MEASUREMENTS OF LIGHT HIGGS COUPLINGS AT ATLAS

on behalf of the ATLAS collaboration

PASCOS 2006, Ohio State University

Francesca Sarri, University and INFN Pisa

OUTLINE

Experimental data.

Production cross sections for SM Higgs at LHC and decay ratios.

Light Higgs discovery potential at ATLAS.

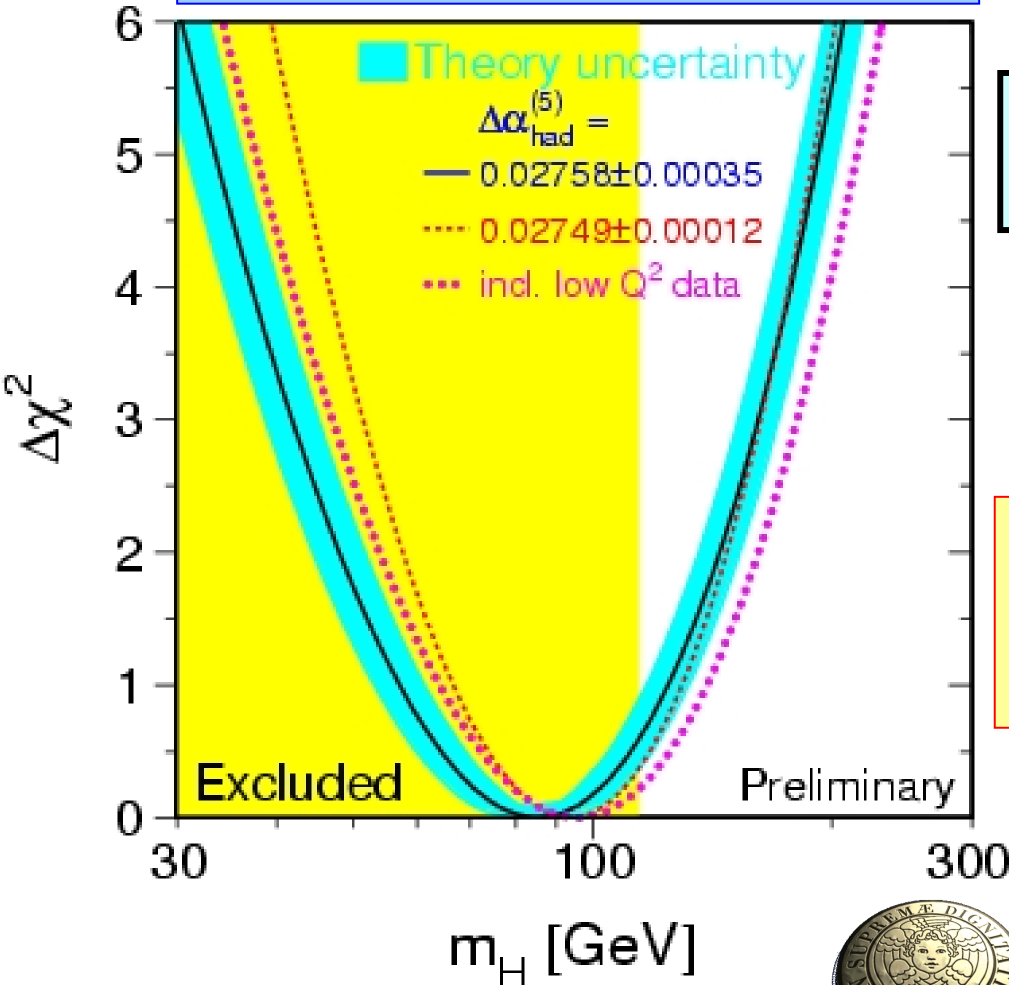
Measurements of Higgs decay rates, widths and couplings and their accuracy in $300fb^{-1}$.

Discrimination between SM and MSSM.

Conclusions.

EXPERIMENTAL DATA

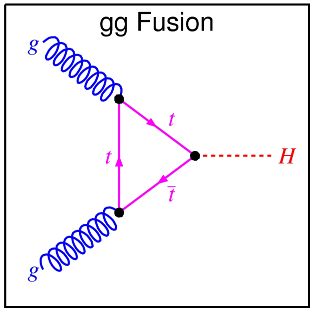
LEP EWWG, JULY 2006

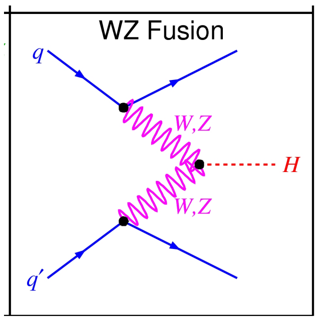


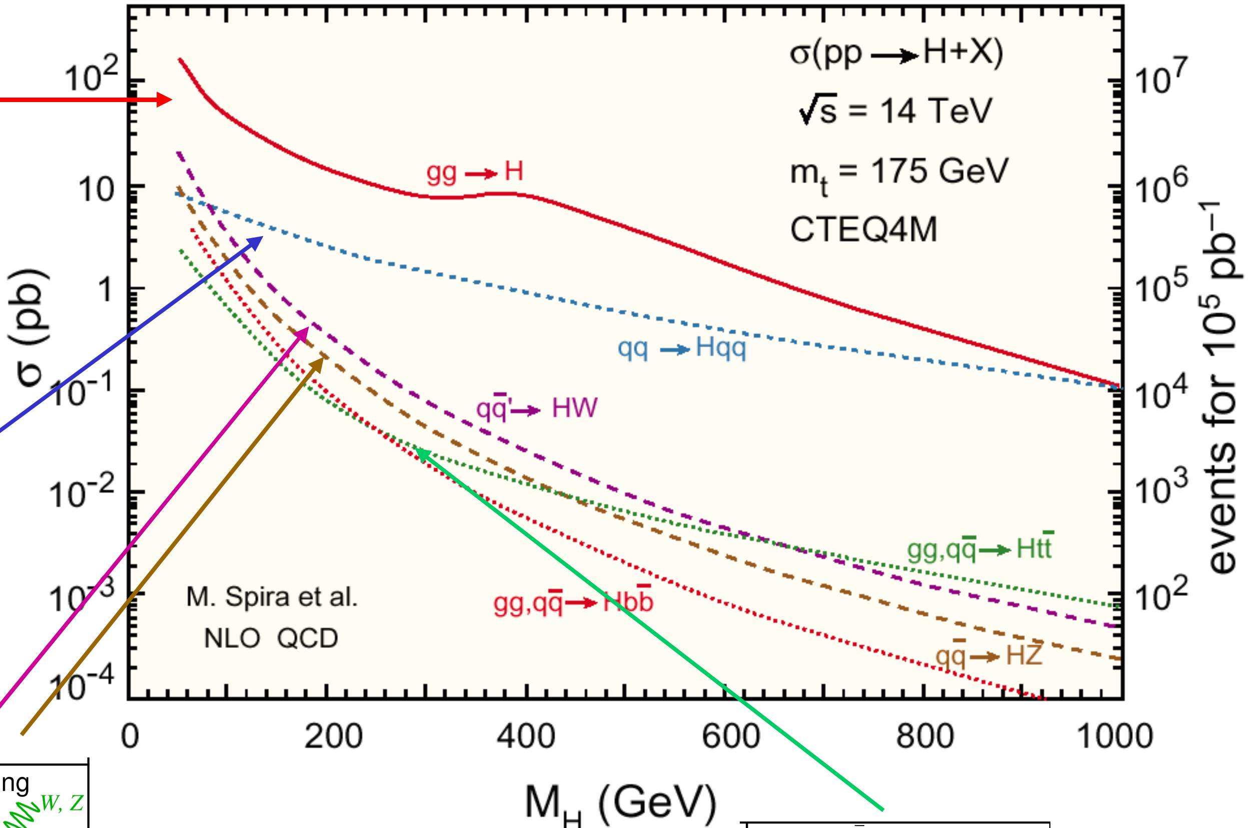
Experimental data :
114 GeV < m_H < 199 GeV (95% CL).

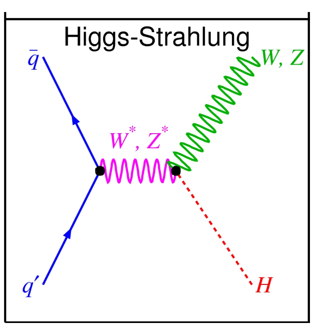
Experimental data prefers a light Higgs (< ~ 200GeV) to a heavy one.

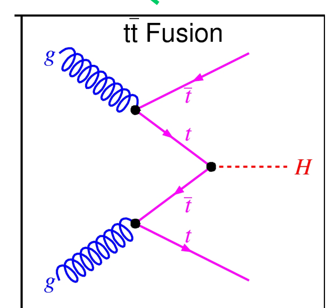
SM HIGGS PRODUCTION AT LHC



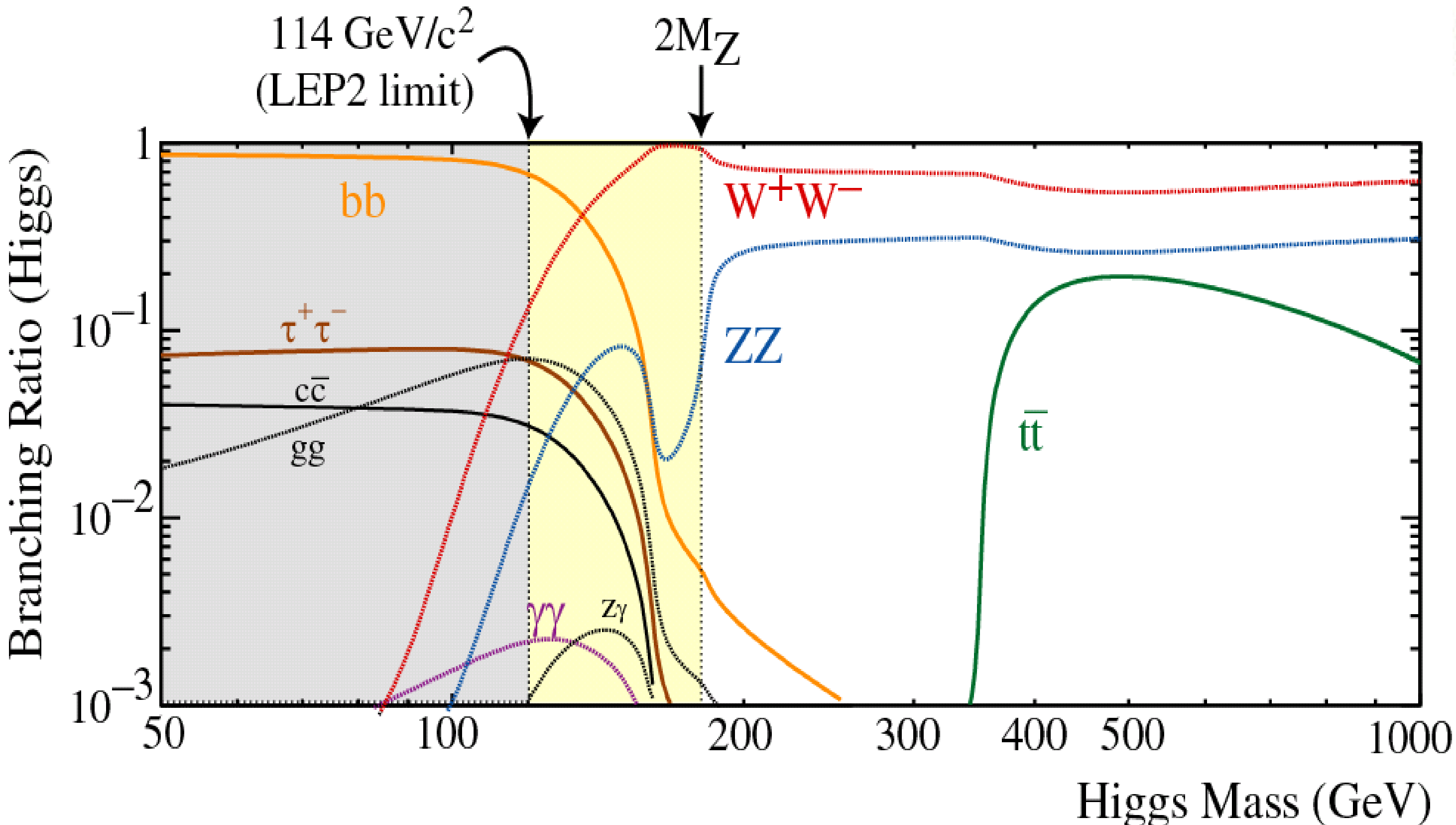








SM HIGGS DECAY MODES



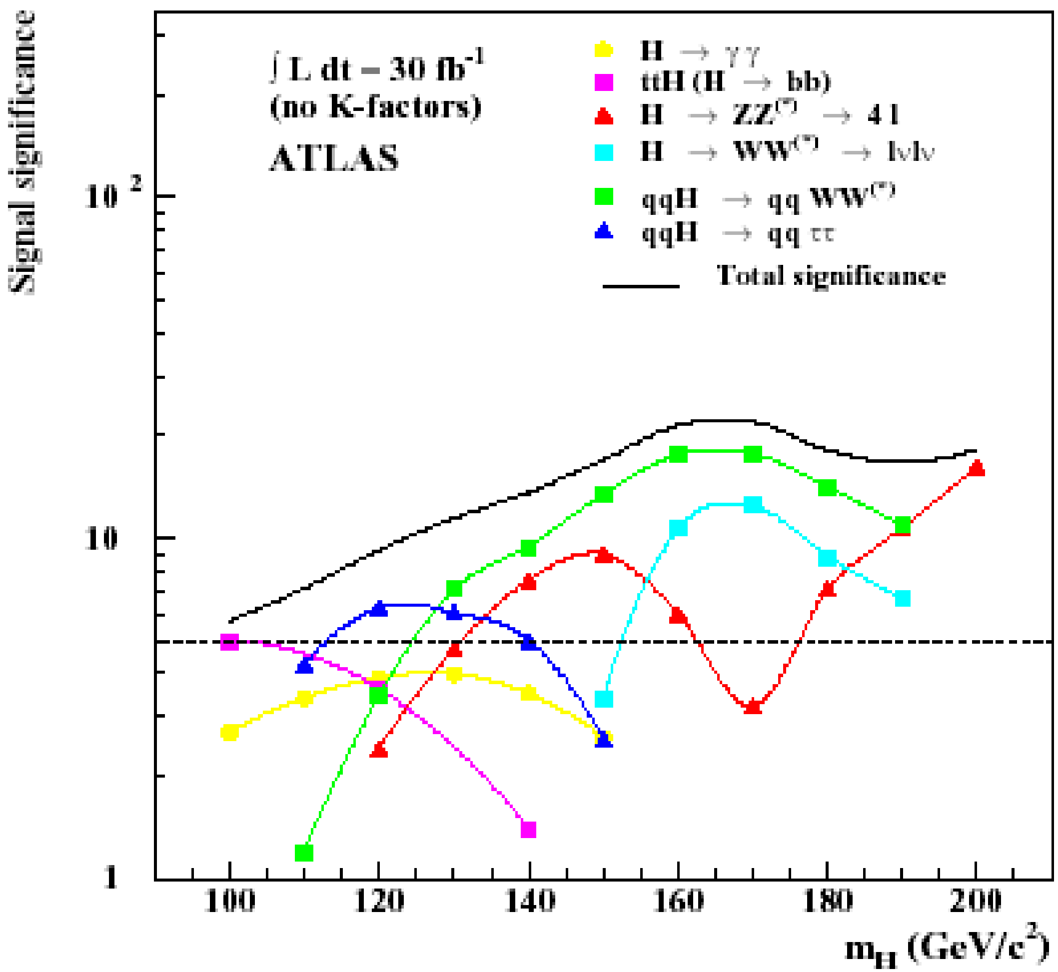
H→bb : feasible in associated production ttH.

H→ττ : important in VBF for masses above LEP limits.

H→γγ : low BR but clear signature.

H→VV : in the whole mass range (V = W,Z).

DISCOVERY POTENTIAL OF SM HIGGS AT ATLAS



30 fb^{-1} of data enough for a SM Higgs discovery.

Once a Higgs signal is observed:
- confirm that it is an Higgs boson;
- measure its properties : mass, spin, *CP*, **couplings**, ...

MEASUREMENTS OF HIGGS COUPLINGS (1)

ATLAS STUDIES

Depending on theoretical assumptions, different sets of coupling parameters are extracted.

All the observable signals are used to perform a global maximum likelihood fit to determine the expected accuracy on the measurements of Higgs coupling parameters.

Taken into account : systematic uncertainties for the detector (luminosity, efficiencies, …) , statistical fluctuations and systematic uncertainties for signal and background.

Production	Decay	mass ranges
Gluon-Fusion $(gg \to H)$	$H \to ZZ \to 4l$	110 GeV - 200 GeV
	$H \to WW \to l\nu\, l\nu$	110 GeV - 200 GeV
	$H \to \gamma\gamma$	110 GeV - 150 GeV
WBF $(qq\,H)$	$H \to ZZ \to 4l$	110 GeV - 200 GeV
	$H \to WW \to l\nu\, l\nu$	110 GeV - 190 GeV
	$H \to \tau\tau \to l\nu\nu\, l\nu\nu$	110 GeV - 150 GeV
	$H \to \tau\tau \to l\nu\nu\, \mathrm{had}\nu$	110 GeV - 150 GeV
	$H \to \gamma\gamma$	110 GeV - 150 GeV
$t\bar{t}H$	$H \to WW \to l\nu\, l\nu\, (l\nu)$	120 GeV - 200 GeV
	$H \to b\bar{b}$	110 GeV - 140 GeV
	$H \to \tau\tau$ (not included)	110 GeV - 150 GeV
	$H \to \gamma\gamma$	110 GeV - 120 GeV
WH	$H \to WW \to l\nu\, l\nu\, (l\nu)$	150 GeV - 190 GeV
	$H \to \gamma\gamma$	110 GeV - 120 GeV
ZH	$H \to \gamma\gamma$	110 GeV - 120 GeV

M.Duhrssen ATL-PHYS-2003-30

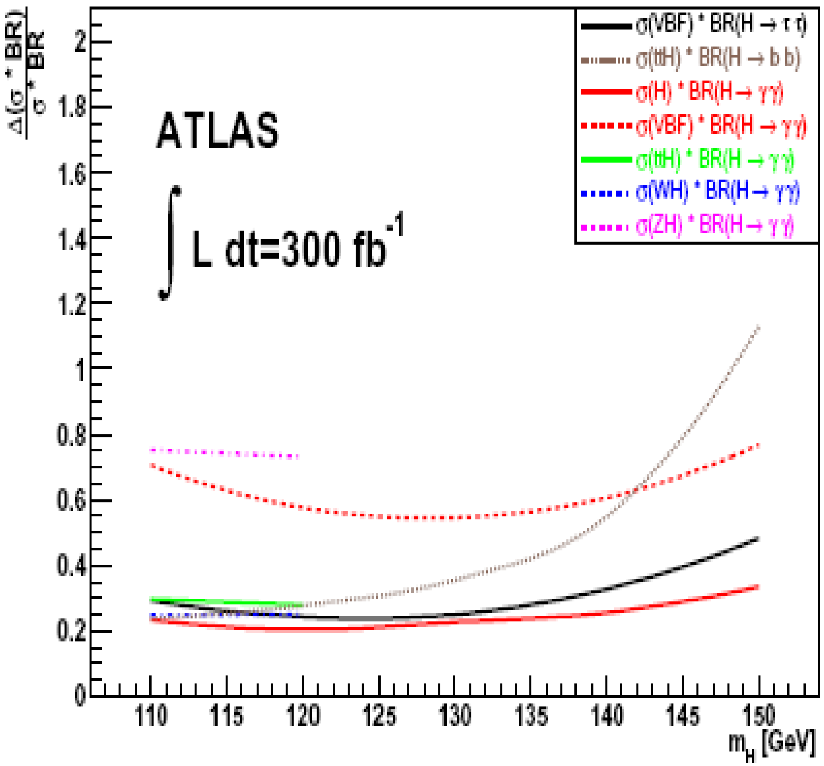
MEASUREMENTS OF HIGGS COUPLINGS (2)

Increasing level of assumptions ↓

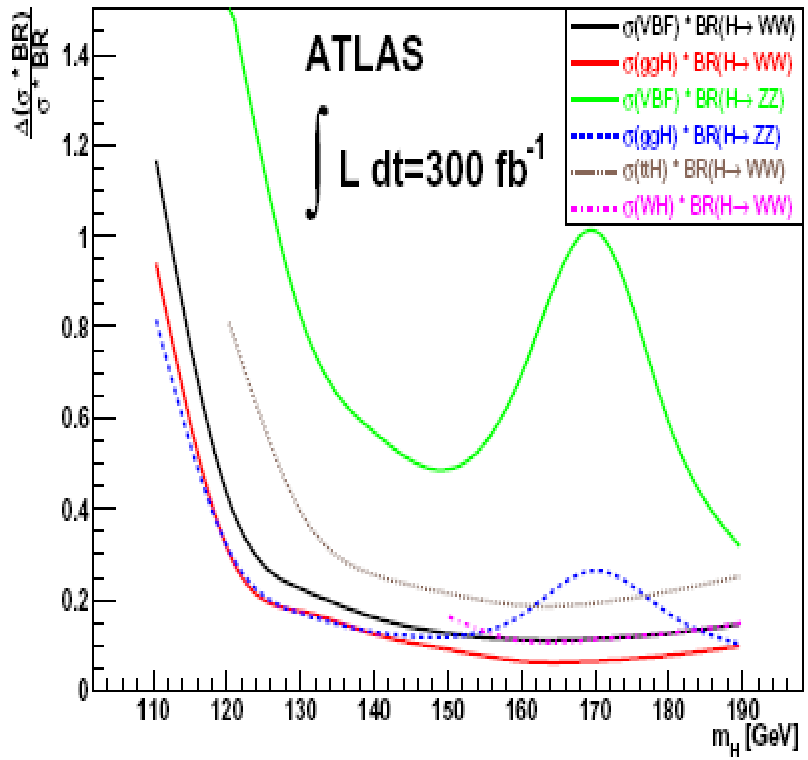
Theoretical assumption	Measurement
CP-even, spin-0	Rates : $\sigma \cdot BR$
+ only one Higgs boson	Relative branching ratios $BR(H \rightarrow XX)/BR(H \rightarrow WW)$; equivalent to partial width ratios Γ_X/Γ_W
+ only SM couplings (no extra particles in loops, no strong couplings to light fermions)	Ratios of Higgs boson couplings g^2_X/g^2_W; lower limit on Higgs total width.
+ sum of all visible BR is of the same size as in the SM (or $\Gamma_V \leq \Gamma^{SM}_V$ V=Z,W)	Absolute couplings and total width.

RATE MEASUREMENTS

Only channels that can be seen for M_H< 150 GeV

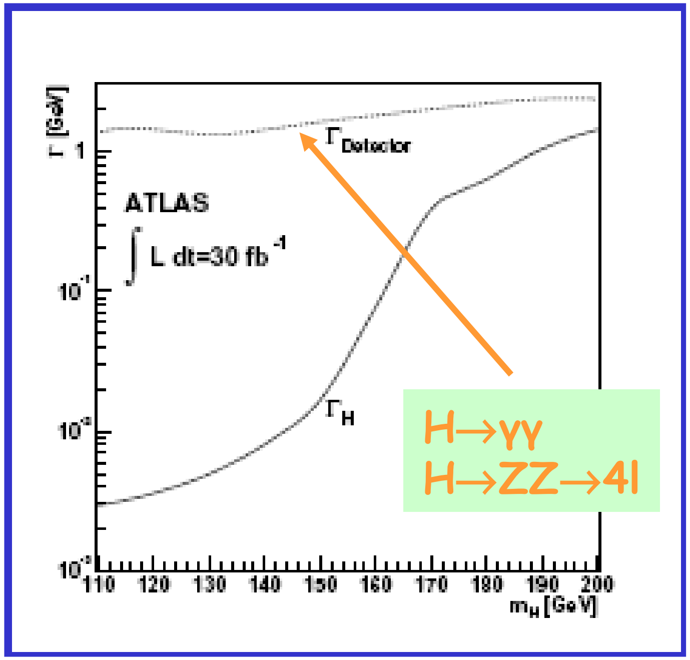


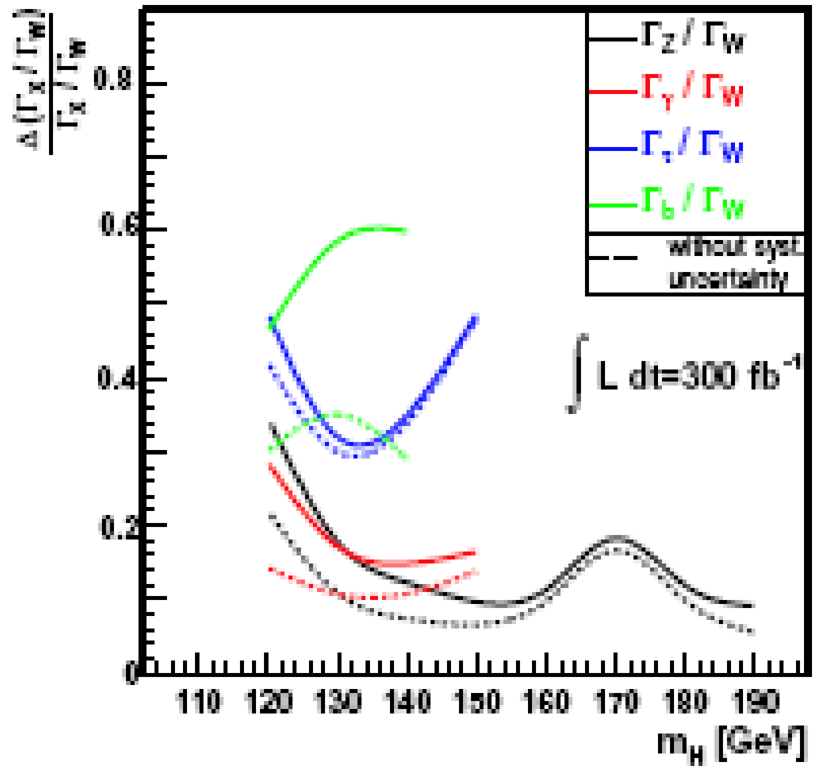
Channels with Z and W in the final state



RATIO OF PARTIAL DECAY WIDTHS

Total width cannot be measured because of detector resolution.





H→bb : low S/B, large systematics; uncertainties on backgrounds dominate.

For the other channels ratio of partial widths can be measured with an accuracy better than 50%.

H→WW used as normalization since it is measured with the smallest error.

MEASUREMENT OF RELATIVE COUPLINGS

Cross sections and branching ratio proportional to the square of couplings.
α and β calculated from theory.

$\sigma_{ggH} = \alpha_{ggH} \cdot g^2_t$ (sys : 20%)

$\sigma_{VBF} = \alpha_{WF} \cdot g^2_W + \alpha_{ZF} \cdot g^2_Z$ (4%)

$\sigma_{ttH} = \alpha_{ttH} \cdot g^2_t$ (15%)

$\sigma_{WH} = \alpha_{WH} \cdot g^2_W$ (7%)

$\sigma_{ZH} = \alpha_{ZH} \cdot g^2_Z$ (7%)

$BR(H\rightarrow WW) = \beta_W(g^2_W/\Gamma_H)$ (sys : 1%)

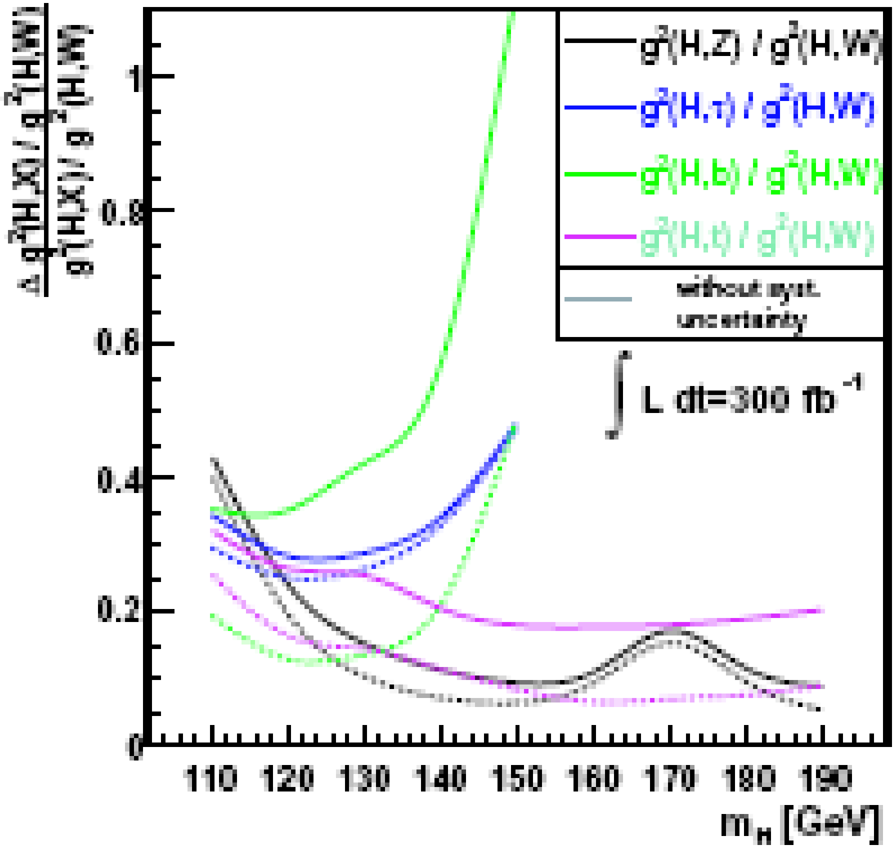
$BR(H\rightarrow ZZ) = \beta_Z(g^2_Z/\Gamma_H)$

$BR(H\rightarrow \gamma\gamma) = (\beta_{\gamma(W)} g_W - \beta_{\gamma(t)} g_t)^2/\Gamma_H$

$BR(H\rightarrow \tau\tau) = \beta_\tau(g^2_\tau/\Gamma_H)$

$BR(H\rightarrow bb) = \beta_b(g^2_b/\Gamma_H)$

$$\frac{g_W^3}{\sqrt{\Gamma_H}} = scale$$



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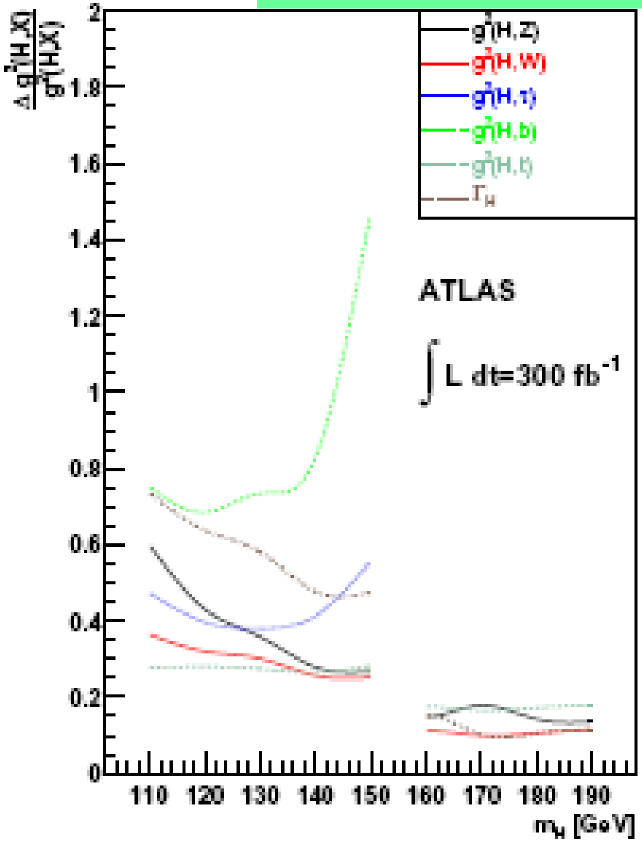
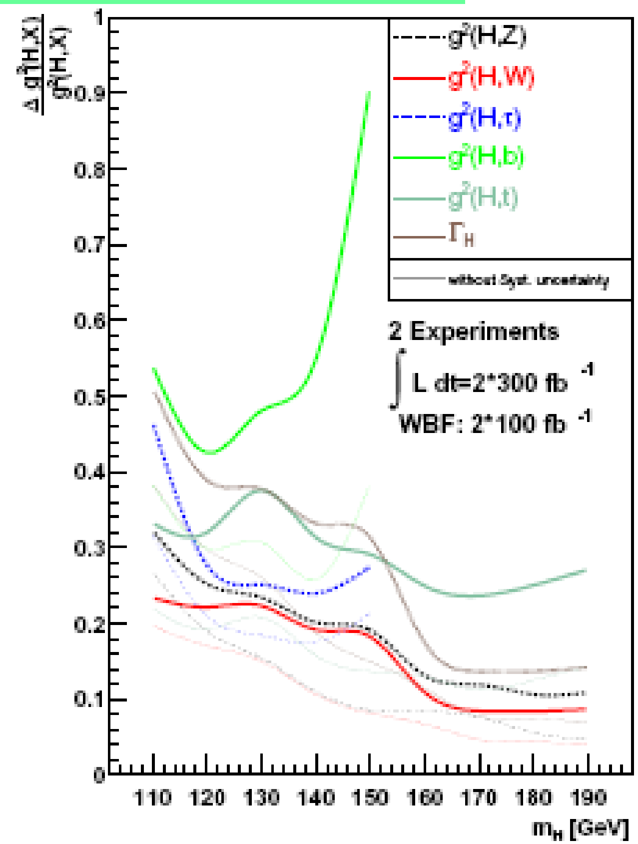
MEASUREMENT OF ABSOLUTE COUPLINGS

Need of a further theoretical assumption.





hep-ph/0407190

Constraint on Higgs total width:

$\Sigma BR(H \to det.) = \Sigma BR(H \to det.)_{SM} \pm \varepsilon_{SM}$

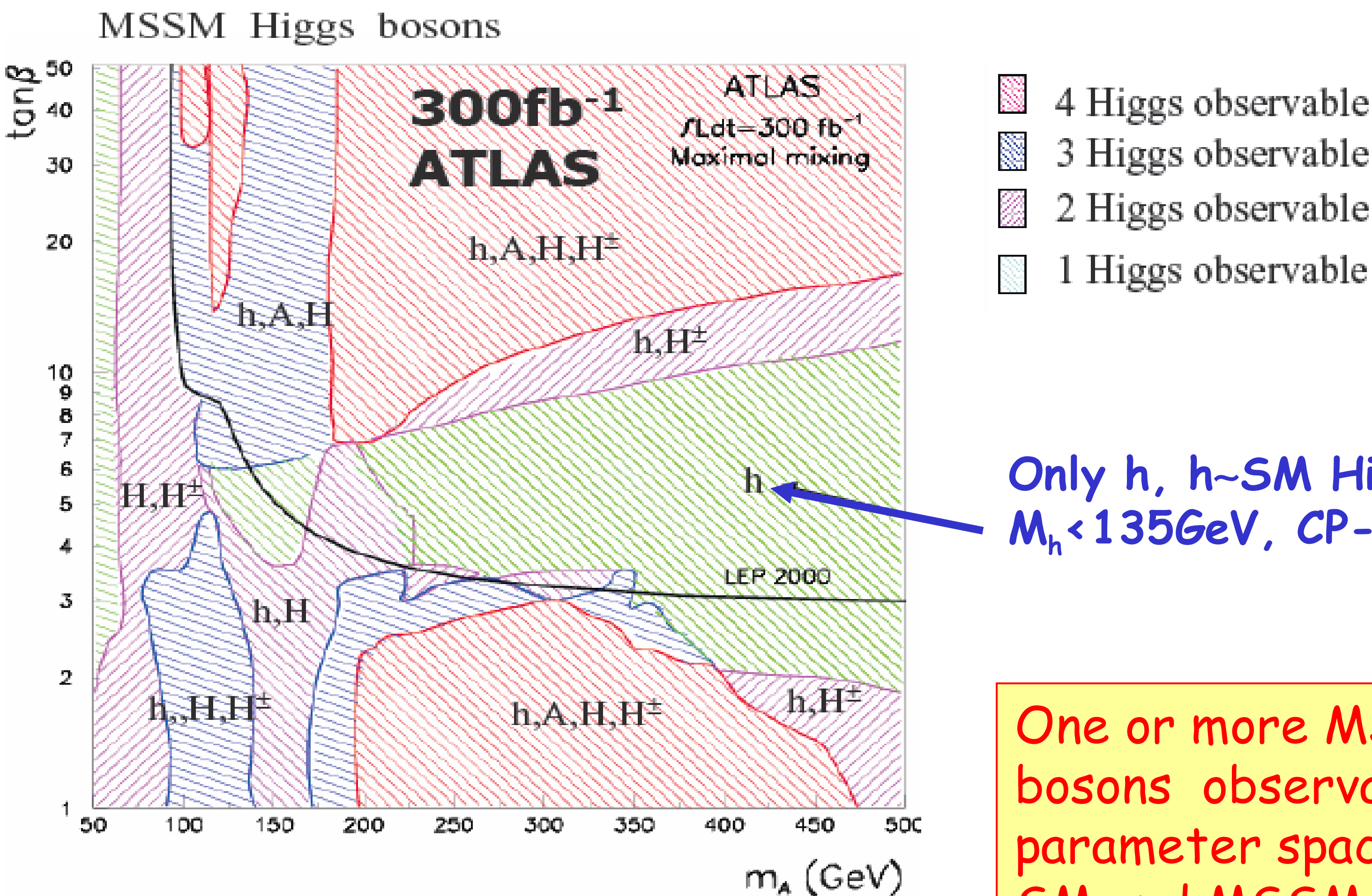
$\varepsilon_{SM} = 1 - \Sigma BR(H \to det.)_{SM}$

Constraint on couplings :

$g^2(H,V) \leq g^2(H,V,SM)$ (V=W,Z)

(in any model with an arbitrary number of Higgs doublets, for example MSSM)

DISCRIMINATION BETWEEN SM AND MSSM (1)



Only h, h~SM Higgs: M_h<135GeV, CP-even.

One or more MSSM Higgs bosons observable in the parameter space : disentangle SM and MSSM directly from the coupling differences.

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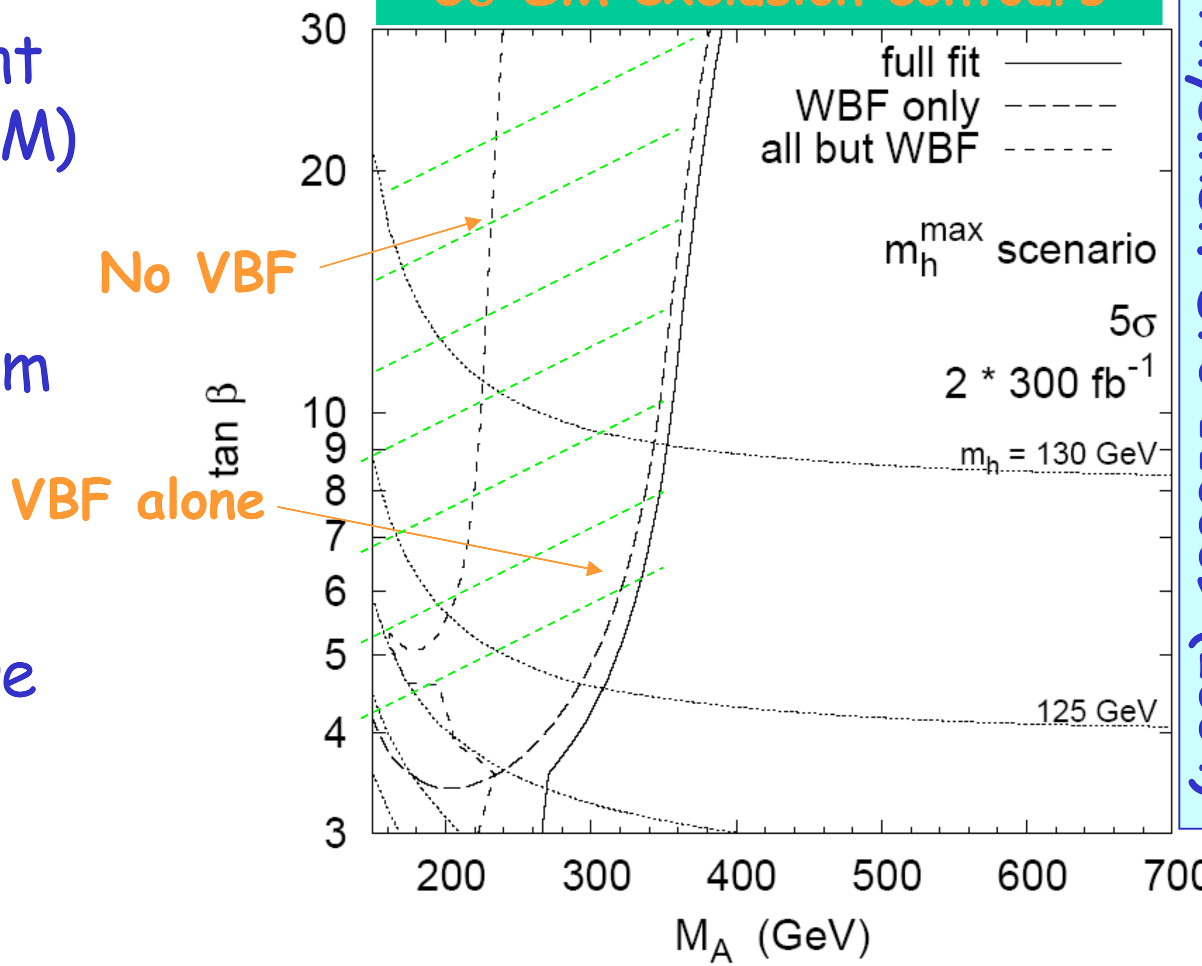
DISCRIMINATION BETWEEN SM AND MSSM (2)

With the constraint
$g^2(H,V) \leq g^2(H,V,SM)$
(V=W,Z),
event rates distinguish SM from a specific MSSM scenario.

$h \rightarrow bb$ and $h \rightarrow \tau\tau$ are enhanced in this region.

5σ SM exclusion contours



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CONCLUSIONS

- Present experimental data prefer a light Higgs boson with $M_H < 200$ GeV

- ATLAS will be able to detect a Higgs signal with significance > 5 σ for all M_H, with 30 fb^{-1} of data.

- After the discovery, precise measurements of its properties have to be done.

- In the low mass region, couplings constants and total width could be measured, using a global Maximum Likelihood fit, combining all available signals with a precision of 10-50% with 300 fb^{-1} of data.

- With the same method it is also possible to exclude SM Higgs at 5σ for $M_A < 400$ GeV.

BACKUP SLIDES

HIGGS BOSON SELF-COUPLINGS (1)

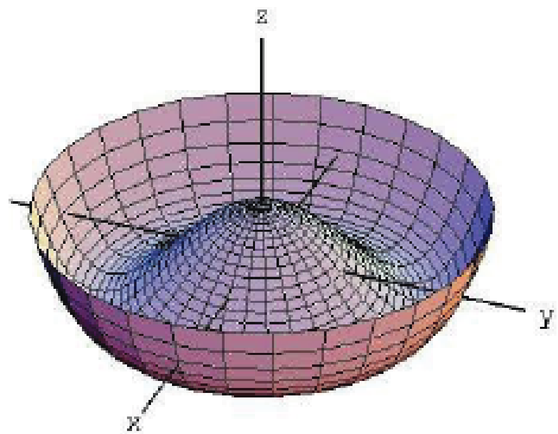
Higgs potential:

$$V(\eta_H) = \frac{1}{2} m_H^2 \, \eta_H^2 + \lambda v \eta_H^3 + \frac{1}{4} \lambda' \eta_H^4$$

η_H: physical Higgs field

$v = (\sqrt{2}\, G_F)^{-\frac{1}{2}}$ vacuum expectation value

SM: $\lambda' = \lambda = \lambda_{SM} = m_H^2/(2v^2)$



- to verify the Higgs mechanism λ (λ') has to be measured
  - experiments must observe HH (HHH) production
  - pp → HHH cross section too small to probe λ' at any machine considered so far
  - concentrate on λ in the following

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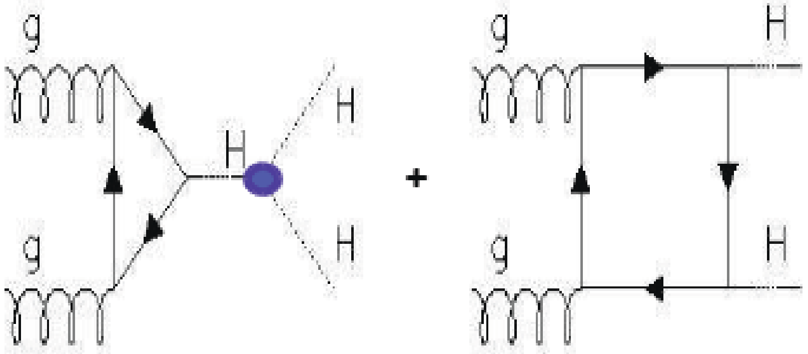
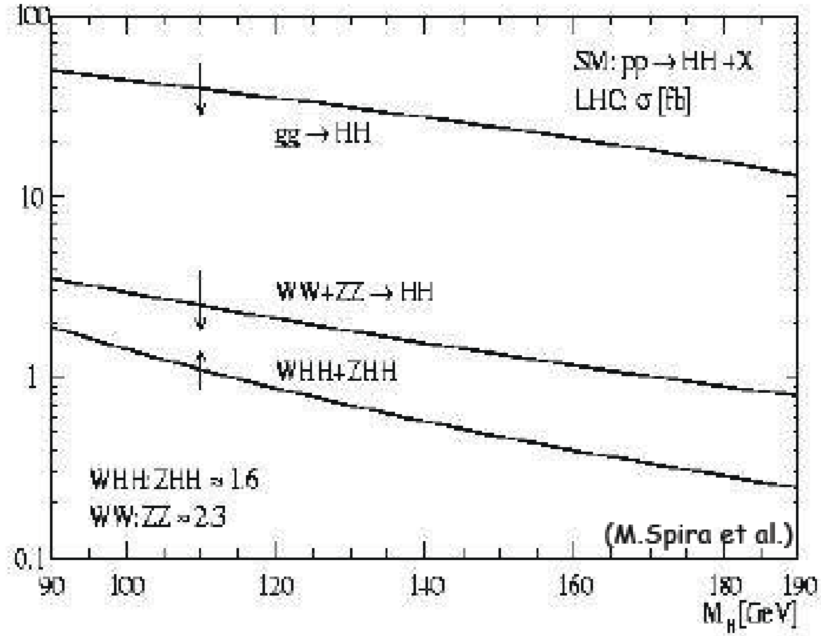
HIGGS BOSON SELF-COUPLINGS (2)

SM diagrams interfere destructively:





- Cross section for qq -> qq HH, WHH, ZHH and tt HH production are a factor 10 - 30 smaller
- for m_H>140 GeV, H->W^+W^- dominates
- Most promising: HH->WWWW->(jj$l^\pm\nu$)(jj$l^\pm\nu$)

Existing ATLAS study: A.Blondel, A.Clark, F.Mazzucato (ATL-PHYS-2002-029)

- Main background sources:
  - tt j (1 b semilep. decay)
  - $W^\pm W^+ W^-$jj (one had. W decay)
  - tt $W^\pm$
- Other background sources:
  - $W^\pm$Zjjjj, $W^\pm W^\pm$jjjj, tttt, 4W, tt Z

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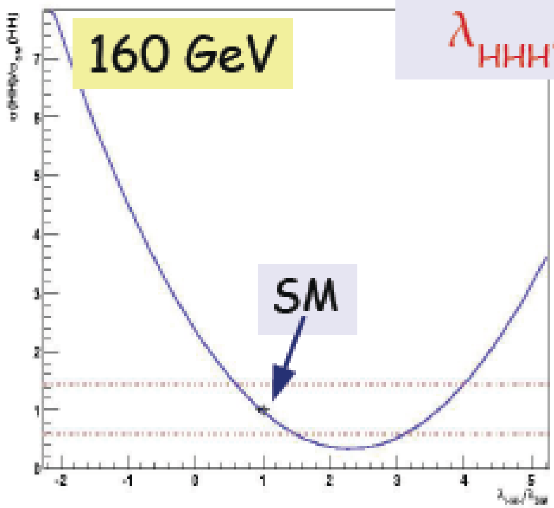
HIGGS BOSON SELF-COUPLINGS (3)

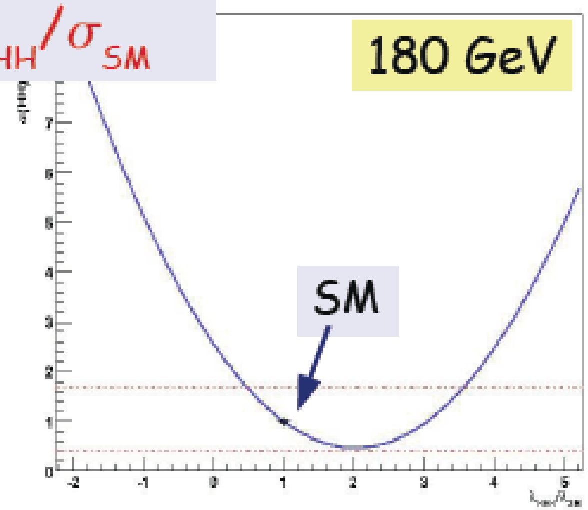
6000 fb^{-1}	150 GeV	160 GeV	170 GeV	180 GeV
Signal	18	54	72	36
ttbar	126	120	144	132
ttW	30	36	36	60
WWWjj	80	113	160	187
S/Bgd	7.60%	20.10%	21.20%	9.50%
$\Delta\sigma_{HHH}/\sigma_{HHH}$	98% -80%	44% -41%	52% -48%	67% -61%

Numbers of events after strict cuts expected for $\mathscr{L} = 3000\ fb^{-1}$ per exp.

ttbar and WWWjj about the same size!

$\lambda_{HHH}/\lambda_{SM}$ vs. σ_{HH}/σ_{SM}





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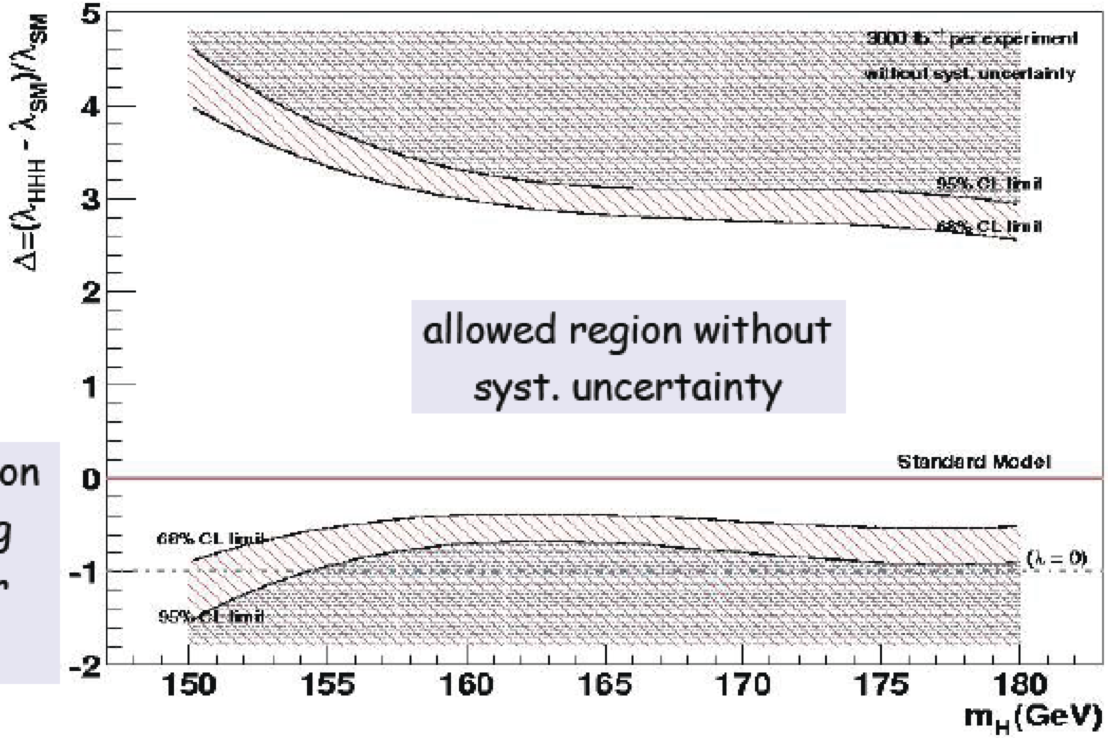
HIGGS BOSON SELF-COUPLINGS (4)

Sensitivity Limits on λ (priliminary)

Preliminary 1σ-limits for $\Delta\lambda_{HHH} = (\lambda_{HHH} - \lambda_{SM})/\lambda_{SM}$ in

$pp \rightarrow HH \rightarrow WWWW \rightarrow \ell^{\pm}\ell^{\pm} + 4j$ by assuming $\mathscr{L}$ = 3000 fb^{-1} per exp.:



The Higgs boson self-coupling vanishes for $\Delta\lambda_{HHH}$ = -1.

- No sensitivity to Higgs self-couplings at the LHC!
- However, for 3000 fb^{-1} per experiment priliminary results show that at least an exclusion of $\lambda = 0$ might still be feasable

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