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PS DIVISION ANNUAL REPORT 1998

Edited by B.W. Allardyce

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18. Muon Collider Studies

Geneva, Switzerland
10 February 1999

Distribution (Abstract)
PS Scientific Staff

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
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Geneva, Switzerland
8 February 1999

1. INTRODUCTION

This was another successful year around the PS complex, with excellent performances attained by the machines, record numbers of both protons and Pb-ions delivered to the customers, and an operational run of 29 weeks, even longer than last year. The first notable event in the year was the so-called "Big Bang" start-up. During the shutdown, work had continued on preparing the PS complex for the LHC era. In particular, new RF cavities were installed in the Booster and the PS, with the intention of running on new harmonic numbers as from the start-up in March. This was a major upheaval and meant that there was a large quantity of new equipment in the machines. Once the old equipment had been removed during the shutdown, there was no going back: it just ***had*** to work. Hence the title of "Big Bang". In fact, all went well at start-up, to the considerable the relief of a lot of people.

During the year two other important milestones were met, with first beam to the experiments in the renovated East Hall in July, and then first beam to the new AD machine in October, both of which are reported on more fully below. We also had a good deal of luck this year. At the end of the shutdown, a final inspection is always made before starting up. During this inspection, the extraction septum of the PS was pulsed and a strange noise was heard, sufficiently worrying to cause the engineers to open up the vacuum system to look at the septum. They found two fragments of metal in the tank, seemingly from the laminations of the septum, although a visual examination using dentists' mirrors failed to show any damage. It was decided to continue with this septum, since to change it would cause delays. The noise disappeared, and the machines started up, although some strange settings had to be used for the extraction of positrons. This situation continued for the first operational period, but when Pb-ions were needed for the second run, there were once again serious problems with extraction. It was found that by steering the beam across the aperture of the septum, good extraction could be obtained close to both edges, but not at the centre. The diagnosis was that a lamination had broken and was obstructing the centre of the extraction channel. To exchange the septum at that moment would have caused about a week's delay to the physics programme, as well as considerable radiation doses to the personnel. So it was decided to live with the obstruction and to steer the beam round it until the end of the year, hoping that the damaged septum would survive till then. It was agreed to exchange the septum in the next shutdown, when it will be very interesting to see exactly what the obstruction was!

2. OPERATION OF THE PS COMPLEX AND ACCELERATOR STATISTICS

The year 1998 ranks highly for performance of the PS machines. The integrated production of protons and Pb ions reached new records with 3.69 10^{19} protons and 1.61 10^{16} charges of Pb^{53+} ions accelerated to PS extraction. The performance of the beam delivered to SPS can be judged from Figs. 1 and 2 where the results of the last few years are plotted, showing a steadily improving performance each year from the machines. The PS complex ran for 6747 hours of which more than 5800 hours were devoted to physics. Overall availability was 90.9% for the proton beams delivered to SPS and 93.2% for the lepton beams, which is a little less than was achieved in 1997. However, intensities were excellent. During the summer the average proton beam intensity per 24 hours was 2.5 10^{13}

protons per cycle, often limited at the request of the SPS. Sometimes, the intensity exceeded 2.8 10^{13} proton per cycle at PS transition. Tables 1, 2 and 3 show the statistics for the whole complex, detailed by type of beam.

Table 1

Operational Statistics for Lepton Operation in 1998

Total number of hours scheduled for lepton operation	6194 hours
Total number of hours achieved for lepton operation	6012 hours
Hours scheduled for lepton production for SPS/LEP	4670 hours
Hours achieved for lepton production for SPS/LEP	4353 hours
Electrons supplied to SPS/LEP	1.68×10^{17}
Positrons supplied to SPS/LEP	1.65×10^{17}

Table 2

Operational Statistics for Proton Operation in 1998

Total number of hours scheduled for proton operation	6723 hours
Hours scheduled for setting-up and MDs	798 hours
Hours scheduled for proton production (SPS)	4136 hours
Hours achieved for proton production (SPS)	3740 hours
Protons produced for SPS (PSB extraction)	4.23×10^{19}
Protons produced for SPS (PS extraction)	3.69×10^{19}
Protons for machine studies & AD (PSB extraction)	6.23×10^{18}
Protons for East Hall test beams (PSB extraction)	4.4×10^{17}
Hours scheduled for ISOLDE operation	2693 hours
Hours achieved for ISOLDE operation	2581 hours
Protons supplied by PSB for ISOLDE operation	7.69×10^{19}

Table 3

Operational Statistics for Pb-ion Operation in 1998

Hours scheduled for ion production (SPS)	1697 hours
Hours achieved for ion production (SPS)	1564 hours
Total charges of Pb^{53+} ions for SPS (PSB extraction)	2.07×10^{16}
Total charges of Pb^{53+} ions for SPS (PS extraction)	1.61×10^{16}

After the long winter shutdown lasting 3 months, dictated by the time required to install the new equipment at the Booster and PS for future LHC proton beams, the PS complex restarted on 2nd March. The year was split into 2 operational periods, with LEP running in both, and with the SPS fixed target programme fed with protons for run 1 and Pb-ions for run 2. The Booster provided protons to ISOLDE, and the PS fed the East Hall experiments during both running periods.

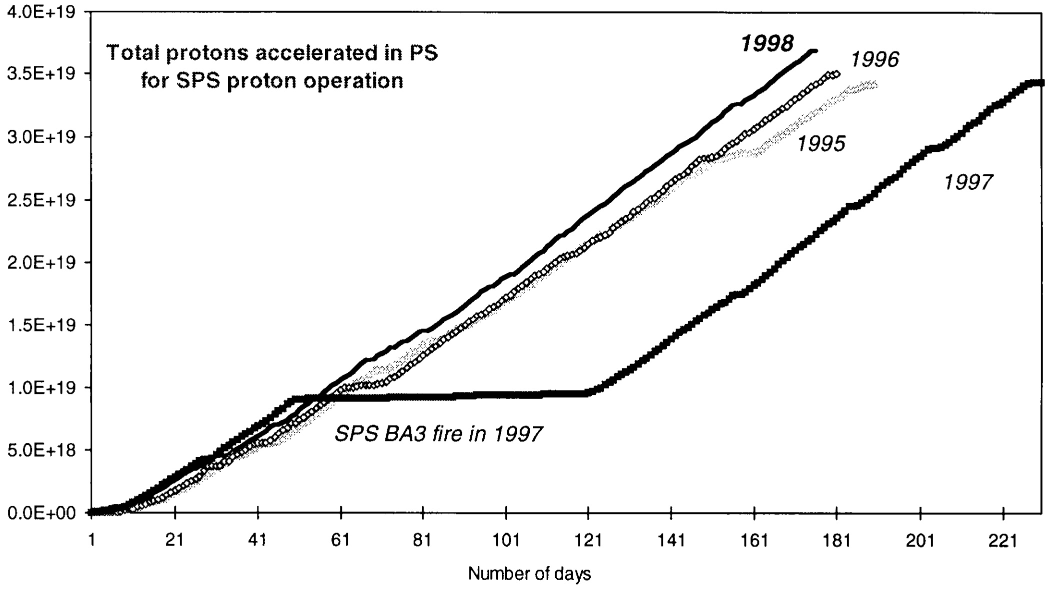


Fig. 1 Integrated number of protons accelerated in the PS in 1995, 1996, 1997 and 1998 as a function of the days of the run

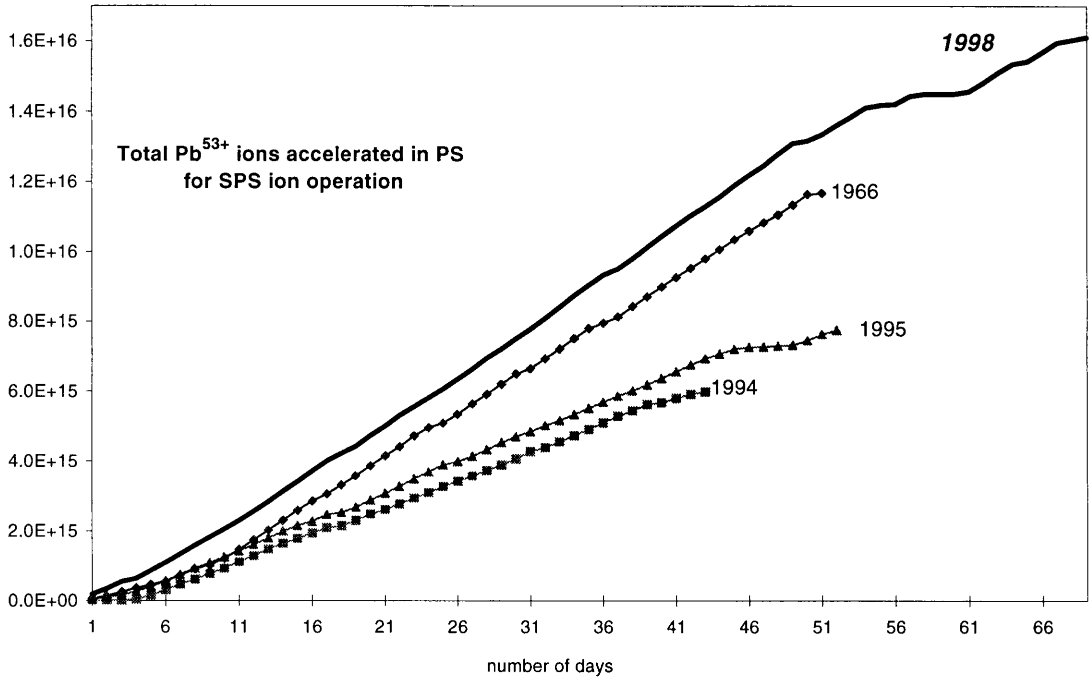


Fig. 2 Integrated number of Pb^{53+} ions accelerated in the PS in 1994, 1995, 1996 and 1998 as a function of the days of the run

2.1 First Operational period (2nd March to 20th September)

At 29 weeks, this operational period was the longest one ever scheduled in the life of the PS Complex. The first 4 weeks in March were devoted to the commissioning of the new systems installed during the winter shutdown for the LHC era. This important milestone (called the PS "Big Bang") was attained successfully thanks to the motivation and dedication of all the equipment specialists and the people involved in operation.

The major modifications concerned the RF systems of the PSB and the PS, leading to new harmonic numbers for all hadron beams accelerated in these machines. For that, it was necessary to set up new beam control systems, to install new RF cavities and to adjust the timing values of the different processes according to the new RF timing trains. In parallel, new magnets and associated power supplies were installed and brought into operation in the PSB-PS transfer line. All this new equipment had to function correctly right from the start, hence the name “Big Bang”.

In spite of many irritating problems that interfered with the start-up, the first 14 GeV/c proton beam was delivered on schedule to SPS on 27th March. The problems were very varied: a blocked vacuum valve at the extraction of PSB ring 2; the unexpected need for a complete cleaning of the Linac 2 water station just after the start-up; the discovery of 2 pieces of metal in a PS septum magnet vacuum chamber; problems in adjusting the working point of the Booster; jitter on the current of the PSB extraction septum magnet due to beam induced noise; and a fault on an RF amplifier of Linac tank 2. However, the proton beam was delivered to SPS on time, and then by the end of March, the lepton beams were also available for the SPS setting-up in April. The only problem with leptons was that positrons could only be extracted from the PS using non-standard settings for the process; this was not explained until much later in the year, when an “obstacle” inside the septum channel was suspected as the reason.

The proton beam for SPS quickly reached a good performance level, rising to 2.5 10^{13} protons accelerated after 2 weeks of operation. ISOLDE requested the beam on the 12th May with a delay of 12 days, and after some tests, started with the “staggered” extraction of 3 Booster rings delivering a total of about 7 10^{12} protons per cycle. Then it switched to high intensity beams of 2.8 to 3.0 10^{13} protons per pulse.

In April the beam availability was acceptable but major events in May and June seriously perturbed the running of the machines and contributed to a large extent to the relatively high fault rates of this operational period:

- A general power failure occurred on the 11th May after the replacement of a 48V interlock power supply on the Prévessin site. Unfortunately the uninterruptable power supply (UPS) did not work because it was not correctly connected to the emergency diesel generators, and as a consequence it took about 30 hours to recover all the beams of the PS Complex.

- On the 10th and 11th June, the production of proton beams was interrupted for 24 hours due to two faults which occurred in parallel on the Booster machine (replacement of a new RF-harmonic 1 cavity installed in ring 3 and problem on the main power supply).
- In June there were numerous beam interruptions due to breakdowns of the PS main power supply (a total of 18 hours over a period of 3 weeks) which were finally traced to a corruption of the message transmitted to the hardware from the control system. After many investigations and trials of temporary solutions, the control and equipment specialists finally installed a new control channel and specific interface.
- Several breakdowns, requiring specialist intervention, occurred on the Linac 2 RFQ power supply and on the new PSB power rectifiers.
- On the 24th June, the coils of the e^+ injection septum magnet in EPA were replaced due to a water leak.

Over the summer the situation improved and the availability of the different beams recovered to a more acceptable value (an average of 93.5%). Apart from several breakdowns due to thunderstorms, the spectacular event occurred on 5th August when an 18 kV cubicle in an old PS substation exploded due to internal arcing. The short circuit current was very high and the automatic protection functioned on several levels causing a general power cut on both CERN sites. It took about 16 hours to restore a normal situation. Then in September, an "obstacle" was identified in the PS septum 16. From the beginning of the year it had been necessary to extract the positrons with a non-standard trajectory and many difficulties were also encountered for the extraction of the Pb-ions during preparations for the last run of the year. In the end, a new extraction setting was found which avoided the obstacle.

Physics in the renovated East Hall started progressively from July as the new lines were commissioned. The East Hall users worked with the 24 GeV/c proton spills delivered by the PS slow extraction on 2 or 3 cycles of the 14.4 sec supercycle, and intensities varied between 2.5 and 3.0 10^{11} protons per cycle.

In September, in preparation for the AD commissioning runs, a preliminary 3.5 GeV/c proton test beam was successfully sent down the ATP line to the AD injection point. In parallel, a new 3.5 GeV/c test beam was prepared, with a new PS beam control adapted to low intensity.

The Pb-ion beam was also adjusted in the 3 machines of the chain (Linac 3, PSB, and PS) in preparation of the following operational run. Machine study sessions were carried out in parallel with physics and also in 3 short, dedicated periods; several sessions were used for the preparation of the new 26 GeV/c LHC-type beam needed for SPS machine developments.

2.2 Second Operational period (22nd September to 8th December)

After a short shutdown used for equipment maintenance, the PS Complex restarted on the 22nd September for the second operational period lasting 11 weeks. The main difference from the previous period was the replacement of proton operation for SPS by Pb-ions supplying fixed target physics. LEP continued to run in parallel until 3rd November.

The performance with Pb-ions was very good, with an exceptionally stable beam and an integrated production of 1.61 10^{16} charges of Pb^{53+} at PS extraction. This figure is a new record for the PS complex, the previous one dating from the last time there was an ion run (in 1996), when the number was about one third lower. Unfortunately, the last two weeks of the run were affected by two major problems. Linac 3 had to be stopped for 36 hours for a thorough cleaning of the ion source following Penning discharges, and the PS injection septum magnet was down for 10 hours due to a vacuum leak. This was also the time of year for EDF "critical days" when electricity consumption has to be reduced, which therefore interrupted the operation for SPS for 6 separate days between the 16th November and the 4th December. In spite of these problems, the lead ion beam availability was 92% over the period.

The lepton beams for LEP continued with a good reliability of 93.2%, and stopped as scheduled on 3rd November. However, LPI ran on longer for local test experiments using electrons in the LEA area and for component tests with the synchrotron light from the EPA ring.

Meanwhile the East Hall worked well with 2 or 3 cycles in each supercycle throughout the operating period. All the test beam lines were brought into operation and the new DIRAC experiment started its commissioning at the beginning of November. ISOLDE ran continuously, often with high proton intensity delivered by the Booster, sometimes above 3 10^{13} protons per cycle. A proton beam from the PS on one cycle in each supercycle was used from October onwards by the AD machine for its commissioning, and the excellent initial result was to decelerate a beam down to 300 MeV/c from the injection momentum of 3.5 GeV/c.

3. LEPTON OPERATION

The LEP Pre-Injector (LPI) is composed of the LEP Injector Linac (LIL) and of the Electron Positron Accumulator ring (EPA) providing 500 MeV leptons. In 1998, the LPI supplied leptons for 6260 hours, most of which (4670 hours) was scheduled for LEP physics. Beams were also provided to three experimental areas (see Section 6 below). The LIL Experimental Area (LEA) received electrons for 1550 h and the two synchrotron light facilities (SLF) received synchrotron light for 470 h. Due to its high flexibility, LPI can serve LEA users in parallel with providing a beam for LEP. In 1998, a second synchrotron light facility (SLF42) was installed and a new mode of operation was introduced allowing a stored beam in the EPA accumulator for SLF users while the LIL provided beam to LEA users.

The LPI performance (intensity/bunch as well as e^+ accumulation rate) continued to be well above that required for physics at LEP. There were two main faults during the year. On the night of 11th May, after the breakdown of a 400 kV transformer, all systems went down, including the computer control, and it took 21 hours to resume LPI operation. Then, on 23rd June, a breakdown of the positron injection septum stopped the machine for 24 hours. Nevertheless, the LPI fault rate was still extremely low, at 2.2 % over the year.

4. PROTON OPERATION

4.1 Linac 2

Linac 2, the CERN proton workhorse, was on line for more than 6800 hours in 1998. Major incidents included: the town-water cooling, where serious corrosion was found at the crucial moment of start-up; the RF tube filament supply on tank 2; arcing on a high voltage supply cable in the RF modulator; and voltage breakdowns in the ion source arc system. The Linac intensity, as measured at the last beam transformer before the PSB, was initially kept down to 155 mA during the running-in of the new PSB radiofrequency system, but was allowed to creep up to 173 mA once the PSB was able to digest it. Indeed, it did prove possible during parasitic study sessions to push the intensity up to 179 mA, very close to the theoretical figure of 180 mA desired for operation in the future with LHC. To attain this beam after 80 metres of beam transport line, the intensity leaving the Linac reached 192 mA.

For some time, the vacuum in the Linac tanks has been under close observation and it has been noted that certain leaks have become worse, and that new ones have appeared. They do not yet compromise the running of the Linac, but they must be monitored and, in the long-term, fixed. Unfortunately, due to the complexity of the Linac design, it is not a simple task to diagnose, nor to repair them. Some were measured more accurately during the annual shutdown, and a trial solution for eliminating one of them was defined. However, there will not be enough time during the next shutdown to carry out the programme safely, so the time will be spent trying further to improve our understanding of the situation.

A contract has been placed with the Institute of Nuclear Research in Moscow to manufacture, install and commission two inter-tank Beam Shape Monitors (BSM's), one after the RFQ and one after tank 1. The aim is to improve the beam diagnostics for machine development sessions related to LHC operation of Linac 2.

4.2 PSB and PS

The Booster and the PS performed excellently and consistently in 1998, allowing new records of integrated beam delivered to the customers to be achieved. The incident of the extraction septum 16 and its probable broken lamination leading to a partial blockage of the aperture has been noted elsewhere.

Machine studies on the PSB and the PS concentrated on the preparation of the LHC beam, improving the slow extracted beam for the East Hall (EHNL project), and setting-up the Pb-ion beam prior to the second run starting in September. For the LHC, the longitudinal characteristics required for the "nominal beam" were almost obtained, profiting from the recent installation of the new 40 and 80 MHz cavities. The slow extraction beam for the East hall took some time to set up because of a low-frequency ripple on the slow extraction spill, whose source was only identified after many frustrating hours of research. An important part of the development time was also spent on the implementation of ABS, the automated beam steering and shaping. Throughout the year one cycle was more or less permanently dedicated in each machine for development studies, setting-up and beam performance optimisation.

5. ION OPERATION

Following the annual shutdown, the ECR ion source was dedicated to studies of the "afterglow" phenomenon. Then in early June, Linac 3 was made available to the PSB so that ion acceleration could be tried for the first time since the major changes to the Booster RF systems. After optimising the optics of the transfer line between Linac 3 and the PSB following the replacement of four DC quadrupoles by pulsed magnets, this mode of operation continued in parasitic mode for machine optimisation throughout the summer.

However, during the latter part of the summer, it became evident that the ion source performance was deteriorating. A major overhaul of the source was decided, with the replacement or cleaning of many of its components, but nevertheless it was ready on time for the scheduled ion run in September. This was an important run, since there had been no scheduled ions for more than a year due to the fire in BA3 in 1997. Unfortunately, a high voltage transformer failure in the radiofrequency chain of the RFQ caused some lost time. But during the next few weeks, the intensity of ions was slowly increased from 22 to 24 μA, with the beam showing remarkable long-term and pulse-to-pulse beam stability. This stability was unfortunately lost following a series of breakdowns due to the demineralised water system over a five-day period. It then became very difficult to improve the intensity beyond 22 μA without serious effects on the pulse-to-pulse beam stability.

In early November, a scheduled technical stop permitted the refilling of the micro-oven used to evaporate lead into the source plasma. At this point the source had been in continuous operation for 41 days with a lead consumption of 4.4 mg/day. After a further 18 days of operation, an intermittent Penning discharge developed in the source extraction region, requiring the replacement of the extraction electrodes. Following this, reconditioning of the source became extremely difficult, probably due to nitrogen absorption on the amorphous lead deposit on the plasma chamber walls. The plasma chamber was therefore exchanged. Eventually, after 36 long hours of installation and reconditioning, the beam was once again available for physics, although instabilities continued for another 12 hours.

The overall availability of lead ions from Linac 3 stayed above 96% for the 1800 hours of operation in period 2. On the PSB and the PS, the lead-ion beam had a good average intensity of 1.7 10^{10}

charges/pulse and there were few problems during the run. These good conditions resulted in the highest integrated beam intensity so far generated, as shown in Fig. 2 above.

6. OPERATION OF THE EXPERIMENTAL AREAS

6.1 LEA (LIL Experimental Area) with Electrons

This facility, situated in the straight-on beam-line from the electron Linac, provided electron beams of 500 MeV whose intensity, pulse duration and repetition rate were adjusted according to the user's requirements. For CMS detector development, the 500 MeV beam was used to measure on-line the damage created by radiation in the forward calorimeter, where quartz fibres are inserted inside iron absorbers. Typical doses of $5.0\ 10^{16}$ electrons were used to irradiate the fibres and absorbers. Such measurements should enable the specification of the best type of fibres to be used in the CMS forward calorimeter, which is sensitive to the electromagnetic component of the hadronic showers. With this facility, several years of LHC running can be simulated.

6.2 SLF (Synchrotron Light Facility)

If the EPA ring is run for an electron energy of 308 MeV, the critical energy of the emitted synchrotron light is 45 eV, the same as the synchrotron radiation that will be produced in the LHC bending magnets with 7 TeV protons. One synchrotron light line (SLF92) was used by the COLDEX experiment, a helium cryostat housing a test cold screen of LHC. The aim is to study gas desorption induced by synchrotron radiation at cryogenic temperatures (2 ^{o}K on the cold bore and 5 ^{o}K to 20 ^{o}K on the beam screen), the same conditions that will be used inside the LHC dipoles.

A new synchrotron light line (SLF42) was created this year and has been used to study the possibility of installing non-evaporable getter (NEG) material in the LHC regions working at room temperature (typically, close to the detectors). The idea is to study the behaviour of such NEG pumps in the presence of a huge dose of photons. One could envisage activating these new NEG pumps at 300 ^{o}C instead of 700 ^{o}C as presently in LEP. These studies will continue in 1999.

6.3 ISOLDE using Booster Protons

There were no major problems concerning the supply of Booster protons to ISOLDE during the year. In the hall, the progressive installation of the REX facility continued.

6.4 East Hall using PS Protons

During the first half of the year, the enormous work of transforming the whole layout of the East Hall continued (the East Hall New Look project). Then, at the end of June and according to schedule, the area was progressively fed with protons and commissioned. The Hall had been out of action for physics for 9 months. First, the irradiation area on the south branch was made operational in July and this allowed tests of silicon detector samples. Next, the 4 secondary lines emanating from the North and South target stations were brought into operation, delivering beam to their users while the DIRAC experiment was still being installed. Finally, at the end of November, the DIRAC experiment was ready on the T8 line and could start a preparatory run for a few weeks before the end of the year. For the first time, two different 24 GeV/c beams were sent to the East Hall; one to produce secondary particles from targets for the test-beam users, and another taking the direct proton beam from the PS for the DIRAC experiment.

7. CONTROL SYSTEM AND COMPUTING

7.1 Accelerator Controls

Besides the day-to-day exploitation of the control system driving the PS Complex, which takes about half the resources of the CO group, new systems were installed for the EHNL and AD projects. For the East hall (EHNL) project, new controls for the beam lines were installed using Power PC's as VME processors. A complicated PPM was introduced to be able to feed the different experiments in the same PS supercycle. For the new AD machine, the experience gained with the East Hall was successfully applied on a much larger scale. But, due to the special nature of the AD machine, as both a cycling machine and as a storage ring, the standard PS controls concepts could not be applied directly. The new approach for the timing and the sequencing systems was tested successfully during the start-up of AD commissioning in October/November, and it will be fully integrated into the central PS timing system in the next shutdown. Thanks to a mixture of the standard Unix environment and dedicated applications running on PC's, the first tests with the new AD machine were made quite painlessly.

The PS-SL convergence activity started in March with the ambition to reach a common software infrastructure by the end of LEP, applicable subsequently to LHC. A working group from the two controls groups was established which defined and launched four sub-projects: a Java equipment access API; a central timing system common to PS and SPS; the extension to SL of the so-called "Passerelle" for accessing the controls through PCs; and a common repository structure for all the software developed in common with SL. Recently an ambitious "middleware" project was launched which will require a large effort from both controls groups and will influence future developments both on the operation interface and on equipment access. As for all the projects, milestones were defined so that concrete validations can be achieved along the way, including the "SPS2001 software rejuvenation project".

Automated Beam Steering & Shaping (ABS) software was further developed with emphasis on data handling through the implementation of a well-structured database. It was successfully applied to the PSB and the PS in 1998. In the MCR, the local NT-based PC server environment proved its reliability and was expanded with machines required by the operators for performing tasks like real-time data storage, archiving, etc. This environment was established to ensure that tasks in the control room are not interrupted by general PC network faults.

7.2 Networks

A year ago, fibre-optic cables were installed by the SL-CO team between our different machines to provide a modern network for our accelerator controls, and local structured networks were installed in the MCR area to allow for higher data rates on individual workstations. The same structure is now being implemented for the PSB controls as the second stage of the project. In addition, the PS CATV network (the local distribution of TV signals associated with the accelerators) was extended to include new machine information displays, and a local network was set up in the East Hall incorporating beam-monitoring displays for the physicists. The CATV activities of both PS and SL Divisions have been merged into a single team to provide easier maintenance and a better co-ordination of the development effort.

7.3 Control System Gateway to the PC Network

The gateway (the so-called "passerelle") between the control system and the PC network has been very busy this year, especially during the commissioning of the AD project for which several PC-based test applications were quickly developed in order to verify and set up the AD equipment. In the framework of the PS-SL convergence project, the existing PS "passerelle" was redesigned so as to separate the generic and the specific control system parts. This made it easily portable to any other control system, which enabled the SL-CO group to start to use it on HP-UX. Now, the PC user can communicate with both PS and SL controls within the same application through a unique interface. At the same time, the performance of the generic part was improved by implementing parallel data processing.

7.4 ISOLDE Controls

The layout and implementation of the new REX control system, as an extension of the existing ISOLDE controls, was started in the middle of 1998 and should be completed by the end of 1999. The new object-oriented front end computer model based on Windows NT has been put into production and some old DOS machines for the beam transfer line between ISOLDE and REX have been replaced. A new database with a dedicated graphical user interface has replaced the old Excel files.

7.5 Office Computing

The deployment of the new printing architecture by IT Division achieved a level of 70%. This architecture was initially designed in PS.

8. BEAM DIAGNOSTICS

The major priority in beam diagnostics is maintaining the large number of diverse diagnostic systems at a high level of performance and reliability. Maintenance concerns not only the hardware, but in an increasing measure also the software, to adapt continuously to the changing controls environment and to the ever-evolving ways of using the accelerators. Apart from this base load of work, considerable effort went towards the projects of AD, the upgrading for LHC, and the East Hall renovation (EHNL).

Dominant was the provision of diagnostics for the new Antiproton Decelerator (AD). In part, this meant adapting existing instruments to new ways of functioning, such as the scrapers, the fast or dc beam transformers and the scintillator screens, all of which had in addition to be converted to a new controls system. It also meant the conception and construction of new diagnostic devices such as the one for the closed orbit measurement. Although using old pick-up electrodes, this new system has to fulfil the challenging requirement of measuring beam position to better than 1 mm over an intensity range from $2\ 10^{10}$ down to as few as 10^{7} particles. Very-low-noise amplifiers were developed, as well as new ways to treat the signals. During the AD tests in October/November, the new system proved to be precise to 0.5 mm with only $5\ 10^{6}$ protons circulating in the AD. This is believed to be a world record. Another important item being developed is a resonant Schottky pick-up which will allow the measurement of essential beam parameters (in particular the Q-value) throughout the deceleration process, again at the lowest conceivable intensities. In the beam lines to the AD experiments, a considerable effort was necessary to prepare a large number of multi-wire chambers for measuring the beam shape at low intensity.

For the high-density beams destined for the LHC, the emittance must be kept within tight limits at each of the many stages of beam handling throughout the PS Complex. Precise measurement of beam size is thus of increased importance. New secondary-emission grids were installed at the injection region of the Booster, to study the multiturn-injection process and to provide a new method of verifying the "betatron matching". New fast wire scanners for the 4 Booster rings were specified and are now under development at TRIUMF. At the PS, the fast wire scanners saw further refinements and the old measurement targets were brought up to new standards of precision. As a contribution from the Division to the LHC machine itself, basic development of dc beam transformers continued, with in particular the development of a new circuit for very tight synchronisation of the modulation current to the mains frequency.

The extension of the East Hall experimental area, with its new beam lines, required the installation of beam transformers, scintillator screens with TV, ionisation chambers, etc. Particular attention was given to the beam towards DIRAC, where a new image treatment system provides 16 images of the beam on the scintillator screens during the 300 ms spill. This greatly facilitates setting up the beam and keeping its position stable throughout the spill.

The closed-orbit observation (CODD) of the PS received a new synchronisation system, permitting measurement at all harmonic numbers from 1 to 20. New beam transformers were installed at several strategic locations in the PS Complex, others were upgraded, and radiation-damaged ones were replaced.

9. PREPARING THE PS COMPLEX TO PROVIDE PROTON BEAMS FOR LHC

A major upgrade of the PS Complex was necessary to generate a proton beam of the required characteristics for LHC. The transverse beam brightness needed is higher than was hitherto achievable, and is limited by space charge. To overcome these problems the new scheme foresees filling the PS with two Booster batches, which implies new RF harmonic numbers in the Booster (1 and 2 bunches instead of 5) and the PS (8 and 16 bunches instead of 20). Space-charge effects in the PS will be reduced by increasing the injection energy from 1.0 to 1.4 GeV. Moreover, the LHC bunch spacing of 25 ns will be imposed on the beam before PS ejection (26 GeV/c), and bunches will be shortened to 4 ns so as to fit into the buckets of the SPS 200 MHz accelerating system.

Most of the new equipment was installed during the long and busy winter shutdown, with hectic activity at both the Booster and the PS; the remaining elements will be installed in the next shutdown. The TRIUMF Laboratory (Vancouver, Canada) provided a sizeable fraction of the new equipment as part of the Canadian contribution to the LHC. Figure 3 shows the new equipment and its origin.

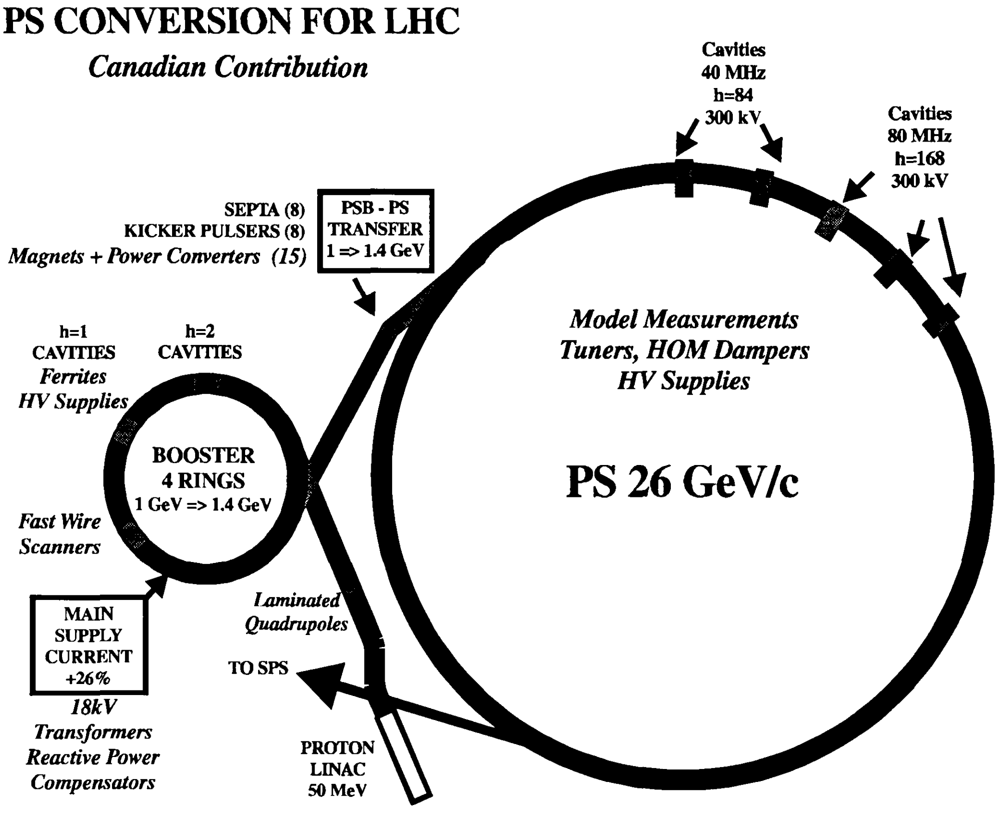


Fig. 3 PS Conversion for LHC: hardware upgrades and the Canadian contribution (in italics)

In the Booster, the new RF accelerating cavities (frequency range from 0.6 to 1.75 MHz) enable one long bunch per ring to be accelerated, while bunch flattening is provided by harmonic 2 radio-frequency cavities. These latter cavities are also employed to split one bunch into two, a novel technique used for certain beams. The main magnet power supply can now pulse up to 1.4 GeV (which means 26.3% more current); five double-transformers replace the old ones, which were filled with the now-prohibited PCB; and a new reactive power compensator keeps the 18 kV mains constant during the Booster pulse. All this equipment was provided by, or financed by Canada. New quadrupole power supplies QF and QD, with higher output voltage and feed-forward loops, have also been introduced to reduce tracking errors. In order to adapt the Booster-PS recombination line to the stiffer beam at 1.4 GeV, many of its elements were renewed. Altogether 15 magnets and their power converters, four ejection septum magnets and their pulsed supplies, and the pulse-forming networks for the vertical recombination kickers were replaced. Much of this equipment also came from Canada.

In the PS, the 25 ns spacing of the LHC beam is generated at 26 GeV/c by a 40 MHz (300 kV) fixed-frequency cavity available since spring 1997. Two new 80 MHz cavities (300 kV each) now enable the beam bunches to be shortened to 4 ns, exploiting non-adiabatic RF procedures. The copper-plating of these rather large devices (~2 m diameter) caused considerable headaches. Higher-order mode dampers and high-voltage supplies for these cavities were contributed by TRIUMF. The low-level electronics for the RF of both the PS and the PSB was partially rebuilt so as to adapt to the new harmonic numbers, and now fully profits from the latest technology ("digital beam control").

At the end of this very busy shutdown, the challenge was to commission all the new equipment without delaying the delivery of beam to the first clients. Hence the phrase "Big Bang" which was coined to describe the start-up, since there was no going back to the old RF systems. Although the commissioning was hampered by several hiccups, the users received their beams on time, much to the relief of all concerned. Later, 1998 turned out a good year when the PS achieved record integrated intensities for both protons and heavy ions, in spite of (or because of?) the many new systems. The new 80 MHz cavities were brought into service, and 80 bunches of 25 ns spacing became available in the autumn for the SPS to start its programme of preparing LHC beams. The procedure to achieve this is illustrated in Fig. 4. The top three traces show the RF voltages applied to the 80 MHz and 40 MHz RF systems, and the pick-up signal giving the bunch length. The bottom two traces show the shortest bunch length achieved for two different intensity levels. The bunch length was ~4 ns for 3 10^{10} protons/bunch, but it is still somewhat too long at the nominal LHC intensity of 10^{11} protons/bunch; further work is required to meet the LHC specifications fully. Also, the transverse beam emittance is still slightly larger than nominal, because running the Booster at 1.4 GeV and the two-batch filling scheme of the PS are both scheduled to become available only in 1999.

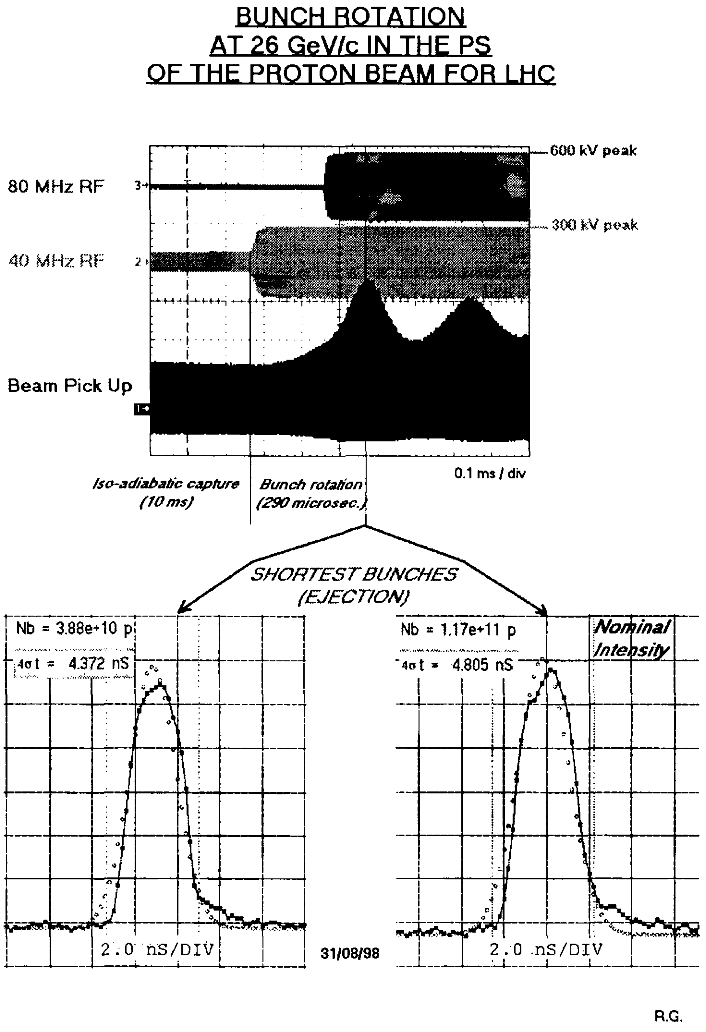


Fig. 4 Radiofrequency procedure in the PS to produce 80 short bunches for the LHC

10. CONSOLIDATION WORK

Each year the Division tries to continue its programme of gradual renovation of old equipment, especially electronics, but what can be achieved depends on the budget made available. This year the effort focused on power converters for the measurement of beam characteristics, particularly kicker power supplies for the Linac, shaver power supplies for the Booster, and beam-scope power supplies for the Booster. In addition, four power converters for correction dipoles near the ISOLDE targets have been prepared for installation in the next shutdown, and the high voltage supplies for the PS 300 kV electrostatic septa were commissioned in March. The continuous modernisation of the electronics of our power converters gives improved reliability, which is very necessary with the reducing staff level, and the evolution of technology (e.g. the IGBT) has allowed several innovations in capacitor discharge power supplies.

Another area where investment is needed every year is in cabling. Once again there was considerable activity in the shutdown aimed at cleaning up the overcrowded and often broken cable trays, ducts and tunnels around the PS complex. Although a somewhat inglorious task, it is nevertheless essential to remove old cabling, in order to make way for the new. This year the main focus was in the rooms around and underneath the main control room (MCR), in the tunnels between the PS experimental halls and the MCR, and in selected other areas where the work had been started in previous shutdowns but was not finished for lack of time. In all, over 1500 cables for a length of about 145 km were removed. An essential part of this work is the computer documentation of our cable runs, and this work also continued during the year; the majority of this documentation is now completed.

11. THE AD PROJECT

11.1 The AD Machine Commissioning

The installation of AD (the Antiproton Decelerator) was completed during the first 8 months of the year, continuing the work started last year. The old Antiproton Accumulator (AA) machine had been dismantled in 1997, and this year it was shipped to Japan for re-use in the future Japanese Hadron Facility. The main tasks this year were modifying the Antiproton Collector (AC) ring to convert it to a decelerator ring, and preparing the Hall to receive the experiments. A major effort was required in preparing the power converters for the new machine and its beamlines. The power converters require a high current-stability and low tracking error over the full dynamic range (a factor of 35 for AD, which is very large). Active filters were added to the main power converters and the old electronics was replaced; new power converters capable of working at very low currents were designed using a new technology; and all the old supplies of the injection lines, as well as those recuperated from LEAR, were renovated and given the latest control electronics. In all, 35 new power converters were ordered and built, and another 70 were completely overhauled.

At the beginning of September, tests of the power supplies and of the control system started in parallel with the bake-out of some critical elements of the ring. The old AC machine could not be baked out and thus the heating of the elements was a new feature that took time and effort to perfect. It was anticipated that each bake-out would take 2 to 3 weeks because many elements can only be heated indirectly and can tolerate only a very slow temperature rise. Several leaks were encountered before a good vacuum (a few 10^{-10} torr) was finally reached around 15th October. The first beam of protons at 3.5 GeV/c was then sent from the PS via the TT2 line, and the new reverse-injection lines (called "8000" and "7000") were used to adjust the transfer lines and to inject counter-clockwise into AD.

The first protons circulated in the ring on 23rd October with a good beam lifetime of about 1 hour; the lifetime of the champagne in the glasses just after this event was considerably shorter! After the first circulating beam, progress was rapid during the 5 weeks remaining before the shutdown. Deceleration of the proton beam down to 300 MeV/c was achieved, and the optics of the ring was tuned and found to be close to what had been predicted. The acceptance was also close to its nominal value (165 instead of the required 185 π mm.mrad), and the new orbit correction system gave encouraging results. Finally, the injection of test protons in the normal (clockwise) direction was also set up, using the normal injection line (with the antiproton production target removed and the ring elements set to inverse polarity). With this beam the stochastic cooling was tested at the injection energy, but so far no tests have been made with electron cooling, although all the modifications necessitated by its removal from LEAR have been done.

Thus the AD project made a great leap forward during this commissioning period but it will still take a major effort next year to reach 100 MeV/c for antiprotons, with both the stochastic and the electron cooling functioning to limit losses and to obtain the small emittances required. This progress was only possible due to the efficient support of many CERN groups from PS and other Divisions and the contribution of the future users. We were lucky to have the enthusiastic help of young people (a total of 12 man-years so far) from, or paid by laboratories in Denmark, Germany, Japan and USA. Some of these visitors will stay on to aid in the operation of the AD.

11.2 The AD Experimental Areas

The main thrust of the activity in the AD hall was of course the construction of the AD ring. However, progress was also made in preparing the experimental beam lines and the infrastructure for the experiments. There will be 3 experiments called ASACUSA, ATHENA and ATRAP and there is an area reserved for tests. The experiments will be installed in the first half of 1999. Extensive calculations have been made of the optics of the different lines, and one excellent result is that in order to switch between the experiments it will be necessary only to activate a switching dipole, the focusing properties of all the beams being identical.

11.3 Decelerating RFQ for the ASACUSA Experiment

Following approval of the RFQD-project to provide a radiofrequency quadrupole for efficient antiproton deceleration in the ASACUSA experiment (and funded entirely by that experiment), detailed technical studies have begun and purchase orders for major heavy components have been placed. A simplified, 1/3 scale model of the RFQD has been built to complement software studies of unwanted RF modes that appear due to its novel design with a floating internal structure. This feature allows the application of a DC high voltage for smooth electrostatic post-deceleration of the beam down to practically zero energy. Practical tests have been started to examine the possibility of testing the structure with a pencil electron beam instead of an antiproton beam, which would allow a drastic improvement of measurement possibilities.

12. CLIC STUDY AND CTF

12.1 CLIC Design

During 1998 the focus of the CLIC study was changed from a 0.5-1 TeV collider to a 0.5-5 TeV collider. The increased energy reach became possible after making several important modifications to the RF power generation system. The parameters have been optimised for a centre-of-mass energy of 3 TeV and follow the general scaling laws for the rational design of an e+e- linear collider that were derived last year. In order to limit the overall extension of the complex to less than 35 km it has been assumed that the collider will operate at a loaded accelerating gradient of 150 MV/m. Such a high gradient is only possible because CLIC has the relatively high RF operating frequency of 30 GHz. The revised CLIC parameter list has a luminosity of 10.6 10^{34} $cm^{-2}s^{-1}$ for the 3 TeV machine with 150 bunches per pulse, and an overall wall-plug power of 206 MW. To obtain this luminosity it has been necessary to allow the mean energy loss during the collision process to go as high as 32% with a beamstrahlung parameter of 8.7. Even with such a strong beam-beam interaction the luminosity spectrum is still acceptable, with more than 30% of the luminosity within 1% of the peak colliding beam energy. To reduce transverse wakefield effects, the number of particles per bunch and the bunch length have been reduced to 4 10^9 and 30µm respectively for a multi-bunch spacing of 20 cm. Simulations show that under these conditions a normalised vertical emittance at the interaction point of 10^{-8} m.rad can be obtained. The parameters for the lower energy (0.5 and 1 TeV) machines are in general less demanding, whereas at 5 TeV the parameter set looks ambitious but cannot be considered out of reach.

12.2 Main Linac

Beam dynamics studies have focused on single and multibunch emittance preservation in the main Linacs for the 3 TeV machine. The overall emittance blow-up is kept to a reasonable value by the use of local bumps which are created at about 10 positions along the Linac by mis-aligning a few upstream cavities. In order to obtain a good beam stability with small emittances, the lattice has to be optimised to take into account both static and time-varying mis-alignments. Simulations of the effects of ground-motion and beam and quadrupole jitter show that after a certain time (typically a few days), the use of bumps and the application of the one-to-one correction scheme are insufficient to keep the emittance small. The whole machine has then to be re-aligned using a beam-based remote control system that repositions the support girders. A new analytical treatment of the dynamics of a single bunch in the presence of wakefields has been developed to complement the information provided by simulation programs and to get a better understanding of how the key parameters affect the stability of the main beam. This analysis provides closed expressions for the transverse off-sets inside the bunch, the tune shifts and the emittance growth. To obtain stable beams with multiple bunches requires a careful design of the accelerating structure to obtain a strong damping of the long-range transverse wakefields. Design studies have focused on the new Tapered Damped Structure (TDS). Each cell of the TDS is damped by its own set of radial waveguides resulting in a Q of 16 for the lowest dipole mode. The structure also has a detuning spread of 5.4%. The top two priorities of the study this year have been to develop a suitable waveguide load and to prepare for an experimental verification of the wakefield performance in the SLAC facility ASSET. A suitable low reflection coefficient (< 0.1), inexpensive and robust silicon carbide load has been developed and tested. Special procedures were developed to measure the complex permittivity of materials like silicon carbide, and as a result it was possible to design the load directly using computer-modelling techniques. The ASSET test will provide a direct measurement of the TDS transverse wakefield. The electromagnetic and mechanical design of the test structure has been completed and fabrication has begun. The test structure is a x2 scaled version of the CLIC design to avoid beam aperture limitations in the ASSET facility. A new "wave number" method of calculating the wakefield has been developed to improve the understanding of the interaction of a beam with a damped periodic structure. The method is based on the direct computation or measurement of the propagation characteristics of the higher order modes, and will provide a second, independent estimation of the TDS wakefield.

12.3 Drive Beam Generator

A new multi-drive-beam-generation scheme has been developed which uses a conventional normal-conducting fully-loaded 937 MHz Linac to produce the initial bunch trains. An 8A, 91 μs beam with an energy of about 1.2 GeV is required, which can be generated with an efficiency of about 97%. The bunches are produced by two separate injectors each consisting of a thermionic gun and a small number of normal-conducting buncher/accelerator structures. The two trains of bunches are then combined by an RF deflector to form a continuous beam. The 937 MHz Linac is powered by conventional long-pulse klystrons. After acceleration, the beam passes through a complex composed of a delay-line combiner and two combiner rings, where groups of leading bunches are delayed to fill in the gaps between trailing bunches. The net effect is to convert the long beam pulse into a periodic sequence of drive-beam pulses with gaps in between. Each pulse has 32 times the initial current, while the bunch spacing is 32 times smaller. This sequence of pulses is distributed from the end of the Linac against the main beam direction down a common transport line. Pulsed kicker magnets deflect each pulse at the appropriate time into a so-called "turn-around". After a "turn-around" each drive beam pulse is decelerated in a 700 m long sequence of low-impedance decelerating structures, and the resulting output power is transferred to the main Linac where it is used to accelerate the high-energy beam. At the end of each 700 m long section, the drive beam pulse is dumped and a new one takes over the job of accelerating the main beam. The complex can be upgraded or downgraded to other energies by simply changing the initial pulse length.

In the drive beam accelerator, beam stability is very important, with particular attention having been given to the focusing required, the amount of cavity damping and detuning needed, injection and quadrupole jitter effects, alignment tolerances, and steering. Preliminary layouts of isochronous lattices for the delay-line, the combiner-rings and the "turn-arounds" have been proposed. The same is true for the chicanes for the path length adjustment and the bunch compressors, both of which have special characteristics due to the unusual energy correlation in the drive-beam bunches.

12.4 Drive Linac

For the drive beam decelerator, the studies have focused on the control of the beam size and eventual beam losses for cavities without rotational symmetry, for non-linearly varying wakefields with transverse displacement, for strong energy variations along the train, and for a large bunch energy spread. Development studies have continued on the 30 GHz power generating transfer structures. The Mafia code work first concentrated on four-channel structures with inner diameters of 20 and 24 mm and shunt impedance (R/Q) of 100 and 62 Ω/m respectively. Six-channel and eight-channel structures with larger apertures were also investigated because they have a better field homogeneity for the decelerating mode. These multi-channel structures are appreciably more difficult to manufacture, especially since damping slits are necessary.

12.5 Injector Systems

Design solutions for the main beam injector are for the moment limited to a centre-of-mass energy collider of 1 TeV with 150 bunches and a repetition rate of 150 Hz. The Linacs are now based on 1.5 GHz and 3 GHz normal-conducting accelerating structures. Simulations for positron production show an adequate yield. Beam simulations indicate that the present design consisting of one pre-damping ring and one damping ring can give the required vertical normalised emittance of 5×10^{-8} m.rad at the entrance to the main Linacs. Further studies with a revised damping ring design will be necessary to obtain the even smaller emittances required for the higher energy machines. It has been shown that the required 30μm long bunches can be obtained using a two-stage bunch compressor with a total compression factor of 100.

12.6 CTF2 Studies

As in previous years, a considerable fraction of the CLIC effort during 1998 was devoted to CTF2. The drive beam RF-gun that was limited to a gradient of about 75 MV/m last year has been replaced. This new gun quickly reached a gradient of 110 MV/m on the cathode, which was maintained throughout the year. The 1m long NAS S-band structure of the drive beam accelerator has been replaced by two high-charge accelerating structures (HCS). These structures were designed and made in close collaboration with LAL-Orsay, but their conditioning was difficult. Due to the unusual 11/12 π-mode utilised in these structures, a transient power reflection occurs causing considerable problems to the klystrons. This was resolved by introducing a sophisticated amplitude and phase programme along the RF pulse. Another problem is the overvoltage in the coupling cells, which resulted from the very difficult matching of the couplers to the 11/12 π-mode. This limits the average accelerating field in HCS to about 35 MV/m, compared to the design value of 60 MV/m. With the installation of the HCS's the two-frequency beam loading compensation for the drive beam accelerator became operational and has produced results which confirm the theoretical predictions. This is the first time that such a scheme has been used for heavy beam-loading conditions.

A total charge of 755 nC in 48 bunches has been produced by the drive beam photo-cathode and accelerated in the HCS's. This is more than the design value of 640 nC. The maximum accelerated single bunch charge was 112 nC. Both are unprecedented values for RF-photoinjectors. However, it was not possible to transport more than 374 nC through the 30 GHz drive beam decelerator. Reasons for this are the too low gradient in the HCS's, a still incomplete understanding of the transverse dynamics, and problems with beam diagnostics and radiation at high charges. A systematic study of these problems was hampered by the inability of the laser/photocathode system to provide high charges for periods longer than 2-3 days.

The higher drive beam charge substantially increased the 30 GHz power transferred to the main beam. The resulting accelerating field in the 30 GHz probe beam accelerator was 59 MV/m using a configuration where the four outputs of 0.5 m long power extraction structures are used to feed one accelerating structure. Agreement between predicted and measured acceleration was reasonable. In a dedicated test with a 1 m long power extraction structure, accelerating gradients of up to 69 MV/m were achieved. The maximum field was always limited by the drive beam charge and not by breakdowns in the 30 GHz structures and networks. Secondary emission wires were installed in the two drive-beam magnet spectrometers and the end-of-line probe-beam spectrometer to get better quantitative measurements of the beam energy spectra. Using this new equipment it was found that the drive beam deceleration was 60% higher than expected for both single- and multi-bunch beams produced by a four-channel damped power extraction structure. The output power levels were, however, correct. This discrepancy is a major concern and needs further analysis and experimentation. No equipment failure or malfunction occurred in the two 30 GHz modules and all systems functioned correctly in the high-radiation CTF2 environment. In particular the active alignment system held the components in position to within ± 2 microns.

During 1998, two more modules were prepared for installation in CTF2 next year. These are nearly identical to the first pair but contain a new alignment-motor control system. On the photocathode side, Rubidium Telluride photocathodes were successfully tested in CTF2, exhibiting similar performances to the normal Cesium Telluride photocathodes. This new materiel has the advantage that it can be regenerated to a quantum efficiency of about 1% after exposing it to air. The CTF2 probe beam photocathode (CsI+Ge) is still functioning after two years operation. A photocathode preparation chamber is being assembled for the probe beam gun and will result in several advantages. It will permit a simplified production of photocathodes and allow them to be removed and replaced under vacuum; it will also provide a reliable alignment aid for the laser; but in particular, it will be possible to activate GaAs photocathodes in situ. The Optical Parametric Oscillator (OPO) is now being used to produce and test various photo-cathode materials in the laboratory. Developments are under way to test Gallium Arsenide (GaAs) photo-cathodes at the correct wavelength for the production of polarised electrons.

Although several components of the CTF laser suffered optical damage, it was possible to reconfigure it and continue the programme. However, the reduced intensity limited the time during which high charges could be extracted from the photocathodes to a few days. Development of the laser energy stabiliser continued, and a Pockels-cell of specially selected UV-grade material will soon be tested. These tests are aimed at reducing the intrinsic losses of the electro-optic material, increasing the linearity of the system, and improving the final stability.

12.7 The Proposed CTF3 Facility

Design studies for a new test facility (CTF3) to demonstrate the feasibility of the new CLIC drive-beam generation system have started. All major problems associated with the new scheme can be studied by generating only one drive beam, and a future installation (CLIC1) to test one complete CLIC drive beam will almost certainly be required before the community is finally convinced. Since this is a very large and expensive installation, a much smaller facility is proposed as an intermediate first step. To reduce costs, CTF3 differs from the RF power source proposed for CLIC in the following ways. The frequency of the drive beam accelerator is chosen to be 3 GHz instead of 937 MHz. This enables the 3 GHz klystrons, modulators, RF power compression units and waveguides from the LEP Injector Linac (LIL) to be used for power production, once LEP has stopped. With ten of these modulator/klystron units, the drive beam energy for a current of 4.1 A (half the nominal CLIC current) is 178 MeV. This is very low compared to the 1.25 GeV for CLIC and obviously makes operation more difficult. CTF3 has only the first two stages of the beam combination scheme, namely the x2 Delay Line Combiner and the 86m circumference (x5) Combiner Ring. The second (x4) 344m circumference Combiner Ring is very expensive and is not considered to be essential for this first demonstration test facility. The compression factor for the Combiner Ring has been increased from 4 for CLIC to 5 for CTF3 to obtain an overall frequency multiplication of 10 for final operation at 30 GHz. The modulators produce a maximum pulse of 4.5μs which, after power compression with LIPS, becomes 1.4μs. This pulse is just long enough after a (x10) power compression to produce the nominal CLIC RF pulse of 140 ns. The drive beam decelerator is limited to a total length of about 15m (7 transfer structures) compared to 687.5m for CLIC. To limit the radiation produced by CTF3 it is proposed to run at 5 Hz instead of 75 Hz. This new facility can be housed in the existing LIL and EPA buildings and can make use of many of the LIL and EPA components. A layout drawing is shown in Fig. 5.

A study of a laser as possible photo-injector for the CTF3 project has been started. Several aspects of the specification place it far beyond what has so far been achieved in other laboratories, but laser experts from outside CERN have been contacted to attempt to identify the most appropriate design.

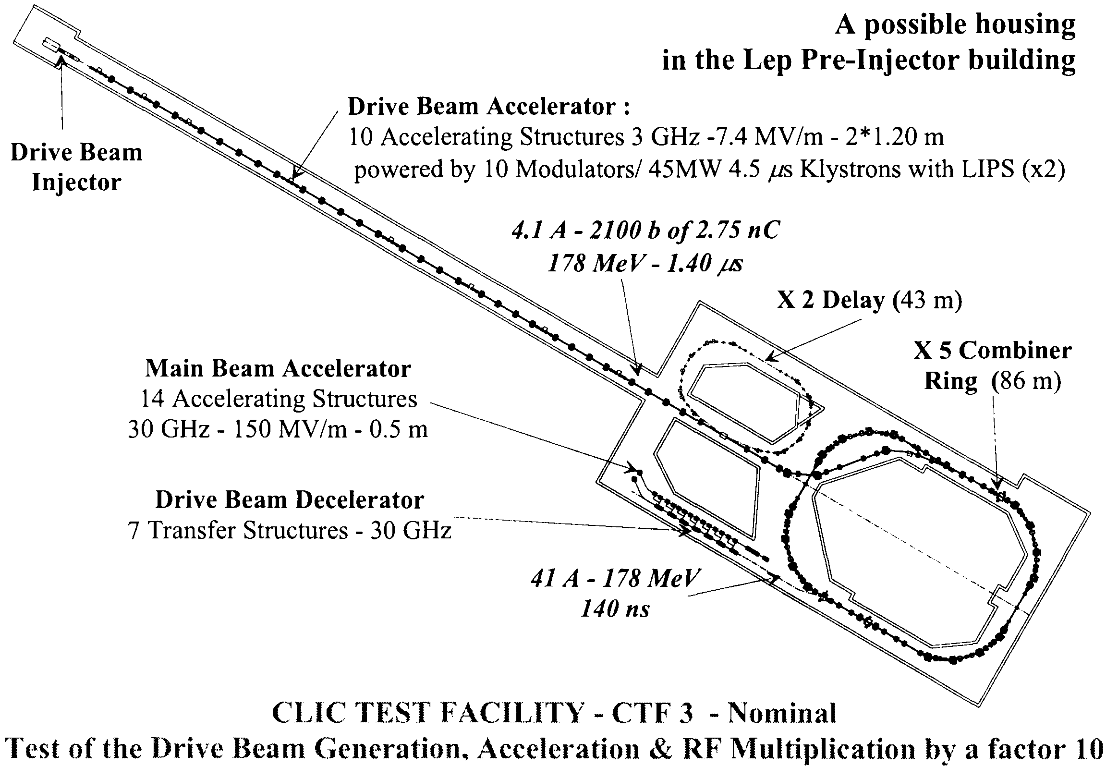


Fig. 5 The layout of the proposed new CTF3 facility in the LIL and EPA buildings, after LEP has stopped

13. FEASIBILITY STUDIES OF A POSSIBLE NEW NEUTRON BEAM

In September 1998 a Letter of Intent by C. Rubbia et al. triggered a feasibility study for an experiment using the PS beam to generate neutrons so as to measure neutron capture cross sections with high resolution. The idea is to extract a 24 GeV/c proton beam of high intensity (~0.7 10^{13} protons/bunch, of r.m.s. length ~7 ns) on to a target consisting of a lead block of size 80cm x 80cm x 40cm. The neutrons produced by spallation will travel to an experimental area located 230m downstream, through an evacuated 80 cm diameter pipe. Use will be made of the existing TT2A tunnel about 7 m underneath the ISR tunnel. A layout of the proposed experiment is shown in Fig. 6. If approved, the project should start in spring 1999 in order to get the experiment ready by April 2000.

The neutron beam is characterised by the following main, and practically unique features:

- a high intensity neutron flux (~ 10^6 n/cm^2/pulse)
- wide energy spectrum (1eV to 250 MeV)
- an energy resolution $\Delta E/E$ of ~10^{-5} measured by time of flight

Studies have been made of the proton beam dynamics, in order to obtain the required very high intensity proton bunches, implying the correction of various collective effects and the shortening of the bunches in the PS before extraction. The hardware modifications necessary close to the present dump target D3 have also been studied; this work cannot be done outside an annual shutdown. Some civil engineering work is needed for the installation of the 230m long vacuum pipe in the TT2A tunnel, together with hardware for the vacuum, instrumentation, collimation facilities, etc.

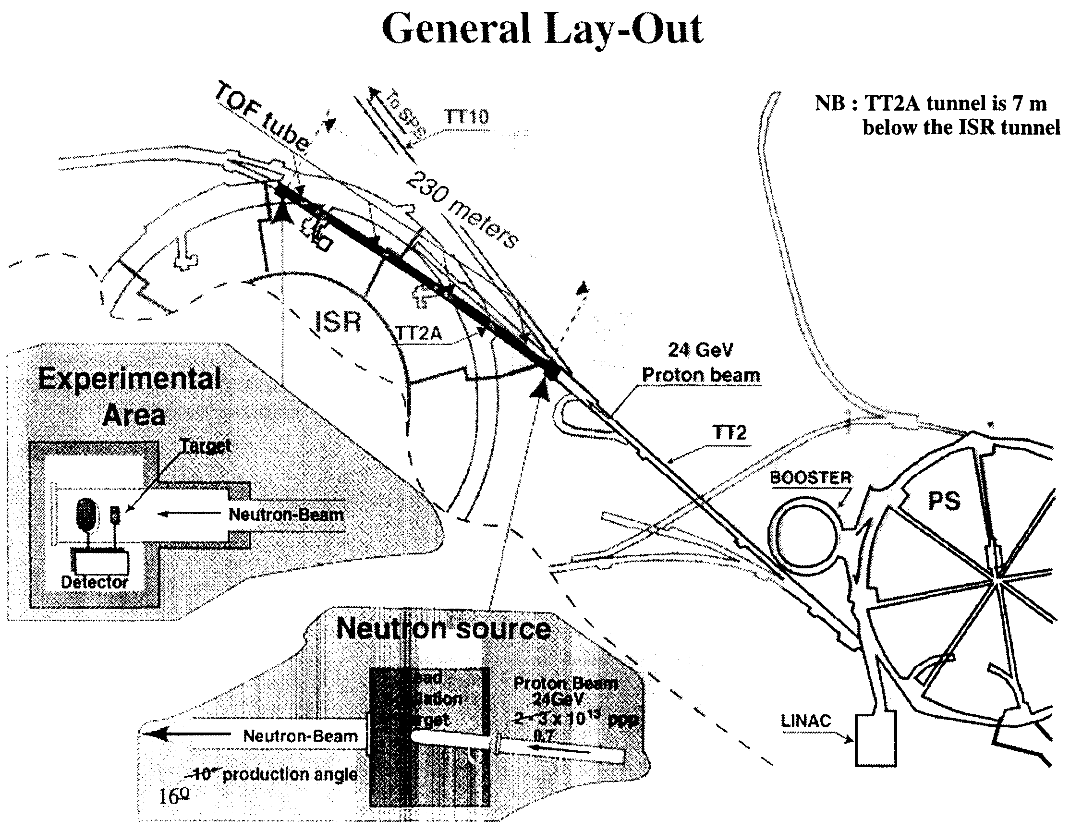


Fig. 6 Layout of the proposed neutron beam generated from a target in the TT2 tunnel

14. LASER ION SOURCE STUDY

The search for the reason for large (± 25 %) shot-to-shot instabilities in the ion current of the laser ion source consumed a good deal of effort in the first part of the year. This led to a better understanding of the extraction of ions from the plasma, but not yet to the identification of the origin of the instabilities. This topic will be addressed further in the future with a research program on x-ray diagnostics of laser-produced plasmas (sponsored by INTAS and involving several EU institutes, the former Soviet Union and CERN). The target region, plasma expansion and ion extraction were reconfigured to allow the matching of plasma density and extraction for a wide range of power densities on the target. For our extraction geometry, the constant of the Langmuir-Child equation (I_{max} = const x $V^{1.5}$) could be established, showing that the required current densities can be obtained with the present extraction potential. Just before the end of this year, part of the expanding plasma was surrounded by a weak magnetic field, when an enhancement of the ion density by a factor 2-3 was observed at the ion extraction point. This requires further investigation.

Transmission efficiency through the LEBT was another topic studied, by improving the alignment, and changing the solenoid configuration and the geometry of extraction; however, this brought the transmission of the desired charge state to only about 30%. So the study of alternatives to this type of LEBT was started. At INR (Moscow), a multi-electrode electrostatic LEBT with grids was assembled before the end of this year and will be commissioned at the LIS next spring.

A second-hand Lumonics laser was acquired, capable of supplying 10 J pulses at 1/3 Hz. It was reconfigured as an amplifier, thus increasing the flexibility of the total laser system. To run experiments to produce heavy ions of interest to our LIS, several configurations are now possible:

- The Lumonics 601 (now 10 years old) providing 30 J at 1/30 Hz in free-running mode;
- The master-oscillator + Lumonics 601 combination resulting in 6 J at 1/30 Hz in single-mode operation;
- The master-oscillator + pre-amplifier combination providing 1 to 2 J at 1/3 to 1 Hz, which makes experiments easier and goes some way towards the conversion of LIS from a "single-shot" to the required 1 Hz system.

The 30 J laser configuration was used with targets of C, Mg, Ti, Cu, Ta, Pb and Au to obtain ion charge-state distributions. Also, using the master-oscillator (100 mJ) in stand-alone mode, C^{4+} was generated from a plastic target. It is interesting to note that the ion current obtained in this test would satisfy the intensity and pulse-length requirements of an ion source for a medical facility such as PIMMS (see Section 16 below).

A 100 J laser amplifier is under construction at TRINITI (Moscow). To refine the key parameters, ion yields from prototype laser systems providing nearly 100 J and pulse lengths of 20-50 ns are being studied. The objective for LIS is to produce $1.4\ 10^{10}$ ions of Pb^{25+} within some micro-seconds. The LIS team participated in several ion measuring campaigns at TRINITI where one promising laser configuration, when scaled to the final source parameters, produced 10^{10} ions of Pb^{26+}.

15. AUTOMATED BEAM STEERING AND SHAPING

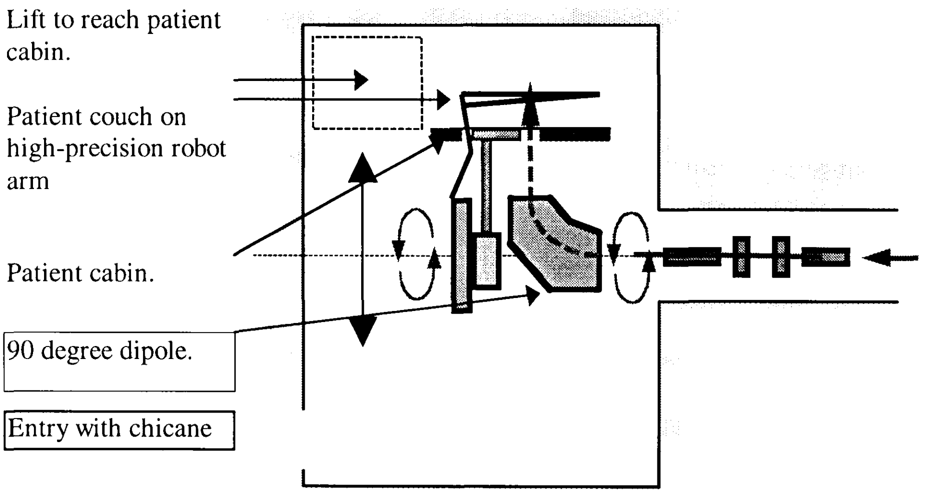
The Automated Beam Steering and Shaping (ABS) project took a major step forward in 1998 with the introduction of the first operational programs to make use of the new PS optics database and the new generic software. A suite of steering and matching applications in the PS complex will be brought up to date to use these new utilities in 1999. The highlight of the year was the ABS workshop organised jointly with SL Division, which took place at CERN from 14th to 16th December. Major laboratories in Europe, USA and Japan as well as many small laboratories were represented among the 70 participants. Since this was the first workshop dedicated to ABS, much of the time was devoted to an overview of what ABS systems, software and algorithms were used by the participants in their home institutions. While the algorithms are the same world-wide, the bigger laboratories have to a large extent relied on in-house development of dedicated ABS software. With the exception of the closed orbit package developed for LEP, the exchange of software has so far been limited. However, with budget and staff reductions, it is now becoming necessary to improve this situation. Indeed in his concluding remarks, Ph. Bryant (CERN) suggested that beam monitor manufacturers might benefit from developing commercial software for the smaller laboratories, which do not have the resources to develop such systems in-house. Another important trend is that ABS software is gaining recognition among the machine operators, who begin to acknowledge the efficiency of automated tasks and start to experience the relief that good ABS tools bring in tuning their machines. In the closing discussion it was decided to establish an ABS Web site at CERN to improve communication, and to set up a series of ABS workshops in the form of biannual events.

16. MEDICAL MACHINE STUDIES

16.1 Proton-Ion Medical Machine Study (PIMMS)

The Proton-Ion Medical Machine Study (PIMMS) is a collaboration between CERN, Med-AUSTRON (Austria), Onkologie 2000 (Czech Republic) and TERA Foundation (Italy) with close contacts with GSI (Germany). The study that has been hosted by the PS Division for three years is now drawing to a close. Three papers that outline the basic design principles were submitted to Nuclear Instruments and Methods at the end of 1998 and the two volumes of the main design report will appear as a PS Divisional Report in 1999. During the first year of the 3-year project, work concentrated on the synchrotron design where a number of new proposals were introduced, in particular for stabilising the slow extraction which is notoriously sensitive to micro-disturbances in the guiding and focusing fields. In the second year, the emphasis moved to the extraction lines and, in the third year, to the beam delivery system, including the gantries.

The design of the extraction lines is based on novel techniques for controlling the horizontal beam size using a "phase shifter" and the vertical beam size using a module called a "stepper". The lines are constructed from modules with fixed magnification of the betatron amplitude functions and integer-π phase advances. This makes it possible to position the "phase shifter" and the "stepper" at the exit to the accelerator so that they can control the beam sizes at all beam delivery points. The study also recommends an alternate gantry known as the "Riesenrad". Gantries make it possible to deliver the beam to the patient over a full circular range of 360°. Conventional iso-centric gantries first bend the beam away from the axis, transport it a short distance in the original beam direction and then bend the beam back to the axis at 90°. Typically this requires 150° to 180° total bending, according to the length of the structure. A variant, known as the "corkscrew" gantry requires even more bending power. The gantry magnets are held in a mechanical structure that turns so that the beam can be delivered from any angle in the full 360°. Such structures only exist for proton beams and are of the order of 10 m in diameter and weigh of the order of 100 tons. When considering the same type of structure for carbon-ion beams, the engineering problems are far more difficult. The "Riesenrad" configuration inverts the conventional iso-centric approach and places the patient in a room that is positioned on a circle several metres in diameter centred on the beam axis and keeps all heavy magnets on the axis. Thus, the "Riesenrad" has the minimum possible bending of all gantry configurations, just 90°, and the problems associated with size, weight, the support of off-axis weights and power consumption are all reduced accordingly. Fig. 7. shows a schematic layout of such a gantry.



Schematic view of a Riesenrad gantry.

Fig. 7 A schematic layout of a "Riesenrad" gantry for delivering the beam to a patient

16.2 Collaboration with the TERA Foundation on the LIBO Project

PS Division has entered into a collaboration with the TERA Foundation on the LIBO (Linac booster) project. The objective is to propose a Linac to act as a booster accelerator to an existing cyclotron, as an efficient and fairly cheap way of generating a beam suitable for therapy. More than 20 cyclotrons exist in the world which can deliver protons of 50 to 60 MeV kinetic energy; 10 of these are already used for proton therapy of eye tumours. The LIBO project is aimed at the development of a 3 GHz Linac to accelerate the beam from such cyclotrons to the energy required for the treatment of deep-seated tumours (~ 200 MeV). The PS contribution consists of the fabrication and test of a 3 GHz accelerator module, made up of 4 tanks with bridge couplers and RF feeder line. PS specialists will co-ordinate the measurement of the first accelerator cell, contribute to the final design of the complete module with the couplers, and organise a test under full RF power (~ 5 MW) in the LIL klystron gallery by the end of 1999. Detailed computations of the RF structure have been made, supported by measurements on cold models of the RF cells.

17. COLLABORATIONS

17.1 Controls Collaboration with IHEP, Protvino

This collaboration is focused on the U-70 accelerator complex upgrade, to provide the IHEP Institute with a modern, efficient and simple control system for its accelerators. The work in 1998 concentrated on conversion of the Booster controls. The groundwork had been done in 1997, and the two runs of the U-70 complex in 1998 were used to bring the new controls into operation. During the spring run, the major components of the new control system were started, and feedback from the operators was collected. Then in the summer, corrections were made to the kernel of the system and the last components were installed. The autumn run was dedicated to the final reception of the new system by the operations team. The successful operation of the new system meant that the old, completely obsolete EC1010 mini-computers (which had been used to control the Booster for more than 15 years) could be disconnected. The next step will be to work on upgrading the main ring, ejection and Linac controls in the years 1999 and 2000. Special thanks must be given to the IHEP project team, whose enthusiasm and hard work resulted in a solid achievement, despite the very difficult situation of the high energy physics laboratories in Russia today. The CERN-IHEP Collaboration Management Board met regularly to monitor progress and review the plans for the completion of the project, and they anticipate that it will be completed in the year 2000 if adequate resources are allocated in Russia to the IHEP Institute.

17.2 Beam Diagnostics Collaboration with IHEP, Protvino

Following the definition (in 1997) of the needs for high-performance, commercial instruments for beam diagnostics in the U-70 upgrade programme, these instruments were procured by CERN and shipped to IHEP. This was the last stage of a collaboration launched in 1990 as part of a balanced technological exchange, in which the USSR delivered components for the LEP2 Project against CERN help for the UNK Project. In the course of the Collaboration, 13 experts from IHEP came to CERN to develop beam diagnostic systems with the help of CERN expertise and facilities. Diagnostics were developed for the 3 TeV UNK-2/UNK-3 Collider (now abandoned); its 400 GeV injector UNK-1 (now redefined as the 600 GeV U-600, and pending); and its pre-injector, the existing 70 GeV U-70. For this latter machine, the diagnostics systems developed at CERN (and tested with Booster pickup signals) were implemented and are now in routine operation. May 1998 was a good moment to formally end the 9-year-long successful collaboration.

18. MUON COLLIDER STUDIES

In June 1998, ECFA recommended that a prospective study be made of Muon Colliders as a future possibility for Europe. The conclusions were to be presented at the December session. As input to this study, the machine parameters of such a Collider had to be investigated. A progressive approach was adopted to cope with the challenging problems of manipulating short-lifetime particles, and it was realised that discussing muon storage rings rather than only Colliders would be more general and more appropriate. The first stage of a future facility might consist of a neutrino factory using the unique opportunities offered by a two-flavour (electron and muon) neutrino beam resulting from muon decay in a muon accumulator of 20 GeV maximum energy. This would need a powerful superconducting Linac making use of LEP-type cavities (and would be about 1 km long), followed by target and collection systems and a recirculator, to accelerate the particles to their final energy. This basic investment could be completed by a cooling facility and a 100 GeV Collider to study Higgs production in the s-channel with an outstanding precision due to the low radiation of the muons. In addition to the precision physics, which complements the LHC programme, the first Collider could test all the techniques required to master muon collisions; especially critical in this respect are ionization cooling, masking the beam decay products in the experimental areas, and achieving a sufficient luminosity. Once the expertise in muon collisions is acquired, a Collider operating at the energy frontier could safely be designed. The major investment would then be the accelerating system needed to reach the collision energy. An interesting possibility would be to use the SPS and LHC tunnels to accommodate the accelerators, thus avoiding much costly civil engineering work. Within the present understanding of beam physics at energies in the several TeV range, the main limitation seems to be imposed by neutrino radiation. The Collider energy has been fixed at 5 TeV in the centre-of-mass. It should be noted that very valuable spin-offs could be expected immediately after construction of the Linac: a new generation of radioactive beams for ISOLDE; a substantial increase of intensity in the CERN PS, resulting in ultimate luminosities for LHC; and more intense pion beams for neutrino physics.