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Transferring polarized proton beam from AGS to RHIC at energies below the spin resonance ($G\gamma=36+\nu_y$) of AGS

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Abstract

The layout of the ATR (AGS to RHIC) transfer line [1,2,3,4] limits the energy range that a polarized proton beam can be transferred from the AGS ring into RHIC [5,6,7]. It is within this limited energy range of the injected beam, that the stable spin direction of the ATR transfer line at the RHIC injection point will closely match the stable spin direction of RHIC.
In order to accelerate a polarized proton beam into this energy window, and subsequently inject the beam into RHIC, it is necessary to overcome all the depolarizing spin resonances, which appear during the acceleration cycle of the proton beam in the AGS.
In this technote we propose a modification of the ATR transfer line which will allow the transfer of a polarized proton beam at a lower energy range which lies below the $G\gamma=36+\nu_y$ depolarizing resonance. Within this lower energy range the stable spin direction of the ATR line at the RHIC injection point, matches the stable spin direction of the RHIC machine at the same point.

Introduction

Part of the experimental program of RHIC is the study of collisions of polarized proton beams. The polarized proton beams are produced in an H^- ion source of polarized protons and subsequently are pre-accelerated by the following accelerators:

a) the 75keV RFQ accelerator
b) the 200 MeV LINAC
c) the BOOSTER, which accelerates the proton beam to a kinetic energy T=1.52 GeV
d) the AGS synchrotron, which accelerates the proton beam to an energy T= 24.2 GeV

The proton beam is subsequently extracted from the AGS and transferred (via the ATR beam transfer line) to be injected into RHIC for further acceleration to the desired energy.
The layout of the ATR beam transfer line requires that the energy of the polarized proton beam, which is extracted from the AGS, lies within a specified window [5,6,7] before it is injected into RHIC via the ATR transfer line. When the energy of the injected proton beam lies within this specified window, the stable spin direction of the ATR line at the RHIC injection point, will almost coincide with the stable spin direction of RHIC at the injection point. This particular transfer energy, for which the stable spin direction of the ATR transfer line, matches that of RHIC, has been calculated [7] and corresponds to

$G\gamma=48.0$[1]. Additional calculations [5,6] (which include the "3 mrad" vertical bend of the ATR transfer line at the RHIC injection region), show that the directional cosine of the stable spin direction of the injected polarized proton beam at the RHIC injection point remains almost constant (at the value of $S_y=0.97\pm0.005$) over an energy range of the injected polarized beam of T=23.1 GeV to 24.2 GeV. This energy range corresponds to a range in $G\gamma$ from 46.0 to 48.0[2] (see Fig. 5. in [5]). However, in order to accelerate a polarized proton beam in the AGS within this energy range, the proton beam must cross many imperfection and intrinsic depolarizing resonances [8] which may affect the final polarization of the beam.
The imperfection depolarizing resonances ($G\gamma$=int.) of the AGS have been successfully overcome using harmonic orbit correctors [8] and lately using the partial snake [9,10].
It is a greater challenge to overcome the intrinsic depolarizing resonances [8,9,10,11,12] of the AGS, which occur at $G\gamma=kP\pm n\nu_y$ (where k and n are integers, P=12 is the super-periodicity of the AGS and $\nu_y\approx8.7$ is the vertical tune). There are seven intrinsic depolarizing resonances to be crossed before the threshold of $G\gamma=46.0$ above which the stable spin direction of the ATR line matches closely the one of the RHIC machine [5 6].
The method of the betatron tune jump was first used in AGS [8] to overcome the intrinsic spin resonances and accelerate a polarized beam of protons to a an energy T=22 GeV/c ($G\gamma=42.07$).
The AC dipole method, used recently [11] in the AGS, proved to be a very effective tool in overcoming the intrinsic spin resonances.
However, overcoming the intrinsic resonance $G\gamma=36+\nu_y$ ($G\gamma\approx44.7$) becomes difficult because of the adjacent intrinsic resonance $G\gamma=36+\nu_x$ which is caused by the linear coupling of the beam when it traverses the solenoidal field of the partial snake. In addition the hybrid resonance [15] which occurs at $G\gamma=60-9-\nu_y$ ($G\gamma\approx42.3$) also requires closed orbit correction. It is therefore worthwhile to investigate the possibility of injecting RHIC with energy lower than the energy where these resonances occur.
In the rest of this technote we will mention few methods that have been proposed in the past for the transport of a polarized proton beam from AGS to RHIC at various energies and more specifically we will propose a method of transferring polarized proton beam from AGS to RHIC at an energy which corresponds to a value of $G\gamma\approx41.5$[3],[4]

Transferring a polarized proton beam from AGS to RHIC via a "spin transparent" ATR beam transfer line

It was mentioned earlier that the layout of the ATR transfer line confines the energy that a polarized proton beam can be transferred from AGS to RHIC to the value of T=24.2 GeV, $G\gamma=48.0$ [7], or better, places the transfer energy within an energy window from T=23.1 GeV ($G\gamma=46$) to 24.2 GeV ($G\gamma=48.0$) [5,6].
This particular proton energy T=24.2 GeV is referred to as "magic energy" [7] and

[1] G=1.7928, G=(g-2)/2 g=gyromagnetic ratio of the proton
[2] Calculation for $G\gamma>48$ where not performed.
[3] The RHIC transition Energy corresponds to a $G\gamma=41.04$
[4] The value of $G\gamma=41.5$ is below both the $G\gamma=36+\nu_y$ and $G\gamma=60-9-\nu_y$ spin resonances

at this energy (or range of energies) the stable spin direction of the ATR transfer line at the RHIC injection point, closely matches the stable spin direction of RHIC, at the same point. When this matching condition of the stable spin direction is satisfied, the ATR line is called “spin transparent”. For reasons discussed earlier it is very desirable to vary the “magic energy” and make the ATR transfer line “spin transparent” at other energies.
One method to vary the “magic energy” is discussed in [6a]. This method, although flexible, is a rather expensive modification of the ATR transfer line since it requires three dipole magnets, (of lengths 1m,2m,1m at a strength of 1.5 T each) to be inserted in the ATR transfer line. A similar method, (also requires the insertion of dipole magnets in the ATR line) of making the ATR transfer line “spin transparent” at any extraction proton energy of the AGS, has been proposed [14]. These methods, which require the insertion of dipole magnets, have the advantage of achieving any “magic energy” by simply tuning the dipole magnets.
An alternative method, which does not require the insertion of any new components into the ATR transfer line, but requires that specific magnets of the ATR transfer line (in the W-line section) be relocated and resurveyed, will be discussed in the remainder of this technote. This method alters permanently the “magic energy” from the value of $G\gamma=48.0$ to a lower value (see next sections) therefore makes the ATR transfer line “spin transparent” within an energy window which lies lower in energy.

Layout and optics of the W-line

The W-line [4] consists of eight combined function dipole magnets of C-type [13] (each magnet bends the beam 2.5^0 to the right for a total bend of 20^0), followed by six matching quadrupoles which are used to match the beam parameters at the end of the W-line to those at the beginning of the X-Y Lines [4]. Each consecutive pair of the combined function magnets in the W-line, forms a FODO cell of 90^0 phase advance in both horizontal and vertical planes (Fig. 1a, 1b) thus making the 20^0 bend achromatic. As part of the W-line there are also two 12.5 mrad vertically pitching magnets (WP1,WP2 see Fig. 2a), one, which bends the beam downwards (WP1), is located in the straight section between the second and third combined function magnets, and the second (WP2) pitching dipole, which bend the beam upwards, is located in the straight section between the second and third matching quadrupoles of the W-line. The vertical phase advance between these two vertically pitching dipoles is 360^0 thus making this section of the line achromatic in the vertical direction.
The beam parameters β_x,β_y,η_x, and η_y of the W-line are plotted and are shown in Fig. 2a.

Effect of the the 12.5 mrad vertical bend of the W-line on the polarization of the beam

The need of the 12.5 mrad vertical bend, in the W-line, mentioned earlier, is to bring the horizontal level of the beam extracted from the AGS, to the same horizontal level as the RHIC machine. The effect of the 12.5 mrad vertical bend on the polarization of the beam has been studied earlier [5,6,7]. The studies have shown that the optimum injection proton energy into the RHIC machine corresponds to $G\gamma=48$. At this energy (called “magic energy”) the W-line is “spin transparent” and there is a minimum loss of polarization after the beam emerges from the second vertical pitching magnet. The value of $G\gamma$ which corresponds to the magic energy is equal to SRA/θ_{bend}. Where $\theta_{bend}=15^0$ is the bending angle of the beam in the six combined function dipole magnets which are placed between the two vertical pitching magnets, and SRA is the spin rotation angle about the stable spin direction in these magnets. The value of the angle SRA must be equal to 4π for the stable spin direction to point in the vertical direction at the exits of the second pitching magnet, and this is achieved only when the value of $G\gamma=48$. It was mentioned earlier that the AGS has a depolarizing resonance at $G\gamma=36 + \nu_y$. This resonance has to be crossed, for the polarized proton beam to be injected into RHIC at the "magic energy". In order to avoid the crossing of the $G\gamma=46 + \nu_y$ depolarizing resonance, one has to lower this "magic energy" below the energy of the $G\gamma=46 + \nu_y$ depolarizing resonance and a method for this to be achieved is discussed in the next section.

Modification of the W-line

A simple way[5] to lower the "magic energy" is to make the following modification of the W-line:

a) Relocate the first pitching magnet in the straight section between the first and second combined function magnets.
b) Relocate the second pitching magnet between the first and second matching quadrupoles so that the vertical phase advance maintains the value of 360^0 and this will assure vertical achromaticity.
c) Survey the section of the W-line between the new location of the first pitching magnet and the old location of the second pitching magnet.

This modification will lower the "magic energy" to a value of $G\gamma= 41.2$. This value is above the RHIC transition energy but well bellow the energy that the depolarizing resonance $G\gamma=36 + \nu_y$ occurs.

Layout and optics of the modified W-line

The proposed modification described above will only change the value of the vertical dispersion between the two pitching magnets but will maintain the beam parameters which correspond to the FODO lattice of the unmodified W-line, and will also keep the same beam parameters at the matching point at the beginning of the X,Y lines. The beam parameters β_x,β_y,η_x, and η_y of the modified W-line are plotted and are shown in Fig. 2b to be compared with the beam parameters of the unmodified W-line, shown in Fig. 2a.

Conclusion

A simple modification of the ATR transfer line (by relocating the WP1 and WP2 pitching magnets in the W-line section of the ATR line), can achieve a lower "magic energy" for the transfer of a polarized proton beam from the AGS to the RHIC. This

[5] Simple in concept. However implementation may require lowering the floor under the WD6 magnet by ~20 cm.

modification does not change the optics of the ATR line, except the vertical dispersion function in between the two pitching magnets.

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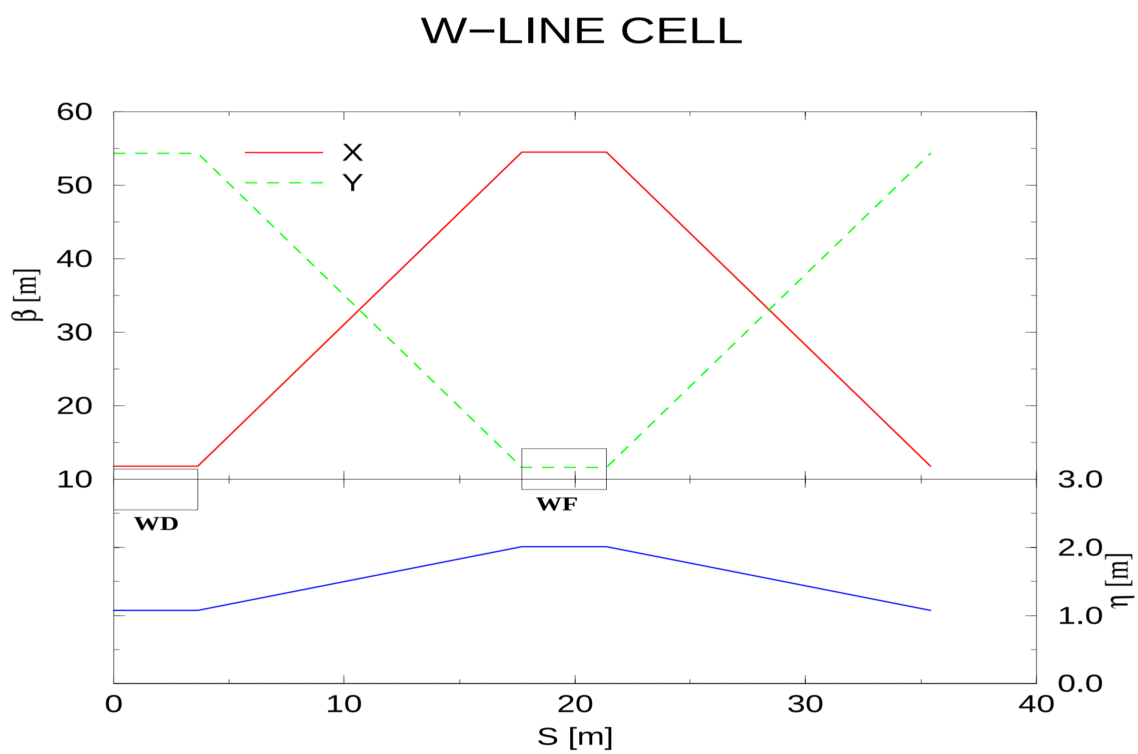

Fig1a Beam parameters β_x,β_y, and η_x for the FODO cell of W-line

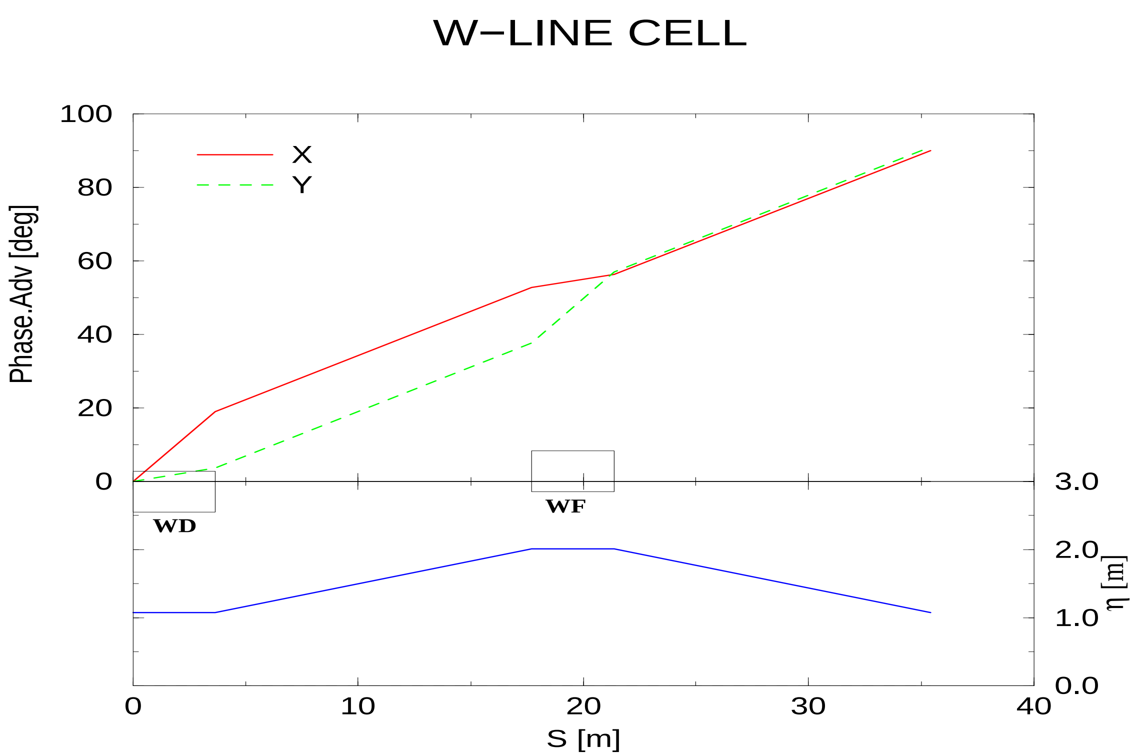

Fig1b. Horizontal and vertical phase advance ψ_x ψ_y and η_x for the FODO cell of W-line

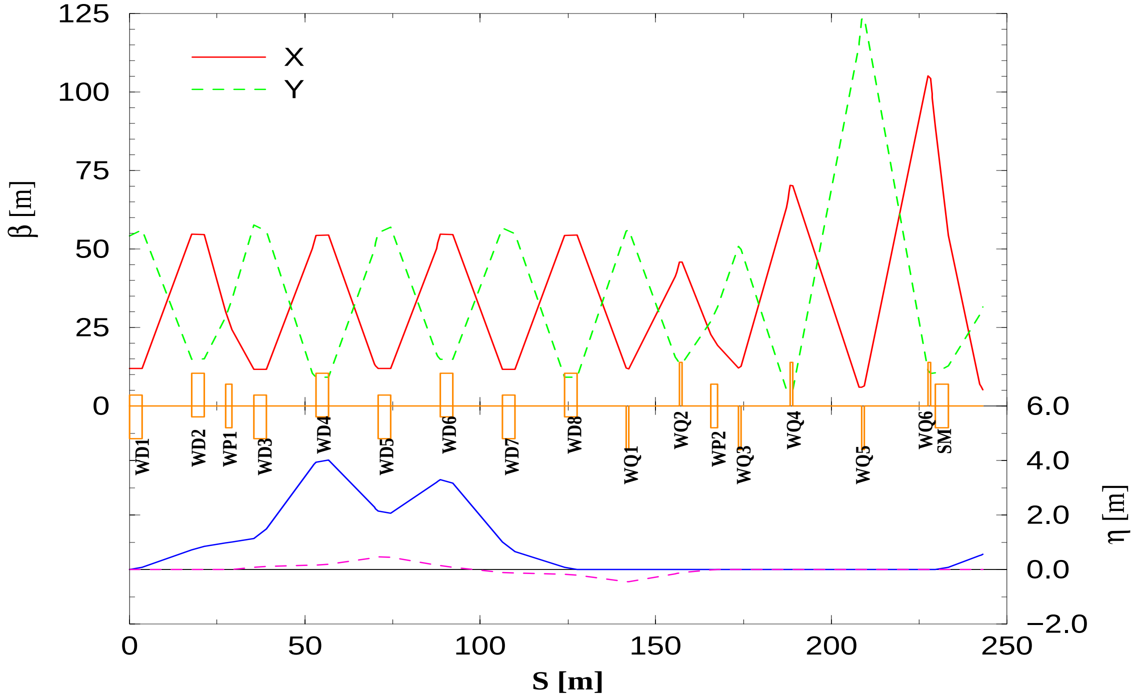

Fig2a. Beam parameters β_x,β_y, and η_x η_y for the unmodified W-line. The Wline ends at the entrance of the switching magnet (SM). Note the location of WP1 and WP2 pitching magnets.

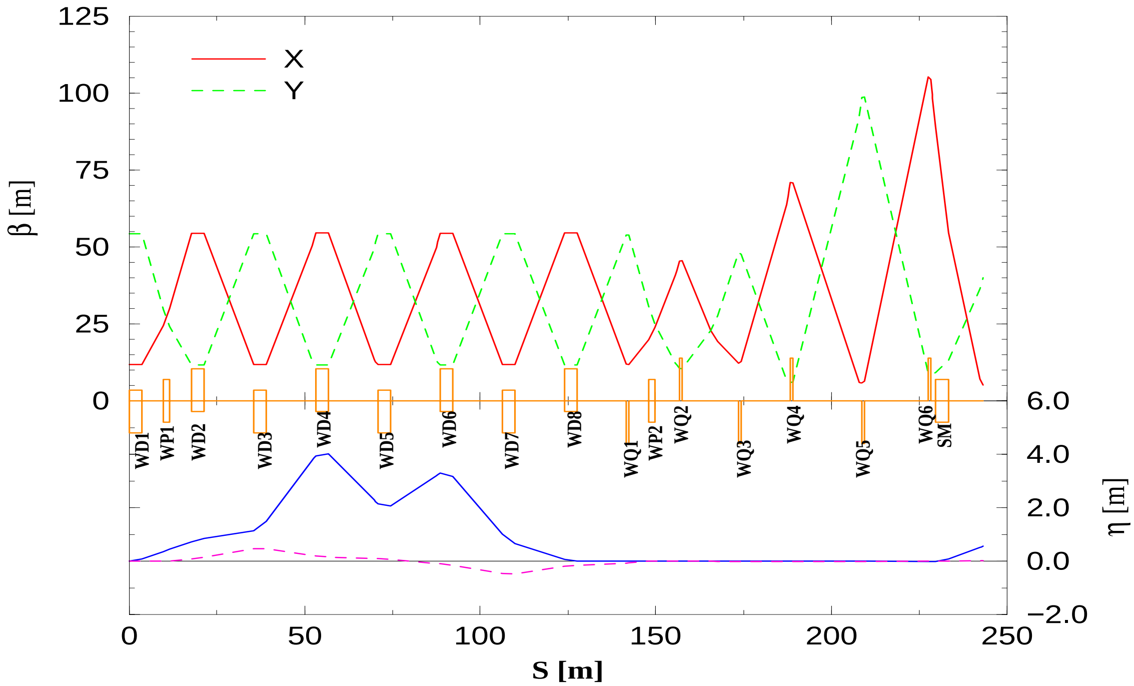

Fig2b. Beam parameters β_x,β_y,η_x and η_y for the modified W-line. Note the new location of WP1 and WP2 pitching magnets. Compare the vertical dispersion with that shown in Fig.2a.