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## AN ANTIPROTON DECELERATOR IN THE CERN PS COMPLEX

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### *Abstract*

The present CERN PS low-energy antiproton complex involves 4 machines to collect, cool, decelerate and supply experiments with up to  $10^{10}$  antiprotons per pulse and per hour of momenta ranging from 0.1 to 2 GeV/c. In view of a possible future physics programme requiring low energy antiprotons, mainly to carry out studies on antihydrogen, a simplified scheme providing at low cost antiprotons at 100 MeV/c has been studied. It requires only one machine, the present Antiproton Collector (AC) converted into a cooler and decelerator (Antiproton Decelerator, AD) converted into a cooler and decelerator (Antiproton Decelerator, AD) and delivering beam to experiments in the hall of the present Antiproton Accumulator Complex (AAC). This paper describes the feasibility study of such a scheme.

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## Abstract

The present CERN PS low-energy antiproton complex involves 4 machines to collect, cool, decelerate and supply experiments with up to  $10^{10}$  antiprotons per pulse and per hour of momenta ranging from 0.1 to 2 GeV/c. In view of a possible future physics programme requiring low energy antiprotons, mainly to carry out studies on antihydrogen, a simplified scheme providing at low cost antiprotons at 100 MeV/c has been studied. It requires only one machine, the present Antiproton Collector (AC) converted into a cooler and decelerator (Antiproton Decelerator, AD) and delivering beam to experiments in the hall of the present Antiproton Accumulator Complex (AAC) [1]. This paper describes the feasibility study of such a scheme [2].

## 1. INTRODUCTION

The scenario of providing today low-energy antiprotons to physics experiments involves four machines, downstream of the antiproton production target: the Antiproton Collector (AC), the Antiproton Accumulator

(AA), the Proton Synchrotron (PS) and the Low Energy Antiproton Ring (LEAR). These machines collect, cool, decelerate and deliver antiprotons to experiments in the following sequence: (i) antiprotons, produced by 26 GeV/c protons on a target, are collected and precooled at 3.5 GeV/c within 4.6 s in the AC; (ii) they are then transferred to the AA where they are accumulated for several hours and further cooled; (iii) a bunch of a few  $10^9$  antiprotons is taken from the AA stack and sent to the PS where it is decelerated from 3.5 to 0.6 GeV/c; (iv) it is then transferred to LEAR where cooling at 3 to 4 intermediate momenta and deceleration alternate to bring the full intensity to low energy.

With electron cooling, typical  $2\sigma$  transverse emittances of the beam obtained at 100 MeV/c are  $1\pi$  mm.mrad and its  $4\sigma$  momentum spread is  $\Delta p/p = 5 \times 10^{-4}$ . Depending on the LEAR extraction mode and on experimental requirements, transfer from AA to PS and LEAR can take place at intervals ranging from 30 mn to several hours. Extraction from LEAR can be single turn or ultra slow with a spill length ranging from microseconds to hours.

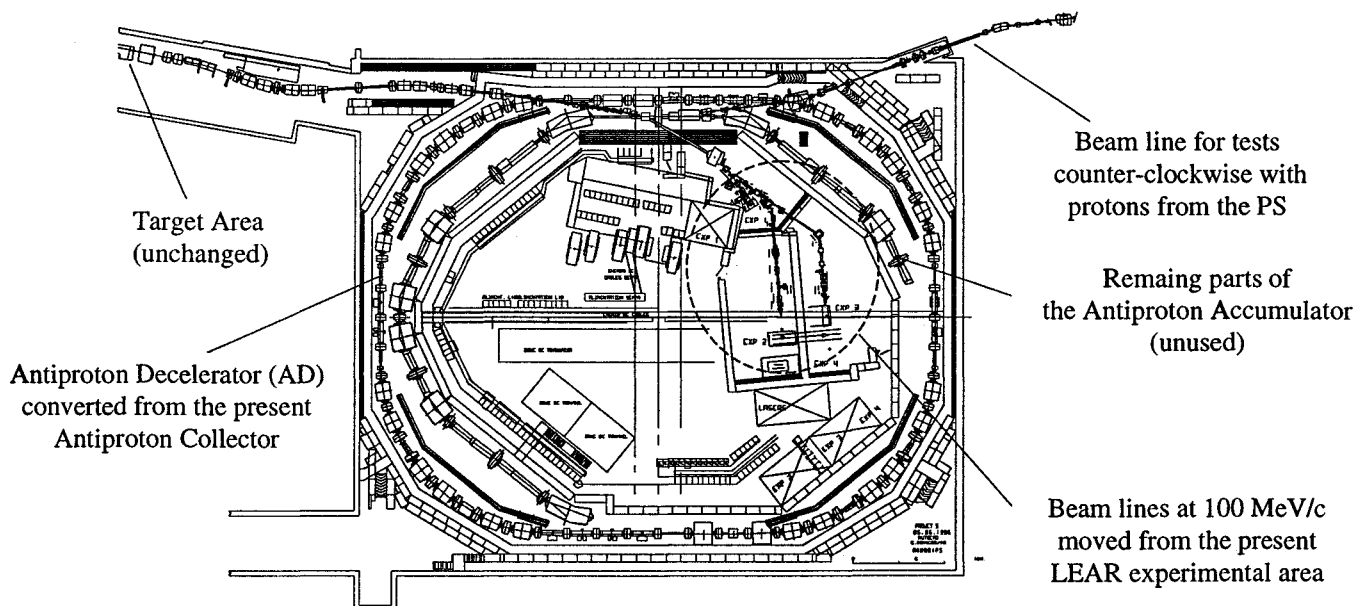


Fig. 1: The Antiproton Decelerator (AD) and its beam lines in the Antiproton Accumulator and Collector (AAC) hall

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This sophisticated scheme will come to an end in december 1996 as the present PS antiproton physics programme will be completed and LEAR will be converted into an ion accumulator for LHC [3].

However, as there is a strong interest in experiments with low energy antiprotons for antihydrogen production to test CPT, to investigate anti-matter gravity and to study the physics of exotics atoms, a simplified scheme making use of only one machine downstream of the production target, to provide antiprotons at 100 MeV/c, has been studied. This machine is the modified AC and is called AD for Antiproton Decelerator.

## 2. AD OVERVIEW

The present target area is used, as well as the AC ring in its present location, whereas the AA is unused and partially dismantled (Fig.1). A primary proton beam of  $10^{13}$  protons, delivered by the PS, hits the target at 26 GeV/c and produces antiprotons of which  $5 \times 10^7$  can be collected at 3.5 GeV/c in the AD. After bunch rotation, they are cooled down to  $5 \pi \text{.mm.mrad}$  in both transverse planes and to  $\Delta p/p = 10^{-3}$  with transverse and longitudinal stochastic cooling. They are then decelerated to 2 GeV/c where again stochastic cooling is applied to compensate for the adiabatic beam blow-up due to deceleration. Then, the beam is further decelerated in several steps.

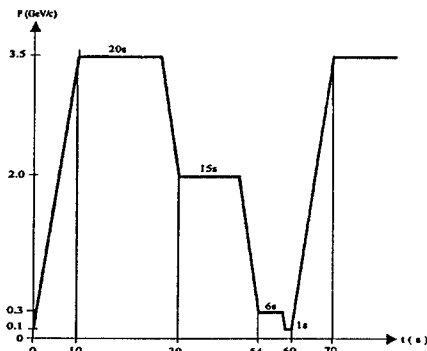


Fig. 2: Basic AD Deceleration cycle

Below 2 GeV/c the next intermediate cooling level is at 300 MeV/c where transverse emittances have grown up to  $33 \pi \text{.mm.mrad}$  and  $\Delta p/p = 2 \times 10^{-3}$ . Electron cooling is then applied and finally after deceleration down to 100 MeV/c, the beam is again electron cooled to transverse emittances of  $1 \pi \text{.mm.mrad}$  and  $\Delta p/p = 10^{-4}$ . Beam

characteristics and cooling times are shown in Table 1.

With an estimated overall transmission efficiency of 25% and an AD deceleration cycle as shown in Fig.2, a bunch of  $1.2 \times 10^7$  antiprotons can be extracted at 100 MeV/c and delivered to one of the beam lines, at a rate of one pulse per minute.

## 3. THE VARIOUS SYSTEMS INVOLVED

**Antiproton production:** The primary beam of  $10^{13}$  protons at 26 GeV/c hitting the antiproton production target will be similar to the present one. It will however benefit from developments carried-out in view of the use of the PS complex as part of the LHC injector chain [4]. They consist mainly of new acceleration systems in the PS Booster and in the PS itself, and of the transfer energy between these 2 machines increased from 1 to 1.4 GeV.

Antiprotons emerging at 3.5 GeV/c from the target will be focused and matched to the transport line acceptance of  $200 \pi \text{.mm.mrad}$  by a magnetic horn pulsed at 400 kA. During the last 4 years a consolidation programme of the target area has been carried-out, therefore only minor overhauling and provision for some spare parts are needed.

**RF systems:** The  $5 \times 10^7$  antiprotons injected in the AD will be trapped by the existing 9.5 MHz ( $h=6$ ) RF system, as in the present scheme, and a bunch rotation will be applied in the longitudinal phase space in order to reduce the beam energy spread. The beam will then be decelerated with the present 1.6 MHz ( $h=1$ ) RF system whose frequency range will be extended down to 0.5 MHz. As this frequency range will not be wide enough to allow deceleration of the beam down to 100 MeV/c with  $h=1$ , changes of harmonic numbers at intermediate energy levels will be performed.

This RF system, on top of its basic use for antiproton deceleration, will also be used to shorten the bunch at 100 MeV/c prior to extraction and to capture and decelerate proton beams coming from the PS and circulating counter-clockwise, during setting-ups.

**Cooling:** Stochastic cooling will be achieved by part of the present AC cooling system, covering the frequency range 0.9 - 1.6 GHz (Band I), 1.6 - 2.4 GHz (Band II), and 2.4 - 3 GHz (Band III). Only Band I will be used to cool the beam at 3.5 and 2 GeV/c although at 2 GeV/c pick-up sensitivity is reduced by a factor of 2 with respect to 3.5 GeV/c. Using Band II and III would not lead to a

Momentum [GeV/c]	Cooling Process	$\epsilon_{\text{initial}}$ [ $\pi \text{.mm.mrad}$ ]	$\epsilon_{\text{final}}$ [ $\pi \text{.mm.mrad}$ ]	$\Delta p/p_{\text{initial}}$ [%]	$\Delta p/p_{\text{final}}$ [%]	Cooling Time [s]
3.5	Stochastic	200	5	1.5	0.1	20
2.0	Stochastic	9	5	0.18	0.03	15
0.3	Electron	33	2	0.2	0.1	6
0.1	Electron	6	1	0.3	0.01	1

Table 1: Initial and final transverse emittances ( $2\sigma$ ) and full momentum spread ( $4\sigma$ ), before and after cooling in the AD at various momenta. Cooling times and processes involved are also indicated.

significant gain in the AD cycle time, therefore components of these 2 Bands will be removed to make space available for installation of the electron cooling system.

For cooling at 0.3 and 0.1 GeV/c, the present LEAR electron cooling system, together with its correctors and with minor modifications will be installed in the AD. It will be located in a dispersion free straight section. For this purpose a local modification of the lattice is under study to allow installation of the electron cooling device.

**Vacuum:** At 100 MeV/c, with the present AC vacuum, the beam lifetime is expected to be a factor of 4 to 100 smaller than at 3.5 GeV/c, depending on acceptance and gas composition. A better AD vacuum is therefore necessary to obtain the smallest equilibrium emittance between the effects of cooling and multiple Coulomb scattering. Addition of titanium and ionic pumps will bring a sizeable improvement and baking of some components should allow to reach a pressure in the level of a few  $10^{-10}$  Torr.

**Power supplies and other components:** The range of currents required between 3.5 and 0.1 GeV/c is large. In order to guarantee current stability at low energy, active filters will be added on the main power converters. As the trimming power supplies would run below their minimum controllable current they will be replaced by new power converters.

The AC beam diagnostics and measurements devices will be used and the closed orbit observation system will be adapted to the low intensity antiproton bunches.

The Nord 100 computer presently installed for the controls of the AC and the AA cannot be used in the future. The AD controls will be integrated in the recently renewed PS control system.

**New experimental area:** Experiments will be housed inside the AD ring. Shielding currently in place in the AAC hall does not allow sufficient floor area, therefore a new shielding configuration is proposed, where the inner support wall is brought as close to the AD ring as possible. Three low energy beam lines of the present LEAR experimental area will be dismantled and remounted in the AD hall, where the AA will be partially dismantled.

The present AC ejection line will still be used and serve a dual purpose. It will match the AD beam to the experiments beam lines, at low momentum. It will also connect the AD to the present AA ejection line with the addition of one extra dipole and will allow transport to the AD of 3.5 GeV/c protons coming from the PS, for setting-up purposes.

#### 4. OPERATION

During setting-up with protons, the radiation level induced by a beam of up to  $3 \times 10^{10}$  protons will be too high to allow access to the hall. Therefore, the hall and the AD ring will be considered as primary zone. During normal

antiproton operation, the new shielding configuration will reduce the dose rate and keep the radiation level in the huts at a very low level. The hall, in this case, will be considered as a secondary zone.

The AD would run continuously for about 3000 h per year, from Monday morning to Friday evening and from April to October, avoiding the PS start-up after shut-down and the winter period where electricity is expensive. The initial start-up could be performed by the team of AD machine supervisors, but users would take care of routine operation of the AD and its beam lines down to the experiments, as is currently the case for ISOLDE and the PS East Hall secondary lines.

The existing PS operation crew could continue to be responsible for the primary production beam up to the production target; a technical supervisor could be available to help the users with day-to-day problems during working hours and each week of regular operation could be supervised by an AD machine supervisor. However, in some cases of a serious breakdown requiring intervention of a specialist outside working hours, the AD might stay off until the following working day.

#### 5. CONCLUSION

The use of the AC as an antiproton decelerator providing  $10^7$  antiprotons/mn at 100 MeV/c seems possible, although further studies have still to be carried-out. It opens the possibility of a low energy antiproton physics programme with fast extracted beams. However, taking into account the lack of CERN's resources, cost and manpower for the project will have to be supported by external laboratories who will also be required to help with the operation.

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