Did LEP find the Higgs ?

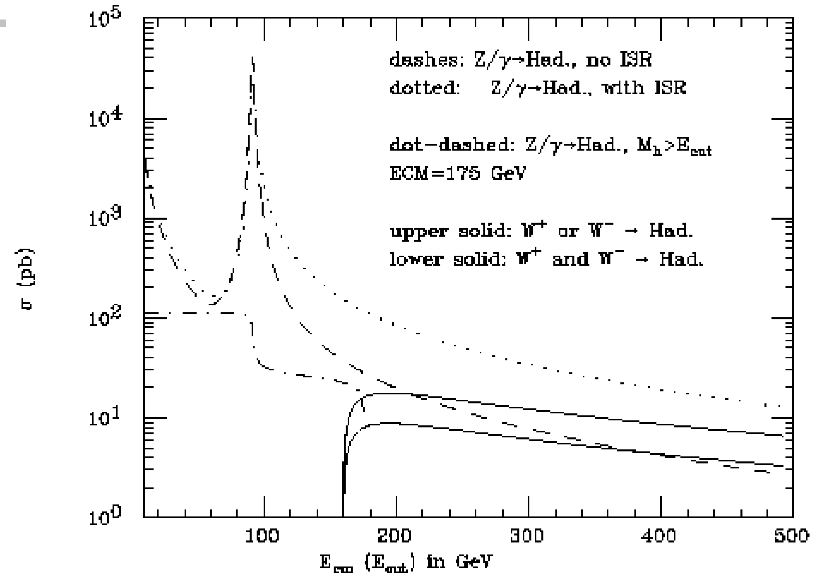
Alessandro De Angelis
Università di Udine and INFN Trieste

- LEP operation
- What LEP certainly found
- What LEP excluded
- A Higgs signal ?

SISSA/ISAS and ICTP Trieste, 20 September 2000

LEP operation before 2000

- 11 years of operation (1989-2000)
- Phase 1 (1989-1995): ~ 4.5 MZ/experiment



- Phase 2 (1995-2000):

Year	$\sqrt{s}$ (GeV)	$\int L\,dt/\exp\left(\mathrm{pb}^{-1}\right)$
1995 (& 1997)	130/136	12
1996	161/172	20
1997	183	55
1998	189	180
1999	192/202	230

LEP operation during 2000

Year 2000 High-Energy Data

August 28 Combination

Experiment	Integrated Luminosity (pb^{-1})
ALEPH	149
DELPHI	160
L3	145
OPAL	140
LEP	594

- ~320 pb^{-1} above 206 GeV

- Average c.m. energy ~ 206 GeV,

  maxima ~ 208 GeV

The plan:

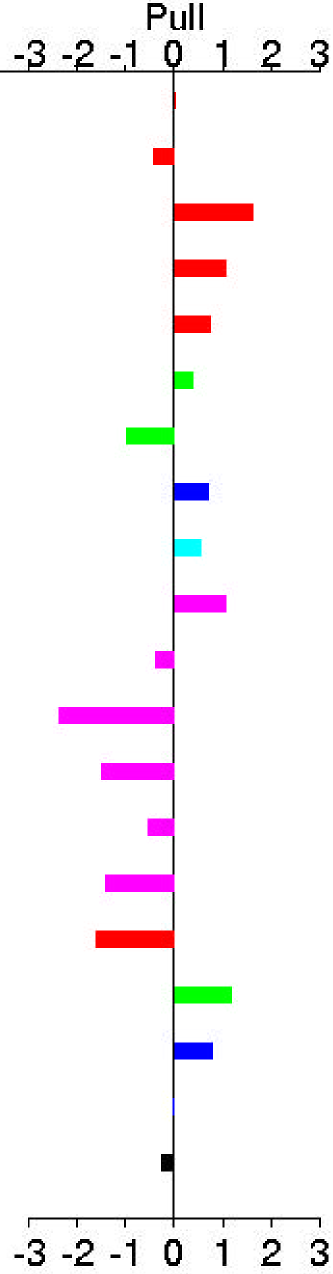
- **Run at maximum energy till Sept 5**
- **Then meeting: evidence for new physics ?**
  - **YES => CONTINUE**
  - **NO => STOP**

What LEP certainly found

- Unprecedented accuracy on the measurement of SM parameters
  - M_Z known at 23 ppm
  - Z couplings
  - M_W known at ±48 MeV

Osaka 2000

	Measurement	Pull
m_Z [GeV]	91.1875 ± 0.0021	.05
Γ_Z [GeV]	2.4952 ± 0.0023	-.42
σ^0_{hadr} [nb]	41.540 ± 0.037	1.62
R_l	20.767 ± 0.025	1.07
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.75
A_e	0.1498 ± 0.0048	.38
A_τ	0.1439 ± 0.0042	-.97
$\sin^2\theta^{lept}_{eff}$	0.2321 ± 0.0010	.70
m_W [GeV]	80.427 ± 0.046	.55
R_b	0.21653 ± 0.00069	1.09
R_c	0.1709 ± 0.0034	-.40
$A^{0,b}_{fb}$	0.0990 ± 0.0020	-2.38
$A^{0,c}_{fb}$	0.0689 ± 0.0035	-1.51
A_b	0.922 ± 0.023	-.55
A_c	0.631 ± 0.026	-1.43
$\sin^2\theta^{lept}_{eff}$	0.23098 ± 0.00026	-1.61
$\sin^2\theta_W$	0.2255 ± 0.0021	1.20
m_W [GeV]	80.452 ± 0.062	.81
m_t [GeV]	174.3 ± 5.1	-.01
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02804 ± 0.00065	-.29



What LEP did not find:
SUSY particle & other “exotics”

- **Charginos**
- **Neutralinos**
- **Sleptons**
  - **~0 lifetime**
  - **finite lifetime**
  - **stable**
- **Squarks**
  - **~0 lifetime**
  - **long lived**
  - **heavy sbottoms**
- **Photons**

LEP SUSY WG

No significant excess - great set of limits...

From the Osaka 2000 summary (Sugawara)

Thank you LEP :

Thank you for finding evidence for the Supersymmetric Grand Unified Theory etc. etc.

Thank you for not finding the Higgs particle.

Scientists find 'God's particle'

Jonathan Leake, Science Editor

LA STAMPA

Interni | Esteri | Cronache Italiane | Economia | Cultura Spettacoli

E' il mattone della materia

Svelata la particella di Dio

di Piero Bianucci

NATIONAL

Science/Health

The New York Times ON THE WEB

Home | Site Index | Site Search | Forums | Archives | Marketplace

September 15, 2000

E-Mail This Article

Physicists Give Themselves One Last Try at Tantalizing Discovery

By THE ASSOCIATED PRESS

NewScientist | home | subscribe | jobs | search

news

LATEST NEWS

Space threat:
The Earth is not sufficiently protected against the risk from asteroid impacts, says an expert report

Massive discovery?

CERN scientists think they have spotted the Higgs particle, the most sought-after prize in particle physics

PHYSICS TODAY *online*

Physics Update | Letters | Search & Discovery | Physics Community | Books | New Products | We Hear That | O

Back to Table of Contents

Feature

Site Index

Related Links:

LEP Higgs Working Group

September Features:

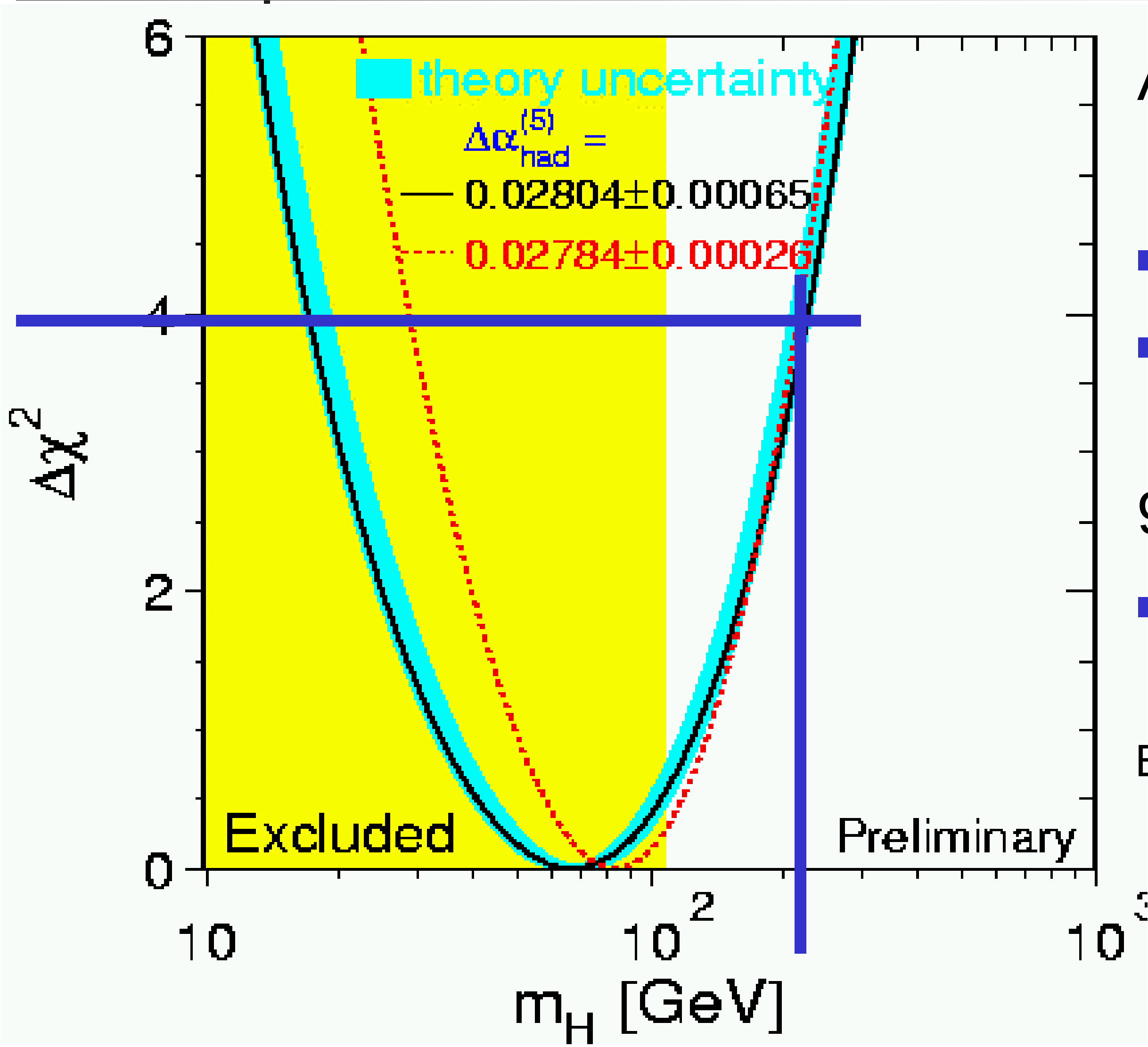
Hints of the Higgs Grant LEP a One-Month Reprieve

- Plus many others (Nature, Corriere, Publico, L.A. Chronicle ...

A selection of titles...

- Le Temps: "On a peut-être vu l'ombre du Higgs"
- BBC News: "Scientists close in on elusive particle"
- La Stampa: "Svelata la particella di Dio"
- El Pais: "El CERN logra posibles indicios de la partícula más buscada"
- New York Times: "Swiss Physicists Face Decision in Race for Atomic Particle"
- Bild der Wissenschaft: "Higgs Boson entdeckt"
- Gazeta Wyborcza: "Czastka Higgsa zlapana?"
- The Sunday Times: "Scientists find 'God's particle'"
- Le Monde: "Le boson de Higgs perturbe les projets des chercheurs du CERN"
- Der Spiegel: "Entdeckten Forscher das "Teilchen Gottes"?"
- Le Figaro: "Le Boson de Higgs en ligne de mire"
- San Francisco Chronicle: "The Search for The Higgs Boson"
- Liberation: "Le Cern est en passe de détecter le mystérieux boson de Higgs."
- Süddeutsche Zeitung: "Das Teilchen Gottes"
- Tagesspiegel: "Ein Higgs im Cocktail"
- The Dallas Morning News: "Hints of elusive particle may be massive find"

SM Higgs limits



At 95% CL:

- **m_H > 113.3 GeV**
- **m_H < 210 (?) GeV**

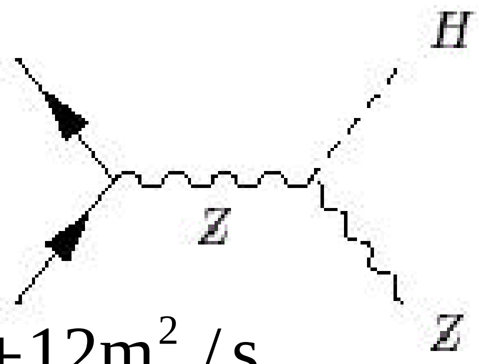
90% CL, two-sided:

- 113.3 < m_H <~210 GeV

But could be lighter in MSSM:
m_H <~130 GeV and SM-like

Higgs production mechanisms & X-section

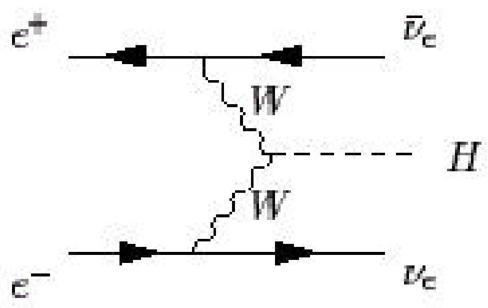
- Dominantly Higgstrahlung



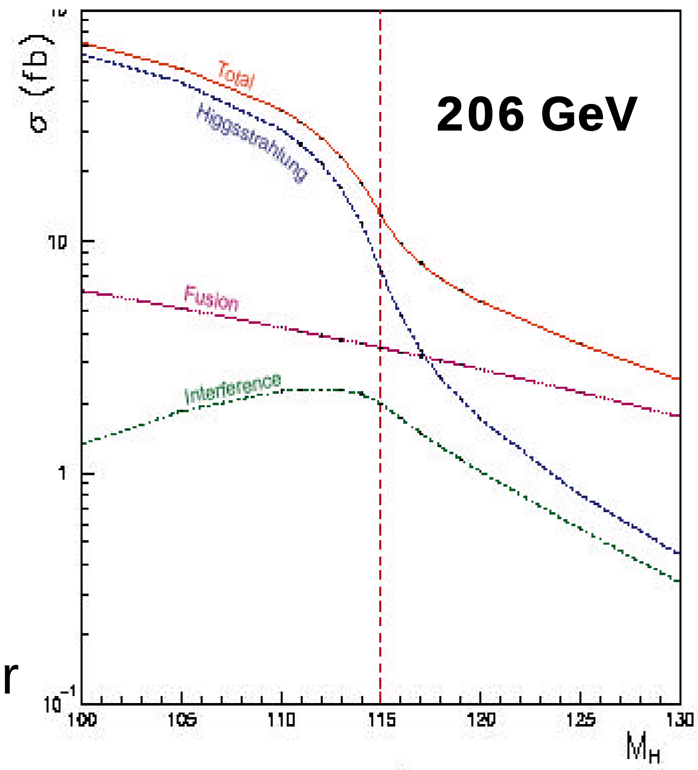
$$\sigma(ZH) = \frac{G_F^2 m_Z^4}{96\pi s}\left(v_e^2 + a_e^2\right)\sqrt{\lambda}\,\frac{\lambda + 12 m_Z^2/s}{\left(1 - m_Z^2/s\right)^2}$$

$$\lambda = \left(1 - \frac{m_H^2}{s} - \frac{m_Z^2}{s}\right)^2 - \frac{4 m_H^2 m_Z^2}{s^2}$$

Linear in (E_{CM} - m_H - m_Z) near threshold

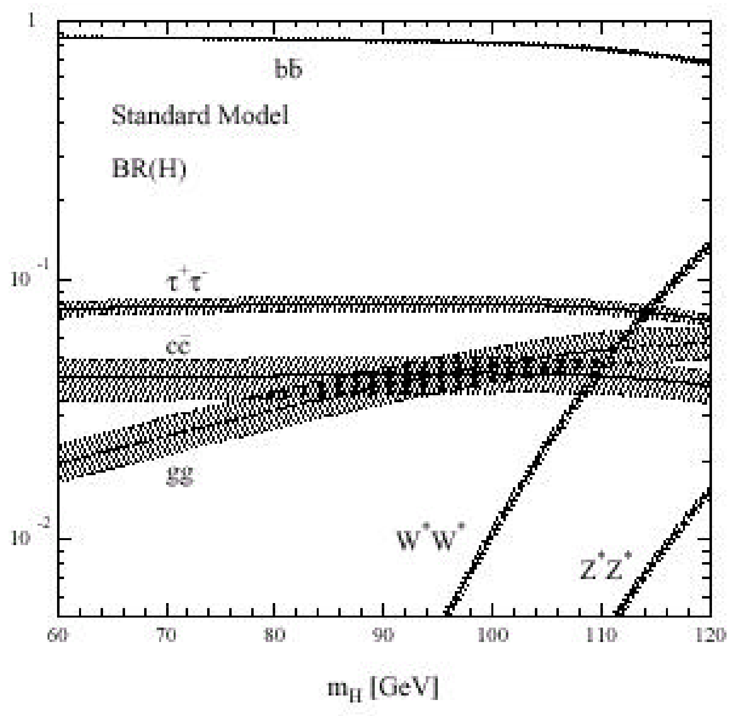


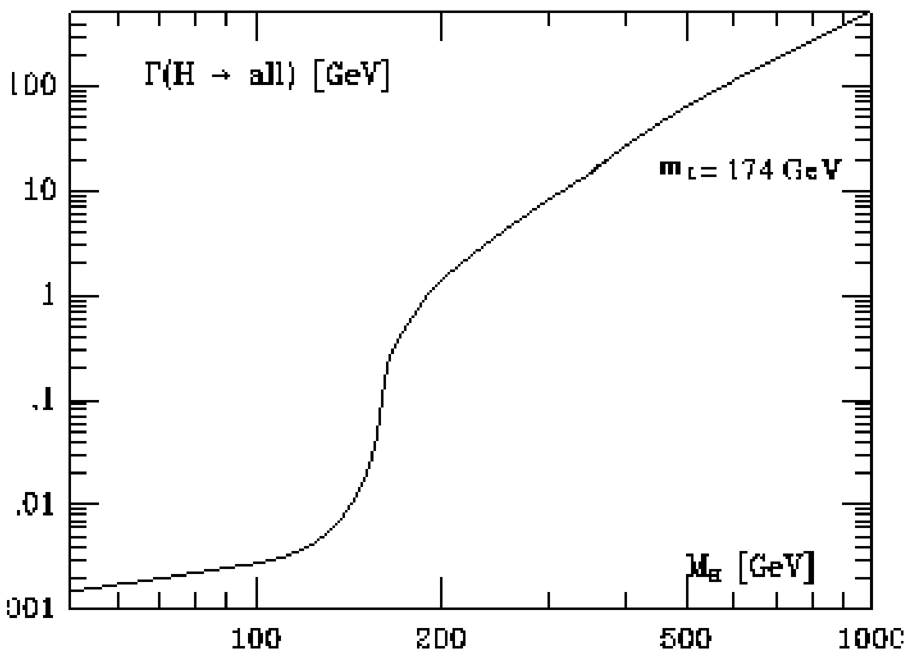
- W fusion and W fusion/Higgstrahlung interference can become important near threshold



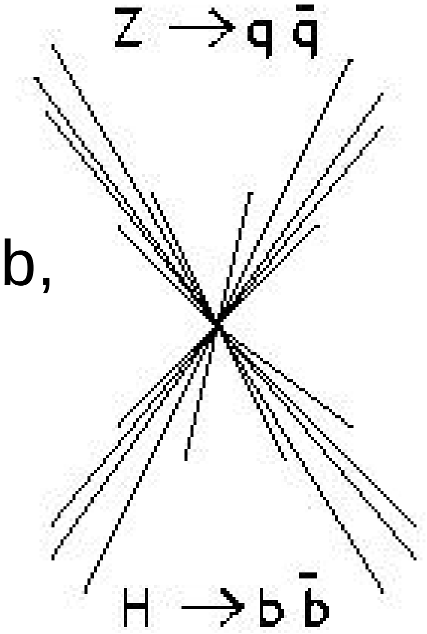
Higgs decay

- Decay dominated by b-bbar, width of a few MeV

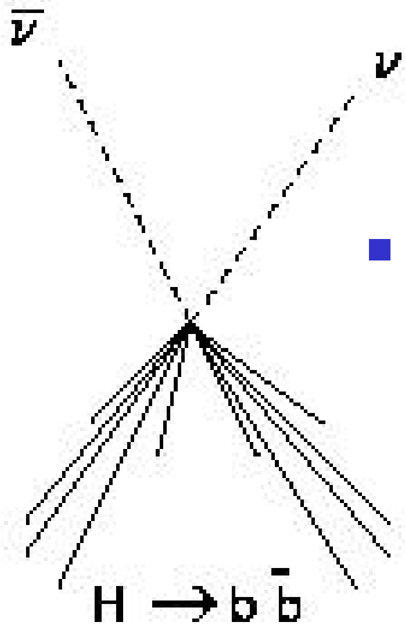




Higgs signatures



- 4jets with at least 2b, ~ 70% of the Higgstrahlung



- 2b and 2ν, ~20% of the Higgstrahlung + the fusion

Not too much room left for the year 2000... But E_{CM}, m_H CRITICAL...

$$\left\langle \sqrt{s} \right\rangle - m_Z - m_H = 1.5\ \mathrm{GeV}$$

$$\sqrt{s}_{max} - m_Z - m_H < 3.8\ \mathrm{GeV}$$

A Higgs accessible to LEP could be between 113 and 116 GeV...

At E_{CM}=206 GeV:

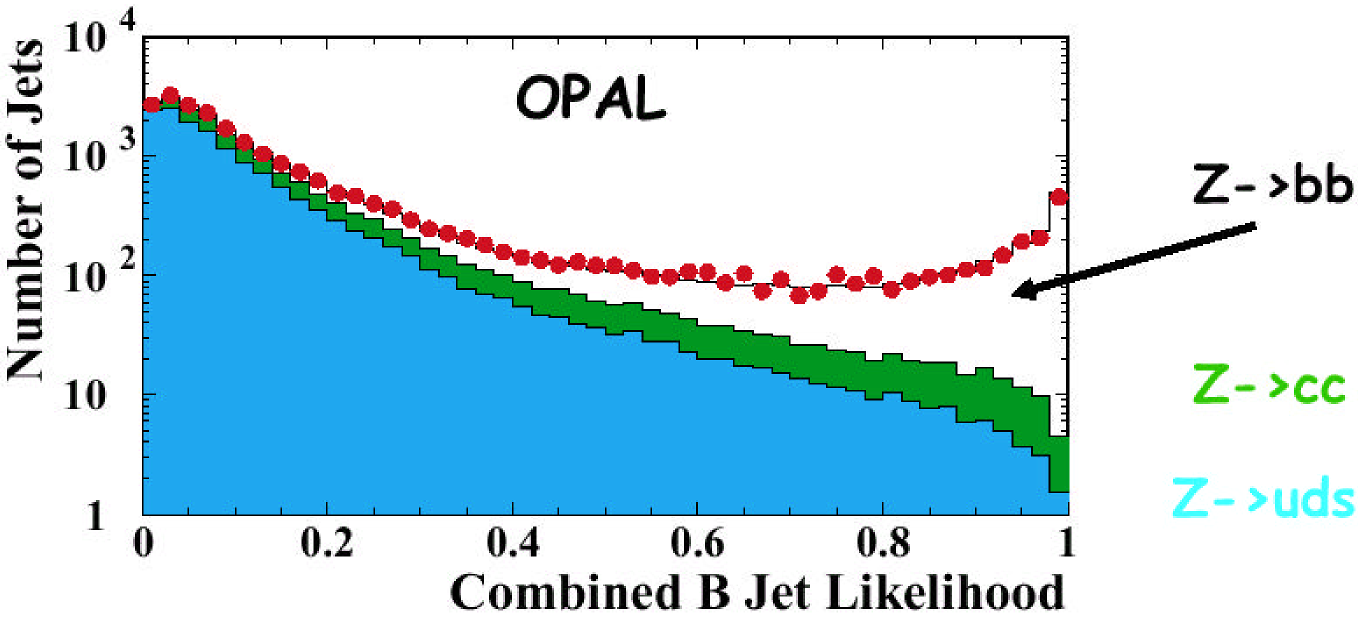
- For M_H=114 GeV, σ_{Hqq} = 0.042 pb, $\sigma_{H\nu\nu}$ = 0.012 pb
- For M_H=115 GeV, σ_{Hqq} = 0.026 pb, $\sigma_{H\nu\nu}$ = 0.008 pb

BUT at E_{CM}=208 GeV:

- For M_H=114 GeV, σ_{Hqq} = 0.072 pb, $\sigma_{H\nu\nu}$ = 0.021 pb
- For M_H=115 GeV, σ_{Hqq} = 0.056 pb, $\sigma_{H\nu\nu}$ = 0.016 pb

Higgs hunting at the kinematical limit: a closer look near the threshold

- If the Higgs is observable, the golden channel is 4jets(2b); second best is 2jets(2b)+missing energy
  - Ratio 7:2 - 5:2, ALL THE REST IS ~ HOPELESS...
- The crucial experimental ingredient is the b tagging (detection of short-lived particles - VD + shape, leptons... => Neural Net...)



The 4-jets channel

- Background from QCD, WW, ZZ
- Problem: 4 jets give 3 mass combinations...

Different solutions:

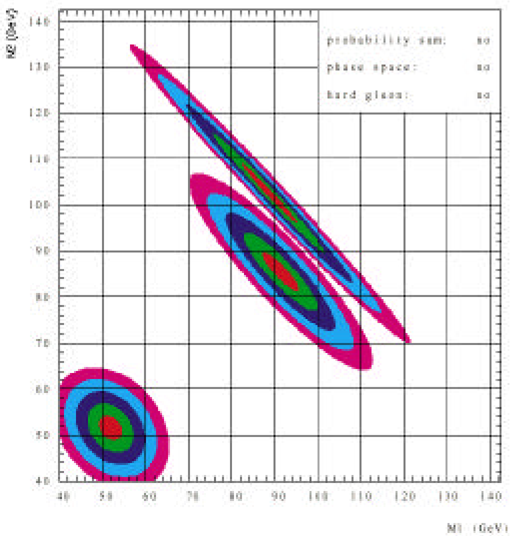
- asking for a Z recoiling (5Cfit)
- asking for jet-b-tagging
- checking the spin of the boson
- the best fit with WW,ZZ or HZ hypo?

L

D,O

A

all



- But in general, mass ambiguities

ALEPH results

- Selections based on sequential cuts & Neural Nets

High Mass Events (>109 GeV)

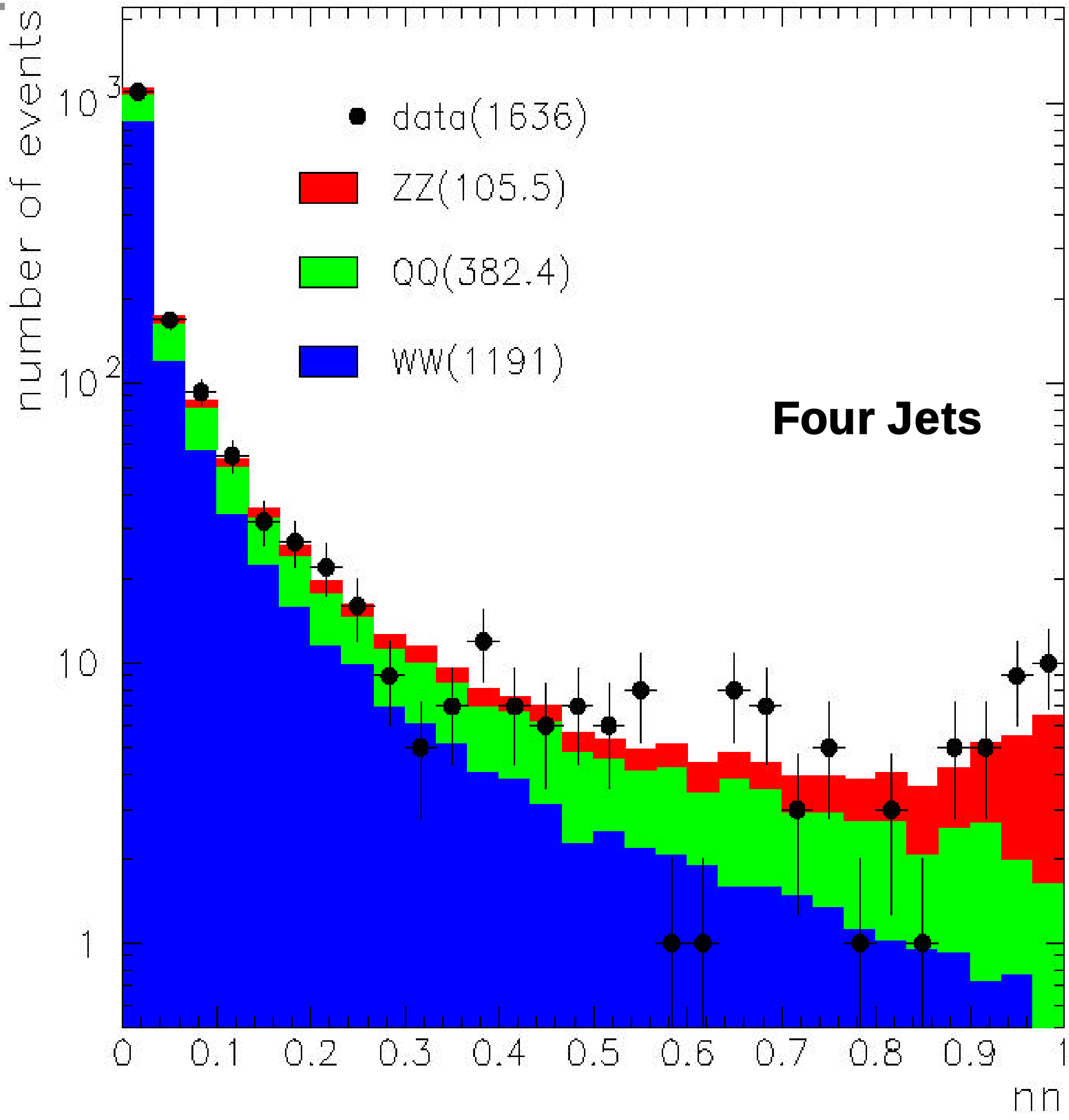
	Data	Bkg	Signal M_H=114GeV
Four Jet	10	5.1	0.9
qq$\nu\nu$	2	2.2	0.2
qqll	4	1.7	0.2
qq$\tau\tau$	2	0.6	0.07

Bkg (>109 GeV): WW ~40%
ZZ ~23%

mass cut:
M_H - 5 GeV

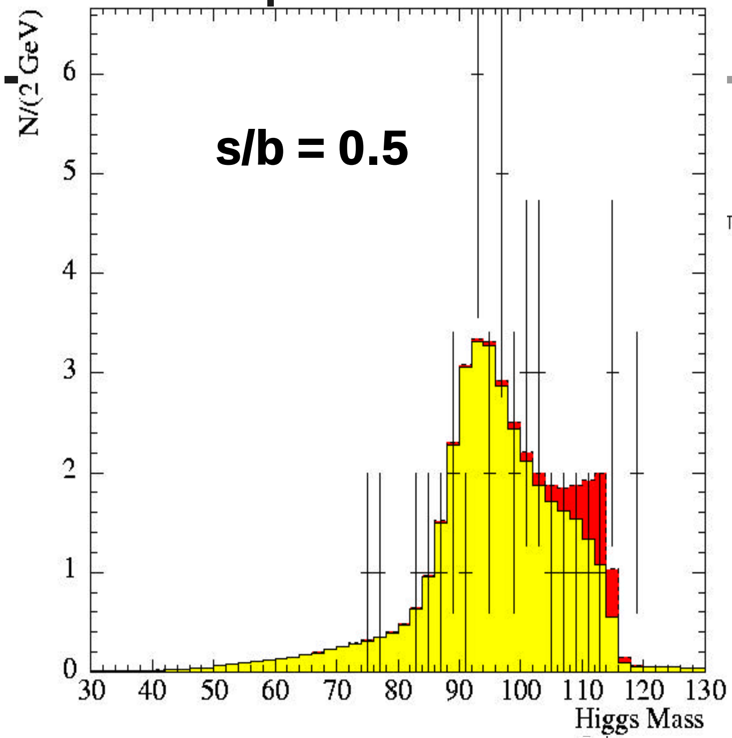
NN output distribution

At very high NN values
ZZ bkg dominates.
e.g.
NN>0.96:
75% ZZ
25% $qq\bar{q}$

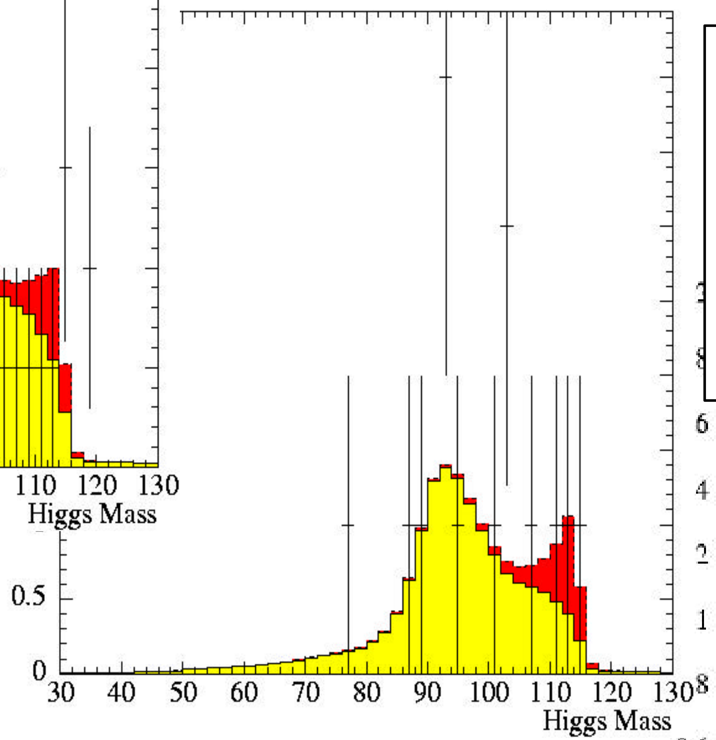


ALEPH high purity selection

s/b = 0.5



s/b = 1.0



s/b = 2.0

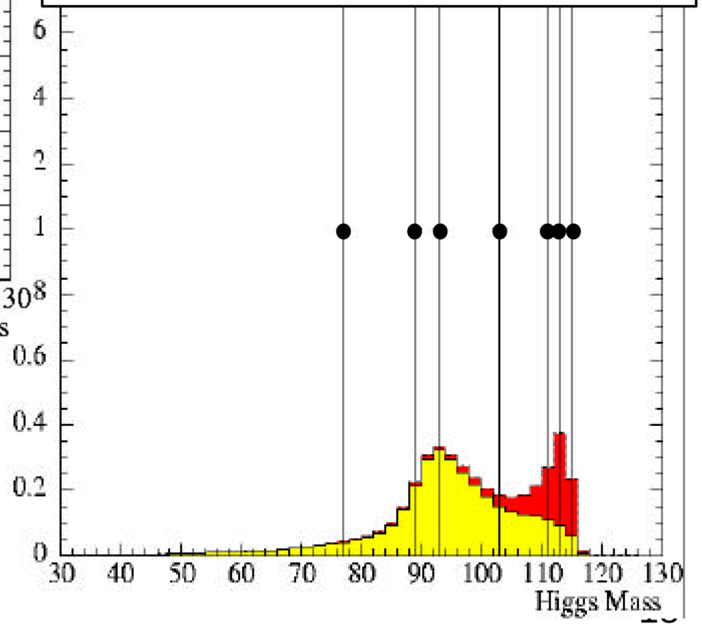
only 4-jet events remain

m>109 GeV:

0.3 bkg 0.6 signal

3 observed

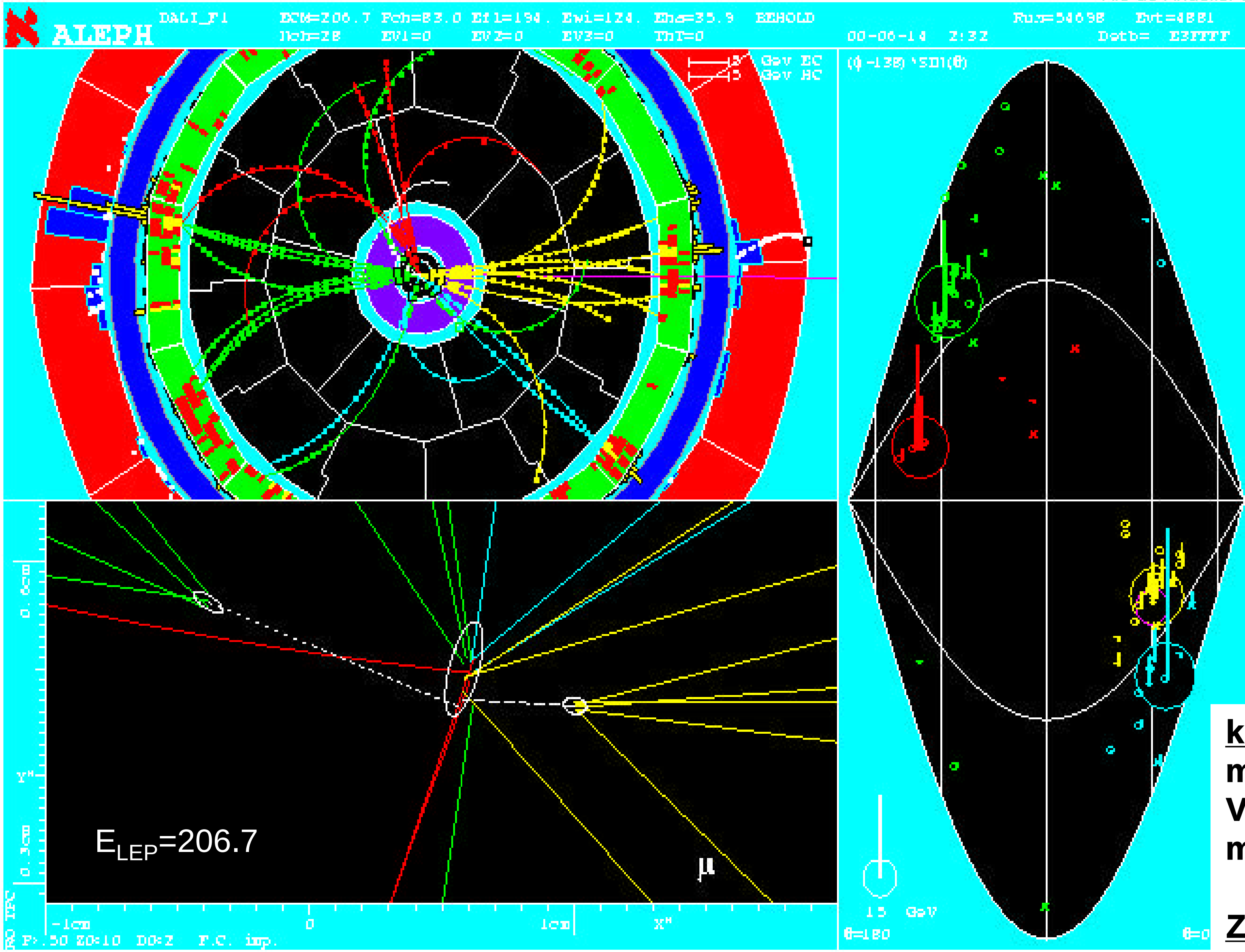
significance= 3.5σ - 3.9σ



bkg

m_H=114 GeV

signal / background ratio at high mass fixed by tuning NN cut on MC



2 b cand.

HZ hyp.
m_H=114 ±3 GeV

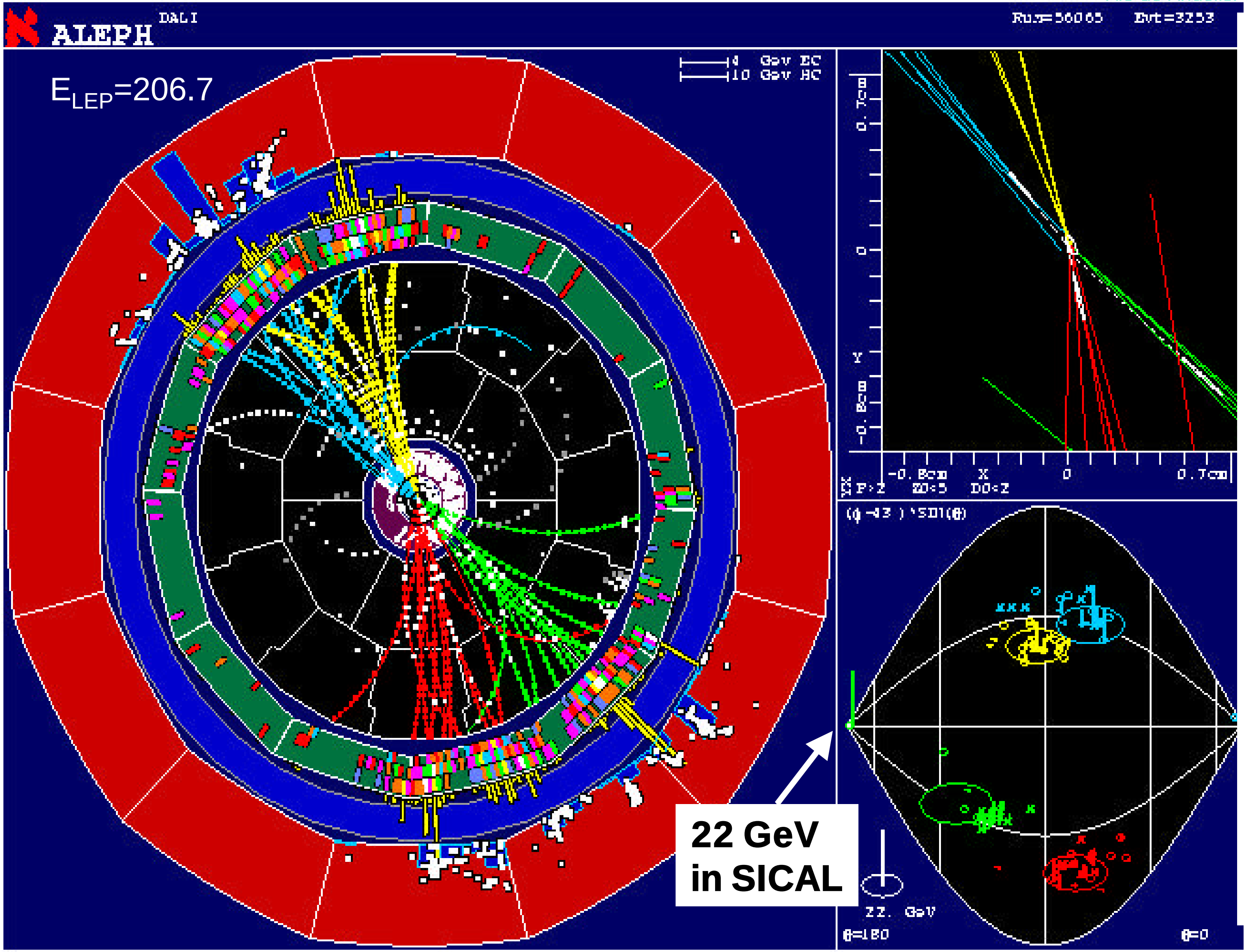
NN = 0.996

jet b-tag:

Z	
1	**0.14**
2	**0.01**
H	
3	**0.99**
4	**0.99**

kin. mass fit
m_H=112.4GeV
m_Z=93.3GeV

ZZ hyp.
m_Z=102 GeV
m_Z=91.7GeV



4 b cand.

HZ hyp.
m_H=
112.8 GeV

NN = 0.997

jet b-tag:

Z
1 0.994
2 0.78

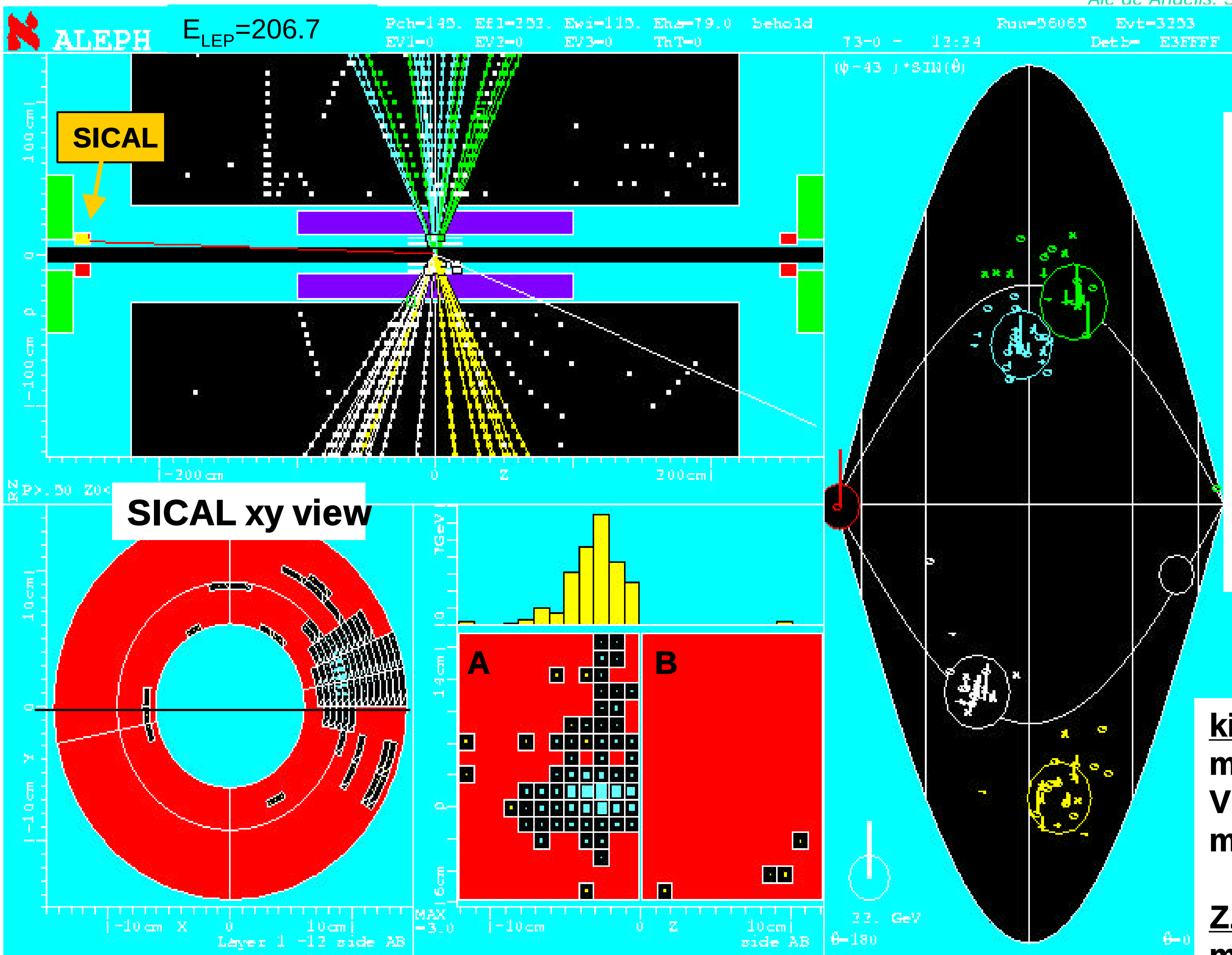
H
3 0.993
4 0.999

Evis=
252 GeV!

very bad
kin. fit!

$\Rightarrow$

assumption: 22 GeV in SICAL is beam related

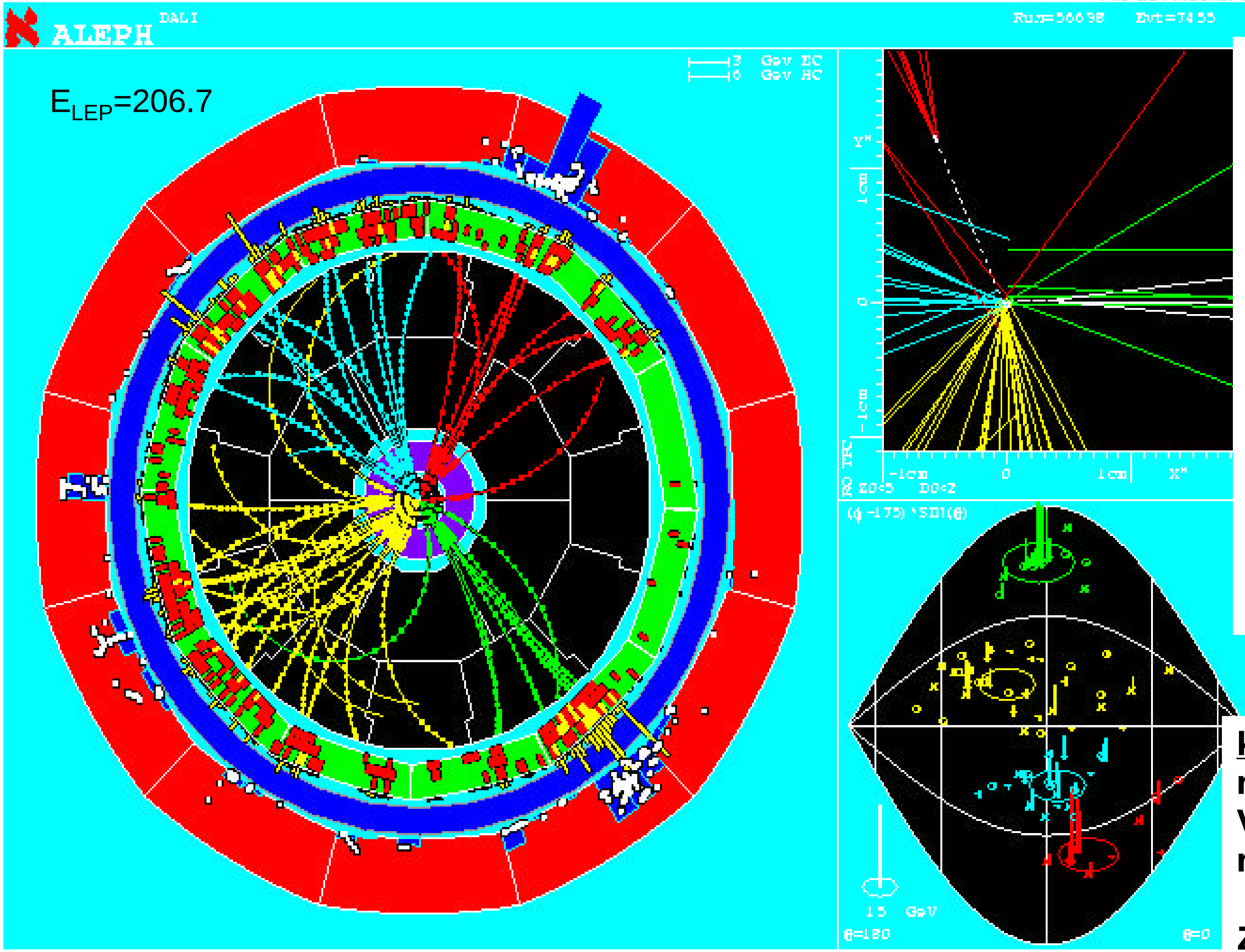


remove extra energy in SICAL

⇒ good fit: m_H=114 ±3 GeV

kin. mass fit
m_H=113.8GeV
m_Z=91.9GeV

ZZ hyp.
m_Z=97 GeV
m_Z=94 GeV



<u>4 b cand.</u>

m_H=110 ±3 GeV

NN = 0.999

<u>jet b-tag:</u>

Z	
1	**0.99**
2	**0.84**
H	
3	**0.99**
4	**0.21**

<u>kin. mass fit</u>
m_H=109.1GeV
m_Z=92.3GeV

<u>ZZ hyp.</u>
m_Z=100 GeV
m_Z= 99 GeV

The three ALEPH 4jet candidates

	evt.: 1	2	3
• very signal like, NN output very high:	0.996,	0.997,	0.999
• very good b-tagging for H cand. jets:	0.990,	0.993,	0.990
(except one jet)	0.990,	0.999,	0.21

• the two evts with m=114GeV have only one jet combination passing all cuts (CUT analysis)

• in second 4b cand., second best jet pairing in NN flips H⇔Z assignment.
$m_{reconst}=m_{12}+m_{34}-91.2$ remains the same!

However, all three candidates also have an acceptable kin. fit (prob = O(1%)) for the ZZ hypothesis.

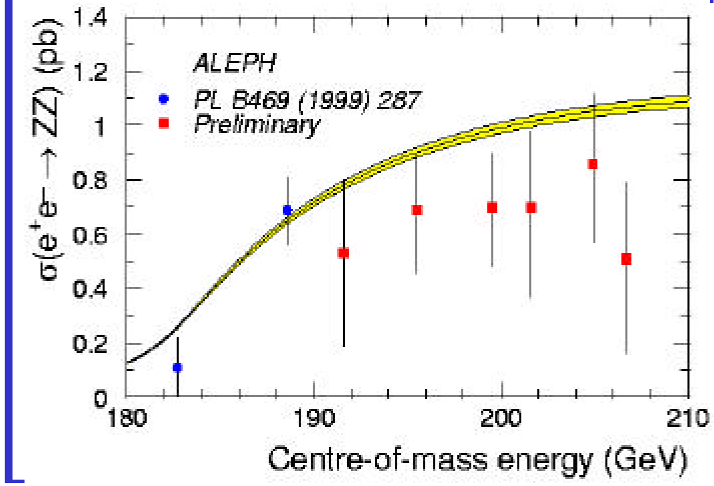
ALEPH: conclusions

- at $s/b \geq 2$ and $m_{rec} > 109$ GeV, ALEPH observes 3 candidates,
  0.3 bkg evts expected (signal ≈ 0.6 evts, m_H =114 GeV)

- 3.5σ - 3.9σ from Standard Model background
  compatible with SM Higgs ~ 114 GeV
  but cross section 1σ - 2.5σ too high

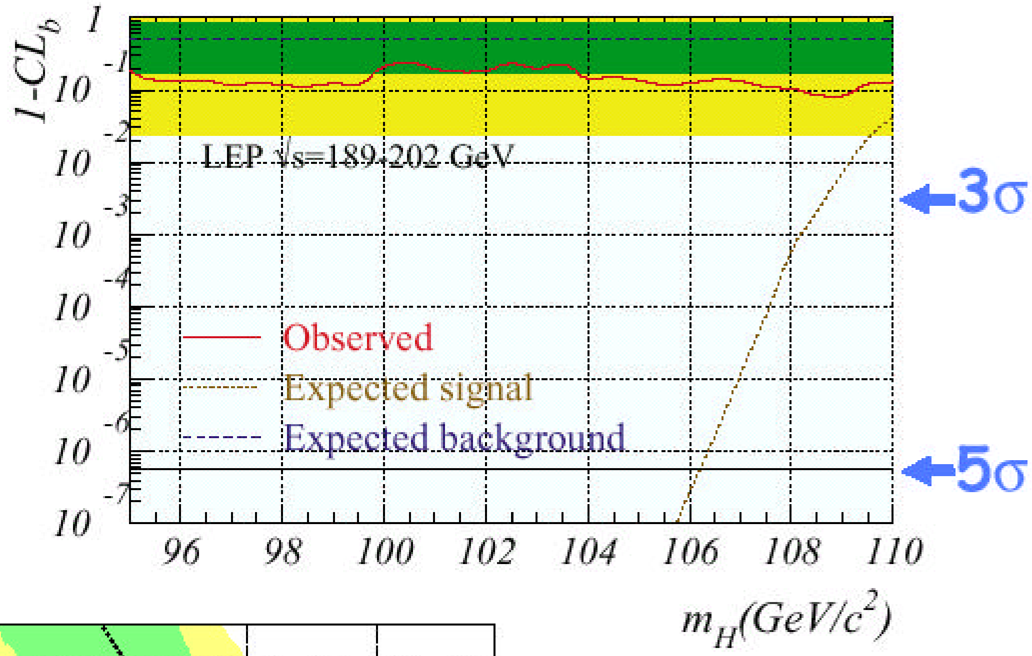
Exciting, but small number of events
and not background free!

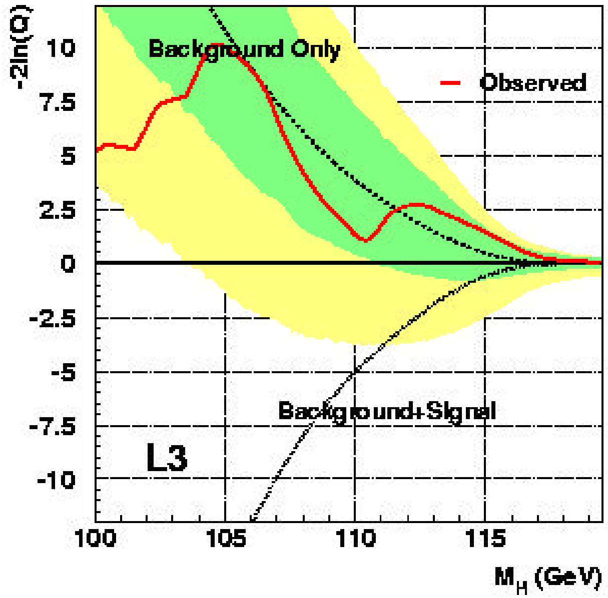
Caveat: σ(ZZ) 2σ low...



Intermezzo: the c_b significance

- Determination of the significance:
  - CL for the background hypothesis, CL_b

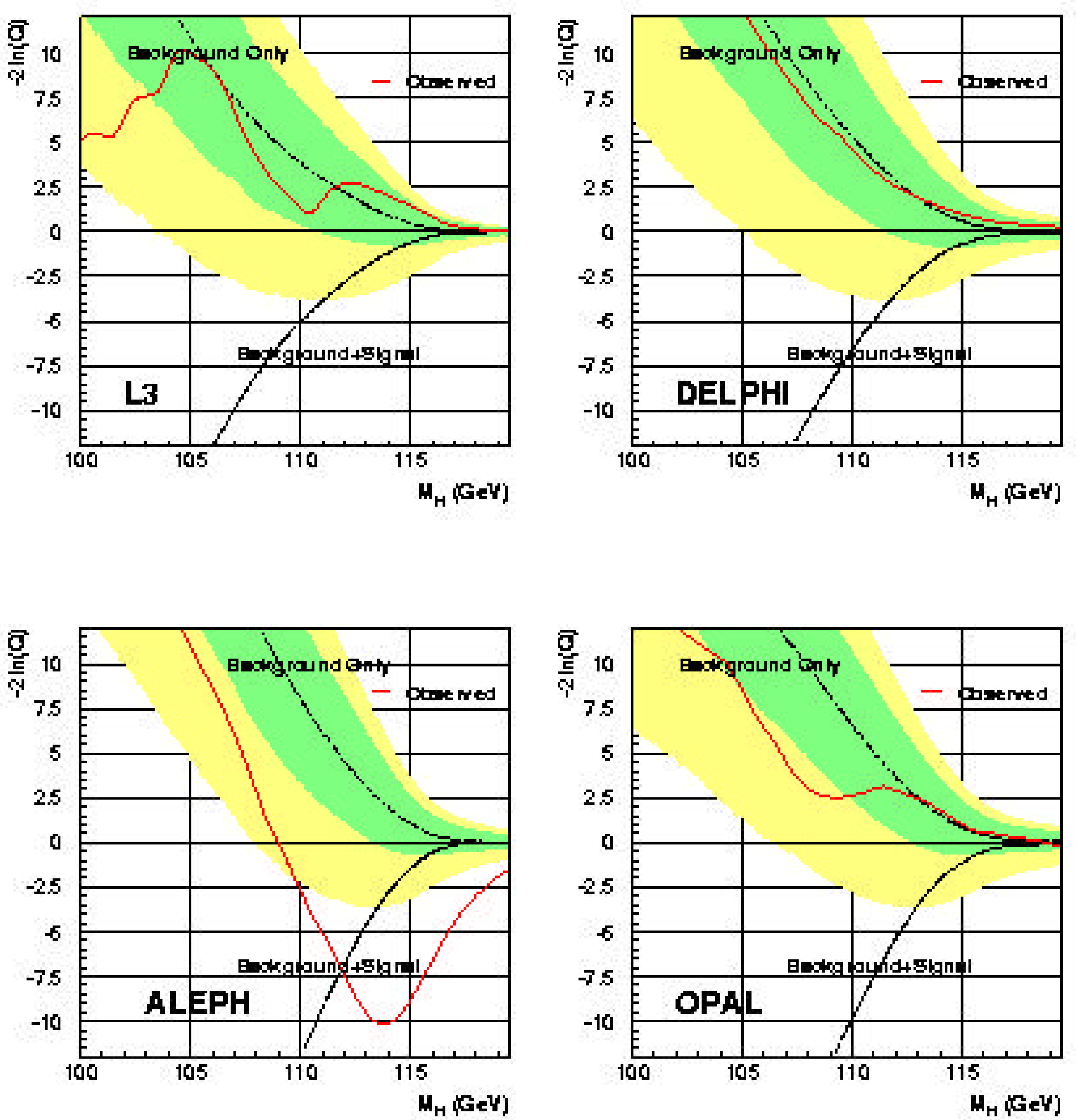




  - $Q = L(s+b)/L(b)$

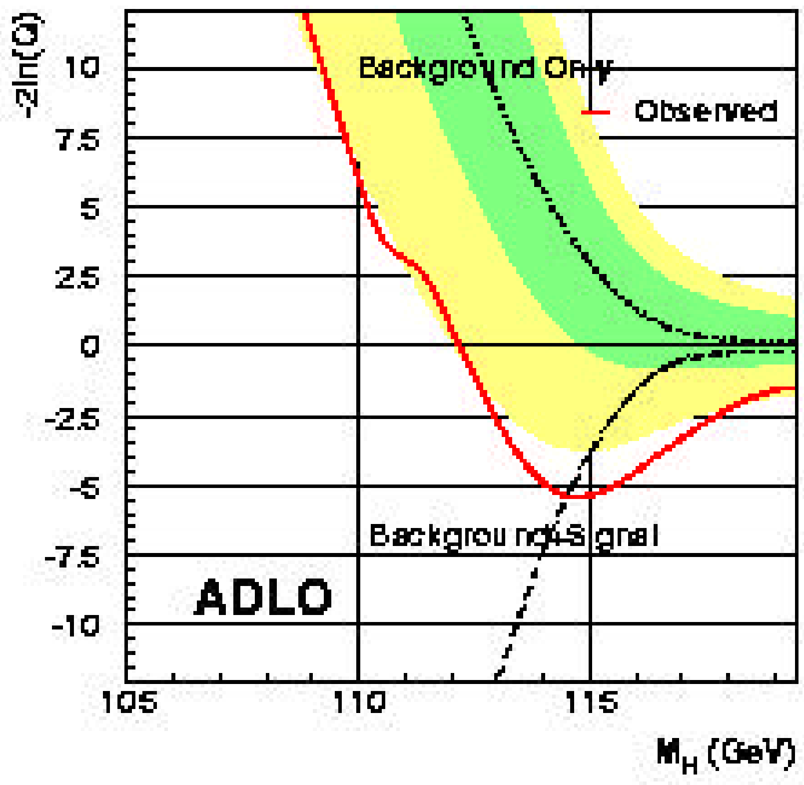
Poisson statistics

ALEPH and the others… as of Sept 5



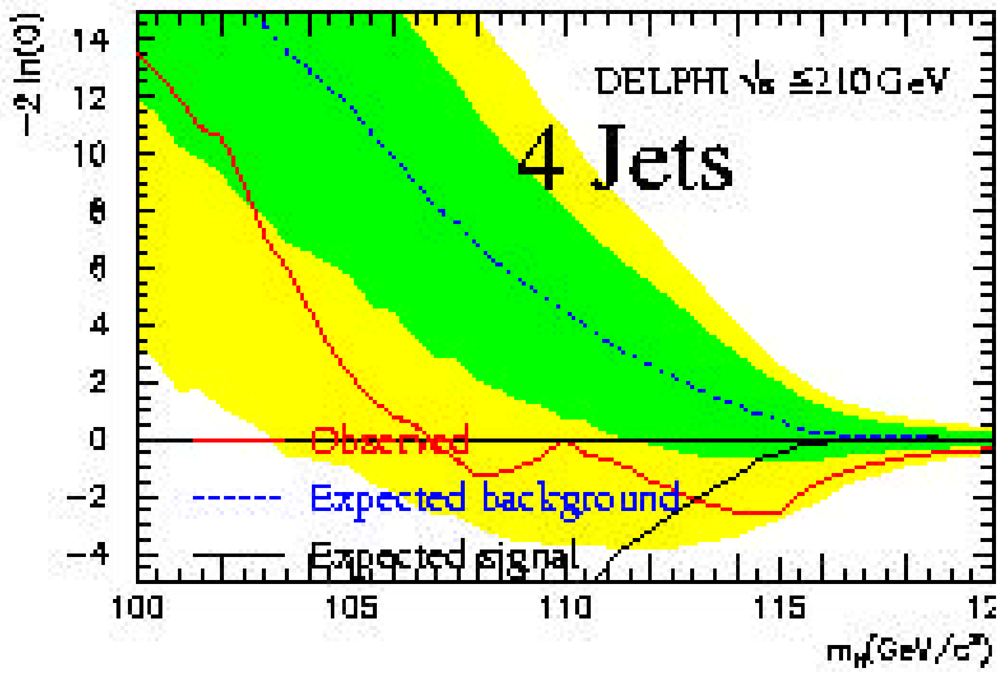
Combined SM result (as of Sept 5)

- Mimimum m_H = 114.9 GeV (2.6 σ), cross section ~OK



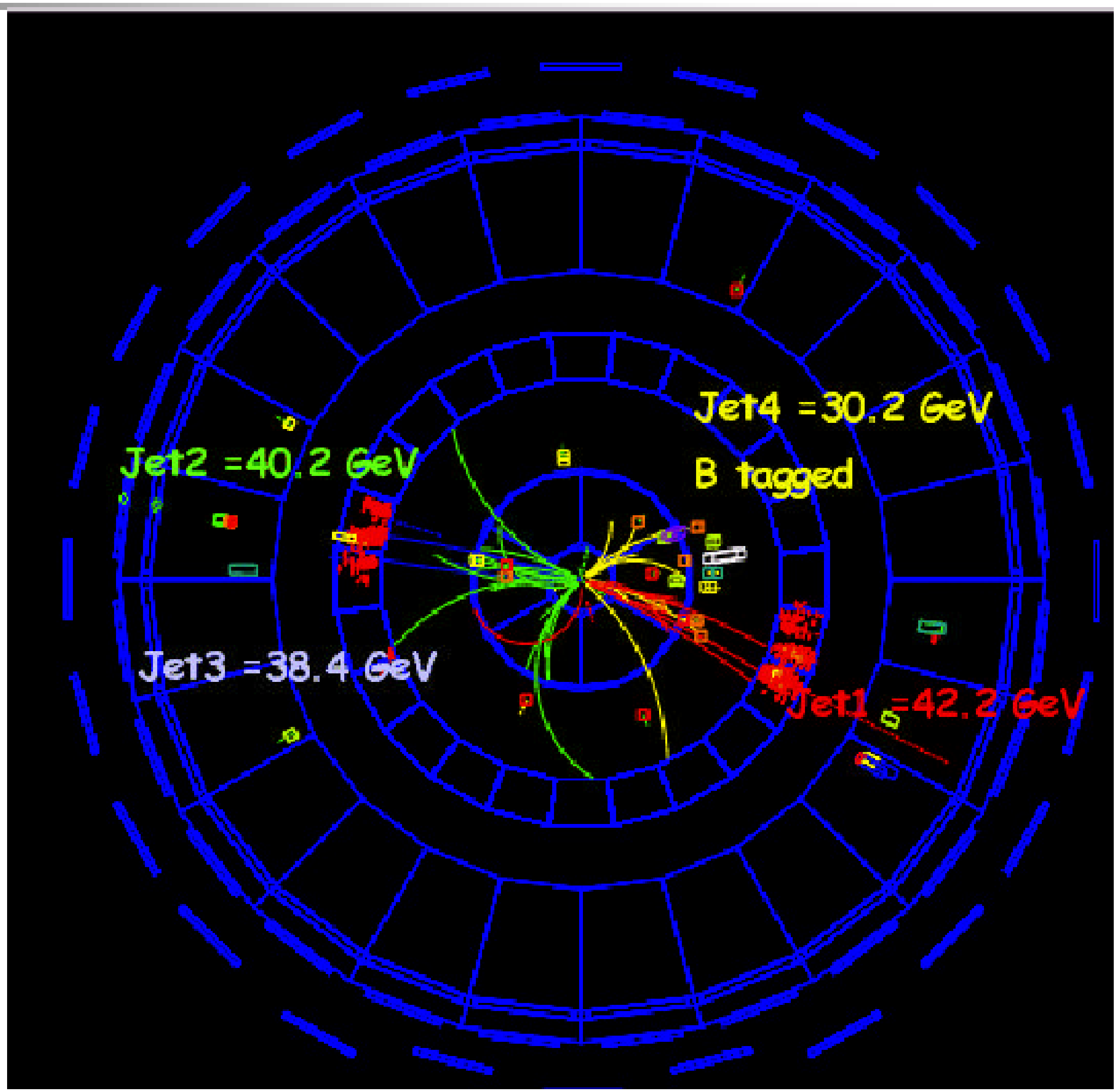
DELPHI: recent reanalysis of the likelihood function

- 4x MC statistics generated in the last days

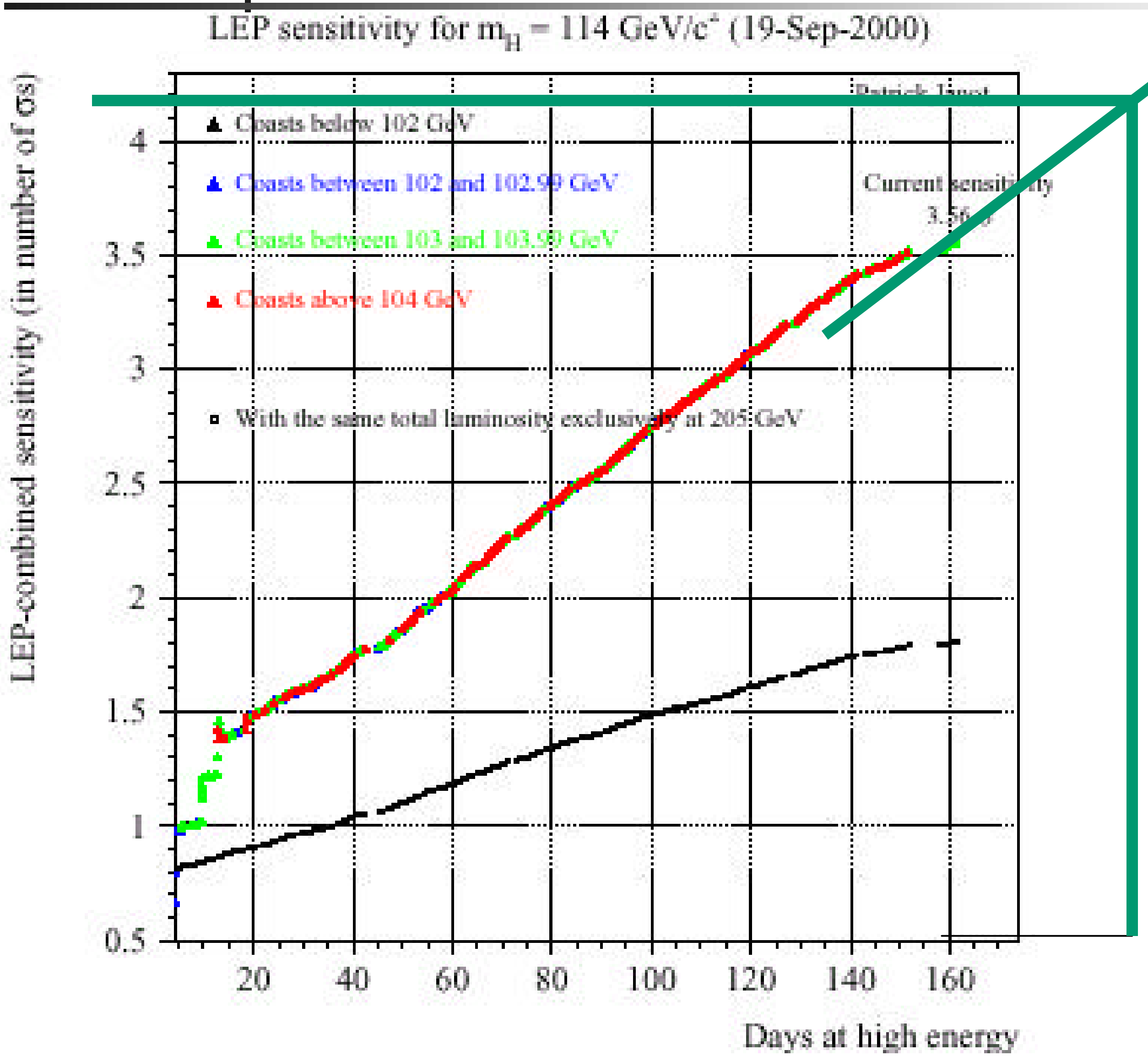


The DELPHI golden candidate

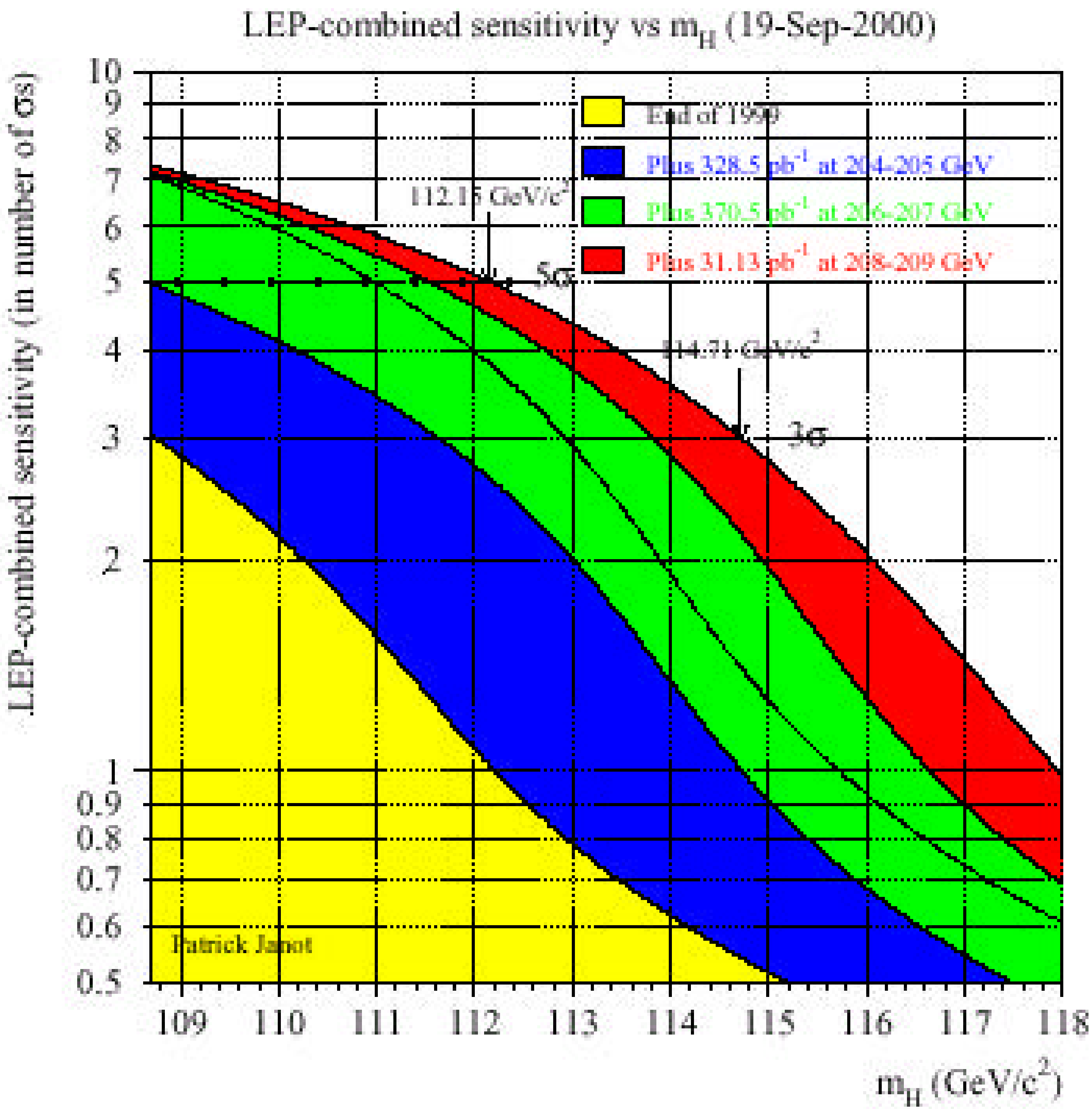
- M_H = 114.3 GeV (HZ hypothesis), kinematically compatible with WW (but b-tag)



What do we expect ?

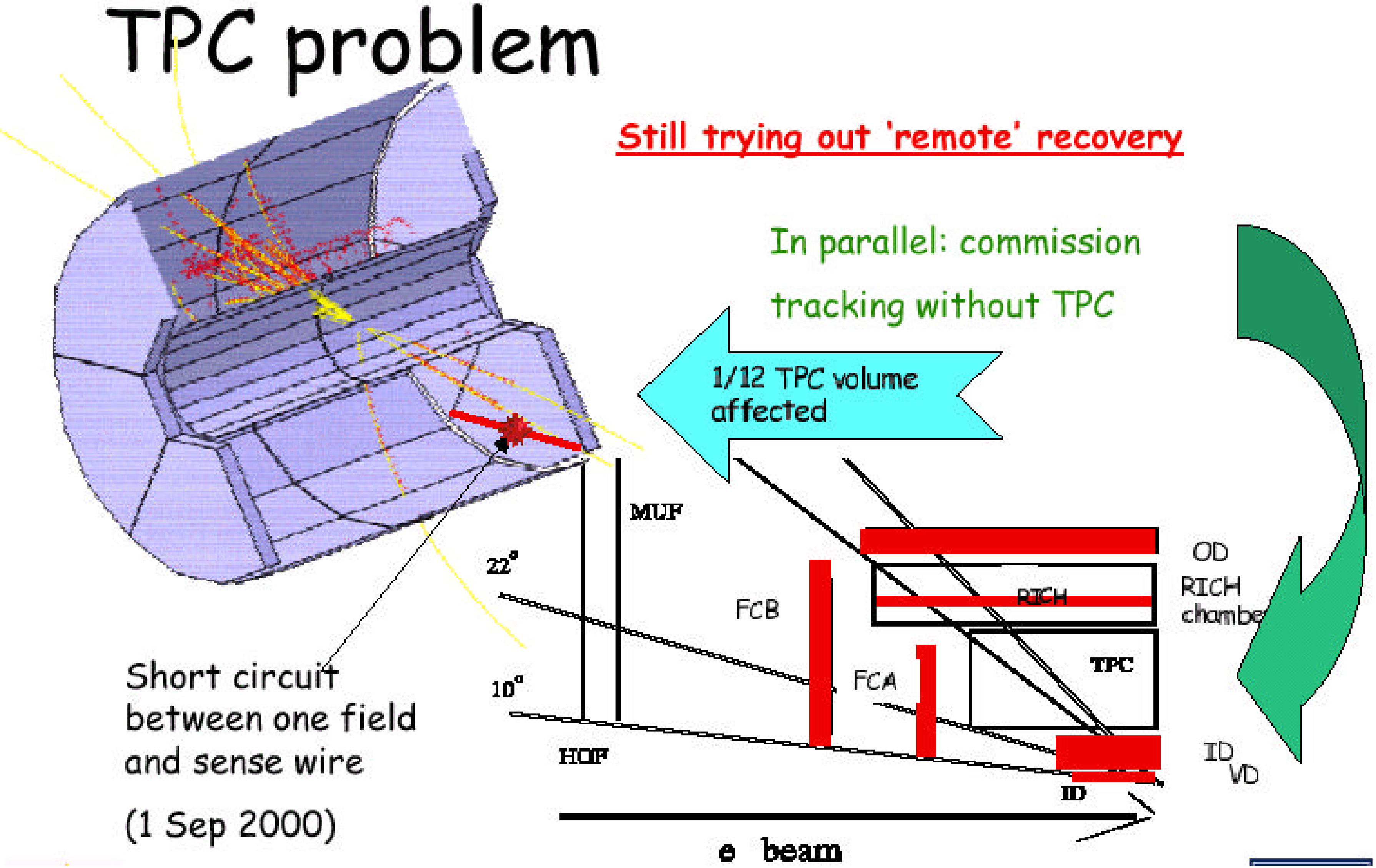


- If the machine works according to its trend (which is optimistic), a sensitivity ~ 4σ for m_H = 114 GeV
- Not yet what could be considered as a discovery, but an evidence…

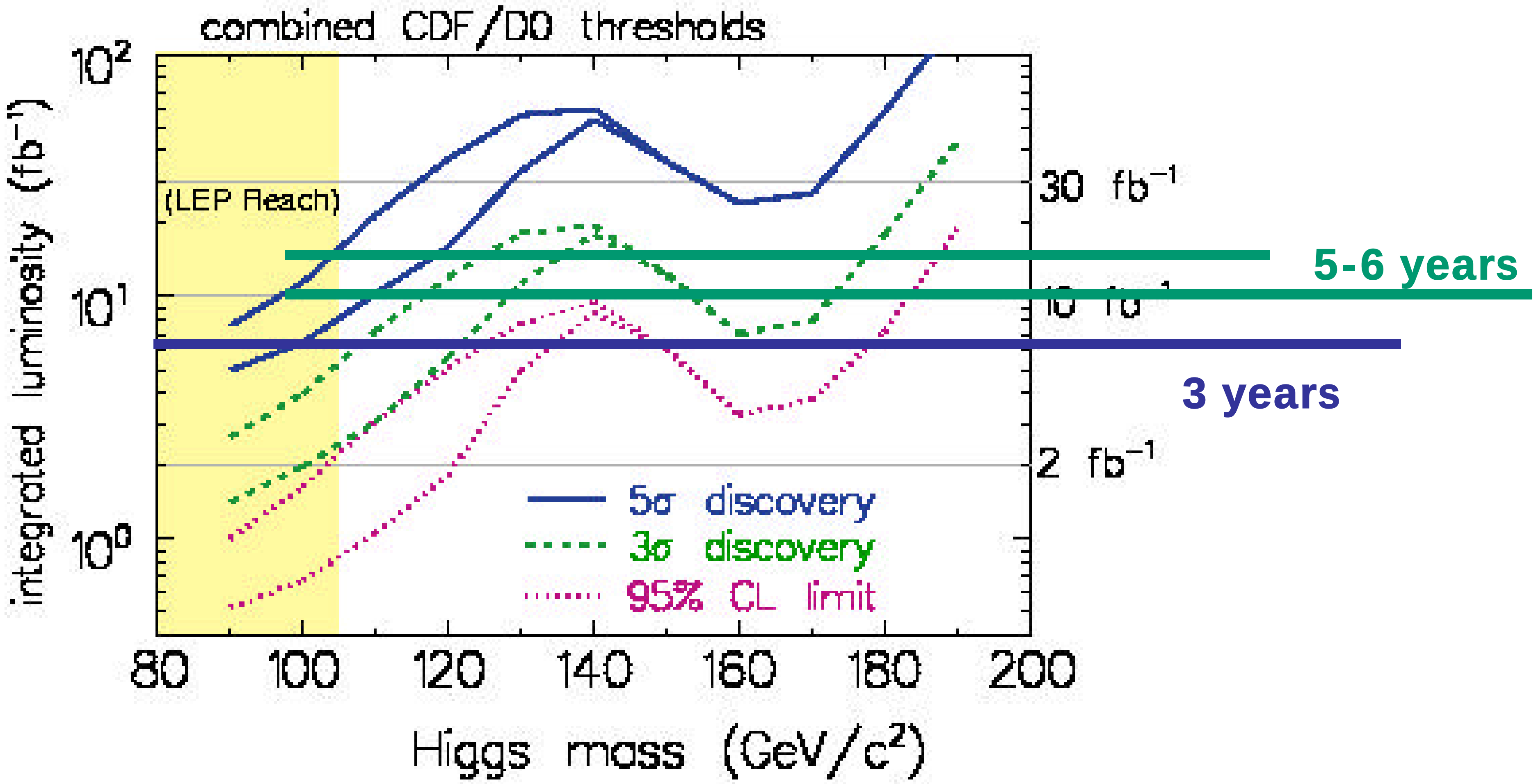


- Careful ! Sensitivity drops quickly with m_H…
- Careful ! Detector & LEP conditions…

Status of DELPHI

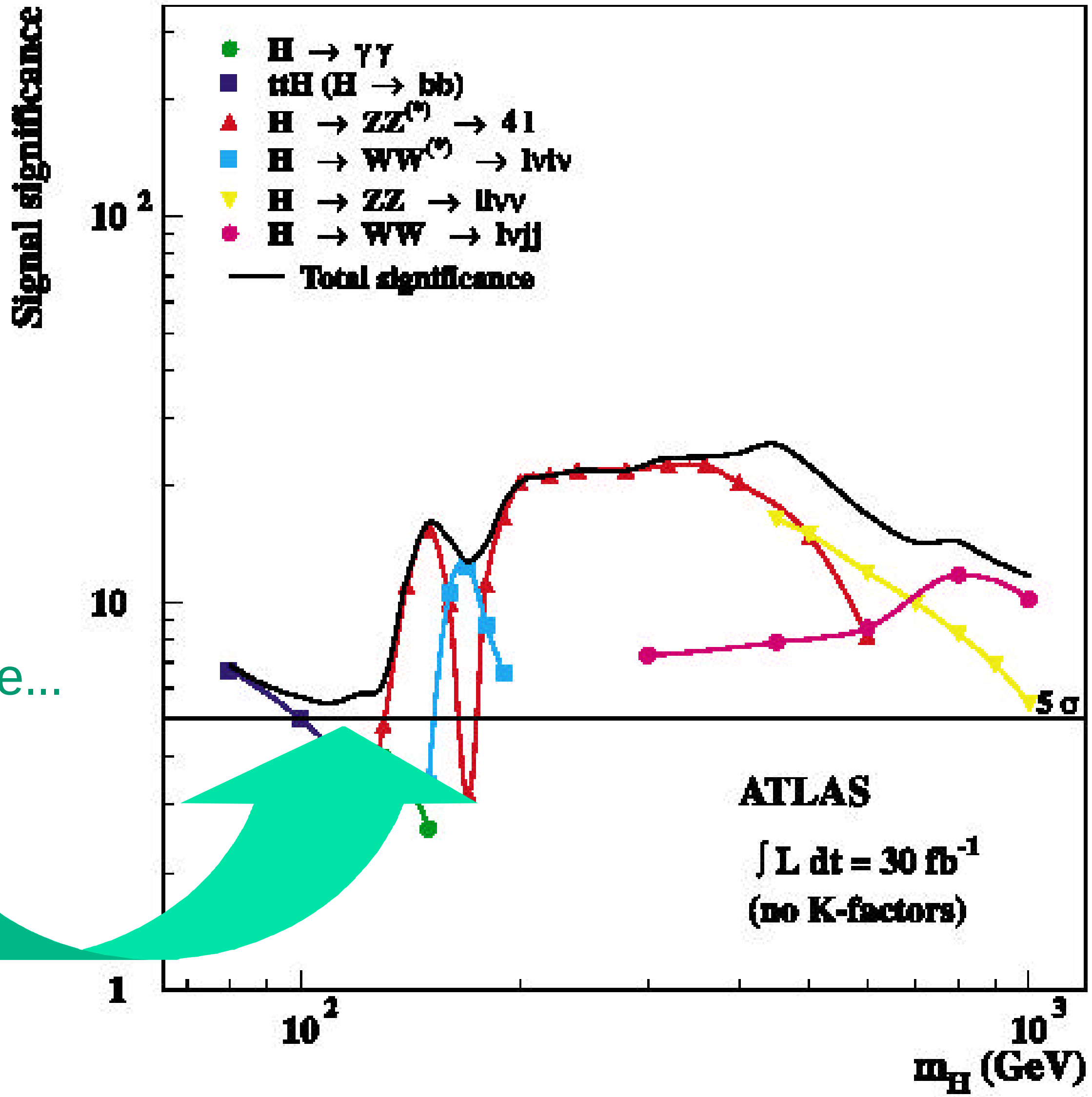


Just a reminder:
FNAL RunII discovery potential



Just another reminder:
ATLAS discovery potential - First 3 years

Most critical place...



Summary

- A SM Higgs ($m_H \sim$ 115GeV) could have been observed at LEP
  - But we are in a corner of the phase space

    (a pity not to have ~100 more cavities: m_H -> +~15 GeV)

  SM background interpretation possible as well

- Wait for more data to clarify (LEP will run till Nov 2); in the best hypothesis, an evidence rather than a discovery
  - A real discovery most likely at the LHC, but

    if the low mass indication from LEP is to be taken seriously, whatch out FNAL