Spin Resonance Free electron ring injector

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Spin Resonance Review

T-BMT Equation:

$$\frac{d\vec{S}}{dt} = \frac{q}{\gamma m}\vec{S} \times \Big((1+G\gamma)\vec{B}_\perp + (1+G)\vec{B}_\|\Big)$$

T-BMT in Spinor form:

$$\frac{d\Psi}{d\theta} = -\frac{i}{2}\begin{pmatrix} f_3 & -\xi \\ \xi^* & -f_3 \end{pmatrix}\Psi.$$

Driving Terms:

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

Spin Resonances Amplitudes:

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

Review Continued:

Froissart-Stora formula

$$\frac{P_f}{P_i} = 2e^{-(\pi|\varepsilon_K|^2/2\alpha)} - 1$$

$$\alpha \approx d(G\gamma)/d\theta$$

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

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

Intrinsics Resonance

Imperfection Resonance

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

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

$$K = N \pm Q_z$$

$$G\gamma = K = N$$

Tell when they are significant

Concept OverView

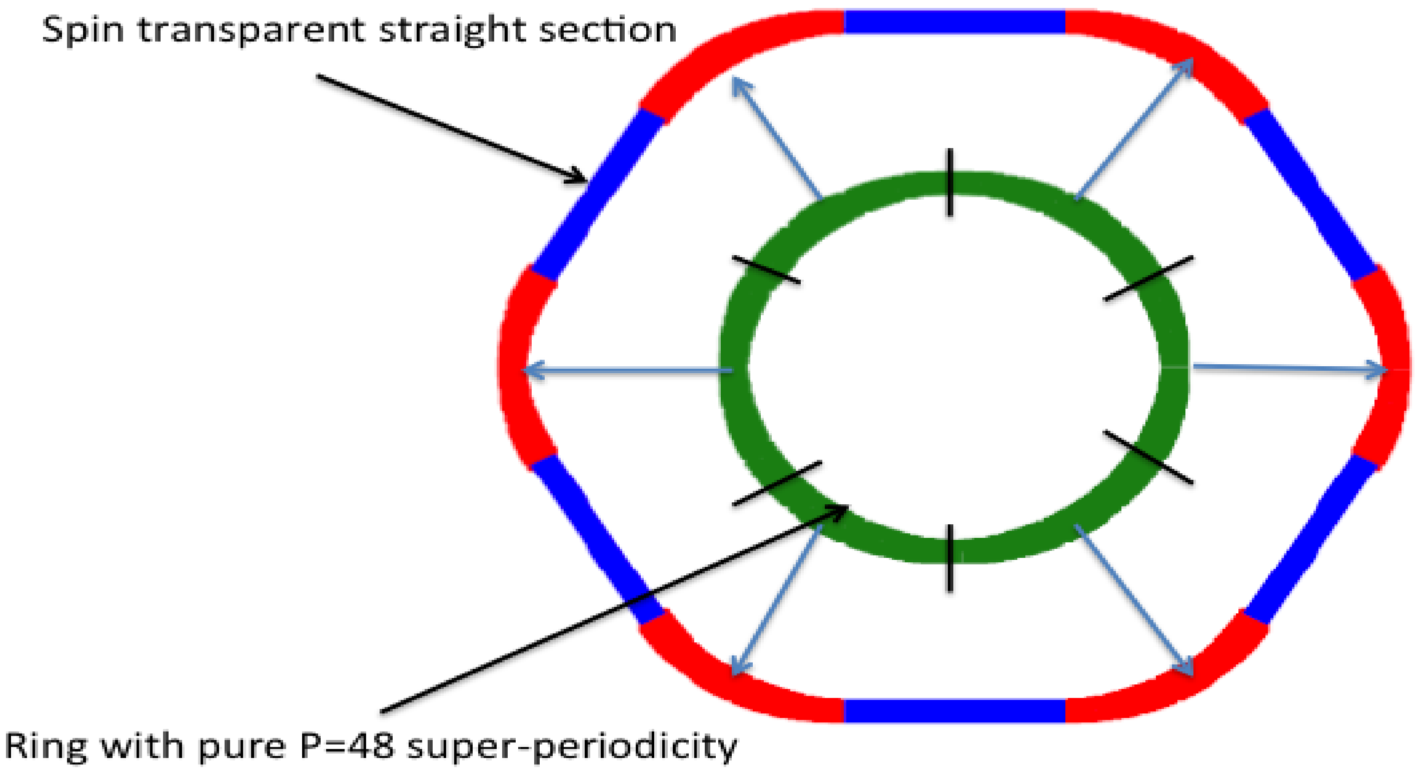
A spin resonance free electron ring injector for an electron ion collider. Such an accelerator will provide spin polarized electrons for energies up to 20 GeV. The proposed device will fit in the existing RHIC tunnel, employ standard technology

- This can be accomplished due to the fact that both the strong intrinsic and imperfection resonances occur at:
  - K = nP +/- Qy
  - K = nP +/- [Qy] (integer part of tune)
- To accelerate from 200 MeV to 20 GeV requires the spin tune ramping from:
  - 0.24 < Ggamma < 45.5.
- If we use a periodicity of P=48 and a tune with an integer value also equal to 48 then our first two intrinsic resonances will occur outside of the range of our spin tunes
    - K1 = 48 – 48.nuy = nuy (nuy is the factional part of the tune)
    - K2 = 2*48 – 48.nuy = 48.nuy
- Also our Imperfection will follow suit:
    - K1 = 48 – 48 = 0
    - K2 = 2*48 – 48 = 48

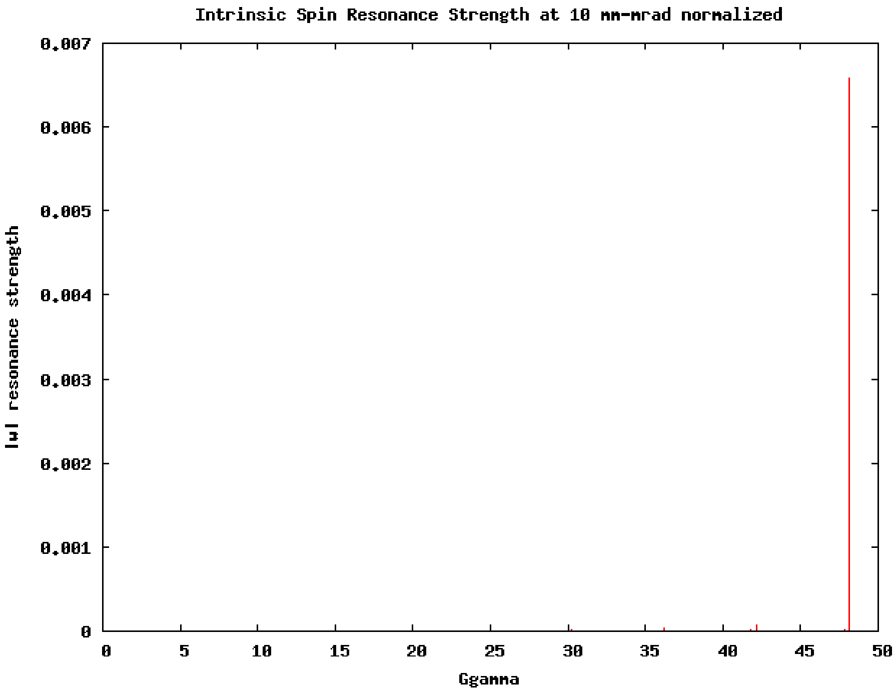
How to make this work in the RHIC tunnel?

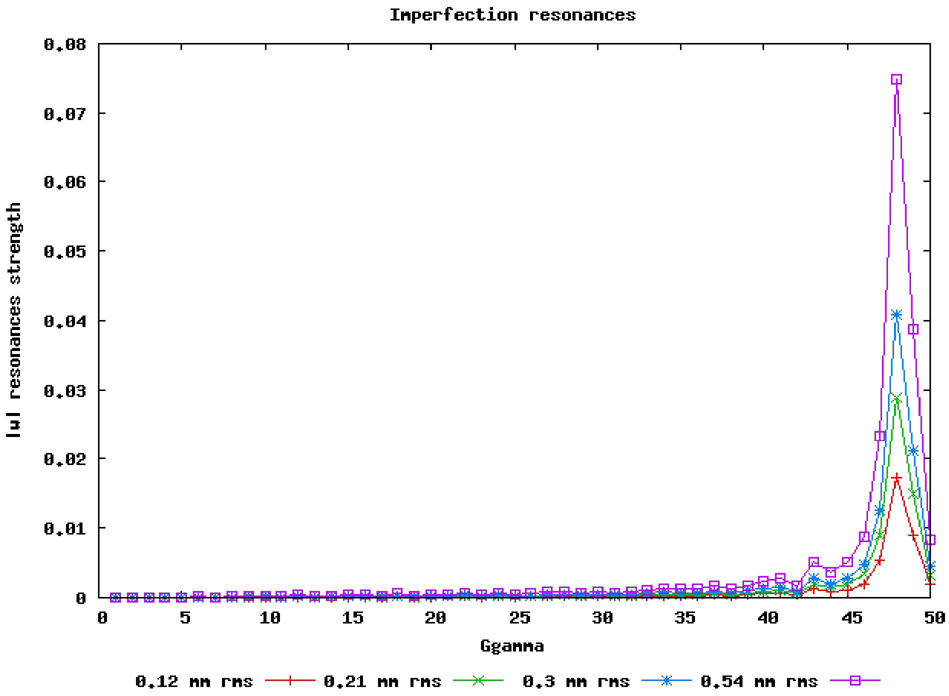
- It is easy to accomplish this with a perfectly circular ring. Just construct a series of FODO cells with bending magnets so that we have total periodicity of 48.
- The problem is that the RHIC tunnel is not circular and has an inherent six fold symmetry.
- The Solution make the spin resonances integrals over the straight sections equal to zero.

Project onto the RHIC tunnel

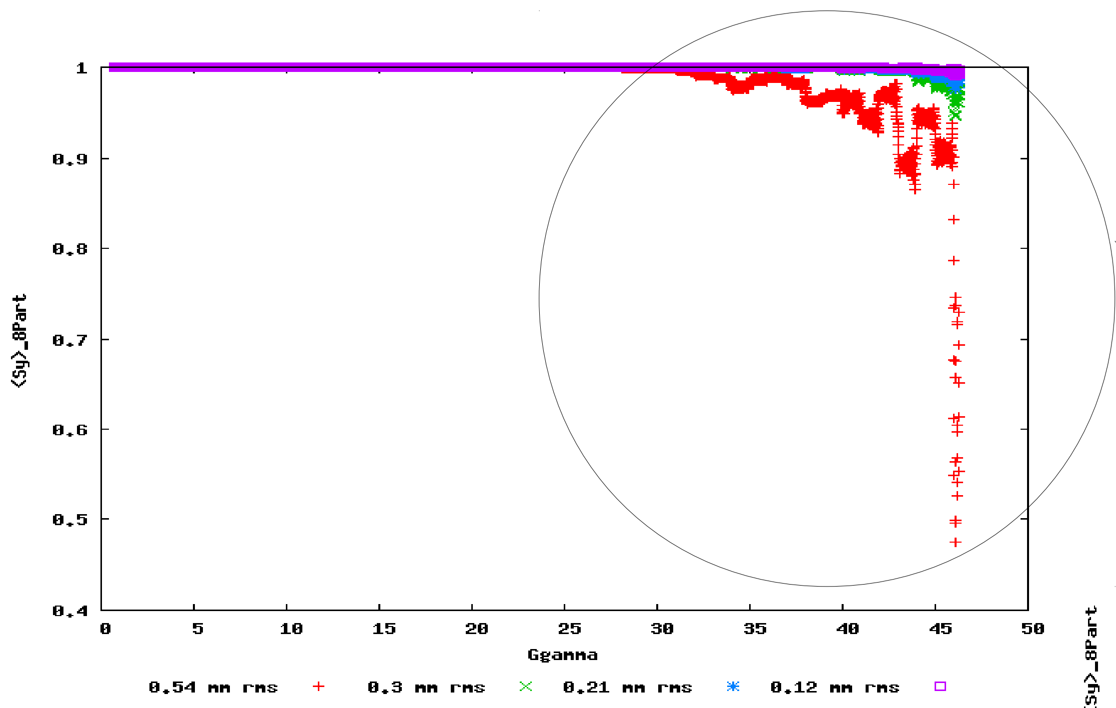


Checking the Spin Resonances with DEPOL





Check with Tracking with closed orbit errors



Zoom at End of Ramp

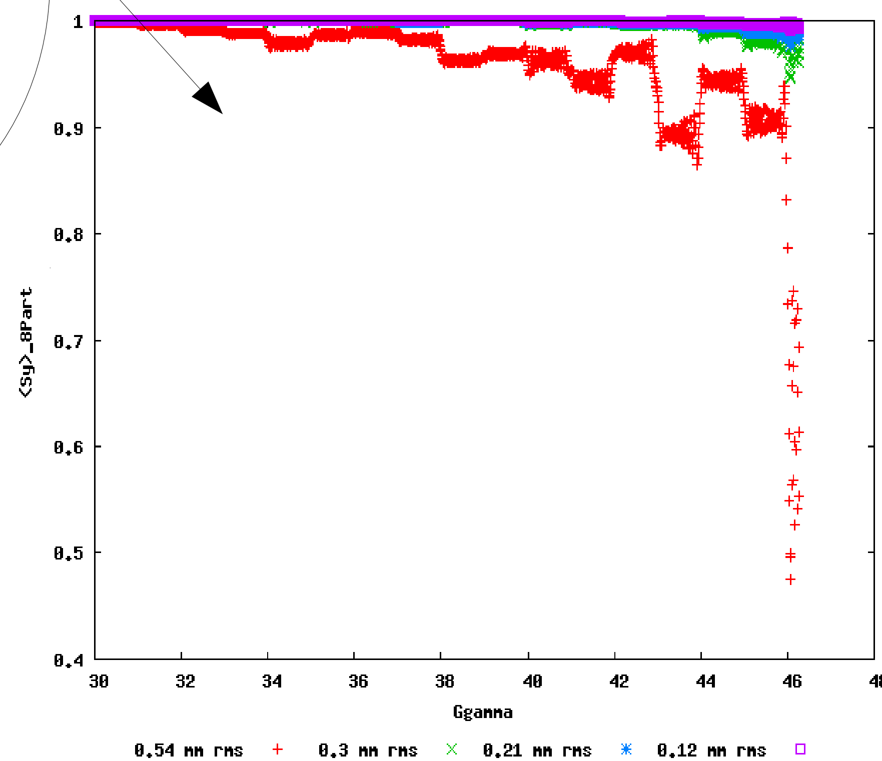


FIG. 5. Zgoubi 8 particle tracking using 50 msec ramp rate with 0.54, 0.3, 0.21 and 0.12 mm rms closed orbit errors. Plot of $G\gamma = 0$ to 46 (top) with a zoom from $G\gamma = 0$ to 46 (bottom)'

Effect of Dipole Roll

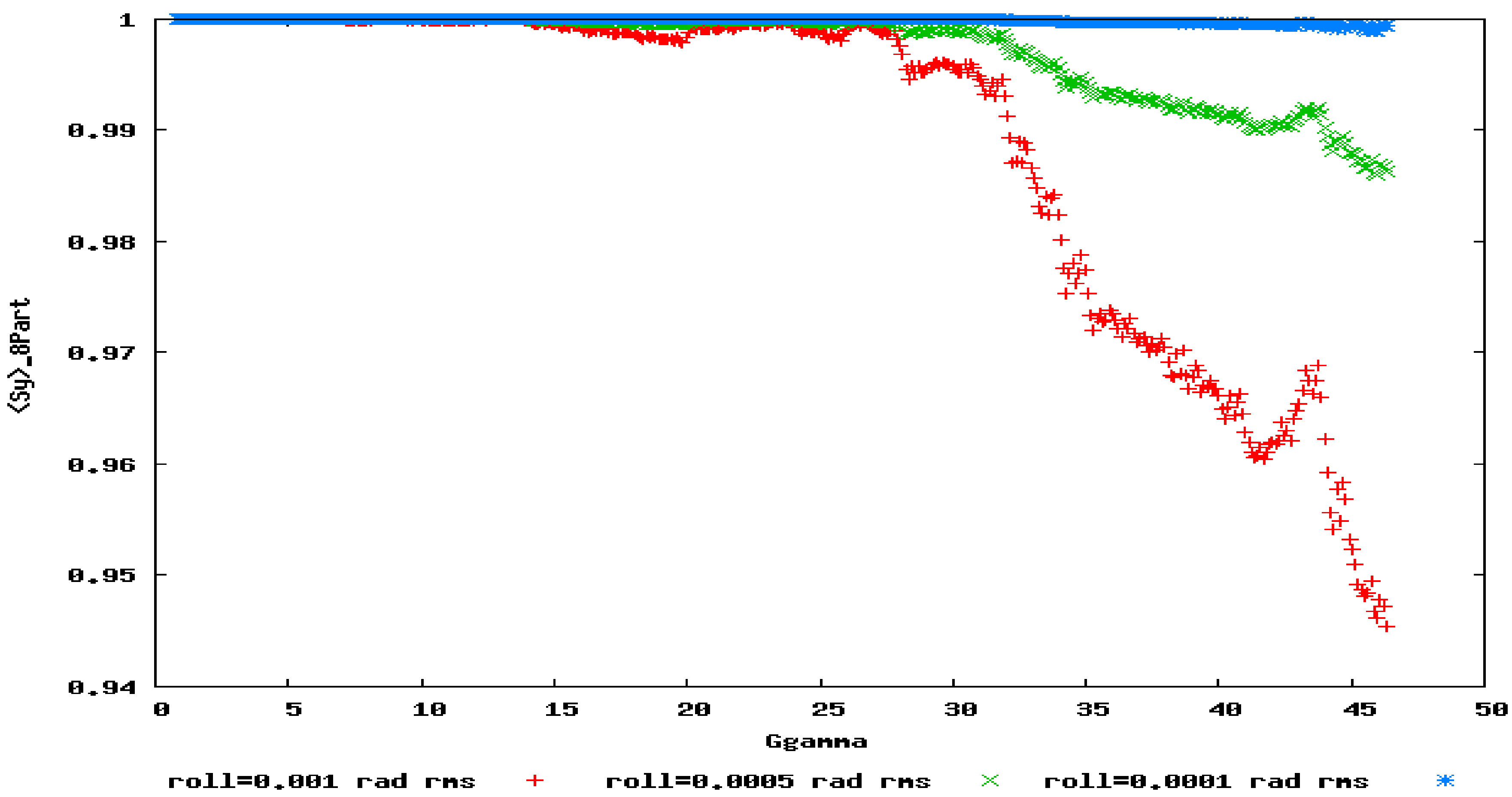


FIG. 8. Zgoubi 8 particle tracking using 5 msec ramp rate with only Dipole Rolls.'

Dipole Rolls with Fast and Slow Ramp rate

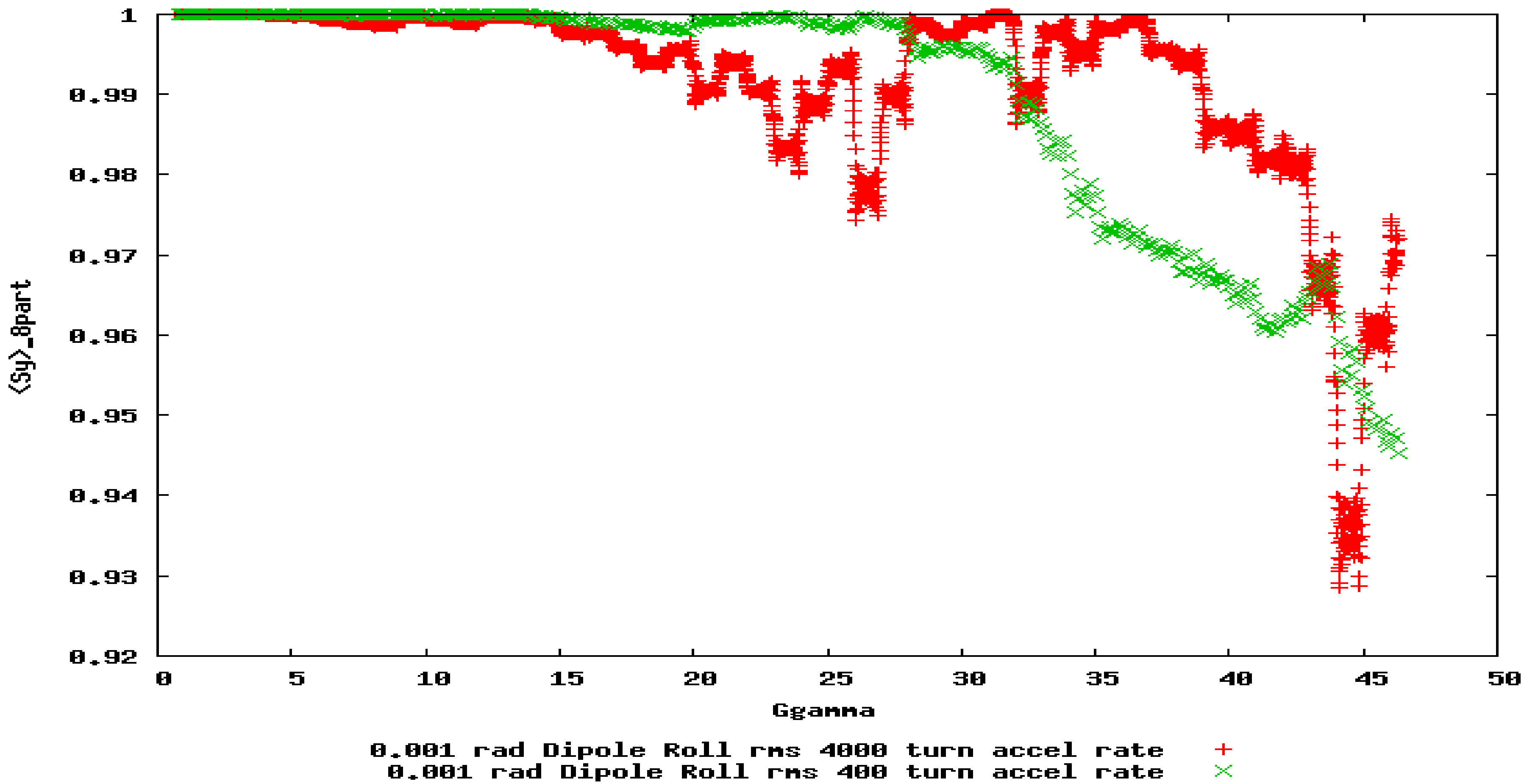


FIG. 9. Effect of ramp rate 5 versus 50 msec ramp rate.

Effect of Ramp Rate 5 to 50 msec with 0.3 mm rms orbit errors

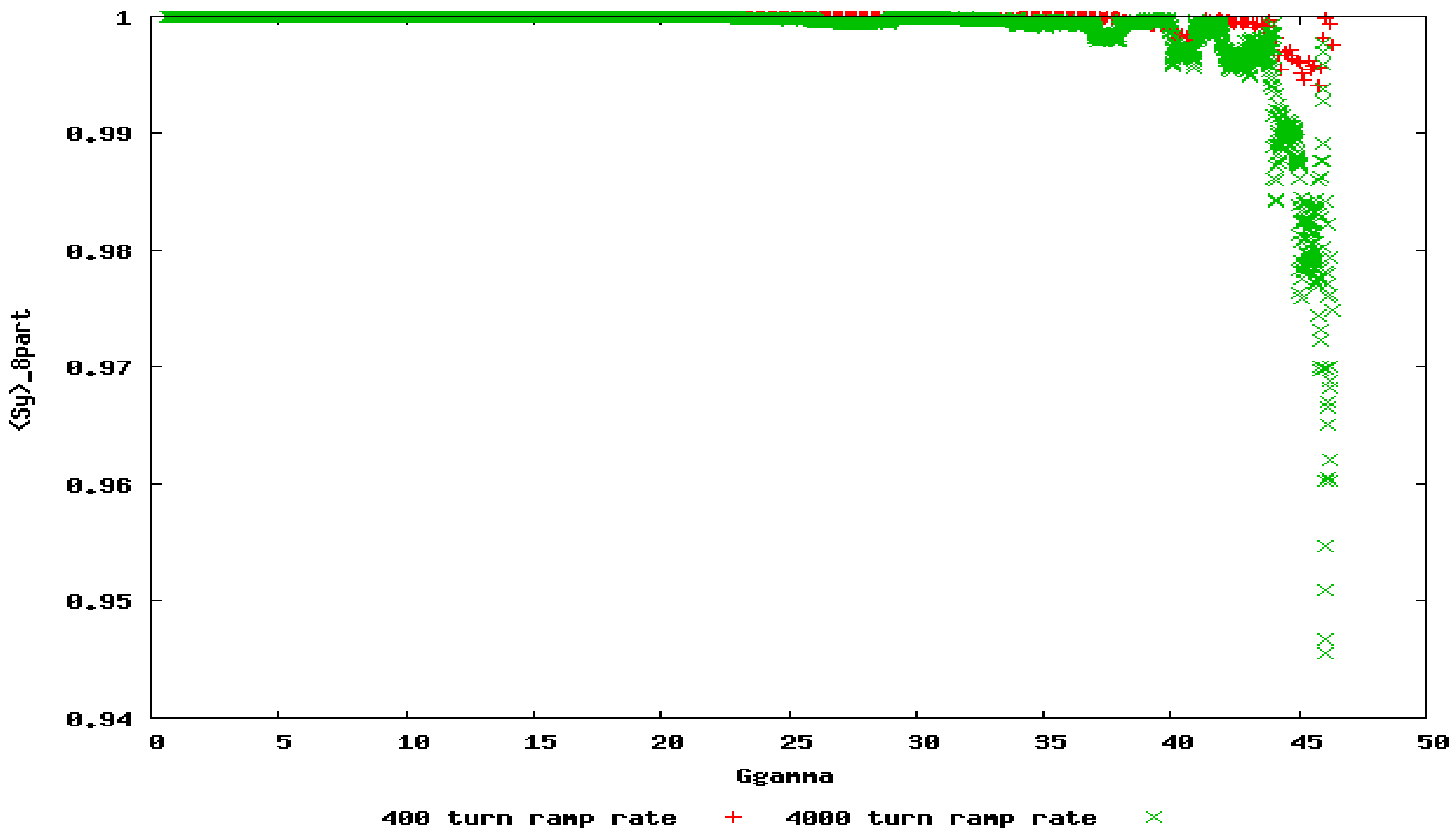


FIG. 6. Effect of ramp rate 5 versus 50 msec ramp rate with closed orbit errors of 0.3 mm rms

Lattice tolerances

- The effect of intrinsic resonances are non-existent (we will run out of aperture before the can effect the spin)
- Major effect from Imperfections and Dipole rolls
  - We can handle up 0.3 mm rms orbit distortion for the 50 msec ramp.
    - This is what RHIC easily does currently.
    - Also these orbit tolerance are in force only at the top end of the ramp so at Ggamma above 44. below 30 Ggamma

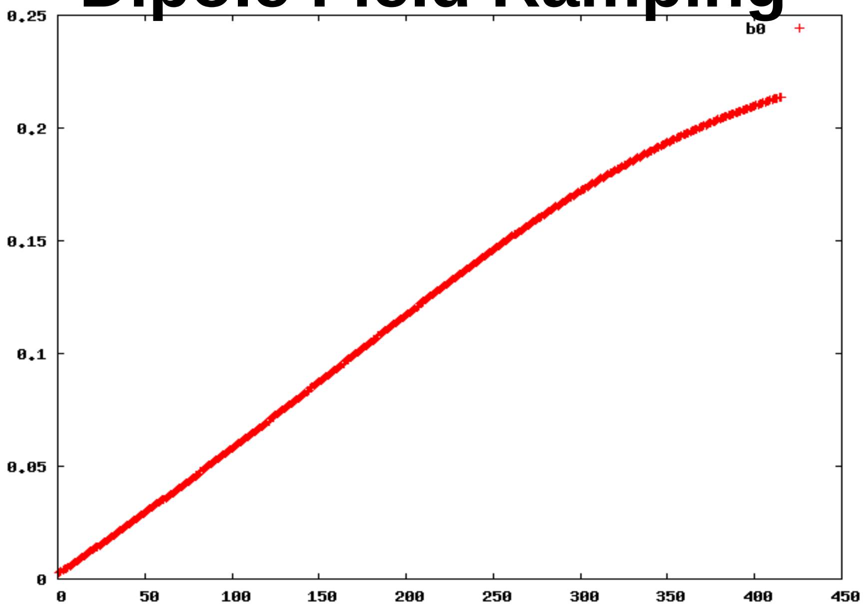
      we could tolerate much more than 0.54 mm rms.
  - We can handle effects due to Dipole rolls less than 0.5 mrad rms.

Can we ramp this fast?

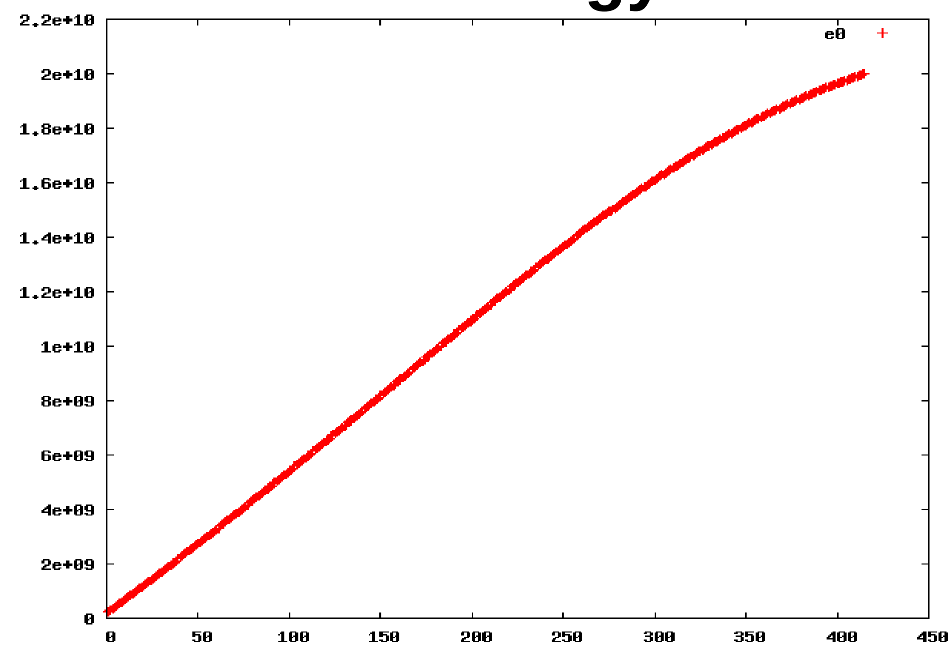
Can we build a cost and risk effective system to take us from 200 MeV to 20 GeV over 5-50 msecs?

- From just the point of view of ramping the dipoles it shouldn't be a problem
  - Dipoles for this lattice are L=4.64 m, angle = 0.016363 rad.
  - At 20 GeV reach peak field of 0.22 Tesla. We should at least be able to cycle in 50 msec (20Hz) (for example ISIS ring at Rutherford Lab does 0.7 Tesla in 50 Hz)
- From the point of view of RF, this might be more challenging.
  - If we account for radiation power loss we can get to top energy over approximately 400 turns using a single cavity powered at a fixed 60 MV per turn and fixed phase.

Dipole Field Ramping



Beam Energy



Outstanding RF Questions

- However there are other issues:
  - What are the tolerances per SRF cavity in terms of mechanical stress to cycle the stored energy over this time frame? Will the system the system drive any mechanical resonances?
    - Over how many cavities will we need to distribute the 60MV to avoid the need for active feedback?
    - How does this escalate the cost?
    - These all depend on the details of the mechanical modes, the quality factor and the Lorentz detuning coefficient kappa, which are undefined right now.

Slower Ramp Rate with Partial Snake

- If we reduce our ramp rate to 500 msec then the tolerances on the orbit might be very difficult to reach.
- However this might be solved by introducing a partial solenoidal snake somewhat similar to what we use to have in the AGS (5-10% snake)
  - Using 7.24 m solenoid ramped from 0.02 T to 4 T over ½ second during acceleration from 200 MeV to 20 GeV.
  - This will take care of the imperfections, however care must be taken so that it doesn't break the symmetry too much and introduce intrinsic resonances that are too large.
  - We are currently studying this option