Studies for Tuning of the ILC BDS and the ATF2 FF line

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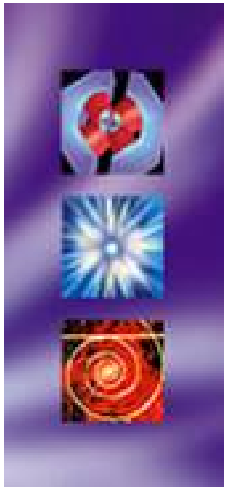


Transport Line Tuning

- For the purposes of this talk I am declaring Tuning simulations to be the correction of errors, random and systematic, that occur on timescales very much longer than any fast correction system will correct, and that produce aberrations as seen at the IP.
- Tuning can correct higher order aberrations using dipole, (skew) quadrupoles, sextupoles, octupoles and higher…

- Initial studies born out of the ATF2 design proposal.
- Mostly interested in the kinds of tolerances one could get away with using full final focus line tuning.
- Work is based on previous studies done for the NLC by Yuri Nosochkov at SLAC.

Transport Line Tuning

- Basic method for creating tuning knobs:
  - Calculate effective change in desired aberration (preferably a measurable one…) per change of variable
    - Variables usually sextupole transverse position, roll angle etc
  - Using 2 or more magnets, create an orthogonal knob to vary aberration independently
    - Minimise the ratio of the major term to the next-major term

- Using a larger number of terms allows a greater degree of orthogonality for a wider selection of variables.

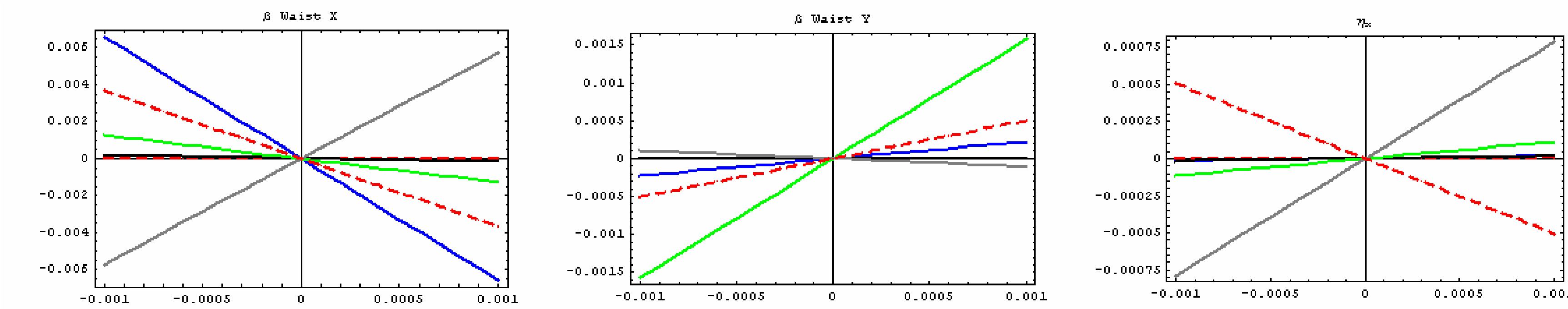
My Solution to this problem

- Do
  - Vary Horizontal Position of Sextupole_i
  - Use MAD to calculate the $\Delta\beta_{x,y}$ shift and the $\Delta\eta_x$
    - Use MAD 'match' to vary drift length so $\alpha=0$ @ IP
    - For $\Delta x \rightarrow \{-0.15,-0.05,0.05,0.15\}$
- For all sextupoles
- Fit parameters using linear regression
- Assume linear superposition applies (!)
  - Invert the generated response matrix using Singular Value Decomposition and generate a set of sextupole movements that produce an ~orthogonal solution

Problems

- Major problem is Linear Superposition does not fully apply!
- Solution given from optimisation is ~ correct
  - Use a secondary optimisation routine to find the optimal solution
- Choose a basic Simplex routine
  - We know we are near to the right solution $\rightarrow$ don’t need to search for the global optima
- Optimise the merit function to maintain linearity of tuning knob and optimise the primary/secondary terms ratio
- Remember: this is a multivariate problem several constraints.

Results from MAD – and initial optimisation (ATF2)



The 6 different sextupoles have widely different gradients for the 3 aberrations

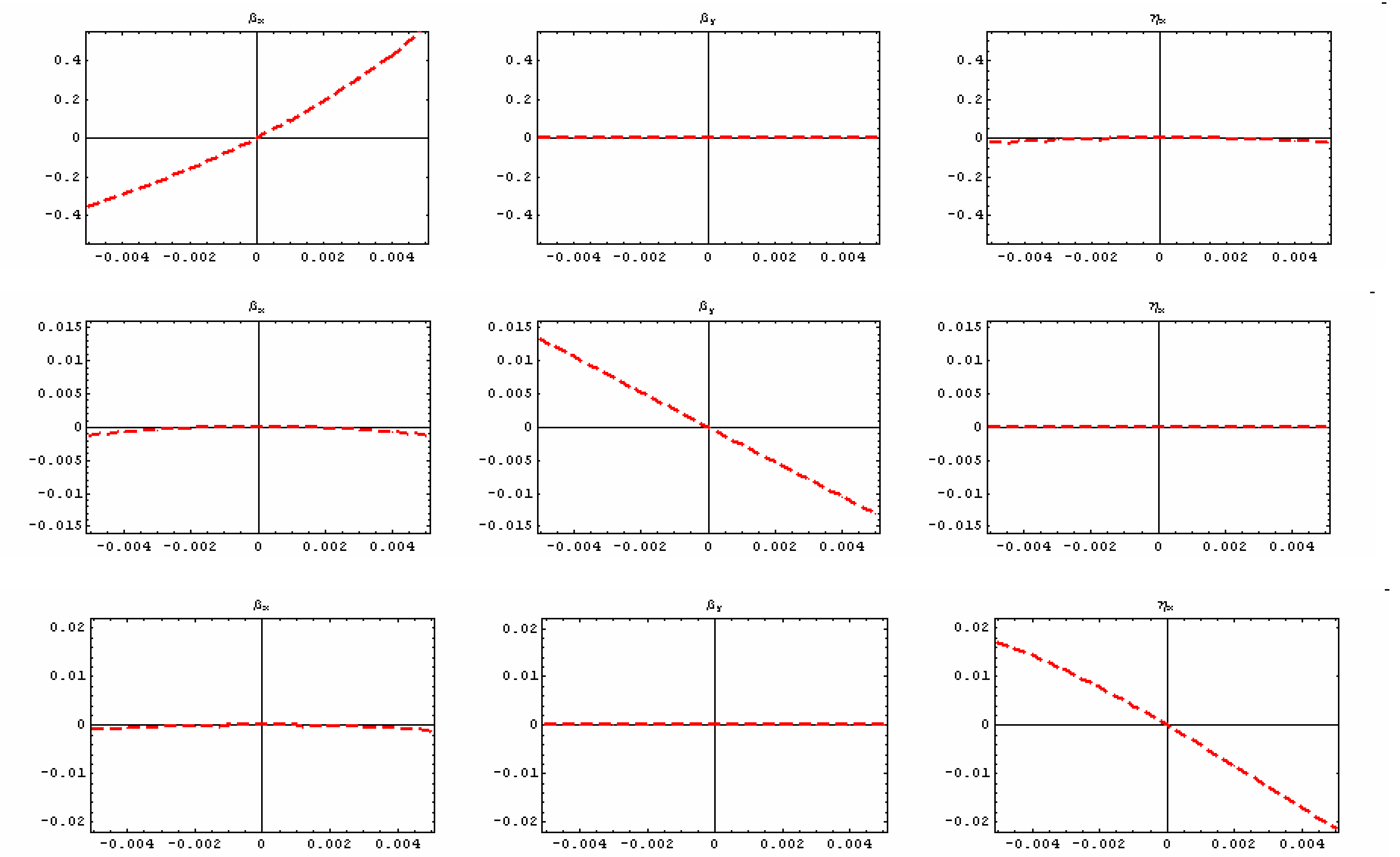
Sexts.	Parameter	Coefficient	Ratio
SF5 SD4	1	-7.22	4633.6
SF6 SD4	2	-7.01	4965.51

With 2-magnets cannot achieve reasonable solution for all three parameters.

Sexts.	Parameter	Coefficient 1	Coefficient 2	Primary Gradient	Ratio
SLQ9 SD0 SF1	1	-6.7	-4.3	2.90658	733.15
SF5 SD4 SF6	2	1.4	-9.9	63.2749	39528.2
SD0 SF6 SF1	3	-4.3	-4.3	3.96256	129.982

But 3-magnets does provide a solution

Secondary optimisation - results



Second Order Knobs

- Exactly the same problem with second order knobs – except there are a lot more of them.
  - It is therefore very important to understand which knobs are relevant to the design in hand!
- How do you do this?
  - Good method is to analyse the dominant higher order components of the beam at the IP using, say, Lie algebra analysis – as was done for the SLC.
  - Record the higher order terms as seen at the IP for various error conditions and weight on the beam size, this should give the dominant error terms given a large number of seeds.
- NB: Its not necessarily important that you create a tuning knob for every dominant term, but that any knobs created are orthogonal to these terms.

Second Order Knobs

- Analysis shows that the dominant knobs are:
  - T112 (K2)
  - T114 (Roll)
  - T122 (K2)
  - T124 (Roll)
  - T126 (K2)
  - T144 (K2)
  - T312 (Roll)
  - T322 (Roll)
  - T324 (K2)
  - T334 (Roll)
  - T344 (Roll)
  - T346 (K2)
  - T422 (K2)
- Where red indicates that a tuning knob could not be created that was sufficiently orthogonal.
- The sextupole motion that gives a handle on a particlular knob is also given in brackets.
- Currently a simplex algorithm has not been applied to these second order knobs, and it is expected that more tuning knobs can be created when this is performed.

Trajectory Correction

- A major part of the tuning process is maintaining the correct trajectory through the magnets.
- This is especially important for the sextupoles which perform the tuning.
- In these simulations the BPM moves with the magnet when an error is applied and with the quadrupoles, but not when an offset is desired for tuning!
- Orbit correction is one of the major limiting factors in the efficiency of the tuning algorithm
  - There still remains the question between using dipolar correctors and quadrupoles on movers…

Application of tuning knobs

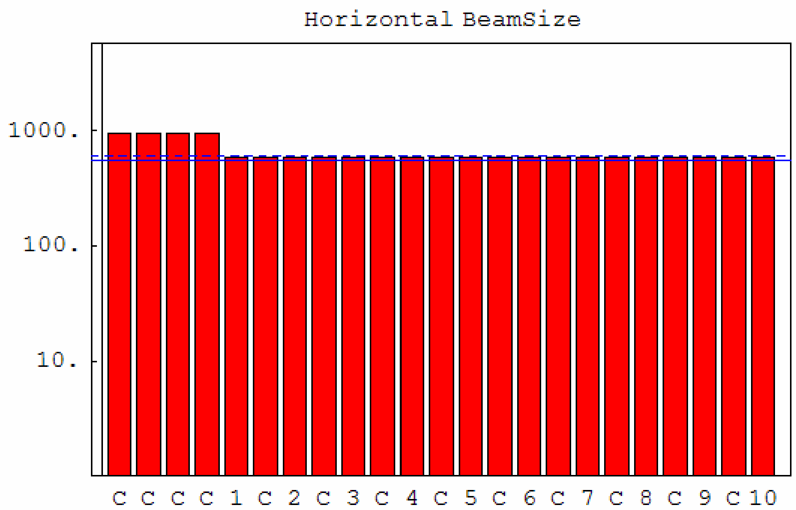
- There are two methods of simulating tuning knobs that I use:
  - Direct measurement of the residual errors using MAD. This works up to second order, and has the advantage that the knob variables are known at all points.
  - A Brent's method implementation where each knob is applied and is fed back on using the IP beam size. This is performed using the tracking code TRACY-II, but this does not allow evaluation of all of the 1st order knobs, and none of the second order knobs.
- I would suggest that the second method is more realistic than the first as it doesn’t not require knowledge of many of the beam parameters.
- It may be possible to measure all of the required 2nd order variables in the real machine, but it is not clear how noisy the data will be, and whether in fact it is desirable to correct specific terms as opposed to the beam size.

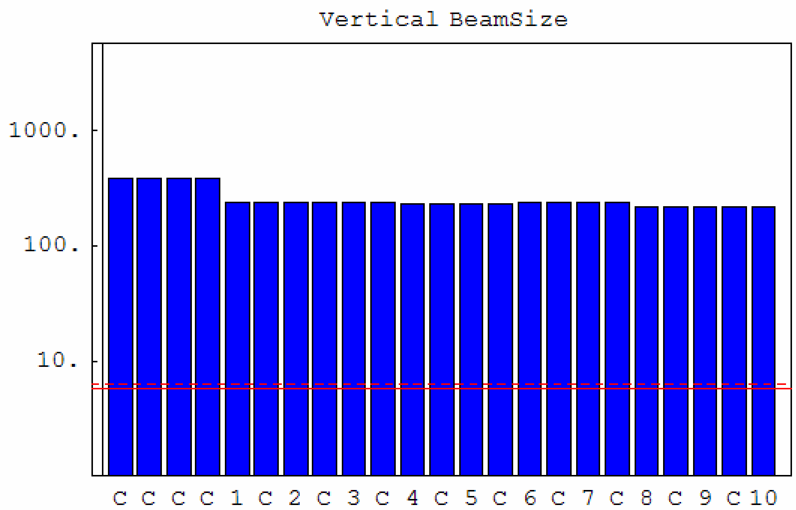
Results (so far)

- Analysis shows that for the ILC all of the tuning knobs created seem to work well.
- Orthogonality is good in most cases.
- Biggest problem so far is trying to minimise the (seemingly) dominant T422 term.
- Linear tuning knobs give very good results
  - Both beta function are minimised (to the extent that alpha=0).
  - Both dispersion parameters are minimised to the 10^{-7} level.
- Alas, have yet to create a viable coupling knob. The effects of coupling on the line are unclear.

Results – an example!

- The result below is representative:
  - Errors applied to quadrupoles and sextupoles in the line.
  - Horizontally: 9µm, vertically: 3µm
  - Orbit correction has little effect (that is apparent)
- Nowhere near the tolerance limit of 2%...





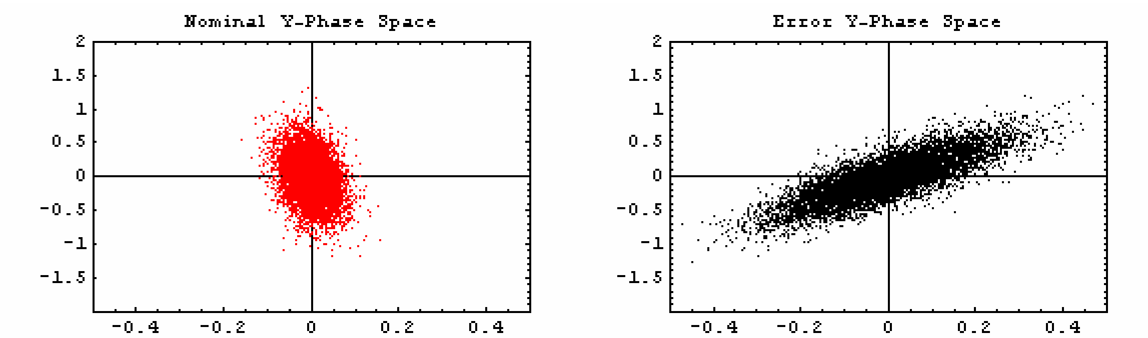
R-Matrix Tuning

- Based on an idea of A. Seryi –
  - Create tuning knobs based on R-matrix of:

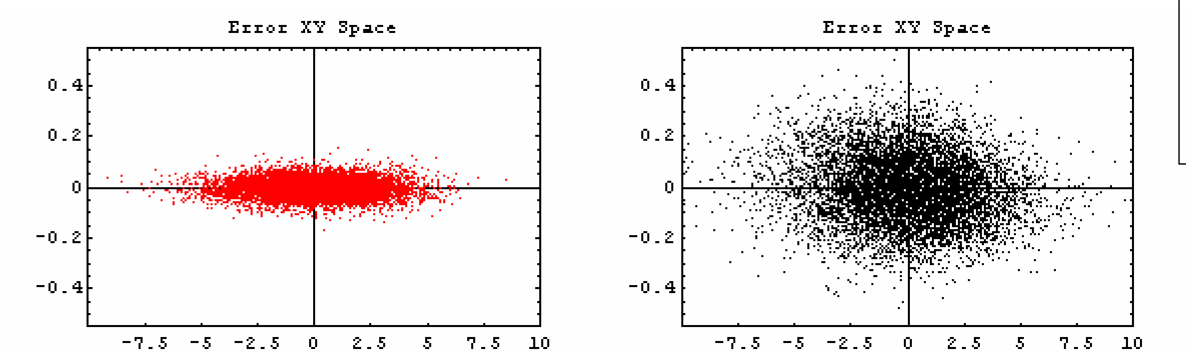
$$\mathrm{beam}_{\mathrm{error}} \rightarrow \mathrm{beam}_{\mathrm{nominal}}$$

- We can use all available handles:
  - Quadrupole rotations, position
  - Sextupole rotations, positions etc
- Create response matrix of beam R-matrix
- Invert using SVD (taking care over number of singular values to retain)
  - Normalise each handle matrix to maximum singular value per handle
- Can also be used to generate 36 orthogonal tuning knobs

Applying the Errors



Y-Phase Space



XY Space

Errors

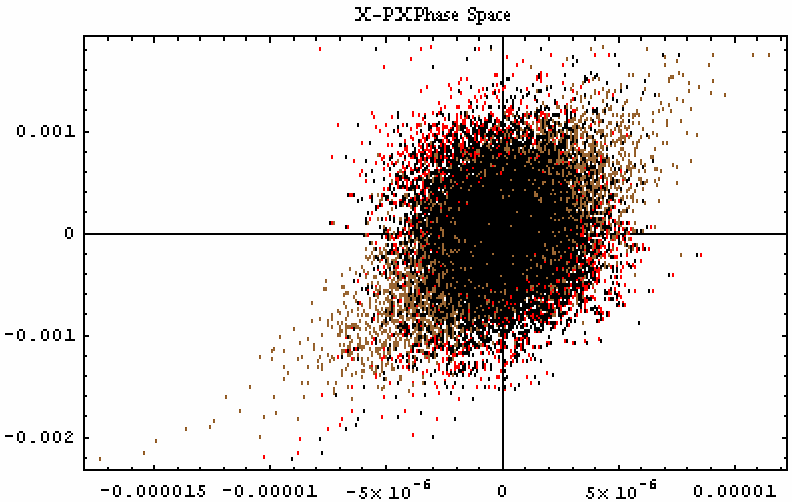
10µm Transverse Position
0.1mrad Roll DPSI
0.01% Quadrupole Field Error
0.1% Sextupole Field Error

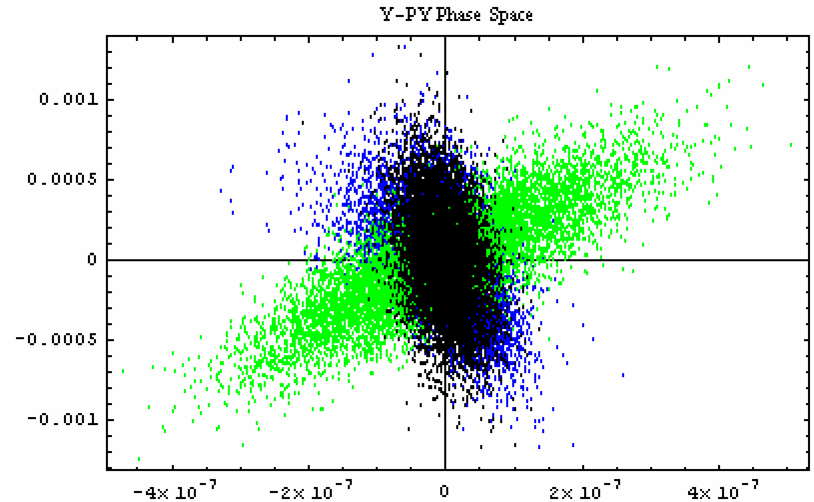
Errors on entire extraction + FF line, correction only in FF!

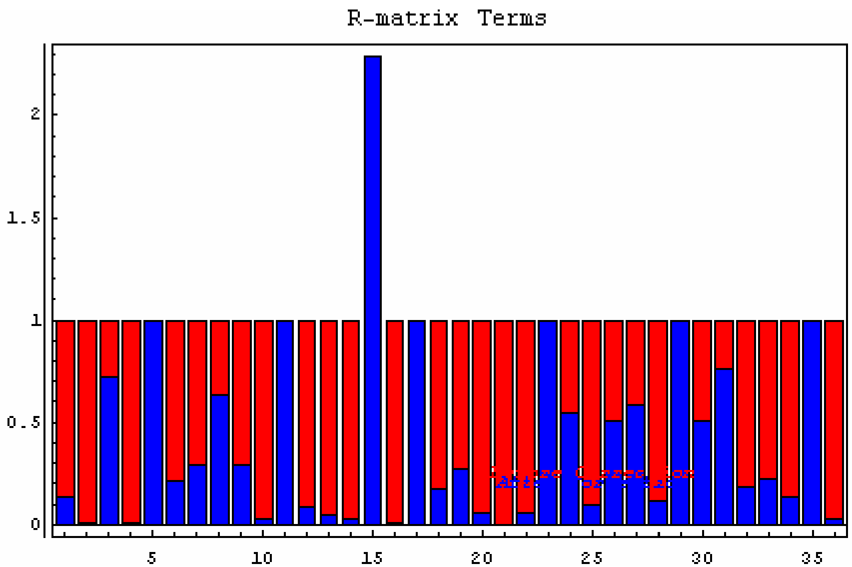
Clearly the Error beam is radically different from the desired nominal beam under error conditions. The R-matrix tuning attempts to restore the nominal beam

After Correction

Black = Nominal; Brown/Green = No Correction; Red/Blue = After 2 iterations







Using the inverted response matrix we can recover close to the nominal beam.

If we look at the ratio of R-matrix terms (from nominal) we see an average reduction of ~2.

(There is no change in 'ct' as this was not included in the tracking)

Conclusions

- A systematic approach to the production and application of tuning knobs for the ILC has been created.
- Although problems currently exist the application of some time and some effort should solve these problems.
- An alternative approach that does not involve the use of matrix observables has also been generated.
  - This presents a more generalised approach and may have uses in some scenarios.
  - I believe it at least could benefit some from more analysis.

- The long term plans are:
  - Getting the tuning knobs to work on all dominant errors!
  - The production of a tolerance specifications for different types of magnet errors and
  - To provide a comprehensive simulation to analyse the expected luminosity with these tuning algorithms in operation.
  - Integration with other integrated simulations to provide a better final number for the ILC luminosity (just like everyone else…).