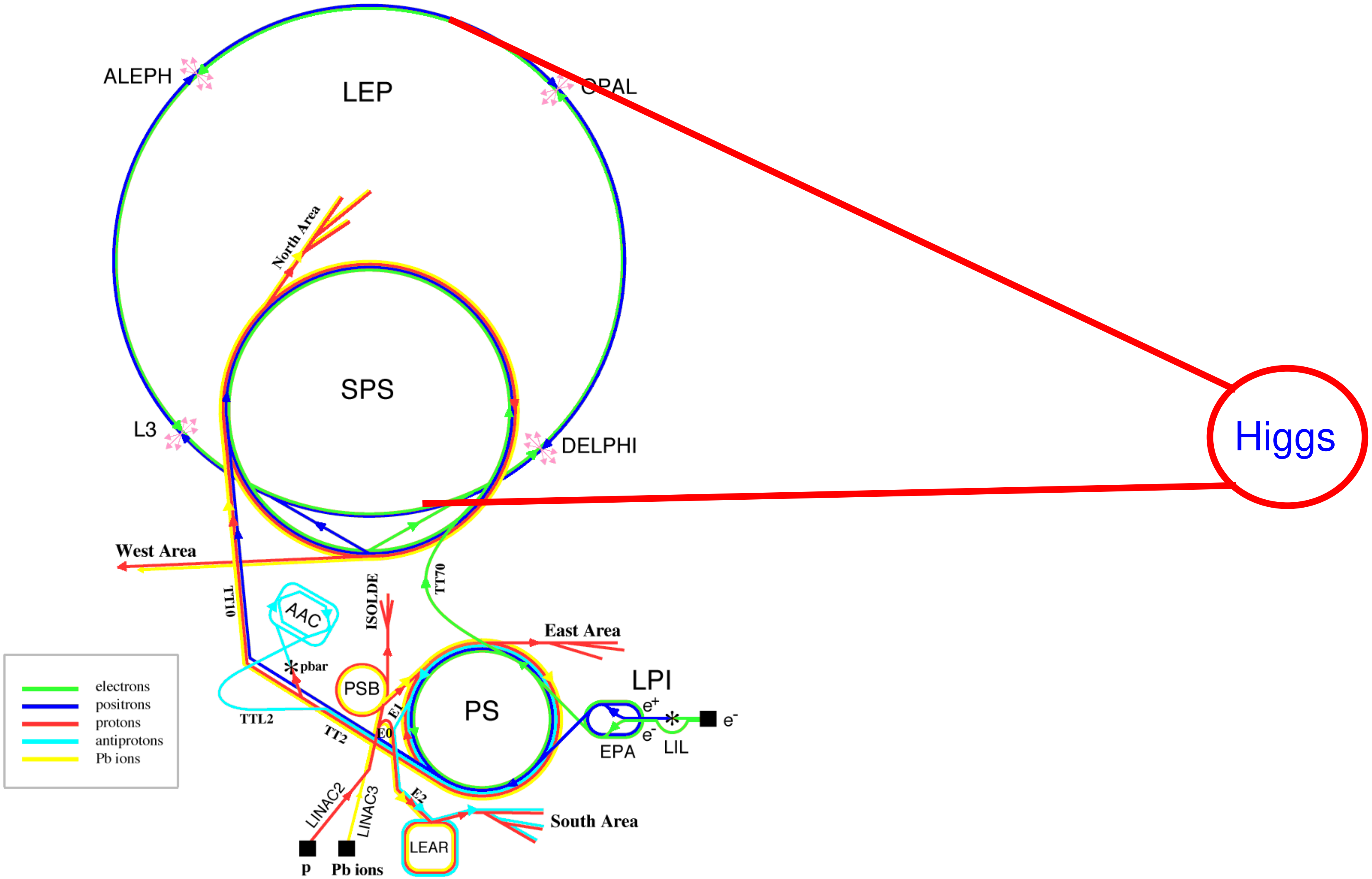
DIE SUCHE NACH DEM HIGGS-BOSON



Stefan Söldner-Rembold, CERN
29 November 2000

Astroteilchenphysiksymposium
Wuppertal

find a Higgs: 9 papers
find t Higgs: 5024 papers....

VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson[3] has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasmon modes of finite mass when the gas is charged.

The simplest theory which exhibits this behavior is a gauge-invariant version of a model used by Goldstone[2] himself: Two real[4] scalar fields φ_1, φ_2 and a real vector field A_μ interact through the Lagrangian density

$$L = -\tfrac{1}{2}(\nabla\varphi_1)^2 - \tfrac{1}{2}(\nabla\varphi_2)^2 - V(\varphi_1^2 + \varphi_2^2) - \tfrac{1}{4}F_{\mu\nu}F^{\mu\nu}, \qquad (1)$$

where

$$\nabla_\mu\varphi_1 = \partial_\mu\varphi_1 - eA_\mu\varphi_2,$$

$$\nabla_\mu\varphi_2 = \partial_\mu\varphi_2 + eA_\mu\varphi_1,$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu,$$

e is a dimensionless coupling constant, and the metric is taken as $-+++$. L is invariant under simultaneous gauge transformations of the first kind on $\varphi_1 \pm i\varphi_2$ and of the second kind on A_μ. Let us suppose that $V'(\varphi_0^2) = 0$, $V''(\varphi_0^2) > 0$; then spontaneous breakdown of U(1) symmetry occurs. Consider the equations [derived from (1) by treating $\Delta\varphi_1$, $\Delta\varphi_2$, and A_μ as small quantities] governing the propagation of small oscillations about the "vacuum" solution $\varphi_1(x) = 0$, $\varphi_2(x) = \varphi_0$:

$$\partial^\mu\{\partial_\mu(\Delta\varphi_1) - e\varphi_0 A_\mu\} = 0, \qquad (2a)$$

$$\{\partial^2 - 4\varphi_0^2 V''(\varphi_0^2)\}(\Delta\varphi_2) = 0, \qquad (2b)$$

$$\partial_\nu F^{\mu\nu} = e\varphi_0\{\partial^\mu(\Delta\varphi_1) - e\varphi_0 A_\mu\}. \qquad (2c)$$

Equation (2b) describes waves whose quanta have (bare) mass $2\varphi_0\{V''(\varphi_0^2)\}^{1/2}$; Eqs. (2a) and (2c) may be transformed, by the introduction of new variables

$$B_\mu = A_\mu - (e\varphi_0)^{-1}\partial_\mu(\Delta\varphi_1),$$

$$G_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu = F_{\mu\nu}, \qquad (3)$$

into the form

$$\partial_\mu B^\mu = 0, \quad \partial_\nu G^{\mu\nu} + e^2\varphi_0^2 B^\mu = 0. \qquad (4)$$

Equation (4) describes vector waves whose quanta have (bare) mass $e\varphi_0$. In the absence of the gauge field coupling ($e = 0$) the situation is quite different: Equations (2a) and (2c) describe zero-mass scalar and vector bosons, respectively. In passing, we note that the right-hand side of (2c) is just the linear approximation to the conserved current: It is linear in the vector potential, gauge invariance being maintained by the presence of the gradient term.[5]

When one considers theoretical models in which spontaneous breakdown of symmetry under a semisimple group occurs, one encounters a variety of possible situations corresponding to the various distinct irreducible representations to which the scalar fields may belong; the gauge field always belongs to the adjoint representation.[6] The model of the most immediate interest is that in which the scalar fields form an octet under SU(3): Here one finds the possibility of two nonvanishing vacuum expectation values, which may be chosen to be the two $Y=0$, $I_3 = 0$ members of the octet.[7] There are two massive scalar bosons with just these quantum numbers; the remaining six components of the scalar octet combine with the corresponding components of the gauge-field octet to describe

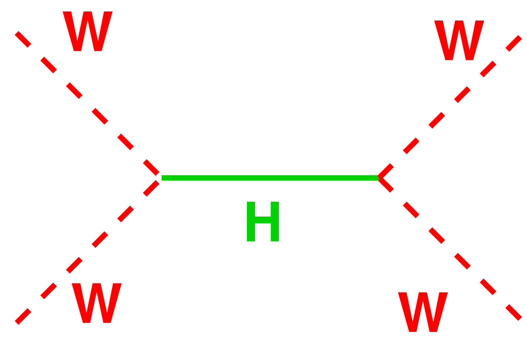
Higgs-Mechanismus im SM:

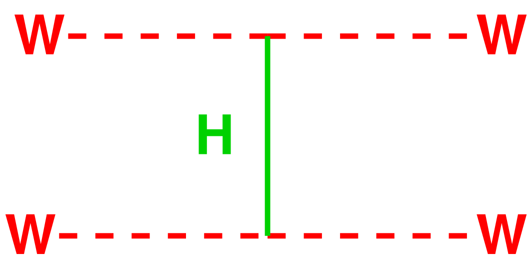
Higgs-Feld 1 Dublett	Elektro- magnetismus U(1)-Symmetrie	schwache WW $SU(2)_L$
ϕ^+ ϕ^-	B	W^+ W^- W^0

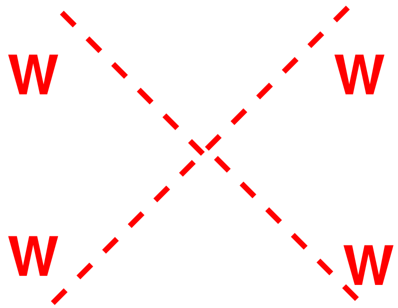
3 Freiheitsgrade des Higgs-Feldes werden die longitudinalen Polarisationen der W- und Z-Bosonen

γ, W^+, W^-, Z, H

Elastische WW-Streuung (tree level):



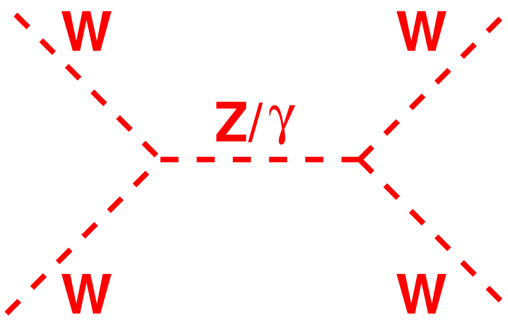


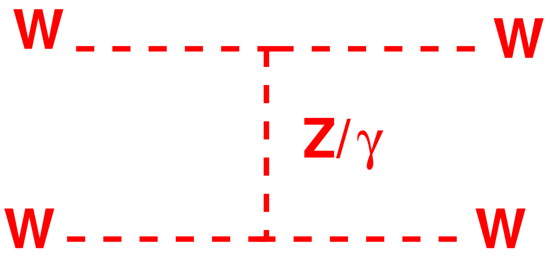


$$\sigma_{WW} \rightarrow \infty$$

für

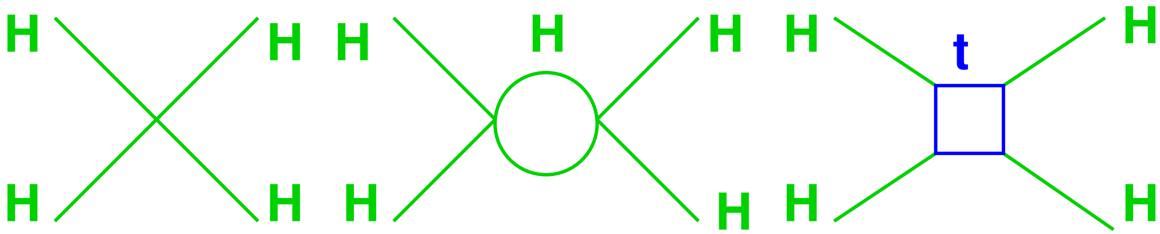
$$m_H \rightarrow \infty$$





Unitarität:

$$m_H^2 \leq \frac{2\pi\sqrt{2}}{G_F} \approx (850\,\mathrm{GeV})^2$$



$\sim\lambda$

Planckskala

GUT

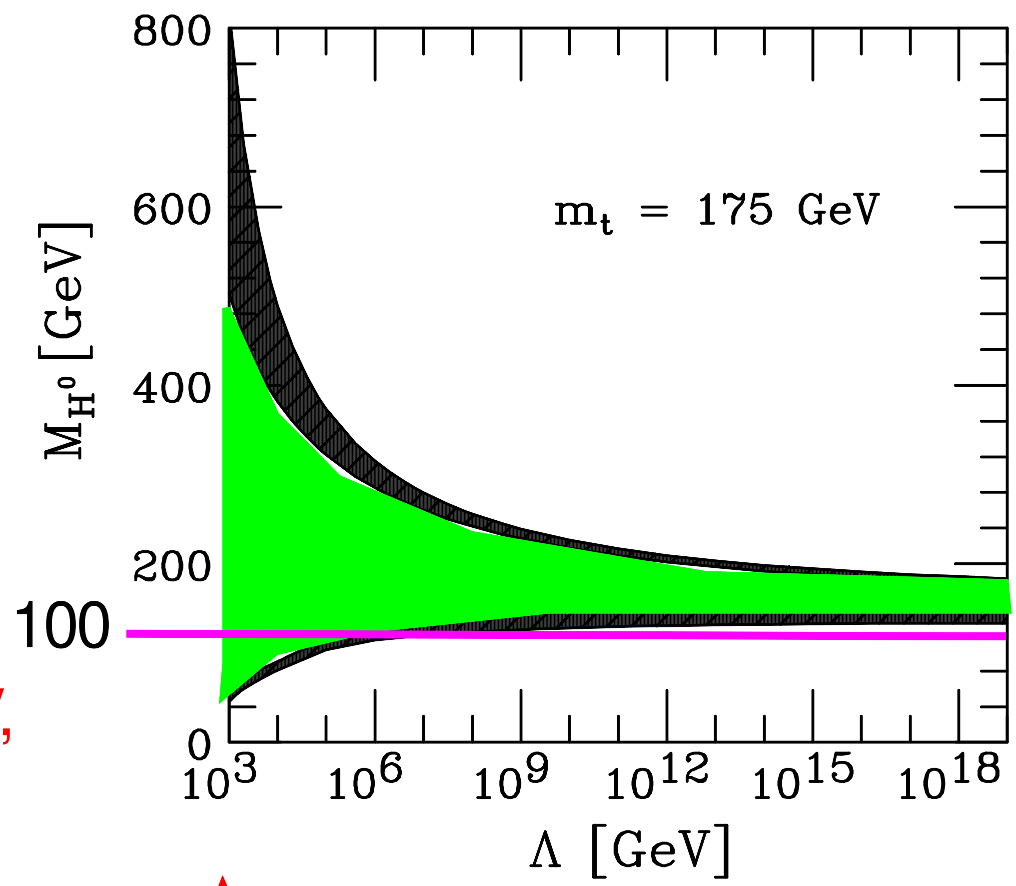
obere Grenze:

$$\lambda(\Lambda) < \infty$$

untere Grenze:

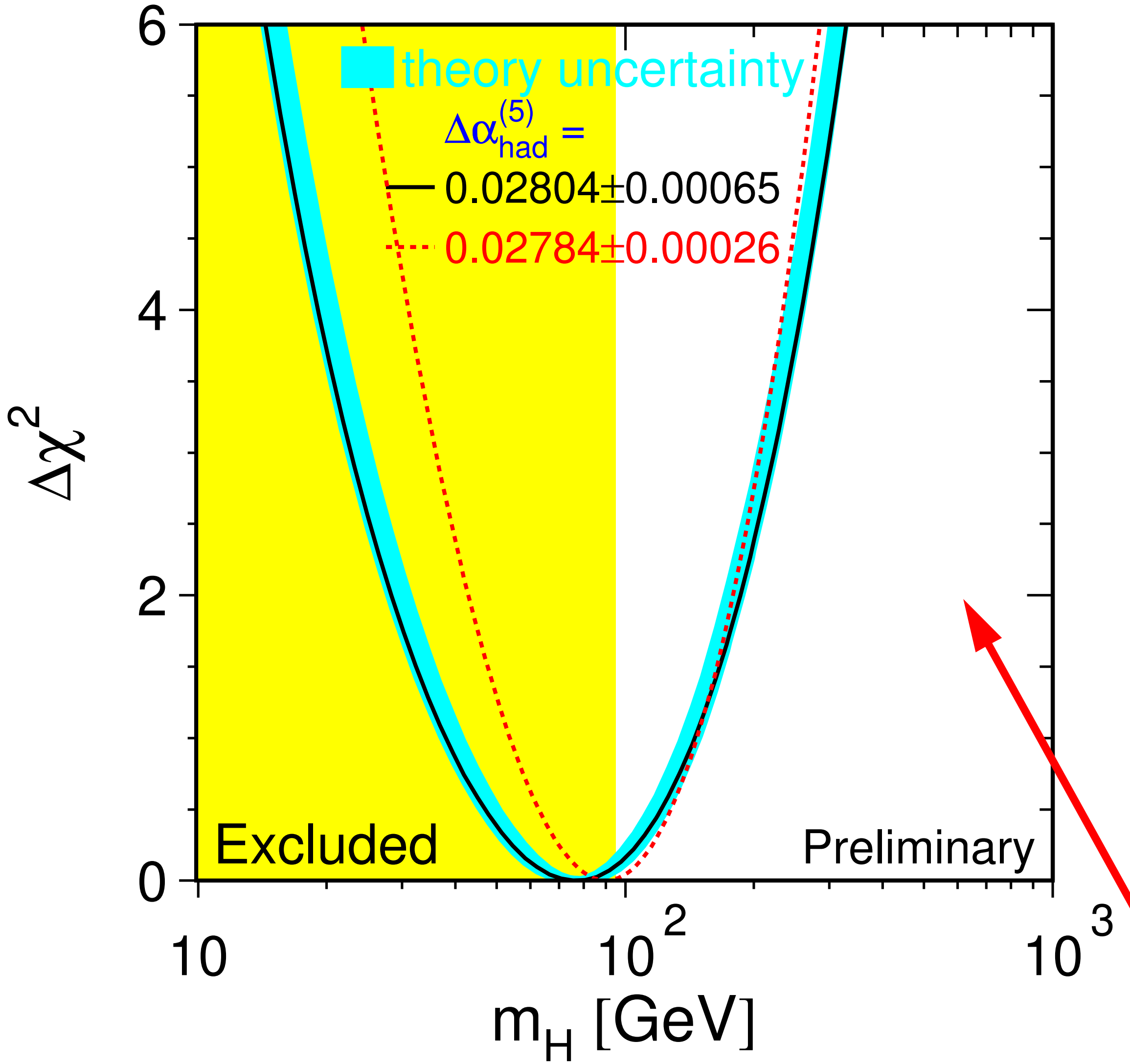
stabiler Grundzustand (Vakuum)

Liegt die Higgs-Masse ausserhalb des Bereichs 130-190 GeV, so muss es neue Physik unterhalb der GUT-Skala geben

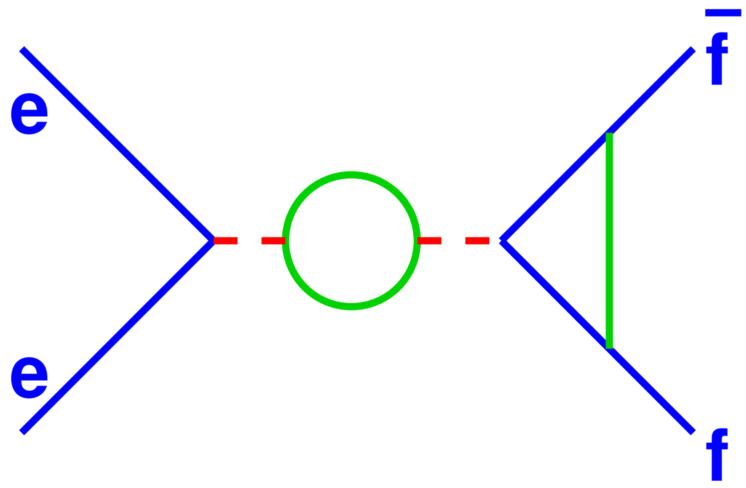


Λ: **Skala der ‘neuen Physik’**

Indirekte Bestimmung der Higgs-Masse



el.-schwache Strahlungskorrekturen:



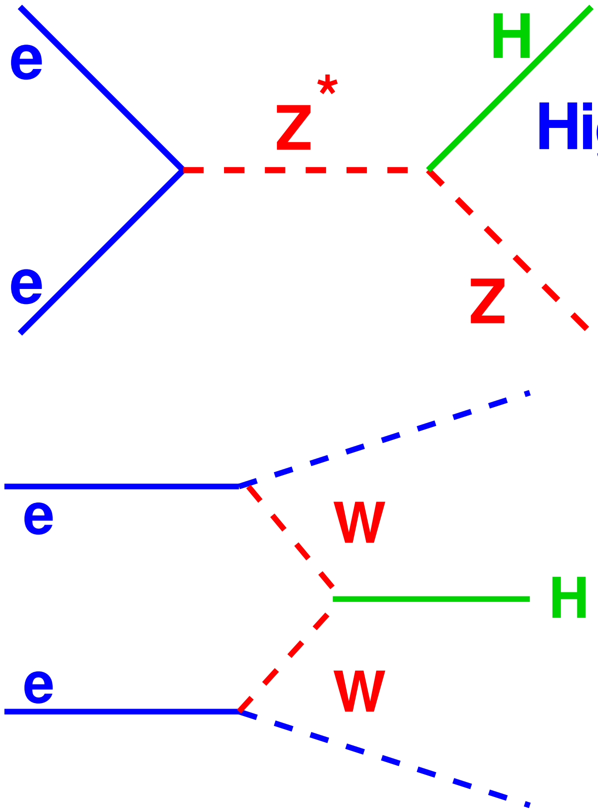
$\sim m^2_t$

$\sim \ln(m^2_H/\mathrm{GeV}^2)$

BES-Daten nicht enthalten

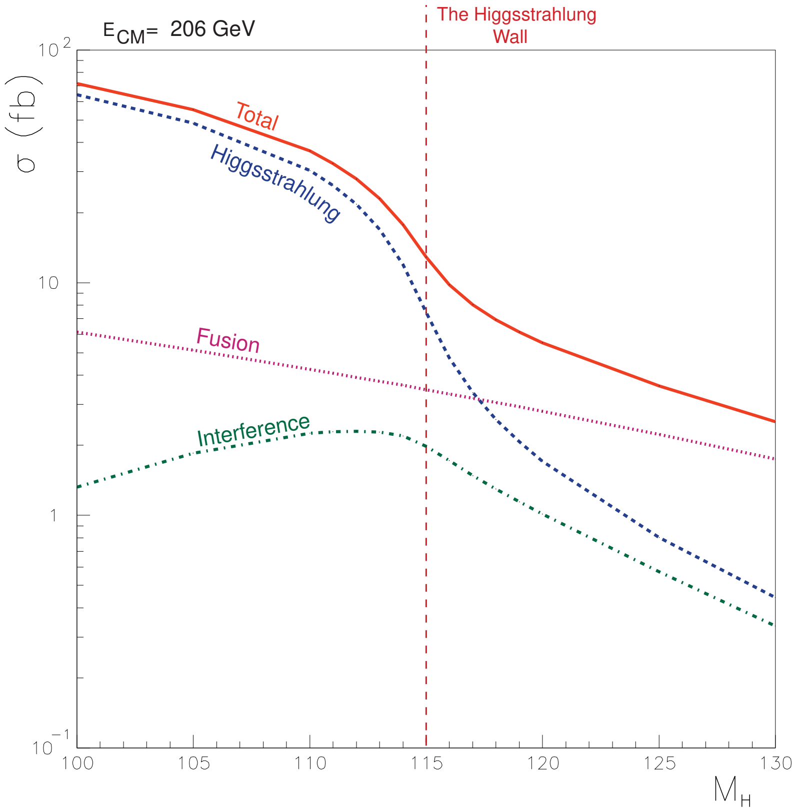
Higgs-Produktion bei LEP

(nur $Z \to \nu\nu$ Kanal)



Higgs-Strahlung

WW-Fusion



(GeV)

E_{cm}=206 GeV m_H=115 GeV   => σ_{HZ} ~0.05 pb

L_{ADLO}(E_{cm}>206 GeV)~500 pb^{-1} => 25 Signal-Ereignisse

Chronik eines dramatischen Sommers

Osaka

- 27. Juli: ICHEP2000, Osaka:

  kein Signal (~120 pb^{-1} bei E_{cm}>206 GeV)

  LEP-Run im ‘Higgs Discovery Mode’ bis Anfang Oktober

- 5. September: LEPC

  ALEPH sieht Ereignisse im 4-Jet-Kanal

  (3.9 σ); ADLO: 2.6 σ

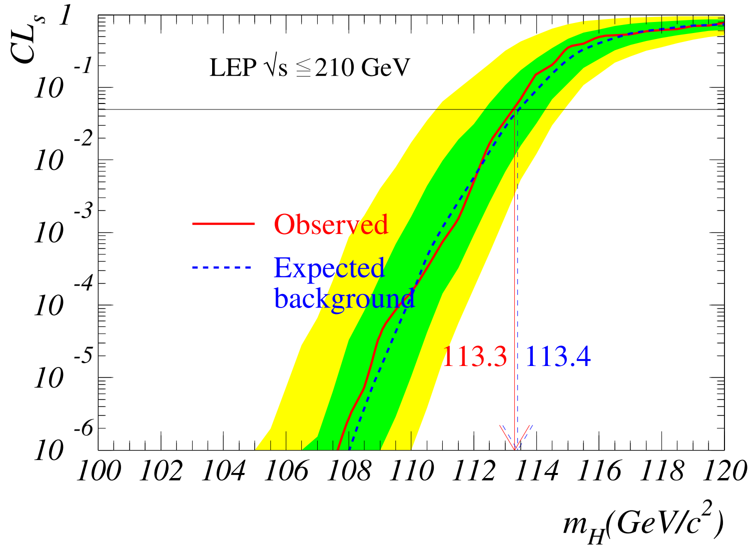
  LEP-Run verlängert bis 3.November

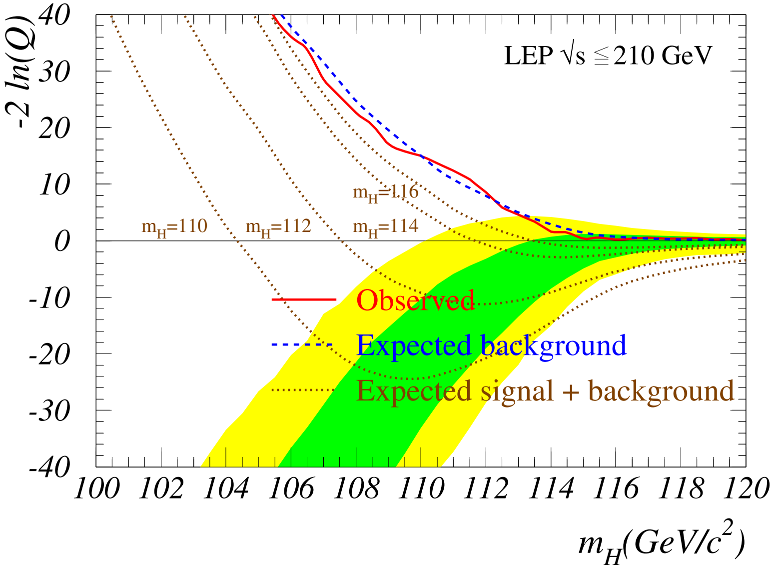
- 3. November: LEPC

  ALEPH: 3.9 σ -> 3.4 σ (Korrekturen)

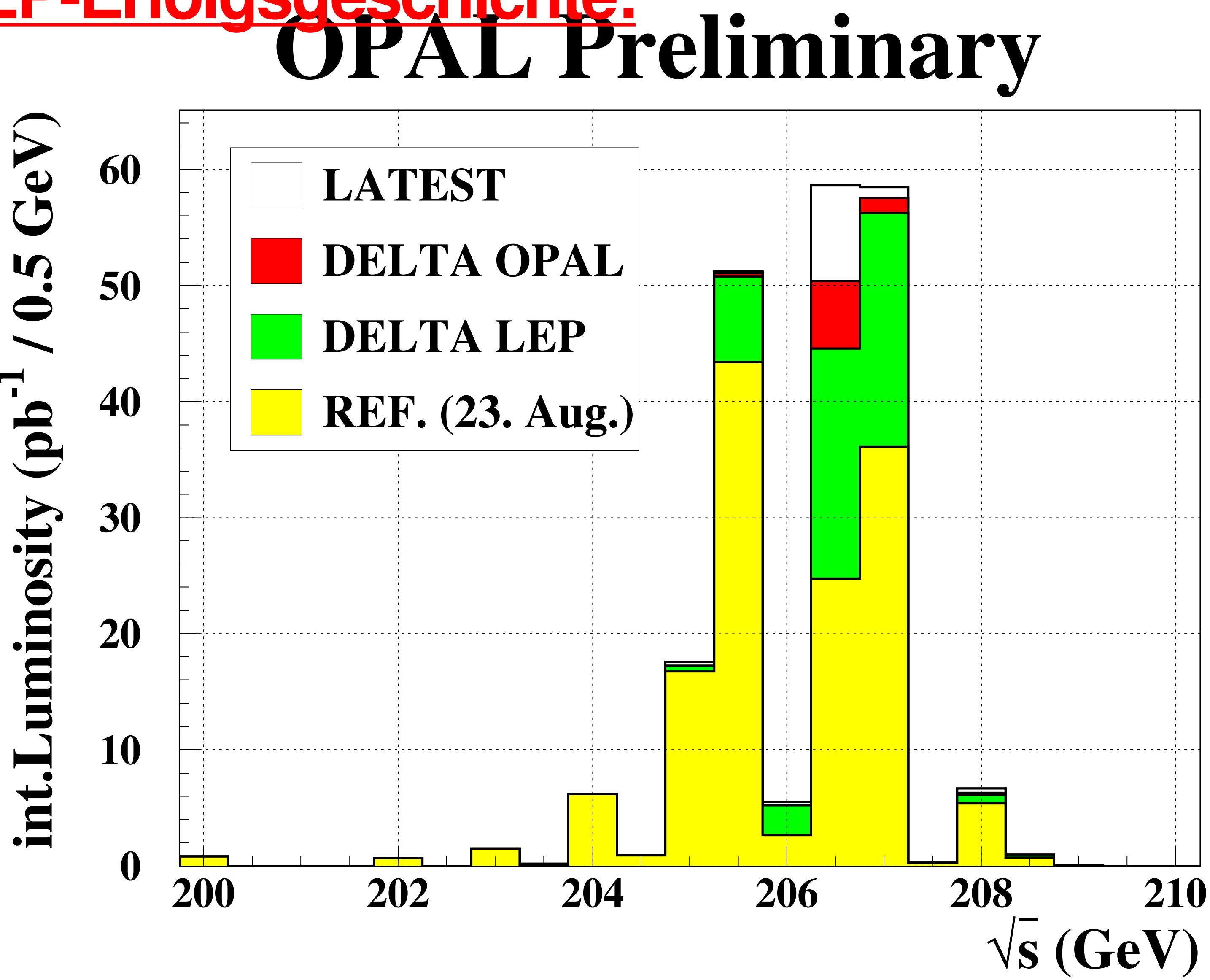
  L3: starker bbνν-Kandidat

  ADLO: 2.9 σ, LEP-Run in 2001 ?





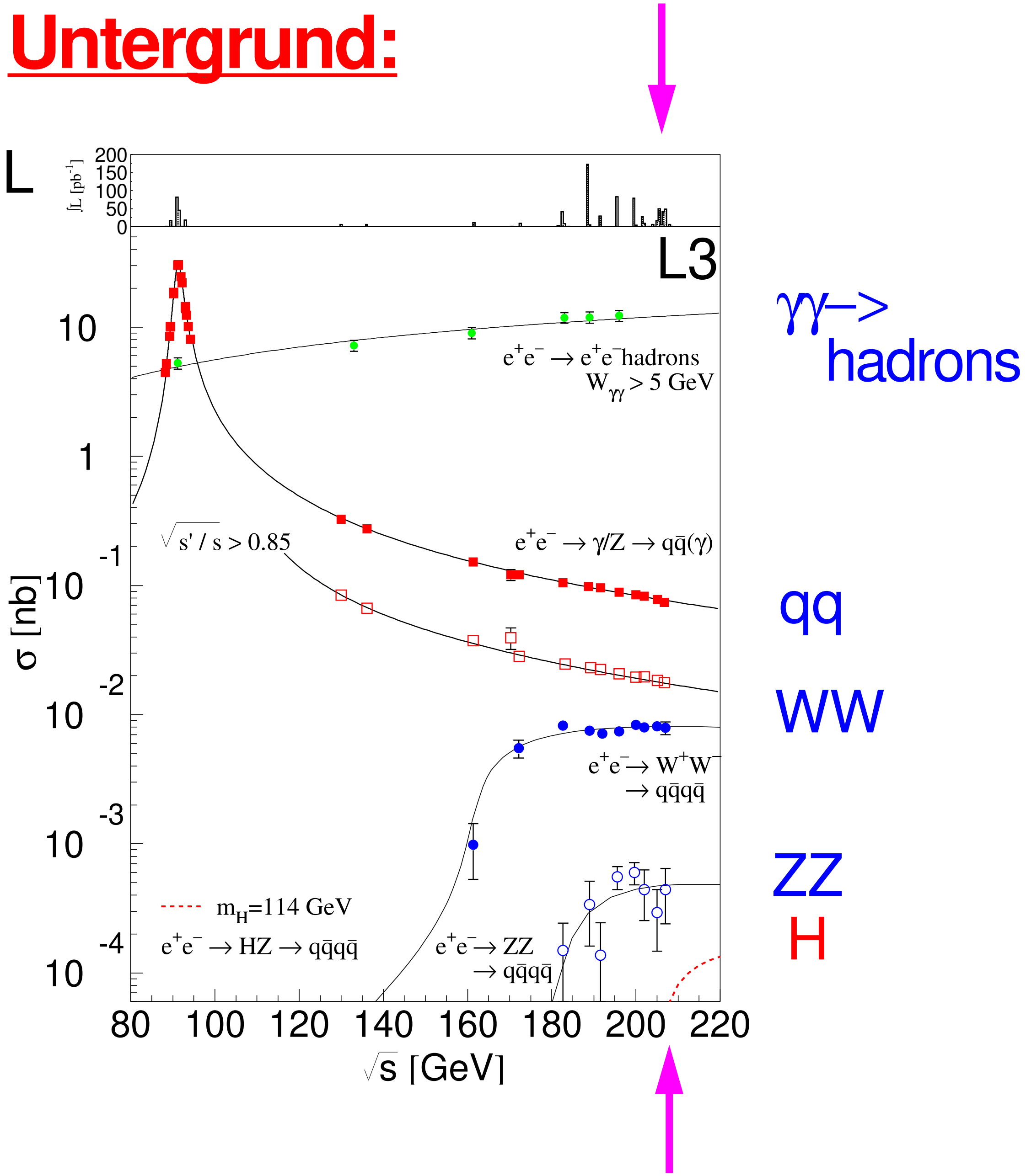
Die LEP-Erfolgsgeschichte:



Nur 2000

Nur OPAL

Untergrund:

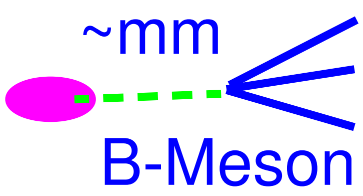


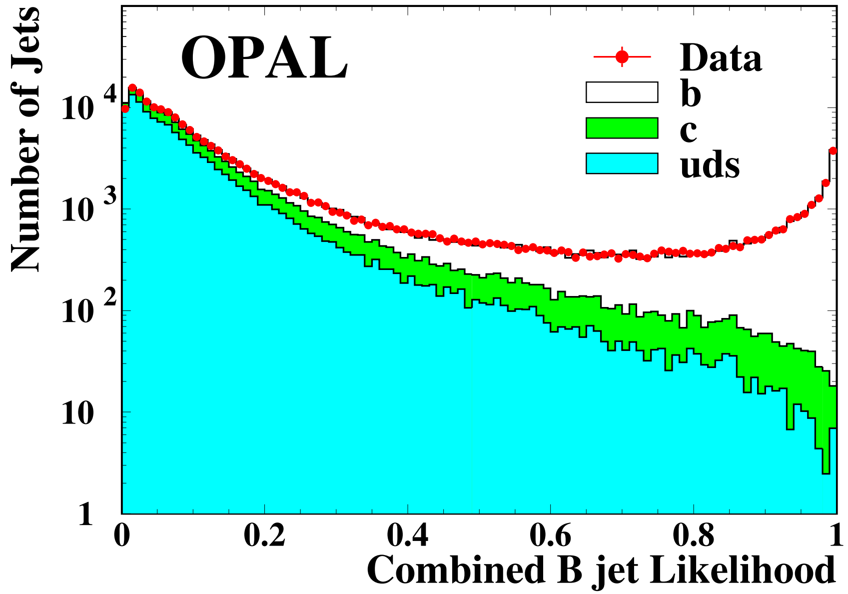
Wie erkenne ich ein Higgs-Ereignis ?

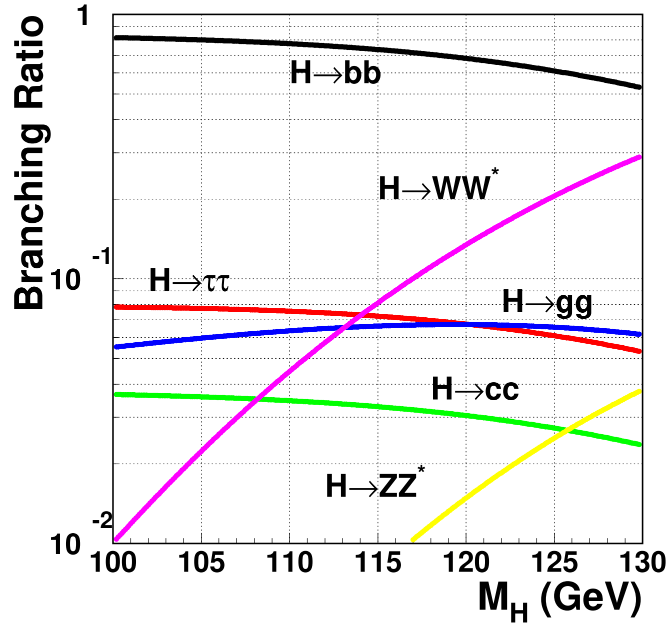
- kinematische Unterschiede (z.B. sichtbare Energie)
- Identifikation des Endzustandes (b-tagging)

Unterscheidung nur auf sta-tistischer Basis möglich

b-Identifikation (b tagging)



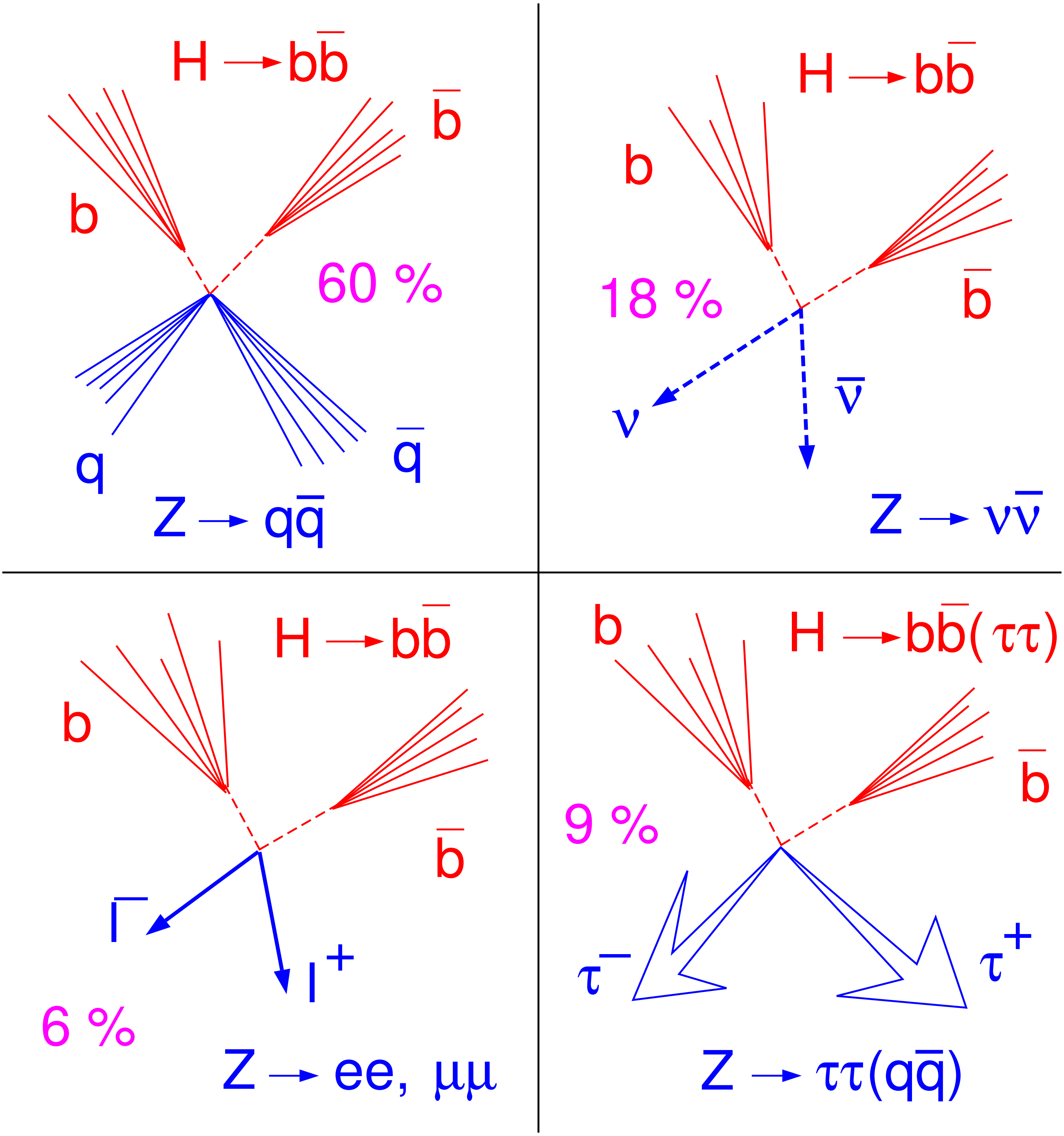




- Sekundärvertizes (Si-Tracker)
  (B-Lebensdauer ~ 1.5 ps)
- Jet-Eigenschaften
- Leptonen mit grossem Transversalimpuls (b->clν)

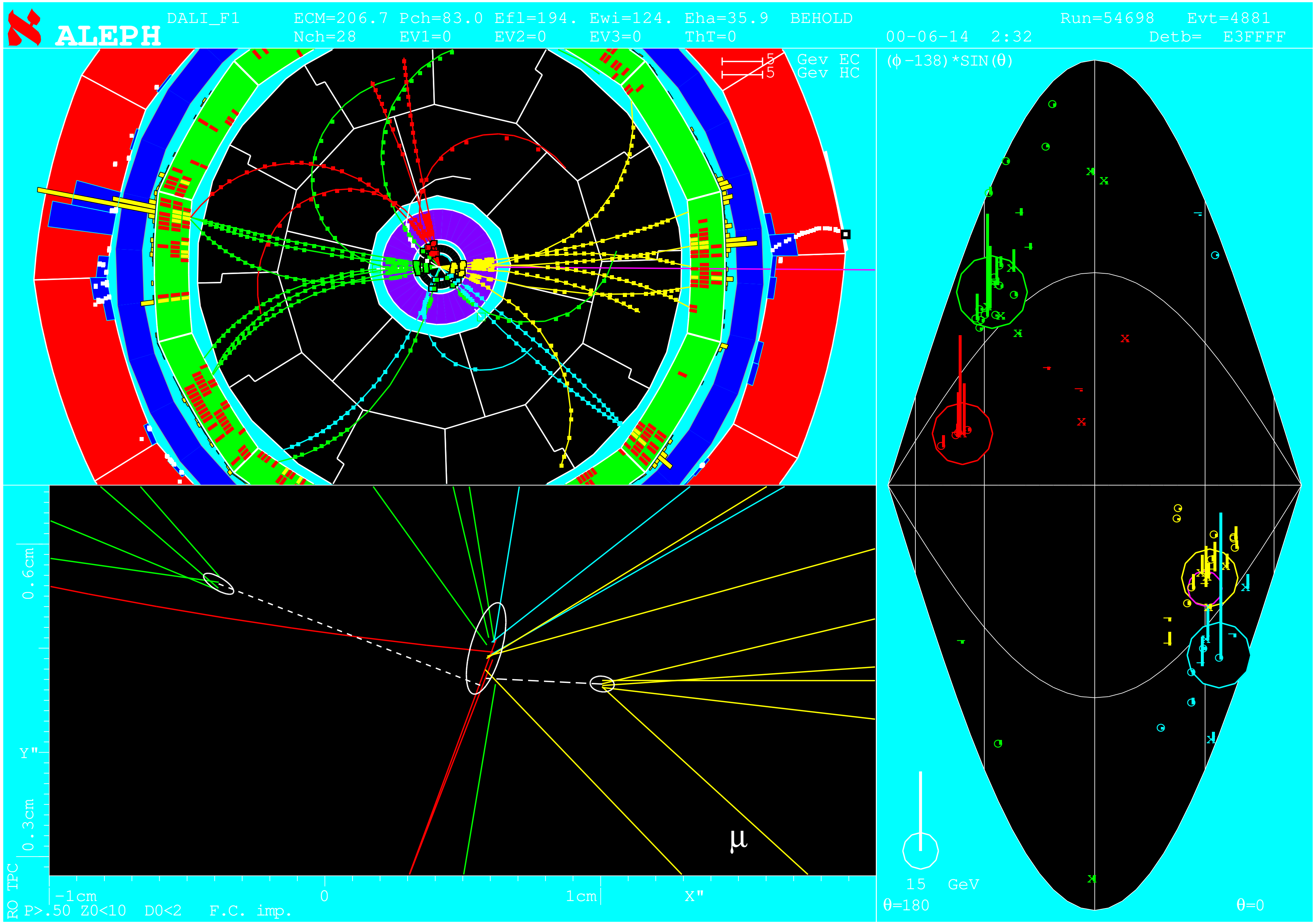
e^+e^- -> HZ (Topologien)

4-jet **Fehlende Energie**



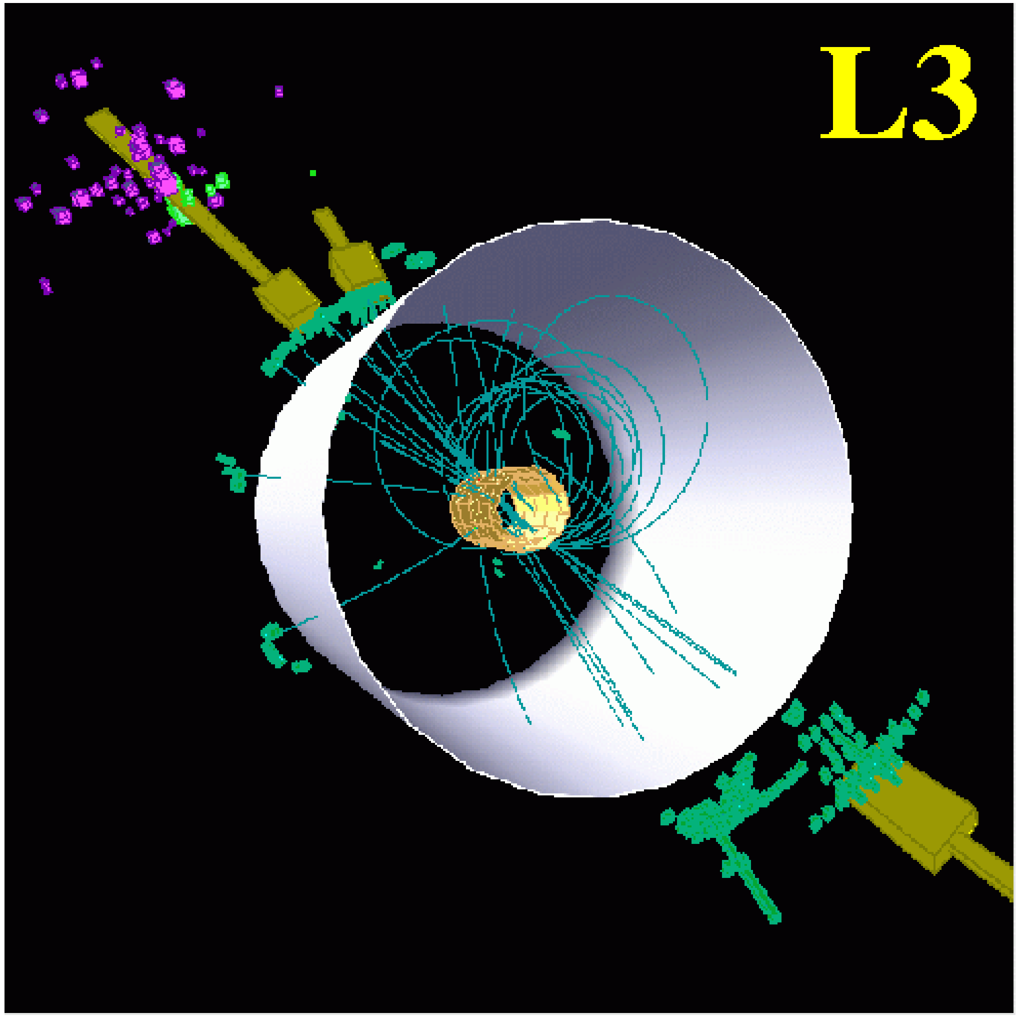
Leptonisch **τ-Kanal**

m_h^{rec}=114.3 GeV

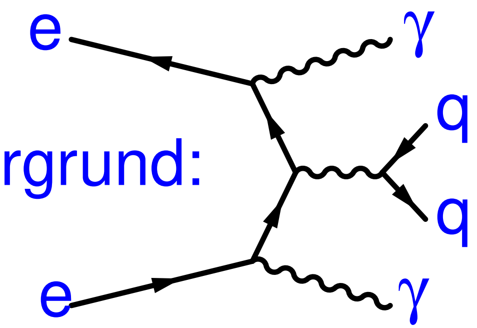


Made on 29-Aug-2000 17:06:54 by DREVERMANN with DALI_F1.
Filename: DC054698_004881_000829_1706.PS_H_CAND

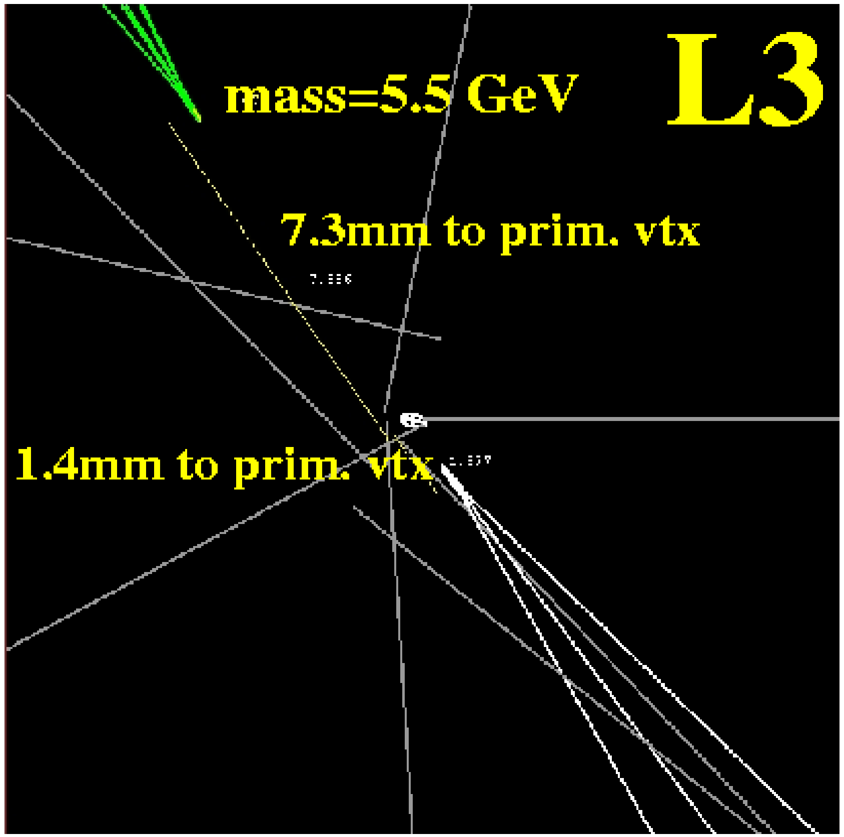
most significant Hνν candidate



Untergrund:



Secondary vtx's view



measured H mass=114.4 GeV

H mass resolution ~3 GeV

- **Kinematischer 5C-Fit im 4-Jet-Kanal:**

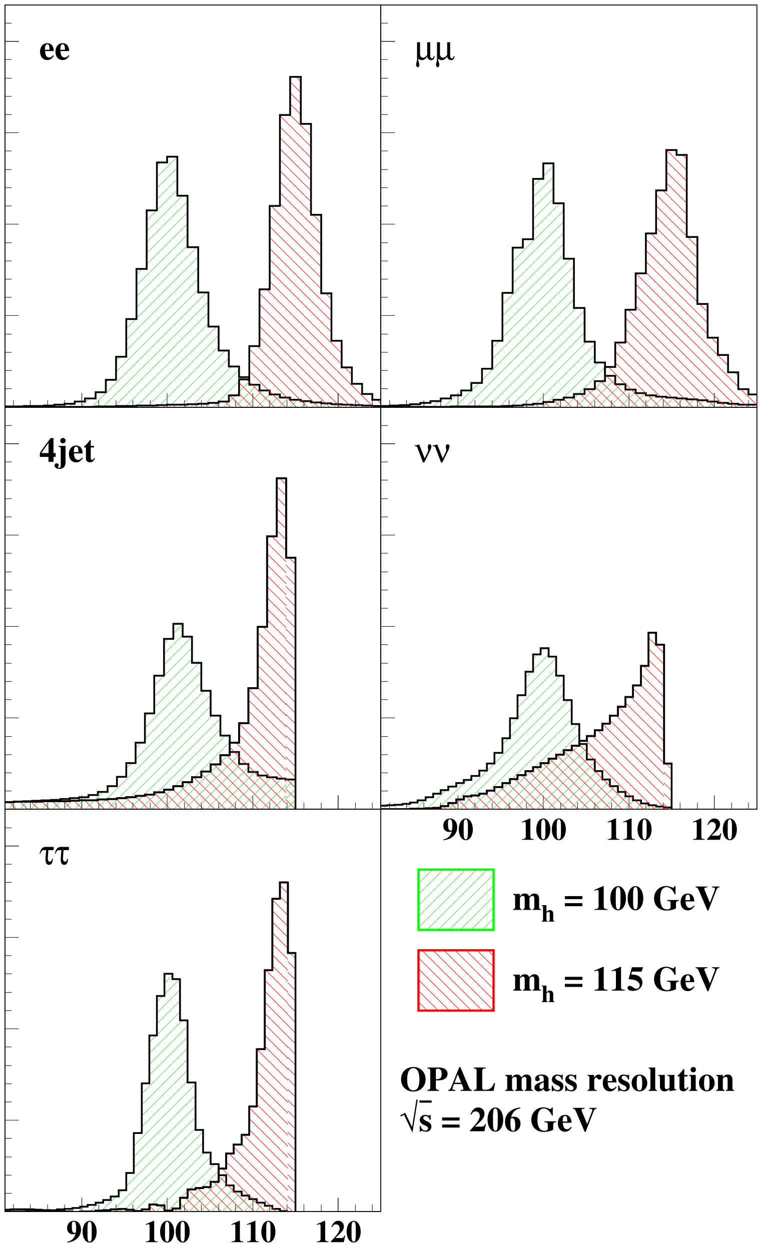
  Energie-/Impulserhaltung

  $M(\text{jet-jet})=M_Z$

- **Beste Jet-Jet Kombination wird mit einer Likelihood-Methode gefunden**

- **scharfe kinematische Kante bei**

  $m_H=(206-91.2)$ GeV~115 GeV

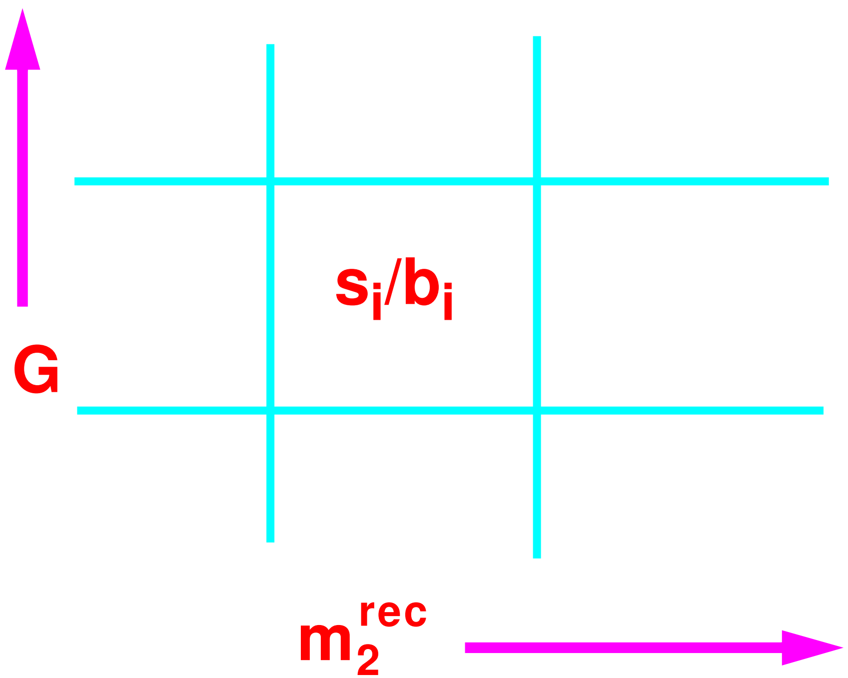


Statistik:

Ziel: Kombination aller Daten der vier LEP-Experimente in allen Kanälen und bei allen Energien

INPUT:

-Rekonstruierte Masse m_2^{rec}
-Globale Variable **G** (b tagging,Kinematik)

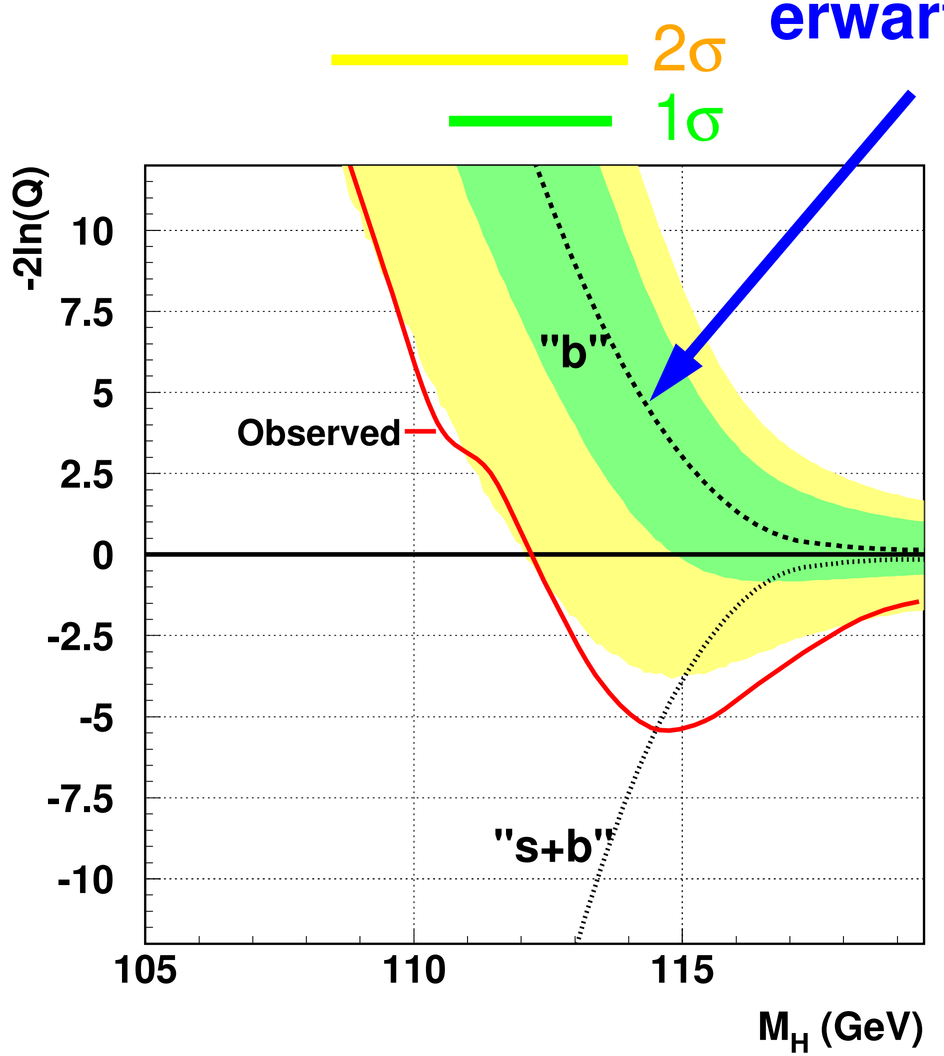


Wie verhält sich das Ereignis in Bezug auf die “s+b”- und die “nur b”-Hypothese ?

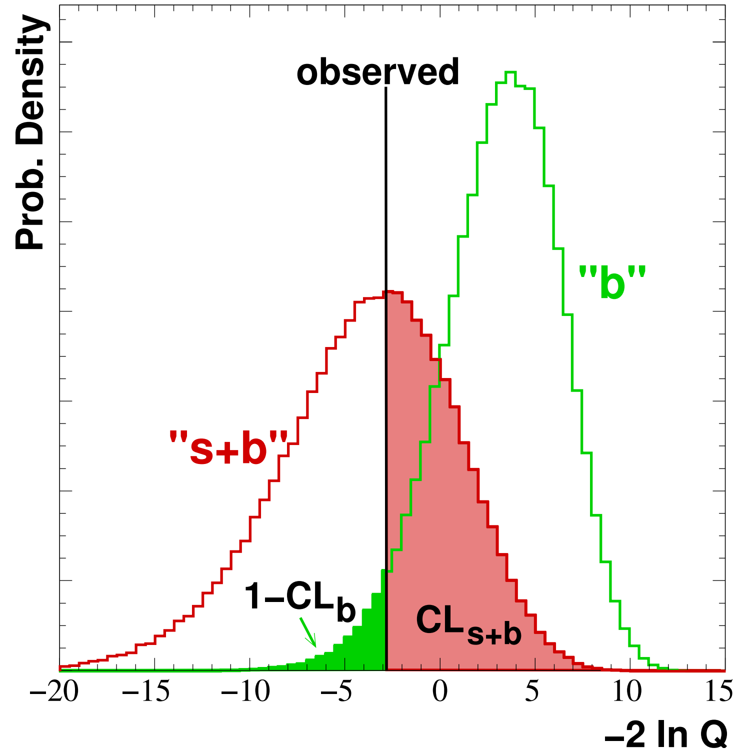
$$Q(m_H) = \frac{L(s+b)}{L(b)}$$

$$-\ln Q(m_H) = \Sigma s - \Sigma N_i \ln\left(1 + \frac{s_i(m_H)}{b_i}\right)$$

erwartet (Median)



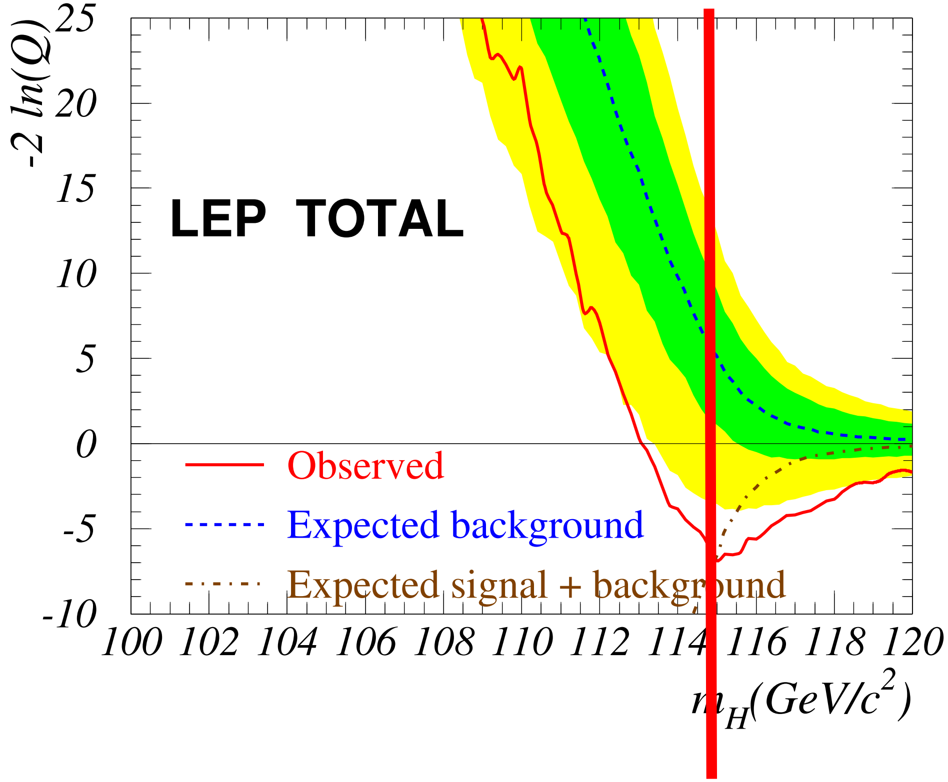
Testmasse



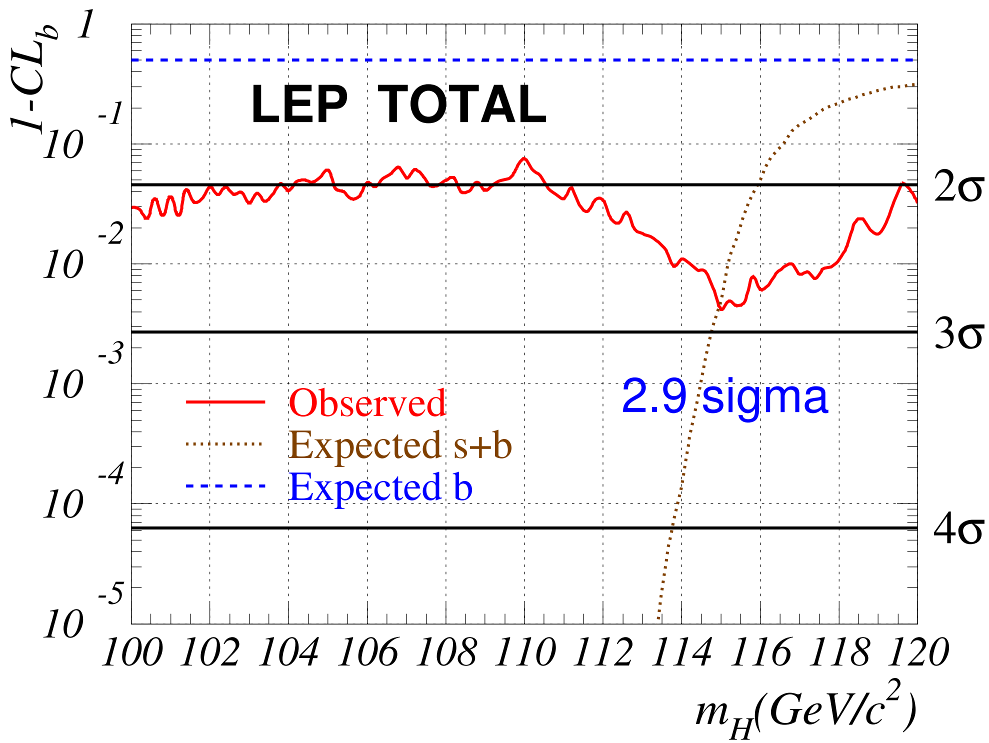
$1\text{-}CL_b$: Inkonsistenz mit der ‘b’-Hypothese

$1\text{-}CL_{S+B}$: Inkonsistenz mit der ‘s+b’-Hypothese

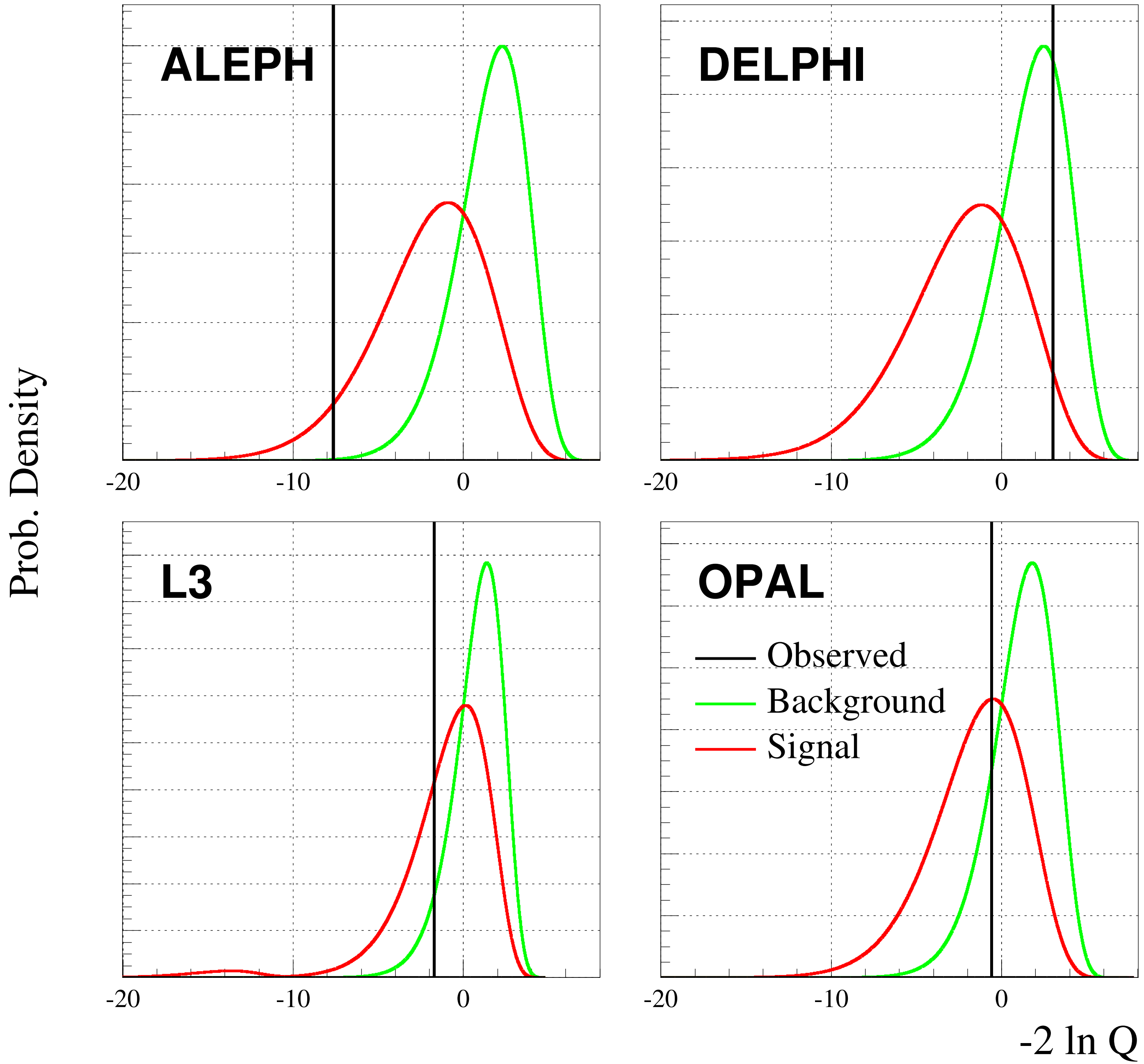
P.Igo-Kemenes, LEPC-Seminar, 3.11.2000

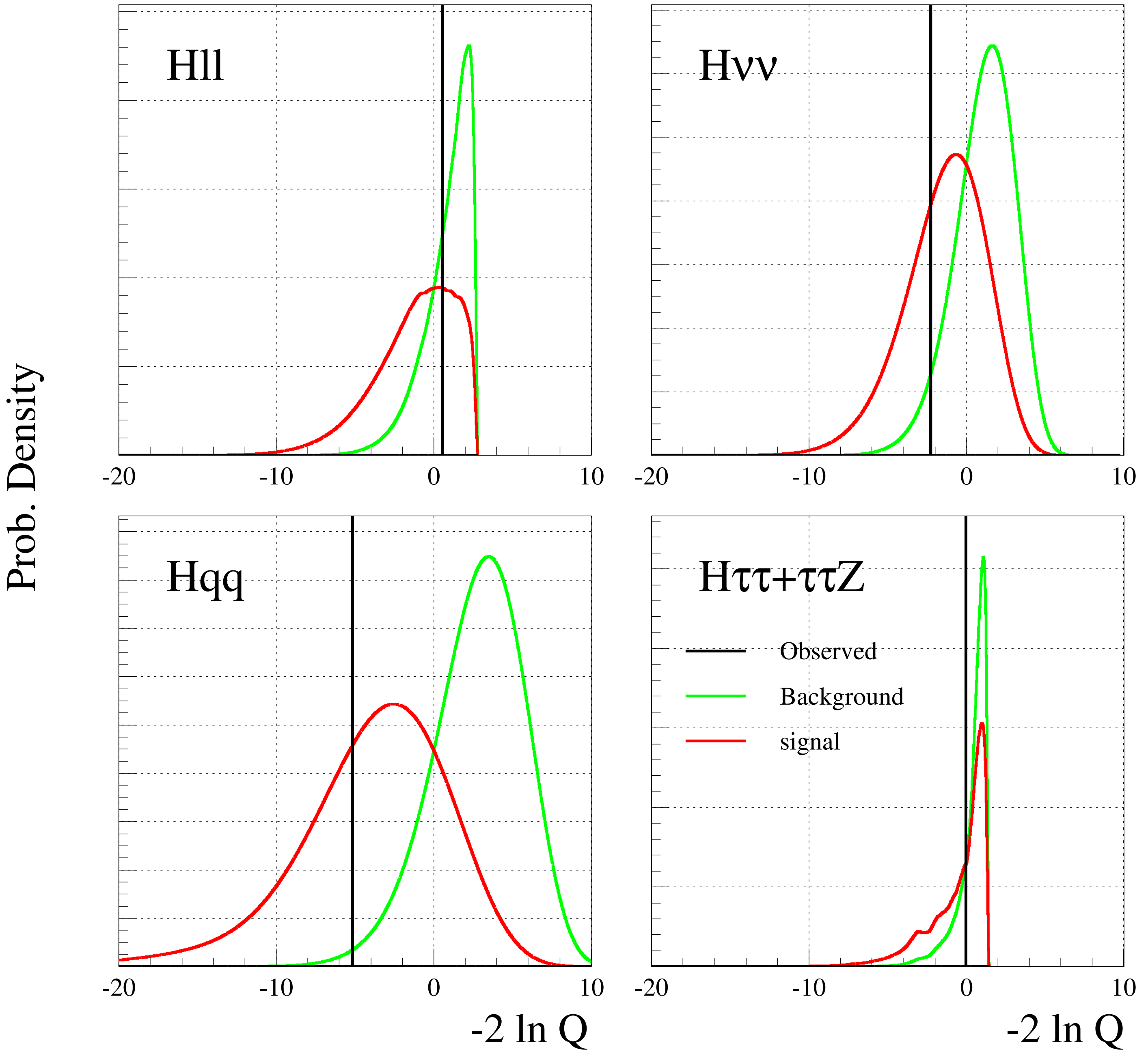


$$m_H = 115^{+1.3}_{-1.9}\,\mathrm{GeV}$$



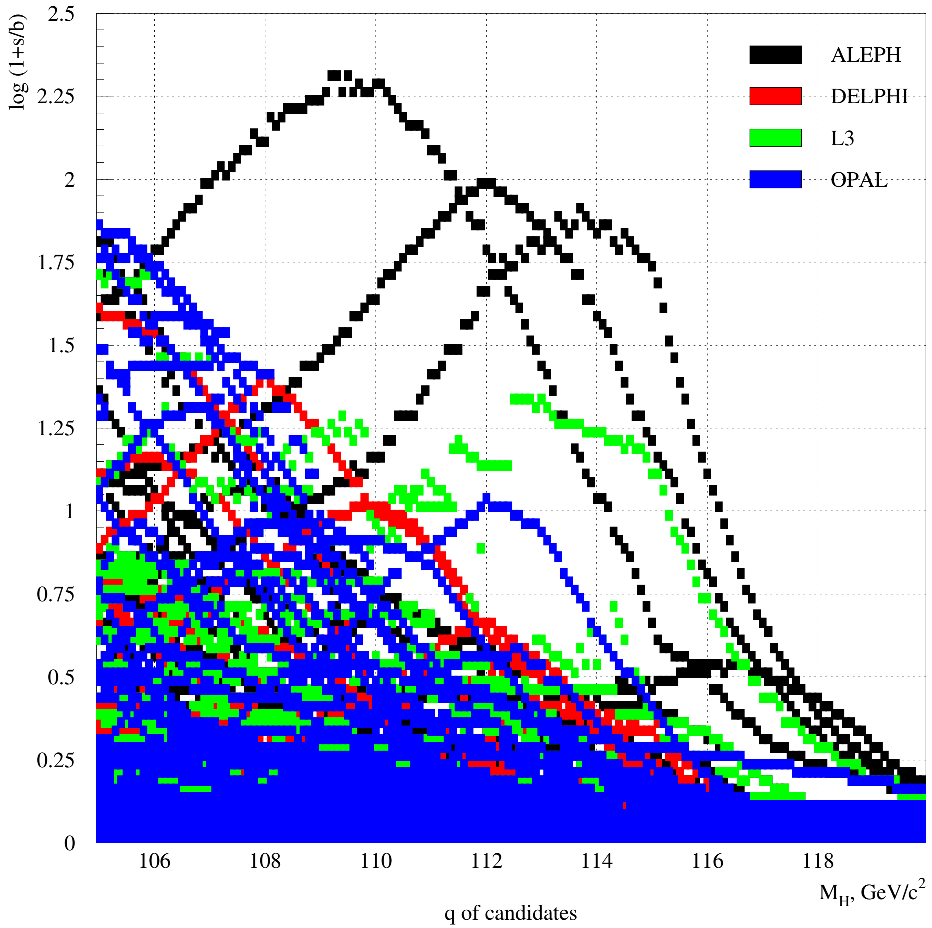
ist konsistent mit dem Wirkungsquerschnitt


ALEPH
DELPHI
L3
OPAL
Observed
Background
Signal
Prob. Density
-20
-10
0
-2 ln Q

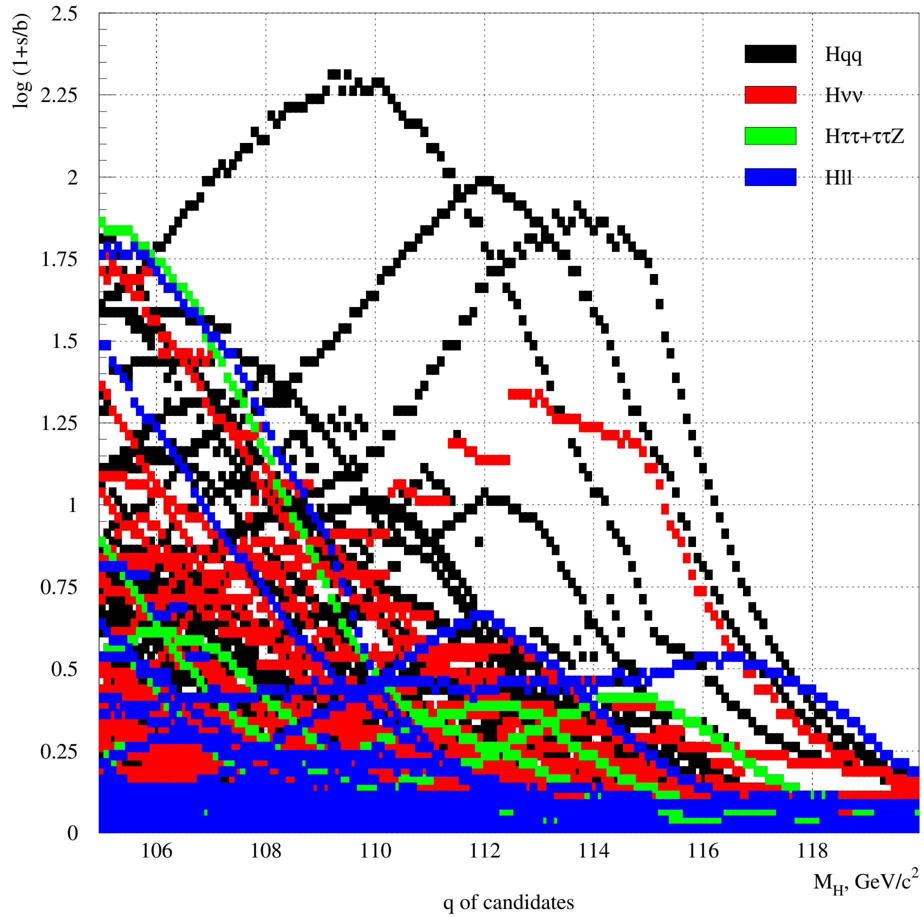

Hll
Hνν
Hqq
Hττ+ττZ
Observed
Background
signal
Prob. Density
-20
-10
0
10
-2 ln Q

Beiträge einzelner Kandidaten: $-2\ln(Q) \sim \Sigma \ln(1+s_i/b_i)$ 'Gewicht'

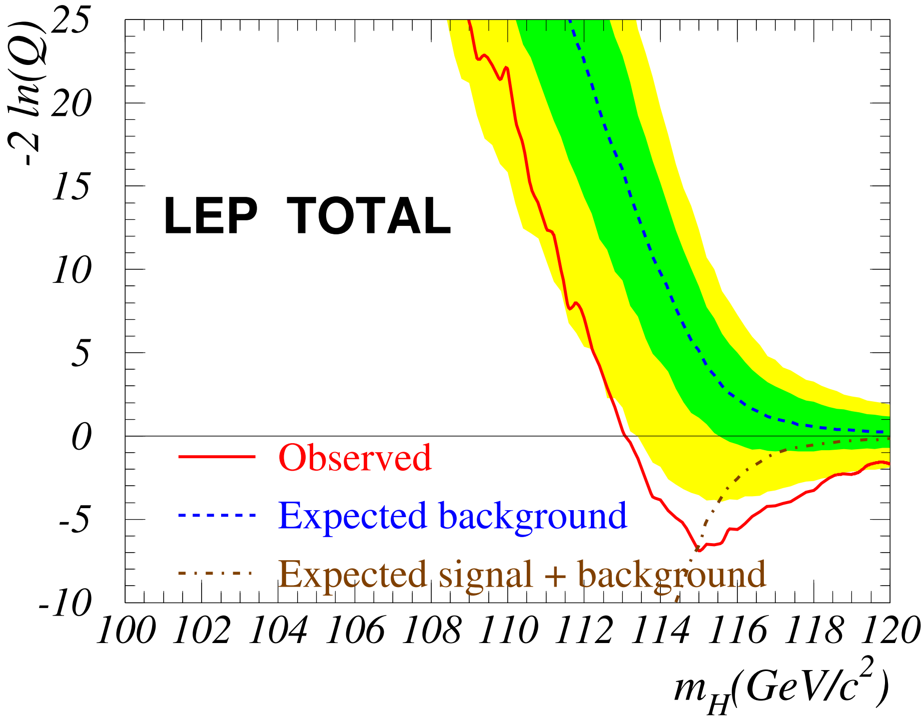
pro Experiment



pro Kanal

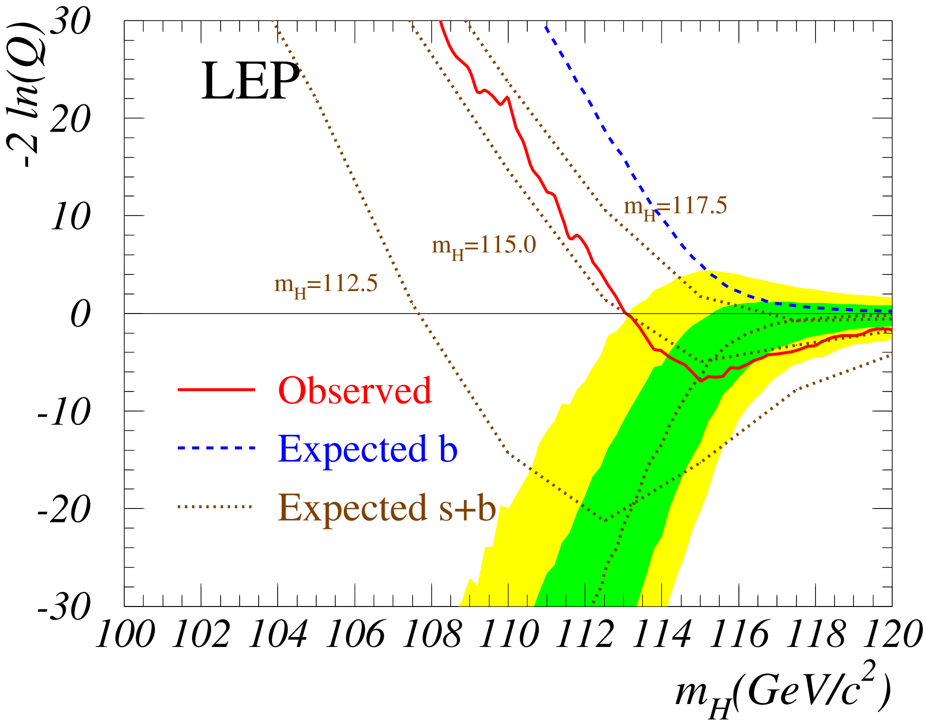


Was erwarten wir bei einer Higgs-Masse von 115 GeV ?

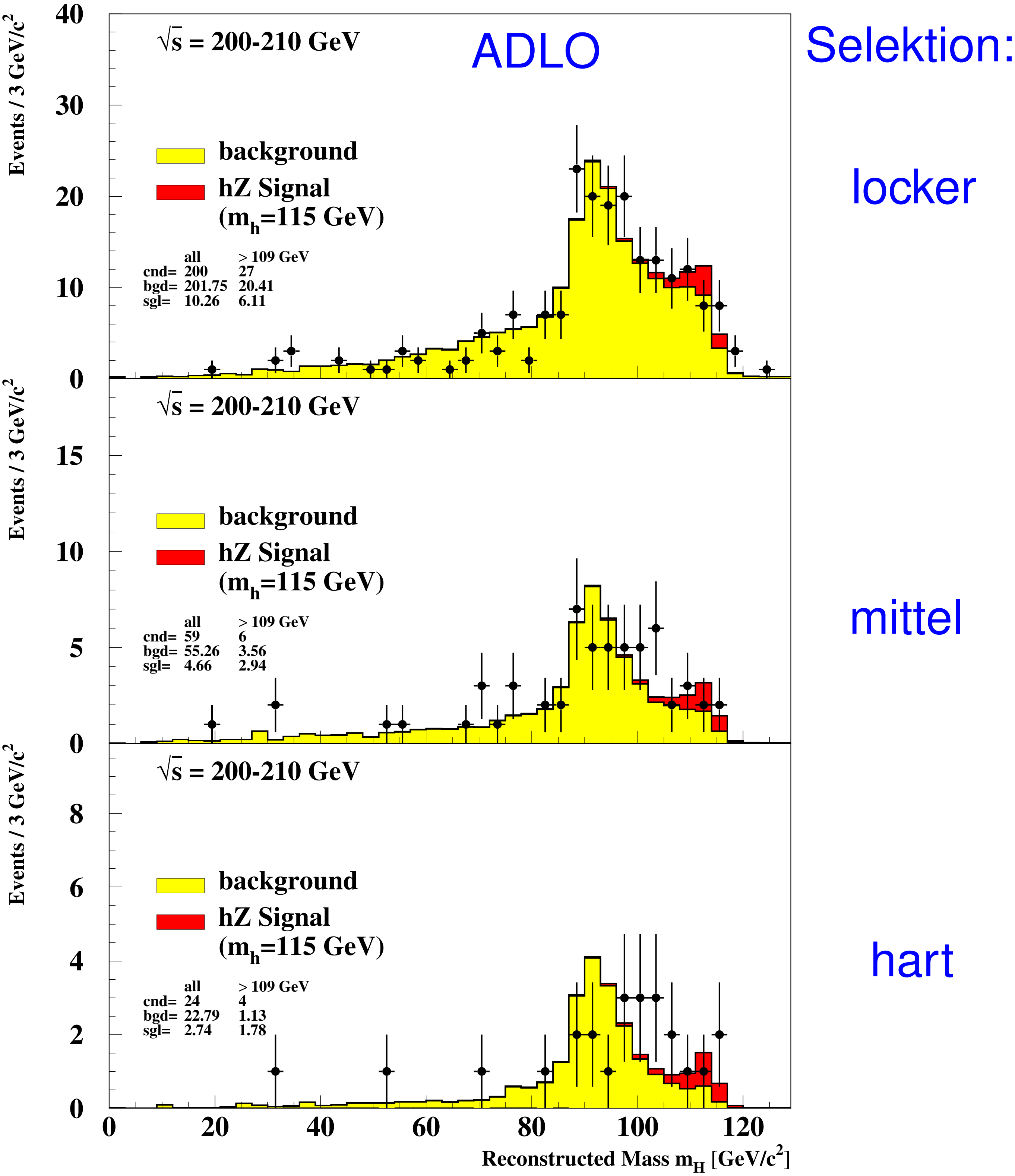


ADLO=4xDELPHI

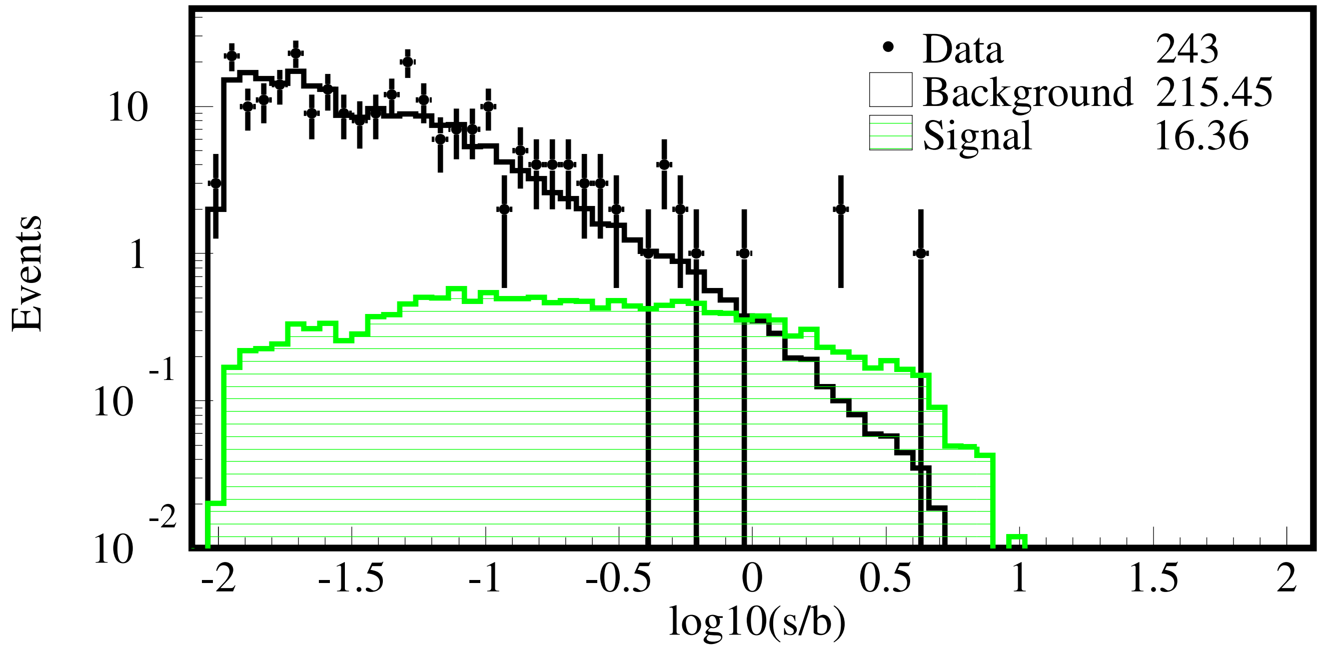
Ein Higgs bei 115 GeV wirkt sich auf kleinere Testmassen aus !



Massenverteilungen...



enthalten nur einen Teil der Informationen.

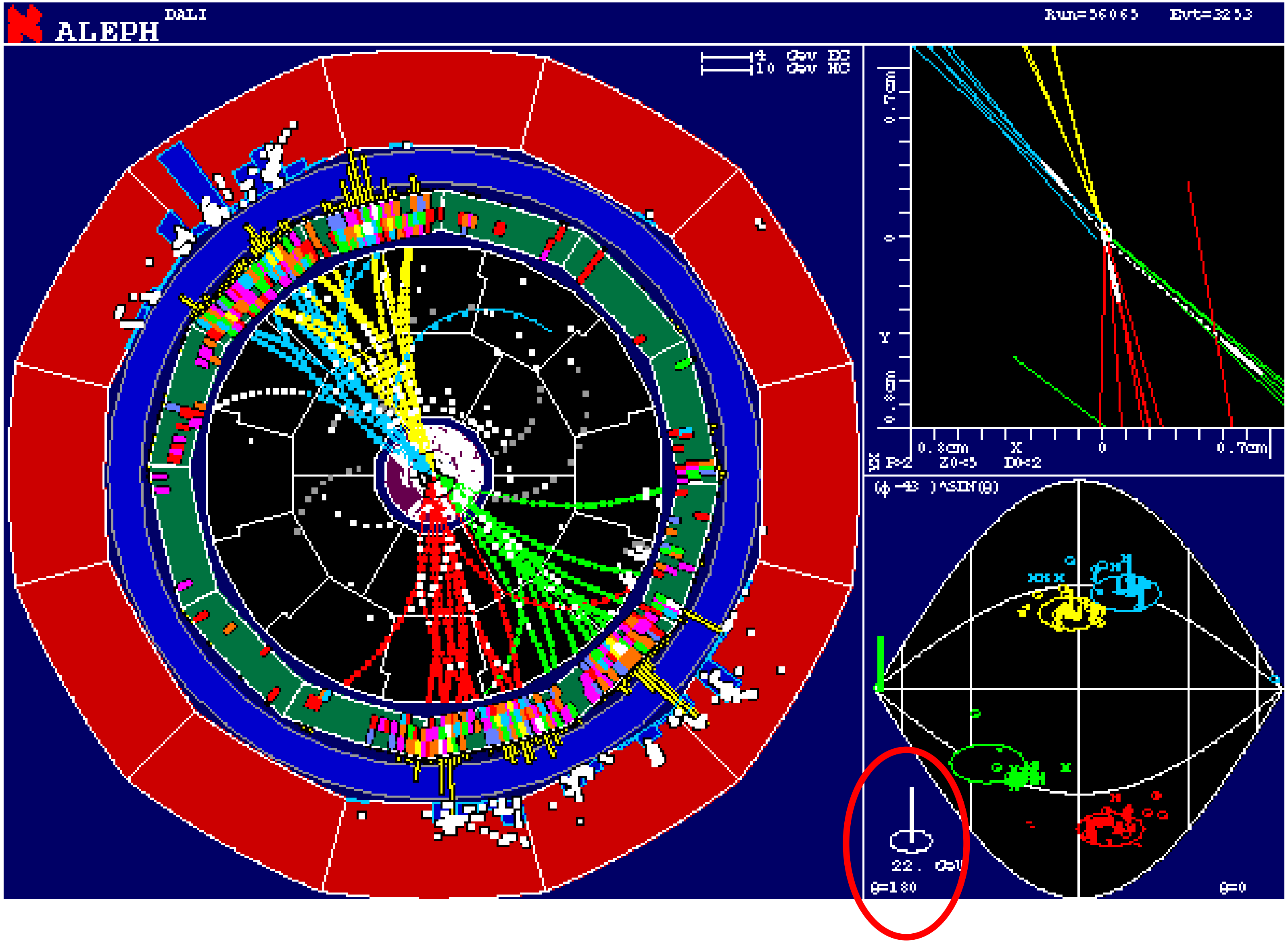


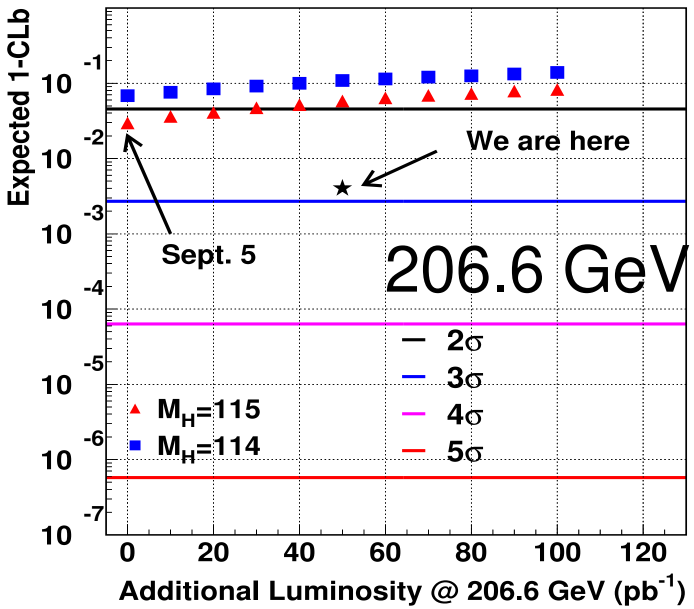
Vergleichbarer Beitrag zum Signal von den Ereignisse mit s/b>1 und s/b<1 !

ADLO-Erwartung für s/b>1:

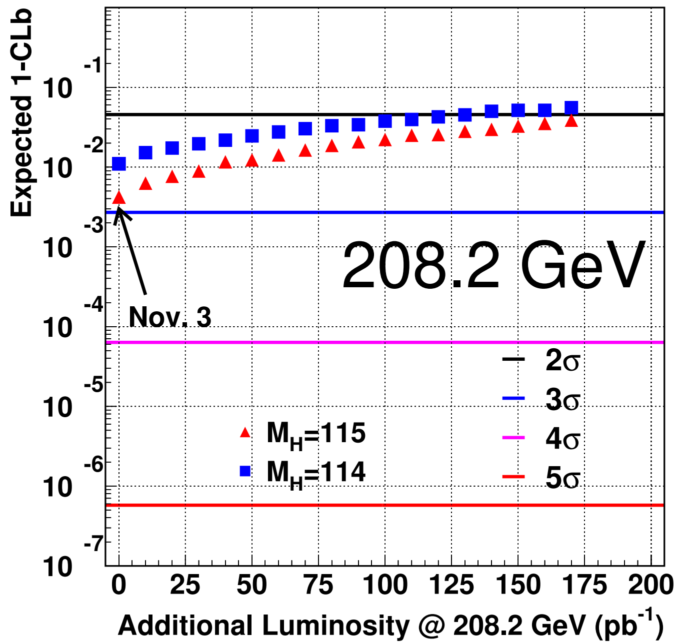
	Untergrund	Signal
4-Jets	0.93	1.60
E_{miss}	0.30	0.46
Lepton	0.35	0.68
Tau	0.14	0.29

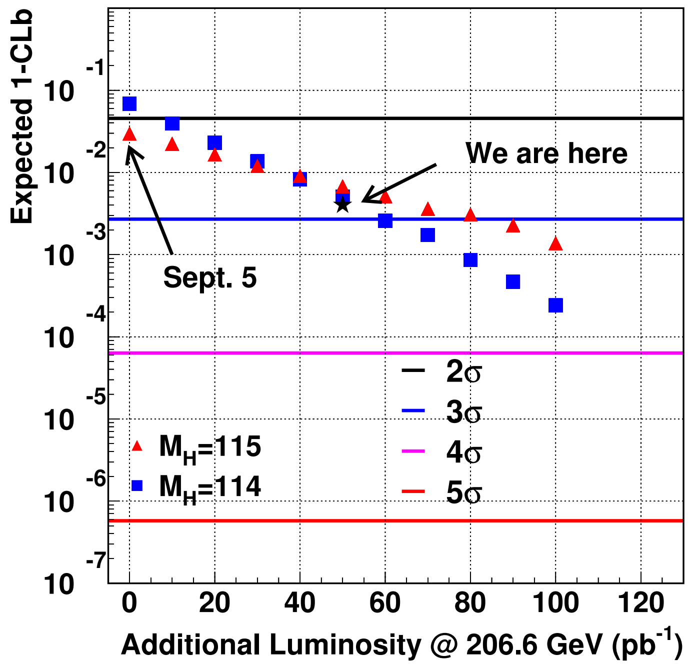
3 b tags, m_h^{rec}=112.9 GeV



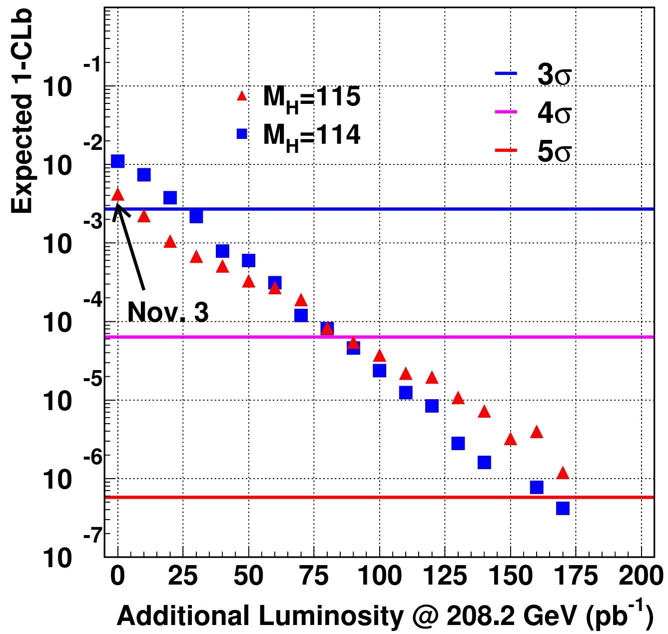


nur
Untergrund





Signal plus
Untergrund



Presseerklärung des Director-General:

8. November 2000:

After extended consultation with the appropriate scientific committees, CERN's Director-General Luciano Maiani announced today that the LEP accelerator has been switched off for the last time.

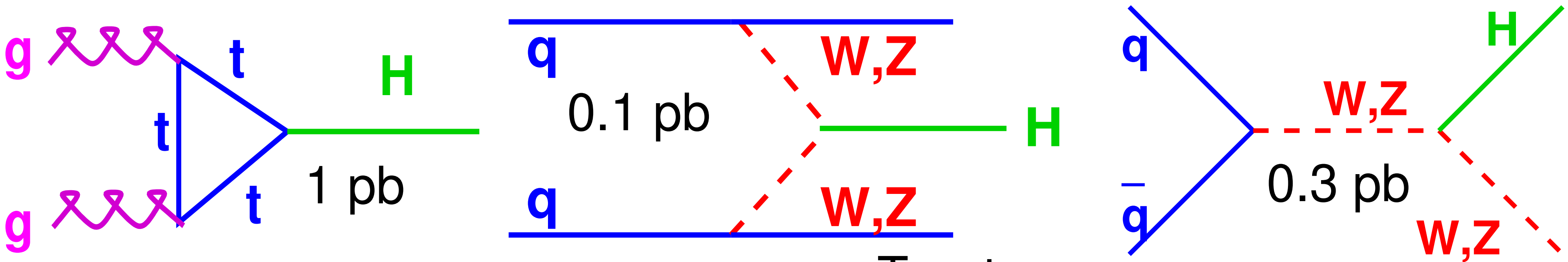
..tantalising signs of possible new physics led to LEP's run being extended until 2 November.

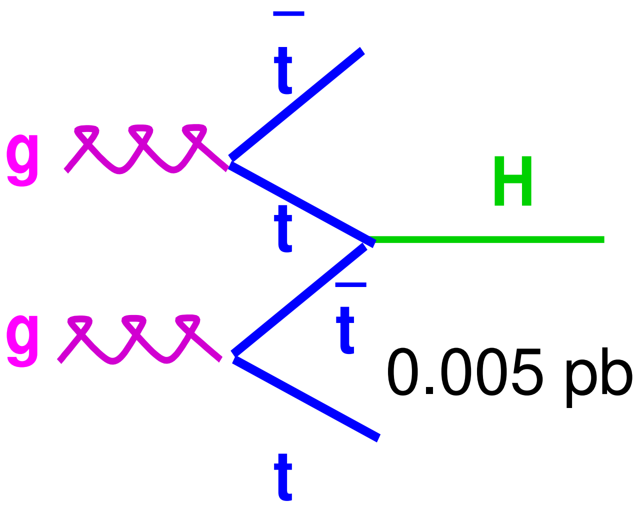
At the end...LEP ..had produced a number of collisions compatible with the production of Higgs particles...These events were also compatible with other known processes.

The new data was not sufficiently conclusive to justify running LEP in 2001, which would have inevitable impact on LHC construction...

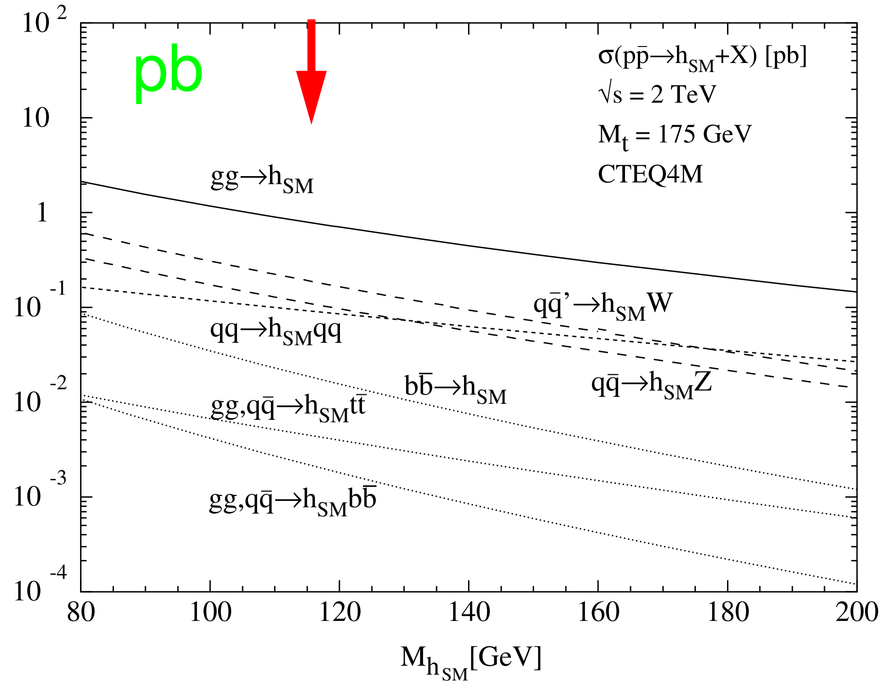
final decision by CERN council: 17. November

Higgs-Produktion in der pp/p̄p-Streuung:

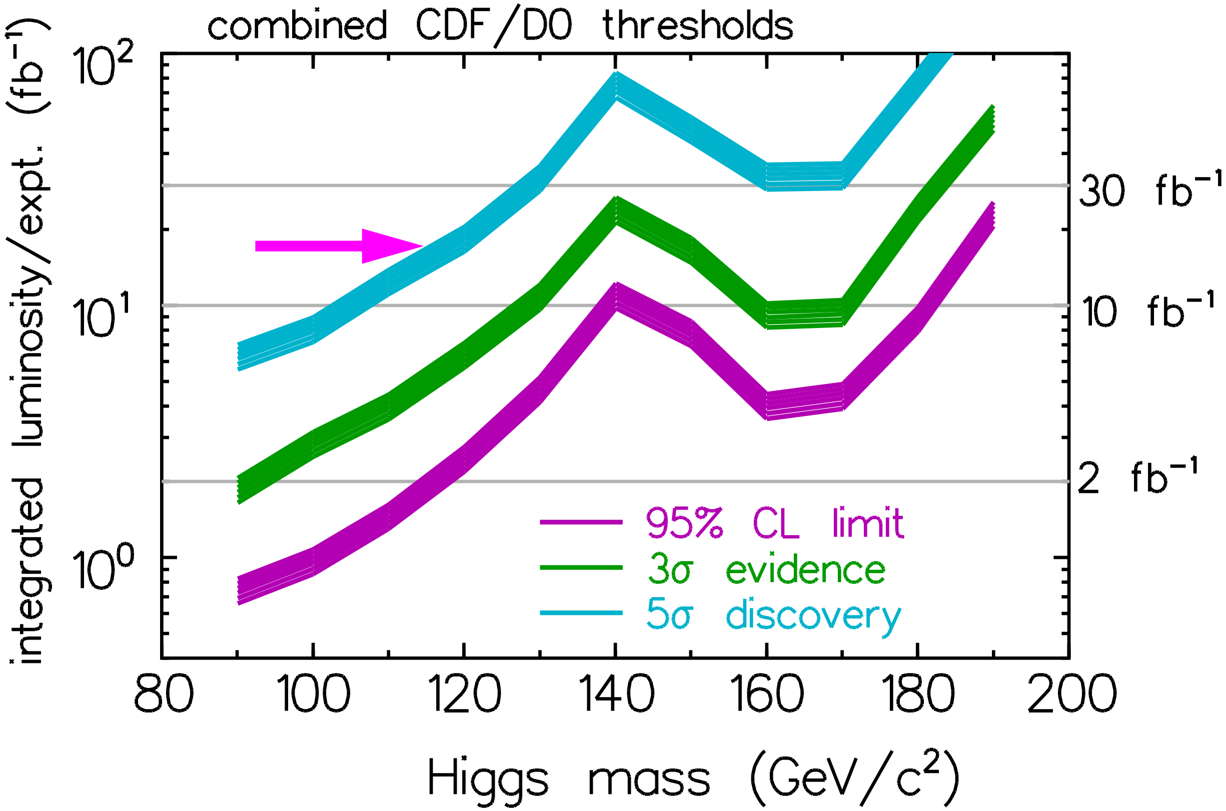




Tevatron



Entdeckung des Higgs-Bosons am Tevatron ?

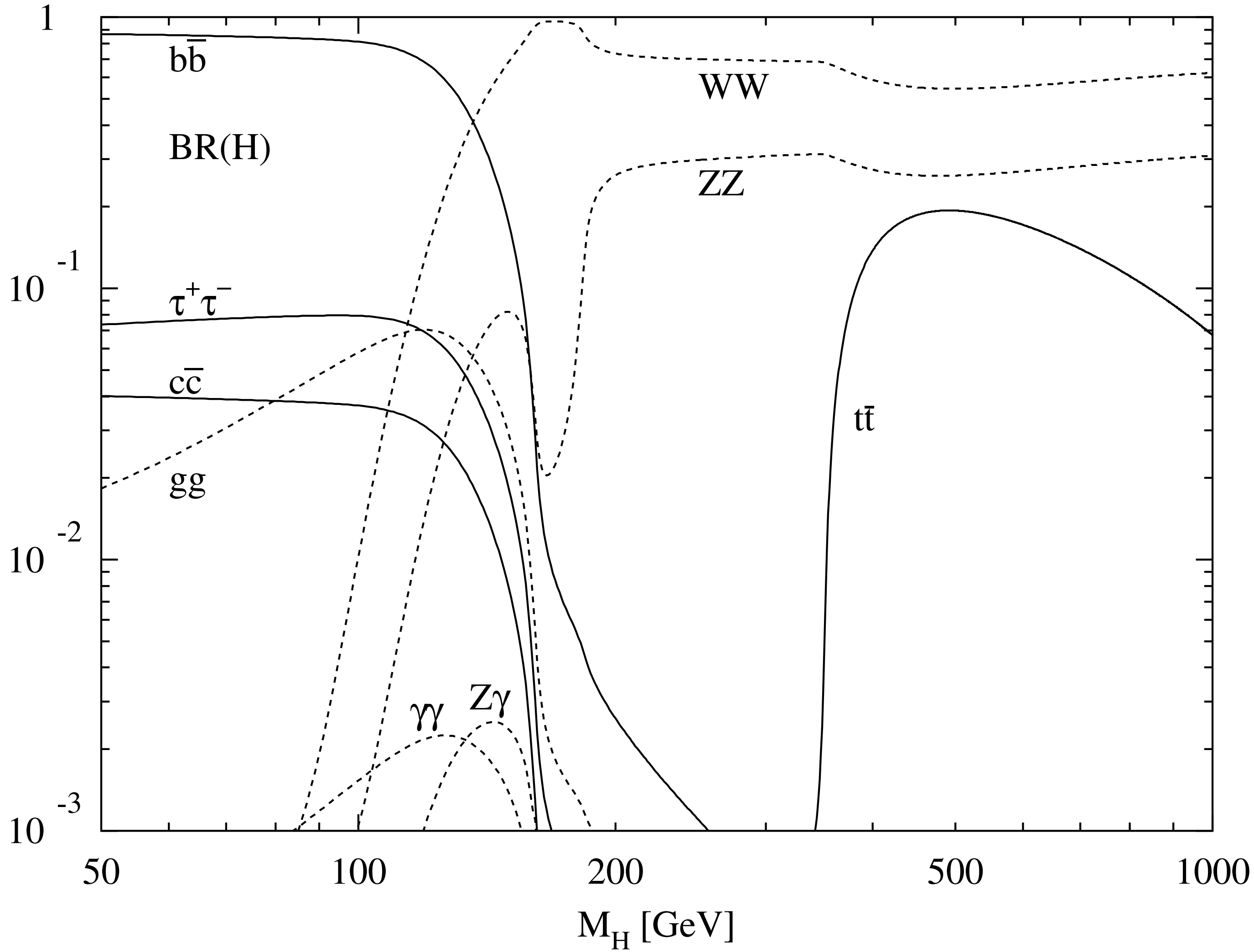


erwartete Luminosität

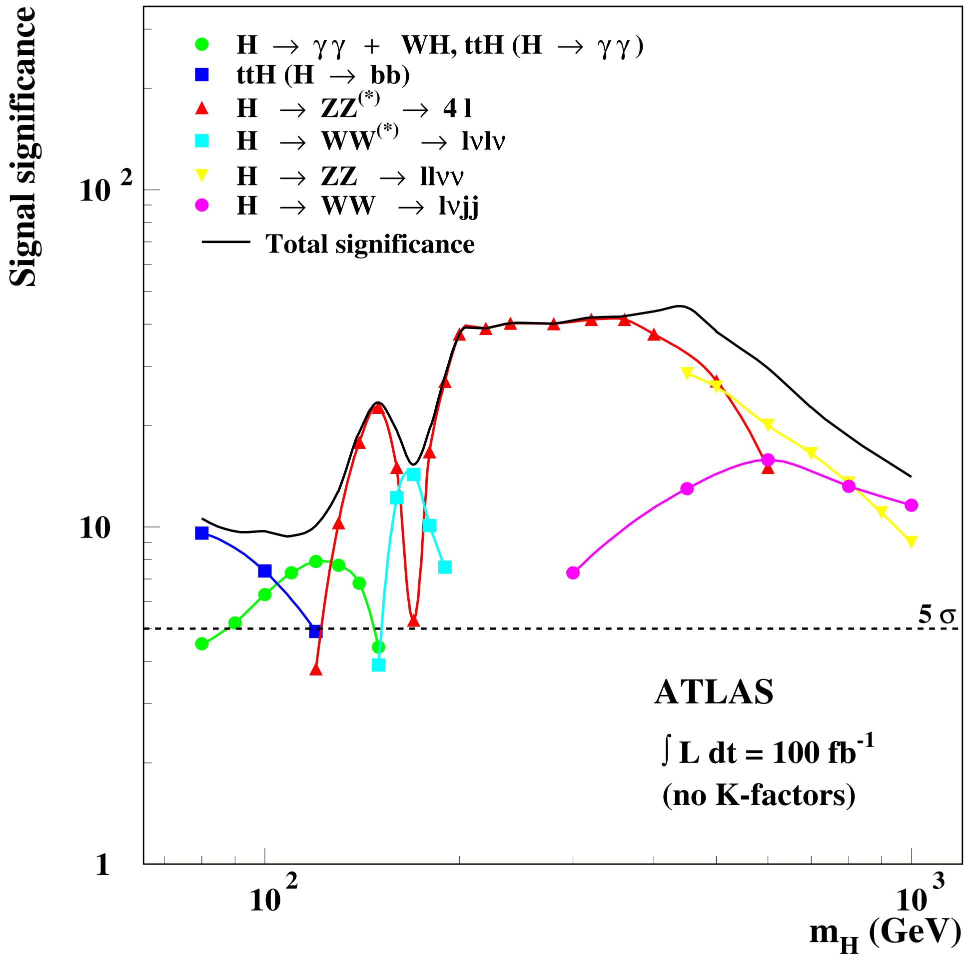
(S. Holmes, ICFA seminar 1999):

- Ende 2006: ca. 11 fb-1
- Ende 2007: ca. 15 fb-1

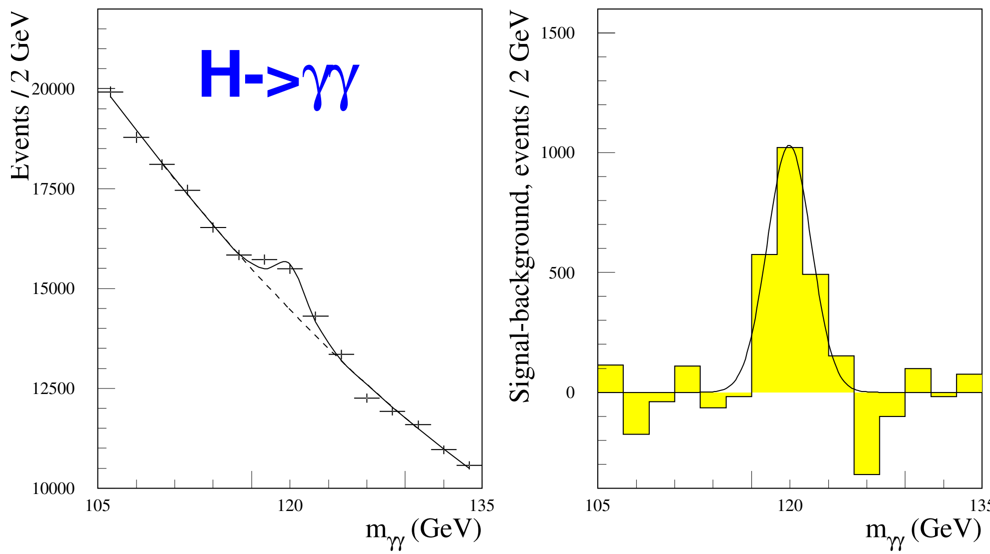
Verzweigungsverhältnisse:



Entdeckung des Higgs-Bosons am LHC ?



$100 fb^{-1}$



2005: Pilot Run
2006: ~1 fb^{-1}
2007: ~10 fb^{-1}

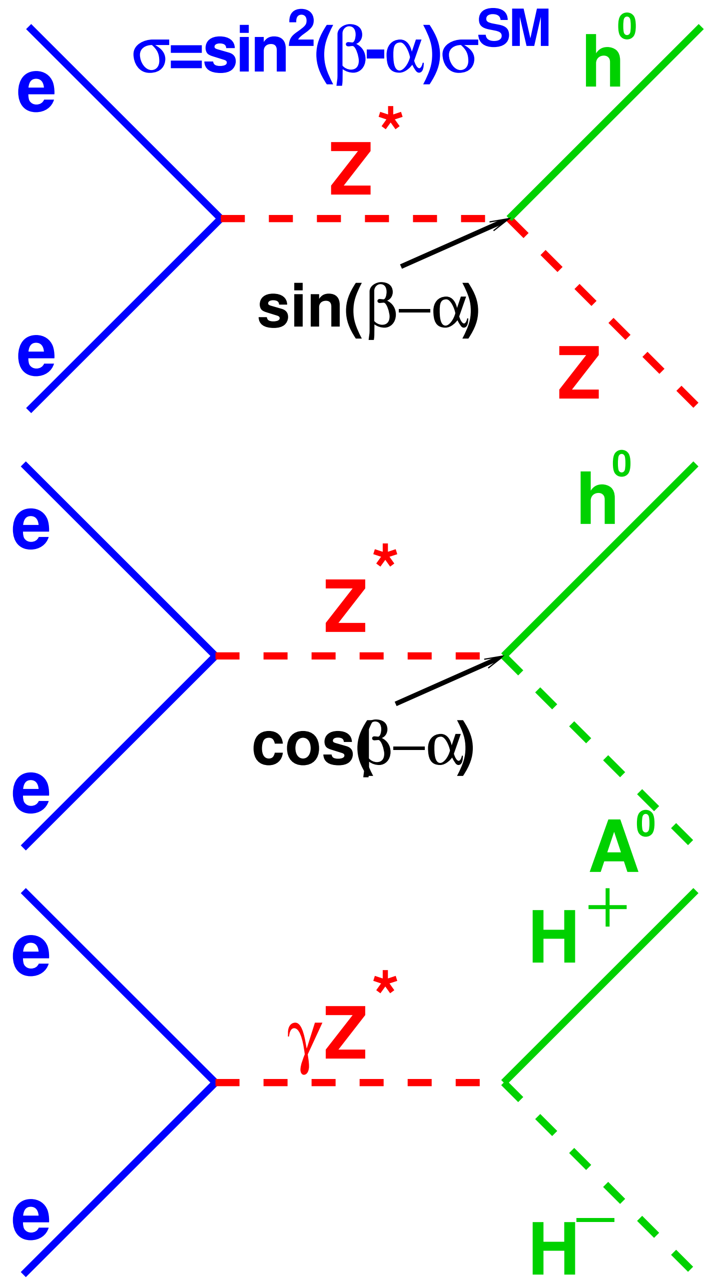
Higgs-Bosonen im MSSM:

Zwei Higgs-Doublets=>
5 Higgs-Teilchen

- h_0: leichtes CP-gerades Higgs
- H_0: schweres CP-gerades Higgs
- A_0: CP-ungerades Higgs
- H^+,H^-: geladene Higgs

m_{h0}<~135 GeV

tan $\beta = v_1/v_2$ (Vakuumserwartungswerte)
α: Mischungsparameter

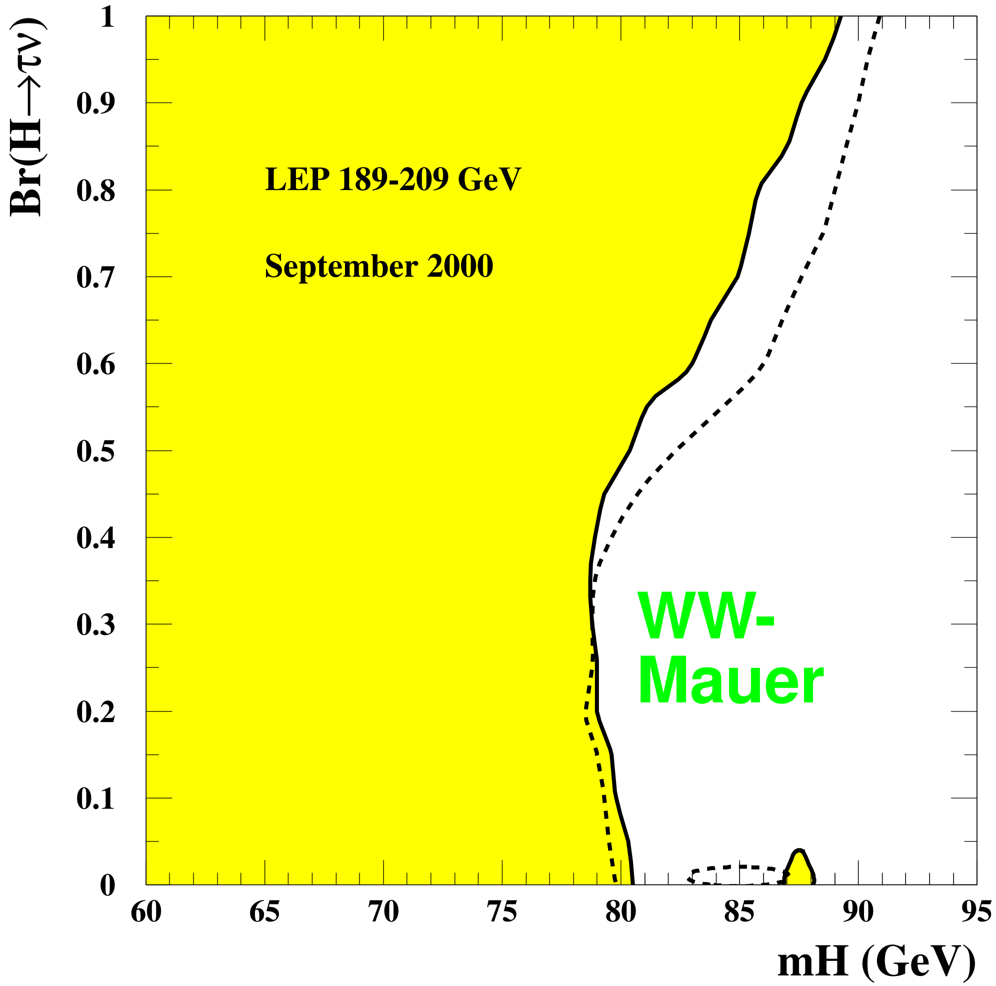


$BR(H^+ \to \tau^+ \nu_\tau) + BR(H^+ \to cs) = 1$

$\tau\nu\tau\nu$

$\tau\nu$cs

cscs

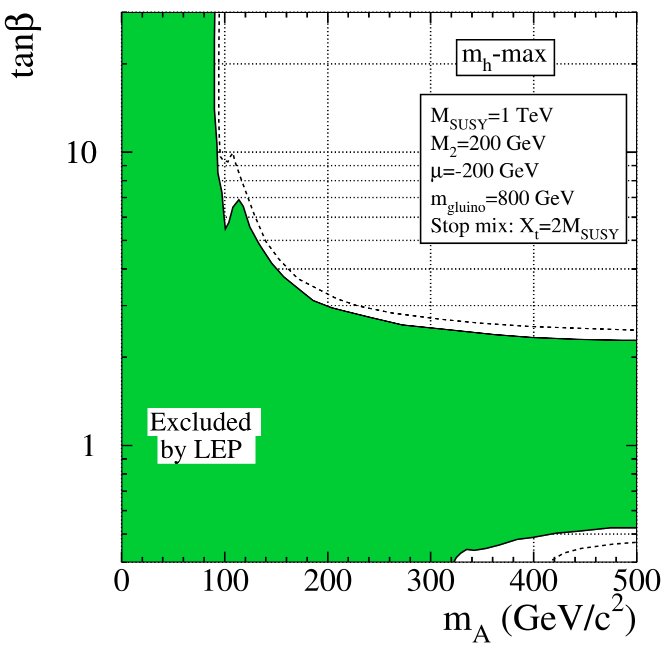


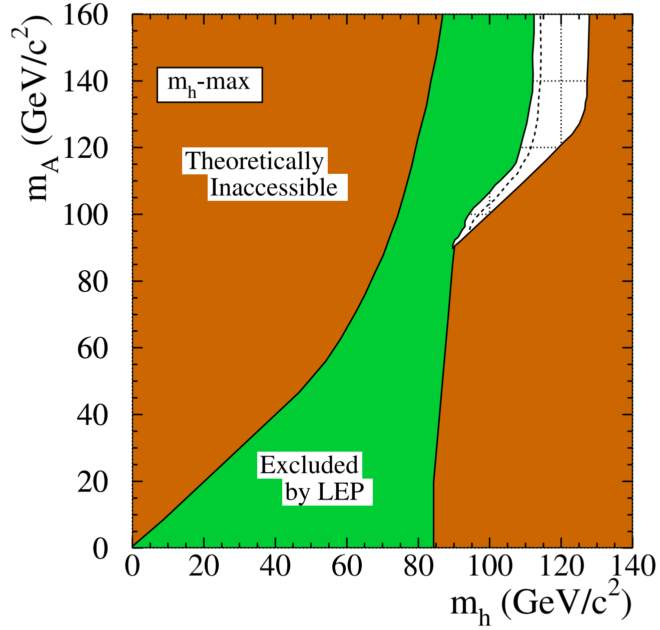
2 Leptonen + E_{miss}

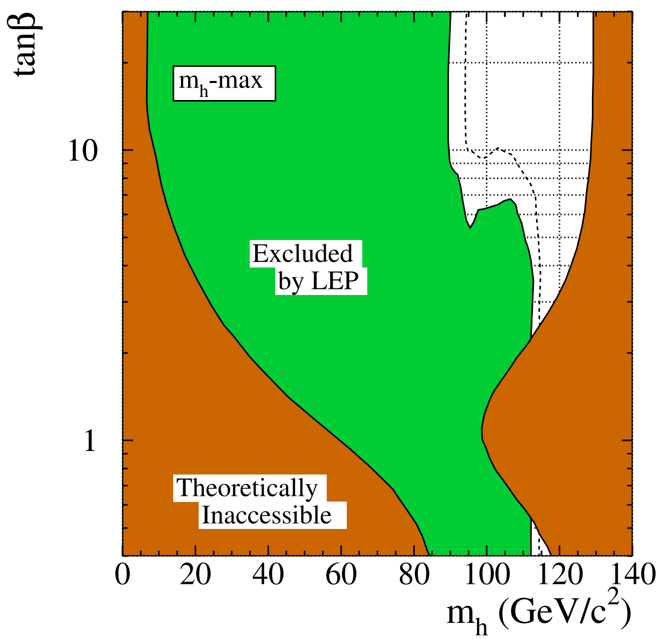
2 Jets, 1 Lepton + E_{miss}

4 Jets

Max-m_h Szenario..







m_h>89.9 GeV (erwartet 93.8 GeV)

m_A>90.5 GeV (erwartet 94.1 GeV)

$0.52<\tan\beta<2.25$

Zusammenfassung

- LEP sieht mit einer Signifikanz von 2.9 σ Anzeichen für die Produktion eines Standard Model Higgs-Bosons mit einer Masse von ca. 115 GeV
- ALEPH und L3 haben bereits veröffentlicht; OPAL und DELPHI sowie die LEP-Higgs-Gruppe werden noch vor Weihnachten folgen.
- Damit wird das Rennen zwischen dem Tevatron und dem LHC eröffnet, bis 2006/2007 diese Beobachtung zu überprüfen
- Higgs-Eigenschaften oder alternative Szenarien ohne Higgs könnten hervorragend bei TESLA untersucht werden