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Imperfection Depolarization Resonance in RHIC

H. Wu

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Collider Accelerator Department

Brookhaven National Laboratory

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Alternating Gradient Synchrotron Department
Relativistic Heavy Ion Collider Project
BROOKHAVEN NATIONAL LABORATORY
Upton, New York 11973

Spin Note

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H. Wu, RIKEN (Japan) / IMP (China)
T. Katayama, INS (Tokyo) / RIKEN
K. Hatanaka, RCNP (Osaka) / RIKEN

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ABSTRACT

The misalignment of installing RHIC magnets system was reviewed. The closed orbit distortion was found at the random distribution of misalignment. Depolarization of accelerated polarized proton was calculated for the imperfection resonance and for it coupled with the intrinsic resonance. The acceleration of polarized proton was found to face a significant problem if proper measures in alignment should not be adopted to reduce the offset value of individual magnet position, or if the COD correction system could not improve the COD as small as $\pm 0.5mm$. Finally, the possibility using RHIC to accelerate the others polarized particle was discussed.

KEYWORDS: Misalignment, Imperfection resonance, Intrinsic resonance

1 MISALIGNMENT OF RHIC MAGNET SYSTEM

As the misalignment of magnets produces an imperfection depolarization resonance, the installation of each magnet at the correct position is very important for the acceleration of polarized particles.

The basic information of misalignment for installation of the RHIC magnet system is given in design book [1]. Measurements were carefully done using conventional triangulation techniques, and alignment error of one or two millimeters is expected over the RHIC radius. By utilizing new technologies, a Kern Mekometer (ME-5000) precision laser distance meter, unambiguous distance measurements can be made within 0.01 mm resolution and 0.1 ppm accuracy over distances from 10m to 10km. By satellite based Global Positioning System (GPS) technology, the maximum allowable error for a single dimensional measurement at 95% confidence level is $S = 3mm + 10^{-8} \times Length$. This measurements accuracy directly determines the accuracy of installing the magnet. The final results of magnet position tolerance at temperiture 4K are:

Dipole position and rotation:

$\Delta x = \Delta y = 0.50$ mm rms

$\Delta s = 1$ mm rms

$\Delta\Theta = 1$ mrad rms

Quadrupole position and rotation:

$\Delta x = \Delta y = 0.25$ mm rms

$\Delta s = 1$ mm rms

$\Delta\Theta = 1$ mrad rms

Sextupole position and rotation:

$\Delta x = \Delta y = 0.13$ mm rms

$\Delta s = 1$ mm rms
$\Delta\Theta = 1$ mrad rms

The one third of magnets have been installed along the ring circumference and the measured value of misalignment have been recently reported by the alignment group [2, 3, 4]. One can found the values as in the following table:

Table 1: The Statistics of measured alignment error of dipoles and CQS magnet [4].

Quantity	Units	Mean value	Standard Deviation
Dipole rotation angle	mrad	-0.8	0.7
offset x	mm	0.1	0.4
offset y	mm	-0.1	0.7
offset s	mm	0.0	0.6
Quadupole rotation angle	mrad	-1.7	0.3
offset x	μm	14	61
offset y	μm	110	64
Sexupole rotation angle	mrad	-0.3	0.7
offset x	μm	15	88
offset y	μm	28	34
Corrector rotation angle	mrad	-4.5	3.9
offset x	μm	70	80
offset y	μm	50	100

The measured misalignment has less orbit offset than that of design value, and has same order of rotation offset.

2 COD AND IMPERFECTION DEPOLARIZATION

2.1 Search for Closed Orbit Distortion (COD)

A closed orbit distortion around the RHIC ring was calculated by MAD program, using the data of misalignment of magnet installation. A typical data of misalignment are as follows: the offset of all magnets are zero, and the standard deviation of alignment error is the magnet orbit error and longitudinal error are in the range of $\pm$ 0.1 mm, magnet rotation angle error are in the range of $\pm$ 0.1 mrad. The misalignment of individual magnet is given by a random values. In figure 1, the calculated closed orbit is given along the orbit of RHIC ring. The maximum of COD position reaches to 0.5 mm.

The calculation of COD indicates that depolarization contributed by COD orbit is more sensitive with the standard deviation of alignment error than the mean value of alignment error. If all the magnets in one part of ring are shift a little with one direction, the COD orbit will shift to same direction, it reduced magnetic field component that contribute to the depolarization. But the standard deviation gives the alignment error, thus magnetic field error directly contributes to depolarization.

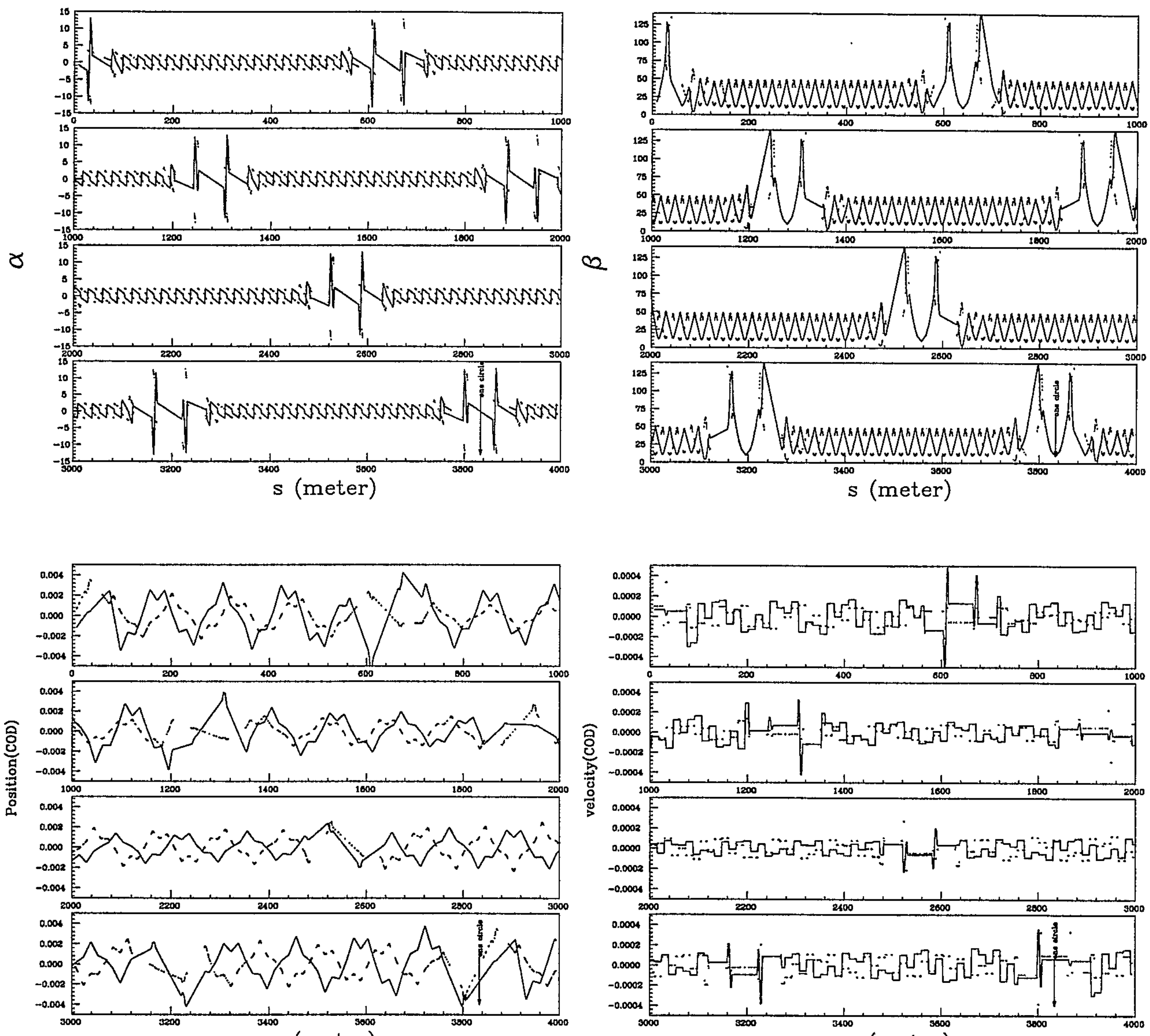

Figure 1: The lattice functions and COD parameters at misalignment 0.1mm in length, 0.1mrad in angle. Solid lines are x component, dot for y component.

2.2 *Imperfection Depolarization Resonance By Misalignment*

During particles are accelerated in the ring, the orbit motion is composed of two kinds of motions, one is the vertical closed orbit errors, the other is the betatron motion. The COD orbit is a closed transport line, independent of the emittance and the energy of particle. With increasing of the beam energy, the amplitude of betatron motion is decreasing, and the total orbit closes to COD orbit.

Spin depolarization resonances due to the close orbit error are called imperfection resonance, and resonances due to the betatron motion are called intrinsic resonances. The imperfection resonance are produced by misalignment of installing the magnets for single energy beam. If magnets are set perfectly, (the offset are zero), the imperfection resonance should be zero.

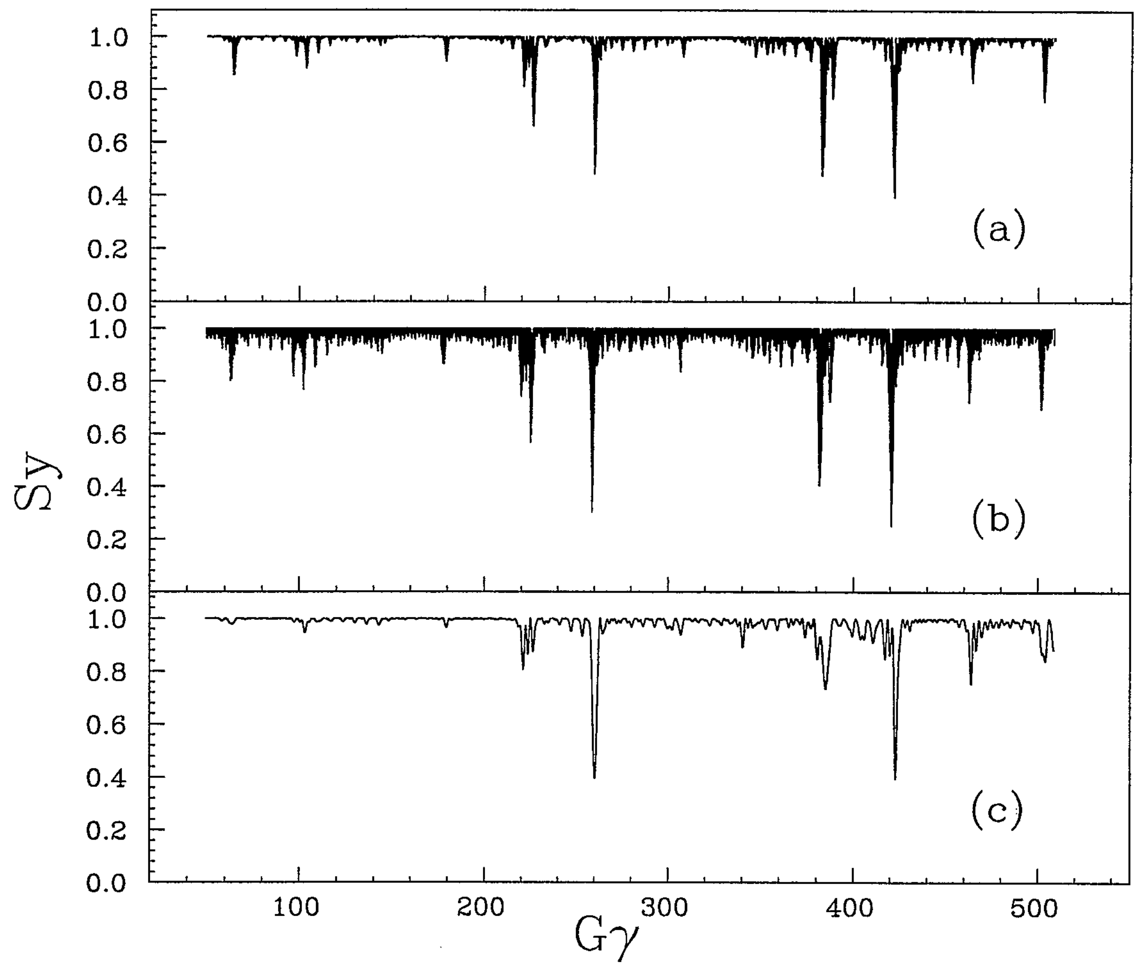

Figure 2: The intrinsic depolarization spectrum (a) for the first order spin tracking with the parameters of Siberian snake at $1.2336T$, $-3.9570T$, $3.9570T$, $-1.2336T$ and (b) for the second order calculation with the parameters of Siberian snake at $1.0723T$, $-3.9328T$, $3.9328T$, $-1.0723T$ at a emittance 7 μrad-m through RHIC accelerator, compared with imperfection depolarization spectrum (c).

The numerical calculation of imperfection depolarization resonance is made by spin tracking on the condition that the betatron motion orbit is set to zero, or the emittance to zero. Figure 2 shows the intrinsic resonances tracking by first and second order, that have been reported in [5, 6, 7], compared with imperfection depolarization resonances. The misalignment of the magnets are set as following, the mean value of alignment error of all magnets to be zero, and the standard deviation of alignment error to be one third of the value of design book [1], namely dipole magnet orbit error: 0.17mm *rms*; quadrupole magnet orbit error: 0.08mm *rms*; sextupole magnet orbit error: 0.04mm *rms*; magnets rotation angle: 0.33 mrad *rms*; longitudinal error: 0.33mm *rms*. The misalignment of individual magnet are give by a random values with gaussion shape distribution.

Imperfection depolarization resonance is independent of the emittance value, because the COD orbit is independent of the emittance. The imperfection depolarization spectrum has similar structure with the intrinsic depolarization spectrum viewing in large scalar. The similar spectrum of imperfection depolarization and intrinsic depolarization also were found in Fourier analysis [8]

In Fig 2(c), the imperfection depolarization peaks have same amplitude as that of intrinsic depolarization, where misalignment error just are assumed at one third of design value. If the design values are used, the imperfection depolarization peaks are too large to be recovered by Siberian snake.

2.3 Imperfection Depolarization By Momentum Dispersion

Beside the misalignment, momentum dispersion also produce the vertical closed orbit errors. This subject have been discussed in [6], here the imperfection depolarization by momentum dispersion is different with that by misalignment. If the beam momentum (energy) have distribution, the orbit for central energy particle are closed orbit along the central axis of magnets, (here, we think a perfectly aligned accelerator), the COD orbit for momentum dispersion particles are a simple motion adding on the previous orbit. The lattice function and COD at $\Delta P/P$=0.002 momentum dispersion are shown in figure 3, the vertical closed orbit errors are only at x direction. The closed orbit errors for momentum dispersion particles produce a simple harmonic depolarization spectrum.

The coupling intrinsic depolarization with this simple harmonic imperfection depolarization, the depolarization spectrum are periodically change to little unstable with increasing momentum dispersion, then to difficult recover the depolarization by Siberian snake at a large momentum dispersion (Fig. 4).

3 COUPLING OF IMPERFECTION AND INTRINSIC RESONANCES

The coupling of imperfection depolarization (here only by misalignment) and intrinsic depolarization is made by coupling with COD orbit and betatron motion. This coupling can increase or decrease the depolarization strength in a local party of ring, but it remarkably increased amplitude of depolarization peaks, special near the intrinsic resonance peaks and where accord with the condition of imperfection depolarization resonance.

Figure 5 shows the coupling depolarization spectrum. The misalignment parameters are set at random values within the range:

$\Delta x = \Delta y = \Delta s = 0.1$ mm,

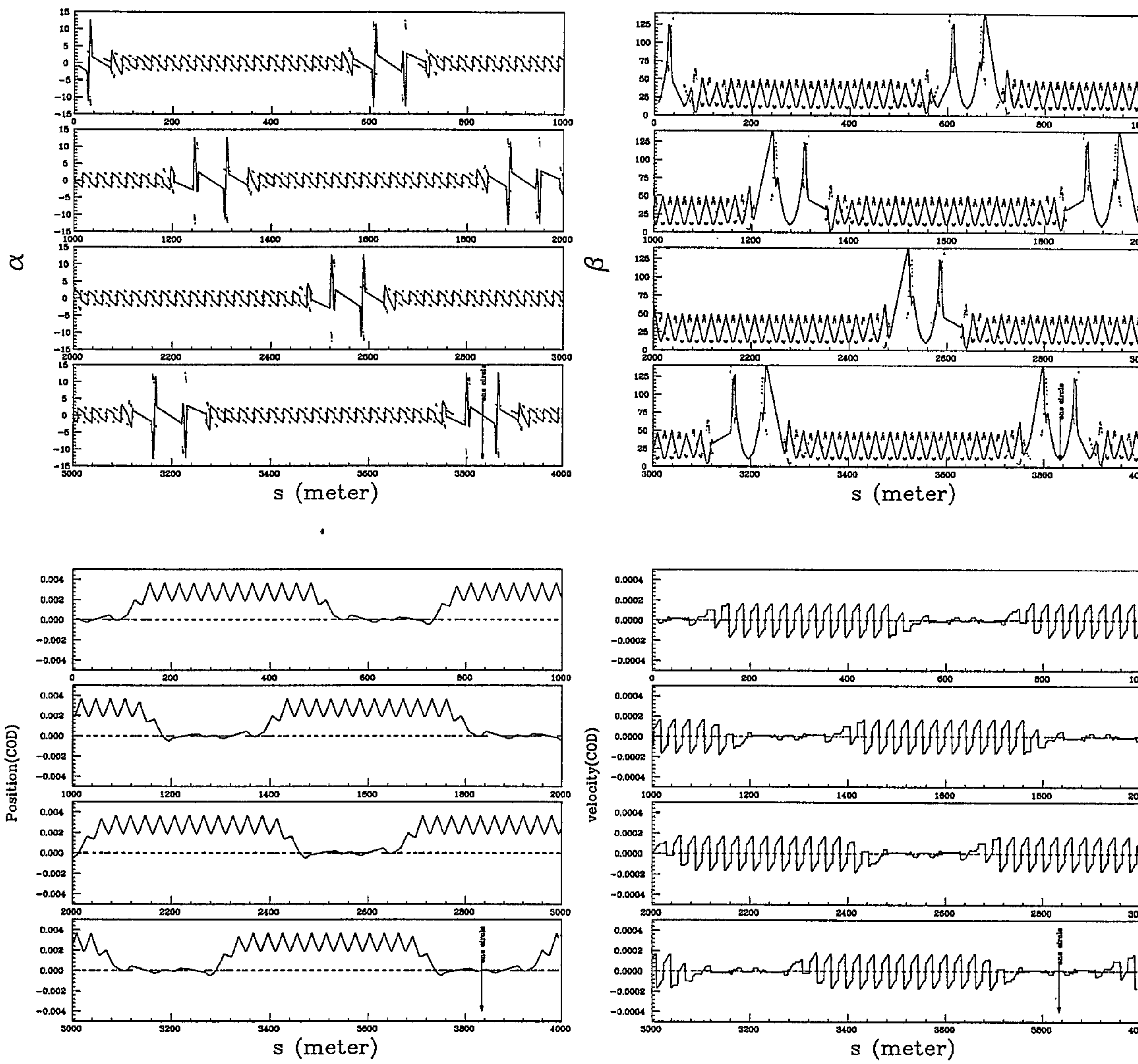

Figure 3: The lattice functions and COD parameters at $\Delta P/P$=0.002 momentum dispersion. Solid lines are x component, dot for y component.

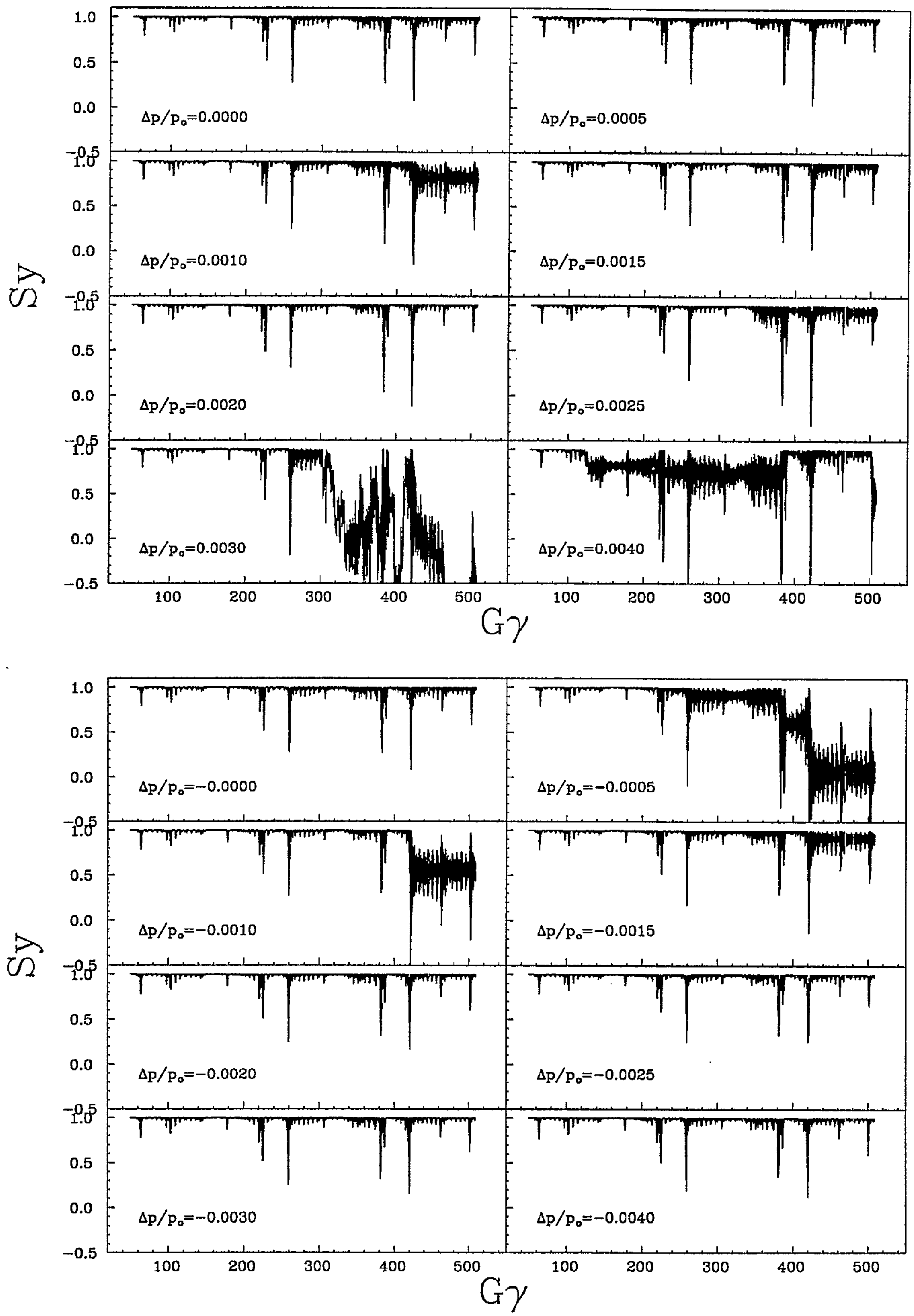

Figure 4: Spin tracking with emittance 10 $\mu rad{-}m$, with different energy (or momentum) dispersion ($\Delta E/p_0c = \Delta p/p_0$) that are indicated in frame.

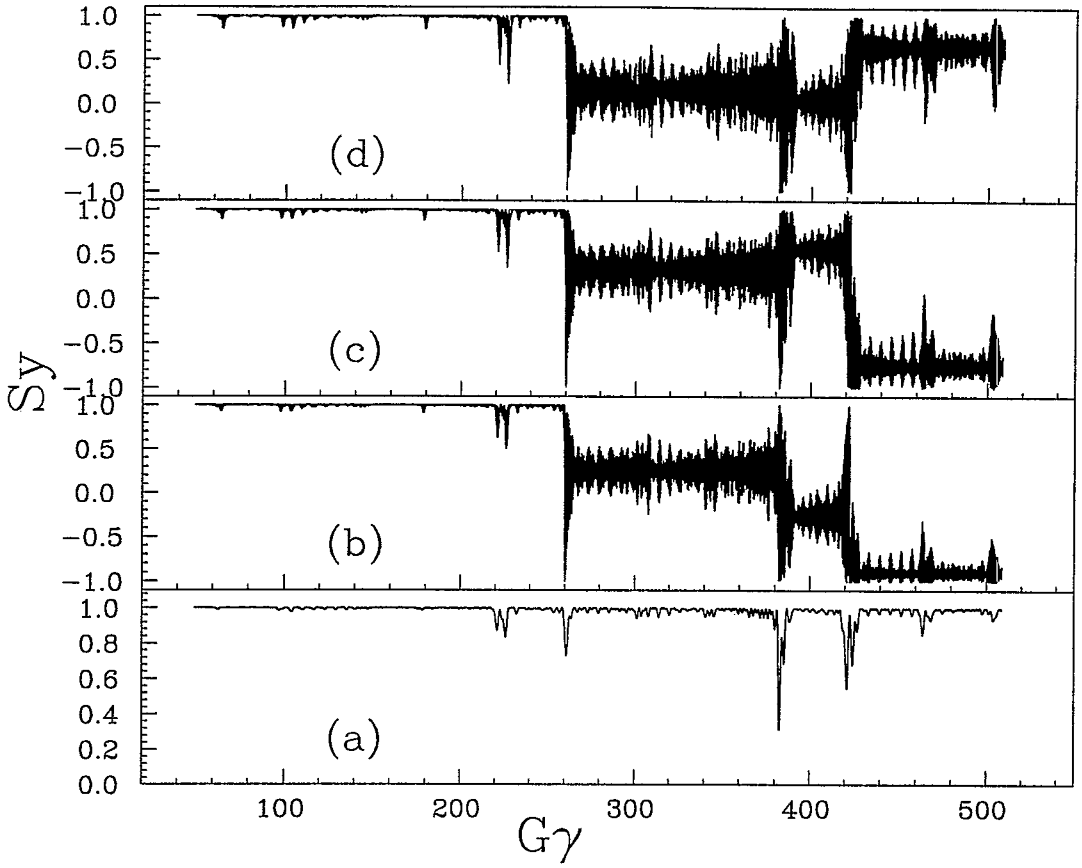

Figure 5: Imperfection depolarization and that coupled with intrinsic depolarization at different emittance. Misalignment parameter is $\Delta x = \Delta y = \Delta s = 0.1$ mm, $\Delta\Theta = 0.1$ mrad.

$\Delta\Theta = 0.1$ mrad for all magnets.
The imperfection depolarization resonance is shown in Fig. 5 (a), the depolarization peaks have same amplitude as that of intrinsic depolarization at an emittance 6-10 $\mu rad - m$. The imperfection depolarization is coupled with intrinsic depolarization at emittance 3 $\mu rad - m$ (b), 5 $\mu rad - m$ (c) and 7 $\mu rad - m$ (d). If misalignment of the accelerator is as large as this offset values, it is difficult to accelerate the polarized proton.

For tracking one particle, the depolarization spectrum is dependent with the initial condition of tracking particle. But if spectrum is stable, the all spectrum for same emittance different initial condition are same. When the spectrum become unstable, the final results of one particle tracking are sensitive with initial condition of this particle. In Fig. 5 (b), the spin change from 1 to -1, it doesn't means all particle with emittance 3 $\mu rad - m$(b) work like Fig. 5 (b). The same, the Fig. 5 (d) doesn't means work better than Fig. 5 (b).

Figure 6 shows the coupling depolarization as figure 5 but with misalignment values within the range:

$\Delta x = \Delta y = \Delta s = 0.01$ mm,

$\Delta\Theta = 0.01$ mrad for all magnets.

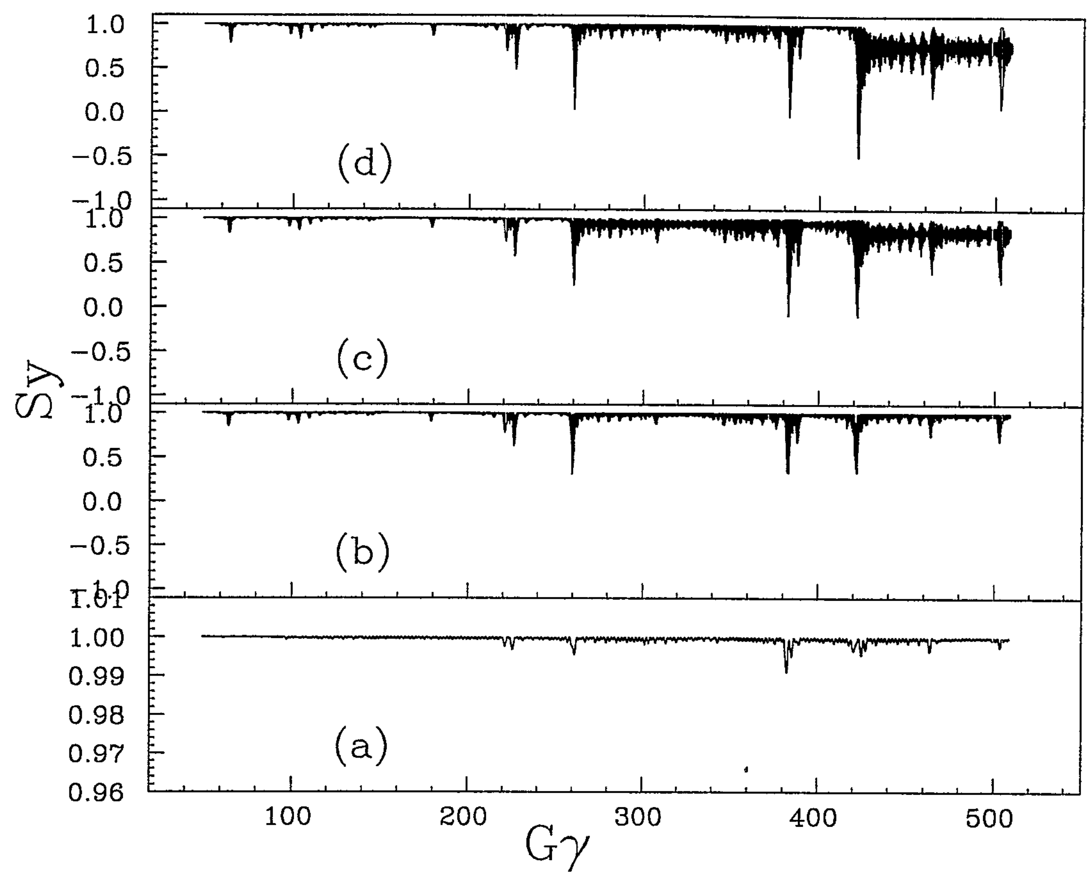

Figure 6: Depolarization spectrum as Fig 5. But misalignment parameter is $\Delta x = \Delta y = \Delta s = 0.01$ mm, $\Delta\Theta = 0.01$ mrad.

Here, the maximum of COD position reaches to 0.05 mm. The imperfection depolarization resonance is shown in (a), the amplitude of depolarization peaks are much smaller than intrinsic depolarization. The coupling spectrum, at emittance 7 $\mu rad - m$ (b), 8 $\mu rad - m$ (c) and 10 $\mu rad - m$ (d), are presented.

The calculated results show that if polarized proton will be accelerated up to 250 GeV, the high quality of magnet alignment should be required. The standard deviation of the magnetic centers relative to the mechanical center should be at the order 0.01 mm, the standard deviation of angle rotation should be at the order 0.01 mrad. Or the COD correction system should improve the COD as small as $\pm 0.5mm$.

4 OTHER POLARIZED PARTICLES

As KEK PS has successfully accelerated polarized ^{2}H, some physicists are interested in if RHIC has the ability to accelerate the other polarized particles. Though RHIC can accelerate projectile from proton up to ^{197}Au, for the polarized beam acceleration, the key point is that whether polarized beam can pass the depolarization resonance area, as

Siberian snake for polarized proton. The Siberian snake will be installed with 4 modules of helical dipole magnets, (the length of each is 2.4 meters, and period is 2π), and working point for proton beam is $B_1 = 1.23$, $B_2 = 3.96$ Tesla with $+B_1\odot$, $-B_2\odot$, $+B_2\odot$, $-B_1\odot$ setup. What parameters of Siberian snake can be used for the other polarized beam?

The ratio GQ/M (G is gyromagnet ratio, M is mass, Q charge states), of relativistic particle deterimines the rotation strength in the magnetic field. Particle ^{3}He with a small ratio, is easily rotated 180^o in a small magnetic field at $B_1 = 0.81$ and $B_2 = 2.60$ Tesla. If the maximum field value is a limitation of acceleration polarized particle, the maximum field of Siberian snake is difficult to reach 10 Tesla.

The one way of improvement is extension the length of helical module. In figure 7, the working point of Siberian snake for polarized proton are shown with a extension length at 10 meters in the range of 0-10 Tesla, the value of each point are much smaller than that with length at 2.4 meters. Using Siberian snake with extension in length, the working point are searched, the results and the general character of polarized particle are presented in Table 2.

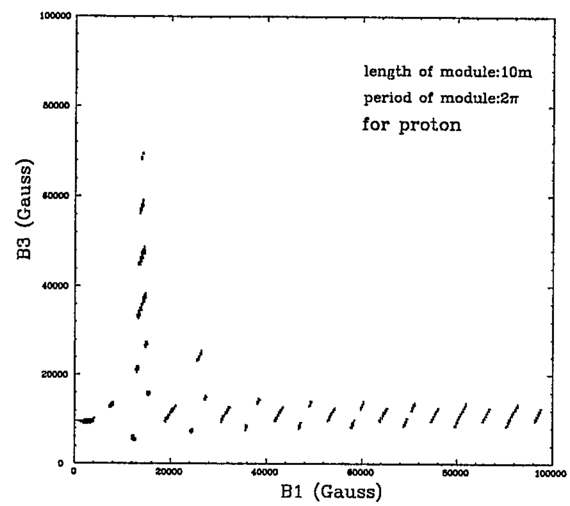

Figure 7: The working points of Siberian snake in RHIC for polarized proton, module length is 10 meter.

As an example, the spin tracking for polarized ^{3}He beam are calculated with 2.4 meter type of Siberian snake. The parameter of working Siberian snake are used as table 2. The intrinsic depolarization spectrum is shown in the figure 8, and compared with the intrinsic depolarization spectrum for proton.

Table 2 The properties of particles and the working point of Siberian snake for polarized particle acceleration in RHIC. The limitation of maximum magnetic field is 10 Tesla.

Particle	J^P	M (MeV)	g	G $=\frac{g}{2}-1$	μ (μ_N)	2.4 m-type B_1	2.4 m-type B_3	5 m-type B_1	5 m-type B_3
P	$\frac{1}{2}^+$	938.2723	5.585695	1.792847	2.27928	1.2336	3.9570	0.5912	1.8995
D	1^+	1875.613	0.85699	-0.14301	0.8574	-	-	-	-
^{3}He	$\frac{1}{2}^+$	2808.39	-6.3679	-4.1840	-2.1275	0.8094	2.6002	0.3885	1.2481
^{7}Li	$\frac{3}{2}^-$	6533.83	5.066	1.533	3.2563	-	-	1.6340	5.2498

The depolarization structure (position of depolarization resonance) are dependent with $G\gamma$ and the structure of ring, independent with the particle. Although both spectrum in figure 8 are for a same particle emittance, the amplitude of depolarization resonance are different.

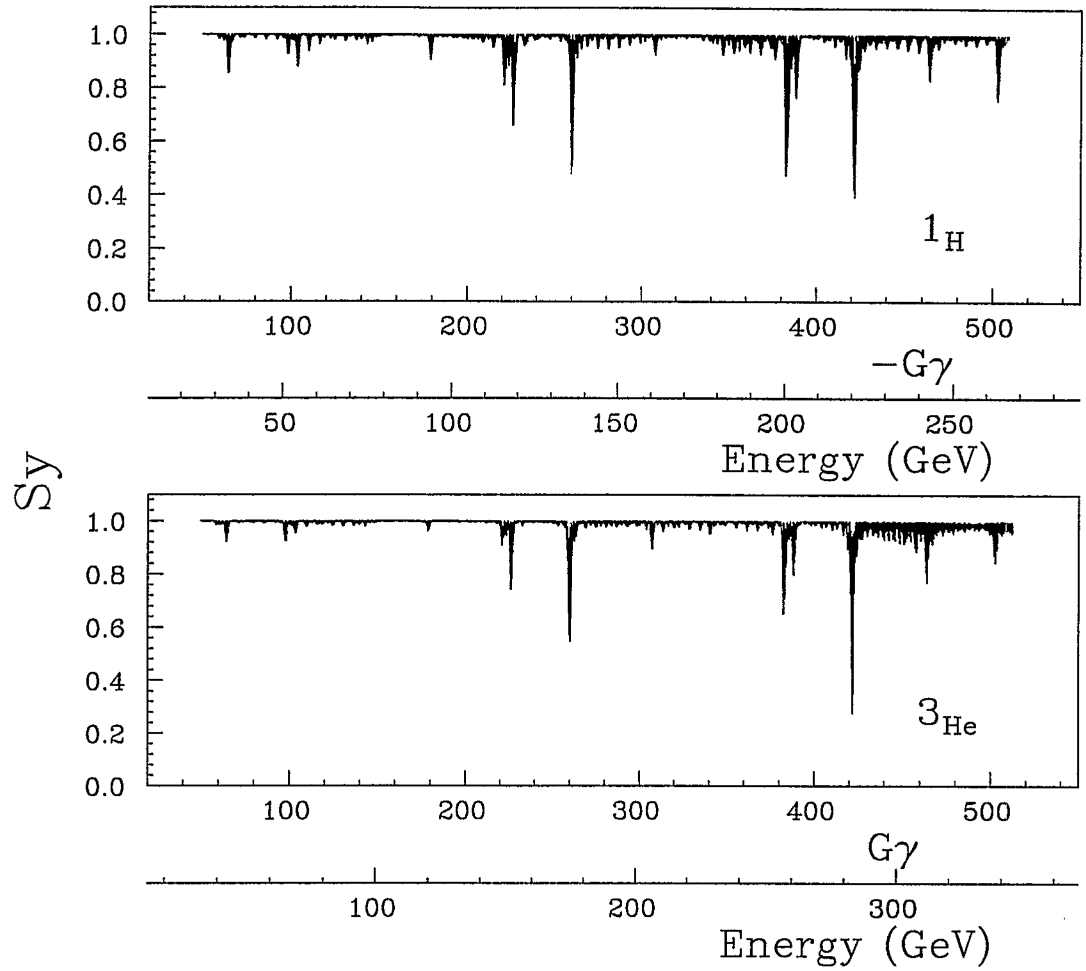

Figure 8: Intrinsic depolarization spectrum for polarized ^{3}He beam with emittance at 7 $\mu rad - m$, compared with that of proton.

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