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# THE ACTIVITIES OF THE PS DIVISION IN 1989

**V. Chohan**

(with major contributions from the PS Staff)

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# Proton Synchrotron Division

The successful operation of the LEP Preinjectors was the year's top priority for the Division and this paid off handsomely for the spectacular start of LEP. The year 1989 also marked the 30th anniversary of the first beams in the PS Ring, and a year in which the 'Particle Sources' Division broke the all time records in various accelerators comprising the PS Complex. The ubiquitous PS Ring broke new records in proton beams for antiproton production, beam for fixed target physics in the SPS as well as in its new role as the Lepton Injector to the SPS. The PS Booster triumphed over previous records in intensity per single ring and the ensemble of Lepton Preinjector Linacs and Electron Positron Accumulator (EPA) produced record intensities in electrons and positrons. The AAC (Antiproton Accumulator and Collector complex) surpassed the mark of $1 \times 10^{12}$ antiprotons stored and, achieved record performances in accumulation rate (Fig. 1). Last but not least, the LEAR ring had the first ever runs with oxygen ($O^{8+}$). For its role as a supplier of protons and antiprotons to the SPS Collider, all time records were broken in the daily production rates (Fig. 2) and the total quantity of antiprotons supplied, leading to record luminosities (Fig. 3). All this was achieved with the different accelerators providing a high degree of availability for physics and, with diminishing human and financial resources. The Division's resources have also been called upon for possible new projects including the construction of a Beauty factory, ISOLDE displacement to the vicinity of PS Booster, CLIC and LHC. Tables 1 to 5 and Fig. 4 illustrate the breakdown of the year's operation of the PS complex.

## LEP Pre-Injector – LPI

The five month shut-down of the LPI at the start of the year during the $p\bar{p}$ collider runs was used intensively to repair the end flanges of the accelerating sections of the linac LIL. This was because six of them had sprung a vacuum leak due to chlorine corrosion at the end of the previous year. This major undertaking was carried out in close collaboration with the CERN central workshop. In parallel, some of the high voltage elements of the LIL modulator/klystron stations which had proved less reliable during the commissioning were replaced to give a better overall system reliability.

After a hectic period for re-installation, re-alignement and HF re-conditioning of the whole linac, the LPI was ready, just in time for the start-up of LEP at the beginning of July. It then remained in operation for the rest of the year, performing extremely well and with an overall availability exceeding 95%.

The reliability of the complex was further improved by operating the $e^-$ to $e^+$ converter in a fixed position, thus avoiding the pulse to pulse mechanical movement in a high radiation area.

Finally, the first part of the consolidation programme has been completed by equipping the key LPI elements with adequate spares and rejuvenating the modulated power supply of the electron gun, the unique source of all leptons at CERN.

## Hadron Injectors – HI

During 1989, both Linac1 and Linac2 functioned well in the usual reliable manner. Linac2, the main source of protons at CERN, underwent upgrades of its mechanical tuning system, the water flow monitoring system, and the RF systems. Linac1 continued to fulfil its role as the normal source of protons for LEAR. It was also the scene of an oxygen/sulphur ion run intended to check out the new hardware and carry out some major improvements. The latter included the improvements to the ECR ion source and, in the quality of vacuum. The new hardware included a means to measure the sulphur content by cycle stealing (needing a pulsed de-grader and new optics) and a novel, almost non-destructive, thin-wire ion beam profile monitor.

The latter was also profitable to the PS Booster (PSB) where the upgraded electronics for bunch phase detection proved beneficial for the low-intensity ion performance. This was the first time that ions were accelerated in the PSB to a magnetic rigidity corresponding to 1 GeV protons (326 MeV/amu). On the proton front, the PS Booster continued to pursue its tradition of being involved in record performances :

(i) The SPS fixed target beam intensity was increased (in the PS at 14 GeV/c) to $2.57 \times 10^{13}$ protons/pulse, mainly due to the use of h = 10 cavities in the PSB which allow the squeezing of an increased number of protons in given emittances.

(ii) The antiproton production beam was increased to $1.75 \times 10^{13}$ protons/cycle (PS at 26 GeV/c) by using both the recombination by an RF Dipole in the 1 GeV PSB-PS line (yielding a beam filling half the PS circumference) and the adiabatic harmonic change scheme in the PS (to squeeze the beam into a quarter of the PS circumference).

(iii) A new sum-of-four-rings record of $3.3 \times 10^{13}$ protons/pulse at 1 GeV/c was obtained, auguring well for the proposed ISOLDE operation near the PSB, which would profit from all the Booster cycles not used by the PS machine. Future operation with ISOLDE would imply a 3-5 fold increase in average PSB beam intensity. The studies of the ensuing higher machine irradiation and other aspects are underway.

The high intensity proton RF Quadrupole accelerator, being developed with a view to replace the ageing 750 kV Cockcroft-Walton pre-accelerator of Linac2, was installed on its test bench, by now fully equipped with ancillary devices. RF measurements, at low level, have shown that the accelerator structure meets design specifications and is ready for beam tests. The beam to be injected into the RFQ (90 keV, about 250 mA) has been analysed and found to be satisfactory.

The HI staff continued their involvement with the major beam diagnostics components (current transformers, position monitors, profile monitors) of the PS Complex for which they are responsible. In addition to making the systems work and improving them, new profile monitors were installed in positions which needed them most urgently.

A development of maybe more general interest is a standard 'Diagnostics Protocol', which enables a central control system to meaningfully communicate with local intelligent devices treating a specific beam monitor. Such a protocol was successfully tested with the PSB slow beam-current-transformer used as a potential application.

## Main Proton Synchrotron

### Operations

The year commenced with the necessary preventive maintenance and important installation activities concerning all of the accelerators of the PS complex. The access control systems of the Booster, Linac2 and LEAR were renewed on schedule and the last week of February saw the first beams in the PS as part of the technical running-in week after the long Christmas shutdown.

The first period of the year was virtually dedicated to the SPS Collider operations upto July, with intensities and luminosities increasing steadily (see Fig. 2 & 3), interspersed with breakdowns somewhat expected for such a long run. A series of major electrical failures which coincided with the long Easter weekend, hence reduced staff, meant that the running through the Easter weekend was rather unfruitful for physics. However, the month of May proved out to be spectacular, with the antiproton accumulation rate often exceeding $50 \times 10^{9}$ antiprotons/hr and, for the first time, the total daily production exceeded the AA design figure of $1 \times 10^{12}$ antiprotons accumulated per day. This led to the figure of 1800 nbarns$^{-1}$ in integrated luminosity achieved over 31 days, an all time record since the birth of the SPS Collider.

The Whitsun weekend running in May saw no major problems as at Easter and the antiproton production beam saw another all time high of $1.55 \times 10^{13}$ protons/pulse on target, using vertical recombination scheme in the PSB-PS transfer line using a RF dipole. This record was further improved in June to $1.63 \times 10^{13}$ protons/pulse. June also saw the first ever production of positrons and electrons by the LEP preinjector; $1.5 \times 10^{11}$ positrons and $1 \times 10^{11}$ electrons in four bunches were injected and circulated in the PS as part of the preparations for the LEP commissioning, which commenced on schedule in July.

The end of the Collider run also enabled further machine development sessions especially for the high intensity, antiproton production beam. In September, using all four Booster rings, vertical recombination in PSB-PS transfer line and longitudinal merging in the PS, a record intensity of $1.75 \times 10^{13}$ protons/pulse in five bunches at 26 GeV/c was achieved. This was an important accomplishment leading to substantial energy savings for the rest of the year because 24 hours were normally sufficient to produce and replenish the Accumulator with antiprotons. For the rest of the year,the Antiproton source complex ran in this energy saving mode with two substantial fills per week sufficient for LEAR consumption. For the remainder of the week, the production chain was usually switched off with the antiproton transfer to LEAR being the only active process.

While the second half of the year was visibly devoted to the LEP commissioning and physics runs, the versatile PS continued the other operations in parallel for the SPS fixed target physics, AAC and LEAR as well as test physics beams for the East Hall Experimental Area. The average availability of the PS complex for leptons was over 91% for the second half of the year. The year's operations ended with several faults due to power cuts beyond CERN's control, causing interruptions in antiproton physics at LEAR and, partly in the lepton transfers to the SPS and LEP.

### Radiofrequency Systems

The new antiproton production beam systems first set-up in November 1988 were further refined during the long SPS Collider run which started in March. Subsequently, $1.5 \times 10^{13}$ protons per pulse were routinely delivered onto the target. As mentioned earlier, record intensities were finally achieved by combining the two processes of funnelling in the Booster-PS transfer line and, longitudinal merging inside the PS at 3.5 and 26 GeV/c. A lot of minor RF hardware improvements in the Antiproton Collector and in the PS helped to achieve an excellent overall reliability despite these sophisticated and complex operations.

For leptons, the RF systems were ready on time to contribute to the successful commissioning of LEP in July. However in September, a vacuum leak in a bellows of the short circuit arm of the 114 MHz cavity interrupted the beam for 40 hours. No other major faults were experienced later, and a standard beam of 4 bunches was regularly delivered to the downstream machines. The two other types of lepton beams as foreseen ('long bunch expansion' & 'double batch ejection') were also successfully prepared, although not immediately needed by SPS or LEP.

A single bunch proton beam was specially set-up on a PS 'A' cycle and was successfully used for the energy calibration of LEP.

For the proton beam used for fixed target physics in the SPS, new intensity records were achieved due to the improved behaviour of the PS ferrite cavities with respect to beam loading, largely contributed by the RF feedback implemented in 1988.

### Instrumentation

In the PS, special electronics and coupling networks have been developed and produced to extend the low frequency sensitivity of the normal closed orbit pickup electrodes over the frequency range of 7 kHz to 2 MHz. Moreover, the closed orbit acquisition system has been modified to allow the acquisition of the trace of a selected bunch over two consecutive turns in the PS, independent of the injecting accelerator.

During the October shut-down, ten beam loss monitors have been installed in the TT2 line and interconnected with the associated electronic chains for measurement and display. The signal display of these ten monitors has been incorporated to the existing hardware and software of the 100 beam loss monitors of the PS ring.

Synchrotron light monitors have been designed, manufactured and installed in section 12 of the PS ring.

### Beam Studies

#### *Leptons*

Studies have continued to prepare the PS for an expected future demand to provide increased intensity to SPS/LEP, namely :

(i) A technique was developed for accelerating leptons with the 114 MHz cavity and ferrite cavities tuned to 3.8 MHz, so as to produce longer bunches. This will let the SPS run tests to capture bunches of leptons with the same density but higher intensity, with the RF system at 100 MHz.

(ii) The maximum intensity of accelerated electron bunches, which is limited by the instabilities created by the ions captured by the beam, was raised to $4 \times 10^{10}$e /bunch using transverse feedback techniques.

(iii) The 3.5 GeV re-synchronization technique was put into operation and can be used to eject two families of four bunches towards the SPS.

Mention should also be made of the contribution of the PS studies team to the LEP start-up and to the orbital correction studies carried out at LEP.

*Hadrons*

Satisfactory trials were carried out for two weeks in May on the first phase of the new slow ejection 62, resulting in the approval of this project.

A special 14 GeV proton beam was prepared for SPS/LEP to make a precise calibration of the nominal running energy of the LEP ring.

*New projects*

Studies were conducted to accelerate lead ion beams in the PS for fixed-target experiments in the SPS and for LHC. In addition, major contributions were made to the 'beauty factory' project in the ISR tunnel, i.e. performance and injector modifications, machine lattice, collective effects, etc.

### PS Ring, Magnets & Septa

During the long shutdown, refurbishment of the PS Ring continued, with the complete overhaul of Octants 3 and 4. The straight sections were also refitted to take the hardware needed for partial slow ejection tests and for installing the synchrotron light monitor.

Problems with cooling water circulation for the AA septa led to the EPA demineralized water station being shifted to the AA and to a new station being built for the EPA.

The Magnets Section carried out the magnetic measurements for the Group and the Division, overhauling and preparing magnets for the experimental areas and undertaking the acceptance of new magnets (some 20 in all). It also took part in design work for a superconducting sextupole coil for the LHC; it designed, produced and tested various solenoid systems for CLIC, LIL and LEAR, drafted the final technical note for the LEAR PFWs, and did the calculations and designed the bumpers for COSY/Jülich.

## Antiproton Accumulator & Collector – AAC

The first half of the year was dedicated to the SPS Collider with only a small fraction of the $\bar{p}$ production going to LEAR. On several occasions, the daily production exceeded $10^{12}$ $\bar{p}$, thanks to the the good performance and reliability of the AAC. The running during the second half of the year was exclusively for LEAR. The low $\bar{p}$ flux required by LEAR permitted intermittent stacking, with reduced power consumption and lower operating costs. The $\bar{p}$ stacking rate has evolved steadily from $12 \times 10^9$/hr in 1988 to $58 \times 10^9$/hr in 1989, thus achieving a factor ten in improvement over the AA operational stacking rate before ACOL.

### Production & Collection

A target made of iridium embedded in graphite continues to be used for $\bar{p}$ production . The primary proton beam hitting the target improved substantially during the year, yielding a larger number of antiprotons, thanks to the various RF gymnastics in the Booster and PS. Despite these higher intensities, no yield degradation due to possible target damage has been observed. The improved primary proton beam was kept in operation with reduced intensity for LEAR runs in the second half of the year.

Various developments have been carried out during the year for improving the collector lenses used immediately after the target. A lithium lens of 20 mm in diameter, pulsed at 480 kA, was the principal lens used operationally and yielded $62 \times 10^{-7}$ $\bar{p}$/proton on the AC injection orbit after various optimisations. Early in the year, it was planned to use a larger, 36 mm lithium lens but, after a flange failure at $1.1 \times 10^6$ A in the development laboratory, beam trials was postponed to July 1989. This lens is mounted inside its toroidal transformer which has been developed in collaboration with INP-Novosibirsk, USSR. The related 200 kJ power supply and pulser have been designed at CERN and built, partly in industry, within a record time of six months. This equipment is able to deliver a current pulse in excess of 1.2 × $10^6$ A within the specifications of 1 ms rise time, 3.5 ms duration and a repetition rate of 2.4 s. After extensive development and life tests, this lens was successfully operated at 1.1 × $10^6$ A for beam trials in July. These trials were very encouraging with 20% improvement in $\bar{p}$ yield with nominal production beam and a 40 % improvement for lower intensity primary beam. It is hoped that the lens will be robust enough to be fully functional for the $p\bar{p}$ Collider run in 1990.

With the financial help of the German Ministry of Research and Technology (BMFT), the development work of a plasma lens for collecting antiprotons has been restarted in early 1989. A new plasma lens model scaled for the AAC target area installation has been designed and built. The neccessary mechanical support structures compatible with the later installation at the target have been assembled together with the lens in the laboratory. A new, modular pulse generator has also been assembled from existing components. Initial high-current operation and relevant measurements commenced before the end of 1989.

### Debunching Cavities

Antiprotons are normally injected into the AC with the 5-bunch structure and are captured, rotated and debunched by means of two cavities. The isoadiabatic debunching was improved after the commissioning of the closed loop phase feedback of these cavities. The efficiency of this operation, given by the ratio of antiprotons existing in 1.5% momentum spread after bunch rotation divided by antiprotons in the 6% momentum bite of the injected beam was 83 %.

### Stochastic Cooling Systems

Additional cryogenic cooling systems were installed in early 1989, reducing the temperature of the combiner boards from 100 K to 30 K and the thermal noise by 4 dB. Further, the function governing the pickup & kicker movements was modified such that the loop gain is increased during the cycle without the reduction of the initial 200 π mm.mrad acceptance. These modifications increased the capabilities of the AAC to work at 2.4 s. After 2.4 s of stochastic cooling in the AC, the measured transverse emittances were about 13 π mm.mrad and, 70 % of the antiprotons produced reached the injection orbit of the AA. It was found that the AA precooling and the stack tail systems were the limiting factors for working in the 2.4 s repetition regime. It was proposed to improve the stochastic cooling speed by a factor two by the installation of additional cryogenic systems in the AA. This would have yielded a 10% improvement in stacking rate at 2.4 s over and above what is possible today in the 4.8 s repetition regime. However, financial and other considerations have prevented the management from funding this improvement. The present 4.8 s stochastic cooling time reduces the transverse emittances to 4 π mm.mrad in both planes.

For the AA, the precooling system has seen some improvements due to the installation of lower noise preamplifiers and additional band II amplifiers.

### Stack Intensities

Using the technique known as beam 'shaking', high stack intensities were achieved without any appreciable loss in the stacking rate. Shaking of the beam modifies the ion amplitude distribution and reduces the excitation of high order resonances. The AA machine design parameter eta is not well matched for high intensities above 8 × $10^{11}$ and, the full cooling bandwith is not used. This leads to the heating of the stack edges, increasing the loss rate and the depletion of a large fraction of the stacking rate. Nevertheless, a maximum stack intensity above 1 × $10^{12}$ was reached with a stacking rate of 30 × $10^9$ $\bar{p}$/hr. The record stack intensity of 1.31 × $10^{12}$ was arrived at with somewhat lower stacking rate.

### Quadrupolar pick-up

For beam transfer between two rings, good transverse matching is required to conserve low emittance. To check the AC/AA and the AA/PS matching with proton beams, a quadrupole pick-up has been installed in the AA to observe the coherent quadrupolar injection oscillations. It is also intended for the observation and the eventual damping of the coherent quadrupolar ion-$\bar{p}$ instabilities. The pickup responds to the coherent beam envelope oscillations at second-order betatron frequencies given by $(n \pm 2q)^* f_0$. The coherent dipole oscillations have to be carefully compensated before the measurement, analyses and correction are carried out with this pick up. This has been done successfully for the PS/AA transfer line and would be extended to the other transfer lines in the coming year.

## Low Energy Antiproton Ring – LEAR

LEAR provided antiprotons by ultra-slow extraction between 105 MeV/c and 1917 MeV/c, physicists having a preference for extreme momenta (105, 200) and (> 1500). For the first time, antiprotons were extracted alternately in slow (200 or 105 MeV/c) and fast extraction (105 MeV/c) for multifilling the Penning trap in Experiment PS196. Since June, the machine has been controlled entirely from DEC-Stations both in the Main and local LEAR control room.

Several stages in machine development and experiment were completed :

- Semi-slow extraction (< 1 ms) was tested at 105 MeV/c (future operation at 61.2 MeV/c for PS189);
- Deceleration at 61.2 MeV/c (kinetic energy 2 MeV) was improved and stochasttic cooling at this energy used to obtain a lifetime of 20 mins for $1.0 \times 10^9$ circulating antiprotons;
- An experimental 'damper' was installed and successfully tested for stabilizing the very dense beams obtained by electron cooling;
- Hope of bringing the electron cooling to pre-operation phase by the end of the year was ruined by the rapid breakdown in collector performance and associated problems. Depsite these setbacks, stable beams of $2.0 \times 10^9$ circulating particles ($dp/p = 5 \times 10^{-4}$, transverse emittance $\approx 3\pi$ mm.mrad) at 200 and 105 MeV/c were obtained (lifetime 2 h). The cooling speed was a few seconds.

Finally, during a special machine study session in November 1989, LEAR injected, accelerated and extracted oxygen 8 for the first time. Multi-injection in longitudinal phase space coupled with electron cooling and the damping meant that up to $1.4 \times 10^{10}$ circulating charges at 147.4 MeV/c/nucleon could be obtained using multi-injection, storing pulses of $3 \times 10^8$ from the linac. The cooling speeds were 0.3 s and 1 s, respectively in the longitudinal and transverse phase spaces. This experiment augurs well for future development of ions at CERN. Ion beams were accelerated and extracted at 408 MeV/c/nucleon. A TIS team used slow extraction of this type (30 s to 20 mins) to measure energy deposits in material equivalent to human tissue.

So far as projects started in 1989 are concerned, the design and construction of pole-face windings (sextupole + vertical dipole) must first be mentioned. These should make it possible to improve the machine at low energies and provide a more flexible regulating system for experiments inside the machine. Studies to replace the electron collector in the electron cooling system have led to an agreement with Novosibirsk (USSR) to deliver a versatile collector in 1990.

Various improvements were carried out for the controls of the vacuum bakeout system for the LEAR ring as well as the design and installation of a transparent vacuum chamber for the Jetset experiment, using new vacuum components based on NEG pumps.

In order to monitor the intensity, position and profile of the very low momentum proton or antiproton beam extracted from LEAR, two new monitors working under the ultra-high vacuum conditions of LEAR have recently been tested; these were a position-sensitive photomultiplier coupled to a thin inorganic scintillator and a double sided silicon strip detector.

## Synchro-Cyclotron

1989 was a vintage year for the SC. Whereas in previous years there was a merry-go-round of rotating condenser (rotco) changes due to breakdowns, for the first time since records were kept, the only rotco change during the year was when the second rotco, which had been specially prepared for $^3He^{++}$ use, was exchanged for the 'proton' mode rotco – a change necessary for the physics programme.

During the year only 137 hours (1.6%) were lost due to breakdowns compared with 913 hours (8.2%) in the previous year.

As previously indicated, both protons and $^3He^{++}$ were accelerated to the main user ISOLDE. Muon spin rotation (μSR) also took some main beam on occasions and there were several parasitic users. Figure 5 shows the experimental layout at the end of 1989 .

The traditional shutdown at the beginning of the year, when the vacuum control system was modernised, was followed by a trouble free start-up and excellent running until March when the two rotcos were interchanged and $^3He^{++}$ successfully accelerated. Back to protons in May and again after a quick start-up, the RF voltage was pushed up to 23 kV (normally 20 kV) during a technical development with only a correspondingly small increase in discharges. Both ISOLDE 2 and ISOLDE 3 had several extremely good runs both before and after the scheduled shutdown in September, and especially in November when the SC beam intensity was improved by 5% to 10% by changing the gas in the ion source.

ISOLDE made progress with a new radioactive beam of selenium, this being the first time that this element had been produced at the SC. A resolution of 7000 for the full machine was obtained at ISOLDE 3 as the SC continued its excellent progress until the end of the year.

A remarkable feature of 1989 was the performance of Rotco 1. Since its last service it had made a total of $1200 \times 10^6$ revolutions up until the end of the year. This is approximately the equivalent of 500 years of normal use of a domestic washing machine!

## Experimental Areas

As usual, the East Area beams were employed extensively for testing and developing detectors used in current or planned physics programmes (some 40 tests during 1989).

The t9 beam can now be operated up to 15 GeV, thereby expanding the useful range of the four test beams, i.e. the particles can now be obtained with an energy range between a few hundred MeV and 15 GeV (protons, pions, electrons and positrons for the most part). In addition, a new beam stopper has been mounted on beam-line t9 and the useful area expanded by almost 150 m$^2$.

The only shadow to be cast on this was a breakdown on a quadrupole in the SE62 ejection supplying these beams with primary particles which stopped working in the last week of 1989.

In the South Area, which takes its antiprotons from LEAR, the latter's second-generation experiments continued to be set up and the Experimental Planning Section made a significant contribution towards these experiments, which have still not quite reached their desired beam quality.

The 105 MeV/c s3 line was adjusted with protons and then with antiprotons. This line supplies experiment PS 189 (measurement of the antiproton mass). For the first time an antiproton beam 'degraded' to 20 MeV/c was used. Since its intensity is considered insufficient for measuring the mass of the antiproton with the requisite precision ($10^{-9}$), a new line with RF quadrupole deceleration will be studied and set up in 1990.

Antiproton physics operations, which were continued throughout the year (almost 3500 hours), led to the first results from Experiment PS 196 (precision comparison of antiproton mass in a Penning trap). They have already confirmed that the masses of the proton and antiproton are equal to a precision of within $10^{-6}$. Experiments PS 189 and PS 196 are expected to produce even more accurate measurements.

Calculations on new low and very low energy beam lines continued, in particular for the anticyclotron deceleration tests planned for 1990 on the S4 line.

A new system for predetecting inflammable gas leaks and fire outbreaks was set up in the South Hall. It is based on air analysis sampled by aspiration and is used to monitor the interior of the detectors used for PS 195 (beam s1) and PS 201 (beam m2). Particular attention was paid in these areas to general safety since inflammable gas is used in large quantities.

Finally, the specification for controlled access doors to secondary beam areas was drawn up so that they can be overhauled in 1990 and 1991.

## Computer Controls

Controls activities during 1989 have been dominated by the first physics runs for LEP and the introduction of the UNIX operating system in the controls software development environment. In addition, the servicing and exploitation of the running control system also constitutes a major part of the ongoing activities, often under the strained circumstances due to the lack of sufficient staff for on-call duties.

The shutdown at the beginning of 1989 was used for the normal preventive maintenance of the computer and interface hardware. The last of the ND-10 front-end computers were replaced by the new ND-120s, with substantial savings in maintenance costs. With ethernet interface and the latest version of SINTRAN III operating system installed uniformly across all of the ND computers, it has been possible to establish communications using the TCP/IP protocol. A significant effort has gone these aspects in order to meet the performance criteria of the stringent controls environment; however, there are severe constraints that limit the performance and it would be necessary to continue to use the existing TITN Message Exchange System in parallel with the ethernet-TCP/IP communications. In addition, new facilities using TCP/IP had to be developed for the automatic software backup and printing due to the closing down of the central CERNET facilities.

The annual shutdown was also used to carry out major modifications to the PS coarse timing system and, to put into operation the control of the PS main magnet motor-generator power supply directly from the main control room. This joint activity with the power group has resulted in substantial manpower savings by the elimination of the need for a local power house operator. The modifications remove the vicious circle of timing events between the Program Line Sequencer (PLS), the main PS sequences (LBS) and the power house controls and, provide a clear, master timing event generation driven by the PLS only. It also includes better diagnostics and recovery facilities and permit easier programming of the PS complex supercycle. At the same time, a general reorganization of the central timing room (CCR) was carried out to increase the overall reliability of this nerve-centre of the PS complex.

Priority was given to the operation of the LEP Preinjector (LP) complex to be ready for the LEP commissioning. For the July start-up, all the application software work necessary to be able to run from the PS main control room was completed, with the exception of electron gun controls. The LP instrumentation systems performed well upto the improvements and modifications conceived after the first LEP injection tests of 1988; this, amongst other aspects, contributed significantly to the reliability of the LP complex and the spectacular start of LEP.

For the operating systems, the introduction of the UNIX system in the PS controls environment in 1989 was the first step towards the unification of control systems at CERN and a key move towards vendor-independence in this domain. The initial experience with a local UNIX network of servers and VAX workstations has been very promising, particularly for the prototype renewal of the Linac remote controls and the provision of a user interface for the PLS; the latter includes the online use of the ORACLE database management system. Much progress has been made in the development of tools for accelerator control using the industrial, X-11 standards for the workstation window management as well as the tools in UNIX for access to the equipment currently controlled by the front-end ND-120 computers. This is an important step necessary for the graceful transition to the future UNIX-based systems. At the equipment control level, work has started on the development of a future front-end processor using the industrial VME standard. The VME chassis includes a Motorola 68K processor running under the OS-9 operating system and permits communications using the TCP/IP protocol. Using software developed for the LEP OPAL experiment, a first version of the CAMAC equipment access software from VME has been implemented. In addition, the Nodal interpreter has been fully rewritten in the language 'C', with obvious benefits and portability to all UNIX and OS9 systems.

For the applications related software, the NAPS (New Application Program Structure) project has been completed. This involves the complete chain of software generation from the ORACLE database down to loading mechanisms for the specific equipment processors. A major PS application equipment module for controlling the power supplies has been converted to this new structure and, is routinely used for the LP complex. On the database aspects, the ORACLE off-line database as a unique source of read-only controls data has been put into routine use. It is accessible both, from the IBM/VM as well as the DEC/ULTRIX(UNIX) systems.

Much progress has been made in the development of an Expert System with applications to the beam injection line of the PS Booster. The system includes control and acquisition of equipment parameters and, will be used as a test-bed for a new Expert System architecture under the aegis of the ESPRIT II initiative of the European Community.

Several developments, improvements or extensions have been carried out to the various systems which fall within the domain of computer controls. These include the development of a new CAMAC timing surveillance module, extensions to the signal observation system, modernising of test and calibration facilities for instrumentation repair, introduction of remote controls for the sulphur ion source, development of modern techniques for computer-aided hardware design, documentation, and software tools for maintenance and graceful recovery of operational conditions after unforseen destruction. For the controls of beam instrumentation systems, several new features have been added to provide additional capabilities and to improve the reliability of measurements. Notable amongst these are the time-tagging of measurement data with a unique, CERN-wide clock, capability for bunch measurements over two turns in the PS and the implementation of a generalized protocol for the Booster beam measurement transformers.

All the developments in the basic building blocks for the new generation of control systems have been done in close collaboration with the SPS/LEP controls group; this is in line with the aim to have uniform control of all the accelerators at CERN.

The Ethernet cabling for the PS Division has been completed and includes both, the laboratories and the offices. The communications laboratory has been equipped with the necessary software and hardware tools to survey the traffic and, for the fault diagnostics. The high availability of this communications medium augurs well for the future.

The office Personal Computer (PC) network was extended by the installation of about 50 additional PCs, two new Novell file servers, and the installation of four printing cluster points around the various buildings of the division. For the office secretaries, it was decided to converge to the CERN administration standard of Macintosh computers, with a bridge to the PC world by the use of Novell servers.

## Research, Development & Projects

### Lead Ion Linac

The optimization of the parameters for the lead ion accelerating facility has continued and resulted in a considerably higher estimate for the number of ions per SPS pulse needed for the fixed target experiments. It seems possible to achieve an intensity of about $4 \times 10^8$ ions at the exit of SPS. This increase stems mainly from the better transmission efficiency between the PS and the SPS and, from the idea to accelerate several charge states simultaneously in the linac. The main worry, however, has been the question of how to supply the LHC with substantially higher intensities and nevertheless stay compatible with what has already been proposed for fixed target physics. The study has shown that the proposed facility can be upgraded in several ways and that the investment proposed would also be useful for LHC. The different possibilities include upgrading of the ion source, a special low energy end with a low charge state (and therefore high current) ion source with subsequent intermediate stripping, storing with cooling after the linac or, storing with cooling at higher energies.

Both LEAR and AAC have been considered for this purpose and look promising. It seems reasonable to choose the final scheme or a combination of these schemes, only when the straightforward possibility of ion source upgrade becomes more clear over the next few years. Cooling, at least to reduce the horizontal emittance, will probably be needed in any case and could be done in the PS.

The interdigital H-structure is still being followed up in order to assess its possible advantages, in conjunction with GSI/Darmstadt.

### Heavy Ion Source Studies

Modest exploratory work to study the possible application of laser ion sources for heavy ions has started. In experiments at the Technical University in Munich, a flashlamp pumped, Q switched Nd :Yag laser (pulse length = 10ns, pulse energy = 0.3 J, wavelength = 1.06 μm) was focussed on a 50 micron spot. This produced a variety of ions including Au and Pb with charge states up to 12+ (ionization potential < 370 eV). This effort continues at the Munich Max Planck Institute for Quantum Optics at higher pulse powers. At CERN, it is planned to further the R & D on a modest scale with a carbon dioxide laser, following the work at Dubna where such a laser has already produced more $Mg^{9+}$ ions than the CERN electron cyclotron resonance $O^{6+}$ source. This development has just begun in collaboration with the AT division who have lent a 2 Joule dye laser for preliminary studies.

Medium and high power $CO_2$ lasers have been acquired in order to extend the ion producing capability at CERN and, the assembly ot the lasers together with their diagnostic equipment is under way.

### CERN Linear Collider (CLIC) Test Facility

In parallel with the operation of the LEP pre-injector, the electron linac expertise of the LP group is being used to set-up a test facility, aimed at the production of electron bunches of high charge ($10^{12}$ particles) and very short length ($\sigma z$ = 1mm). The interaction of these bunches, with specialized structures developed to extract power at high frequency (30 GHz), will enable the basic problems of CLIC drive beam to be studied. A blockhouse, close to Lep Injector Linacs(LIL), is under construction and will house an HF gun based on photocathodes illuminated by a laser and fed with power from the spare LIL klystron/modulator. A low power prototype of the gun has been machined by the central workshop, measured and readjusted. A high power version is in preparation.

First 10 nsec pulses of $1 \times 10^{12}$ particles have been obtained in a DC gun at 70 kV from a multi-alkaline photocathode, made in an on-line preparation chamber and illuminated by a laser, an excellent example of a close multi-division collaboration.

### Ferro-electric Crystals

It has been the aim to encourage a number of new ideas – at least up to the point of being able to judge if they are likely to be of some use in designing the accelerators which will replace LEP and the LHC. The emission of electrons from ferro-electric crystals during phase transition is one such example. A no-cost collaboration between CERN and the Universities of Katowice in Poland and Thessaloniki in Greece, using borrowed equipment, has given very intense electron emission from a PLZT ceramic with a high zirconium concentration. The zirconium broadens the phase transition so that a high voltage pulse of 40 kV redistributes a large fraction of the ferroelectric structure into a paraferroelectric state, releasing electrons bound to the surface. It is too early to say very much about the perveyance of the beam emerging into the vacuum. See : Pulsed Electron Emission from Ferroelectrics by H. Gundel, H. Riege, J. Handerek, K. Zioutas – CLIC Note 82 and submitted to JAP.

### Open Resonators

Another collaboration, with Naples University, was originally set up to investigate the use of open resonators (opposing spherical dishes) to produce intense high frequency fields. The open resonator has a high Q and the waist in the standing wave can be very narrow and intense, limited to a few microwave wavelengths. Fields of GeV/m exist over a short distance and, in some modes of the resonator, might be used to focus particles at the final focus of a linear collider. Another application may be to produce an improved version of the interference beating suggested by Hora in 'Nature' (26.05.88) as a means to accelerate in vacuum. Discussions are also underway with Rochester University about the use of open resonators as axion detectors and as a new kind of pickup for cool beams.

There has been a recent interest in using these open resonators as part of a beat-wave experiment in the microwave range. This is part of a collaboration between the Rutherford-Appleton Laboratory (UK) and Naples presently unter the aegis of the EEC.

| MACHINES | INTENSITIES or ACCUMULATION RATES | | | Dates |
|---|---|---|---|---|
| AAC | AA Stack | | 1.31 E12 pbars | Aug-08 |
| | Accumulation Rate | | 5.8 E10 pbars/h | May-26 |
| PS | 20 bunches at 14 GeV/c | (Beam for SPS) | 2.57 E13 protons / pulse | Aug-26 |
| | 5 bunches at 26 GeV/c | (AAC production) | 1.75 E13 protons / pulse | Sep-12 |
| | Leptons e- | | 4.5 E10 e-/bunch | Nov-06 |
| | e+ | | 5 E10 e+/bunch | |
| PSB | 20 bunches to Measurement Line (1 GeV) | | 3.3 E13 protons / pulse | Nov-13 |
| LPI | Intensities in EPA | e- | 1 E12 e- | |
| | (8-bunch mode) | e+ | 8 E11 e+ | |
| | Accumulation rates | e- | 1.2 E11 e- / bunch / s | |
| | (8-bunch mode) | e+ | 8.0 E9 e+/ bunch / s | |
| LEAR | O8+ at 400 MeV / nucl. | | 1.3 E10 charges | Nov-15 |
| | protons at 2 MeV | | 1 E9 protons ; lifetime : 18 min. | |

*Figure 1*
*1989 – PS Complex – Records*

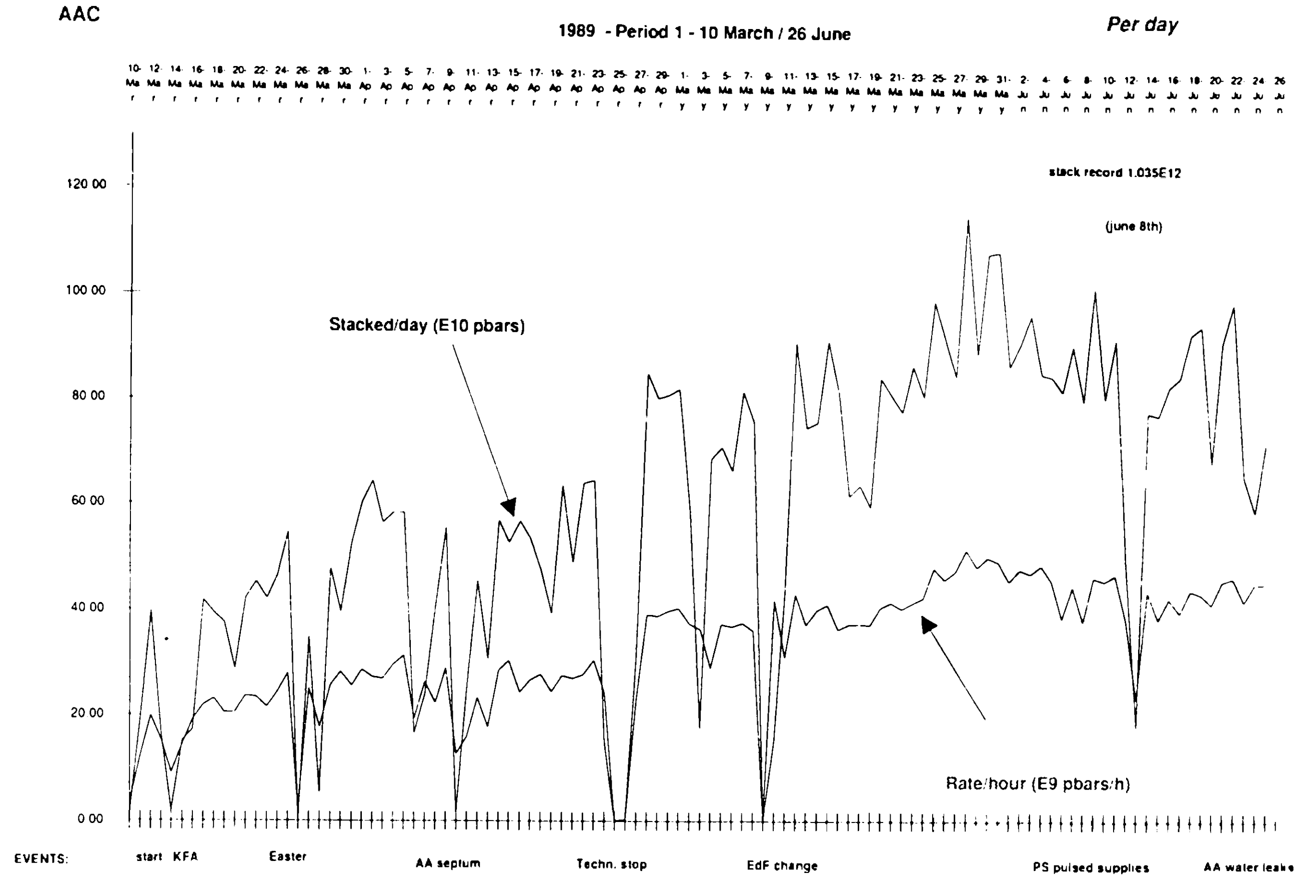


*Figure 2*

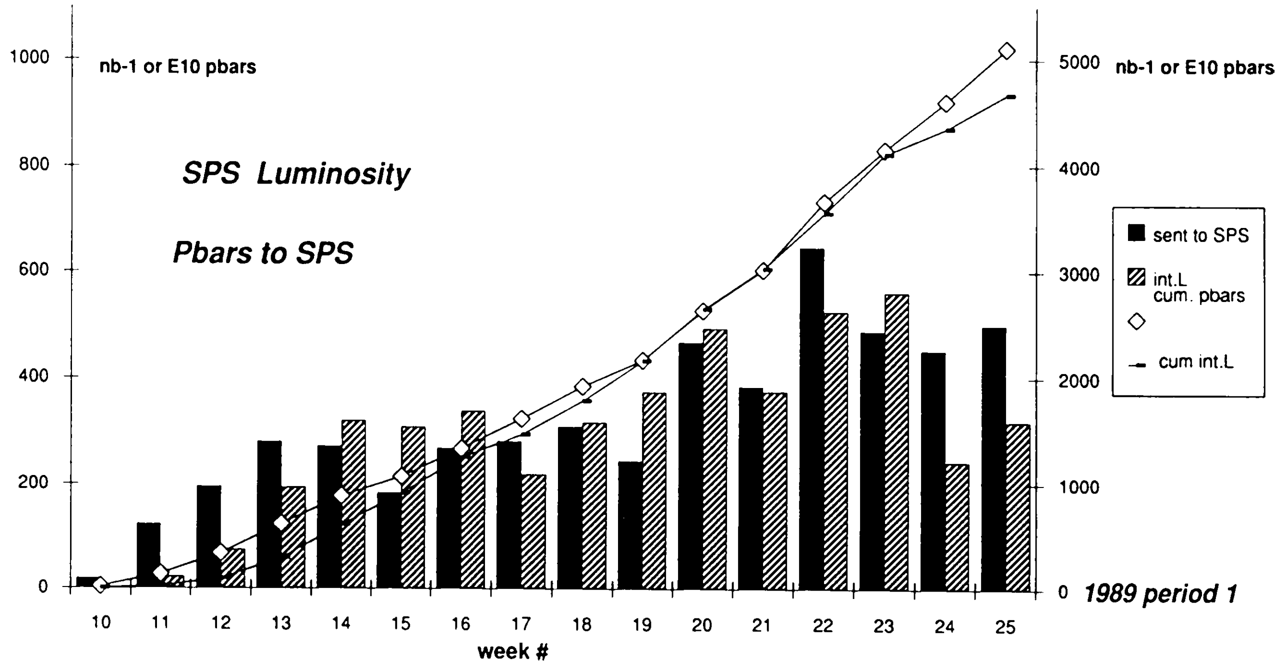
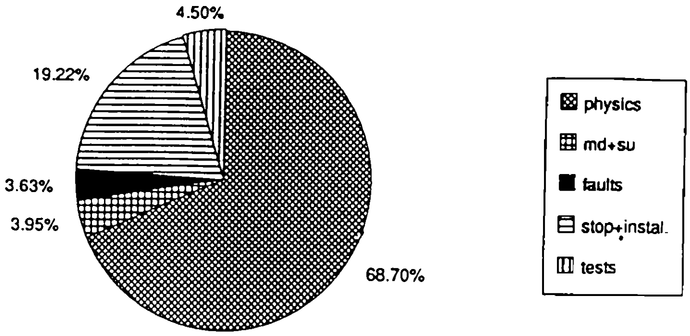
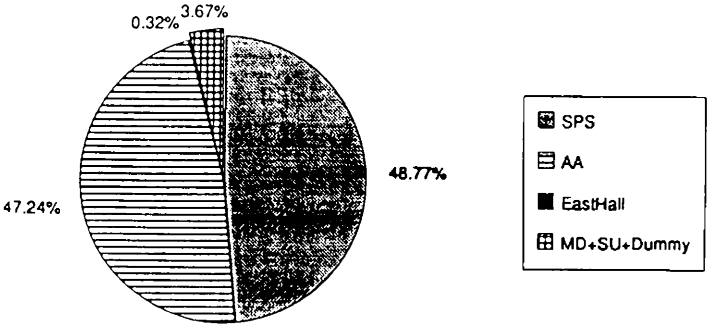


*Figure 3*

1989 PS hours distribution

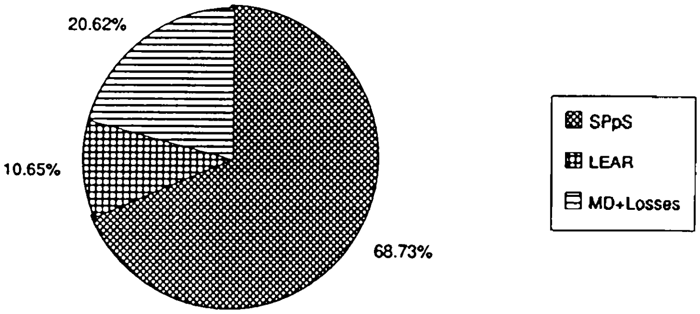


1989 Protons distribution



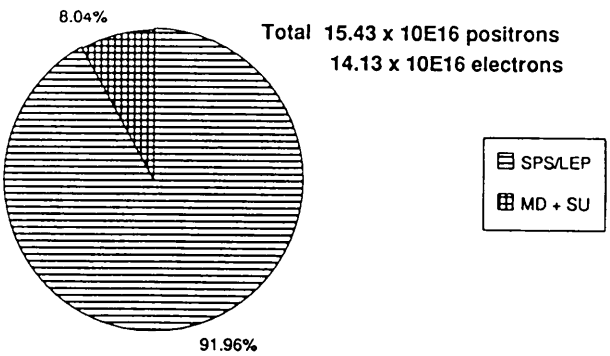
Total 62.7 x 10E18 protons

1989 Antiprotons distribution



Total 74.2 x 10E12 antiprotons

1989 LEPTONS distribution



Total 15.43 x 10E16 positrons
14.13 x 10E16 electrons

*Figure 4*

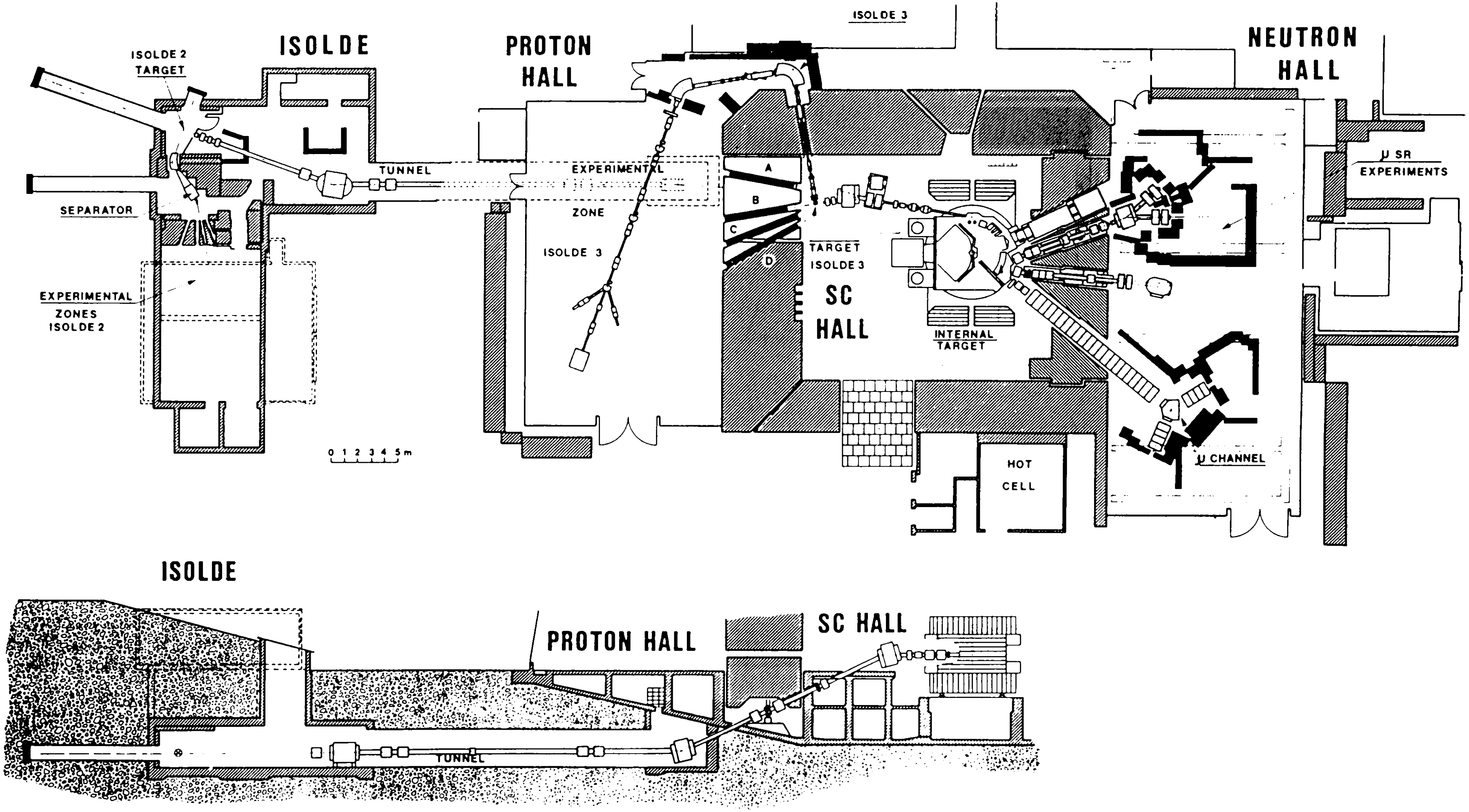


Figure 5
*Layout of the SC experimental area at the end of 1989*

*Table 1*
*Statistics for PS Ring operation in 1989*

| | |
|---|---|
| Scheduled physics running time | 6329 hours |
| Achieved physics running time[1] | 6018 " |
| Scheduled setting-up time[1] | 353 " |
| Total ejected proton beam intensities | |
| antiproton production | $2.97\times10^{19}$ |
| SPS collider | $4.87\times10^{17}$ |
| SPS fixed target | $3.05\times10^{19}$ |
| East Hall slow ejection | $2.11\times10^{17}$ |
| To beam dump | $0.17\times10^{19}$ |

[1] Includes some machine development

*Table 2*
*Statistics for AAC operation in 1989*

| | |
|---|---|
| Scheduled running time | 5838 hours |
| Achieved running time | 6037 " |
| Total number of antiprotons produced | $7.4199\times10^{13}$ |
| Average production rate | $3.1\times10^{10}$/h |
| Maximum stack during 1989 | $1.31\times10^{12}$ |
| Total number of antiprotons sent to SPS | $5.1033\times10^{13}$ |
| Total number of antiprotons sent to LEAR | $0.7897\times10^{13}$ |
| Accidental stack losses | $1.5269\times10^{13}$ |

*Table 3*
*Statistics for LEAR operation in 1989*

| | |
|---|---|
| Scheduled physics running time | 3483 hours |
| Scheduled setting-up time | 1820 " |
| Achieved setting-up time[1] | 1848 " |
| Total number of pulses injected | 2070 |
| Total number of pulses extracted for physics | 1656 |
| Total number of antiprotons injected | $7.1\times10^{12}$ |
| Total number of antiprotons ready for extraction for physics | $4.5\times10^{12}$ |

[1] Includes physics, setting-up and machine development

*Table 4*
*Statistics for LEP Preinjector operation in 1989*

| | |
|---|---|
| Scheduled lepton production time | 4050 hours |
| Achieved lepton production time | 3797 " |
| Scheduled production time for LEP | 3624 " |
| Achieved production time for LEP | 3391 " |
| Total number of electrons sent to SPS/LEP | $13.1\times10^{16}$ |
| Total number of positrons sent to SPS/LEP | $14.2\times10^{16}$ |

*Table 5*
*Statistics for SC operation in 1989*

| | |
|---|---|
| Scheduled physics running time | 4019 hours |
| Achieved physics running time | 3839 " |
| Scheduled machine development & setting-up time | 913 " |
| Achieved machine development & Setting-up time | 934 " |