THE CERN PPBAR FACILITY

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The proton-antiproton facility at CERN has been described at least once every year since its conception in 1978. Hence, only the briefest outline of the overall scheme is given below. This paper will concentrate on the most recent additions to the facility, with some emphasis on the stochastic cooling devices in use operationally. Lastly, the latest performance of the ppbar facility is described.

Antiproton Production, Accumulation and Exploitation

The CERN Proton Synchrotron (PS), along with the Linac and Booster, first accelerates some 10^{13} protons to 26 GeV/c and concentrates them into one quarter of its circumference. This is to match the burst length to the smaller circumferences of the antiproton rings. The protons, in five separate short bunches, are then ejected through a transfer line towards the antiproton production zone and focused onto a high density target. The emerging burst of antiprotons at 3.5 GeV/c, selected via a spectrometer, is injected into the Antiproton Collector (AC) ring. The antiprotons retain the five bunch structure of the 26 GeV/c protons. The AC ring contains a 9.5 MHz radiofrequency system which captures the antiprotons in five stationary "buckets" (leaving one bucket empty and hence the time for injection kicker manipulations) and rotates and debunches them such as to reduce their momentum spread from 6% down to 1.5%.

Transverse stochastic cooling next reduces both vertical and horizontal emittances of the beam from 200 to 25 π mm.mrad: this should take about one second. Finally, the momentum spread is reduced from 1.5 to 0.2% in a further second using the same stochastic cooling pick-up and kicker structures but rearranging the signal processing and amplification systems.

After cooling, 300 msec remain before the next PS proton burst is due to arrive on target. In this time the antiprotons are rebunched with a 2 MHz (first harmonic) radio-frequency system and then ejected and transferred to the original antiproton accumulator (AA) ring for accumulation and further cooling.

Upon their arrival in the injection region of the AA, the antiprotons are first subjected to some vertical and momentum pre-cooling before they are moved into the tail region of the stack. This AA pre-cooling system has just less than 2.4 sec (the PS repetition rate) to act before the AA injection region has to be cleared to receive the following antiproton burst. These AA pre-cooled antiprotons are moved into the stack-tail with a 1.85 MHz radio-frequency system and then stochastically stacked into the core region whereafter each successive pulse of antiprotons is accumulated. The stack core is itself cooled in all three phase planes with large bandwidth (up to 4 GHz) systems replacing the old AA stochastic cooling devices.

After some tens of hours of accumulation, the dense core of the accumulated stack is next tapped for bunches of antiprotons. Each bunch extracted from the core is first shaped on the AA ejection orbit with the 1.85 MHz radio-frequency system before being ejected and looped back to the PS. There they are accelerated to 26 GeV/c and again suitably massaged by the PS 9.5 MHz radio-frequency system to make them acceptable to the injection conditions of the Super Proton Synchrotron (SPS) in the collider mode.

Six antiproton bunches are consecutively transferred to the SPS collider every 2.4 sec. Just before this happens, six dense 26 GeV/c proton bunches will have been transferred from the PS to the SPS and allowed to circulate in the opposite direction to the antiprotons. These circulate, equidistantly spaced around the circumference, awaiting the arrival of the counter-rotating antiproton bunches. Upon arrival of the last antiproton bunch, the acceleration procedure of the SPS is set into motion and the energy of both proton and antiproton beams is increased to 315 GeV whereat they coast for several tens of hours during which time the collider takes physics data.

The six proton and six antiproton bunches would naturally collide at twelve intersection points. When this is allowed to happen the space charge interaction between proton and antiproton bunches changes the focusing properties of the collider to such an extent that the circulating beam intensity in the antiproton bunches decays dramatically in less than two hours. This is avoided by separating the beams in (nine of the ten) "unwanted" intersection points while retaining collisions at the two intersections containing the detectors of UA1 and UA2. Beam separation is effected by means of electrostatic deflectors and results in restoring the lifetime of the antiproton bunches to the order of 100 hours.

In order to achieve the goal of a peak luminosity in the collider of 4×10^{30} $cm^{-2}sec^{-1}$, each antiproton bunch should contain 10^{11} $\bar{p}$'s (and each proton bunch around twice this amount). The longitudinal emittance of each bunch of this magnitude extracted from the core of the AA is about twice that which can be readily captured by the regular 200 MHz radiofrequency system of the SPS. This is overcome by using six new 100 MHz cavities which create larger radiofrequency bucket areas to accommodate the doubled longitudinal emittance of the intense antiproton bunches. Acceleration starts with this new system and the bunches are adiabatically "passed-on" to the 200 MHz system which gradually takes over as the coasting mode approaches.

However, more longitudinal emittance also means that more momentum aperture is needed in colliding mode. In order to achieve the latter a more sophisticated chromaticity correction scheme, using five sextupole families instead of four, has been recently implemented.

Antiprotons are not only exploited in the collider at the highest possible energies, but also, the CERN $\bar{p}$ facilities provide for a thriving physics programme at the lowest possible energies in the Low Energy Antiproton Ring (LEAR). Single $\bar{p}$ bunches containing between 2 to 10×10^{9} particles may be injected into LEAR at 609 MeV/c after having been first decelerated in the PS ring down from the AA extraction momentum of 3.5 GeV/c.

The main mode of operation of LEAR [4] has been as a variable energy antiproton stretcher ring, with stochastic cooling to improve beam quality. Electron cooling has also been employed successfully on an experimental basis. Stochastic systems are also used for ultra-slow extraction from LEAR with spill times enduring from 15 min to 5 hours and a variable extraction momentum from 105 to 1700 MeV/c.

Each of the machines mentioned above are quite complicated links in the whole chain that makes up CERN's $p\bar{p}$ facility. The individual performance of each machine is described in great detail elsewhere in this conference. Some special features of the stochastic cooling systems are illustrated below. The conclusion summarizes the latest performance figures for the accumulator and collider complex.

Stochastic Cooling
New Features at CERN's ppbar Facility

Stochastic cooling theory and experiment are by now well documented [1,2,3,4]. However, the design of pick-ups and kickers is still a highly skilled relatively new and continuing activity. There are essentially three dominant types currently in use and these are illustrated in fig. 1.

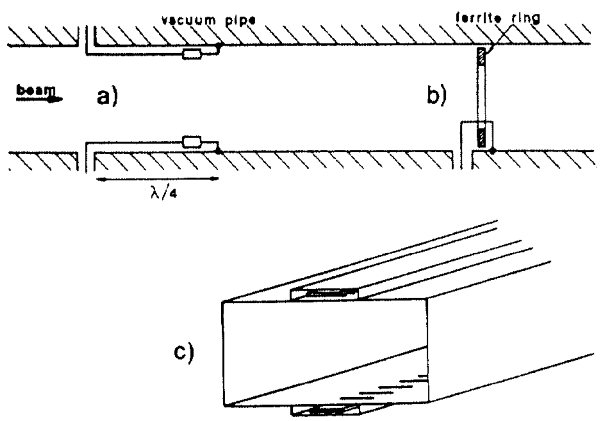

Fig. 1 : The three main structures for stochastic cooling.

They are: (a) the quarter wave coupling loop or antenae
(b) the ferrite ring single-turn current transformer
(c) the slot-coupled transmission line.

All three have been used in the antiproton accumulator complex. The ferrite ring type is no longer used because of the limitations in bandwidth that accompanies the use of ferrite. The latest stochastic cooling systems [5] operate at large bandwidths with frequencies extending up to 8 GHz in the latest slot-coupled transmission lines used at the AAC in the AA ring.

Amongst the most sophisticated of the coupling loop type is that shown in fig. 2. This operates in the 1 to 3 GHz microwave range and has a number of unique features. The signals from each loop are summed up on a ceramic "combiner board" fixed to a mobile girder. During operation the upper and lower girders are moved inwards towards the circulating antiproton beam following its reducing cross-section as the transverse stochastic cooling proceeds. Both girders are quickly withdrawn to make room for the next "hot" large cross-section burst of antiprotons. The pick-up and kicker structures are essentially similar except for cryogenic cooling of the preamplifiers (and eventually the girders and combiner boards) in each pick-up whereas in each kicker water cooling is employed to cool the kilowatts, in total, dissipated in the terminating resistors of the antenae. Flexible strip line connections with nominally 50 Ω impedance and a minimum of reflection had to be specially designed for the task. The girders are moved by pre-programmed electric motors external to the vacuum tanks.

Some work has also been carried out on structures aimed essentially at higher frequency broader-band devices. A corrugated wave-guide structure [6] operating at around 8 to 12 GHz has been used at the SPS for experiments on the transverse cooling of bunched beams. An infrared (laser diode) optical data link is used directly through the atmosphere between pick-up and kicker stations. The emitter was installed on the roof of one of the auxiliary buildings with the receiver on a pylon 2 km away providing a line of sight above the trees.

Another prototype pick-up has been tested in the AA ring [7]. This is based upon the detection of Cerenkov microwave radiation at around 5 to 6 GHz. Again the principle is based upon the exploitation of a "loaded" waveguide, the corrugations of the SPS pick-up being replaced by, in principle, side-walls of dielectric material. Electromagnetic waves excited by the Cerenkov effect in the relevant slow waveguide modes have been observed and much learnt about the behaviour of such pick-ups in the presence of the AA circulating beam.

The advantages of the above structures over the more usual antenae and slotted guides is that at the higher frequencies and bandwidths the structural geometries are still reasonably simple and hopefully cheaper to manufacture.

Cooling e.g. at LEAR, at very low energies presents different problems because antiprotons move at very low velocities (with respect to the velocity of electromagnetic waves). Some prototype work on very slow wave structures [8] has been carried out at LEAR. The transverse pick-up is based on strip-line technology where the conducting "strip" deposited on a plane ceramic base, meanders, much like a slow-moving river over flat pasture land, along and around the direction of the particle beam. Electromagnetic signals can thus be arranged to move along the strip-line as slowly as the beam of particles.

Conclusions
Present Performance and Future Expectations

The new facilities for antiproton production and accumulation have as a goal for 1988/1989 a factor of ten improvement in both accumulation rate and luminosity over the 1986 performance [9]. During the last weeks of 1987 the collider was used for physics data-taking with the new facilities and although accumulation rates exceeded the 6×10^{9} $\bar{p}$ /H of 1986, no spectacular gains were made in overall integrated luminosity. During the first half of this year, all the antiprotons produced were used for injection into LEAR, and up to 10^{10} $\bar{p}$ per shot (about once per hour) with very low cooled emittances were regularly transferred with ~100% efficiency.

The present AAC performance and that estimated for the collider run planned for the end of this year, 1988, are outlined in table 1.

It is seen that, with some optimism, the goal of a factor of ten improvement in peak luminosity, is within our grasp.

Acknowledgements

The author wishes to thank all those members of the accelerator and support divisions of CERN who worked hard to bring the ACOL project to a worthwhile conclusion. Thanks are also due, in particular, to my immediate colleagues in the DI, AR, ML and RF groups of the PS and SPS divisions for help with supplying drawings and information for this contribution to the conference.

	ACOL Goals	Present Performance mid 1988	Expected Performance end 1988
Protons/pulse (on target)	2×10^{13}	6.5×10^{12}	1.3×10^{13}
Pbars/pulse (AC)	10^{8}	3.7×10^{7}	0.8×10^{8}
Pbars/pulse (AA)	4×10^{7}	1.92×10^{7}	4×10^{7}
Pulse cycle time	2.4s	4.8s	4.8s
Stacking rate	6×10^{10} $\bar{p}$/H	1.44×10^{10} $\bar{p}$/H	3×10^{10} $\bar{p}$/H
Collider luminosity	4×10^{30} cm^{-2}sec^{-1}	3.5×10^{29} cm^{-2}sec^{-1}	1.4×10^{30} cm^{-2}sec^{-1}
AA stack intensity	10^{12} $\bar{p}$'s	2×10^{11} $\bar{p}$'s	8×10^{11} $\bar{p}$'s

Table 1

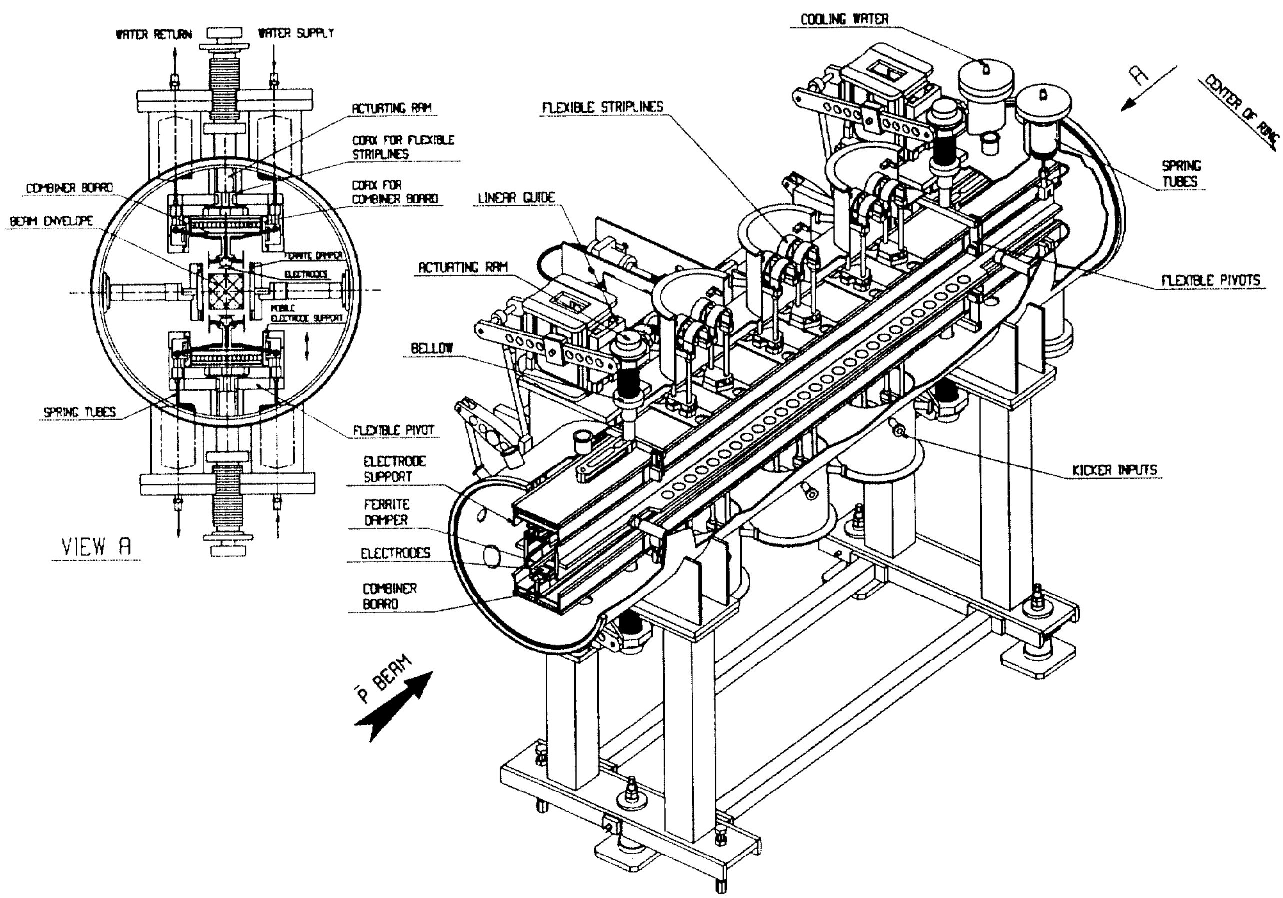

Fig. 2 : The AC Stochastic Cooling Kicker

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