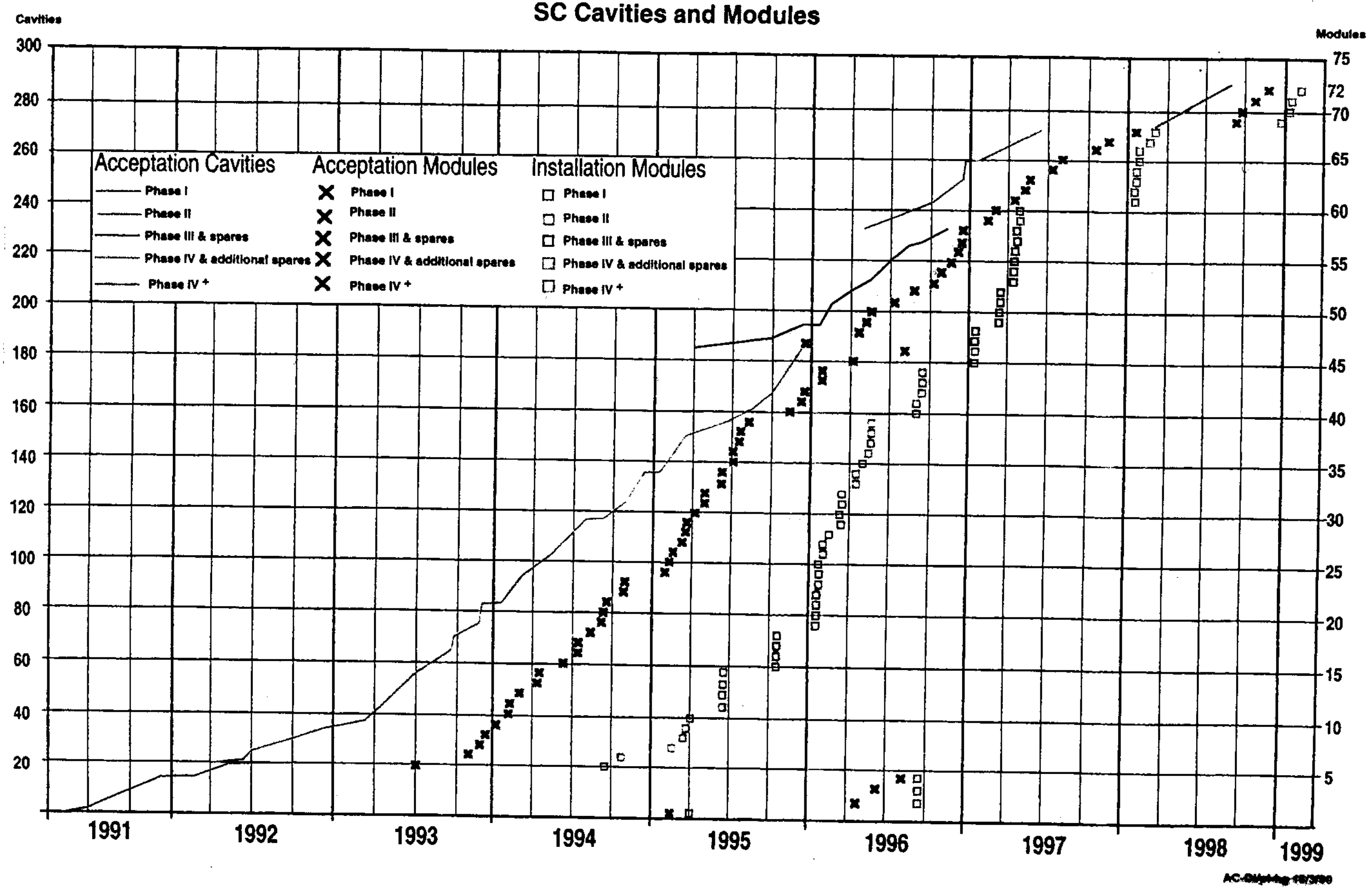
THE ROAD TO LEP 200/2000

C. H. Llewellyn Smith

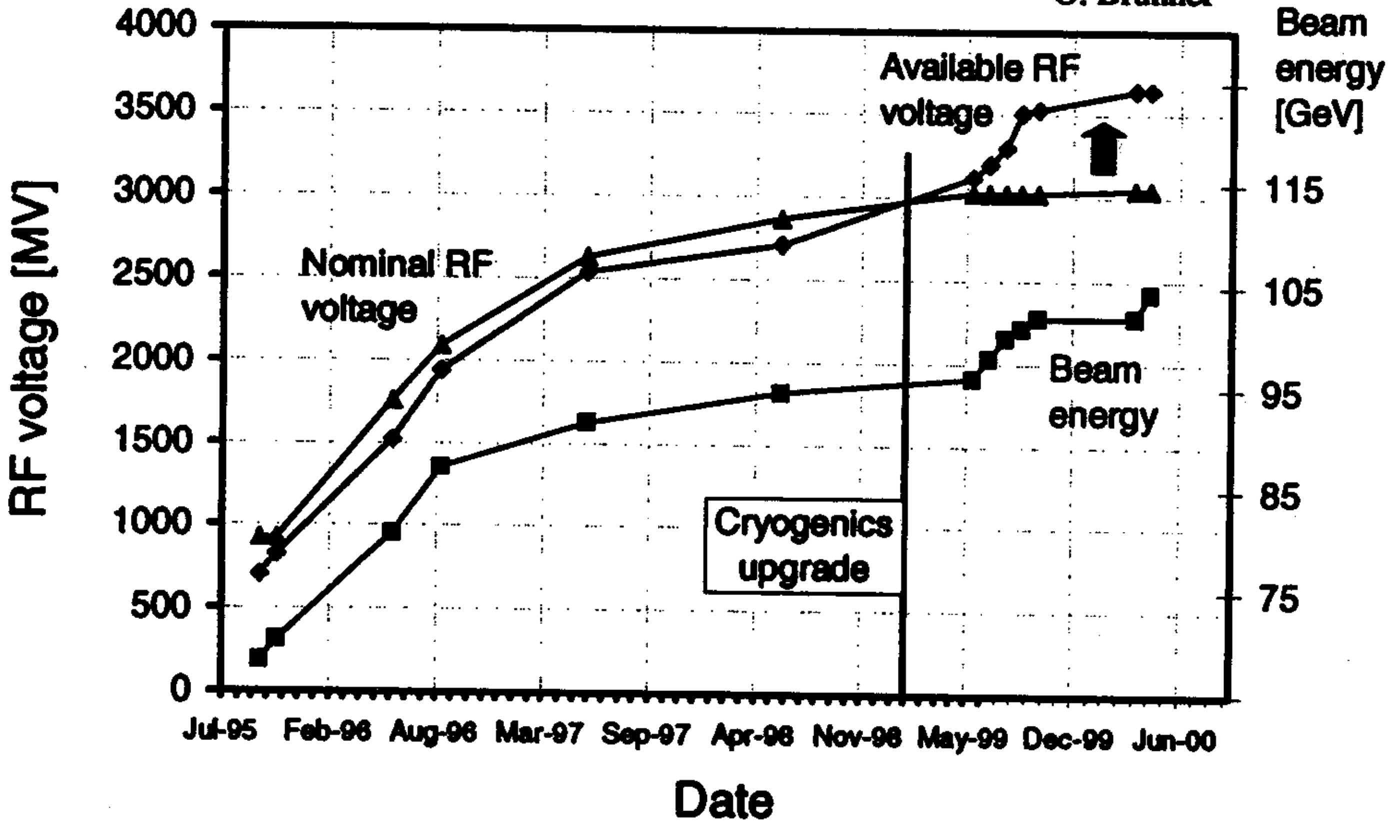
- Arguments for highest possible energy from 1978 LEP Summer Study (Theoretical Convenor – CHLIS)
- *Fast forward (1980-94)*
- Push for
  - top energy (1995): 224 SC cavities foreseen 1993
→288 (final number) end 1998 ☞
additional cooling power (1997) ☞
  - operation in 2000 (1997-98)

LEP 2
SC Cavities and Modules



RF voltage (design and actual):

O. Brunner



Improvements:
- Progressive installation of additional RF cavities
- Increase accelerating gradient

Beam energy follows available RF voltage...

1978 LEP SUMMER STUDY

CERN Yellow Report 79-01

Note: W and Z not discovered until 1983 [1978 opinion "Either the $p\bar{p}$ collider or Isabelle should discover the Z... (they may also discover the W but this looks more difficult)"!]

Nevertheless study correctly foresaw most LEP physics, except*

– limits/discovery potential much better than anticipated: hermetic detectors

– B Physics not anticipated: microvertex detectors

[only one sentence on supersymmetry]

* also precision

1978 ARGUMENTS FOR LEP 2

- triple gauge boson vertex
- Higgs (if not found in Z decay), or whatever else is responsible for mass – "It is hard to be precise about critical mass/energy but clearly this is a powerful argument for pushing for the highest possible energy at LEP"
- ......?

Note: earlier in 1978 John Adams wrote a note proposing that the LEP tunnel should be large enough to house a SC proton synchrotron; in presenting the summer study, argued for largest possible LEP → highest possible energy for subsequent proton machine.

FAST FORWARD

- **1979** – R & D on SC cavities started

- **1981** – LEP approved

[•**1984** – first major LHC study (ECFA 84/85; CERN 84-10); CHLIS theoretical convenor]

- **1988** - Medium Term Plan,1989-1992 (Schopper's last), foresaw "LEP completion" in three stages:

  I - 32 sc cavities (Region 2) "manufacture 1990-91"

  if successful then

  II - 32 more sc cavities (Region 6) "installation could start 1992"

  after careful review decide whether or not →

  III - 128 more sc cavities

- **1990** - "Considerations on the Long-Term Scientific Strategy of CERN" → 192 Cavities operating in 1994; LHC (to be installed above LEP) commissioning 1998!

- **1993** - Long Term Plan: 1995-2005 → LEP2 in stages starting late 1995-1999 with 192 + 32 (replacing Cu) SC cavities; LHC commissioning 2002

- **1994** – fight for LHC: approved (two stages) in December (decision to dismantle LEP and install LHC on floor)

APPROVAL OF STAGE IV + EQUIPMENT OF SPARE CAVITIES 1995

Note – Council very nervous about new initiatives post LHC approval (lack of resources; impact on non-member state negotiations)

- **March** – K Hübner presented proposal (buy 32 new sc cavities; equip 16 spares) to SPC
- **May** – Medium Term Plan (1996-1999) based on 're-optimisation of resources in the December 1994 plan': considering two new elements – LEAR in 1997/LEP energy upgrade
- **June** – Concentrating on LEP upgrade; liked by Council Committees, although nervous ☞
- **July – December** – soliciting special contributions to upgrade (3.6 MCHF obtained from A, Fi, I, CH)
- **September** – full presentation to Council Committees (→ physics arguments, funding, sacrifices ☞), then incorporated in paper for **December Council when proposal was approved**

FROM COMMITTEE OF COUNCIL MINUTES, JUNE 1995:

The DIRECTOR-GENERAL said that since a full presentation of the document had been given in the Finance Committee and would also be made to the Council, he would limit his introduction to the two following issues. Firstly, regarding the pressure from the scientific community to run LEAR for a further year in 1997, he informed the Committee that the Research Board had reluctantly concluded that the physics case, though excellent, was not commensurate with the considerable resources required. The Management had therefore decided to maintain its decision to close the facility at the end of 1996.

Secondly, concerning LEP2, he reported that strong arguments had emerged for a further upgrade to maximise LEP's full potential, requiring 32 additional superconducting cavities, which had not been included in the previous long- or medium term plans. The upgrade cost would be in the region of 10 MCHF per annum over three years. Concerning the scientific case, the discovery and confirmation in recent months of the top quark by Fermilab and further precision measurement at LEP over the last year had greatly strengthened the physics interest in the energy range to which the further upgrade would give access. He would present a full report to the Council on the exciting physics which had prompted both the Research Board and the Scientific Policy Committee to urge the Management to explore ways to accommodate the cost of the energy increase within the available financial envelope. The Management was prepared to do so under the strict boundary condition that the funding and the schedule for LHC should not be touched. It would report back to the Scientific Policy Committee in September on the sacrifices which would be needed. Naturally, any extra contributions from Member States in the form of components would greatly ease the situation.

The Management would welcome the Committee's first reactions on the proposed upgrade; indications from Member States which might be able to consider voluntary in-kind contributions would also be very helpful.

Dr ESCHELBACHER, appreciating the information provided, said that his delegation had been surprised at the strong priority attached to the upgrade of LEP2 in the document whilst it had not been mentioned during the discussions in 1994. His concern was that the measures should in no way affect the funding and time-table planning for LHC, whose establishment had demanded major efforts in 1994, and no contributions from non-Member States should flow into that channel.

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COMPLETION OF THE LEP UPGRADE

(Paper for SPC, FC, CC and Council – December 1995)

➪ **Physics**

- Standard Model Higgs ☞
- SUSY Higgs
- Charginos ☞

➪ **Resources** (36 MCHF needed + 3MCHF early LHC spend on He tanks)/**necessary sacrifices:**

Table 2 - Scope of reductions (MCHF, in 1995 prices)

SCOPE OF REDUCTIONS	Revised Nov. 95
General reduction in support & services in '95	5.2
Optimisation of payment schedule of IBM computer	3.4
Reduction of annual LEP running time over '96-99	5.7
Reduction of annual SPS running time over '96-99	4.3
Reduction and slowdown in CLIC over '96-99	3.8
Reduction in support to LEP experiments	3.8
Contribution from special reserve fund	6.2
Voluntary contributions	3.6
Total	**36.0**

5.2 – anticipating reductions needed in 1996 onwards

5.7 – drop 8 weeks (→ June to October)

4.3 – stop by end of November

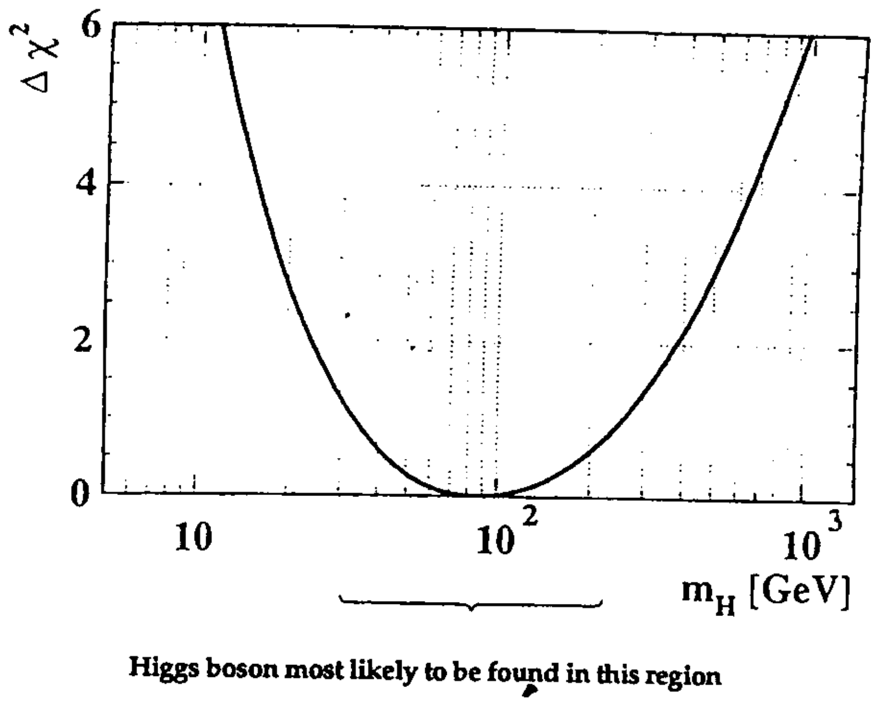
} **made possible by fantastic performance of LEP & SPS**

3.8 – great success anyway

"FROM COMPLETION OF THE LEP UPGRADE", DECEMBER 1995:

Various experimental and theoretical considerations support the *a priori* guess that the Higgs boson might be in the region that could be explored by LEP2 operating at 192 GeV. First, precision data from LEP and other facilities are sensitive to the mass of the Higgs boson through "virtual" processes. These are processes in which, utilising the quantum mechanical possibility of "borrowing" energy for infinitesimal time intervals as allowed by Heisenberg's uncertainty principle, Higgs bosons can be temporarily emitted – even if this violates energy conservation – and then reabsorbed. This subtle effect has a small influence on the real processes that are observed, and the data therefore can be analysed to determine M_H within errors, which however are large since the effect is small. This determination is represented in terms of a quantity called $\Delta\chi^2$ shown in Figure 1.

Figure 1 - The existing data are indirectly sensitive to the mass of the Higgs boson (M_H). The figure shows the quantity $\Delta\chi^2$ obtained from a fit to the best available data. The Higgs boson is most likely to be found in the region where $\Delta\chi^2$ is smallest



The most likely value of M_H is at the minimum of $\Delta\chi^2$ which is in the LEP2 region, although it should be cautioned that there is a 32% [5%] probability that the Higgs mass is in the region where $\Delta\chi^2$ is greater than 1 [4]. It is worth noting that a similar analysis was used by CERN to successfully predict the mass of the top quark (m_t) before it was observed in a real process – see the Director-General's Status Report for 1994 (CERN/2079).

"COMPLETION OF THE LEP UPGRADE" (cont.)

Supersymmetry

Supersymmetry connects fermions ("constituent particles") to bosons ("force carrying particles") and is aesthetically very appealing, as well as perhaps being required to underwrite the stability of the Standard Model. When combined with the equally appealing idea of "grand unification" between the nuclear and electroweak force, supersymmetry successfully explains the strength of the nuclear force – see Figure 2 – and must therefore be taken very seriously.

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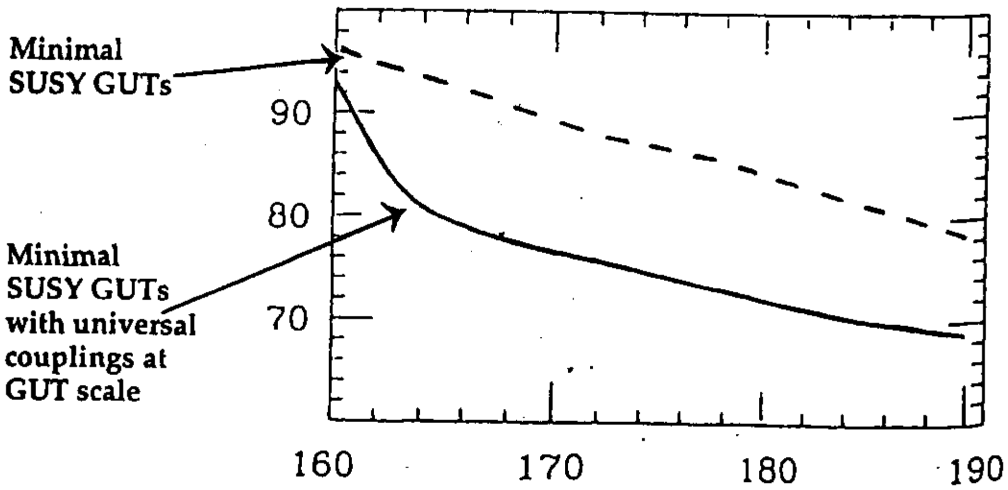
If supersymmetry is correct, electrically charged supersymmetric particles ("charginos" or "sleptons") must exist which could be discovered by LEP2. In fact, a class of attractive grand-unified supersymmetric models leads to the expectation that charginos lie in the LEP2 region, as shown in Figure 4.

Figure 4 - Plausible (but not obligatory) upper limits on the masses of charginos



In Figure 4, the bounds can be avoided by "fine-tuning" adjustable parameters to 10% accuracy. Allowing "fine-tuning" to 5% [1%] raises the limits by a factor of 1.4 [3.2], e.g. an 80 GeV bound would become a 110 GeV [250 GeV] bound if fine-tuning to 5% [1%] accuracy is considered tolerable.

Conclusion

The above arguments should be treated with due caution as they are rather theoretical in nature and depend on a number of assumptions and hypotheses which, while plausible, have not been tested. Nevertheless, they show that the completed LEP2 will have a spectacular discovery potential, and that, at the least, completion of the LEP upgrade will provide significant tests of leading models, and ensure a comfortable and safe overlap of the capabilities of LEP and the LHC.

INTERLUDE – 1996:

Fighting for single-stage LHC, and non-Member State contributions to make it possible, in face of D/UK budget attack, **but**

Plan for single stage LHC, approved December 1996, includes

> *"LEP is scheduled to stop at the end of 1999, taking full advantage of the recently approved upgrade programme (LEP – Phase IV). The dotted line in Figure 1 in 2000 indicates that it should be technically possible to operate LEP to the end of that year, but no longer, without affecting the LHC timetable. The CERN Management considers that this highly desirable option must be kept open, to be decided in late 1998 on the basis of the scientific case and the resources available at that time. However, the necessary resources cannot be found in the framework of the programme and budget estimates presented here."*

while the unanimous Council Resolution ⟶ statement that Council

> *"encourages additional contributions to enhance the vitality of the general scientific programme during the LHC construction period."*

Meanwhile - September 1996 confidential estimate of 63 MCHF cost for LEP 2000

THE LAST STEPS, 1997 – 98

- **March 1997** – start soliciting additional contributions for LEP 2000

- **June 1997**: Medium Term Plan, emphasised very strong case for LEP 2000 in a section on **"Missed scientific opportunities?"** which began *"The resources available to support the programme described in this plan are now at the minimal possible level, while the scientific programme itself is extremely narrow"* and cited *"The recent decision to bring forward the upgrade of the LEP cryogenic plants, which is needed for the LHC, will allow a further final step in the energy of LEP in 1999. This makes it highly desirable to continue operation in 2000".*

- Following encouragement from Council, a "White Paper" was sent to Delegates explaining the case in **July 1997**☞

- Over the next nine months, continued presentation to Council Committees plus search for additional contributions (aided by **December 1997 Council Resolution** urging help☞)

- **June 1998** Medium Term Plan formally proposed **operating LEP in 2000**, which (not without some difficulty ☞) **was approved by Council on 19 June**

  [Contributions totalling 12.6 MCHF quoted in the plan, from Austria, Denmark, Germany, Italy, Spain, and Switzerland; current total is 17.2 MCHF, including contributions from the Czech Republic, Finland, France, Israel, Norway, Portugal and the UK]

Original : English
15 July 1997

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

OPERATION OF LEP IN THE YEAR 2000

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4.— CONCLUSIONS

The scientific case for operating LEP in the year 2000 is very compelling. The extra energy that will be available in 1999 combined with an additional year of operation would increase very significantly the exciting prospect of discovering a Higgs boson,[1] which would unblock progress to a deeper understanding of nature, and/or supersymmetry, which would radically alter our view of the microstructure of matter. An early decision is very desirable for *i)* CERN, in order to allow the planning that is needed to minimise the costs and optimise the overall use of CERN's resources, *ii)* the outside funding agencies that support the LEP experiments, and *iii)* the scientists involved.

Member States and non-Member States that are willing to consider making additional contributions to allow the operation of LEP in the year 2000 are asked to inform the CERN Management as soon as possible.

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[1] The discovery of a Higgs boson, or of supersymmetry, at LEP would strengthen the case for the LHC. In the absence of any new physics ("beyond the Standard Model") below the ("Planck") energy scale where the effects of quantum gravity become important, the Higgs boson must have a mass *greater than* 130 GeV. Discovery of a Higgs boson at LEP (i.e. *below* 104 GeV) would therefore indicate the existence of new physics at a relatively nearby energy scale, probably(?) supersymmetry and probably below 1000 GeV, i.e. in reach of the LHC. If supersymmetry is correct, the LHC will be essential for studying and understanding this whole new aspect of nature (even if LEP discovers one or more supersymmetric particles, most of the supersymmetric world must be out of LEP's reach).

COUNCIL RESOLUTION
CONCERNING THE OPERATION OF LEP IN THE YEAR 2000

COUNCIL

Taking into account that

- following the adoption of a single-stage construction schedule for the LHC in December 1996, it has been found possible to schedule the civil engineering work for the LHC so that LEP can continue to operate in the year 2000 without delaying the start-up of the LHC;
- an additional year of LEP operation would improve knowledge of particle physics substantially, and could lead to important breakthroughs;
- further exploration of physics in electron-positron collisions at 200 GeV is not possible at any other existing or approved facility world-wide;
- it is of vital importance for the CERN Member State physicists to limit the length of the period preceding the start-up of LHC during which no front-line facilities will be operating at CERN

Considering

- its Resolution (CERN/2179) adopted in December 1996, which encouraged "additional contributions to enhance the vitality of the general scientific programme during the LHC construction period";

Noting further that

- the strong case for operation in the year 2000 is greatly enhanced by the decision to bring forward the upgrade of the LEP cryoplants, which is needed for LHC, thereby making it possible to operate the LEP cavities at higher accelerating gradients and achieve higher energies from Spring 1999;
- the cost of operating LEP in 2000 is small compared to the total investment in LEP;

1. **Expresses** its desire that LEP should operate in 2000 in view of the extremely powerful scientific case for this very cost-effective option; and, in conformity with the Resolution (CERN/2179),

2. **Urges** all countries whose physicists participate in LEP experiments to provide additional resources in order to make operation in 2000 possible.

* * *

1998 MEDIUM TERM PLAN (1999–2002):

1.1.3 Funding of LEP2000

The estimated cost of operating LEP in 2000 is 50 MCHF. As noted above, thanks to the manpower element in the supplementary contributions, the manpower cost (10 MCHF) can be covered without asking for an increase in the personnel budget. CERN had hoped to cover the material cost[1] (40 MCHF) through supplementary contributions. At the time of writing, however, only 12.6 MCHF had been offered (from Austria, Denmark, Germany, Italy, Spain and Switzerland). However, seven other Member States are known to be actively seeking the means to contribute, and in this plan supplementary contributions towards the operation of LEP in 2000 of 20 MCHF are assumed.

The Management proposes that the remaining cost be covered by *i)* taking 10 MCHF from the Special Reserve account (which currently has a balance of 13.1 MCHF – see CERN/2238 – CERN/FC/4057), subject to Council's approval and *ii)* allowing a small increase in the debt that will be incurred during the peak LHC construction period (2002 onwards; the actual cost in 2000 will be covered by the accumulated reserve) as it is not possible to find significant additional savings inside the CERN budget (see Section 1.3).

THIS RAN INTO SOME TROUBLE:

Secondly, while the German delegation could support the Management's proposal in § 1.1.3 of the document to take 10 MCHF from the Special Reserve towards the financing of LEP2000 provided that the Management was prepared to bear the associated risk, it would have great difficulty in agreeing to covering the outstanding balance of 10 MCHF by an increase in borrowing from 2002 rather than through additional savings. His delegation considered that such an increase in the borrowing requirement was excluded under the terms of the LHC decisions of 1994 and 1996 and that the necessary financial flexibility given to the Management in cash flow management applied to the LHC and not to activities which were generally acknowledged to have a lower priority than the LHC.

The DIRECTOR-GENERAL, ...

Expressing some disappointment at the remarks of the German delegation concerning the financing of LEP2000, he emphasized that there was no intention to borrow money for an additional year of LEP operation in the year 2000, since the Organization would still be in credit in that year, but rather to defer some LHC expenditure. That would have the effect of slightly increasing cash-flow difficulties at a later stage, which would nevertheless be resolved within the boundary conditions set by the Council. He hoped that delegations would be able to go along with such an approach.

CONCLUSIONS

1) LEP 200 was

- a major, very challenging, high-tech project
- a triumphant success

2) The arguments for the final upgrade and operation in 2000 succeeded because (as for LHC) they were very strong and were supported by the whole hep community

As for Physics.....