Prospects for Higgs at LHC

L. Poggioli, LAPP, Annecy, France

Standard Model Higgs

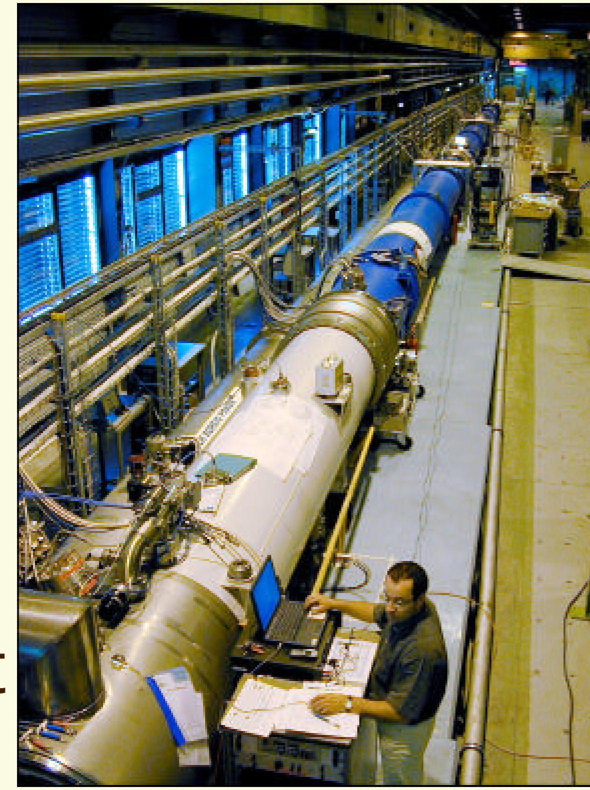
MSSM Higgs

Measurements

LHC

WIN 2002

- Machine
  - Final design for dipoles
  - Pre-series OK
- Current schedule
  - 04/2006 (pilot run)
  - 08/2006-03/2007 10 fb^{-1}
  - -> 2008 30 fb^{-1}/year/expt
  - Then 100 fb^{-1} 100 fb^{-1}/yr
- Few months potential delay
  - Magnets procurements



Detectors (1)

- ATLAS and CMS
  - Optimized for low mass Higgs
    - Small & narrow signals, large backgrounds
  - Signatures : γ, $e/\mu/\tau$, E_T^{miss}, SUSY, t, jets
  - Experimental effects
    - Efficiencies, background rejection, particle ID, resolution, non-gaussian response
    - fully simulated (GEANT)
    - Checked with test beam when possible

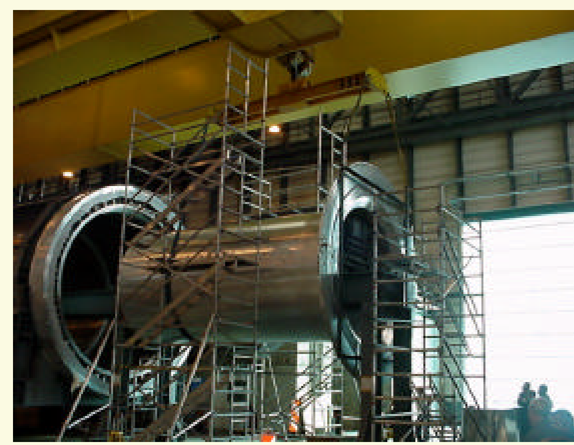
Detectors (2)

CMS magnet system

CMS HCAL

ATLAS EM
LARG calorimeter

ATLAS barrel cryostat



Approach

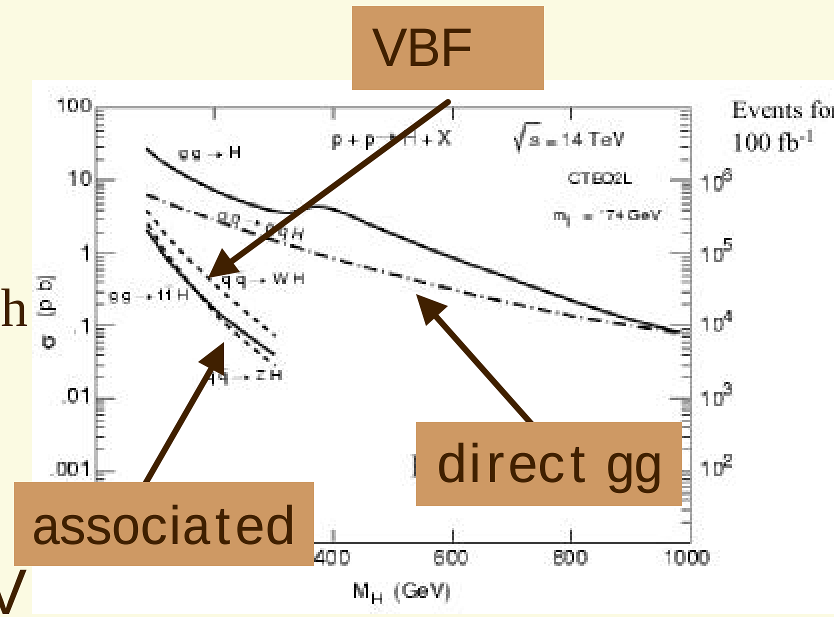
✓ Results

- Processes simulation (signal, backgrounds)
  - No K-factor (σ_{LO}/σ_{NLO} ~ 1.1 -1.9) -conservative
- No “hopeless” channels (multijets..., WH)
- Redundancy
- Discovery: 5s (S/ÖB) per expt / channel
  - When background poorly known
    - control tools (side-bands, jet veto)
    - systematics on background included
- Simple analyzes (simple cuts)
  - Neural Nets less reliable if bkgd poorly known

SM Higgs (1)

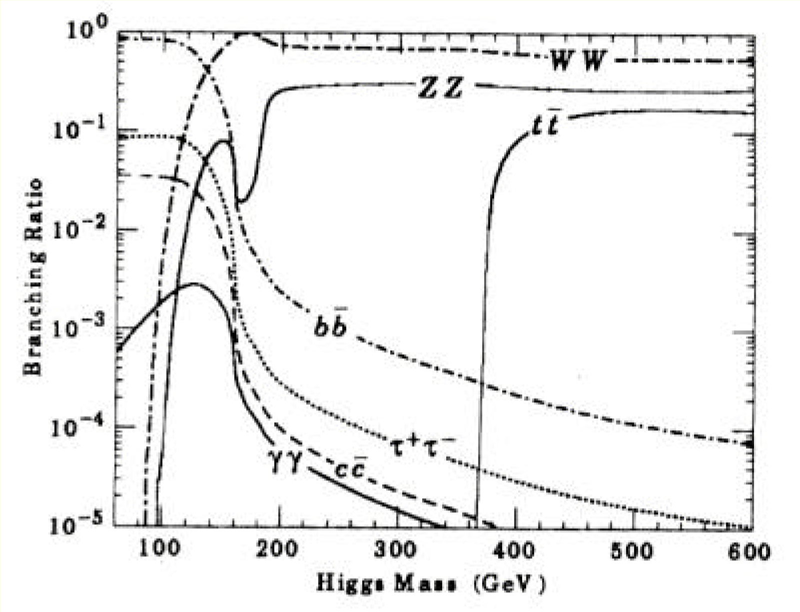
✓ Production

- Direct
  - Via gg dominant
  - Via VBF qqH
    - ~ 20% gg
    - 2 quarks @ large h
- Associated
  - ttH, WH, ZH
  - pour m_H < 200 GeV
  - ~ 1-10% gg



SM Higgs (2)

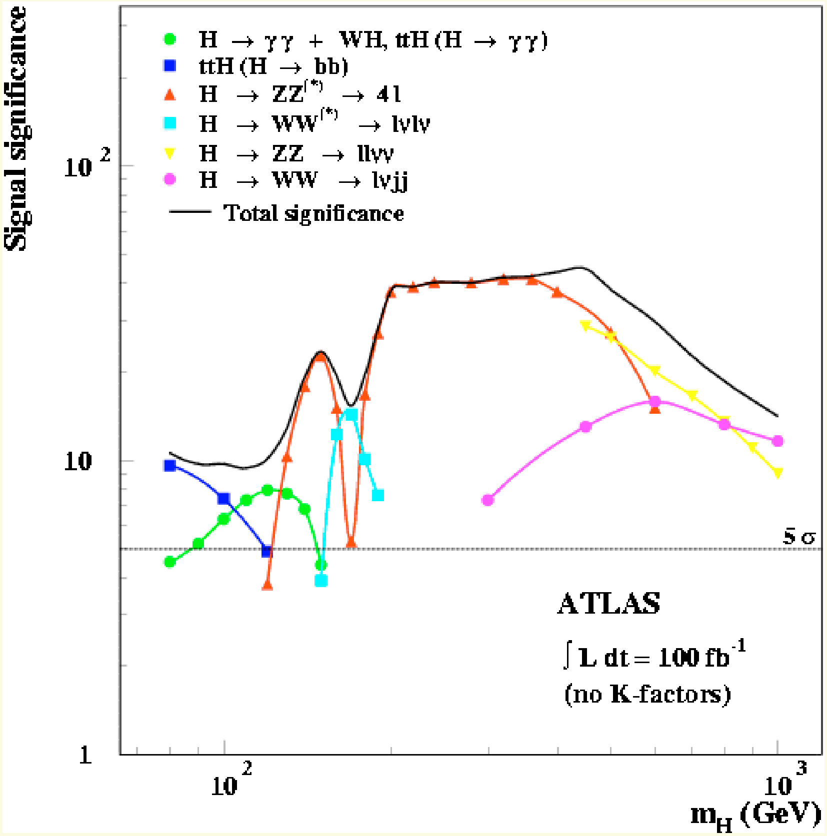
- Final state
  - $m_H < 2m_Z$
    - ttH → lbb+X
    - H → gg (direct & associated)
    - H → ZZ* → 4l
    - H → WW* → lνlν
  - $m_H > 2m_Z$
    - H → ZZ → 4l
    - qqH → ZZ → llνν
    - qqH → WW → lνjj



with forward jets

SM Higgs (3)

✓ All channels together

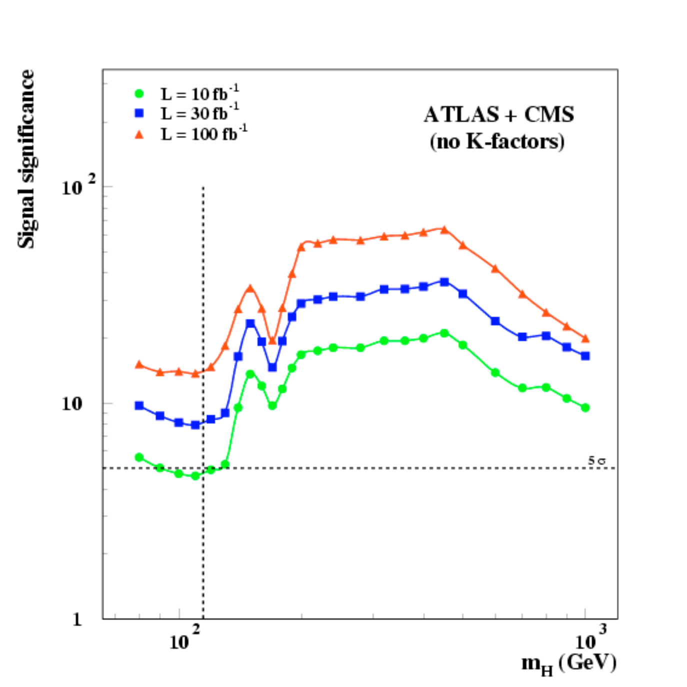


- 80 - 1TeV region covered
- m_H < 180 GeV : many complementary channels (gg, bb, 2l, 3l, 4l)
- m_H > 180 GeV : easy with $H \to ZZ \to 4l$

Not included yet: VBF channels at low mass

SM Higgs (4)

✓ Sensitivity



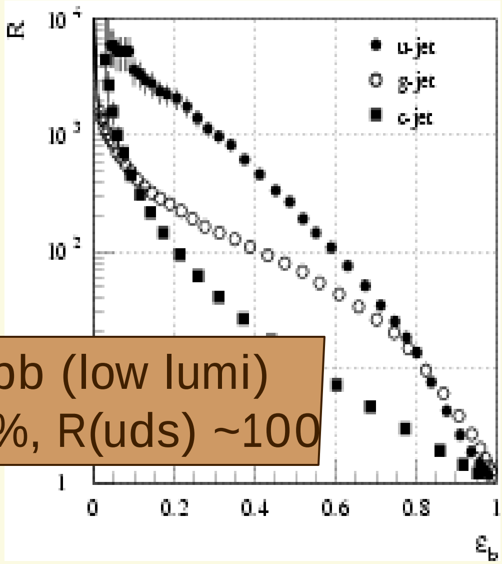
ATLAS + CMS

- All region excluded @ 95% CL after **1 month**
- Discovery with **10 fb^{-1}** (~2007) for m_H < 150 GeV
- Faster for m_H > 150 GeV
- Conservative results (e.g. WH $\rightarrow$W bb not included)

- **For m_H < 150 GeV**
- gg, bb dominant
- NEW qq $\rightarrow$ qqH $\rightarrow$ qq $\tau\tau$, qqWW under study

SM Higgs(5)

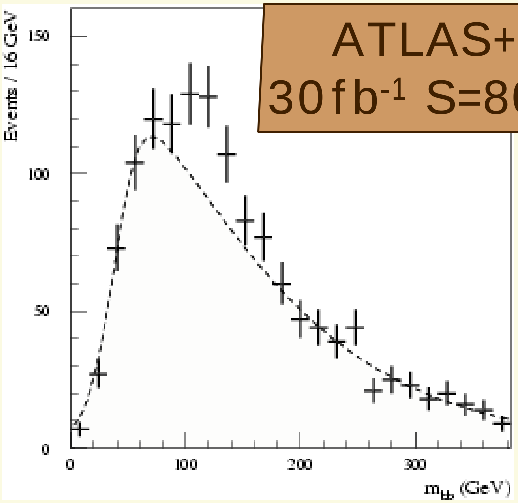
✓ $H \rightarrow bb$ via ttH (WH, ZH difficult)



H -> bb (low lumi)
ε_b ~ 60%, R(uds) ~100

- Complex final state : 4b,2jets
- Bckd reduced by 2 tops reconstruction
- **b-tagging essential**
- $\Delta(m_{bb})$ ~ 15%
- complementary to γγ

- **Crucial**: bckd knowledge (60% ttbb), with ttjj
- $5\sigma \rightarrow$ 130 GeV if bckd known
- $5\sigma \rightarrow$ 120 GeV if 5% systematics on bckd



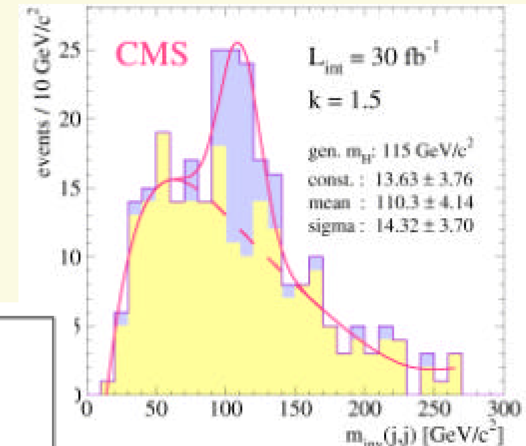
ATLAS+CMS
30fb^{-1} S=80 B=320

SM Higgs (6)

✓H → bb via ttH (cont'd)

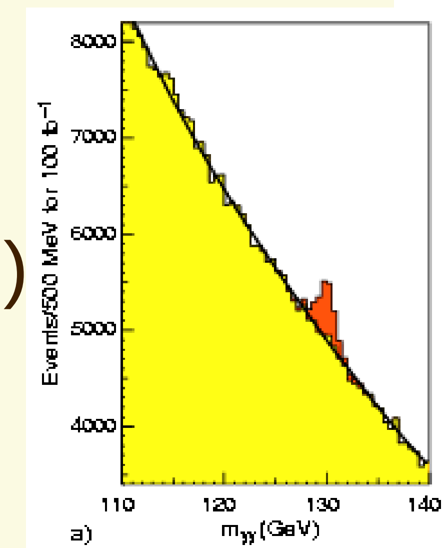
CMS 30fb^{-1}
S=38 B=52

- CMS study
- Use likelihood for t decays & event kinematics
- Use COMPHEP for ttjj



✓H → gg

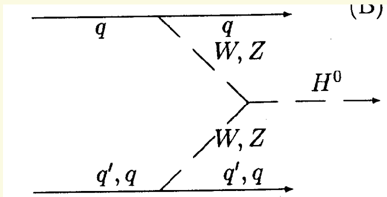
- Direct & associated (ttH,WH)
- Well assessed
- Background
  - dominant: gg -well measured from side bands



CMS
100fb^{-1}
K=1.6, S/B ~4%

SM Higgs VBF (1)

✓ Motivation (D. Zeppenfeld et al.)

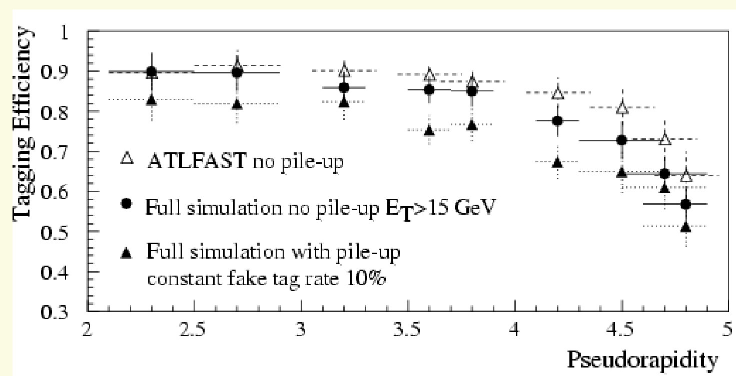


- Extra potential for discovery
- Access to couplings (Htt), G_H
- Invisible Higgs

- •2 forward jets
- •Well assessed for m_H> 400 GeV

✓ Forward jet tagging

- Efficiencies critical
- Assessed with full simulation



- •Double tag efficiency ~ 50%
- •Fake tag < 1% @ 10^{34}

SM Higgs VBF (2)

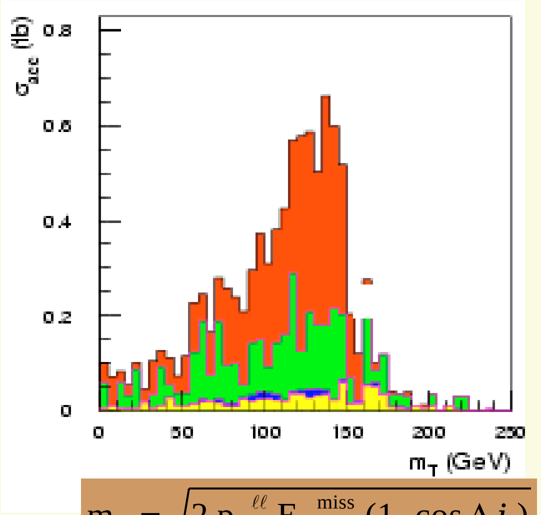
✓ qqH →qqWW → qq lν lν

- Backds: tt, WW cont.
- p_T(tot) cut & jet veto

m_H (GeV)	130	150	170	190
S	10	30	55	40
S/B	0.3	0.9	1.5	1.1
S/ÖB	1.4	5.0	8.8	6.3

- Counting expt @ low mass
  - 5% systematics included in B
- Results worse than @ particle level
  - ISR/FSR, jet calibration, efficiencies

ATLAS, e m, 10 fb^{-1}
m_H = 160 GeV



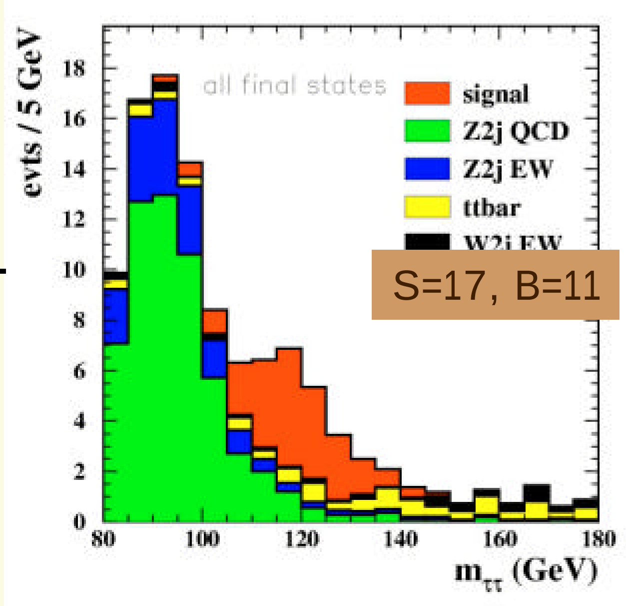
$$m_T = \sqrt{2\, p_T^{\ell\ell}\, E_T^{miss}\, (1 - \cos \Delta j)}$$

SM Higgs VBF (3)

- qqH → qq ττ → qq lνν lνν
  - Similar to WW
  - t reconstruction using collinear approximation

ATLAS, 30 fb^{-1}
m_H = 115 GeV

m_H (GeV)	115	120	130	140
S/ÖB 10fb^{-1}	2.6	2.6	2.3	1.3
S/ÖB 30fb^{-1}	4.3	4.3	3.8	2.7



  - Systematics to be included
  - (l, had) mode under study

SM Higgs VBF (4)

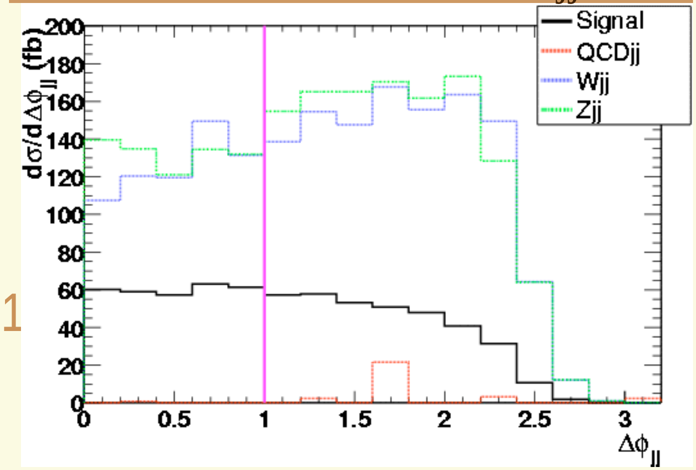
✓ qqH $\rightarrow$ qq Invisible (Preliminary)

– Bckds: QCD jj, Wjj, Zjj

– Cuts

- Lepton & jet veto
- $\phi_{jj} < 1$
- Isolation cut kills QCD bckd: $\Delta(\phi(p_T^{miss}) - \phi(j_1, j_2)) > 1$

ATLAS after isolation & ϕ_{jj} cuts



– Counting expt

- Zjj, Wjj to be known to few %
- Zjj can be normalized using lljj

– Trigger: Rates OK, under study

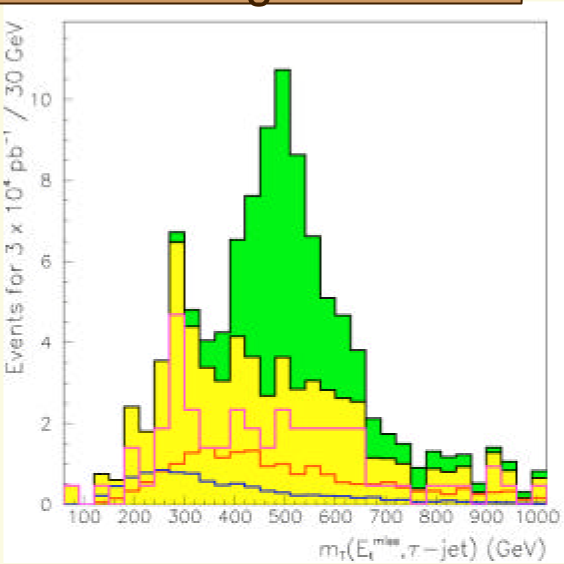
MSSM Higgs (1)

- Large variety of observation modes
  - SM-like : h $\rightarrow$ gg, bb ; H $\rightarrow$ 4l
  - MSSM-specific : A/**H** ® mm,tt,tt ;
    H $\rightarrow$ hh, A $\rightarrow$ Zh ; $H^{\pm} \rightarrow \tau\nu$
  - If SUSY accessible: H/A $\rightarrow$ c^2_0 c^2_0, $c^2_0 \rightarrow$ h c^1_0
- Study in 2 steps
  - SUSY does not contribute
  - SUSY contributes in production/decays
    - Impact on Higgs decay to SM particles is small
    - h $\rightarrow$ gg 10% smaller, A/H $\rightarrow$ SM at most 40% smaller

MSSM Higgs (2)

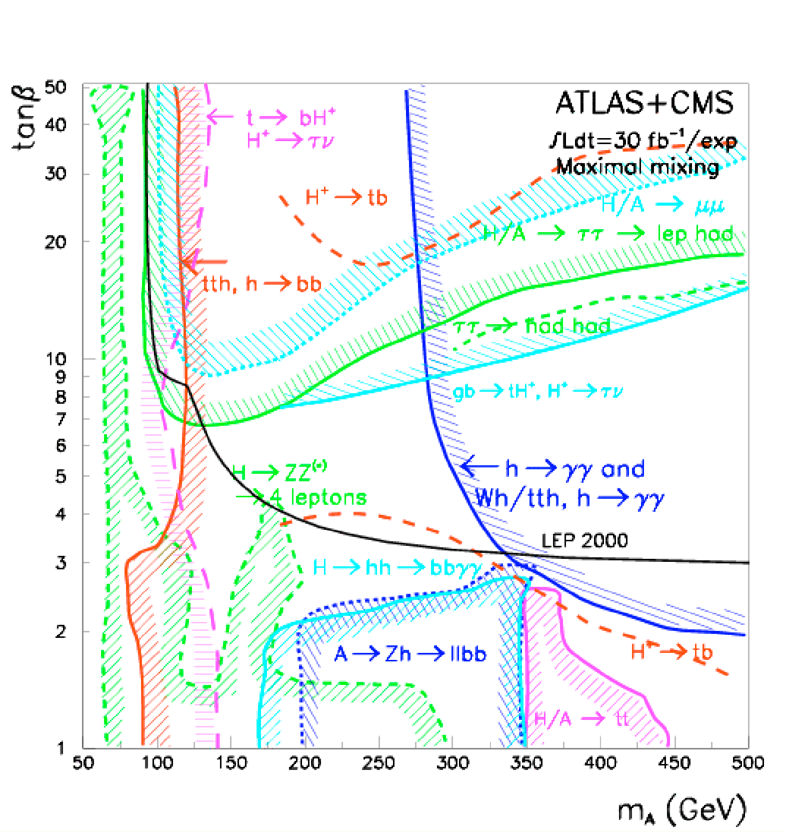
- ✓ A/H $\rightarrow$ t t $\rightarrow$ $h^+ \nu\ h^- \nu$
  - Extends the range for large m_A wrt (l,h) mode
  - Requests 2 stiff isolated tracks, $p\!\!\!/_T$, 1 b-jet (bbA)
  - Challenge : QCD bckd rejection (also for trigger
- ✓ gb $\rightarrow$ t $H^\pm$, $H^\pm \rightarrow$ t ν
  - Extends the reach for lower tan β & m_A up to 500 GeV (compared to $H^\pm \rightarrow$ t b)

CMS, 30 fb^{-1}
m_A = 500 GeV,
with b-tag



MSSM Higgs (3)

✓ All together

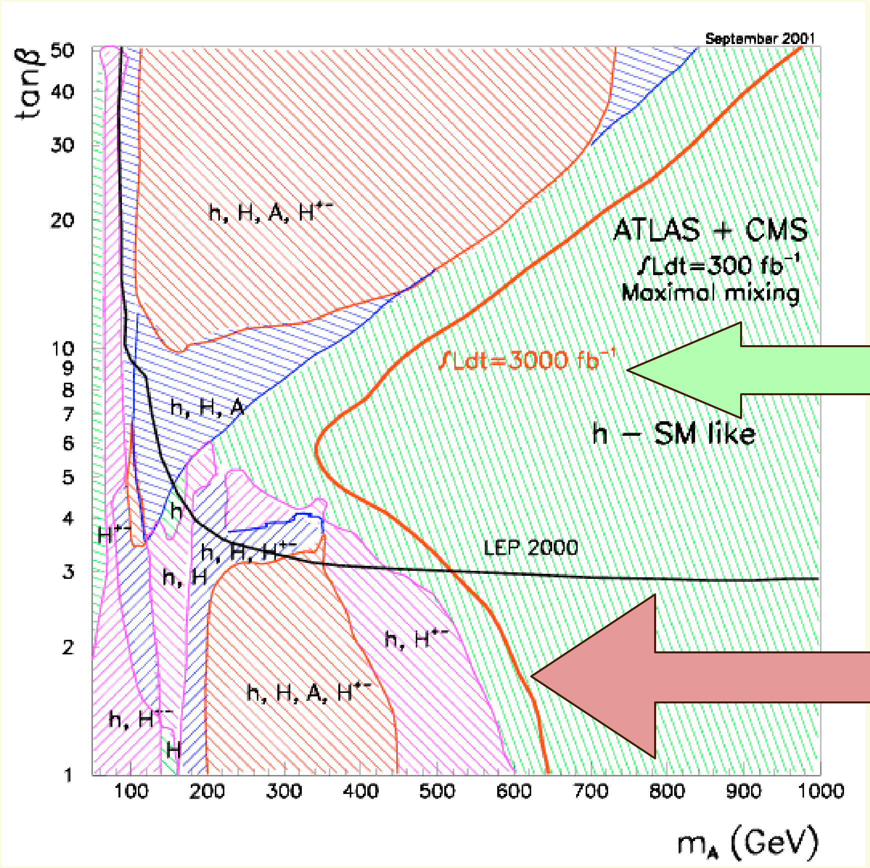


ATLAS + CMS
30 fb^{-1}; m_{SUSY} = 1 TeV

- Plane totally **covered**
- 2 ou more Higgs can be seen in a big plane fraction → **separation SM/MSSM**
- At very large tan β , m_h ~ 110 GeV, h may not be seen → **bbh -> bb μμ** under study
- If LEP excess from hZ, LHC will see h in any case, and A, H, H$^{\pm}$ for moderate m_A & large tan β

MSSM Higgs (4)

✓ SM versus MSSM



- 4 Higgs observable
- 3 Higgs observable
- 2 Higgs observable
- 1 Higgs observable

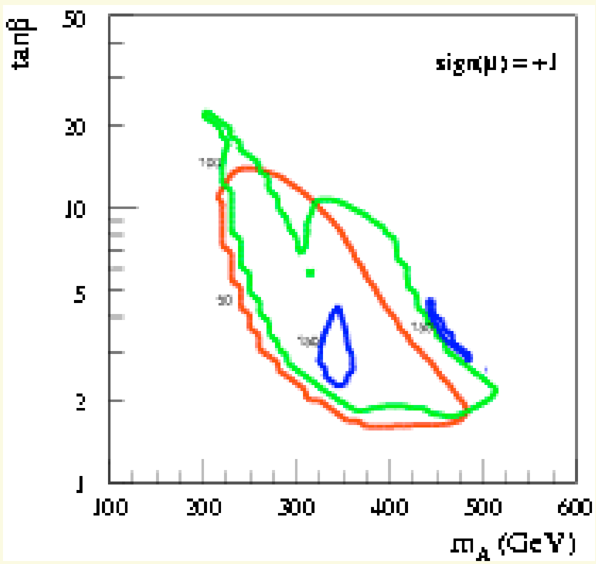
Here only SM-like h observable if no SUSY interplay

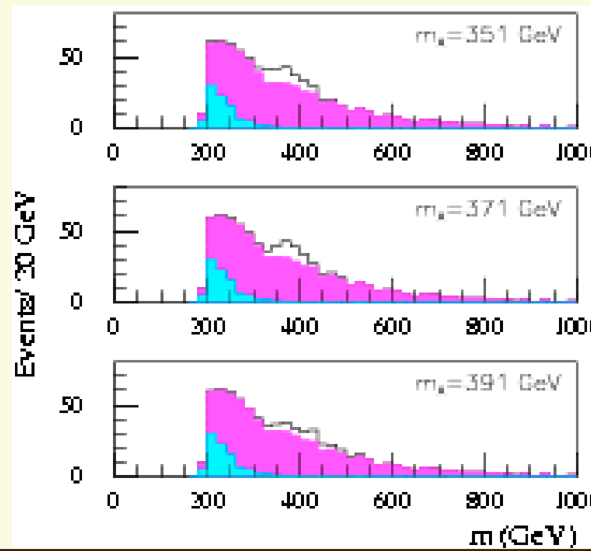
But region can be reduced with SLHC @ 10^{35} (5σ contours)

MSSM Higgs (5)

- SUSY contribution
  - Decay into SUSY particles (m_A < 500 GeV)

    $H/A \to c^2{}_0\, c^2{}_0 \to l\, l\, c^1{}_0\, l\, l\, c^1{}_0$



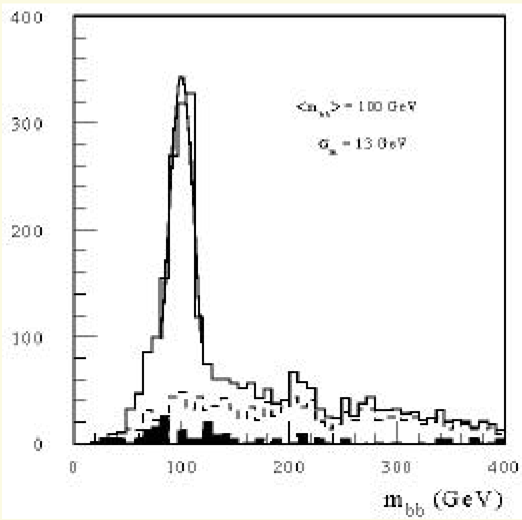


Region m_A ~ 200-400 GeV; tan b ~ 2-20 covered

Reconstruction of m_A possible (end-point ll)

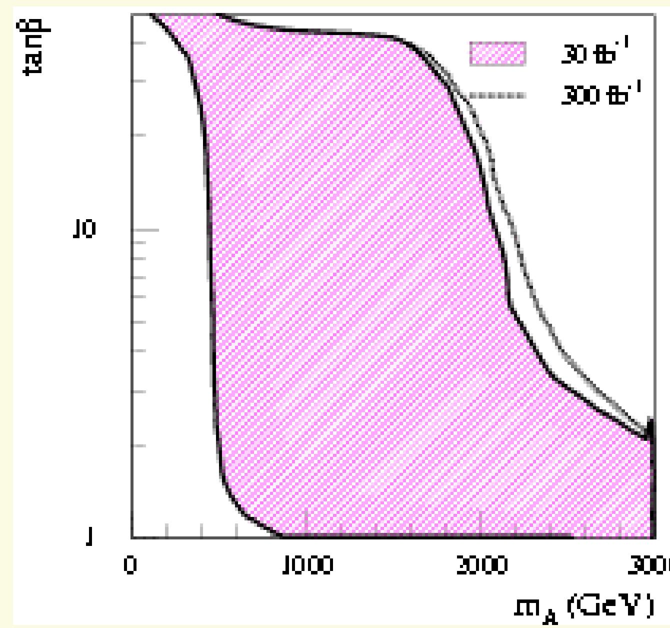
MSSM Higgs (6)

– Higgs in SUSY cascade (m_A > 500 GeV)



$c^2_0 \rightarrow h\ c^1_0$, h -> bb (A/H too heavy)

ATLAS 5s contour



•Clear signal

•h -> bb but **without leptons**

→ no SM

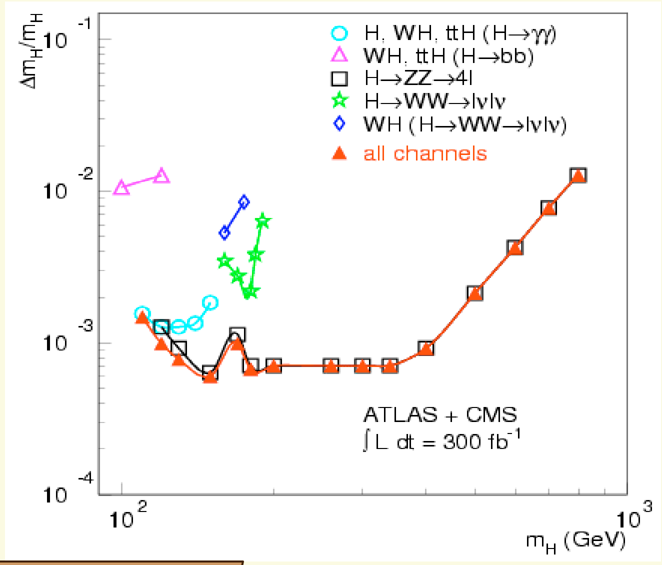
•Covers a wide region

m_A > 400- 5 00 GeV; tan b > 5

(no senstivity in MSSM)

Measurements (1)

✓ Higgs mass



SM

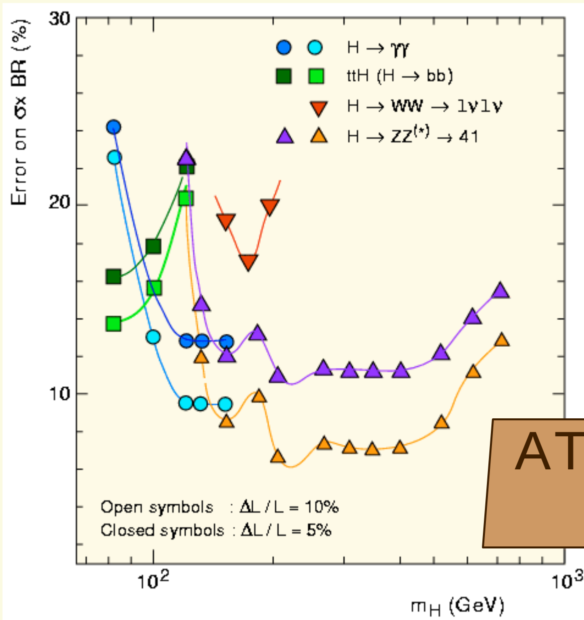
- No theoretical error (mass shift for large Γ_H)
- Error dominated by absolute energy scale
  → 0.1% for l/γ (using Z → ll)
  → 1% for jets

MSSM

- h as in SM
- H/A ~ 0.1-0.5% in modes γγ, 4l,μμ ;
  1-2 % in modes bb, bbγγ (hh), bbll (Zh)

Mesurements (2)

✓ s.BR



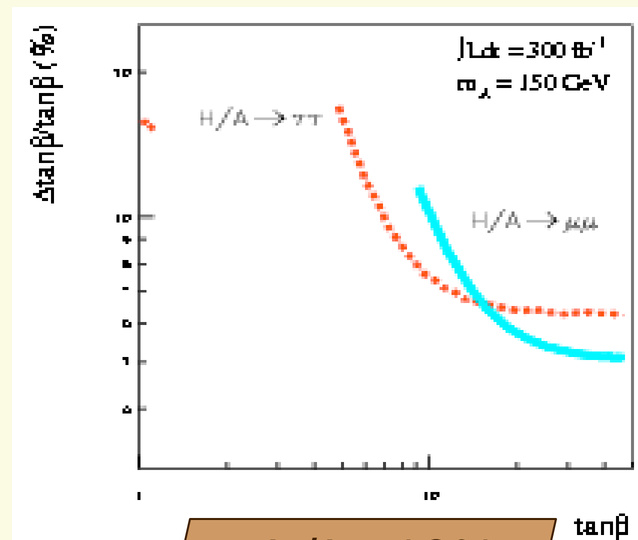
ATLAS+CMS
300fb^{-1}

•Dominant errors: statistics, luminosity (5-10%), systematics on bckd (10%)

•Precision ~ 7-20%

✓ tan b

σ(bbA/H) increases fast with tan b

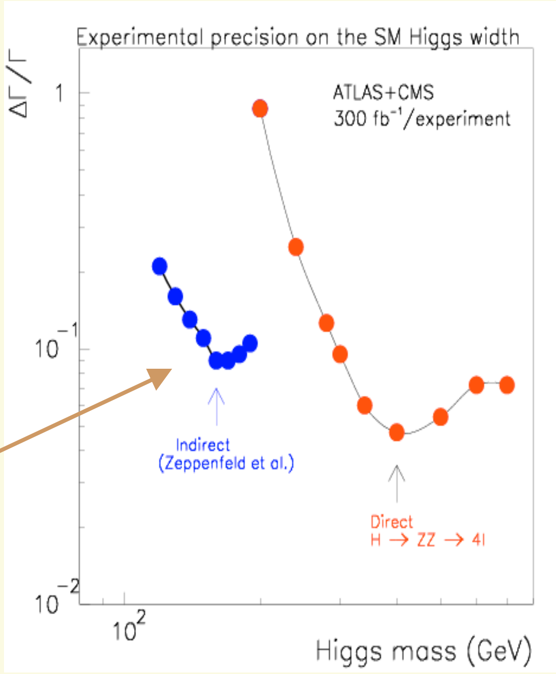


ΔL/L =10%

Mesurements (3)

✓Width

- **Direct**
  - Mass peak width for m_H > 200 GeV ($G_H > G_{exp.}$ in SM)
  - Limited by radiative decays (1.5%)
  - MSSM : possible for A/H → μμ
- **Indirect (under study)**
  - From rates of qqH in γγ, ττ, WW
  - Assume BR in cc, non-standard < 10%

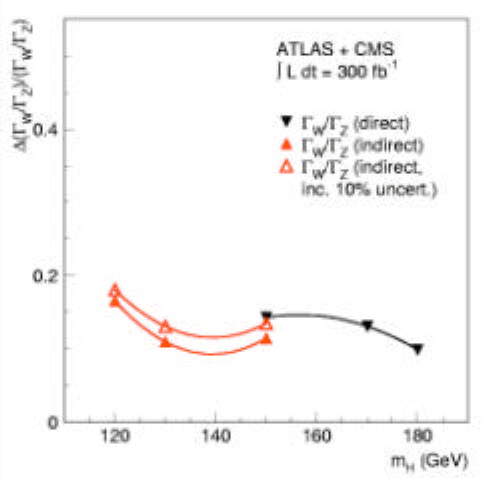


✓Higgs self-coupling (prel.)

- SM HH → WWWW → lν jj lν jj
  - expect S~30, S/B ~ 1 for 600 fb^{-1}
- MSMM H → hh → 4b final state

Measurements (4)

✓ Couplings & BR



- Boson/Boson couplings

•**Direct**

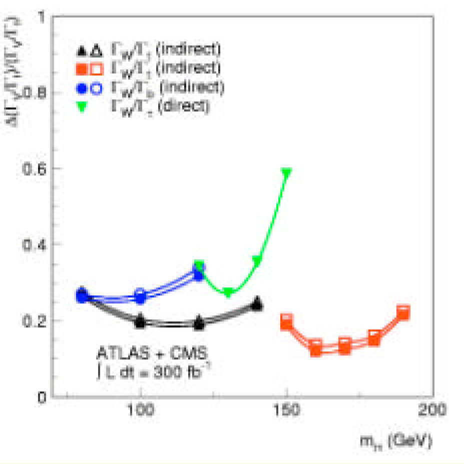
$$- \frac{\sigma \times BR(H \to WW^*)}{\sigma \times BR(H \to ZZ^*)} = \frac{\Gamma_g \Gamma_W}{\Gamma_g \Gamma_Z} = \frac{\Gamma_W}{\Gamma_Z}$$

•QCD corrections cancel

•**Indirect**

$$- \frac{\sigma \times BR(H \to \gamma\gamma)}{\sigma \times BR(H \to ZZ^*)} = \frac{\Gamma_g \Gamma_\gamma}{\Gamma_g \Gamma_Z} \sim \frac{\Gamma_W}{\Gamma_Z}$$

•Use proportionality between Γ_W and Γ_Z (theoretical input needed 10% assumed)



- Boson/fermion couplings
- Errors are **statistics** dominated (~ 15-20%) → **SLHC will help**

Prospects

- SM Higgs
  - Discovery over full mass range with 10 fb^{-1}
  - LHC/Tevatron competition in 2006-2007
- MSSM
  - Full coverage of the parameter space
  - Weak region recovered with SUSY/SLHC
- Measurements & Theory constraints
  - Masses, width, couplings (SLHC will help)
  - LHC/Tevatron complementarity
- Ongoing efforts
  - VBF, H spin, invisible Higgs, H self-coupling