Design of Tuning System for Compact LC FFS

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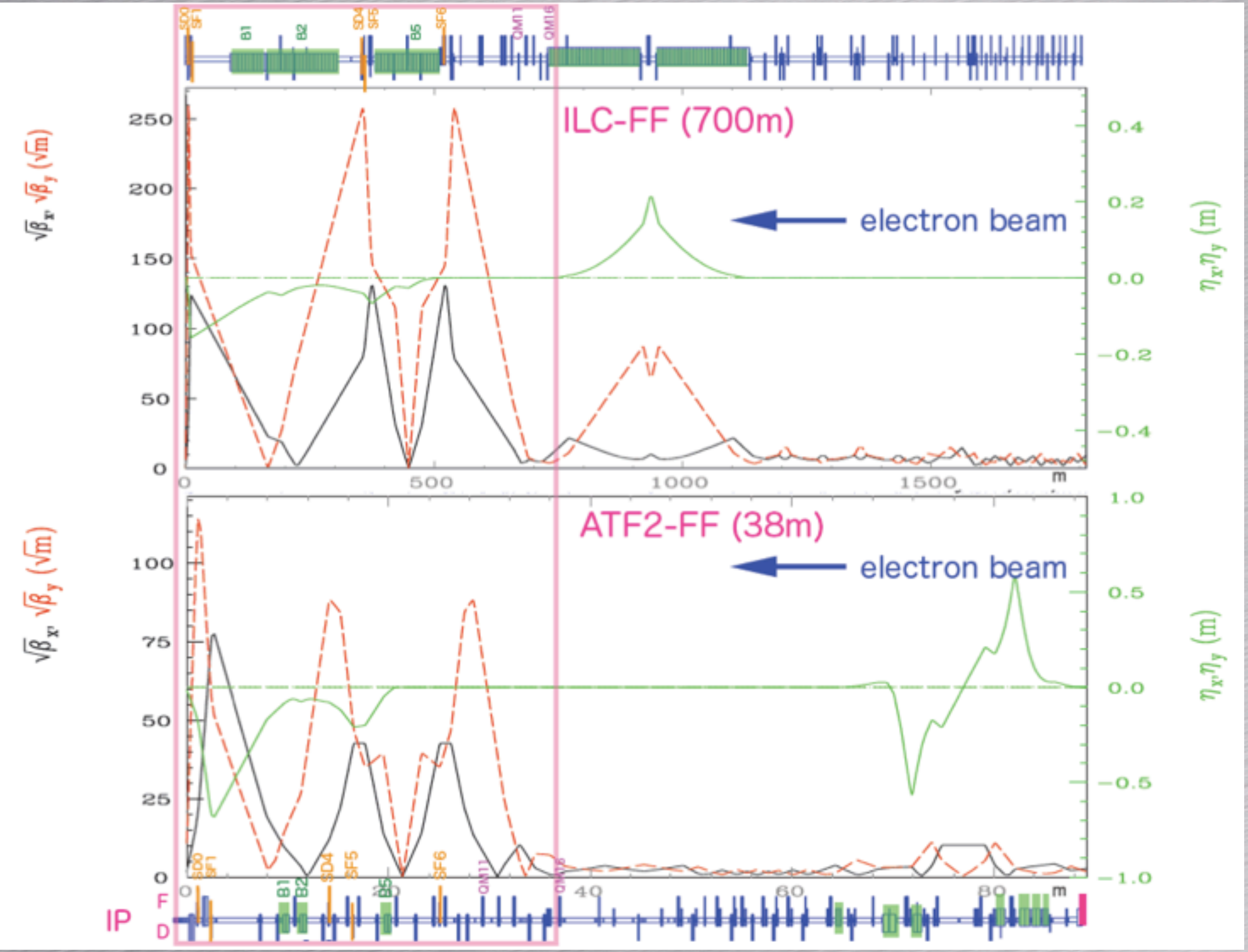
SLAC Accelerator Physics & Engineering

Overview

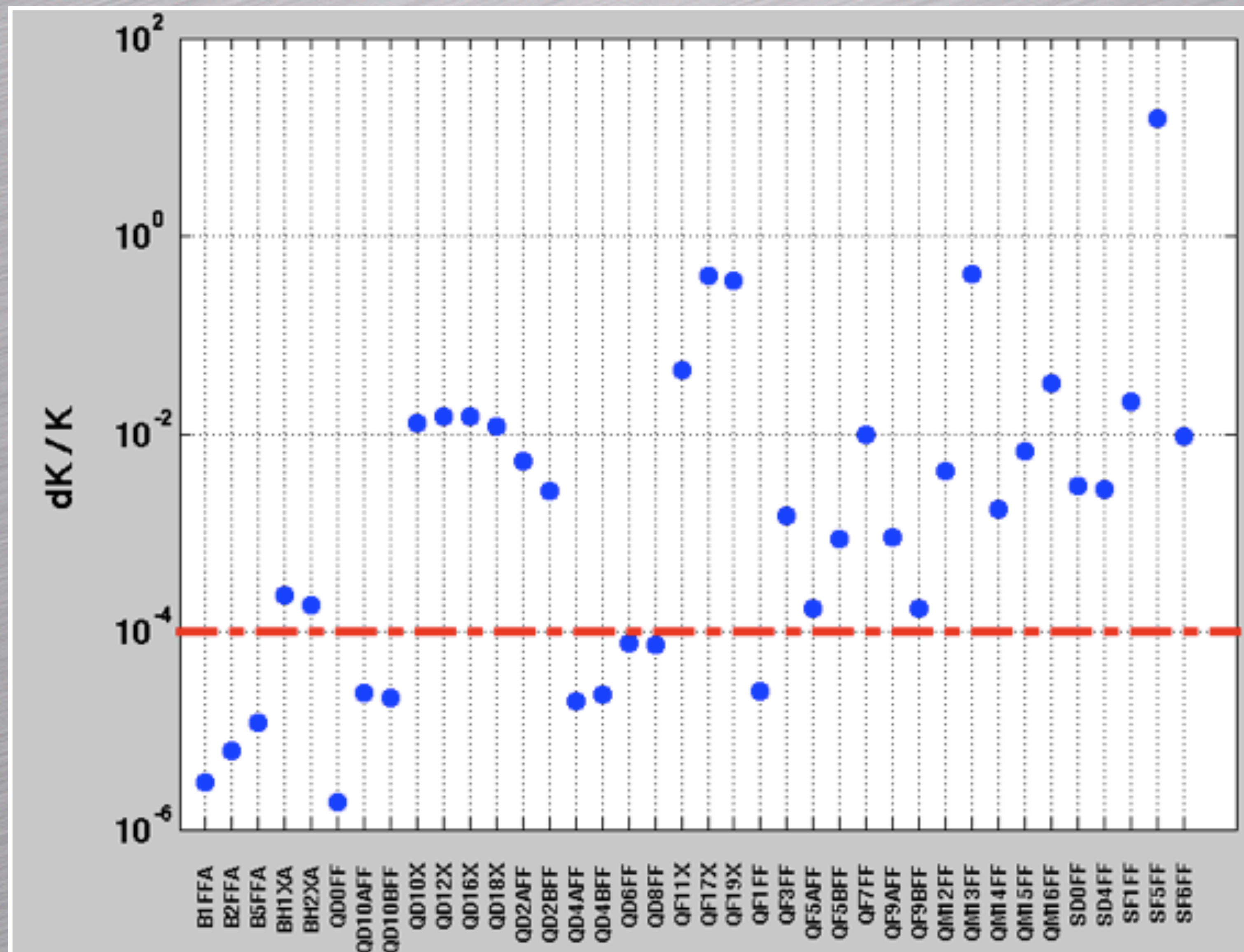
- **Design of tuning procedure applicable for the final focus system of ILC (RDR) and implementation for ATF2 test accelerator.**
- **LucretiaMC**
  - Development of heterogenous parallel compute environment for Monte Carlo style analysis of errors in non-linear optics.
- **Simulation of expected tuning performance for ATF2.**
- **First experiences tuning beam at ATF2.**

ATF2 - Test of ILC FFS



- "Nominal" ATF2 Parameters
  - β_y=0.1mm
  - σ_y=35nm
  - W(ATF2) ~ W(ILC)
- Robustness with installation / operational errors?

Magnet Strength Sensitivities



- **Relative setting error of magnets to produce an increase in vertical spot size at IP of 1nm.**

Online Tuning Algorithm Development

1. Specify list of errors
    1. Generate a database which characterises every unknown aspect of the accelerator
2. Generate 100 versions of machine lattice
    1. Each lattice has a different set of errors generated from error table.
    2. Typically, each error condition is generated from a gaussian distribution.
3. Simulate initial steering/BBA/coupling,dispersion correction etc for each lattice seed.
4. Calculate list of aberrations present at IP (up to 3rd order required).
5. Make a knob to correct most common aberration from 100 seeds being simulated.
6. Iterate 4&5, each iteration generate a knob which is orthogonal with other knobs generated previously. Repeat until no further improvement seen in IP spot size on average across simulated seeds.

Lucretia Software Development

- **LucretiaMC**
  - Extension to Matlab-based Lucretia particle tracking program to enable real-time parallel consideration of multiple Beamline ‘seeds’.
  - Use Matlab “Distributed Computing Server and toolbox” tools to distribute multiple versions of beamline arrays across multiple host machines and operate on these globally.
- **Extend Lucretia tracking engine to deploy in a parallel fashion on either a GPU or multi-core CPU**

Generation of Linear IP Tuning Knobs

- **Calculate linear response of desired set of aberrations at IP to desired set of potential knob coefficients from particle tracking.**
- **Form linear response matrix equation:**
  - M.k = a
    - k = vector of knob coefficients
    - a = vector of IP aberration gradients
    - M = response matrix
- **Use Matlab "lscov" function to solve linear least-squares problem:**
  - $(a-M.k)'.\mathrm{diag}(1/w^2).(a-M.k)$
  - Use weight vector w to control solution to give approximately orthonormal knobs.

Required IP Tuning Knobs Generated

- **Main Knobs generated to control dominant aberration sources at IP:**
  - Vertical waist
  - Vertical dispersion
  - <x'y> coupling
  - T326
  - T322
- **Additional aberrations included in constraint vector:**
  - Horizontal waist
  - Horizontal dispersion
  - U3122

Vertical Dispersion Knob

	SF6	SF5	SD4	SF1	SD0	QD0
X						
Y	-0.623		-0.126	0.514	0.549	
Roll						-1

<x′y> Coupling Knob

	SF6	SF5	SD4	SF1	SD0	QD0
X						
Y	0.516		-0.176	0.032	0.242	
Roll						1

Vertical Waist Shift Knob

	SF6	SF5	SD4	SF1	SD0	QD0
X	0.461		-1	0.206		
Y	-0.154		0.047	0.696	0.418	
Roll						

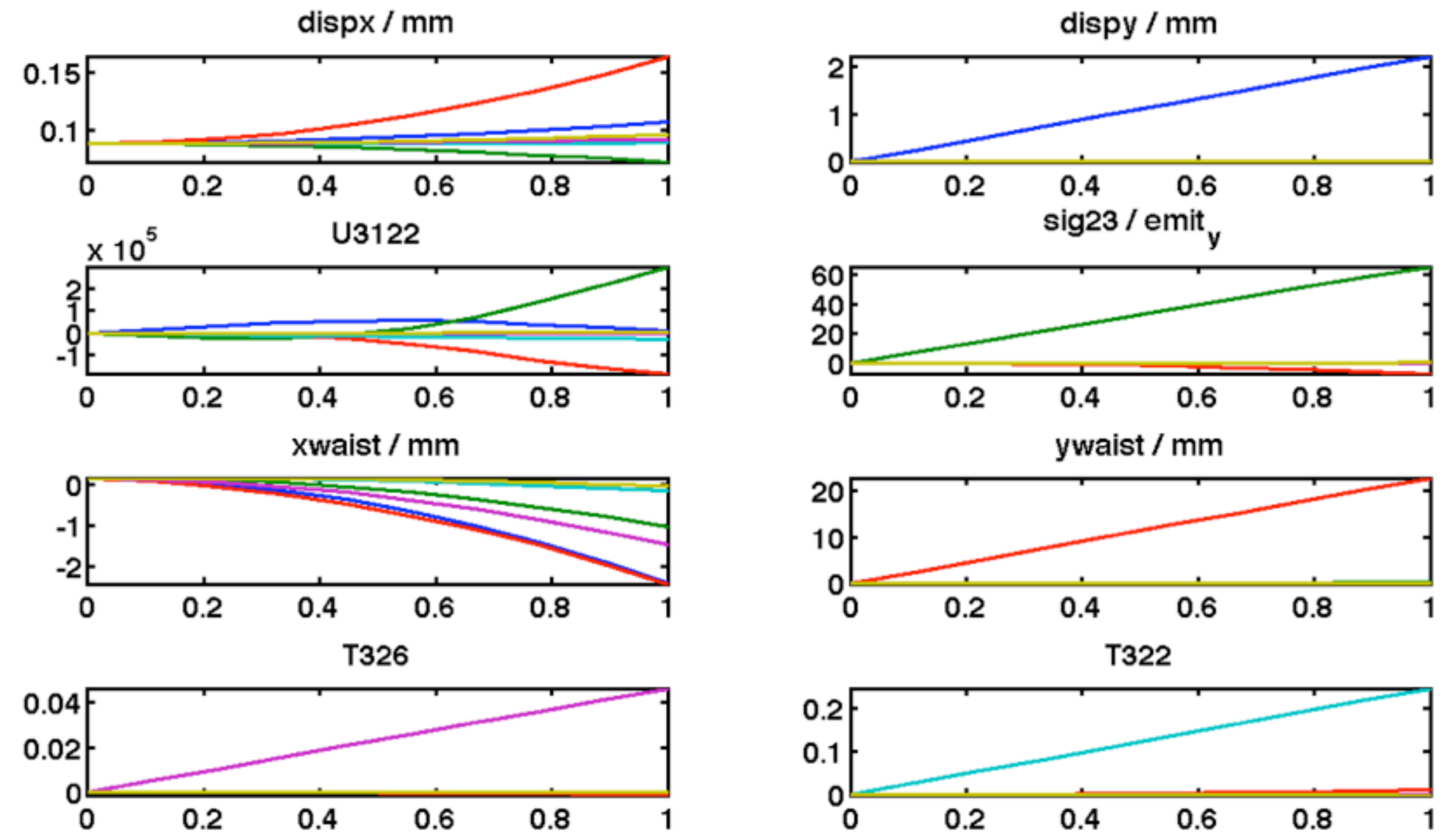
T322 Knob

	SF6	SF5	SD4	SF1	SD0	QD0
X						
Y	0.417		-0.17	0.833	0.649	
Roll						1

T326 Knob

	SF6	SF5	SD4	SF1	SD0	QD0
X						
Y	-0.717		0.294	0.311	0.035	
Roll						-1

MultiKnob Responses

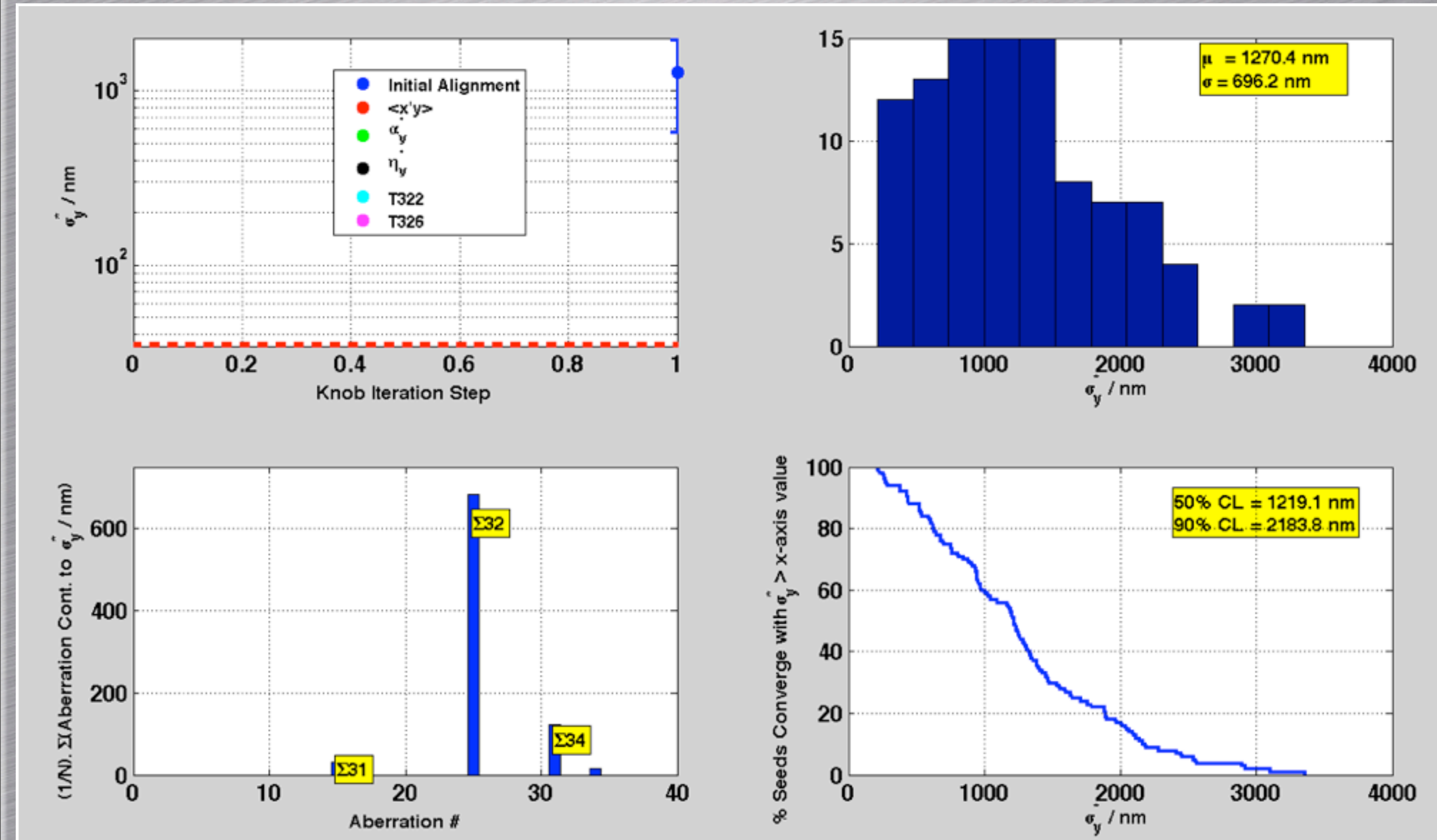


Simulated Tuning Process

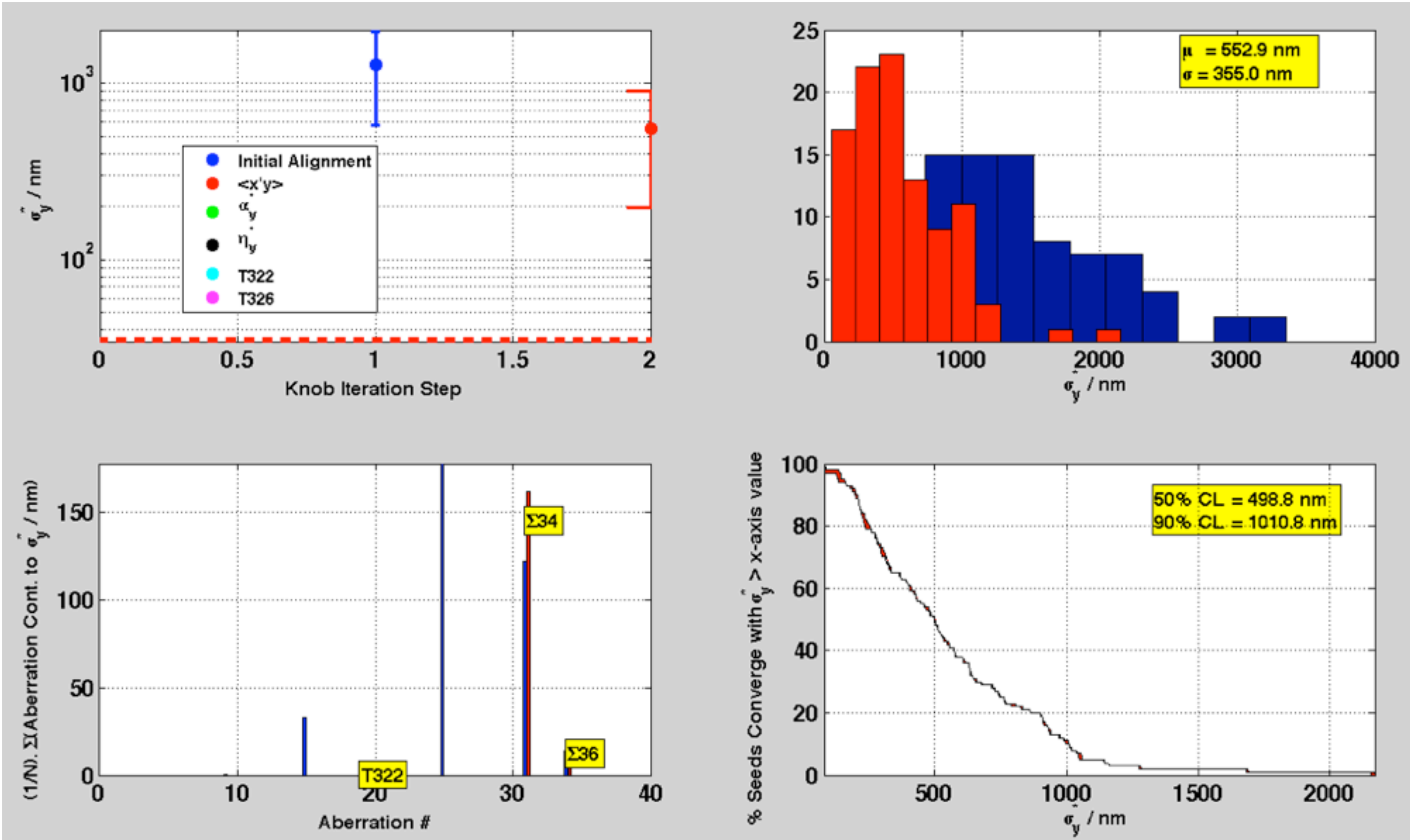
- Apply expected error distributions.
- Use EXT correctors + BPMs (EXT FB) to get orbit through EXT.
- Use FFS FB to get beam through FFS.
- Correct Dy/Dy' in EXT using skew-quad sum knob.
- Correct coupling in EXT using coupling correction system.
- Use FFS FB for launch into FFS.
- FFS Quad BPM alignment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

Considered Error Sources

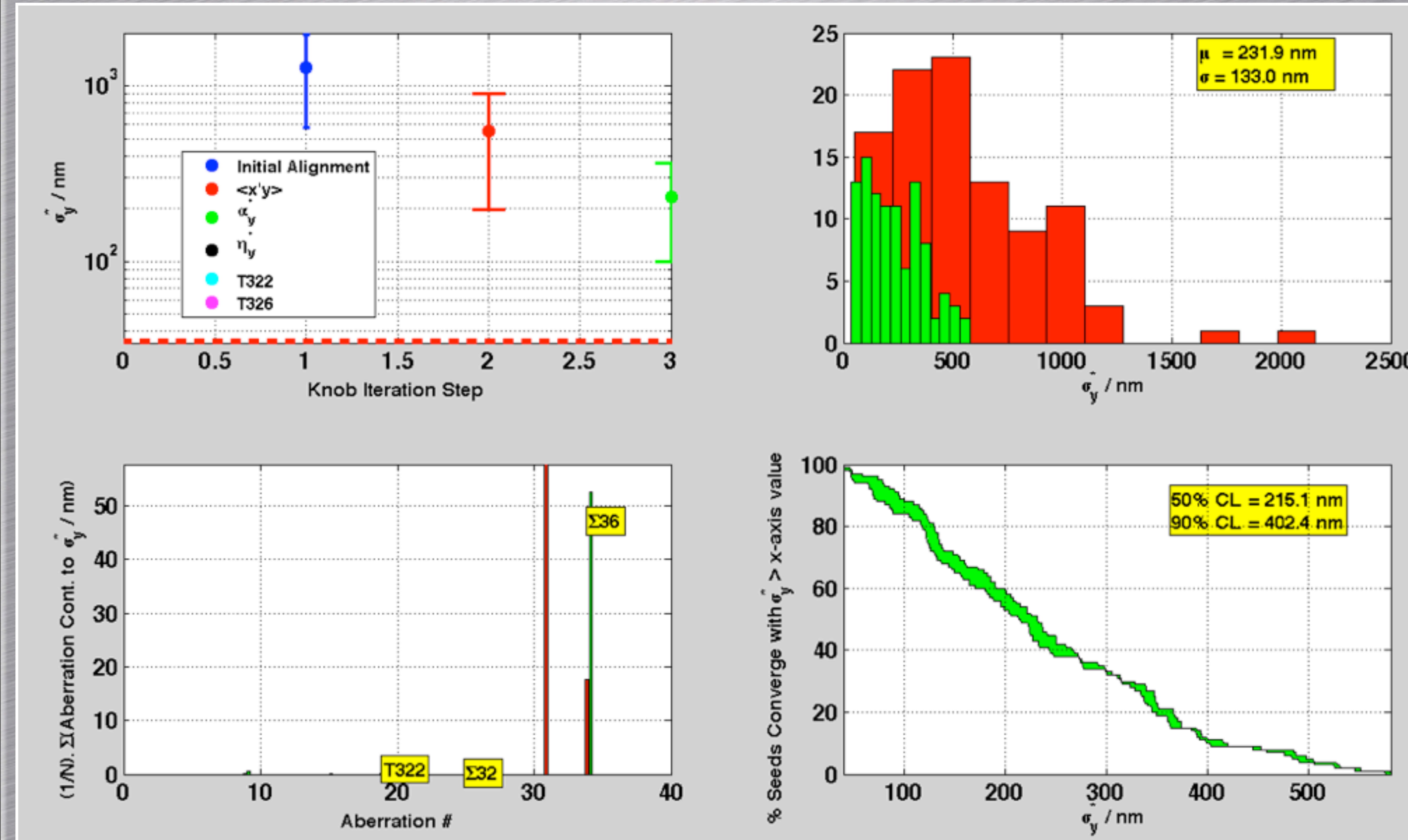
Error Parameter	Error magnitude
x/y/z Post-Survey	200 um
Roll Post-Survey	300 urad
BPM - Magnet field center alignment (initial install) (x & y)	30 um
BPM - Magnet alignment (post-BBA, if BBA not simulated) (x & y)	10 um
Relative Magnetic field strength (dB/B) (systematic)	1e-4
Relative Magnetic field strength (dB/B) (random)	1e-3
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



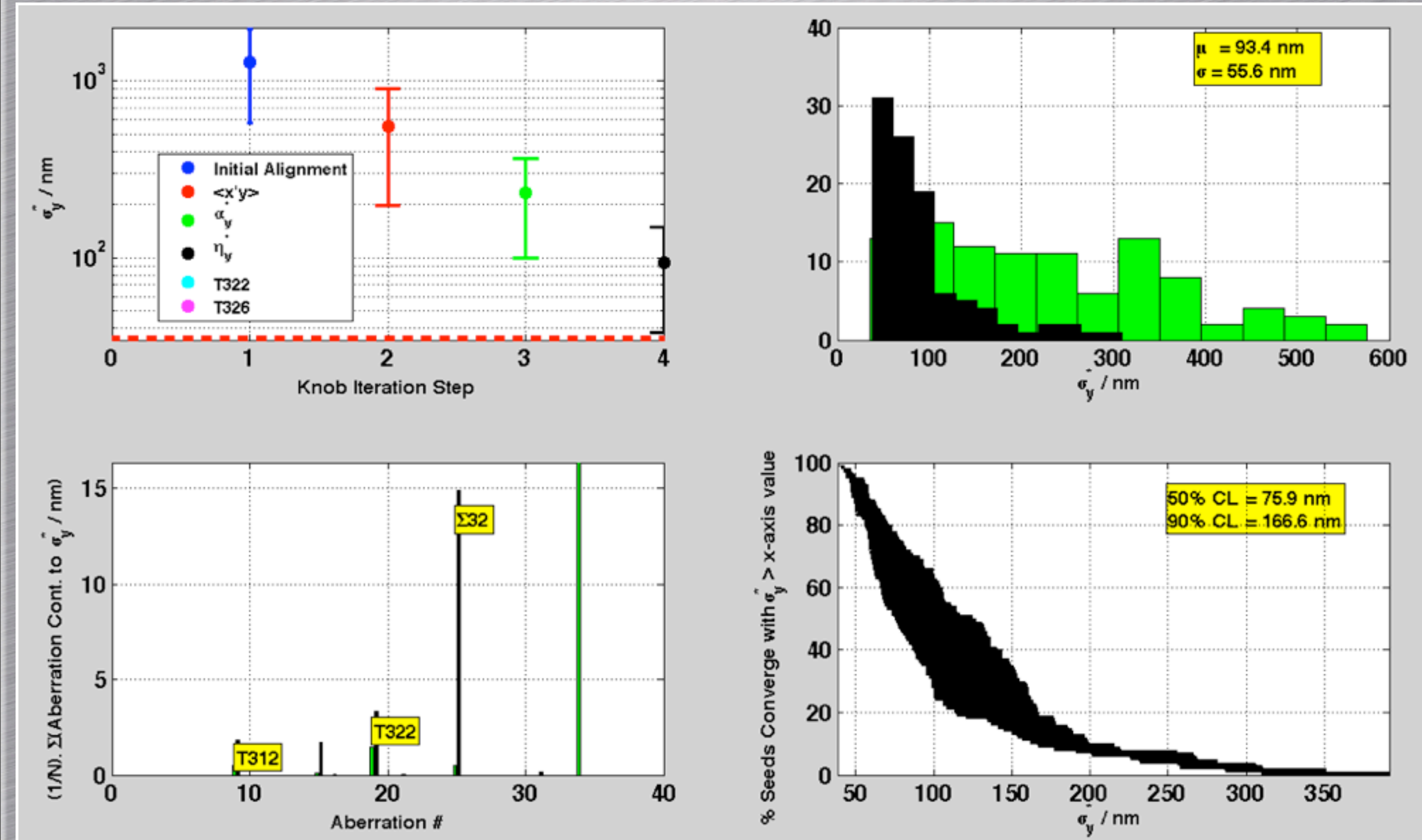
Initial Alignment
<x'y>
T322
T326
Knob Iteration Step
μ = 1270.4 nm
σ = 696.2 nm
Aberration #
Σ31
Σ32
Σ34
50% CL = 1219.1 nm
90% CL = 2183.8 nm
% Seeds Converge with σy > x-axis value



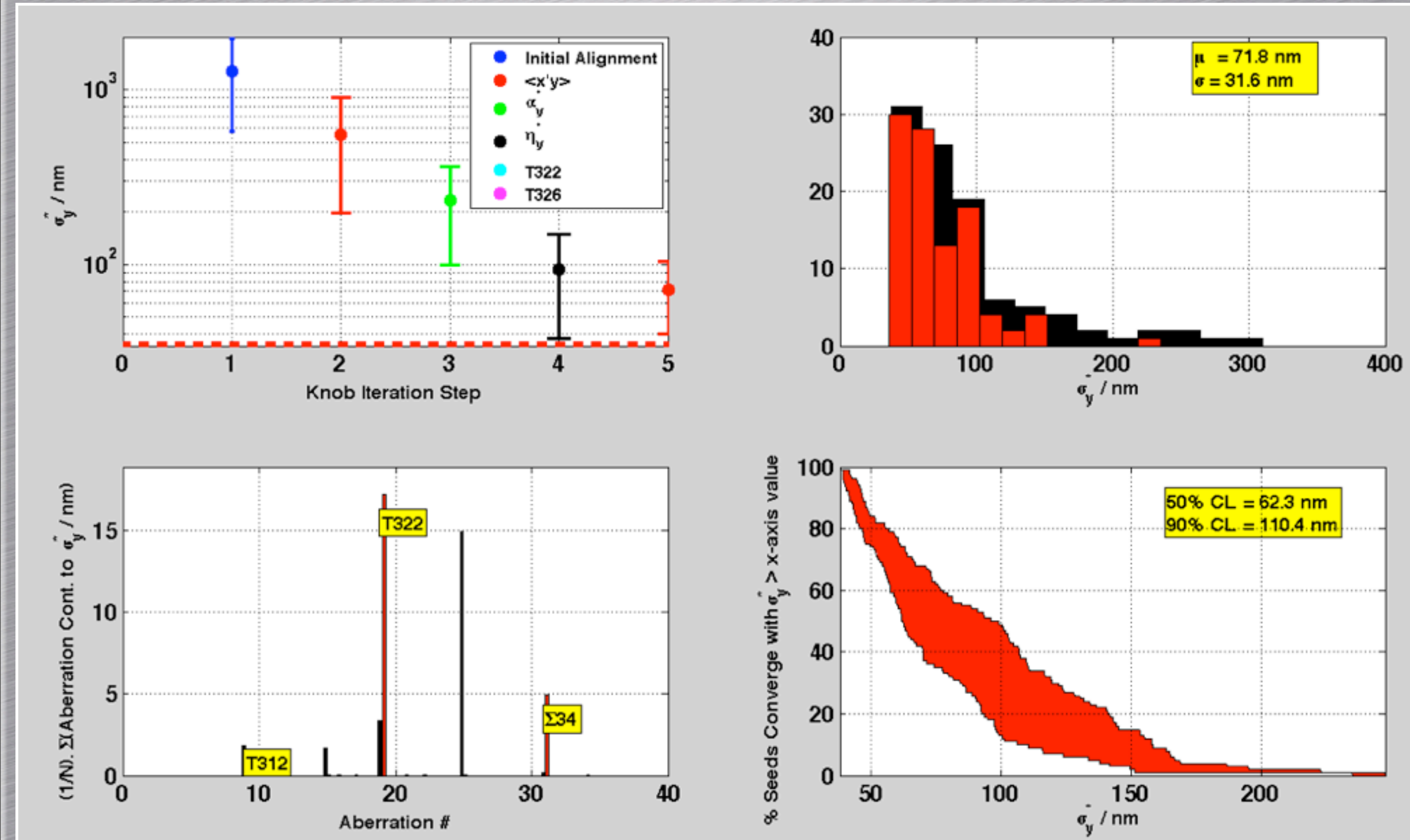
Initial Alignment
<x'y>
α_y^*
η_y^*
T322
T326
σ_y^* / nm
Knob Iteration Step
μ = 552.9 nm
σ = 355.0 nm
σ_y^* / nm
(1/N). ΣAberration Cont. to σ_y^* / nm)
Σ34
Σ36
T322
Aberration #
% Seeds Converge with σ_y^* > x-axis value
50% CL = 498.8 nm
90% CL = 1010.8 nm
σ_y^* / nm



Initial Alignment
<x'y>
T322
T326
Knob Iteration Step
σ_y^* / nm
μ = 231.9 nm
σ = 133.0 nm
T322
Σ32
Σ36
Aberration #
(1/N). ΣAberration Cont. to σ_y^* / nm
50% CL = 215.1 nm
90% CL = 402.4 nm
% Seeds Converge with σ_y^* > x-axis value



Thursday, October 21, 2010



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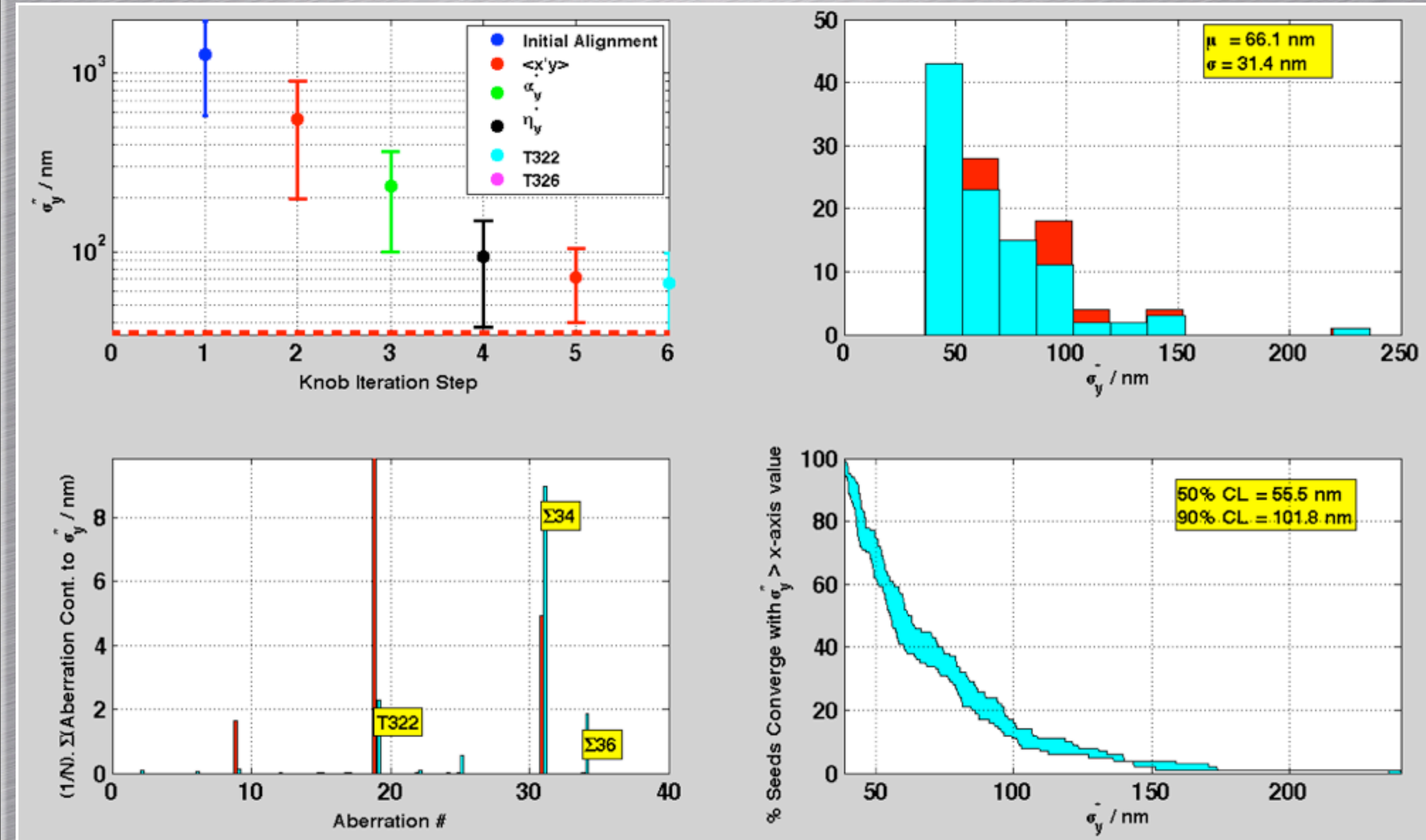
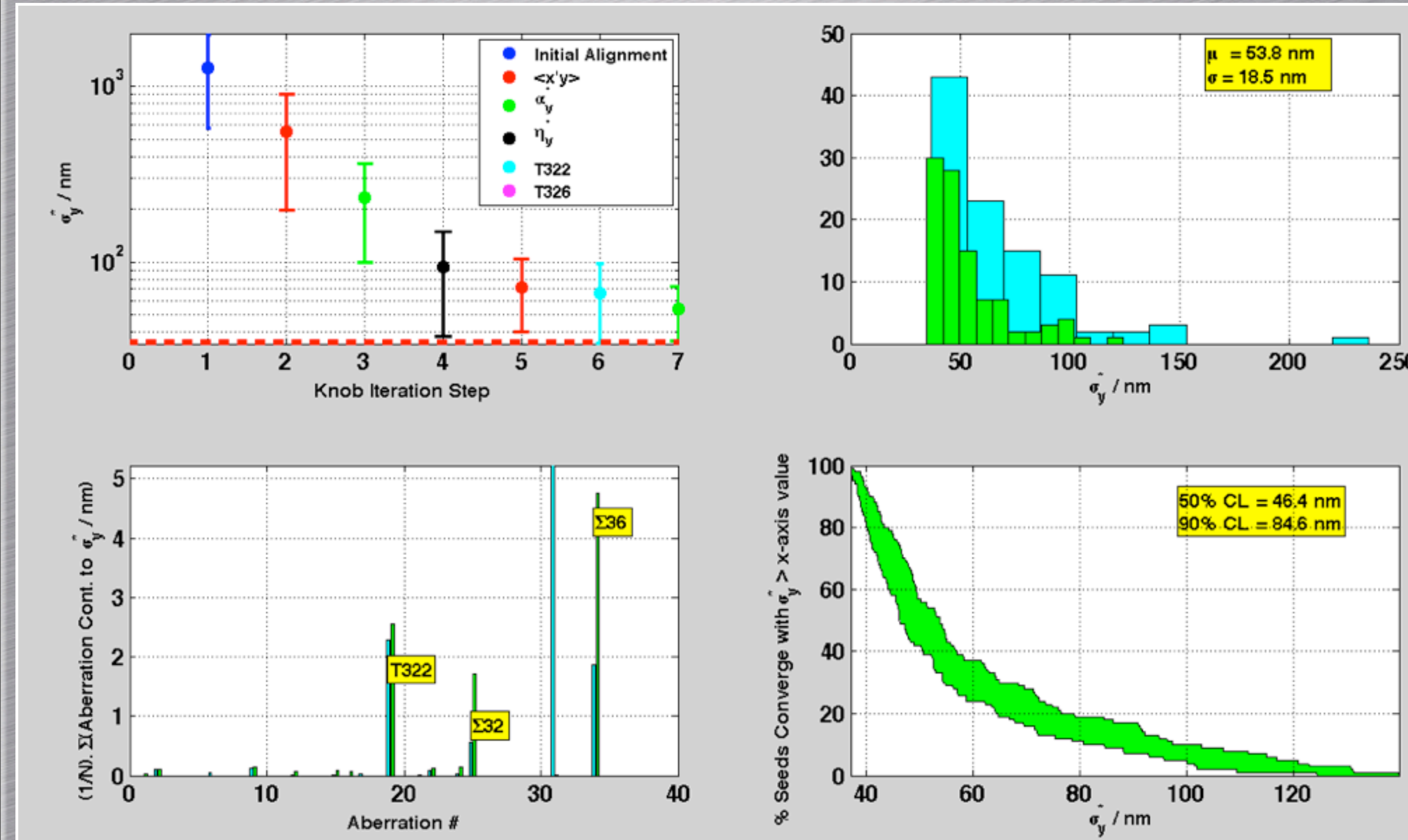
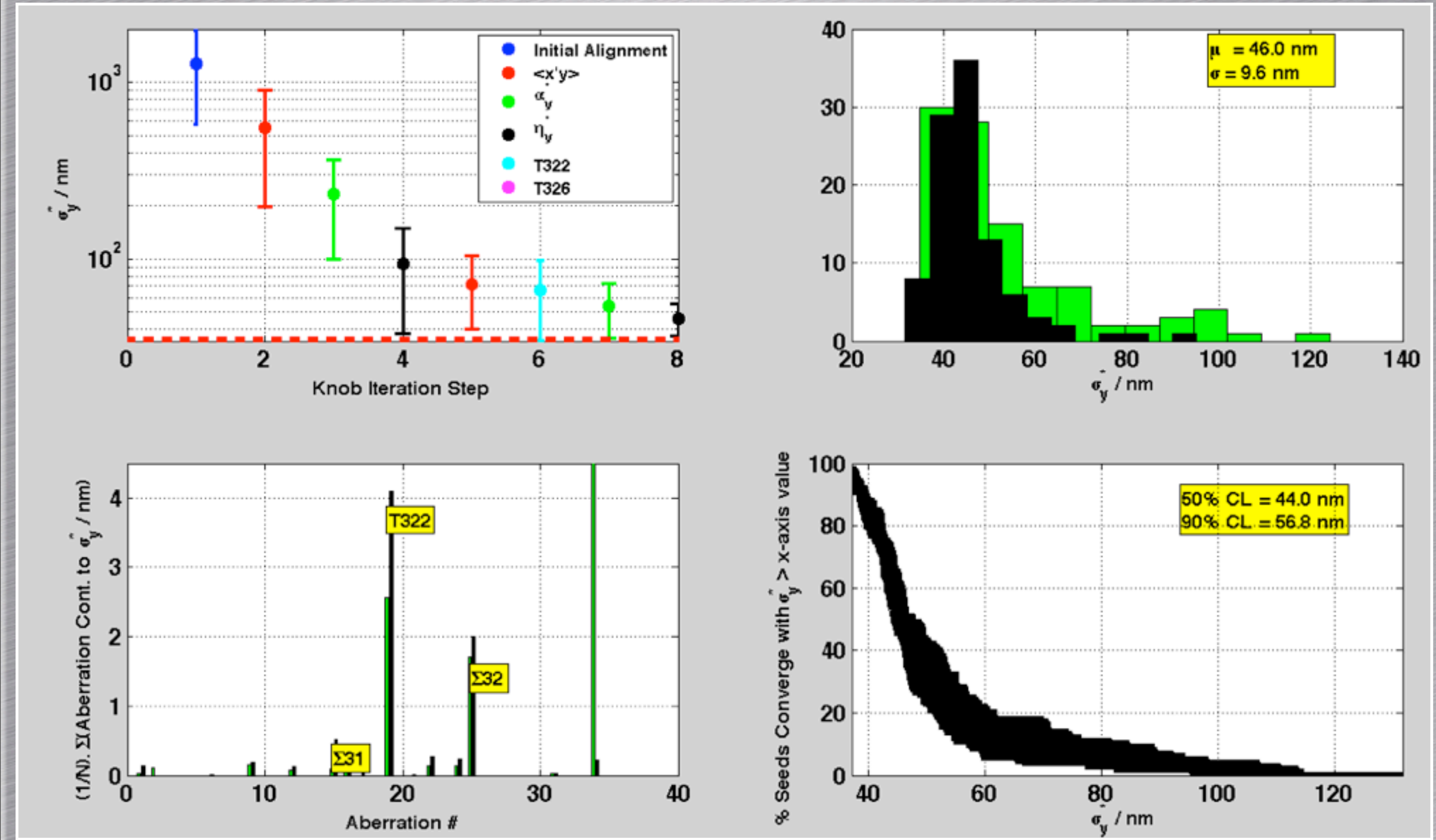
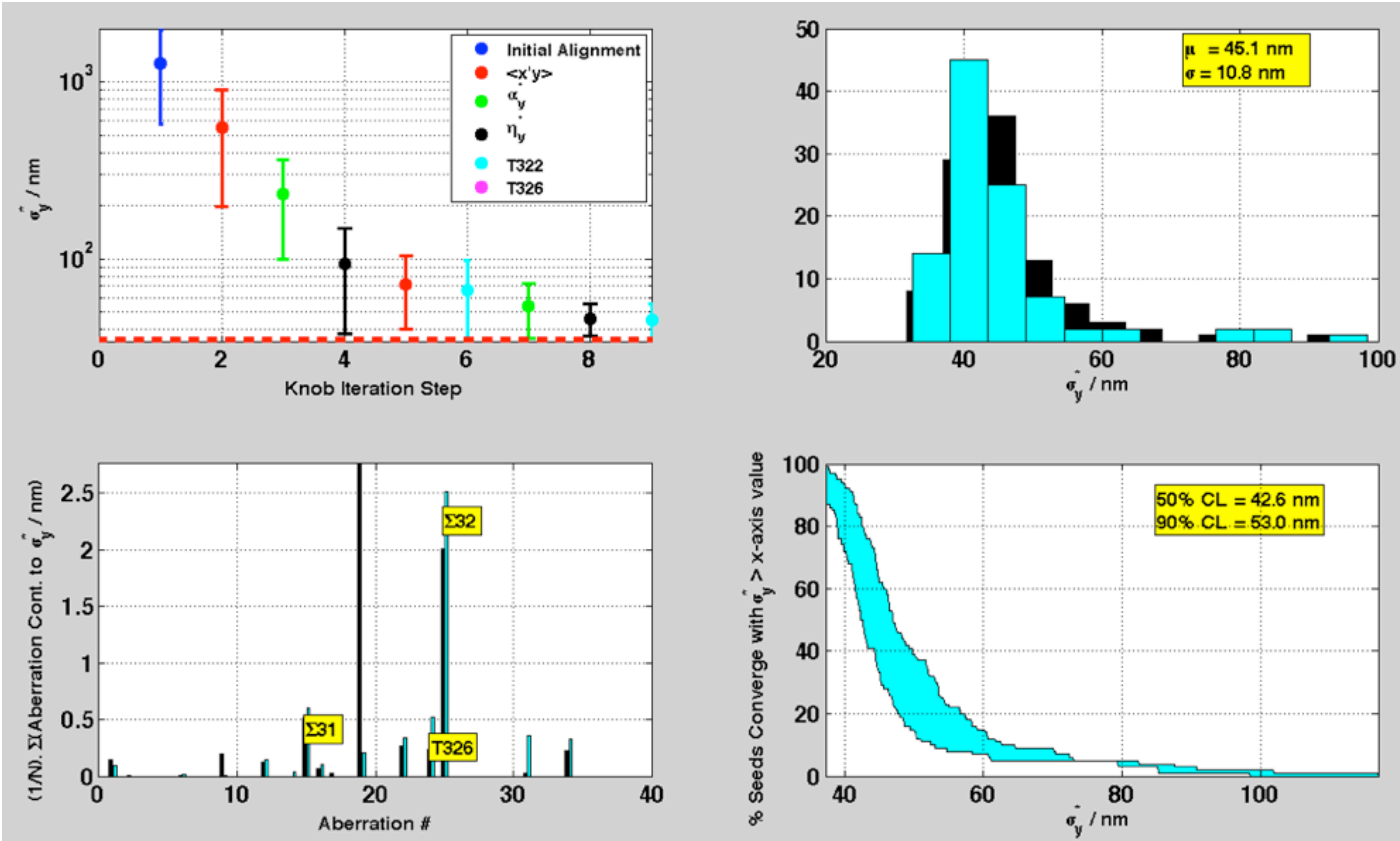


Initial Alignment
<x'y>
T322
T326
Knob Iteration Step
μ = 66.1 nm
σ = 31.4 nm
Σ34
T322
Σ36
Aberration #
50% CL = 55.5 nm
90% CL = 101.8 nm
% Seeds Converge with

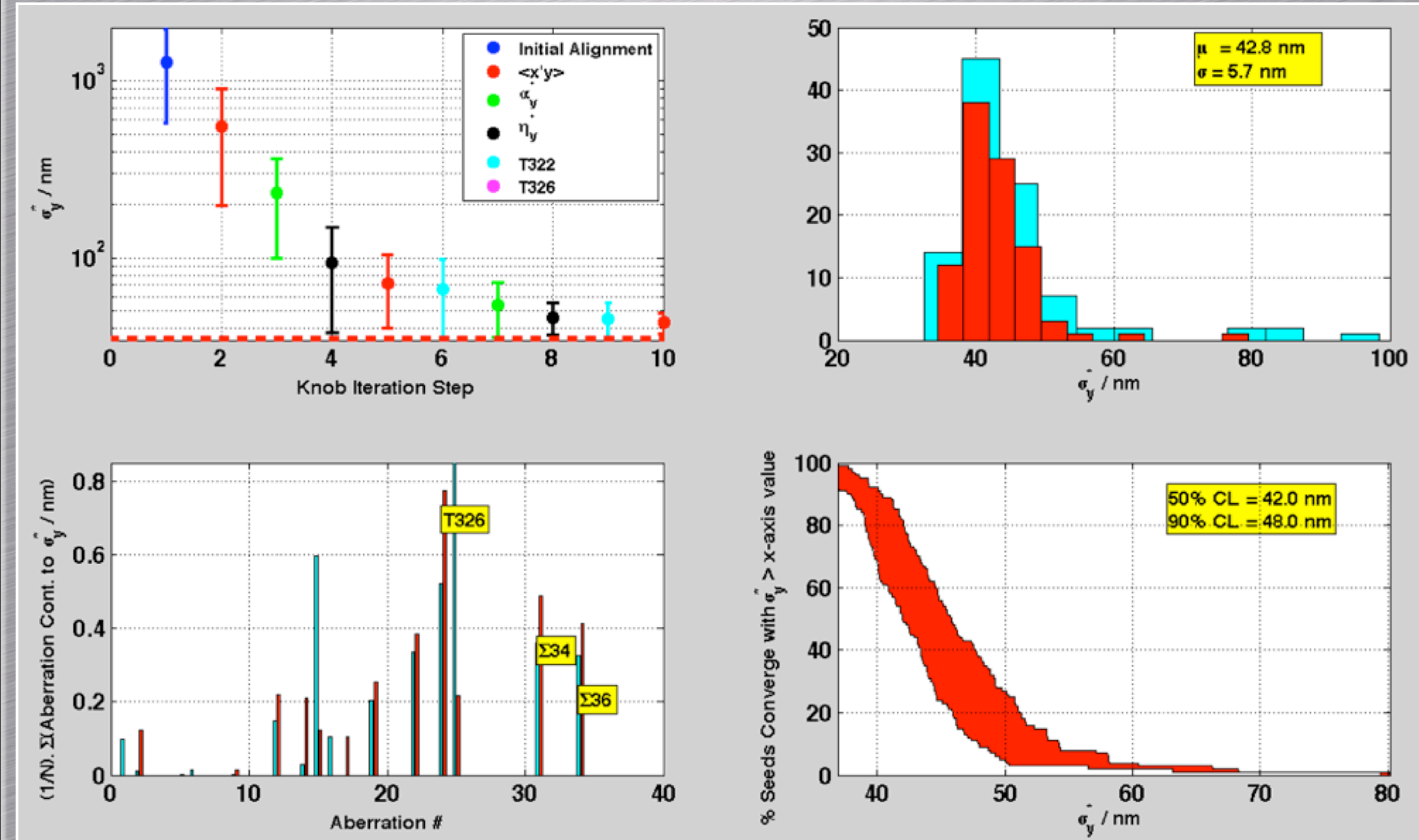

Initial Alignment
<x'y>
T322
T326
Knob Iteration Step
σ_y^* / nm
μ = 53.8 nm
σ = 18.5 nm
σ_y^* / nm
(1/N). Σ(Aberration Cont. to σ_y^* / nm)
T322
Σ32
Σ36
Aberration #
% Seeds Converge with σ_y^* > x-axis value
50% CL = 46.4 nm
90% CL = 84.6 nm
σ_y^* / nm



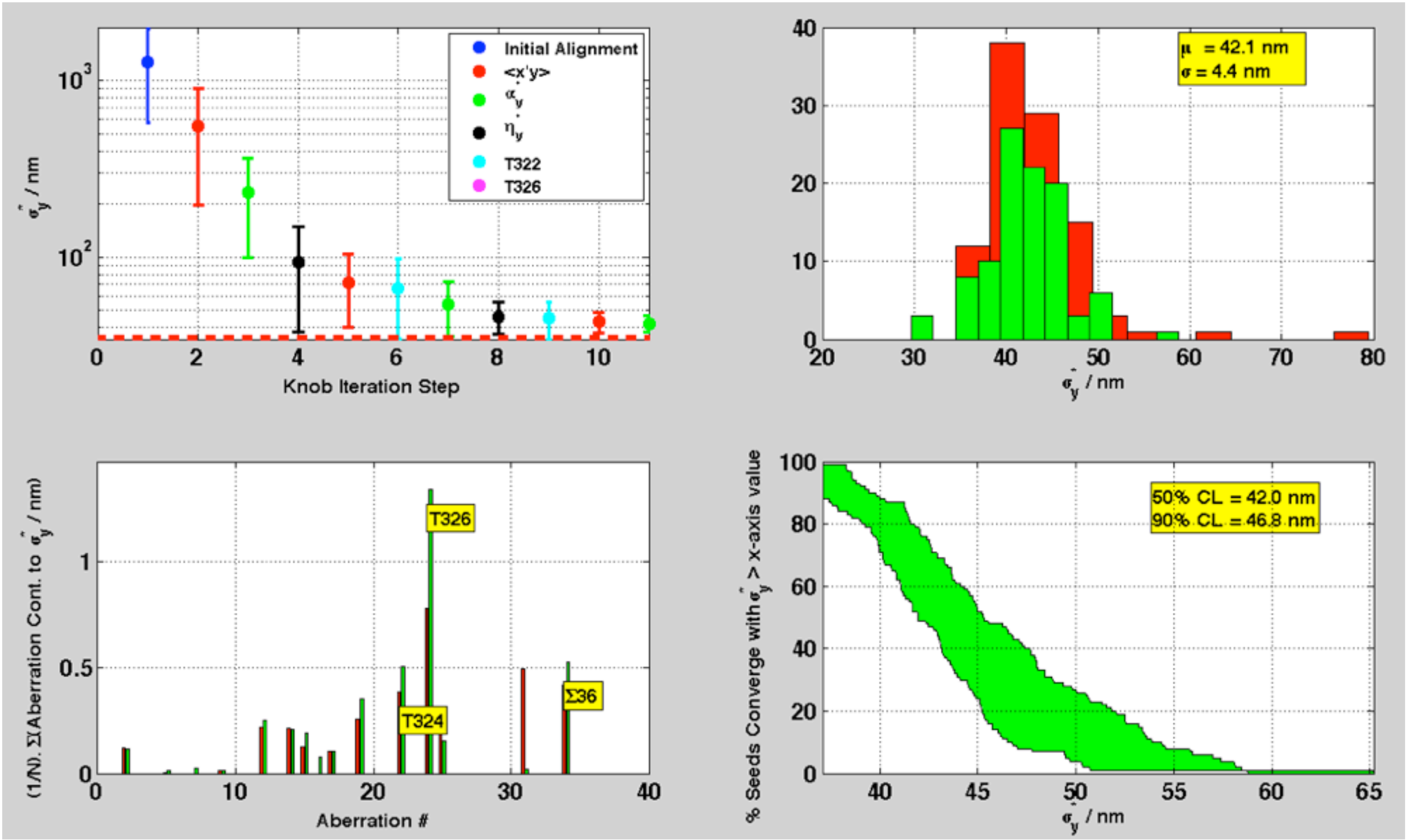
Initial Alignment
<x'y>
T322
T326
Knob Iteration Step
σ_y / nm
μ = 46.0 nm
σ = 9.6 nm
(1/N). ΣAberration Cont. to σ_y / nm)
T322
Σ32
Σ31
Aberration #
% Seeds Converge with σ_y > x-axis value
50% CL = 44.0 nm
90% CL = 56.8 nm

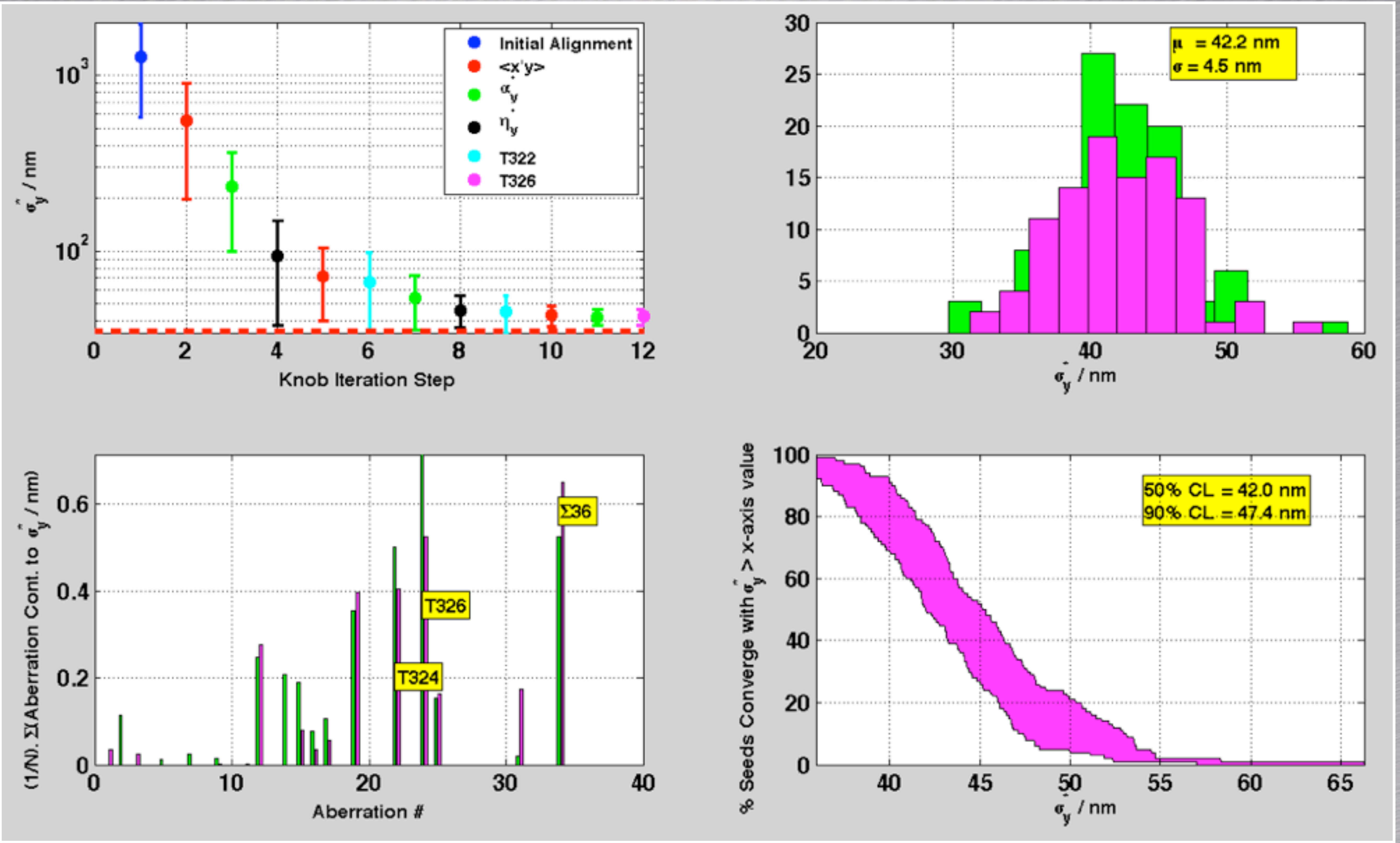


Initial Alignment
<x'y>
T322
T326
Knob Iteration Step
μ = 45.1 nm
σ = 10.8 nm
Σ32
Σ31
T326
Aberration #
50% CL = 42.6 nm
90% CL = 53.0 nm
% Seeds Converge with σy > x-axis value

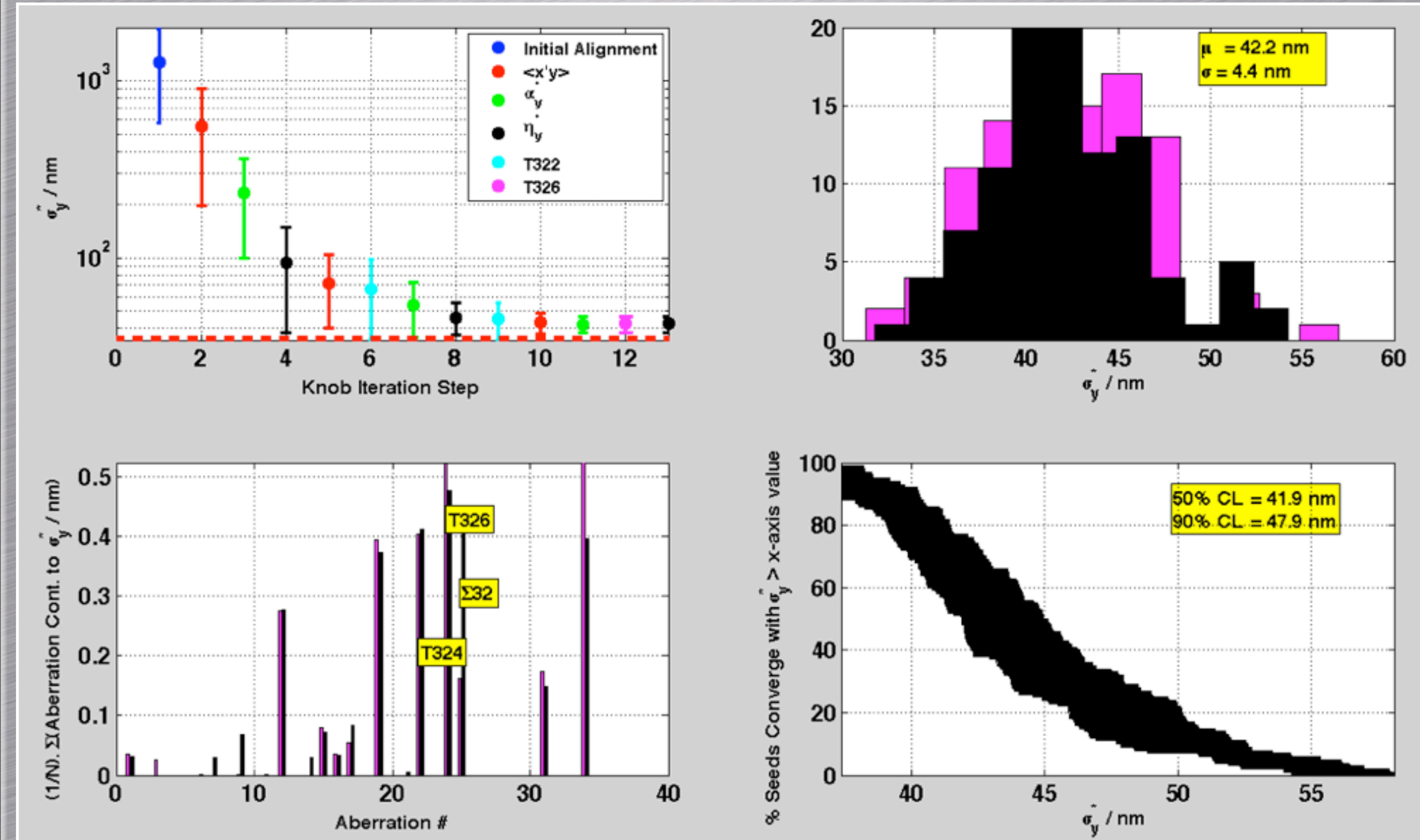


Initial Alignment
<x'y>
T322
T326
Knob Iteration Step
σ^*_y / nm
μ = 42.8 nm
σ = 5.7 nm
(1/N). Σ(Aberration Cont. to σ^*_y / nm)
Aberration #
T326
Σ34
Σ36
% Seeds Converge with σ^*_y > x-axis value
50% CL = 42.0 nm
90% CL = 48.0 nm

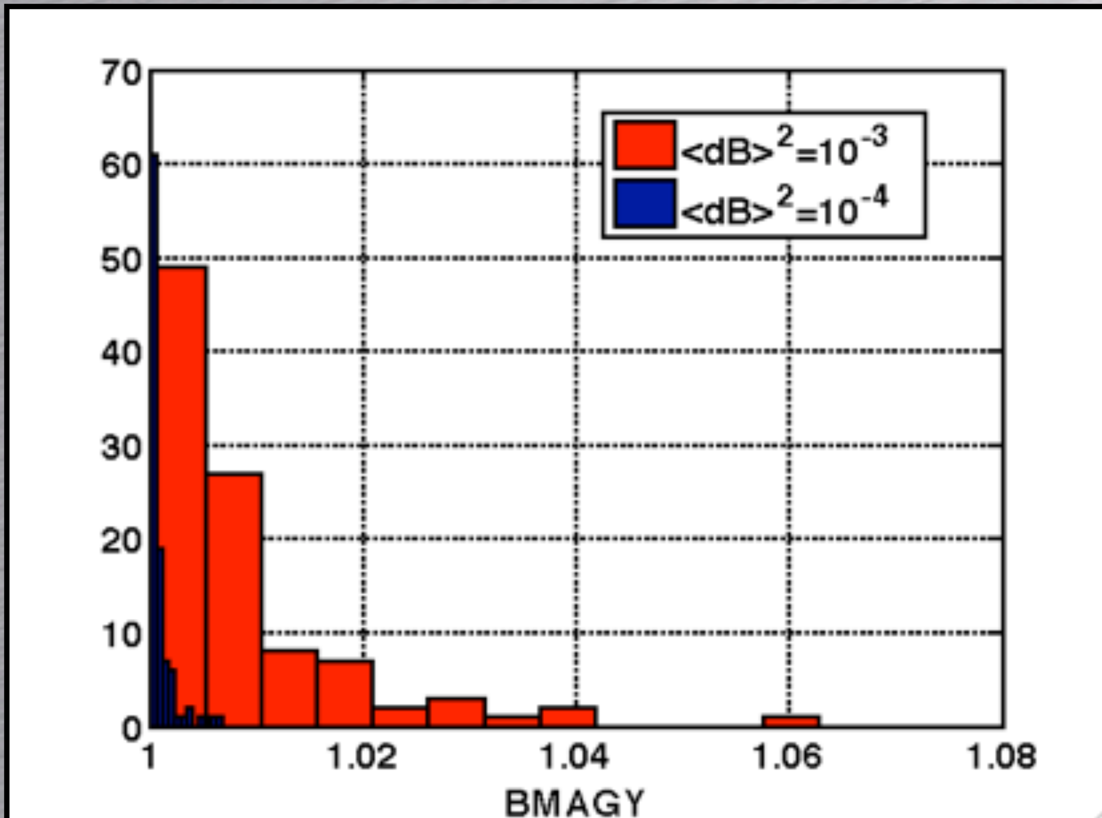

Initial Alignment
<x'y>
α^*_y
η^*_y
T322
T326
σ^*_y / nm
Knob Iteration Step
μ = 42.1 nm
σ = 4.4 nm
σ^*_y / nm
(1/N). ΣIAberration Cont. to σ^*_y / nm)
T326
T324
Σ36
Aberration #
% Seeds Converge with σ^*_y > x-axis value
50% CL = 42.0 nm
90% CL = 46.8 nm
σ^*_y / nm

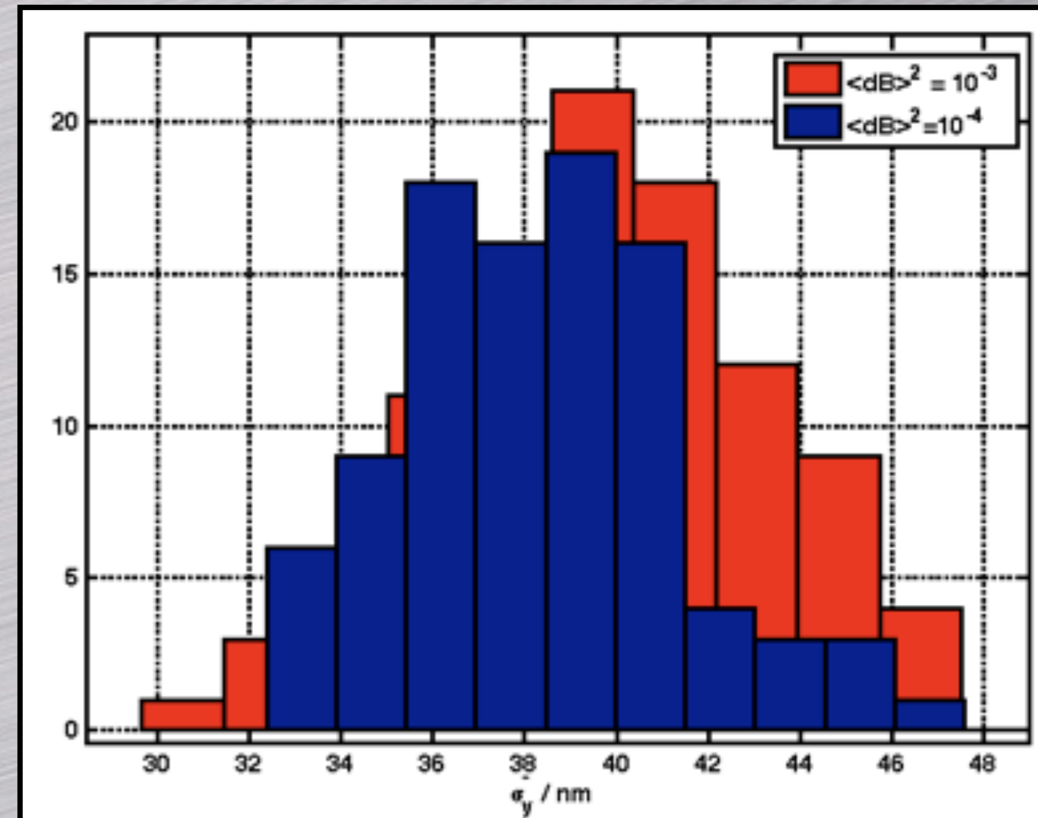


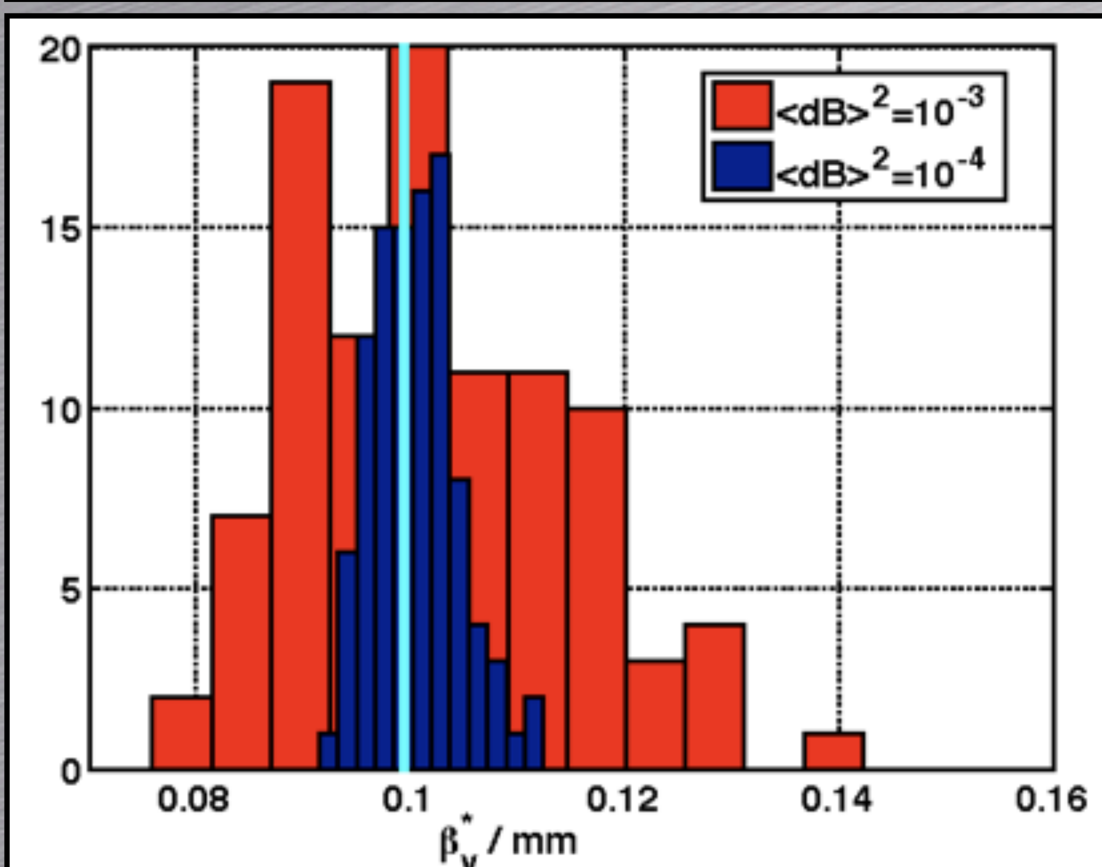
Initial Alignment
<x'y>
T322
T326
Knob Iteration Step
$\hat{\sigma}_y$ / nm
μ = 42.2 nm
σ = 4.5 nm
$\bar{\sigma}_y$ / nm
(1/N). ΣAberration Cont. to $\hat{\sigma}_y$ / nm)
Aberration #
T326
T324
Σ36
% Seeds Converge with $\hat{\sigma}_y$ > x-axis value
50% CL = 42.0 nm
90% CL = 47.4 nm
$\bar{\sigma}_y$ / nm


Initial Alignment
<x'y>
T322
T326
Knob Iteration Step
σ*y / nm
μ = 42.2 nm
σ = 4.4 nm
(1/N). ΣAberration Cont. to σ*y / nm
T326
Σ32
T324
Aberration #
% Seeds Converge with σ*y > x-axis value
50% CL = 41.9 nm
90% CL = 47.9 nm

Effect of Magnet Field Errors

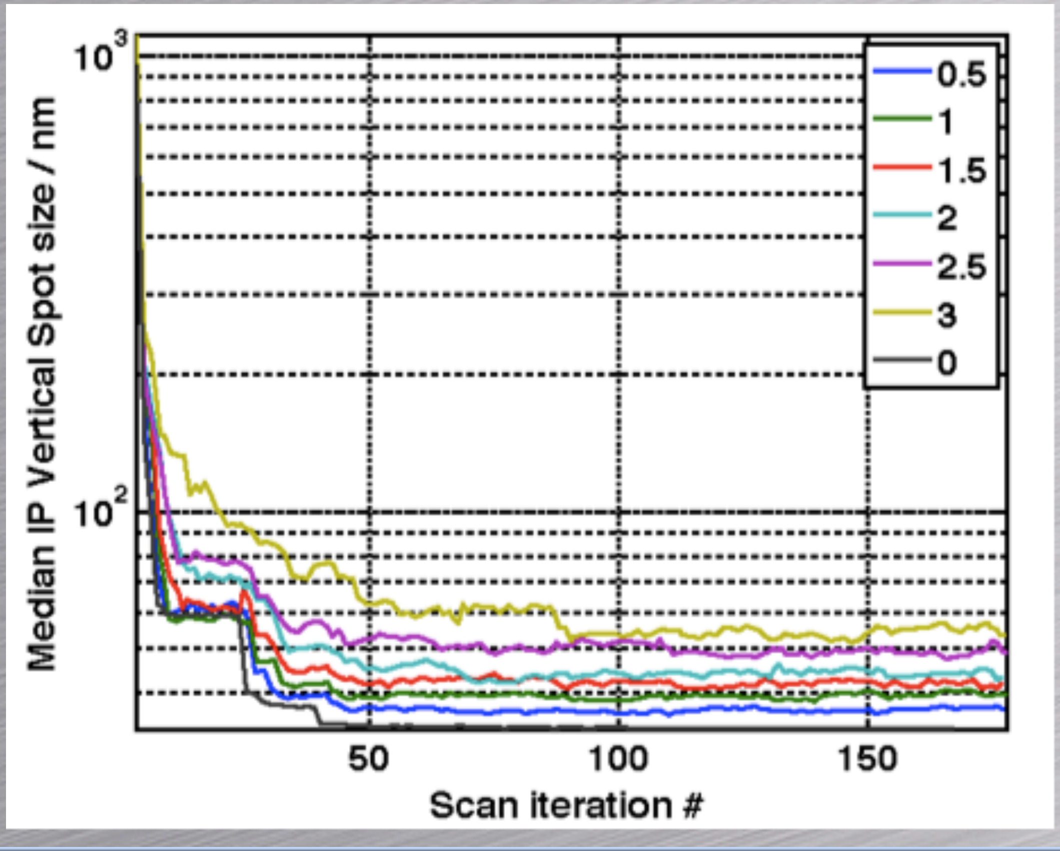


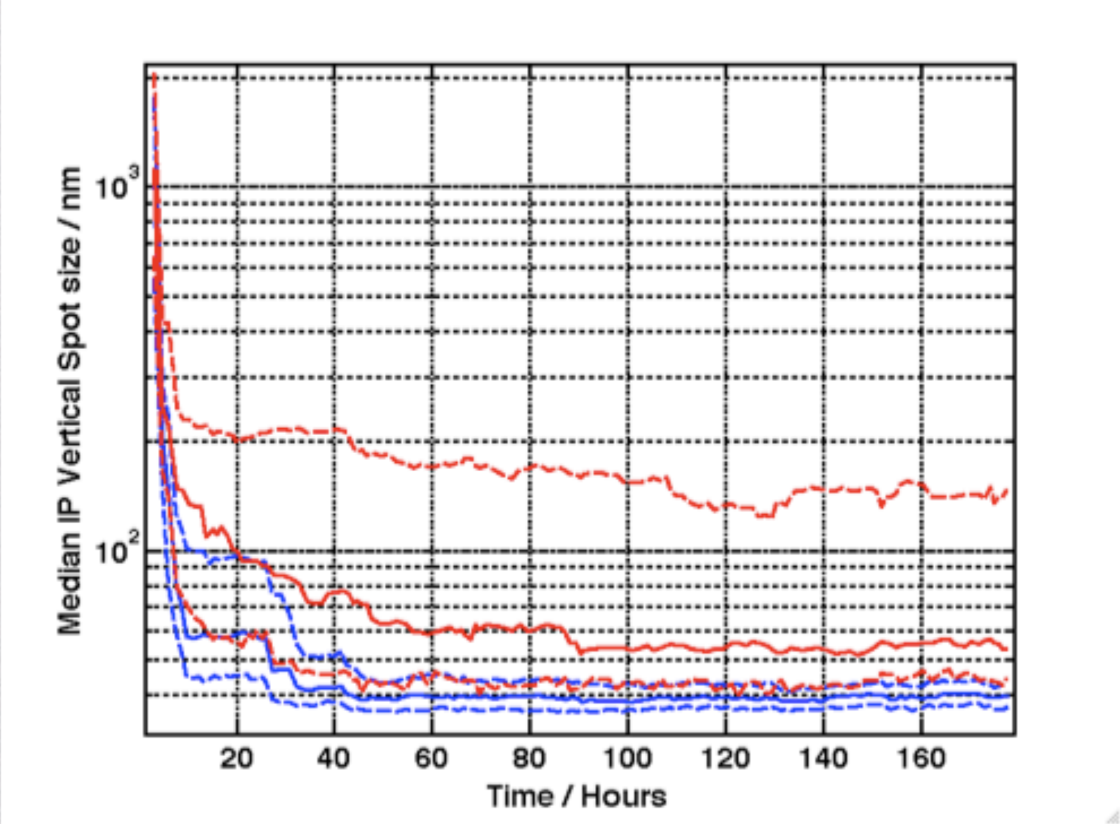


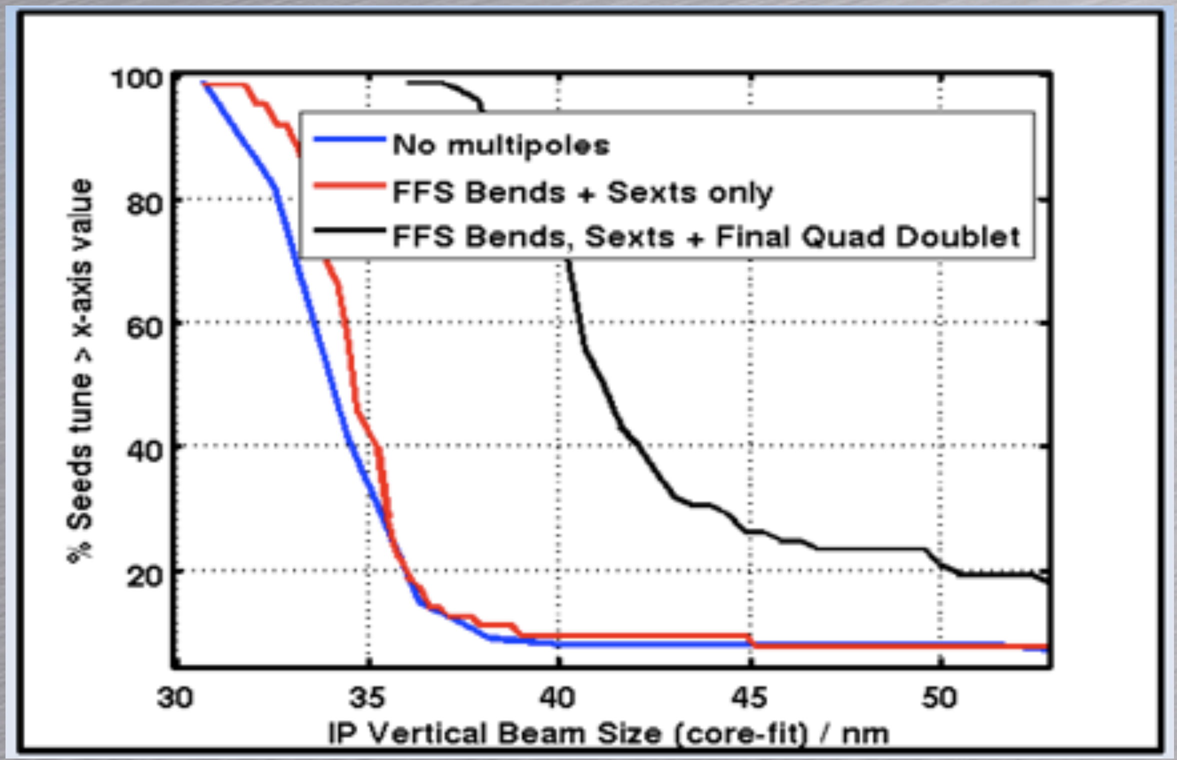


- **Increased magnetic field errors produce undetectable betatron mismatch at IP.**
  - Produces small spread in beam size due to variable focusing, but also damages performance of Sextupole aberration compensation and degrades orthogonality and operability of designed multiknobs.
- **Work to keep small where sensitivities highest.**

Long-Timescale Tuning

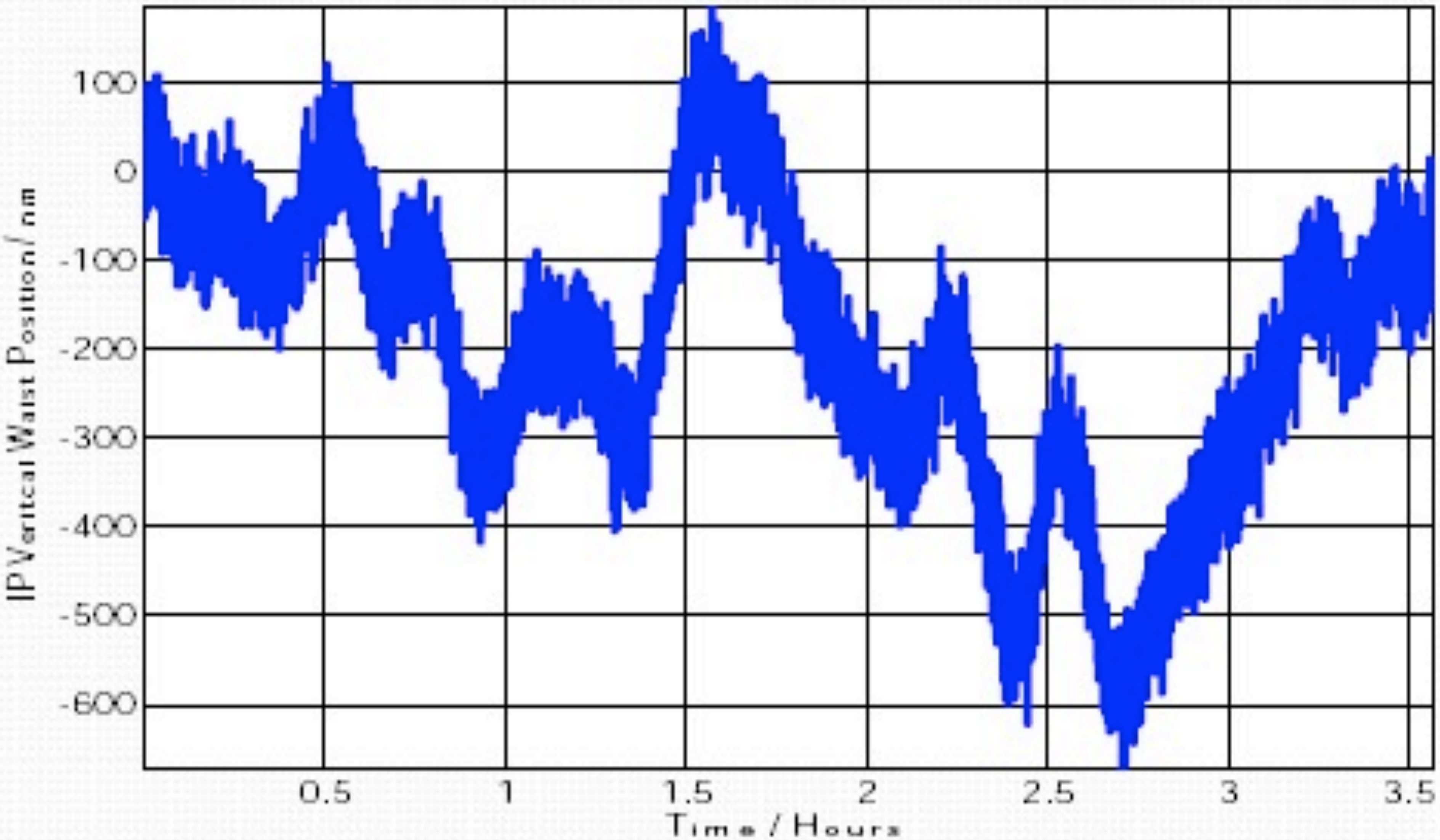






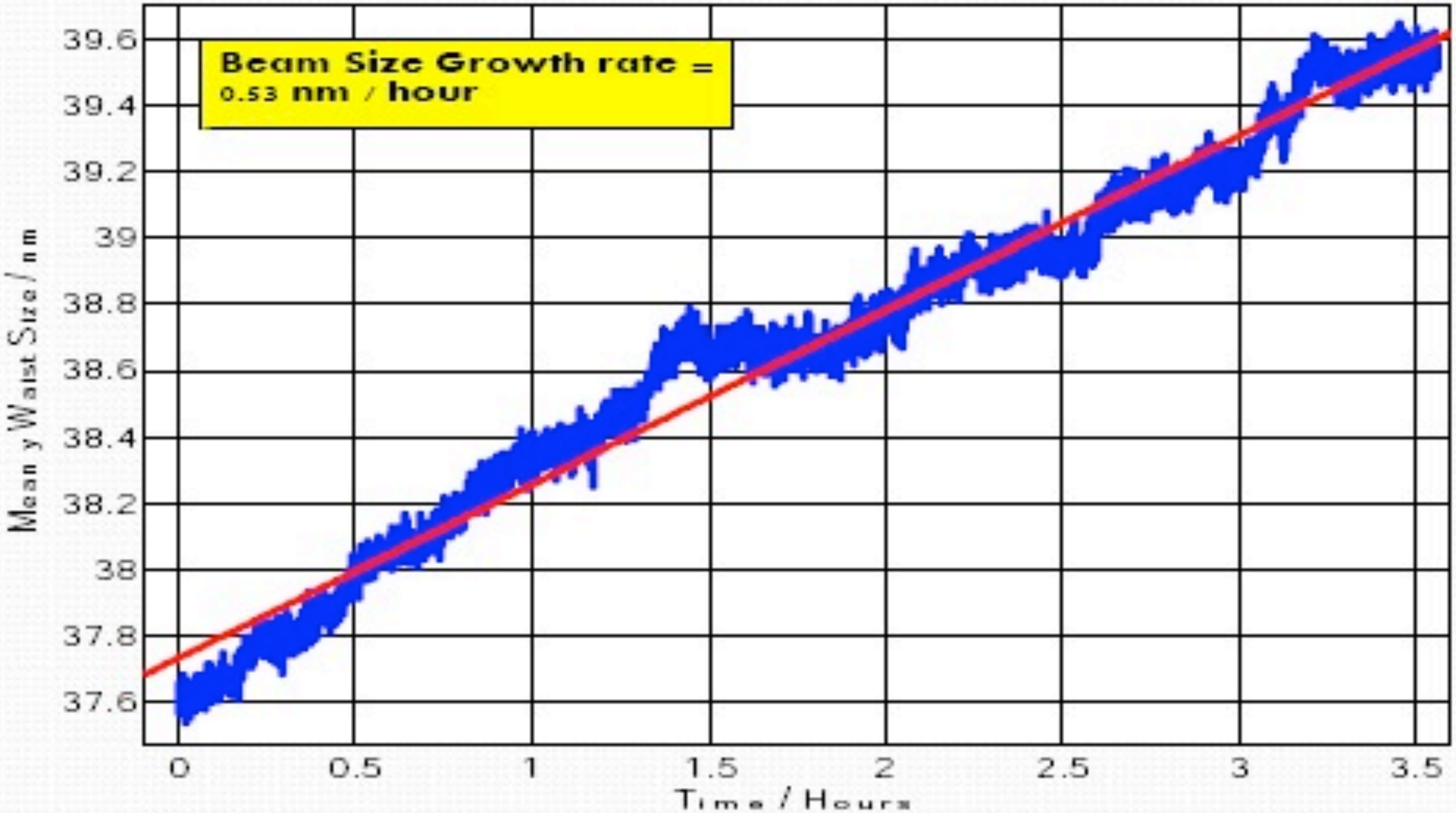
- Application of more basic tuning knobs over long timescales
- Strongly dependent on uning source noise (here Shintake Monitor)

IP Motion



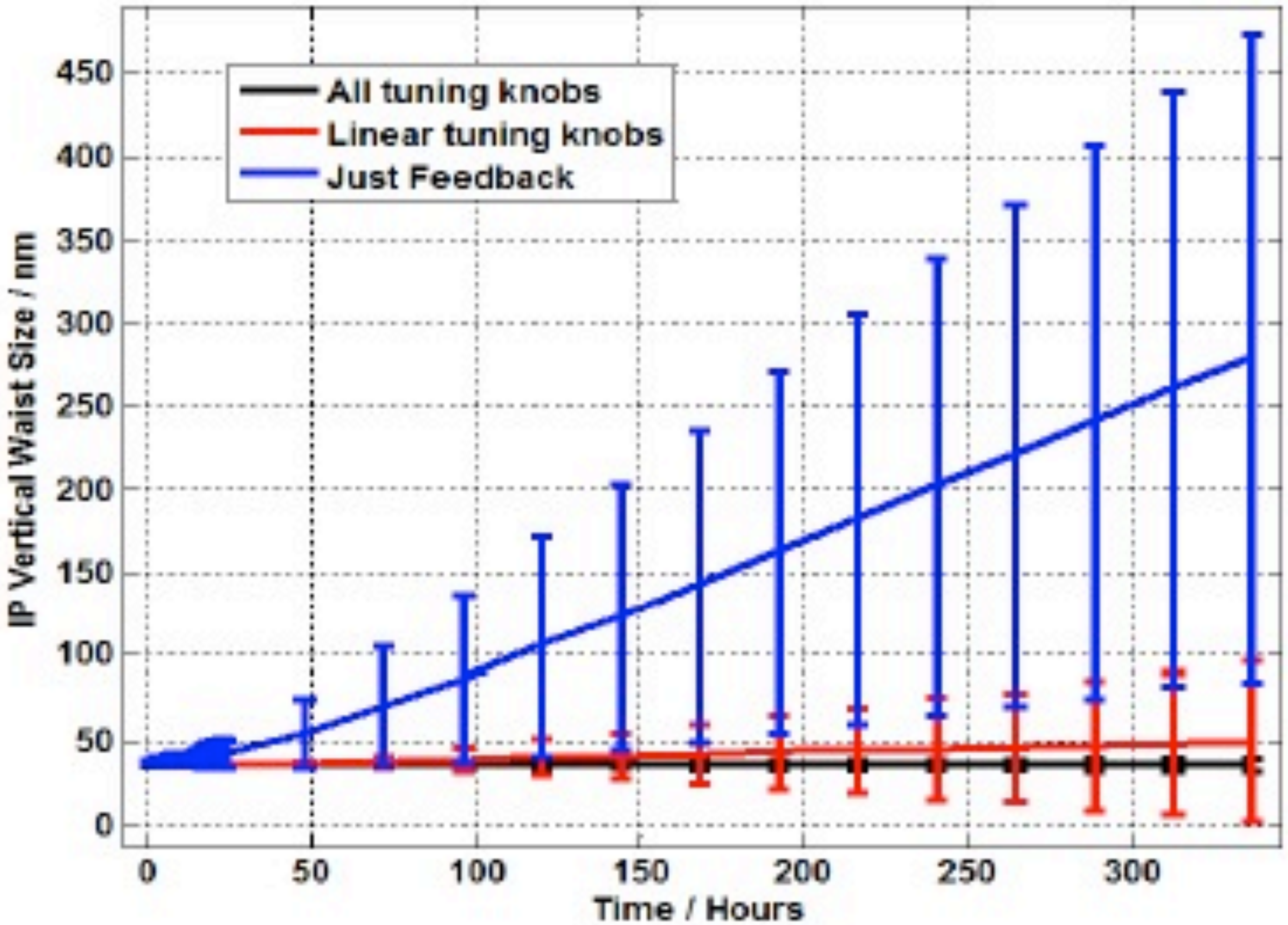
- 20,000 pulses @ 1.56 Hz (1 seed)
- IP vertical position drifts around on scales of a few 100 nm an hour.
- Slow enough that this can be 'de-trended' using Shintake Monitor as IP position monitor.

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

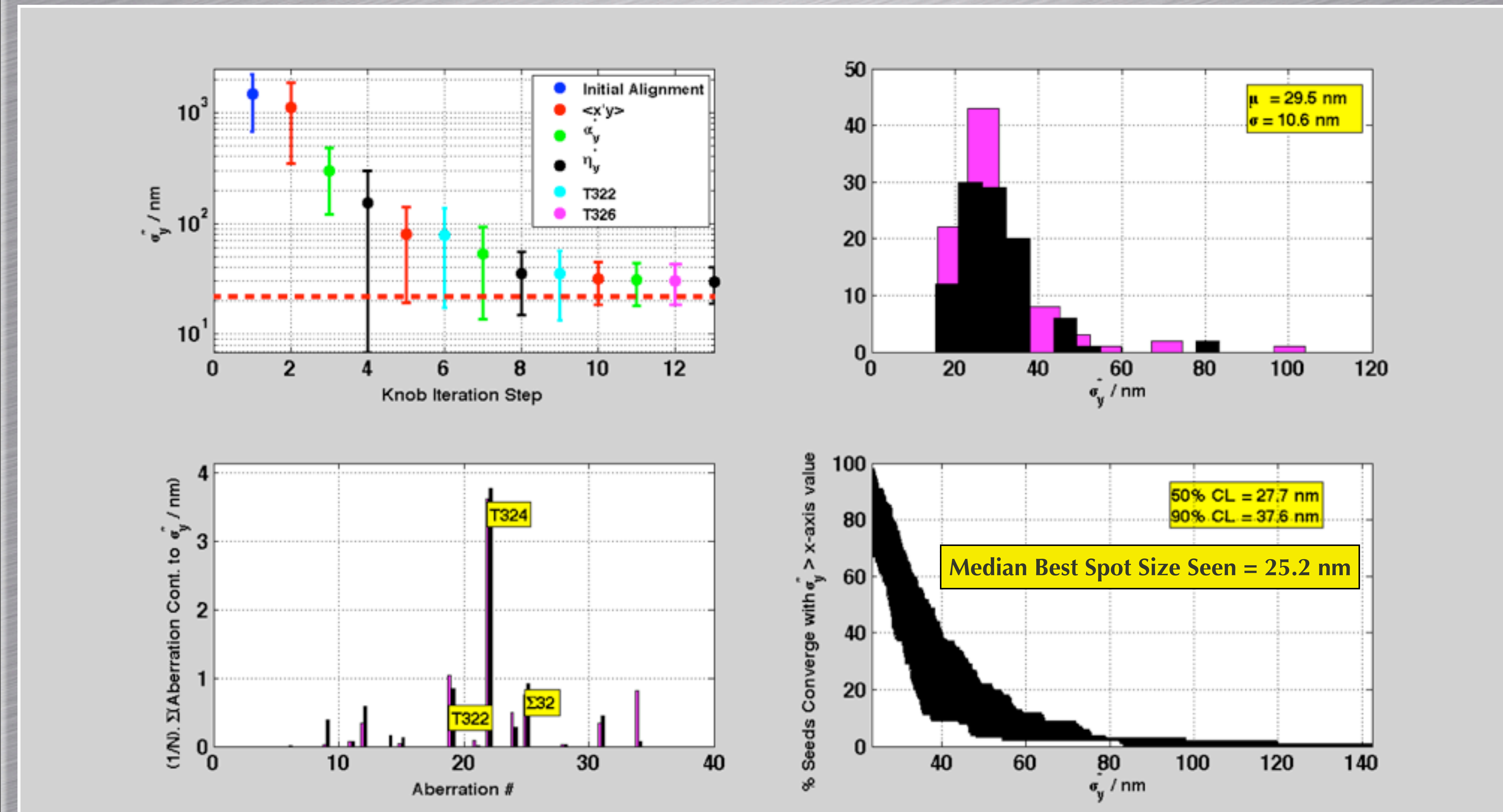
Long – Timescale Performance



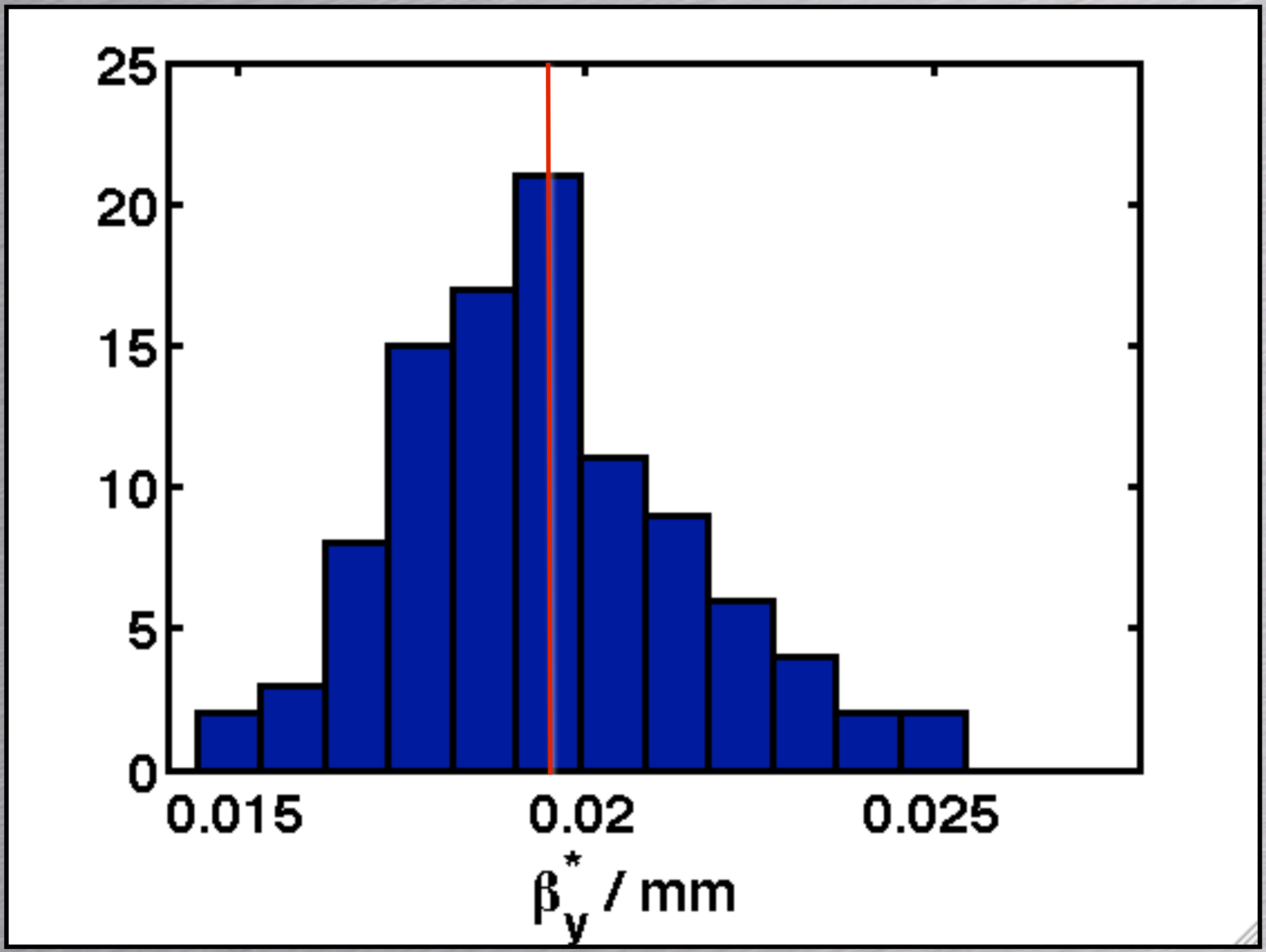
At each point, none, linear (waist, dispersion and coupling) and full tuning knobs (include sextupole strength and tilt scans) applied. For blue, red and black respectively.

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

0.03mm β_y Optics Test

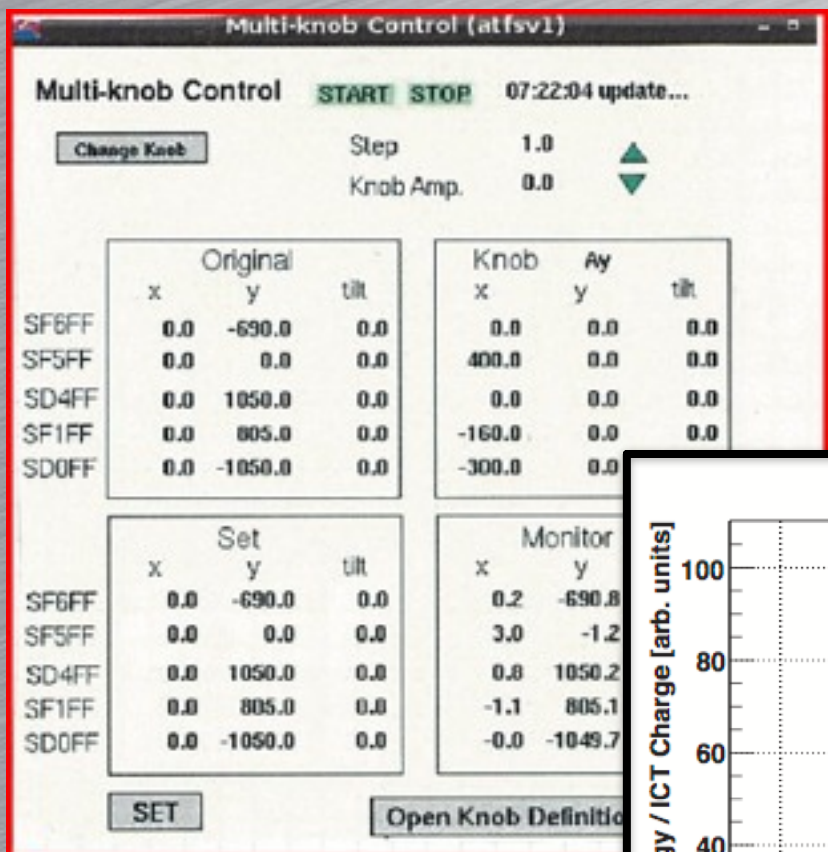


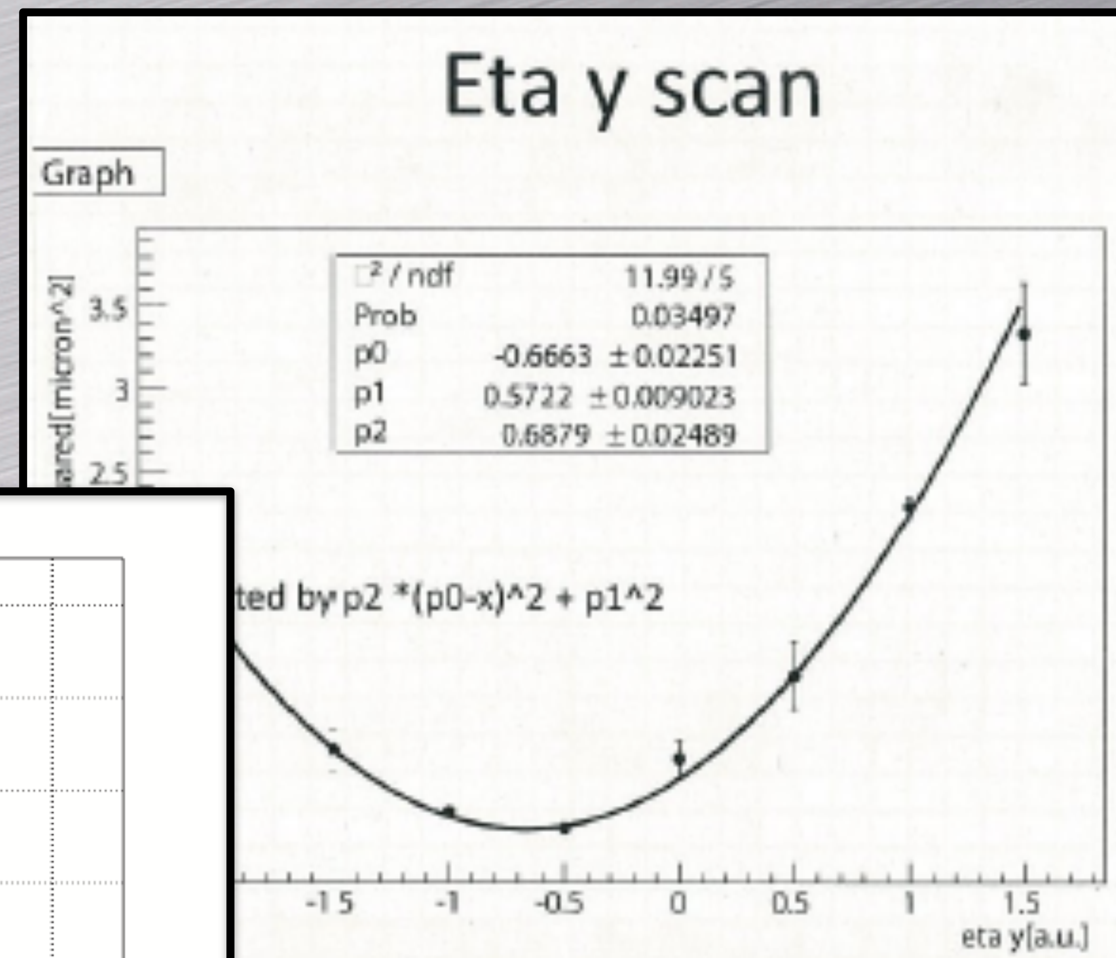
0.03mm β_y Optics Test

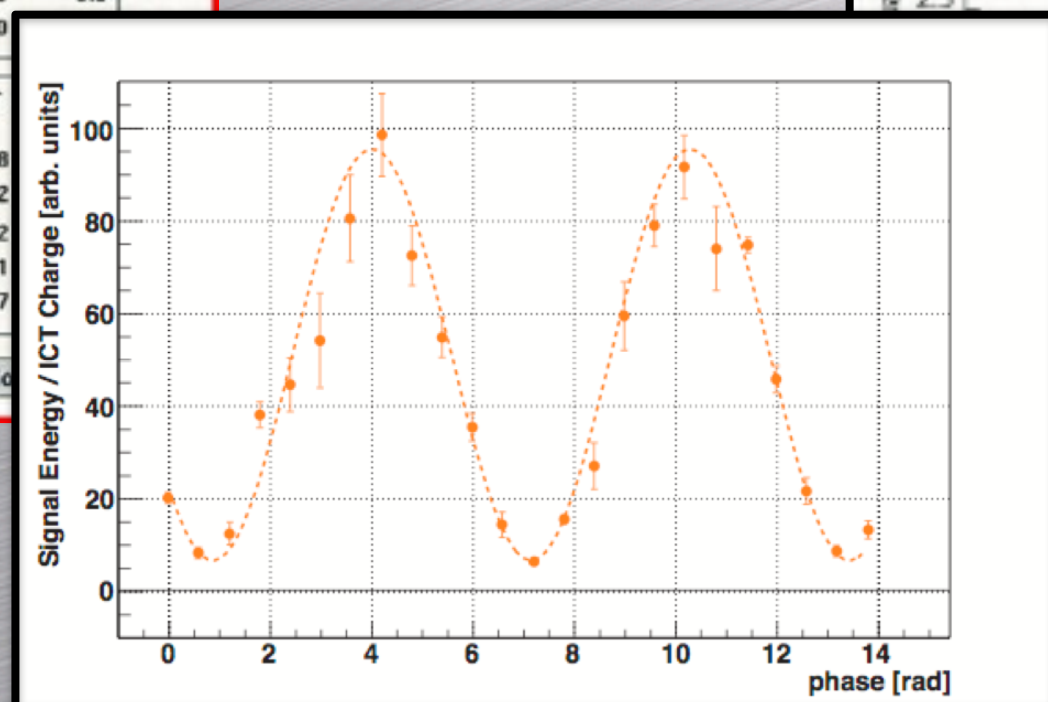


- **Spread in effective IP beta function post tuning.**
- **Initial**
  - betay 0.019 mm
  - emitx 3um
  - emity 12pm
  - sigy (Fit) 18nm
  - sigy (RMS) 21nm
  - sigy(1/2/3) 19.1/19.2/15.1 nm

IP Tuning with FFS Sextupole Multiknobs @ ATF2

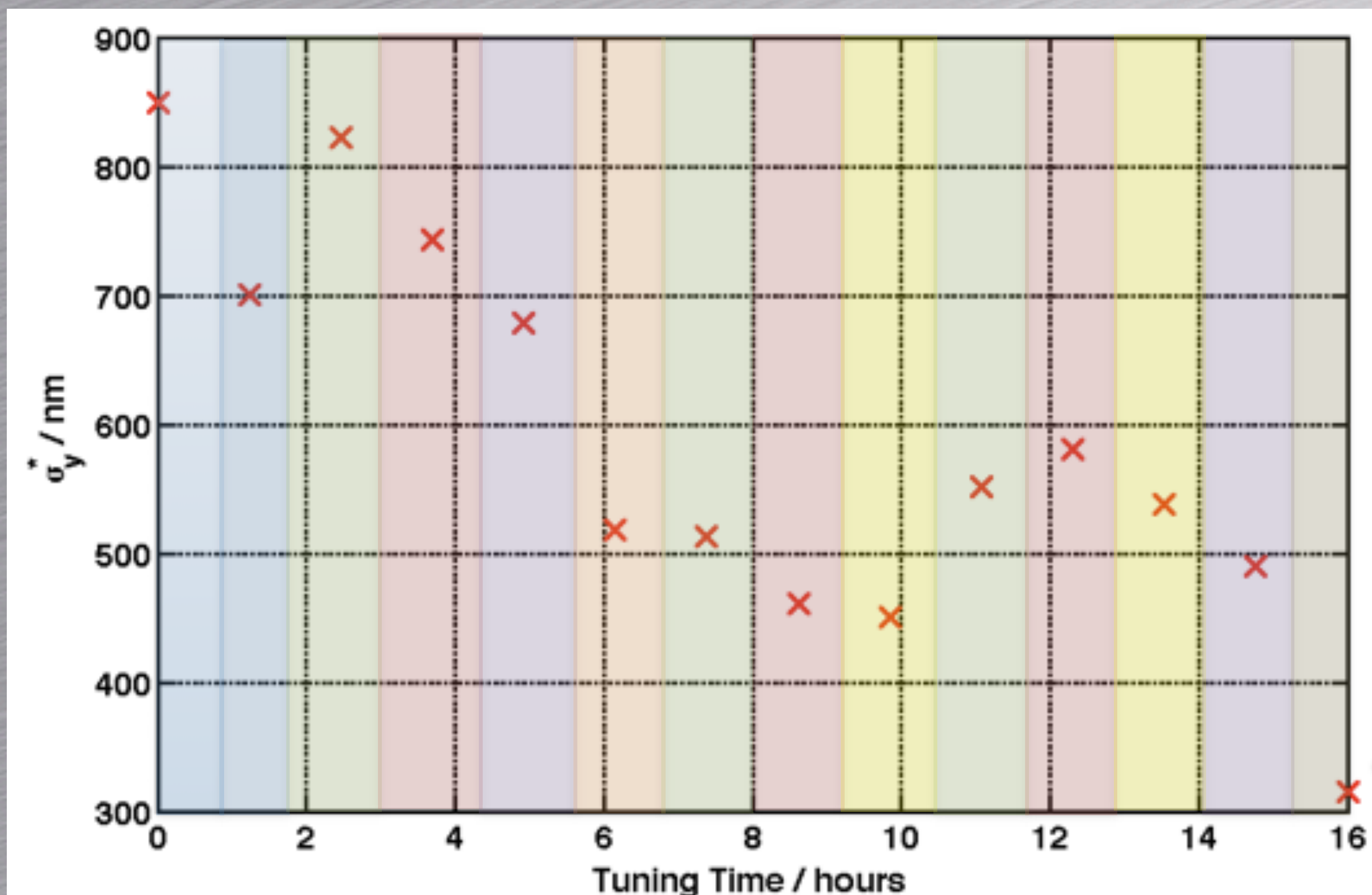


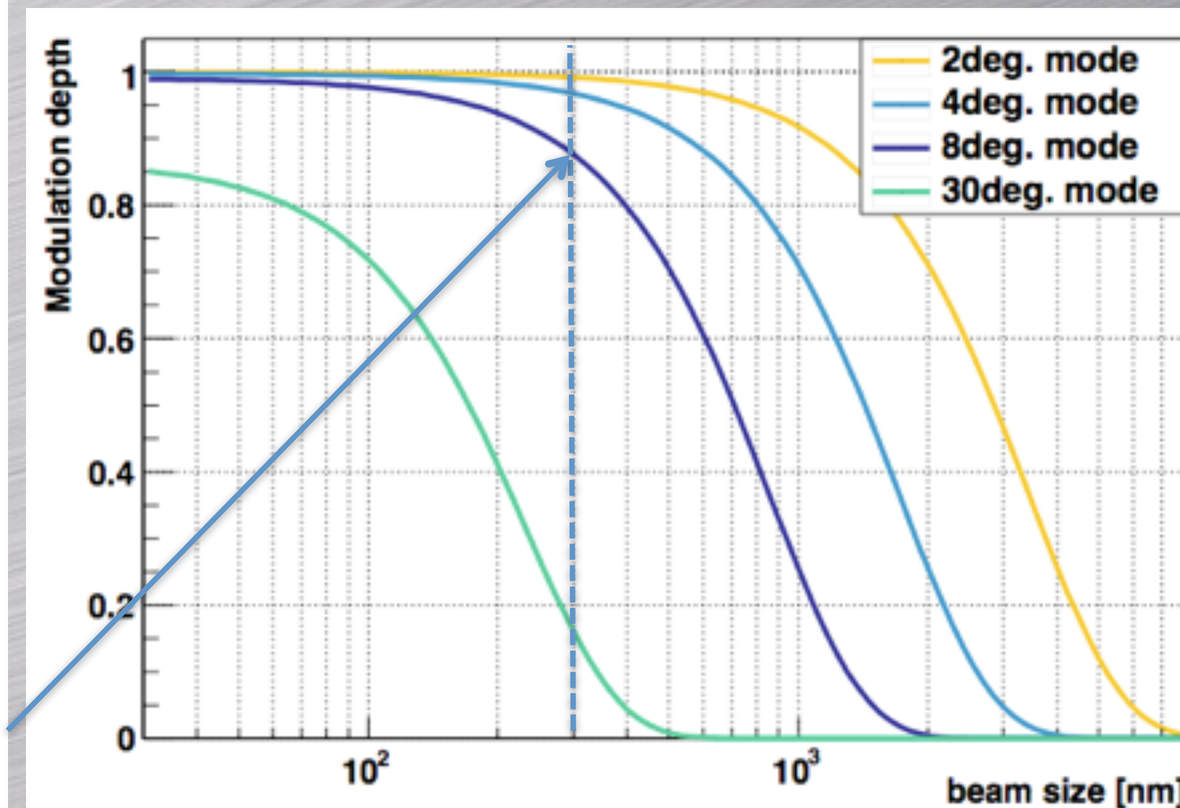




- Iterative use of various knobs to bring down IP spot size by scanning with IPBSM.

IP Tuning Results During Continuous Operations Week





- **Experience of application of tuning knobs during May running period at ATF2 with 10X nominal β^* optics (expected beam size ~150nm).**

Summary

- **Software for FFS tuning algorithm generation developed using parallel computing extensions to Lucretia beam tracking code.**
- **Used for developing tuning strategy for ATF2.**
- **Next plan to attempt to develop tuning strategy for "pushed beta" optics.**
  - Non-linear knobs required with increased FFS chromaticity?
- **Apply experience to generation of tuning strategy for ILC SB2009 and CLIC BDS.**