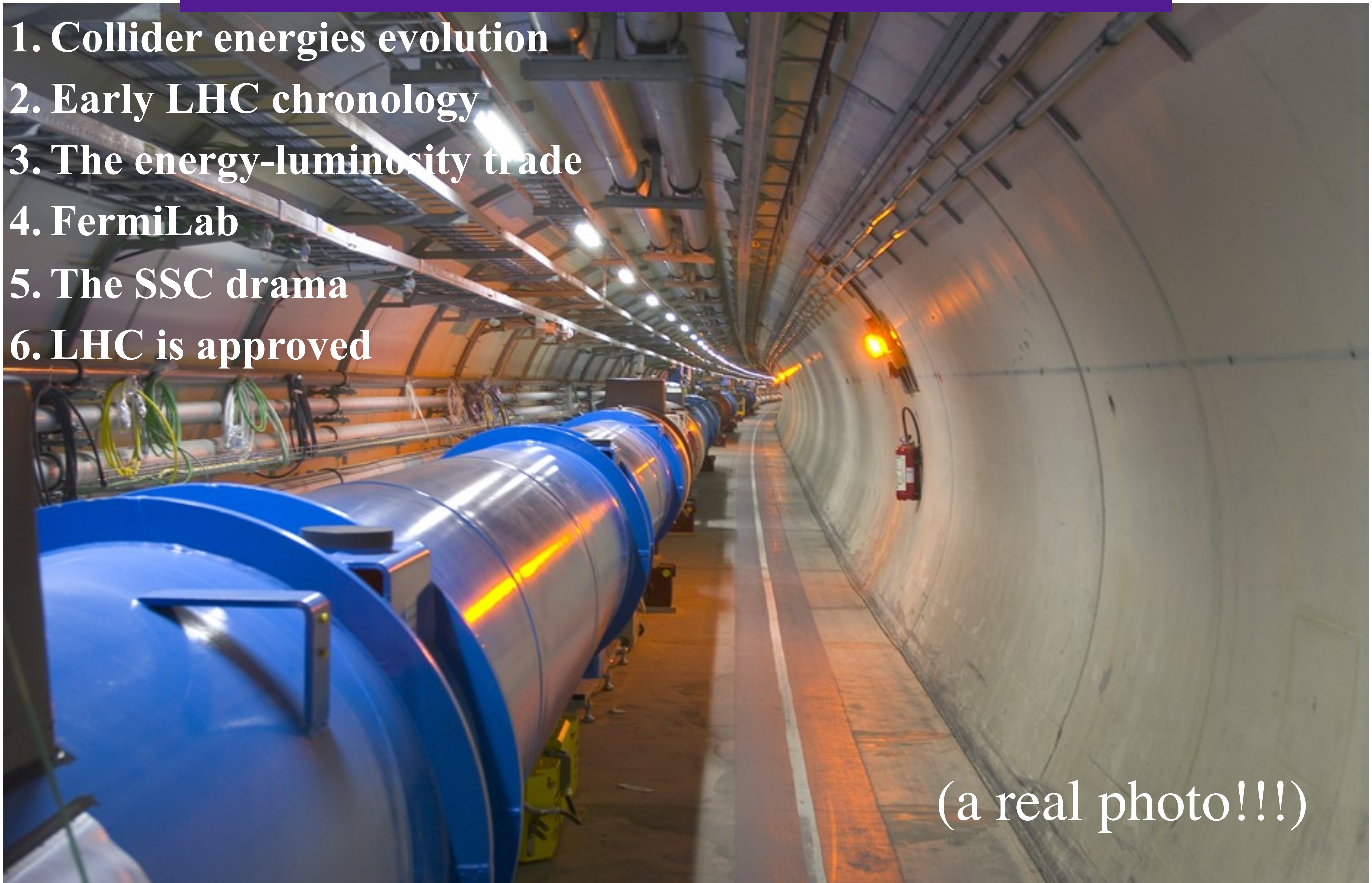
Luciano Maiani:

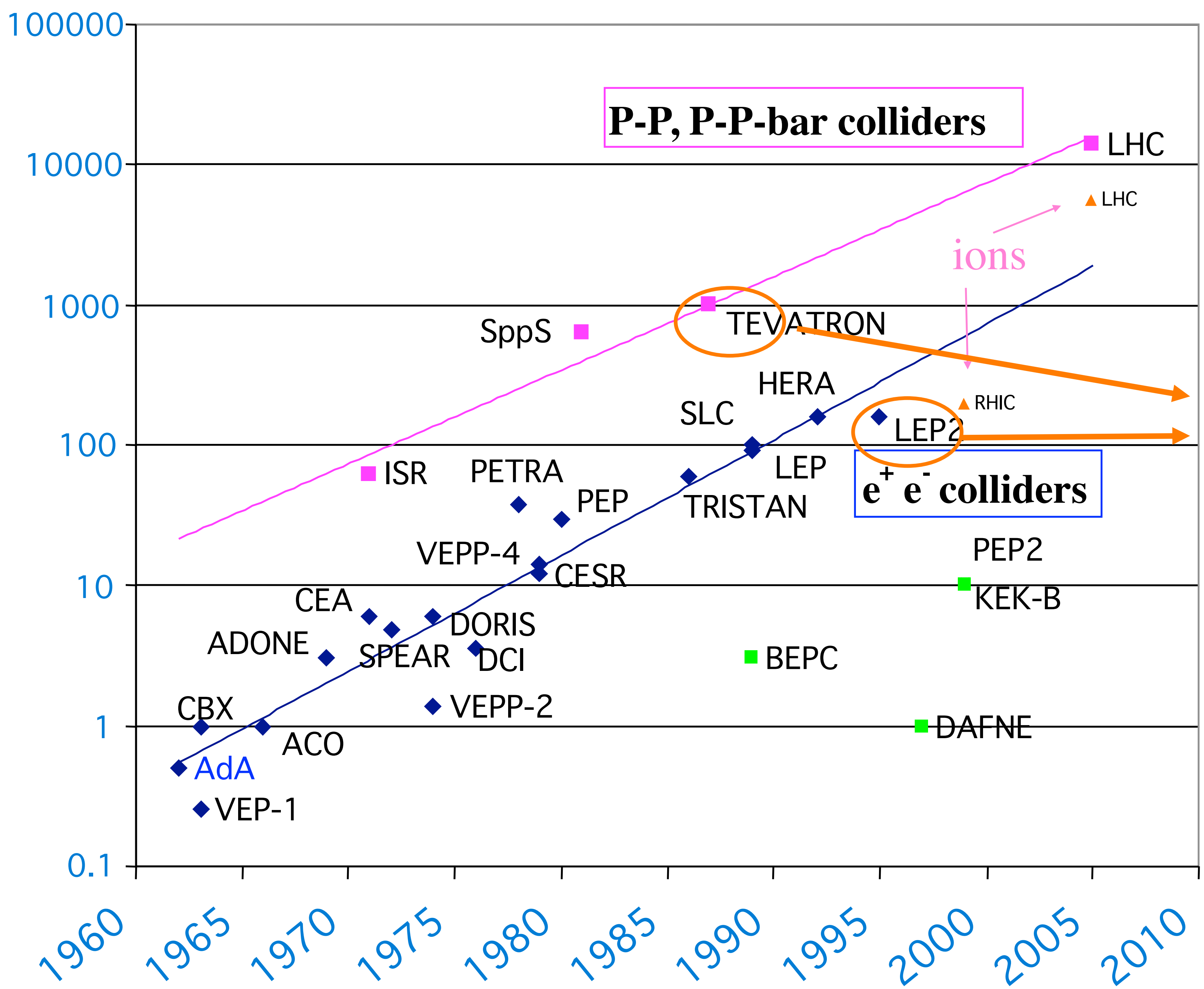
. Lezione Fermi 25

Dal LEP a LHC

1. Collider energies evolution
2. Early LHC chronology
3. The energy-luminosity trade
4. FermiLab
5. The SSC drama
6. LHC is approved



1. Collider energies evolution



LHC planning started in between these two machines !

Jets and QCD evolution

- **1982** SppbarS in operation: jets
  1983 Discovery of W&Z
  The discovery of jets (i.e. interactions of the constituents) in p-pbar has played a crucial role because it showed the possibility to study basic interactions even with hadron beams. No problem to get to high energy, compared to e+e-
- QCD evolution shows that there is no much gain in p-pbar vs. p-p collisions (gluons and sea constituents dominate). No problems with luminosity such as with pbar.
- By 1984-1985 the idea of a high energy proton collider in the LEP tunnel had gained momentum
- **July 1989 first Z0 at LEP.**

THE LEP TUNNEL

- The size of the LEP tunnel has been a delicate aspect
- Physicists had thought to make it wider than what was strictly needed, so as to be able to install later a proton machine with superconducting magnets
- The ECFA study made in Roma in 1978, chaired by A. Zichichi, had made a recommendation in this direction, nothwitstanding the resistence of those afraid that the implied cost increase would have put the very same LEP project at danger
- as a compromise, a tunnel of 4 meters diameter was accepted. This was not enough for a cryogenic system with two independent magnets (such as was designed for the SSC).
- CERN was forced to develop the more advanced design: “two-in-one”, more compact and and less expensive
- The choice of tunnel’s dimensions, all in all, is a positive story: an admirable compromise that made it possible to prolong the lifetime of CERN by certainly more than 20 years.

LHC two-in-one magnet in an early design (1990)

		Length (m)	magnets
Dipoles	$B_o = 10$ T	9.00	2 x 1792
Quadrupoles	G = 250 T/m	3.05	2 x 642
Tun. quads,	G = 120 T/m	0.72	2 x 400
Sextupoles	B" = 4500T/m^2	1.0	2 x 800
Orbit corr. dipoles	$B_o = 1.5$ T	1.0	2 x 552
Higher-order multipoles			2 x 1600

A more detailed review of the LHC magnets is given in Reference[7].

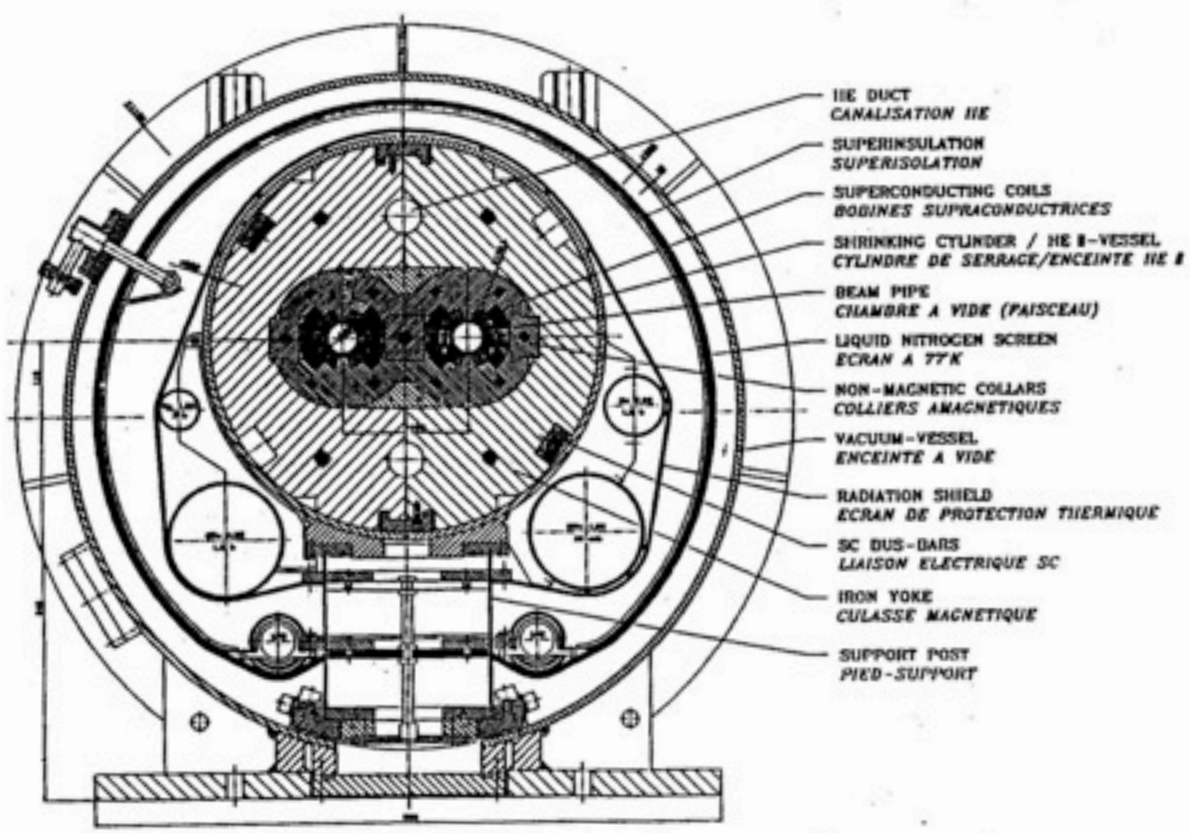


Fig. 3 : LHC dipole standard cross-section

2. Early LHC chronology

- **1981** Lausanne ECFA workshop: LHC in LEP tunnel
- **1986** La -Thuile workshop: first design (G. Brianti)
- **1988** Feasibility of High Luminosity expts at LHC, Geneve meeting
- **1990** **Aachen meeting**: main lines are delineated.

- **G. Kalmus** (closing remarks): It (the Aachen meeting) has marked a watershed, the time, when the LHC project…**graduated ..to being the way forward for European particle physics.**

- **C. Rubbia: high luminosity makes LHC competitive with the SSC (compensating for an energy ratio 40/16 – really 14)**
- A lot of wishful thinking:
  - schedule: start civil engineering in 1992, commissioning in 1998 (6 years).
  - In reality…start civil engin. in 1997 (+5), commiss. in 2008 (+5+5=+10 years).
  - It was still considered possible to install in the tunnel together with LEP and run LEP and LHC concurrently (possibility was kept alive until 1995 when C.LL.S in Beijing mentioned that probably LEP had to be dismantled…I got protests by I. Mannelli)
  - no cost mentioned.
- 1992 Council declares that the LHC ***“will be CERN’s next facility”***,
- 1992 Expressions of Interest for experiments are presented in Evian; the LHC experiments Committe is created.

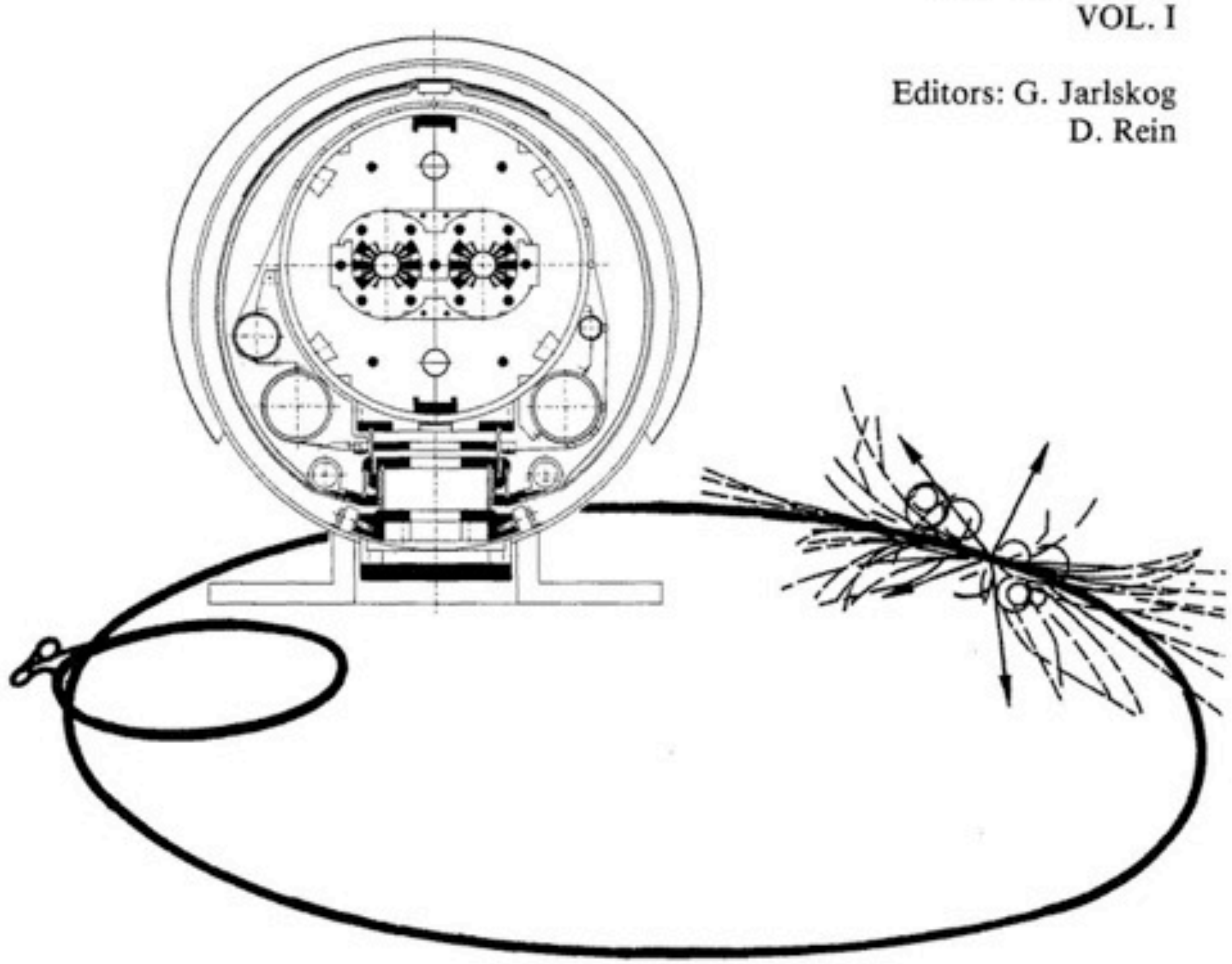
CERN 90-10
ECFA 90-133
Volume I
3 December 1990

EUROPEAN COMMITTEE FOR FUTURE ACCELERATORS

Large Hadron Collider Workshop

PROCEEDINGS
VOL. I

Editors: G. Jarlskog
D. Rein



Aachen, 4-9 October 1990

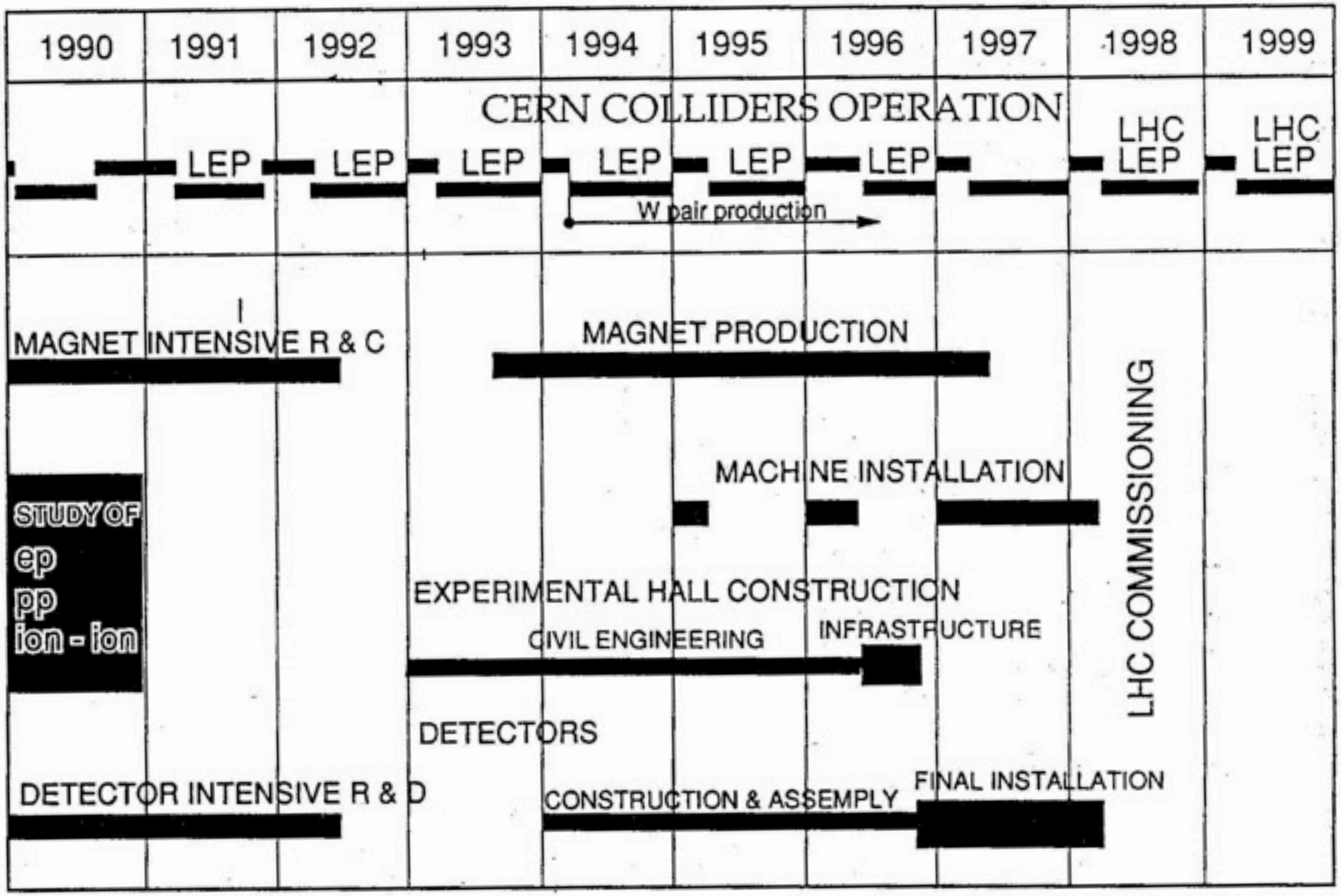


Figure 18 – Construction schedule of the LHC

Presented in Aachen, 1990

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

DIRECTOR - GENERAL

CERN
CH-1211 GENEVA 23
SWITZERLAND

Telephone : GENEVA (022) 767 23 00
Telex : 419000 CER CH
Telegram : CERNLAB-GENEVE
Fax : (022) 767 75 55

Professor
L. Maiani
TH Division
CERN

Your reference:
Our reference: DG/CR/mcd/13651/7392

Geneva, 10th July 1992

Dear Professor Maiani,

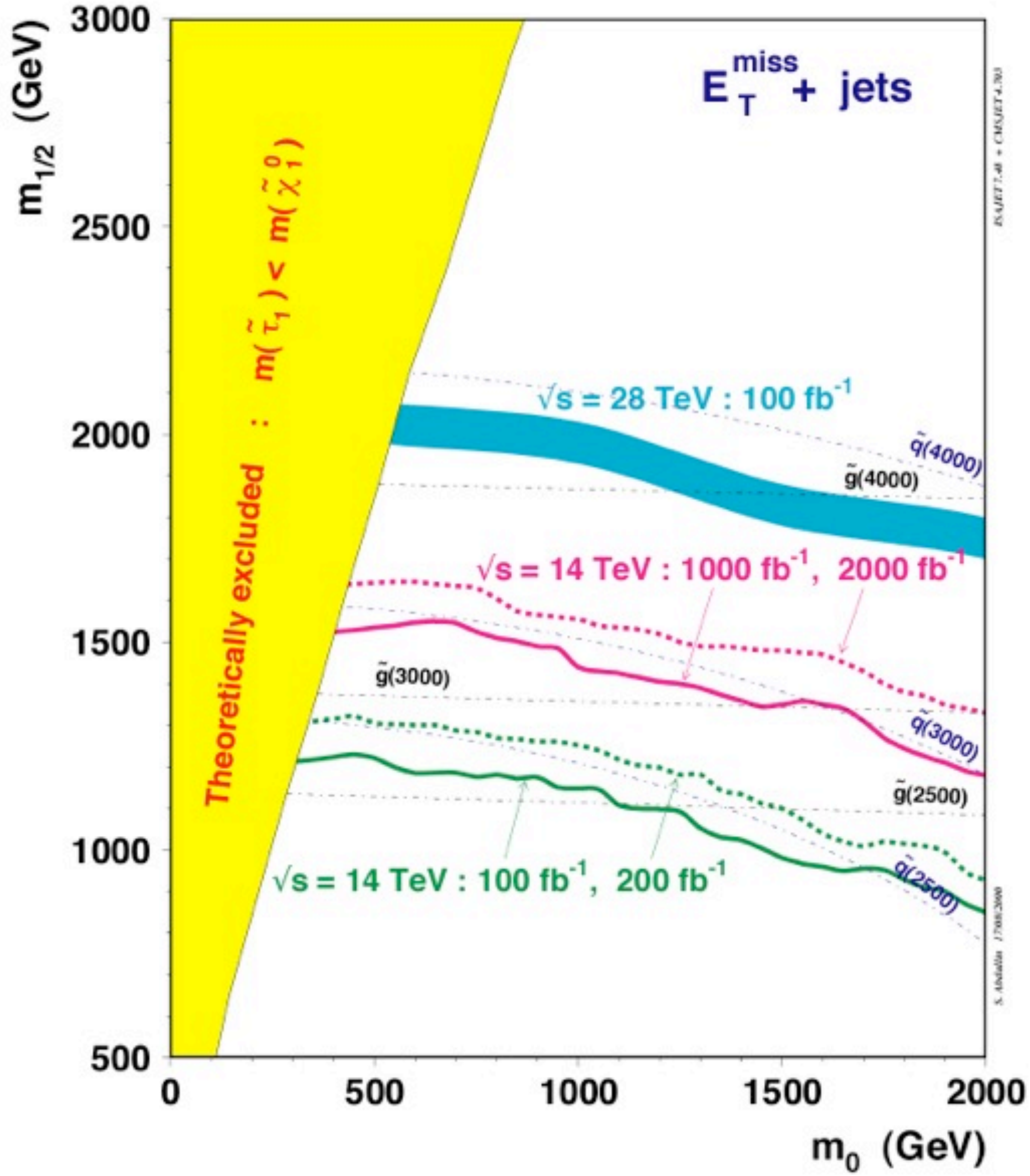
As you know, the CERN Council has declared that the LHC will be CERN's next accelerator facility. Part of the requirements for the final approval will be a definition of the experimental programme. Preparations for this programme already started some time ago. In a very successful meeting in Evian last March, Expressions of Interest were presented. The meeting demonstrated the large interest in the physics opportunities of the LHC and the large amount of work which has already gone into the design of possible detectors.

With the SPC an experimental strategy has been outlined which foresees that first Letters of Intent should be submitted by 1st October 1992. An experimental committee, the LHCC, should evaluate these Letters of Intent, recommend to the CERN Management which collaboration should proceed with a technical proposal and monitor the development of these proposals, eventually leading to an approved programme at the time that the LHC gets its official go-ahead. It is planned that the LHCC will closely interact with the DRDC, the committee which has been instrumental in setting up a well focussed detector R & D programme, in evaluating technical aspects of the

3. Energy vs. Luminosity

- The first design of the LHC in the LEPtunnel have been presented in March 1984, ECFA workshop in Lausanne.
- Not competing on energy with the SSC, LHC invested in luminosity
- the ***energy-luminosity trade***:
  - since the proton energy is anyway >> parton energy, with high luminosity you can catch the rare collisions from high energy partons which are always present in the proton.
- high luminosity was a risky business:
  - betting in a machine that we knew (perhaps!) how to build
  - with detectors that we did not know for sure how to make.
- A long R&D was necessary. Today we know!!!

The “Luminosity-Energy trade”: reappears now with the SLHC !!



Energy reach for SUSY particle searches of a PP collider vs E&Lum.

Indicative Physics Reach

Fabiola Gianotti: ICFA Seminar

Units are TeV (except $W_L W_L$ reach)

$\int Ldt$ correspond to 1 year of running at nominal luminosity for 1 experiment

PROCESS	LHC 14 TeV 100 fb^{-1}	SLHC 14 TeV 1000 fb^{-1}	LHCx2 28 TeV 100 fb^{-1}	VLHC 40 TeV 100 fb^{-1}	VLHC 200 TeV 100 fb^{-1}	LC 0.8 TeV 500 fb^{-1}	LC 5 TeV 1000 fb^{-1}
Squarks	2.5	3	4	5	20	0.4	2.5
$W_L W_L$	2σ	4σ	4.5σ	7σ	18σ	90σ	
Z'	5	6	8	11	35	8 *	30 *
Extra-dim (δ=2)	9	12	15	25	65	5-8.5 *	30-55 *
q*	6.5	7.5	9.5	13	75	0.8	5
Λ compositeness	30	40	40	50	100	100	400

* indirect reach (from precision measurements)

Approximate mass reach of pp machines:

$\sqrt{s}$ = 14 TeV, $L=10^{34}$ (LHC) : up to ≈ 6.5 TeV

$\sqrt{s}$ = 14 TeV, $L=10^{35}$ (SLHC) : up to ≈ 8 TeV

$\sqrt{s}$ = 28 TeV, $L=10^{34}$: up to ≈ 10 TeV

$\sqrt{s}$ = 40 TeV, $L=10^{34}$: up to ≈ 13 TeV

$\sqrt{s}$ = 200 TeV, $L=10^{34}$ (VLHC) : up to ≈ 75 TeV

4. FermiLab time line (cont' from Lecture 22)

- 1976. The project: Energy Doubler/Saver starts under Bob Wilson leadership
  - doubling the energy and saving energy because magnet will be alimented by superconducting cables: first large scale application of superconductivity to particle physics
- 1978. Bob Wilson dimissionates because of insufficient funding of the Energy Doubler
- 1978. Leon Lederman becomes director of FermiLab
- 1983. Energy Doubler reaches 500 GeV
- the discovery of W and Z at CERN...
- 1984. Energy Doubler reaches 800-1000 GeV, world record
- 1985. Starts the p-pbar Collider mode: 2 TeV in the center of Mass, the Tevatron. Will continue until 2010, when LHC takes over.
- ...but the effective mass one can reach in the q-qbar system is not much higher than 300 GeV...
- Fermilab and elsewhere in USA, physicists start thinking about a Very Big Collider (VBG)

November 1988.
Fermilab loses the competition for hosting the SSC
SSC approved at a new site: Wakahachi, Texas,

Leon Lederman, wearing a Stetson hat, announces to the Laboratory that Fermilab has not been chosen as the SSC site. 10 November 1988. FNAL Visual Media Service.

Shaft to the SSC tunnel di SSC, located at about10 meters underground. The planned tunnel had a circumference of 87 km.

5. The SSC drama

- The SSC (Superconducting Super Collider) was proposed in the US in the first '80s: proton-proton, very high energy, 20 TeV/beam;
- **1988** **SSC approved,** proton-proton, 20 TeV/beam, 87 km tunnel, cost 4-5 B US$;
  1989 SSC construction starts.
- **1993** SSC discontinued by the US Congress after a bitter discussion which invested all the scientific community (projected cost >10 B US$)

The Supercollider That Never Was (Scientific American, 2013)

... When canceled, about 20 percent of the SSC was complete—specifically, two dozen kilometers of tunnel had been drilled with 17 access shafts, and 18,600 square meters of buildings erected. Over $2 billion had already been spent, mostly by the DoE, but also $400 million by the state of Texas.

At its end the project was already employing 2,000 people at the site or in Dallas, about 200 of whom were scientists, plus a contingent of Russian physicists employed after the end of the Cold War. Another 13,000 jobs linked to the project never materialized. About half the SSC scientists left the field of physics, according to a 1994 survey by *Science* magazine, some to become analysts in the financial industry. Many took a loss on homes sold in a sudden buyer's market.

....The SSC was an epic project that ended in failure. The U.S. has yet to stride again its own once prominent footsteps; but perhaps worse, it no longer dares to dream in color. Whatever the future for high-energy physics the U.S. and the world, the hulking beast that would have been the Superconducting Super Collider will not soon be forgotten.

6. LHC is approved

Caccia al Bosone di Higgs, L. Maiani, R. Bassoli (Mondadori, 2013)

- the cancellation of the SSC programme made a terrible shock-wave in Europe, firing back on particle physics and CERN.
- Top discovery had a very good balancing effect (as seen from Italy)
- the first prototype of 10m superconducting LHC magnets was presented at CERN Council in Dec. 1993 with a positive effect
- Luckily, on the basis of the SppbarS and LEP successes, CERN project has been approved in December 1994.

First prototype of 15 m superconducting LHC dipole by CERN-INFN-Ansaldo Energia collaboration,1998.

The 1994 approval of LHC

Le Conseil du CERN

1) Déclare que la décision d'inclure le LHC dans le Programme de base vaut pleine approbation de la construction d'un collisionneur de 14 TeV, mais que, compte tenu des plans actuels et des recettes escomptées, cette construction devrait se faire en deux étapes.

2) Déclare que les éventuelles contributions d'Etats non-membres serviront à accélérer et améliorer le projet, et non à permettre de réduire les contributions des Etats membres.

3) Prend note avec gratitude des engagements de la France et de la Suisse de verser des contributions volontaires pour aider et accélérer la réalisation du LHC.

4) Déclare que l'indice global de variation des coûts à appliquer aux contributions des Etats membres devrait être nul dans la période de 1995 à 1997.

5) Décide que la planification devrait reposer sur l'hypothèse d'une inflation de 2% et d'une indexation des contributions des Etats membres au taux de 1% à partir de 1998.

6) Convient que l'examen complet de l'avancement du projet LHC, qui devra être effectué avant la fin de 1997, portera sur la question de savoir si le LHC doit être construit en une étape au lieu de deux.

2 stages

Role of non- MS contr.s

2% indexation
+ special contr.s

Indexation model

15/12/94

CERN/2039(a) (REV 2)
DRAFT

DRAFT RESOLUTION
APPROVAL OF
THE LARGE HADRON COLLIDER (LHC) PROJECT

COUNCIL,

HAVING REGARD TO

the Resolution (CERN/1904) it adopted at its 93rd Session on 20 December 1991 stating that the LHC is the right machine for the advance of the subject and *for* the future of CERN;

CONSIDERING

The proposal to construct a Large Hadron Collider ***with a centre of mass energy of 14TeV*** in the LEP tunnel (CERN/SPC/679-CERN/CC/2016; CERN/SPC/677-CERN/CC/2014; CERN/SPC/677/Add.-CERN/CC/2014/Add.; CERN/CC/2030; CERN/2039; ***CERN/SPC/695-CERN/CC/2072, including the budget scenario in table 2)***;

the Resolution it adopted at its 99th Session on 15 April 1994, which again endorsed the scientific case for the LHC, supported the promotion of the LHC as the central element of the long-term programme of CERN, expressed a wish that the LHC be implemented as part of the basic programme of the Laboratory, and endorsed the proposed comprehensive review of the progress of the project, to be carried out at an appropriate moment and in any case before the end of 1997 in order to define more precisely the timetable for execution of the project in the light of the foreseen funding;

Articles II, III and V of the CERN Convention;

Luciano Maiani
Volker Soergel

LHC agreements: 1966 to 1997

Chris Llewellyn Smith (right), with Hubert Curien, President of Council (center)receives a Daruma Doll from Kaoru Yosano, Japan Minister of Education, Science and Culture, June 1st 1995 at the signature of the Japan-CERN agreement for Japan participation in LHC (machine and experiments.

CERN personnel protest against budget cuts requested by CERN Council to approve LHC construction. December 1996

Signature of the USA-CERN agreement for the US participation in LHC (machine and experiments), Washington 8 decembere 1997. From left: Neil Lane, Director NSF, Federico Pe~na, Secretary for Energiy, Luciano Maiani, President of Council, Chris Llewellyn Smith, Director General of CERN.

CERN/2179 (Dec. 1996)

RESOLUTION

concerning the construction of the LH and the funding of the Organization

DECIDES

1.
that the LHC Project shall be completed in a single stage and planning shall proceed on the basis that the LHC shall be commissioned in 2005;

2.
that funding of the LHC will be preserved as foreseen when the project was approved, in the framework then agreed (CERN/2075 and the statement annexed thereto), albeit with a reduction in the Member States 'annual contributions to the Organization of 7.5%in 1997,8.5%in 1998-2000,and 9.3%in 2001 and thereafter,compared to the level foreseen in December 1994;

3.
that it will make every effort to ensure that the ordinary contributions from each Member State during the period 1997-2008 will not fall below the level implied by its above decisions;

URGES

all Member States to make every effort to pay their full ordinary annual contributions during the first quarter of each year, and to examine the possibility of making advanced payment of their ordinary annual contributions;

AND ENCOURAGES

additional contributions to enhance the vitality of the general scientific programme during the LHC construction period.

L’accordo di Dicembre 1996

Caccia al Bosone di Higgs, L. Maiani, R. Bassoli (Mondadori, 2013)

- L'accordo confermava i tagli richiesti dalla Germania ma, allo stesso tempo, approvava la costruzione in un unico stadio del progetto con inizio dei lavori nel 1997. Il CERN, da parte sua accettava il taglio, con l'impegno di riassorbirlo nel bilancio generale del laboratorio, entro il 2009. La data di inizio del funzionamento di LHC era stata fissata al 2005. Chris aveva ottenuto il suo scopo, seppure al prezzo di spingere le nubi in avanti nel tempo.

- Un certo numero di avvertimenti furono messi a verbale nell'occasione, per essere prontamente dimenticati dalle delegazioni dei vari Paesi.

- Con le riduzioni di bilancio il progetto non aveva piu’ alcun margine di rischio contro gli imprevisti di spesa e neanche per la ricerca e sviluppo nel campo dei magneti superconduttori, che come abbiamo visto erano il cuore tecnologico dell'impresa. L'unica valvola di sicurezza del progetto, in una situazione di bilancio costante, era la possibilita’ di allungare i tempi di costruzione: nelle parole di Chris, *time is LHC contingency*, 'Il tempo e’ la riserva per gli imprevisti di LHC'.

- Inoltre, l'attivita’ scientifica del laboratorio, negli anni della costruzione, avrebbe dovuto ridursi a zero, cosa assai pericolosa per la preparazione del laboratorio alle sfide che LHC avrebbe imposto.

- Su tutto, prevalse la soddisfazione per l'approvazione di LHC e per la prospettiva del sospirato inizio degli scavi nel 1997. La fisica mondiale delle particelle aveva adesso il suo obiettivo. Ricercatori di ogni parte del mondo potevano tirare un sospiro di sollievo e dedicarsi allo sviluppo dei rivelatori, lasciando allo staff del CERN il non facile compito della realizzazione della macchina.