LEP seminar, February 27th, 2001

DELPHI status report

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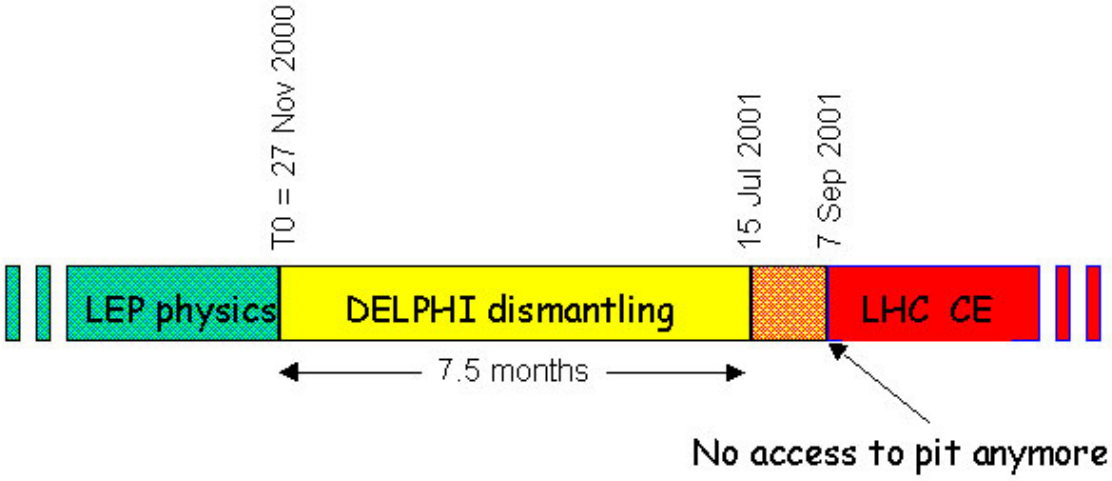
CERN-EP Division

- DELPHI dismantling and final LEP 2 data processing
  - cause of TPC sector 6 failure
- PRELIMINARY results for Moriond/La Thuile
  - SM measurements
  - Higgs and SUSY searches

DELPHI dismantling



➡ work progressing smoothly

➡ on schedule for dismantling of:
(thanks to perfect organisation by Ch.Joram)

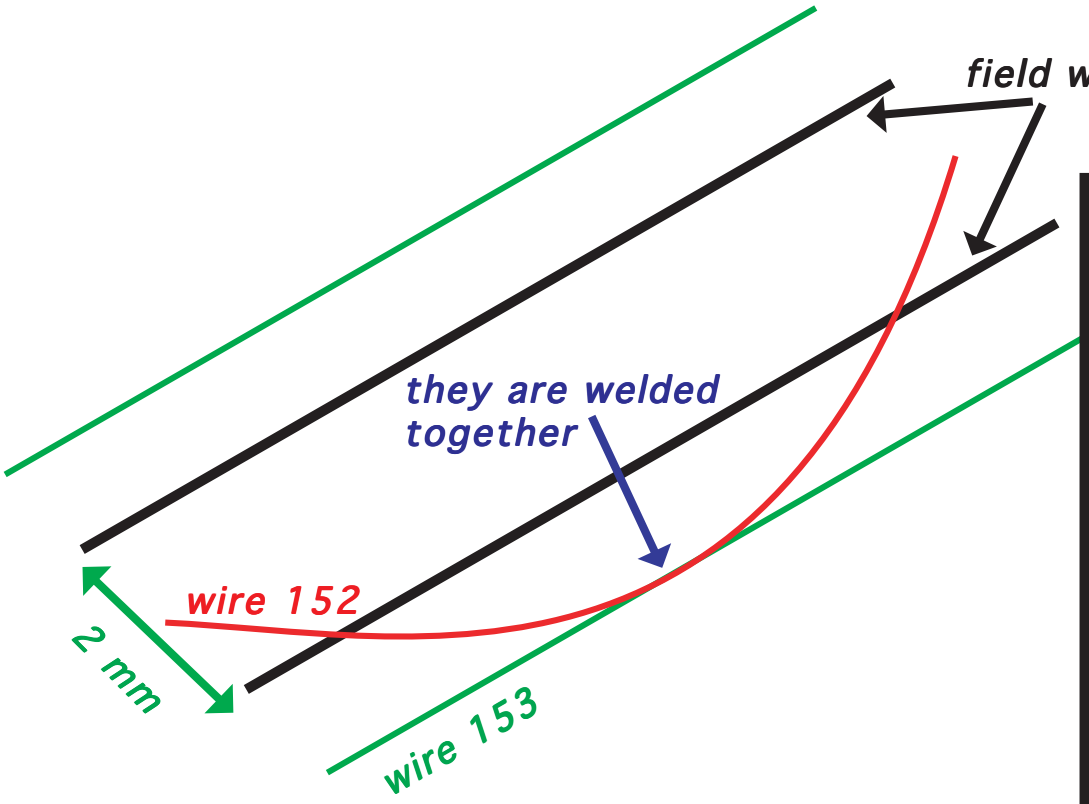
- Endcaps A and C
- counting houses (partly LHCb reuse)
- gas platforms

➡ joint DELPHI-LHCb Exhibition Project

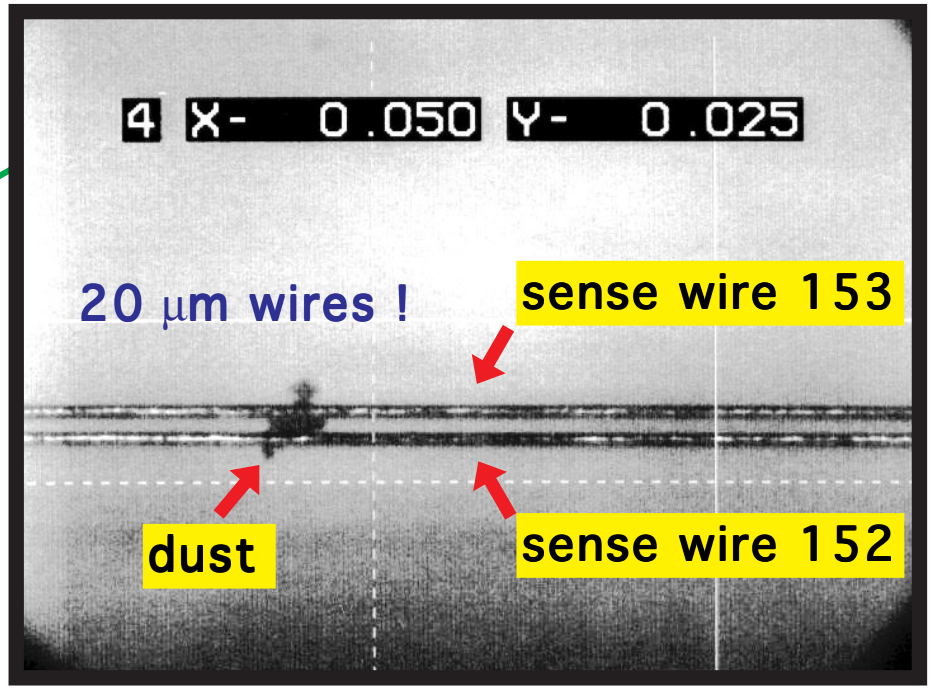
⇒ DELPHI-Barrel will stay in Pit 8

examination of TPC sector 6 (died September 1st)

➡ short due to slack sense wire 152



➡ microscope in the lab.:

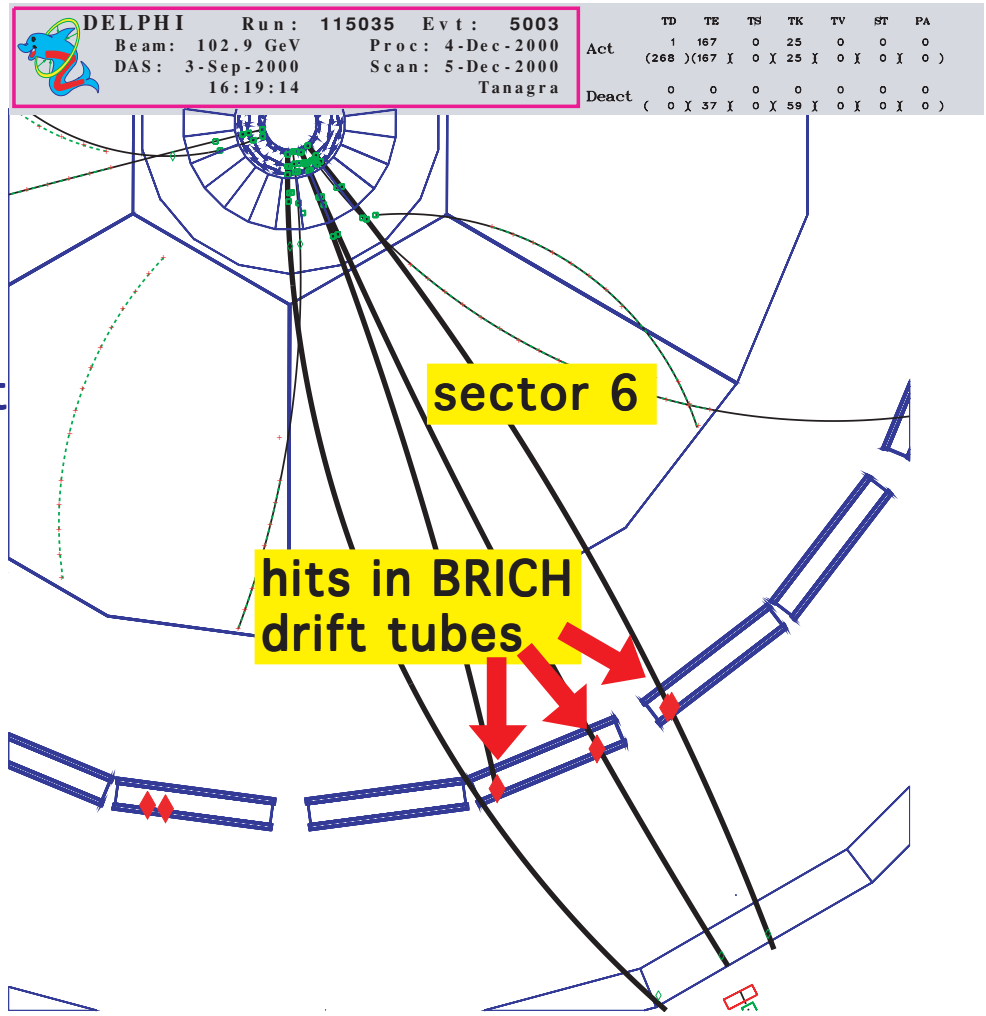


➡ inspection of field cage:

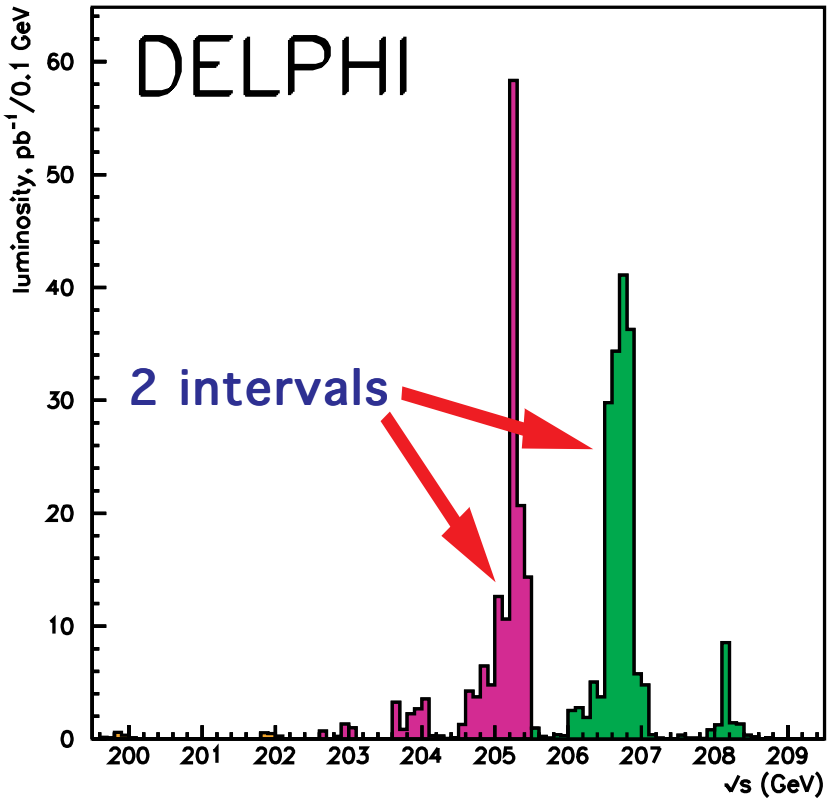
- verified known shorts

final LEP 2 data processing

- use final detector calibrations and latest reconstruction code
- include BRICH track point to recover from sector 6 failure
- goal: homogenous LEP 2 data set in time for summer conferences
  (+ data archiving aspect, for use in OO-analysis framework)
- reminder:
  all Y2K results include data from special processing for sector 6
  ⇒ 2 data sets at analysis level



data taking in 2000



➡ data taking efficiency 95.3 %

➡ data collected above m_Z:

year	√s	total
1995	130/136	6 pb^{-1}
1996	161/172	21 pb^{-1}
1997	183	55 pb^{-1}
	130/136	6 pb^{-1}
1998	189	158 pb^{-1}
1999	192-202	228 pb^{-1}
2000	204-209	226 pb^{-1}

➡ total 688 pb^{-1} above WW threshold

➡ 8.6 pb^{-1} around √s = 208 GeV

most of the results are preliminary, all limits are 95 % C.L.

Standard Model measurements

LEP 2

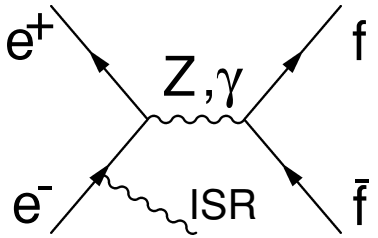
- 2 fermion production ←
- heavy flavours ←
- γ and $\gamma\gamma$ final states ←
- single W and Z production
- WW and ZZ production ←
- (N)TGCs
- W mass ←
- $\gamma\gamma$ physics
- QCD studies ←

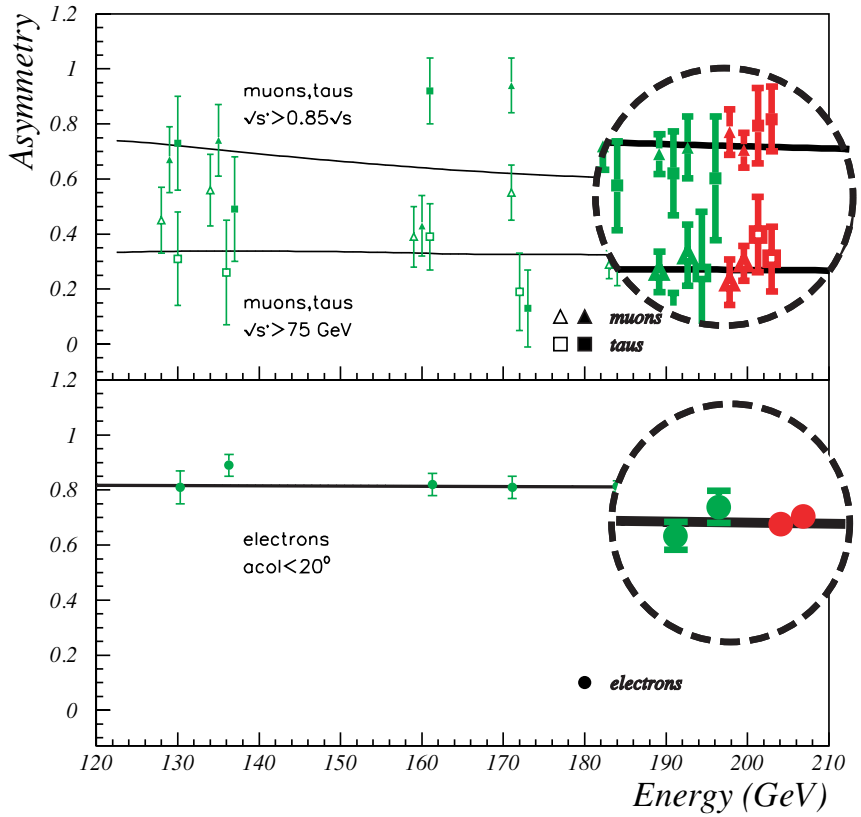
LEP 1

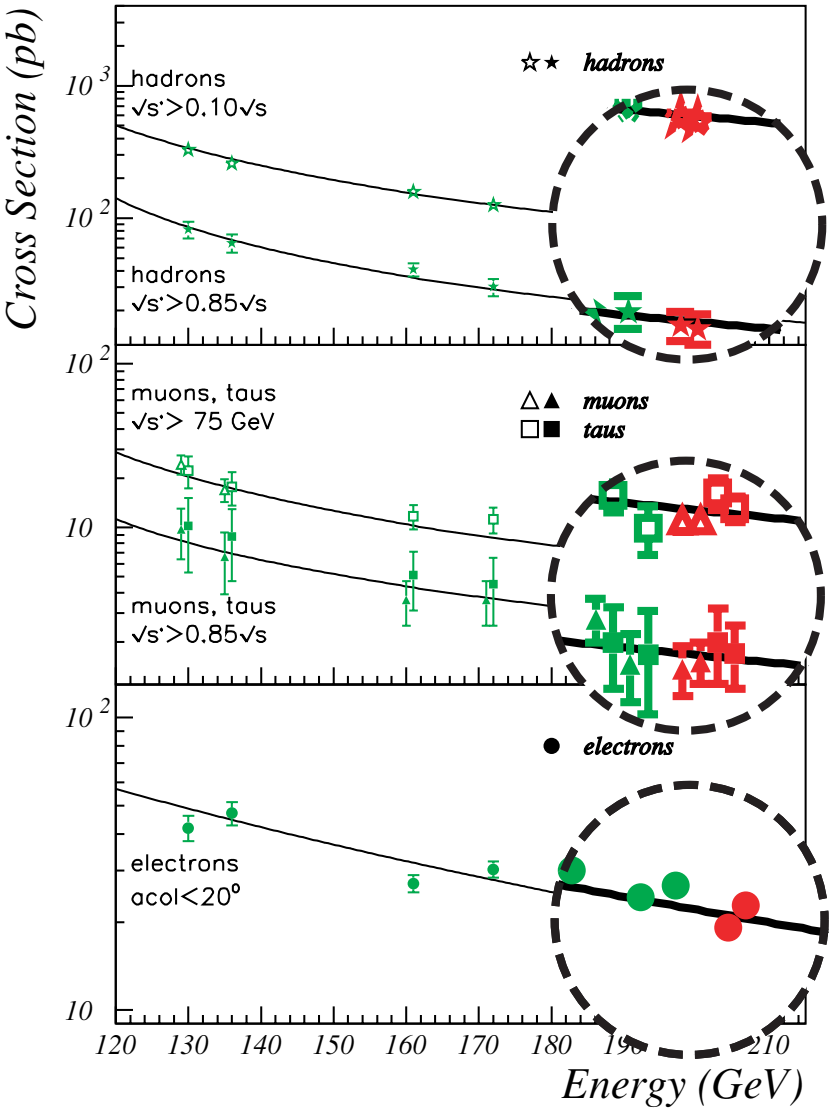
- heavy flavours ←
- tau physics ←

2 fermion production

- **cross-sections, asymmetries**
  + interpretation
- **ISR → √s´**



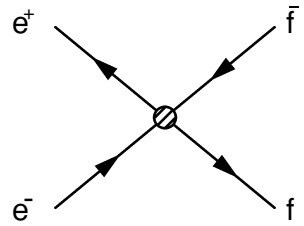




examples for constraints on new physics

Backup

contact interactions:

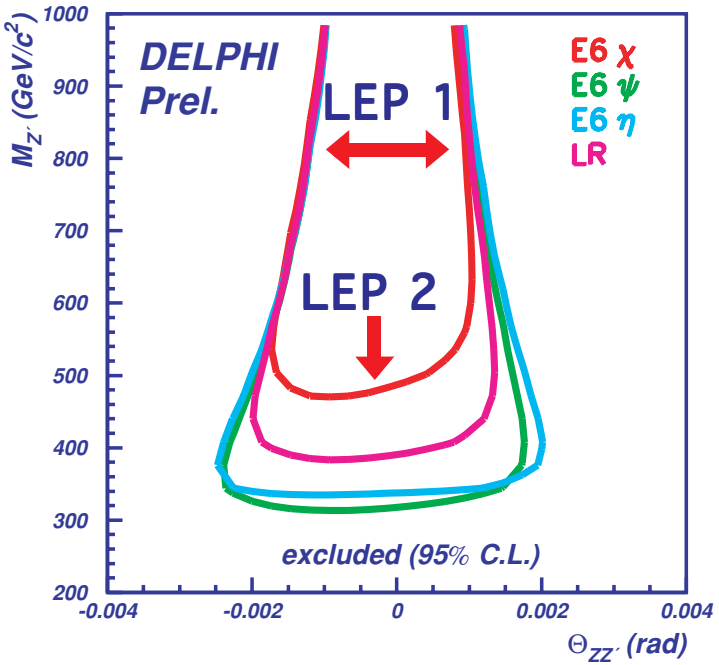


- add to Lagrangian:

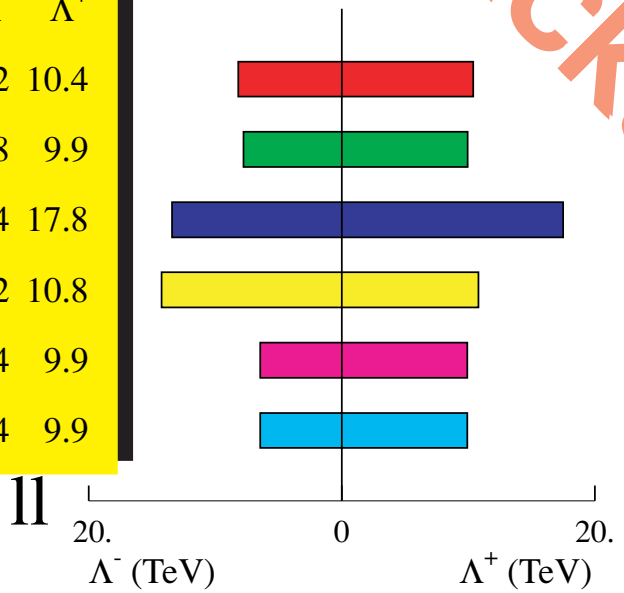
$$L_{eff} = \frac{4\pi}{\Lambda_{\pm}^2} \sum_{i,j=L,R} \pm 1\,(\bar{e}_i \gamma^\mu e_i)(\bar{f}_j \gamma^\mu f_j)$$

- parameter: $\Lambda^2 = 4\pi M^2/\lambda$

{ μ-decay: $\Lambda = (4\pi\sqrt{2}/G_F)^{-1/2} \sim O(1\ \text{TeV})$ }



	Λ^-	Λ^+
LL	8.2	10.4
RR	7.8	9.9
VV	13.4	17.8
AA	14.2	10.8
RL	6.4	9.9
LR	6.4	9.9



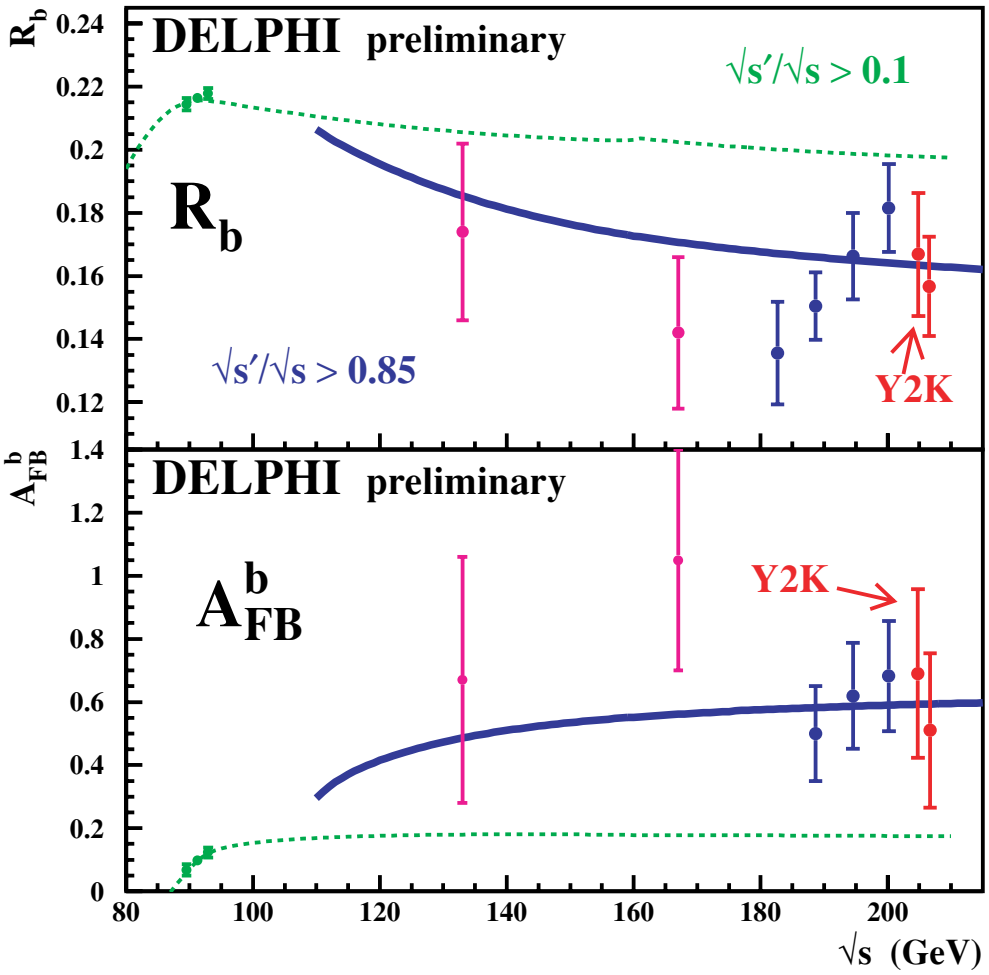
fit to μμ and ττ cross-sections and asym.

Z´ limits:

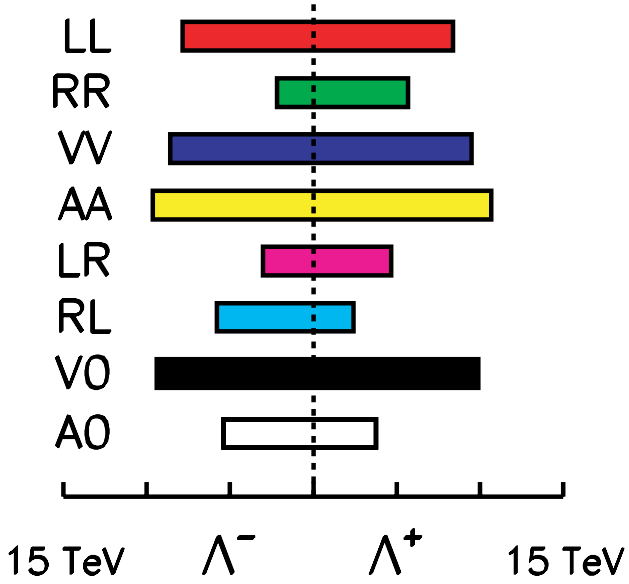
- GUT theories (ex. E6)
  - ⇒ broken to SM+...
  - ⇒ additional U(1),SU(2),...
  - ⇒ Z´ bosons

→ mixing between Z and Z´

b-quark production at LEP 2



- process $e^+e^- \to b\bar{b}(\gamma)$
- measure:
  - $R_b = \sigma_{ee\to bb}/\sigma_{ee\to qq}$
  - A_{FB}^b
- contact interactions:

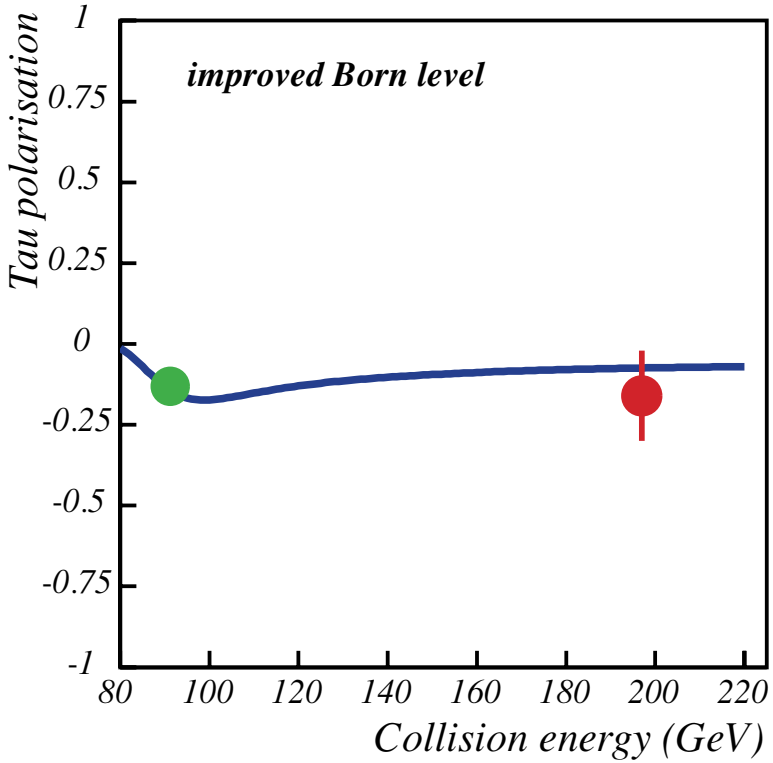


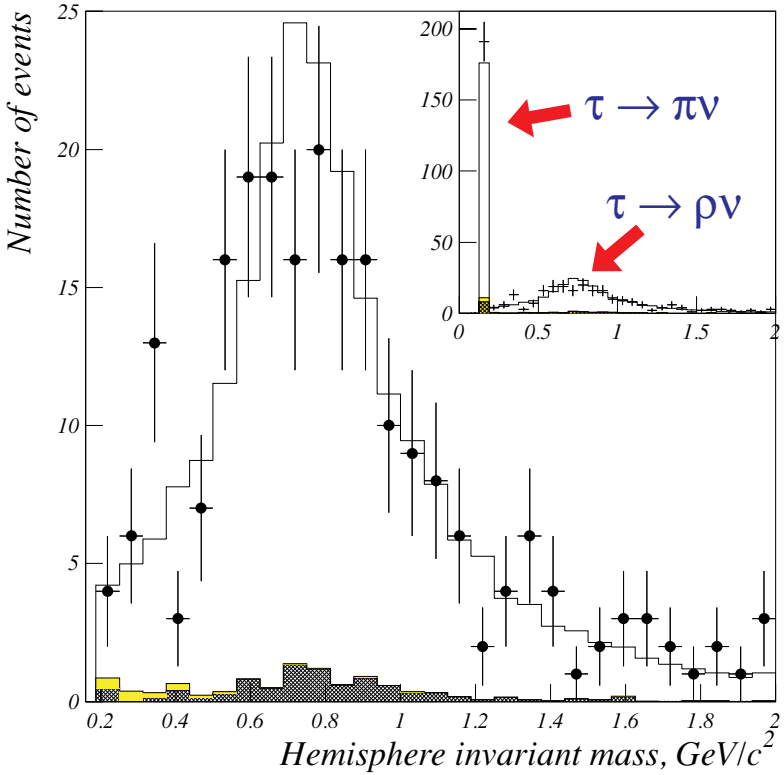
@ 95% CL

tau polarisation at LEP 2

NEW!

- process $e^+e^- \to \tau^+\tau^-(\gamma)$
- 1-prong hadronic decays (inclusive)
- 2 dimensional analysis of τ and daughter (ρ) decay angles





- averaging 183-202 GeV data:

  $P(\tau) = -0.16 \pm 0.13 \pm 0.05$

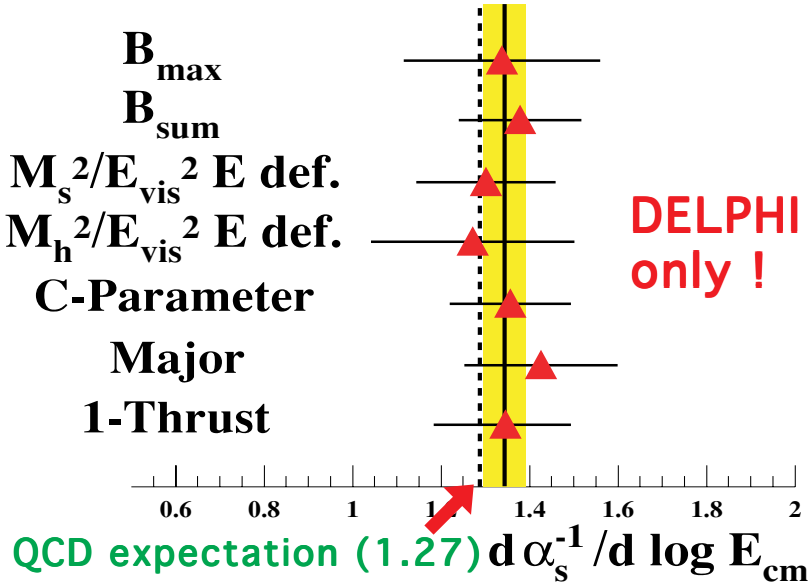
- first measurement at LEP 2

QCD: energy dependence of events shapes

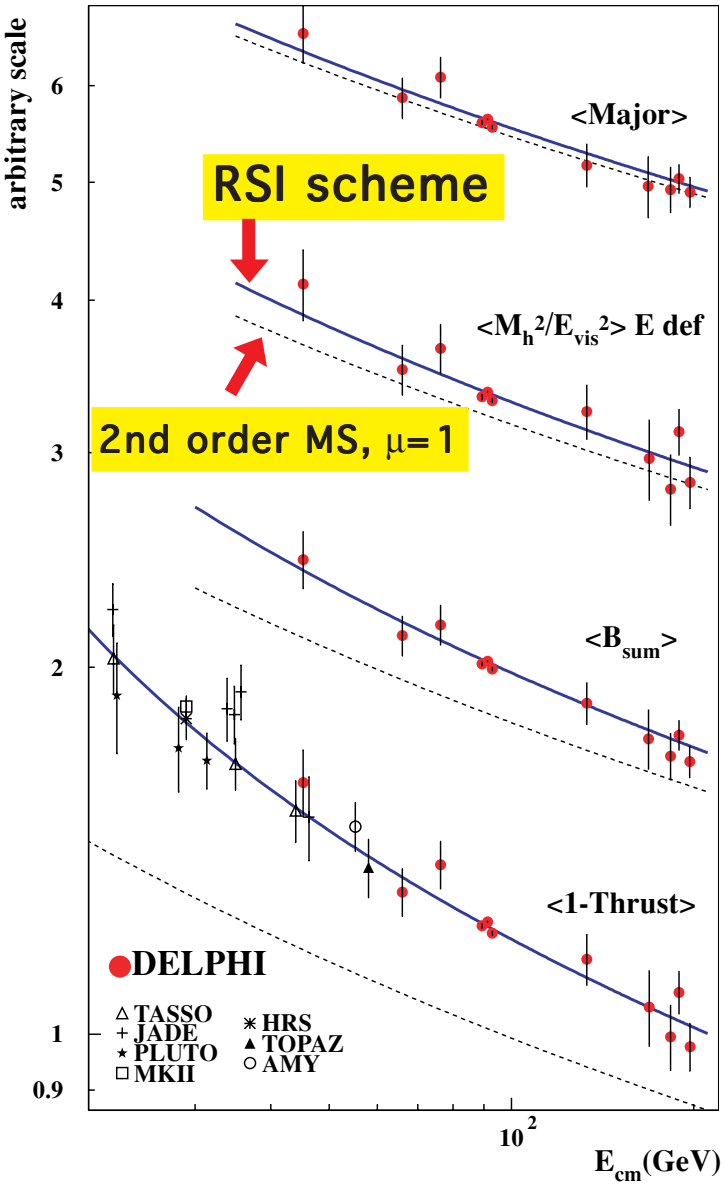
- measure running of α_s
- importance of hadronisation corr. ?
- → RSI *(Renormalisation Scale Independent)* Scheme

  A.Dhar et al., dating back to 1984 !
- eliminates μ scale dependence on INCLUSIVE event shapes means
- no hadronisation correction
- → implies: evolution of event shapes measures directly β-function

NEW!



DELPHI only !



single γ production

➡ process: $ee \rightarrow \nu\bar{\nu}\gamma$

➡ „Z-return“ sensitive to N_ν:

$N_\nu = 2.80 \pm 0.10 \pm 0.14$

➡ sensitive to new physics:

- graviton exchange in 4+n dim.:

  $\sigma < 0.13$ pb @ 95 % CL

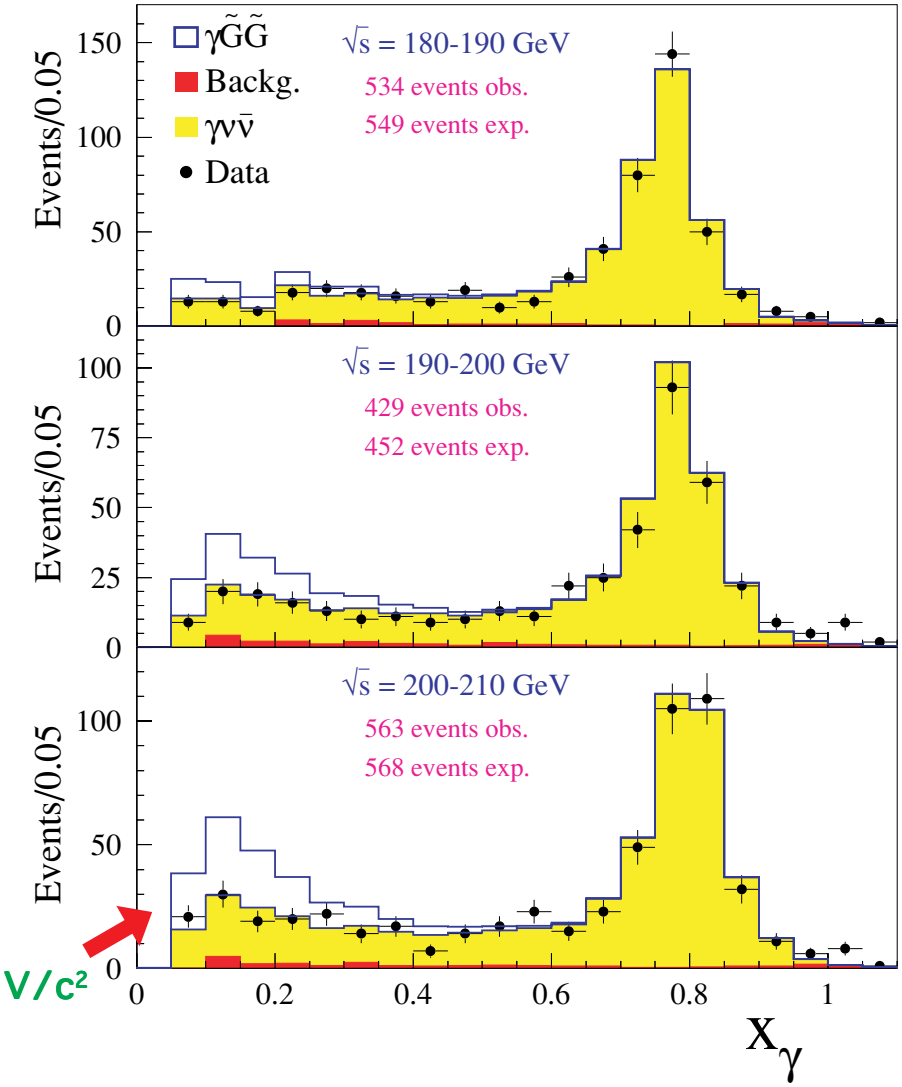
  limit on fundamental mass scale:

  $M_D > 1377$ GeV/c² (n=2)

  $M_D > 839$ GeV/c² (n=4)

- gravitino mass limit for $ee \rightarrow \tilde{G}\tilde{G}\gamma$:

  $m_{\tilde{G}} > 11.2 * 10^{-6}$ eV/c²



$m_{\tilde{G}} = 7 * 10^{-6}$ eV/c²

QED-test in ee → γγ(γ)

➡ **test QED-cutoff parameter:**

$$\left(\frac{d\sigma}{d\Omega}\right)_{\Lambda_-} = \left(\frac{d\sigma}{d\Omega}\right)_{Born} - \frac{\alpha^2 s}{2\Lambda_-^4}(1+\cos^2\theta)$$

$\Lambda \sim$ **scale** (eγ-vertex no longer point-like)

➡ **sensitive to:**

- **e* in t-channel**
- **graviton exchange in 4+n dim.**

$$\frac{d\sigma}{d\cos\theta} = A(\cos\theta) + B(\cos\theta)\left[\frac{\lambda}{M_s^4}\right] + C(\cos\theta)\left[\frac{\lambda}{M_s^4}\right]^2$$

$M_s \sim$ **eff. string scale**

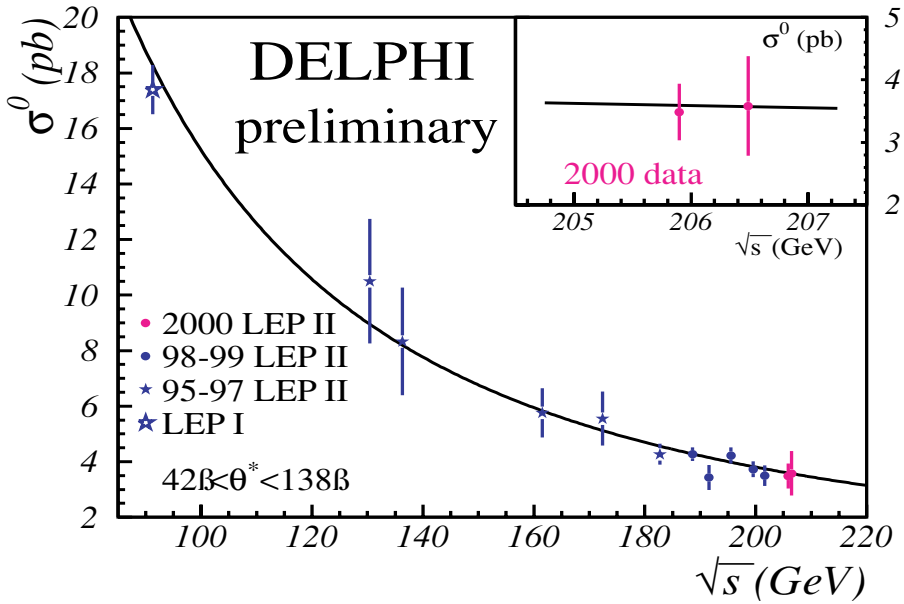
➡ **limits:**

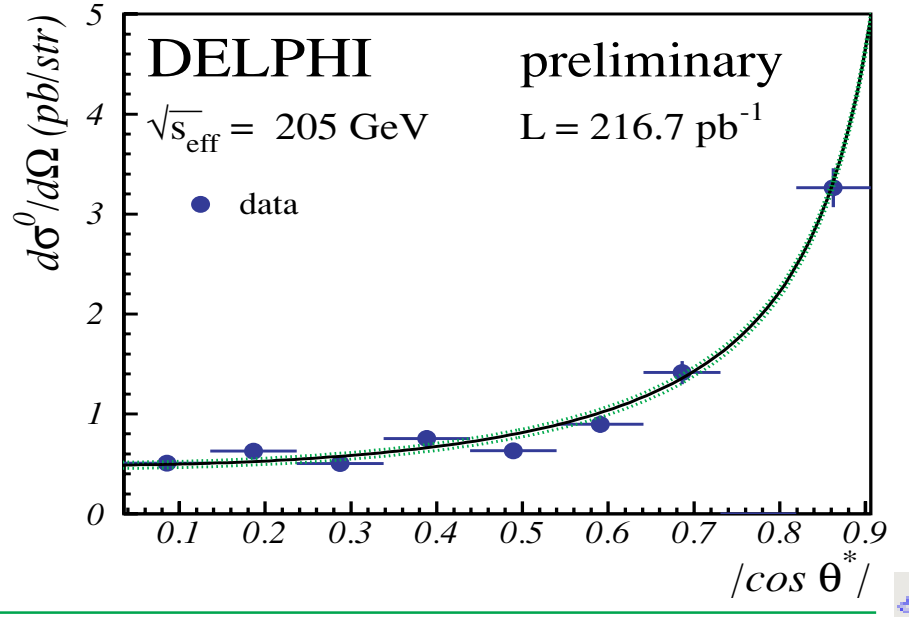
$\Lambda_+ > 354$ GeV $\Lambda_- > 338$ GeV

$m_{e^*} > 339$ GeV/c²

$M_s > 765$ GeV/c² (λ=+1)

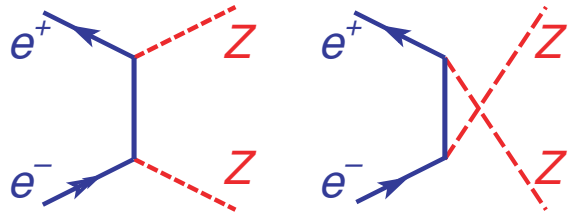
$M_s > 730$ GeV/c² (λ=-1)



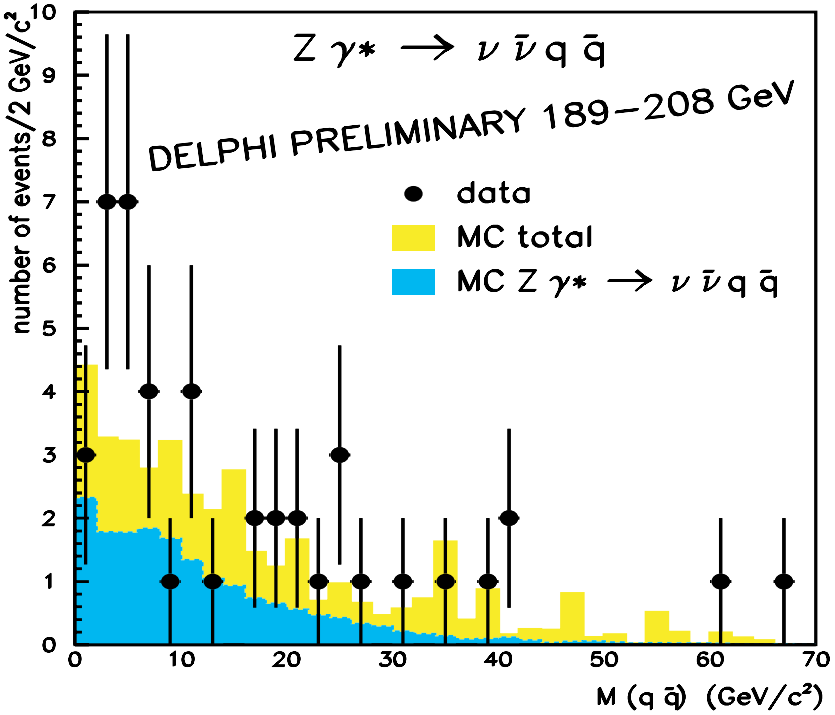


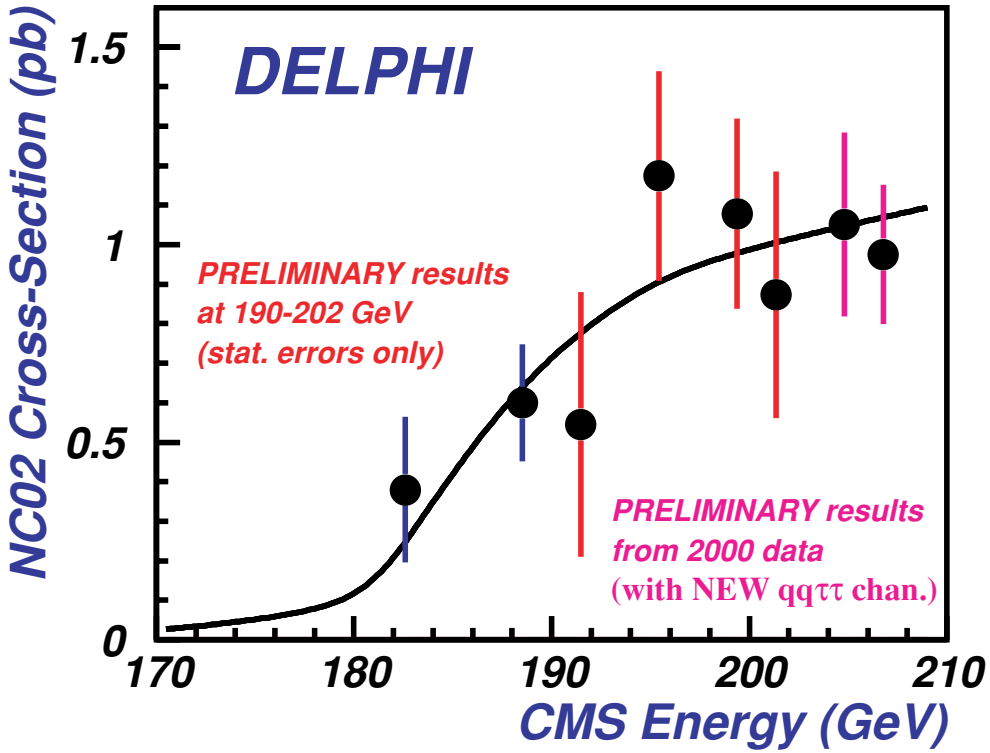
ZZ and Zγ* cross-section

➡ ZZ definition (NC02):



"double resonant"





➡ Zγ* ~ "single resonant"
(Zγ* ↔ NC06 - γ*γ*)

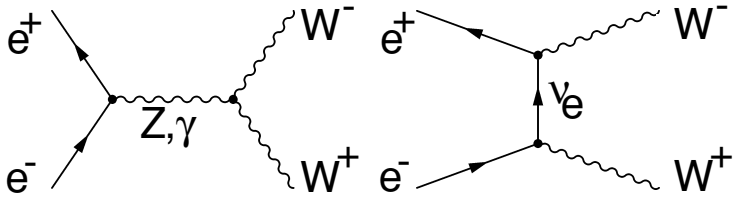
➡ ννqq channel → "mono jets"

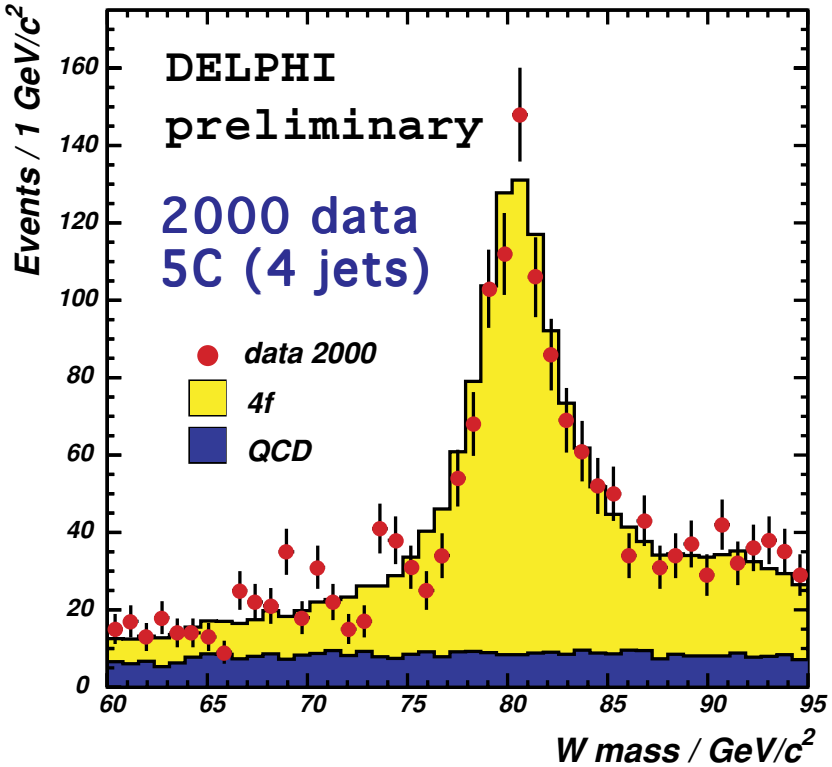
$\sigma_{Z\gamma^*} = 0.129 \pm 0.035 \pm 0.017$ pb

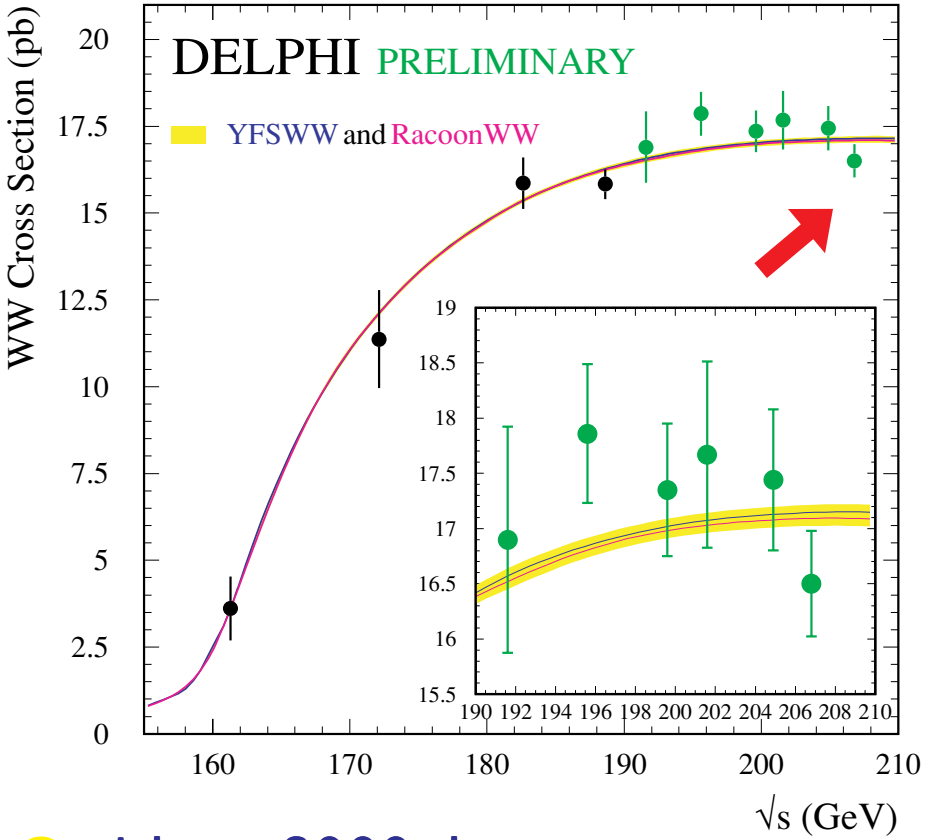
dedicated study for vector resonances
(m(qq) < 2 GeV/c²)

W cross-section and mass

definition (CC03):







without 2000 data:

$m_W = 80.381 \pm 0.053_{stat} \pm 0.034_{sys} \pm 0.030_{FSI} \pm 0.016_{LEP}$ GeV/c²

$\Gamma_W = 2.090 \pm 0.118_{stat} \pm 0.058_{sys} \pm 0.044_{FSI}$ GeV

includes final 189 GeV results

W branching ratios

Backup

- all final states measured
  ⇒ branching ratios
- results consistent with lepton-universality
- hadronic branching ratio:

  $BR(W \to had) = 1 - 3 \times BR(W \to l\nu)$
- interpretation ~ CKM-matrix:

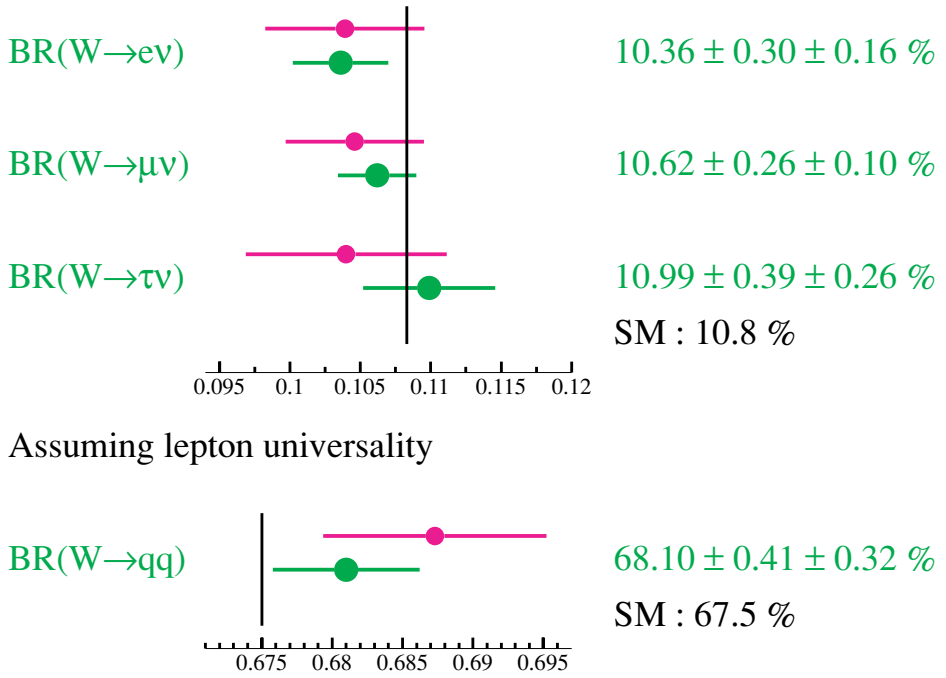
$$\frac{BR_{had}}{1 - BR_{had}} = \sum_{i=u,c\ j=d,s,b} |V_{ij}^2| \left(1 + \frac{\alpha_s}{\pi}\right)$$

- use PDG for $v_{ij} \neq v_{cs}$
- yields: $|v_{cs}| = 1.003 \pm 0.025$

not using CKM-unitarity

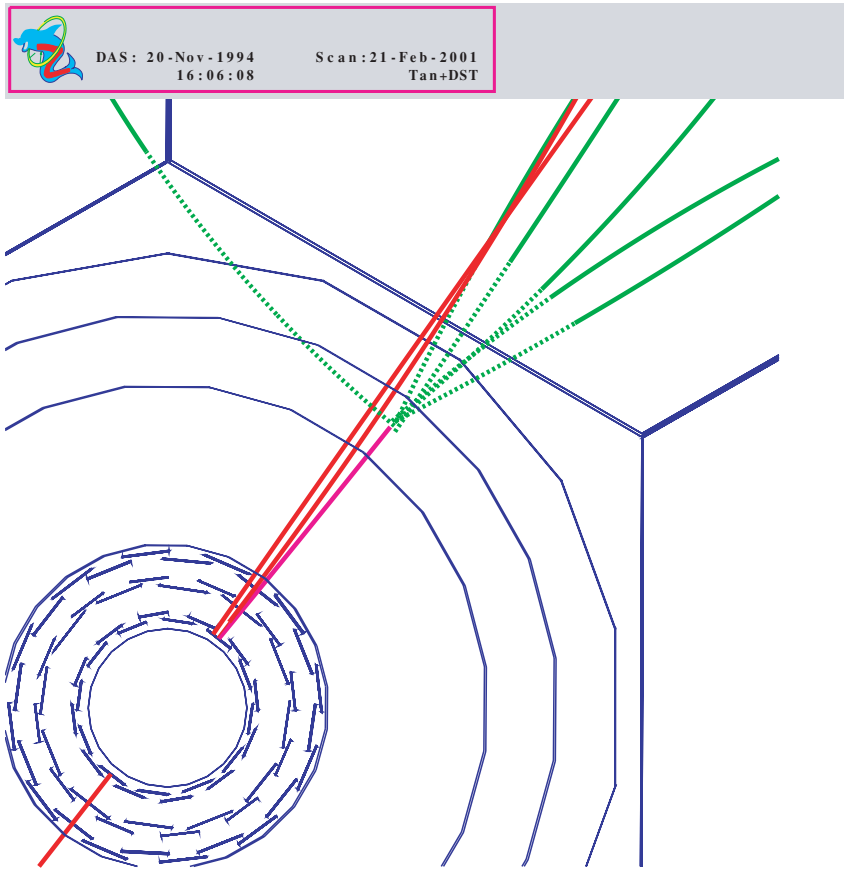
DELPHI W decay Branching Ratios

2000 data (PRELIMINARY)
All data (PRELIMINARY)



LEP1: tau topological branching ratio

- inclusive 1-, 3- and 5-prong BR
- relies on excellent efficiency for primary decay tracks
- remove secondaries from:
  - hadronic interactions
  - photon conversions



- Result:

$BR(1\text{-prong}) = (85.316 \pm 0.093_{stat} \pm 0.048_{sys})\%$

$BR(3\text{-prong}) = (14.569 \pm 0.093_{stat} \pm 0.046_{sys})\%$

$BR(5\text{-prong}) = (\ 0.115 \pm 0.013_{stat} \pm 0.006_{sys})\%$

factor 2 more precise than PDG average

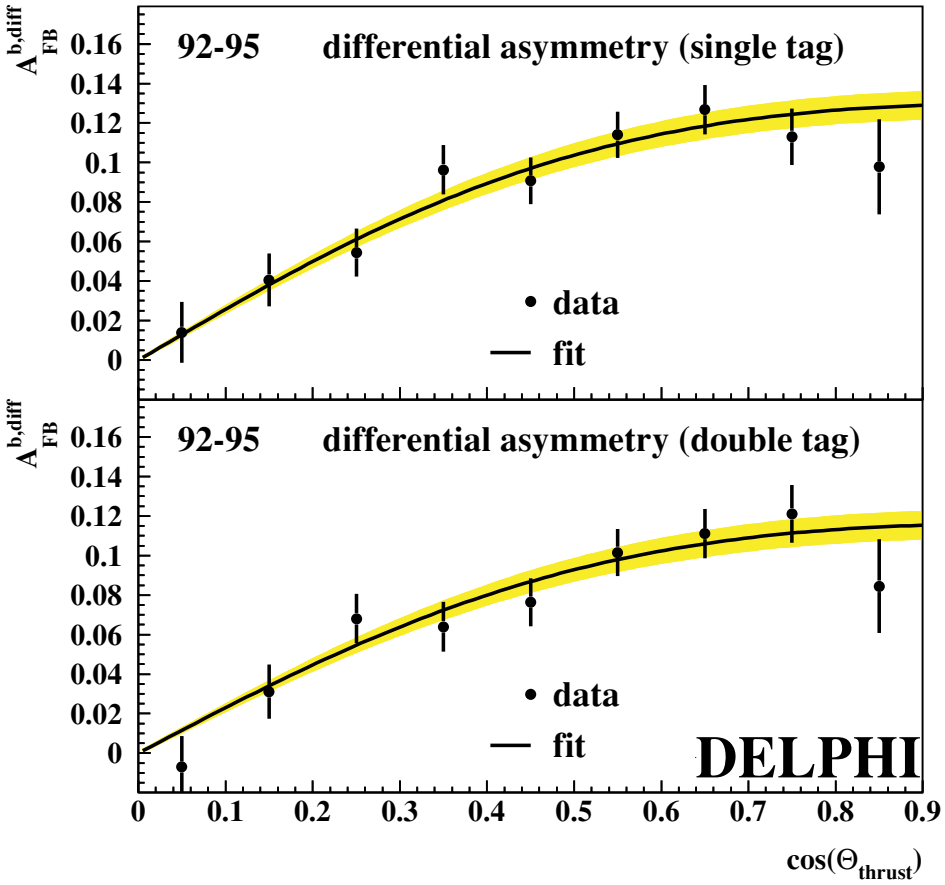
LEP1: precise result on b-quark pole asymmetry

NEW!

- high purity b-tagged sample
- Neural Network b-charge tag:
  - vertex-charge
  - B_x flavour tags
  - identified kaons+protons
  - jet-charge + prompt leptons
- self calibration using hemisphere double-tagging (like R_b):

$$N(\text{opp.}) \propto \omega_b^2 + (1-\omega_b)^2$$

$$N(\text{same}) \propto 2\,\omega_b\,(1-\omega_b)$$



- b-quark pole asymmetry :

$$A_{FB}^{b,0} = 0.0956 \pm 0.0034 \pm 0.0015$$

Searches for SUSY and Exotica

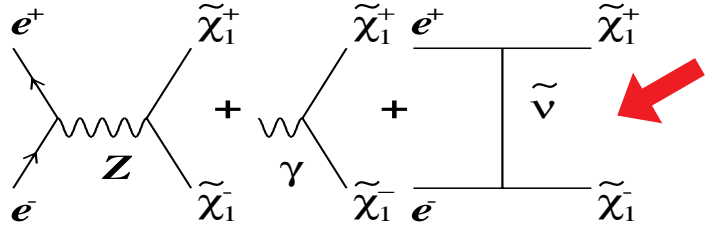
SUSY

- chargino and neutralino ←
- Sleptons and Squarks ←
- MSSM parameter scan ←
- GMSB stau and neutralino NLSP ←
- Gluino LSP ←
- Sgoldstino
- RPV via LLE and UDD couplings
- single top production (RPV)

Exotica

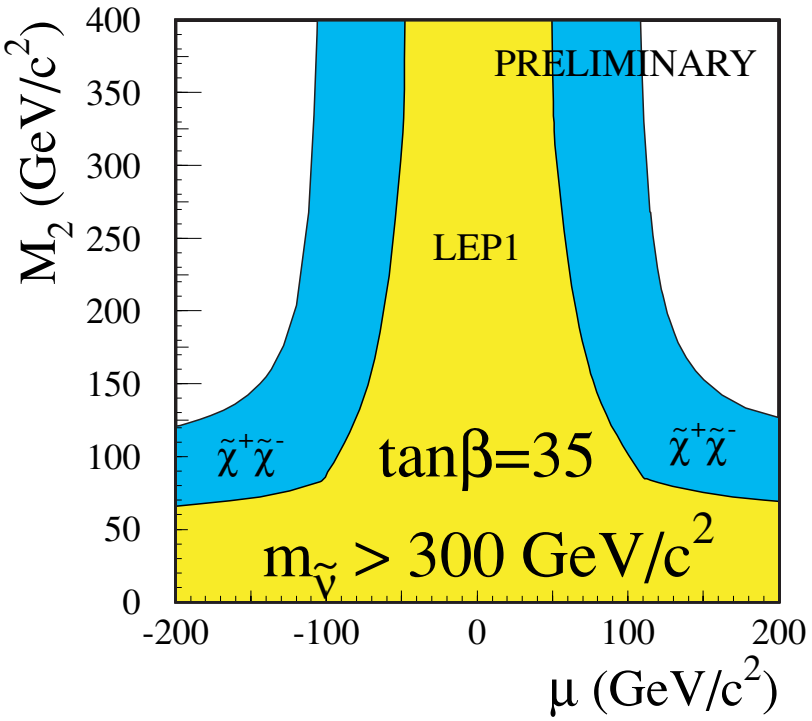
- Technicolor ←
- excited leptons
- Leptoquarks
- FCNC

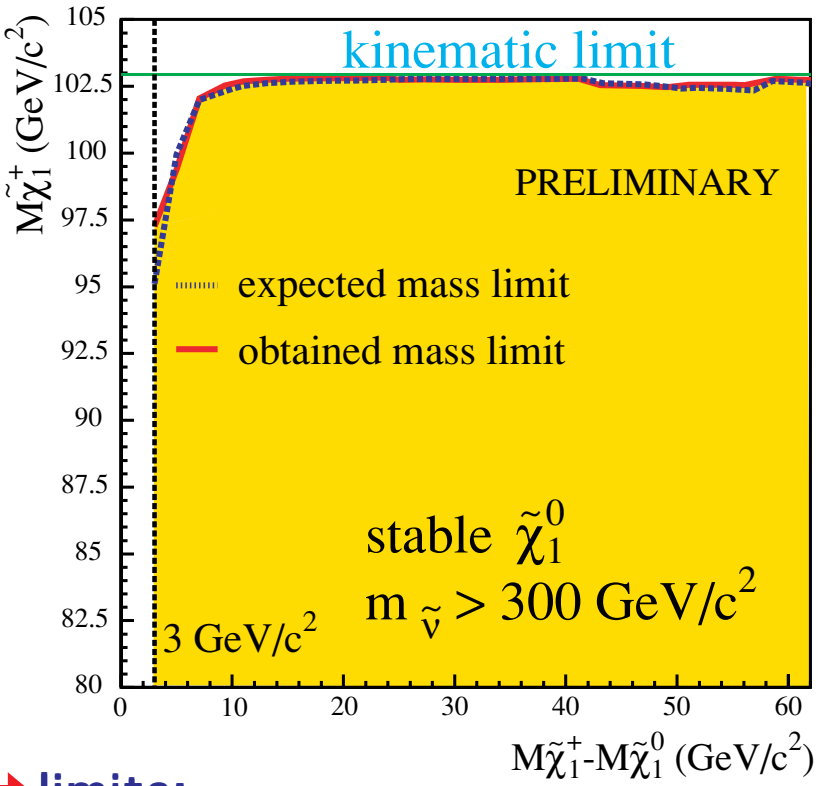
search for Charginos



➡ search for $\tilde{\chi}_1^+ \rightarrow W^* \tilde{\chi}_1^0$ in: (or cascade)

4j+E_{mis}, 2j+l+E_{mis}, 2l+E_{mis}





➡ **limits:**

$m\tilde{\chi}^{\pm} > 102.5$ GeV/c²

for ΔM>10 GeV/c² and $m_{\tilde{\nu}}$>300 GeV/c²

$m\tilde{\chi}^{\pm} > 97.3$ GeV/c²

for ΔM = 3 GeV/c² and $m_{\tilde{\nu}} > m\tilde{\chi}^{\pm}$

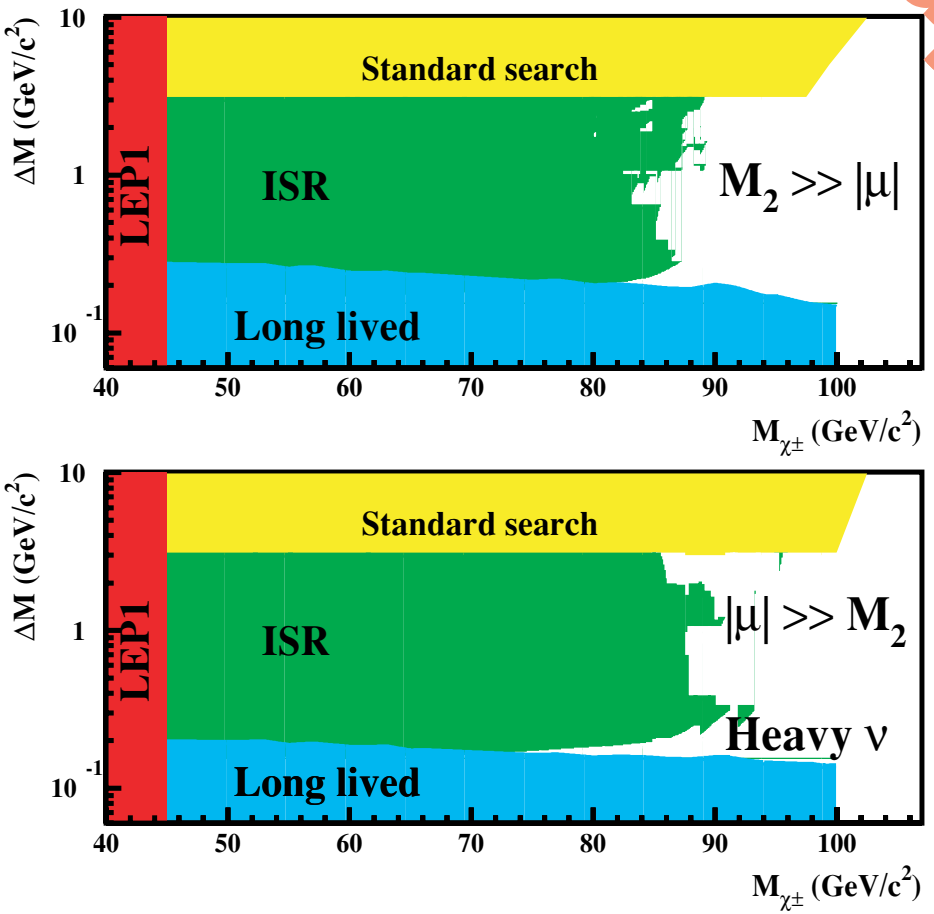
➡ at 205.9 GeV (no „S6“ data yet !)

Backup

- special analyses to cover very degenerate region:
  - tagging of ISR photon for medium small ΔM
  - impact parameter+kinks
  - heavy stable particles
- two scenarios:
  - higgsino region ($M_2 >> |\mu|$)
  - gaugino region ($|\mu| >> M_2$)
- update using 2000 data:

$m\chi^{\pm} > 82$ GeV/c² (higgsino)

$m\chi^{\pm} > 74$ GeV/c² (gaugino)



constrained MSSM parameter scan and the LSP limit

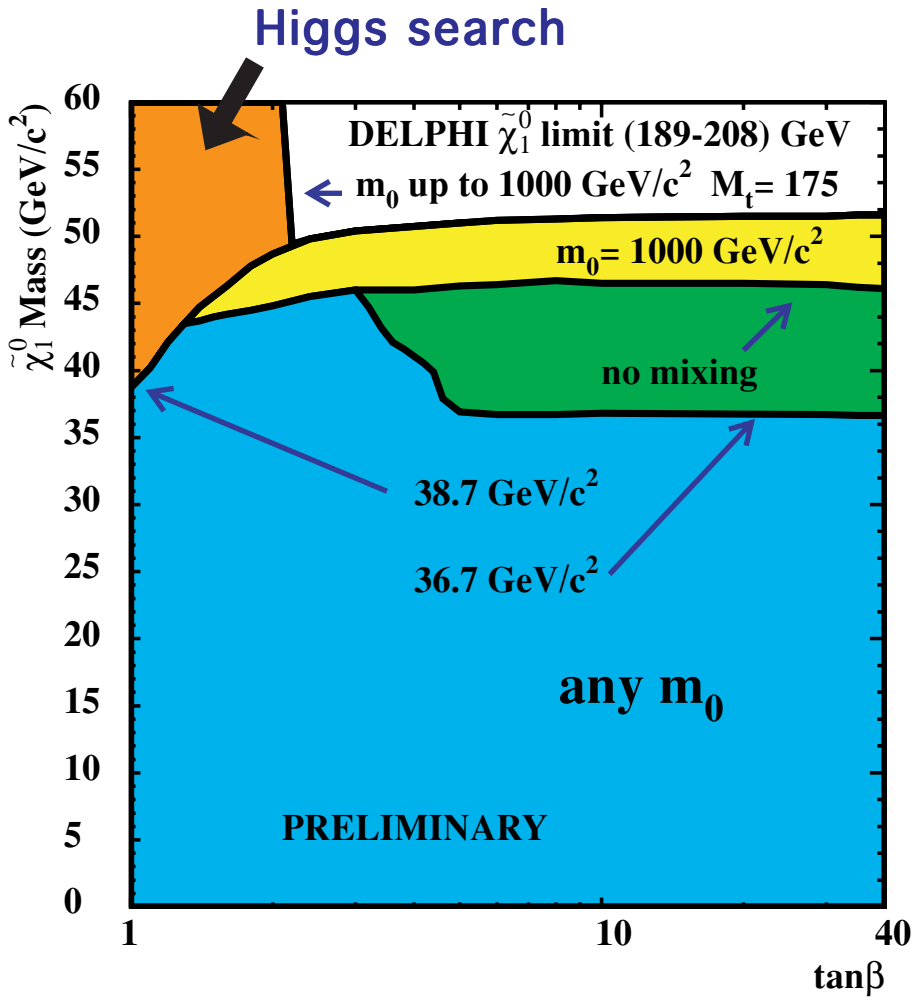
➡ generalised MSUGRA:

- gauge mass unification
- sfermion unification
- do not use EW symmetry breaking to determine $|\mu|$

➡ use cross-section limits from:

- Squark and Slepton searches
- chargino and neutralino searches

updated with 2000 data



➡ neutralino (LSP) mass limit:

$m\tilde{\chi}_1^0 > 46$ GeV/c^2 (no mixing)

for any m_0, M_2, $1 \leq \tan\beta \leq 40$, μ range for χ_1 LSP

➡ including 3rd family (stau) mixing:

$m\tilde{\chi}_1^0 > 36.7$ GeV/c^2

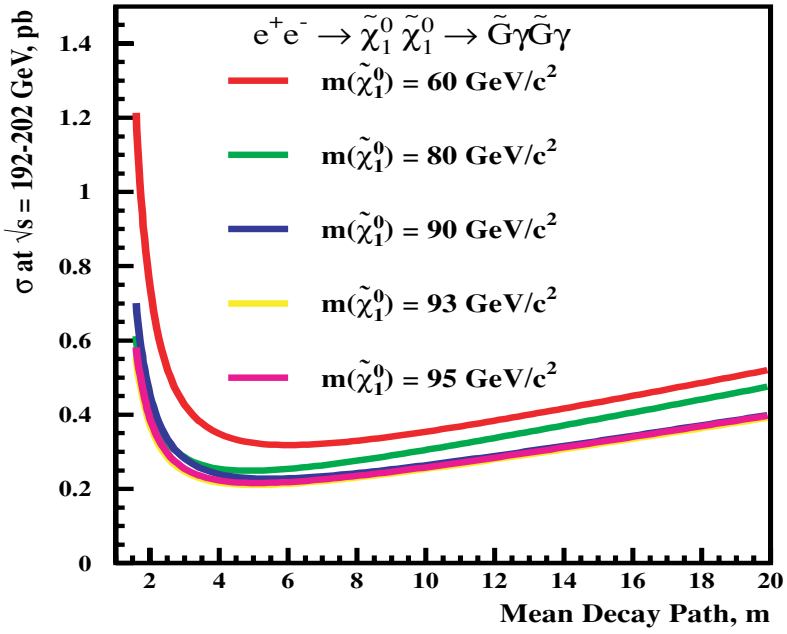
GMSB searches

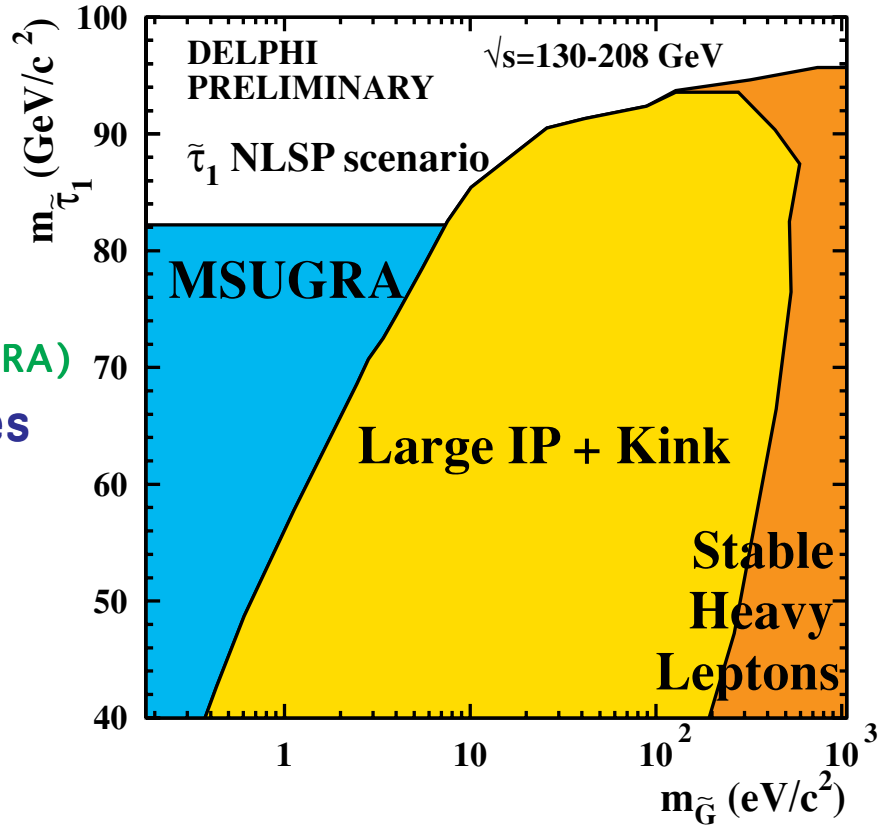
➡ LSP is gravitino $\tilde{G}$ (≈massless), phenomenology depends on NLSP

➡ if NLSP = $\tilde{\tau}_1$ ⇒ $\tilde{\tau}_1\tilde{\tau}_1 \rightarrow \tau\tilde{G}\,\tau\tilde{G}$

● decay length ∝ $M_{\tilde{G}}^2$

- $c\tau << L_{det}$ acoplanar leptons (≈MSUGRA)
- $c\tau = L_{det}$ kinks + displaced vertices
- $ct >> L_{det}$ stable heavy leptons





➡ if NLSP = $\tilde{\chi}^0$ ⇒ $\tilde{\chi}^0\tilde{\chi}^0 \rightarrow \gamma\tilde{G}\,\gamma\tilde{G}$

- $c\tau << L_{det}$ acoplanar photons
- $c\tau = L_{det}$ non pointing photons
- $ct >> L_{det}$ invisible (indirect searches)

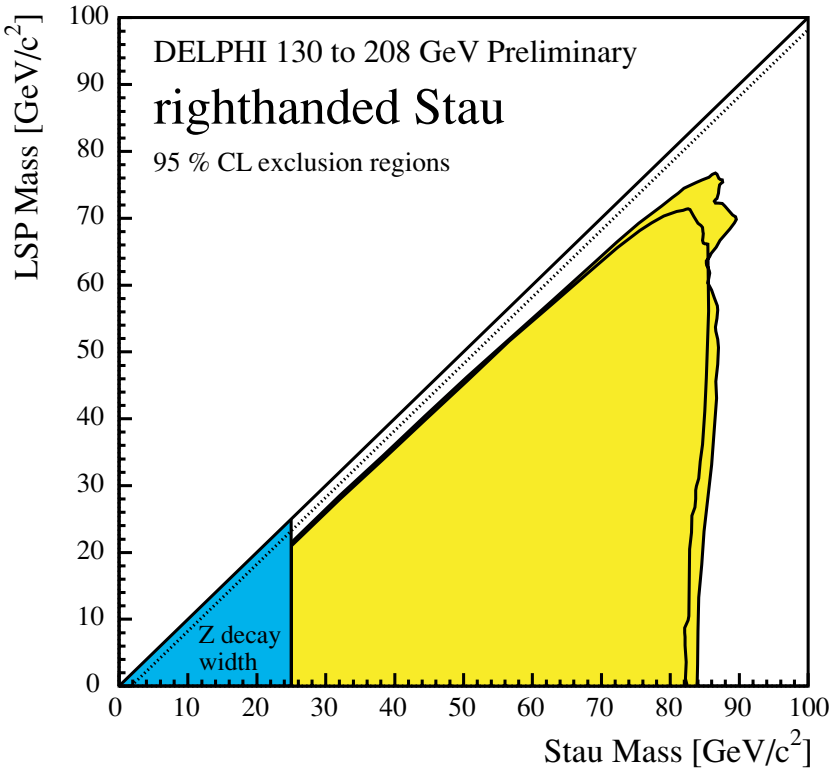
search for Sfermions

➡ process: $ee \to \tilde{t}\,\tilde{t} \to c\tilde{\chi}^0\, c\tilde{\chi}^0$

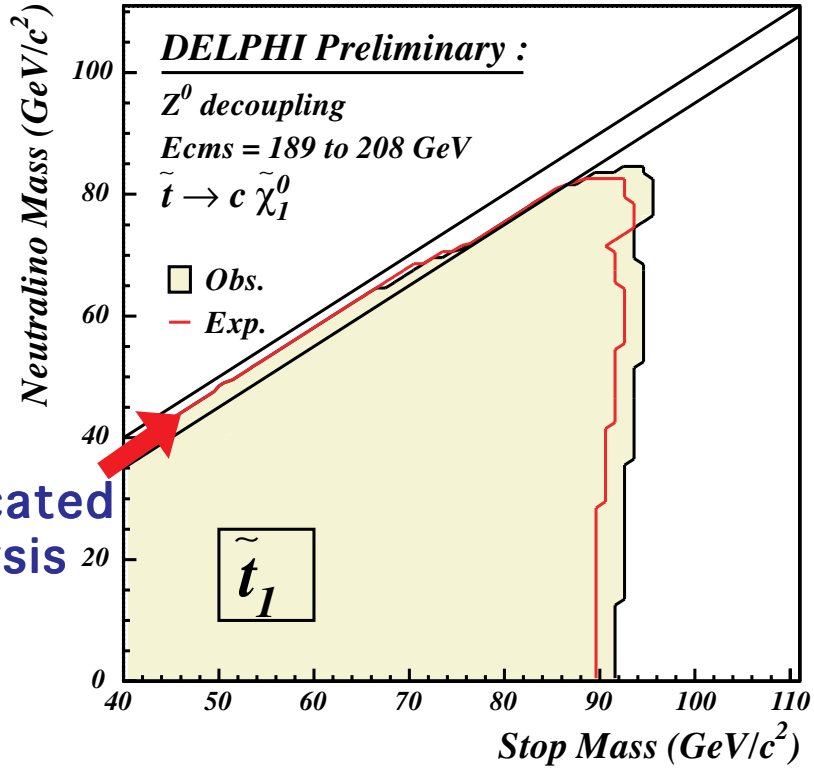
limits for $\Delta M > 15$ GeV/c² :

$m_{\tilde{b}} > 89$ GeV/c² ($\theta = 68°$)

$m_{\tilde{t}} > 92$ GeV/c² ($\theta = 56°$)



dedicated analysis



➡ process: $\tilde{\tau} \to \tau\,\tilde{\chi}^0_1$

➡ limits for $\Delta m > 6$ GeV/c² :

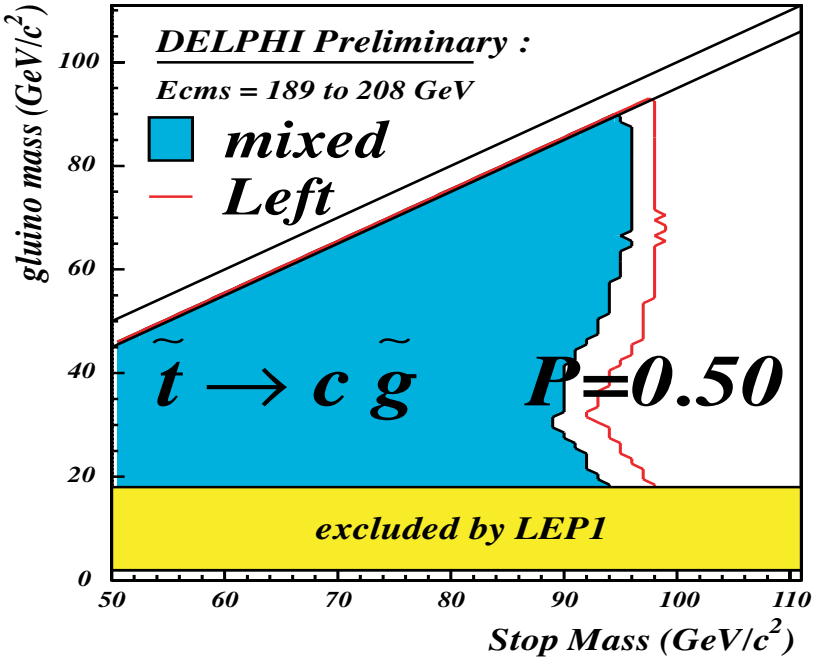
$m(\tilde{\tau}) > 83.9$ GeV/c² (righthanded)

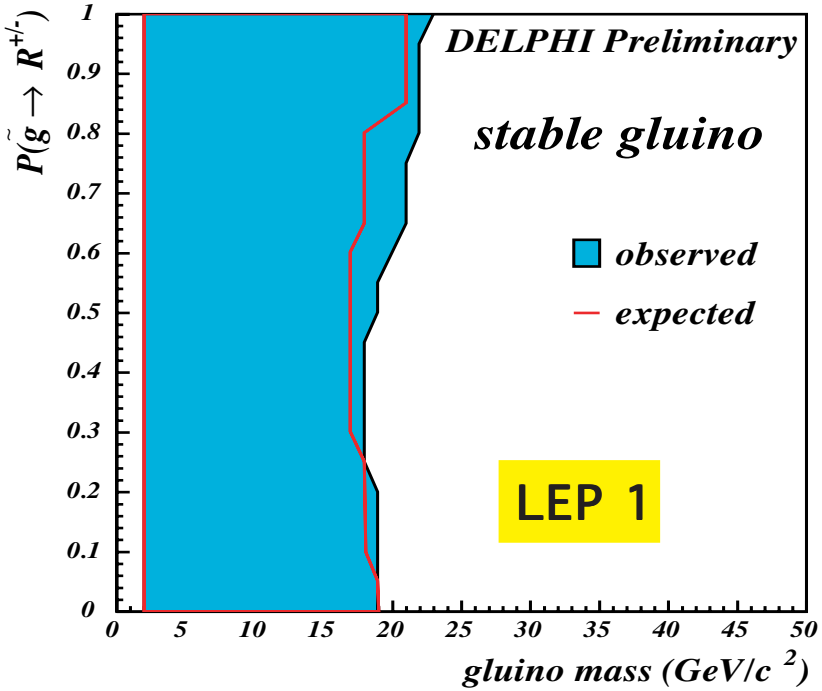
$m(\tilde{\tau}) > 82.9$ GeV/c² (min. x-sec.)

Gluino as LSP

- model exist where gluino is lightest gaugino (LSP) (Mafi et al., Baer et al.)
- $\tilde{g}$ is stable and carries color charge

  $\Rightarrow$ fragments into $\tilde{R}$ hadrons
- charged $\tilde{R}^{\pm}$ $\rightarrow$ high dE/dx in TPC
- neutral $\tilde{R}^{0}$ $\rightarrow$ some energy in calorimeters + E_{mis}





- search for (LEP 2):

  $ee \rightarrow \tilde{t}_1\tilde{t}_1 \rightarrow c\tilde{g}\ c\tilde{g} \rightarrow \tilde{R}\ \tilde{R}$ + jets

  $ee \rightarrow \tilde{b}_1\tilde{b}_1 \rightarrow b\tilde{g}\ b\tilde{g} \rightarrow \tilde{R}\ \tilde{R}$ + jets

  and for (LEP 1):

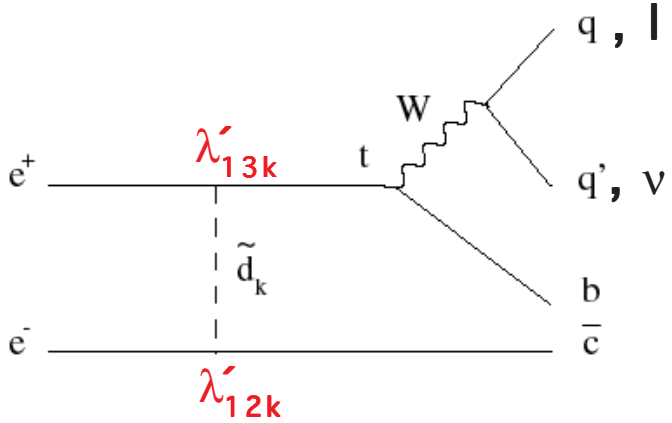
  $ee \rightarrow qq\ g$ with $g \rightarrow \tilde{g}\ \tilde{g}$

P = prob. for charged R-hadron

search for $e^+e^- \to t\bar{c}$ in RPV-models

Backup

- FCNC negligible in SM
- $e^+e^- \to t\bar{c}$ with R-parity violation:



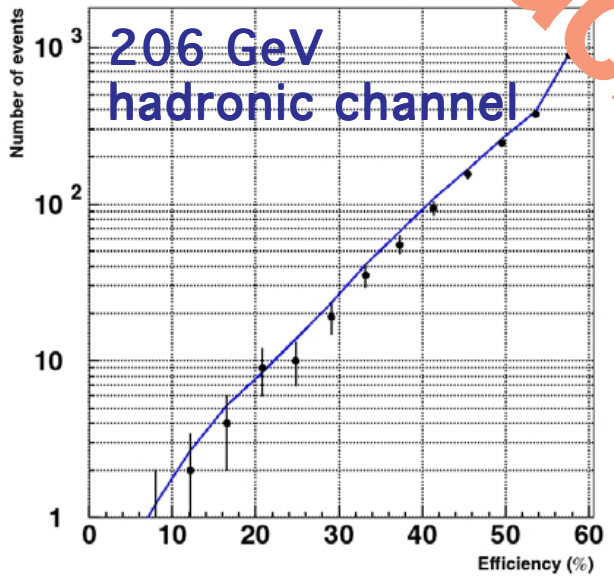
- 4 jet or jj lν final states, top + W mass constraints
- cross-section limits:

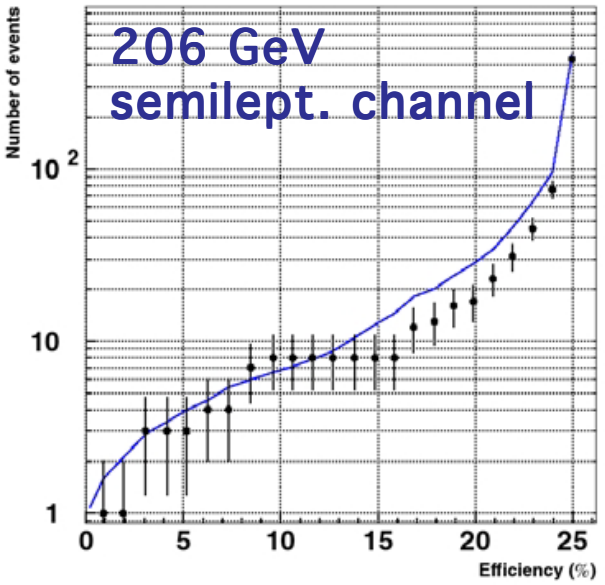
  4 jet : $\sigma_{ee \to tc} < 0.31$ pb (95% CL)

  jj lν : $\sigma_{ee \to tc} < 0.24$ pb (95% CL)

  data 189 GeV
- coupling limit: $|\lambda'_{1jk}\lambda'_{13k}| < 0.11$

  (j,k = 1,2 , $m(d_k)=100$ GeV/c^2)





Excited leptons

Backup

➡ direct search for single l* or ν* in s-channel Z/γ exchange:

ee → l l* with l* → l γ, l Z, ν W

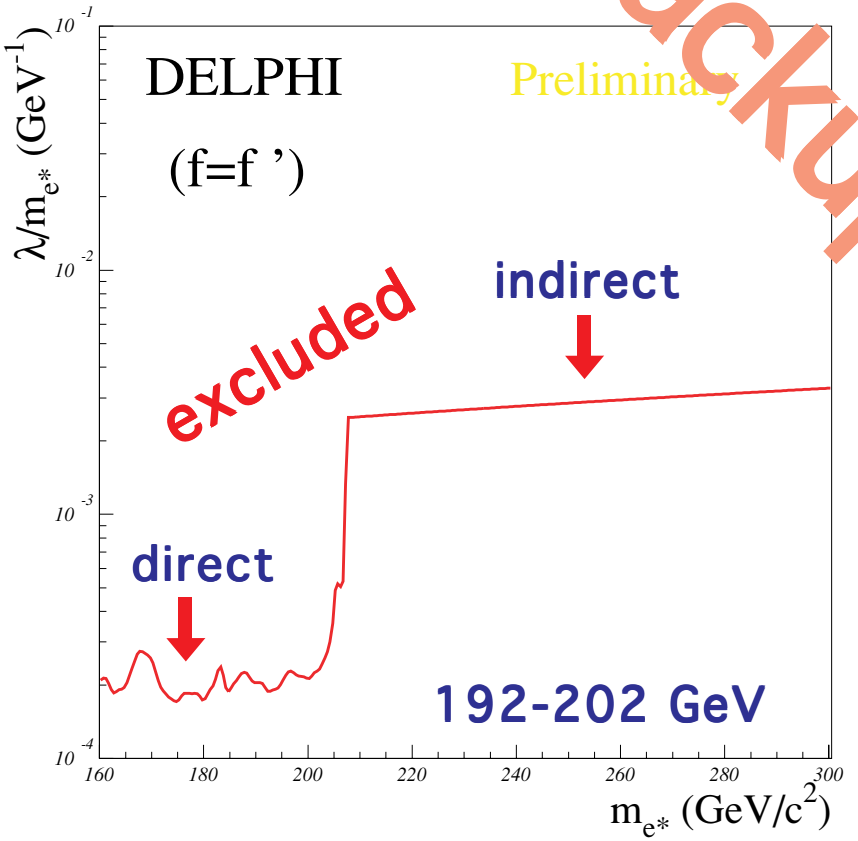
ee → ν ν* with ν* → ν γ, ν Z, l W

+ e* and ν* in t-channel contribution

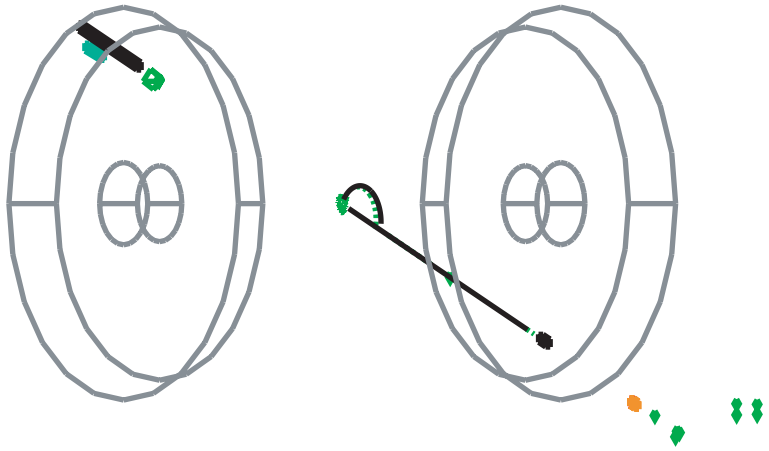
➡ limits on compositness scale Λ:

$f/\Lambda\sqrt{2} = \lambda/m_{l^*}$

f(′) ~ charged/neutral current coupling



➡ a nice μμ* candidate:



➡ combine e* direct search with indirect limits from σ(ee→γγ(γ))

⇒ extend exclusion over kinematical limit

search for technicolor

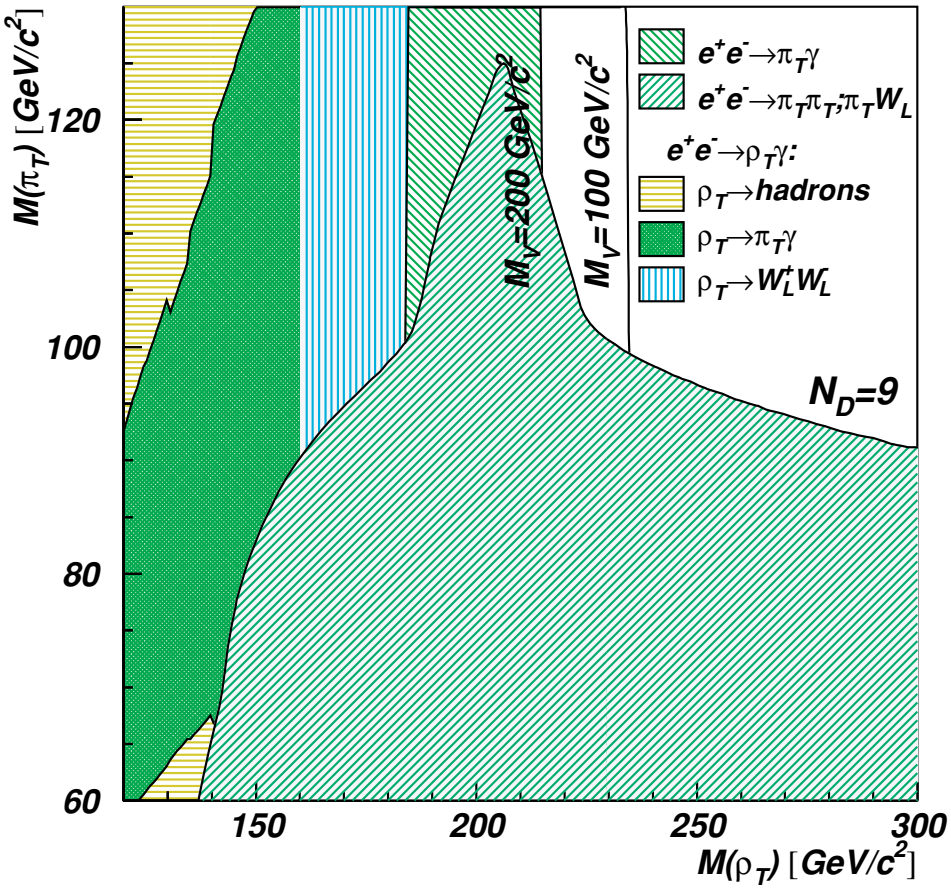
- "walking technicolor"
  not excluded by precision data

- involves $N_D \geq 2$ technidoublets
  $\Rightarrow$ scalar (π_T, π_T') and
  vector (ρ_T, ω_T) mesons

- search for ρ_T and π_T production:
  $e^+e^- \rightarrow \rho_T(\gamma)$ or $\rho_T^{(*)}$
  $\rho_T \rightarrow W_L W_L$ / $\pi_T\pi_T$ / $\pi_T^0\gamma$ / $f\bar{f}$

- 4-jet or jj$\gamma(\gamma)$ final states,
  including b-quarks

- example: $e^+e^- \rightarrow \rho_T^{(*)} \rightarrow \pi_T^+\pi_T^- \rightarrow \bar{c}bc\bar{b}$



Higgs searches

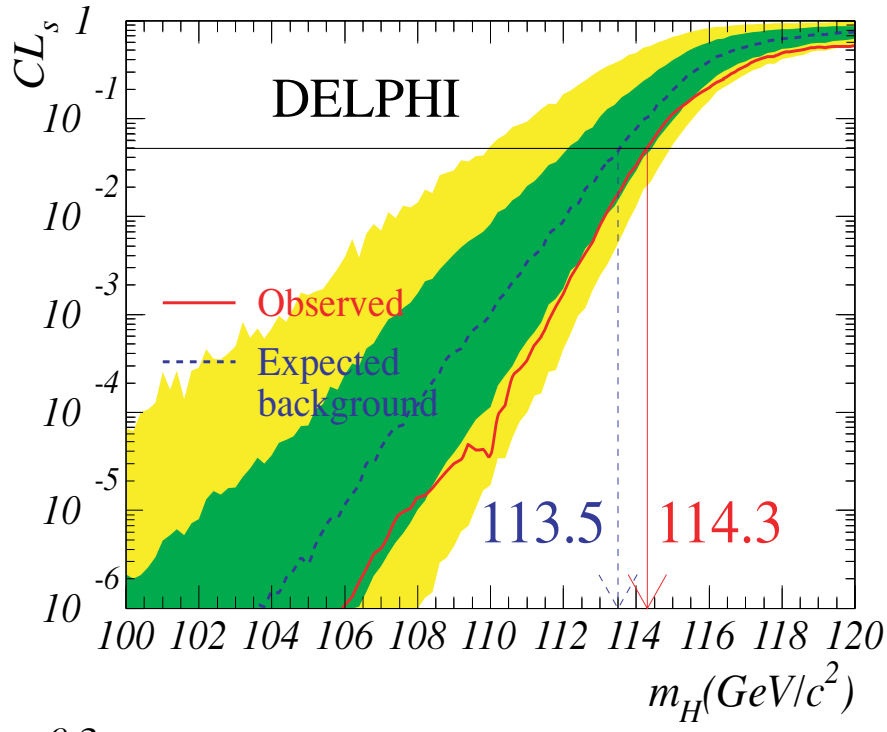
- Standard Model ←
- MSSM neutral Higgses ←
- H^+H^- searches ←
- invisible Higgs ←
- fermiophobic Higgs
- flavour blind Higgs

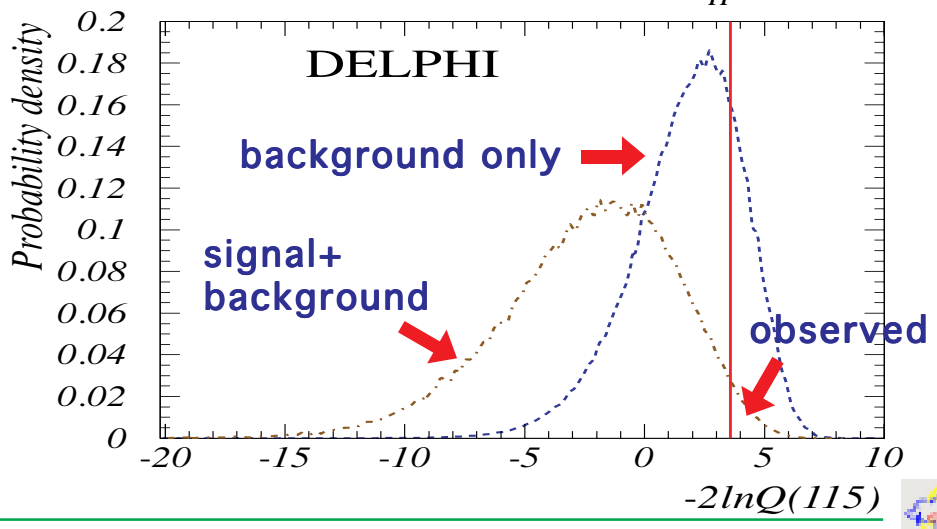
standard model Higgs

- published "fast" paper in time for LEP combination
- ≈ no change w.r.t. last LEPC:
  - added last missing 10 pb^{-1}
  - refined eeqq channel analysis
  - compatible with background only
  - slight deficit in leptonic channels
- limit slightly higher than expected:

  $m_H > 114.3$ GeV/c^2 (113.5 exp)
- DELPHI alone:

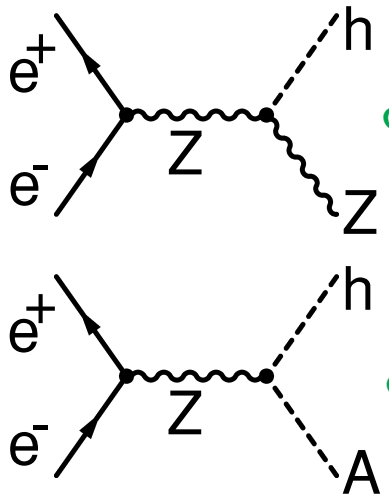
  "limited" sensitivity for Higgs at 115 GeV/c^2





MSSM neutral Higgs searches

➡ **processes:**



$\sigma \propto \sin^2(\alpha-\beta)$

$\sigma \propto \cos^2(\alpha-\beta)$

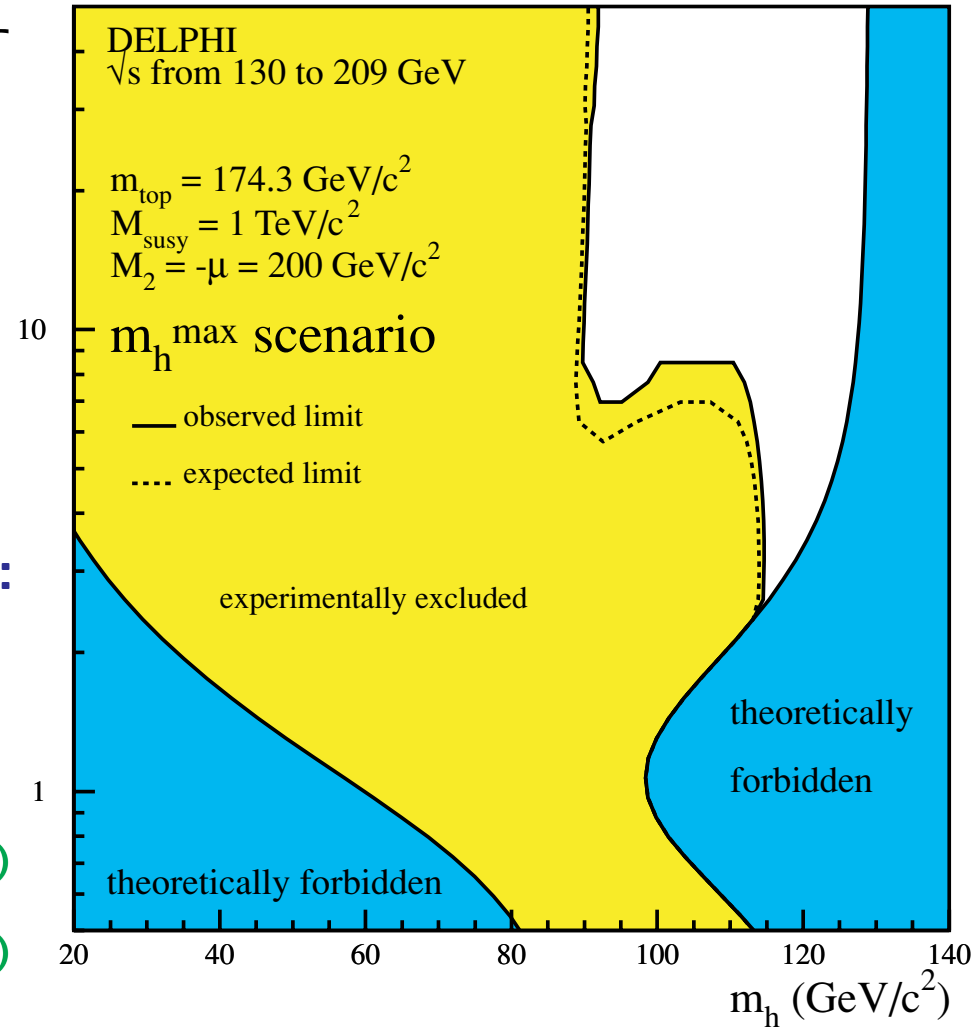
➡ **exclusion plot for m_h^{max}-scenario:**

$0.49 < \tan\beta < 2.36$

➡ **limits** ($\tan\beta > 0.6$):

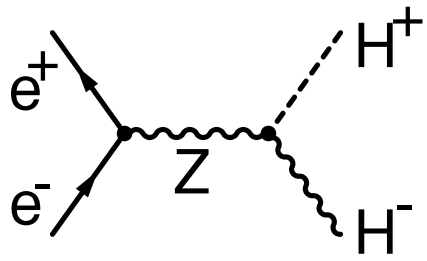
$m_h > 89.8$ GeV/c² (89.0 exp.)

$m_A > 90.9$ GeV/c² (90.1 exp.)



search for H^+H^-

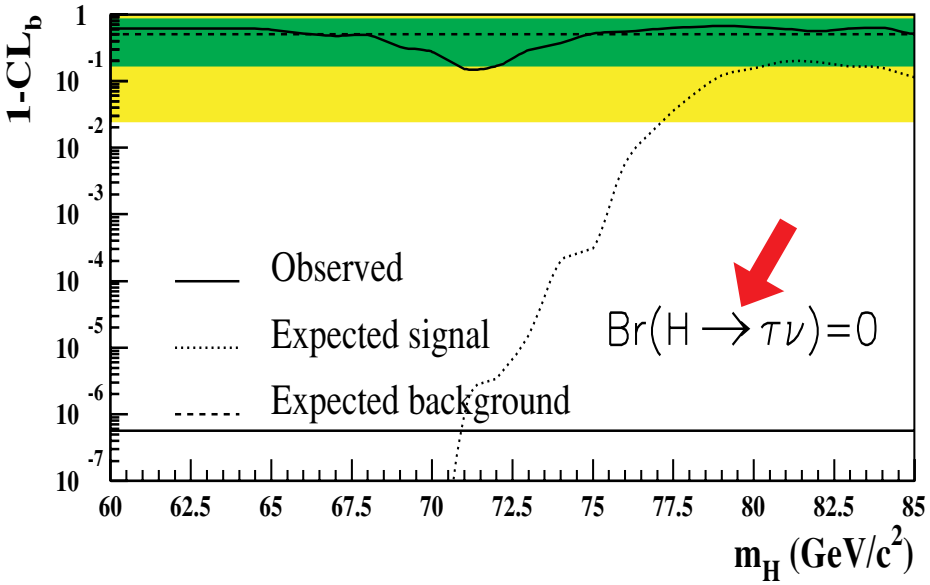
➡ process:

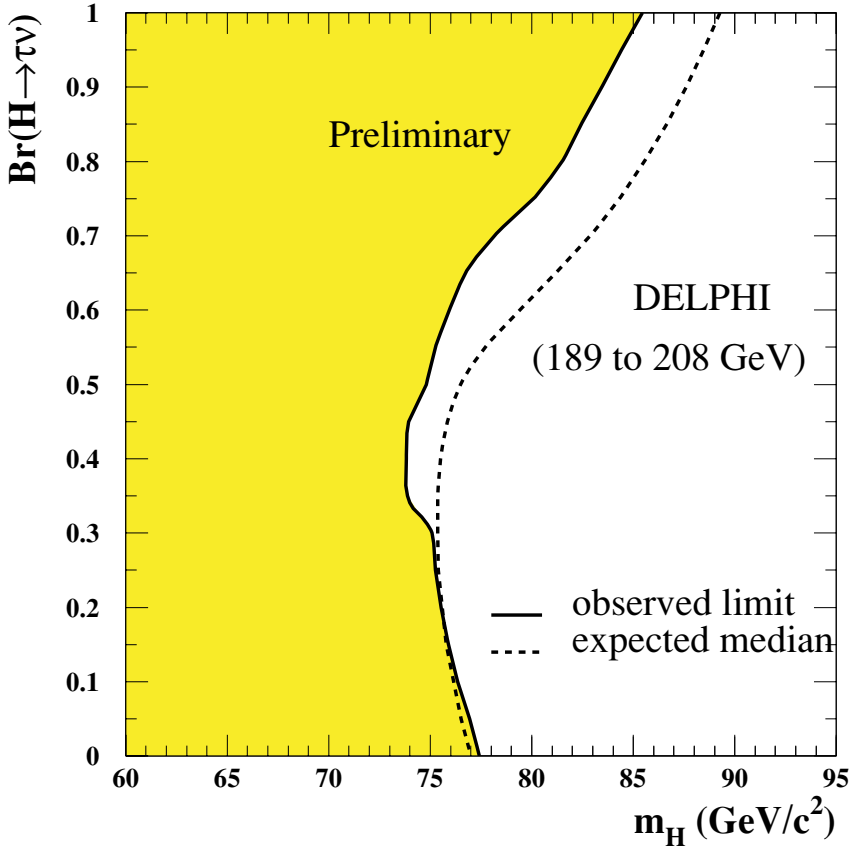


➡ decay modes: $H^+ \to \tau^+\nu$, $c\bar{s}$

➡ direct limit:

$m_{H^\pm} > 73.8$ GeV/c² (75.4 exp)





➡ limit below MSSM allowed region, applies to more general 2 Higgs doublet models

invisible Higgs

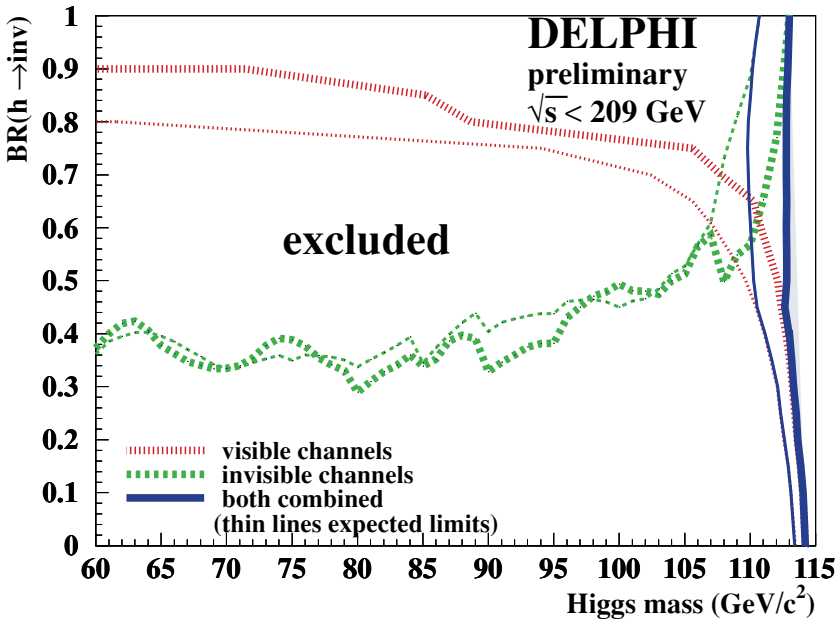
➡ process:

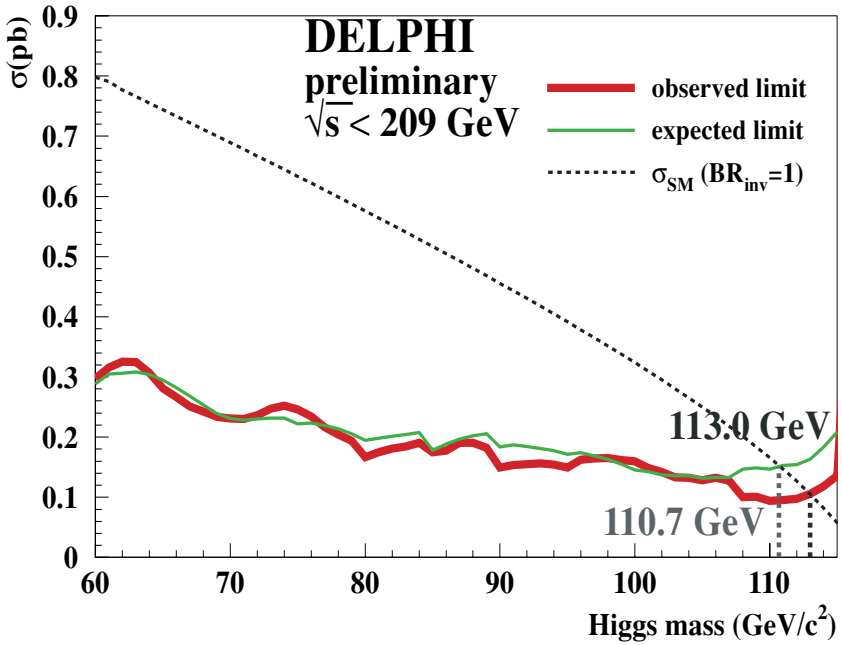
ee → hZ with h → invisible

DAMA "evidence" for a light WIMP

➡ 2 jets or leptons + E_{mis}

➡ cross-section limit for BR(inv)=1 :





➡ limit for BR(inv) = 1 :

m_h = 113.0 GeV/c^2 (110.7 exp.)

➡ combine with visible Higgs search:

m_h = 112.6 GeV/c^2 (109.8 exp.)

for any BR(inv)

non fermionic Higgs decays

Backup

➡ possible scenarios:

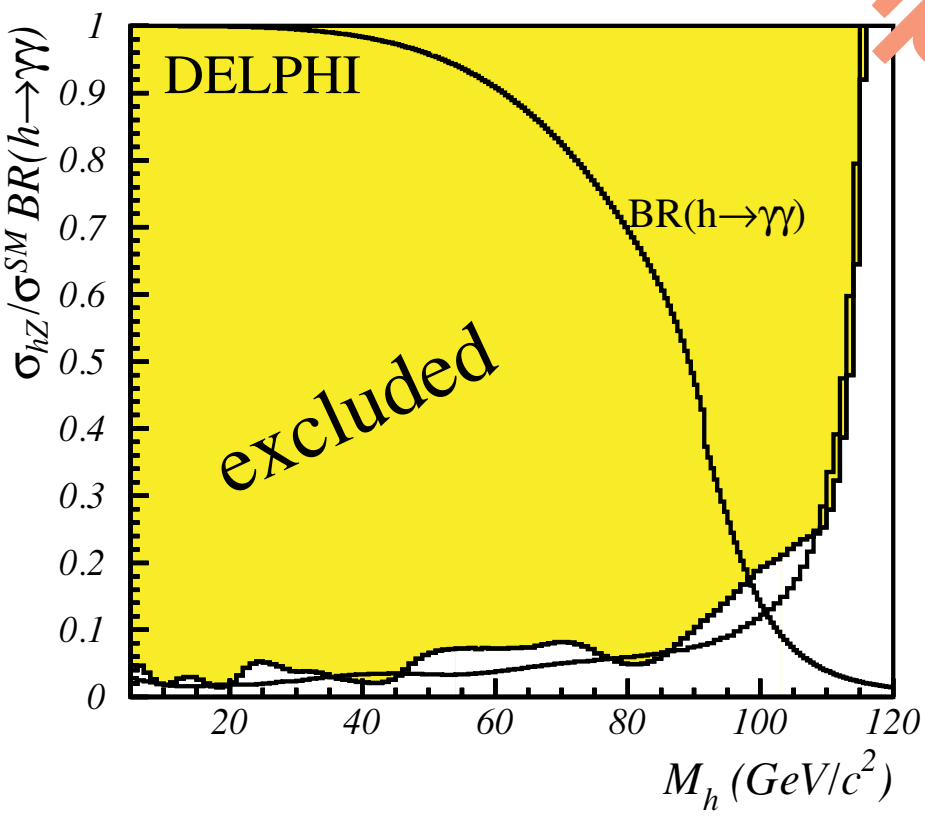
- anomalous couplings
  - ee → hγ → γγγ, bbγ
  - ee → hZ → γγνν
  - ee → hZ/γ* → γγqq

  would contribute to anomalous TGC

- 2 Higgs Doublet Models:
  - ee → hA → γγγ, γγbb
  - ee → hA → AAA → bbbbbb
  - ee → hZ → γγqq, γγνν

➡ example: limits on fermiophobic Higgs from γγqq + γγνν

(line : BR(h → γγ) in 2HDM)



➡ limits:

$m_h > 116$ GeV/c² (BR = 100 %)

$m_h > 98$ GeV/c² (BR = 18 % in 2HDM)

summary

- DELPHI has found no evidence for physics beyond the Standard Model
  - → $m(h) > 114.3\ \mathrm{GeV}/c^2$ (SM)
  - → $m(\tilde{\chi}_1^0) > 36.7\ \mathrm{GeV}/c^2$ (LSP)
- DELPHI is a very active Collaboration
  - → many analyses on measurements at LEP 2 and LEP 1
  - → many results on searches at LEP 2
- many new results for the winter conferences
- we are keen to fully exploit the potential of LEP data
  - → combination of LEP results whenever possible
  - → sharing of experience: e.g. Higgs or WW workshops