HIGH LUMINOSITY PERFORMANCE OF THE SPS PROTON-ANTIPROTON COLLIDER

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Introduction

In September 1988, the CERN SPS collider was brought into operation for the first physics production run with the improved antiproton production and accumulation complex (AAC). The increased antiproton flux immediately resulted in a considerable improvement in the machine performance with initial luminosties exceeding $2.4 * 10^{30}$ cm^{-2} s^{-1} and weekly integrated luminosties an order of magnitude greater than achieved in the past. In this paper, performance statistics and operational experience in this new regime are discussed.

Description of Operation

During the years 1981 to 1987, the CERN SPS was used as a proton-antiproton collider, providing high energy collisions for two major experiments located in adjacent sextants of the accelerator. This operation was almost always with three dense bunches of protons in collision with three rather weak bunches of antiprotons, with no separation of the beams at the unused crossing points.

Towards the end of this period and during early 1988, the CERN antiproton complex upgrade was completed and now provides significantly more antiprotons [1]. In 1988 the available stack of antiprotons in the accumulation machine was normally between 4 and $7 * 10^{11}$ particles, reaching a maximum of $8.5 * 10^{11}$, compared with the previous best stack before the upgradeof $4.5 * 10^{11}$. Furthermore, the average accumulation rate was about $3.3 * 10^{10}$ particles per hour, with a maximum rate of over $3.8 * 10^{10}$, compared with $1.2 * 10^{10}$ achieved previously.

To make best use of this increased supply of antiprotons, the number of bunches of both protons and antiprotons injected into the collider was in 1988 increased to six.

After optimisation of the injection cycle with protons and low intensity antiproton pilots, the filling sequence is as follows. First, six bunches of 26 GeV protons, fabricated in the CERN PS complex, are injected into the SPS at 2.4 second intervals, such that they are equally spaced around the circumference of the accelerator. Six bunches of antiprotons are then extracted from the antiproton stack, again at 2.4 second intervals, and injected via the PS into the collider. The timing of these antiproton injections is carefully set to ensure that collisions will occur in the centre of the experiments.

With twelve bunch crossings per turn of the machine, beam-beam effects make it necessary to separate the beams in order to accommodate the particles in betatron tune space [2]. During the injection of the twelve bunches, the proton and antiproton bunches are electrostatically separated in the horizontal plane at all crossing points around the ring using one of the three available seperators.

Immediately after the last antiproton injection the two beams are accelerated to an energy of 315 GeV. During the first two seconds at 315 GeV, the beta functions (which were detuned for the injection) are squeezed down to their final values of 1 m horizontally, 0.5 m vertically. The collider then passes into storage, and the two other separators are activated, to achieve separation at the unused crossing points away from the experiments.

The whole process of injection, acceleration and beta function squeezing is achieved in a 43.2 second cycle, see Figure 1, and the coast separation scheme takes a further few seconds to complete. The experiments can then raise the magnetic fields in the detectors, and data taking normally starts within a few minutes.

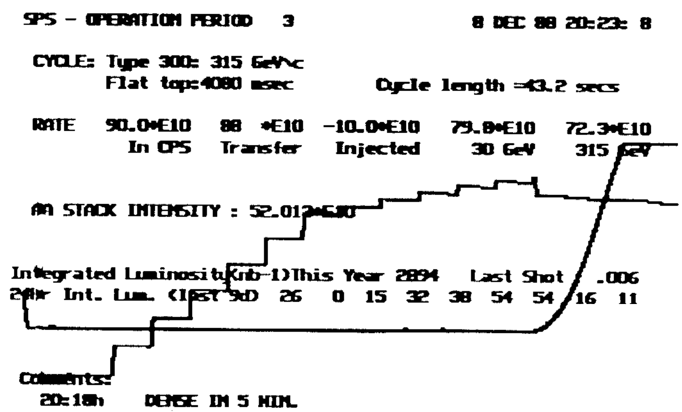

Figure 1: The Injection Sequence of the SPS Collider

Filling the collider typically consumes about 70% of the accumulated antiprotons; the SPS then remains in storage for around fifteen hours of physics data-taking while the antiproton facility replenishes the stack ready for the next fill.

Performance of the Collider

Protons

The CERN PS, is capable of producing proton bunches of up to $2 * 10^{11}$ particles with a longitudinal emittance of 0.5 eV.s. Typical operational practice is to take bunches of 1.6 to $1.7 * 10^{11}$ particles, with a normalised transverse emittance between 10 and 12 pi.mm.mrad. This results in an intensity in storage in the SPS of between 1 and $1.1 * 10^{11}$, with good transverse emittance conservation.

Antiprotons

From a typical antiproton stack of $5.5 * 10^{11}$ particles, six bunches of about $6 * 10^{10}$ are extracted and accelerated to 26 GeV in the PS with only a few percent loss. These bunches have the same longitudinal emittance as the protons, 0.5 eV.s, and a normalised transverse emittance of 6 to 8 pi.mm.mrad. By the time they are in storage in the SPS, the intensity of such antiproton bunches has fallen to $4 * 10^{10}$, again with a good conservation of transverse emittance. Losses caused by the beam-beam interaction are observed for protons as well as for antiprotons, which is not surprising since both single-beam and beam-beam effects are now of comparable order for both beams.

Luminosity

The intensities and emittances in storage quoted, result in an initial luminosity of order 1.5 * 10^{30} cm^{-2} s^{-1}, and this was typical of many collider stores in 1988.

The following table summarises the important parameters and performances during 1988 in comparison with the previous most productive year of the collider, 1985.

Table

		1985	1988
Energy	(GeV)	315	315
Horizontal beta function	(m)	1.0	1.0
Vertical beta function	(m)	0.5	0.5
Number of bunches		3*3	6*6
Separation		no	yes
Protons per bunch	(10^{10})	16	11
Antiprotons per bunch	(10^{10})	2	4
Proton trans. emittances	(pi.mm.mrad)	23	11
Antiproton trans. emittances	(pi.mm.mrad)	12	7
Initial luminosity	(10^{30} cm^{-2} s^{-1})		
Peak		0.4	2.5
Average		0.13	1.3
Integrated luminosity	(nb^{-1})		
Year		655	3375
Peak per store		23	71
Peak per week		77	480
Average per store		8.2	31.5

Figure 2 shows a typical period of operation and gives the initial and integrated luminosity per store. The initial luminosity is a function of the number of antiprotons in the accumulator and the efficiency of transfer down the injection chain. Under optimum conditions, more than 70% of the antiprotons that left the accumulator arrive in the Collider at 315 GeV after squeezing and separation (see figure 3).

The luminosity lifetime, which was around 20 hours in previous years, was only about 8 hours at the start of a store. Higher local densities of both beams, coming from the smaller transverse emittances and the higher antiproton intensities, are responsible for the low lifetime through the mechanism of intrabeam scattering.

Nonetheless, a fifteen hour store with these luminosity conditions resulted in an integrated luminosity for the store of around 40 inverse nanobarns (40 *10^{33} cm^{-2}).

In the 100 days scheduled for Collider operation in 1988, 55% of the time was spent with colliding beams. There were 107 stores with an average duration of 12.4 hours. This latter figure was determined by the lower luminosity lifetime compared to the 3 bunch mode of operation. Twenty-five stores were terminated prematurely by equipment failures. The integrated and maximum initial luminosity per week, in 1988, are shown in figure 4.

Prior to the introduction of 6 bunches of protons and antiprotons, the best initial luminosity was 4*10^{29}. In 1988 this figure was increased by a factor of 6 to 2.49 * 10^{30} within 4 weeks of the period. With this increase came a corresponding increase in integrated luminosity. The best weeks production was 480 inverse nanobarns, again a factor 6 increase on the previous best performance. The integrated luminosity per week decreased during the second part of the run, due mainly to the larger emittances of the antiproton bunches from the accumulator and interruptions in the electricity supply.

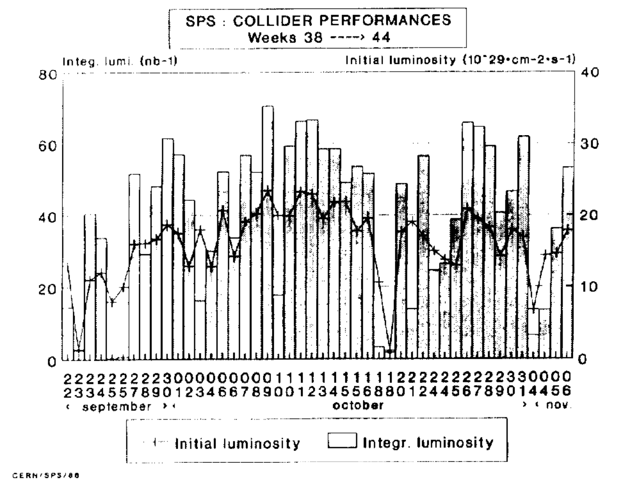

Figure 2: Collider performance 22 Sept-10 Nov 1988
Initial and Integrated Luminosity per store

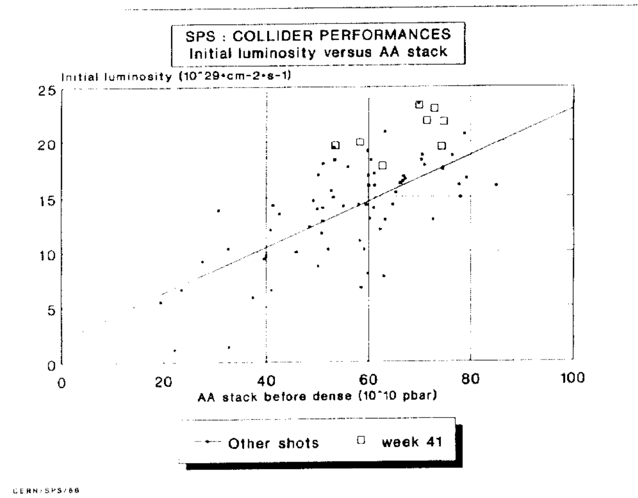

Figure 3: Initial Luminosity, and Transmission
as a function of the accumulator intensity

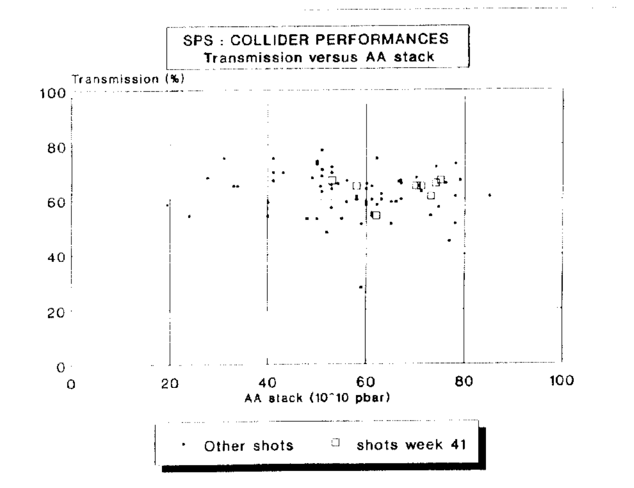

Figure 5 shows a comparison of the Collider performance in 1988 with previous years performance since the first operation for physics in 1981.The years 1986 and 1987 were the years devoted to the accumulator and detector upgrades. The production of 3375 nb^{-1} in 1988 should be compared with a total of about 1000 nb^{-1} in all the previous years.

Improvements for 1989

A 100 MHz RF system will be used in 1989, during capture and acceleration, to supplement the 200 MHz cavities used up to now. The tests in 1988 showed that the extra large bucket enabled the capture loss to be reduced to a few percent. Furthermore the SPS can then accept bunches with larger longitudinal emittance into the longer RF buckets. This has the desirable effect of reducing the local particle density, and so reduces the Laslett tune spread, giving more room for manoeuvre in the betatron tune diagram.Losses on the resonances will be reduced. This will ease the operational setting up.

The present separation scheme used during injection causes separation of the proton and antiproton bunches of between 1 and 7 sigma in the different crossing points. The variation is determined by the machine lattice. An improved separation at the crossing points with least separation would reduce both the beam-beam induced resonance strength and the magnitude of the beam-beam tune spreads. A new scheme will be brought into operation during the 1989 collider run.

In storage, extra 200 MHz cavities will be available to augment the longitudinal acceptance of the RF buckets. The local density can be reduced by creating bunches, both for protons and antiprotons, of larger longitudinal emittance, thus reducing the intrabeam scattering effect on the lifetime.

Summary

During 1988 the SPS collider has been operated in a routine manner to produce instantaneous luminosities of over $2 * 10^{30}$ cm^{-2} s^{-1}, with weekly integrated luminosities in excess of 300 inverse nanobarns. A total integrated luminosity of 3.4 inverse picobarns was produced, a factor of 5 greater than the best achieved in previous years.

The limitations on these values are understood and are dominated by effects arising from the higher local particle densities in both proton and antiproton bunches. There is scope for improvement both on the average integrated luminosity per store as well as a reduction in the time between stores.

By bringing into operation a new 100 MHz RF system in 1989, it is hoped to improve even further the performance of the collider without requiring fundamental changes to the accelerator.

Acknowledgements

The operation of the SPS collider complex demands the close collaboration between the operations teams, the equipment groups, the machine physicists and the experimental physicists for whom the machines are run.
The success of the operation in 1988 reflects the success of these close collaborations and those with the engineers and physicists of the AAC and PS complexes.
The authors would like to thank all the members of the operation, both in the SPS AAC and PS for their support in this venture. Thanks are due also to B. Desforges, G. Cultrut and P. Edwards for the production of the statistics and poster.

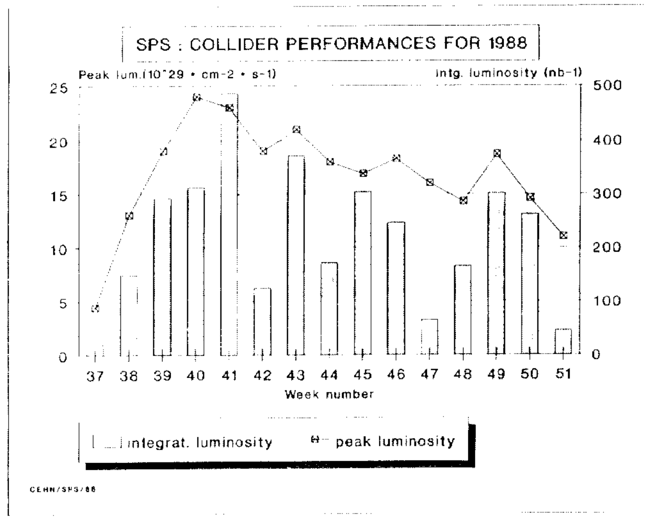

Figure 4: Collider Performance 1988
Weekly Integrated Luminosity and Peak Initial Luminosities

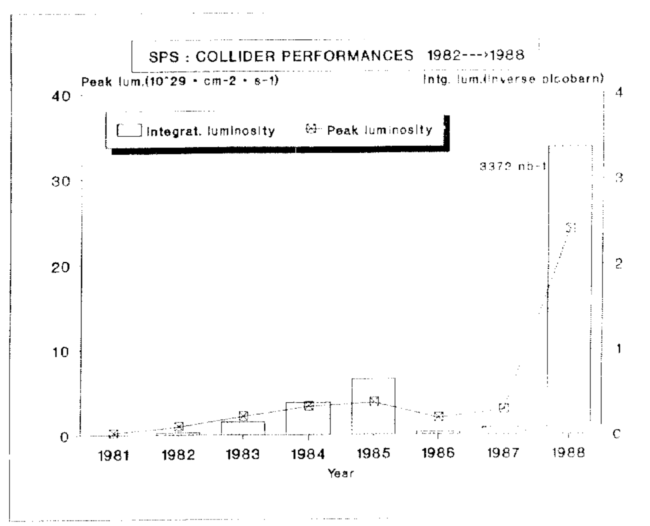

Figure 5: SPS Collider performance
Comparison of 1988 with previous years

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