Recent Results from LEP II

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CERN-EP / OPAL

- Standard Model Tests
- Indirect Tests for New Physics
- Higgs
  — in the SM
  — in the MSSM
  — and beyond
- Searches
- Conclusions / Outlook

The LEP2 $e^+ e^-$ Collider

Stage	$\sqrt{s}$ (GeV)	Year	Luminosity (pb^{-1})
LEP1	$\approx$ 91	1989-1995	175
LEP1.5	130-140	1995	5
LEP2	161-172	1996	20
	183	1997	55
	189	1998	150-180
	192-206	1999-2000	$>$ 300

in 1999	98 GeV	100 GeV	101 GeV
max. currents (mA)	$\sim$ 6.2	$\sim$ 5.5	$\sim$ 5.0
peak lumi. ($cm^{-2}s^{-1}$)	10^{32}	$8 \cdot 10^{31}$	$8 \cdot 10^{31}$

▷ **4 pb^{-1} per day reached**

LEP Delivered Luminosities

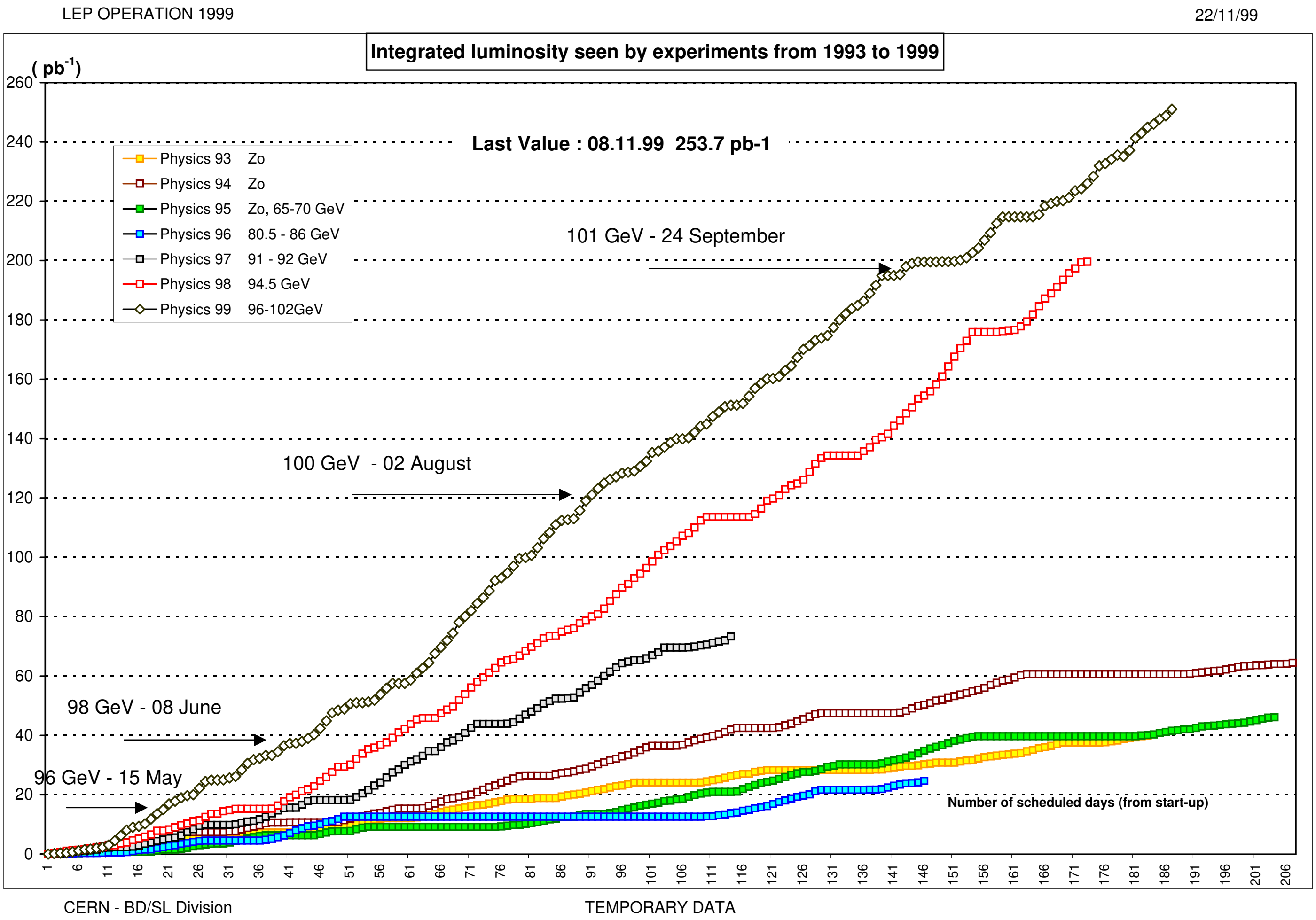
- **Delivered luminosity in 1999:**

96 GeV $\longrightarrow$ $31.2\ \mathrm{pb}^{-1}$

98 GeV $\longrightarrow$ $86.7\ \mathrm{pb}^{-1}$

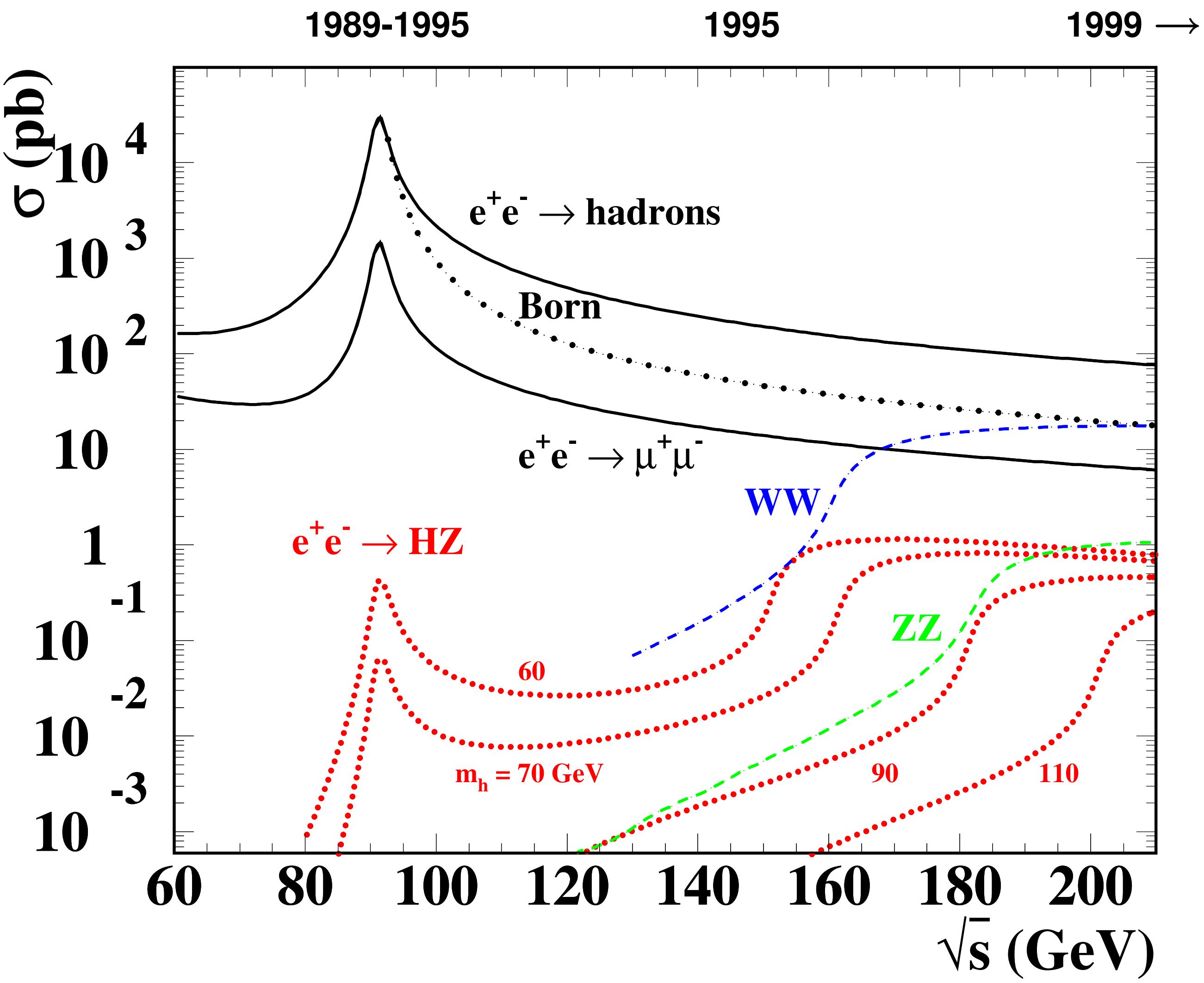
100 GeV $\longrightarrow$ $89.1\ \mathrm{pb}^{-1}$

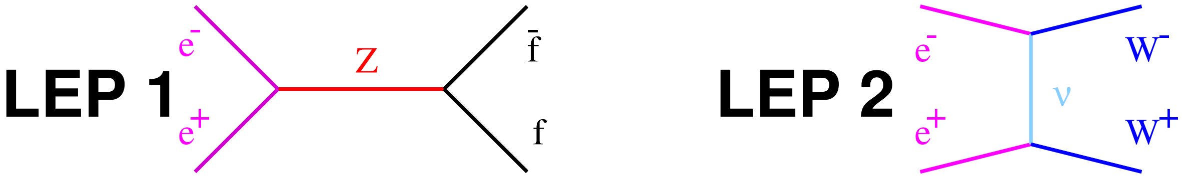
101 GeV $\longrightarrow$ $42.4\ \mathrm{pb}^{-1}$



- **Experiments have collected** $\sim$ **500** pb^{-1} **each at LEP2.**

Processes at LEP2





- **Cross section:**

  1000 - 10000 pb: $e\gamma$ **and** $\gamma\gamma$ **collisions**

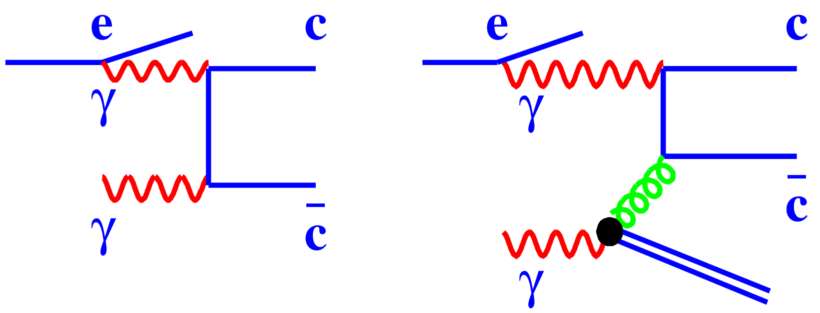
  10 - 100 pb: $e^+e^- \longrightarrow f\bar{f}$ **(EW, QCD)**

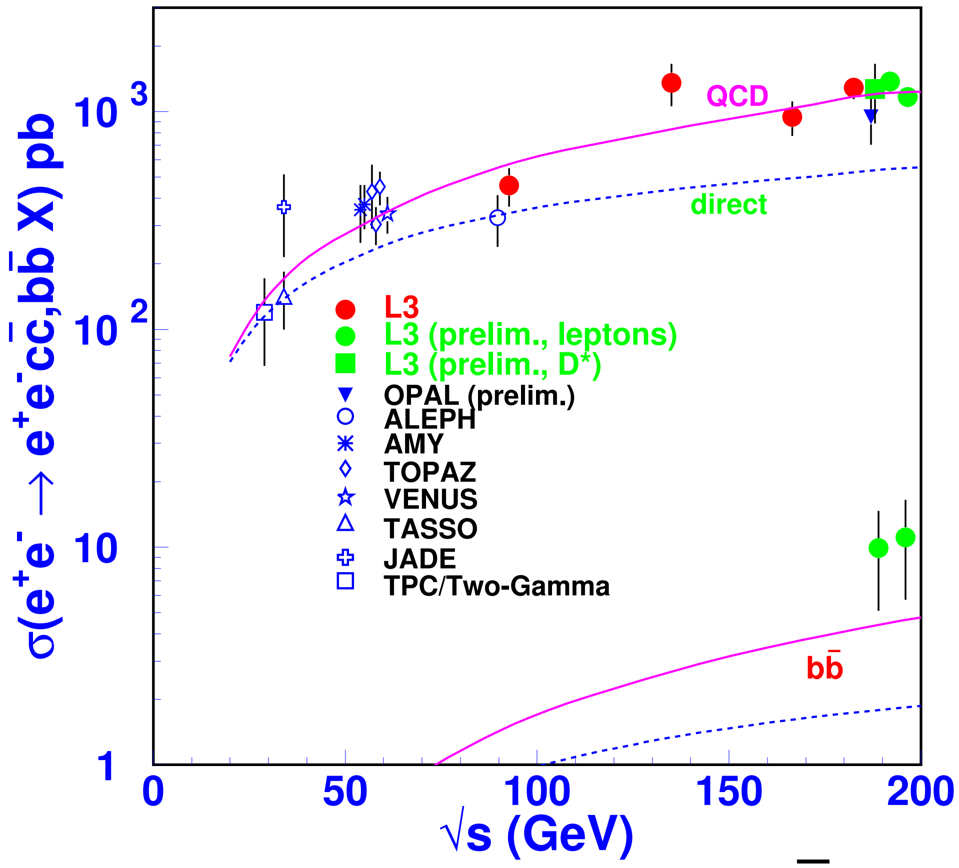
  1 - 15 pb: **W-physics**

  0.1 - 1 pb: **search sensitivity**

$\gamma\gamma$ Physics

- **Highest cross section at LEP !**
- **Production of b and c quark: good test of perturbative QCD**





- **First measurement of $b\bar{b}$ and $F_{2,c}^{\gamma}$ in $\gamma\gamma$ collisions!**

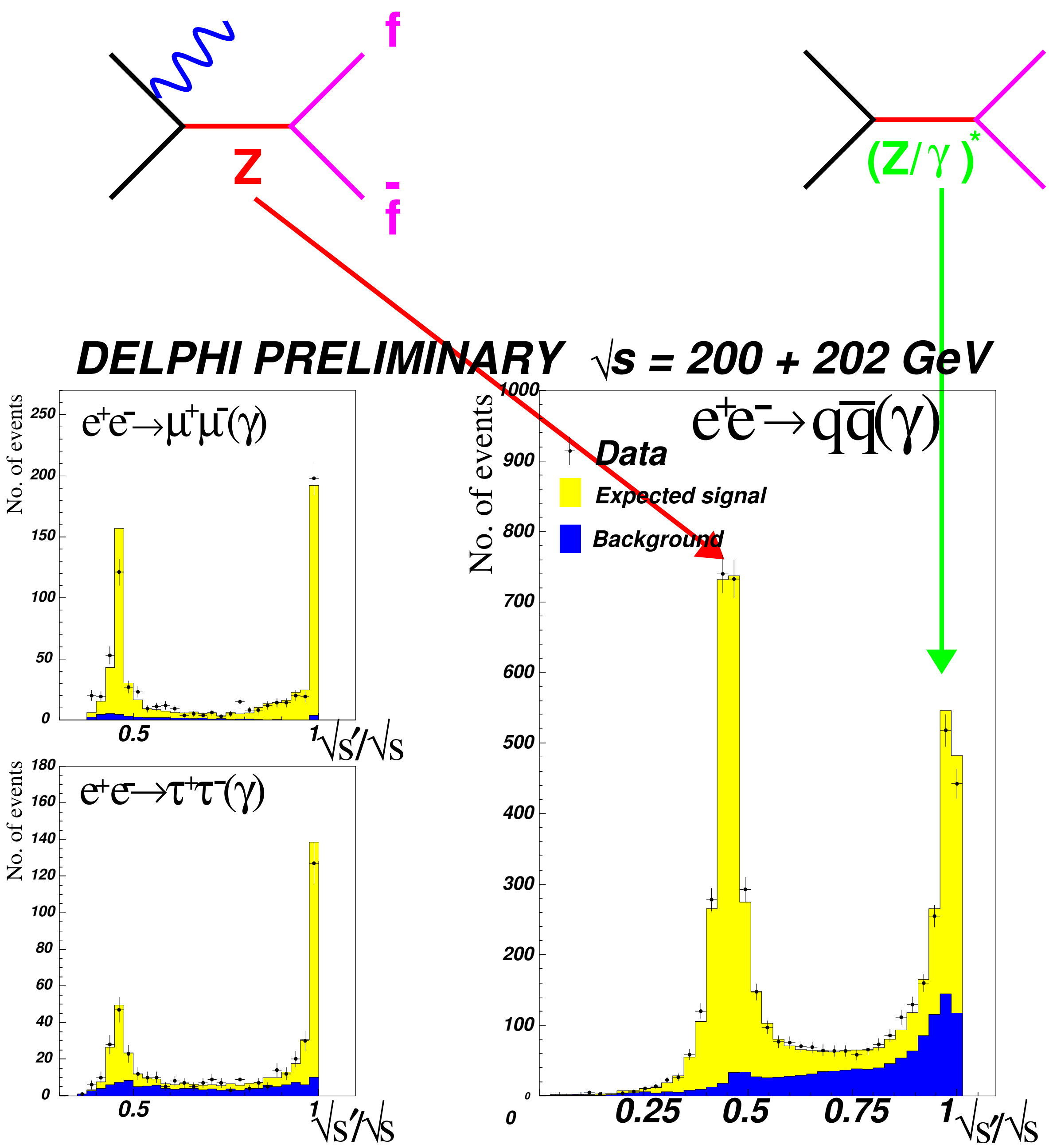
Fermion Pair Production

Fermion-pair production at LEP2: $\sqrt{s'} = M_{propag.}$

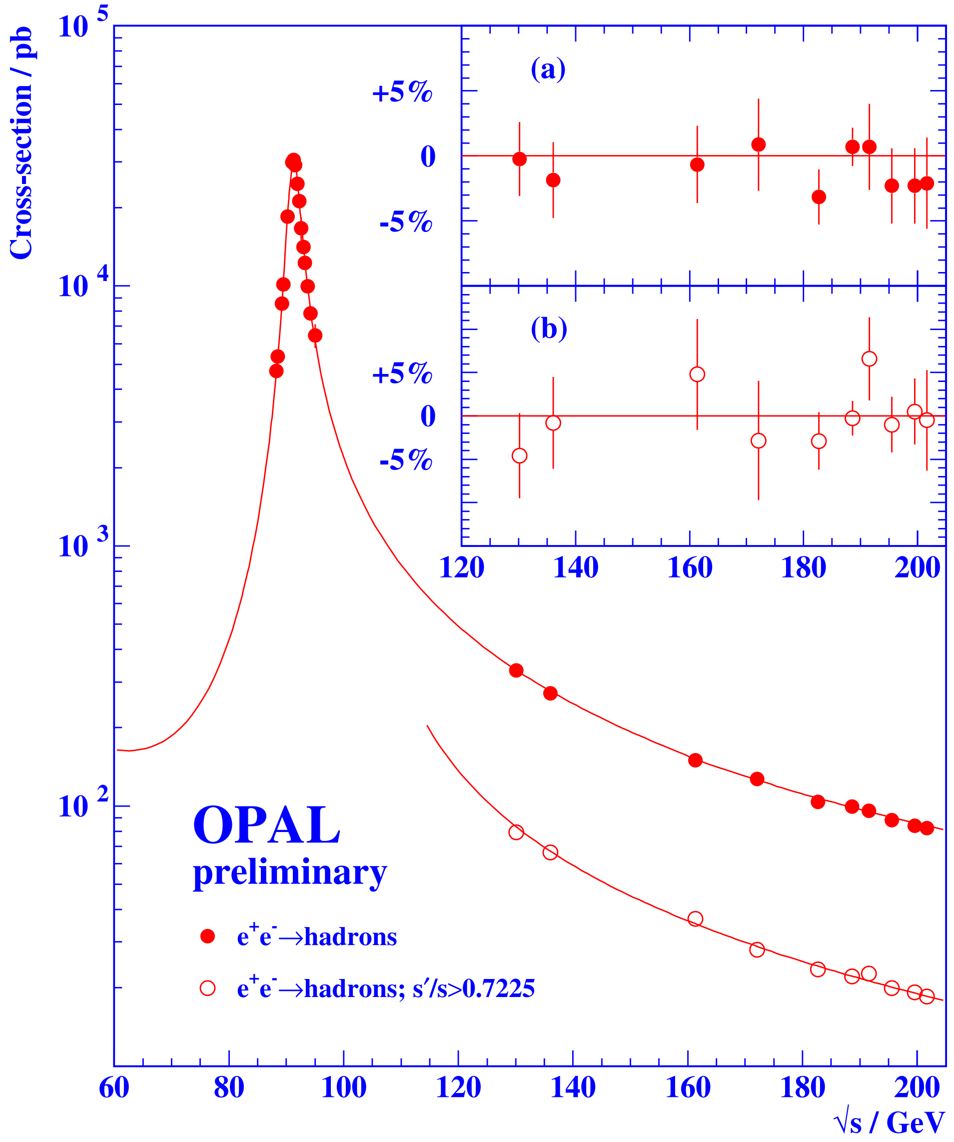
▷ **Full energy events:** $(\sqrt{s'} = \sqrt{s})$

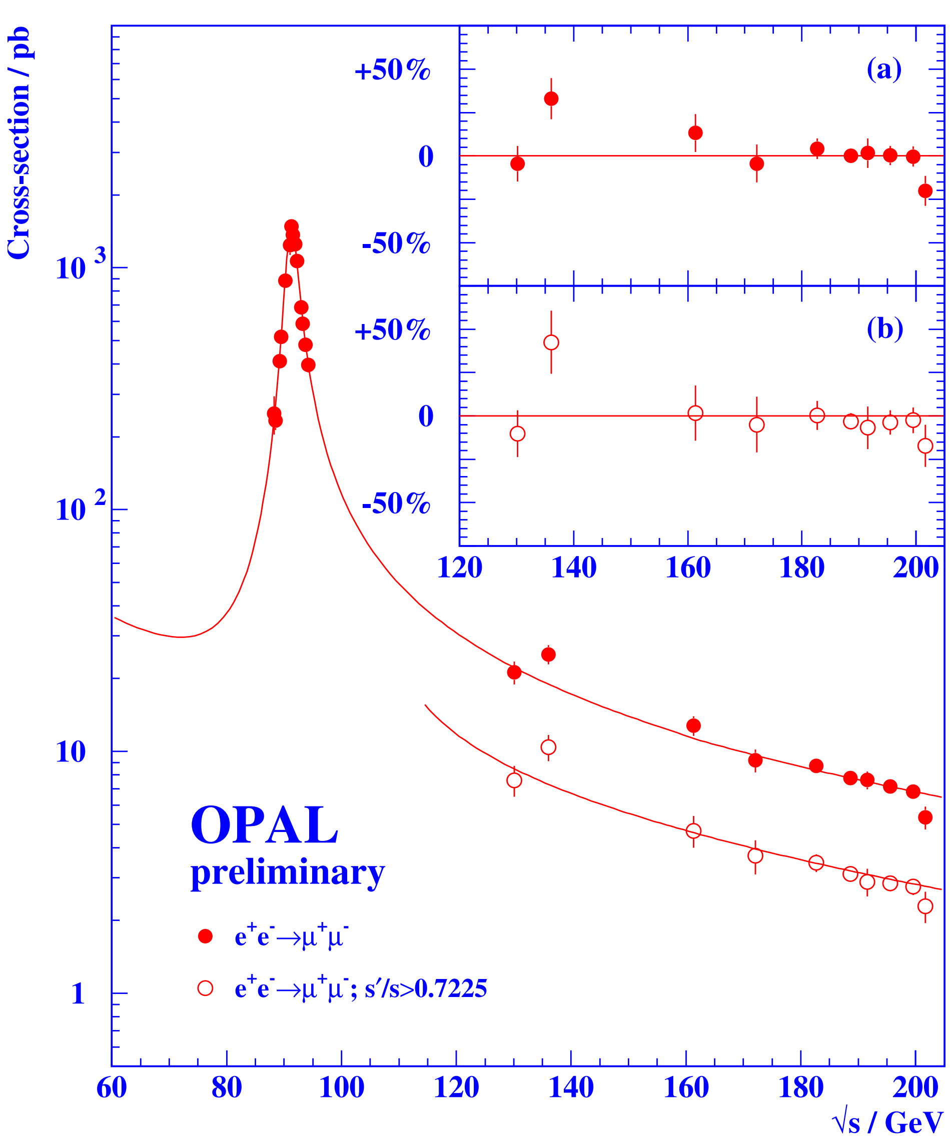
▷ **"Radiative return" to the Z:** $(\sqrt{s'} = M_Z)$

$\Rightarrow$ **Perform precise QCD and electroweak tests**

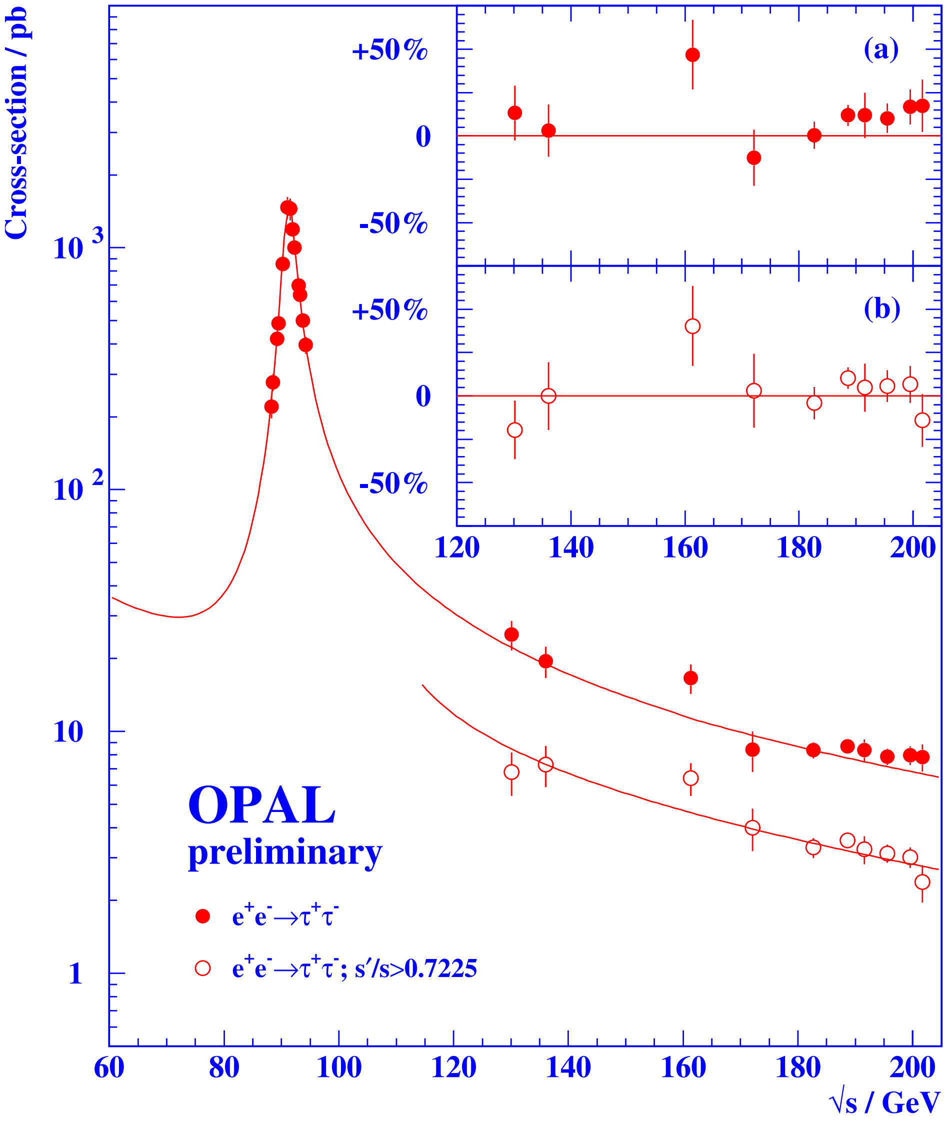


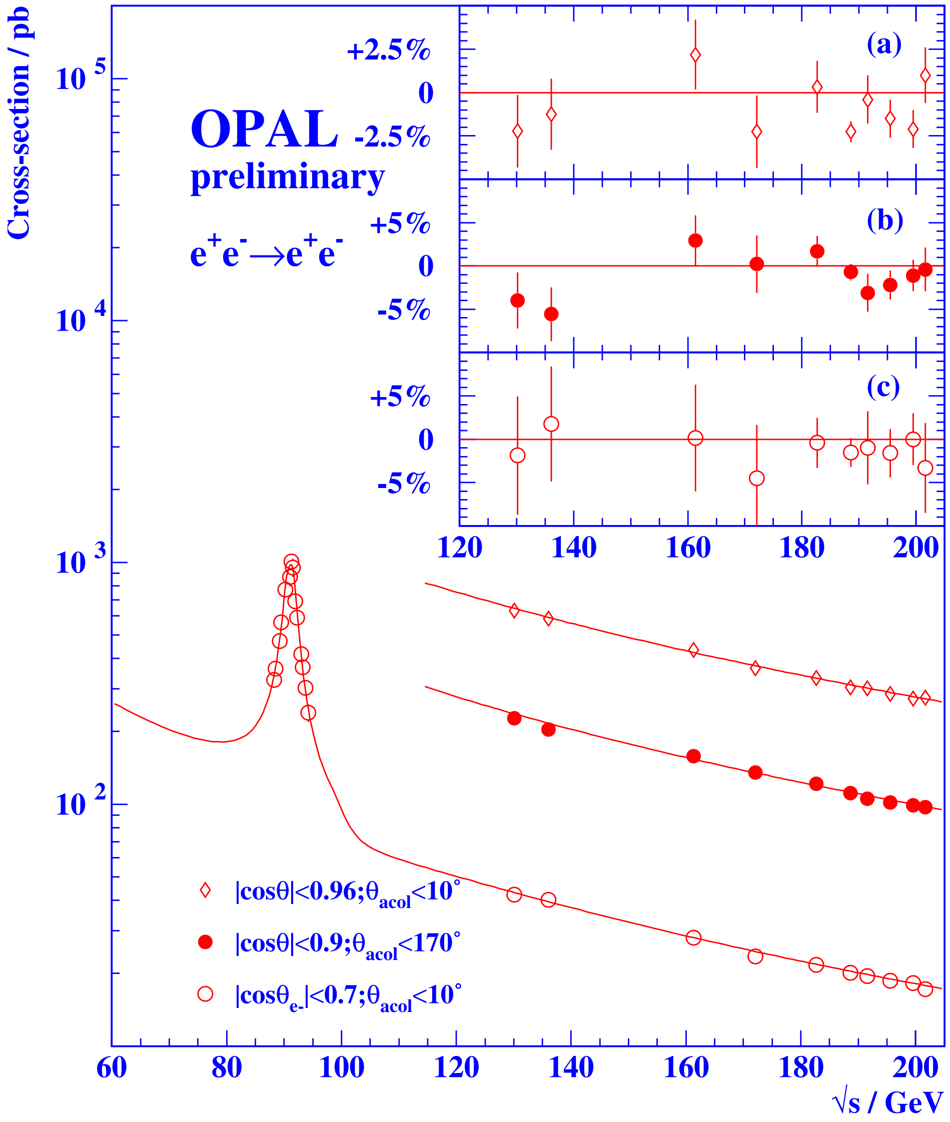
Fermion Pair Production





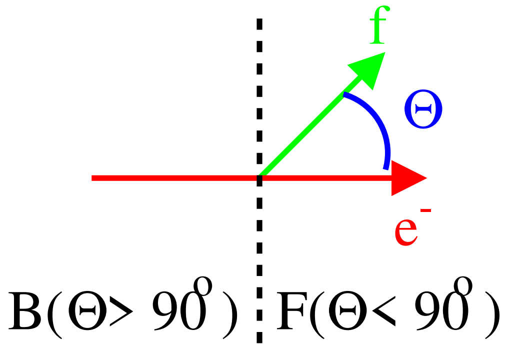
Fermion Pair Production

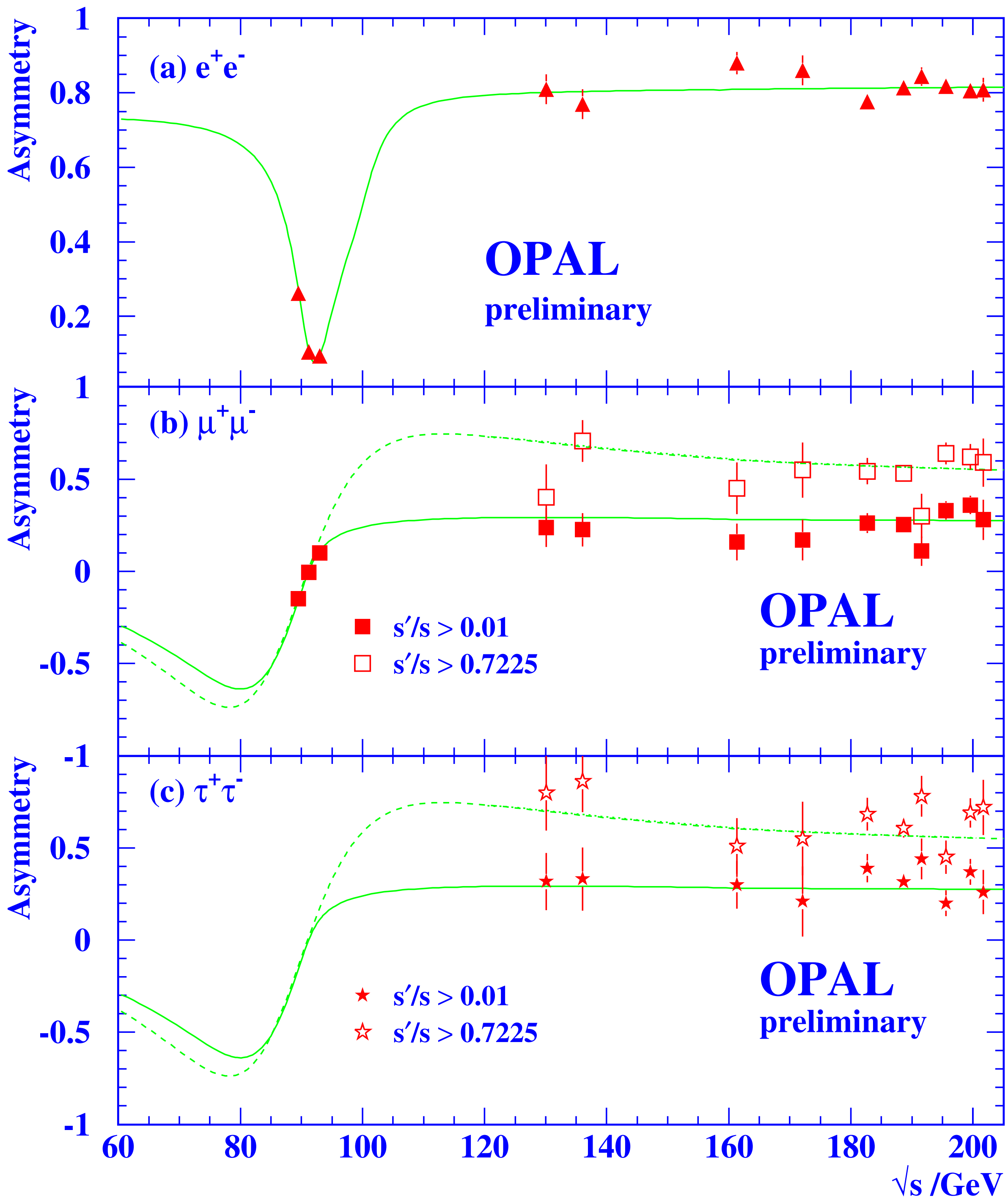




Lepton-Pair Asymmetry

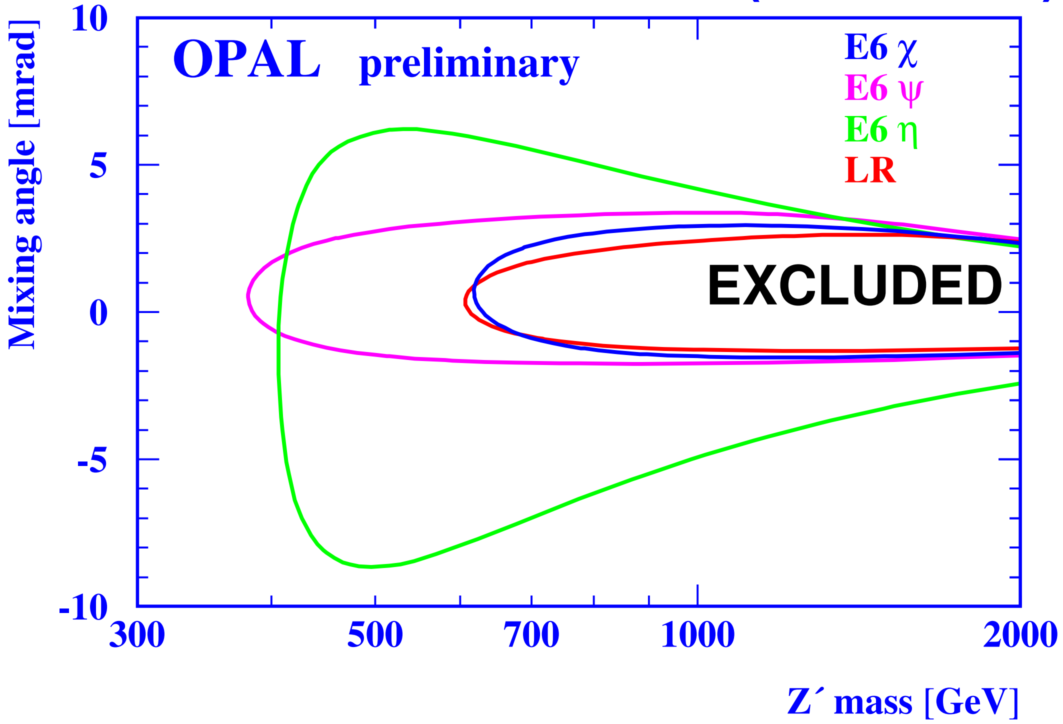
$$A_{FB} = (\sigma_F - \sigma_B) / (\sigma_F + \sigma_B)$$





Constraints on the Z'

- **Use LEP1 and LEP2 cross-sections and asymmetries**
- **95% c.l. exclusion limits (OPAL 1999)**



for the first time competitive

Model:	χ	ψ	η	LR
$\mathrm{M_{Z'}^{low}(GeV)}$	676	424	438	684
$\theta_{\mathrm{M}}^{\mathrm{up}}(\mathrm{mrad})$	2.48	2.84	4.92	2.21
$\theta_{\mathrm{M}}^{\mathrm{low}}(\mathrm{mrad})$	-1.15	-1.28	-7.23	-0.97
$\mathrm{M_{Z',CDF}^{low}(GeV)}$	595	590	620	630

- **Mass limits increased by 15-60% wrt 1989 data**
- **Erler and Langacker (hep-ph/9910315):**
  - ▷ latest peak cross sec $\sigma_{had}^{\mathrm{LEP1}}$ ($\Rightarrow \mathrm{N}_\nu = 2.9835 \pm 0.0083$)
  - ▷ effective weak charge $Q_W(Cs)$ in APV ($\Rightarrow$ 2.3 σ below SM)

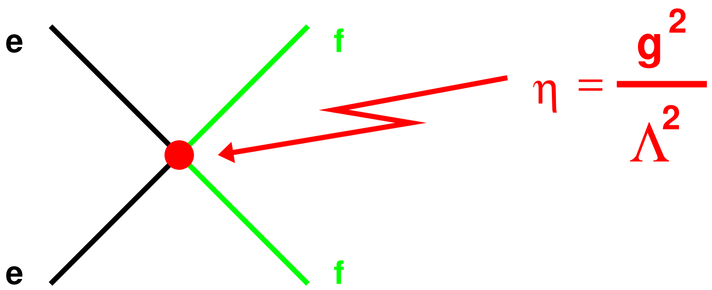
χ-model as example

$$\mathrm{M_{Z'}} = 812^{+339}_{-152}\mathrm{GeV}, \mathrm{M_H} = 145^{+103}_{-61}\mathrm{GeV}$$

$$\sin\Theta = (-1.12 \pm 0.80) \times 10^{-3}$$

Limits on Contact Interactions

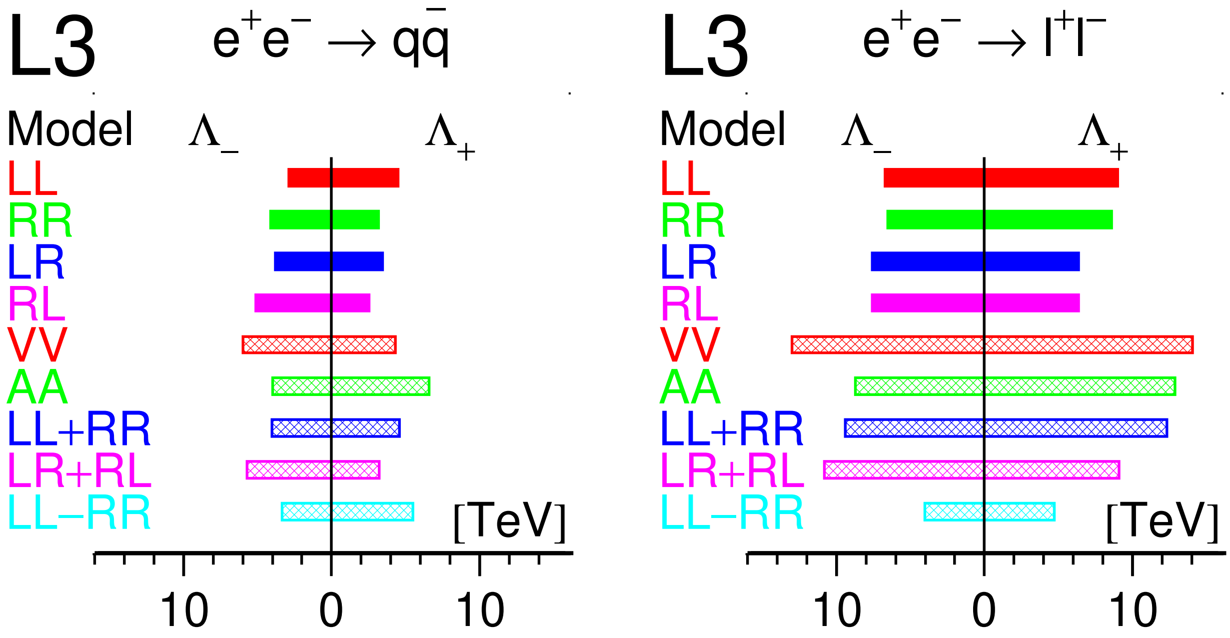
- New interaction at an energy scale Λ ($\Lambda \gg \sqrt{s}$) can be described by four-fermion contact interaction.



$$\frac{g^2}{4\pi} = 1$$

by convention

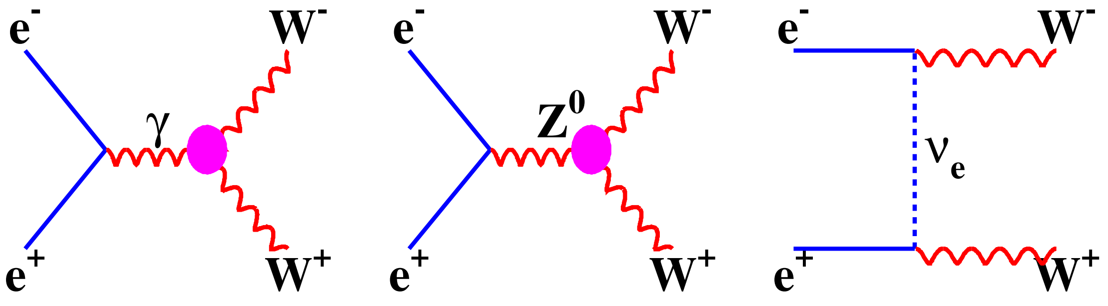
- Use LEP1+2 cross-sections and asymmetries
- 95% c.l. exclusion limits

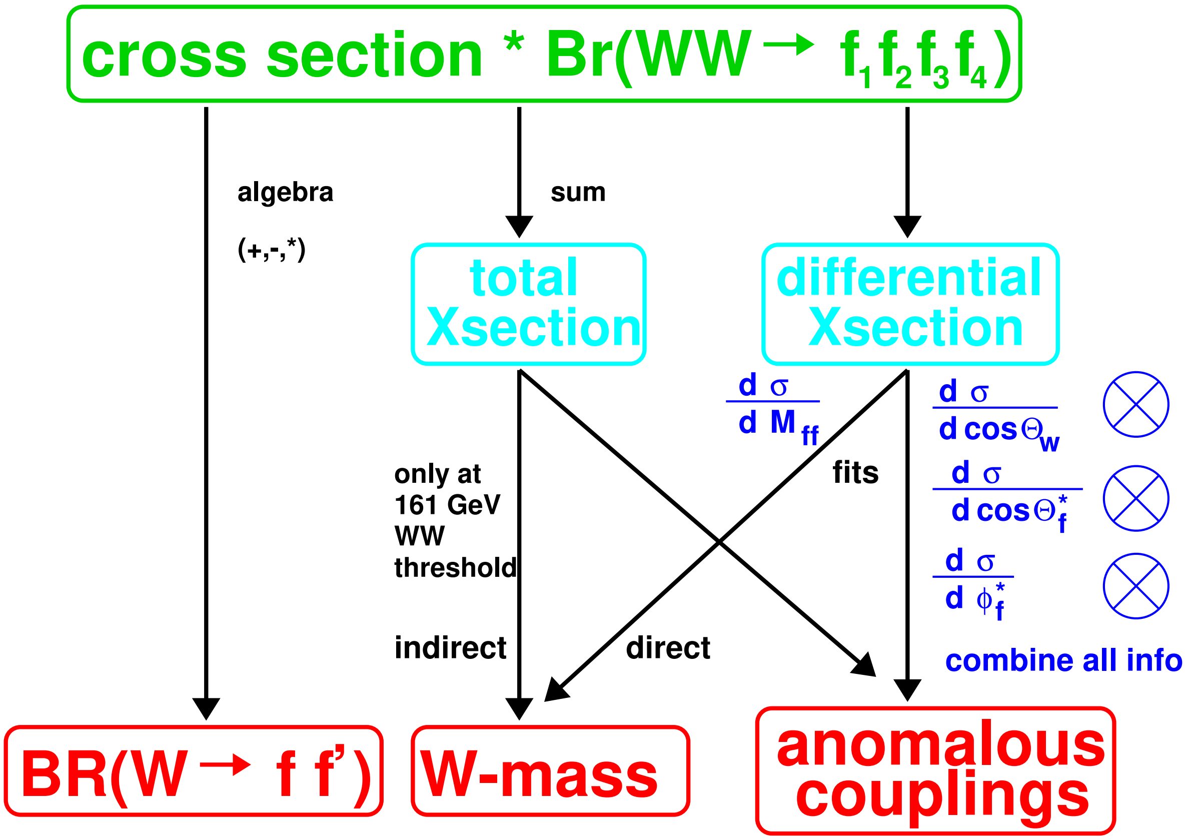


▷ Sensitivity increased by 20 to 30% in leptonic channels wrt 189 GeV data.

▷ 95 % CL limits in 5 - 15 TeV range

WW Cross-Section



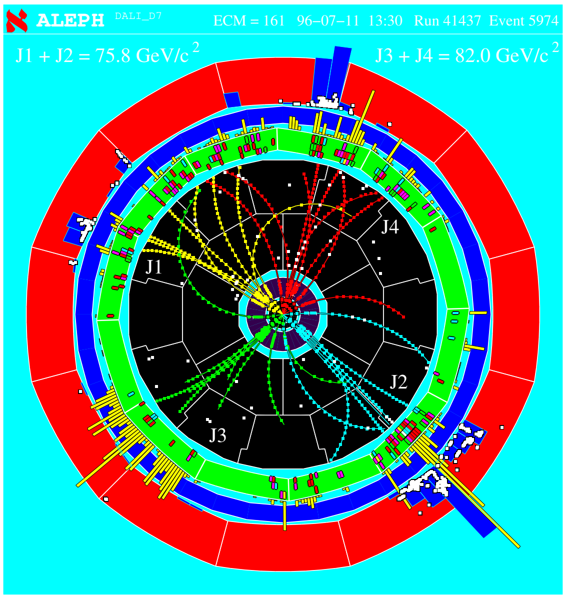


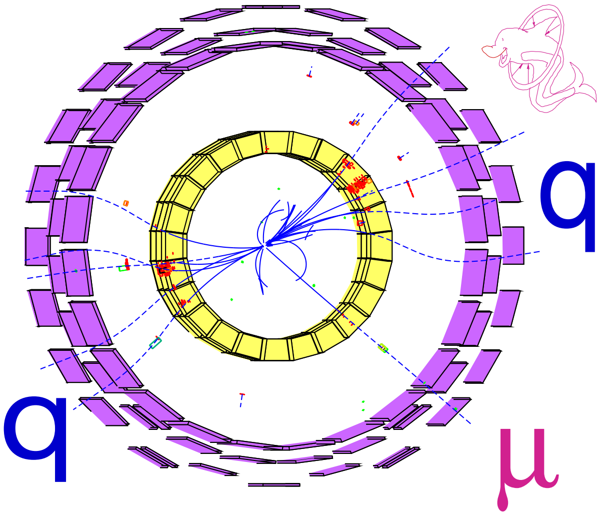
SM prediction:

- $BR(WW \rightarrow q\bar{q}q\bar{q}) = 46\%$
- $BR(WW \rightarrow q\bar{q}l\bar{\nu}) = 44\%$
- $BR(WW \rightarrow l\bar{\nu}l\bar{\nu}) = 10\%$

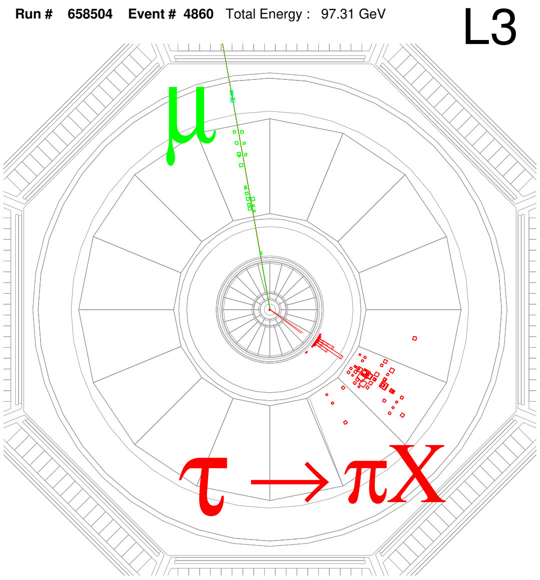
WW Event Topology

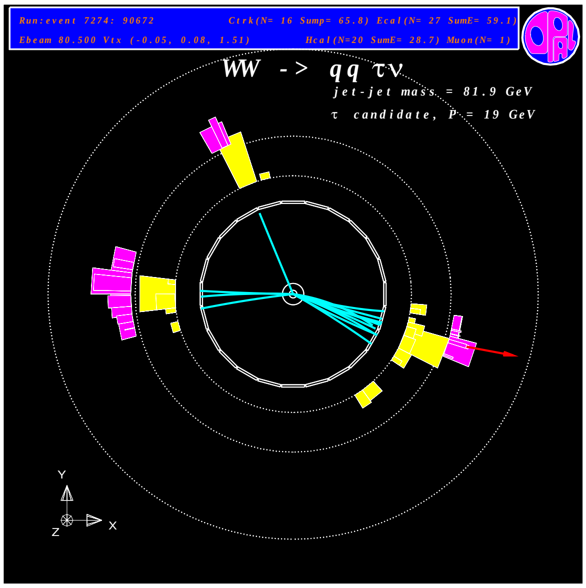
- $W^+W^- \longrightarrow q\bar{q}q\bar{q}$
- $W^+W^- \longrightarrow q\bar{q}l\nu_l$





- $W^+W^- \longrightarrow l\nu_l l'\nu_{l'}$
- $W^+W^- \longrightarrow q\bar{q}\tau\nu_\tau$



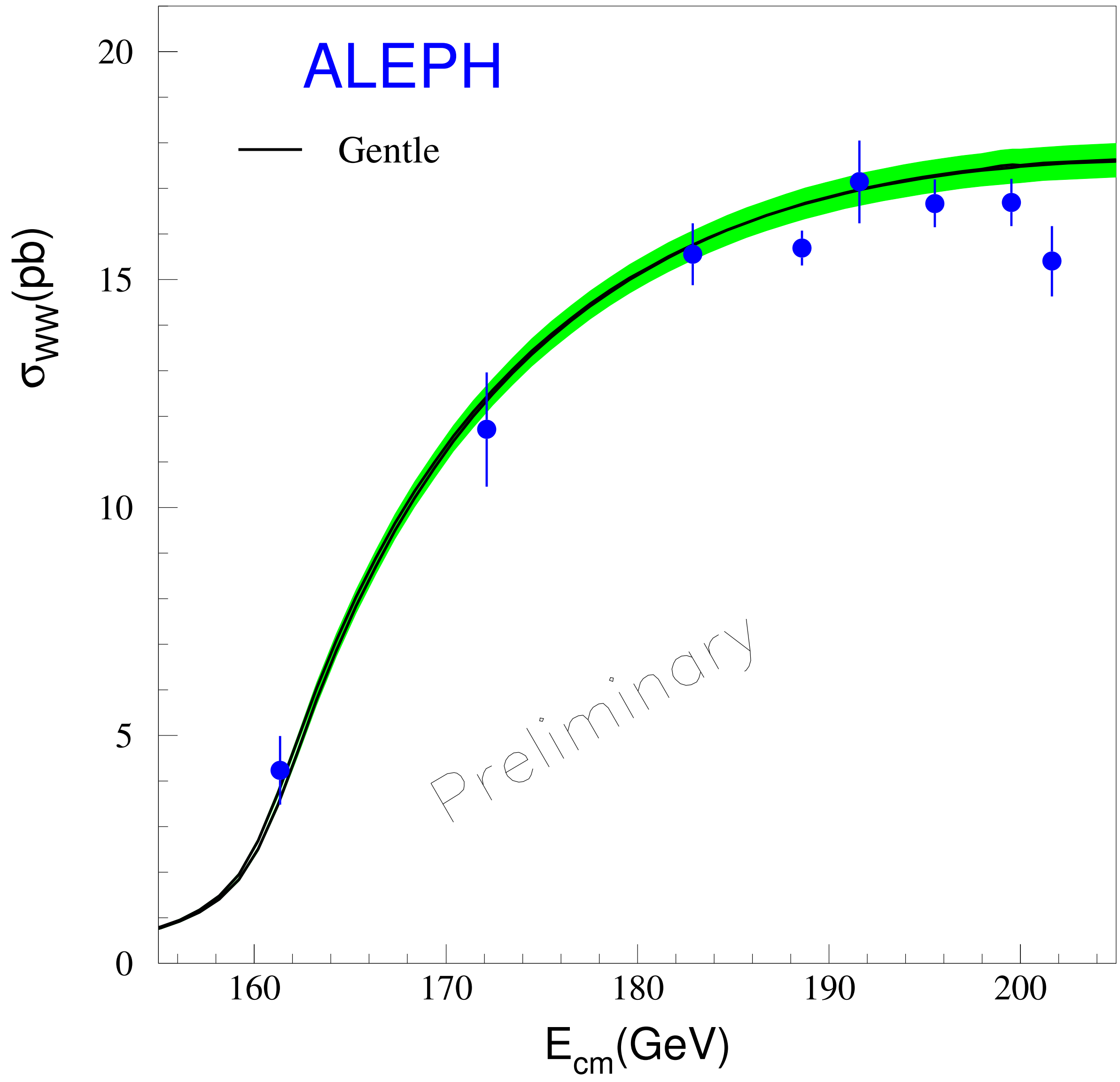


OPAL:

$\sqrt{s}$ (GeV)	$\int \mathcal{L}$ (pb^{-1})	nr.events	ϵ (%)	purity (%)
192 - 202	176	3018	$\sim$ 85 - 87	$\sim$ 85 - 86

▷ **all decay modes accessible !**

WW Cross Section

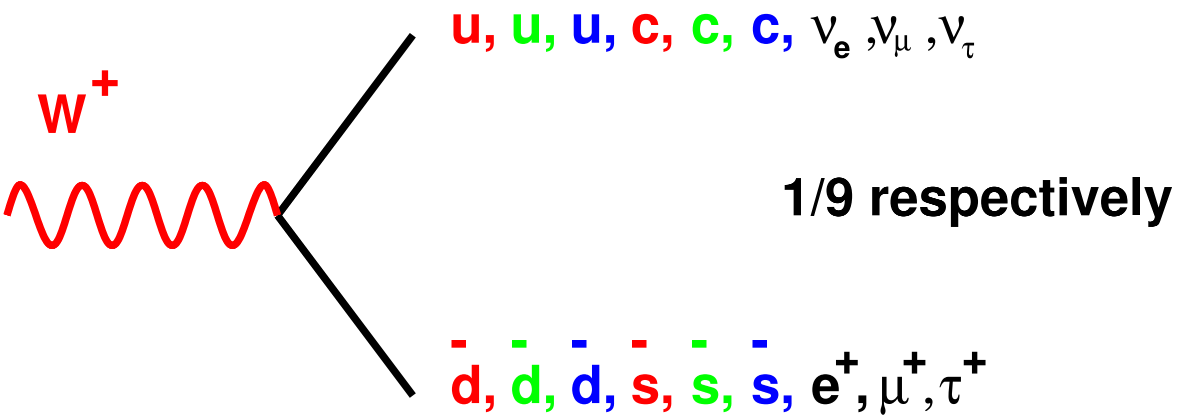


- **cross-section reasonably well described by theory (GENTLE)**

  ▷ **(Indirect: $\mathrm{M_W^{LEP}} = 80.40 \pm 0.20$ GeV)**

WW Branching Ratios

- **W-decays:**



1/9 = 11.11%

with small α_s correction in SM: 10.83 %

- **First time all BR's measured directly**

ALEPH (all LEP-II data)			SM
$Br(W \rightarrow e\nu)$	=	$(11.29 \pm 0.33 \pm 0.25)\%$	
$Br(W \rightarrow \mu\nu)$	=	$(10.95 \pm 0.31 \pm 0.25)\%$	10.83%
$Br(W \rightarrow \tau\nu)$	=	$(10.70 \pm 0.39 \pm 0.25)\%$	
$Br(W \rightarrow qq')$	=	$(67.06 \pm 0.47 \pm 0.50)\%$	67.5%

- $\mathrm{N_c} = 3$ **QCD colours independently confirmed**

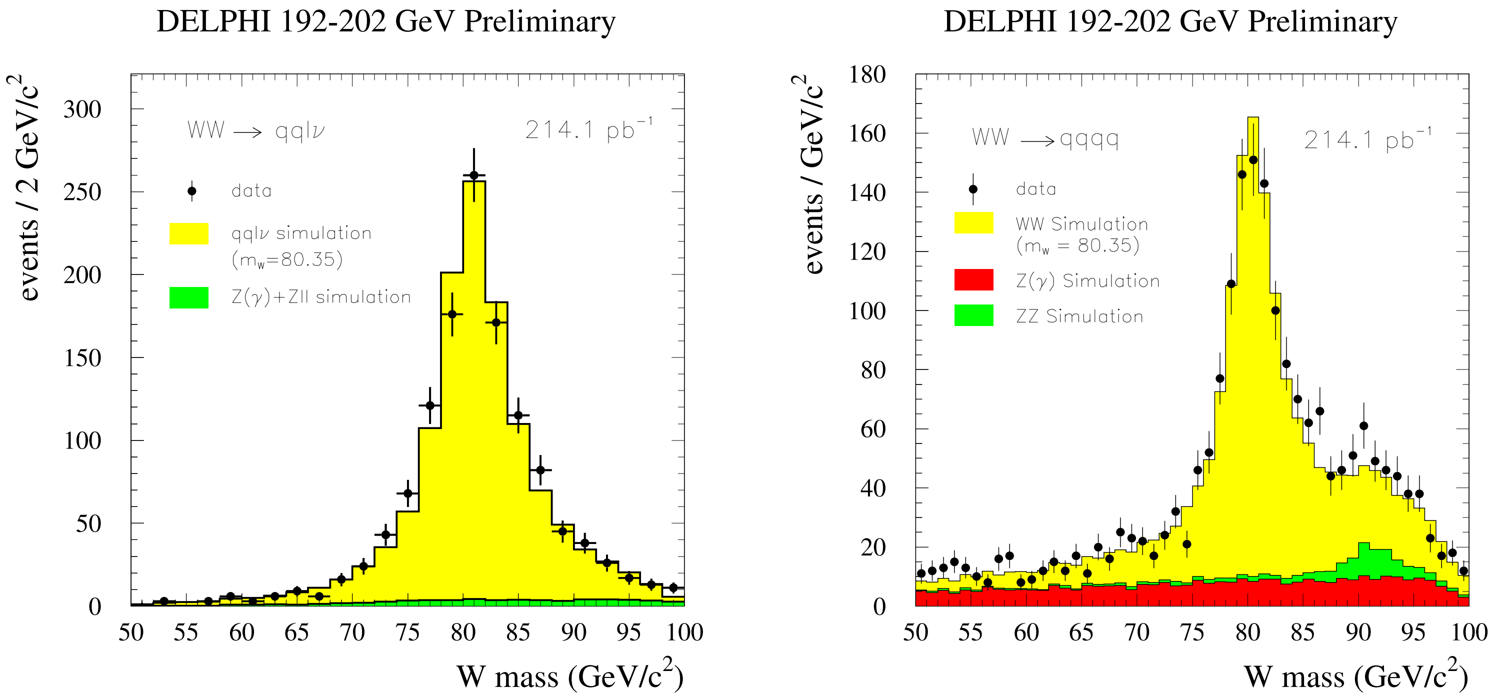
W Mass Measurement

- $\mathrm{WW} \longrightarrow \mathrm{q\bar{q}q\bar{q}}$ and $\mathrm{WW} \longrightarrow \mathrm{q\bar{q}l}\nu$

- qqqq channel:
  Good mass resolution ($\sim$ 1 GeV) comes from
  kinematic fit :
  Constrain total (E, p) to $(\sqrt{s}, 0)$, $\mathrm{M_{W_1}} = \mathrm{M_{W_2}}$
  $\longrightarrow$ need $\mathrm{E_{beam}}$ from LEP

- $\mathrm{qql}\nu$ channel:
  kinematic fit without neutrino momentum
  for qq$\tau\nu$ require $\mathrm{E_{qq}} = \mathrm{E_{beam}}$
  $\longrightarrow$ mass resolution $\sim$ 3 GeV

First look into new data ...



... but real challenge control of systematics :

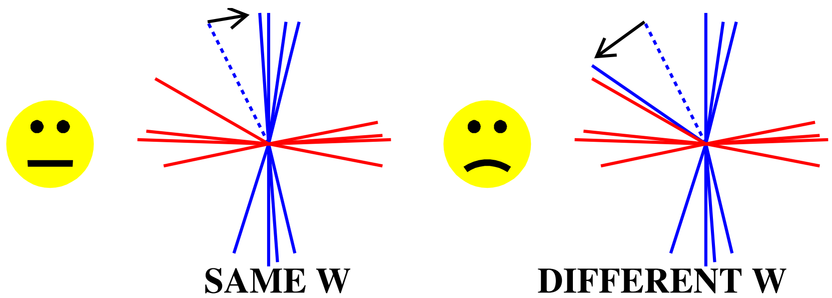
W Mass Uncertainties in $q\bar{q}q\bar{q}$

Bose-Einstein Correlations

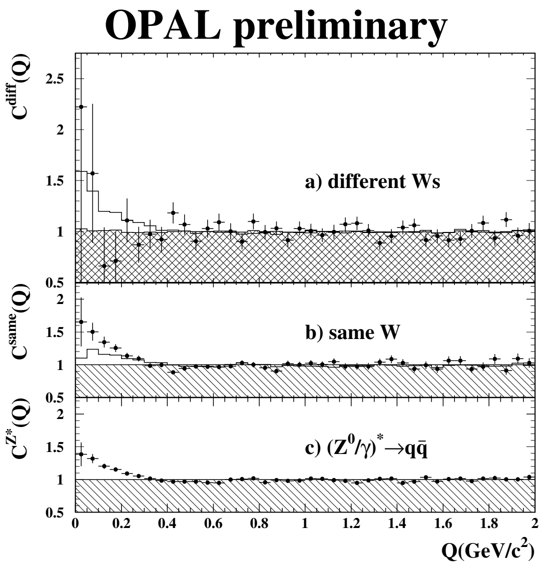
▷ BEC - Quantum mechanical effect

▷ Like-sign pions tend to be produced close in phase space.

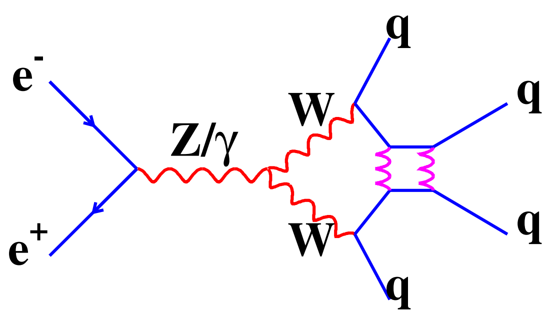
▷ BEC between pions from different W's ?



▷ Estimate effect from data ($q\bar{q}q\bar{q} \leftrightarrow q\bar{q}l\nu \leftrightarrow q\bar{q}$).



Colour Reconnection



▷ Also here estimate effect from data ($q\bar{q}q\bar{q} \leftrightarrow q\bar{q}l\nu$).

▷ Suppressed by 2 gluon exchange & colour

Hadronization Phase (non-pert.)

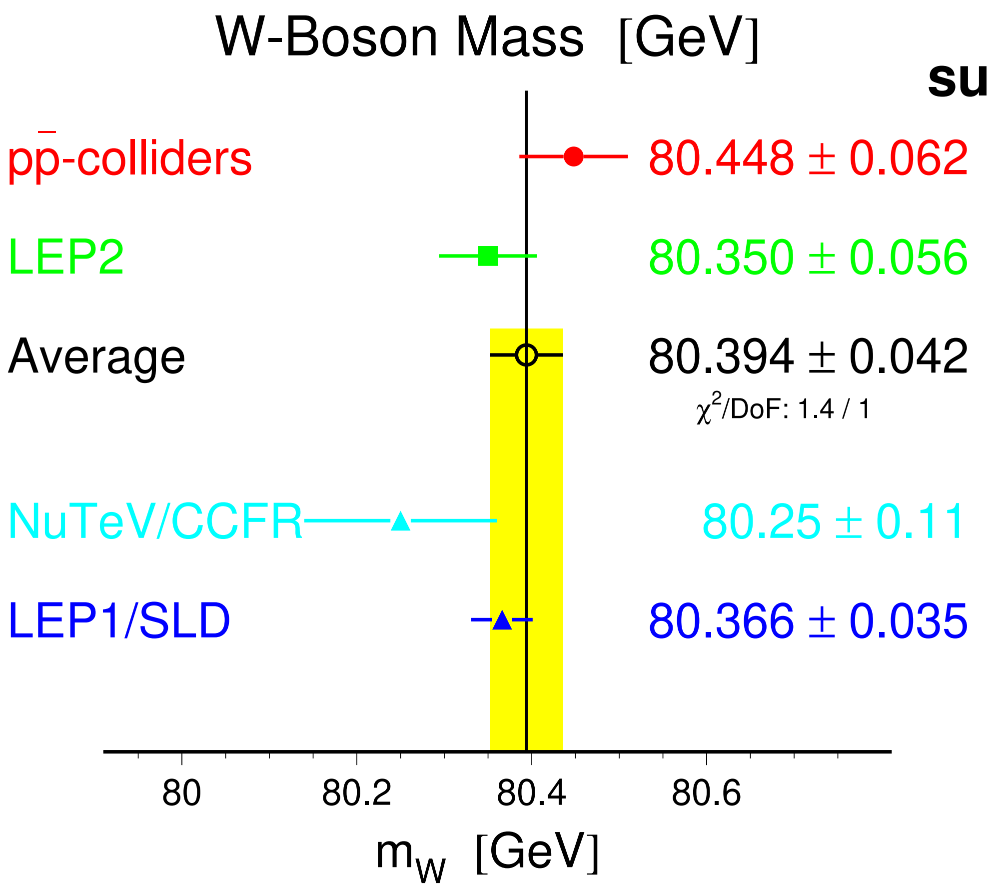
▷ W decay (< 0.1 fm); hadronisation ~ 1 fm

$\Rightarrow$ non-independent fragmentation ? Compare MCs.

W Mass Uncertainties (cont'd)

- **Typical Uncertainties (LEP combined) :**

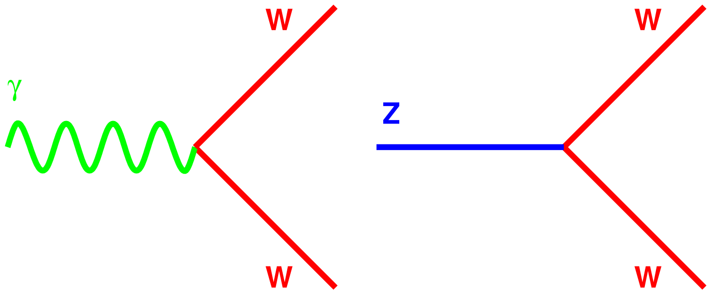
Source	$\Delta M_W^{\leq 189}$ (MeV)	ΔM_W^{LEPII} (MeV)
Statistical	35	20
Detector calibration	30	$\ll$ statistical
QCD background	10	~ 0
MC statistics	10	~ 0
Hadronization	30	< 10
Initial state radiation	10	< 10
Beam energy	20	10
Final State Interactions	50	< 50
Total	56	??? ($\ll 56$)



status: summer 1999

Triple Gauge Couplings

General $WW\gamma$ and WWZ interaction: 14 parameters



Apply C and P invariance
& use low-energy constraints
$\longrightarrow$ 3 parameters

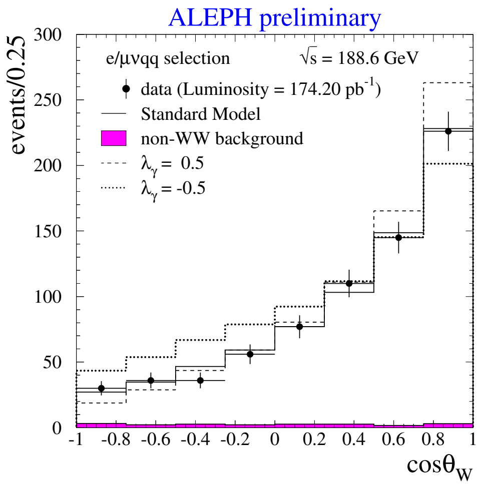
Conventionally κ_γ, g_1^Z and λ_γ, (1,1,0) in SM

$$\mu_W = (e/2M_W)(1 + \kappa_\gamma + \lambda_\gamma),\ q_W = (e/M_W^2)(\lambda_\gamma - \kappa_\gamma)$$

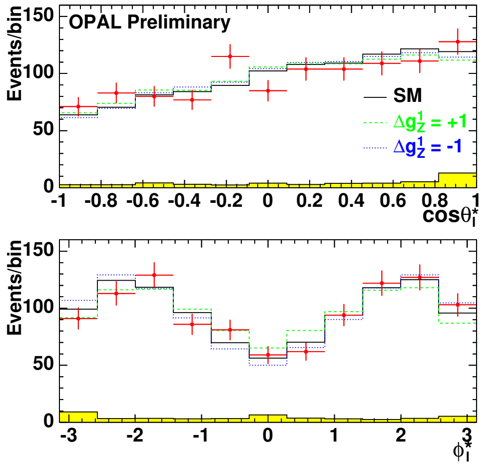
Study effects on:

- ▷ total WW cross-section
- ▷ angular distribution of W^- production
- ▷ helicity mixture of W's via $W \longrightarrow f$ decay angles

W production angle



W decay angles



One-parameter fits (LEP combined preliminary)

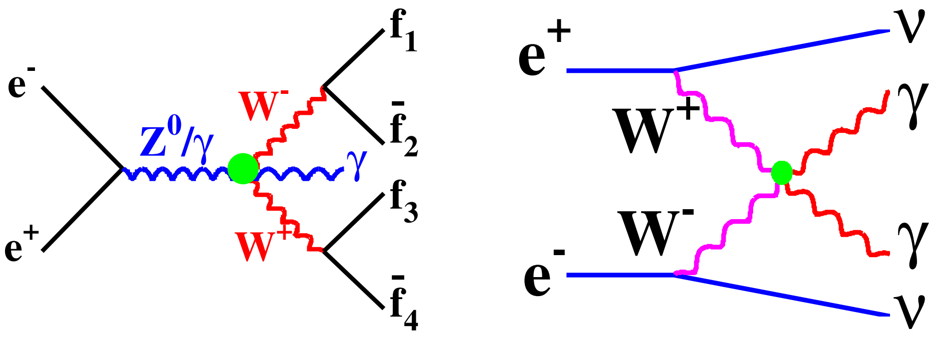
κ_γ	=	1.04 $\pm$ 0.08
g_1^Z	=	0.99 $\pm$ 0.03
λ_γ	=	-0.04 $\pm$ 0.04

Interpretation as W_L/W_T production

f(W_L in $e^+e^- \longrightarrow W^+W^-$) =

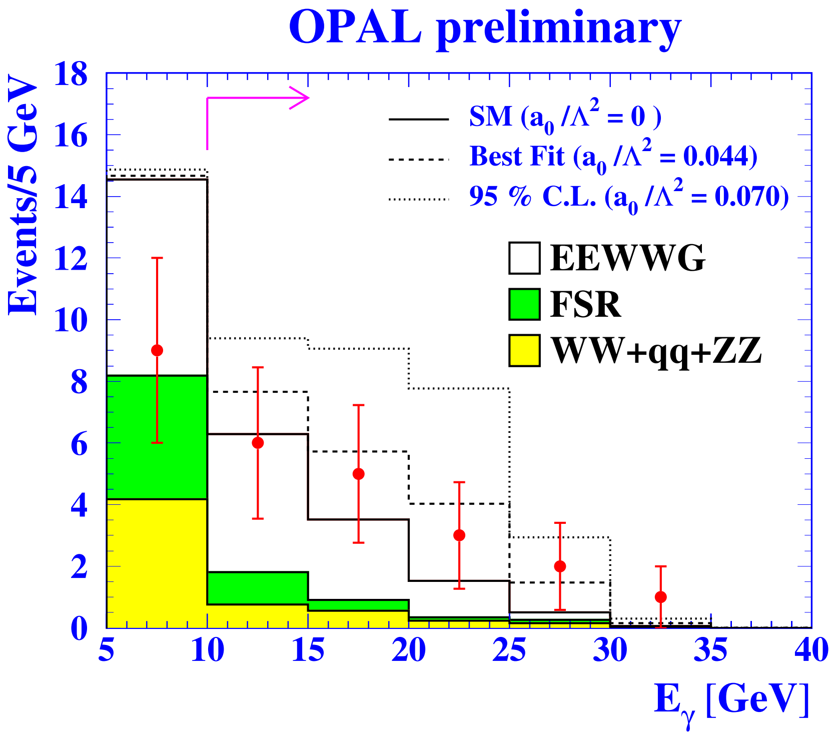
24.4 $\pm$ 4.8 $\pm$ 3 %	L3 at 189 GeV
26 %	SM

Anomalous Quartic Gauge Couplings



Couplings exist in SM, but small

- Select 17 $W^+W^-\gamma$ events with large $E_\gamma > $ 10 GeV from 189 GeV data.

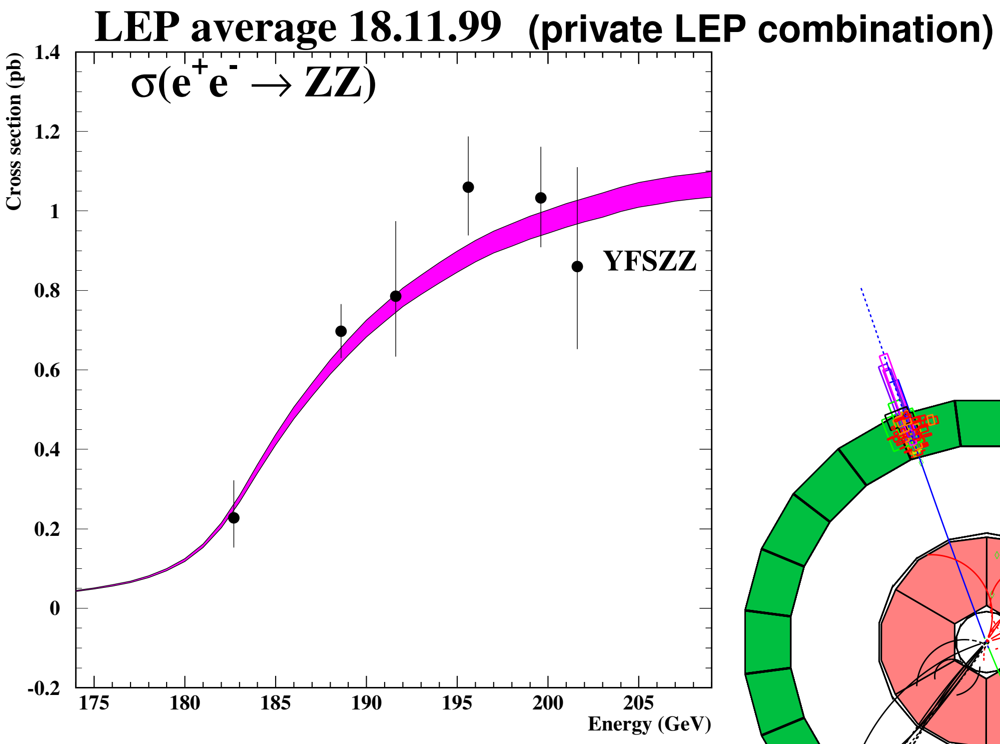


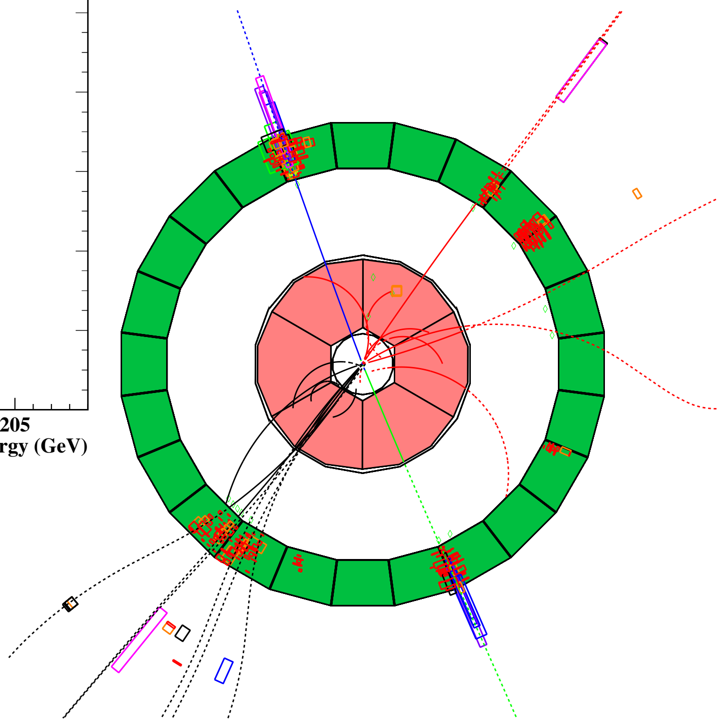
- Combined limits from $W^+W^-\gamma$ and $\gamma\gamma\nu\nu$ on anomalous QGC's a_o, a_c and a_n (Λ new physics scale)

$$
\begin{aligned}
-0.065\,\mathrm{GeV}^{-2} < \quad & a_0/\Lambda^2 \quad < 0.065\,\mathrm{GeV}^{-2}, \\
-0.13\,\mathrm{GeV}^{-2} < \quad & a_c/\Lambda^2 \quad < 0.17\,\mathrm{GeV}^{-2}, \\
-0.61\,\mathrm{GeV}^{-2} < \quad & a_n/\Lambda^2 \quad < 0.57\,\mathrm{GeV}^{-2}
\end{aligned}
$$

- First DIRECT limits

ZZ Cross Section



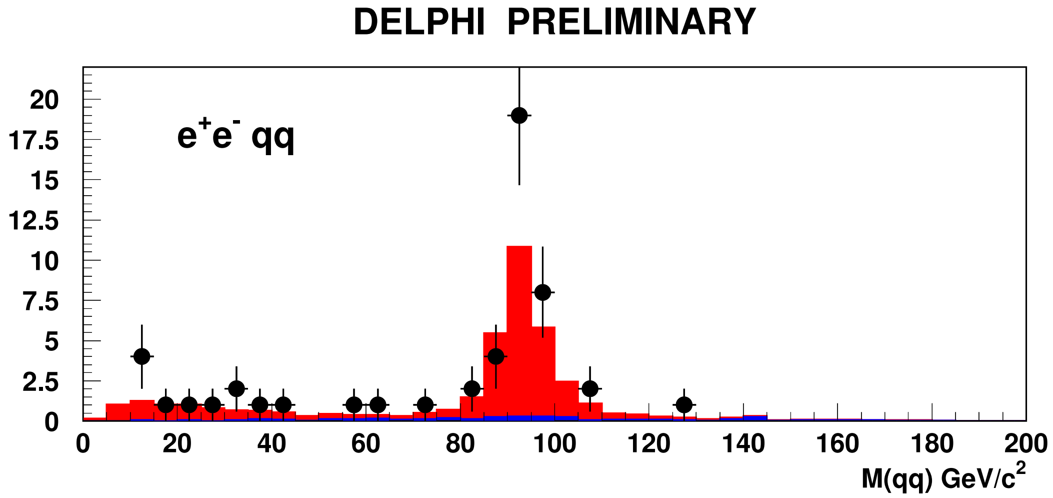


- **Observed events for $\sqrt{s} > 190$ GeV (OPAL):**

final state	observed	expected
$l^+l^-l^+l^-$	1	1.6
$q\bar{q}l^+l^-$	25	15.7
$q\bar{q}\nu\bar{\nu}$	23	23.4
$q\bar{q}q\bar{q}$	92	81
total	141	122

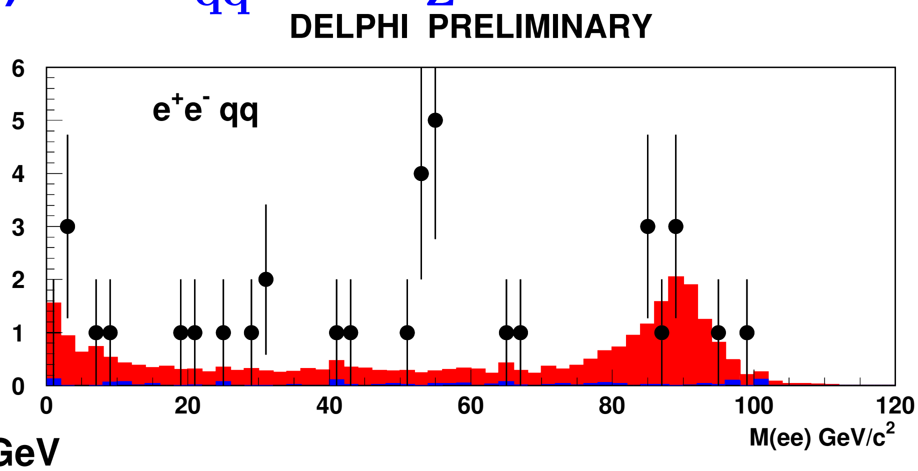
llqq Events

- **DELPHI mass spectrum from 400 pb^{-1} collected at LEP2**



excess in M(qq) of e^+e^-qq channel around $\mathrm{M_{qq}} \sim \mathrm{M_Z}$

look into M(ee) for $\mathrm{M_{qq}} \sim \mathrm{M_Z}$:

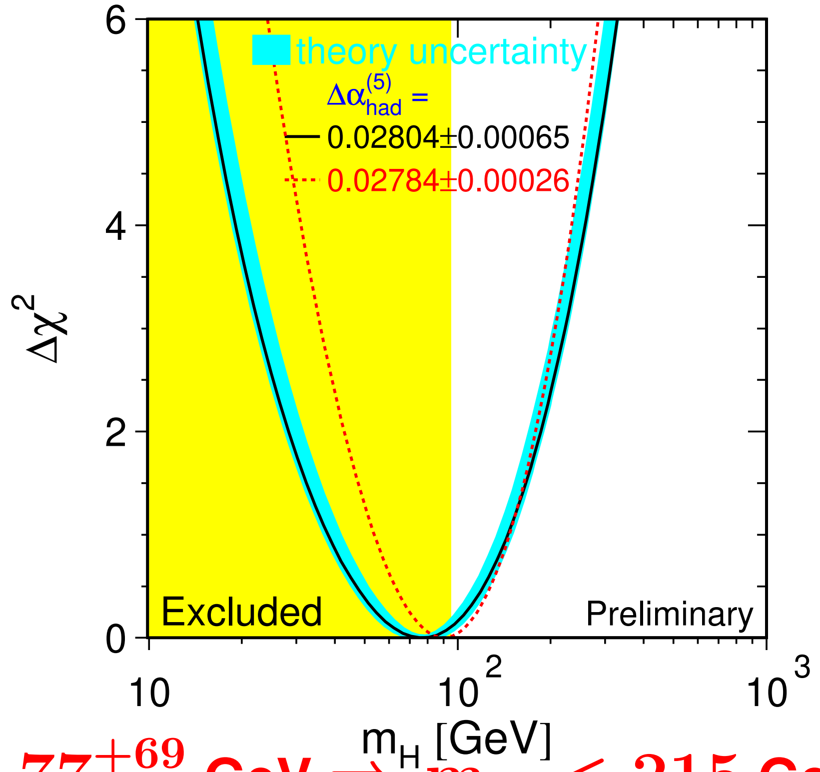


- **resol. in M(ee) ~ 1.7 GeV**
- **10 events in 50-56 GeV observed**
- **0.79 $\pm$ 0.06 events expected**

Angular distribution and charge asymmetry SM-like.
Work and cross checks in other experiments ongoing.
$\mu^+\mu^-$qq channel looks ok.

Search for the SM Higgs-Boson

- **Fit to electroweak data**

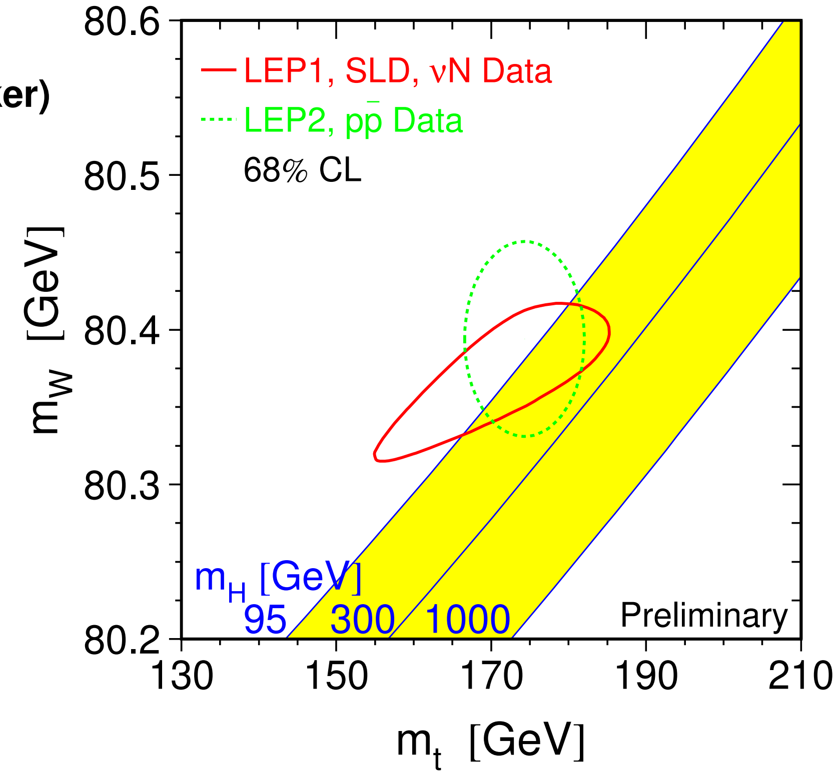


$$\mathbf{m_H = 77^{+69}_{-39}\ \text{GeV} \Rightarrow m_H < 215\ \text{GeV}}\ \text{(95\% CL)}$$

(LEP-EW with Eidelmann & Jegerlehner)

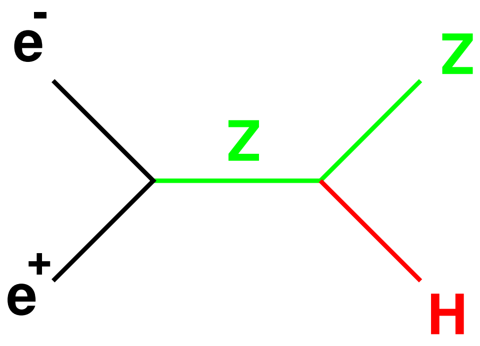
$$\mathbf{m_H = 92^{+57}_{-38}\ \text{GeV}}$$

(LEP-EW with Davier & Höcker)



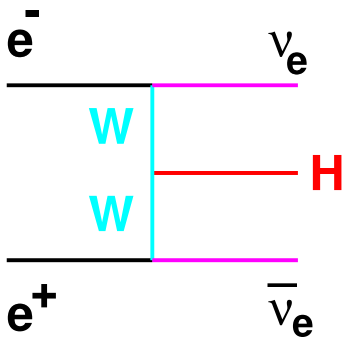
SM Higgs Production at LEP

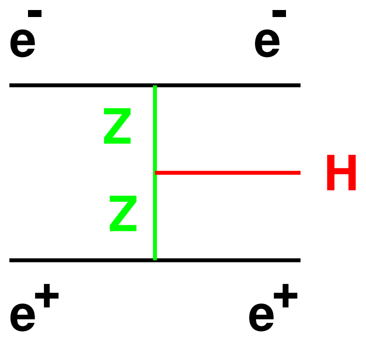
Higgs-Strahlung

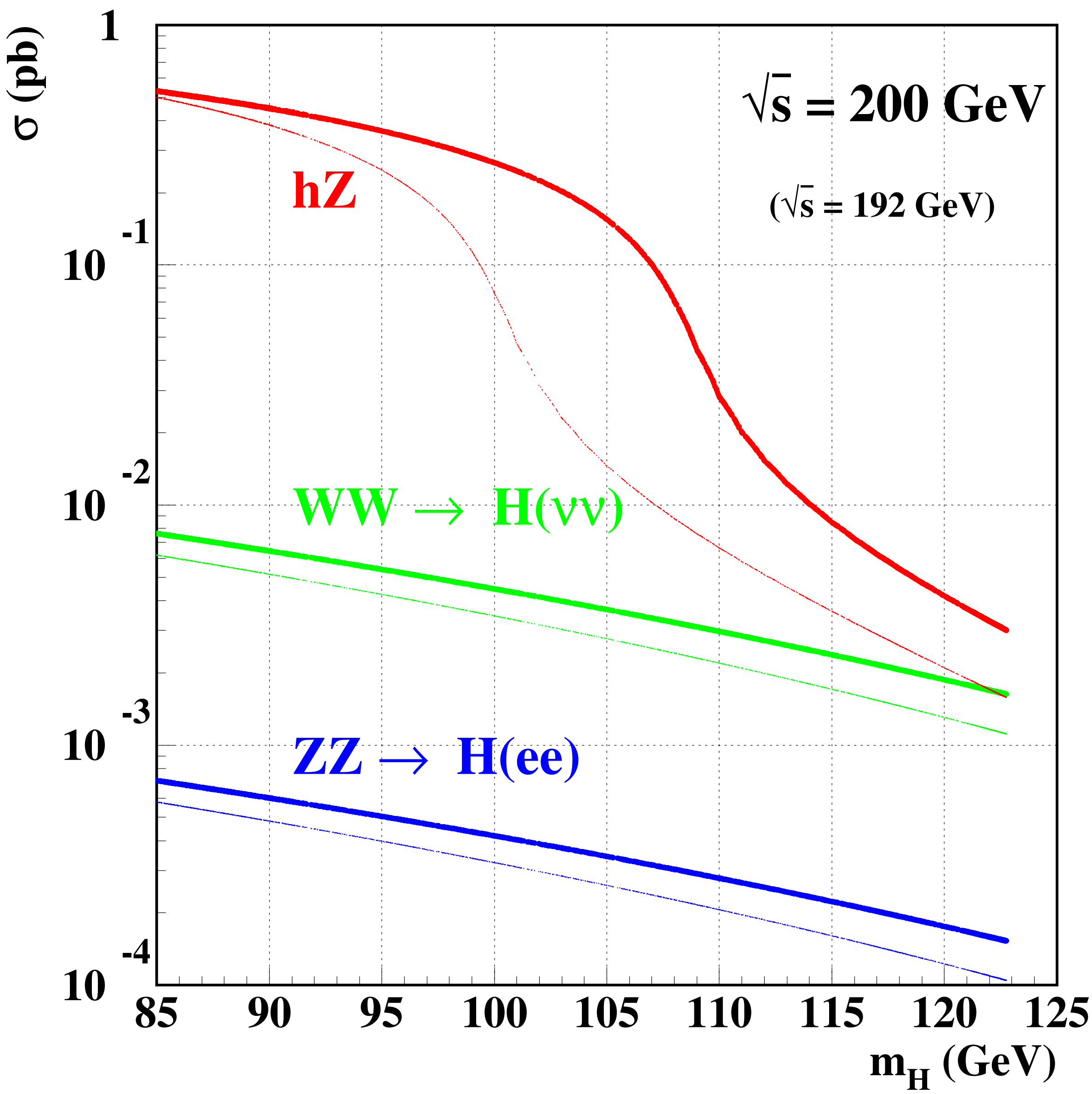


WW and ZZ fusion

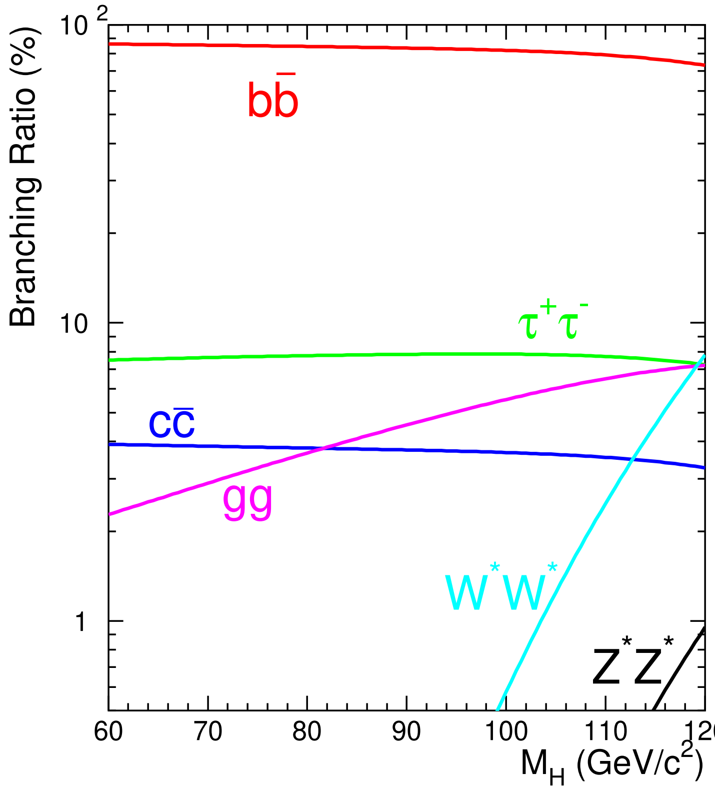
(small contribution)





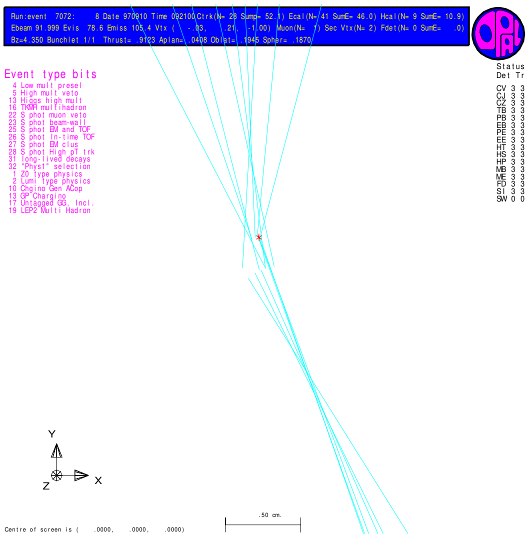


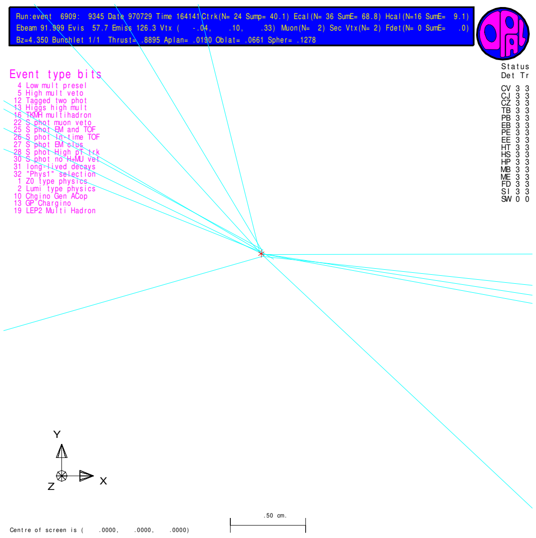
SM Higgs Decays to Bottom Quarks

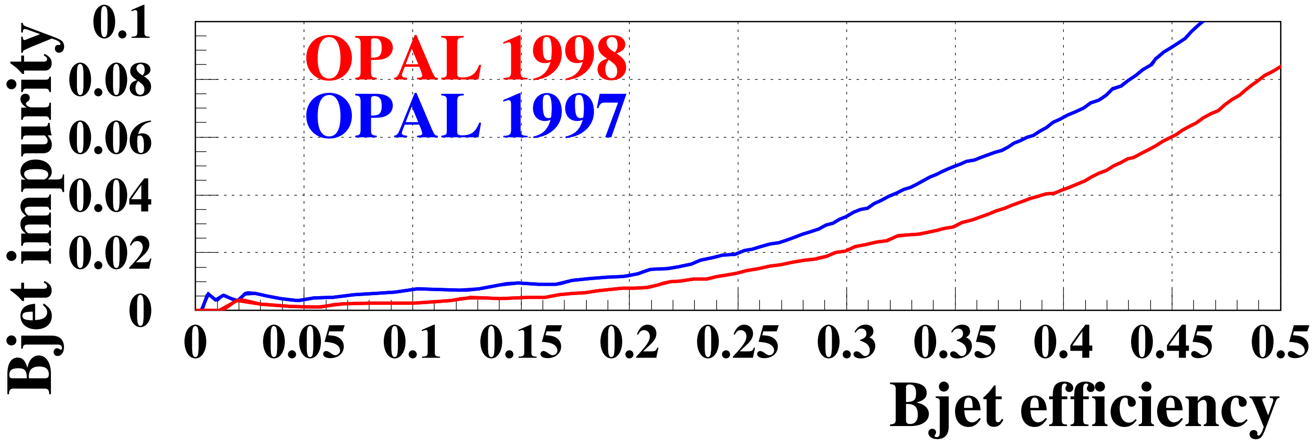


- **A SM Higgs boson decays $> 83\%$ to $\mathrm{b\bar{b}}$**
- **b-tag is essential to tag Higgs in the mass range accessible at LEP**

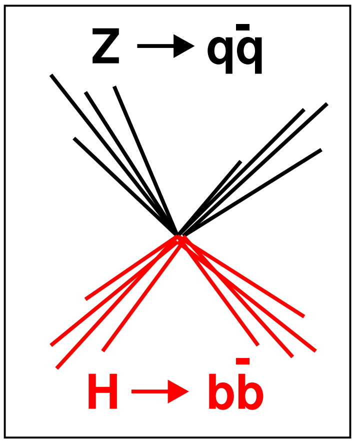
$$e^+e^- \rightarrow \mathrm{ZH} \rightarrow \nu\bar{\nu}\mathrm{b\bar{b}} \qquad e^+e^- \rightarrow \mathrm{ZZ} \rightarrow \nu\bar{\nu}\mathrm{q\bar{q}}$$



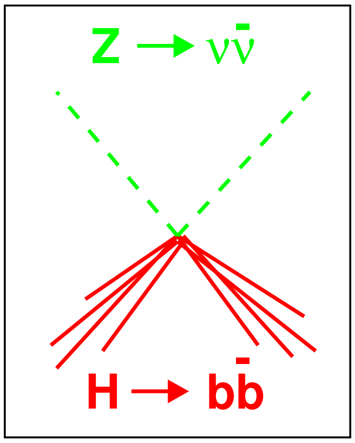




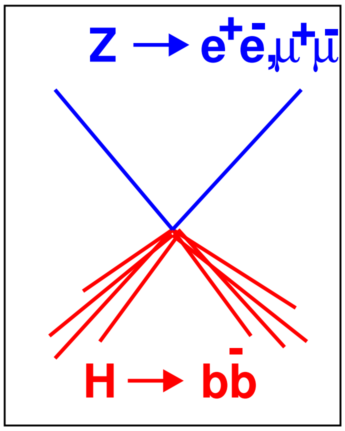
Higgs Search Topologies at LEP



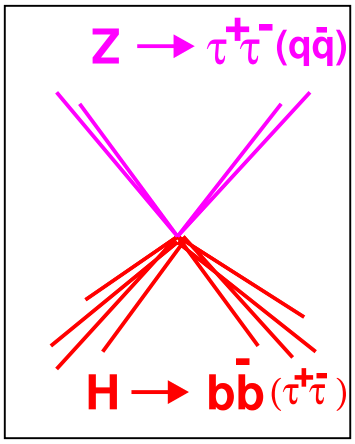
- **Four Jets :** (58% in SM)
  - ▷ Energy-momentum conservation
  - ▷ The 2 most probable b-tagged jets recoil against a di-jet compatible with a Z-boson
  - ▷ eff 40-50 %



- **Missing Energy :** (17% in SM)
  - ▷ The recoil mass of the 2 b-tagged jets is compatible with a Z-boson
  - ▷ eff 30-40 %

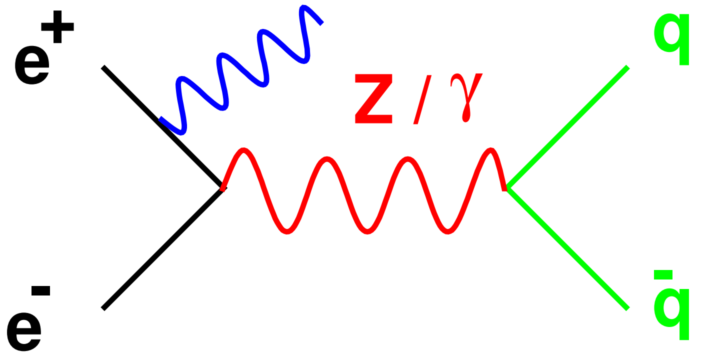


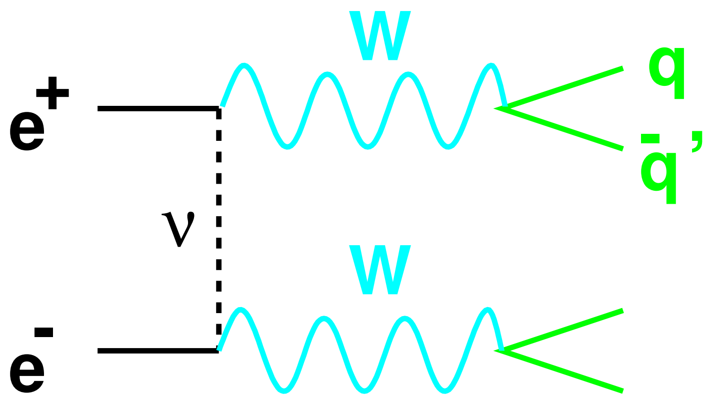
- **Leptons :** (6% in SM)
  - ▷ 2 high energetic leptons with a mass compatible with a Z-boson recoil against 2 jets
  - ▷ eff 50-60 %, clean channel

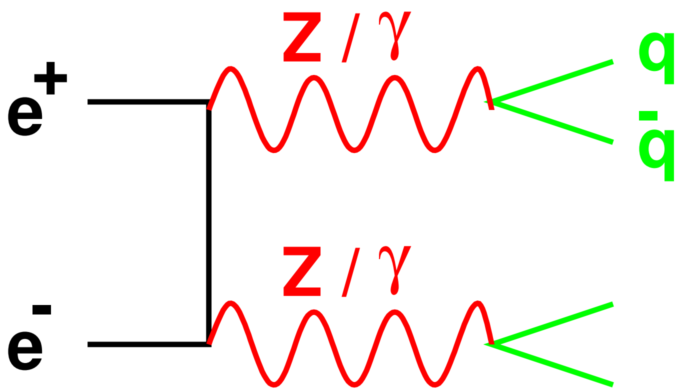


- **τ's :** (10% in SM)
  - ▷ 2 low multiplicity jets compatible with a Z-boson and 2 b-tagged jets
  - ▷ eff 35 %

Backgrounds: ZZ, WW & qq



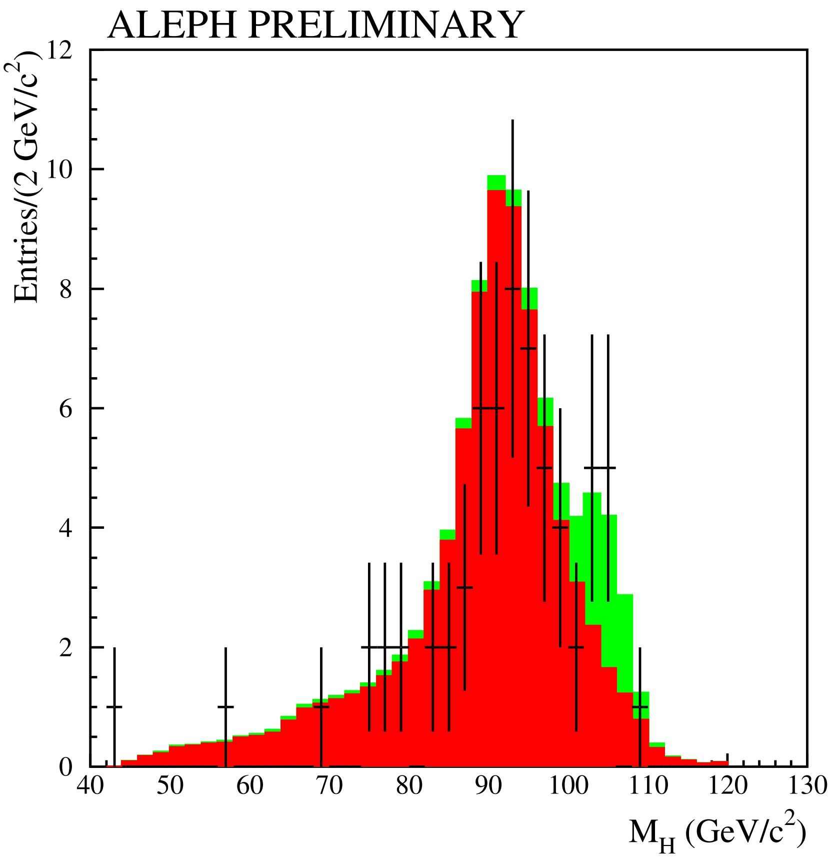




- **The most severe background is the Higgs-like irreducible ZZ production**

- **SM Higgs decays to b-quarks $>$ 83% of the time.**
  Only good b-tag will reduce ZZ and WW bgds

Latest ALEPH Results



Compare $\sim$ 237 pb^{-1} of data

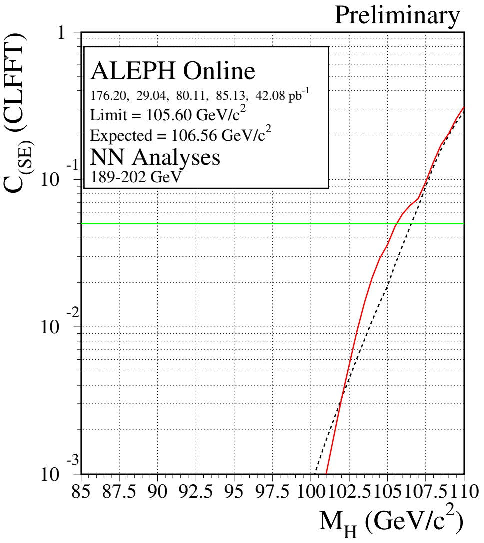
to signal ($m_H = 105$ GeV)

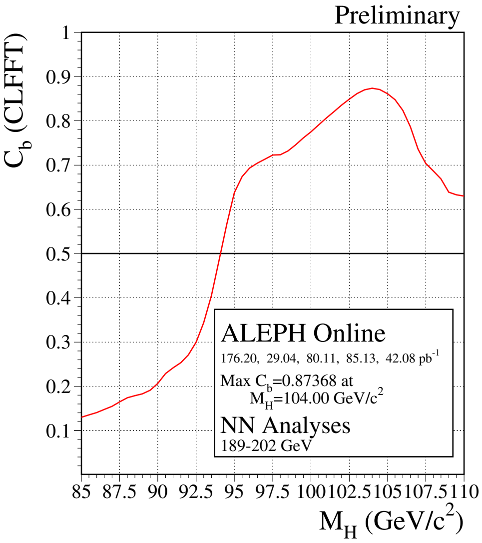
plus background

excess around 104 GeV is

1.15 σ effect

- **Mass plots can be misleading ! They add events**
  - ▷ with different $\sqrt{s}$
  - ▷ with different b-tagging quality
  - ▷ channel dependent mass resolution (always $>$ 3 GeV)





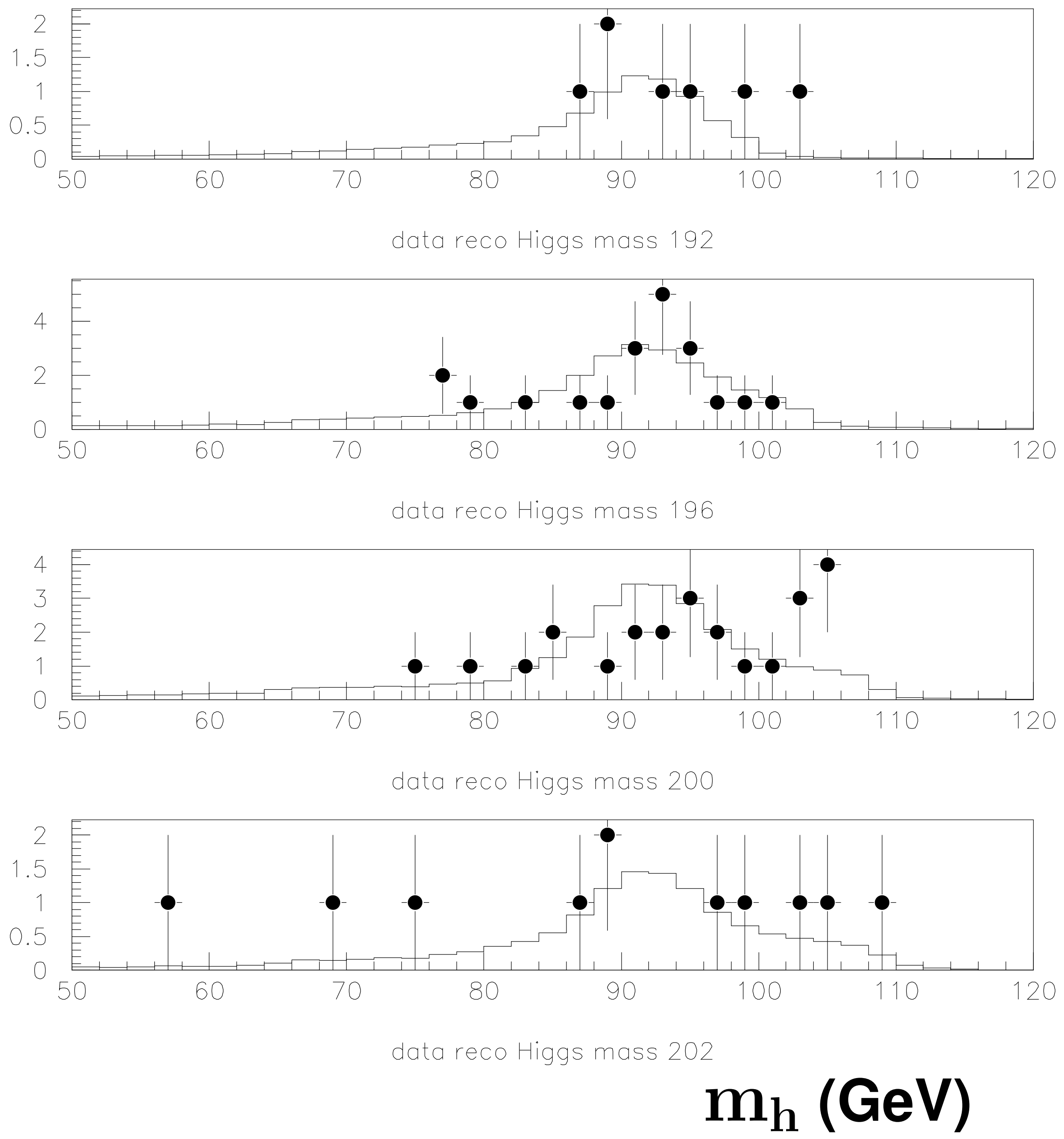
5 σ discovery

would be

1-$C_b < 6 \cdot 10^{-7}$

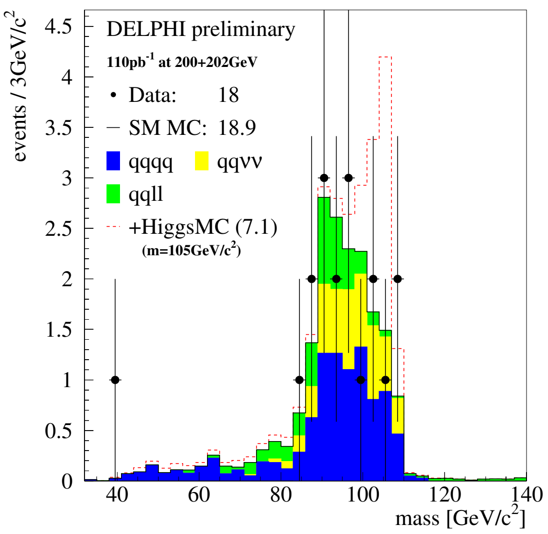
$m_H >$ **105.6 GeV (exp. = 106.5 GeV)** at 95% CL

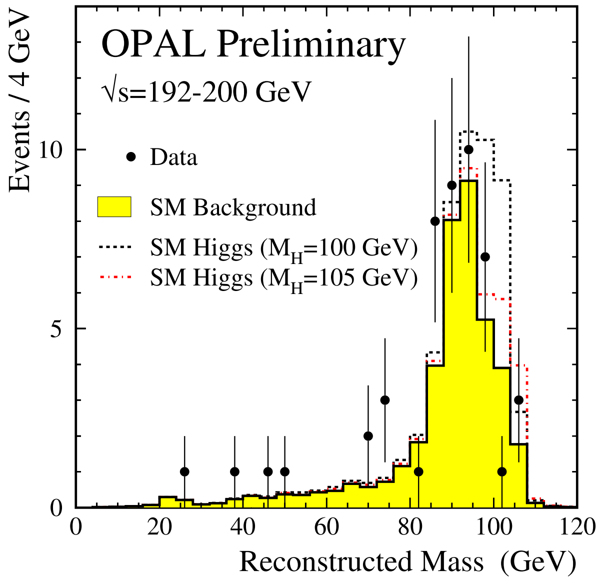
(Preliminary)


2
1.5
1
0.5
0
50 60 70 80 90 100 110 120
data reco Higgs mass 192
4
2
0
50 60 70 80 90 100 110 120
data reco Higgs mass 196
4
3
2
1
0
50 60 70 80 90 100 110 120
data reco Higgs mass 200
2
1.5
1
0.5
0
50 60 70 80 90 100 110 120
data reco Higgs mass 202
m_h (GeV)

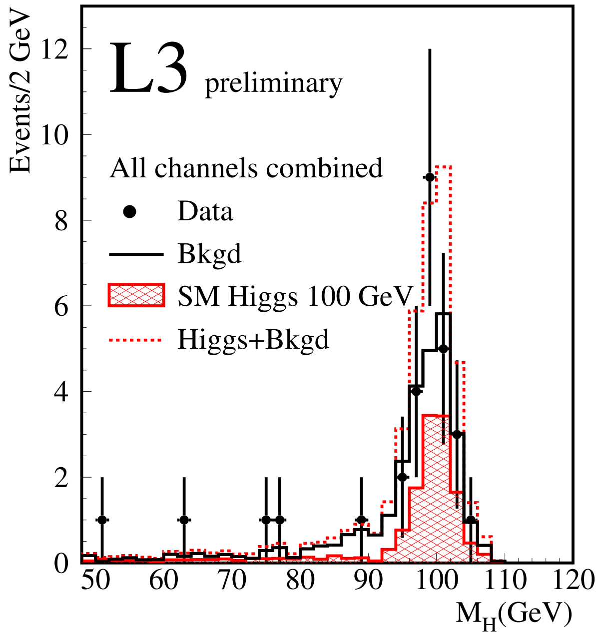
Latest DLO Results

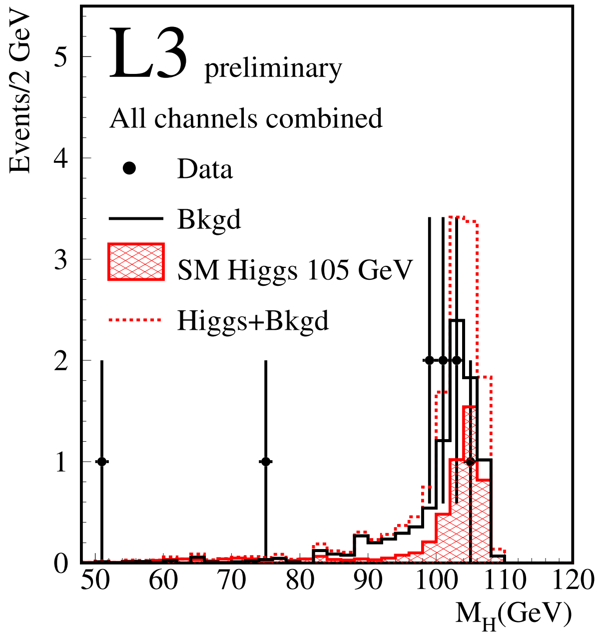
- Compare $\sim$ 115 (D), 220 (L) and 170 (O) pb^{-1} of data to SM-Higgs signal at 100 or 105 GeV





- For each Higgs mass hypothesis perform a different optimised analysis:





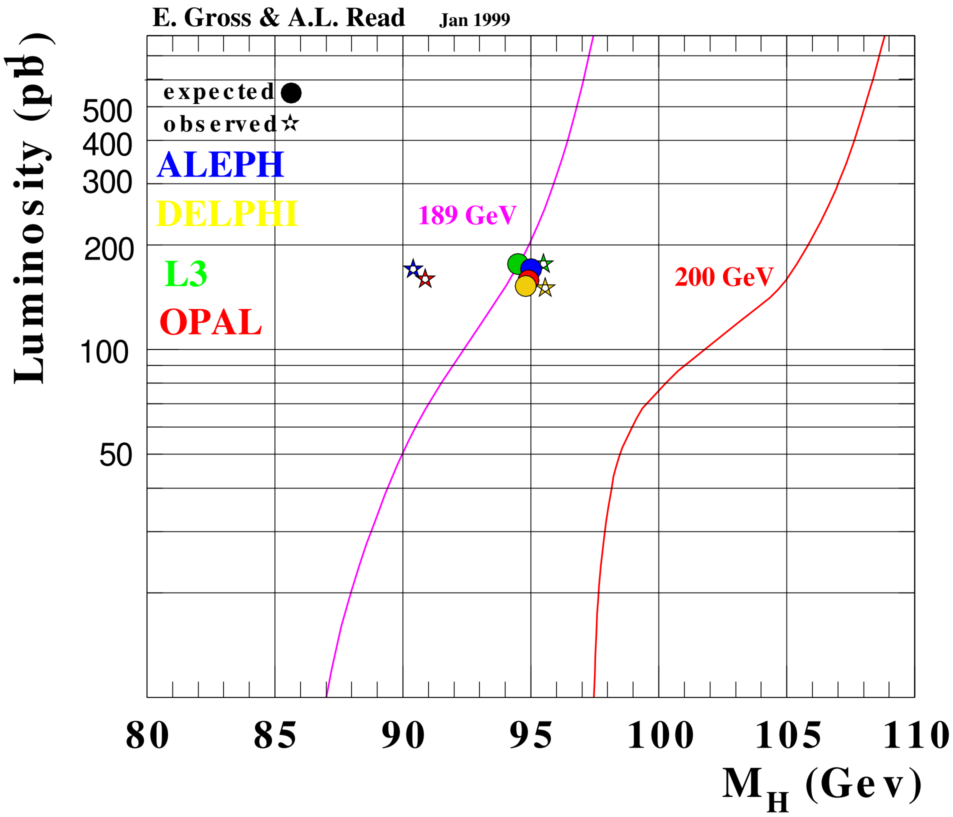
▷ ALEPH effect not confirmed but keep looking.

Not all data analysed yet ...

SM Higgs Reach at LEP

Experiment	observed limit	expected limit
ALEPH	105.6 GeV	106.5 GeV
DELPHI	106.2 GeV	105.2 GeV
L3	101.0 GeV	104.0 GeV
OPAL		
LEP^{196}	102.2 GeV	102.6 GeV

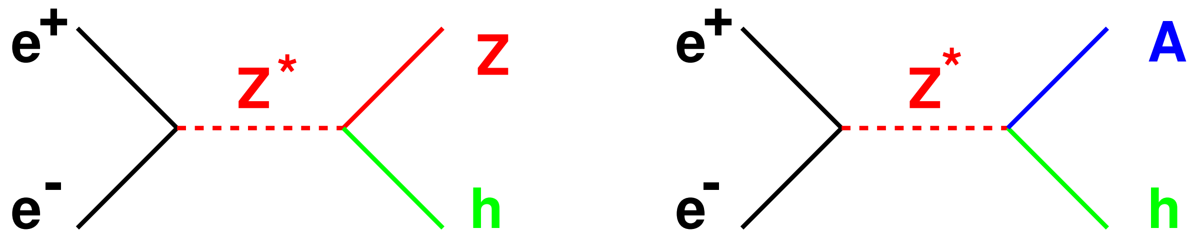
Note: Not all data included yet !



- **LEP discovery reach next year presumably close to 109 - 110 GeV**

5 physical Higgs Bosons

2 CP-even neutral Higgses	$\mathrm{h^0, H^0}$	$\mathrm{m_h < m_H}$
1 CP-odd neutral Higgs	$\mathrm{A^0}$	
2 charged Higgses	$\mathrm{H^\pm}$	
Free parameters:	$\tan\beta = v_2/v_1$	(VEV ratio)
	α	(mixing angle of h, H)
tree level:	$\mathrm{m_h < m_Z < m_H}$	
rad.corrected:	$\mathrm{m_h} < 135$ GeV	



"Higgsstrahlung"

$\sigma = \sin^2(\beta - \alpha)\,\sigma_{HZ}^{SM}$

- largest at small $\tan\beta \approx 1.4$
- SM topologies
- recycle SM searches

"Associated Production"

$\sigma = \cos^2(\beta - \alpha)\bar{\lambda}\sigma_{\nu\bar{\nu}}^{SM}$

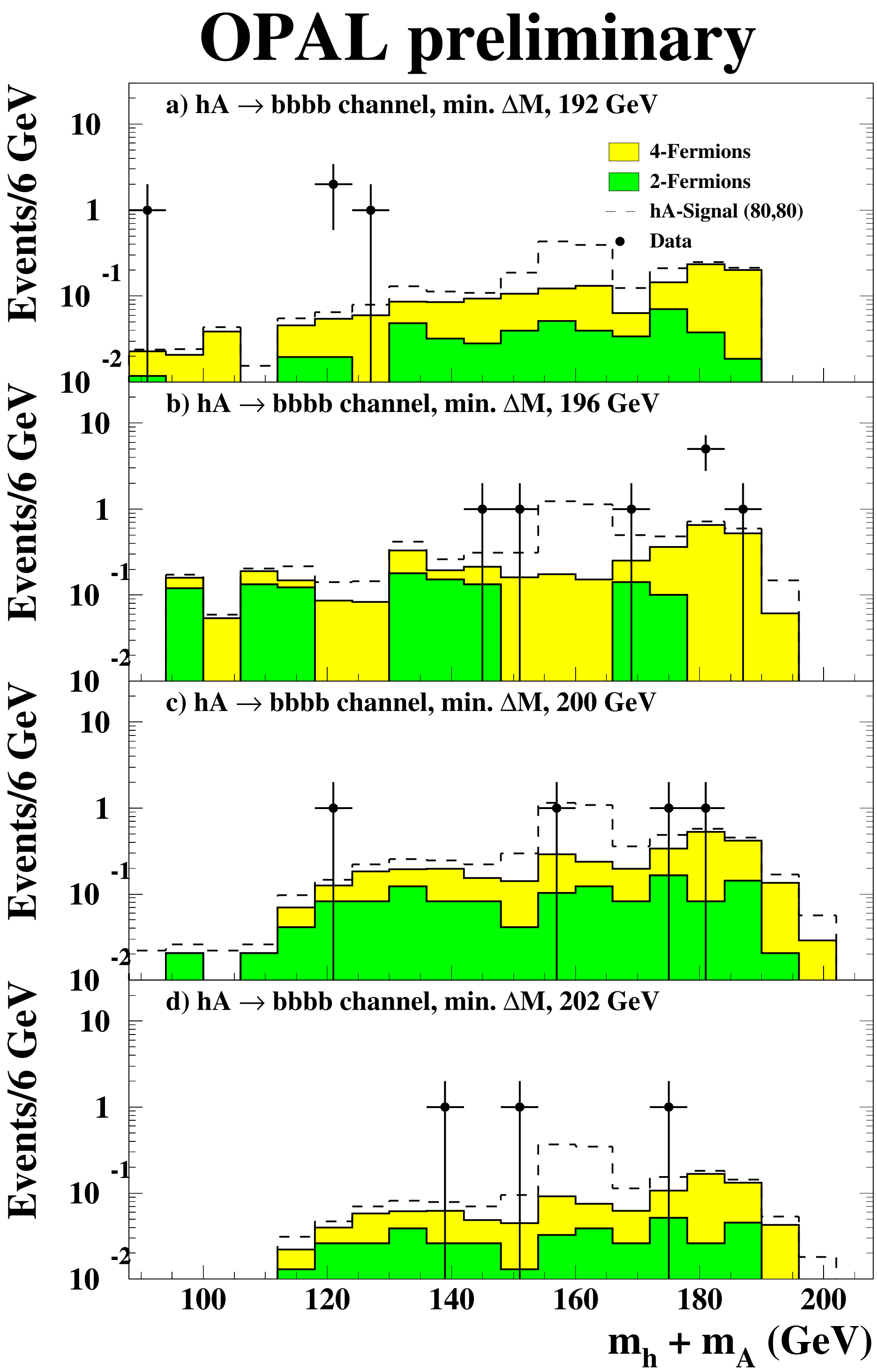
- largest at $\tan\beta > 15$
- typically $\mathrm{m_A \approx m_h}$
- new topologies
- dedicated searches:

$\mathrm{hA \rightarrow b\bar{b}b\bar{b}, hA \rightarrow \tau^+\tau^- b\bar{b}}$

$e^+e^- \rightarrow h^0A^0$

Channel (OPAL)	N_{DATA}	N_{BG}	ϵ
$A^0h^0 \rightarrow b\bar{b}b\bar{b}$	19	8.8 ± 2.3	$\sim$ 50%
$A^0h^0 \rightarrow \tau^+\tau^-b\bar{b}$	5	7.1 ± 3.1	$\sim$ 45%

$\sim 190\ \mathrm{pb}^{-1}$ OPAL data at $\sqrt{s} = 192 - 202$ GeV

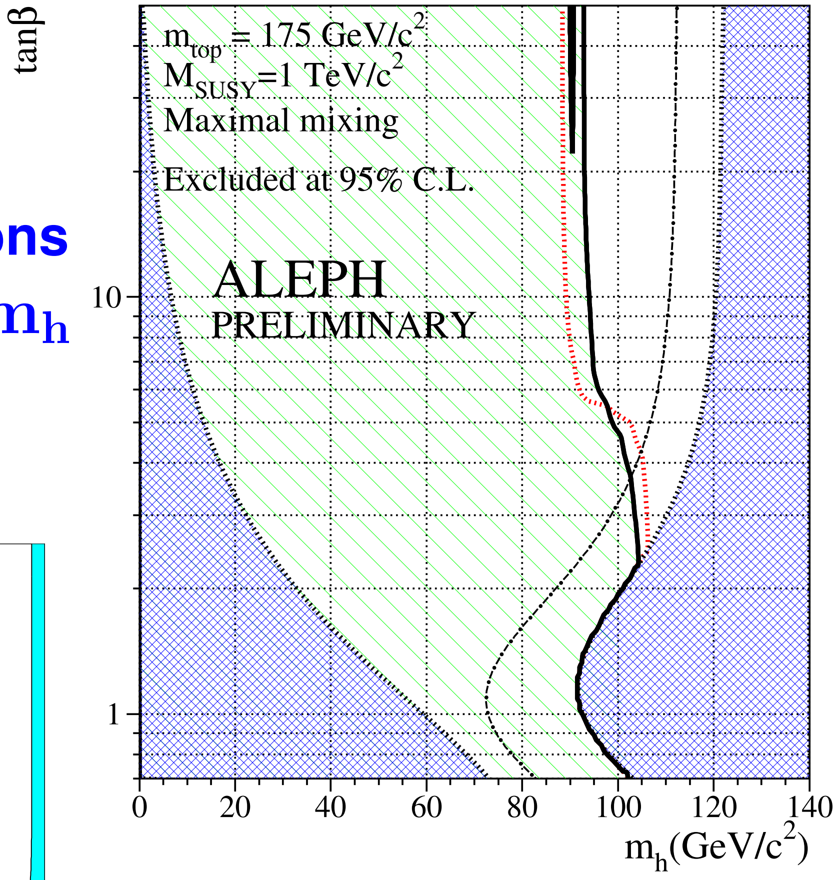


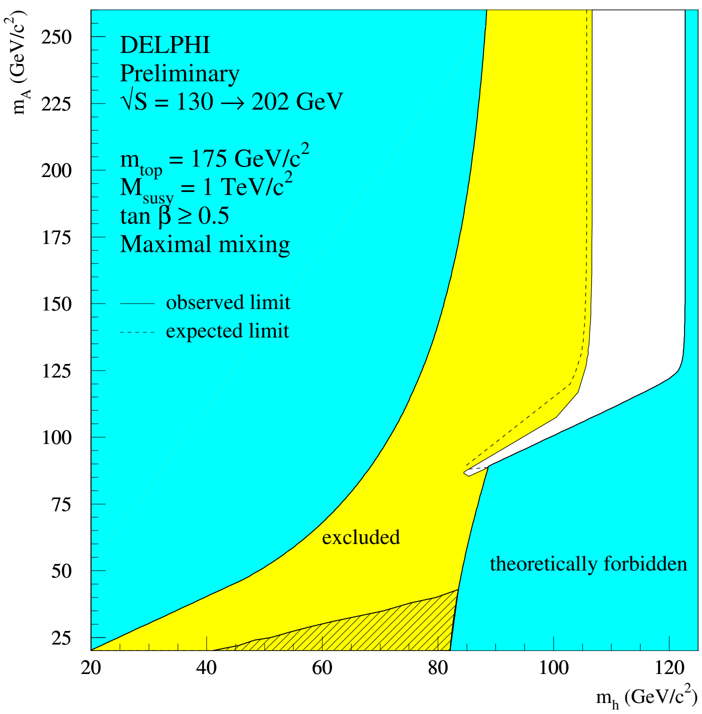
MSSM Higgs Boson Exclusion

μ = -100 GeV, $m_0 = 1$ TeV, $M_2 = 1.6$ TeV

m_t = 175 GeV, $A_t = 0$ or $\sqrt{6}m_0$ (minimal or maximal stop mixing)

- typical $\tan\beta$ exclusion 0.7 - 2.2
- improved calculations will increase max. m_h by $\sim$ 5 GeV

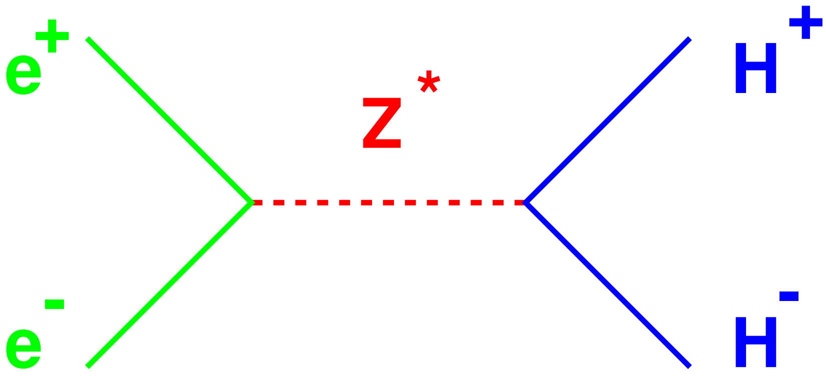




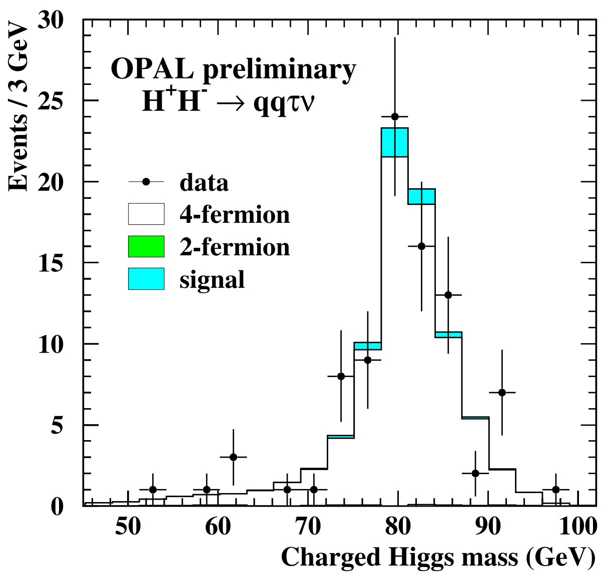
- for large m_A approach SM limit

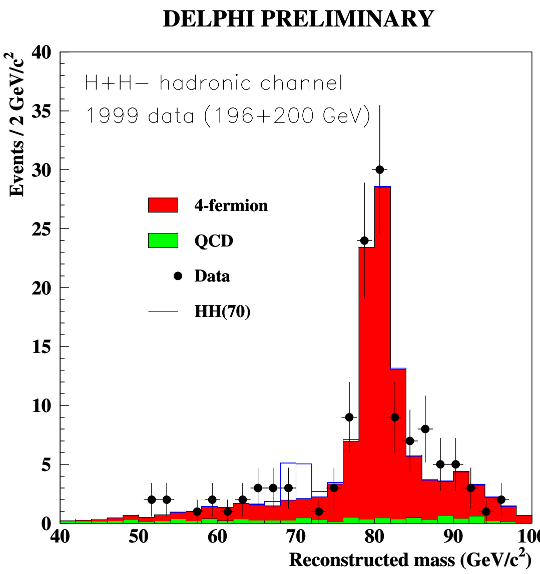
experiment	m_A (GeV) $>$	m_h (GeV) $>$
ALEPH	—	89.9
DELPHI	$\sim$ 85	$\sim$ 85
L3	82	81
OPAL		
LEP^{196}	84.3	84.5

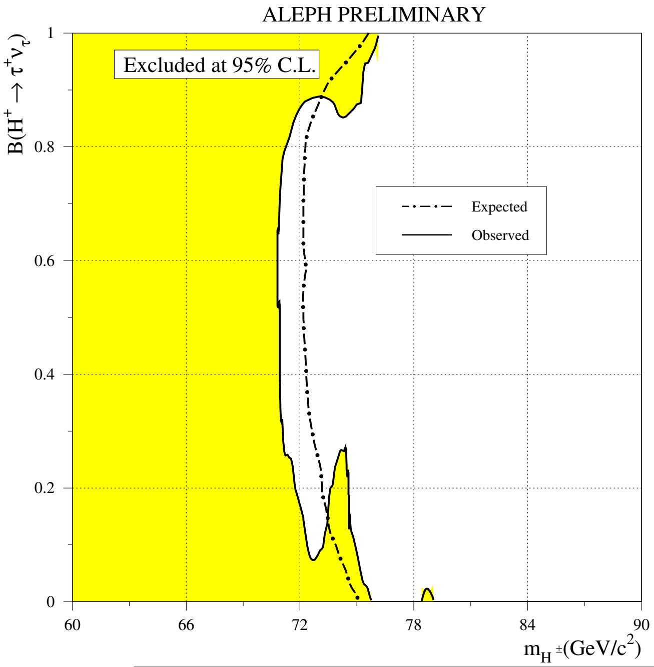
Charged Higgs at LEP



- in the MSSM at tree-level: $m_{H^\pm} > m_{W^\pm}$
- rad. corrections can yield $m_{H^\pm} < m_{W^\pm}$
- decays to $H^\pm \to \tau^\pm \nu$, $c\bar{s}$







typical limits (ALEPH):

$m_H > 71.0$ GeV observed

$m_H > 72.2$ GeV expected

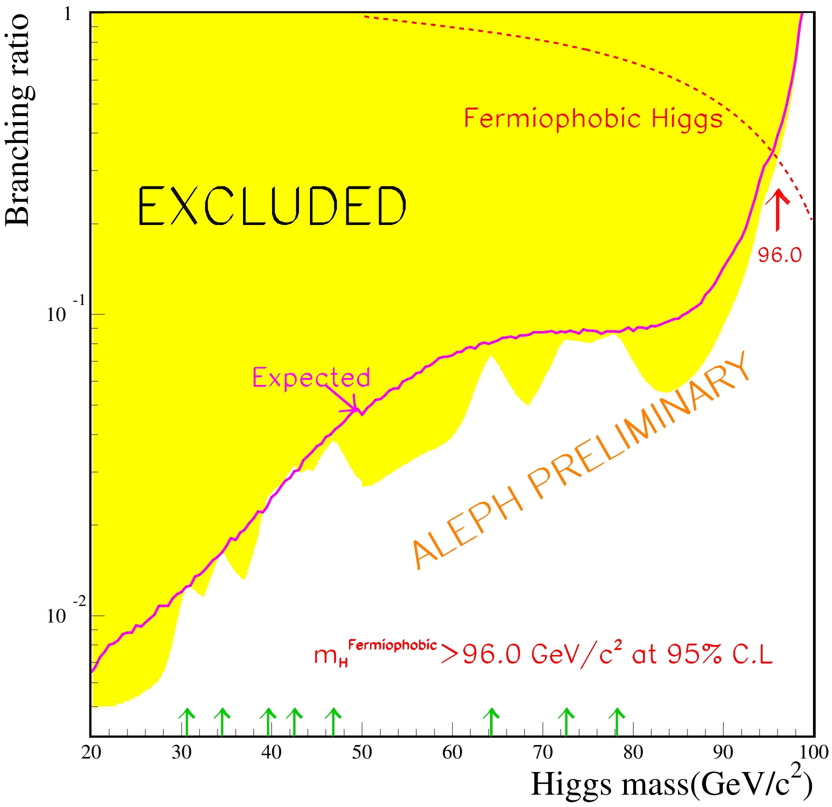
$LEP^{196} > 77$ GeV

$H \longrightarrow \gamma\gamma$

- In the SM: no Higgs-Photon coupling but beyond SM there might be effective HZγ- and H$\gamma\gamma$-couplings.

- "fermiophobic Higgses" $\Rightarrow$ large Br(H $\longrightarrow \gamma\gamma$) for $m_H \leq 100$ GeV

- signature at LEP:
  - ▷ multiphotons
  - ▷ (+ missing energy)
  - ▷ (+ jets)



- LEP $m_H > 96$ - 97 GeV
- CDF/D0 $m_H > 77$, 82 GeV

SUSY Searches at LEP

Spin	0	1/2		1
	$\tilde{\ell}^{+}$, $\tilde{\nu}$ - *sleptons*	ℓ, ν		
	$\tilde{q}$ - *squarks*	q		
		$\tilde{g}$ - *gluinos*		g
	H^0, h^0, A^0	$\tilde{\gamma}$ $\tilde{H}$, $\tilde{Z}$ $\tilde{h}$	} Mix, $\tilde{\chi}^0_i$ *Neutralinos*	γ Z
	$H^{\pm}$	$\tilde{H}^{\pm}$ $\tilde{W}$	} Mix, $\tilde{\chi}^{\pm}_j$ *Charginos*	$W^{\pm}$

Two: $m(\tilde{\chi}^{\pm}_1) < m(\tilde{\chi}^{\pm}_2)$

Four: $m(\tilde{\chi}^{0}_1) < m(\tilde{\chi}^{0}_2) < m(\tilde{\chi}^{0}_3) < m(\tilde{\chi}^{0}_4)$

Assume R-Parity conserved $\Rightarrow$ SUSY particles produced in pairs

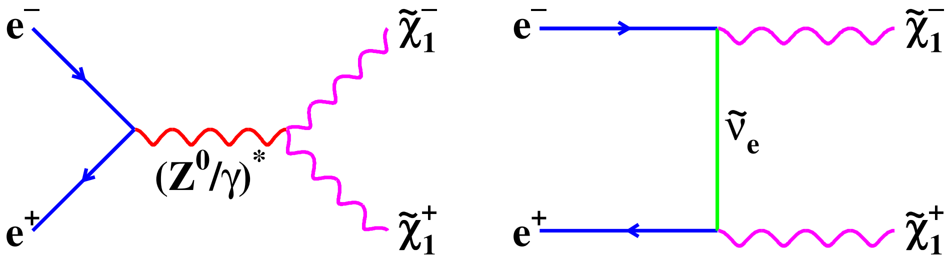
$R = (-1)^{3B+L+2S}$ $\Rightarrow$ decays to lightest SUSY particle (LSP), escapes detector

Masses, Cross Sections, Br's of $\tilde{\chi}^{\pm}_j$ and $\tilde{\chi}^{0}_i$ from:

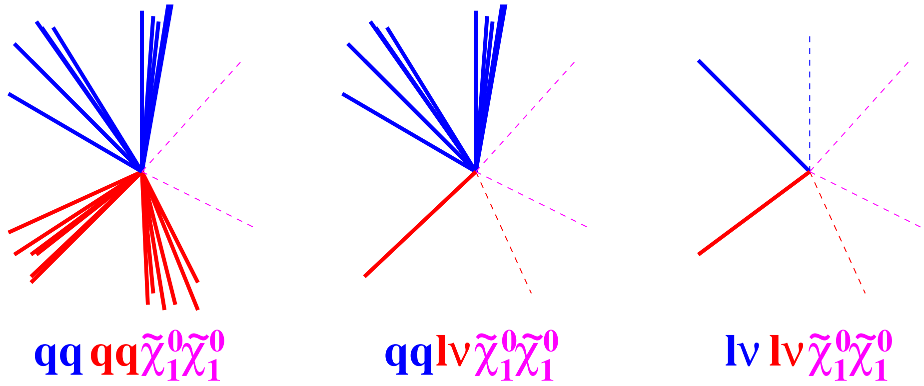
- M_2, SU(2) gaugino mass @ electroweak scales
- $\tan\beta$, ratio of vacuum exp. values of Higgs doublets, $\langle v_2\rangle/\langle v_1\rangle$
- μ, superpotential Higgsino mass (enters gaugino-Higssino sector)
- m_0, common mass of squarks and sleptons at GUT scales

(GUT: $M_1 = \frac{5}{3} M_2 \tan^2\theta_W$)

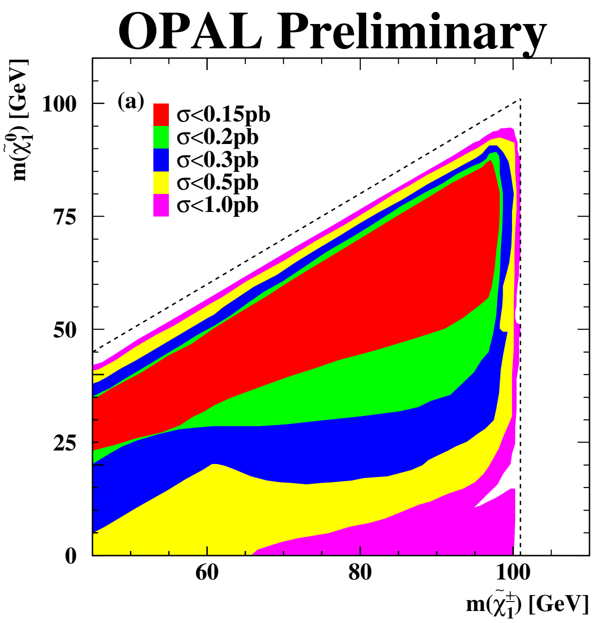
Charginos

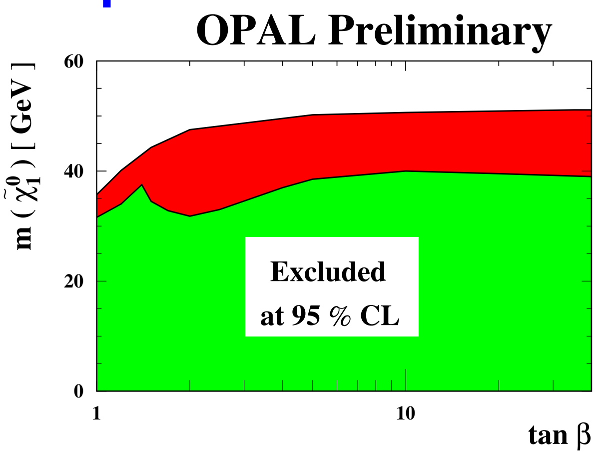


- **Chargino decay via W** (in a large fraction of MSSM space)
- **Signature : W^+ W^- plus missing energy**



- **Data consistent with SM expectation**





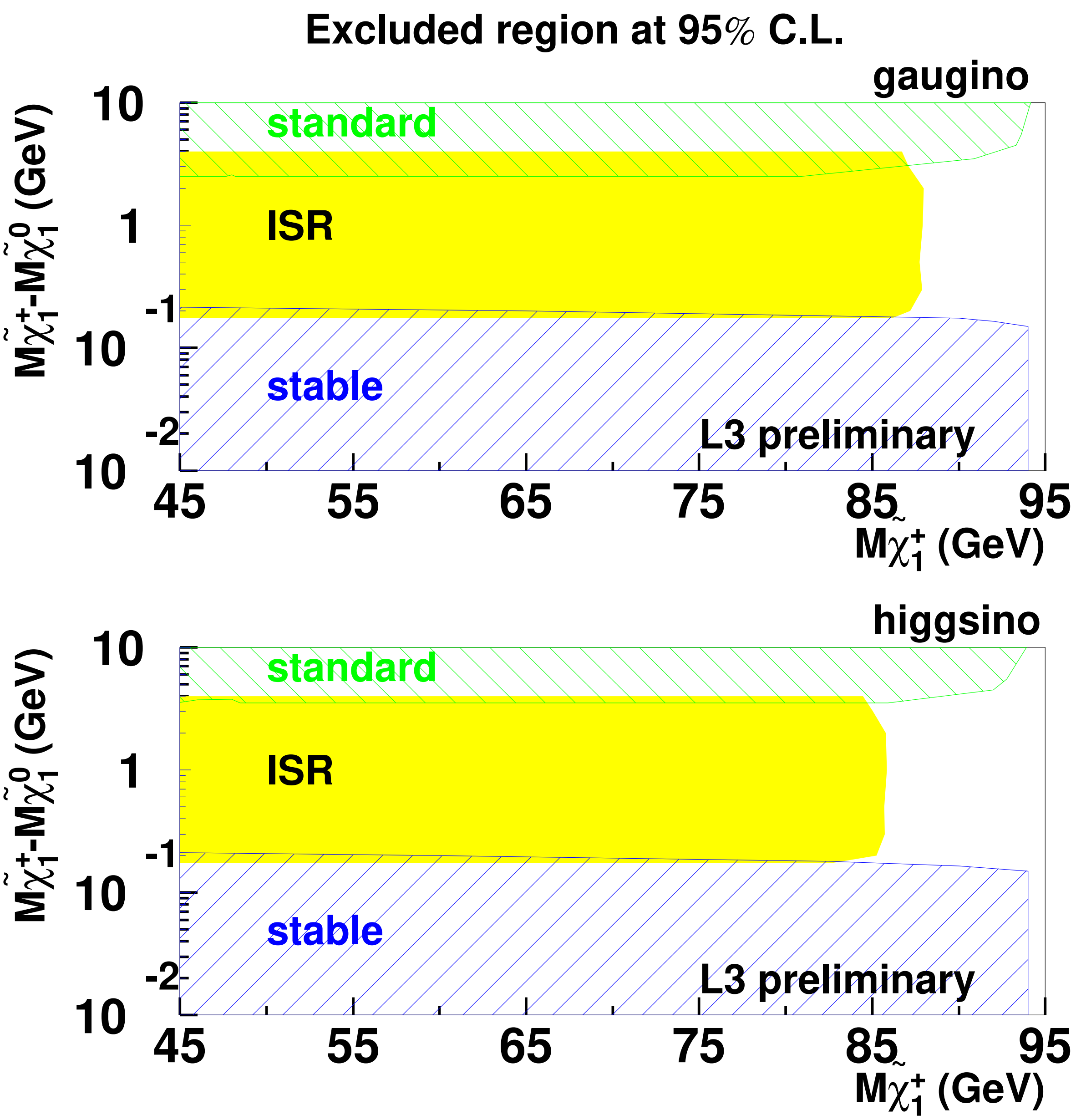
- **Absolute lower limits (CMSSM):**

$$m_{\tilde{\chi}_1^0} > 35.6 \text{ GeV} \qquad (m_0 \geq 500 \text{ GeV})$$

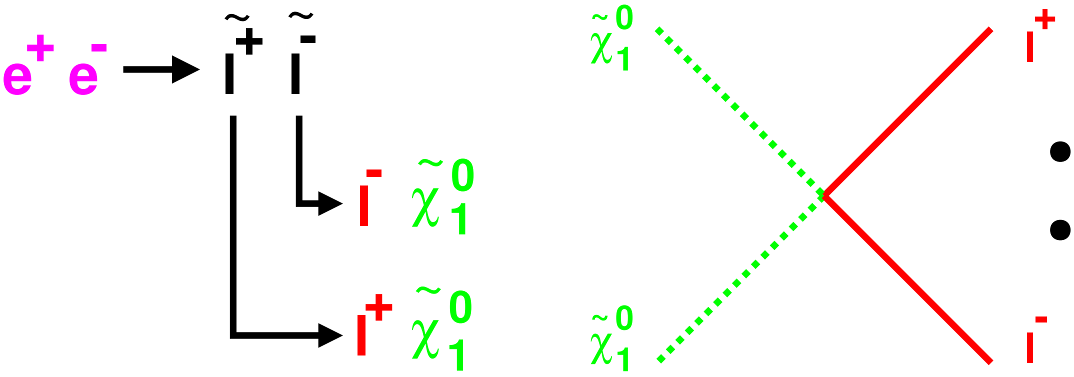
Charginos Mass Limit

- **Standard search on chargino:** $\Delta M \geq 2.5$ GeV
- **Search for stable heavy particle:** $\Delta M \leq 170$ MeV
- **Probe the intermediate ΔM region with :**

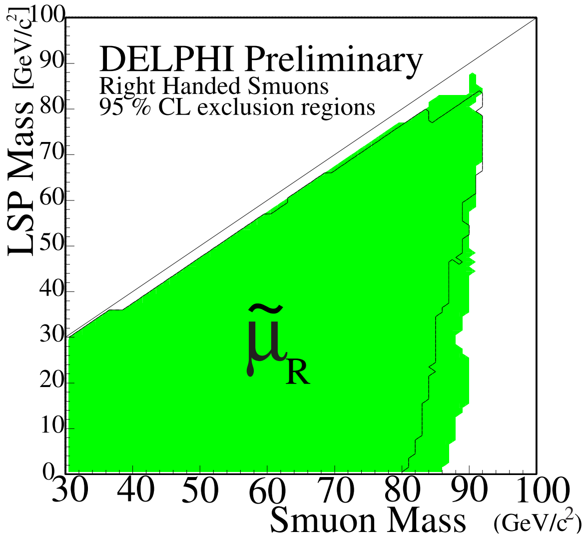
$$e^+e^- \rightarrow \gamma\tilde{\chi}^+\tilde{\chi}^- \rightarrow \gamma\tilde{\chi}^0_1\tilde{\chi}^0_1 X$$

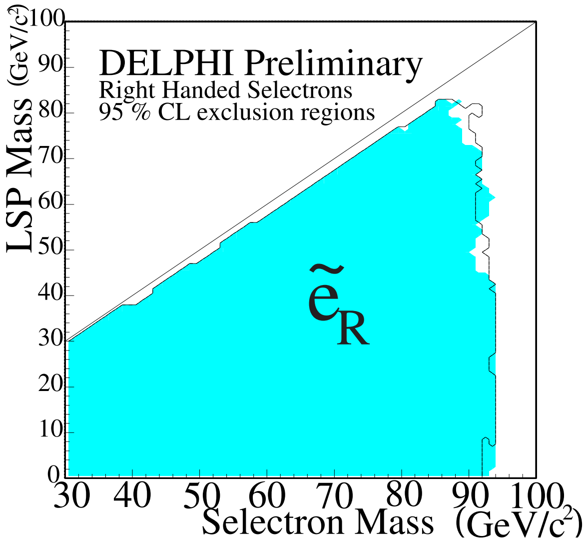


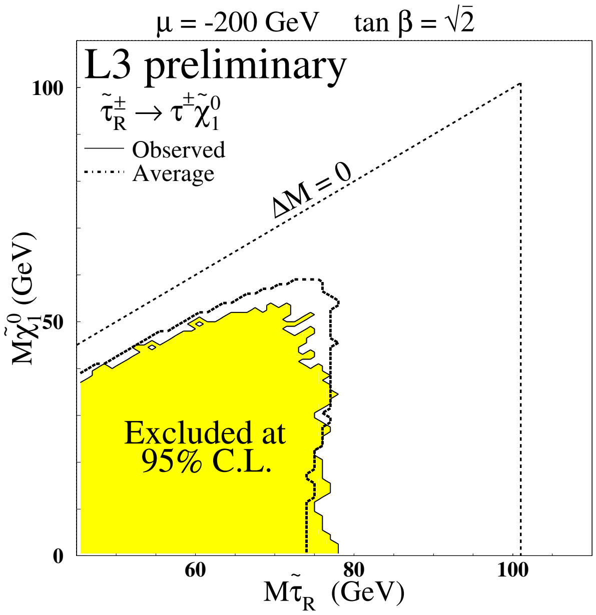
Sleptons Searches



- acoplanar leptons
- missing E_T







- **Typical limits :**

$m_{\tilde{e}} > 92 - 94$ **GeV**

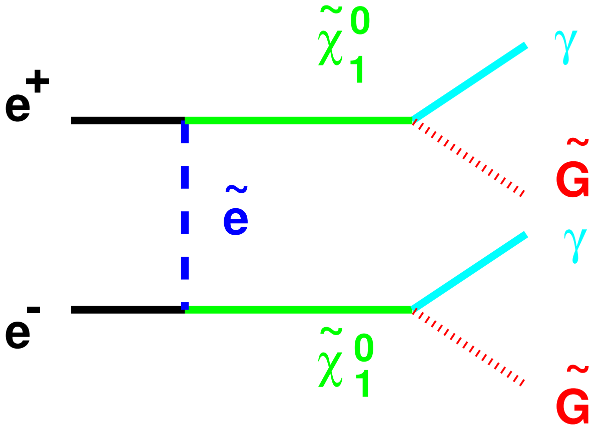
$m_{\tilde{\mu}} > 81 - 85$ **GeV**

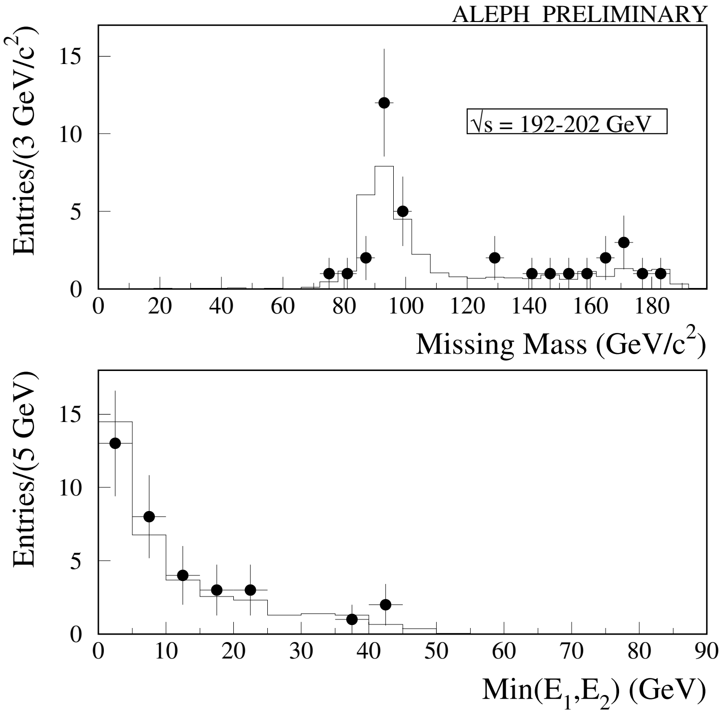
$m_{\tilde{\tau}} > 72 - 74$ **GeV**

Limits improved by $\sim$ 4 GeV wrt to 189 GeV data.

GMSB SUSY with $\tilde{\chi}_1^0$ NLSP

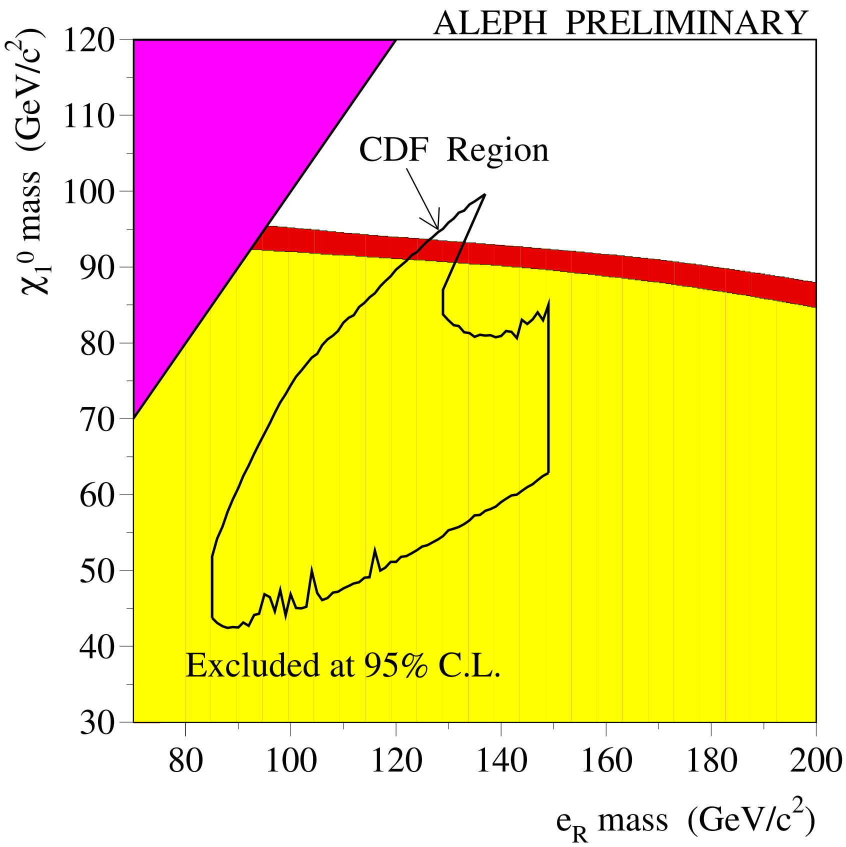
Here gravitino is the lightest SUSY particle (LSP).
If $\tilde{\chi}_1^0$ is the NLSP search for :





spectra of missing mass and minimum photon energy

exclusion region



Search for Technicolour Production

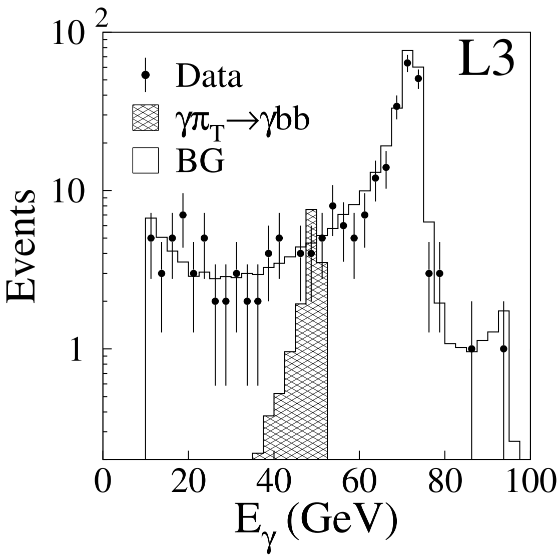
- Dynamical breaking of EW symmetry
- Role of Higgs boson performed
  by several multiplets of technihadrons
- considered parameters:
  $m_{\pi_T}, m_{\rho_T}, \sin\chi(\text{mix } W_L, \pi_T), Q$
- BR($\pi_T \longrightarrow b\bar{c}, b\bar{b}$) $\sim 50 - 90\%$
- signals:

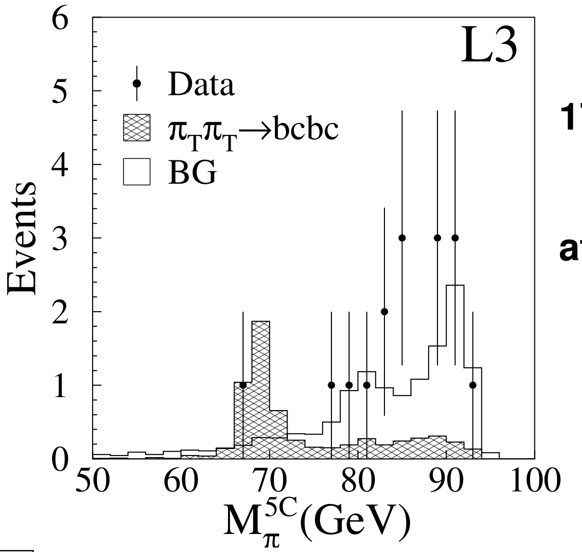
$\sigma(ee \rightarrow WW) < 0.47$ pb

$ee \longrightarrow \gamma\pi_T \longrightarrow \gamma bb$

$ee \longrightarrow W_L\pi_T \longrightarrow l\nu bc$

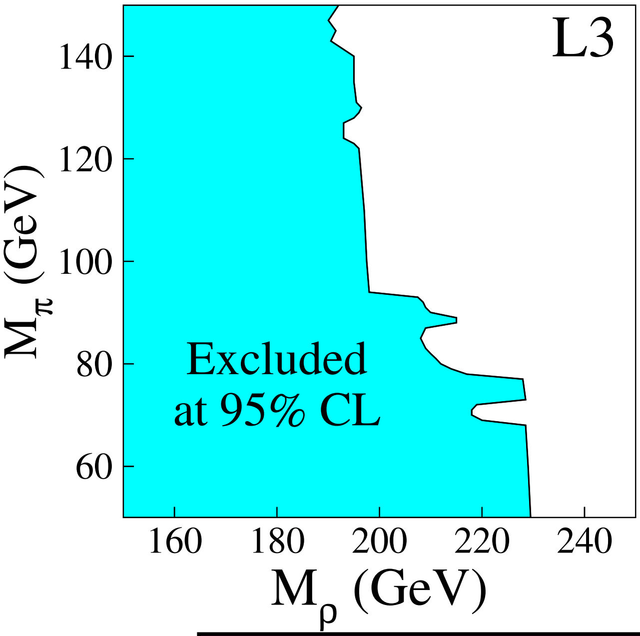
$ee \longrightarrow \pi_T\pi_T \longrightarrow bcbc$





176.4 pb^{-1}

at $\sqrt{s}$ = 188.6 GeV



for $0 < \sin\chi < 1$,
$Q = -1, 0, \frac{5}{3}$

(status EPS '99, Tampere)

Summary

- **Impressive performane of LEP**
  delivered more than 250 pb^{-1}
  up to 101 GeV per beam

- **Good agreement with SM prediction:**
  Preliminary estimates for cross sections at high energies of :
  fermion pair production, WW, ZZ

- **Resulting limits on new physics (Z$'$, CI)**
  competitive with Tevatron

- $\mathrm{M_W}$ **uncertainties decreasing,**
  more systematic studies ongoing
  $\mathrm{M_W^{LEP}} = 80.350 \pm 0.056$ **GeV (prelim.)**

- **Limit on anomalous gauge couplings**
  (some for the first time)

- **DELPHI excess in llqq under investigation**

- **Good performance in the Higgs, SUSY**
  and other searches, but ...

Outlook

LEP in 2000 ...

▷ replace crygenics turbines
$\Rightarrow$ total cooling power non longer limiting

▷ re-install 8 copper cavities (adds 15-20 MV)

▷ use horizontal corrector magnets as additional dipoles $\Rightarrow$ gain $\sim$ 0.2 GeV / beam

▷ Running with only one klystron in reserve (was 2)

▷ On last day of 1999 run successful test of 102 GeV / beam in collision
$\Rightarrow$ hope to go up to 103 GeV / beam