THE CERN ANTIPROTON ACCUMULATOR COMPLEX (AAC):
CURRENT STATUS AND OPERATION FOR THE NINETIES

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ABSTRACT

The AAC has evolved from the one-ring Accumulator in the early eighties to the Complex of Collector and Accumulator rings supplying antiprotons to both the SppS Collider and LEAR since 1987. This has culminated in the final high-luminosity physics run for the experiments at the Collider in 1990. The Collider run in 1990 ended with over 7.2 inverse picobarns in integrated luminosity, almost twice the combined total of two previous years 1988-89 and with LEAR physics also receiving an order of magnitude increase in the antiproton flux compared to the early eighties. This paper reviews the activities in the AAC for the last major dual-client run for the Collider and LEAR and elucidates the plans for the single-client (LEAR) operations for the future. Some of these activities included the successful exploitation of a larger diameter (34 mm) lithium lens in the production chain, economical production and supply of antiprotons in a novel energy saving mode of operation and the complete renewal of operation consoles by modern hardware and software for assured maintenance. For the future single-client runs, it is foreseen to trade-off peak performance with sustained reliability, using the magnetic horn as a collecting lens after the target.

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ABSTRACT
The AAC has evolved from the one ring Accumulator in the early eighties to the Complex of Collector and Accumulator rings supplying antiprotons to both the SPS Collider and LEAR since 1987. This has culminated in the final high-luminosity physics runs in 1990 and the experiments at the Collider in 1990. The Collider run in 1990 ended with over 7.2 inverse picobarns in integrated luminosity, almost twice the combined total of two previous years 1988-89 and with LEAR physics also receiving an order of magnitude increase in the \( \bar{p} \) flux compared to the early eighties. This paper reviews the activities in the AAC for the last major dual-client run for the Collider at LEAR and elucidates the plans for the single-client (LEAR) operations for the future. Some of these activities included the successful exploitation of a larger diameter (34 mm) lithium lens in the production chain, economical production and supply of antiprotons in a novel energy saving mode of operation and the complete renewal of operation consoles by modern hardware and software for assured maintenance. For the future single-client runs, it is foreseen to trade-off peak performance with sustained reliability, using the magnetic horn as a collecting lens after the target.

1 INTRODUCTION
The CERN AA, ACOL project and the \( \bar{p}p \) facility has been the subject of many papers [1-5] and the performance of the \( \bar{p} \) production, collection and accumulation facility has also been subject of other publications [6,7]. This paper reviews the current status and operation of the latter, with particular emphasis on the dedicated operation for the LEAR facility. The last high-luminosity Collider run for the UA2 experiment ended in 1990 with the AAC supplying \( \bar{p} \)s sufficiently and regularly to achieve 7.2 inverse picobarns of luminosity in the Collider, working in the mode of 6 batches of \( p \)s colliding against six batches of \( \bar{p} \)s. The 1991 run was planned to be a low-luminosity run for the UA4 elastic scattering experiment, with three batches of protons colliding against three \( \bar{p} \) batches and with matched and reduced intensities per batch of around \( 10^{11} \) particles. Figure 1 illustrates the progression in luminosity during the run in 1990, as seen by the UA2 experiment, while Fig 2 illustrates the same for the number of elastic events recorded at UA4 in 1991. The AAC typically operates for around 6000 h per year. For most of the year in 1990 and in 1991, LEAR was the main client with different experiments in the LEAR experiment hall being the ultimate users. However, for an intensive period of three months, the AAC had to supply beams to the Collider as well as LEAR; in this period, sufficient production has to be maintained, needing a clear-peak performance of the AAC. The PS normally supplies 750 \( \bar{p} \) production cycles of 26 GeV/c \( p \)s per hour.

This permits the AA to arrive at increasing accumulated beams (around \( 9 \times 10^{11} \) to \( 10^{12} \)) daily. The LEAR physics typically took 15% to 20% of the daily production while the Collider took the rest. This mode of running since the beginning of ACOL in 1987 demanded a consolidated performance as tabulated in Ref. [7]. Overall for the year 1991, the SPS Collider ran only for a reduced number of weeks in a low luminosity mode; this resulted in the annual distribution of \( \bar{p} \)s of around 31% for the SPS and 40% for LEAR, the remaining 29% attributable to losses, excess production and machine experiments.

![Integrated Luminosity as seen at UA2](image)

Fig. 1 - Integrated Luminosity as seen at UA2

2 ANTIPROTON PRODUCTION AND YIELDS
For the 1991 joint Collider-LEAR run with medium to low luminosity needed at the Collider, a reduced performance was permissible, facilitating the use of a 400 kA magnetic horn as a collector lens after the target instead of a 20 mm or a 34 mm diameter lithium lens used in previous joint runs. The costs, engineering, long-term maintenance and reliability aspects of Li lens impose much more constraints than the classical horn collector lenses [8]. The 34 mm diameter Li lens was made with a stronger steel container, hence the reduction in diameter from the calculated 36 mm diameter lens; the latter has the potential of a substantial increase (25%) in yields over the 20 mm Li lens when pulsed at 1.3 MA but, had container failures in laboratory life tests in 1989. Yield here is defined as the number of \( \bar{p} \)s measured on the injection orbit of the AC ring per incident 26 GeV/c protons striking the production target. While the reduced diameter increased the operational reliability of the 34 mm lens, it decreased the effectiveness of cooling and consequently reduced the maximum current the lens could support in the solid lithium region to about 1 MA. It is for this
reason that the 34 mm lens registered only a small increase in yields (around 6-7%). Table 1 gives the operational yields achieved with these three collector lenses, averaged over several months in operation. The yield figures are somewhat dependent on the primary production beam and a slight yield degradation has been systematically observed for high-intensity (1.6x10^{13}) production beam instead of the nominal 10^{13} protons on target.

![Progression of the number of elastic events recorded at UA4 in 1991](image)

**Fig. 2 - Progression of the number of elastic events recorded at UA4 in 1991**

<table>
<thead>
<tr>
<th>Lens Configuration</th>
<th>Yield (10^{-7})</th>
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<tbody>
<tr>
<td>20 mm Ø Li Lens (1989)</td>
<td>53</td>
</tr>
<tr>
<td>34 mm Ø Li Lens at 1 MA (Sept-Dec 1990)</td>
<td>56</td>
</tr>
<tr>
<td>400 kA horn (April-Dec 1991)</td>
<td>46</td>
</tr>
</tbody>
</table>

Table 1. Operational yields with 1.5 x 10^{13} protons on target

The 400 kA horn collectors (1 mm thick, 60 mm diameter) have been subject to several laboratory and development tests. It has been observed that these devices in the laboratory have been operating very close to their fatigue limits with recurring mechanical failures. For this reason, the development of another horn (1.4 mm thick) has taken place with improved cooling. One such device has been subject to laboratory tests and has been put into operation in May 1992. Preliminary results so far show that this horn, pulsed at around 400 kA performs at least as well as the previous, 1 mm thick version and further laboratory tests still need to be done.

Finally, it should be mentioned that during a week of machine experiments and beam tests in May 1992, the plasma lens [9] has also produced yields comparable to the 60 mm collector horns. Unlike the 1991 tests, the 1992 beam tests included high-intensity (1.2x10^{19}) proton beams on target and corresponding yield measurements. Figure 3 summarizes the yields of all the collector lenses after target as a function of the proton intensities striking the target.

3 THE AC AND AA RINGS

The AC and AA rings have had fairly stable operation since 1990. No major changes have been carried out; however, the different stochastic cooling systems need a constant surveillance, maintenance and adjustments at the level of detailed hardware. A somewhat reduced contribution to the overall core cooling performance has been observed near the top range of frequencies (6-8 GHz); therefore, the 4-8 GHz range has been extended downwards operationally to cover the 2-8 GHz spectral bands. For the core systems, common mode problems have been observed at stacks above 3x10^{11} P's, implying misalignment of the pickup with respect to the beam; this has significant effects at larger values of stacks (over 7x10^{11} P's) needing orbit-position corrections within the pickup using the main magnet trim power supply. The solid-state power amplifiers for the AC ring stochastic cooling have been operating since 1987 with no major problems and augur well for such large-scale (7 kW installed CW sine-wave power) installation. Overall, the current performance of the AAC complex has been limited to maximum stacks of around 1x10^{12} P's, with curtailed rates in storage when one exceeds 7 to 8x10^{11} particles in the core and needing fine working point adjustments.

4 ENERGY SAVING OPERATION MODES

Depending on the ultimate LEAR physics clients, the P flux needed at LEAR extraction varies from a few 10^{9} P's to a few 10^{10} P's every few hours. The PS functions in an interleaved mode with varying number of cycles for P production and other cycles used for physics at SPS, LEPI or for the PS Experimental Area. Often, it has been found judicious to stack with a maximum number of PS production cycles, filling the AA stack to over 5x10^{11} P's in as short a time as possible. After this, the accumulation process is stopped and the AC ring is switched off, saving around 4 MW of power. The P delivery to the PS and LEAR would of course continue from the AA stack while the PS production cycles are either converted to other use or put in standby mode, further increasing the power savings. This mode of operation has been particularly useful for the long LEAR-only physics runs with minimal changes in

![Yields vs. Intensity for different Collector lenses](image)

**Fig. 3 - Yields vs. Intensity for different Collector lenses**

![Economy mode LEAR deliveries from AAC](image)

**Fig. 4 - Economy mode LEAR deliveries from AAC**
LEAR extraction or energies. In 1991, of the total 6300 h of operation of the AAC, around 2500 h were accounted for by this energy-saving, economy mode of operation. Figure 4 shows the regular LEAR deliveries from the AA in this mode of operation.

5 DIAGNOSTIC SYSTEMS

The beam diagnostics systems have continued to be fully exploited for the day to day running of the AAC. In particular, the real-time π efficiencies and momentum distribution via spectral analyses of Schottky signals have been heavily relied upon. Using a commercial, dynamic signal analyser, a new suite of programs running directly on the AAC front-end Norsk Data computer have been developed. These give a real-time snapshot of the performance of the AAC complex from π's injected into the AC ring up to the final number of π's arriving and adding to the accumulated stack core in the AA, i.e. a complete check of the performance (averaged over ten beam pulses for each point of measurement) from the AC injection, after the rf bunch rotation in the AC, after the completion of the cooling processes in the AC (nine systems), rf bucket-to-bucket capture and beam transfer from the AC to the AA and finally, through the stages of precociling and stack tail systems in the AA before arriving in the stack core. Figure 5 illustrates a typical performance check output.

Fig. 5 - AAC Performance Snapshot

6 OPERATION CONSOLES

With ageing hardware and expensive maintenance and repair possibilities, the AAC touch terminal operation consoles are being upgraded to modern workstations. With significant amount of high level, operational application software developed over 10 years, the philosophy adopted was to attempt a true and total emulation of console functions like toch actions, graphics display and simple keyboard interaction onto a multiple-windows workstation [10]. Within the usual accelerator shutdown constraints, planned hardware maintenance and budget profiles over several years, the true emulation environment has provided a significant bonus in permitting multivendor, modern hardware and software to be successfully introduced, in parallel with operation as well as the graceful decommissioning of the existing consoles.

7 CURRENT NEEDS

The AAC operates in the single-client (LEAR) mode since the beginning of 1992, the Spps Collider physics programme having come to an end in December 1991. For this type of operation, it is no longer necessary to maintain a peak performance in π production, collection and storage except when special circumstances impose it. In fact, the 1991 Spps Collider run, in conjunction with LEAR, already saw the beginning of a new era whereby daily stacking rates of 5 x 10^11 π's (in 18 h or so) were sufficient to supply both the SPS and LEAR. A sustained storage rate of 10^11 π's in 3 h was amply achieved using the full complement of 750 SPS production cycles per hour and with the 400 kA horn as a collector lens after the target. Specifically, it was not necessary to use the higher yielding Li lens of 20 mm or 34 mm in diameter, nor the highest possible intensities in the PS production beam striking the target. This scenario (with the horn as a collector lens and 1.4 x 10^13 π's on target) gave an overall system performance of around 70% of the performance with the previous year's scenario, i.e. 34 mm diameter Li lens and 1.6 x 10^13 π's on target, together with all systems in the AC and AA driven to the limits of performance.

ACKNOWLEDGEMENTS

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REFERENCES