ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-WEPOPT020

MODELING RHIC SPIN TILT AS LATTICE IMPERFECTIONS

V. H. Ranjbar*, F. Meot, E.C. Aschenauer, H. Huang, A. Marusic, V. Schoefer
Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

A tilt in the spin direction from the vertical has been observed for a number of years in the RHIC collider during store. This tilt has been extensively studied by scanning snake strengths, energies and orbital angles during the 2017 polarized proton run, and more recently during the 2022 polarized proton run. Using a spin transport model, we attempt to model this spin tilt by fitting all the relevant data.

INTRODUCTION

Since the 2013 polarized RHIC polarized proton run at 255 GeV a tilt in the spin at the location of Carbon target polarimeter has been observed. During the 2017 polarized RHIC [1]run we conducted several studies to better understand the cause of this tilt. These tests involved scanning the energy and snake settings and orbital angles at the snakes to observe the response of this spin tilt.

FITTING SINGLE IMPERFECTION SPIN RESONANCE

Our initial hypothesis was that possibly there might be some significant de-tuning of our snakes. That our snakes were not achieving the full 180 degree rotation about the ±45 degree angle relative to the beam trajectory. However other studies scanning the energy and snake settings at injection energy showed that deviations of the magnitude necessary to tilt the spin by the observed 15 degrees at 255 GeV would also perturb the spin tune and perturb the spin direction at injection energies as well. While there was some spin tilt at injection as we scanned the energy. The amount of spin tilt was too small to account for a systematic difference in the snakes even accounting for the energy difference. Additionally studies going on that year involving the spin tune and spin flipper didn't point to deviations in the performance of the snakes on the level to account for the observed spin tilt. Thus we believed that the source of the spin tilt was due to imperfection spin resonances, either due to a local or global source.

Using a simple spin transport model including snakes and single spin resonance we varied the phase and magnitude of an imperfection near the 255 GeV energy to see how well the introduction of such a perturbing spin resonance might explain the data. We modeled the snakes using the 2D spinor transport form:

$$\begin{aligned} e^{-i\frac{\mu}{2}(\cos\phi_s\sigma_1+\sin\phi_s\sigma_2)} &= \cos\frac{\mu}{2} - i(\sigma_1\cos\phi_s + \\ &\quad \sigma_2\sin\phi_s)\sin\frac{\mu}{/2} \\ &= T_s(\mu,\phi_s) \end{aligned} \quad (1)$$

where $\sigma_{1,2,2}$ are the 2x2 pauli spin matrices, μ is the angle of spin rotation and ϕ_s the angle of the axis relative to the direction of the beam about which the spin is rotated. Between the snakes the spin is transported using a solution to the Thomas-BMT equation for a single spin resonance:

$$(\theta_f,\theta_i) = e^{-i\frac{K}{2}\theta_f\sigma_3}e^{\frac{i}{2}((K-G\gamma)\sigma_3+w_r\sigma_1-w_i\sigma_2)(\theta_f-\theta_i)}e^{i\frac{K}{2}\theta_i\sigma_3} \quad (2)$$

Here K is the value of Gγ where the spin resonance is present, w_i and w_r the real and imaginary part of the spin resonance strength. The total spin transport once around the ring starting from the polarimeter where the tilt is measured now becomes:

$$T = t(2\pi,\theta_s+\pi)T_s(\mu,-\phi_s)t(\theta_s+\pi,\theta_s)T_s(\mu,\phi_s)t(\theta_s,0) \quad (3)$$

Here θ_s=2.04460321 rad is the location of the first blue snake relative to the polarimeter. From this one turn map the components of the closed orbit stable spin vector can be calculated using:

$$\begin{aligned} S_1 &= T^*_{1,1}T_{2,1} + T_{1,1}T^*_{2,1} \\ S_2 &= i(T^*_{1,1}T_{2,1} - T_{1,1}T^*_{2,1}) \\ S_3 &= |T_{1,1}|^2 - |T_{2,1}|^2 \end{aligned} \quad (4)$$

The angle relative to the vertical can then be estimated using $\theta = \arctan(S_3/S_1) - \pi$. Using this our best fits to the data for the first set of runs involving energy and snake scans yielded an imperfection at Gγ=486. This is relative to our nominal energy at 487. Including a 4 degree bump caused by the orbit through the snakes, we found an imperfection resonance strength with a total magnitude of about 0.07 with equal imaginary and real parts, could reproduce some (though not all) of the structure, as shown in Figures 1-5. However a later scan involving changing the orbital angle at the second snake (the one near 9 'oclock) showed that the best results involved using a single resonance K at Gγ of 487 with a magnitude of about 0.12 and real and imaginary strength of 0.01 and 0.12 respectively. In Figure 6 this fit is plotted along with the previous using K=486.

ANALYSIS AND FUTURE WORK

The use of this simple model does demonstrate that near 255 GeV modest imperfection resonances can produce tilts on the order observed. In some cases it does a decent job of capturing the tilt response, still a fully consistent picture alludes it. This suggests that a model with more complexity is required. This simple model has been extended to include multiple nearby spin resonances using an approach involving a magnus type of integrator which has been developed previously [2]. Perhaps more useful in the long run would

* vranjbar@bnl.gov

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-WEPOPT020

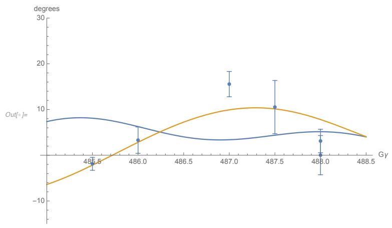

Figure 1: Energy Scan with nominal snake settings (Iout=323 A, Iin=100 A) compared to model with snakes only and with imperfection resonances at K=486 and strength with magnitude of 0.07.

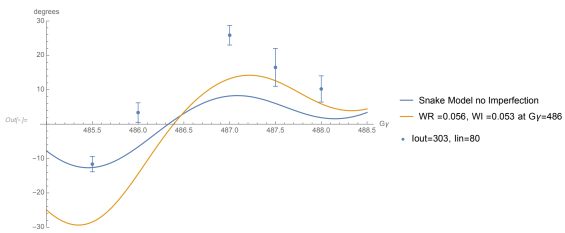

Figure 2: Energy Scan with snake settings Iout=303 A, Iin=80, compared to model with snakes only and with imperfection resonances at K=486 and strength with magnitude of 0.07.

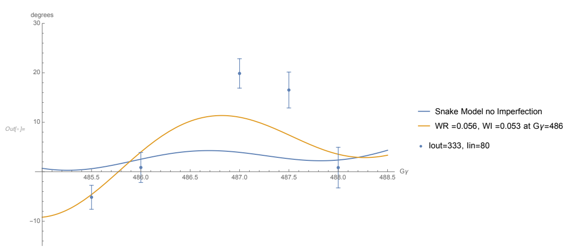

Figure 3: Energy Scan with snake settings Iout=333 A, Iin=80, compared to model with snakes only and with imperfection resonances at K=486 and strength with magnitude of 0.07.

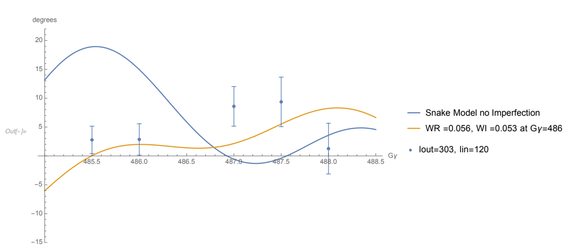

Figure 4: Energy Scan with snake settings Iout=303 A, Iin=120, compared to model with snakes only and with imperfection resonances at K=486 and strength with magnitude of 0.07.

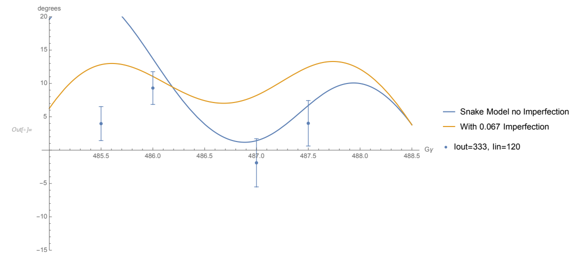

Figure 5: Energy Scan with snake settings Iout=333 A, Iin=80, compared to model with snakes only and with imperfection resonances at K=486 and strength with magnitude of 0.07.

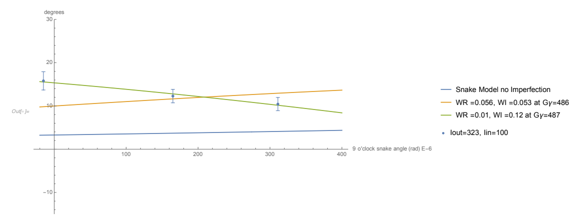

Figure 6: 9 o'clock snake angle scan with snake settings Iout=323 A, Iin=100, compared to model with snakes only and with imperfection resonances at K=486 and strength with magnitude of 0.07 and a best fit model using K=487 with magnitude of 0.12.

be to develop a fit using the a full 6D tracking model, as has been done with the Zgoubi code. In this case varying a set of orbit correctors could be used to fit this data to develop a fully self-consistent model. The virtue of this approach is that it builds on much of the effort this year (2022) [3] used to characterize the snakes and spin rotators in Zgoubi.

ACKNOWLEDGEMENTS

Work supported by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704.

REFERENCES

[1] V. H. Ranjbar *et al.*, "RHIC Polarized Proton Operation for 2017", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 2188–2190. doi:10.18429/JACoW-IPAC2017-TUPVA050

[2] V. H. Ranjbar, "Calculating the polarization lifetime from the Thomas-Bargmann-Michel-Telegdi equation," *Phys. Rev. Accel. Beams*, vol. 22 no. 9, ps. 091001, 2019. doi:10.1103/PhysRevAccelBeams.22.091001

[3] F. Meot *et al.*, "RHIC Blue Snake Blues", in Proc. 13th Int. Particle Accelerator Conf. (IPAC'22), Bangkok, Thailand, Jun. 2022, paper WEPOPT019, this conference.