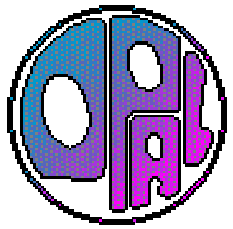
Search for Higgs Bosons with OPAL at LEP



Fredrik Åkesson, Universität Bonn

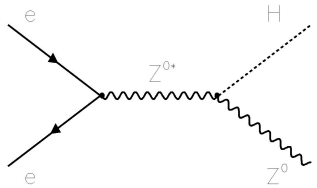
Standard Model Search
- Introduction
- Analysis Strategy
- Analysis Results

Other Higgs Searches
- MSSM Higgs
- Charged Higgs
- Flavour Independent
- Fermiophobic Higgs
- Invisible Higgs

Production of Higgs Bosons in the SM

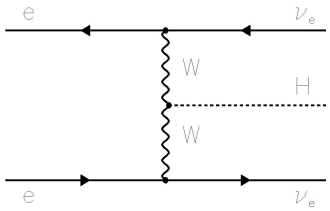
Main production processes

(at energies within reach of LEP)



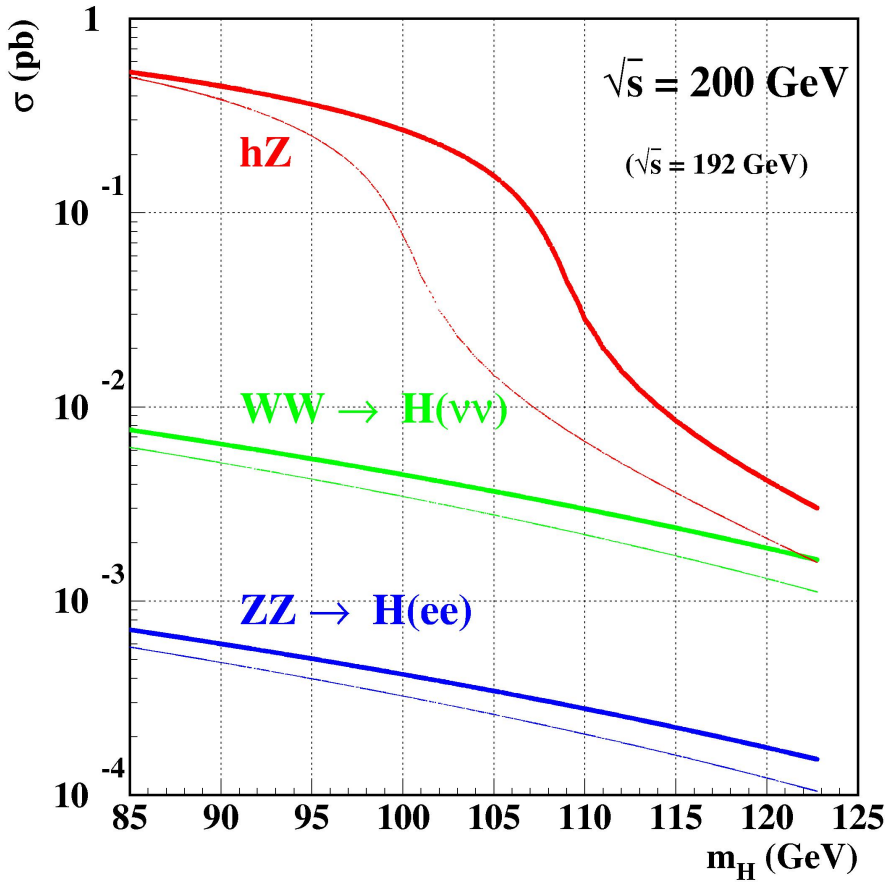
$m_H \sim (\sqrt{s} - m_Z)$

Higgs Strahlung
(dominant mode)

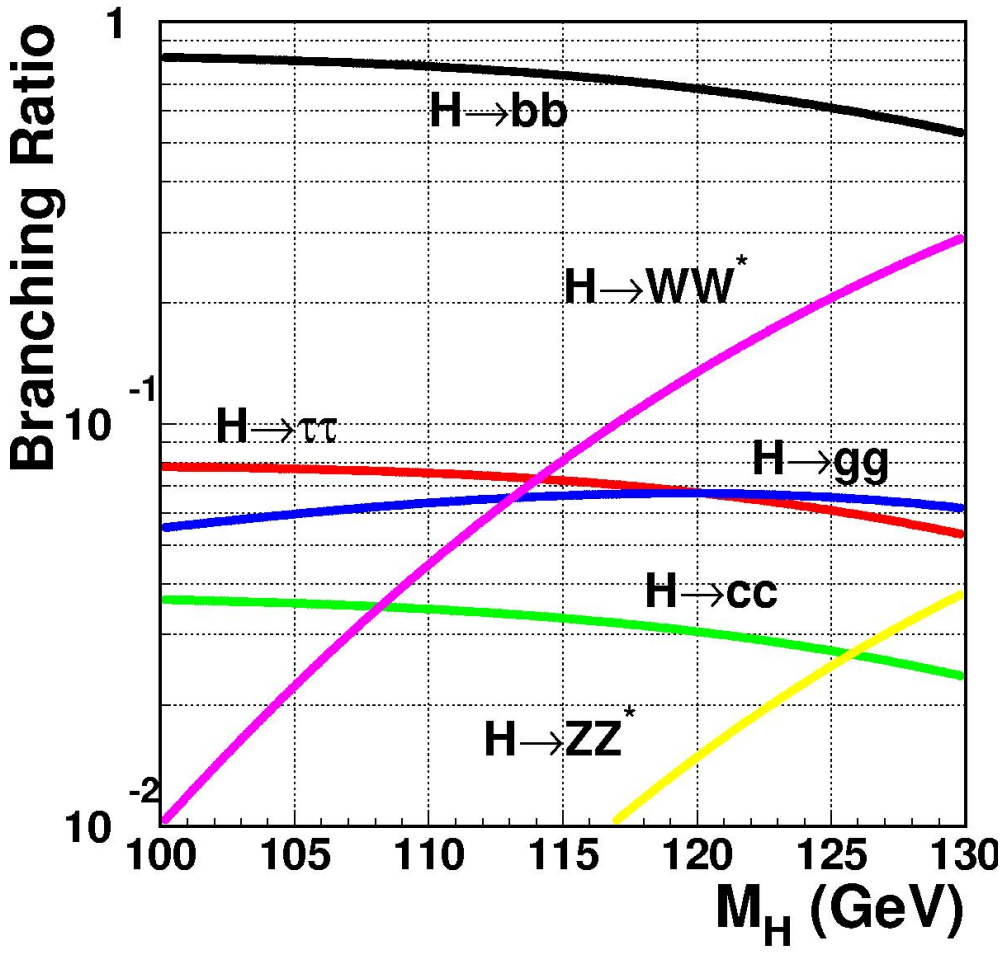


$m_H > (\sqrt{s} - m_Z)$

Fusion Processes
(small contribution)



Decay of the Higgs Boson

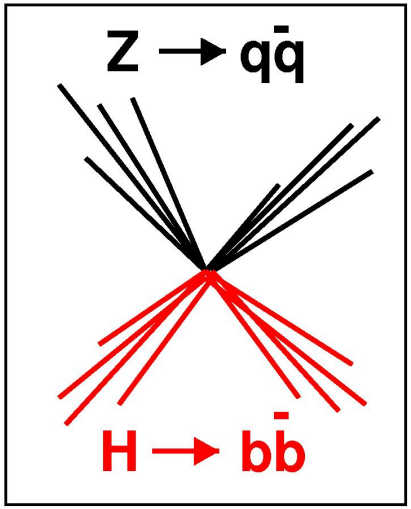


→ coupling to light fermions suppressed

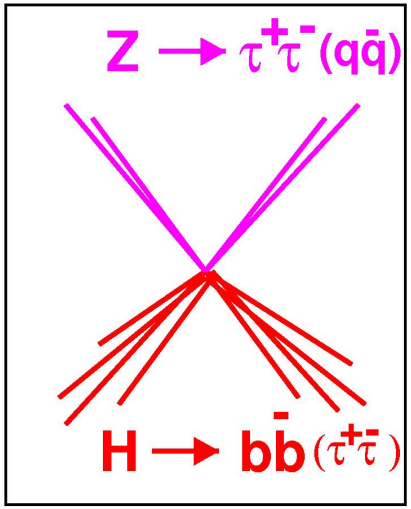
→ decay of Higgs to $b\bar{b}$ at LEP (BR~75-85%)

→ b-tag is essential

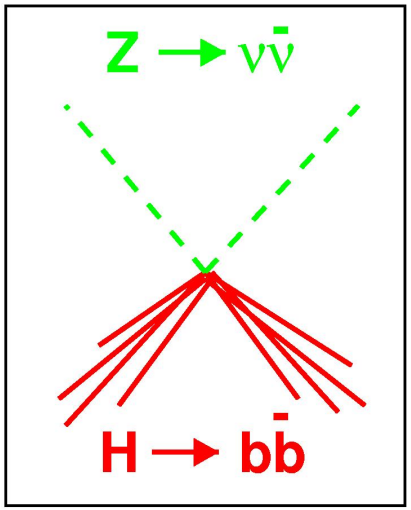
Search Topologies at OPAL



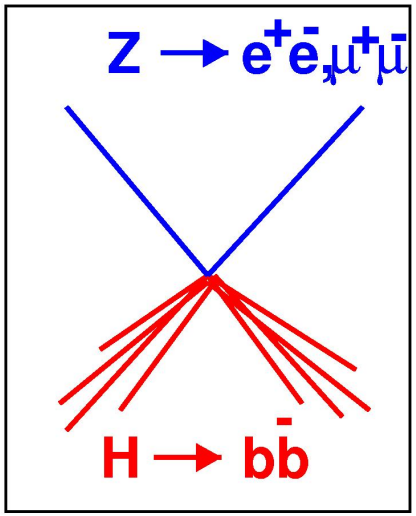
Four Jet Channel
- 50-60% in SM
- efficiency 40-50%



Tau Channel
- 10% in SM
- efficiency ~35%

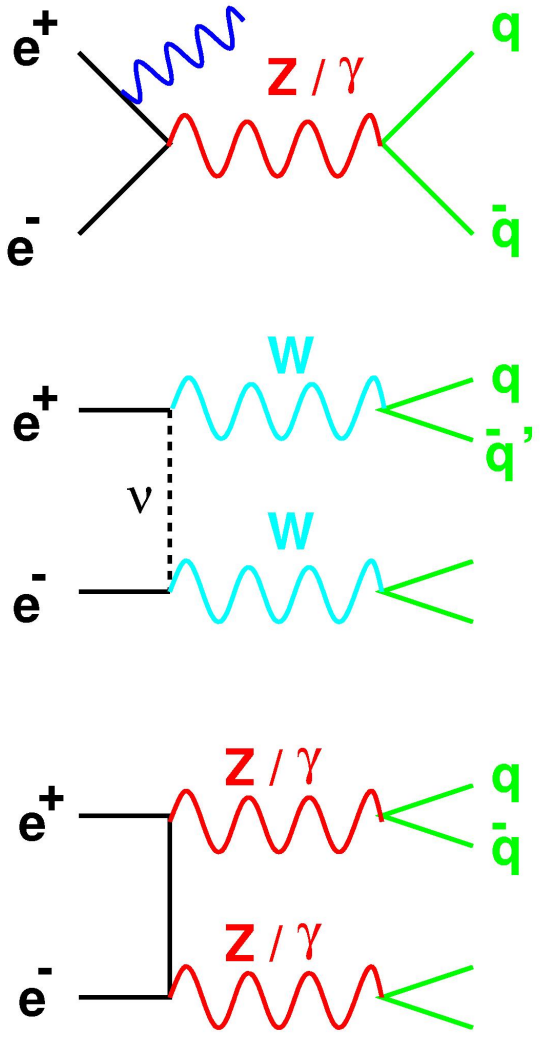


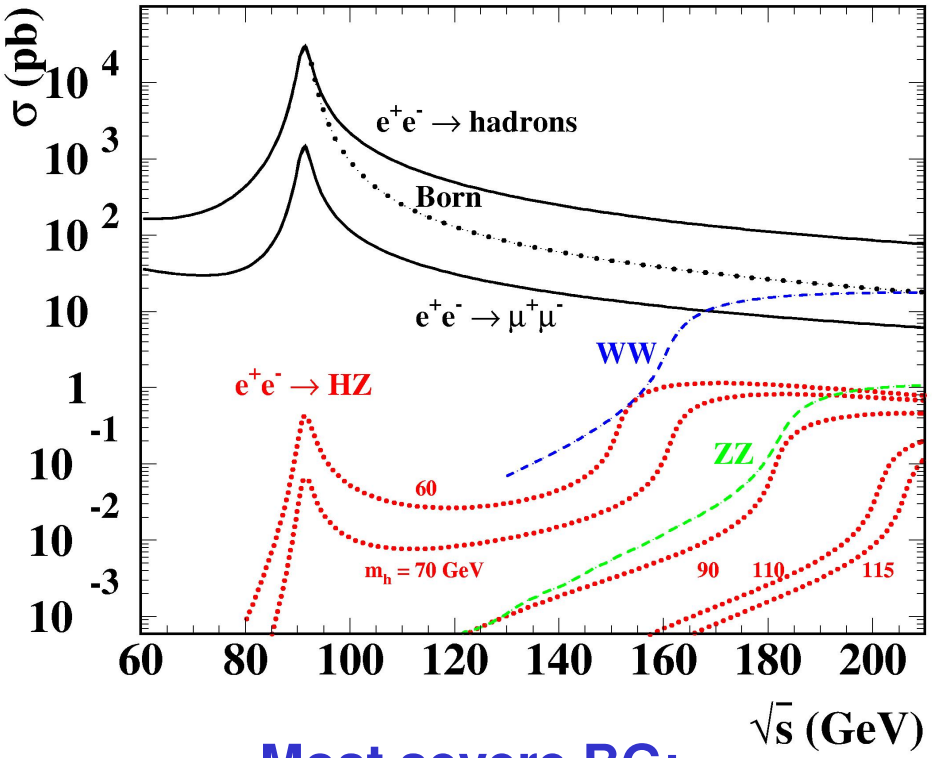
Missing Energy
- 17% in SM
- efficiency 30-40%



Lepton Channel
- 6% in SM
- efficiency 50-60%

Background Processes



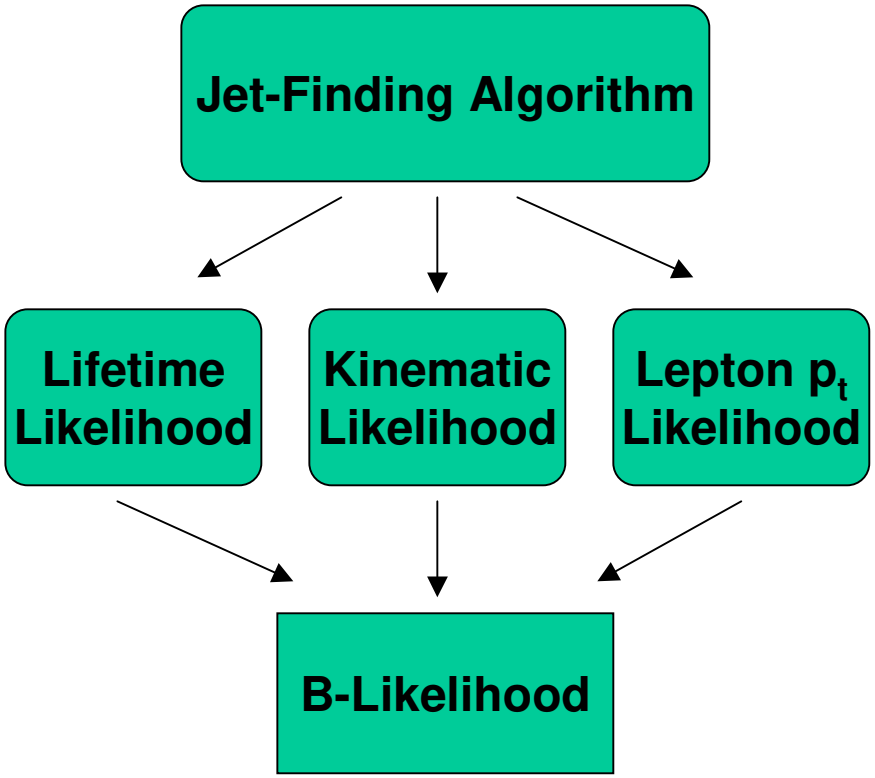


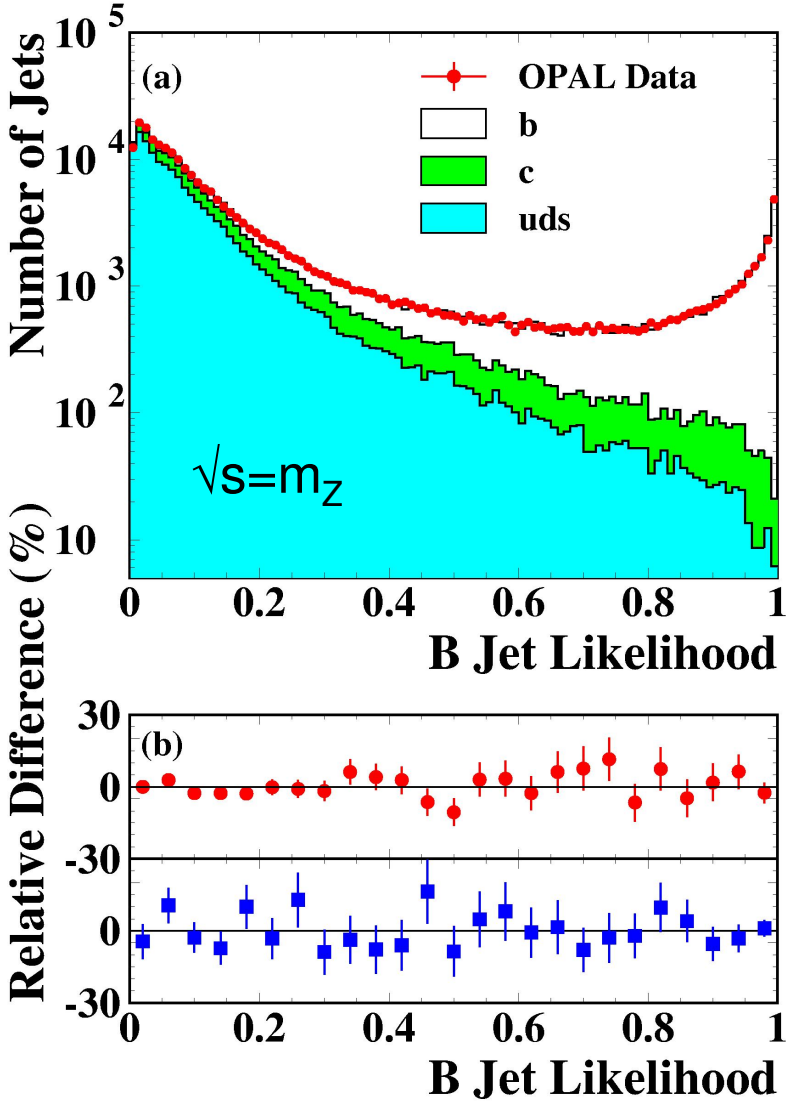
Most severe BG:
- **irreducible ZZ**
- **qq at higher m_H**

Only good b-tag will reduce ZZ and WW bgd

B-Hadon Tagging

Determination of ‚B-content' in Jet

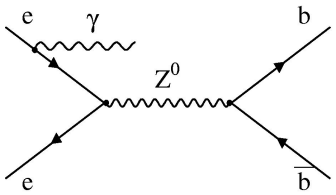




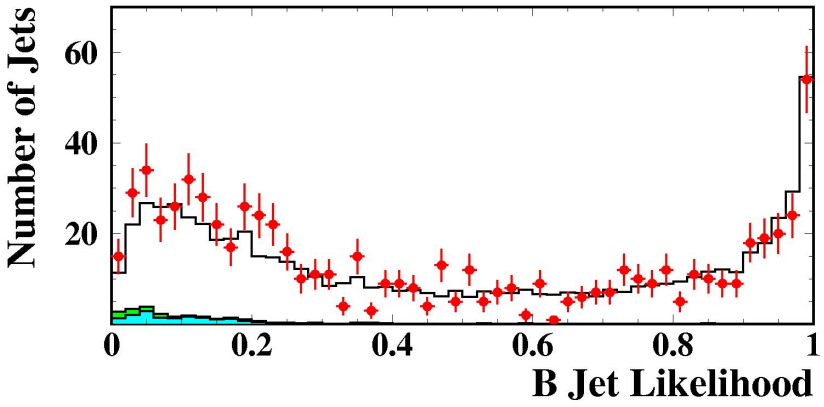
High Energy Check of B-Tagging

Efficiency Check

Select Radiative Returns



- tag and remove photon
- force event into two jets
- tag one b-jet
- check b-LH of second jet



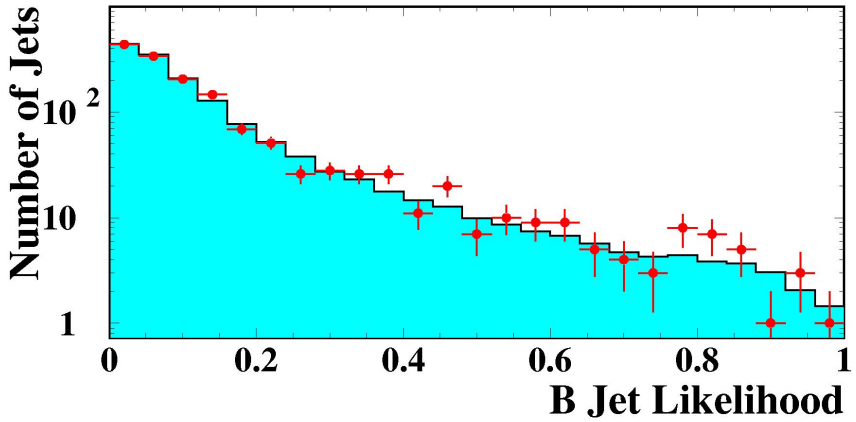
Fake Rate Check

Select Non-b sample

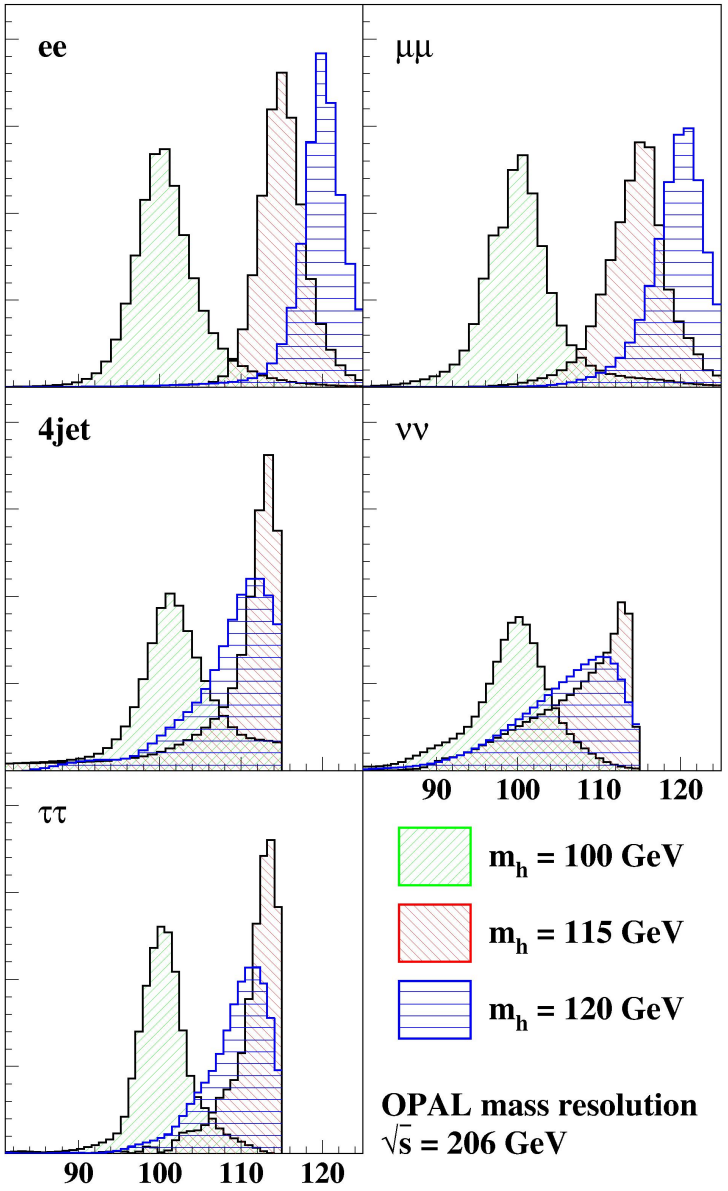
$ee \rightarrow WW \rightarrow qqe\nu,\ qq\mu\nu$

(W→bq: CKM suppressed)

- tag and remove lepton
- force event into two jets
- check b-LH of the jets



Mass Reconstruction



Lepton Channels:

- recoil mass

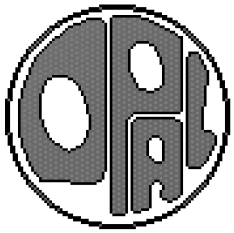
4-Jet Channel:

- energy-momentum conservation
- M(jet-jet)=m_Z
- Best jet-jet combination with LH

4-Jet/Tau/Missing Energy:

- kinematic fit
- sharp kinematic edge at (206-m_Z) GeV ~ 115 GeV

Analysis Strategy



1. **Soft Preselection**
   - visible energy
   - number of charged tracks
   - ....

Generic topological cuts

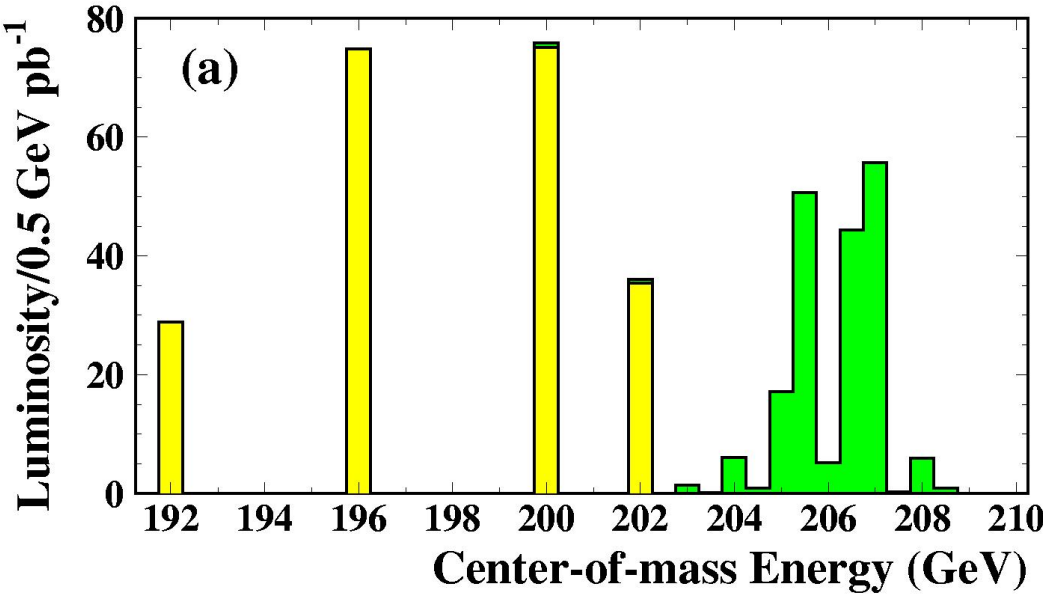
2. **Likelihood-Selection**
   - b-Tag
   - kinematics
   - ....

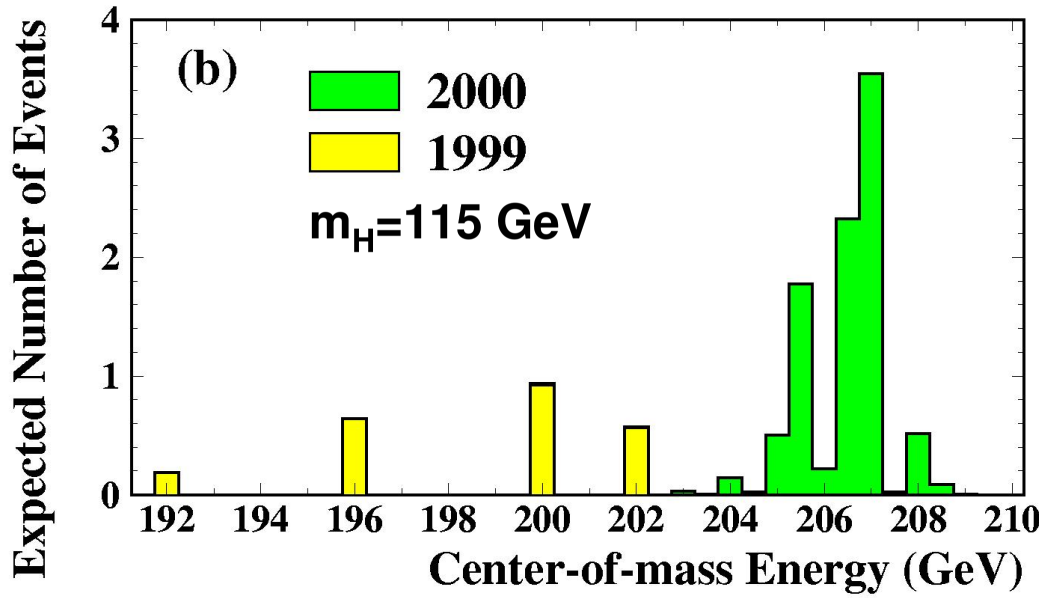
Signal to backgroud separation

3. **Discriminating Variable**
   - reconstructed mass m_H
   - likelihood value
   - ....

Additional separating power

Data Set Y1999+Y2000

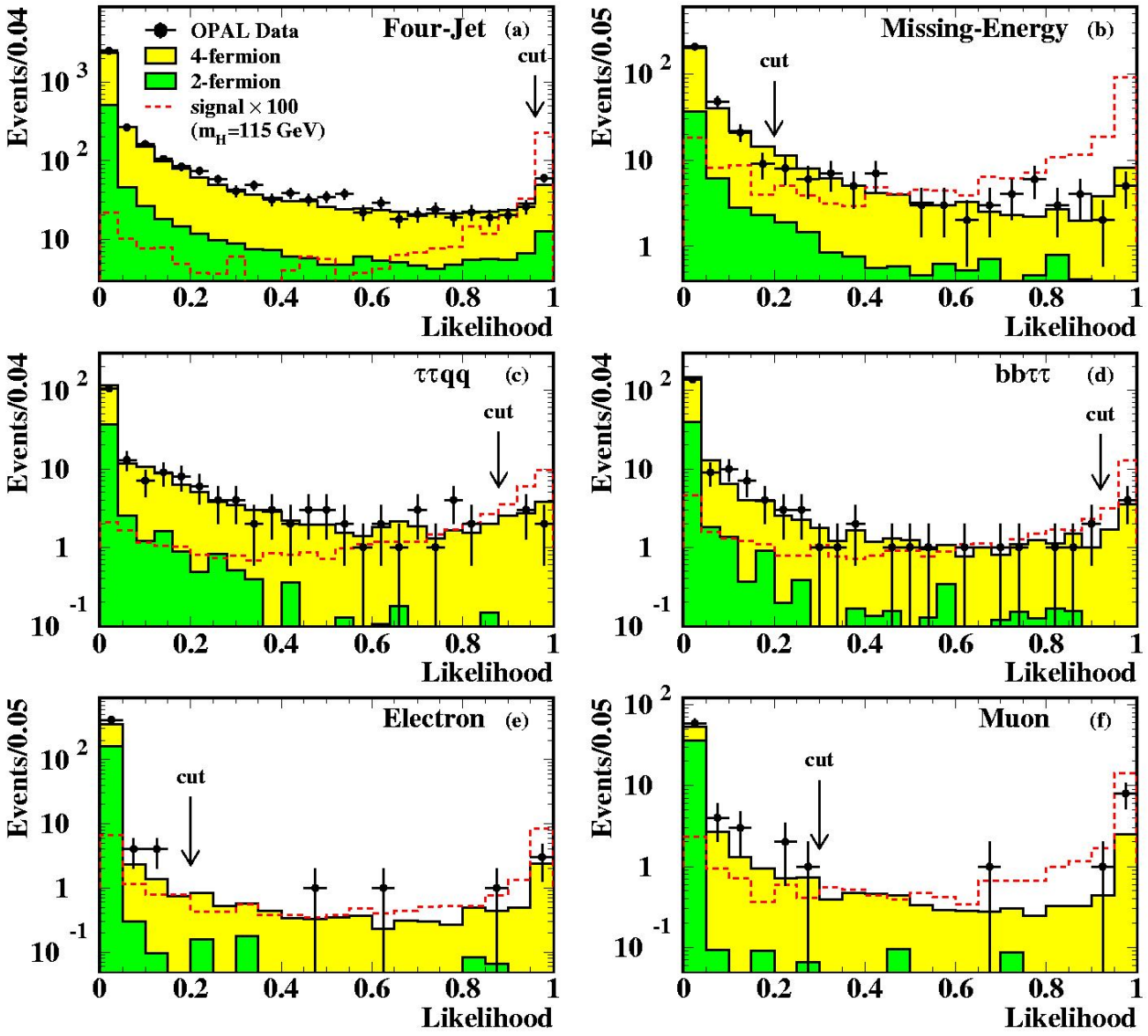




Total Luminosity ~430 pb^{-1}

Expected signal events (m_H=115 GeV) ~11 Events

Likelihood Distributions

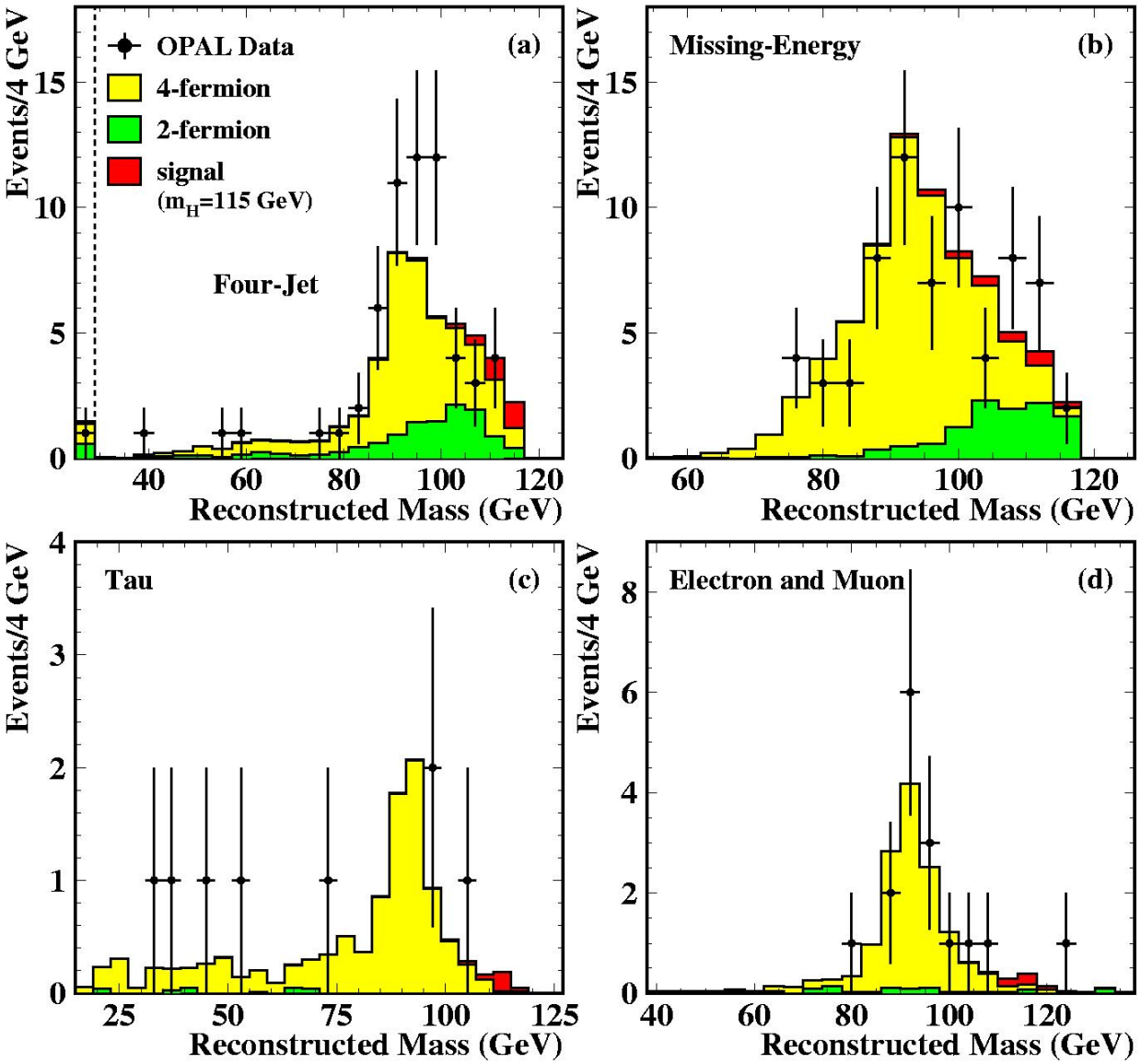


Good agreement between data/MC

Apply likelihood cut →

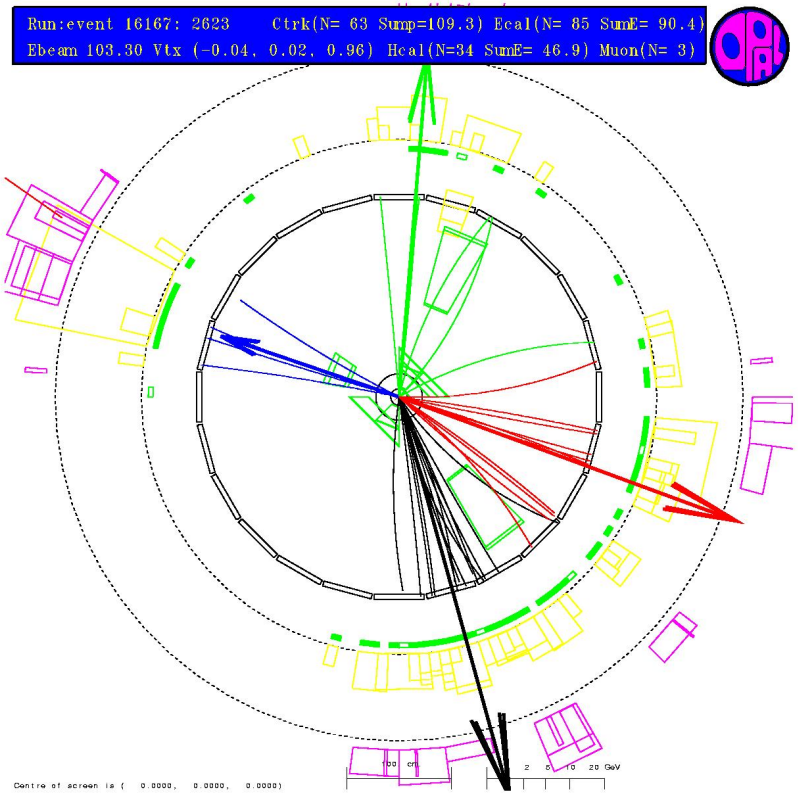
Selected Events

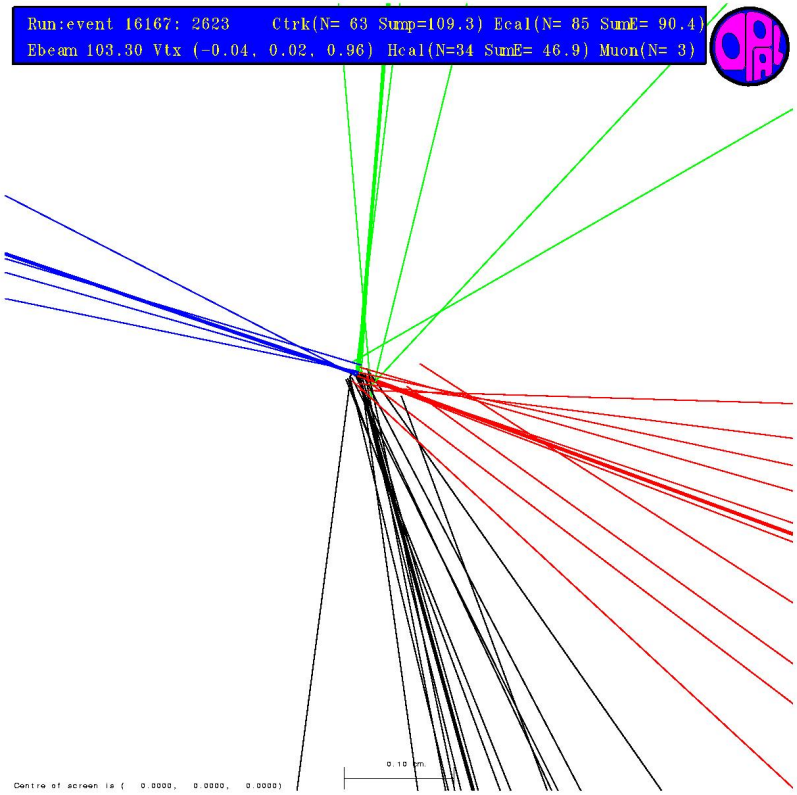
Channel	Data	Total bkg.	qq	4f	Eff. (signal ev.)
Four-jet	60	49.8±6.0	12.8	37.0	41.8 (2.24±0.10)
Missing-E	68	69.7±8.6	10.6	59.1	43.9 (1.68±0.10)
Tau	8	11.1±1.2	0.4	20.7	22.9 (0.25±0.01)
Electron	6	8.5±1.3	0.3	8.2	48.7 (0.17±0.01)
Muon	10	7.0±1.0	0.2	6.8	59.9 (0.23±0.01)



→ no visible excess

4-Jet Higgs Candidate



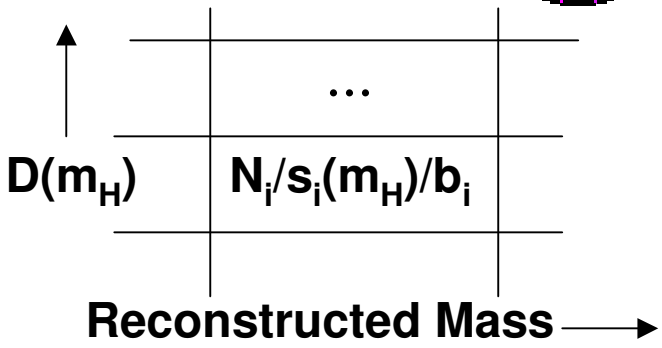


Event 16167:26233

- B_{Jet1}=0.838
- B_{Jet2}=0.944
- LH=0.995

Reconstucted Mass m_H=110.7 GeV

Statistics



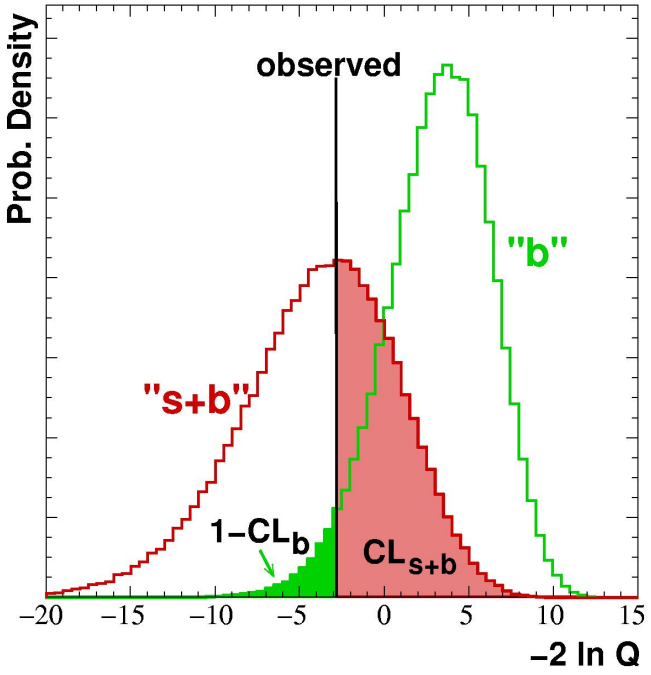
1. Inputs from all channels binned in
• reconstructed Higgs mass
• discriminating variable $D(m_H)$
(containing b-Tag, kinematics, jet-properties ...)

2. Likelihood Ratio for test mass m_H

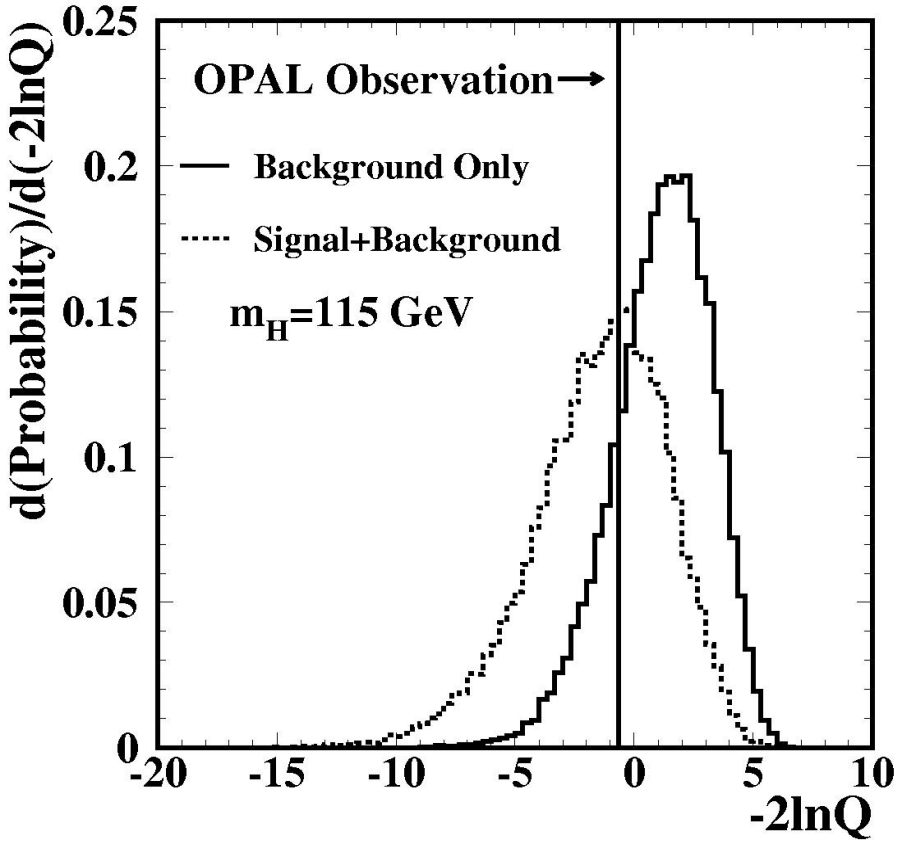
$$Q(m_H) = L_{s+b}/L_s$$
$$-2\ln Q(m_H) = 2s_{tot} - 2\sum_i N_i \ln(1+s_i(m_H)/b_i)$$

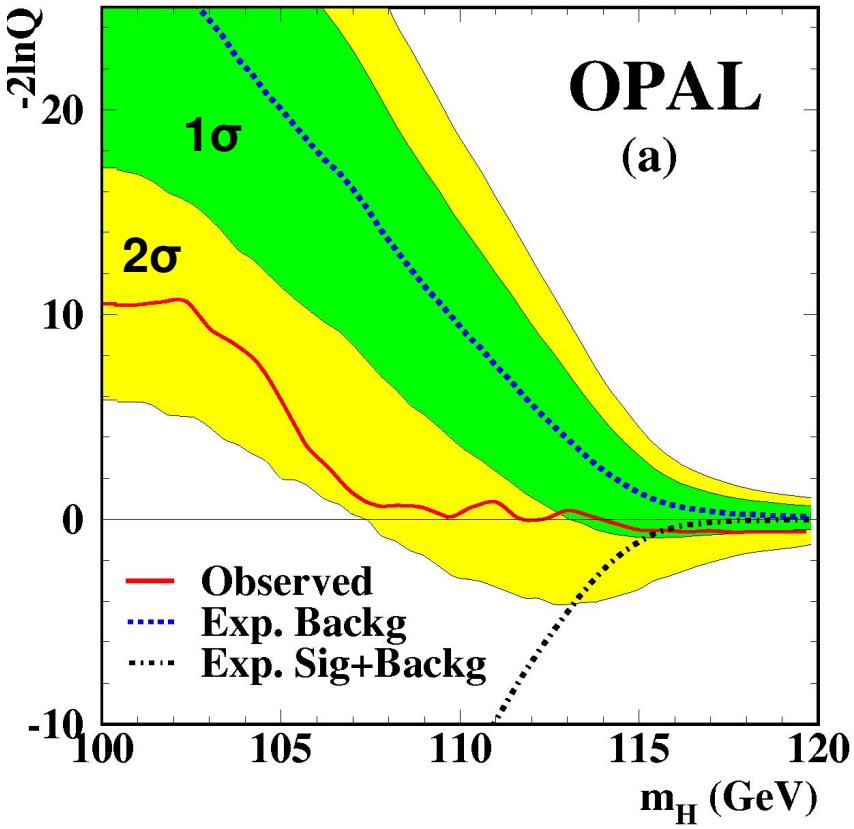
replace data by MC sets of (b+s) or (b)

3. Confidence Levels
• CL_{s+b} - comptatibility with (s+b) hypthesis
• $(1-CL_b)$ - comptatibility with (b) hypthesis



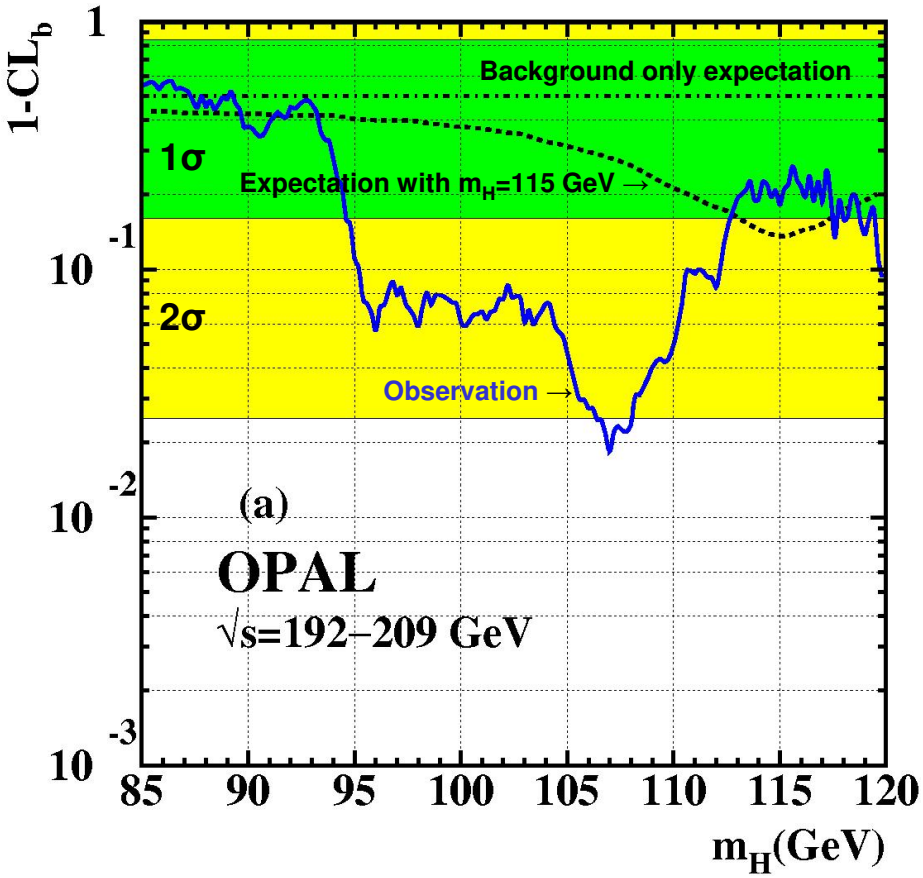
Analysis Results

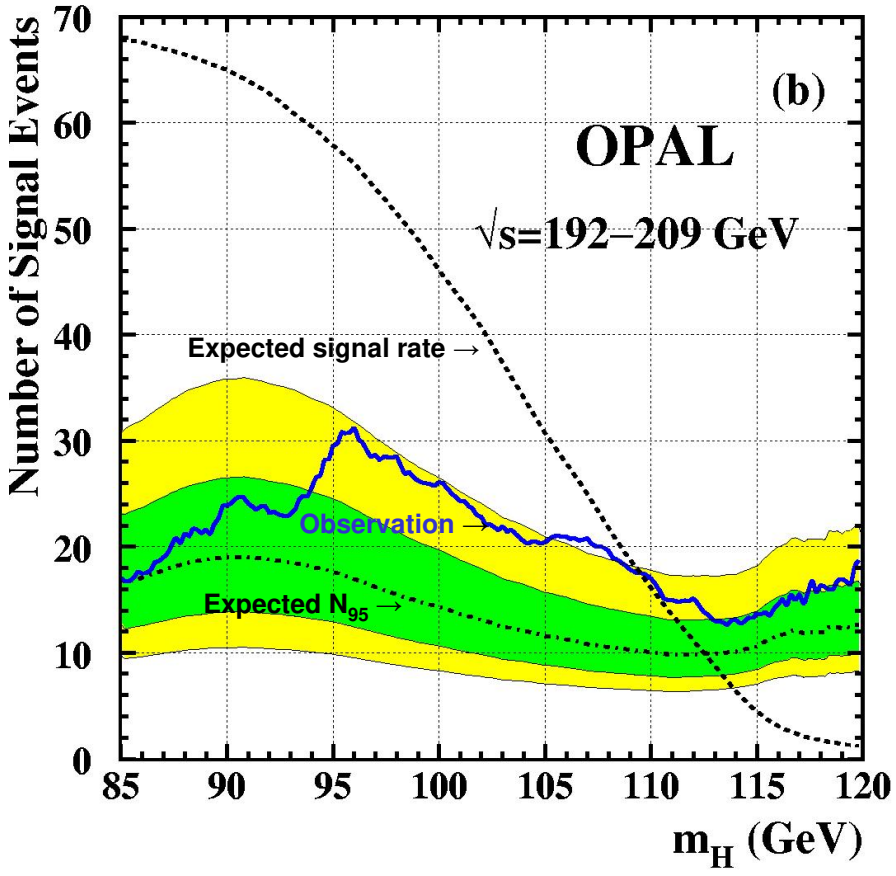




Low sensitivity for OPAL alone at m_H=115 GeV

1-CL_b and N_{95}

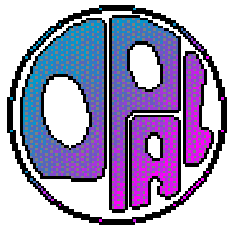




m_H=115 GeV → 0.9σ deviation
m_H=107 GeV → 2σ deviation

Expected m_H limit: 112.5 GeV
Observed m_H limit: 109.7 GeV

Summary
Standard Model Higgs Search at OPAL



- Results of Searches in Y1999 and Y2000 data
- Data taken with $\sqrt{s}$=192-209
- Integrated luminosity ~ 430pb^{-1}
- Slightly more data than expected

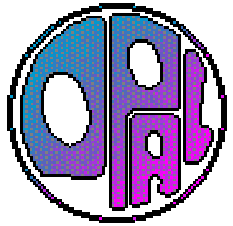
  $(1\text{-}CL_b)(m_H=107\ GeV)=0.02$

  $(1\text{-}CL_b)(m_H=115\ GeV)=0.20$
- Observed Limit of the Higgs Boson mass

  $m_H > 109.7\ GeV$

Paper: CERN-EP-2000-156, Phys. Lett. B499 (2001) 38-52

Search for MSSM Higgs Boson(s)



Two Higgs Doublets and 5 physical states

2 CP-even neutral Higgses	h^0, H^0
1 CP-odd neutral Higgs	A^0
2 charged Higgses	$H^\pm$

Free Parameters

tanβ	VEV ratio
α	mixing angle of h0, H0

Other Parameters

μ	Higgs mass parameter
A_0	common trilinear coupling

Neutral Sector:

$e^+e^- \rightarrow hZ$ (Higgs Strahlung)

$\sigma_{hZ} = \sin^2(\beta-\alpha)\sigma_{hZ}(SM)$

- SM topologies
- recycle SM searches

$e^+e^- \rightarrow hA$ (Associated Production)

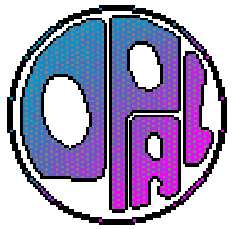
$\sigma_{hA} = \cos^2(\beta-\alpha)\lambda\sigma_{\nu\nu}(SM)$

- new topologies
- dedicated serches

  $hA \rightarrow bbbb$

  $hA \rightarrow \tau\tau bb$

Search for MSSM Higgs Boson(s)



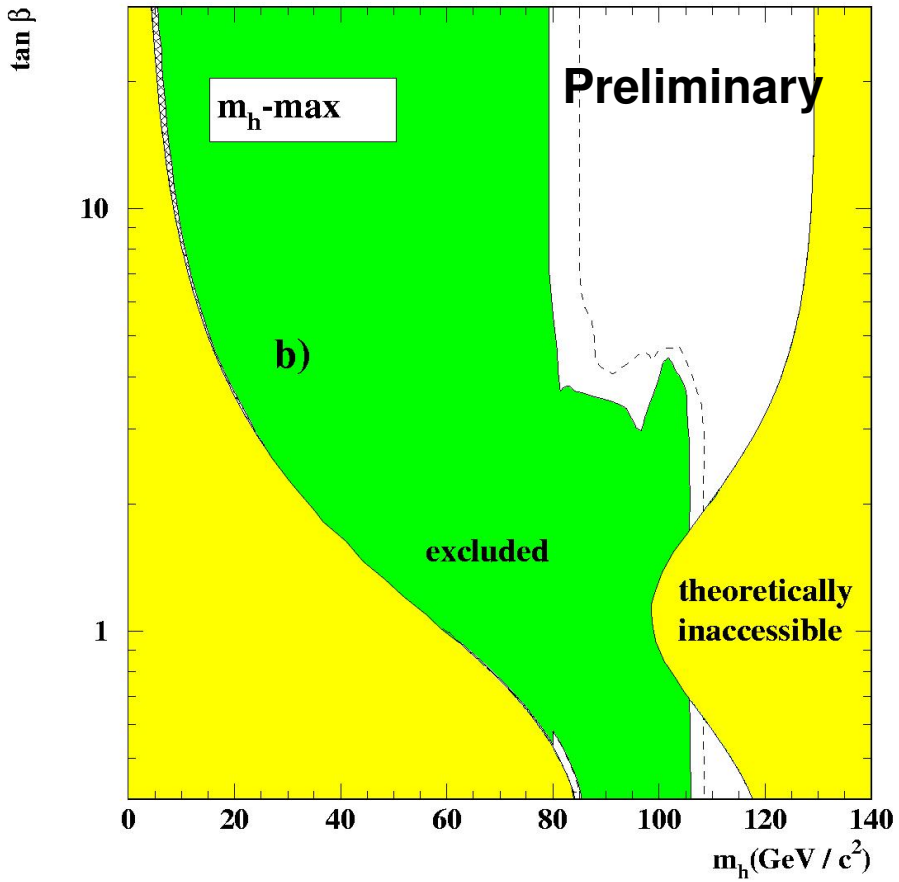
MSSM benchmark scans

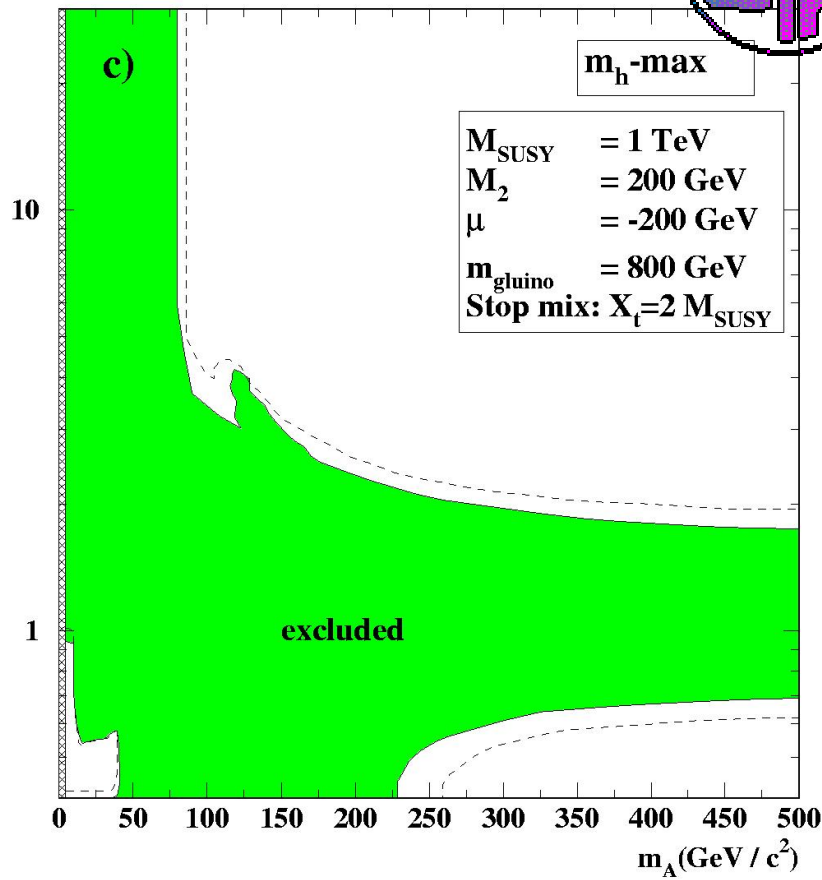
(A) ‚No mixing' ... In stop sector
$X_t = A - \mu \cot(\beta) = 0$
... Reduced parameter space

(B) ‚Max m_h' ... Large mixing ... $X_t \approx 1$ TeV
... Extended parameter space
→ Conservative limits

(C) ‚Large μ'
... ‚pathological' points with BR(h → bb) << 1
→ need flavour indipendent analysis

MSSM Parameter Scan - Maximal m_h

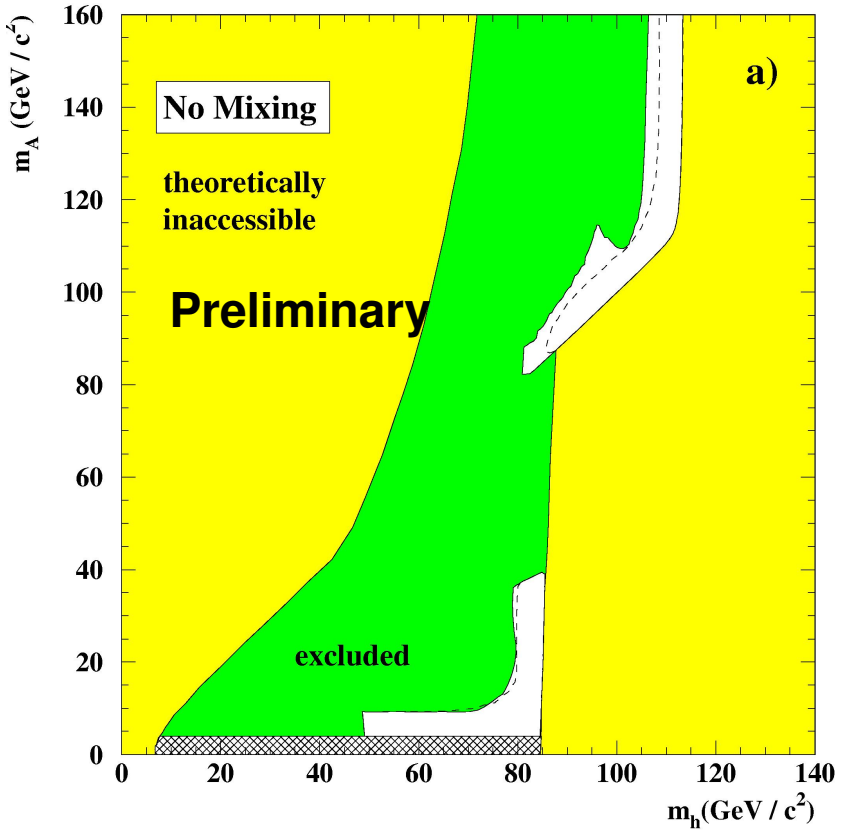


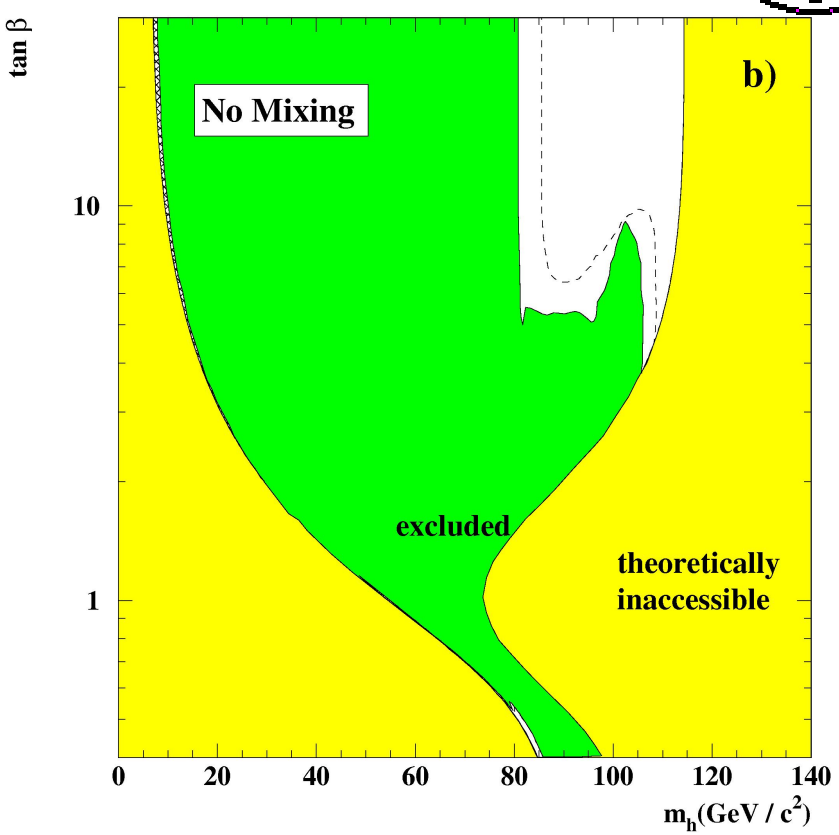


Limits for tanβ>1.2:
mh>79.3 GeV (85.1 GeV)
mA>80.6 GeV (86.9 GeV)

Limits on tanβ:
0.9<tanβ<1.7 (1.0<tanβ<1.9)

MSSM Parameter Scan - No mixing

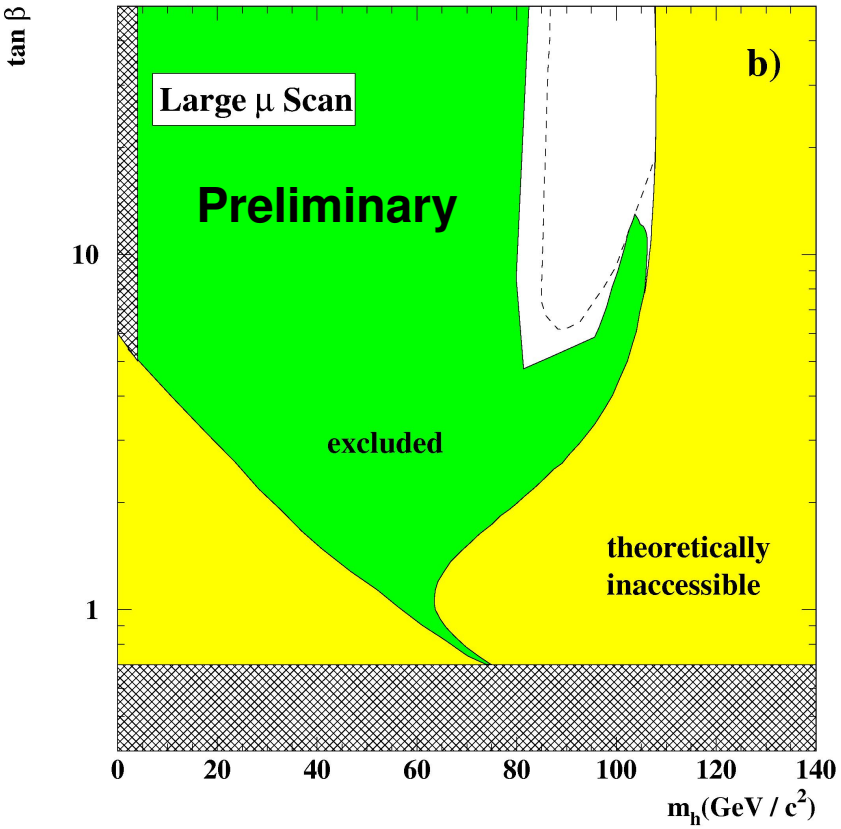


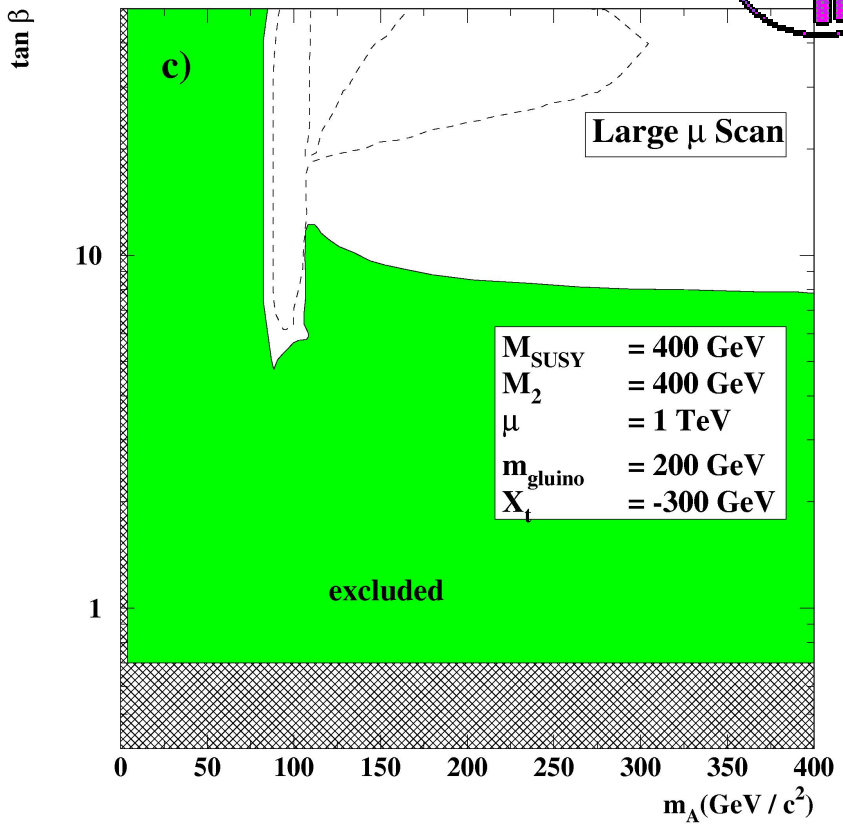


Limits for tanβ>1.2:
mh>80.9 GeV (85.6 GeV)
mA>82.3 GeV (86.9 GeV)

Limits on tanβ:
1.2<tanβ<3.8 (1.2<tanβ<4.5)

MSSM Parameter Scan - Large μ

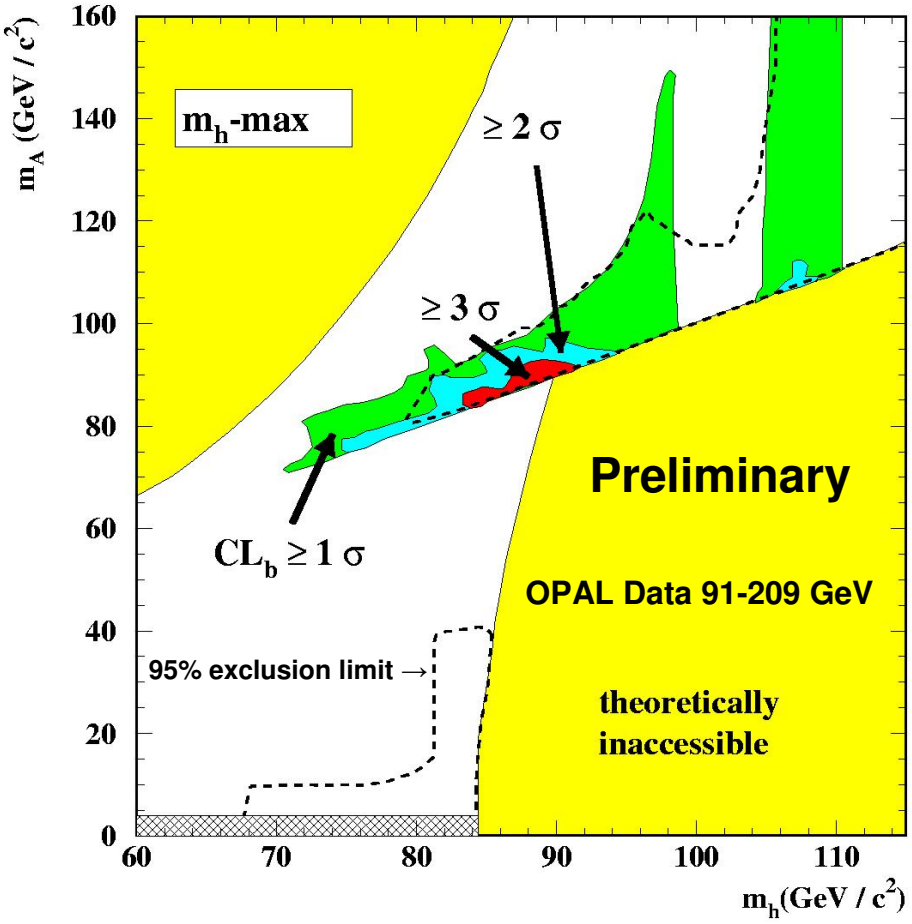




Limits for tanβ>1.2:
mh>79.8 GeV (84.9 GeV)
mA>82.4 GeV (88.0 GeV)

Limits on tanβ:
0.7<tanβ<4.8 (0.7<tanβ<6.2)

MSSM CL_b



Excess at mh~91 GeV due to bbbb candidates taken at 196 GeV

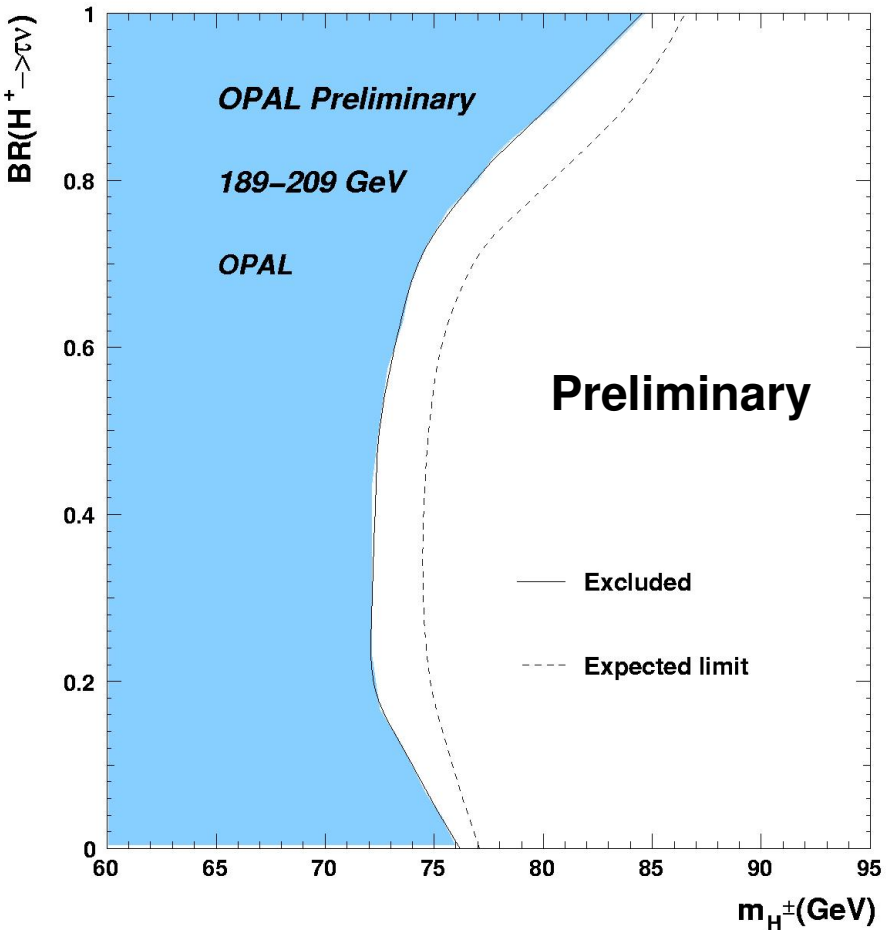
Excess at mh~83 GeV due to bbττ candidates taken at 189 GeV

Charged Higgs Boson Searches

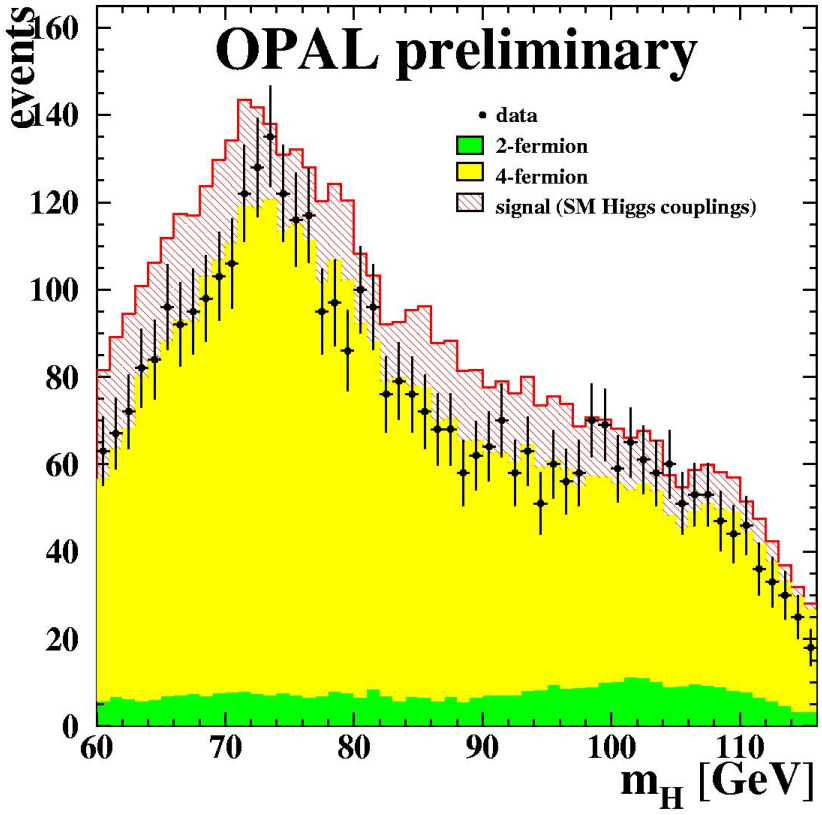
Search channels for H^+H^- :

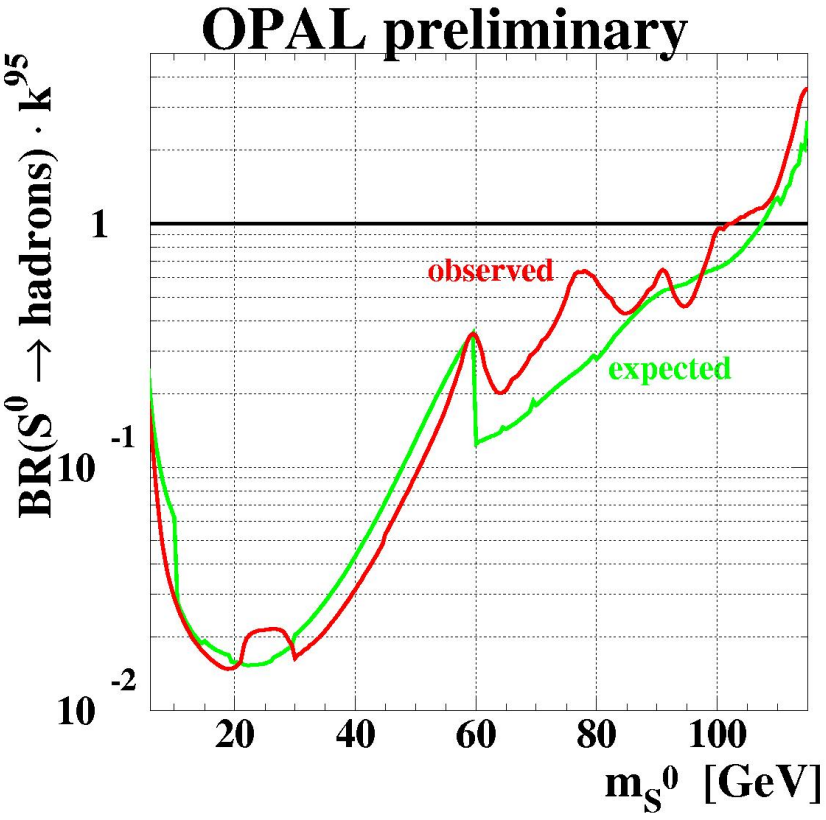
- qqqq (4 jet final state)
- τντν (leptonic final state)
- qqτν (semileptonic channel)

Excluded at 95% C.L.
$m_{H^\pm} < 72.2$ GeV (74.5 GeV)



Flavour Independent Search



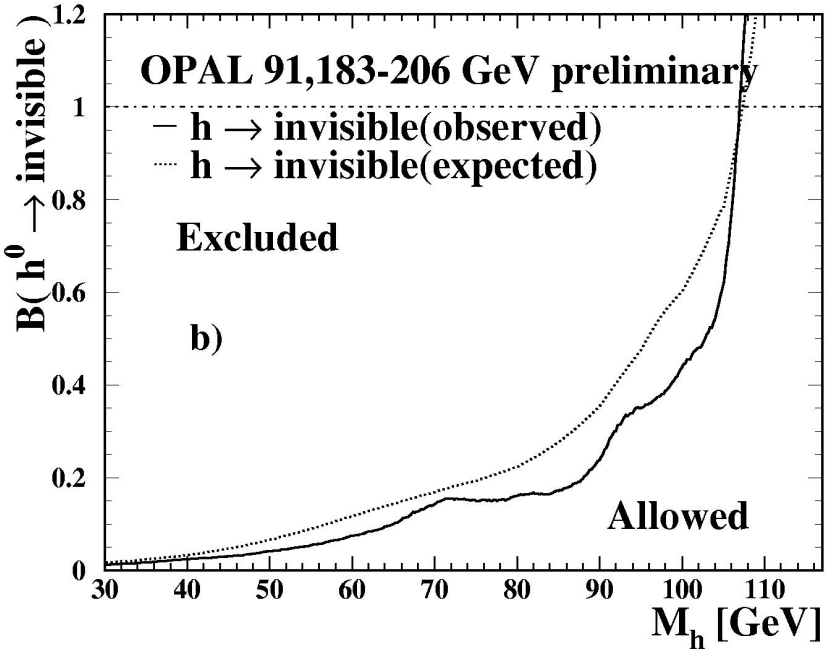


- Search for a scalar Boson S^0 and a Z^0
- Branching Ratio S^0 to hadrons set to 100%
- No b-tagging in the analyses
- Mass dependent 4 jet analysis

$m_{S0} > 101.8$ GeV(107.3 GeV)

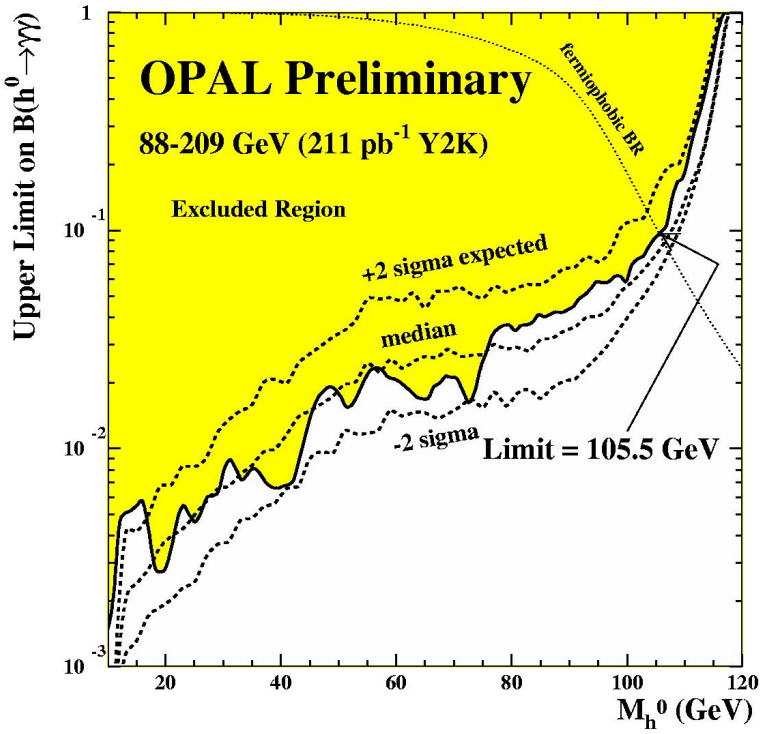
Invisible and Fermiophobic Higgs

H→invisible



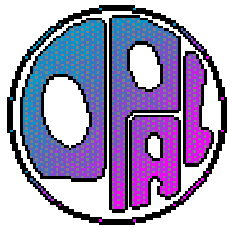
Excluded at 95% C.L.
m_H<107.0 GeV(107.4 GeV)

Fermiophobic H→γγ



Excluded at 95% C.L.
m_H<105.5 GeV(106.4 GeV)

Summary
Other Higgs Search Results (Preliminary)



- **Limits on MSSM Higgs ($\tan\beta>1.2$) and $\tan\beta$**

No mixing	Max. m_h	Large μ
$m_h>80.9$ GeV	$m_h>79.3$ GeV	$m_h>79.8$ GeV
$m_A>82.3$ GeV	$m_A>80.6$ GeV	$m_A>82.4$ GeV
$1.2<\tan\beta<3.8$	$0.9<\tan\beta<1.7$	$0.7<\tan\beta<4.8$

- **Other exclusions**

Charged Higgs:	$m_{H^\pm}<72.2$ GeV
Invisible Higgs:	$m_H<107.0$ GeV
Fermiophobic Higgs:	$m_H<105.5$ GeV
Flavour independent:	$m_{S0}<101.8$ GeV

OPAL Physics Note: PN472, Feb. 2001