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PS DIVISION ANNUAL REPORT 1997

Edited by B.W. Allardyce

Geneva, 12 February 1998

Distribution (Abstract)

PS Scientific Staff

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN - PS DIVISION

CERN/PS 98-005 (DI)

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Edited by B.W. Allardyce

Geneva, Switzerland
11 February 1998

1. INTRODUCTION

This was the first year since 1981 that the PS complex ran without an antiproton beam, and because of the abandonment of the Pb-ion run after the SPS fire, it was also without a heavy ion beam, except for some tests in LEIR (formerly known as LEAR). However, the proton and lepton beams achieved new record levels, and the year proved to be a vintage one, with exceptionally low fault rates and very high intensities. It was also an unusual year because of the longest physics run ever scheduled: 27 continuous weeks, interrupted only by two short technical stops.

During the year an important milestone was reached when the Booster synchrotron had its 25th birthday. A suitable celebration was organised, and we were reminded by the speakers how the machine was conceived, was born, and gradually developed into the high-performance accelerator we know today; over the years it has improved so much that the original design performance has been exceeded by more than a factor 3. In the future the Booster will be a key link in the LHC injector chain, so it can look forward to many more years of development.

The year also saw a large number of staff members leave the PS, for the most part by retirement; in all, 28 people left the Division, unfortunately taking their accumulated expertise with them. However, we have been able to recruit some young people, and the result is that the average age of staff in the Division is now 48.6, which is not far from the average age for the whole of CERN.

2. OPERATION OF THE PS COMPLEX

The year 1997 was one of the best ever for our accelerators, with an excellent beam performance and a very low fault rate. The PS complex ran for 6336 hours, of which more than 5600 hours were devoted to physics. Overall availability was 94.9% for the proton beams delivered to SPS and 94.8% for the lepton beams, which is the best performance yet achieved for leptons, since the beginning of LEP nine years ago. Each year we have come to expect records to be broken, and 1997 was no exception. New peak intensity values were obtained in all three machines of the proton chain, with Linac 2 producing 176 mA, at the same time that 3.45 10^{13} protons per cycle were accelerated in the Booster, and 3.115 10^{13} protons per cycle were accelerated to transition in the PS. These high intensities contributed to another record, that of the total number of protons accelerated during the year, being 1.37 10^{20} and beating last year's record value by 6%. Tables 1 and 2 show the performance figures for the whole complex, detailed by type of beam.

Table 1

Operational Statistics for Lepton Operation in 1997

Total number of hours scheduled for lepton operation	4504 hours
Total number of hours achieved for lepton operation	4377 hours
Hours scheduled for lepton production for SPS/LEP	3000 hours
Hours achieved for lepton production for SPS/LEP	2843 hours
Electrons supplied to SPS/LEP	$1.01\ 10^{17}$
Positrons supplied to SPS/LEP	$0.96\ 10^{17}$

Table 2

Operational Statistics for Proton Operation in 1997

Total number of hours scheduled for proton operation	6326 hours
Hours scheduled for setting-up and MD's	715 hours
Hours scheduled for proton production (for SPS)	4043 hours
Hours achieved for proton production (for SPS)	3837 hours
Total number of protons extracted from PSB	$1.37\ 10^{20}$
Protons supplied to SPS (at PSB extraction)	$4.09\ 10^{19}$
Protons for machine studies (at PSB extraction)	$9.84\ 10^{18}$
Protons for East Hall test beams (at PSB extraction)	$5.70\ 10^{17}$
Hours scheduled for ISOLDE operation	2734 hours
Hours achieved for ISOLDE operation	2646 hours
Protons supplied by PSB for ISOLDE operation	$8.55\ 10^{19}$

After the two and a half month shutdown dedicated as usual to general equipment maintenance and to new installations or modifications in all our machines, the PS complex restarted on 3rd March. As in previous years recently, three operational periods were originally planned, with the usual physics users: SPS fixed-target physics to receive protons in runs 1 and 2, and Pb-ions in run 3; LEP to run in periods 2 and 3; ISOLDE to be served by Booster proton beams; and the experiments in the East Hall to be fed by PS protons. However, as a consequence of the fire in the SPS auxiliary building BA3 on 13th May, the CERN physics schedule had to be modified, and the Pb-ion run foreseen for October/November was cancelled. In place of an ion run, the second SPS physics proton run and the LEP run were extended in time, but the physics programme was not prolonged beyond the originally planned date of 10th November, as an economy measure (although ISOLDE and some low-power machine tests were able to continue for a further two weeks).

2.1 First Operational Period (3rd March to 24th May)

The first two weeks of March were dedicated to testing all the equipment installed in the shutdown for the last slice of the renovation of the PS control system, under beam conditions. The elements concerned were the general timing of the machines (Linac 2, Booster and PS), the main power supplies of the Booster and PS, various PS power supplies, and all the LPI beam diagnostics. The accelerators started up in the following order: Linac 2 on 27th February, Booster on 3rd March and PS on 10th March. These tests were entirely successful and consequently the chain of the 3 proton accelerators was ready by 14th March to start setting up the 14 GeV/c beam for SPS, which was available on schedule in the middle of the following week.

After the pause over Easter, the PS complex restarted rapidly and the PS intensity was progressively increased to 2.10^{13} protons per cycle as requested by the SPS physics programme. In parallel, the other beams were adjusted on the other cycles available in the supercycle: the 24 GeV/c proton beam for the East Hall, the 26 GeV/c proton beam for SPS machine studies, and first trials at high intensity in the Booster and the PS for later use by ISOLDE and SPS. In April and May, the PS proton intensity for SPS was increased to $2.4\ 10^{13}$ and even reached $2.6\ 10^{13}$ protons per cycle. But unfortunately this operation was stopped on 13th May by the fire in the SPS auxiliary building BA3.

For the direct users of the PS beam, the East Hall started in April for the experiments using slow extraction at 24 GeV/c. This operation ran for 5 weeks, but was switched on 12th May to the fast-extraction mode at 3.5 GeV/c which was requested by the experiment PS211 installed in the T7 line, with occasional runs also at 2.5 GeV/c. At the Booster, ISOLDE also started in April and ran until the end of the period. The SPS fire did of course not affect these users.

On the lepton side, LPI started well after the Easter pause with electron beams accelerated to 500 MeV in LIL and accumulated in EPA. Positrons were also accelerated in LIL and accumulated after the running-in of the new positron production target installation. The electron beam was first used locally by the irradiation experiments for LHC, then both electrons and positrons were sent to the PS on 28th April and finally to SPS on 5th May for the setting-up procedure of LEP. However the SPS fire brutally interrupted this, although it did permit the lepton beams to be used instead for some unplanned machine studies and irradiations.

2.2 Second Operational Period (28th May to 29th November)

At 27 weeks, this second operational run was the longest one ever in the history of the PS complex. The running of the accelerators was interrupted for only two short technical stops for the maintenance of the water stations and the PS main generator respectively.

At the beginning of the run, during the forced stop of SPS and LEP for cleaning up after the fire in BA3, the proton beams of the PS complex were used for machine developments, and for physics by ISOLDE and the East Hall users. They were able to profit fully from the absence of competition for the beam by obtaining a maximum number of Linac 2 pulses in the supercycle: for instance, 3 pulses out of 12 for the East Hall and 9 pulses out of 12 for ISOLDE. Most of the time, ISOLDE ran with high intensity (above $2.8\ 10^{13}$ protons per cycle), but during the first week of July used the newly-commissioned "staggered extraction" of 3 Booster rings sequentially delivering a total of about $6.0\ 10^{12}$ protons per cycle. The East Hall experiments received spills of 2.0 to $3.0\ 10^{11}$ protons per pulse depending on the number of cycles requested in the PS supercycle. In the same period, before LEP operation restarted, LPI worked with its lepton beams for irradiation tests and for various machine studies.

After re-commissioning all the equipment damaged by the fire, the SPS restarted on 8th July with lepton beams and a week later with low intensity protons. This allowed LEP to receive its first beam of the year on 13th July and rapidly to start experimental physics. During the whole operational period, the PS complex delivered positrons and electrons on the usual 2 cycles of the supercycle (2 extractions of 4 bunches per cycle). For protons, the SPS initially requested a low intensity of about 3.0 10^{12} protons per cycle for the first two weeks but then the intensity was increased progressively to 2.4 10^{13} protons per cycle. During August and September, this performance was improved dramatically by careful optimisation by all the specialists involved in the operation of the machines, and new records were obtained in the PS accelerator chain. By the end of August, more than 3.0 10^{13} protons were accelerated each cycle to transition energy in the PS. One month later, on 26th September, a new peak value was reached of 3.115 10^{13} protons per cycle at PS transition, whilst the intensity at extraction at 14 GeV/c was 3.05 10^{13} protons per cycle.

Linac 2 worked extremely well during this period with average currents of 160 to 165 mA delivered to the Booster. Both synchrotrons benefited from this high current, and many parameters were adjusted to optimise the quality of the beam and the transmission efficiencies. Acceleration, bunch shape and synchronisation at extraction were all improved on the Booster, and injection, the low energy working points and acceleration were all carefully adjusted on the PS. With these excellent operating conditions, the average intensity per PS cycle at 14 GeV/c was maintained between 2.5 and 2.7 10^{13} protons per pulse which represents a real improvement in comparison to previous years. But working near this top performance required frequent measurements and re-adjustments and constant surveillance by the operating crew and the machine supervisors. In October, a lot of time was spent on the measurement of transverse emittances, following a slight degradation of the SPS injection efficiency which could be due to beam blow-up at PS extraction, or in the transfer line to SPS. This problem is still under investigation and will remain a first priority in 1998 since no conclusive results were obtained.

Meanwhile the East Hall experiments ran continuously until 22nd September, mainly with 2 spills of 400 msec every 14.4-second supercycle. Then a long 9-month shutdown began in the East Hall for the complete renovation of the beam lines, the installation of the DIRAC experiment, and the provision of improved test facilities for LHC experiments (see Section 8 below). At the Booster, ISOLDE worked right up to the end of the running period, often using intensities above 3.0 10^{13} protons per cycle, benefiting from the improvements mentioned earlier on Linac 2 and the Booster.

A number of proton beam machine developments took place on Linac 2, Booster and PS during a dedicated session on 1st September and on four Wednesdays, sometimes in parallel with lepton operation. Then, at the end of the run after SPS and LEP physics had stopped, 2Ω weeks were devoted to tests and studies, most concerning the preparation of future LHC beams using the new RF harmonic numbers on the Booster and the PS. On the lepton side, in parallel with LEP operation which remained the first priority, LPI also ran machine study sessions and test experiments.

The only serious fault during this operating period occurred on 9th July on a bending magnet (BR.BHZ16-2) of the Booster ring. After a long investigation of the main power supply itself which had tripped out, the specialists finally discovered a water leak which had caused a minor fire on a power cable insulator on one of the Booster magnets. After replacing all the defective pieces, it was necessary to carry out a complete cleaning of the elements contaminated by chlorine released from the PVC magnet covers. This stop lasted a total of 33 hours, but fortunately it occurred just before the start-up of SPS after its fire, and only concerned the small number of East Hall users. Later in July, two other less serious, power supply faults occurred almost exactly in parallel: a ground interlock was changed on the Booster main supply and a heat exchanger was replaced on the PS, for a total interruption of nearly 16 hours. In spite of these difficulties, this run was an excellent one, with beam availabilities of 94.6% for SPS fixed target physics and 95.5% for the leptons.

3. LEPTON OPERATION

The LEP Pre-Injector (LPI) is composed of the LEP Injector Linac (LIL) and the Electron Positron Accumulator (EPA) providing 500 MeV leptons. In 1997, LPI supplied beam for 4377 hours of which 2843 hours were used for LEP and 890 hours were devoted to setting up and machine developments; beam was provided to the two experimental areas (see Section 6 below) for the rest of the time. The LPI performance continues to be at least a factor 2 above the minimum required for physics at LEP. Accumulation rates of 5.0 10^9 and 5.0 10^{10} particles per bunch per second for positrons and electrons respectively were routine, and the LPI fault rate was extremely low at 2.1 % (of which nearly one half was due to external faults such as the electricity supply).

In 1997 a new positron converter was installed, which worked very well. The new plug-in system now allows the whole production target assembly to be changed rapidly in case of failure, this being a highly radioactive area. Positron yields of about 0.5% were achieved. One way to improve this yield is to make bunch length measurements using Çerenkov emission and optical transition radiation with a streak camera. On the modulator-klystron side, two units were removed from LIL and the power of the remaining ones was redistributed and increased to 22 MW; this means that fewer klystrons are in use, and since they have a finite lifetime and are expensive, it means an economy in the long term. Finally, a system of double PPM (pulse-to-pulse modulation) was installed on the dipole magnets in both transfer lines between the EPA and the PS to allow a cleaner operation with leptons and to avoid losing beam on the PS injection septa.

4. HADRON OPERATION

4.1 Protons in Linac 2

Reliability of Linac 2 this year was extremely good, with less than 1% non-availability of the beam due to all causes. However, beam loading did give rise to some stability problems for the RF. A new, unified timing system was commissioned with only minor problems and a new high-energy beam optics gave a much more stable beams, with drastically reduced losses. Re-calibration of the radiofrequency level in the RFQ raised the beam intensity from 145 mA to 160 mA; further work then allowed a record intensity of 176 mA to be accelerated on the long 120 μs pulses for the SFTPRO and ISOLDE beams during a test in the Booster. Following other fine adjustments, Linac 2 supplied a regular beam of 170 mA from early October onwards on these two long pulses.

4.2 Booster and PS synchrotrons

The new pulsed recombination septum SMV20 installed in the Booster-to-PS transfer line at the beginning of the year operated perfectly, but towards the end of the year a leak developed on a septum in this same line which could not be localised before the start of the shutdown. Consequently for the last 2 weeks of November, only 2 Booster rings could be extracted to ISOLDE.

At the PS, optimisation of the "continuous transfer" process was improved by the introduction of remotely controlled fine delays. The hadron injection kicker KFA45 was equipped with a new kick-strength unit so that now such devices control both the injection and ejection kickers. As far as septa are concerned, a pressure test performed during the shutdown indicated that the slow extraction septum SMH57 had a leak, so it had to be replaced before the PS start-up. Meanwhile, for the whole year the electron injection septum SMH74 operated with only one cooling circuit, as it has done since the summer of 1996 when a water leak appeared in one of the circuits; this can be permitted because very little cooling is needed, thanks to the use of only 2 lepton cycles per supercycle for LEP filling.

4.3 Transfer lines

Documentation on all the transfer lines was put into the "Sibelius" database so that most of it is now available on the computer network; this should prove a distinct advantage in the future.

4.4 Machine Developments using protons

At the Booster, the closed orbit of the beam was corrected by adjusting the tilt of one particular quadrupole, and some of the timings and special cycles needed for 1998 operation were prepared. One of the cycles foreseen for 1998 allows acceleration to 1.4 GeV and deceleration down to the present extraction energy of 1.0 GeV. This was the first time the Booster had been used to decelerate particles.

On the PS, theoretical and experimental studies of coupled Landau damping as well as of natural coupling were made. The closed orbit distortion induced by the injection bump was corrected thanks to the Automated Beam Steering and Shaping procedure recently implemented (see Section 14 below). Towards the end of the year, measurements and studies were undertaken to investigate the decrease in transmission that had occurred in the high intensity beam sent to the SPS, which was causing some disquiet; as yet there is no satisfactory outcome and the subject will be looked at again next year.

4.5 Pb-ions in Linac 3

After the annual shutdown, the ECR source and Linac 3 were originally intended for tests with LEIR, followed by a running period for fixed-target physics; however, the SPS fire meant that more time could be given to LEIR ion accumulation. Firstly, tests were made to demonstrate that the RF system of Linac 3 could run at 10 Hz, as the source had already been shown to do. Then, running at a repetition rate of 1 Hz, a demonstration was made of energy ramping of the beam from about -0.4% to +0.6% around the nominal energy with pulses of 70 to 200 μs, using tank 3 and a debuncher. This mode was later used operationally for injecting into LEIR for the accumulation tests (see Section 5 below) through the so-called "combined multi-turn injection" scheme. After a while the Linac 3 cycling rate was pushed to 2.5 Hz, this being limited by a few pulsed quadrupoles after tank 3; ultimately 10 Hz is required. During the LEIR tests, reliability of the Linac was generally good but there was a major problem on the ECR source due to a roughing pump failure, requiring a full strip down and cleaning; about 10 days were lost altogether, including reconditioning the source.

Time was also found for the latest in a series of tests on tank 2 of Linac 3, in collaboration with GSI. The power level at 200 MHz in the inter-digital cavity was increased from its nominal value of 350 kW to over 1.3 MW in order to test the voltage holding capability of the IH cavity. The corresponding increase in accelerating field amounts to 84%, a considerable gain. The success of this test opens new perspectives. Firstly, future IH cavities could be much more compact. Secondly, it would be possible to accelerate ions with lower charge states in the Linac 3 structures, provided the tank and inter-tank triplets are up-graded accordingly. Pb-ions of charge state 15+ instead of 27+ would then be feasible, which means that the existing ECR source would in principle be able to deliver a much higher number of ions to the Linac, provided the low energy beam transport line is also upgraded. The full impact of this exciting possibility on the LEIR scheme for supplying ions to LHC remains to be evaluated.

5. ION ACCUMULATION TESTS IN LEIR

What is LEIR? After completion of the CERN antiproton programme at the end of 1996, the LEAR machine was re-christened LEIR, for Low Energy Ion Ring. This machine will be used in the future as an accumulator ring for heavy ions prior to their acceleration in the PS and subsequent injection into LHC. The LHC scheme calls for about 500 bunches per LHC filling, with an intensity of 1.0 10^8 ions/bunch; but this requires bunches of 3.0 10^8 ions at the front end of the injector chain, because of losses en route. However, present-day ion sources are a factor 50 short of this performance. The idea is to gain back this factor by accumulating ions at low energy (4.2 MeV per nucleon) in LEIR, prior to further acceleration. The ions will come from the present ECR (electron cyclotron resonance) ion source feeding Linac 3, which will have an increased cycling rate of 10 Hz, and then via a beam transport line to LEIR for stacking. A "combined multi-turn injection" scheme exploiting both the longitudinal and the transverse acceptance of LEIR is foreseen, working together with electron cooling; this method cools the beam pulse as soon as it arrives, thereby increasing its density and slightly moving its orbit so as to leave space for successive injected bursts. In order to reduce the cooling time and make the whole injection process more efficient, the electron cooler was doubled in length for the 1997 tests, which reduced the cooling time by a factor 2. The final scheme calls for LEIR batches of up to 1.2 10^9 ions (for 4 LHC bunches) every 3.6 seconds (with an approximately 2 second stacking time).

Earlier tests in LEAR in 1995 had revealed an anomalously fast beam loss for lead ions of charge state 53+ due to recombination with cooling electrons. This problem has been solved for LEIR by switching to neighbouring charge states 52+ or 54+ which can be obtained with practically the same intensity, but which have a 5 to 10 times longer lifetime in the presence of electron cooling. The phenomenon is still puzzling the atomic physicists. The 1997 series of tests were the last ones possible, because the electron cooling system (which prior to LEAR had been part of the famous ICE experiment dating from 1977) is needed for the new AD facility under construction, and its removal date was fixed by that schedule. LEIR work started in June and carried on more or less independently of the other PS machines until the last possible moment in November, when the electron cooling system had to be removed. It turned out to be very convenient for the LEIR tests that Pb-ions were not required by fixed-target experiments at SPS because of the fire there.

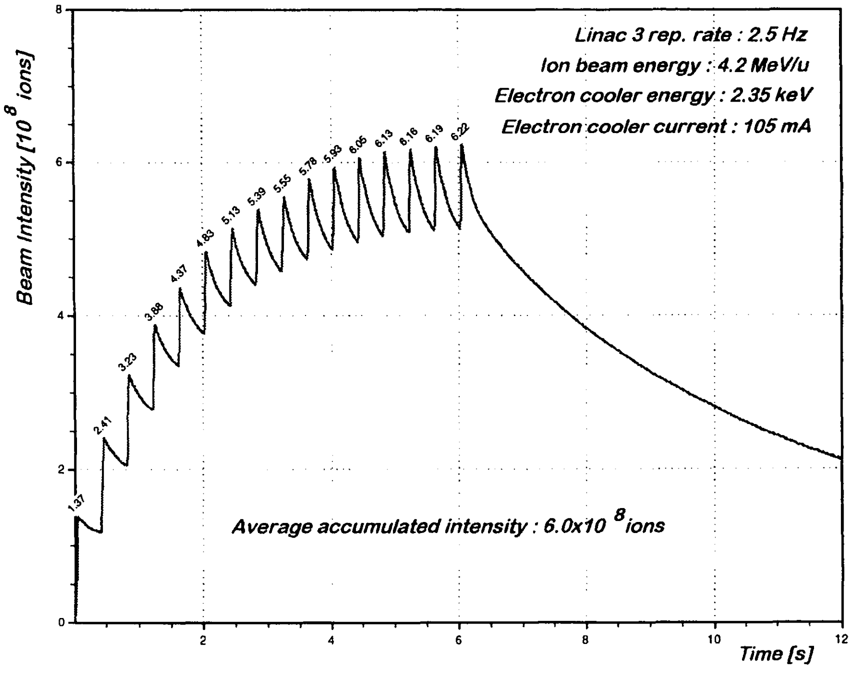

Figure 1

Accumulation of Pb-ions in LEIR (using charge state 54+). When this data was obtained, the lifetime was 6.5 seconds (due to the prevailing vacuum and electron cooler conditions).

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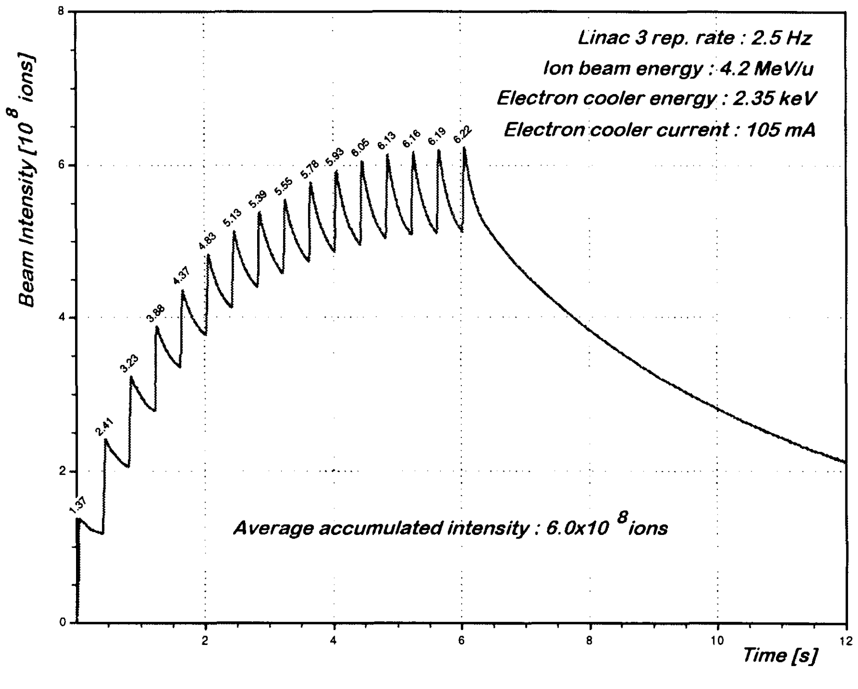

Figure 1

Accumulation of Pb-ions in LEIR (using charge state 54+). When this data was obtained, the lifetime was 6.5 seconds (due to the prevailing vacuum and electron cooler conditions).

A wealth of experience gained with running LEAR was called on to combat space-charge effects and beam instabilities in the high intensity cooled beams of LEIR, with considerable success. The feasibility tests this year were done with Linac 3 pushed to work at a cycling rate of 2.5 Hz. Fig. 1 shows the accumulation of more than 6.0 10^8 ions (the equivalent of 2 LHC bunches); occasionally there were peaks of 7.0 10^8 ions, depending on the vacuum conditions and on the parameters of the electron cooling. Such intensities were routinely obtained in the tests towards the end of the run, and are only a factor 2 lower than what is needed for LHC. During each Linac 3 pulse, about 0.8 10^8 ions are multi-turn injected (~ 20 effective turns) and about 10 pulses are electron cooled and stacked before saturation occurs. At this point, the loss of ions due to the beam's lifetime of between 4 and 7 seconds balances the incoming flux. Further work will be necessary to gain the missing factor of two in intensity for LHC, but one can now be confident that by a careful upgrading of Linac 3 to reach a cycling time of 10 Hz, by improving further the LEIR vacuum to improve the ion lifetime, and by installing a new, optimised electron cooling to reduce the cooling time, the LHC specifications are within reach.

6. EXPERIMENTAL AREAS OPERATION

6.1 East Hall

Despite the unusually early stop of the East Hall to allow a 9-month shutdown for the planned transformation (see Section 8 below), the slow extracted beam from the PS was delivered there for more than 3500 hours during the year. This beam served a total of 270 physicists in 23 experimental groups, of which 9 belong to LHC experiments. In May, the last 10 days of run of the TARC experiment took place, being the successor of the Energy Amplifier test started in 1994 in the t7 beam line; it was then dismantled. Machine Development time was devoted this year to checking the feasibility of future operations in the East Hall, with beams of variable characteristics for different users in PPM.

6.2 ISOLDE Area

A test station for the ISOLDE 60 kV pulser was equipped and tested. Meanwhile, commissioning of the REX experiment started.

6.3 LEA (LIL Experimental Area)

This irradiation facility, situated in the straight-on beamline from the electron Linac, used electron beams of 500 MeV. The intensity, pulse duration and repetition rate could all be varied to suit the requests, which came from experimenters preparing the LHC-B and CMS detectors. For LHC-B, two prototypes of an electromagnetic calorimeter received doses of 50 kGy, representing about 4.0 10^{15} electrons over an area of 10 x 10 cm^2, in order to check their performance under the severe radiation conditions to be expected at LHC. For the CMS experiment, three types of optical fibre were tested, covering the range of optical wavelengths from 400 to 600 nm. It was discovered that a serious degradation occurs between 500 and 600 nm after only 10 hours of irradiation. However it is hoped that the fibres may be regenerated by using UV light.

In August, another test was set up to compare different optical fibres in a 250 kg detector prototype, when it was found that quartz/plastic fibres were less sensitive to radiation and were a factor 7 less expensive than quartz/quartz. This was an important result for CMS.

6.4 SLF (Synchrotron Light Facility)

When the EPA storage ring operates at 308 MeV, the critical energy of the synchrotron light emitted is 45 eV, the same as the synchrotron radiation that will be produced in the LHC with 7 TeV protons. The synchrotron light line (SLF92) was used by LHC Division to study the crucial issue of gas desorption from the LHC vacuum chambers under constant bombardment by this radiation, leading to the generation of electrons and unacceptable heat loads to the cryogenics. The initial chambers had reflection coefficients for this light as high as 82%, corresponding to about 20 W/m heat load; but by coating the chambers with a 1 μm layer of TiZr baked at 350 ^{0}C, the coefficient was reduced to 22%, resulting in a significant reduction in the heat load. However further work is needed to reach the LHC design goal of around 1 W/m. A second synchrotron light line (SLF42) will be installed in 1998 to accelerate the studies. One line will be dedicated to gas desorption studies at room temperature while the other line will be used for cryogenic temperatures (2 ^{0}K).

6.5 South Hall and the AD Experimental Area

With the end of the LEAR physics programme in 1996, the experiments in the South Hall were taken apart in 1997, although some remain and will be reborn in a new guise for the AD programme. For these, it was too early to remove to the new experimental area in the centre of the AD ring, which will happen late next year.

7. PREPARING THE PS COMPLEX TO PROVIDE PROTONS FOR LHC

The project to prepare the PS complex as an adequate proton pre-injector for LHC became necessary because the LHC demands a much brighter beam than what is currently available in the PS complex. A critical phase was reached in 1997 as a large amount of new equipment arrived for installation in the 1997/8 winter shutdown in the Booster and the PS machines, especially RF equipment and power supplies for the Booster and transfer line. The TRIUMF Laboratory in Vancouver has provided a sizeable fraction of this equipment, in the framework of the Canada-CERN Collaboration on LHC.

On the RF side entirely new cavities are needed, in order to run at new harmonic numbers required by the LHC filling scheme. The major RF gymnastics involved in doing this were first tested with beam in the Booster using prototype RF systems in one ring (ring 3), and once the dual harmonics operation had been mastered, a beam intensity of 8.2 10^{12} protons was achieved, which is above the maximum used for physics and approaches the previous record value of 10^{13} protons per ring. Four variable-frequency (0.6-1.75 MHz) systems for harmonic h=1 in the Booster are ready for installation in the next shutdown; the ferrite rings and high-voltage supplies for these were delivered by TRIUMF. In the PS machine, where the prototype

40 MHz system was already installed at the end of 1996, the debunching/rebunching process was studied, showing defaults in older equipment that will have to be repaired. But two 80 MHz fixed-frequency RF cavities (h=168) for the PS have reached their design voltage of 300 kV each, and are ready for installation. They will enable the shortening of each of the 81 bunches to 4 ns, with a spacing of 25 ns, before they are sent to the SPS. The high voltage supplies and higher-order mode dampers were also supplied by TRIUMF. Both Booster and PS synchrotrons will run in 1998 at the new RF harmonic numbers, but the tests made so far give confidence that this new regime will not cause too many headaches.

The LHC scheme requires the upgrading of the Booster main magnet supply to 1.4 GeV, and for this, five double transformers (to replace the old ones filled with the now-prohibited PCB) as well as a reactive power compensator were financed by TRIUMF and were installed at the end of the year. Adaptation of the controls circuitry as well as new Q-tuning supplies are foreseen as well. Also, paving the way for operation of the PSB-PS vertical recombination line at 1.4 GeV in 1999, some 15 new magnets and their power converters arrived from TRIUMF. These are necessary because the beam is 26 % stiffer at 1.4 GeV than at 1.0 GeV. In addition, four superimposed ejection septum magnets and their pulsed (half sine-wave) supplies, as well as more powerful pulse-forming networks for two vertical recombination kickers were built in CERN and are awaiting installation.

The small-sized LHC beam, together with the tight transverse emittance budget calls for high-resolution beam profile monitors. A prototype vertical fast wire scanner installed in one Booster ring has delivered excellent signals over the energy range 50 MeV to 1 GeV, when exploiting secondary emission signals at the low energy end, which paves the way for production of more of this type of monitor. Monitoring the beam trajectory in the PS-to-SPS transfer line is the task of two new wide-band position monitors (measuring the position of each of the 81 bunches) downstream of the PS extraction channel; their analogue signals were made available in the main control room, and a system for digitising the bunch positions is in preparation.

8. EAST HALL NEW LOOK (EHNL) PROJECT

The design of the beam optics of the four modified secondary lines and of the new primary line for the DIRAC experiment was completed by mid-1997. The new layout is shown in Fig. 2. Dismantling work started immediately after the stop of East Hall operation in late September. First the far end of the hall was cleared, which will be occupied by the beam dump of the new primary beam line to DIRAC. Then all the secondary beam lines were dismantled, together with all the local counting rooms of the experimental teams, and the Control Room, EBCR. There was intense activity in the hall for the last three months of the year as shielding blocks and beamline elements were moved to their new positions. About 5000 tons of iron and 15,000 tons of concrete had to be moved during these operations. The work will continue in 1998 as the experimenters reinstall their equipment ready for the start-up in June.

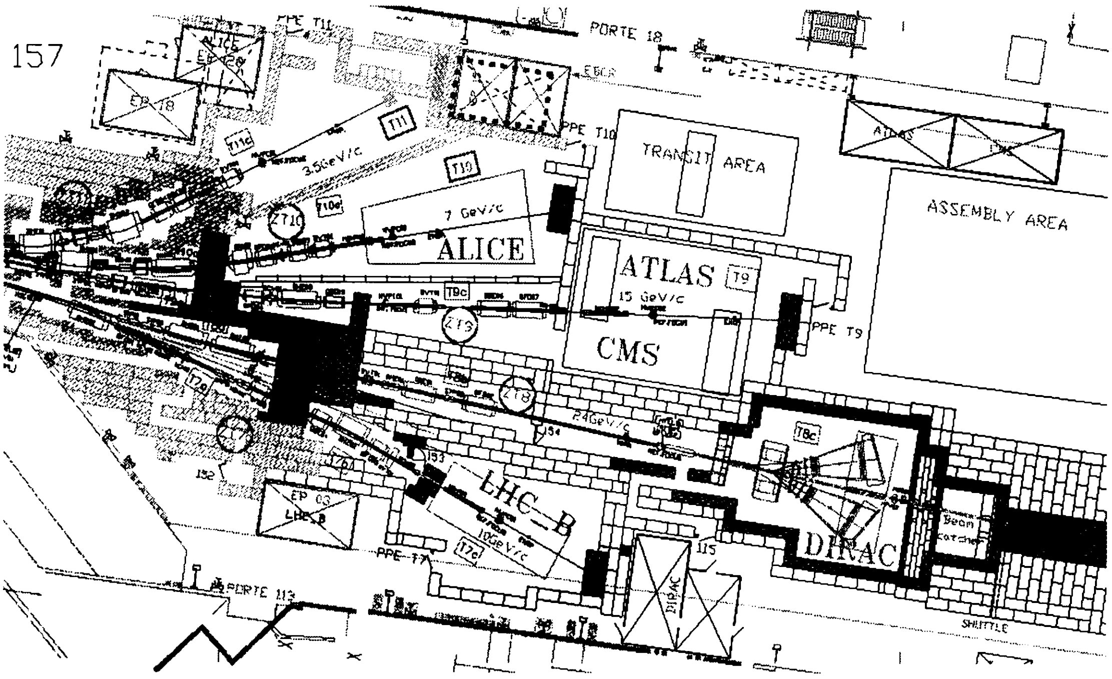

Figure 2

The East Hall layout as it will be from mid-1998 after the reconstruction work.

9. THE AD PROJECT

Following approval of the AD Project in February 1997, work in the AAC area was started immediately. The Project consists in removing the AA (Antiproton Accumulator) and converting the AC (Antiproton Cooler) into the AD (Antiproton Decelerator), a machine in which antiprotons will be stored, cooled, and then decelerated to the required very low energy. The antiprotons will be produced in a heavy metal target just as they have always been produced, and no modifications to the target area are foreseen. Stochastic cooling will be done using recuperated and upgraded equipment from the AC, and the electron cooler will use the device previously installed in LEAR. This will then permit a beam of very low energy antiprotons to be delivered to experiments situated in a new area in the centre of the AD ring. Beam diagnostics will be provided by monitors recuperated from LEAR, and from the South Hall beamlines.

Of course, the AA machine had first to be dismantled, which meant moving close to 7000 tons of concrete shielding and over 1000 tons of iron. The magnets and vacuum chambers were treated very carefully so that they could be re-used one day, since it became clear that there was an active interest from Japan to take over the now-redundant AA magnets for their Japanese Hadron Facility. By June, the AA had been completely removed and its magnets stored in a section of the ISR tunnel awaiting transport to their new home. Work on modifying AC could then begin. The AAC hall took on a new look as shielding, cable trays, water pipes, etc. were removed or modified. Some AC elements were sent to the laboratory for improvements and others for vacuum tests aimed at obtaining a better vacuum; the AD requires a vacuum of about 10^{-10} torr, a factor of at least 20 better than that obtained in the AC machine. Likewise, certain dipoles were transported to the laboratory to study how their "good field" regions behaved as the current is reduced, as will happen during the deceleration process; it was also necessary to determine the sextupole component in some quadrupoles. One should bear in mind that these magnets were originally optimised and shimmed for the fixed momentum of 3.5 GeV/c of the AC machine, a storage ring. But the new AD ring has not only to maintain its former characteristics at high energy (i.e. to have a high acceptance in order to store the maximum number of antiprotons as they are produced, and to be able to cool them with the stochastic cooling system), but it must also permit a reduction in momentum of the circulating beam by the enormous factor of 35, without losing it. The extracted beam will have a momentum of 100 MeV/c, corresponding to 5.3 MeV kinetic energy. Extensive theoretical calculations were made and the most suitable lattice structure was finally chosen for the new machine, which then allowed all the hardware to be specified, especially the power supplies, and modifications to the stochastic and the electron cooling systems. By the end of the year, manufacturing of the new pieces was in full swing.

Unlike other accelerators at CERN, AD will be entirely funded from outside by the users, who will also provide 12 man-years of effort from their home institutes to help build it, and then further manpower to help in the operation of the facility. The expected start-up date is in the Autumn of 1998, with tests due to last until the end of the year. Then, after the 1998/1999 annual shutdown, the big moment when the first beam will be delivered to the AD experiments! Three experiments have been approved for the new facility, called ATRAP, ATHENA, and ASACUSA, and Fig. 3 shows their respective zones in the new experimental hall. For one experiment, ASACUSA, a feasibility study of a post-decelerator is under way, in order to further reduce the final energy of the antiprotons to below 100 keV; this device will be a decelerating RFQ (radiofrequency quadrupole), chosen because it has a transmission at least an order of magnitude higher than the "traditional" method of reducing the antiproton energy by degrading the beam with thin foils. The RFQ has the novel feature of an inner structure mounted on ceramic insulators so as to allow the final energy to be adjusted by changing the d.c. voltage on the electrodes. This device, if it is built, will be funded by the ASACUSA experiment.

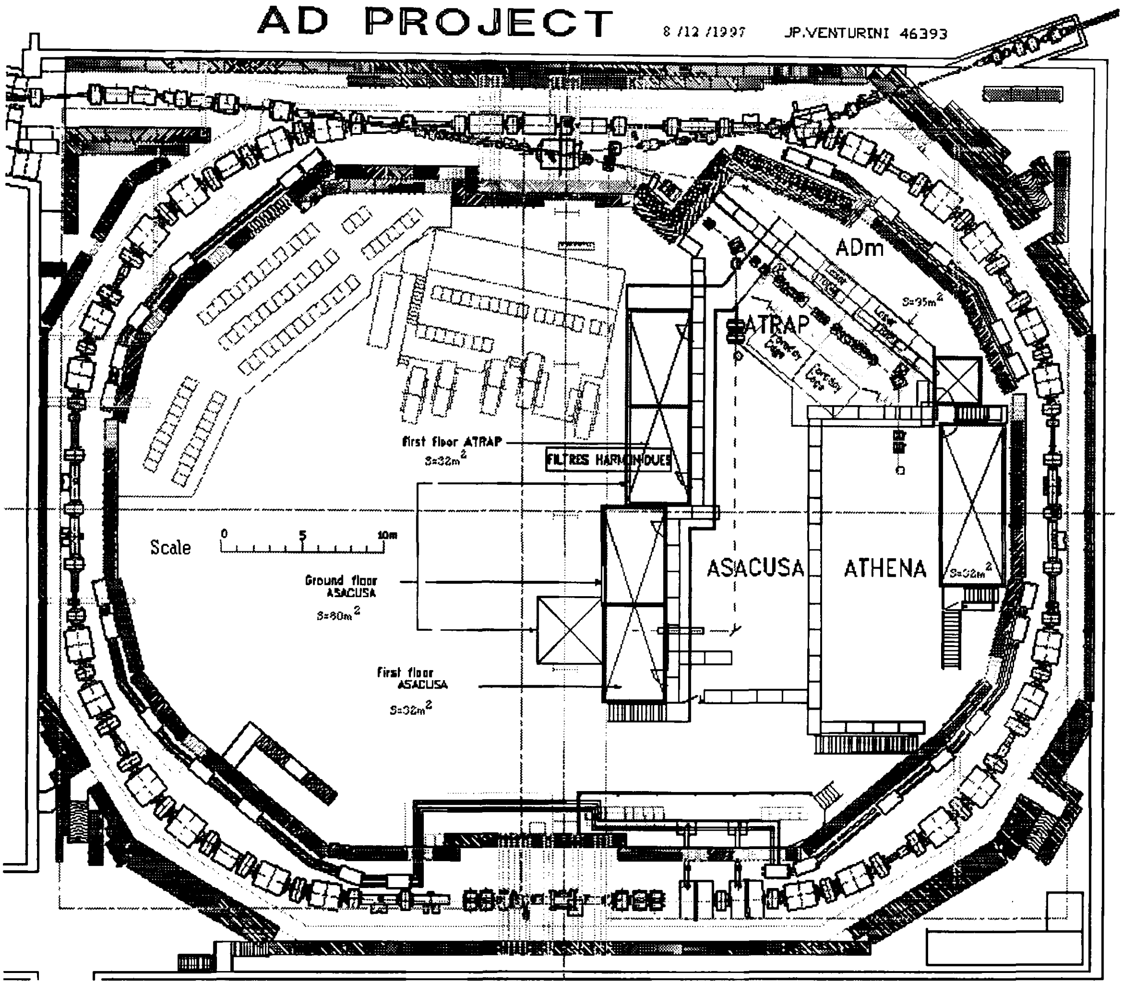

Figure 3

Layout of the new AD facility showing the AD ring surrounding the three experiments.

10. BEAM DIAGNOSTICS

A major preoccupation for the Division is the maintenance and operation of the numerous and extremely varied beam diagnostics apparatus spread along the accelerators and transfer lines. Obviously this includes upgrading the existing systems and adding new ones, as the PS complex evolves. This year, particular attention was devoted to beam transformers, the most important means of measuring beam intensity. The request from ISOLDE to receive beam from the Booster in "staggered" mode (with adjustable intervals between the pulses from the different rings), necessitated a complete change of both hardware and software for all the electronics, acquisition and data treatment of beam transformers in the lines between the Booster, ISOLDE and PS. Then in the ejection lines after the PS, several beam transformers built originally for a particular kind of beam, were converted to measure all kinds of beam. In parallel, studies on the basic limitations of d.c. beam transformers led to a better understanding of the importance of the magnetic properties of the core material and of the spectral purity of the modulator current; this has resulted in a considerable improvement in drift properties of the transformers.

At the PS, the closed orbit measurement received new specific controls at the beginning of the year. Effort then focused on a new synchronisation scheme for the pick-up electronics and data acquisition, so that the system would work with the new harmonic numbers of the accelerating RF to be used from 1998 onwards. A prototype was ready in time to be tested with the last PS beams in 1997, and series production started immediately. At the same time, development work proceeded on the transformation of the closed orbit measurement of the AC. Once the AC becomes the AD machine, the closed orbits will have to be measured with beams of as few as 10^7 antiprotons, which requires an unprecedented sensitivity.

On the Booster, the transverse feedback system was improved by equipping all 4 rings, in both horizontal and vertical planes, with the newly developed "Beam Offset Signal Suppressors". These devices greatly reduce the power required and improve the signal-to-noise ratio, thus guaranteeing stability of the beams at the highest intensities and preparing the way for emittance preservation of the high-density beams for LHC. The prototype fast wire-scanner installed in ring 3 of the Booster was tested, and then comparisons were made with other emittance-measuring devices. The results were most encouraging and proved the value of this device under the conditions prevailing in the Booster. Particularly pleasing was the fact that it even worked at the low energy of 50 MeV at injection. This paves the way for making the final design and fitting all 4 rings with horizontal and vertical wire-scanners.

At LIL and EPA the performance of the slow wire-scanners had been deteriorating over recent years, but this year they were equipped with new drive controls, data acquisition and specific controls and their restored performance was warmly welcomed by the users. Also, the "Intensity Statistics" system of LIL and EPA was entirely rebuilt, with much of its hardware and all of its software renewed. Further, long-awaited improvements were made to the drive electronics of the internal dump in the PS. Finally, an improved version of the old measurement targets inside the PS was prepared for installation and testing, also equipped with the new drive electronics.

For LHC, studies were made of beam loss monitoring as part of the "LHC Instrumentation and Diagnostics Working Group". The developments reported above on d.c. beam transformers will also be useful for fulfilling the LHC requirements on the beam.

11. CONTROLS AND OFFICE COMPUTING

11.1 Accelerator Controls

Since 1991 there has been considerable controls activity every year in the framework of the Controls Renovation Project (D-067), common to PS and SL Divisions. 1997 saw the last slice of this work, dealing with areas deliberately neglected earlier due to lack of funding. This was the upgrading of both Booster and PS main power supplies, the control of the PS injection kicker, and the introduction of completely new standard timing systems for the Linacs and the Booster. All these new features were commissioned in two weeks of tests at the start-up of the PS complex after the annual shutdown. During the same period, the nAos digital system for the observation of the LPI analogue signals was installed, and an identical system was implemented for the

Booster signals, thus completing the replacement of the old SOS system for the whole PS complex. Only the video observation system now remains hard-wired and has still to be upgraded to digital.

A major task for 1997 was the preparation of the control system for the new AD machine (see Section 9 above). Important steps were the design of the architecture and the definition of how this decelerator will be operated (which will be completely different to all the other machines of the PS complex). It was decided to use PowerPC processors for the local controls, and to introduce Java for developing the application programs, in order to achieve the increased productivity required by the tight schedule and limited manpower resources available. Another important task, in the framework of the project to prepare the PS complex as LHC proton injector (see Section 7 above), concerned the "emittance budget" of the beam; there are tight constraints on how much beam blow-up can be tolerated for LHC. So it became urgent to fully incorporate the concept of Automated Beam Steering and Shaping (ABS) into the operational environment, which resulted in the regular use of automatic corrections on both the injection and the transfer lines of the Booster (see Section 14 below). This will be further developed next year.

With an eye to the more distant future, the active collaboration between the Controls groups of PS and SL was further developed in 1997. Several important subjects were tackled, such as the central timing systems where the objective is to use the same controls philosophy and the same hardware modules. Common pieces of software have been produced, and preliminary studies were launched to handle new requirements of the SPS supercycle. In the same spirit, both PS and SL control systems were analyzed by an outside expert, resulting in a clear functional comparison and a set of practical recommendations to achieve convergence in a few years time, although a first stage is already to be implemented in 1998.

11.2 Replacement of the Controls Ethernet

The replacement of the PS controls Ethernet (copper cable) network by a fibre-optic network is long overdue. A first phase was tackled this year, implemented by the SL-CO network team which will be responsible for its operation. This is a Sector project spread over a 3-year period, with structured cabling and local nodes as opposed to the old daisy-chain network, in order to allow higher data rates.

11.3 ISOLDE Controls

The development of the REX-ISOLDE control system is proceeding rapidly. The layout of the system is in progress and the first on-line tests are planned for the transfer line to REX. At the same time, the ISOLDE controls are being upgraded: new user-friendly graphical interfaces and a new Access database have been installed; Microsoft ActiveX and Visual Basic 5 are being introduced; and the Windows NT operating system is to be introduced for new developments.

11.4 Link between the Controls network and Desktop machines

The so-called "passerelle" allows access to the Unix-based controls equipment from a desktop PC. It was used extensively (with more than 65 million connections in 1997), especially for machine studies, machine setting, and for storage and prototyping. It showed a very high reliability, and proved its value as an easy tool for the operation of temporary controls during machine development sessions. For the Main Control room, a Windows NT application server was installed to safely handle all the data and tools required to assist the operating crew.

11.5 Desktop computing

The Controls group has always dealt with the maintenance of desktop equipment in the Division, but this year responsibility for improving the network printers and for upgrading all desktop equipment was transferred to the group. Four new printers were installed and about 25 new PC's were purchased to replace old or low-performance models. Major contributions to the NICE environment were made, especially with regard to the CERN-wide printing service by introducing into the "Printer Wizard" a new architecture which allows direct printing to UNIX hosts.

12. CLIC STUDIES

12.1 CLIC design

Considerable effort has been devoted to establishing a general set of scaling laws for the rational design of e+e- Linear Colliders. It has been shown that as long as the beam and Linac parameters are chosen to fulfil the "BNS damping" condition, and as long as optimum structure parameters are selected to maximise the RF efficiency, operation with a higher acceleration gradient using high-frequency structures (as opposed to lower frequency) results in: the same or better RF efficiency; the same or better luminosity/power ratio; and the same beam quality for equivalent correction schemes. This has lead to the CLIC parameters being updated. For both the 0.5 and 1 TeV machines the charge and bunch length have been decreased to reduce transverse wakefield effects. The revised CLIC parameter list has luminosities of $6.1 \times 10^{33} cm^{-2} s^{-1}$ and $14.1 \times 10^{33} cm^{-2} s^{-1}$ for the 0.5 and 1 TeV machines, with 60 bunches per pulse and an overall wall-plug power of 92 MW and 161 MW respectively. Since high frequencies permit the accelerating structures to be operated at high accelerating gradients which reduces the length of the Linacs (and therefore the cost), multiple-TeV machines can also now be envisaged. Parameters for machines up to 5 TeV have been found to be feasible.

12.2 Main Linac

Beam dynamics studies for the main Linac have focused on single and multibunch emittance preservation. BNS stability can be obtained by introducing a 1% correlated energy spread across the bunch, making micro-wave quadrupole structures unnecessary. The resulting rms energy spread at the end of the Linac in this case is 0.25%. More emphasis has been placed on the use of simple correction schemes to achieve the specified machine performance, in preference to the previously used "wakefield-free" or "dispersion-free" trajectory corrections. Simulations with 60 bunches at 1 TeV have shown that the vertical emittance growth can be kept below 70%.

Design studies of main Linac accelerating structures for multibunch operation are continuing. Three different RF designs have been analysed. A 30 GHz version of a SLAC-type damped detuned structure (DDS) was found to be unsuitable for the current CLIC parameters. A design based on symmetry discriminating damping using radial slots cut through the irises of a disc-loaded waveguide structure was shelved although it gave promising wakefield results. The third design which combines moderate amounts of both damping and detuning was found to be the most promising. The damping is obtained by introducing four output waveguides into the outer wall of every cell. Beam simulations using wakefields calculated from this structure give much less beam blow-up than those calculated from the other designs.

Simulations have shown that the power-generating transfer structures also require damping to reduce long-range transverse wakefields in the drive Linac. The damping has been investigated using both model tests and MAFIA calculations. By making radial slits in the cross-section of the existing design at a suitable place, it has been possible to achieve a damped Q better than 90 for the 20mm aperture high impedance (100 Ω/m) structure.

12.3 Drive Linac

An updated drive beam generation scheme based on 200 MHz superconducting cavities has been devised. The beam for each drive Linac is generated by combining the outputs of 10 pairs of mini-Linacs in a magnetic switchyard. Generation of the bunches using a 30 GHz FEL (free electron laser) is however still being considered. The total installed voltage (for two drive beams) is 14.6 GV. The use of 200 MHz cavities was necessary to have enough stored energy available to accelerate the required 30 μC per drive beam. The over-all wall-plug to beam efficiency is 11.2%.

Progress has also been made with the alternative "multi-drive-beam" or "ring" scheme. One drive beam in this case is used to power a 100 GeV section of the main Linac. Use of multiple beams reduces the power in each drive beam and makes it much easier to handle. The bunches are initially produced by a laser-driven RF gun with a spacing of 32 cm and an rms length of 3 mm. After acceleration to 2.1 GeV by superconducting cavities, the trains are stored in a 5 km circumference Collector ring where they are compressed to an rms length of 0.6 mm. The trains are then interleaved in two successive Combiner rings of 31.25 m and 125 m circumference to give a final distance between bunches of 2 cm. The ten trains of 1024 bunches per train are then alternately switched by a magnetic kicker into the two drive Linacs. For a main Linac operation with 60 bunches at 1 TeV a total charge per drive beam of 9 μC is required. The total installed RF voltage is only 2.4 GV and the wall-plug to beam efficiency of this scheme is 12.7%. Work started also on an alternative using a normal-conducting fully-loaded 625 MHz Linac to produce the initial bunch trains. A 100 μs beam of 5A with an energy of about 1.5 GeV is needed. The technology to accelerate this beam seems reasonably straightforward. After acceleration the beam is frequency-multiplied (x16) and pulse-compressed by the "ring" system. The final drive beam for one 625m long section of the 1 TeV machine has 1360 bunches with 11.7 nC per bunch and an energy of about 1.1 GeV.

In parallel with these design studies, an essential activity has been to simulate the behaviour of the bunched beams in their power-generating drive Linacs. The full analysis including beam dynamics in the presence of collective effects and resistive structures is far too complicated to be treated by a single simulation program and in some cases new programs had to be written. Some of the issues examined individually were: effects of electromagnetic field inhomogeneity on single particle dynamics; the choice of optimum transport lattices; beam disruption due to resistive-wall and synchronous wakefields; and the management of low-level losses in terms of beam control and structural heating. This information was then fed back into the overall design study.

12.4 CTF2

In order to demonstrate the feasibility of two-beam power generation, a fully equipped 3-meter length of drive and main Linacs has been installed and commissioned with beam, making CTF2 the world's first operating 30 GHz two-beam accelerator. Fig. 4 shows the layout of the equipment. The 30 GHz Linacs integrate the prototype hardware already developed in the course of the CLIC study including accelerating structures, transfer structures, and the micron precision active-alignment system. The total acceleration of 6.5 MeV obtained so far is still very modest. It was achieved using a 90 nC drive beam that produced 1.5 MW of 30 GHz power in each transfer structure, giving 11.6 MeV/m acceleration to the 0.5 nC main beam. The 30 GHz RF power is presently restricted by the drive beam charge, which is limited to about 100 nC by the provisional 3 GHz acceleration system. A substantial improvement will come when the two specially designed high-charge accelerating structures are installed in early 1998.

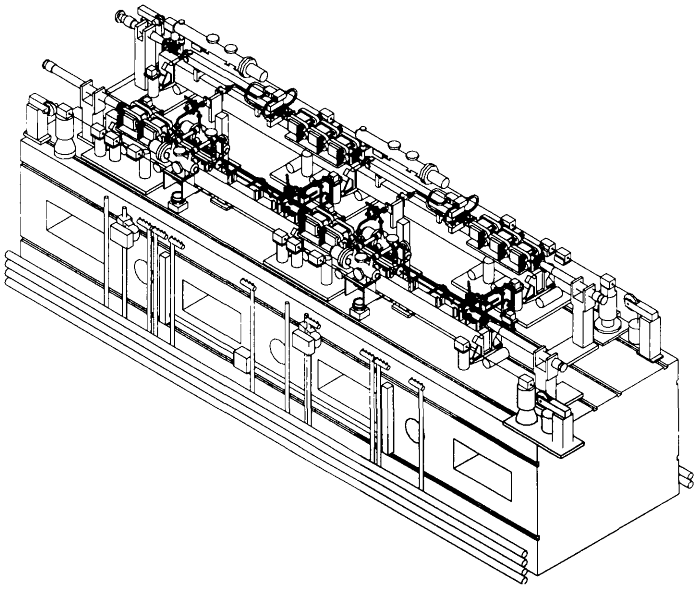

Figure 4
Schematic layout of the two-beam accelerator CTF2

The drive beam RF gun was limited this year to about 75 MV/m but has produced a single bunch charge of 50 nC. In multibunch mode (48 bunches) a maximum charge of 450 nC has been measured downstream, from which the total charge out of the gun can be inferred to be about 600 nC. The probe beam was run very reliably but transmission was limited to 50%. A series of transverse beam emittance measurements as a function of the bunch compressor setting was performed. These experiments showed clear evidence of emittance growth induced by the coherent synchrotron radiation effects of short intense bunches in the achromatic bend of the bunch compressor. A novel monitor allows non-destructive bunch length measurements down to 0.5 ps rms and a newly developed damped transfer structure with four output wave guides was tested with beam. The induced output power was found to be independent of beam position, confirming that the transverse mode energy had been effectively removed. Finally, the automatic RF conditioning system was further developed and ran routinely throughout the year. In its role as a general purpose test facility for linear collider studies, the beam was used by two teams from DESY to test prototype beam position monitors foreseen for the X-ray FEL of the TESLA test facility.

An improved vacuum level in the RF gun due to the reduced repetition rate of 5 Hz, and the lower field of 75 MV/m resulted in a much longer lifetime for its caesium telluride photocathode: almost 3 months with no significant reduction in quantum efficiency was achieved. In the probe beam RF gun the caesium iodide photocathode has now been in use for more than a year in spite of being let up to air twice. Laboratory tests were made on potassium and rubidium telluride as well as gallium arsenide photocathodes and an optical oscillator is being developed that will enable alkaline photocathodes to be tested in the UV region, and gallium arsenide in the near infra-red. Instrumentation has also being developed to measure the energy of the laser beam arriving at the photocathodes, while a numerical imaging system to measure the profile of the laser and the electron bunches is now operational. The reliability of the CTF laser has been improved by a complete re-optimisation of the whole system which has enabled the output power to be significantly reduced. For successful CTF operation, the pulse-to-pulse energy jitter of the laser must be stabilised. Instrumentation based on sampling and direct charging of the pockel cell with a photo-diode have been developed to do this. First results in the laboratory indicate that the jitter can be reduced to 1% but that the transmission drops drastically to 30%.

13. LASER ION SOURCE

This project aims at investigating whether an intense source of heavy ions can be produced by a laser, so that the resulting beam could be directly injected into the accelerators for LHC ion operation. This would be an alternative to obtaining the required LHC intensity by stacking heavy ions from a conventional source in the LEIR ring (see Section 5 above). Encouraging progress has already been made, and 1997 was used for further technical improvements, particularly on understanding the low energy beam transfer and the observed beam losses at high, multi-charge-state ion currents.

The project calls for a very high power laser (100 Joules), which will strike a target to generate a plasma. A collaboration was set up with two institutes in Moscow which have expertise in the field of lasers, the Institute of Theoretical and Experimental Physics and the Troitsk Institute for Innovation and Fusion Research, the idea being that the high-power amplifier for the laser would be constructed in Russia, once a grant had been arranged through the ISTC (the International Science and Technology Center, Moscow). This took some time to arrange, but the most important event of the year for the project was the approval of the funding jointly between ISTC and CERN. Thus the construction of a high energy, high repetition-rate, highly reliable laser-amplifier could commence. It will be built in Russia and delivered in the year 2000. The purpose of this device is to amplify the output of a master-oscillator. A single mode, single frequency, laser master-oscillator has already been obtained from Russia via the collaboration, and was commissioned during the year in the laboratory in CERN. It provides quasi-identical laser pulses from shot to shot, and after completion of a digital closed loop circuit to control the cavity length, several hours of stable operation at a repetition rate of 1 Hz were possible. This is very encouraging for the future.

14. AUTOMATED BEAM STEERING AND SHAPING (ABS)

Providing bright beams to the LHC sets unprecedented tolerances on beam size and shape, and on the control of beam blow-up along the injector chain. A programme of automated beam steering and shaping (ABS) was launched already several years ago in the Division to ensure a fast and reliable particle trajectory correction in all the machines of the PS complex. But in 1997, this programme was extended to the beam envelopes in two critical areas for the LHC beam: the Linac 2 beamline and the Booster-to-PS transfer line.

The beam's size has to be carefully monitored after Linac 2, before the switching magnet which distributes it to the four Booster rings. The emittance is measured in a dedicated line using slits. An iterative least-square solver developed for trajectory correction (and including space charge effects) was successfully applied to the beam shape correction in this beamline, and thus demonstrated the universality of the correction algorithm. The correction to the beam shape was achieved using just two quadrupoles, a very satisfactory result.

In the transfer line from Booster to PS, the problem is to match the beam from the four Booster rings simultaneously. A theoretical study revealed that edge effects of the recombination quadrupoles could no longer be neglected with the tight tolerances imposed by LHC, and so additional quadrupoles have to be installed to make the optical functions for the four beams coincide at the entry to the PS. Since the new magnetic elements do not yet exist, measurements had to be restricted to matching the beam from ring 3 only. The procedure that had been applied for the Linac 2 beamline was repeated, but the correction matrix was evaluated analytically (since space charge is irrelevant at 1 GeV), and the beam profiles were measured with secondary emission monitors rather than slits. The results were equally encouraging.

The ABS programme aims at providing the operating crew with a set of user-friendly application programs to monitor the transverse properties of the beam under all circumstances. Its components are a database which serves as a repository for all the machine data, a correction algorithm, and various application programs. All the components are interconnected. The database has been designed not only for general documentation but also for providing the input to the symbolic optics program BeamOptics and to the computation of the correction matrices. The application programs have been made portable by splitting them into two parts, one specific to the correction for a given machine, the other being a general interface with the correction algorithm. In this way, control modules can be applied to a variety of tasks or machines; indeed, this approach will be extended to the SPS machine in 1998.

15. CONSOLIDATION WORK

Each year, a few jobs are tackled from a long list of items requiring renovation because replacement parts are no longer available from industry due to their age, or because the norms have changed since the equipment was first installed. For example, the last of 3 overhead cranes handling 4 tons was installed in the PS tunnel, which is now equipped with modern cranes replacing the original ones dating from 1954. Renovation of the electronics of the numerous fast kickers of the PS complex has again figured on the programme, the aim being always to standardise as much as possible, thereby making maintenance work and diagnostics easier. Similarly, the programme of modernisation of power supplies has continued with the Booster "shavers" and "beamscope" supplies, the high voltage supplies for electrostatic septa, various supplies in the Linac-to-Booster transfer line, the installation of switched mode power amplifiers for the low energy correctors on the PS, and the PS slow extraction septum supply.

The progressive clean-up of the cable ducts around the PS complex also continued in 1997, focusing on the Booster control room, the RF building at the centre of the PS ring, and the link from there to the main control room. In all, over 200 km of old cables were removed during the shutdown. Later, as part of preparations for the new beam layout there, about 50 km of old cables were removed from the East Hall.

16. COLLABORATIONS

16.1 Proton-ion medical machine study (PIMMS)

As science budgets tighten across Europe there has been a healthy growth of collaborations, one of which took root in the PS Division in January 1996 when CERN agreed to host a group formed by the TERA Foundation from Italy, and Med-AUSTRON from Austria. Their aim was to create a generic design for a cancer therapy synchrotron that could later be adapted to specific national needs. From the start, the group had close ties with GSI, Darmstadt and in 1997 the team was strengthened by a member from Onkologie 2000 in the Czech Republic.

The modern trend in cancer therapy is towards the use of light ions and high precision scanning. This moves away from the traditional proton cyclotron-based facility towards a synchrotron using slow extraction, which picks up the theme of the earlier EULIMA study that was also made in the PS Division. It is no accident that the PS should be chosen for such studies. The years of experience that have been built up with slow extracted beams for physics with the invention and development of such exotic techniques as empty-bucket-channelling and beam shaping by stochastic noise create a situation that is extremely fertile for technology transfer. The appearance of such features in a medical machine broadens the outsiders' view of accelerator physics as well as providing useful spin-off. The accelerator specialists have also widened their experience with the revival of the betatron core that is now rarely seen in a high-energy laboratory, and the development of fully rotational optics that is a new field for the PS.

Performance parameters are defined by clinical needs. The maximum energy of the machine is set to 400 MeV/nucleon for carbon ions and 250 MeV for protons. The beam intensities and repetition rates have been adjusted to deliver a single treatment, known as a "fraction", of about 2 Gy in 2 litres in about two minutes when in the active-scanning mode. In the more conventional passive-scattering mode, the treatment volume is larger and a "fraction" would last for a nominal two and a half minutes. The basic principles have been studied and a first draft of the machine parameters compiled. The final report on the ring, transfer lines and gantries will be presented during 1998.

16.2 IHEP Protvino, Controls Collaboration

Two years ago, following the decision by IHEP to upgrade the controls of the U-70 accelerator complex in order to provide IHEP with a high energy accelerator facility which will later become the injector to the future UNK machine, the goals of this Collaboration were redefined towards providing an efficient and simply-operated control system for U-70. The new control system should subsequently be extended to UNK. The CERN-IHEP Collaboration management board met regularly at Protvino and CERN to monitor progress and to review the plans. A key component in the success of the Collaboration was the continuous presence at CERN of an IHEP representative.

The year 1997 was dominated by producing a detailed project design and implementation schedule. An international review of the proposal was carried out in April, including the technical solution adopted, the budget, manpower and time planning, and the strategy for the transition phase from the old to the new control system. The proposal was very well received, the Review Committee being fully convinced that the new control system will provide the IHEP accelerator complex with powerful tools and enough flexibility and development potential for the future activity of the laboratory.

This permitted the project to go ahead at full steam, since all parameters, which had hitherto been open, were frozen at the project review. The first major step was to renew the Booster controls, in order to eliminate the ancient and no-longer-supported 16-bit micro-computers, EC1010. Some of the CAMAC (SUMA) crates were re-used, as was the link by CAMAC branch to the Equipment Controller Assembly (a Multibus I crate equipped with a newly-developed ME-186, embedded micro-processor) which connects to the VME front-end computer (FEC) by the MIL1553 bus. The FEC runs the advanced real time operating system LynxOs, the same as is used in the PS and SL control systems. A new timing system was put into operation with pulse-to-pulse modulation (PPM) for the new control system. This uses a message broadcasting distribution, generated from a central real time generator. Two user interfaces (the operator consoles) were developed: for the equipment rooms, PC's running Windows 3.1 were provided, equipped with a limited set of applications; for the main control room, X-terminals as the front end of powerful work-stations running Unix were installed. The majority of the applications programs were written and presented to their future users (the U-70 operators and accelerator physicists) who gave useful feedback for further developments. The first milestone was reached at a live demonstration of the control of U-70 during the technical run in November/December, which was a great success. The next step will be to operate the system in the 1998 spring physics run.

16.3 IHEP Protvino, Beam Diagnostics Collaboration

Following the decision to focus on the existing 70 GeV synchrotron U-70, the activities in the beam diagnostics area of the Collaboration gathered momentum in 1997. The needs of the U-70 upgrade programme for high-performance commercial instruments for laboratory work and observations in the control room were defined by the CERN and IHEP experts, and suitable instruments were ordered.

16.4 ICFA Working Group on high-brightness, high intensity hadron beams

The 4th ICFA Beam Dynamics Mini-Workshop was organised at CERN in November on the subject of "Transverse emittance preservation and measurements", a key issue for hadron collider injectors. The dynamics of intense beams was discussed, together with performance requirements and the different diagnostic methods available. Experience gained in the various laboratories was shared. Altogether 44 participants took part from the laboratories especially interested in these issues: BNL, CERN, DESY, FNAL, KEK, RAL and TSL.