STABLE SPIN DIRECTION INVESTIGATIONS IN RHIC*

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Abstract

Beam and spin dynamics investigations are part of the preparations and studies regarding RHIC collider runs, they are part as well of the efforts dedicated to improving stored beam polarization, and in view of the eRHIC EIC project. Some recent studies and their outcomes are discussed.

INTRODUCTION

We present and discuss spin dynamics investigations performed recently as part of the preparations regarding RHIC collider runs, of the efforts dedicated to improving stored beam polarization, and in view of eRHIC project [1]. In the first Section below, we investigate polarized $^3He^{2+}$ transport through AGS to RHIC (AtR) beam line. In the second Section, we investigate perturbations to the stable polarized proton spin direction in RHIC under the effect of snake angle errors.

HELION TRANSPORT THROUGH ATR

In preparation of RHIC/eRHIC plans concerning polarized $^3\mathrm{He}^{2+}$ beams ($^3\mathrm{He}^{2+}$ will be stored in Blue ring), the question arises of the optimum extraction energy from the AGS. This requires computing the transport of the spin $\vec{n}_0$ vector, via the non-planar AtR line (AGS and RHIC differ in elevation by 1.73 m - Fig. 1), from its periodic, non fully vertical, orientation at G10 extraction kicker in the AGS, to the downstream end of RHIC Blue ring injection kicker where it is expected to be as close as possible to the periodic, vertical, RHIC $\vec{n}_0$. As a matter of fact, due to the interleaved horizontal and vertical bends in the AtR, the image of the AGS $\vec{n}_0$ at RHIC injection point varies with beam energy. A goal in this study is to investigate possible causes for polarization loss through the AtR.

Snakes

Partial "snakes" (helical dipoles) are employed to overcome imperfection depolarizing resonances in the AGS. For $^3\mathrm{He}^{2+}$ acceleration quasi-equal warm and cold snake strengths, $14 \sim 15\%$, are considered (by contrast with polarized proton beams for which the two snakes have non-equal strengths, respectively 6 and 11%). This study leans on recent work regarding the AGS snake field maps [2], and on earlier similar study regarding polarized proton beams [3].

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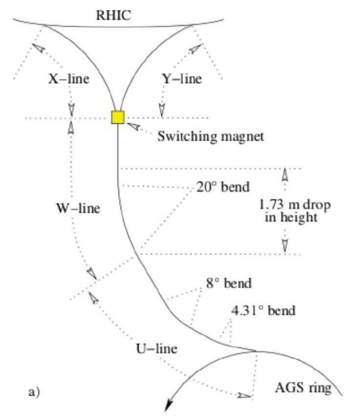

Figure 1: The "AtR" line from AGS to RHIC.

Periodic $\vec{n}_0$ at H10

Local stable spin vector $\vec{n}_0$ at the extraction septum "H10" in the AGS is first found on the closed orbit, in the presence of the extraction orbit bump, upstream of the extraction kicker "G10", and then transported to the extracted side of H10 septum with G10 switched on.

Figure 2: Red curve : horizontal orbit in G10 kicker and H10 septum regions in the AGS, in the presence of the extraction bump. Green : the extraction path when G10 is switched on. x=0 is the unperturbed AGS orbit.

That "extracted" $\vec{n}_0$ at H10 is the quantity which is transported along the AtR down to RHIC injection kicker. A scan is then performed based on these methods, covering the $G\gamma$ region of interest, results are displayed in Fig. 3.

Transport to RHIC

The model of the AtR line includes the H10 septum, the stray field region of H11, H12 and H13 AGS main magnets that the line goes along, the AtR line proper extending from

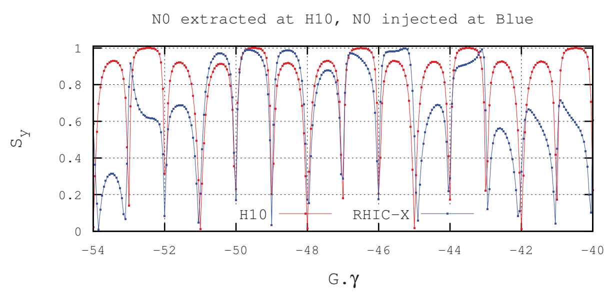

Figure 3: Vertical component of the spin vector $\vec{n}_0$ at AGS H10 septum (red curve) and at RHIC Blue injection kicker (blue curve).

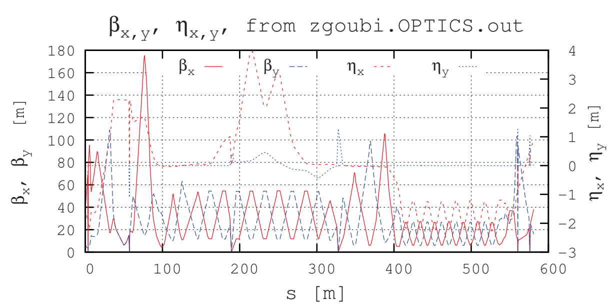

Figure 4: Optics of the AtR line from "UBEGIN" to RHIC Blue ring kicker.

"UBEGIN" start point of "U" line (Fig. 1) to RHIC Blue ring kicker via the "W" and "X" lines, optics as shown in Fig. 4.

The vertical projection of the $\vec{n}_0$ vector at RHIC Blue kicker is then computed over $G\gamma \in [-54, -40]$, Fig. 3. That scan allows determining the optimum $G\gamma$ for AGS extraction : it has to be close to a half-integer value, and such that the vertical projection of the $\vec{n}_0$ is closest to 1 at the injection kicker at the downstream end of the X line.

Perturbations

In an effort to find out possible causes for polarization loss through the AtR [4], perturbations have been introduced in the "ideal" beam conditions at "UBEGIN". Perturbations investigated include momentum spread, horizontal and vertical beam mis-centering in position and angle, and vertical emittance, details in [5]. The former first two types of perturbations only have marginal effect on beam polarization at RHIC.

The latter case does reveal non-negligible effects, this is displayed in Fig. 5, obtained is the following manner : a bunch is launched from "UBEGIN", comprised of 10^3 particles in Gaussian emittance $\epsilon_y = 0,\ 1,\ 2,\ 5,$ or 10 times $2.5\,\pi\mu$m, normalized, truncated at $9\sigma_{\epsilon_y}$. The effect of vertical emittance is apparent : depending on $G\gamma$, $< S_y >$ varies by up to several % (absolute).

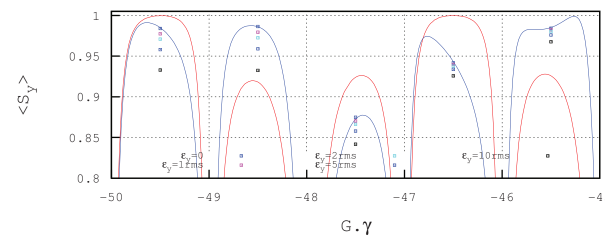

Figure 5: Effect of non-zero vertical emittance. Markers : case of vertical emittance $\epsilon_y = 0,\ 1,\ 2,\ 5,$ or $10{\times}2.5\,\pi\mu$m. Solid lines are in the zero-emittance case (as in Fig. 3).

$\vec{N}_0$ AT RHIC POLARIMETER

Recent analysis of run13 p-carbon polarimeter measurements showed that polarized proton stable spin direction was tilted a significant 14 deg from vertical, both at injection, 23.8 GeV, and at store, 255 GeV. A possible origin of the tilt is in spin rotation defects in one or both RHIC snakes. This hypothesis is investigated by scanning the snake axis angle μ, and the spin rotation angle at the snake, ϕ, in the vicinity of their nominal values, details in [6].

Working hypotheses

- RHIC Blue ring is considered,
- 255 GeV store is considered,
- The method in this study consists in changing (i) the orientation of the snake axes, which are contained in the plane of the ring with $\mu_1,\ \mu_2$ their angle to the beam axis, and (ii) the spin rotation angle at the snakes, $\phi_1,\ \phi_2$, within the following limits :

  - snake axes are maintained at constant $\Delta\mu = 90$ degrees from one another (the design value)

  - ϕ_1 and ϕ_2 are moved away from the 180 degrees design value independently from one another.
- For any (μ, ϕ) arrangement, just one set of random orbit defects is run : it remains to be confirmed that this does give a correct idea of the value of the y-normal tilt of spin $\vec{n}_0$ around the ring (by y-normal, it is meant a rotation with axis contained in the horizontal plane, which moves $\vec{n}_0$ away from the vertical).

Method :

A fitting procedure is used to find $\vec{n}_0$ from the lattice once the snake axis angles μ_1, μ_2 or the snake angles ϕ_1, ϕ_2 have been changed.

RHIC optics in these simulations is summarized in Figs. 6, 7. A vertical orbit may be considered, in that case it is scaled from that displayed in Fig. 6; the horizontal orbit is scaled similarly, with the same *rms* value. Orbit separation configuration has also been considered, superposed on the previous random one, Fig. 8.

Typical results

An angle scan in the reference case, zero vertical orbit, is displayed in Fig. 9.

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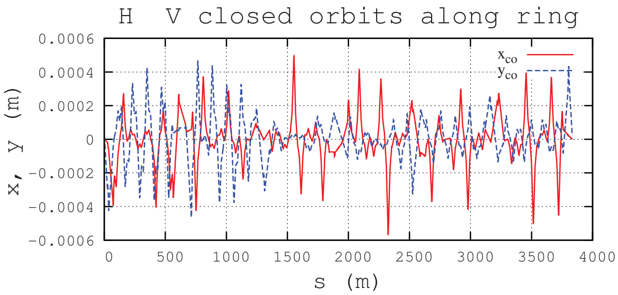

Figure 6: H and V orbits. The *rms* value of the vertical orbit in the arcs is 25μm.

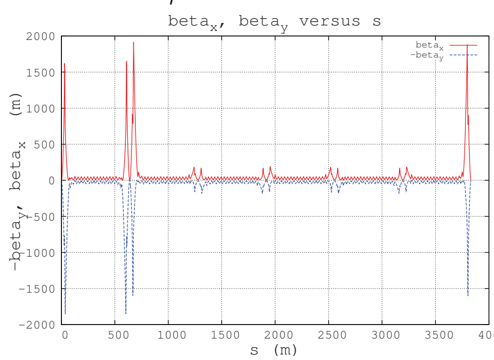

Figure 7: Horizontal and vertical optical functions.

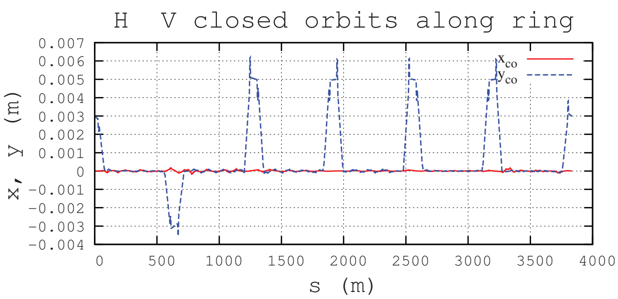

Figure 8: H and V orbits. The left two bumps (IP6 and IP8 collision points) are canceled during collision. The rms value of the vertical orbit in the arcs is 25μm.

The angle scan in Fig. 10 is in the case of a 0.26 mm *rms* vertical orbit (same as in Fig. 6, scaled, no vertical separation bumps).

The angle scan in Fig. 11 is in the case of a 0.025 mm *rms* vertical orbit and with vertical separation bumps at all IPs but IP6, IP8.

Outcomes

Assuming correct orientation of the spin precession axes, +45 and -45 deg at RHIC snakes, the following results from these snake axis and spin angle scans :

- In the presence of the vertical separation bumps, a $\pm$10 deg. error on the snake angles ϕ_1, ϕ_2 may entail $\sim$11 deg. $y^{\perp}$-tilt of spin $\vec{n}_0$ at the polarimeter,
- Without separation bumps the effect is $\sim$8 deg,
- A defect of $\pm$5 deg in the orientation of the spin precession axis marginally impacts on these results.

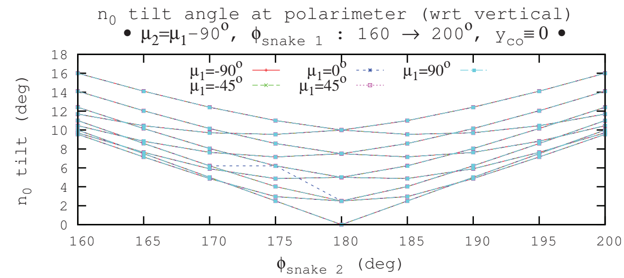

Figure 9: A scan of the tilt angle at polarimeter with respect to vertical, reference case (zero orbit)

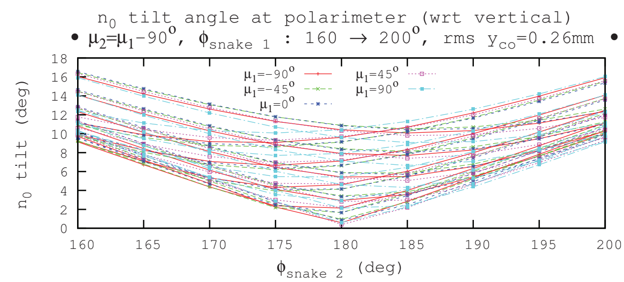

Figure 10: A scan of the tilt angle at polarimeter with respect to vertical, case of 0.26 mm *rms* vertical orbit defect, with vertical separation bumps at all IPs but IP6, IP8.

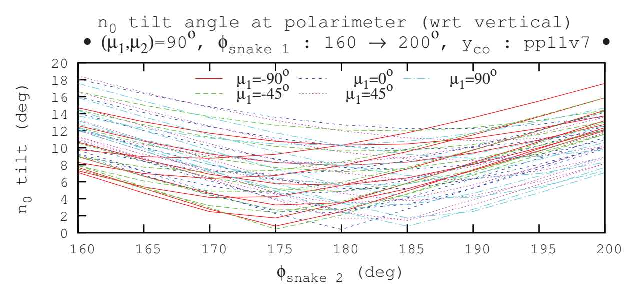

Figure 11: A scan of the tilt angle at polarimeter with respect to vertical, case of vertical separation bumps at all IPs but IP6, IP8, and 25 μm *rms* vertical orbit defect.

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