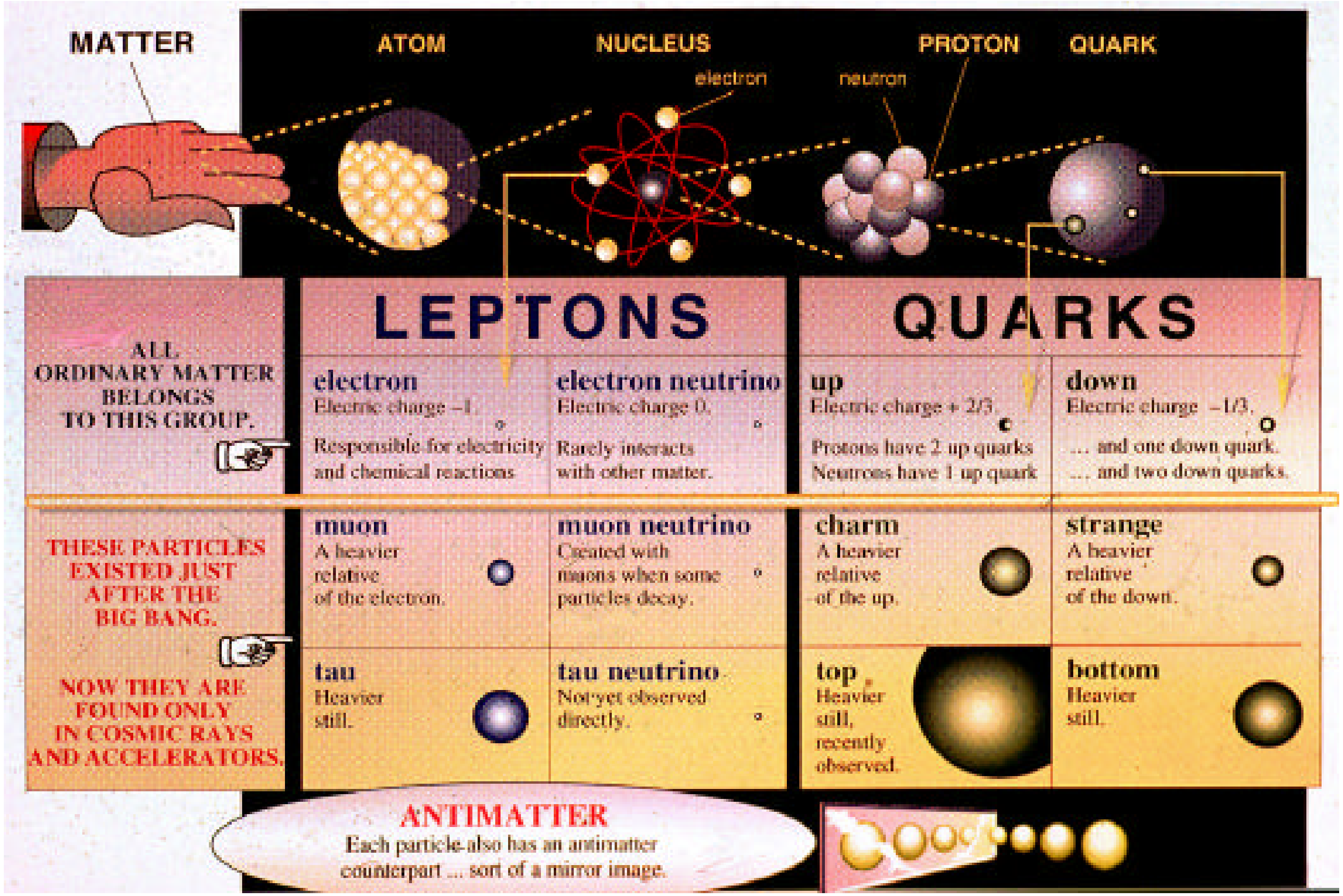
Why all this excitement about the Higgs boson ?

Why the Higgs boson ?

How do we look for it ?

A look at the material world



A theoretical inconsistency

- In the 70's the theory of fundamental interactions was inconsistent with the observation that particles had masses ! … worse… introducing mass terms in the equation would spoil the theory
- What is mass? In our everyday life it is associated to the inertia of an object… the way we look at it in our experiments is more related to the relation

  E=mc2

  that is the inertia of an object is equal to its energy content when the object is at rest

The Higgs mechanism

- One known way to introduce masses in the theory is to assume that all particles move in a space 'filled' by *something* that *gives* them inertia. In slightly more rigorous terms we call this a *field* which *interacts* with the particles providing them mass.
- This field has to be a scalar and not a vector (else mass would be different depending from the direction we look at the particle!)
- The field has to be a constant: if it varied from point to point then masses would be different if we move from one point to the next

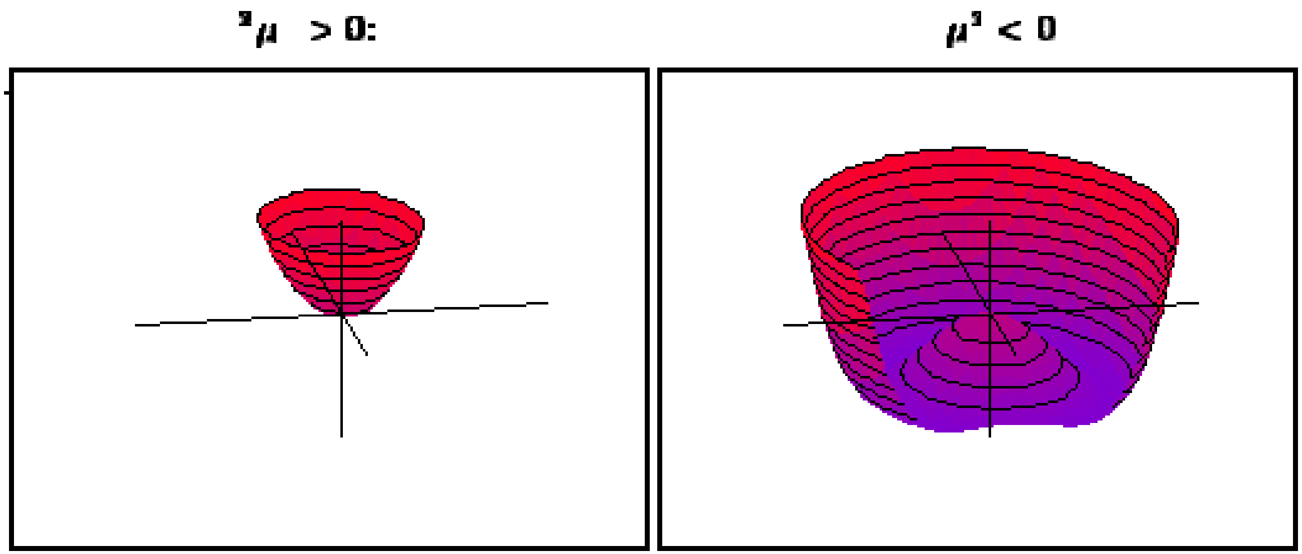
The PROBLEM: the only 'obvious solution' is a 'dumb' field equal to 0 everywhere

The Higgs solution

(borrowed from superconductivity)

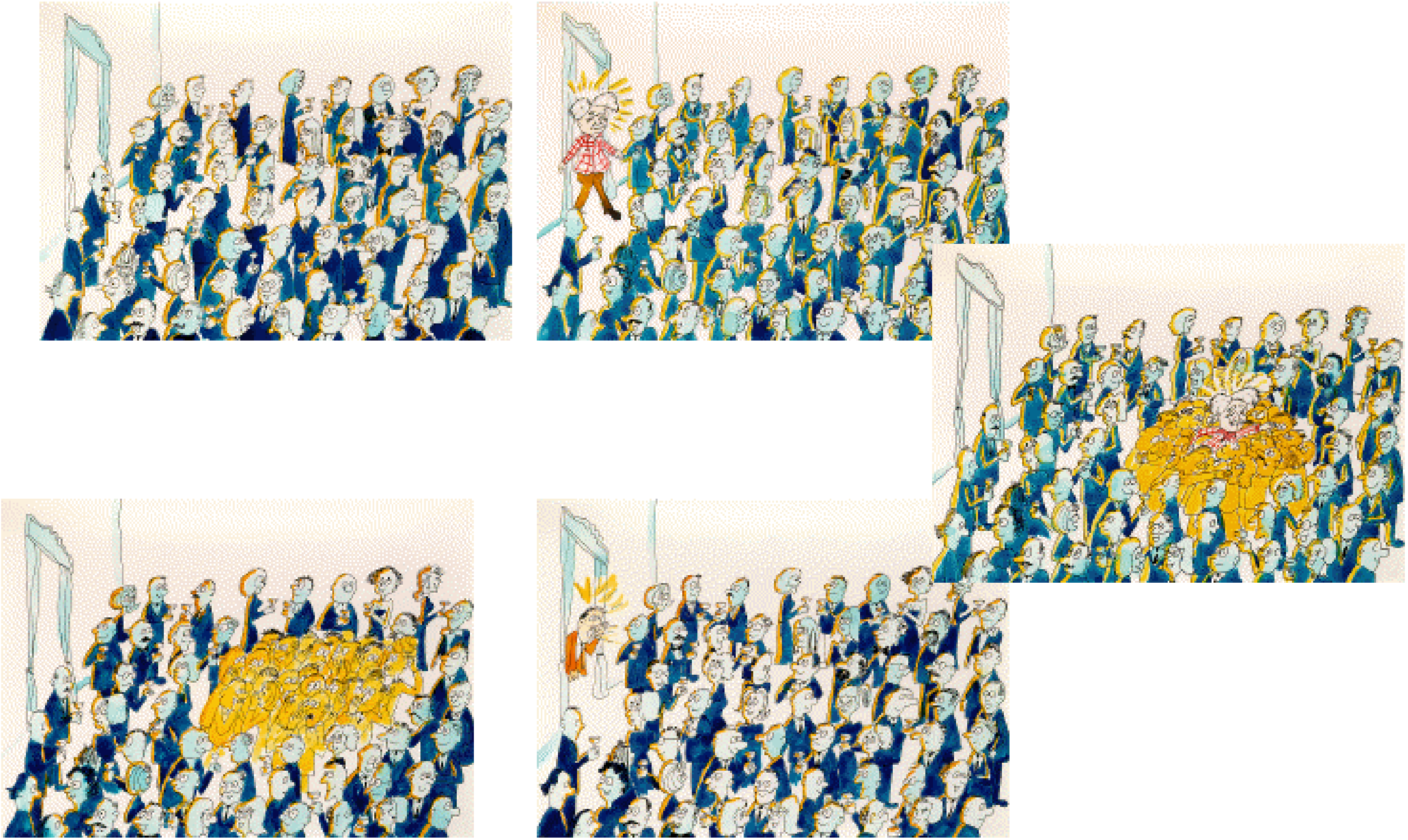
This space is 'special' (isospin):for example a 'rotation' is equivalent to transform an electron into a neutrino. The 'rotation' operator in this example would be a W particle

$$V(\Phi) = \mu^2\Phi^\dagger\Phi + \lambda(\Phi^\dagger\Phi)^2$$



The operator which fixes the direction of the minimum without spoiling the symmetry of the theory is related to the Higgs particle

An Higgs metaphor



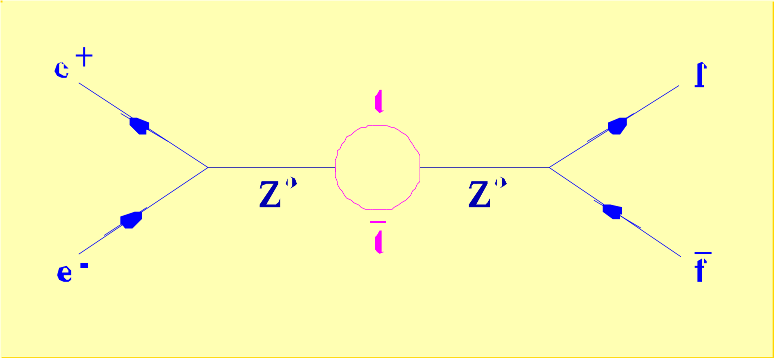
Is the Higgs mechanism true ?

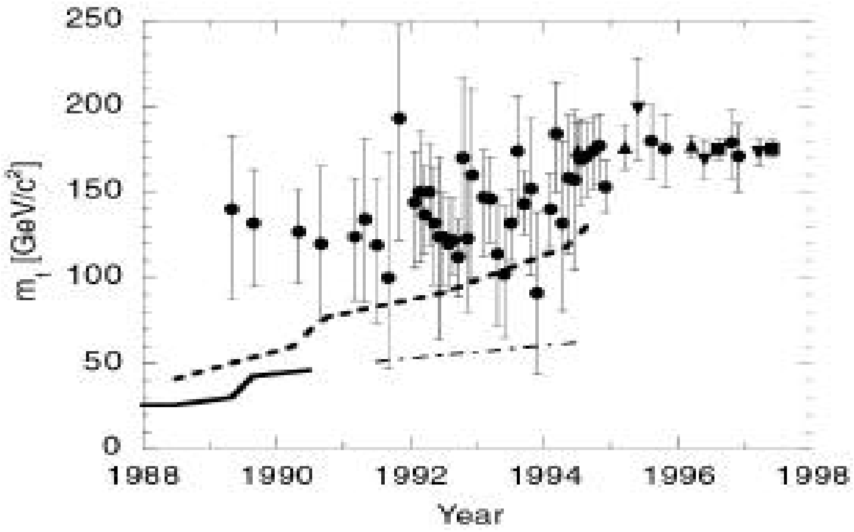
- Predictions:
  - Particles have mass (… uhhmmmm)
  - There shall be a new particle which for lack of imagination will be called Higgs particle
- How to check ?
  - Indirect effects of Higgs particle
  - Discover it ⇨ LEP, LHC

Indirect effects of Higgs

- Higgs particles couples to ordinary particles proportionally to their masses and proportionally to the log of its mass. It affects detailed calculations about the behaviour of particles in any of the reaction we study at LEP. *The unknown value of the mass can be constrained from the comparison of the calculation*

Do we believe that ?

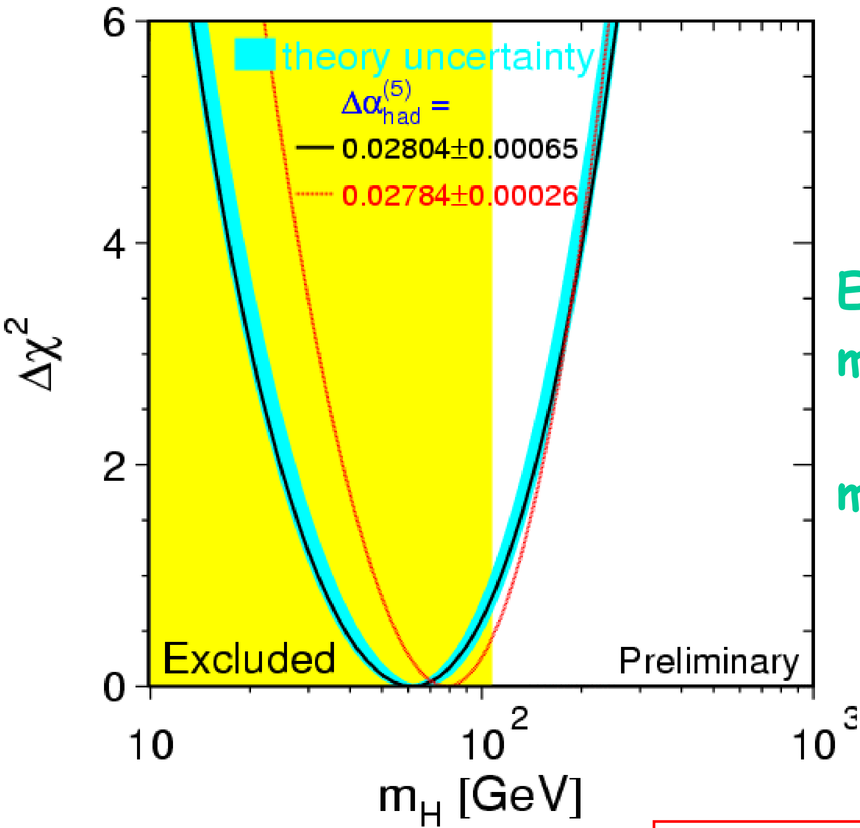




Indirect evidence

Osaka 2000

	Measurement
m_Z [GeV]	91.1875 ± 0.0021
Γ_Z [GeV]	2.4952 ± 0.0023
σ^0_{hadr} [nb]	41.540 ± 0.037
R_l	20.767 ± 0.025
$A^{0,l}_{fb}$	0.01714 ± 0.00095
A_e	0.1498 ± 0.0048
A_τ	0.1439 ± 0.0042
R_b	0.21649 ± 0.00072
R_c	0.1683 ± 0.0038
$A^{0,b}_{fb}$	0.0989 ± 0.0020
$A^{0,c}_{fb}$	0.0689 ± 0.0035
A_b	0.922 ± 0.023
A_c	0.632 ± 0.026
$\sin^2\theta^{lept}_{eff}$	0.2321 ± 0.0010
m_W [GeV]	80.427 ± 0.046
$\sin^2\theta^{lept}_{eff}$	0.23098 ± 0.00026
$\sin^2\theta_W$	0.2255 ± 0.0021
m_W [GeV]	80.448 ± 0.062
m_t [GeV]	174.3 ± 5.1
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02804 ± 0.00065



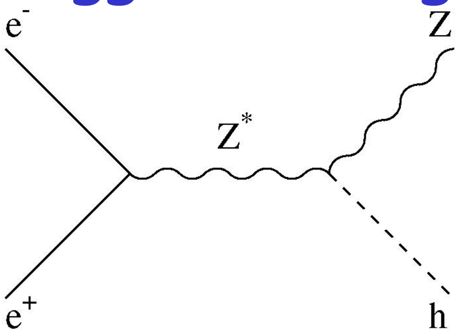
EW precision measurements

$m(H)=62^{+53}_{-30}$ GeV/c^2

$m(H) \leq 170$ GeV/c^2 at 95% CL

Higgs production at LEP

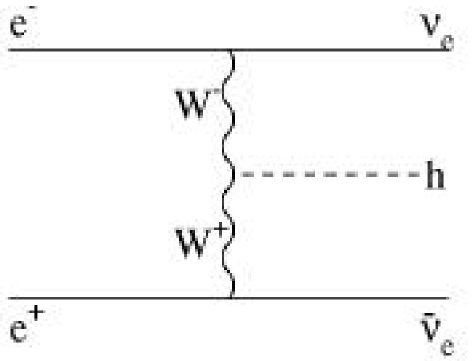
Higgsstrahlung



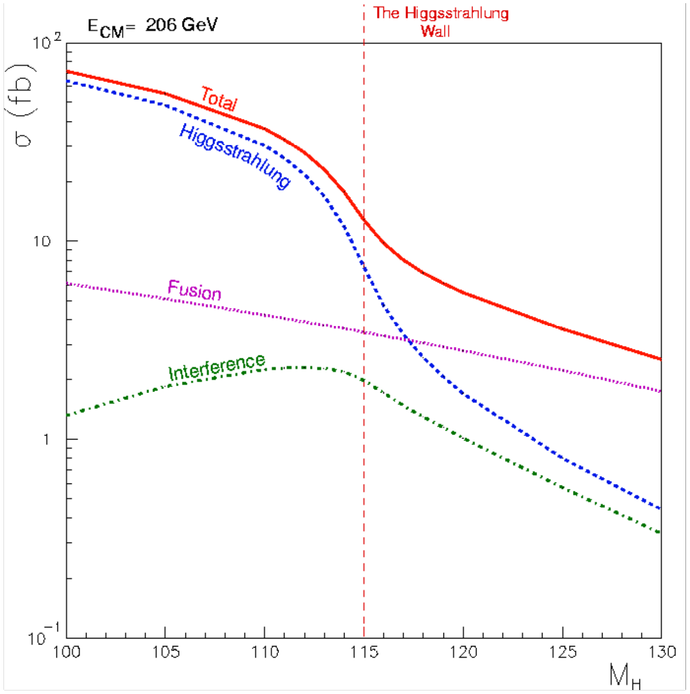
Dominant mode

$m(H) \leq 2E_{beam} - m(Z)$

WW fusion

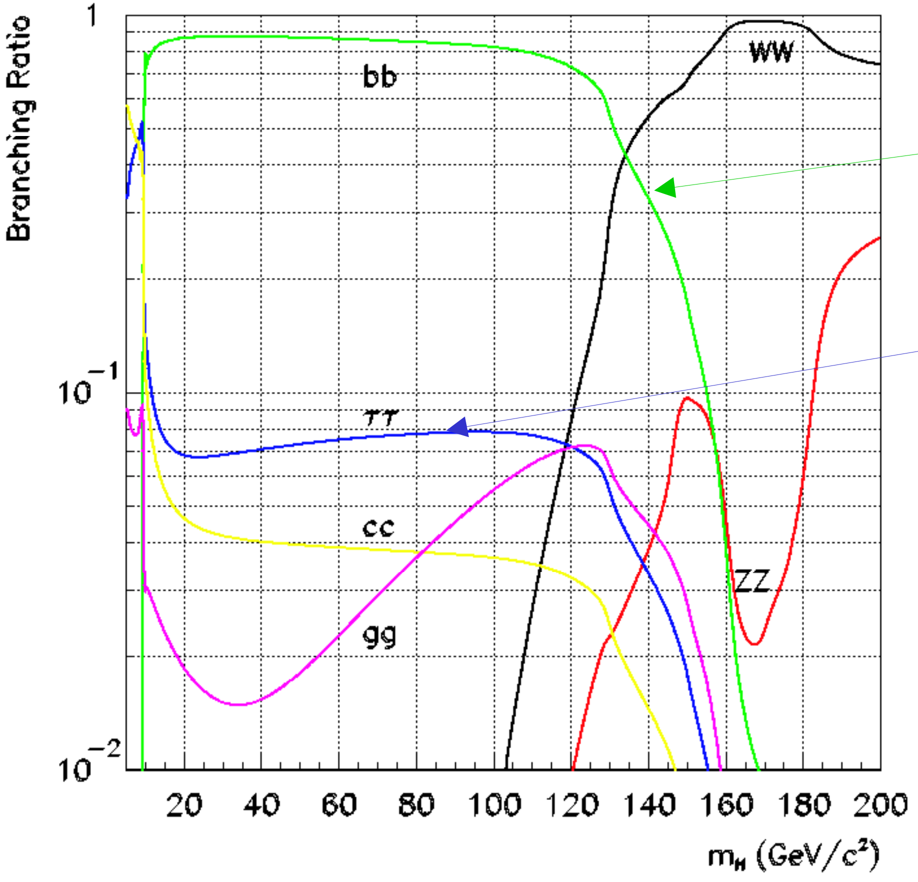


possibility to go beyond !



E_{cm}(GeV)	91	130	136	161	172	183	189	192	196	200	202	204-209
Lum(pb^{-1}) per exp.	175	2.5	2.5	11	11	55	160	30	80	80	40	~150

How is the Higgs boson seen?



Most of the time (85%)

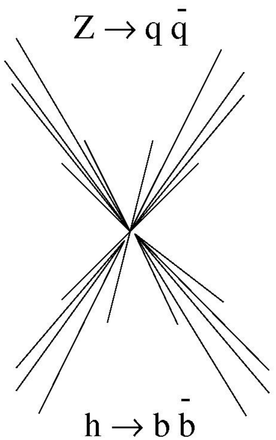
b, anti-b quark pairs

Some time $\tau^+\tau^-$ pairs (8%)

For the masses we look for also WW and gluon gluon are possible

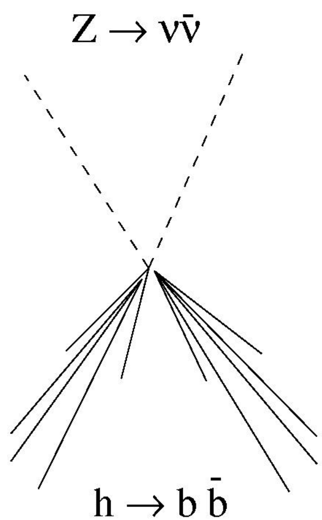
What do we see in our detectors?

4 jets



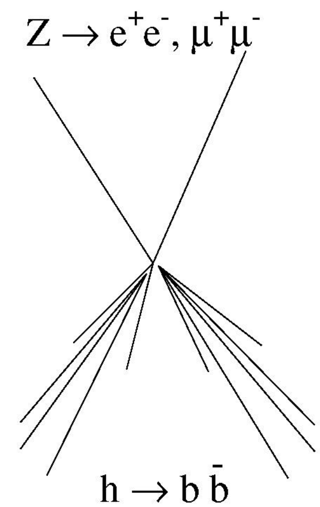
60%

2 jets & missing energy



19%

2 jet & 2 lepton



6%

The Z and the H disintegrate

in less than 10^{-24} s

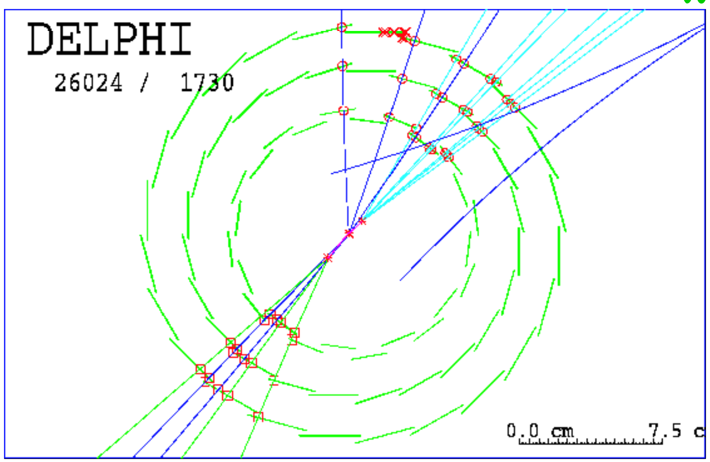
Or a τ instead of the b

Experimental tools: b tagging

b quark mass m(b) ≈ 4.5 GeV/c^2

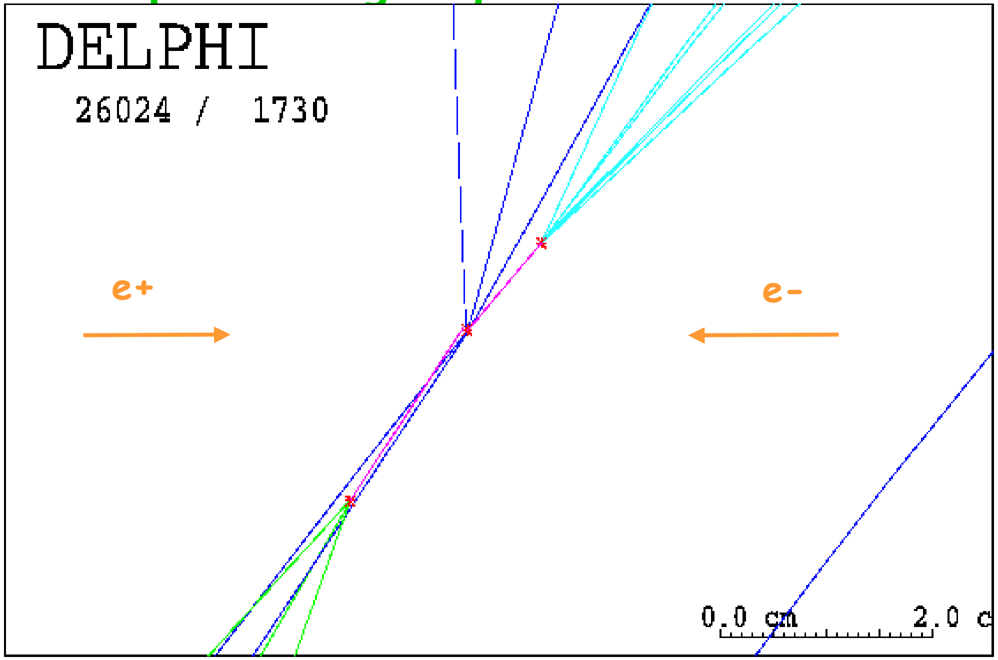
b quark life-time τ(b)= 1.564±0.014 ps

The B hadrons produced at LEP will fly for few millimeters and the decay products will have large p_T and large Impact Parameters with respect to light quark hadrons

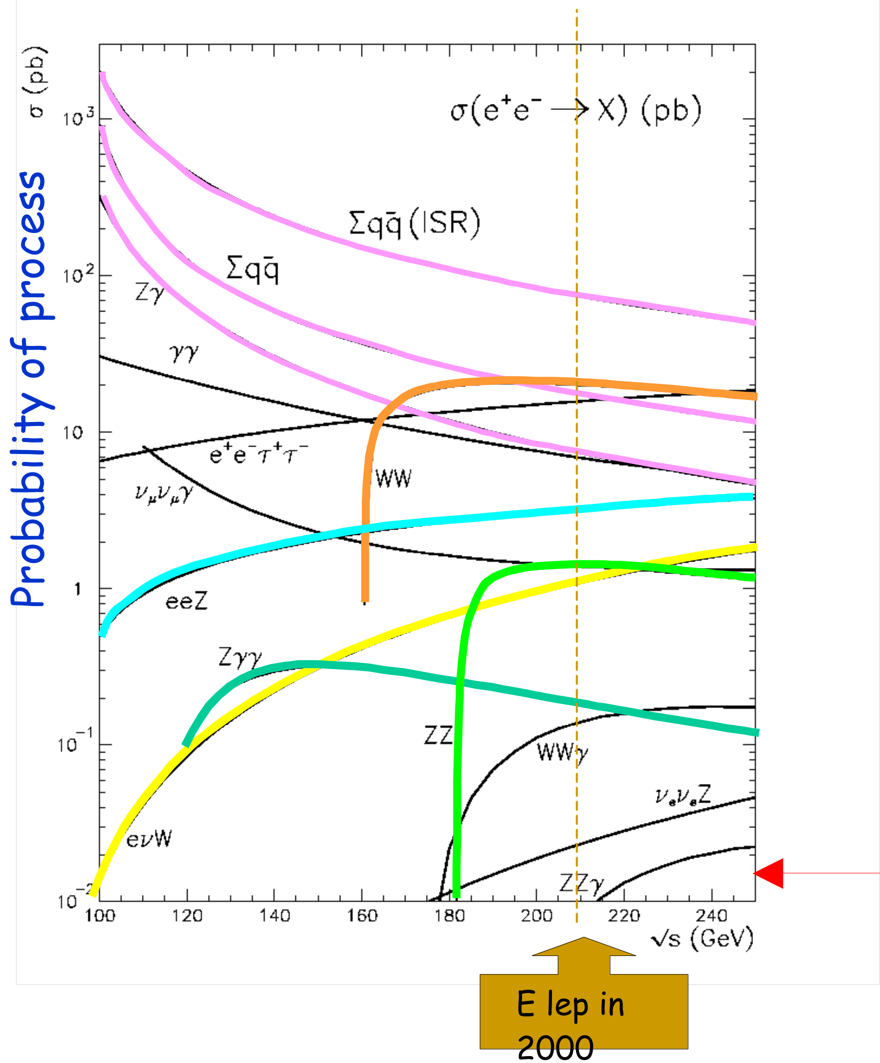


Silicon Microvertex detectors !

ee -> Z -> bb



What else are we detecting ?

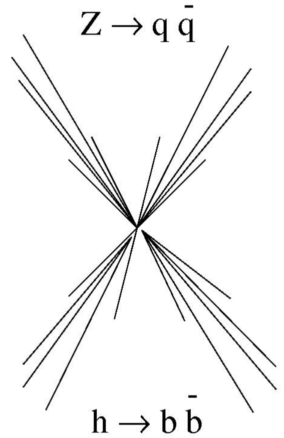


Known backgrounds have to be rejected in order to make the Higgs visible.

Background rejection needed varies between 100000 and 100.

Probability to produce a Higgs with mass 115 GeV

The 4 quarks final state



Backgrounds:
QCD (qqgg)
WW
ZZ

Problem: The jet pairing

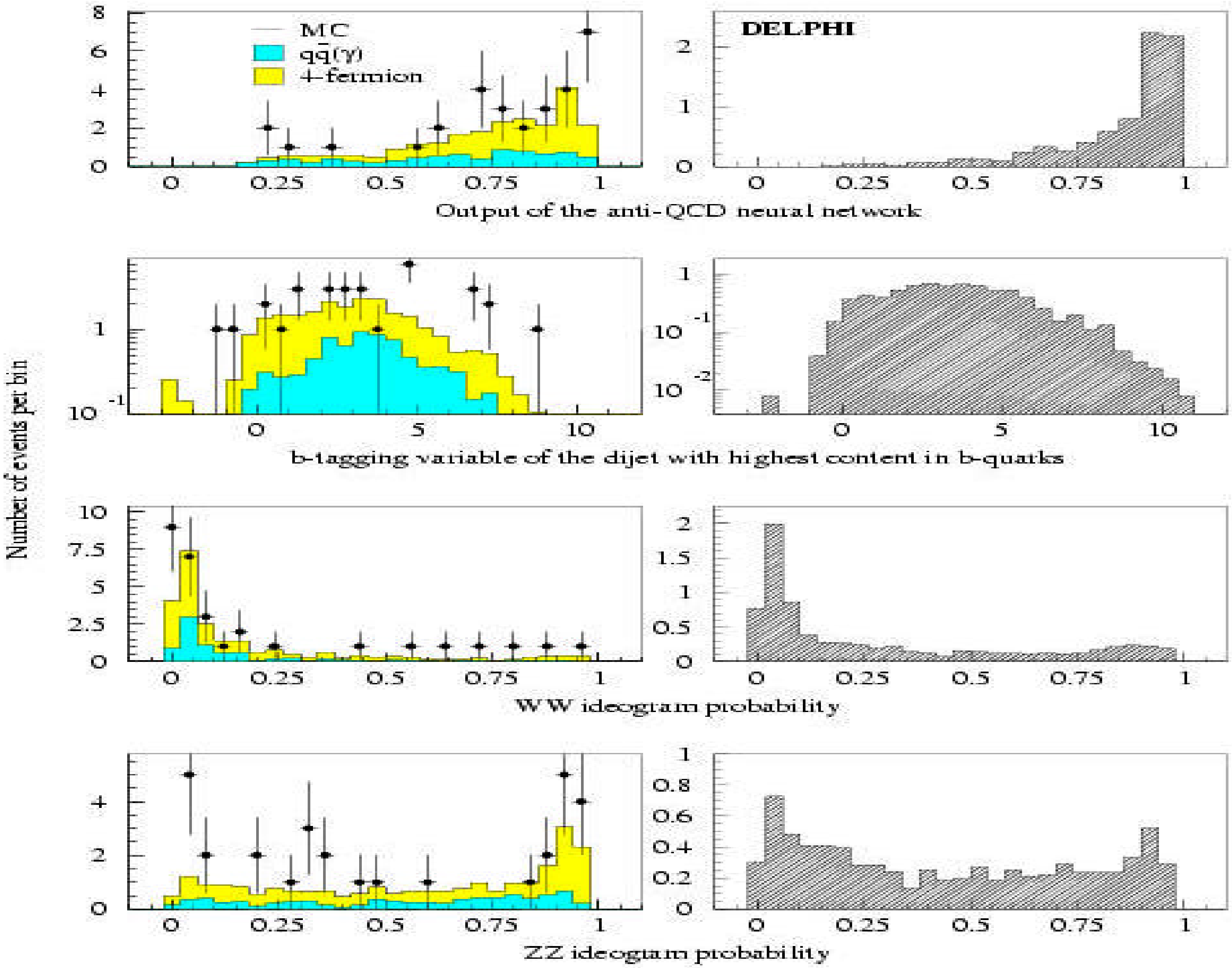
When the event is a 4-jets -> 3 combinations
if it is a 5-jets -> 10 combinations

Different solutions:

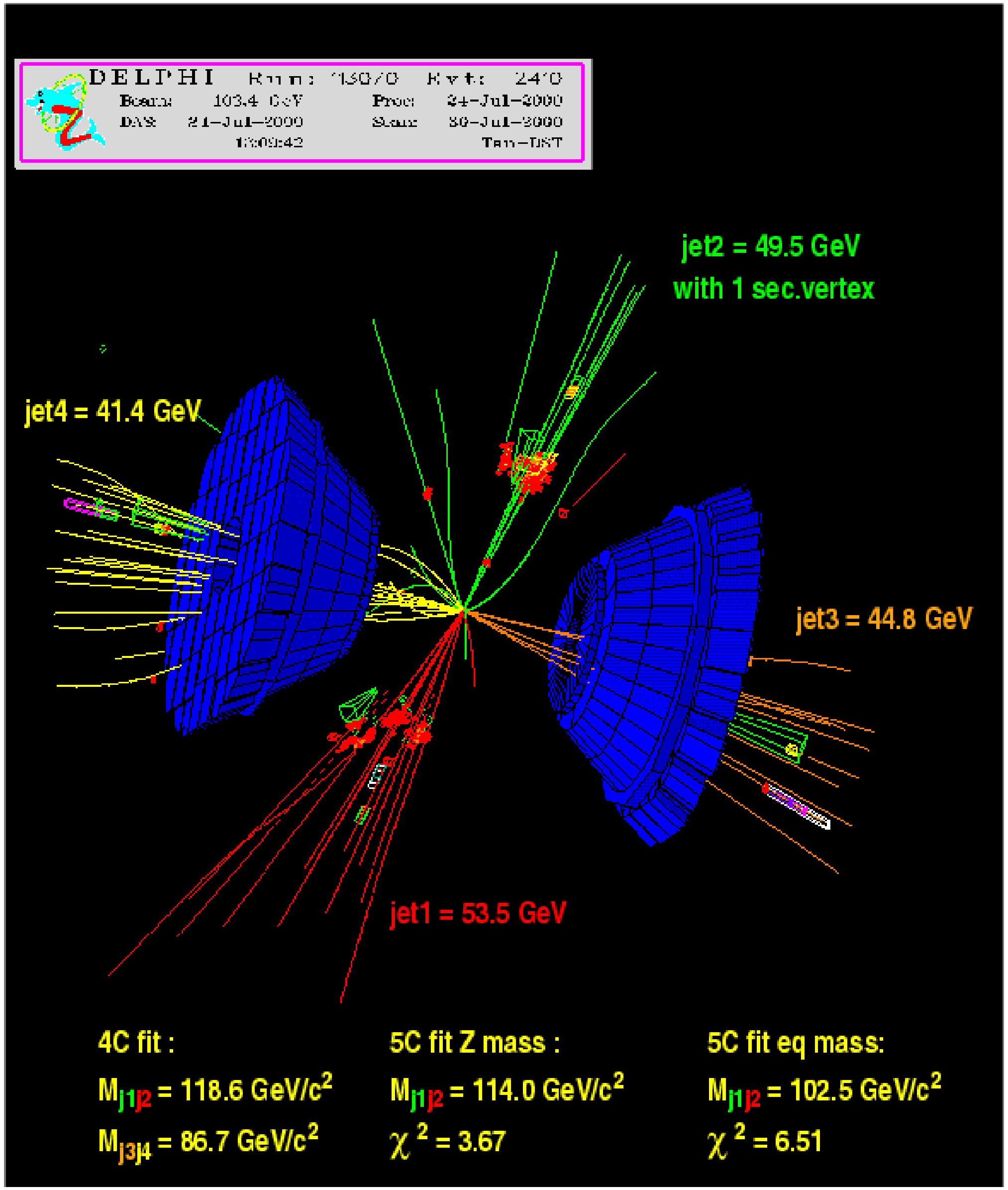
- asking for a Z recoiling (5Cfit)
- asking for jet-b-tagging
- checking the spin of the boson
- the best fit with WW,ZZ or HZ hypo.

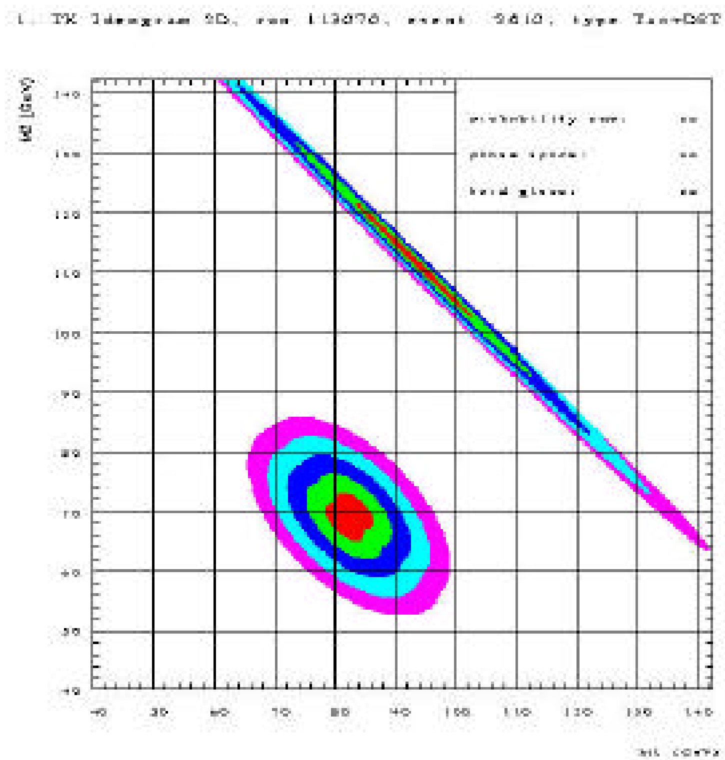
L
D,O
A
all

Higgs Signal



DELPHI qqbb

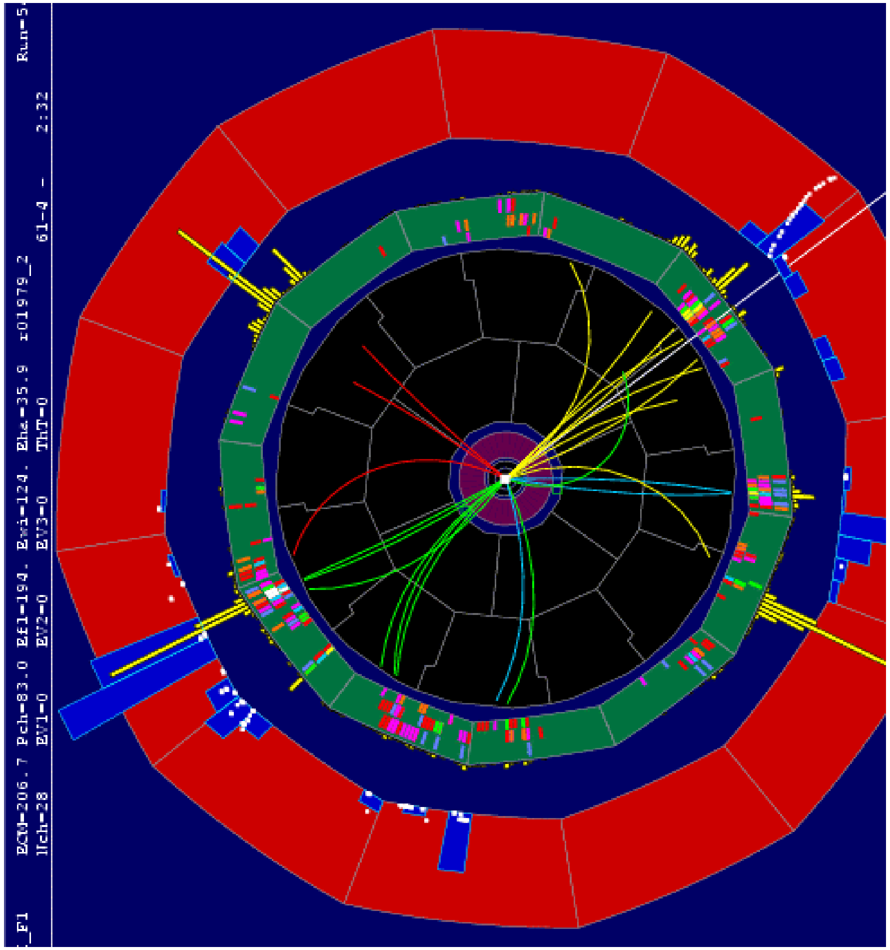




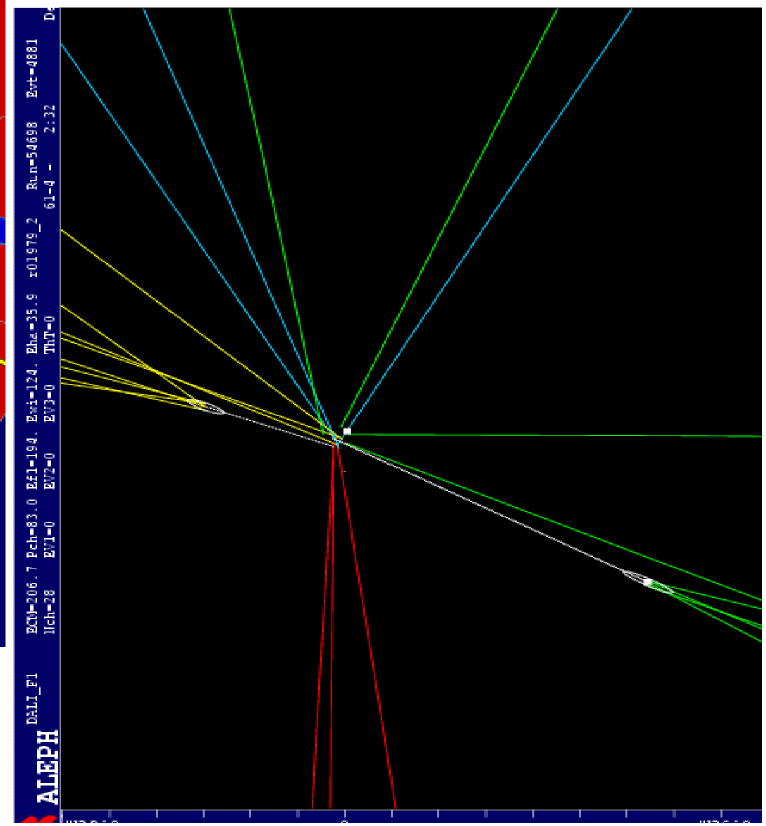
m(bb)≈114 GeV

ALEPH qqbb

E_{cm}=206.7 GeV



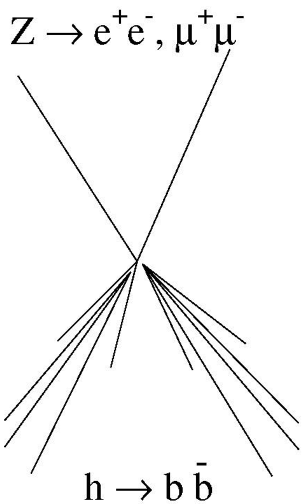
m(bb)≈115 GeV



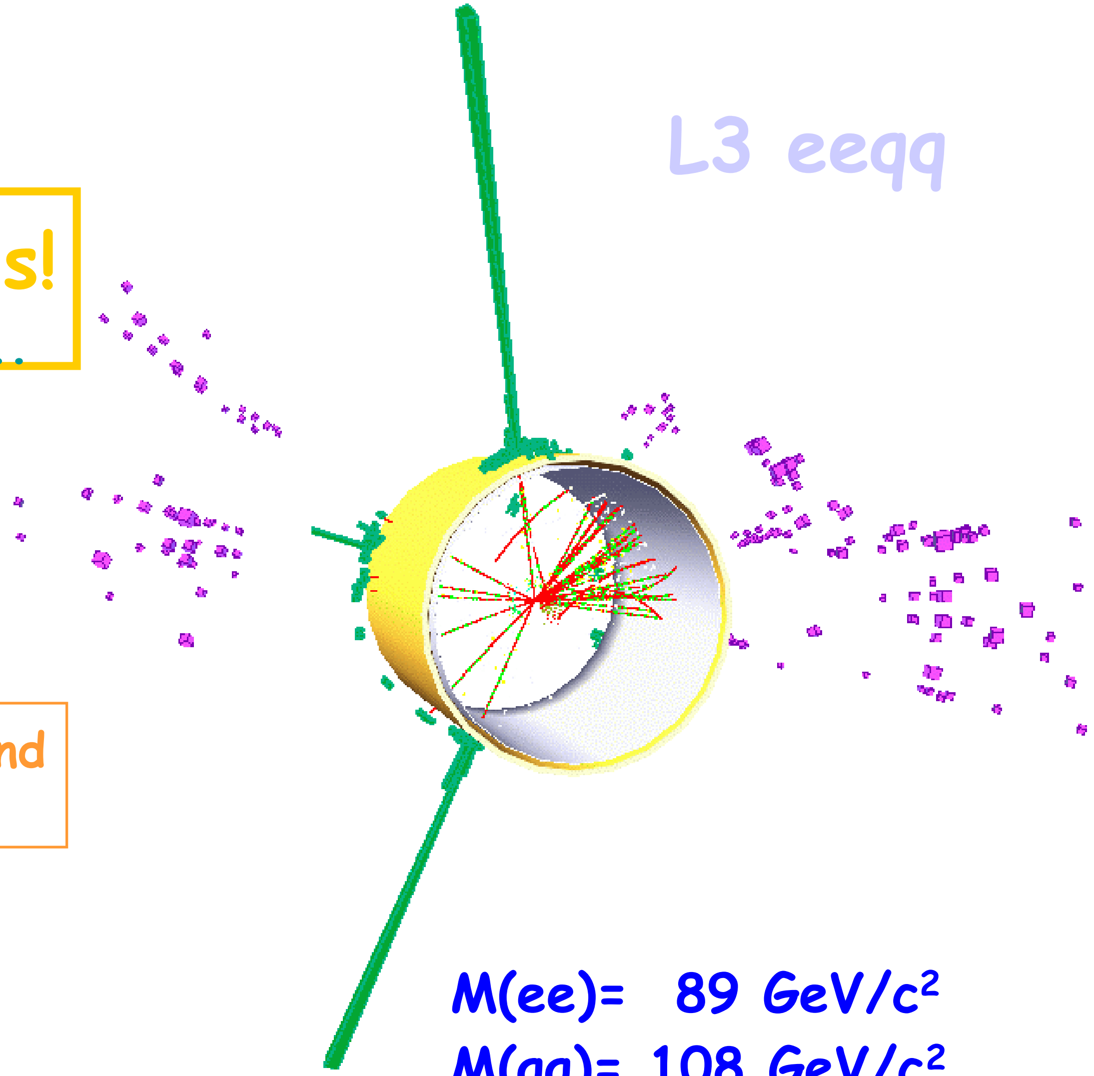
2 jets and 2 leptons

the golden candidates!

but BR = 3 % for each flavor...



Background
llqq

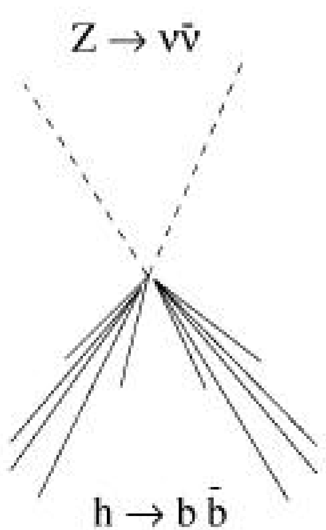


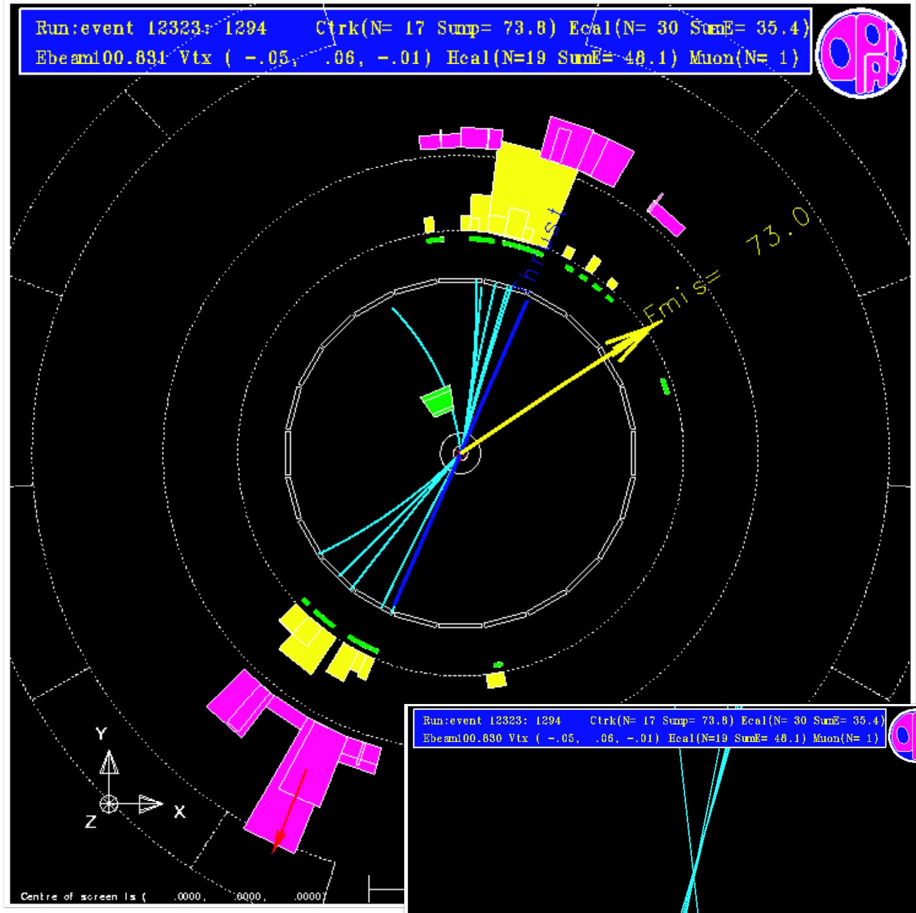
M(ee)= 89 GeV/c²
M(qq)= 108 GeV/c²

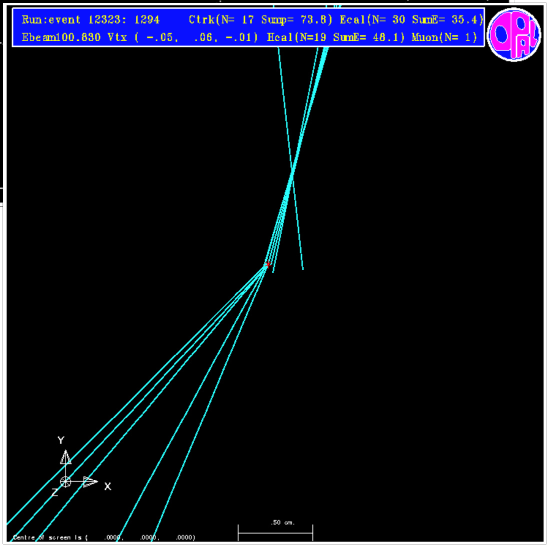
The missing energy channel

Background:

- qq(g)
- evW, eeZ
- ZZ
- Zgg







Acoplanar jets , b-tagged

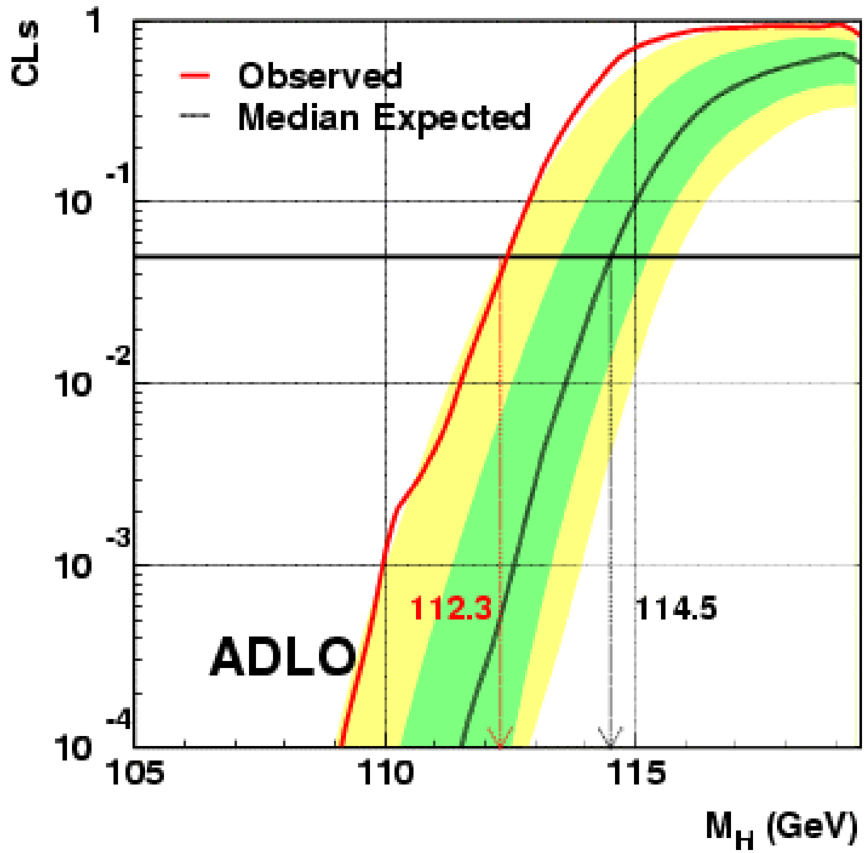
M(qq)=106.9 GeV/c^2

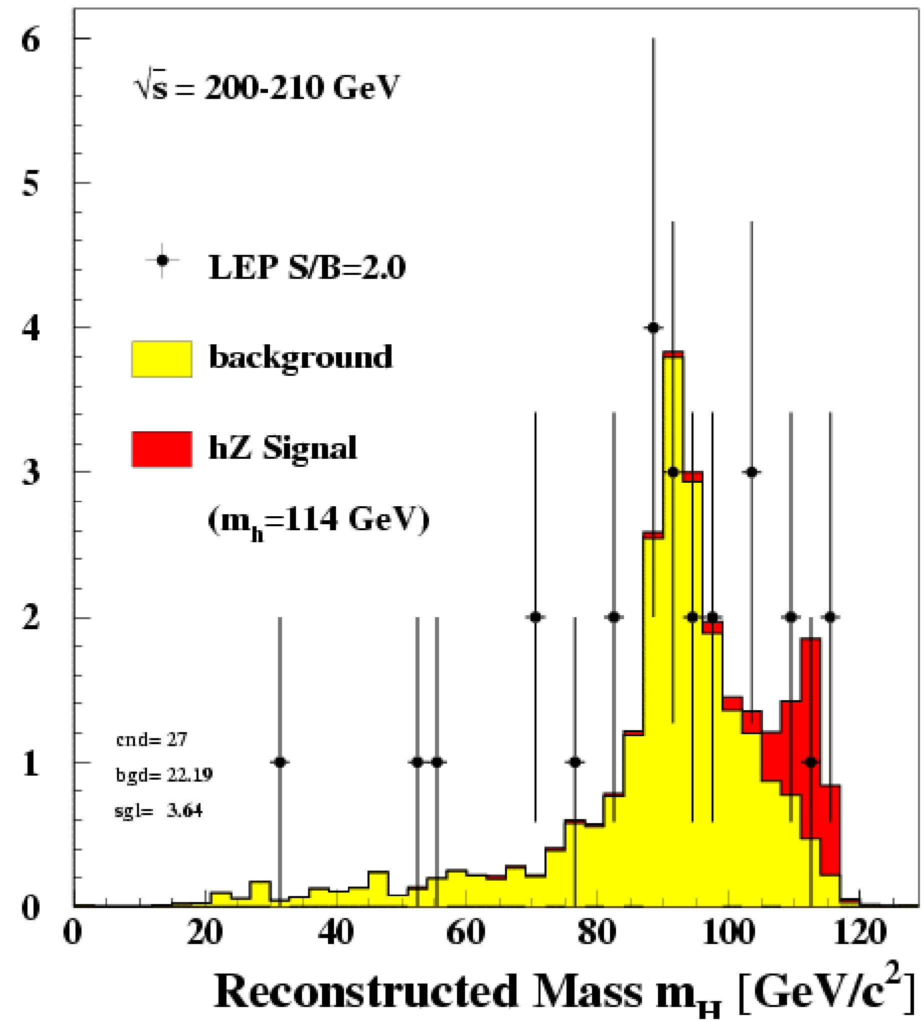
The mass estimation:

if the Z is on shell M($\nu\nu$) = M(Z)

if not (WW-fusion process) : poor resolution.

Results from HWG (sep 5 2000)

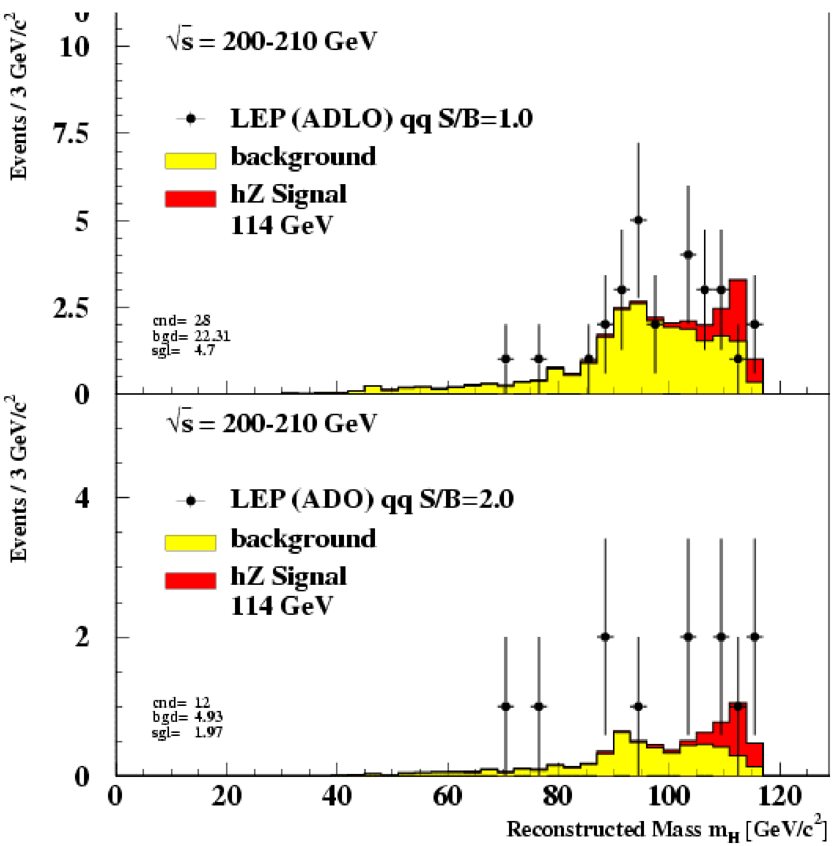


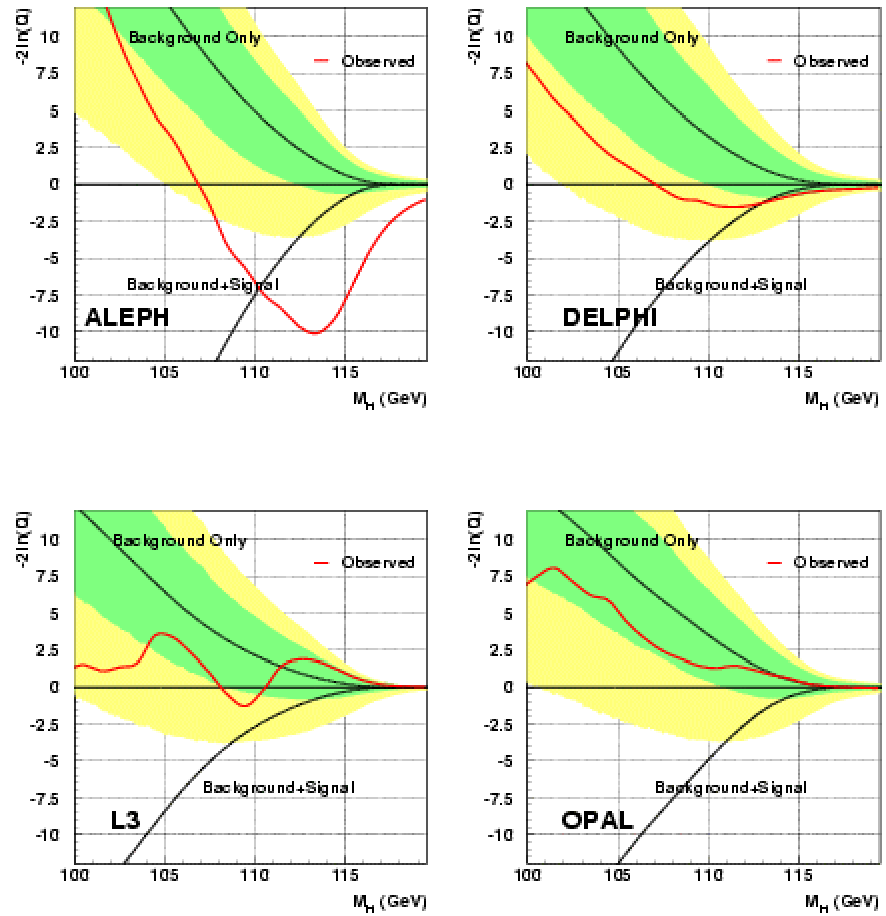


M_H > 112.3 GeV (measured)

Expected 114.5 GeV

4 jets excess



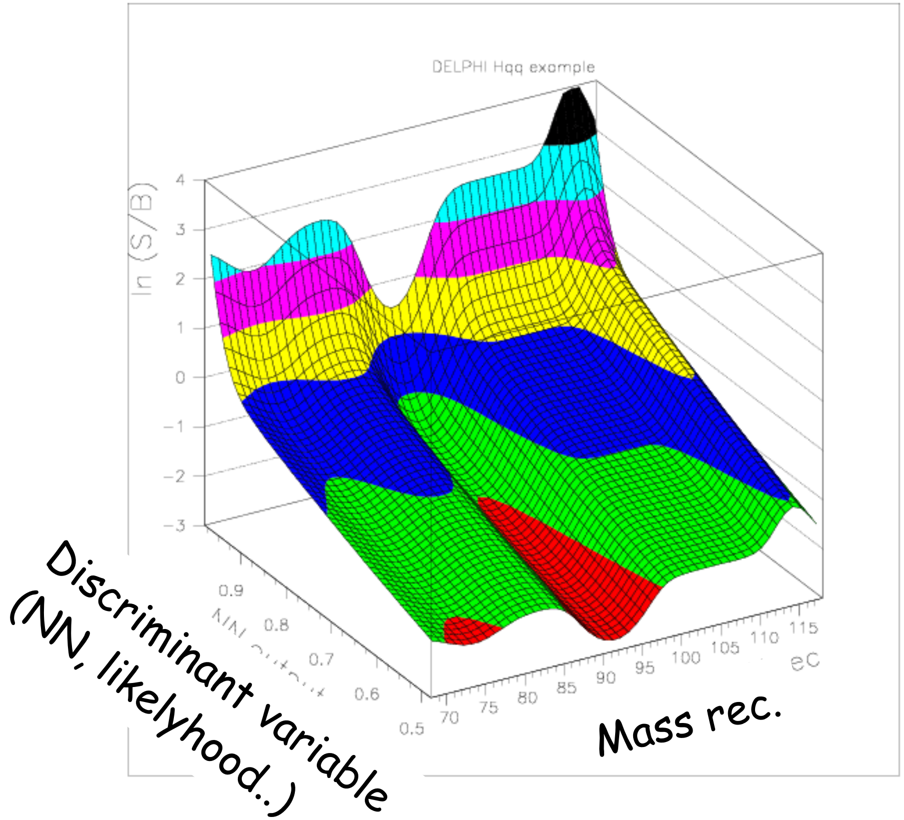


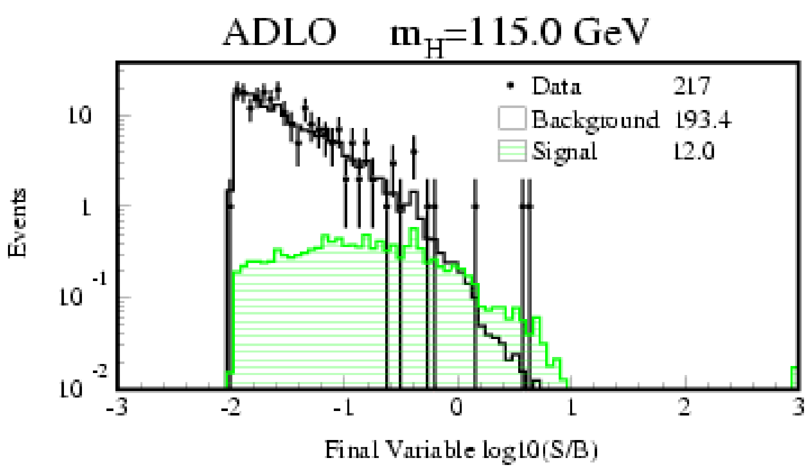
· 4-Jet Excess in ALEPH Data $(1 - \mathrm{CL_b} = 7 \cdot 10^{-5})$

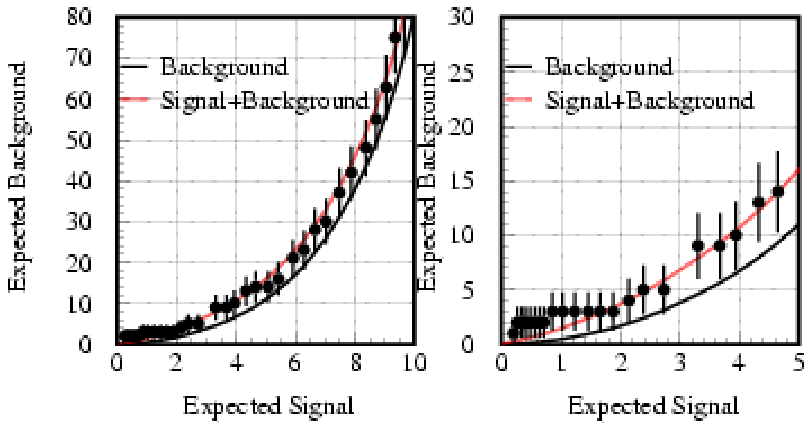
2.0σ 4-Jet Excess in DLO Data $(1 - \mathrm{CL_b} = 2 \cdot 10^{-2})$

Result (continued)

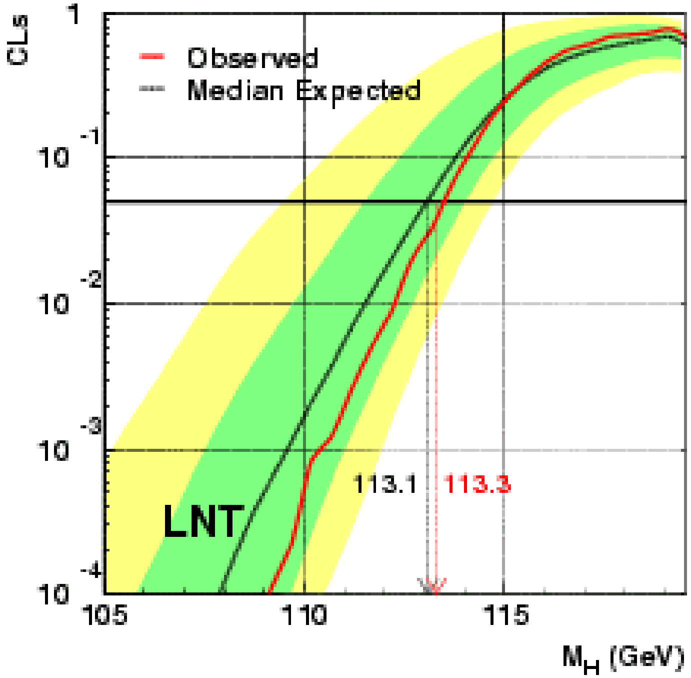
Weight of events :
Ratio of probability of signal/background
(mapped using simulated events)







Anything in the other channels ?



LNT Mass Limit

Observed:

113.3 GeV

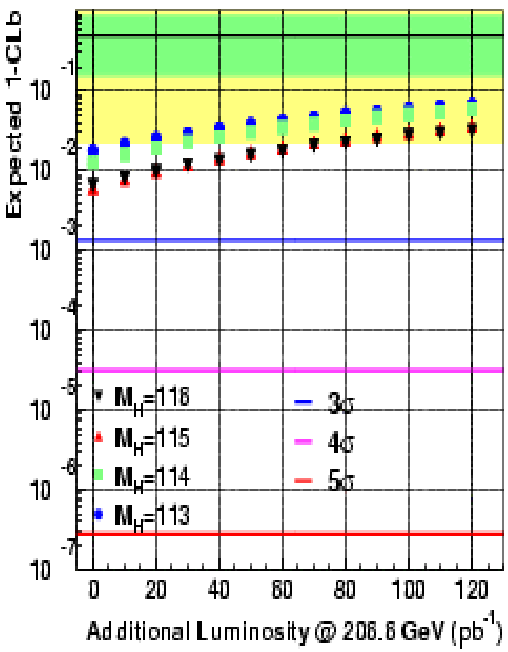
Median Expected:

113.1 GeV

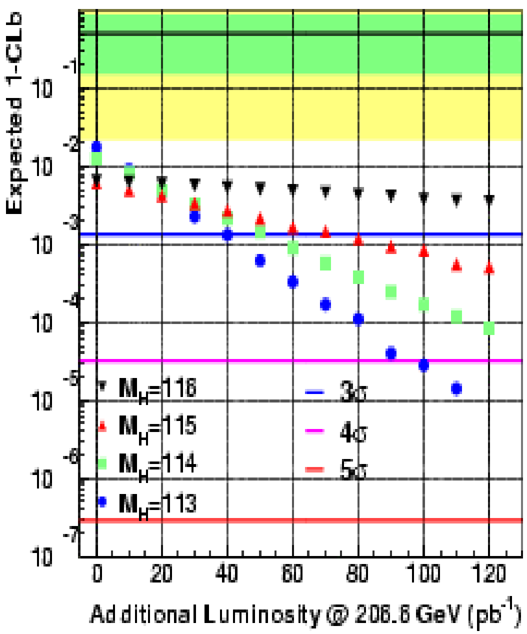
NO… but we expect only (after folding in efficiency) 0.2-0.3 signal events/experiment from qqvv and 0.2-0.3 /experiment from qqll from a 114 GeV Higgs … might be coming anytime soon (if it is there..)….

Potential of discovery

Case 1: Accumulating Background-Only:



Case 2: Accumulating Background+Signal:



What are the issues ?

- Excess driven by one of the three possible channels (4 jets) and no sign is seen in the others
- Excess driven by one experiment (ALEPH) with some 'support' from DELPHI.

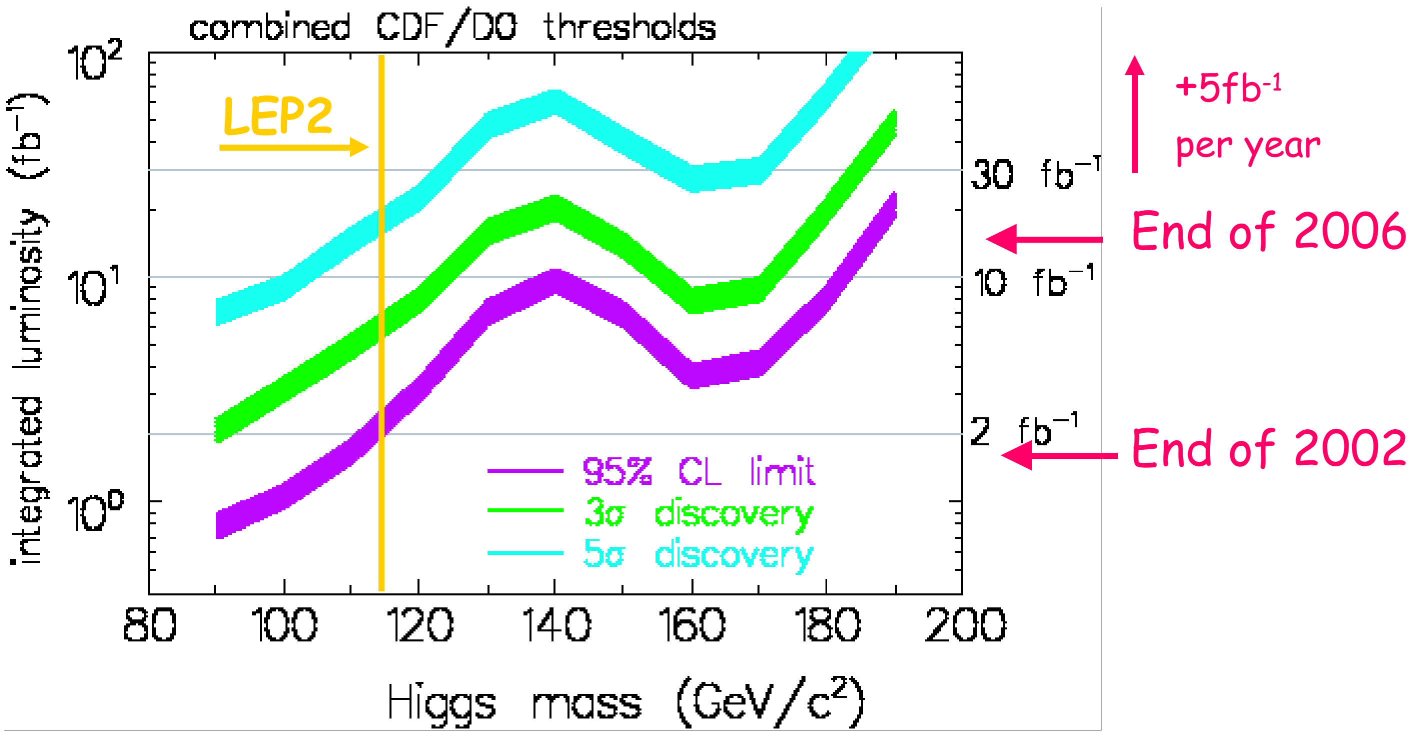
Both conditions are statistically possible: only more statistics will make clear if we have

- A systematic effect in the 4 jets
- A lucky fluctuation in ALEPH

On the other hand if the Higgs is really there the significance of it will increase and become more coherent (signal seen by more experiments/in more channels)

The competition: Tevatron

Disclaimer: this is what Tevatron people claim



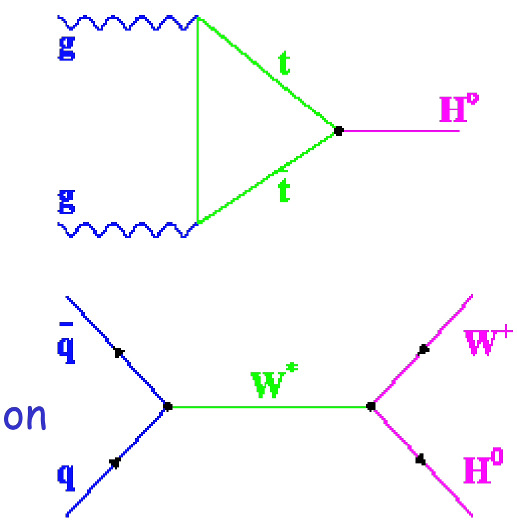
Combining all the channels

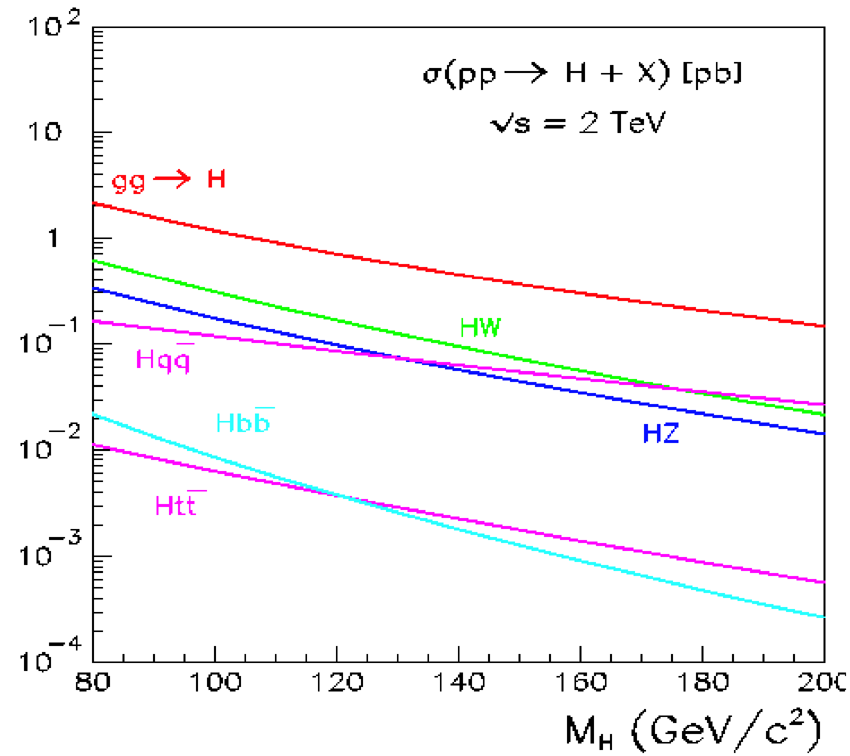
assuming 10% resolution on M(bb),30% improvement in S/B

Tevatron: more info

Gluon fusion

Associated production





In house: LHC pp, E_{cm}=14 TeV

2005-2008: $L_{peak}=10^{33}\ cm^{-2}s^{-1}$ L(year) = $10fb^{-1}$

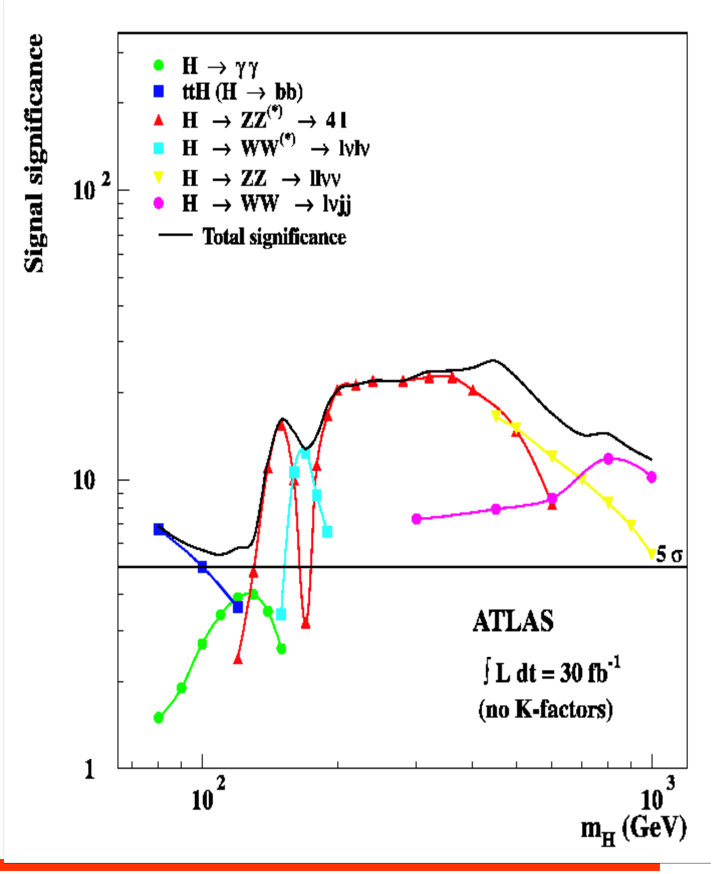
2009 -> : $L_{peak}=10^{34}\ cm^{-2}s^{-1}$ L(year) = $100fb^{-1}$

Summing all the channels for $30fb^{-1}$:

m_h<130 GeV/c² : h->γγ, bb

m_h<180 GeV/c² : h->WW

m_h>180 GeV/c² : h-> ZZ



IF Higgs discovered before then:

~0.1% -1% accuracy on Mass

~20% precision on couplings and BR

SM vs MSSM nature

A diversion: the analysis process (DELPHI example)

- Data: ~10 milllion of collected (pre-selected) events to shift through (over LEP1 and LEP2)
- Simulation: between 10 and 100 times the collected data
- Analyses: in DELPHI ~ 150 different streams each running on their private n-tuple
- N-tuple production: typically the debugging and commissioning requires 10-20 rerun on the whole dataset (DST of both data and MC stored in robot)
- Access to single events full info for selected events (event servers, sophisticated graphics manipulation)
- Final analysis steps: development of cuts, study of stability (look at variables distributions vs cuts etc.): a couple of hundred stressed physicists/experiments running over the whole n-tuple between 1 and 20 times per day (more when close to conferences/analysis week). Of course at these times an AFS problem or a robot problem can be cause of severe mental derangement!

Conclusions

We are living through exciting times: if the Higgs

is discovered at LEP the physics program of LHC will be richer than ever

The continous support of IT division is fundamental in our achievements

thank you all !