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POLARIZATION TRANSMISSION AT RHIC, NUMERICAL SIMULATIONS * †

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Abstract

Typical tracking simulations regarding the transmission of the polarization in the proton-proton collider RHIC are discussed. They participate in general studies aimed at understanding and improving polarization performances during polarized proton-proton runs.

INTRODUCTION

The transmission of beam polarization during the acceleration ramp in RHIC, in various conditions of orbit and other possible machine defects, is routinely investigated by means of spin tracking. The results reported here are a follow-on of works that have been subject to earlier publication, e.g. in IPAC-10, -11 and PAC11 Conferences, and can be referred to for details on tracking tools and methods.

As input data the simulations discussed here use *measured* beam properties : orbits, tunes, chromaticities. In addition to studying the transmission of polarization in RHIC, they are part of benchmarking efforts regarding the spin tracking codes in use [1, 2]. They also illustrate the methods employed - a lot more can be found in the C-AD "Spin Meeting" minutes [3].

In this paper Zgoubi simulations are first presented and discussed. Then UAL-SPINK simulations in similar optical conditions are addressed.

ZGOUBI TRACKING RESULTS

Optics conditions

RHIC optical conditions accounted for are the so-called "Run 11, pp11v7" settings, namely, tunes and chromaticites satisfy

$Q_x = 28.685,\ Q_y = 29.673,\ Q'_x \approx Q'_y \approx 2,$
conditions include (i) measured orbits, featuring 25μm rms horizontal and vertical amplitude in the arcs, (ii) together with vertical orbit separation at interaction points (IP), whereas (iii) store β^* values are taken, namely :

IP location	6	8	10	12	2	4
$\beta^*_{x,y}$	0.65	0.65	6.5	6.5	3	6.5

In future simulations it is planned to account for the change of β^* values during the ramp as displayed in Fig. 1,

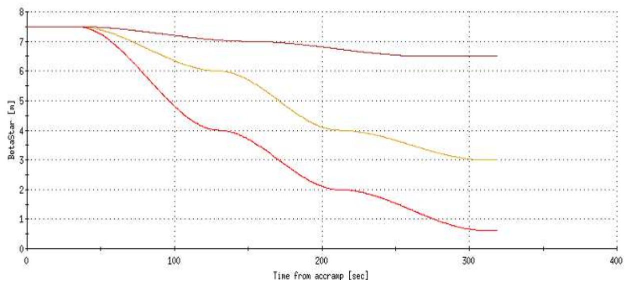

Figure 1: Design β^* values at IPs during the ramp. The timings at the crossing of the three strongest resonances ($G\gamma$ =231+Qy, 411-Qy, 393+Qy) are respectively 150, 208, 228 ms about.

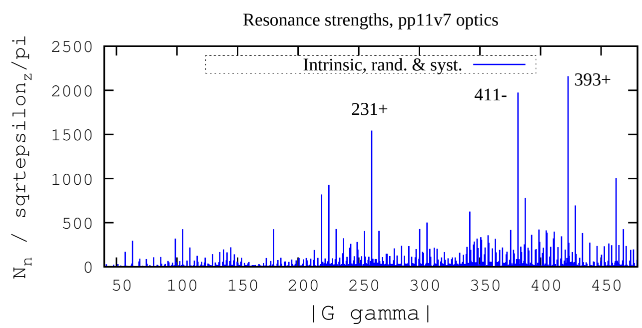

Figure 2: Strengths of the intrinsic depolarizing resonances in the "thin lens" model, normalized to $\sqrt{\epsilon_y/\pi}$.

namely, the actual values at IP6 and IP8 should be 4 m at $G\gamma = 231 + Q_y$ and 2 m at $G\gamma = 411 - Q_y$ and $G\gamma = 393 + Q_y$, locations of the major three depolarizing resonances crossed during the acceleration ramp (Fig. 2).

4032 particles are tracked. Initial coordinates are sorted at random in 2-D transverse densities (x,x'), (y,y') Gaussian in projection, with $\sigma_{\epsilon_y} = 2.5\pi$mm.mrd normalized rms emittance, cut-off at $4\sigma_{\epsilon_y}$, and Gaussian momentum spread with rms value $\sigma_{dp/p} = 1.4 \times 10^{-4}$ at 250 GeV, cut-off at $2\sigma_{dp/p}$ (Fig. 3).

All particles are launched with spin vertical for simplic-

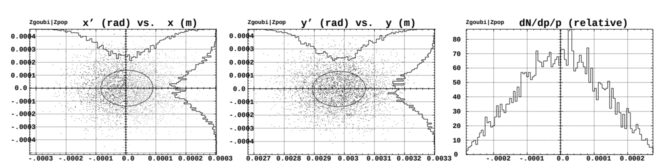

Figure 3: Left, middle : (x,x'), (y,y') phase space densities in the initial object and their Gaussian projections. Right : Gaussian momentum spread. Case $G\gamma = 411 - Q_y$ shown.

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ity, however (i) spins converge to stable precession motion in a few hundred turns at the start of the tracking, and so does their vertical projection $<S_y>$, (ii) the subsequent spread of $<S_y>$ happens to be small, since the starting $G\gamma$ value is far from any strong resonance. The strengths of the intrinsic depolarizing resonances in these "Run 11, pp11v7" optics are given in Fig. 2.

Finally, the ramp is covered with 80 kV peak voltage, 150 degrees synchronous phase, which corresponds to $d\gamma/dt = 2.3$, i.e. twice the actual Run 11 conditions. The reason for that is in the saving of a factor 2 on CPU time, the duration of the tracking across each resonance is 35 hours about, on NERSC's Hopper computer.

Turn-by-turn average of $<S_y>$

Observation location is at the first of two snakes in RHIC. The 3 samples, 1000, 3000, 4000 particles in Fig. 4 show the convergence of the results.

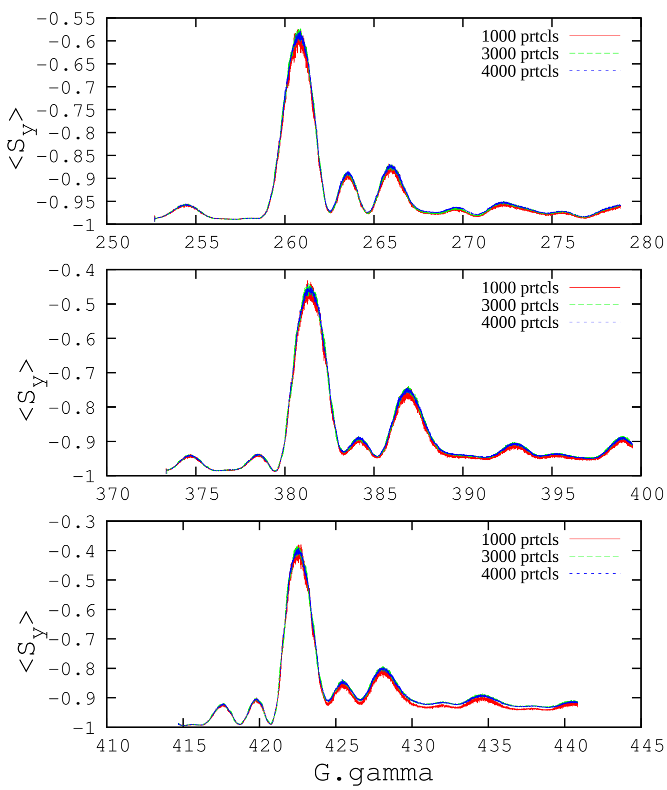

Figure 4: Average of the projection of spins on the vertical, turn by turn. From top to bottom : crossing of $G\gamma$ =231+Qy, 411-Qy, 393+Qy resonances.

Transmission efficiency

Initial polarization : (i) all particles are launched with their spin vertical, thus requiring a number of turns for $<S_y>$ to stabilize ; (ii) the starting point may not be a local minimum. For these reasons, $<S_y>$ at start is approached numerically by interpolating over a few hundred turns at a nearby minimum, this is described in Fig. 5.

Final polarization is computed at a $G\gamma$ value taken in the high energy end of the tracking range (the right end of the $<S_y>$ curves in Fig. 4), at a location that coincides with a local minimum of $<S_y>$. This is detailed in Fig. 5.

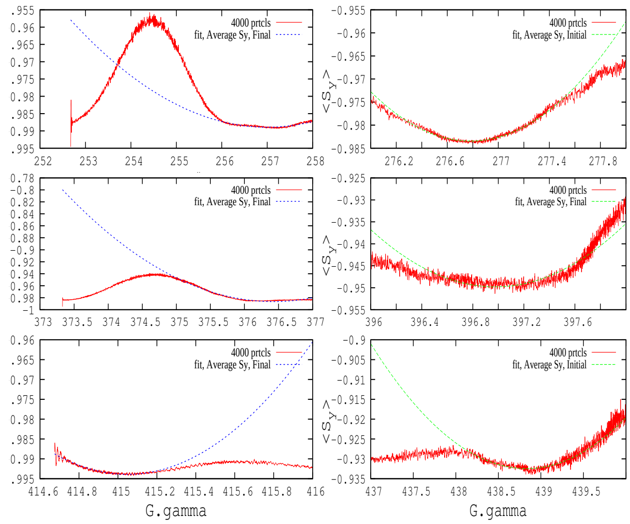

Figure 5: $<S_y>$ at local initial (left) and local final (right) minimum of $<S_y>$. From top to bottom : $G\gamma$ =231+Qy, 411-Qy, 393+Qy.

Case of zero orbit

This tracking aims at serving as a reference. It differs from the previous conditions by both H and V orbits, including the separations at IPs, being zero-ed.

The location of observation of turn-by-turn average of S_y is at the first snake. The model, dashed curve in the bottom Fig. 6, is [4]

$<S_y>= 1-8b^2(1-b^2),\ b=\frac{|\epsilon|}{\lambda}\sin\frac{\pi\lambda}{N_s}$

with strength on rms invariant value, after Fig. 2, $|\epsilon| \approx 2200\times\sqrt{\epsilon_{y,rms}/\pi}\approx 0.22$.

Some outcomes

Tab. 1 gives the transmission of polarization in the two cases, pp11v7 optics including 25μm rms H and V orbits in the arcs and vertical separation bumps at IP, or with zero orbit.

Polarization profiles as well as spin tunes can be drawn from these tracking data, this is a work in progress.

UAL-SPINK SIMULATIONS

Optical conditions in these simulations slightly differ from the above, as follows. The lattice was squeezed to 2 m at the two collision IPs (6 and 8), without separation bumps at IPs, tunes $Q_x = 28.685$, $Q_y = 29.675$, chromaticities set to 2 for both planes. Closed orbit distortions were about 120 μ m rms yielding a maximum imperfection resonance strength of 0.03.

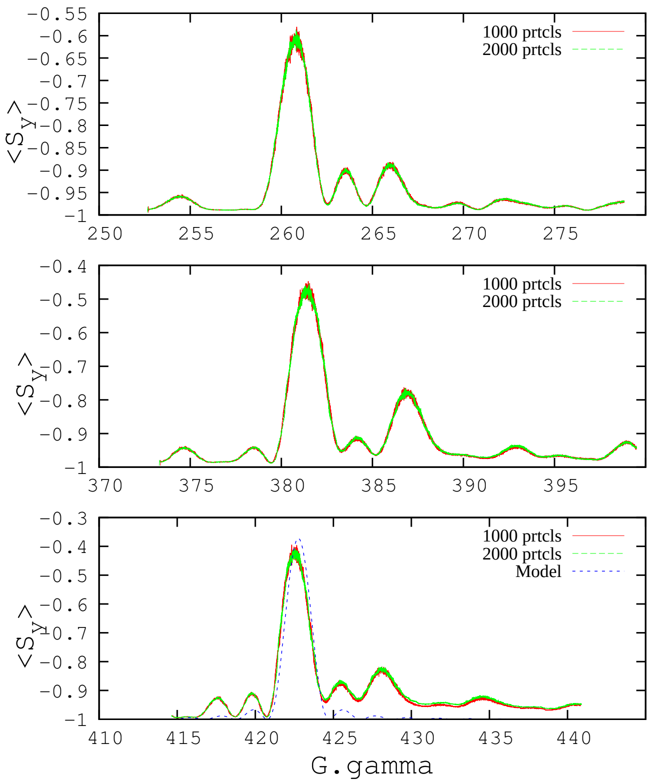

Figure 6: Average of S_y projection of spins, turn by turn. From top to bottom : $G\gamma$=231+Qy, 411-Qy, 393+Qy.

Table 1: Polarization transmission.

	Orbits set		No orbit	
	At start	At end	At start	At end
(1) 231+Qy :				
$<S_y>$	-0.9889	-0.9834	-0.9891	-0.9889
Polar. ratio	1	0.99444	1	0.99987
(2) 411-Qy :				
$<S_y>$	-0.9864	-0.9498	-0.9871	-0.9777
Polar. ratio	1	0.96284	1	0.99052
(3) 393+Qy :				
$<S_y>$	-0.9939	-0.9324	-0.9943	-0.9624
Polar. ratio	1	0.9382	1	0.9679

Fig. 7 shows turn-by-turn $<S_y>$ for 6-D spin tracking of 32760 particles from $G\gamma$=214 to 488 (flattop). Initial transverse distribution was Gaussian $3.33\,\pi$mm-mrad rms emittance normalized and cut at 2 sigma. The longitudinal distribution was Gaussian with rms sigma of 3 nsecs cut at 2 sigma. This was done using the new UAL-SPINK GPU code using MPI + CUDA run on 12 NVIDIA GPU nodes at NERSC's Dirac machine. The total simulation took about 5 days. The acceleration rate was about 8 times the nominal RHIC acceleration rate, or $d\gamma/dt \approx 8.55$. The results yielded an average vertical polarization of 0.87 representing a loss of about 13% during the ramp.

In the two Fig. 8, 9, the red curve is the 4D tracking of 1024 particles (no longitudinal distribution) using the UAL-SPINK GPU code compared with the green curve

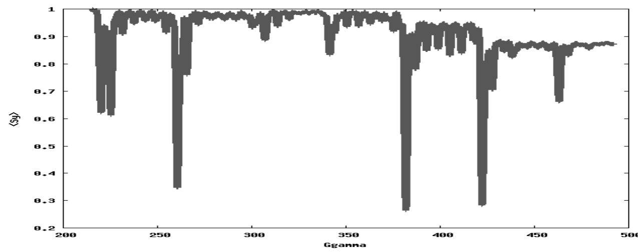

Figure 7: $<S_y>$ over $G\gamma$: $214 \rightarrow 488$, 6-D tracking.

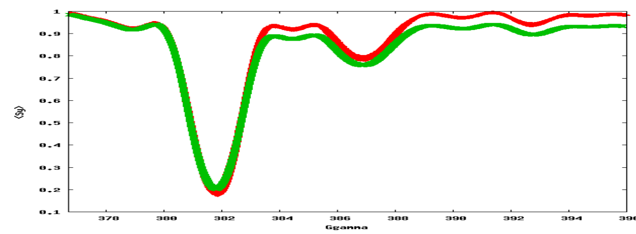

Figure 8: Crossing of $411 - Q_y$, 4-D tracking (red curve) and 6-D tracking (green curve).

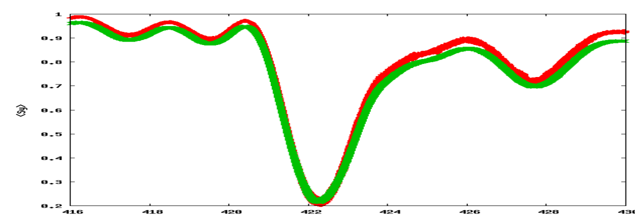

Figure 9: Crossing of $393 + Q_y$, 4-D tracking (red curve) and 6-D tracking (green curve).

6D tracking using 32760 particles with longitudinal distribution 3 nsecs sigma Gaussian distribution cut at 2 sigma. These show crossing the last two strong intrinsic resonances $411 - Q_y$ and $393 + Q_y$. It would appear that the inclusion of longitudinal dynamics adds several percent loss at each resonance crossing.

COMMENTS

Similar simulations have been performed or undertaken with different working conditions (optics, defects, etc.), and are expected to allow assessing effects of various parameters participating in the transport and the optimization of the polarization.

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