The Search for the Origin of Mass

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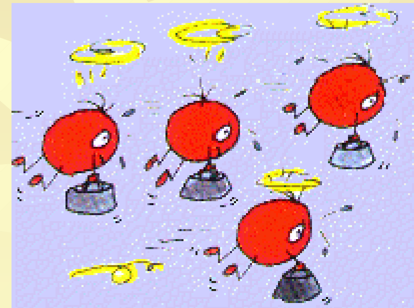
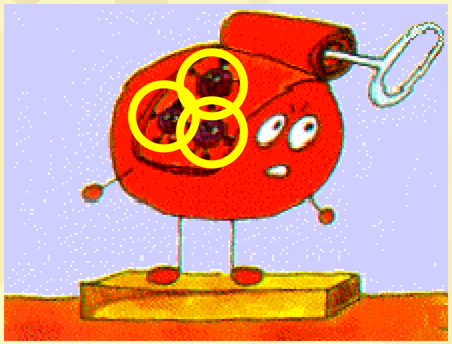
Outline

- Motivation
  - What, if...
  - What do we want to know about mass?
- Theory
  - Gauge Symmetry
  - Spontaneous Symmetry Breaking
  - Constraints on Higgs
- Experiment
  - Pre-LEP
  - Final LEP Search Results
  - Future

Which kind of mass we are talking about?

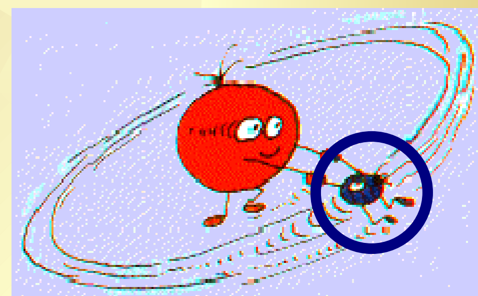
- ~~Relativistic (kinetic) mass~~ ?





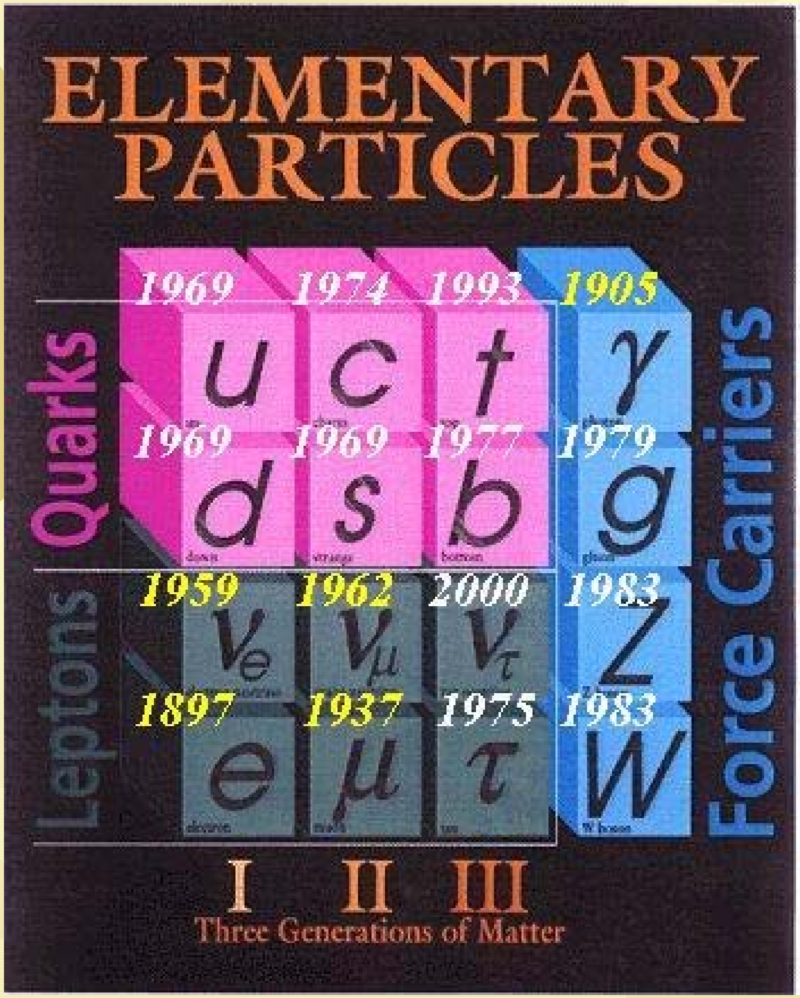
- ~~Mass of bound systems~~ ?

- ***Mass of elementary particles !***



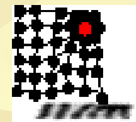
Elementary particles in the Standard Model

- **Matter and Forces:**



- **Mass creation:**

Higgs Field and



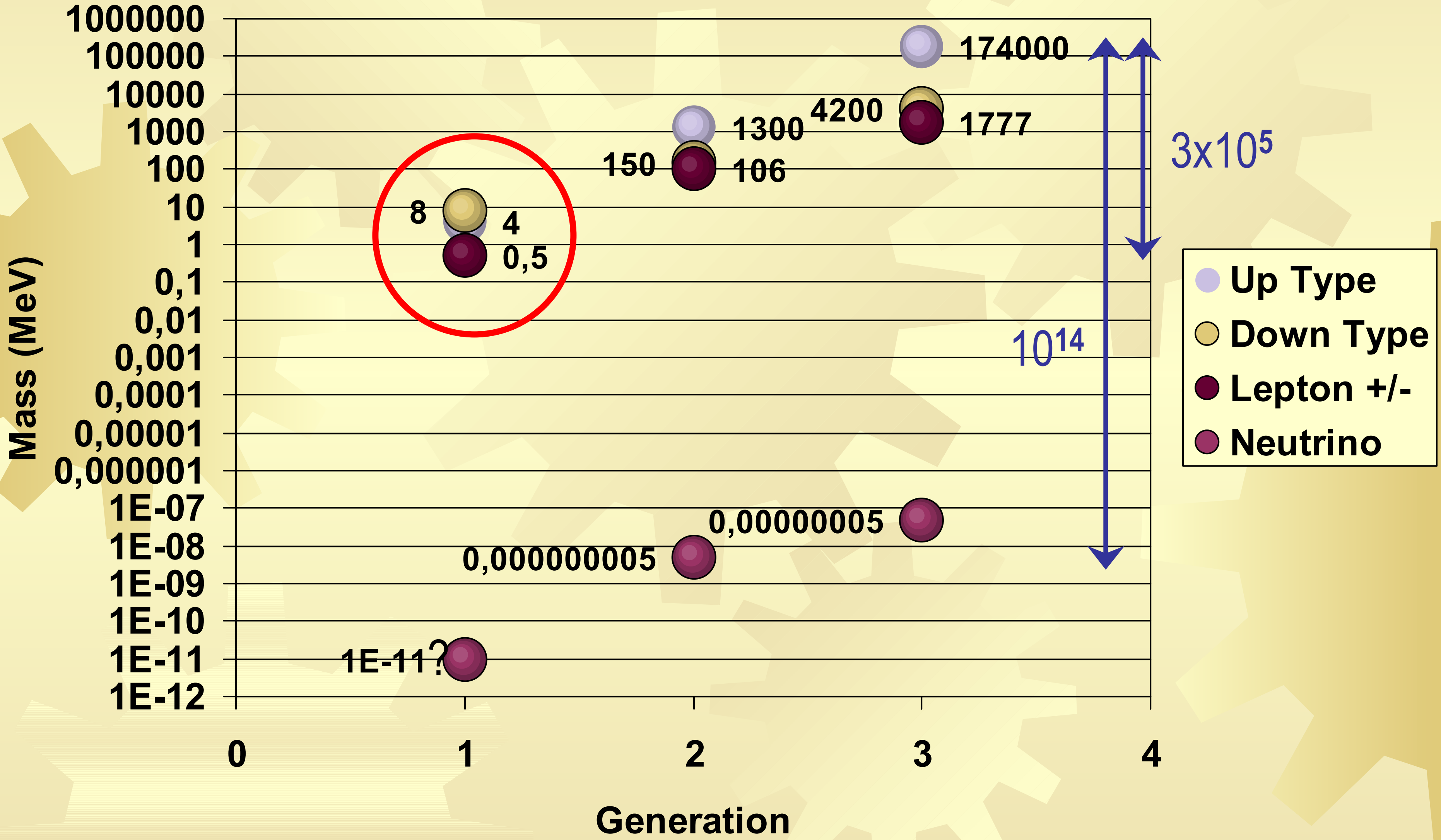
Higgs Boson

- introduced by P.W.Higgs et al. between 1963 – 1966
- Only missing ingredient, to be discovered in ***200x***

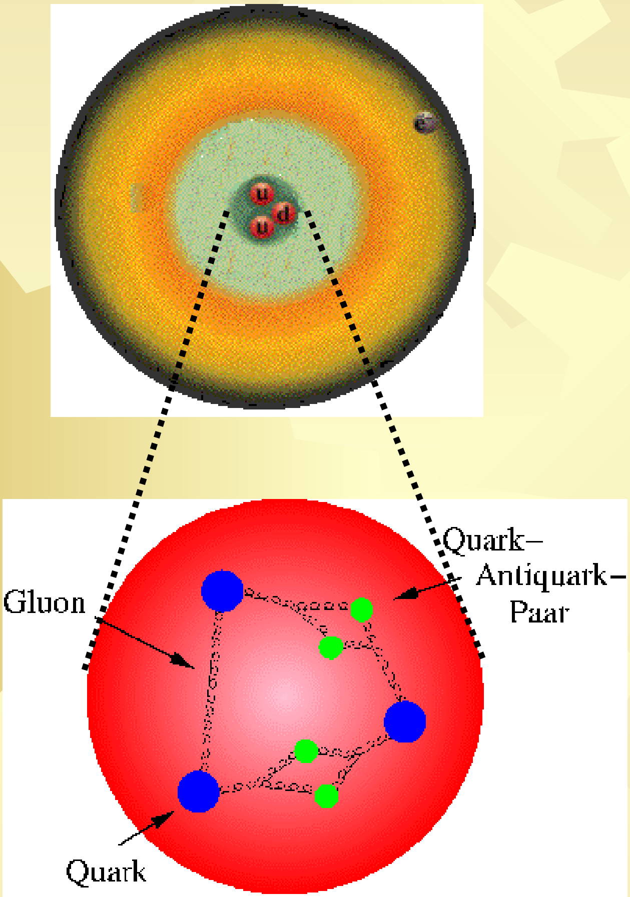
Why do we care?

The Masses of the Building Blocks

span a range of $3x10^5$ w/o Neutrinos and > 10^{14} including Neutrinos



What makes matter massive?



- *For Hydrogen (or any other) atom*

  $m_p + m_e$ = 938.8 MeV

  $2m_u + m_d + m_e$ = 16.5 MeV

  → 2% is rest mass of constituents

  →98% is effective mass

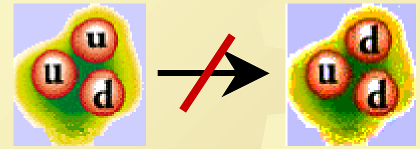
  from
  - Gluon emission
  - Relativistic motion

- *Changing m_u ,m_d or m_e would have*
  - small effects on macroscopic masses
  - Small effects on Ω_{matter}
  - potentially huge effects on behaviour of matter

- *Let‘s see why...*

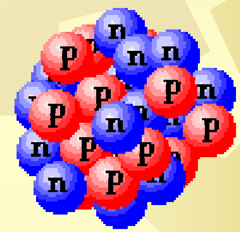
What makes nuclei stable?

- Hydrogen nucleus: $p \not\rightarrow n + e^+ + \nu_e$, since
  - $m_n - m_p$ = 939.6 MeV – 938.3 MeV = 1.3 MeV, due to

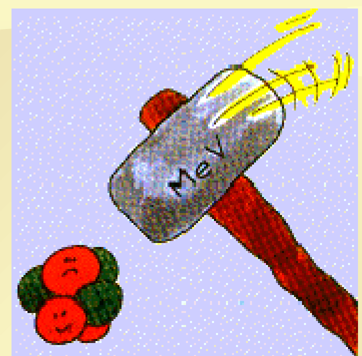


    - Δm_{mass} = "$m_d - m_u$" ≈ 3 – 4 MeV
    - $\Delta m_{elec} = \alpha_{em}(Q^2_d - Q^2_u) / \langle \mathbf{r}_{qq} \rangle$ = – 0.5 MeV / $\langle \mathbf{r}_{qq}$ (fm) $\rangle$ ≈ – (2 – 3) MeV

- Heavier nuclei: $n \not\rightarrow p + e^- + \bar{\nu}_e$, since
  - $E_b(n) - E_b(p) > m_d - (m_u + m_e) + \Delta m_{elec}$ = 0.8 MeV



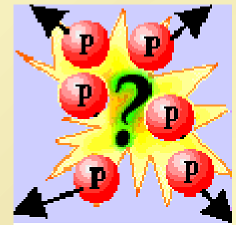
- Delicate interplay between
  - Strong force : $E_b(n) - E_b(p)$, $\langle \mathbf{r}_{qq} \rangle$
  - Electromagnetic force: α_{em}
  - Masses: m_d , m_u , m_e



What, if just m_d changed by a small amount ?

$\leftrightarrow$ typical mass range of $3x10^5$ to 10^{14} !

Increase m_d by 8 MeV (factor 2)



- allows $n \rightarrow p + e^- + \bar{\nu}_e$ in heavier nuclei, since
  - $E_b(n) - E_b(p) < m_d - (m_u + m_e) + \Delta m_{elec} = 8.8$ MeV
  - $\rightarrow$ nuclei with $Z \approx A$, broken up by Coulomb force above ~$_6^6C$
- $\rightarrow$ no Oxygen, no water, no life as we know it

Decrease m_d by 1 MeV (factor 1 / 1.1)

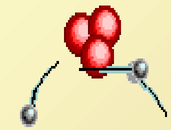
- allows K-capture in Hydrogen: $p + e^- \rightarrow n + \nu_e$, since
  - $(m_p + m_e) - m_n = 937.8$ MeV – 937.6 MeV = 0.2 MeV
- star formation from stable n, $n+n \rightarrow D + e^- + \bar{\nu}_e$, $D+n \rightarrow {}^3He + e^- + \bar{\nu}_e$
- No Hydrogen atoms, Deuterium replaces Hydrogen

Decrease m_d by 4 MeV (factor 1 / 2)

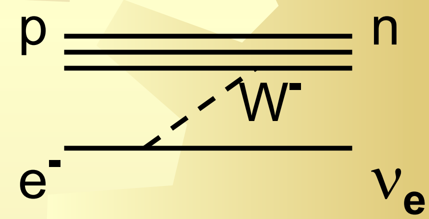
- allows $p \rightarrow n + e^+ + \nu_e$, also in D, since
  - $m_p - m_n = 934.3$ MeV – 931.6 MeV = 2.7 MeV
- forbids $n+n \rightarrow D+e^- + \bar{\nu}_e$, since $2m_n < (m_D + m_e)$
- $\rightarrow$ no protons, no stars, just neutrals (n, γ, ν) left over

What, if just m_e changed by a small amount ?

- Electron mass governs **energy** and **distances**
  - Rydberg energy $R=0.5\ \alpha^2_{em}\ m_e$
  - Bohr radius $a=1\ /\ \alpha_{em}\ m_e$



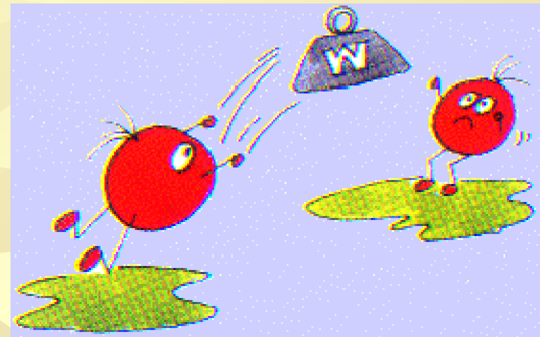
- **Decrease m_e to 0.02 MeV (factor 1 / 25)**
  - Huge atoms, small binding energies
    - Human „giants“ are 45 m tall
    - covalent bindings, e.g. $CH_4 \rightarrow C+2H_2$- (0.75 / 25) eV, break at T=60 °C
- **Increase m_e to 1.5 MeV (factor 3)**



  - Same effect as decreasing m_d by 1 MeV, i.e.
    - K-capture in Hydrogen: $p + e^- \rightarrow n + \nu_e$
    - star formation from stable n, Deuterium replaces Hydrogen
  - In addition:
    - Human „dwarfs“ are 60cm tall, can see UV light
- **Increase m_e to 5 MeV (factor 10)**
  - Same effect as decreasing m_d by 4.5 MeV, i.e.
    - no protons, no stars, just neutrals (n, γ, ν) left over

Masses of Force Carriers

- Massless: Photon $m_\gamma=0$, Gluon $m_g=0$
- Heavy: Weak Bosons $m_W=80450$ MeV, $m_Z=91187$ MeV
  - Origin of weak mass scale at 100000 MeV unknown
  - m_W governs $p+p \rightarrow D + e^+ + \nu_e$ in stars



- Increase m_W by factor of 2
  - Sun burns slower, less radiation pressure
  - Radius down by factor $\sqrt{2}$, surface temperature up by $\sqrt[4]{2} = 1.2$
  - More UV radiation
- Decrease m_W by factor of 2
  - Sun bigger, colder, burns faster $\sigma * \rho \sim (m_W)^{-4} (m_W)^{1.5}$
  - Just bacteria would have had enough time (1.5×10^9 years) to develop
  - → W must not be much lighter for life on earth

Why do we want to know more about mass?

- Elementary fermion masses m_d , m_u , m_e
  - Appear to be extremely (10^{-4}) finetuned with respect to
    - each other
    - electromagnetic interaction
    - strong interaction
- Weak boson mass scale m_W
  - „Just right“ for star burning and life

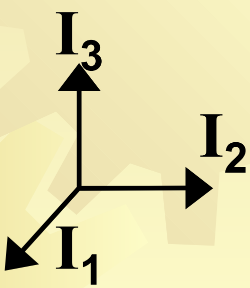
Why do they have these mass values?

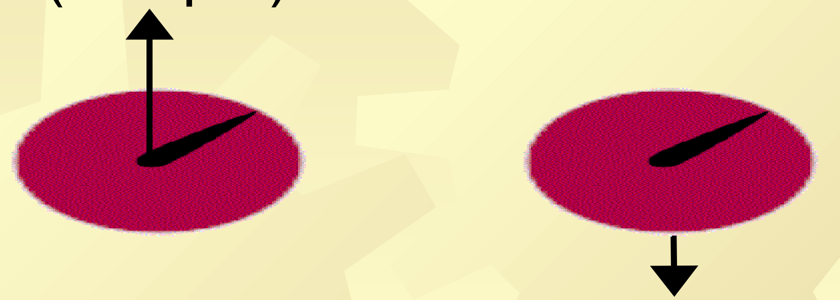
- But is this the right question? Better ask first:

What is mass, after all?

The Weak Gauge Symmetrie

- Symmetry in Weak Charge (Isospin) vector I



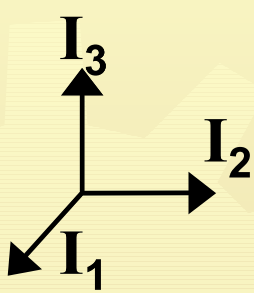


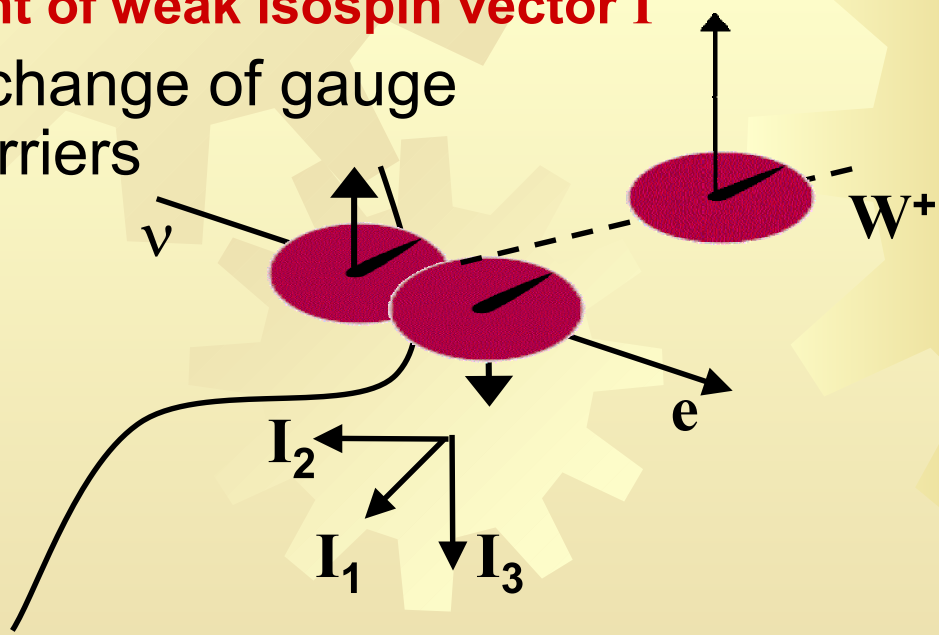
Neutrino: $I_3 = ½$ Electron: $I_3 = -½$

Up-Quark: $I_3 = ½$ Down-Quark: $I_3 = -½$

Idea: (ν, e) , (u, d) are pairs of identical particles, differ only in 3. component of weak isospin vector I

- Invariance under local change of gauge
  → emit/absorb force carriers





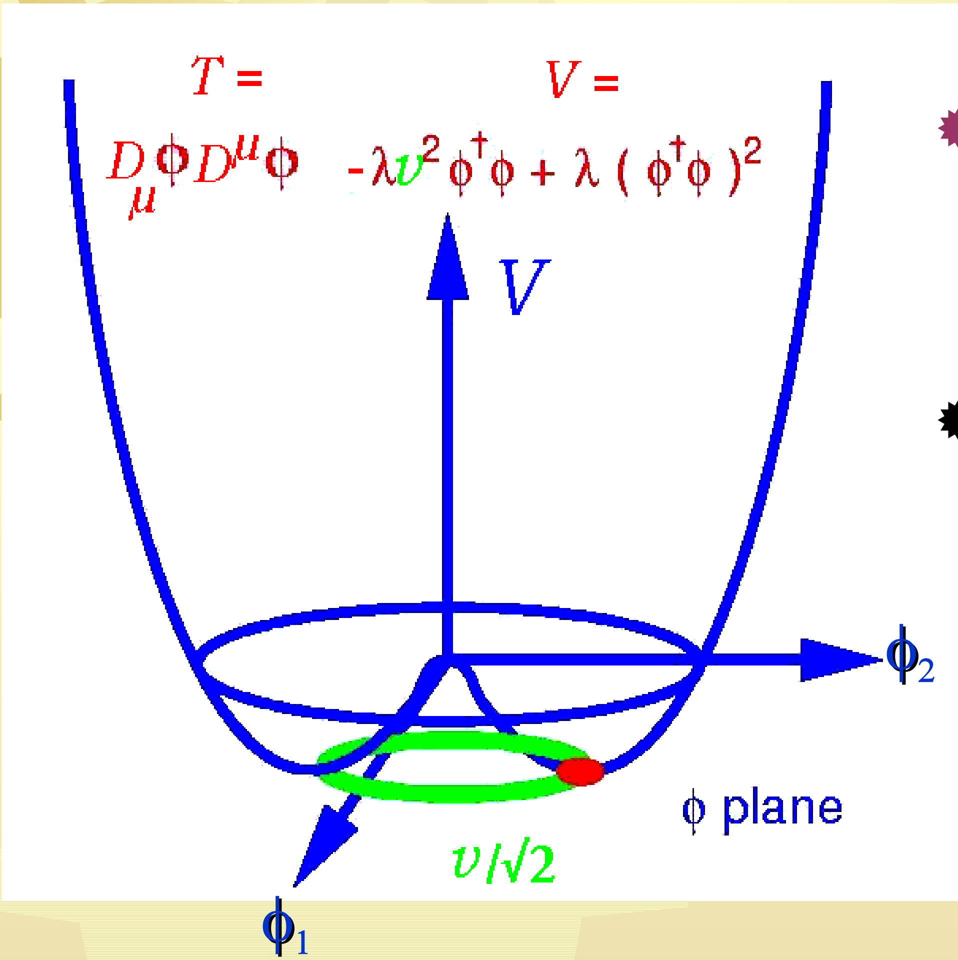
Electroweak SU(2)xU(1) gauge symmetry

- *1961 S. Glashow*
  Gauge symmetry in weak isospin and hypercharge describes electromagnetic and weak interactions
  - \+ In accordance with experiment
  - \+ ***only 2 free parameters (couplings g,g‘)***
  - \+ Renormalizable due to local gauge symmetry (proven by t‘Hooft, Veltman 1971)
  - \- with ***massless*** gauge Bosons γ , Z, W^+,W^-
  - \- with ***massless*** Fermions e,μ,...

Explicit mass terms would destroy gauge symmetry

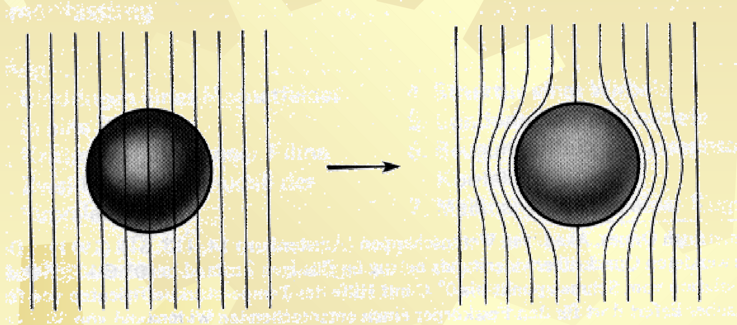
Solution: spontaneus symmetry breaking

- Ground state (vacuum) does not preserve underlying gauge symmetry



- Minimal model:
  - 1 complex doublet field ϕ
  - Present everywhere
  - Non-vanishing v.e.v.
- **2 free parameters:**
  - vacuum expect. value υ
  - Potential steepness λ
- Effects
  - Hinders particle movement → *mass creation*
  - Field Excitation → Higgs Boson

An analogue for physicists: superconductivity



Meisner Effect: B-fields (photons) acquire finite range (mass) in a background field

	Higgs mechanism	Superconductivity
Background field	Higgs field	Cooper Pairs
nature	Bosonic, S=0	Bosonic, S=0
Amplitude V	υ	$\sqrt{(n / M)}$
w/o field	$m_W = 0$	$m_\gamma = 0$
Coupling Q	g / 2	2e
damping	$\exp(- m_W r)$	$\exp(- r/ \lambda)$
Range λ=1 / QV	0.0025 fm	10 - 100 nm
Mass 1/ λ = Q V	$m_W = \frac{1}{2} g \upsilon$	$m_\gamma = 2e\sqrt{(n / M)}$

Mass creation

- ***W,Z masses through gauge invariance***

$$m_W = ½\, g\, \upsilon$$

$\upsilon = (\sqrt{2}\, G_F)^{-½} = 246$ GeV known from μ-decay in Fermi theory

- ***Higgs Boson Mass from potential parameter***

$$m_H = \sqrt{(2\lambda)}\, \upsilon$$

λ (nearly) completely free

- ***Fermion masses added „by hand“ as Yukawa couplings***

$$m_f = ½\, g_f\, \upsilon$$

couplings $g_f = 2m_f / \upsilon$ completely free: **9+6(?) parameters**

couplings identical to Higgs field and to Higgs Boson
→ verifiable by Higgs Boson decay branching ratios !

Predictive Power?

- Is the Higgs hypothesis verifiable?
  - **YES! Discover the Higgs Boson(s) *and* precisely measure its BRs**
- Do we learn what mass is?
  - **YES! The amount of coupling of a particle to the Higgs field**
- Does the Higgs mechanism predict the masses?
  - **NO! Apart from the m_W / m_Z ratio**
- Does it then help at all in understanding mass values?
  - **YES! We will know better what deeper question to ask**
    - Weak Bosons: Why is υ = 246 GeV ?
    - Fermions: What determines the couplings g_f ?

Other Effects

- ***Enables*** quark mixing and CP violation

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{CKM} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

weak eigenstates, **4 free parameters**, mass eigenstates

- ***Requires*** $(B, W^3) \leftarrow \sin\theta_w \rightarrow (\gamma, Z)$ mixing, yielding

$$e = g \sin\theta_w$$

(not a genuine prediction of Higgs mechanism)

- ***Predicts*** Z/W mass ratio

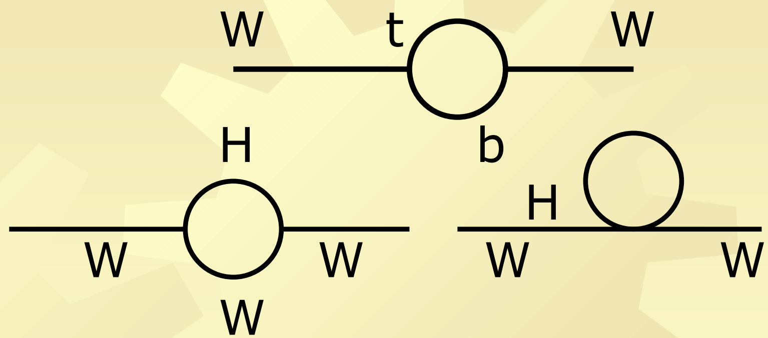
$$M_W = M_Z \cos\theta_w$$

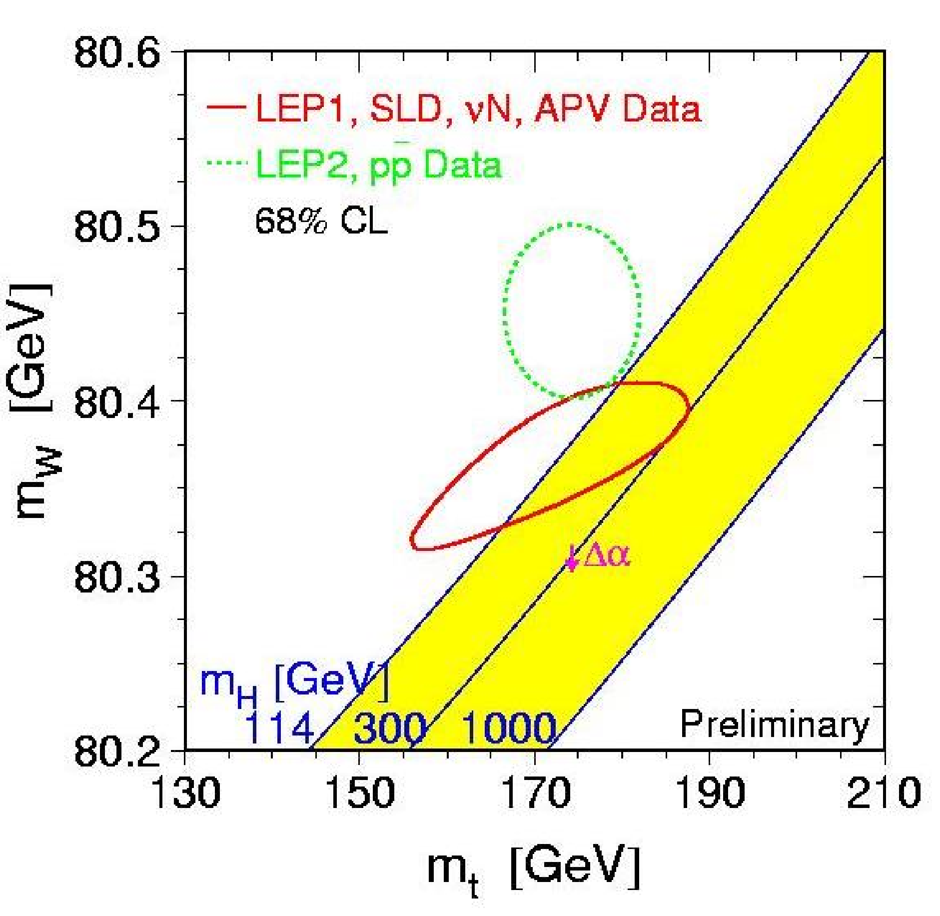
Central Prediction of Higgs ***doublet*** models (Born level)

Indirect Higgs mass prediction

Higher order corrections:

$M_{\mathbf{W}} = M_{\mathbf{Z}} \cos\theta_w + f\,(M_{\mathbf{t}}, \ln(M_{\mathbf{H}}/M_{\mathbf{Z}}))$

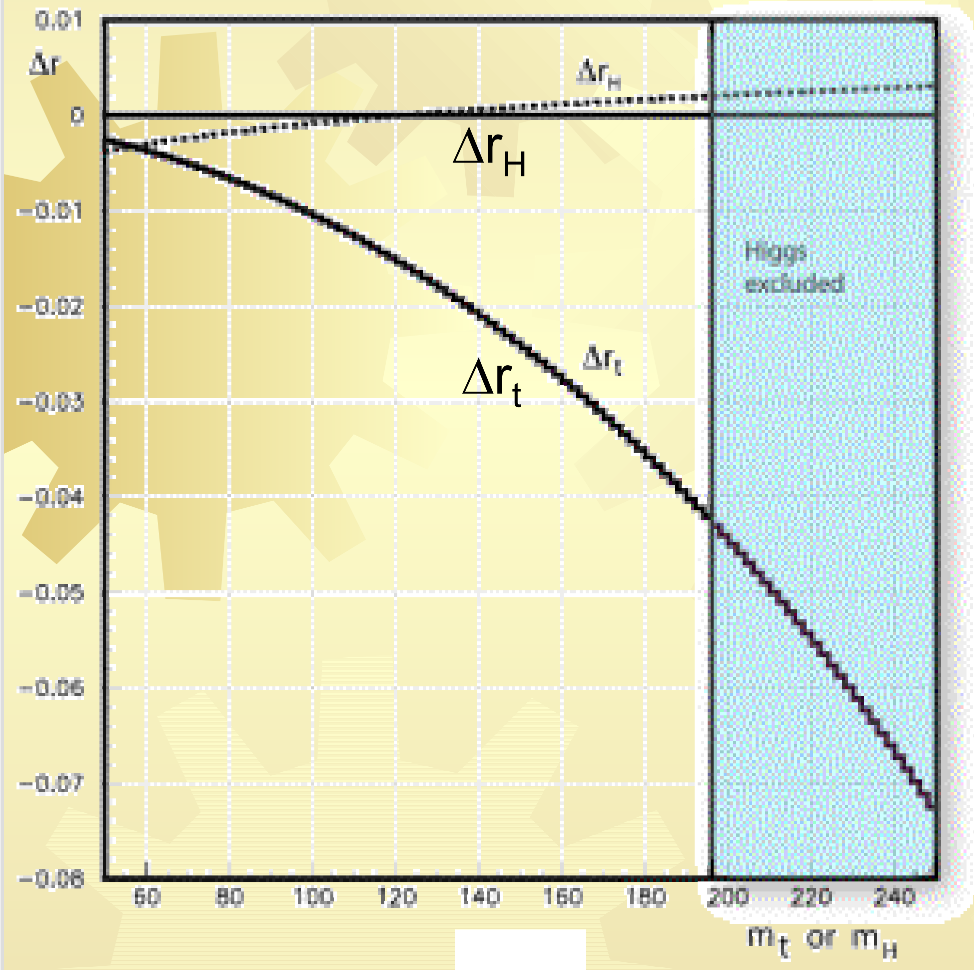




- SM prediction:
  $M_{\mathbf{W}}$=(80.380 ± 0.023)GeV
- Direct measurement:
  $M_{\mathbf{W}}$=(80.450 ± 0.033)GeV
- Difference:
  Δ = (0.070 ± 0.040)GeV

- Fit for Higgs mass:
  $M_{\mathbf{H}}(\alpha_{th}) = (106^{+57}_{-38})$GeV
  $M_{\mathbf{H}}(\alpha_{exp}) = (81^{+52}_{-33})$GeV

Do we really *see* the Higgs?



- Fermi Constant:

  $G_F \sim \alpha / (\sin^2\theta_w M_W^2 (1-\Delta r))$

- Contributions of t and H

$$\Delta r_t = -\frac{3 G_F m_W^2}{8\sqrt{2}\pi^2} \frac{m_t^2}{m_W^2} \frac{\cos^2\theta_W}{\sin^2\theta_W} + \cdots$$

$$\Delta r_H = \frac{11}{3} \frac{G_F m_W^2}{8\sqrt{2}\pi^2} \left(\ln \frac{m_H^2}{m_W^2} - \frac{5}{6} \right) + \cdots$$

- **Measured** contribution of H, (in $\overline{\text{MS}}$ renormalisation @ $\mu = M_Z$) is zero w/in experimental errors from $\Delta\alpha_{had}$ and Δm_t:

  $\Delta r_H = (-0.6 \pm 3.1) \times 10^{-3}$

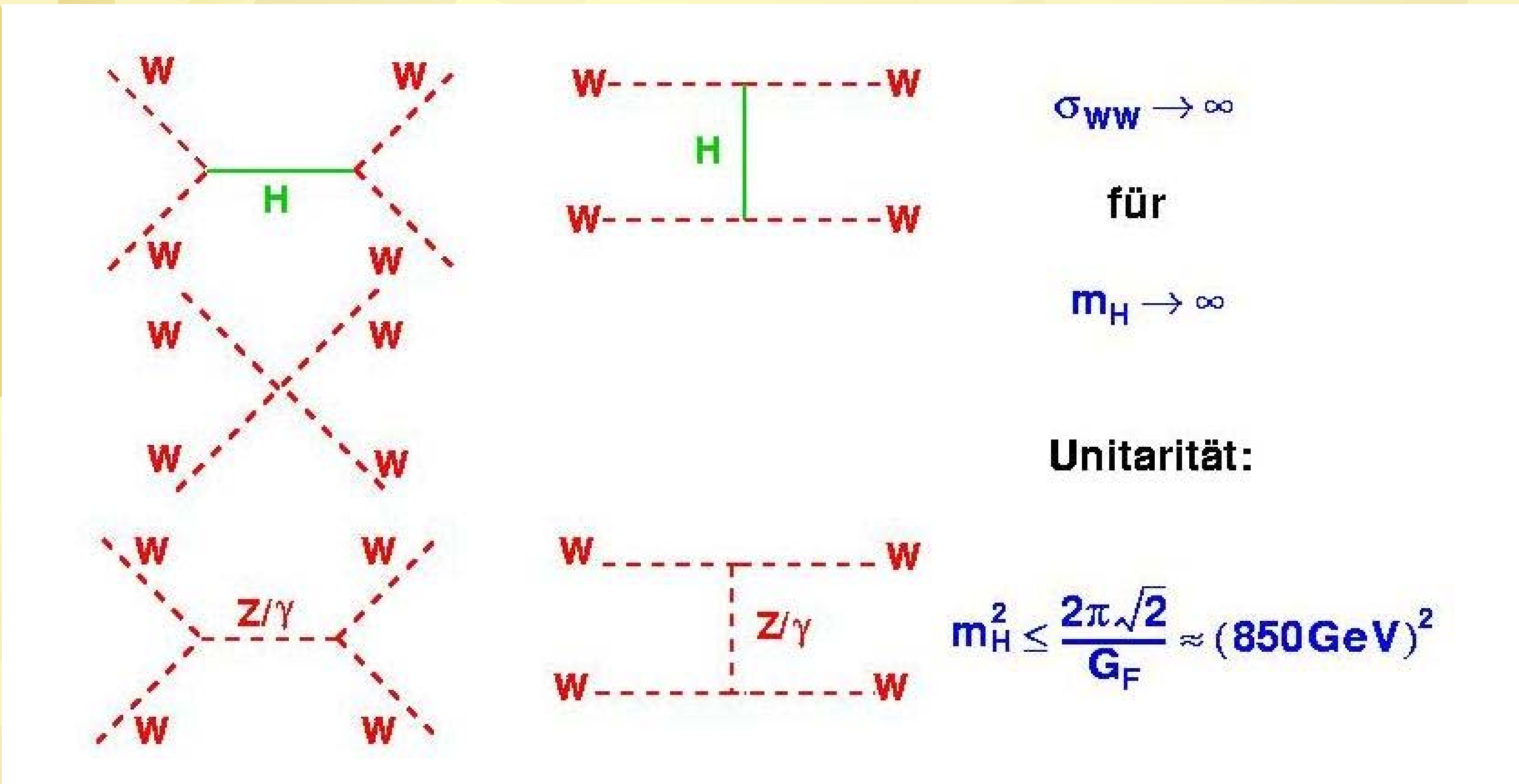
  expecting $O(\alpha/2\pi\sin^2\theta_w) \sim 5\times10^{-3}$

(B.A.Kniehl, A.Sirlin, EPJC 16 (2000) 635, $\Delta r_{H,eff} = (0.05 \pm 0.96) \times 10^{-3}$, typ. $O(2\times10^{-3})$)

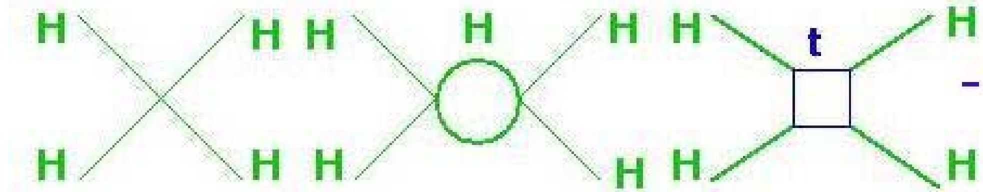
→ **limits on certain non-Higgs scenarios**

Theoretical constraints I

- Elastic WW scattering (tree level)



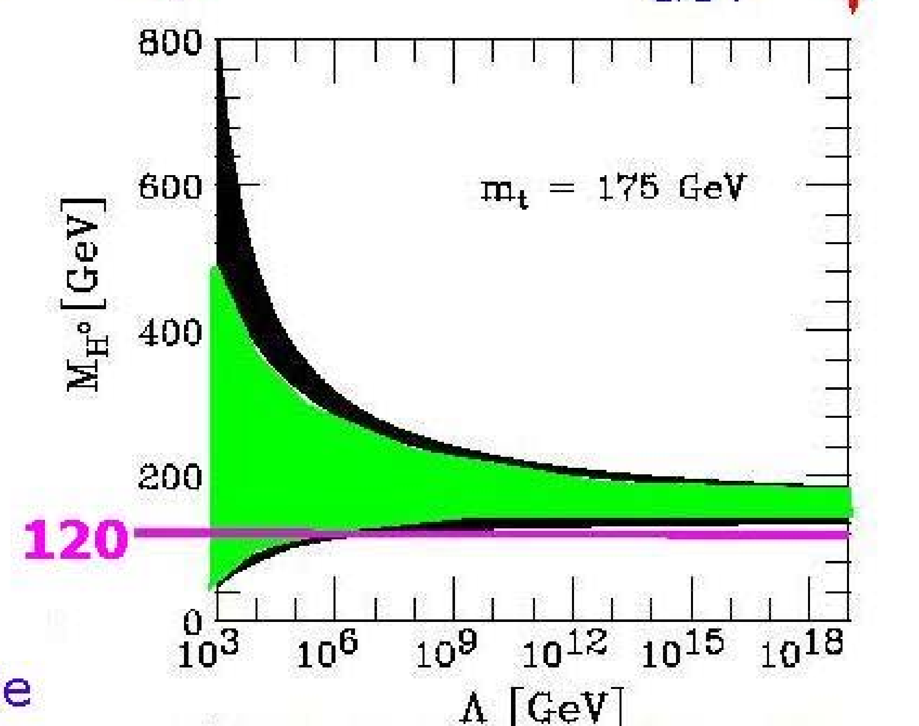
Theoretical constraints II



$\to \lambda(q^2, M_H)$

Planckskala

GUT



Λ: Skala der 'neuen Physik'

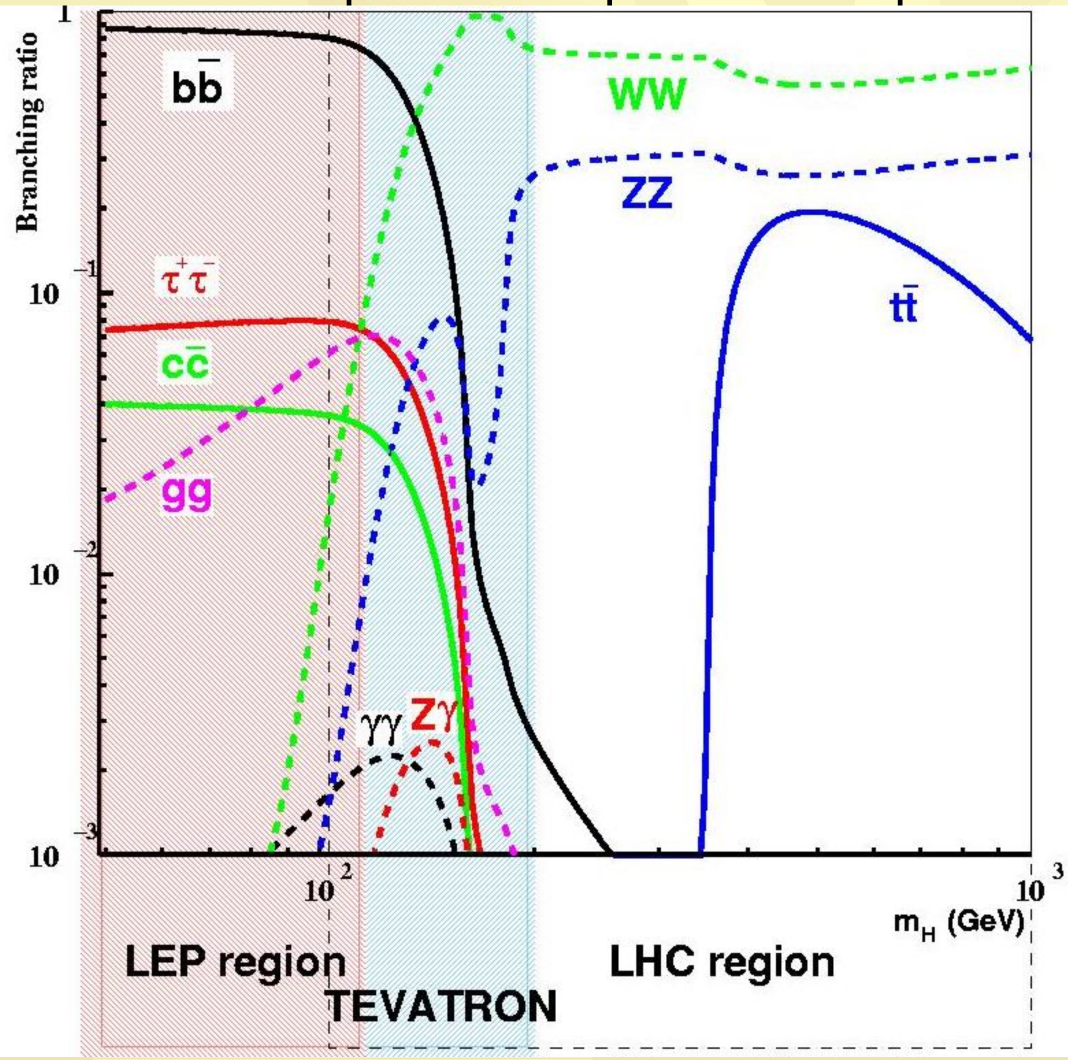
upper limit from Higgs loop:
$\lambda(q^2, M_H) < \infty$ for all $q^2 < \Lambda^2$

lower limit from top box:
$\lambda(q^2, M_H) > 0$ for all $q^2 < \Lambda^2$
(vacuum stability)

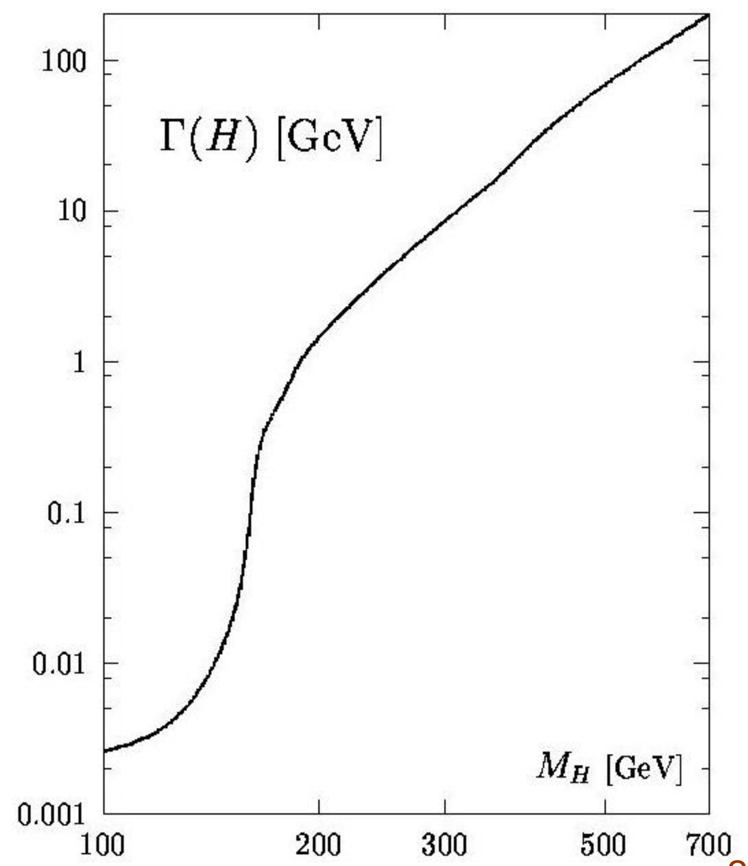
A Higgs Boson mass outside 130-190 GeV requires new physics below the Planck scale

How to find the Higgs?

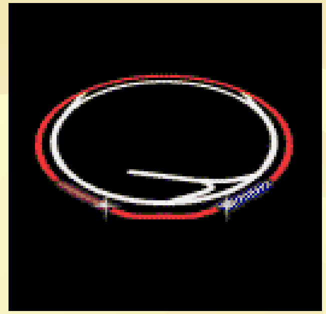
- Final state branching ratios for Standard Model Higgs uniquely predicted:
  - Above threshold $\propto m^2_f$ for Fermions , $\propto m^2_H$ for Bosons (W,Z)
- Production process depends on experiment

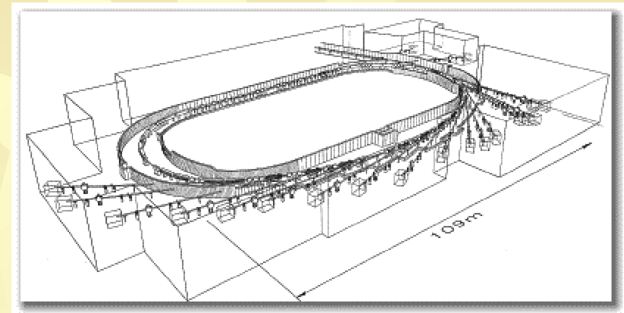


$$\Gamma(M_H = 130\,GeV) \approx 10\,MeV$$
$$\Gamma(M_H \approx 1\,TeV) \approx \tfrac{1}{2}M_H^3(TeV) \approx \tfrac{1}{3}\,TeV$$

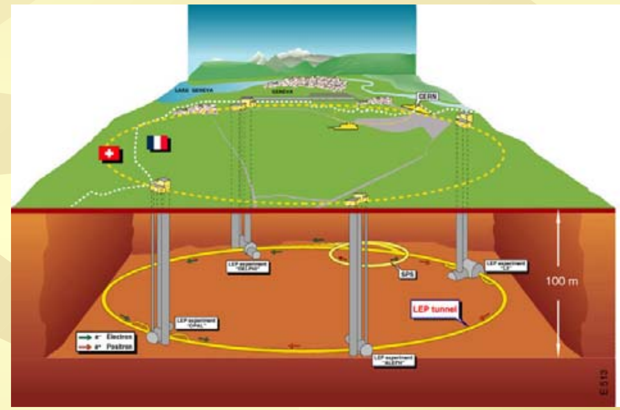


The place to find the Higgs ?





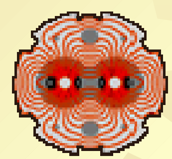
- **Past:** e^+e^- machines
  - CESR, Cornell and DORIS, DESY $\sqrt{s}$ =10GeV
  - L(arge) E(lectron) P(ositron) collider CERN, $\sqrt{s}$ = 85 –208 GeV

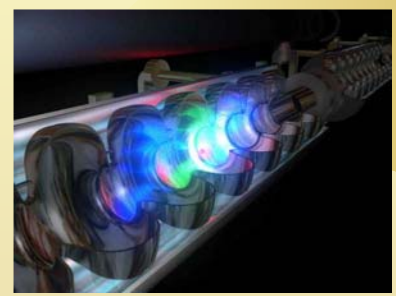


- **Present:** $\bar{p}p$
  - Tevatron, FNAL $\sqrt{s}_{\bar{p}p}$ = 2 TeV

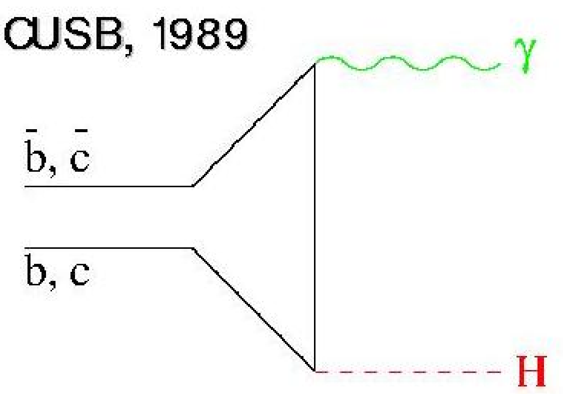
Fermi National Accelerator Laboratory
A Department of Energy National Laboratory Managed by Universities Research Association

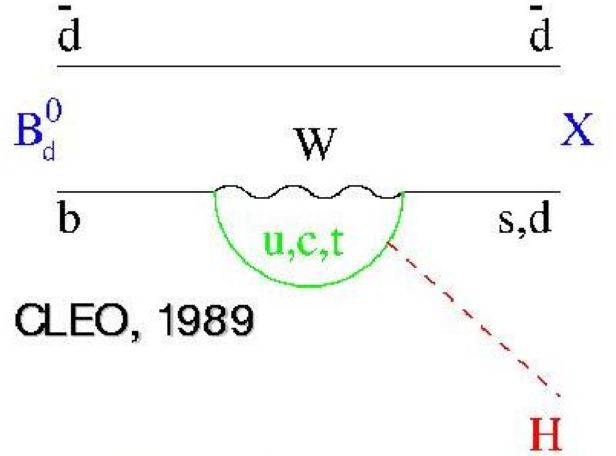
- **Future:**
  - pp: LHC, CERN, $\sqrt{s}_{pp}$ = 14 TeV
  - e^+e^-: TESLA, DESY(?), $\sqrt{s}$ = 0.5-0.8 TeV





The Pre-LEP Aera





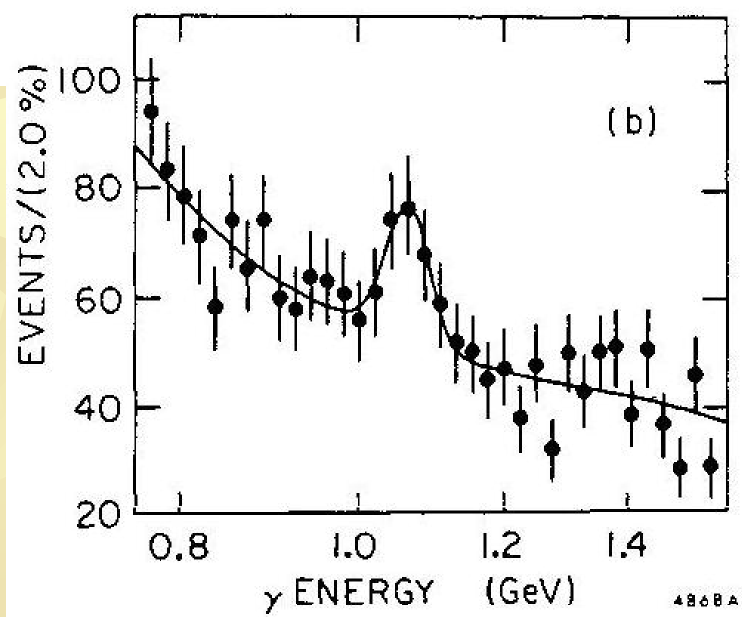
- Higgs Production
  - from real $b\bar{b}$ (Υ)
  - from virtual t
- Higgs Decay
  - $\tau^+\tau^-$
  - $\mu^+\mu^-$
  - inclusive

No excess seen, but …

No unambiguous limit set

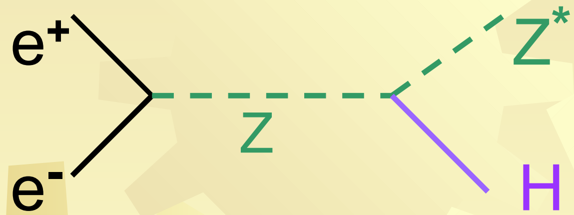
(Large theoretical uncertainties on the predicted decay rates.)

- One of the First Higgs „discoveries"
  - 1984: Crystal Ball, DORIS, DESY
    - 4 s.d. „effect" in $\Upsilon \rightarrow \gamma\, \mathbf{X}$ at m_X = 8300 MeV
    - Not confirmed by CUSB, CLEO, ARGUS, CBall 1986

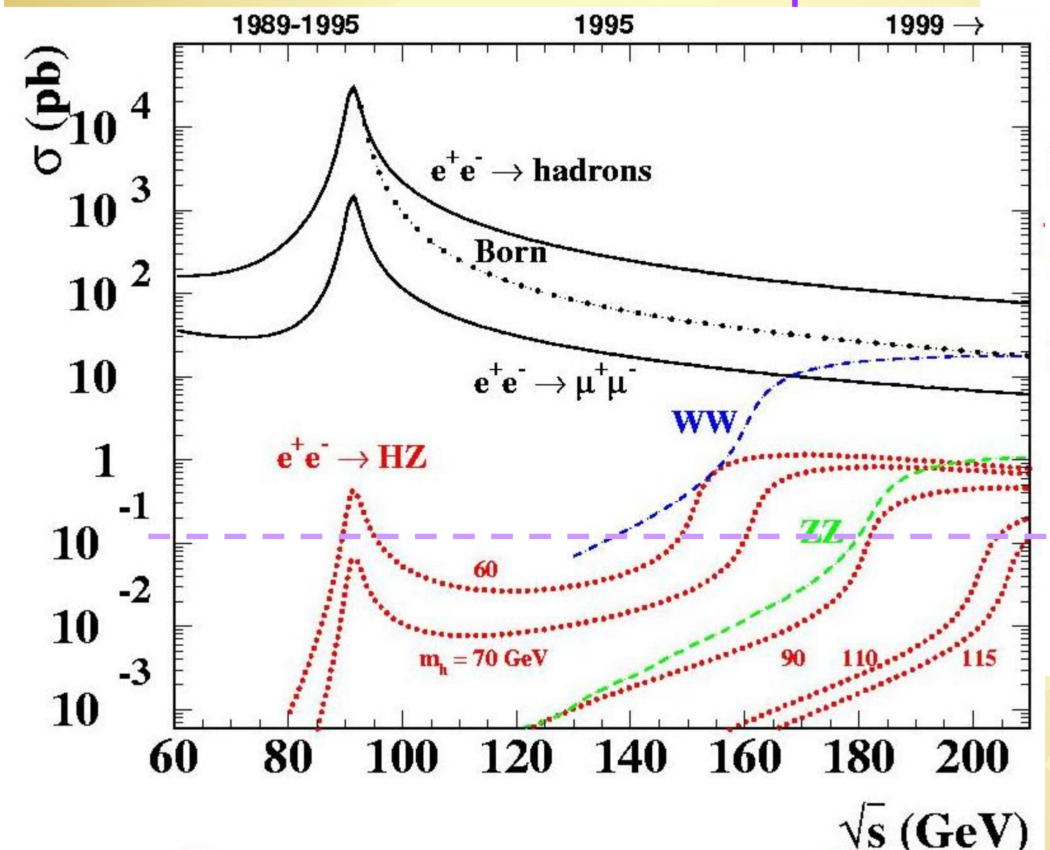


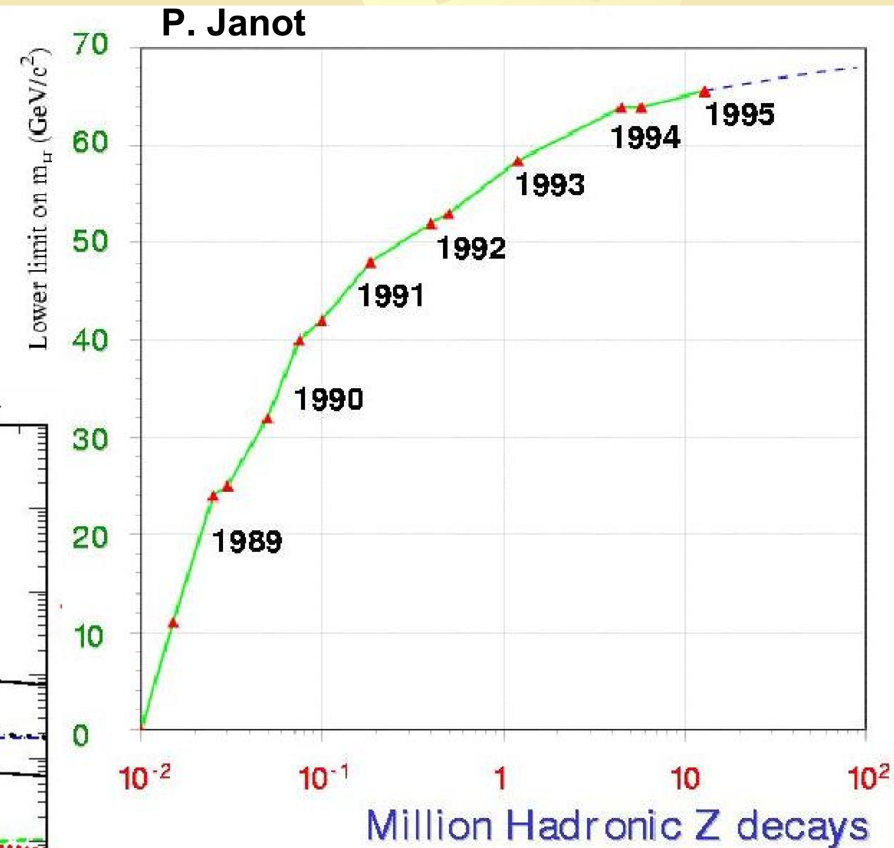
The LEP Aera at $\sqrt{s} = m_Z$ (LEP I)

- Dominant Process:



- LEP typically sensitive to x-sections down to ~0.1 pb

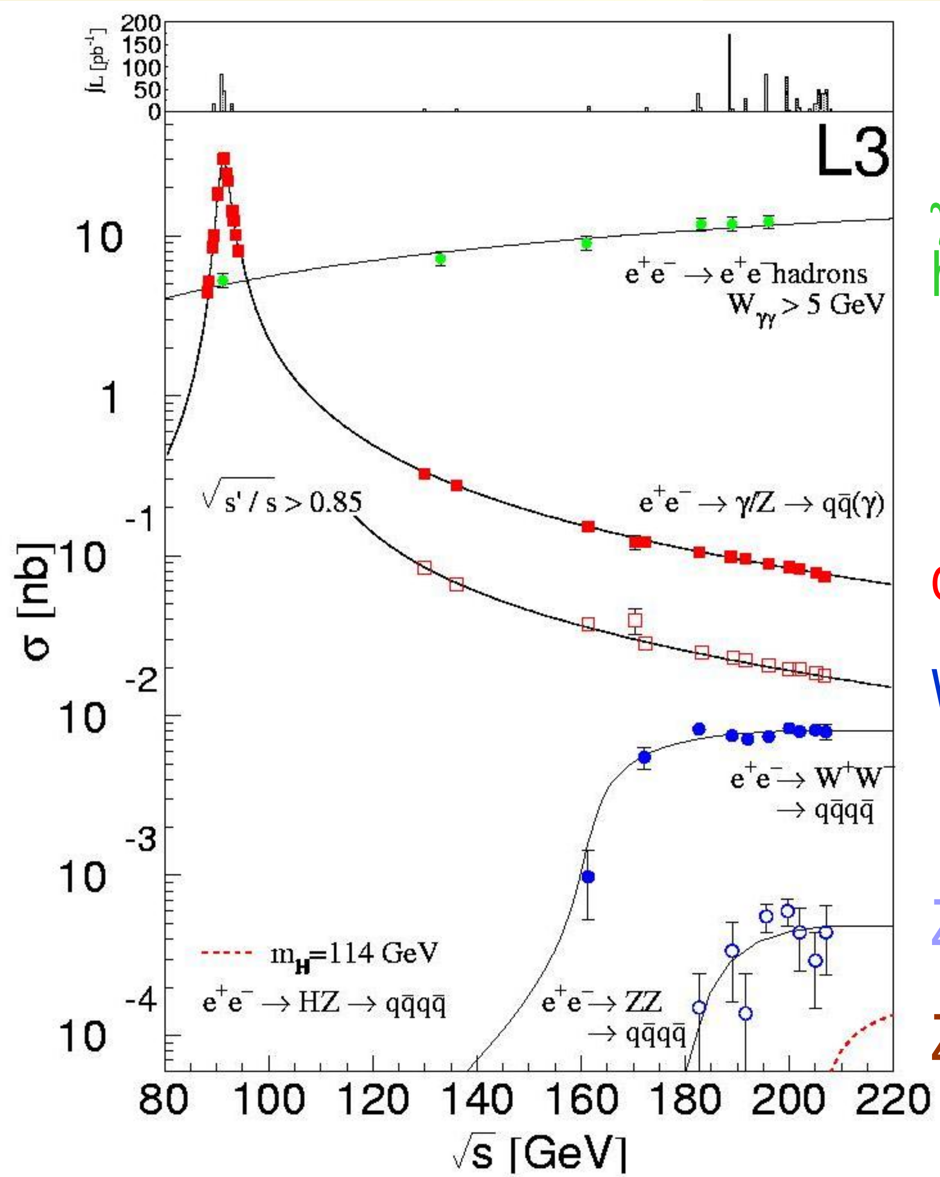




$0.0 < m_H < 65.6$ GeV/ c^2
Excluded at 95% C.L.

by LEP I

The LEP Aera at highest √s=200-208 GeV



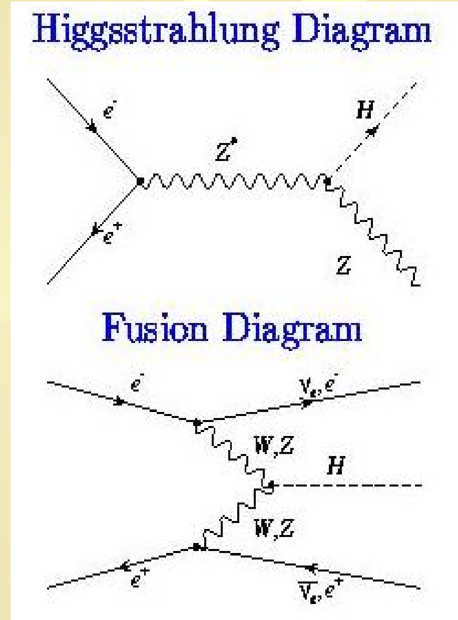
γγ–> hadrons

qq

WW

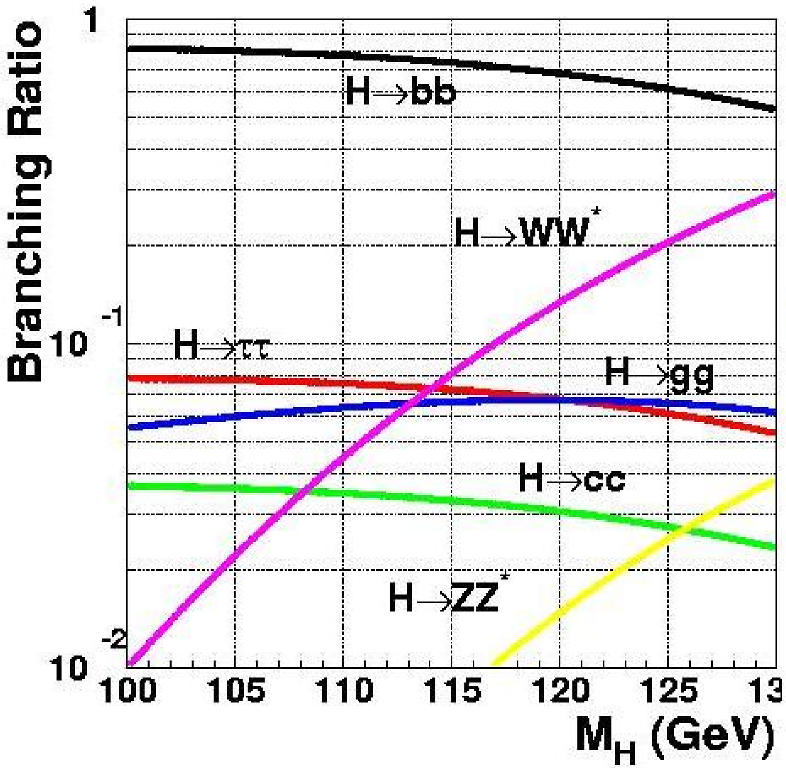
ZZ

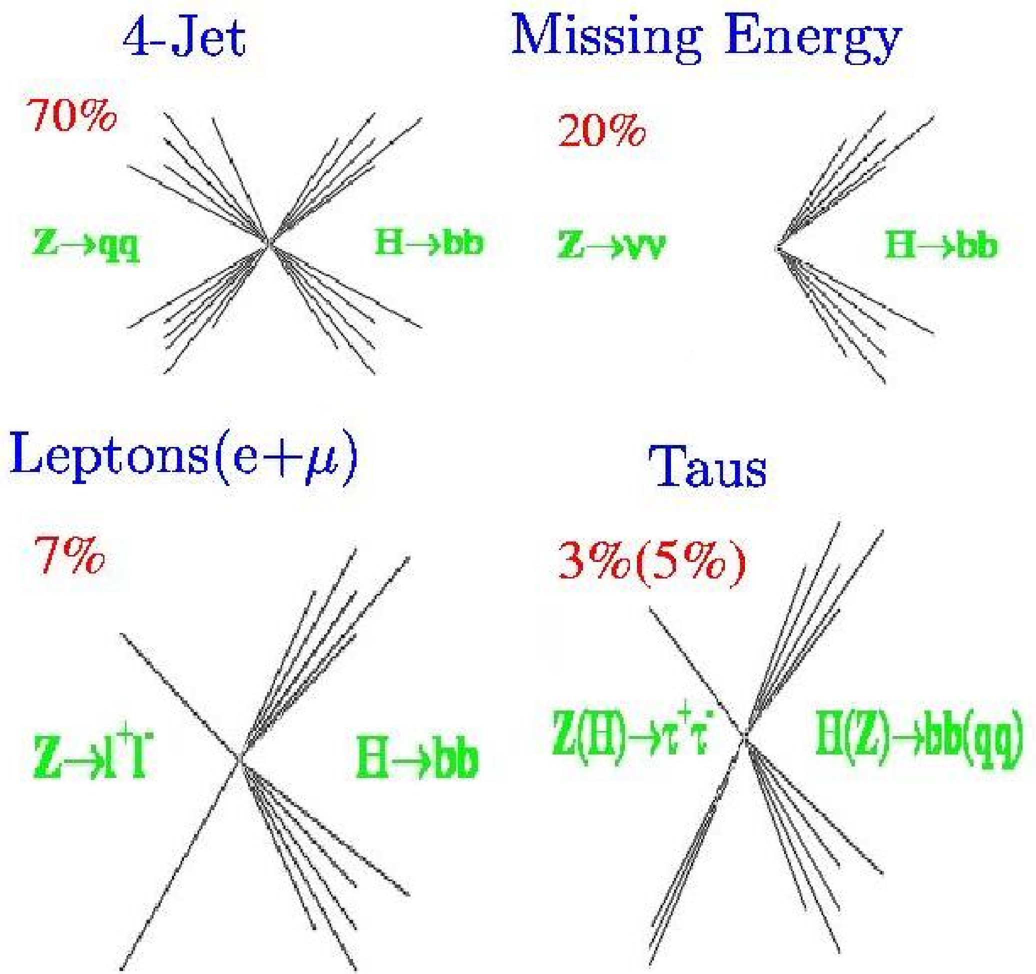
ZH(114)



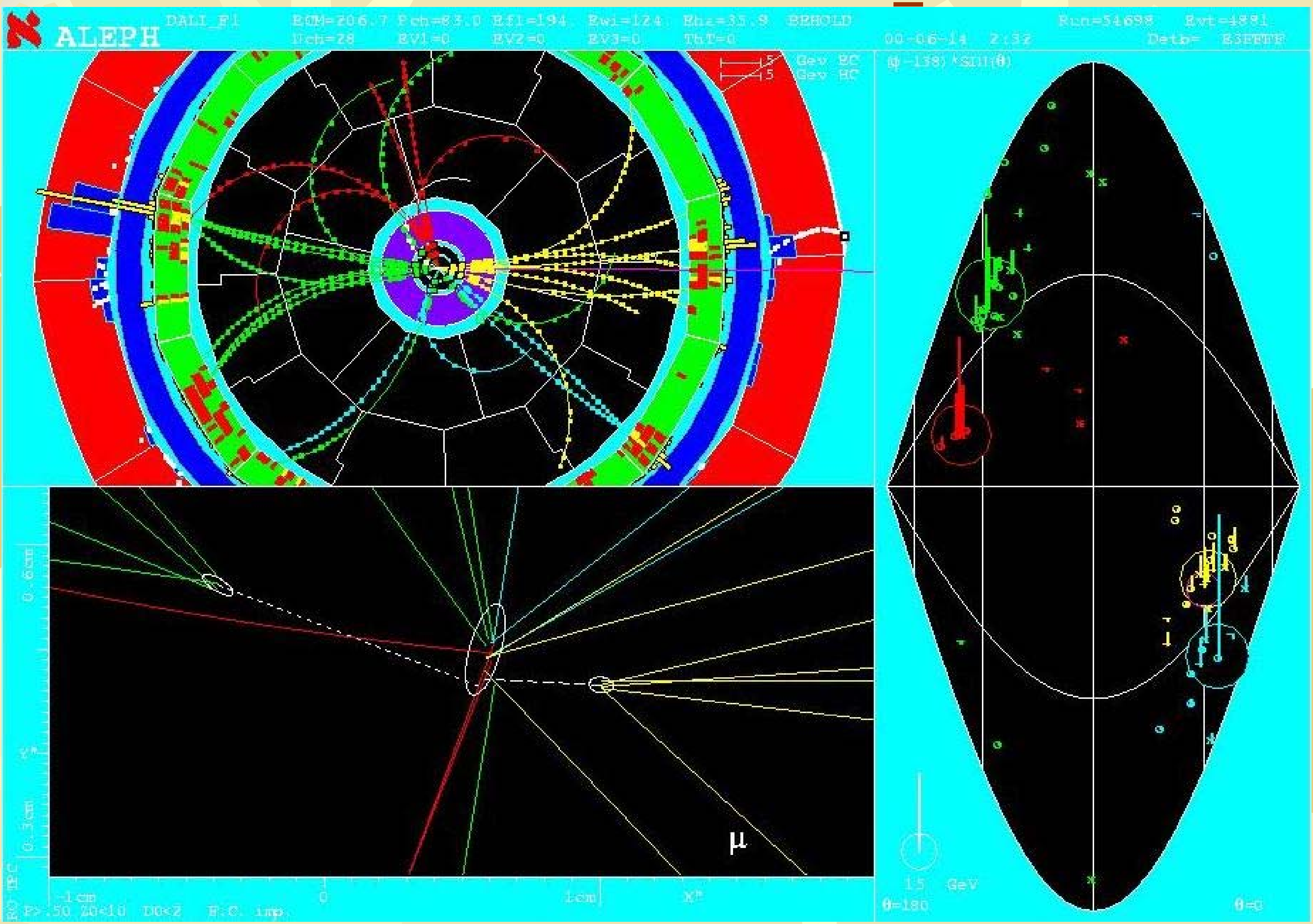
- signal / backgr. separation only on statistical basis
- Crucial ingredients
  - B-tag of H decay
  - H mass from kinem. Fit
  - ZZ and WW veto
  - Correct jet pairing
  - ...

Signal topologies





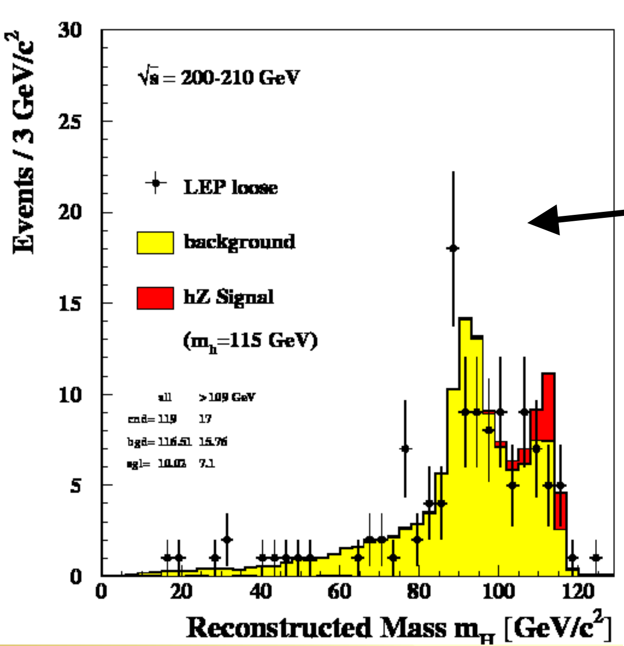
Example: ALEPH candidate (M_H=114.3 GeV)



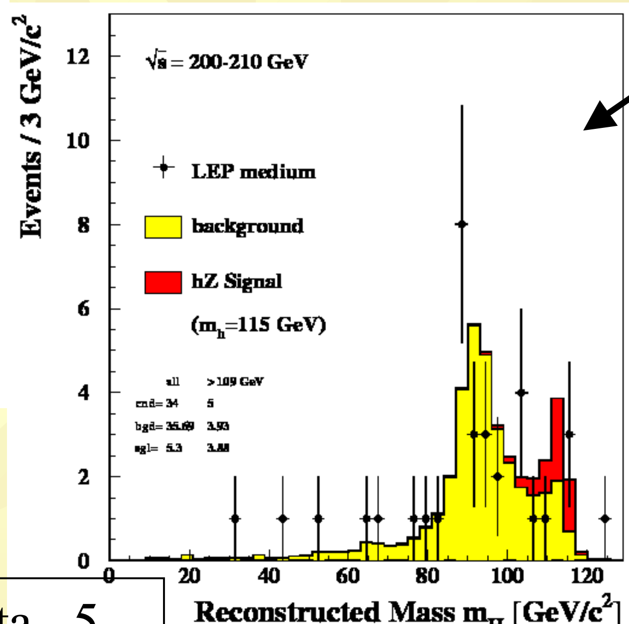
Mass Distributions

S/N for m(H) > 109 GeV/c²

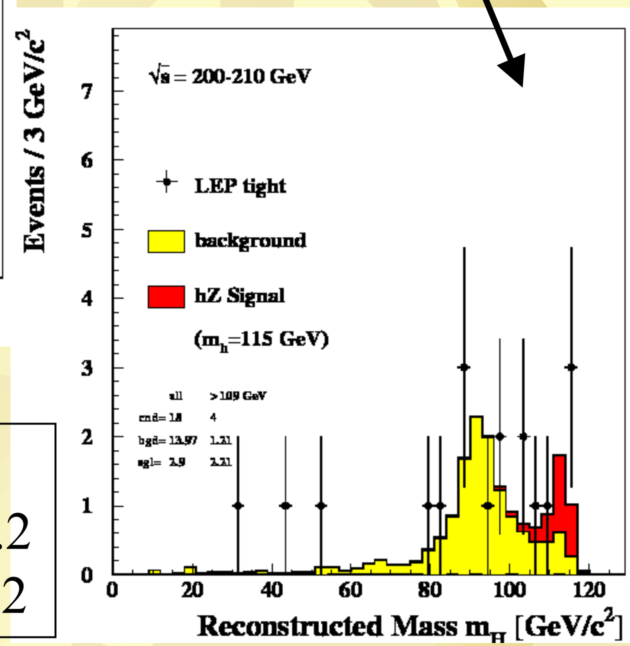
> 0.5   >1   >2



Data	17
Bkg	15.8
Sig	7.1



Data	5
Bkg	3.9
Sig	3.8

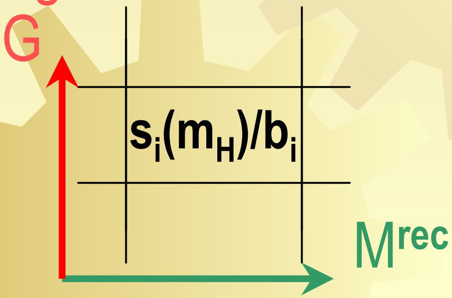


Data	4
Bkg	1.2
Sig	2.2

- Special selection, for purpose of display, only
- Need more than just mass info

Full statistical method

As function of assumed (true) m_H
combine all data in bins of
- reconstructed Higgs mass M^{rec}
- global variable G (b-tag,kinematic,etc.)



Input in each bin:
- **MC signal $s_i(m_H)$**
- **MC backg. b_i**
- **obs. Data n_i**

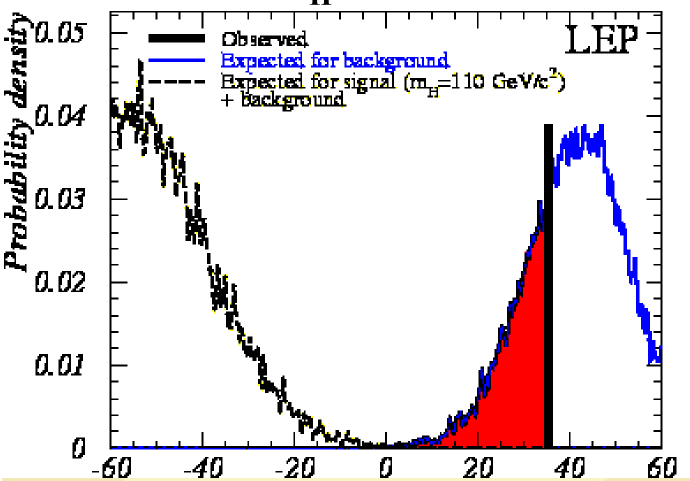
- Construct a parameter that orders outcomes as more signal-like, or less signal-like

$$Q = \frac{P_{poiss}(data \mid signal + background)}{P_{poiss}(data \mid background)}$$

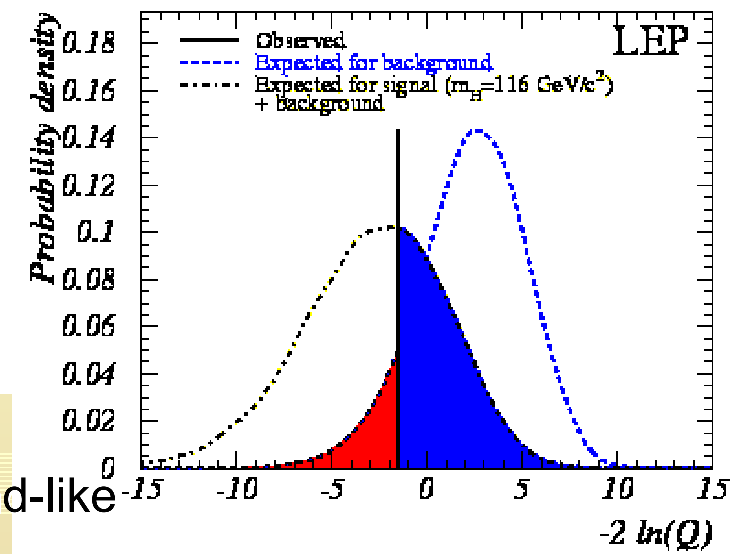
$$\log Q = -s_{tot} + \sum_{bins} n_i^{data} \log\left(1 + \frac{s_i}{b_i}\right)$$

Plot Q as function of assumed Higgs mass m_H

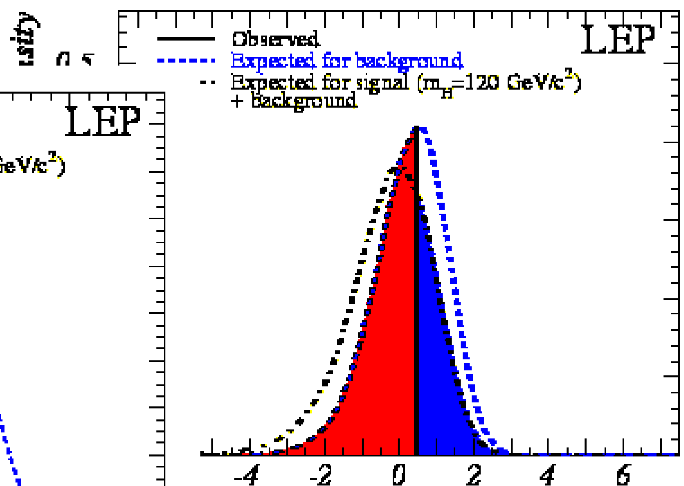
m_H=110 GeV



m_H=116 GeV



m_H=120 GeV

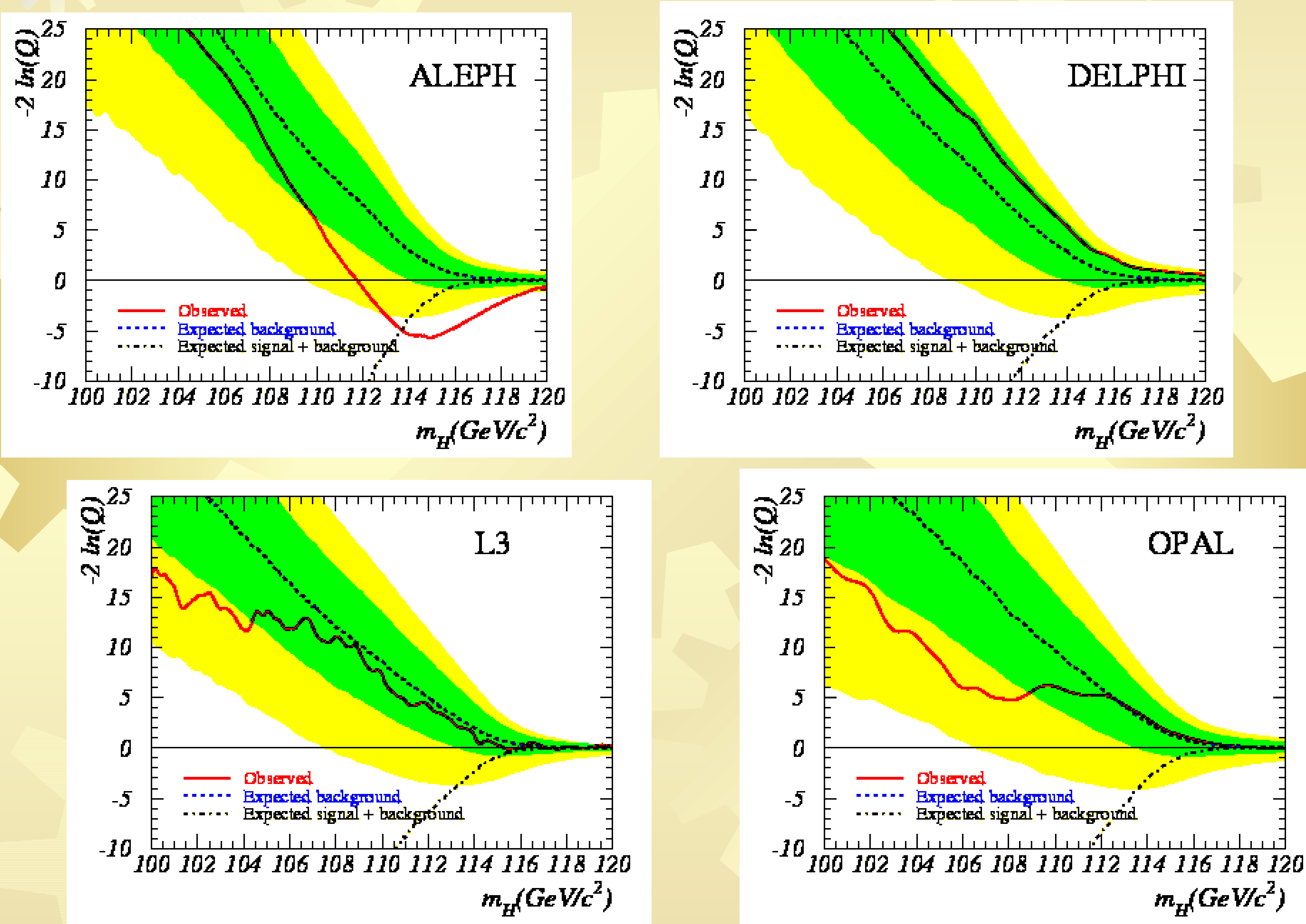


-2 ln (Q)

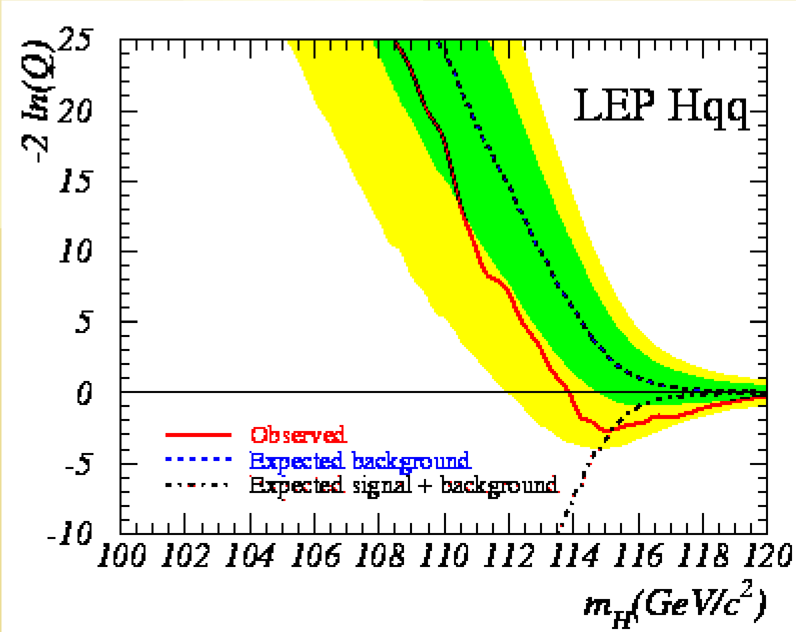
-2 ln (Q)

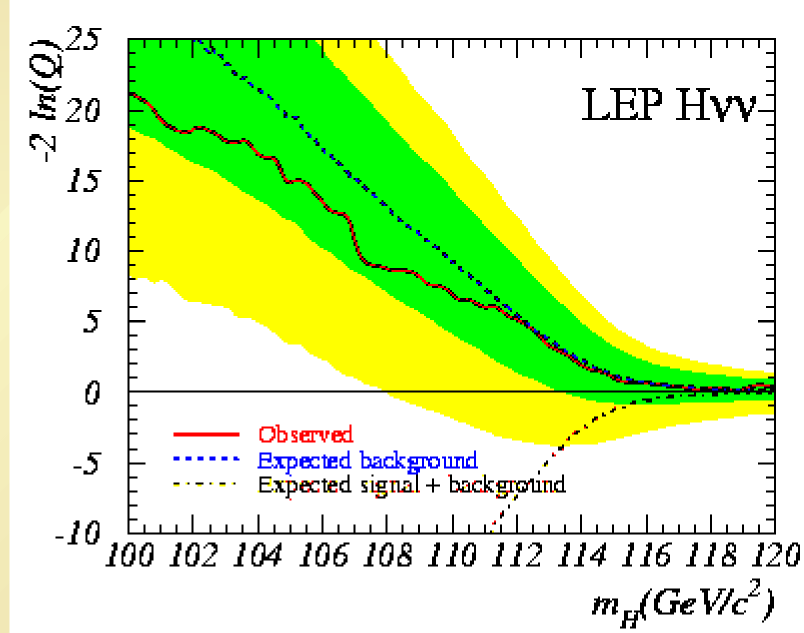
Signal-like ← → background-like

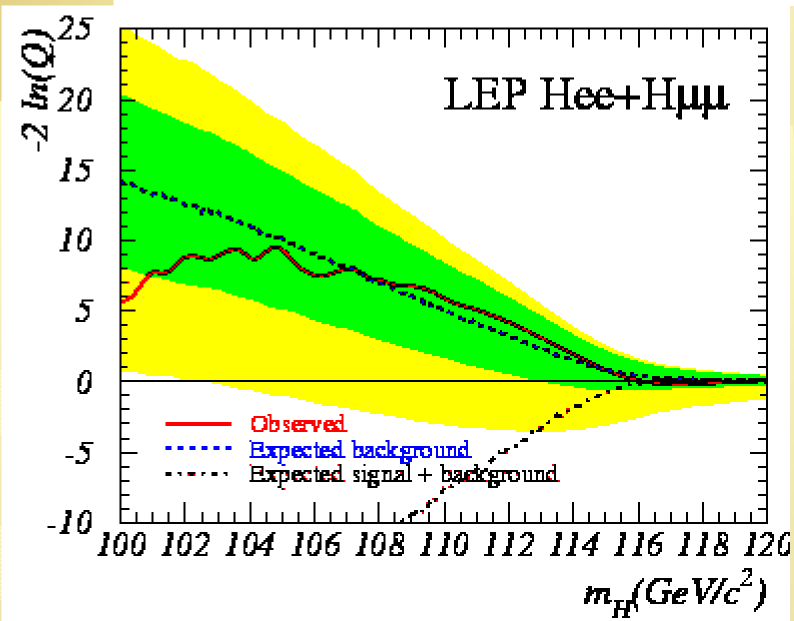
Results of each experiment

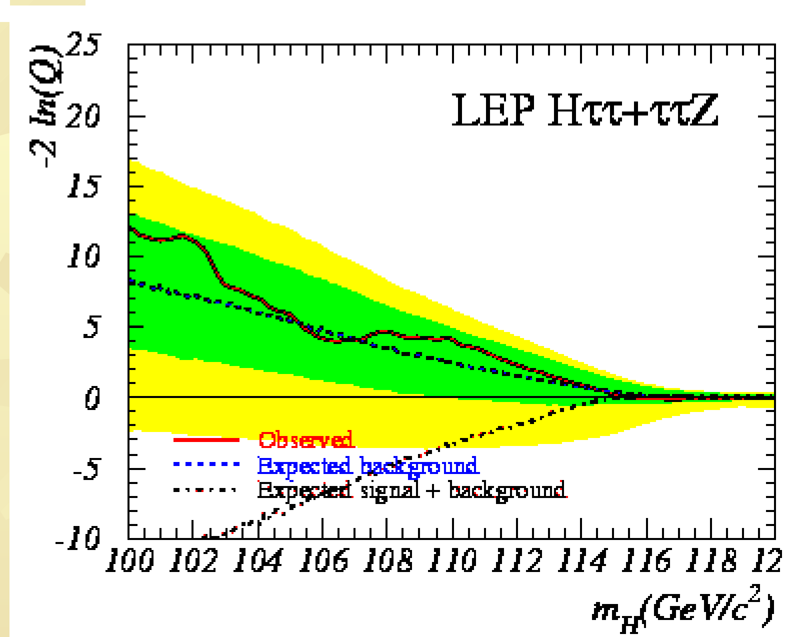


Results per Channel

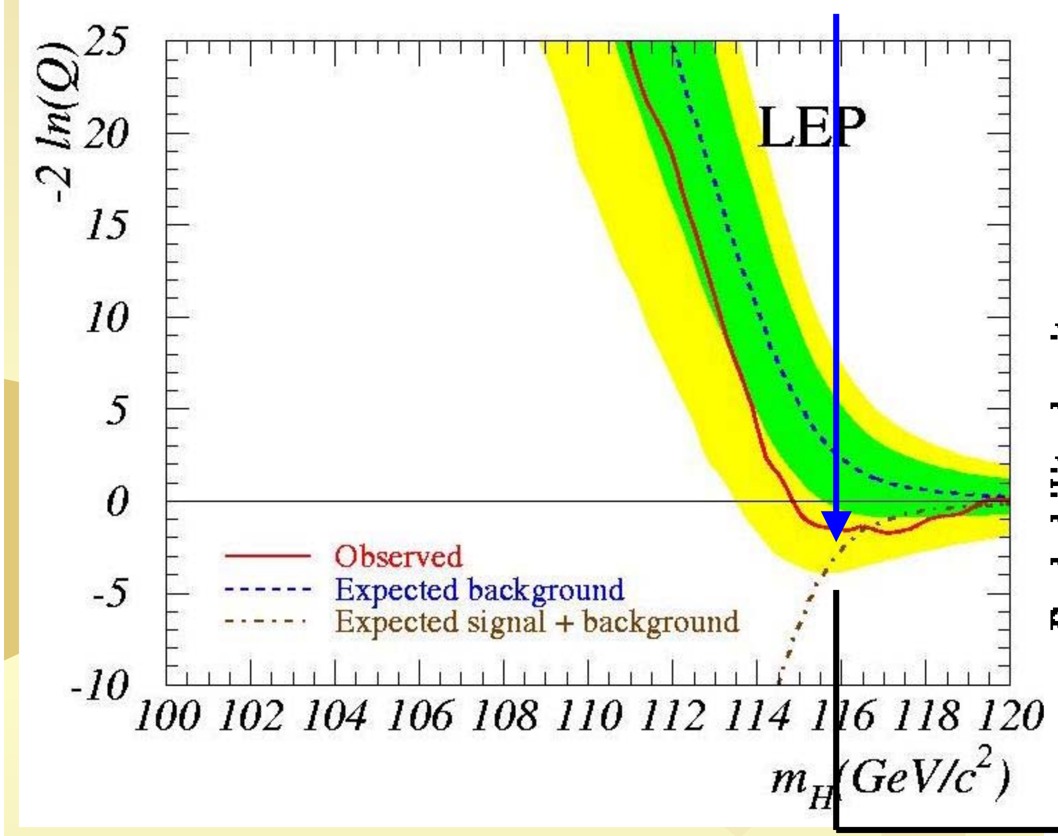


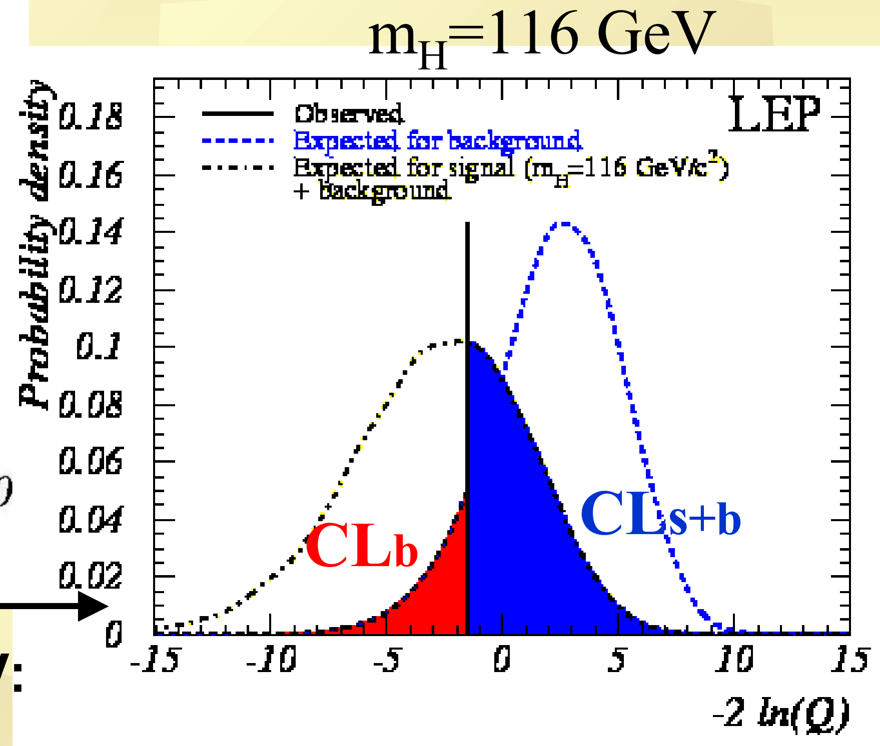






Final LEP Result 2002





Slice at m_H=116 GeV:

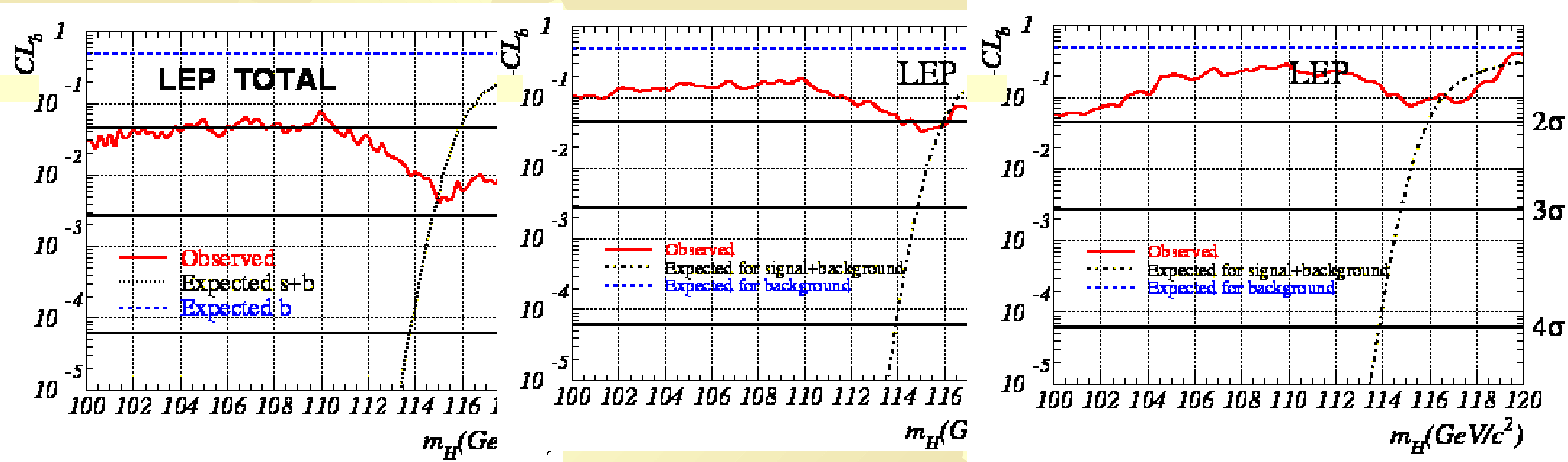
CL_b = 10%

CL_{s+b} = 37%

- Higgs exclusion for CL_{s+b} / CL_b **< 0.05**
  →Mass limit: m_H > 114.4 GeV

expected for bckg only:115.3 GeV

History from End 2000 to Final



CL_b^{115} = 0.42 %
m_H>113.5 GeV
(115.3 expected)

CL_b^{115} ~ 3 %
m_H>114.1 GeV
(115.4 expected)

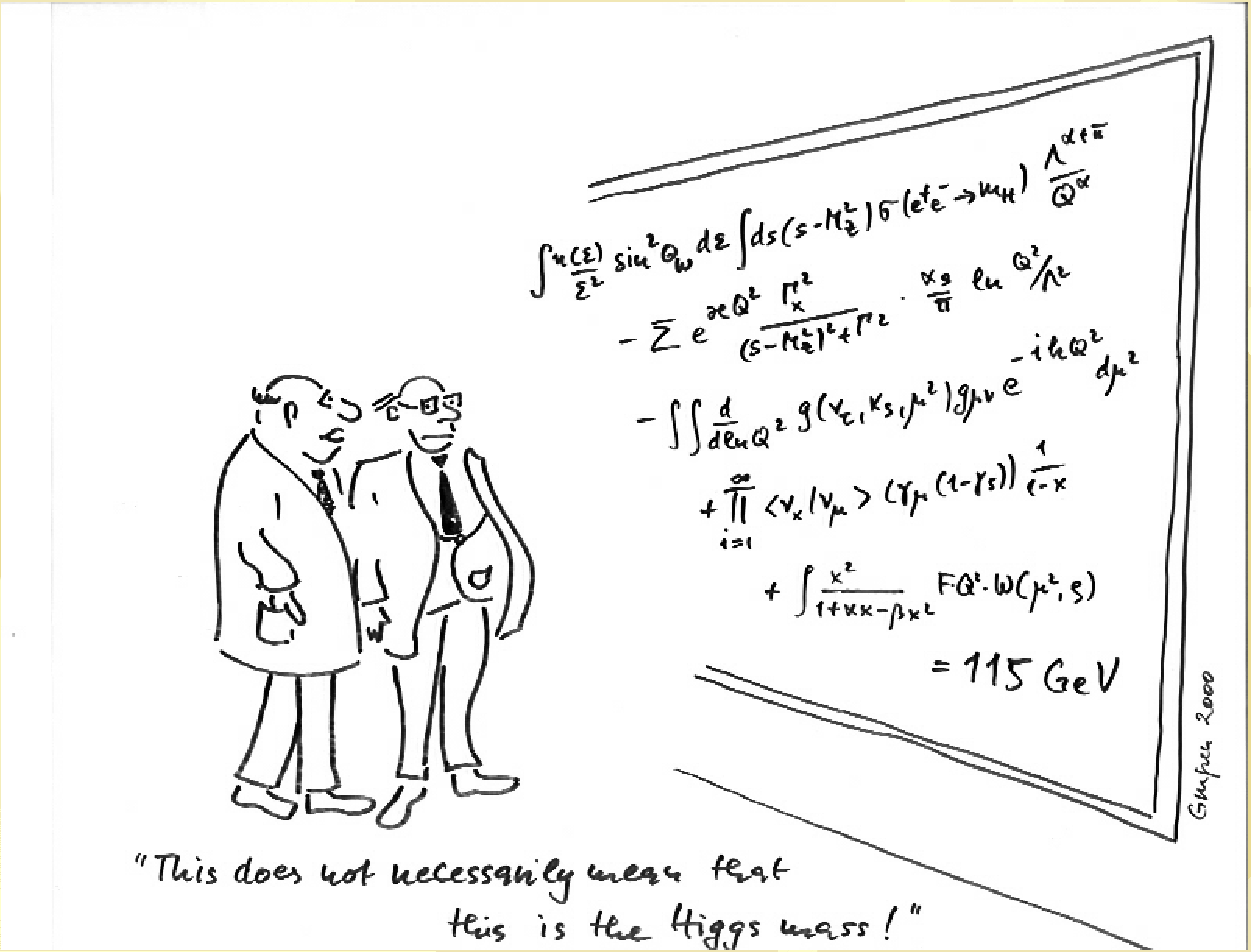
CL_b^{115} ~ 9 %
m_H>114.4 GeV
(115.3 expected)

Background Probabilities CL_b (m_H=115)

	Nov 2000	→	July 2001	→	final
ALEPH:	0.00065	→	0.0015	→	0.0024
DELPHI:	0.68	→	0.77	→	0.73
L3:	0.068	→	0.32	→	0.32
OPAL:	0.19	→	0.20	→	0.50

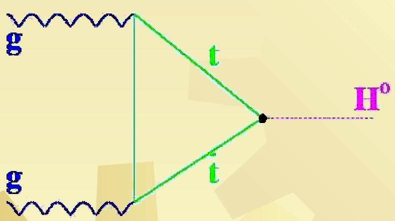
Changes: final Ebeam, detector calibrations
- **Aleph:** 2D correlation in Hqq
- **Delphi:** Hee optimized; New MC for sig and bkg
- **L3:** more MC
- **OPAL:** better bgk estim.; New analyses, new mass rec.

Final LEP Summary

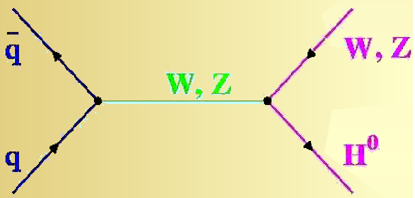


Higgs Search at the Tevatron (Run II)

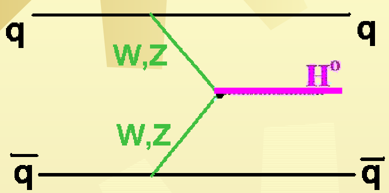
Gluon Fusion



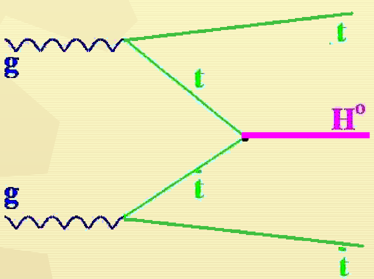
Associate Production



Weak Boson Fusion

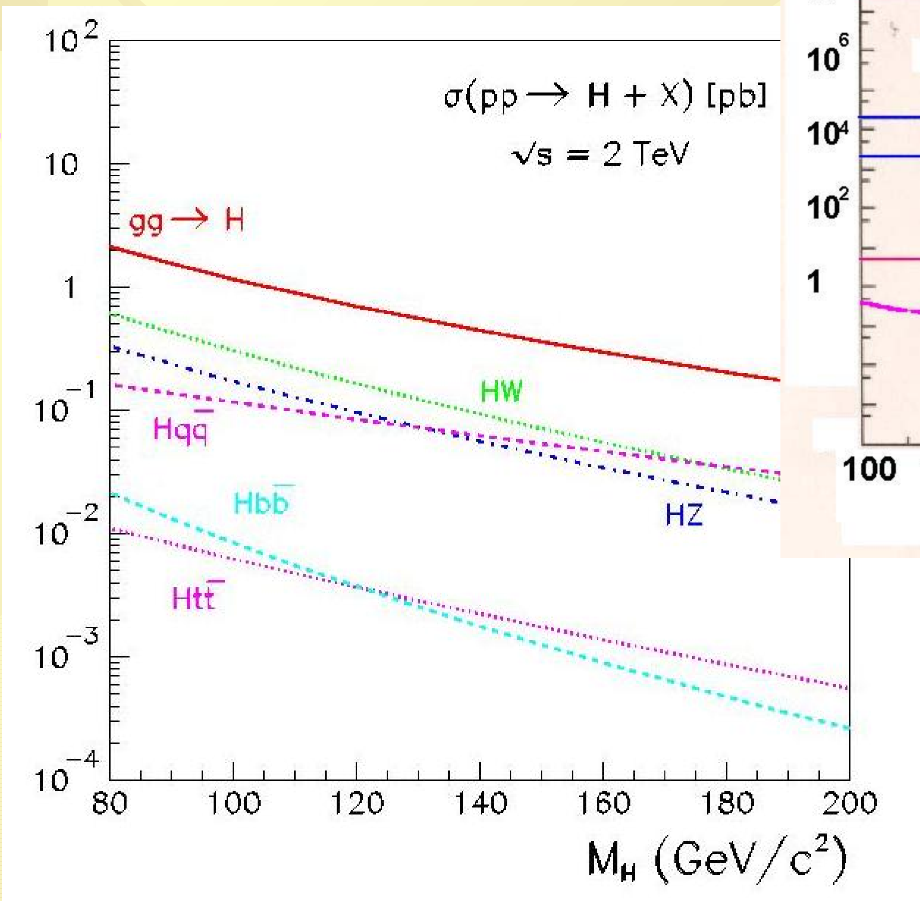


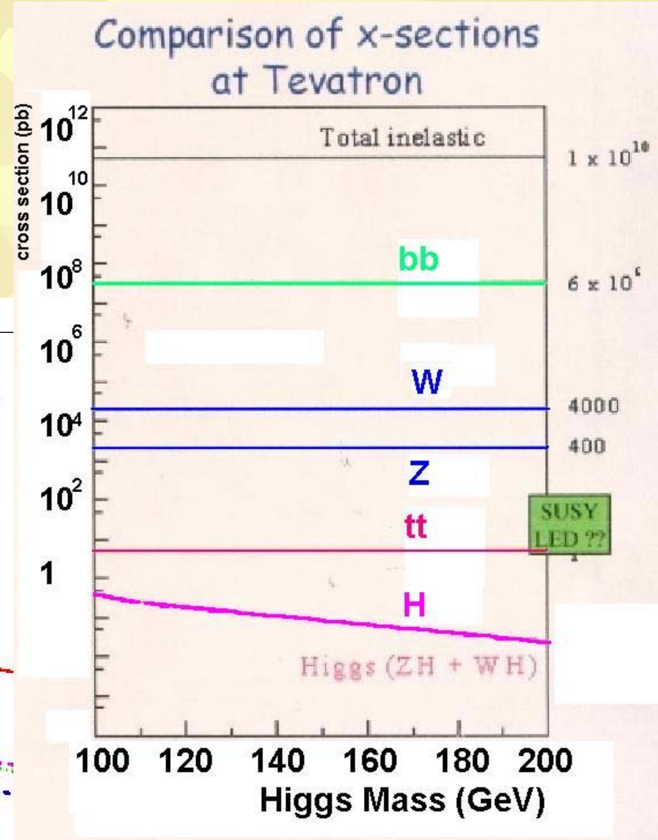
Yukawa Process



Decay:

- M_H < 130 GeV: $\bar{b}b$ dominant
- M_H > 140 GeV: WW dominant



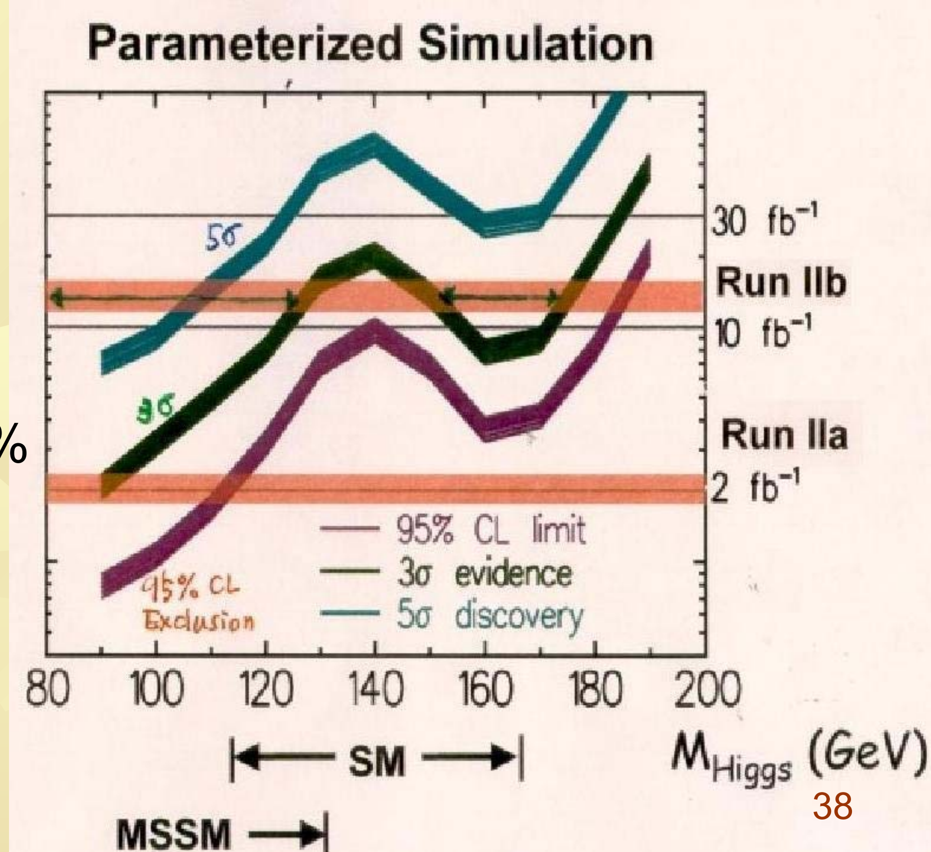


Tevatron Run II expectations

- „New“ Accelerator:
  - More $\bar{p}$, $\bar{p}$ recycling
  - Better cooling

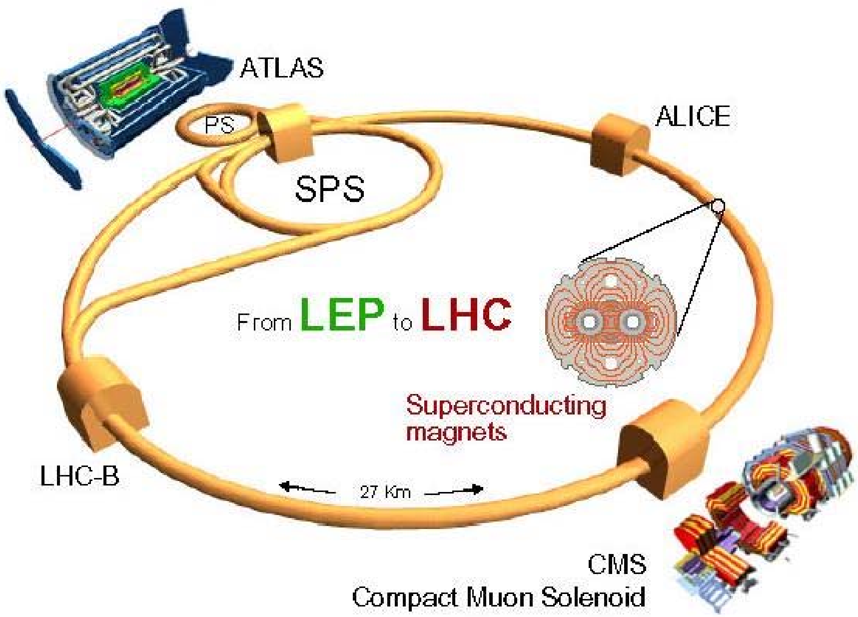
Run I b (maximum) For 1 year	Run I I a (average) For 2 years	Run I I b (average) For 3 years
6×6 bunches	36×36 bunches	140×103 bunches
3.2 pb^{-1}/ week	17 pb^{-1}/ week	105 pb^{-1}/ week
Delivered! → 0.14 fb^{-1}	1.5 fb^{-1}	14 fb^{-1}

- „New“ Detectors
- Schedule:
  - Run IIa in progress
  - Run IIb from 2005 (?)
- Goals:
  - Dijet mass resolution 15% → 10%
  - Efficiencies increase by 30%
  - Trigger efficiencies doubled
  - Bands assume 30% error on this

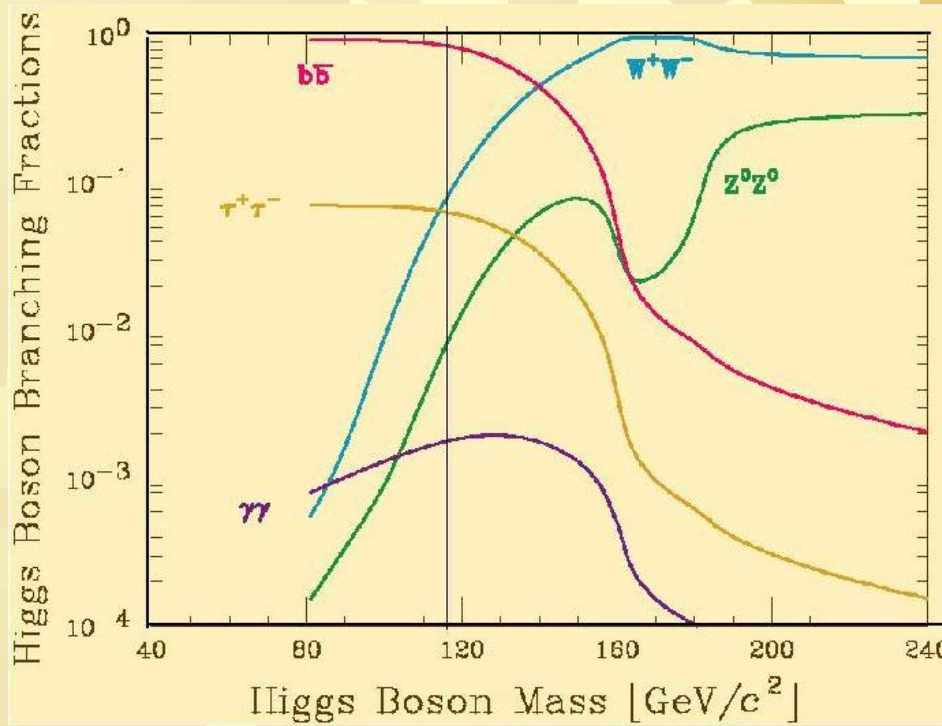


The Higgs search at LHC

- LHC schedule
  - 2007: first collisions
    detector comissioning
  - 2008: 10fb^{-1} „low lumi“
  - from 2009: 100fb^{-1}/a „high lumi“

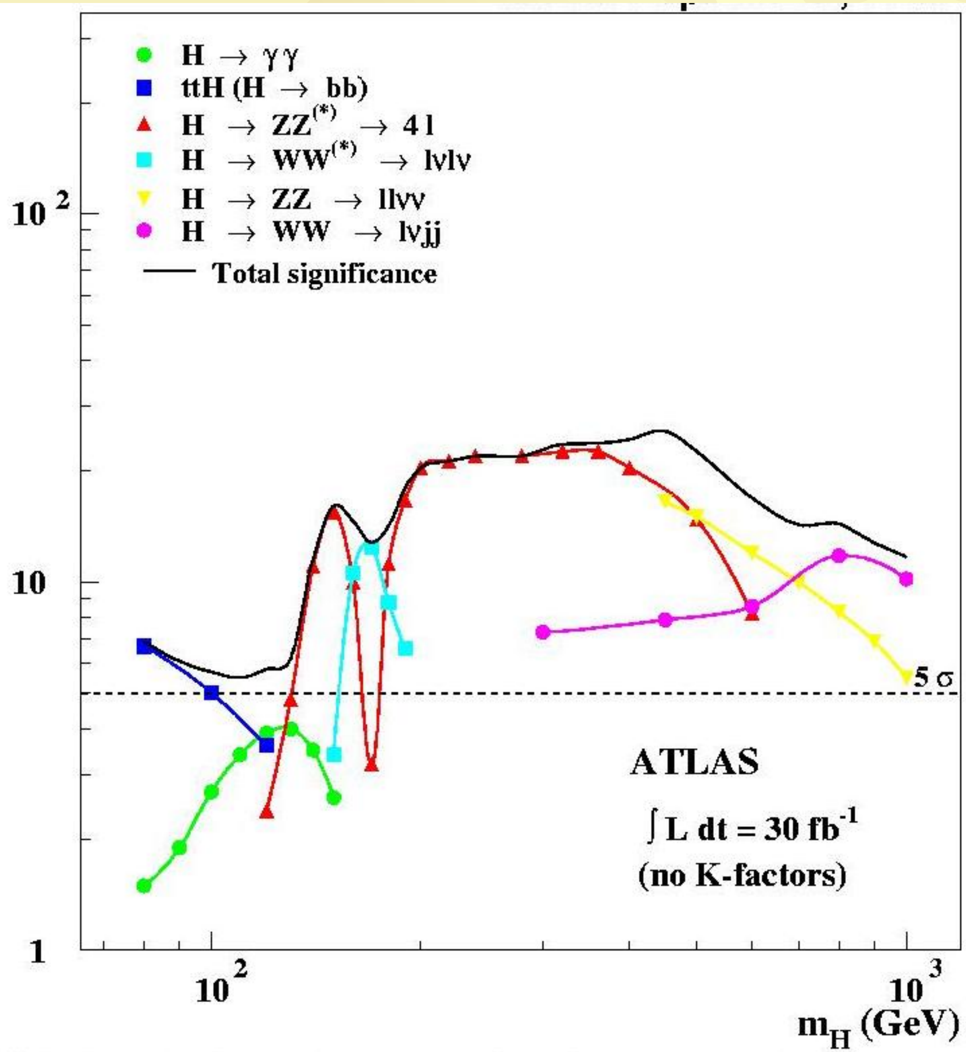


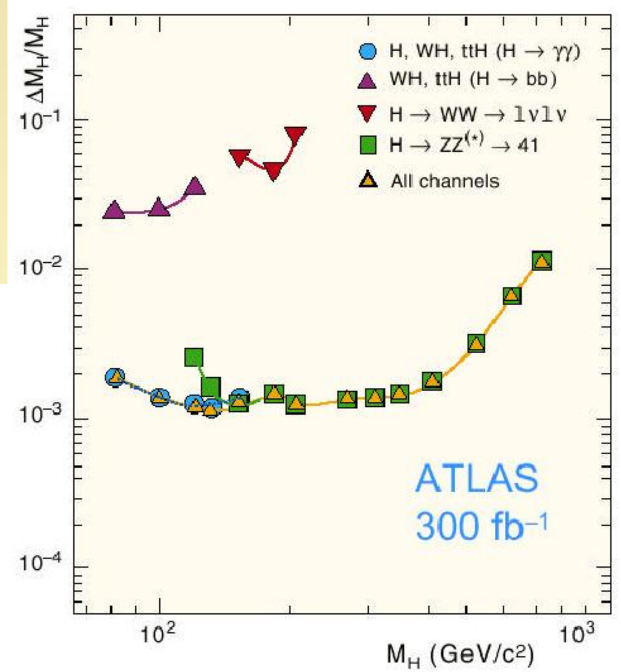
	Beams	Energy		Luminosity
LEP	e^+ e^-	200	GeV	10^{32} cm^{-2}s^{-1}
LHC	p p	14	TeV	10^{34}
	Pb Pb	1312	TeV	10^{27}



LHC Summary: discovery, mass (and width)

- 5σ discovery:
  - With 30 fb^{-1} from 100 to 1000 GeV





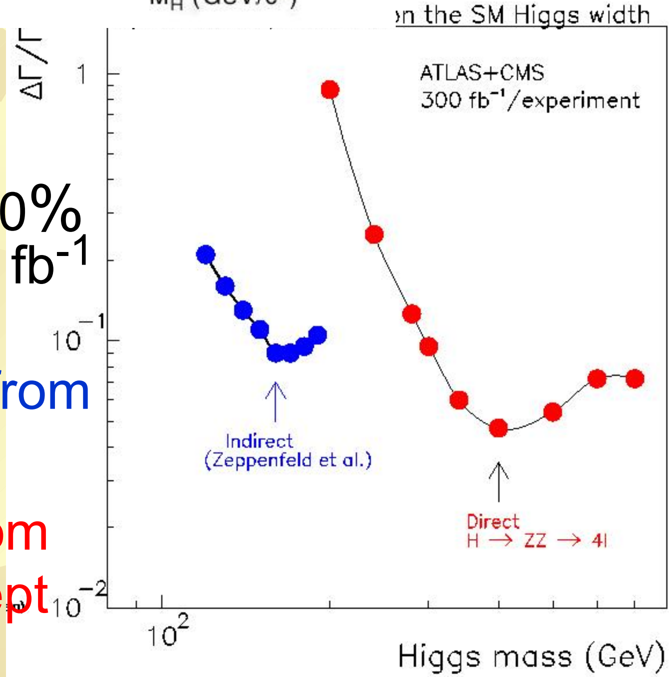
Mass resolution with 300 fb^{-1} :

~10^{-3} for m_H below 500 GeV

$\Delta\Gamma/\Gamma$ ~10% with 300 fb^{-1}

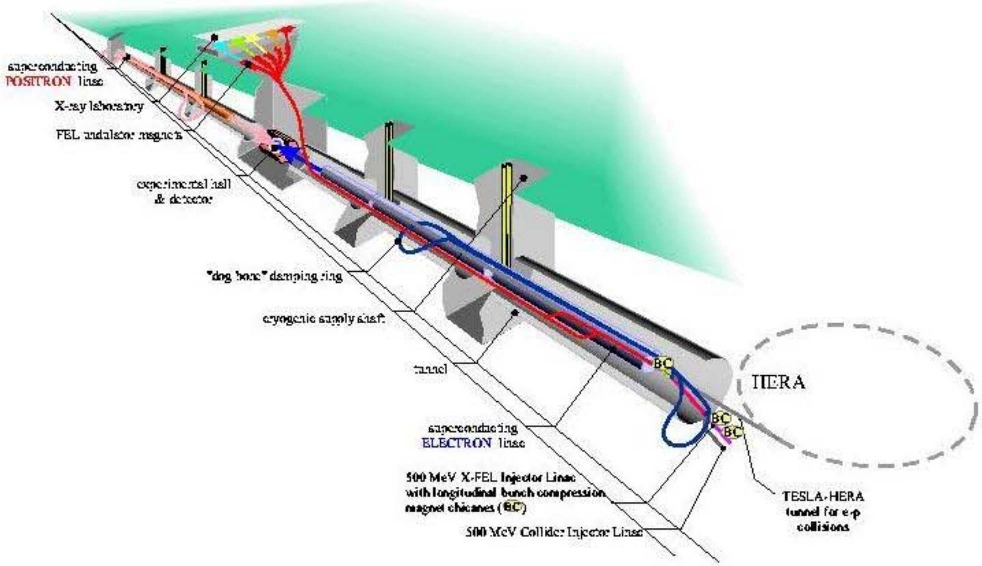
indirect from rates

direct from ZZ→4 lept



The TESLA linear collider

TESLA = **T**eV **E**nergy **S**uperconducting **L**inear **A**ccelerator



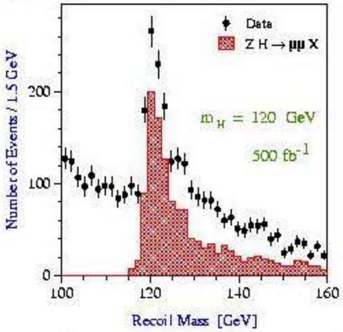
▷ e^+e^-- collisions from $\sqrt{s} = M_Z$ to about **1 TeV** and $\mathcal{L}$ = 2-5 × 10^{34} cm^{-2} s^{-1}

- Primary Goal: Higgs Precision measurements
  - Branching ratios to few %
  - Higgs self coupling λ→Higgs potential
  - CP quantum numbers,
  - Higgs mass to 50 MeV, model independent selections ...
- **Pin down the Higgs model precisely: need for SUSY?**

Higgs Physics at TESLA

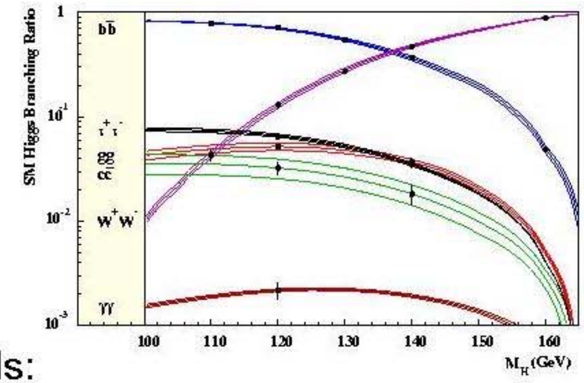
model-independent Higgs search:

$e^+e^- \rightarrow HZ^0 \rightarrow Hl^+l^-$



$\Delta\sigma_{ZH} \approx 3\%$

measurement of branching ratios:



$\Delta BR(H \rightarrow f\bar{f}) \approx$

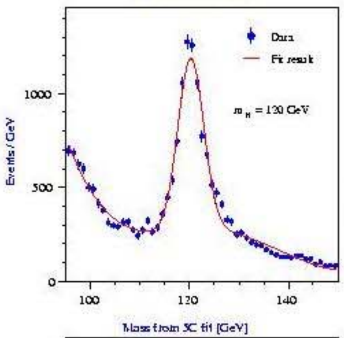
2.4 - 5.0% @ 120 GeV

2.6 - 19.0% @ 140 GeV

depending on channel

2.5-20 % for W and γ

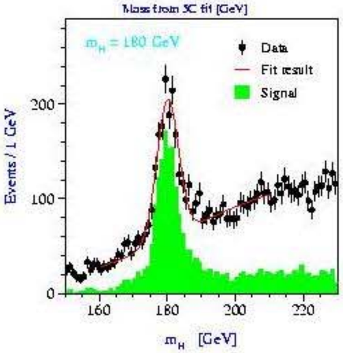
exclusive channels:



$q\bar{q}b\bar{b}$

$\Delta m_H \approx 50$ MeV

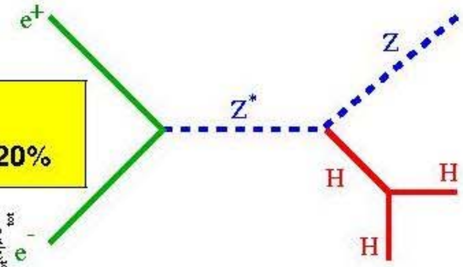
$\Delta m_H/m_H \approx 3-5\times10^{-4}$

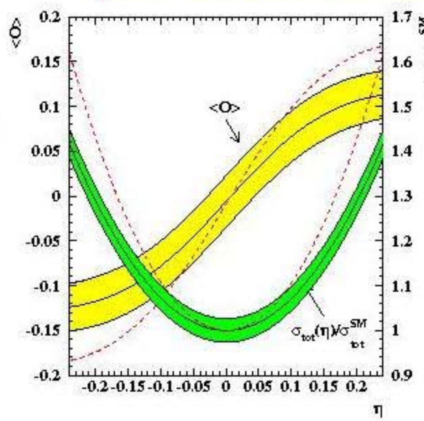


$q\bar{q}W^+W^- \rightarrow$ 6 Jets

Higgs Self-Coupling

$\Delta\lambda_{HHH}/\lambda_{HHH} \approx 20\%$





CP Quantum numbers from

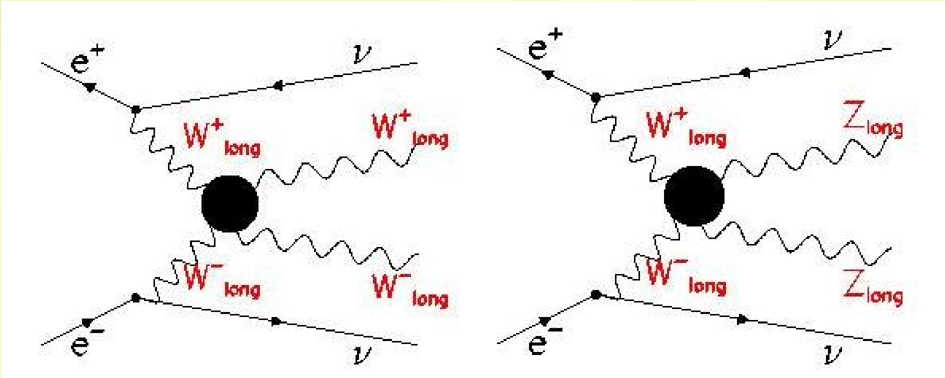
- optimal Observables $<\mathcal{O}>$ angular distributions and
- σ_{tot} ...

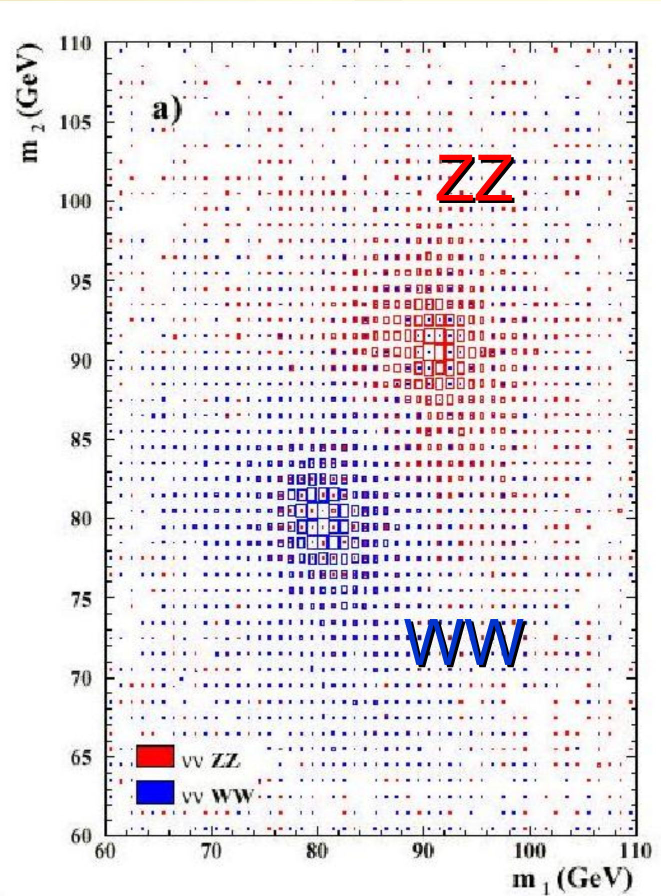
... and many more ...

August 2001, Mainzer Klausurtagung - Bullay , *Arnulf Quadt*

What if no Higgs is found?

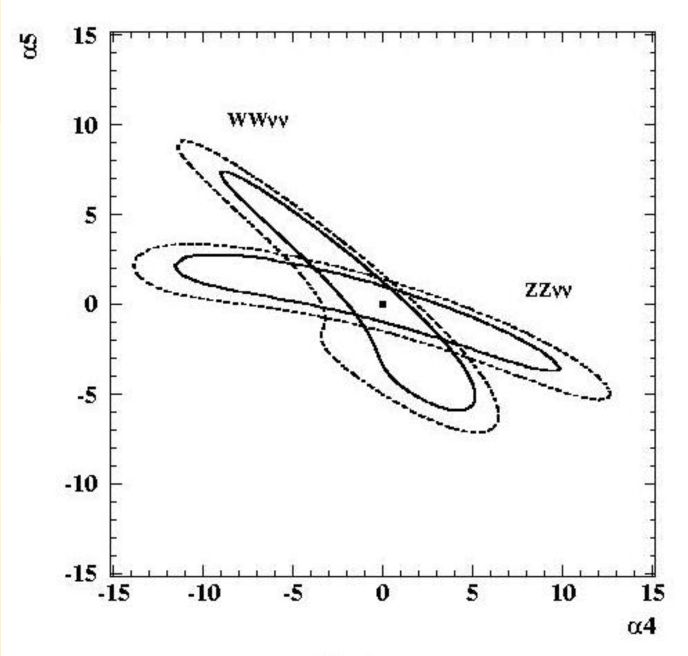
- Need for a strong WW interaction below 1 TeV
  - Benchmark test: 30% jet energy resolution (WW vs ZZ)





Measurement of anomalous QGV (Quartic Gauge Vertex) couplings up to

new strong interaction scales of 2-5 TeV



Summary

- First generation fermion and Gauge Bosons masses amongst key issues for universe and life evolution
  - Appear to be extremely finetuned with respect to each other, the electromagnetic interaction, and the strong interaction
- Need to validate or disprove Higgs mechanism to
  - understand what mass is
  - ask the right questions about the origin of mass values
- Predictive power of Higgs mechanism enables
  - tests of the Higgs model
  - investigations about need for SUSY or other new physics
- New experiments are planned or operating
  - Tevatron by 2008
    - 5σ discovery (3σ evidence) for S.M. Higgs up to 115 (170) GeV
  - LHC by 2009
    - 5σ discovery for S.M. (and by 2011 other) Higgses below 1 TeV
  - TESLA from ~2010 onwards
    - Precision test of all parameters of the Higgs sector