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INTERMEDIATE ENERGY ELECTRON COOLING OF ANTIPROTONS TO IMPROVE THE LUMINOSITY OF ANTIPROTON-PROTON COLLIDERS

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Introduction

In order to improve the luminosity of $\bar{p}p$ colliders increased antiproton accumulation and decreased antiproton emittance are necessary. We show how the cooling of antiprotons using electrons in the energy range of a few MeV can be used. A high quality electron beam with very large current (~few amps) is being constructed by the National Electrostatic Corp. of Middleton, Wisconsin. We present some results of the first tests of this device and discuss the applications to electron cooling as well as possible application to a Free Electron Laser.

It has been shown at FNAL that electron cooling of protons is a very efficient way to reach high luminosity in a proton beam.[1] The emittance of the 120 KeV electron beam used at Fermilab corresponds to a cathode temperature of 0.1 eV. In order to apply cooling techniques to GeV proton beams, MeV electron energies are required. In a recent experiment the emittance of a 3-MV Pelletron electron accelerator was measured to determine that its emittance scaled to a value appropriate for electron cooling.

The use of electron cooling is very appropriate for certain beam conditions as described in Table 1a where electron cooling and stochastic cooling are reviewed. Table 1b gives the relevant hardware needed for the two different kinds of beam cooling.

Table 1a

DEPENDENCE ON	ELECTRON COOLING	STOCHASTIC COOLING
$p,\bar{p}$ intensity	Weak (but never tested > 10^9)	Strong ($\tau \propto N$) 1 s at 10^7 part. 1 day at 10^{13} part.
$p,\bar{p}$ energy	strong ($\beta^4\gamma^5$) 1 s at 0.1 GeV/c 1 day at 2 GeV/c	Weak
Beam size and $\Delta p/p$	Works best for cool beam	Works best for hot beam

Thermal Emittance Estimate of the NEC Device

The thermal emittance ε of the beam will be defined to be the area in phase space in which 90% of the beam trajectories lie. The only contribution to the perpendicular velocity of the particles is assumed to be the perpendicular thermal velocity of the electrons as they are emitted from the cathode. The area of the phase ellipse is then

$$\varepsilon = \pi x_{max}\theta_{90}. \qquad (1)$$

In evaluating ε, it is assumed that the cathode emits electrons uniformily over its surface. Thus x_{max} is the radius of the cathode. In this case $x_{max} = 7.6\times10^{-3}$m. The quantity θ_{90} is defined to be the angle with respect to the beam axis that contains 90% of the electron trajectory angles.

Table 1b

	ELECTRON COOLING	STOCHASTIC COOLING
Hardware	Needs high power electron beam one system for cooling in all 3 planes	Needs fast low level electronics total of three systems for $\varepsilon_H \varepsilon_V, \Delta p$ cooling
Space	Needs one large piece of space	Needs many small pieces of space
Compatibility with ultra-high vacuum	Some problem needs care	No basic problem
Change of energy	Retuning of gun voltage	Retuning of all lines and filters
Change of machine working point	No basic problem	Needs additional elements

$$\theta_{90} = P_\perp / P_{\parallel} = MV_{\perp 90}/\gamma MC\beta \qquad (2)$$

We evaluate $V_{\perp 90}$ by assuming a one-dimensional Maxwell distribution with the cathode temperature KT = 0.1eV. This yields $\varepsilon = 1.8$ πmm-mrad for $\gamma = 5$ and $\varepsilon = 1.5$ πmm-mrad for $\gamma = 5$ and $\varepsilon = 1.5$πmm-mrad for $\gamma = 6$ as the estimates of thermal emittance.

Luminosity Improvement of a $\bar{p}p$ SSC

Although the earliest schemes for making $\bar{p}p$ colliders used some electron cooling, so far this technique has not been utilized.[1,2] The major reason for this is that the existing electron devices have been limited to a few hundred kilovolts - and the corresponding antiproton momentum would be below 1 GeV/c. Such low momenta are not favored in the production of antiprotons. Thus in order for electron cooling to be useful, it is necessary to develop several MeV electron beams of very high current.

The intense several MeV electron beam being developed by the Fermilab-Wisconsin group in collaboration with the National Electrostatics Corporation could be used for electron cooling of (5-10) GeV/c antiproton and proton beams. Electron cooling might be used to assist in the accumulation of antiprotons and could be useful to cool a core or stack to the small emittance required for injection into the SSC.

Electron cooling has two potential advantages:
(1)The drag force is very large and can assist in accumulation and stacking of <u>small</u> emittance $\bar{p}$ beams (i.e. precooled beams).
(2)The cooling for precooled beams is independent of intensity (unlike stochastic cooling) and can result in

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a strong reduction of the emittance of a beam. Small emittance beams are necessary for the operation of the SSC to reduce the good field aperture.

To illustrate point (2), we give an example worked out for the LAMPF II accelerator that could give (2-4) × 10^8 $\bar{p}$/sec using a (11-30) GeV proton synchrotron.[3] The scheme uses a debuncher followed by a fast Betatron stochastic cooling accumulator (with good mixing) to reduce the emittance of the antiproton beam from $W_{\bar{p}}$ = 205 μm to 10^{-6}m. Using an electron cooling device as shown in Fig. 1, the accumulation rate is

$$\dot{\bar{p}}/\bar{p} = \frac{1}{W_{\bar{p}}^2} 10^{-12} \frac{I_e}{(\dot{\beta}\gamma)} \quad (3)$$

with η = 1/10 (the fraction of the circumference of the antiproton accumulator ring occupied by the electron cooling system). For a 5-amp beam and βγ = 4, the accumulation rate is 0.02 Hz. This gives (2-4) × 10^8 $\bar{p}$/sec accumulation rate.

A more important use of the electron cooling device may be to cool the core of a stochastically accumlated beam to a very small emittance (longitudinal). This application may find use in the current generation of antiproton sources and would even be necessary as the intensity of these $\bar{p}$ sources approaches the limits set for stochastic cooling. In this case a beam with emittance 10^{-5} πm cooled with an electron beam of 5 amps over a distance of 15 meters is collapsed in phase space in ≈ 1500 seconds. The key idea is that precooled beams cool rapidly by electron cooling techniques - so for a final cooldown electron cooling becomes useful!

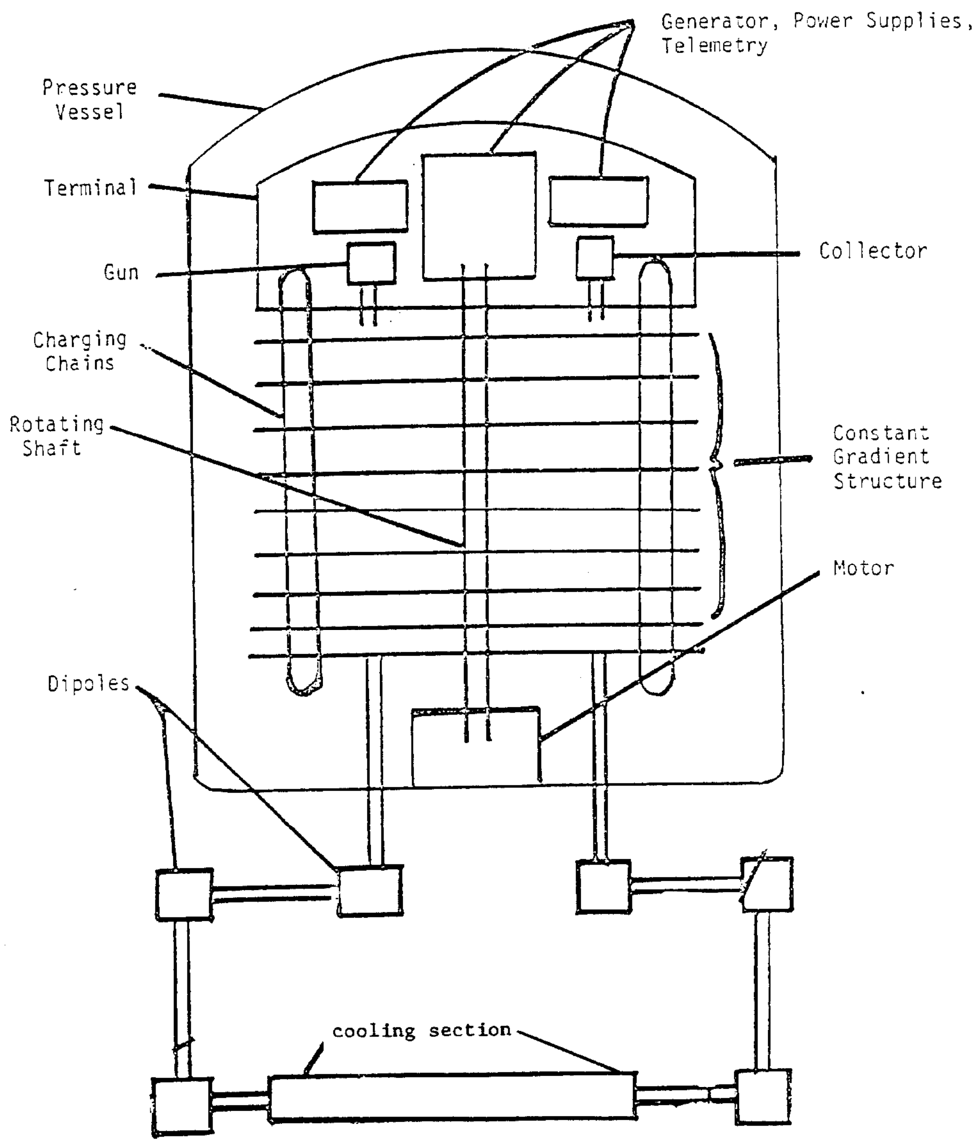

Figure 1. Schematic of the Electron Cooler

We now turn to the development of the electron beam at the National Electrostatics Corporation (NEC) near Madison, Wisconsin. During the period of 1982-83, the emittance of a similar beam being developed for a free electron laser was measured to be near the theoretical limit.[4] The key to a very high current electron device is to use a very efficient collector and high reliability beam recovery. This technique has been perfected for the low energy electron cooling experiments at Fermilab.[5]

During the last two years an intense effort has been undertaken to design a 3MeV, very high current D.C. electron beam device. This device uses a Pelletron accelerator and could reach currents as large as 5 amps. The key ingredient is a very high efficiency collector for the energy recovery system. During the period of 1985-86, it will be possible to test this device and to continue with calculations for antiproton accumulation and core cooling.

References

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