Integrated ATF2 Dynamic Tuning Simulations

Glen White, LAL/SLAC
ATF2 Software Workshop
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- Simulation overview.
- Tuning for 37nm IP vertical beam size.
- Dynamic stability.
- Further work and FS integration.

Overview

- Make a detailed dynamic simulation of ATF2 alignment and tuning steps to assess feasibility of getting and maintaining ~37nm spot size when considering all error sources.
- All simulations in Matlab with Lucretia.
- Try and include all tuning steps after initial commissioning (ie beam gets to end of beamline).
- Review further work and steps towards Flight Simulator integration.

Error Parameters

- Errors are normally distributed with mean=ref. orbit and quoted standard deviations.
- EXT BPM alignment not directly modeled yet, assume 10um quad-bpm alignment here.
- Model for SM measurement: mean spot size from 90 consecutive pulses +/- 2nm RMS error.
- Poisson-calculated multipole errors in FFS dipoles.
- Measured final quad doublet errors available, not in simulation yet

x/y/z alignment errors	**200 um**
Quad, Sext / Bend roll alignment	**300 urad**
Initial BPM-magnet field center alignment	**30 um**
dB/B for Quad, Sexts	**1e-4 syst. + 1e-4 random**
Mover step size (x & y)	**50 nm**
BPM resolutions	**100 nm**
Power supply resolution (not included in this simulation as shown)	**20 (FFS)/11 (EXT) bit**
Shintake Monitor Resolution	**2nm (+ dyn. Err cont.)**

Dynamic Errors

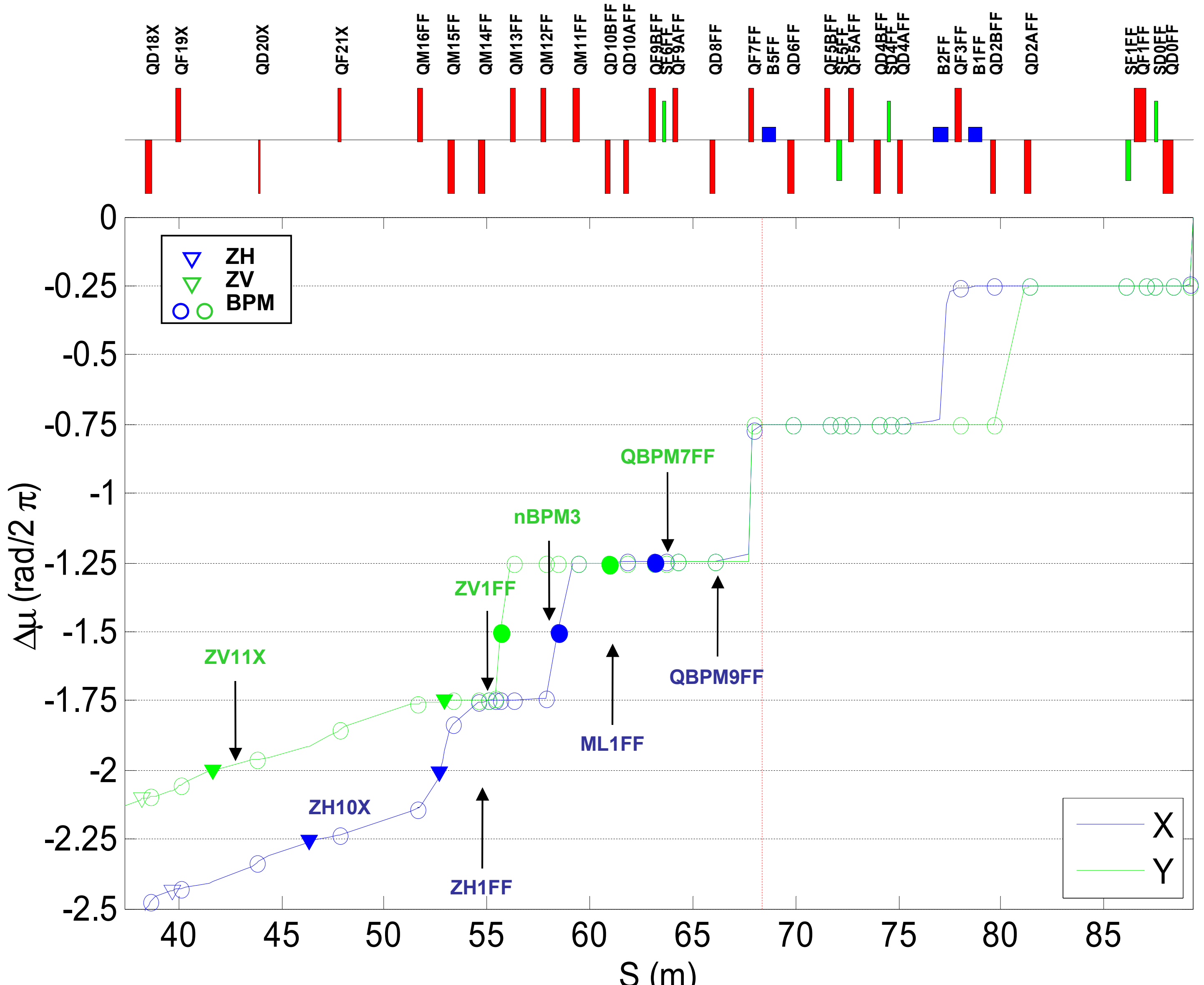
- RMS pulse-pulse errors:
  - Component jitter: 25 nm.
  - Energy error: 1E-4.
  - Ring extraction jitter: 0.1 sigma (x,x',y,y').
- Pulse-pulse feedback using FFS FB + EXT steering algorithm.
- Ground motion: use modified model K from ATF measurements:

Ground motion ATF. Tentative version				K model
'Parameter A of the ATL law,	A [m**2/m/s]	'	1.00000E-17	
'Parameter B of the PWK,	B [m**2/s**3]	'	5.00000E-18	
'Frequency of 1-st peak in PWK,	f1 [Hz]	'	1.60000E-01	
'Amplitude of 1-st peak in PWK,	a1 [m**2/Hz]	'	4.00000E-13	1.00000E-11
'Width of 1-st peak in PWK,	d1 [1]	'	5.00000E+00	
'Velocity of 1-st peak in PWK,	v1 [m/s]	'	1.0000E+03	-1.0000E+03
'Frequency of 2-nd peak in PWK,	f2 [Hz]	'	2.50000E+00	
'Amplitude of 2-nd peak in PWK,	a2 [m**2/Hz]	'	3.00000E-15	1.00000E-15
'Width of 2-nd peak in PWK,	d2 [1]	'	3.00000E+00	
'Velocity of 2-nd peak in PWK,	v2 [m/s]	'	3.00000E+02	-4.0000E+02
'Frequency of 3-rd peak in PWK,	f3 [Hz]	'	9.00000E+00	
'Amplitude of 3-rd peak in PWK,	a3 [m**2/Hz]	'	3.00000E-17	1.00000E-17
'Width of 3-rd peak in PWK,	d3 [1]	'	2.80000E+00	
'Velocity of 3-rd peak in PWK,	v3 [m/s]	'	2.50000E+02	-4.0000E+02

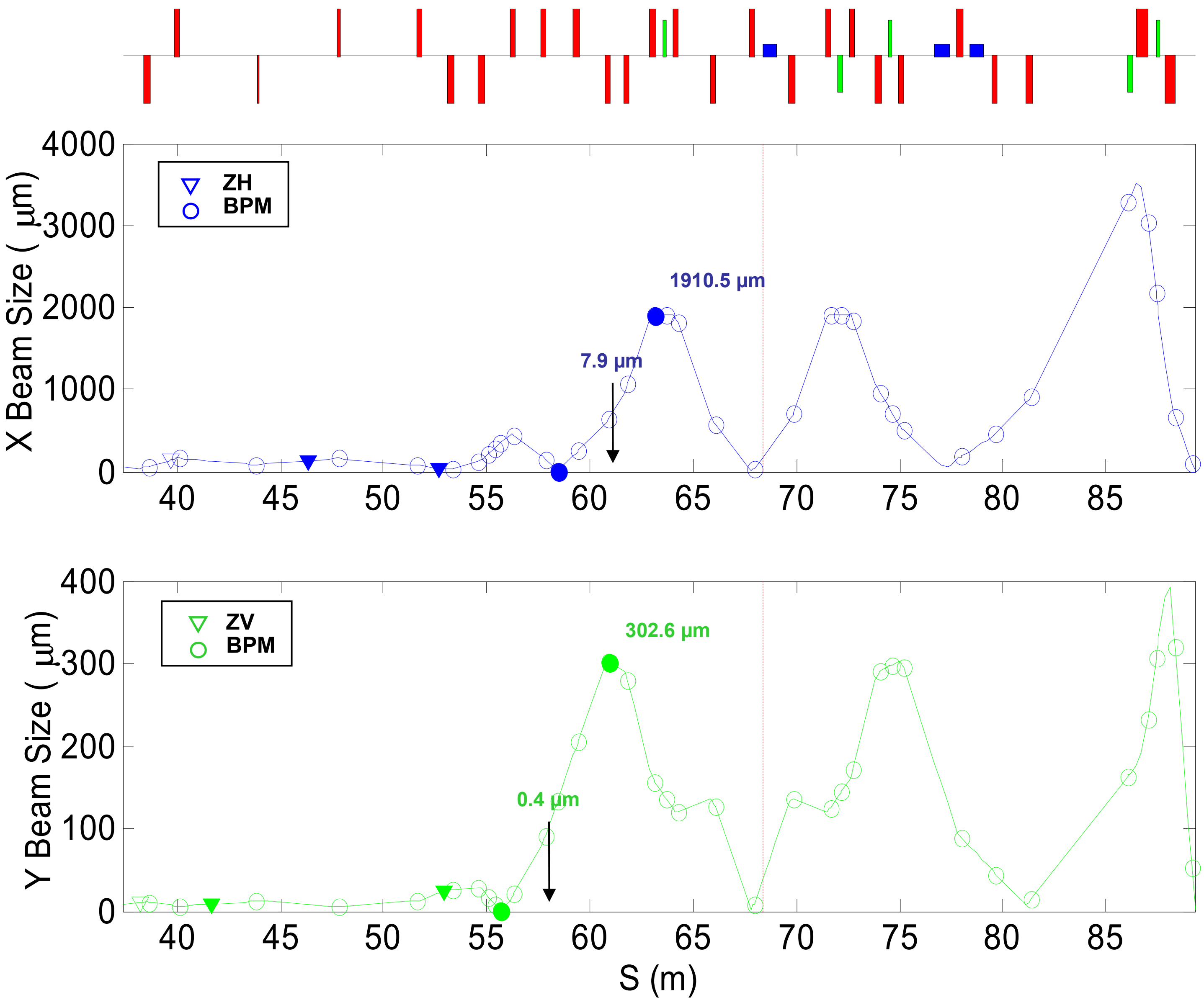
Pulse-Pulse Feedback

- Use pulse-pulse feedback to get initial beam orbit through EXT and FFS and maintain orbit when GM drifts added.
- FFS FB/EXT FB gain ration 10/1 (orbit stability most important in FFS).
- EXT feedback "least-squares matrix-inversion" steering using all correction magnets (ZV*X & ZH*X) and quad BPMs.
- FFS feedback 2 kicker-BPM pairs for x & y feedback at 90-degree phase separations.

ATF2 pulse-to-pulse feedback devices (v3.7)



ATF2 pulse-to-pulse feedback devices (v3.7)



IP Beamsize Measurement

- Shintake monitor measurement range 35nm – 350nm.
- Wirescanner for >1 micron waist sizes.
- Between 350nm and ~1um, 'Honda Monitor'.
- In this simulation, just use Shintake monitor resolution- when using sextupole knobs, arrive in SM range quickly (1 or 2 iterations usually).

Tuning Procedure Overview

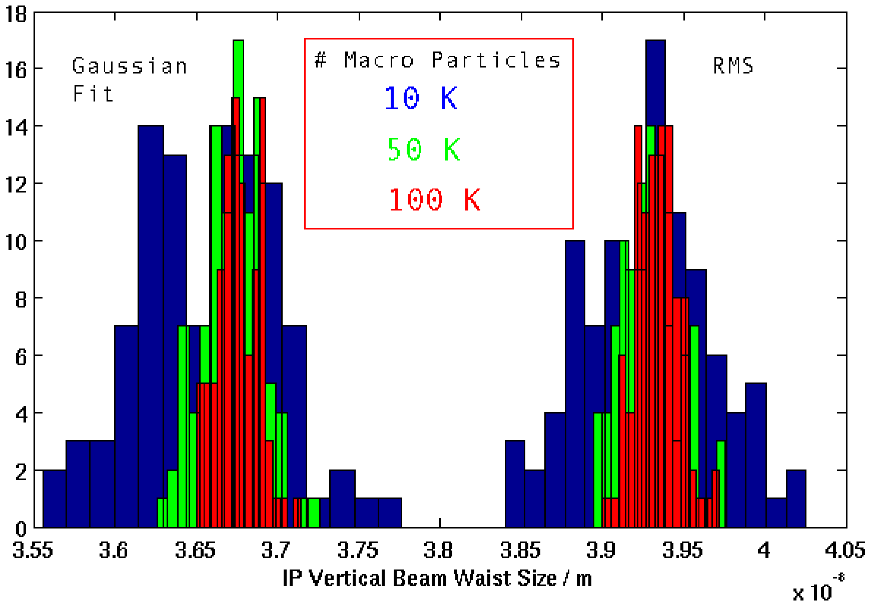
- Use EXT correctors + BPMs (EXT FB) to get orbit through EXT.
- Use FFS FB to get beam through FFS.
- Correct Dy/Dy' in EXT using skew-quad sum knob.
- Correct coupling in EXT using coupling correction system.
- Use FFS FB for launch into FFS.
- FFS Quad BPM alignment using quad shunting with movers.
- FFS Quad mover-based BBA.
- FFS Sext BPM alignment using Sext movers and downstream BPMs.
- 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.

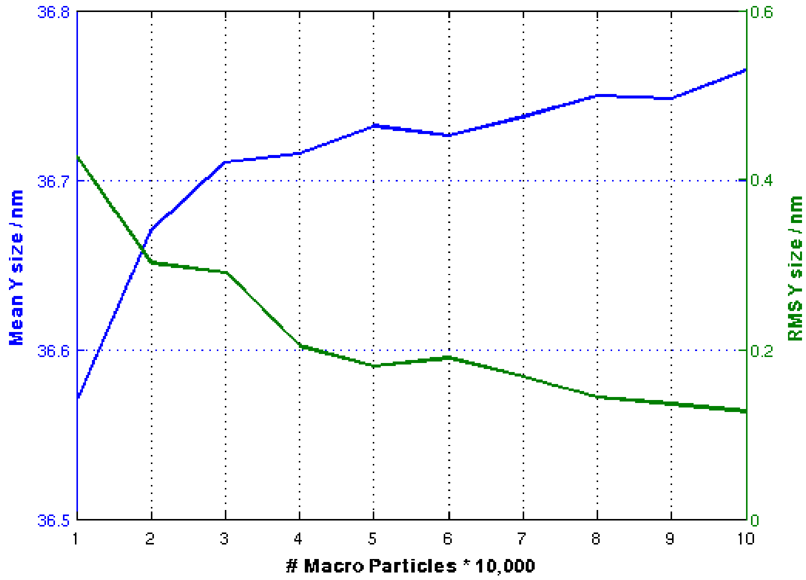
Simulation Notes

- Ideal simulation includes tracking every bunch, including inter-pulse jitter effects on IP size measurement (90 pulses per measurement).
- This takes a LONG time with macro-particle bunches.
- Simulation includes GM effects (ie. 90 / 1.5Hz GM added for every IP size measurement).
- Effect of fast jitter during 90 pulse IP size measurement is modeled as effective degradation of IP measurement resolution.
- For dynamic errors studied here, pulse-pulse jitter effects add 1.3nm (in quadrature) to 2nm SM measurement (giving res. ~2.4nm).

Beam Model

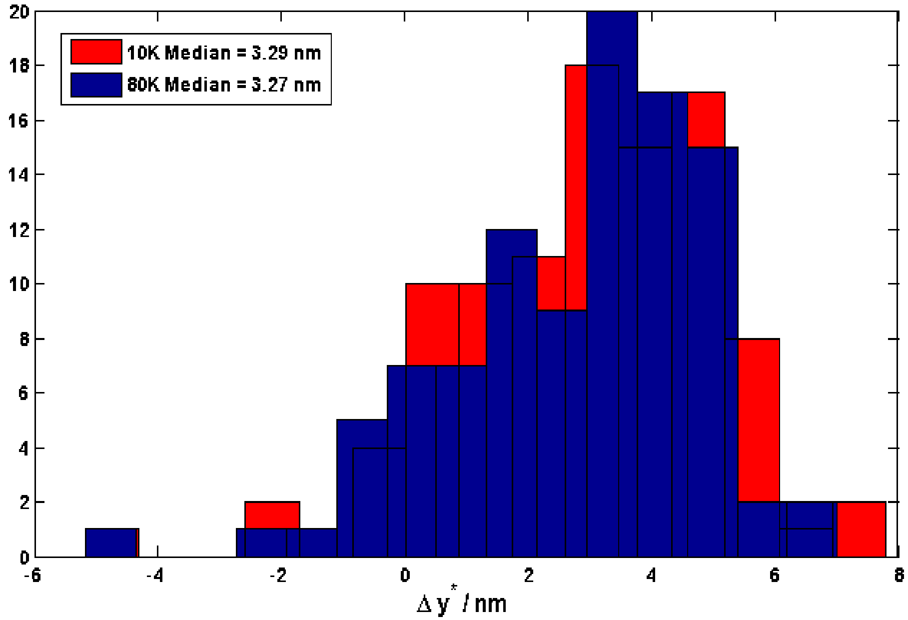
- Lucretia beam models:
  - 'Sparse' := 2nd order moment tracking in transverse
  - 'Macro-particle':= better for handling higher-order effects- non-Gaussian beam. Slower.





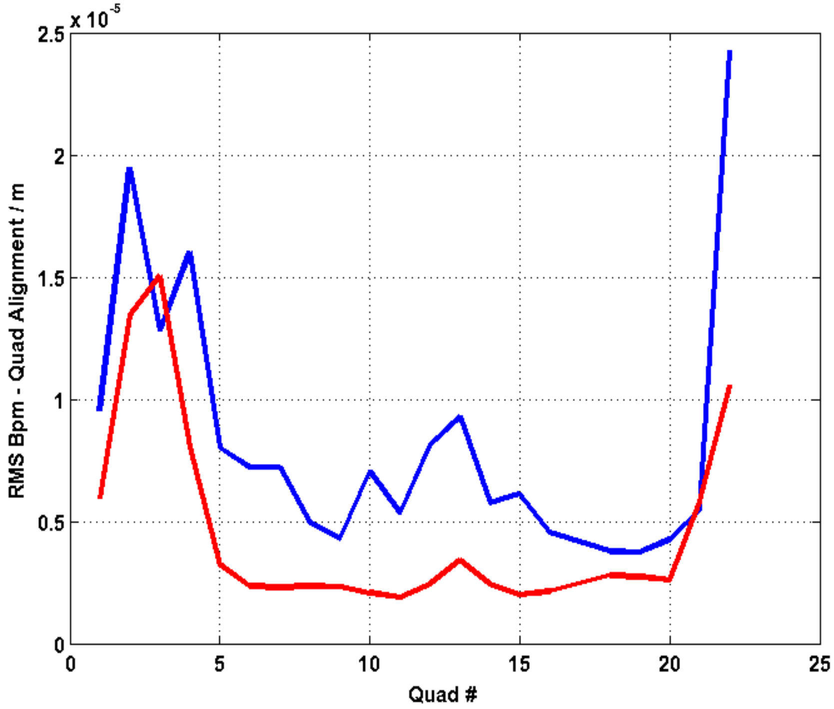
- Tracking through perfect lattice (100 generated bunches)
  - Sparse beam gives 35.0 nm
  - IP beam non-Gaussian, higher-order effects important as well as measurement of beam size.

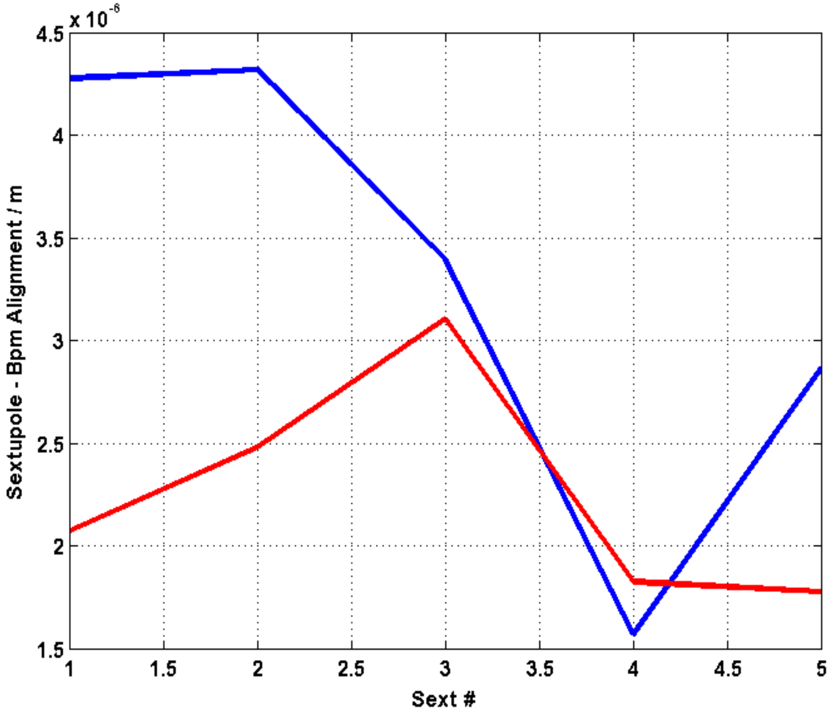
EXT Tuning Results



- With an error-free FFS, tune EXT with 10K and 80K macro-particle beams (100 seeds).
- Median results the same.
- Probably ok to do full tuning with 10K bunch with same perfect-lattice performance as the mean 100K-case.
- Use 10K bunch for simulation results shown in this talk.

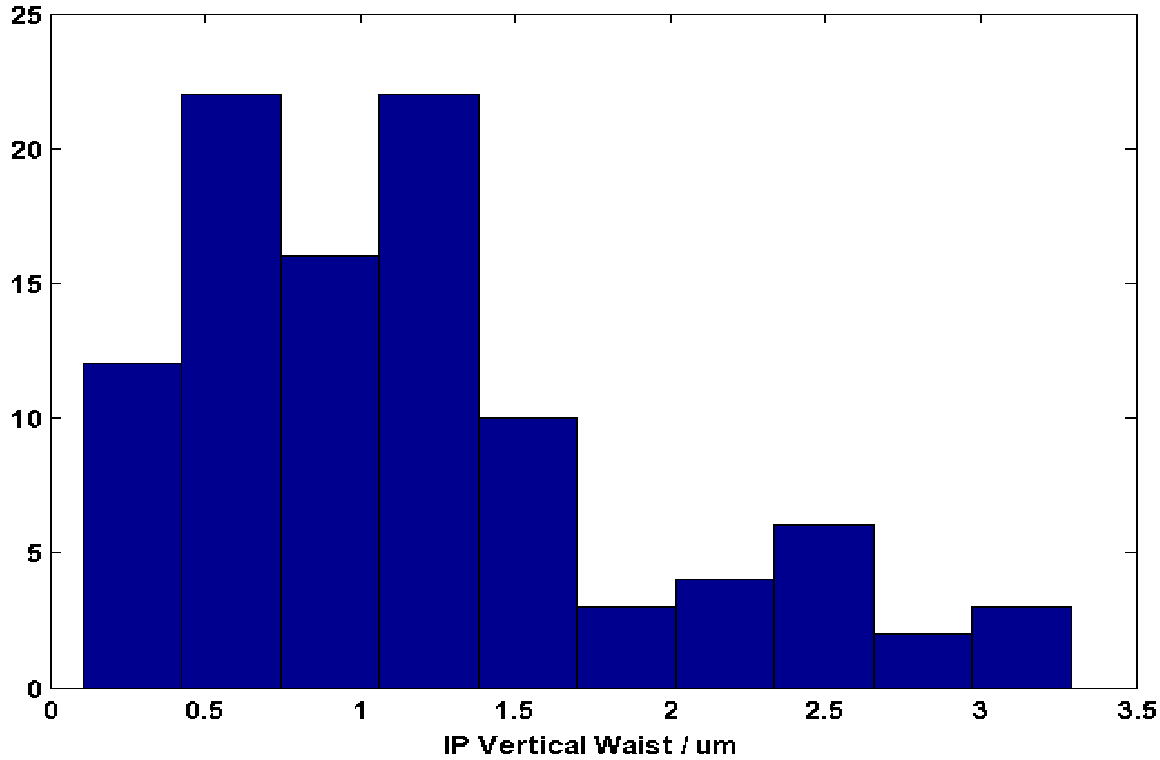
Quad & Sext BPM Alignment





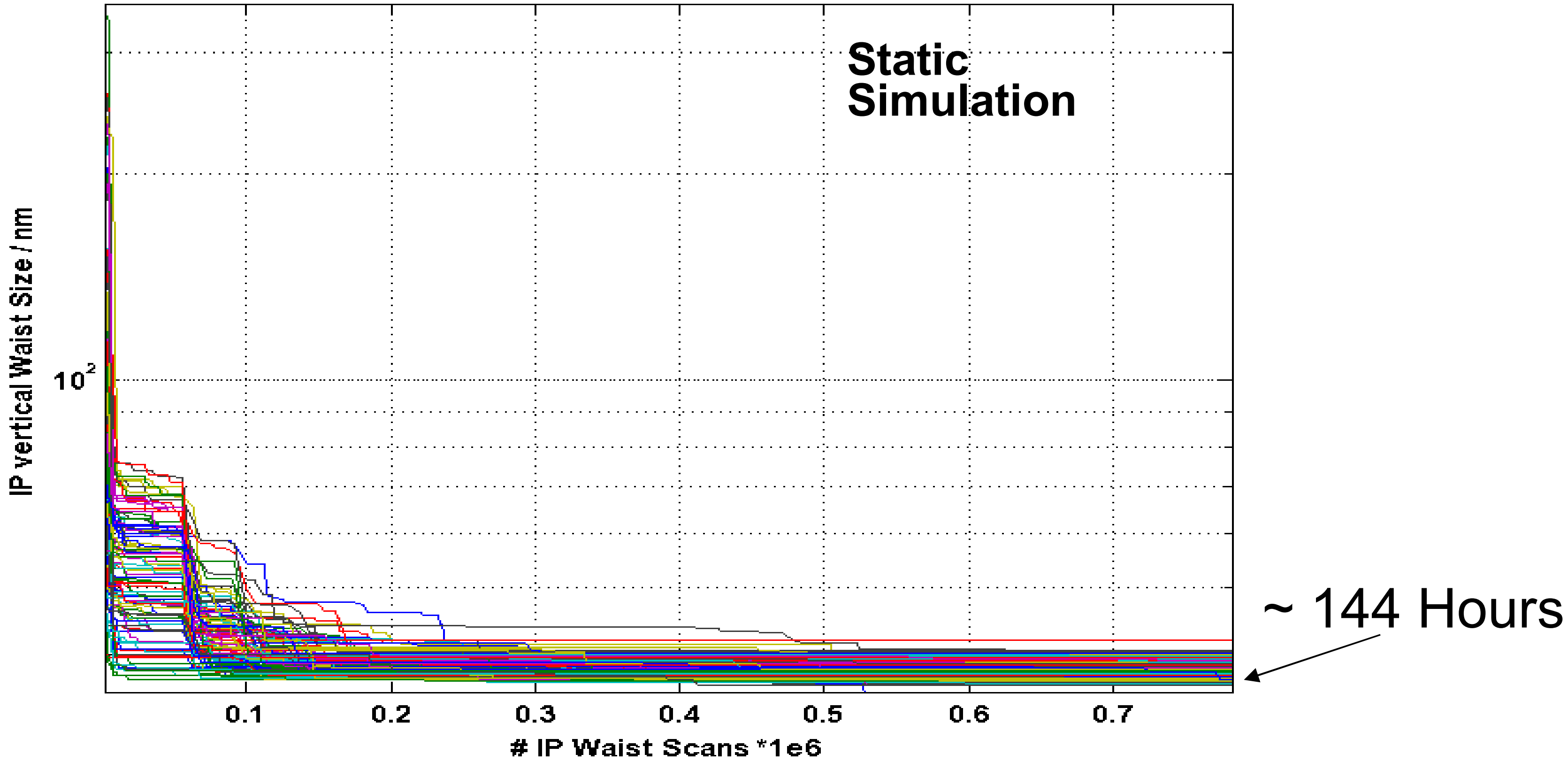
- RMS alignment of Magnet field centre – electrical centre of magnet BPMs (100 seeds).
- Blue = x Red = y.

Beamsize after BBA



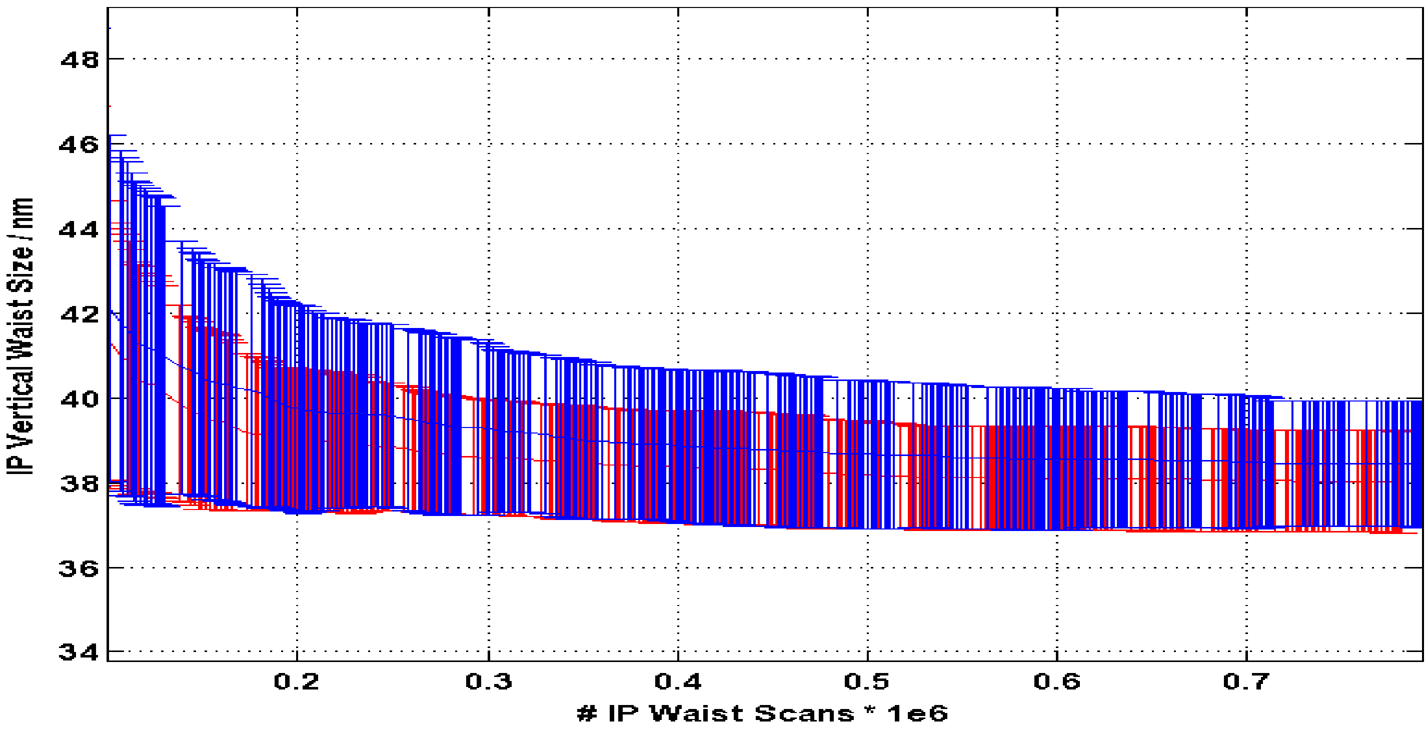
- IP waist size before sextupole FFS tuning knobs applied (100 seeds).

Multi-Knob Tuning Results



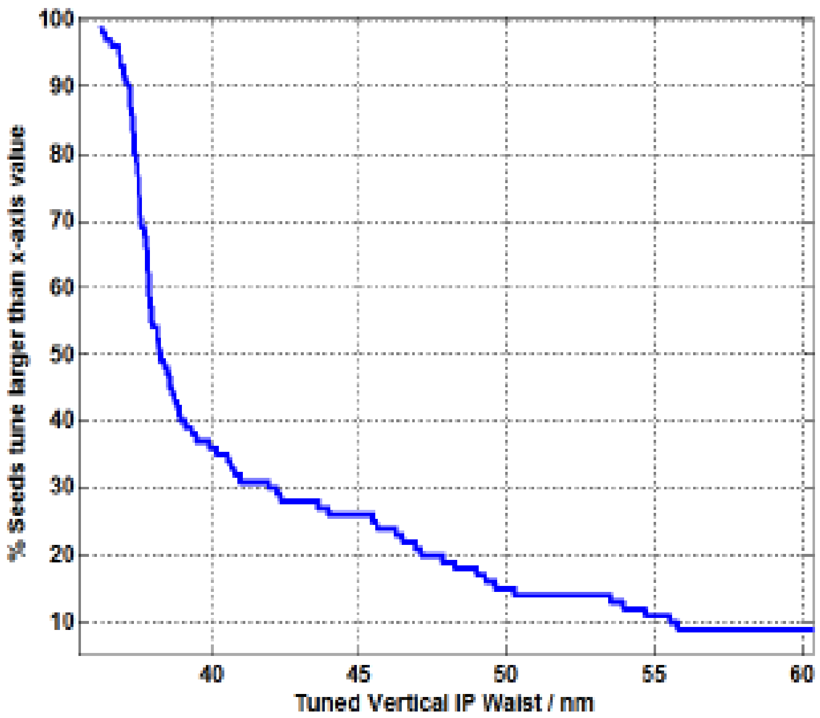
- IP spot size vs. # of pulses (assuming 90 pulses per IP size measurement).
- Fast convergence <100nm (after fixing waist + dispersion).

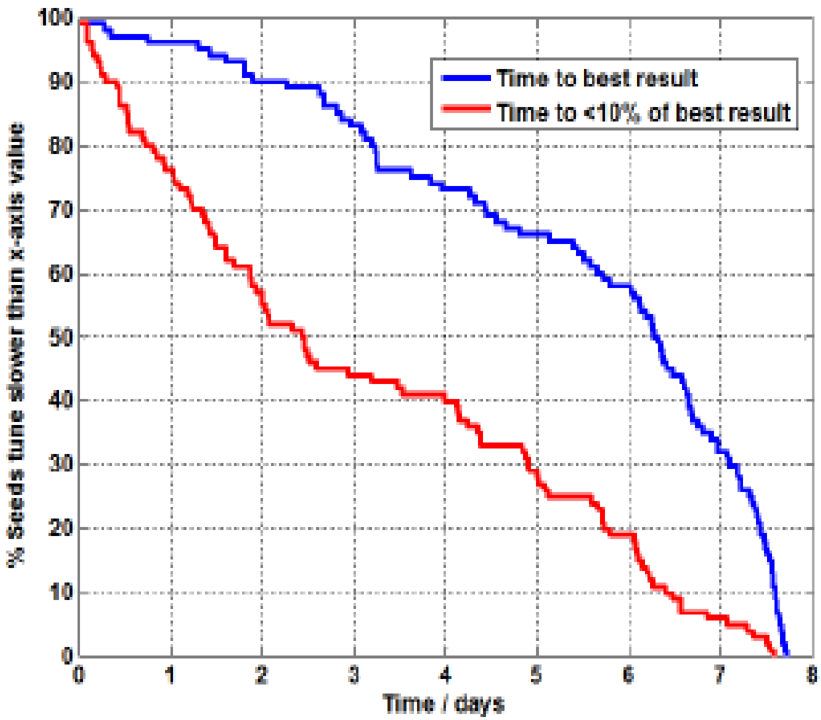
Best Spot Size Achieved



- Min IP waist size achieved vs. pulse #
- Mean and +/- 1 sigma plotted from 100 seeds.
- Red = static, blue = dynamic.

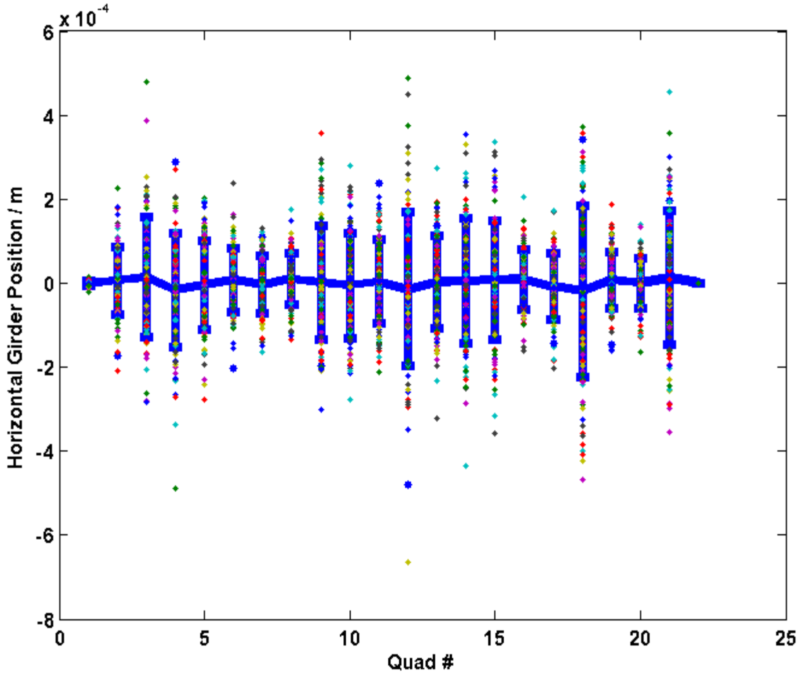
Tuning Results

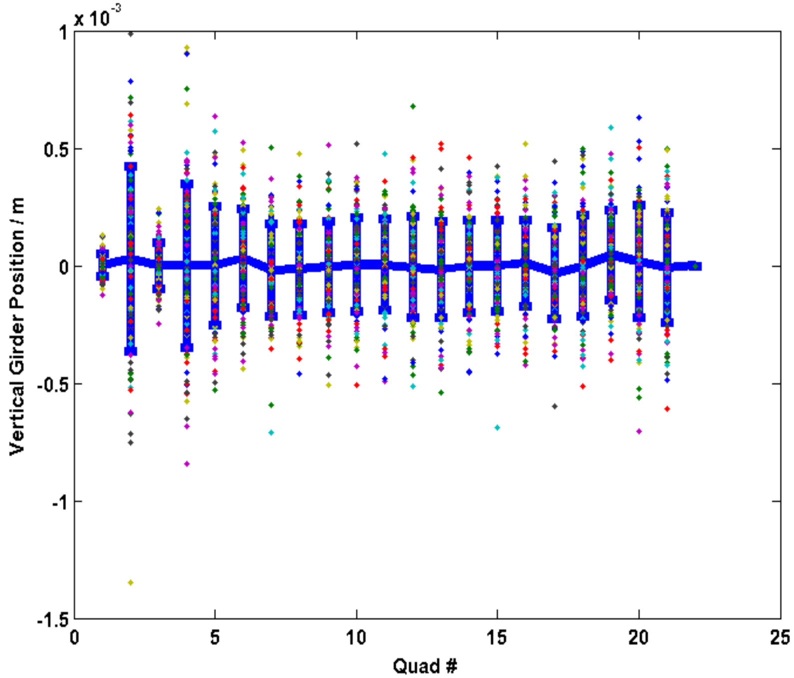




- Best achieved vertical waist size for 100 seeds (left)
- Time taken to converge on best waist size, and time to converge within 10% of best waist size (right)

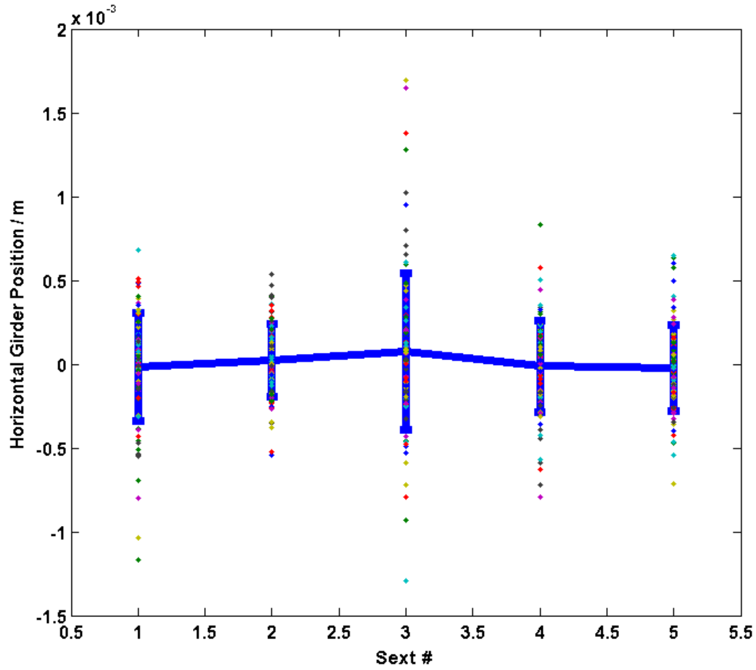
Final Quad Mover Positions

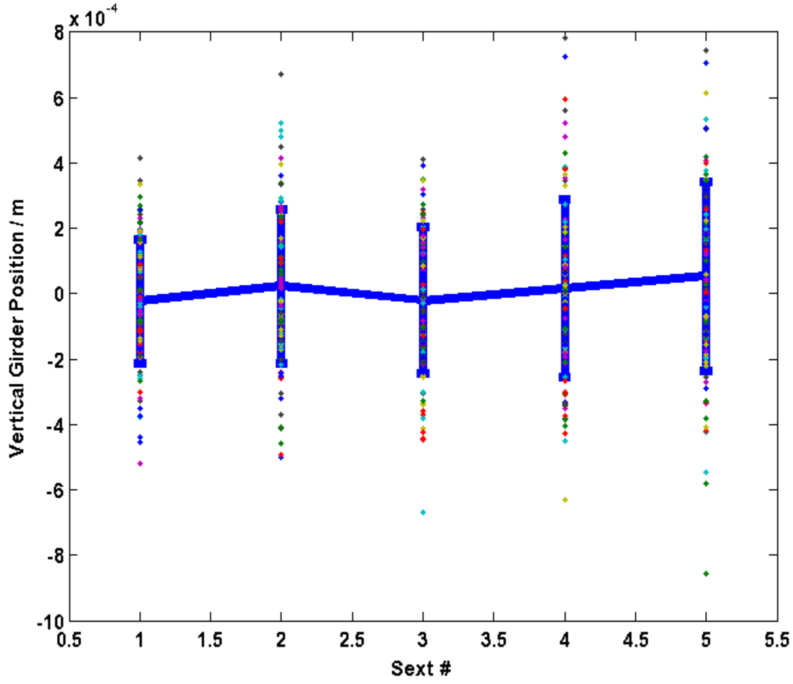




- Position of Quad Magnet Movers after tuning.
- x/y moves ~<2mm possible, but have to take into account map of x,y,roll phase space.
- Need to check don't try to move outside this phase space.

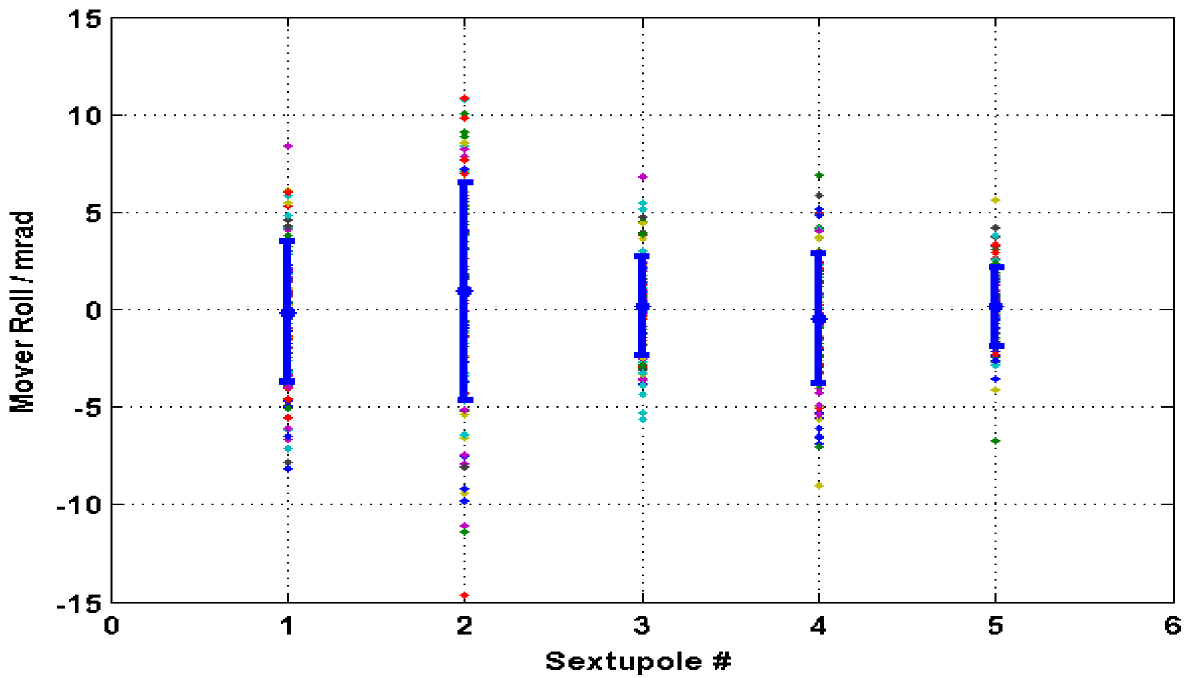
Final Sextupole Mover Positions





- x/y positions of Sext movers after tuning.

Final Sextupole Mover Rolls



- Final roll positions of sextupole movers.

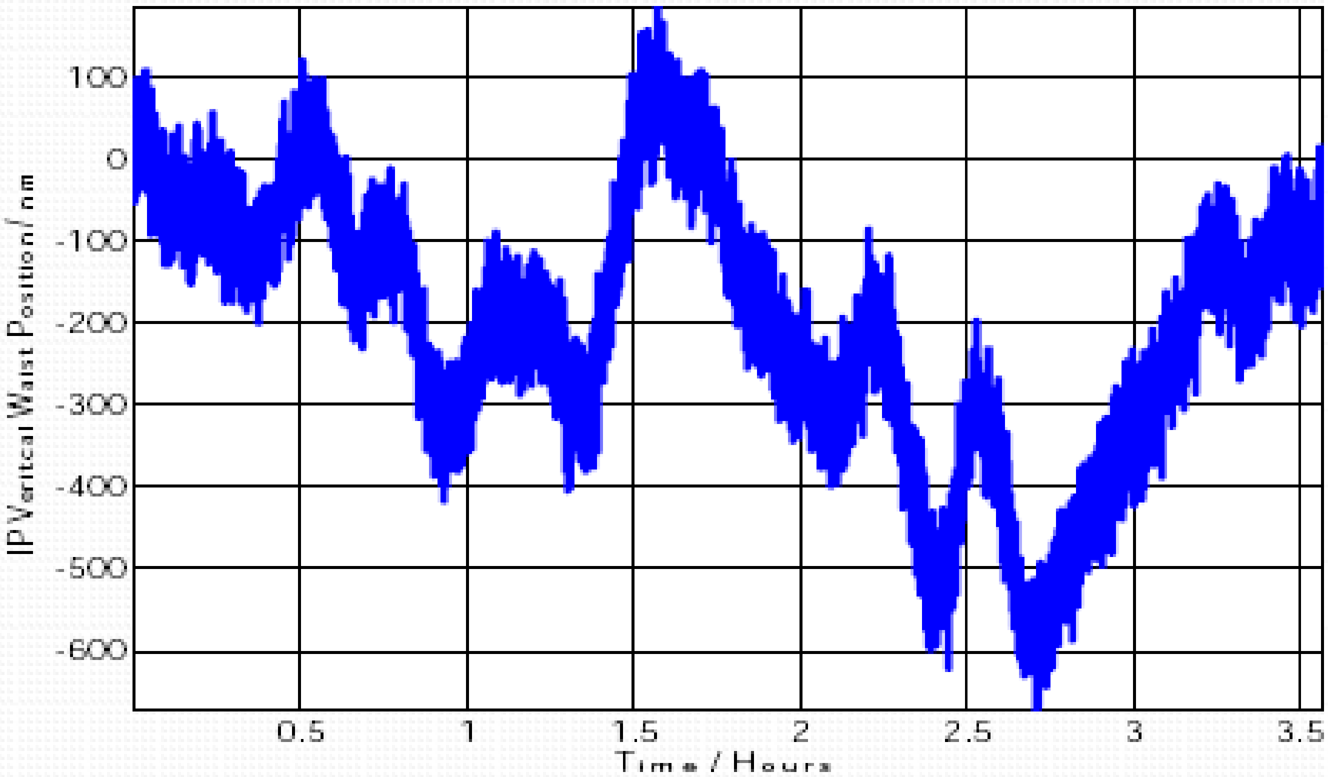
Magnet movers in tuning code

- Include mover limits in tuning algorithms
  - Stop simulation if mover attempts to break limit
- 100 seeds – 28 failed due to mover limits
  - 14 during initial steering
  - 10 during BPM-quad alignment
  - 4 during the final sextupole tuning
- The 4% failure for sext tuning may ignored as negligible
  - These could be fixed by realigning the machine.
- 24% failure during initial steering and alignment <u>not</u> negligible
  - Must alter algorithms
    - Tighter constraints on magnet motion?

‘Nominal’ Jitter Parameters

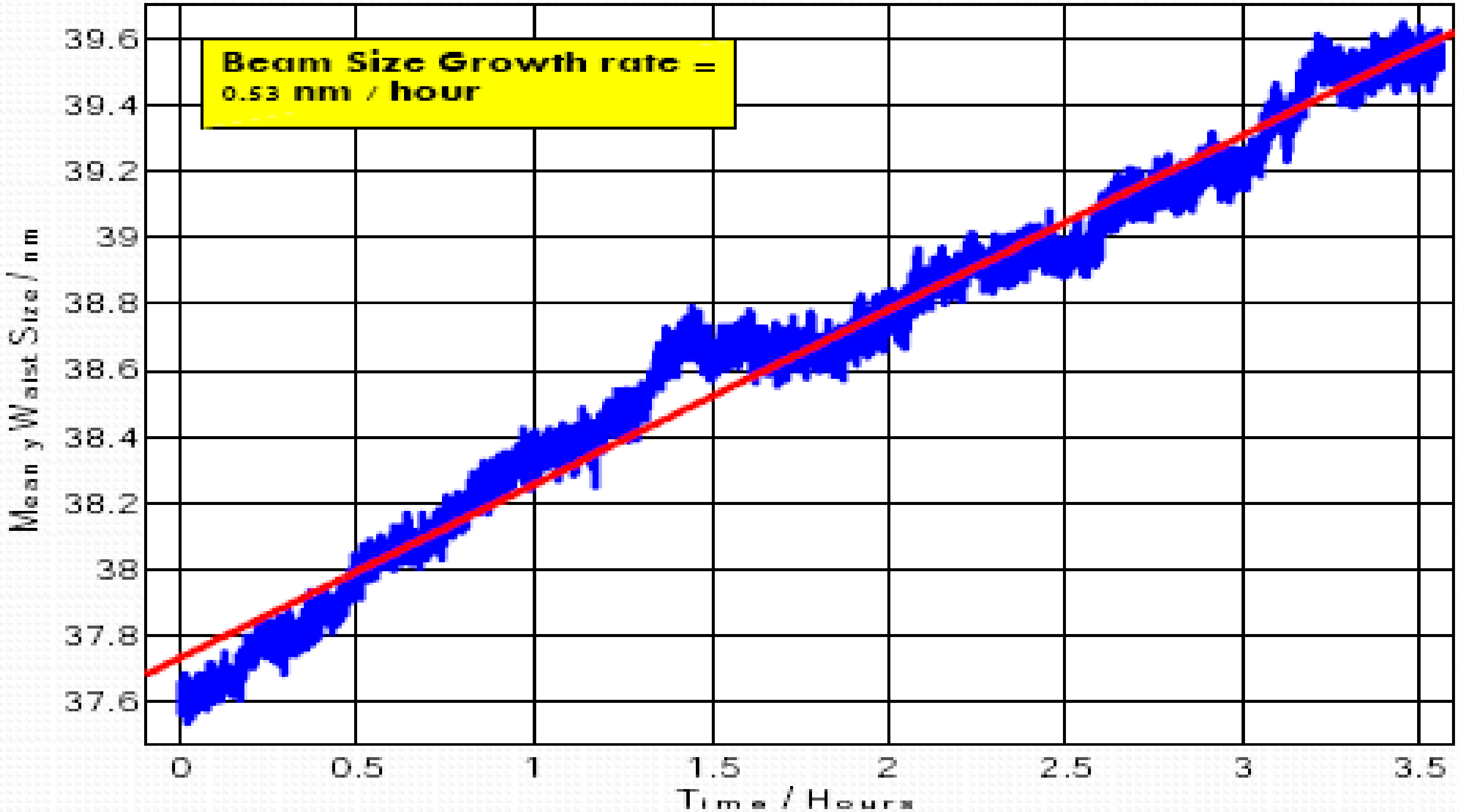
- 0.1 sigma x,x',y,y' RMS ring extraction jitter
  - 13 um/2.8 urad (x/x’) 0.6 um/0.4 urad (y/y’)
- 1e-4 dE/E error
- 10 nm magnet vibration
- 1e-4 strength errors pulse-pulse on corrector magnets
- 100 nm BPM resolution
- ATF fitted GM model
- Simulation performed with 100 random seeds

IP Motion



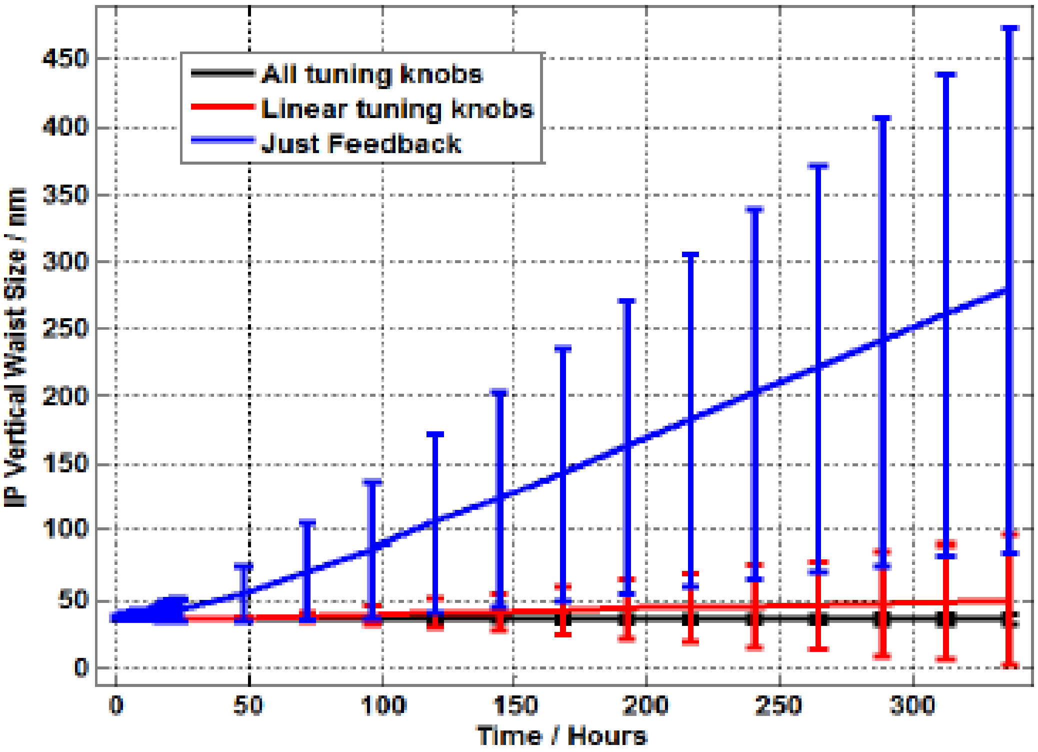
- 20,000 pulses @ 1.56 Hz (1 seed)
- IP vertical position drifts around on scales of a few 100 nm an hour.
- Slow enough that this can be 'de-trended' using Shintake Monitor as IP position monitor.

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

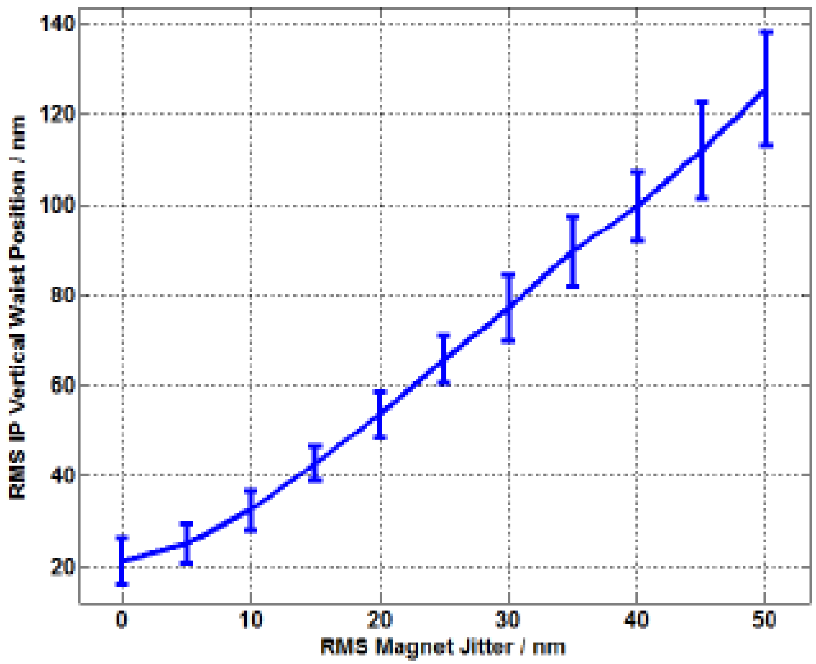
Long – Timescale Performance

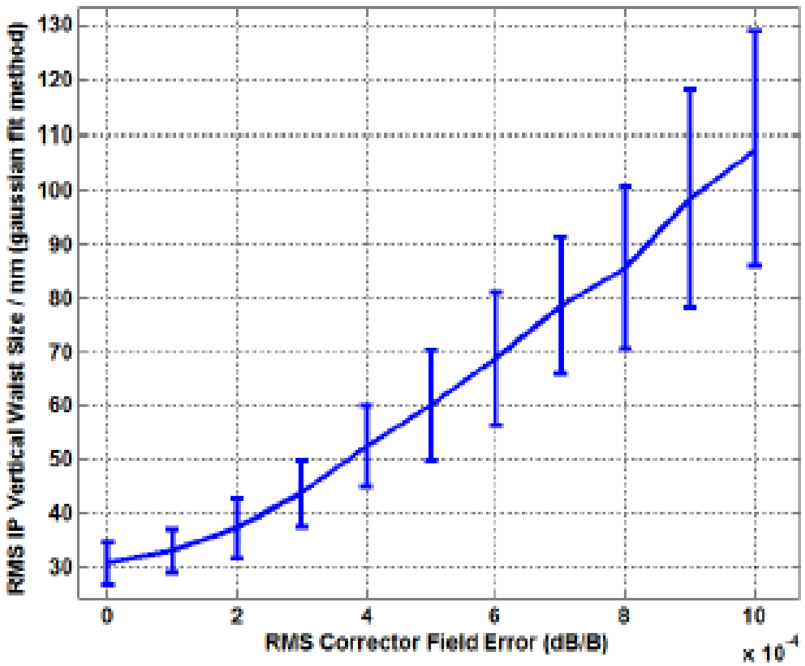


At each point, none, linear (waist, dispersion and coupling) and full tuning knobs (include sextupole strength and tilt scans) applied. For blue, red and black respectively.

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

Most Important Jitter Sources



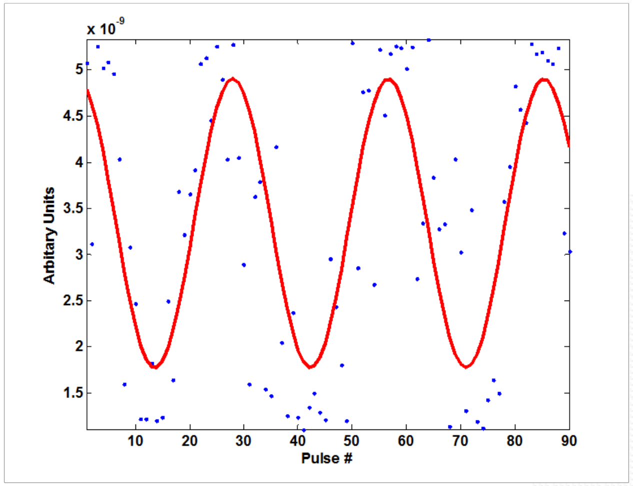


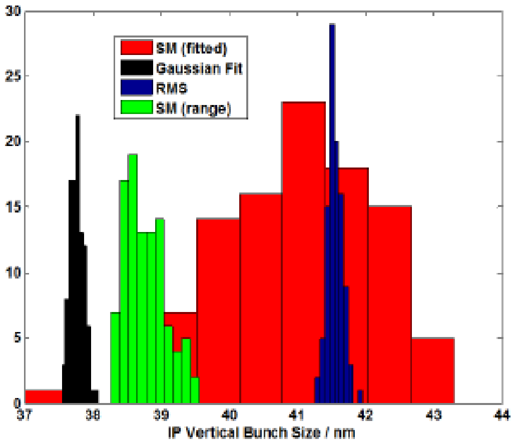
- Final Focus Magnet vibrations and jitter of EXT corrector magnetic field
- Expected jitter from 'Nominal' Parameters = ~35 nm RMS pulse-pulse

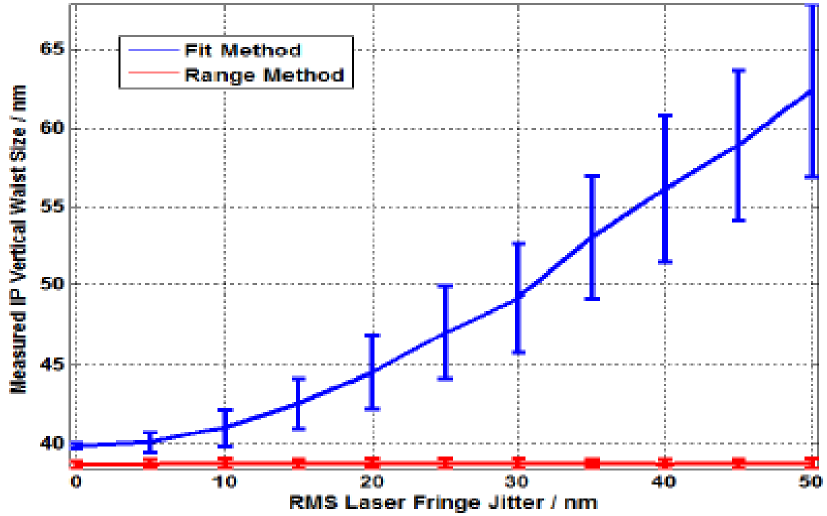
Jitter Source Concerns

- From Shintake BSM group:
  - 2nm IP measurement resolution with ~30nm jitter between laser fringe and beam
- 10nm expected jitter from laser
- BUT expect >~35nm for beam from jitter sources studied here... Need IP beam-based multi-bunch feedback?
- Only 11-bit corrector PS's in EXT line?
  - 1-bit of noise= 1e-3 fluctuation of corrector, not 1e-4 as in 'nominal' jitter source set simulated here.
  - Means 110nm IP jitter!

BSM Measurement Simulation







- Taking a tuned lattice (an average case)
  - track 90 bunches with nominal jitter parameters with IP beam position jitter removed
  - Increase level of fringe jitter and look at 100 seeds (mean and rms values plotted)

Further Work / Conversion of Code to FS

- EXT BBA
  - simulation needed
- FFS BBA
  - Simulation and FS code exists for Quad shunting
  - Simulate and compare ballistic alignment/DFS
- EXT Disp. Correction
  - Effects of DR freq. ramp other than E sweep?
  - Need EPICS interface to DR freq. Ramp to include in FS.
- EXT/FFS Steering/ Feedback
  - Need global Feedback FS code (all feedbacks)

Further Work / Conversion of Code to FS

- EXT coupling correction.
  - Add wirescanner errors to simulation
  - Need EPICS wirescanner interface for inclusion into FS.
- Add more realistic constraints to sim
  - Respect apertures
  - Radiation monitoring during BBA.
- Model Effects on tuning of jitter sources with medium-length timescales
  - ~few mins drift of water temp etc

Further Work / Conversion of Code to FS

- Final Tuning Procedure
  - Need to improve on simulations (method)- look at other methods in integrated simulation environment, proper comparison of different techniques...
  - Better % of seeds closer to tuning goal, faster convergence rate (better tuning algorithm)
  - Understand and include BSM measurement analysis
  - Alter procedures to fix cases where magnet movers go out of range
  - Jitter conditions look too bad?
  - FS inclusion needs IP monitors in EPICS

Further Work / Conversion of Code to FS

- IP multi-bunch feedback to mitigate IP beam jitter for BSM measurement
  - Feasibility study
  - When would hardware to do this be available
  - Who could do this?