1.4 million cubic metres of achievement

Waiting to cut the ribbon marking the end of LEP tunnelling. Left to right, M. Meloni, works director of the Jura tunnelling consortium; M. Masson (wearing coat), mayor of Crozet (under whose territory the LEP ring passes); project leader Emilio Picasso; CERN engineer Bruno Bianchi; and Henri Laporte, head of CERN civil engineering.

(Photo CERN X143.2.88)

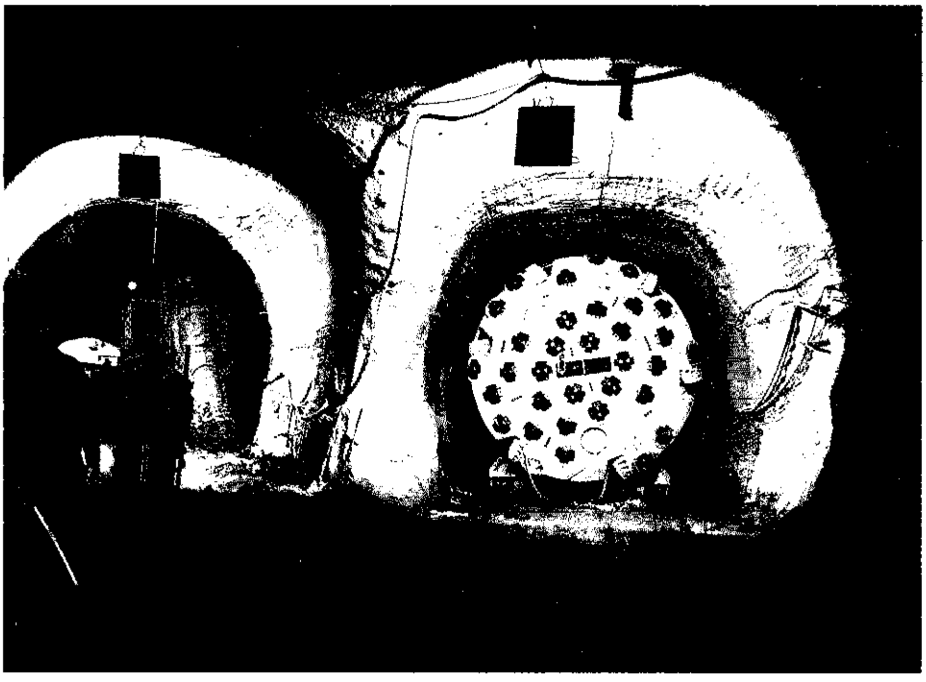
After five years of civil engineering work, the accent at CERN's 26.7 kilometre LEP electron-positron collider is now on installation. The first 2.8 kilometre section is now virtually complete and awaits the first positron test beam this summer, while the preparations for the four big detectors enter their final phase.

It was more than a decade ago that the idea of a large electron-positron ring at CERN first emerged to spearhead European high energy physics effort in the years to come.

LEP's dimensions are a compromise between capital cost and energy losses. As a beam of electrons is bent by a magnetic field, it loses energy ('synchrotron radiation'), which has to be compensated by bursts of radio-frequency energy. The larger the ring, the less the electron beams have to be bent, and the smaller the energy losses. On the other hand, a larger machine costs more.

The siting of the ring was critical. The existing CERN accelerator network has to be used to give the LEP electrons and positrons their initial burst of energy. The stringent requirements for stable beams also require the machine to be built in firm bedrock. Moreover the terrain around CERN is far from flat – the Jura range with peaks of 1700 metres is only a few kilometres away.

Between the Jura and CERN, the underlying rock is 'molasse' - alternate layers of sandstone and marl with all intermediate compositions. Although requiring some special measures, this material is relatively



Most of the excavation work for LEP used roadheaders (left) and full-face tunnelling machines (right).

(Photo CERN 170.7.85)

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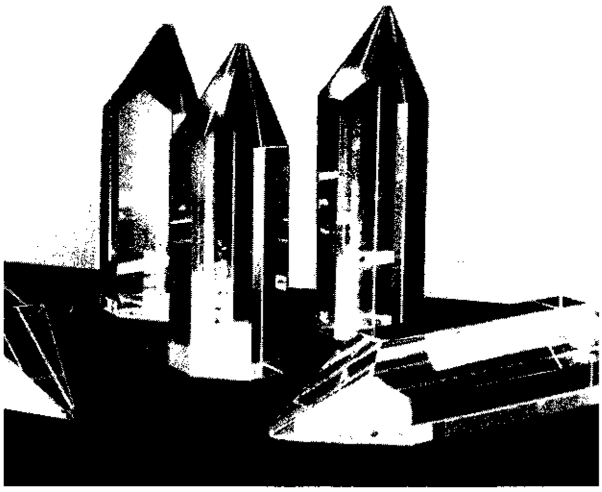

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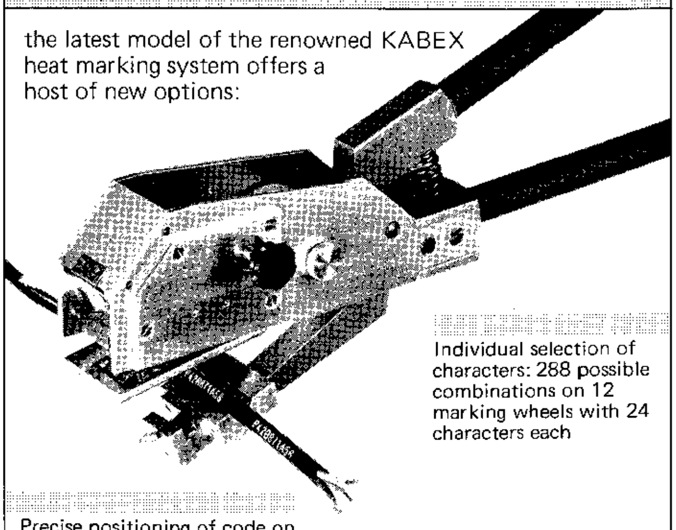

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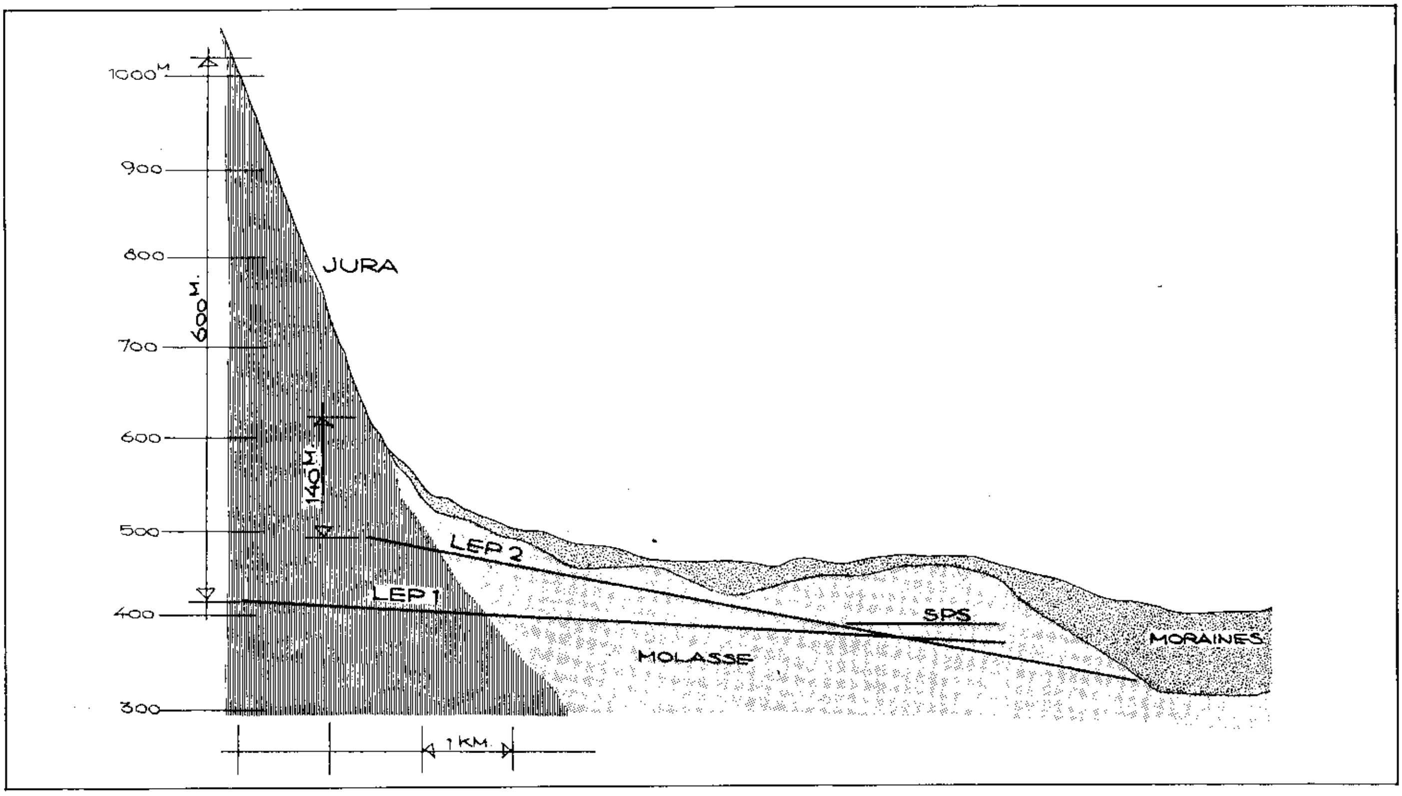
Built on a tilt. Schematic cross-section of the terrain around CERN, showing how the location of the LEP ring was swung away from the Jura mountains and tilted. This minimized risky tunnelling under the Jura and benefited from the 'molasse' (sandstone and marl) in the plain, good for tunnelling.



good to excavate using roadheaders and boring machines. Its characteristics were well charted at CERN after experience in building the 7 kilometre SPS Super Proton Synchrotron ring in the early seventies.

The older Jura range was severely fractured when the neighbouring Alps appeared, so that geological faults and folds in the Jura limestone are common, and sometimes large.

The first LEP design envisaged a 31 kilometre ring, tangential to the existing SPS ring (to facilitate injection), but penetrating deep under the Jura, with rock overburdens of over 1,000 metres at some points.

To reduce the penetration under the Jura, a second solution reduced the ring to its present size of 26.7 kilometres, but maintaining a position tangential to the SPS ring still called for 8 kilometres of tunnel under the mountains at depths of up to 600 metres.

Between 1980 and 1982, numerous geological, geophysical and hydrological studies were carried out. A 3.6 metre diameter reconnaissance gallery cut one kilometre into the Jura from the bottom of a 60 metre shaft, while boreholes were drilled, one over 1000 metres deep.

This careful work revealed potential difficulties due to geological faults and/or underground water, possibly at high pressure. To minimize these risks, known from the outset, the position of the LEP ring was swung away from the Jura to reduce the amount of tunnel under the mountains. Inclining the LEP ring slightly (1.4 per cent) also cut the depth under the Jura to less than 200 metres.

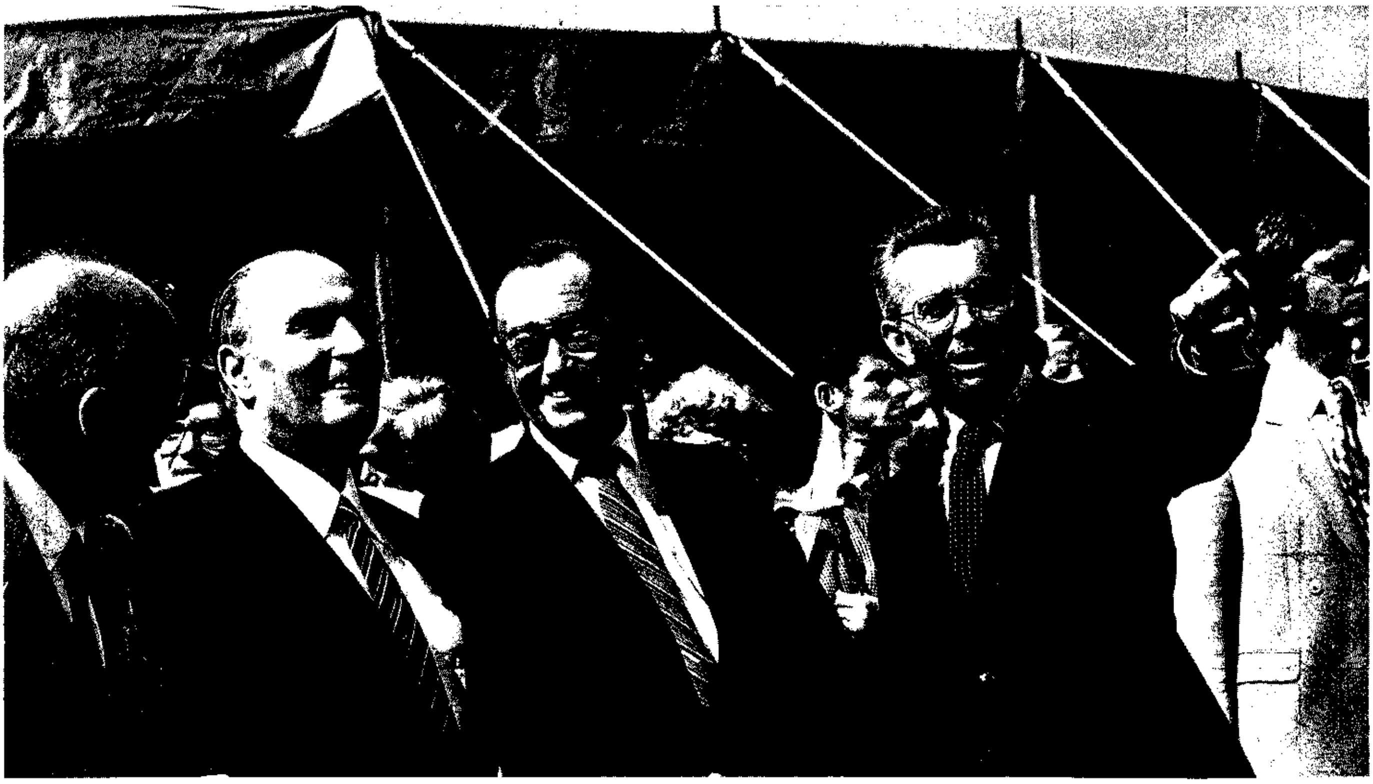
This bold decision – the first time a major particle accelerator has been built on a tilt – added to the already complex tasks of design and machine assembly, but reduced the total length of access shafts, and ensured that in populated areas the machine passes deep underground.

With the position of the ring known, legislative procedures got underway, complicated by having to negotiate with authorities in two countries – Switzerland and France, each with special requirements. In France, for example, land ownership extends in principle to the centre of the Earth, so that tunnelling required individual agreements with private landowners. The implications of the huge machine for its environment were detailed in an in-depth study ('etude d'impact').

With the Swiss authorization received in June 1982 and the French 'Déclaration d'utilité publi-

LEP Project Director Emilio Picasso (left) and CERN Director General Herwig Schopper (right) accompany French President François Mitterrand and Swiss President Pierre Aubert as groundbreaking for LEP starts on 13 September 1983.

(Photo CERN 195.9.83)



que' issued in May of the following year, work could begin.

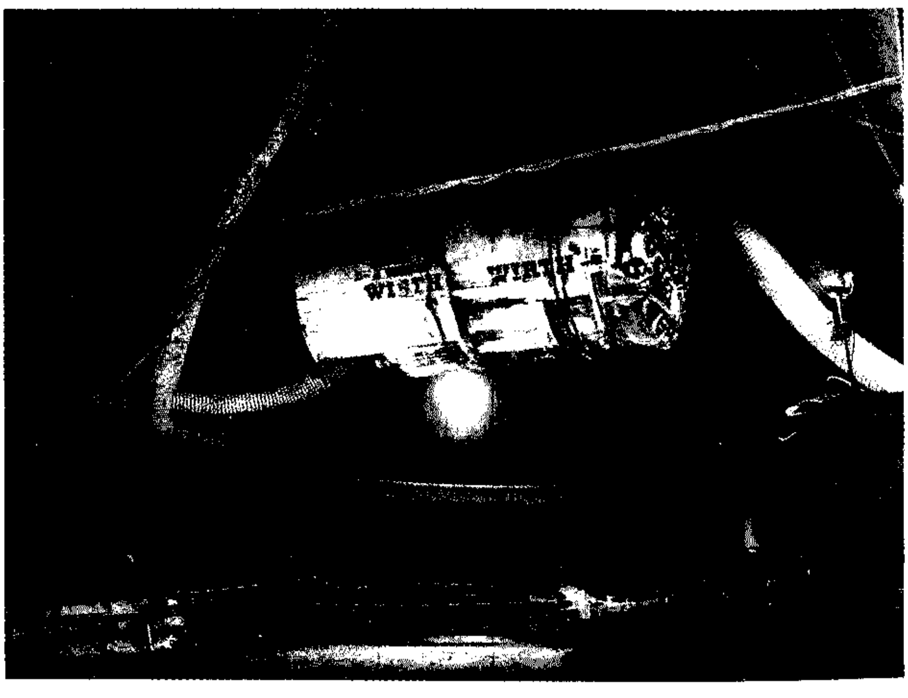
On 13 September 1983, the start of LEP construction was marked by a formal groundbreaking ceremony with French President François Mitterrand and Swiss President Pierre Aubert as guests of honour.

Before attacking the tunnel, access shafts had to be dug, with depths varying from 40 to 150 metres. At some points, special equipment was brought in to freeze the ground so that work could penetrate the water tables unhindered. The 19 access shafts plus the four huge underground caverns to house the LEP experiments represent about half of the total excavation volume.

With the tunnel being built to house a particle accelerator handling beams to micron precision, there was never any question of

Specially built by Wirth of West Germany, the LEP tunnelling machines pushed ahead at an overall average daily rate of 25 metres.

(Photo CERN 67.10.85)



A LEP tunnelling breakthrough. Project leader Emilio Picasso with (centre) tunnelling team leader M. Bacuzzi and (right) LEP Division Leader Gunther Plass.

(Photo CERN 312.7.86)

moving its path to avoid obstacles encountered on the way – the ring as designed on paper had to be faithfully cut through rock and stone.

Tunnelling work was dividing into two separate projects. The 24 kilometres through sandstone and marl were attacked by the 'Eurolep' consortium (led by Fougerolle of France, with Astaldi of Italy, Entrecanales Y Tavora of Spain, Philip Holzmann of West Germany and Rothpletz, Lienhard of Switzerland) using three full-face tunnel boring machines specially built by Wirth of West Germany. Built to cut at up to 5.4 metres per hour, these machines and their crews performed magnificently, with a record eight-hour shift advance of 23 metres, a record daily push of almost 60 metres, over 200 metres in one five-day week, and 760 metres in one month, and an overall average of 25 metres per day.

To complement the sterling work of CERN's own survey specialists (see April 1984 issue, page 103), tunnelling was guided by a laser/computer system from the UK, ensuring that deviations averaged only a few centimetres.

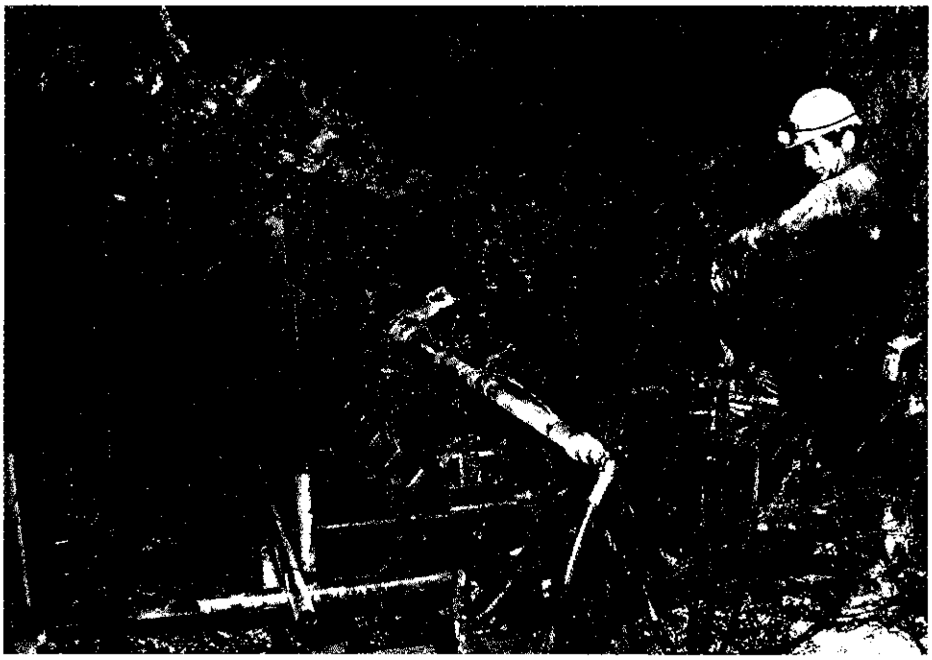
The double-shield support system allowed an initial prefabricated concrete lining to go up as the rams progressed, making for rapid progress and continuous tunnel support. The final tunnel lining was poured later with the tunnel floor. To feed LEP, two mighty plants can provide over a hundred cubic metres of concrete per hour.

Despite inevitable delays and hitches in a project of these dimensions (petrol deposits were twice encountered, requiring removal of 250 tonnes of hydrocarbon-bearing material), this portion of the tunnel was completed in January 1987, just two years after the first 170 ton boring machine was lowered into position.

Auxiliary galleries, shafts and caverns were handled by an army of roadheaders, with temporary support provided by shotcrete, wire mesh and rockbolting ('New Austrian tunnelling method').

The potentially problematic 3.5 kilometre stretch under the Jura was tackled by a second consortium (led by Locher of Switzerland, with Les Chantiers modernes and Intrafor-Cofor of France, CSC Impresa Costruzioni of Italy, and C. Baresel and Wayss and Freitag of West Germany).

Protected by probe borings to gauge the rock ahead, careful drilling and blasting by the 'Canadian cut' technique went remarkably well until September 1986, when, with some three kilometres of tunnel already accomplished, the



▲ Under the Jura mountains, careful probing tested the rock ahead.

teams were stopped by a 100 litre/second inrush of water from behind!

Progress was halted for several months while the tunnel lining and the surrounding rock were solidly reinforced and delicate probing tried to ascertain the extent of the problem ahead. After the resumption of tunnelling last year, a second water problem resulted in further delays before work could begin again last autumn.

At a poignant moment earlier this year, the clearing of the last few metres of rock was screened to an audience of several hundred people in the huge experimental hall at Point 4, 150 metres below ground.

Despite the delays, the progress of the overall project continues relatively unperturbed, thanks to some highly flexible planning and resource control gymnastics behind the scenes. By the end of the year, the tunnel lining will be complete, providing the final insulation against all natural eventualities.

In total, the LEP tunnel, shafts and pits required the removal of 1.4 million cubic metres. Despite being equivalent to about a third of the Great Pyramid, this spoil is now almost invisible, having been discharged close at hand (making also for minimal intrusion by heavy road transport), thanks to excellent cooperation with local authorities. In addition, the road system in France was substantially improved, funded by local and central French government and by CERN.

Although civil engineering work is not yet complete, the LEP tunnel is a great achievement, especially for the teams of Henri Laporte (civil engineering) and Michel Mayoud (surveying) and all their advisors and contractors.

Despite a big safety drive, three fatal accidents occurred underground and two more (not connected with the tunnelling and which could have happened anywhere, anytime) on the surface. A plaque will be mounted to commemorate these five men who lost their lives in this gruelling endeavour.

▼ 3 kilometres into the Jura mountains, LEP tunnelling was temporarily stopped by an inrush of water from behind the rock face.