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THE ACTIVITIES OF THE PS DIVISION IN 1990

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with major contributions from the PS Staff

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Introduction

1990 will go down as a watershed year in the history of the 'Particle Sources' Division. While certain activities and physics programmes have come naturally to the end of their life-cycle, new invigorating ones have again required the PS to undergo a technical rejuvenation. This is on top of it's role of providing a diverse multitude of particles - a role in which the PS excels almost to the extent of being taken for granted by all the physics programmes at CERN. Notably, the Synchrocyclotron ended its historic 33rd and last year of operation. However, its main client, ISOLDE, has been given a new and better lease of life thanks to the decision to construct a new ISOLDE area to be supplied by the PS Booster. While the major proton-antiproton collider operations ended after ten years of intense activity at the end of 1990, a second-generation antiproton physics programme at LEAR is in full swing and even minor collider operations are foreseen for the SPS. Similarly, LEP continues to be an exacting client demanding increased production of electrons and positrons. The successful sulphur run in 1990 augers well for the future ion programmes at CERN, already given a further boost by agreements with certain countries to participate in the development of a Lead Ion Facility at CERN. Looking ahead, studies to produce high brightness proton beams for the LHC have continued and for the distant future, a facility to study the production of very short and intense electron bunches for the CERN Linear Collider is under construction. A feasibility study to construct a B-meson factory in the ISR tunnel has been been completed in collaboration with the Paul Scherrer Institute, Switzerland and the division's resources have also been called upon to provide the technical know-how and conceptual design of a proposed tau-charm facility in Spain. The Division has provided expertise for the Technical Training Programme at CERN, in particular for courses in beam diagnostics and an introduction to accelerator physics. Major contributions have also been made to the LHC design study and elaboration of systems for beam diagnostics and controls. CERN's ongoing programme of assistance to the UNK project in USSR has also benefitted from the active involvement of PS staff. It is with deep regret that the Division noted the passing away in 1990 of one of its eminent accelerator physicists, Eifionydd Jones.

Tables 1 to 5 and Fig. 1 illustrate the breakdown of the year's operation of the PS Complex. Fig. 2 illustrates the new beam records established in 1990 while Figs. 3 & 4 show the performance of the antiproton physics programme in 1990 and to date. Fig. 5 permits a view of the new ISOLDE facility under construction while Fig. 6 exposes the versatility of the PS complex in providing the diverse types of particles, energies and intensities to the different users, all within a magnetic supercycle of 19.2 seconds .

PS Complex Operation

The year's operation comprised three long running periods separated by very short shut-downs. The first two periods were devoted to LEP with SPS and LEAR physics in parallel, while the last period was exclusively for the SPS Collider with LEAR as a minor client. The year's statistics show an all time record of 6861 hours of running with 6012 hours used for physics.

The year commenced with a long shut-down dedicated to preventive maintenance and major installation or construction activities in all the machines of the PS Complex. These included the civil engineering for the beam transfer line from the Booster to the new Isolde location. The renewal of the controlled-access system for LPI and the transfer tunnels was completed on schedule and the general start-up of the PS Complex began on the 26th February. In spite of a major fault due to an unwanted coupling between the two PSB main quadrupole power supplies, all the beams were ready in time to be delivered to the different users.

The first period from end-February to mid-June was devoted to LEP physics and machine studies; this was in parallel with other operations for the SPS fixed target physics, AAC & LEAR and test beams for the East Hall. Over this period of 15 weeks, the CPS had the availability of 94 % for protons in the SPS and 92% for leptons . The major faults were due to breakdowns of power converters, water cooling affecting the PS 114 MHz cavities and several general power cuts caused by thunderstorms. The PS supercycle was modified frequently to optimize the particle distribution to the users and to permit beam studies in parallel with the routine operation. A combined machine development session was used successfully by the CPS and the SPS to prepare for the ion operation in the summer. Several studies were carried out in the PSB and the CPS for their possible roles in the LHC injection chain; a notable success in this context was the harmonic 2 recombination in the PSB and injection into the CPS of a bunch of 5.10 E11 protons with normalized emittances smaller than 10 pi.mmm.mrad in both planes; this was kept on the 1 GeV plateau without a substantial blow-up of the beam; the behaviour of the beam at 26 GeV/c in the longitudinal plane was also studied. After the LEAR startup, regular transfers of antiprotons were carried out ranging from 1E9 to 1.5E10 per pulse. For the AAC, often working in the energy-saving mode, a reasonable performance was achieved; yields of up to 58 E-7 pbar/proton were measured with the 20 mm Li lens used for antiproton focussing. A stack of more than 1E12 antiprotons was kept in the AA for 6 days with reasonably low loss rates (1.5 E9 pbars/h).

The first part of the second operation period (mid-June to end-August) was very similar to the previous one with the same clients. A successful test of a prototype pulsed target for ISOLDE with the PSB proton beams took place during the machine start-up. The second harmonic PSB cavities were put into operation in order to reduce the transverse emittances and to allow stable intensities of about 2.2 E13 protons per pulse in the PS. Several experiments at 400 GeV/c in the SPS benefitted from this improvement. At the same time, LPI delivered the usual 7 E10 leptons per cycle to the PS for LEP. The major faults affecting all the beams were due to general power cuts, caused by line transients or severe thunderstorms. These cuts, coupled with failures in the uninterruptable power systems caused severe disruption to the physics programmes. Hence, the PS availability for this period was somewhat lower, with 92.5% for proton and 89.3% for lepton physics.

During the second part of this period, ion beams replaced the protons for the SPS fixed target experiments. After numerous adjustments of the machines and joint development sessions with the SPS, the PS Complex was ready to deliver 4 batches of ions per supercycle on 26th July. The ion source ran particularly well with good stability and with only small interruptions for adjustments. The ion beams were transmitted through Linac1 and Booster with relatively good efficiency and the separation between the oxygen and the sulphur ions was done in the PS by adjusting the frequency at transition. About 3 E9 to 4 E9 charges of S16+, representing more than double the numbers available in 1987, were accelerated per supercycle in the PS and sent to the SPS. For the first time, 8 different beams were running operationally in the new supercycle of 19.2 s and supplying all the users of the PS Complex with 6 types of particles, i.e. p, pbar, O8+, S16+, e+ and e- (see Fig. 6). These 8 beams represented the upper limit permitted by certain equipment and the controls system to operate the PS Complex in this 'pulse to pulse modulation' mode.

Both the AAC and LEAR continued to work well in parallel with the ions. LEAR supplied the different experiments in the South Hall with antiprotons at several energies, i.e. 105, 600 and 900 MeV/c. A notable first for LEAR was the antiproton deceleration and extraction at 72 MeV/c (2.7 MeV kinetic energy).

The third operation period from September to Christmas was the last major collider run foreseen for the antiproton experiments. A large part of the month of September was used for the setting-up and adjustments; the antiproton source was equipped with the new Lithium lens of 34 mm and reasonable yields were achieved. However, stacking rates remained low during three weeks due to several breakdowns or problems in the AAC or the PS, i.e. a water leak on the Li lens cooling system, faults on the AA low level RF system, beam orbit problems in the AA ring, power cuts in the PS ,etc. At the end of September, the mean antiproton production per hour was of the order of 5 E10 ; however, this soon progressed to a new record of 6.14 E10 pbars/h, largely due to the improved quality of the production beam (thanks to the new one-turn longitudinal feedback systems installed on each of the PS 9.5 MHz cavities) and the 34 mm Li lens.

After the replacement of a malfunctioning vacuum valve in the PS to SPS extraction line, the antiproton transfer efficiencies improved dramatically and up to two , dense six-batch transfers per day became routine , with over 97% efficiency between the AA and PS extraction. November was the best month in the history of Collider operation : an average of 7 E11 antiprotons were sent to the SPS per day and the integrated luminosity recorded over the 30 days was around 4760 inverse nanobarns, equivalent to the total four-month run figure of 1989 ! (see Figs. 3 & 4)

Several major faults perturbed the operation during this period; these included the failure of a water pump in the AAC, frequent breakdowns of the AA main quadrupole power supply and of several power supplies in the PS and the PSB, poor temperature regulation of the PS main magnet and so on. The last eighteen days of operation for this period was very poor; this was largely due to the extreme weather conditions , leading to reduced power consumption and day-time shut-downs imposed by the electricity contracts with the supplier. While the AA stack intensities reached 1.2 E12 pbars on several occasions, unwanted power cuts prevented their consumption.

On the PS side, a new record of 1.85 E13 protons per pulse in 5 bunches was obtained for the antiproton production beam. The losses in the PSB to PS transfer line and at PS injection were kept low to around 3.5 E12 protons per pulse.

LEAR was supplied with antiprotons too, but suffered from the AAC and PS problems. Several extraction energies were catered for, including the 72 MeV/c for the anticyclotron test, 3 successive energies for the Jetset experiment, 200 MeV/c for experiments PS195 and PS197, 105 MeV/c for experiment PS196, 309 Mev/c for experiment PS201 and 609 MeV/c for experiment PS199. About 15 daily antiproton transfers and fills were carried out to achieve a total of 1110 spills used for physics during this long period.

LEP Pre-Injector - LPI

For the second year of injector operations for LEP, the LPI performed very reliably with a beam availability of around 95% . The peak performance over the design figures showed an improvement of a factor three in positrons and a factor ten in electrons. In parallel with the routine operation, the second phase of the LPI consolidation has been completed. A new modulator/klystron station of the Linac LIL has been set-up. It will serve as a spare as well as for the high power tests of the RF elements in the CLIC Test Facility, built close by. A modulator test station is under construction for the intensive tests of the improved components. A LIPS cavity prototype in stainless steel, part of the RF pulse compressor scheme, has been tested at full power (35MW). Three sets are being built to improve the vacuum reliability and performance of the operational LIPS systems. A simplified and modernized front-end of LIL , composed of a new electron gun modulator and a bunching system, has been developed and reviewed with specialists from various European laboratories during a special workshop. After careful measurements of the electron gun on a dedicated test stand, the whole front-end has been installed and tested with the beam in the LIL tunnel, taking advantage of the LEP shut-down during the p-pbar run at the end of the year. It demonstrated excellent performance with up to 5E11 electrons on the converter target and a positron yield of .45 %. The new front-end, equipped with an improved instrumentation and matching section will be left in operation and a spare is under fabrication. The Electron Positron Accumulator(EPA) has been equipped from July with a feedback system specially developed by the RF experts to damp the longitudinal , coupled bunch instabilities observed at high intensity. Skew quadrupoles have been introduced in the lattice to control the transverse coupling. Finally, in preparation for the future LEP luminosity increase, a proposal for an improved positron production rate in the LPI is being studied.

Hadron Injectors - HI

The outstanding event around the Hadron Injectors was the splendid performance of the new Radio Frequency Quadrupole (RFQ2): within one hour of beam tests, RFQ2 accelerated its design proton current of 200 mA to 750 keV on its test bench; later, almost 240 mA was obtained. This is the highest current ever achieved with an RFQ intended as a linac injector. Preliminary measurements have shown that the beam is within specified emittance and energy spread. The intention is to replace the huge, high-voltage (Cockcroft- Walton) pre-accelerator by moving this RFQ2 in front of the Linac2.

During 1990, the two Linacs and the PS Booster (PSB) functioned in the usual reliable manner, with Linac2 providing the high intensity proton beams and , Linac1 providing oxygen and sulphur ions to the PSB and the subsequent synchrotrons. LEAR continued to use the protons from Linac1 for its machine studies. The tricky procedures to generate the antiproton production beam ,ie, the RF gymnastics in the PSB to shorten the bunches and , the vertical funnelling of pairs of PSB rings by means of an RF dipole in the 1 GeV PSB-PS line (thus putting the full PSB intensity into half the PS circumference) , have now become routine operations.

During the four-week oxygen/sulphur run in the summer, the PS was able to deliver more than twice the sulphur intensity of the last (1987) ion operation period. This was mainly due to (i) thorough analysis of the ion source (ECR) behaviour , resulting in improved settings and pulse-to-pulse stability and , (ii) improved capability of the PSB low-level electronics to tackle very low intensity ion beams. The operational experience gained with this ion run is invaluable for the proposed Lead Ion Facility ,which will profit from some of the technologies currently employed. In addition, much development work for this project is going on in the HI Group. In particular, this includes work for the main linac structure (model measurements, beam dynamics codes, etc) , the ion RFQ, and for the beam separation and measurement line, all in collaboration with the outside laboratories participating in this project.

The Hadron Injectors are getting ready for a new demanding client, namely the ISOLDE Isotope Separator Facility. There is a natural involvement in most practical aspects of the ISOLDE move (installation work, space problems, use of the PSB spare parts, safety aspects). of particular concern is the "loss management" in the PSB, i.e. , seeking ways for reducing the machine irradiation in spite of a four fold increase in the proton flux.

A very challenging task for the Hadron Injectors is the production of high brightness (ratio intensity/emittance) proton beams to fulfill the very demanding requirements of the proposed LHC. At present, beams from the PS Complex (considered as part of the LHC injector chain) fall short by a factor 2 to 3 in terms of brightness. Possible scenarios to achieve these dense beams have been contemplated and hardware implications studied. Most scenarios include the high-intensity proton RFQ mentioned earlier, and fast (single-turn) injection into the PSB. A fast PSB injection kicker used in the early seventies for the running-in period of the PSB has been re-installed and beam tests have started.

HI staff look after the exploitation of major beam diagnostics components of the PS Complex (current transformers, position monitors, profile monitors, scintillator screens). Major new developments /installations are (i) the beam instrumentation for the 120 metre transport line between the PSB and ISOLDE; (ii) position monitors and scintillator screens for the electron beam in the CLIC Test Facility and, (iii) a novel optical beam profile monitor making use of the photons emitted from excited electrons of the residual gas at beam passage ; for the latter, promising profiles have been obtained with 750 keV protons.

Antiproton Accumulator & Collector - AAC

The first half of the year for the AAC was dedicated to the LEAR operation while the second half was for both , the SPS and LEAR, the former taking the bulk of the antiproton production. The low antiproton flux required by LEAR permitted considerable energy savings in the early half of the year with intermittent stacking but regular transfer of antiprotons to LEAR in this so called economy mode of operation. A new record in accumulation rate of 6.13E10 pbar/h was obtained and reached several times during routine operation.

A lithium lens of 20 mm in diameter, pulsed at 480 kA, was used as a collector lens during the first part of the year and yielded 58E-7pbars/proton . During the second part of the year, a lithium lens of 34 mm in diameter was used. This lens , pulsed at 1.0 MA, gave an increase of a few percent in yield. In spite of a water leak which developed halfway into the collider run (and which could not be repaired due to radiation), it was kept successfully in operation until the end of the run. The gain in yield was less than expected because it was not possible to run at the desired current of 1.3 MA (for which the transformer and the pulser were designed) due to the temperature and fatigue limitations of the lithium lens itself.

With the financial help of the German Ministry of Research and Technology , the development work of a plasma lens for collecting antiprotons had already restarted in early 1989. A new plasma lens model scaled for the target area installation was designed, constructed and tested. The necessary mechanical support structures compatible with the later installation at the target have been assembled together with the lens and tested successfully in the laboratory. First high current operation and yield measurements are planned in March 1991.

The AA stochastic system has been improved by reducing the hardware coupling in the 4-8 GHz system (the transverse HF cooling) and reasonable Beam Transfer Functions have been measured. However, due to the combination of intrabeam scattering and a too high a machine-design parameter eta , problems were encountered to explore the full 4-8 GHz bandwidth at high stack intensities (Schottky bands overlap). This was partially cured by extending the core cooling band to the lower frequencies with the new 2-8 GHz preamplifiers and the 2-4 GHz power amplifiers.The quadrupolar pickup installed and tested in 1989 has been successfully used to check the AC/AA and the PS/AA beam transfer line matching. With the new collector and these improvements, good stacking rates were achieved upto and beyond medium stack intensities , even surpassing the factor ten on the performance of the antiproton complex prior to ACOL. A major upgrade of the operating consoles was carried out with the emulation of the touch-panel and other console interactions on an Olivetti Personal Computer. This work was later extended to carry out a similar emulation on DEC workstations running under UNIX and X-Windows. This permits the renewal of aging console hardware by using modern workstations and without doing any changes to the existing higher level & accelerator dependent software.

Main Proton Synchrotron

The main activity in the PS Ring during the 1990 shut-down has been the overhaul of octants 5 and 6. The first quadrupole of the Slow Extraction-62 beam line has been replaced and the whole beam line recabled prior to the replacement of all the mechanical supports scheduled for 1991.

An evaluation of the PS complex has been carried out in order to provide the required beam characteristics for the LHC. Theoretical and experimental studies in the PS have been devoted to the space charge phenomena at low energy as well as to the causes of longitudinal instabilities during debunching at high energy. The modifications required to produce the lead ion beam intensities and characteristics for the ion-ion option of the LHC project have also been studied. In these studies, the possible use of LEAR , PS or the AAC machines as intermediate storage or cooler rings have been analysed and compared. For the Lepton beams for LEP, experimental and theoretical studies have been pursued on coherent, incoherent and missing bunch effects induced by CO ions trapped by the electron beams.

For the RF systems, modern commercial solid state amplifiers have been installed as drivers for the ferrite cavities and power amplifiers. A major project has been completed to implement a "one turn delay feedback"on these cavities ; this is to reduce the transient beam loading at the revolution frequency due to the partial filling of the accelerator. It involved the design of 8 different digital electronics modules amongst the total of 120 units constructed. The full system was installed during the one-week machine shutdown at the end of August and was operational through the last run of 1990 for the SPS Collider. The performance was as expected , with substantial improvement in the quality of the antiproton production beam. In practice, this meant that the beam losses in the PS were reduced and the longitudinal emittance of the beam was smaller, giving tighter and denser bunches on the production target. Both of the two 114MHz cavities were kept in the ring during the 2 runs for LEP, one system acting as a fall back solution in case of need. This set-up gave full satisfaction with an overall RF availability of 99.4% and 99.7% for these runs .

For the new Slow Extraction scheme, design and production of relevant equipment have been going on in view of completion of the new scheme for March 1992. These include the new vacuum chambers ready for installation in the magnet units and straight sections 24 and 25 and the Septa regions of sections 57 and 61 .The design of the septum tank for straight section 57 has been completed ; it is suitable for ultra-high vacuum with its bakable,circular and modular conception. This tank is intended to be the prototype for all future septum tanks in the PS and is on order while the 2 septum magnets for straight section 61 are under production in the MT Division workshops.

The Kicker tank KFA71 which experienced troublesome high voltage breakdowns in the course of 1989 was replaced during the winter shutdown by a spare unit. It performed satisfactorily for the rest of the year. Remote controlled short -circuits were installed and tested successfully on the output ports of the injection kickers magnets TIK. These enabled the doubling of the kick strength with the same pulse generators but, at the cost of doubling the rise/fall times. This method has proved itself as a viable technique for the generation of the injection kick length needed for the lead ions in the PS.

In the course of the year, a fault on an old-fashioned mercury thermometer used for the temperature interlock of the main magnet led to the decision to replace all these obsolete devices with a more modern system . Another serious breakdown has been the development of a small vacuum leak on the pbar extraction septum SMH26 ; however, one could carry on the pbar beam transfer operation to LEAR without replacing the septum because it necessitates the use of the septum magnet for only a few times per day.

The Fast Wire Beam Profile Monitor has again been successfully used, especially during the Collider run. Tests with high intensity beam have shown that the Beryllium wire can withstand and measure beams up to 1.8E13 protons circulating in the machine. The system has now been further improved in view of its use for the machine studies in the PS , the latter mainly for the LHC. Two new mechanisms have been ordered to allow carbon wire tests in the laboratory, and VME interface hardware has been purchased for its conversion to more sophisticated controls.

Low Energy Antiproton Ring - LEAR

The Lear Ring has been substantially improved in 1990 by the insertion of pole-face windings (both sextupolar and vertical dipolar coils) on the main bending magnets. These windings permit (a) the reduction of non-linear transverse coupling and keeping low the second order chromaticities and, (b) the correction and adjustment of vertical orbit , especially in the regions where the Jet-set experiment and the electron cooling system have been installed in the ring. This major installation work was carried out successfully under a tight schedule and the physics programme commenced on time.

The stochastic cooling system has been consolidated, making it more reliable and simpler to adjust. In addition, a prototype of the transverse feedback system has been installed. It helps to avoid the beam instabilities for high density beams obtained by the cooling process. Around the electron cooler,tilted solenoids have been installed to compensate simultaneously the dipolar effect of the toroids and the coupling effect of the main solenoid. At 200MeV/c , the dense beams obtained by electron cooling [N=8E9 particles,dp/p(FWMH) =1.5E-4, emittances<3pimmmrad] were stabilized using this feedback system. A programme of measurement of the machine impedance has been launched to understand the limitations of such dense beams. For the first time, the electron cooler has been used in routine operation for the TRAP experiment. New types of detectors (multi-photomultipliers,silicon strips, electrons emitters) have been installed and tested with success, using the slow-extracted low momenta beams.

A new beam line has been designed to permit the beam sharing between OBELIX and the CP violation experiments and will be installed in 1991. The Jet-set experiment received its first beam in 1990 and achieved a luminosity of 1.0E30 cm-2s-1 . Upgrading of the stochastic cooling at high energy and careful control of beam instabilities are foreseen to further improve he machine for this experiment. For the CP violation experiment requiring a constant flux of particles(2E6 /sec), progress has been made to decrease the ripple on the spill using a feedback technique. Fluxes of more than 1E6/sec and an extraction efficiency of 80% for the complete one hour spill have been observed.

Towards low momenta ,the P118T experiment has been supplied with the 72MeV/c beam of antiprotons. The present short life time of the circulating beam at very low energy limits the flux and extraction time to 5E4/sec and 15 mins respectively.

Experimental Areas And ISOLDE

Isolde

The project "Transfer of ISOLDE to the PS-Booster" will permit one to pursue physics with the radioactive isotopes by means of the isotope separators Isolde 2 and Isolde 3 after the closing down of the SC. The isotopes will be produced by interaction of the 1 GeV PS-Booster proton beam on the Isolde target, instead of the 600 Mev beam from the SC and with the interleaved PSB spare cycles, unused by the PS. With the help of other Divisions (PPE, ST, AT, MT and TIS) and the future users, a detailed lay-out of the transfer line, target and experimental areas has been defined. The new Isolde experimental area will be installed on a current parking enclosure close to the PS-Booster (see Figure 5). It is composed of 4 buildings: access area, target area, service and control room, and a 700 m2 experimental hall. Digging of the tunnel took place early this year and was completed early enough to allow the start-up of the PSB on schedule in February. The project was presented to the PSCC early in April and was approved by the Director General on the 4th of May. In October, soon after the approval by the finance comittee of the construction of the new buildings, the civil engineering work started. At the end of the year, the terracing was completed and the first concrete work could start. The buildings should be ready by Autumn 1991 and the Isolde Physics at the PS-Booster should start in March 1992 after the annual shut-down.

Experimental area (South)

In the South Hall, antiprotons extracted from LEAR have been distributed to 11 experiments which took data from Easter till the end of December for more than 4000 hours. The first tests of the new beam line S4 began with protons at 105 MeV/c for the LEAR start-up in March. This line, designed to feed the anti-cyclotron of P118T with antiprotons of very low energy, has subsequently been fed with antiprotons at 72 MeV/c in the slow extraction mode. Beam steering has been carried out with the help of Position Sensitive Photo Multipliers. Beam optics calculations have been confirmed by the measurements and a beam of 2 mm half width in both planes has been obtained on a new monitor, a Double Sided Silicon Strip Detector. This beam has been injected in the anti-cyclotron where the antiprotons have been decelerated and brought to a rest. The overall efficiency has still to be improved for the beam life time but, for the first time, antiprotons of momentum lower than 105 MeV/c have been transported and injected in an experiment. Calculations for the new line S3 have been completed in collaboration with the physicists of the experiment PS189 and the new lay-out of the area has been finalised. In this new line, antiprotons will be decelerated down to 20 MeV/c by means of a Radio-Frequency Quadrupole (RFQ). Installation work has started and will be continued at the beginning of 1991, with the first tests planned for Easter 1991 . This experiment, complementary to the PS196, is designed to compare the inertial mass of the proton and of the antiproton.

New project of beam sharing in South area

To improve the sharing conditions of the antiproton beam in the South area , an additional beam line is under study. This new line will permit parallel running of two of the three experiments, ie, Crystal Barrel, CP Violation and Obelix and , could be put into operation in 1991.

Experimental area (East)

The East area has been actively used as usual for detector developments or to test detector improvements. A new type of filament for Gas leak detection as well as a new type of an electrovalve for water distribution has been successfully tested. Quantities will be purchased to replace the present devices in the experimental areas.

Synchro-Cyclotron

This, the 33rd year of operation of Cern's oldest accelerator, the 600 MeV synchrocyclotron, turned out to be not only another excellent year from the operational point of view, but also to be an historic one.

In spite of a number of minor problems mostly associated with the ageing of various elements of the machine, the performance was good. Protons were accelerated for the major part of the year, but there was an interlude of 3-helium running in the Spring when internal currents of 6 microamps were regularly achieved, and over 2.5 microamps were delivered to the Isolde targets. Proton currents were typically 4 microamps internally, with the RF running at 20 kV, a safe level where the number of Rf discharges was quite low, ariund 10 per hour or so; such conditions are sufficient for most Isolde experiments, and excellent results were obtained at both IS2 and IS3, where the separator achieved its highest resolving power yet, over 10,000. Beam was also provided for MuSR experiments for the last time, thus ending a 14-year period of such experiments at Cern.

There were two innovations in the running schedule during 1990. For the 3-helium period the SC was forced to change its rhythm to running only 5 days out of 7 because there were insufficient operators due to departures of staff for health reasons. After initial hesitation, this rhythm turned out to be a popular one, but clearly allowed less physics to be accomplished. Thus, when it was announced that the SC would close at the end of the year, there was strong pressure from the physicists to return to a full-time running schedule, in order to maximise the physics time available. The solution adopted was to engage some Isolde research students as temporary operators. Three students were found and given an accelerated training before working alongside the regular SC operators for the last 4-month period of the SC's life. This arrangement worked extremely well from every point of view and allowed the SC to run at full steam right up to the end.

It had been clear for several years that the SC would soon need rejuvenation not only of old equipment for which spares were no longer available in industry, but also of the staff, many of whom had been working at the machine since the early 1960's. The idea was born during 1989 to transfer the Isolde facility to a new experimental hall fed by a new beamline from the 1 GeV PS Booster, thus maintaining the Isolde physics programme at Cern but allowing the SC machine to be switched off. This proposal was accepted in May 1990, and so it was decided to stop the SC in December. Carlo Rubbia delivered the "coup de grace" at the stroke of noon on 17th, thus ending an era, with many vivid memories of the early days of Cern and anecdotes about some of the now-famous physicists who came to use the SC. This machine was one of the best cyclotrons ever constructed, and it survived for such a long period because of its excellent performance and the devotion of its staff. One recurring theme throughout the SC's life has been been the question of closing it down.......well now its done!

Le SC est mort, vive Isolde au Booster!

Computer Controls

Controls activities during 1990 have been dominated by the long LEP run and the last high intensity run for the p-pbar collider. The other major activity was the preparation of the consolidation program for the PS and SL controls system, in close collaboration between the two divisions. In addition, the servicing and exploitation of the running control system constitue 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 1990 was used for the normal preventive maintenance of the controls computers network and interface hardware. The two ND-500 machines used for development and on-line modelling were replaced by a new ND-5400, with substantial savings in maintenance costs. The effort to clean up the timing has continued and, with the installation of a new "General Timing Module", all master timing event generators were centralised in the central timing room and well equipped with software diagnostic tools.

The LEP Preinjector (LP) complex was furnished with the last application software facilities, mainly in the field of instrumentation. Full beams statistics were also added on. A redesign of the fast timing system of the LP complex has resulted in a significant simplification of the associated real-time software. The achieved reliability of the LP controls system contributed noticably to the spectacular results of the LEP run.

The p-pbar run benefitted from the improvement of the timing system and the new diagnostic tools. Unfortunately, some major problems in the non-interruptable power supply caused severe disruption in accelerator operation.

The major activity during this year was the preparation of the joint PS/SL project for consolidation and upgrade of the controls systems. A close collaboration between the two divisions was established and, working groups for architecture and application of controls finalised their conclusions by the end of the year. Simultaneously, regular contacts with the large community of users was set up through the Control Users Forum. The conclusions of the working groups were presented to this Users Forum. A specialized interdivisional group looks after the control protocols between the specific equipment and control systems. Conclusions from this group are expected in early 1991. All this work confirms the general architecture for controls, namely, VME châssis running OS9 real time operating system for the equipment front end, a network with TCP/IP protocols suite and, UNIX file servers and workstations with a X-windows system.

Within this overall framework of the CERN controls architecture, joint development and collaborations have been initiated. On the hardware side, a VME module which gives access to the current PS timing and PLS system was designed and first production is expected in early 1991. A collaboration for design and inplementation of a common timing receiver module has commenced in parallel. A CAMAC serial highway VME module was developed in collaboration with Sofia Institute, Bulgaria. This will permit the continual usage of the vast investment existing in CAMAC for equipment interface.

On the software side, the basic tools for the Device Stub Controller-DSC (a VME châssis, and OS9 real time operating system) has been developed. This include the CAMAC driver, its associated ESONE access routine library, the video driver, and the Nodal interpreter. Infrastructure and development environment have been set up for embedded microprocessors on a VME board.

The initial test of ORACLE data base was done on a UNIX platform. This is the first step towards the evaluation of the capability of such a facility for on-line control.

First control protocol prototyping and validation has been conducted on a CAMAC beam instrumentation system. This facility shows its full power for similar use on another class of beam instrument devices. The porting of this facility to the DSC environment has begun.

For the user environment in the DEC workstation, MOTIF and X-window toolkit from OSF (Open System Foundation) have been installed. Dedicated widgets for accelerator controls, equipment access, and hardcopy services were developed. The first validation of this general operator console environment was carried out for the PS closed orbit program. The X-windows MOTIF system was also successfully used for the new remote control of the hadron Linac and for the prototyping of the new user interface to the Program Line Sequencer of the PS complex. Design and implementation of the user interface continues in close collaboration with the Operations Group and, will be applied on the PS 1GeV injection process.

For the consolidation of the controls system, the first slice for 1991 was defined after a careful and detailed analysis. It will be the LEP preinjector process, with the goal to replace completely the two ND-120 computers by a small number of DSCs. A detailed analysis of the complete project budget was carried out in close collaboration with the SL Division. A resource distribution for financing this project over the five years was worked out from this analysis.

A collaboration to design the control system of the UNK accelerator in IHEP Protvino (USSR) has been established in the Division. Key personnel of the control team from USSR visited CERN and has achieved the conceptual design and has prepared the first phase (prototyping and tests) of the implementation.

The Controls/Operations joint project to investigate possibilities and advantages of knowledge based methods (expert systems) for the PS complex has developed a Beam Diagnostic Expert System to the level of a large scale demonstration. It is applied on the beam transfer line between the LINAC and the Booster. In conjunction with these developments, participation of the PS Division in the European Community, Esprit II project-2256 called ARCHON (Architecture for Cooperative Heterogeneous On-Line Systems), has continued. Preparation of the PS expert systems BEDES and CODES as test bed facilities for ARCHON have commenced and the first tests are expected for 1991.

Research ,Development & Projects

Lead Ion Accelerating Facility

The main parameters of the Lead Ion Accelerating Facility at CERN have been determined and work continues on the refinement of certain related aspects. However, the principal activity in 1990 has been of organizing collaborations with several laboratories in different countries.The main items for the planned facility will come from outside institutes, hence proper coordination is very important. While this may be a common practice for physics experiments , it is rarely invoked in the field of accelerator construction. A rare exception few years ago has been the project for oxygen ion acceleration, a collaboration between the LBL, GSI and CERN. The major differences from a high energy physics collaboration are the aspects of equipment integration into existing accelerator facilities, stringent reliability criteria for routine use and operations by existing crew. Extensive technical meetings were held for this purpose, mainly with teams from the laboratories of GANIL, Legnaro (INFN), IAP Frankfurt, GSI and University of Torino. Formal agreements will be signed in the near future and other laboratories are still expected to join in.
Accelerating structure measurements and detailed beam dynamics calculations have been carried out at CERN, the latter with active collaboration of CEN Saclay.

CERN Linear Collider (CLIC) Test Facility & Injection Schemes

The construction of the blockhouse and equipment gallery of the CLIC Test Facility (CTF) has been completed in early 1990. After the installation of the waveguide system and utilities, the first item under test was the buncher for the LEP Injection Linac . Subsequently, work started on a key element for the CLIC drive beam ,i.e. the laser driven 3 GHz electron gun. The gun was constructed in the CERN central workshop and was conditioned up to its design field of 100MV/m on the axis. After the installation of a short beam line, a CsI photocathode in the gun and a laser system, an electron beam was produced just before the end of the year. Despite the provisional nature of the laser system (asynchronous to the RF), the trial has shown a reasonable correspondence between the measured and computed beam energy. Due to lack of manpower, no progress could be made with the design of a system for making photocathodes in situ for the gun.Consequently, the photocathodes which can be transported in air will continue to be used in 1991. These cathodes have low quantum efficiencies and the beam intensities will remain modest but they are sufficient to commence trials with the CLIC structures before the end of 1991. The cathode evaporation chamber in the photocathode laboratory was modified and the photoemission can now be monitored during evaporation.The chamber, the DC gun and the beam line permit high temperature bake-outs..The quantum efficiency of the Cs3Sb cathodes has been increased to about 2%. Preparing metal cathodes by ion bombardment will soon be attempted.

In parallel to the building and running in of the CLIC Test Facility, a possible scheme for the CLIC injector complex, able to produce both positron and electron beams for the main linac has been worked out. For the nominal single bunch operation, it is composed of elements based on conventional technology: an electron gun modulated in intensity, two S-band Travelling Wave linacs of 3.35 GeV, an electron to positron converter target adapted to a mean beam power of 65 KW, two damping rings providing low emittances beams and a bunch length compressor. The characteristics of the beam all along the injector complex progressively converge to the parameters requested by the main linac. Damping Rings based on compact lattices specially developed to provide extremely low transverse emittances (epsillon*beta*gamma = 1.6E-6 pie*rad*m) and strong damping have been shown to fulfill all the required parameters. Studies are progressing on the dynamic aperture, sensitivity to errors and collective effects. The consequences of multibunch operation on the performance of the CLIC injector complex are quite severe especially for (a) the electron gun (b) the converter target with a mean power of more than half a megawatt and (c) the 3 GHz accelerating structures with the generation of a strong beam loading effect. This highlights the necessity for the continued R and D work on efficient electron to positron conversion as well as on the RF gun with a laser-driven photocathode, as envisaged for the CLIC drive beam.

B-Meson & Tau-Charm factories

A feasibility study for a B-meson factory to be installed in the ISR tunnel was carried out in collaboration with the Paul Scherrer Institute, Switzerland . B-meson factories are e+ e- colliders with a center of mass energy of about 10.5 GeV. This is achieved in the proposed scheme by asymmetric energy collisions of 8 GeV electrons against 3.5 GeV positrons. The approach adopted has been to propose a machine which can start with a luminosity of 10^33 cm-2 s-1, but choosing major components such that it would have the potential to go to 10^34 cm-2 s-1 in the second stage, based on the experience gained earlier. A preliminary design of the machine has been made in order to estimate the cost. Considerable savings can be achieved by making use of the old ISR infrastructure and of the new LEP injector. The facility could be operated without any interference to the ongoing physics programme at CERN.

A conceptual study of a tau-charm factory (an e+ e- collider of 2.0 GeV per ring) to be constructed in Spain was made on request of the Spanish authorities. It included a description of the scope and layout of the new laboratory and the conceptual design of the facility together with the injector system. A synchrotron light source using the same injector complex was also proposed. The time scale and necessary resources have also been estimated and the document is presently under study by the Spanish authorities.

"Crab crossings"

For very high luminosity lepton colliders such as factories of phi, tau-charm, B-mesons, linear colliders or e-p interactions, collision at a finite angle may be very attractive. Using a geometric separation of the bunches instead of a magnetic separation in the case of head-on collisions, the bunch frequncy may be very high so that, for given luminosity and tune-shift per crossing, the number of particles per bunch is small and the beam emittance can be reduced. The combination of low beam emittance and the absence of dipole field in the interaction region creates the best conditions for a small photon background. Furthermore, the optics can be independent for the two rings and therefore, tiny values of the vertical beta function have been contemplated (in the 1mm-1cm range for circular colliders). Insertions have been designed using analytical methods based on symbolic computations. Their performance is limited by their chromaticity and by the bunch length which must be somewhat shorter than the beta value. The final focus is achieved with permanent quadrupoles whose field gradient is of the order of 100 T/m for an aperture radius of 1 cm. The drawbacks of the finite crossing angle are the reduction in luminosity due to the lack of full overlap of the colliding bunches and the excitation of synchro-betatron resonances. Both of them are cured by tilting the bunches so that they move parallel to each other in the interaction region. This motion is nicknamed crab-crossing and is applied to the bunches using RF deflecting fields in cavities located at a quarter betatron wavelength from the crossing point. In the case of a B meson factory, these fields would be produced in the superconducting RF cavities with an integrated deflecting field of 2.5 MV at 500 MHz.

Linac-on-Ring Colliders

Linac-on-ring schemes for high-luminosity colliders are based upon collisions between an intense positron beam in a conventional storage ring and relatively low intensity bunches of electrons from a high-repetition rate superconducting linac. The electrons are highly disrupted as they pass through the positron bunch in a low-beta section of the positron ring, and the electron bunch envelope suffers a longitudinal pinch that varies in form according to the chosen beam parameters. The beam-beam effects and the consequences of linac beam fluctuations on positron beam stability have been examined for a variety of parameter sets. The special requirements for the low-beta section and it's optics have also been studied.

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Accelerator Applications of Ferroelectric Electron Emission

The strong electron emission from the surface of ferroelectrics by excitation with short external electric field pulses has been confirmed for a variety of ferroelectric materials. Intense pulses (10 nC) of electrons have been emitted from PLZT ceramics at repetition rates up to 2 MHz. Strong electron emission was also obtained with excitation voltages as low as 300 V from (Ba,Sr)TiO3 samples of 0.5 mm thickness. These features open the possibility to build pulsed, (gated or modulated) cold electron sources with a wide range of charge and current density, geometry and time structure.

The first successful application of the ferroelectric electron emission at CERN is a ferroelectric trigger beam source for a high-power, low-pressure gas switch which may be used for the beam dump system of the future large hadron collider, LHC. Further applications are envisaged in the field of intense beam sources for the electron and heavy ion linacs.

TABLE 1
Statistics of PS ring operation in 1990

Scheduled physics running time	6336 h
Achieved physics running time	6012 h
Scheduled setting-up time 1)	525 h
Total ejected proton beam intensities	
antiproton production	$3.44\ 10^{19}$
SPS collider	$4.57\ \times 10^{17}$
SPS fixed target	$1.89\ \times 10^{19}$
East Hall slow ejection	$2.92\ \times 10^{17}$
To beam dump	$0.66\ \times 10^{18}$
1) Includes some machine development	

TABLE 2
Statistics for AAC operation in 1990

Scheduled running time	5733 h
Achieved running time	5715 h
Total number of antiprotons produced	$8.3616\ \times 10^{13}$
Average production rate	2.64×10^{10}/h
Maximum stack during 1990	1.23×10^{12}
Total number of antiprotons sent to SPS	$4.4684\ \times 10^{13}$
Total number of antiprotons sent to LEAR	$1.7224\ \times 10^{13}$
Accidental stack losses	$2.1706\ \times 10^{13}$

TABLE 3
Statistics for LEAR operation in 1990

Scheduled physics running time	4114 h
Scheduled setting-up time	1314 h
Achieved setting-up time 1)	1158 h
Total number of pulses injected	2673
Total number of pulses extracted for physics	2442
Total number of antiprotons injected	$1.16\ \times 10^{13}$
Total number of pbars ready for extraction for physics	$0.91\ \times 10^{13}$
1) Includes physics, setting-up and machine development	

TABLE 4
Statistics for LEP pre-injector operation in 1990

Scheduled lepton production time	4218 h
Scheduled lepton production time	3932 h
Scheduled production time for LEP	3821 h
Achieved production time for LEP	3575h
Total number of electrons sent to SPS/LEP	13.34×10^{16}
Total number of positrons sent to SPS/LEP	$9.93\ \times 10^{16}$

TABLE 5
Statistics for SC operation in 1990

Scheduled physics running time	4558h
Achieved physics running time	4124 h
Scheduled maintenance/modifications/shutdowns	4202 h

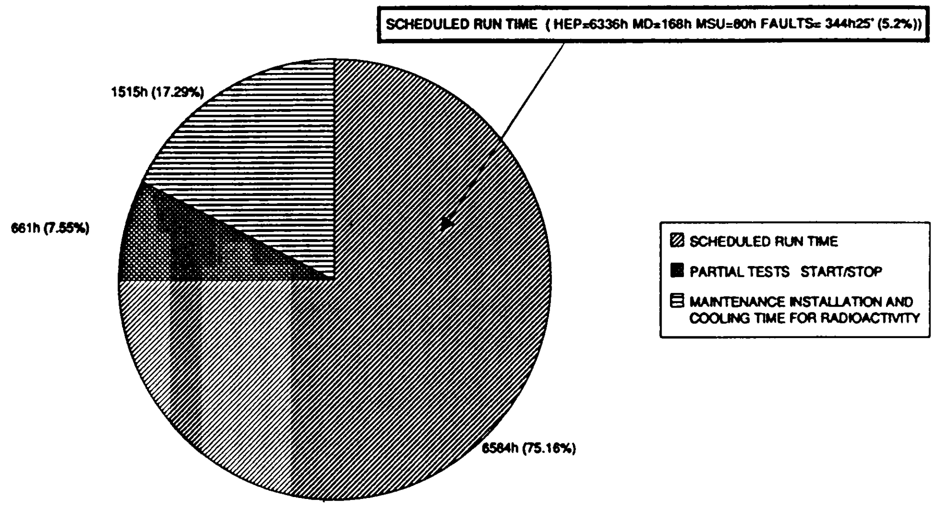


Fig.1 DIVISION OF PS COMPLEX ACTIVITIES IN 1990

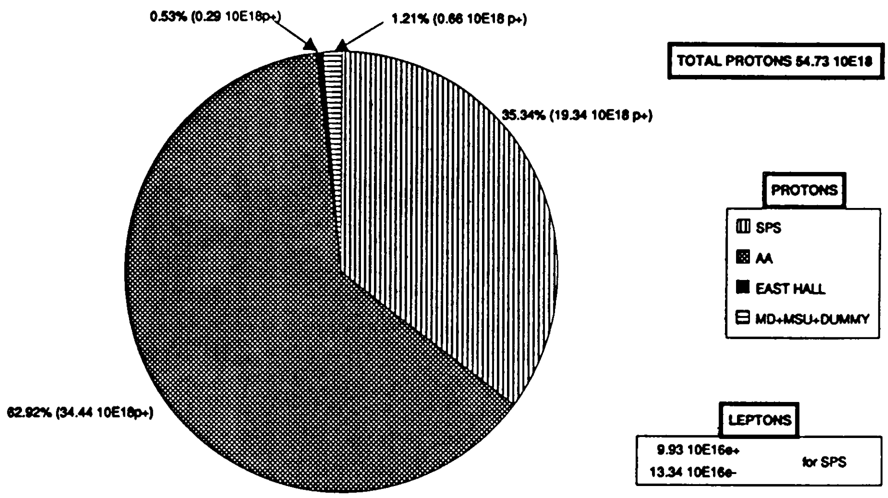


Fig.2 GENERAL DISTRIBUTION OF PROTONS AND LEPTONS ACCELERATED BY THE PS IN 1990

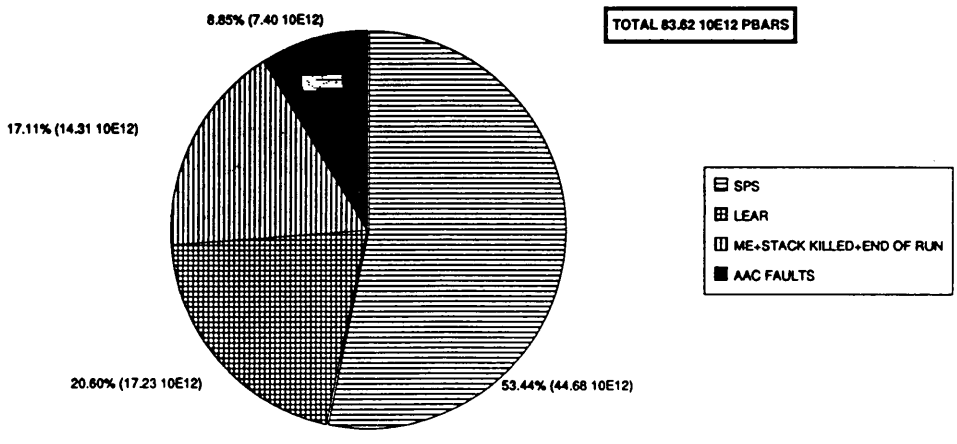


Fig.3 GENERAL DISTRIBUTION OF PBARS BY AA IN 1990

Fig. 1

1990 - PS COMPLEX RECORDS

MACHINE		
PS	Total hours scheduled	6861 hours
	Intensity of 5 bunches at 26 GeV/c	1.85 E13 protons / pulse
	(AAC production beam)	
AAC	Accumulation Rate / hour	6.14 E10 pbars/h
	Accumulation Rate / 24 hours	1.15 E12 pbars/24h
LPI	Accumulation rates in EPA e-	7.2 E10 e-/s
	(in operation) e+	6.6 E9 e+/s
LEAR	the lowest pbar momentum at extraction	72 MeV/c (2.7 MeV kinetic)
LIN1/PSB/PS	Ions (Sulphur S16+ after PS transition)	4.8 E9 charges / supercycle

Fig. 2

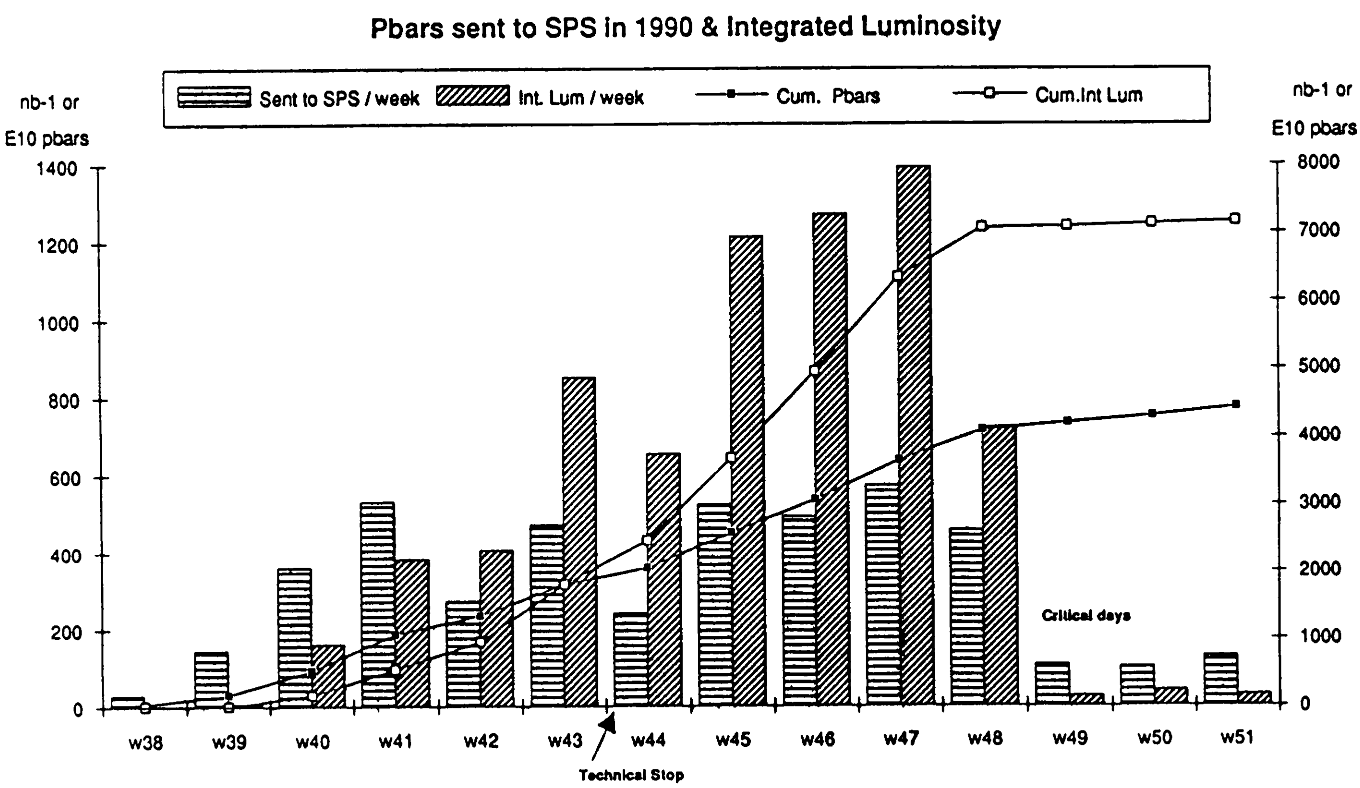


Fig. 3

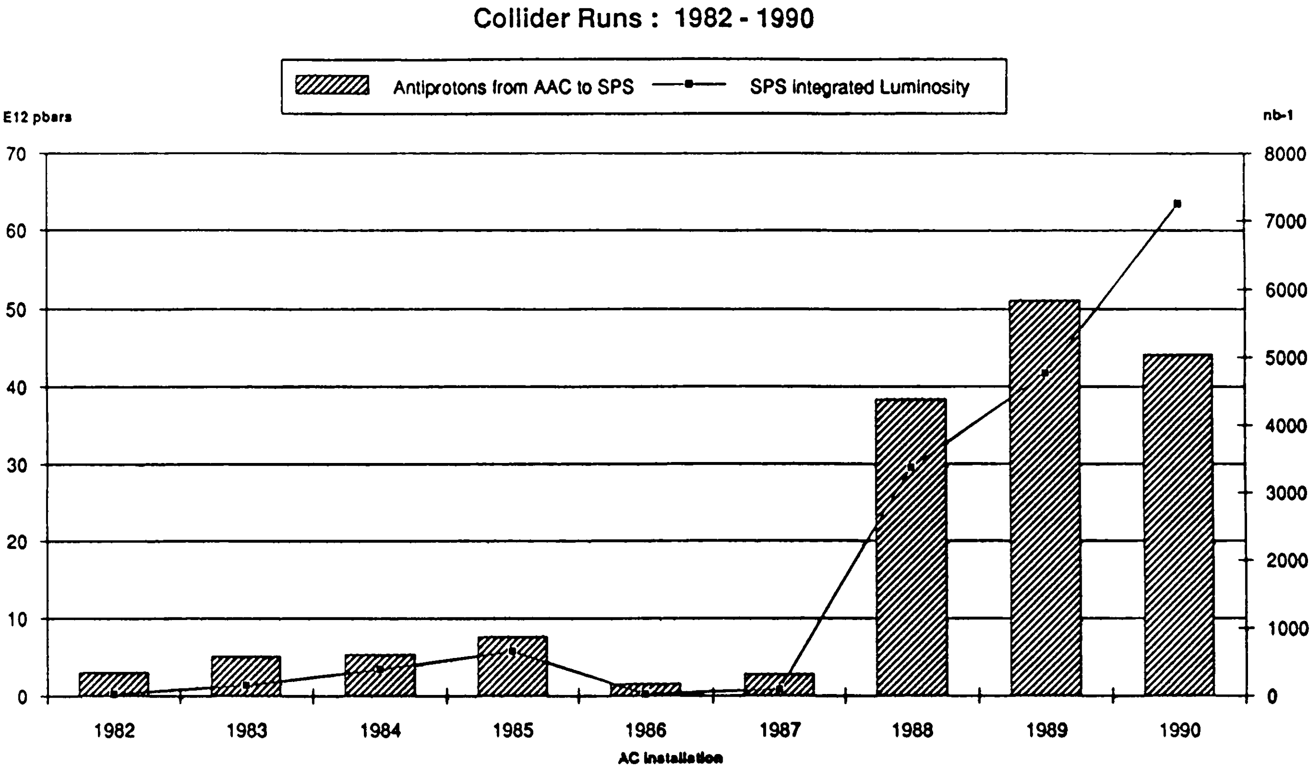
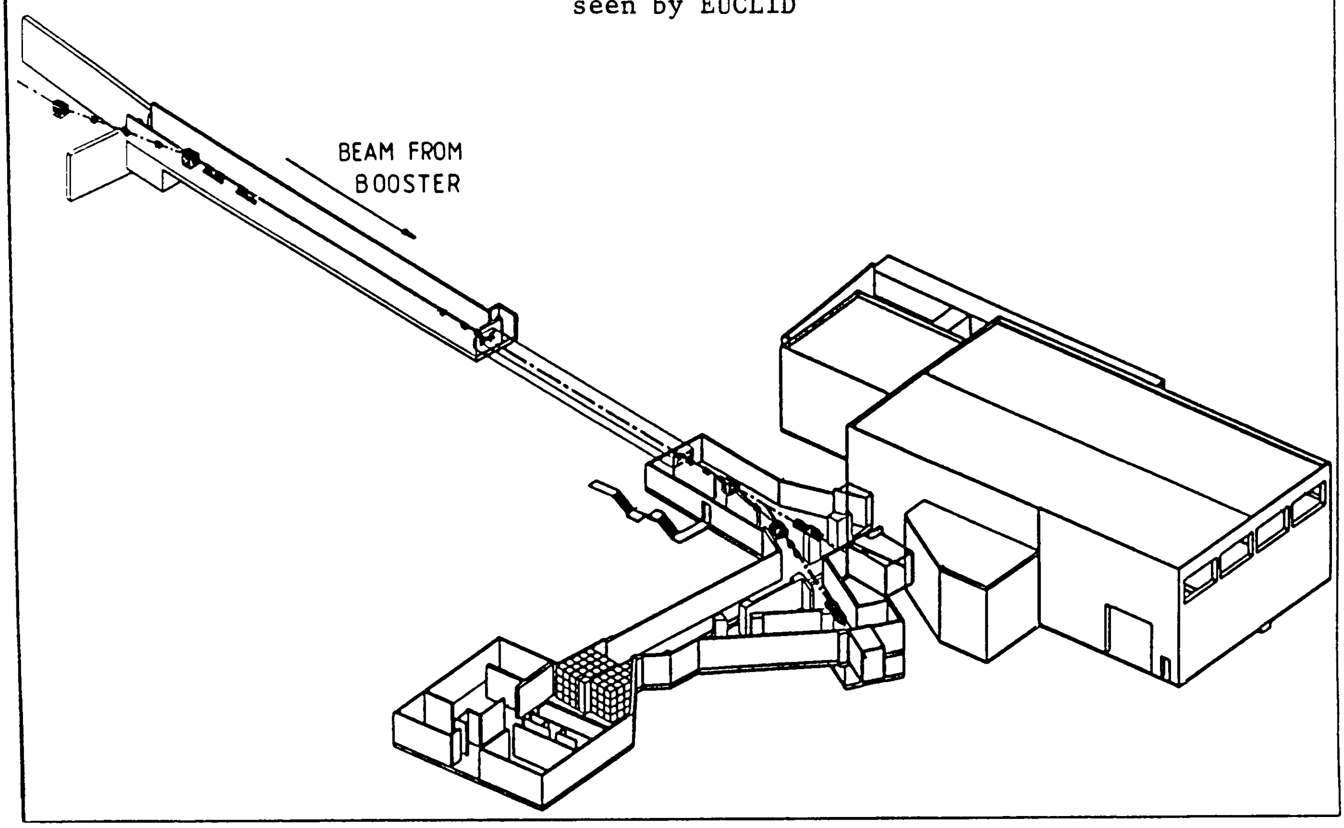
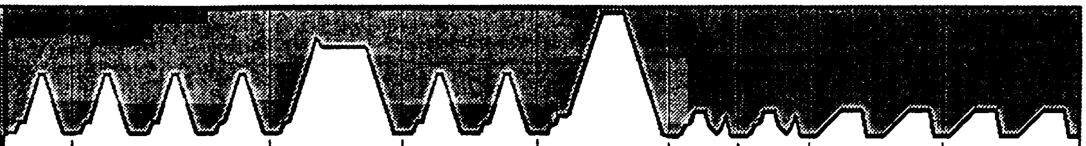


Fig. 4

Fig. 5 : The future Booster-Isolde facility seen by EUCLID





CPS magnetic supercycle [19.2 s]									
particle	p	S^{16+} / O^{8+}	p	S^{16+} / O^{8+}	p	$\bar{p}$	p	e^+	e^-
energy	20 GeV/c		24 GeV/c	20 GeV/c	26 GeV/c	3.5/0.6 GeV/c		3.5 GeV/c	
user	SPS	SPS	PS EAST HALL	SPS	AAC	LEA	AAC	SPS / LEP	
intensity	2.10^{10}	O^{8+} : 9 10^9 S^{16+}: 8 10^8	4 10^{11}	O^{8+}: 9 10^9 S^{16+}: 8 10^8	1.3 10^{13}	5 10^9	10^{11}	7 10^{10} (x 4)	

PS Supercycle - August 1990

Fig. 6