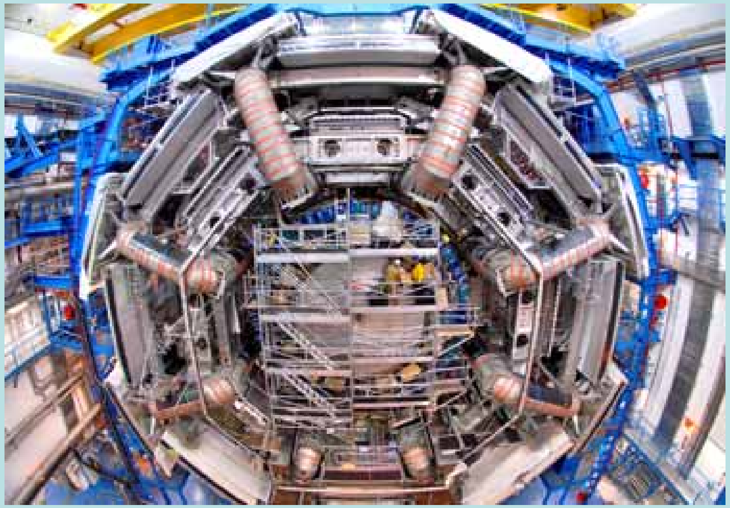
Beyond the Standard Model Higgs in ATLAS and CMS



Tord Ekelof Uppsala University

Brief motivation for beyond SM searches

However successful the Standard Model (SM) has been so far in describing current experimental data it is at the same time **plagued by instabilities** due to quadratically divergent loop corrections at higher energy. Different schemes “beyond the Standard Model” have been proposed to cure these instabilities;

- **Supersymmetry** which introduces superpartners to the SM particles which have loop corrections of the same magnitude but opposite sign to all orders. SUSY symmetry braking scale needs to be of order 1 TeV.

- **Little Higgs** which introduces a set of heavier vector bosons and top-antitop quarks that provide a limited cancellation and push the divergences up to order 10 TeV

- **Extra dimensions** which has the SM interactions confined to four dimensions and gravity occupying also the extra dimensions.

MSSM

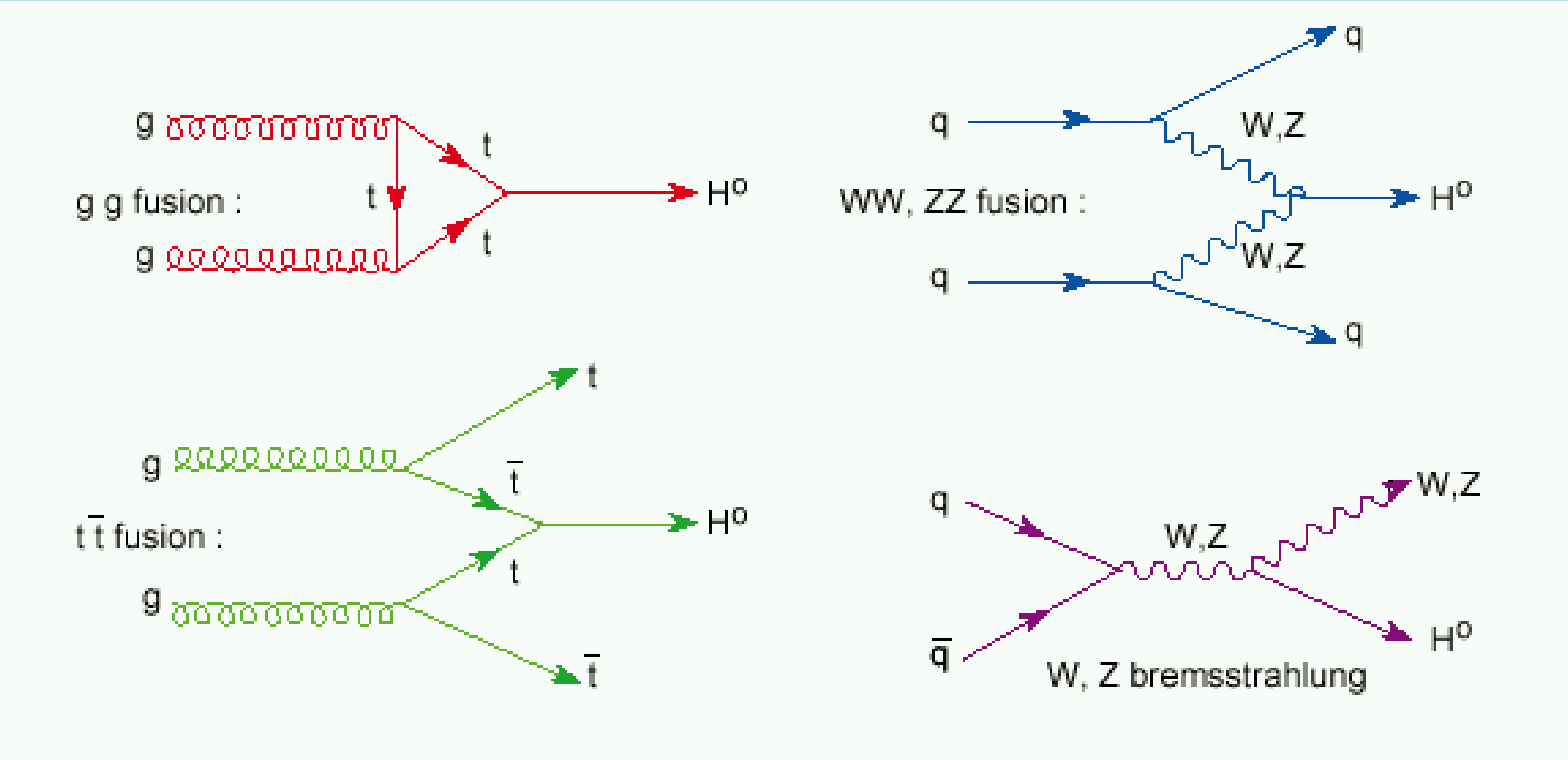
With Supersymmetry more than 100 extra parameters are introduced. For practical applications the model thus has to be constrained, like it is in the constrained **Minimal Supersymmetric** model (MSSM) which is the minimal supersymmetric extension of the SM with 7 free parameters.

MSSM introduces two complex Higgs field doublets which is the minimal Higgs structure needed to keep the theory anomaly free and to give mass to the fermions.

MSSM predicts **five Higgs bosons**, three neutral Higgs, of which two, h and H, are CP-even and one, A, is CP-odd, and two charged Higgs, H^+ and H^-. In order to further constrain the number of free parameters four benchmark scenarios have been proposed for which 5 of the 7 parameters are given fixed values. The predictions of the theory is displayed as function of the two remaining parameters, often chosen as tanβ, the ratio of the vacuum expectation value of the two Higgs doublets, and M_A, the mass of the CP-odd Higgs boson. The values of the other 5 parameters in the four proposed **benchmark scenarios** are (unit GeV);

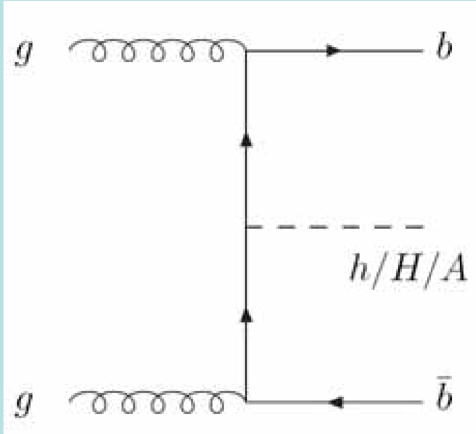
Name	M_{SUSY}	μ	M_2	X_t	$m_{\tilde{g}}$
m_h-max	1000	200	200	2000	800
No mixing	2000	200	200	0	800
Gluophobic	350	300	300	-750	500
Small α	800	2000	500	-1100	500

Higgs production mechanisms



Associate b$\tilde{b}$Φ production, Φ->μμ

For large tanβ b$\tilde{b}$Φ represents a dominant Higgs production process and provides the best measurements for the heavy Higgs H and A.



Different Φ decay channels have been investigated by CMS:

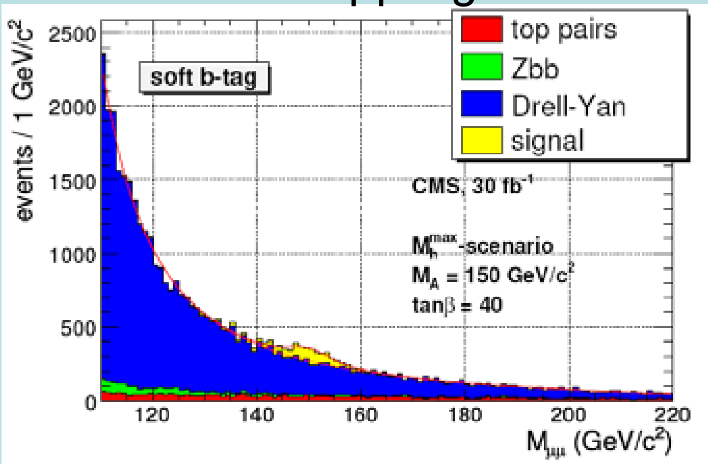
Φ->μμ
->ττ with the τ decaying to e, μ and jets
->bb

The ττ final state has the largest Φ discovery reach whereas the the μμ final state provides the best mass resolution, comparable to the natural width of the Higgs, sensitive to tanβ.

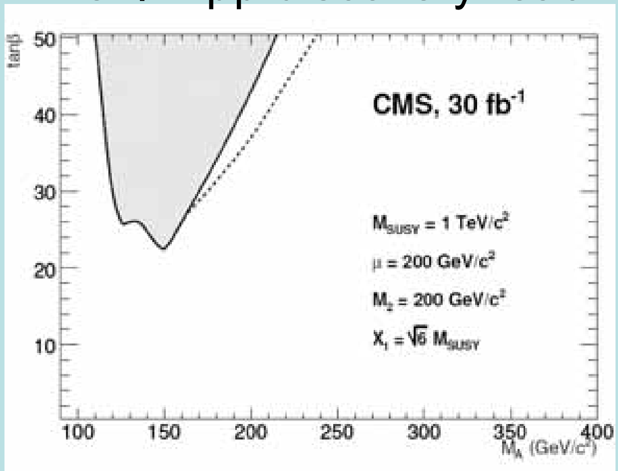
The presence of two b quarks is used to suppress Drell-Yan production.

Associate bb̃Φ production, Φ->μμ

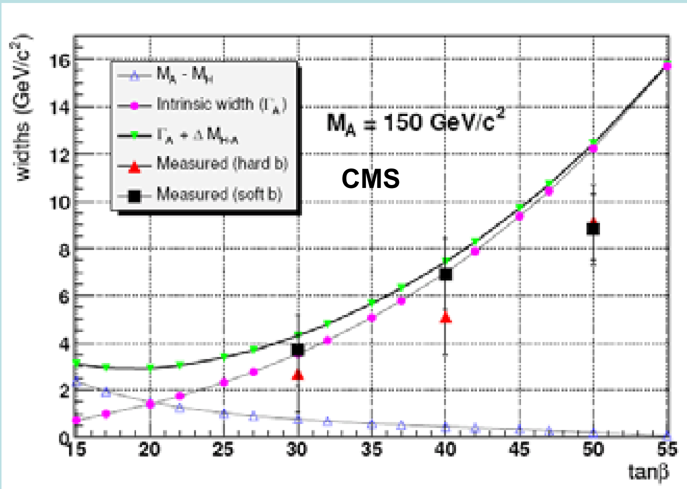
The Φ->μμ signal



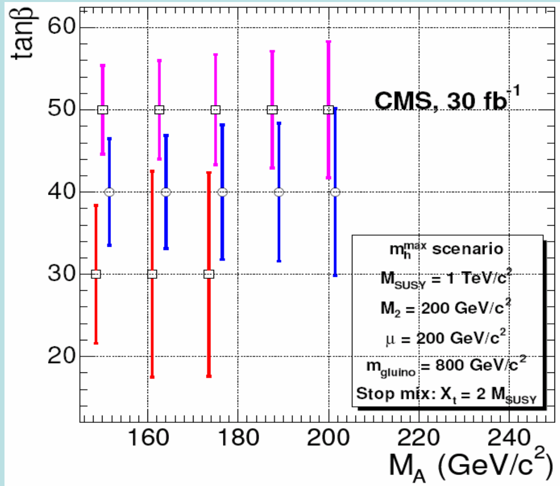
The Φ->μμ discovery reach



The measured Φ width



The determination of tanβ



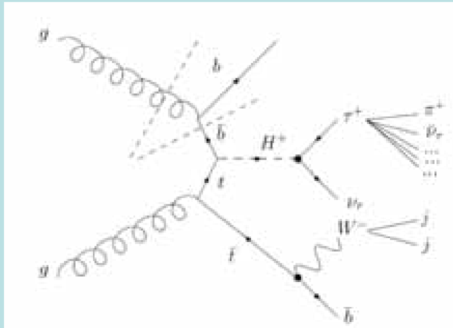
Ref.: CMS TDR 8.2

Referred to yesterday in the talk of Marcela Carena

Search for charged Higgs

Charged Higgs decay to $\tau\nu_\tau$

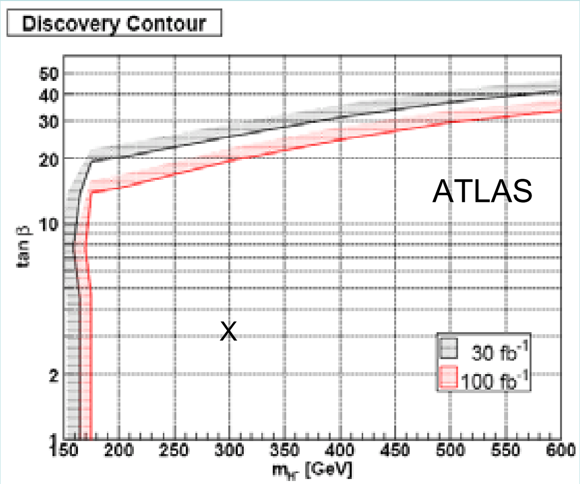
It has been shown that the $H^+ \to \tau\nu_\tau$ channel can be used to search for H^+ for all tanβ values up to just below the top mass. For such mass values H^+ is produced through top decays $t \to bH^+$.
For H^+ masses greater than m_t the dominant production process is gluon fusion. **The $H+ \to \tau\nu_\tau$ remains the best search channel up to large H+ masses**. The H+->tb decay has been found to suffer from a large QCD background.
A discovery reach analysis has been made in ATLAS using a **high p_t jet and large missing transverse momentum at large angle** as distinctive feature.

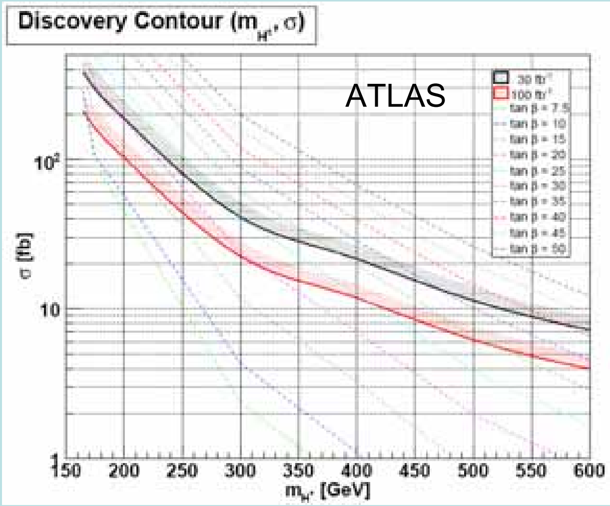


In the transition region around the top mass the two processes $gg \to tbH^+$ and $gb \to tH^+$ both count which leads to **double counting.** This problem has recently been solved with the MC program MATCHIG (Ref. J. Alwall (2006) hep-ph/0503124) in which the doubly counted events are subtracted.

Charged Higgs decay to $\tau\nu_\tau$

Discovery reach





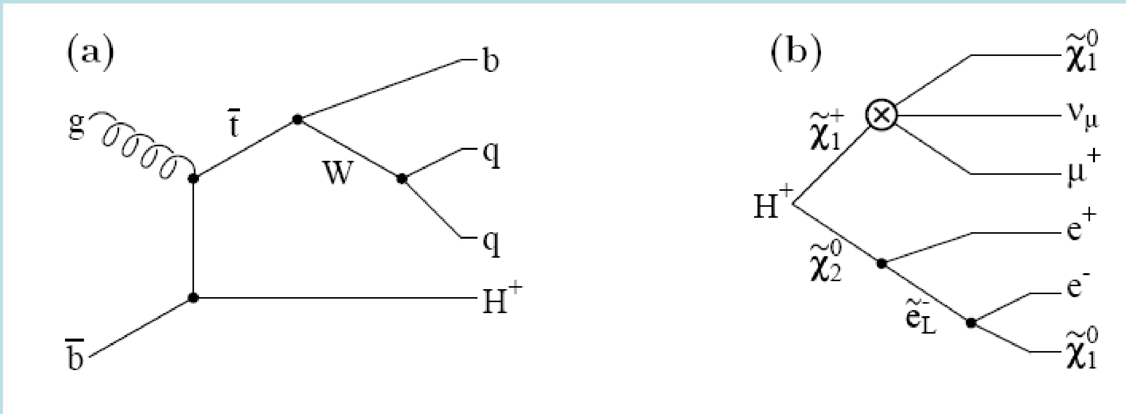
The total systematic uncertainty at m_{H+}=300 GeV is estimated at 9.3 % which moves the 30 fb-1 limit in the left plot at ca tanβ=24 up to ca tanβ=35 (x)

Ref.:ATL-PHYS-PUB-2007-006

Charged Higgs decay to SUSY particles

LEP has excluded low tanβ values < ~4 at all M_A. The previously mentioned $H^+ \to \tau\nu_\tau$ search analysis covers the region down to tanβ~20. The intermediate region is difficult to cover with H^+ searches due to a minimum in the tbH^+ coupling around tanβ~7.5 .

An analysis of the discovery potential for a H^+ decaying in the chargino-neutralino channel has been made in ATLAS with the goal to cover the intermediate tan β region. For this analysis was chosen a MSSM parameter point at which the branching ratio to a chargino and a neutralino is maximized. The parameter values of this point are;
M_2=210GeV, μ=135GeV, $m_{\tilde{l}R}$=110Gev, $m_{\tilde{\tau}R}$=210GeV, $m_{\tilde{g}}$=800GeV, $m_{\tilde{q}}$=1000GeV

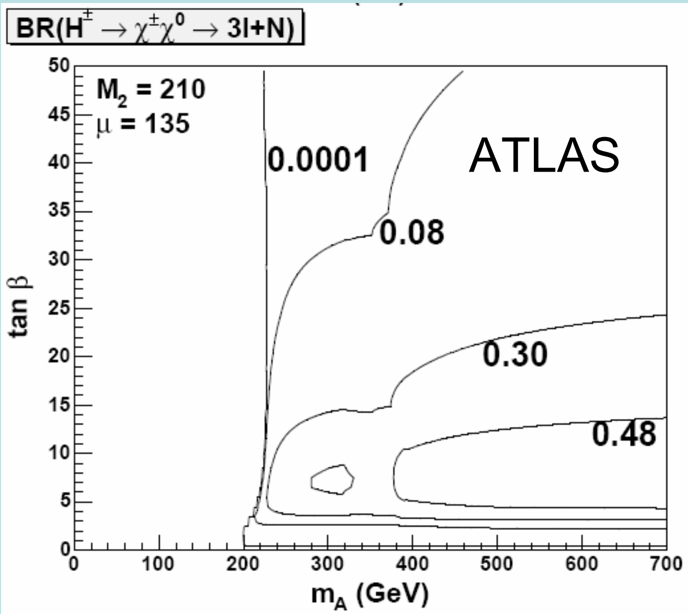


The signature used is;
- three hard leptons and
- substantial missing transverse energy from the neutralino and chargino decays and
- three hard jets from the hadronic top decay.

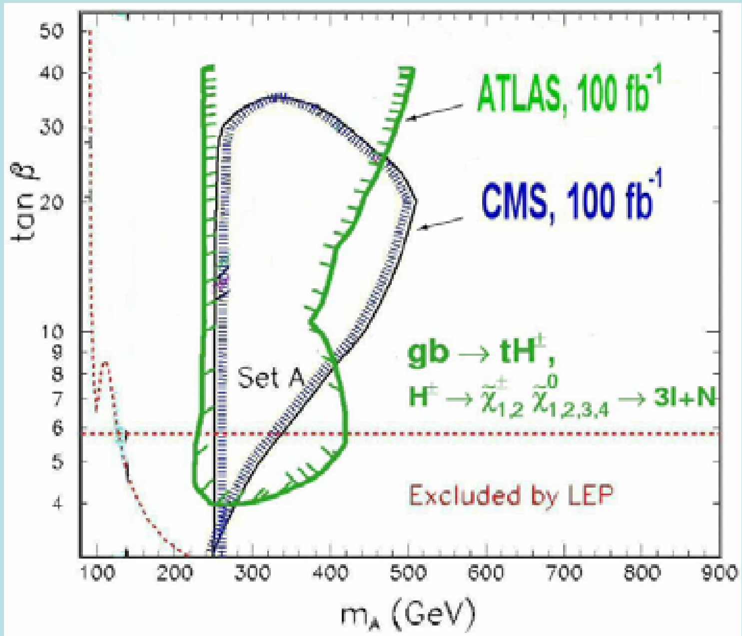
Charged Higgs decay to SUSY particles

Branching H^+->SUSY particles Is high for tanβ~5-10 and large values for M_A

H^+ discovery region covers tanβ~5-30 and large values for $250<M_A<500$ GeV

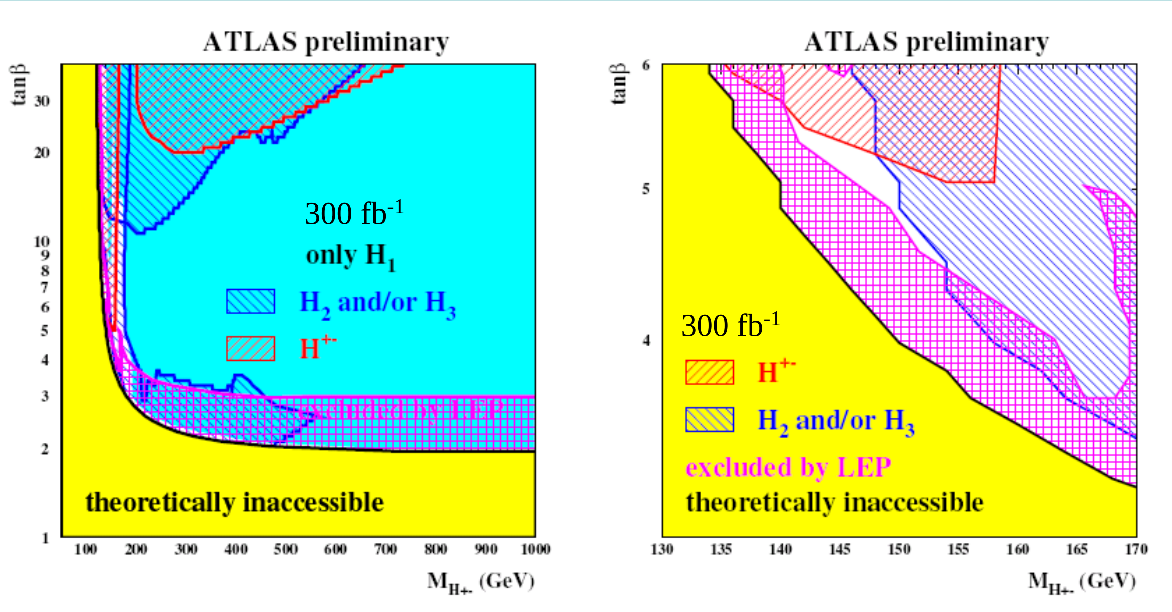


Ref.:SN-ATLAS-2005-050



MSSM with CP violation

The massive terms appearing in the soft SUSY braking terms can be **complex with non-trivial CP-violating phases**. One of the consequences of such CP violation is that the **three neutral MSSM Higgs mix into states H_1, H_2 and H_3 which have no definite CP parity**. The discovery potential for a certain CP-violating MSSM benchmark point **CPX** has been investigated in ATLAS by reinterpretation of studies made within the SM and MSSM. Note that no absolute limit was provide by LEP (like for CP conserving MSSM m_h>92 GeV), since CP-violating Higgs do not couple to Z.



CERN-Ref.: CERN-2006-009

Higgs searches in non-SUSY models

Search for the radions of the Randall-Sundrum model

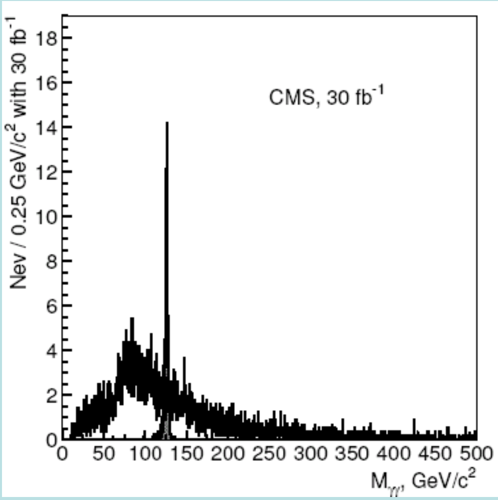
In the RS model there are **two four-dimensional branes located at the boundary of the fifth dimension**. The SM fields are on the visible brane and all mass terms, which are of order Planck mass, are rescaled to order TeV by an exponential factor. The fluctuations in the metric in the fifth dimension are described by a **radion scalar field Φ** which has a vacuum expectation value Λ_Φ. The radion has mass m_Φ and mixes with the Higgs boson h with a mixing parameter ξ.

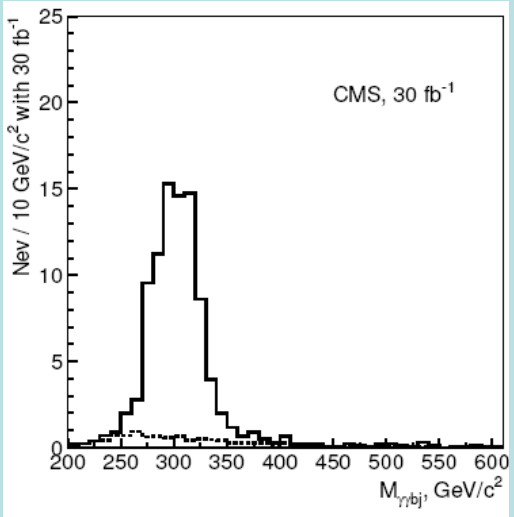
Radions are produced from gluon fusion gg->Φ->hh. The final states of interest are $\gamma\gamma b\tilde{b}$ and $\tau\tau b\tilde{b}$. A search analysis has been made by CMS assuming m_h=125 GeV, m_Φ=300 GeV and Λ_Φ =1000 GeV.

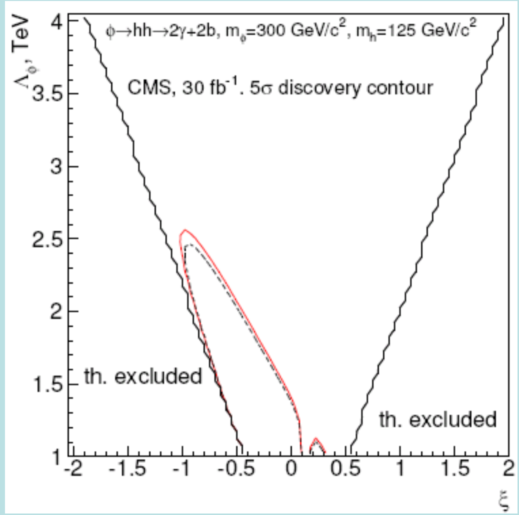
Search for the radions of the Randall-Sundrum model

Results | m_h | m_Φ | Discovery contours

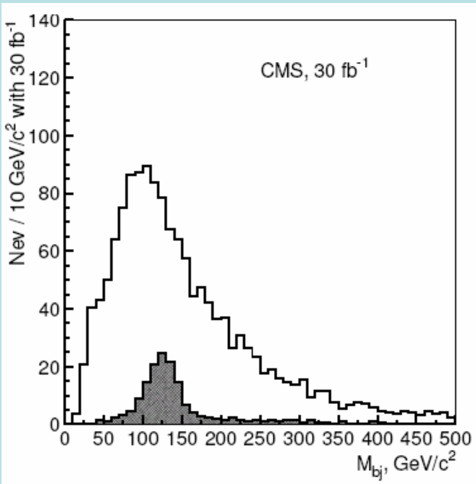
γγbb

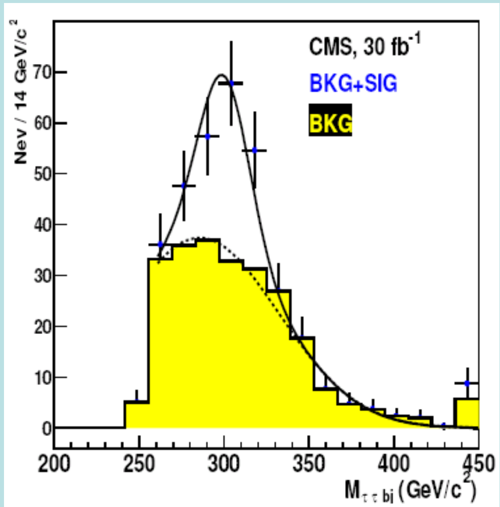


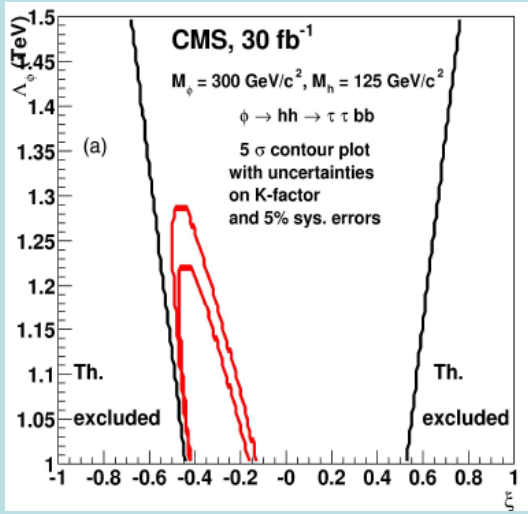




ττbb







Ref.: CMS TDR 8.2

Search for the doubly charged Higgs of the Littlest Higgs model

In the Littlest Higgs model, extra heavy gauge bosons W' and Z' and a vector like heavy quark pair T, $\tilde{T}$ are introduced to stabilize the one-loop quadratically divergent radiative corrections.

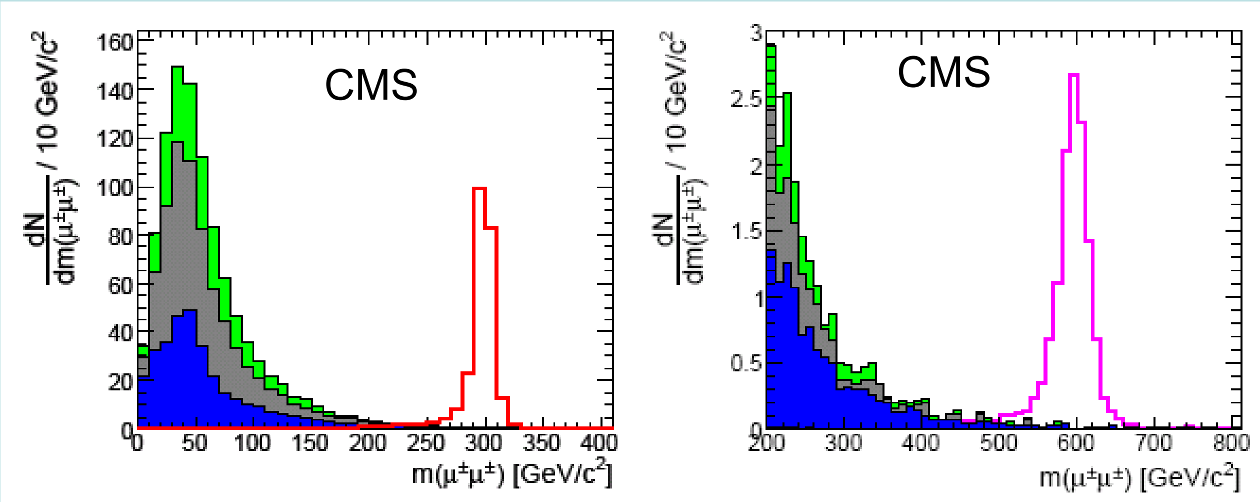
A prediction of this model is the existence of a doubly charged Higgs Δ^{++} which can be Drell-Yann produced in pairs. The Δ^{++} decays into like sign leptons.

A study has been made by CMS in which the pair-produced charged Higgs decay into four muons. Background processes are;

tt -> W+W-bb -> 4μ
Zbb ->4μ
ZZ ->4μ
ZZ ->2μ 2τ

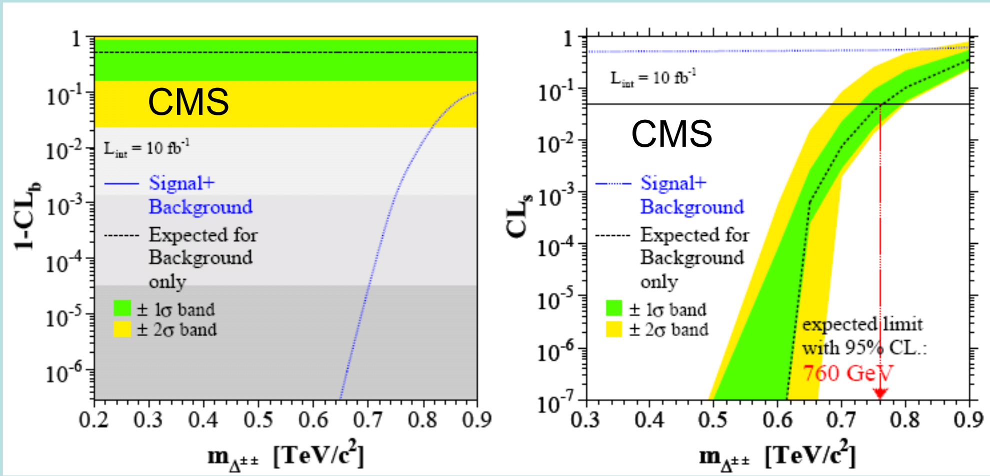
Search for the doubly charged Higgs of the Littlest Higgs model

Signal and background with 10 fb^{-1}



$1\text{-}CL_b$ =probiblilty that background fakes a signal (5σ discovery limit at 650 GeV)

CL_s = probability of excluding an existing signal (95% CL exclusion limit at 760 GeV)



Ref.: CMS TDR 8.2

Invisible Higgs

Higgs decaying into undetectable particles at LHC can only be triggered and reconstructed from particles produced in association with the Higgs particle. Such invisibly decaying particles appear in MSSM (decay into the lightest neutralinos and gravitinos) and also, e.g., in models with large extra dimensions (decay into massive neutrinios) or in the SM with extra singlets as discussed by Jochum van der Bij yesterday.

The discovery potential for the invisible Higgs produced in association with a Z, with the Z decaying into leptons, has been investigated in ATLAS. The dominant (irreducible) background is ZZ->llvv. This is a counting experiment (no mass peak reconstruction possible) and the detection of a signal relies on the accuracy of the **absolute normalization** which is found to of the order 4% at 100 fb^{-1}.

$$\xi^2 = BR(H \to inv.) \frac{\sigma_{ZH}^{BSM}}{\sigma_{ZH}^{SM}}$$

L (fb^{-1})	m_H (GeV/c^2)	120	140	160	180	200	300	400
30	N_S	126	98.7	73.5	54.9	41.7	9.9	2.1
	N_B				472.5			
	Significance S (w.o. syst.)	5.86	4.58	3.41	2.55	1.93	0.46	0.10
	Significance S	3.52	2.75	2.05	1.53	1.16	0.28	0.06
	ξ^2_{95}	0.47	0.60	0.81	1.08	1.42	5.99	28.2
100	Significance S	5.89	4.6	3.43	2.56	1.94	0.46	0.10
	ξ^2_{95}	0.28	0.36	0.48	0.64	0.85	3.57	16.9

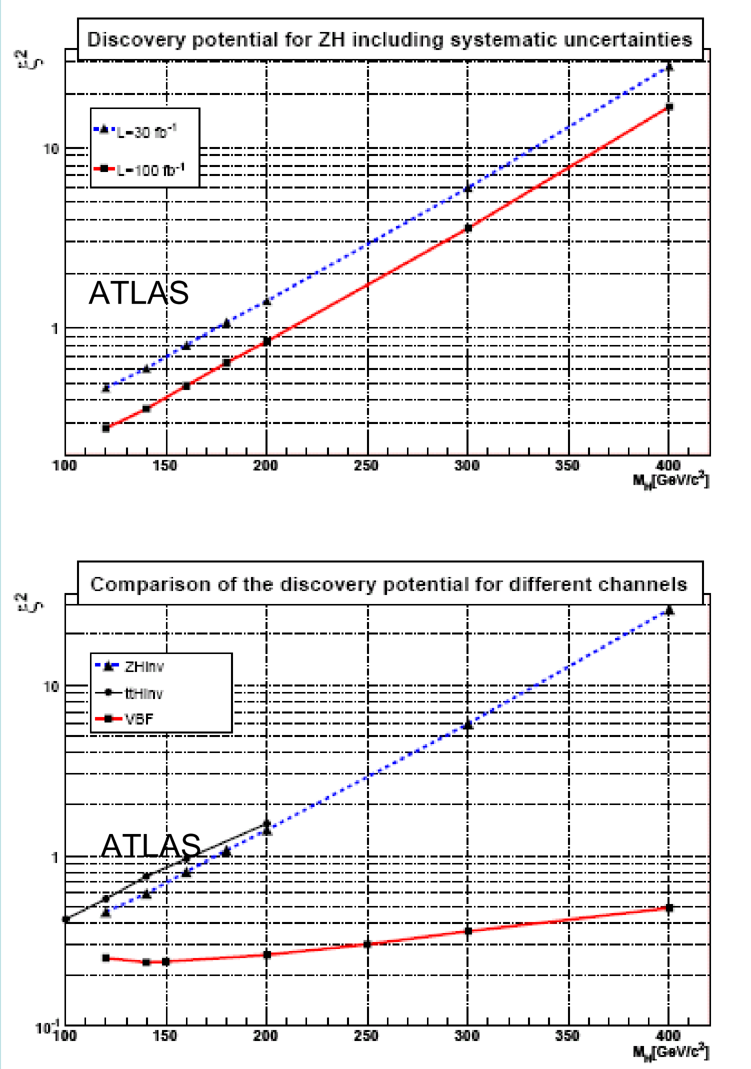
Invisible Higgs

The branching ratio

$$\xi^2 = \mathrm{BR}(\mathrm{H} \to \mathrm{inv.}) \frac{\sigma_{\mathrm{ZH}}^{\mathrm{BSM}}}{\sigma_{\mathrm{ZH}}^{\mathrm{SM}}}$$

as function of invisible Higgs mass

Comparison with Vector Boson Fusion production (qqH) and ttH production – note that VBF is more difficult to trigger on than ZH production



Ref.: ATLAS-PYS-PUB-2006-009

Concluding remarks

- *Discovery analyses using simulated ATLAS and CMS data are now in quite an advanced state with many interesting ideas and results*
- *There are however several frontiers at which we need to work further before we are ready to confront the massive amounts of real data from LHC in 2008 – among these are;*
- *Further development and unification of physics generator codes*
- *Optimization of Fastsim and Fullsim codes with regards to the requirements on simulation accuracy and event statistics*
- *Application of more advance multivariate analysis methods rather than uncorrelated cuts methods*
- *Fully fledged use of the LCG grid to guarantee full analysis capacity*
- *And finally, innovation of not-yet-thought-of physics ideas and schemes, all with the aim to be able to handle the situation we all are hoping for –* ***new, unexpected and surprising physics showing up at LHC.***

Back-up slide

Scan of MSSM Higgs discovery region

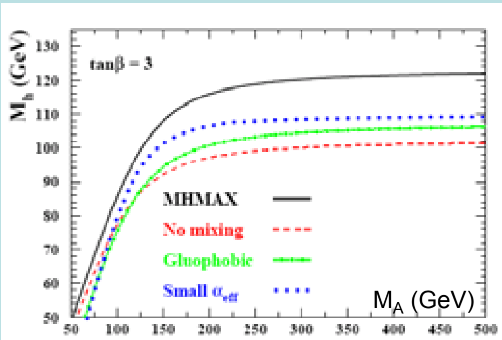
1.Evaluate masses, decay widths, couplings and branching ratios for the parameter values of each benchmark point

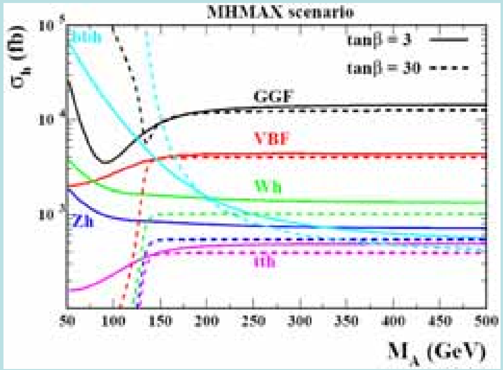
2. Calculate the signal rates using the SM with the couplings modified to fit the MSSM

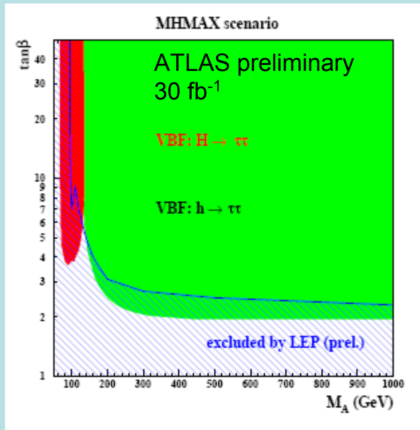
	up type quark	down type quark/ charged lepton	W and Z boson
h	$\cos\alpha / \sin\beta$	$-\sin\alpha / \cos\beta$	$\sin(\alpha-\beta)$
H	$\sin\alpha / \sin\beta$	$\cos\alpha / \cos\beta$	$\cos(\alpha-\beta)$
A	$\cot\beta$	$\tan\beta$	none

3. Obtain the observable number of signal events from the above signal rates, multiplied with the efficiencies from available MC studies and the observable background directly from the same sources.

4. The statistical significance for the expected observation of a signal is then calculated from these numbers

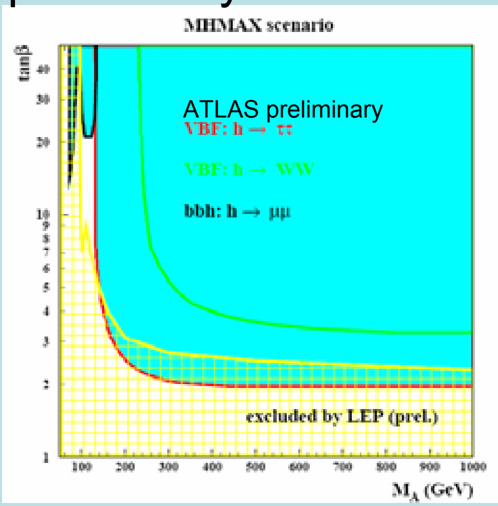


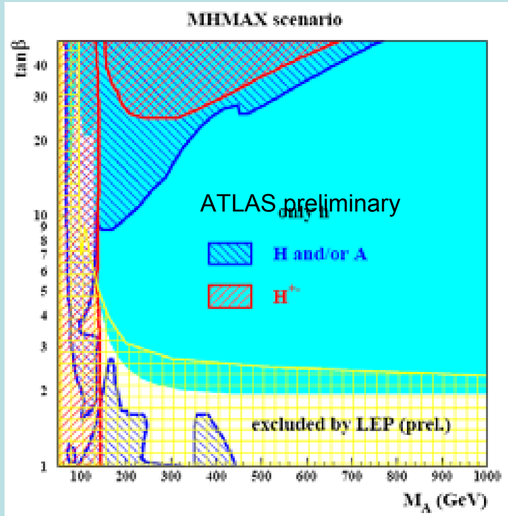




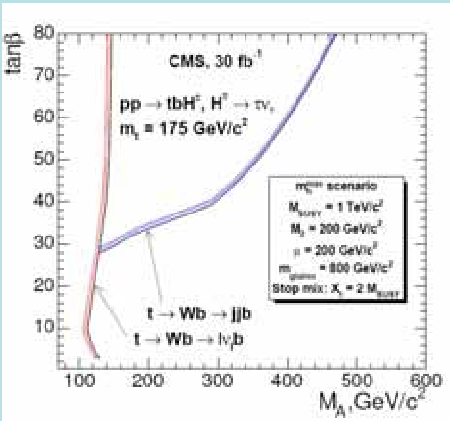
Combined 5σ discovery potential in the m_h^{max} benchmark scenario with 30 fb^{-1}

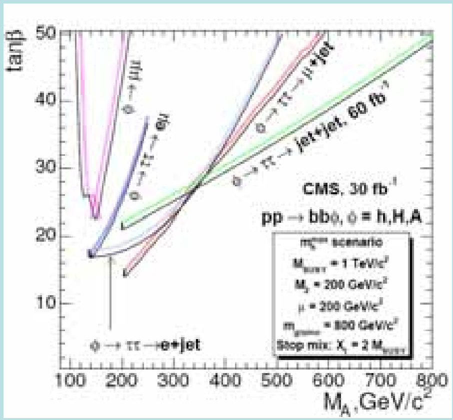
ATLAS preliminary

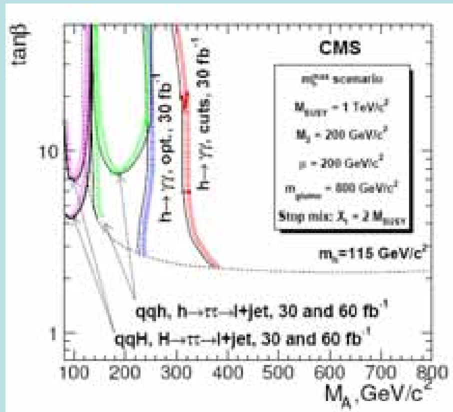




CMS







Ref.: CMS Physics TRD