DELPHI results from year 2000

Vincent Hedberg - University of Lund

Forward Chamber A
Forward RICH
Forward Chamber B
Forward EM Calorimeter
Forward Hadron Calorimeter
Forward Hodoscope
Forward Muon Chambers
Surround Muon Chambers

Barrel Muon Chambers
Barrel Hadron Calorimeter
Scintillators
Superconducting Coil
High Density Projection Chamber
Outer Detector
Barrel RICH
Small Angle Tile Calorimeter
Quadrupole
Very Small Angle Tagger
Beam Pipe
Vertex Detector
Inner Detector
Time Projection Chamber

Part 1. Standard model measurements

Part 2. Supersymmetric searches

**Part 3.** The search for the Higgs boson

Running during 2000

TPC problems since first of September

Short circuit in 1 out of 12 TPC prop. chambers
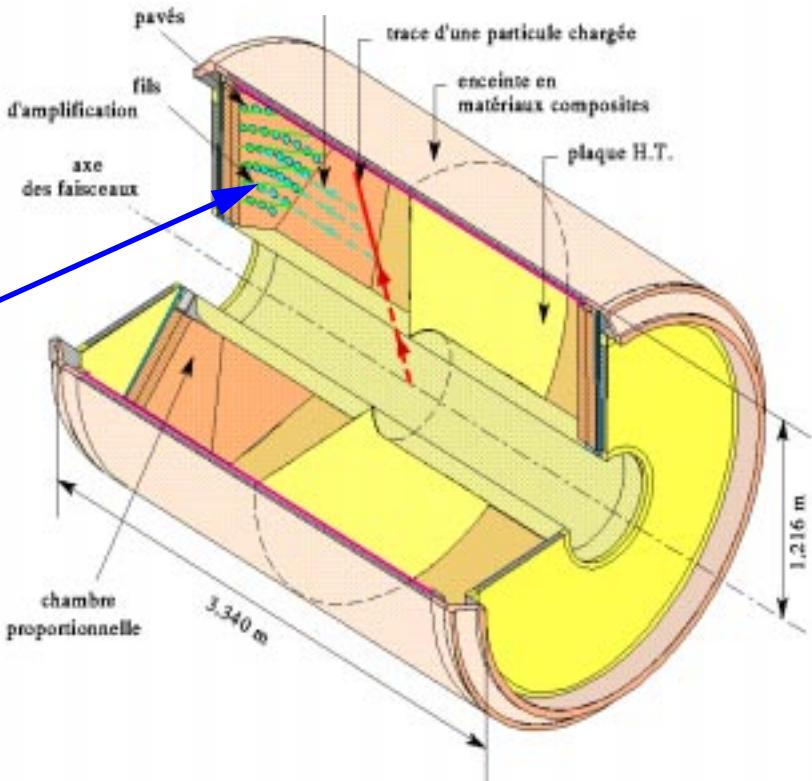
➡ New track reconstruction has been made.

➡ New Monte Carlo samples have to be produced.

➡ New processing of data and Monte Carlo events have to be made.

➡ Only data recorded up to September 1 will be shown today !

| $\sqrt{s}$	203-206 GeV	206-207 GeV	207-209 GeV
$L < 1$ Sep.	$75\ pb^{-1}$	$77\ pb^{-1}$	$9\ pb^{-1}$
$L > 1$ Sep.	$6\ pb^{-1}$	$28\ pb^{-1}$	$0.6\ pb^{-1}$

Standard Model Measurements
Two fermion processes
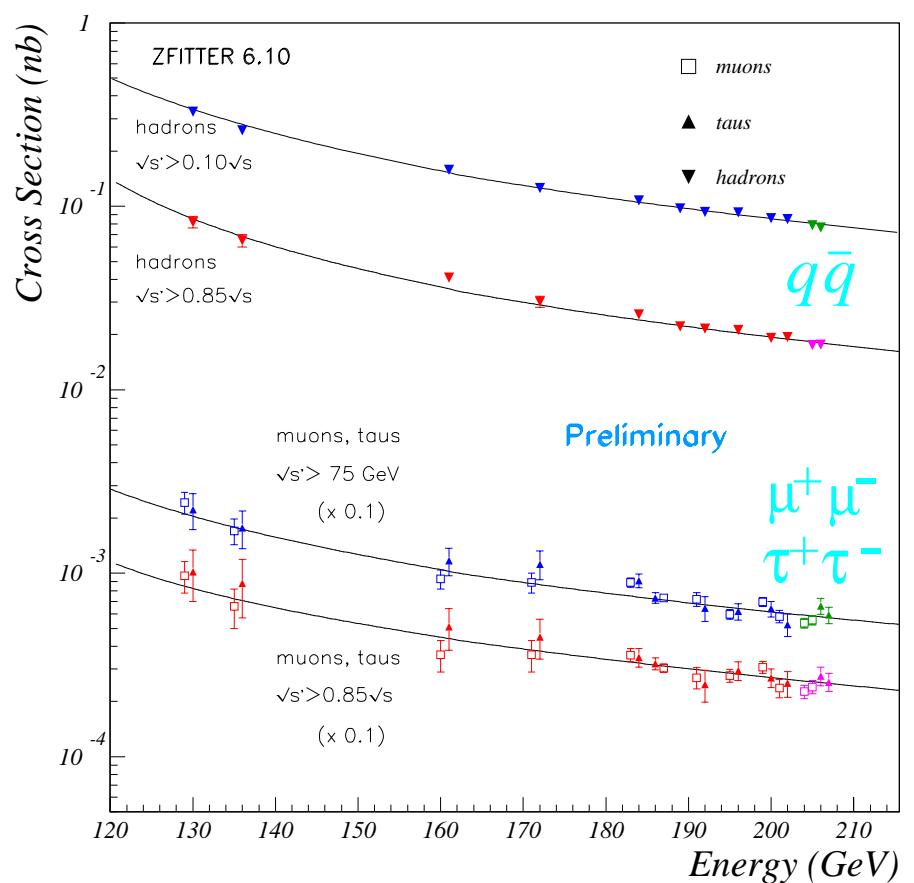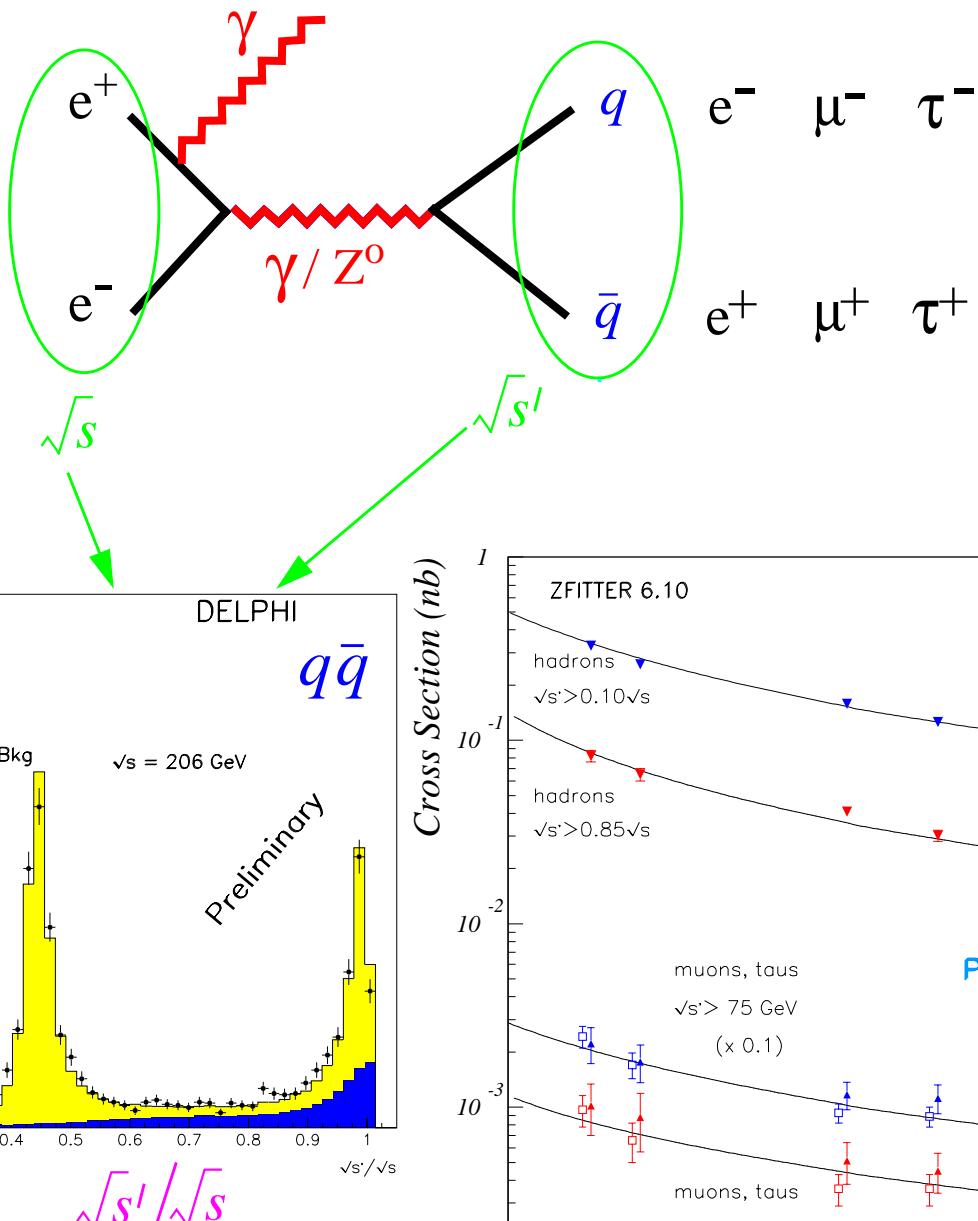
Standard Model Measurements

$$R_b = \sigma_{b\bar{b}} / \sigma_{had}$$

DELPHI preliminary

R_b

$\sqrt{s'}/\sqrt{s} > 0.1$

$\sqrt{s'}/\sqrt{s} > 0.85$

Y2K

- ● This measurement.
- ▼ 130-172 published
- ▲ LEP1 on-, off-peak

Zfitter $\sqrt{s'}/\sqrt{s} > 0.1$, 0.85

$\sqrt{s}$ (GeV)
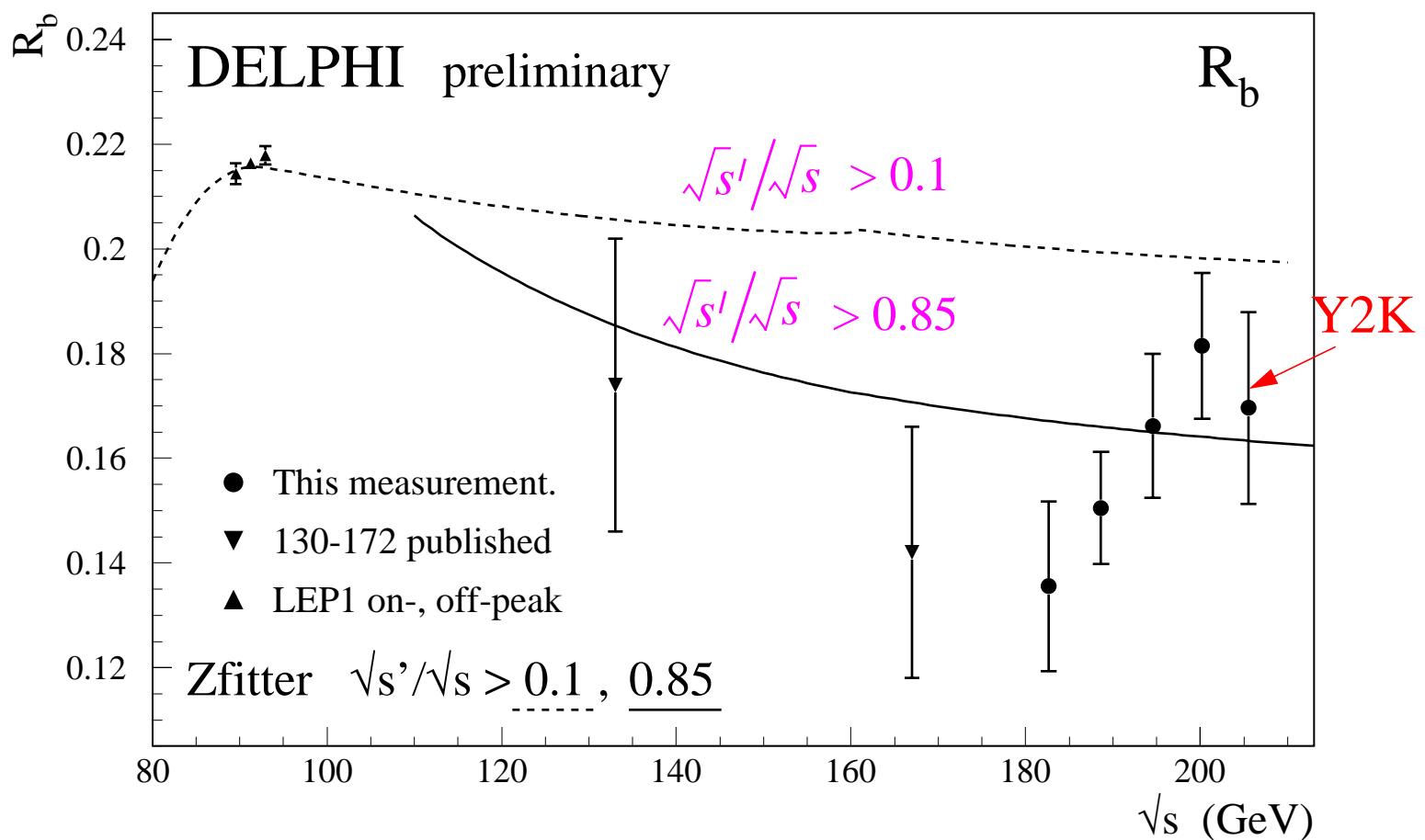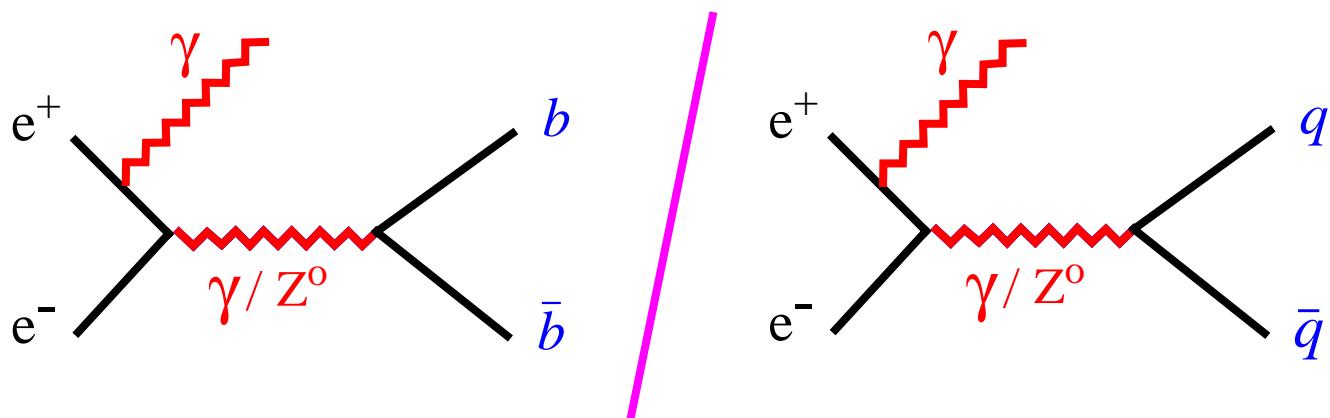
# Standard Model Measurements

WW cross section
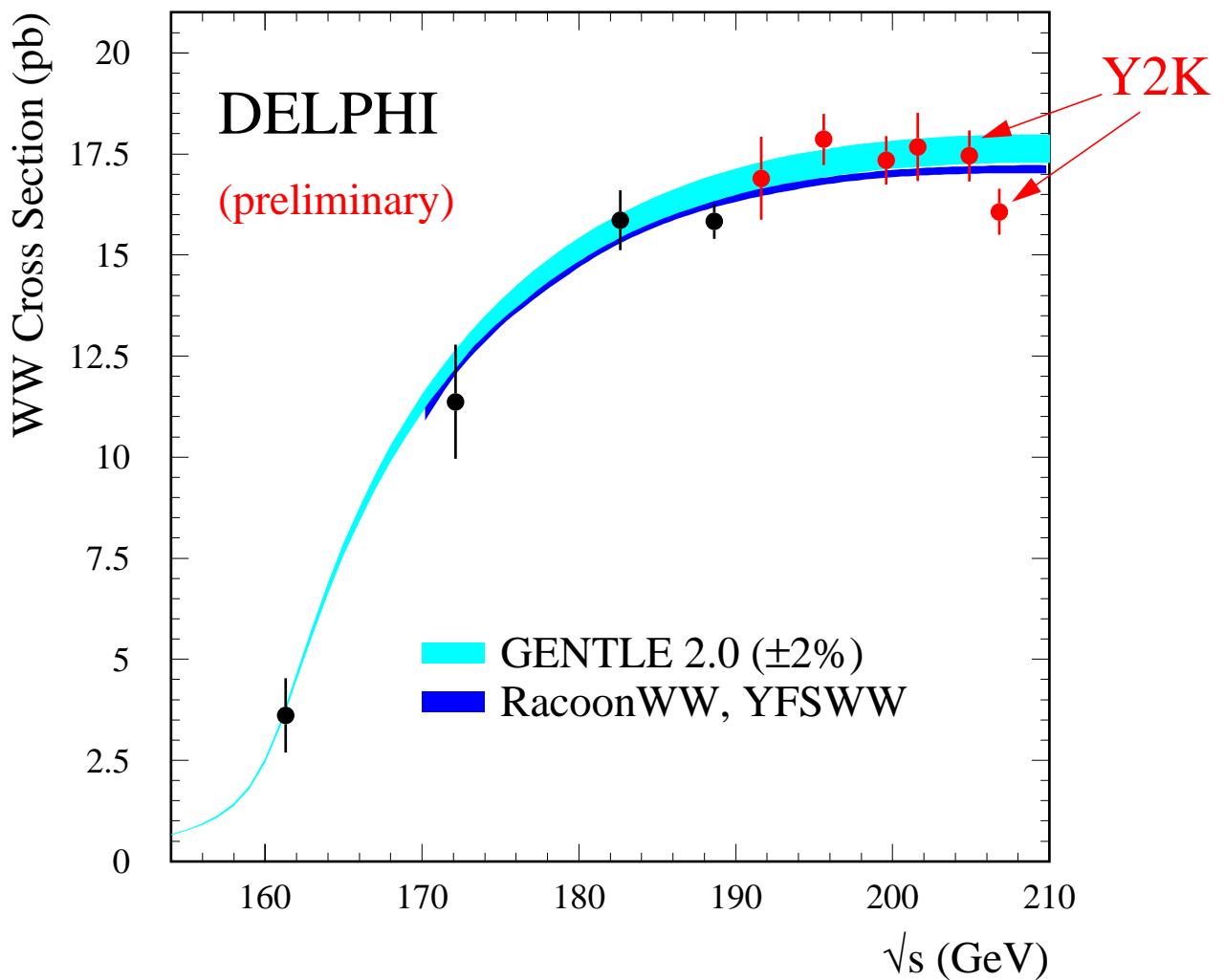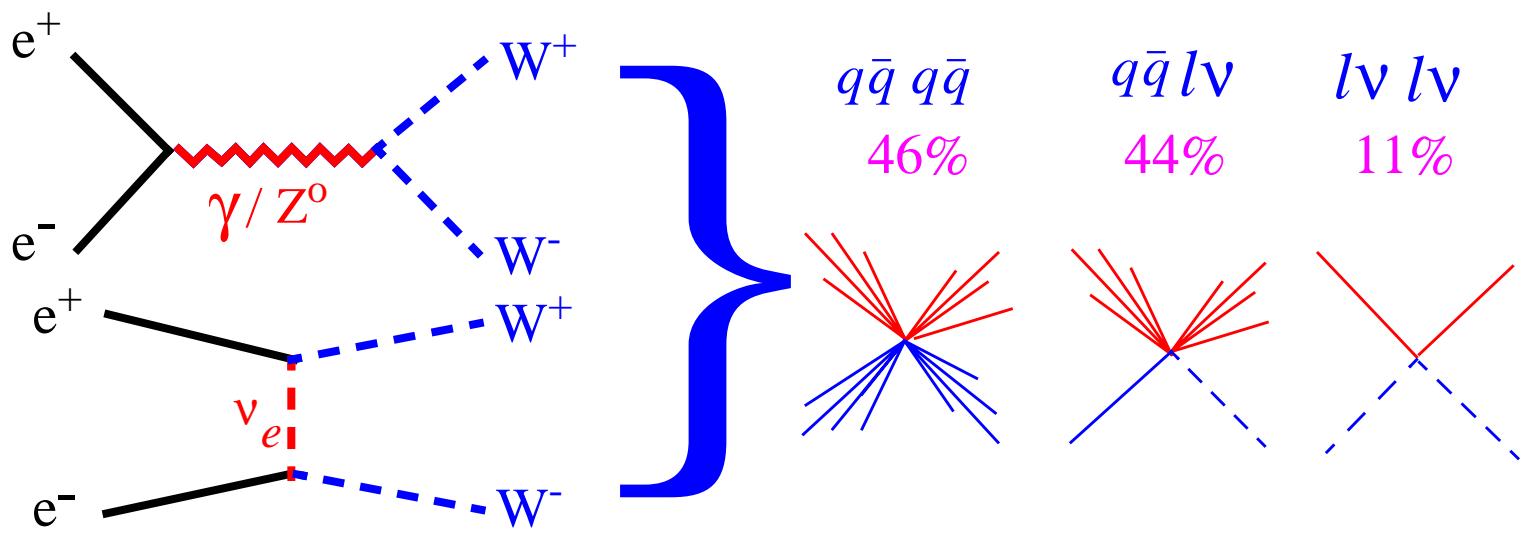
Standard Model Measurements
The mass and width of the W
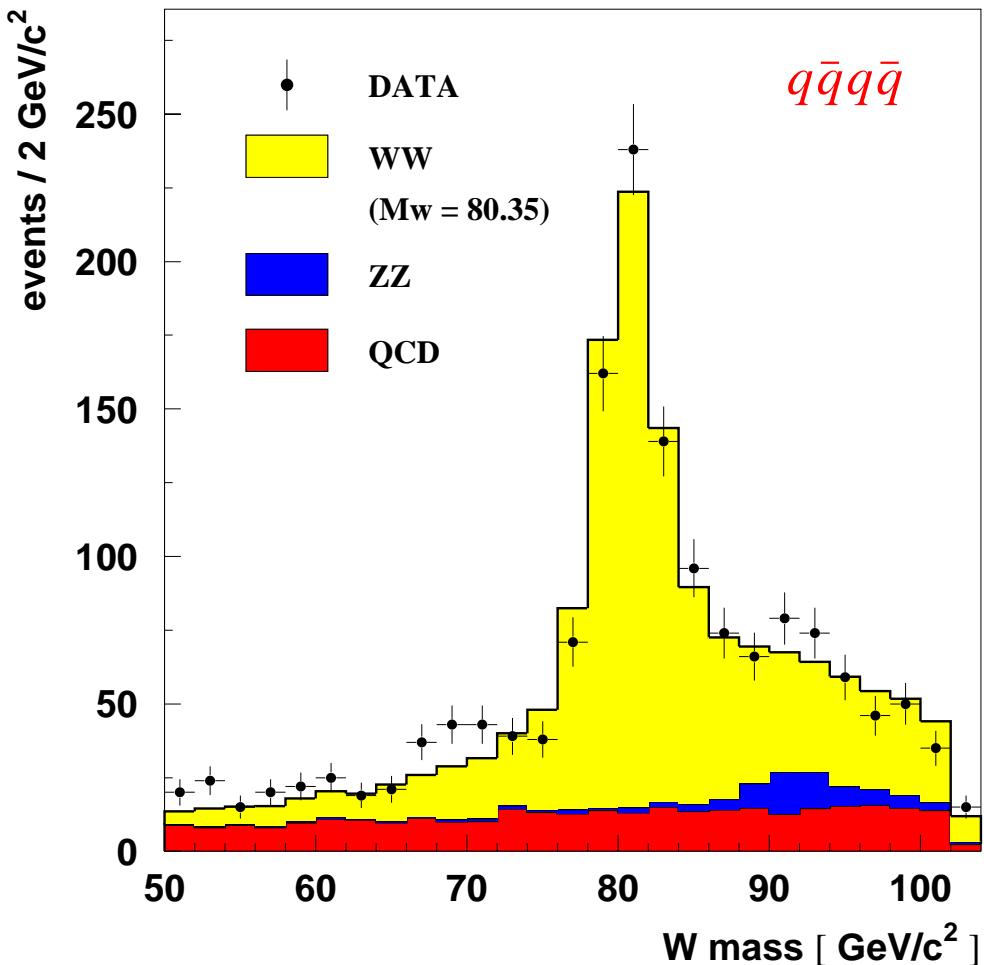
Without 2000 data:

$$M_W = 80.380 \pm 0.053(stat) \pm 0.034(syst) \pm 0.029(FSI) \pm 0.016(LEP)$$

$$\Gamma_W = 2.090 \pm 0.120(stat) \pm 0.062(syst) \pm 0.070(FSI)$$

Standard Model Measurements

ZZ cross section

e^+ ——————— Z^o }
e^- ——————— Z^o }

$q\bar{q}\,q\bar{q}$	$q\bar{q}\,\nu\bar{\nu}$	$q\bar{q}\,l\bar{l}$
49%	28%	14%
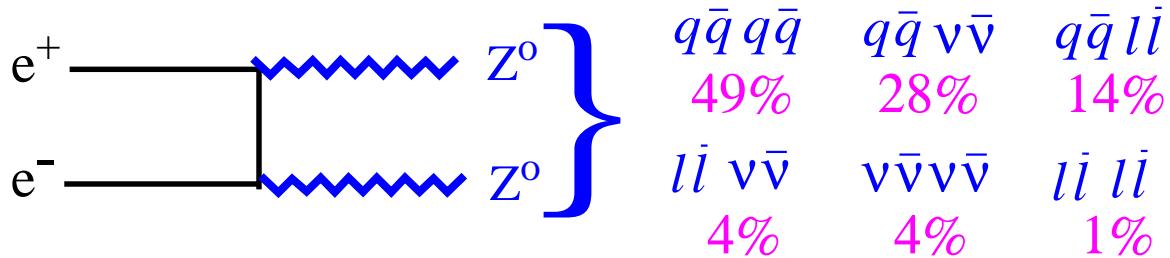
$l\bar{l}\,\nu\bar{\nu}$	$\nu\bar{\nu}\nu\bar{\nu}$	$l\bar{l}\,l\bar{l}$
4%	4%	1%

Mass distrib. of
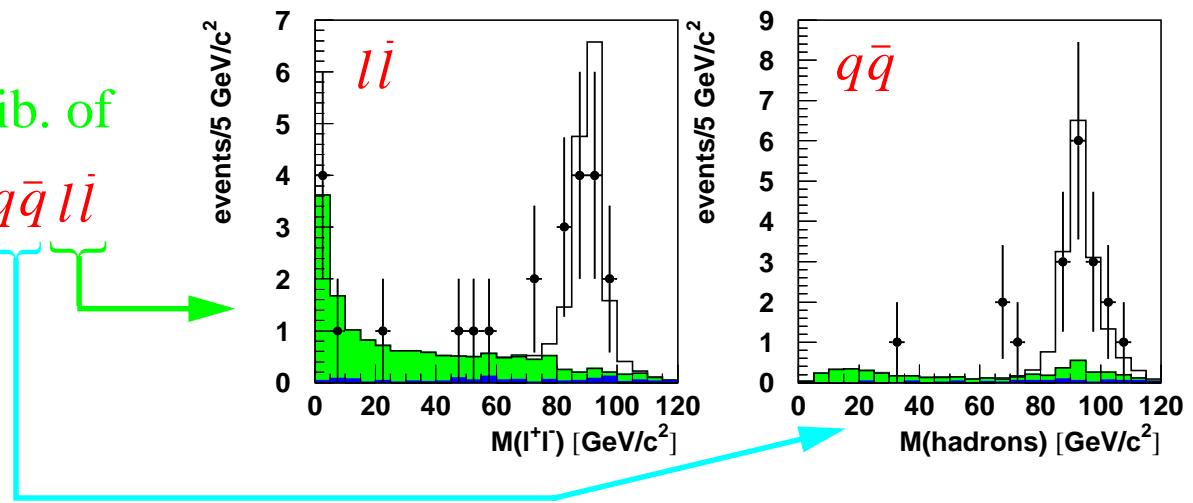
$ZZ \rightarrow q\bar{q}\,l\bar{l}$

Cross section of

$ZZ \rightarrow q\bar{q}\,q\bar{q}$

$ZZ \rightarrow q\bar{q}\,\nu\bar{\nu}$

$ZZ \rightarrow q\bar{q}\,l\bar{l}$

$ZZ \rightarrow l\bar{l}\,l\bar{l}$

$ZZ \rightarrow \nu\bar{\nu}\nu\bar{\nu}$

Result at 182.60 GeV :
0.38 ± 0.18 (stat) ± 0.04 (syst)
Result at 188.65 GeV :
0.60 ± 0.13 (stat) ± 0.07 (syst)

PRELIMINARY results
at 190-202 GeV
(stat. errors only)

Y2K update (172 pb^{-1})
VERY PRELIMINARY
(with NEW qqττ chan.)

Y2K
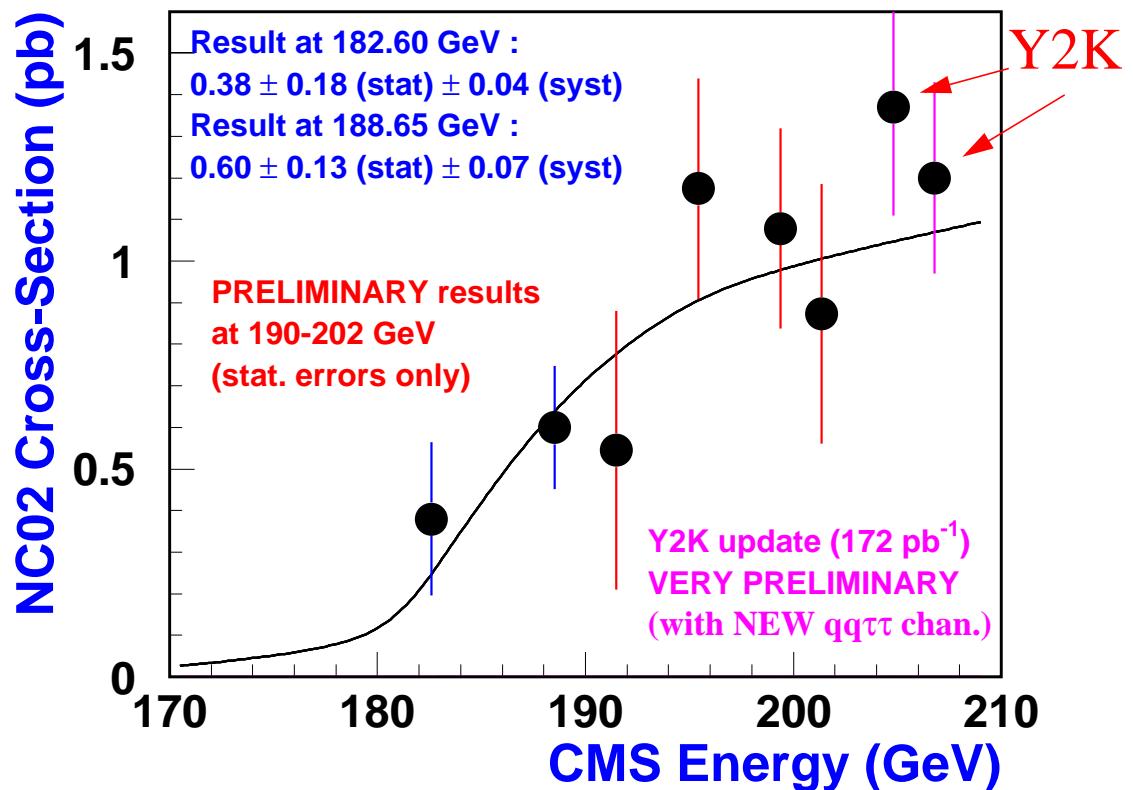
Summary and conclusions of part 1
Standard model measurements

✔ Two-fermion measurements OK

✔ $b\bar{b}$ measurements OK

✔ WW and ZZ cross sections OK

✔ WW and ZZ mass distributions OK

Supersymmetry

|	SUGRA SUSY breaking mediated by gravitational field.	GMSB SUSY breaking mediated by gauge boson fields.
LSP:	$\tilde{\chi}^0_1$	$\tilde{G}$
charginos $e^+e^- \rightarrow \tilde{\chi}^-_i \tilde{\chi}^+_j$	✔	✔
neutralinos $e^+e^- \rightarrow \tilde{\chi}^0_i \tilde{\chi}^0_j$	✔	✔
sleptons $e^+e^- \rightarrow \tilde{l}\tilde{l}$	✔	✔

+ MSSM Higgs

Supersymmetry
Charginos

$\sqrt{s}$ 207-208 GeV	$\tilde{\chi}_1^- \tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 W^* + \tilde{\chi}_1^0 W^*$			$\tilde{\chi}_1^- \tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 W^* + \tilde{\chi}_1^0 W^*$ $\quad \llcorner \gamma \tilde{G} \quad \llcorner \gamma \tilde{G}$ $+ 2\gamma$
	$q\bar{q}q\bar{q}\not{E}$	$q\bar{q}l\not{E}$	$ll\not{E}$	
Obs. events:	20	2	51	2
Background:	16	3	54	4

DELPHI $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ limits at 205.32 GeV

PRELIMINARY

Kinematic limit

$\tilde{\chi}_1^0$ LSP

$m_{\tilde{\nu}_e} > 300$ GeV

3 GeV/c^2

$m_{\tilde{\chi}_1^+}$ (GeV/c^2)

$m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0}$ (GeV/c^2)
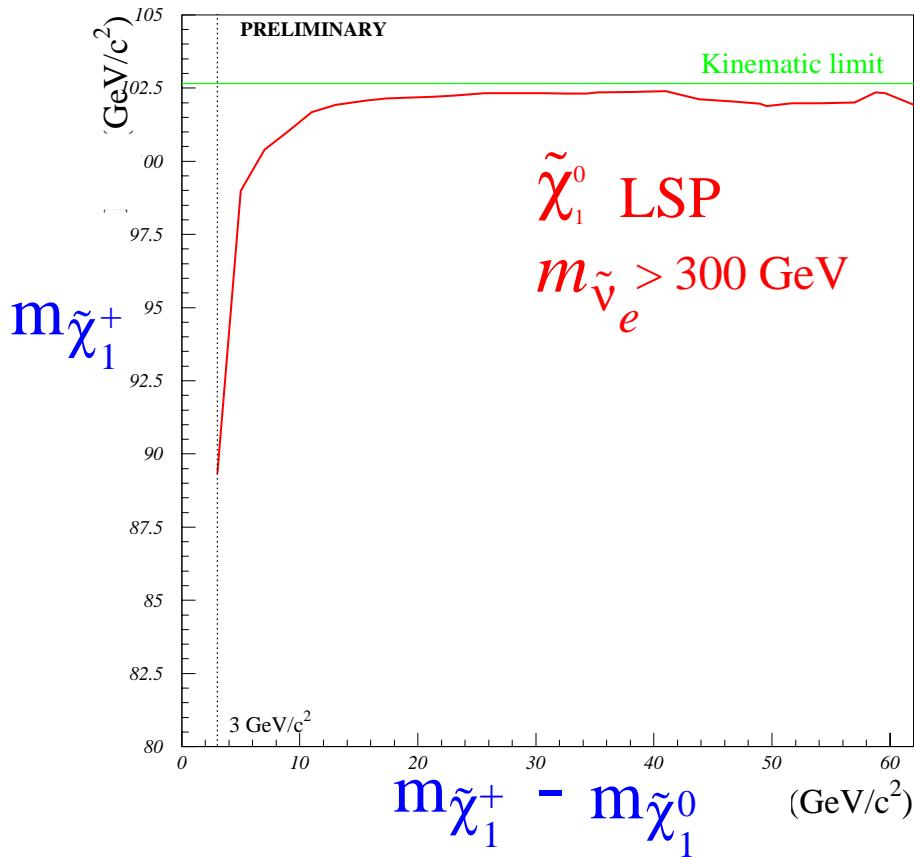
Supersymmetry
Neutralinos
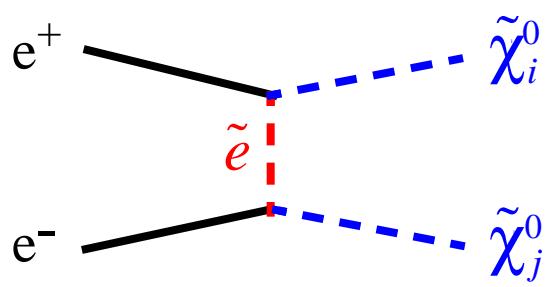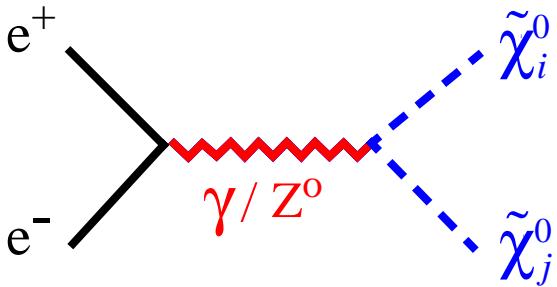
SUGRA

$$\tilde{\chi}_1^0 \, \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + \tilde{\chi}_1^0 \, Z^0$$

$q\bar{q}\,\not{E} \qquad ll\,\not{E}$

GMSB

$$\tilde{\chi}_1^0 \, \tilde{\chi}_1^0 \rightarrow \gamma \tilde{G} + \gamma \tilde{G}$$

$\gamma\,\gamma\,\not{E}$

Scan using searches for neutralinos, charginos, sleptons, squarks and higgs.
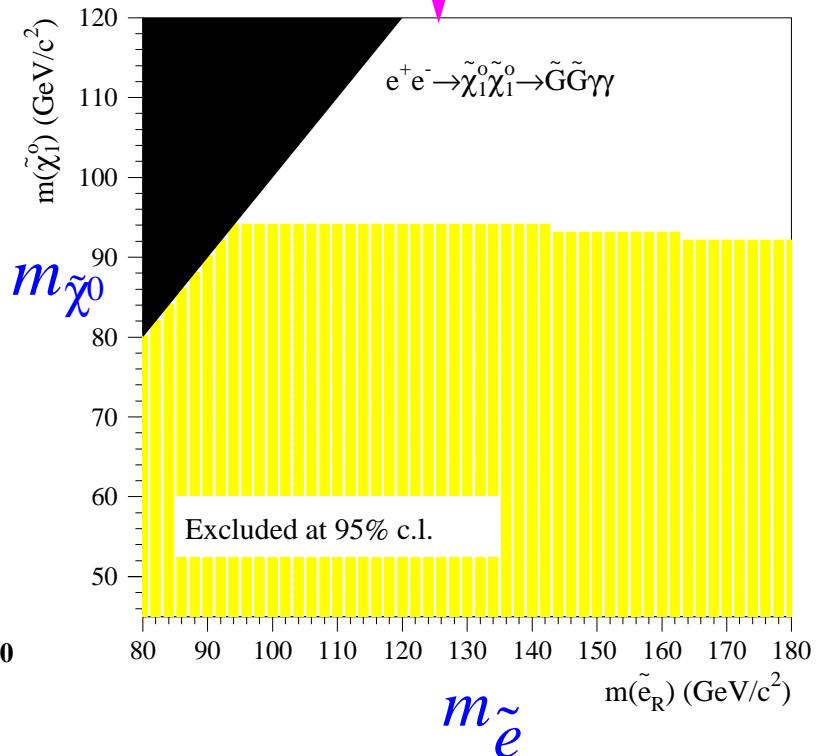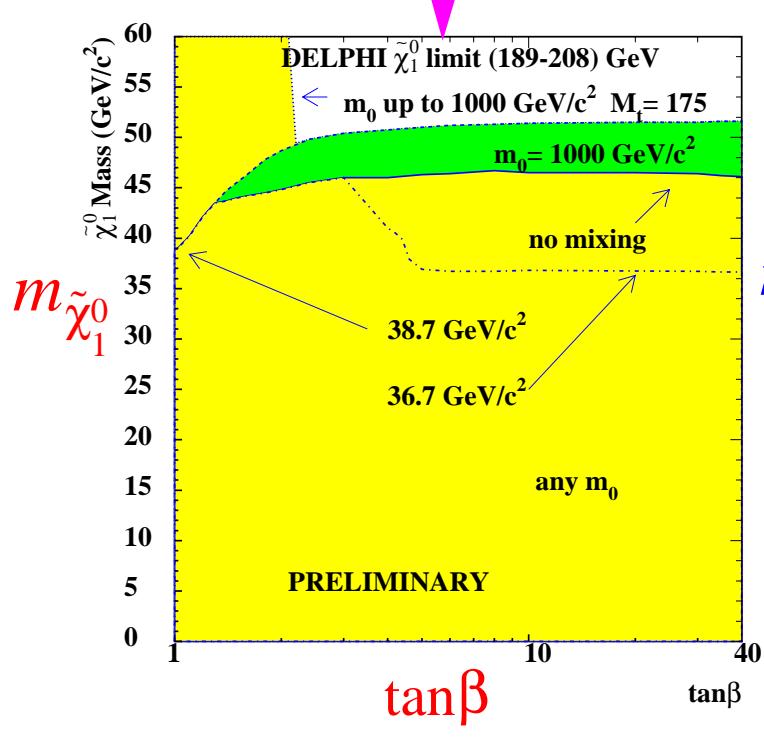
Supersymmetry
Sleptons
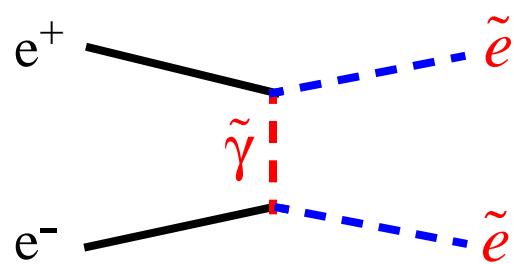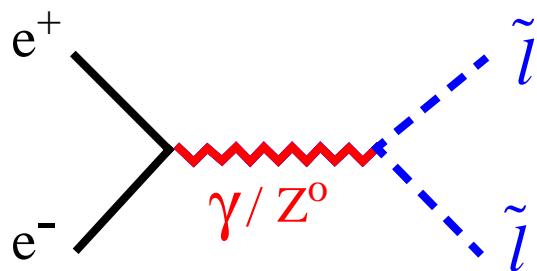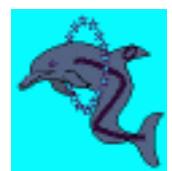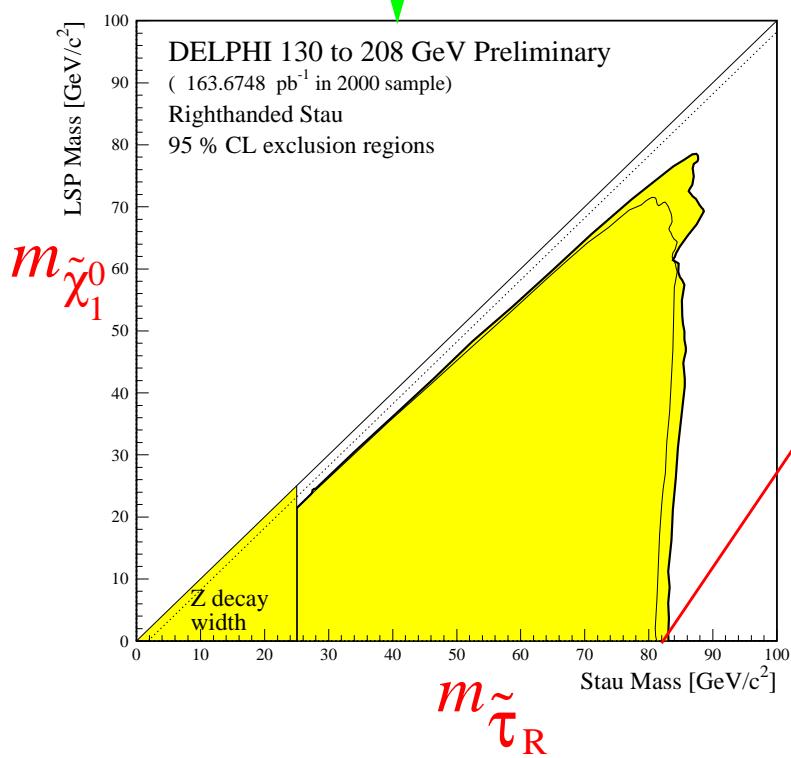
$$\tilde{l}\tilde{l} \rightarrow l\tilde{G} + l\tilde{G}$$

GMSB

Slepton decay length $\propto m_{\tilde{G}}^2$

$L_{\tilde{l}} \ll$ exp.   Acoplanar leptons

$L_{\tilde{l}} \approx$ exp.   Kinks + Displ. vtx

$L_{\tilde{l}} \gg$ exp.   Heavy stable particle

SUGRA

$$\tilde{l}\tilde{l} \rightarrow \tilde{\chi}_1^0\, l + \tilde{\chi}_1^0\, l$$

$m_{\tilde{\chi}_1^0}$

DELPHI 130 to 208 GeV Preliminary
(163.6748 pb^{-1} in 2000 sample)
Righthanded Stau
95 % CL exclusion regions

Z decay width

Stau Mass [GeV/c^2]

$m_{\tilde{\tau}_R}$

√s=130-208 GeV

DELPHI PRELIMINARY

$m_{\tilde{\tau}_R}$

MSUGRA $\tilde{\tau}_R$

Vertex and IP

Stable Heavy Lepton

$m_{\tilde{G}}$

m$_{\tilde{G}}$ (eV/c^2)
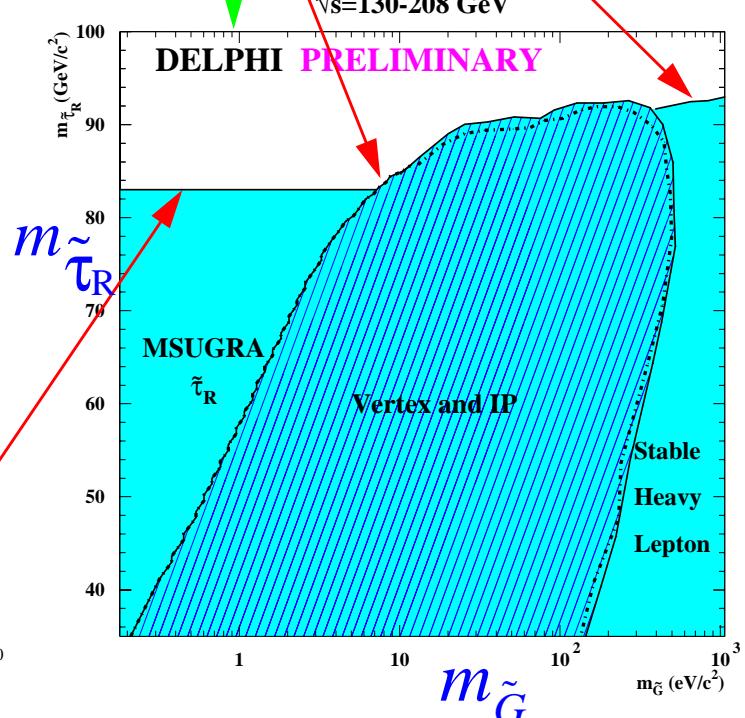
Supersymmetry

Higgs

Two Higgs field and five physical Higgs states in MSSM

e^+ $\quad$ h^0 $\quad$ H^0 $\quad$ A^0

e^- $\quad$ Z^o

e^+ $\quad$ h^0 $\quad$ H^-

e^- $\quad$ Z^o $\quad$ A^0 $\quad$ H^+

$b\bar{b}$

$b\bar{b}$

DELPHI

ECM=204-208 GeV

L=160.78 pb^{-1}

PRELIMINARY

Expected signal for

$m_A = m_h = 100$ GeV

$\tan \beta = 20$

0.3 events

DATA 11 ev.

MC   4.3 ev.

$m_A + m_h$ $\quad$ (GeV)
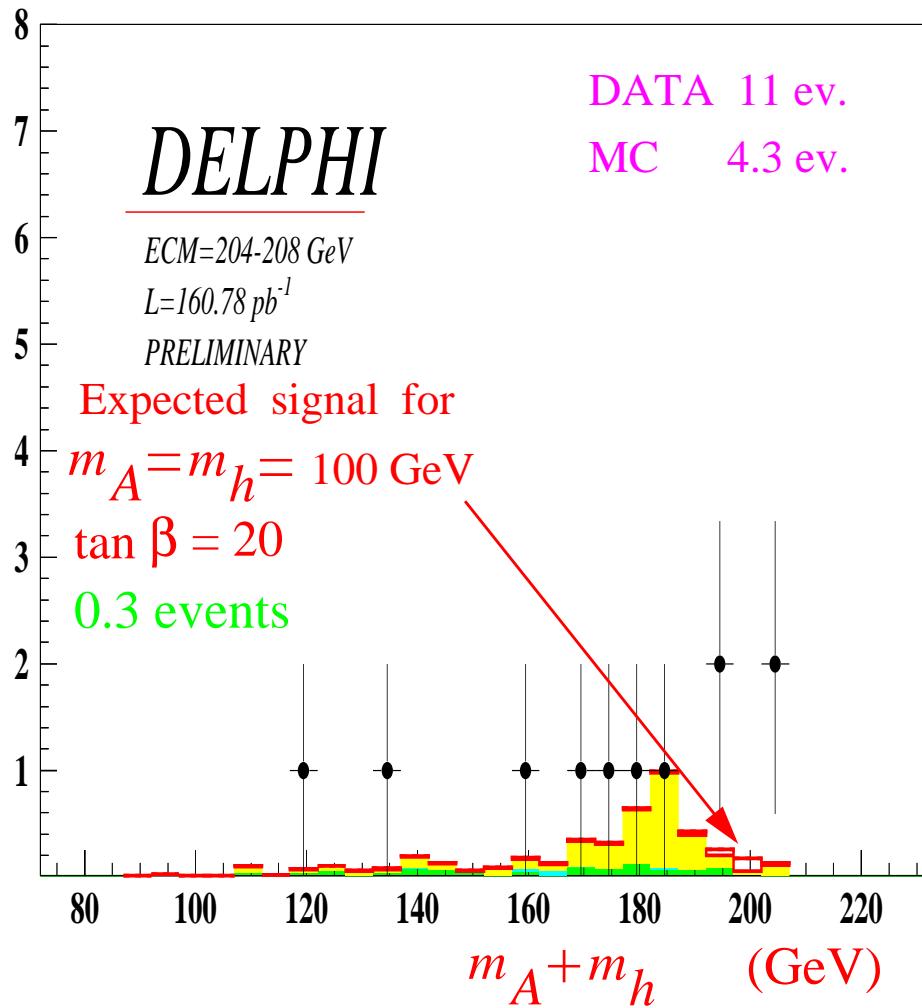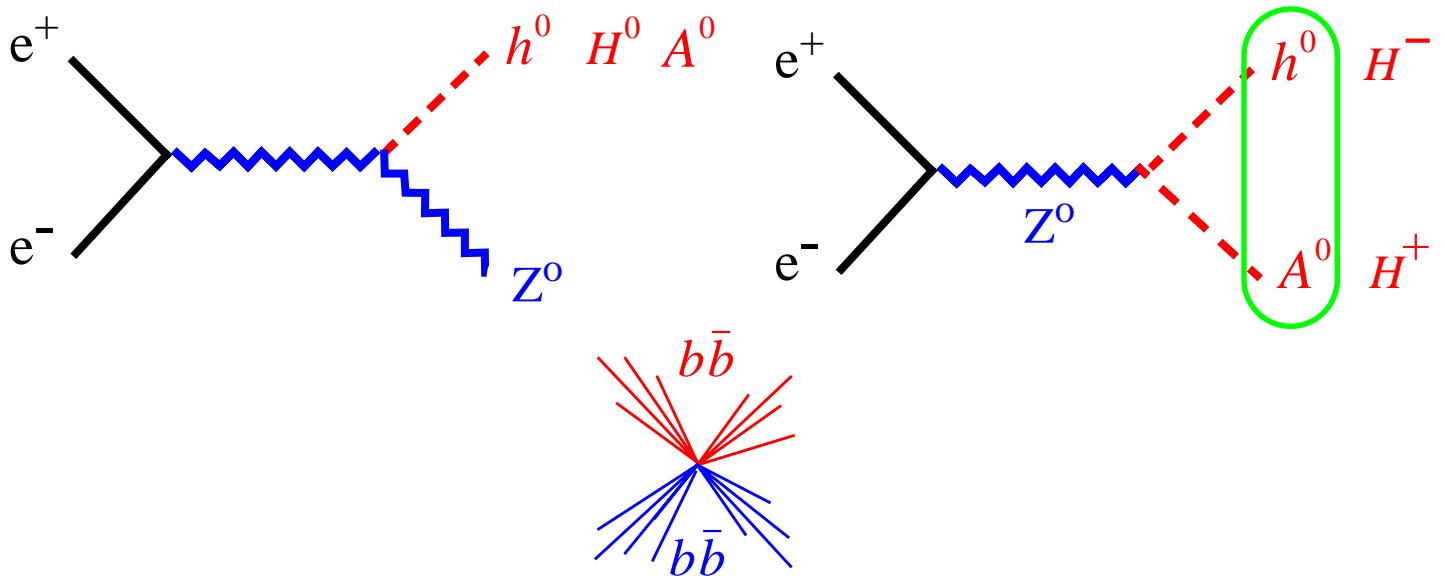
Summary and conclusions of part 2
Supersymmetric searches

✔ Nothing that can be interpreted as a signal has been observed in searches for charginos, neutralinos, sleptons and squarks.

✔ An excess of 4b-jet events is observed in a MSSM Higgs search but the expected cross section in this mass region is small.

Standard Model Higgs search

Motivation

A global fit to electroweak data gives

$m_H < 165$ GeV at 95% CL

Standard Model Higgs search

$$e^+ \qquad H^0 \rightarrow \quad b\bar{b} \quad \tau\bar{\tau} \quad WW \quad gg \quad c\bar{c}$$
$$\qquad\qquad\qquad 74\% \quad 8\% \quad 8\% \quad 6\% \quad 4\%$$

$$e^- \qquad Z^o \rightarrow \quad q\bar{q} \quad \nu\bar{\nu} \quad ee \quad \mu\mu \quad \tau\tau$$
$$\qquad\qquad\qquad 70\% \quad 20\% \quad 3\% \quad 3\% \quad 3\%$$
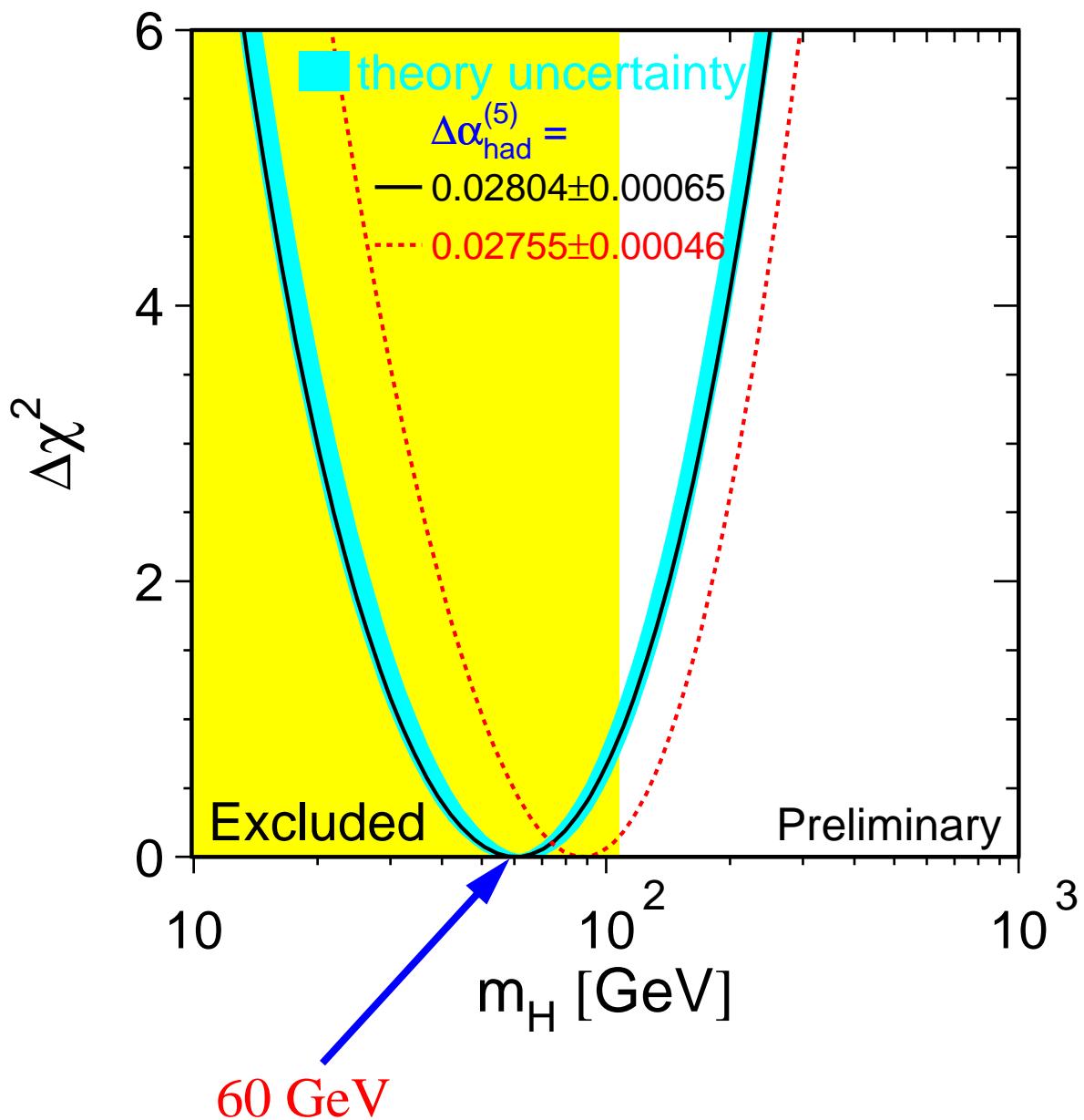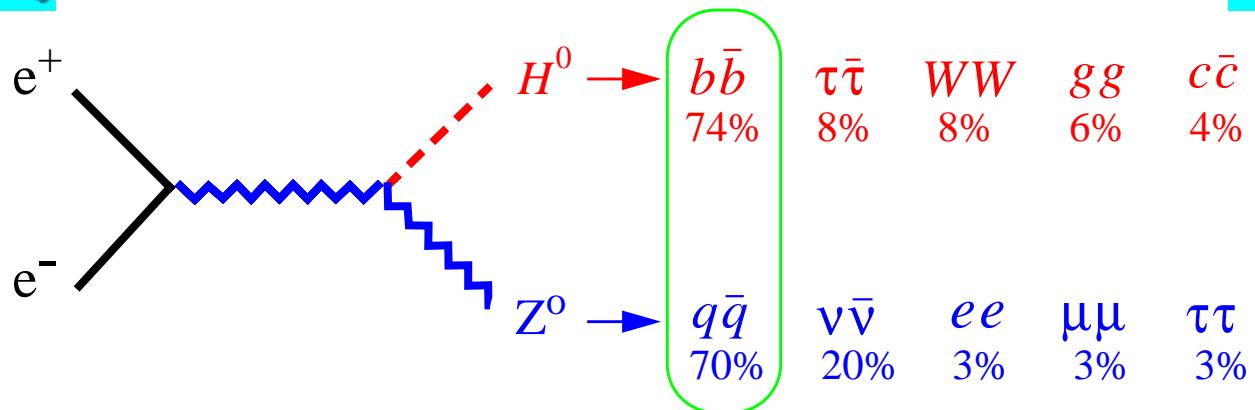
Significant candidates with $m_H > 108$ GeV
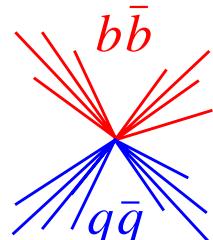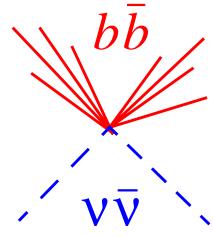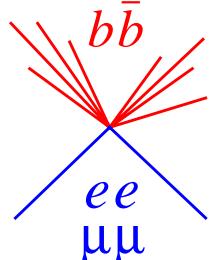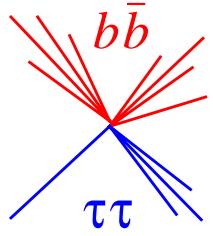
$b\bar{b}$ / $q\bar{q}$	**3 events**
$b\bar{b}$ / $\nu\bar{\nu}$	**No events**
$b\bar{b}$ / ee $\mu\mu$	**No events**
$b\bar{b}$ / $\tau\tau$	**No events**

Standard Model Higgs search

B tagging

$$e^+e^- \rightarrow Z^0 \rightarrow q\bar{q}$$

udsc quarks

b quarks

B-tagging variable

$$e^+e^- \rightarrow WW \rightarrow q\bar{q}l\nu$$

Not WW events

B-tagging variable
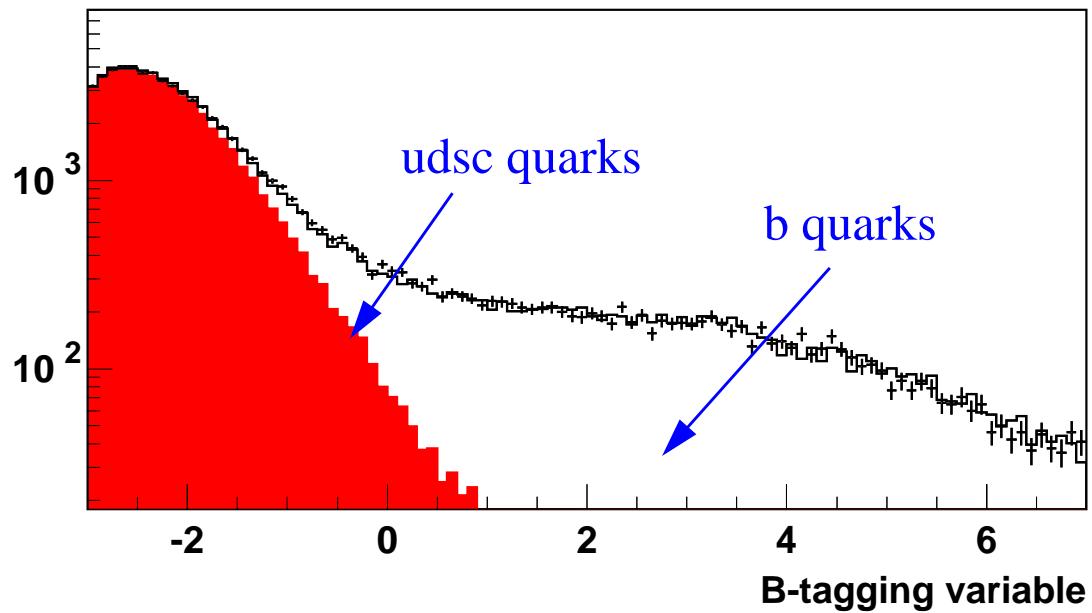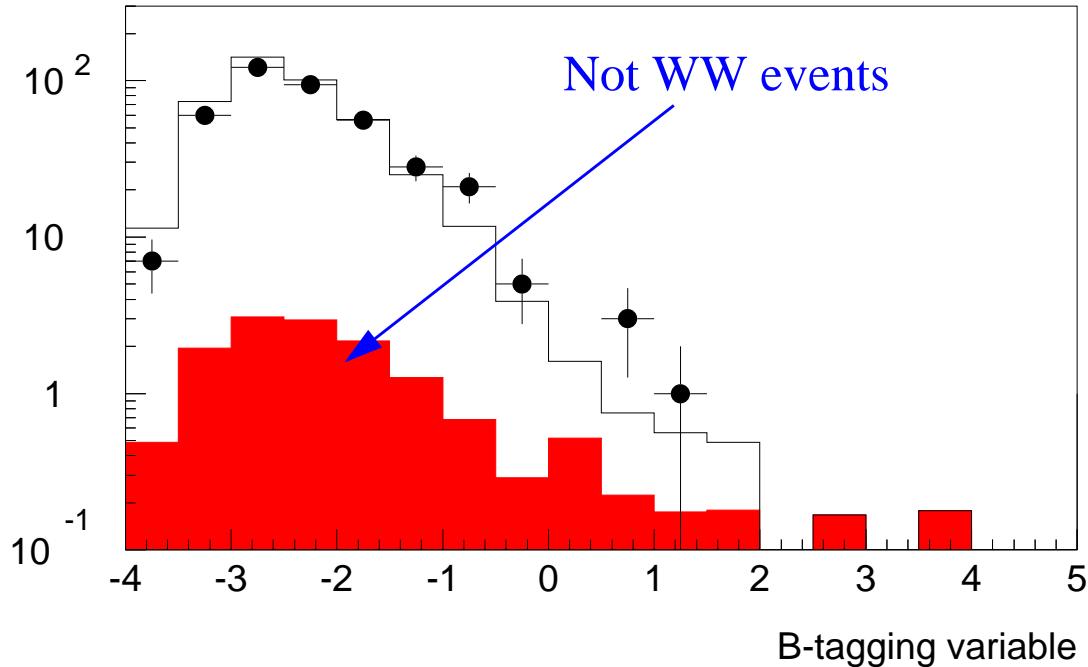
Standard Model Higgs search

Neural Network Input

After preselection:
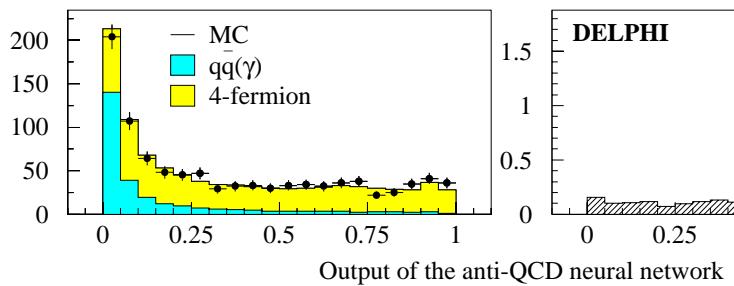
Higgs:
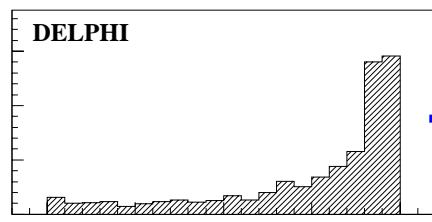
MC
$q\bar{q}(\gamma)$
4-fermion

DELPHI

Output of the anti-QCD neural network

Number of events per bin

b-tagging variable of the dijet with highest content in b-quarks

WW ideogram probability

ZZ ideogram probability

QCD
b tag
WW
ZZ
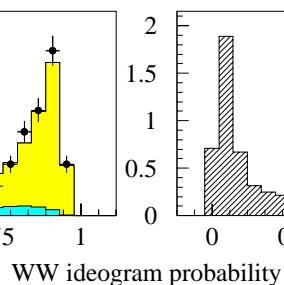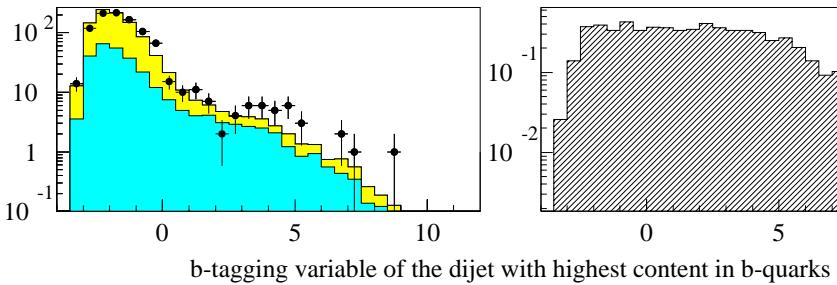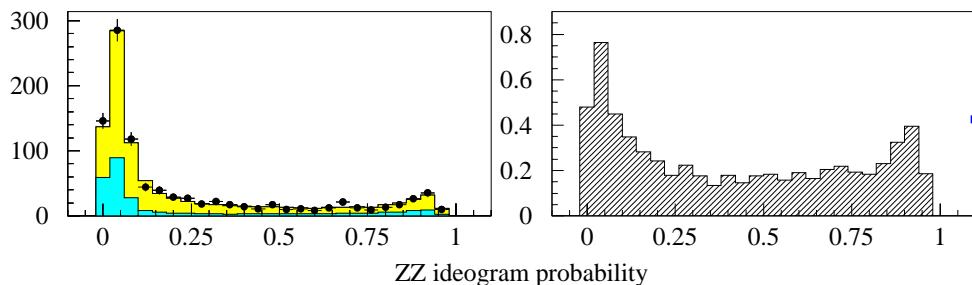
Neural Network

NNW output

Standard Model Higgs search

Neural Network Output

Data

Higgs at $m_H = 114$ GeV

WW $\rightarrow q\bar{q}\, q\bar{q}$

Higgs $m_H = 114$ GeV

$\begin{cases} Z\,\gamma \rightarrow b\bar{b}gg\gamma \\ ZZ \rightarrow b\bar{b}\,q\bar{q} \end{cases}$

Data

Monte Carlo

161 pb^{-1}

161 pb^{-1}
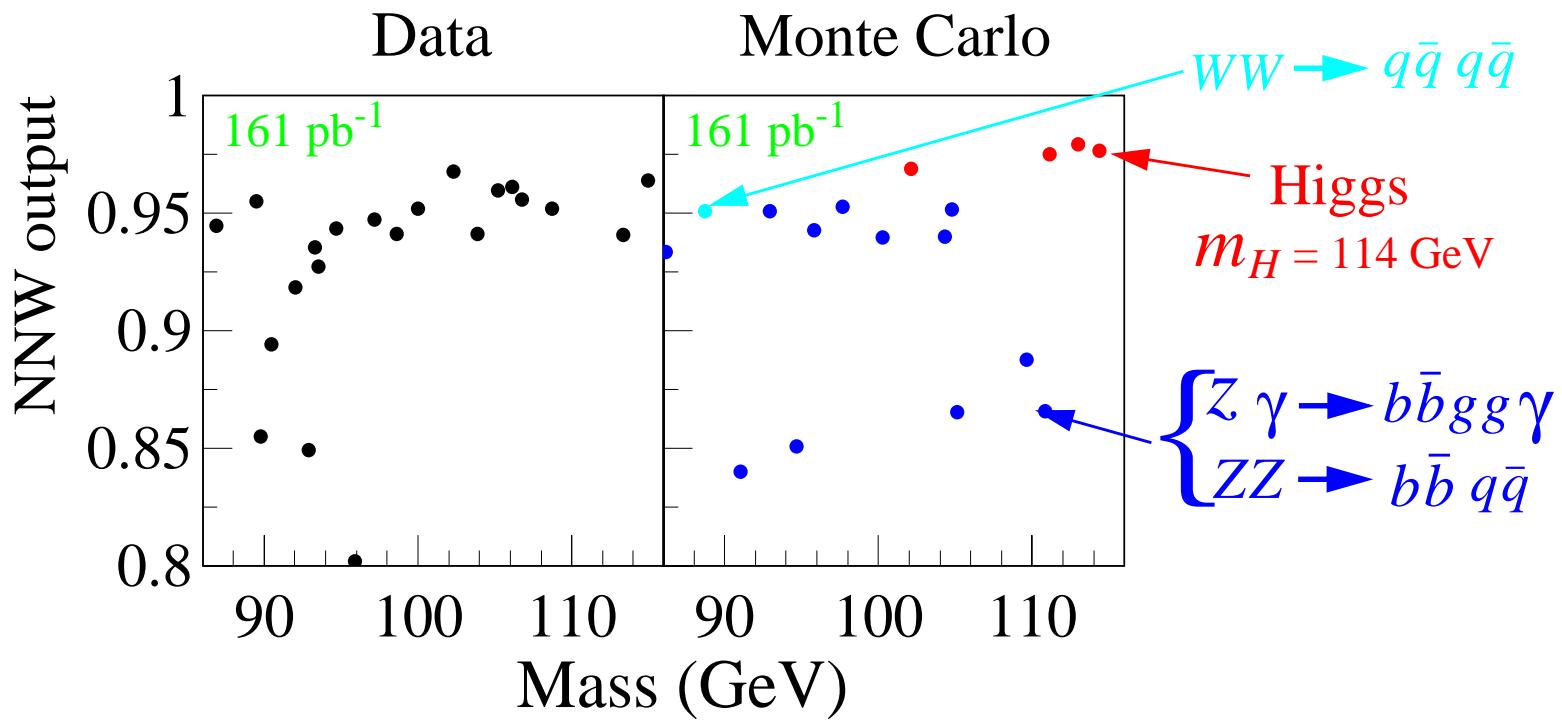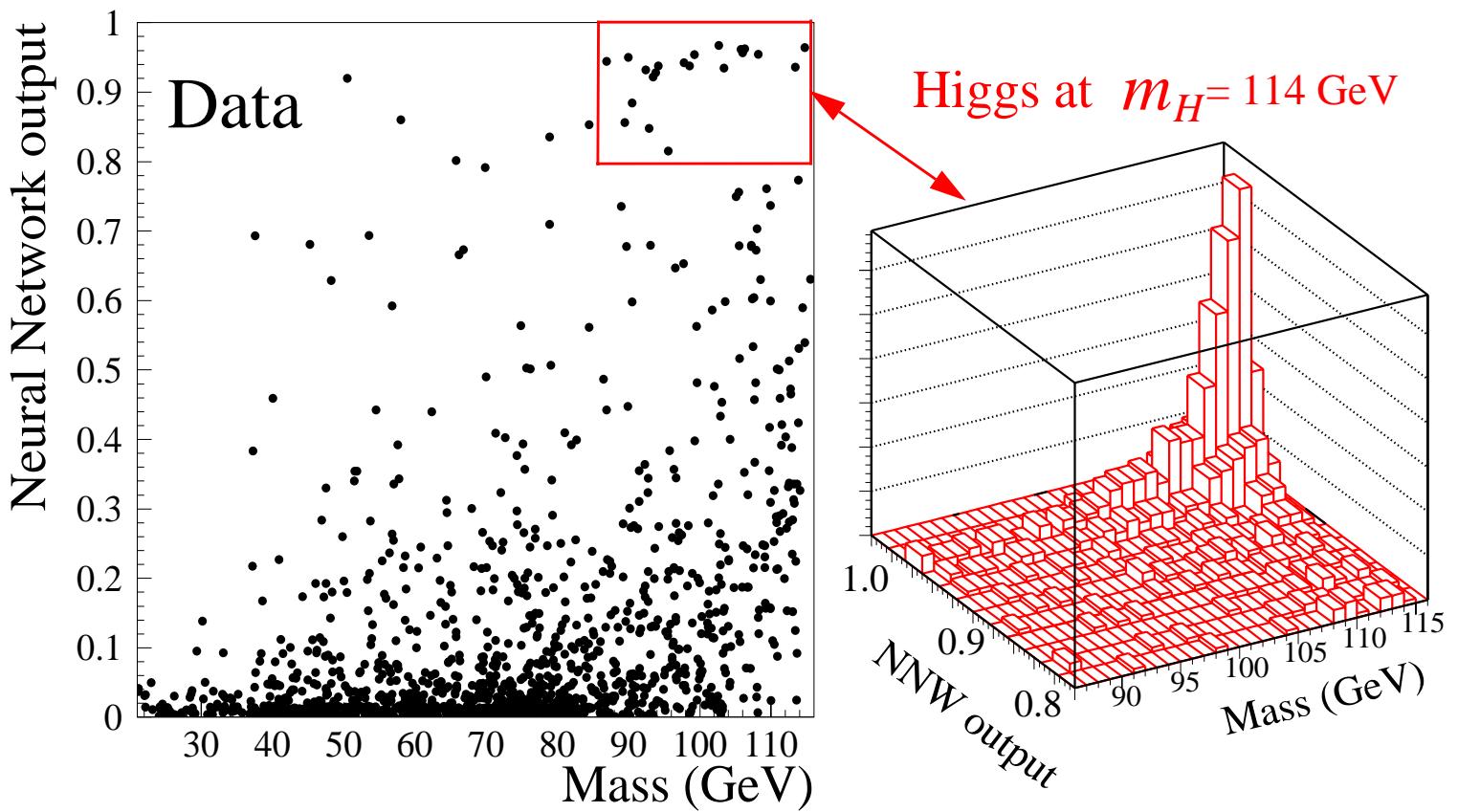
Standard Model Higgs search

Data - Monte Carlo (dis)agreement
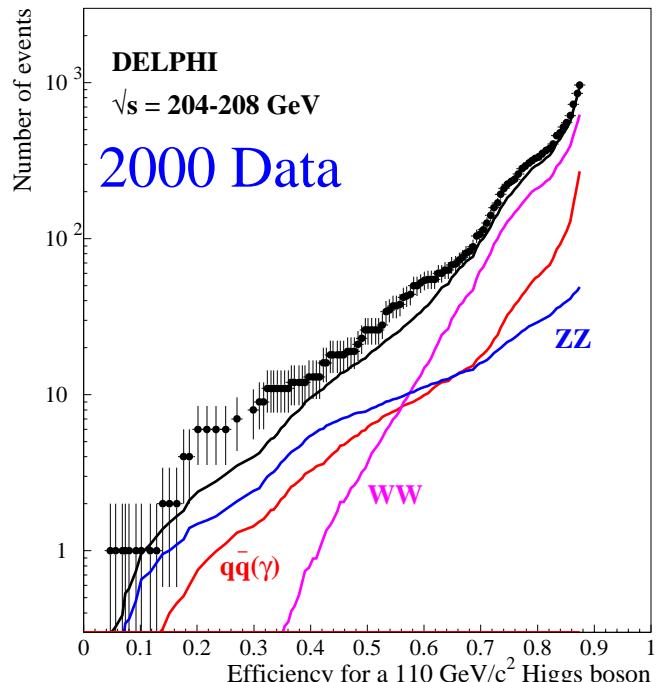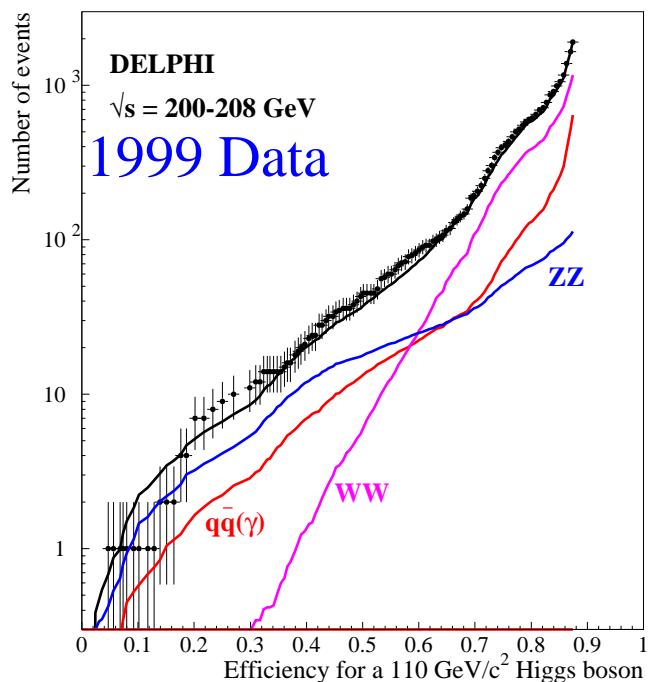
$$e^+e^- \longrightarrow ZZ \longrightarrow b\bar{b}\, q\bar{q}$$
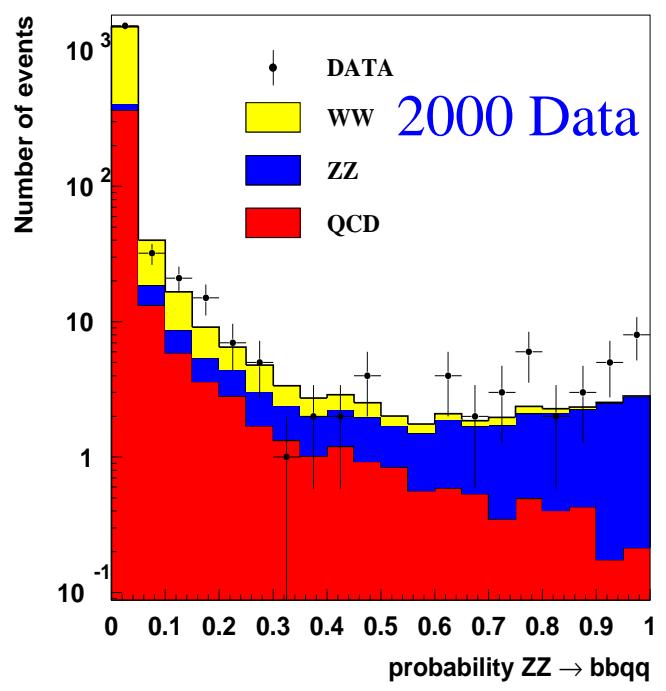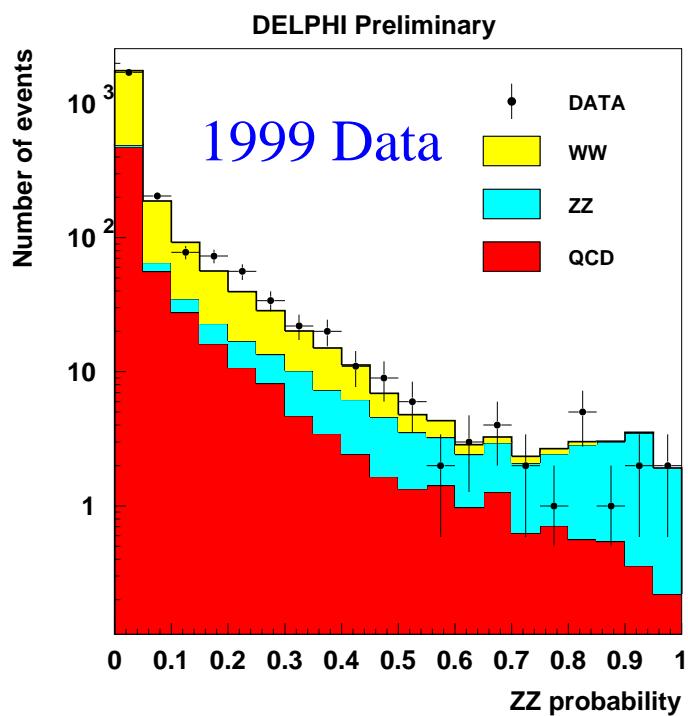
Standard Model Higgs search

Mass distributions

4-jet channel

NNW > 0.9
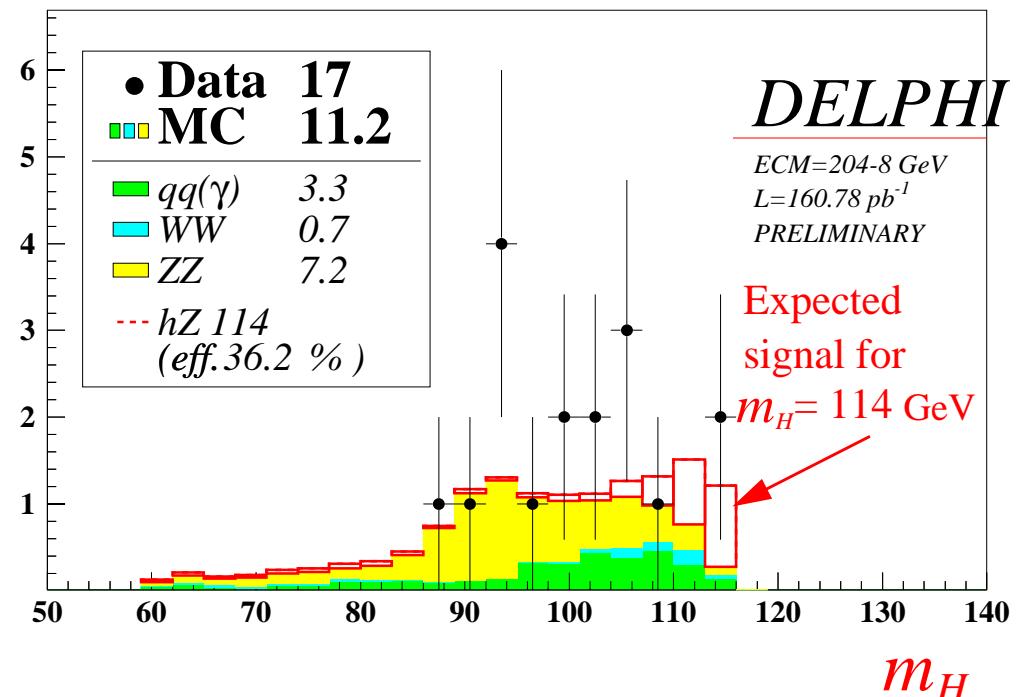
• Data	17
MC	11.2
$qq(\gamma)$	3.3
WW	0.7
ZZ	7.2
--- hZ 114	
(eff. 36.2 %)	

DELPHI

ECM=204-8 GeV
L=160.78 pb⁻¹
PRELIMINARY

Expected signal for m_H= 114 GeV

m_H

All channels

$\sqrt{s} < 206$ GeV

Signal/Back. > 1

DELPHI   *PRELIMINARY*

E_{cm}=204-206 GeV
L=86 pb⁻¹

• Data	14
MC	14.9
signal	2.45
(mH=112)	

Expected signal for m_H= 112 GeV

m_H

All channels

$\sqrt{s} > 206$ GeV

Signal/Back. > 1

DELPHI   *PRELIMINARY*

E_{cm}=206-208 GeV
L=75 pb⁻¹

• Data	12
MC	13.5
signal	2.14
(mH=114)	

Expected signal for m_H= 114 GeV

m_H
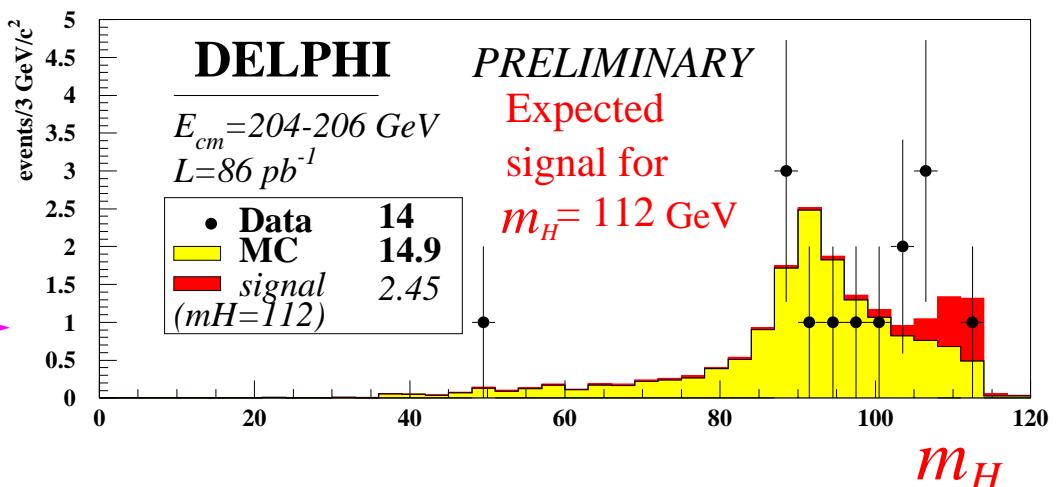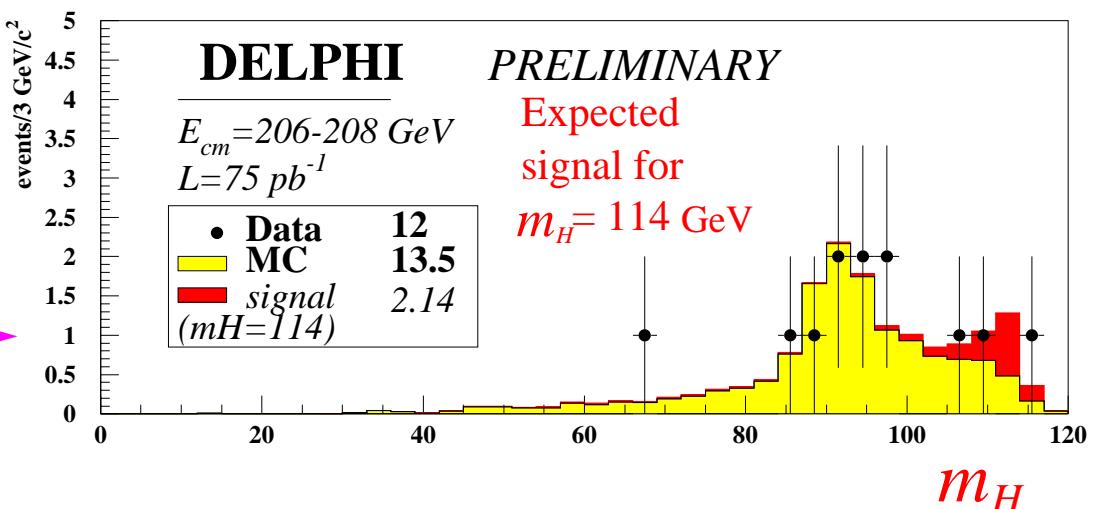
Standard Model Higgs search

Statistical treatment of data

The Likelihood ratio estimator

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

Input: $\begin{cases} S(m_H, m, NNW) \\ B(m, NNW) \end{cases}$ Probability dist. for signal and background

Obtained from smoothed 2-dim. Monte Carlo dist.

$S(m_H = 114 \text{GeV}, m, NNW)$

Before smoothing

Old smooth. alg.

Mass (GeV)

$S(m_H = 114 \text{GeV}, m, NNW)$

New smooth. alg.

Mass (GeV)
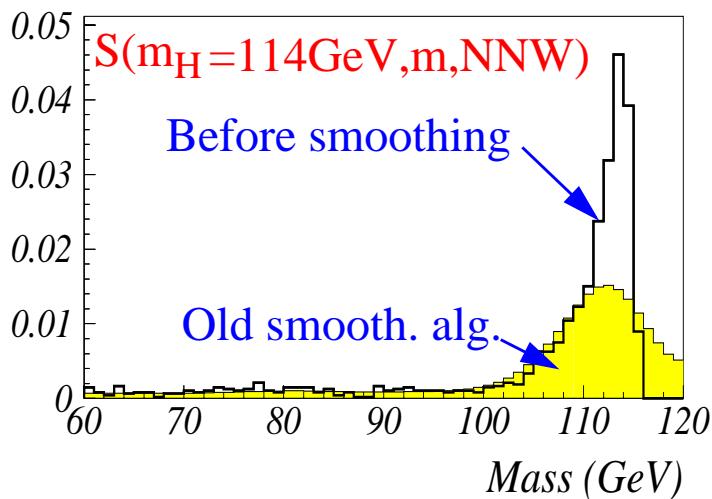
Problem with the smoothing algorithm solved by
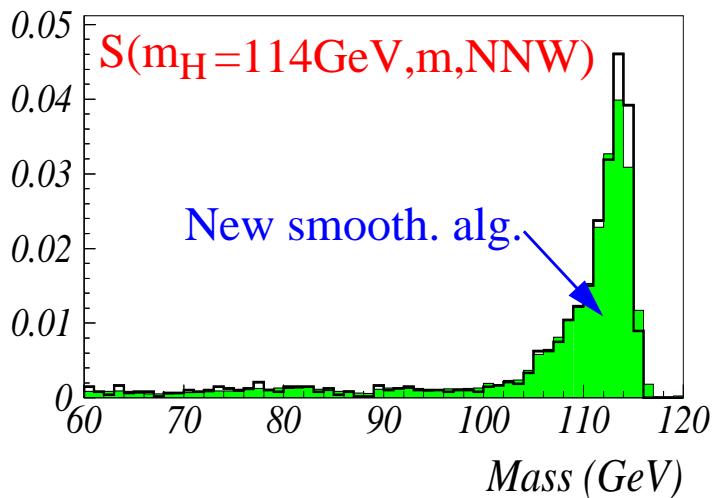
✓ Generation of 3.5 million new Monte Carlo events

✓ Improvement of the algorithm

☞ The expected exclusion limit was increased by 1.4 GeV

Standard Model Higgs search

Log Likelihood distributions

$$-2 \ln(Q) \quad \text{versus} \quad m_H$$
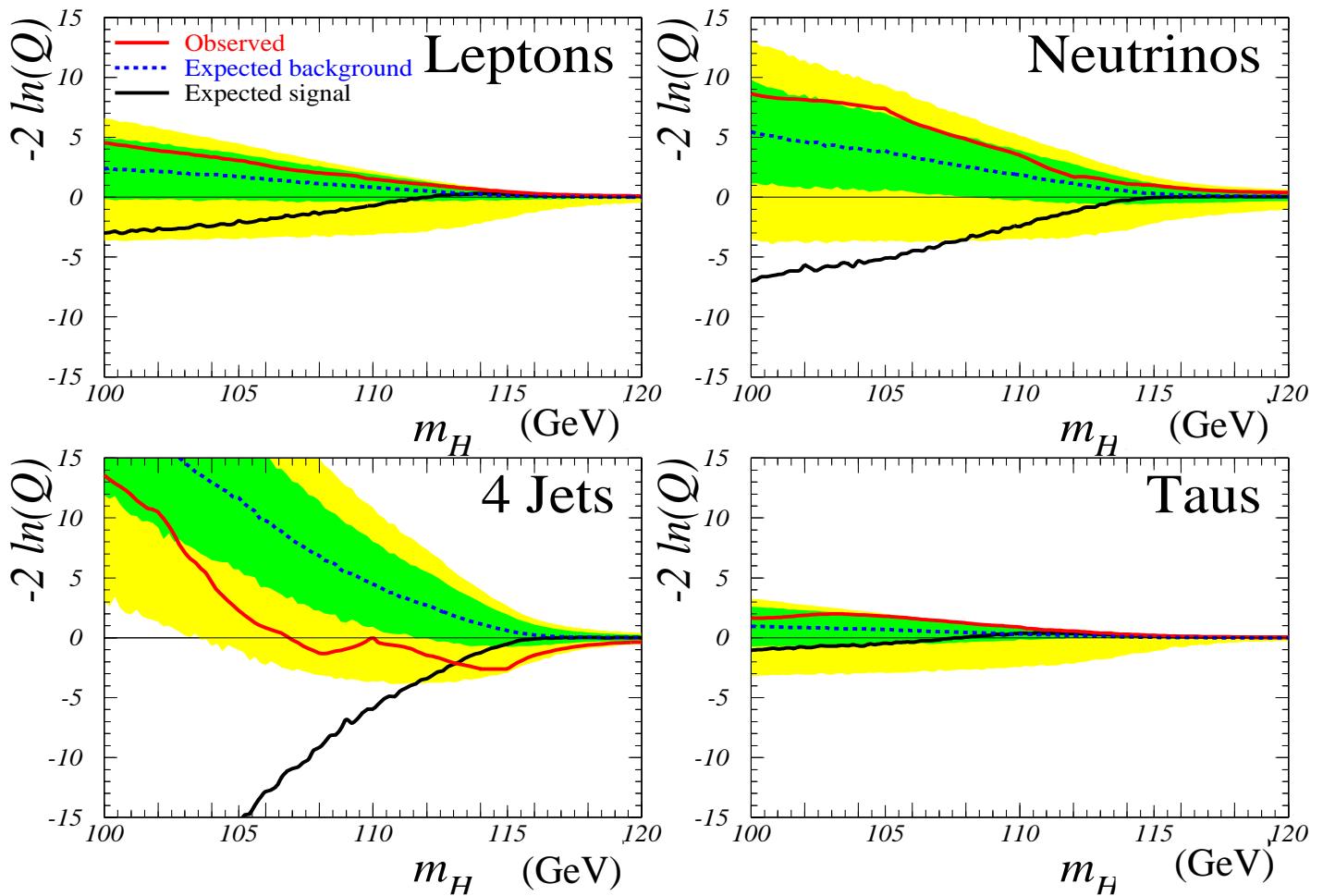
Standard Model Higgs search

All channels combined
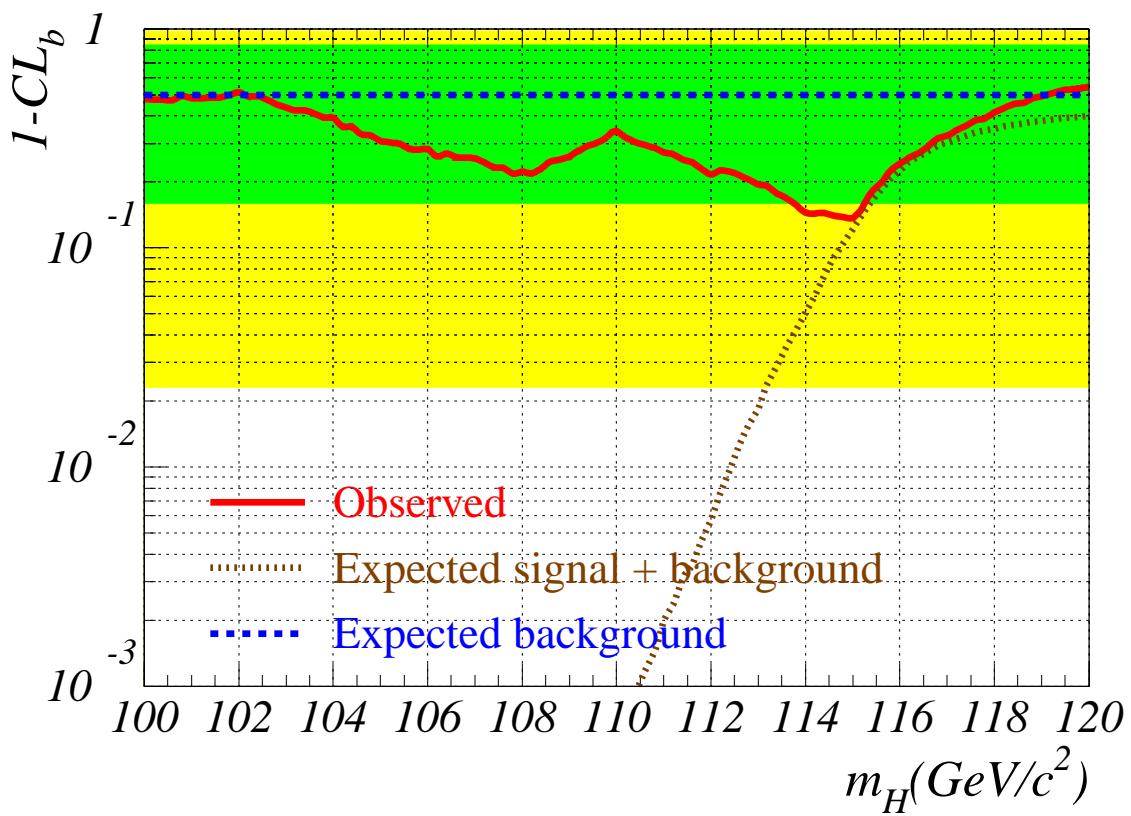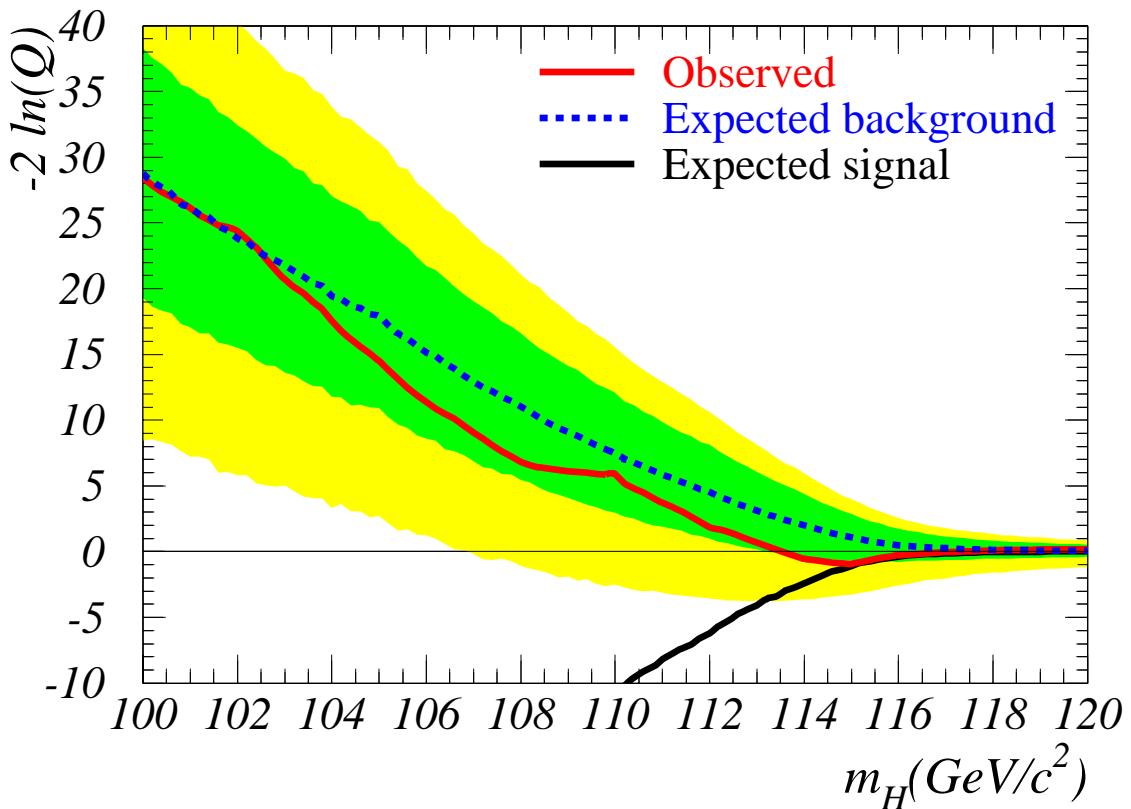
Standard Model Higgs search

Higgs Candidates

udsc quarks

b quarks

10^3

10^2

-2   0   2   4   6

B-tagging variable

Event 16533

b-tag: 2.9 , 1.9 (2 sec. vtx)
-1.0 , -1.4

m_H= 108.9 GeV

NNW = 0.96

Event 947

b-tag: 2.9 , -0.7 (1 sec. vtx)
-0.9, -1.6

m_H= 114.3 GeV

NNW = 0.96

$m_h = m_A = 100$ GeV
$b\bar{b}\, b\bar{b}$ candidates

Event 5726

b-tag: 0.7 , 0.6 (1 sec. vtx)
-1.3, -1.4

m_H= 113.6 GeV

NNW = 0.95

Neural Network output

Mass (GeV)

1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8

85   90   95   100   105   110   115

Event 5797

b-tag: 4.8 , 2.6 (2 sec. vtx)
-0.0, -0.5

m_H= 97.3 GeV or 113.4 GeV

NNW = 0.95

1

Standard Model Higgs search

Event 947

Jet 1   40 GeV

Jet 2
38 GeV

Jet 4
42 GeV

Jet 3   30 GeV
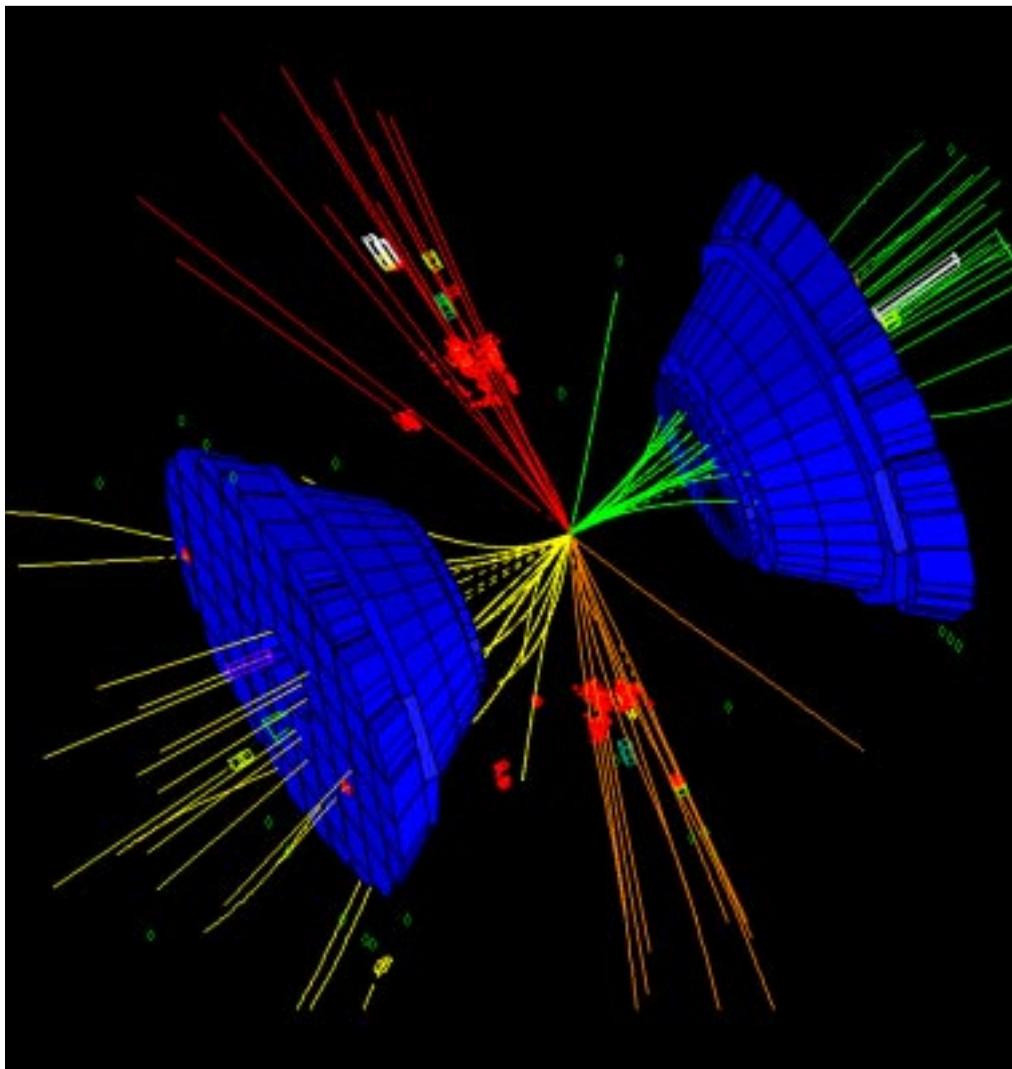
5C fit $\begin{cases} m_{j2j4} = 114.3 \text{ GeV} \\ m_{j1j3} = m_Z \end{cases}$

b-tag: 2.2   1-QCD: 0.02

WW: 0.94   ZZ: 0.03

NNW = 0.96

Standard Model Higgs search

Jet 1   61 GeV

Jet 3
48 GeV
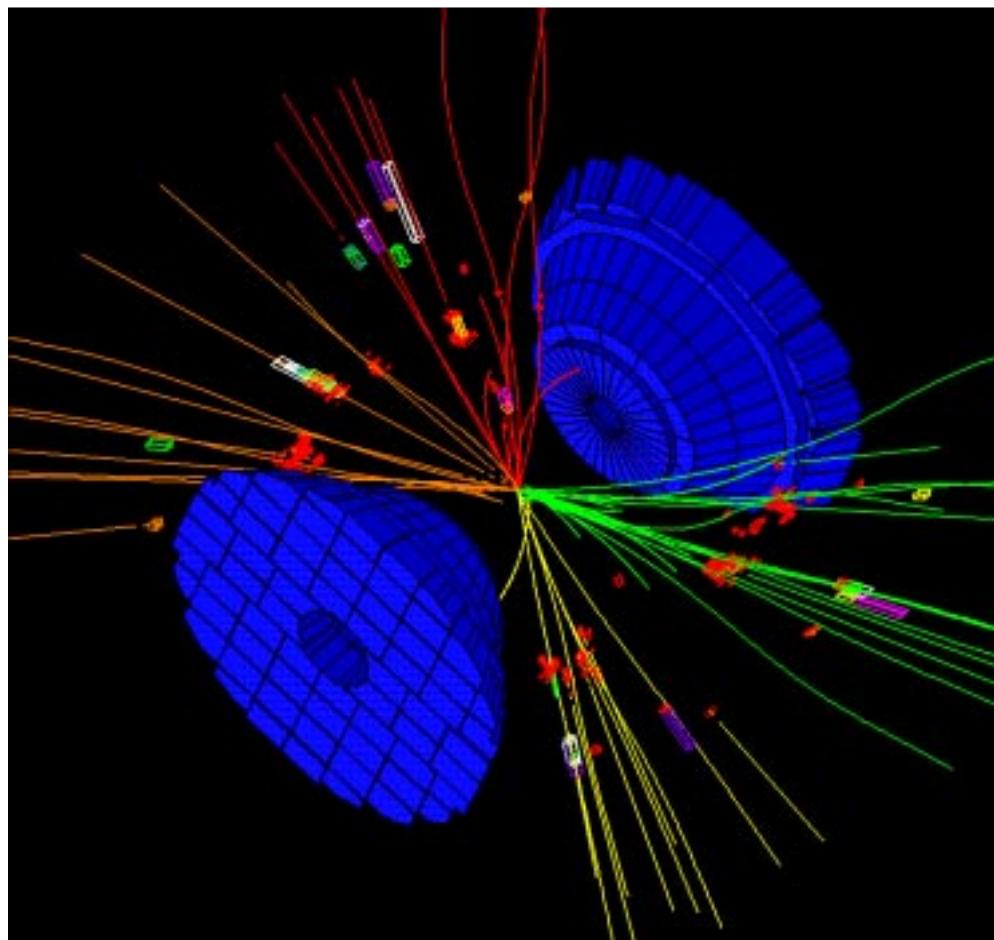
Jet 2
47 GeV

Jet 4   42 GeV

5C fit $\begin{cases} m_{j1j4} = 113.6 \text{ GeV} \\ m_{j2j3} = m_Z \end{cases}$

b-tag: 1.3   1-QCD: 0.07
WW: 0.01   ZZ: 0.93

NNW = 0.95

Standard Model Higgs search

Event recorded on October 3

Jet 4   29 GeV   1 sec. vtx.

Jet 3
41 GeV

Jet 2
48 GeV
1 sec. vtx.

Jet 1
51 GeV
1 sec. vtx.
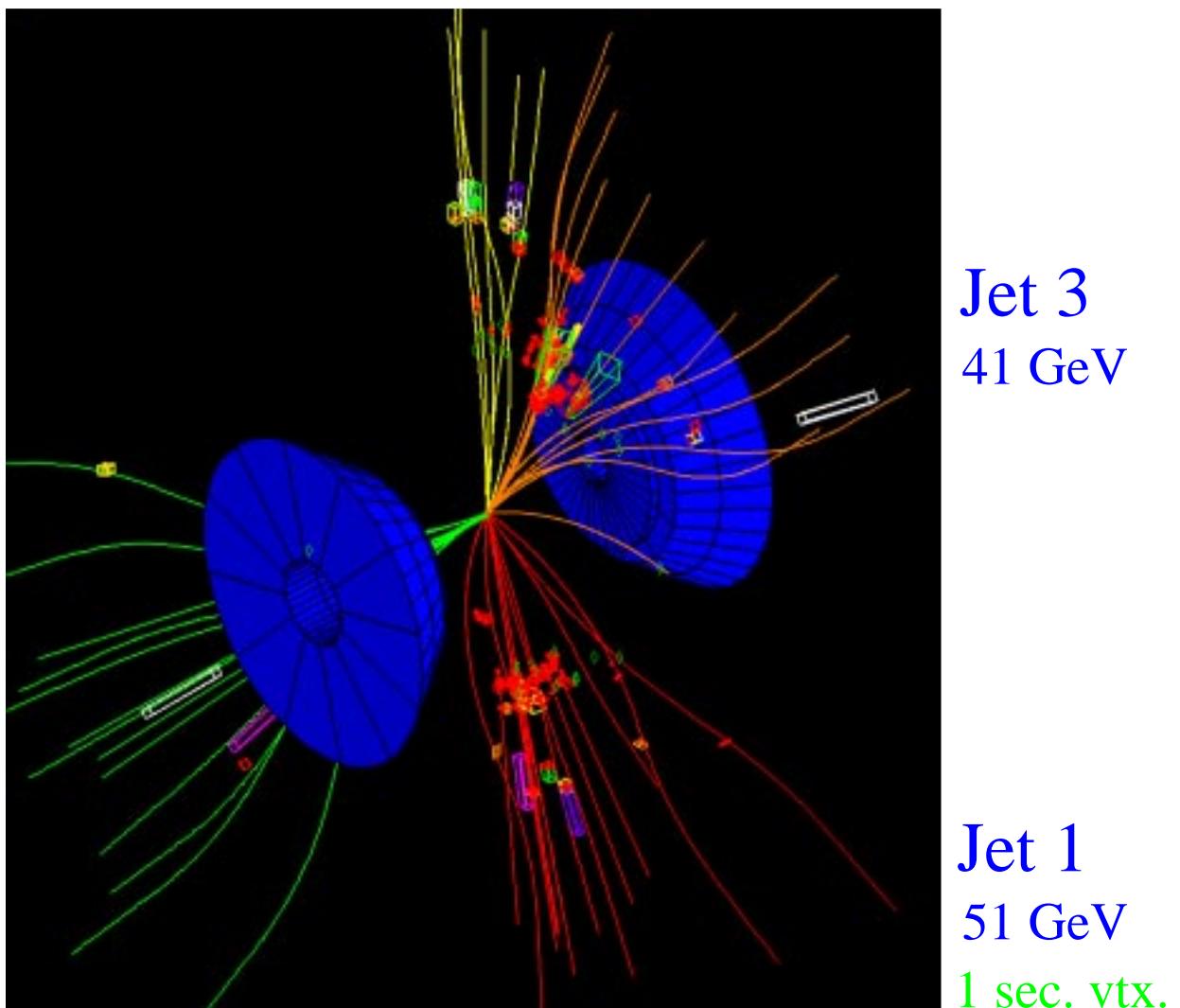
5C fit $\begin{cases} m_{j1j4} = 111.5 \text{ GeV} \\ m_{j2j3} = m_Z \end{cases}$

b-tag: 0.5   1-QCD: 0.13

WW: 0.07   ZZ: 0.39

NNW = 0.97

Summary and conclusions of part 3
Search for the Higgs boson
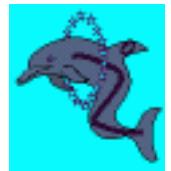
✔ An excess of 4-jet events with b-tagged jets is observed in several physics analysis.

✔ There are too many of these events to be able to explain all of them by a 114 GeV Higgs.

✔ DELPHI has a few 4-jet events that are compatible with the expectation of a 114 GeV Higgs but they do not by themselves constitute a significant signal.

✔ No candidates have been observed in leptonic channels.

The DELPHI collaboration is grateful to LEP for a magnificent year and to the IT division for help with simulation.

A copy of the transparancies is available at http://hedberg.home.cern.ch/hedberg/lepfest.ps