EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN - PS DIVISION

CERN/PS 95-36 (AR)

THE ANTIPROTON DECELERATOR (AD), A SIMPLIFIED ANTIPROTON SOURCE (FEASIBILITY STUDY)

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Abstract

In view of a possible future physics programme concerning antihydrogen, a simplified scheme for the provision of antiprotons of a few MeV has been studied. It uses the present target area and the modified Antiproton Collector (AC) in its present location. In this report all the systems are reviewed and their modifications discussed.

Geneva, Switzerland
9 November 1995

1. INTRODUCTION

Simplified schemes for the provision of antiprotons of a few MeV have been studied and were presented at the Antihydrogen Workshop in Munich, in July 1992 [1]. This study has been updated [2], taking two new developments into account:

1) The momentum favoured for transfer to the traps, for antihydrogen production, is now 100 MeV/c (i.e. about 5 MeV kinetic energy), instead of 60 MeV/c (~2MeV) as assumed in [1].
2) The use of LEAR as a heavy-ion accumulation ring is now part of the LHC design proposal [3].

A scheme, compatible with these new boundary conditions, is the use of the AC [4] alone as an antiproton cooling and decelerator ring. It is the subject of the present feasibility study.

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) is desirable. The solution proposed, using the modified AC, is called AD (Antiproton Decelerator). In this report, we review all the systems needed for the AD and discuss their modifications.

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. The figures for stochastic cooling at 300 and 100 MeV/c are included for comparison purposes. 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 $\overline{p}$ are injected at 3.5 GeV/c and with an estimated overall efficiency of 25%, 1.2×10^7 $\overline{p}$ are available at low energy.

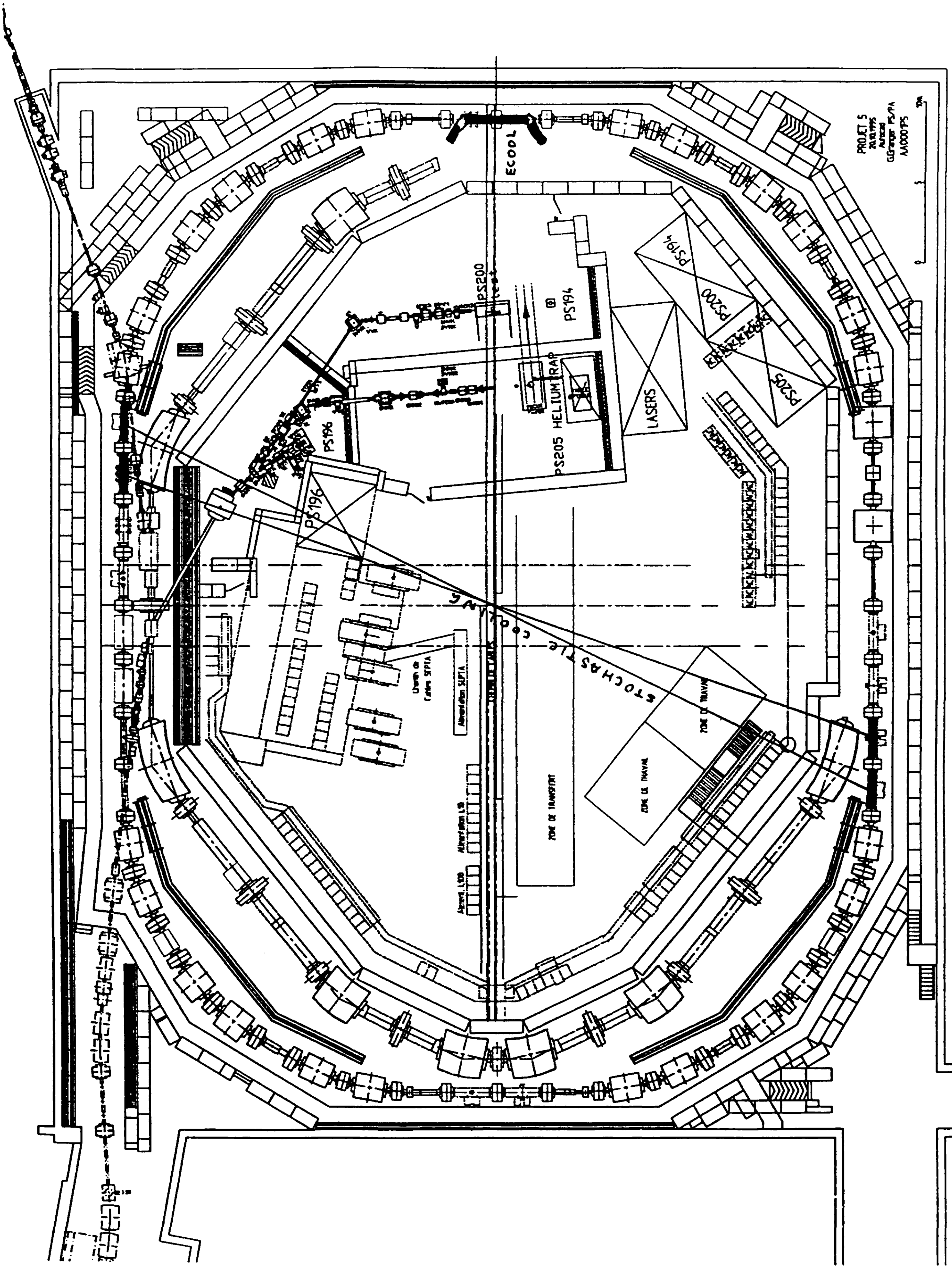

Fig. 1: AD Layout in building 193

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

	STOCHASTIC COOLING					ELECTRON COOLING				
p [GeV/c]	ε_i [π mm·rad]	ε_f	$\Delta p/p_i$ [%]	$\Delta p/p_f$	t [s]	ε_i [π mm·rad]	ε_f	$\Delta p/p_i$ [%]	$\Delta p/p_f$	t [s]
3.5	200	5	1.5	0.1	20					
2.0	9	5	0.18	0.03	15					
0.3	33	10	0.2	0.1	20	33	2	0.2	0.1	6
0.1	30	7	0.3	0.1	40	6	1	0.3	0.01	1
0.1 bunched	–	–	-	-	-	6	1	0.3	0.1	1

The AC vacuum pressure is at present of the order of 3×10^{-9} Torr. The lifetime at low momenta would be very short, a few seconds at 100 MeV/c. An improvement of the vacuum by a large factor is necessary, in order to obtain a lifetime of the order of a few minutes.

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. If only stochastic cooling is used, about 10^7 $\bar{p}$ can be ejected in one bunch of ~2 μs length, or in several shorter bunches. The cycle time in this case is about two minutes. 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. As most time is spent at low momenta, the average electricity consumption is low.

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 at least 40 s of cooling for each injected batch. 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 [5], 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.

* 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

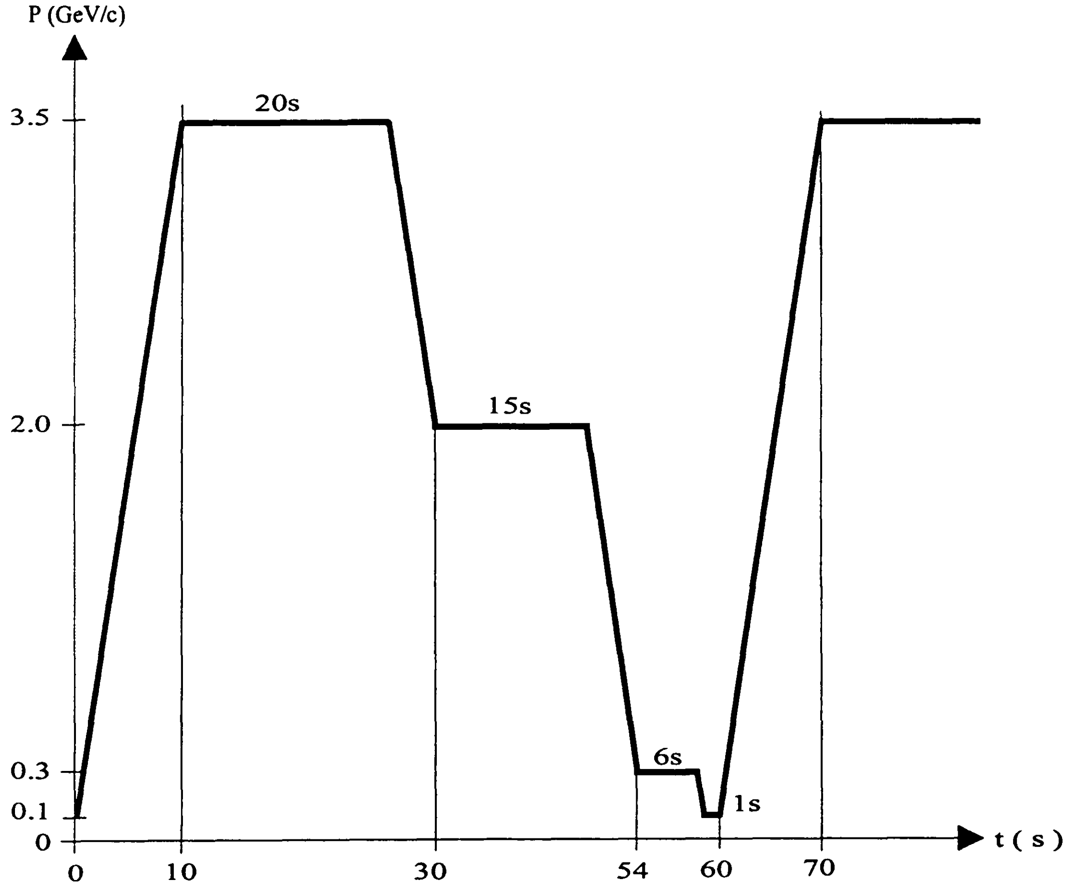

Fig. 2

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, similar to the present one [6]. 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 [7]. 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 will be retained to permit the shortest possible cycle time in the single pulse mode. In accumulation mode, the bunch rotation cannot be used as it would blow up the already circulating antiprotons.

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 – 1.59 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,
- 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

3.4.1. Normal cycle

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 (about 10 s) would not be significant and space is needed for the electron cooling system.

For use at 3.5 GeV/c there will be no modification except for electronically controlled variable attenuators for the longitudinal and transverse cooling systems and phase shifters (new dynamic phase compensators) for the transverse systems. They should allow continuous adjustment of optimum conditions and thus reduce the cooling time.

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.

3.4.2. Stacking option

For the accumulation option, the rf system for the bunch rotation has to be replaced by stochastic precooling of the large momentum spread. This can be realized by an extension of the present system. The modification consists essentially in disabling the notch filter of the band I momentum cooling and placing an inverter in the signal transmission path. Preliminary tests have shown that in this way a $\Delta p/p$ reduction from 6% to 1.5% can be achieved in 20 seconds. Thereafter the usual cooling takes another ~20 s to merge particles with the stack and reduce $\Delta p/p$ to 0.1% before bunching and injecting of a new pulse.

3.5 Electron Cooling

Electron cooling will be applied at low momenta, especially at 300 and 100 MeV/c (Fig. 2). 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. The expected performances are given in table 2.

To accumulate lead ions for the LHC, a strong cooling device is needed. It is foreseen to construct a "state-of- the-art" cooler (in about 1999) for this purpose. The series of experiments on LEAR to test ion accumulation will be finished in 1997, in time to allow the transfer of the present cooling system.

Table 2 - Characteristics of the cooler

Antiproton momentum, p	[MeV/c]	300	200	100
Cooling length, L_{cool}	[m]	2.2	2.2	2.2
L_{cool}/circumference, η_c		0.0116	0.0116	0.0116
Electron energy, U_{ecin}	[keV]	25.48	11.48	2.894
Electron current, I_e	[A]	3.5	1	0.5 (0.1)
Perveance of electron beam, p_g	[10^{-6} $AV^{-3/2}$]	0.58	0.77	2.6 (0.52)
Electron beam radius	[mm]	25	25	25
Space charge potential U_{Sp}	[kV]	1.034	0.432	424.6
Cathode voltage, U_{cath}	[kV]	26.52	11.911	3.318
Betatron functions at cooler, β_{HV}	[m]	6.0	6.0	6.0
Initial, final emittances ε_i, ε_f	[π mm·mrad]	40, 10	20, 5	15, 1
Cooling time constant, τ_c	[s]	3.7	0.6	0.05 (0.3)
Total cooling time, t_c	[s]	6.0	0.9	0.14 (0.7)

3.5.1. Implementation

The cooler will be located in a straight section (Fig. 1) where the dispersion of the orbit (D) is zero. The insertion of the electron cooler induces perturbations to the antiproton beam:

- a closed orbit distortion due to kicks induced by the toroids ,
- coupling of the horizontal and vertical betatron motion due to the solenoid,
- a tune shift due to the electron beam and residual coupling from the solenoid

We propose to re-mount the LEAR cooler in an U-shaped arrangement (where gun and collector point to the same side). This has advantages for the electron optics but needs a more elaborate compensation scheme. However, the present LEAR correction dipoles are perfectly suited for this compensation.

Horizontal-vertical coupling will be compensated by the same type of solenoids installed on LEAR. They will be connected in series with the main solenoid.

The tune shift due to the electron beam is in the order of 10^{-3} and therefore does not require any special form of compensation.

3.5.2. Lattice modification

To provide a longer straight section for the cooler, an insertion i.e. a local modification of the AC lattice has been studied. Results indicate that it is possible to obtain a sufficient free space to accommodate a device with a cooling length of 3 m and optical properties well suited for electron cooling (increase of $\beta_{H,V}$ from 6 to 10 m). If necessary, these modifications could be installed to reduce the cooling time even further.

3.6 Experimental Area

3.6.1. Experiments in the AD hall at low momenta with fast extraction

The beam lines in the South Hall will be dismantled and remounted in the AD hall. The housing of the four experiments (PS205, PS200, PS194 and PS196) for low momenta in the AD hall is geographically feasible [11] (Fig. 1.). The difference of beam height between LEAR and AD does not cause a problem since most of the equipment has adjustable supports. PS205 is positioned on rails such that it is possible to roll it downstream of PS200 for data taking when the latter is not working.

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,
- 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, and future removal of the heavier sections (concrete beams of 17 m × 1.5 m × 0.5 m of weight 37 t) would be difficult and hazardous.

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.

The second layer of roof shielding, and any extra side shielding can be made from existing blocks and beams. The existing shielding above stochastic cooling kickers can be retained, the first layer of roof shielding will require a series of reinforced concrete beams. These beams would be made of standard section (80 cm × 80 cm) with various lengths to suit the proposed configuration.

3.6.3. Gas distribution

The gas installation is made on the assumption that inert gases (Ar, N_2, CO_2, He) can be stored and distributed from within the hall.

As much of the present distribution system as possible that is used in the South Hall will be transferred and re-adapted to the experiments in their new location.

Flammable gases must nonetheless be stored in specific conditions on the outside of the building. This means that a suitable storage shed be constructed in the area adjacent to the cooling tower. Such a siting would facilitate delivery of the gas bottles.

3.6.4. Civil and structural engineering

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. This platform would be of a simple but sturdy steel construction.

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

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. Two conditions have been studied:

3.7.1. Injection of protons at 3.5 GeV/c for beam tests into the AD ring via the loop

Assuming that 3×10^{10} protons per 2.4 s may enter the AD ring through the TTL2 loop, a side and roof shield of 3.4 m of concrete would be needed to keep the dose rate due to local full loss of the beam below 25 μSv/h. Assuming local losses to be below 10% will still require a roof and side shield of 2.4 m thickness. In the forward direction, which concerns the outer shield of the ring, the shielding needed would be at least 4 m of concrete.

In order to limit the amount of shielding necessary it is therefore recommended not to allow access to the hall during operation with protons.

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. On average the intensity was

1.7 pulses/14.4 s. Since future operation will be at 1 pulse/minute the average dose rates measured now have to be divided by 7.3 to arrive at the expected rates in this area. One can then expect dose equivalent rates of up to 12 μSv/h. This is 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.

As in all PS areas, radiation dectectors are needed to monitor the radiation level and produce an alarm in case unexpected levels are encountered.

3.7.3. Access

There are two operation modes:

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

During the setting-up, 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.

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 different effects of the residual gas important at low energy are:

- losses due to the single Coulomb scattering (with an angle larger than the acceptance),
- blow-up of the beam emittance due to the multiple Coulomb scattering.

Both the loss and the blow-up per unit time scale with beam momentum as $(p^2\beta)^{-1}$ and thus become very important at low momenta.

At present, the single scattering lifetime in the AC is in the order of 20 h. Scaled to 100 MeV/c, this would yield a lifetime of only 5 s. Thus a large improvement of a vacuum pressure is necessary to obtain a lifetime in the order of a minute. The influence of multiple Coulomb scattering can be estimated using Hardt's formula [8]. This leads to a heating rate of the emittance $d\varepsilon/dt|_{MS} \cong 10\pi$ mm·mrad/s at 100 MeV/c assuming a nitrogen equivalent pressure of 3×10^{-9} Torr as in the "present AC". Again a large improvement is desirable to obtain a small equilibrium emittance

$$\varepsilon_{eq} = \left.\frac{d\varepsilon}{dt}\right|_{MS} \tau$$

where $\tau \sim 1$ s is the cooling time constant.

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. The present precision of the power supplies is listed in Table 3

Table 3 - Present $\Delta I/I$ precision of the power supplies

Power supplies	3.5 GeV/c	100 MeV/c
Bending	$\sim 10^{-4}$	10^{-3}
Quadrupole	2×10^{-4}	$\sim 3 \times 10^{-3}$
Trimming (B+Q)	10^{-3}	10^{-2}

Some of the 30 power supplies used at low energy for the experiments will be placed in the hall and the remainder in the equipment room close to the AAC control room.

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. The CO exploitation team will take care of AD controls as it does for the other machines of the PS complex.

In order to simplify the conversion to the new control system, some of the existing programs could be used as a base for writing new applications. As considerable effort has been invested in the current AC setting-up and measurement programs, conserving the experience accumulated in these programs could significantly reduce the effort to get the new software working. The programs concerned are mainly those that will be used for setting-up at 3.5 GeV/c and static control of equipment. A new set of application software is required for deceleration, electron cooling and ejection.

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. Although some CAMAC hardware maybe maintained, most of the systems will have to be converted to VME, with concurrent investments in new specific hardware and software. The new application programs will use the concepts of the present, highly evolved application codes, to minimize effort and to maintain the high level of information treatment..

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. The important data are shown in Table 4 and a simulated kick waveform is given in Fig. 3.

Table 4 - Parameters for the AD 100 MeV/c ejection kicker

Kick strength $\int Bdl$	[Tm]	0.00328
Deflection θ	[mrad]	9.84
Kick flat top duration	[ns]	variable 0-500
Flat-top ripple	[%]	±1
Kick rise time (10-90%)	[ns]	~93
Kick fall time (90-10%)	[ns]	~93
Number of pulse generators/magnets		1
Pulse generator Pfn voltage	[kV]	13.4
Magnet tank position		K50.2

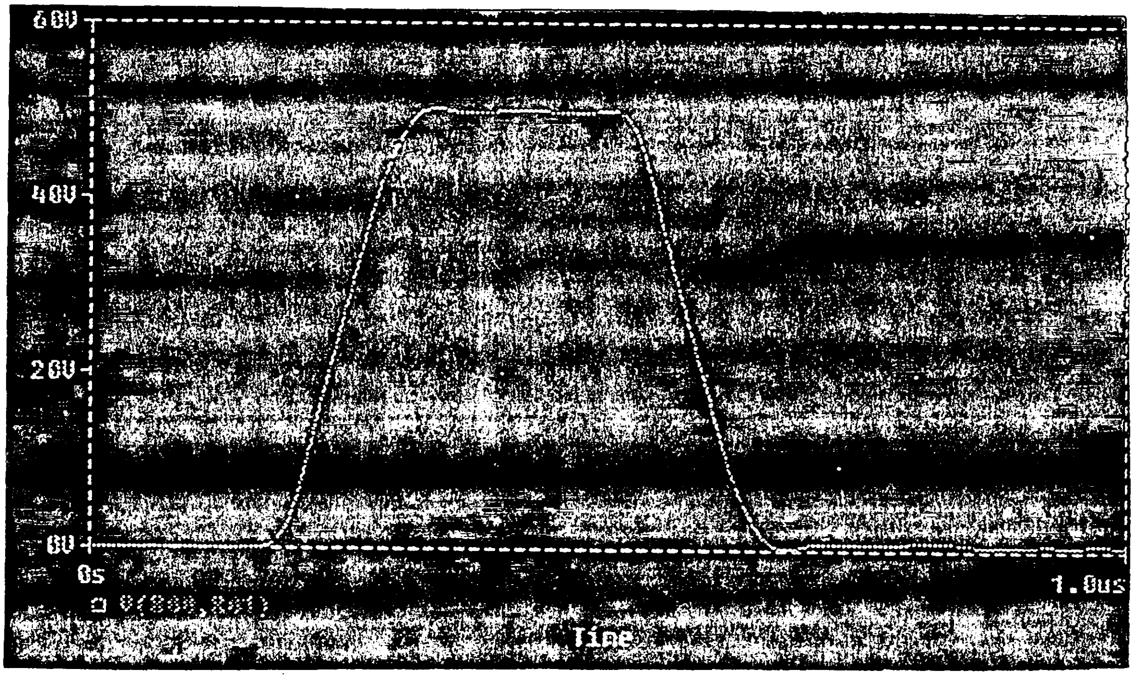

Fig. 3 - Calculated kick waveform

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 kickers will be available for this operation; however, there is just enough kick strength with those remaining modules. The parameters for this operation are given in Table 5.

Table 5 - Parameters for the AD 3.5 GeV/c proton injection kicker

Kick strength $\int Bdl$	[Tm]	0.1173
Deflection θ	[mrad]	9.84
Kick flat top duration	[ns]	variable 0-500
Flat-top ripple	[%]	±1
Kick rise time (10-90%)	[ns]	~207
Kick fall time (90-10%)	[ns]	~207
Number of pulse generators/magnets		3
Pulse generator Pfn voltage	[kV]	74.3
Magnet tank position		K35-1, K35-2, K50-1

3.13 Water Cooling

As the AA is not running, the activity of the cooling tower is reduced in spite of the requirements of the experiments. A minor consolidation of this old installation is needed.

3.14 Operation

3.14.1. 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 also 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. 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.

4. SLOW EXTRACTION OPTION

As an option, slow extraction has been studied for the experiment PS197 (Crystal Barrel, Fig. 4).

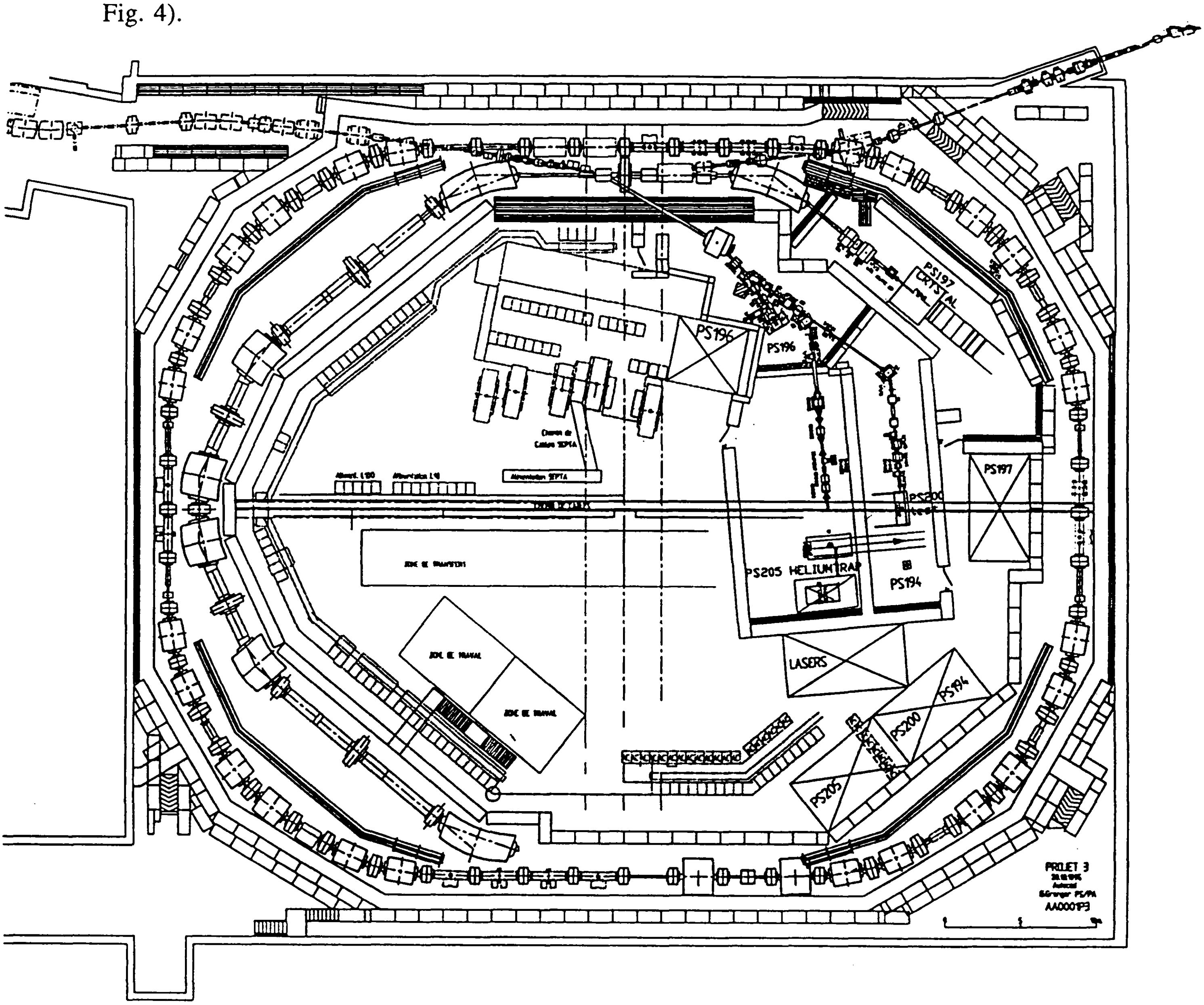

Fig. 4 - AD layout with PS197

A reasonable goal could be to extract some 10^7 antiprotons from the AD at a rate up to 10^5 $\bar{p}$/s leading to a slow extraction of 100 to 300 s. A stochastic extraction of the LEAR type [10] is envisaged as it gives a good duty factor (very small ripple on the extracted flux). The resonance $3Q_H = 17$ can be used without modifying too much the AC machine optics. To get the smallest possible beam emittance the technique of separatrix alignment is used.

The smallest kick of the electrostatic system is required when the alignment of separatrix is obtained at the magnetic septum. But in the AD, this condition cannot be fulfilled due to the lack of space and the presence of bending magnets between the two septa. The present pulsed magnetic septum cannot be used, a dc one should be built together with the electrostatic septum needed for slow extraction. A possible location for the electrostatic septum is the short section 47. Using the lattice functions at this septum, as well as a chromaticity of 0.6, particles have been tracked around the machine (Fig. 5). A kick of 6 mrad at the electrostatic septum gives a separation of 6 mm at the magnetic septum. But the place which is left for the circulating beam is very small. As there is no dispersion at the magnetic septum, we cannot profit from particle acceleration ($\delta p/p \sim 4 \times 10^{-3}$) to separate the particles at the resonance from the particles in the stack. Thus the extraction efficiency would be very poor.

Another scheme which should permit a good extraction at momenta lower than 2.2 GeV/c is based on the use of an electrostatic and 2 magnetic septa:

- A 1.5 m long bakeable electrostatic septum with 80 kV for a 10 mm gap is used.
- An additional 1.5 m long, ~2 mm thickness magnetic septum is installed. It provides 11 mm separation at the next magnetic septum.
- A dc magnetic septum outside the vacuum chamber provides a field of about 0.65 T. The AA septum magnet could be used for this purpose.

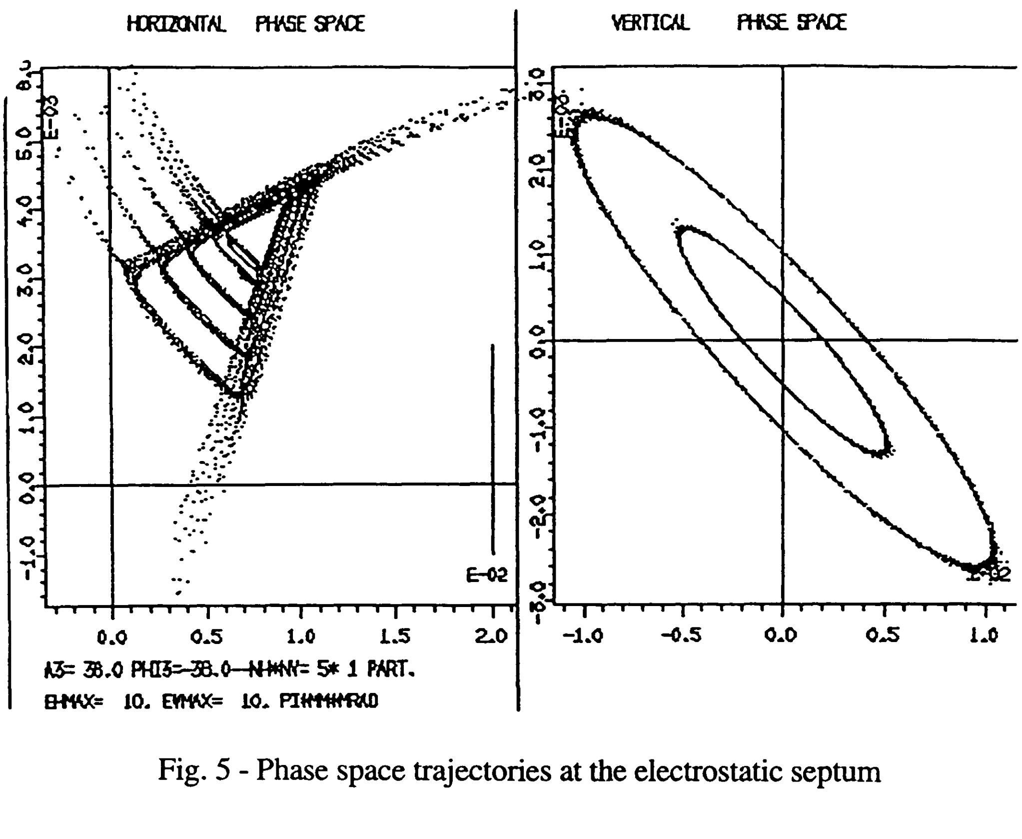

Fig. 5 - Phase space trajectories at the electrostatic septum

This scheme implies that the present ejection line has to be modified. So a detailed study should be done.

Other studies and items are necessary for slow extraction must include:

- Search for a better optics to ease the extraction.
- Further vacuum upgrade to improve the beam lifetime.
- Dipoles and power supplies for the bumps at the magnetic septum.
- A longitudinal kicker with its ceramic vacuum chamber and the associated stochastic noise generation equipment.
- The pulsed power supplies in the ejection line should be replaced by dc power supplies.
- Sextupoles to control the chromaticity, to excite the $3Q_H = 17$ resonance and to avoid non-linearities intrinsic to sextupoles.
- Stochastic cooling systems at low energies.

The housing of PS197 in the AD Hall is feasible in principle but in this case a quarter of the AA ring has to be dismantled to free the space for the transfer line and the experimental set-up [11]. The height of axis of the spectrometer is 1.6 m while the AD ring stands at 1.2 m. As there is not sufficient space available to install two vertical bending magnets, an excavation of a floor is required.

5. CONCLUSION

The use of the AC as an antiproton decelerator appears feasible and can open the possibility for a new antiproton physics programme based on fast extracted beams.

Slow extraction is more difficult and needs further study. It is an option which could be added later.

ACKNOWLEDGEMENTS

As one can see from the long list of authors, many hardware and accelerator specialists have contributed to this feasibility study. The precious advice received from J. Buttkus, G. Granger, A. Krusche, M. Le Gras, R. Ley, J.P. Potier, and M. Paoluzzi is gratefully acknowledged.

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