Compact Spin Rotator Studies with Bmad Review & Status

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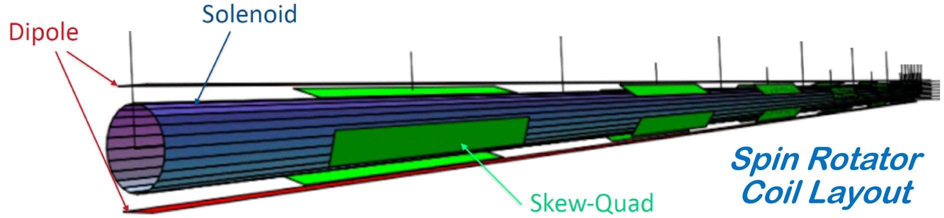
Implementing Uli Wienands' Concept

12 Oct 2022

Compact spin rotator

from Y. Peng



Follows Uli Wienands' (Argonne National Laboratory) idea and direction:

- replace some existing ring dipoles on both sides of the IP with the dipole-solenoid combined function magnets and keep the original dipole strength to preserve the machine geometry
- Install 6 skew-quadruple on top of each rotator section to compensate for the x-y plane coupling caused by solenoids
- Original machine can be recovered by turning off sol-quad field + retune

(BNL expertise in construction of direct wind magnets suitable for these magnets)

Compact spin rotator

from Y. Peng

Working Constraints for the Design

- **Transparency**: Need to maintain the original **beam dynamics,** make the spin rotator transparent to the ring as much as possible (the spin rotator is for the polarization purpose only)
- **Physical constraints**: All new magnets must be manufacturable and installable. Brett Parker (BNL) provided these preliminary physical constraints
  - Solenoid strength can not exceed **5** T
  - Skew-quad can not exceed **30** T/m (~ 3T at the coil)
- Yuhao Peng (UVic) used BMAD, working with Uli Wienands (ANL) & Demin Zhou(KEK) and consulting with David Sagan (Cornell), found a solution under these constraints
  - Demin provided SAD lattice files for HER translated for BMAD

Modelling dipoles with Hkicks in BMAD

- Hkick strength is set to be the same as the dipole
- Initially sliced into 6 pieces to match the number of skew-quads
- Use patches to shift the reference orbit(x,x',y,y') at the exit of each piece
- Increase the number of slices to obtain a better model of the dipole

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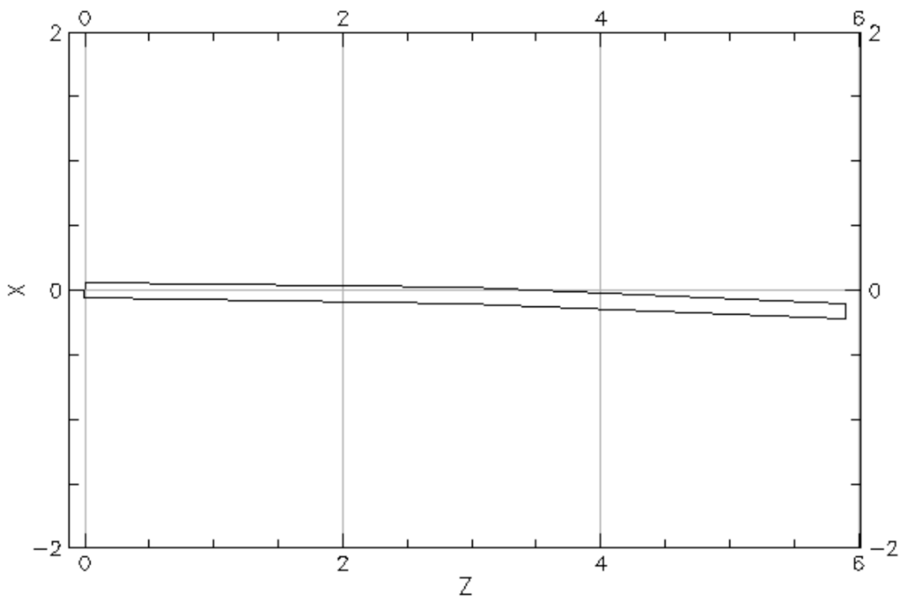
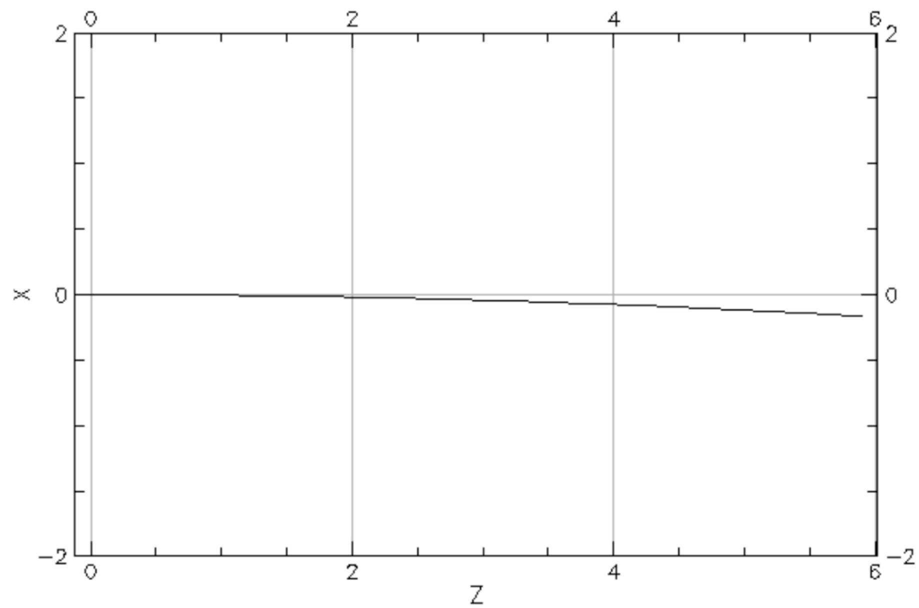
Comparison of geometry between the B2E and the Hkick after fixing the reference orbit with patch



B2E



Hkick(6-piece sliced)

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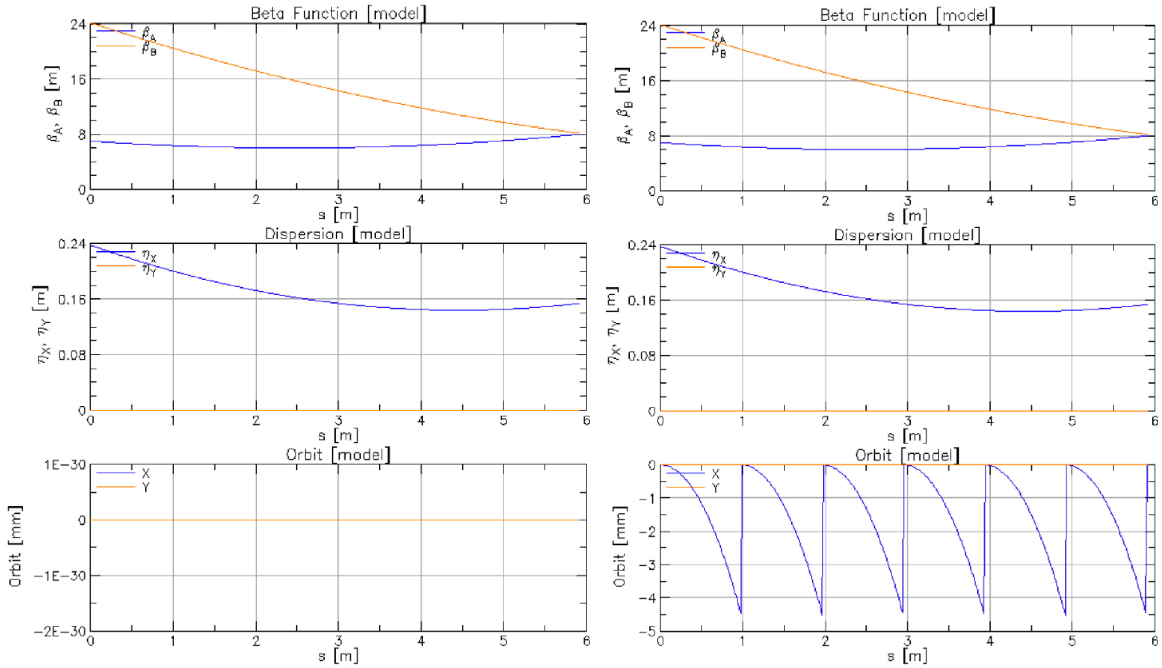
Comparison of orbit and Optical functions

Beta

Dispersion

Orbit



Original B2E   Hkick(6-piece sliced)

The sawtooth shape orbit excursion is not physical, it's an artificial effect due to using the patch elements

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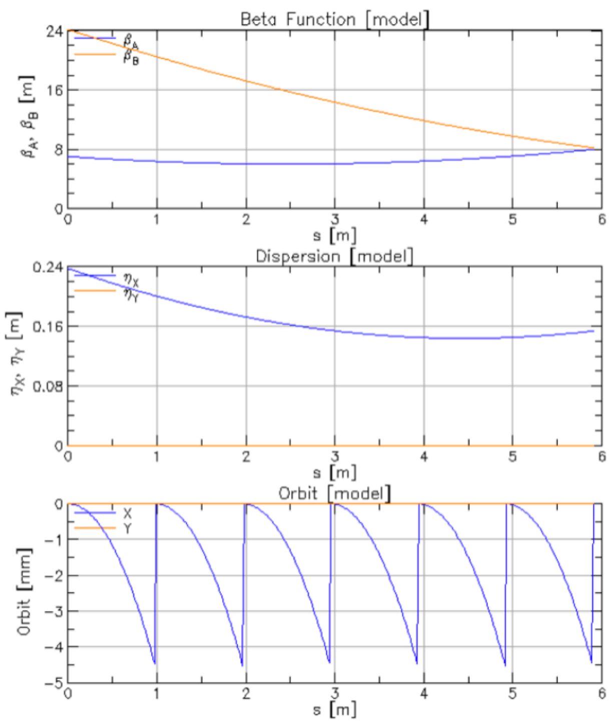
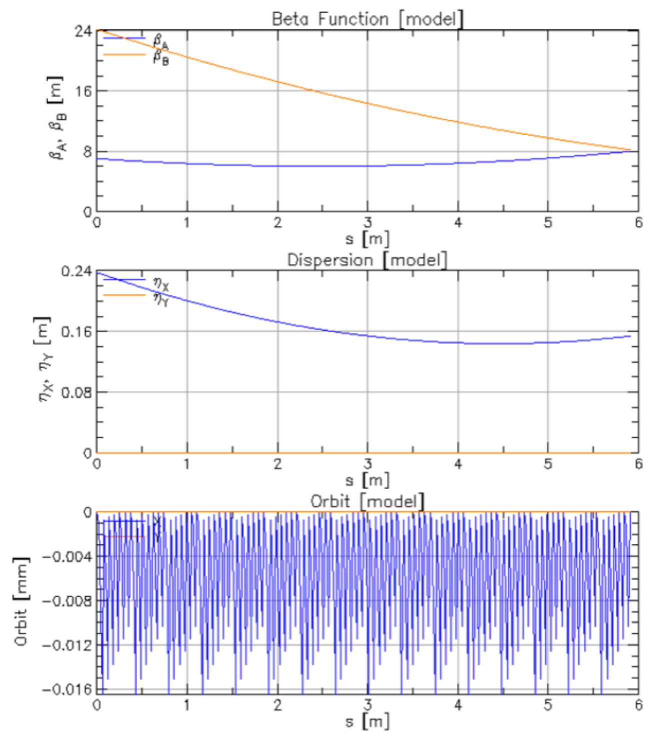
Slice Model



Stand-alone Model(6-pieces)



Slice Model(96-pieces)

In order to reduce the non-physical orbit excursion, each piece of the hkick is further sliced into 16 pieces, 96 in total

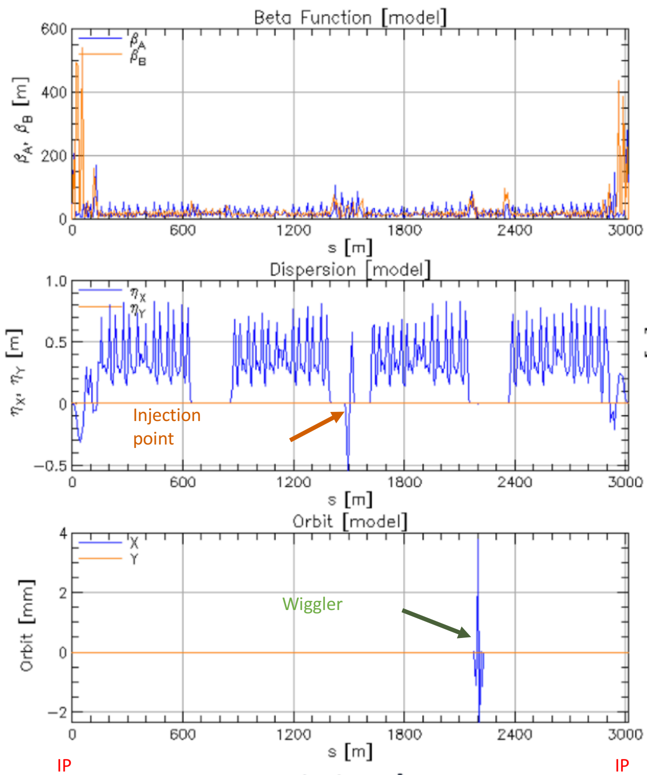
Validating Hkick modelling of dipoles

Replace 4 “B2E”(where the rotator magnets will be installed) with hkicks(no solenoid-quadrupole) in the full HER lattice

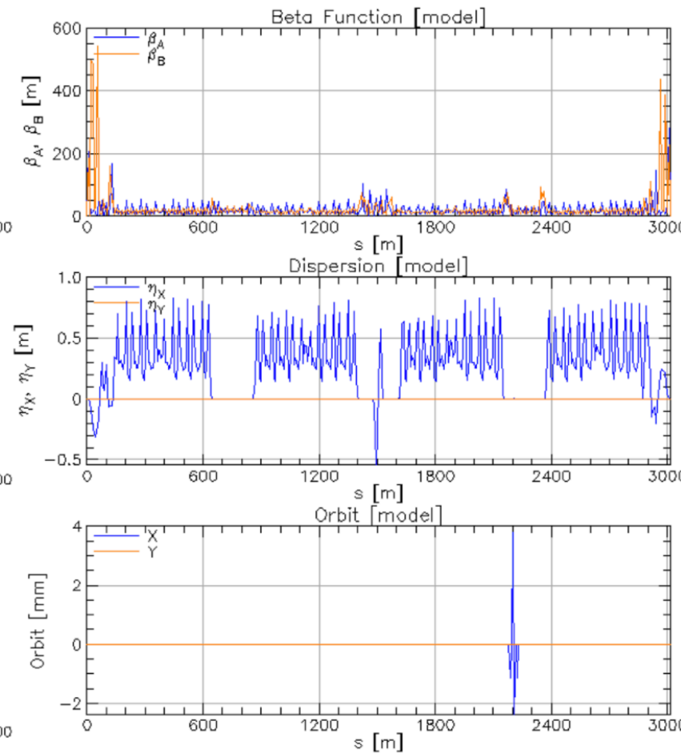
- Check if the floor coordinate is the same as the original (global geometry)

- Check if the orbit, optical functions, and ring parameters… are the same as the original

Comparison of original HER with version having Hkick modelling of the 4 B2E dipoles



Original



Hkick (Slice Model)

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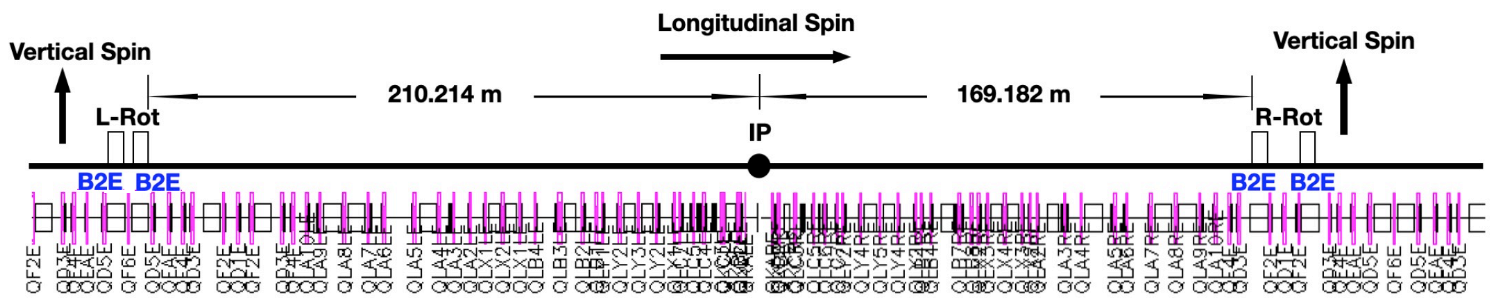
Compact spin rotator

from Y. Peng

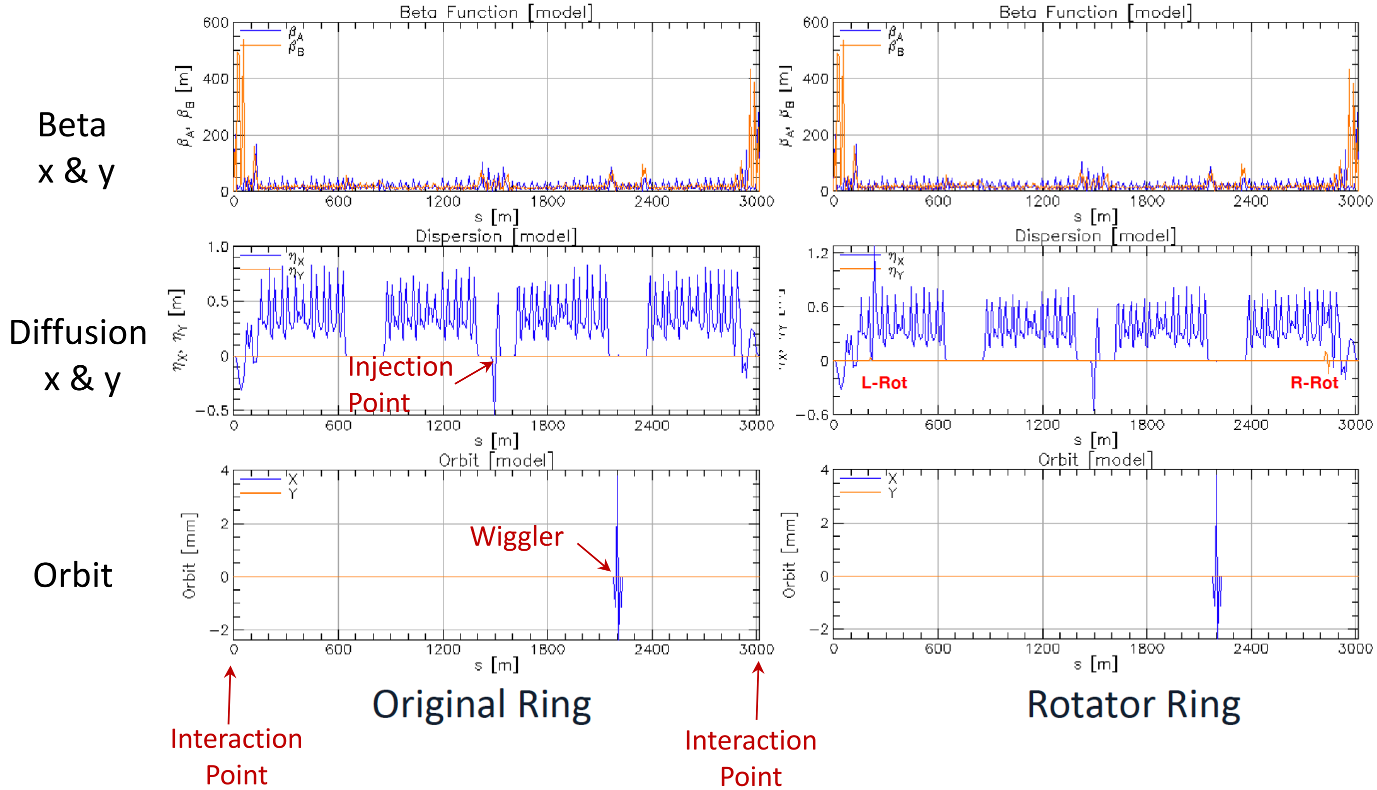


- Left Rotator (L-Rot) rotates the spin from the vertical to the horizontal plane
- Right Rotator (R-Rot) rotates the spin back to the vertical direction
- 4 **B2E** dipoles (using SAD lattice naming convention for HER) shown above to be replaced with the spin rotator magnets

Compact spin rotator

from Y. Peng

Full lattice Comparison with L/R-Rot installed & matched in the HER ring



Compact spin rotator

from Y. Peng

Ring parameter comparisons with BMAD following closed-geometry optimization and after matching tune and chromaticity to the original HER

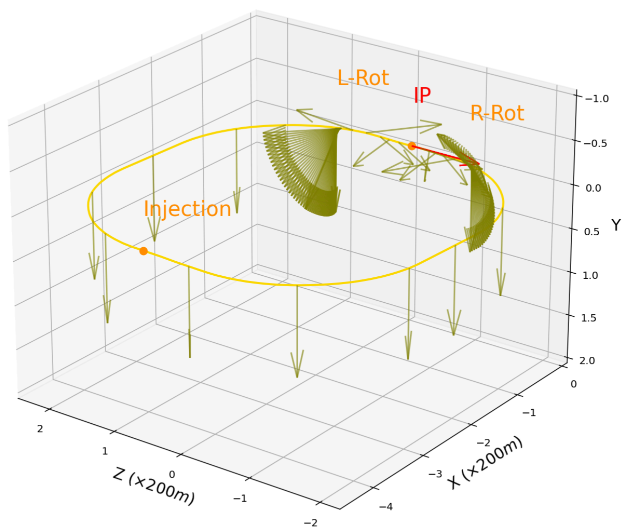
Machine Parameter	Original Ring	Rot Installed
Tune Q_x	45.530994	45.530994
Tune Q_y	43.580709	43.580709
Chromaticity ξ_x	1.593508	1.593508
Chromaticity ξ_y	1.622865	1.622865
Damping partition J_x	1.000064	0.984216
Damping partition J_y	1.000002	1.005266
Emittance ε_x (m)	4.44061×10^{-9}	4.89628×10^{-9}
Emittance ε_y (m)	5.65367×10^{-13}	3.96631×10^{-12}

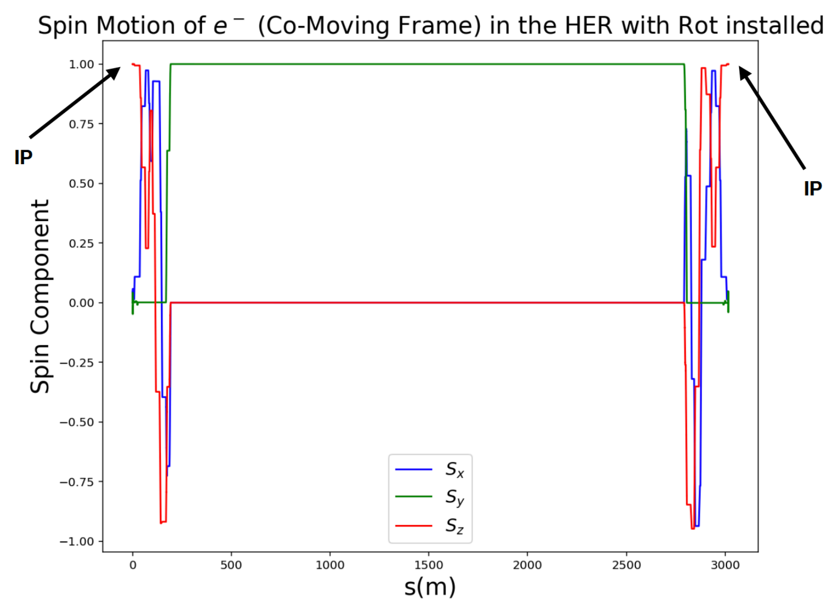
Compact spin rotator

from Y. Peng

Single Particle Spin Tracking Result

Spin Component	Entrance of the L-Rot	IP	Exit of the R-Rot
X	-0.0000450734	0.0000066698	0.0000538792
Y	0.9999999959	0.0000926945	0.9999999959
Z	-0.0000788085	0.9999999957	-0.0000728110





Compact spin rotator

from Y. Peng

	Solenoid	Field (T)
L-Rot	B2EALSQ	-4.8431
	B2EBLSQ	-2.5774
R-Rot	B2EARSQ	-3.6084
	B2EBRSQ	-3.9420

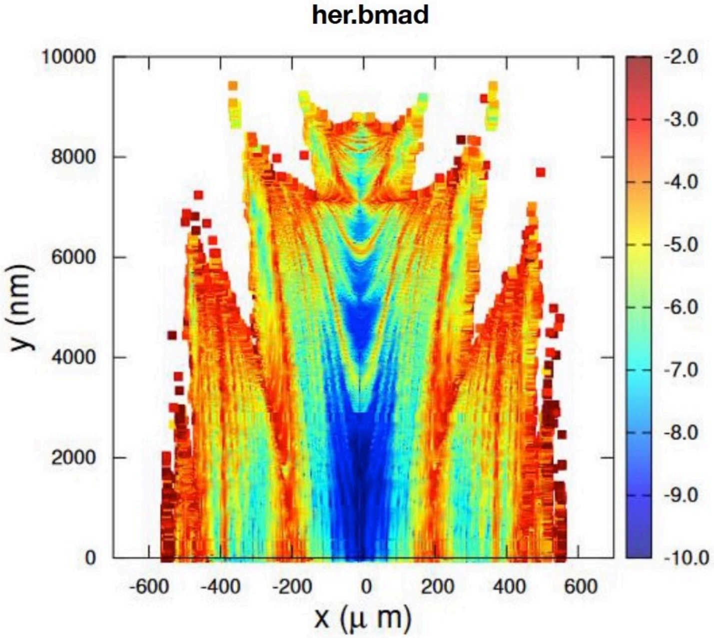
- Solenoid fields below 5 T limit
- Maximum skew-quad strength is ~20 T/m, below 30T/m limit
- Maximum Ring quad is ~ 14 T/m, which is achievable

Compact spin rotator

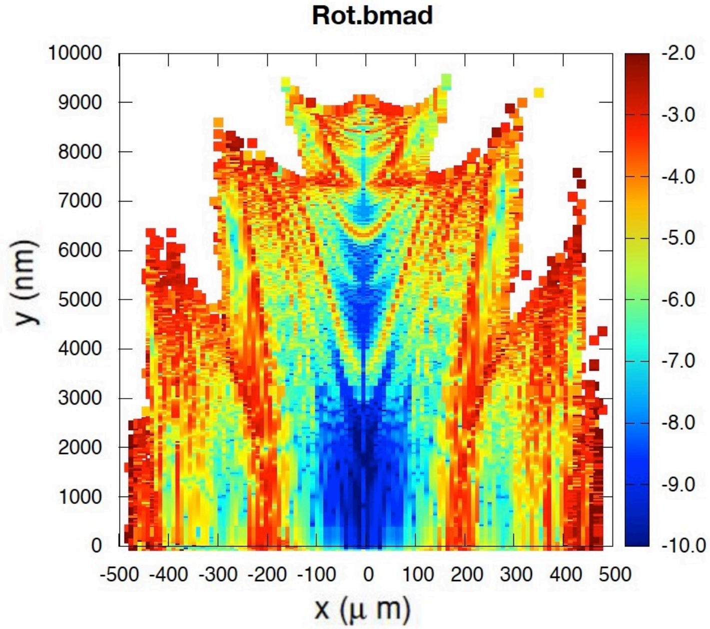
Initial preliminary Frequency Map Analysis (FMA) dynamic aperture studies using BMAD

work by Noah Tessema (UVic)

Original HER Lattice



HER Lattice with spin rotator



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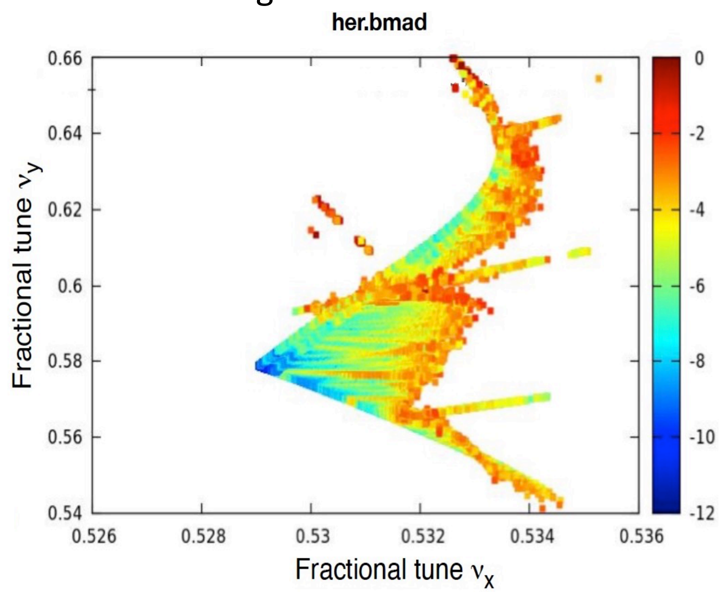
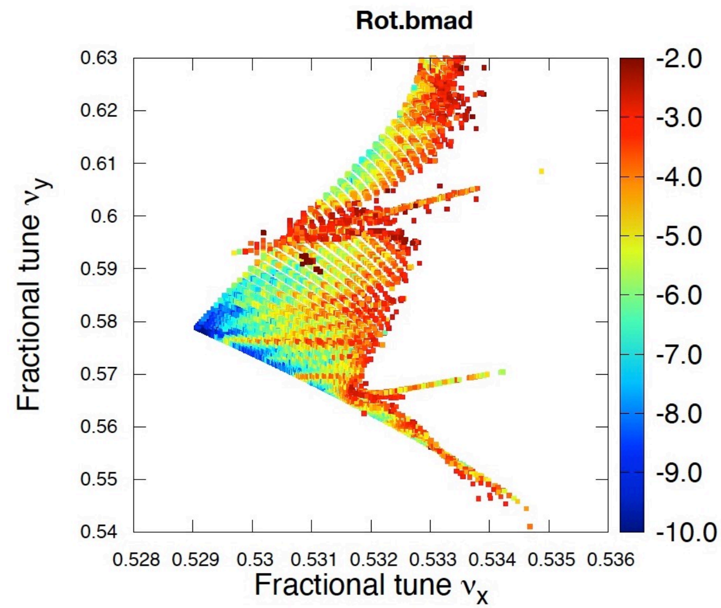


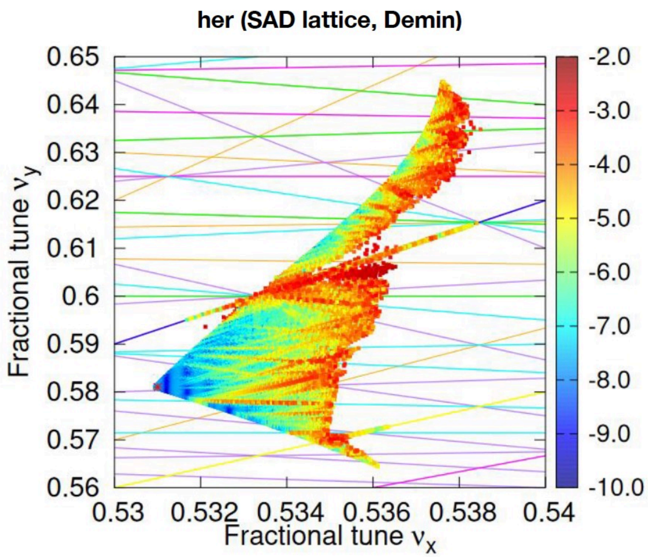
HER Lattice with spin rotator



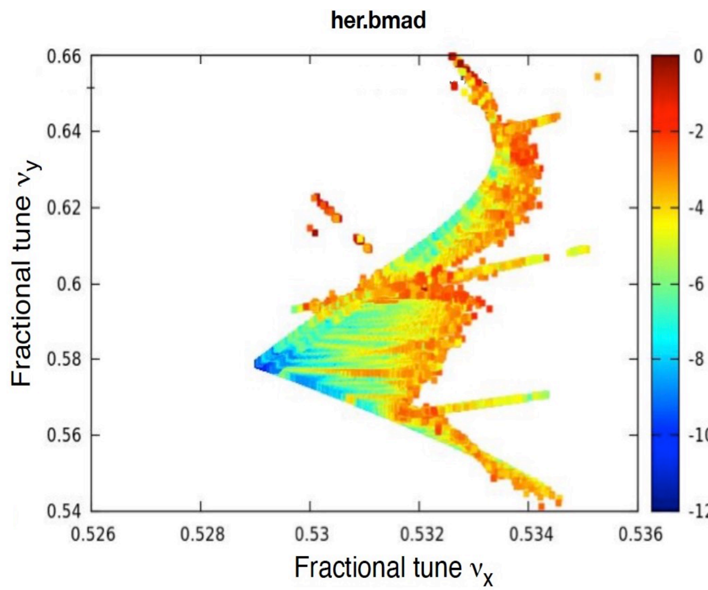
Next steps: Long Term Tracking studies with radiation damping and radiation fluctuations/quantum excitation

Comparing SAD FMA to BMAD FMA in original HER Lattice

Original HER Lattice with SAD



Original HER Lattice with BMAD

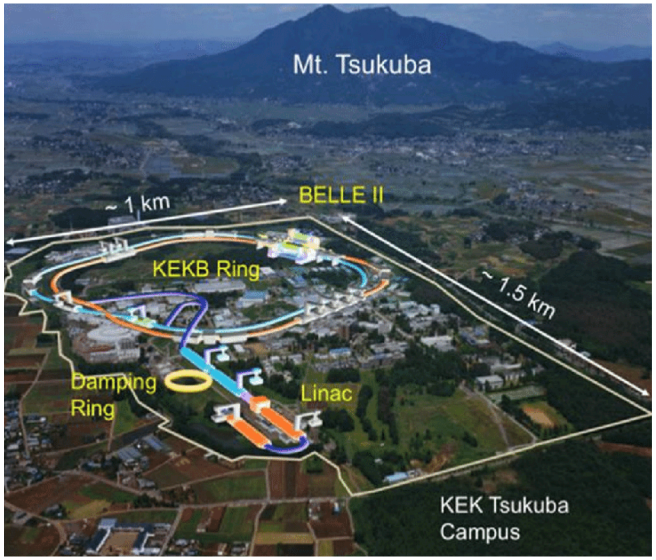


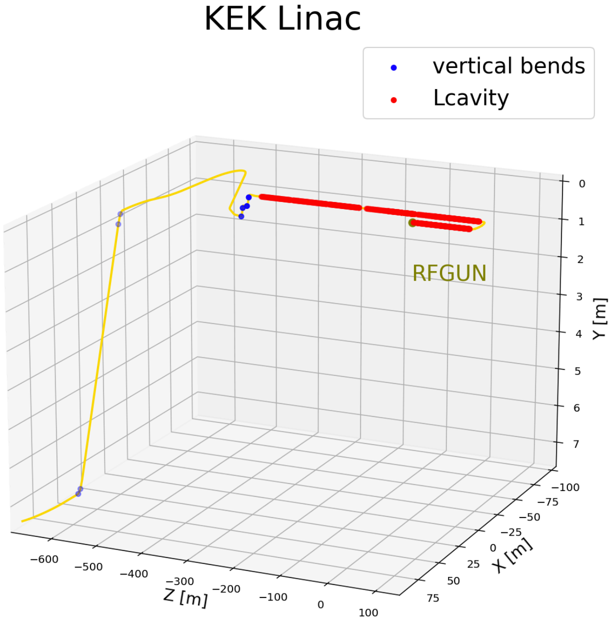
Long Term Tracking studies (Y. Peng)

- Confirmed a transverse spin is transferred to HER
- Spin lifetime studies in HER > 10hrs

KEK Injection Linac polarization BMAD studies

Y. Peng

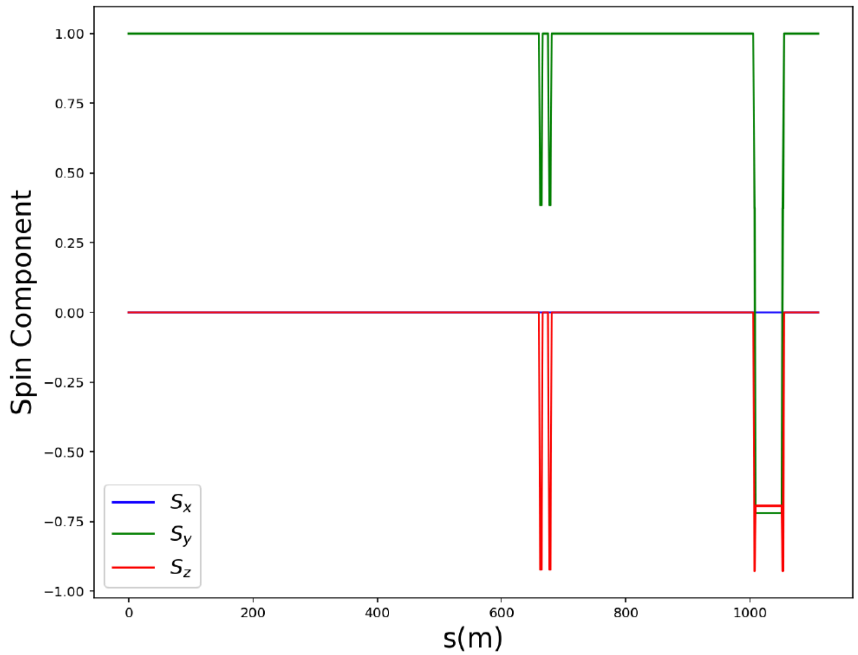




Need transversely polarized beam at the injection point of the e- storage ring (High Energy Ring -HER)

Spin motion in the KEK Injection Linac

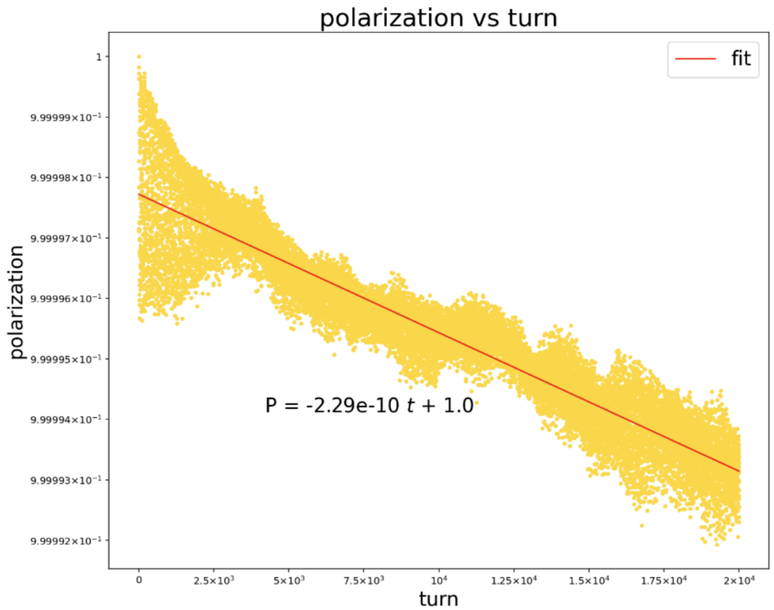
Y. Peng



These spin tracking using BMAD show if the electron starts with vertical spin (0,1,0) at the source, after all the vertical beam motion, it will end up with a vertical spin at the injection point, as desired.

Validation of transverse spin lifetime in the HER

Y. Peng



- Tracking 100 particles for 20000 turns in the HER with BMAD
- Based on this study, the estimated polarization lifetime > 10 hours

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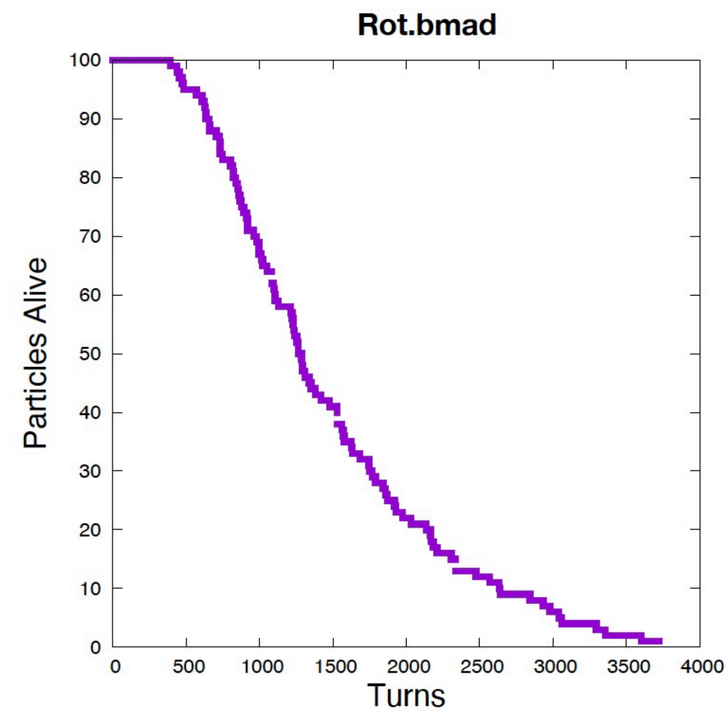
Initial Long Term Tracking studies with Spin Rotator

- Initial LT tracking show that when the radiation fluctuations option in Bmad turned on, the beam starts to be lost after 500 turns. Unexpected given the Dynamic Aperture plots
- Now working on understanding cause of this
- First step: rule out the effect as an artifact of Bmad hkick description of the dipoles
- Noah Tessema ran LT tracking with HER lattice with dipoles replaced by hkicks : ‘hkick HER’ – i.e. rotator solenoid and skew-quads are off

hkick Long Term Tracking

- 20,000 turns, 100 particles tracking
- All particles survived after 20,000 turns
  - For comparison, Rot.bmad lost all particles in 3600 turns

- Ran with and without OpenMP
  - Without OpenMP: about a day and a half
  - With OpenMP: just under two hours computation time (!!!!)
    - This was done with 4 nodes, each with 8 CPUs.
    - OpenMP is well suited to multi-particle tracking.



(Noah Tessema)

Initial Long Term Tracking studies with “hkick HER”

(Noah Tessema)

hkick <x> versus <y>

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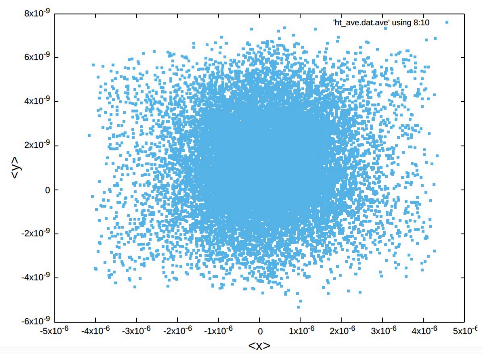
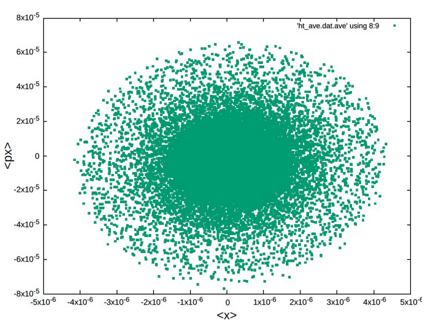


hkick <x> versus <px>



hkick <y> versus <py>

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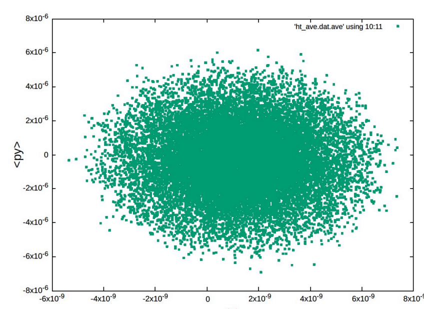

hkick <z> versus <pz>

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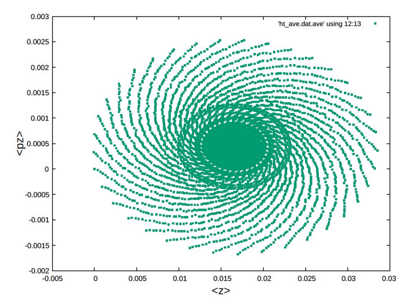

Initial Long Term Tracking studies with “hkick HER”

(Noah Tessema)

hkick Polarization versus Turns

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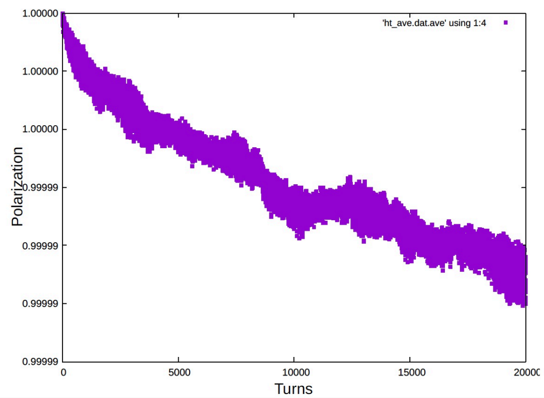

Minimal change on vertical scale

hkick Emittance versus Turns

(Can also plot data for skew, “kurtosis”, and elements of 6x6 sigma matrix)

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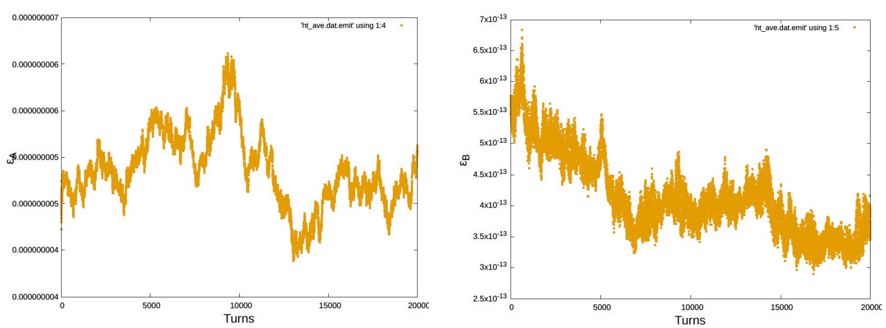

Conclusion: beam loss is not from hkick treatment of dipoles in Bmad

(Noah Tessema)

Initial Long Term Tracking studies

Uli Wienands advises next effect to rule out:
artifact of modelling rotator with solenoid as finite straight pieces in Bmad, whereas the actual magnet will be curved

- Beam going off-center in the solenoid slices would develop an angle against the solenoid. As solenoid slices are modeled as straight pieces, the beam will develop an angle against the field.
- This will cause a transverse field component; while being small on a relative scale, a small fraction of a 5 T field may still be considerable

Next step: Double no. of slices to see if beam loss sensitive to this

(Noah Tessema)

Next steps cont…

- Demin has mentioned that Noah should look into using a different reference point than the IP, the PMID:

  a beam crossing point where dispersion, couplings, and alpha functions are close to zero and preferred reference point by SuperKEKB team.
- Momentum aperture studies
- Modelling pre-existing 3D models of the various SuperKEKB elements (Bmad has capacity to incorporate these)