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THE ANTIPROTON DECELERATOR: AD

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Abstract

In view of a possible future programme of physics with low-energy antiprotons, a simplified scheme for the provision of antiprotons at 100 MeV/c has been studied. It uses the present target area and the modified Antiproton Collector (AC) in its present location. In this report the modifications and the operation are discussed.

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1. INTRODUCTION

A simplified scheme [1] for the provision of antiprotons of a few MeV has been studied taking into account that:

1) The momentum favored for transfer to the traps, for antihydrogen production, is 100 MeV/c (i.e. about 5 MeV kinetic energy).
2) The use of LEAR as a heavy-ion accumulation ring is part of the LHC design proposal [2].
3) It is highly desirable to lighten the operation of the antiproton complex by reducing the number of machines involved.

A scheme, compatible with these conditions, is the use of the AC [3] alone with appropriate modifications to function as an antiproton cooling and decelerator ring.

Let us briefly recall the scenario of providing low-energy antiprotons in operation today. It involves 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 been desirable. The solution proposed, using the modified AC, is called AD (Antiproton Decelerator).

2. AD OVERVIEW

The present target area and the AC ring in its present location (Fig. 1) are used. The 26 GeV/c production beam remains 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 present 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.

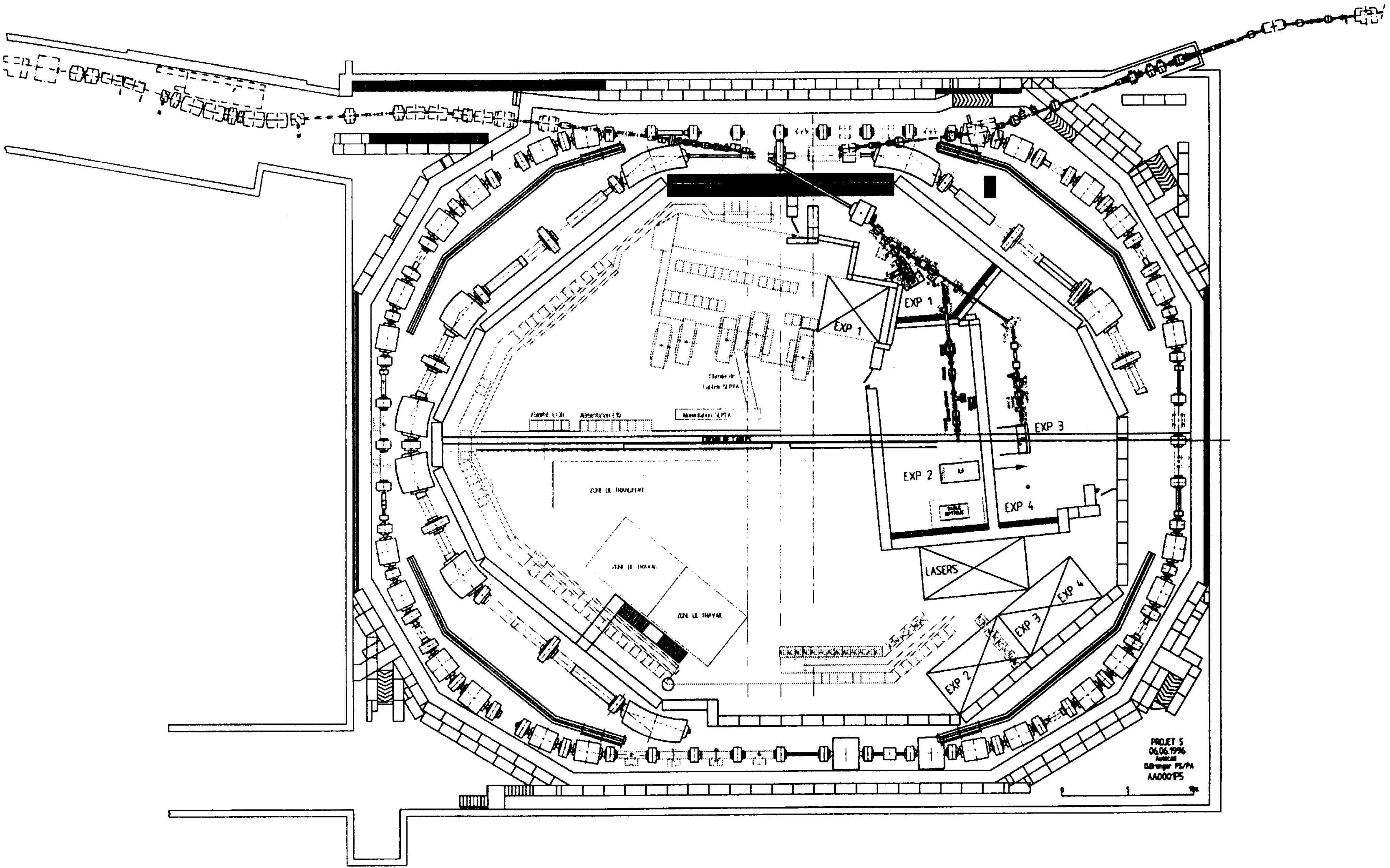

Fig. 1 : AD Layout

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

p	ε_i	ε_f	$\Delta p/p_i$	$\Delta p/p_f$	t	
[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	

The new experimental area will be on the inside of the AC ring. By adding some shielding, the physics teams are allowed access to the experimental area during $\bar{p}$ production and deceleration.

Only minor modifications of the present ejection system are necessary for fast extraction at low energy. With the addition of electron cooling, 10^7 $\bar{p}$ 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 in Fig. 2.

Basic AD deceleration cycle

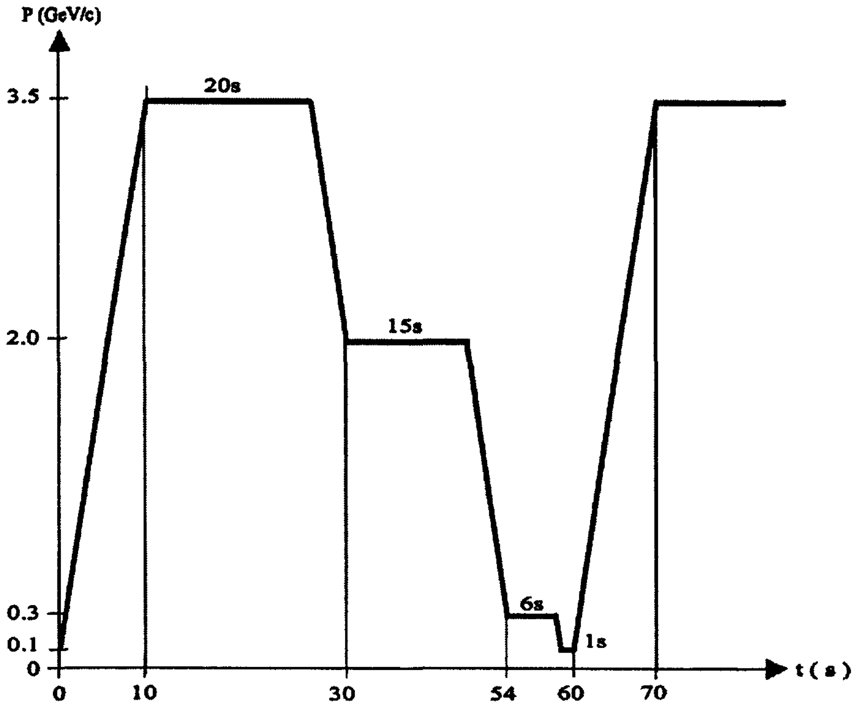

Fig. 2

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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.

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 onto 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 present method for producing the proton beam will be replaced by a more efficient technique [4], profiting from developments required in view of the LHC. In particular, 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.

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.

3.2 Target Area

All the $\bar{p}$ production systems remain unchanged. A magnetic horn will be used as the collector [5]. During the last 4 years, a consolidation programme of the target area has been carried out. For the AD era, 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. For AD this rf system serves four distinct purposes:

- Deceleration of antiprotons,
- Bunching of the already cooled antiprotons at 3.5 GeV/c when several pulses are being accumulated (stacking option),
- Bunching and bunch rotation of the cooled antiproton beam at the extraction momentum of 100 MeV/c,

- Capture and deceleration of proton test beams (10^9 to 2×10^{10} protons per pulse) for setting up.

The low level rf system will be converted from the present analogue to a digital system using standard modules already being used in the PS Booster and the PS. A B-train generator based on a coil in one of the bending magnets will be required to drive the rf frequency program.

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 electrostatic 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 present 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 we can still use the band I pickup but its 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 present LEAR system. It is therefore proposed to transfer the existing LEAR cooler with only minor modifications.

To provide a longer straight section for the electron cooling device, an insertion i.e. a local modification of the AC lattice has been studied. In this straight section (Fig. 1) the dispersion of the orbit (D) is zero.

The electron cooler induces perturbations to the antiproton beam:

- a closed orbit distortion due to kicks induced by the toroids which can be compensated by the present LEAR correction dipoles.
- coupling of the horizontal and vertical betatron motion due to the solenoid which can be compensated by the same type of correction solenoids installed on LEAR.
- a tune shift due to the electron beam and residual coupling from the solenoid of the order of 10^{-3} which does not require any special form of compensation.

3.6 Experimental Area

3.6.1. Experiments in the AD hall

The beam lines in the South Hall will be dismantled and remounted in the AD hall. The housing of the four experiments for low momenta in the AD hall is geographically feasible (Fig. 1). At least one of their four areas can be foreseen to accommodate a number of small experiments in a rapid succession.

The part of the beam line between the AD extraction point and the common switch to the three lines serves a dual purpose:

- to match the beam from the AD to the transfer lines for the experiments at low momenta,
- to connect the AD to the present AA ejection line by adding one extra dipole. This new transfer line will be used to take protons at 3.5 GeV/c from the PS via the TTL2 loop for the AD setting-up.

3.6.2. Shielding

The installation of experiments requires a new configuration of the shielding on one side of the hall.

The shielding currently in place would not allow sufficient floor space for the experiments foreseen, therefore, a new layout is proposed. The outer support wall must stay in place whereas the inner support wall is brought as near to the AC machine as possible. This would make sufficient space available for the experiments. The roof shielding would have to be changed accordingly.

As the experiments use the central part of the hall, the rf amplifiers for the bunch rotation system should be moved. The lengths of the coaxial lines to the rf cavities must be kept to a minimum. The amplifiers will therefore be mounted on a platform adjacent to the shielding and the AA ring has to be locally dismantled.

Experimental huts will be put on platforms on top of the shielding where dose rates are low. Below the hut a Faraday cage can be mounted for the high voltage power supplies of the electron cooler.

3.7 Radiation Safety Aspects and Access

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.

There are two operation modes:

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

3.7.1. Operation with protons

Assuming that 3×10^{10} protons per 2.4 s may enter the AD ring through the TTL2 loop, 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 to the hall (door 301) will be electrically locked and controlled by the operation crew from the Main Control Room.

3.7.2. Operation with antiprotons

Measurements have been carried out inside the AC hall to determine the present dose equivalent rate arising from muons and neutrons. These detectors were placed at beam height level and they were exposed for a period of operation. Taking into account that future operation will be at 1 pulse/ minute the average dose rates are still too high for permanent occupancy in experimental huts. It is therefore recommended to add a layer of 80 cm of concrete in the injection region over a length of 18 m. This will locally reduce the dose rates by one order of magnitude and keep the radiation level in the huts, on top of the shielding roof, at a very low level.

During the operation with antiprotons, the door 301 will be open, and the hall is considered as a secondary zone. The experimental areas will be equipped with the new access system similar to that of the East Hall.

3.8 Vacuum

The effects of the residual gas at different energies are:

- At 3.5 GeV/c, losses mainly due to nuclear scattering.
- At 100 MeV/c, losses due to the nuclear and Coulomb scattering, but mainly to Coulomb scattering (with an angle larger than the acceptance).
- Blow-up of the beam emittance due to the multiple Coulomb scattering.

The single Coulomb scattering loss depends strongly on acceptance. Table 2 shows the reduction factor of the beam lifetime at 100 MeV/c compared to 3.5 GeV/c as a function of gas and aperture.

Table 2

	200π mm·mrad	100π mm·mrad
Hydrogen	4	15
Nitrogen	28	110

Reduction factor of beam lifetime between 3.5 and 0.1 GeV/c

Heating is due to the multiple scattering counteracted by cooling. So 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.

A sizeable improvement can be obtained by adding titanium sublimation pumps and ionic pumps. In additon, some baking can be applied with the aim of reaching a pressure in the low 10^{-10} Torr region.

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.

3.10 Controls

It is proposed that the controls will be integrated in the PS control system (hardware and software), as developed along the DØ67 project. This will ensure use of standard software, standard equipment access, as well as common graphic interface from the workstations.

3.11 Instrumentation

The AD will use the existing beam diagnostics devices and measurement systems of the AC, its injection and ejection lines, and the target area. New front-end electronics and signal treatment is needed for the pick up system, to allow observation of a closed orbit with low-intensity $\bar{p}$ bunches.

3.12 Kickers

3.12.1. Ejection at 100 MeV/c from the AD

One pulse generator and one terminated magnet of the existing AD ejection equipment, working at 13.4 kV, will provide sufficient deflection for ejection of the $\bar{p}$ beam from the AD. The termination will be recovered from the AA injection system and minor circuit adaptations must be made to obtain a good kick flat top.

3.12.2. Injection at 3.5 GeV/c into the AD via the loop

The injection of protons into the AD via the TTL2 loop will be done as at present. The exception is that only three kicker modules will be available for this operation (the fourth one is used to eject the beam at 100 MeV/c); however, there is just enough kick strength with those remaining modules.

3.13 Operation

3.13.1. 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 main 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 foreseen for the MCR Operation crew after the end of 1996.

3.14.2. Routine operation

We assume that the facility will run continuously from Monday morning to Friday evening, but not over weekends, for about 3000 h each year between April and October avoiding the PS start-up after the shutdown and the critical day 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 $\bar{p}$ 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 specialist 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.

5. CONCLUSION

The use of the AC as an antiproton decelerator seems possible and holds the promise to deliver dense beams of 10^7 $\bar{p}$/min at low energy (100 MeV/c) with bunch lengths between 200 and 500 ns. It opens the possibility for a new antiproton physics programme based on fast extracted beams.

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.

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