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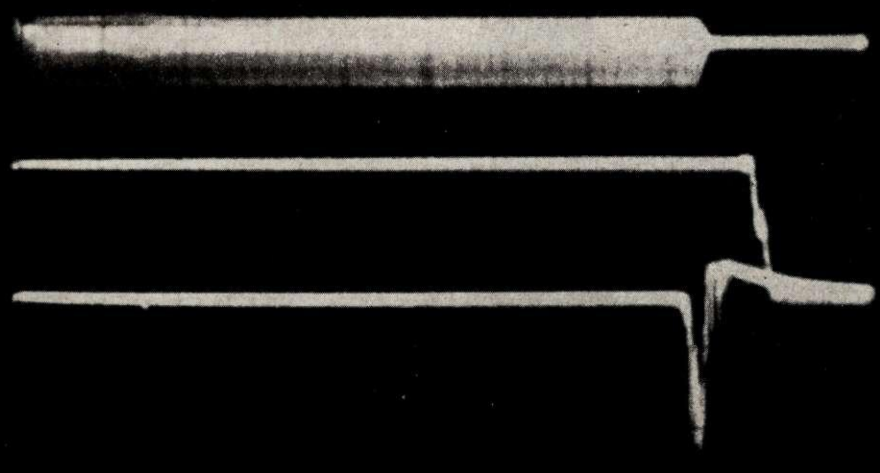
European Organization for Nuclear Research

10th anniversary of the first operation of the CERN proton synchrotron



24 November 1959 24 GeV

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Comment

On the night of 24 November 1959, a polaroid picture similar to the one on the cover was pushed into an empty vodka bottle and parcelled off to Moscow. The vodka had been given to John Adams a few months earlier by Vladimir Nikitin labelled 'Not to be opened until 10.1 GeV' (surpassing the 10 GeV peak energy of the synchro-phasotron at the Dubna Laboratory which was then the highest energy machine in the world). The polaroid picture showed an oscilloscope trace of the beam in the CERN proton synchrotron stretching out to 24 GeV for the first time.

This issue of CERN COURIER celebrates the 10th Anniversary of the acceleration of protons in the PS to full energy with articles describing the excitement of that night ten years ago, the development of the machine since then, and the physics that the machine has made possible. The physics is the important outcome of the building of the PS and the accelerator is just a part, though obviously a crucial part, of the whole complex of equipment and organization involved. Nevertheless, bringing the PS into operation can stand by itself as a most remarkable achievement.

Discussion of a European Laboratory built around a large particle accelerator began about 1950. By 1952, the 'Provisional Council' of CERN came into being and a Proton Synchrotron Group was set up to study a 10 GeV scaled-up version of the 3 GeV Cosmotron in the USA. Late that year, the new idea of alternating gradient focusing was carried back from Brookhaven and the study switched abruptly to consider a higher energy machine. In October 1953, a new design for a machine of about 30 GeV (later pruned to 25 GeV) based on the alternating gradient principle was successfully presented at a meeting in Geneva.

Thus began a great adventure in technical accomplishment and a great adventure in European collaboration. They were adventures because no-one really knew whether either the machine or the collaboration could work.

Adams replied to a question at a CERN Council Meeting in 1959, 'Machines such as the proton synchrotron consist of an enormous number of parts, and there are therefore several million reasons why they might not work'. Construction of the PS

Contents

Cover photograph : Oscilloscope traces taken with a polaroid camera on the night of 24 November 1959. The upper trace from a pickup station shows the proton beam circulating without loss up to an energy of 24 GeV. The middle trace is of the magnet voltage producing a magnetic field rising in about one second to 12 kG. The lower trace is from a counter giving a signal at the end of the acceleration cycle when the beam is lost.

Ten Years Ago

...some personal reminiscences

Hildred Blewett

called for unprecedented precision in large-scale engineering. Its operation depended on the new principle which had question marks in it even on paper. How much beam, for example, could the machine keep under control when it was accelerated through 'transition' — the energy at which the beam behaviour changes and the accelerator has rapidly to follow suit.

All these problems were in the hands of a brilliant but inexperienced team. They were solved. They were solved on schedule (within six years of the signing of the CERN Convention) and they were solved at a cost (120 million Swiss francs) reasonably close to the estimate worked out in 1955.

The success of the collaboration was perhaps even more impressive. To propose that Belgians, British, Dutch, French, Germans, Greeks, Italians, Scandinavians, Swiss and Yugoslavs could work successfully together on a huge project — demanding the highest technical skill, the production of a million components by manufacturers scattered throughout Europe, very careful planning, and the closest cooperation — was idealistic. But it worked.

In 1969, with CERN a large and experienced organization, it is easy to forget the pioneering spirit of those years. But the building of the PS left its mark on all who were involved. They will still talk intensely about what they did and about their 'fierce pride' in doing it. It is their achievement in particular that we are honouring this month.

Remember the night of November 24th, 1959 ? Of course I do. I was sitting in the Canteen eating supper with John Adams, as we had done many times that Fall. There was not a wide choice of food in those days — spaghetti or ravioli or, occasionally, fried eggs — but our thoughts were not on the meal. We had hardly spoken, our spirits were low, then John lit his pipe and said, *'Well, now that we've finished eating, we might as well walk over and see if anything is happening.'* As we went in the direction of the PS buildings, I asked him, *'Shall we go to the Main Control Room or over to the Central Building ? Chris Schmelzer said that Wolfgang Schnell has that radial phase-control thing working'.* John pulled on his pipe, *'Probably doesn't matter, it may not do much good.'* Our hopes had been dashed fairly often. Then after a few more steps, he added, *'Let's go to the Central Building and see what they're up to.'* It was about quarter to seven.

Trudging along, I thought back over the past weeks, back to September 16th when, during the Accelerator Conference at CERN, Adams had made the electrifying announcement that protons injected into the PS had gone one turn around the magnet ring. Since that time, attempts to put the PS into operation had brought a few triumphant moments but most of the time we had been discouraged, puzzled by the beam's behaviour, frustrated by faulty equipment or, after quick trials of this remedy or that, in despair over the lack of success. The protons just didn't want to be accelerated.

During the summer of 1959, Adams had written to invite me to stay on at CERN after the Conference since it looked as if the PS would be ready for running-in tests and Brookhaven had agreed because information from these trials would be very useful for the start-up of the AGS that would probably occur during the following summer. But I had to go back soon to help on the AGS. Pressure for high-energy protons in the United States was mounting even higher with the imminent production of European ones, so I had already booked passage to sail home. For some time I had been saying to everyone that we

This photo, almost as famous a record of the night of 24 November 1959 as the polaroid photo on the cover, shows the seraphic contentment of Hildred Blewett when full energy had been achieved. She was scheduled to leave Geneva the following day and that night was her last chance to see the PS in. Hildred has become known as the mid-wife of large accelerators having been present at the first operation of the Brookhaven Cosmotron, the CERN PS and the Brookhaven AGS, and close to the first operation of Saturne at Saclay and the ZGS at Argonne. She is now at CERN for three years during which time she hopes to continue her reputation by seeing in the Intersecting Storage Rings.

(Photo J. Sharp)

must get the protons through 'transition' before I left. Now it was November 24th, I must leave Geneva the following day, but the prospects were bleak. Would this beam-night be any different ?

Although the PS had been ready to accept protons from the Linac in September, a great deal of final testing had not been completed and installation and cabling was going on in the ring and the Main Control Room. Consequently, for the first few weeks, beam tests could be scheduled only for Tuesdays and Thursdays from six to ten in the evening; during the final weeks of my stay there was also some time on Friday evenings. During these sessions, our spirits ranged from high to low as the beam behaved somewhat as expected or baffled us completely.

Shortly after the Conference, when the first pickup electrodes were operating, we had happily seen the injected beam spiral in, under the influence of the rising magnetic field (without r.f.), observed betatron oscillations for the first time, and eagerly estimated Q-values from the beating patterns. But the spiralling time was wrong and the Q-values were off, with radial and vertical values different. Why ?

Another night, beam from the Linac was on its way but nothing at all could be seen on the scopes in the MCR. After many checks, it was found that a resistor had burned out in the power supply of the electrostatic inflector. Adams, Hine and Lapostolle rushed into the main-ring tunnel, glared at the offending item, hustled to have it replaced. It burned out again — and again — an evening wasted and home discouraged.

Early in October, the programmed part of the r.f. system was ready for trial. Schmelzer and Hans Geibel were in the Central Building and Pierre Germain was peering at scopes in the Main Control Room. Linac said beam was ready and inflector working. Hine was in the MCR, looking at the injected beam, adjusting quadrupoles, changing inflector voltage, rushing from one scope to another. *The beam isn't spiralling properly... wait... all right, go ahead r.f.... Central Building says it's on, programme on. Yes, beam is being captured... it's accelerated... but lost after a few milliseconds. Changes in the r.f. programming... is the beam better... yes, now it goes for 10 milliseconds... no, it's 15... now it's gone again.* But we went home satisfied — some beam had been captured, there had been some acceleration.

More evenings with trials of the r.f. programme followed, mostly unsatisfactory, then a surge of hope spread through the group. Careful checking of the inflector area showed that a temporary observation-flag was sticking into the vacuum chamber at the entry point and, even worse, some of the mechanical structure of the inflector seemed to cut off part of the circulating beam. Mixed with the chagrin at not finding these things earlier was a feeling that here, at last, was the source of the injection troubles. Next night, there was decided improvement in the spiralling, beam was more reliable, but still there was coupling between the vertical and radial betatron oscillations and the Q-values were still wrong. In spite of this, the r.f. programme was tried again, Schmelzer and the r.f. group busy in the Central Building and Hine, Adams, Pierre Germain and the rest of us anxiously looking at the scopes in the MCR. But, although occasionally captured and accelerated for a few milliseconds, the beam again dribbled off and was lost.

The r.f. system had been designed to run with a frequency programme to a few GeV, then to switch over to an automatic system with a phase-lock and with errors in the beam's radial position fed back to the r.f. amplitude for correction. When this automatic system was ready, it was tried with switching-in much earlier than planned and this did succeed in accelerating the beam somewhat longer. But then it was lost, usually in a series of steps and all gone after a few tens of milliseconds. I don't remember if we reached 2 or 3 GeV on an occasional pulse, but certainly no more. The behaviour of the beam remained erratic and unstable. What was wrong?

Measurements of the beam's position on the radial pickup electrodes were hastily plotted by Adams to show that the closed orbit was off in some places, but only by a few centimetres, surely not enough to prevent some beam from going to transition. The rate of rise of the magnetic field was varied to look for eddy-current troubles. Colin Ramm and the Magnet Group rushed around the ring in the daytime, searching for stray fields or remanence effects. Jean Gervaise scanned the survey data for possible errors in magnet positions while Jack Freeman hunted for signs of beam disappearances with radiation monitors. More trials of the r.f., with and without phase-lock, more diagnostic equipment hurriedly inserted, more measurements. But the protons made no progress.

During those Tuesday and Thursday evenings in October and early November, many of the PS builders gathered around the tables in the centre of the Main Control Room. Only the most essential of the control racks were there, the rest were being installed and, while we worked, men in blue coats were busy behind the racks cabling or, from time to time, accidently uncabling. I cannot remember all the people who were there, but *always* there was Hine, usually Adams, Johnsen, Hereward, Schoch, Schmelzer, Pierre Germain. Sometimes Sagnell and Sharp would stop working to take 'candid' photos (often in the way of the *serious* observers). Konopasek would be improving pickup stations, Munday investigating vacuum gauges, disembodied voices coming from Linac, Power House, or Central Building. To try to bring order out of chaos, an Engineer-in-Charge was appointed for each session and among those taking a turn were Bonaudi, Brianti, Fischer, Jacob and Reich.

At one stage, to save (or prevent ?) people from going home to eat and being late for the scheduled 6 p.m. start-up, Hine arranged cold meats, cheese and bread to be sent to the MCR. As I recall, this was not a rousing success.

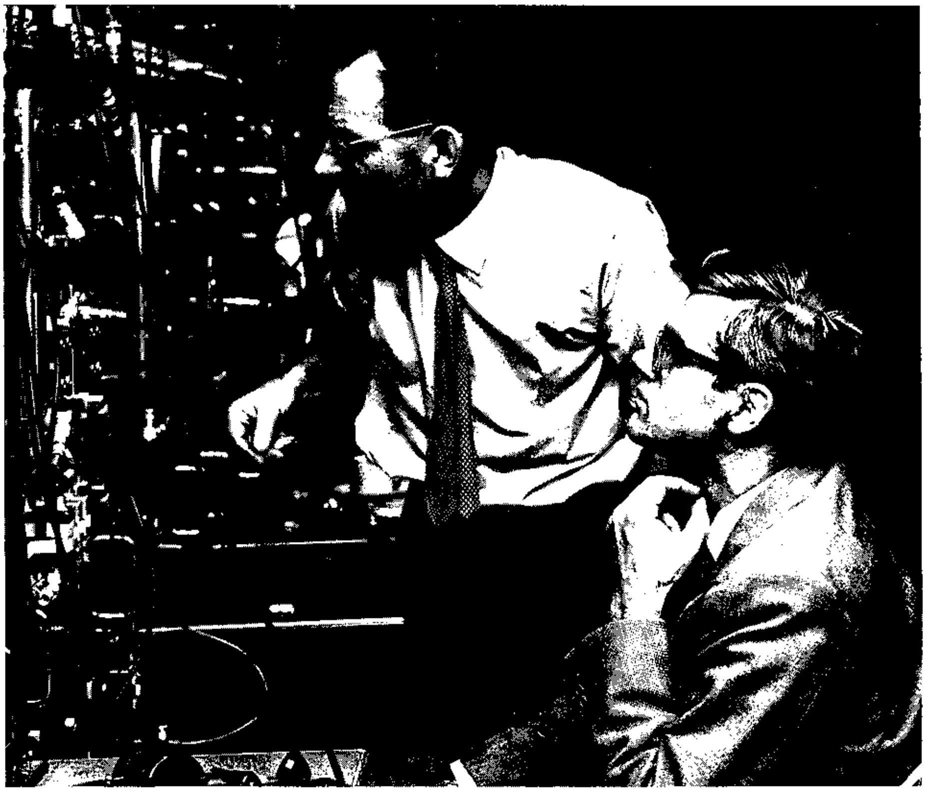
There were periods of frantic activity. *Beam is on... let's try this... with r.f.... without r.f.... look at the scope... measure this... photograph that...* But there were also long periods of waiting. *Inflector is off again... the high-voltage set feeding the Linac is sparking over... instruments not ready... something disconnected.* We sat at the tables and waited and waited. One night, just as beam came on, all the lights went out — trouble at the CERN

Commissioning days

Pierre Lapostolle (left) and Mervyn Hine do not give the impression of having been highly delighted with the way things were going.

Below : Mervyn Hine and Kjell Johnsen also looking a bit short on confidence in what they were doing.

(Photos B. Sagnell)

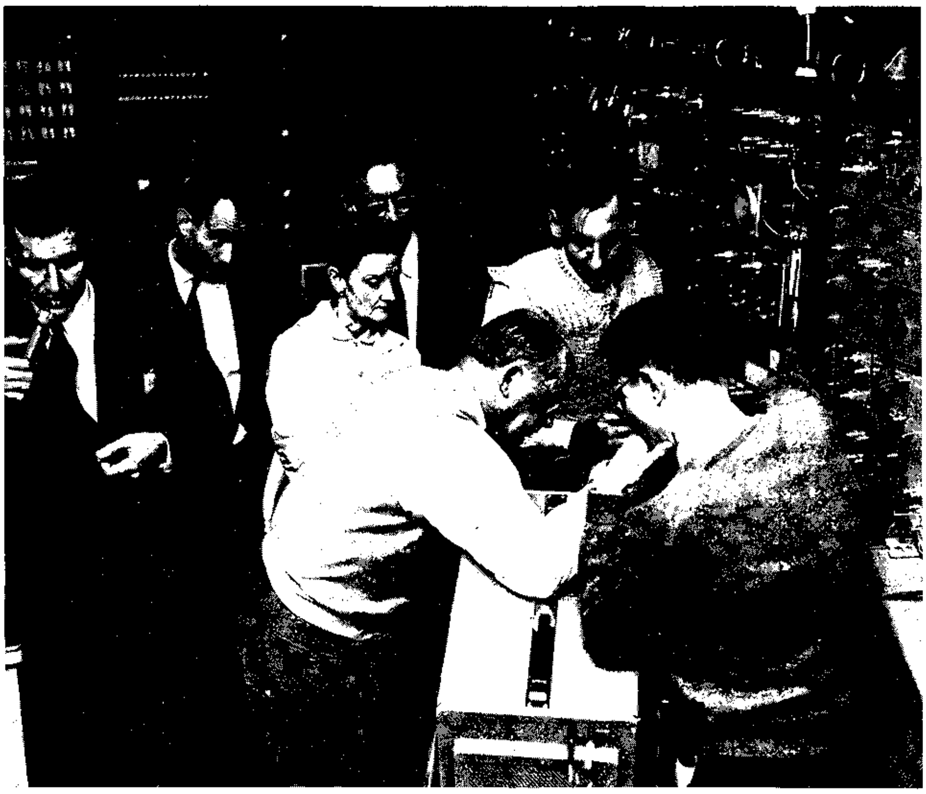


main power house — and we groped our way out in darkness, Adams striking matches all the way.

During the days, many activities were going on : tests on the magnets and pole-face windings, Linac running, tests on r.f. components, tests in the Power House, interminable cabling. Throughout the buildings, there were sets of call lights which flashed in various patterns. One pattern was repeated so often that I finally asked whose it was. It was for Kees Zilverschoon, whom we seldom saw. He was in charge of all installation and coordination and was always off in tunnels, chasing workmen, following missing items, running from place to place.

I had a desk in Mervyn Hine's office where in the mornings, particularly after beam-nights, one after another would come in — Johnsen, Hereward, Schoch, Schmelzer, sometimes Adams, many others — and the talk would start. *Are the closed-orbit deviations causing serious trouble ? Is the Linac emittance all right ? What about the missing bunches, caused by the poor performance of the inflector ?* Every Monday morning, in the PS Conference Room, there was a meeting of the 'Running-in Committee', starting at 9 a.m. sharp and lasting until well after 1 p.m. or even 2 p.m. Discussions and arguments — on and on.

But sometimes it was quiet, when Hine and the others were off preparing for the evening runs. Then, I might go down the hall to a nearby office where Ed Regenstreif was compiling the full story of the PS and we would talk of the time back in 1951 when, at the request of the early CERN Council, he had come to the United States to look at the construction of the Brookhaven Cosmotron and the Berkeley Bevatron. Regenstreif had earned the eternal gratitude of the Cosmotron builders (then an unknown and inexperienced group) for his praise of our design that resulted in the CERN Council's decision, at first, to build a scaled-up Cosmotron of 10 GeV. It had been to reduce the costs of this machine that Stan Livingston, in a spirit of international goodwill, had first considered possibilities for size reduction by reversing blocks in a Cosmotron-like magnet. This was in the summer of 1952, at Brookhaven after the Cosmotron had



Expressions still worried as some of the commissioning team cluster around an oscilloscope. Left to right : John Adams, Hans Geibel, Hildred Blewett, Lloyd Smith, Chris Schmelzer, Wolfgang Schnell, Pierre Germain.

(Photo B. Sagnell)

successfully operated. We had been looking forward to a visit by Dahl, Goward and Wideröe to discuss the plans for the proposed European high-energy accelerator. Further work by Livingston, Courant and Snyder had led to the alternating-gradient design principles in time for presentation to our European visitors.

Often, in the daytime, I went over to the Linac Building, to look at the 50 MeV beam, to watch measurements being made by Pierre Lapostolle, Peter Standley, Colin Taylor, Bryan Montague and others. Over there another American visitor was frequently watching or helping — Lloyd Smith, at CERN a year on leave from Berkeley. Later on, he was to be so impressed by the performance of the CERN PS that he would go back to Berkeley with a set of parameters for a similar machine of 100 GeV, infect his coworkers with his enthusiasm and begin serious design. Afterwards, this would be changed to a design for 200 GeV that would find support from the US high-energy-physics community, culminating in the large accelerator at Batavia.

Occasionally, on a Sunday, I would go along the lake to visit my good friends, Kjell and Aase Johnsen, and we would recall the days in 1953 when the first designs for the PS were being worked out by groups in various places (Harwell, Paris, Heidelberg, Bergen, etc.) all under the leadership of Odd Dahl in Bergen. John Blewett and I had spent some months in Bergen in the summer of 1953 and, during that time, Johnsen had been working on the behaviour of the beam at transition energy (where there is no phase stability). His calculations had given us the first confidence that beam could be accelerated through this dangerous region. Or, the Johnsens and I would go back to November 1952, when a small group (including Kjell and myself) had come to Geneva and been taken out near the French border to see the fields where some day a large Laboratory might be built. This trip was after a meeting in Paris where the main topic of discussion had been the recent work of Adams, Hine, and Lawson on the serious effects of magnet inhomogeneities and their discovery of frightening resonances. Or, we would come back again to 1953, to early October, when the PS Design Group had come to Geneva (a risky business with no governmental commitments and finances on a month-to-month basis) to start work at the Physics Institute of the University of Geneva. There we had all worked hard to prepare for a Conference, held later that October, where papers on the design of a 30 GeV machine (later reduced to 25 GeV by the Council) had been presented to an audience of accelerator experts, Council members and their advisors. The Design Group had been nervous — it could not be proved that this novel type of accelerator would work, so many hazards, such inexperience, the future of European high-energy physics at stake. I had been nervous, too. I had worked up some cost figures, based on Cosmotron costs, and the totals were *much* in excess of what had been anticipated. Would the Council accept it ? But these reminiscences with the Johnsens would be broken off by the sudden arrival of Hine, bringing us back to 1959, to the problems of the PS. He had a new theory. What did we think ? Should we try this next week ?

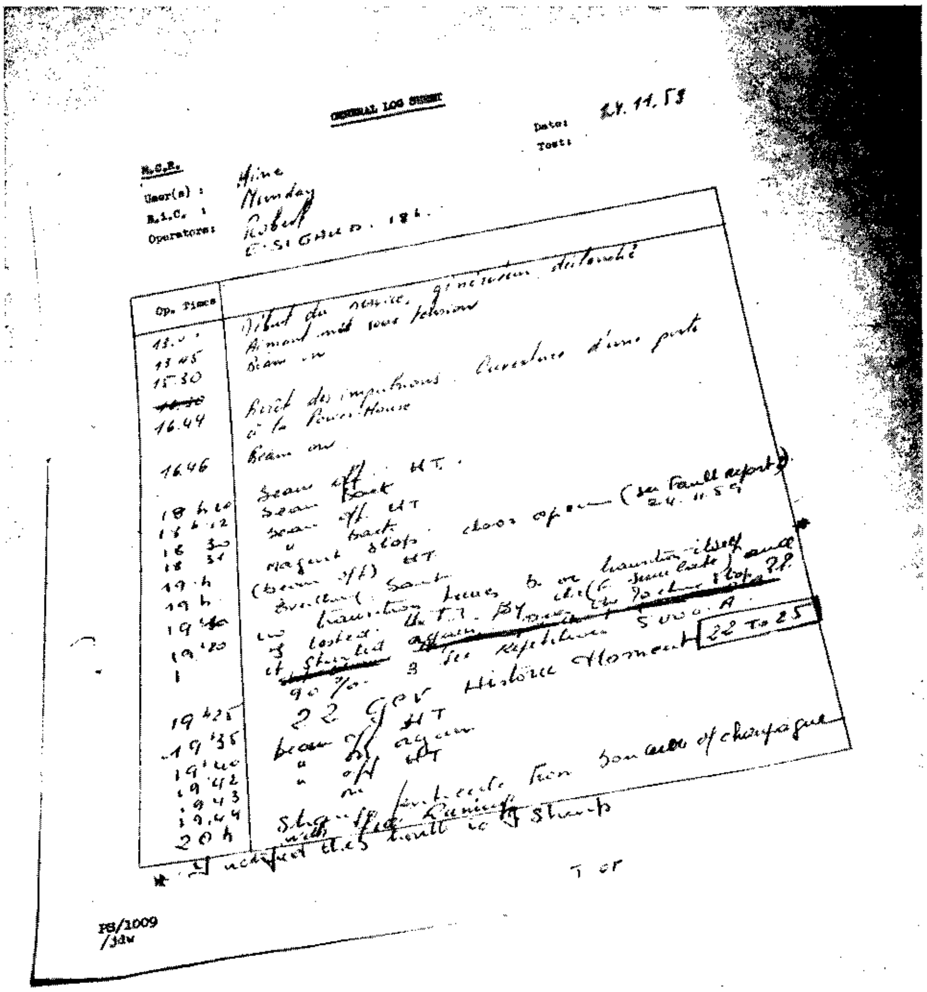
Many of these things were in my thoughts as Adams and I approached the Central Building. I was depressed at having to leave the next day, with the protons still balking. I had wanted so much to see this machine operate successfully before I left. All through the years, I had been so involved with CERN and its PS that I had felt a glow of pride with each milestone passed during construction. More than ever, over these past weeks, I had felt that it was partly my machine too. John interrupted my thoughts with *'Well, Hildred, we haven't done much during your stay. It's hardly been worthwhile, you haven't learned...'.* I broke in, *'Wolfgang thinks this radial phase-control will really work, he's very optimistic, and maybe...'.* But I knew that no one else had great hopes for any improvement. Even Schmelzer had thought it was hardly worth the effort, but Schnell had gone ahead over the last couple of weeks wiring it up for a quick test. Just a few days before, I had been down in the basement lab, listening to his enthusiasm. The idea was to use the radial-position signal from the beam to control the r.f. phase instead of the amplitude. With this system, the sign of the phase had to be reversed at transition and, in his haste, Schnell had built this part into a Nescafé tin, the only thing of the right size. But could Nescafé tins help ? There had been so many disappointments. Perhaps something really fundamental was wrong. I felt a certain last desperate hope, but I wasn't optimistic.

Adams opened the door of the Central Building. For a moment the lights blinded us, then we saw Schmelzer, Geibel and Rosset — they were smiling. Schnell walked towards us and, without a word, pulled us over to the scope. We looked... there was a broad green trace... *What's the timing... why, why the beam is out to transition energy ?* I said it out loud — *TRANSITION !*

Just then a voice came from the Main Control Room. It was Hine, sounding a bit sharp (he was running himself ragged, as usual, and more frustrated than anyone), *'Have you people some programme for tonight, what are you planning to do ? I want to...'.* Schnell interrupted, *'Have you looked at the beam ? Go and look at the scope'.* A long silence... then, very quietly, The page from the PS log book, 24.11.59. At 19 h. 35, it reads '22 GeV Historic Moment'. By 20 h. 00 the entries had become rather incoherent.

Below : Congratulations Italian Style. Gilberto Bernardini embraces John Adams in the Main Control Room.

(Photo J. Sharp)


GENERAL LOG SHEET

Date: 24.11.59

Test:

M.C.R.

User(s):

R.I.C.:

Operators:

Op. Time

22 GeV Historic Moment

22 To 25

PS/1009
/Jdw

Hereward's voice, *'Are you going to try to go through transition tonight ?'* But Schnell was already behind the racks with his Nescafé tin, Geibel was out in front checking that the wires went to the right places, not the usual wrong ones. Quickly, quickly, it was ready. But the timing had to be set right. *Set it at the calculated value... look at the scope... yes, there's a little beam through... turn the timing knob* (Schnell says I yelled this at him, I don't remember) *...timing changed, little by little... the green band gets longer... no losses. Is it... look again... we're through... YES, WE'RE THROUGH TRANSITION !*

How far ? What's the energy ? Something below 10 GeV because the magnet cycle is set for lower fields and a one-second repetition rate for testing. Hurried call to Georgijevic in the Power House. *Change the magnet cycle to full field.* Beam off while we wait. The long minutes drag by. Will the beam come on again ? This is just the time for that dratted inflector to go off again, or the high-voltage set to arc over. *Hurry up, Power House !* I remember Schnell murmuring, *'I promised you we'd get through transition'.* But we were all rather awed by it. No one spoke — Schmelzer lit a cigar, Adams relit his pipe, we waited.

Finally, the call came through — magnet on again, pulsing to top field. *Call the Linac for beam. Beam on, it's injected, inflector holding, beam spiralling. R.f. on, all set as before with the blessed phase-control and the Nescafé tin. Change timing on the scopes, watch them and hold your breath. One second (time for acceleration) is a long time. The green band of beam starts across the scope... steadily, no losses... to transition... through it... on, on how far will it go... on, on IT'S ALL THE WAY ! ! Can it be ? There it goes again, all the way as before... and again... and again. Beautiful, smooth, constant, no-loss green band... Look again at the timing... all the way... it must be 25 GeV !* I'm told I screamed, the first sound, but all I remember is laughing and crying and everyone there shouting at once, pumping each other's hands, clapping each other on the back while I was hugging them all. And the beam went on, pulse after pulse.

Slowly, we came back to earth. John Adams was first. Looking very calm, he

John Adams announces the news to the CERN staff in the Main Auditorium the following morning. In his hands the famous vodka bottle and the polaroid photograph it was to carry to Dubna.

went to the phone to ring up the Director General, C.J. Bakker, to tell him the news but Bakker didn't seem to grasp it right away (could it be that John was just a little incoherent?) Schmelzer was beaming, for once even his cigar forgotten, cold on the ashtray. Schnell looked supremely happy, he was the hero of the hour. Gradually, I collected my wits enough to write out a telegram to Brookhaven that Geibel dashed off to send immediately. We went over to the Main Control Room and found Hine calling round to locate some sort of counter for checking the energy. Johnsen was saying, heatedly, *'Did someone change the timing on this scope ? I just turned away from it for a moment and here is the beam going out...'* How could it be 25 GeV without poleface windings on ? But all the scopes showed the same smooth green trace, one second long — it really *was* 25 GeV. Even more unbelievable, the signal on the pickup electrodes gave an intensity of about 10^{10} protons per pulse. No, that can't possibly be right, we're lucky if it's 10^{9}. Check and recheck... look at the calibrations... yes, that number *is* right, 10^{10}.

The rest of that evening has been described many times. People came flooding in, I don't know who told them the news. Polaroid pictures of the scope traces were passed around for signatures on the back, cherished souvenirs. Bottles appeared, by magic, including the famous bottle of vodka given to Adams by Nikitin. Bakker arrived with a bottle of gin under his arm. Bernardini bounded in, hugged Adams and Hine, launched into a description of what he wanted to do as a first experiment, then lapsed into pure Italian. Miss Steel and the secretaries were there, smiling happily — they had had to put up with our complaints and bad humours. I remember Colin Ramm muttering, *'Where do we go from here ? What about two or three hundred GeV ?'* (He was ahead of the times.) I left shortly before midnight to pack my suitcases.

Early next morning (at 2 a.m. New York time) I had a phone call from John Blewett offering congratulations from Brookhaven and asking questions. My telegram had come as a bombshell and the word had spread rapidly across the United States. What had brought success ? I told him about the phase-control system and, since it was similar to the one being built for the AGS, it was a relief to know that this was just what the protons liked.

Then out to the Lab for final goodbyes, over to the Auditorium to hear Adams tell the story to all CERN, my PS friends grinning proudly but no one happier than I. Then, Hine was driving me to the station and many of these good friends there to see me off with, *'Well, we did it for you !'* General euphoria in the air. Just one complaint — Kjell Johnsen, wistfully, *'You know, we've been cheated. It all happened too fast. I thought we would be happy to reach transition, then, after a while another good feeling at 10 GeV, a week or so later maybe 15 GeV and, perhaps after a month or more, 25 GeV. Now it's all happened at once, there is only one moment of triumph. We've been cheated'.*

But the train is moving and there is Pierre Germain waving from across the tracks. The train passes the CERN site. There is the great PS ring and the glorious memories of the previous evening. Now to hurry and get protons around the AGS.

1959-1969 Ten years in the life of a machine

Operation and development of the PS have brought a dramatic improvement in its capabilities. This article describes the years of getting to know the machine and of developing its potential, picking out some major landmarks on the way. The article was put together with the help of P.H. Standley (PS Division Head), C.S. Taylor (Linac), G. Plass, W. Richter (Main Ring), M. Georgijevic (Power Supply), J.H.B. Madsen (Operation), and G.L. Munday (Experimental Areas).

Parameters of the 28 GeV Proton Synchrotron

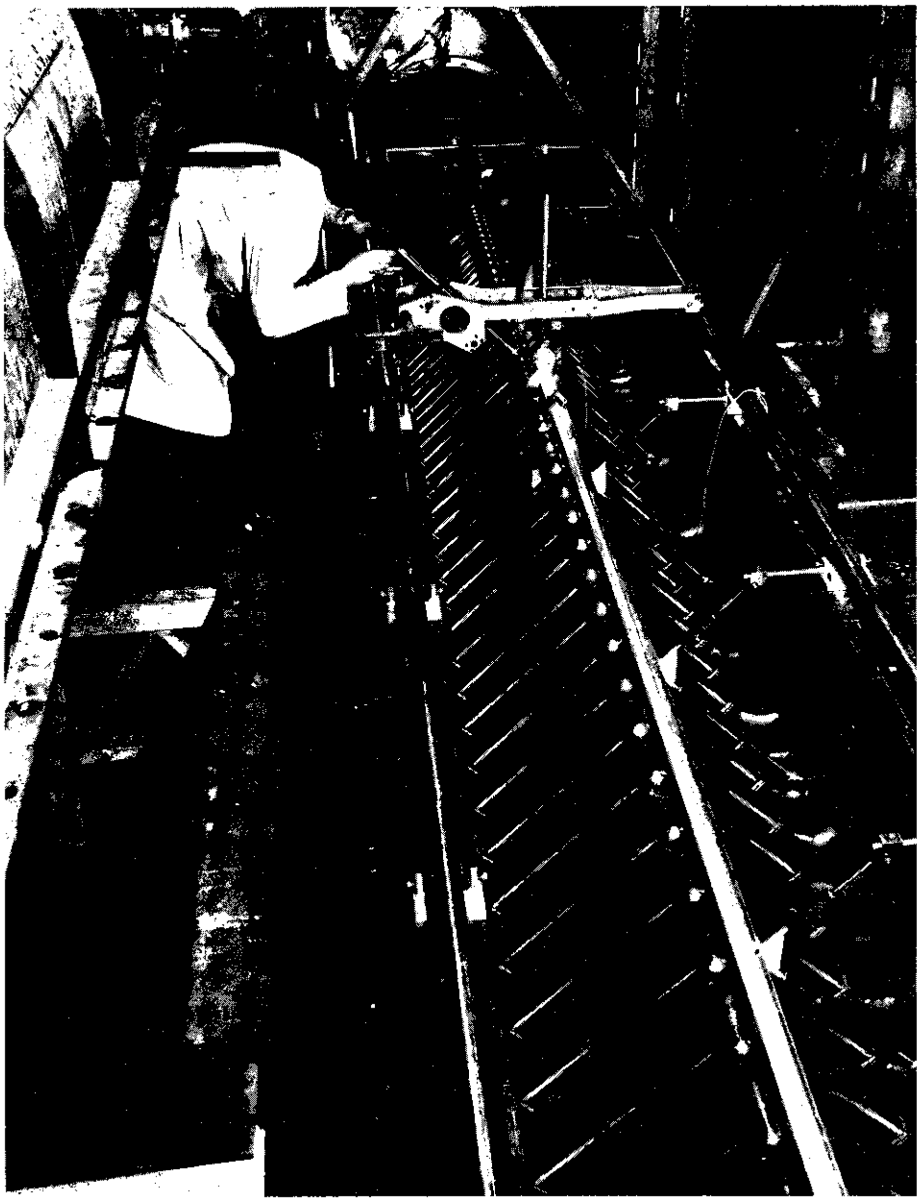
	1959	1969
Linac		
Type of ion source	r.f.	duoplasmatron
Pre-accelerator (Cockcroft Walton)	500 kV	500 kV
Number of Linac cavities	3	3
Final energy	50 MeV	50 MeV
Pulse length	10 μs	20 μs
Intensity of 50 MeV beam	about 3 mA	about 110 mA
Peak Linac intensity	4.8 mA	140 mA
Main Ring		
Diameter of ring	200 m	200 m
Magnetic field	147 G to 14 kG	147 G to 14 kG
Number of magnets in ring	100	100
Weight of magnet	3 400 tons	3 400 tons
Vacuum chamber circumference	628 m	628 m
Vacuum chamber cross-section	14.5 × 7 cm^2	14.5 × 7 cm^2
Number and type of pumps	70 oil diffusion	60 oil diffusion 24 sputter ion
Vacuum pressure	about 3 × 10^{-6} torr	below 2 × 10^{-6} torr
Number of r.f. units	16	14
Frequency range	2.9 to 9.55 MHz	2.9 to 9.55 MHz
Peak voltage of r.f. system	133 kV	143 kV
Energy gain per turn	54 keV (at 12 kG/s)	75 keV (at 16.7 kG/s)
Number of protons accelerated per pulse	about 3.10^{10}	about 2.10^{12}
Power Supply		
Type of power supply	Three phase motor alternator Twelve phase static convertor	Three phase motor alternator Two twelve phase static convertors
Rotation speed	3 000 rev/min	1 000 rev/min
Weight of flywheel and rotor	28 tons	90 tons
Magnet losses	1.6 MW	2.8 MW
Pulse repetition time for a 20 ms flat top	3 s (25 GeV/c) 5 s (28 GeV/c)	1.7 s (25 GeV/c) 1.9 s (28 GeV/c)
Operation	(Early 1960)	
Number of internal targets	1	3
Number of ejected beams	None	2 fast, 1 slow
Number of external targets	None	4
Number of experiments fed per pulse	2 to 3	7 to 8 (plus 3 to 4 testing/parasiting)
Experimental Facilities	(Early 1960)	
Experimental floor area	about 2 500 m^2 (North and South Halls partially available)	9 000 m^2 (North, South, East and South-East Halls, plus two bubble chambers)
Bubble chambers	30 cm hydrogen (in March 1960)	81 cm and 2 m hydrogen 1.2 m heavy liquid
Number of beam transport elements	3	about 250
Maximum power consumption in Halls	about 0.5 MW	21 MW

When the PS was designed many of the techniques and the associated apparatus which are now in everyday use on the machine had not been dreamed up or were then just not technologically feasible. No-one could predict either the growing demands of particle physics or the growing expertise in the use of the machine which has led to continuous development of its versatility. It is amusing to remember the feeling of slight unease which mingled with the triumph among the machine builders when the synchrotron first came into action. The machine was built and most of the design staff expected to return home — this was the simple assumption on which most of them had come to Geneva.

But ten years of experience have taught that an instrument of this kind will probably never be 'ready' — ready in the sense of a machine that is switched on and off and runs without change. During these years many modifications have been introduced and new systems have been added — to increase its capabilities as a source of high energy particles, to ease operation, to improve control of the many parameters, and to reduce damage due to irradiation of the synchrotron components. Even more radical changes will be forthcoming within the next three or four years as part of the PS Improvement Programme.

Linac

In 1960, when the linear accelerator began to provide a beam for the PS on a regular basis, the task of the Linac Group seemed to be fairly clear and straightforward. The staff consisted of the physicists, engineers and technicians who had actually built the machine (the theoreticians and designers having moved to other jobs) and the priorities were only too obvious to the practically-minded, the reliability of component parts being measured directly in terms of lost sleep and lost week-ends. The beam behaviour seemed reasonably clear as well. Early measurements suggested that the energy spread, and the beam diameter and divergence, were about what one expected. The problem, mainly, was to increase the intensity, since it appeared that the PS could use more protons if the Linac could provide them.



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The Linac with the lid off. The drift-tubes in one of the three resonant cavities, which accelerate the protons to their injection energy of 50 MeV, being aligned prior to first operation of the injector. The beam enters from the ion source column at the top of the photograph.

On the other hand, as operational necessity forced more people to learn about the machine as a whole, the realization dawned that the classical theory of the 1950's which had been brilliantly successful in producing a machine that worked, was only a rough approximation to the reality. The reality was a very imperfect thing — non-linear, coupled, imperfectly aligned, unstable and unreliable. The challenge which emerged then was three-fold; to improve the reliability, to increase the intensity, and to understand how it actually worked as distinct from how it was supposed to work.

These three aims became very closely coupled together, partly because no distinction was drawn initially between operation and development work. Thus as the engineering improved and the Linac became more reliable, stable and reproducible, better measurements could be taken which made it possible to pin-point and reduce beam losses and to increase the intensity, but which also made it possible to ask more questions about the general behaviour of the machine.

One simple event in the early 1960's had a profound effect on the subsequent studies. That was when one first faced up to the basic fact that the distribution of particles in a cross-section of the beam or in energy was bell-shaped, so that the beam diameter and divergence (or the combined property known as emittance) lost its clear-cut simplicity, and could vary within wide limits depending on the sensitivity of the detector. Equally one could get a range of energy spread images on the TV screen by playing with the TV controls. This led to thinking in terms of the distributions themselves rather than of arbitrary limits and this approach has been followed up to the present day.

Another landmark, trivial in retrospect, was the realization that the Linac does a good deal of scrambling of the beam in the early part of acceleration, so that whatever is put in to the Alvarez cavities comes out Gaussian and spread-out, although the beam can remember to some degree if it went in at an angle. This spreading-out behaviour led to a variant statement of Parkinson's law — 'a beam always tends to fill up the available acceptance' — of which more later.

The real vintage year for the Linac was 1966, when 100 mA was first accelerated to 50 MeV (a world first too, followed by the Serpukhov Linac a year later). This resulted from the installation of a new ion source of the duoplasmatron type combined with a high gradient accelerating tube. Basically the idea was to accelerate particles through the low-energy region as quickly as possible in order to reduce the destructive effects of space charge. This change signified the end of the era in which higher intensities could be obtained by making holes in the pre-injector bigger, and to mark the event the Linac Group was presented with a metal reamer, complete with protective cork.

Experience with the 100 mA beam (140 mA peak value in fact) has shown that high intensity beams at these energies have to be handled with extreme care if density is to be conserved. There is another law of nature, a manifestation of Murphy's law, akin to the second law of thermo-dynamics, which states that anything that you do to a beam will tend to spoil it.

If one is trying to conserve density in an intense beam, then even letting it drift will do it a mischief; if one tries to bunch it together it will ooze out sideways, and so on. This is really another way of saying that the beam up to and including 50 MeV is not 'matched' in the theoreticians' sense of being distributed in such a way that it does not change its properties with time. Until now the distribution has been that imposed by the ion source and it remains to be seen whether a better distribution can be found, and once found how long it can be maintained before it re-shuffles into the familiar Gaussian.

As an example of the Man-Machine symbiosis the past 10 years have been particularly satisfying. Apart from the obvious Freudian symbolism of working with the Linac, the machine has been generous in its rewards, if sometimes capricious in its demands. A whole week-end of synchrotron operating time was lost once due to pre-injector breakdown but that in itself was beneficial since the Linac Group, harassed by beam customers, vowed

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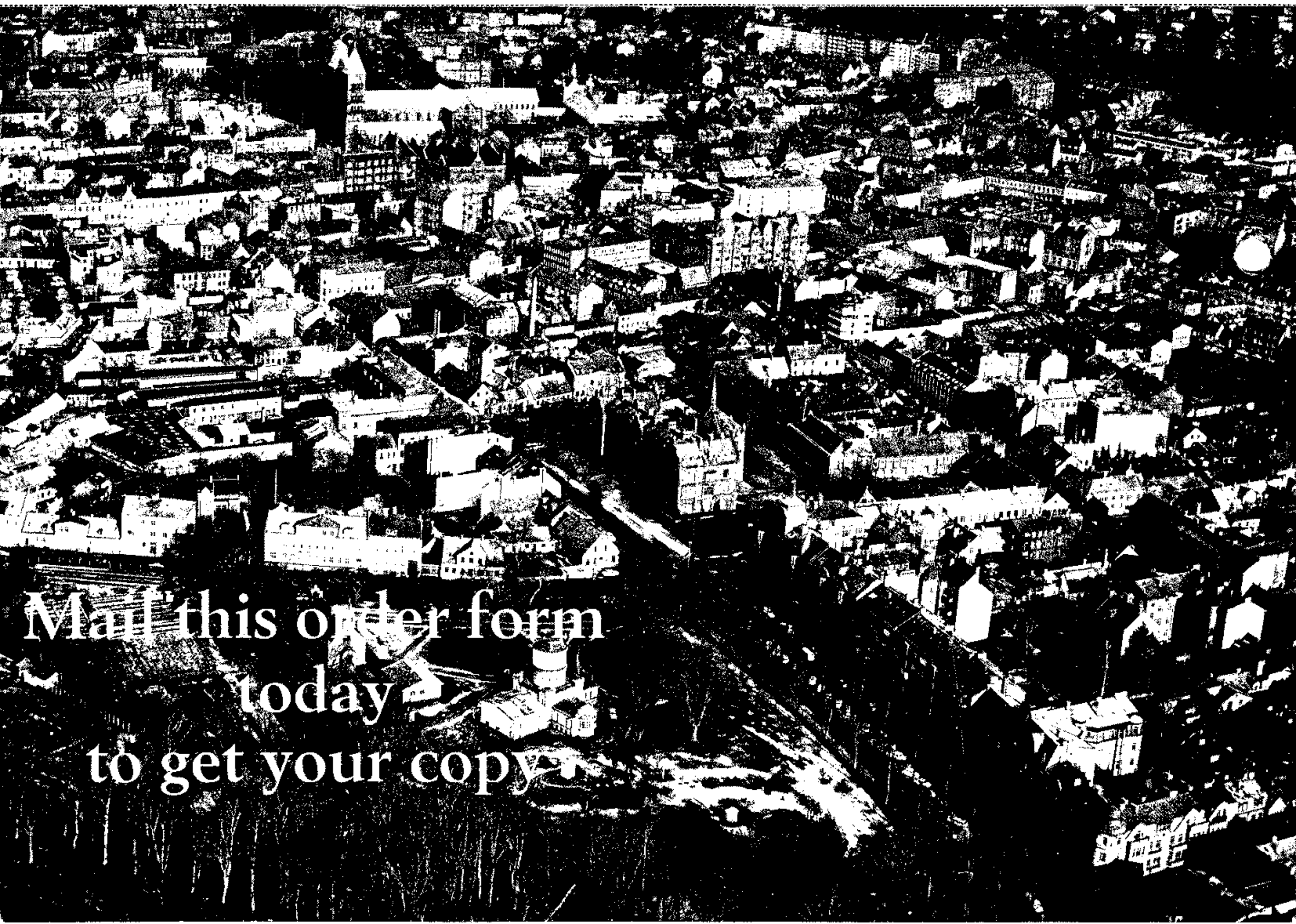
The Lund Conference report will as the reports from the previous conferences of this kind, present the last year's advances in the Elementary Particles Physics, as it is represented by the 440 contributions to the Conference, and summarised by the rapporteur's talks. A new feature of the Conference report is, however, the invited review talks which give a coherent picture of the state of the field prior to the Conference. These review talks are responsible for the increase in volume, by about 15 percent, with respect to previous conference reports. They should give the report a lasting value and also make it useful as a textbook for advanced studies in Elementary Particle Physics. The Organising Committee feels that this feature is an important part of the aim to make these types of conferences of pedagogical value to advanced students, as well as a meeting place for the specialists.



An early view inside the then comparatively uncluttered main ring. Several of the alternating gradient magnet units can be seen positioned in the ring.

'never again' and set about a complete redesign of the 500 kV accelerating tube with simplicity foremost, as if in response to a valuable lesson from the machine. The whole process can be seen rationally, but human beings are not always rational — anthropomorphism sets in and one sees the machine as having a personality and a will of its own. On one occasion a drink to celebrate something or other just after start-up was interrupted when the telephone rang and the MCR announced that the Linac was delivering only 35 MeV instead of 50 MeV; the person who is far gone in fantasy sees that the machine was protesting at being left out of the party.

It is curious how this awareness of life in the machine diminishes when it is switched off for a long shutdown. Then it reverts to being much more just another inanimate collection of copper and steel, and it requires a real effort of imagination to visualize a beam of protons passing through things which are so obviously problems in mechanical tolerances and vacuum and r.f. technology.

One becomes fond of a machine which has played such a large part in ones life in the past ten years or so. It will be sad if it is insulated from people in the future and told what to do by a computer. But no doubt the Linac will have the perception to see that the computer is only an amiable idiot doing what *it* is told, and that its true friends are always there to hold its hypervolume when it feels ill.

Main Ring

Magnet

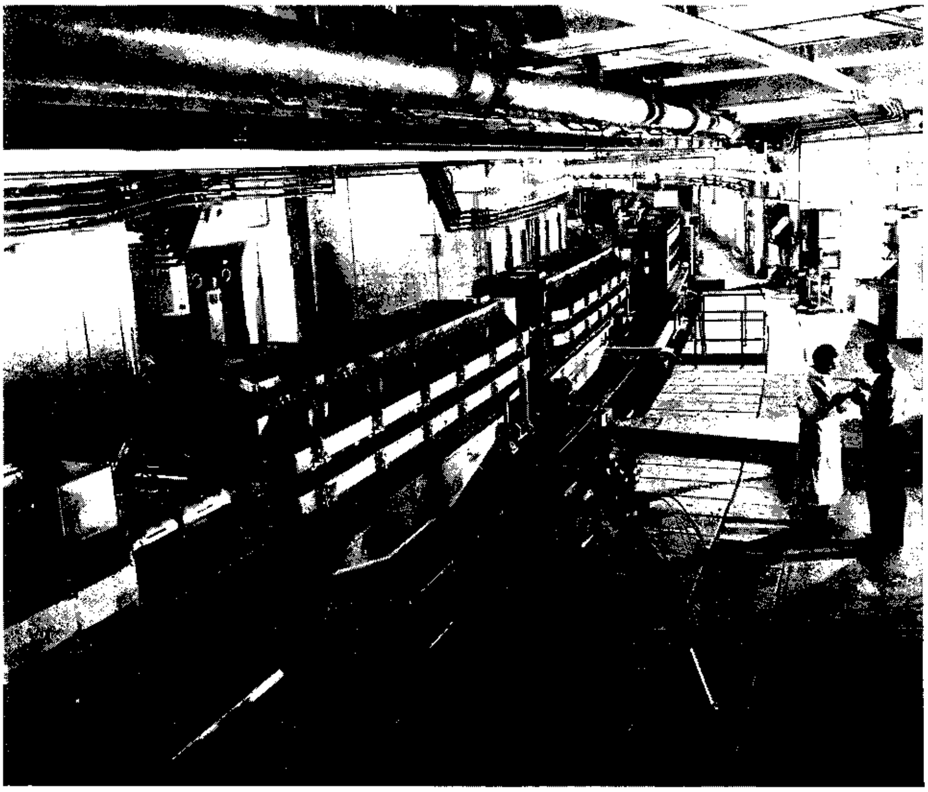
Stability of the magnet ring, in the sense of keeping the 100 separate magnet units accurately aligned around their circle of 200 m diameter, was one of the prime concerns when the PS was built. A special system of suspension was used for the concrete beams on which the magnets sit and this has proved very successful.

Neither Atlantic tides (which were recorded on the CERN site in Geneva more than 500 km from the coast during the survey for the PS), nor earthquakes in the Valais mountains (which had lamps swinging in Geneva) were felt by the synchrotron. However local excavation work at the PS — for the East Hall and for the Synchrotron Injector — did cause the magnet to rise by 2 to 3 millimetres. It settled back close to its original position once the normal loading of the area was re-established.

There are still 99 out of the original 100 magnet units in the PS tunnel. Only one has had to be replaced by a spare (in 1967) due to radiation damage. In anticipation of more magnets being damaged, particularly those near internal targets and near ejection points, more spare units and spare pole-face windings (which are particularly susceptible to radiation damage) are on order. Substantial work has also gone into 'radiation hardening' of magnets. Many magnet units have exchanged their places in the tunnel in order to provide space for new ejected beam lines (only one of which was planned in the PS design, whereas the fourth is now being installed and ironically the one which was planned has been removed).

Many new correction elements have been installed in addition to those provided at the outset, particularly in order to compensate defects of the field pattern at very low field levels. These have included vertical dipoles and low-current back-leg windings (instead of horizontal dipoles) and different types of quadrupoles — approximately 80 units in all. Special high-power windings or special magnets in straight sections have been installed to provide the orbit deformations necessary for ejection purposes. Much effort has also gone into the many special power supplies and their controls or servo-loops which are necessary for pulsing magnet elements in connection with operations like injection, ejection, and targeting.

An important question on the PS magnet will need an answer in the next year or two. After ten years of operation and with much higher beam intensities coming up, some of the synchrotron magnet units are almost certain to receive more radiation than they can stand. Will it be necessary to replace the whole magnet ring with new magnets using more radiation resistant components (and maybe without pole



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Then and now. Two aerial views of the proton synchrotron —

1. Taken towards the end of 1959

2. Taken in August of this year.

In 1959 the wheel shape of the PS was clearly visible and the North and South Experimental Halls dominated other buildings. Now, one has to look hard to distinguish the PS ring. The large East Hall and the South East Hall have been added and many other buildings are crowded close together. Construction work on the new Synchrotron Injector and on the Intersecting Storage Rings is off left.

face windings) ? Or will the magnet units be rebuilt one after another spread over many years ? (This problem is the result of the performance of the machine far exceeding expectations. Since the magnets have withstood ten years of operation at beam intensities very much higher than they were designed for, they might — from the radiation point of view — have survived a thousand years if they had operated with the 'design' beam. This would probably have been adequate... even for particle physics !)

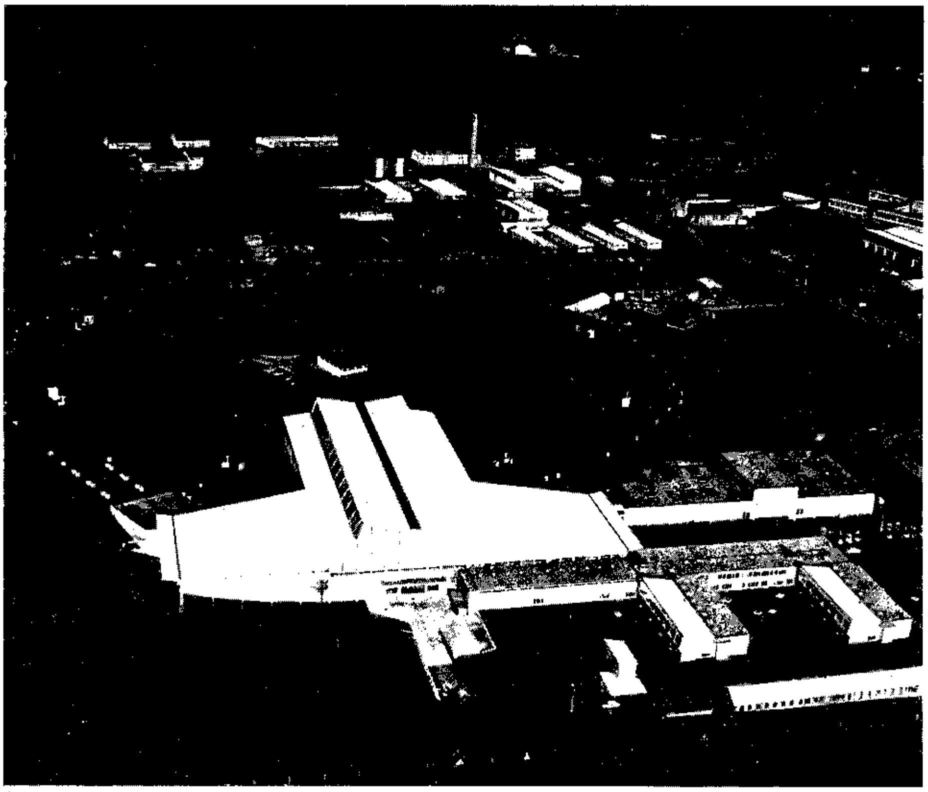
Acceleration system

Sixteen r.f. accelerating cavities were installed initially, of which fourteen are still left in the ring. However, the total acceleration voltage available per turn is now higher than in the early days. It is now possible to run, with the new magnet power supply, at an increased rate of energy gain because the voltage on each accelerating gap was raised by 25 % in total following modifications in 1963 and 1966.

This, however, is only one of many modifications on this system. It is hard to imagine that initially it took three operators — in the Central Building, the Main Control Room, and the so-called 'Computer Room' — to run the acceleration system. It now normally runs for many days with only little adjustment.

Many man-years have been spent in the replacement of most of the electronic circuits of the original system (including the famous circuit in the Nescafe tin) by simpler, more reliable, automatized ones, and in the painstaking job of improving reliability and reducing sensitivity to radiation of the high-power components. By May 1969, the r.f. cavities had worked for a total of 50 000 hours.

New facilities are being added such as voltage and phase modulation for injection studies, and cavity detuning and voltage reduction in order to avoid r.f. structure in the slow ejected beam. A critical examination of the behaviour of the acceleration stations under the conditions of much higher beam intensity is under way, and a completely new design of the phase-lock system (to remedy the technological shortcomings of the 'old' design and to meet the requirements of the improvement programme) has reached the stage of prototype tests.



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Also, a new set of accelerating cavities, together with amplifiers and power supplies, is about to be ordered. The new cavities will be powerful enough to cope with the load produced by a beam ten or twenty times more intense than the present one. They will also have substantially reduced sensitivity to radiation since much of the equipment will be installed in a building in the centre of the ring rather than in the tunnel.

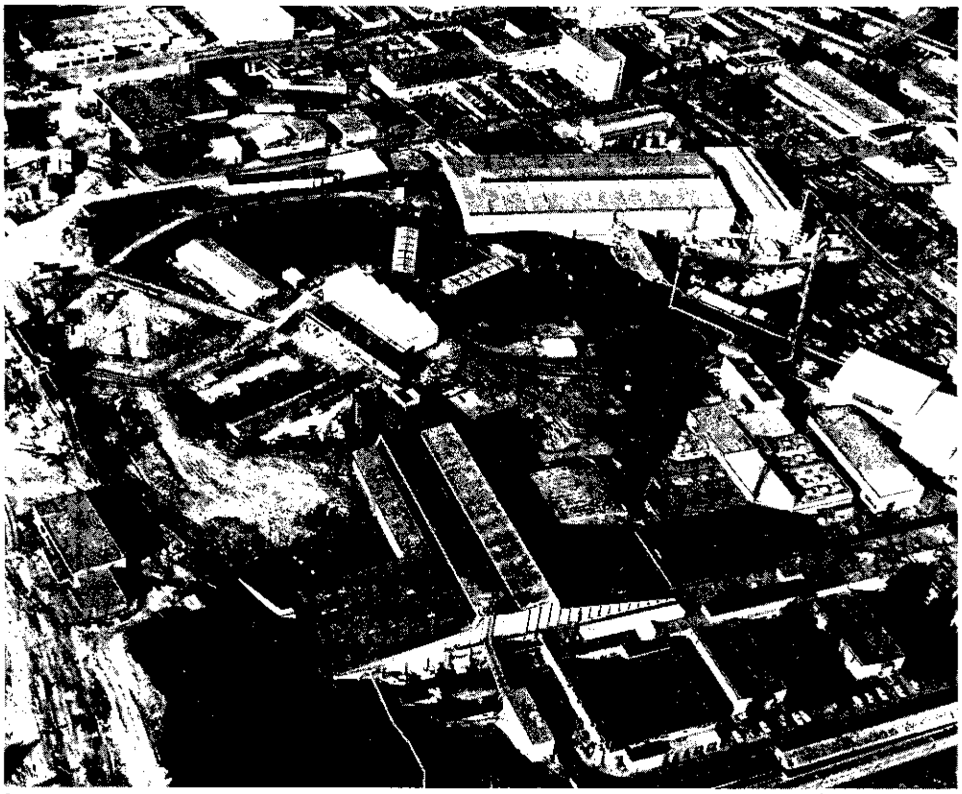
Vacuum System

In 1960, the installation of targets in the PS vacuum chamber required parts of the chamber to be opened up rather frequently. At that time the pump controls were located next to each pump and each time that air was let in or pump-down re-started, a vacuum man had to pass from pump to pump opening and closing the control cubicles. The mysterious tool used for this job became the 'badge-in-trade' of the vacuum group.

Things are now rather more sophisticated. Modifications started when more and more equipment began to be installed in the vacuum chamber. New tanks for kicker magnets and septum magnets needed additional large diffusion pumps but it was not always possible to compensate for increased outgassing rates. Attention had to be paid to types of material and to methods of construction for components used in the vacuum chamber. A blind hole — trapping a small volume of air — would no longer pass the installation test.

The different ejection systems required enlarged chambers. The first of them was a large insulated chamber made from reinforced araldite which resisted all efforts to make it vacuum tight. This led to a much simpler design with two independent chambers side by side. By now the technique of producing enlarged vacuum chambers is well understood and more than 10 % of the chambers have been enlarged for the ejection systems.

Increasing beam intensities caused radiation damage to rubber gaskets and though only a small fraction of the 2 000



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CERN/PI 72.8.69

gaskets in the machine have needed to be changed regularly, these gaskets are situated at the 'hottest' points of the ring. Metal seals were developed to fit the existing chambers and began to be installed two years ago. About 40 % have been replaced to date.

Pressure measurements from the 100 straight sections and complete information on the state of each pump are transmitted to the MCR.

The vacuum chamber has not always been empty when the proton beam has been switched on ! Once the operating crew were busy for more than an hour searching for what proved to be a rag left in the way of the beam. On another occasion, a washer was left lying on the floor of the vacuum tube. As the magnetic field rose, it pulled the washer up the wall of the tube from where it fell back to the floor. The effect of this was to swallow a changing fraction of the beam during each cycle. The effect was so clear-cut and reproducible that it is a wonder that washers have not been strewn around the machine for some method of beam control.

After ten years of continuous operation the pumps units — roughing and diffusion pumps — are being replaced by sputter-ion pumps. This change will avoid the increasing maintenance effort for the old pump units, and will improve the pressure by a factor of 5 to 10. At the same time, the change over to metallic seals will be completed all around the machine and the existing araldite chambers will be replaced by chambers made from ceramic. The controls and power supplies for the new pumping system will be grouped together in the Central Building to allow maintenance with a minimum of work inside the ring tunnel where higher radioactivity levels will prevail.

In those places in the ring where high radioactivity is a problem, remote handling devices are intended to do most of the work. Preliminary tests with a remotely controlled robot proved their capabilities but also showed a limitation due to the very slow working speed. A second version, using a servo-controlled manipulator with two arms, is expected to be much faster and more versatile.

Machine Instrumentation

Space around the accelerator circumference is highly valuable — it is one of the things that cannot be bought for money once the machine is built. A development has therefore been started to produce pick-up electrodes which disappear in the vacuum manifolds on each magnet unit. A pair of the old units — which were insufficient in number anyway — took almost a complete straight section of the machine. The design of an automatic measuring system was subsequently undertaken. It will make it possible to measure the beam orbit around the machine in 40 places within one revolution and the computer will print the result. This can be compared to the present system where the taking of oscillograph photos alone takes about 30 minutes with the analysis time to be added.

Many other instruments have been newly developed during these ten years : various timing systems, measurement of mean radial beam position, measurement of the betatron frequency, a broadband pick-up system for the investigation of the bunch-shape, etc.

Ejection Systems

Ejection systems — now of tremendous importance in everyday running as a means of distributing the accelerated protons to the maximum number of experimenters — were virtually neglected at the design stage of the PS (apart from one report which established that a certain type of ejection would be possible in principle). Maybe one sees here most clearly just how much of a step into the unknown these machines were at the time.

Development work started more than ten years ago on two distinct systems : fast ejection (ejection of the whole beam or part of the beam within two microseconds — the time taken for the beam to travel one turn in the machine) and slow ejection (production of a long burst of protons). It involved entirely new apparatus for which there was very little technological precedent — fast kicker magnets and septum magnets for short and long pulses, together with pulse generators for short high voltage pulses or long high current pulses. This development work

The new magnet power supply commissioned in 1968 which increases the repetition rate of the PS to about twice its previous value for normal operation.

Some figures from ten years of PS operation.

* *The figures for 1969 are taken up to the start of the shutdown on 11 October.*

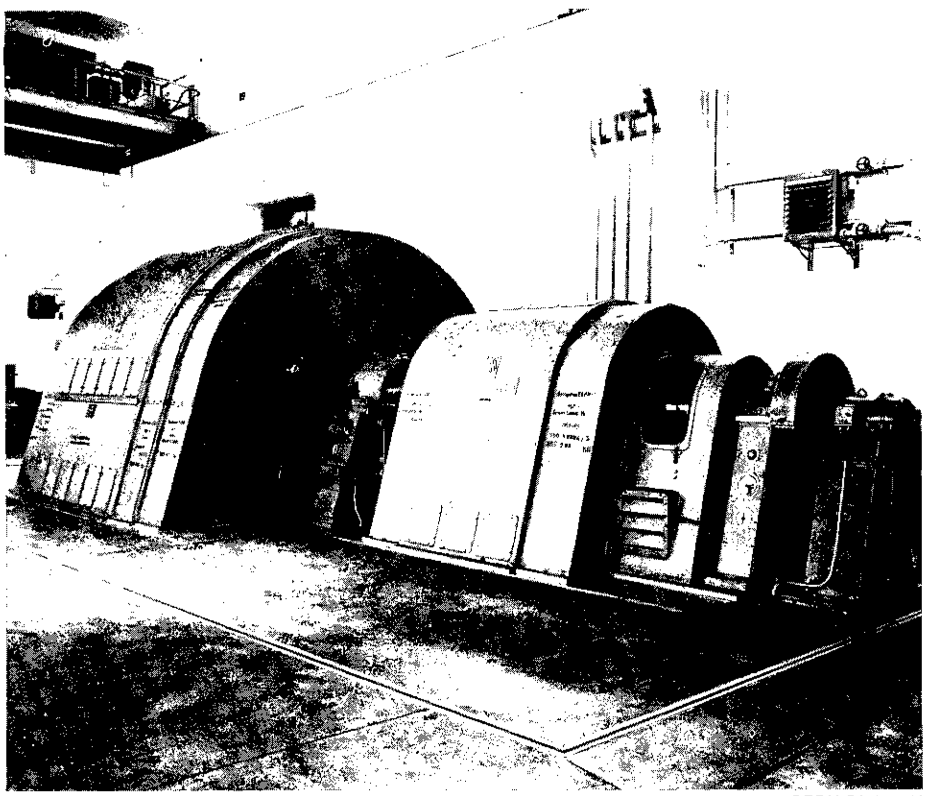
** *The bump in 1966 for the percentage of time lost was mainly due (18.1 %) to the major breakdown of the magnet power supply.*

continues today as the demands become still more stringent.

When it became clear during 1969 that experiments with high energy neutrinos could be performed at the PS, provided the whole accelerated beam was available to the experiment, the development of the fast ejection system was pushed with high priority. The first tests on fast ejection into the South Hall were made in spring 1963, and the first neutrino experiment took place during the summer of the same year.

Though unchanged in its basic concept, the fast ejection system has since been improved and almost entirely rebuilt. It is now very flexible as far as ejection energy, number of bunches ejected, and number of shots per cycle are concerned, ejecting equally well towards the East and South-East Halls and soon also towards the Intersecting Storage Rings. The excellent performance of the present system — using a kicker magnet of small aperture which is pushed into the machine aperture, in each cycle — has decreased, for the moment, the urgency of changing over to a system with a static full-aperture magnet. However, for high intensity operation with the concomitant larger beam size and higher radiation levels in the ring tunnel, such a system is being built.

The study of slow ejection began towards the end of 1960 when it was realized that betatron resonances could be put to use to make protons jump the current strip of a septum magnet. Schemes previously considered yielded very low efficiencies. The first slow ejection for test purposes was achieved in August 1963 into the South Hall and two years later a slow ejected beam became available in the East Hall. A large amount of work went into the adaption of a number of components of the synchrotron, into the stabilization of pulsed currents, and into making the necessary measuring equipment. In fact, it took almost up to this 10th Anniversary of the machine to find designers and users of the system equally content — or at least moderately so — the former as to efficiency and the understanding of what happens, and both parties as to the duration and the smoothness of the proton burst. The next generation of slow ejection systems is already being studied aiming to achieve still higher efficiency and to have parallel running with internal targets.



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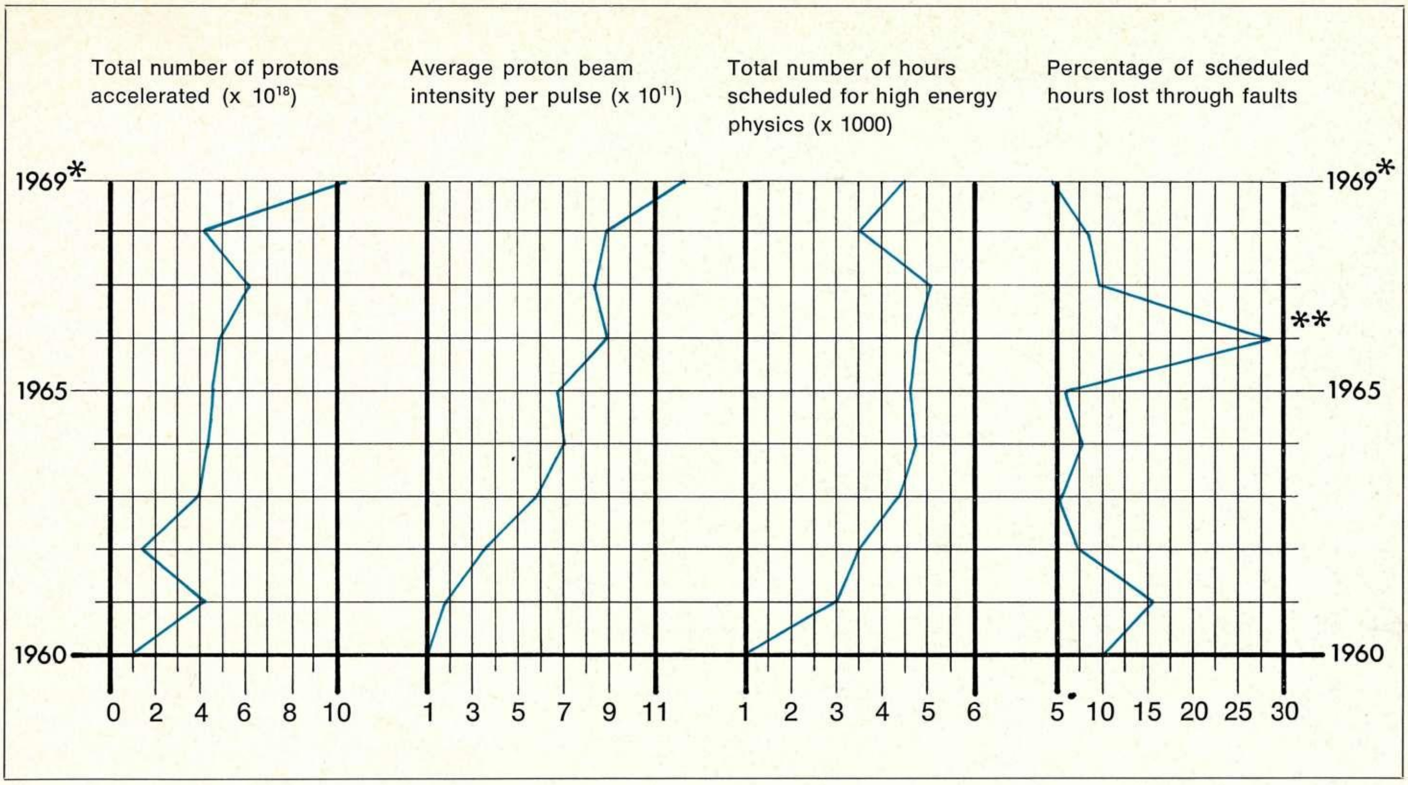
Power supply

Meanwhile... in an adjoining building, many tons of rotating plant have been providing the surges of power for the PS magnet. The magnet power supply is obviously crucial to the operation of the machine. When the power supply stops, everybody stops. It is also perhaps the most vulnerable component of the machine, having to withstand a fierce mechanical cycle every time the PS pulses. The first power supply, that came into operation in 1959 and saw the PS through its first nine years, had its troubles, but there was only one very serious failure and that was after 40 924 500 pulses.

A new power supply is now in action and the original one stands by as a spare. The power supply history can thus be divided into two parts. In the first, up to the end of 1965, the original power supply was developed in several steps to its final status. In the second the new power supply was designed, built and brought into operation to give a substantial increase in the pulse repetition rate of the PS.

In May 1960 the first improvement of the original power supply was carried out when the grid control of the main rectifiers was modified in order to make a 'flat-top' on the magnet cycle which was necessary for production of a long spill of particles from a target. This had not been specified in the original design. In November of the same year a further modification to the grid control gave a flat-top of good quality having a uniform ripple with a basic frequency of 600 Hz. However, the reproducibility from cycle to cycle of the maximum field was not satisfactory (varying within 2 %) and the voltage ripple during flat-top was high (more than 2 kV peak to peak).

The reproducibility problem was solved in April 1961 when a mean speed regulator was brought into service. This resulted in a cycle to cycle reproducibility of better than 0.1 %.



In October 1961 a new M-pulse generator was put into service producing precise timing pulses in a fixed relation to the magnet cycle. This was necessary for general control and measurement. The timing improved further in 1963 when a new master timer came into action. The general timing was then adapted to new operational conditions and its reliability was improved.

The problem of high voltage ripple during flat-top was largely solved in 1963 when a dynamic ripple filter reduced it to 30 to 40 V peak to peak. This was vital for the operation of the slow ejection system but also improved in general the flat-top operation.

In December 1965 the last of the major modifications to the original power supply was carried out when a new grid control was put into service giving more flexibility in the magnet cycle (such as multiple flat-top operation) and better reliability.

It was the following February that the major failure of the power supply occurred. Circular steel bands covering the overhang part of the rotor windings in the main driving motor ruptured either due to fatigue or to local overheating caused by a short circuit. The PS was out of action for 3 1/2 months while repairs, using a new technique to improve reliability, were carried out. The new power supply had been ordered the week before the breakdown !

The new supply was planned as part of the improvement programme of the PS, the aim being greatly to increase the number of protons accelerated per second. While developments on the main ring and particularly the addition of the synchrotron injector will increase the number of protons per pulse, the role of the new power supply is to increase the number of pulses per second. Its design drew heavily on experience with the original supply.

It came into operation in September 1968 and roughly doubled the pulse repetition rate. In April of this year, a filter was added in the alternator exciter rectifier to improve the flat-top stability. In July, the grid control was replaced which has resulted in a much better overall shape and reproducibility of the flat-top.

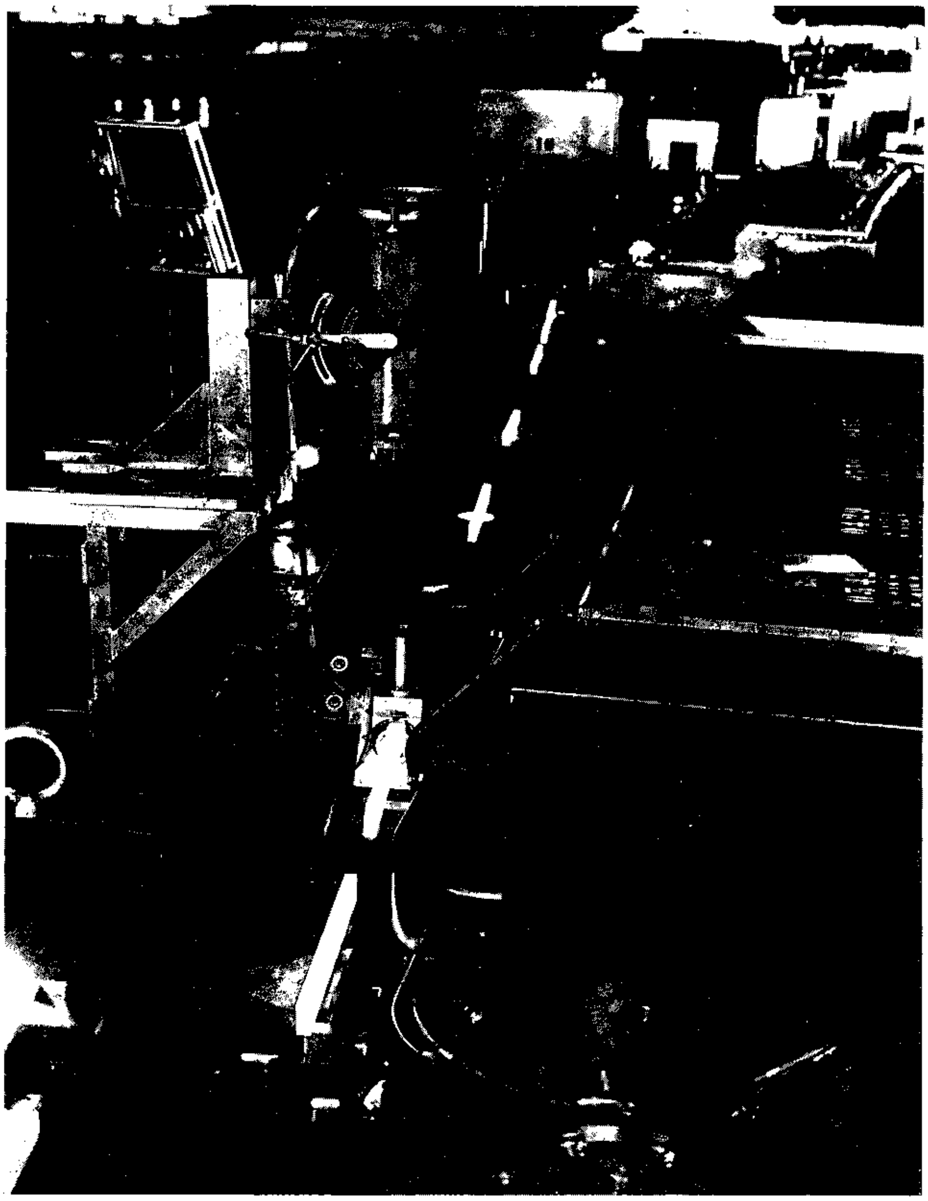
Operation

Operation of the PS has also been an adventure in the sense of always moving ahead confronting new problems. The operators have never been able to rest on their laurels with a machine that they could handle thoroughly well, for the potentialities of the machine have been continually developing both in terms of intensity and of versatility in providing particles for the experiments.

All these improvements could be made thanks to the numerous additions and modifications to the machine and the increased understanding of the physics of the accelerator. The operators proved capable of making good use of the new tools as they became successively available and their part in the success of the PS is significant. They have lived through many landmarks in machine performance, and have enjoyed them with other people who helped prepare the achievements. But operating staff have been also on the receiving end of the complaints of those most demanding customers — the experimental physicists. It has helped that over the years they began to acquire a better understanding of the desires and worries of the physicists running their experiments.

During 1960, a large percentage of the running time was devoted to studies of the accelerator itself, mainly performed by the designers. It soon became clear, however, that continuous running for experimental physics should be entrusted to a professional operating staff and this has been done from the end of 1962. A staff strength in the Main Control Room (MCR) of one shift engineer and two operators has been kept constant over the years — in spite of the various extensions for new equipment and of the more complex operational schemes. This was accomplished by introducing job-tailored controls, improved operating procedures and, more recently, by involving more and more a process control computer.

To make the most efficient use of the accelerated protons has been one of the guiding principles in the development of the machine. In 1960, short and long beam spills were produced on internal targets, but they were not perfect — there was a lack of stability in the spill and the spill rate on the target was not constant. The introduction of an electronic filter in the main magnet power supply in 1962 resulted in an almost complete suppression of the ripple modulation in the beam spill. In 1963 new target mechanisms came into operation with accurate radial and vertical positioning of the target heads and a servo-system to keep the spill rate constant. With complete mastery of simultaneous target sharing techniques, one concluded a line of development on producing beams from internal targets. Further refinements were introduced later, but the next big



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The first fast ejected beam from the PS was obtained on 12 May 1963. This photograph shows the beam lighting up blocks of plastic scintillator as it travels in air on its way into the South Hall.

step forward was not made until the construction in 1968 of fast moving targets, with which the time needed between successive operations in the same machine cycle is reduced.

The PS in 1963 was the first accelerator to have fast ejection. Numerous improvements to the ejection system made it a very reliable tool and it has taken over, from internal targets, the majority of the work for bubble chambers.

Three months later, the first slow ejected beam was obtained from the machine. Contrary to fast ejection, slow ejection did not then create much interest amongst the experimentalists as they were happy with the internal target operation and the possible advantages of slow ejection could not easily be assessed. The first experiments using a slow ejected beam started in 1965 and more followed the next year using a more permanent beam arrangement.

Operating the slow ejection system has been a headache for the operators from the start because of the incomplete understanding of the slow ejection process and the hardware problems involved. The performance of the system has, however, been significantly improved this year : higher efficiencies, longer spill times and less structure. At this point it is perhaps appropriate to remember that slow ejection offers important advantages over internal targeting : reduction of proton losses in the machine (essential for future high intensity operation) and more freedom in the lay-out of secondary beams around the target.

Efficient use of the accelerated beam is rather difficult to define, but the other aim in machine development is simple to define — to increase the beam intensity. Beam intensity depends, in the first place, upon the intensity and quality of the beam accelerated up to 50 MeV in the Linac. The impressive improvements in the Linac beam in the course of the years have made it possible to obtain higher intensities in the PS.

During the first months of operation, acceleration of up to 2.10^{10} p/p was achieved with a Linac beam up to 5 mA, but already by the summer of 1960 unexpectedly good intensities were obtained : 30.10^{10} p/p with about 15 mA from the Linac. The intensity continued to show considerable increases up to 1964 and the PS managed to beat the Brookhaven AGS by a short head in reaching the figure of 1 terraproton/pulse (10^{12} p/p). In the following years the intensity only increased slightly despite much more intense Linac beams — up to 140 mA — obtained with a new preinjector in 1966. Many other factors also determine beam intensity, such as magnetic conditions at injection, the r.f. accelerating system, vacuum pressure, space charge effects, and adequate instrumentation. Further work on these factors resulted in a spectacular jump in intensity to over 200.10^{10} protons per pulse this year. In addition, the coming into operation of the new main magnet power supply in 1968 has more than doubled the pulse repetition rate of the machine.

After ten years the sense of adventure in PS operation still remains. In the immediate future there are the challenges of still further increasing the PS intensity with a longer Linac pulse in refined multiturn injection and r.f. capture, improving slow ejection efficiency with a thin electrostatic septum, and mastering the slow ejected beam structure.

Experimental Halls and Equipment

It is in the experimental halls of the PS that the activities of nearly every Division in CERN come together. The experimenter is influenced in his concept of the experiment by the theoretician and he is also influenced, and perhaps limited, by a host of other people — by the electrical engineer who thinks in MVA, by the electronic engineer who thinks in nanosecond pulses, and by the pipe-fitter, mason, wireman, mechanic, electrical fitter, all of whom contribute to the ultimate success of the experiment. The computer programmer and the computing capacity he has available may seem remote from the hardware on the experimental hall floor but he too reflects back in terms of the time taken for an experiment. And, of course, the experimental halls and equipment feel the ubiquitous influence of the man from finance. These are all added to the influence of the performance of the PS itself.

Efficient planning and organization of the experimental facilities involving so many different professions took time to develop. When the PS first operated in 1959, somewhat ahead of the most optimistic expectations of the experimenters, CERN was just not ready to begin an experimental programme. Now, with ten years experience, the programme is densely packed — in space and in time — and the experimental facilities are vast and still growing. What follows is a historical run-through of some of the major events of the past ten years.

During 1959, there was active preparation for a somewhat ill-defined experimental physics programme. Beam transport magnets and quadrupoles were designed and ordered. The South Generator House was built and orders were placed for the first generators to power experimental equipment and for a water-cooling system to cool the magnets in the South Hall. But when the PS started to run for physics experiments at the beginning of 1960, none of the items had arrived. The first beams were made without lenses and with magnets begged or borrowed from various sources. Welding generators were put into service as power supplies and the ordinary town water was used for cooling. Something like a third of the South Hall was still a workshop and the North Hall was still being used as an assembly area by the PS Division. (The East Hall was at the preliminary planning stage.)

In March there was the first bubble chamber run with the 30 cm hydrogen bubble chamber which took three days and nights collecting 50 000 pictures. This was known as 'The Long Run' preceded by a mountain of memoranda ranging from instructions to the Engineer-in-charge to feeding arrangements. The magnet of the chamber was powered by a generator at the synchro-cyclotron via a cable link to the PS.

By the end of 1960, quite a number of beam transport items had arrived, the water cooling equipment and the new generators had been put into service. At the far end of the South Hall, in addition to the 30 cm chamber, there was now the Ecole Polytechnique Heavy Liquid Chamber. There were already 12 groups using the PS, and the exposures made by the Emulsion Group had already gone to 32 Laboratories, 11 of which were in non-member States.

During this time many problems had to be faced: radiation safety, the use of liquid hydrogen and the efficient use of the protons available from the PS. Target sharing was introduced so that a bubble chamber (short burst) and electronics experiments (long spill) could be served on the same PS cycle.

In 1961 there was a large extension in the physics facilities. The 81 cm hydrogen chamber from Saclay, the CERN Heavy Liquid Chamber and the Wilson Cloud Chamber (CERN/ETH) came into operation. Almost all of the North Hall and a larger share of the South Hall were made available for physics.

The first electrostatically separated beam was made for low momentum antiprotons to go into the 81 cm chamber. The two separators were made by the University of Padova (one of them, Zadig No. 1, is still in use after considerable modifications and some lenses were borrowed from Saclay. By the end of the year, the first two of the CERN 10 m electrostatic separators had been brought into operation, one for the beam in the North Hall and one in the South Hall.

Delivery of a second batch of beam transport equipment started and, by the end of the year, a third order of 55 additional beam transport elements was placed. This was done with the future East Hall in mind.

The main civil engineering work for the East Hall was completed during 1962, together with the East Generator Building, and it came into use the following year for the first technical runs with the 1.5 m British National Hydrogen Bubble Chamber.

In 1963 the newly installed fast ejection system was used for the neutrino experiment with the CERN Heavy Liquid Chamber as principal detector. Electronic experiments were then being served in the South and East Halls by sharing the long spill using a servo-target.

In 1964 the 1.5 m chamber started operating successfully with the o_2 beam which, with its 30 m of electrostatic separator, was able to give a reasonable yield of 6 GeV/c kaons. Late in the year, the 2 m hydrogen chamber had its first cool down and preliminary tests, and beams were prepared for its use in the following year. There were then five bubble chambers around the PS.

In the South Hall, in the main, the programme and the beams continued as before and the first use in CERN of a computer on-line took place in the Missing Mass Experiment.

Studies were under way on new separators and new types of beam transport elements. In particular, the development of new alumina coated electrodes led to the first successful tests, under experimental conditions, of a 3 m separator in which the electric field gradient, for a given gap, was nearly doubled. This replaced a 6 m separator with stainless steel electrodes. The studies on beam transport elements were made with an eye to increasing the over-all beam layout efficiency ; a number of these elements were ordered for delivery in 1965.

During 1964 there were many worries that there would not be sufficient power on the site to carry out the PS experimental programme as planned, and for a while the use of large magnets had to be staggered. However, this problem was resolved with the helpful cooperation of the Services Industriels de Genève.

Three new ejected beams came into operation in 1965, two of them following the same line (fast or slow ejection from straight section 58 to the East Hall) and protons were transported for the first time into the East Hall. In the South Hall, fast ejection from straight section 1, at 11 GeV/c, was used to inject protons into the muon storage ring for the g-2 experiment.

The growing use of ejected proton beams solved some problems, but also created new ones. The intensive studies made for a new neutrino beam showed that a neutrino installation in the South

A view of the congested East Hall taken in September before the present PS shutdown. In the photograph can be seen the beam-lines, the huts which serve as local control rooms for the experimentalists (many housing on-line computers) and, everywhere, concrete shielding blocks.

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Hall would be an inefficient and unsatisfactory arrangement. It was decided therefore to have an independent neutrino area with an ejection system starting from straight section 74.

The 2 m hydrogen chamber was fed with 10 GeV/c negative kaons from the new r.f. separated beam using the new fast ejection system ; prior to this a preliminary test of the r.f. beam had been made using an internal target together with the 1.5 m chamber. The 1.5 m chamber completed its programme of physics and prepared to leave CERN.

The plans that had been made for new beams were completely re-evaluated at the time of the breakdown of the magnet power supply early in 1966. This affected particularly the East Hall where all the beams were remade. The construction of the new neutrino area (to be known later as the South-East Area) began and plans were made for installing the heavy liquid chamber, Gargamelle, at the end of the neutrino area.

For the first time, in 1967, only ejected beams were used into the East Hall. The slow ejected beam from straight section 62 was divided into three primary proton beams feeding a complex of five secondary beams.

The neutrino area had its first run with the CERN Heavy Liquid Chamber filled with propane and took 1.1 million pictures with a spark chamber experiment collecting data at the same time. Soon after the neutrino run had finished, the Heavy Liquid Chamber was moved to the so-called 'Jet-Area' behind the 2 m chamber.

At the beginning of 1968, the 'Jet-Area' was brought into operation. The beam used was a short extension of the r.f. separated beam feeding the 2 m chamber, and those particles that did not interact in the 2 m chamber were transported on into the Heavy Liquid Chamber.

In summer 1968, there was an abnormally long shutdown of four months for piercing the PS shielding with the tunnels towards the ISR and the Synchrotron Injector. In this period, practically all beams were either considerably modified or completely rebuilt. In the South Hall, with the completion of the g-2 experiment, the fast ejected beam was removed.

The pattern of beams in the Halls has remained essentially the same during 1969. Nevertheless two major modifications took place in the slow ejected beam complex in the East Hall. There are only two targets in series in the proton beam instead of three, which has eased some of the operational problems existing previously. The installation of a stopped kaon beam from an external target gave a forewarning of the problems that will be faced when the PS intensity is greatly increased ; installation had to be carried out in a compact shielding area where induced radioactivity levels were high.

Early this year, k11, the first secondary beam in the South East Area, was used in conjunction with the CERN Heavy Liquid Chamber. The programme was interrupted when a fire broke out on the magnetic horn that was under test in an ancillary tunnel. A few days later, the 2 m chamber took its ten millionth picture.

And to come...

A brief sketch of the further developments in PS performance and in experimental facilities which will come about in the next few years in the context of the PS Improvement Programme and the coming into operation of the Intersecting Storage Rings.

At the December Session of the CERN Council in 1965 an Improvement Programme was approved to increase the capacity of the PS for particle physics at energies up to 28 GeV. This programme has five prongs :

1. To increase the PS repetition rate by installing a new magnet power supply
2. To increase the PS accelerated beam intensity by means of a new higher energy injector (second stage of PS improvement programme)
3. To provide facilities for Gargamelle, a large heavy liquid bubble chamber built by Saclay
4. To build a large hydrogen bubble chamber (BEBC) in cooperation with France and Germany
5. To build a large spectrometer magnet and spark chamber system (the Omega project).

At the same meeting, the Intersecting Storage Rings (ISR) project was approved and in addition to the storage rings themselves was included an experimental hall for 28 GeV physics (the West Hall), somewhat larger than the total area of the existing South, North and East Halls.

To date, the first point of this programme is completed — the new main magnet power supply was commissioned in mid 1968; the rest of the programme is scheduled to come into operation as follows :

- 1970 ejection from PS towards ISR, commissioning of Gargamelle
- 1971 commissioning of ISR and BEBC
- 1972 commissioning of Omega and the higher energy injector (the Synchrotron Injector or Booster).

Thus, in the next three years the complexity of the PS facility will increase considerably. BEBC, Omega and other electronics experiments in the West Hall will require both fast and slow ejected beams down the same channel. The technique of sharing simultaneously between this slow ejection and the internal target in straight section 1, feeding the South Hall experiments, must be developed, and, as now, fast ejected beams will be necessary in the East Hall (for the 2 m chamber) and the South East Area (for Gargamelle). All this during the same machine cycle.

The ISR will make more stringent demands on the quality of the accelerated beam; the PS will become an injector and not just a provider of protons for internal or external targets.

All these operations will have to be carried out with a beam intensity an order of magnitude greater than in 1968. The double problem facing the PS is, firstly, the production of this higher intensity, with the minimum beam blow-up, and, secondly, living with this beam once it has been achieved.

The first proposal to increase the PS intensity per pulse was to replace the 50 MeV Linac by a Linac of 200 MeV; it was demonstrated, however, that a multi-ring slow-cycling booster synchrotron operating between 50 and about 800 MeV would, for about the same cost, give more flexibility and greater development possibilities, particularly for the ISR. A detailed design study for a four-ring booster (described in CERN COURIER vol. 8, page 3) was completed in 1967 and in January 1968 the Synchrotron Injector Division was formed to build it.

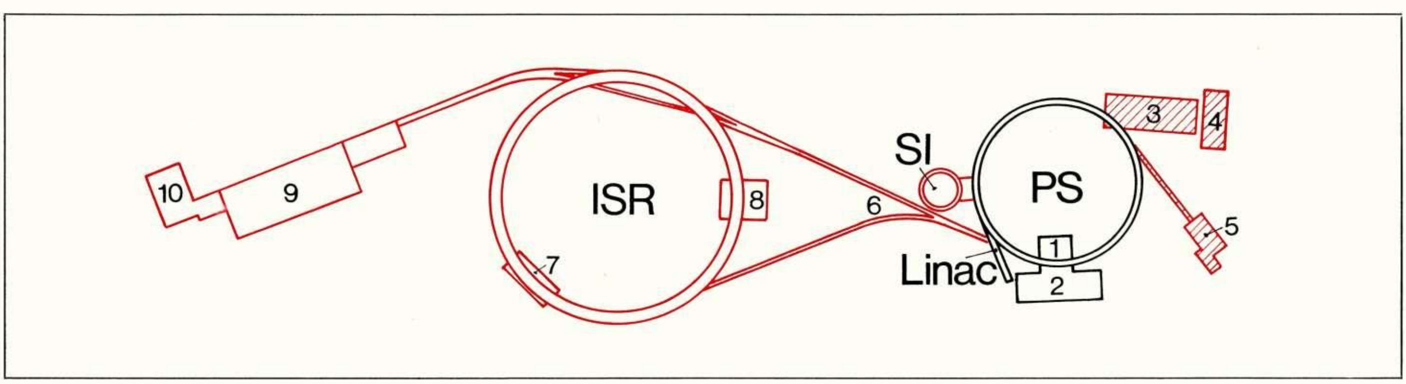
With adding the Synchrotron Injector, considerable modifications are necessary to the PS itself. The repetition rate of the Linac must be doubled and its beam pulse length increased to 100 μs. In order to cope with the increased beam loading due to the higher intensity beam and to provide the higher accelerating voltages necessitated by the increased rate of rise of the magnetic field, the r.f. acceleration system will be replaced. Sputter ion pumps are being installed to improve the vacuum. A variety of instrumentation will be added to keep a good watch on, and good control of, the beam.

In order that beam losses (and thus induced radioactivity) are kept within manageable limits the average operational efficiency of ejection must be kept very close to the peak efficiency obtainable, despite the necessity of sharing with targets. To this end considerable effort is going into computer control of ejection. Here again good instrumentation is of great importance. Equipment inside the ring and especially around internal and external targets and ejection systems must be radiation hardened and designed for rapid maintenance (or maintenance by remotely-controlled manipulator).

By the mid-1970's the PS complex really will be complex. A proton leaving the ion source will have a wide variety of opportunities for its immediate future. It will be accelerated to 50 MeV in the Linac. From there it can go into any one of four vertically stacked rings in the synchrotron injector where its energy will be taken to 800 MeV (crossing the Franco-Swiss border over a million times in the process) before being transferred (in various possible combinations with its friends who went into the other three rings) into the main PS ring. There it can be taken to peak energy of 28 GeV and then the possibilities really open wide. It can remain in Switzerland and be fired into an internal target to feed experiments in the South Hall, slow ejected to feed experiments in the East Hall, or fast ejected to feed 'local' bubble chambers — Gargamelle or the 2 m hydrogen. It can return to France and travel several kilometres to the West Hall being slow ejected for the Omega or fast ejected for BEBC. If it is not tired of going round and round, it can spend as much as a full day at it by choosing fast ejection into one or other of the storage rings.

Hopefully all these manœuvres will not in fact be at the will of the proton but under the control of the PS operators. However, bringing all these systems into operation together efficiently is a challenge which sustains the interest which fired the first builders of the PS.

The PS : past, present and future. Drawn in black are the Linac, the PS ring and the North (1) and South (2) Experimental Halls which existed in 1959.
In hatched red are the additions up to 1969 — the East Experimental Hall (3), the 2 m bubble chamber (4) and the South East Area (5) to be used eventually for Gargamelle.
In red are the coming additions — the synchrotron injector (SI), the intersecting storage rings (ISR) with the beam transfer lines (6) and experimental halls (7, 8), the West Experimental Hall (9) and the large European bubble chamber (10).



A list of Universities, Institutes and Laboratories who have participated in the experimental programme of the proton synchrotron during the past ten years. This participation may have been in electronics experiments, in film analysis from bubble chambers or in nuclear emulsion analysis. Teams from many centres, especially of course those from CERN Member States, have been heavily involved in the programme for many years. Others have participated only briefly but all have drawn some material for their physics research from the PS.

AUSTRIA
Institute for High Energy Physics, Vienna

BELGIUM
Institut Interuniversitaire des Sciences Nucléaires, Bruxelles
Laboratoire des Hautes Energies, Bruxelles
Université de Louvain

CZECHOSLOVAKIA
University of Prague

DENMARK
Institute for Theoretical Physics, University of Copenhagen

FEDERAL REPUBLIC OF GERMANY
DESY Laboratory, Hamburg
Institute for High Energy Physics, University of Heidelberg
Institute for Experimental Nuclear Physics, Karlsruhe
Institute for Experimental Physics, Hamburg
Max-Planck-Institute for Nuclear Physics, Heidelberg
Max-Planck-Institute for Physics and Astrophysics, Munich
Physics Institute, Aachen
University of Berlin
University of Bonn
University of Munich

FINLAND
University of Helsinki

FRANCE
Centre d'Etudes Nucléaires, Saclay
Centre de Recherches Nucléaires, Strasbourg
Collège de France, Paris
Ecole Polytechnique, Paris
Institut de Physique Nucléaire, Orsay
Institut de Physique Nucléaire, Paris
Institut du Radium, Paris
Laboratoire de l'Accélérateur Linéaire, Orsay
Laboratoire d'Ivry
Université de Bordeaux
Université de Caen
Université de Clermont-Ferrand
Université de Lyon

GERMAN DEMOCRATIC REPUBLIC
Research Centre for High Energy Physics, Berlin

GREECE
Nuclear Research Centre 'Democritus', Athens
Nuclear Physics Laboratory, Athens

HUNGARY
Central Research Institute of Physics, Budapest

INDIA
Osmania University, Hyderabad
Tata Institute of Fundamental Research, Bombay
University of Chandigarh

IRELAND
University of Dublin

ISRAEL
Weizmann Institute, Rehovoth

ITALY
Frascati Laboratory, Rome
National Institute for Nuclear Physics
University of Bari
University of Bologna
University of Florence
University of Genoa
University of Messina
University of Milan
University of Naples
University of Padua
University of Pisa
University of Rome
University of Trieste
University of Turin

NETHERLANDS
Foundation for Fundamental Research of Matter, FOM
University of Amsterdam
University of Nijmegen

NORWAY
University of Bergen
University of Oslo

PAKISTAN
Atomic Energy Centre, Dacca
Atomic Energy Centre, Lahore

POLAND
University of Cracow
University of Warsaw

RUMANIA
Institute of Atomic Physics, Bucharest

SPAIN
University of Madrid
University of Valencia

SWEDEN
University of Lund
University of Stockholm
University of Uppsala

SWITZERLAND
Ecole Polytechnique, Lausanne
ETH, Zurich
Institut de Physique, Neuchâtel
University of Berne
University of Friburg
University of Geneva

UK
Daresbury Nuclear Physics Laboratory
Imperial College London
Queen Mary College London
Rutherford High Energy Laboratory
University College London
University of Birmingham
University of Bristol
University of Cambridge
University of Durham
University of Edinburgh
University of Glasgow
University of Liverpool
University of Oxford

USA
Argonne National Laboratory
Brookhaven National Laboratory
University of Arizona
University of Athens, Ohio
University of California at Los Angeles
University of California, Berkeley
University of Chicago
University of Illinois
University of Maryland
University of Michigan
University of Nebraska
University of Wisconsin

USSR
Institute of Physics, Alma-Ata
Institute of Physics, Tashkent
Institute of Physics, Yerevan
Joint Institute for Nuclear Research, Dubna
Lebedev Institute, Moscow

Research at the PS

Two articles bringing out some of the highlights of the particle physics research carried out at the proton synchrotron during the past ten years. The articles divide between the two techniques — 'electronics' experiments involving the use of counters and spark chambers, and bubble chamber experiments involving the use of hydrogen and heavy liquid bubble chambers.

1. Electronics experiments

G. Cocconi

During the past ten years, a good fraction of the research at CERN has centred on the use of the proton synchrotron. The nature and the quality of this research are so intimately connected with the possibilities offered by the accelerator, that, in tracing the history of this period, it is not clear whether the main responsibility for the achievements (and even for the few failures) rests with the physicists who performed the experiments or with the engineers who operated the accelerator and organized the experimental halls.

As a physicist who spent most of this time around the PS, I will present my recollections and my appreciation of the research with the so-called 'electronics' techniques, i.e. with apparatus incorporating detectors giving electronic responses, such as scintillation counters, Cherenkov counters, and spark chambers.

At the beginning of 1960, when 25 GeV protons first started to hit the PS internal targets regularly, the relatively small group of physicists present at CERN was not really ready for experimenting with the various possible beams of secondary particles. Though this is a situation that easily arises whenever a facility far superior to the already existing ones enters into operation, in 1960 our preparation was abnormally poor : in post-war Europe there was no tradition of high energy research, and in CERN (only a few years old) most of the activity had been devoted to the construction of the accelerator itself. In 1960, the secondary beams were analyzed using a total of only three small bending magnets (borrowed from the 600 MeV synchro-cyclotron) and with no quadrupoles. Only at the beginning of 1961 did the first standard 1 and 2 m bending magnets arrive, and also some quadrupoles, and by the end of that year we could count on 20 units (now we have about 400 units). Fortunately, good electronics, with resolving times in the nanosecond range, was available in situ, thanks to the research which had been in progress for some years at the synchro-cyclotron. Also, the analysis of the secondary beams was facilitated by the availability of a differential Cherenkov counter that a group in CERN had built and studied in advance.

This slow start explains why the first results were rather modest, and gives more meaning to the present flourishing status of European high energy research. Although it would be interesting to follow, year by year, the chronicle of all experimental achievements, I will select only a few lines of research that have flourished at the PS.

As a first example I will take the series of 'missing-mass' measurements. In a collision between two particles, the detailed measurement of the momentum spectrum of one of the particles emerging from the interaction gives valuable information about the mass of the 'missing' body formed by all the other particles produced. Measurements of this kind in proton-proton collisions were started at the very beginning of PS operation, and showed that the missing masses which are associated with the production of a baryon preferred some well-defined values, the first indication of what is known today as the 'peripheral' production of baryonic states.

The same principle, applied in 1964 to pion-proton collisions, where bosons plus one proton are produced, led to the discovery of several massive mesons. The search for meson resonances soon took advantage of a new technique : the wire spark chamber, which was invented at CERN by F. Krienen and which is now, connected on-line with a computer, of wide-spread use in high energy research.

An aim of the missing-mass experiments is to find how large is the population of excited baryons and mesons. So far, more and more excited states have been discovered as higher and higher mass regions have been investigated. We do not know how far the complexity of hadronic matter, this matter that can be created by pumping energy into a few particles, can go. Is there a 'uranium' for these particles ? It is to pursue this kind of research into the region where still heavier bosons could be produced, that a CERN-Swiss group is preparing to work with the more energetic particles available at the 76 GeV Serpukhov accelerator.

Another avenue of research that has a strong CERN imprint is the study of proton-proton scattering. This started in the very first years of PS operation, when the proton beam was that scattered out of an internal target. Later (1965) the study benefited greatly from the existence of an ejected proton beam. (The slow ejection was by itself a remarkable feat of the CERN accelerator experts.) Precise measurements of the proton-proton differential cross-section at small, as well as at large, scattering angles, revealed that the proton is not a point-like 'elementary' particle but has a complex structure, of about 1 fermi (1×10^{-13} cm) radius, whose boundaries become sharper as the collision energy increases. The experiment is still going on as one feels that better precision and higher energies can give a clue to the nature of the complexities hiding inside the nucleons.

The study of neutrino interactions is an interesting story. It started unsuccessfully when in 1961 a still inhomogeneous and inexperienced group tried to observe interactions of neutrinos produced by the secondary beams created in the PS, and made some mistakes in evaluating the fluxes of particles available. In the meantime, physicists from Columbia working at Brookhaven, discovered that the neutrinos produced by muons behave differently from those produced in nuclear beta-decay; an unexpected result of deep significance for the understanding of the weak interactions.

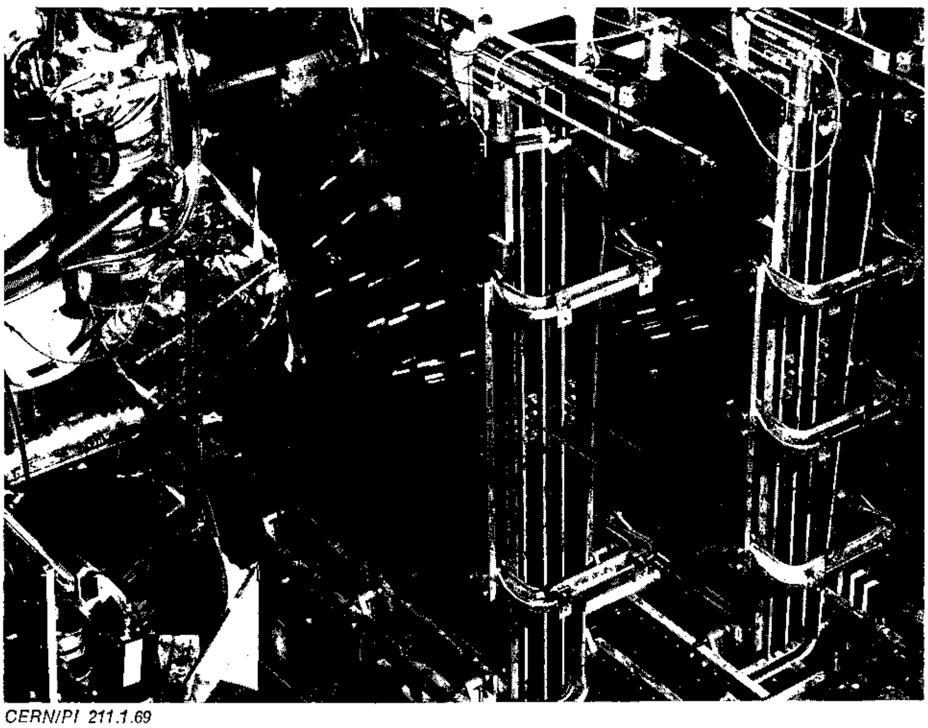
Further experiments at CERN, both with spark chambers and with a heavy liquid bubble chamber, coupled with original improvements in the handling of the secondary beams (the famous neutrino horn of S. Van der Meer), brought to Europe other important results in this field. For instance, it was found that the proton behaves also for neutrinos as a complex body of about 1 fermi radius, and not as a point, as many theoreticians expected. Furthermore, the neutrino-nucleon cross-section was observed to increase as the energy of the neutrino increases. This suggested that the neutrino, which at the energies explored

Wide gap spark chambers detecting charged particles in a 'missing mass' type of experiment recently completed at the proton synchrotron. This particular experiment extended the search, which had previously revealed seven new mesons, into a range where still heavier mesons could be detected. The search is to be extended still further in 1970 by a CERN/Serpukhov team at the 76 GeV proton synchrotron in the Soviet Union.

thus far interacts with matter only very weakly, could perhaps become as strongly interacting as the hadrons, at cosmic energies. The clarification of this point must wait for accelerators providing beams of energy substantially higher than those available at present.

The search into the unknown is pursued with a high energy machine like the PS, not only by attempting experiments that can bring to light new unexpected phenomena, but also by testing the limitations of theories whose validity is well confirmed by the existing experimental evidence. In CERN the best example of research of this kind is the test of electrodynamics performed by measuring the magnetic moment, μ, of the muon. Quantum electrodynamics predicts, with an uncertainty of some units in the last figure, that the gyromagnetic ratio of the muon has the value $g = \frac{4\,\mu}{eh/mc} = 2.00\,233\,174$.
Measuring the precession of mono-energetic muons in a magnetic field it is possible to check this prediction with a precision that depends on the energy of the muons. The first attempt was started at CERN in 1959 by a team of European and American physicists, using 200 MeV/c muons produced by the synchro-cyclotron. The result (1961) was $g = 2.002324 \pm 0.000010$. This confirmed the theory within about 1 part in 10^5. In 1964, a new apparatus was built that permitted the use of 2 GeV/c muons from the PS, and the work of five years has now produced the figure $2.00233232 \pm 0.00000062$. This checks the theoretical expectation within some parts in 10^7. We are now starting to assemble an apparatus which, using 3.2 GeV/c muons, will permit a gain of another factor of at least ten in precision.

Obviously, the possibility of pushing the test of a theory to these limits has an esthetic beauty in itself, but it also gives us more confidence in our understanding of the vast class of phenomena governed by electrodynamics. On the other hand, as the precision of these measurements progresses even further, we will be brought inescapably into contact with the limitations of the theory, and will have to face the reasons why the theory is no longer valid beyond a certain level.



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I will end this selective description of the PS research programme with two examples of more recent trends. One project started in 1964, after the discovery by Fitch and Cronin at Brookhaven in 1963 of the anomalous decay of the long-lived (5×10^{-8} s) neutral kaon into two pions — anomalous because the decay into two pions is permitted for the short-lived (8×10^{-10} s) kaon but should not occur, according to the known rules of quantum mechanics, for the long-lived. What produces this anomaly? The problem is still open, notwithstanding the concentrated effort of many teams of physicists on both sides of the Atlantic. What is involved here is the apparent violation of what was believed to be one of the fundamental tenets of quantum mechanics, the invariance of CP (charge and parity conjugation).

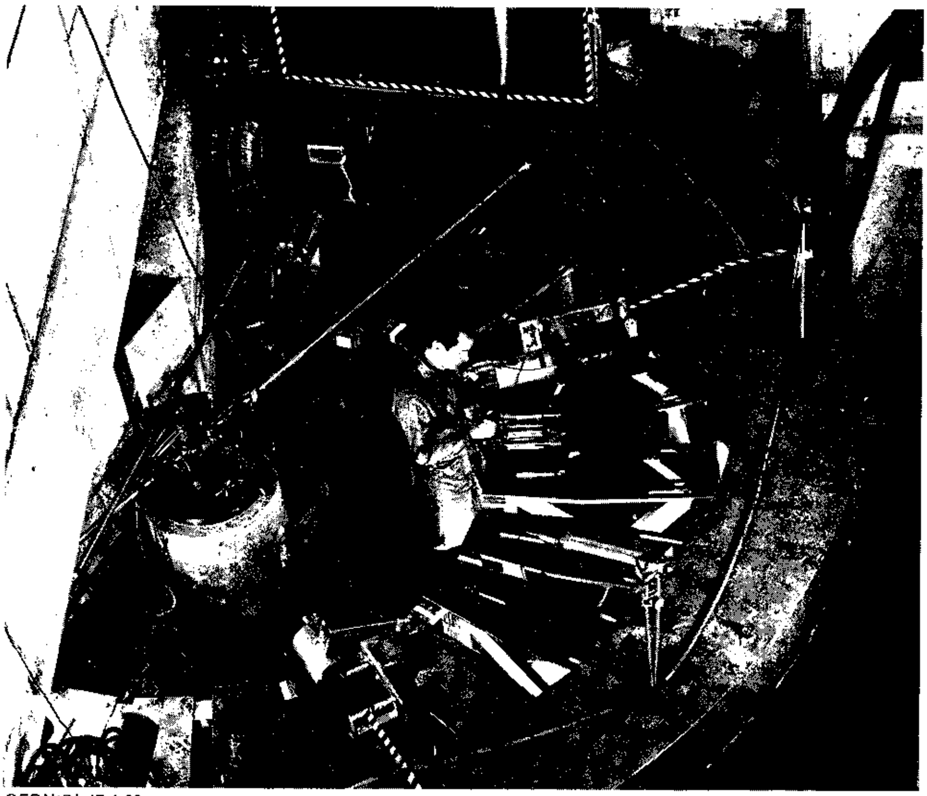
In CERN, no less than six teams have conducted some of the most elaborate and ingenious experiments, involving Cherenkov counters, optical spark chambers and wire spark chambers, in an attempt to resolve this anomaly. Next year three new experiments will continue the search.

The common aim of the second group of 'recent trend' experiments is the detailed study of the scattering of various particles by protons, so as to be able, for example, to establish the quantum numbers of the resonances produced, or the nature of the forces that give rise to the scattering.

Until a few years ago it was hoped that, at each energy, the precise measurement of the differential cross-section as a function of the polar angle of scattering, averaged over all azimuthal angles, could give sufficient information. It turned out that while this is perhaps true for the study of the states with the lowest quantum numbers, as soon as the complexity of the system increases it becomes imperative not to average over the azimuth. This means that we have to utilize not isotropic but polarized targets, where the protons have all their spins aligned in a fixed direction.

Scattering experiments with polarized targets have been vigorously pursued in CERN during the last few years, and the most advanced systems built thus far for high energy research have been realized

The muon storage ring which was used in the measurement of the 'g-2' of the muon. This experiment was the most refined test to-date of the limits of the validity of quantum electrodynamics. A fan of counters to detect the electrons produced as the muons decayed, can be seen inside the ring.



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here with the help of a team of physicists from the solid-state laboratory of A. Abragham in Paris. Three teams are at present carrying out experiments of this kind, with targets in which up to 50 % of the protons are polarized.

The fact that I have described only six lines of research that have developed with success around the PS during the last decade, should not give the impression that the many other experiments concluded or in progress are less interesting or less promising. And the fact that I reported the results in a rather simple way should not give the impression that the knowledge acquired is commonplace and somewhat anticipated.

It is the habit of people who try to interrogate Nature and, from the answers, to formulate new questions, to show a certain detachment and apparent coldness towards the finished experiments, even when the results are new and of great moment. This is because the scientist is trained to accept Nature as the norm of truth, and Nature's ever deeper and more astonishing variety is to him a continuous reminder of his ignorance. But there is no doubt that in the experiments I have described, as also in many of the others, the results were radically different from what experimentalists and theoreticians expected. Ten years ago we were convinced that the properties of strongly interacting elementary particles, in the GeV ranges and beyond, could in some circumstances be similar to those of a hard ball and in others to those of centres radiating a few kinds of mesons and baryons. The weak interactions were expected to be all of one type, obeying the rules learned from the behaviour of the decay of nuclei. In both cases we were grossly wrong, and if I am allowed to enclose within a unique frame the complex variety of phenomena that has manifested itself during the last ten years, I would say that as the energy per particle increases, all interactions — strong, electromagnetic and weak — are showing the common property of producing complex states, of ever increasing mass and rather constant lifetime : a mechanism that resembles the opening of a Pandora's box containing more and more winds as more energy is compressed into it.

The problem that we are now facing after ten years of research is, 'What kind of wind is contained in our Pandora's box ?' That elusive stuff is called by the more determined physicists 'quarks', by others 'partons' (a synonym of dust). Whatever its name, the most astonishing property of this 'matter' is its ability, given enough energy, to build structures of greater and greater complexity, short-lived in our time-scale, but lasting long enough in the particle's time-scale, to possess well defined structure.

Faced with this new, complex world, we find ourselves (to finish with a timely comparison) like a man from the moon who from his experience was led to think that atoms could combine only in the simple molecules found in rocks and dust — the molecules that even the scorching solar wind is not able to destroy on the lunar surface. On landing on our planet, he discovers that the possibilities of the world of molecules are much more numerous and complex. That carbon, hydrogen, oxygen and a few other atoms, when put together in a 'gentle' way, can give rise to organic molecules that are rather unstable but are of almost infinite variety and millions of times heavier than those of the inorganic world.

How large can the big 'molecules' built with quarks or partons become; and how do they behave ? These are the questions that our work has allowed us to formulate and that summarizes the direction of our future efforts.

It is for these reasons that I think that here in CERN we can feel confident of having fulfilled, during these ten years, the augury made by Niels Bohr at the PS inauguration ceremony on 5 February 1960.

'The main human lesson drawn from investigations of phenomena ever more remote from ordinary experience is the recognition of the inseparability of objective knowledge from our ability to put questions to Nature by means of experiments suited to give unambiguous answers. It is therefore imperative that physicists taking part in such inquiry can have the opportunity of getting experience about all aspects of the situation. This would, however, be impossible for scientists from countries with more limited resources, if it were not by means of such co-operative efforts as those we are witnessing in CERN.'

And for the same reasons I feel that I can paraphrase the famous answer given by Faraday to the Minister who was asking whether his research on electromagnetic induction was leading to something useful. While Faraday said *'Sir, I do not know to what it will lead, but I am sure that eventually you will tax it'*, I think that to the same question, asked about high energy physics, we can reply, *'Sir, I do not know to what it will lead, but I am sure that eventually you will need it to understand what you are'*.

A photograph taken during the latest series of neutrino experiments at CERN. The heavy liquid bubble chamber was filled with propane and the photograph shows the interaction of a neutrino with a 'free' proton, the first time such interactions had been observed. The neutrino enters from the bottom of the photograph and interacts with a proton to give a proton (short track to the right) a muon (long upward track) and a positive pion which decayed into a positron (the tight spiral).

2. Bubble chamber experiments

J. Meyer

Before the PS came into operation it was evident that a great deal of physics research could be undertaken with bubble chambers, the principle of which had just been discovered by Glaser and which were coming into use in great numbers in the United States. CERN plunged into the use of this technique constructing hydrogen and heavy liquid (to take propane or freon) chambers and supporting the operation for many years of chambers constructed in some Member States.

A whole series of complex technological problems had to be tackled with regard to the bubble chambers themselves, the particle beams to feed them and the techniques for their analysis. Successful and, in some cases, original solutions in the provision of pion, kaon, proton and anti-proton separated beams, and in the processing of events recorded on photographic film have enabled more than 20 million pictures to be taken and analysed by European physicists over the past ten years, producing important results.

The bubble chamber is, in a way, a complementary instrument to electronics equipment. It enables collisions to be detected and measured with uniform efficiency in all directions. On the other hand, only about ten incident particles may be analysed per PS cycle. Electronics equipment can accept over 100 000 particles, but their detection efficiency is generally strongly dependent on a complicated geometric arrangement of detectors. The heavy liquid chamber adds to detection possibilities since it may record and yield efficient measurements of electrons and gamma rays, which is more difficult with hydrogen chambers.

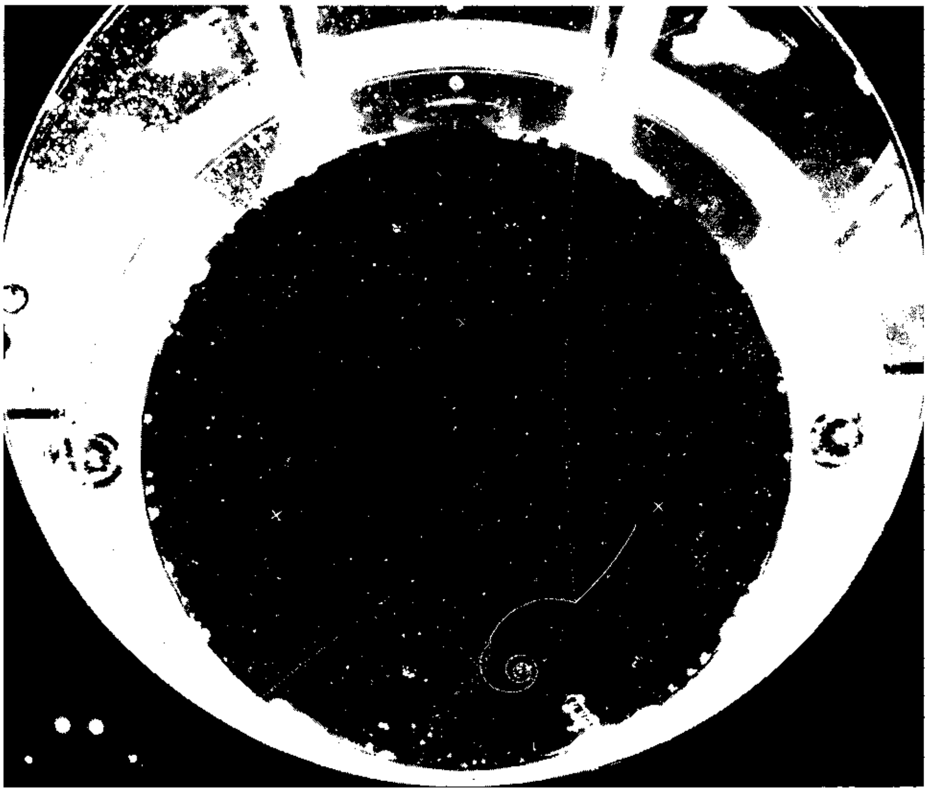
The physics results obtained from bubble chambers have been largely the result of collaborations between various European groups, some of which have included CERN scientists and some of which have been entirely external groups. These large collaborations have been necessary to tackle the problem of obtaining significant statistics — hundreds of thousands, even millions, of pictures must be taken and the processing of this mass of information is long and complex. The collaborations have been set up between different groups in different Member States and to a lesser extent in other European countries or in the United States. In this way over a million events have been measured in the last twelve months.

In a short summary it is not possible to enumerate all the results obtained over the past ten years since the PS started operating, because they are so numerous and also because it is not always easy to judge their intrinsic value : what was important yesterday may not be so today and results which are considered of little account today may prove to be important tomorrow in the light of theoretical developments. Therefore, I shall limit myself to giving a sample of certain important studies and cases where the contribution made by European Laboratories was of a pioneering nature : when the discovery of phenomena was made in Europe or when it was made simultaneously with USA work, or when the results obtained from pictures taken at CERN made a decisive contribution towards a better understanding of important physical processes.

I shall list some major results obtained with hydrogen and heavy liquid chambers in three broad fields of elementary particle physics: weak interactions, the discovery and study of particles and resonances, and the study of the production mechanism in high energy collisions.

Weak interactions

1) Verification of the rule $\Delta S = \Delta Q$. This rule states that the distribution in time of neutral kaons decaying into a pion and a lepton pair follows a well defined law. A heavy liquid chamber experiment showed that within experimental errors, the law is valid.
2) The study of leptonic decays of charged sigma hyperons in a batch of more than a million sigmas has made it

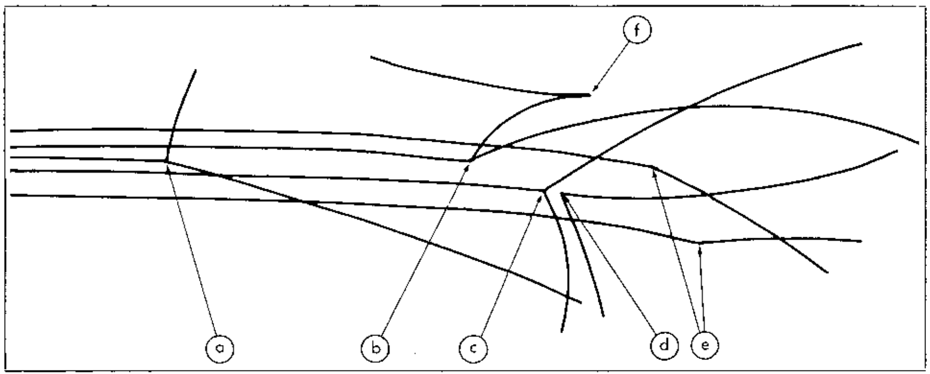


possible to measure the ratio of the axial and vector coupling constants and to check the agreement with theory. On the other hand, a search of decays contrary to the rule $\Delta S = \Delta Q$ was undertaken and an upper limit to the rate of violation of this law was obtained. Lambda hyperon leptonic decays were also analysed in order to measure the ratio of the coupling constants.

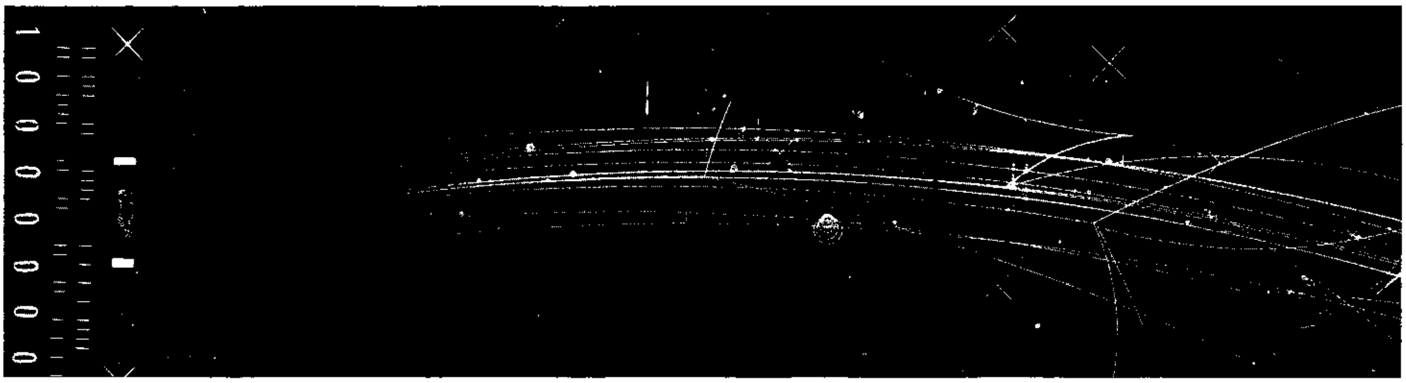
3) Various experiments were made to verify the law $\Delta I = 1/2$ in strange particle decays.
4) Precise measurements were taken of the form factor of the positive kaon decaying into a pion, a muon and a neutrino.
5) Large heavy liquid bubble chambers provide an adequate target for the study of neutrino interactions. This is a most interesting field and the CERN chamber, exposed to neutrino beams has provided valuable information on the 'elastic' interaction of the neutrino with a neutron yielding a muon and a proton.
6) One of the great discoveries of recent years has been the decay of the long-lived neutral kaon into two pions. This phenomenon indicates a CP violating kaon decay and numerous experiments have been carried out in Europe and in the United States to measure the decay rate. The literature contains various contradictory results on the rate into two neutral pions. The measurement in a heavy liquid chamber experiment at CERN gave a value which was not in disagreement with the 'super-weak' theory.
7) Precise measurements have been taken of the average life-times of the neutral xi and the positive and negative sigma hyperons.

Particles and resonances

1) The anti-particle of the xi-hyperon, with strangeness —2, was discovered during the study of antiproton-proton collisions at 3 GeV/c.
2) The relative parity of the lambda and neutral sigma hyperons was found to be positive from a study of the decay of the sigma into a lambda and an electron pair.
3) Different meson resonances have been discovered and in many cases their branching ratios and quantum numbers have been measured, in particular the following states: f^0, A_1, A_2, C, D, E, the $K\bar{K}$ threshold effect, g, K^* (1400), L (1800). The importance of the contribution of physicists using pictures taken at CERN may be appreciated when one considers that at the present time only about thirty meson states have been conclusively identified.
4) The spin and the parity of K^* (890), whose existence was firmly established previously, have been measured by an original method using stopping antiprotons.
5) Baryon resonances of strangeness -1 in the mass region 1600 to 1900 MeV have been the object of an exhaustive study in a systematic 'formation' experiment. A new resonance Λ (1830) has been discovered and its spin and parity have been determined. Spin and



The ten millionth photograph taken in 1968 with the 81 cm hydrogen bubble chamber which came to CERN in 1961 initially on loan from Saclay. Positive kaons with a momentum of 0.98 GeV/c enter from the left. Two of them decay (e) while three others interact with protons in the chamber: at (a) an elastic scattering takes place, at (b) the interaction gives a pion, a positive kaon (which decays at (f) and neutral particles, at (c) the interaction gives a positive pion, a proton and a neutral kaon which decays into two charged pions, at (d). The 2 m hydrogen bubble chamber also reached ten million pictures in September of this year.



parity together with branching ratios have been successfully measured for Λ (1660), Λ (1670), Λ (1690), Σ (1760) and Λ (1815).

6) Three baryon resonances of strangeness —2 have been identified by means of European bubble chambers : Ξ^*(1820), Ξ^*(1930) and Ξ^*(2530) — these constitute about 50 % of the Ξ * family currently known.

High Energy Production Mechanisms

1) Since the first experiments in 1960, it has become evident that a large number of high energy collisions are of a 'peripheral' nature. This means that in reactions of the type
$\pi^{\pm} + p \rightarrow p +$ mesons
$K^- + p \rightarrow \Lambda +$ mesons
$K^- + p \rightarrow \Sigma^{\mp} +$ mesons
$\overline{p} + p \rightarrow \Lambda + \overline{\Lambda}$
baryons are produced preferentially with a low kinetic energy. The study of many reactions with a momentum exceeding 3 GeV/c has shown subsequently that 'peripheralism' is a dominant characteristic in high energy interactions.

2) The characteristics of bubble chambers which enable several reactions to be studied simultaneously have made possible the discovery of the importance of two-body and quasi two-body reactions. This affects reactions of the type $A + B \rightarrow C + D$ where C and D are either stable particles or resonances. At high energies these reactions are responsible for a sizable fraction of the total cross-section.

3) The differential cross-sections for thirteen quasi two-body channels have been analysed in detail and breaks have been shown to exist there. These results indicate that the structure observed in a channel may be correlated with the nature of the particles (or trajectories) exchanged. The measured cross-sections were compared with various theoretical models.

4) Information has been obtained on the nature of exchanged particles by measuring the density matrix elements of the resonances produced in quasi two-body reactions, for example — the study of K *(890) produced in the reactions $K^- + p \rightarrow \overline{K}$ *(890) + nucleon and $K^+ + p \rightarrow K$ *(890) + p at high momenta.

5) Backward peaks have been discovered in the quasi two-body reactions for pion-proton and kaon-proton interactions. They are evidence for the baryon exchange mechanism and have been interpreted in terms of this mechanism.

6) A systematic study of the variation of two-body and quasi two-body cross-sections has been made in terms of the incident momentum. It was found that they varied as p^{-n} and all the reactions could be classified roughly in four groups, according to the value of n, each group corresponding to exchange processes of a well defined nature.

From this list it is evident that European physicists, using bubble chamber photographs taken at CERN, have made a very positive contribution to elementary particle physics. Although the bubble chamber is an instrument essentially adapted to the study of strong interactions, significant and sometimes very precise measurements have been taken in the field of weak interactions. In the domain of strong interactions, physicists have succeeded in discovering numerous resonant states and in determining their properties and the properties of others already discovered elsewhere. The results thus obtained have made a significant contribution to the main theoretical developments of the last few years, namely the classification of particles and resonances by unitary symmetry models and Regge trajectories.

Finally, several extremely important experimental laws governing the field, which was completely untouched ten years ago, of high energy collisions were discovered in bubble chamber experiments and their interpretation has stimulated theoreticians to a deeper insight into elementary particle interactions.

For entertainment

Suppose the PS is running non-stop all the year round, accelerating 10^{12} protons per pulse every two seconds... try to guess (or even calculate) how long you would need to run the machine —

a) To accelerate the same number of protons as there are in a small drop of water (50 mm³) ?

b) To accelerate as much charge as passes through a 100 watt bulb (250 volt mains) in one second ?

c) To accelerate as many protons as would fit onto a CERN COURIER page (21 × 30 cm²) if they could be laid side by side ?

Answers at the bottom of the column.

Nature, it seems, is the popular name
for milliards and milliards and milliards
of particles playing their infinite game
of billiards and billiards and billiards.

This is a grook (short aphoristic poem) called 'Atomyriades' from the book 'Grooks' by Piet Hein produced by MIT Press, Cambridge, Mass. ($1.5 paperback).

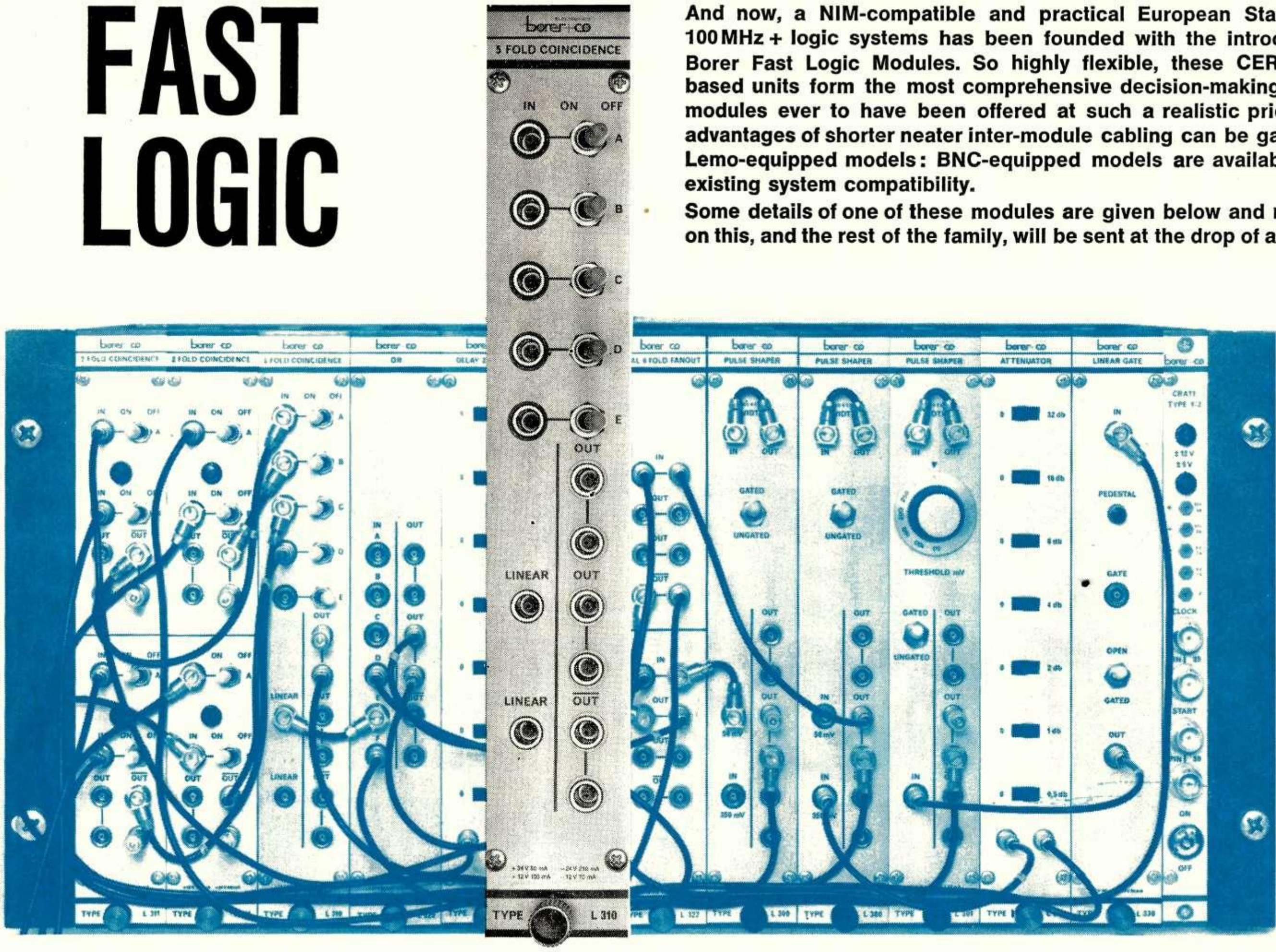
What does a European pay to have CERN in 1969 ? It depends a little where he comes from but, looked at in terms of Swiss francs per head, it is not too frightening :

Austria	*0.63*	*Italy*	*0.485*
Belgium	*0.94*	*Netherlands*	*0.90*
Denmark	*1.12*	*Norway*	*0.85*
Federal Republic of Germany	*1.01*	*Sweden*	*1.37*
France	*0.99*	*Switzerland*	*1.38*
Greece	*0.17*	*U.K.*	*0.96*

It averages out at 0.90 Swiss francs per man, woman and child in the twelve Member States. The price of a litre of beer. And some might say that it is not a bad idea to deprive at least the child of a litre of beer in this way.

a) About 1000 years
b) About 2 months
c) 4000 million years which is about the age of the earth. The first forms of life unfortunately did not display sufficient intelligence to build a proton synchrotron...

FAST LOGIC



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Some details of one of these modules are given below and more data on this, and the rest of the family, will be sent at the drop of a postcard.

Inputs	Impedance		50 ohms ± 2 %
	Reflections 'ON'		20 % max (capacitive)
	Reflections 'OFF'		15 % max (inductive)
	Voltage		– 700 mV typ. } for coincidence – 600 mV min. } for coincidence – 100 mV max. for anti-coincidence
	Overlap	LIN	2 ns min. for singles 2 ns min. for 5-fold
		OUT, $\overline{\text{OUT}}$	1.5 ns min. for singles 1.25 ns min. for 5-fold
Linear outputs	Impedance		High, 16 mA current sources. Unused outputs need not be terminated.
	Rise Time		1.8 ns max.
	Fall Time		2.0 ns max.
	Width, equal to		(Overlap + 1.0) ns for singles (Overlap — 1.0) ns for 5-fold
	Rate		200 MHz max.
	Propagation delay		6 ± 0.75 ns for singles Decreases by 0.5 ns max for 5-fold
	Feedthrough		± 15 mV max for n-1
Logic outputs	Impedance		High, 32 mA current sources, unused outputs must be terminated.
	Width	OUT	8.5 ± 1 ns
	Width	$\overline{\text{OUT}}$	9.0 ± 1 ns
	Rise time	OUT	1.5 ns max.
	Fall time	OUT	2.2 ns max.
	Rise time	$\overline{\text{OUT}}$	2.0 ns max.
	Fall time	$\overline{\text{OUT}}$	2.2 ns max.
	Rate		Greater than 50 MHz
	Propagation delay		10.5 ± 0.75 ns for singles Decreases by 0.5 ns max for 5-fold

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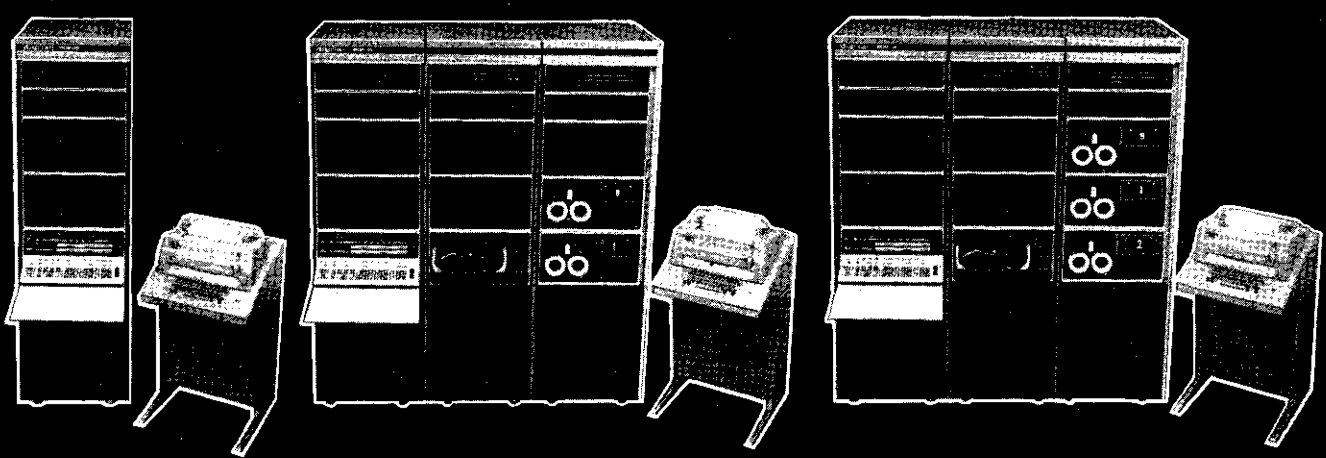

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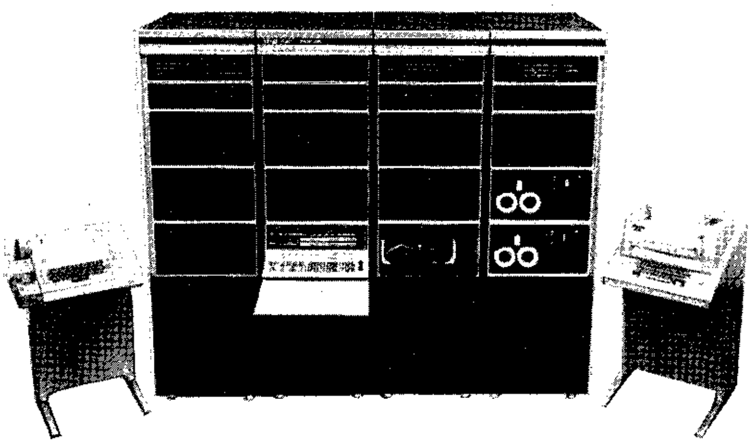
PDP-15/40 Disk-Oriented Background/Foreground System: 24,576 words of core memory, KSR-35 Teletype, Automatic Priority Interrupt System, Memory Protect System, high-speed paper tape reader/punch, two DECtape transports and control unit, RF15 DEC-disk control and two RS09 random-access disk files, real-time clock, and a second on-line Teletype for background use. Disk-oriented version of the Background/Foreground Monitor System, allowing concurrent execution of real-time tasks and background computation, in addition to all standard Advanced Monitor functions.



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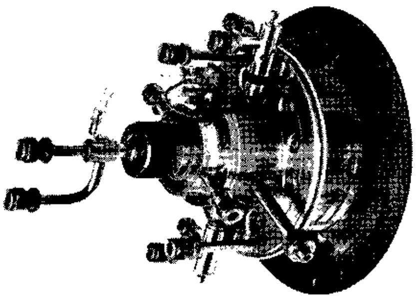

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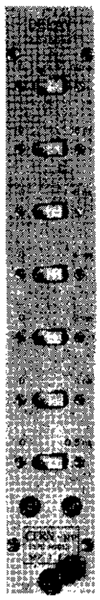

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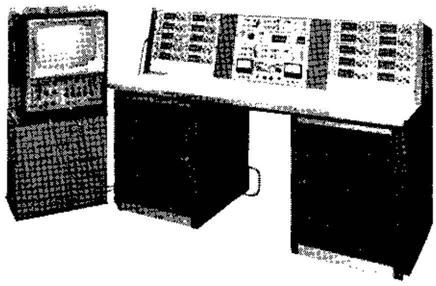

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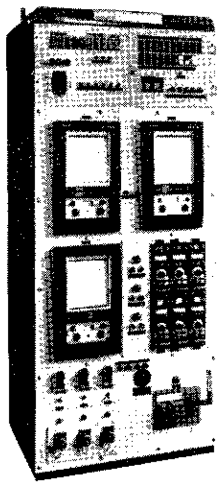

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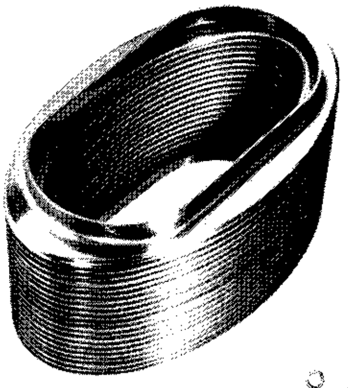
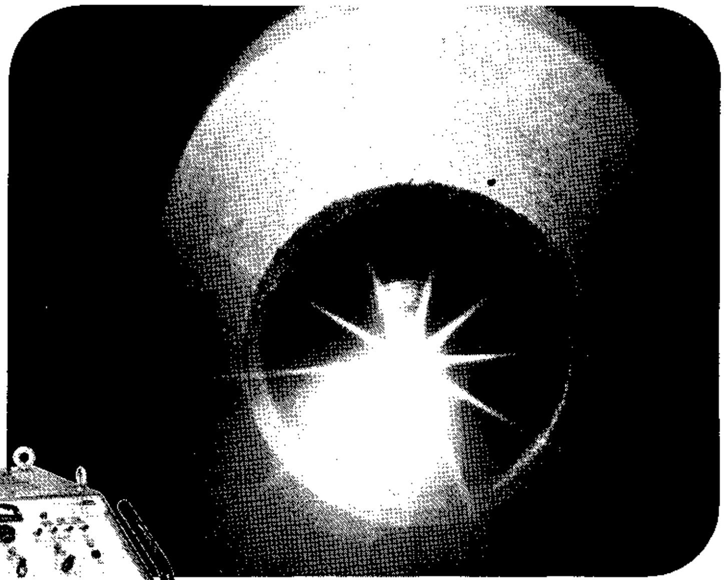
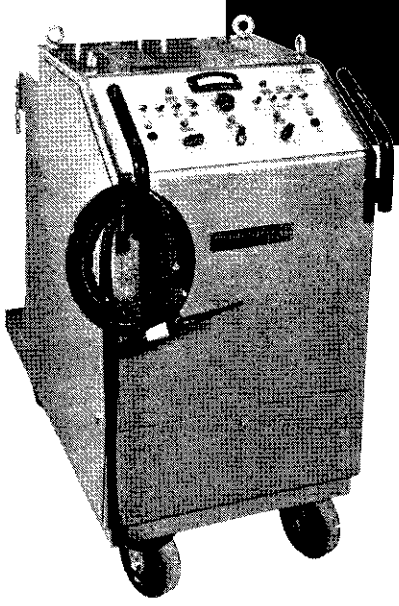
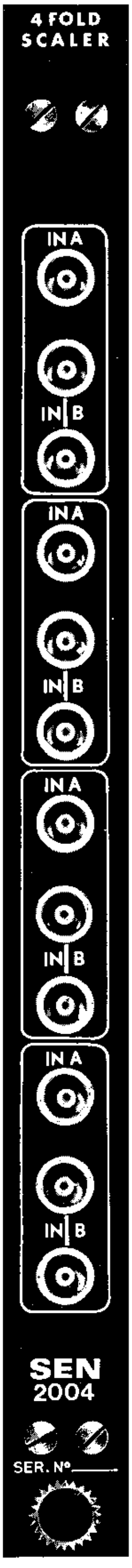






Type 2004 FOUR-FOLD CAMAC SCALER

The type 2004 four-fold scaler is a simple, general purpose CAMAC scaler with 16 bit capacity. Low price was the main design objective. Thus, useful functions only have been incorporated and the input specifications are those readily obtainable with current TTL technology.



DESCRIPTION AND SPECIFICATIONS.

1. Input

Each scaler has a 50 ohm input (IN A) and an unterminated dual connector input (IN B). Both inputs accept fast NIM pulses or levels and enter an AND gate. Thus, either input A or B can be used as count input or as gate input. While using A cas count input, B may be left open. Input B allows bridging connection of a gate line for reduced fan-out requirements.

- Scaling Rate: typically 40 MHz
- Input Pulses, A or B: 12 ns pulses are typically required, -200 mV is max. "O", -600 mV is min. "L",
- Maximum Amplitude: -2 V, diode limited
- Connectors: LEMO RA 00 C 50

2. Overflow outputs

Overflows are brought out separately on the back of the module. Nim pulses of approximately 1 μs duration are produced. Individual overflow outputs may be very useful for triggering a "Direct Memory Increment"- module.

3. CAMAC Functions Used in the Module

Function 0:	Read the scaler selected by the subaddress, Clear the corresponding overflow flag, Produce a Q-response for the duration of the Camac cycle.
Function 2:	Read the scaler selected by the subaddress, Reset the scaler, Clear its overflow flag, Produce a Q-response for the duration of the Camac cycle.
Function 25:	Increment all 4 scalers, Produce a Q-response.
Function 8:	Test L. This function produces a Q-response if the scaler selected by the subaddress has its overflow set **and** its L enabled.
Function 17:	Write a 4 bit mask. This 4 bit mask -written from the W1 to W4 lines- enables the individual sources of L request.
Clear and initialize:	Reset all scalers, Clear all overflow flags and set the L-mask at 0000.
Inhibit:	Close the input gate of all 4 scalers.

The L-mask register is a particulary powerful device when the L signal is used as a computer interrupt request. Managing nested interrupt service routines is much easier because priority assignment is under program control.

4. Physical

Single unit CAMAC module, fully shielded construction.

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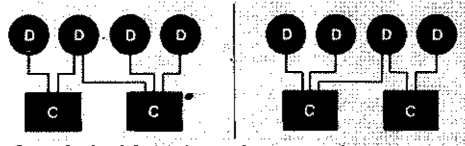

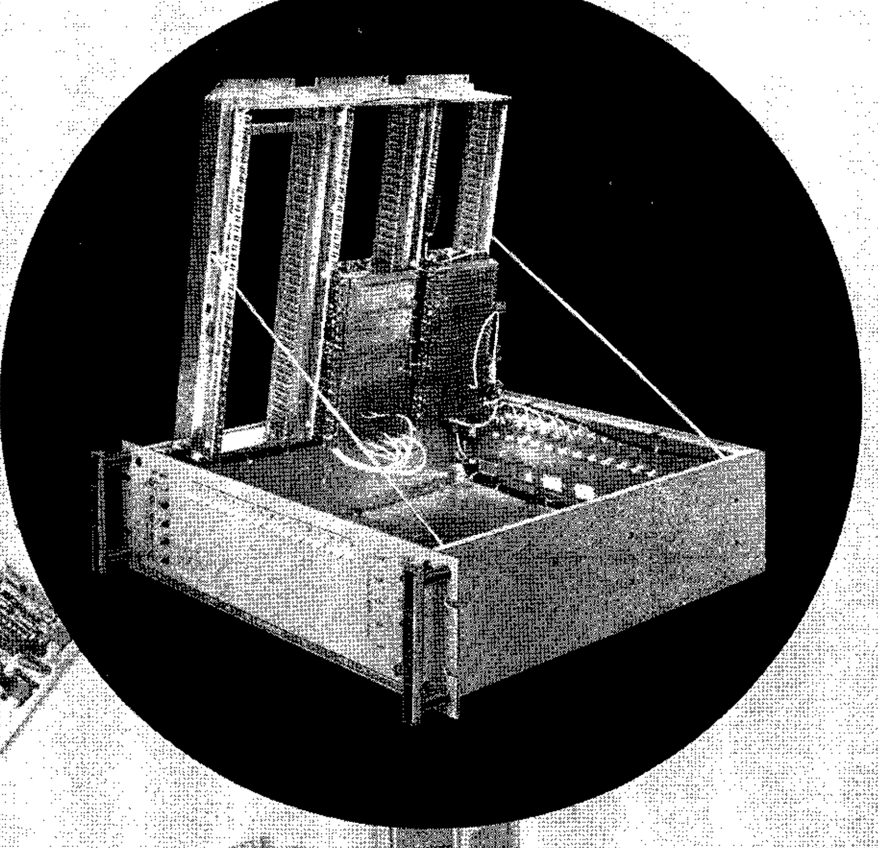

Coupled with high-performance low-cost photomultiplier tubes, MCEL enables the experimenter to construct hodoscopes of great complexity (at about $125 per channel between counter and computer, including the discriminator) with logic re-routing by computer during experiments to accommodate the increasing sophistication of studies in high-energy physics.

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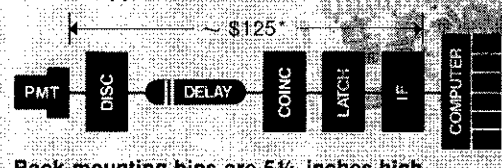

Rack-mounting bins are 5¼ inches high. All fast inputs and outputs are NIM-compatible level on 50 Ohms. Fast outputs are available to control data-acquisition instruments such as spark chambers. Latches "set" with a 3-nsec pulse-pair overlap. Delay-curve widths can be as low as 4 nsec. Test points and monitor lights show system performance.

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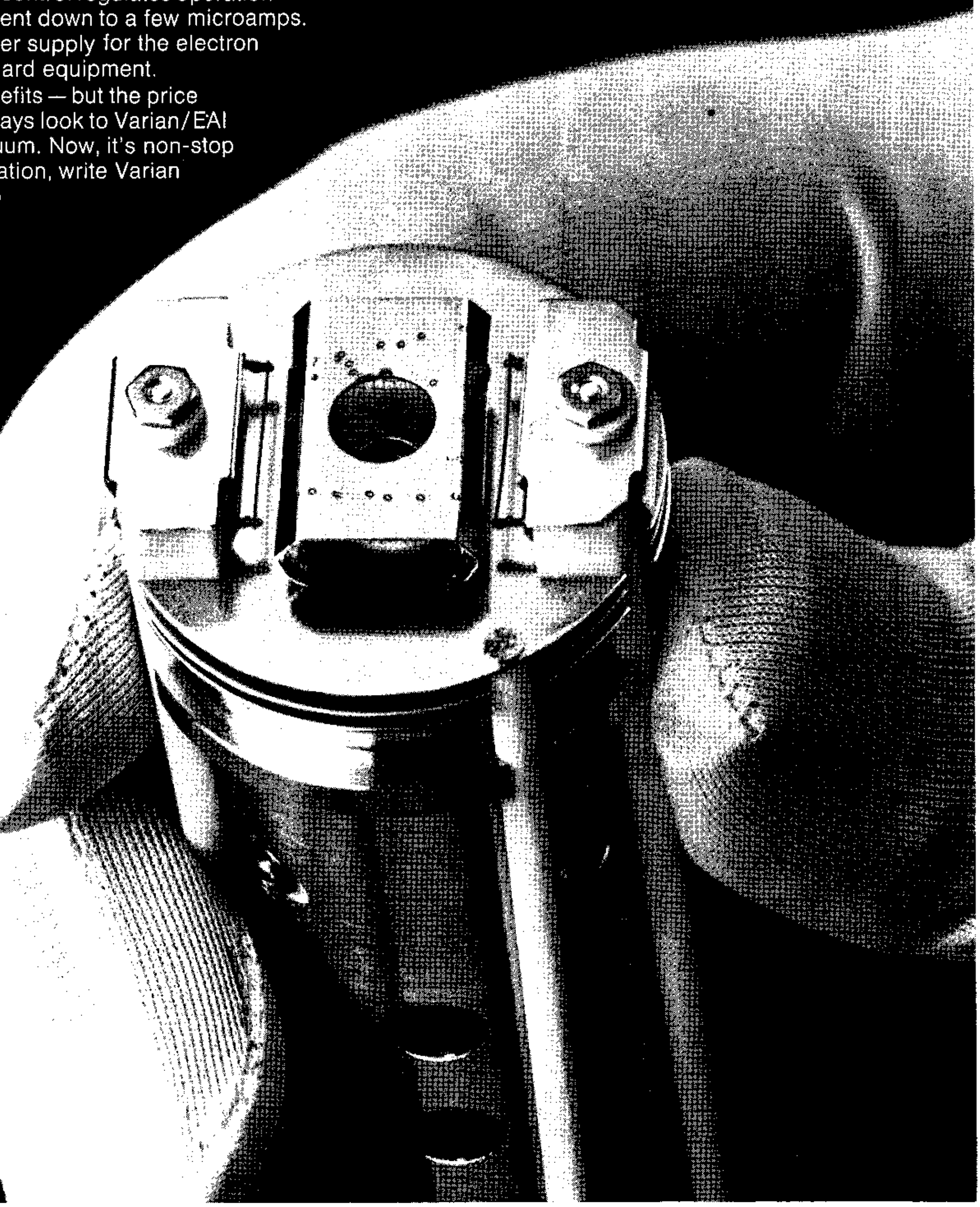
Now the foremost RGA is even better. You can switch filaments without breaking vacuum. Two filaments are premounted and prealigned on a block in the ion source region. The entire block can be replaced as a plug-in unit.

You can also switch between the electron multiplier and Faraday detector without venting the system. A simple external cable change does it.

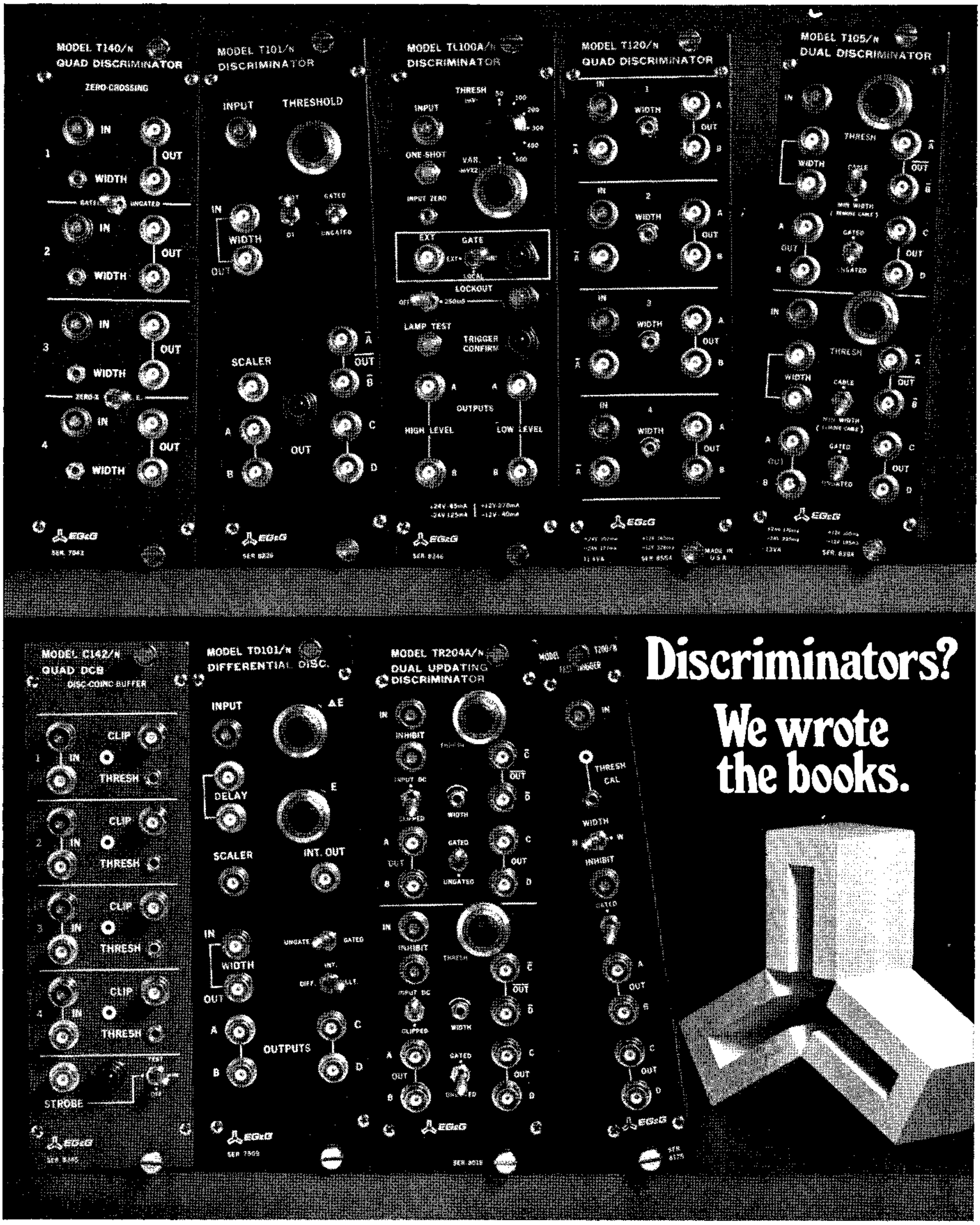
Other significant improvements: A new sweep circuit betters linearity at slow sweep speeds. An improved emission control regulates operation and monitoring of current down to a few microamps. The variable 3 kV power supply for the electron multiplier is now standard equipment.

All these added benefits — but the price remains the same. Always look to Varian/EAI for innovations in vacuum. Now, it's non-stop RGA. For more information, write Varian Vacuum Division, Palo Alto, California; Zug, Switzerland; Georgetown, Ontario.



varian
vacuum
division

™Electronic Associates, Inc.

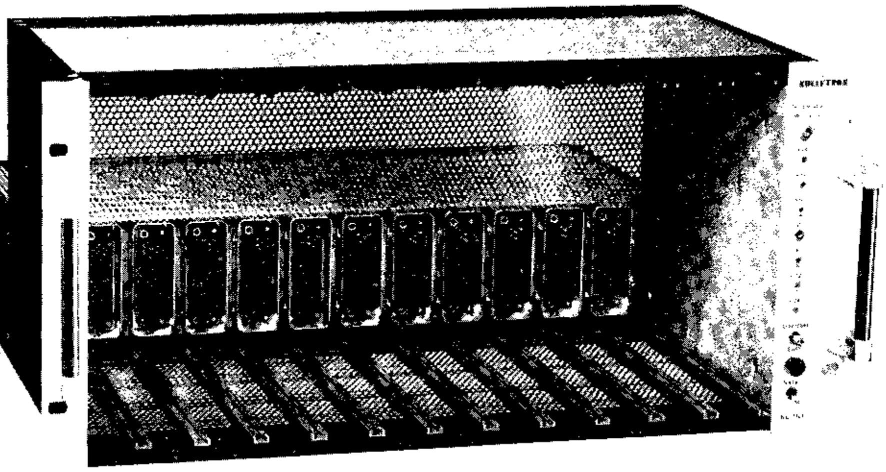


MODEL T140/N
QUAD DISCRIMINATOR
ZERO-CROSSING
MODEL T101/N
DISCRIMINATOR
MODEL TL100A/N
DISCRIMINATOR
MODEL T120/N
QUAD DISCRIMINATOR
MODEL T105/N
DUAL DISCRIMINATOR
MODEL C142/N
QUAD DCB
MODEL TD101/N
DIFFERENTIAL DISC.
MODEL TR204A/N
DUAL UPDATING
DISCRIMINATOR
Discriminators?
We wrote
the books.

NUCLETRON

AEC/NIM

19"-ÜBERRAHMEN MIT NETZTEIL



- ± 24 V; 1,5 A
  ± 12 V; 2 A
  ± 6 V; 5 A
- NETZABSCHALTUNG BEI ÜBERLAST
- KURZSCHLUSSFEST
- THERMISCH GESCHÜTZT
- STABILER ALU-RAHMENBAU

ANWENDUNG: In allen Labors der Kernphysik, Hochenergiephysik und überall, wo vielseitige Impulsverarbeitung erforderlich ist, findet dieses Netzgerät mit Überrahmen Anwendung. Es entspricht der von der AEC (Atomic Energy Commission) herausgegebenen Norm bezüglich der Abmessungen und Versorgungsspannungen (TID-20893). **Alle auf dem Markt erhältlichen Einschubmodelle, die nach der AEC/NIM-Norm gefertigt sind, können in diesem Rahmen betrieben werden.**

AUFBAU: Die Spannungsversorgung (24 V, 12 V, 6 V) ist als Kompaktnetzteil ausgeführt und an der Rückseite des Überrahmens montiert. Als Steckverbindung zwischen Netzteil und Kassette dient der Stecker AMP N. 202516-3 mit den zugehörigen Kontaktverbindungen.

THERMISCHER SCHUTZ: Optische Anzeige der Innentemperatur bei 50° C und Netzabschaltung bei einer Kühlkörpertemperatur von 90° C.

KURZSCHLUSS-SICHERHEIT: Jede Spannung ist durch eine eigene Strombegrenzung gesichert, die auf 1,1 des Nennstroms eingestellt ist. Bei Kurzschlüssen, die zwischen zwei Spannungen auftreten, ist das Gerät durch Dioden bzw. Zenerdioden am Ausgang geschützt.

ÜBERLASTABSCHALTUNG: Die Überlastkarte trennt das Netzteil bei Kurzschluss gegen Null, Kurzschluss zweier Spannungen, Ausfall einer Spannung, Über- bzw. Unterspannung vom Netz. Die Überlastkarte ist in der Standardausführung des AEC-Rahmens nicht eingebaut.

Auf Wunsch kann statt 6 V auch 5 V Ausgangsspannung geliefert werden.

TECHNISCHE DATEN

NU 312 C

AUSGANGSSPANNUNG:
± 24 V, 1,5 A / ± 12 V, 2 A / ± 6 V, 5 A

GESAMTAUSGANGSLEISTUNG: 128 W

NETZKONSTANZ:
bei Netzspannungsschwankung ± 10 %
± 6 V: $\leq 3 \times 10^{-5}$
± 12 V: $\leq 1 \times 10^{-6}$
± 24 V: $\leq 1 \times 10^{-6}$

TEMPERATURKOEFFIZIENT: $5 \times 10^{-5}/°$ C

INNENWIDERSTAND: mit Steckverbindung 0,015 Ohm (alle Spannungen)

LASTKONSTANZ: < 500 µV für Laständerung von 0 auf 100 % (ohne Steckerübergangswiderstände)

BRUMM:
≦ 200 µVss bei Leerlauf (für alle Spannungen)
< 1 mVss bei Vollast (für alle Spannungen)

WECHSELSPANNUNGSAUSGANG: 115 ∿, 0,5 A

NU 311 C
Wie **NU 312 C** jedoch

AUSGANGSSPANNUNG:
± 24 V, 1,5 A / ± 12 V, 2 A / ± 6 V, 2 A

GESAMTAUSGANGSLEISTUNG: 96 W

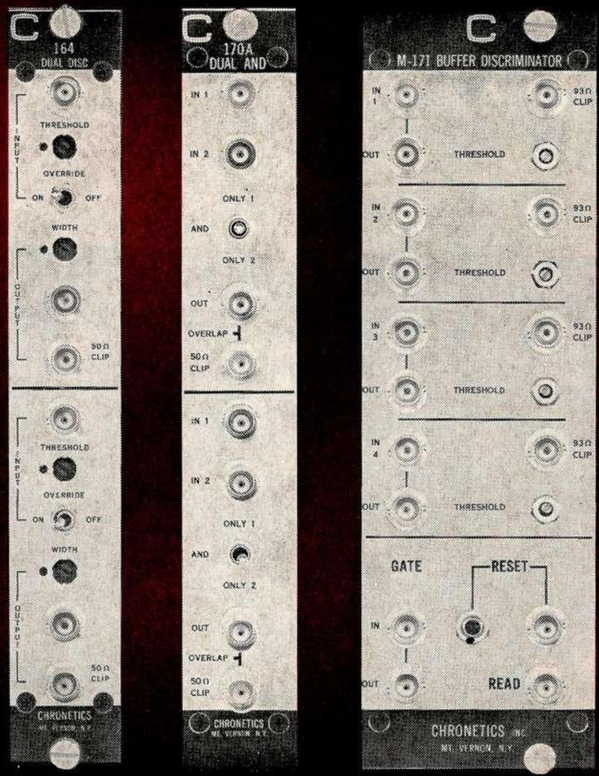
NU 310 C
Wie **NU 312 C** jedoch

AUSGANGSSPANNUNG: ± 24 V, 1,5 A / ± 12 V, 2 A

GESAMTAUSGANGSLEISTUNG: 72 W

NUCLETRON

GESELLSCHAFT FÜR NUCLEONIC UND ELECTRONIC MBH
8 MÜNCHEN 50 - Gärtnerstrasse 60 - Telefon (08 11) 54 60 81 - Telex 05-24 208



Lower Cost Nanologic. A Giant Step Sideways

While we lament the budget situation as much as anyone, we're not tearing our hair or downgrading the product. Instead, we'd like to call your attention to three Nanologic modules, among others, that give you all of the performance you need and expect and at significantly lower prices.

Model 164 is a single-width dual Discriminator, DC-coupled, with Updating and Override Modes, operating on inputs at better than 200 MHz. Continuously variable input thresholds and output width, 5 ns pulse pair resolution at 200 MHz, 1.0 ns output risetime. Switch selectable normal or complement standard logic level output.

Model 170A is a dual AND capable of resolving time of better than 1.5 ns at 200 MHz. Output is fast (1 ns rise and fall times) standard logic with output width precisely equal to input coincidence overlap timing. Mode selection for Only A, A and B coincidence, Only B. DC-coupled.

In Model 171 you can have four channels of Discriminator-Coincidence-Buffer operation with 5 ns pulse pair resolution at 200 MHz. A strobed coincidence preceded by discriminators. Variable input threshold. Coincidence resolution better than 1.5 ns. Front panel Gate, Read, Reset. All of the logic for fast hodoscopes without the usual expense.

Nanologic performance is Nanologic performance. It stays. You can, though, trade-off some flexibility for cost—and this is what has been done. No sacrifice in performance or quality. It's Nanologic . . . as always.

Maybe it's sideways but it's a giant step.

For more information on fitting lower cost Nanologic to your counting/logic needs, please write or 'phone.

CHRONETICS. 500 Nuber Avenue, Mt. Vernon, N.Y. (914) 699-4400. In Europe: 39 Rue Rothschild, Geneva, Switzerland (022) 31 81 80.

CHRONETICS