400 GeV . . . and beyond

Experiments begin soon on the 400-GeV Super Proton Synchrotron (SPS) at CERN, Geneva. **David Davies** has been visiting the laboratory

SPS comes on line within budget and on schedule. After six years of awaiting the complicated multinational approval, and a further five of building an accelerator of radius 1.2 km which circles some 40 metres below ground, the physics starts in earnest in early December when the first high-energy particles are fed to a whole array of experiments. Major construction still continues, as the plans are for two completely separate experimental areas, only one of which is yet finished. But already questions are being asked: what do we build next?

CERN started life with a 600 MeV synchrocyclotron (SC) commissioned in 1957 and still in use. In 1959 a 28-GeV proton sychrotron (PS), fed successively by a 550-KeV electrostatic generator and a 50-MeV linear accelerator, was added. Although there is still an active physics programme on the PS, it also serves to feed the two other machines—the intersecting storage rings (ISR) and the SPS. ISR was completed in 1971, and comprises two rings of diameter 300 metres in which 28 GeV protons can travel for up to 40 hours in opposite directions crossing over and colliding at eight equally spaced positions—at six of which experiments are sited. The performance of the ISR in terms of storage current and luminosity is continually improving, and plans for its use well into the 1980s are being discussed at present (see page 314).

The advantage of machines in which beams travelling in opposite directions collide is that almost all the energy is available for particle production: SPEAR at Stanford and the projected PETRA at Hamburg are further examples, in which electrons and positrons are ranged against each other. In accelerators which bombard stationary targets, a large fraction of the energy goes in recoil of the target particles. On the other hand, storage rings are restricted to a much smaller range of experiments—in other accelerators the primary beam is very often converted at a target to secondary beams of completely different particles.

The protons for the SPS are peeled off the PS in a continuous ribbon which eventually fills ten-elevenths of the SPS's seven-kilometre circumference. Once in the ring the 10^{13} protons encounter the magnetic field both of dipoles (which bend the protons in a horizontal plane) and quadrupoles (which keep the beam focused). There are 744 dipoles (peak field 1.4 Teslas) and 216 quadrupoles and the mean power consumption is 34 MW. The vacuum is 10^{-7} Torr. Acceleration of protons occurs at only one point on the ring, in a straight stretch of 40 metres where there are two radio-frequency cavities. Each journey through this section adds about 2.5 MeV to the protons' energy. After 150,000 circuits, which take 3.7 seconds, the protons are up to to an energy of 400 GeV and ready to be ejected into either of the experimental areas, West or North. West Area is the first to be completed, North follows early in 1978.

The proton ribbon can either be extracted all in one turn or can be progressively peeled off over a period of up to a second. Bubble chamber experiments tend to need the short burst, electronic counter experiments the longer time. The beam can be used in the West Area in three ways:

- It can be directed on to an underground target at up to 40 GeV to produce pions and kaons which decay within 430 metres of their journey to the surface into muons and neutrinos. The muons are absorbed in steel and earth and the beam as it reaches the surface is solely of neutrinos which pass through the Big European Bubble Chamber (BEBC), two counter experiments and the heavy-liquid bubble chamber Gargamelle.
- The protons can be directed to a second underground target to produce 75-GeV kaons or 110-GeV antiprotons which run into BEBC.
- The beam can be brought to the surface and split into three on entering the West Hall. Three targets are available to feed the twelve separate experiments set up in the West Hall with secondary beams of up to 150 GeV. The dimensions of the building—which existed prior to the SPS—preclude using higher energies; the North Area will be custom built for 400 GeV.

Why, it may be asked, has CERN built a 400-GeV proton accelerator when the Fermilab at Batavia, Illinois, installed a comparable machine more than four years ago—is it not needless duplication? The answer is complex and depends as much on subjective opinion as objective fact. But the list of SPS experiments approved at CERN gives some idea of the differences. Most striking are the number of neutrino experiments—13 out of 28. These take advantage of both the extremely high event rate anticipated from the neutrino beam-line and the excellent bubble chamber facilities. A second unique feature of CERN is the hyperon beam-line, yielding Ξ and Σ particles: an experiment on the decay characteristics of these particles will be watched with interest. A third will be the muon facility in the North Area.

It is also a mark of CERN's distinctive character that although roughly half of all experiments planned on the SPS are devoted to the "new physics" —hunts for J/ψ, intermediate vector bosons (maybe!), heavy leptons and charm—the other half tend to be "spectroscopic" experiments in the realms of "normal physics", painstakingly filling in gaps in knowledge without spectacular expectations.

Those who have worked in both Fermilab and CERN comment on the difference in style— Fermilab has a lot of flair, is able to latch on very quickly to new ideas, is vulnerable to failures (the magnets break down with

What SPS costs . . .

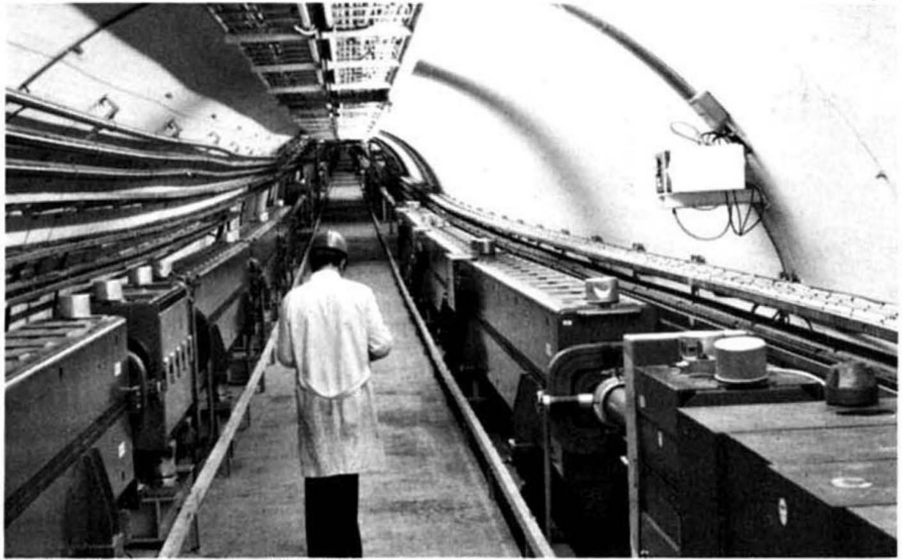
Item	Swiss Francs[1] (millions)
Total CERN expenditure in 1975	**647.9**
of which SPS construction	237.9
SPS contract expenditure to October 1975: on	
site buildings and equipment	214.7
normal machinery components	194.6
special machinery components	89.7
Total	**499.0**
of which British contractors received	75.8
Projected total cost of building SPS (1970 prices)	**1150**

[1] SFr 2.4 = $1 SFr 4.0 = £1

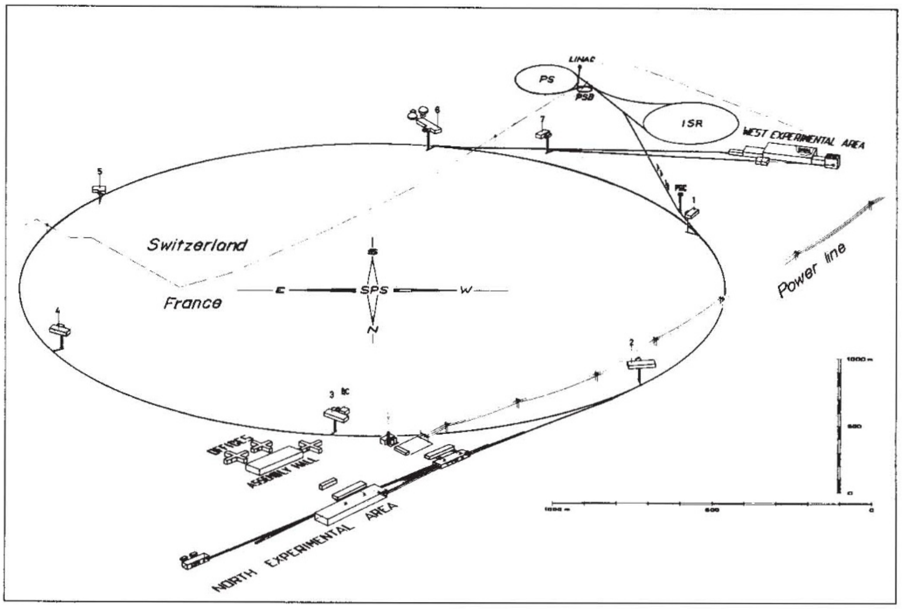
. . . and who pays

Country	% in 1976	% in 1971
Austria	2.22	1.96
Belgium	4.02	3.77
Denmark	2.29	2.26
France	21.49	19.90
West Germany	25.40	23.27
Italy	13.34	12.89
Netherlands	5.30	4.43
Norway	1.60	1.52
Sweden	4.55	4.59
Switzerland	3.38	3.20
UK	16.41	21.61

Contributions are based on GNP


CERN

Looking towards West Area from SPS



CERN

SPS plan, showing link with PS and experimental areas

depressing regularity); CERN is more bureaucratic in its planning of experiments, is less prone to serendipity and yet runs so consistently well (SPS is expected to be extremely reliable) that much excellent definitive work can be done. As one physicist put it "at Fermilab you practically bring your experiments in cardboard boxes and stick them under tarpaulins; here look at the huge echoing halls and the gold-plated equipment!".

One of the problems that CERN is facing is the growing reliance of the high-energy physics community on one central facility as national facilities are tapered off. An exception is in Germany, where many reckon PETRA will produce some very exciting physics, and again will undoubtedly attract an international clientele; but otherwise there is nowhere else to go. Maybe the average number working on an experiment, which is 6 on the SC, 12 on the PS, 18 on the ISR and 25 on the SPS, reflects in part an increased complexity of experiment. But some believe that there are too many working on the SPS and that the quality of experience both for graduate students and research worker suffers accordingly. Another concern, raised first by Professor Jentschke last year when he was director of CERN's Laboratory I, is that very few physicists from CERN's smaller member states are finding their way into the teams for the SPS.

There is, on the other hand, some feeling around that CERN staff get a better deal than those who simply visit. The tax-free salaries are generous, to say the least, even allowing for the high cost of living in Geneva. And the cost of CERN's on-site services means that many (British, in particular) bring in their own technical staff.

Not surprisingly, there is a little apprehension at the moment at what financial adjustments the United Kingdom may try and negotiate at CERN's December Council. Dr J. B. Adams, the Director-General, is phlegmatic as always—"last year the Germans had some difficulties, the year before it was the French; these things come and go". But the real question is not a short term one. It is whether over the next five or ten years the nations contributing not only to CERN but also to other major accelerators are going to sustain their support for high-energy physics.

Within CERN itself there are already ideas circulating for new machines. The tunnelling for the SPS cost a relatively small fraction of the total bill, and some would like to see the SPS ultimately acquire an intersecting ring for proton/proton or even proton/antiproton studies. Such discussions, however, are often coloured by a feeling that since the weak and electromagnetic interactions seem to be more fruitful sources of new states than strong interactions, a CERN venture into an electron machine might be a good next step. The European Committee for Future Accelerators has had a working party look at the physics potential of a 100-100 GeV electron-positron storage ring.

Fermilab, meanwhile, is exploring the possibilities of superconducting magnets to push its peak energy up to 1,000 GeV. The intellectual drive to get up to this level is that the postulated carrier of the weak force, the intermediate boson, probably has a mass so high (at least 37 GeV) that 1,000 GeV protons would be needed to unearth it. The prize from this could be unification of theories of weak and electromagnetic forces. CERN initially planned superconducting magnets in the SPS but eventually dropped back to conventional ones because the technology was not far enough advanced.

At the same time Soviet physicists are looking to a 2,000 GeV proton synchrotron at the Institute of High Energy Physics, Serpukhov, as the next step from their 76-GeV synchrotron. Again, superconducting magnets are envisaged, to deliver the fields of up to 5 Teslas. Plans also include the simultaneous construction of a 20-GeV electron synchrotron with the capacity for proton-electron collisions.

It seems that plans for the next generation of machines are too far advanced in the United States and the Soviet Union for there to be any possibility of global collaboration. Attention has therefore turned to the idea of the next accelerator-but-one being a truly world machine, if only because a multi-billion-dollar price label is bound to be attached to it. A proton synchrotron at more than 10,000 GeV is a possible. But this is up to the politicians. □