Approaches to Optimizing Spin Transmission in Lattice Design

Vahid Ranjbar

ICAP October 22, 2018

Outline

- SOptim program overview
- RHIC Lattice spin optimization
  - Minimizing weak interfering spin resonances
- eRHIC injector RCS spin optimization
  - Geometry
  - Detector bypass
  - Spin resonance strengths
- Imperfection Bumps with SVD
- Summary

SOptim Program structure

Python code using Scipy Optimization routines

↓

Drives MADX giving it madx sequence, magnet names and strengths.

↓

MADX returns optics which are then used to calculate spin resonances across a pre-set energy range using a native python DEPOL algorithm.

↓

The spin resonances along with optics parameters are then given weights for a global penalty function

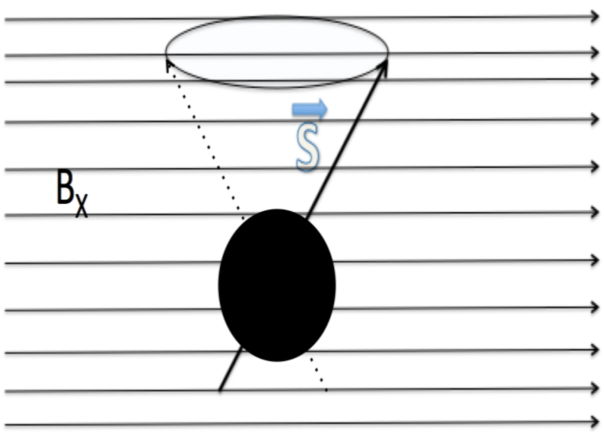
↓

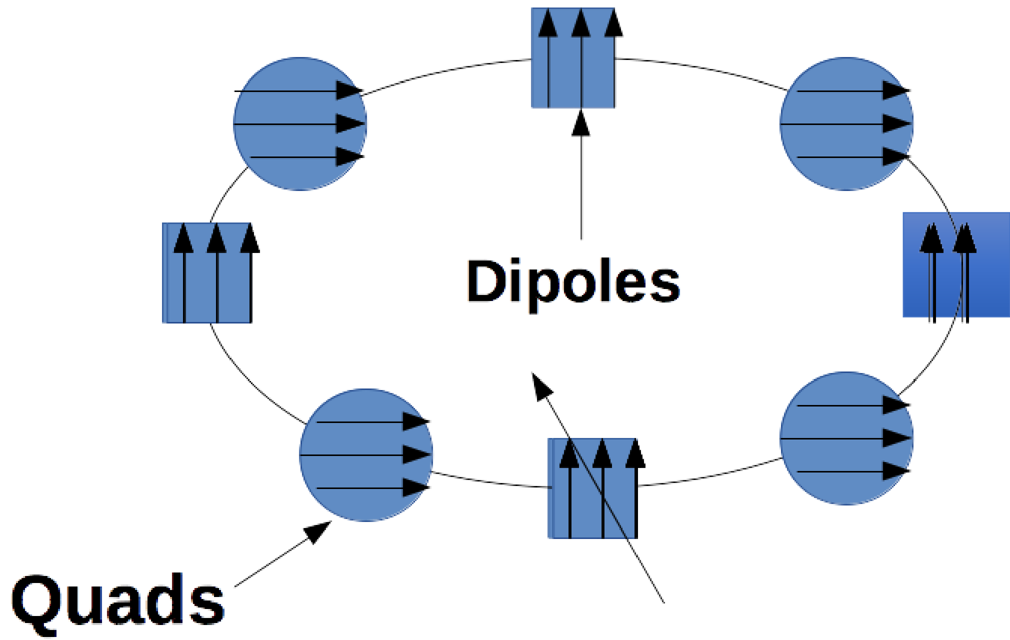
This penalty function is then minimized using Scipy's Minimize function from their optimize library using different optimizers.

Spin Resonance Review

Spinor Form

T-BMT Equation: $$\frac{d\vec{S}}{dt} = \frac{q}{\gamma m}\vec{S} \times \left((1+G\gamma)\vec{B}_\perp + (1+G)\vec{B}_\parallel\right) \longrightarrow \frac{d\Psi}{d\theta} = -\frac{i}{2}\begin{pmatrix} f_3 & -\xi \\ \xi^* & -f_3 \end{pmatrix}\Psi.$$





Spin Resonance: Spin Tune = Rate of Horizontal field kicks
(vertical motion through Quads)

Gγ = N +/- Qz Intrinsic or **Gγ = N** Imperfection
Due to vertical betatron Due to vertical closed orbit error

Spin Resonance Driving terms

$$\xi(\theta) = F_1 - iF_2 = \sum_K \varepsilon_K e^{-iK\theta}$$

$$\varepsilon_K = -\frac{1}{2\pi}\oint \left[(1+G\gamma)(\rho z'' + iz') - i\rho(1+G)\left(\frac{z}{\rho}\right)'\right] e^{iK\theta} d\theta$$

Spin Resonances come from vertical motion mostly. The z'' term dominates

$$z = z_\beta + z_{co}$$

Intrinsics Resonance

$$K = N \pm Q_z$$

Imperfection Resonance

$$G\gamma = K = N$$

$$\zeta_P\left(\frac{K \pm Q_z}{P}\right)$$

$$\zeta_P(x) = \frac{\sin(P\pi x)}{\sin(\pi x)}.$$

Tell when they are significant

Concept Overview: Spin Resonance Free Lattice

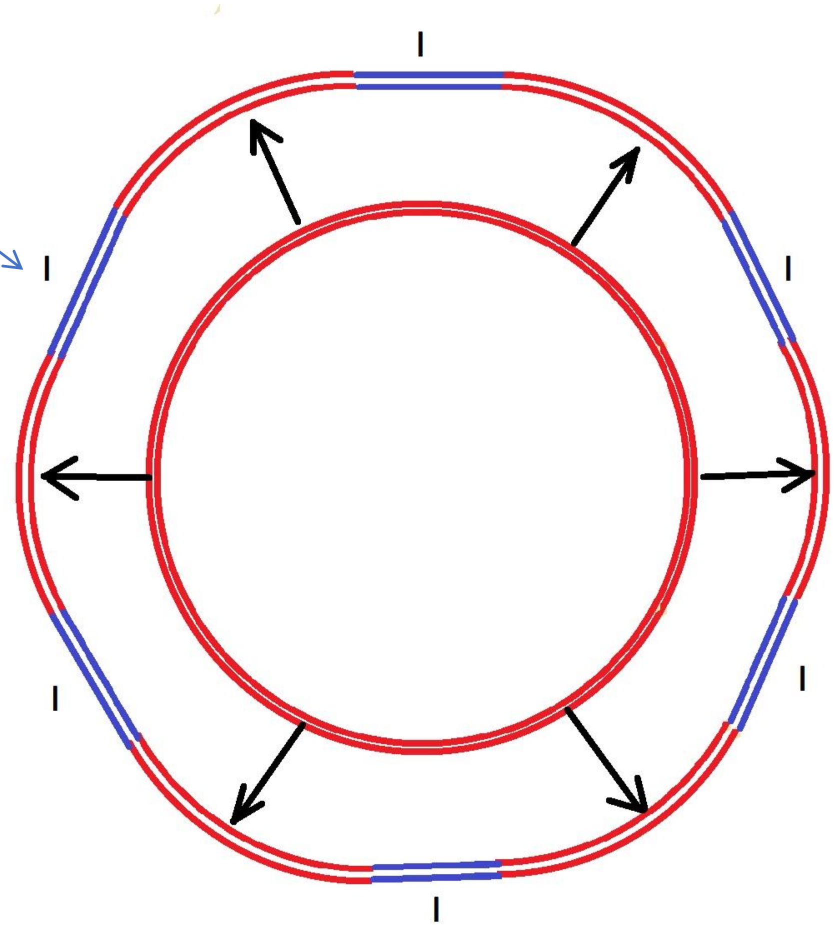
- Both the strong intrinsic and imperfection resonances occur at:
  - K = nP +/- Qy
  - K = nP +/- [Qy] (integer part of tune)
- To accelerate from 400 MeV to 18 GeV requires the spin tune ramping from
  - **$0.907 < G\Upsilon < 41.$**
- If we use a periodicity of P=96 and a tune with an integer value of 50 then our first two intrinsic resonances will occur outside of the range of our spin tunes
  - K1 = $50+\nu_y$ (ν_y is the fractional part of the tune)
  - K2 = 96 – ($50+\nu_y$) =$46-\nu_y$
  - Also our imperfection will follow suit with the first major one occurring at K2 = 96 – 50 = 46

How to make this work in the RHIC tunnel?

- It is easy to accomplish this with a perfectly circular ring. Just construct a series of FODO cells with bending magnets so that we have total periodicity of 96.
- The problem is that the RHIC tunnel is not circular and has an inherent six fold symmetry.
- The solution make the spin resonances integrals over the straight sections equal to zero.

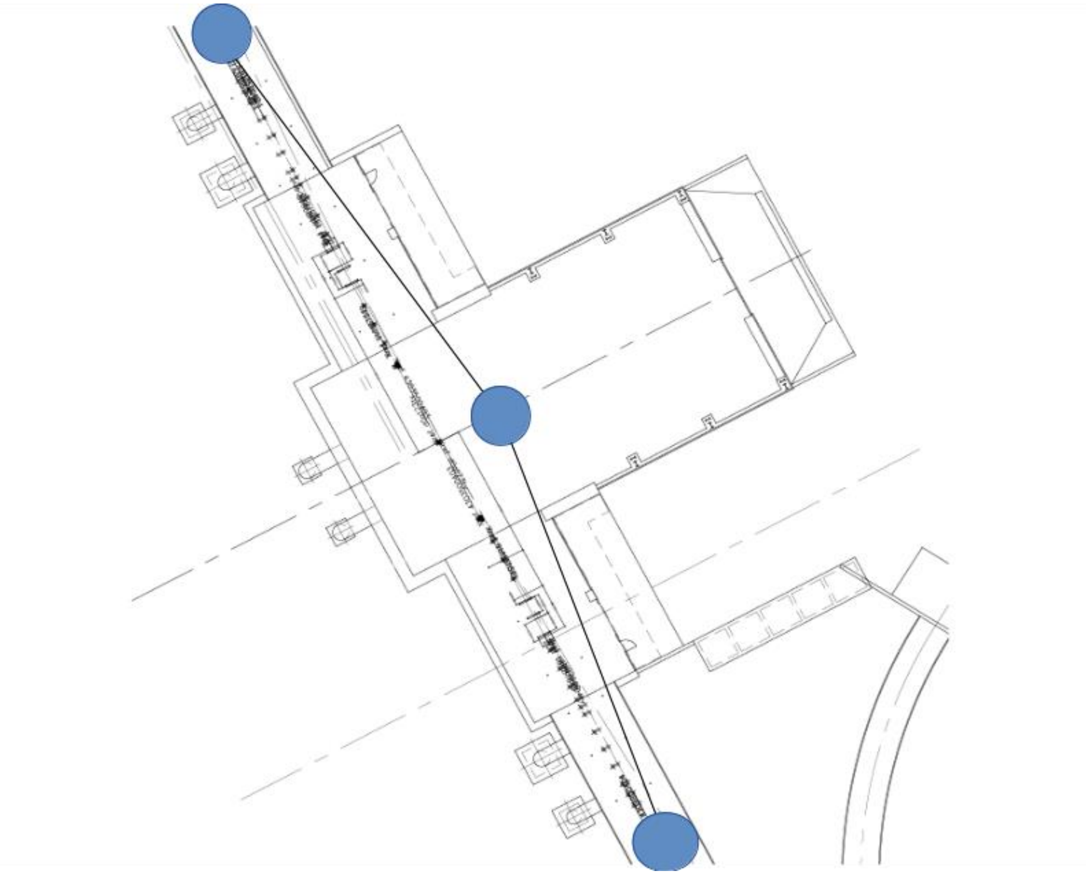
Project onto the RHIC tunnel

RHIC Tunnel

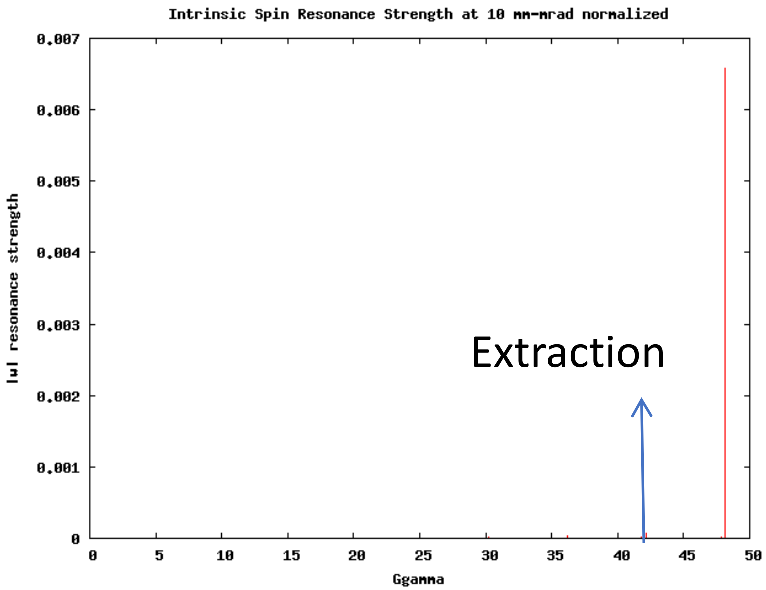


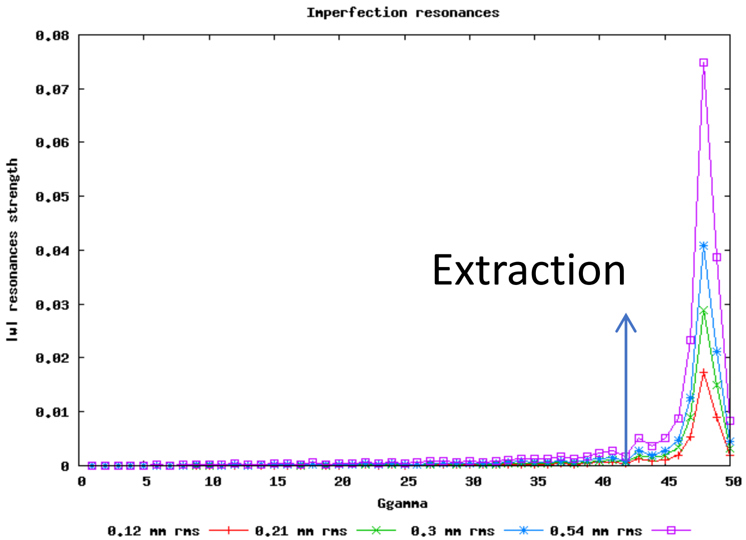
The Use of SOptim for Bypass design

- We added a bypass option to the straight sections.
  - Consists of moving last bend magnets in arc to center of straight section.
  - Achieves ~ 3-4 meter bypass at the IP.
  - Impacts symmetry of lattice.
    - However by using SOptim on the quad strengths in the bypass region we recovered low intrinsic losses



Calculating Spin Resonances



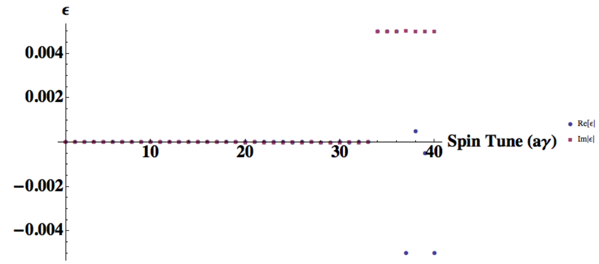


- No polarization loss from cumulative effective of intrinsic spin resonances for distributions with rms normalized emittance > 1000 mm-rad (100 msec ramp rate).
- At 200 mm-mrad rms normalized emittance, we can tolerate beyond 2% field errors and still maintain above 95% polarization transmission.
- Issue to control: Imperfection spin resonances ~ vertical rms orbit 0.5 mm to keep losses < 5%.

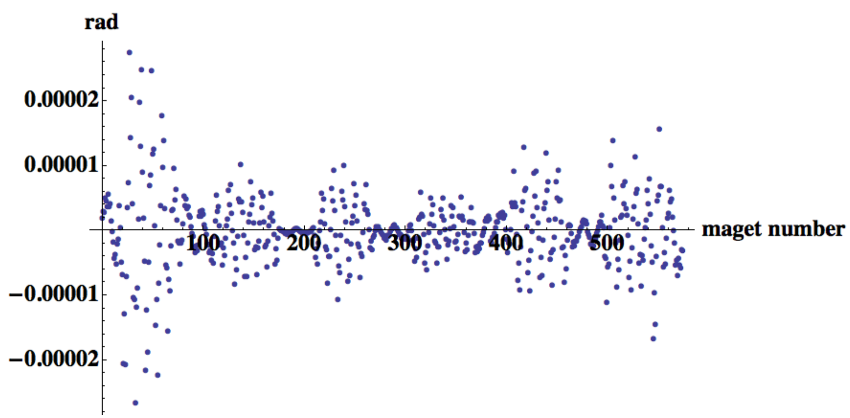
Polarization Performance

- Intrinsic resonance as calculated by DEPOL yield no cumulative depolarization loss for a beam with below 1,000 mm-mrad rms normalized emittance.
- Imperfections could however potentially cause greater than 5% losses during ramp.
  - Due primarily to quadrupole misalignment
  - Survey estimates are 0.2 mm rms with a 2 sigma cut off. This yields an estimated rms orbit distortion of between 3-6 mm rms.
  - Extracting at 10 GeV RCS can handle > 3 mm RMS orbit with < 5% pol. Loss.
  - With appropriate BPM and corrector pairs this can be corrected down to below 0.5 mm rms and push our polarization losses below 5%
  - Once corrected, dynamical changes of the relative field strength in the quads and dipoles of greater than 0.5% can be tolerated with little effect on polarization transmission.
  - Orthogonal imperfection bump scheme to fix any remaining losses beyond SVD orbit smoothing.

Orthogonal Imperfection Bumps using SOptim

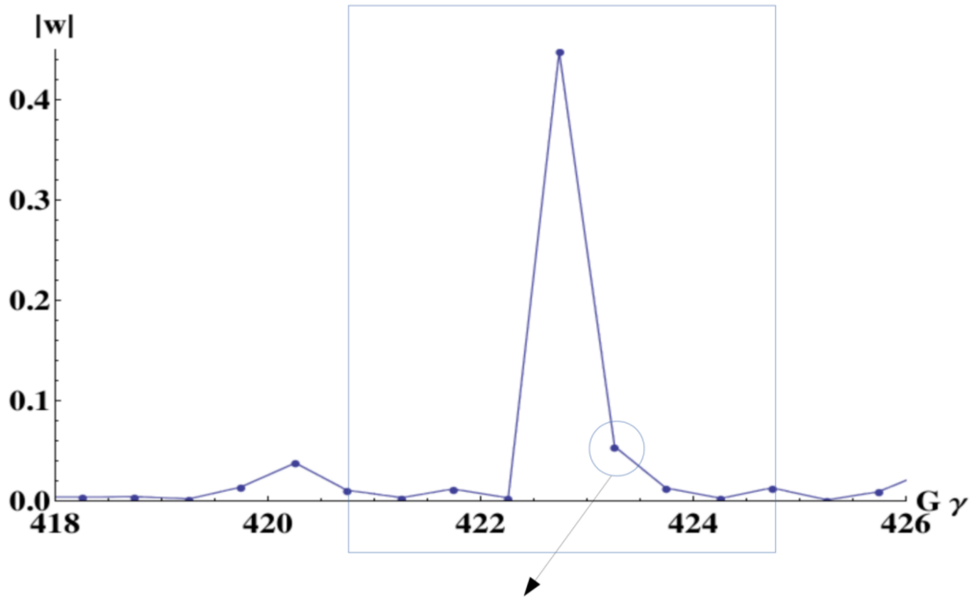


- **Static imperfection** bumps at any imperfection resonance location on the ramp.
- **Bumps are orthogonal** to each other and localized in energy space → no required bandwidth beyond what is needed to ramp the dipoles with the energy.
- **Example Shown on Right**: 10 to 15% (0.005 res.) Depolarization Kick Imaginary and Real no kicks anywhere else.



RHIC lattice Optimization

Analysis of FY12 lattice Crossing 393+NU resonance



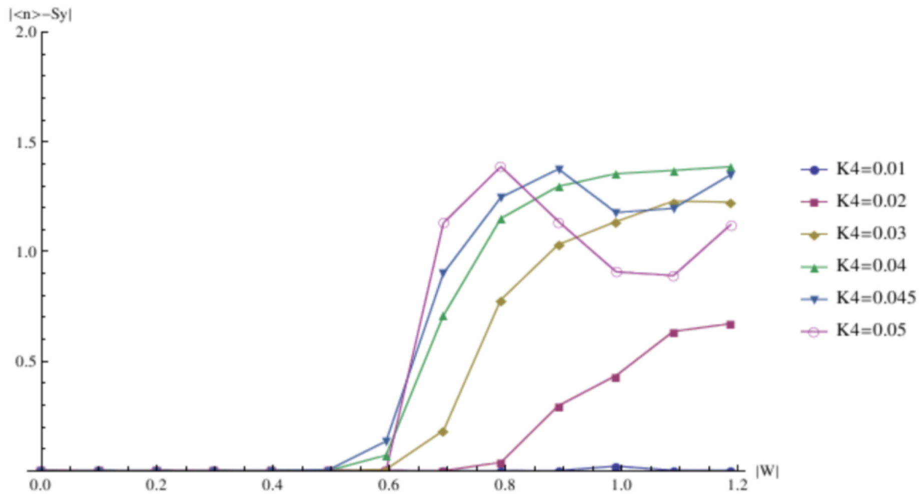
K4=423.325 largest nearby resonance.

Spin transport with two orthogonal snakes during the RHIC acceleration ramp revealed the importance of interfering spin resonances:

- At Gγ=422.685 it was found that the weak spin resonance located at Gγ = 423.325 plays an important role
- Minimizing this and other nearby spin resonances can improve the total spin transmission

RHIC lattice Optimization (cont)

K4 seems singular in determining polarization aperture.



Lattice independent tracking with 5 resonance from FY12 varying K4=423.325 strength

We used the SOptim code to reduce these neighboring resonances. The result was an expansion of polarization transmission versus emittance.

Similar optimization was applied around the three major spin resonances at Gγ=422.685, 382.325, and 260.685 for both the Blue and Yellow RHIC rings.

Summary

- Recently developed SOptim python code for optimizing spin-orbit effects
- Used for design of RCS
- Imperfection bumps in RCS
- Optimization of RHIC lattices