ELECTRON COOLING AT FERMILAB

Introduction

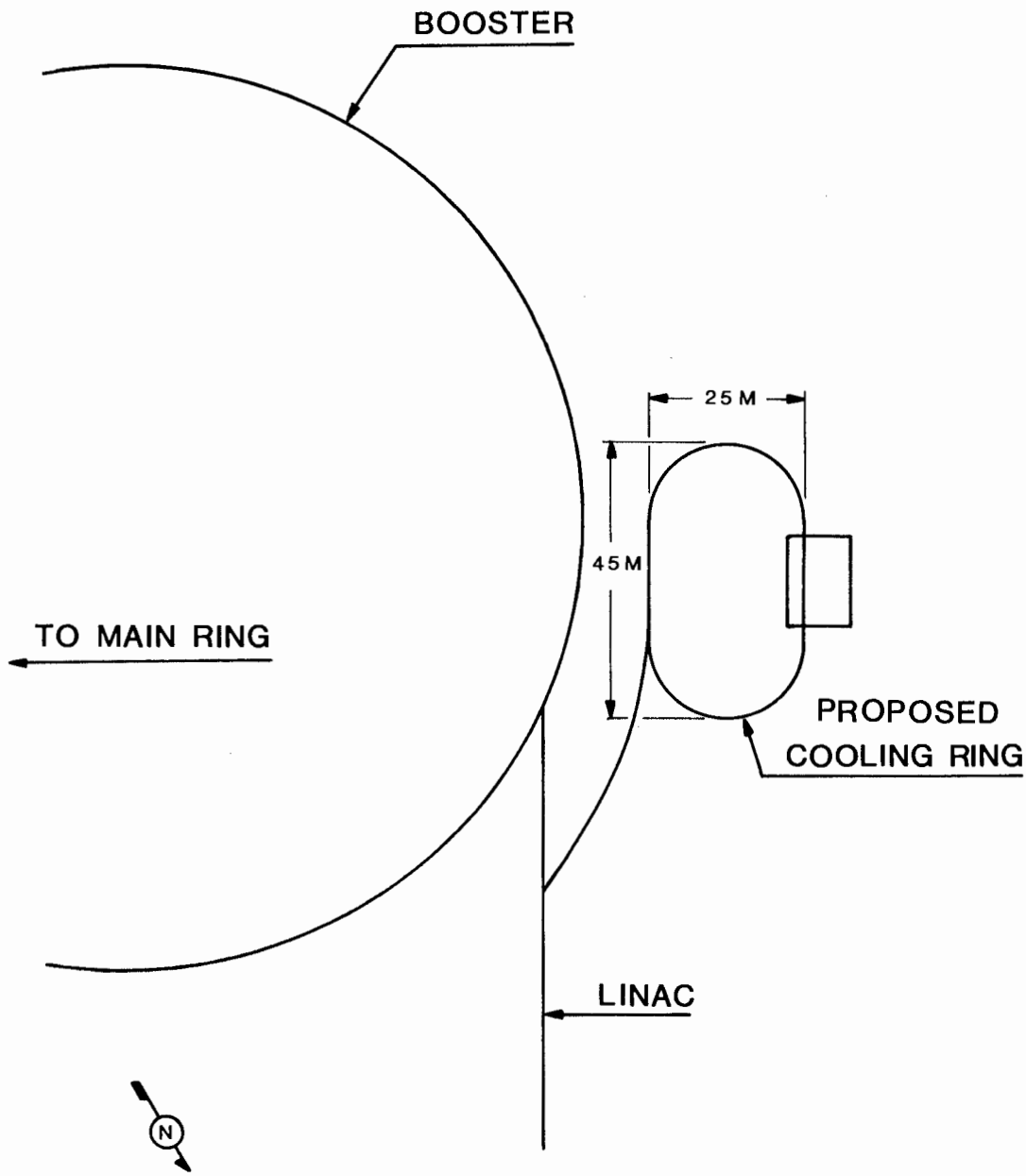
Electron cooling, the damping of the oscillations of a proton beam by interaction with an electron beam, has been demonstrated experimentally by G. I. Budker and his colleagues at the Institute of Nuclear Physics, Novosibirsk, USSR. This success has led a group here to consider the use of electron cooling at Fermilab and the Laboratory has submitted a proposal to the National Science Foundation to study electron cooling in a small ring that would be constructed just west of the Booster. If these tests are successful, it will be possible to utilize electron cooling in several ways at Fermilab. For example, it will be possible to build at modest cost a proton-antiproton colliding-beam facility that can be used to explore an entirely new energy region and to search for the intermediate vector boson that is believed to moderate the weak interaction. It will also be possible to improve the intensity of the Fermilab beam by reducing its size and thereby reducing losses during injection and acceleration.

Electron cooling of baryon beams was first proposed by Budker as a means to make intense antiproton beams. An electron beam is made to travel parallel to the baryon beam at the same speed in a long straight section of a storage ring. Collisions with electrons reduce the oscillation amplitudes and momentum spread of the baryons and, consequently, reduce the volume of phase space occupied by the baryon beam. The beam is then denser and has higher luminosity. This higher density and luminosity make electron cooling attractive for proton-antiproton colliding beams.

All the experimental work to this time has been carried out on the NAP-M storage ring constructed for this purpose at Novosibirsk. In their experiments, a beam of 65-MeV protons has been cooled by a 35-keV electron beam. They find that the relative difference in speed $\Delta v/v$ between the proton and electron beams must be less than 2×10^{-3} for cooling to take place. When there is cooling, the lifetime of a coasting proton beam in NAP-M is increased from 900 to 5000 seconds. The proton beam damps from an amplitude of 2 cm to a final amplitude of 0.8 mm, a figure in reasonable agreement with the predictions of the theory. The damping time depends linearly on the electron beam current, as predicted. The quantitative agreement of predicted and measured damping times is not yet clear.

Proposed Cooling Tests at Fermilab

It is important to verify the Novosibirsk results and to study in more detail the cooling time and its dependence on various parameters of interest. For these studies, it is proposed to construct a storage ring in an above-ground temporary building just west of the Booster. The location and size of the ring are shown in the figure. A beam of protons from the linac will be used to fill the ring. One of the two long straight sections will be used for this injection, while the other will be used for cooling apparatus. Linac beam is available, of course, while main-ring acceleration is in progress, and an extracted 200-MeV beam is already in existence for the proton-radiography studies now going on. The linac energy of 200 MeV is advantageous for these tests, because the cooling time increases rapidly with energy (as γ^5) and cooling experiments would therefore become much more difficult at higher



Proposed cooling ring location.

energy. The electron-beam energy is fixed at 110 keV by the requirement that the proton and electron speeds match. It is planned that the electron gun in the Fermilab cooling ring will have higher current density than has been available at Novosibirsk, making use of the technology of an electron gun developed for the SPEAR rf system.

The table below is a listing of the important parameters of the proposed storage ring.

Storage-Ring Parameters

Proton Energy	200 MeV
Electron Energy	110 keV
Electron Current Density	1.3 A/cm^2
Magnetic Radius	4.7 m
Maximum Dipole Strength	4.6 kG
Long Straight Sections	
Number	2
Length	22 m
Limiting Apertures	
Horizontal	15 cm
Vertical	6 cm
Tunes $\nu_h = \nu_z$	3.7

The storage-ring parameters are determined by the experiments planned. It is not a difficult ring to build. The field strengths required are small and the aperture only slightly larger than that of the Main Ring. A modest rf system is planned for use in beam manipulation and stacking.

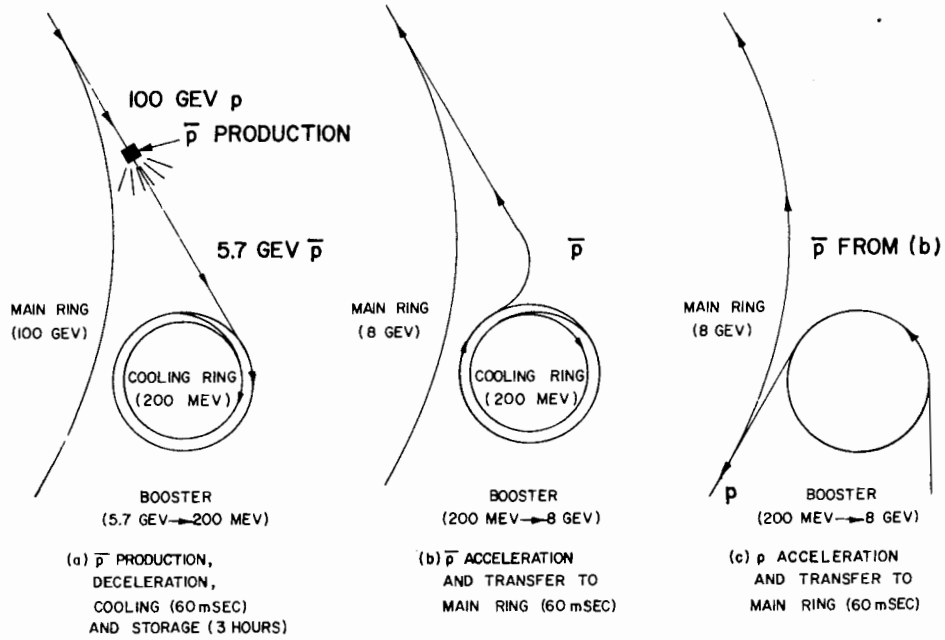
Applications of Cooling at Fermilab

If the tests of electron cooling are successful, there are a number of possible applications of the method here at Fermilab. One simple, straightforward application would be to reduce the size of the beam injected into the Booster. This would make it possible to reach higher beam intensity at full

energy, since a significant amount of beam is now scraped off during Booster injection. One could also consider using electron cooling to reduce beam size at other times in the acceleration cycle. These beams of higher luminosity could also be advantageous for the proton-proton colliding-beams systems being discussed.

An application that holds great promise for physics experiments has been proposed by Cline, McIntyre, Mills, and Rubbia. In this plan, antiprotons of 5 to 6 GeV energy are produced by 100-GeV main-ring protons on a target in F sector. The antiprotons are transported to the Booster, injected and decelerated to 200 MeV. They are then transferred to a 200-MeV cooling ring installed in the Booster tunnel. This ring is presently envisaged as an expanded version of the experimental cooling ring discussed above. The cooling time is calculated to be 60 milliseconds. Cooled antiprotons are collected in the cooling ring for several hours to achieve a total stack containing of the order of 10^{11} antiprotons. This stack is then injected into the Booster, accelerated to 8 GeV and injected into the Main Ring, going in the opposite direction to that of protons. Then one Booster batch of protons is accelerated to 8 GeV and injected into the Main Ring. Both protons and antiprotons are then accelerated together in the Main Ring to full energy, and brought together to collide at a long straight section. This scheme is shown schematically in the figure on the following page.

When the Energy Doubler/Saver is completed, it can also be used, both for acceleration and for storage of $\bar{p}p$ colliding beams. It will then be possible to have a center-of-mass energy of 2 TeV without construction of a major new ring.



Schematic plan of $\bar{p}$-p colliding beams.

It should be understood that the antiproton-proton facility being discussed will not initially give luminosities comparable to those that can be achieved in proton-proton colliding beams, but they would provide a unique glimpse of elementary-particle physics in an entirely new energy range. In this new range, it will be possible to search for the intermediate vector boson, now predicted to have a mass of 64 GeV/c^2 for the charged state and 79 GeV/c^2 for the neutral state. Center-of-mass energies of several hundred GeV are needed to produce these bosons in proton-proton or proton-antiproton systems. Even in an electron-positron system, a center-of-mass energy of 80 GeV (40 GeV in each beam) is needed. No existing or approved accelerator

can reach these energies, whereas the ring discussed here could survey the region thoroughly at a cost far smaller than that of constructing a totally new facility.

There are many other interactions to be explored in this totally new energy range. At much lower luminosities, cosmic rays have produced many unexplained super-high energy events. The antiproton-proton facility will permit these processes to be explored. In addition, one might hope to produce heavy leptons, Higgs bosons, or even free quarks.

All these applications make the study of electron cooling of great interest for Fermilab, with a possible large impact on future directions of the Laboratory. Cooling studies are now being pursued as a Laboratory effort, collaborating with interested users, to learn more about this important accelerator-physics development.