

HIGGS

A photograph of a forest floor with several mushrooms. The most prominent is a large bolete mushroom with a thick, textured stem and a wide, slightly flattened cap. Other smaller mushrooms are scattered around it. The background shows a dense forest with tall trees and green foliage.

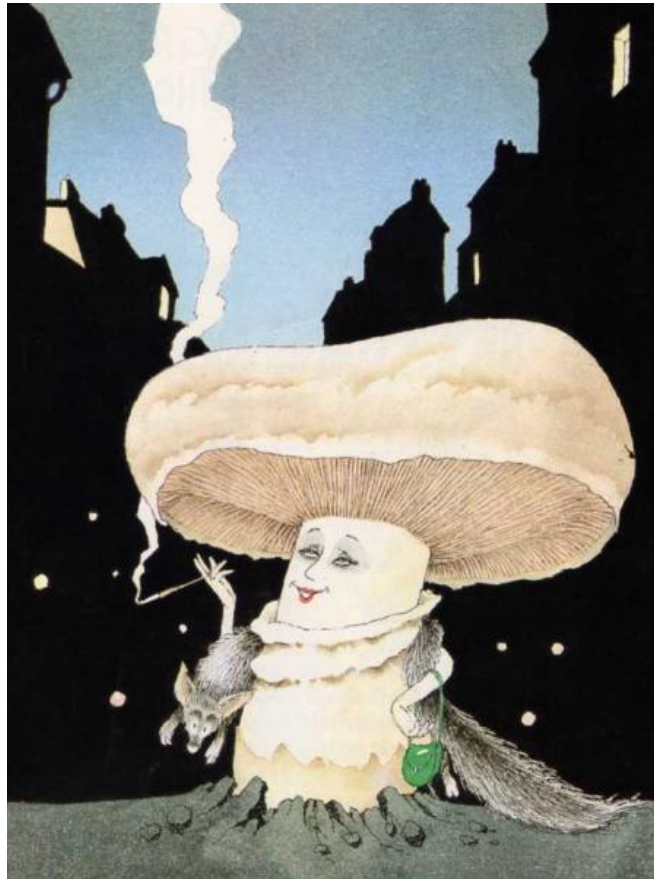
Treasure Hunt

Pik 21.10.2010

**What is the mass
of the Higgs
boson?**

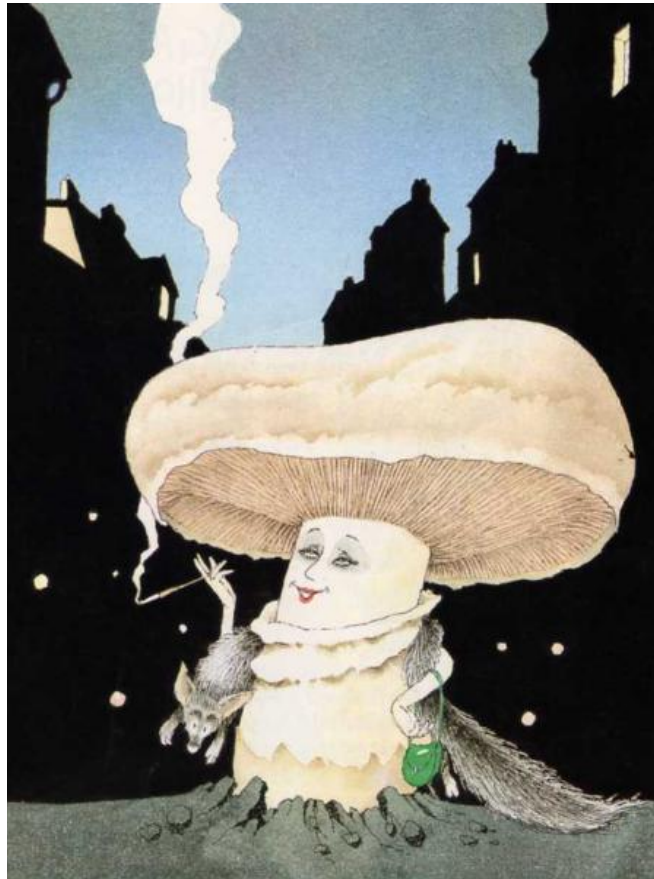


Ask George Mikenberg ...
He should know



Ask George Mikenberg ...
He should know

Do I
know
???



***This is how it all started ... Back
in 1989***

Everything was „light“ ...

- ***Neutrino mass = 0***

Everything was „light“ ...

- *Neutrino mass = 0*
- $M_{top} = 40 \text{ GeV}/c^2$ *(By decree)*

(80-GeV Toponium studies)



Everything was „light“ ...

• **Neutrino mass = 0**

• **$M_{\text{top}} = 40 \text{ GeV}/c^2$ (By decree)**

(80-GeV Toponium studies)

And the Higgsjust around the corner”

Where the Higgs was not ...



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

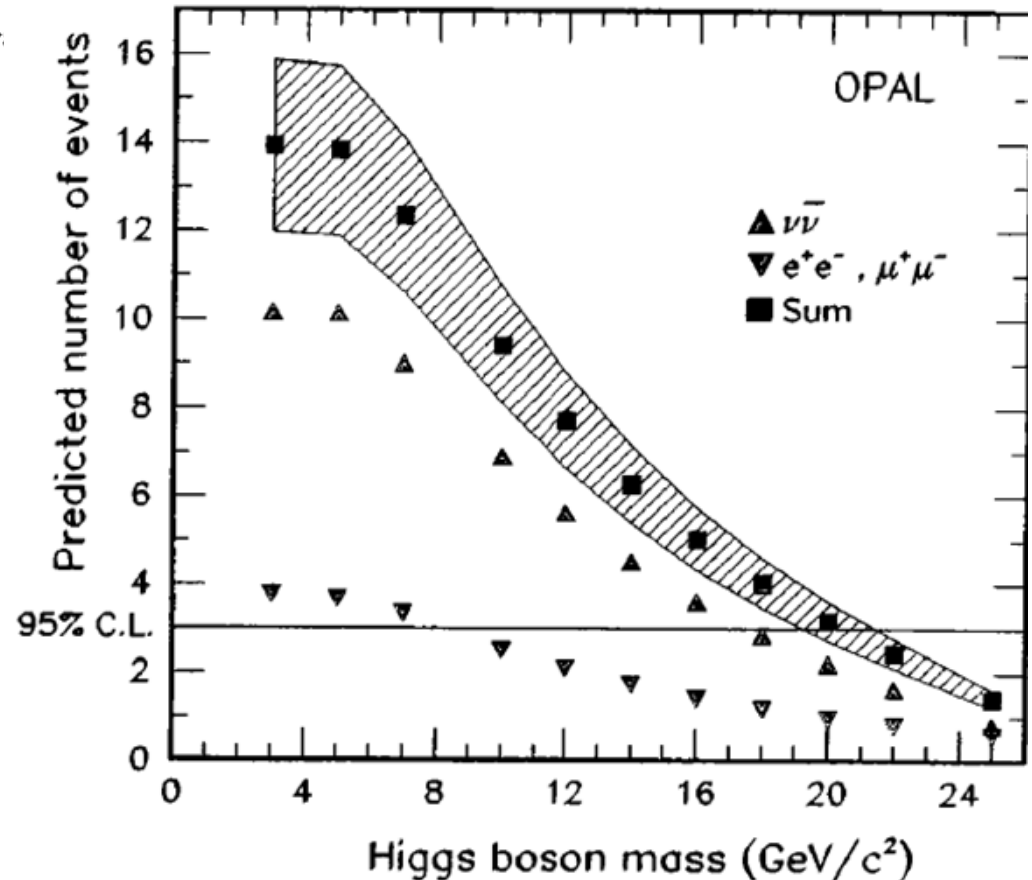
CERN-EP/89-174
December 22, 1989

Mass Limits for a Standard Model Higgs Boson in e^+e^- Collisions at LEP

The OPAL Collaborator

December 1989
 825 nb^{-1}

$3.0 < m_H < 19.3 \text{ GeV}$
excluded
(95% C.L.)



Where the Higgs was not ...



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/89-174
December 22, 1989



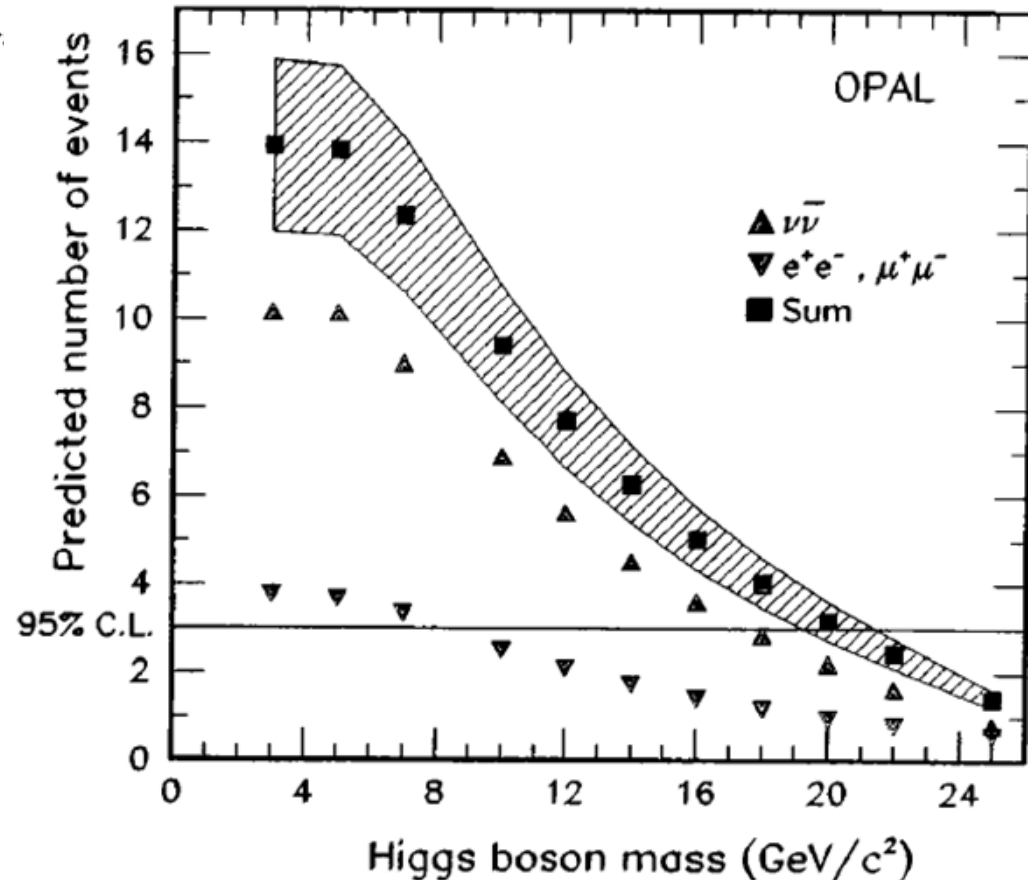
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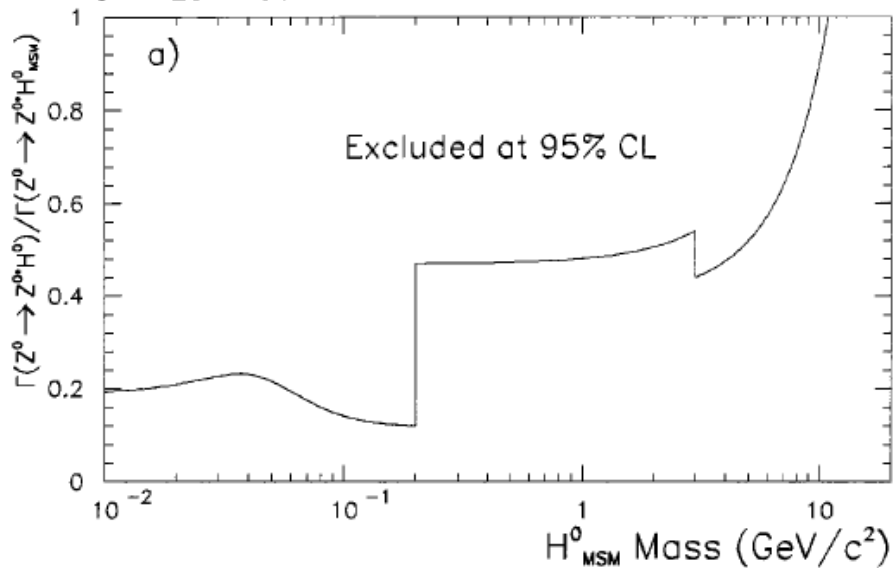
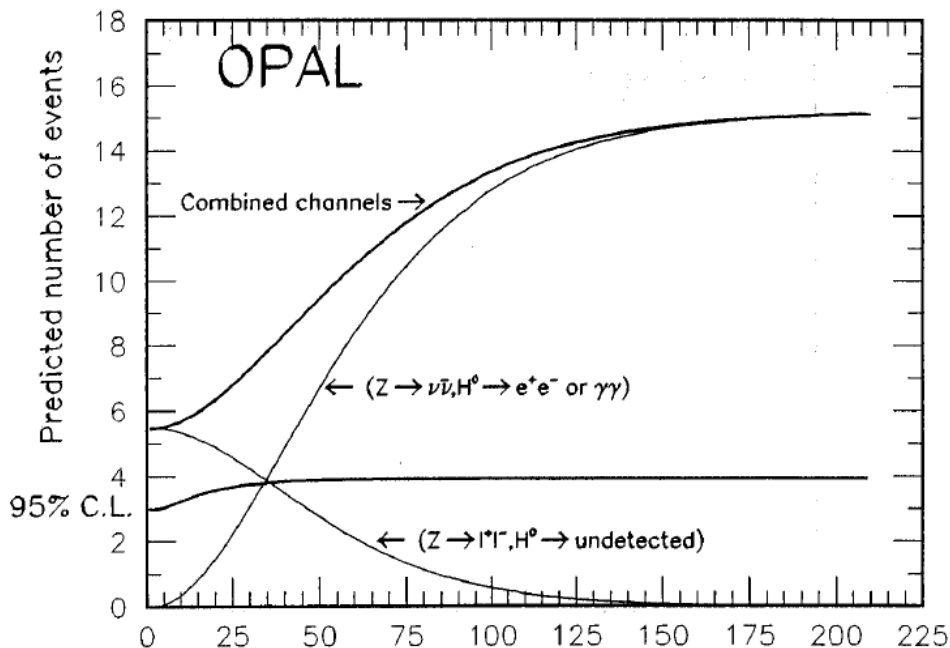
$3.0 < m_H < 19.3 \text{ GeV}$
excluded
(95% C.L.)

Little hole ...
below $3 \text{ GeV}/c^2$



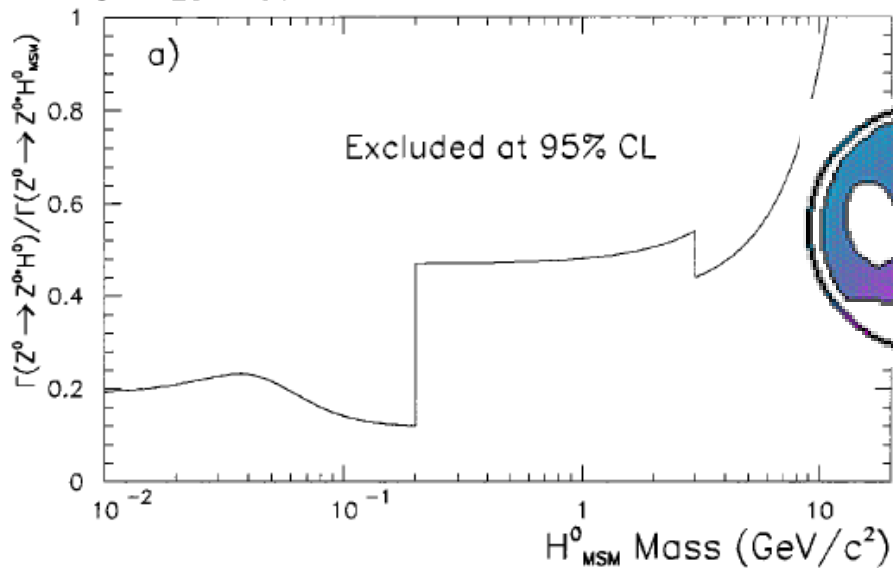
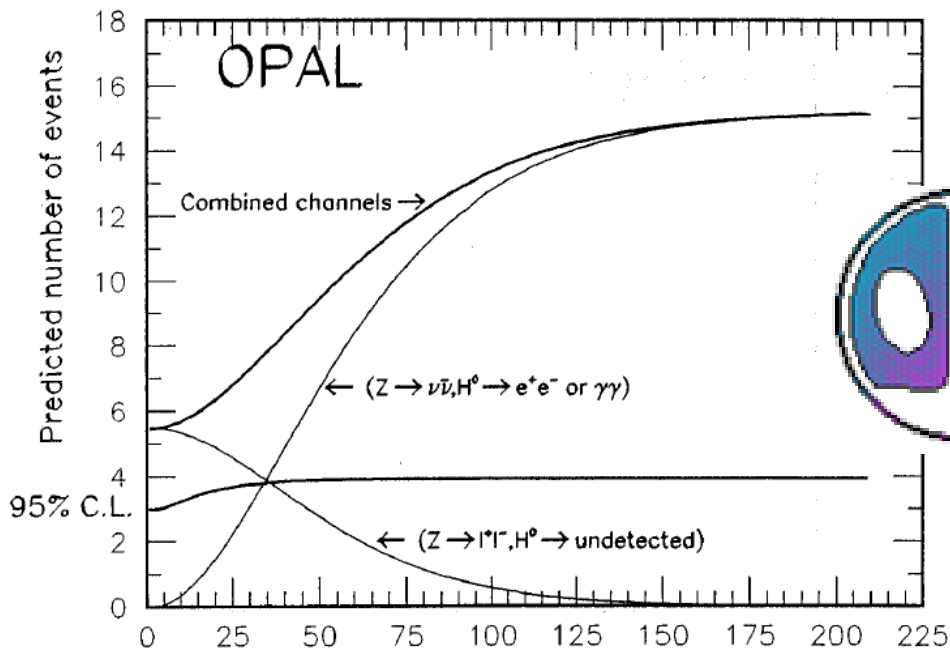
Search for the „light“ Higgs

July 1991
Decay-mode independent
search for a Light Higgs
Boson



Search for the „light“ Higgs

July 1991
Decay-mode independent
search for a Light Higgs
Boson



LEP I ... More data ... Sensitivity to higher masses

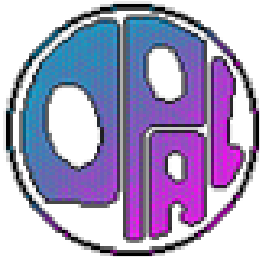


End of LEP 1 ...

CERN-PPE/96-118
August 14, 1996

Search for Neutral Higgs Bosons in Z^0
Decays Using the OPAL Detector at
LEP

The OPAL Collaboration



$m_H < 59.6 \text{ GeV} / c^2 \dots$
Excluded at 95 % c.l.

LEP 2 ...

135, 171, 189, 202,
209 GEV

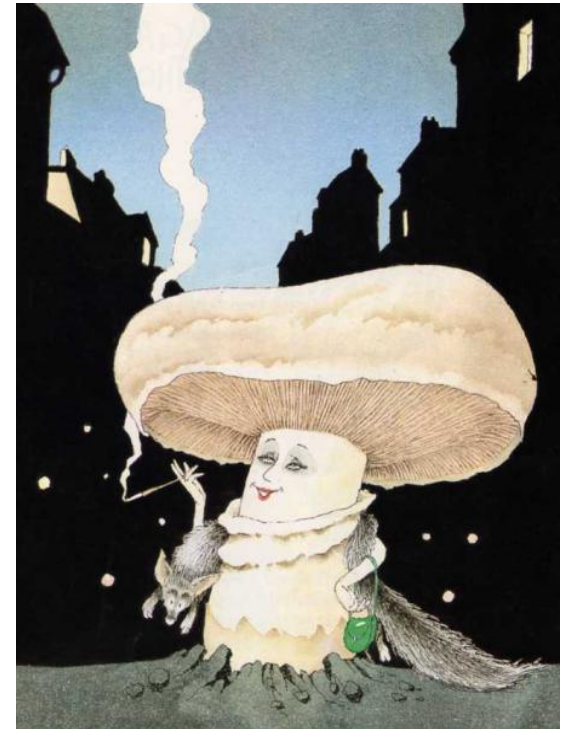
GREAT
EXPECTATIONS

LEP 2 ...

135, 171, 189, 202,
209 GEV

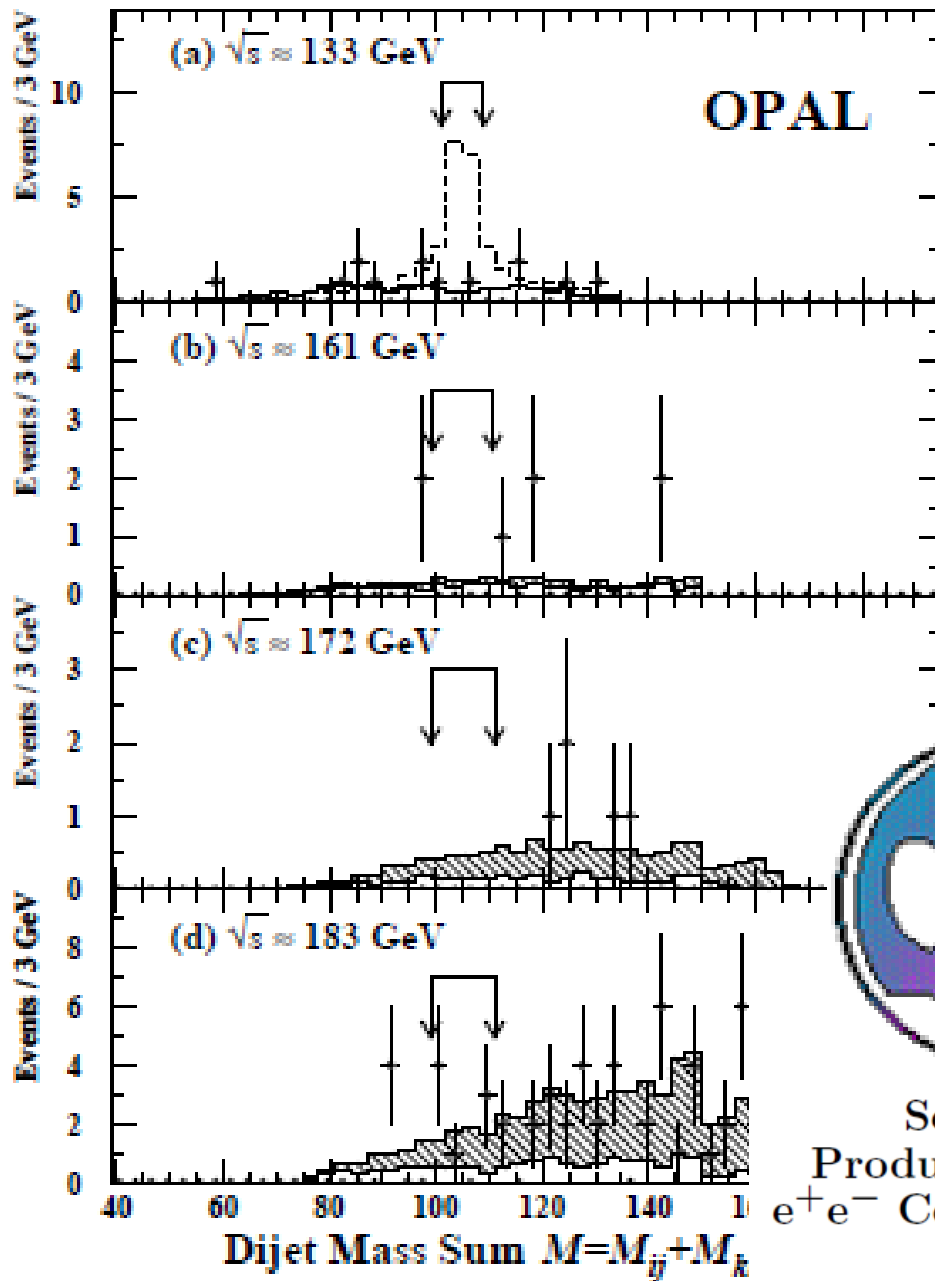
GREAT
EXPECTATIONS

It must
be there
!!!



· Diversion: The ALEPH
four-jet „ambush”





OPAL



CERN-EP/98-013
29 January 1998

Search for an Excess in the
Production of Four-Jet Events from
 e^+e^- Collisions at $\sqrt{s} = 130 - 184$ GeV

The OPAL Collaboration

Our own Diversion:

QUATORZE JUILLET
1997

... just following an energy
upgrade





Gabriella ... on shift



Gabriella ... on shift

Satoru ... analysing off-line



Curious
Accumulation of
events ... at about
the same mass !!!

Excitement !

... Calling for
immediate action



Physics coordinator called



Gail Hanson



OPAL „crisis” meeting called Next
morning at 9:00 (Building 28)

Working through the night

- Some events did not pass basic pre-selection cuts
- Others were double-counted (Gabi - Satoru)

By sunrise ... Two events survived

The effect was gone

Apologies



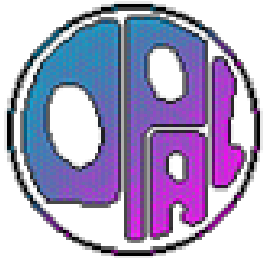
More seriously ...

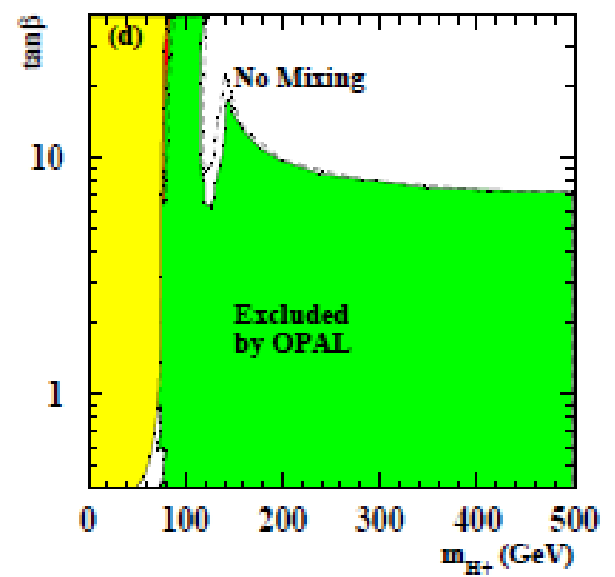
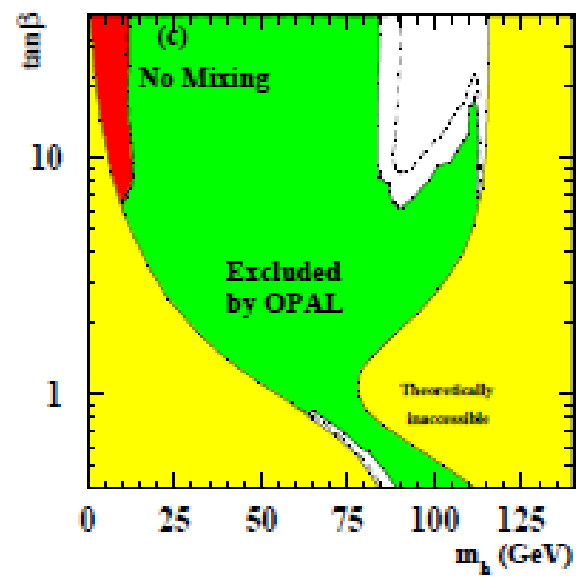
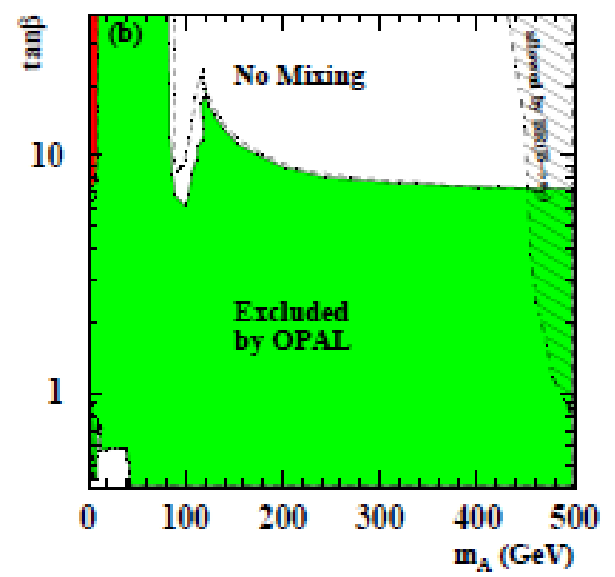
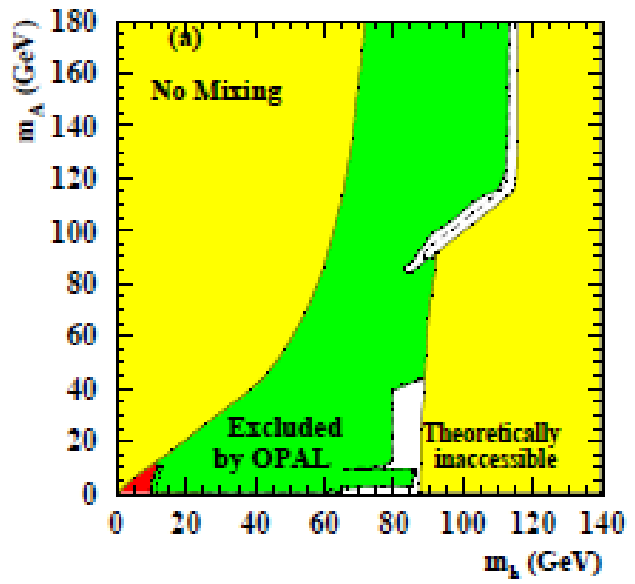
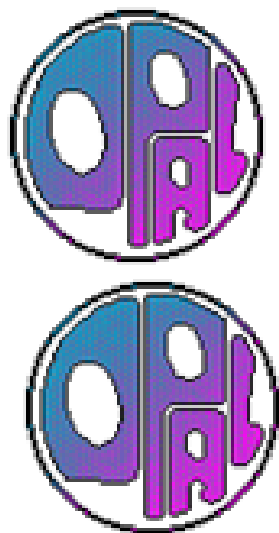
SUSY Higgs bosons

$$m_h < 84.5 \text{ GeV} / c^2$$

$$m_A < 85.0 \text{ GeV} / c^2$$

*Excluded (95% c.l.)
(LEP 2)*





Charged Higgs

$$M_{H^\pm} < 80 \text{ GeV} / c^2$$

*Excluded, 95% c.l.
(LEP2)*

*Still in the Ed. Board
(Special price)*



„Invisible” Higgs

... Ex-aequo with
Charged Higgs





Searches for
Exótica

fermiophobic



bosophilic





photonics

gluonic





Kalusa-Klzin
statçs

... other oddities



1997 ... Change of paradigm



**LEP Higgs Working
Group**

Not always obvious

Mistrust

No exchange of „events“

.....

Probability densities

„Test statistics“

„Test mass“

„Pea-values“

„Ellen Queue“ $(-\ln Q)$

„Sea Ellesse“ (CL_s)

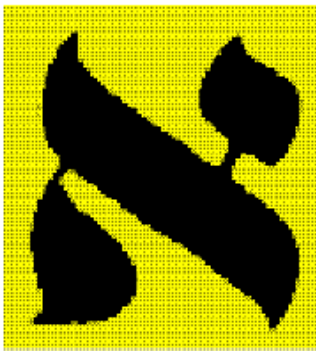
„Sea Elle Bee“ (CL_b)



„Higher level abstraction“

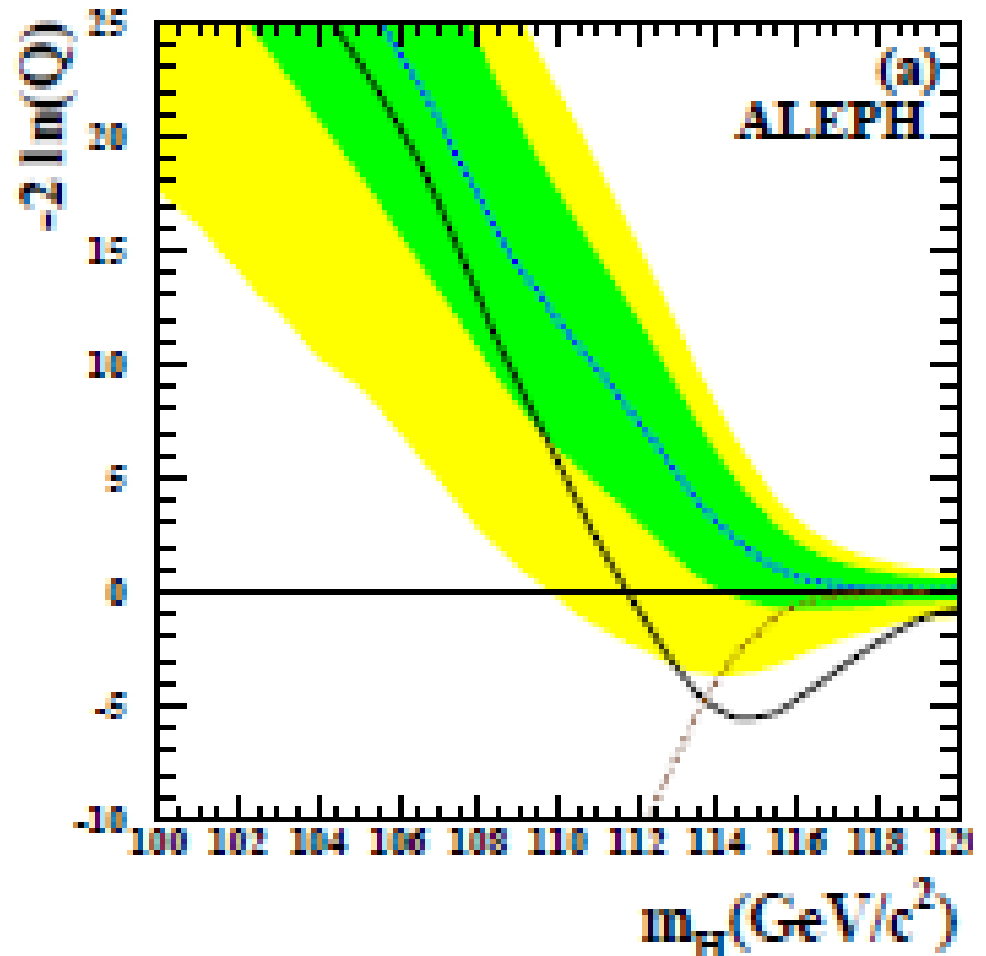
September 2000

... shortly before the final LEP shutdown



Four-jet „Higgs“
candidates

$$m_H = 115 \text{ GeV}/c^2 \quad (3.9 \sigma)$$



Busy times for the LEP Higgs Working Group

- ***Fast succession of LEP combinations***
... Weekly reporting to the DG and LEP C
Harrassement by the Media
- ***One month of LEP extension accorded***
- ***Nov.3 : Final reporting to LEP C***
LEP : 2.9 σ „effect“ at 115 GeV/c²
Request for LEP extension by one year

... Not accorded ...

LEP - fest



LEP Legacy



Available online at www.sciencedirect.com



Physics Letters B 565 (2003) 61–75

PHYSICS LETTERS B

www.elsevier.com/locate/npe

Search for the Standard Model Higgs boson at LEP

ALEPH Collaboration¹

DELPHI Collaboration²

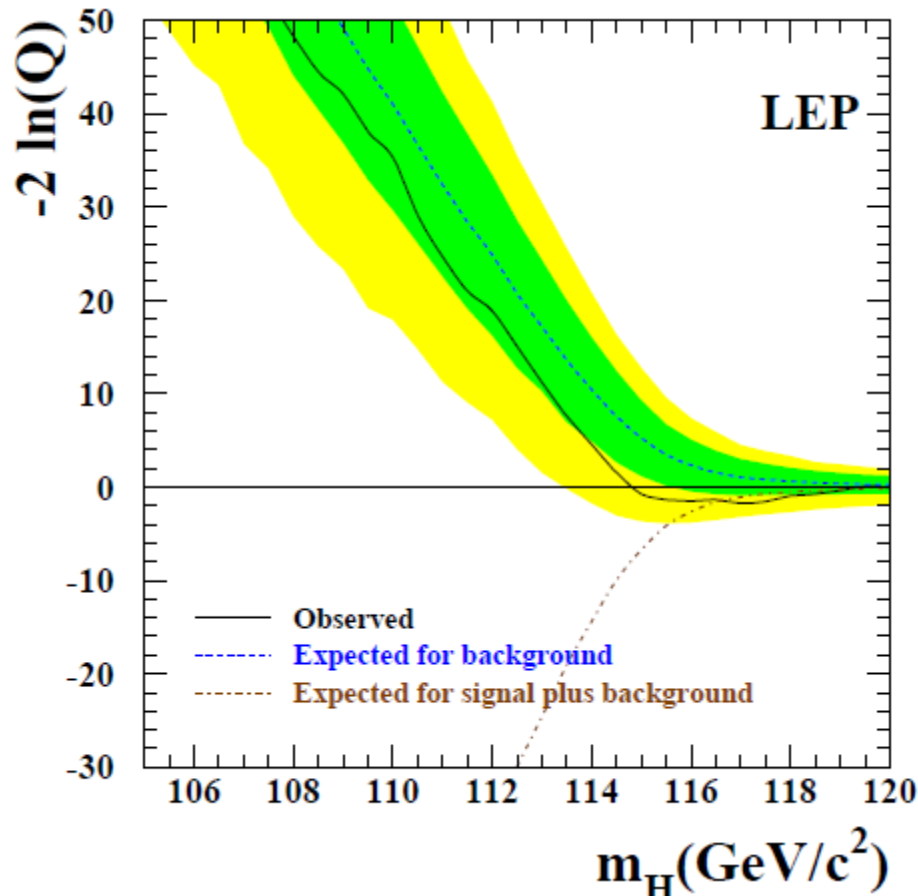
L3 Collaboration³

OPAL Collaboration⁴

The LEP Working Group for Higgs Boson Searches⁵

Received 7 March 2003; received in revised form 25 April 2003; accepted 28 April 2003

Editor: L. Rolandi



$$m_H > 114.4 \text{ GeV}/c^2$$

(95% c.l.)

1.7σ „effect” at $115 \text{ GeV}/c^2$

focus ... TeVatron

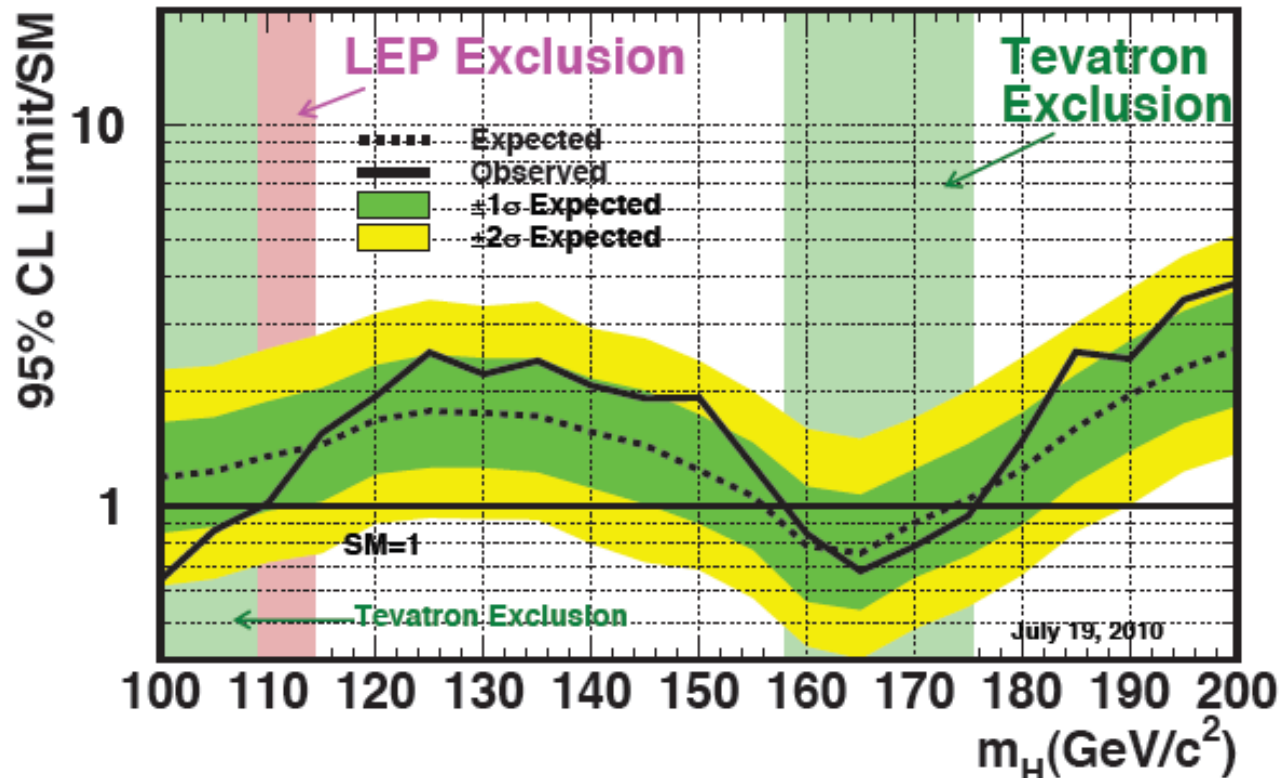
*CDF and D0 ... Collecting data steadily since years
Machine and detectors ... Understood
Analysis procedures well in hand*

CDF and D0 ... Combined

8 fb⁻¹ on tape, 6.7 fb⁻¹ analysed

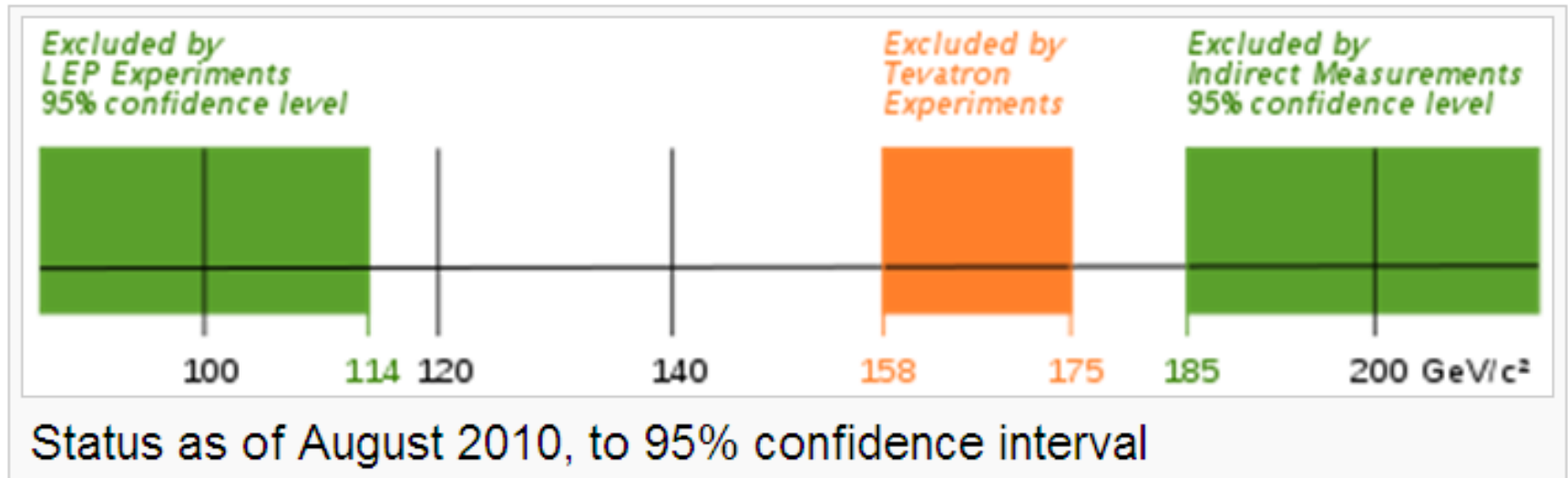


Tevatron Run II Preliminary, $L \leq 6.7 \text{ fb}^{-1}$



Ben Kilminster, ICHEP 2010

CDF and D0 ... Combined
8 fb-1 on tape, 6.7 fb-1 analysed



Ben Kilminster, ICHEP 2010

Indirect constraints on m_H ... improving

Electroweak constraints

$$\ln M_H \propto \Delta M_W \propto M_t^2$$



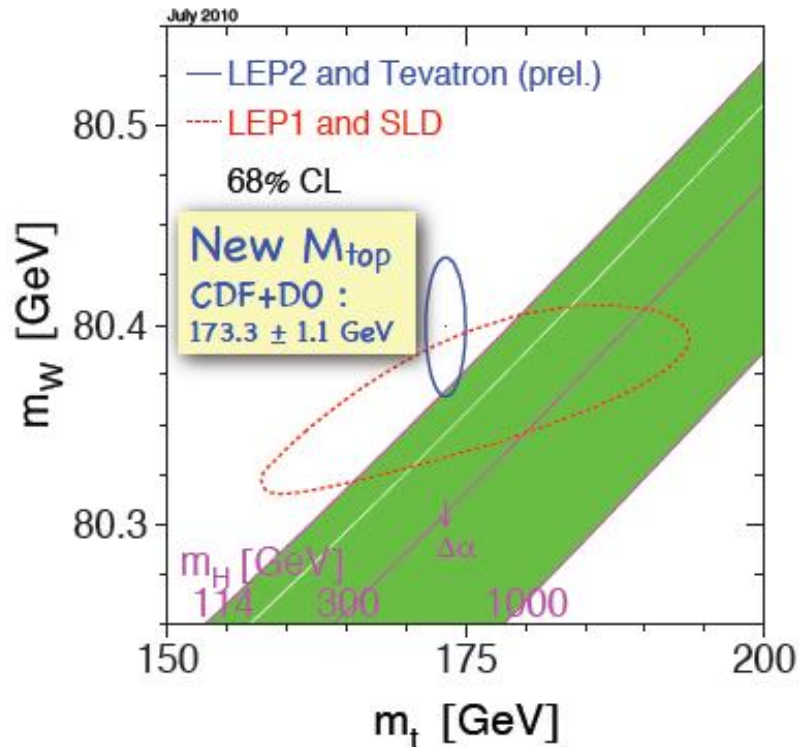
- ▶ Other precision electroweak observables

LEP direct searches

- ▶ $m_H > 114.4$ GeV @ 95% CL

Top quark direct searches

- ▶ $m_t > 173.1$ GeV @ 95% CL



Precision Fit finds

$$m_H = 89.0^{+35}_{-26} \text{ GeV}$$

$m_H < 158$ GeV @ 95% CL

Search for Supersymmetric Higgs boson

- Supersymmetric models extend Higgs sector

- $\Phi = (H^0, A^0, h^0)$, and H^\pm

- Introduces $\tan \beta = \langle H_u \rangle / \langle H_d \rangle$ parameter

- $\sigma(\Phi)$ enhanced by $(\tan \beta)^2 \sim 1000$ over SM

- Branching ratio

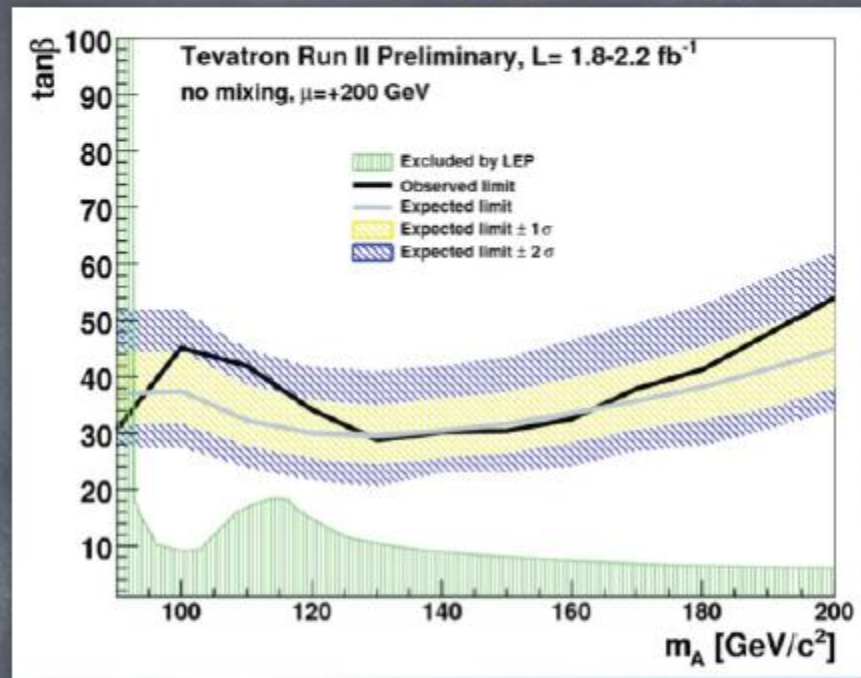
- $\sim 90\% bb, 10\% \tau\tau$

- Tevatron has comprehensive MSSM Higgs program

- $\Phi \rightarrow \tau\tau$

- $\Phi + b \rightarrow bb + b$

- $\Phi + b \rightarrow \tau\tau + b$



- CDF & D0 combined search for $\Phi \rightarrow \tau\tau$ with 2 fb^{-1}

- Probes interesting value of $\tan \beta \sim m_t/m_b \sim 30$

TeVatron ... Pleading for extension

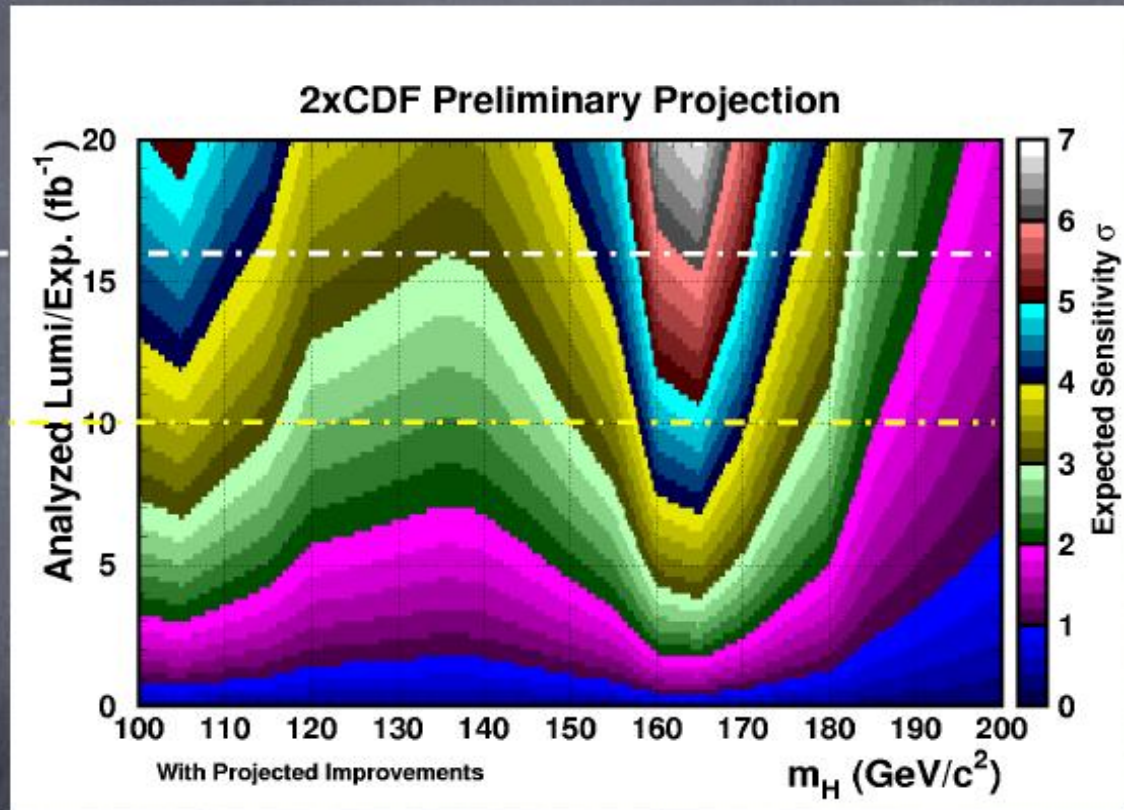
Prospects for Higgs evidence

~16 fb⁻¹ :*

> 3 σ expected
sensitivity from
100 – 185 GeV
4 σ @ 115 GeV

End of 2011:

> 2.4 σ expected
sensitivity across mass
range
3 σ at 115 GeV



* 16 fb⁻¹ : based on "Run III" proposal to run 3 more years

... and the LHC ?

*Beautiful (technical) achievements
shown at JCHEP 2010*

With time ...

*Comprehensive search up to the
TeV scale*

... but still a long way to go !

The race is „on“ !

Who will be celebrating ?



Illustrations ...

