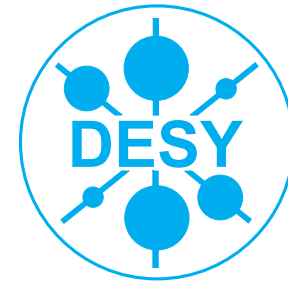


A Spin rotator for the ILC



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FLC

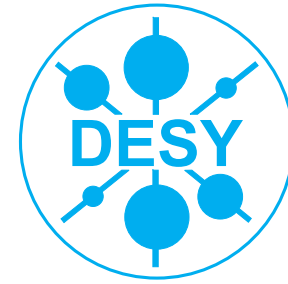
- ❑ Spin transport at the linear collider
- ❑ Spin rotator design requirements
- ❑ Outline of the system
- ❑ Solenoid settings required
- ❑ Results of stability studies
- ❑ Analysis for a Linac following the curvature of the earth
- ❑ Analysis for non-zero crossing angles

Introduction



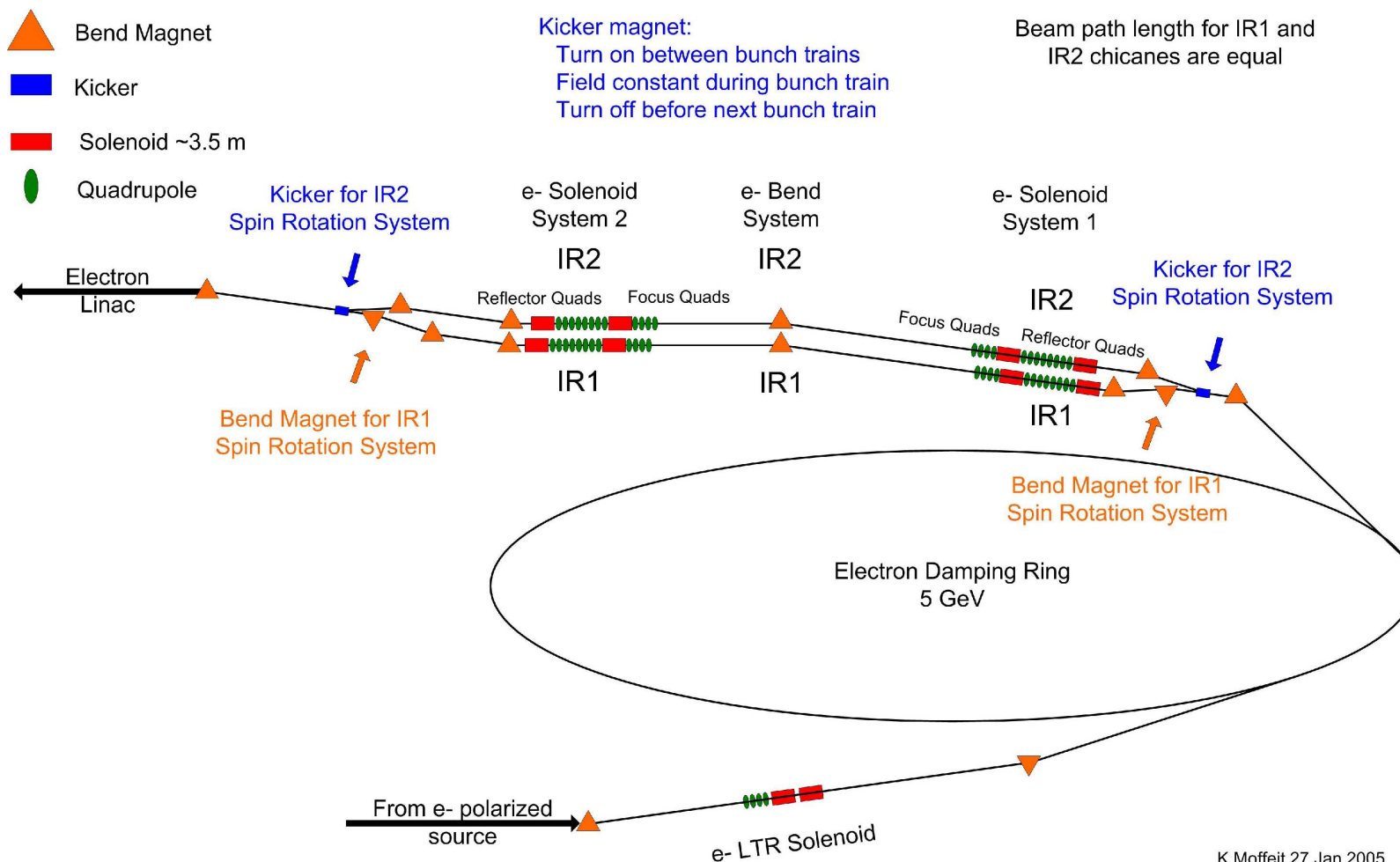
- ❑ Polarized electrons are a requirement for the ILC; polarized positrons are very desirable.
→ cross-sections increase
- ❑ Currently there are two interaction regions (IR).
- ❑ Running the two IRs (almost) concurrently is a plus, e.g. by alternating each train.
- ❑ The beams at the IRs are not parallel, the crossing angles are 2×1 mrad and 2×10 mrad, respectively.
- ❑ Both helicities have to be provided for positron and electrons at the IRs considering the crossing angles.

Spin transport considering two IRs



- ❑ Since the IPs are not parallel, the spins must be aligned differently for each of the IRs at the entrance of the linac to achieve longitudinal polarization.
 - Two parallel rotator lines are required, which have to be stackable side by side.
- ❑ Solenoids and horizontal bends are utilized, minimizing the vertical emittance dilution in comparison to chicane based systems.
- ❑ The path length in both rotators has to be identical within the electron bunch length.

Spin transport for electrons



K Moffeit 27 Jan 2005

Spin rotator design requirements



- ❑ Flexible design: Longitudinal IP spin orientation has to be achieved. Additionally, the option to adjust spin polarization in any direction is desired.
- ❑ The rotator must not significantly dilute the transverse emittances ($\frac{\Delta\epsilon_y}{\epsilon_y} < 2\%$).
- ❑ The system should be short ($\lesssim 100$ m) and as stable as possible.
- ❑ Emittance increase caused by synchrotron radiation should be negligible at 5 GeV beam energy.
- ❑ The dilation factor must be small, otherwise energy fluctuations are transferred into longitudinal position fluctuations comparable to the bunch length.

Spin-rotating building blocks

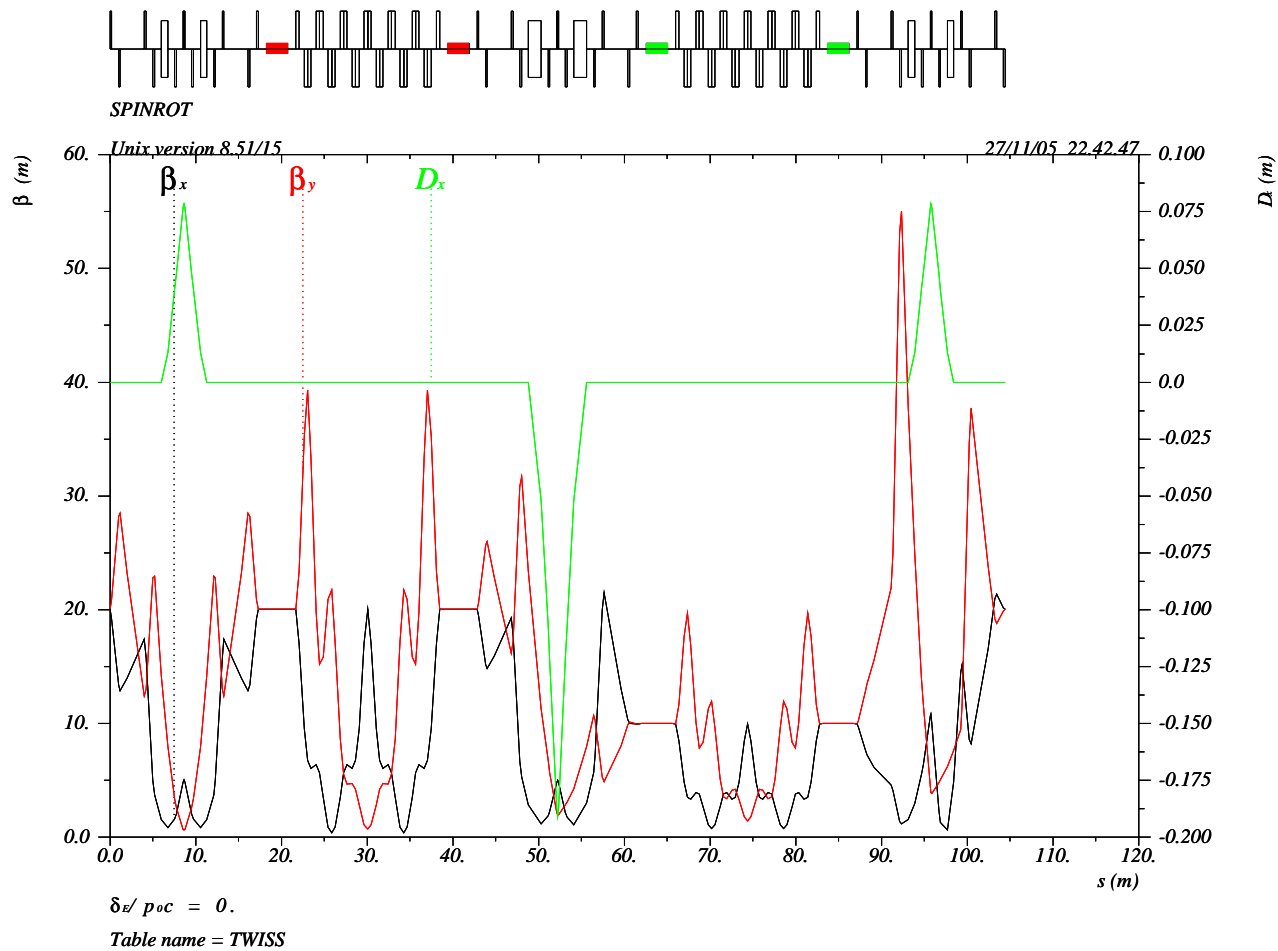


- ❑ Dipoles rotate spins: $\theta_s = \gamma \frac{g-2}{2} \theta_b$
- ❑ Solenoids rotate spins: (Larmor rotation)
$$\Delta\theta_s = \left[1 + \frac{g-2}{2}\right] \frac{B_s L_s}{B_0 \rho} \approx \frac{B_s L_s}{B_0 \rho} = 2\theta_r$$
- ❑ Caveat: Solenoids cause cross-plane coupling. The vertical emittance increases (≈ 100 times for ILC parameters)
- ❑ Solenoid pairs with a corrector (*reflector*), removing cross plane coupling for on-energy particles, are required.
(+I transformation in x , -I transformation in y)
- ❑ For electrons,
$$\frac{g-2}{2} = 1.16 \times 10^{-3},$$
 gyromagnetic anomaly a .
- ❑ θ_b , bending angle
- ❑ θ_r , roll angle of the beam
- ❑ $B_0 \rho$, beam rigidity
- ❑ $B_s L_s$, field integral

The spin rotator consists of:

- ❑ three bends: total net deflection is zero.
center arc rotates beam by 8° ; thus spins by 90° .
- ❑ two solenoid pairs, each equipped with a reflector

Optics layout of the spin rotator



Solenoid settings required



A spin polarized along the vertical direction (originating from the damping ring) has to be converted into one which is longitudinally polarized.

- Total deflection angle is zero.
- Center bend deflects spins by 90° .
 $\theta_s = \frac{\pi}{2} = a\gamma\theta_b \Rightarrow \theta \approx 8^\circ$
outer bends: $R_y(\pi/4)$, center arc: $R_y(-\pi/2)$
- two solenoid pairs rotate the spins by the total angle ϕ_1 or ϕ_3 , respectively $R_z(\phi_1)$, $R_z(\phi_3)$

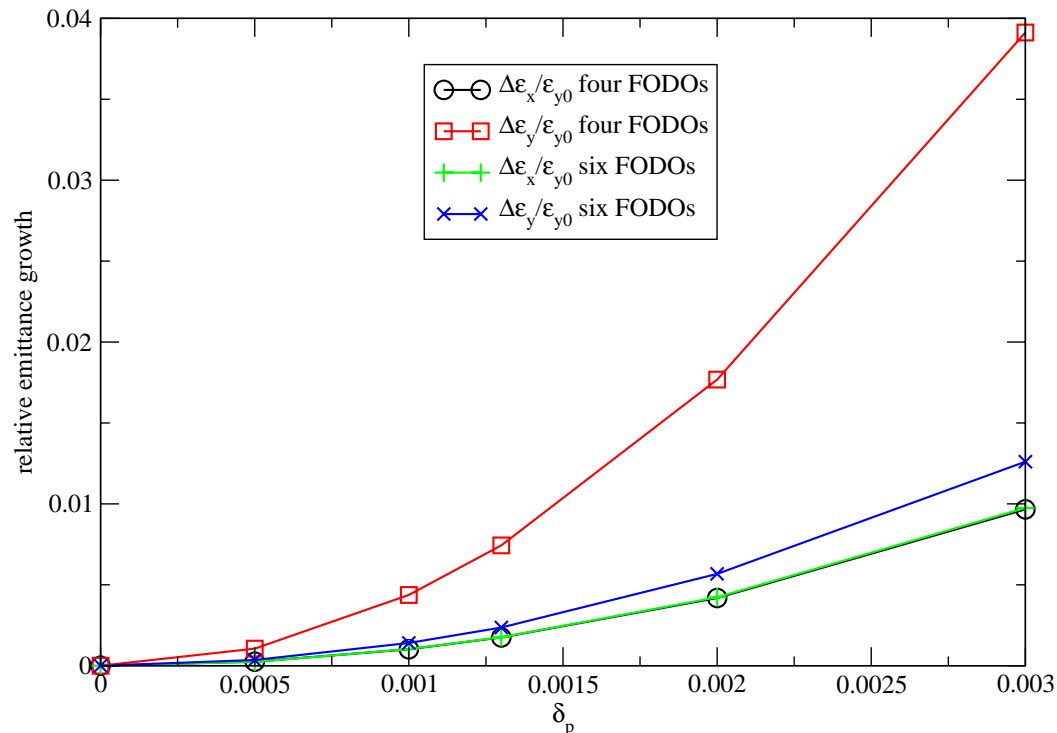
- a : gyromagnetic anomaly
- Energy is 5 GeV
- $R_y(\phi)$: Rotation around y with angle ϕ
- $R_z(\phi)$: Rotation around z with angle ϕ
- θ_b : bending angle

Emittance dilution of the system

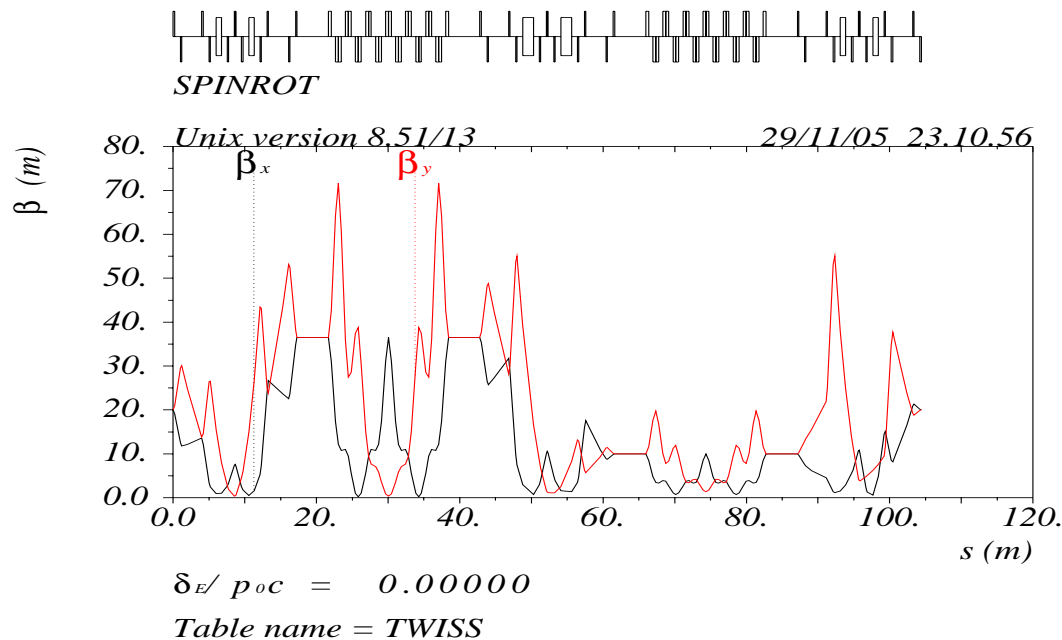


- initial system (TESLA): $\frac{\Delta\epsilon_y}{\epsilon_y} = 8.3\%$
- new system utilizing four FODO cells: $\frac{\Delta\epsilon_y}{\epsilon_y} = 7.4\%$
- new system utilizing six FODO cells: $\frac{\Delta\epsilon_y}{\epsilon_y} = 2.4\%$

- nominal $\delta_p = 1.3 \times 10^{-3}$
- initial normalized emittances: $\gamma\epsilon_x = 8 \times 10^{-6}$ m rad, and $\gamma\epsilon_y = 2 \times 10^{-8}$ m rad.
- beam energy is 5 GeV



Solution for 2×10 mrad crossing angle



- nominal $\delta_p = 1.3 \times 10^{-3}$
- initial normalized emittances: $\gamma\epsilon_x = 8 \times 10^{-6}$ m rad, and $\gamma\epsilon_y = 2 \times 10^{-8}$ m rad.
- emittance dilution: $\frac{\Delta\epsilon_x}{\epsilon_x} = 9.6\%$ and $\frac{\Delta\epsilon_y}{\epsilon_y} = 6.7\%$ (not optimized)

Solution for a curved linac



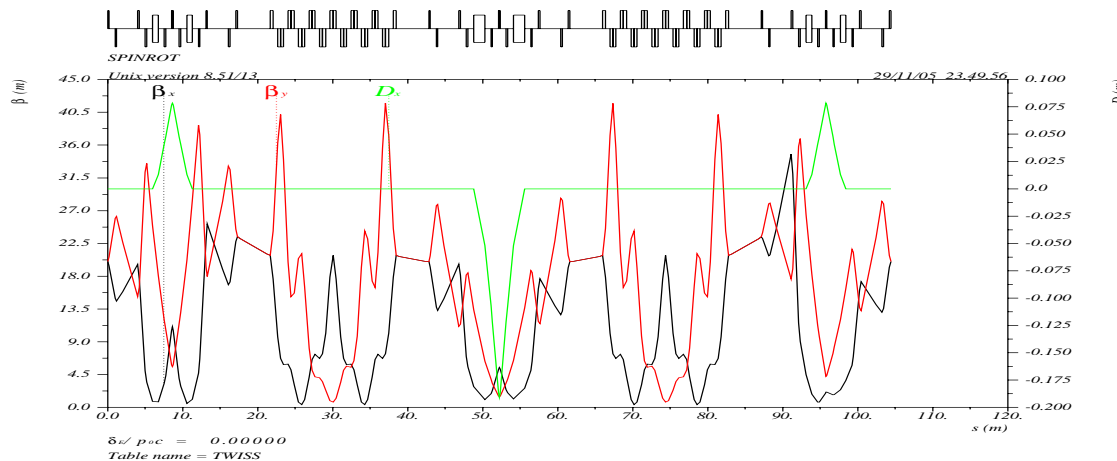
- A 20 km linac following the curvature of the earth causes a spin rotation of 109.5° around the x -axis (horizontal). → checked with Merlin
- The excitations for the solenoids and the matching sections are very different than those for a laser straight linac.
- A viable solution is $\phi_1 = 0.24$ rad and $\phi_3 = -0.25$ rad, for transforming a spin polarized parallel to the vertical into one which is longitudinal at the IR.

- nominal $\delta_p = 1.3 \times 10^{-3}$
- initial normalized emittances: $\gamma\epsilon_x = 8 \times 10^{-6}$ m rad, and $\gamma\epsilon_y = 2 \times 10^{-8}$ m rad.
- emittance dilution:

$$\frac{\Delta\epsilon_x}{\epsilon_x} = 4.5\%$$

$$\text{and } \frac{\Delta\epsilon_y}{\epsilon_y} = 1.7\%$$

(not optimized)

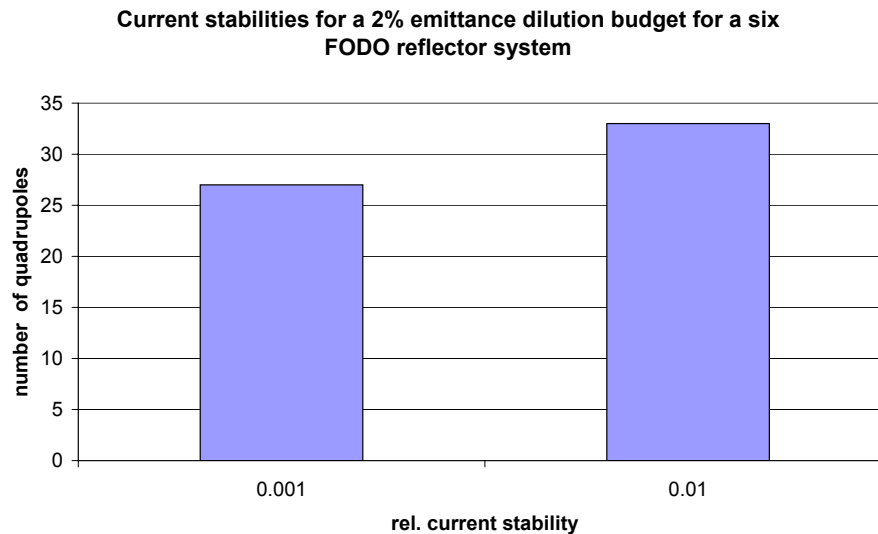


Results of the stability studies I



Requirements for power supplies: $\left(\frac{\Delta\epsilon_y}{\epsilon_y} < 2\text{‰}\right)$

At maximum a relative stability of 1‰ is required.

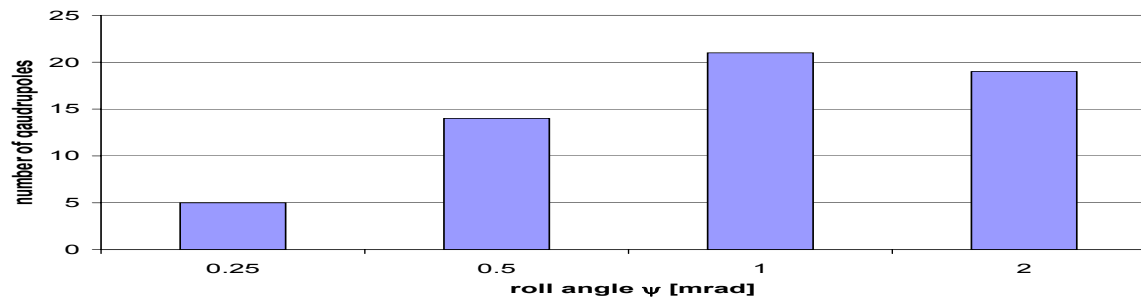


Results of the stability studies II



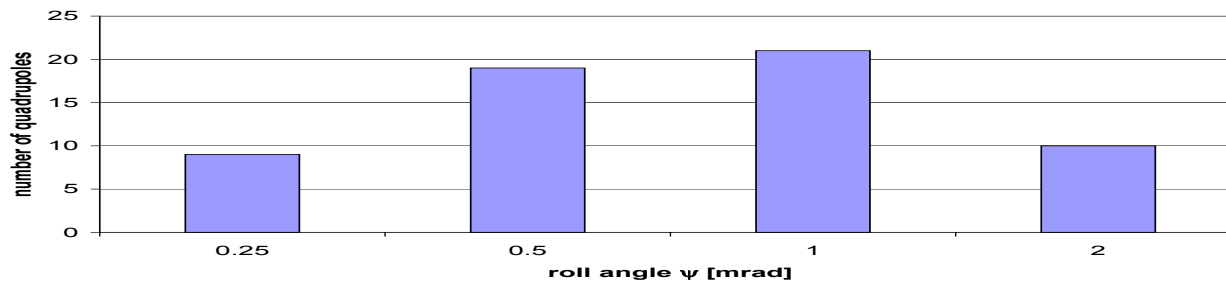
Roll tolerances for the quadrupoles:

Roll tolerances for a 2% emittance dilution budget for a six FODO reflector system



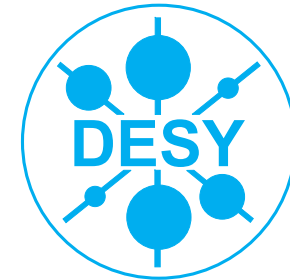
straight

Roll tolerances for a 2% emittance dilution budget for a six FODO reflector system tuned for a linac following the curvature of the earth



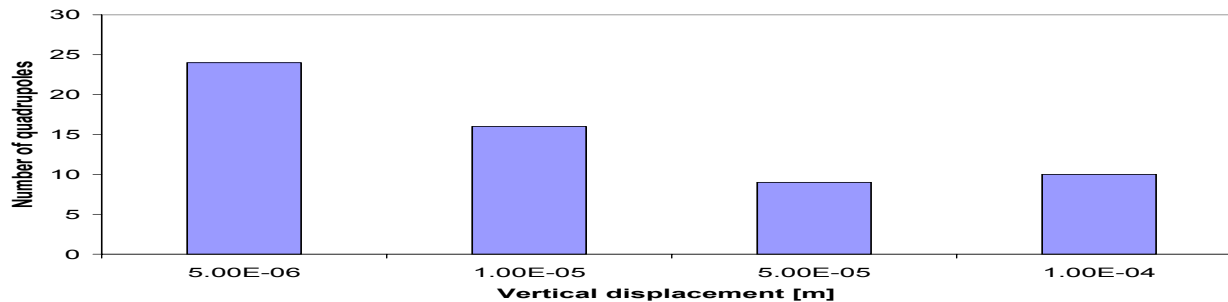
curved

Results of the stability studies III



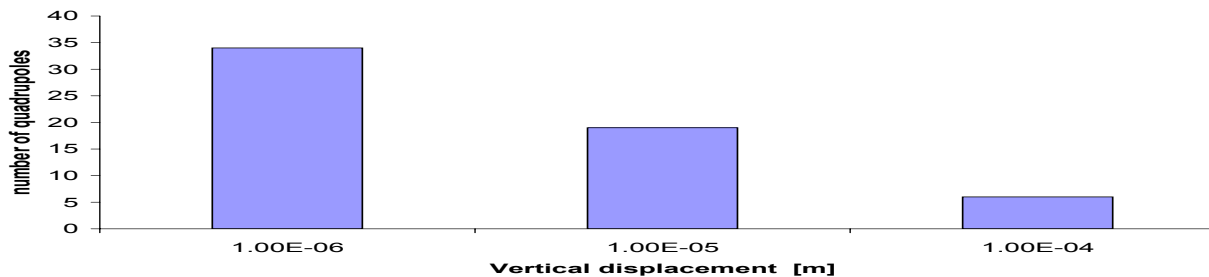
Vertical misalignment tolerances of the quadrupoles:

Vertical displacement tolerances for a 2% emittance dilution budget for a six FODO reflector system



straight

Vertical displacement tolerances for a 2% emittance dilution budget for a six FODO refelector system tuned for a linac following the curvature of the earth



curved

Summary



- ❑ Successful manipulation of the spins is viable for all required orientations and IRs, if
 - the roll tolerances of 0.25 mrad
 - the tolerances of 1 μm for vertical displacement for the most sensitive quadrupoles can be met and
 - if the vertical spin direction can be flipped by some external facility.

- ❑ Depolarization effects due to misalignment seem to be a non-issue at 5 GeV. Displacing the most sensitive quadrupoles by 10 mm is required to cause an appreciable effect. The only depolarizing effect originate from parasitic dipole field components caused by misaligned quadrupoles.