ILC BDS Static Beam-Based Alignment and Tuning

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1. Aims.
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3. Overview of alignment and tuning procedure.
4. Results from 100 seed Lucretia simulation.
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Aims and BDS Model Used

- Snowmass ILC-IR1 20mrad BDS model.
- USSC parameter set, BDS vertical emittance growth budget ~6nm, so initial ε_y = 34nm.
- Aim is to show can go from post survey BDS -> design luminosity in as realistic a manner as possible.
- Achieve as many seeds as possible < 18% vertical emittance growth and demonstrate design lumi.
- Lucretia used as modeling tool (track 2000 macro particles / bunch during alignment & tuning, 80,000 tracked for results), 100 seeds.

Error Parameters

- All magnets have an associated BPM and x, y movers (sextupoles additionally have roll movers).
- Magnet RMS mis-alignment / rotation: 200um / 300urad.
- Initial RMS BPM-magnet centre alignment: 30um.
- RMS relative magnetic strength error: 0.1%.
- Magnet mover resolution (x & y): 50nm.
- BPM resolution: 1um (100nm for Sextupole BPMs).
- Power supplies – 14bit resolution.
- Final sext/oct/quad doublet assumed fixed within final cryomodule (with sext/oct co-wound).
  - Whole assembly assumed to have x,x’/y,y’ DoF.
  - BPM’s attached to Sextupoles provide front and back orbit reference.
  - BPM-Sext errors as above, BPM’s then aligned to Sext.
  - SEXT/OCT field centre alignments? (10um/100urad used here)

Alignment and Tuning Strategy

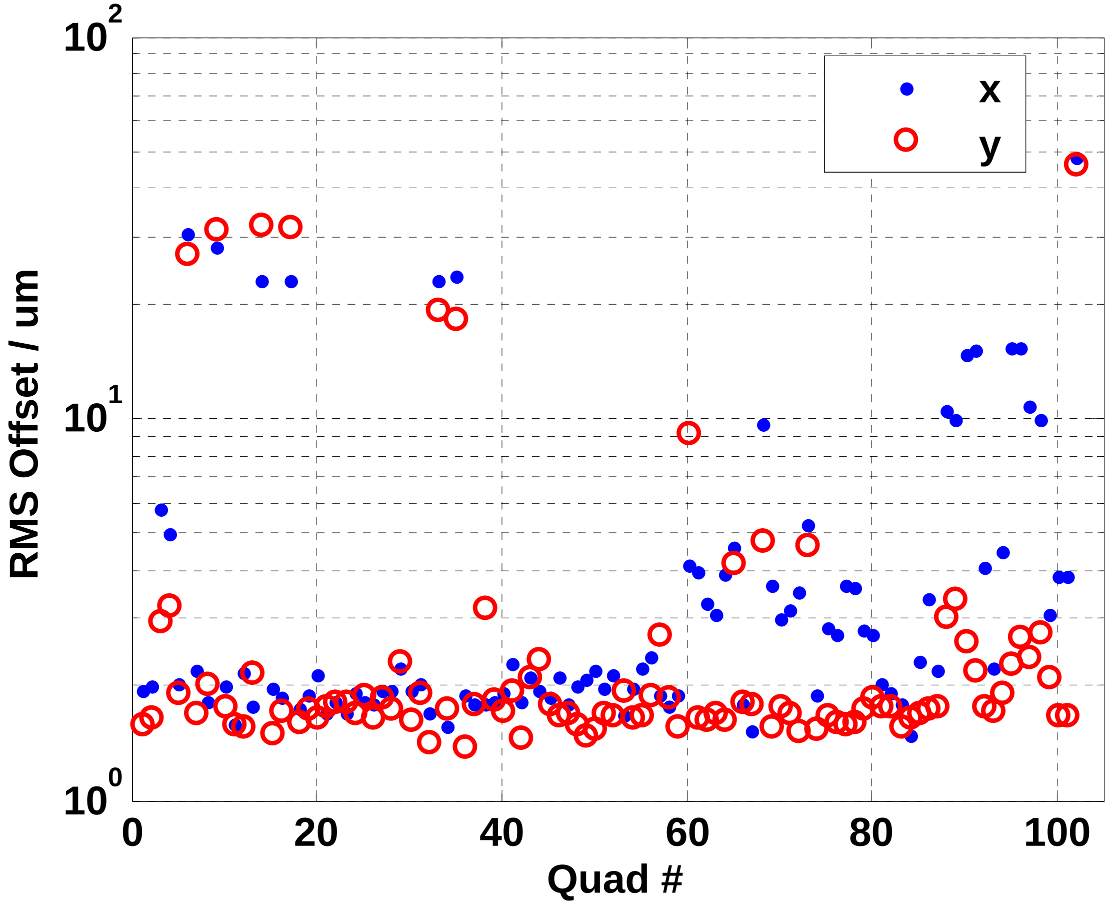
1. Switch off sextupoles & octupoles, get rough initial alignment in Quads with movers.
2. Use nulling Quad-shunting technique to get BPM-Quad alignments.
3. Use Quad movers and global alignment algorithm to put Quads in a straight line in x and y with beam going through Quad field centers, use linear move of whole BDS to align e- beam with e+ beam.
4. Get BPM-sextupole/octupole alignment with movers using a fit to downstream BPM responses.
5. Switch on sextupoles/octupoles and use sextupole multi-knobs to tune IP waist, dispersion and coupling (first and second order knobs required).

Quad-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 weighted-fit to downstream BPM readings based on model transfer functions:**

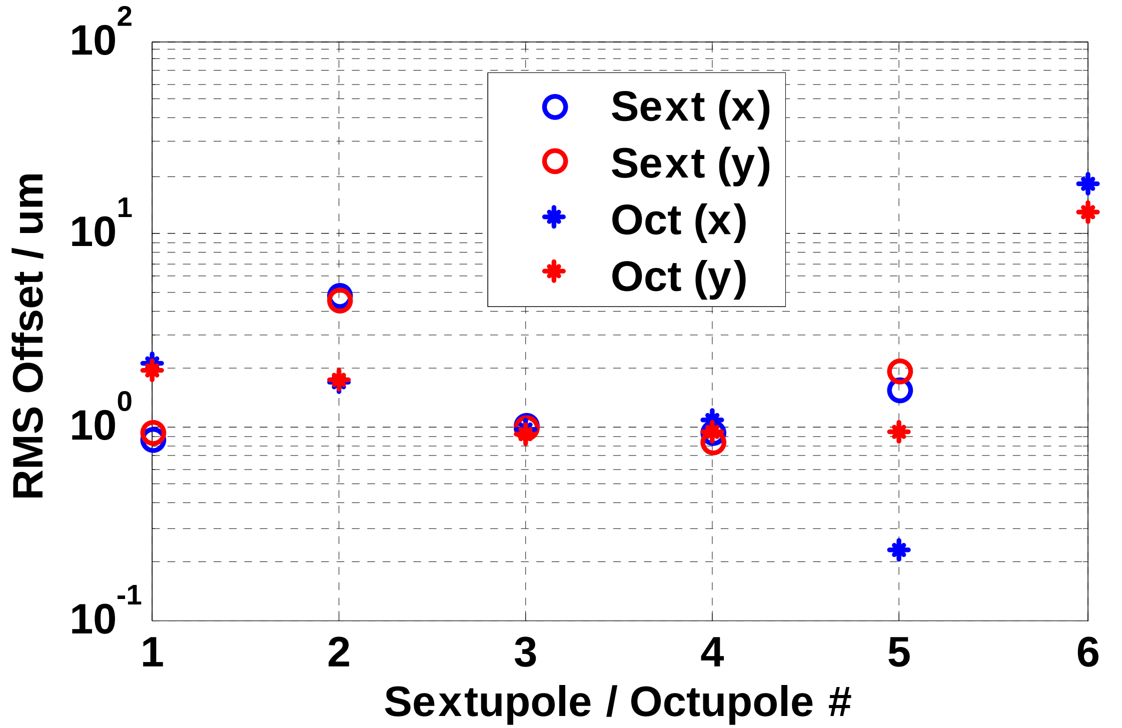
$$x_{Quad} = \Delta x_{BPM} / \left(\Delta R_Q(1,1) * R(1,1) + \Delta R_Q(2,1) * R(1,2) \right)$$

Quad - BPM Alignment Results



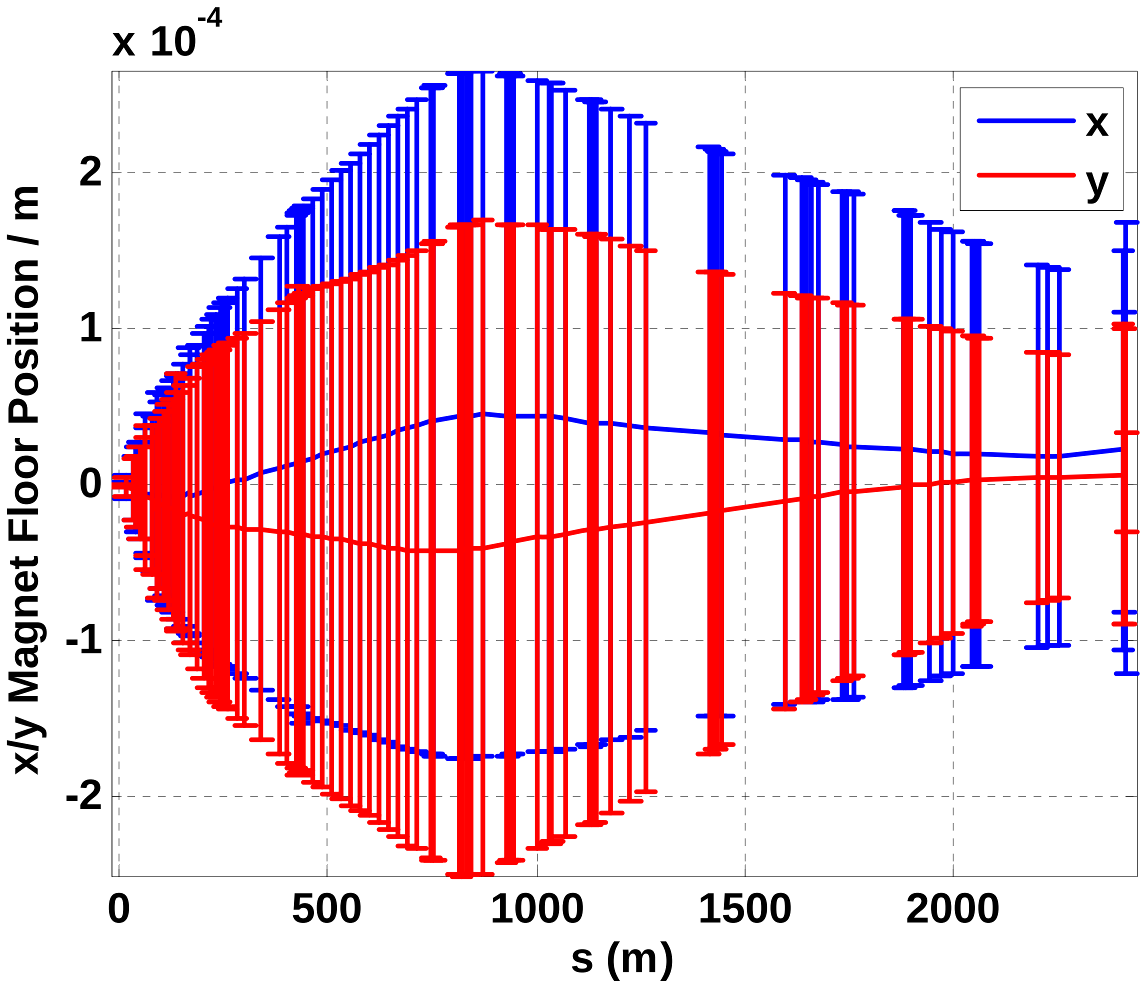
- RMS alignment of BPM readout center – Quad field center for 150 seeds.

Sext/Oct – BPM Alignment



- Use x-, y-movers on higher-order magnets and fit 2nd, 3rd order polynomials to downstream BPM responses (for Sext, Oct respectively).
  - Alignment is where 2nd, 3rd derivative is 0 from fits.
- RMS alignment of BPM readout center – Sext/Oct field center for 150 seeds shown.

Beamline Post-Alignment



- Quad locations after bba (Mean and RMS spread for 100 seeds).

Linear IP Tuning Knobs

- After BBA:
  - x/y IP beam spot sizes many times nominal.
  - Considerable IP Dispersion, waist-shifts and coupling.
- Correct using orthogonolised linear IP tuning knobs.
  - Use x- and y-moves of sextupoles to correct waist and dispersion.
  - Tuning of coupling terms performed by orthogonal strength adjustment of 4 skew quads in BDS coupling correction system plus one in FFS.

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

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

Linear IP Tuning Knobs

- Use orthogonal x-moves of SF6, SF1, SD0 to tune on x/y waist and Dx.
- Use orthogonal vertical moves of SD0 and SD4 and dK for SQ3FF to tune Dy and dominant coupling term (<x'y>).
- Use additional 4 skew quads in BDS coupling section to perform orthogonal tweaks of other coupling terms.
- Waist terms minimised by minimising x- and y- IP beam spot sizes. Other terms 'measured'.

D_y	
SD0	**SD4**
-1	0.938

	SF6	SF1	SD0
Waist (x)	-1	0.154	0.283
Waist (y)	-0.020	0.616	1
D_x	1	0.843	0.016

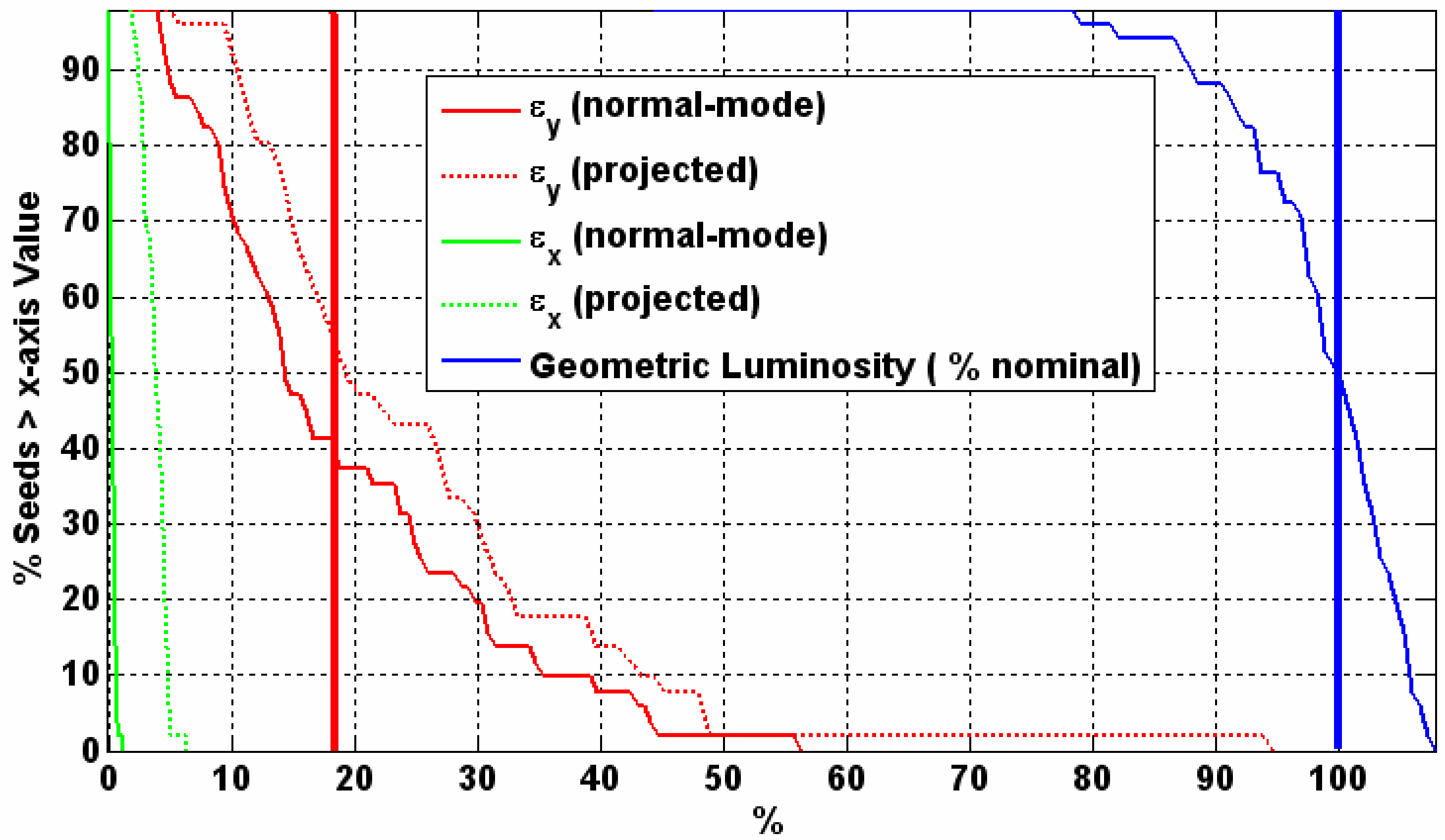
2^{nd} Order Tuning Knobs

- After application of linear knobs, significant emittance growth still exists in many seeds.
- Use dK and tilt of sextupoles to couple to higher-order terms.
- No attempt made to orthogonalise these knobs, from experimentation the following were found to be effective:
  - Tune on σ_x using dK(SF1 + 0.4*SD4)
  - Tune on σ_y using dK and tilt with SD0.
- Through iteration of these knobs and re-application of linear knobs emittance growth criteria are met.

Feedback

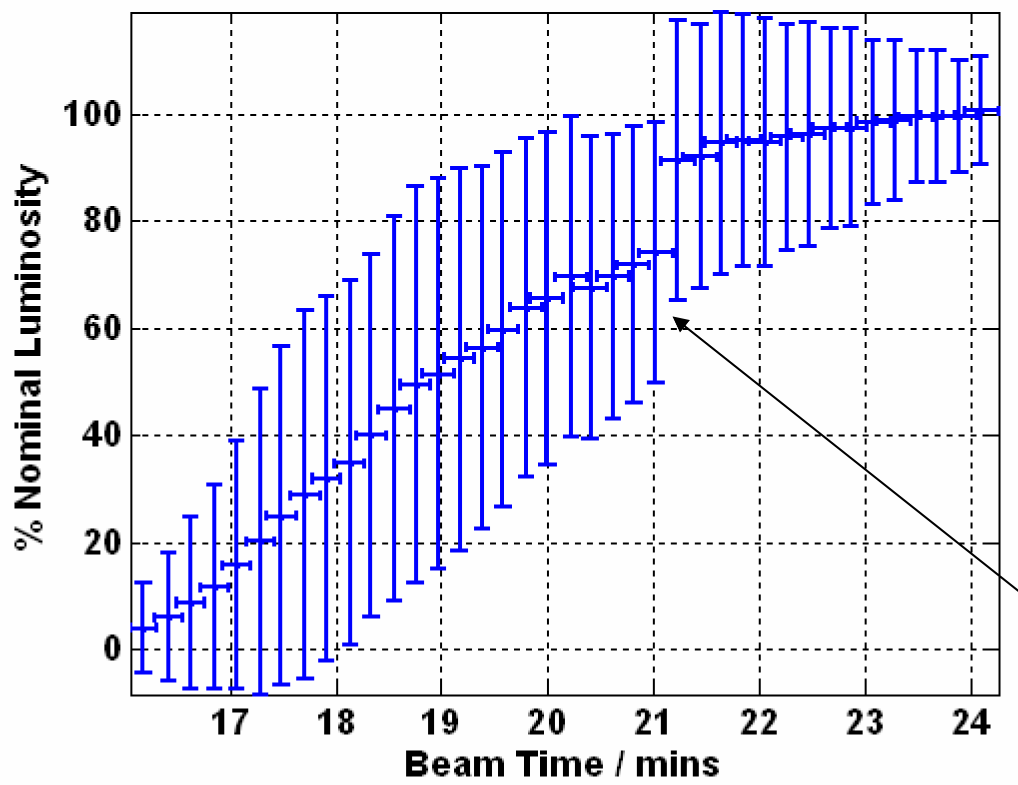
- During application of tuning knobs, beam trajectory is maintained using 5 Hz feedback system.
- This uses the 5 Sextupole BPMs and 6 correction dipoles.
- Works well with absence of GM + other shot-shot noise, need to improve for GM studies.

Post-Tuning Results



- For the 100 seeds modeled, % seeds > than shown emittance growth and % seeds > % nominal geometric luminosity shown.

Luminosity vs. Tuning Time



Second-order tuning knobs applied from here

- Application of multiknobs- mean and RMS beam time vs. geometric luminosity.

Future Refinements

- Things I'm cheating at currently:
  - 'Measuring' IP coupling terms.
  - Using perfect measurement of x- and y- IP spot sizes for waist and 2nd order knob minimisation routines.
  - No apertures respected.
  - No treatment of energy errors.
  - No GM or incoming orbit error.
- Future plans:
  - Improve 2nd-order knobs, reduce ε_y in more seeds.
  - Fix above cheats.
  - Model both beams, use real lumi (GP) calculations.
  - Incorporate in integrated simulation (time evolved with GM + component jitter).
  - Can place design tolerances on magnet specs etc…