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CONCEPTUAL DESIGN OF AN ANTIPROTON FACILITY AT BNL

This facility is considered in 3 stages: direct manipulation of antiprotons through the AGS Booster; accumulation with cooling in a separate storage ring, with subsequent disposal to deceleration through the Booster and ultimately its injector, or to acceleration in the AGS; and use of the Accumulator ring as a $\bar{p}p$ collider. These 3 stages can be developed to a large degree sequentially, provided that each state is designed with adequate allowance for later installation of the next stage.

I. First Stage: $\bar{p}$'s in the Booster [1]

The concept is outlined in Figure 1. In each AGS cycle the Booster is filled with protons and operates normally, ejecting into the AGS. After acceleration in the AGS, fast extraction of protons occurs at I-10, where they are focused on an antiproton production target. The antiprotons are collected by a lithium lens and transported at 4 GeV/c, near peak production, to the Booster where they are injected through the proton extraction channel, running in reverse direction around the Booster. They are then extracted in one straight section with a moderately thick septum tangent to the AGS and transported directly to experimental area in the 80-inch bubble chamber complex, or an extension thereof, in case the (g-2) experiment is mounted there. The extraction and transport occur during the AGS spill. The Booster is then ready to accept the next charge of protons at the usual repetition rate. Table 1 lists properties of the antiproton beam produced.

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Table 1. BOOSTER ANTIPROTON BEAM CHARACTERISTICS

Momentum range:	0.65 - 5.2 GeV/c
Momentum acceptance: $\Delta p/p$	.02
Angular acceptance:	40 msr
Maximum $\bar{p}$ flux $(10^{13}$ beam prot.$)^{-1}$:	4×10^7
Purity $\pi^-/\bar{p}$ (all momenta):	0:1
Length (meters):	(not relevant)
$\bar{p}$ production target location:	I-10 (muon target)
Experimental Area:	80" bubble chamber building

The cost summary in Table 2 assumes the use of an extraction system at I-10 and all shielding in the proton target area already provided for the muon g-2 experiment, as well as the same target. If it should not prove possible to use the same target, the Booster option must include the cost of a primary target station.

Table 2. COST SUMMARY - BOOSTER OPTION

	Cost (K$)	Labor (MW)
Target region	945	123
50° bend and $\bar{p}$ transport to Booster	1016	378
Booster magnet modifications to reach 6.3 GeV/c	990	284
Transport to 80" bubble chamber	626	175
Experimental area	430	25
TOTAL	4107	985

According to Appendix 6 of Ref. 1, the post-booster AGS will accelerate in every cycle 12 buckets of 0.5×10^{13} protons each, of which 3 are extracted to produce antiprotons while the other 9 bunches are available for the rest of the program. The result is 6×10^7 per $\bar{p}$ pulse, which must be ejected from the Booster each cycle of about 2.5 seconds. Typical AGS performance is some 10^3 pulses/hr for about 10^2 hr/week when the SEB program is running, a total of around 10^5 pulses/week. The SEB program of the AGS has approached 20 weeks' running time in a normal year. Thus the potential antiproton yield is of order

$$Y(\text{Booster}) = 10^{14}\ \bar{p}/\text{year}$$

This yield can be increased to 10^{15} $\bar{p}$/yr by dedicated running: use all 12 buckets of the AGS to produce $\bar{p}$'s and cycle at twice the repetition rate, 1.4 sec^{-1}. Since this use of the AGS would be exclusive and non-parasitic, the full running costs would accrue to the $\bar{p}$ users.

The availability of this first stage can be that of the Booster, if funds for the $\bar{p}$ modifications are supplied on a compatible schedule. Given the funding and initial construction of the Booster rf in FY 1988, the $\bar{p}$ facility should be available some time in calendar 1991.

II. Second Stage: The Accumulator

A severe limitation of the Booster as a $\bar{p}$ source is the necessity to clear it every AGS cycle in order to provide the protons for generating the next pulse of $\bar{p}$'s. This means that the antiprotons must be handled as single pulses of order 10^7 without much time for manipulation of the pulse--a situation that will lead to great losses in either deceleration or acceleration.

For example, the potential $\bar{p}$ yield at 4 GeV/c described in Section I is not all available at kinetic energies of 200 MeV or 20 KeV. If antiprotons are simply collected and decelerated in the Booster, the transmission will go as the acceptance of the system, which shrinks as the momentum squared. Thus, $\bar{p}$'s decelerated from 4 GeV/c to 200 MeV will lose a factor of 36 in intensity; another factor of 23 occurs in deceleration to 750 KeV, for a total reduction of 0.8×10^3; and to 20 KeV, another factor of ~ 40, leading to a total loss factor of 3×10^4 in intensity.

Only a single procedure is known to avoid this loss: (stochastic) cooling of the $\bar{p}$ beam before deceleration. Cooling essentially beats Liouville's theorem, so that the $\bar{p}$ beam is reduced without substantial loss down to an emittance characteristic of the final momentum, before deceleration begins. The entire deceleration loss is then reduced to a factor of order 2.

It is not possible to incorporate cooling into the Booster design, because not enough space is available for the pickup and kicker systems. Moreover, cooling is a time-consuming process, while the Booster must be cleared every AGS pulse. It will therefore be necessary to construct a separate cooling ring, which will function as an Accumulator to stack the pulses while cooling proceeds.

The Accumulator would be a straight-sided ring [2] somewhat smaller than the Booster, as shown in Figure 2, and could be positioned as in Figure 3. In order to keep the size small and the operating frequency high, the bending magnets would have fairly strong fields--about 2.4 tesla, probably iron core with superconducting windings. The other (quadrupole) magnets would be conventional. The straight sections would be about 12 meters each, the bending magnets have a radius of 10 meters, and in each corner a short straight section of about 5 meters splits the bending magnets into two elements of 45°. These corner straight sections would be for injection/extraction; two opposite long straight sides would accommodate pickups and kickers to effect cooling. The total circumference would be about 130 - 150 meters.

The Accumulator magnets should be capable of some accommodation in momentum--say from 4 to 7 GeV/c, but fast ramping would not be necessary. Likewise, the rf system to track this variation would be minimal. The magnets would have the Booster aperture of 3-1/4" with costs comparable to those of the Booster, since extreme superconducting technology is not required: say, about $1.0 M total. The power supplies and cabling should be conventional, costing another $1.0 M. The rf system is less special than for the Booster and can be cheaper; say, 4 stations at $0.5 M for a total of $2.0 M. The stochastic cooling system involves both transverse and longitudinal cooling and will be the main expense of the ring, about $5-6 M, to judge from the Fermilab experience. Civil engineering costs will be about like those of the Booster, $2.5-3.0 M. Additional beam lines transporting $\bar{p}$ to/from the Accumulator may cost about $1.0-1.5 M. Adding 35% for EDIA and contingency leads to a preliminary cost estimate of about $18 M. The time schedule for completion is on the same scale as the Booster: 3-4 years after initiation.

The beam connections to the Accumulator in Figure 3 will allow some flexibility in operation. The accumulation/cooling phase can be accomplished without passing each pulse of $\bar{p}$ through the Booster, as in stage I. Only when the $\bar{p}$ stack is to be decelerated would it proceed through the Booster. The previous beam line from the Booster to the experimental hall would be replaced by one from the Accumulator acting as a source. A direct output line from the Accumulator could be fed to the AGS for accelerating an occasional large pulse of $\bar{p}$ to high momenta for other particle physics experiments.

III. Third Stage: $\bar{p}p$ Collider

A third possible stage of development can be envisioned for the Accumulator as a $\bar{p}p$ collider. After a sufficient stacking period - say 1 day - a single bucket of protons is injected from the Booster into the Accumulator in the reverse direction. The two unoccupied straight sides are fitted with low-beta sections to maximize the luminosity, which can reach several units x 10^{30} cm^{-2} sec^{-1}.

It is this possibility that sets the momentum requirements for the Accumulator. Colliding $\bar{p}p$ beams of 7 GeV/c yield a center-of-mass energy just over 14 GeV, which is sufficient to explore excited states of the Υ system. To pursue such details, however, will require exceptionally precise momentum definition of the colliding beams: $\Delta p/pp \gtrsim 10^{-5}$. This will be possible only if the $\bar{p}$ and p bunches can be simultaneously cooled in the Accumulator. While there appears to be no fundamental principle that precludes this combination, its realization would constitute a whole development project in itself.

If this operation can be established, a further interesting question will be continuous operation of the collider: replenishment of the $\bar{p}$ and p stacks by parasitic increments acquired during occasional AGS pulses.

References

1. BNL 52082, Proceedings of Antiproton Beams Workshop, Brookhaven National Laboratory (1986), Section 4, Appendices 6 and 7.

2. This outline follows suggestions in CERN/PS 85-39 (May, 1985).