ILC Spin Rotator

Super B Workshop III

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Based on NLC Spin Rotator by Paul Emma, SLAC

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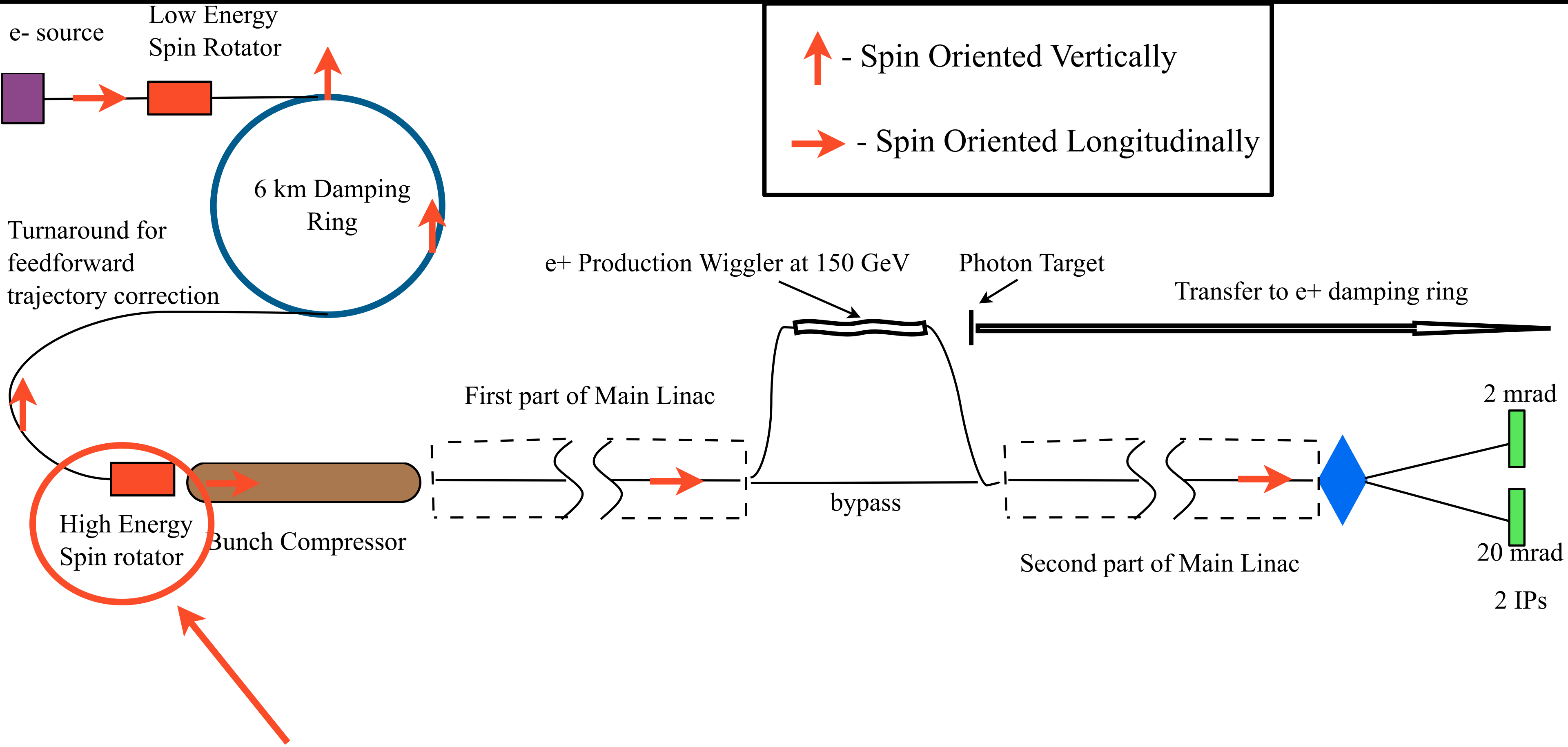
ILC Layout with Spin Rotators



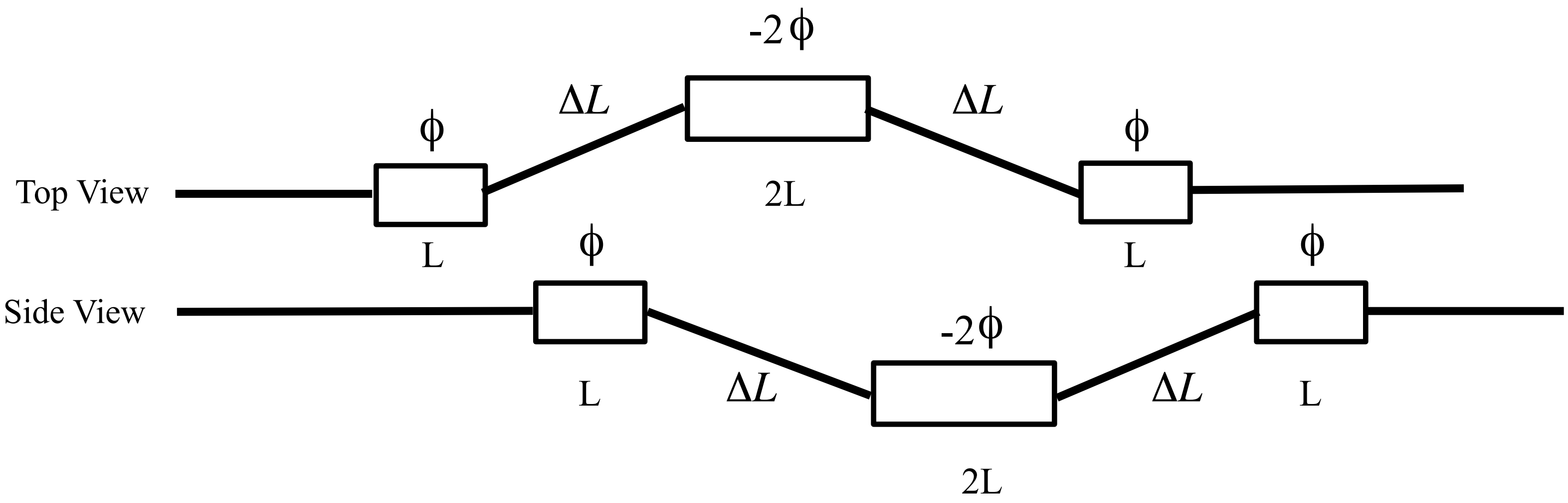
- The High Energy Spin Rotator after Damping Ring (at 5 Gev) will be discussed here.

Spin Rotator Requirements

- Particle spins must be oriented vertically in order to pass undisturbed through the damping rings
- Full flexibility in IP Spin orientation
- Post-Damping Ring Spin Rotator must fulfill the following criteria:
  - Full flexibility in outgoing spin orientation
  - Preserve transverse emittances
  - Net momentum compaction must be small to preserve longitudinal position
  - placed where energy spread is small for energy band pass issues => before BC
  - System should be robust over entire range of operation

Use a Half Serpent?

- Could use nested horizontal and vertical chicanes to manipulate spin
  - Simple design
  - But must be careful about synchrotron radiation emittance growth and R_56 term...



Half Serpent Emittance Growth

- Emittance dilution due to synchrotron radiation for vertical chicane:

$$\Delta\gamma\varepsilon_y = 8x10^{-8} \cdot E^6 \frac{\theta^5}{L^2}\left[\Delta L + L + \frac{\hat{\beta}+\breve{\beta}}{3}\right]$$

using some reasonable parameters:

$$\Delta L = 2L, \quad \phi_{spin} = \frac{\pi}{2} = a\gamma\theta, \quad \breve{\beta} = 2\hat{\beta} = L_{tot} = 8L$$

Requiring the ILC normalized vertical emittance of 20 nm not to grow more than 2% results in the scaling between bend length and beam energy:

$$L[m] > 190 \cdot E[GeV] \Rightarrow 190 \cdot [5GeV] > 950\,\text{meters}$$

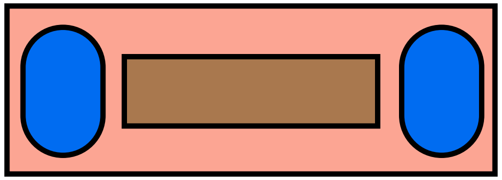
Likewise,

$$R_{56} = 2\theta^2\left(\Delta L + \frac{2}{3}L\right) \Rightarrow R_{56}[M] > \frac{480}{E[\text{GeV}]}$$

The Solenoid Solution

- A Solenoid can be used instead to perform the spin manipulation
  - However, solenoids also roll the beam introducing x-y coupling
  - The key is rotating the spin and decoupling the beam.
    - This can be done by spitting the solenoid in half and introducing a canceling symmetry between the two halves.

Emma Rotator



- First solenoid rotates spin by half the desired total
- Then a transfer line which is +1 in x and -1 in y will reflect the beam about the y-axis
- Finally, the second solenoid (of equal strength) rotates the spin the rest of the way as it rotates the beam back to a flat state.

– Changing the spin rotation angle is simply done by changing the strength of the two solenoids.

Fully Flexible System

- By placing a horizontal bend section between the split solenoid sections as described above then a fully flexible spin rotator can be created where any arbitrary outgoing spin orientation can be achieved assuming the incoming orientation is vertical.
- Let each solenoid rotate the spin up to 45 degrees about the longitudinal axis and the arc a fixed amount of 90 degrees about the vertical then the net spin rotation through the system

$$\Omega_{tot} = \Omega_{sol34} \cdot \Omega_{bend} \cdot \Omega_{sol12} = \begin{pmatrix} \cos\phi_{sol34} & -\sin\phi_{sol34} & 0 \\ \sin\phi_{sol34} & \cos\phi_{sol34} & 0 \\ 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} \cos\frac{\pi}{2} & 0 & \sin\frac{\pi}{2} \\ 0 & 1 & 0 \\ -\sin\frac{\pi}{2} & 0 & \cos\frac{\pi}{2} \end{pmatrix} \cdot \begin{pmatrix} \cos\phi_{sol12} & -\sin\phi_{sol12} & 0 \\ \sin\phi_{sol12} & \cos\phi_{sol12} & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

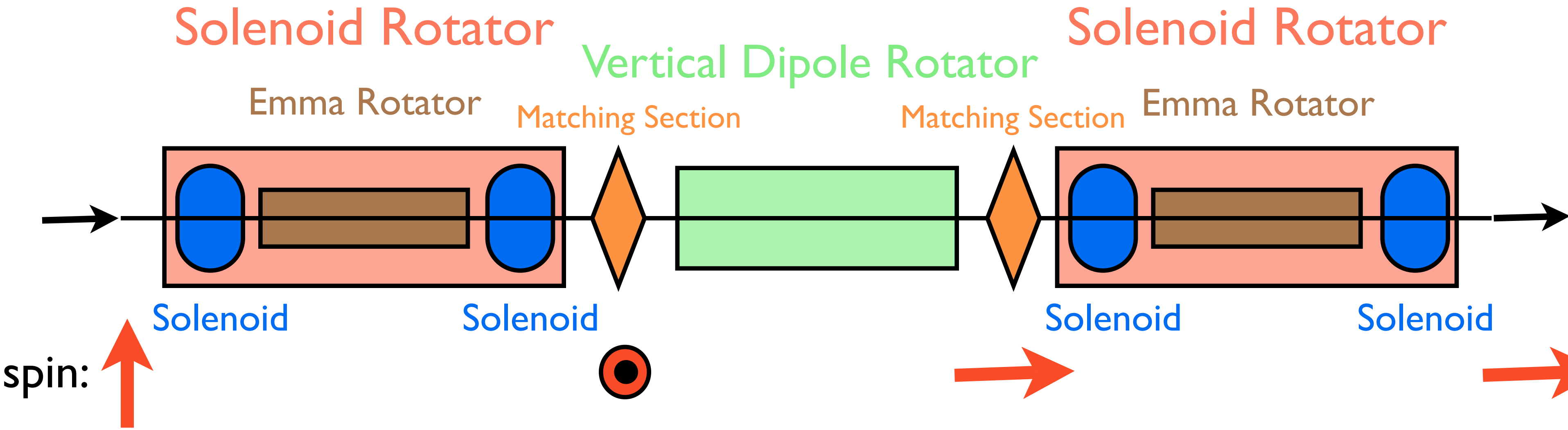
$$= \begin{pmatrix} -\sin\phi_{sol34}\sin\phi_{sol12} & -\sin\phi_{34}\cos\phi_{12} & \cos\phi_{sol34} \\ \cos\phi_{sol34}\sin\phi_{sol12} & -\cos\phi_{34}\cos\phi_{12} & \cos\phi_{sol34} \\ -\sin\phi_{sol12} & \sin\phi_{sol12} & 0 \end{pmatrix}$$

- The incoming orientation is vertical, so

$$\bar{S} = \Omega_{tot} \cdot \begin{pmatrix} 0 \\ \pm 1 \\ 0 \end{pmatrix} = \begin{pmatrix} \mp\sin\phi_{sol34}\cos\phi_{sol12} \\ \pm\cos\phi_{sol34}\cos\phi_{sol12} \\ \pm\sin\phi_{sol12} \end{pmatrix}$$

- If the solenoidal fields are reversible then any arbitrary spin orientation can be achieved.

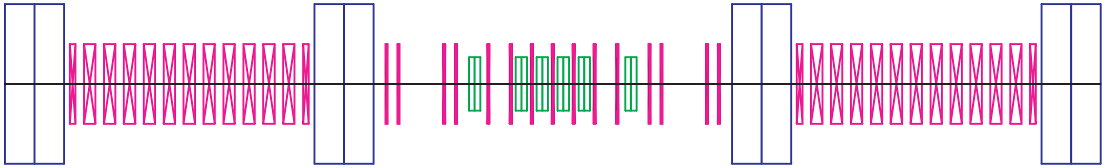
ILC Spin Rotator

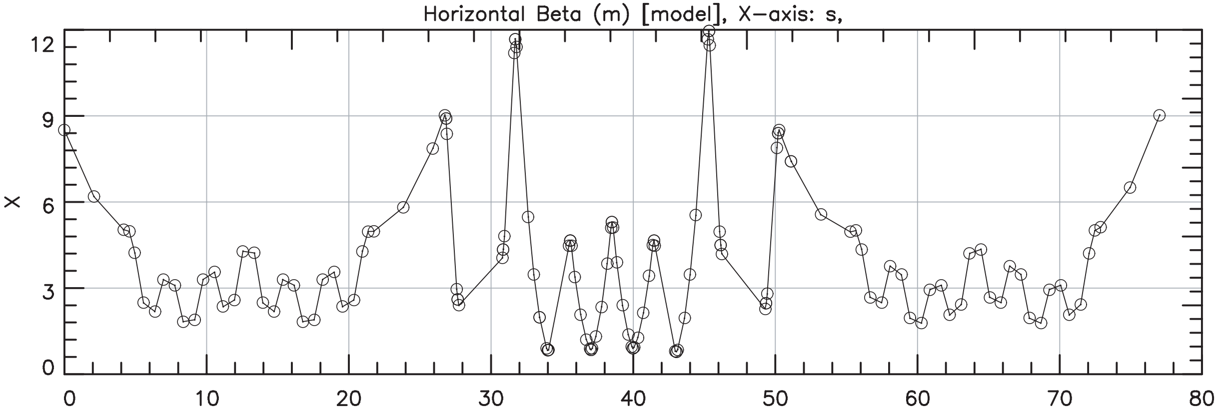


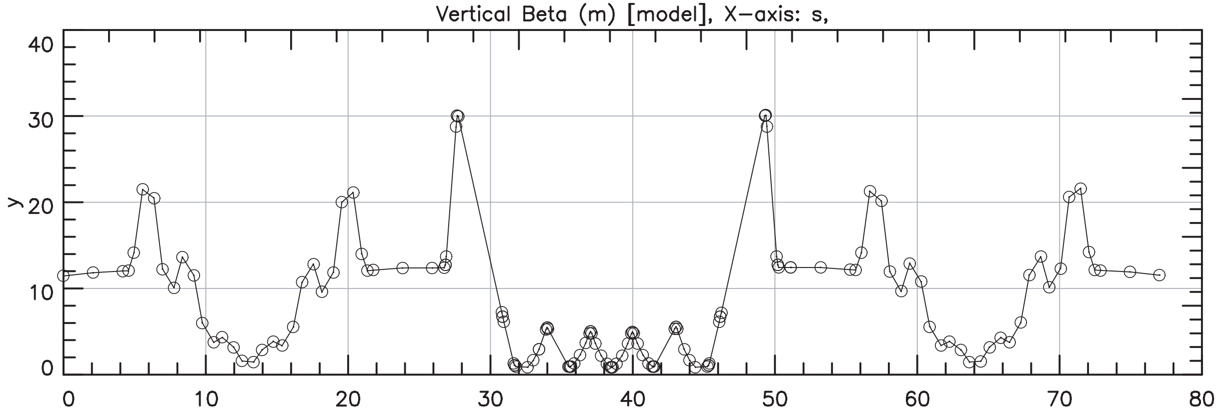
- Solenoids will rotate the spin about the longitudinal axis, however, they also introduce transverse coupling.
  - An Emma Rotator performs a +I rotation in x and -I in y.
  - Two solenoids separated by an Emma Rotator will rotate the spin and remove the transverse coupling.
- The combination of two Solenoid Rotators and a Vertical Dipole Rotator (horizontal bend) will allow for arbitrary final spin orientation and result in no transverse coupling.

Current Design

- System works over entire range of exit polarization
  - However, matching regions must be tuned as the solenoid focusing strengths slightly change.




Horizontal Beta (m) [model], X−axis: s,


Vertical Beta (m) [model], X−axis: s,

Current Design Characteristics

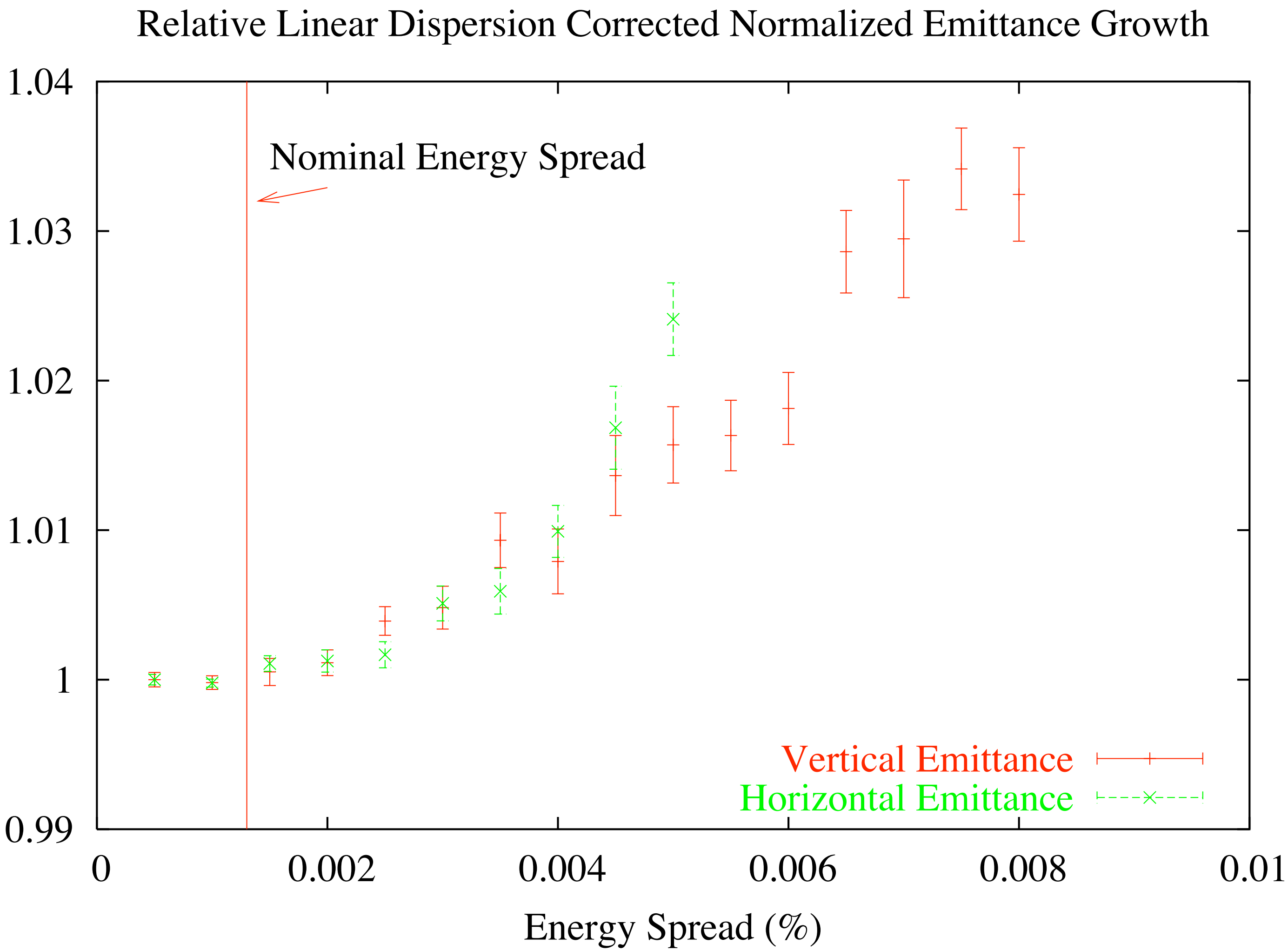
- Full flexibility on outgoing spin by manipulating solenoid strengths.
- Emittance tends to blow up in Emma Rotators due to chromaticity
  - decreasing phase advance per Emma FODO cell and lengthening the quads lowers emittance growth
  - Spin Rotator must be before bunch compressor or large energy spread will blow up emittance
  - current design limits the growth to 0.01 nm in ideal case (no misalignments)
- R_56 = -6 mm which is miniscule compared to the -800 mm in bunch compressor
- Changing solenoid strengths changes solenoid focusing so matching sections do need to be tweaked to maintain beta functions. Optimizing the matching sections also improves emittance dilution.

Alignment studies

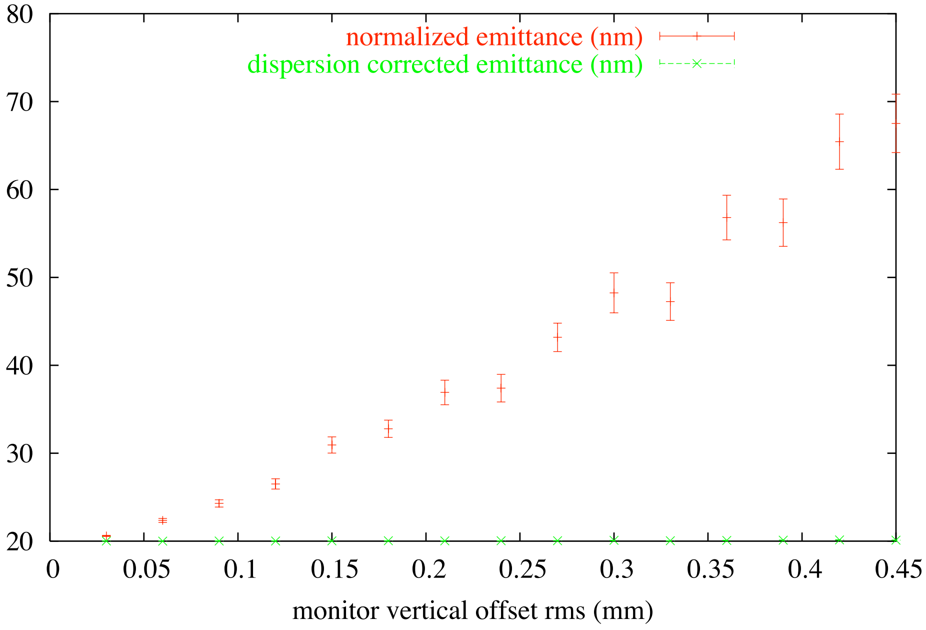
- Emittance dilution, spin vector error and spin polarization studies have been performed for a nominal beam extracted from damping ring.
- Simulations performed in ILCv
  - based on the BMAD beam dynamics library developed at Cornell
  - tracks phase space and spin vectors of particle beams
- Beam-Based Alignment studies are ongoing and in their infancy
- In the following studies the plotted misalignment was applied then the beam was re-steered to zero the BPMs. Then averaged over 100 seeds.

Energy Band-Pass

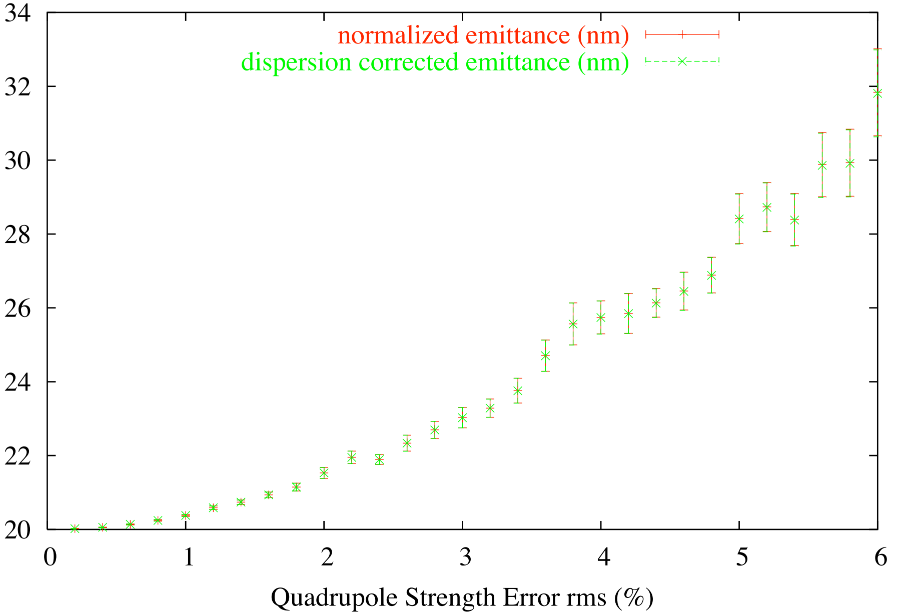
- Energy band-pass good enough for ILC -- but only upstream of bunch compressor where energy spread is 0.13% (versus 3% energy spread downstream of bunch compressor).
- Key to energy band-pass is limiting chromaticity in Emma rotators



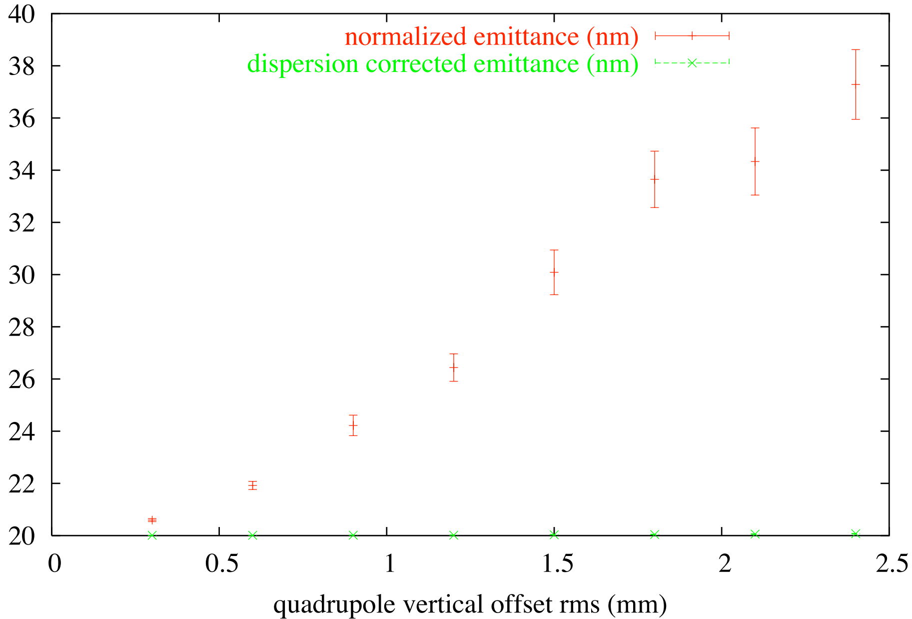
Emittance Sensitivity to Monitor Offset



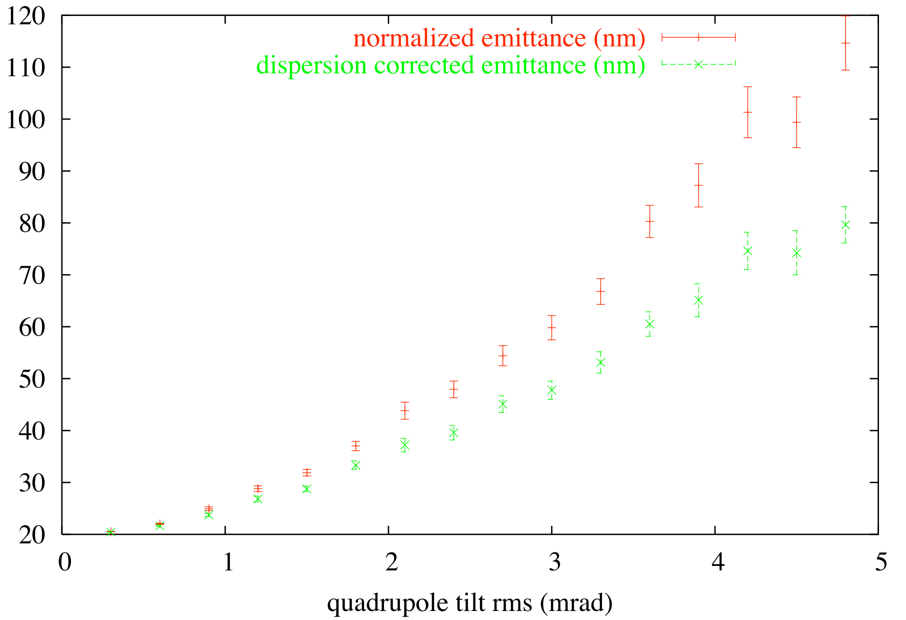
Emittance Sensitivity to Quadrupole Strength Error

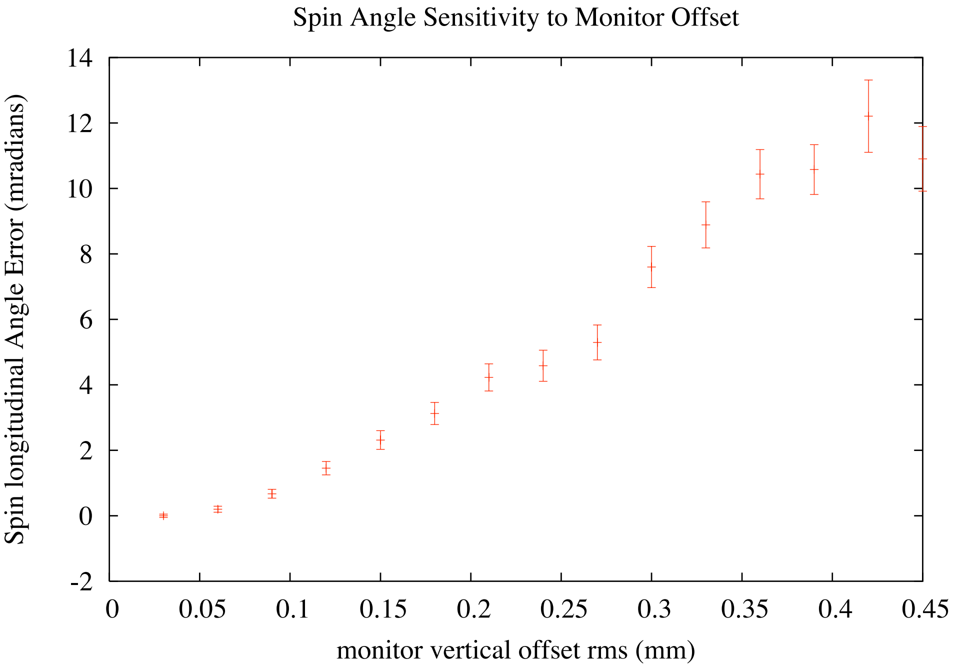


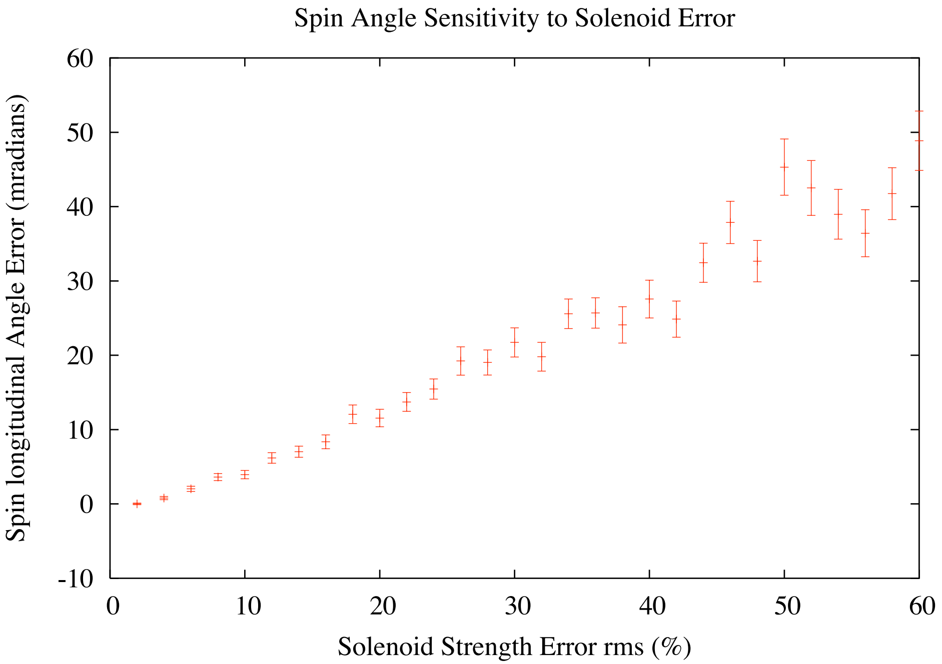
Emittance Sensitivity to Quadrupole Alignment



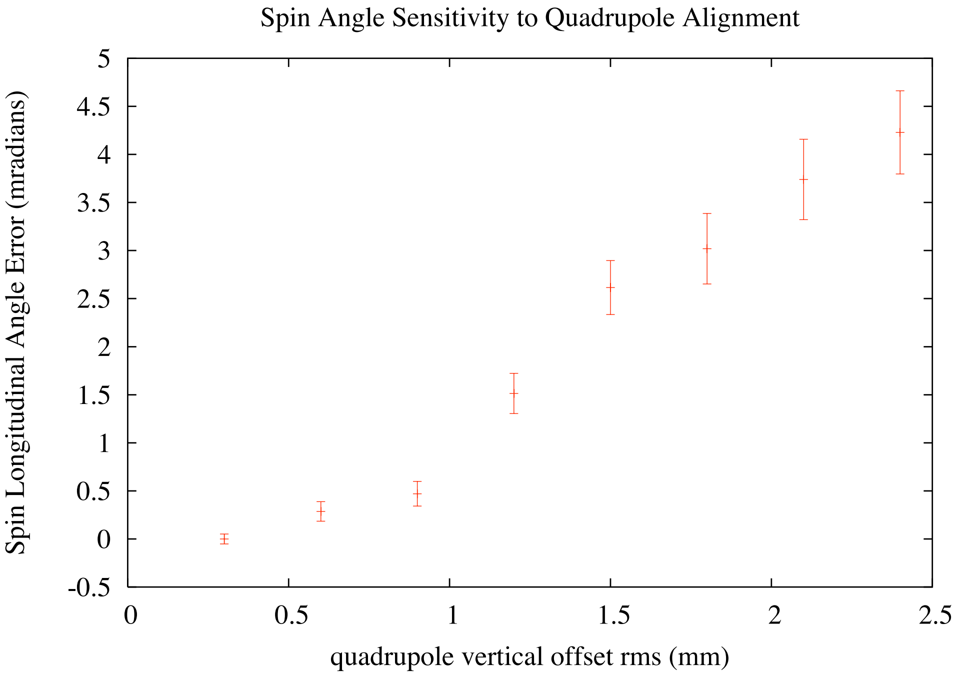
Emittance Sensitivity to Quadrupole Tilt







In general, emittance dilution due to component misalignments is much more of a serious problem than is spin orientation errors.



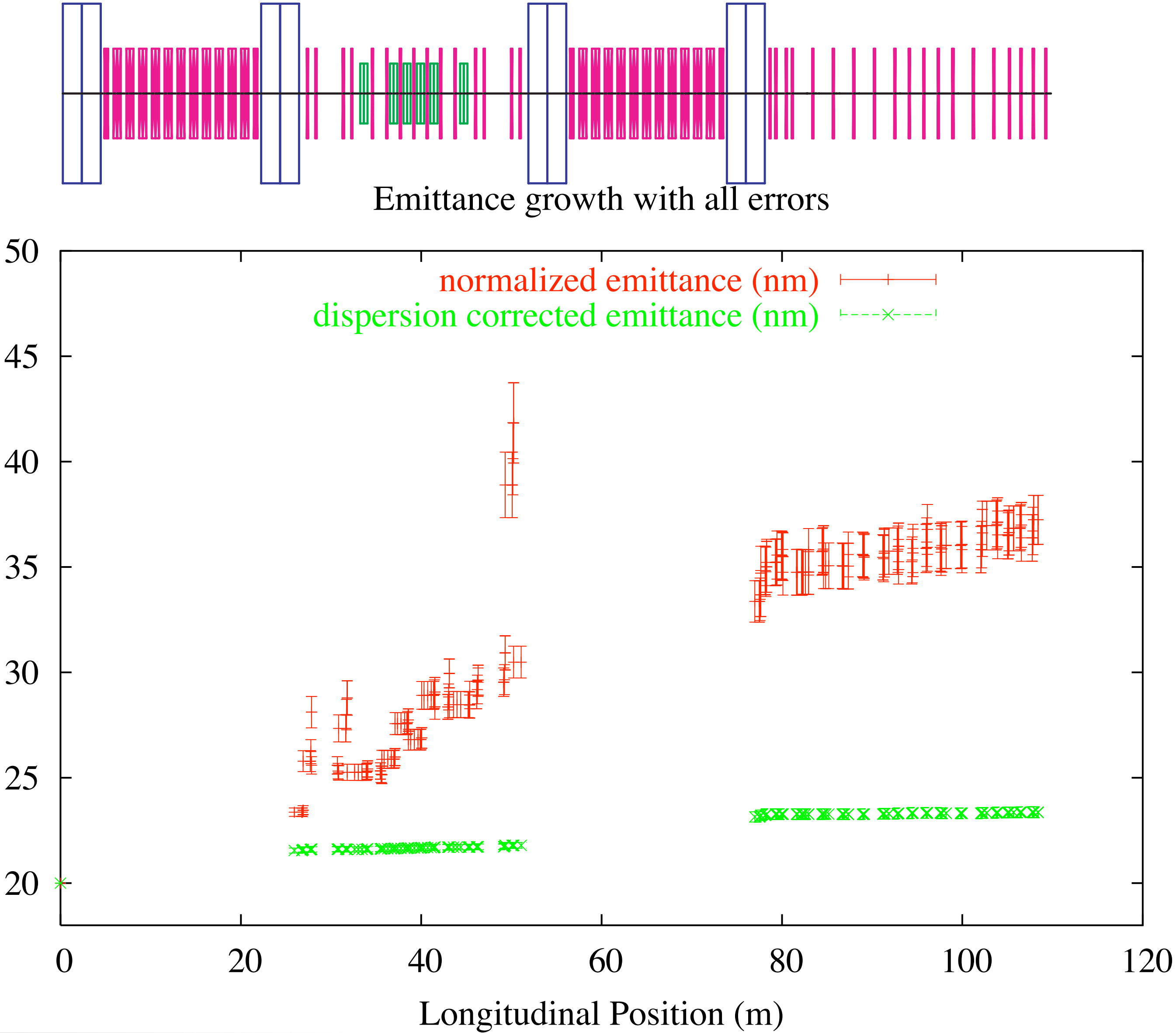
Design Misalignments

- A more telling analysis is with including all misalignments at their nominal values.

Error	Tolerance	With Respect To…
Quad Offset	150 μm	Cryostat
Quad Tilt	300 μrad	Cryostat
BPM Offset	70 μm	Quadrupole
BPM Resolution	1 μm	True Orbit
Quad Strength Error	0.25%	Design k1
Bend Strength Error	1.0%	Design angle
Solenoid Strength Error	1.0%	Design ks

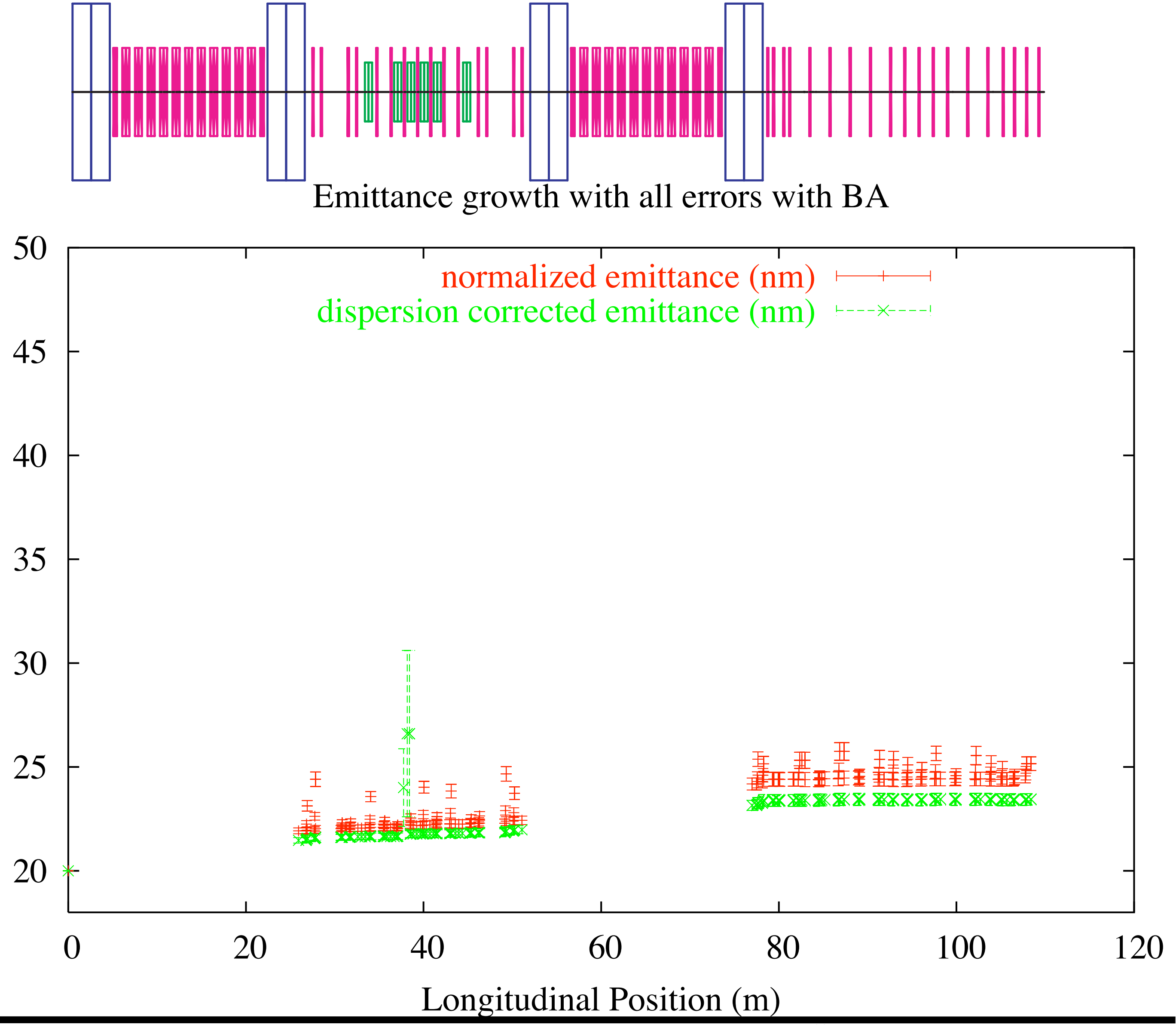
1-to-1 steering

- Simply Zeroing the BPMs results in large residual projected emittance growth,
- However, almost completely linear dispersive.



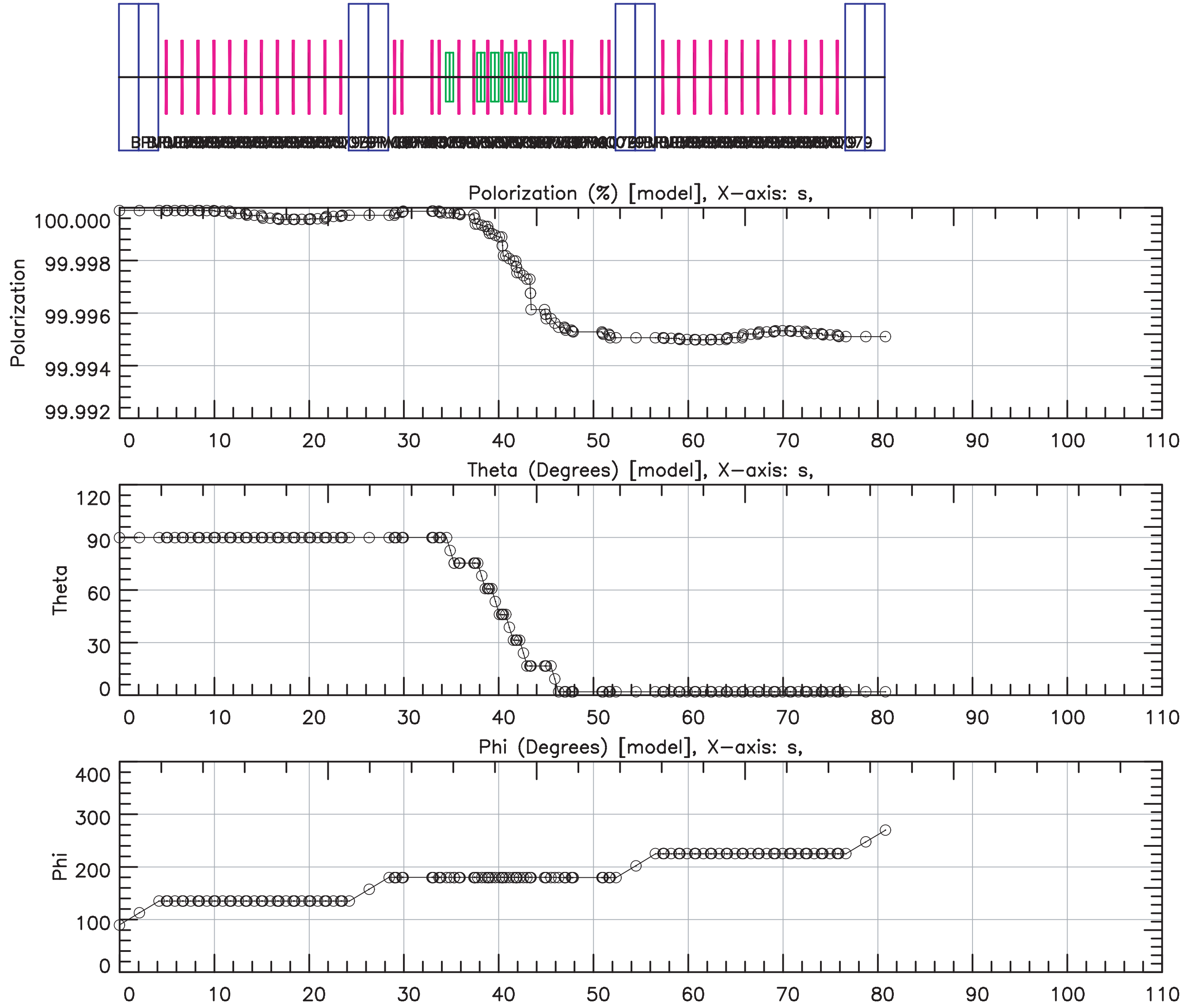
Ballistic Alignment

- Ballistic Alignment almost completely removes the linear dispersive emittance growth.
- But still some dispersion corrected growth. Virtually all of which is due to x-y coupling.
- Skew corrections should be able to elliminate most of the resultant growth



Spin Dynamics

- In nominal condition rotates polarization from vertical to longitudinal
- depolorazation should not be a problem in spin rotator even with large misalignments
- However, placing this in a ring may be a completely different story... 0.004% depolarization every turn for 25,000 turns completely depolarized the beam.



Can it be used in Super B?

- Perhaps
  - If spin rotator is located in storage ring then there are all kinds of problems not experienced in a linac:
    - Would probably have to get the small depolarization under control -- probably by lengthening bends a bit (or decreasing energy spread).
    - As it stands, it’s 80 meters long. Would take up a lot of space in a ring. Long length mainly to reduce emittance growth.
    - Spin-orbit coupling? Spin depolarizing resonances? Don’t know much about these but would have to be seriously investigated.
    - Depolarization due to collision? Again, never studied this. HeLiCal collaboration is looking into this for ILC.
    - In any event, not a simple matter and there would have to be a serious endeavor to investigate the feasibility.
  - If beam only goes through spin rotator a couple of times (even a couple hundred) then probably no problems.