Simulations of orbit and dispersion correction in the ILC Technical Design Phase baseline lattice

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Outline

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Simulation Objectives

- The specified vertical emittance for the ILC DR is 2 pm
- That is very challenging goal considering it is significantly lower than the lowest vertical emittance ever achieved in any storage ring (3.2 pm at the SLS)
- The dominant sources of vertical emittance are the vertical dispersion and betatron coupling
- In order to achieve such low emittances an effective diagnostics and correction system will be needed

However:

- BPMs add impedance to the ring
- Diagnostics and correctors add complexity and cost

Simulation Objectives

It is therefore necessary to:

- Design and specify a correction system that will correct the vertical dispersion and the coupling at the necessary level, using as few components as possible
- Understand the issues and optimize the design

As a first step, it is possible to:

- Look at the sensitivity of the vertical emittance to vertical alignment errors on the quadrupoles and sextupoles (errors that are expected to be a major contributor in vertical emittance growth)
- Investigate the effectiveness of a simple combined correction of the orbit and the dispersion in minimizing the vertical emittance

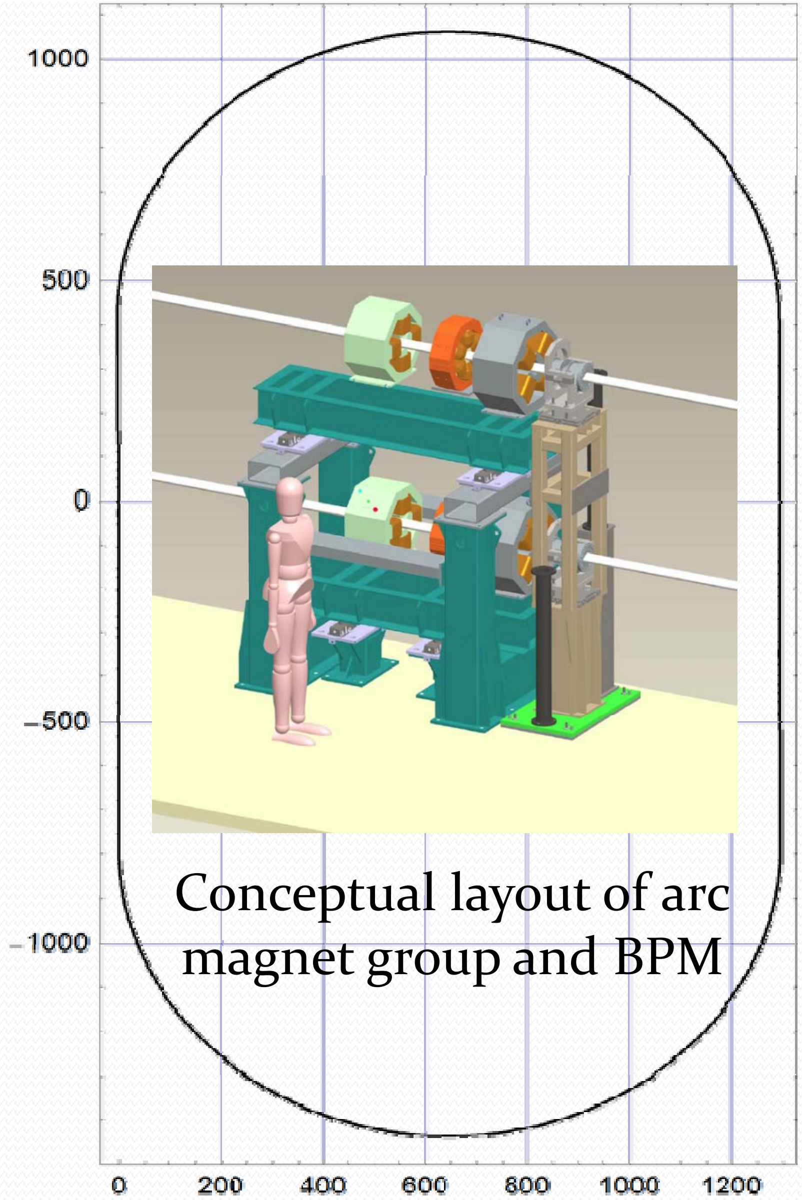
Simulation Objectives

- This approach will provide the foundation for a more complete studies , using a more realistic model where other types of errors are introduced, such as BPM noise and rotation

Lattice Configuration Scenarios

- The present baseline lattice for the ILC damping rings has a circumference of 6476m and a racetrack layout

- Two arcs, each consisting of 96 FODO cells are connected by 2 long straights containing the damping wiggler, RF cavities and injection/extraction systems



Conceptual layout of arc magnet group and BPM

Lattice Configuration Scenarios

- To provide operational flexibility, the momentum compaction factor is tunable between 1.3 x 10^{-4} and 2.8 x 10^{-4}
- Adjustment of the compaction factor is achieved by changing the phase advance in the arc cells
- Under ideal conditions the equilibrium emittance is dominated by the lattice functions in the wiggler
- However, orbit distortion and dispersion in the arcs can make a significant contribution to the vertical emittance if not corrected carefully
- Therefore our simulations need to look at a number of different working points, covering the operational tuning range of the lattice

Lattice Configuration Scenarios

The performed simulations involved the following scenarios:

Scenario	Arc Phase Advance	Arc BPM Locations
I	72^o	every quad
II	90^o	every quad
III	72^o	every D-quad
IV	90^o	every D-quad
V	72^o	2/3 D-quads
VI	90^o	2/3 D-quads

Orbit and dispersion correction

- The beam position is measure with a set of *N* BPMs which are distributed over the ring depending on the scenario
- The beam is steered using a set of *M* correctors.
- The BPM readings are represented by a vector u, the corrector kicks by a vector θ and measured dispersion at the BPMs is represented by a vector D
- The orbit response matrix (ORM) A describes the change in beam position at each BPM resulting from a change in strength of each corrector
- Similarly, the dispersion response matrix (DRM) B describes the change in dispersion at each BPM resulting from a change in strength of each corrector

Orbit and dispersion correction

- For both orbit and dispersion to be corrected simultaneously, a set of corrector kicks θ must be found that solves the following system of linear equations:

$$\begin{pmatrix} (1-\alpha)\vec{u} \\ \alpha\vec{D}_u \end{pmatrix} + \begin{pmatrix} (1-\alpha)A \\ \alpha B \end{pmatrix}\vec{\theta} = 0 \qquad (1)$$

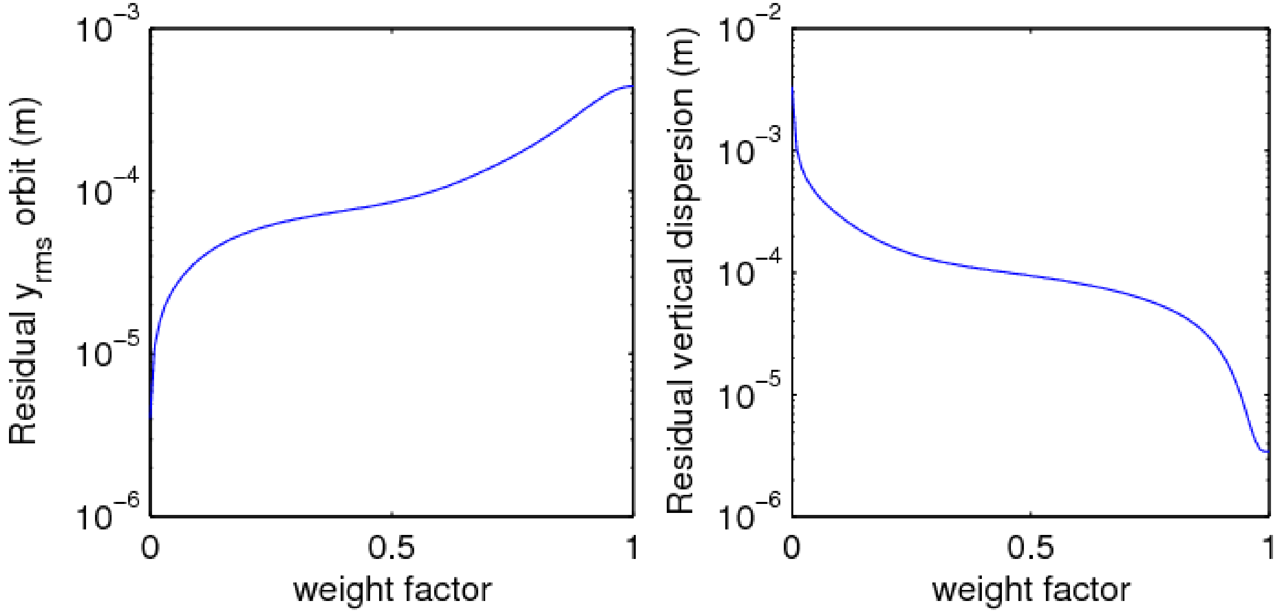
- In general, there are 2N equations in M unknowns. If, as is the case here, 2N > M then it is not possible, in general to find exact solutions for the kicks θ
- However, using singular value decomposition (SVD), we can find a solution that minimizes the residual orbit and distortion

Orbit and dispersion correction

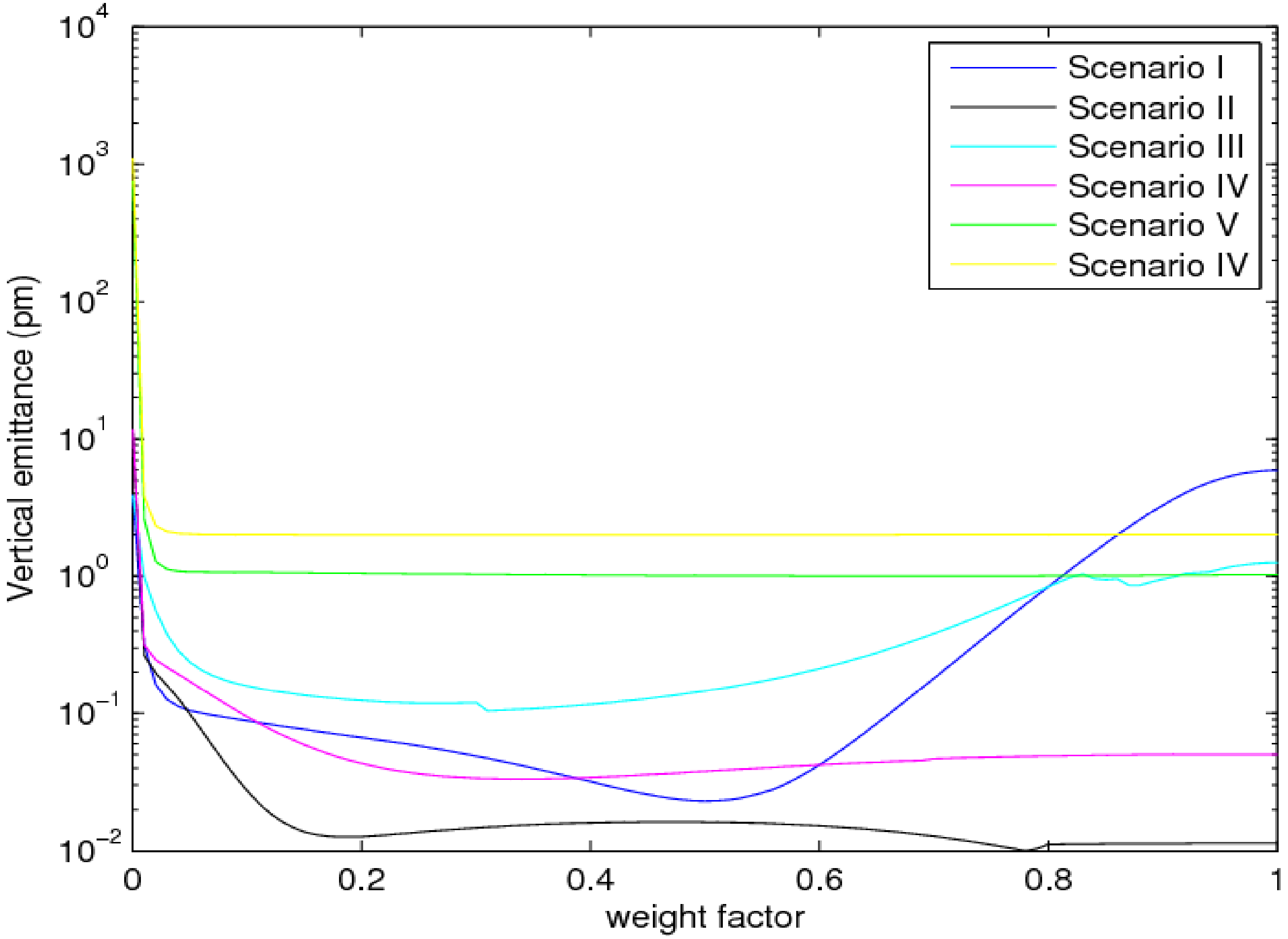
- The factor α appearing in equation (1) determines whether more weight is given to correcting the orbit (α=0) or to correcting the dispersion (α=1) in finding the solution
- The optimum value of α (weight factor) for minimizing the vertical emittance depends on the lattice and the arrangement of BPM and correctors
- One of the goals in this task is to investigate this dependence
- For each scenario in our simulations, we first obtain the ORM and DRM. For a given set of random misalignments, we then find the closed orbit and dispersion at each BPM. The solution for the corrector strengths (eq. 1) can be obtained (for a given weight factor) by SVD

Simulation results

- The simulations were performed with Merlin using the lattice definition (DCO) from MAD
- For each scenario, we apply random vertical misalignments to all quadrupoles (50 μm rms) and to all sextupoles (100 μm rms)
- First we look at how the orbit and the dispersion behave as we apply the correction:



Simulation results



Comparison of the final vertical emittance as a function of the weight factor for scenarios I to VI

Simulation results

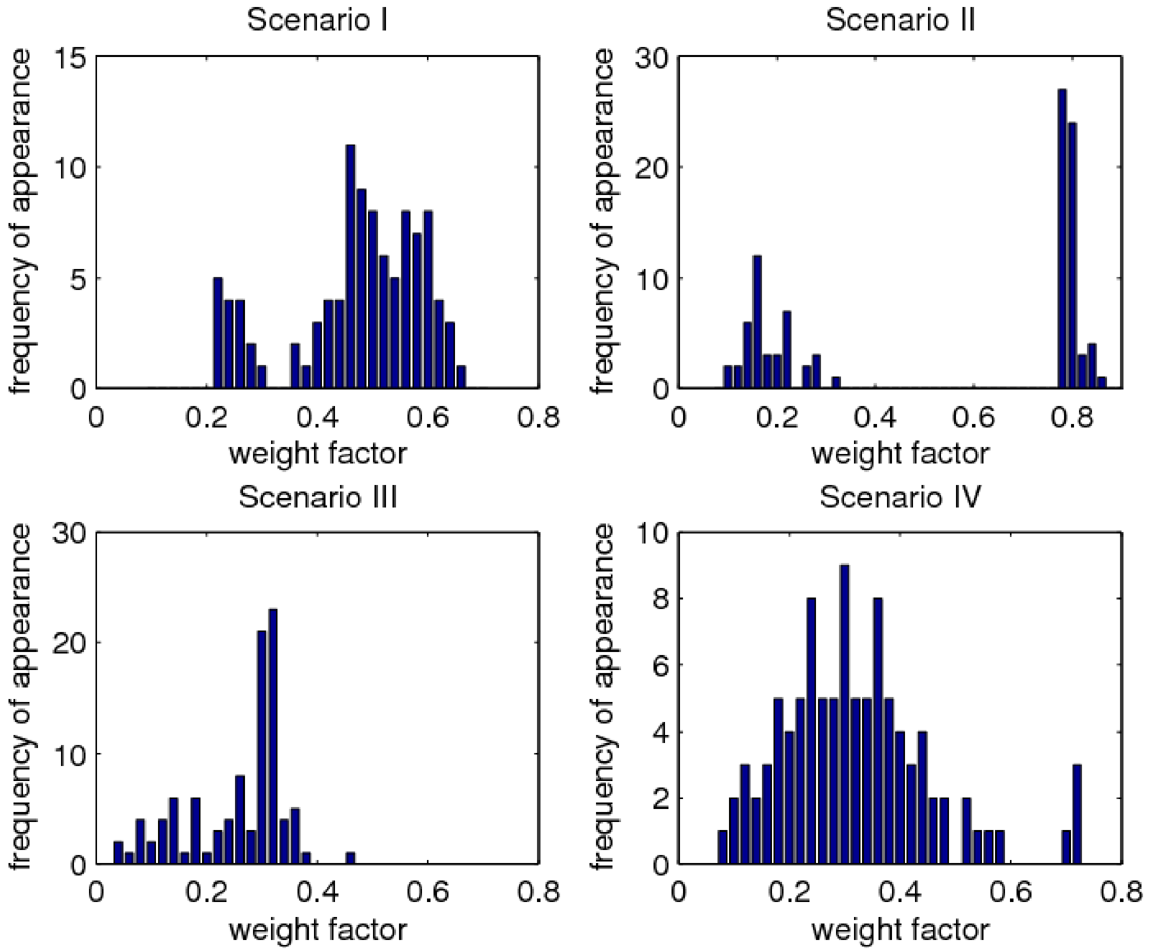
- In several scenarios, the final vertical emittance is lower than 1 pm. This is not realistic and is due to the limited types of errors applied in the model
- On the other hand, in scenarios V and VI the vertical emittance does not come below 10 pm , so we focus our attention to scenarios I to IV
- As well as a distribution in the final emittance, there is a distribution in the weight factor that gives the minimum vertical emittance
- This weight factor distribution is particularly important for tuning the machine in practice; i.e. without explicit knowledge of the magnet misalignments it is convenient to know the weight factor that is most likely (in a statistical sense) to lead to a minimized emittance

Simulation results

The optimum weight factors can be defined as follows:

- For a given scenario and set of random errors we can determine the weight factor that leads to the minimum emittance
- We can repeat for a number of sets of random errors, recording the best weight factor for each set
- Thus the weight factor recorded have some distribution and the optimum weight factor can be selected as the point at which the distribution peaks

Simulation results



Distribution of weight factors leading to the lowest emittance for each of 100 seeds of random errors

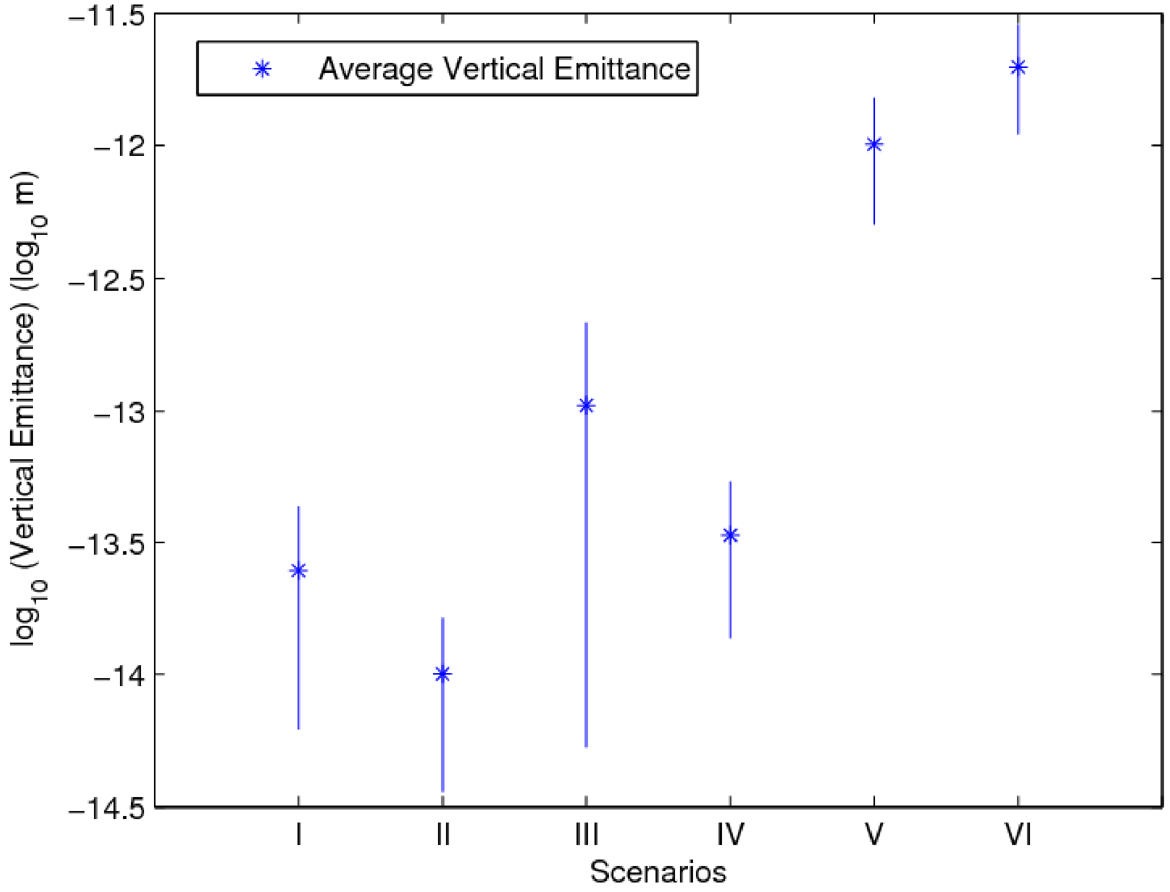
Simulation results

The width of the distribution is also important:

- A lattice that has a very wide distribution for the optimum weight factor may be harder to tune than a lattice with a very narrow distribution, since the statistical optimum weight factor is less likely to be close to the "best" weight factor in any given case
- On the other hand, if the final vertical emittance has a very broad minimum, then the correction may not be very sensitive to the weight factor

Simulation results

- We can apply the correction to each of a number of sets of random errors, using a single optimized weight factor for each scenario



Simulation results

Note that:

- The absolute values obtained are not realistic , because of the idealized nature of the simulations
- The relative value obtained (and the spread in each case) gives some indication of how the different scenarios behave in comparison to each other

Conclusions

- A combined correction is most effective when a BPM is located at every quadrupole (scenarios I and II)
- However, the correction is almost as effective if, in the arc cells, the number of BPMs is reduced by half (scenarios III and IV)
- Further reduction of the BPM number, by omitting BPMs in one out of every 3 arc cells, leads to a degradation in the performance of the correction algorithm
- There is some indication that a lower final vertical emittance is achieved in the lattices with phase advance of 90^{o} per arc cell, though the differences to the lattices with phase advance 72^{o} is not large

Conclusions

- Focusing on scenarios I to IV, we observed some variation in the optimum weight factor to use in each case
- Even when the distribution of weight factors had a relatively large width, it was possible to obtain an effective correction using a single optimized weight factor for a given scenario

The next steps in these simulations will be to include other types of errors , like BPM tilts and noise, so that the current model becomes more realistic.

Ultimately, having understood the issues that affect the emittance in the damping rings, the goal will be to suggest a coupling correction system and procedure that will enable reliable operation of the damping rings with vertical emittance < 2 pm.

Thank you for your attention!