THE CERN PS COMPLEX : A VERSATILE PARTICLE FACTORY

D.J. SIMON, for the PS Staff
CERN, Geneva, Switzerland

ABSTRACT

The CERN Proton Synchrotron started up in 1959, accelerating only protons from a 50 MeV Linac. Since then, it has evolved into a complex of nine machines, delivering in 1995 interleaved beams of protons, antiprotons, electrons, positrons and lead ions of various energies and intensities. It operates for about 7000 hours per year, sending beams to the SPS, to LEP via the SPS, and to four experimental facilities respectively supplied by the PSB, LEAR, LIL and the PS itself. Numerous original beam manipulation techniques are regularly applied and new ones are currently being implemented and tested to adapt the PS complex to its future role as the proton and ion injector for LHC. This paper summarizes the present status and describes the foreseeable future over the next twenty years.

1. GENERAL DESCRIPTION

Thirty seven years after its construction, the 200 m diameter combined function PS machine remains the heart of the PS Complex (fig. 1) [1]. With 3 RF systems (9.5, 114 and 200 MHz), 4 injection and 4 extraction channels, it routinely processes five types of particles (p^+, p^-, e^+, e^-, Pb^{53+}) at momenta ranging from 0.6 to 26 GeV/c and at intensities between 10^8 and 2.5×10^{13} particles per pulse (ppp).

The rest of the complex consists of:

- Linac 2, producing protons from a duo-plasmatron source followed by a 750 keV RFQ and 3 Alvarez tanks operating at 200 MHz. Proton pulses are delivered at 50 MeV every 1.2 s, with a length from 10 to 150 μs and an intensity of up to 180 mA,
- Linac 3 [2], the last born of the PS machines, which uses one 101 MHz RFQ accelerating Pb^{27+} ions up to 250 keV/u, followed by a cascade of three IH structures (one at 101 MHz, the other two at 202 MHz). The Pb^{27+} ions are injected from an ECR source running in after-glow mode. After stripping by a carbon foil at the exit of the linac, 25 μA of 4.2 MeV/u Pb^{53+} ions are routinely delivered in 400 μs pulses.
- The PS Booster (PSB), an assembly of four vertically stacked synchrotrons of 50 m diameter which accelerate the linac beams respectively up to 1.69 GeV/c for protons and 0.43 GeV/c/u for Pb^{53+}.
- The Antiproton Accumulation Complex (AAC) [3], made of the antiproton accumulator (AA), supplemented in 1987 with a collector (AC). Nine stochastic cooling systems are used in each ring.
- A 78.54 m circumference Low Energy Antiproton storage Ring (LEAR) [4]. It is equipped with six stochastic cooling systems, an electron cooler, a gas-jet target, and both fast and ultra-slow extraction systems.
- The LEP Pre Injector (LPI), consisting of a double 100 Hz Linac (LIL-V and LIL-W) which sequentially provides e^- or e^+ beams at 500 MeV to a 125 m long, racetrack-shaped accumulator (EPA). LIL uses 16 traveling wave accelerating sections powered by five 3 GHz klystrons, 4 of which benefit from energy doublers called LIPS.

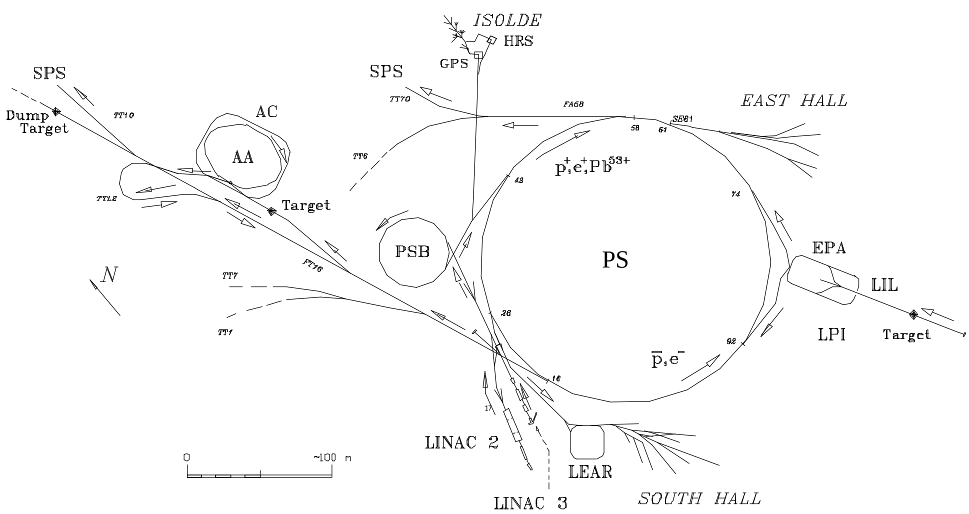

Figure 1. General map of the PS Complex

Beam Label	User	Particle	Inj./ej momentum [GeV/c]	Intensity [ppp]	RF harm. Nr	No of bunches	ε_x , ε_y [µm] (1)	$\varepsilon_{//}$ [eVs]	Bunch length [ns]	Inj./ej. straight section	Peculiarities
SFT	SPS	p^+	1.69 / 14	2.5 10^{13}	20, 420	420x5	11 / 7	0.1	5	42 / 16	Highest intensity beam, 5 turn extraction
SPP	SPS-LEP	e^+	0.5 / 3.5	2 10^{11}	8 + 240	8	0.05 / 0.01(2)	0.01	4	92 / 16	Robinson wiggler to change J_e & J_x
SPN	SPS-LEP	e^-	0.5 / 3.5	2 10^{11}	8 + 240	8	0.05 / 0.01(2)	0.01	4	74 / 58	Robinson wiggler to change J_e & J_x
AA	AAC p^- product ion	p^+	1.69 / 26	1.6 10^{13}	10, 12, ..., 20	5	13 / 9	2	20	42 / 16	Transverse funneling, longitudinal merging and batch compression
TSTAAC	AAC p^- transfer simul.	p^+	1.69 / 3.5	2 10^{10}	20, 6	1	4 / 1.5	0.5	70	42 / 16	Test beam for steering adjustments of AA-PS transfer line
LEAR	LEAR p^- physics	p^-	3.5 / 0.6	10^{10}	10	1	2 / 2	0.2	160	16 / 26	Deceleration on a digital frequency program
PHYSE	East Hall	p^+	1.69 / 24	3 10^{11}	20	N/A	3 / 5	0.2	N/A	42 / 61	Slow extraction (400ms)
SFTION	SPS	Pb^{53+}	0.43 / 5.1(3)	2 10^8	20	20	1.7 / 1.6	0.04 (4)	11	42 / 16	Stripped to 82+ in the transfer line to SPS
PHYFE	East Hall	p^+	1.69 / 3.5	10^9	20	1-5	2.0/1.5	0.5	30	42 / 61	Low but precise intensity

(1) $\varepsilon_{x,y} = \beta\gamma\, \sigma^2 / \beta_{x,y}$ (2) non normalized (3) [GeV/c/u] (4) [eVs/u]

Table 1: Characteristics of the PS extracted beams

2. THE DIFFERENT TYPES OF BEAMS

The detailed characteristics of the most representative beams delivered by the PS are listed in Table 1.

Protons. The PSB is able to supply up to 3.10^{13} ppp in 20 bunches at 1 GeV every 1.2 s. The PS machine accelerates these beams and tailors their longitudinal characteristics to the specific needs of every user. Longitudinal emittance is blown-up in a controlled way, using the 200 MHz RF systems. Bunch lengths and number of bunches are changed with traditional debunching/rebunching techniques, as well as more involved “gymnastics” [1, 3], using the wide frequency range of the RF systems and the flexibility of their controls [5]. Ultimately a large variety of proton beams is routinely available:

- debunched and slow extracted (~ 400 ms spills) at up to 24 GeV/c to the East Hall experiments,
- bunched at 200 MHz and “continuously ejected” over 5 turns at 14 GeV/c to SPS,
- compressed into 1/4 of a turn (5 bunches) at 26 GeV/c and fast extracted to the AAC p^- conversion target.

In addition to feeding the PS, the PSB also provides intense (~$3x10^{13}$) p^+ beams at 1 GeV to the ISOLDE facility.

Antiprotons. Antiprotons are collected at 3.5 GeV/c in batches of $5x10^7$ from the AAC iridium target, stochastically cooled for 4.8 s in the AC, and then transferred and stacked into the AA [3]. Up to 10^{12} p^- can be stacked in the AA.

A few times per hour, a single bunch of $2x10^9$ to $5x10^{10}$ p^- is RF captured, ejected to the PS machine, decelerated down to 609 MeV/c and sent to LEAR. The beam can then be accelerated (< 2 GeV/c) or decelerated (> 100 MeV/c), and stochastic- and electron- cooling are extensively used (electron below 350MeV/c, stochastic above) [4]. The LEAR beam can be used on an internal gas-jet target (typical coast life-time 30 h) or ejected by fast extraction (20-500 ns) or ultra-slow extraction (0.1-5 h).

Electrons and Positrons. The 180 MeV LIL-V e^- beam produces e^+ in a tungsten target. The 12 ns lepton beams are further accelerated to 500 MeV by LIL-W and longitudinally stacked in one of the 8 EPA buckets. Whereas $5x10^{11}$ electrons are collected within a PS basic period of 1.2 s, it takes a full PS supercycle to accumulate the same amount of positrons. Once every supercycle, the eight e^+ (and 1.2 s later e^-) bunches are fast ejected to the PS, accelerated to 3.5 GeV with the 114 MHz system, then transferred to the SPS in 2 batches of 4 bunches spaced by 30 ms.

Heavy ions. The 4.2 MeV/u Pb^{53+} ions from Linac 3 are first accelerated to 94.8 MeV/u in the PSB where a change of the RF harmonic number is needed to cope with the large variation of beam velocity. The PS accelerates the ions using a dedicated, high sensitivity beam control, then extracts the 20 bunches to the SPS. They are fully stripped to Pb^{82+} by a 1 mm thick aluminum foil in the transfer line.

3. OPERATING MODES

The users of the PS Complex receive their own particle beam according to pre-established sequences, called supercycles. A PS supercycle is made of various magnetic cycles, one or several cycles being allocated to each user. Fig.2 shows a typical supercycle of 19.2 s duration used during the lead ion physics run in 1995.

For the pulsed machines, most of the parameters in the equipment - several thousands for PS or Booster - must be refreshed every cycle. This mode of operation, called pulse to pulse modulation [5], has regularly increased in complexity and flexibility during the past 20 years. Nowadays up to 24 potential beams can be prepared and instantly put in operation as soon as required.

The composition of the supercycle changes frequently during a machine run according to the accelerator schedule or even in real-time, to adapt to the users' requests. For example, during the infrequent antiproton transfers, the supercycle is temporarily modified.

The scheduled running time of the PS Complex for 1996 exceeds the all-time record of 6800 hours with about 5600 hours devoted to antiproton physics (4900 in 1995). The beam availability is generally higher than 92% for SPS and LEP and 87 % for LEAR physics.

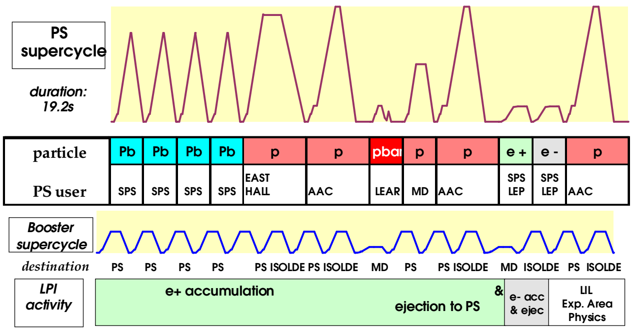

Figure 2. Example of a supercycle used in fall 1995

4. FORESEEABLE FUTURE

LEP. LEP energy is scheduled to increase up to a maximum of 96.5 GeV/beam in the middle of 1999. Leptons need then to be delivered until the year 2000. Depending on the experimental request for the e-p option in LHC [6], leptons will be again needed later during the 21st century.

LHC. Solutions have been designed to meet the stringent requirements of the beams for LHC with limited modifications to the PS complex.

- For protons, the major issues are the increase of the PSB energy from 1 to 1.4 GeV and the installation of new RF systems in the PSB and in the PS [7]. Following the initial demonstration of the validity of the proposed scheme in 1993 [8], a project was launched which is due for completion for the start-up 1999.
- For Lead ions the proposal is based on a low energy ion accumulator ring, stacking multiple pulses from LINAC 3 running at 10 Hz, and increasing beam density in all planes with electron cooling. Some tests have already been performed [9] and more are foreseen before the shutdown of the LEAR facility, in 1997.

SPS. Fixed target physics in the SPS North Area, test beams and possibly neutrino physics with 450 GeV primary protons will maintain a strong pressure for high intensity proton beams from the PS complex well after 2005.

PS Experimental facilities. Requests for beam-time in the PS experimental area are increasing because of the needs of calibration of the future LHC detectors. A project for upgrading the East Area has been submitted for approval [10].

The lepton beams from LIL and EPA are already in demand nowadays for LHC equipment testing, and will probably be even more so as time goes by.

The ISOLDE physics community foresees requests for much beam time, especially if the first stage of radioactive ion accelerators experiment (REX) at CERN lives up to its promises.

Antiproton facility. The present low energy antiproton facility with its 3 dedicated machines (AC, AA and LEAR) will be stopped at the end of 1996. A low-cost installation called the "Antiproton Decelerator" (AD) [11] is proposed to continue the antihydrogen studies at CERN. It would collect, cool, decelerate and eject about 1/10th of the present flux of antiprotons to a small number of experiments. If approved in 1996, data taking could begin during the first half of 1999.

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