With early installation in LEP in mind, four similar cavities and cryostats are under construction, two at CERN and two in industry.

Electron cooling in LEAR

At the end of October, a CERN/Kernforschungzentrum Karlsruhe collaboration, led by H. Hase-roth and H. Poth, harvested the fruit of several years of work on the development of an electron cooling system for CERN’s LEAR Low Energy Antiproton Ring.

Electron cooling has been in the shadow of the spectacular success of stochastic cooling but was in fact the first beam cooling technique to operate. The idea of using a well-defined electron beam to tame a less well behaved beam was invented at the Soviet Novosibirsk Laboratory and was demonstrated in the NAP-M ring in 1974.

The first proposed implementation in the West (to cool antiproton beams for CERN’s Intersecting Storage Rings) followed a visit of P. Strohlin to Novosibirsk. To test the idea at CERN, the ring used for measuring the anomalous magnetic moment of the muon was converted and rechristened ICE (for Initial Cooling Experiment). Success came in 1980, under F. Krienen and H. Herr, but in the meantime electron cooling had been overtaken by CERN’s stochastic method better adapted to high energy beams.

A Fermilab team demonstrated electron cooling in 1981, while working on their antiproton source, and retain interest in the technique, both for the source and for cooling stored beams in the Tevatron.

Throughout the world, some ten low energy ion storage rings are constructing, or have proposed, electron cooling systems to improve the quality of their beams. This effort has been considerably stimulated by the decision to go ahead with electron cooling in LEAR.

At LEAR the aim is to complement the stochastic cooling already installed. While the stochastic method works best on high energy (‘hot’) beams, since it needs to detect deviations from desired values, the electron method works best on low energy (‘cold’) beams since the interaction between the beam particles and the electrons increases as the two velocities approach.

Though it remains to be convincingly demonstrated, electron cooling should cope better with higher intensity beams since the cooling rate is less dependent on the number of particles to be cooled.

Several experiments, accepted and proposed, for LEAR require very cold beams in the ring. For extraction to external experiments the beam momentum spread has to be increased, diminishing what has been achieved by cooling, though the cooling still provides slimmer
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beams, and can help the experiments wanting decelerated particles.

The electron gun from the ICE ring was converted for LEAR. The cooling had to be achieved along a shorter interaction length, a 1.5 m straight where the electron beam overlaps with the orbiting particles, compared to 3 m in ICE, and the problem of firing an intense electron beam into the very high vacuum of LEAR (2.5 A into $10^{-11}$ torr) had to be confronted. Special diagnostics had to be developed, including scattering of laser light on the electron beam, observing the microwave radiation from the spiralling of the electrons in the magnetic field, and observation of the X-rays caused by stray electrons.

In the October tests cooling was observed from the very first injection of a proton beam into LEAR using Schottky scans and the detection of neutral hydrogen. This latter technique can only be applied while working on proton beams — neutral hydrogen atoms emerge from the straight section undeviated by the magnetic fields of the ring or of the electron cooling system. This is a useful tuning aid, since hydrogen production increases as the two beam velocities approach (the ideal condition for cooling). Production rates of a few thousand hydrogen atoms per second were observed and the method still worked with low proton intensities, about $10^6$, when Schottky scans were no longer sensitive.

Major achievements included slimming the proton beam from a few centimetres across to a few millimetres in seconds, while the energy spread was pared from several parts per thousand to better than one part in ten thousand. The short time available for the tests saw a number of beam physics experiments. The cooling of a bunched beam was demonstrated and very short bunches were achieved. The electron energy was moved off the optimum value and the proton energy was seen to follow. Too much cooling induced beam instabilities. The equilibrium between the stochastically introduced heating of the proton beam for beam extraction and the electron cooling gave a measure of the cooling power.

Further tests with antiproton beams are eagerly awaited, when the cooling rates can be compared with those of protons. Experiments at Novosibirsk indicate that over a range of parameters electron cooling works more than twice as fast for negatively charged beams (like antiprotons).

Much work remains to convert the system used for these experiments into a reliable system for regular operation of LEAR, however the tests have shown convincingly that electron cooling adds another effective weapon for taming beams of antiprotons and other ions.

Ground state of protonium

'Exotic atoms' — where everyday orbital electrons are replaced by other negatively charged particles (muons, pions, kaons, antiprotons) provide physicists with another window on the strong nuclear force to supplement what is learned from scattering experiments.

These synthetic atoms have long been a speciality of CERN research,