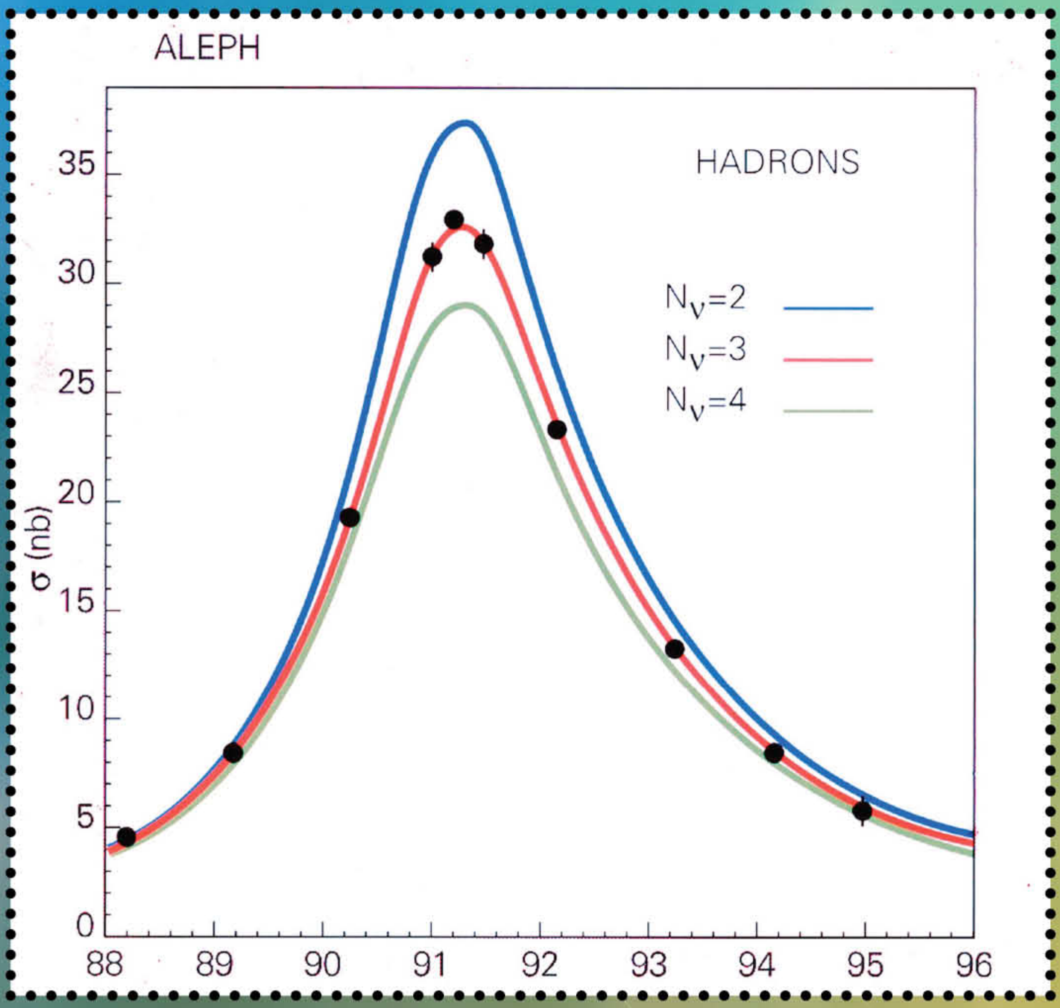
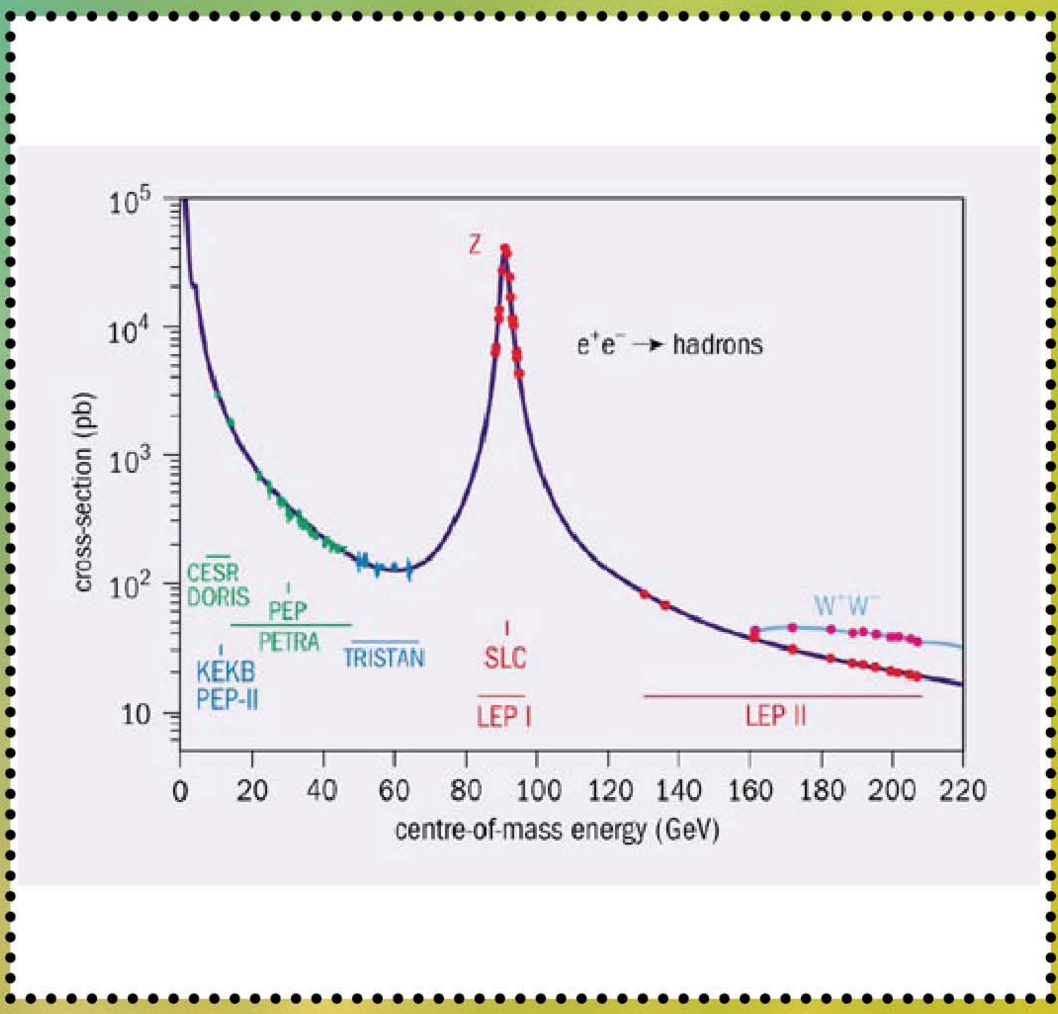
Z physics *at LEP*

From 1989 to 1995 - 18 million Z bosons

LEP experiments show that three and only three families of particles exist.





Here, the total cross-section for electron-positron collisions is plotted against energy as LEP scanned through the mass of the Z particle. The result is a clear peak corresponding to visible Z decays. But the Z can also decay into neutrinos that escape the detectors unseen. Shown on this plot along with the data are predictions in which two, three and four kinds of neutrinos have been assumed.

The experimental analyses of the Z line-shape of branching ratios and asymmetries were performed with a precision unprecedented in high-energy experiments.
The electroweak sector of the Standard Model successfully passed the examination at the per-mille level – truly in the realm where quantum theory is the proper framework for formulating the laws of nature.

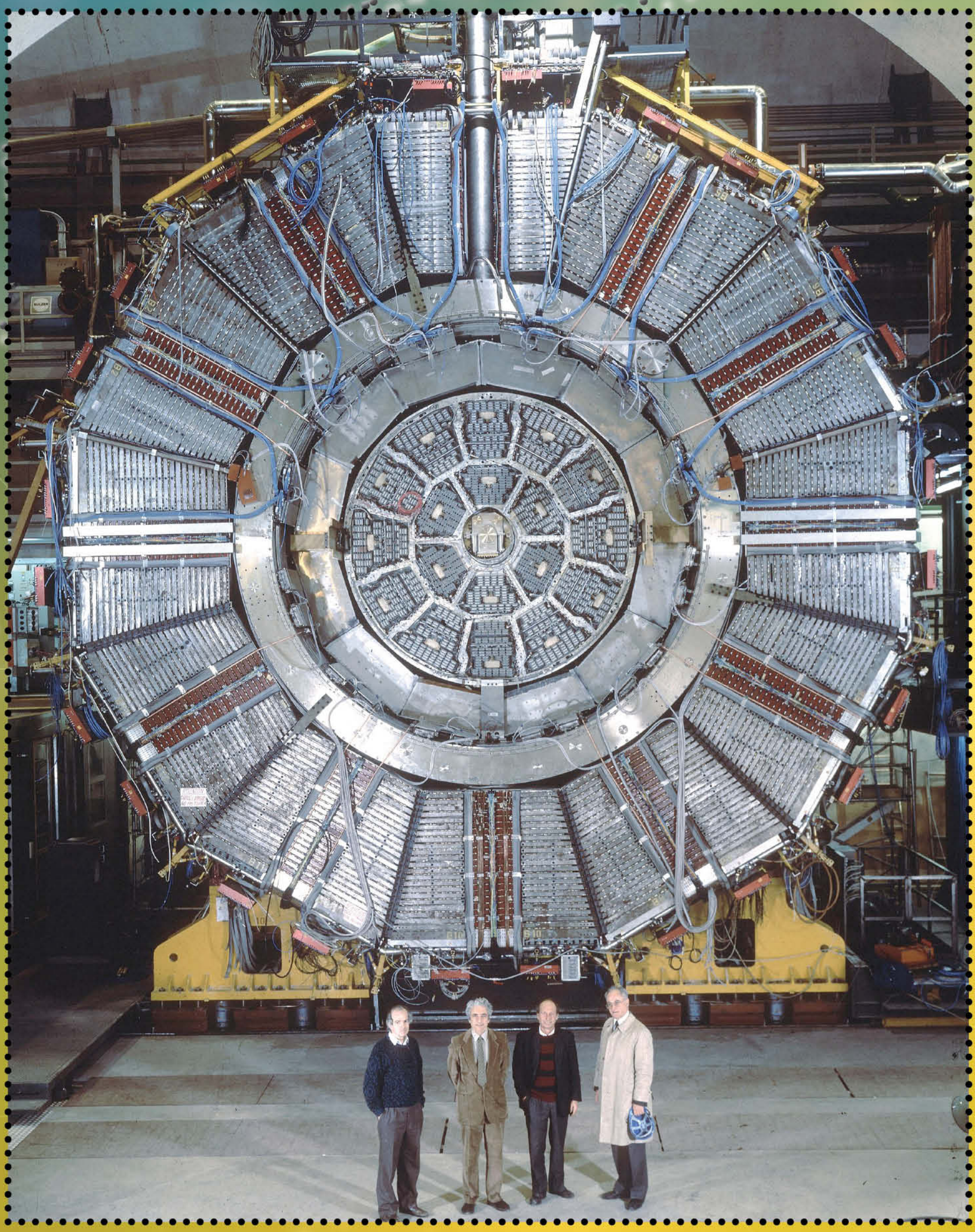
The physics of the top quark was another LEP success story. Not only could the existence of this heaviest of all quarks be predicted from LEP data, but the mass could also be pre-determined with amazing accuracy from the analysis of quantum corrections.

Z physics at LEP has also contributed to knowledge of Quantum Chromodynamics, which helped to put the theory on a firm experimental basis and provided measurements of the strong coupling constant. This allowed exploration of the exciting possibility that the electromagnetic, weak and strong forces of the Standard Model may be unified at an energy scale close to 10^{16} GeV, if supersymmetry comes into play at very high energies.

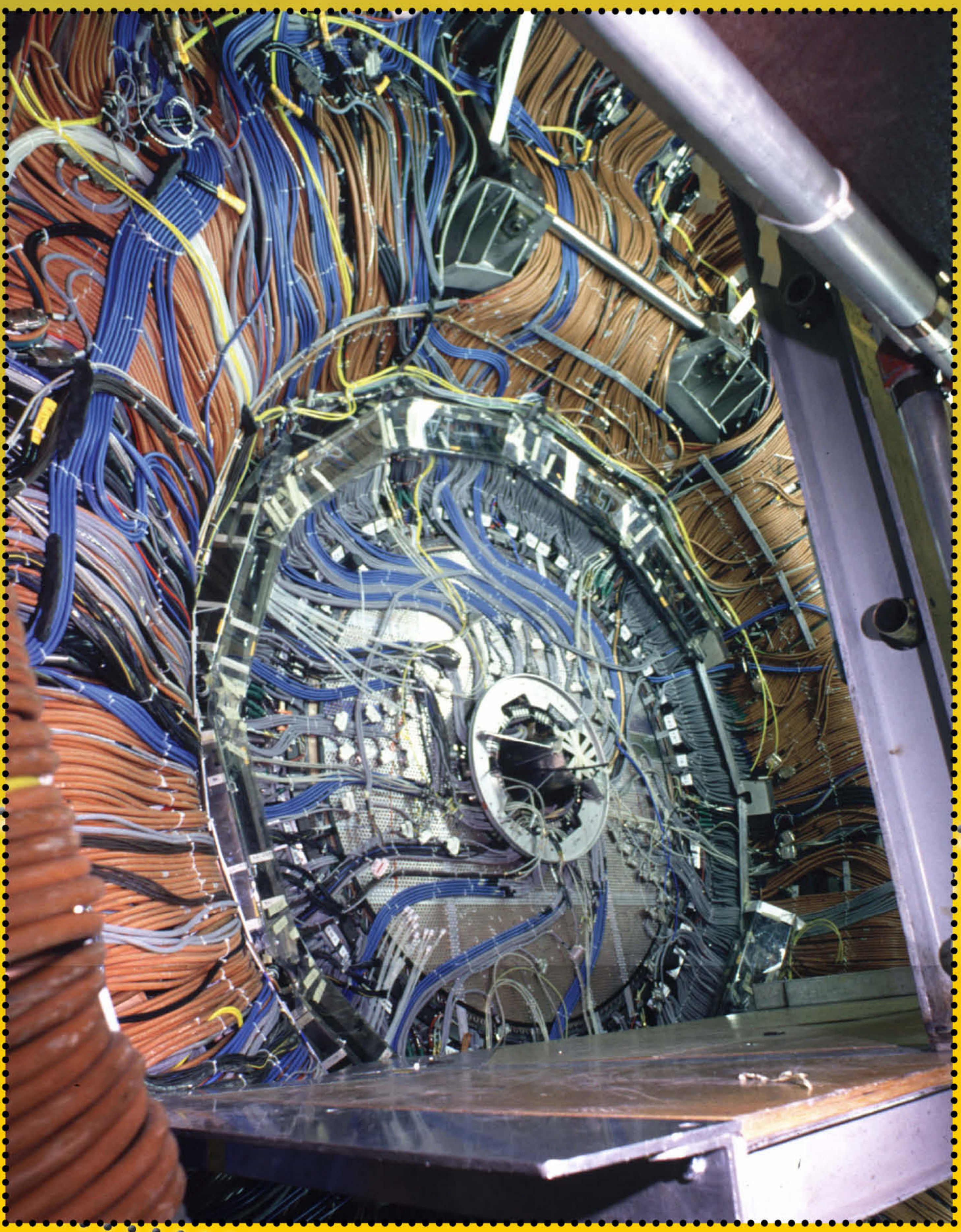
"LEP started up in 1989, and I would like to recall the intense emotion I felt when the first Z particle was clearly identified about ten minutes after we had decided to get the two beams to interact. These were ten long minutes of waiting: we did not know if the two beams would in fact meet. There was a large explosion of joy when Aldo Michelini, the leader of the OPAL group, called the control room to tell us that they had identified the first Z. It was the 13 August 1989 and at that moment I thought that my role as Project Leader was almost complete." Emilio Picasso, Infinitely CERN, 2004

The LEP

In their day, LEP and its four detectors were the biggest of "big science," both in the size of the detectors and the international collaborations that produced them. Initially each detector had certain measurements in which it excelled, and with later upgrades they all performed well across-the-board. By making overlapping measurements, but using different methods, the results from the four detectors reinforced each other.

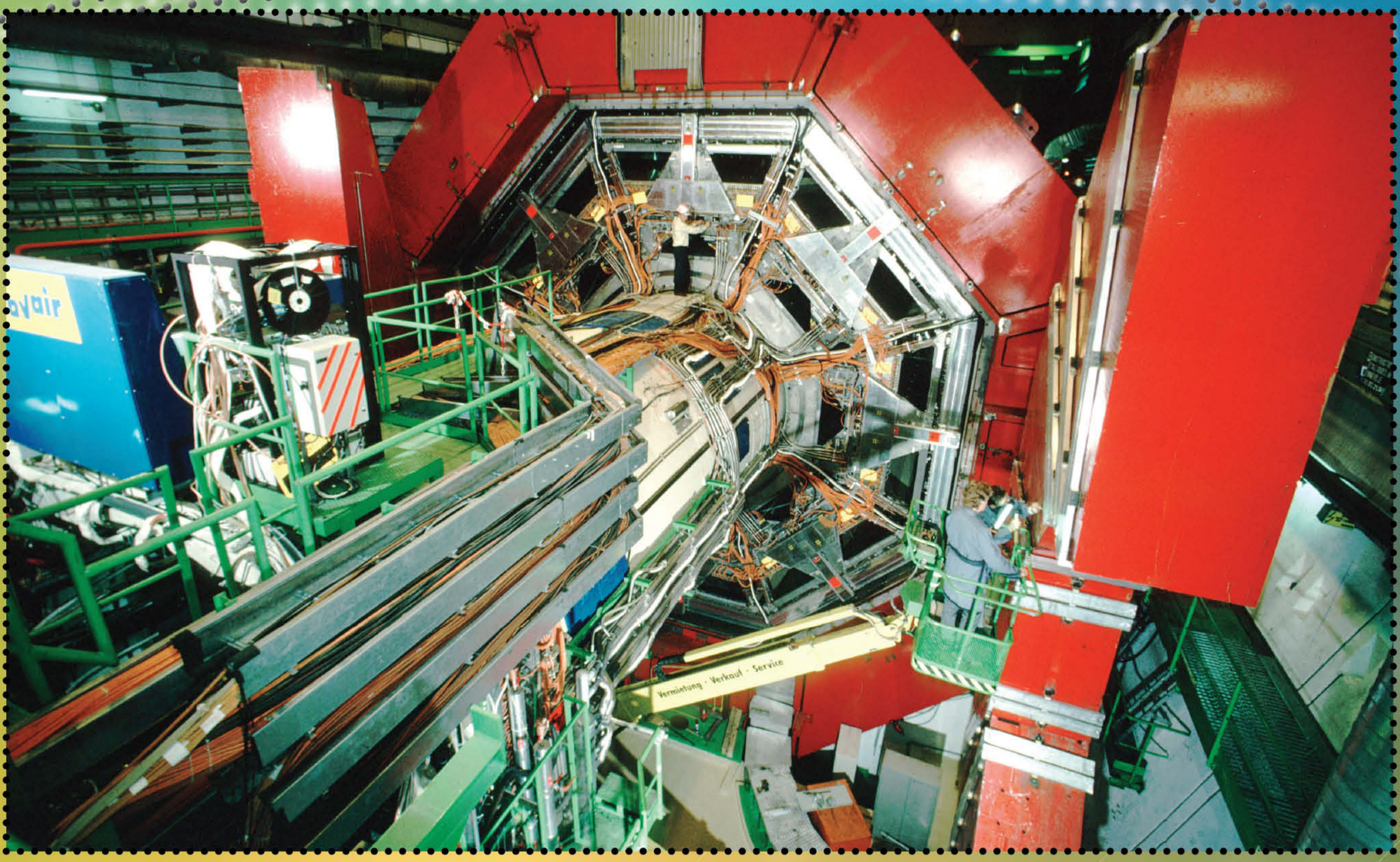


For detecting the direction and momenta of charged particles with extreme accuracy, the ALEPH detector had at its core a time projection chamber, for years the world's biggest. The experiment also became renowned for its innovative software for visualizing particle collisions.

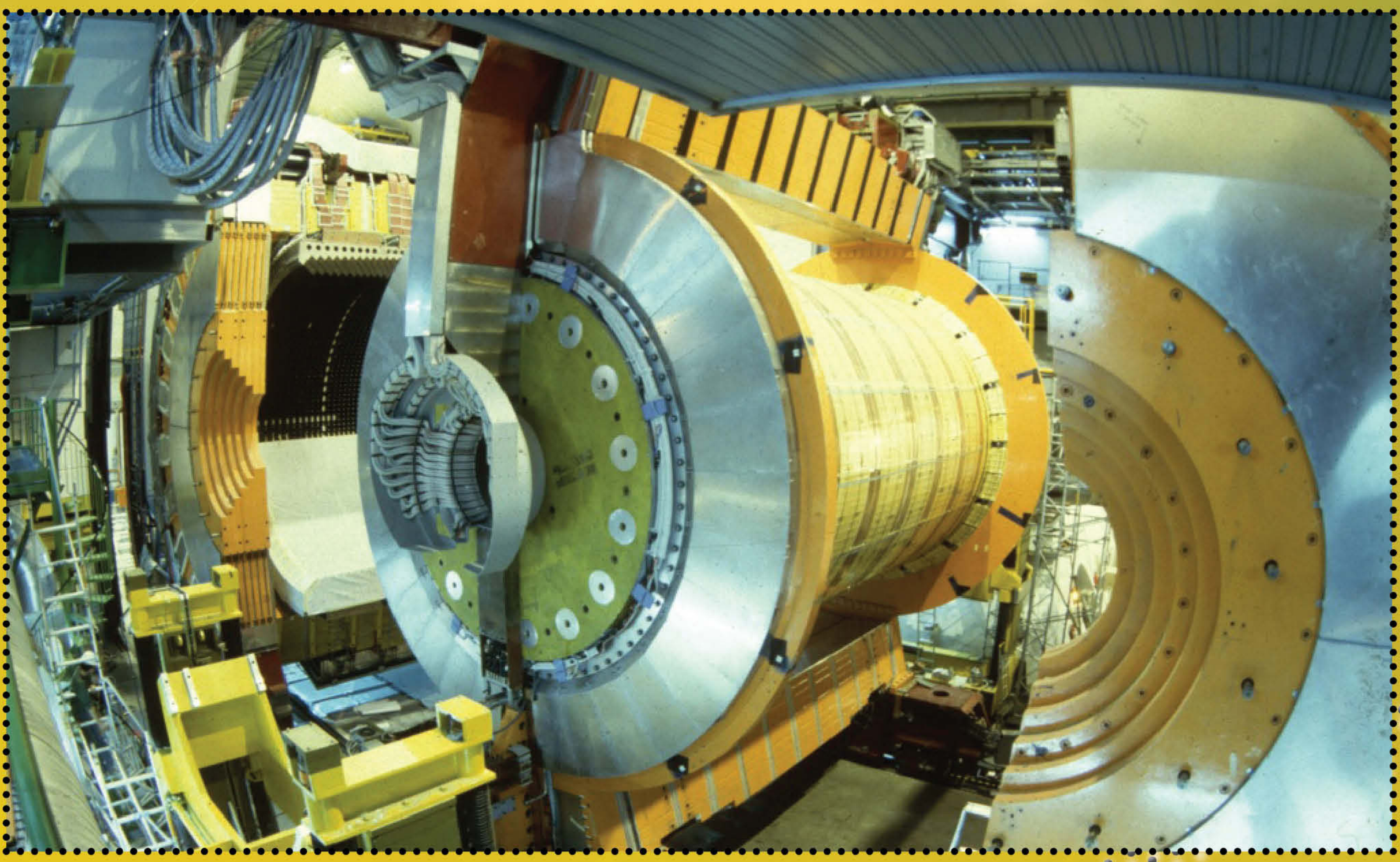


Of the LEP detectors, DELPHI was the most innovative, including what was the world's largest superconducting magnet. One of DELPHI's main strengths was its ability to unambiguously identify many types of charged particles.

experiments



L3's strong point was accurate measurements of the momenta of electrons and their heavier cousins, muons. The detector was surrounded by a magnet that weighed as much as the Eiffel Tower and created the world's largest magnetic volume, 2700 cubic metres.

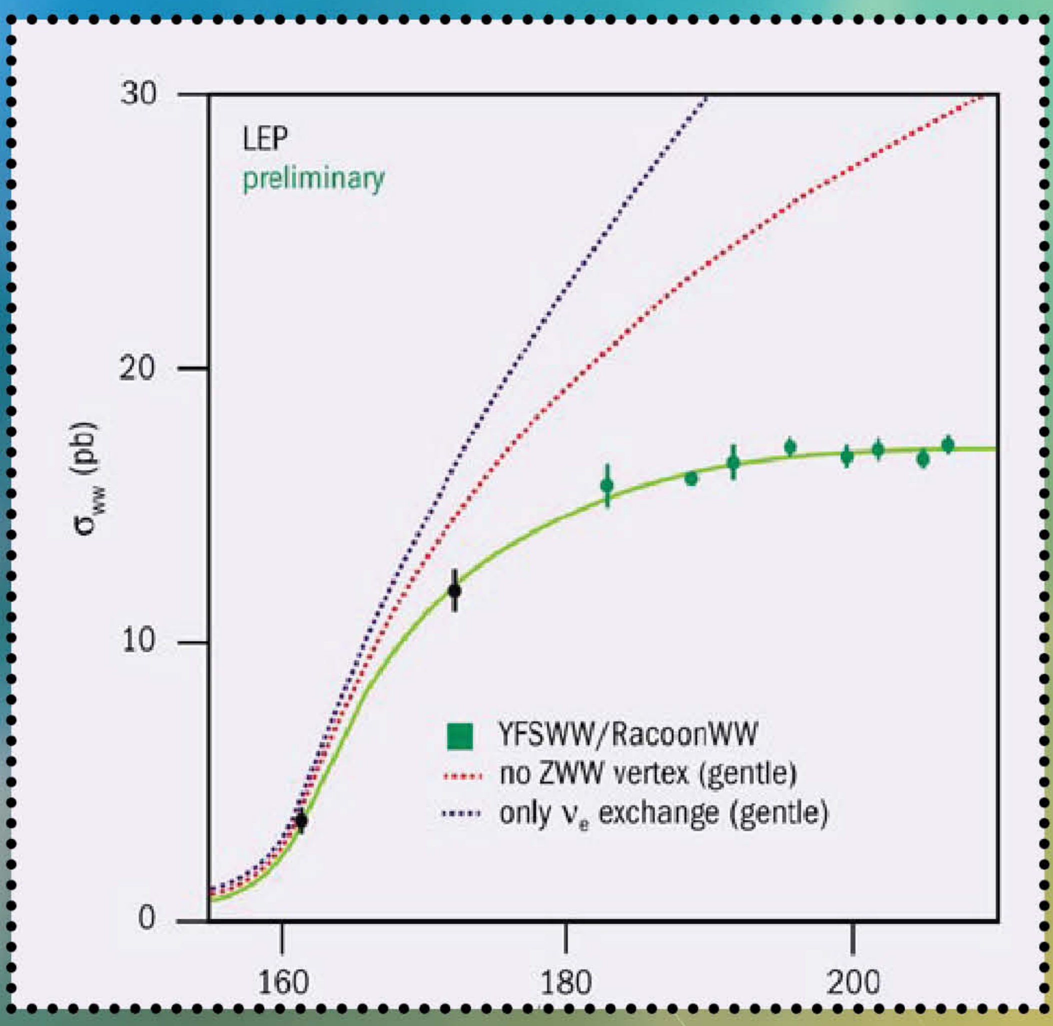


Based on tried-and-true technology, OPAL was the safest bet among the LEP detectors. It was also the first LEP detector to record data, observing a Z boson decay on 14 August, 1989.

Registering 18 million Z boson decays in its first six years, and later 40 000 pairs of W bosons, LEP's highly-accurate results confirmed the Standard Model of particle physics, extended the model to much higher energies and pointed the way to discoveries at future accelerators, such as the LHC.

W physics *at LEP*

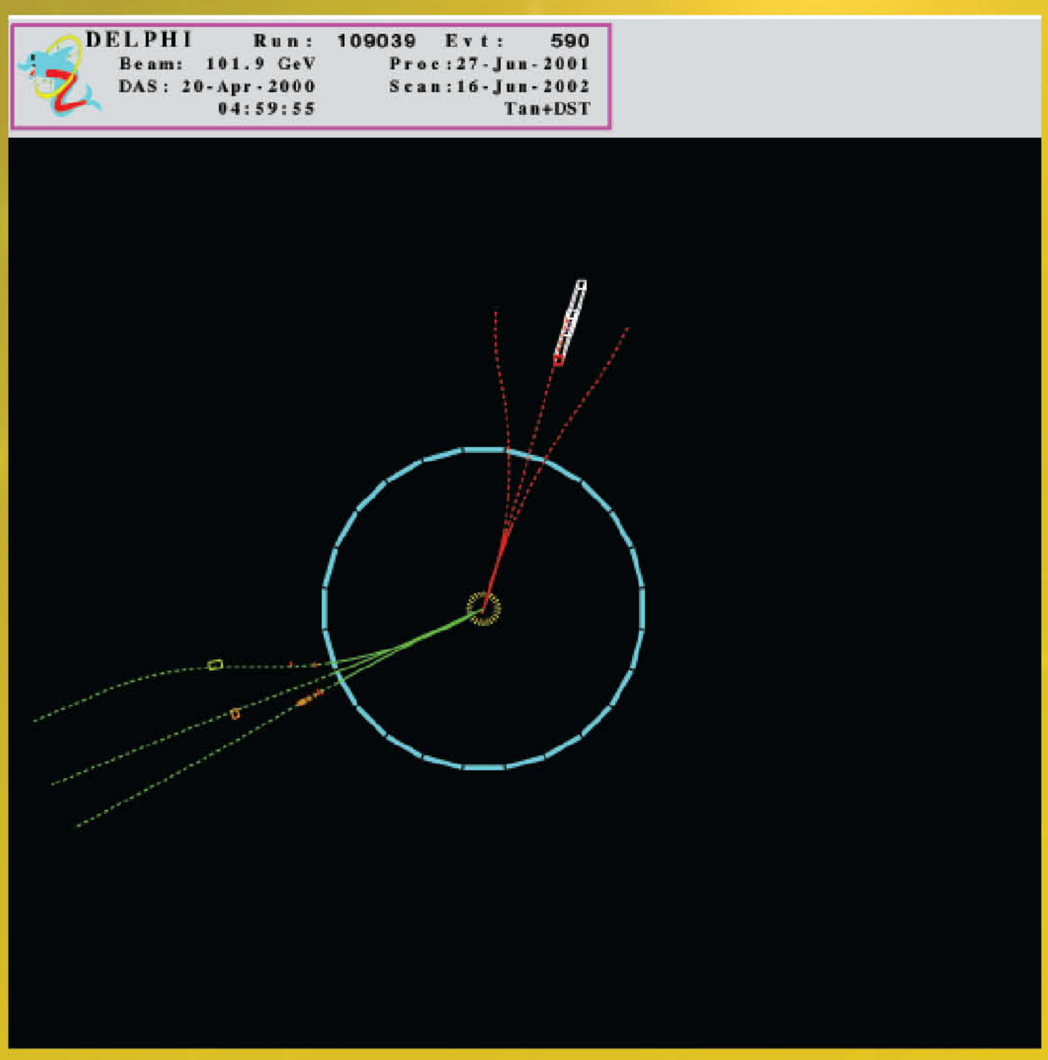
From 1996 to 2000 - 80 000 W bosons

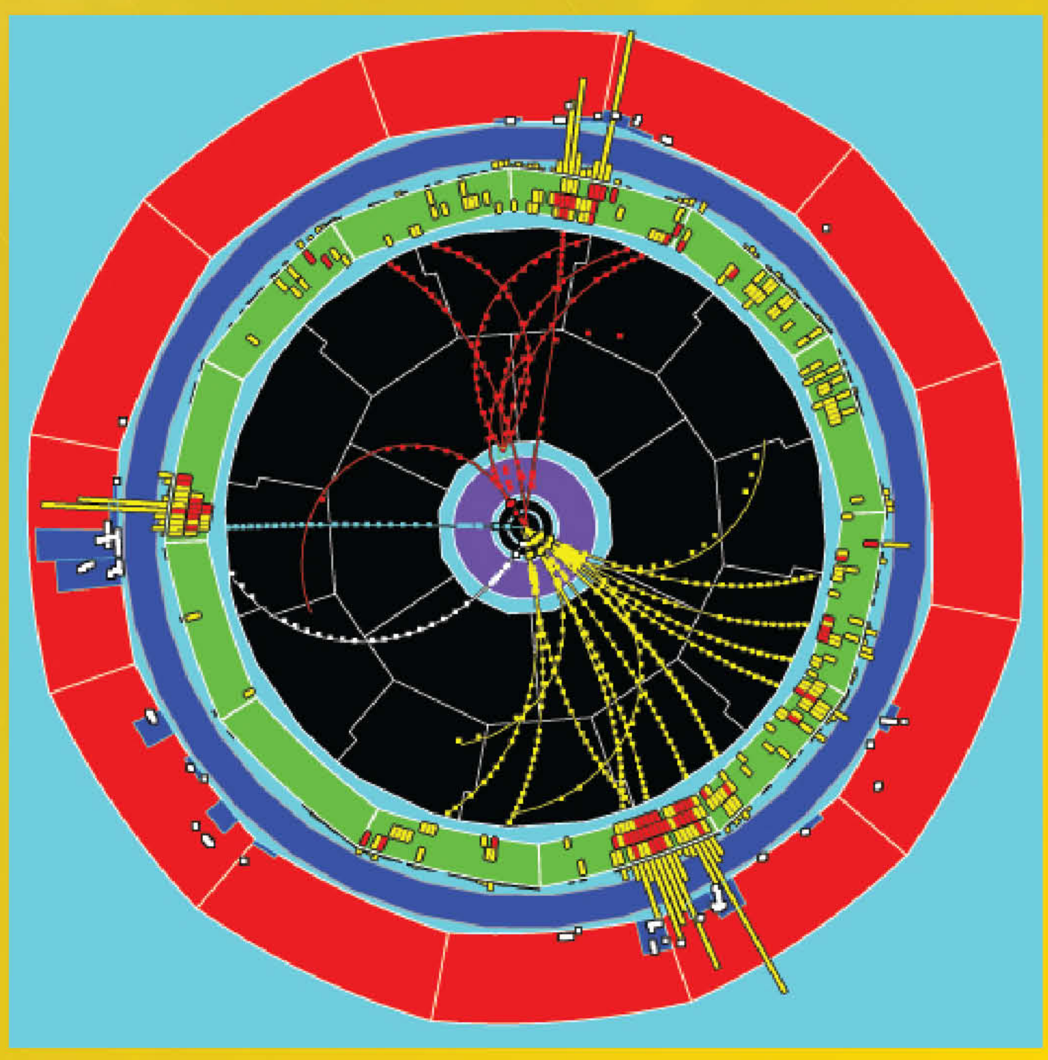


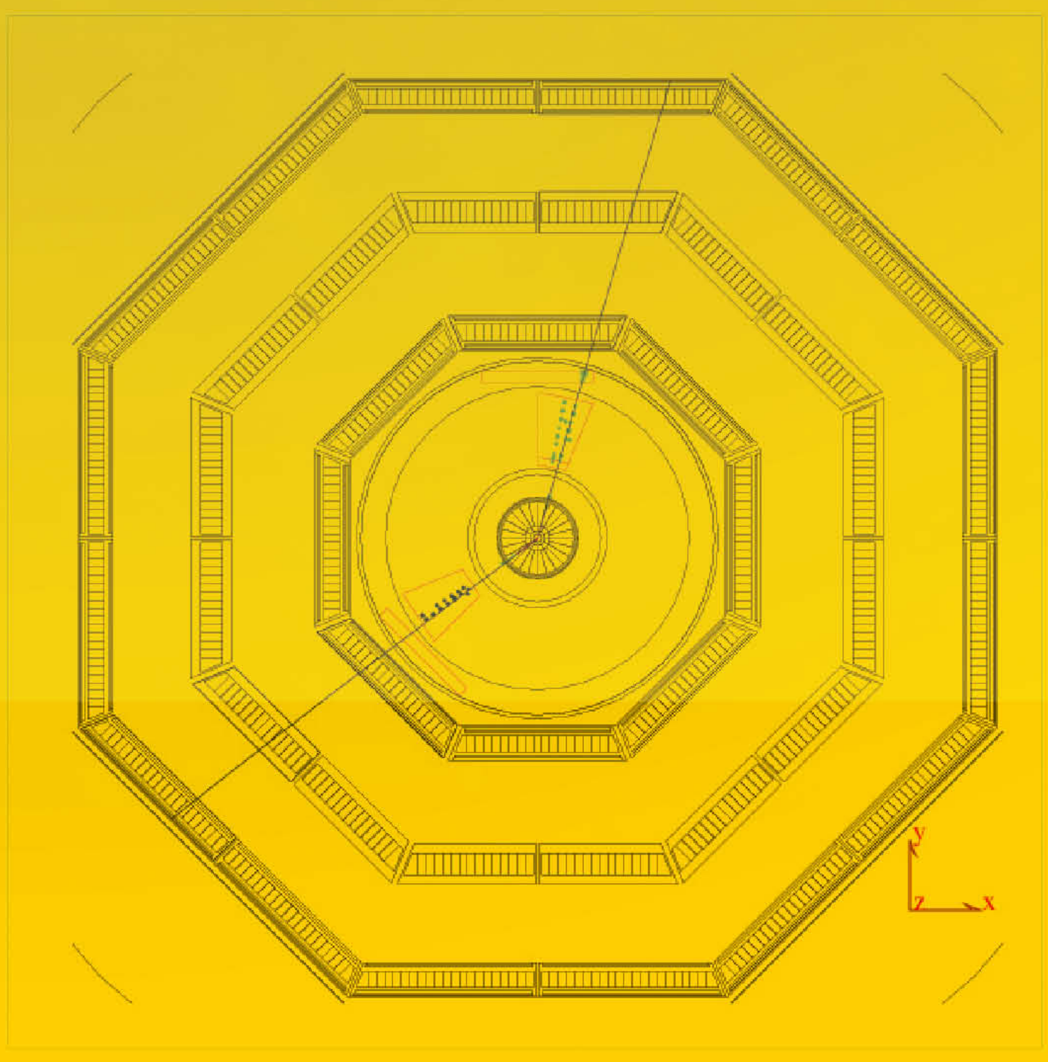
One of the central tasks of the LEP experiments at energies beyond the W-pair threshold was the analysis of the electroweak three-gauge-boson couplings. A first glimpse was also caught of the corresponding four-boson couplings.

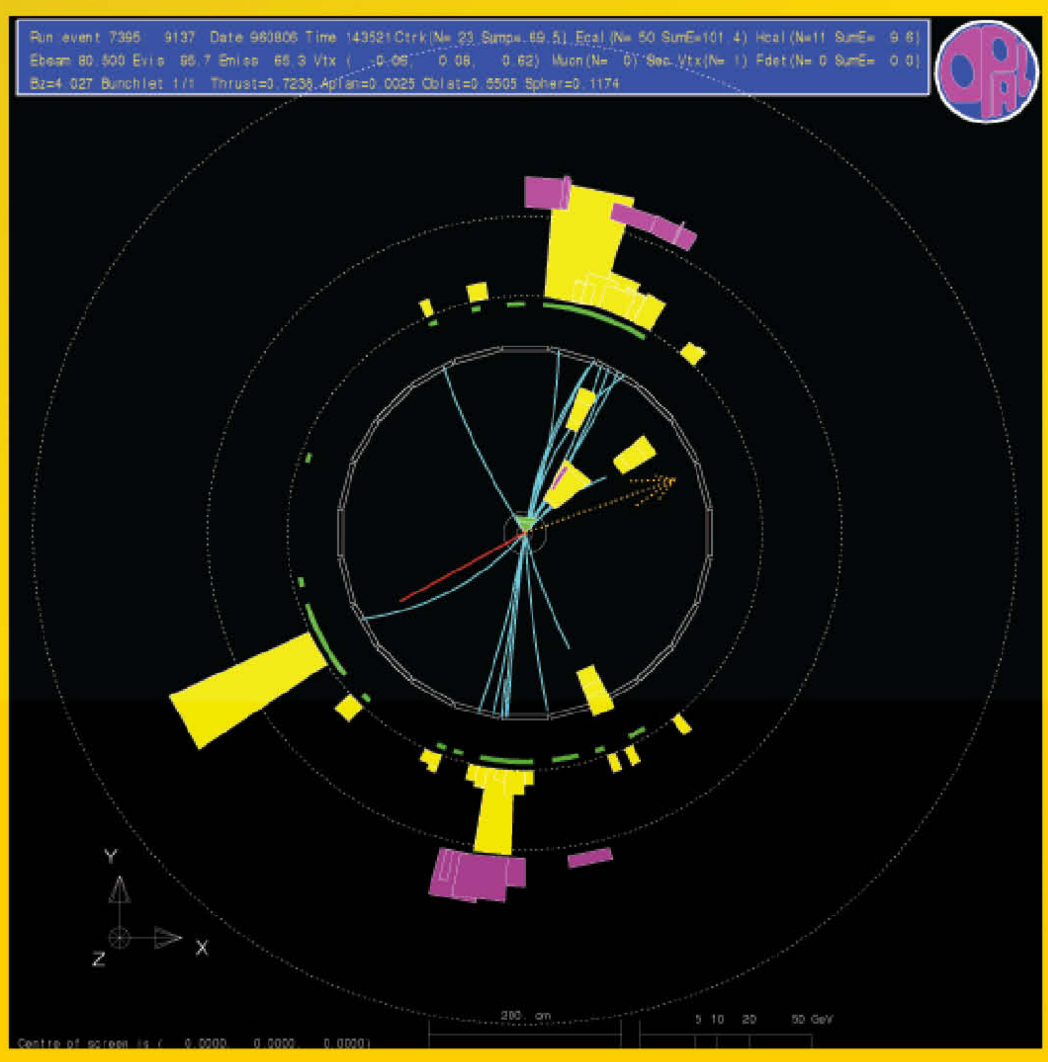
Any of the three production mechanisms for W^+W^- pairs, if evaluated separately, leads to a cross-section that rises indefinitely with energy. However, the amplitudes interfere destructively as a result of the gauge symmetry, and the final cross-section is damped for large energies. The prediction of gauge cancellations is clearly borne out by the LEP data.

W and Z analysis at LEP was truly a triumph of high-precision experimentation coupled with theoretical high-precision calculations at the quantum level of the Standard Model.



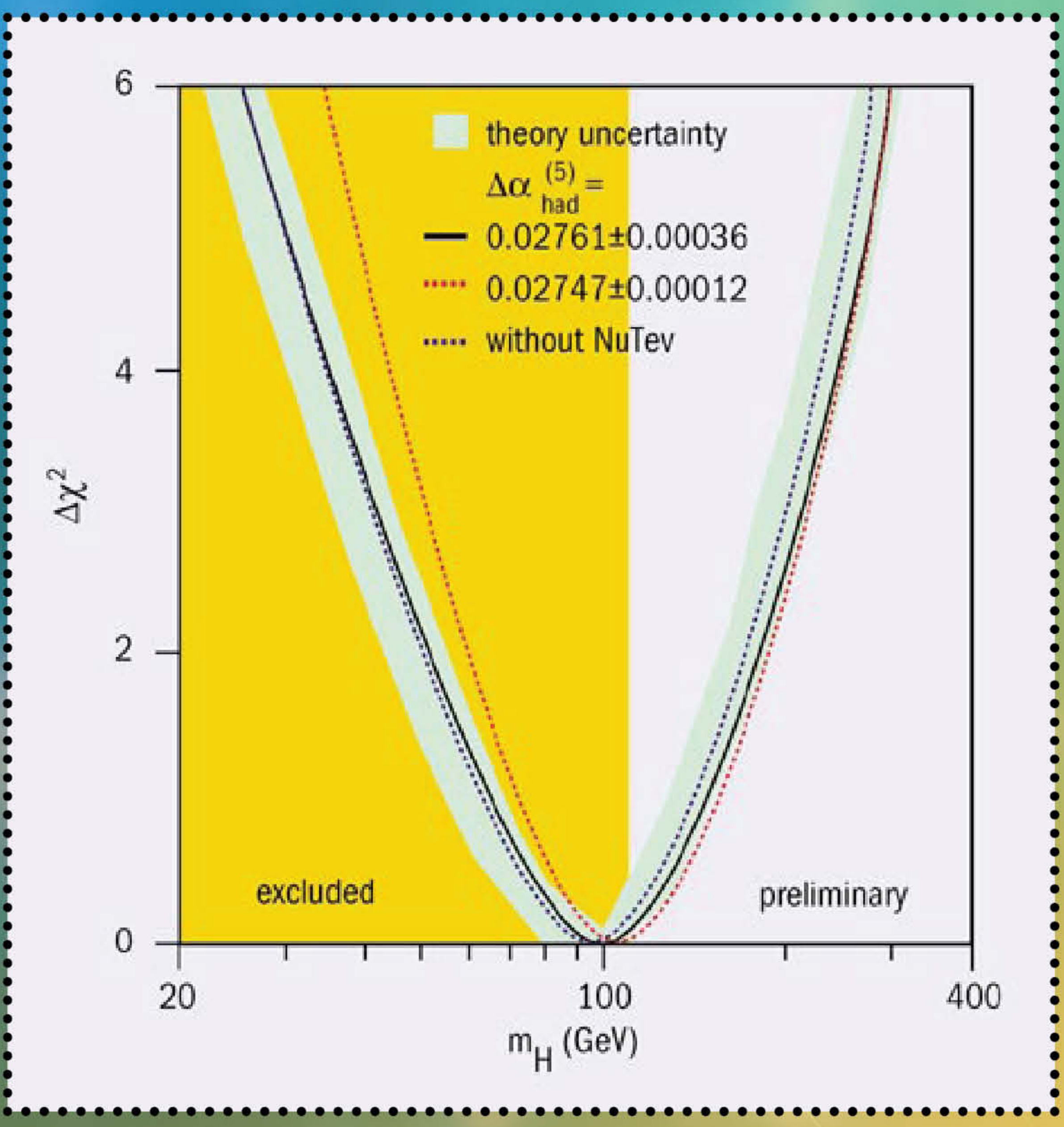






Hunting the **Higgs** at LEP

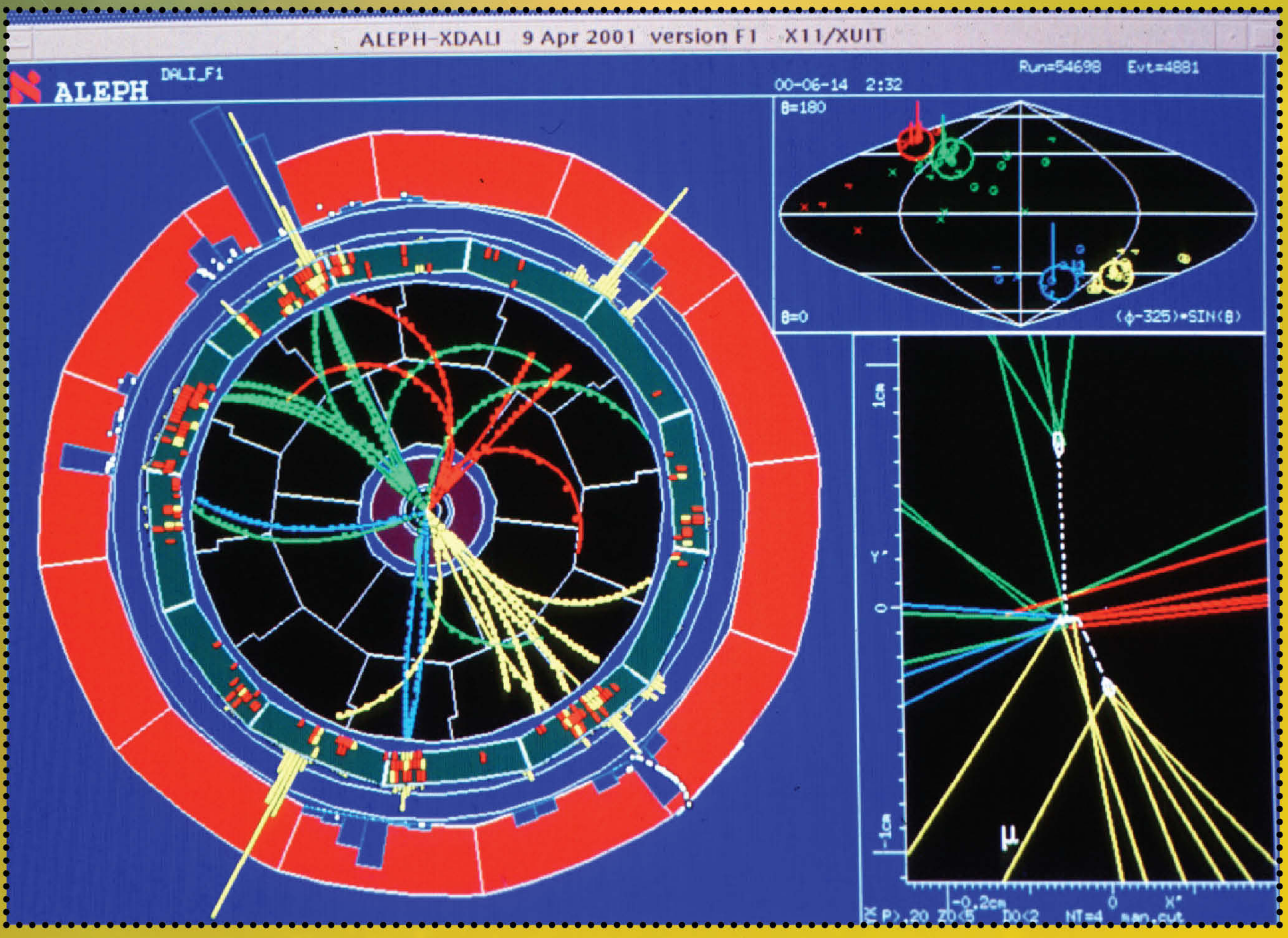
LEP results gave an estimate of the mass of the Higgs when acting as a virtual particle. By emitting and reabsorbing a virtual Higgs boson, the masses of W and Z bosons are slightly modified.



In addition, the direct search for the real production of the Higgs particle at LEP through the "Higgs-strahlung" process, $e^+e^- \rightarrow ZH$, set a stringent lower limit on the mass of the particle in the Standard Model.

However, there remained a 1.7 sigma effect for Higgs masses in the vicinity of 115 GeV, mainly fuelled by candidates in the four-jet channel in one experiment.

"This deviation, although of low significance, is compatible with a Standard Model Higgs boson in this mass range, while also being in agreement with the background hypothesis."
LEP Higgs Working Group



Aleph Higgs candidate

"The year 2000 saw a final burst of excitement. A few months before the scheduled shutdown of LEP, one collaboration reported events bearing the marks of the Higgs boson. […] All eyes turned towards the LEP Higgs working group. At stake was a possible extension of the LEP programme by a full year with all its personal and financial consequences. […] In the end, the only objective statement that we could make was 'perhaps'. This was not enough to grant an extension, so LEP was shut down and the quest for the Higgs boson passed on to future experiments. It would have been wonderful to end the LEP programme with such an important discovery, but Nature once again pronounced her eternal message: have patience.»

Peter Igo-Kemenes, Infinitely CERN, 2004

These 3 panels on LEP physics are based on an article in the CERN courier (Christine Sutton and Peter Zerwas, May 2004) and a presentation at the symposium held at CERN in September 2003 "The anniversary of CERN's discoveries and a look into the future"