



SUSY and BSM Higgs @ ATLAS

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(NIKHEF)

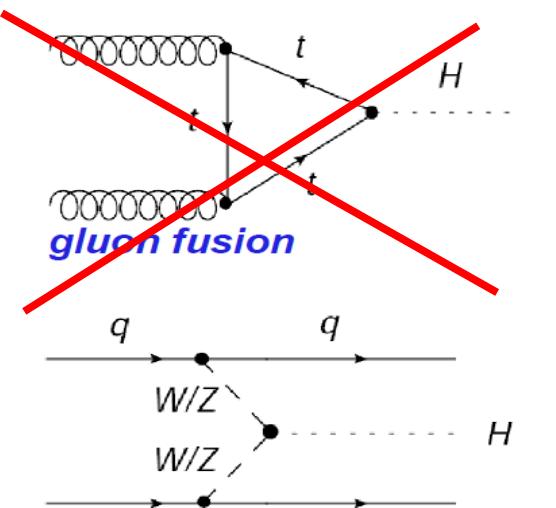
on behalf of ATLAS collaboration

- Fermiophobic $H \rightarrow \gamma\gamma$
- Neutral MSSM $H \rightarrow \tau\tau$
- Charged $H^+ \rightarrow \tau\nu$
- Charged $H^+ \rightarrow c\bar{s}$
- Doubly Charged $H^{++} \rightarrow \mu^+\mu^+$

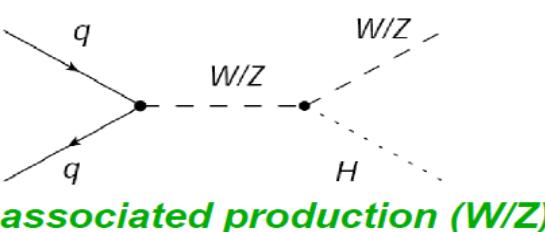
- *See talk by N.Bousson for searches of Higgs decaying to pair of long-lived particles*



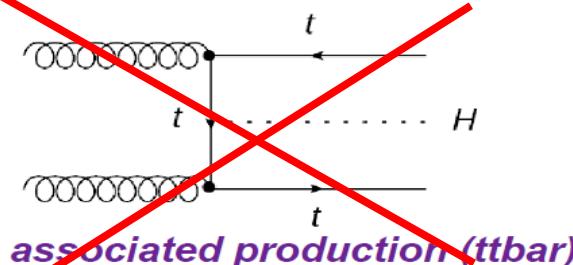
Fermiophobic Higgs



gluon fusion



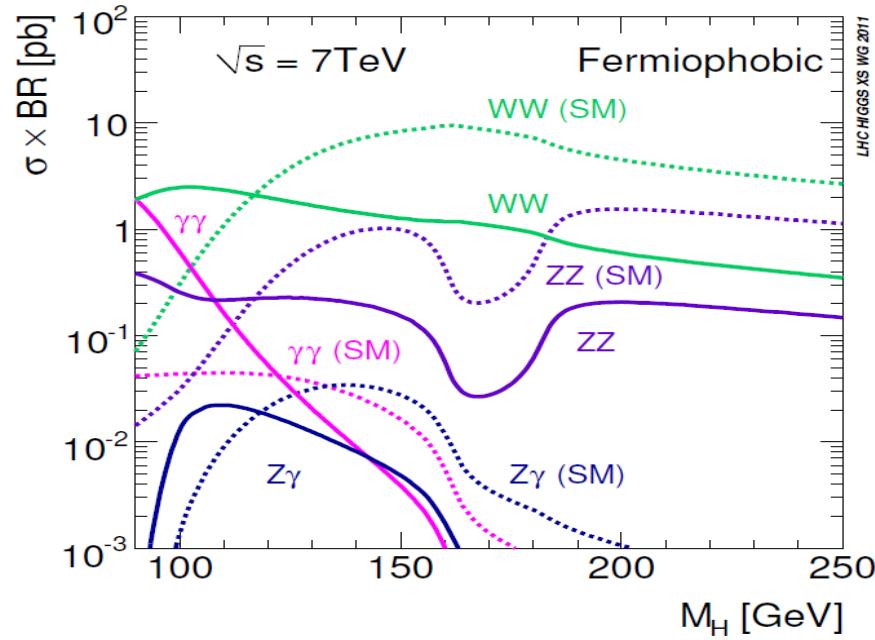
Vector-Boson-Fusion (VBF)



associated production (W/Z)

associated production (ttbar)

- No Hff vertices:
- produced via Vector Boson Fusion and associated production VH
 - Decays to $\gamma\gamma$, WW , ZZ , $Z\gamma$
 - Focus on $\gamma\gamma$ decay for light Higgs





New

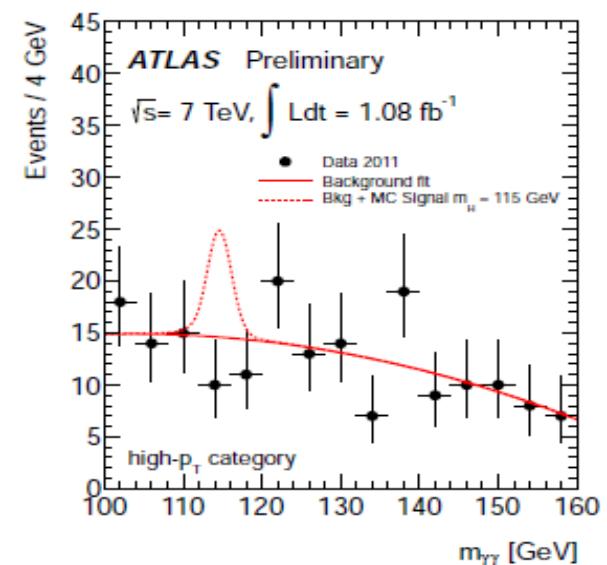
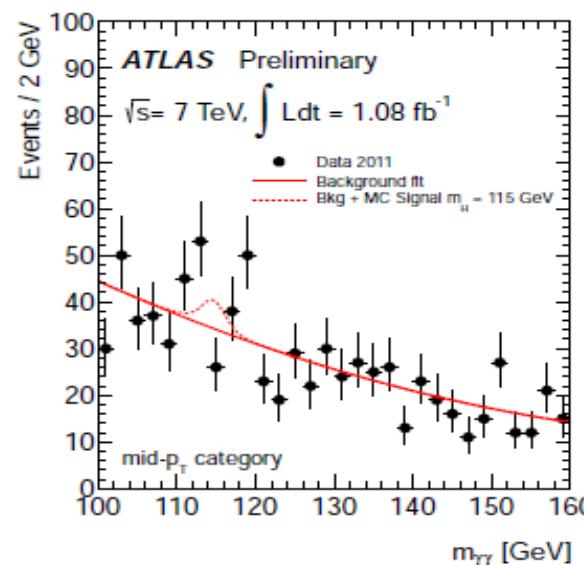
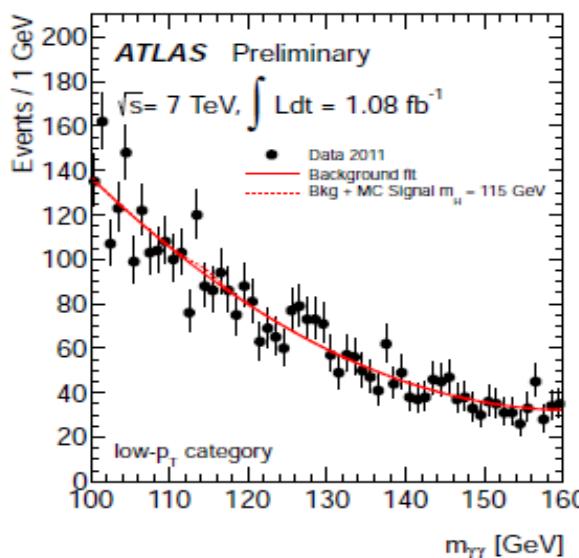
Fermiophobic Higgs

1.08 fb^{-1} NIKHEF

- 2 isolated photons $p_T > 40, 25 \text{ GeV}$
- $M(\gamma\gamma) \in [100, 160] \text{ GeV}$
- Analyse 3 $p_T(\gamma\gamma)$ bins separately:
[0,50], [50, 100], [100, ∞)

ATLAS-CONF-2011-149

$m_H \text{ [GeV]}$	$\sigma \times BR \text{ [fb]}$	Number of expected events	Fraction of events		
			low- p_T	mid- p_T	high- p_T
110	163.4	60.3	0.32	0.38	0.30
115	90.4	35.0	0.32	0.38	0.30
120	52.8	21.1	0.32	0.37	0.31
125	20.5	13.3	0.29	0.39	0.32
130	3.9	8.9	0.29	0.38	0.33
Events in data		5063	4073	805	185



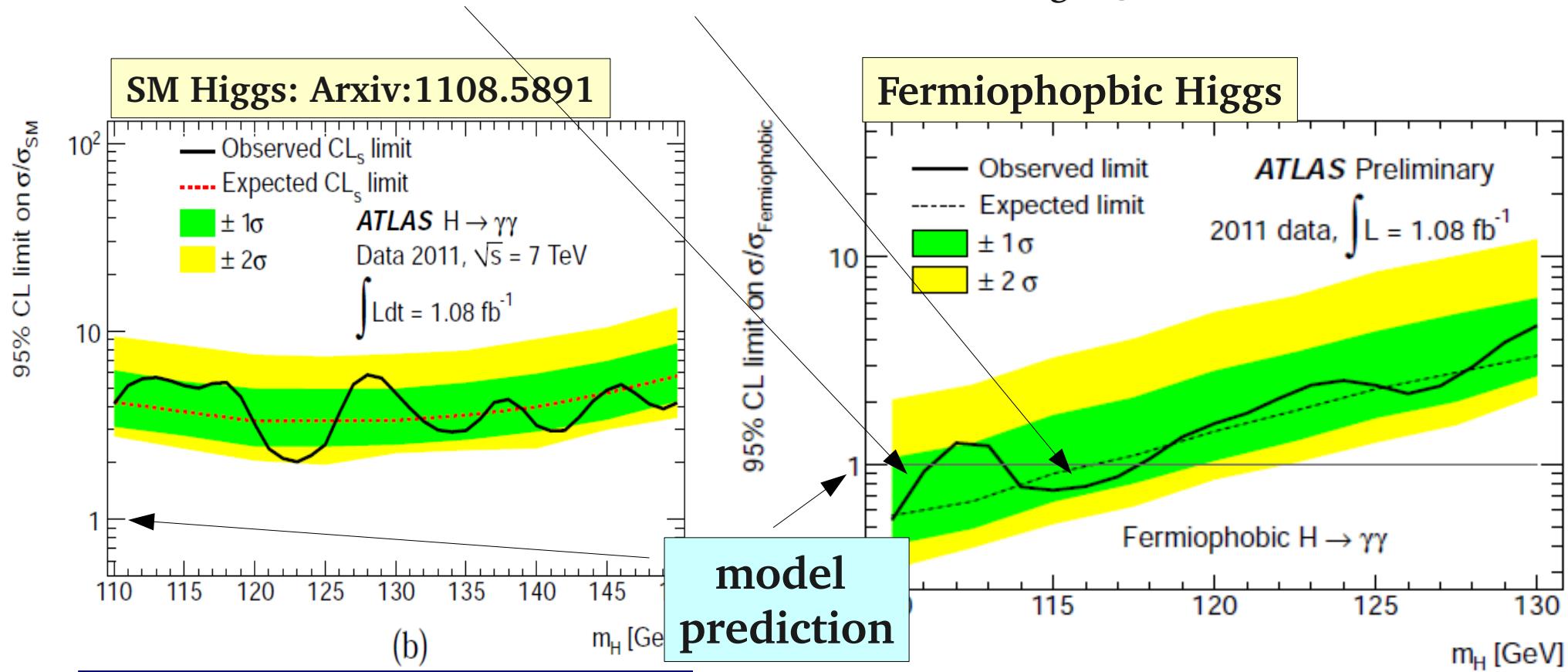


New

Fermiophobic Higgs results

NIKHEF
1.08 fb^{-1}

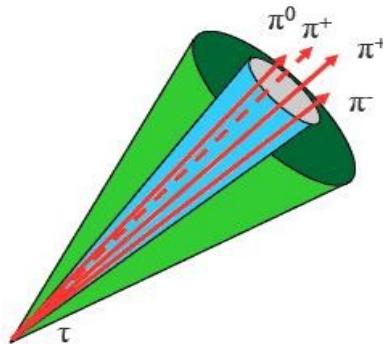
- No significant excess found in any of $\text{pt}(\gamma\gamma)$ bins. **ATLAS-CONF-2011-149**
- Set Upper limits on simplistic fermiophobic Higgs extension of SM (keep SM diagrams with no Hff vertexes)
- Exclude [110-112] and [113-118] GeV mass range @ 95%CL





MSSM $H \rightarrow \tau\tau$

- MSSM has 5 Higgs bosons (CP even h and H ; CP odd A ; H^+ ; H^-)
- Production via gluon fusion or in association with b quark
- Higgs decays via WW , ZZ are suppressed or absent. $\tau\tau$ decays are dominant for medium/large $\tan\beta$



Decay mode	Br
$\tau\tau \rightarrow e\mu 4\nu$	6%
$\tau\tau \rightarrow e\tau_{had} 3\nu$	23%
$\tau\tau \rightarrow \mu\tau_{had} 3\nu$	23%
$\tau\tau \rightarrow \tau_{had}\tau_{had} 2\nu$	42%

- Many neutrinos in tau decays – leptons are softer than in $H \rightarrow WW$ decays
- hadronic tau decays (narrow low track multiplicity jet) are polluted by QCD low multiplicity jets
- Triggering is complicated (use high p_T thresholds or use complex triggers like lepton+MET, tau+lepton)



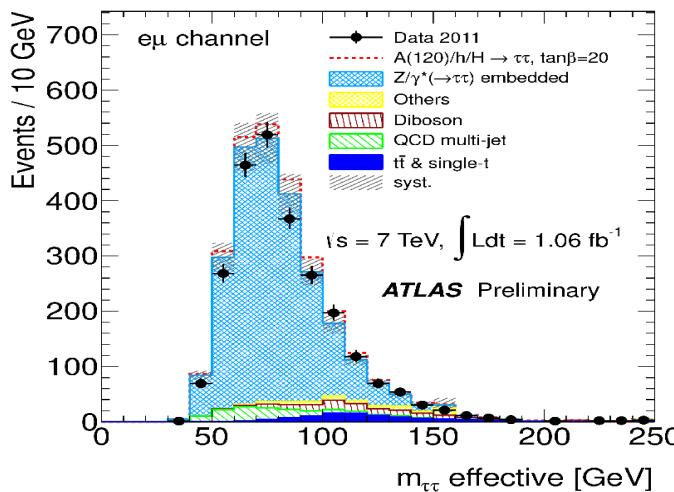
MSSM $H \rightarrow \tau\tau \rightarrow e\mu 4\nu$

1.06 fb^{-1}

NIKHEF

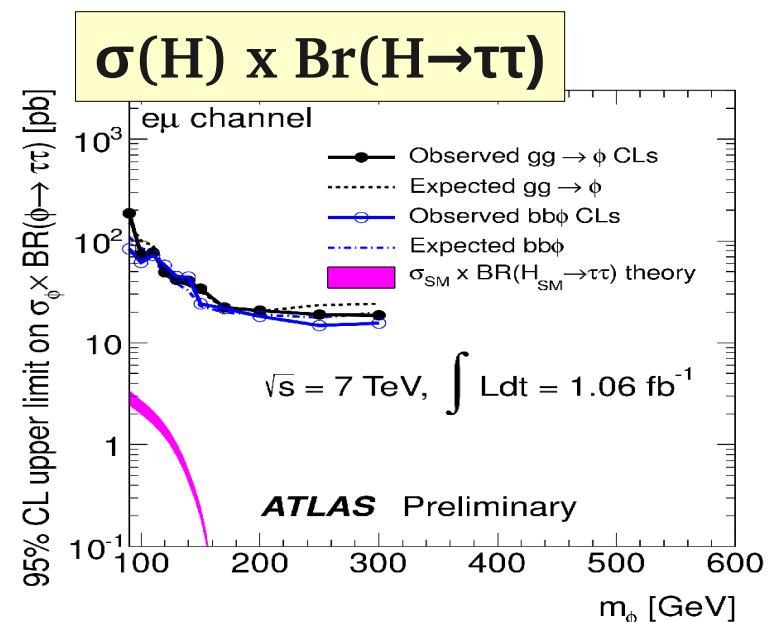
- $pT(e) > 22 \text{ GeV}, pT(\mu) > 10 \text{ GeV}$
or $pT(e) > 15 \text{ GeV}, pT(\mu) > 20 \text{ GeV}$
- azimuthal angle(e, μ) $> 2 \text{ rad}$
- $pT(e) + pT(\mu) + \text{MET} < 120 \text{ GeV}$
- Use effective mass

$$m_{\tau\tau}^{\text{effective}} = \sqrt{(p_{\tau^+} + p_{\tau^-} + p_{\text{miss}})^2},$$



Phys.Lett.B705(2011)174

Data	2471
Backgrounds	$(2.6 \pm 0.2) \cdot 10^3$
signal ($m=120, \tan\beta=20$)	155 ± 6
Efficiency for $m=120/200 \text{ GeV}$	9 / 11 %





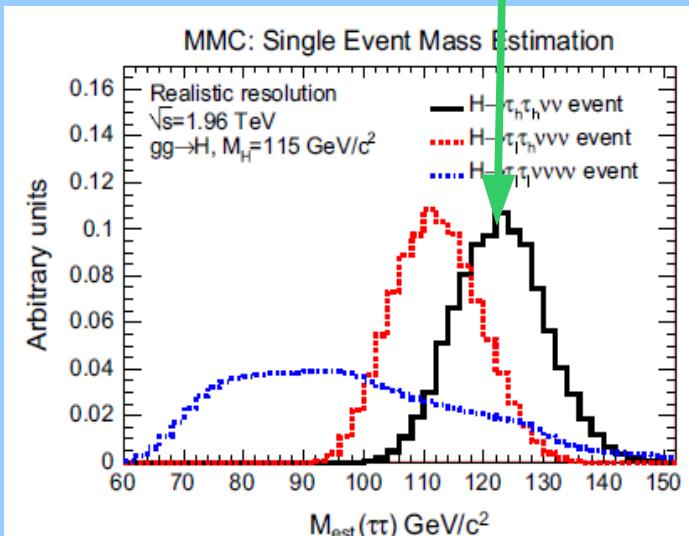
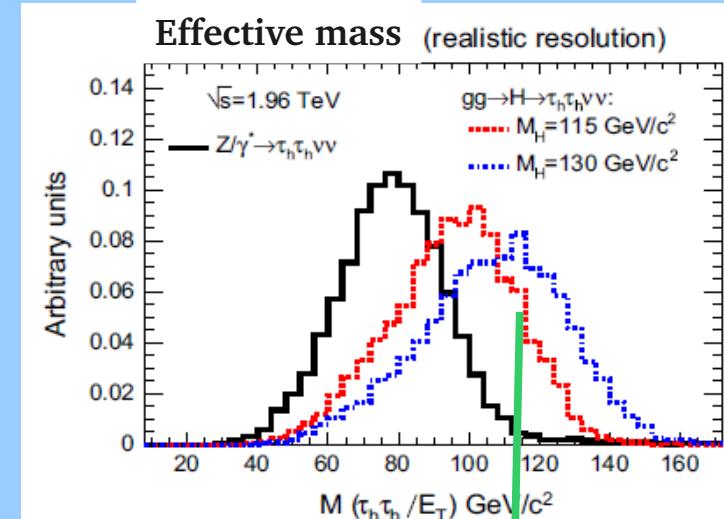
MSSM $H \rightarrow \tau\tau \rightarrow e/\mu + \tau_{\text{had}} 3\nu$

- $pT(e) > 25 \text{ GeV}$, $pT(\mu) > 20 \text{ GeV}$
 $pT(\tau_{\text{had}}) > 20$, MET $> 20 \text{ GeV}$
- veto double leptons, $mT < 30 \text{ GeV}$
- Missing Mass Calculator:

$$\begin{aligned} E_x^{\text{miss}} &= p_{\text{miss}_1} \sin \theta_{\text{miss}_1} \cos \phi_{\text{miss}_1} + p_{\text{miss}_2} \sin \theta_{\text{miss}_2} \cos \phi_{\text{miss}_2}, \\ E_y^{\text{miss}} &= p_{\text{miss}_1} \sin \theta_{\text{miss}_1} \sin \phi_{\text{miss}_1} + p_{\text{miss}_2} \sin \theta_{\text{miss}_2} \sin \phi_{\text{miss}_2}, \\ m_\tau^2 &= m_{\text{miss}_1}^2 + m_{\text{vis}_1}^2 + 2 \sqrt{p_{\text{vis}_1}^2 + m_{\text{vis}_1}^2} \sqrt{p_{\text{miss}_1}^2 + m_{\text{miss}_1}^2}, \\ &\quad - 2 p_{\text{vis}_1} p_{\text{miss}_1} \cos \Delta\theta_{\text{vm}_1}, \\ m_\tau^2 &= m_{\text{vis}_2}^2 + 2 \sqrt{p_{\text{vis}_2}^2 + m_{\text{vis}_2}^2} \cdot p_{\text{miss}_2}, \\ &\quad - 2 p_{\text{vis}_2} p_{\text{miss}_2} \cos \Delta\theta_{\text{vm}_2} \end{aligned}$$

split Missing ET on 2 vectors,
solve equations as function of 2 neutrino angles
weight with expected probability of these angles
take maximum of obtained di-tau mass distribution

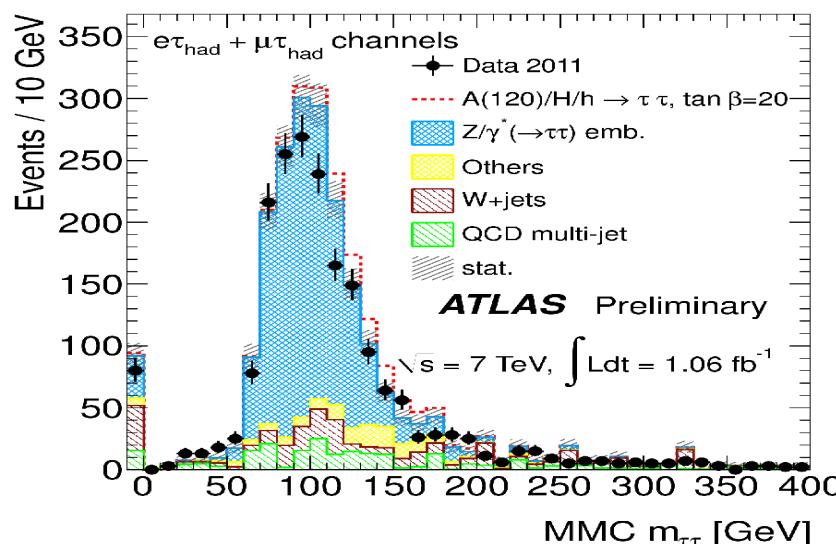
Tevatron example:



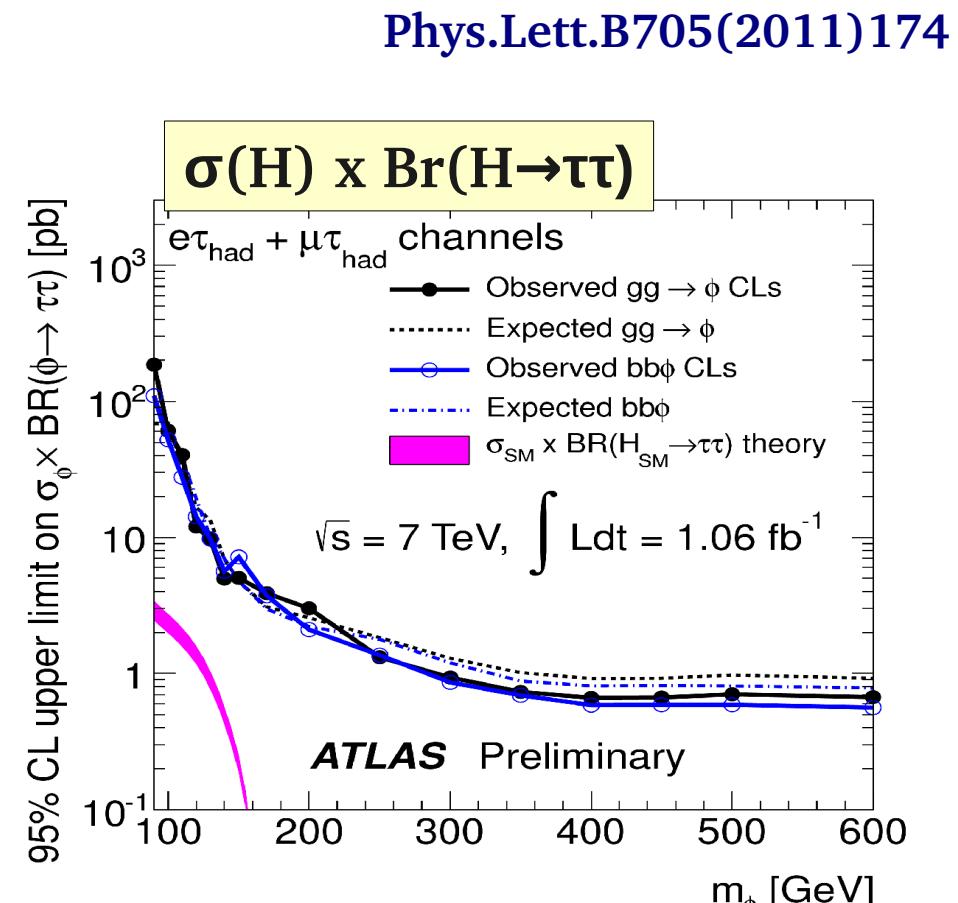


MSSM $H \rightarrow \tau\tau \rightarrow e/\mu + \tau_{\text{had}} 3\nu$

1.06 fb^{-1}



	$e\tau_{\text{had}} 3\nu$	$\mu\tau_{\text{had}} 3\nu$
Data	626	1287
Backgrounds	775 ± 40	1378 ± 43
signal ($m=120$, $\tan\beta=20$)	41 ± 4	75 ± 5
Efficiency for $m=120/200$ GeV	3/8 %	3/8 %





MSSM $H \rightarrow \tau\tau \rightarrow 2\tau_{\text{had}} 2\nu$

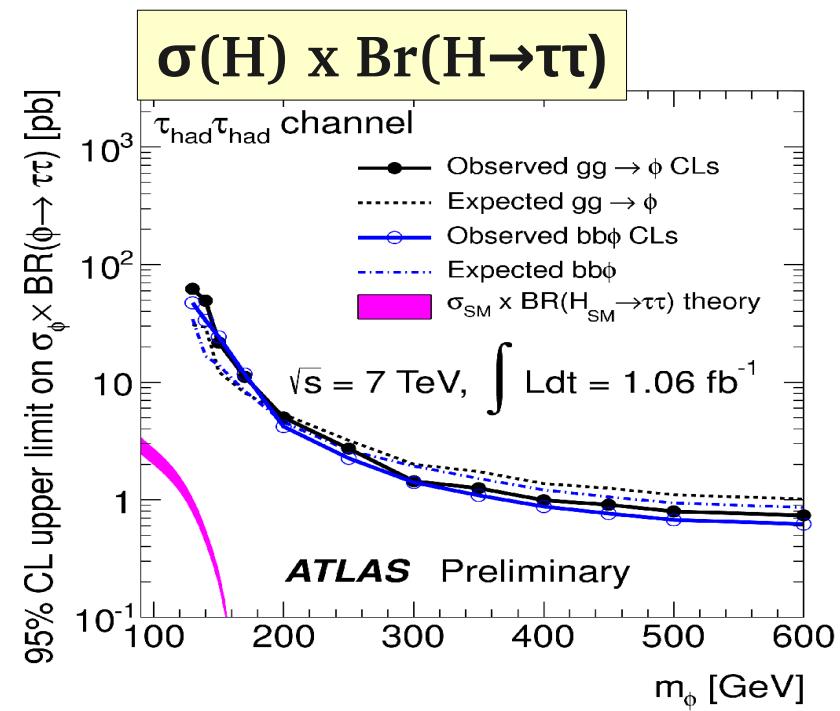
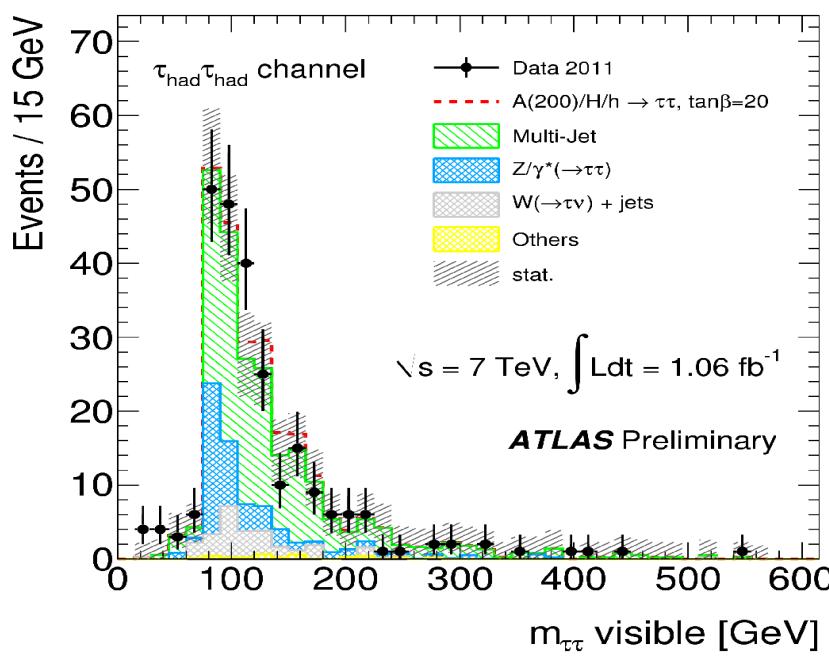
1.06 fb^{-1}

NIKHEF

Phys.Lett.B705(2011)174

- $pT(\tau_{\text{had}}) > 45 \text{ GeV}$, $pT(\tau_{\text{had}}) > 30 \text{ GeV}$,
- MET $> 25 \text{ GeV}$
- veto events with electron or muon
- Visible mass $m(2\tau_{\text{had}})$ is used

Data	245
Backgrounds	233^{+44}_{-28}
signal ($m=200$, $\tan\beta=20$)	19 ± 1
Efficiency for $m=120/200 \text{ GeV}$	0.1 / 1.3 %





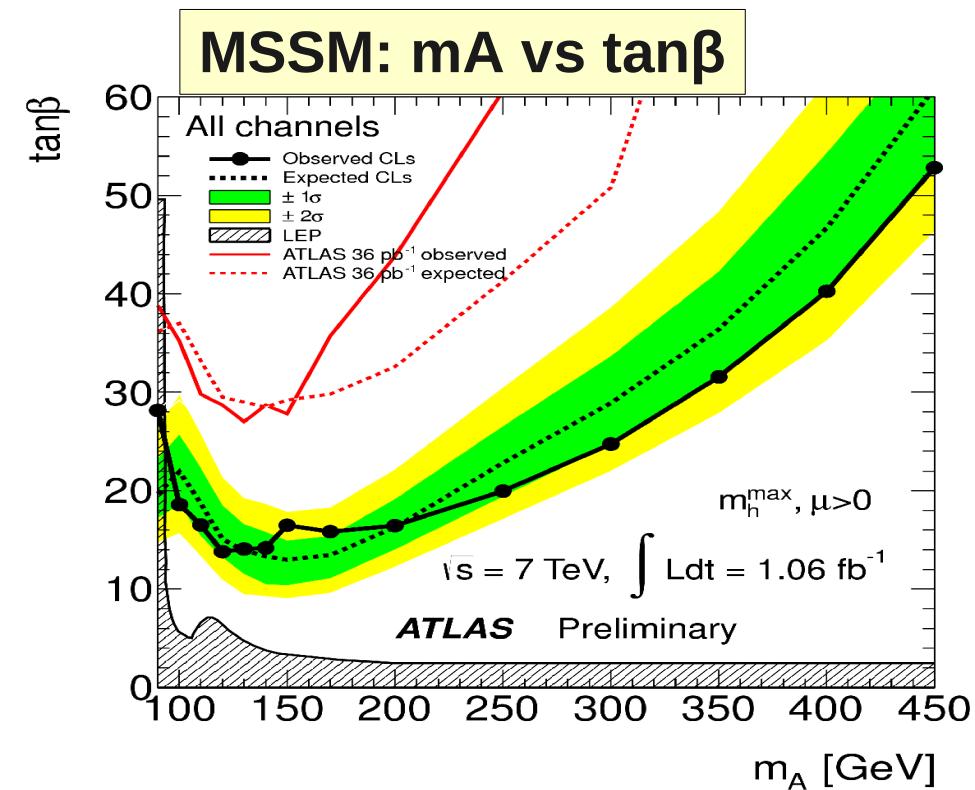
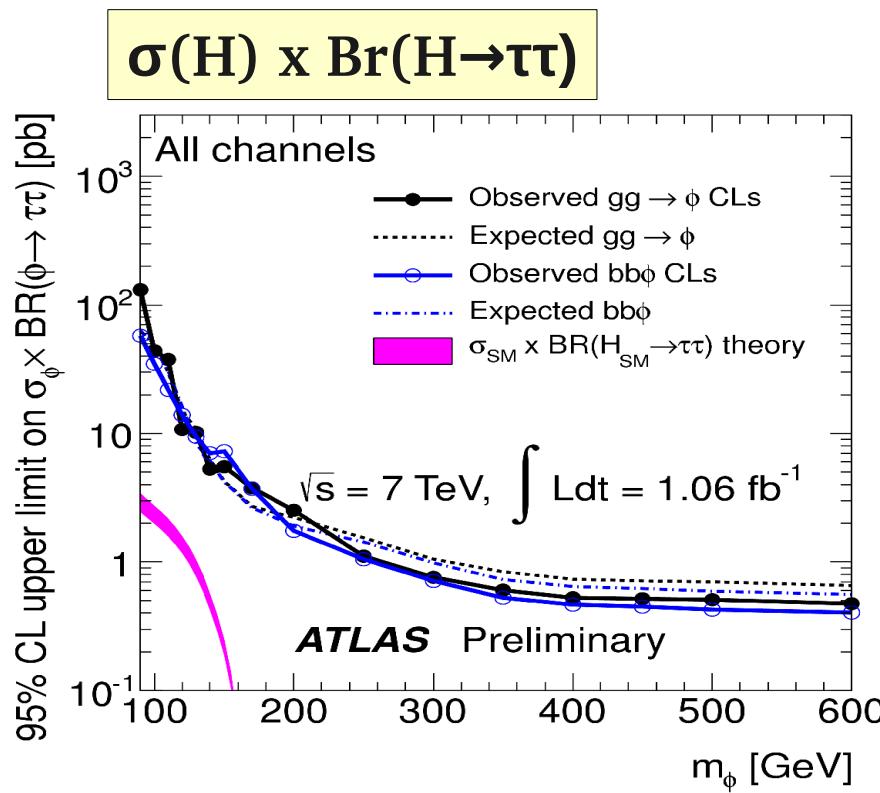
MSSM $H \rightarrow \tau\tau$

1.06 fb^{-1}

NIKHEF

Phys.Lett.B705(2011)174

- No signal found so far
- Set upper limit on production of generic Higgs and on $A/h/H$ assuming MSSM model

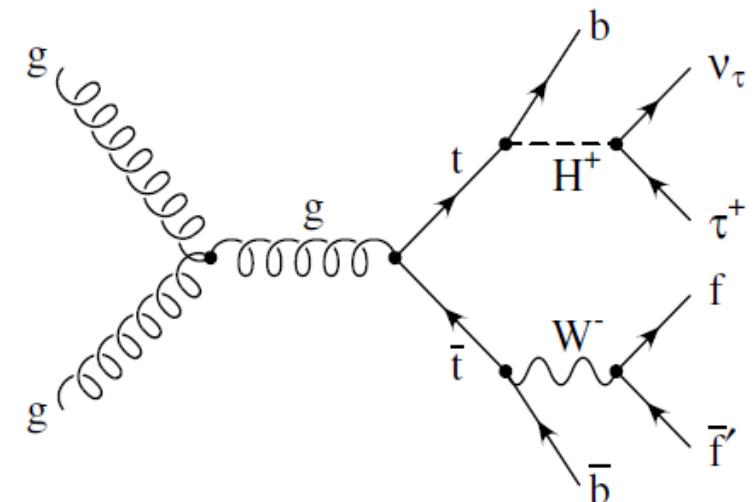




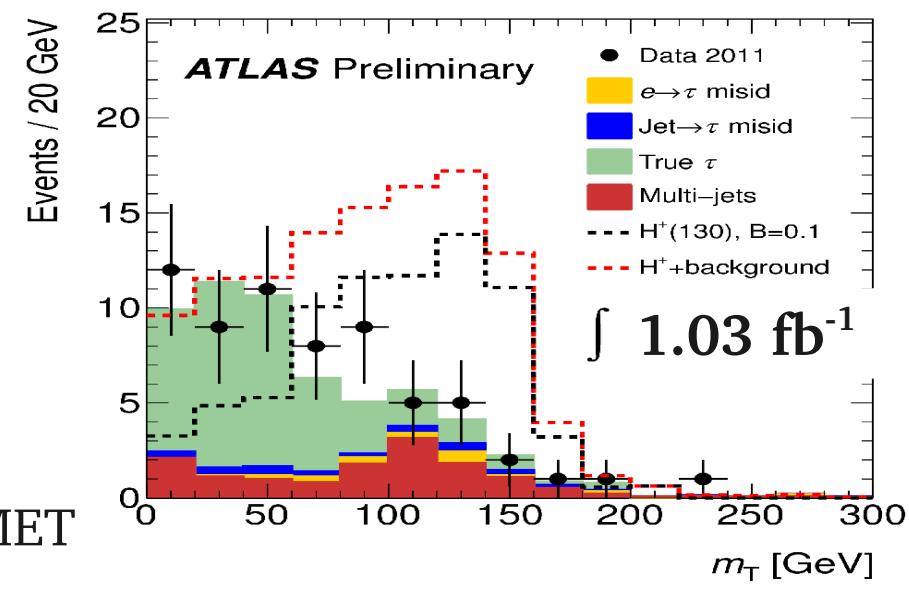
Charged Higgs $H^+ \rightarrow \tau\nu \rightarrow \tau_{\text{had}} 2\nu$

ATLAS-CONF-2011-138

- Predicted in MSSM, in models with Higgs triplets and two Higgs doublets
- If lighter than top quark, then produced dominantly through top decays
- With $\tan\beta > 3$, prefer to decay to $\tau\nu$



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

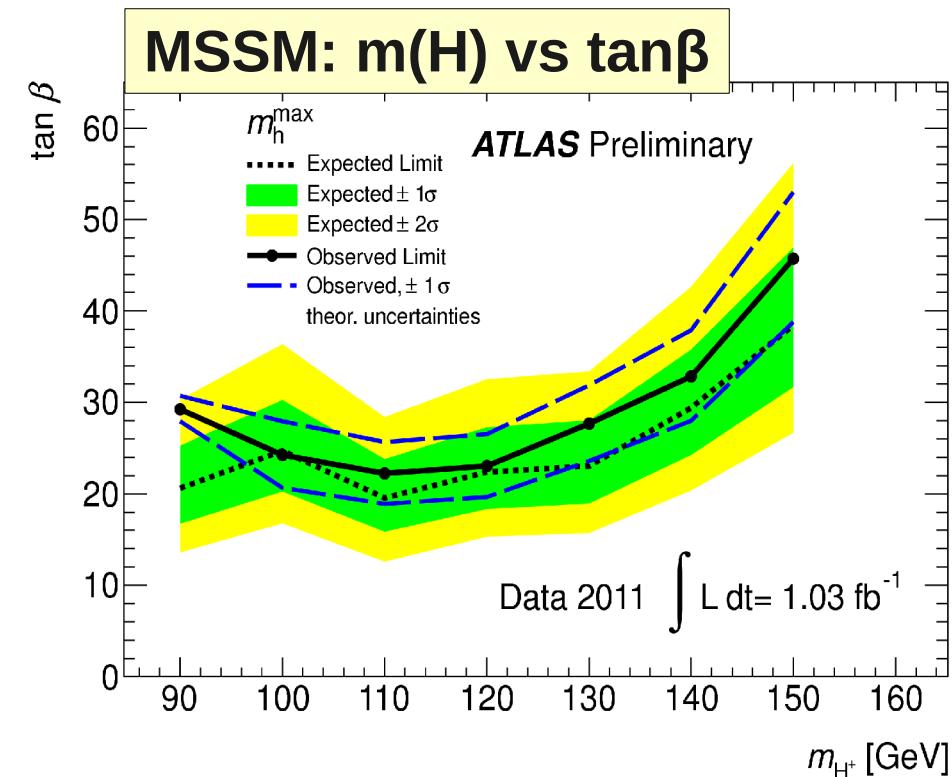
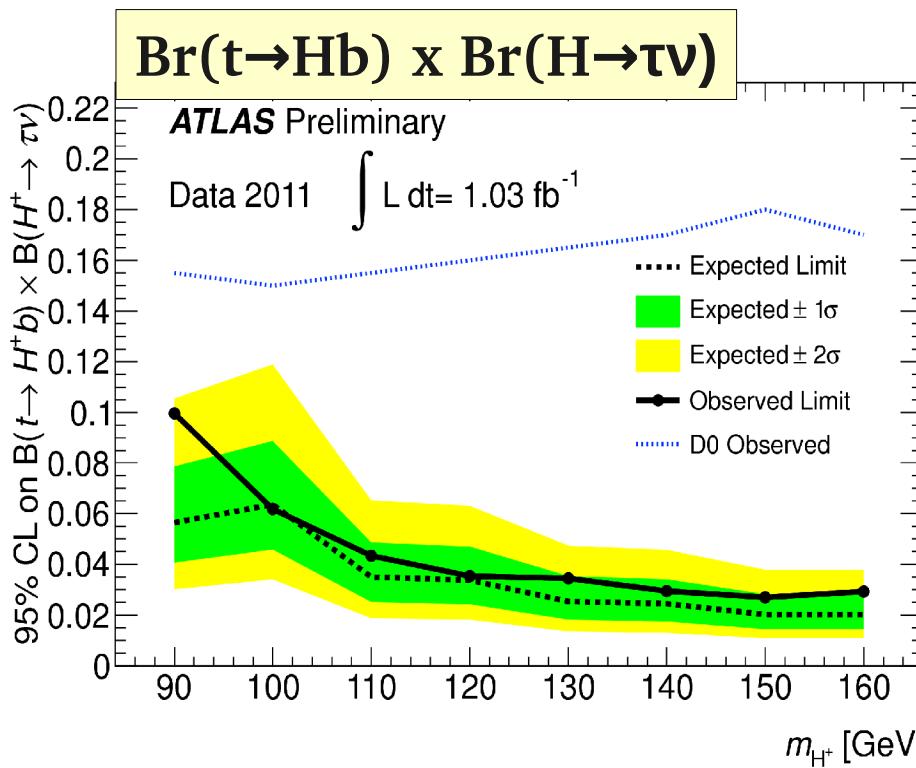




Charged Higgs $H^+ \rightarrow \tau\nu \rightarrow \tau_{\text{had}} 2\nu$

1.03 fb^{-1}

- No signal is seen
- Upper limits on branching ratio $\text{Br}(t \rightarrow Hb) \times \text{Br}(H \rightarrow \tau\nu)$ and on MSSM parameter space of Higgs mass vs $\tan\beta$ are set @ 95%CL





New

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

NIKHEF
1.03 fb⁻¹

- Single lepton:

$pT(e) > 25\text{GeV}$ or $pT(\mu) > 20\text{GeV}$.

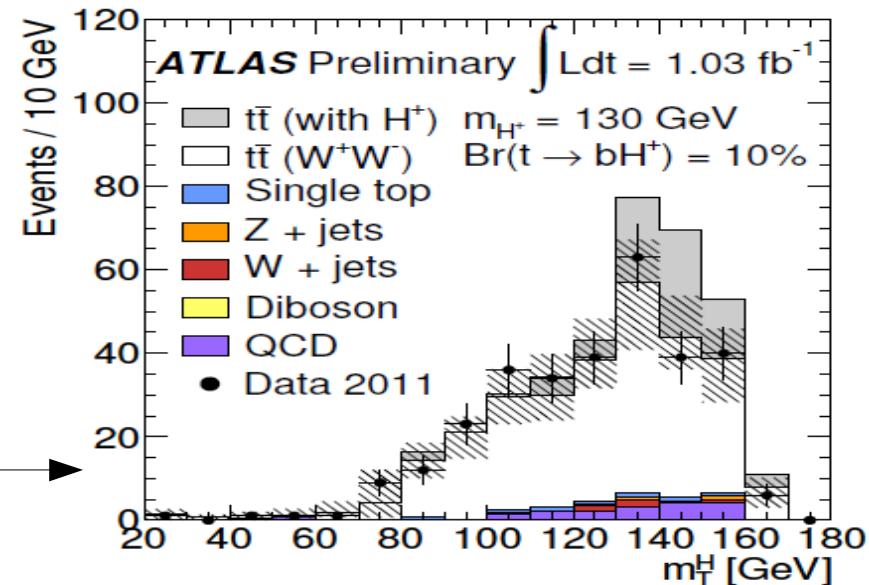
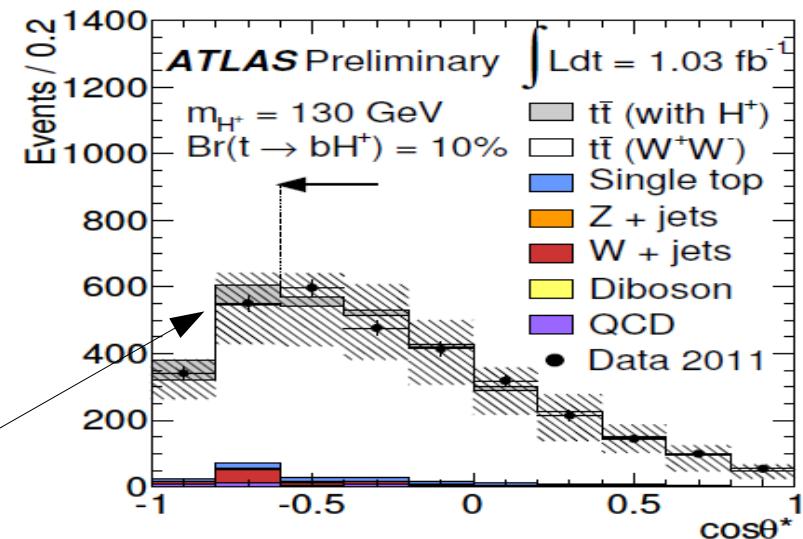
at least 4 jets $pT > 20\text{GeV}$, $|\eta| < 2.5$

- 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 $t \rightarrow Hb$, constrain second top, maximize transverse Higgs mass

$$(m_T^H)^2 = \max_{\left\{ \begin{array}{l} p_z^{\text{miss}}, E^{\text{miss}} \\ (p^{\text{miss}} + p^l + p^b)^2 = m_{top}^2 \end{array} \right\}} [(p^l + p^{\text{miss}})^2].$$





New

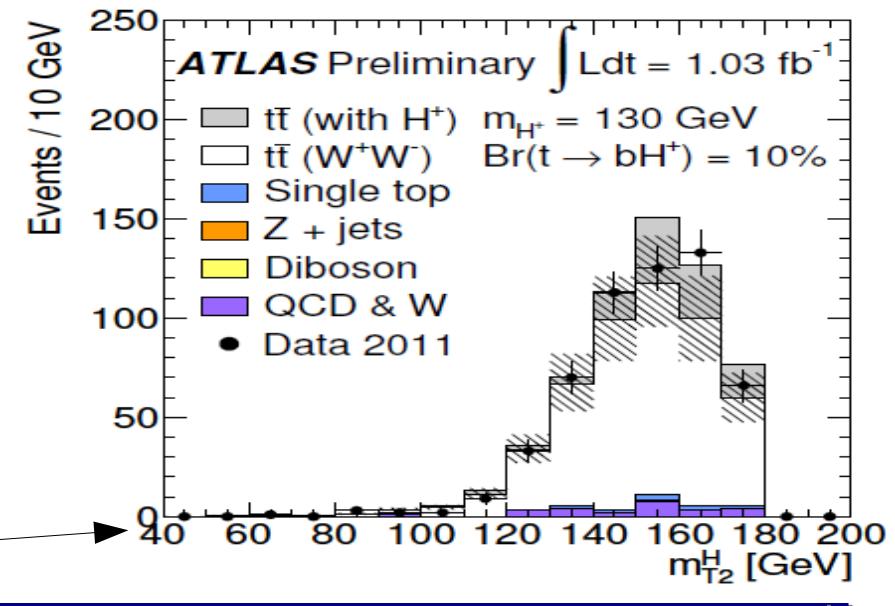
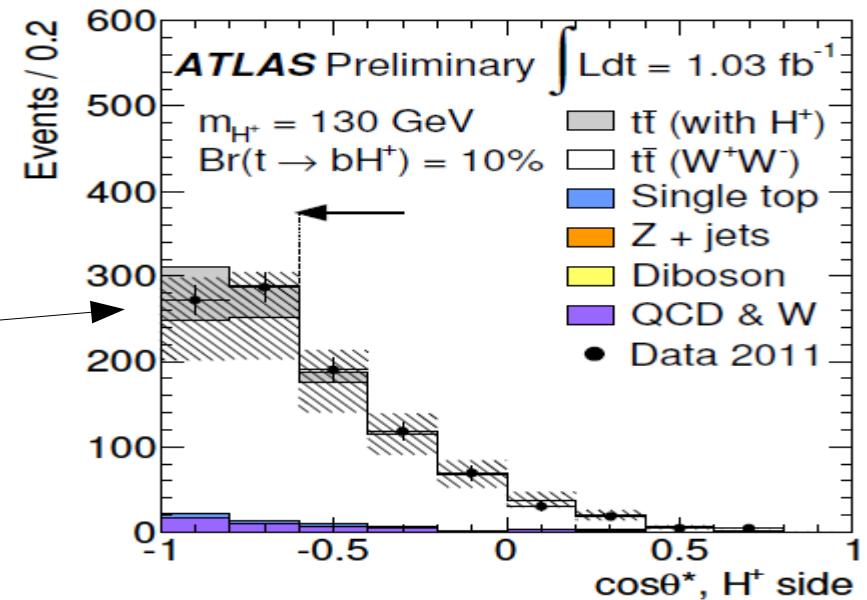
Charged Higgs $H^+ \rightarrow \tau\nu \rightarrow e/\mu 3\nu$

NIKHEF
1.03 fb^{-1}

- Double lepton final state:
- 2 oppositely charged leptons
- 2 jets $p_T > 20\text{GeV}$, $|\eta| < 2.5$,
- cut on $\cos\theta_l^*$
- split missing E_T 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





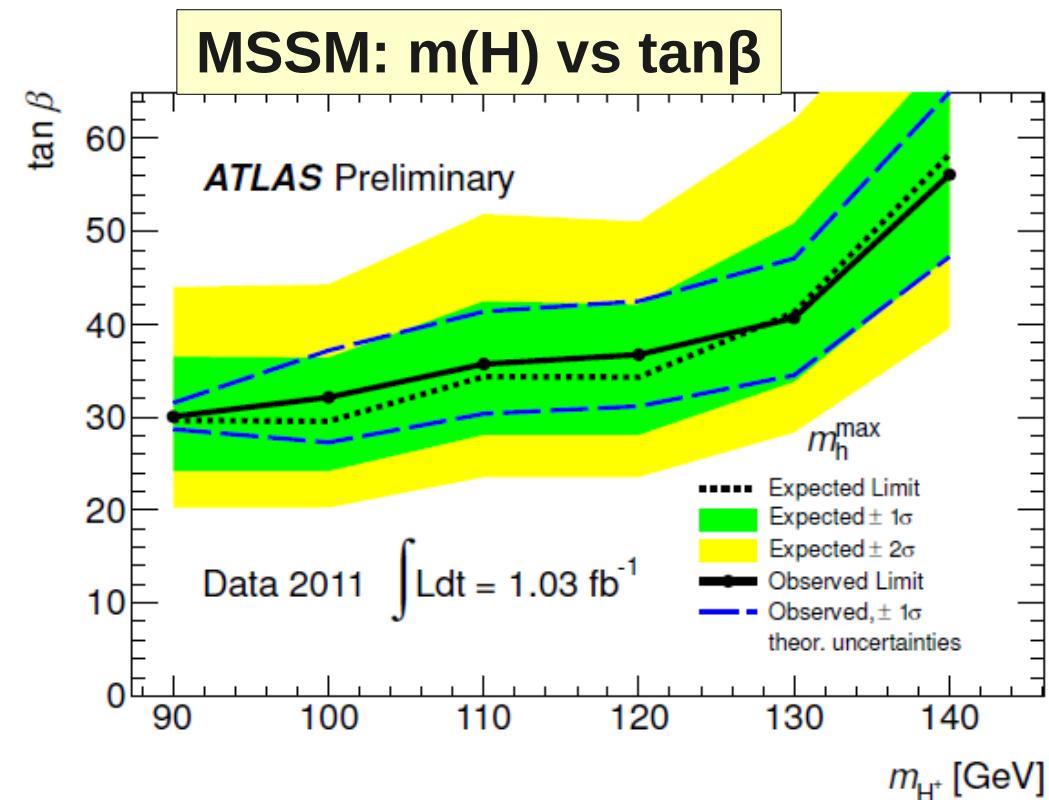
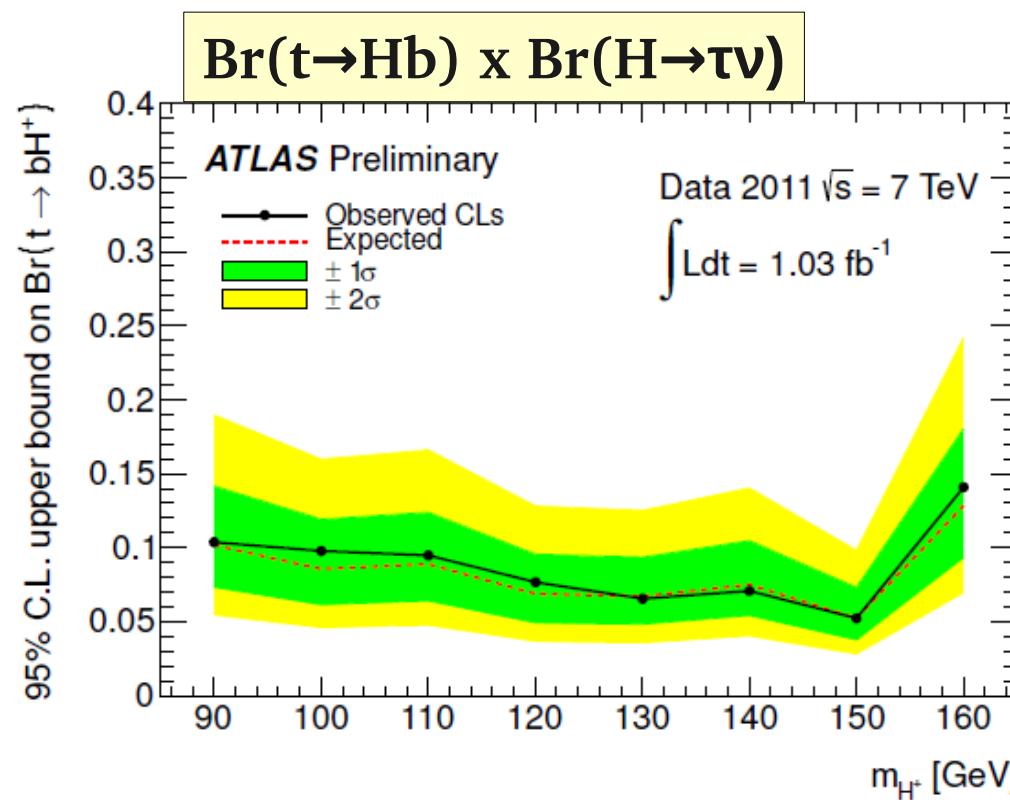
New

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

NIKHEF
1.03 fb^{-1}

- No signal is seen
- Upper limits on branching ratio $\text{Br}(t \rightarrow Hb) \times \text{Br}(H \rightarrow \tau\nu)$ and on MSSM parameter space of Higgs mass vs $\tan\beta$ are set

ATL-CONF-2011-151



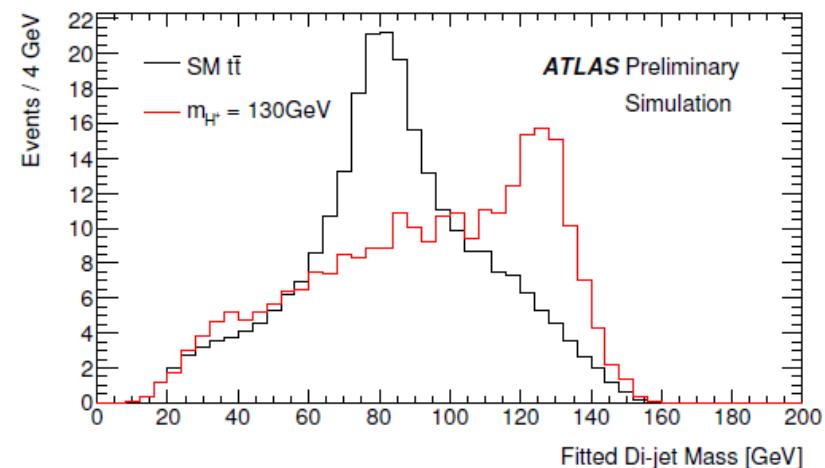
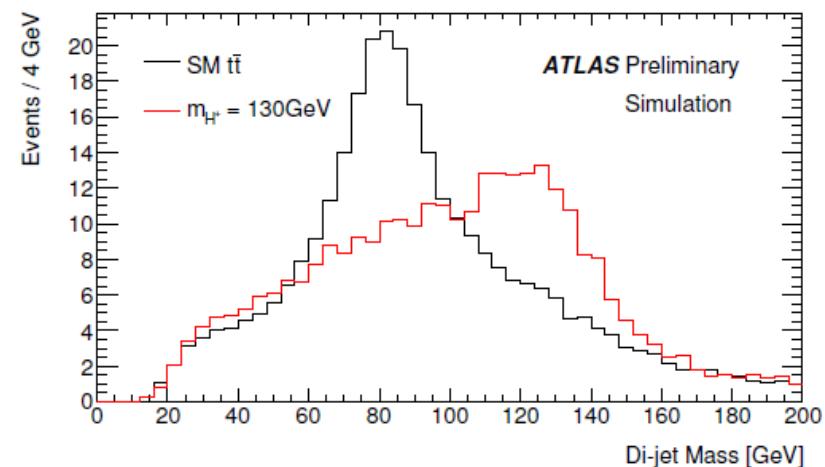


Charged Higgs $H \rightarrow c\bar{s}$

35 pb⁻¹

- Same production channel as for $H^+ \rightarrow \tau\nu$ via decays top quark
- 2 jet decay dominates at $\tan\beta < 1$
- Use e/μ decay of second top to tag events; $\text{MET} > 20/30\text{GeV}$, $mT > 25\text{GeV}(e)/ mT + \text{MET} > 60\text{GeV}(\mu)$
- 4 jets with $p_T > 25\text{GeV}$, $|n| < 2.5$
- Kinematic fit of the event with top constraint to find best Higgs candidate

ATLAS-CONF-2011-094



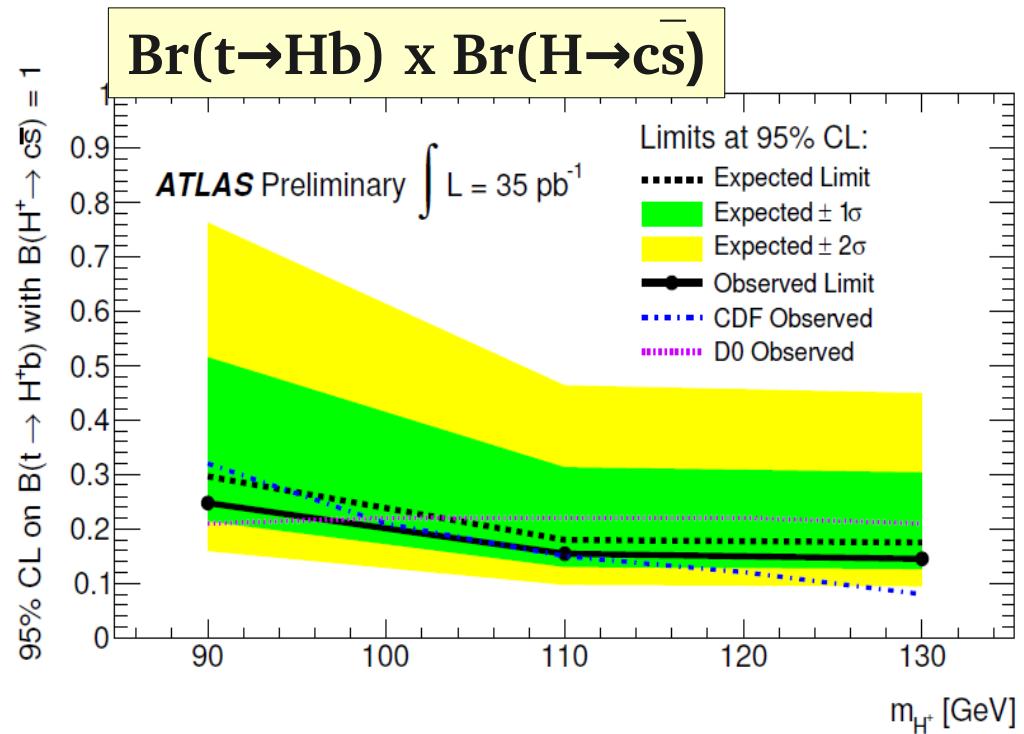
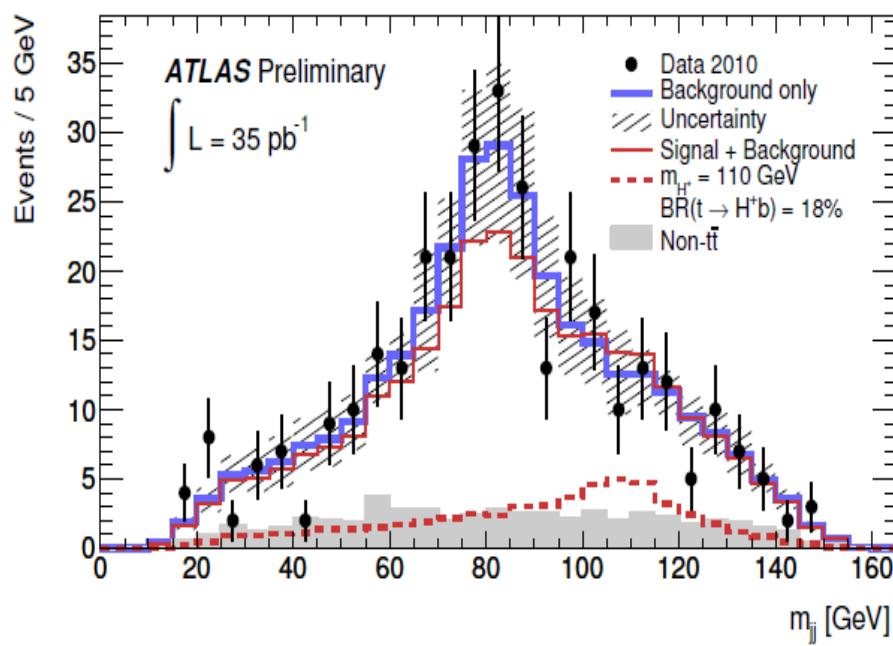


Charged Higgs $H \rightarrow c\bar{s}$

35 pb⁻¹

ATLAS-CONF-2011-094

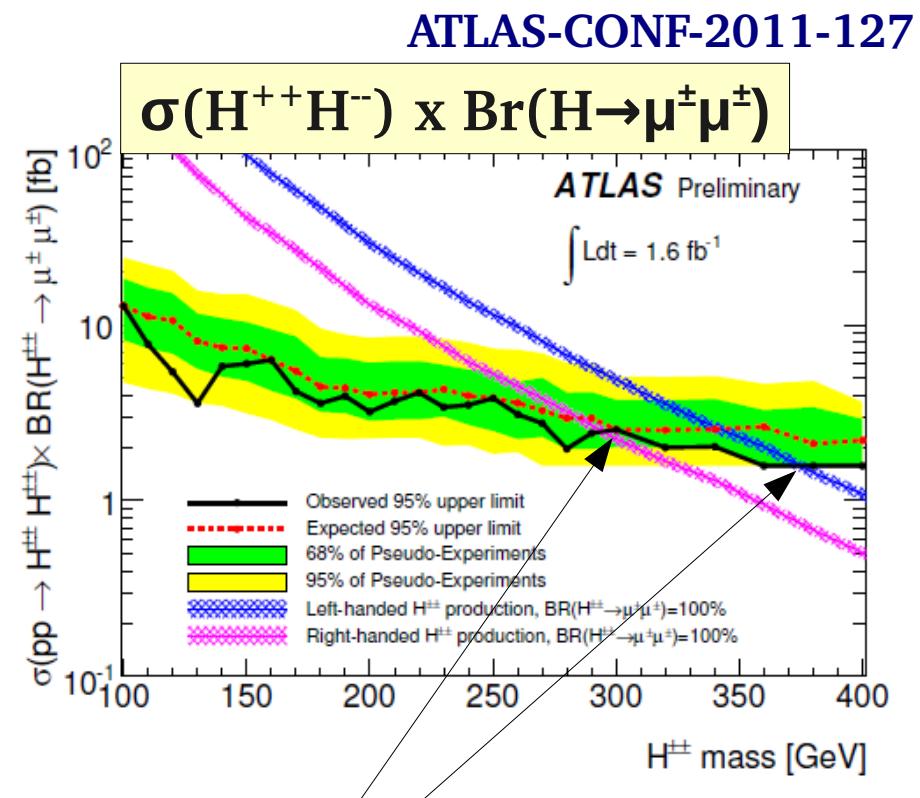
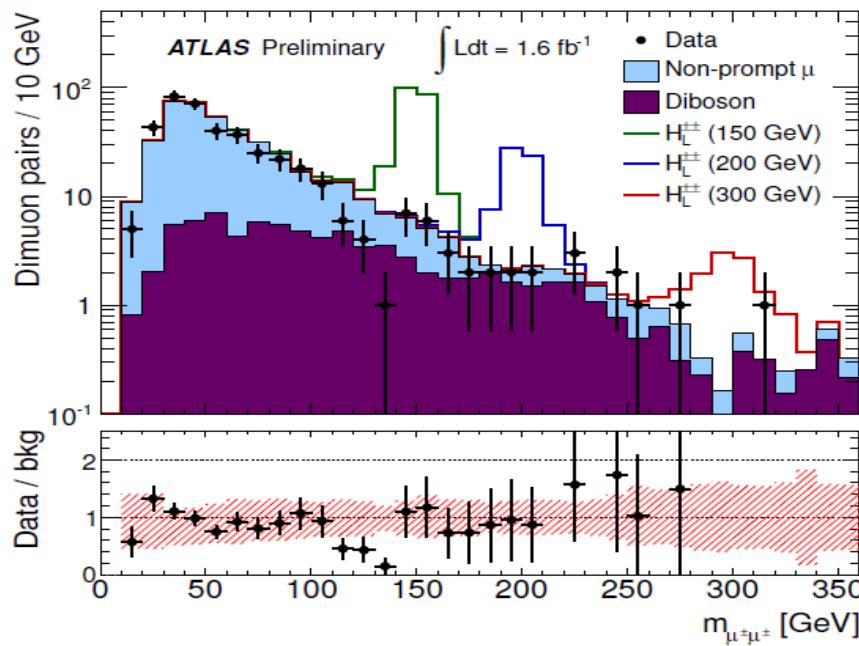
- No signal seen
- Upper limit on branching ratio $\text{Br}(t \rightarrow H^+ b) \times \text{Br}(H^+ \rightarrow c\bar{s})$ is set





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

- Predicted in little Higgs, Higgs triplet and left-right symmetric models
- $pT(\mu_1) > 20\text{GeV}$, $pT(\mu_2) > 10\text{GeV}$
Same charge muons **1.6 fb^{-1}**
- Look for di-muon mass resonance



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

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



Summary

- Wide range of non-Standard Model probed
- Excellent performance of detector is reached
- No excess observed so far in any of the searches :
 - fermiophobic $H \rightarrow \gamma\gamma$
 - MSSM $H \rightarrow \tau\tau$
 - Charged $H^+ \rightarrow \tau\nu$, $H \rightarrow c\bar{s}$
 - Doubly charged $H^{++} \rightarrow \mu^+\mu^+$
- Strict upper limits are set on corresponding production cross-sections within a number of models

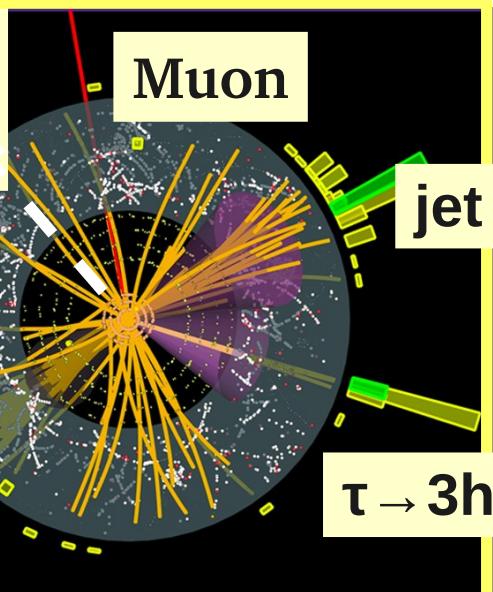
Still space for non-SM Higgs to hide – stay tuned



$\mu + \tau + \text{jet} + b\text{-jet} + \text{missing Et}$

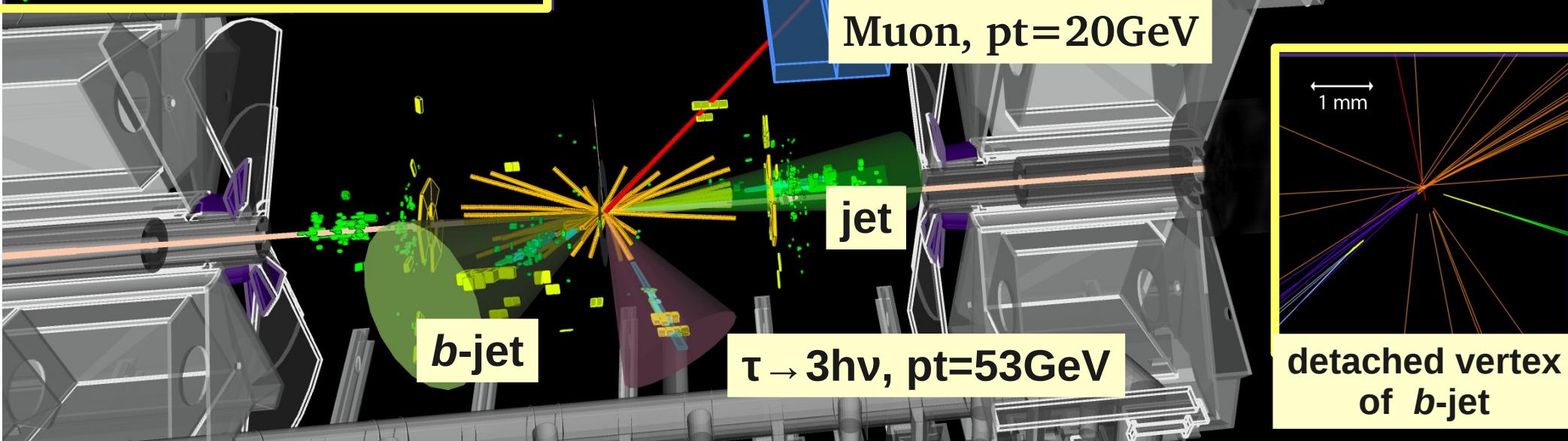
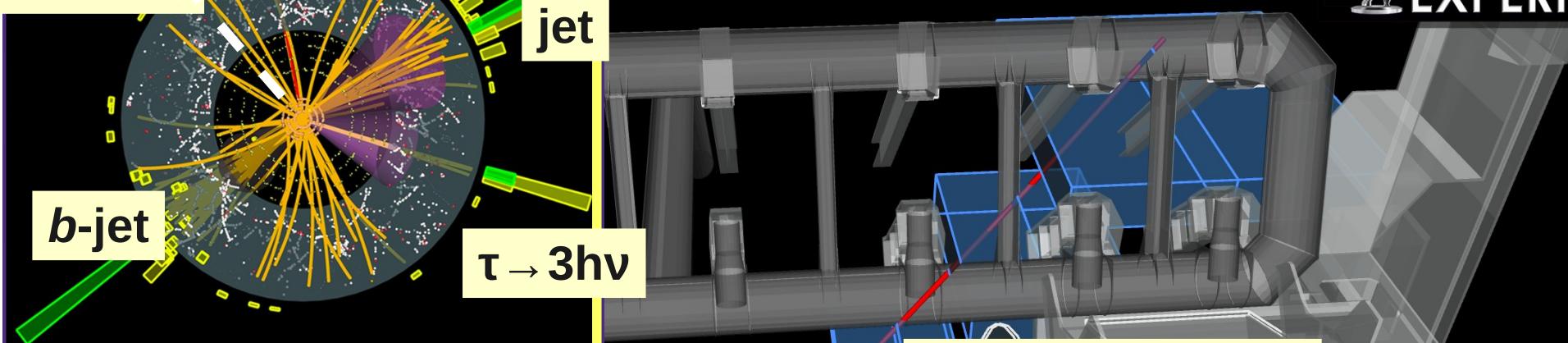
NIKHEF

transverse
missing
energy
 $= 39 \text{ GeV}$



? $t\bar{t} \rightarrow Hb\mu\nu b, H \rightarrow \tau\nu$?

ATLAS
EXPERIMENT

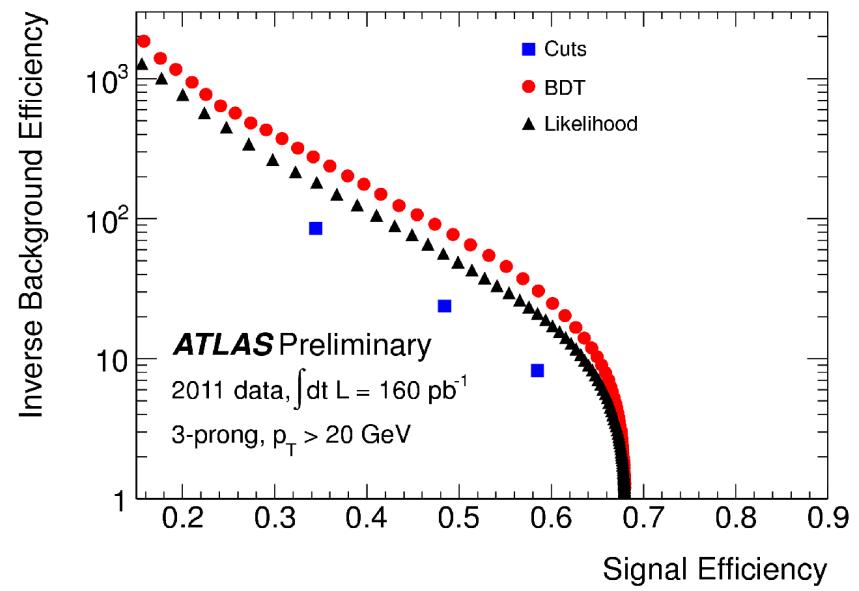
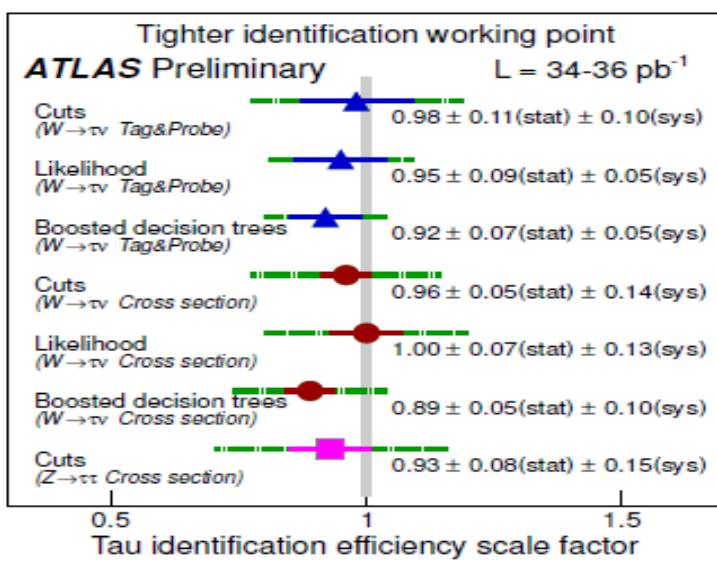
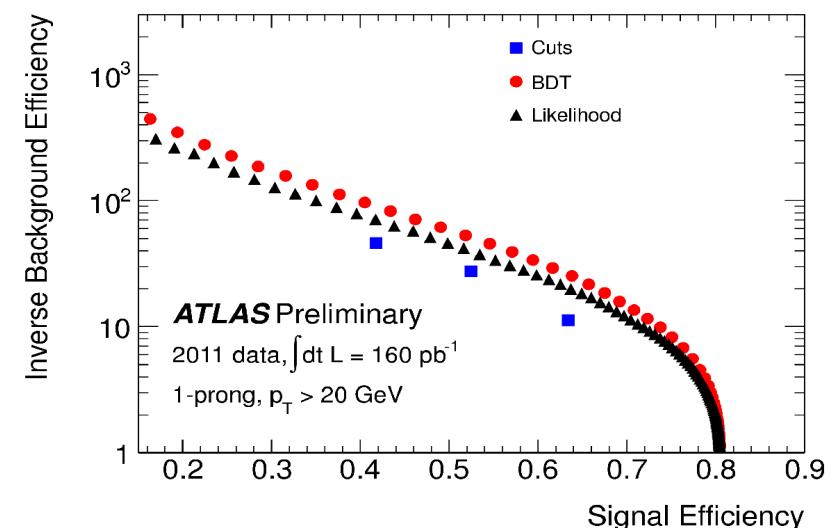
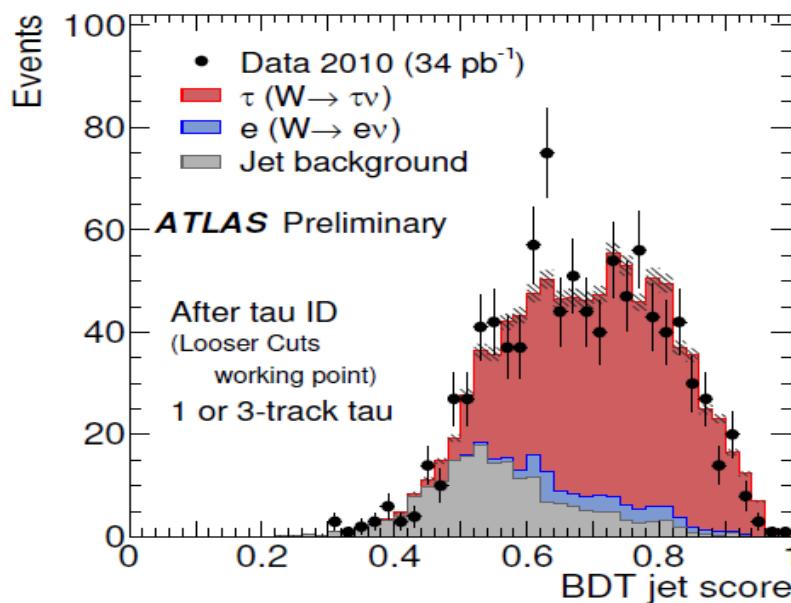




Backup



τ_{had} identification





CL_s confidence limits

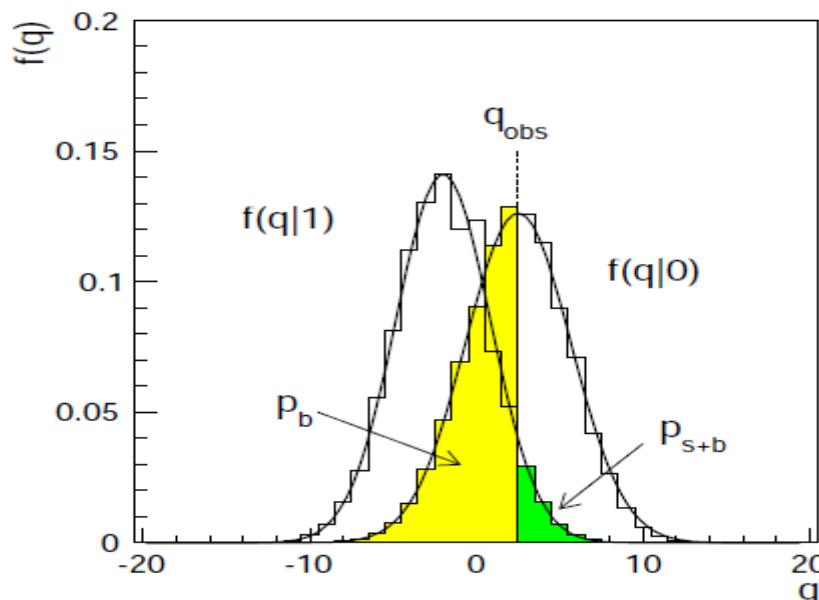


Figure 1: Distributions of the test variable q under the $s+b$ and b hypotheses (see text).

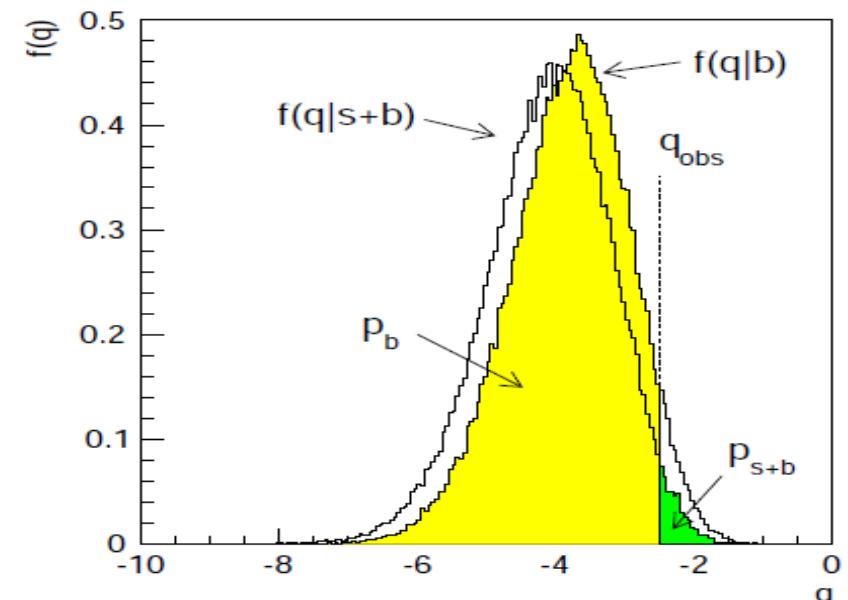


Figure 2: Distributions of the test variable q under the $s+b$ and b hypotheses in an example where one has very little sensitivity to the signal model.

$$\text{CL}_s \equiv \frac{P_{s+b}}{1 - P_b} < \alpha$$

A.Read, J.Phys. G28 (2002) 2693,
ATLAS,CMS, ATL-PHYS-PUB-2011-011