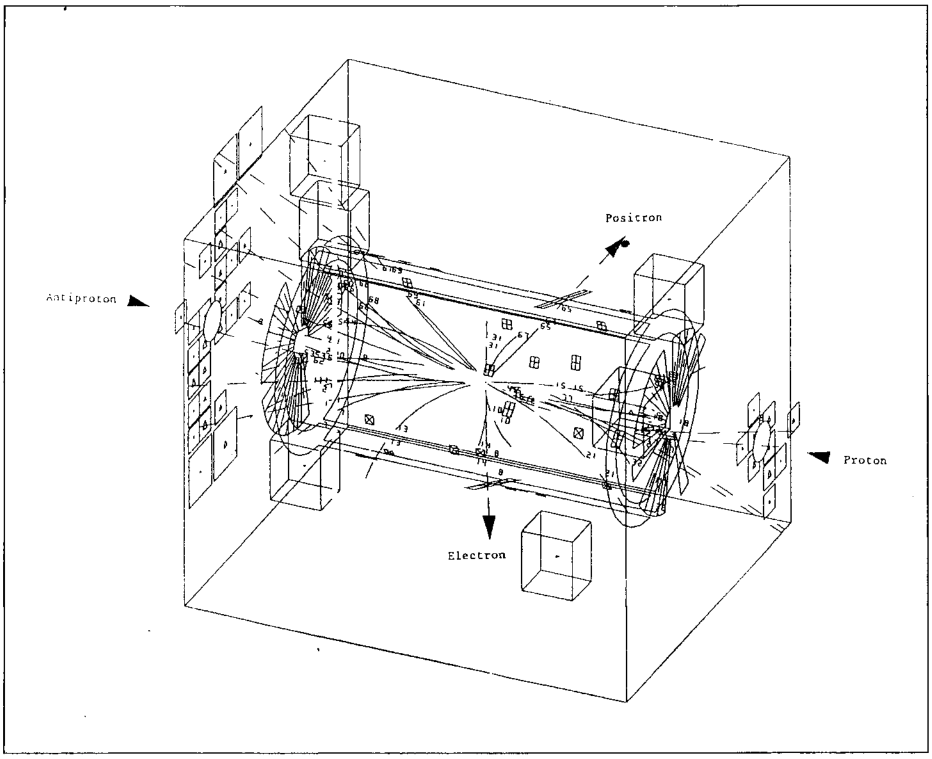
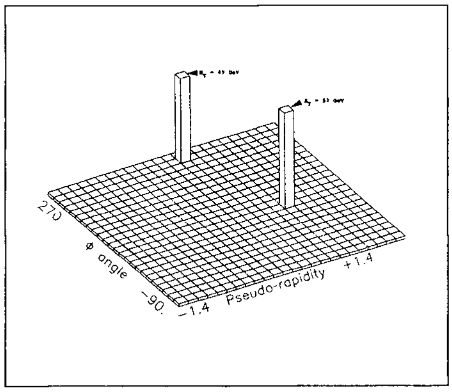
Physics monitor

Forerunner of millions to come. The first-ever Z decay, as seen by the UA1 detector at CERN's proton-antiproton collider in May 1983. Top, an high energy electron-positron pair, produced by the decay of a Z particle, emerges from the collision debris. Below, the clean 'lego plot' of the electron-positron pair.





A decade of heavy light

Ten years ago, in May 1983, the UA1 experiment led by Carlo Rubbia at CERN's proton-antiproton collider saw the first Z particle, the heavy (91 GeV) electrically neutral carrier of the weak force. The press announced the discovery of 'heavy light', a highly apt description which has unfortunately fallen into disuse.

The weak force comes in two varieties - one which permutes electric charges (the classic example being the beta decay of a neutron into a proton and an electron), and a neutral variant which does not. Each has its carrier particle, and both were discovered at CERN - first the charged W, in January 1983, and then the Z, a few months later.

For both experiment and theory, the Z discovery was the culmination of a long and diligent quest without parallel in the history of modern physics. The missing piece of the 'electroweak' jigsaw finally clicked into place, and for ever after electromagnetism would be firmly linked with the weak nuclear force.

It was the twentieth-century remake, with a much bigger cast, of the story which began in 1864 when James Clerk Maxwell wrote down his four famous equations linking electricity and magnetism. This was the birth of a new science - electromagnetism.

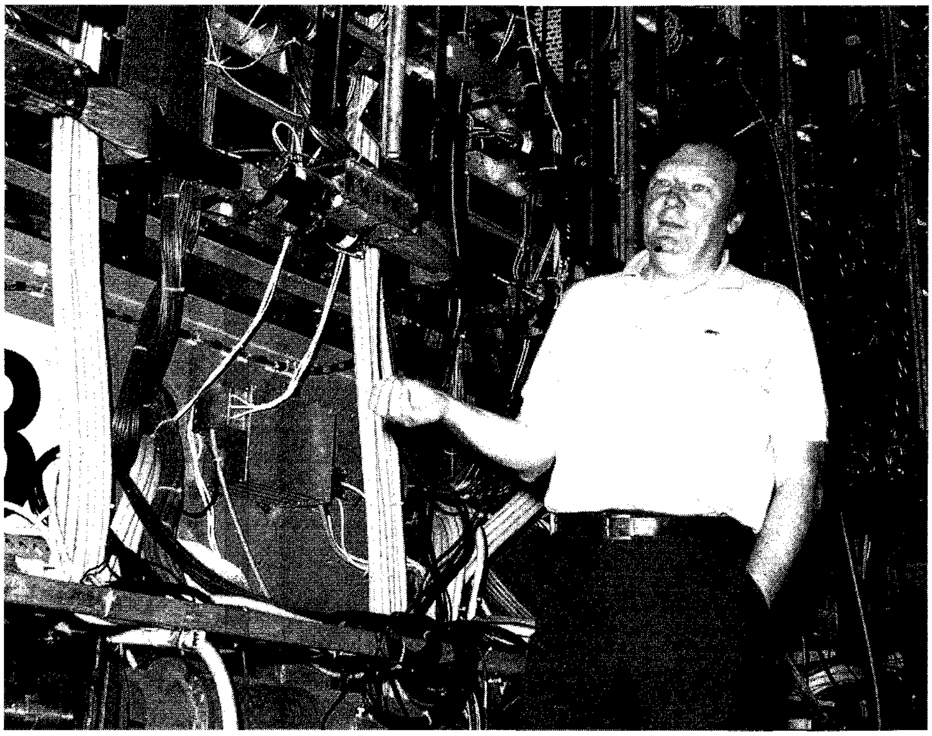
But Maxwell's equations suggested also that electromagnetic effects could be transmitted as waves travelling at the speed of light. As well as light itself, a complete spectrum of wavelengths should exist. Ten years later Heinrich Hertz' famous experiment revealed a new, invisible, component of electromagnetic radiation.

Extending Maxwell's electromagnetic unification (in quantum terms the emission and absorption of photons), the gauge theory ideas of twentieth century physics culminated in the 1960s in the work by Sheldon Glashow, Abdus Salam and Steven Weinberg which unified electromagnetism with the weak force. This idea had first been proposed in the 1930s and had regularly resurfaced, but a successful conclusion had to wait until all the necessary techniques were firmly in place.

Until then, all weak interactions were seen to switch round electric charge, but the Glashow/Salam/Weinberg picture predicted a new aspect to the weak force, the 'neutral current'. In 1973 - exactly twenty years ago (page 4) - this previously unseen mechanism was found at CERN. Neutrinos passing through the Gargamelle bubble chamber had jolted other particles in their wake.

The Uncertainty Principle says that the range of a force is inversely proportional to the mass of its carrier particle. The photon, the carrier of the long range electromagnetic force, is massless, but the W and Z 'radiation' of the short range weak force, had to be heavy, so much so that they were out of reach of conven-

A constant driving force in CERN's antiproton project, from inception through scientific discoveries, was Carlo Rubbia, seen here at his historic1983 stamping ground at the UA1 detector. In 1989 he became CERN's Director General.



tional experiments. New techniques were needed, and the CERN proton-antiproton collider, with its huge detectors was the solution.

A special session of the European Physical Society's International Conference on High Energy Physics in Geneva in 1979 marked CERN's 25th anniversary. Describing CERN science, CERN's Research Director-General at the time, Leon Van Hove, compared Hertz' discovery of electromagnetic radiation with what hundreds of people at CERN were busy doing.

'All you have to do,' joked Van Hove, 'is to replace Hertz' rudimentary radiation emitter and coil detector with, respectively, the proton-antiproton collider now being constructed at CERN's 7-kilometre SPS proton synchrotron and the huge UA1 and UA2 detectors!'

As well as embodying the difference between 19th-century and 20th-century science, that big CERN project also marked the dawn of a new era in particle physics. Building on Simon van der Meer's suggestions for beam cooling, it showed that the beam gymnastics required for new physics goals required careful planning and teamwork as well as consummate skill. Physics experiments broke new ground in sheer scale and complexity, with hundreds of people involved in the design, installation and operation of huge detectors and the analysis of the recorded data.

With Van Hove's challenge met, the 1984 Nobel Prize for Physics was awarded to Carlo Rubbia and Simon van der Meer 'for their decisive contributions to the large project which led to the discovery of the field particles W and Z, the carriers of the weak interaction'.

As well as being crowned with success, the proton-antiproton achievements also prepared the research community for the next stage - colliding beam projects with even larger detectors, such as those for CERN's LEP electron-positron collider.

From May 1983 to June 1989, high energy proton-antiproton colliders were the only source of Zs. Fermilab joined the hunt in 1985, when the big CDF experiment captured its first events at the Tevatron collider.

Meanwhile big new projects were taking shape. To cash in on electroweak physics, CERN was building its 27-kilometre LEP electron-positron collider, the world's first Z factory, while at Stanford the two-mile linear accelerator was adapted to become the SLC - Stanford Linear Collider - the world's first electron-positron linear collider.

In the summer of 1989 the upgraded Mark II detector at SLC saw several hundred Zs, a large number when the total count at the two proton-antiproton colliders at the time was less than a thousand. Rather than simply catching Zs, an electron-positron collider can be tuned to sweep across the Z resonance. The first glimpse of the Z profile at SLC suggested strongly that there are only three neutrino decay channels open for the Z. With its three quark pairs and three types of lepton, the Standard Model looked to be capped.

Later that summer LEP turned on, and before the end of the year its four experiments - Aleph, Delphi, L3 and Opal - had bagged some ten thousand Zs. The lid was sealed on Standard Model particles. Since then LEP has not looked back, with the current Z score 4.5 million.

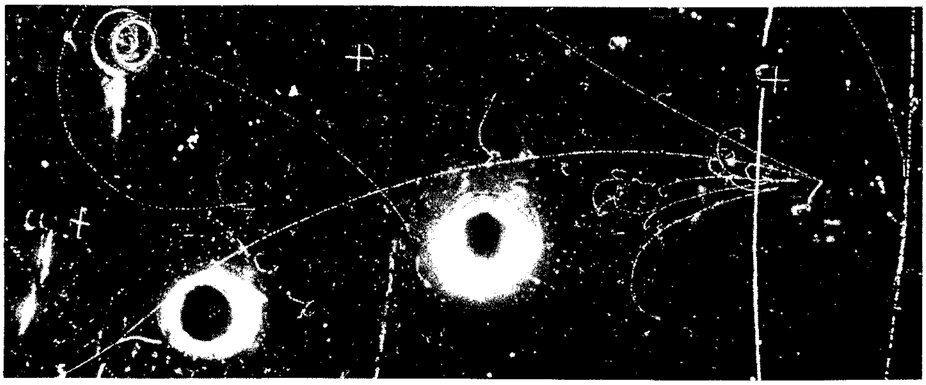
Although out of the running for sheer numbers of Zs, the SLC has the so far unique ability to make Zs from polarized (spin oriented) beams,

providing added value to the data sample.

Z physics has come a long way since May 1983.

Thirty Years of Weak Neutral Currents!

Ten years of searching preceded the discovery of the neutral current at CERN in 1973.



Twenty years ago at CERN, a new form of interaction, the neutral current, was discovered. However for the preceding ten years physicists already had been searching for variants of this interaction, so a symposium held on February 3-5 by the Pacific Ocean in Santa Monica, California reviewed a total of thirty years of neutral current research.

The meeting began with an overview of the development of the understanding of weak interactions from the 1930s to 1950s. Laurie Brown (Northwestern) led this discussion, which was followed by a tribute to the milestone accomplishments of the late Ben Lee and J.J. Sakurai (UCLA).

In the Weak Neutral Currents (WNC) discovery, neutrinos were seen to interact with target particles but still continued on their way as neutrinos. This was the first time that the weak interaction had revealed a disdain for electric charge - previously all weak interactions had been seen to permute the electric charges of the participating particles. It opened the door to new synthesis and un understanding.

The discovery had followed a decade of careful search, in which one major target had been Flavor Changing Weak Neutral Currents (FCWNC) - in which neutral current interactions would be accompanied by transitions of the strange quark. David Cline (UCLA) looked at the initial unsuccessful attempts to detect WNC at Brookhaven and CERN in the 1960s and the early search for FCWNC.

The absence of strange quark transitions set the stage for the introduction of a fourth quark ('charm') - the GIM mechanism - and the subsequent emergence of the Standard Model.

The era of the WNC discovery in 1973 was described by science historian Peter Galison (Harvard). Dieter Haidt (DESY) represented the Gargamelle Collaboration at CERN credited with the discovery, while Al Mann (Penn), representing the Harvard-Penn-Wisconsin-Fermilab (HPWF) collaboration, put the observations in the context of Fermilab's appearance on the physics scene, with a new detector in an unexplored neutrino energy range.

Lively discussion between the audience and members of the Gargamelle and HPWF groups recalled the experiences of 1973. Paul Langacker (Penn) gave an overview - "The Five Phases of Weak Neutral Currents."

Sid Bludman (Penn) described the first gauge theory of weak interactions as well as the success of the Weinberg-Salam-Glashow model. Nicola Cabibbo (Rome) described the early days of quark mixing, recounting how he came to invent the first quark mixing theory. His talk was followed by George Snow (Maryland) recounting early data from hyperon decays and the then new Cabibbo model.

In 1974 came a seminal paper on charm by Ben Lee, Marie K. Gaillard and Jon Rosner. Two of the authors were at Santa Monica: Marie Gaillard (Berkeley) described a model of strong WW interactions, while Jon Rosner (Chicago) spoke on the current status of mass constraints on the sixth ('top') quark.

The meeting then changed direction to discuss the implications of neutral currents in astrophysics. David Schramm (Chicago) and James Wilson (Livermore) explained how supernovae explode, while George Fuller of San Diego looked at how supernova data can restrict electron-neutrino/tau neutrino mixing.

For the arrival on the scene of proton-antiproton colliders and the discovery of the W and Z particles at CERN by the team led by Carlo Rubbia, Andy Sessler (Berkeley) gave a beautiful review of the history of colliding beams concepts from invention (1957) to the idea of stochastic cooling by Simon Van der Meer (1968). A review and discussion of the development of the proton-antiproton colliders at Fermilab and CERN and the important discoveries at CERN was led by