Search for Higgs bosons and new physics at LEP

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On behalf of the LEP Collaborations:

Les Rencontres de Physique de la Vallée d'Aoste,

La Thuile, March 14, 2003

End of data taking at LEP on December 2000

Many interesting results presented in several occasions:

Higgs, SUSY, exotica...

I review a small set of selected topics

Overview

- Standard Model Higgs (MSSM Higgs)
- Gluino and squark search
- Extra dimensions
- Search for branons

FINAL LEP RESULTS

Search for the Standard Model Higgs boson at LEP,
CERN-EP/2003-??, to be submitted to Phys. Lett. B

All LEP experiments published their final results:

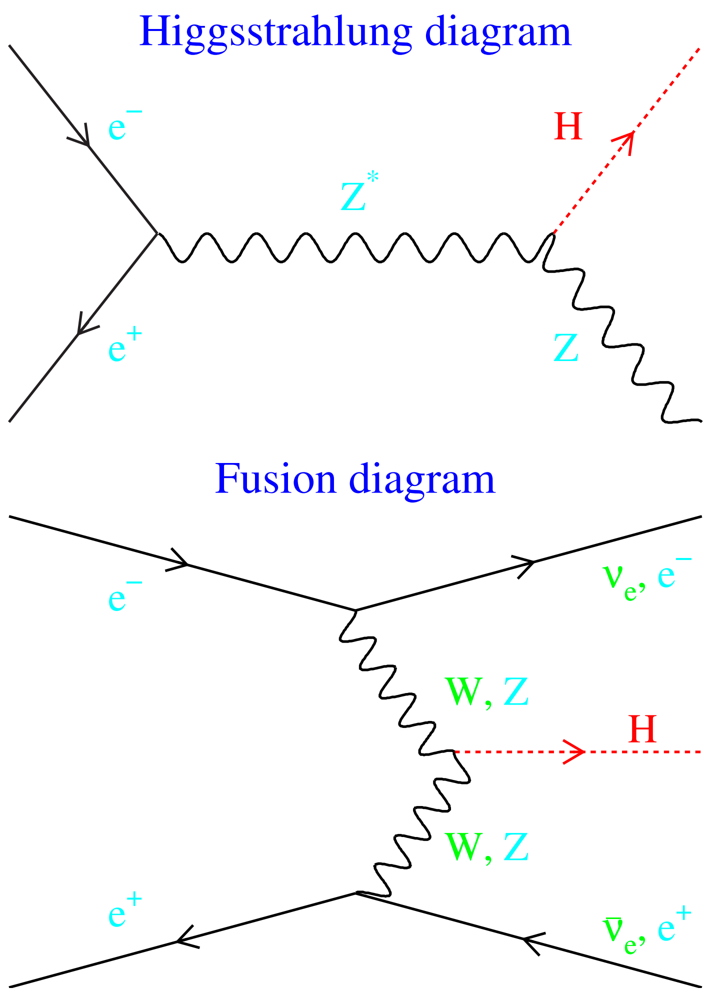
ALEPH Collab., R. Barbate et al., Phys. Lett. B 526 (2002) 191

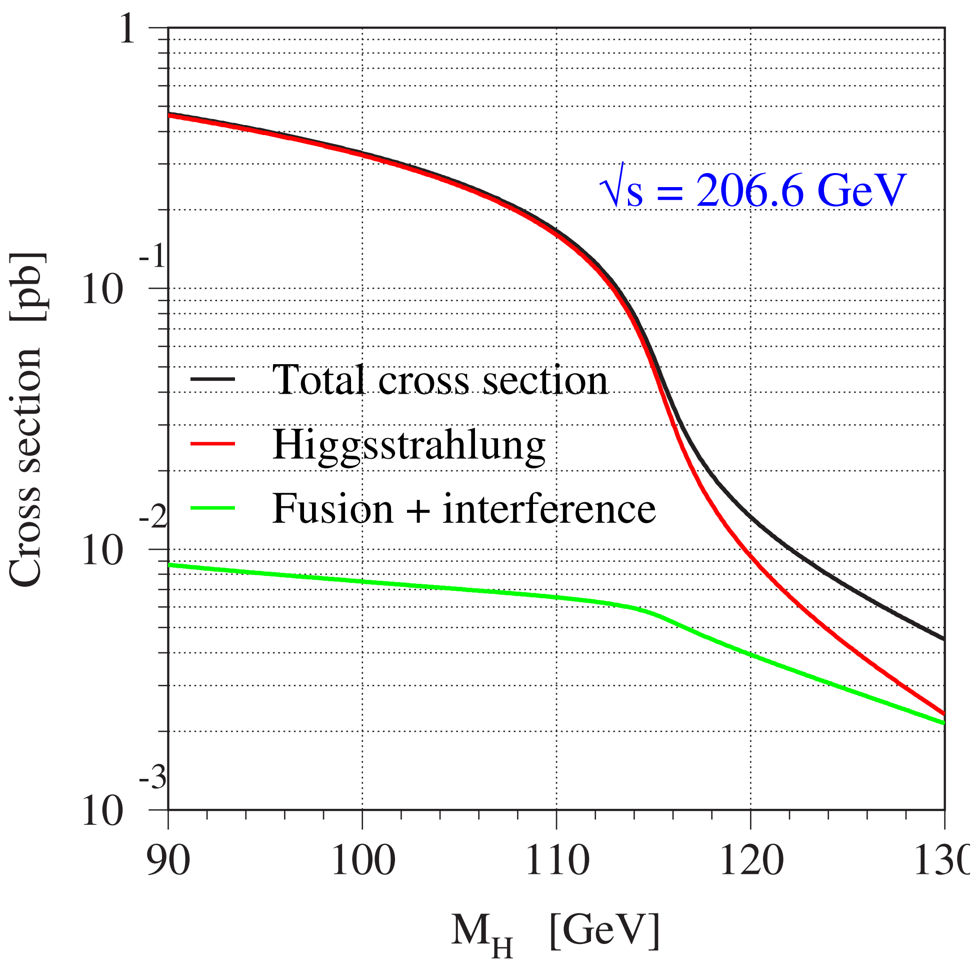
DELPHI Collab., J. Abdallah et al., CERN-EP/2003-008, to be published in Eur. Phys. J. C

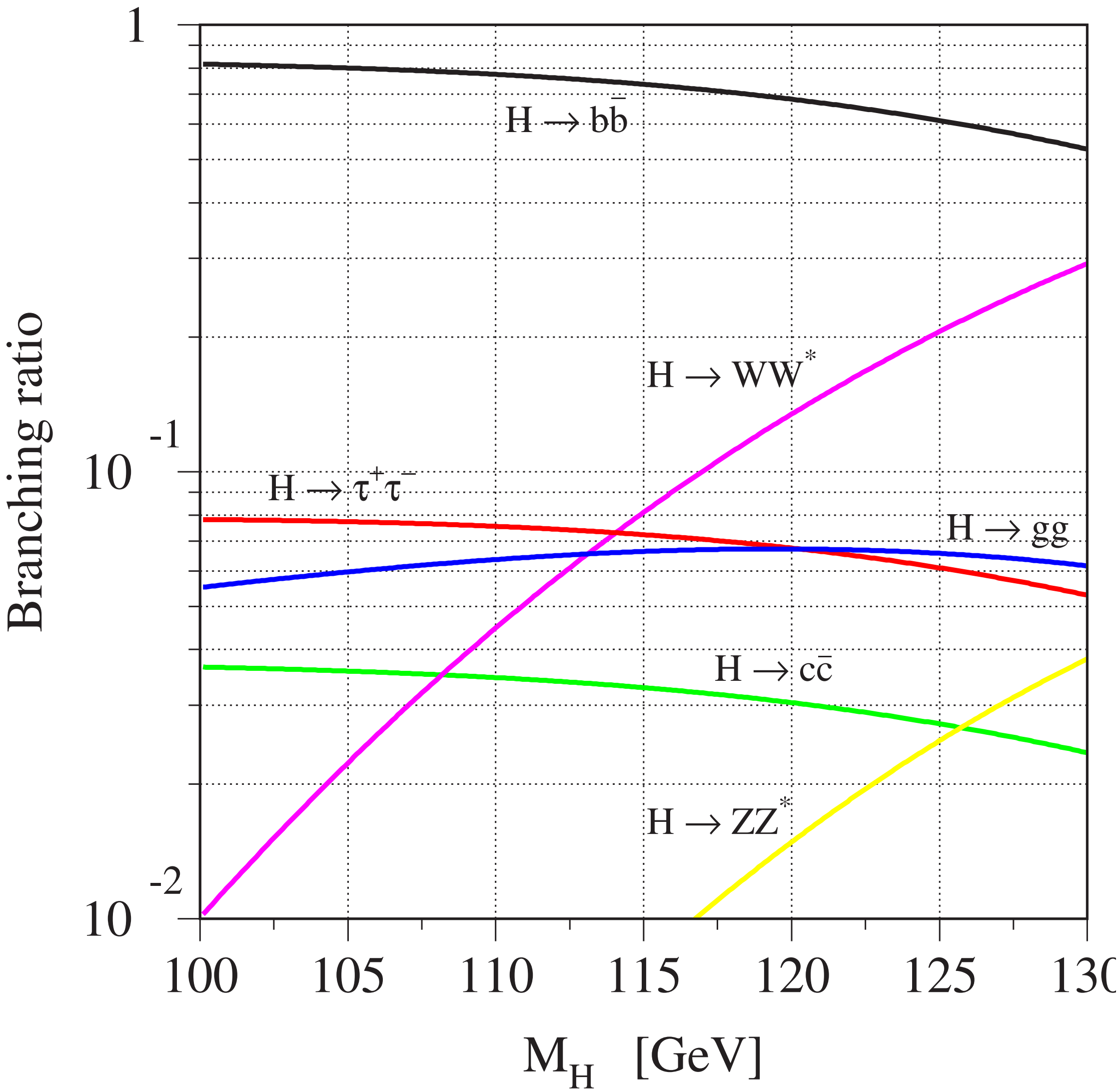
L3 Collab., M. Acciarri et al., Phys. Lett. B 517 (2001) 319

OPAL Collab., G. Abbiendi et al., CERN-EP/2002-059, to be published in Eur. Phys. J. C

Higgs production at LEP







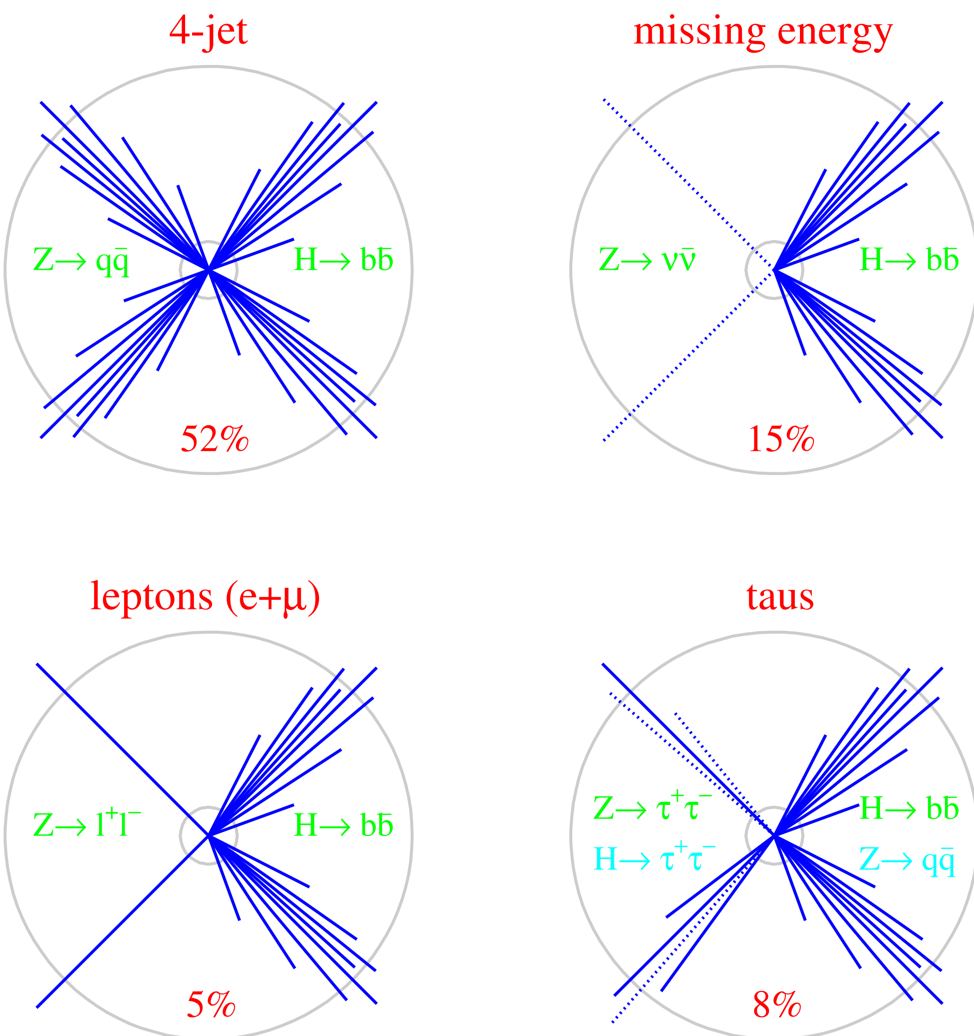
Br (Z → hadrons) = 69.9%

Br (Z → invisible) = 20.0%

Br (Z → $\ell^+\ell^-$) = 3.4%

Topology of the final states

About 80% of the final states exploited

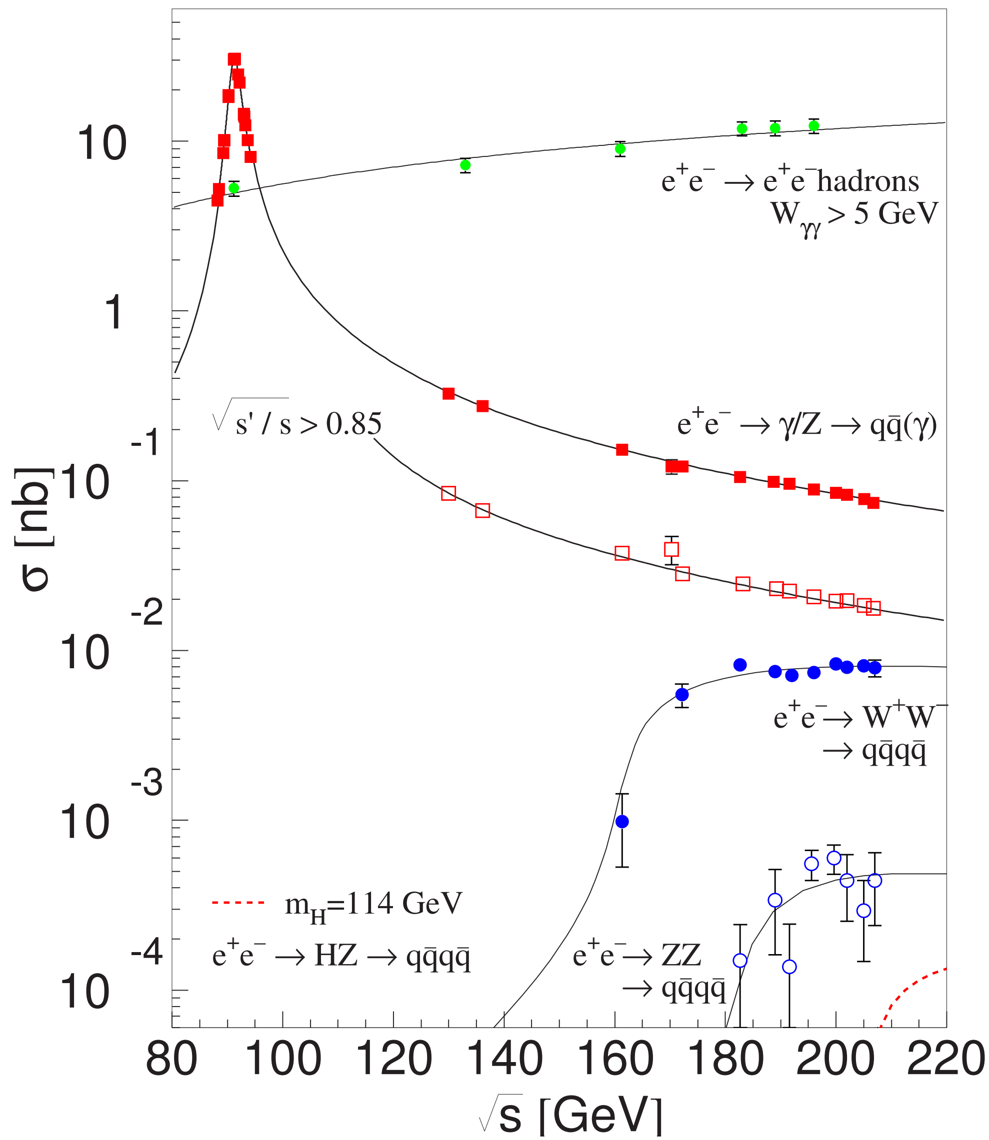


Assuming:

$$\sqrt{s} = 207\ \text{GeV}$$
$$\mathcal{L} = 500\ \text{pb}^{-1}$$
$$\varepsilon = 50\ \%$$

Expected signal events for a $m_{\text{H}} = 115\ \text{GeV}$ Higgs:

4-jet	=	**6.5**
missing energy	=	**1.9**
taus	=	**1.0**
leptons (e+μ)	=	**0.6**
All channels	=	**10**

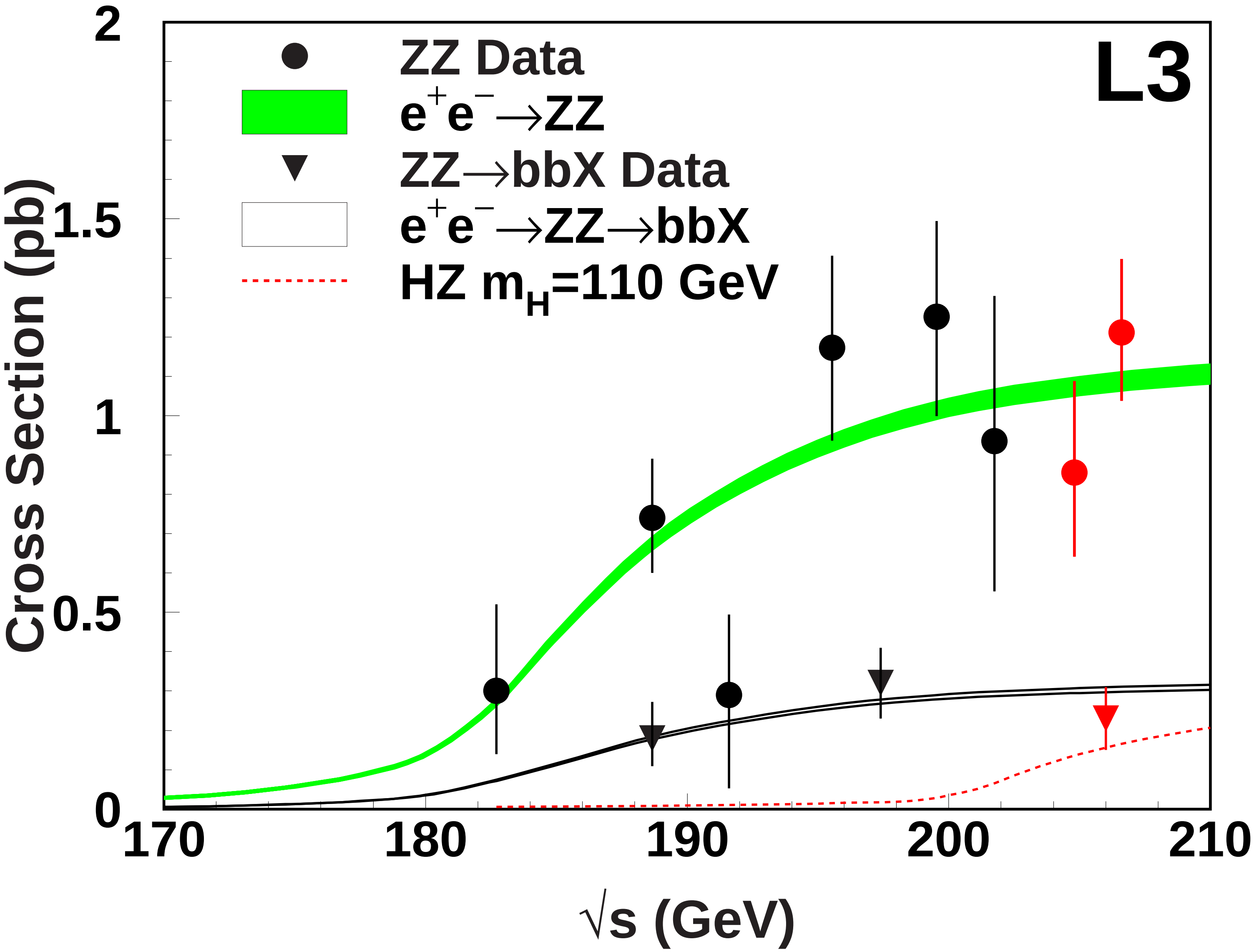


The main backgrounds are:

$e^+e^- \rightarrow q\bar{q}(\gamma)$, W^+W^- **and ZZ**

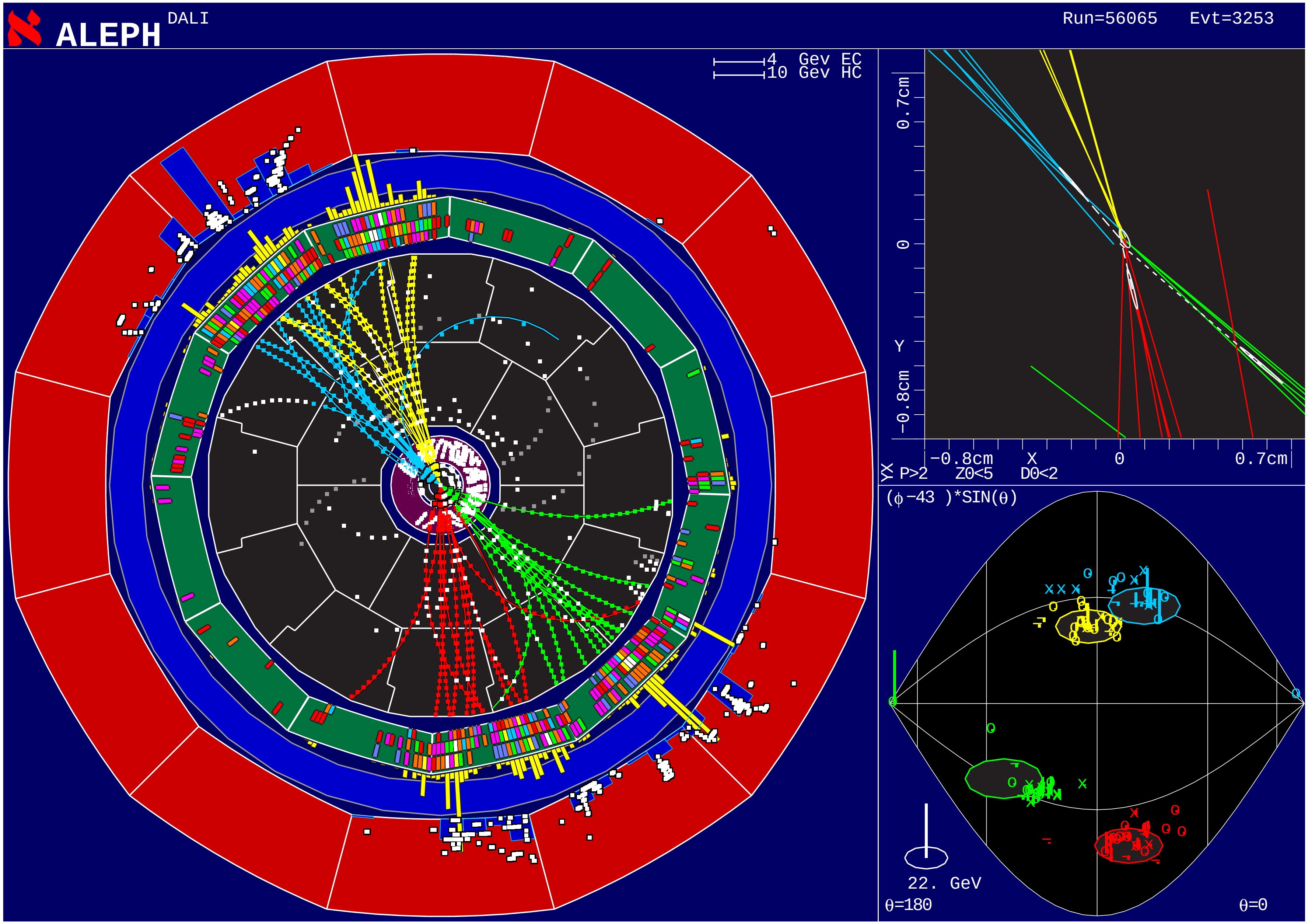
B-tagging is essential

Few hundred background events expected

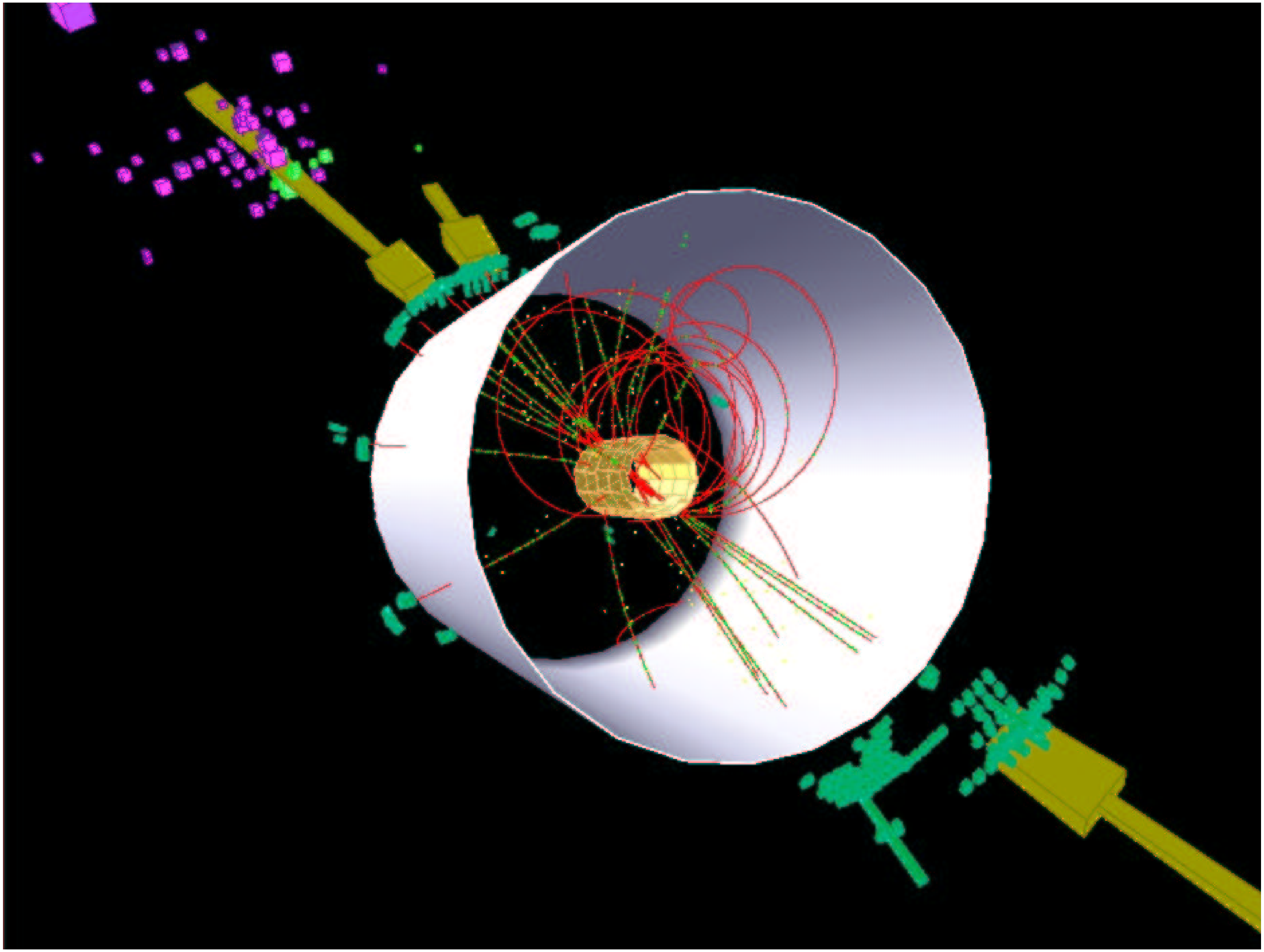


L3
ZZ Data
e+e−→ZZ
ZZ→bbX Data
e+e−→ZZ→bbX
HZ mH=110 GeV
Cross Section (pb)
√s (GeV)
0
0.5
1
1.5
2
170
180
190
200
210

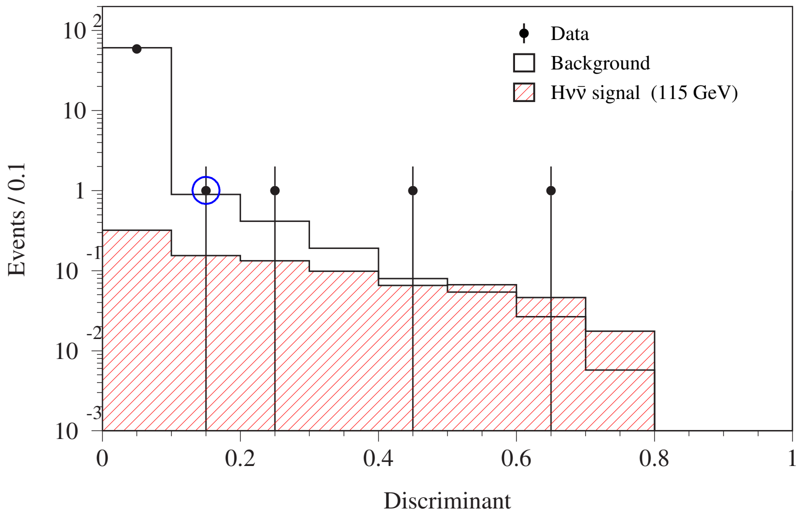
A tipical Hq$\bar{q}$ event



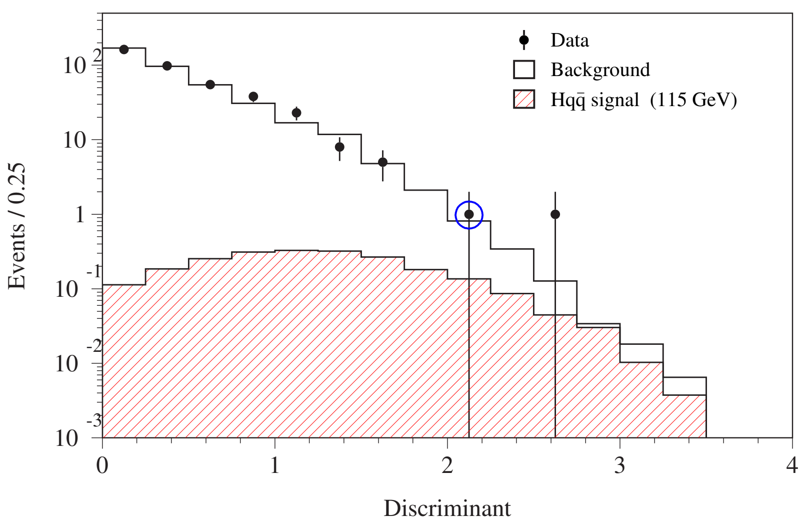
A tipical H$\nu\bar{\nu}$ event



Combination of channels



Combine channels with equal s/b ratio

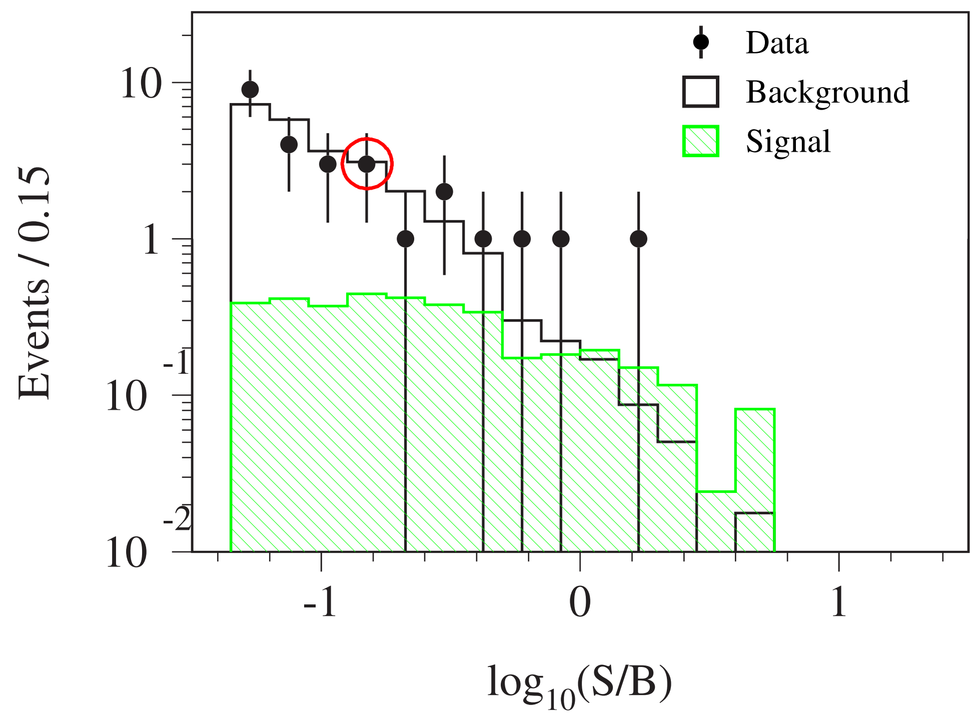


LEP treated as a single analysis:

4 experiments × 4 channels × 15 beam energies

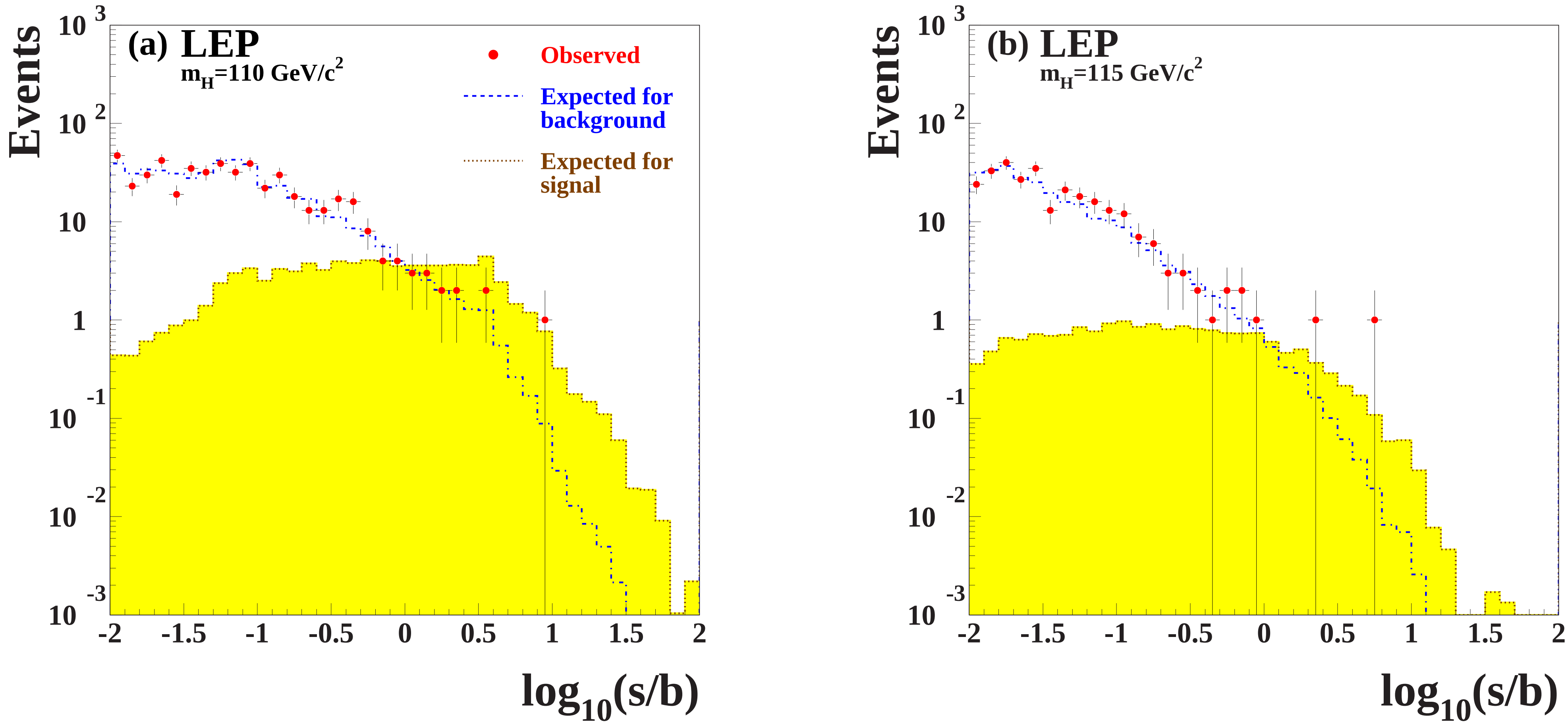
=

240 analyses combined



The shape of the distributions depends on the Higgs mass hypothesis !

LEP combined s/b distribution



Some events at high values of s/b for $m_{\rm H}$= 115 GeV

Statistical Method: -2ln(Q)

Likelihood Ratio test-statistic:

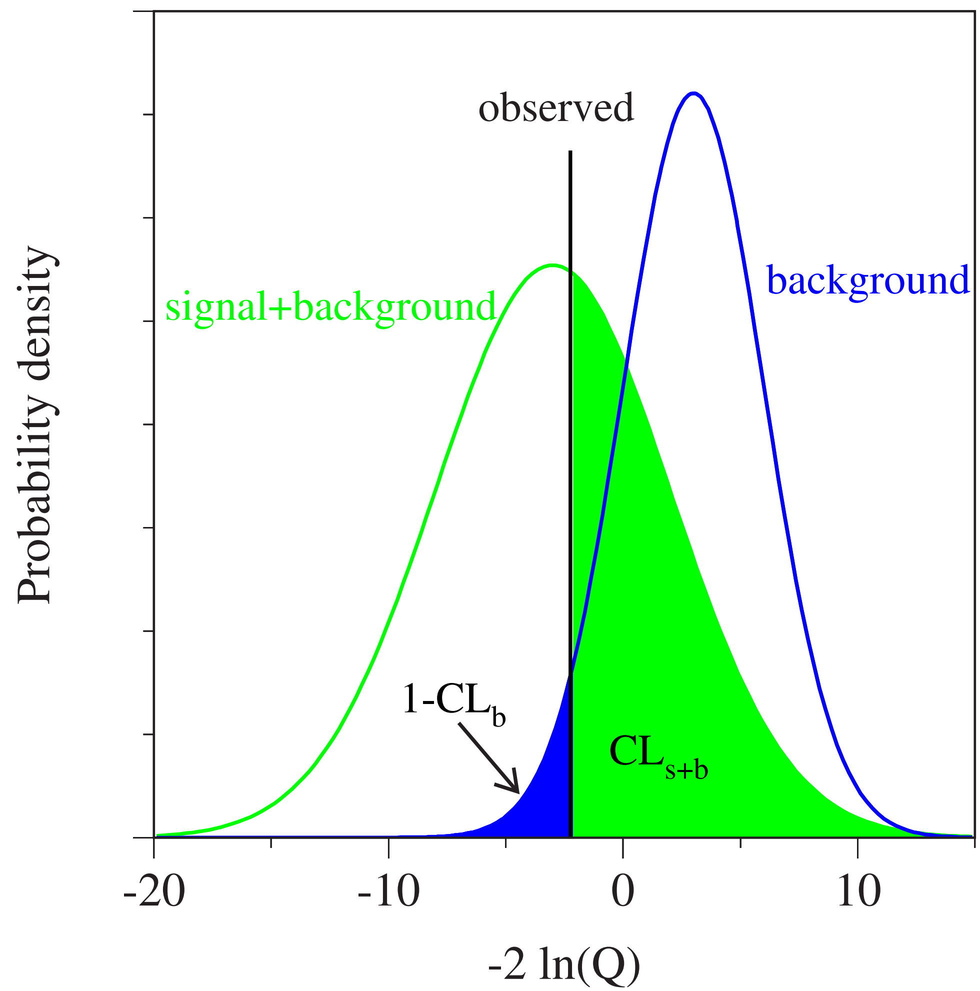
$$Q = \frac{\mathcal{L}(s+b)}{\mathcal{L}(b)}$$

Each bin (i) in the final variable is treated as a Poisson counting experiment:

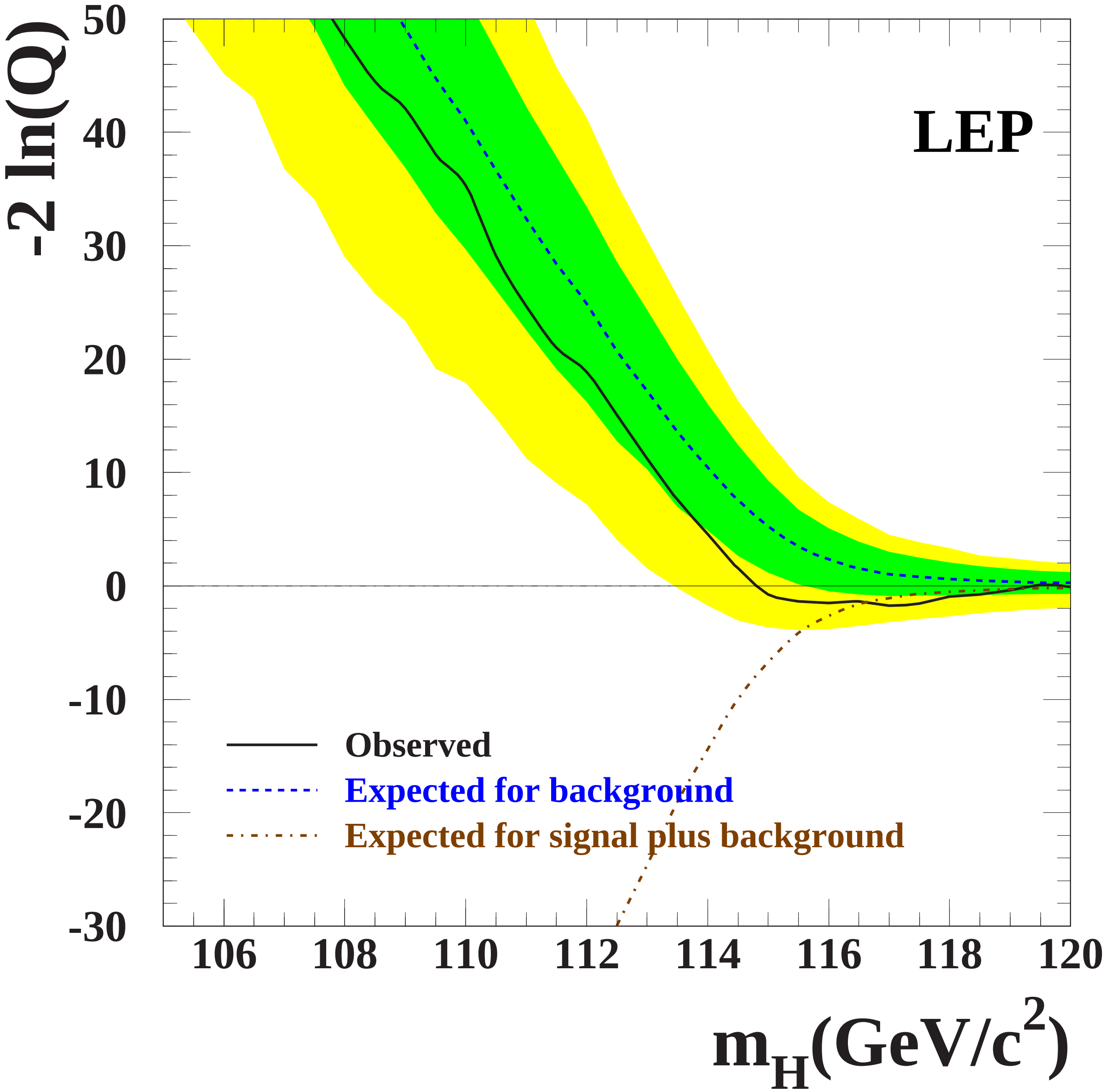
$$\ln(Q) = -s_{tot} + \sum_{i=1}^{N} n_i \ln\left(1 + \frac{s_i}{b_i}\right)$$

In the high statistics limit:

$$-2\ln(Q) \rightarrow \Delta\chi^2$$

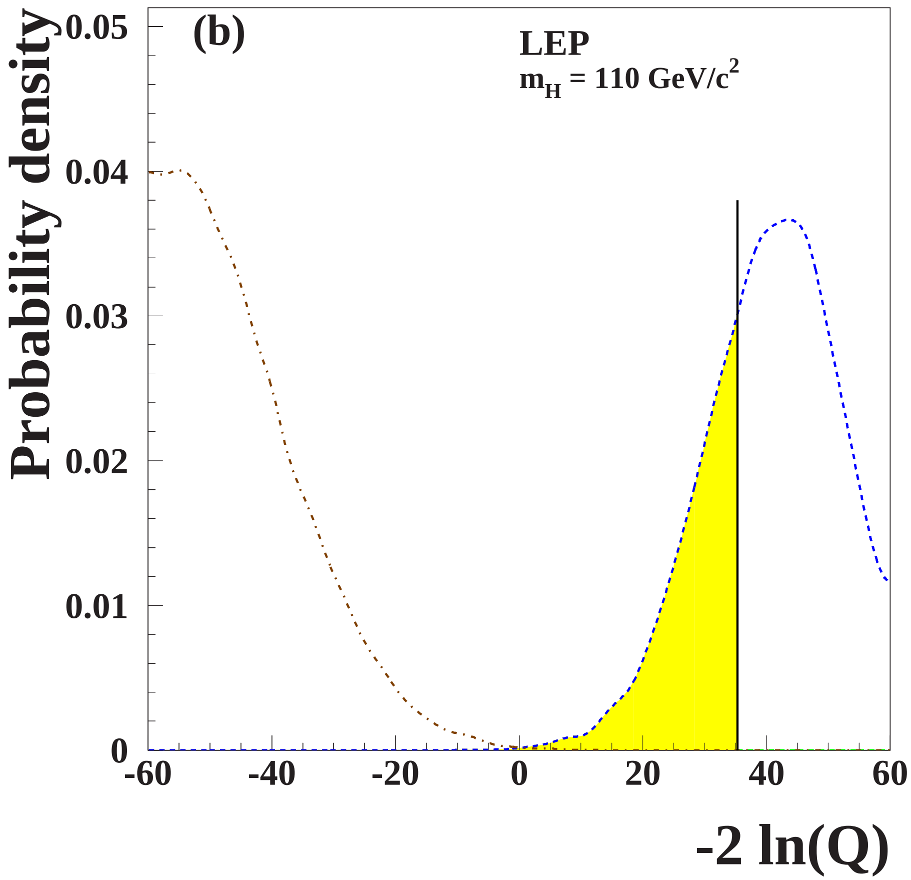


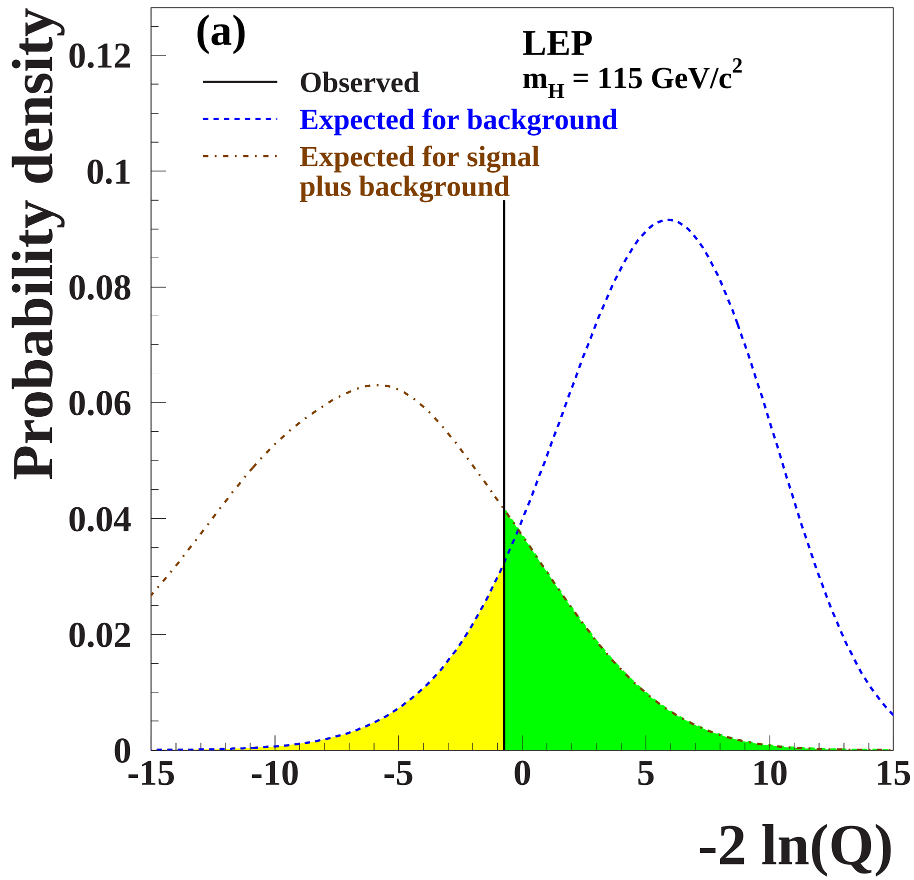
LEP combined -2ln(Q)



Background-like below 114 GeV

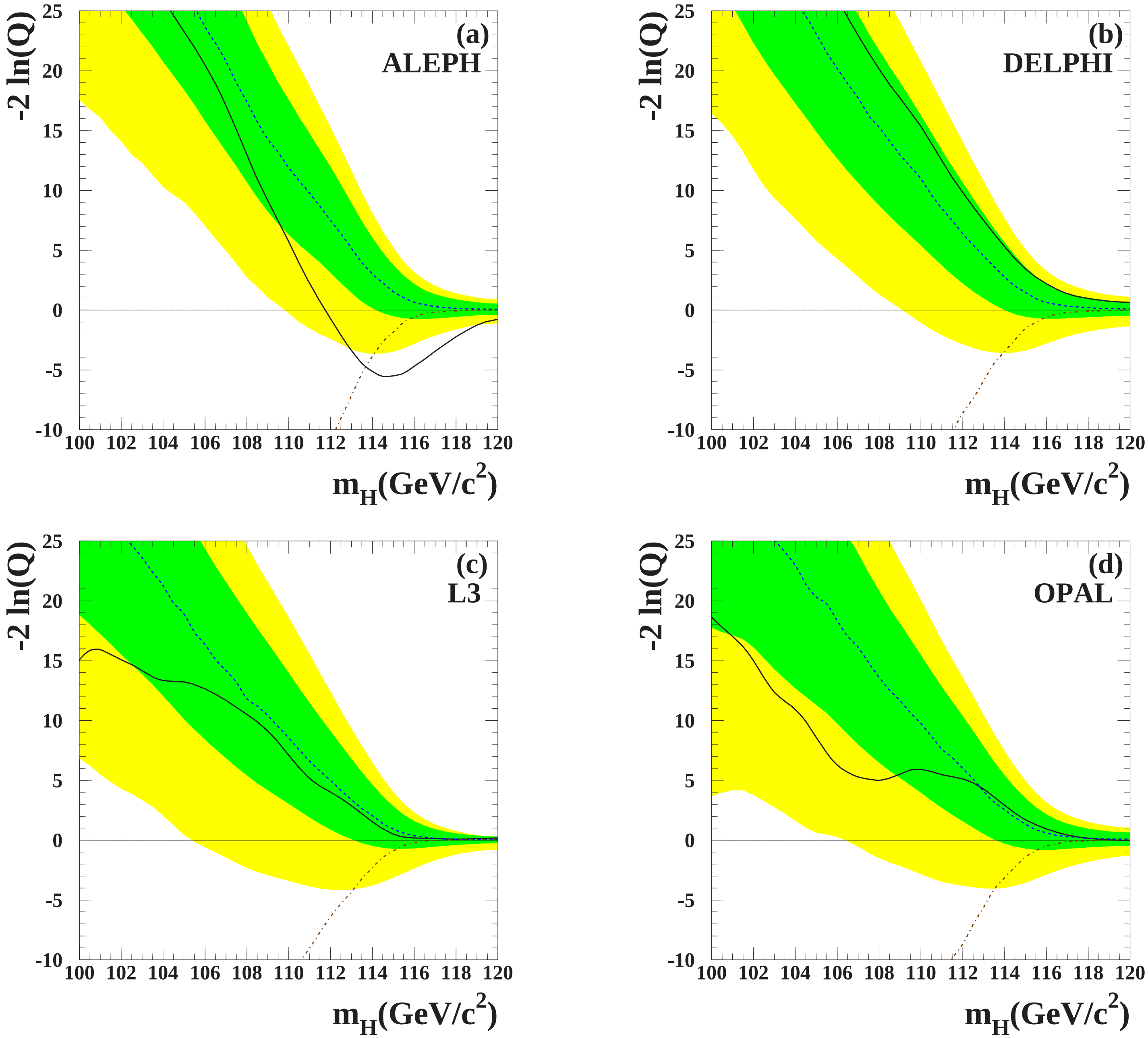
Slight excess around 115-117 GeV

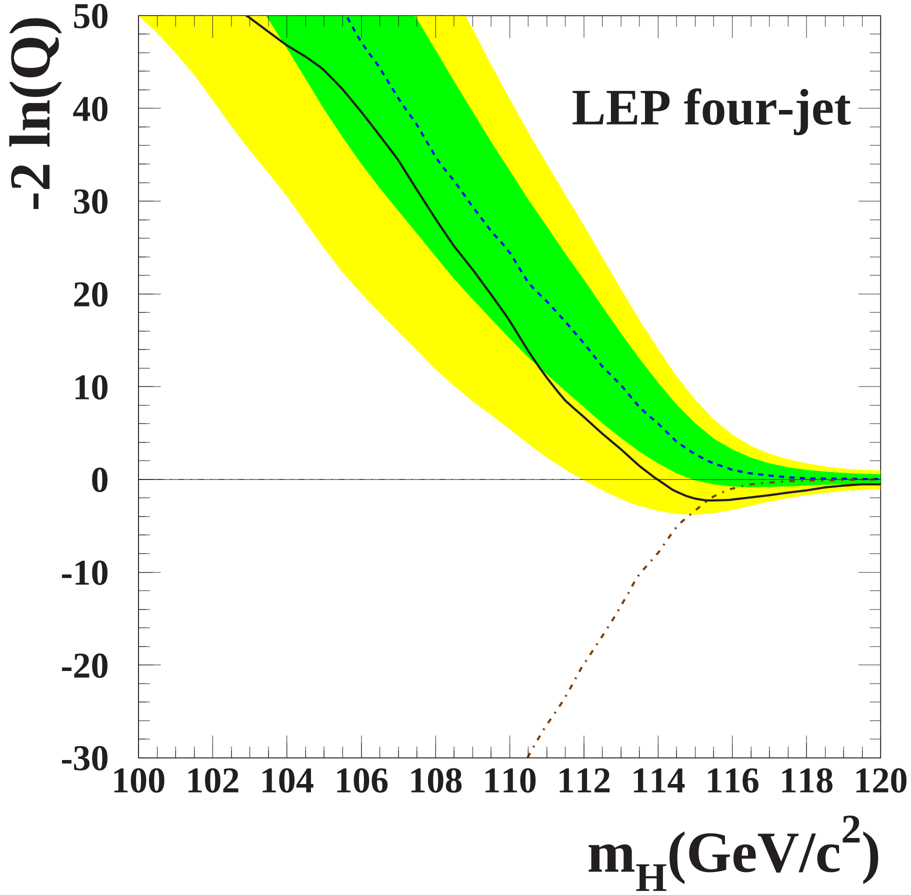


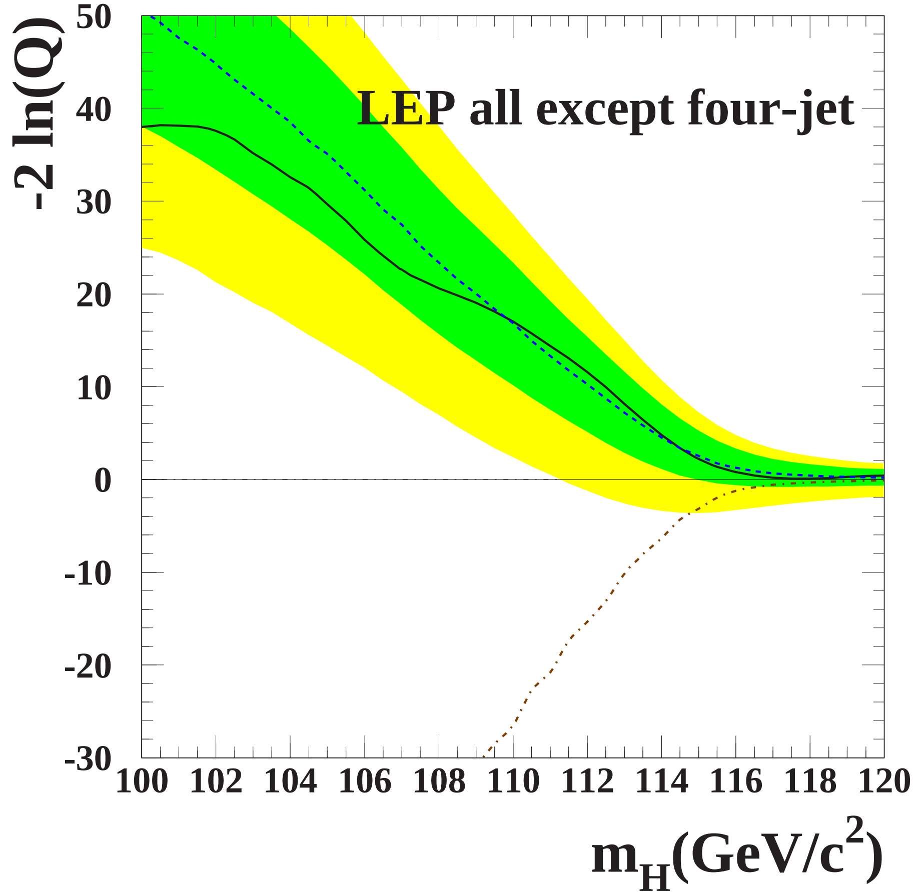


Significant discriminating power of the combined LEP data for $m_{\mathrm{H}} = 110\ \mathrm{GeV}$, which is rapidly decreasing for higher masses.

-2ln(Q) per experiment

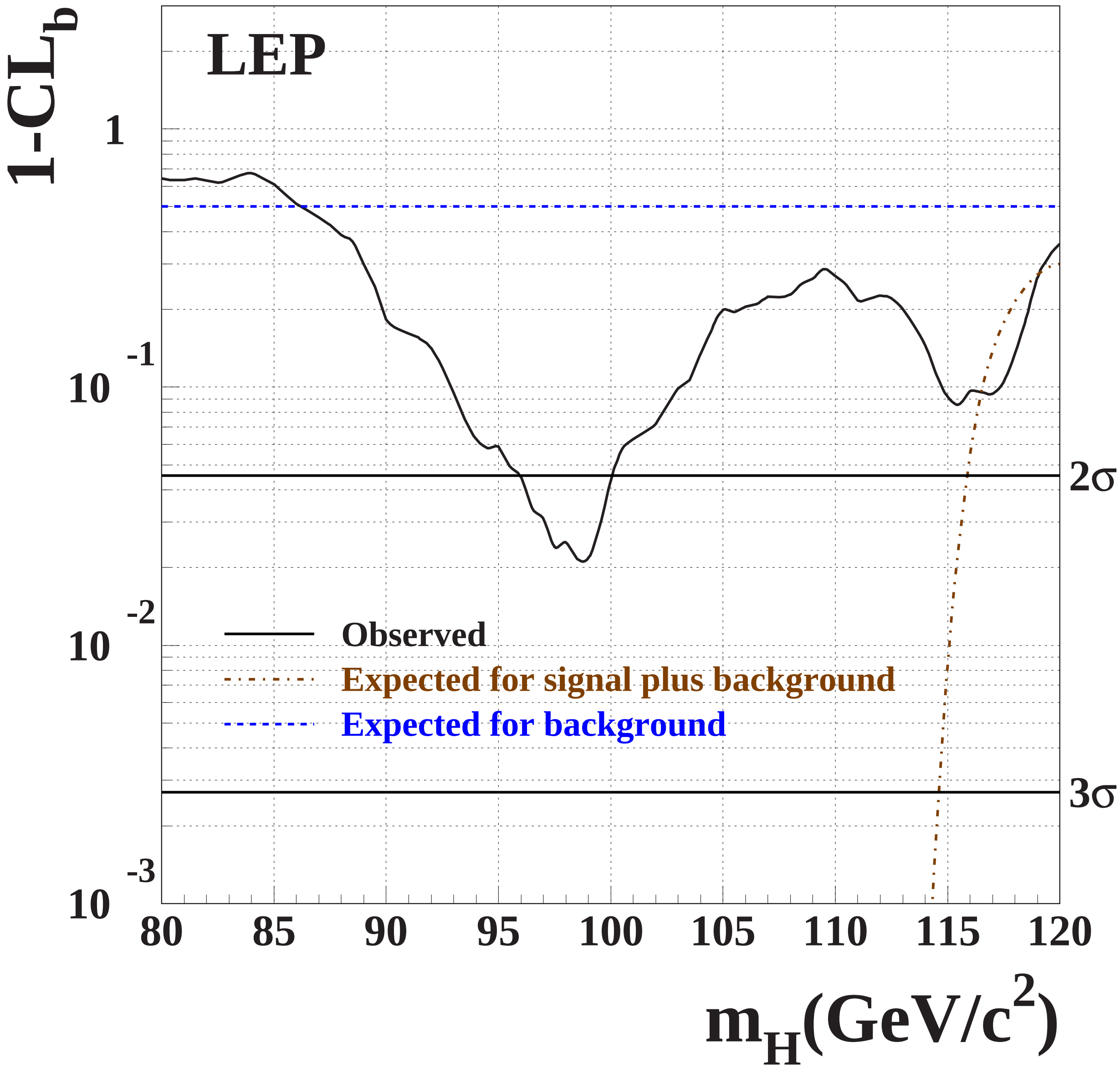






The excess is concentrated on the 4-jet channel

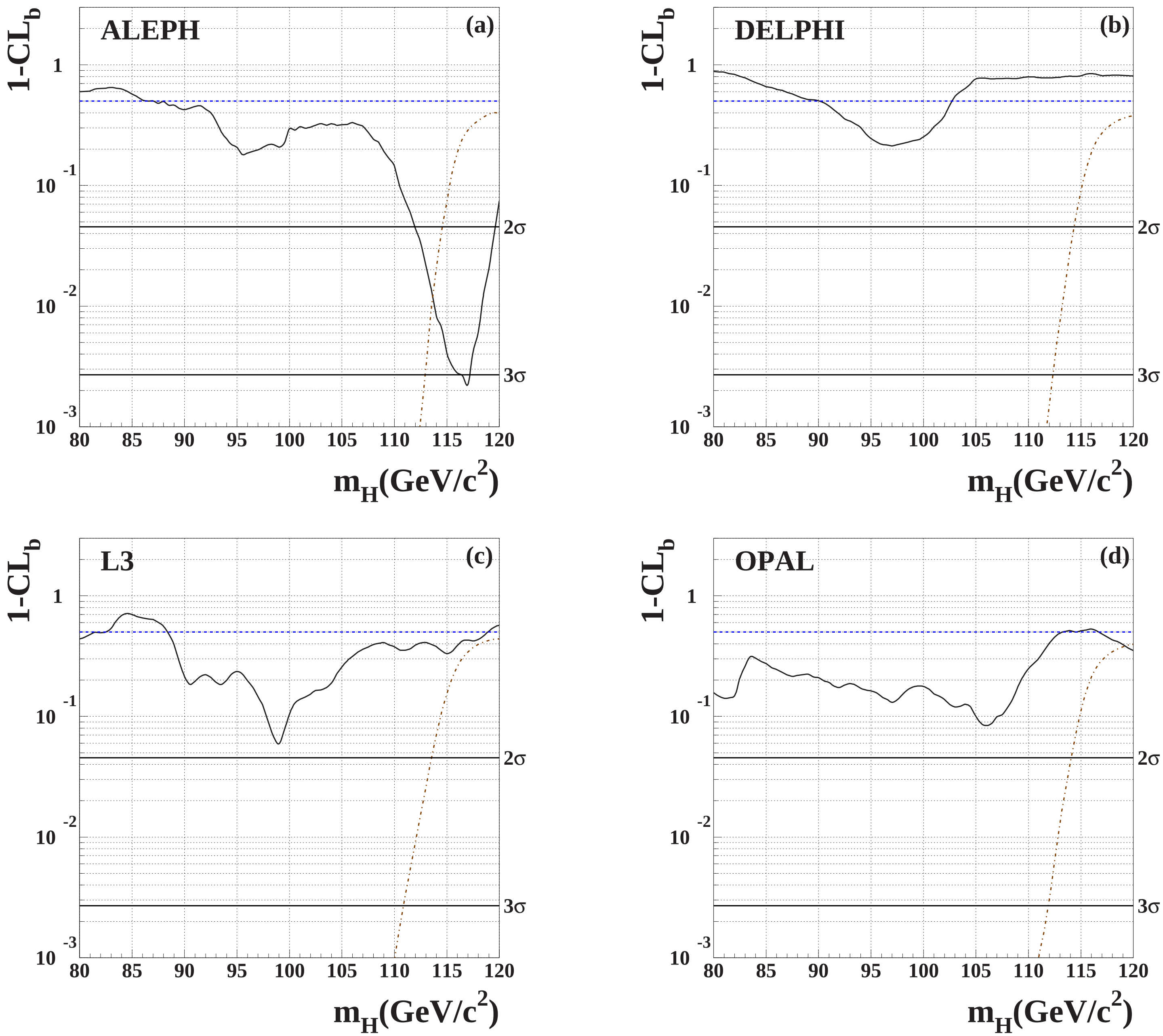
Compatibility with the background



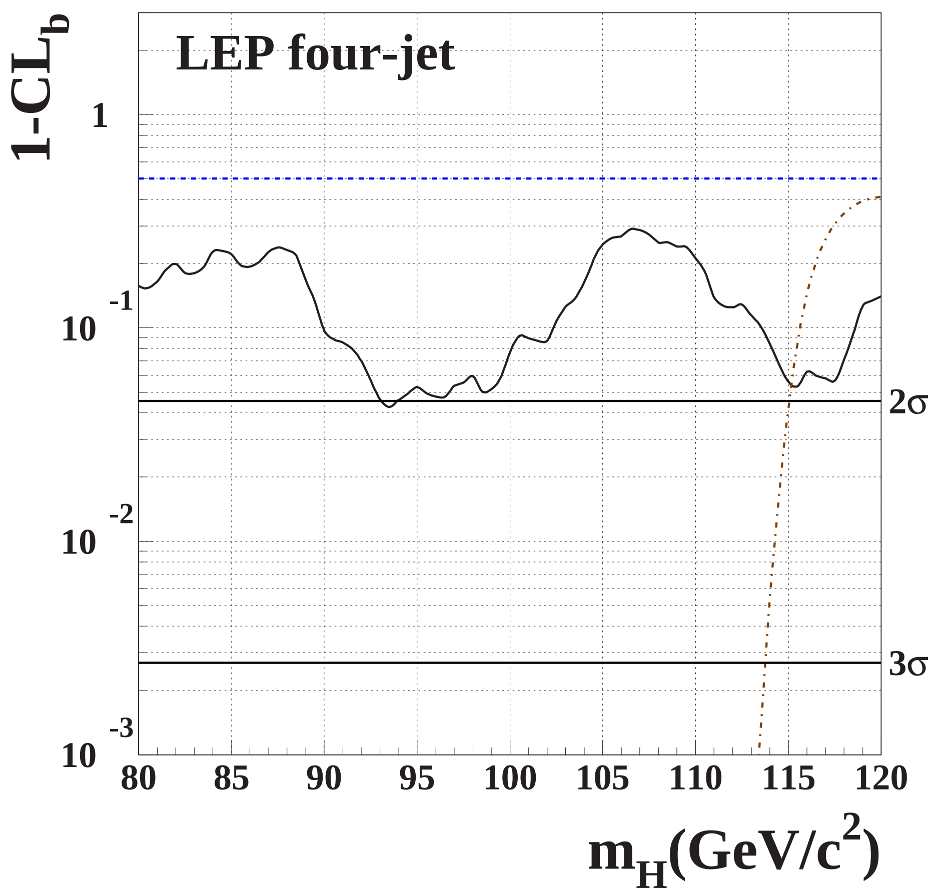
Excess around 95-100 GeV irrelevant for SM Higgs but maybe not for MSSM

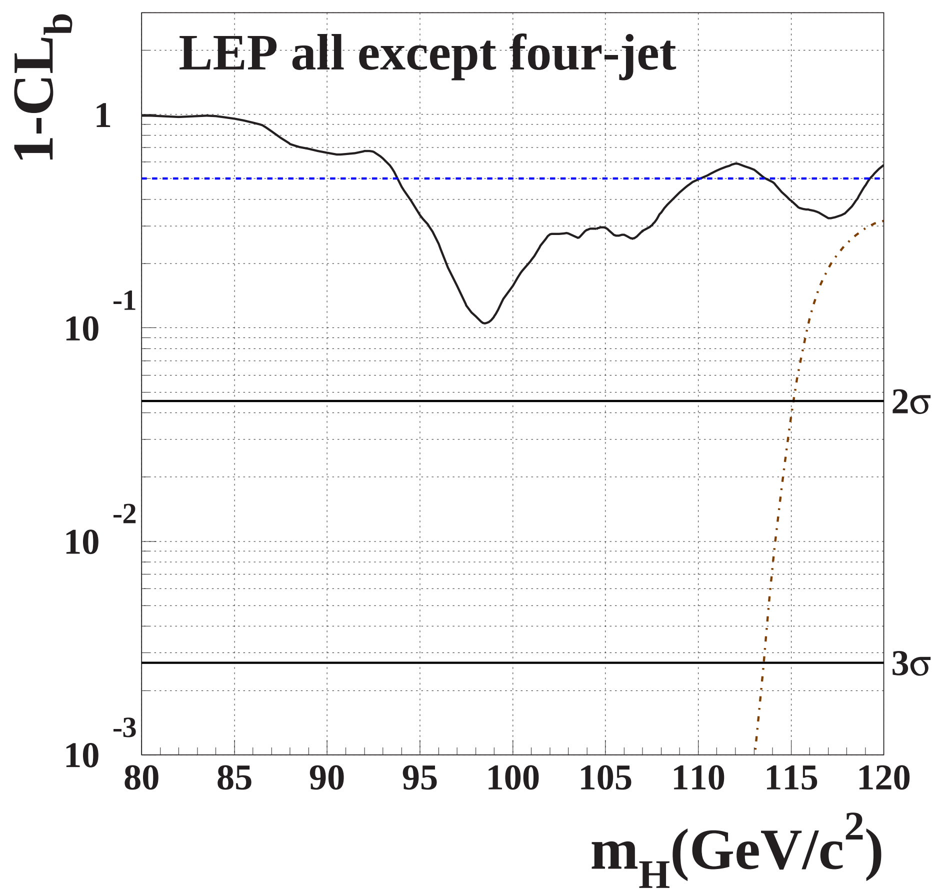
Slight excess around 115-117 GeV

$1 - CL_b$ per experiment



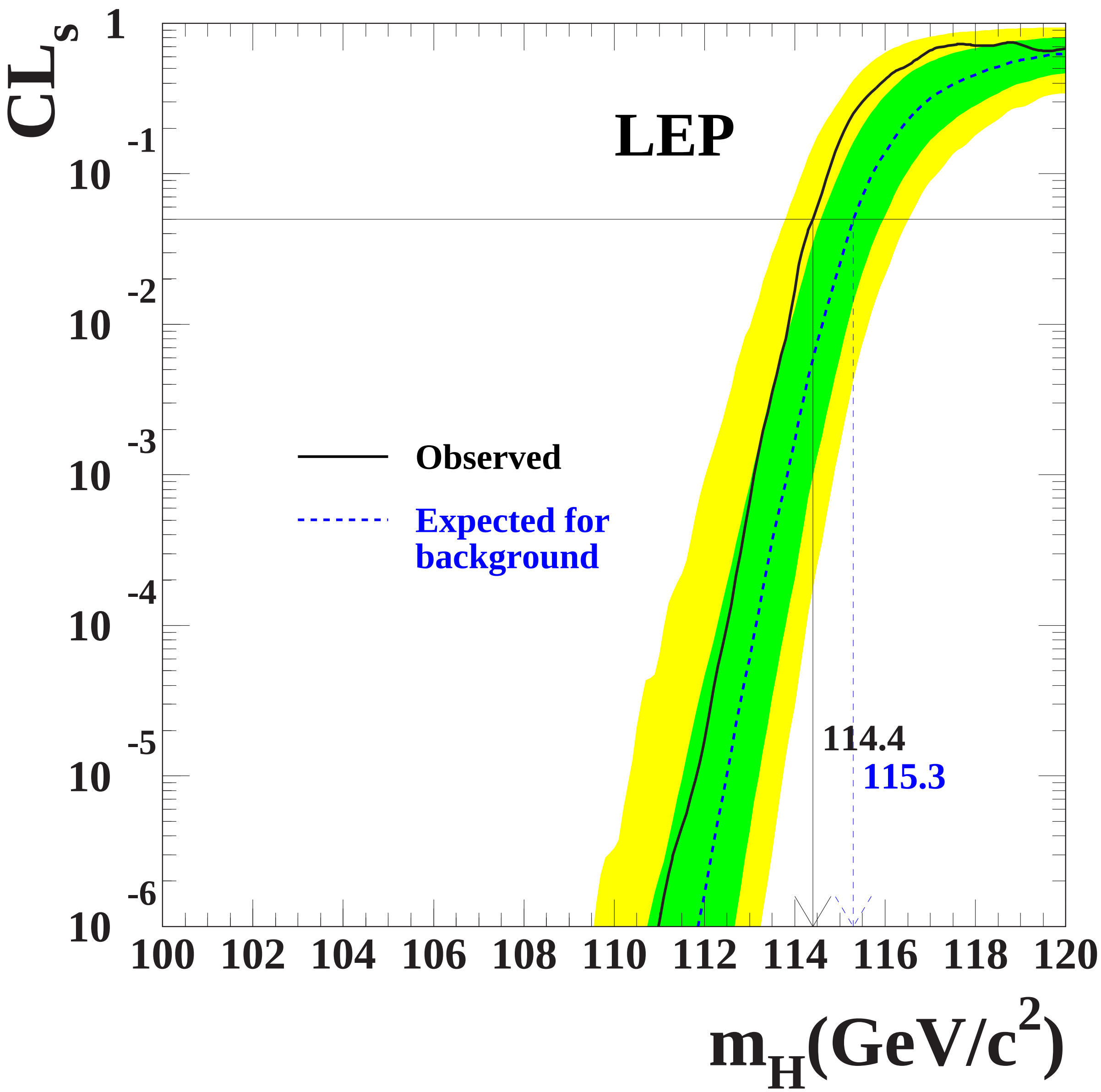
$1 - CL_b$ per channel





The excess around 95-100 GeV is not restricted to the 4jet channel !!

Limit on the Higgs mass



No evidence for a SH Higgs signal

Mass limits at 95% confidence level

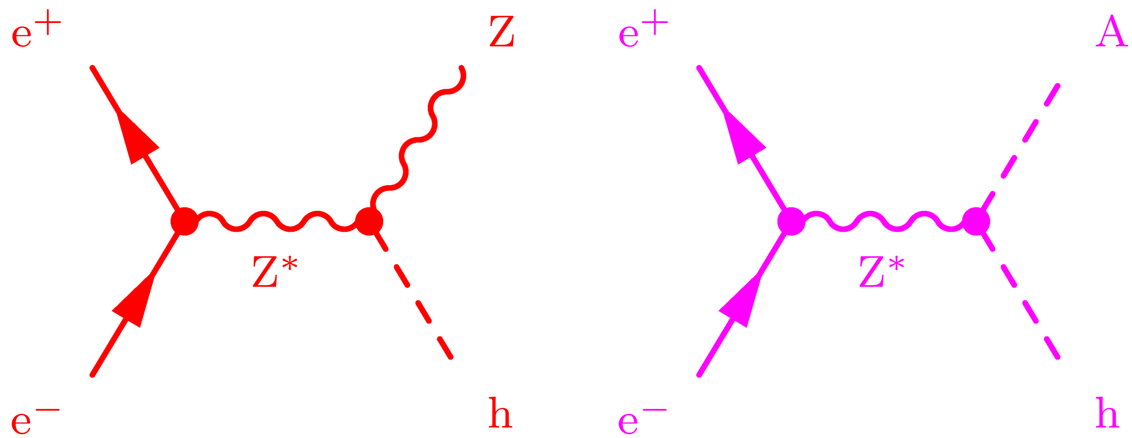
Observed	114.4	GeV
Expected	115.3	GeV

The Higgs sector of the MSSM

Two Higgs doublets. CP conservation is assumed.

Physical Higgs bosons: h and H (CP-even), A (CP-odd) and $H^{\pm}$

Processes at LEP: **ee$\longrightarrow$Zh** ($\sigma \sim \sin^2(\beta - \alpha)$) **ee$\longrightarrow$hA** ($\sigma \sim \cos^2(\beta - \alpha)$)



Almost the same analyses as for the SM Higgs (some new channels)

The same combination procedure and statistical method.

Benchmark scenarios

Test for MSSM Higgs using constrained model: $M_{\rm SUSY}$, M_2, μ, A, $\tan\beta$, $m_{\rm A}$, $m_{\tilde{\rm g}}$

- **no-mixing scenario:** **no mixing between scalar partners of $t_{\rm L}$ and $t_{\rm R}$**

$$M_{\rm SUSY} = 1 \ \text{TeV}, M_2 = 100 \ \text{GeV}, \mu = -200 \ \text{GeV},$$
$$X_t \equiv A - \mu \cot\beta = 0, 0.4 < \tan\beta < 50$$
$$4 \ \text{GeV} < m_{\rm A} < 1 \ \text{TeV}, m_{\tilde{\rm g}} = 800 \ \text{GeV}$$

- **$\mathrm{m}_h^{\max}$ scenario:** **yield maximal value of $m_{\rm h}$ in the model**

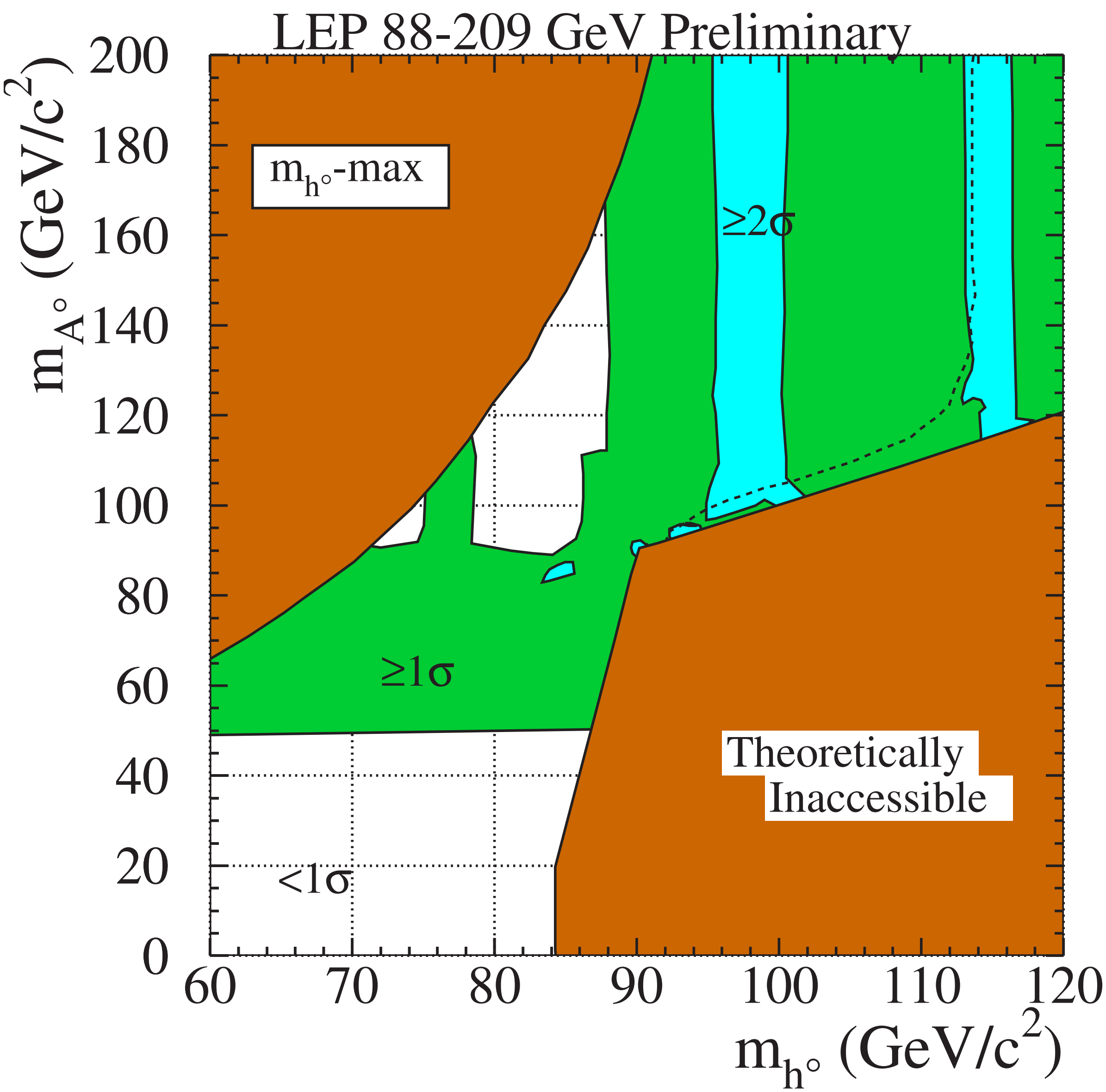
same parameters as "no-mixing" except $X_t = 2\, M_{\rm SUSY}$, $\tan\beta < 30$

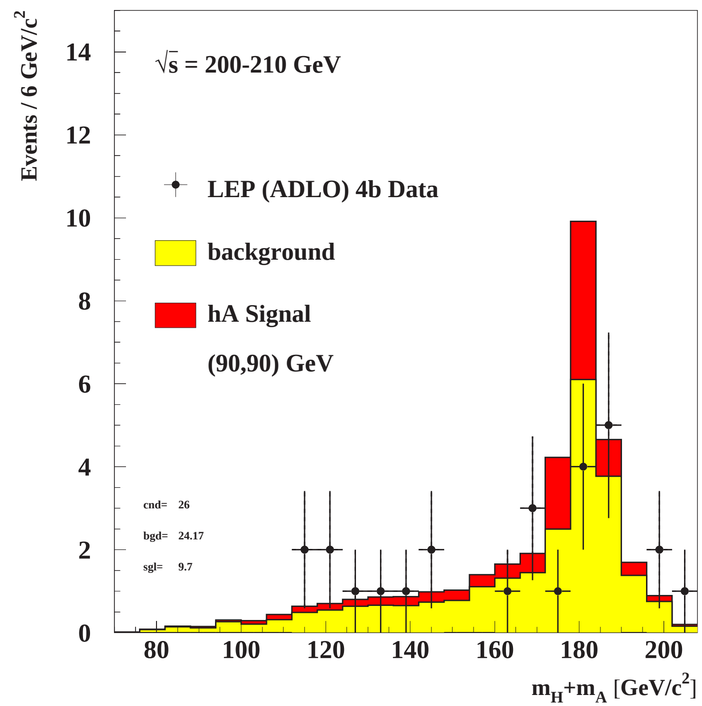
most conservative range of excluded $\tan\beta$ for fixed values of m_t, $M_{\rm SUSY}$

- **large μ scenario:** **the Higgs boson h does not decay in b quark pairs**

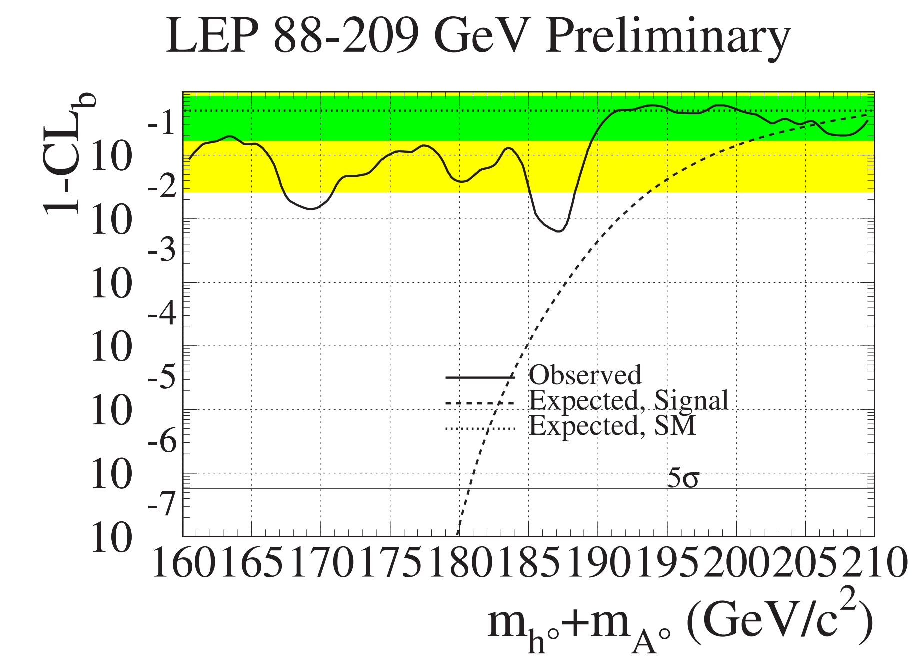
$$M_{\rm SUSY} = 400 \ \text{GeV}, M_2 = 400 \ \text{GeV}, \mu = 1 \ \text{TeV},$$
$$X_t = -300 \ \text{GeV}, 4 \ \text{GeV} < m_{\rm A} < 400 \ \text{TeV}, m_{\tilde{\rm g}} = 200 \ \text{GeV}$$

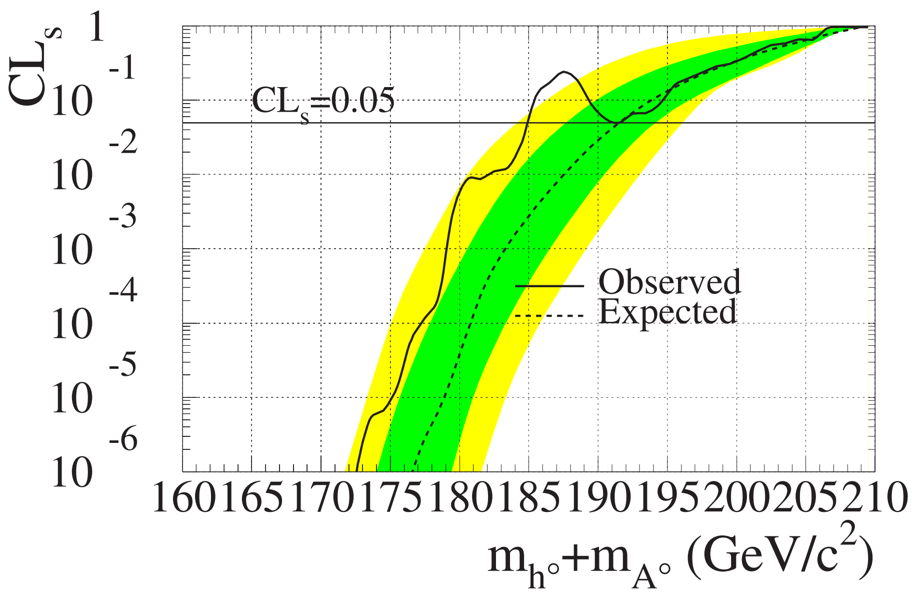
CL_b in the (m_h, m_A) plane





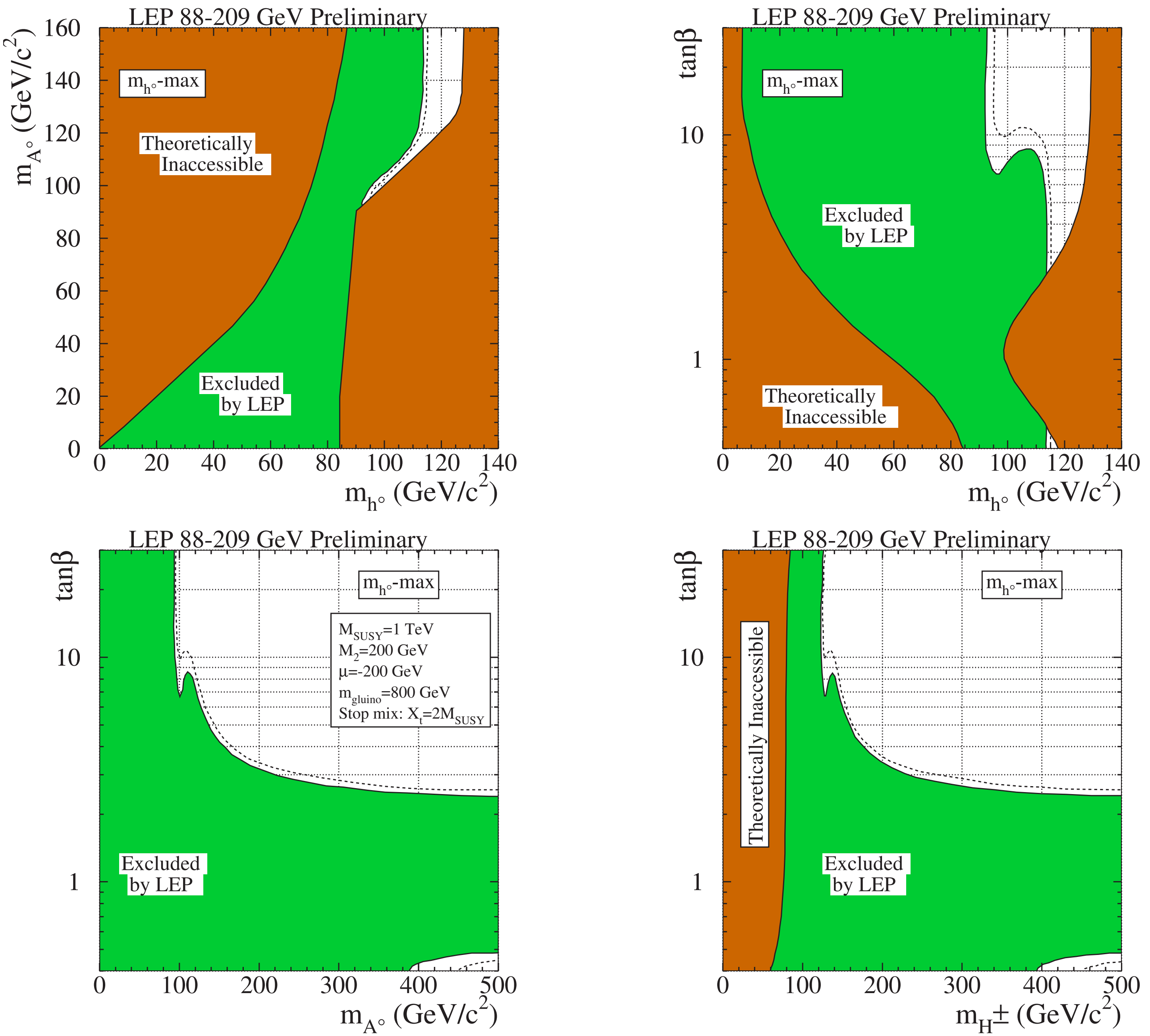
$1 - CL_b$ and CL_s for $m_h \approx m_A$





2σ excess at $m_h \approx 97$ GeV
mainly due to data taken at 189 GeV

Exclusion for the m_h-max scenario



Exclusion limits on m_h, m_A and $\tan\beta$

- **m_h^{max} scenario:**

$$m_h > 91.0 \ \text{GeV} \ (94.6 \ \text{GeV})$$
$$m_A > 91.9 \ \text{GeV} \ (95.0 \ \text{GeV})$$

$$0.5 < \tan\beta < 2.4 \text{ for } m_t \leq 174.3 \ \text{GeV}$$
$$(0.5 < \tan\beta < 2.6)$$

- **no-mixing scenario:**

$$m_h > 91.5 \ \text{GeV} \ (95.0 \ \text{GeV})$$
$$m_A > 92.2 \ \text{GeV} \ (95.3 \ \text{GeV})$$

$$0.7 < \tan\beta < 10.5$$
$$(0.8 < \tan\beta < 16)$$

Search for stable hadronising squarks & gluinos

Scalar-quark search at LEP energies is relevant as the scalar top could be the LSP partner of all SM fermions

Previous results assume the LSP is the lightest neutralino, yielding an absolute limit of $m_{\tilde{t}} < 63\ \mathrm{GeV}$ (95% CL)

This limit does not apply if LSP is the gluino or the scalar quark (LSP or "sufficently" stable)

The topology of the signal events (missing energy) differ from that in the standard SUSY searches (LSP=neutralino)

Search for stable hadronising squarks & gluinos

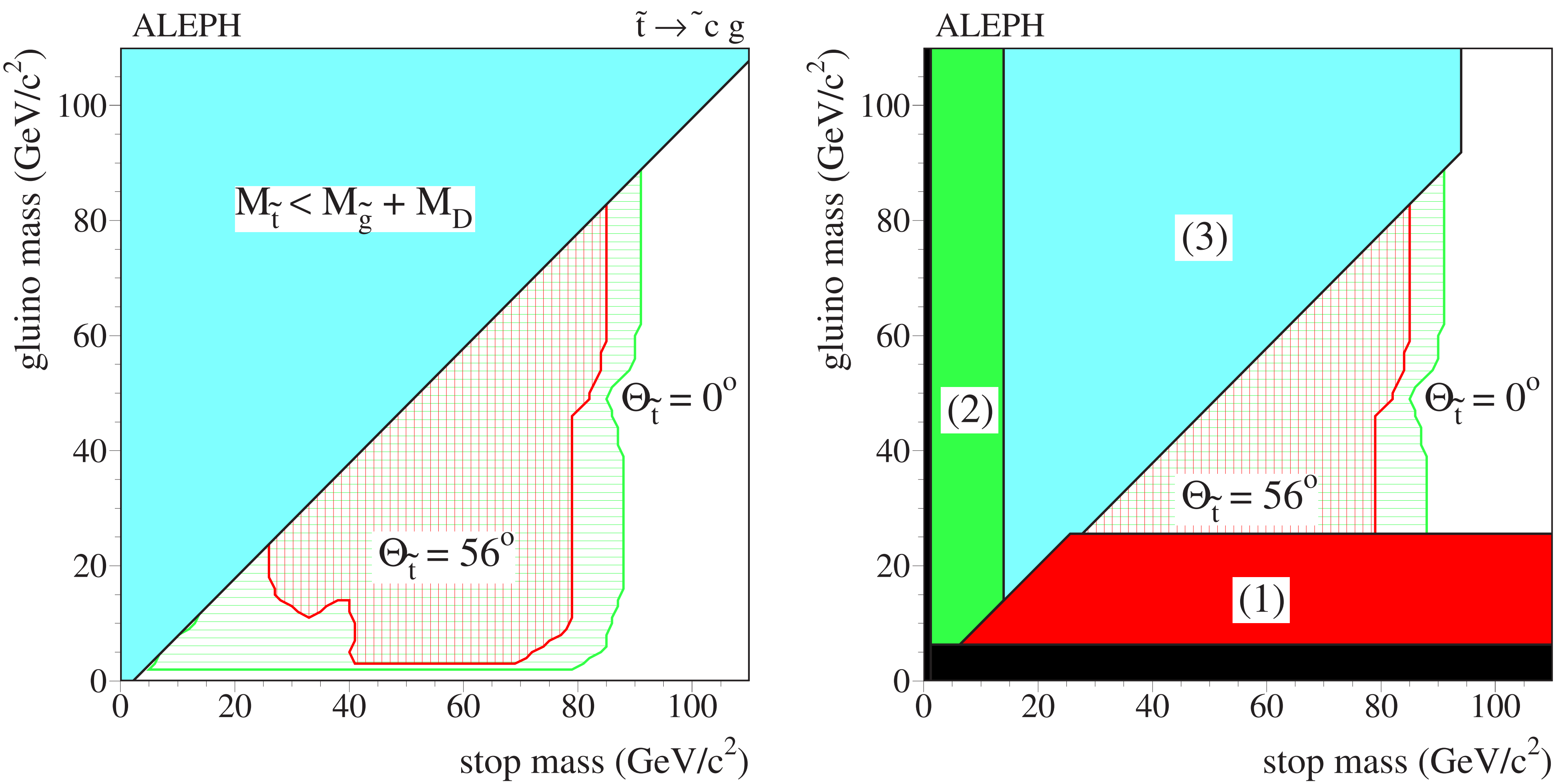
Search for missing energy and for stable heavy charged particles are well suited for the search of sqarks and gluinos:

- $e^+e^- \longrightarrow q\bar{q}\tilde{g}\tilde{g}$, with a gluon splitting into a pair of stable gluinos (LEP1)
- $e^+e^- \longrightarrow q\bar{q}\tilde{q}\bar{\tilde{q}}$, with a gluon splitting into a pair of stable squarks (LEP1)
- pair production of stable squarks $e^+e^- \longrightarrow \tilde{t}\bar{\tilde{t}}$ and $\tilde{b}\bar{\tilde{b}}$ (LEP2)
- pair production of scalar top decaying in stable gluinos,
  $e^+e^- \longrightarrow \tilde{t}\bar{\tilde{t}} \longrightarrow c\tilde{g}\bar{c}\tilde{g}$ (LEP2)

Cover all possible configurations in the plane $(m_{\tilde{g}}, m_{\tilde{q}})$ with a sqark or a gluino LSP

Exclusion limits on stop and gluino mass plane

The observed events in all the analyses are in agreement with the expectations from standard model processes



Results on gluino and stop search

- **gluino LSP excluded for** $m_{\tilde{g}} < 25.6$ GeV
- **down-type squark LSP excluded for** $m_{\tilde{q}} < 92$ GeV
- **up-type squark LSP excluded for** $m_{\tilde{q}} < 97$ GeV
- **if LSP is a gluino, sbottom NLSP excluded for** $m_{\tilde{b}} < 26$ GeV
- **if LSP is a gluino, stop NLSP excluded for** $m_{\tilde{t}} < 78$ GeV
  otherwise $m_{\tilde{t}} < 63$ GeV

These limits apply in any supersymmetric model in which squarks and gluinos are long-lived

Extra dimensions

- $\mathrm{M_{P\ell}} \sim 10^{19}$ GeV $\gg \mathrm{m_{ew}} \sim 10^{2}$ GeV
- **Standard Model tested at** $1/\mathrm{m_{ew}}$
- **Gravity far from being tested at** $1/\mathrm{M_{P\ell}}$

Arkani-Hamed et al. PLB 544 (1988) 263

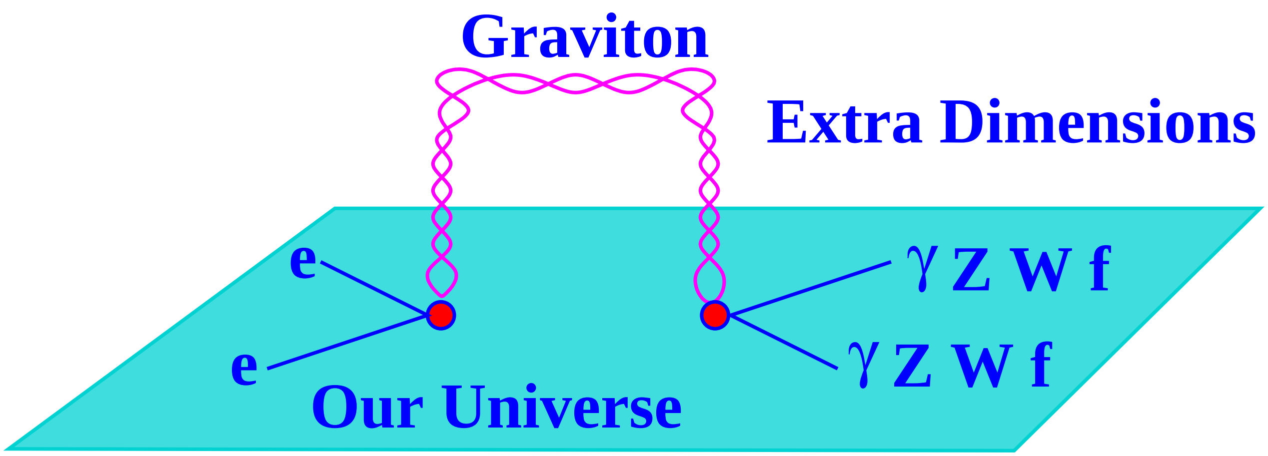
- **The scale of Gravity,** $\mathrm{M_S}$**, is of order** $\mathrm{m_{ew}}$
- **There are n extra dimensions of size R shuch that with Gauss' theorem:**

$$\mathrm{M_{P\ell}}^2 \sim \mathrm{R}^n \, \mathrm{M_S}^{n+2}$$

$$\mathrm{M_S} \sim 1 \text{ TeV} \quad n = 1 \quad \mathrm{R} \sim \text{Solar System}$$
$$\mathrm{M_S} \sim 1 \text{ TeV} \quad n = 2 \quad \mathrm{R} \sim 1\text{mm}$$

Low Scale Gravity

Spin 2 gravitons propagate in these extra dimensions interacting with Standard Model particles in our four ones



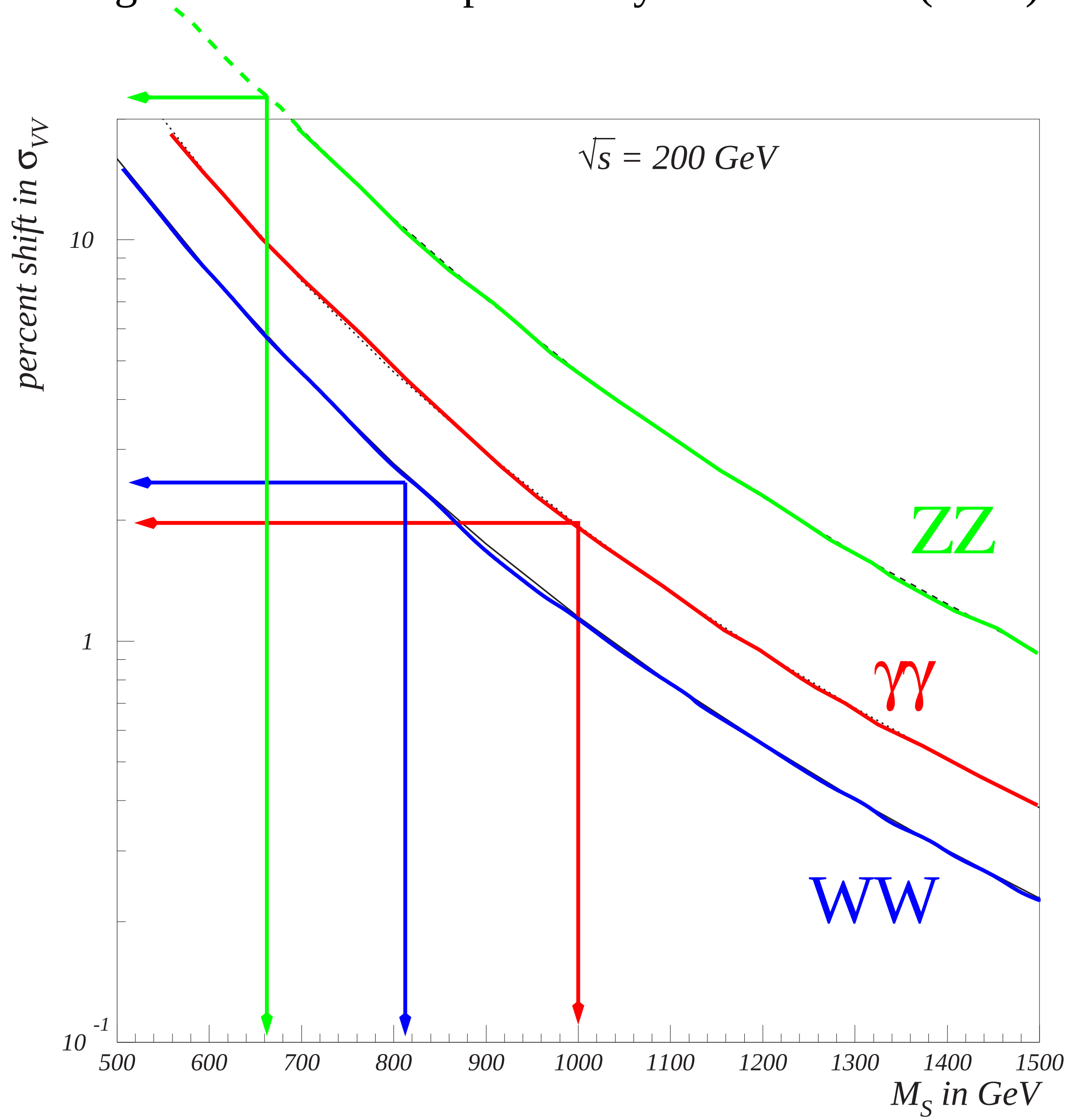
$$\frac{d\sigma}{d\Omega}(s,t) = \frac{d\sigma^{SM}}{d\Omega}(s,t) +$$

$$+\frac{\lambda}{M_S^4}\alpha \,\text{Interference}\,(s,t) + \frac{\lambda^2}{M_S^8}\beta \,\text{Low Scale Gravity}\,(s,t)$$

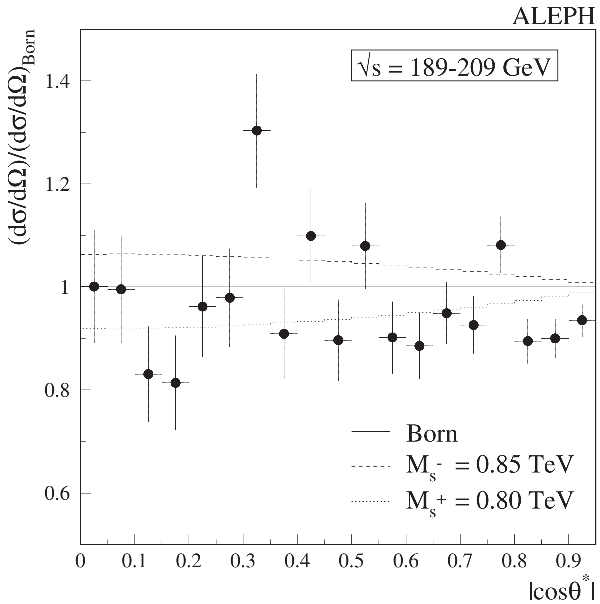
λ depends on the (unknown) full theory, use ± 1 for different signs in interference

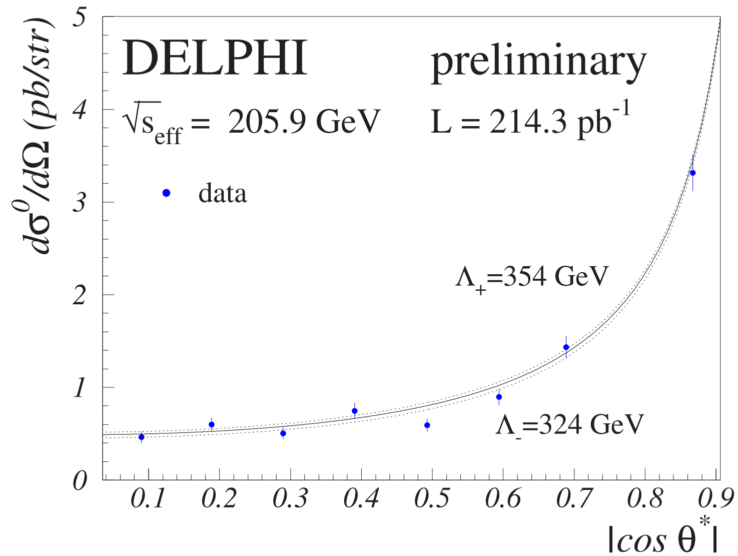
LSG from LEP results

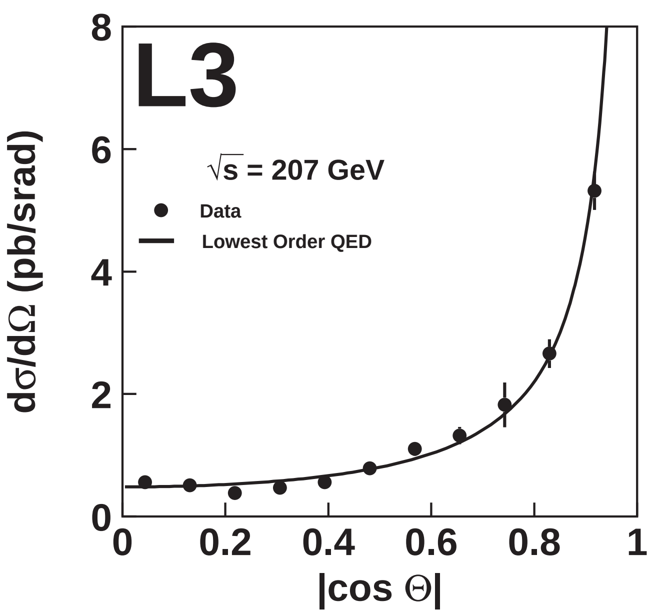
K.Agashe & N.G.Deshpande Phys. Lett. B 465 (1999) 60

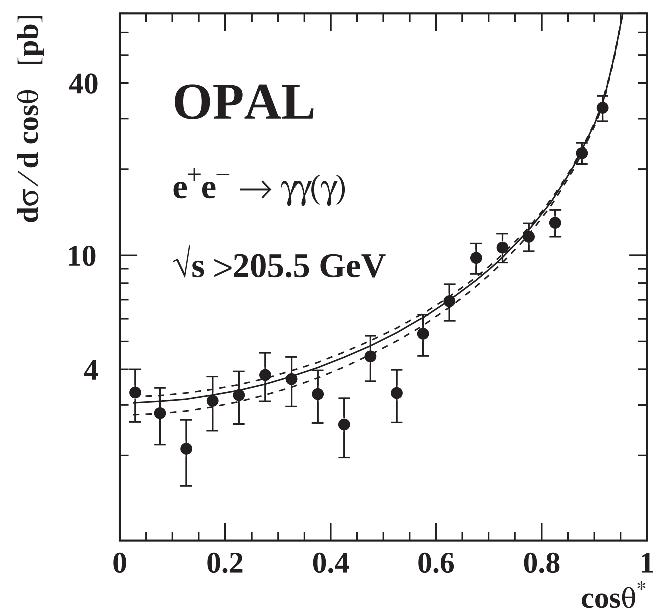


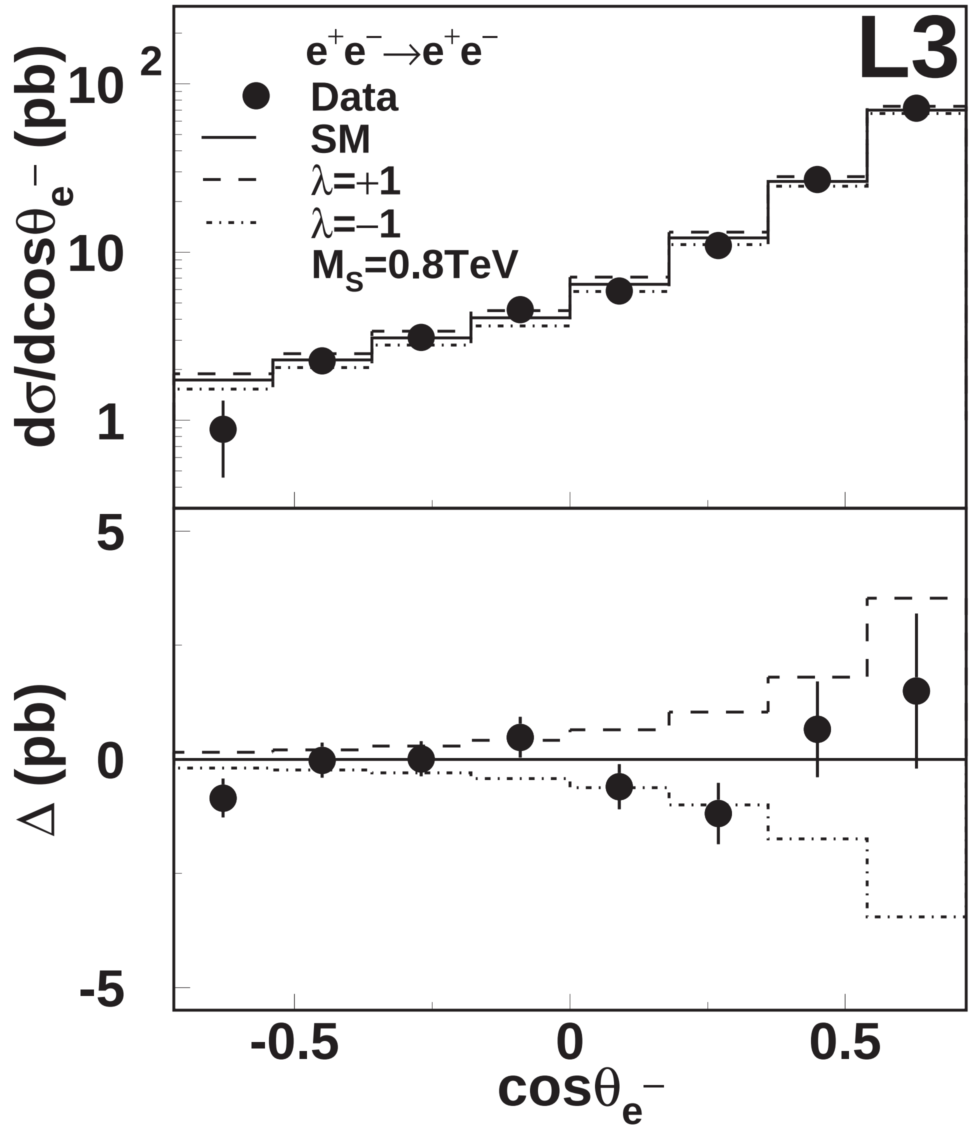
The $e^+e^- \to \gamma\gamma$ differential cross section









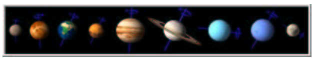
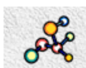


High sensitivity as large interference with SM t-channel

Combined LEP limit: $M_S > 1$ TeV for $\lambda = \pm 1$

Excluded size of the Extra Dimensions from Exp. Limits (in meters)

REFERENCE SIZES

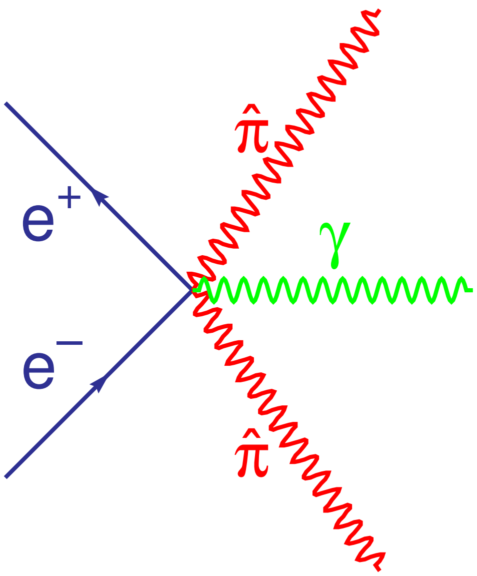
- 1 light Year ~ 10^{+16}
-  1 AU = $1.5\times10^{+11}$
-  Typical cell size ~ 10^{-5}
-  DNA Molecule size ~ 10^{-7}
- Typical Molecule size ~ 10^{-8}
-  Bohr Radius = 0.53×10^{-10}
- $\lambda_{COMPTON}$ of the electron = 3.8×10^{-13}
-  Typical Nucleus Size ~ 10^{-14}
- Proton Size ~ 2.8×10^{-15}
- electron or quark size ~ 10^{-18}

δ	$\lambda=+1$	$\lambda=-1$
1	$1.7 \times 10^{+13}$	$1.6 \times 10^{+13}$
2	1.7×10^{-3}	1.6×10^{-3}
3	7.7×10^{-9}	7.5×10^{-9}
4	1.6×10^{-11}	1.6×10^{-11}
5	4.1×10^{-13}	4.1×10^{-13}
6	3.5×10^{-14}	3.5×10^{-14}
7	6.1×10^{-15}	6.0×10^{-15}

A branon $\hat{\pi}$ is a (pseudo-)Goldstone boson, which appears when a higher-dimensional space-time symmetry is spontaneously broken by the presence of a brane. They are kind of new scalar field.

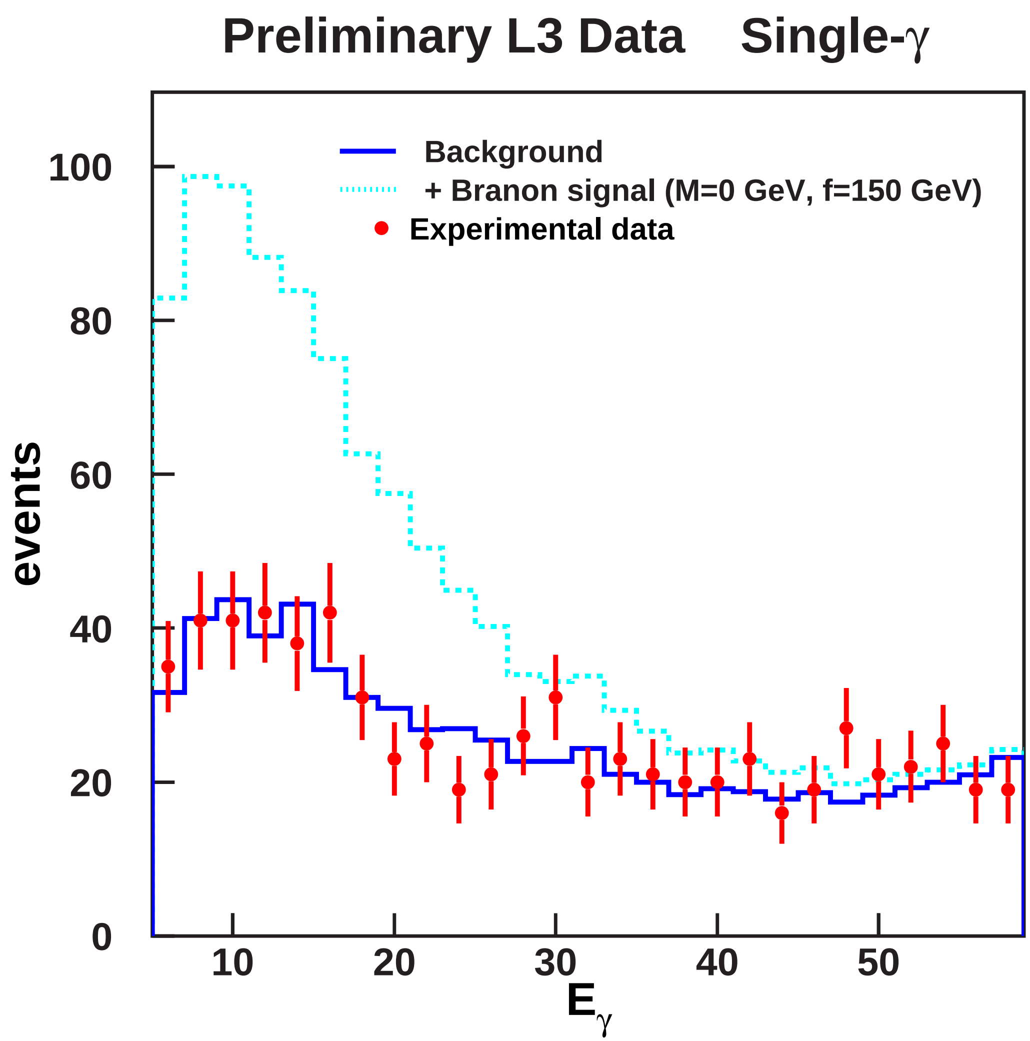
The branon mass is related to the metric properties of the extra space. They are massles only in simple cases like flat space.

The branon interaction presents vertices coupled to SM diagrams:



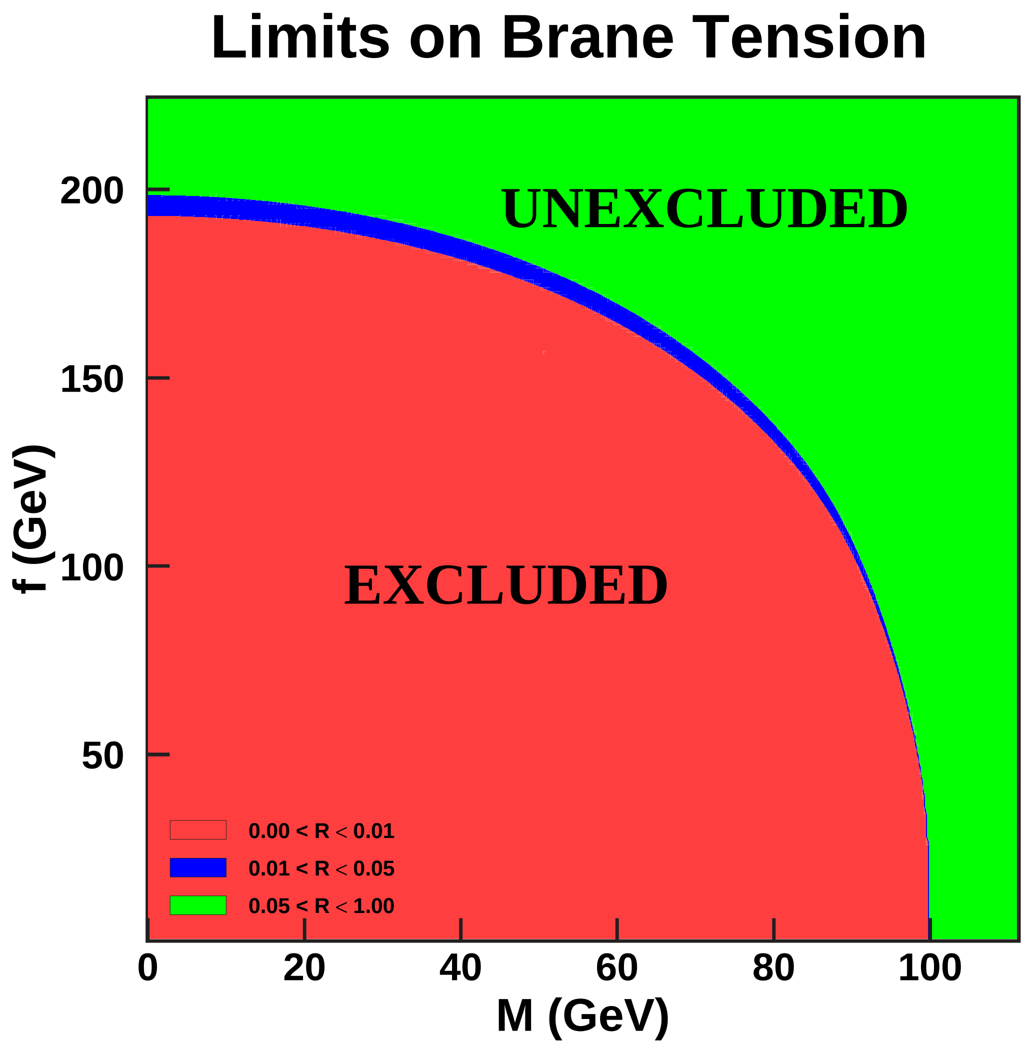
In L3, branons are searched for in the processes $e^+e^- \rightarrow \hat{\pi}\hat{\pi}\gamma$ and $\hat{\pi}\hat{\pi}Z$. Additional cross section parametrised in terms of n (number of branons), M (mass) and f (brane tension scale).

Search for branons in single γ



Similar analysis performed for the channel $e^+e^- \longrightarrow \hat{\pi}\hat{\pi}Z$.

Exlusion limits in the M-f plane



For $M = 0$, $f > 197$ GeV. Restrictions on f disappear for $M > 100$ GeV.

Limits from $e^+e^- \to \hat{\pi}\hat{\pi}Z$ are less stringent: $f > 48$ GeV for $M = 0$

No clear indication for new physics at LEP

Search for Higgs bosons in different phenomenological scenarios continues: flavour independent, fermiophobic, invisible...

as well as the search for SUSY signatures under the scope of different models

New LEP combined results will come soon