Lezione Fermi 18

Tutto quello che ... 2

Il bosone nella teoria elettrodebole

1. Da Glashow (1961) a Weinberg-Salam (1967-1968)
2. Doppietto scalare e la massa dei bosoni intermedi
3. Estensione ai quark e completamento dello SM
4. La ricerca del bosone di Higgs al LEP
5. Le Roy est mort-Vive le Roy

Il messaggio di Brout-Englert-Higgs e’ stato prontamente raccolto

nel 1967, S. Weinberg e A. Salam, indipendentemente, arrivano alla stessa soluzione.

Lo schema era quello delineato da S. Glashow nel 1961 (in post-doc a Copenhagen) a partire dalla teoria di Yang-Mills del 1954.

Per dare una massa ai campi di gauge e all’elettrone, Glashow aggiungeva all’Azione di Y-M dei termini (di massa) ad hoc, che violano la simmetria (e che, ora sappiamo, non sono consistenti con la rinormalizzazione).

Nello schema di Weinberg e Salam, il gruppo di simmetria e’ lo stess di Glashow, ma l’Azione e’ perfettamente simmetrica

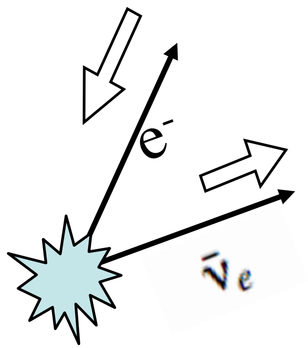
sono presenti dei campi scalari aggiuntivi, il cui condensato rompe la simmetria e provvede alle masse richieste.

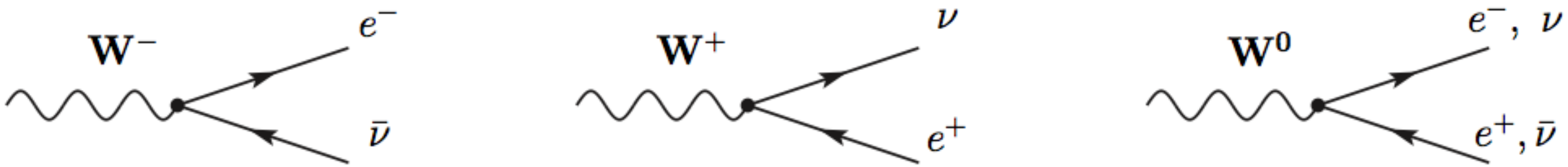
We come to my own work (Glashow, 1961), done in Copenhagen in 1960, and done independently by Salam and Ward (Salam and Ward, 1964). We finally saw that a gauge group larger than SU(2) was necessary to describe the electroweak interactions. Salam and Ward were motivated by the compelling beauty of gauge theory. I thought I saw a way to a renormalizable scheme. I was led to the group SU(2) $\times U(1)$ by analogy with the approximate isospin-hypercharge group which characterizes strong interactions. In this model there were two electrically neutral intermediaries: the massless photon and a massive neutral vector meson which I called B but which is now known as Z. The weak mixing angle determined to what linear combination of SU(2) $\times U(1)$ generators B would correspond. The precise form of the predicted neutral current interaction has been verified by recent experimental data. However, the strength of the neutral current was not prescribed, and the model was not in fact renormalizable. These glaring omissions were to be rectified by the work of Salam and Weinberg and the subsequent proof of renormalizability. Furthermore, the model was a model

$SU(2) \otimes U(1)$ doppietto e singoletto :

$$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}, \; e_R$$

- Campi di gauge e vertici, a partire da





SU(2)

U(1)

Doppietto di Higgs:
= 4 campi reali

$$\begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \begin{pmatrix} \frac{\phi_1+i\phi_2}{\sqrt{2}} \\ \frac{\phi_3+i\phi_4}{\sqrt{2}} \end{pmatrix}$$

nberg, Nobel lecture)

spontaneous breakdown of SU(2) ⊗ U(1) to the U(1) of ordinary electromagnetic
nvariance would give masses to three of the four vector gauge bosons: the charged
$W^\pm$, and a neutral boson that I called the Z^0.

rth boson would automatically remain massless, and could be identified as the ph

g the strength of the ordinary charged current weak interactions like beta decay w
iated by $W^\pm$, the mass of the $W^\pm$ was then determined as about 40 GeV/sinθ, wher
Z^0 mixing angle.

urther, one had to make some hypothesis about the mechanism for the breakdown
⊗ U (1).

y kind of field in a renormalizable SU(2) ⊗ U(1) theory whose vacuum expectatio
ould give the electron a mass is a spin zero SU(2) doublet (φ^+, φ^0), so for simplic
l that these were the only scalar fields in the theory.

ss of the Z^0 was then determined as about 80 GeV/sin 2θ.

Doppietto di Higgs:
= 4 campi reali

$$\begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \begin{pmatrix} \frac{\phi_1 + i\phi_2}{\sqrt{2}} \\ \frac{\phi_3 + i\phi_4}{\sqrt{2}} \end{pmatrix}$$

- possiamo sempre fare in modo che il condensato sia in φ_3
- i campi $\varphi_1, \varphi_2, \varphi_4$ sarebbero i campi di Goldstone, ma spariscono con una trasformazione di gauge
- resta solo un campo fisico, φ_3
- i quanti di φ_{3quant}, sono delle particelle neutre di spin zero: il Bosone di Higgs ,
- la particella da cercare a conferma che e' proprio il meccanismo di B-E-H a dare la massa all'elettrone e ai bosoni intermedi.

s this model renormalizable?

Ve usually do not expect non-Abelian gauge theories to be renormalizable if the ector-meson mass is not zero, but our **A** *and B mesons get their mass from the pontaneous breaking of the symmetry, not from a mass term put in at the eginning.*

ndeed, the model Lagrangian we start from is probably renormalizable, so the uestion is whether this renormalizability is lost in the reordering of the erturbation theory implied by our redefinition of the fields.

And if this model is renormalizable, then what happens when we extend it to nclude the couplings of **A** *and B to the hadrons?*

Renormalizability of the BEH mechanism for a non- abelian gauge theory
A first proof was given in 1972, by Gerhardt ‘t-Hooft and Martinus Veltman.
The final proof of the cancellation of the Adler-Bell-Jackiw anomalies among quarks a leptons of each generation was obtained by Claude Bouchiat, John Iliopoulos and Phil Meyer in 1973.

one tried to extend the theory to the hadrons using the three quarks introduced by ell- Mann and the Cabibbo description of the weak currents, the exchange of Z^0 w oduce strangeness-changing neutral current processess to a level firmly excluded e then available experiments.

1970, Sheldon Glashow, John Iliopoulos and Luciano Maiani showed that the troduction of a fourth quark, coupled to the superposition of down and strange qu thogonal to the Cabibbo, would produce, in lowest order, only strangeness-conse utral current processes, in agreement with data.

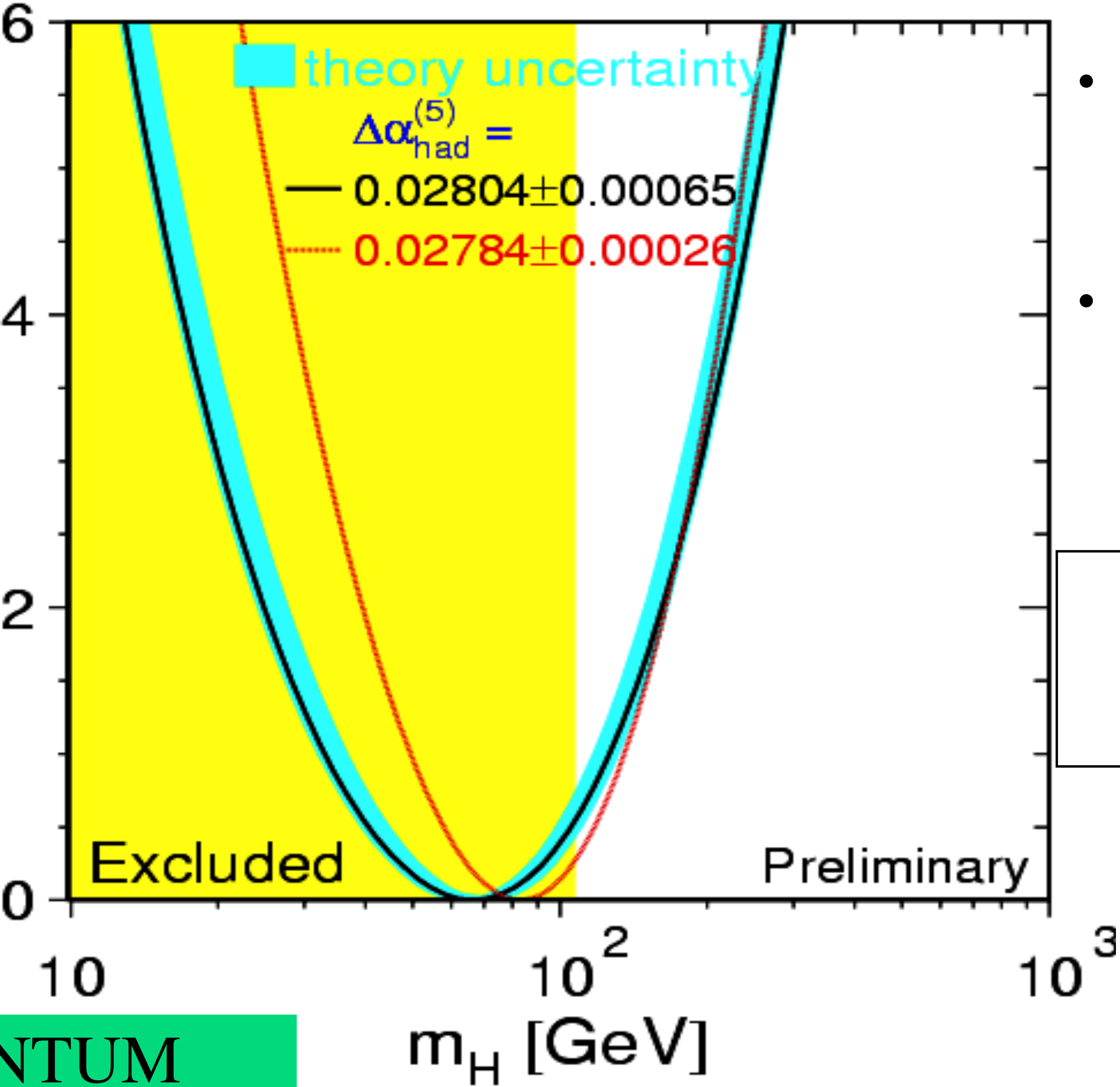
ne Standard Model was essentially completed in 1973, with

- the discovery of asymptotic freedom
- the proposal af a third generation, by Makoto Kobayashi and Toshihide Maskawa, to describe CP violation

season opened of great experimental discoveries, which have made SM into one e greatest and better controlled constructions of modern physics:

- neutral current neutrino processes (CERN, 1973),
- the observation of the charm quark (Brookhaven and SLAC, 1974),
- the observation of the first particles of the third generation with the τ lepton (SLAC, 19 and the b quark (FermiLab, 1976),
- the $W^{\pm}$ and Z^0 bosons (CERN, 1982) and the t quark (FermiLab, 1994)

M_H prediction from precision Electroweak Measurements:



- Includes all electroweak pre
  measurements;
- Constrained by direct m_W an
  determinations;

$$m_H = (77^{+69}_{-39})\ \text{GeV}/c^2$$

NTUM
ILITY
70 GeV Λ ~ 10^{19}

m_H < 188 GeV/c² at 95%C.L.

campagna di ricerca al LEP II per
rvare un bosone di Higgs con massa
a circa 115 GeV

$$e^+ e^- \longrightarrow Z + H$$

$$Z \longrightarrow q + \bar{q}, l + \bar{l}, \nu + \bar{\nu}$$

$$H \longrightarrow b + \bar{b}$$

nali studiati:

4 jets, com massa invariante di due jet = M_Z

2 jet+ energia mancante (corrispondente a Z→nu+nu)

2jet + 2 leptoni (corrispondente a Z→l+l-bar)

Nei jet, si applicava per quanto possibile il b tagging, per esaltare gli eventi con un possibile H

enti interessanti raccolti da ALEPH nell' estate 2000, nel canale 4 jets
b-tagging, massa 114 GeV;

a fine, sui 4 esperimenti, l' evidenza per un Higgs di 114 GeV e' di
ca 2 standard deviations

arrivare a questo, sono state fatte analisi statistiche molto raffinate

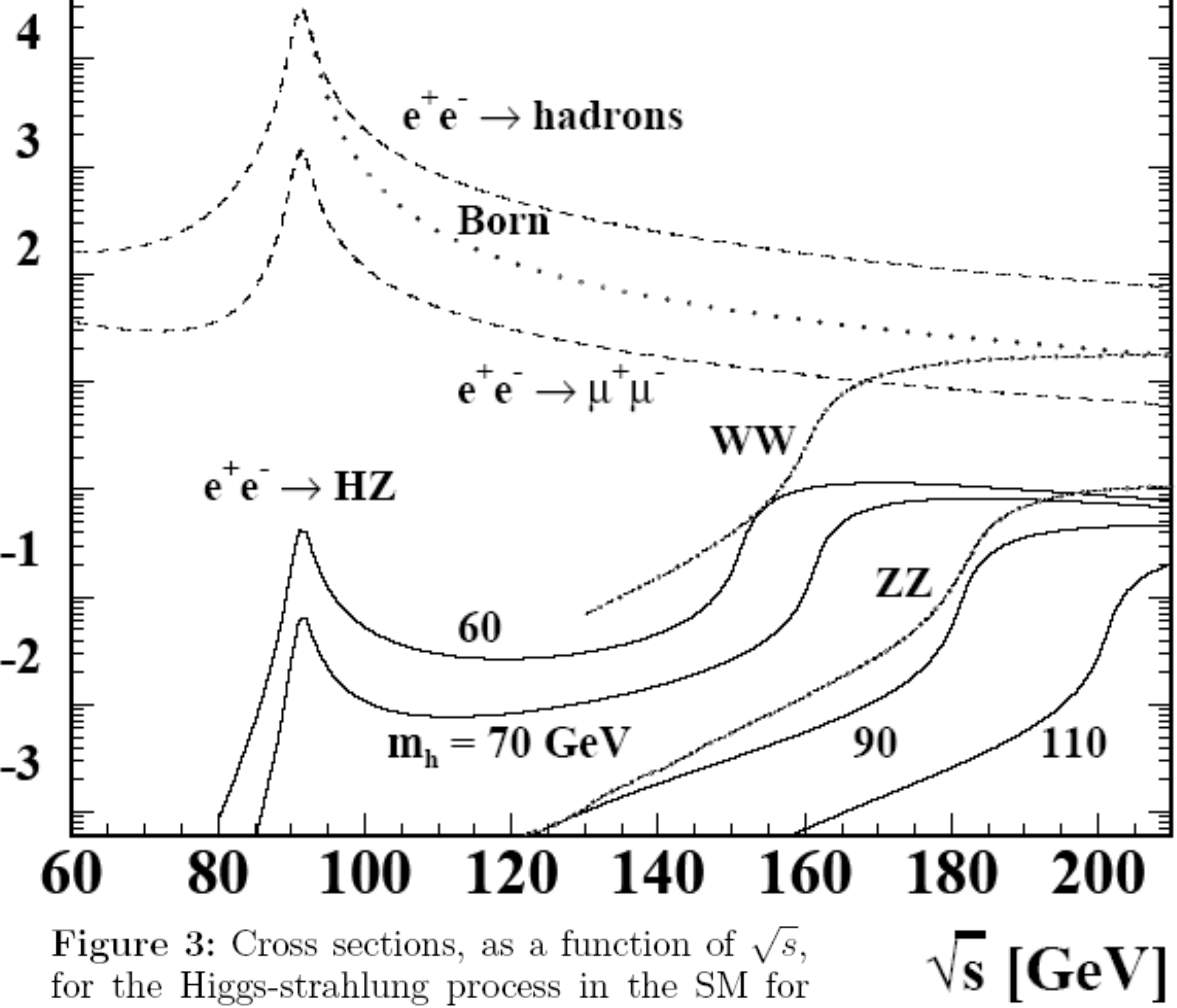
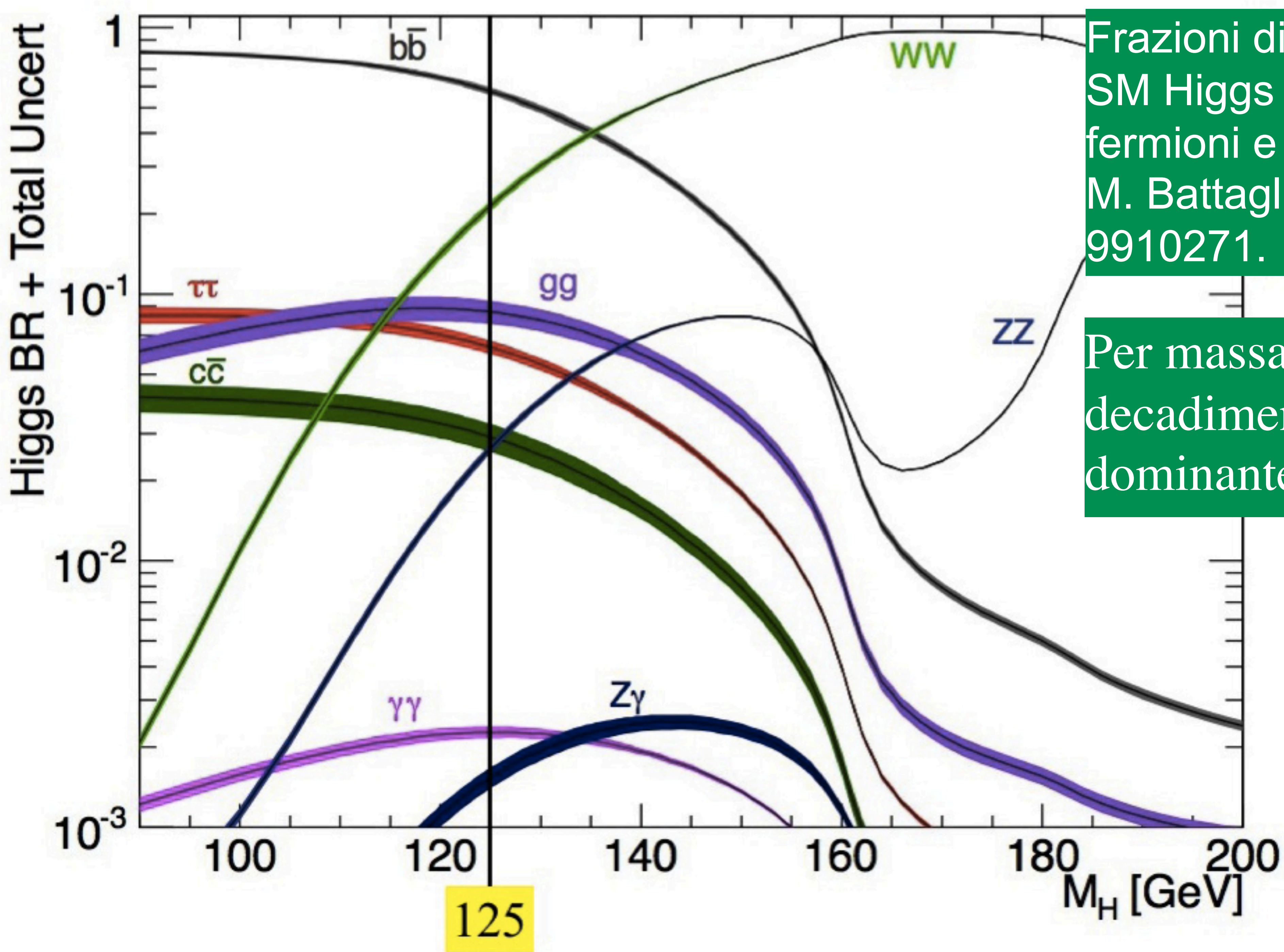


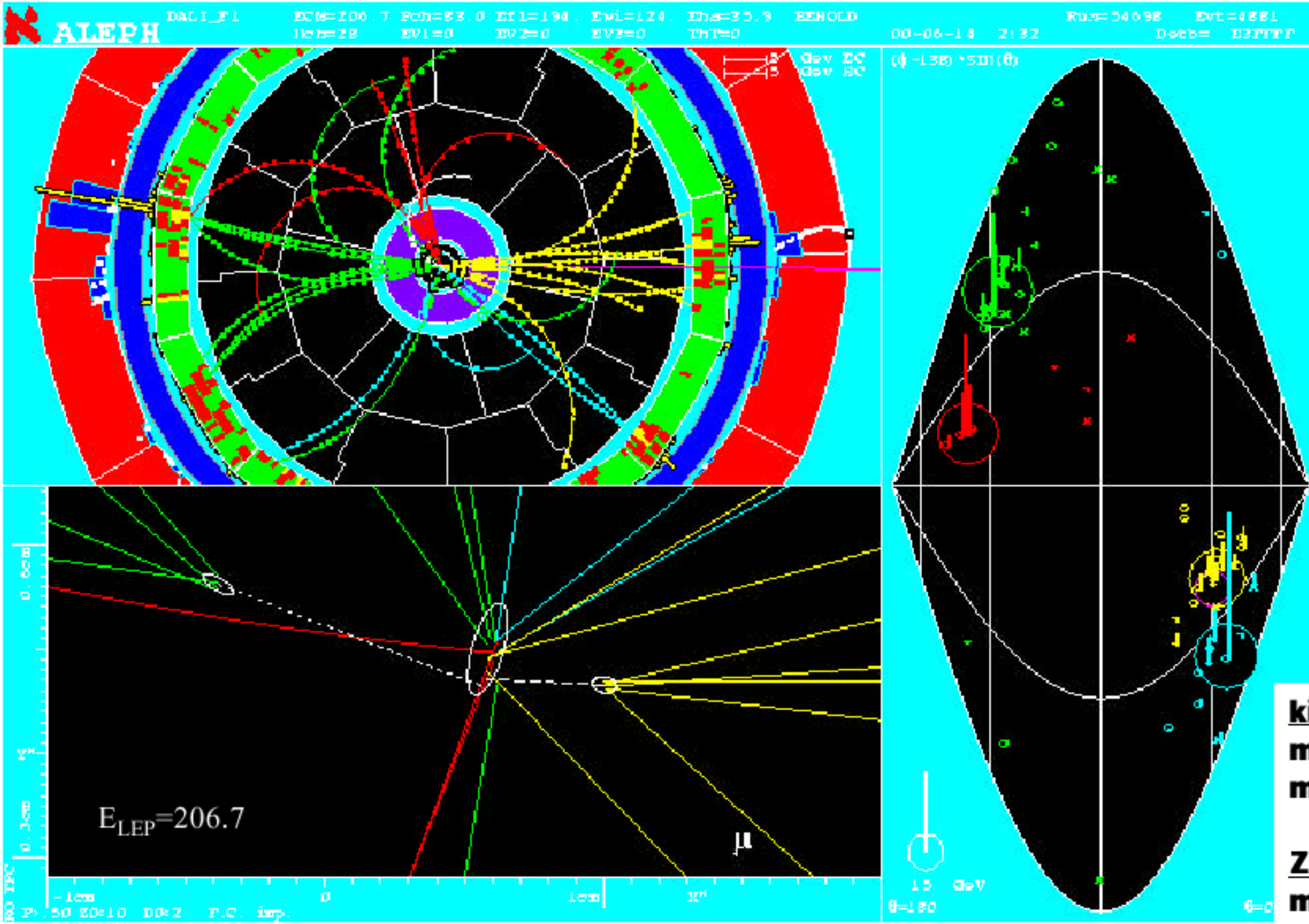
Figure 3: Cross sections, as a function of $\sqrt{s}$, for the Higgs-strahlung process in the SM for fixed values of m_{H^0} (full lines), and for other SM processes which contribute to the background.



Frazioni di decadimen
SM Higgs in coppie di
fermioni e VV.
M. Battaglia, hep-ph/
9910271.

Per massa <130 GeV
decadimento in b b-b
dominante

Summer 2000)



2 b

HZ

m_H

NN

jet

1

2

3

4

kin. m

m_H=1

m_Z=93

ZZ hy

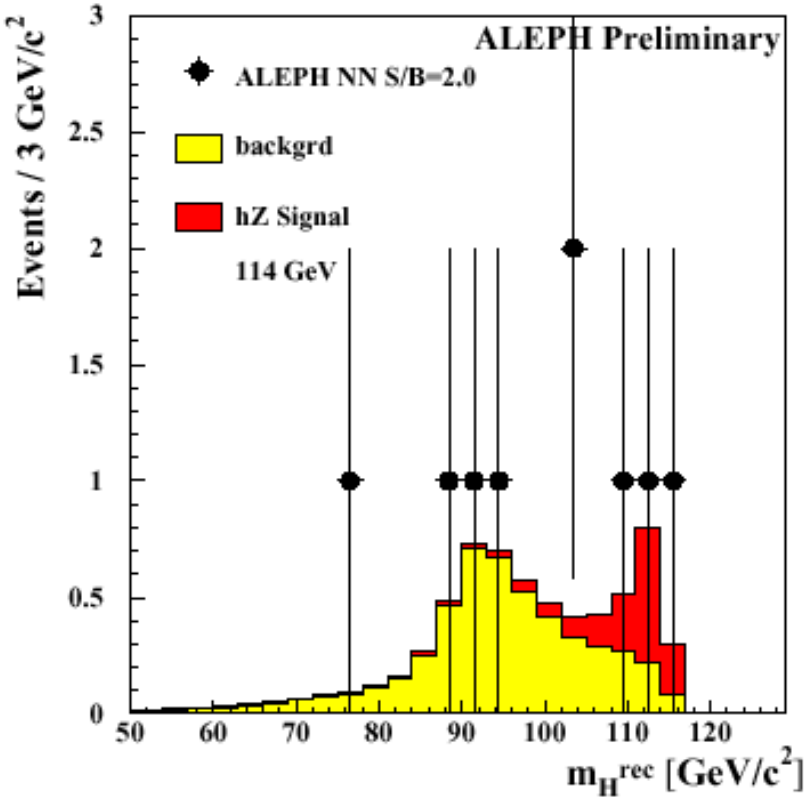
m_Z=10

m_Z=91

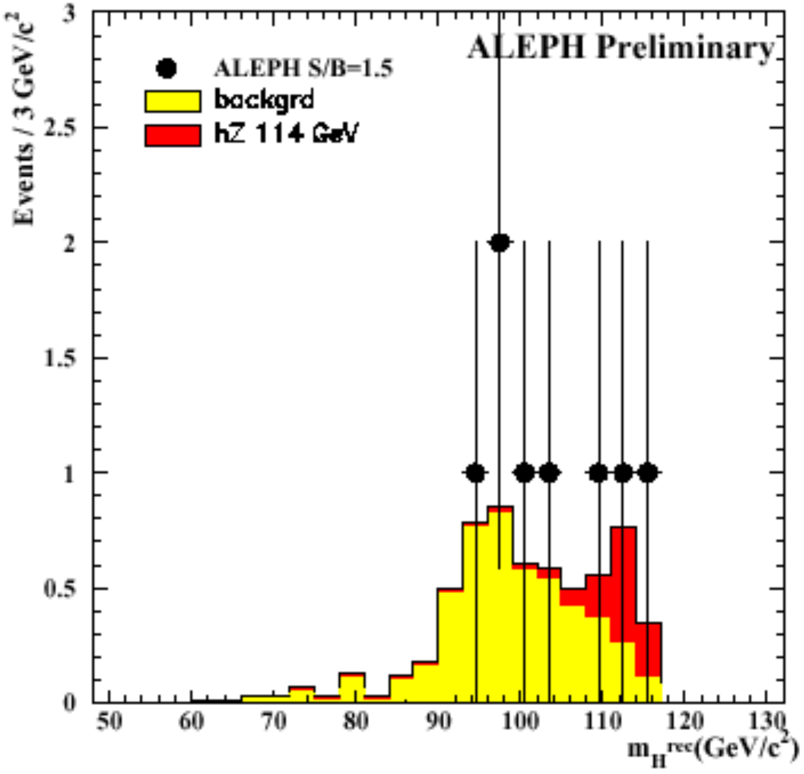
ass plot by ALEPH (Sept. 2000)

Mass Plot - Tight Cuts

NN Analysis



CUT Analysis



When cuts are tightened, both accept the same three four jet events with $M_H > 109$ GeV/c^2

The survival of these three candidates indicates that they are indeed quite signal-like

P in Year 2000

- P has obtained important results in the last months of ration in the year 2000
- dence for a Higgs particle at about 115 GeV/c^2.
- P Collaborations requested a further run in 2001(from Ma Dctober) in order to consolidate the data.

eement with SM Higgs cross-sect. for

$m_H = 115.0^{+1.3}_{-0.9}$ GeV

P. Igo-Kemenes - LEP Seminar - Nov. 3, 2000

Statistical Significance

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

in September and October has been very beneficial: signific eased, better understanding of background

ers are leaving on schedule and within budget; ≈ 1.7 BCHF committed (CE
noney+ special contributions)

civil engineerings have gone through a difficult phase, with comparatively l
amage (≈ 6 months delay)

superconducting dipoles of the pre-series perform brilliantly

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

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

ector construction is taking off

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

updated estimate of the LHC schedule, which takes into account further del
LEP dismantling was reported to CC of Nov. 17 and included in the LHC st
eport. 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 can be discovered at ≈ after ≈1 year of operation (10 fb^{-1}/ eriment) for $m_H \approx 150$ GeV

covery faster for larger masses

ble mass range can be excluded at 95% after ~1 month of running at 10^{33} ^{2} s^{-1}.

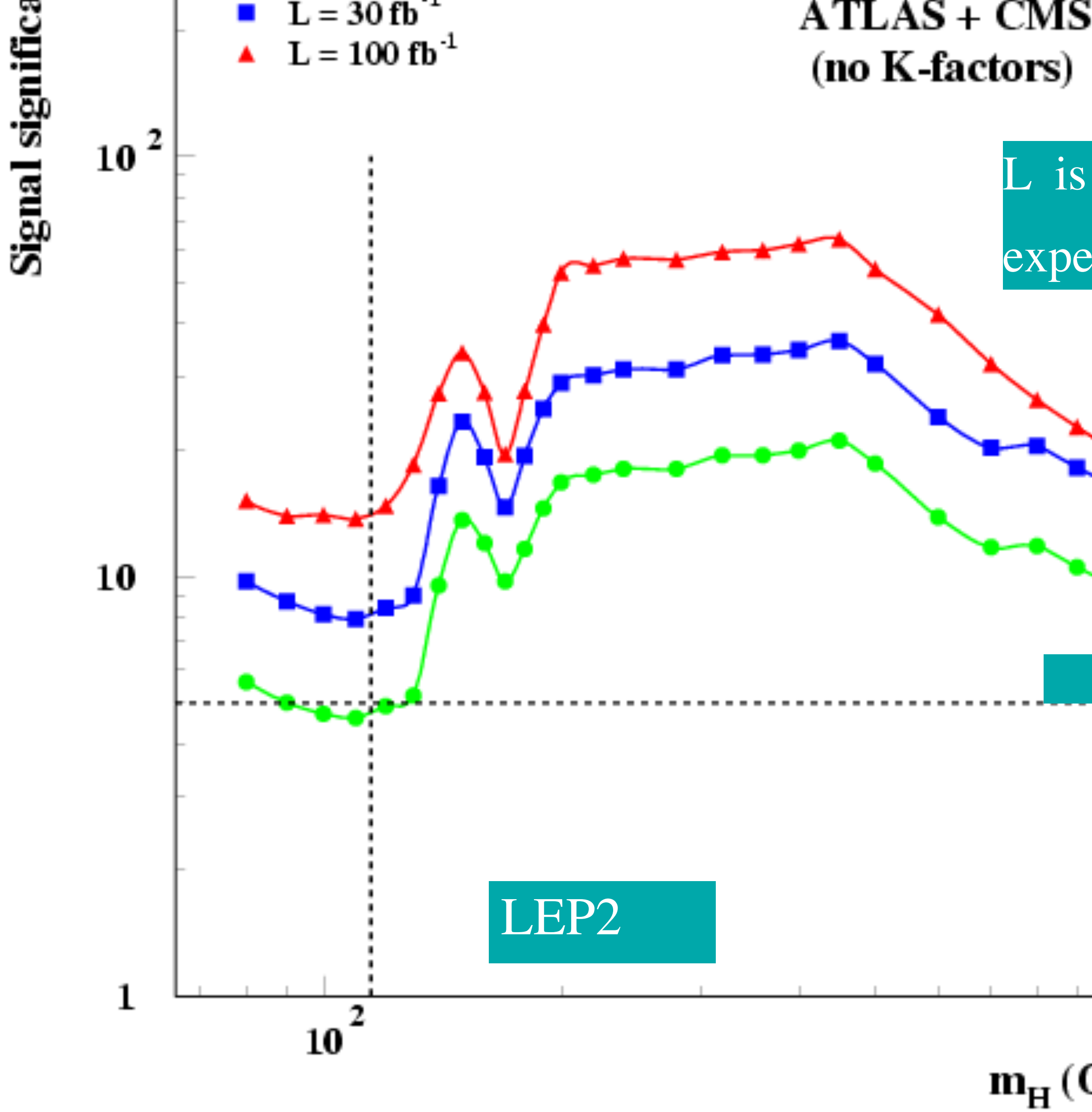
<u>s are conservative:</u>

k-factors

nple cut-based analyses

nservative assumptions on detecto rformance

annels where background control is ficult not included, e.g. $WH \to \ell\nu b\bar{b}$



SEQUENCES

n energy of 104.1 GeV (+1.5GeV), integrated luminosity o

M_H= 115: 2.9σ → 5.3±0.5σ
M_H= 116: 2.6σ → 4.3±0.5σ

may be inconclusive

itional cost: 110 MCHF (40 LEP running, 70 pena
heduling...)

ay to the LHC ≈ 1 year

RN manpower is decreasing: $\Delta_{manpower}$≈ -100 FTE/year:

reported by one year will find less manpower to be executed

eements with CERN Non- Member States on the LHC ?

tement

h November 2000, the CERN Committee of Council held a meeting to examine a propos Director-General concerning the continuation of the existing CERN programme, which f decommissioning of the LEP accelerator at the end of the year 2000.

nmittee has expressed its recognition and gratitude for the outstanding work done by the lerator and experimental teams.

ken note of the request by many members of the CERN Scientific Community to continue ing into 2001 and also noted the divided views expressed in the Scientific Committees co nis subject.

asis of these considerations and in the absence of a consensus to change the existing ramme, the Committee of Council supports the Director-General in pursuing the existin N programme."

ecision moves us definitely into the LHC era
verful complex, machine and detectors, to f
e the Higgs and SUSY region

Le Roi est mort
Vive le Roi !!

hits the LEP/LHC tunnel: the LHC era begins