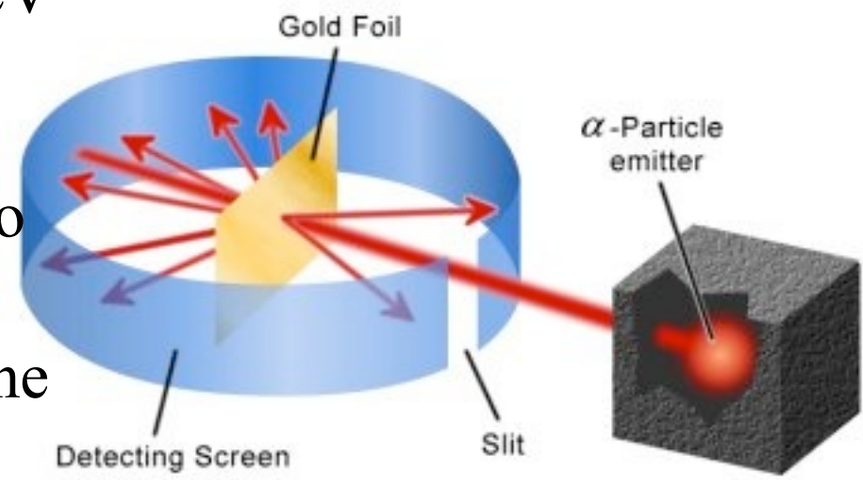
Luciano Maiani:
Lezione Fermi 7
Strumenti per le nuove particelle: la creazione del CERN

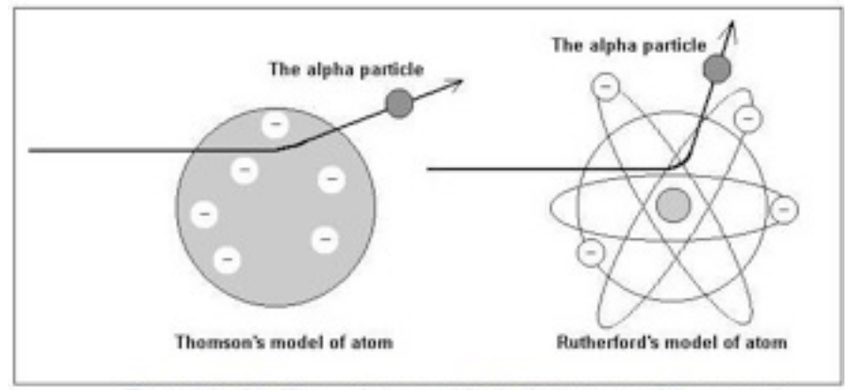
Sommario

1. Alte Energie
2. L'acceleratore massimale di Fermi
3. La creazione del CERN
4. LEP
5. CERN oggi

1. Alte Energie, per il nucleo e per le particelle

- Primi proiettili utilizzati: le particelle alfa (nuclei di Elio) emessi da alcune sostanza radioattive, es. Radio (energie ~ MeV
- la statistica delle deflessioni ci da' un'idea della distribuzione delle cariche nell'atomo: eventi con riflessione all'indietro segnalano la presenza di un nucleo di materia concentrata entro un raggio ~ 1fermi << raggio dell'atomo~ 1 Angstrom
- per penetrare nel nucleo, il proiettile deve superare la repulsione tra la carica positiva delle particelle alfa e dei protoni del nucleo: le energie delle alfa della radiattivita' naturale non bastano piu'
- di qui la spinta a costruire delle macchine acceleratrici, prima basate sull'accelerazione elettrostatica in strutture lineari (Cockroft e Walton), poi con campi elettrici a radiofrequenza applicati a particelle tenute in orbite circolari da campi magnetici: ciclotroni (E. O. Lawrence) e i suoi derivati successivi, sincrociclotroni, sincrotroni)
- L'energia disponibile nella collisione proiettile-bersaglio puo' essere utilizzata per "creare" nuove particelle, es. i mesoni di Yukawa, a partire dalla relazione: $E= mc^2$.
- per creare un pione occorrono pero' 140 MeV (raggi cosmici)
- e per creare un antiprotone nella reazione: su bersaglio fisso, occorre un'energia cinetica ≧ 5.6 GeV (E ≧ 6.6).





The models of the Thomson's atom and Rutherford's atom; and the expected aberrations of alpha particle in both cases.

$1\ \text{A} = 10^{-8}\ \text{cm}$
$1\ \text{fm} = 10^{-13}\ \text{cm}$

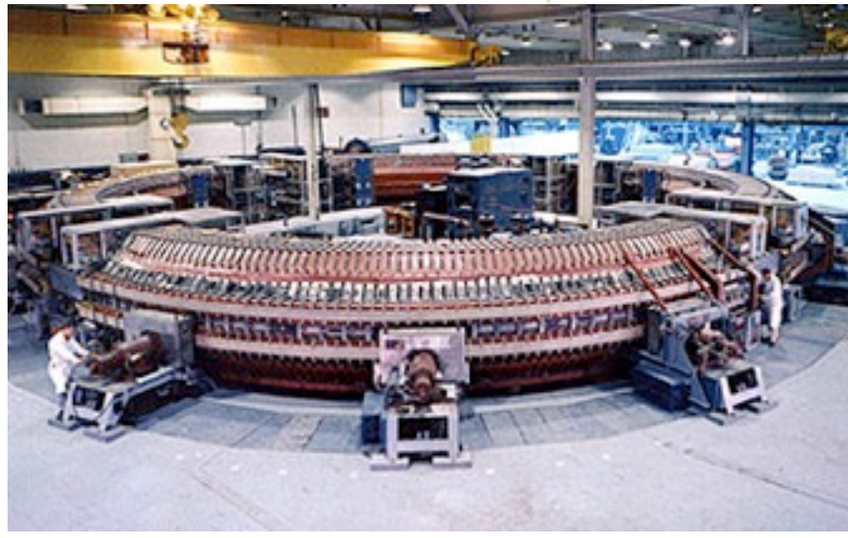
$$p(E) + p(\text{staz.}) \rightarrow p + p + p + \bar{p}$$

Gli acceleratori giganti negli USA

1949
The magnet's completion is the cover story for the *Bethlehem Review*, a news bulletin for the employees of the Bethlehem Steel Corporation (above).

- Ciclotrone di Chicago, E. Fermi studia le collisioni di pioni su nucleone e scopre la prima risonanza adronica, Δ, uno stato eccitato del nucleone,

- Cosmotron (AEC, Brookhaven, 1953), E= 3.3 GeV,
  - permetteva di estrarre un fascio da mandare su bersaglio fisso
  - era possibile produrre e studiare i mesoni π e K, che erano stati osservati fino ad allora solo nei raggi cosmici (quindi il nome)

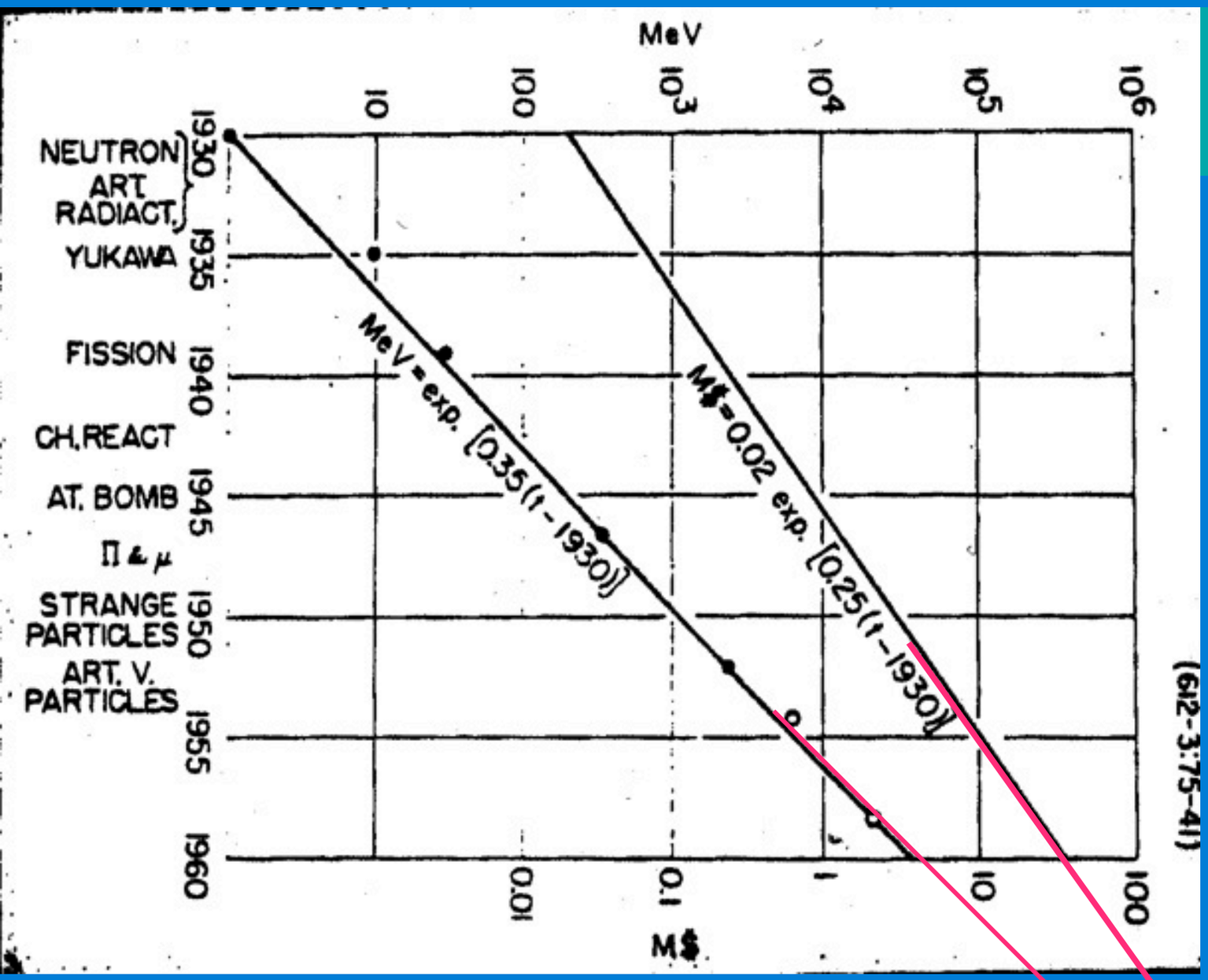


- Bevatron (UCLA, Berkeley, 1954), E=6.2 GeV
  - cotruito per osservare l'antiprotone (E. Segre', O. Chamberlain, 1955)

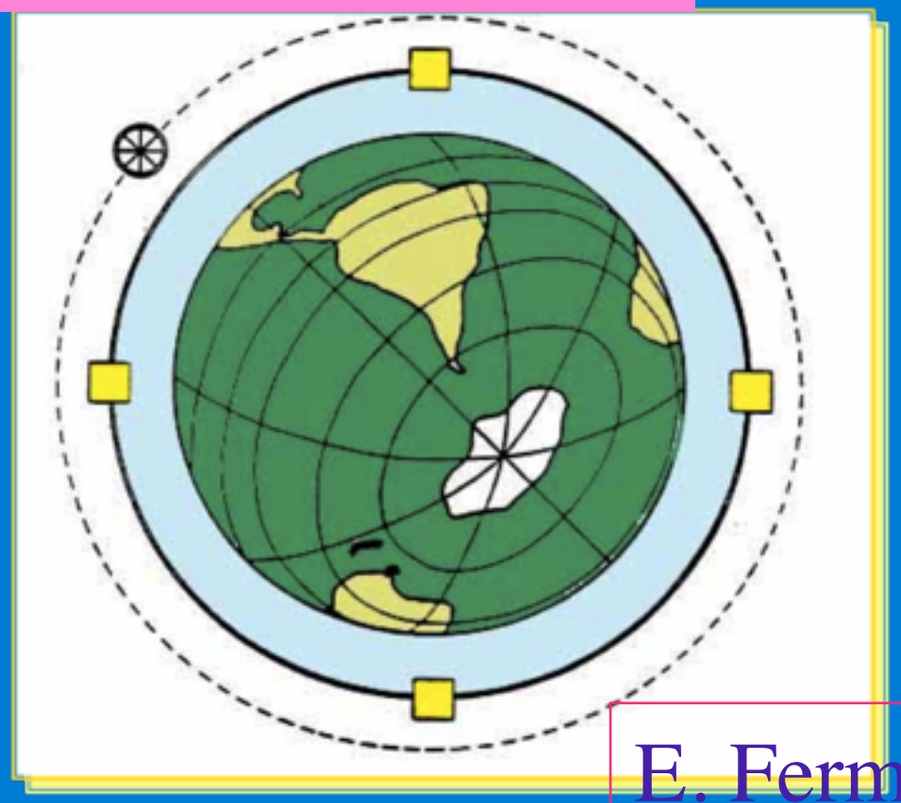
- negli anni '60, Luis Alvarez (premio Nobel 1968) e il suo gruppo, espongono diverse camere a bolle a idrogeno liquido al Bevatron e scoprono numerose nuove particelle che sono gli stati eccitati dei mesoni π e K, dei barioni e degli iperoni.

2. E. Fermi 's maximal accelerator (Seminar at APS, 29.01.1954)

Thanks to Fabiola Gianotti, James Pilcher



VLHC project logo



E. Fermi

Year 1994
Cost 170 B$

2 Tesla

$E_{Beam} = 5\ 10^3$ TeV

Fermi maximal accelerator (cont 'd)

THE UNIVERSITY OF CHICAGO LIBRARY

Thanks to Mark Oreglia, Adrienne Kolb

For these reasons....clamoring for higher and higher....
Slide 1 - MeV - M$ versus time.
Extrapolating to 1994...5 hi 9 Mev or hiest cosmic...170 B$....preliminary design....8000 km, 20000 gauss
Slide 2 - 5 hi 15 eV machine.

Whay we can learn impossible to guess....main element surprise....some things look for but see others.....Experiems on pions....sharpening knowledge....spin zero and ~~odd symmetry~~.....certainly look for multiple production...

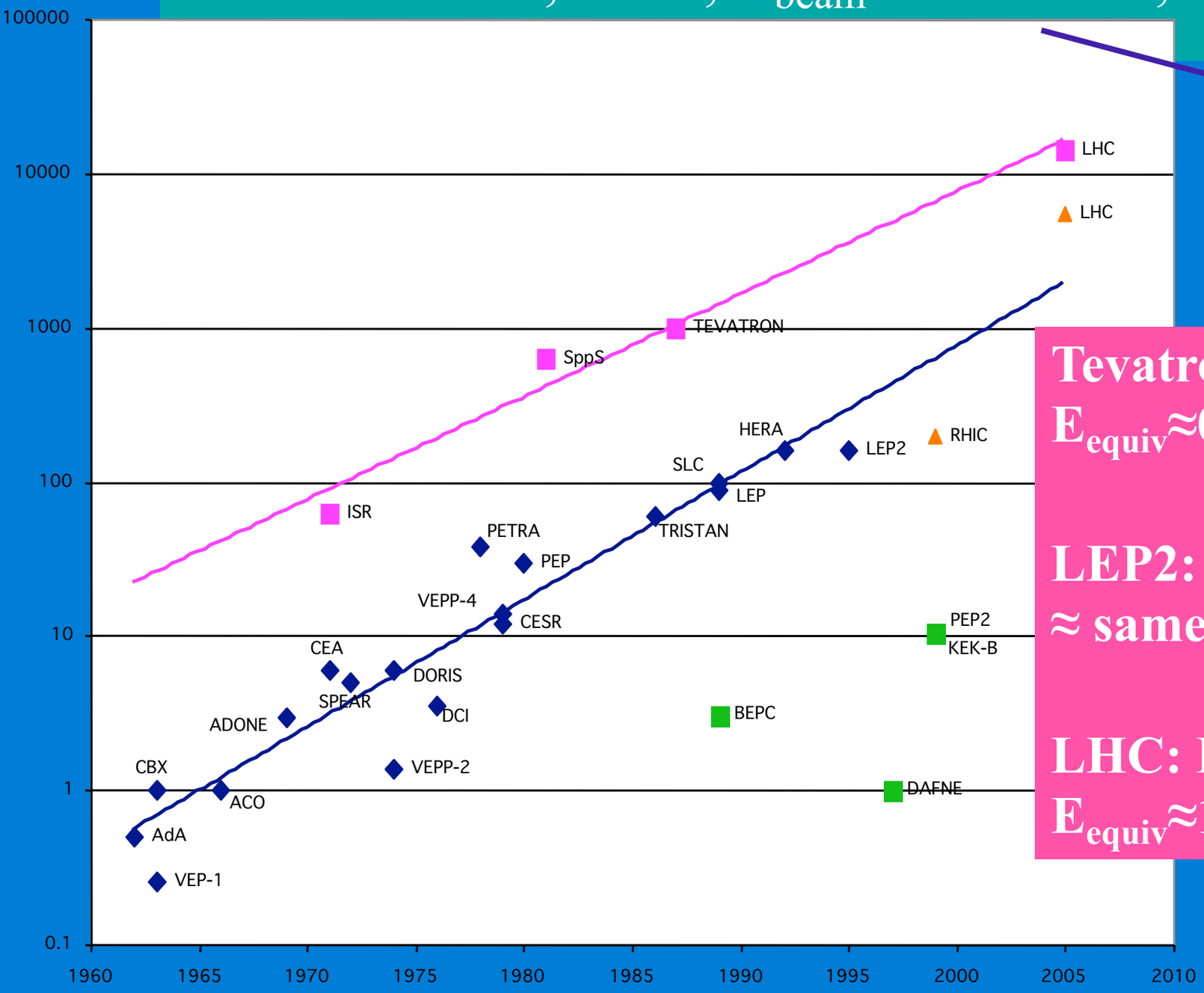
Naturally interest in strange particles....Cosmotron work by Shutt and others....very very cloudy crystal ball....Puzzle of long life times.... large angular moment?....double formation?....at present more probable... ....tried to ~~xxxxxxxx~~ photograph what I saw in the ball....and made slide...
Slide 5 - Strange particles in pion nucleon collisions.
...should realize this picture retouched....may have the wrong scale... may be wrong curve.....lots of other things could be seen...could not make them out.....

...ultimate result...understanding...need of precise data.....expect complication....collision of atoms.....however, staring at a problem... ...also possibility of a ~~xxx~~ lucky break....or theoretical leap.... or more probably a combination of hard work, ingenuity and a little bit of good luck.

Fermi's successors did not fare so badly...

Fermi: P-P, 1994, $E_{beam} \approx 5 \cdot 10^{15}$ eV, 170B US$

(3 TeV in c.o.m. !)



Tevatron: P-Pbar, 1987
$E_{equiv} \approx 0.5\ 10^{15}$ eV

LEP2: e^+ e^- , 1995
≈ same en. range as Tevatron

LHC: P-P , 2006
$E_{equiv} \approx 1.1 \cdot 10^{17}$ eV, ≈5B US$

+ X-factories
+Heavy Ions...

La lettera di Louis De Broglie

- Fu letta alla European Cultural Conference, Lausanne, 8 Dicembre, 1949, da Raoul Dautry, Amministratore-Generale del CEA (Commissariat à l' Energie Atomique)
- Nella lettera, De Broglie proponeva di creare
- "*a laboratory or institution where it would be possible to do scientific work, but somehow beyond the framework of the different participating states. .... this body could be endowed with more resources than national laboratories and could, consequently, undertake tasks which, by virtue of their size and cost, were beyond their scope* ".
- La collaborazione nella ricerca scientifica tra Paesi Europei sarebbe stata piu' facile
- avrebbe aperto la strada ad altri tipi di collaborazione.
- Dautry menziono' astronomia e astrofisica come possibili scopi di un laboratorio europeo, con la costruzione di un potente telescopio, nonche' l' energia atomica.

La risoluzione di Rabi

- Avanzata da Isidor I. Rabi a nome della delegazione US alla V Conferenza Generale dell' UNESCO, Firenze 7 Giugno, 1950.
- La risoluzione chiedeva all' UNESCO di
- "*assist and encourage the formation and organization of regional research centers ... in the search of new knowledge in fields where the effort of any country in the region is insufficient for the task.*" .
- Rabi chiariva nella presentazione che stava pensando all' Europa come alla prima "regione" dove un centro potesse essere creato.
- il centro doveva essere dedicato alla fisica delle particelle con la costruzione di un grande Ciclotrone "*of the type which exists in the United States, in such places as the MIT, the University of Chicago, Columbia University in New York and Berkeley, California*".

- La resolution e' considerata dal CERN come la vera nascita del Laboratorio. Nel Febbraio 1952, quando fu creato il CERN provvisorio, i delegati inviarono a Rabi un telegramma dal testo:
- "WE HAVE JUST SIGNED THE AGREEMENT WHICH CONSTITUTES THE OFFICIAL BIRTH OF THE PROJECT YOU FATHERED AT FLORENCE. MOTHER AND CHILD ARE DOING WELL AND THE DOCTORS SEND YOU THEIR GREETINGS."

Un confronto duro

- Due posizioni si sono fronteggiate anche duramente.

- UK, Danimarca ed i Paesi Nordici, proponevano una struttura di coordinamento, volta a rinforzare le strutture esistenti (in UK, Svezia e Danimarca) e solo successivamente diretta alla costruzione di un grande acceleratore.

- Francia, Italia, Belgio, Germania e, successivamente, l' Olanda proponevano un Laboratorio interamente nuovo, che ogni Paese potesse considerare come il *suo* laboratorio, centrato sin dall' inizio su una macchina di dimensioni tali da non poter essere realizzata da alcun Paese da solo.

Una visione a lungo termine

- Le riserve avanzate da grandi personalita' come Kramers, Bohr, Chadwick ed altri furono alla fine superate dal cruciale, paziente lavoro di Auger e di Amaldi.
- "*Their goal was not merely to construct a medium-sized accelerator, it was to awaken Europe and, through the construction of a giant accelerator, to make her understand the urgency and necessity of developing fundamental scientific research on a large scale as had happened in the US since the war*".

"The History of CERN" (Vol.1, p.130)

P. Auger, E. Amaldi, L. Kowarski

Difficolta’ con la popolazione

- Un tentativo di proporre un sito italiano, in Como, fu effettuato nel Dic. 1951 (Lanfranco Belloni, "Da Fermi a Rubbia", Rizzoli, Milano, 1988).
- Il tentativo ando’ a vuoto a causa delle resistenze locali. Una campagna di disinformazione collego’ l’ acceleratore agli ordigni nucleari, e porto’ a credere che il centro sarebbe potuto divenire il bersaglio di un possibile attacco nel caso di una guerra nucleare (allora considerata non cosi’ improbabile).
- Risoluzioni contro il Centro Europeo furono presentate al Consiglio Comunale di Como da:
  - Segreteria Partigiani per la Pace;
  - Commissione Interna Tintoria Italiana Bruno Pessina;
  - Commissione Interna Tintoria Subalpina.
- Maurice Bourquin ha ricordato un analogo attacco, a Ginevra, nell’ Ottobre 1952, da parte del "Parti du Travail", per impedire la localizzazione del CERN. La questione fu posta a referendum con risultato positivo per il CERN (Maurice Bourquin, Heloge du CERN, Allocution a l' occasion du Prix 1999 de la Fondation pour Geneve, 8 Novembre 1999).
- Come risultato, tuttavia, il CERN fu localizzato a Meyrin, il piu’ lontano possibile dal centro di Ginevra,
- una vera fortuna, che ha permesso al CERN di costruire l’ SPS e il LEP, occupando il sottosuolo del "Pais de Gex”.

La pianura di Gex vista dal Jura, guardando le Alpi

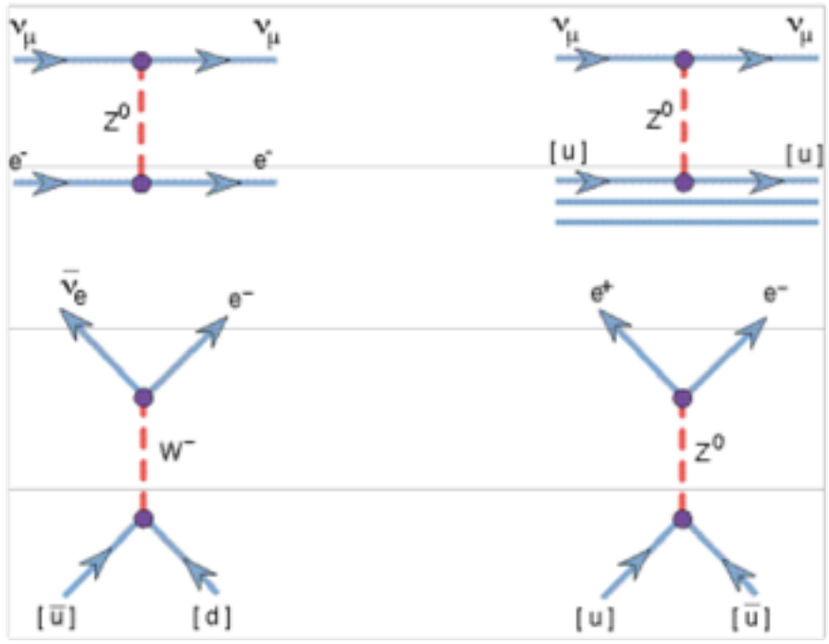
Le grandi scoperte

CERN–EP–2003–073
CERN–TH–2003–281
December 1st, 2003

Proceedings
Symposium celebrating the
Anniversary of CERN's Discoveries
and a Look into the Future

1973: Neutral Currents
1983: $W^{\pm}$ & Z^0 Bosons

Tuesday 16 September 2003
CERN, Geneva, Switzerland



Editors: Roger Cashmore, Luciano Maiani & Jean-Pierre Revol

Preparing the way

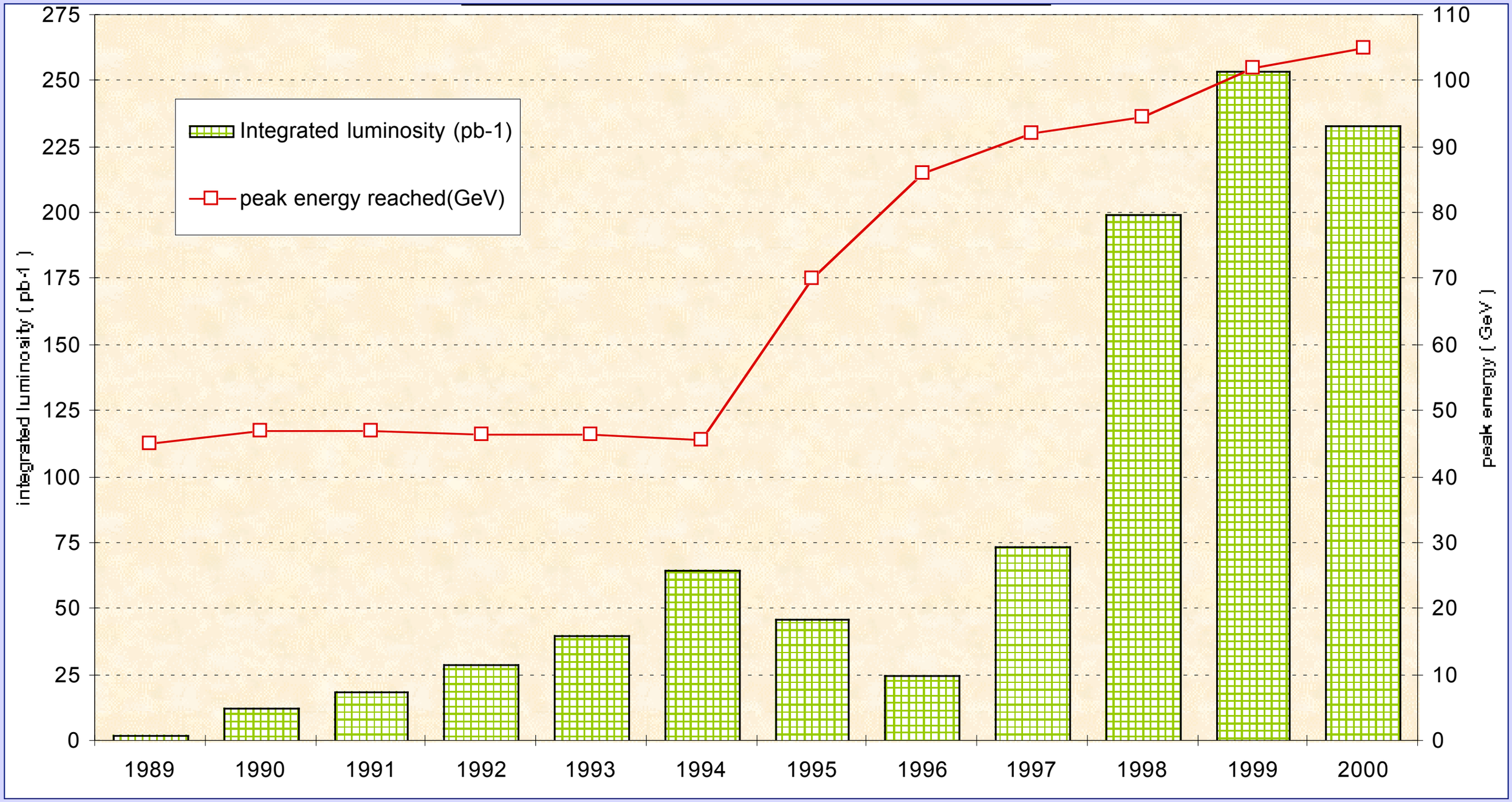
- **1976 B. Richter at CERN: study of parameters of a big e+e- circular at CERN**

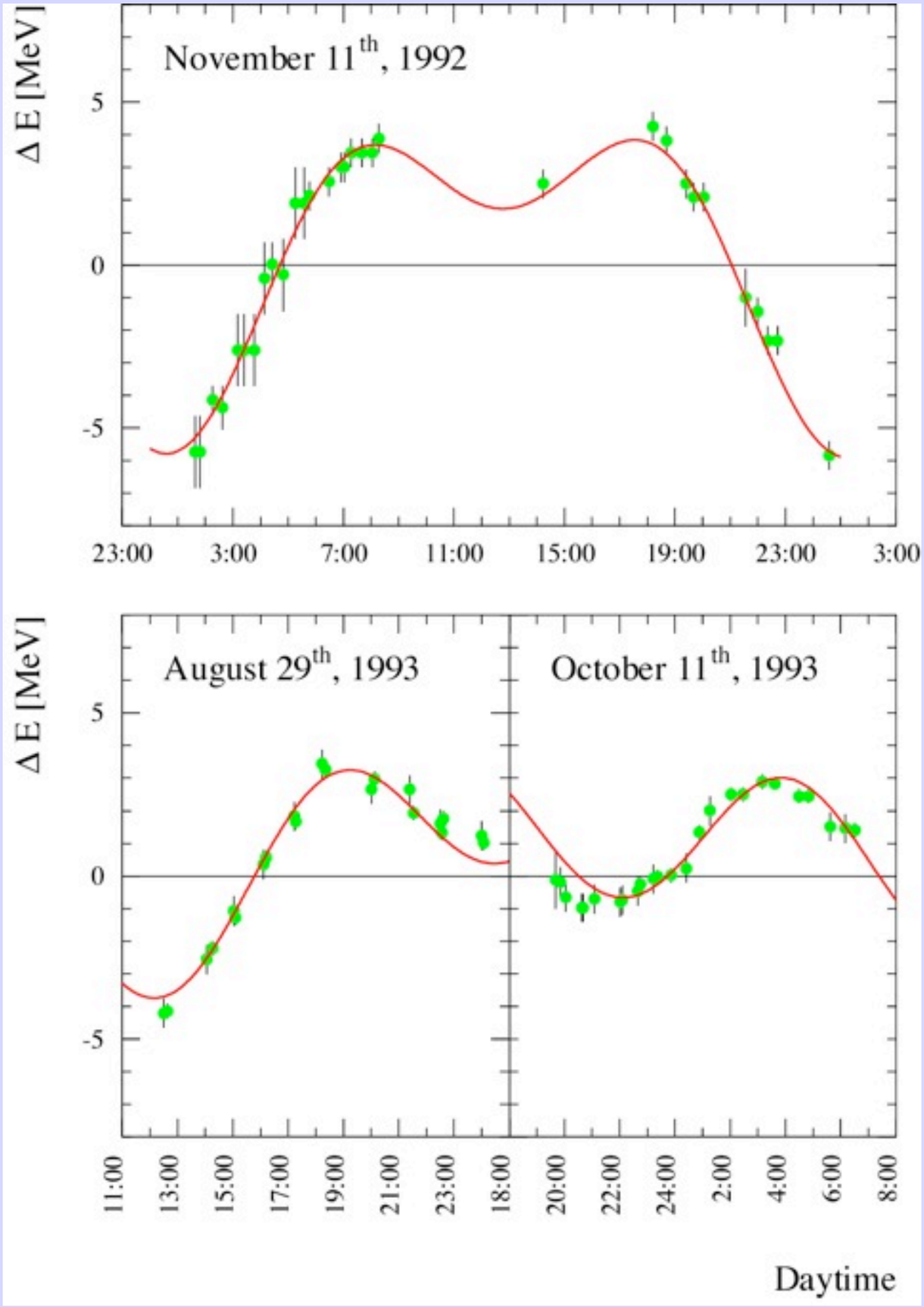
  Computing the optimal dimensions of an e+e- circular collider at the WW threshold, found a radius of 5-6 km, well suited to fit in the Gex plain
- CERN commissioned three study groups, starting in 1977.
- **1981** LEP project approved by CERN Council:
  - (i) conventional macchine up to 50 GeV/beam,
  - a second stage up to the WW threshold with sc radiofrequencies
  - Emilio Picasso Project Leader.

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.

LEP performances evolution from 1989 to 2000

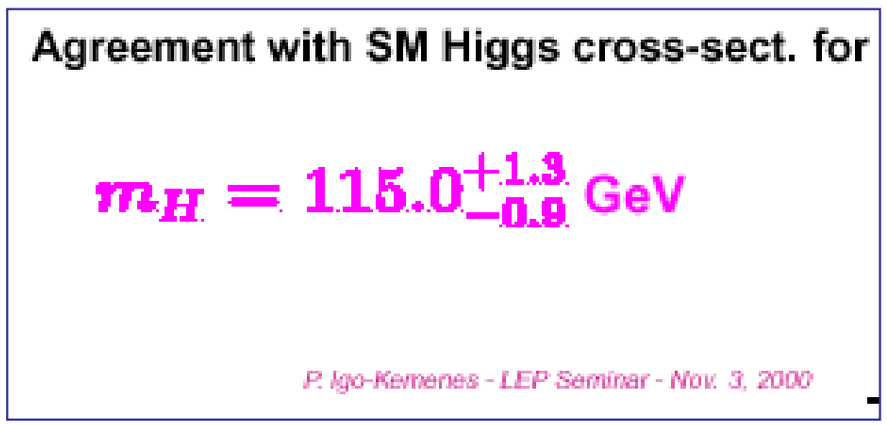




LEP calibration and Earth tides due to Sun and Moon

LEP in Year 2000

- LEP has obtained important results in the last months of operation in the year 2000
- evidence for a Higgs particle at about 115 GeV/c^2.
- LEP Collaborations requested a further run in 2001(from May to October) in order to consolidate the data.



Statistical Significance

2.2σ	September 5
2.3σ	LEP fest
2.9σ	November 2

- Run in September and October has been very beneficial: significance increased, better understanding of background

LHC project

Orders are leaving on schedule and within budget; ≈ 1.7 BCHF committed (CERN money+ special contributions)

The civil engineerings have gone through a difficult phase, with comparatively little damage (≈ 6 months delay)

The superconducting dipoles of the pre-series perform brilliantly

One cryoline prototype is qualified, other two are being tested, contracts next year

ALL LHC COMPONENTS HAVE BEEN TESTED (MAC, Nov.15)

Detector construction is taking off

LHC-C agrees they will fit in this schedule (but manpower problems)

The updated estimate of the LHC schedule, which takes into account further delays in LEP dismantling was reported to CC of Nov. 17 and included in the LHC status report. It foresees:

commissioning in 2005;

a physics run at limited luminosity (~1-2 fb^{-1}) in 2006;

a higher luminosity run (~10 fb^{-1}) in 2007.

Higgs Boson at the LHC

- SM Higgs boson can be discovered at ≈ 5 σ after ≈1 year of operation (10 fb^{-1}/ experiment) for $m_H \approx 150$ GeV
- Discovery faster for larger masses
- Whole mass range can be excluded at 95% CL after ~1 month of running at 10^{33} cm^{-2} s^{-1}.

<u>results are conservative:</u>

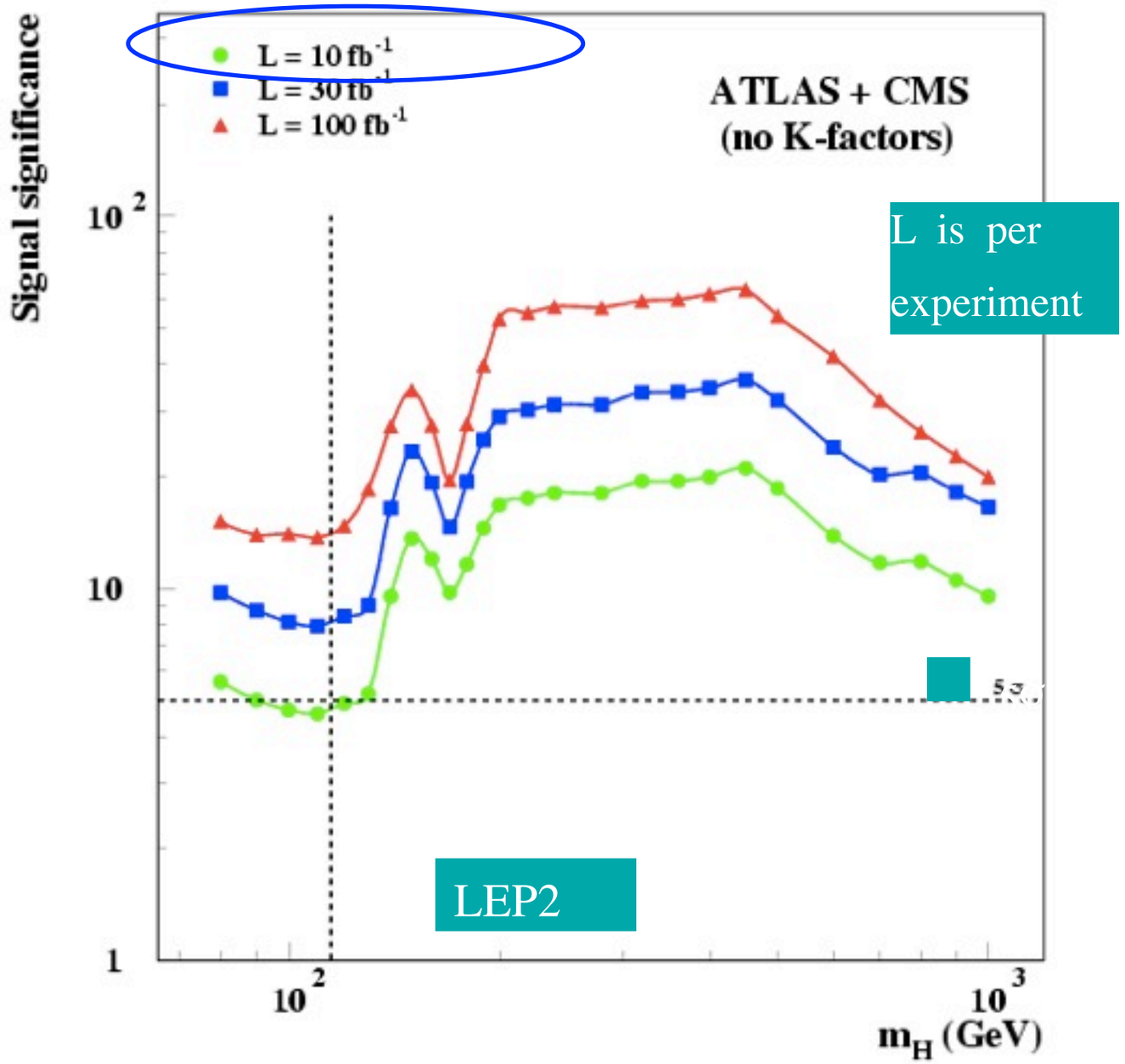
-- no k-factors

-- simple cut-based analyses

-- conservative assumptions on detectc performance

-- channels where background control is difficult not included, e.g. $WH \rightarrow \ell\nu b\bar{b}$

Higgs boson discovered in 2012 with ~ $20fb^{-1}$



The future of CERN is in the LHC !!!

CC Statement

"*On 17th November 2000, the CERN Committee of Council held a meeting to examine a proposal by the Director-General concerning the continuation of the existing CERN programme, which foresees the decommissioning of the LEP accelerator at the end of the year 2000.*

The Committee has expressed its recognition and gratitude for the outstanding work done by the LEP accelerator and experimental teams.

It has taken note of the request by many members of the CERN Scientific Community to continue LEP running into 2001 and also noted the divided views expressed in the Scientific Committees consulted on this subject.

On the basis of these considerations and in the absence of a consensus to change the existing programme, the Committee of Council supports the Director-General in pursuing the existing CERN programme."

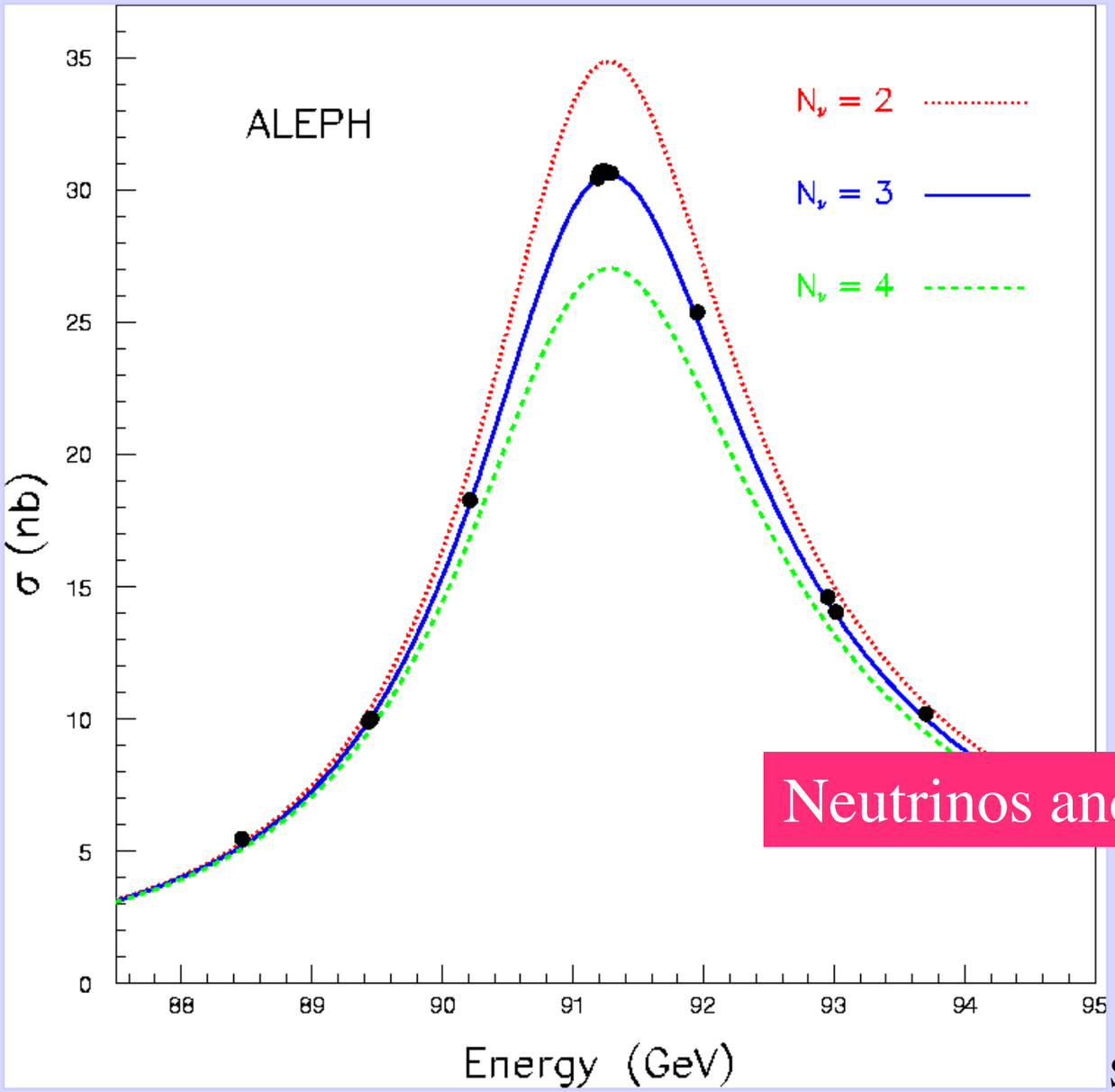
This decision moves us definitely into the LHC era

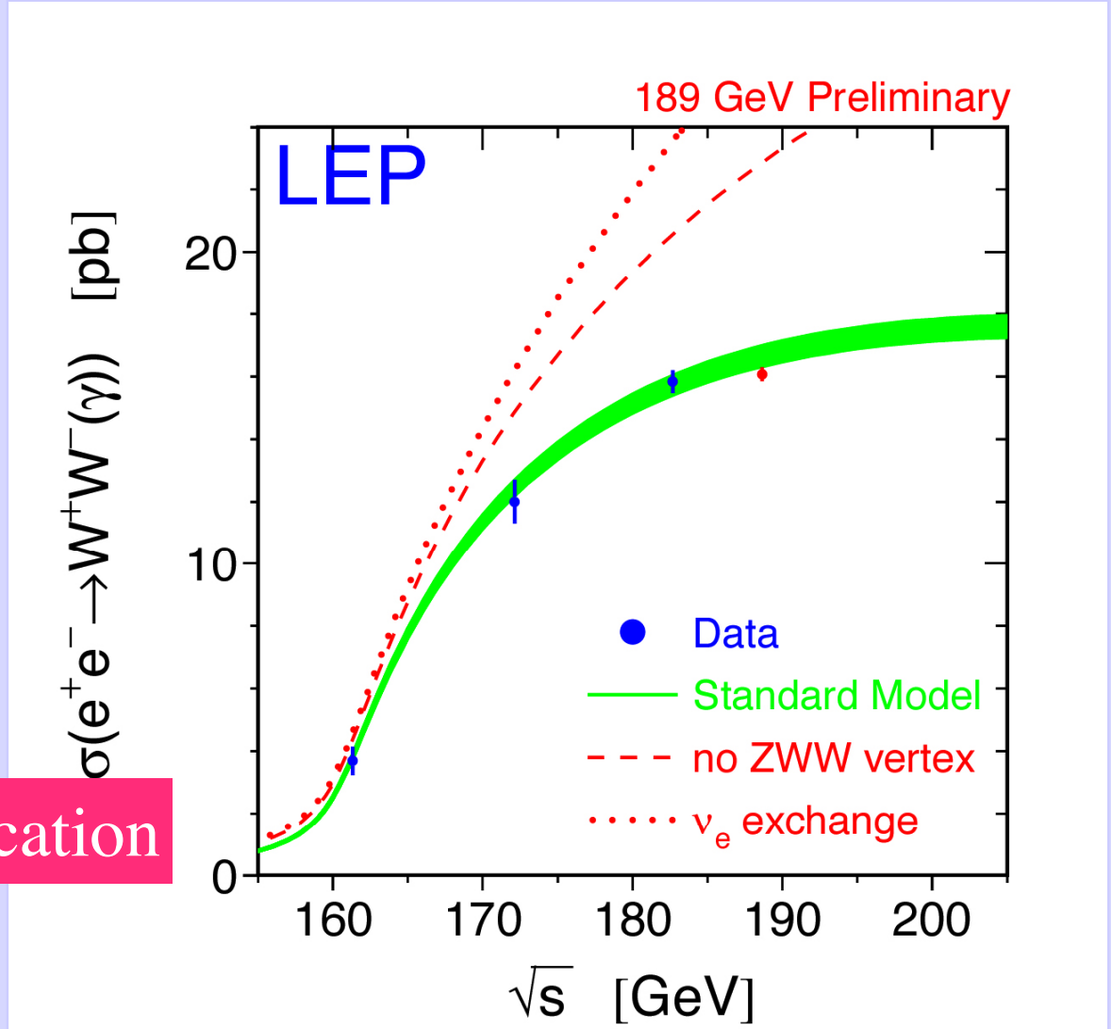
A powerful complex, machine and detectors, to fully explore the Higgs and SUSY region

Le Roi est mort
Vive le Roi !!

2. Hommage to LEP

ECFA, Dec. 2000 …. express to the LEP Community their admiration for the excellent performance of the machine and experiments. The many beautiful measurements at LEP have established the Standard Model beyond doubt and events recorded at the highest energies have led to a strong indication of a Higgs boson around 115 GeV.

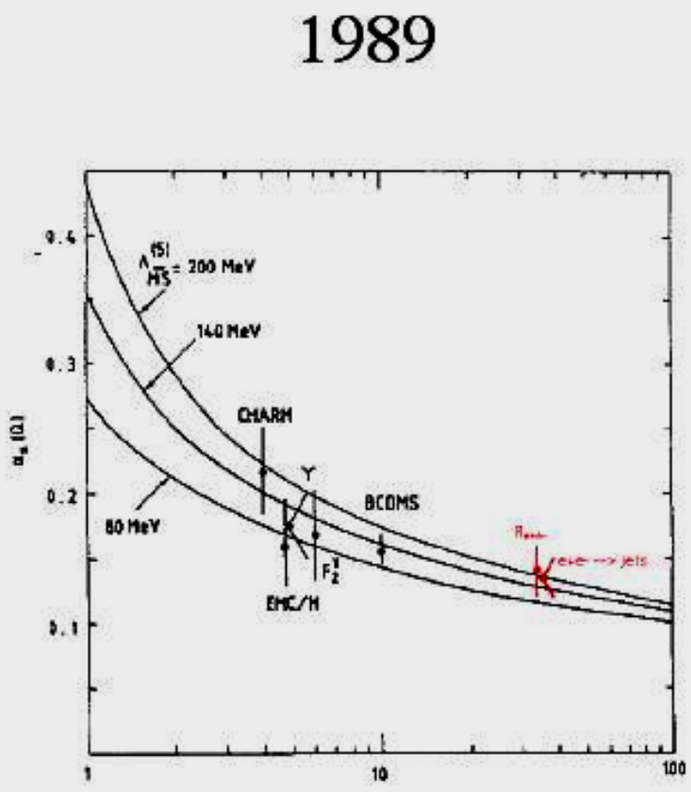




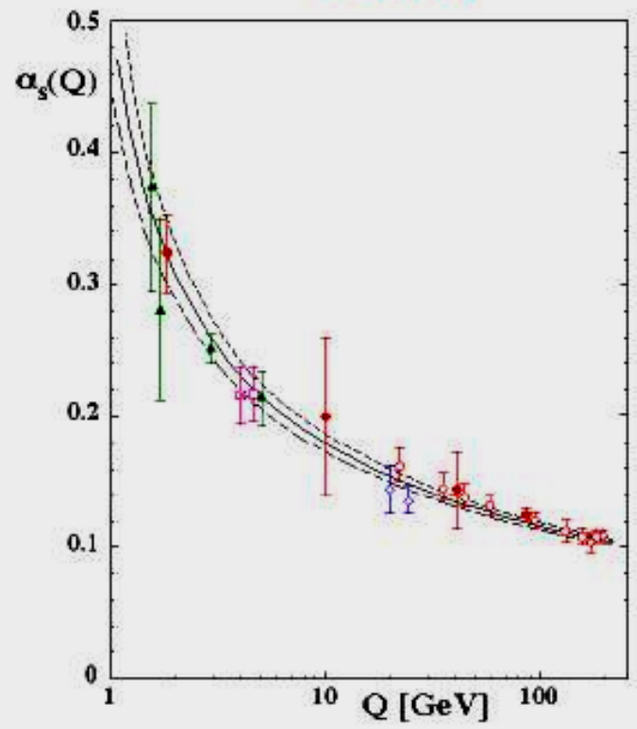
Neutrinos and Unification

Colour and asymptotic freedom

α_S World summary

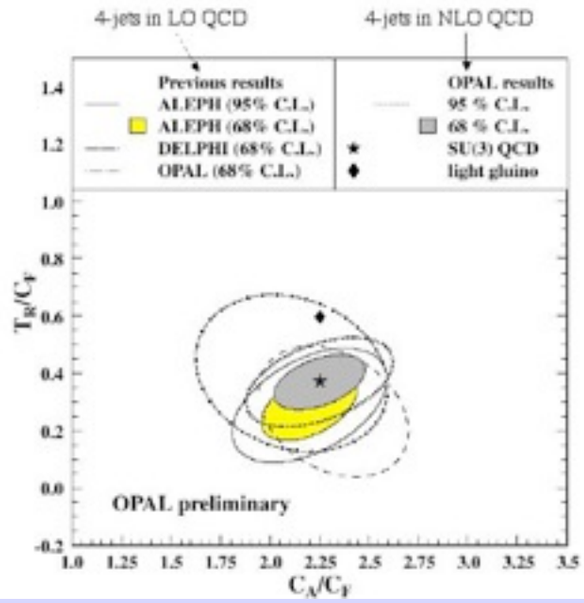


$$\alpha_s(M_Z) = 0.110^{+0.006}_{-0.008} \text{ (NLO)}$$



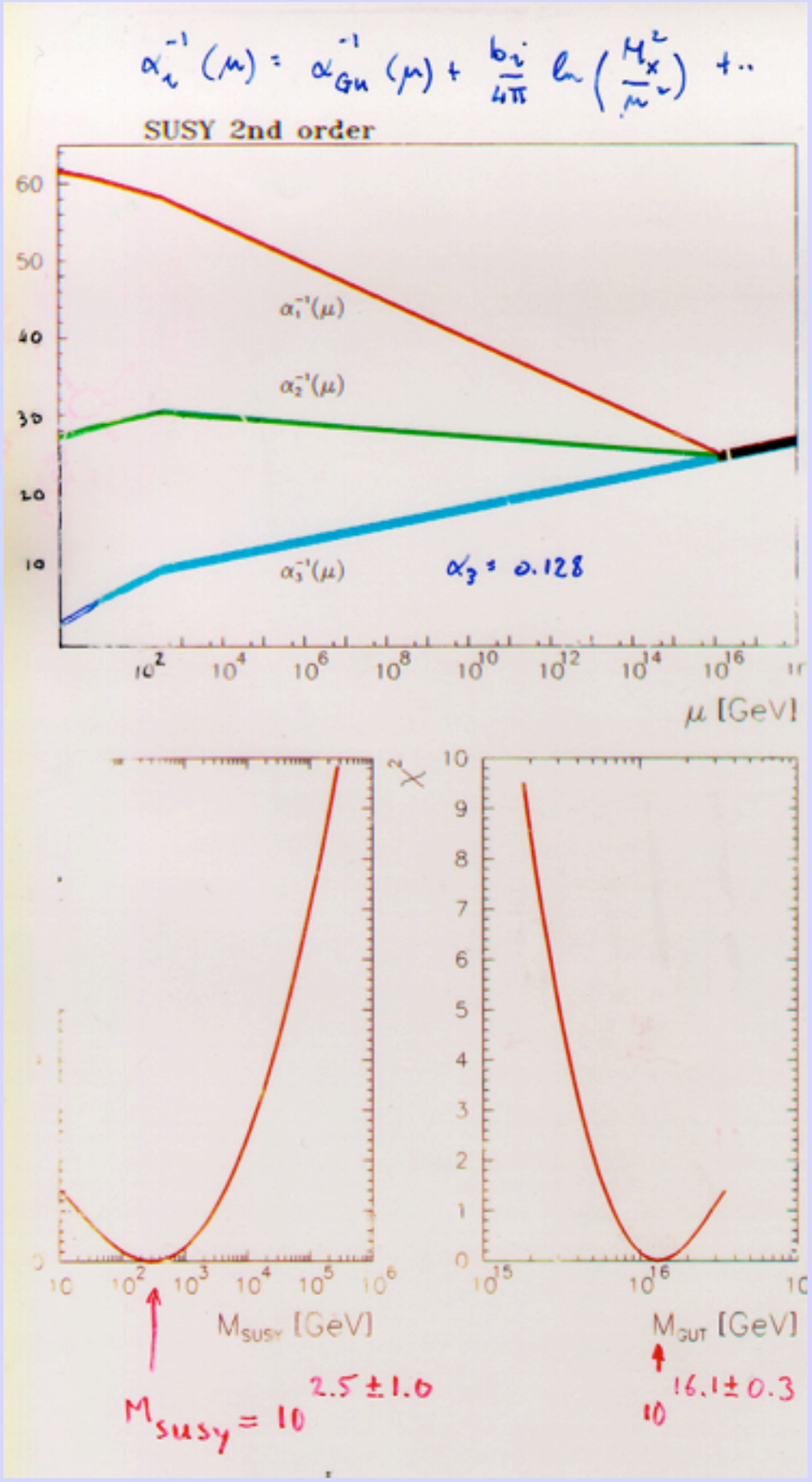
$$\alpha_s(M_Z) = 0.1184 \pm 0.0031 \text{ (NNLO)}$$

Non-Abelian gauge structure from 4-jet events



Unification Hints

MSSM



Amaldi, de Boer, Furstenau

See also :
Ellis, Kelley, Nanopoulos;
Langacker, Luo

Courtesy of
G. Ross, LEP fest

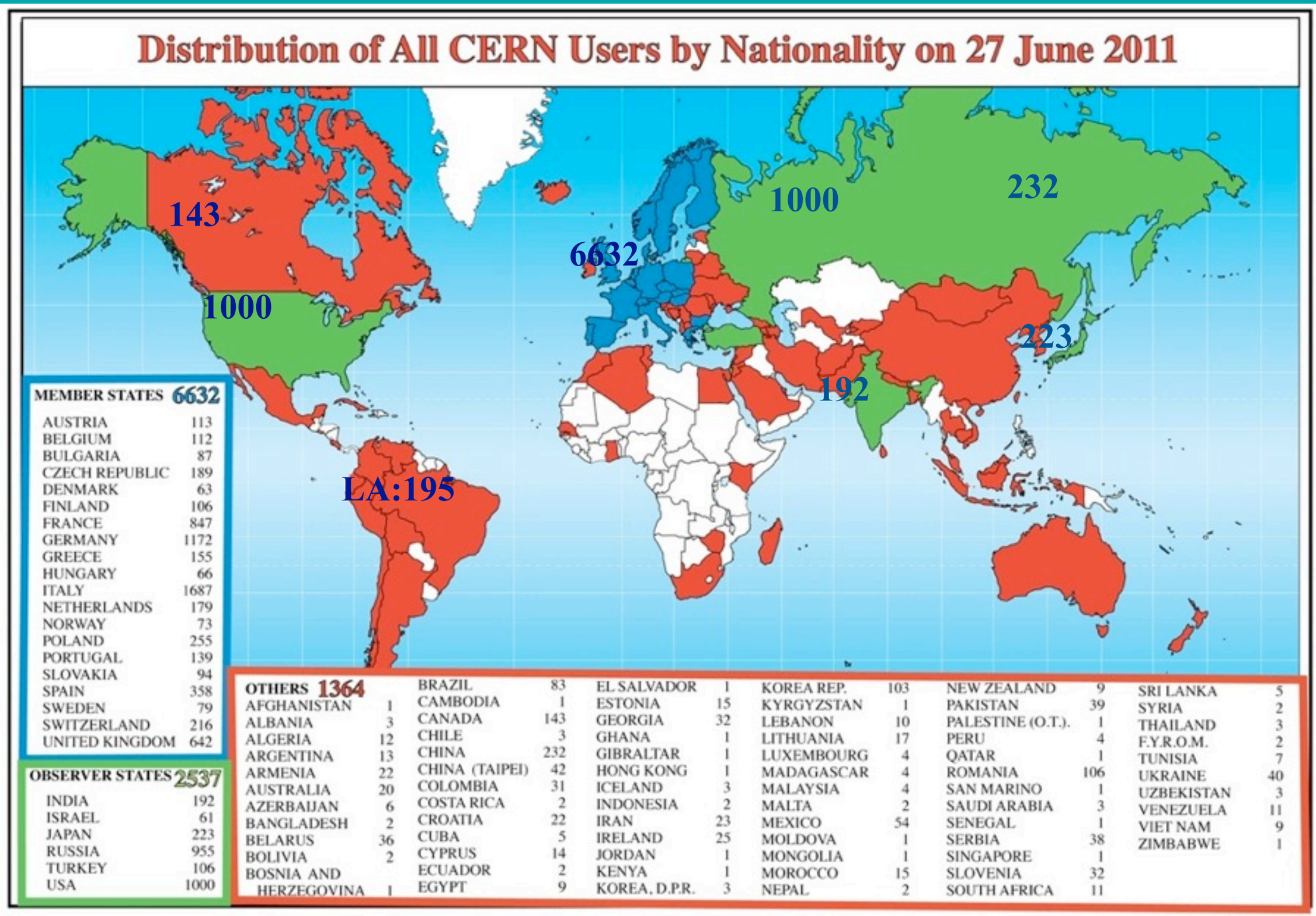
Dimopoulos, Raby, Wilczek
Ibanez, GGR

4. CERN oggi

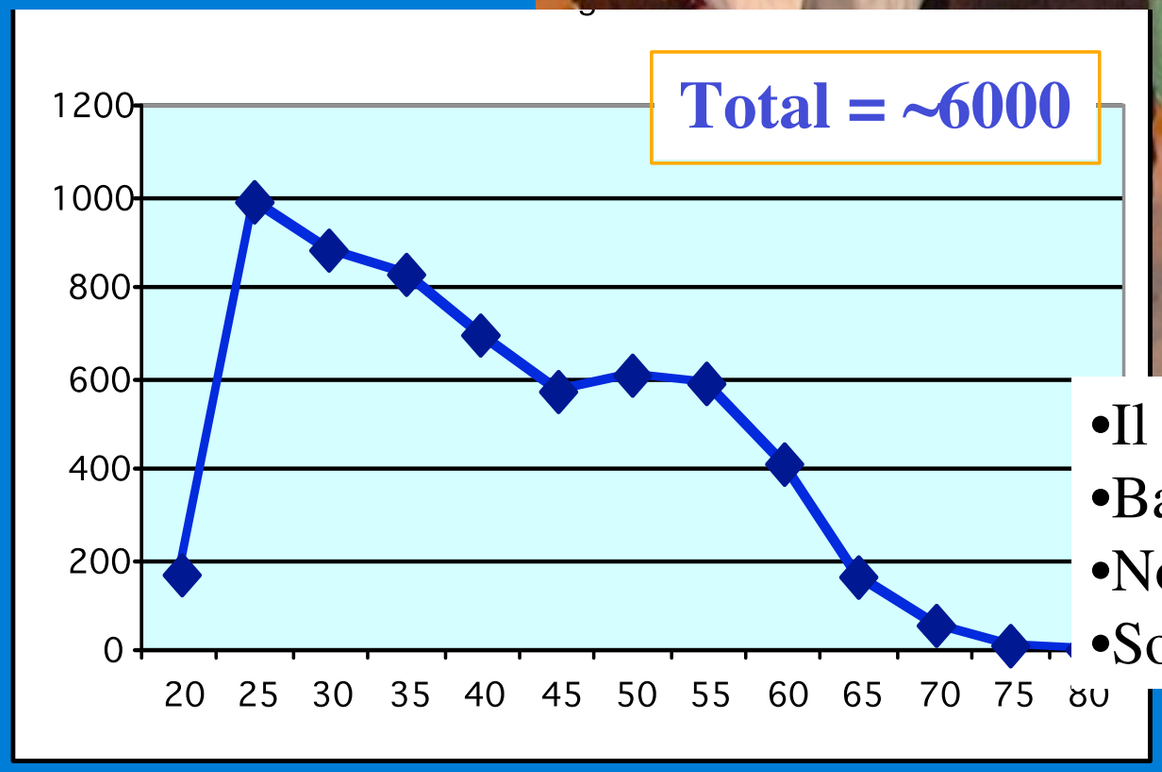
Osservatori:
EU, Israele,
Turchia, India,
Giappone,
Russia, USA

Stati Membri

Distribuzione degli Utilizzatori del CERN (Luglio 2011)



Fisici dell’ esperimento DELPHI



- Il CERN è “fatto dai giovani”;
- Basati nelle loro Universitá;
- No ***brain drain***;
- Sono una grande risorsa per il CERN e per l’ Europa

Tesi di Dottorato

negli esperimenti LEP (su dieci anni):

ALEPH: 210
DELPHI: 227
L3: 250
OPAL: 198