CONF-890299--6

Advanced Hadron Facility Accelerator Design Workshop, LANL, February 20-25, 1989.

BNL-42638

A STRETCHER FOR THE BROOKHAVEN AGS*

BNL--42638

DE89 012532

Horst W.J. Foelsche
Brookhaven National Laboratory
Upton, NY 11973

Abstract

Brookhaven National Laboratory is proposing to add a Stretcher ring to increase the capacity and the quality of the experimental physics program at the AGS. At the present time a typical AGS cycle is about equally divided between the task of accelerating the beam to full energy and the task of distributing it on a 30 Gev flattop. The Stretcher, a 30 GeV dc storage ring, will take over from the AGS the distribution of the high energy beam with a continuous slow spill, and the AGS can then provide beam for the program at more than twice the present repetition rate. In this manner the average current delivered to the experimenters will be more than doubled, and the duty cycle of the spill will increase from the present optimum of about 40% to nearly 100%. The Stretcher proposal continues the gradual evolution of the AGS toward a high intensity hadron factory. At the present time the AGS provides about 1 μA average proton current. With the booster alone, now under construction, this is expected to increase to above 4 μA, and with the Stretcher to about 8-10 μA, an order of magnitude higher than now.

Introduction

Since its beginning more than 28 years ago the 30 GeV AGS has developed into a facility which supports a great variety of experiments in high energy and nuclear physics. There are now many accelerators providing much higher collision energies, but the ongoing AGS experimental program now is exactly what provides the rationale for numerous proposals for future high intensity hadron facilities: the study of very rare processes in kaon decays, the search for gluonic states, the study of QCD with high p_t exclusive processes, and many more. The four rare kaon decay experiments on the AGS floor at present, for example, are already sensitive to effects from mass scales higher than what will be directly accessible with the SSC, and higher sensitivity is sought for future experiments. Moreover, the AGS accelerates polarized protons, and provides heavy ion beams for fixed target experiments. While the experimental conditions are already excellent for such experiments at the AGS, there is now a clear call for

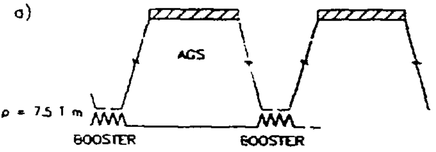
---

*Work performed under the auspices of the U.S. Dept. of Energy.

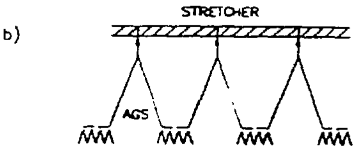
higher intensity proton beams at these intermediate energies, and as the intensity increases, for improvements in the quality and duty cycle of the beam spill.

At the AGS these improvements are being provided in a step by step manner, in response to the most urgent needs of the physics program, in a way which minimizes the disruption of the ongoing operations. A Booster is under construction which will raise the injection energy of the AGS from 200 MeV to 1.5 GeV, thus raising the space charge limited beam intensity of the AGS by a factor of 4-8. The Booster will also provide higher injection energies for the heavy ions, such that even the heaviest species can be injected into the AGS in the fully stripped state. Finally, it will serve as an accumulator of polarized proton pulses from the rapidly pulsing 200 MeV Linac, thus increasing polarized beam intensities by an order of magnitude as well. Although the improved duty cycle and the intensity increases made possible by a Stretcher had been given very high priority by the AGS physics community[1], the booster was constructed first in order to provide the broadest possible program base, particularly also with a view toward the planned construction of the Relativistic Heavy Ion Collider (RHIC).

When the AGS Booster is completed, a 30 GeV Stretcher can be added to the AGS. It will take over the task of providing a slow beam spill to the experiments. This will make it possible for the AGS to deliver beam at more than twice its present cycling rate, thus more than doubling the average current, while the Stretcher will increase the duty cycle of the slow beam spill from about 40% to nearly 100% (see Fig.1). It is equally important to the experimenter that the microscopic duty cycle of the slow spill be improved as well. Quite frequently, the AGS spill now contains structure with instantaneous intensity fluctuations of a factor of 2-3, such that the most sensitive experiments must throttle back their beam flux to avoid excessive accidental coincidences with background events. With an improved spill structure expected from the Stretcher, such sensitive experiments may expect to perform at 4-6 times the rates which would be possible with the Booster alone.



AGS CYCLE



AGS & STRETCHER CYCLES

Figure 1.

Two design studies of an AGS Stretcher, based on different sets of premises, have preceded the present one. The first of these (the "AGS Tunnel Option",[2]) assumed that the Stretcher would be located in the existing AGS tunnel, but this option was characterized by massive program interruptions during the construction and commissioning phases. Moreover, because of space constraints it was not possible to construct beam transfer lines between the machines, which would preserve the vertical polarization of the protons. The second study ("Superconducting Option",[3]) assumed an external tunnel, and provided a beam transfer configuration which preserved beam polarization. The external tunnel was to have half the circumference of the AGS to minimize conventional construction costs, and the ring was therefore assumed to employ high field superconducting magnets. This entailed certain technical complications in compressing the AGS bunch trains to fit into the Stretcher, as well as, of course, the complexity of the superconducting magnet environment. In fact this proposal included, provisionally, an rf system in the Stretcher which was to preserve the bunch structure of the beam long enough to permit the 12 AGS beam bunches to be individually stacked, one by one. Despite such complications, however, this option remains a viable one, if it turns out to be significantly cheaper than others. It does avoid extended shutdowns of the ongoing programs during the construction phases.

AGS Stretcher Design

The new AGS Stretcher design[4] summarized in this paper assumes an external tunnel, equal in circumference to the AGS (= 807.12 m), with normal warm low field magnets, and with straightforward single turn beam transfer from the AGS. The ring is laid out more or less to the south of the AGS ring, in a two-fold symmetric racetrack pattern, with two 86 m long straight sections (see Figure 2). The easterly straight section serves for the extraction of the beam toward the existing East Experimental Area beam switchyard, the westerly one for injection. There is no rf system in this machine. The polarization of the beam is preserved. Technically this is the simplest and most flexible conceptual design,

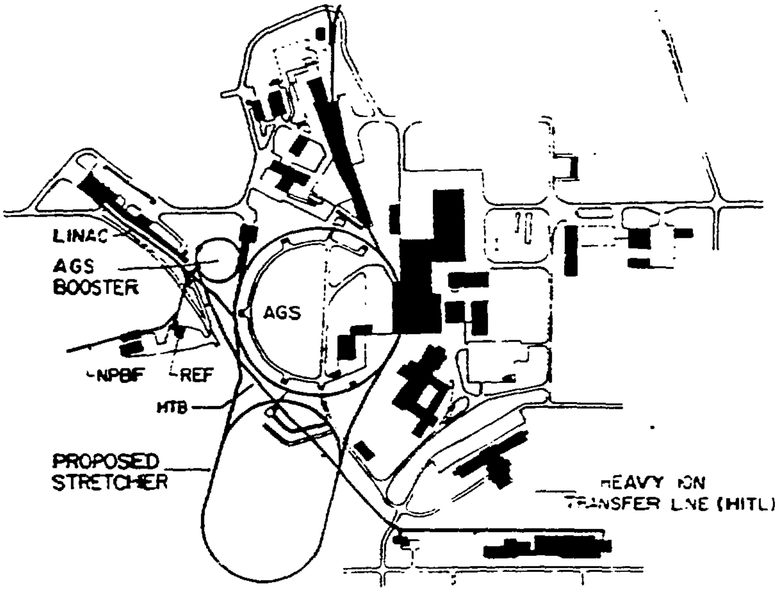


Figure 2

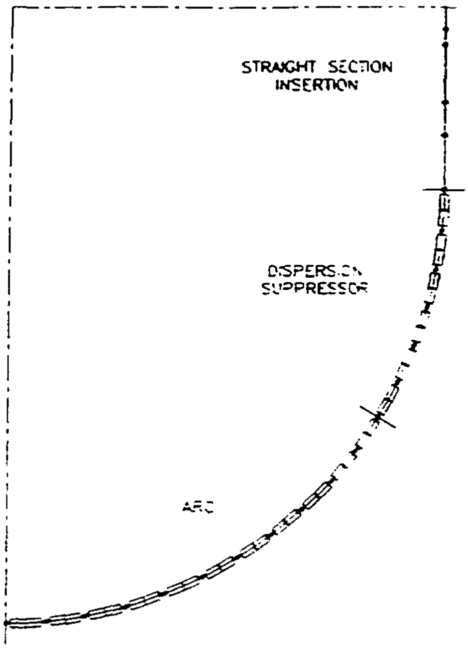
but it may well be more expensive than the other options to construct. Again, the construction can proceed with minimal impact on the ongoing program.

The Stretcher is a "distribution ring", operating continuously at a constant energy, up to 30 GeV. It will be supplied with full energy beam provided by the AGS, which will be cycling at its maximum repetition rate of about 0.6-0.8 Hz (see Fig 1.), and it will distribute this beam in a slow continuous spill, interrupted only briefly when the AGS is ready to supply a new pulse. The beam will arrive as a train of 12 bunches, having been extracted from the AGS in a single turn over a time interval of 2.7 microseconds. Due to its inherent momentum spread the beam will quickly lose its bunch structure, in about 10-20 milliseconds. The ring is then reset immediately to start slow extraction toward the experimental areas of the AGS, while the AGS cycles back for another pulse. Any beam which may remain in the ring when the next pulse is about to arrive, will be ejected to the beam dump by the same fast kicker magnet which deposits the arriving beam on the injection orbit. Overall, the filling and initial reset operations will consume less than 5% of the entire spill time, so that the spill duty cycle will be greater than 95%.

The Stretcher will be available for all three operating modes of the AGS program which use the slowly extracted beam in the East Experimental Area: unpolarized high intensity proton beams, polarized proton beams, as well as heavy ion beams. The single turn extraction of bunched beams, traditionally employed for neutrino physics and for other specialized experiments, will remain available directly from the AGS in the North Experimental Area, as before.

Lattice and Straight Section Design

The Stretcher lattice is shaped importantly by the requirements of the slow extraction systems. Its overall racetrack pattern is illustrated in Fig. 2, and for further detail of its major features Figure 3 shows one quarter of the ring. To achieve the most flexible parameters for extraction, 86 m long straight sections are inserted between the two halves of the ring. These straight sections are dispersion-free. Therefore there are dispersion suppressors at each end of the half-circles of the arcs. The arcs are made up of standard separated function FODO cells, with 60 degree betatron phase advance per cell. The straight sections represent a phase advance of about 360 degrees each. The machine operates at a betatron tune of about 7.7 in both planes, in fact on the horizontal 7-2/3 resonance for slow extraction most of the time.



STRETCHER QUADRANT

Figure 3

The betatron functions of the lattice are illustrated in Figures 4, 5, and 6, for the arc cells, the dispersion suppressor, and for the straight sections, respectively. All the spaces between quadrupoles in the arcs and in the dispersion suppressors are filled with bending magnets, with sufficient room, of course, for beam instrumentation and correction magnets. The six quadrupoles at each end of the arcs are individually powered so as to achieve the desired match into the straight sections with zero momentum dispersion. Also included in each of these four regions are six sextupoles, which make this match as achromatic as possible.

Each straight section encompasses ten quadrupoles arranged symmetrically around its center, and the betatron functions in the central portion can be adjusted to optimize the performance of the extraction and injection systems. The extraction septum is located in the central 10 m long free space of the easterly straight section, and a relatively large beta value is desirable there to minimize the angular divergence of the beam. The injection kicker is located in the opposite straight section, also in the central free space, but it is possible that a different beta value will be optimum there. Running both straight sections at the same excitations

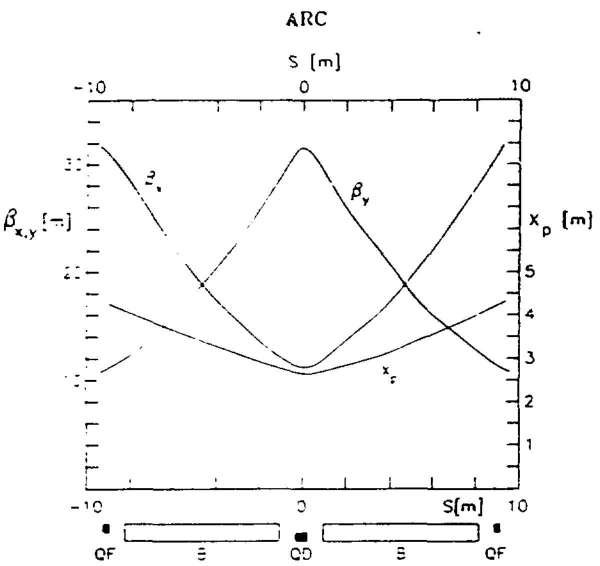

ARC

Figure 4

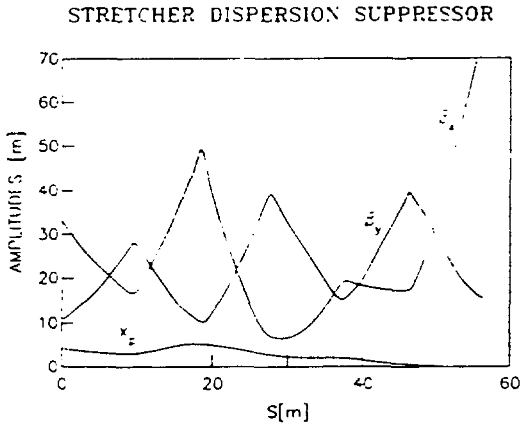

STRETCHER DISPERSION SUPPRESSOR

Figure 5

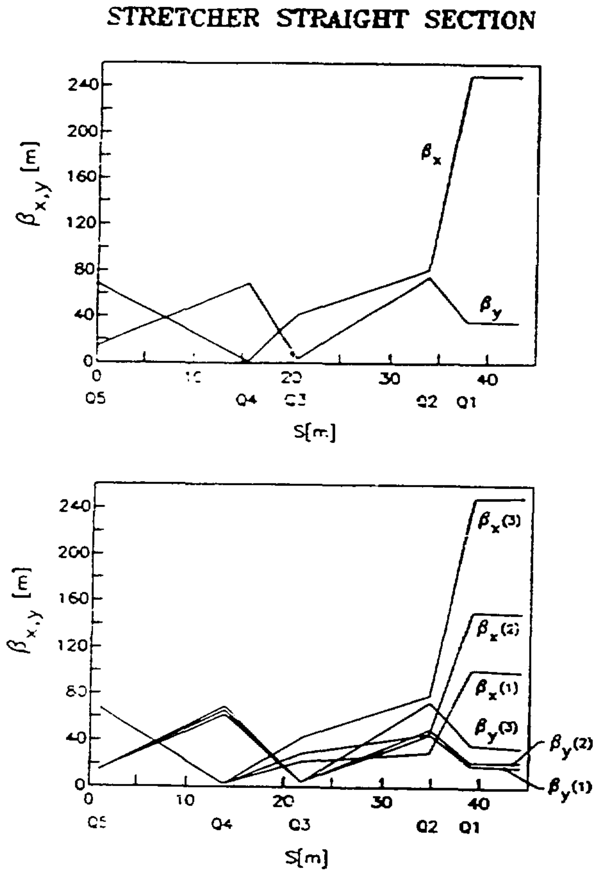

STRETCHER STRAIGHT SECTION

Figure 6

would suppress a systematic half integral stopband at a tune of 7.5. Figure 6b illustrates the horizontal and vertical beta functions in the straight sections for several choices of the central value. The horizontal beta at the center is variable from 10 - 1000 m; the extremes are unlikely to be used.

The natural chromaticity of the lattice is about -14. This is quite adequate for the control of the extraction process, where one makes use of the chromaticity to drive particles of different momentum across the resonance at different times. From the point of view of extraction it is therefore not necessary to correct the natural chromaticity of the ring. The chromatic properties of the straight section require some attention, because as the momentum content of the beam changes during the spill, one does not like to see significant variations of the lattice functions in the region of the extraction septum, which might result in variations of spill quality or extraction efficiency. This is the reason why sextupoles are included in the dispersion suppressor sections. They can be set to make the dispersion cancellation independent of momentum, and residual variations of the beta functions become small enough to be of no further concern. A summary of the major lattice parameters is given in Table 1.

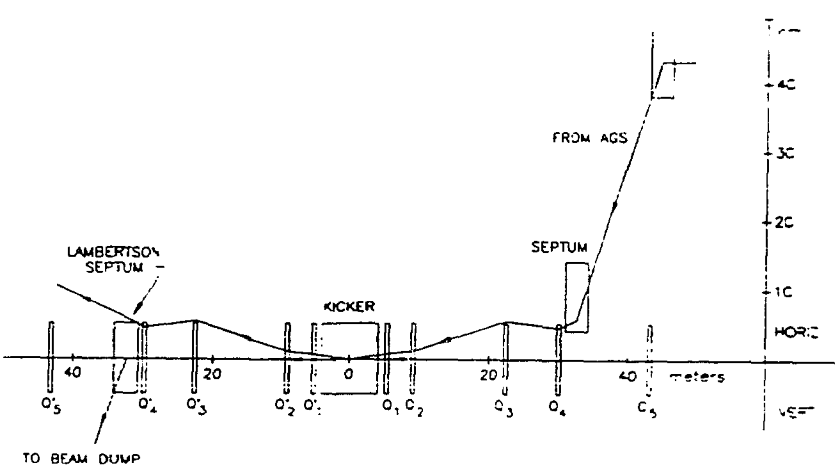
TABLE 1

STRETCHER PARAMETERS

Magnetic Rigidity (30 GeV)	100	Tm
Circumference	807.12	m
Periodicity	2	
Cycle Period	1.2	sec
Protons / Cycle	$> 6 \times 10^{13}$	
Normalized Beam Emittance	60	π mm mrad
Betatron Admittance	10	π mm mrad
Momentum Acceptance	± 1%	
Betatron Tune	7.67	
Natural Chromaticity	- 14	
Transition Energy, Gamma	6.5	

Injection

Injection into the Stretcher is a straightforward analogue of the single turn extraction process at the AGS. The circumference of the central orbit is the same for the two machines. The layout of the injection straight section is illustrated in Figure 7. The beam arrives as a train containing 12 bunches, each separated from its neighbor by 224



INJECTION & DUMP STRAIGHT SECTION

Figure 7

nsec in time. It approaches the Stretcher in the horizontal midplane, passes through a current septum magnet located in the free space between Q5 and Q4 at the upstream end of the straightsection, very near the circulating beam envelope, and is aimed through the quadrupoles into the center of the injection kicker located in the central free space near Q1. By the time the beam starts to pass through the kicker, residual beam in the machine is already in the process of being ejected into the beam dump along a trajectory which mirrors the injection path. After all the bunches have passed, the kicker turns off, with a fall time of less than 200 nsec, quickly enough so as not to disturb the leading bunch which is about to complete the first pass around the ring.

The injection current septum is a pulsed magnet (1 msec pulse length), 3.6 m long with a field of 1 T, providing 36 mrad of horizontal deflection. The fast kicker, with a length of about 4 m and a field of 0.045 T, will provide a 1.8 mrad horizontal deflection.

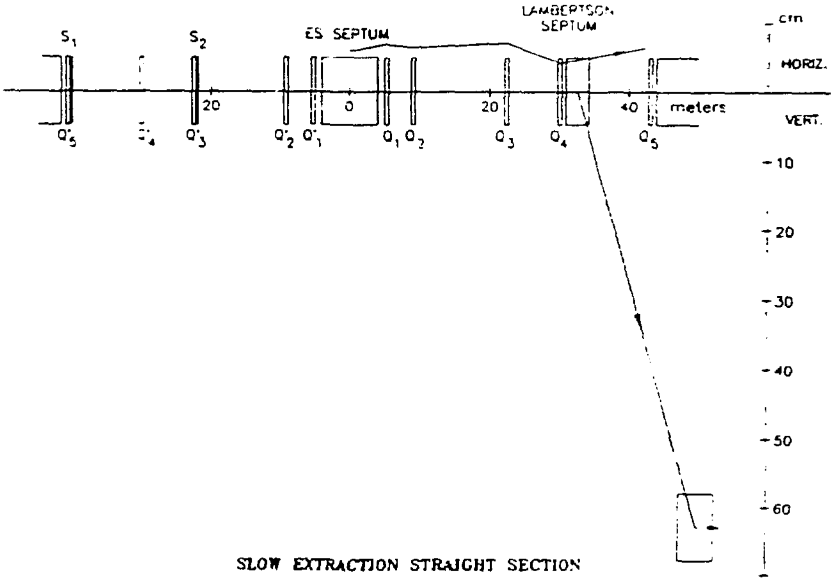
Prior to ejection from the AGS the longitudinal phase space has been manipulated to introduce a momentum spread of about ± 0.3% in the beam. In the Stretcher the beam bunches begin to dilute in space, until after about 10-20 msec the bunches have sufficient overlap to appear as a continuous beam. At this time one restores the ring onto the horizontal resonance which causes beam to spiral slowly across the extraction septum. The AGS recycles immediately to bring up another pulse train about 1.2 seconds later.

The beam transfer line between the AGS and the ring is not yet designed in detail, but its general geometry is such that the polarization of the transferred beam will not be lost. For reasons of local geography and radiation shielding the

Stretcher ring is located at a lower elevation than the AGS, and in addition there are some horizontal trajectory changes. To avoid losing control over the precession of the vertical polarization vector, it is necessary to assure that there are no horizontal bends between the two vertical deflection points where the beam is directed downward and then restored to the horizontal level. This requirement is met in the proposed layout, and there is sufficient space to assure nondispersive transport to the Stretcher, employing focusing cells similar to the ones used in the Stretcher lattice.

Slow Beam Extraction

The beam is extracted from the machine by exciting a third order resonance, $3\nu_x=23$, and by slowly changing the horizontal tune of the machine to drive the particles of varying momentum across the resonance as time evolves. Unstable particles will spiral outward into the electrostatic septum, which deflects them horizontally into a Lambertson septum magnet, which in turn deflects them vertically out of the ring. The layout of the extraction straight section is illustrated in Fig.8.



SLOW EXTRACTION STRAIGHT SECTION

Figure 8

The third-order resonance is established by powering a pair of small sextupoles, located next to the two quadrupoles denoted as Q5 and Q3, at the upstream end of the extraction straight section. The strength of these sextupoles controls the spiralling rate at the septum.

The betatron tune of the machine is driven by four small auxiliary quadrupoles located symmetrically next to each of the quadrupoles denoted as Q1, in both the extraction and the injection straight sections. The rate of change of these four elements controls the rate of spill between refills. An external beam monitor can provide feedback to these magnets to assure a uniform spill rate.

The optical parameters of the straight section are flexible to permit a wide choice of beta values at the extraction septum. The horizontal beta value at the extraction septum is chosen, provisionally, to be 250 m, and this value may also be acceptable at the corresponding location in the injection straight section (for two-fold lattice symmetry). The resonance sextupoles are set so that the spiralling rate is equal to the gap of the extraction septum, which is here assumed to be 2 cm, and which is assumed to support a field of 60 kV/cm. Assuming a wire thickness of effectively 0.05 mm, one expects the electrostatic septum to intercept, theoretically, about 0.3% of the beam. The electrostatic septum is assumed to be 9 m long, and will provide a deflection of 1.8 mrad, which will result in a 4 cm displacement at the entrance to the Lambertson septum. The 3.6 m long Lambertson septum, with a field of about 1 T, will provide an upward deflection of 36 mrad.

A simulation of the extraction process in horizontal phase space at the electrostatic extraction septum is illustrated in Figure 9. The septum is placed about 6 cm to the outside of the central orbit. The illustration shows unstable particles leaving the stable region near the center along the separatrices of the third order resonance, with a spiralling rate, near the septum, of about 2 cm for every third turn.

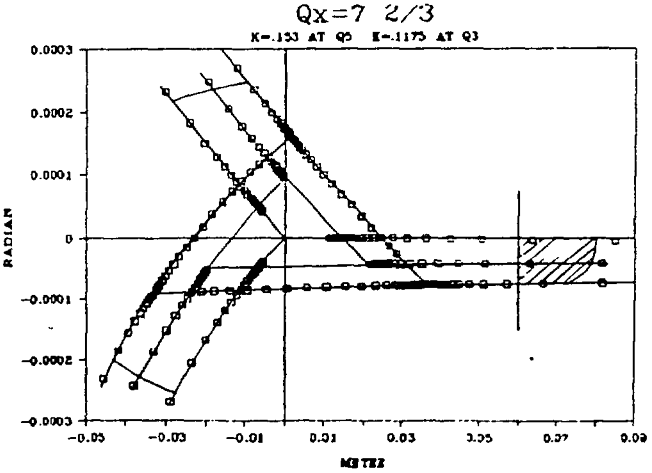


Figure 9.

It is expected that a small fraction of the beam will remain in the ring without having responded to the resonance. In the AGS this amounts to several percent of the beam, and the exact amount will not be known for the stretcher until more detailed beam simulations have been performed. In any event, as we have mentioned above already, when a fresh load arrives from the AGS, whatever beam may be remaining in the Stretcher will be ejected by the injection kicker magnet onto a beam dump.

Although we are discussing extraction on the third order resonance in this paper, half-integer extraction may prove advantageous. The final choice can be made after further detailed study in the future.

After leaving the Stretcher, the beam is first restored to a horizontal level, then bent horizontally for a proper aim toward the AGS, and finally bent upward and levelled out before entering the AGS experimental area switchyard. As is the case with the injection transfer line, such an arrangement assures that the vertical polarization vector will not precess out of control.

Polarization

The Stretcher will preserve the vertical polarization of the beam, just as the AGS does now, if the energy is chosen to avoid the various depolarization resonances.[5] Depolarization occurs at energies where the beam encounters certain lattice harmonics of horizontal magnetic fields in resonance with the frequency of precession. Depolarization can be caused by the intrinsic focusing fields of the quadrupoles (intrinsic resonances), or by the horizontal imperfection fields due to, for example, improperly leveled dipoles or improperly aligned quadrupoles (imperfection resonances). Intrinsic depolarization resonances occur where $G\gamma = nP \pm \nu_z$, and imperfection resonances where $G\gamma = k$, with G being the anomalous magnetic moment of the proton ($= g/2-1 = 1.79285$), and γ being the energy of the proton in units of its rest energy. The indices n and k are integers, and P is a periodicity of the focusing lattice.

Imperfection resonance harmonics are therefore spaced about 0.523 GeV apart on the energy scale, and because of the 2-fold lattice periodicity intrinsic resonances are present within all of these intervals as well. An analysis of the strength of these various effects shows[4] that the most significant intrinsic resonances to be avoided are in the vicinity of 14.8 and 20.8 GeV ($G\gamma = 34 - \nu_z + 2$, and $= 34 + \nu_z - 2$, reflecting the very strong 34-fold periodicity of the arc cells alone), and the imperfection resonances in this vicinity tend to be strong as well.

Most resonances in the stretcher are expected to be sufficiently weak so that one may operate in the energy intervals between them, as one does at the AGS, avoiding the neighborhood of the strongest intrinsic resonances, and if necessary by suppressing the nearest imperfection harmonics with a compensating set of dipole correction magnets. In the AGS we have reached polarized beam energies up to about 22 GeV ($G\gamma = 43$), with polarization about 50%, using these techniques.[5] It may be possible to install a pair of Siberian Snakes in the free spaces of the long straight sections. This remains to be studied in the future.

ACKNOWLEDGEMENT

This paper is a summary of a Conceptual Design Report[4] which is the joint effort of the following individuals: D. Barton, E. Bleser, G. Bunce, G. Cottingham, E. Dale, G. Danby, J. Feldman, H. Foelsche, E. Jablonski, J. Jackson, J. Milutinovic, S.Y. Lee, Y.Y. Lee, E. Lessard, P. Mohn, L. Ratner, A. Ruggiero, M. Schaeffer, J. Spinner, K. Welch, W. Weng, and R. Witkover, all of BNL.

REFERENCES

1. Report of the AGS II Task Force, G.A. Smith (Chairman), issued under the auspices of the High Energy Discussion Group (HEDG), representing the high energy physics user community of BNL (February 1984).

2. AGS Stretcher, AGS-NSLS Study Group, A. van Steenbergen (Editor), Informal Report BNL 37752 (January 1986).

3. AGS Superconducting Stretcher Ring, ADD-AGS Superconducting Stretcher Committee, L.G. Ratner (Editor), Informal Report BNL 39142 (November 1986).

4. AGS Stretcher Conceptual Design, AGS Stretcher Task Force, H. Foelsche (Editor), Internal Report AGS/AD/89-3, April 1989.

5. For a comprehensive review of the AGS polarized proton program see: F.Z. Khiari, et al., Phys. Rev. <u>D39</u>, 46, (1989).