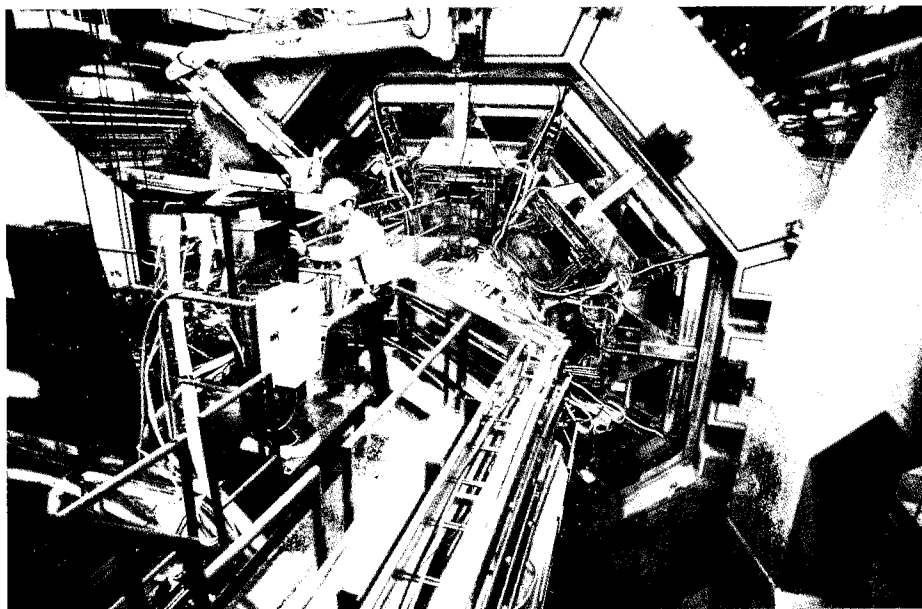


L3 detector

The L3 detector at CERN's LEP electron-positron ring – blazing a trail in worldwide physics collaboration.

(Photo P. Dhinaut)

This is the final article in the CERN Courier series marking a decade of the four big experiments – Aleph, Delphi, L3 and Opal – at CERN's LEP electron-positron collider. Data-taking started soon after LEP became operational in July 1989, followed by substantial runs in 1990 and 1991. Because of the long lead times involved in today's major physics undertakings, preparations for these four experiments got underway in the early 1980s. For Aleph, see January/February 1991, page 1; Delphi, November 1990, page 1. Opal's decade was covered in the June 1991 issue, page 4.



Eleven years ago, with design work for CERN's proposed 27-kilometre LEP ring well advanced, physicists started to think seriously about the big experiments to monitor LEP's electron-positron collisions. In June 1981, the alpine resort of Villars was the setting for the traditional ECFA (European Committee for Future Accelerators) major user community meeting to put the case for the new machine and study the physics possibilities.

That year Sam Ting's Mark-J experiment at the PETRA electron-positron ring at DESY, Hamburg, was well into its research programme, and the 1976 co-Nobel prizewinner was looking to the future. The electron-positron route could be continued at CERN's LEP ring, but there was another route, for protons, elsewhere. The idea for L3 was born when Ting visited Hans Hofer and his colleagues at the Swiss Federal

Technical Institute (ETH) in Zurich in April 1981.

The Mark-J collaboration included Aachen (III) in Germany, MIT in the US, NIKHEF from Amsterdam, JEN in Madrid and the Beijing Institute of High Energy Physics. (Mark-J was the first western scientific project in which Chinese physicists participated following the 1977 cultural revolution.) As well as ETH, Antonino Zichichi's group, with valuable experience in studying lepton pairs, was eager to join any new Ting venture.

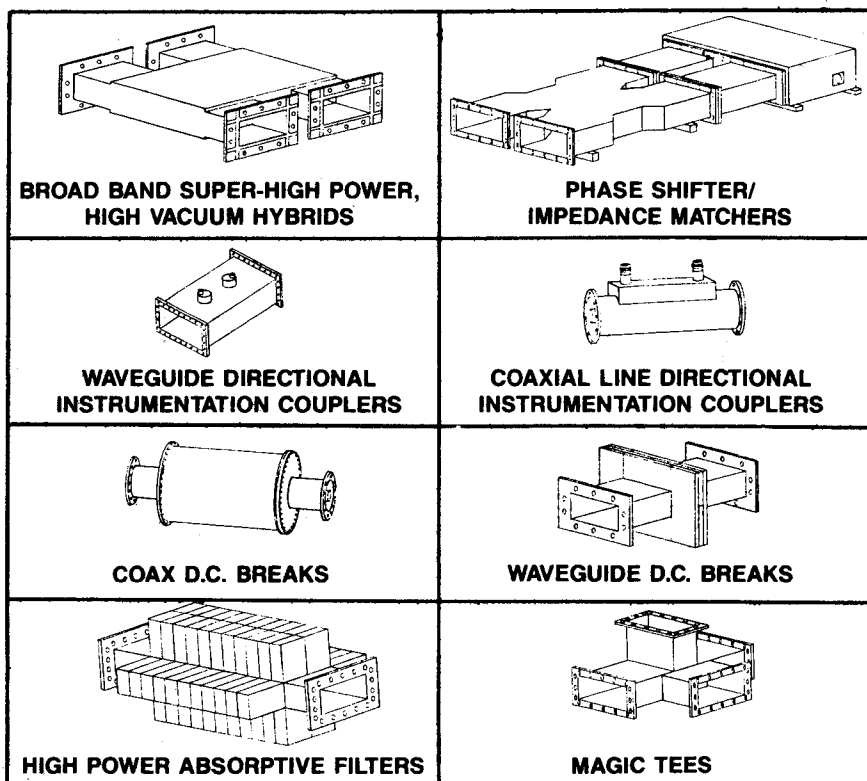
What came to be known as L3 (it was the third Letter of Intent to be submitted for approval in 1982) looked very different to the other LEP detector plans. While these concentrated primarily on the hadron (strongly interacting) and lepton (weakly interacting) products of the electron-positron collisions, Ting's plan was to construct a detector to emphasize the leptons and photons produced in electron-positron annihilation, looking deep inside the electroweak mechanism to see what makes it work.

As well as being large, L3 is also a truly world collaboration, the first major physics team to span Europe, the US, USSR, the People's Republic of China, and Asian countries.

Despite its \$150 million pricetag, funding for the detector was never a major problem, with the USA, the Soviet Union and the Eurasian countries each contributing about a third of the total cost. However Ting says that setting up the worldwide team, for example with Soviet and Chinese scientists working alongside each other – a rarity in those days, took a lot of patient preparation.

Once outlined, the initial L3 design, with a large magnet enclosing a modular detector aimed at precision measurements of photon, electron and muon momenta, did not change very much. The need for an outer magnet to provide the required momentum measurement precision meant that the detector had to be big. Unlike the other LEP detectors, constructed on the push-pull principle with a 'garage' position away from the circulating beams, L3 had to be built in situ. As in effect it formed part

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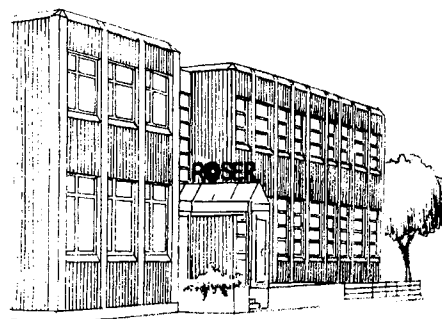
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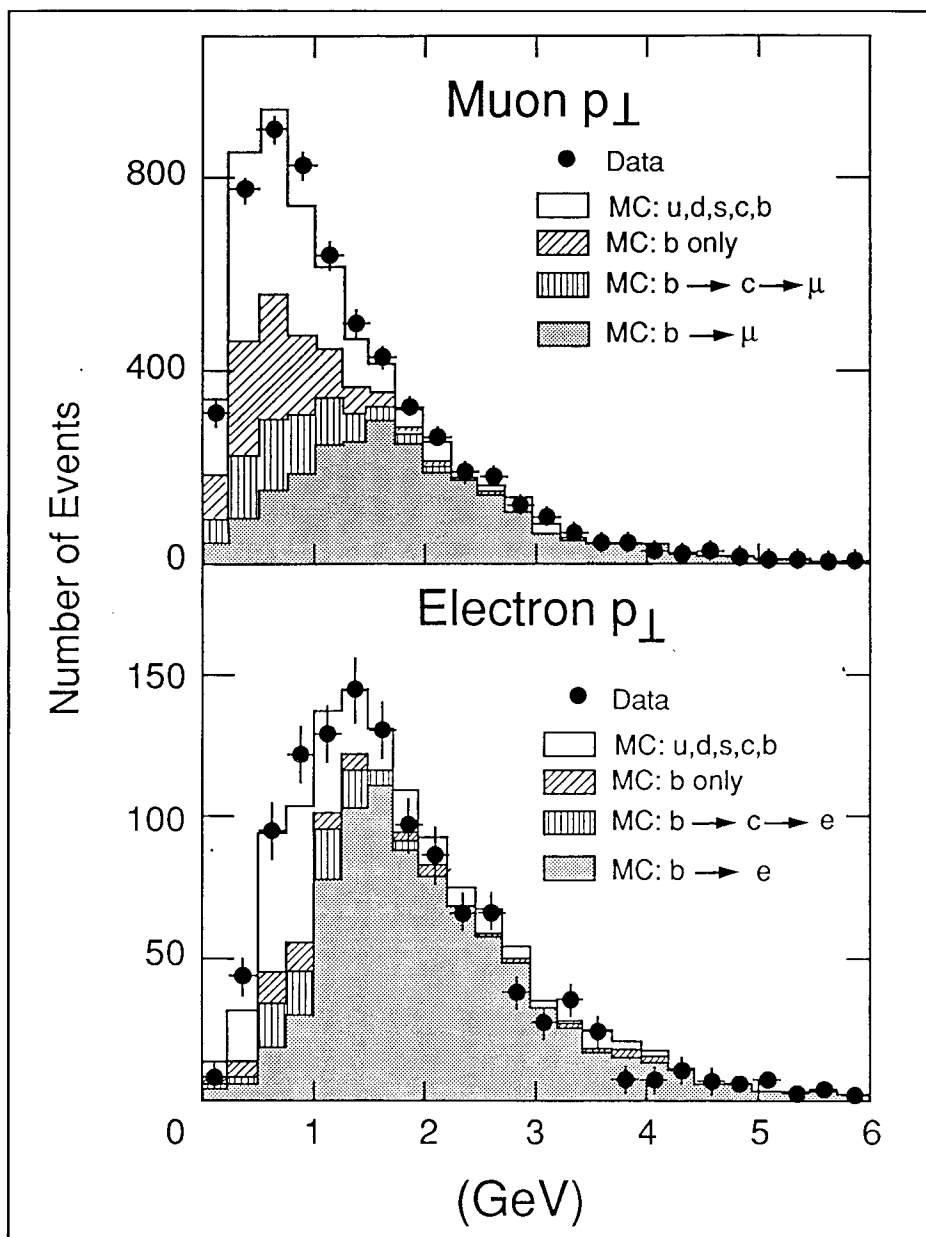
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B particle physics is one of L3's emerging specialties. Cutting off muon and electron transverse momentum below 2 GeV gives a clean sample.



of LEP's infrastructure, L3 had to be ready and operational on LEP Day One. This was a powerful driving force in L3 installation.

Another novel L3 feature is the use of bismuth germanium oxide (BGO) for the electromagnetic calorimeter. Twelve tons of this material are used in the complete detector, which drove the material's market price down

from \$18 to \$5 per cubic centimetre. The BGO raw material was supplied by the Soviet Union, but crystal production was in the capable hands of the Shanghai Institute of Ceramics.

Responsibility for the 8000-ton magnet, 15.6 metres high, 13.6 long and providing a central field of 0.5 T, and the large experimental area was

shared by the big guns of the collaboration – CERN, ETH Zurich, ITEP Moscow and MIT.

Inside the magnet are the muon large muon chambers (NIKHEF Amsterdam/Madrid/ETH Zurich/Harvard/Naples/Leningrad/ MIT/Northeastern) to give resolution of one per cent or better at the Z mass working point. Under Ulrich Becker of MIT, research and development work for this major detector component went through many iterations – it took two years to produce the first octant for the ultra-precise muon central barrel spectrometer – before an optimal design emerged and production could begin. Precision laser monitoring systems were specially developed to ensure accurate octant alignment.

Inside the muon chambers, the hadron calorimeter (Aachen/ Florence/ITEP Moscow/Michigan/Rome/ Bombay/ETH-EIR Zurich) with copper and Soviet uranium absorbers was assembled at the Swiss Federal Institute for Nuclear Research (EIR). Here too extensive initial R and D work paid dividends.

Inside the hadron calorimeter, the BGO electromagnetic calorimeter (including a luminosity monitor) is also delegated to a highly international team (Aachen/Annecy/ Beijing/ Budapest/Caltech/Carnegie-Mellon/ CERN/Geneva/Hofei/ Lausanne/ Lyon/Madrid/Munich/Moscow/ NIKHEF/Princeton/Rome). In place for the 1991 run are the endcaps, making the original L3 design finally complete.

The 'Time Expansion Chamber' vertex chamber currently at the heart of the detector was built by a European team (Aachen/Zeuthen-Berlin/ Zurich) after considerable prototype development at Aachen, Geneva and ETH Zurich.

L3's Governing Board – the Execu-

L3's Higgs candidate – explained as a Z decaying into a Higgs and a pair of muons (top left), the Higgs subsequently giving the particles, including a lone muon (right), corresponding to a beauty (b) quark-antiquark pair.

tive Committee – includes key delegates from the collaborating research centres with vital responsibility for subdetector units. Other groups represented on the Committee look after physics goals, detector improvements, assembly and parameters, the magnet and the experimental area, on- and off-line data analysis, triggering, and instrumentation R and D. The sessions are open to all L3 collaborators.

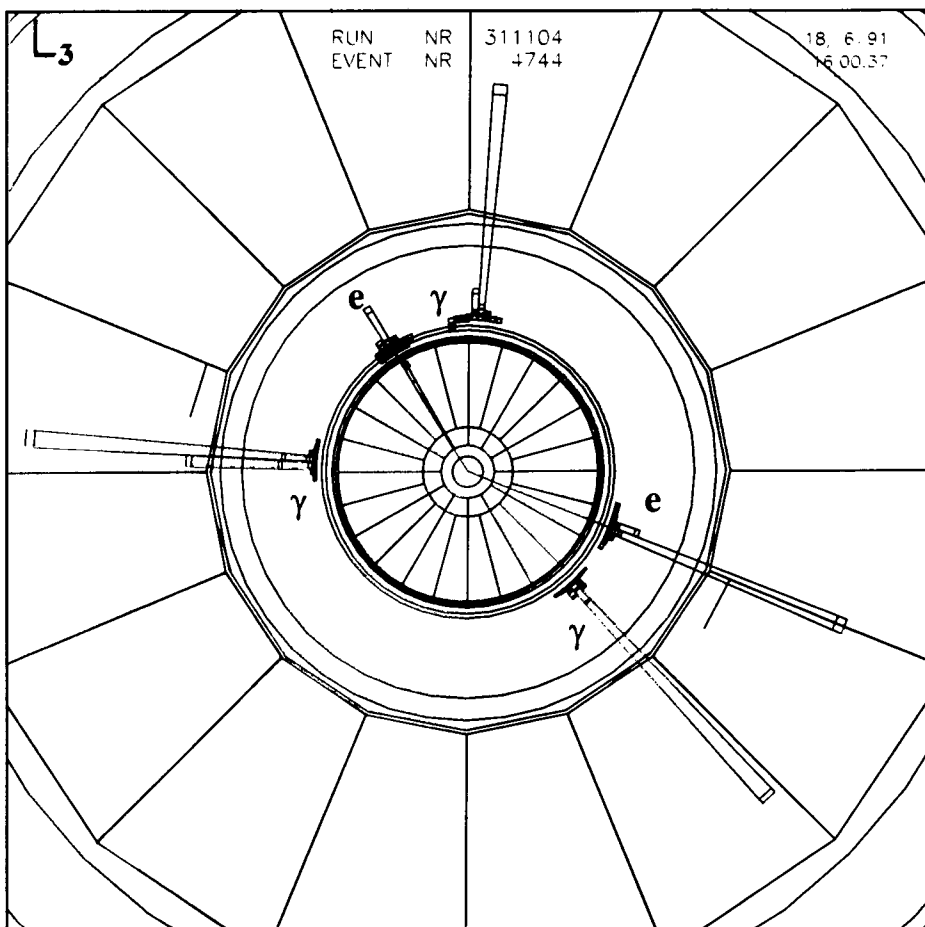
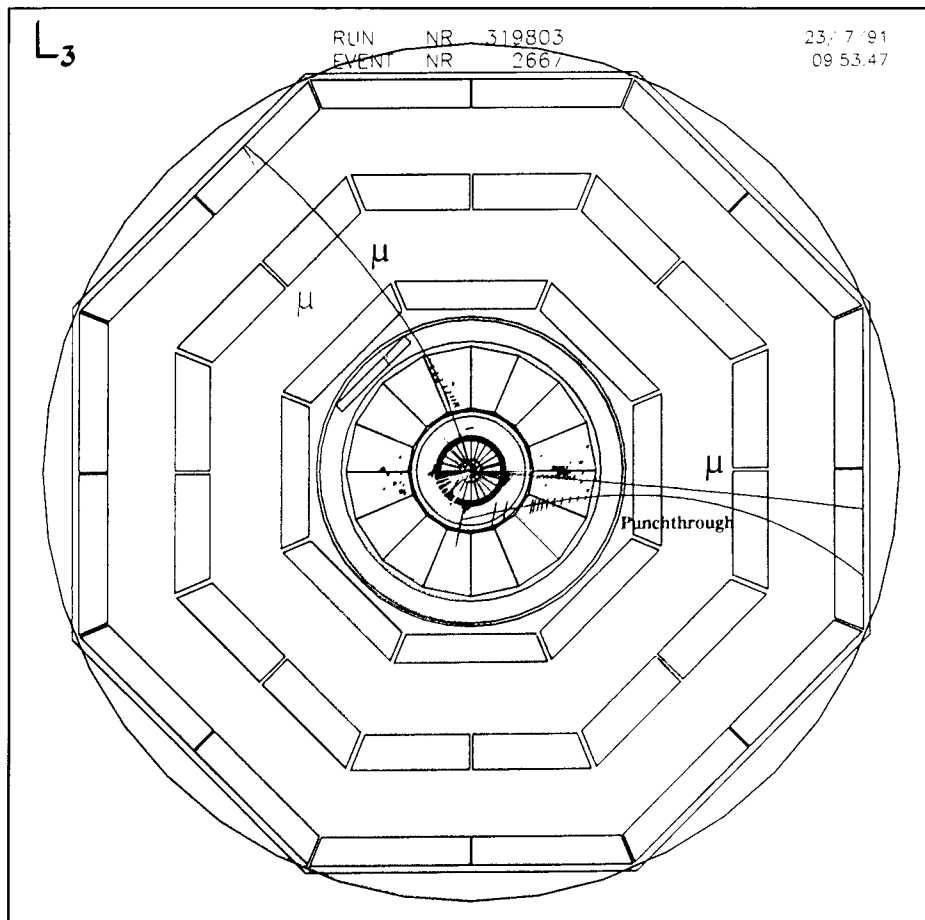
Special L3 roles are played by Hans Hofer of ETH Zurich with overall responsibility for coordination and finance (L3 has its own Finance Committee) and Frederic Eppling of MIT in administration and communications. At CERN, François Wittgenstein led the magnet team, while Alain Hervé and Mike Harris looked after engineering support.

The collaboration was boosted in the mid-80s with the advent of the World Laboratory. Under Antonino Zichichi, this project aims to capitalize on the science and technology base of the major industrialized nations to promote projects in developing countries. A World Laboratory contingent is now the largest single institute team in L3, sharing responsibility for much of the experiment's data analysis hardware and software.

In this way young scientists from developing countries get valuable experience in front-rank high technology, providing a strong springboard for future careers and a catalyst for technology sharing.

During L3 installation, cabling turned out to be a tough task, but monthly meetings under Lars Leistam sorted this out. Such a widespread collaboration also

An interesting Z decay from L3, giving an electron-positron pair and three high energy gamma rays.



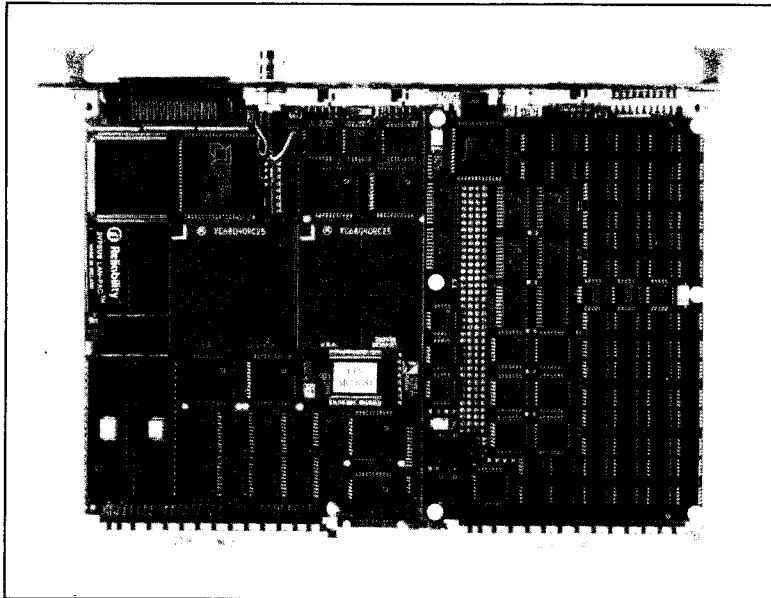
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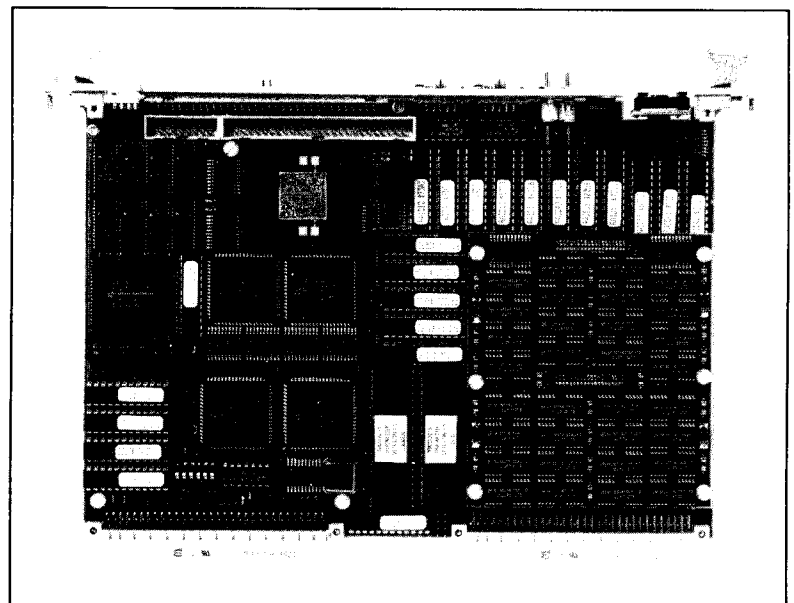
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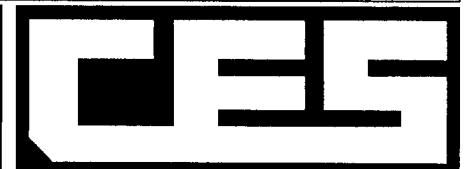


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Around the Laboratories

needed a special effort in data communications. Richard Mount of Caltech looked after the international computer network.

L3 has its own dedicated computer for data analysis. Provided by US Department of Energy funds, it currently uses an advanced IBM 3090-200J processor.

Despite its size and complexity, the detector worked very well when LEP provided its first beams in the summer of 1989. A few dead sectors in the vertex chamber were soon replaced.

Sam Ting sees the three data taking seasons so far as only the beginning of a long career for L3. With the current data samples there is little to choose between the four detectors, he explains. However specific design objectives should come into their own in the next few years, when the experiments have each a few million Z decays under their belts. He highlights the first L3 results on B physics (particles containing the fifth 'beauty', or 'b', quark) as a pointer to L3's future capabilities. These results include branching ratios for semi-leptonic b quark decays, the affinity of the Z particle for b quarks, the mixing parameter of the neutral B mesons, and the lifetime of B particles.

Also for the future, L3 is installing forward-backward muon chambers to extend muon coverage down to 22 degree angles. This will be particularly important for running at higher LEP energies to study the physics of W particle pairs. L3 will also be fitted with a microvertex detector inside the Time Expansion Chamber and immediately around a new narrow beam pipe, to improve tracking for very short-lived particles.

Despite the complexity of the detector and the size of the experimental collaboration, L3's results are

presented publicly in a refreshingly clean and easy-to-assimilate form. 'Physics comes from transmission of simple ideas,' explains Ting. 'You don't have to go into too many details.'

A specially developed streak camera at CERN's LEP electron-positron collider can give top (left) and lateral views of the circulating particle bunches. In this photograph, the development of the bunches (each a few centimetres long, about a millimetre high and a few millimetres across) in successive (bottom to top) turns around the 27-kilometre ring shows delicate oscillations. This camera has proved invaluable in understanding the complex behaviour of the LEP beams.

(Photo CERN CO 36.11.91/3)

CERN LEP vintage 1991

When CERN's 27-kilometre LEP electron-positron collider finished its 1991 run in mid-November, the four big experiments – Aleph, Delphi, L3 and Opal – had each amassed about 300,000 Z particles over eight months. This was about twice the figure for the 1990 run, so that the total number of Zs seen by the four detectors since experiments got underway in August 1989 now exceeds two million.

1991 started on an optimistic note. Lessons had been learned, and a healthy crop of Zs was expected. In addition, LEP would continue to scan around the Z energy to see how behaviour changes across the resonance.

After the experience of the 1990

