ATF2 & ILC BDS Alignment and Tuning Strategies

Glen White - SLAC National Accelerator Laboratory
CLIC08 Workshop, Oct 2008

- Overview.
- Summary of ILC strategy and simulation results.
- ATF2 EXT and FFS tuning
  - Expected performance based on realistic simulation studies.
  - Implementing tuning strategies on the accelerator.

Overview

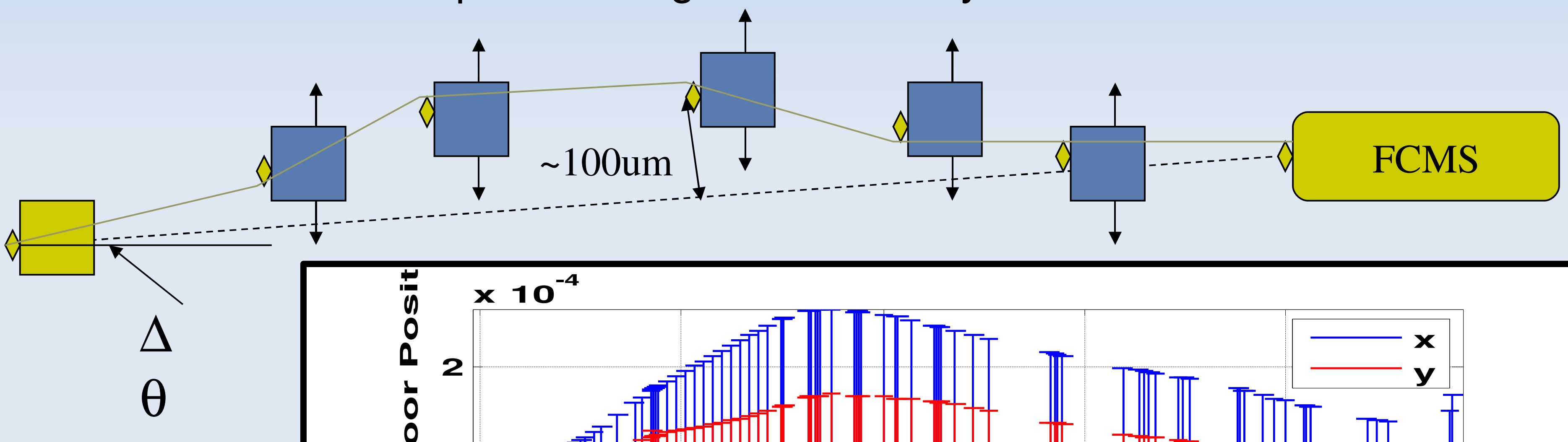
- Goal of ILC BDS alignement and tuning studies
  - Start with expected intial conditions after installation and survey, tune beams to design IP sizes and luminosity and maintain.
- ATF2 FFS built to test ILC-like optics and test tuning procedures.
- ILC IP ~ 550nm * 5nm (250 GeV per beam)
  - ATF IP ~ 3um * 35nm (1.3 GeV)
- ILC tune on luminosity (pair signal – fast)
  - ATF, use Shintake monitor at IP (~ 1 min. Per measurement) – tuning time important factor.

ILC Simulation Steps

- Apply expected errors (static + dynamic).
- Perform initial steering to get beam to IP.
- Quadrupole BPM alignment (quad shunting).
- Perform Quadrupole BBA.
- Align Sextupole BPMs.
- Move final doublet girder to minimize 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.

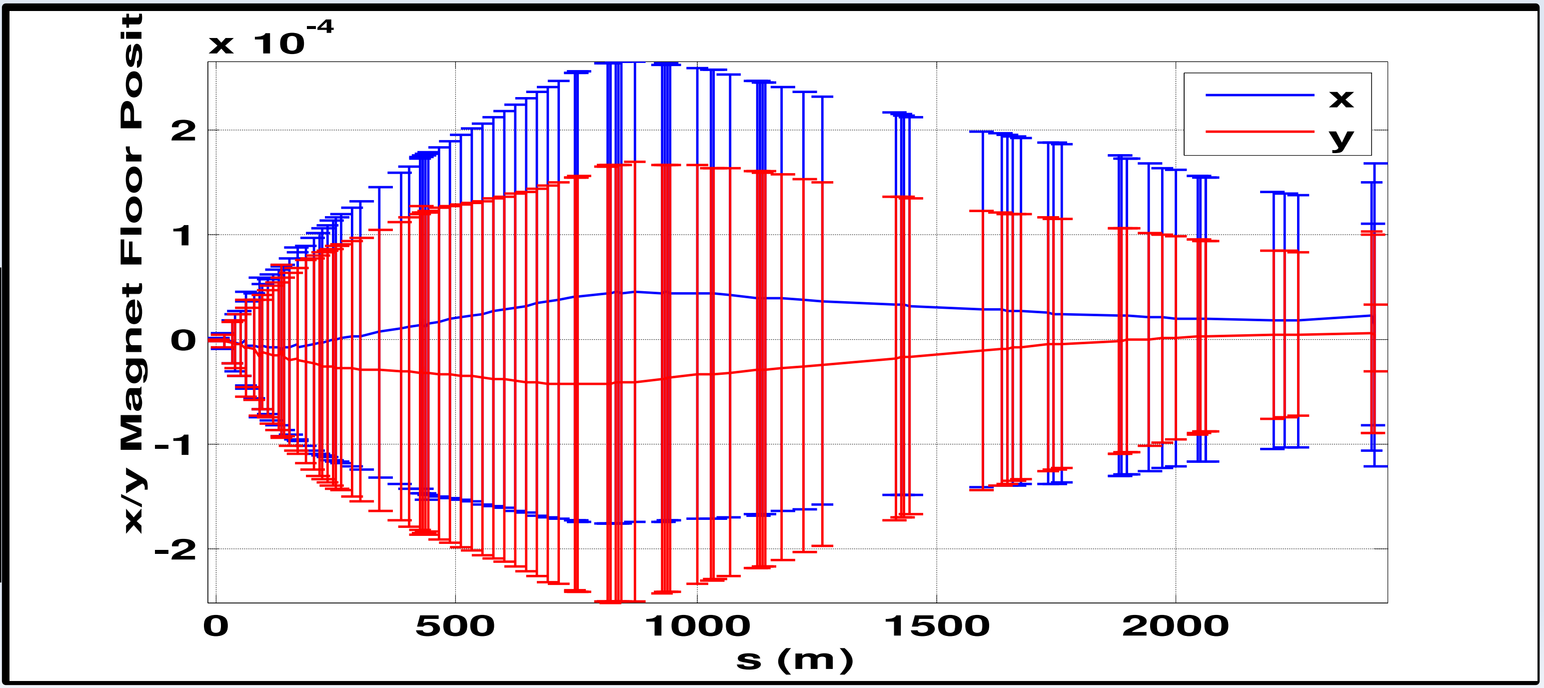
Beam-Based Alignment of Quads

- 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.



•Simulation results.

•RMS Quad floor positions shown (100 seeds).



BBA Algorithm

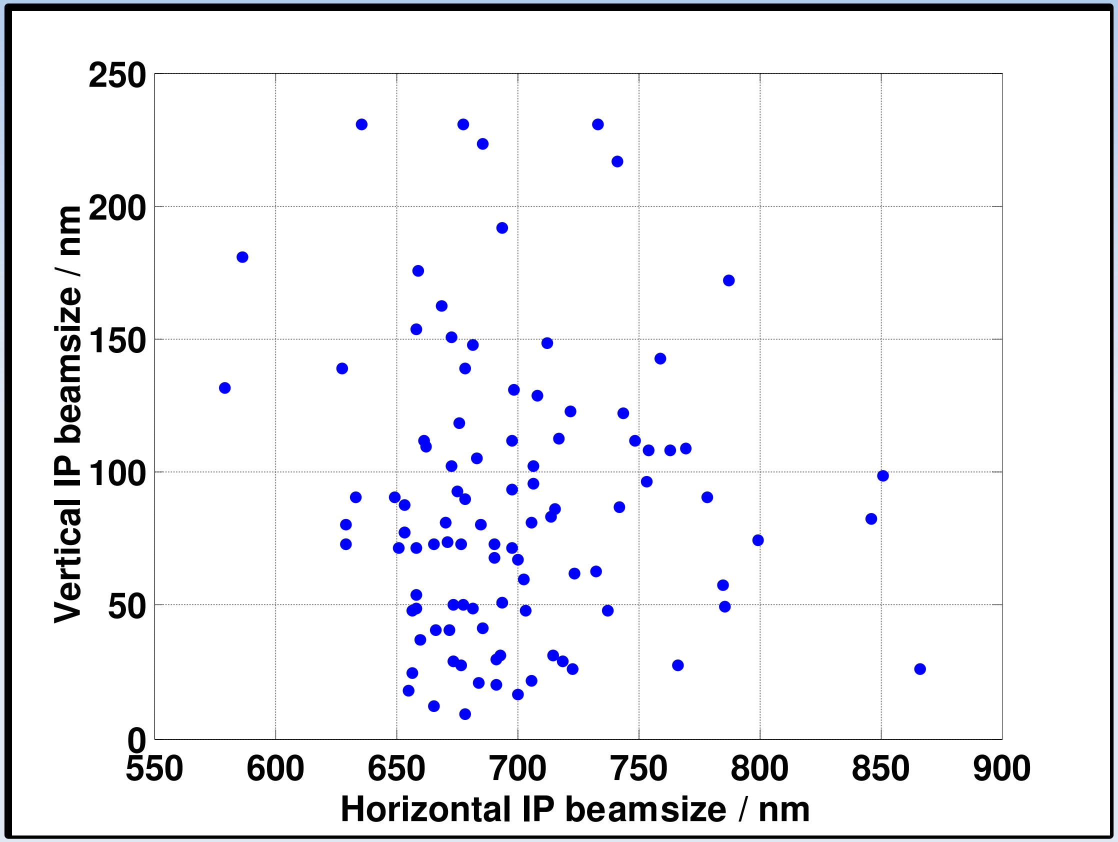
- DFS + mover minimisation solution, use Matlab lscov to solve in a least-squares sense, A*c=b with weight vector, ie. minimise: (b- A*c)'*diag(1/w^2)*(b - A*c), where:

$$b = \begin{pmatrix} B_x^0 \\ B_y^0 \\ B_x^- \\ B_y^- \\ B_x^+ \\ B_y^+ \\ c \end{pmatrix} \quad B = \begin{pmatrix} b_2 \\ b_3 \\ \vdots \\ b_n \end{pmatrix} \quad A = \begin{pmatrix} T^0 \\ T^- \\ T^+ \\ diag(1) \end{pmatrix}$$

$$\begin{aligned}
M_{i,j}^{XX} &= R_i^q(2,1).R_{i,j}(1,2) + \left(R_i^q(1,1) - 1\right)R_{i,j}(1,1) + R_i^q(3,1).R_{i,j}(1,3) + R_i^q(4,1).R_{i,j}(1,4) \\
M_{i,j}^{XY} &= R_i^q(2,3).R_{i,j}(1,2) + R_i^q(1,3).R_{i,j}(1,1) + \left(R_i^q(3,3) - 1\right)R_{i,j}(1,3) + R_i^q(4,3).R_{i,j}(1,4) \\
M_{i,j}^{YY} &= R_i^q(1,3).R_{i,j}(3,1) + R_i^q(2,3).R_{i,j}(3,2) + \left(R_i^q(3,3) - 1\right)R_{i,j}(3,3) + R_i^q(4,3).R_{i,j}(3,4) \\
M_{i,j}^{YX} &= \left(R_i^q(1,1) - 1\right)R_{i,j}(3,1) + R_i^q(2,1).R_{i,j}(3,2) + R_i^q(3,1).R_{i,j}(3,3) + R_i^q(4,1).R_{i,j}(3,4)
\end{aligned}$$

$$T = \begin{pmatrix}
-1 & 0 & 0 & \cdots & \cdots & R_{1,2}(1,2) & 0 & 0 & 0 & \cdots & \cdots & R_{1,2}(1,4) \\
M_{2,3}^{xx} & -1 & 0 & \cdots & \cdots & R_{1,3}(1,2) & M_{2,3}^{xy} & 0 & 0 & \cdots & \cdots & R_{1,3}(1,4) \\
M_{2,4}^{xx} & M_{3,4}^{xx} & -1 & \cdots & \cdots & R_{1,4}(1,2) & M_{2,4}^{xy} & M_{3,4}^{xy} & 0 & \cdots & \cdots & R_{1,4}(1,4) \\
\vdots & \vdots & \ddots & \ddots & \ddots & \vdots & \vdots & \vdots & \ddots & \ddots & \ddots & \vdots \\
M_{2,n}^{xx} & M_{3,n}^{xx} & M_{4,n}^{xx} & \cdots & M_{n-1,n}^{xx} & R_{1,n}(1,2) & M_{2,n}^{xy} & M_{3,n}^{xy} & M_{4,n}^{xy} & \cdots & M_{n-1,n}^{xy} & R_{1,n}(1,4) \\
0 & 0 & 0 & \cdots & \cdots & R_{1,2}(3,2) & -1 & 0 & 0 & \cdots & \cdots & R_{1,2}(3,4) \\
M_{2,3}^{yx} & 0 & 0 & \cdots & \cdots & R_{1,3}(3,2) & M_{2,3}^{yy} & -1 & 0 & \cdots & \cdots & R_{1,3}(3,4) \\
M_{2,4}^{yx} & M_{3,4}^{yx} & 0 & \cdots & \cdots & R_{1,4}(3,2) & M_{2,4}^{yy} & M_{3,4}^{yy} & -1 & \cdots & \cdots & R_{1,4}(3,4) \\
\vdots & \vdots & \ddots & \ddots & \ddots & \vdots & \vdots & \vdots & \ddots & \ddots & \ddots & \vdots \\
M_{2,n}^{yx} & M_{3,n}^{yx} & M_{4,n}^{yx} & \cdots & M_{n-1,n}^{yx} & R_{1,n}(3,2) & M_{2,n}^{yy} & M_{3,n}^{yy} & M_{4,n}^{yy} & \cdots & M_{n-1,n}^{yy} & R_{1,n}(3,4)
\end{pmatrix} \quad c = \begin{pmatrix} q_2^x \\ q_3^x \\ \vdots \\ q_{n-1}^x \\ k_1^x \\ q_2^y \\ q_3^y \\ \vdots \\ q_{n-1}^y \\ k_1^y \end{pmatrix}$$

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:

$$\Delta s_{x,y} \sim \Delta x . K_2^s L \beta_{x,y}^s \beta_{x,y}^* \cos(2.\mu)$$

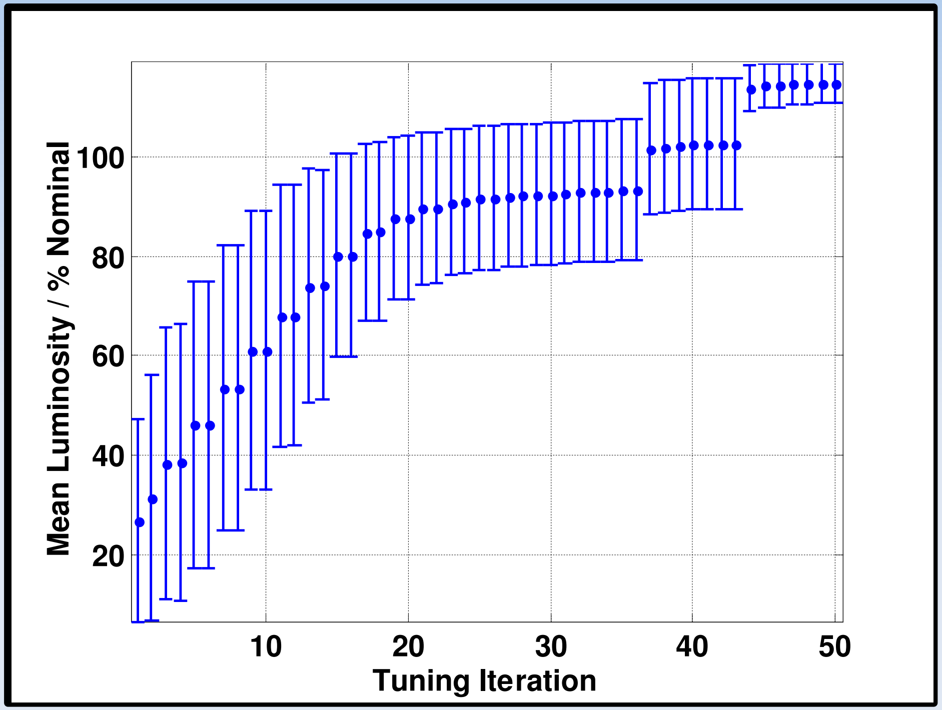
$$\Delta \eta_{x,y}^* \sim \Delta(x,y) . K_2^s L \eta_{x,y}^s \sqrt{\beta_{x,y}^s \beta_{x,y}^*} \sin(\mu)$$

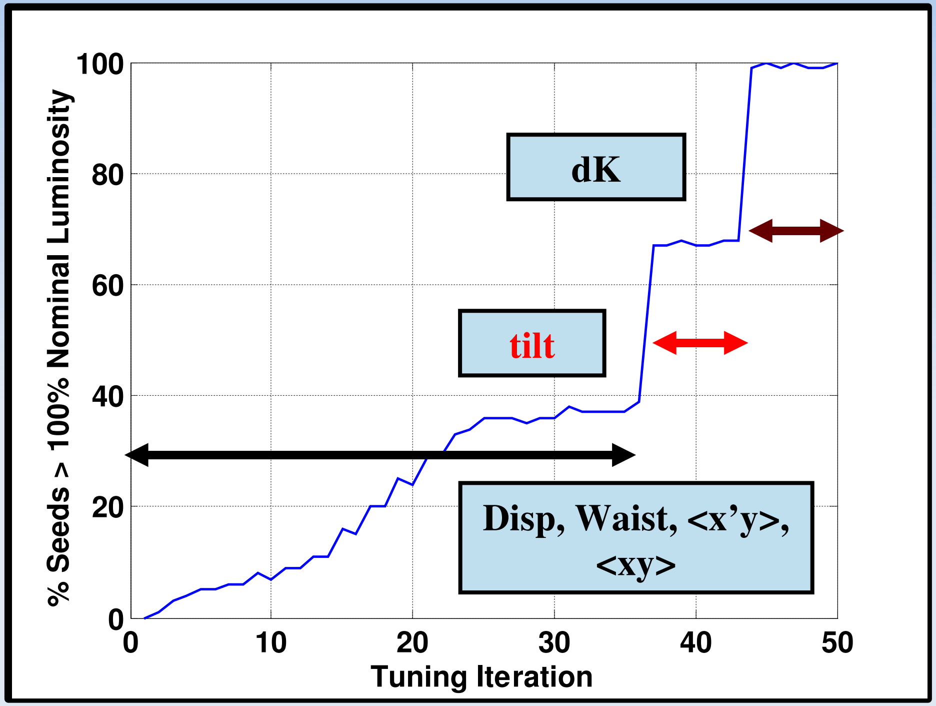
  - Orthogonal knobs are computed by inverting the sextupole move -> IP aberration matrix formed by scanning the sextupoles in turn and measuring the IP terms.
- The dominant IP coupling term <x'y> is tuned-out using SQ3FF.
- The 4 skew quads in the BDS coupling correction system are iteratively scanned to remove any <xy>.

Sextupole Multi-Knobs

- The linear knobs are applied iteratively until no further improvement.
- Higher-order IP terms are dealt with globally by tuning on the roll and strength changes of the first 3 FFS Sextupoles.
- These are applied iteratively interleaved with the linear knobs again.

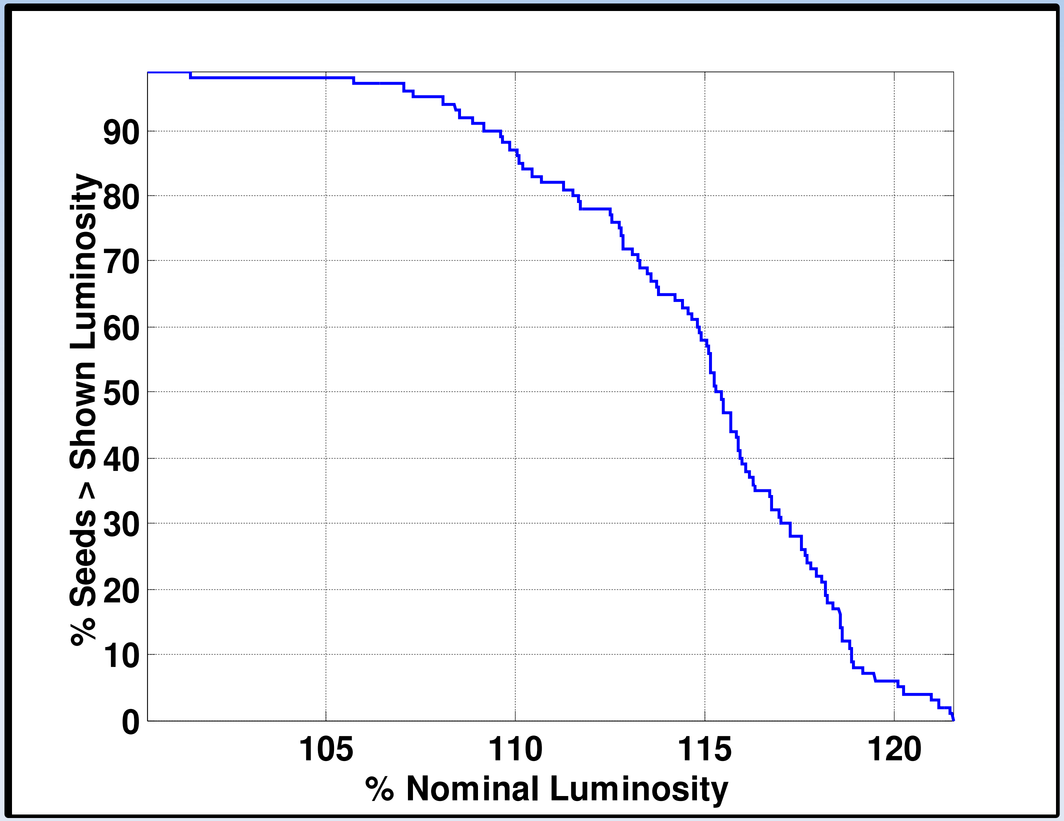
Application of Multi-Knobs





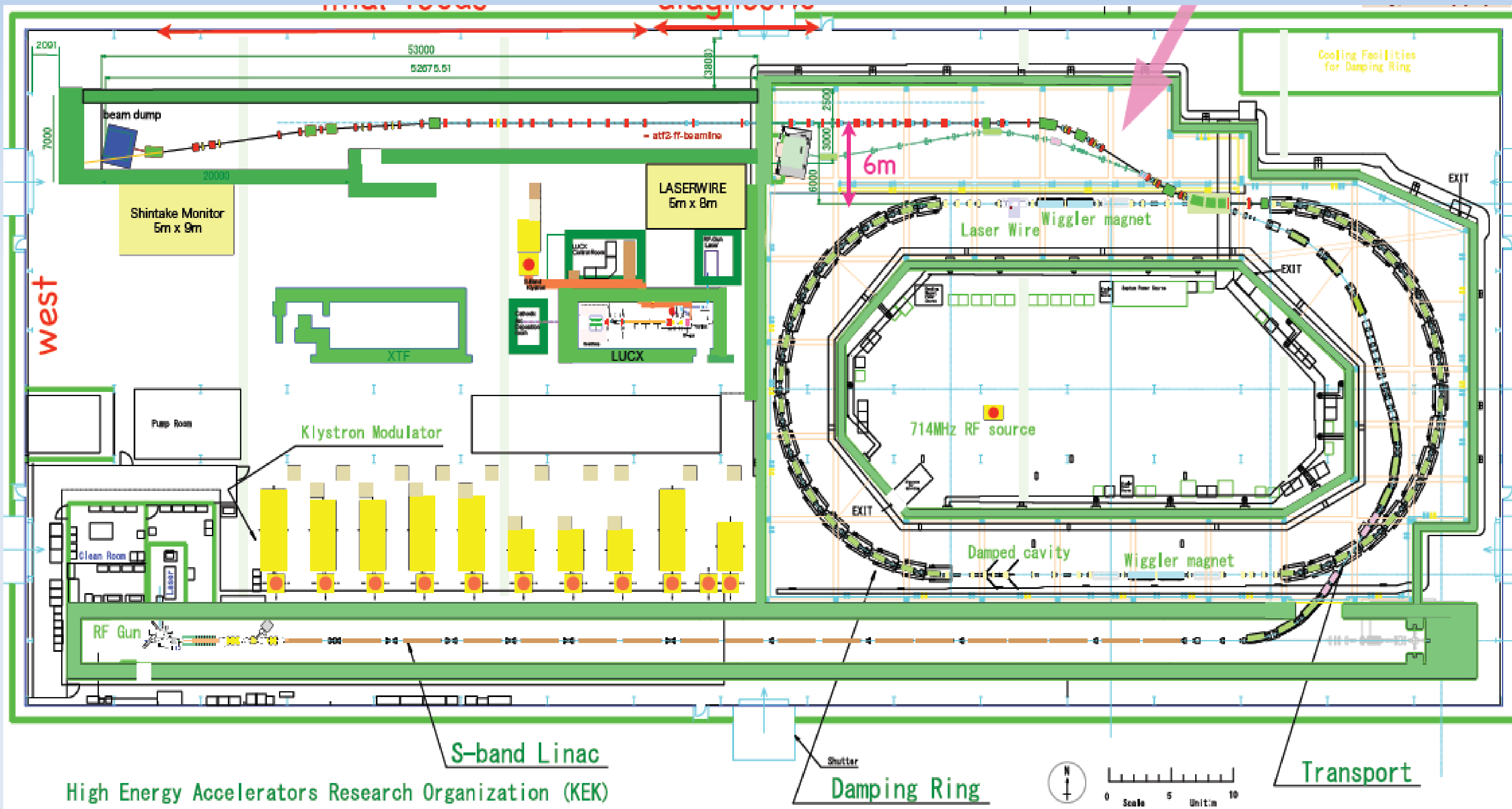
- About 35% of seeds produce >100% luminosity with just linear knobs.
- 100% seeds produce >100% luminosity when also include non-linear knobs.

Luminosity Results



- Median lumi overhead ~15% (with 6nm emittance growth budget for BDS).

Test of FFS Optics @ ATF2



Tuning Goals and Methods

- Achieve ~35nm vertical spot size as measured by Shintake BSM
  - ~3.2 um horizontal spot
  - Have ignored horizontal in simulations so far, except that Sextupole knobs were orthogonalised to minimise extra x growth when reducing y.
- Construct multi-knobs to reduce from initial size ~<3um after initial alignment.
  - Sextupole x/y moves, final doublet dk, skew-quads (waist, dispersion, coupling)
  - Sextupole tilts / dk (higher-order IP terms)
- IP measurement speed v.slow w.r.t. ILC (~1 min), need to ensure efficient and orthogonal knobs.

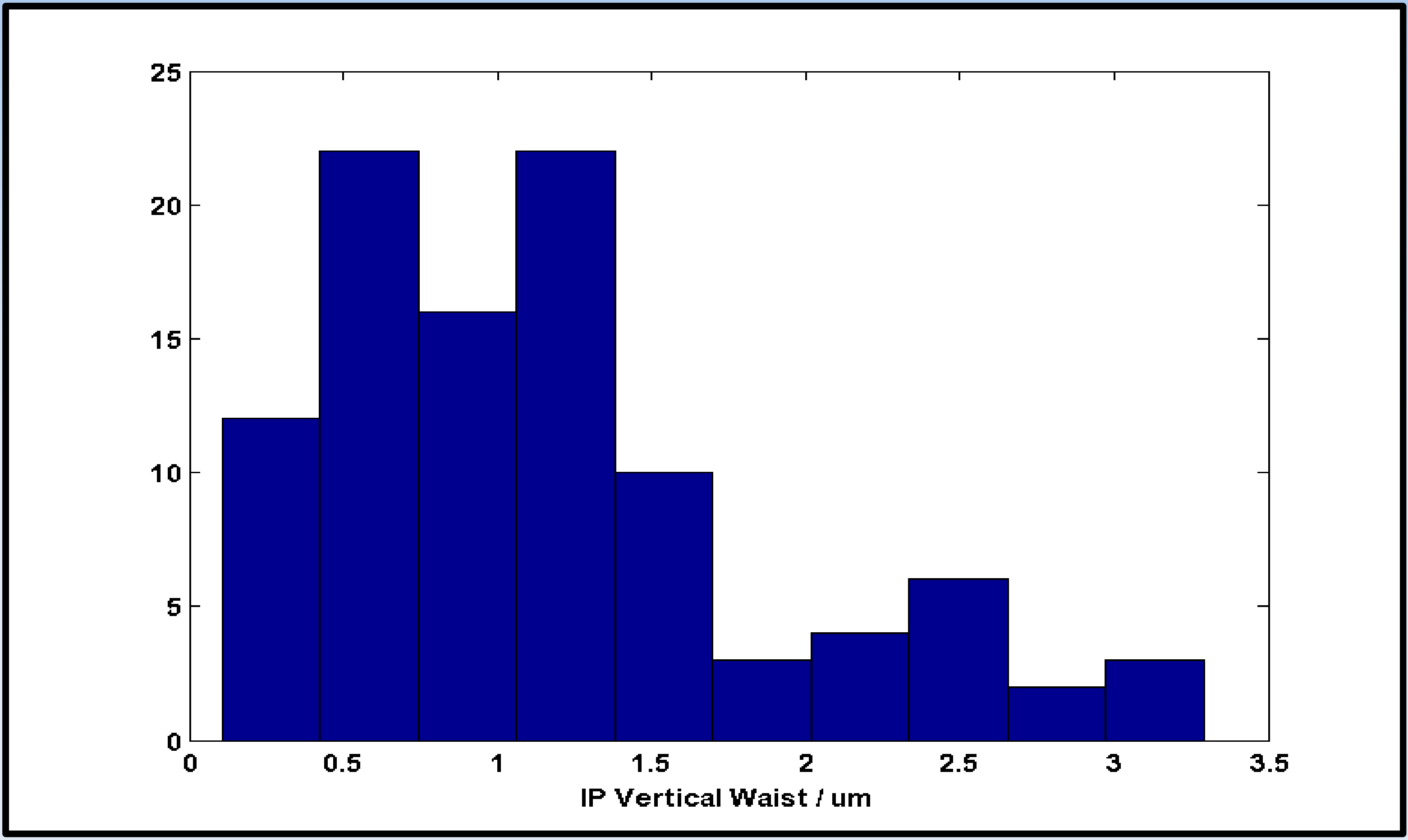
Simulation Studies

- 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.

Simulation Procedure

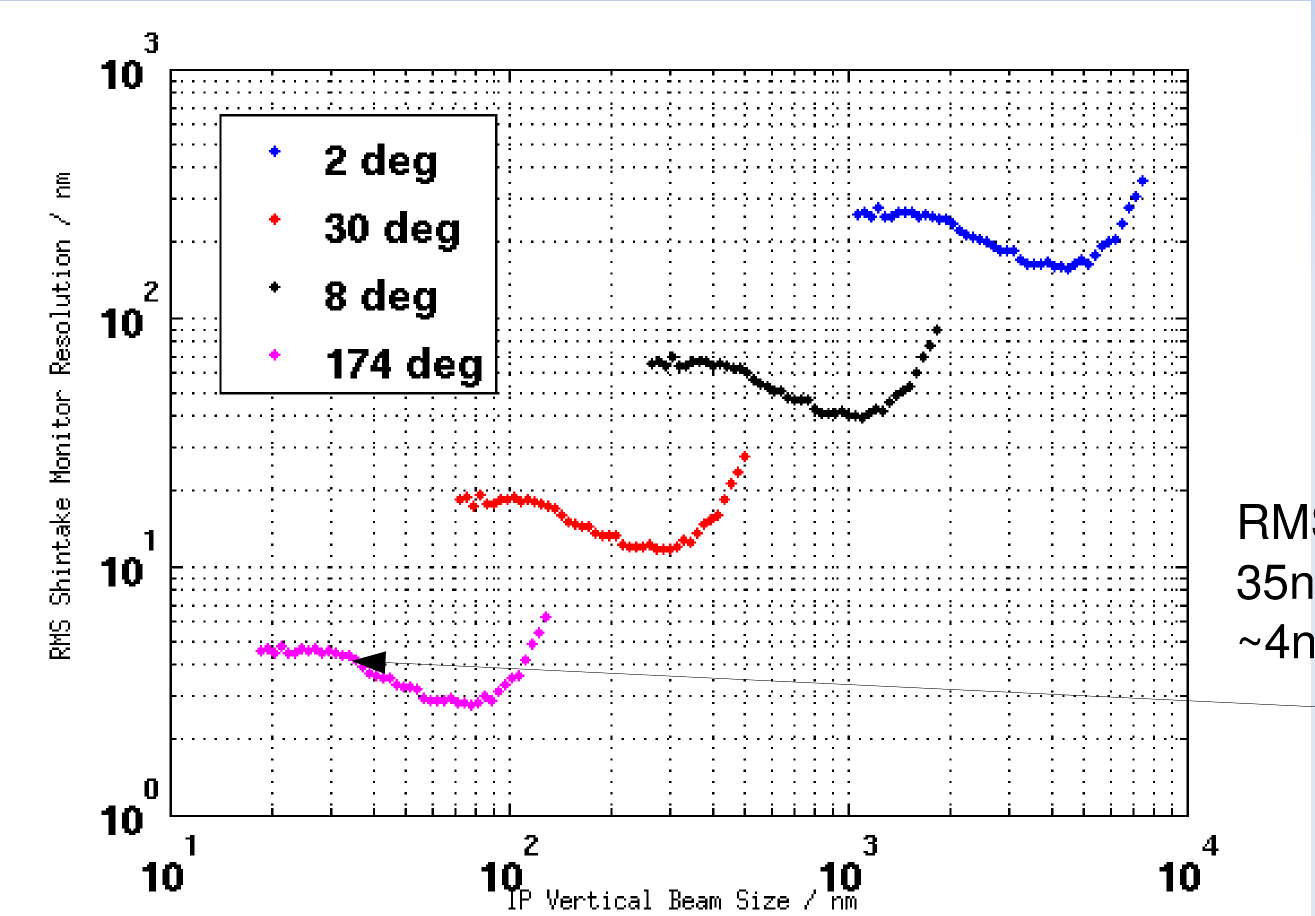
- Use EXT correctors + BPMs (EXT FB) to get orbit through EXT.
- Use FFS FB to get beam through FFS.
- EXT dispersion + coupling correction.
- FFS Quad BPM alignment using quad shunting with movers.
- FFS Quad mover-based BBA.
- FFS Sext BPM alignment using Sext movers and IP BPM.
- Sextupole mover tuning knobs to get final spot size
  - Vertical IP dispersion and Waist
  - <x'y> coupling
  - Higher order terms collectively through Sext rolls + dK.
- Can 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)

IP Vertical Beamsize After BBA



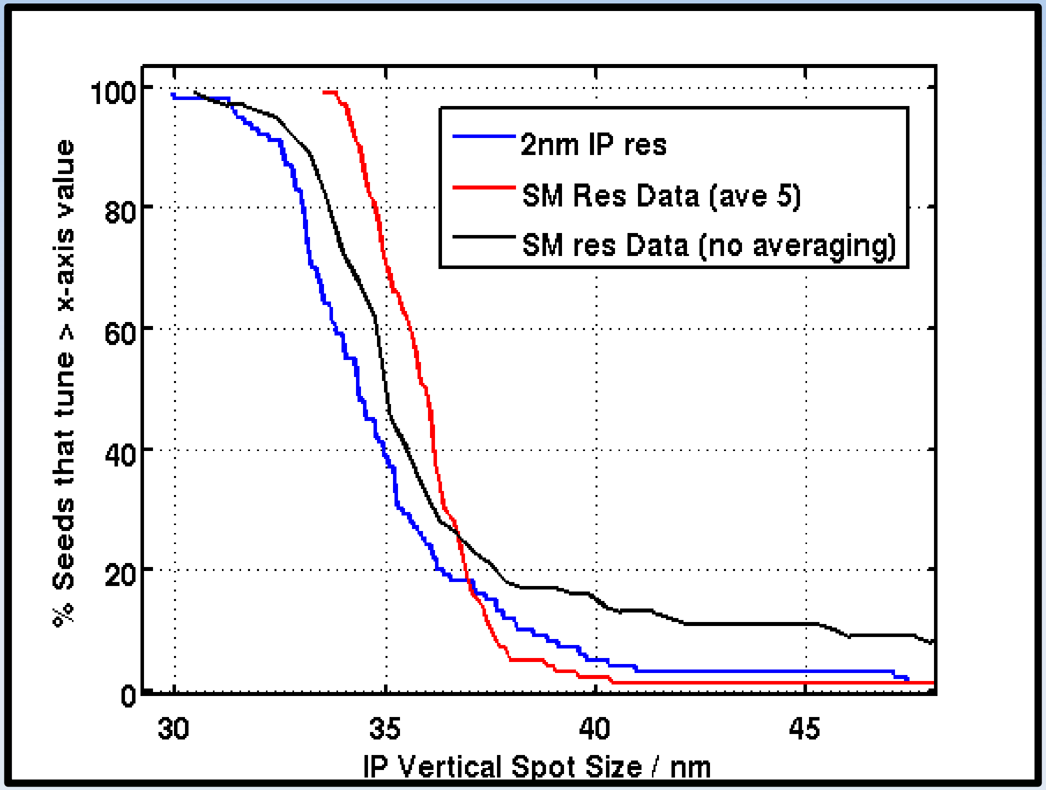
- IP waist size before sextupole FFS tuning knobs applied (100 seeds).

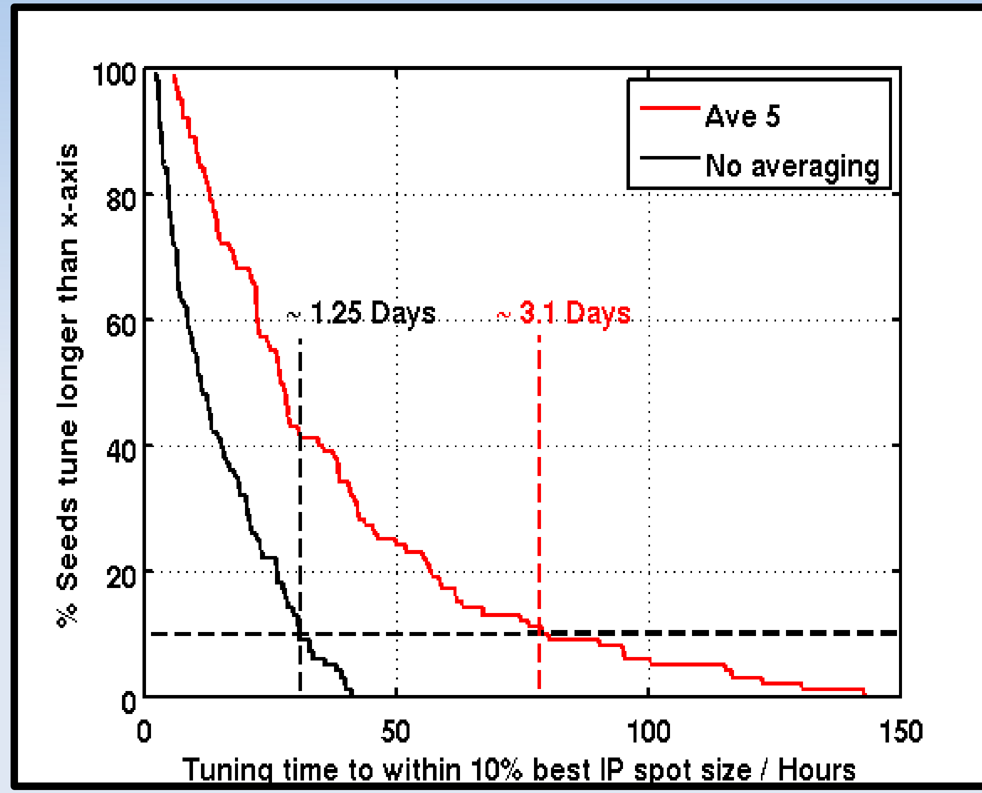
Shintake Monitor IP Beamize Measurement Resolution



RMS resolution at 35nm goal spot size ~4nm

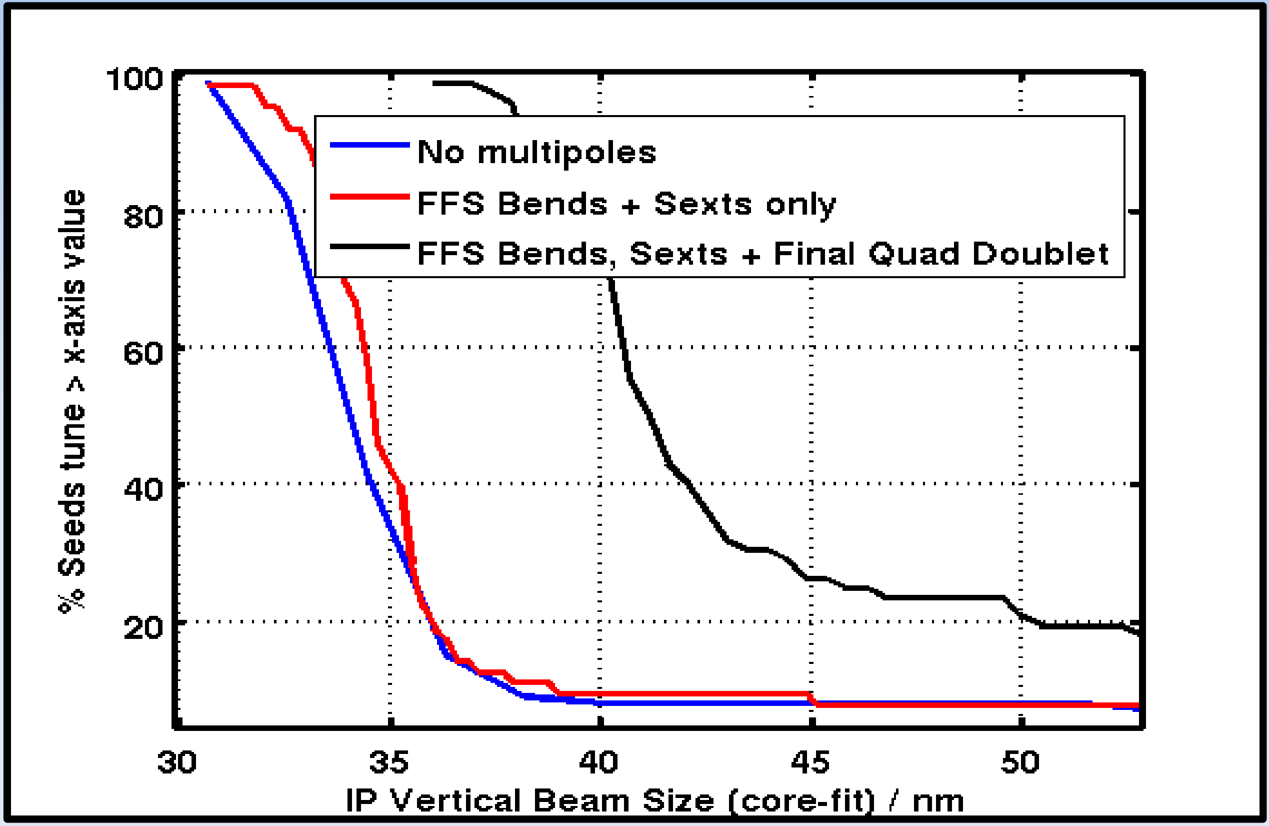
Tuning Performance





- Evaluating the effect of the Shintake Monitor resolution (100 seeds used in simulation).
- 90% of seeds tune close to design beam size in 1.25 days (continual automated running).

Effect of Measured Magnet Multipoles

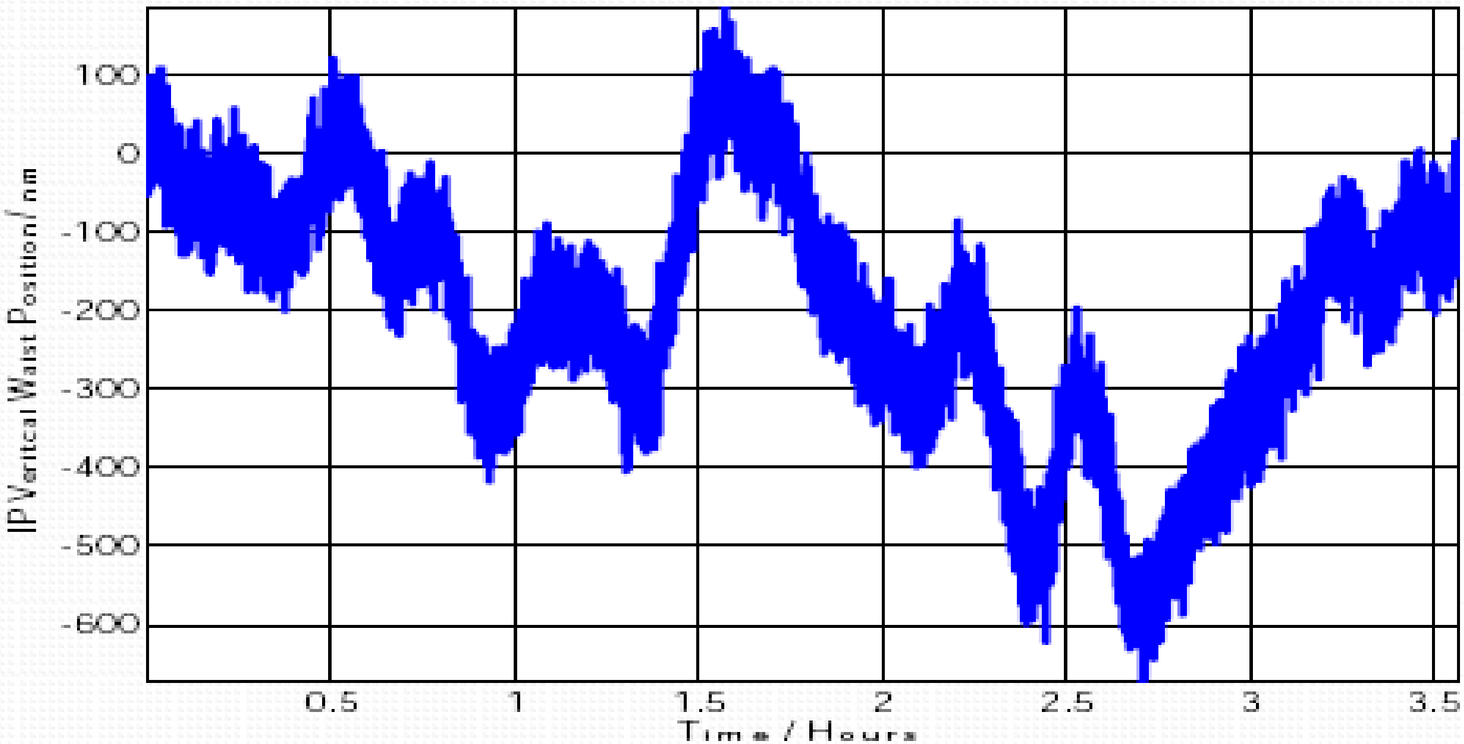


- FFS Bend, Sextupole and final quad doublet multipoles measured and put in model.
- QF1 + QD0 sextupole, and QF1 8 and 12-pole cause significant IP beam size growth.
- Can hopefully fix by re-matching FFS optics.

Sextupole Mover System

- 5 Mover systems under FFS Sextupoles most important of all movers
- Need to move sextupoles during multi-knobs as quickly and accurately as possible.
- Need accurate move size vs. time vs. accuracy data to properly model (will be provided)
- Need faster motor drivers for these magnets (salvage old nanobpm motor drivers)
- Use Sext BPMs as readback, not LVDTs (more accurate and faster).
  - Only faster if not have to do too much averaging.

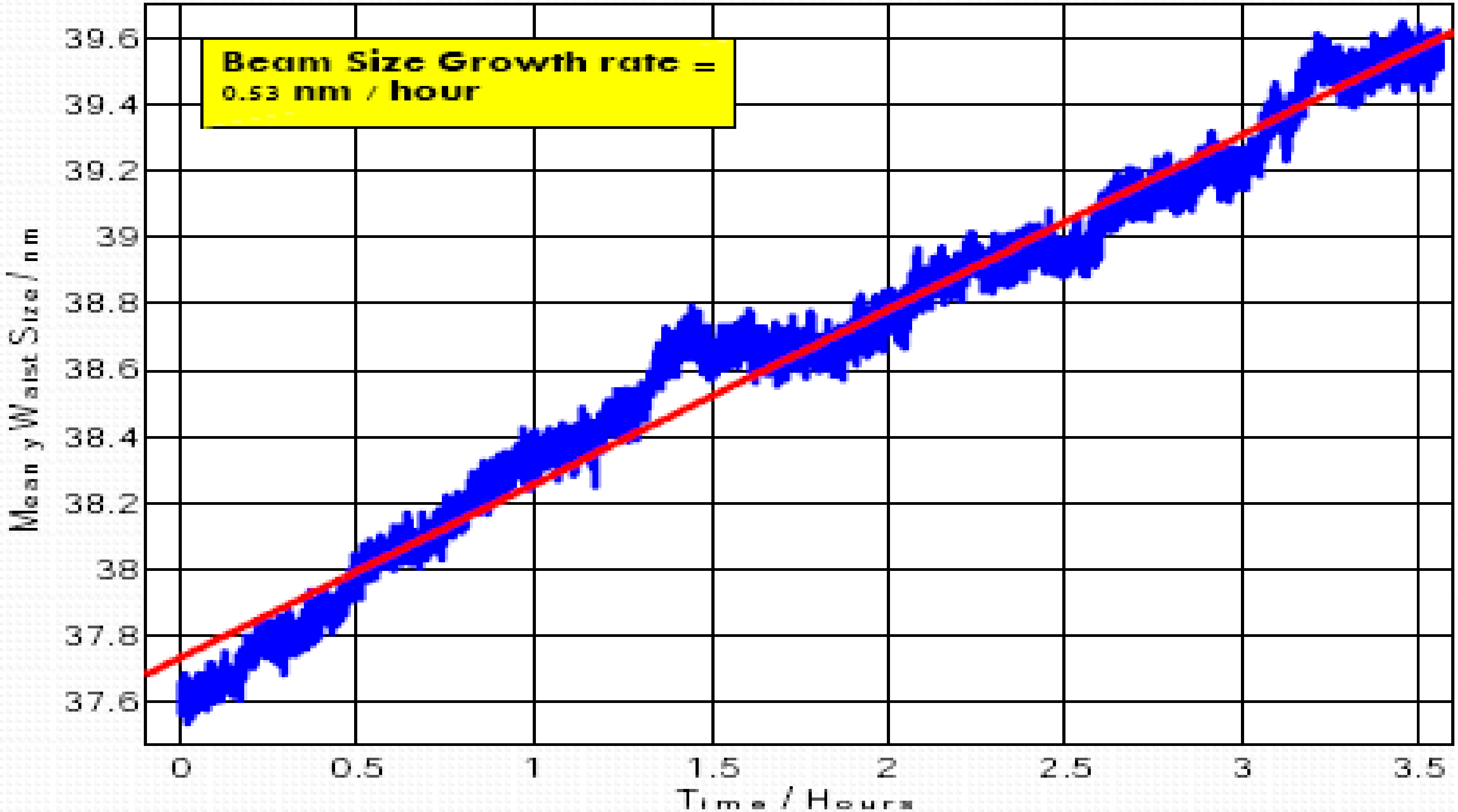
IP Motion



- 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.

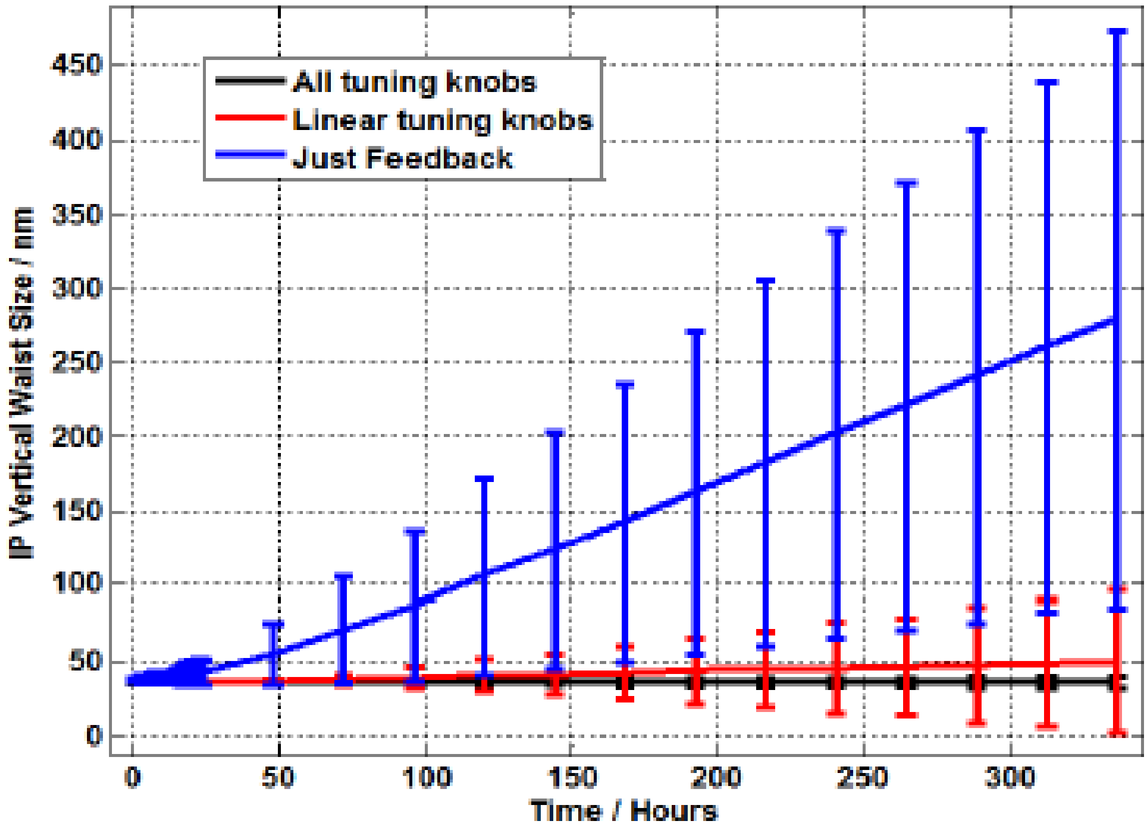
- Fast jitter effects at IP removed from Shintake monitor readout using very high resolution IP BPM

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

Implementation of Tuning @ ATF2

- All algorithms for results shown here written and tested using Lucretia beam tracking code (under Matlab).
- Important to maximise automation to do tuning as fast as possible at ATF2.
- Developed ATF2 ”Flight Simulator” concept which allows code to be developed, tested in simulation and applied at ATF2 in the same environment.
- Based on extention to Lucretia, but also allows direct access from other tools (e.g. PLACET).
- Tested successfully at last ATF run in May using both Lucretia and PLACET tools.