BNL-101975-2014-TECH
AD/RHIC/63;BNL-101975-2013-IR

Effect of the Vertical Bends in ATR Transfer Line on the Polarized Proton Operation

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January 1990

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U.S. Department of Energy
USDOE Office of Science (SC)

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ABSTRACT

The transfer line from AGS to RHIC (ATR) has a section of 15° horizontal bends between two ± 10 mrad vertical bends. The intermix between the vertical and the horizontal bends could rotate the spin direction away from the vertical direction. We found that there is a magic energy at which the ATR transfer line is spin transparent to the vertical polarization.

1. Introduction

The physics of polarized of polarized protons has been important to the understanding of the interaction of fundamental particles. At high energy, the role of spin in the strong interaction is unknown. Since AGS has the capability of accelerating polarized protons, it is naturally to extend the spin physics to the RHIC collider energy, i.e. up to 500 GeV cm energy for the proton.

There are studies on the polarization preservation in RHIC[1] by using the local spin rotator called Siberian snake invented by Derbenev and Kondratenko.[2] There are also successful snake experiments at the cooler ring at Indiana University Cyclotron Facility (IUCF).[3]

One remaining question for the RHIC polarized proton operation is the transfer line between the AGS and RHIC (called ATR line), where there is a section of 15° horizontal bend between two vertically pitching dipoles ± 10 mr. The problems is the question whether the section prevents the polarized proton operation in RHIC. We shall study this question in this paper.

[1] S.Y. Lee and E.D. Courant, Phys. Rev. D41, 292 (1990).
[2] Ya. S. Derbenev and A.M. Kondratenko, Particle Acc. 8, 115 (1978).
[3] A. Krisch et al., Phys. Rev. Lett. 63, 1137 (1989).

2. Spin Rotation in the ATR Line

The transfer line from AGS to RHIC (ATR) has been carefully studied by Claus and Foelsche,[4] and is shown in Fig. 1. At the 20^o bend section, a level drop of 1.40 m is achieved by two compensating vertical bends of $\pm$ 10 mrad each. Table 1 taken from ref. 4 lists the components wp1 to wp2A section. Between these two 10 mrad vertical bends, 6 horizontal bend dipoles gives a total of 15^o degree rotation.

When the polarized proton passes through a dipole with orbital angle $\theta = B\ell/B\rho$, the spin is precessed an angle $G\gamma\theta$ relative to the orbital direction around the dipole direction, where $G = (g-2)/2 = 1.7928$ for the proton. For the transfer line, most of the dipoles are horizontal bending dipoles, where the vertical spin will remain vertical without depolarization.

When the vertically polarized proton passes through the first vertically pitching dipole of θ_v the spin direction is tilted away from the vertical axis by

$$\Theta = G\gamma\theta_v \tag{1}$$

relative to the particle moving frame. When the particle passes through $\theta_H = 15^o$ degree dipoles, the polarization is then swept around the vertical axis of the particle moving frame by

$$\Phi = G\gamma\theta_H \tag{2}$$

At the condition that $\Phi = n \cdot 2\pi$, the polarization direction will return to the original direction before the $-\theta_V$ of the vertical pitching dipole. In this special condition, the compensating vertical pitching dipole $-\theta_V$ will restore the vertical spin direction. The magic γ value is then given by

$$G\gamma \cdot \theta_H = 2n\pi$$

or

$$\gamma \simeq 26.77 (G\gamma = 48)$$

Fig. 2 shows the polarization direction (S_x, S_y, S_z) as a function γ after passing through the vertical pitching dipole section. A broad matching section can be used for polarized proton injection into RHIC.

Since the spin precessing angle depends on the momentum, the spread in the spin direction due to the momentum spread is given by

$$\Delta\Phi = 2G\gamma\theta_H \cdot \frac{\Delta\gamma}{\gamma} \tag{4}$$

[4] J. Claus and H. Foelsche, Beam Transfer from AGS to RHIC, RHIC–47, 1988.

Table 1. ATR Beam Line taken from ref. 4, p. 25.

Pos Name	Length [m]	Bend [mrad]	ρ [m]	$B'/(B\rho)$ $[m]^{-2}$
45	6.111450			
46 wp1	1.828800	10.	182.88	
47	6.111450			
48 w3d	3.657900	43.633	83.833108	-0.023528529
49	14.051700			
50 w4f	3.657900	43.633	83.833108	0.023528529
51	14.051700			
52 w5d	3.657900	43.633	83.833108	-0.023528529
53	14.051700			
54 w7f	3.6576	43.633	83.833108	0.023528529
55	14.051700			
56 w7d	3.657900	43.633	83.833108	-0.023528529
57	14.051700			
58 w8f	3.657900	43.633	83.833108	0.023528529
59	13.972064			
60 vq1d	0.740000			-0.1204328
61	14.457299			
62 vq2f	0.740000			0.11939398
63	8.214856			
64 wp2a	1.828800	-10.	182.88	
65	5.991919			
66 vq3d	0.740000			-0.13049325
67	14.072442			
68 vq4f	0.740000			0.12684975
69	19.581019			
70 vq5d	0.740000			-0.11365668
71	18.138067			
72 vq6f	0.740000			0.13605879
73	0.532168			
74 swm	3.657600	47.165	77.5775756	0.
75	9.955836			
76 g1d	3.657600	47.419	77.1392391	-0.0380886
77	4.624169			
78 g2f	2.946400	38.199	77.1367914	0.0380886
79	1.284570			
80	0.715			
81 g3f	3.657600	47.419	77.1392391	0.0380886
82	0.450000			
83 g4d	3.657600	47.419	77.1392391	-0.0380886
84	0.715000			
85	0.7150000			
86 g5d	3.657600	47.419	77.1392391	-0.0380886
87	0.450000			
88 g6f	3.657600	47.419	77.1392391	0.0380886
89	0.715000			

where we have assumed a momentum spread of $\pm\Delta\gamma/\gamma$. The factor 2 corresponds to the total spread. The spread due to the vertical pitch is negligible. Using $G\gamma\theta_H = 4\pi$ of Eq. (3), we obtain $\Delta\Phi \simeq 25\frac{\Delta\gamma}{\gamma}$. For $\Delta\gamma/\gamma \leq 5 \times 10^{-3}$, we expect 0.3% depolarization due to the momentum spread.

3. Impact on AGS and RHIC

Since the polarized protons have been accelerated in AGS up to $G\gamma = 44$ and the critical resonance location is at $G\gamma = 51$, and we anticipate no difficulty to reach $G\gamma \simeq 48$. As this energy $\gamma = 26.77$ is also two unit above the RHIC $\gamma_T = 24.6$, we also expect therefore no difficulty in the transfer and acceleration of the polarized proton in RHIC.

The remaining task is to install two snakes per collider ring for the spin resonance correction and four spin rotators per experimental area for helicity experiment.

Demonstrations of polarized proton acceleration in AGS up to $G\gamma = 48$ should be carried out in the future. Some experimental proof of the snake have also been carried out in IUCF cooler ring in Indiana.

With the completion of the AGS Booster, the polarized proton intensity is expected to reach 10^{11} per bunch; the luminosity for the polarized proton can therefore reach easily $2 \times 10^{32}/\text{cm}^2$ sec (with $\beta^* = 0.5$ m and 114 bunches).

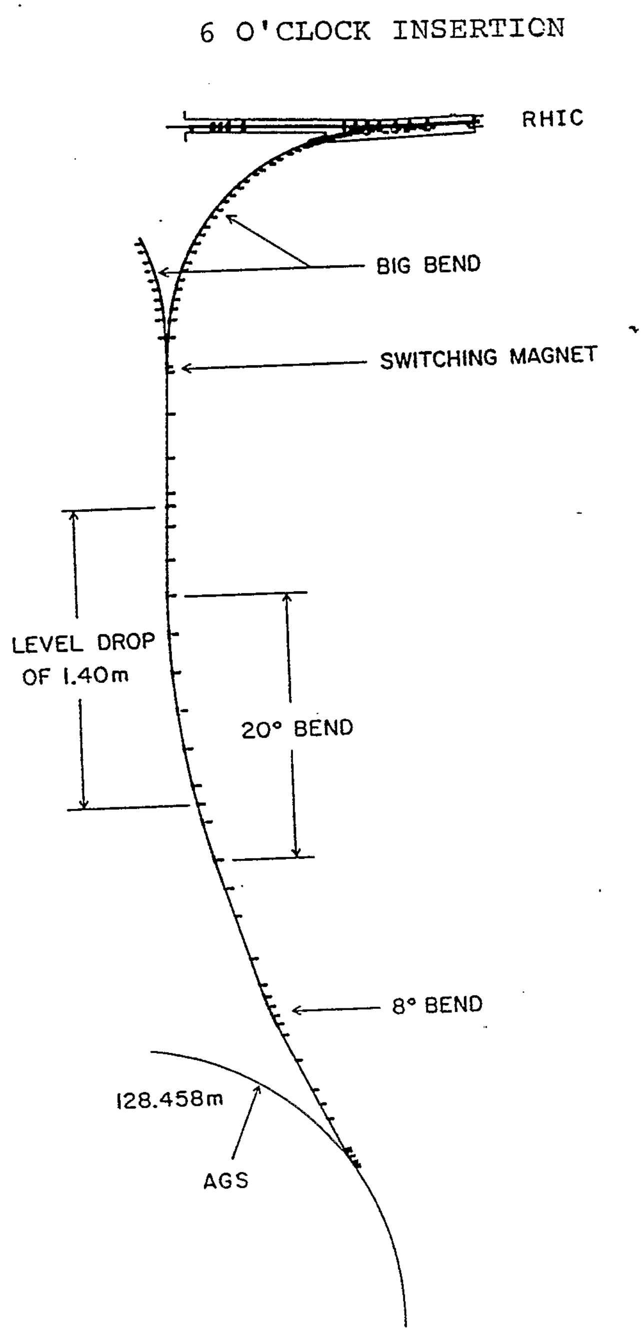

Fig. 1 General layout of beam transport system between AGS and RHIC.

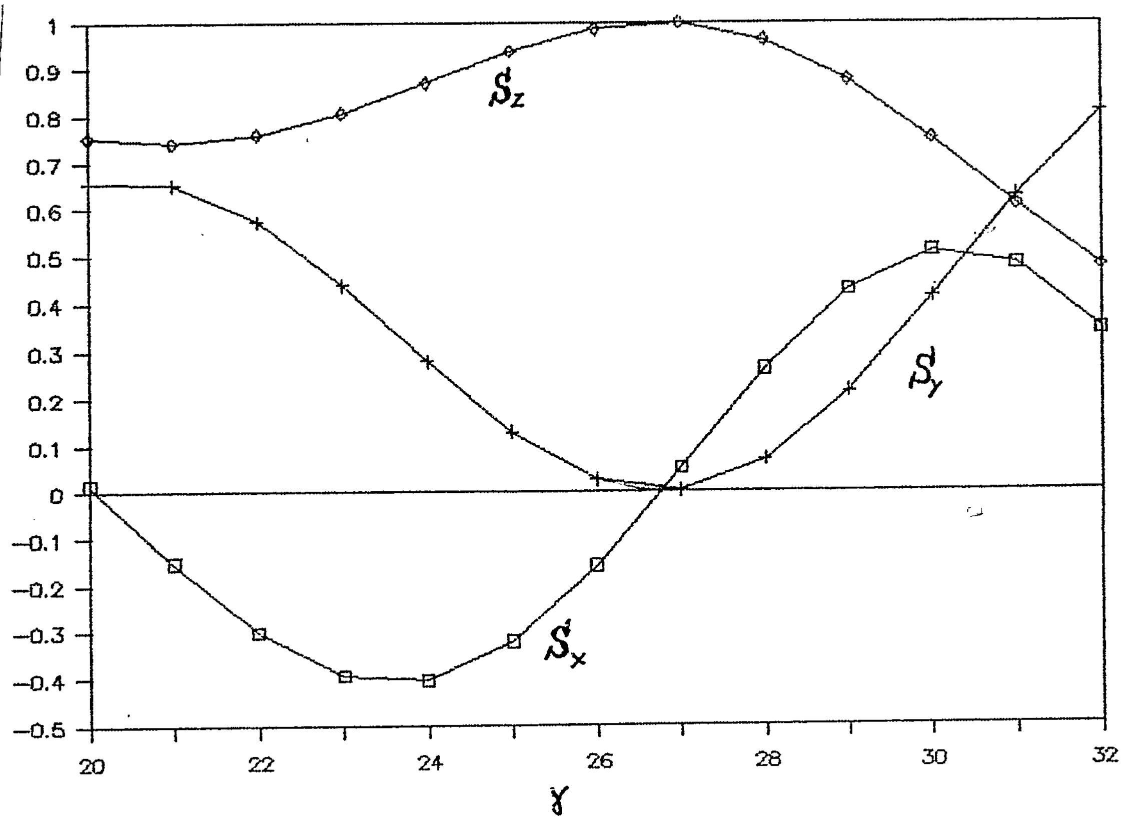

Fig. 2 Spin direction in the beam particle coordinate system after passing the section of mixing vertical and horizontal bends.