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Acceleration of Polarized Proton in RHIC

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ABSTRACT

We examine the possibility of polarized proton in RHIC collider. The issues needed for the future study is also discussed. With the improved source and AGS booster, we expect that the luminosity for polarized beam could be 0.4*10^32/cm^2/sec at energy of 250 Gev in RHIC. There we need 4 snakes and 4 spin rotators in the collider.

1. Background

It is known that AGS has accelerated polarized proton up to 22 Gev/c with 45% of polarization(ref.1). Thus we may be interested in the problem of collider with the polarized proton. To begin the task of studying the feasibility of the polarized protons in RHIC, we shall list the following parameter for the AGS polarized proton.

TABLE 1. PARAMETER of POLARIZED PROTON in AGS

		Present	with BOOSTER
			with improved source
No. of particle/bunch		1/6*10^10	0.3*10^12
Normalized Emittance@inj		10 pi	33 pi mm mrad
	@ gamma=22	50-100 pi	?
maximum gamma	(present)	23.4	28 (from AGS)
	(future)	28	
	(limited by G*gamma=60-nu)		
Polarization		45%	?
maximum resonance strength			
@10 pi mmmrad(60-nu)		.15	

It appears no difficulty to accelerate the polarized proton in AGS up to gamma=28. The resonance at 60-nu limits higher energy protons. The energy of the polarized proton from AGS at γ=28 is already above the RHIC transition energy. Therefore there is no difficulty of the transition energy passage. Based on the above data, we shall try to evaluate the possibility of accelerating polarized proton in RHIC.

2. Relevant issues in the polarized proton acceleration.

A. Resonance strength(ref.2)

Assuming a normalized emittance of 10 pi mm mrad, we observe that the intrinsic resonance strength varies from .15 at 20 Gev to .75 at 320 Gev(see Fig.1). At these resonance strength, the conventional method of resonance compensation becomes inefficient. Fortunately, snakes can be used to correct the spin depolarizing resonances. We expect that two snakes are enough to restore the polarization(see ref. 3).

B. Luminosity and Beam size consideration.

The established emittance of 95% of the beam from the tracking results is 1 pi mm mrad at beta*=6m and .3 pi mm mrad at beta*=3m (see ref.5). At present, the AGS polarized beam is about 2-3 pi mm mrad at maximum energy. Therefore the stability limit is only about 3 sigma instead of 6 sigma. At this low intensity, we do not expect important intra-beam Coulomb scattering. The beam size should be smaller as the energy is increased. Improvement in the AGS resonance jumping scheme would certainly improve the situation.

Assuming that we have the improved polarized source, we can obtain 3*10^11 particles/bunch at the normalized emittance of 75 pi mm mrad and 57 bunches. The collision will be available at energy higher than 75 Gev at the beta*=6m collision mode. The luminosity becomes

$$L = \gamma * 0.75 * 10^{29} /cm^2/sec$$

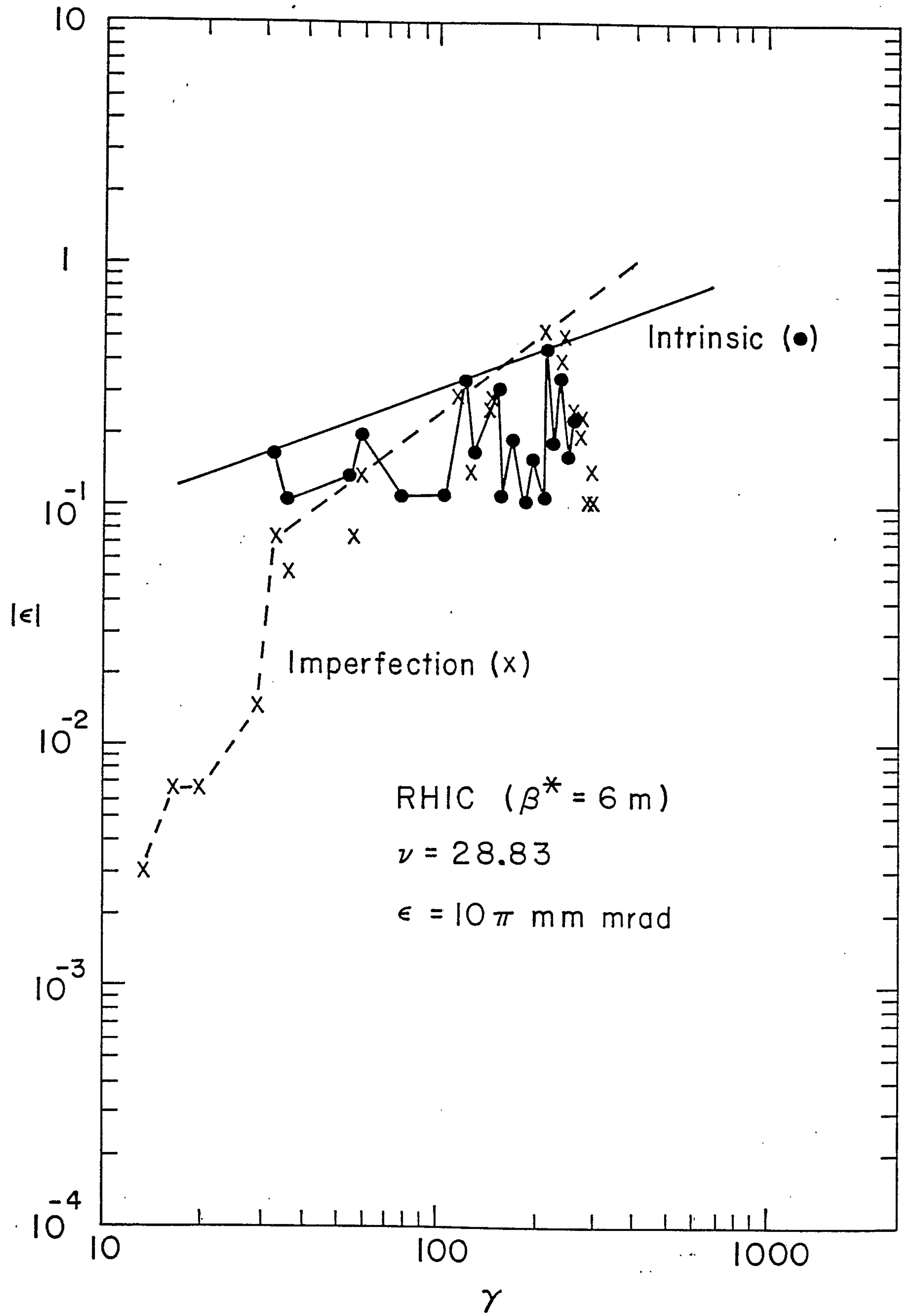
Above 175 Gev, the beam is available for beta*=3 m optics, the luminosity becomes,

$$L = \gamma * 1.5 * 10^{29} /cm^2/sec$$

where the luminosity at 250 Gev is about 0.4*10^32/cm^2/sec.

C. Transition energy consideration in RHIC

It is likely that the AGS can deliver the polarized proton at gamma=28 in the future. There is no forseeable difficulty in this issue. However, even if the the AGS delivers the polarized proton at 22 Gev/c, the RHIC can be tuned to lower transition gamma by changing the arc quadrupoles. Appendix A shows an example of tuning the machine to transition gamma of 18.


10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
|ε|
10
100
1000
γ
Intrinsic (•)
Imperfection (x)
RHIC (β* = 6 m)
ν = 28.83
ε = 10π mm mrad

D. Snakes Resonances(ref.3)

It is known that we need minimum a pair of snakes to compensate the spin depolarizing resonances in RHIC. We expect that the snake resonance up to 3rd order may be important, i.e.

$$m(\nu_s \pm \ell K) = \text{integer} \qquad \ell = 1, 3, \cdots, 2m-1. \quad m = 1, 3$$

where K and ν_s are the resonance position and snake tune respectively. Since the resonance position related to the vertical betatron tune by,

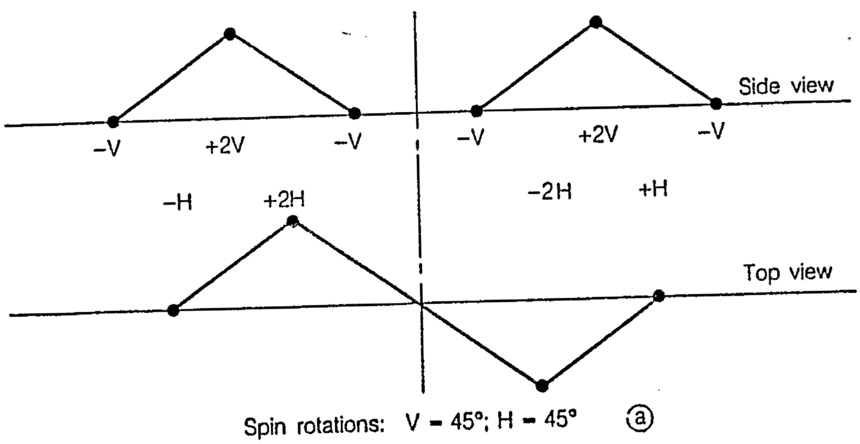
$$K = kP \pm \nu_y$$

we expect that the tune of the bunch should be maintained within 1/30 to avoid the snake resonance.

A special important issue should be addressed is that the overlaping resonances between the imperfection and intrinsic is very dangerous to the spin depolarization. The imperfection resonance should be corrected to about 1/10 strength of the intrinsic resonance.(see section F)

E. Snake configuration(ref.6)

A snake is a combination of constant transverse field dipoles, which rotate the spin without changing the closed orbit in the ends. There are a few design available at present, e.g.



Suggested Siberian snake with precession angle $\alpha = 180°$.

The beam is deflected with an angle $\theta = \varphi / \gamma G$ in each magnet, where φ is the spin precession angle. Each magnet has the integral field $\int B\, dl = 1.745 * \varphi$ Tm. The maximum deflection of the closed orbit inside the snake is therefore

$$\Delta X = 3L\theta = 5.24\, \varphi^2 / \gamma B G \quad \sim 5 \text{ cm} \quad @ 25 \text{ GeV}$$

where G=(g-2)/2=1.793 for proton. The total length of the snake is given by the length of 14 dipoles and some free spaces between magnets. Since each magnets may be about 1m to .5 m long, the total length of the snake is about 20 m. This depends on the configuration of the snake slightly. The snake does not change the closed orbit on both ends. It is however best located at the location of the accelerator where the dispersion function is small. IN the RHIC lattice, there is a 34 m free space between Q3-Q4 in each insertion with dispersion function smaller than .3 m. This space should be available for snakes. To obtain a good degree of polarization, we need 2 snakes per ring. 4 snakes is thus needed. To achieve spin tune of 1/2, we need two type of snakes. Besides the snakes, 2 pairs of spin rotator is needed to obtain the helicity collision mode. They should be located at Q3-Q4 as well. These spin rotator may be considered as a half snake. Since the particle has to pass through the beam crossing dipoles, BC2-BC1 after the spin rotator. At the present geometric configuration, there is a net bending of 3.888 mrad in BC2-BC1 unit for the zero crossing angle collision mode. The spin will precess an angle of γG *0.003888 radians. The design of the spin rotator has to be adjusted to achieve a desired helicity at the desired energy.

F. Overlapping resonances(ref.4)

Recent study shows that snakes can not restore the spin when there are intrinsic and imperfection resonances near to each other. The strength of the imperfection resonance should be less than 0.1 if the strength of the intrinsic resonance is .75. Therefore orbit correction scheme is very important. Fig.1 shows that the imperfection resonance strength is of the same order as that the intrinsic resonance strength with the assumption of .1 mm misalignment error in the quadrupoles. Orbit correction can decrease the strength by a factor of 10. Careful analysis is needed to obtain best correction scheme.

3. Future Improvement and studies

To assure good luminosity for the polarized beam in the RHIC, there are a few improvements needed to be addressed

A. Polarized source:
This is one of the important projects. At present (ref.7) the source is available about a factor of 5. Addition factor of 2 may be achieved.

B. AGS BOOSTER and AGS RESONANCE CORRECTION

AGS booster is design to accumulate 20 or more linac pulses. With h=3, the number of particles per bunch would be about 3*10^11 The normalized emittance would be around 20-30 pi mm mrad. Injection into AGS, the emittance should be kept as small as possible. According to the theoretical analysis(ref.8) the emittance blow-up should be less than 15% in every tune jump unless the tune is near to resonances. It would be nice to have the polarized beam from AGS at gamma=28 with normalized emittance less than 50 pi mm mrad.

C. RHIC

There are many questions needed to be addressed, such as better orbit correction scheme to avoid overlapping resonances, the design of the spin rotator, and the effect of the smalle but nonzero dispersion at the snake location, better snake configuration, or better spin restoration schemes etc.

Reference:

1. L Ratner, L Ahren,et al, paper submited to the 9th international symposium on spin physics. Protvino,Russia 1986

2. E. D. Courant, S.Y. Lee, and S. Tepikian, AIP proceedings 145, p174, 1986

3. S.Y. Lee, and S. Tepikian, Phys. Rev. Lett. 56,1635(1986)

4. S.Y.Lee,and X.F.Zhao,"Spin with two snakes and two resonances"

5. F.G Dell and G. Parzen,IEEE NS-32,1620(1986)

6. K. Steffen, AIP conference proceedings 145,p154(1986)
   K. Steffen, DESY/PET 78/11(1978)
   E.D. Courant, BNL-36181(1984)
   J. Buon,K. Steffen, LAL/RT/85-14(1985)

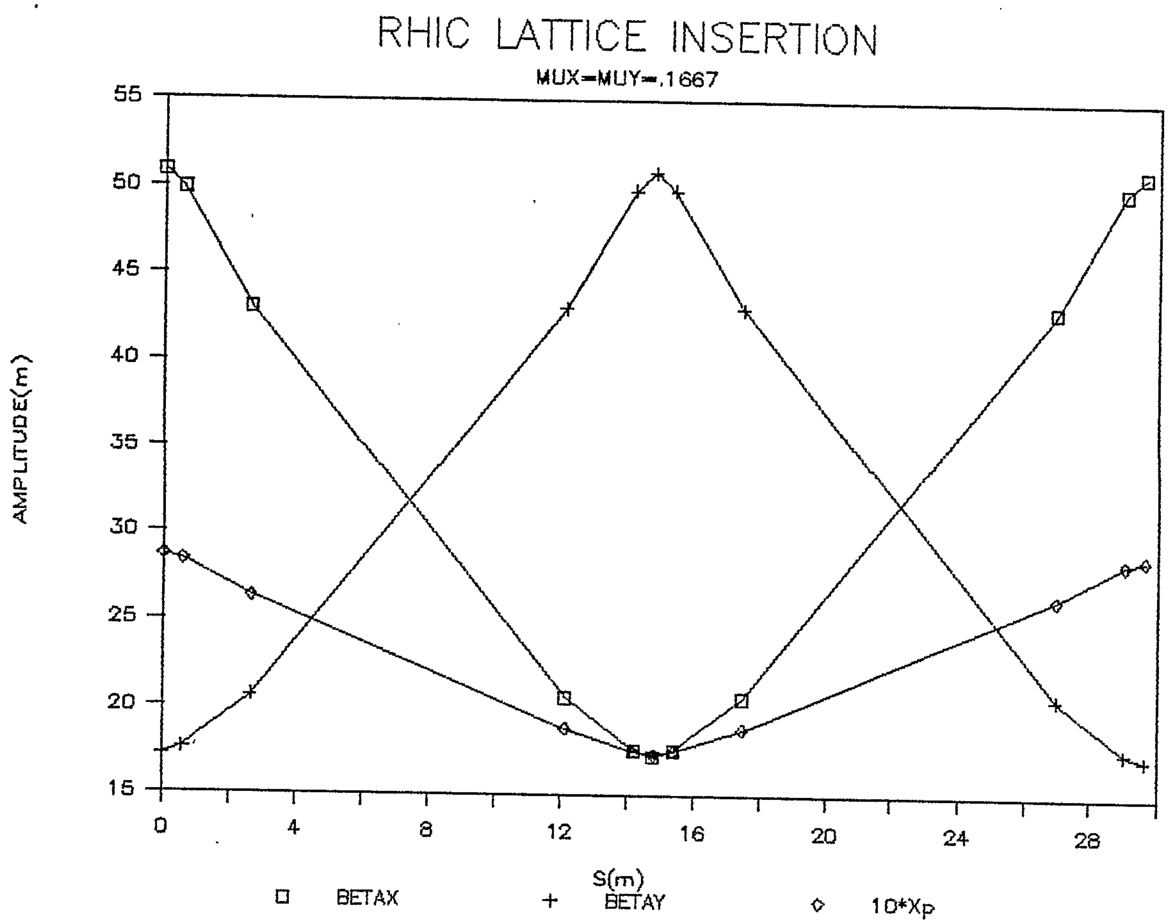
7. L. Ratner, private communication --- a factor of 2 more in intensity quoted from L.R.
   BOOSTER DESIGN MANUAL, BNL—

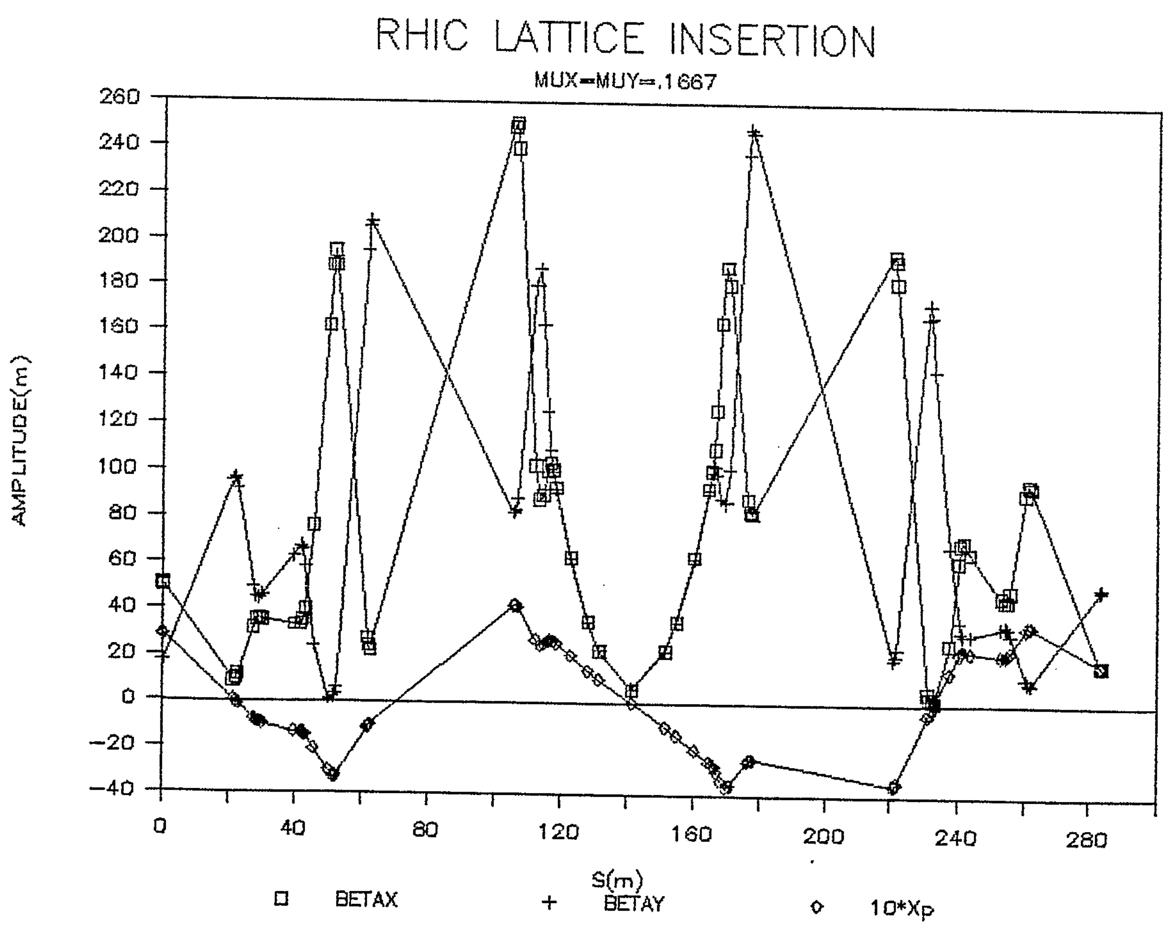
8. E.D.Courant, and S.Y.Lee," emittance blow-up due to the resonance tune jump", AGS accelerator tech-note
   S.Y. Lee, AGS accelerator tech-note 251
   X.F.Zhao,and S.Y. Lee, AGS accelerator tech-note 252.

Appendix A. DEMONSTRATIVE RHIC LATTICE with = 18.

Appendix A. DEMONSTRATIVE RHIC LATTICE with $\gamma_t = 18$.

Although there is no reason that the AGS can not deliver the polarized beam at gamma = 28, which is above the transition energy(γ_t= 26) of the RHIC collider, we shall be interested in the appendix demonstrate that the collider lattice can be tuned to transition gamma of 18. This can be accomplished by decreasing the phase advance in the arc cells, and then match the quadrupole strength in the insertion. Figs. A1 and A2 shows the betatron amplitudes in this procedure. The change of the phase advance from 90 degrees to 60 degrees is rather large. The lattice will be matched better at smaller phase advance jump. Since AGS has achieved polarized proton at gamma=23.5, we can increase gammt to about 22 to obtain a better matching.


RHIC LATTICE INSERTION
MUX=MUY=.1667
AMPLITUDE(m)
S(m)
BETAX
BETAY
10*Xp


RHIC LATTICE INSERTION
MUX=MUY=.1667
AMPLITUDE(m)
S(m)
BETAX
BETAY
10*Xp