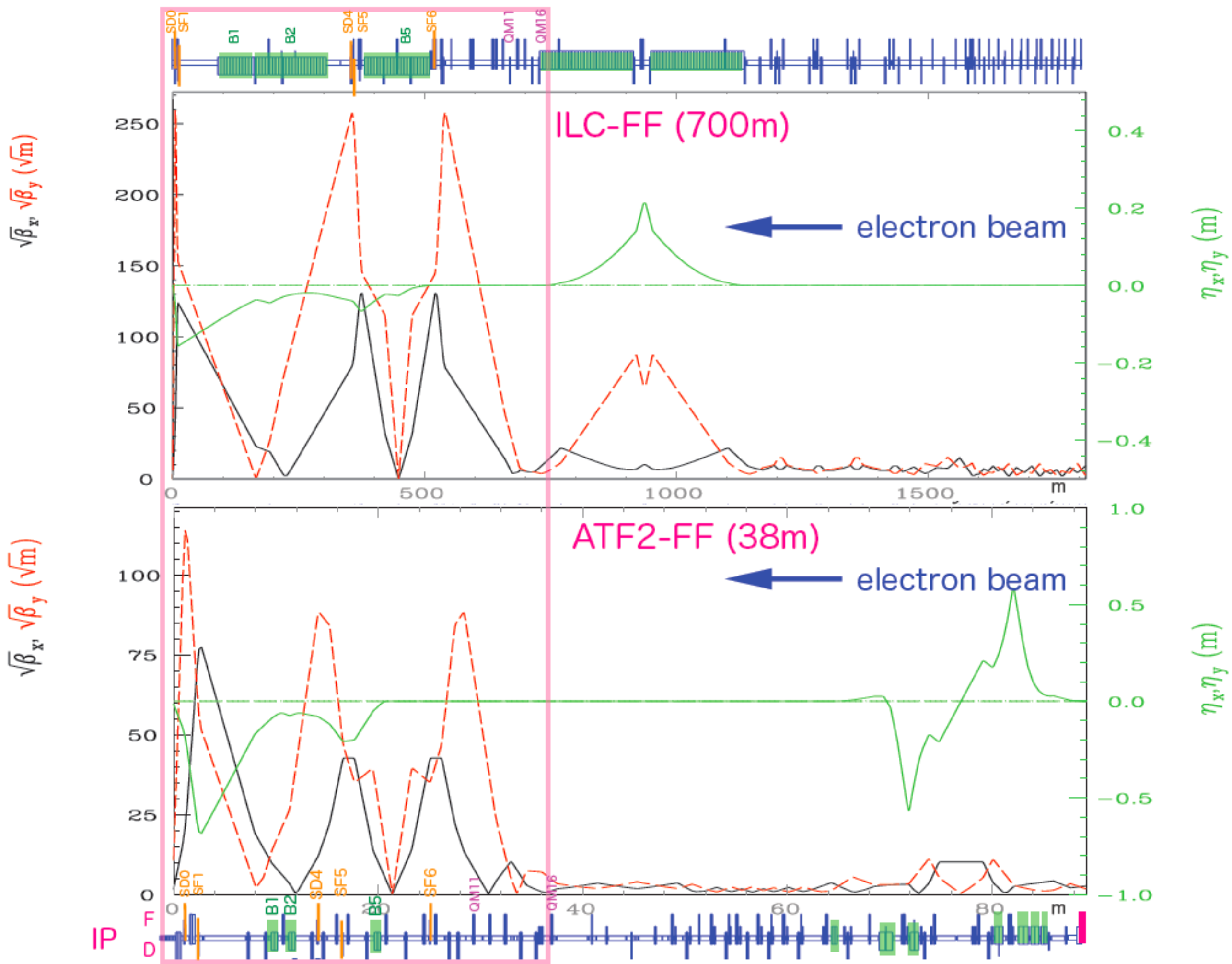
Extraction Line (EXT)

•Extract beam from DR

•Correct for coupling and dispersion errors

•Correctly match beam into final focus system.

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.

<u>Typical DR Parameters</u>

$\varepsilon_x / \varepsilon_y$ = 1.3nm / 8-10pm

E = 1.282 GeV

<u>ATF2 IP parameters</u>

β_x / β_y = 4cm / 0.1mm

σ_x / σ_y = 6um / 37nm

Rep. Rate = 1.56 Hz

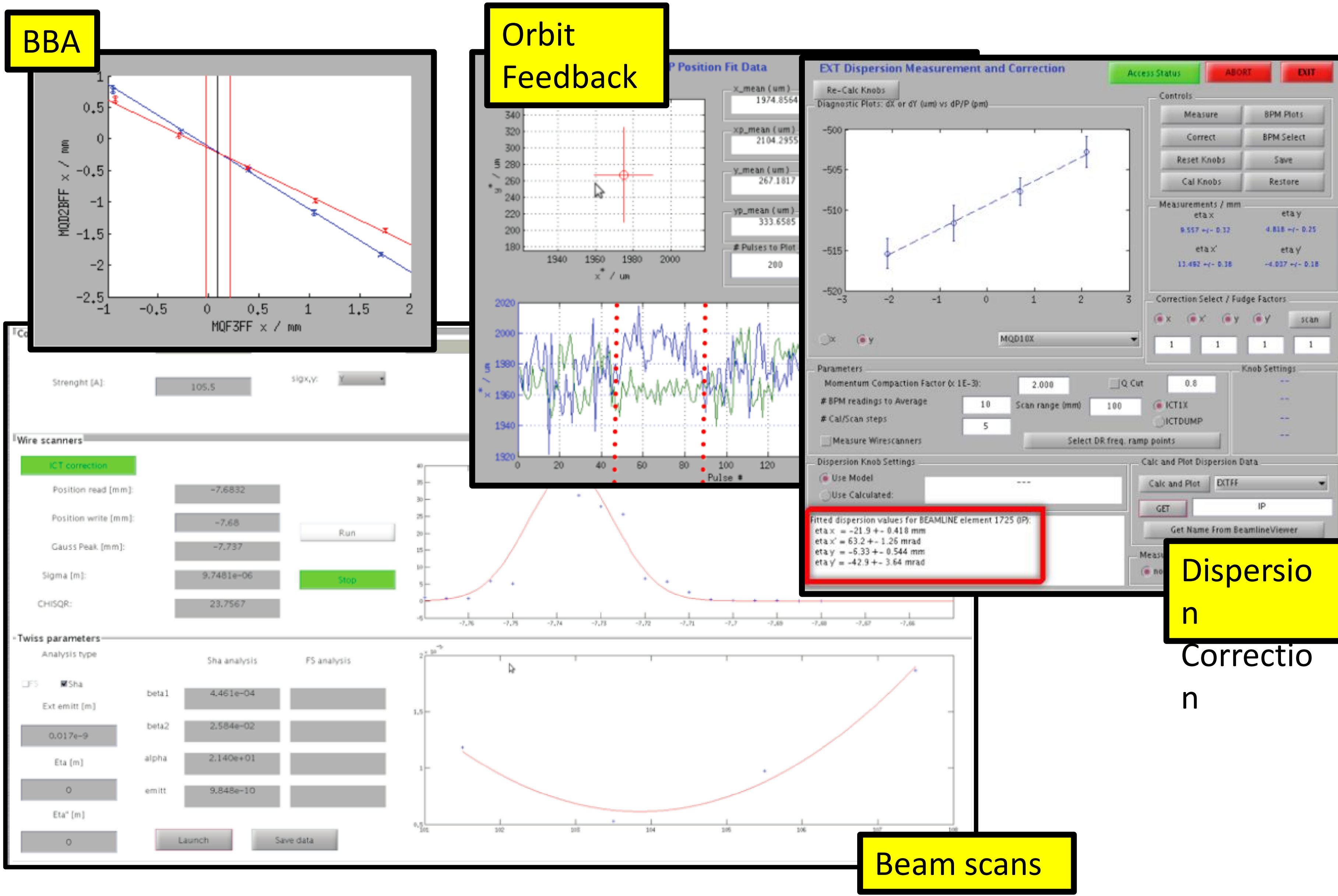
ATF2 Operations

- Initial commissioning started Dec 2008
- 2009 Operations based on "R&D" mode
  - ~50% of shifts allocated to ATF2 commissioning tasks
  - 2-3 weeks operations per month Jan-Jun Oct-Dec
  - Concentrate on isolated hardware and software commissioning items (e.g. cavity BPM system)
  - Test of individual tuning tasks (e.g. correction of EXT dispersion, coupling).
- First "continuous operations" run in May 2010
  - Last week, one dedicated week just for ATF2 tuning
  - First merging of full EXT and FFS tuning procedures

High-Level Controls for Commissioning and Tuning

- Main system used = VSYSTEM + SAD online model
  - Mainstay for accelerator operations, tested, maintained and stable.
- Alternate system developed based on EPICS+ Matlab + Lucretia beam dynamics code: ATF2 “flight-simulator”
  - Portable for offsite code development and testing
  - Same software runs either in production or simulation mode using simulation mode of low-level EPICS controls.
  - Can interface to other code through tcp/ip socket layer or EPICS DB interface.

Example Flight Simulator Tuning Tools



Tuning Procedure (week May 17 – 21)

- DR tuning
  - COD, dispersion, coupling, E match …
- EXT + FFS steering, setup
  - Cav. BPM cal, BBA, steering, background reduction
- EXT tuning
  - Dispersion, coupling correction.
  - Matching into FFS
- FFS tuning
  - Check match conditions at IP
  - “Coarse” IP matching (beta, alpha, dispersion)
    - e.g. “Irwin Knobs”, MAD/SAD rematching
  - Fine tuning of IP aberrations with “multiknobs” and IPBSM “Shintake Monitor”.
    - Waist, dispersion, coupling, sensitive second-order terms.
    - Sextupole mover-based multiknobs, FD roll scans, EXT skew-quad scans…

ATF2 Optics

- Difficulty in tuning (length of tuning time, probability of tuning close to design IP spot size) is related to the magnitude of chromaticity in the final focus optics.
- Currently running with 10 x nominal beta functions at IP (40cm / 1mm).
  - Min vertical beam size with this configuration @ 12pm emittance is ~110nm.
- Background levels at IPBSM become larger at lower IP beta sizes (with increasing beam divergence).
  - Last week, tested with ~0.5mm vertical beta and beam size measurements still possible.

Extracted Emittance

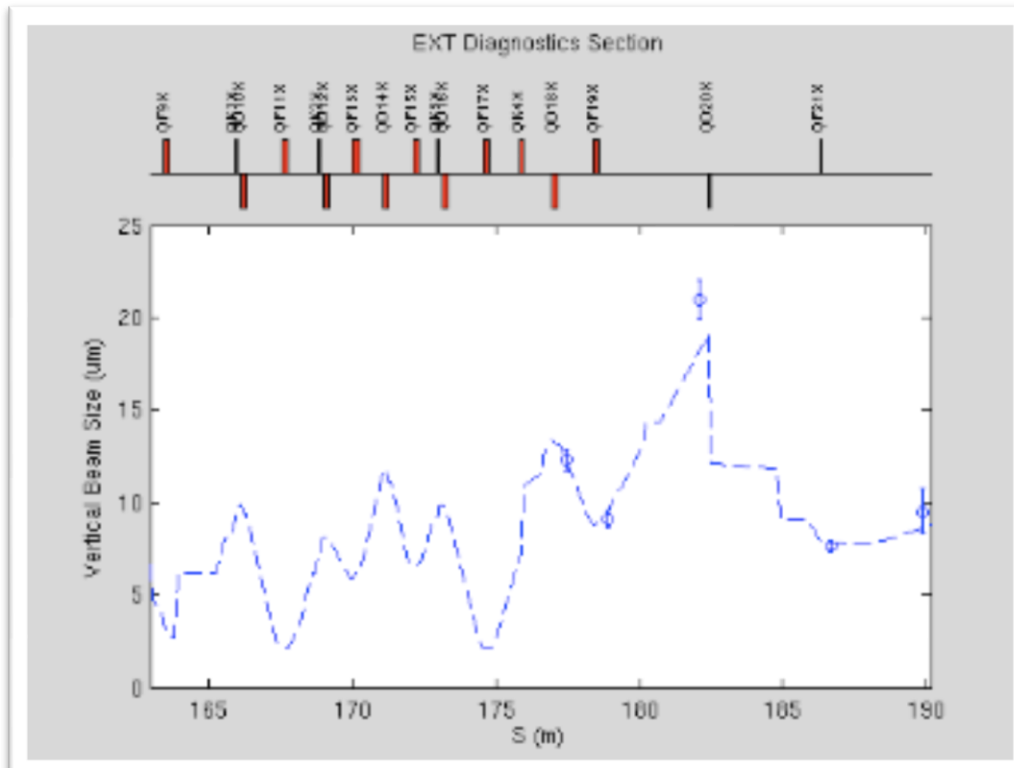
(DR emit_y = 10pm)

sigt	sigd	sigw	sig
13.63	5.31	2.50	12.30
10.47	4.57	2.50	9.08
23.07	9.20	2.50	21.00
8.97	3.89	2.50	7.68
10.30	3.00	2.50	9.53

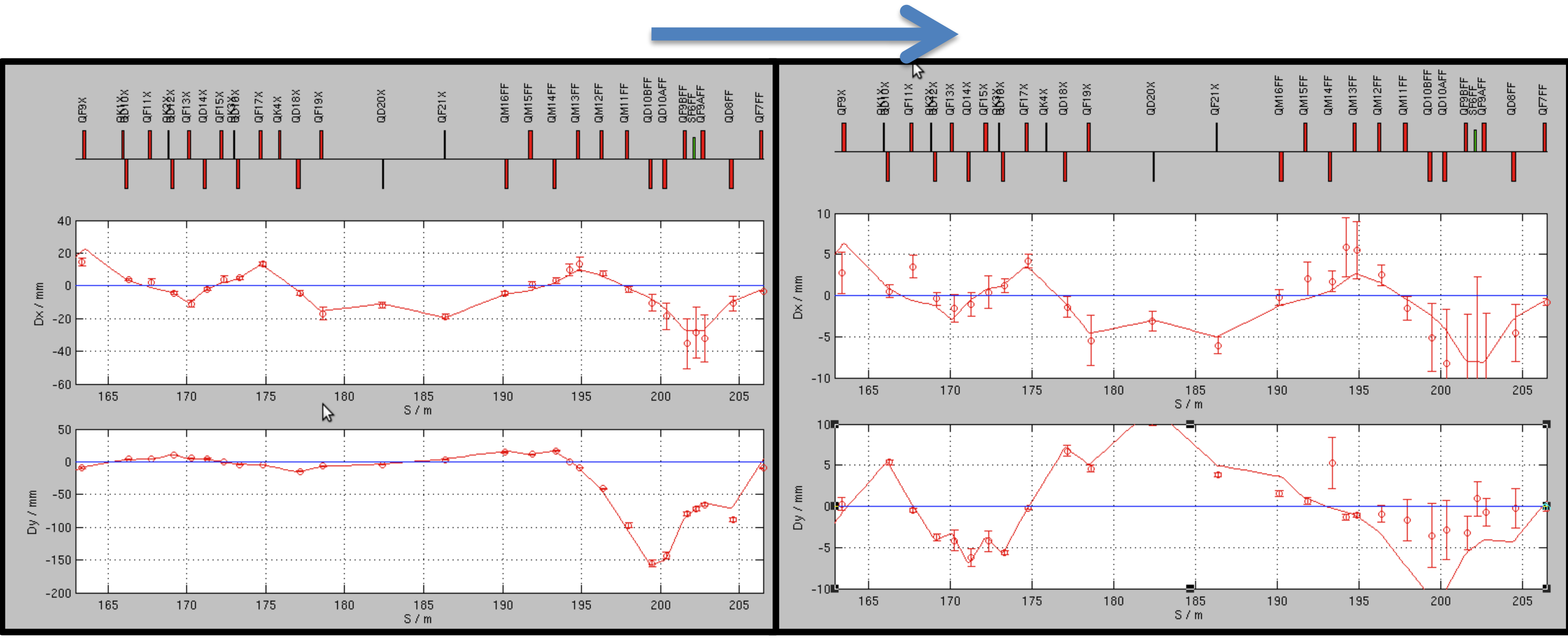
Vertical emittance parameters at MW0X

---

energy = 1.2817 GeV
emit = 11.7381 +- 2.2922 pm
emitn = 29.4427 +- 5.7495 nm
emitn*bmag = 42.2019 +- 1.9205 nm
bmag = 1.4334 +- 0.2490 (1.0000)
bmag_cos = 0.0448 +- 0.0000 (0.0000)
bmag_sin = -0.7150 +- 0.0000 (0.0000)
beta = 12.6951 +- 2.0753 m (8.4774)
alpha = 3.5809 +- 0.4296 (3.0756)
chisq/N = 7.9155

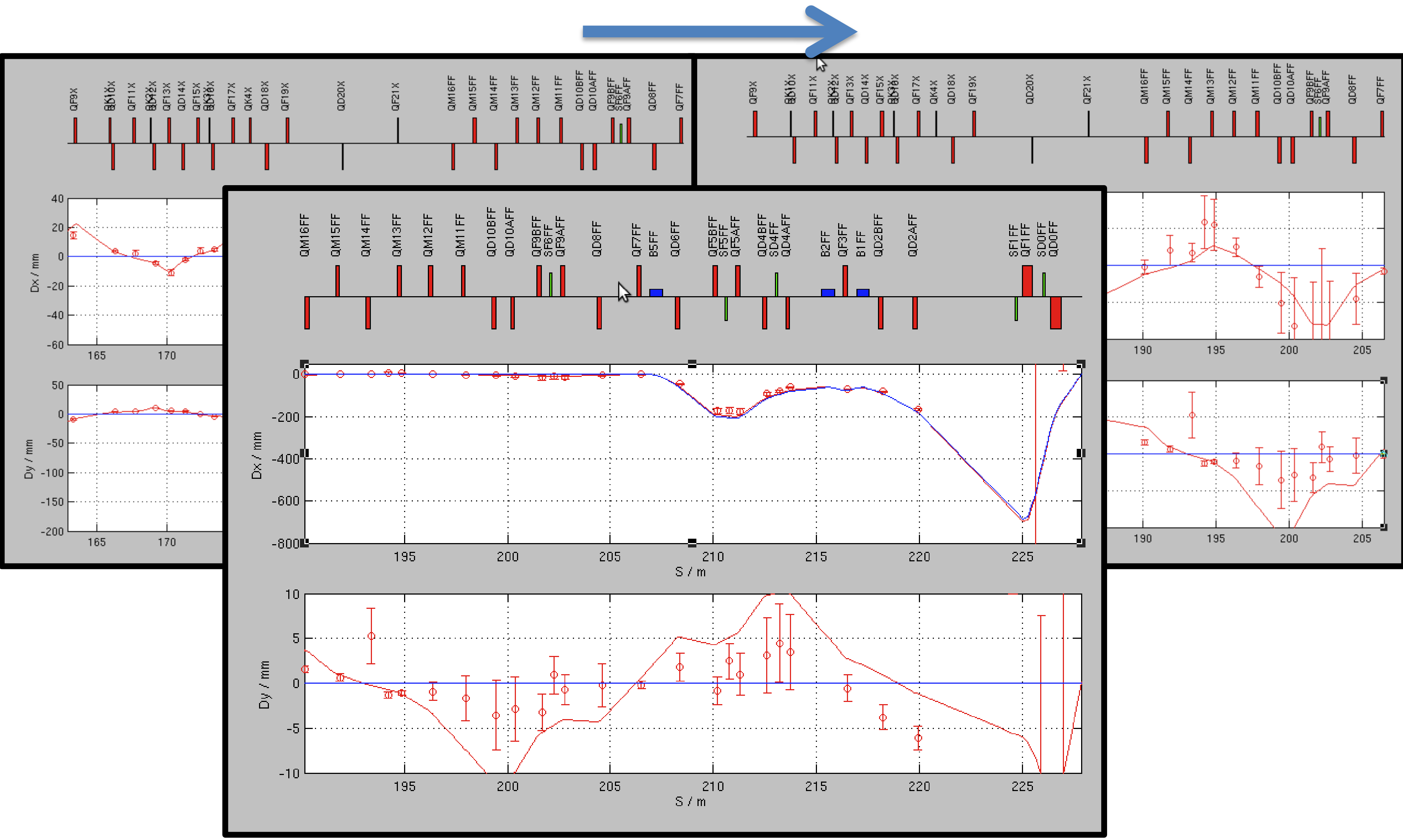


EXT Dispersion Correction

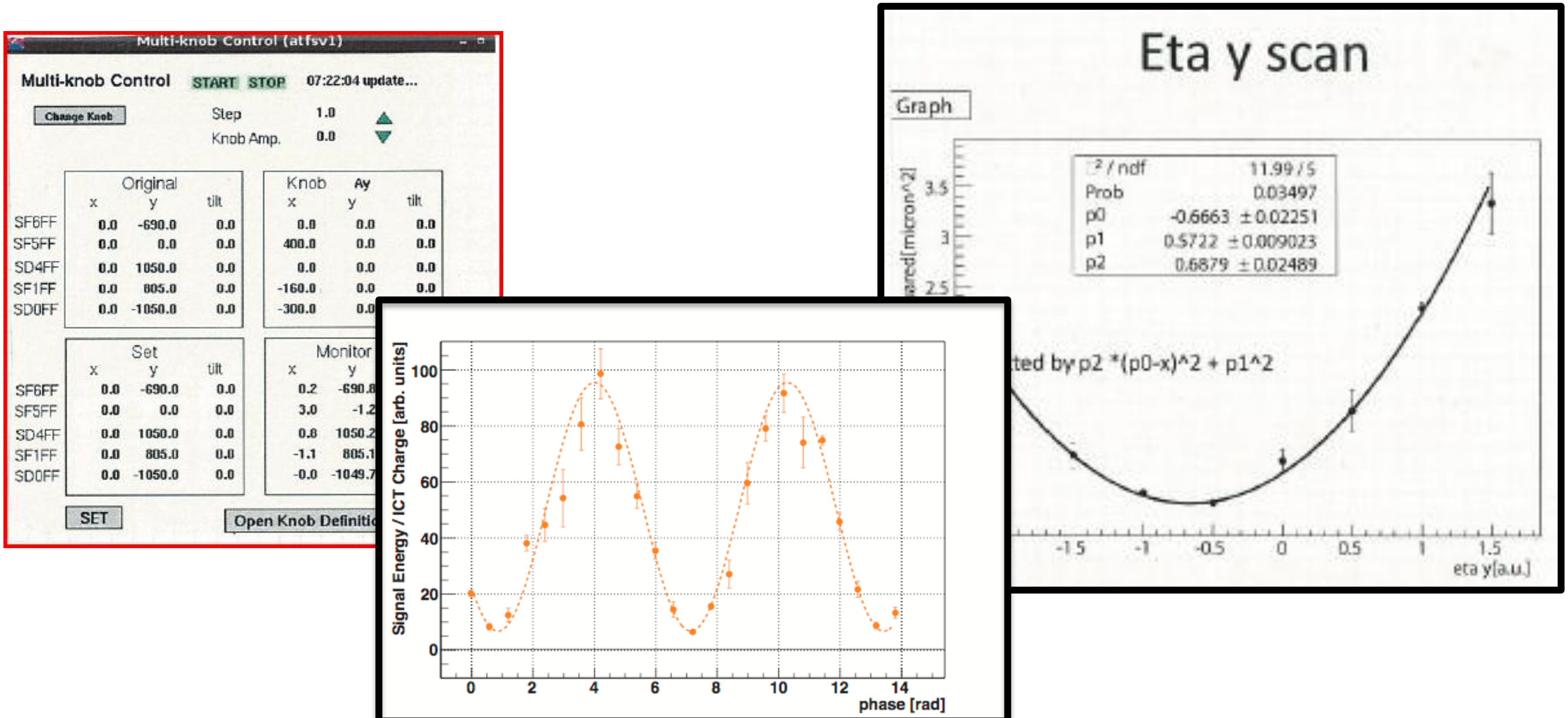


- Dispersion propogation to IP corrected <1mm x/y
- Residual vertical dispersion fine-tuned with FFS Sextupole multiknobs

EXT Dispersion Correction

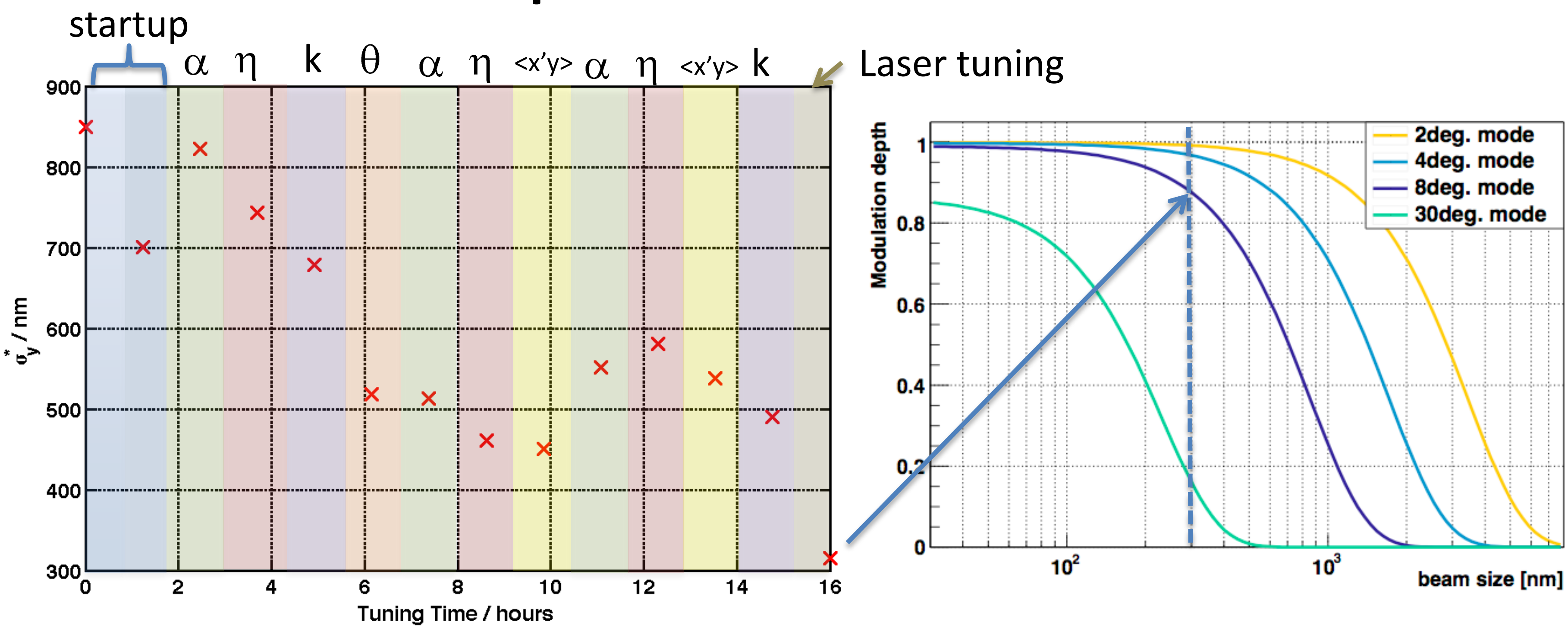


IP Tuning with FFS Sextupole Multiknobs



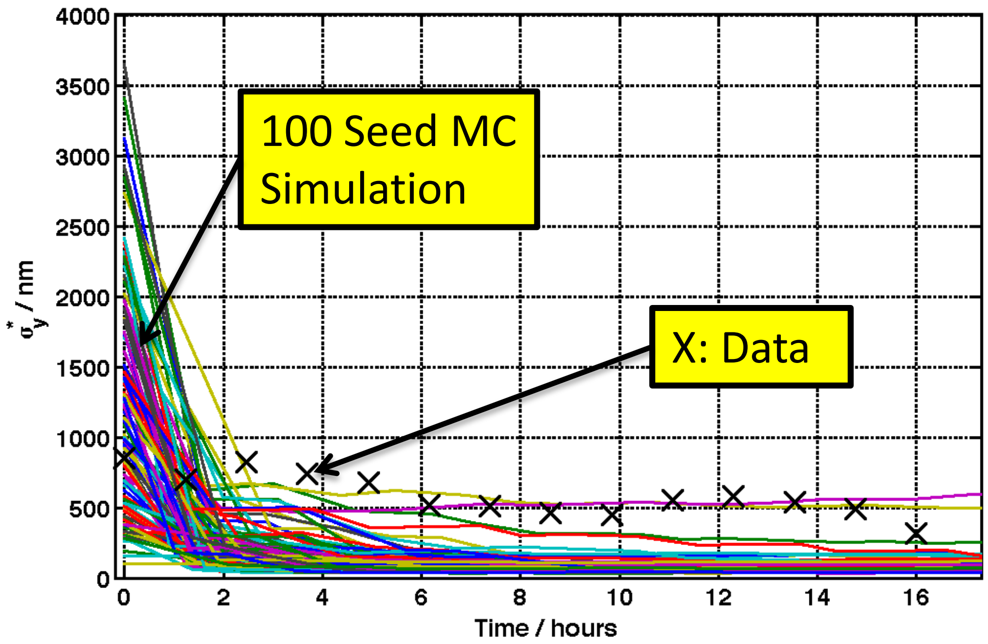
- Iterative use of various knobs to bring down IP spot size by scanning with IPBSM.

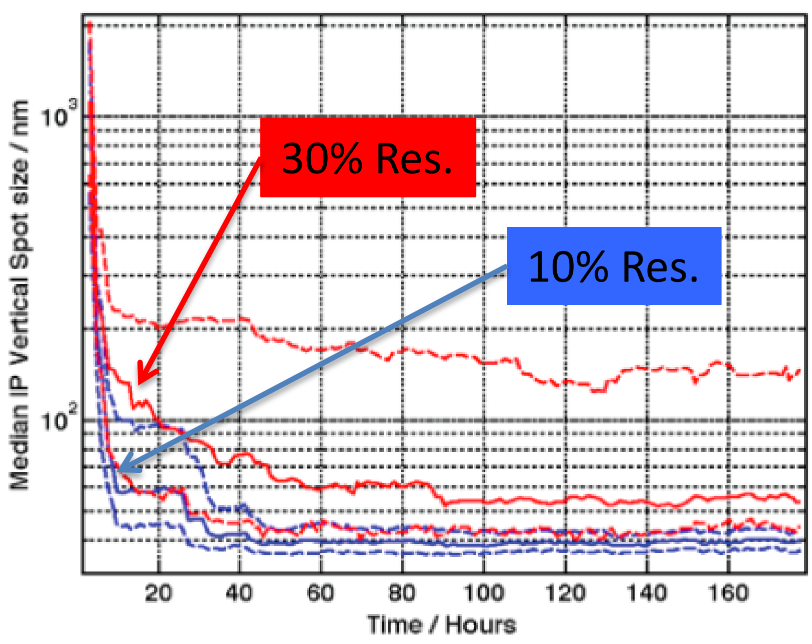
IP Tuning Results During Continuous Operations Week



- Tuning from initial setup of 850nm down to 300nm during 2 consecutive shifts last Thursday.
- Beam size cross-checked on IPBSM 8-degree & 30-degree mode.
- Trouble reducing beam size past 300nm in 30-degree mode as do not have the resolution to scan higher beam sizes.

Data vs. Simulation





- Initial tune up in mid-range expected from Monte Carlo simulations.
- Convergence time slower than simulated as tuning software not yet fully automated.
- This will be essential to be able to achieve goal beam size ~<1 operations week

Work to Do

- ATF2 tuning experience will be very useful showing how well BDS tuning simulations map to reality.
  - Can push IP parameters from ILC-like to more CLIC-like (increasing chromaticity) and see how tuning performance scales.
- ATF2 tuning speed most critical (1.5 Hz beam rate, complicated IP size measurement procedure).
- Initial priority based around understanding limitations to ATF2 tuning performance and speed in simulations and comparison/useage in ATF2 experiment.
- Experience can then be applied to ILC tuning simulation environment and assesed.
- Need to understand slowest/worst seeds
  - Destruction of optics config between FFS Sexts? How to restore?
  - Any particular error parameters that dominate? Think not.
  - Try amalgamation of different tuning ideas in addition to sext multiknobs…