SUSY Higgs Searches with ATLAS

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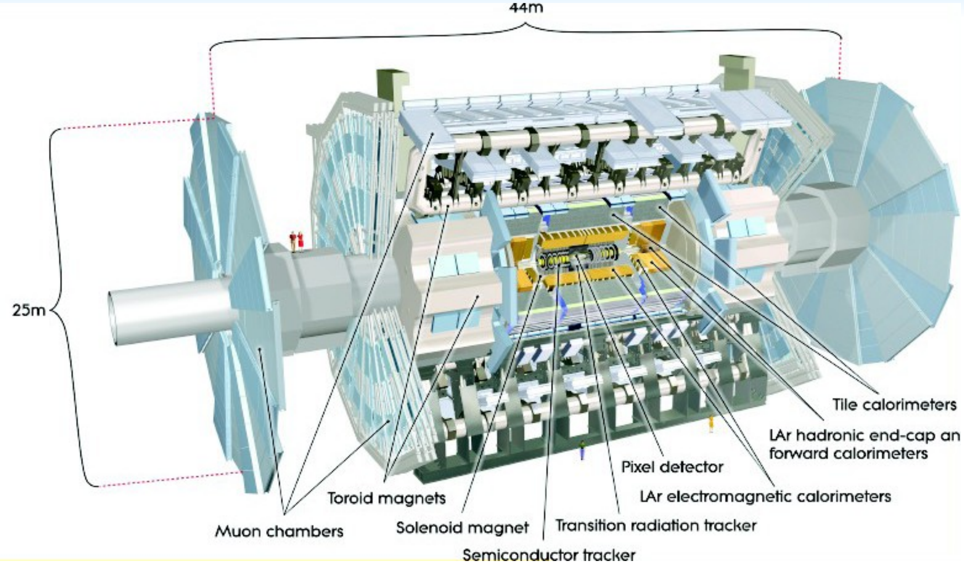
(on behalf of the ATLAS collaboration)

Outline

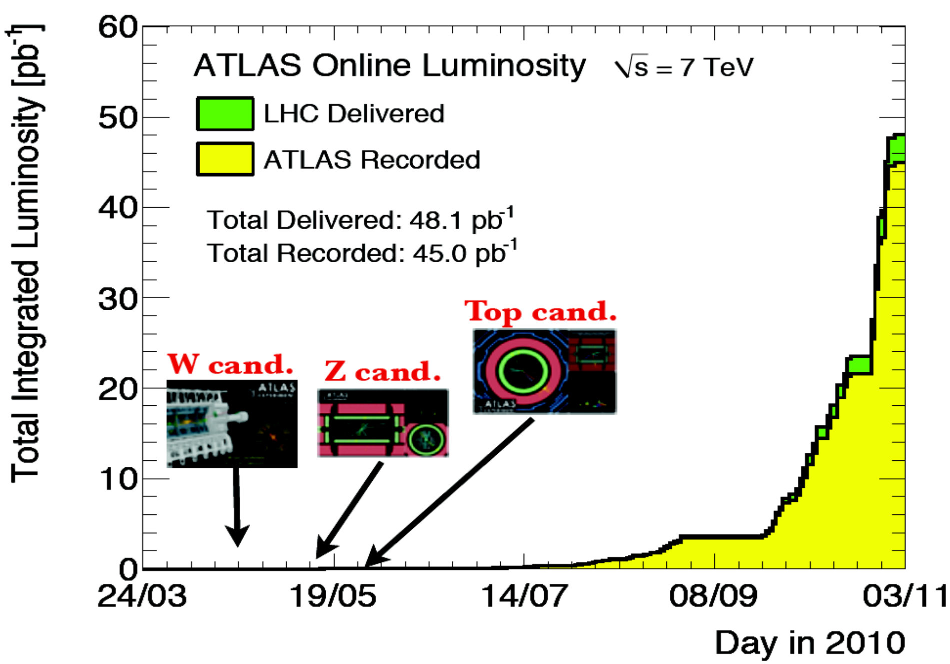
- ATLAS detector, datataking 2010
- Higgs in SUSY
- I: MSSM: Neutral Higgs
- II: MSSM: Charged Higgs
- III: NMSSM: $a_1 \rightarrow \mu\mu$
- Summary

ATLAS, datataking 2010



ATLAS (A Toroidal Lhc ApparatuS)

- General-purpuse detector
- Traditional build
  - tracking detectors
  - calorimeters
  - muon spectrometer
- Good coverage



2010 was a great year

- Calibrating ATLAS at 7 TeV
- "Rediscovering" the SM.
  The first W, Z, top candidates observed one year ago
- Lots of data in uncharted territory, 35-40 pb^{-1} for analyses

Higgs sector in MSSM

MSSM
(Minimal Supersymmetric Standard Model):

- Why add supersymmetry to SM?
  - (is doable)
  - cure hierarchy problem ...
  - maybe get Dark Matter candidate ...
  - gauge unification at high scale ...
  - symmetry needed in String Theory...
  - ...
- Every SM field (dof) gets a SUSY partner (dof) with spin differing by ½
  - particle content doubled (and more)
- But SUSY must be broken ...
- Breaking details unknown:
  - add all allowed couplings...
  - introduces 105 free parameters
  - (if R-parity conserved)

Higgs sector in the MSSM

- *Two* complex Higgs doublets needed
  - 8 dof – 3 to feed Z and $W^{\pm}$ = 5 scalar fields
    - 2 neutral CP-even: **h** and **H**
    - 1 neutral CP-odd: **A**
    - 2 charged: $\mathbf{H^{+}}$ and $\mathbf{H^{-}}$
- Governed by only 2 parameters at tree level
  - $\mathbf{m_A}$ and **tanβ** (ratio of the two Higgs doublet VEVs)
- For **A** somewhat heavier than **W**:
  - **h** decoupled (below 135 GeV)
  - **A**, **H**, $\mathbf{H^{\pm}}$ degenerate

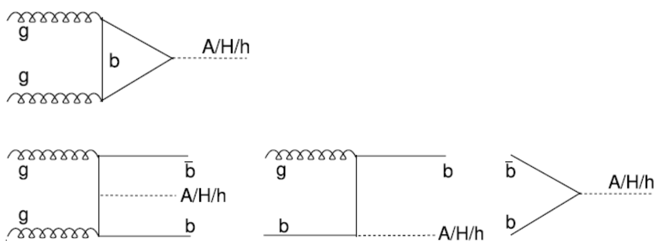
- Subgroup of the 2HDM: type II
  - One doublet gives masses to up-type fermions
  - another gives masses to down-type fermions
- Radiative corrections important for **h**
  - $\mathbf{m_h}$ perturbed from below $\mathbf{m_Z}$ to within 135 GeV
    - sensitive to stop mixing (top mass, ..)
    - ($\mathbf{m_h}$-max scenario)

MSSM Higgs: rise and fall

Production mechanisms:

I: Neutral Higgses:

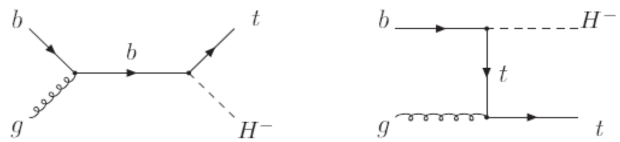
- direct
- in association with b's
  (esp. for larger tanβ)



For **A** and **H**: σ prop. to **~(tanβ)^2**
→ enhancement for large **tanβ**

II: Charged Higgs:

- m(H$^\pm$) < m(t) : in top decay mainly
- m(H$^\pm$) > m(t) : gb → tH$^\pm$



And in SUSY cascades

- Extra activity can make such channels very favourable (large MET, hard jets)
- Not considered further here

Decays

- Higgs fields couple to mass, general preference: decay into heaviest available particles
- MSSM vs SM
  - **tanβ** enters the couplings
  - Decay into dibosons strongly suppressed
    - A → ZZ/WW: absent
    - H → ZZ/WW: suppressed by cos(α-β)
    - h → ZZ/WW: kinematically closed
  - Enhanced decay into down-type fermions
  - Enhanced decay into third generation
- **Neutral, A / H / h**
  - → bb often dominant (but exp. difficulty)
  - → ττ significant: can reach 10%
  - → μμ very small (~0.03%), but distinct exp. signature
- **Charged, H$^\pm$**
  - → tb dominant if H$^\pm$ is heavy
  - → τν dominant if H$^\pm$ is light
  - → cs subdominant if H$^\pm$ is light

I: A/H/h → ττ (#1) [Data]

ATLAS-CONF-2011-024

36.1 pb^{-1}

Search in the semi-leptonic channel: $\tau_h\ \tau_{e/\mu}$

- $BR(\tau\tau \rightarrow \tau_h\ \tau_{e/\mu}) = 46\%$

Event selection

- $N_e + N_\mu = 1$, $p_T > 20/15$ GeV (e/μ)
- $N_\tau = 1$, $p_T^{\tau,vis} > 20$ GeV
- opposite-sign
- $E_T^{miss} > 20$ GeV *(have 3 ν's)*
- $M_T < 30$ GeV *(to suppress W, tt, t)*

where $M_T = \sqrt{2 p_T^{e/\mu} E_T^{miss} (1 - \cos\Delta\phi)}$

For Higgs events the selection efficiency is

- 3% for mA = 120 GeV
- 8% for mA = 200 GeV

SM Backgrounds

W(→lν) + jets

- l=e/μ/τ, jet misidentified as τ_h
- Large cross-section

Z/γ*(→ll) + jets

- ll=ττ: irreducible
- esp. problematic if Higgses light
- ll=ee/μμ: e/μ/jet misidentified as τ_h

tt, single-t, diboson, QCD

- less important

Cross-sections:

- Signals (m_h-max scenario, tanβ = 20, m_A = 120/200 GeV)
- SM backgrounds

Process	Cross section × BR [pb]
$bbA/H/h,\ A/H/h \to \tau^+\tau^- \to \ell\tau_h,\ m_A = 120$ GeV	3.57/0.33/3.43
$bbA/H/h,\ A/H/h \to \tau^+\tau^- \to \ell\tau_h,\ m_A = 200$ GeV	0.56/0.56/0.03
$gg \to A/H/h \to \tau^+\tau^- \to \ell\tau_h,\ m_A = 120$ GeV	2.25/1.01/1.87
$gg \to A/H/h \to \tau^+\tau^- \to \ell\tau_h,\ m_A = 200$ GeV	0.14/0.17/0.50
$W \to \ell$+jets ($\ell = e, \mu, \tau$)	10.46×10^3
$Z/\gamma^* \to \ell^+\ell^-$+jets ($m_{\ell\ell} > 10$ GeV)	4.96×10^3
$t\bar{t}$	164.6
Single-t ($t-$, $s-$ and Wt-channels)	58.7, 3.9, 13.1
Di-boson (WW, WZ and ZZ)	46.2, 18.0, 5.6

I: A/H/h → ττ (#2) [Data]

SM MC predictions consistent with data

- in both channels, $\tau_h e$ and $\tau_h \mu$
- **Data: 74+132 = 206**
- **SM MC-only (w/o QCD)**: 70(±3)+137(±4) = **207(±6)**
  [see table, statistical error only]

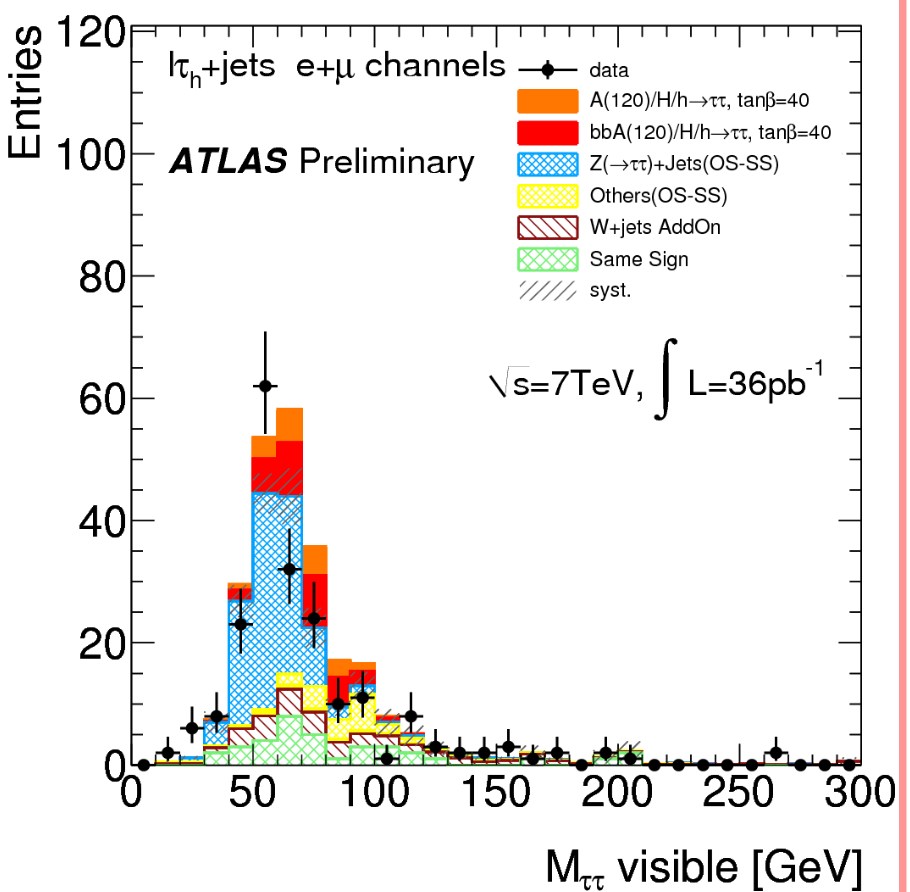
Datadriven SM estimates gives similar numbers:

- **SM: 195 ± 33** (stat and syst err)
  [breakdown consistent with MC-only estimation]

Higgs signal would add 43/19 events
(tanβ=40, m_A=120/200 GeV)

	$N_\tau = 1$	$E_T^{miss} > 20$ GeV	$M_T < 30$ GeV
Electron channel			
Observed data	1413	581	74
Total MC expectation (w/o QCD)	1350±10	700±10	70±3
W+jets	710±10	590±10	26±2
Di-boson	3.61±0.05	2.68±0.05	0.26±0.01
Single-t	4.4±0.1	3.9±0.1	0.40±0.06
$t\bar{t}$	26.3±0.4	23.8±0.4	2.8±0.1
$Z/\gamma^* \to e^+e^-, \mu^+\mu^-$	451±7	41±2	9.8±0.9
$Z/\gamma^* \to \tau^+\tau^-$	150±4	40±2	30±2
$A/H/h$ signal (m_A = 120 GeV, $\tan\beta$ =40)	62±1	23.4±0.6	17.9±0.5
$A/H/h$ signal (m_A = 200 GeV, $\tan\beta$ =40)	16.4±0.2	9.7±0.2	7.3±0.2
Muon channel	$N_\tau = 1$	$E_T^{miss} > 20$ GeV	$M_T < 30$ GeV
Observed data	1627	841	132
Total MC expectation (w/o QCD)	1680±20	1050±10	137±4
W+jets	1030±10	860±10	41±2
Di-boson	4.88±0.07	3.93±0.06	0.42±0.02
Single-t	5.7±0.1	5.1±0.1	0.65±0.05
$t\bar{t}$	33.2±0.4	30.0±0.4	3.9±0.1
$Z/\gamma^* \to e^+e^-, \mu^+\mu^-$	253±5	48±2	11±1
$Z/\gamma^* \to \tau^+\tau^-$	350±20	97±3	81±3
$A/H/h$ signal (m_A = 120 GeV, $\tan\beta$ = 40)	103±1	42.9±0.9	35.4±0.8
$A/H/h$ signal (m_A = 200 GeV, $\tan\beta$ = 40)	23.8±0.3	14.6±0.2	11.4±0.2

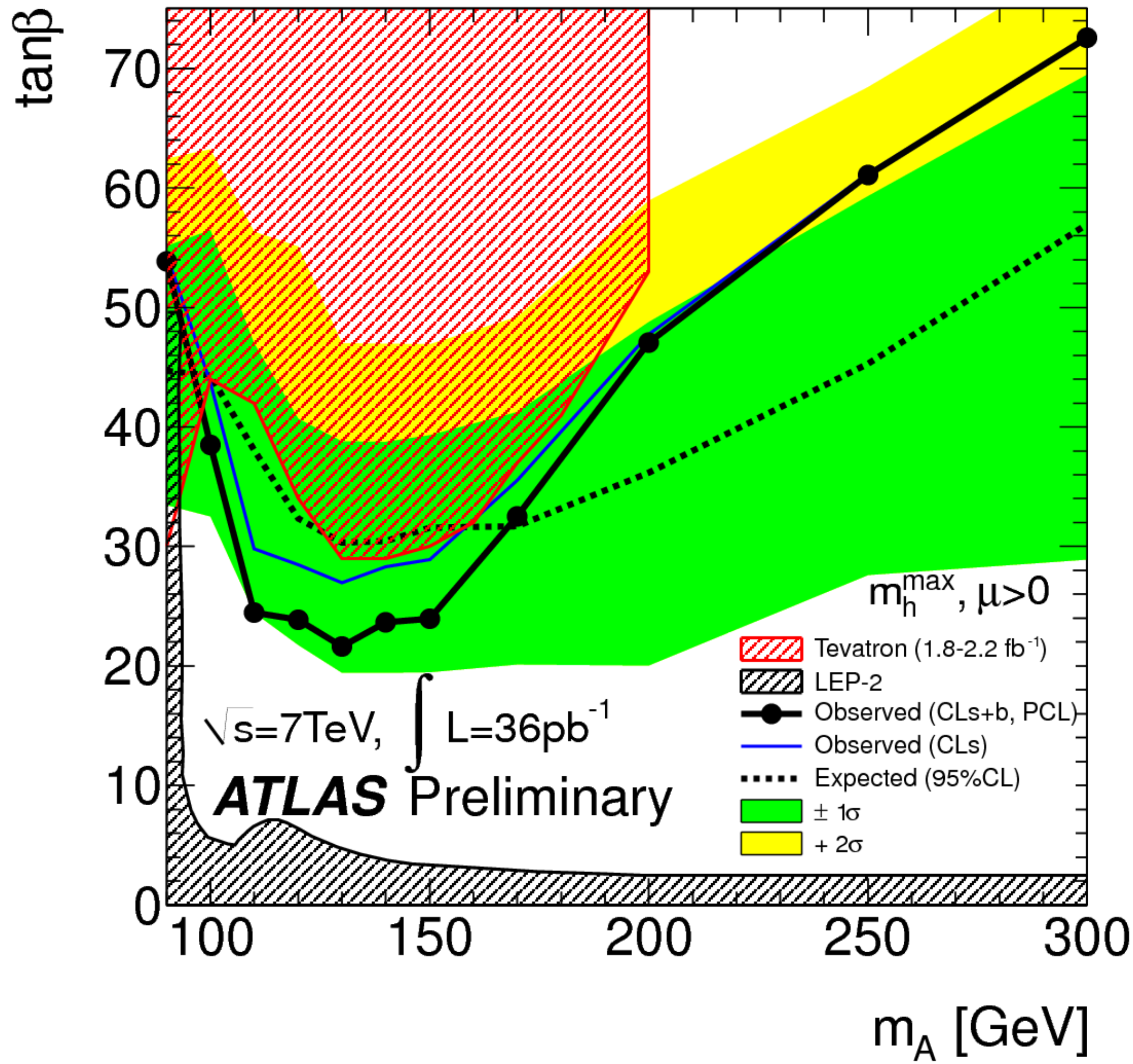
No excess observed
Use $m_{\tau\tau}^{vis}$ distribution to set exclusion limits



I: A/H/h → ττ (#3) [Data]

Exclusion limits

- m_A-tanβ plane, m_h^{max} scenario
- based on $m_{\tau\tau}^{vis}$ distribution
- Region above "**Observed (CLs+b, PCL)**" is excluded at 95% CL
- Extends exclusions by LEP and Tevatron (NB: different statistical methods used)
- CLs limit shown for direct comparison with Tevatron



I: A/H/h → μμ [MC, $1fb^{-1}$]

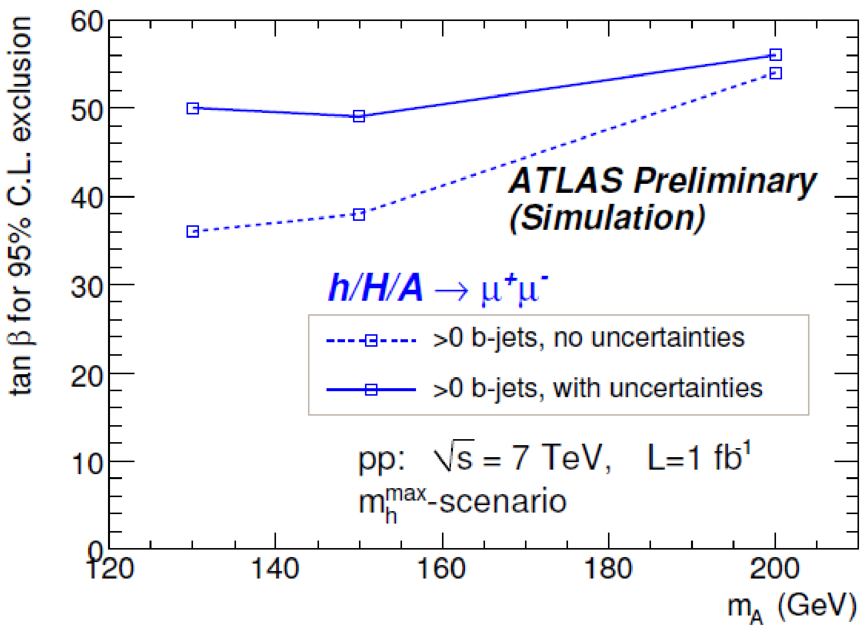
ATLAS-PHYS-PUB-2010-009

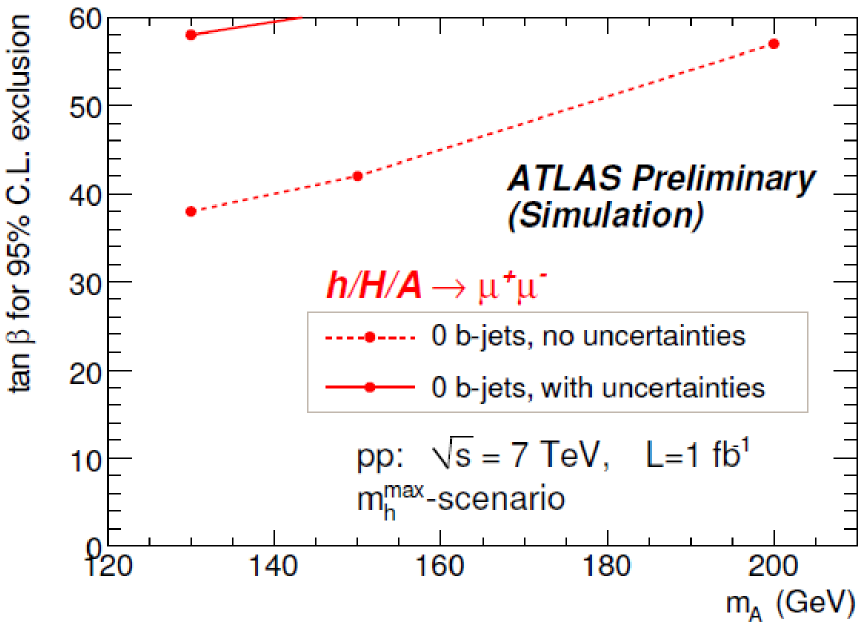
For neutral Higgses to μμ no search results have have been published yet.
Show the MC prospects for 1 fb^{-1}.

Large tanβ enhances coupling to down-type fermions
- μμ-channel BR enhanced
  - still very low BR: ~0.04% (at tanβ=40)
  - but very clean
- production in association with b is enhanced:
  - can require **b** in event selection

Exclusion plots in mA-tanβ plane
- region above curves (to be) excluded at 1 fb-1
- left: ≥1 b's , right: 0 b's
- **dashed:** syst. uncertainty on bck and signal not included
- **full-line:** syst. uncertainty on bck and signal included
- b-tag selection (left) strongest

[results based on rescaling 10 TeV analysis]



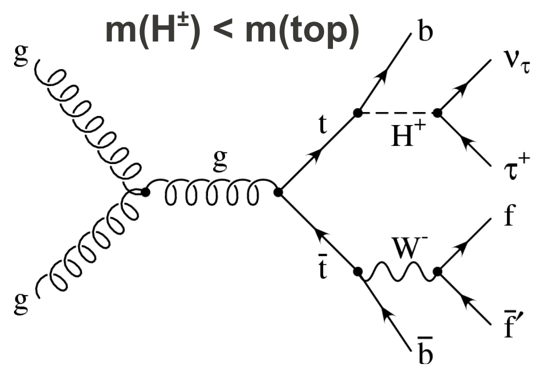


II: $H^{\pm} \rightarrow \tau_h \nu$ [Data]

"Data-driven estimation of the background to charged Higgs boson with hadronic taus"

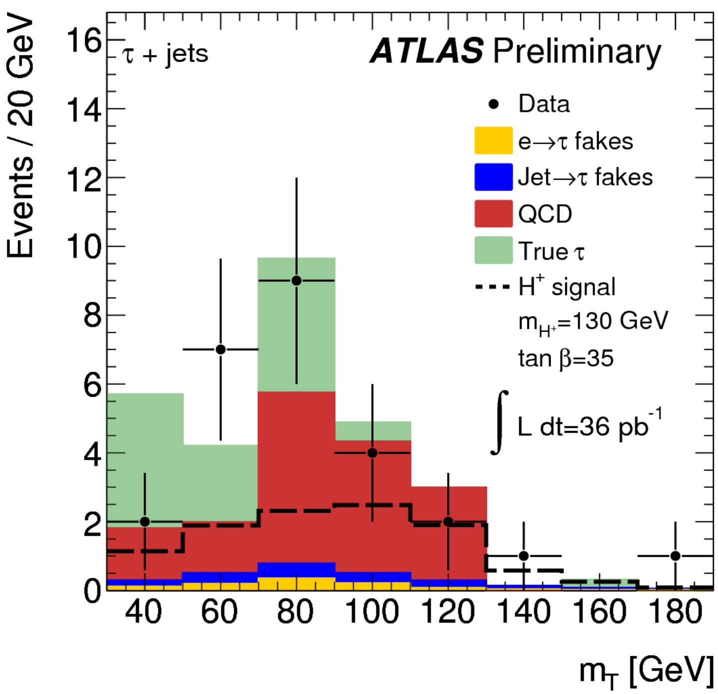
Hadronic tau, *hadronic* W

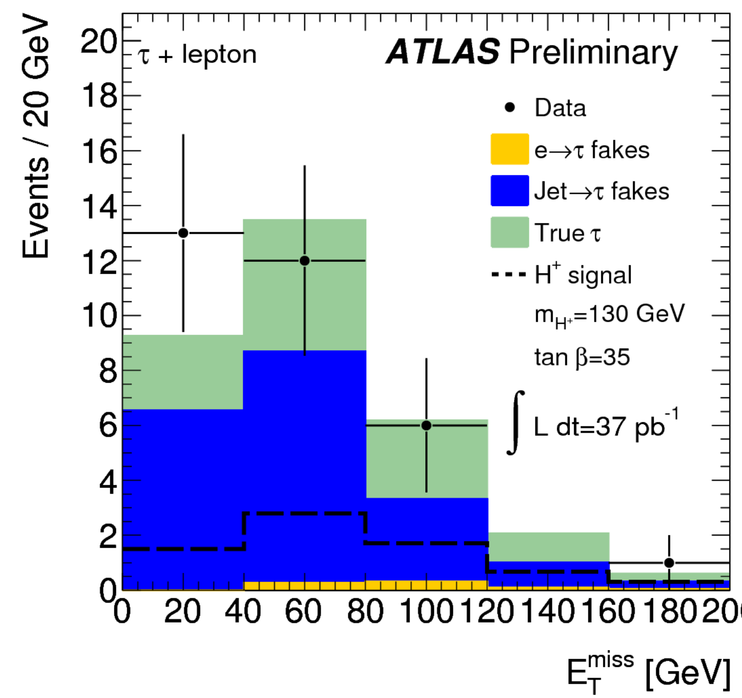
- $b\tau_h\nu$ bqq ↔ 1 taujet, 2b, 2q, 2ν
- largely datadriven SM estimates
- good agreement so far



Hadronic tau, *leptonic* W

- $b\tau_h\nu$ blν ↔ 1 taujet, 2b, 1l, 3ν
- largely datadriven SM estimates
- good agreement so far





	Expected					Observed
	True τ jets	Jet $\rightarrow \tau$ fakes	$e \rightarrow \tau$ fakes	QCD	Sum	Data
All events	$10.8 \pm 3.1^{+3.2}_{-2.4}$	$1.7 \pm 0.2 \pm 0.3$	$1.1 \pm 0.0 \pm 0.4$	$18.8 \pm 6.2 \pm 3.0$	$32 \pm 9 \pm 7$	33
$m_T > 70$ GeV	$4.7 \pm 1.3^{+1.4}_{-1.1}$	$1.2 \pm 0.2 \pm 0.2$	$0.7 \pm 0.0 \pm 0.3$	$11.3 \pm 3.7 \pm 1.7$	$18 \pm 5 \pm 4$	17

	Expected				Observed
	True τ jets	Jet $\rightarrow \tau$ fakes	$e \rightarrow \tau$ fakes	Sum	Data
Events	$6.9 \pm 0.3 \pm 1.4$	$7.9 \pm 1.1 \pm 1.6$	$0.65 \pm 0.01 \pm 0.04$	$15.5 \pm 1.4 \pm 3.0$	11

II: $H^{\pm} \rightarrow \tau_{e/\mu} \nu$ [Data]

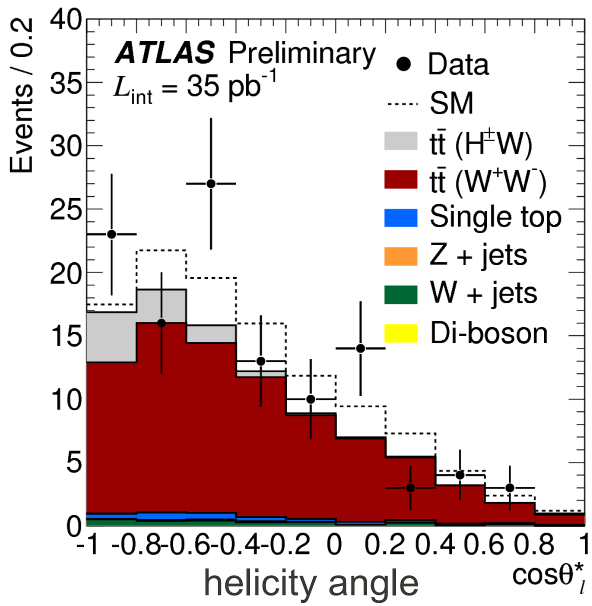
"Study of discriminating variables for charged Higgs boson searches with leptons"

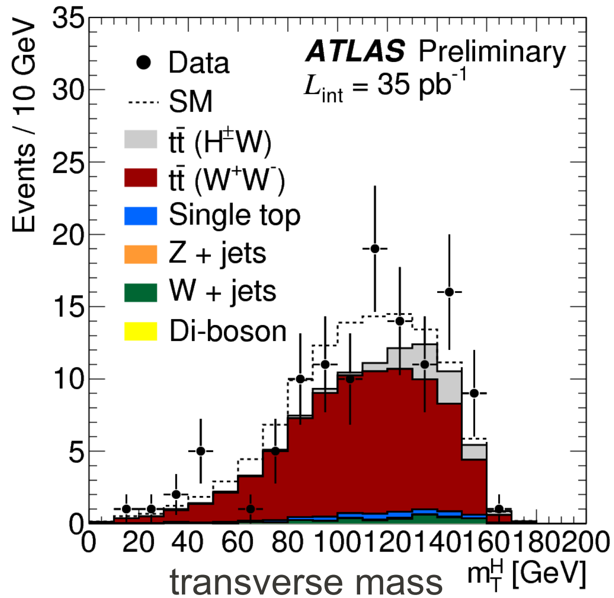
Leptonic tau, *hadronic* W

- $b\tau_{e/\mu}\nu\, bqq \leftrightarrow 1\ell$, 2b, 2q, 3ν
- SM estimates from MC only
- Distributions of discriminating variables
  - fair agreement with SM
  - signal alters the distributions
  - more luminosity needed to distinguish

Leptonic tau, *leptonic* W

- $b\tau_{e/\mu}\nu\, bl\nu \leftrightarrow 2\ell$, 2b, 4ν
- similar plots (not shown)
- exclusion plots for 1 fb^{-1} MC study





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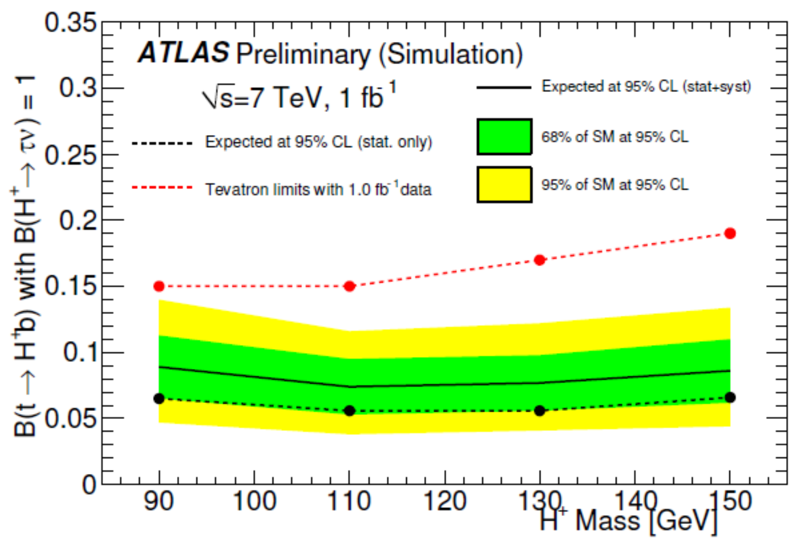
Exclusion limits in terms of BR(t→H±b) in di-leptonic channel [Simulation]

(assuming BR(H±→τν)=1)



II: $H^{\pm} \rightarrow cs$ [MC, $1fb^{-1}$]

ATLAS-PHYS-PUB-2010-009

No search results yet.
Look at MC prospects for $1fb^{-1}$.

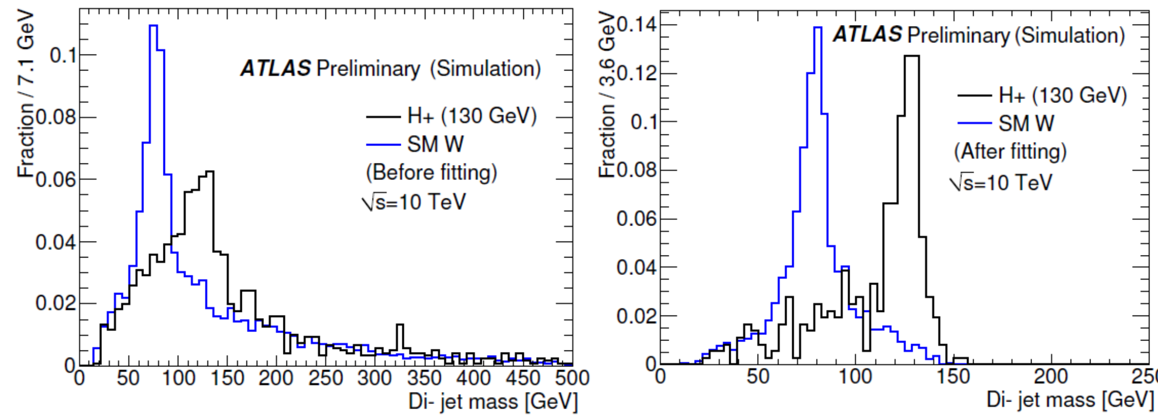
For $m(H^{\pm}) < m(top)$:

- $H^{\pm}$ produced in ttbar decays
- $H^{\pm} \rightarrow cs$ subdominant, relevant at low tanβ where it can reach a few percent
- $tt \rightarrow bH^{\pm}\, bW \rightarrow bcs\, bl\nu$

Event selection:

- 1 e/μ with pT > 20 GeV
- ≥4 jets with pT > 20 GeV, two **b**-tagged
- E_T^{miss} > 20 GeV

Improved cs mass resolution from full ttbar event reco, refitting (right)

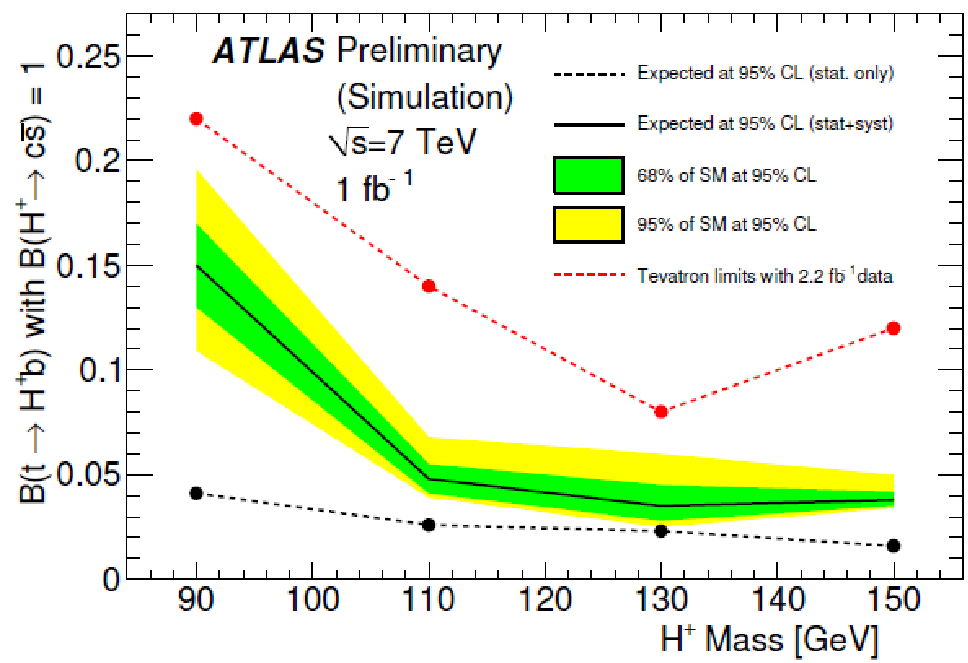


1 fb-1 estimates of SM bck and signals:

- BR(H± → cs) = 10% assumed
- SM fully dominated by ttbar

	no cut	all cuts
$H^+ \rightarrow c\bar{s}$, 90 GeV	9.5×10^3	148
$H^+ \rightarrow c\bar{s}$, 110 GeV	9.5×10^3	144
$H^+ \rightarrow c\bar{s}$, 130 GeV	9.5×10^3	98
$H^+ \rightarrow c\bar{s}$, 150 GeV	9.5×10^3	56
SM $t\bar{t}$, not all hadronic	87.4×10^3	1370

Exclusion limits in terms of $BR(t\rightarrow H^{\pm}b)$ [assuming $BR(H^{\pm}\rightarrow cs)=1$]



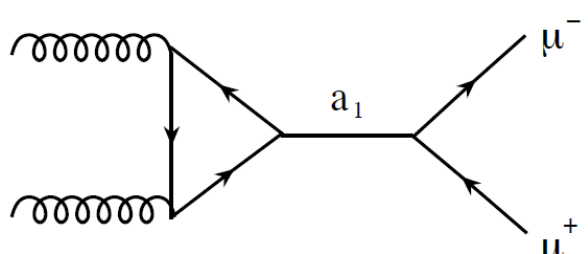
III: NMSSM: $a_1 \rightarrow \mu\mu$ (#1) [Data]

ATLAS-CONF-2011-020

NMSSM

(Next-to-Minimal Supersymmetric Standard Model)

- Add complex singlet scalar field S to the MSSM
  - generates μ-term as VEV of S
    [solving the μ-problem of the MSSM]
- Extended Higgs sector:
  - 3 CP-even higgses: h_1, h_2, h_3
  - 2 CP-odd higgses: $\mathbf{a_1}$, a_2
  - 2 charged higgses: h^+, h^-
- Phenomenology may be significantly altered:
  - a_1 can be very light, e.g. 10 GeV
  - $h \rightarrow a_1 a_1$ can be dominant
  - $H^\pm \rightarrow a_1 W^\pm$ can obscure standard channels
- *"Ideal Higgs scenario"* of the NMSSM
  - $m(a_1) < 2m_B$: b's absent from Higgs decays
  - ($a_1 \rightarrow \tau\tau$, cc, gg preferred)
  - $\mathbf{a_1 \rightarrow \mu\mu}$: clean channel (BR ~ 0.3%)



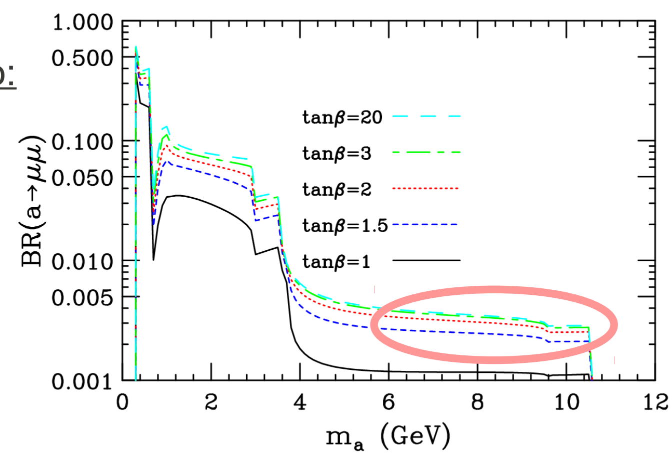
Two relevant parameters:

- **tanβ** and $\boldsymbol{\theta_A}$: CP-odd Higgs boson mixing angle

$$a_1 = \cos\theta_A a_{MSSM} + \sin\theta_A a_S$$

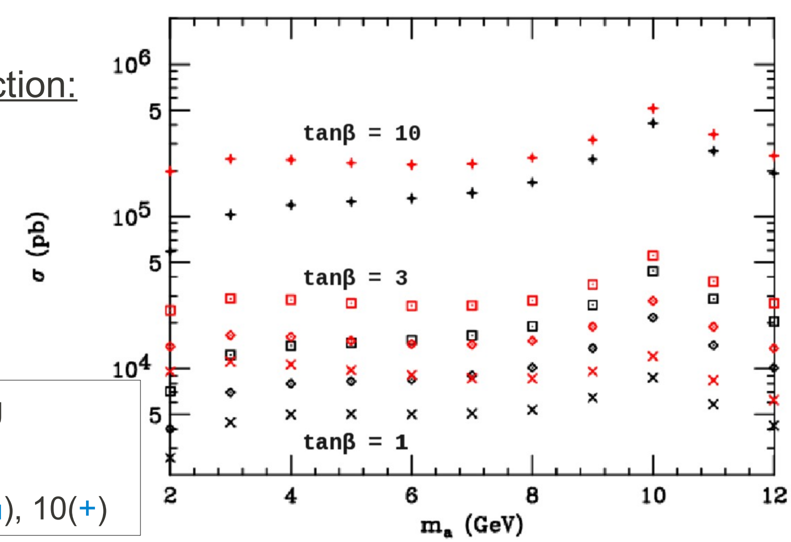
Ex.: **σ×BR ~ 3 pb** for $m(a_1)$=8 GeV, tanβ=10, $\cos\theta_A$=0.1

Branching ratio:



Phys. Rev. D 81 055001 (2010)

Cross-section:



red: includes $gg \rightarrow a_1 g$
$\cos\theta_A$ = 1
tanβ = 1(×), 2 (◊), 3(□), 10(+)

III: NMSSM: $a_1 \rightarrow \mu\mu$ (#2) [Data]

Event and Candidate selection :

- $\geq 2\mu$ with $p_T > 4$ GeV, $|\eta| < 2.5$
- all opposite-sign muon pairs with $4.5 < m_{\mu\mu}$/GeV < 14 subjected to likelihood-ratio selection

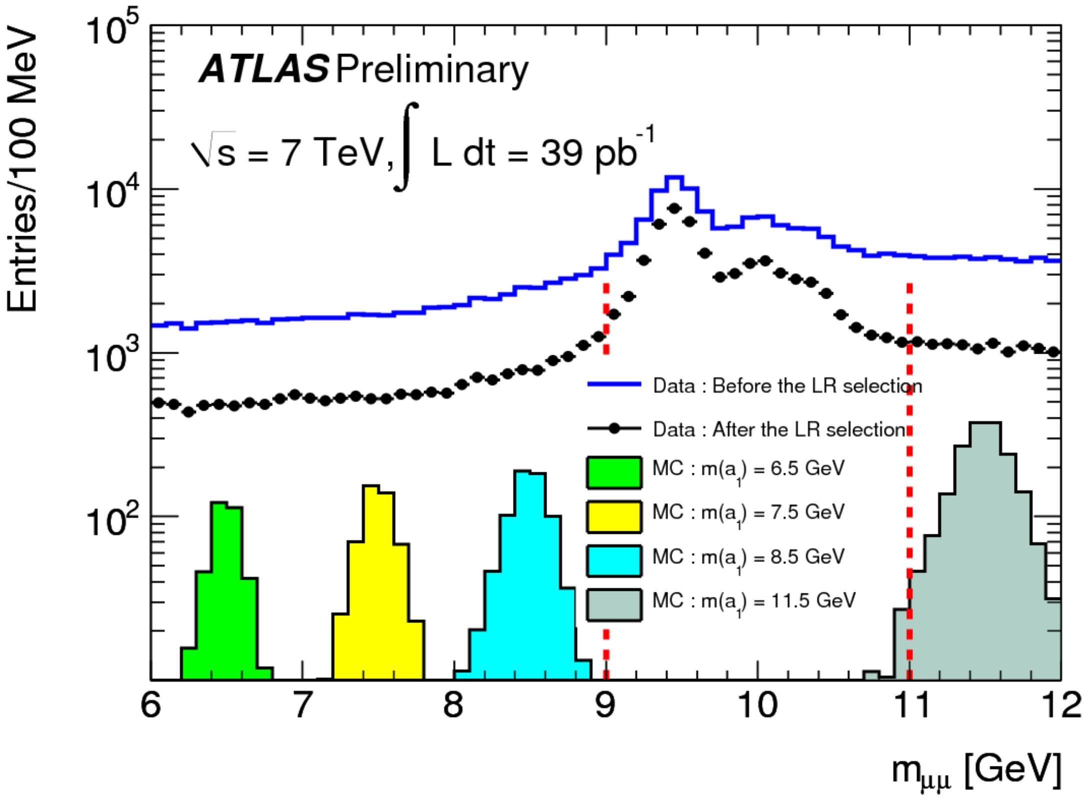
Likelihood-ratio selection :

[to enhance prob. that dimuons have same source]

- construct pdfs from
  - dimuon vertex fit quality (χ^2/dof)
  - E_T^{cone}/p_T for each muon
- Signal pdf from Υ(1S), 9-10 GeV
  [minus sideband (6, 7.5) and (11.5, 12) GeV]
- Bck/continuum pdf from "outer sideband", 4.5-5.5 and 12.5-14 GeV

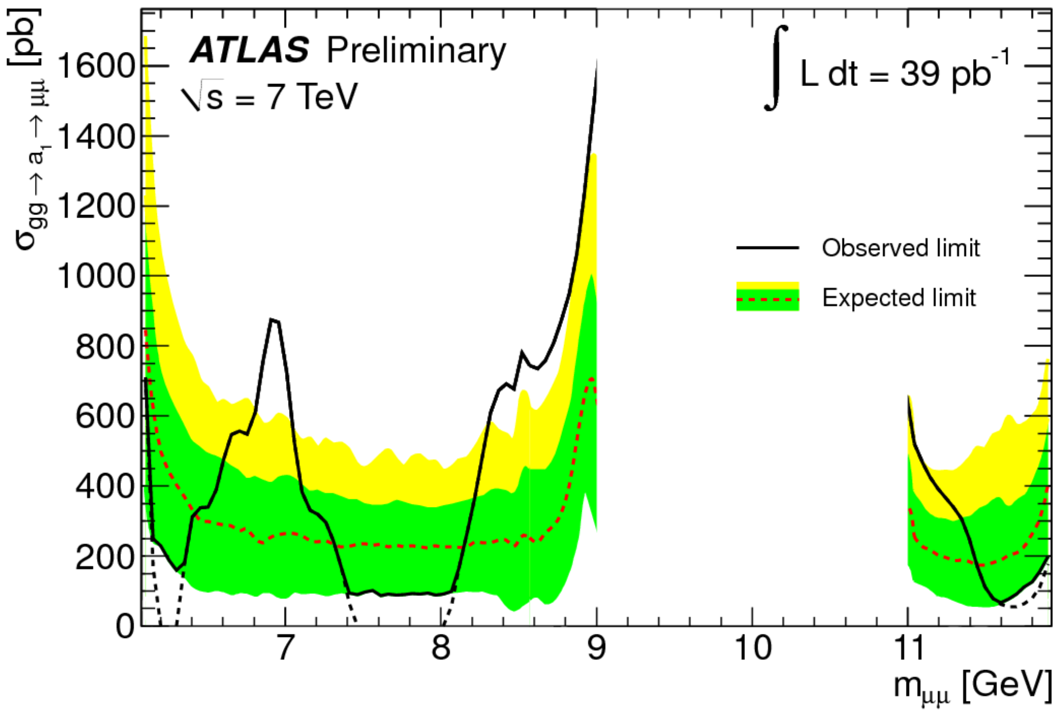
Blue: simple selection
Black: with Likelihood-Ratio selection

- Υ-resonances clearly visible in 9-11 GeV
- Only regions **6-9** and **11-12 GeV** used for $\mathbf{a_1}$ search
- MC-signals (arbitrary normalisation) shown
- No sign of any $\mathbf{a_1}$ resonance in data
- Can set limits



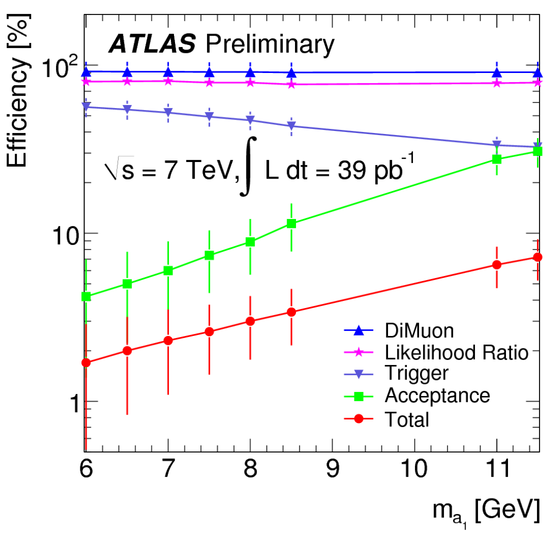
III: NMSSM: $a_1 \rightarrow \mu\mu$ (#3) [Data]

Exclusion limits:



To set cross-section limits, need to determine the selection efficiency

$$\varepsilon = \varepsilon_{\text{acc}} \cdot \varepsilon_{\mu\mu} \cdot \varepsilon_{\text{trig}} \cdot \varepsilon_{\text{LR}}$$



Limits extracted with Profile-Likelihood method :

- Likelihood function defined in 50 MeV-bins in $m_{\mu\mu}$
- Separate fits performed in two regions, 6-11, 9-12 GeV

- **Black:** observed limit shown as 16% PCL (Power Constrained Limits)
  - Observed limit goes up at edges due to potential signal-cutoff
  - Trial factor of the look-elsewhere-effect is 70-90 (the increase in the probability of observing a statistical fluctuation due to the scan over mass values)

- If interpreted in terms of NMSSM, values at **high tanβ** and **high $\cos\theta_A$** will be constrained

Summary

- 2010 has been a very good year for ATLAS
- Searches for SUSY Higgses are on track
- With 36-40 pb^{-1} of 2010 data ATLAS has extended previous limits in two channels
  - **A/H/h → $\tau_h\tau_{e/\mu}$** (MSSM)
  - **a_1 → μμ** (NMSSM)

  and started to estimate backgrounds and look at discriminating variables for
  - **Charged Higgs searches in the τν channels [for m($H^\pm$) < m(top)]**
- With O(1 fb^{-1}) of 2011(-12) data *[and longer term]* these and more searches will be continued:
  - A/H/h → μμ
  - $H^\pm$ → cs, *[tb]*
  - *[Higgses in SUSY cascades]*
  - *[Higgses decaying into SUSY particles (including "invisible" Higgs)]*
  - ...
- 2011 has already provided over 250 pb^{-1} of new data ...

BACKUP

BACKUP

BACKUP

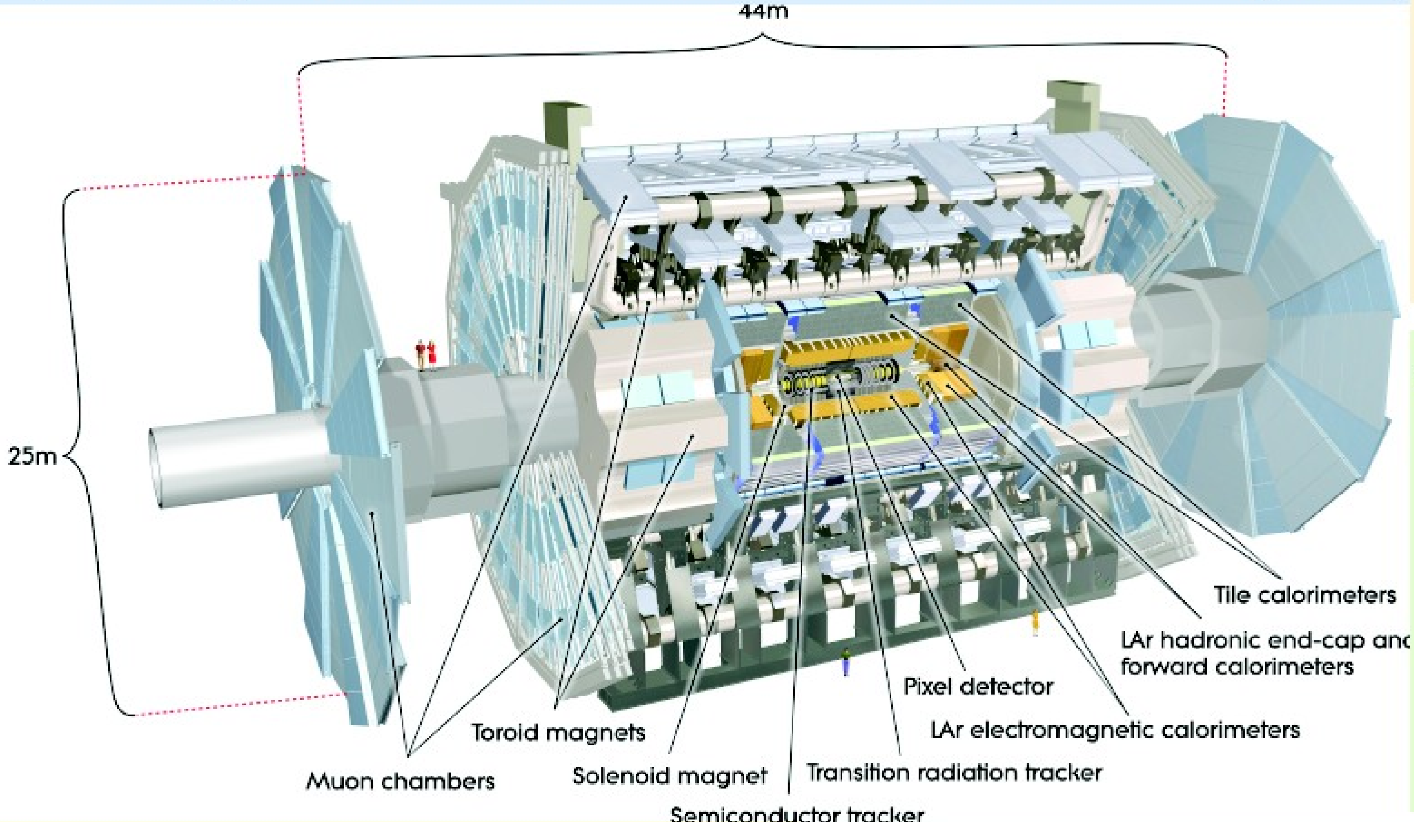
BACKUP

BACKUP

BACKUP

A Toroidal Lhc ApparatuS (ATLAS)

- Muon Spectrometer($|\eta|<2.47$):
  - air-core toroids with gas-based muon chambers
  - Muon trigger and measurement with momentum resolution < 10% up to PT(mu) ~ 1 TeV



- General :
  - ~10^8 electronic channels
  - ~3×10^3 km of cables
  - weighs 7000 tons (metal structure of Eiffel Tower)
  - ~3200 authors, 174 institutions from 38 coutries

Inner Detector ($|\eta|$ < 2.5, B=2T):
- (Si Pixel layers(Pix), Stereo pairs of Si microstrips (SCT), transition radiation tracker (TRT)
- precise tracking and vertexing
- Nice e and Pi separation
- Momentum resolution : sigma/pT < 4% for pT up to 100 GeV

EM calorimeter ($|\eta|<3.2$):
- LAr calorimeter with accordion geometry for phi symmetry and faster signal readout
- electron, photon identification and measurement
- energy resolution : sigma/E ~ 10%/sqrt(E)

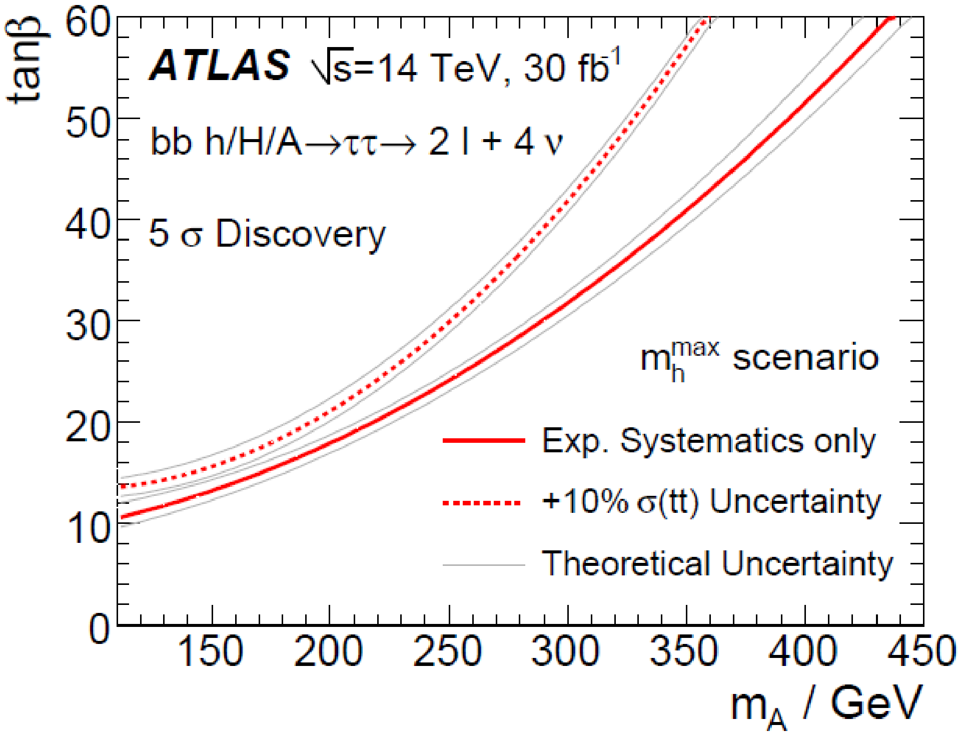
Hadronic Calorimeter ($|\eta|<5$):
- Tile (steel and scintillators) calorimeter ($|\eta|<1.7$)
- Cu/LAr sampling calorimeter ($1.5<|\eta|<3.2$)
- Forward calorimeter ($3.1<|\eta|<5$)
- Jets and Missing energy measurement
- energy resolution : sigma/E ~ 50%/sqrt(E)+0.03

IV: A/H/h → ττ→ 2l 4ν [MC, 14 TeV]

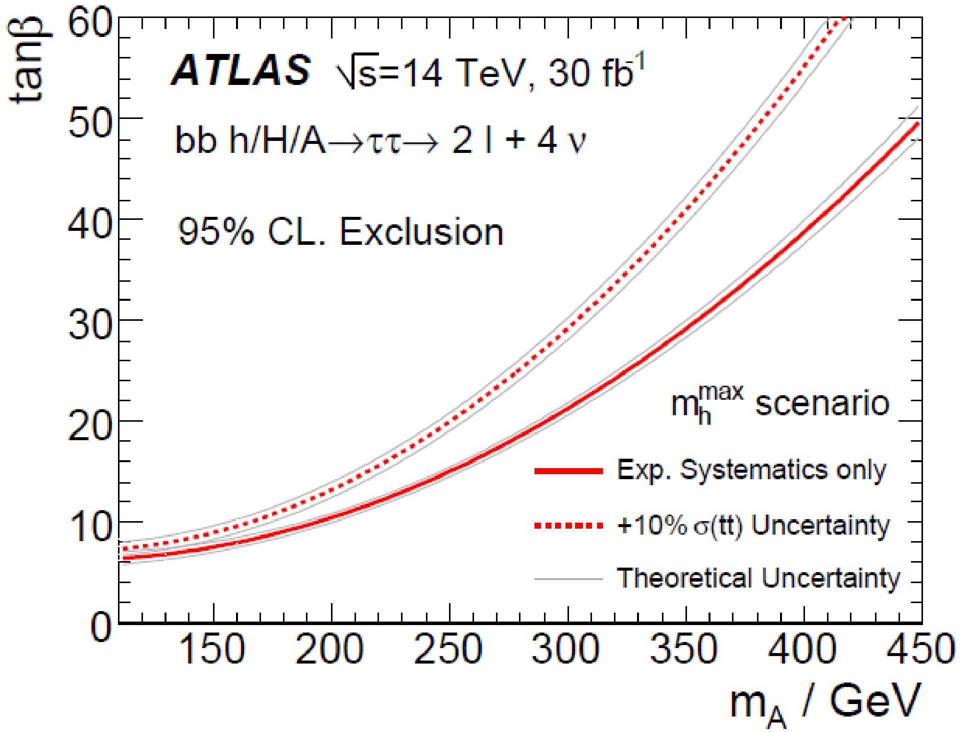
CERN-OPEN-2008-020
(ATLAS BOOK)

14 TeV, 30 fb^{-1}

Discovery



Exclusion

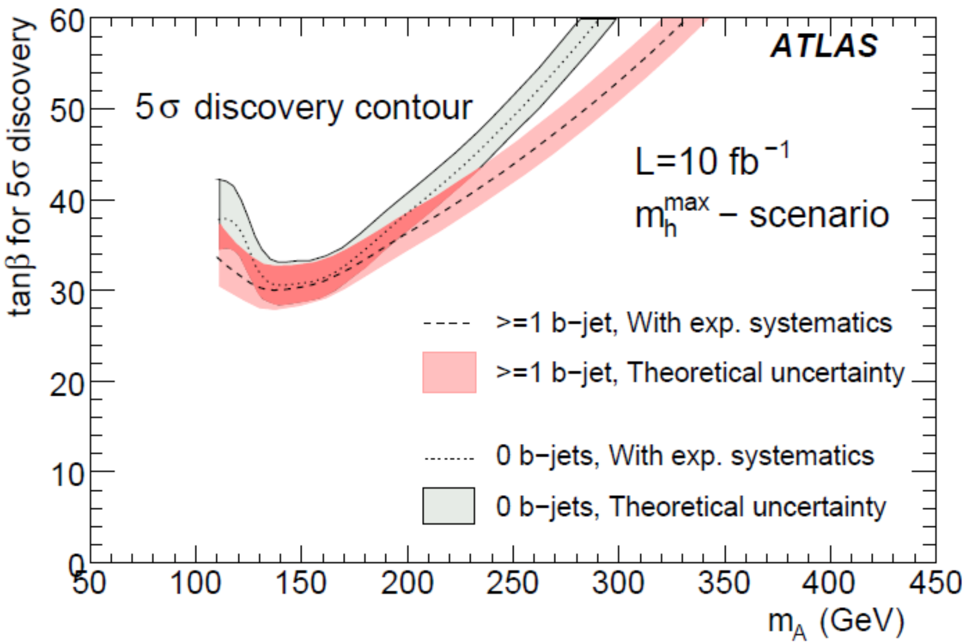


IV: A/H/h → μμ [MC, 14 TeV]

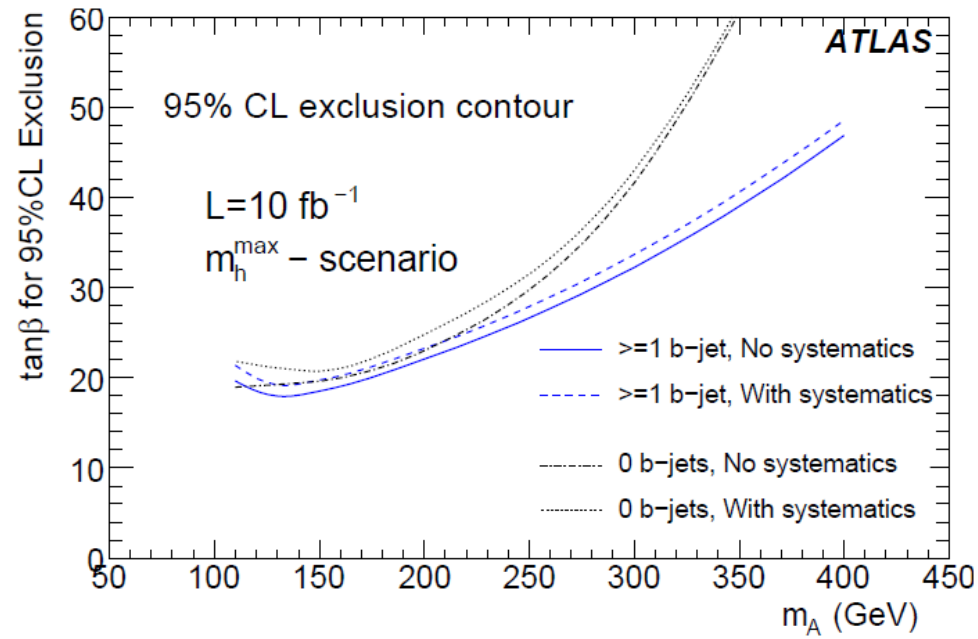
CERN-OPEN-2008-020
(ATLAS BOOK)

14 TeV, 10 fb^{-1}

Discovery



Exclusion



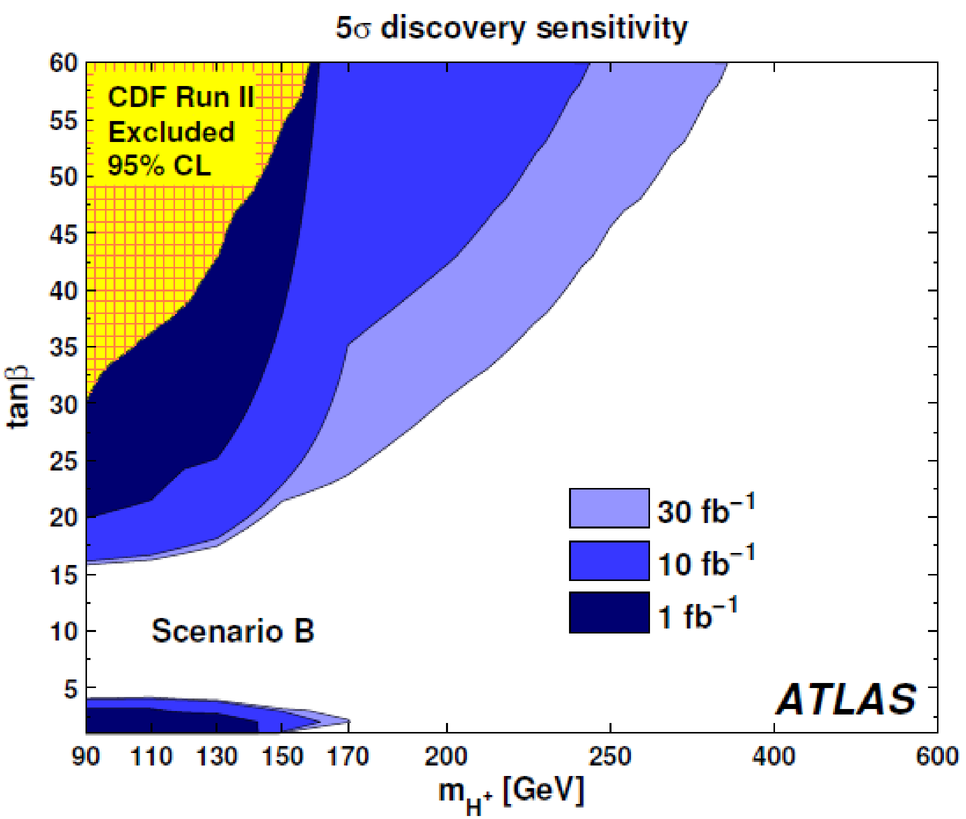
IV: Charged Higgs [MC, 14 TeV]

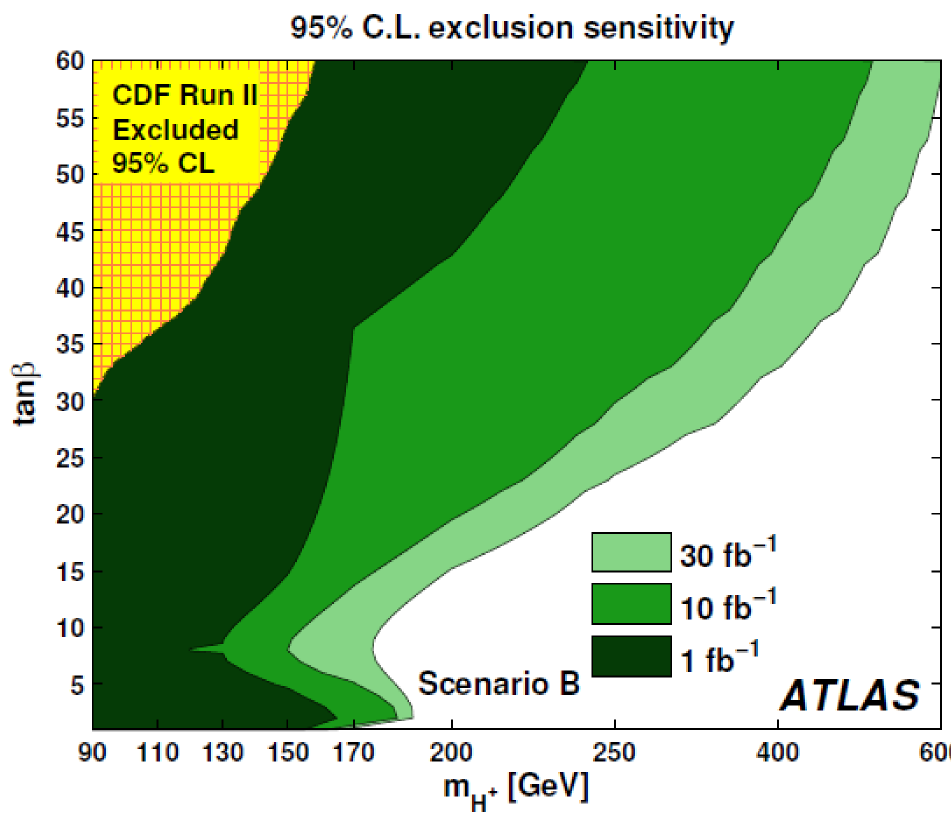
Combined results for

- **[m(H$^\pm$) < m(t)]:** $tt \to bH^\pm + bW \to b\tau_h\nu + bqq$
- **[m(H$^\pm$) < m(t)]:** $tt \to bH^\pm + bW \to b\tau_l\nu + bqq$
- **[m(H$^\pm$) < m(t)]:** $tt \to bH^\pm + bW \to b\tau_h\nu + bl\nu$
- **[m(H$^\pm$) ≥ m(t)]:** $gg/gb \to t[b] + H^\pm \to bqq[b] + \tau_h\nu$
- **[m(H$^\pm$) > m(t)]:** $gg/gb \to t[b] + H^\pm \to bW[b] + tb \to bl\nu[b] + bbqq$

CERN-OPEN-2008-020
(ATLAS BOOK)

14 TeV, 1/10/30 fb^{-1}

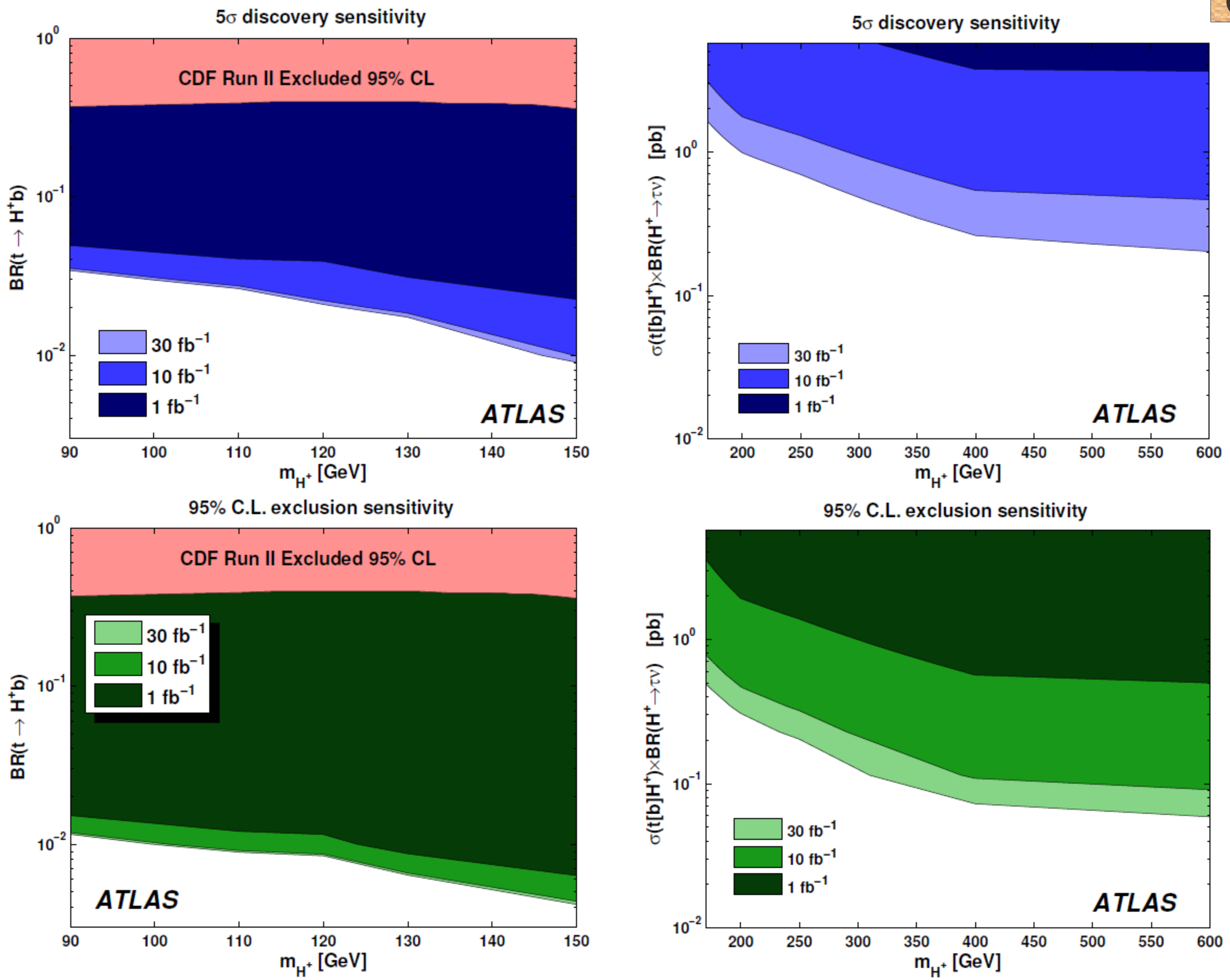




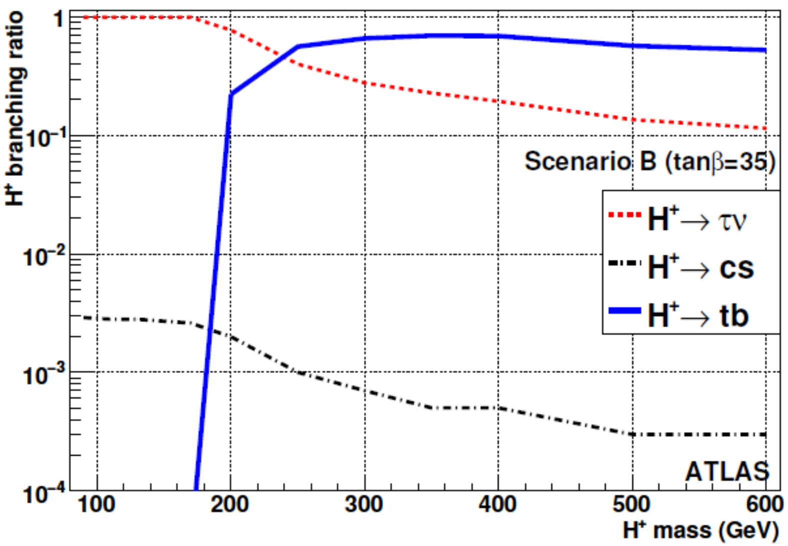
IV: Charged Higgs [MC, 14 TeV]

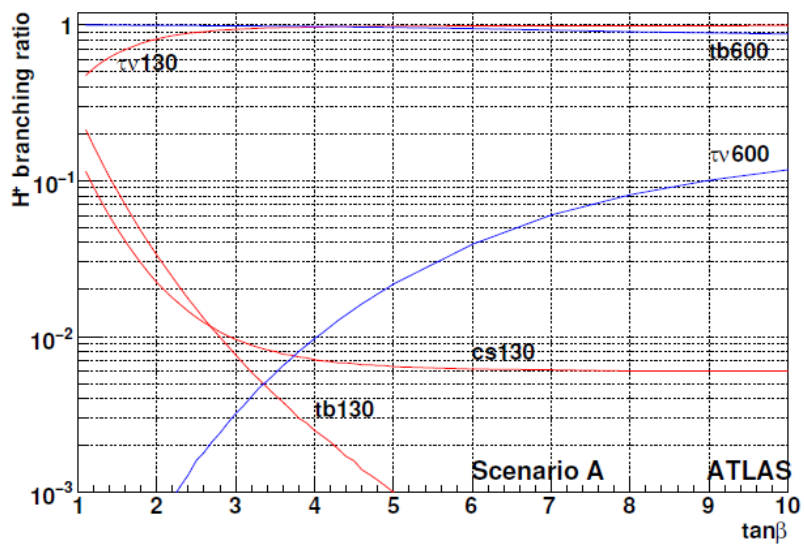
CERN-OPEN-2008-020 (ATLAS BOOK)

Model-independent limits



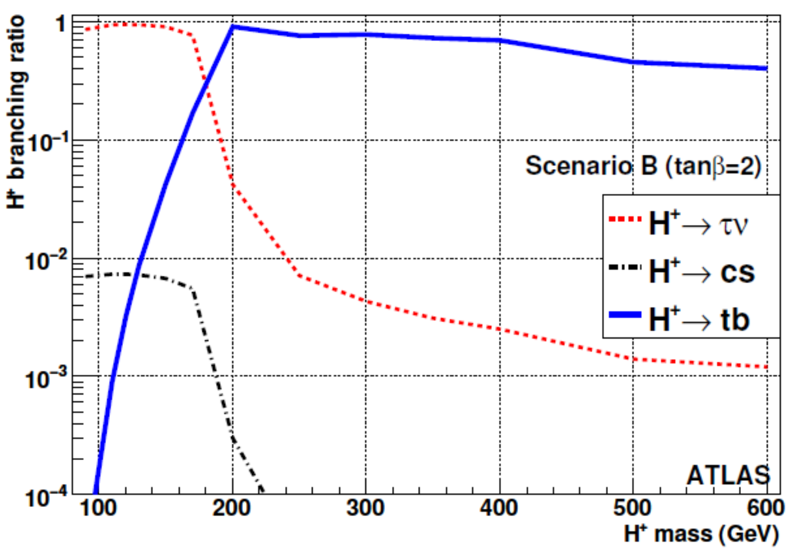
Charged Higgs: Decays

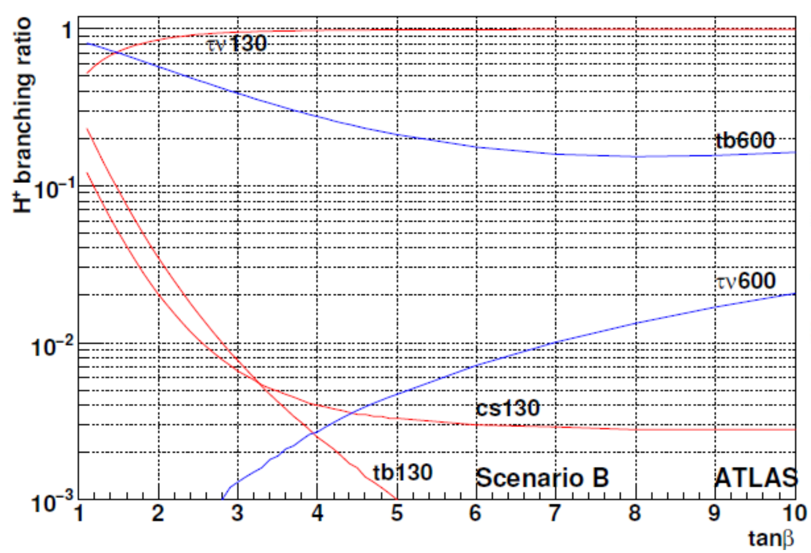




Scenario A:

- $m_t = 175$ GeV
- $M_{\mathrm{SUSY}} = 500$ GeV
- $A_t = 1000$ GeV
- $\mu = 200$ GeV
- $M_2 = 1000$ GeV
- $M_3 = 1000$ GeV



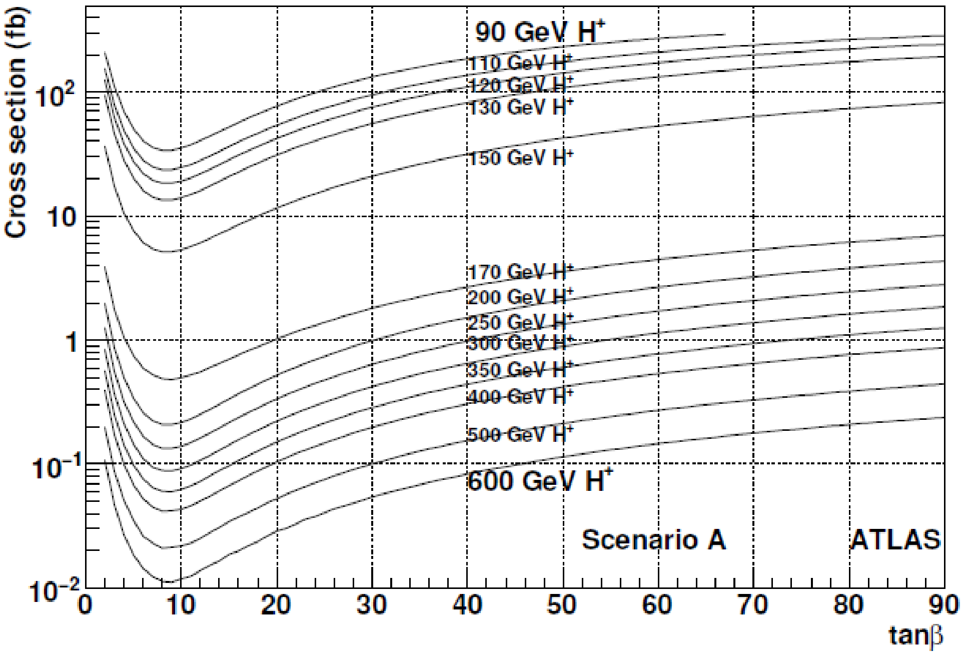


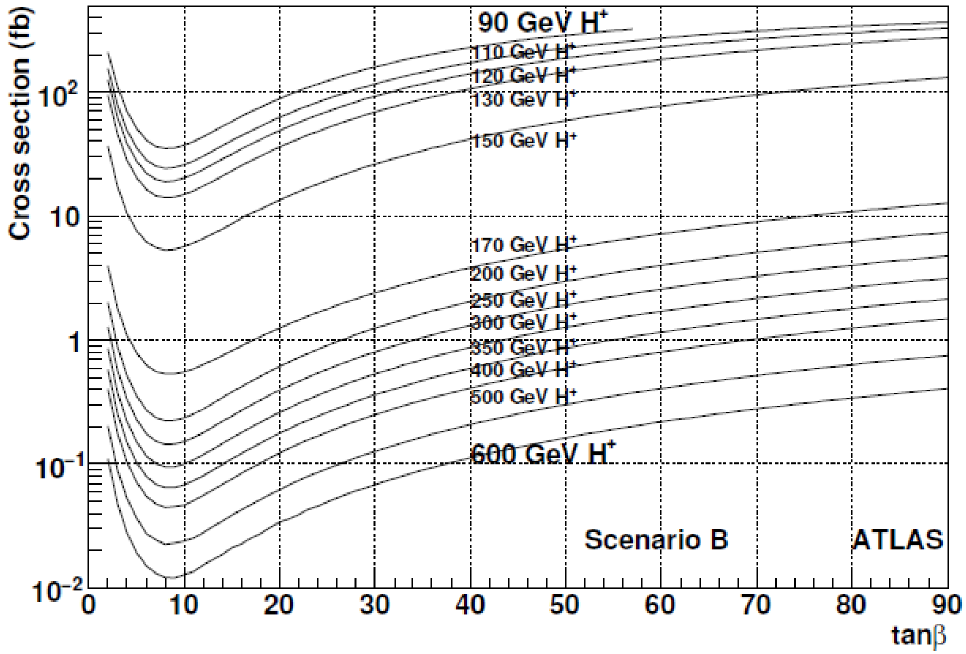
Scenario B ("m_h-max"):

- $m_t = 170$ GeV
- $M_{\mathrm{SUSY}} = 1000$ GeV
- $X_t = 2000$ GeV, where $A_t = X_t + \mu / \tan\beta$
- $\mu = 200$ GeV
- $M_2 = 200$ GeV
- $M_3 = 800$ GeV

H±: Intermediate tanβ region

Figure 4 shows the results for the tbH^+ final state as a function of $\tan\beta$ for the MSSM scenarios A and B. The production cross-section has a minimum at $\tan\beta \approx 7$. This is caused by a mimimum in the H^+tb Yukawa coupling and renders the so-called intermediate $\tan\beta$ region $(4 < \tan\beta < 10)$ which is experimentally hard to reach.





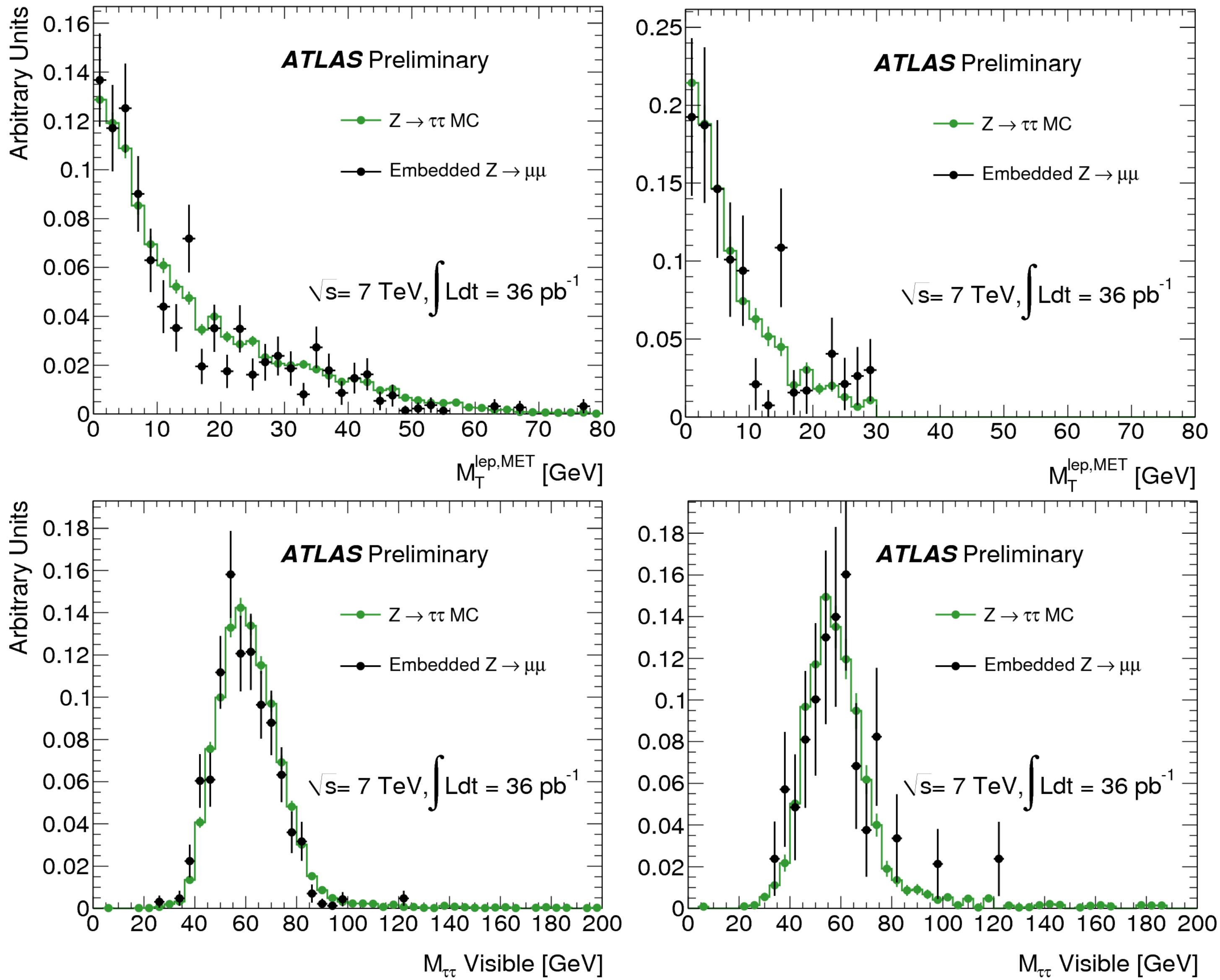
A/H/h → ττ : datadriven bck est. #1

$Z \to \tau_h \tau_{e/\mu}$ mass shape from embedding taus in real $Z \to \mu\mu$ events

- Select pure $Z \to \mu\mu$ from data
- Remove muon tracks and associated calo cells
- Insert two taus in place of the muons
- Decay with TAUOLA
- pass through ATLAS sim.
- Combine original μμ-subtracted event with ττ-addition
- Reconstruct

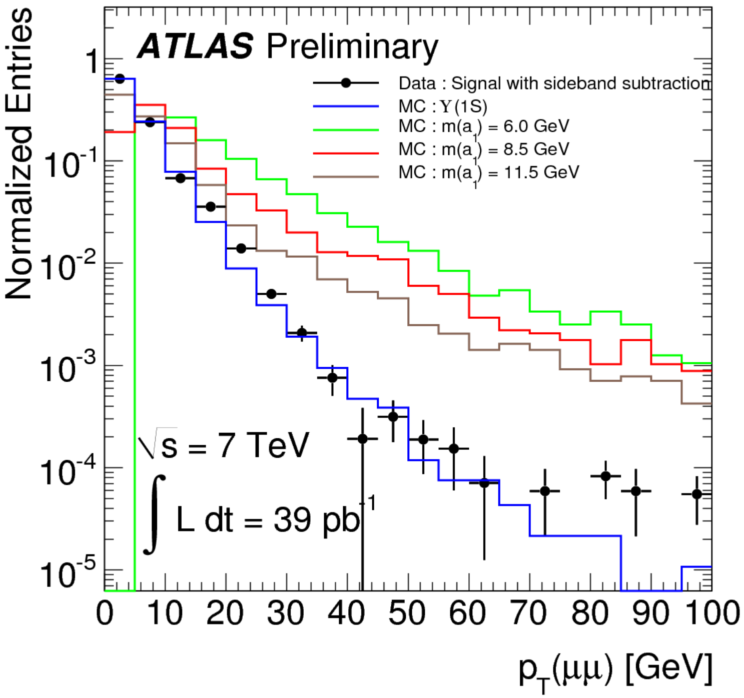
Resulting shapes agrees well with MC

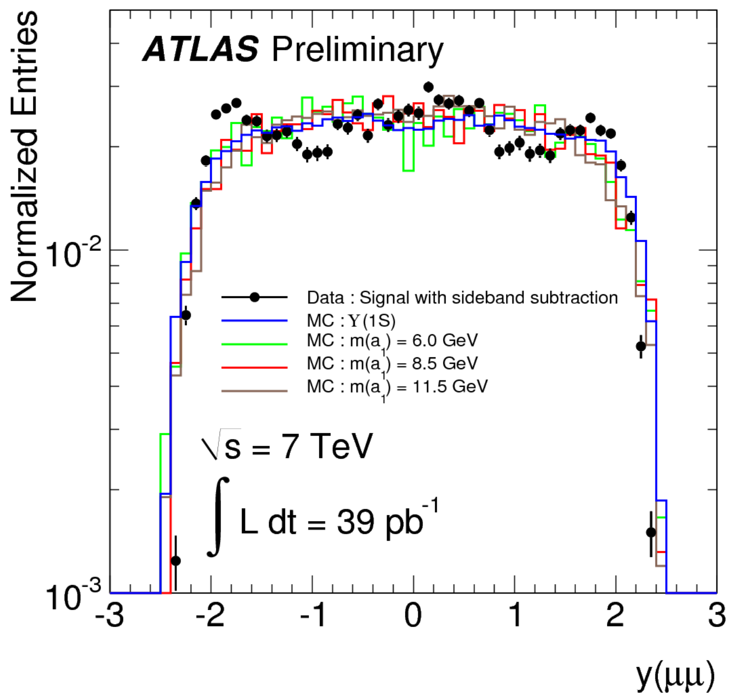
- use MC (since checked)
- normalise to theoretical cross-section



Left: prior to E_T^{miss} and M_T cut
Right: full selection

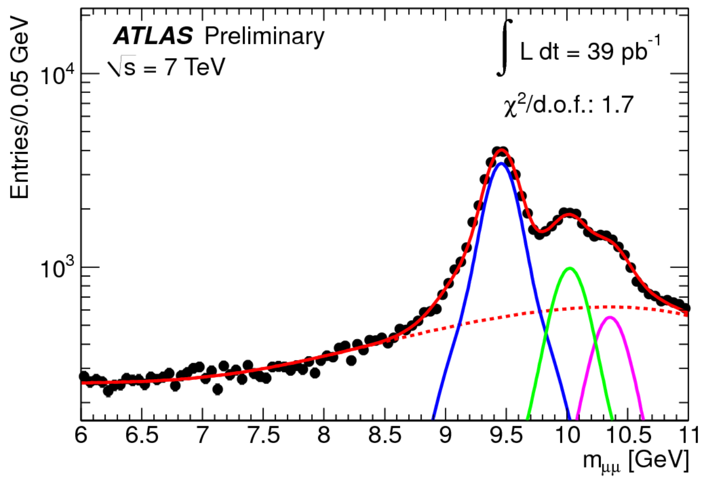
NMSSM: $a_1 \rightarrow \mu\mu$ (#4)

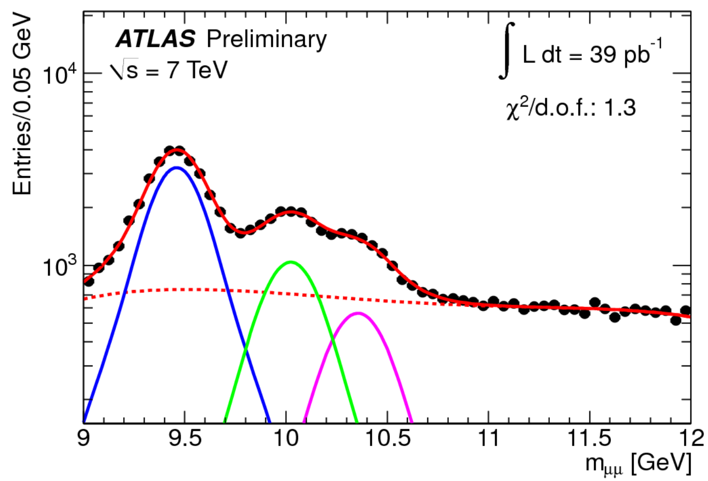




Kin.vars pT and η of Y(1S)

- Black: from data (sideband subtracted)
- Blue: MC
- Fine agreement
- expected distributions for various signals also shown





Fits to LR-selected distributions

- Two regions (due to complication in bck modelling)
- Resulting fit parameters for Y-resonances consistent

MSSM Higgs

Some tree-level relations:

Higgs masses (tree-level):

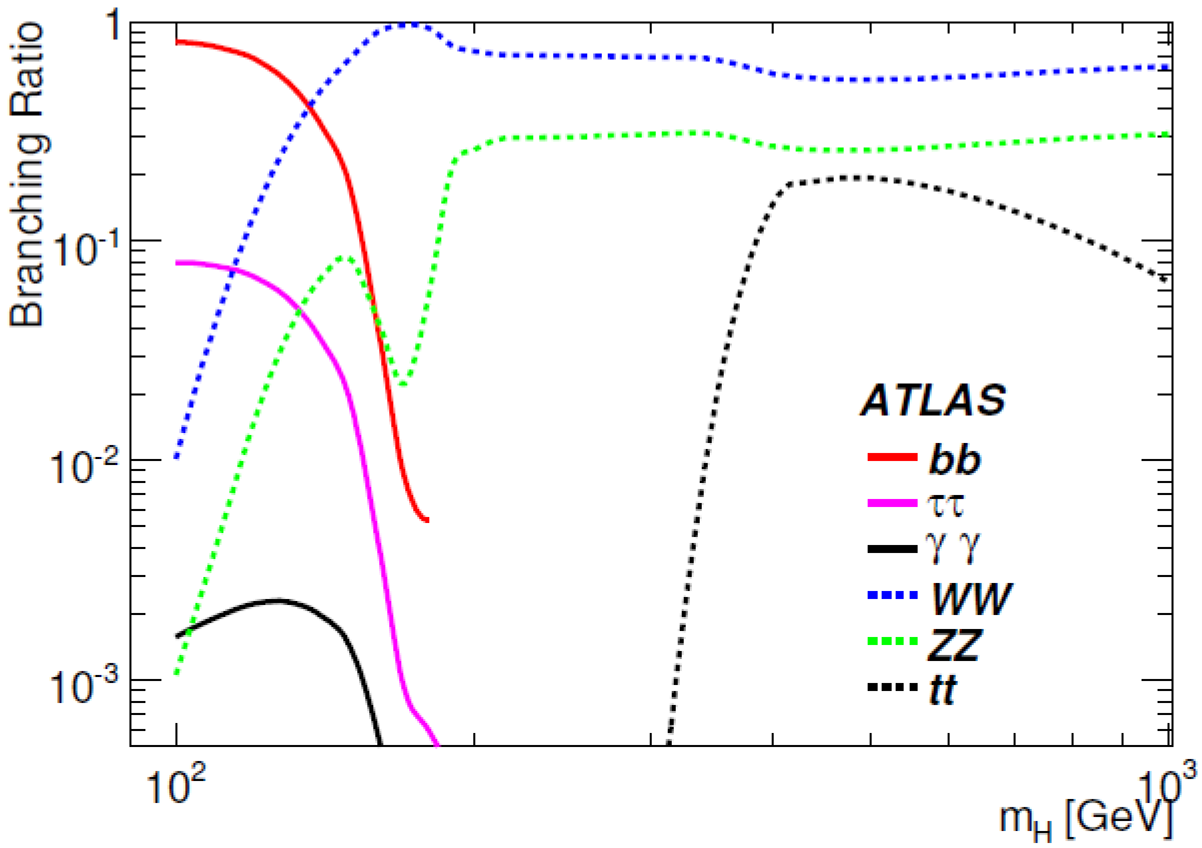
$$m^2_{h^0,H^0} = \frac{1}{2}\Big(m^2_{A^0} + m^2_Z \mp \sqrt{(m^2_{A^0} - m^2_Z)^2 + 4m^2_Z m^2_{A^0}\sin^2(2\beta)}\Big)$$

$$m^2_{H^\pm} = m^2_{A^0} + m^2_W$$

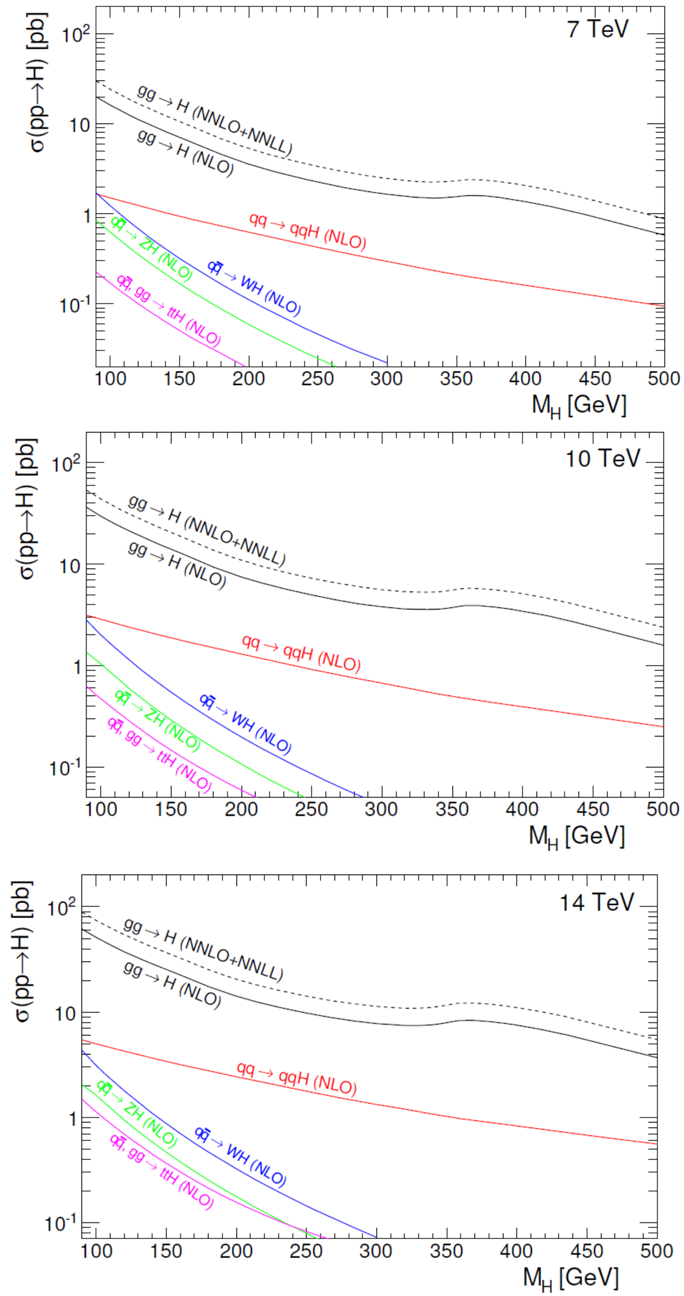
Higgs mixing angle (tree-level):

$$\frac{\sin 2\alpha}{\sin 2\beta} = -\left(\frac{m^2_{H^0} + m^2_{h^0}}{m^2_{H^0} - m^2_{h^0}}\right), \qquad \frac{\tan 2\alpha}{\tan 2\beta} = \left(\frac{m^2_{A^0} + m^2_Z}{m^2_{A^0} - m^2_Z}\right)$$

SM Higgs



Branching Ratio
1
10^{-1}
10^{-2}
10^{-3}
ATLAS
bb
ττ
γ γ
WW
ZZ
tt
10^2
10^3
m_H [GeV]



7 TeV
10 TeV
14 TeV
σ(pp→H) [pb]
gg → H (NNLO+NNLL)
gg → H (NLO)
qq → qqH (NLO)
$q\bar{q}$ → WH (NLO)
$q\bar{q}$ → ZH (NLO)
$q\bar{q}$, gg → ttH (NLO)
M_H [GeV]