EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN - PS DIVISION

CERN/PS 99-50 (HP)

THE ANTIPROTON DECELERATOR (AD)

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Abstract

To continue an important part of the LEAR physics programme, a simplified scheme for the provision of antiprotons at 100 MeV/c is being implemented. It uses the present target area and the Antiproton Collector (AC) which is refurbished to include the deceleration from 3.5 GeV/c to 100 MeV/c. In this report the operation and the expected performance are discussed.

Paper presented at the LEAR Symposium
CERN, May 15, 1999

Geneva,
August 1999

1. INTRODUCTION

After the completion of the LEAR physics programme a simplified scheme for the provision of antiprotons of a few MeV [1] is now being implemented. It will considerably lighten the operation of the antiproton complex by reducing the number of machines involved.

Let us briefly recall the LEAR scenario for providing low-energy antiprotons used until the end of 1996. It involved four machines (AC, AA, PS and LEAR) to collect, cool and decelerate antiprotons in the following sequence:

1) Antiprotons, produced by 26 GeV/c protons on the production target, are collected and precooled at 3.5 GeV/c in the AC.
2) They are then transferred to the AA where they are accumulated and further cooled.
3) A bunch of a few 10^9 $\bar{p}$ is taken from the AA and sent to the PS every 30 minutes to several hours.
4) This bunch is decelerated in the PS from 3.5 to 0.6 GeV/c.
5) It is then transferred to LEAR, where cooling (at 3 or 4 intermediate momenta) and deceleration alternate to bring the full intensity to low energy. With electron cooling, typical emittances at 100 MeV/c are 1π mm·mrad and $\Delta p/p = 5 \times 10^{-4}$.

A simplification of this scheme (which was designed as an annex to the antiproton source for the Sp$\bar{p}$S) has become desirable. The new solution uses the modified AC, now called AD for Antiproton Decelerator, as the only antiproton machine.

2. AD OVERVIEW

The target area and the AC ring [2] in its original location (Fig. 1) are used. The 26 GeV/c production beam remains basically the same and the antiprotons produced in the target are collected at 3.5 GeV/c. After bunch rotation, the antiprotons are stochastically cooled to 5π mm·mrad in the transverse planes and 0.1% in $\Delta p/p$. They are then decelerated to 2 GeV/c where band I (0.9 to 1.6 GHz) of the AC transverse and longitudinal stochastic cooling is used to compensate the adiabatic beam blow-up due to the deceleration. Then, the beam is further decelerated in several steps. Below 2 GeV/c the next intermediate cooling level is at 300 MeV/c where the transverse emittances have grown to 33π mm·mrad and $\Delta p/p$ = 0.2%. Now electron cooling can be applied. The beam characteristics and the cooling times are shown in Table 1. Two or three intermediate levels at low momenta are necessary also for the change of the rf harmonic number. This avoids excessive frequency swings. About 5×10^7 $\bar{p}$ are injected at 3.5 GeV/c and with an estimated overall efficiency of 25%, 1.2×10^7 $\bar{p}$ are available at low energy.

The new experimental area will be inside the AC ring. By adding some shielding, the physics teams are allowed access to the experimental area during $\bar{p}$ production and deceleration. The AA ring, which was located inside the AC in the same hall, is no longer needed and is being dismantled to free the space.

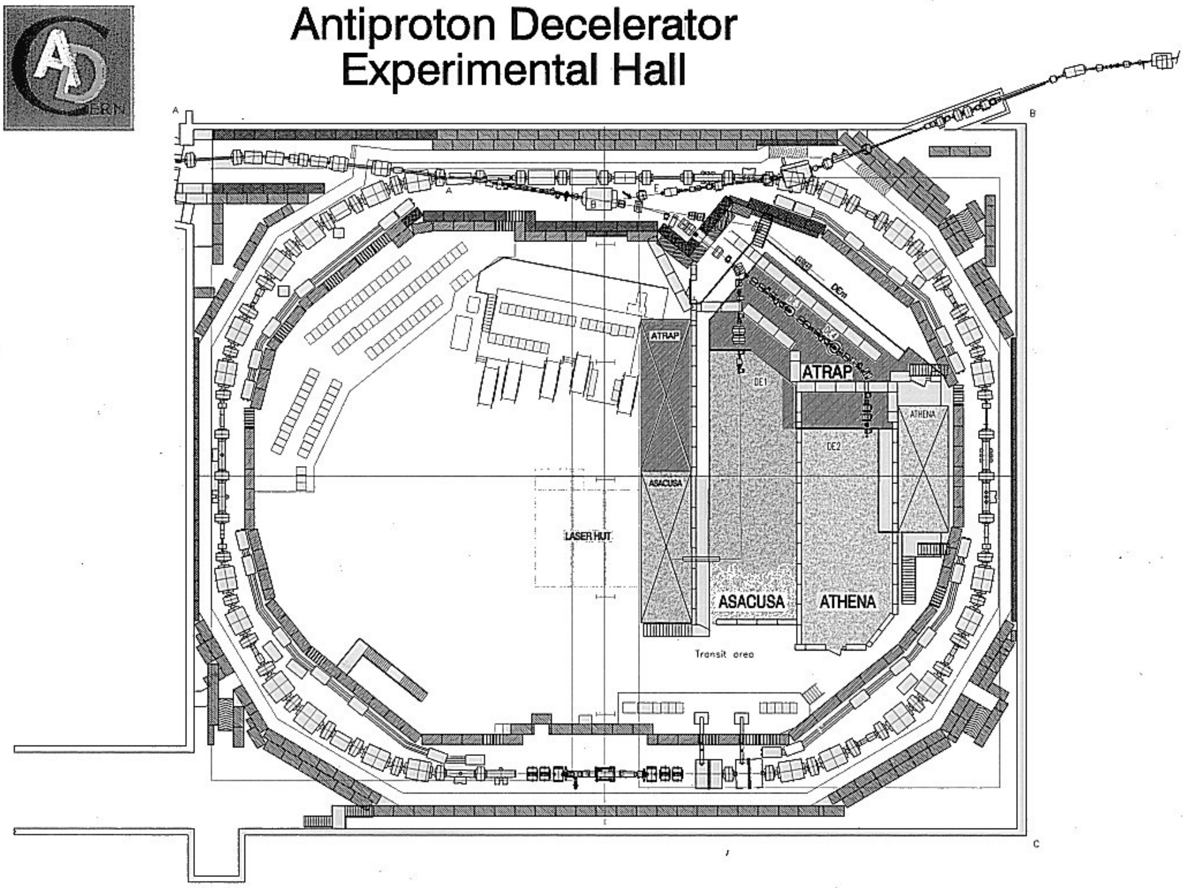

Figure 1

Table 1 - Transverse emittances and momentum spreads before (i) and after (f) cooling and cooling times. Only adiabatic increase due to deceleration is considered[*] .

p	ε_i	ε_f	$\Delta p/p_i$	$\Delta p/p_f$	τ	Cooling Method
[GeV/c]	[π mm.mrad]		[%]		[s]	
3.5	200	5	1.5	0.1	20	STOCHASTIC COOLING
2.0	9	5	0.18	0.03	15	
0.3	33	2	0.2	0.1	6	ELECTRON COOLING
0.1	6	1	0.3	0.01	1	

Only minor modifications of the AC ejection system are necessary for fast extraction at low energy. With the addition of electron cooling, 10^7 $\bar{\mathrm{p}}$ can be ejected in one pulse of 0.2-0.5 µs length, with a cycle time of about 1 minute. The basic AD cycle with the different intermediate levels is shown schematically in Fig. 2.

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[*] 2σ-emittances [$\varepsilon = (2\sigma)^2/\beta$] and $4\sigma_p$-momentum spread [$\Delta p = 4\sigma_p$] are used throughout in this report.

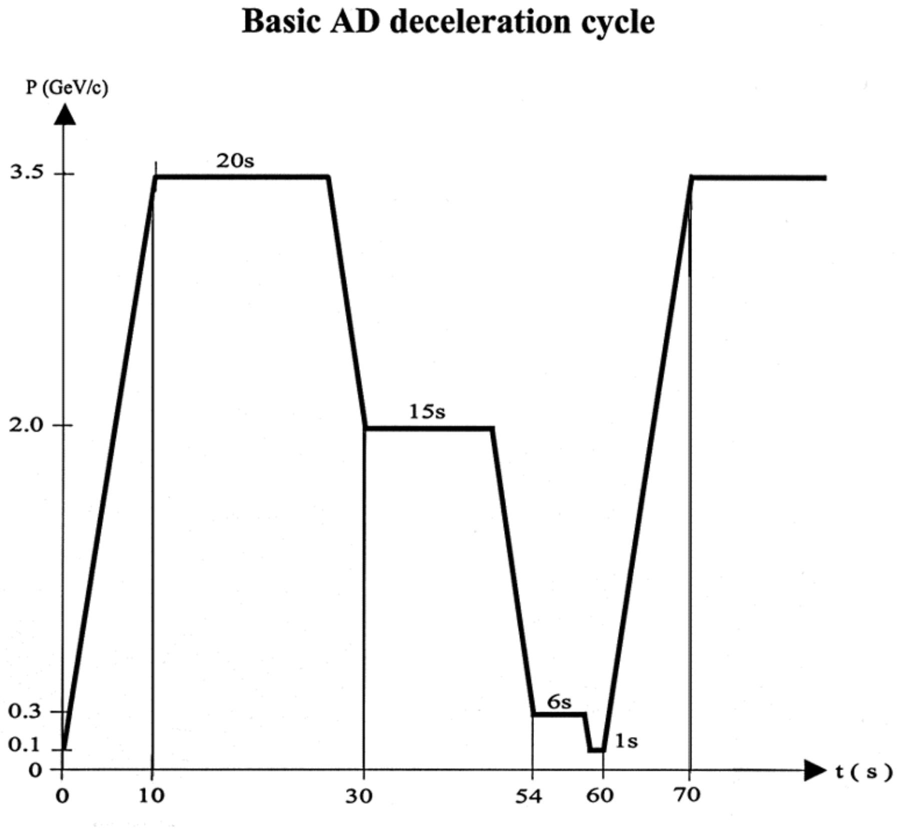
Basic AD deceleration cycle

Fig. 2

As an option, a small number (~5) of pulses could be stacked at 3.5 GeV/c, prior to deceleration, by bunching the stack and injecting the new beam into the free part of the circumference. With the existing systems which are designed to cool 10^8 $\bar{p}$, this stacking mode requires more time for cooling. Thus the intensity per pulse is increased but, because of the longer cycle time, the number of $\bar{p}$ per second is not significantly improved.

3. REVIEW OF DIFFERENT SYSTEMS

3.1 Antiproton Production Beam

A 26 GeV/c production beam of 10^{13} protons is necessary in order to inject the required 5×10^7 antiprotons into the AD.

The methods for producing the proton beam used during the $\mathrm{Sp\bar{p}S}$ and LEAR era are replaced by a more efficient technique [4], that benefits from developments made for the LHC.

Acceleration in the PS of the production beam will take place on $h = 8$ up to 26 GeV/c, where a compression scheme is applied. The harmonic number is increased stepwise from 8 to 20, keeping the beam in 4 adjacent bunches. On the flat top, at 26 GeV/c, bunches are shortened by a non-adiabatic rf manipulation, and the beam is ejected and sent onto the production target. Protons will be accelerated on the harmonics $h = 1$ and 2 in the PS-Booster, and on $h = 8$ and 16 in the PS. The purpose is to fill half the PS ring with bunch to bucket transfer of the beam from the 4 PS Booster rings.

3.2 Target Area

All the $\overline{p}$ production systems remain unchanged. A magnetic horn will be used as the collector [5]. During the last years of LEAR, a consolidation programme of the target area has been carried out. Therefore, only minor overhauling and the provision of some spare components is needed.

3.3 Radiofrequency systems

3.3.1. Bunch rotation rf system

The existing 9.5 MHz ($h = 6$) bunch rotation system is retained to permit the shortest possible cycle time in the single-pulse mode.

3.3.2. Deceleration rf system

The present 1.6 MHz ($h = 1$) rf system will be modified to cover a frequency range of 0.5 – 1.6 MHz.

A phase pick-up is essential to achieve efficient deceleration. The sensitivity of this phase pick-up and its shielding from rf parasites determine the lowest antiproton intensity that can be decelerated. A new pick-up with high sensitivity, especially at low momentum, could be made resonant and remotely tunable if necessary.

3.4 Stochastic Cooling

Stochastic cooling is needed at 3.5 GeV/c and 2 GeV/c (Fig. 1), for which band I (0.9 to 1.6 GHz) of the AC systems will be employed. All its pick-ups and kickers remain in their present location. Band II (1.6 to 2.4 GHz) and band III (2.4 to 3.2 GHz) are not used as the gain in the cycle time would not be significant and space is needed for the electron cooling system.

At 2 GeV/c, the band I pickups can still be used but their sensitivity is reduced by a factor of about 2. The kicker consists of modules, individually accessible, such that their phasing can be adjusted by means of relays on the drivers of the rf power amplifiers. Switchable delays in the signal transmission have also to be added for commutation from 3.5 to 2 GeV/c.

3.5 Electron Cooling

Electron cooling will be applied at low momenta, especially at 300 and 100 MeV/c. The requirements of AD are met by the LEAR system. It has therefore been transferred for the AD with only minor modifications.

To provide a long straight section for the electron cooling device, an insertion i.e. a local modification of the AC lattice has been implemented. In this straight section (Fig. 1) the dispersion of the orbit (D) and the focusing functions have values suitable for electron cooling.

3.6 Experimental Area

3.6.1. Experiments

Three experiments [3] have been accepted and will be mounted in the AD hall (inside of the ring: ATHENA ("Antihydrogen Production and Spectroscopy"), ATRAP ("Production and Study of Cold Antihydrogen") and ASACUSA ("Atomic Spectroscopy and Collisions Using Slow Antiprotons). The housing of these experiments in the AD hall is geographically feasible (Fig. 1).

Experimental huts will be put on platforms on top of the shielding where dose rates are low.

3.7 Radiation Safety Aspects and Access

There are two operation modes:

- setting-up with protons,
- operation with antiprotons.

Studies and measurements have been done to evaluate the safety measures necessary to allow physics teams to be present inside the AD hall during operation.

3.7.1. Operation with protons

Assuming that 3×10^{10} protons per 2.4 s may enter the AD ring, the radiation level is too high to allow access to the hall during the setting-up.

So, the hall and the ring are considered as a primary zone. The entrance door to the hall will be electrically locked and controlled by the operation crew from the Main Control Room.

3.7.2. Operation with antiprotons

Sufficient shielding is foreseen to keep the radiation level in the huts, on top of the shielding roof, at a very low level, so that during the operation with antiprotons occupancy is feasible. The door 301 will then be open, and the hall is considered as a secondary zone.

3.8 Vacuum

The AD vacuum is determined by the need to have small equilibrium emittance resulting from the interplay between the cooling and the multiple Coulomb heating at 100 MeV/c. The aim is to reach a pressure in the low 10^{-10} Torr region, a factor of 20-50 improvement over the AC. A sizeable improvement can be obtained by adding titanium sublimation pumps and ionic pumps. In addition, baking will be applied wherever the equipment can support the high temperatures.

3.9 Power Supplies

The range of the current between 3.5 GeV/c and 100 MeV/c is large. In order to guarantee a current stability of about 5×10^{-4} at low energy, active filters must be added on the main power converters. The trimming power supplies will have to run below the present minimum controllable current. It is proposed to build new power converters which will be stable down to a very small current. Additional supplies and trims are needed for the lattice insertion for electron cooling and for the orbit correction system, required at momenta below 3.5 GeV/c.

3.10 Operation

3.10.1. AD commissioning

The initial running-in will require the participation of the system specialists, plus a small number of "dedicated" accelerator physicists. In addition it is hoped that each of the experiments will supply at least one physicist/engineer to help with all phases of the running-in. A number (4-5) of these experts will then form the basis of the team of AD machine supervisors for routine operation. Some experienced operation technicians will be needed to help full time with the commissioning of the facility. They would be temporarily detached from their other duties in the PS Operation structure. These new qualified AD operators will be part of the regular PS/PSB operation team for the MCR Operation crew.

3.10.2. Routine operation

It is assumed that the facility will run continuously from Monday morning to Friday evening, but not over weekends, for about 3000 h each year. The runs will be scheduled between April and October, thus avoiding the PS start-up after the shutdown and the critical period in November and December. The initial start-up for each running period will be performed by the team of the AD machine supervisors assisted by the qualified AD operators. Each week of regular operation will be supervised by an AD machine supervisor. The existing PS Operation crew will continue to be responsible for the primary production beam as far as the production target, but the routine facility operation will be left to the users themselves, along the same lines as is currently done for ISOLDE and the EAST Hall secondary beam lines. This implies a high degree of automation. However, the AD will be a complex installation with $\overline{\mathrm{p}}$ production, injection, deceleration and extraction; therefore, in order to assist the users with the day-to-day problems, a technical supervisor will be available to help them during normal working hours. For operational problems that the users encounter outside normal working hours, they will be able to contact the MCR Operation crew or the machine supervisor, but as a rule, other specialists will not be called until the following working day. This means that in case of serious breakdowns the AD will be off until the following working day.

4. CONCLUSION

The use of the AC as an antiproton decelerator holds the promise of delivering dense beams of 10^7 $\overline{\mathrm{p}}$/min at low energy (100 MeV/c) with bunch lengths down to 200 ns. It opens the possibility for a new antiproton physics programme based on fast extracted beams with emittances of a few π mm mrad and a momentum spread of a few 10^{-4}.

Taking into account the lack of resources at CERN, the cost and manpower of the project must be largely supported by external laboratories who will also be required to help with the operation. First beam to be given to the users is expected for the second half of 1999 so that the very successful LEAR programme can be continued after a not too long pause.

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