BSM Higgs in ATLAS and CMS

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Introduction

- Extensions to Standard Model: additional Higgs bosons.
- Neutral Higgs similar to SM Higgs, but different couplings.
- Branching ratios (BR) for Higgs decays can be enhanced significantly depending on parameter space.

MSSM Higgs Searches at LHC

- 5 physical Higgs bosons: Φ (h^0, H^0, A^0) and $H^\pm$
- $\Phi \to \tau^+\tau^-$, $\Phi + b \to \tau^+\tau^- + b$
- $H^+ \to \tau^+\nu_\tau$,$H^+ \to c\bar{s}$

Extended Higgs sector models

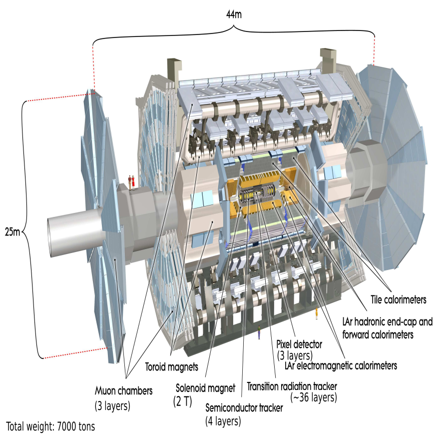
- Doubly Charged Higgs ($H^{\pm\pm}$).
- NMSSM.
- ...

Fermiophobic Higgs Model (FHM)

- BR to fermions highly suppressed: Higgs couples primarily to bosons.
- $\Phi \to \gamma\gamma$
- based on SM Higgs results, not shown here.

The Tools: the ATLAS and CMS detectors

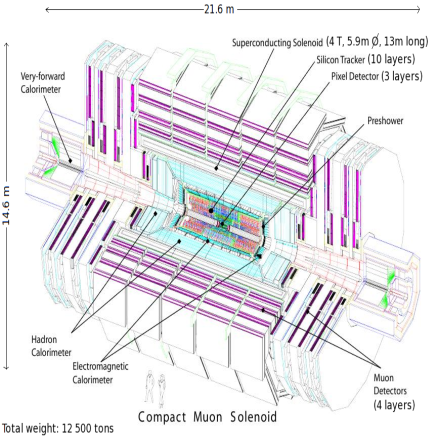
ATLAS



Tracker: $\sigma/p_T \simeq 5 \times 10^{-5} \times p_T \oplus 0.01$

Muon standalone @ 1 TeV: $\sigma/p_T \simeq 0.07$

CMS



Tracker: $\sigma/p_T \simeq 1.5 \times 10^{-5} \times p_T \oplus 0.005$

Muon standalone @ 1 TeV: $\sigma/p_T \simeq 0.10$

Summary of channels covered in this talk

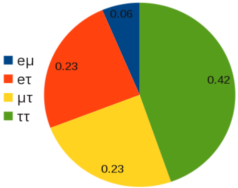
Channel	ATLAS	CMS
	MSSM	
$\Phi \to \tau^+\tau^-$ $b\bar{b} + \Phi \to b\bar{b} + \tau^+\tau^-$	$e\mu$, $e/\mu\tau_{had}$, $\tau_{had}\tau_{had}$ 1.06 fb^{-1} ATL-CONF-2011-132	$e\mu$, $e/\mu\tau_{had}$ 4.6 fb^{-1} CMS-PAS-HIG-11-029
$pp \to t\bar{t} \to H^+W^-b\bar{b}$, $H^+ \to \tau^+\nu_\tau$ $pp \to t\bar{t} \to H^+H^-b\bar{b}$, $H^\pm \to \tau\nu_\tau$	$\tau \to e, \mu, \tau_{had}$ 1.03 fb^{-1} ATL-CONF-2011-138,-151	$e+\mu$, $\mu+\tau_{had}$, *hadronic* 0.98 fb^{-1} CMS-PAS-HIG-11-008
$pp \to t\bar{t} \to H^+W^-b\bar{b}$	$H^+ \to c\bar{s}$ 0.035 fb^{-1} ATL-CONF-2011-094	- - -
	Extended Higgs sector	
$pp \to H^{++}H^{--}$, $pp \to H^{++}H^-$	$H^{\pm\pm} \to \mu^\pm\mu^\pm$ 1.6 fb^{-1} ATL-CONF-2011-127	$H^{\pm\pm} \to l^\pm l^\pm$, $H^\pm \to l$, $l = e, \mu, \tau$ 0.98 fb^{-1} CMS-PAS-HIG-11-007
	NMSSM	
$a_1 \to \mu^+\mu^-$	0.039 fb^{-1} ATL-CONF-2011-020	- -

Physics Objects Reconstruction and Identification

- Objects used: electrons, muons, taus, jets, b-jets.

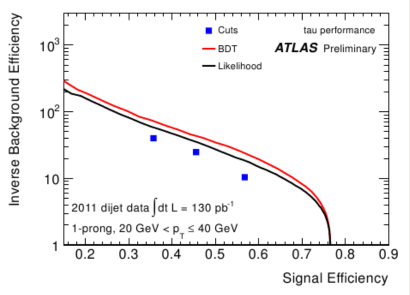
Object	Building Blocks	Identification	Isolation
Electrons	tracks, ECAL clusters	Shower shape. Tight for selection, Loose for rejection	tracks+Calo deposits $\Delta R = 0.2-0.4$, absolute or relative
Muons	central+muon tracks	Fit quality, inner hits. Tight for selection, Loose for rejection	tracks+Calo deposits $\Delta R = 0.2-0.4$, absolute or relative
Jets	Tracks, ECAL+HCAL clusters. Anti-k_T 0.4/0.5 ATLAS/CMS	Particle Flow (CMS)	-
Hadronic Taus	Jets, tracks, ECAL+HCAL clusters	Likelihood, BDT (ATLAS), PF-based decay topologies HPS, neural net (CMS)	-
b-tagging	tracks, secondary vertices	Track counting, Flight decay significance. Loose WP.	-

Performance of tau-ID Algorithms

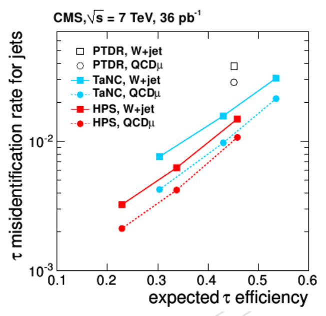


- All decays considered.
- Hadronic decays: tau ID, very similar performances for ATLAS and CMS.

ATLAS

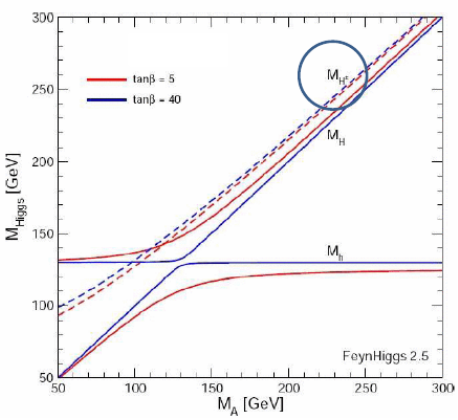


CMS

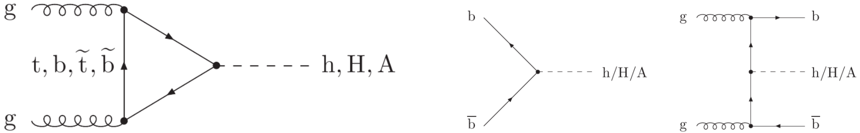


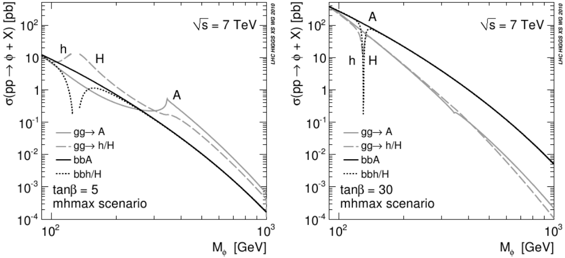
MSSM Higgs Sector

- Five Higgs bosons: h, A, H, H^+, H^-.
- At tree level, Higgs sector of MSSM defined by m_A and $\tan\beta$. Radiative corrections: dependence on additional parameters.
- Upper theoretical limit on $m_h \simeq 135$ GeV.



The $pp \to \Phi + X$, $\Phi \to \tau\tau$ channel

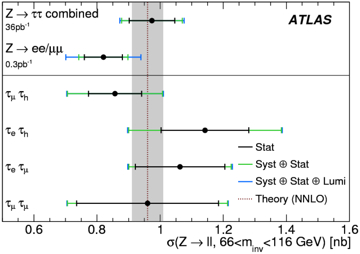




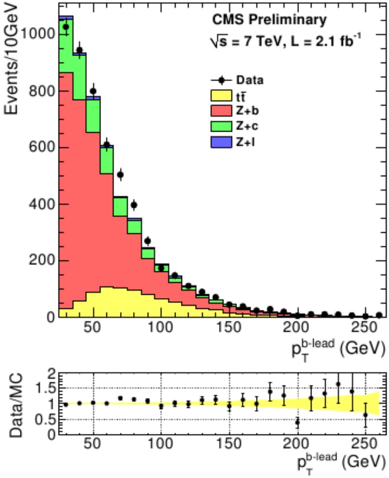
- Coupling enhanced: at tree-level $g(bbA^{MSSM}) = g(bbA^{SM}) \times tan\beta$.
- $\sigma^{SM}(gg \to H) = 20 - 10$ pb for $m_H = 115 - 140$ GeV.
- BR($\Phi \to \tau\tau$)$\simeq$ 10%.

Validation with SM measurements

$Z \to \tau\tau$



Z+b process



Analysis Setup

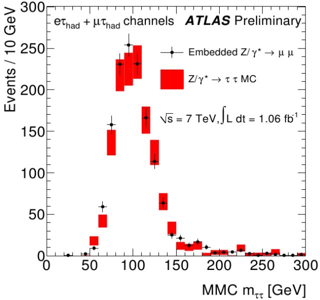
	$e\mu$	$e/\mu\tau$	$\tau\tau$
CMS			
iso e,μ	$p_T > 20, 10$ GeV	$p_T > 20/15$ GeV	-
	$\lvert\eta\rvert < 2.5, 2.1$	$\lvert\eta\rvert < 2.1$	-
	opp charges		-
	veto other leptons		-
τ_h	-	$p_T > 20$ GeV	-
	-	$\lvert\eta\rvert < 2.3$	-
W+jets rejection	$P_\zeta - 0.85 P_\xi^{vis} > -25$ GeV	$P_\xi - 0.5 P_\xi^{vis} > -20$ GeV	-
Jets	Max 1 jet $p_T > 30$ GeV		-
b-jet	TCHE, $p_T > 20$ GeV		-
ATLAS			
iso e,μ	$p_T > 22, 10/20, 15$ GeV	$p_T > 25/20$ GeV	-
	$\lvert\eta\rvert < 2.47, 2.5$	$\lvert\eta\rvert < 2.47, 2.5$	-
	opp charges		
	veto other leptons		
τ_h	-	$p_T > 20$ GeV	$p_T > 45, 30$ GeV
	-	$\lvert\eta\rvert < 2.5$	$\lvert\eta\rvert < 2.5$
W+jets rejection	$p_T^e + p_T^\mu + MET < 120$ GeV	$MET > 20$ GeV	$MET > 25$ GeV
	$\Delta\phi(e,\mu) > 2.0$	$m_T < 30$ GeV	

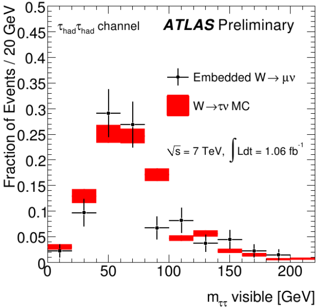
Background Evaluation Methods

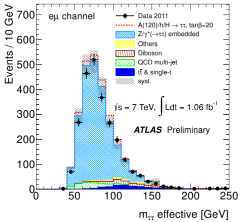
- Reconstruct $\tau\tau$ mass for each final state.
- Use data-driven shape for dominant backgrounds.
- Z$\rightarrow\tau\tau$: embedding method, using Z$\rightarrow\mu\mu$ events replacing muons by simulated taus with same kinematics event-by-event.
- QCD/W+jets: ABCD method, use sign and isolation criteria to define signal and bkg regions, $n_A = n_B \times \frac{n_C}{n_D}$
- Several definitions of m$_{\tau\tau}$.
- Likelihood fit, add systematics as nuisance parameters.

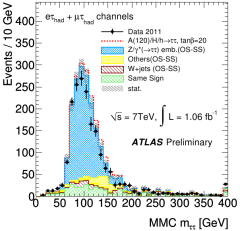
	CMS	ATLAS		
all	eμ	e/$\mu\tau$	$\tau\tau$	
Mass	likelihood	$m_{\tau\tau}^{eff} = \sqrt{(p_{\tau^+} + p_{\tau^-} + p_{miss})^2}$	m_{MMC}	$m_{visible}$
Reso@130GeV	21%	?	17%	24%
Z$\rightarrow\tau\tau$	Z$\rightarrow\mu\mu$	Z$\rightarrow\mu\mu$		
QCD	same-sign	ABCD	same-sign	ABCD
W+jets	same-sign	MC	same-sign	MC/embedding W$\rightarrow\mu\nu$
Others	MC	MC	MC	MC

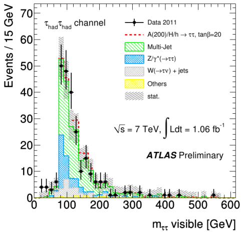
ATLAS Control Plots





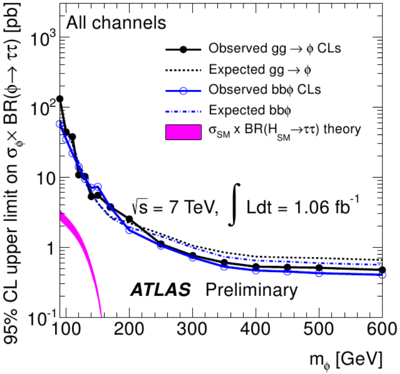


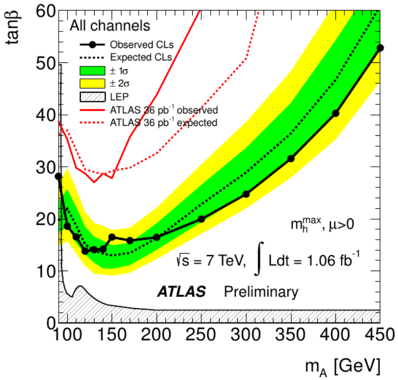




ATLAS Results

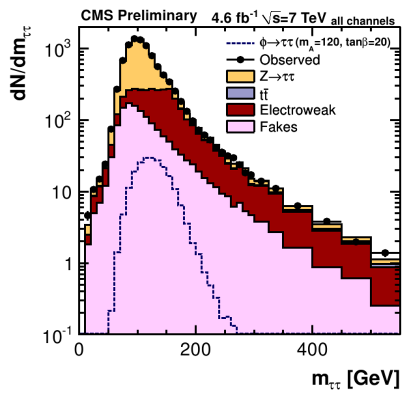
- All channels combined.
- Fully hadronic channel improves high-mass limits.



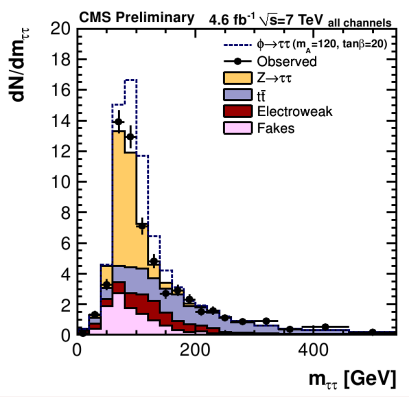


CMS Control Plots

No b-tag

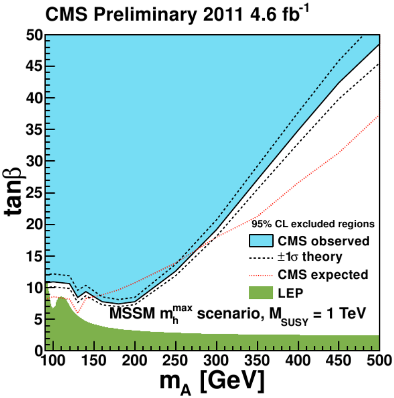


At least one b-tag



CMS Results

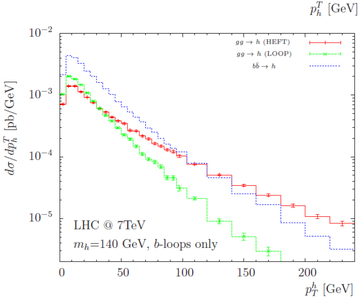
- Most up-to-date exclusion with full 2011 dataset.
- Better limits: improved by using b-tagging.
- Reach $\tan\beta = 7.8$ at $m_A = 160$ GeV.



Issue with LHC simulation

- Only top-loop included in $gg \to \Phi$ simulation in LHC analysis.
- MSSM with high tanβ and mhmax scenario: b-loop dominates $\Rightarrow$ softer spectrum for pT(Φ).
- After final analysis acceptance: small effect.

J. Alwall, Q Li, F. Maltoni arXiv:1110.1728

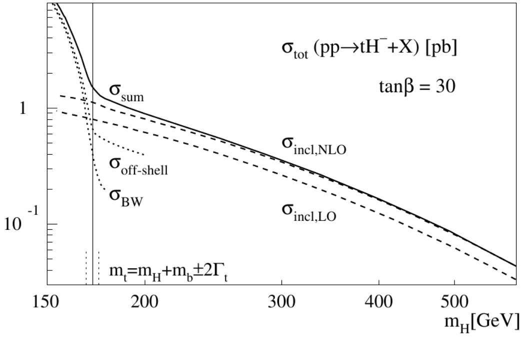


M_H [GeV]	Acceptance, PYTHIA gg $\to$ H	Acceptance, re-weighted for b-loop	Correction factor
140	0.072 ± 0.001	0.070 ± 0.001	0.97 ± 0.01
400	0.149 ± 0.001	0.152 ± 0.001	1.02 ± 0.02

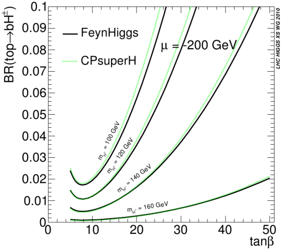
Table 1: The $e + \tau_h$ acceptances before and after re-weighting to correct for b-loop contribution.

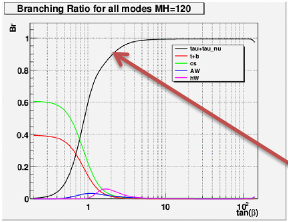
MSSM Charged Higgs Sector

- Production: $gg \to t\bar{t} \to H^{\pm}W^{\mp}b\bar{b}, H^{+}H^{-}b\bar{b}$ for $m_{H^\pm} < m_t$ or $gb \to tH$ for $m_{H^\pm} > m_t$.
- BR($t \to Hb$) highly dependent on tanβ.
- BR($H^{\pm} \to \tau\nu_{\tau}$)$>$ 95% for tan$\beta > 3$.

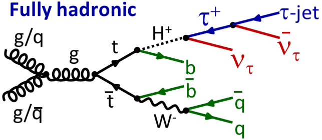


T. Plehn et al., hep-ph/0312286



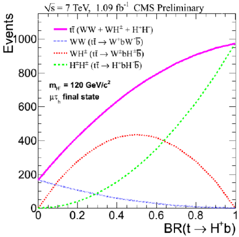


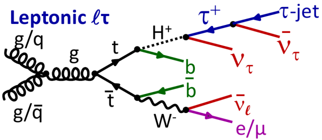
Topologies considered



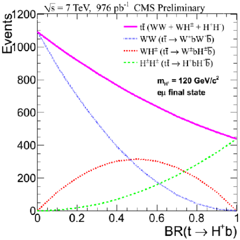
BR($H^{\pm}/W^{\pm} \to \tau\nu_\tau$)=1/0.1

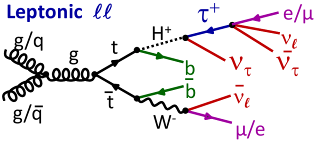
$$\mathcal{N}^{SUSY}_{t\bar{t}} > \mathcal{N}^{SM}_{t\bar{t}}$$





$$\mathcal{N}^{SUSY}_{t\bar{t}} > \mathcal{N}^{SM}_{t\bar{t}}$$



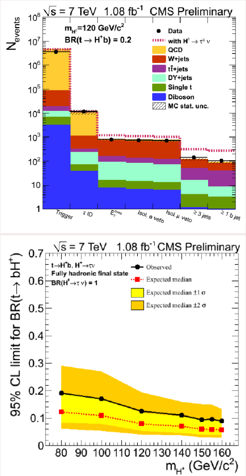


Very soft leptons from $H^{\pm}$

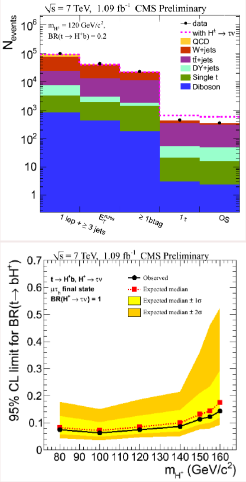
$$\mathcal{N}^{SUSY}_{t\bar{t}} < \mathcal{N}^{SM}_{t\bar{t}}$$

CMS Results channel-by-channel

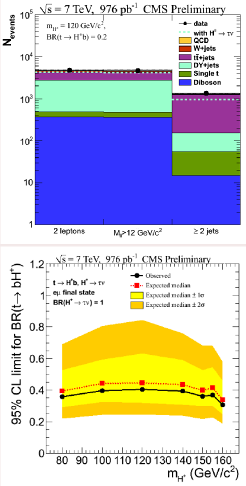
Fully Hadronic



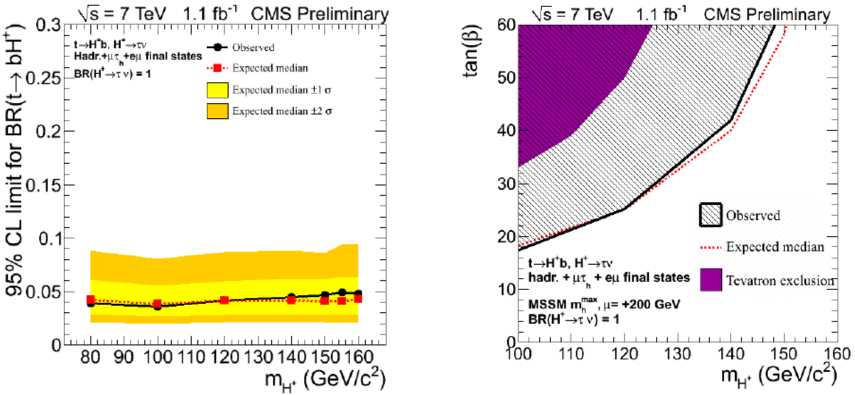
Leptonic $\mu\tau$



Leptonic $e\mu$



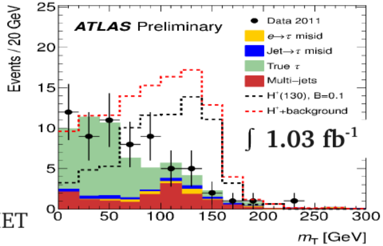
CMS Results combined

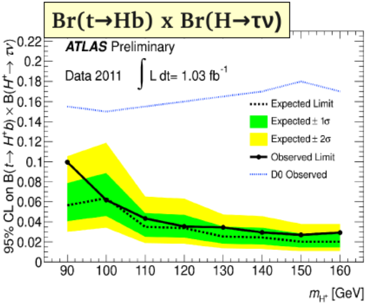


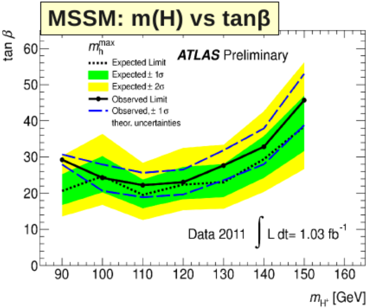
- Results being updated for Moriond 2012 with 2 fb^{-1} and shape analysis.

ATLAS analysis in fully hadronic channel

- Search in tau+jets events
- $pT(\tau_{had}) > 35$GeV, MET>40GeV, MET significance > 8,
- at least 4 jets with at least 1 b-jet
- Reconstruct transverse mass of τ and MET







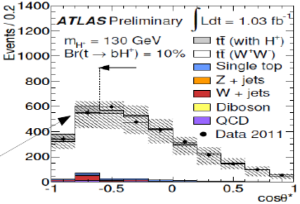
ATLAS analysis in single-lepton channels

New — Charged Higgs $H^+ \to \tau\nu \to e/\mu 3\nu$

NIKHEF 1.03 fb^{-1}

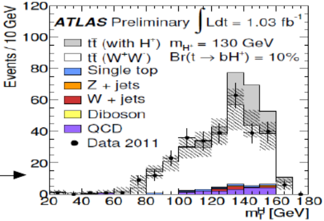
- Single lepton:
  pT(e)>25GeV or pT(μ)>20GeV.
  at least 4 jets pT>20GeV, |η|<2.5
- 2 *b*-jets, large MET
- Cut on

$$\cos\theta_l^* = \frac{2m_{bl}^2}{m_{top}^2 - m_W^2} - 1 \simeq \frac{4\, p^b \cdot p^l}{m_{top}^2 - m_W^2} - 1$$



- Reconstruct t→Hb, constrain second top,
  maximize transverse Higgs mass

$$(m_T^H)^2 = \max_{\substack{\{p_z^{miss}, E^{miss} \\ (p^{miss}+p^l+p^b)^2 = m_{top}^2\}}} [(p^l + p^{miss})^2].$$



Olga Igonkina   *HCP 2011 : SUSY and BSM Higgs @ ATLAS*   ATL-CONF-2011-152   13

ATLAS analysis in di-lepton channels

New

Charged Higgs $H^+ \to \tau\nu \to e/\mu 3\nu$

NIKHEF

1.03 fb^{-1}

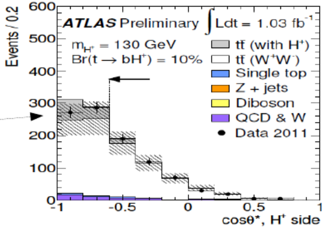
- Double lepton final state:

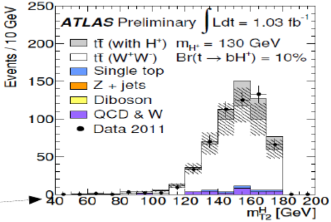
  2 oppositely charged leptons

  2 jets pT>20GeV, |η|<2.5,
- cut on $\cos\theta_l^*$
- split missing Et on 2 vectors
- Solve:

$$
\begin{aligned}
(p^{H^+} + p^b)^2 &= m_{\text{top}}^2,\\
(p^{\ell^-} + p^{\bar{\nu}_\ell})^2 &= m_W^2,\\
(p^{\ell^-} + p^{\bar{\nu}_\ell} + p^{\bar{b}})^2 &= m_{\text{top}}^2,\\
(p^{\bar{\nu}_\ell})^2 &= 0,\\
\vec{p_T}^{H^+} - \vec{p_T}^{\ell^+} + \vec{p_T}^{\bar{\nu}_\ell} &= \vec{p_T}^{\text{miss}}.
\end{aligned}
$$

- maximize transverse Higgs mass over remaining free parameters





Olga Igonkina

HCP 2011 : SUSY and BSM Higgs @ ATLAS

ATL-CONF-2011-152

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Results for ATLAS analysis in leptonic channels

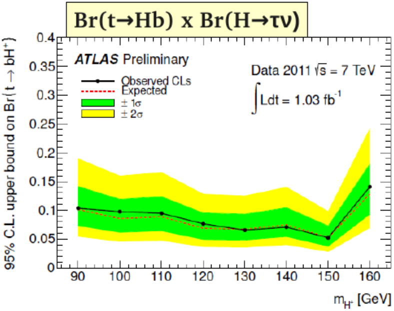
New

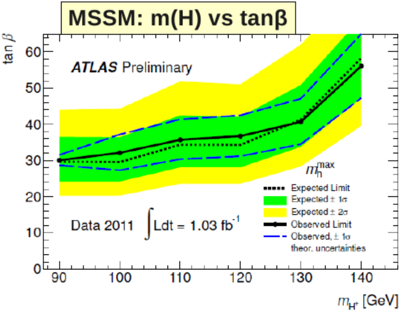
Charged Higgs $H^+ \rightarrow \tau\nu \rightarrow e/\mu 3\nu$

NIKHEF 1.03 fb^{-1}

ATL-CONF-2011-151

- No signal is seen
- Upper limits on branching ratio Br(t→Hb) x Br(H→τν) and on MSSM parameter space of Higgs mass vs tanβ are set





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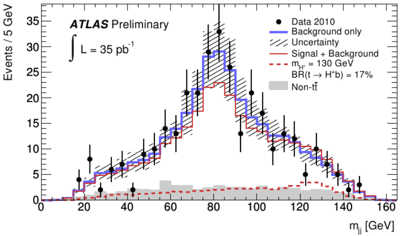
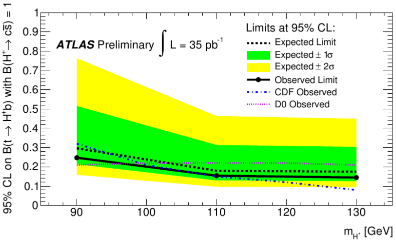
ATLAS Results for low tanβ $H^+ \to c\bar{s}$ channel

- Old analysis with 2010 data, valid at low tanβ.



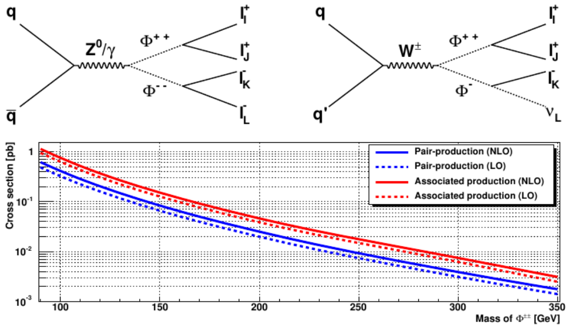


Search for doubly charged Higgs

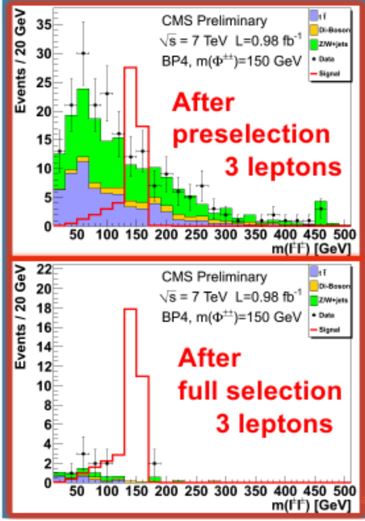
- Higgs boson triplet Φ^0, Φ^+, Φ^{++} is predicted in little Higgs models
- Φ^{++} Yukawa coupling matrix $Y\Phi_{l_i l_j}$ is proportional to the light neutrino mass matrix and allows to test the neutrino masses by measuring $BR(\Phi^{++} \rightarrow l_i l_j)$
- A.Hektor, M. Kadastik, M. Muntel et al., Nucl.Phys. B787 (2007) 198-210

4 Leptons

3 Leptons



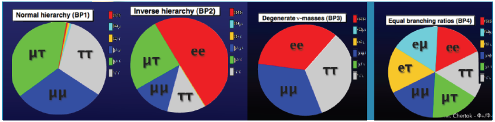
Event selection and backgrounds at CMS

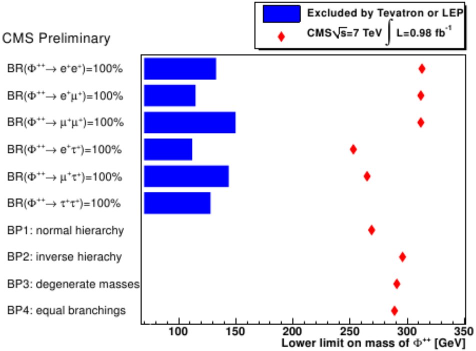


- 3-4 lepton final states
  - Muons: P_T >5 GeV
  - Electrons: P_T>15 GeV
  - Taus: P_T>15 GeV
  - At least two leptons with 35 and 10 GeV
  - Dilepton trigger 17/8
- Backgrounds
  - Z/W + jets
  - top antitop
  - ZZ, WW

10 three-lepton events and 1 four-lepton event found

CMS Results


Normal hierarchy (BP1)
μτ
ττ
μμ
Inverse hierarchy (BP2)
μτ
ee
μμ
ττ
Degenerate ν-masses (BP3)
ee
ττ
μμ
Equal branching ratios (BP4)
eμ
ee
eτ
ττ
μμ
μτ

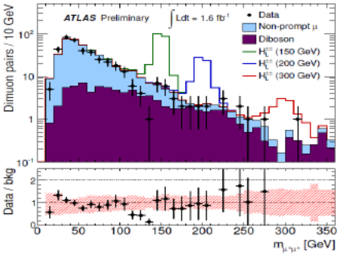

Excluded by Tevatron or LEP
CMS √s=7 TeV ∫ L=0.98 fb⁻¹
CMS Preliminary
BR(Φ⁺⁺→ e⁺e⁺)=100%
BR(Φ⁺⁺→ e⁺μ⁺)=100%
BR(Φ⁺⁺→ μ⁺μ⁺)=100%
BR(Φ⁺⁺→ e⁺τ⁺)=100%
BR(Φ⁺⁺→ μ⁺τ⁺)=100%
BR(Φ⁺⁺→ τ⁺τ⁺)=100%
BP1: normal hierarchy
BP2: inverse hierachy
BP3: degenerate masses
BP4: equal branchings
100
150
200
250
300
350
Lower limit on mass of Φ⁺⁺ [GeV]

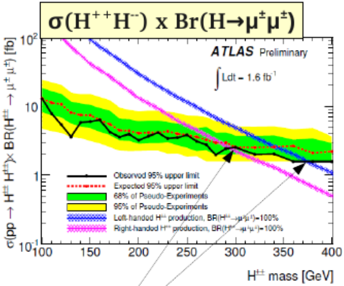
Doubly Charged Higgs $H^{++} \to \mu^+\mu^+$

ATLAS-CONF-2011-127

- Predicted in little Higgs, Higgs triplet and left-right symmetric models
- $pT(\mu_1)>20GeV$, $pT(\mu_2)>10GeV$

  Same charge muons **$1.6\ fb^{-1}$**
- Look for di-muon mass resonance



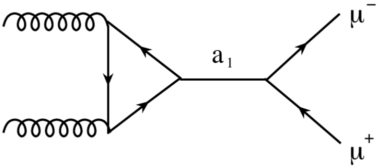


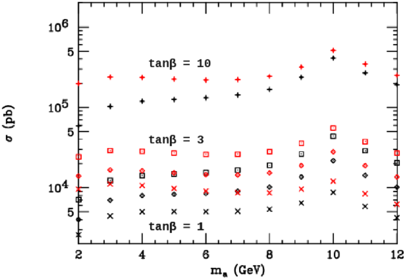
Right-handed Higgs mass < 295GeV
Left-handed Higgs mass < 375GeV
@ 95%CL if $Br(H^{++}\to\mu^+\mu^+) = 100\%$

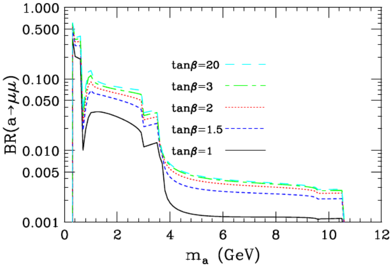
Limits on $Br(H^{++}\to\mu^+\mu^+)$ as function of Higgs mass are also available

Search for NMSSM Higgs $a_1 \to \mu\mu$

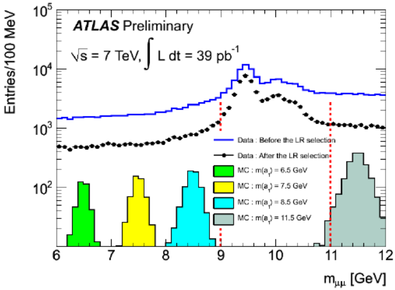
- NMSSM solves MSSM "m-term problem" by introducing additional complex singlet scalar field S.
- neutral Higgs boson sector expands to three CP-even scalars (h1,h2,h3), two CP-odd scalars (a1,a2).
- "Ideal"- NMSSM Higgs scenarios : $2m_\tau < m_{a1} < 2m_b$ (prefers m_{a1} close to $2m_b$), Dermisek, Gunion 2010.

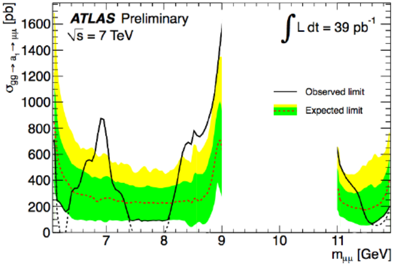






ATLAS Results





Conclusion

- BSM Higgs well-covered at LHC. Some channels studied at Tevatron not covered yet at LHC: e.g. MSSM bbH to bbb.
- Similar channels covered by ATLAS and CMS.
- Fully hadronic MSSM H$\rightarrow \tau\tau$ improves ATLAS limits, but CMS limits also much improved by requiring b-tagging.
- Parameter space closing in for MSSM H$\rightarrow \tau\tau$: going now as low as tan$\beta = 7.8$ at m$_A = 160$ GeV.
- Most results expected to be updated for Moriond 2012 on full 2011 dataset.

Backups

BACKUPS

ATLAS and CMS calorimeters

ATLAS Calorimeters

- EM: $|\eta| < 3.2$,
  - Pb/LAr calorimeter,
  - 22-26 X_o, 1.2 λ,
  - 3 longitudinal sections,
  - $\Delta\eta \times \Delta\Phi = 0.025 \times 0.025 - 0.1 \times 0.1$
  - $\sigma/E \simeq 10\%/\sqrt{E}$.
- Central Hadronic: $|\eta| < 1.7$,
  - Fe/Scintillator sampling calorimeter
  - 7.4 λ,
  - 3 longitudinal sections,
  - $\Delta\eta \times \Delta\Phi = 0.1 \times 0.1 - 0.2 \times 0.1$,
  - $\sigma/E \simeq 50\%/\sqrt{E} \oplus 0.03$.
- EndCap Hadronic: $1.7 < |\eta| < 3.2$,
  - Cu/LAr sampling calorimeter,
  - 4 longitudinal sections,
  - $\Delta\eta \times \Delta\Phi = 0.1 \times 0.1 - 0.2 \times 0.2$
- FCAL: $3 < |\eta| < 4.9$,
  - EM: Cu/LAr, HAD: W/LAr calorimeter,
  - 10 λ,
  - 1 EM + 2 HAD longitudinal sections,
  - $\Delta\eta \times \Delta\Phi = 0.75 \times 0.65 - 5.4 \times 4.7$

CMS calorimeters

- EM : $|\eta| < 3$,
  - $PbWO_4$ cristals,
  - 24.7-25.8 X_o, 1.1 λ,
  - 1 longitudinal section + preshower (3 X_o),
  - $\Delta\eta \times \Delta\Phi = 0.0175 \times 0.0175$,
  - $\sigma/E \simeq 2 - 5\%/\sqrt{E}$.
- HCAL : $|\eta| < 3$,
  - Brass/Scintillator sampling calorimeter,
  - 6-10 λ
  - 2 longitudinal sections + Outer HCAL (3 λ for $|\eta| < 1.4$)
  - $\Delta\eta \times \Delta\Phi \geq 0.0875 \times 0.0875$,
  - $\sigma/E \simeq 100\%/\sqrt{E} \oplus 0.05$.
- HF : $3 < |\eta| < 5$,
  - Fe/Quartz fibers, Cerenlov light
  - EM 90 X_o, HAD 9.5 λ
  - 1 EM + 1 HAD longitudinal sections