HADRON BEAMS SESSION -- SUMMARY*

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INTRODUCTION

The Hadron Beams Session was organized by Lee Teng. There were contributions in three areas. One was the status of presently operating polarized beams, with presentations on the polarized beams at Fermilab, the AGS, and KEK. The second area involved new developments in Siberian Snakes, with talks on helical Snakes, applications and design considerations of Siberian Snakes, Snake resonances, and an upcoming experimental test of the Siberian Snake principle. The third was self-polarization of a beam in situ: a talk was given on a proposed method for an antiproton beam splitter for LEAR.

OPERATING POLARIZED BEAMS

A) Fermilab Polarized Proton and Antiproton Beam

The presentation was made by Fred Luehring for the E581/704 Collaboration. Polarized protons and antiprotons are produced in a Fermilab beam line by the parity violating decays of Λ° and $\bar{\Lambda}^\circ$, which are created by the interaction of the primary 800 GeV proton beam on a Beryllium target. The polarized beam line layout is shown in Fig. 1. The virtual source of each decay proton or anti-

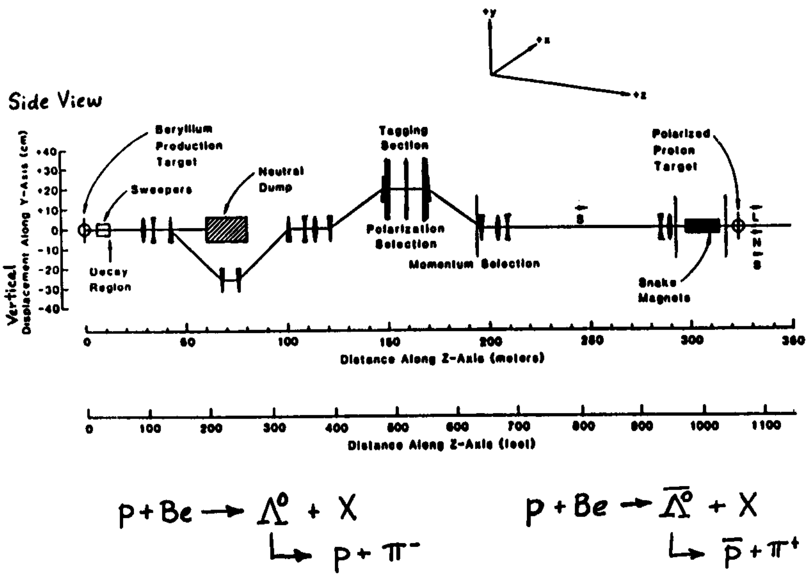

Fig. 1. FNAL polarized secondary beam line.

proton is used to determine its polarization; its momentum is also determined. The required measurements are made with a magnet and a counter hodoscope system, which has a position measurement accuracy of about 2 mm. The set of Snake magnets at the end of the line can rotate and reverse the spin direction.

The beam has been brought on line at its design specifications. For 10^{12} incident 800 GeV protons the system produces a tagged beam of about 8 x 10^6 protons and 4 x 10^5 antiprotons at 185 GeV/c, with an average polarization of 45% for both beams. This is the highest energy polarized proton beam, and the only polarized antiproton beam.

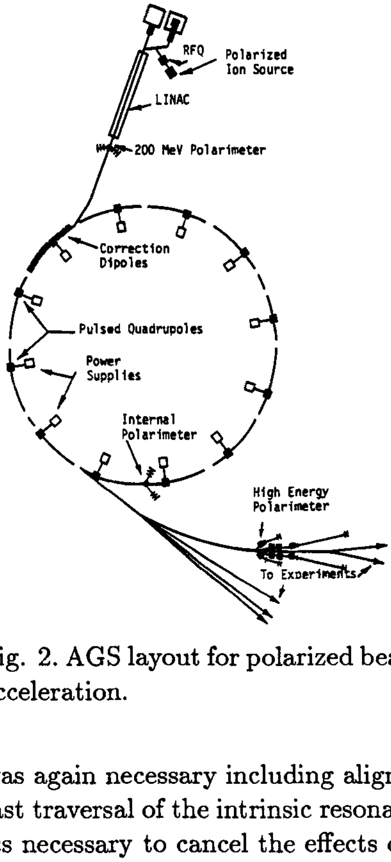

Fig. 2. AGS layout for polarized beam acceleration.

B) AGS Polarized Proton Beam

Lief Ahrens discussed the 1988 18.5 GeV/c polarized beam operation at the AGS. This was the third polarized beam tune up and run. The polarized beam was initially accelerated to 16.5 Gev/c in 1984, and to 22 Gev/c in 1986. The AGS modifications required for polarized beam acceleration are shown on Fig. 2. The machine characteristics were changed somewhat from the 1986 run, the major difference being the necessity of using a backup main ring power supply which lowered the acceleration rate by a factor of 0.6, which effectively strengthened the resonances. In addition, the main ring magnets and ferrite quadrupoles were realigned both vertically and horizontally. The standard tune-up and commissioning was again necessary including aligning the timing of the pulsed quadrupoles for fast traversal of the intrinsic resonances and determining the correction harmonics necessary to cancel the effects of the machine misalignments at each imperfection resonance. The tune-up commissioning period took about 2.5 weeks, and the physics run was 3 weeks. In the future, the time spent tuning should be further reduced as the procedures become even more established. The accelerated beam intensity was about 2 x 10^{10} protons per 2.8 second pulse, with a average polarization of 43%.

There has also been a new development of major importance: the partially excited Snake, discussed at this Conference by Thomas Roser, might be applicable for the AGS; this would allow the avoidance of resonances and thus considerably decrease the tune-up time. Major improvements in the beam intensity can be expected from the upgraded source presently under development and a factor of 20 should come from the AGS Booster now under construction.

C) KEK PS Polarized Beam

S. Hiramatsu gave a progress report on the polarized beam at KEK. The polarized beam acceleration system is shown in Fig. 3. The first acceleration test at the 500 MeV Booster was in 1983, when 15% polarization was obtained. In 1986 the polarized beam was successfully accelerated in the Main Ring to 3.5 GeV/c, with a polarization of 38%. Since then physics experiments have been carried out at 3.5 GeV/c, and the beam has been accelerated to 5 GeV/c with 25% polarization. The resonance crossing techniques used are adiabatic spin flip for the stronger resonances, and correction and fast traversal for the weaker ones. There is a significant polarization loss in the Booster that the group attributes to synchroton oscillations, which lead to multiple non-adiabatic crossings of a single resonance. Data illustrating the dependence of the polarization at 500 MeV on the accelerating rf voltage, is shown in Fig. 4. Normal polarized beam operation is at an rf voltage of 12 kV, and beam losses preclude operating much below there. The situation could be improved by adding sextupoles to adjust the betatron tune dependence on the momentum, but space limitations make this difficult.

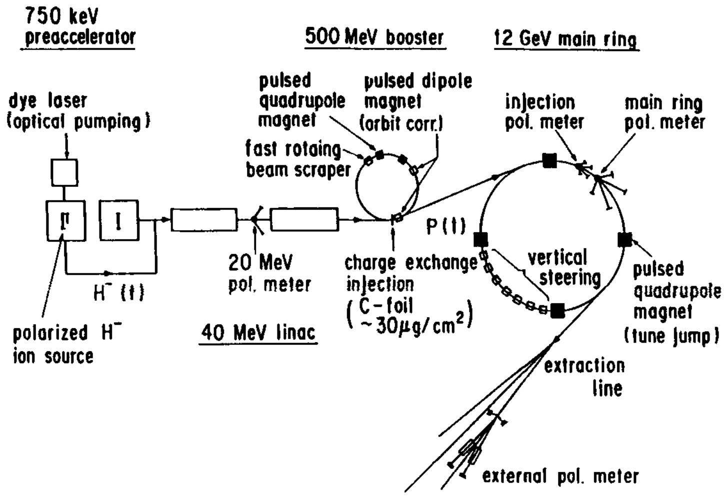

Fig. 3. KEK layout for polarized beam acceleration.

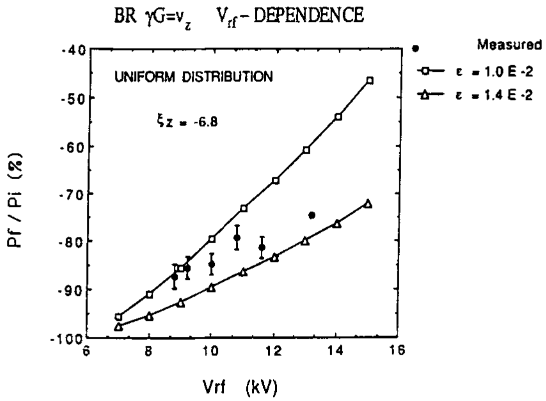

Fig. 4. KEK Polarization at 500 MeV as a function of the accelerating rf voltage.

NEW DEVELOPMENTS IN SIBERIAN SNAKES

The Siberian Snake concept was proposed by Derbenev and Kondratenko[1] in the mid 1970's. The idea is that if the spin direction was flipped 180° around a horizontal axis, then the depolarization generated in one period before the flip would be removed in the following period. This leads to a spin tune of 1/2, independent of energy, and therefore no resonances to cross during acceleration. The following talks in the Hadron Beams Session were on further developments in this field.

A) Helical Snakes

Ernest Courant discussed his proposal to use a distributed helical Snake rather than a set of uniform 45° or 90° spin rotating dipoles to generate the spin flip. The problem with the standard approach is that unacceptably large excursions occur at low energies near 10 GeV. The helical design, like a Free Electron Laser wiggler, has considerably smaller excursions. Orbits through an example of his system are shown in Fig. 5. The excursion can be further decreased, but requires a longer helix. There is a major limitation to this approach: for designs which have been found so far, the precession axis is always approximately

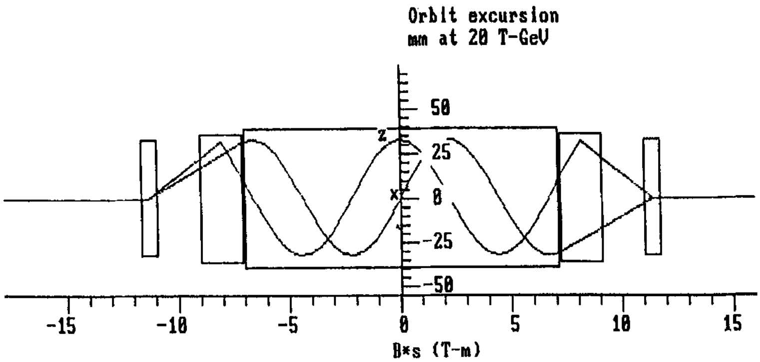

Fig. 5. Orbit in a sample helical snake.

longitudinal, so that the Snake is Type I. Since Type II Snakes, which rotate about a transverse axis, are necessary in multi-snake accelerators, the Helical Snake is limited to lower energy single Snake machines.

B) Future Applications of Siberian Snakes

Klaus Steffen reported on his work on general design principles for Snake systems in circular accelerators. He has created a number of specific Snake designs as examples; possibilities suitable for the SSC are shown in Fig. 6. He also shows how an SSC might be constructed with the potential for adding Snakes later. A 26 Snake pair system could be handled in the initial design by the removal of 1/2 bending magnet every 6 cells, which would change $\int Bdl$ by 0.7% and cause a ± 2.5 cm orbit move.

His paper stresses the usefulness of 'local' Spin Matching which involves decreasing the amount of local spin precession away from the vertical. This decreases the depolarizing resonance strengths and enables the Snake systems to handle higher beam energies successfully. Steffen strongly recommends that any SSC design should include the possibility of Snakes and Spin Matching.

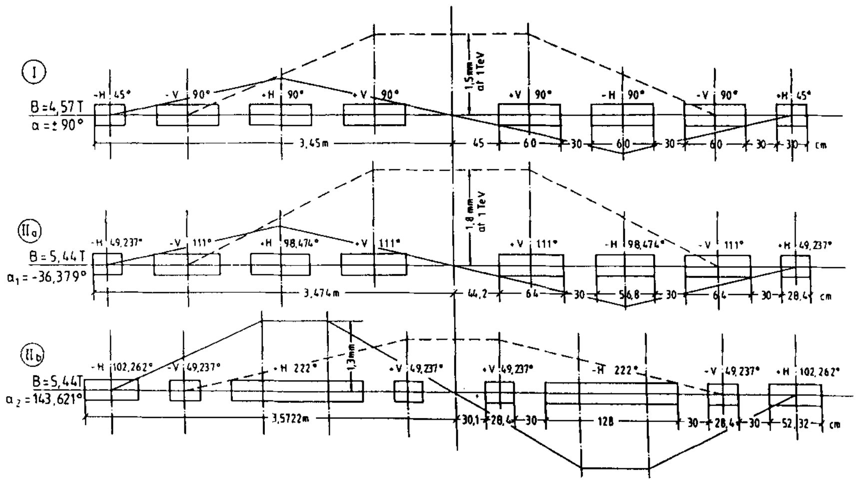

Fig. 6. Orbits in a set of sample SSC snakes.

C) Studies of Spin Resonances with Siberian Snakes

S.Y. Lee described work on Snake resonances, resonances that are generated by the introduction of Snakes. He and S. Tepikian showed the existence of such resonances in their 1986 paper.[2] Figure 7 illustrates the effect on the polarization of the passage through resonance for a two Snake accelerator. There are polarization losses at particular rational values of the fractional part of the vertical betatron tune. Hence, if these particular tune values are avoided, resonances

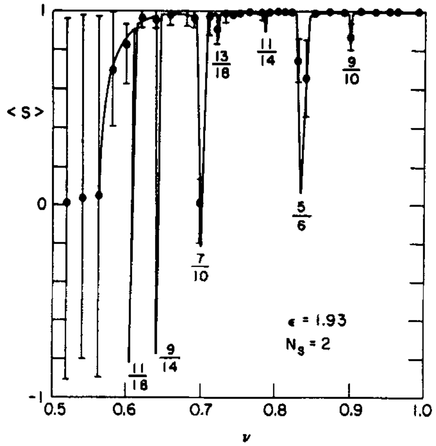

Fig. 7. Polarization of the beam after passage through a single spin resonance in the presence of a single pair of Snakes as a function of the fractional part of the vertical betatron tune.

will not appear during the acceleration process. As the resonance strength increases, the number and width of regions to be avoided also increase, even with the addition of more Snakes. For a given number of Snakes, N_s, the value of the depolarizing resonance strength, ϵ, must be less than a critical value, ϵ_c. He discussed results of spin tracking programs which showed that this critical resonance strength increased with N_s, crossing the linear curve $\epsilon = N_s/2$ at $N_s = 8$, then falling below it. If the resonance strengths are less than the critical value, there are regions free of Snake resonances that can be exploited. So for a maximum ϵ of 5, about 12 Snakes or 6 Snake pairs should be sufficient–for the single isolated intrinsic resonances being considered. However, coupling with nearby imperfection resonances also exists. Tracking results indicate that for two Snakes, nearby imperfection resonance strengths should be kept under 0.1 to avoid losses. Work is continuing on this coupling problem.

D) Experimental Test of a Solenoidal Snake at IUCF

Alan Krisch reported on a Michigan/Indiana/Brookhaven experiment which is getting underway to make the first experimental test of the Siberian Snake method of resonance avoidance. Since this Snake scheme is essential to the success of future projects to accelerate polarized protons to high energies there is clearly a need to have an experimental test before major commitments are made. A Cooler Ring has just been constructed at the Indiana University Cyclotron Facility, which is an excellent place to make the test. There is a polarized beam from the IUCF Cyclotron; the Cooler Ring has an imperfection resonance at 108 MeV and an intrinsic resonance at 179 MeV and the energy range is low enough that an available 6m straight section is suitable for inserting a superconducting solenoid 180° rotator Snake. A schematic layout of the Cooler Ring is shown in Fig. 8. Polarized protons from the Cyclotron are injected on orbit into the Cooler with a fast ferrite dipole kicker magnet. With a single kicker, beam can

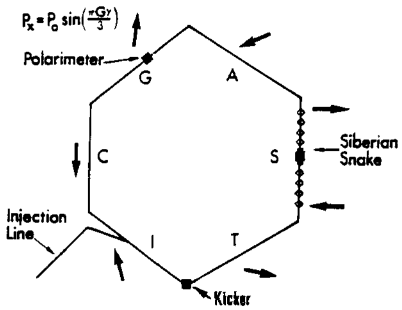

Fig. 8. The Cooler Ring at the Indiana University Cyclotron Facility with components to study the effects of a solenoidal Siberian Snake.

be injected for only one turn. Two runs have taken place, without the Snake, in May and July 1988, which have demonstrated injection and cooling of polarized protons and a measurent of the polarization of the stored beam. A second kicker has been installed which should allow beam stacking with a considerable increase in stored intensity. For the future program, the two resonances will be studied without the Snake using vertically polarized protons. Then the orbit behavior with the Snake and adjacent orbit compensating quadrupoles in place will be investigated with the unpolarized beam. If all works out well then horizontally polarized beam (the stable direction for a Type I solenoid Snake) will be injected with the Snake active to study resonance avoidance. When the basic Siberian Snake concept is firmly established, a number of other studies will be of interest: the partially excited Snake, the possibility of stable vertical polarization and the investigation of Snake resonance phenomena.

BEAM POLARIZATION IN SITU

The high energy spin physics community would be vitally interested in a method of polarizing proton beams at full energy and intensity. The synchrotron radiation mechanism useful for electrons (Sokolov-Ternov effect) is not feasible for protons. A possible approach has been suggested, as described below.

A) Antiproton Beam for Lear

Robert Rossmanith discussed a proposal for achieving a polarized antiproton beam in LEAR. This proposal was based on his and T. Niinikoski's suggestion that the Stern-Gerlach splitting mechanism might be made to work in a circular particle accelerator. The idea is that if a magnetic field gradient force on the magnetic moment can be kept in phase with the particle's vertical betatron oscillation, these oscillations would be driven appreciably and oppositely by the opposite forces in the two spin states. This idea has generated considerable discussion.

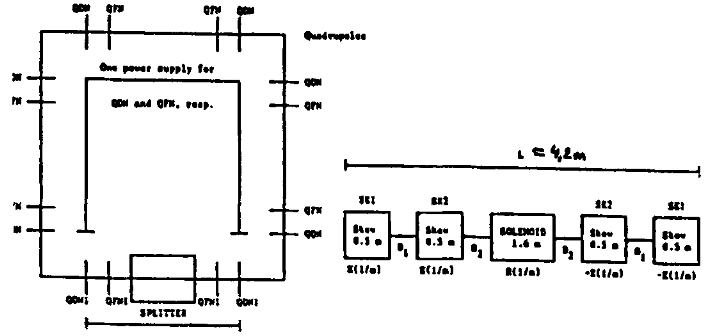

Fig. 9. The position of the spin splitter in LEAR (left) and the arrangements of the magnets in the spin splitter (right).

One question raised was whether quantum mechanics precludes this long term separation; this was studied with the conclusion that separation was quite consistent with quantum mechanics. Another problem is that the driving resonance condition is also the condition for a depolarizing resonance. The proposers believe they can handle this by using a solenoid 180° rotator Snake to get the spin tune close to 1/2. The spin-splitter layout using the Snake is shown in Fig. 9. Calculations show that at a momentum of 300 MeV/c an orbit separation of 1 - 2 mm/hr can be obtained. A letter of intent for this experiment has received positive support during the past two years. A proposal for the project has just been submitted.

REFERENCES

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1. Ya.S. Derbenev and A.M. Kondratenko, Sov. Phys. Doklady, 20, 562 (1976); Ya.S. Derbenev and A.M. Kondratenko, 10th Int. Conf. on High Energy Accel., Vol 2, 70 (Protvino, 1977).
2. S.Y. Lee and S. Tepikian, Phys. Rev. Lett. 56, 1635 (1986).