1983:
first W and Z decays in UA2

CERN
31 October 2023

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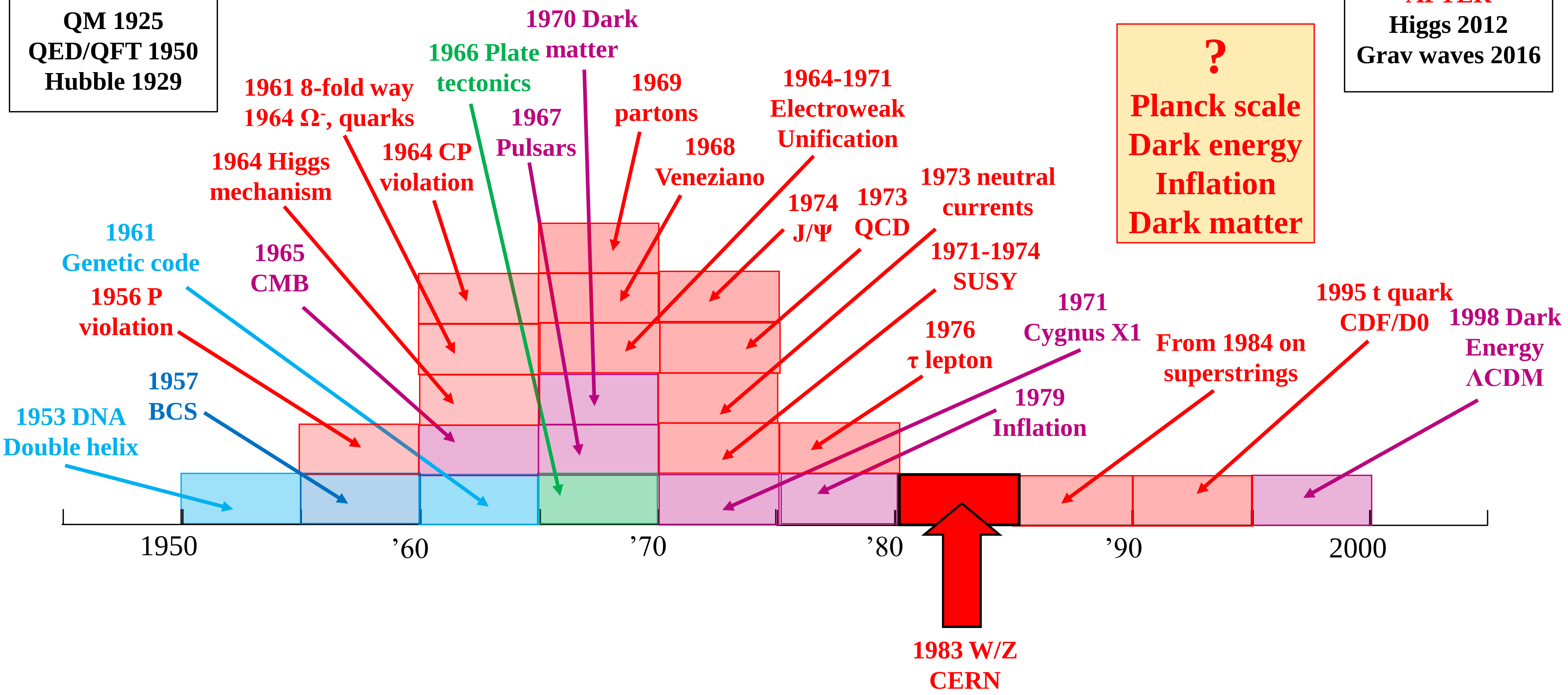
SECOND HALF OF THE TWENTIETH CENTURY
SOME MAJOR SCIENCE LANDMARKS

BEFORE
Sp Rel 1905
Gen Rel 1915
QM 1925
QED/QFT 1950
Hubble 1929

AFTER
Higgs 2012
Grav waves 2016



In the late 70's, science had just gone through one of its richest harvests of new ideas and discoveries. The Standard Model was urging to search for W, Z, t and H.

Several future accelerators and colliders
were being considered for such a task

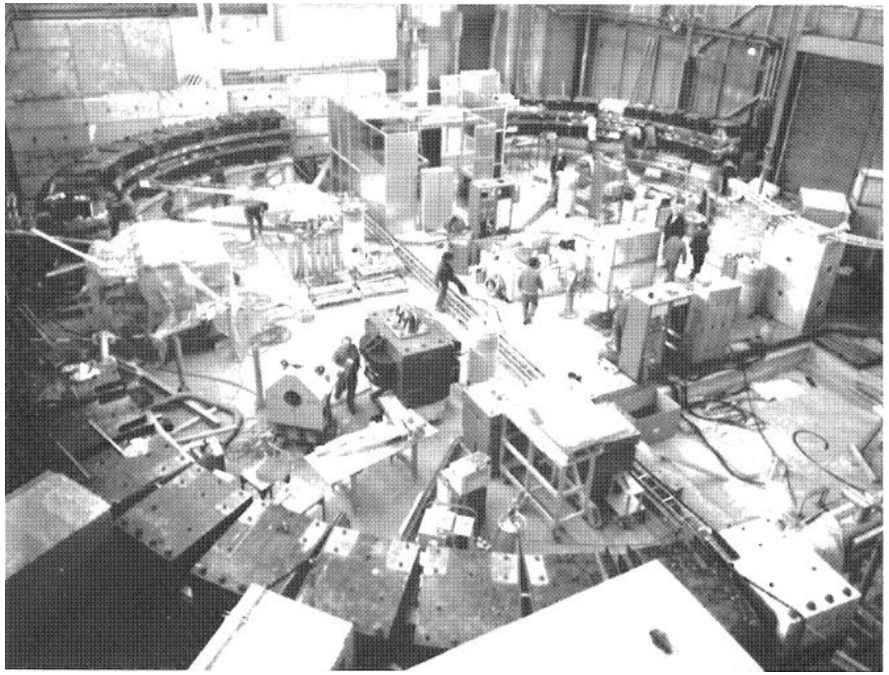
At CERN as soon as the SPS started operation (1976),
Rubbia, McIntyre and Cline proposed to use it as a p-pbar collider.

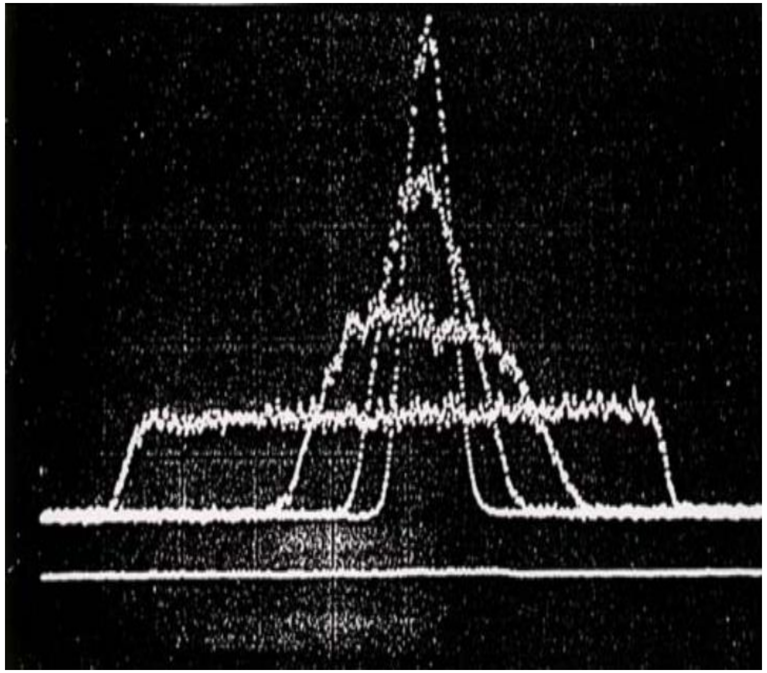
After completion of the ISR (1974) several options were considered:
– CHEEP: 27 GeV electrons (new ring) against 270 GeV SPS protons,
– LSR/SISR: pp collider with 400 GeV per beam (*Luigi CERN 76-12*),
– MISR: 60 GeV protons (storage ring using ISR magnets) against SPS protons,
– SCISR: 120 GeV protons colliding in ISR tunnel using superconducting magnets,
– p-pbar collisions in the SPS tunnel (new antiproton source),
– Large Electron-Positron (LEP) ring in a new tunnel (*me CERN 76-18*).

1978: decision to go for p-pbar in SPS as medium-term project,
and concentrate on LEP as the future long-term flagship.

In the US: ISABELLE (200+200 Gev pp), construction stopped in 1983
to give way to SSC (pp 40 TeV √s) abandoned in 1993.
p-pbar project at FNAL stopped in 1978 due to insufficient vacuum.

Only transverse stochastic cooling had been demonstrated at the ISR by Simon Van der Meer. In February 1977, ICE was assembled to prove simultaneous stochastic cooling in all three dimensions. In May 1978, it delivered successful results and in June the decision was made to go for p-pbar in the SPS. The Antiproton Accumulator (AA) was built from 1979 to 1980. It was a 3.5 GeV/c pbar storage ring, fed by a target hit by 26 GeV/c PS protons, 157 m in circumference and stochastically cooled. The SPS vacuum was upgraded from the design 200 nTor to less than 2 nTor, low-beta insertions were installed for UA1 and UA2, electrostatic deflectors were produced to separate the beams, and the rf system was upgraded. New transfer lines were built to and from the AA and from the PS to the SPS.





As soon as the p-pbar project was given the green light, Luigi Di Lella, Marcel Banner and I, together with colleagues and members of another French team, joined effort to propose a detector. At strong variance with Carlo, none of us had been advocating a particular future accelerator/collider option but we were actively following progress and in particular taking part in the working group for designing the UA1 detector.

Our main asset was a solid experience and familiarity with collider experiments at the ISR and with related theory thanks to M. Jacob, J. Ellis and M.K. Gaillard.

Carlo had done the hard work, against many opponents, in spite of serious tune-shift concerns from SLAC, for several years; we were joining at the last moment to share with him the harvest of his efforts.

We were accordingly recognizing and respecting him as the King,
even if not belonging to the court and, as I wrote jokingly twenty years ago,
we were enjoying the very rare moments when the King was naked.

In the end of 1978, our proposal, was submitted to the selection committee in competition with one from Sam Ting's group, and retained with the condition that its cost should be much less than UA1's. We were soon after joined by teams from Bern, Copenhagen and Pavia who took responsibility in the construction of forward trackers while Orsay was in charge of the central tracker, Saclay of the forward calorimeters and CERN of the central calorimeter

M. BANNER, **R. BATTISTON**, **Ph. BLOCH**, **F. BONAUDI**, **K. BORER**, **M. BORGHINI**, **J.-C. CHOLLET**, **A.G. CLARK**, **C. CONTA**, **P. DARRIULAT**, **L. DI LELLA**, **J. DINES-HANSEN**, **P.-A. DORSAZ**, **L. FAYARD**, **M. FRATERNALI**, **D. FROIDEVAUX**, **J.-M.GAILLARD**, **O. GILDEMEISTER**, **V.G. GOGGI**, **H. GROTE**, **B. HAHN**, **H. HÄNNI**, **J.R. HANSEN**, **P. HANSEN**, **T. HIMEL**, **V. HUNGERBÜHLER**, **P. JENNI**, **O. KOFOED-HANSEN**, **E LANÇON**, **M. LIVAN**, **S. LOUCATOS**, **B. MADSEN**, **P. MANI**, **B. MANSOULIÉ**, **G.C. MANTOVANI**, **L. MAPELLI**, **B. MERKEL**, **M. MERMIKIDES**, **R. MOLLERUD**, **B. NILSSON**, **C. ONIONS**, **G. PARROUR**, **F. PASTORE**, **H. PLOTHOW-BESCH**, **M. POLVEREL**, **J.-P. REPELLIN**, **A. ROTHENBERG**, **A. ROUSSARIE**, **G. SAUVAGE**, **J. SCHACHER**, **J.L. SIEGRIST**, **H.M. STEINER**, **G. STIMPFL**, **F. STOCKER**, **J. TEIGER**, **V. VERCESI**, **A. WEIDBERG**, **H. ZACCONE** and **W. ZELLER**

BERN, CERN, COPENHAGEN, ORSAY, PAVIA, SACLAY

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/SPSC/78-13
SPSC/P 93/S
February 1st, 1978

PROPOSAL
TO STUDY ANTIPROTON-PROTON INTERACTIONS
AT 540 GEV CM ENERGY

***

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SUMMARY

We propose an experiment, the main purpose of which is to detect the production and decay of the $W^{\pm}$ and Z^0 bosons at the SPS $p\bar{p}$ facility. The design of the apparatus combines large solid angle coverage, with compactness and simplicity of operation. It includes electromagnetic and hadronic calorimetry in the central region and magnetic spectrometers in the forward and backward cones equipped for electron detection. In addition a small azimuthal wedge in the central region is instrumented to cover other aspects of $p\bar{p}$ collisions, such as a possible quark search, the study of large transverse momentum jets, etc...

1) CEN-Saclay, France.
2) CERN, Geneva, Switzerland.
3) LAL-Orsay, France.
* Presently CERN fellow.

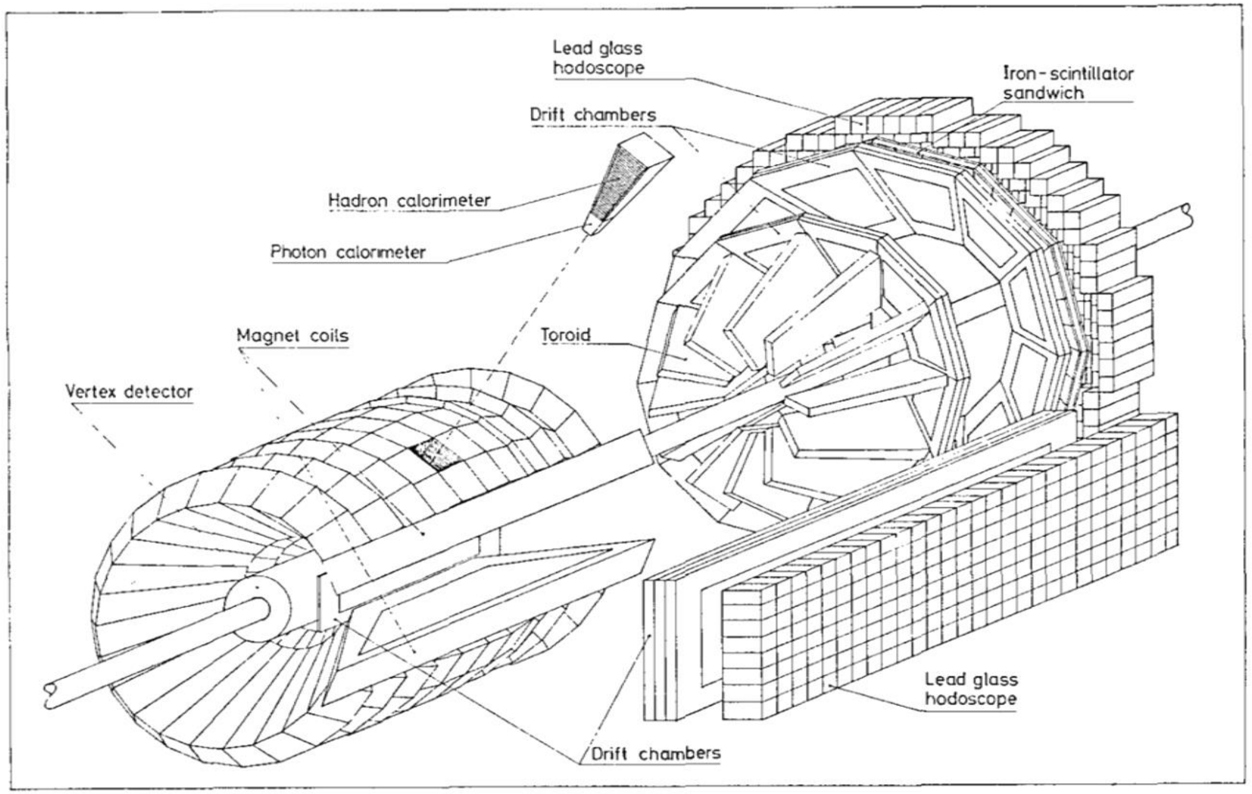

Figure 4

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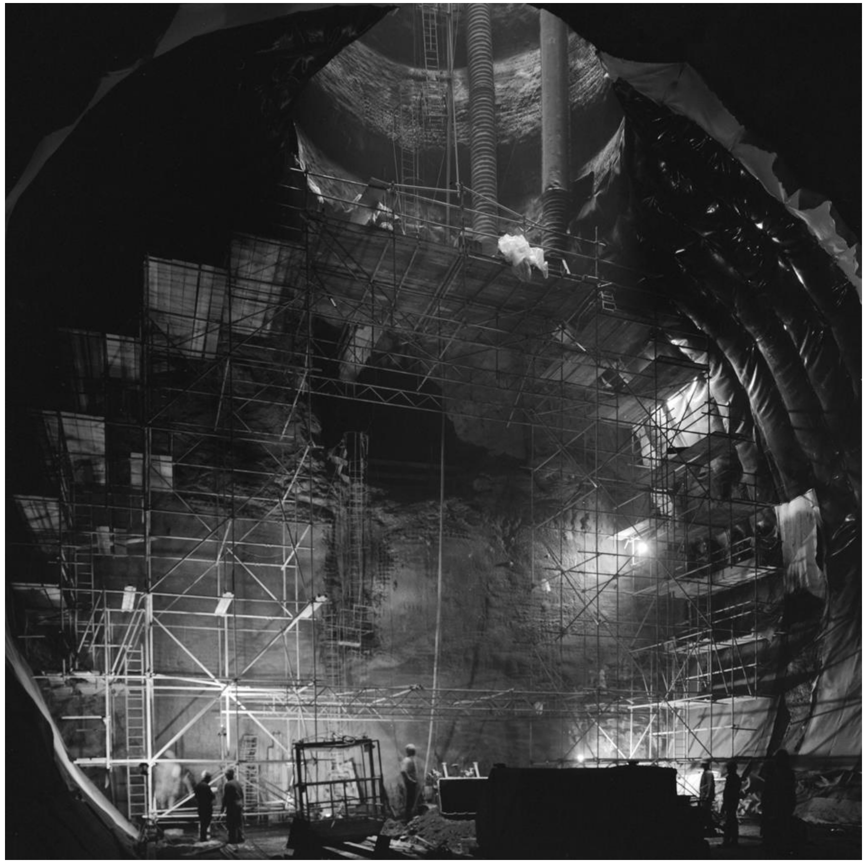
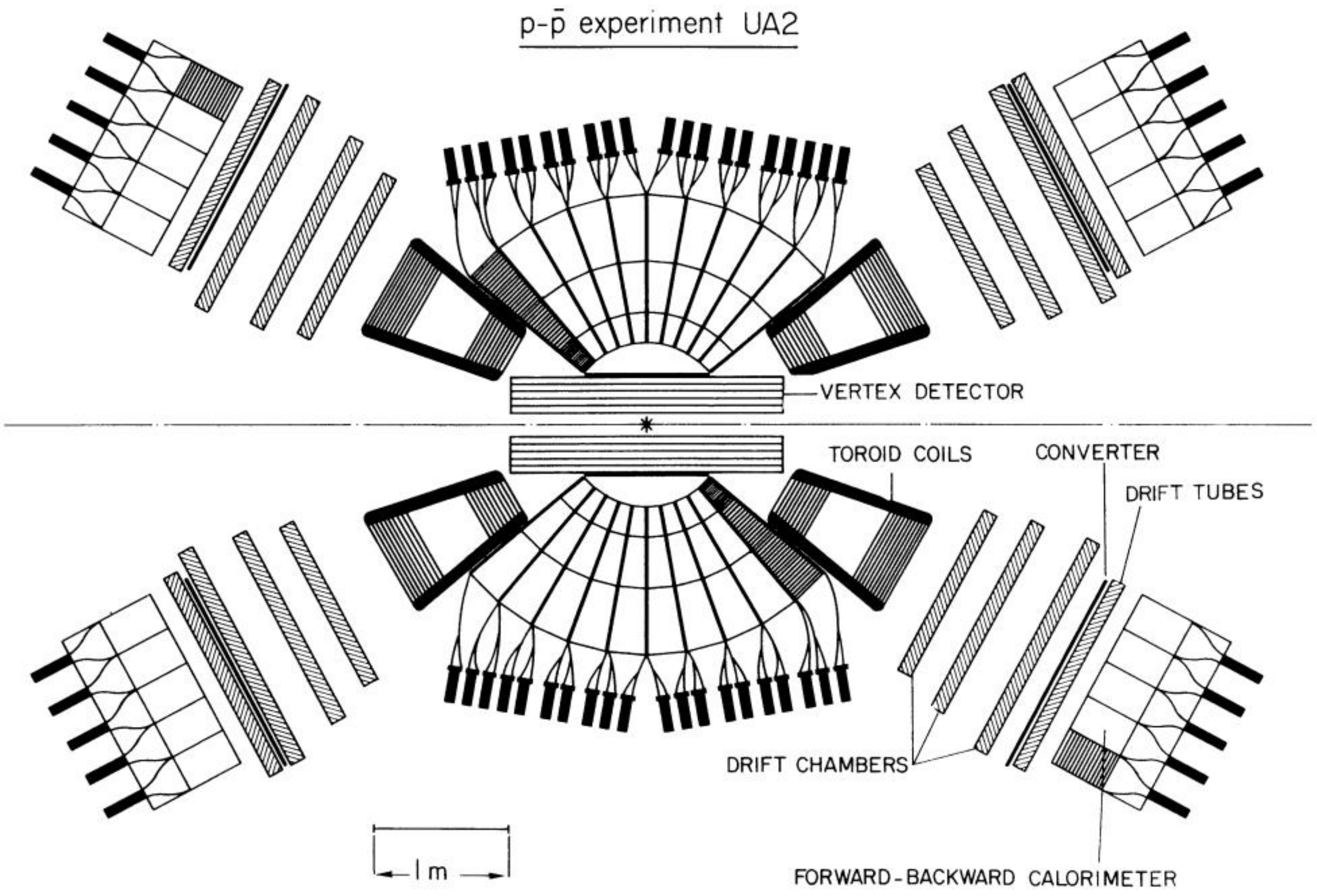
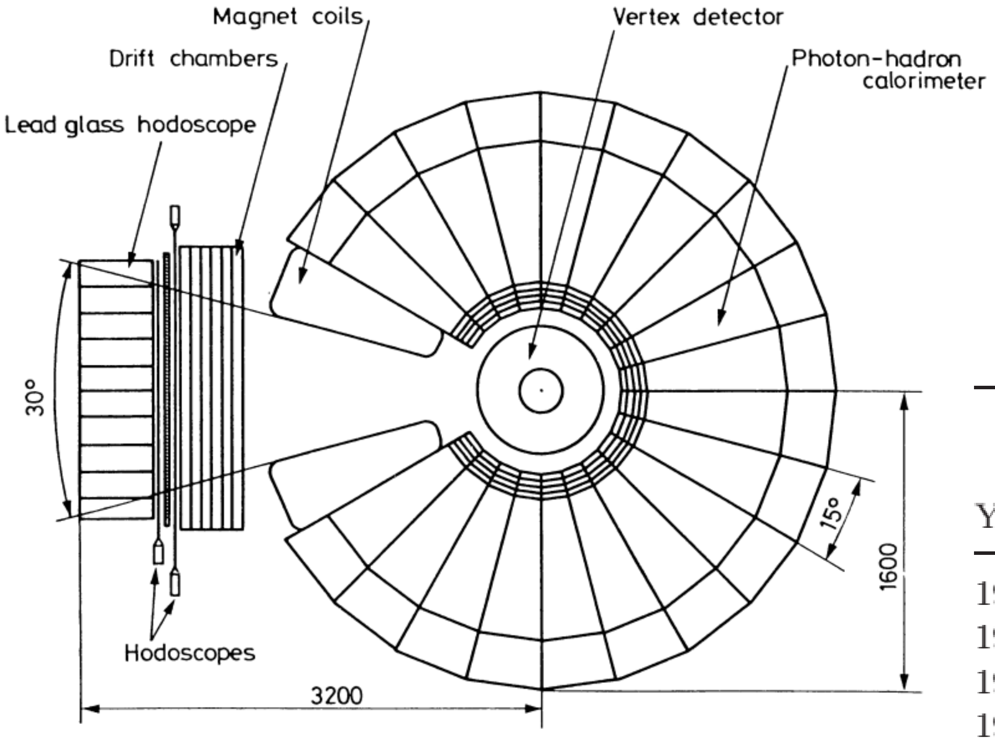
Titanic and excellent civil engineering work was immediately undertaken in LSS4, near Ferney-Voltaire, under the direction of Gerard Bachy and Carlo Lamprecht, who both left us in April last year, just a few days apart.

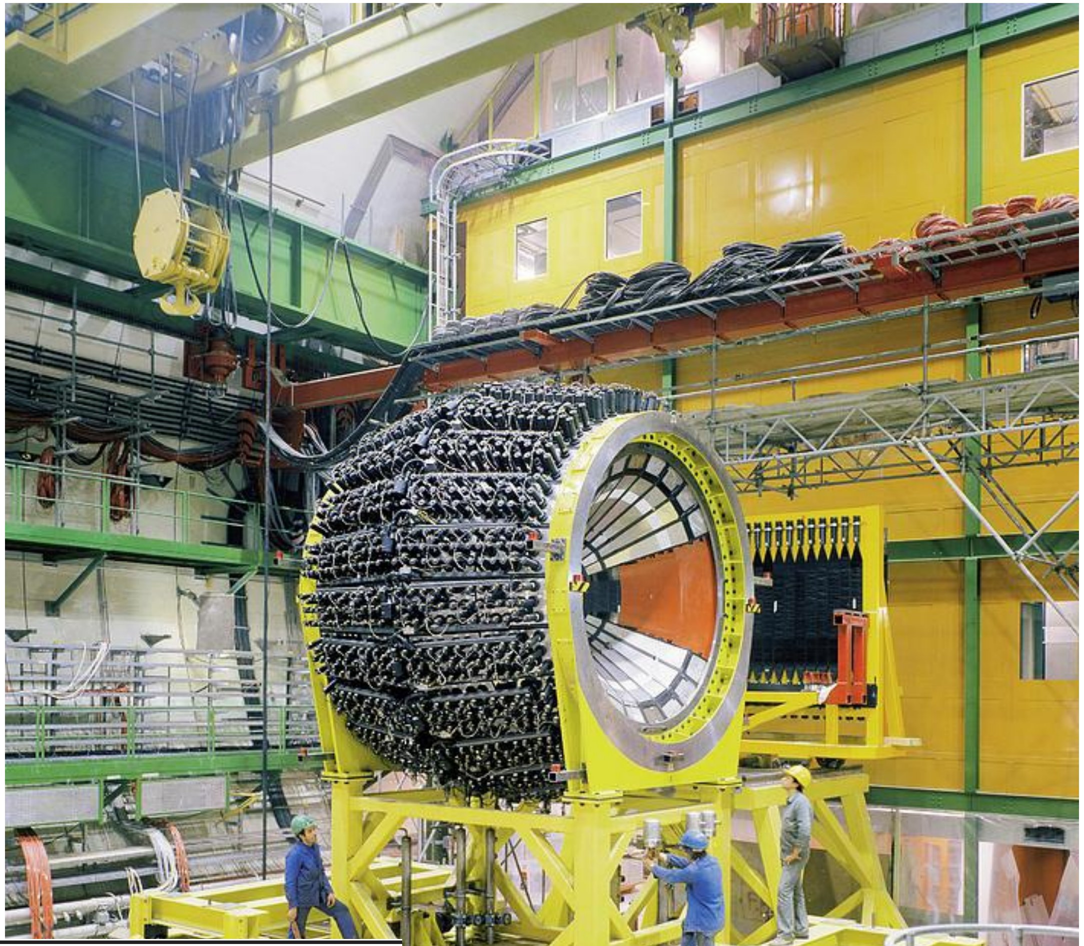


Collider detectors are never perfect: they have to obey conflicting constraints. Their design implies compromises which are made according to the adopted physics priorities. In our case, priority was given to the detection of the W and Z decays to the electron channels, with magnetic bending in the forward cones, as well as to detecting jets interpreted as fragmenting partons. At variance with UA1, we could not detect muons.

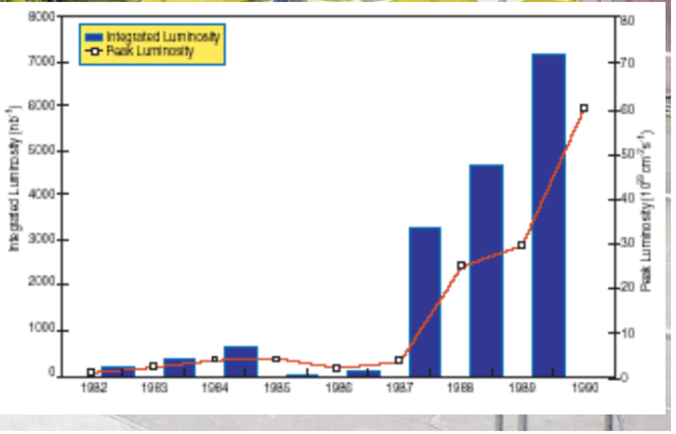


In 1981 and 1982, a 30º (60º) wedge was left open in the central calorimeter to make room for a single arm magnetic spectrometer (drift chambers, scintillator hodoscopes and lead glass array).

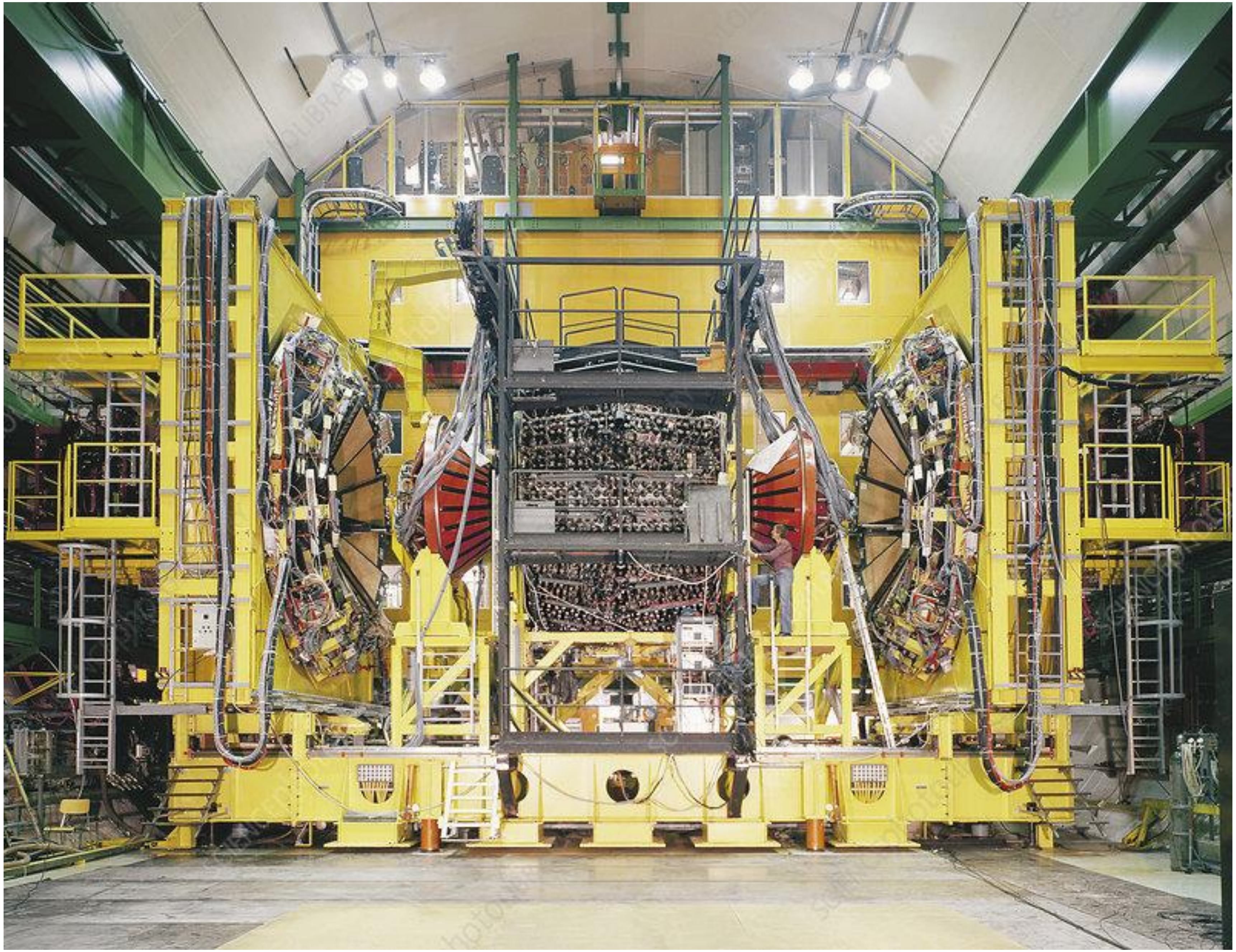


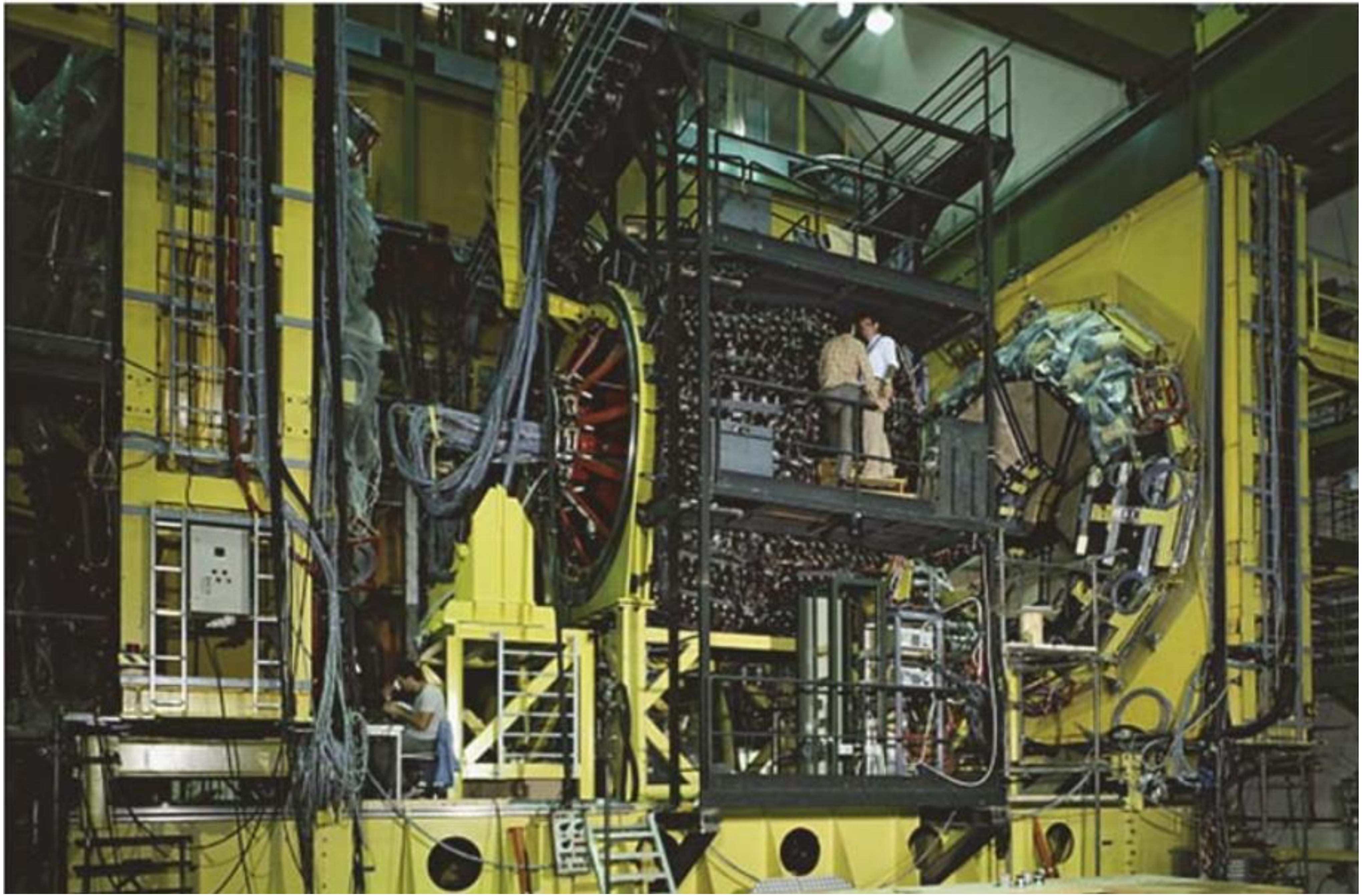


Year	Collision energy (GeV)	Peak luminosity ($cm^{-2}\ s^{-1}$)	Integrated luminosity (cm^{-2})
1981	546	$\sim 10^{27}$	2×10^{32}
1982	546	5×10^{28}	2.8×10^{34}
1983	546	1.7×10^{29}	1.5×10^{35}
1984–85	630	3.9×10^{29}	1.0×10^{36}
1987–90	630	3×10^{30}	1.6×10^{37}

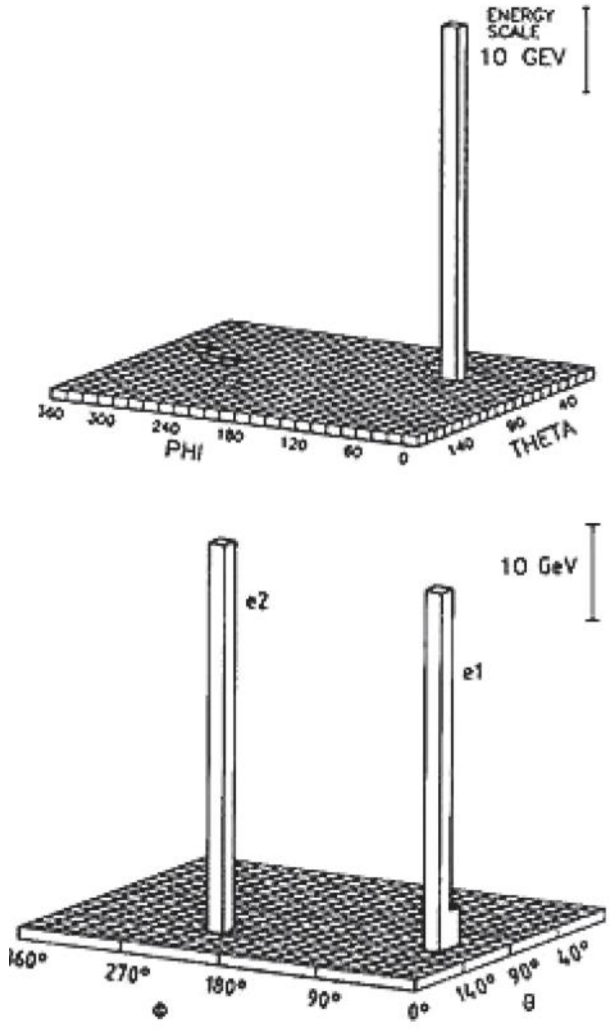


a

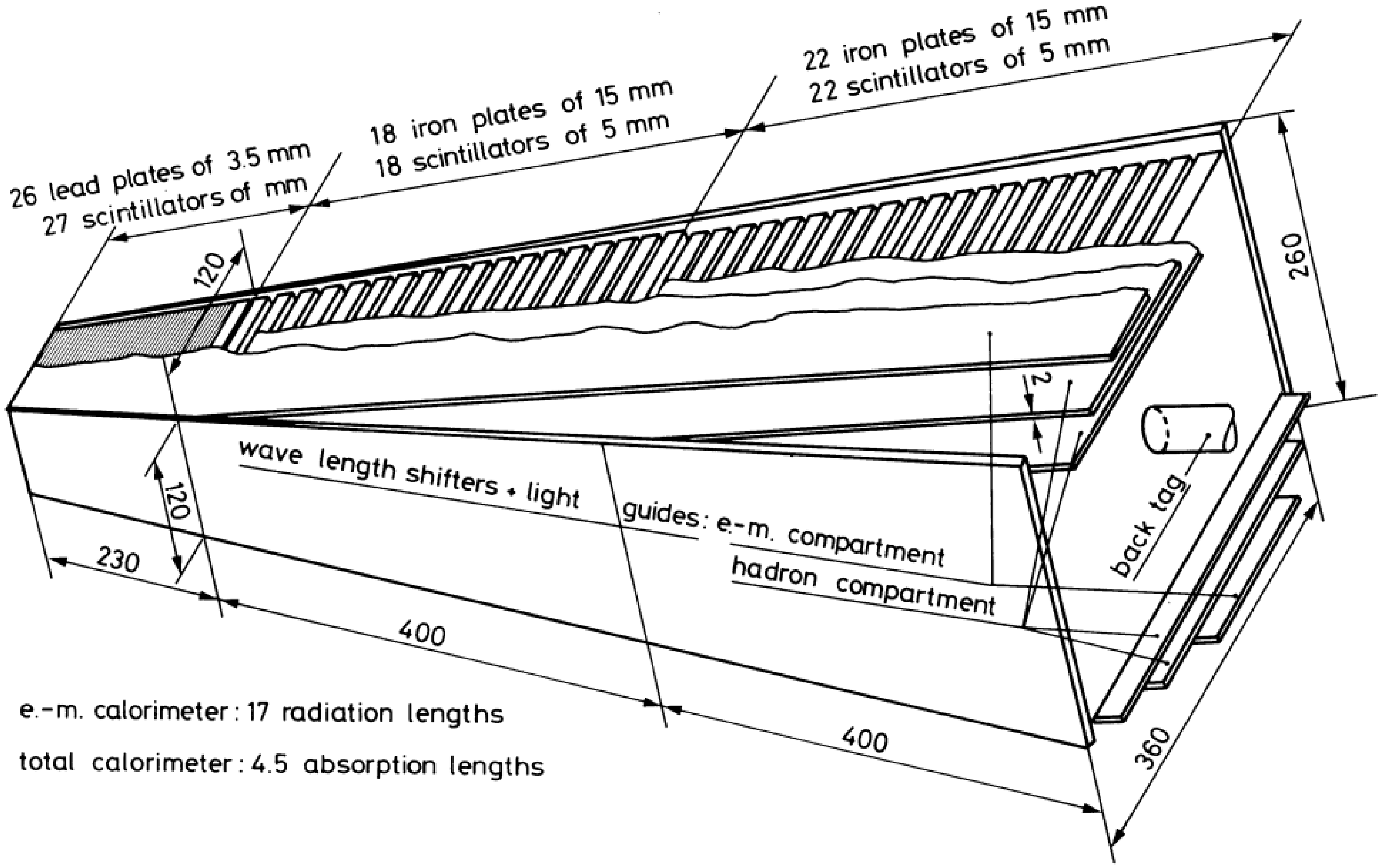




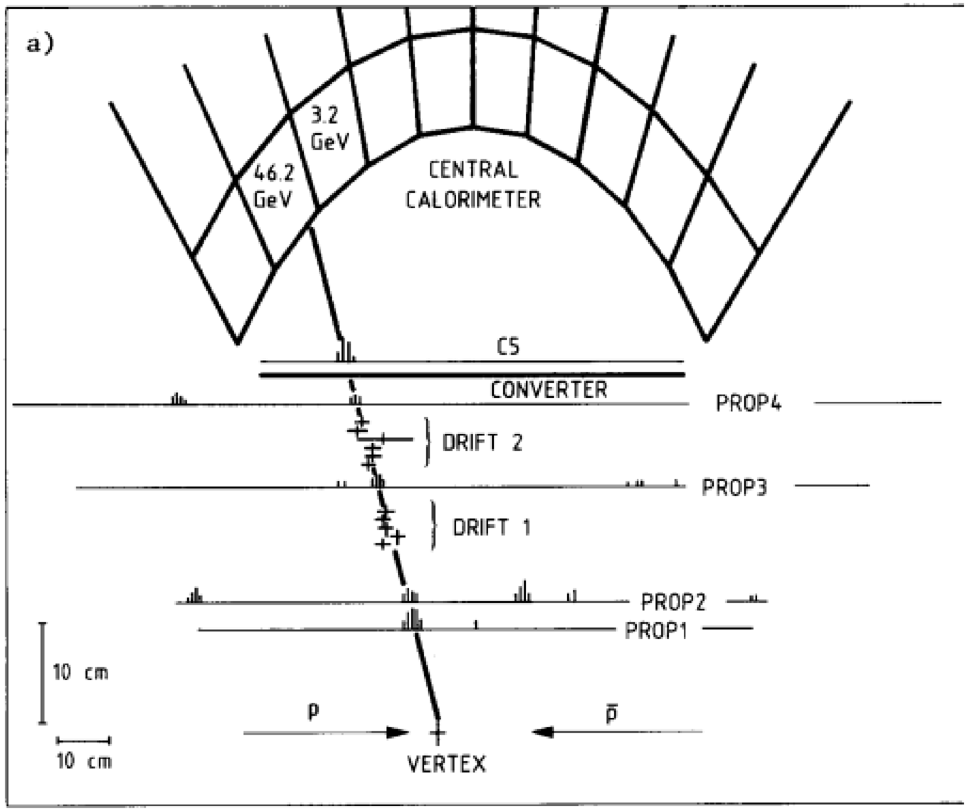
The central calorimeter had separate sections for electron/photon and hadron detections

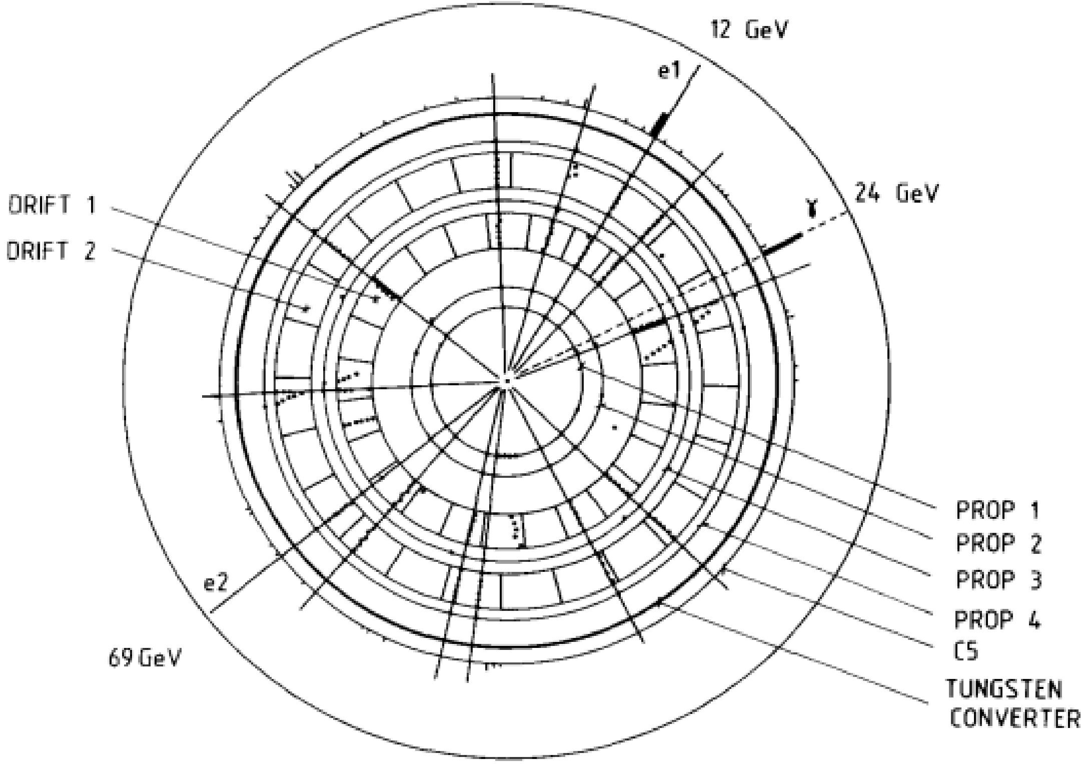


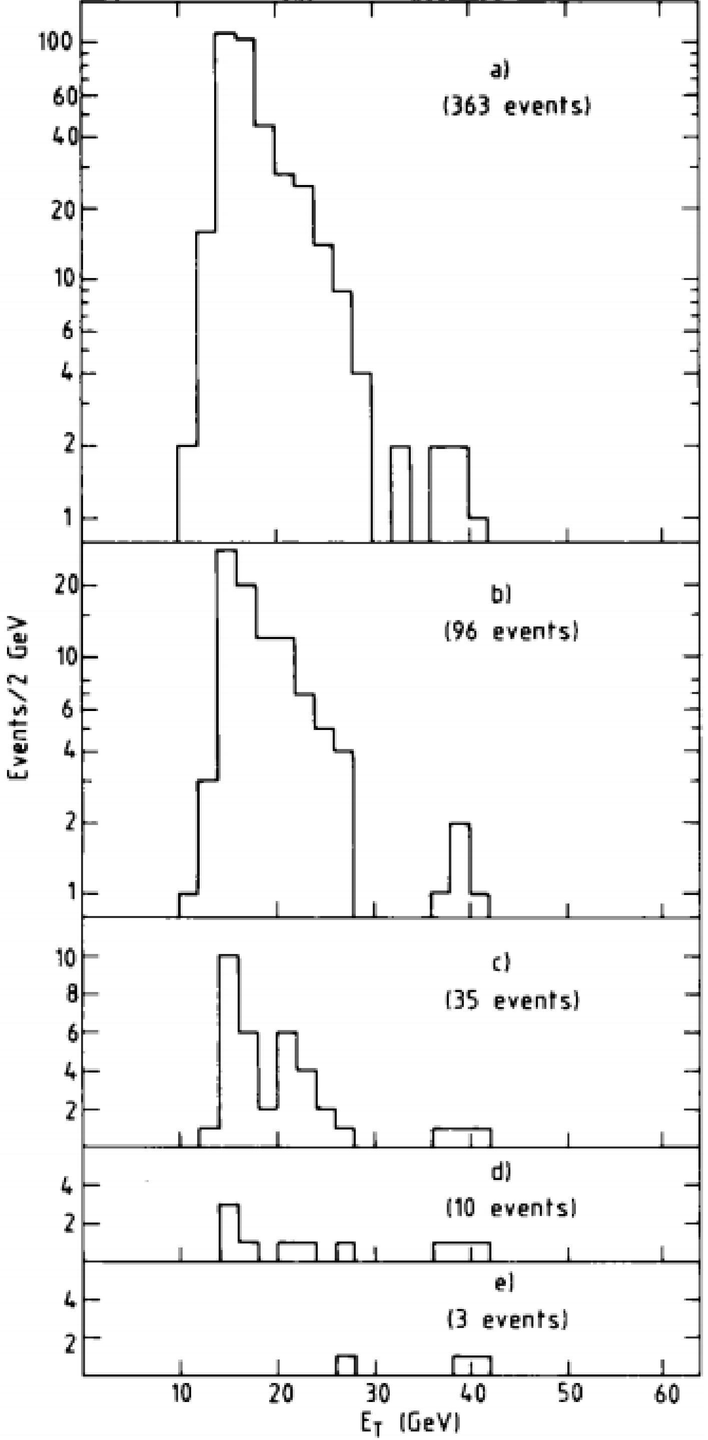
(b)



The central tracker, which had to fit within a very tiny cylinder, included both proportional and drift chambers, the latter with charge division read-out. The vertex was reconstructed with a precision of ±1 mm.



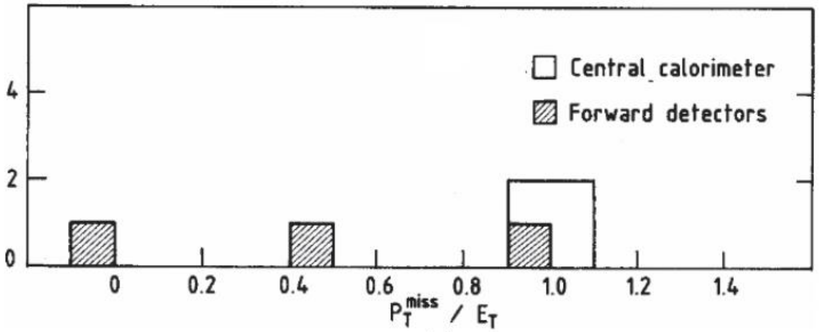




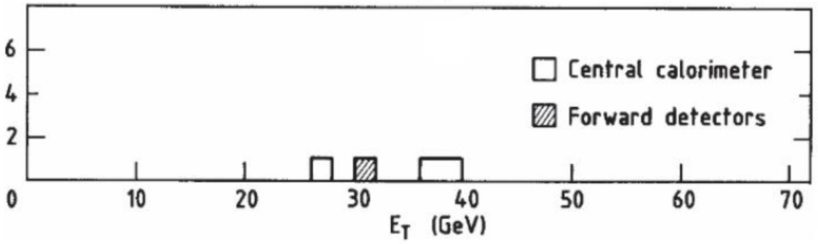
First "W" events (15 February 1983)

Simple criteria aimed at selecting single isolated electrons reduce the original event sample to four events with E_T>15 GeV and large missing transverse momentum consistent with expectations from p+pbar → (W→eυ)+…

In the central calorimeter the criteria are: small cluster (a), single charged track pointing to it (b), e-m shower produced in W converter (c), isolated (d) and well matched (e). Similar criteria are applied in forward/backward detectors.



(a)

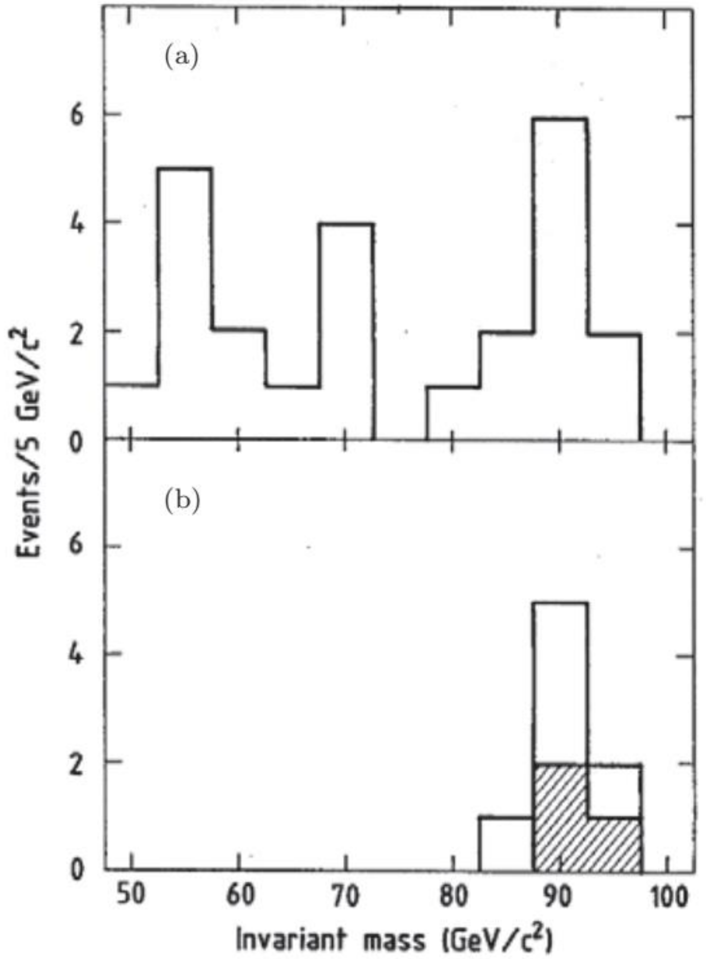


(b)

A fit to the E_T distribution gives $M_W=80^{+10}_{-6}$ GeV/c^2

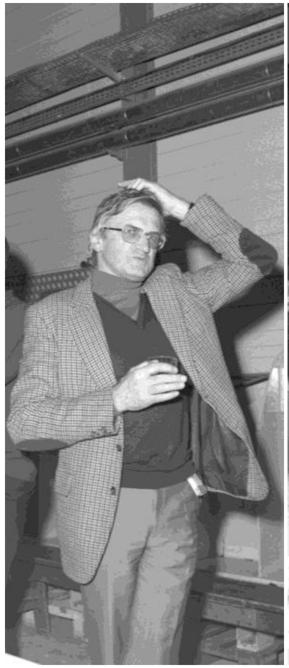
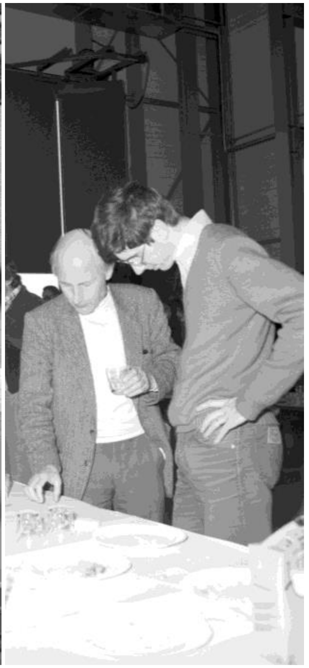
11 August 1983: From a search for electron pairs produced in p-pbar collisions at $\sqrt{s}$= 550 GeV we report the observation of 8 events which we interpret as resulting from the process pbar+p⟶ Z_0+anything, followed by the decay $Z_0 \rightarrow e^+e^-$ or $Z_0 \rightarrow e^+e^-\gamma$ where Z_0 is the neutral Intermediate Vector Boson postulated by the unified electroweak theory. We use four of these events to measure the Z° mass: M_z=91.9±1.3±1.4 GeV/c^2.

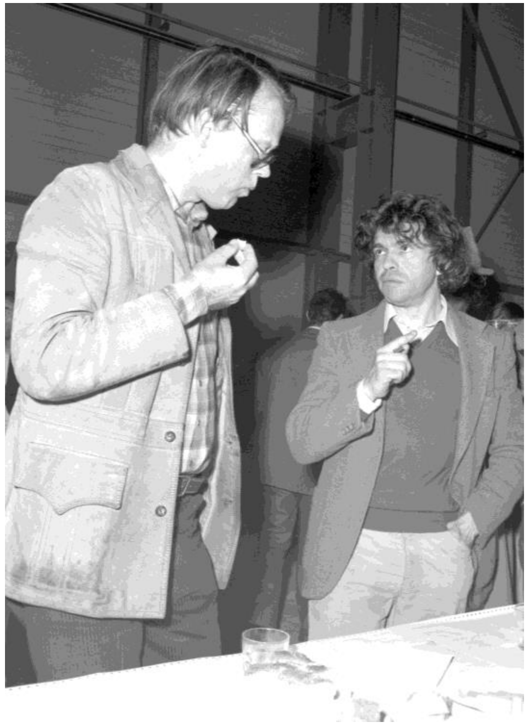
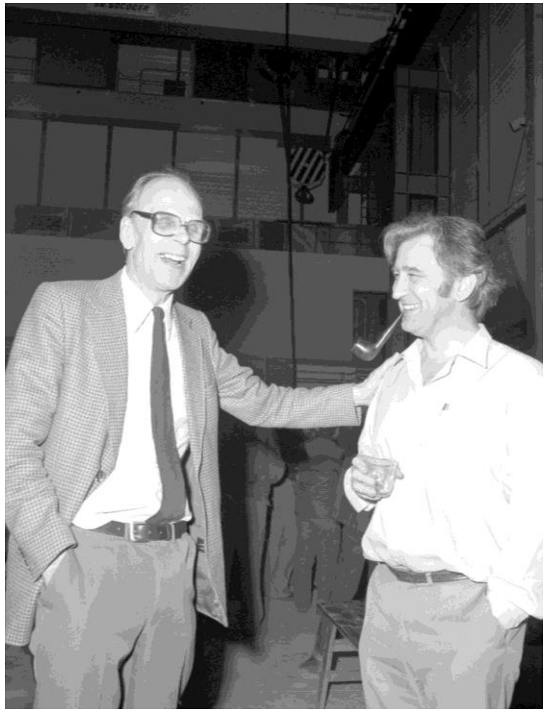
Using only calorimeters and post-converter chambers to select a pair gives result (a) with important two-jets background. Requiring in addition a good match with the track and the conversion behind the converter for only one leg of the pair (b) leaves us with 8 events, 3 of which obey the stricter cuts on both legs. One event has a leg in a magnet coil, the 4 others suggest contributions from the minimum bias component



After the January 1983 announcements, we celebrated …



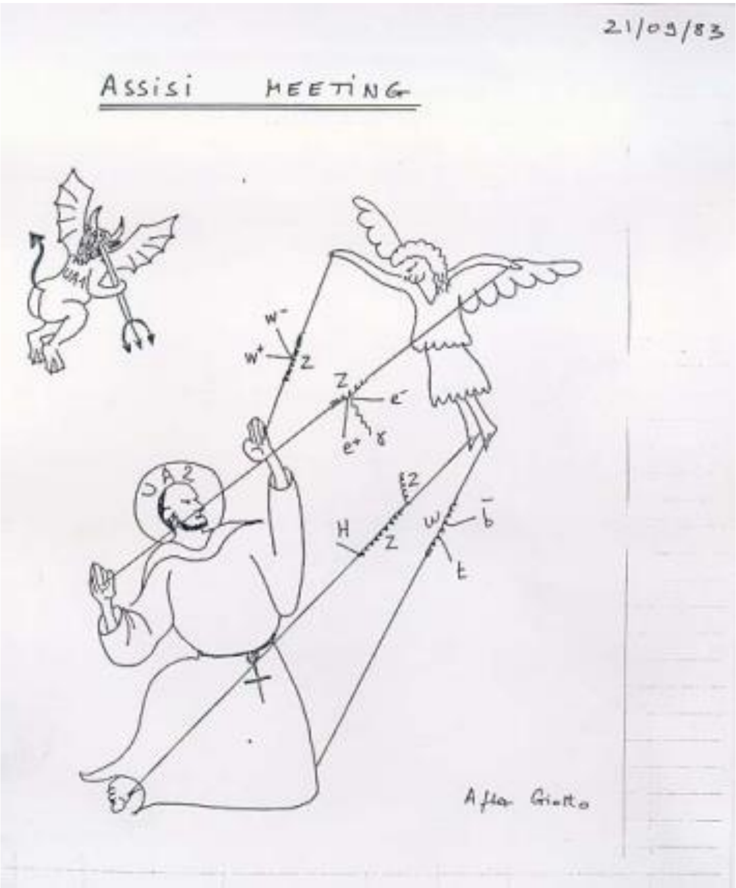
… but our happiness was in part spoiled (not much though…) by the reactions to our presentations taking the form of a psychodrama which has been described and commented on by many (e.g. John Krige in Isis).

Instead of enjoying the evidence that the p-pbar programme at CERN had been shown to be successful and had many years of guaranteed excellent physics ahead of it, which after all was not that obvious only two years earlier, one seemed to care only about who would be first, who would be first to “claim” a discovery. It was so childish, so ridiculous, so unscientific.

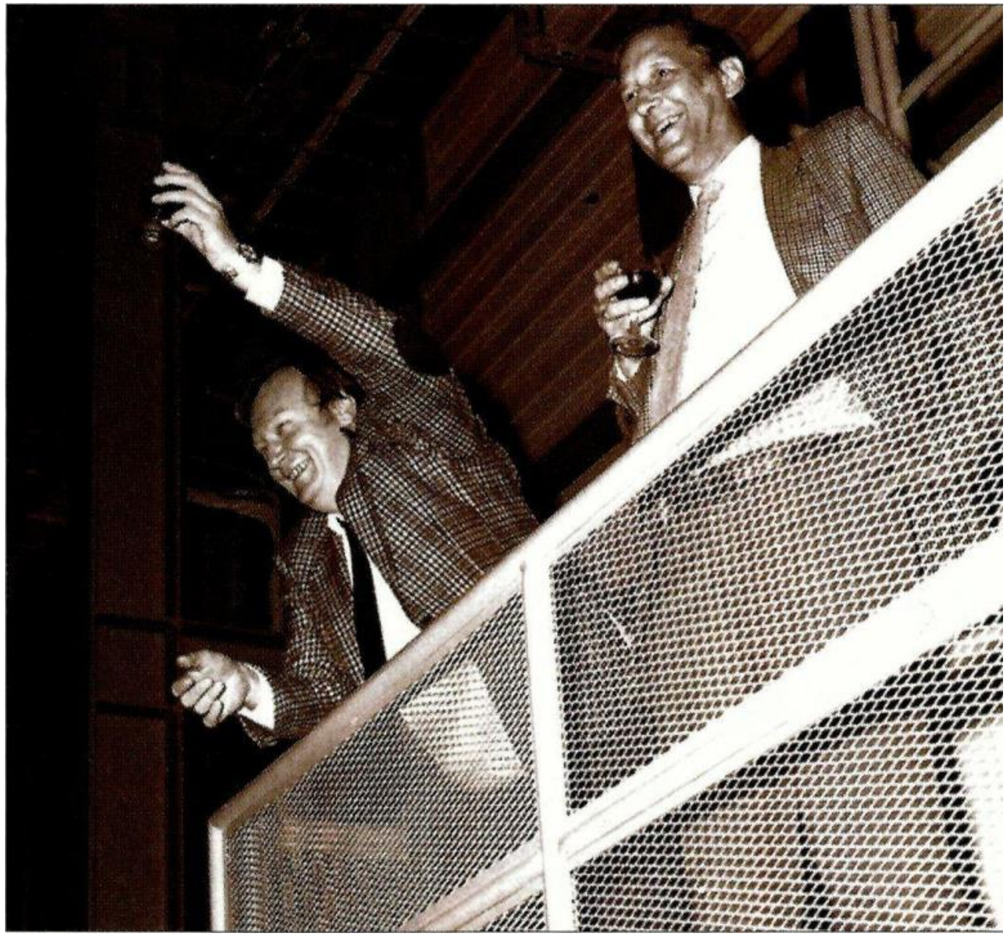
We were feeling that many people outside the community of UA1 and UA2 physicists, including in the CERN upper management, were not conscious of, and had no respect for, our work and the work of hundreds of people over so many years.

Today, 40 years later, I feel the same, if anything more strongly.

Science is not a horse race. Scientists are not bookmakers.



Our competition with UA1was intense, but friendly and somewhat for fun. Each of us usually had a few friends in the other collaboration and we were generally concerned with maintaining good relations between the two collaborations. In this context I remember that Alan Astbury, from UA1, was playing a very positive role.



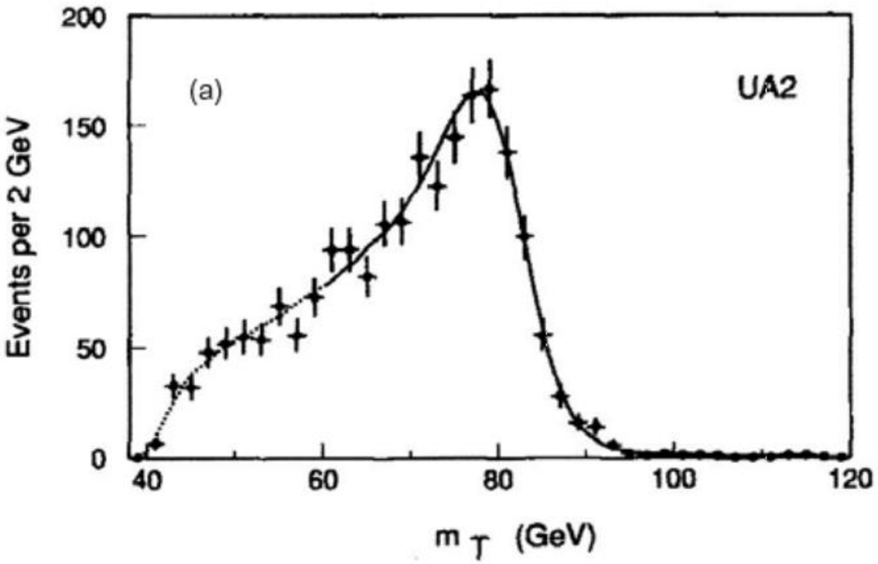
We were deeply conscious of our debt toward Carlo and Simon: without them, there would have been no p-pbar physics, no legacy of the invaluable experience it meant to help the construction of the future accelerators and detectors at LEP and LHC, no LEAR physics.
Without us, UA1 and UA2, there would have been a UA3 and I am sure that they would have done a good job

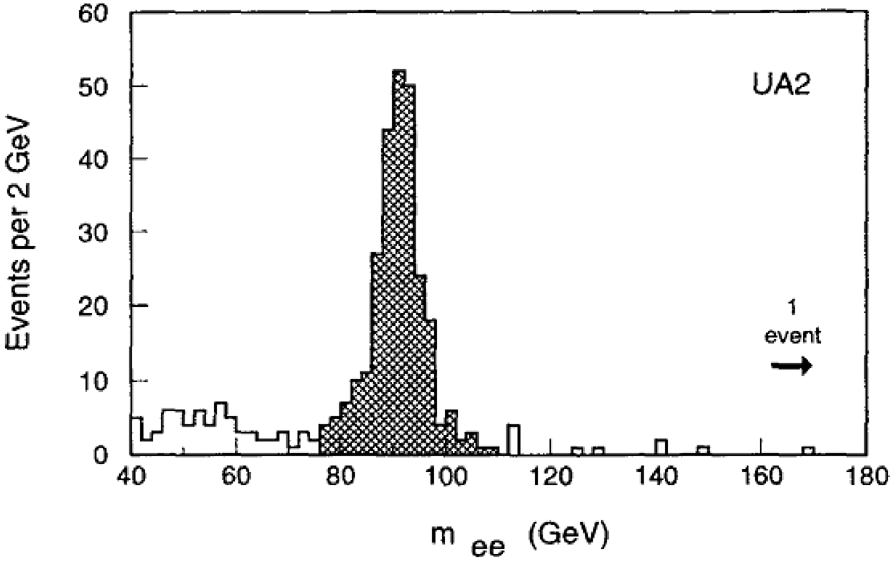
And we shared their joy when, less than two years later, they were awarded a well-deserved Nobel Prize

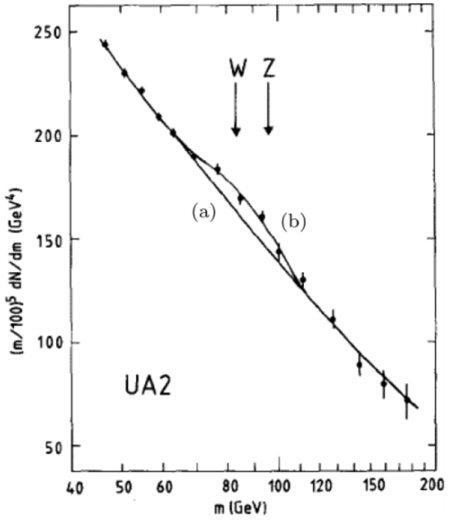
1985-1987: AC added to AA and UA2 upgraded for better hermeticity and central tracking.

New members joined: Cambridge, Heidelberg, Milano, Perugia, Pisa

Under the guidance of Luigi Di Lella, and of Peter Jenni for the CERN team, UA2 collected a harvest of major new results.







$m_W = 80.84 \pm 0.22 \pm 0.17 \pm 0.81$ GeV

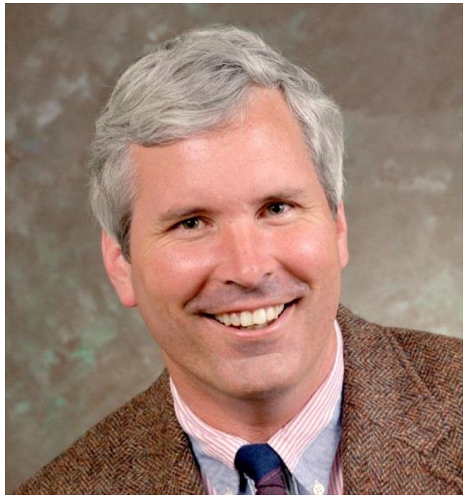
$m_Z = 91.74 \pm 0.28 \pm 0.12 \pm 0.92$ GeV

$\Gamma_W = 2.10 \pm 0.16$ GeV

$\sin^2\theta_W = 0.2234 \pm 0.0072$

$\alpha_S(M_W^2) = 0.123 \pm 0.018 \pm 0.017$

UA2 has been home to many bright postdocs and brilliant PhD students and its legacy has opened the way to ATLAS at LHC






Today, when I remember these happy days, and when I think of the past two decades in Vietnam, where we have been leading a daily fight for science and its ethic of intellectual and moral rigour, a daily fight for freedom of speech and against ignorance … I wonder… I wonder what should we be doing to be better recognized and supported?

Some relevant references

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Thank you for your attention

$$\frac{m_W}{m_Z} = 0.8813 \pm 0.0036 \text{ (stat)} \pm 0.0019 \text{ (syst)}$$

can be multiplied by the value of m_Z measured at LEP,[47] $m_Z = 91.175 \pm 0.021$ GeV, to give a more precise value of the W mass:

$$m_W = 80.35 \pm 0.33 \text{ (stat)} \pm 0.17 \text{ (syst) GeV}.$$

This value is in good agreement with the W mass measured by the CDF experiment, $m_W = 79.91 \pm 0.39$ GeV.[48] If the two results are combined the value

$$m_W = 80.14 \pm 0.27 \text{ GeV}$$

This value is in good agreement with the W mass measured by the CDF experiment, $m_W = 79.91 \pm 0.39$ GeV.[48] If the two results are combined the value

$$m_W = 80.14 \pm 0.27 \text{ GeV}$$

$$\sin^2\theta_W = 0.2234 \pm 0.0072 \qquad \text{(UA2)},$$

$$\sin^2\theta_W = 0.2274 \pm 0.0052 \qquad \text{(UA2 + CDF)}.$$

$$\sigma_W^e = 682 \pm 12 \text{ (stat)} \pm 40 \text{ (syst) pb},$$

$$\sigma_Z^e = 65.6 \pm 4.0 \text{ (stat)} \pm 3.8 \text{ (syst) pb}.$$

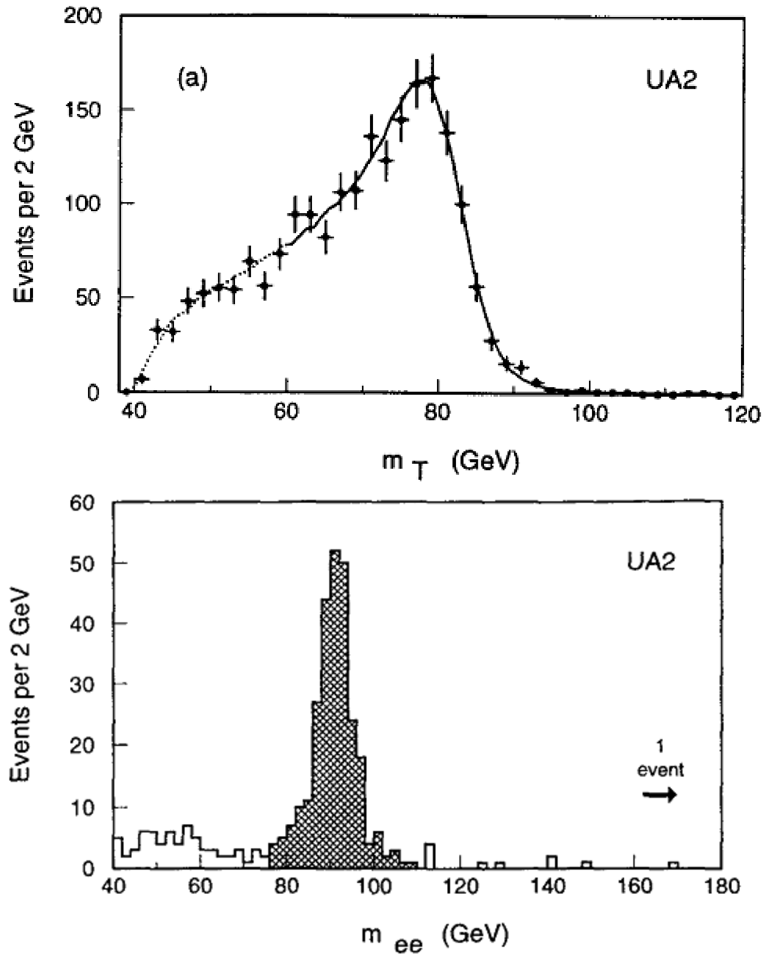
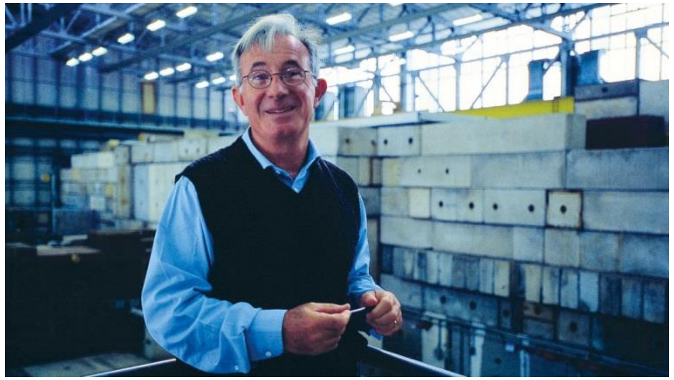
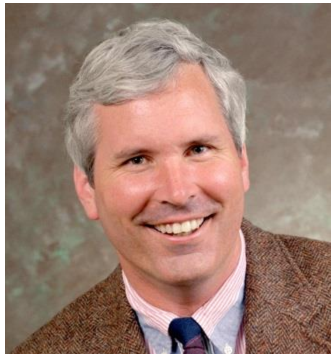


Table 6. Compilation of Γ_W measurements.

Experiment		Int. luminosity		Γ_W (GeV)
UA1	Ref. 52	5.3 pb^{-1}	(1983–1989)	2.19 ± 0.30
UA2	Ref. 44	13.0 pb^{-1}	(1988–1990)	2.10 ± 0.16
CDF	Ref. 53	4.4 pb^{-1}	(1988–1989)	2.20 ± 0.16
CDF, prel.	Ref. 54	18.4 pb^{-1}	(1992–1993)	2.03 ± 0.09
D0, prel.	Ref. 54	7.4 pb^{-1}	(1992–1993)	2.08 ± 0.25



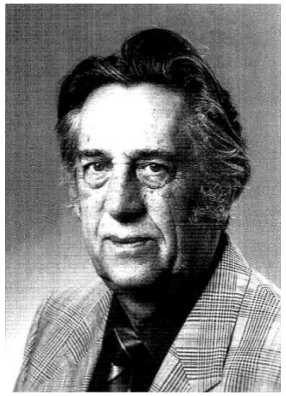


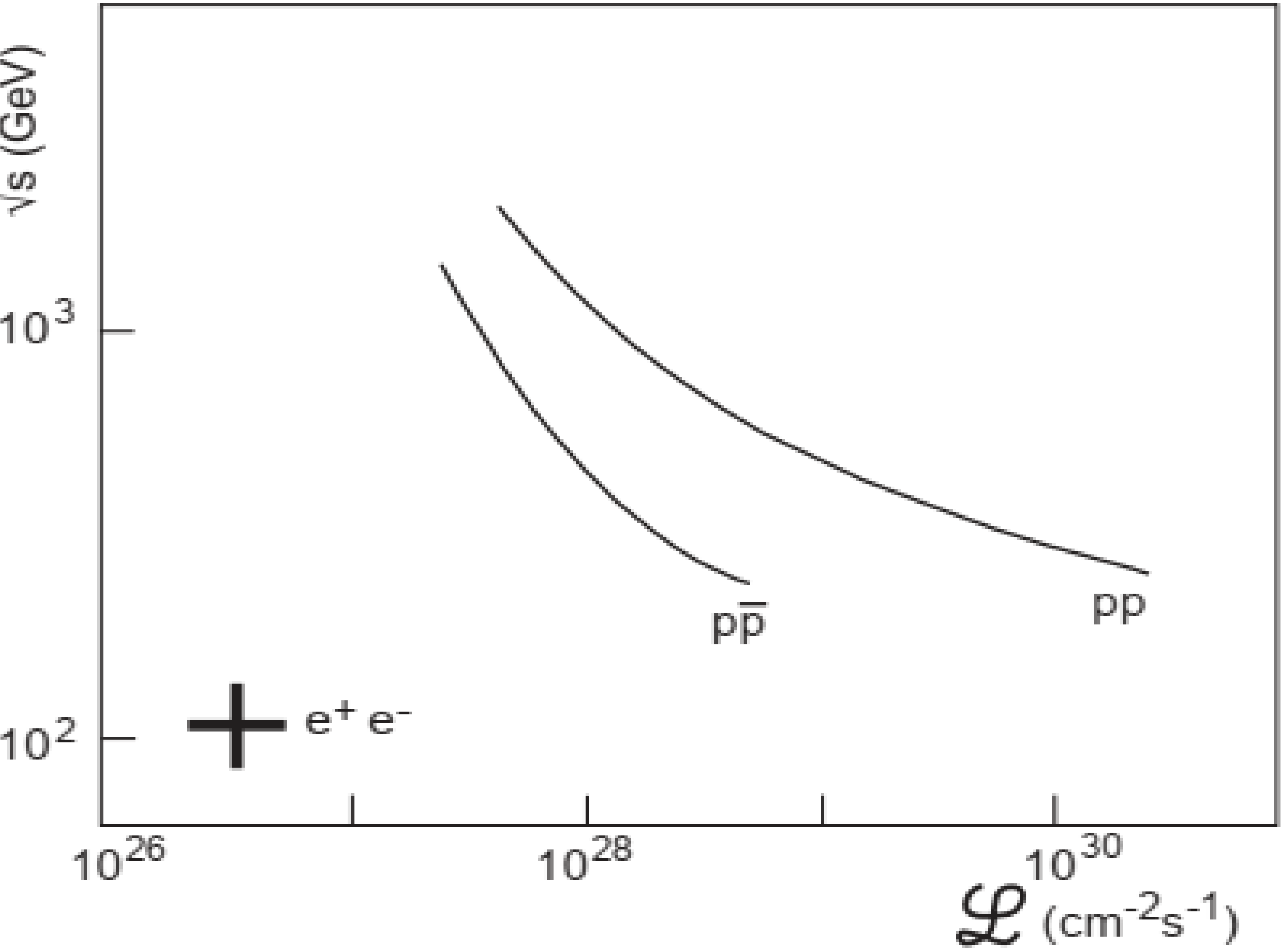




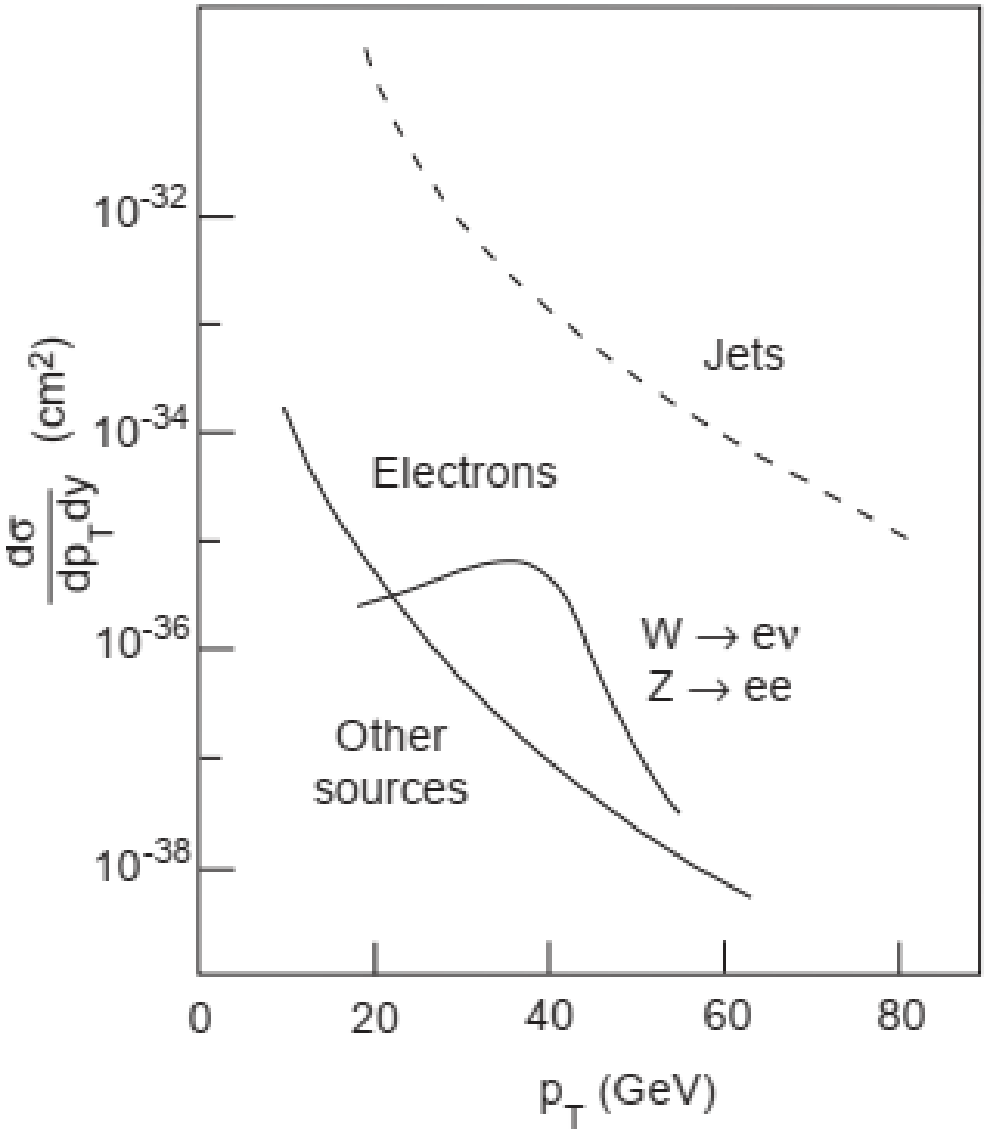




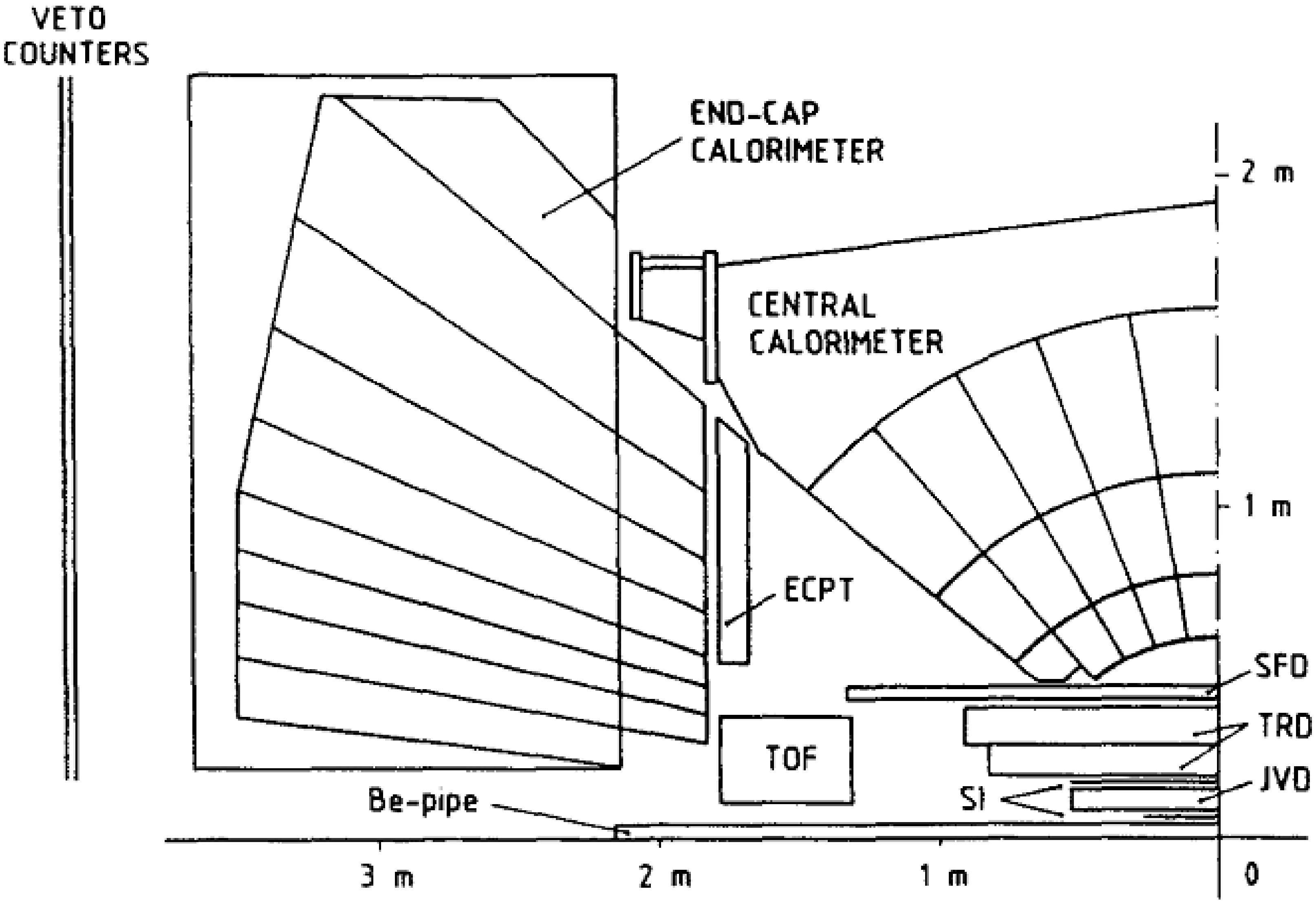

LEP
STOCHASTIC
COOLING
UA-1
CERN
UA-2



√s (GeV)
10^3
10^2
pp̄
pp
e+ e-
10^26
10^28
10^30
ℒ (cm-2s-1)



dσ/dp_T dy (cm2)
10^-32
10^-34
10^-36
10^-38
Jets
Electrons
W → eν
Z → ee
Other sources
0
20
40
60
80
p_T (GeV)



VETO
COUNTERS
END-CAP
CALORIMETER
CENTRAL
CALORIMETER
ECPT
TOF
SFD
TRD
JVD
SI
Be-pipe
2 m
1 m
3 m
2 m
1 m
0

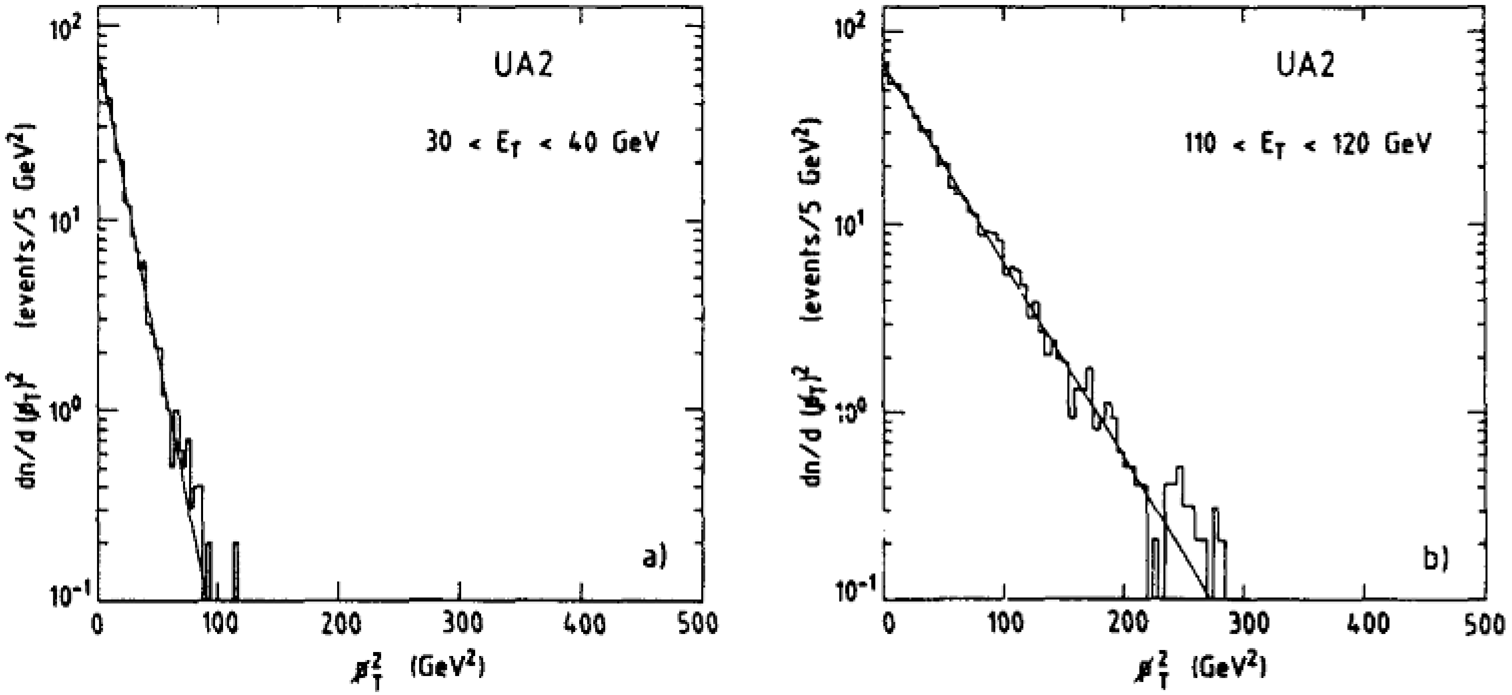
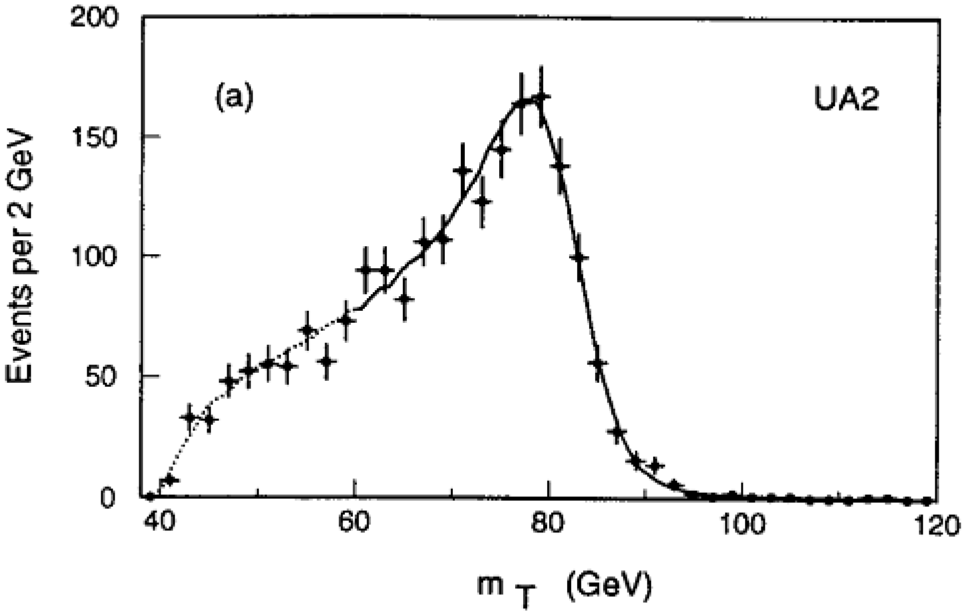


Fig. 6. The distributions of $\not{P}_T^2$ for two representative $\sum E_T$ intervals.

$$m_W = 80.84 \pm 0.22\ \text{(stat)} \pm 0.17\ \text{(syst)} \pm 0.81\ \text{(scale)}\ \text{GeV}\,,$$

$$m_Z = 91.74 \pm 0.28\ \text{(stat)} \pm 0.12\ \text{(syst)} \pm 0.92\ \text{(scale)}\ \text{GeV}\,.$$



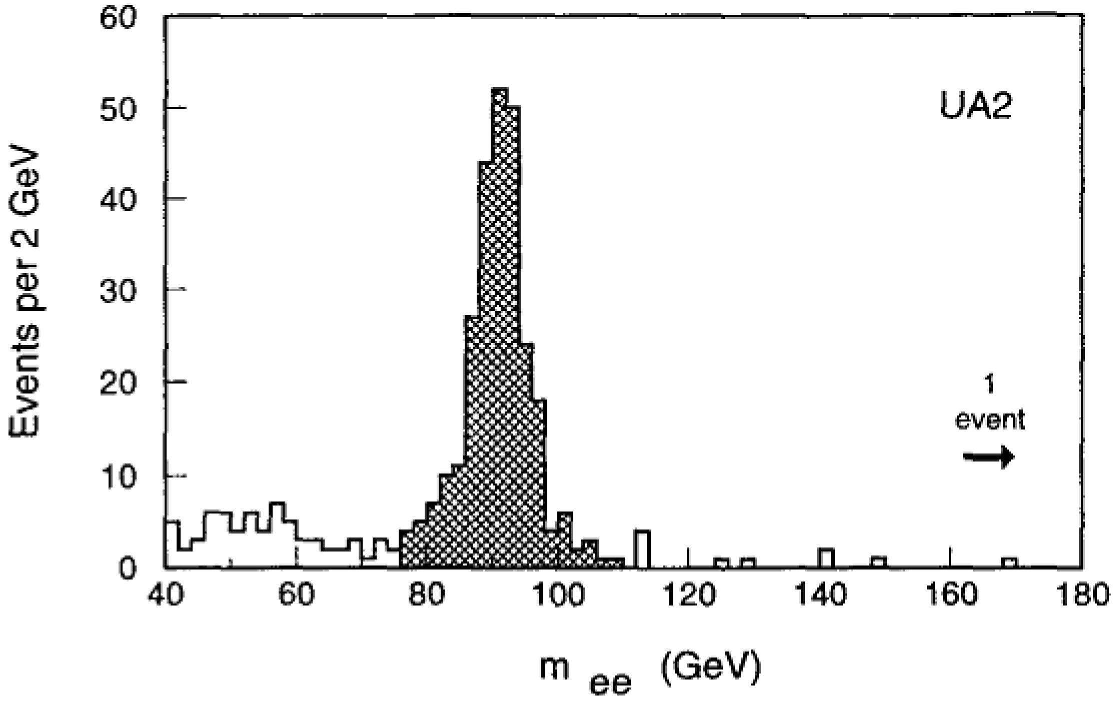


Table 6. Compilation of Γ_W measurements.

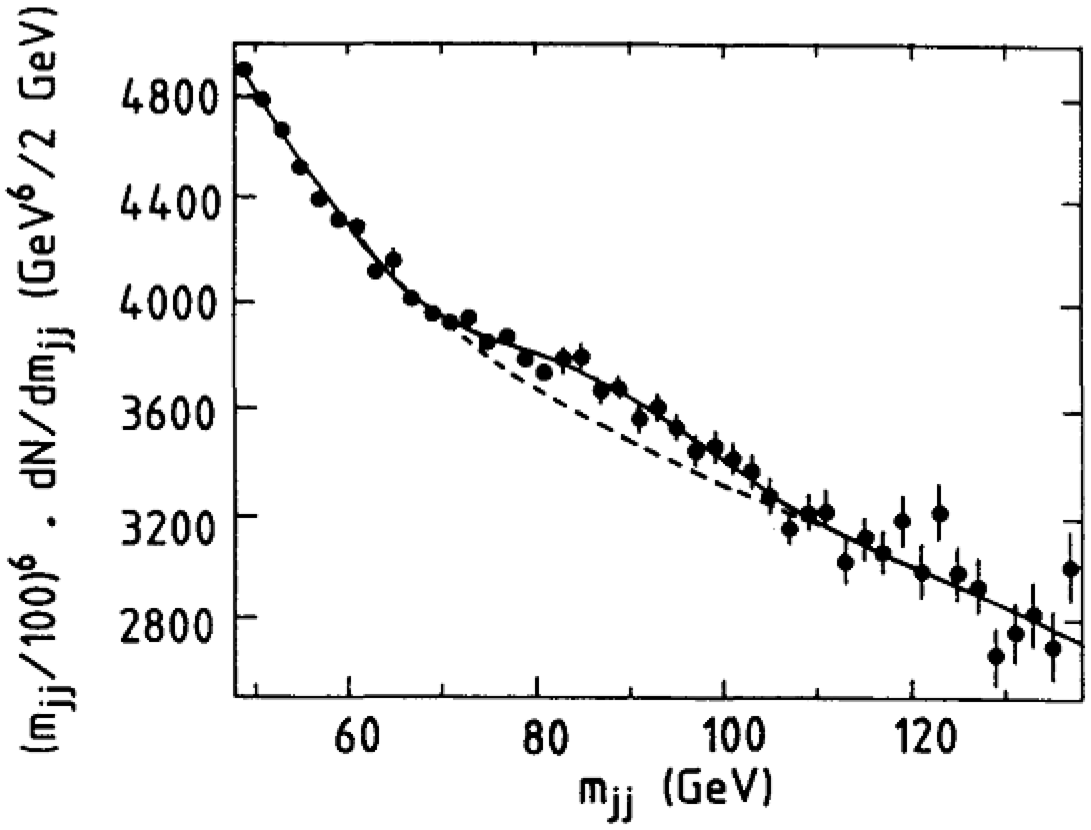
Experiment		Int. luminosity		Γ_W (GeV)
UA1	Ref. 52	5.3 pb^{-1}	(1983–1989)	2.19 ± 0.30
UA2	Ref. 44	13.0 pb^{-1}	(1988–1990)	2.10 ± 0.16
CDF	Ref. 53	4.4 pb^{-1}	(1988–1989)	2.20 ± 0.16
CDF, prel.	Ref. 54	18.4 pb^{-1}	(1992–1993)	2.03 ± 0.09
D0, prel.	Ref. 54	7.4 pb^{-1}	(1992–1993)	2.08 ± 0.25

eliably. Using the value $\Gamma_Z = 2.487 \pm 0.010$ GeV from LEP,

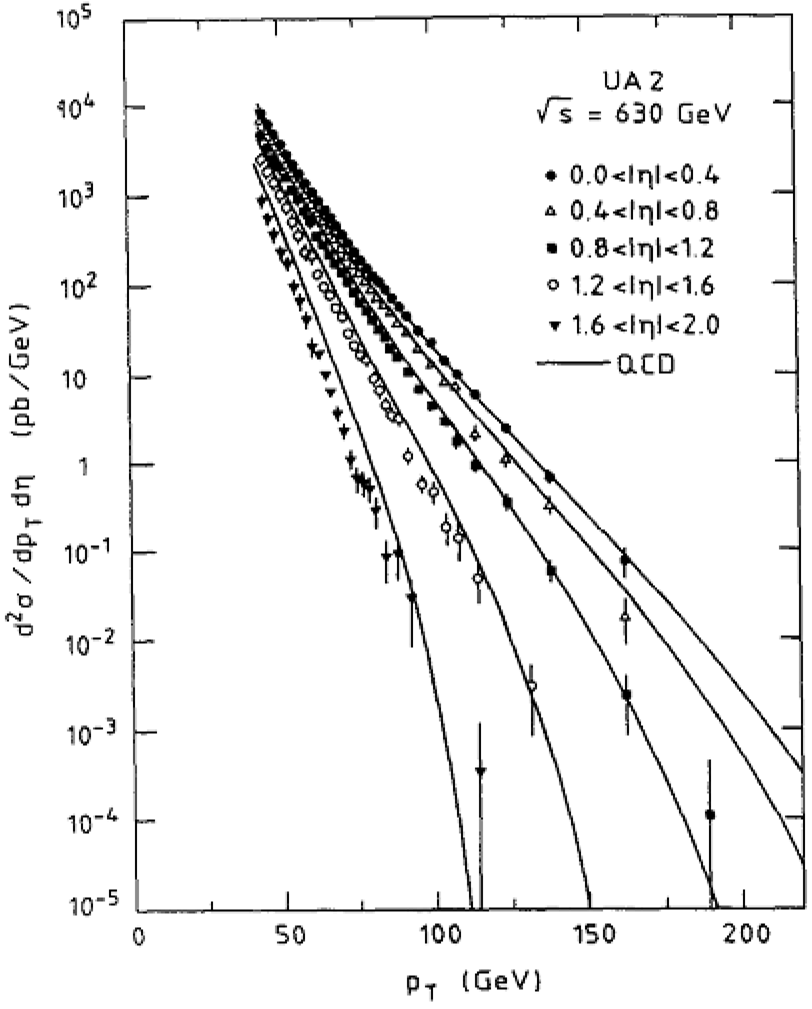
$$\Gamma_W = 2.10 \pm {}^{0.14}_{0.13}\,(\text{stat}) \pm 0.08(\text{syst})\ \text{GeV}\,.$$

$$m_t = 160^{+50}_{-60}\ \text{GeV} \qquad \text{for} \quad m_H = 100\ \text{GeV}\,,$$

$$m_t < 250\ \text{GeV} \quad (95\%\ \text{CL}) \quad \text{for} \quad m_H < 1\ \text{TeV}\,.$$



$(m_{jj}/100)^6 \cdot dN/dm_{jj}$ (GeV^6/2 GeV)
4800
4400
4000
3600
3200
2800
60
80
100
120
m_{jj} (GeV)



UA 2
$\sqrt{s}$ = 630 GeV
$0.0<|\eta|<0.4$
$0.4<|\eta|<0.8$
$0.8<|\eta|<1.2$
$1.2<|\eta|<1.6$
$1.6<|\eta|<2.0$
QCD
$d^2\sigma/dp_T\,d\eta$ (pb/GeV)
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
50
100
150
200
p_T (GeV)