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THE AGS COMPLEX AS AN ANTIPROTON FILLING STATION*

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A transportable antiproton storage device to store and transport low energy antiprotons for use away from the production facility has been proposed.[1] In this note we examine the AGS complex as a filling station for such a device.

In previous notes[2] we explored the possibility of using the AGS as a very low energy antiproton source and its implication to the AGS complex. The scheme was to decelerate antiprotons in the AGS Booster to a kinetic energy of 200 MeV, reinject these antiprotons into the linear accelerator backward at the high energy end. The structure of the Linac would decelerate the antiprotons to the normal proton injection kinetic energy of 750 keV. The further deceleration would be accomplished with the RFQ linac to a final energy of 30 keV. The scheme allows the antiprotons to be extracted from the system at any point during deceleration inside the Booster; however, once the particles are injected into the linac, it only can be extracted at the low energy end, i.e., 750 keV or 30 keV at the end of the RFQ.

The production and collection rate of antiprotons can be estimated in the following way. We show in Figure 1 the AGS antiproton production rate for collection solid angles of 5 and 40 millisteradians.[3] We then apply several correction factors to these rates. The fraction of surviving antiprotons corrected for the focal depth of the lithium lens and the finite length of the target can be approximately expressed as[4]

$$\frac{2}{L}\,\beta_o \tan^{-1}\left(\frac{L}{2\beta_o}\right) \qquad (1)$$

where L = length of the target,

$\beta_o = r_o/\Delta\theta$ at target center,

r_o = incident beam radius,

$\Delta\theta$ = angular acceptance.

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The fraction of incident beam interacting in the target segment can be expressed

$$df = 1/\lambda \cdot e^{-\ell/\lambda} \cdot d\ell \qquad (2)$$

where λ = nuclear absorption length.

The fraction of the produced antiprotons that survive to the end of the target is

$$e^{-(L - \ell)/\lambda} \qquad (3)$$

By combining (2) and (3), and integrating

$$L/\lambda \cdot e^{-L/\lambda} \qquad (4)$$

Combining (1) and (4), one obtains the total production and collection efficiency

$$E = \frac{2\beta_o}{\lambda} e^{-L/\lambda} \tan^{-1} \left(\frac{L}{2\beta_o}\right)$$

For example, taking λ = 10 cm, r_o = 0.5 mm, $\Delta\theta$ = 100 mr, one gets a broad maximum around L = 2.7 cm where E = 0.093. We will assume this efficiency for estimating the intensity of antiprotons.

The intensity of the extracted antiproton beam depends on several factors. Since transverse emittances of the beam changes inversely proportional to the momentum of the particle, one expects to lose antiproton intensities by a factor of the momentum squared while decelerating inside the Booster. Since the normalized admittance of the AGS linac is about 90 π mm-mr, which is larger than that of the Booster at 200 MeV, one does not expect to lose antiprotons due to the transverse aperture of the drift tube structure. However, the longitudinal acceptance (rf bucket size) of the linac is estimated to be 3.5×10^{-4} eV-sec at 200 MHz, which is about a factor of 30 smaller than expected longitudinal emittance of the antiprotons inside the Booster.[5] Table I summarizes the expected intensity at various points assuming the antiprotons are produced at 2.5 GeV/c by three rf bunches of a post-Booster AGS and are not cooled in the Booster.

Table I
Expected Intensity Without Cooling

ENERGY	INTENSITY (per 1.5×10^{13} protons)
2.5 GeV	7.2×10^7
200 MeV	4.8×10^6
750 keV	1.6×10^5
30 keV	1.6×10^5

An obvious solution to losing intensity in six dimensional phase space is to cool the beam inside the Booster. Adequate cooling can be achieved by means of stochastic cooling. Figure 2 shows the antiproton yield and relative time constant for ideal stochastic cooling in the Booster versus antiproton momentum. Since the whole production and deceleration cycle should be within the AGS cycle, certain compromises must be made as to the momentum which antiprotons are collected at for maximum intensity and the cooling time required.

The following is one possible scenario for the antiproton collection and deceleration cycle. We chose 2.5 GeV/c as the production momentum as a compromise between production and coolability. The antiprotons are then pre-cooled transversely for 200 milliseconds before decelerating to 200 MeV. At this point, the antiprotons are cooled both transversely and longitudinally before bunching to the linac frequency. The cooling time required is estimated to be 20 milliseconds.

In order to be a filling station, antiprotons should be available at all reasonable energies. The scheme mentioned above lacks availability between 200 MeV and 750 keV. One solution is to decelerate the beam further in the Booster. First, we examine the lowest energy one can reasonably decelerate to in the Booster. One of the many functions of the Booster is to pre-accelerate heavy ions of initial kinetic energy as low as 1 MeV per nucleon. The radio frequency system for this mode is capable of tuning to antiproton kinetic energy of as low as 1 MeV. For an iron dominated accelerator ring magnet, one may assume good magnetic field for pole tip fields of above 100 Gauss.

This would correspond to an antiproton momentum of 65 MeV/c or kinetic energy of 2.3 MeV. For this scheme, the cooling of the transverse emittance of the beam is essential to avoid losses of over a factor of 100 in transverse emittance blowup. Longitudinal cooling is not required because the rf bucket size is big enough to contain the bunches. At this point, one could extract and inject into a suitably designed RFQ linac to decelerate to 30 keV. Table II summarizes the available fluxes at various energies.

TABLE II
Available Antiproton Intensity with
Cooling per 1.5 x 10^{13} AGS Protons

ENERGY	LINAC	BOOSTER
	cooling	cooling
2.5 GeV/c - 0.644 GeV/c (1.75 GeV - 200 MeV)	7.2 x 10^7	7.2 x 10^7
	cooling	cooling
< 644 MeV/c - 66 MeV/c (200 MeV - 2.3 MeV)	N/A	7.2 x 10^7
37.5 MeV/c* (750 keV)	6.9 x 10^7	N/A
7.5 MeV/c (30 keV)	6.9 x 10^7	6.9 x 10^7**

*Bunching efficiency assumed at 95%.
**New RFQ required.

References

1. T. Kalogeropoulos, private communication.
2. Y.Y. Lee and D.I. Lowenstein, Proceedings of the Rand Antimatter Workshop, 1987.
3. BNL 52082, Proceedings of the 1986 Workshop on Antiproton Beams, 1986.
4. F.E. Mills, Proceedings of the Rand Antimatter, Workshop, 1987.
5. We would like to thank Dr. F. Mills for pointing this out.

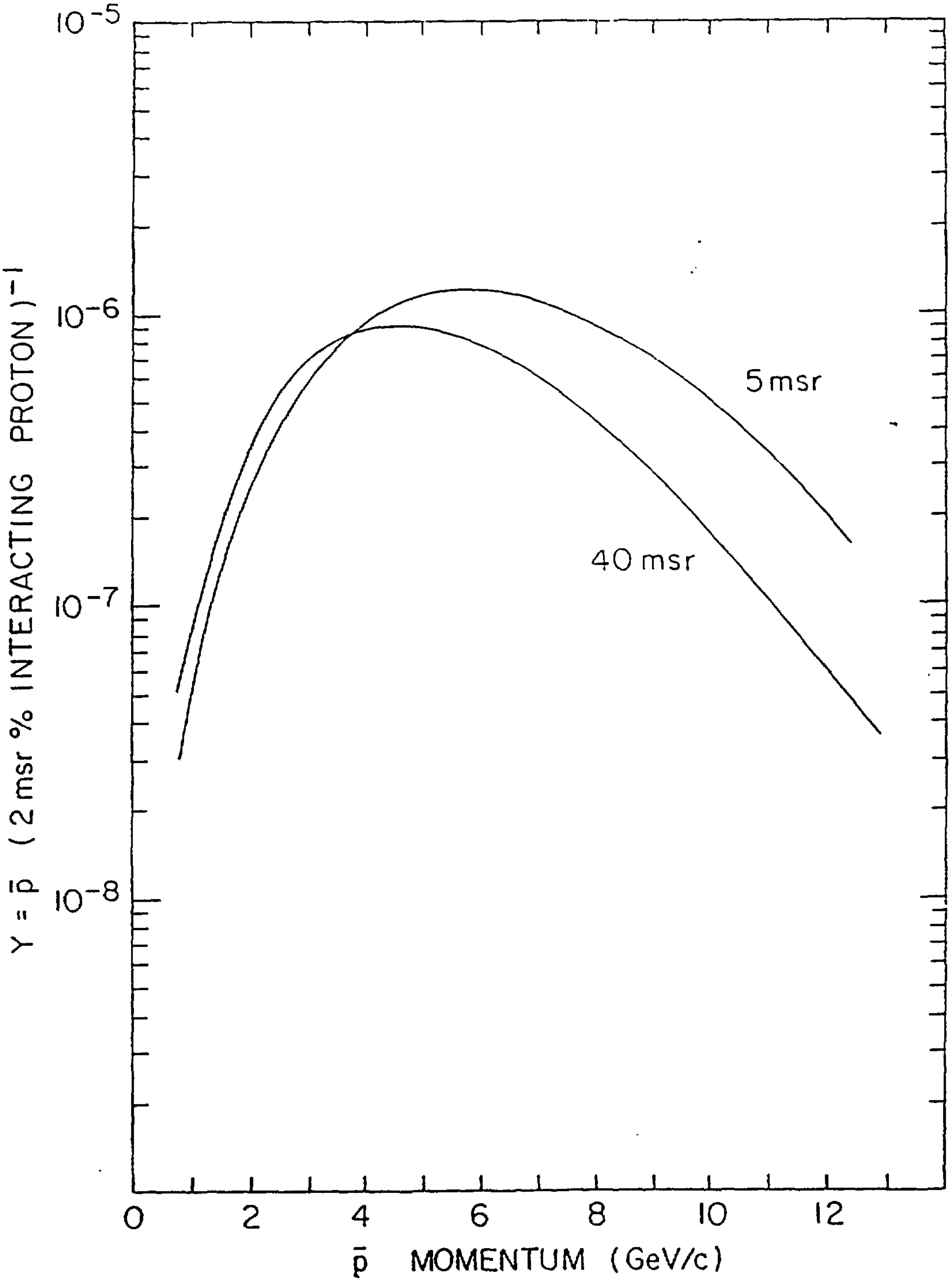
$Y = \bar{p}$ (2 msr % INTERACTING PROTON $)^{-1}$
10^{-5}
10^{-6}
10^{-7}
10^{-8}
5 msr
40 msr
0
2
4
6
8
10
12
$\bar{p}$ MOMENTUM (GeV/c)

Figure 1

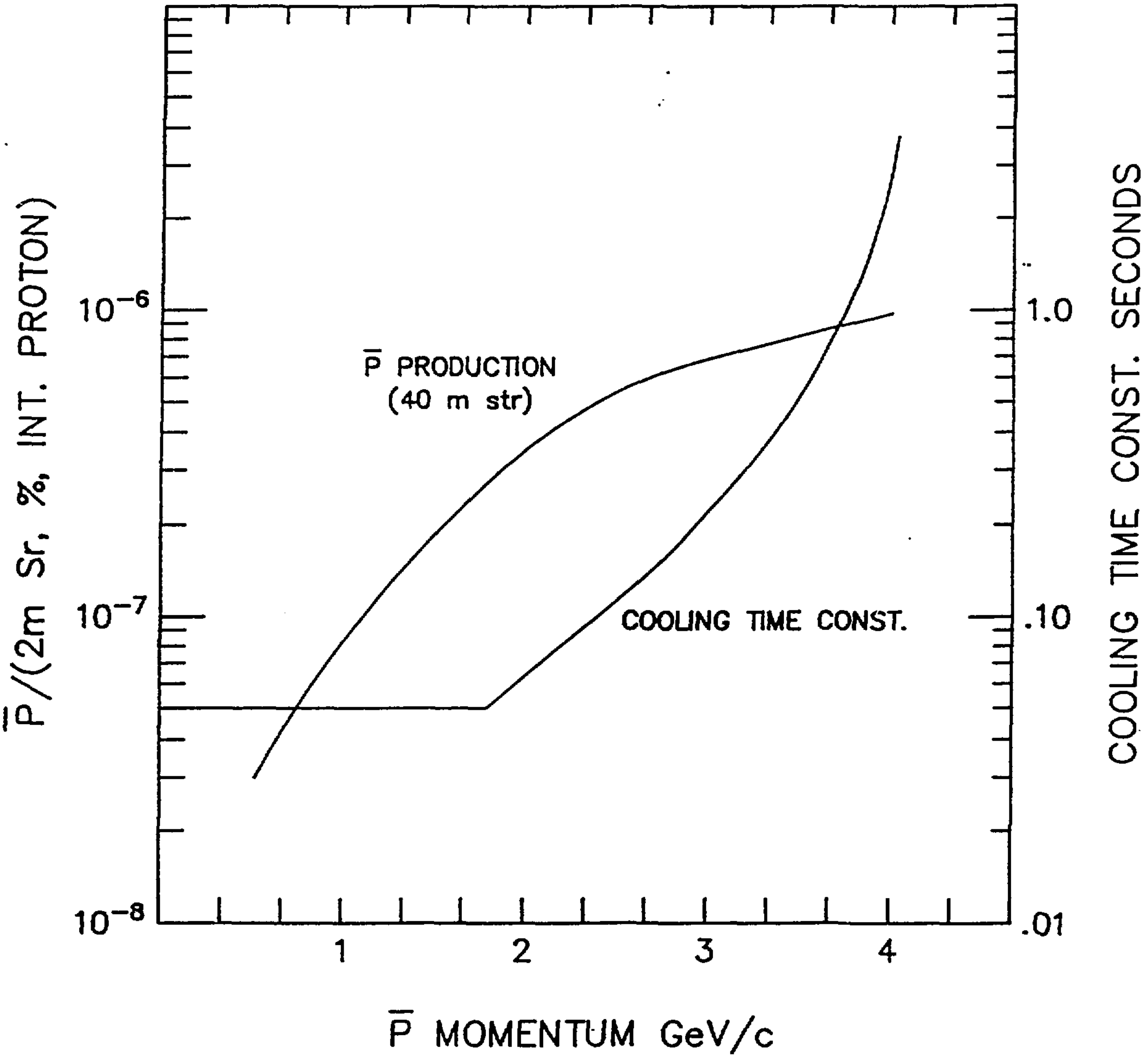
$\bar{P}/(2m\ Sr,\ \%,\ INT.\ PROTON)$
10^{-6}
10^{-7}
10^{-8}
$\bar{P}$ PRODUCTION
(40 m str)
COOLING TIME CONST.
1.0
.10
.01
COOLING TIME CONST. SECONDS
1
2
3
4
$\bar{P}$ MOMENTUM GeV/c

Figure 2