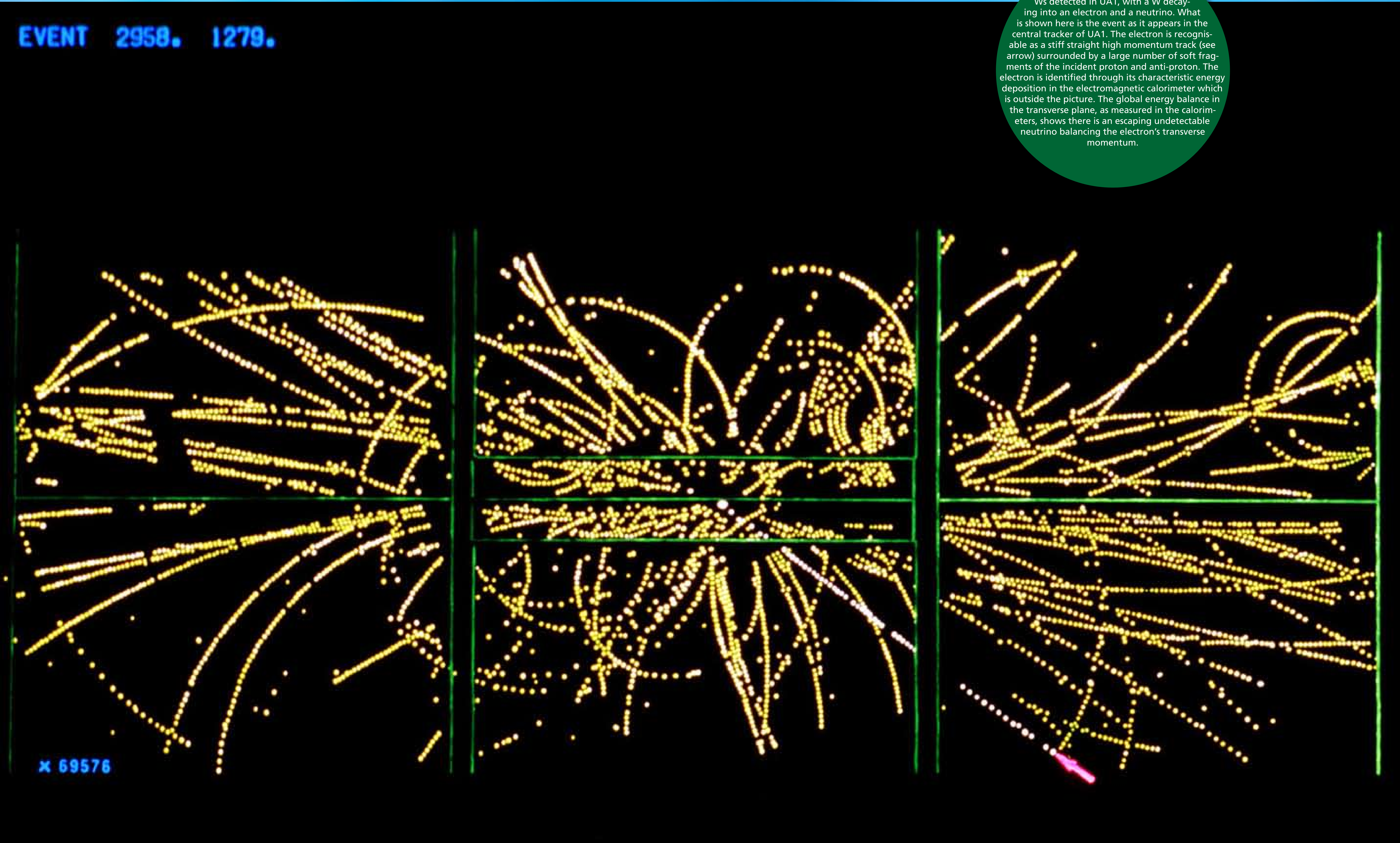
The Weak Force

discoveries

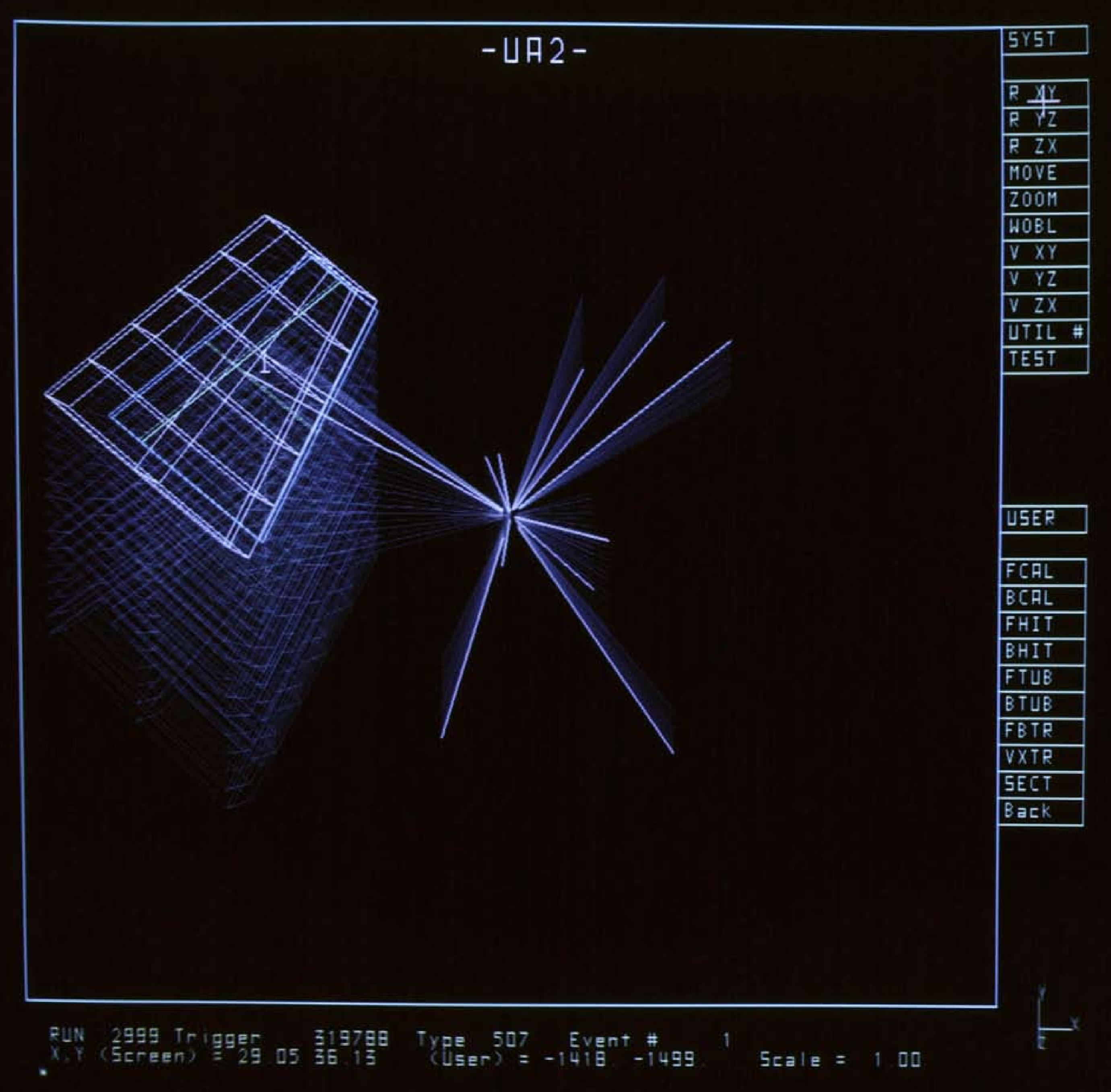
A neutrino, entering from the right, emits a virtual Z boson which is absorbed by a quark inside a neutron. The energy which is deposited creates quark-antiquark pairs. These combine with the neutron quarks to make a proton and two pions, π^0 and π^-. The proton is knocked on and the π^0 decays immediately into 2 photons which convert into electron-positron pairs. The π^- interacts with a proton creating another π^0 which immediately produces 2 photons which in turn become electron-positron pairs.

from neutral currents...

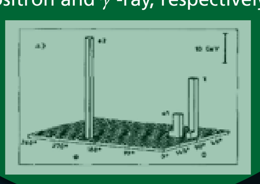
CERN



This event shows one of the first Ws detected in UA1, with a W decaying into an electron and a neutrino. What is shown here is the event as it appears in the central tracker of UA1. The electron is recognisable as a stiff straight high momentum track (see arrow) surrounded by a large number of soft fragments of the incident proton and anti-proton. The electron is identified through its characteristic energy deposition in the electromagnetic calorimeter which is outside the picture. The global energy balance in the transverse plane, as measured in the calorimeters, shows there is an escaping undetectable neutrino balancing the electron's transverse momentum.



A Z –> e+e- γ decay observed by UA2 in 1983 in a relatively rare configuration with the γ -ray emitted at large angle to both the electron and positron. On the left, a view of the event normal to the proton-antiproton line of flight: the track at ~1 o'clock is identified as the electron, while the γ -ray conversion is detected at ~2 o'clock. The positron is the track shown at ~8 o'clock: it is detected in one of the forward UA2 detectors as shown on the right. In this "Lego" plot of the event, the heights of the three towers are proportional to the transverse momentum components of the electron, positron and γ -ray, respectively.



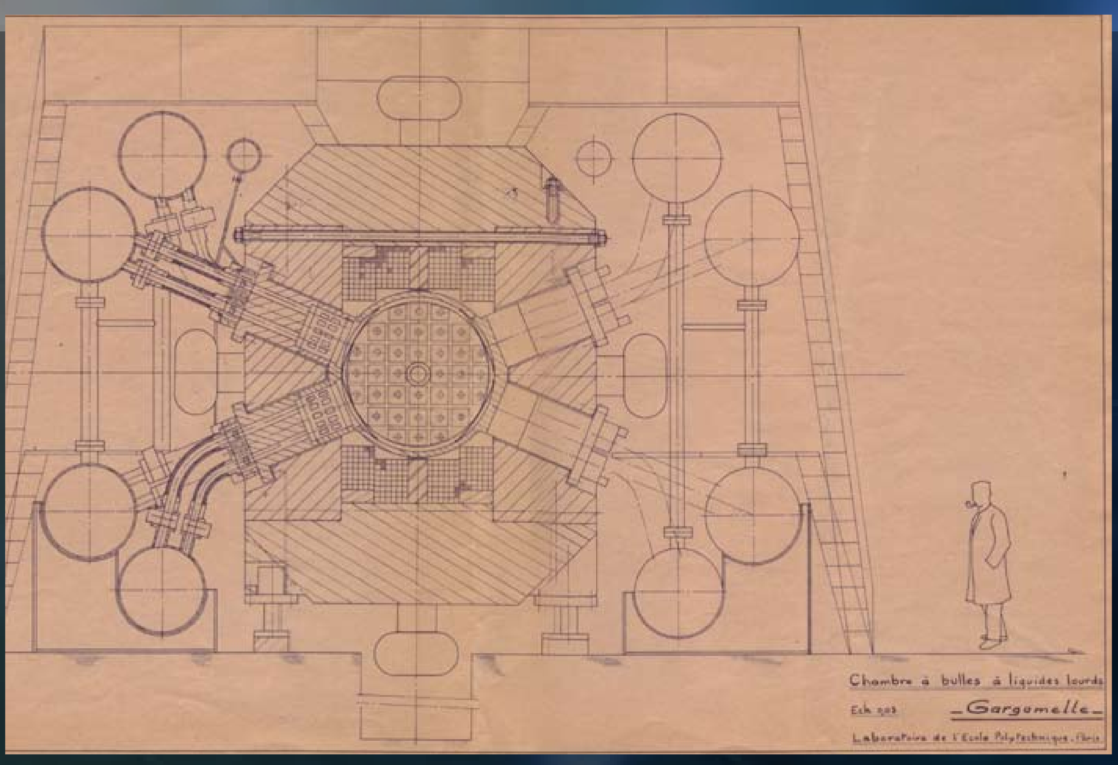
...to the W and Z

Making the neutrino beam *at the PS*

Neutrinos and antineutrinos are ideal for probing the weak force because it is effectively the only force they feel.

Protons fired into a metal target produce a tangle of secondary particles. The magnetic horn, invented by Simon van der Meer, selected pions of a given electric charge and focused them into a parallel beam. Pions decay into muons and neutrinos or antineutrinos. The muons were stopped in a wall of 3000 tons of iron and 1000 tons of concrete, leaving the neutrinos or antineutrinos to reach the Gargamelle bubble chamber. A simple change of magnetic field direction on the horn flipped between focusing positively- or negatively-charged pion beams, and so between neutrinos and antineutrinos.

The magnetic horn.



Assembly in progress inside the Gargamelle heavy-liquid bubble chamber.

The Gargamelle bubble chamber was built at Saclay in France and came into operation at the PS in 1971. The chamber had a cylindrical body 4.8 m long and 1.85 m wide, with a volume of 12 cubic metres.

Neutral currents *in Gargamelle*

Major breakthroughs came in 1972 and 1973. At CERN, André Lagarrigue and his colleagues found evidence for neutral currents in Gargamelle bubble chamber pictures.

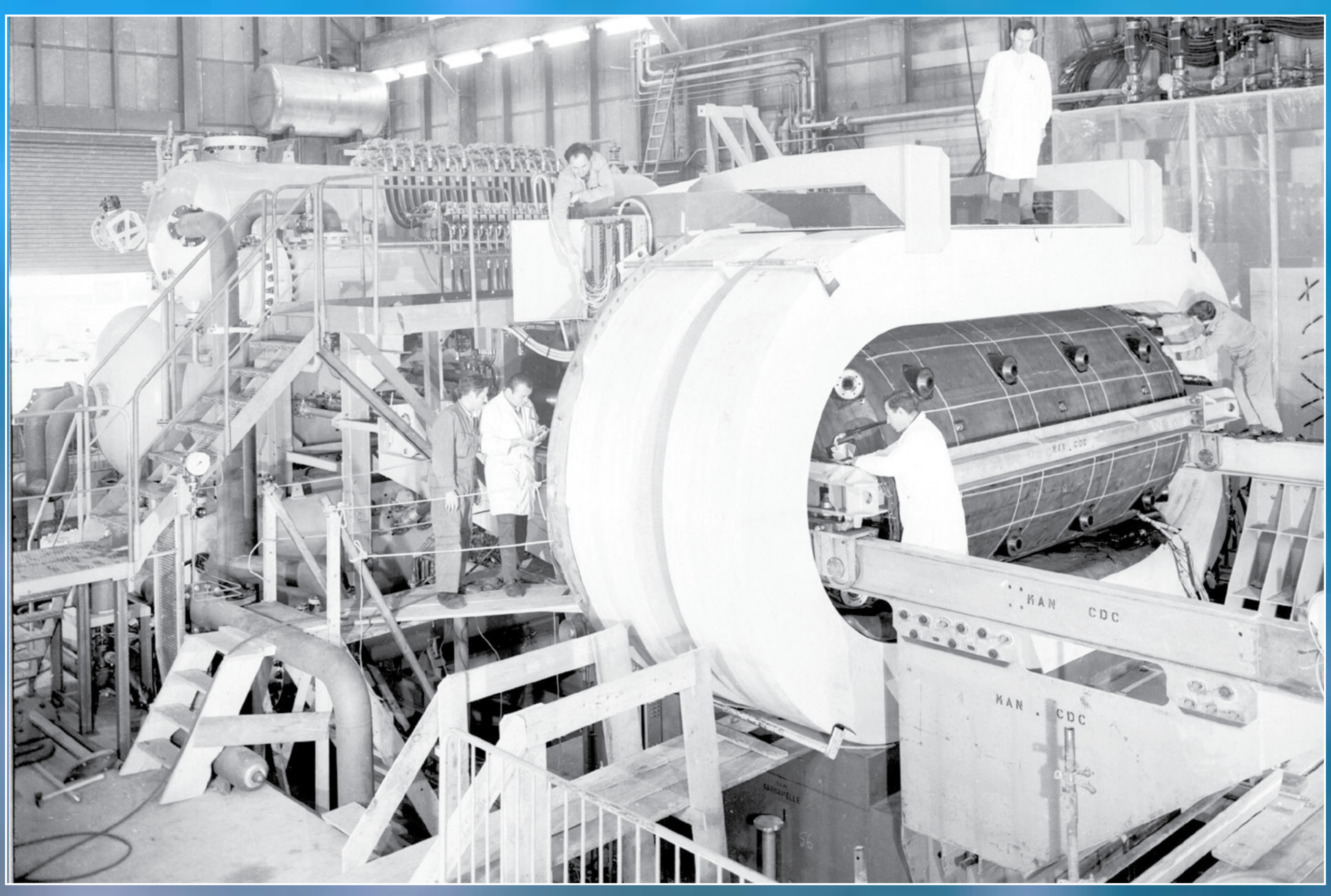
Intense beams of neutrinos and antineutrinos were fired through the liquid-filled chamber. Very infrequently a neutrino (or antineutrino) interacted with a particle and in some cases it survived. This proof that neutral currents existed was a triumph for theory and experiment.

Neutral currents, whose existence was extremely hypothetical in those days, were only eighth on the planned list of experiments for Gargamelle.

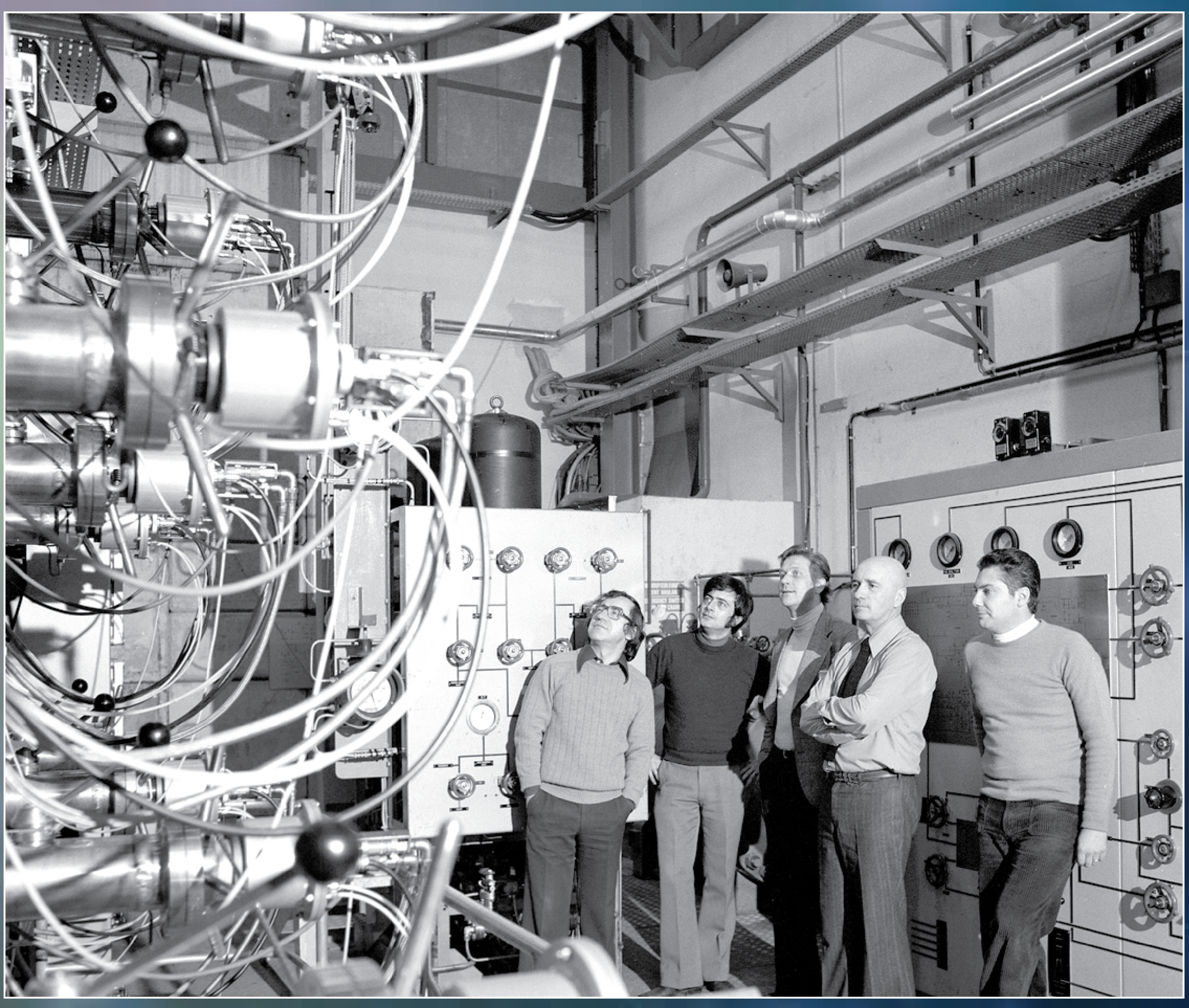
"We quickly found candidate events for neutral currents but I was still very doubtful until a meeting at CERN in May 1972, when all the laboratories involved in the collaboration presented photos of their candidates. I came away firmly convinced, as did many of my colleagues. That was when we really began to get excited because, after finding so many semi-precious stones in our experiments over the past ten years, we were now starting to glimpse a genuine diamond!"

Violette Brisson, Infinitely CERN, 2004

The hunt for the W and Z particles, vectors of the weak force at the origin of neutral currents, would now well and truly begin. Meanwhile, Gargamelle went on to make other discoveries. In 1976, the chamber was moved to the SPS where it ran for another 3 years.



Gargamelle inside its magnet coils.



Looking at Gargamelle: P. Musset, M. Price, W. Birr, R. Gregoire, A. Scaramelli.

The SPS

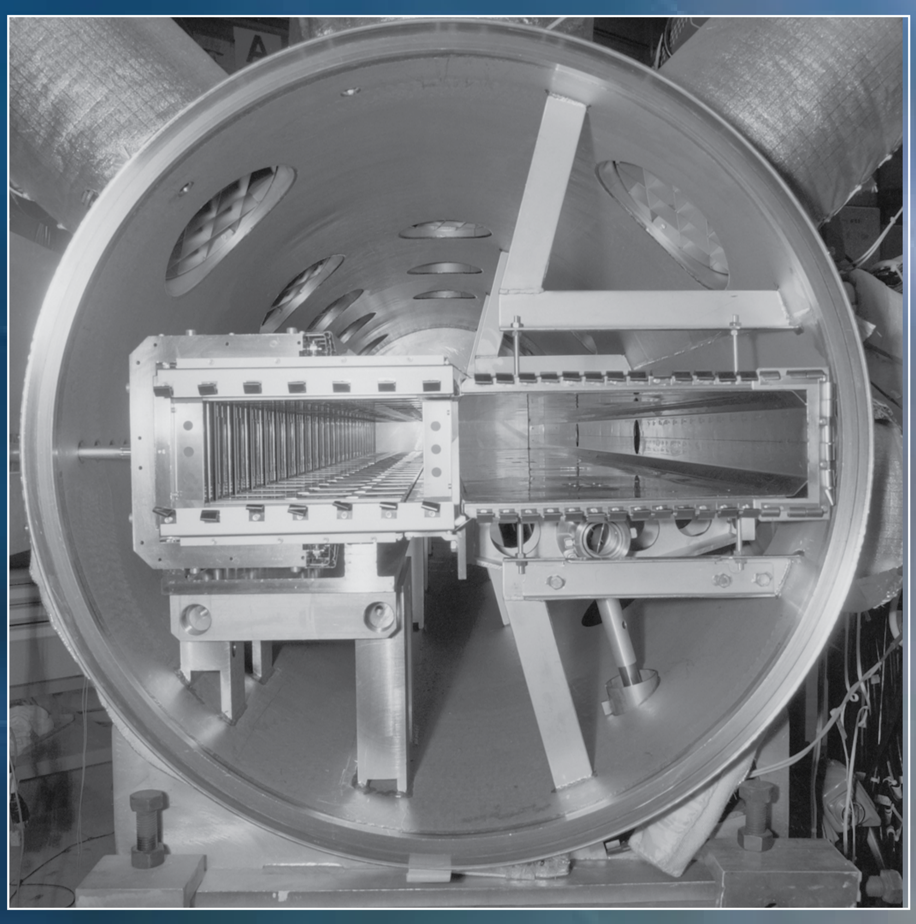
The idea of W and Z bosons weighing 80 GeV and 90 GeV respectively was not easily accepted. Could such massive elementary particles really exist? The ultimate proof would be to create them. How could enough energy be found?

Head-on collisions release much more energy than firing a particle into a stationary target. So Carlo Rubbia suggested turning the Super Proton Synchrotron (SPS) into a proton-antiproton collider.

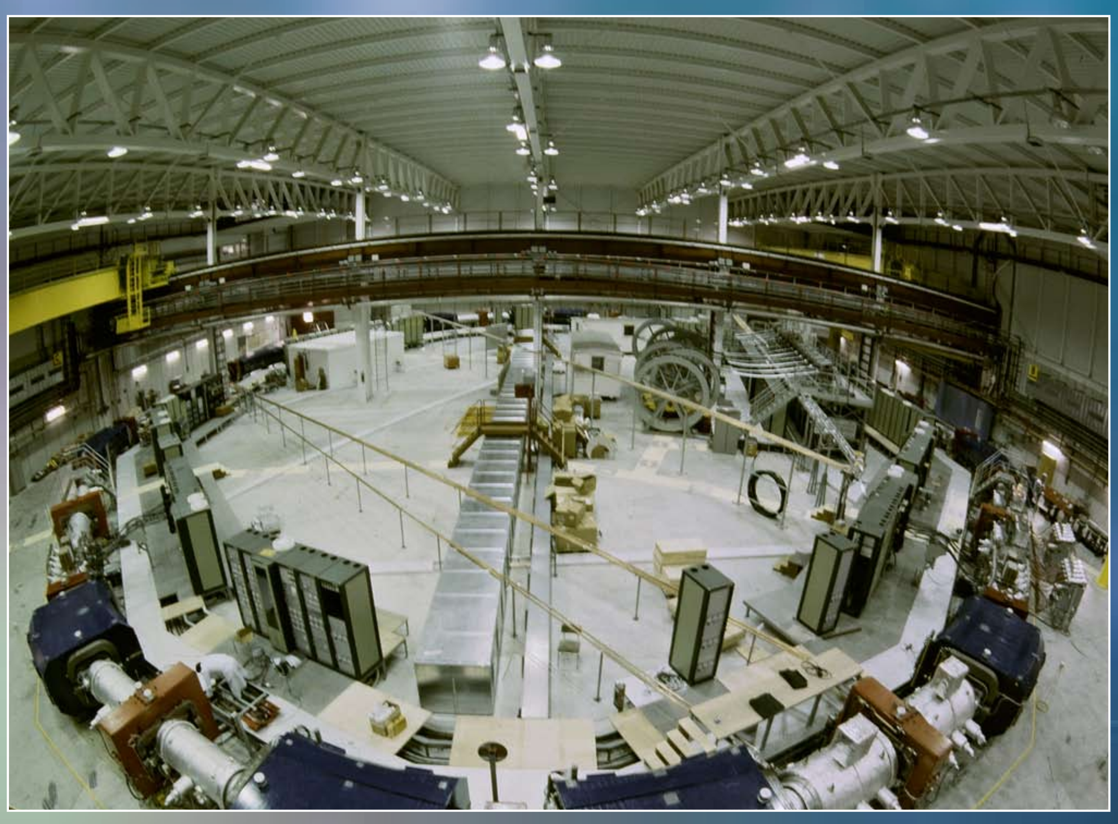
The high energy SPS had been running for only 2 years, but Rubbia convinced CERN's Management that such a dramatic change of direction was a risk worth taking. In June 1978 the Research Board gave the go ahead.

The accelerator physicists faced the challenge of producing very intense beams of antiprotons, to ensure a good chance of collisions with protons in the new SPS.

Stochastic cooling invented by Simon van der Meer made this possible. This technique concentrates particles into a dense beam by reducing their random motion. A slice of the beam is observed at one point of the ring and signals are sent on a short cut across the ring to meet the slice and kick it into line. This process is repeated millions of times, progressively concentrating the particles.



A stochastic cooling pick-up at the Antiproton Accumulator (AA).



The AA hall in 1980.

"The challenge of designing, constructing and assembling the anti-proton source and detectors, and of getting them to work in such a short time, was enormous; as was that of digging and equipping the large experimental halls required for housing the new detectors that had to be alternately rolled in and out between collider and fixed target periods; and that of transforming the SPS into a collider. The amount of ingenuity that went into all these achievements was truly outstanding." Pierre Darriulat, CERN courier, April 2004

Completion of the boring of the SPS tunnel in 1974.

A section of the SPS tunnel in 1977.

Breaking through from the SPS into the LHC transfer tunnel in May 2001.

CERN

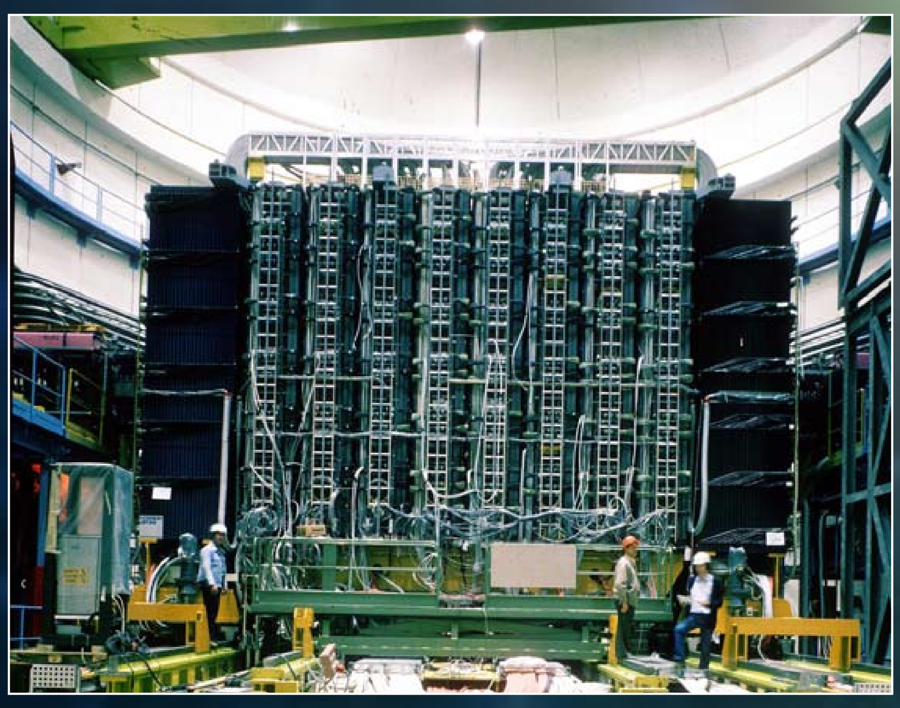
UA1 & UA2

To a packed CERN auditorium on the 20th and 21st January 1983, UA1 and UA2 presented their first candidate Ws. At a press conference on the 25th, UA1 announced the discovery of the W boson. Summer brought the Zs. The characteristics of these long-awaited particles were just as the electroweak theory predicted.

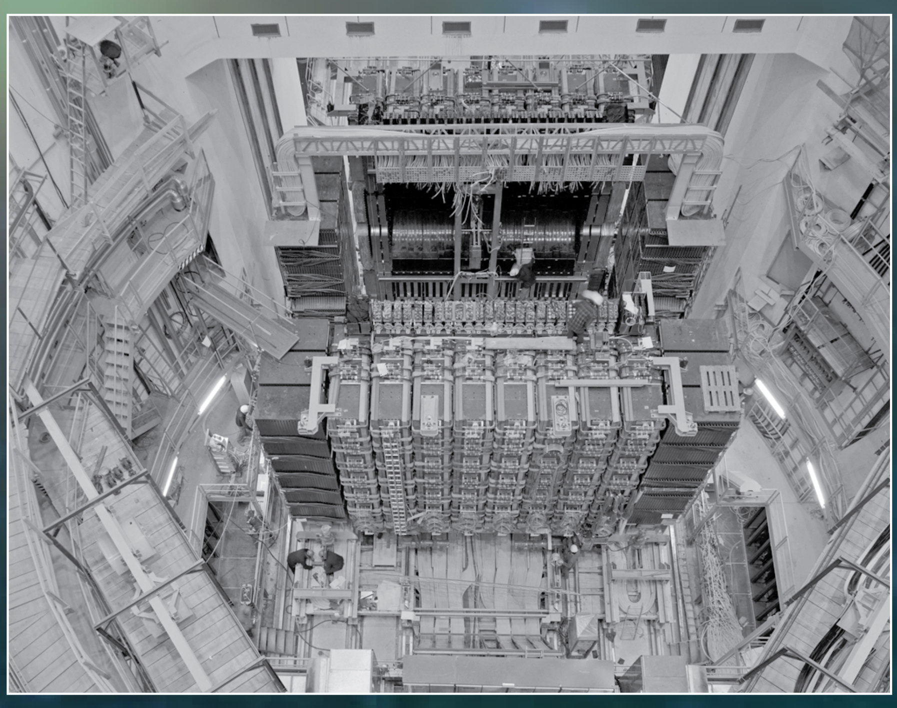
The discovery was the culmination of theoretical inspiration, technological excellence, dedicated experimentation and teamwork on a scale never before seen in particle physics. This tremendous effort was rewarded in 1984 when Carlo Rubbia and Simon van der Meer shared the Nobel physics prize.

Carlo Rubbia and Simon van der Meer in 1984.

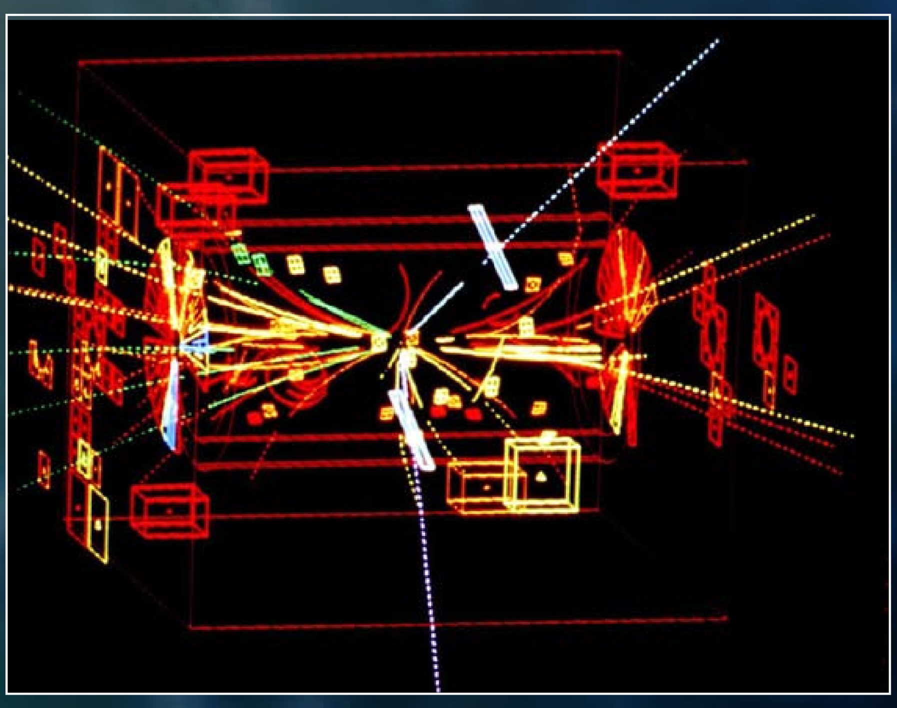
"The discovery of the W and the Z, promptly recognized by the Nobel Committee, was then the tip of the iceberg of a marvellous and unique adventure in which many remarkable people from many different countries, several of whom unfortunately no longer with us, have proudly contributed. […] The time has come for a generation change and a new CERN is now in place. To quote Simon van der Meer: "If they have some idea — however crazy it is — they should check up on it. Once in a hundred times it will turn out to be a good idea." Carlo Rubbia, Infinitely CERN, 2004



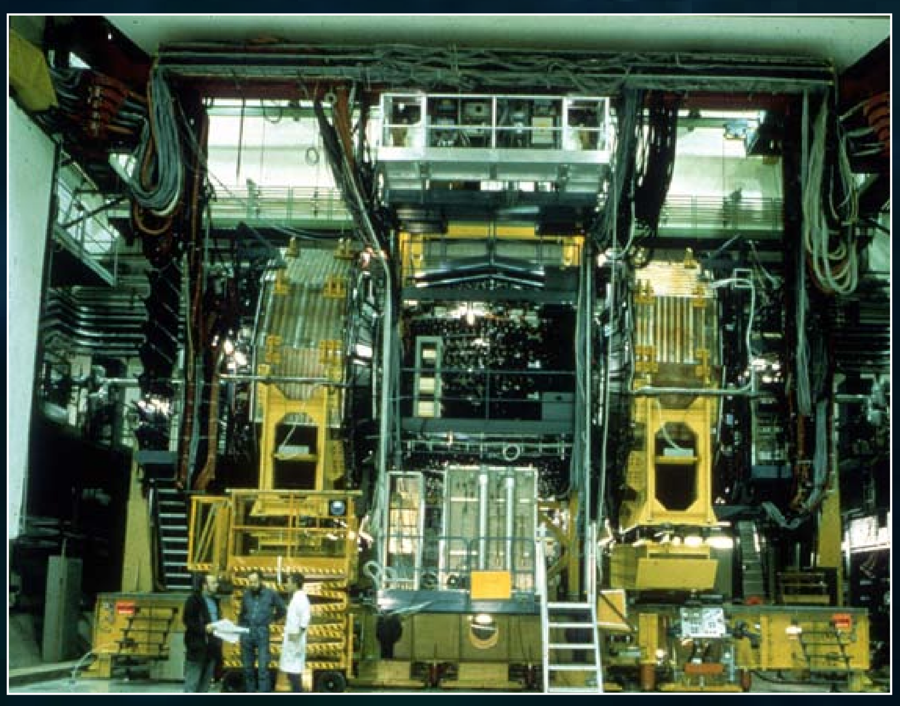
UA1 during assembly, April 1981.



Looking down into the UA1 pit, February 1981.



UA1 first Z.



The UA2 detector in 1987
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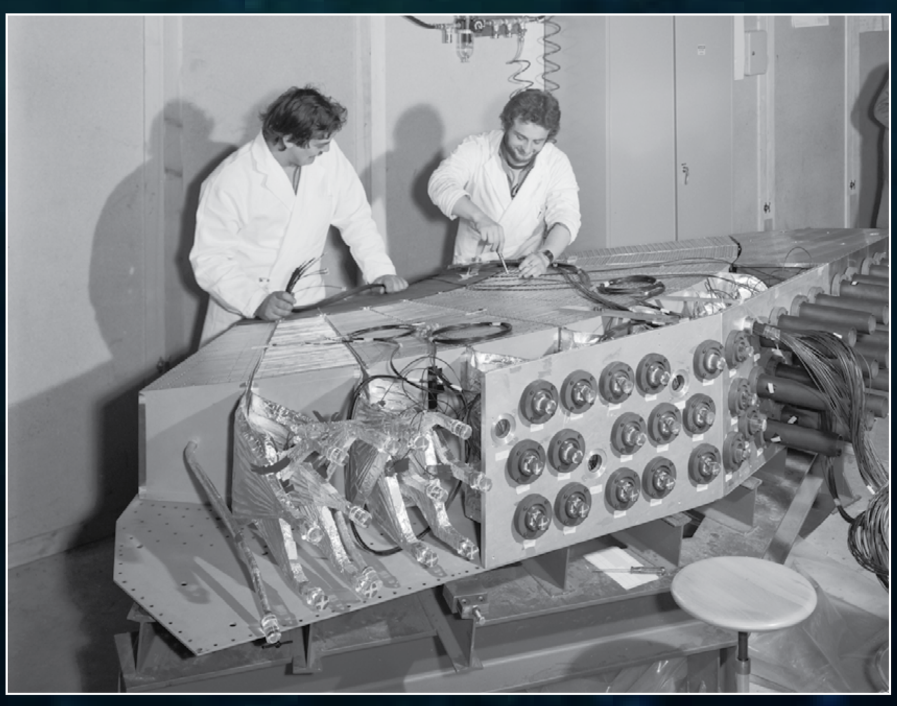
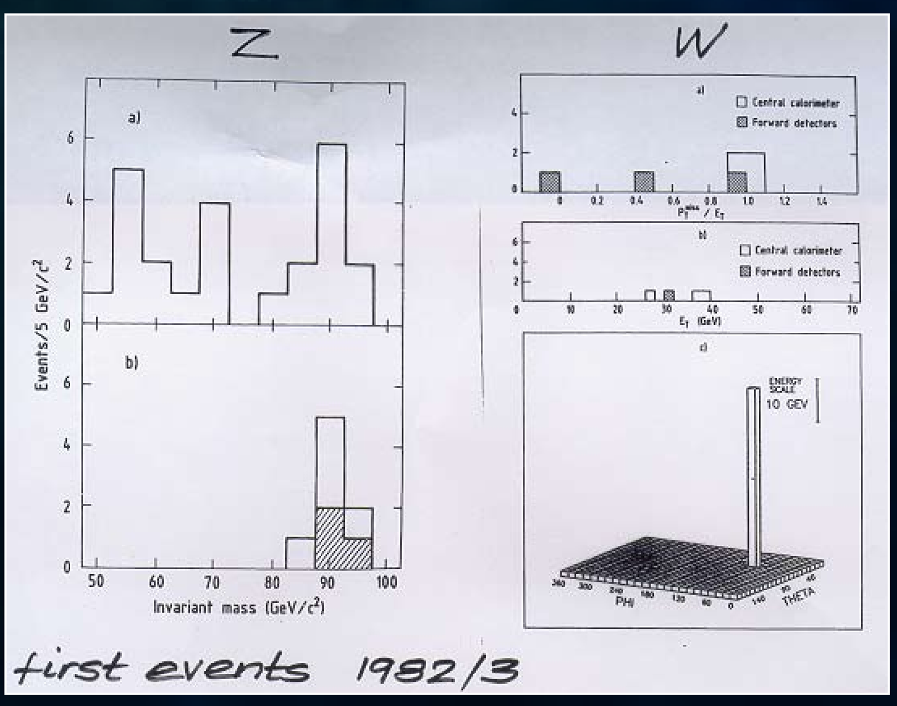


Assembling the UA2 calorimeter in 1980.



UA2 first Wand Z.