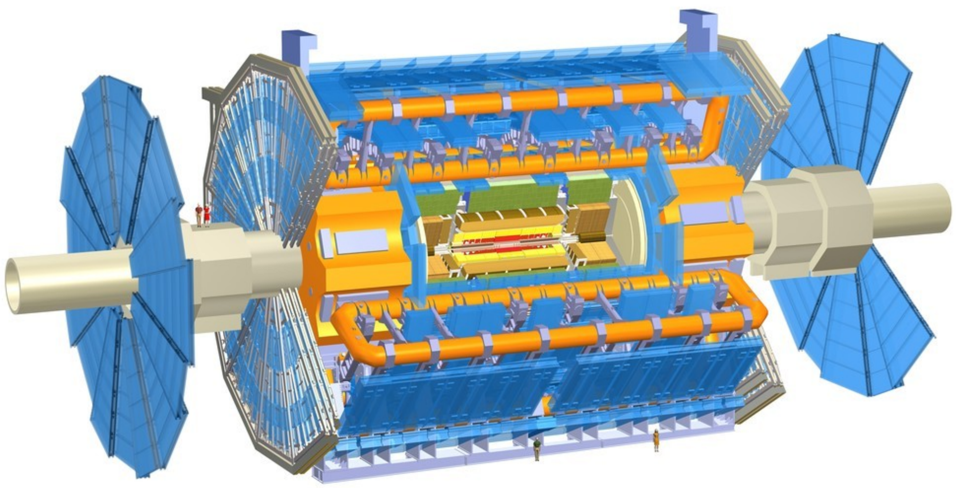
Beyond-SM Higgs Searches: An ATLAS perspective

Nikolaos Rompotis
University of Washington

Overview

Higgs boson: "Standard" is not enough



MSSM-ispired Higgs searches
- ◇ Neutral Higgs
- ◇ Charged Higgs

Other Searches
- ◇ $h \rightarrow a_1 a_1 \rightarrow \gamma\gamma\gamma\gamma$
- ◇ Higgs to long-lived particles
- ◇ Heavy Higgs

Discussion

Disclaimer: my target is not just to give an ATLAS overview, but to discuss the experimental searches in order to initiate discussions about the future prospects/plans and get feedback

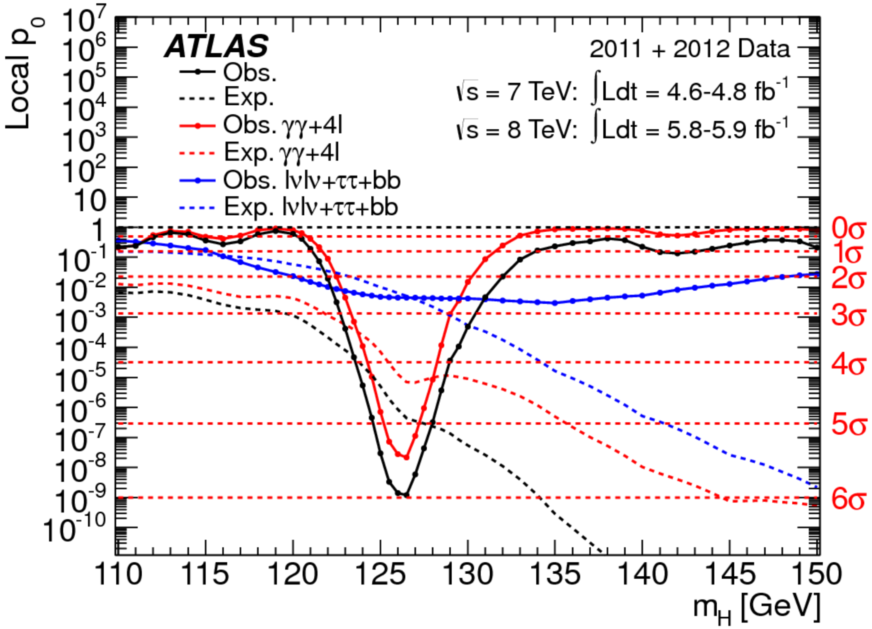
The highlight of 2012

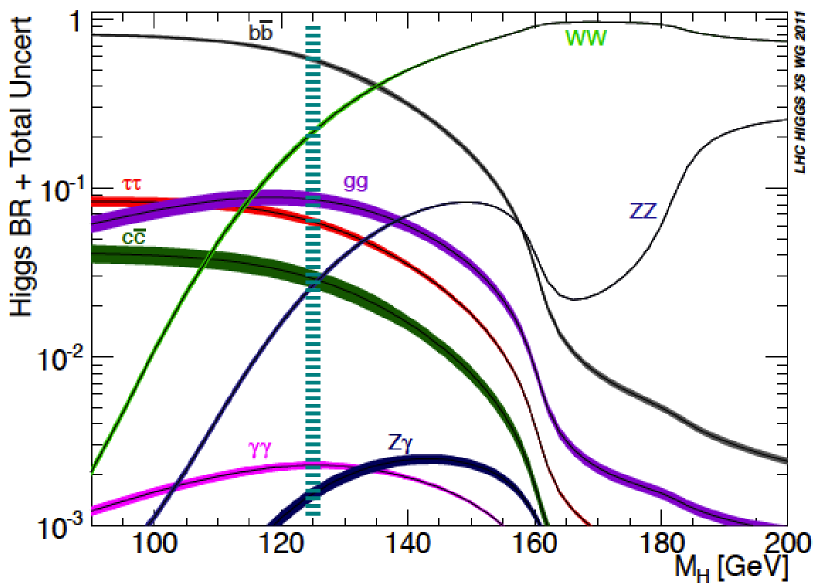
- The discovery of a particle compatible with the SM Higgs boson has been the most important highlight in the field for 2012

Phys. Lett. B 716 (2012) 1-29

◇ Its low mass (~125 GeV) allows its study in many different channels

◇ A large "industry" has been initiated to measure couplings and other properties





The community that once was interested on "SM Higgs" searches is now shifting focus on "how SM-Higgs-like" the new particle is

A SM Higgs boson?

- Reminder: the majority of experts in this field agree that:

The existence of the SM Higgs boson, i.e. an $SU(2)_L x U(1)_Y$ (**2**,**1**), is a rather exotic option, which is **most probably not realized in nature**

Fundamental scalars are unstable when considering radiative corrections (naturalness):
Possible answers:

◇ There are no fundamental scalars (Technicolor, composite Higgs, ...)

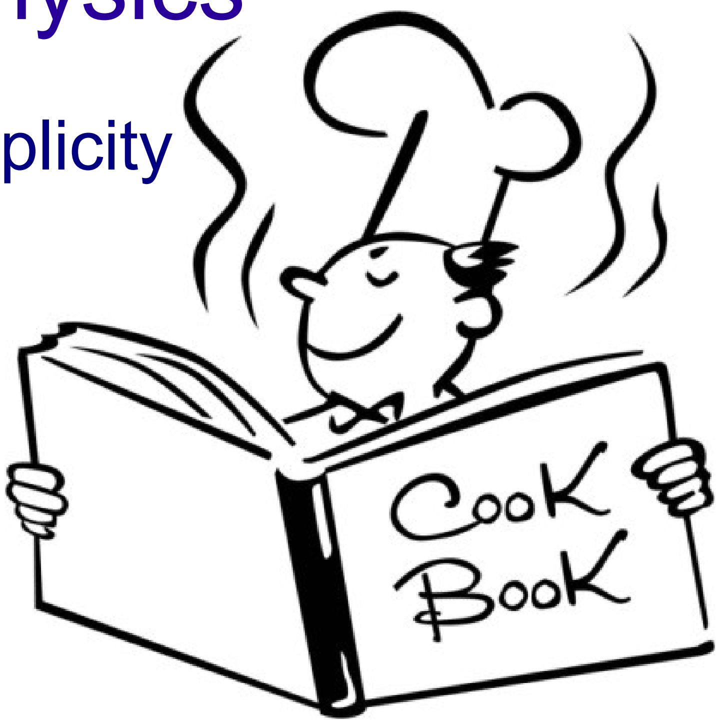
◇ Mass is somehow protected, e.g. by some symmetry (SUSY, Little Higgs)

But even if you don't care about naturalness, there is no reason to stick to the simplest one-SU(2)-doublet model

In all these cases the SM scalar sector is extended and new particles appear at the TeV scale; some of these theories include a SM-like Higgs boson.

--> The direct search for Beyond SM Higgs bosons is critical for understanding the SM scalar sector and complementary to the Higgs properties measurements

Searching for BSM Physics



- A successful search recipe combines simplicity & physics motivation

→ Choose a theory which is highly motivated from a physics point of view

e.g. SUSY, ED, TC, ...

→ Try to find a simple extension to a successful theory: if you have many parameters it is difficult to interpret your data; c.f. SM Higgs search: only one parameter

Experimentally accessible "**Benchmark scenarios**" are very important
◇ help to organize the searches
◇ large phycological effect on the experimenters
Reminder: a benchmark scenario doesn't necessarily mean that we have paramount reasons to believe that this is what nature does; this is mostly to help us explore regions of the parameter space, which otherwise would have been uncovered

ATLAS BSM Higgs searches

A quick overview of the latest public ATLAS results in BSM Higgs searches

Channel	Lumi (7 TeV)	Reference
$H \rightarrow \tau\tau$ / $\mu\mu$ (MSSM)	4.7–4.8 fb^{-1}	arXiv:1211.6956
$H^{\pm} \rightarrow \tau^{\pm}\nu$	4.6 fb^{-1}	JHEP 1206 (2012) 039
$H^{\pm} \rightarrow \tau^{\pm}\nu$ (LF Universality violation)	4.6 fb^{-1}	arXiv:1212.3572
$H^{+} \rightarrow c\bar{s}$	4.7 fb^{-1}	HIGG-2012-10
SM with a 4^{th} fermion generation	1.0-2.3 fb^{-1}	ATLAS-CONF-2011-135
Fermiophobic Higgs search	4.9 fb^{-1}	arXiv:1205.0701
Light scalar Higgs ($a \rightarrow \mu\mu$)	0.039 fb^{-1}	ATLAS-CONF-2011-020
Higgs to light scalar particles (4γ)	4.9 fb^{-1}	ATLAS-CONF-2012-079
Doubly Charged Higgs	1.6 / 4.7 fb^{-1}	PRD85,032004(2012); ATLAS-CONF-2012-069
Higgs to long-lived particles	1.9 fb^{-1}	PRL 108 (2012) 251801
Higgs to displaced muon jets	1.9 fb^{-1}	arXiv:1210.0435

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/WebHome

MSSM-inspired Higgs searches

The MSSM Higgs Sector

- The Minimally Supersymmetric SM incorporates all the "good-search-recipe" properties
  - Highly motivated: a world with SUSY is more natural ♥
  - Higgs sector is extended in a minimal way: a 2 Higgs doublet model (2HDM) is a simple way to preserve ρ=1
    - 5 Higgs bosons: 2 CP-even (h, H); 1 CP-odd (A); 2 charged $H^{\pm}$
    - Simple to interpret: only 2 parameters at tree level (m_{H+}, tanβ) or (m_A, tanβ), where tanβ = v.e.v ratio of the 2 Higgs doublets
  - MSSM can decouple from SM: every observable can be as SM-like as you like as soon as you increase the mass scale of the extra degrees of freedom

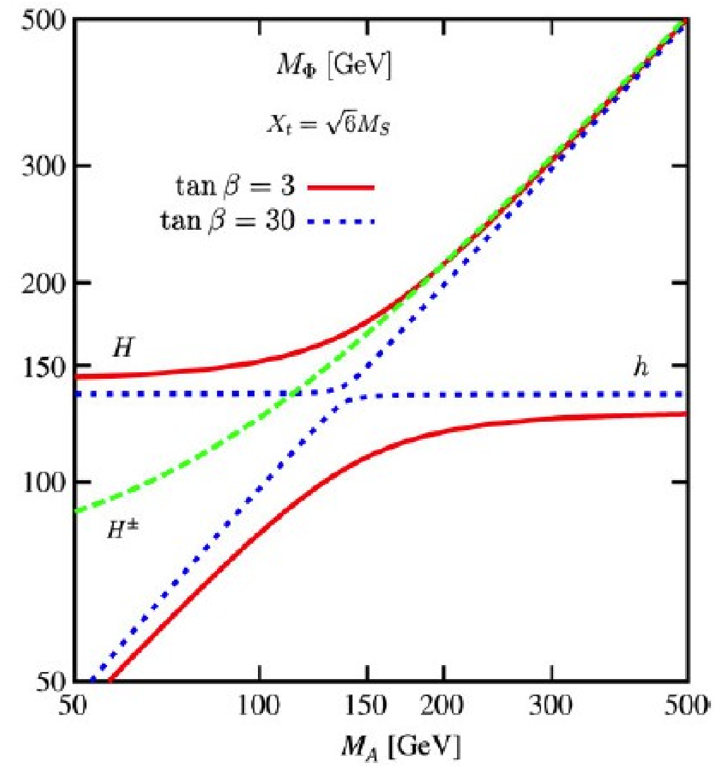
The MSSM Higgs sector is perfectly compatible with the existence of a 125 GeV SM-like Higgs boson

The MSSM Higgs Sector

- MSSM restricts & interrelates the mass of the Higgs bosons wrt e.g. a more general 2HDM

$M_h = M_Z \cos 2\beta \leq M_Z \; (tree \;\; level) \longrightarrow M_h < 135\, GeV \; (radiative \;\; corrections)$

$$M_{H\pm}^2 = M_A^2 + M_W^2$$



Large tanβ (>10) and large M_A (>130 GeV) *

$M_A \simeq M_H \simeq M_{H^+}$ and $M_h \simeq 130\, GeV$

Large tanβ (>10) and small M_A (<130 GeV) *

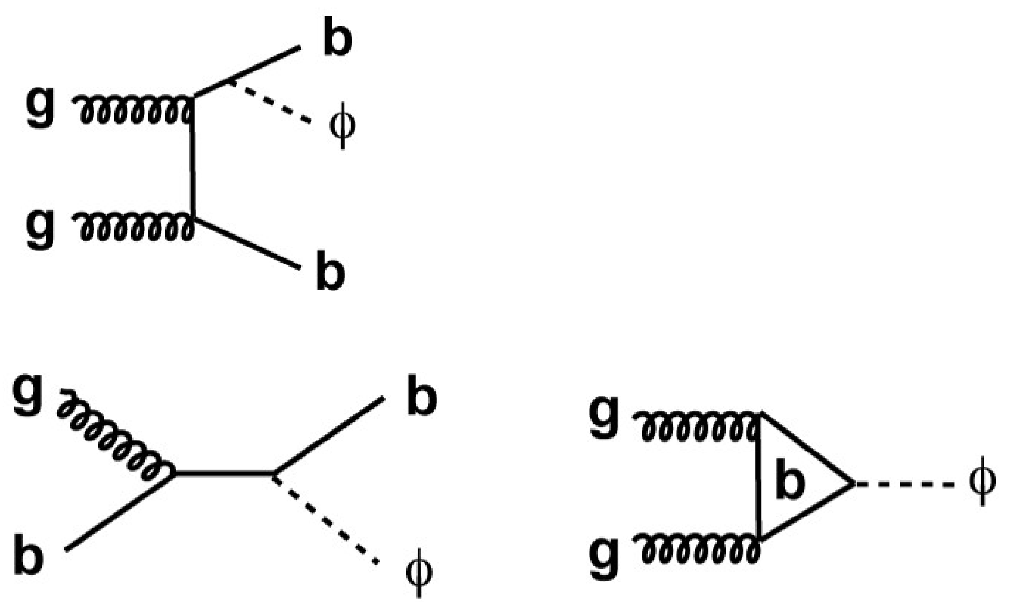
$M_A \simeq M_h$ and $M_H \simeq 130\, GeV$

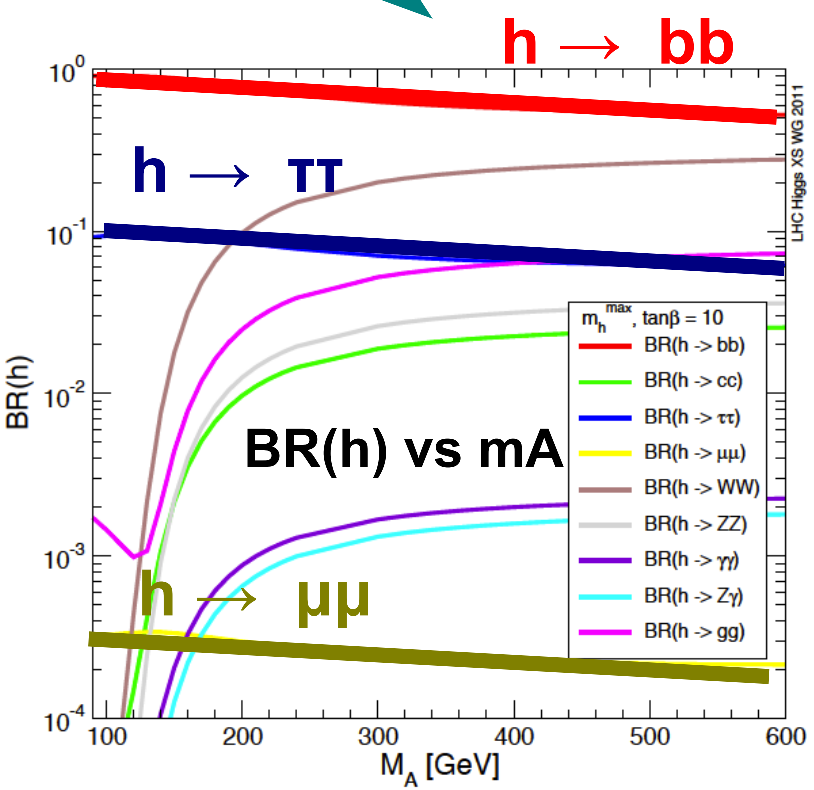
* these values may depend on scenario; values shown here are valid at least for “”mh-max” and “maximal mixing”

MSSM: Neutral Higgs

Neutral MSSM Higgs Production & Decay

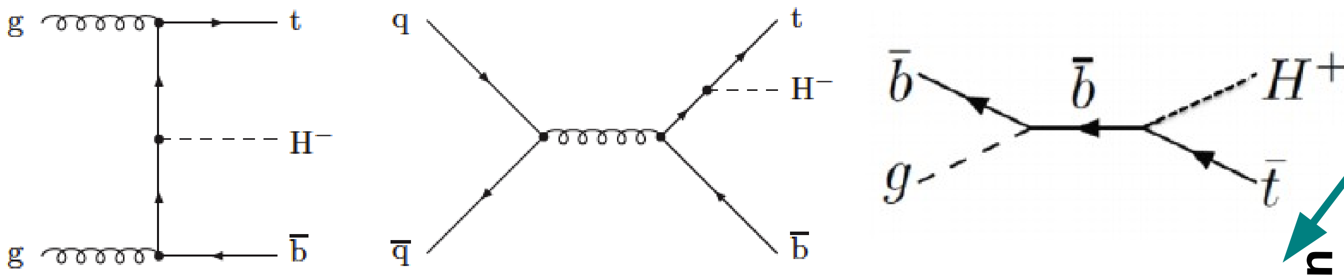
Production through gluon-gluon fusion or in association with b quarks, with the latter being more and more important at high tanβ



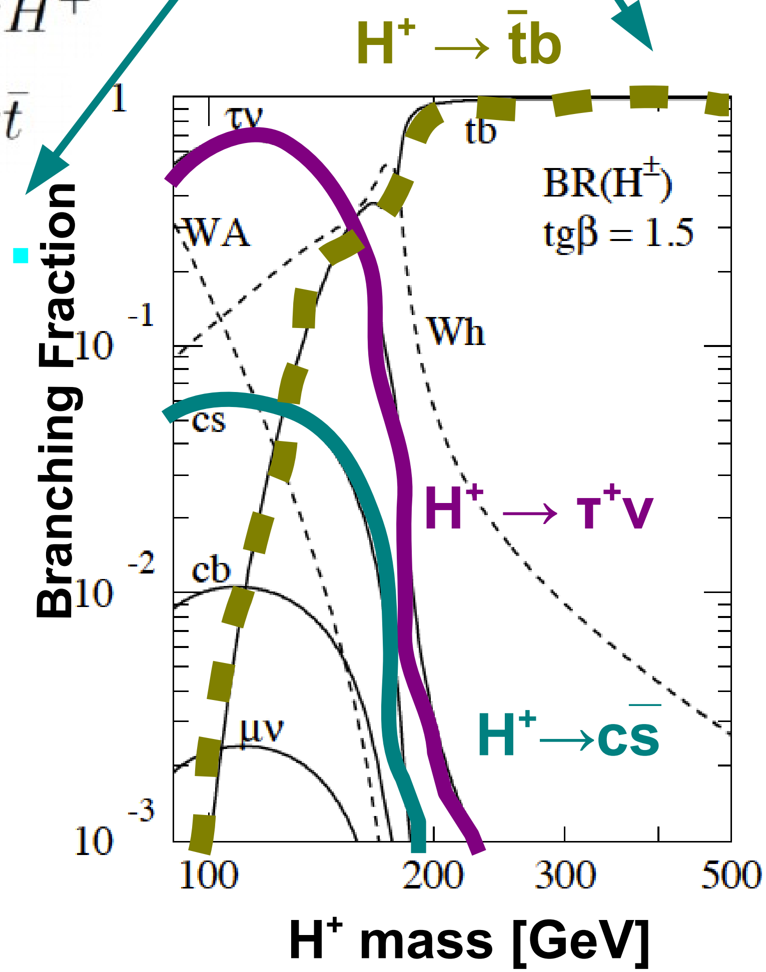


MSSM: Charged Higgs

Heavy Charged Higgs

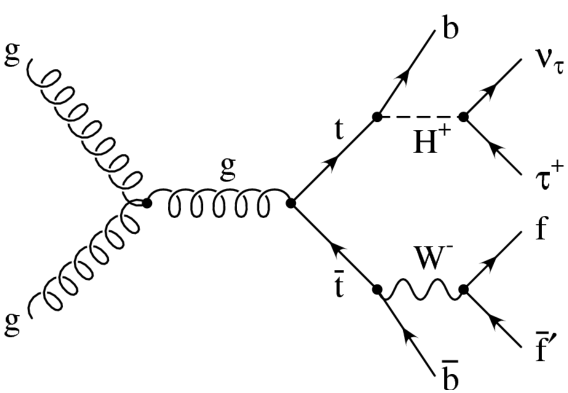


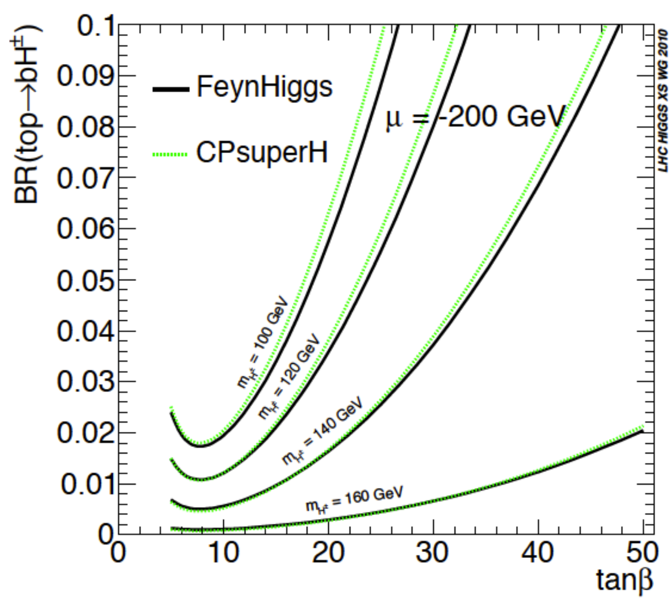
Charged MSSM Higgs Production & Decay



hep-ph/9704448

Light Charged Higgs





BR(Top → bH⁺) vs tanβ

MSSM-inspired H → τ τ / μ μ

- H → ττ: most promising channel for neutral MSSM Higgs
- H → μμ interesting despite the very low branching fraction: good mass resolution & clean signature

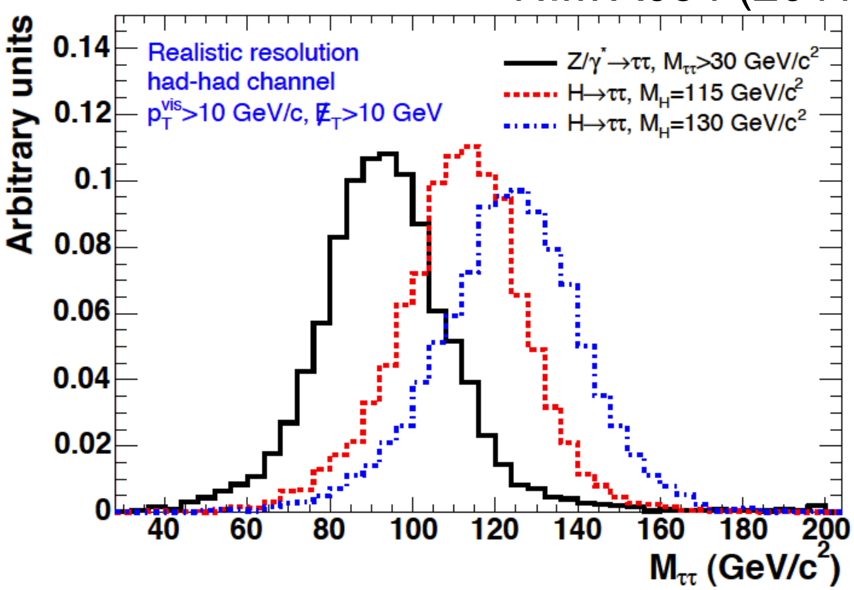
H → τ τ	BR ~ 10%	Comment	ATLAS search
τ τ → τ(e/μ) τ(had)	BR ~ 46 %	Most sensitive	✓
τ τ → τ(had) τ(had)	BR ~ 42 %	Important at high mass	✓
τ τ → τ(e) τ(μ)	BR ~ 6 %	Important at low mass	✓
τ τ → τ(μ) τ(μ)	BR ~ 6 %		
H → μ μ	BR ~ 10^{-4}		✓

- Production mode (gg fusion, “b-associated”) motivates sample splitting using the presence or absence of b-tagged jets: **“b-tagged”** and **“b-vetoed”** samples

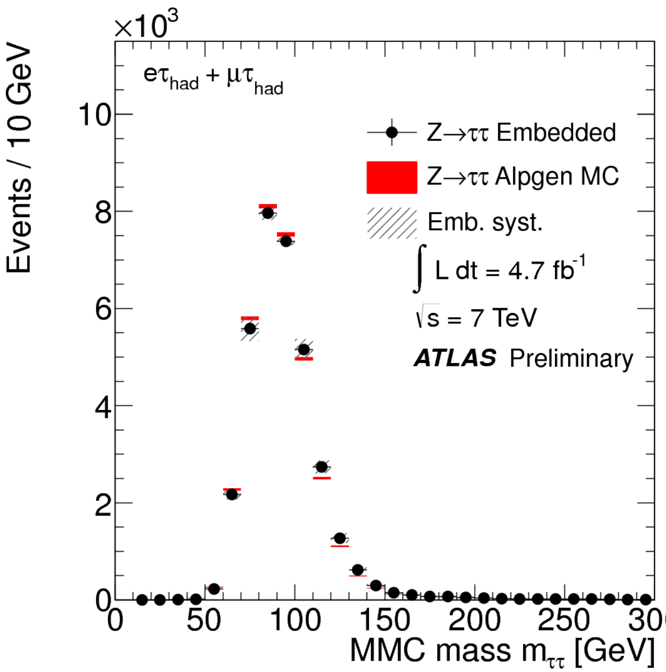
Tau Interlude

- Di-tau mass resolution: very poor due to the presence of neutrinos in the final state
  - Visible mass (mass of visible objects)
  - "Missing Mass Calculator" (MMC):

Constrain unknown neutrino momenta using τ decay kinematics NIM A654 (2011) 481



- Z → τ τ : very important background source



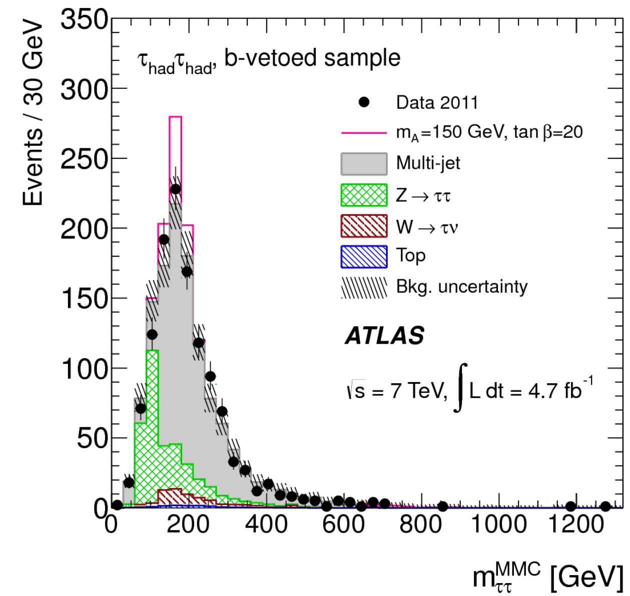
"τ-embedded" Z → μμ data events: select Z→μμ events from data and replace μ with a simulated τ

MSSM-inspired H → τ τ

τ(had)τ(had)

2 τhad pT > 30/45 GeV; Opposite sign; MET > 25 GeV

“b-vetoed” sample: leading jet (pT >20GeV) is a b-jet; Leading tau pT > 60 GeV	**“b-tagged” sample:** leading jet (pT >20GeV) is a b-jet; leading (b-)jet pT < 50 GeV

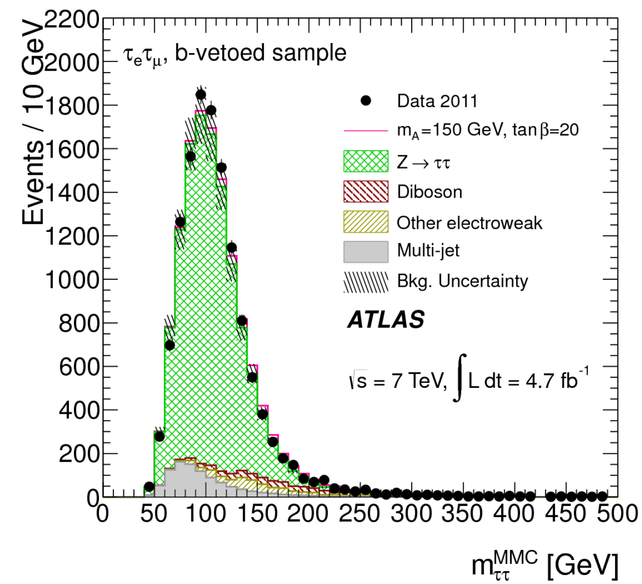


τ(lep)τ(lep) using τ(e)τ(μ) final state

1 isolated e pT>15-24GeV; **1 isolated μ** pT>10-20 GeV

Opposite sign; ΔΦ(e,μ)>2; m(e,μ)>30 GeV

“b-vetoed” sample: no b-jets (pT >20GeV) + topological and other cuts	**“b-tagged” sample:** exactly 1 b-jet (pT >20GeV) + topological and other cuts



arXiv:1211.6956

MSSM-inspired H → τ τ

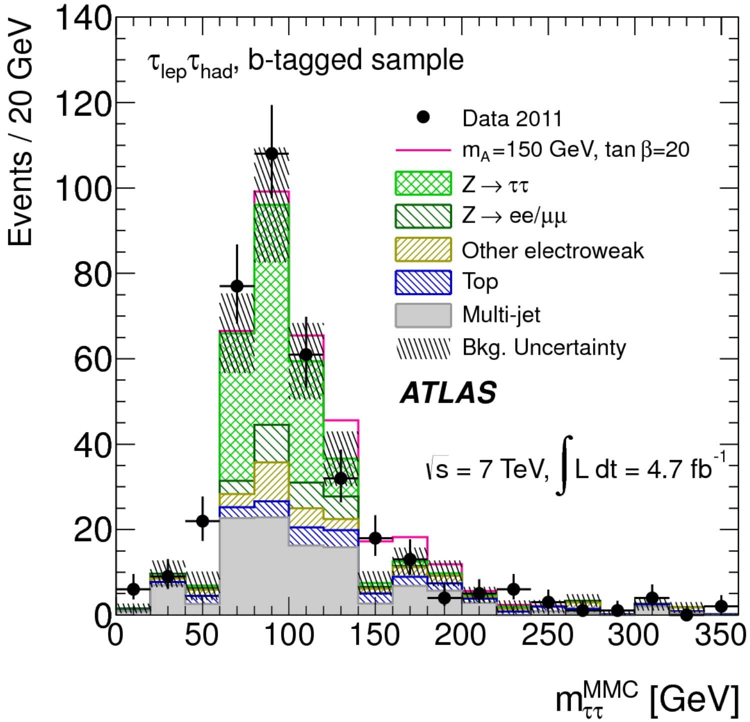
τ(e/μ)τ(had)

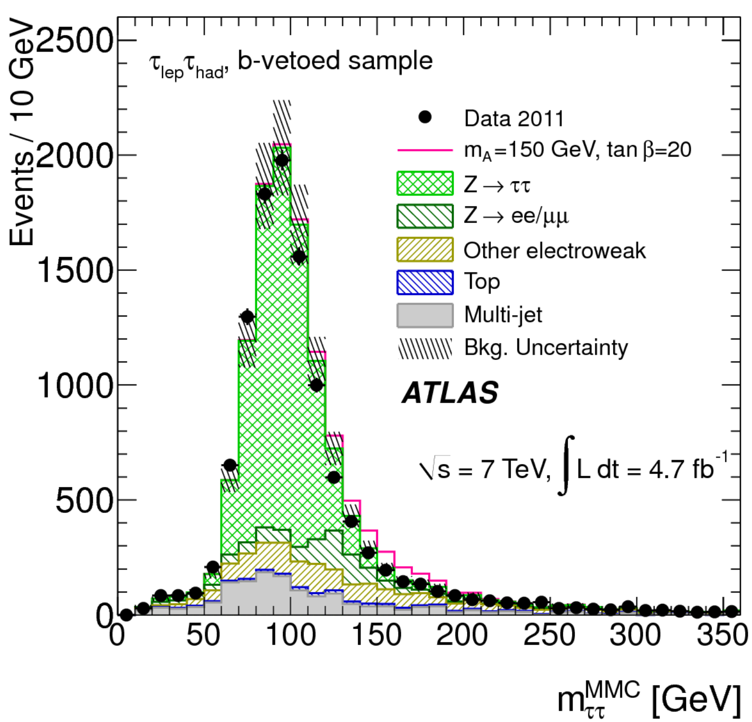
isolated e / μ with p_T >25/20 GeV; **τhad** with p_T > 20 GeV;

Opposite sign; M_T < 30 GeV

"b-tagged" sample: leading jet (p_T >20GeV) is a b-jet; Leading (b-)jet p_T < 50 GeV	**"b-vetoed" sample:** leading jet (p_T >20GeV) not a b-jet; MET > 20 GeV

arXiv:1211.6956





MSSM-inspired H → μ μ

H → μμ

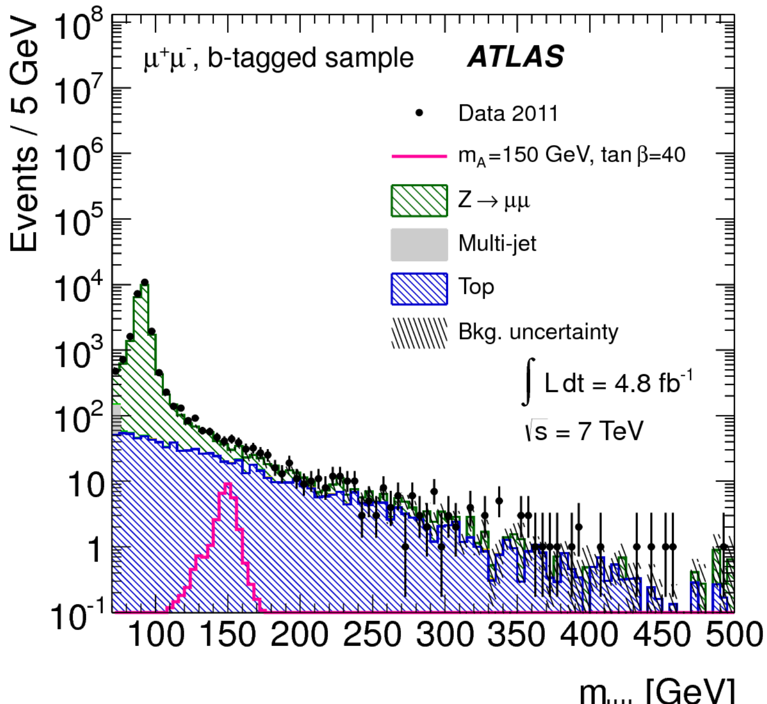
2 μ with p_T > 15/20 GeV; Opposite sign; MET < 40 GeV; m(μμ) > 70 GeV

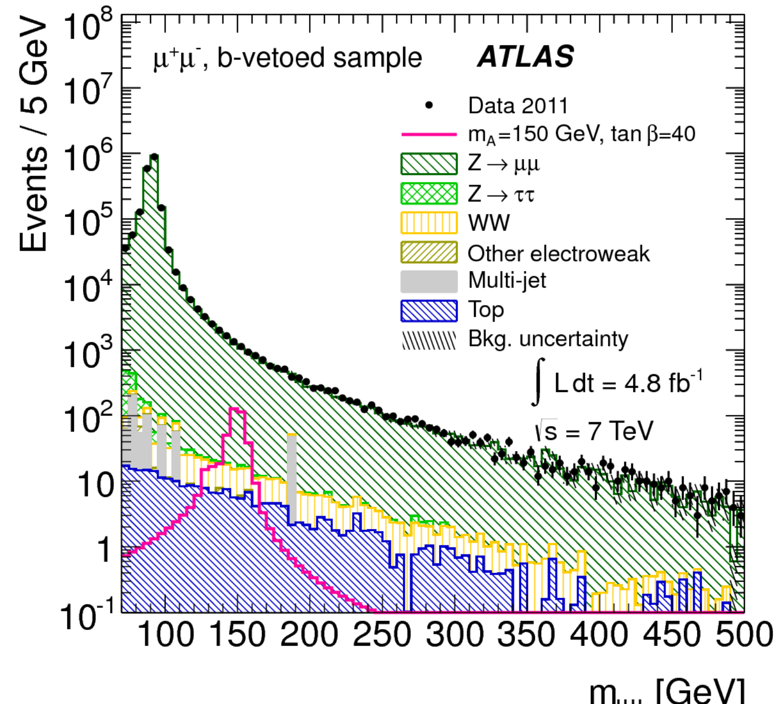
“b-tagged” sample: at least one b-jet (p_T >20GeV)	**“b-vetoed” sample:** no b-jet (p_T >20GeV)

Bkg model: (Z/γ* interference) ʘ (Gaussian resolution); ʘ = convolution operator

Signal model: (Breit-Wigner) ʘ (Gaussian resolution)+Landau

arXiv:1211.6956





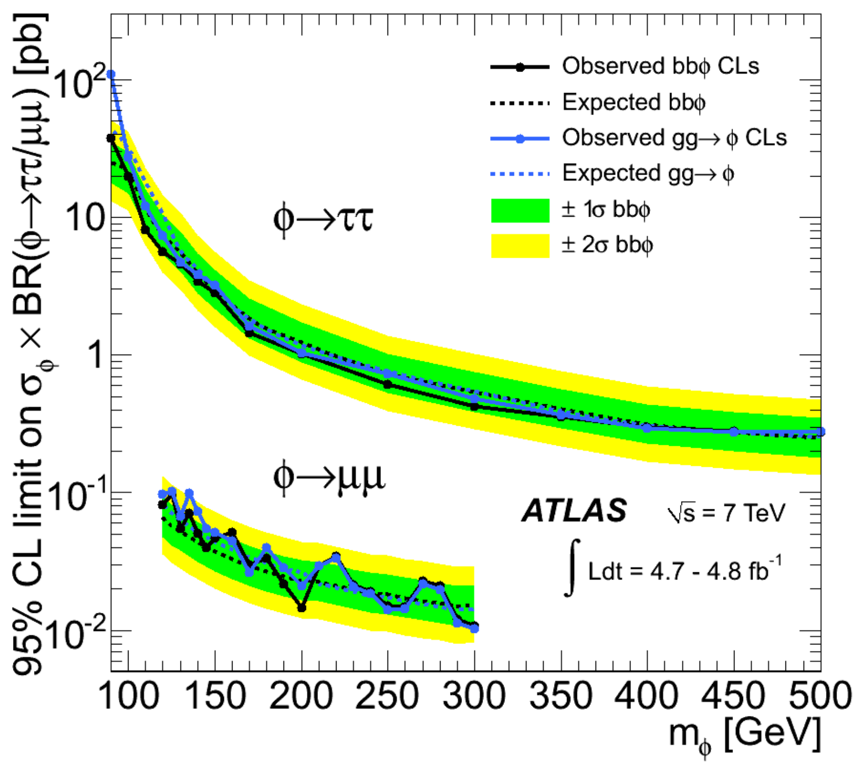
Simulated backgrounds are shown here only for demonstration: not used in the final result

MSSM-inspired H → τ τ / μ μ

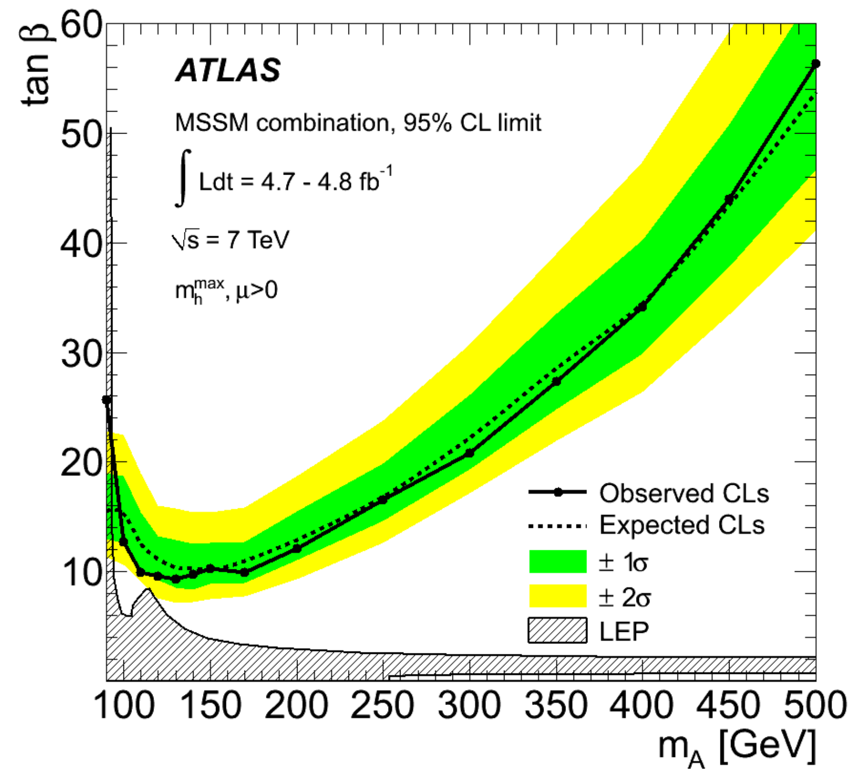
arXiv:1211.6956

- Exclusion Limits: all channels combined

Limit on σ BR(φ → ττ)

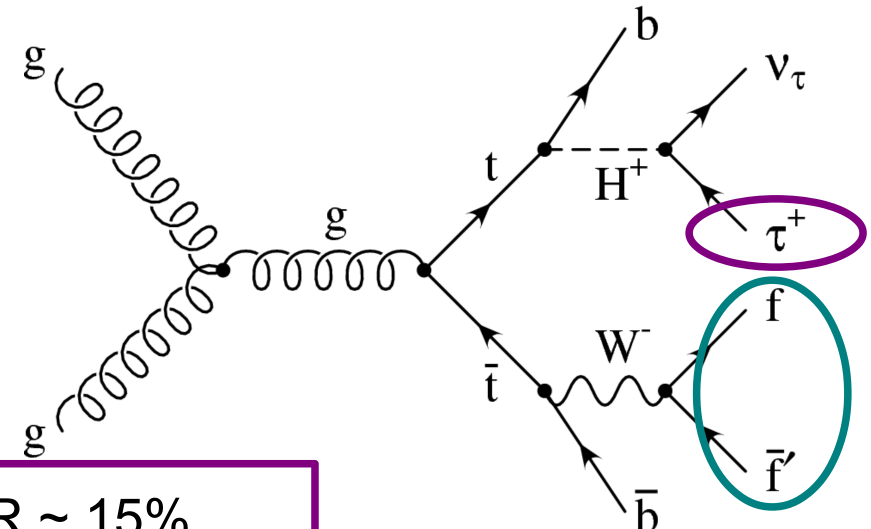


"m_A-tanβ" space limit m_h^{max}



Charged Higgs Searches

- Search for a light ($m < m_{top}$) charged Higgs produced in top decays and decaying: $H^{\pm} \rightarrow \tau^{\pm}\nu$ / cs



Channel topology organized according to W and tau decay

$H^{\pm} \rightarrow \tau^{\pm}\nu$

τ(lep)+W(→lν):	$tt \rightarrow bbWH \rightarrow bb\,(l\nu)\,(\tau_{lep}\nu)$	BR ~ 15%
τ(had)+W(→lν):	$tt \rightarrow bbWH \rightarrow bb\,(l\nu)\,(\tau_{had}\nu)$	BR ~ 14%
τ(had)+W(→jets):	$tt \rightarrow bbWH \rightarrow bb\,(qq)\,(\tau_{had}\nu)$	BR ~ 46%
τ(lep)+W(→jets):	$tt \rightarrow bbWH \rightarrow bb\,(qq)\,(\tau_{lep}\nu)$	BR ~ 25%

τ(lep) = τ(e) or τ(μ)

$H^{\pm} \rightarrow cs$

$H^{+}(\rightarrow cs)+W(\rightarrow l\nu)$: $tt \rightarrow bbWH \rightarrow bb\,(l\nu)\,(cs)$

$H^\pm \rightarrow \tau^\pm \nu$ search

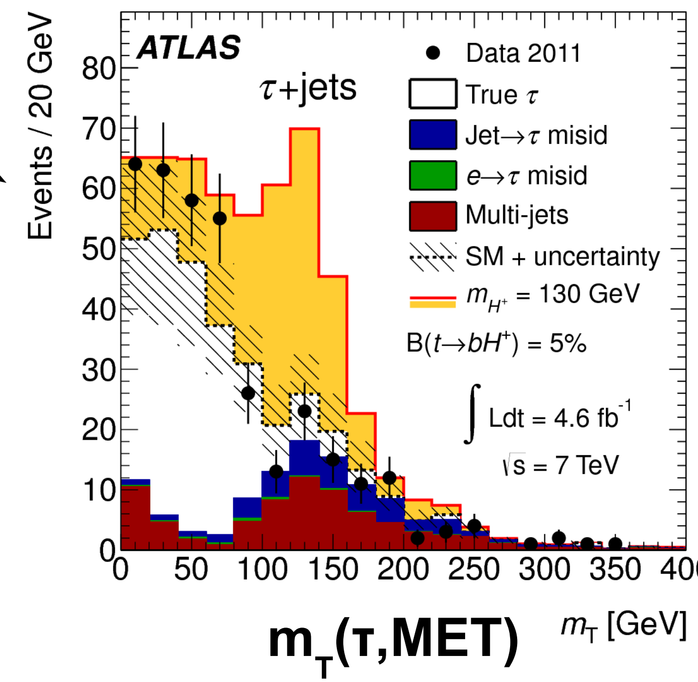
JHEP 1206 (2012) 039

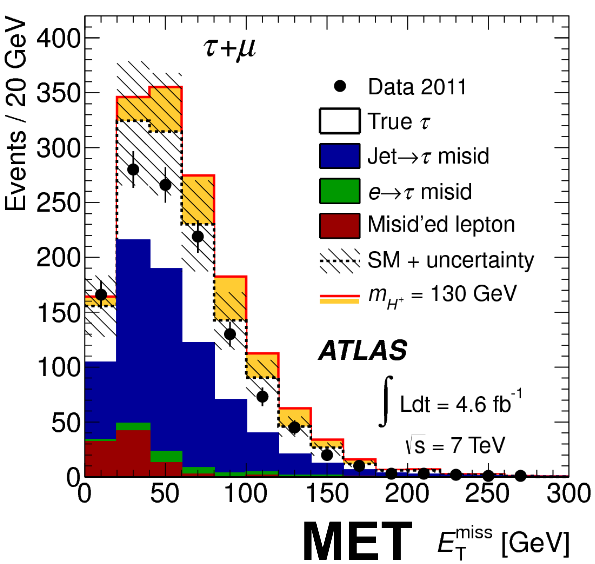
ATLAS $H^\pm \rightarrow \tau^\pm \nu$ search uses 3 channels:

τ(had)+W(→jets) **τ(had)+W(→lν)** **τ(lep)+W(→jets)**

τ(had) + W(→ jets)
1 τ_{had} with $p_T > 40$ GeV
At least 4 jets (pT>20 GeV) with at least 1 b-tagged
MET > 65 GeV (tighter at high Σ p_T(tracks)) 120 GeV < m(jjb) < 240 GeV

Most sensitive channel, but the absence of a light lepton makes triggering on these events not trivial: tau + MET trigger





τ(had) + W(→ lν)
1 isolated e/μ, $p_T > 25/20$ GeV; 1 τ_{had} with $p_T > 20$ GeV
At least 2 jets (p_T>20 GeV), with at least 1 b-tagged
vertex $\Sigma p_T > 100$ GeV

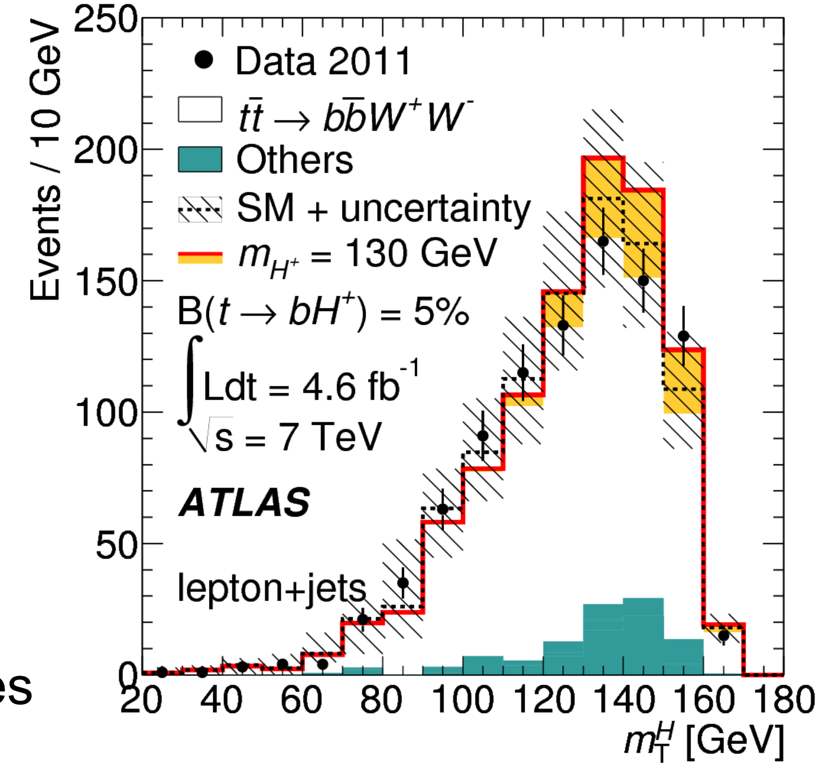
$H^{\pm} \rightarrow \tau^{\pm}\nu$ search

ATLAS $H^{\pm} \rightarrow \tau^{\pm}\nu$ search uses 3 channels:

JHEP 1206 (2012) 039

τ(had)+W(→jets) **τ(had)+W(→lν)** **τ(lep)+W(→jets)**

τ(lep) + W(→ jets)
1 isolated e/μ, p_T > 25/20 GeV
At least 4 jets (p_T>20 GeV) with exactly 2 b-tagged
MET > 40 GeV (tighter if Δφ(lepton,MET) small) $\cos\theta^*_l$ < -0.6; m_T(lepton,MET)<60 GeV



Very challenging to separate signal from tt → bbWW → bb+jj+lν (main background)

kinematic fit to associate b-jets to the top candidates

$$\cos\theta^*_l = \frac{2m^2_{bl}}{m^2_{top} - m^2_W} - 1$$

b-jet+ charged lepton invariant mass

$$(m_T^H)^2 = \left(\sqrt{m^2_{top} + (\vec{p_T}^l + \vec{p_T}^b + \vec{p_T}^{miss})^2} - p_T^b\right)^2 - \left(\vec{p_T}^l + \vec{p_T}^{miss}\right)^2.$$

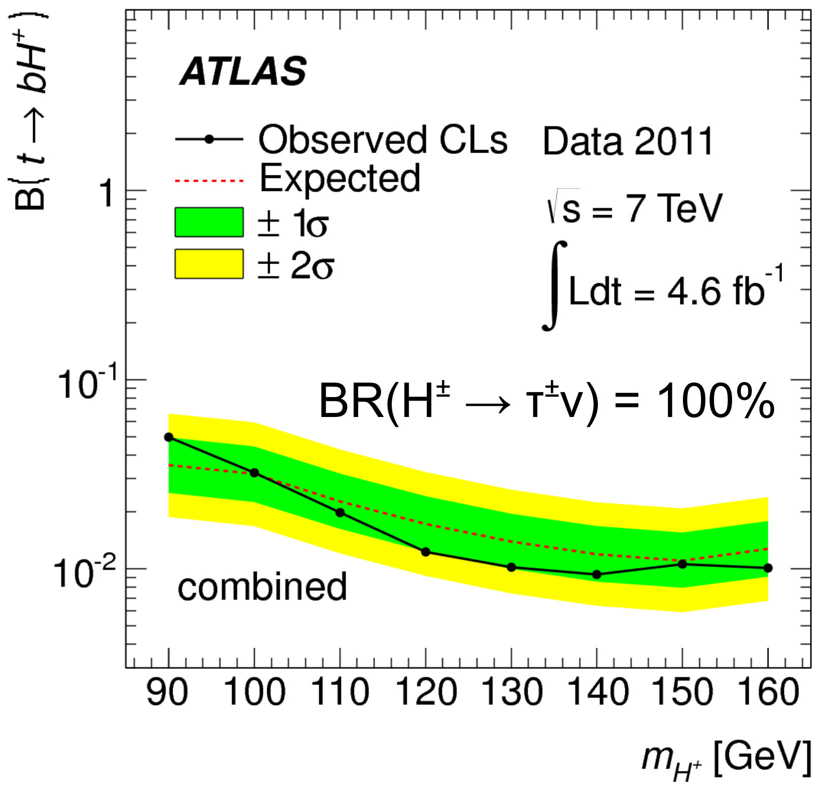
Higgs transverse mass

$H^{\pm} \rightarrow \tau^{\pm}\nu$ search

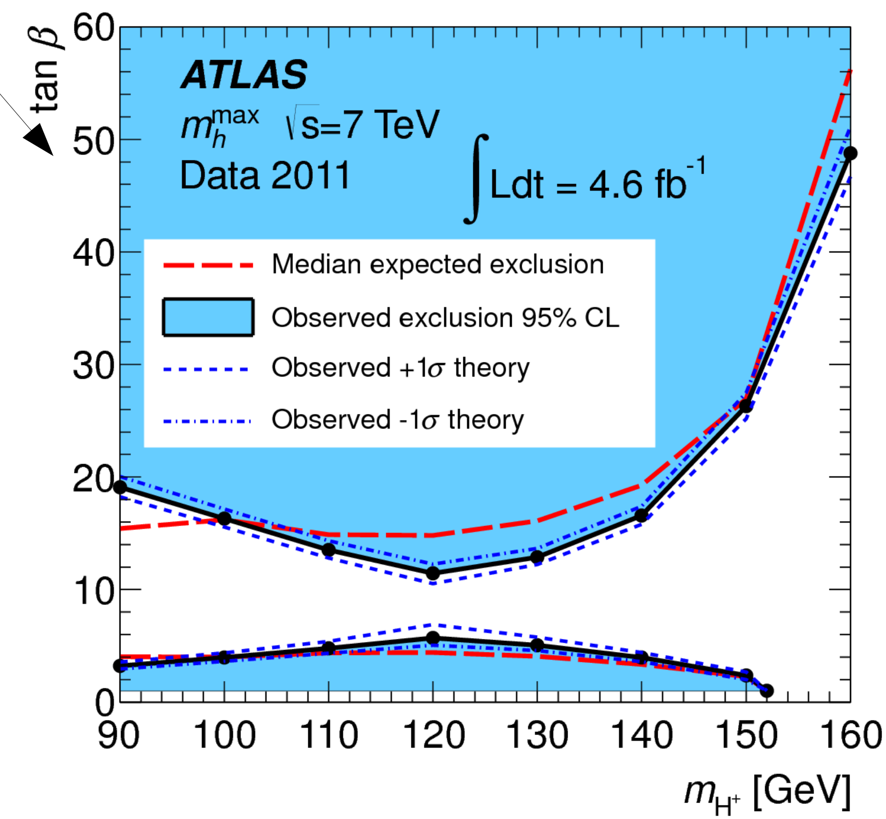
JHEP 1206 (2012) 039

Search result interpretation in the MSSM: low mass $H^{\pm}$ allowed phase space is heavily constrained

Branching fraction limits



MSSM interpretation



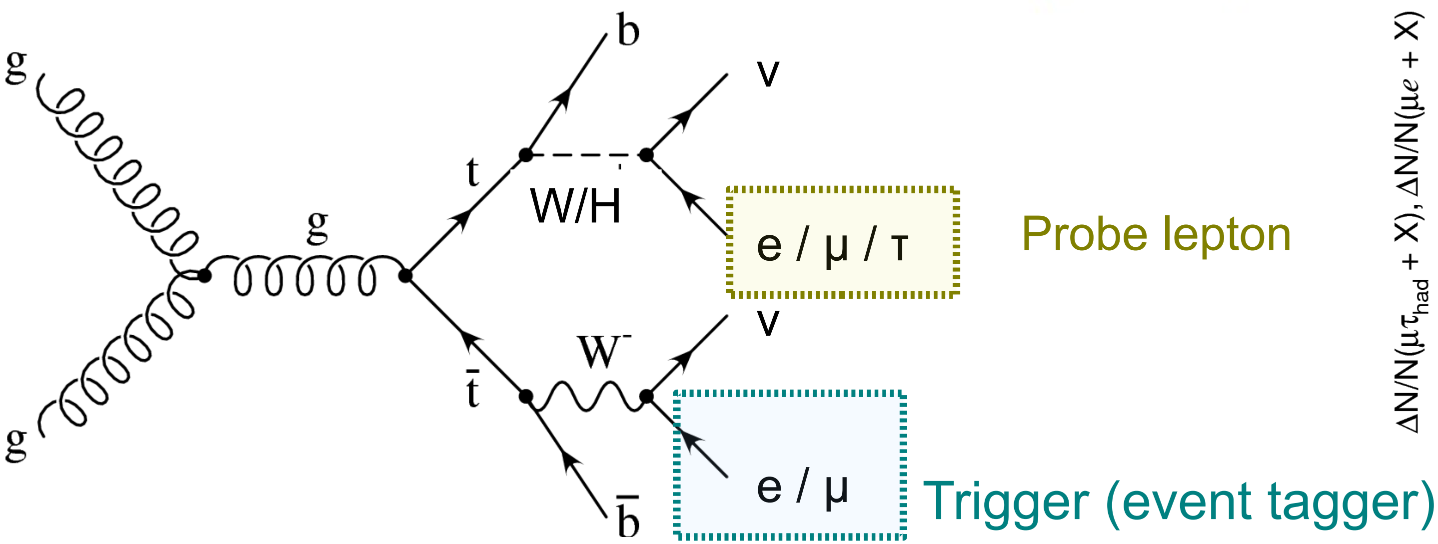
$H^{\pm} \rightarrow \tau^{\pm}\nu$ search with the "Ratio" method

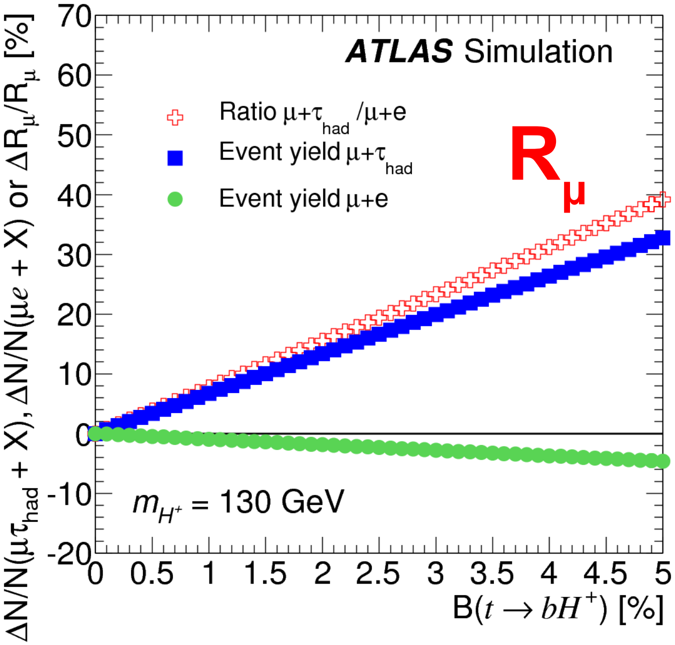
- If a $H^{\pm}$ boson is produced in top decays its preferred decay mode to $\tau\nu$ can be observed as **lepton flavour universality violation**:

In the absence of new physics $R_e = 1$ and $R_\mu = 1$ to a very good approximation

arXiv:1212.3572

$$R_e = \frac{\mathcal{N}(e + \tau_{\text{had}})}{\mathcal{N}(e + \mu)} \qquad R_\mu = \frac{\mathcal{N}(\mu + \tau_{\text{had}})}{\mathcal{N}(\mu + e)}$$





$H^{\pm} \rightarrow \tau^{\pm}\nu$ search with the "Ratio" method

$H^{\pm} \rightarrow \tau\nu$ using lepton flavour universality violation: W(→ lν) + l' or τ

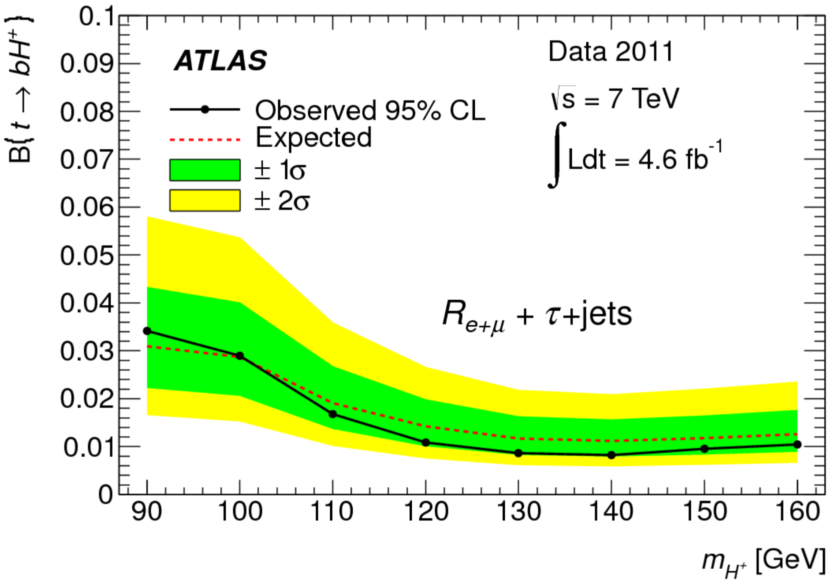
1 isolated e/μ, $p_T > 25$ GeV; MET > 40 GeV

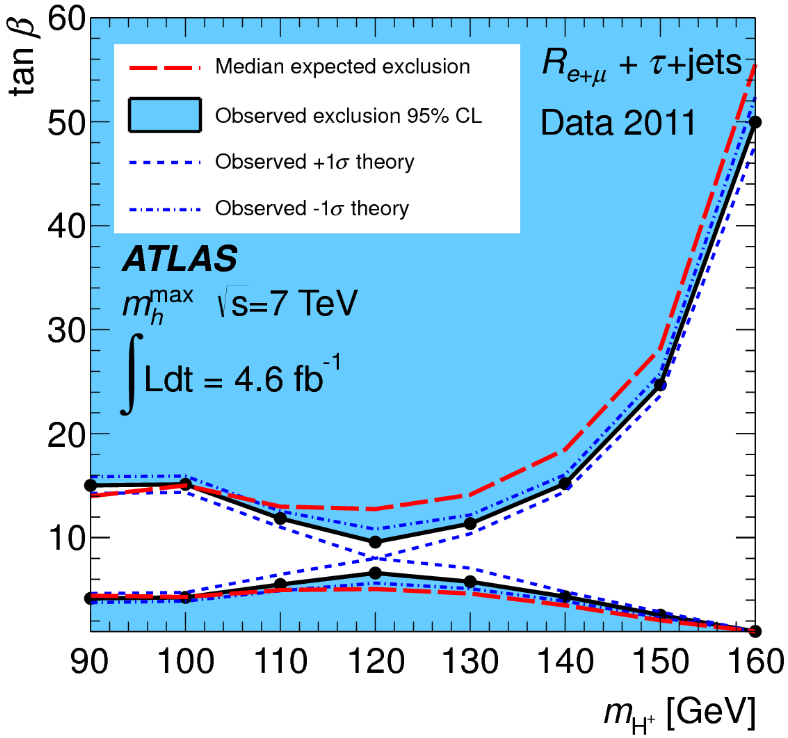
At least 2 jets (p_T>20 GeV), with exactly 2 b-tagged

(1 τ_{had} $p_T > 20$ GeV and no other lepton) **or**
1 additional lepton p_T>25 GeV of a different flavour wrt the lepton tagged the event

arXiv:1212.3572

The result is combined with the direct $H^{\pm} \rightarrow \tau\nu$ search in the τ(had)+W(→jets) channel





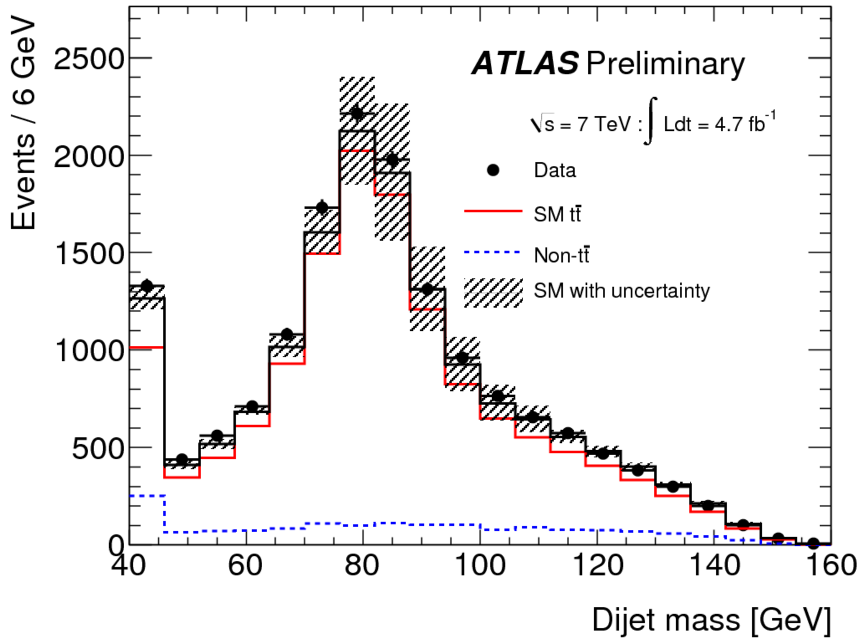
$H^+ \rightarrow c\bar{s}$ search

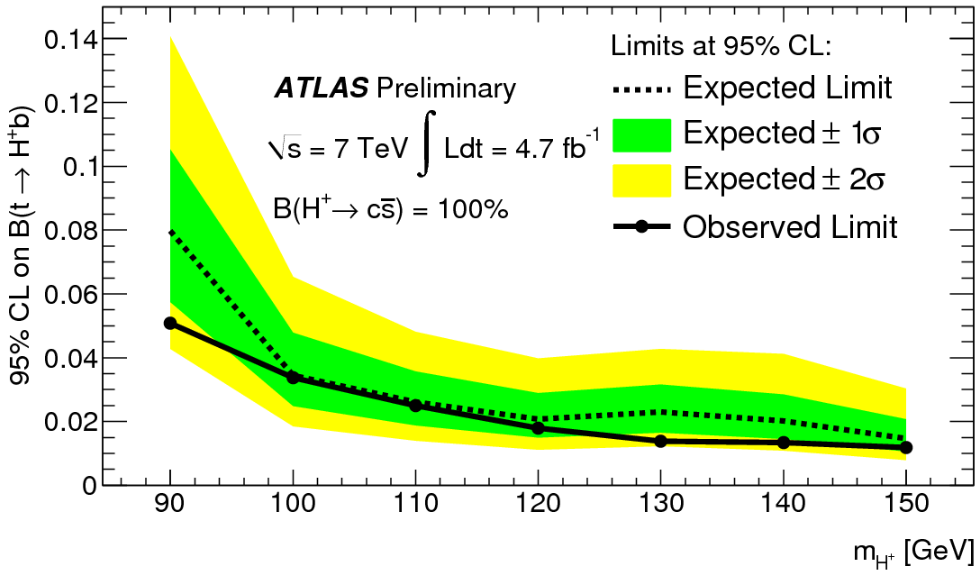
ATLAS HIGG-2012-10

ATLAS-CONF-2011-094

- Important at low tanβ:
  - Br(H→cs) ~ 40%, tanβ<1, mH^+ ~130 GeV

$tt \rightarrow bW\ bH^+ \rightarrow b\ (e/mu)\ v\ \ b\ cs$
1 isolated e/μ to trigger the event
kinematic fit to separate signal from background



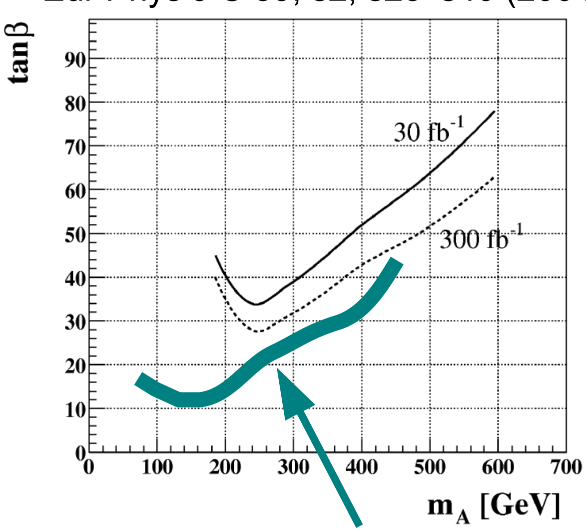


Heavy Charged Higgs

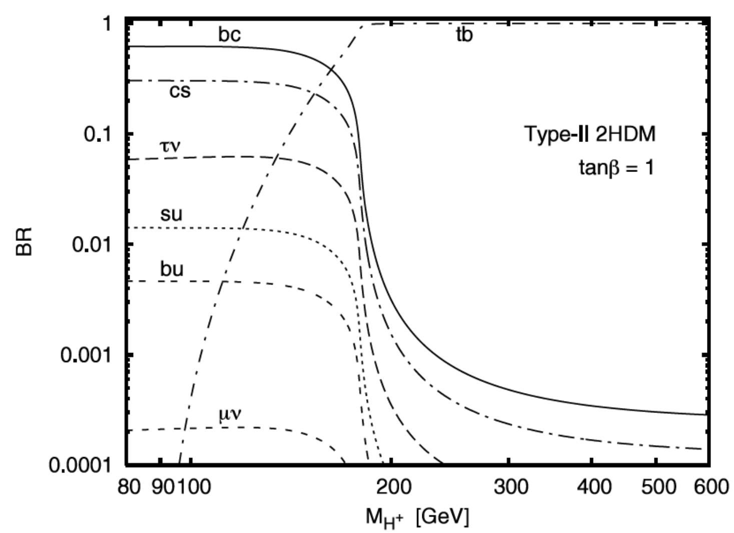
- The extension of Charged Higgs searches to heavy mass opens new opportunities
  - $H^{\pm} \rightarrow \tau\nu$ and $H^{\pm} \rightarrow tb$ have been discussed from the TDR times
  - Their prospects for MSSM are complementary but not competitive to the neutral Higgs searches; but for probing 2HDM are excellent

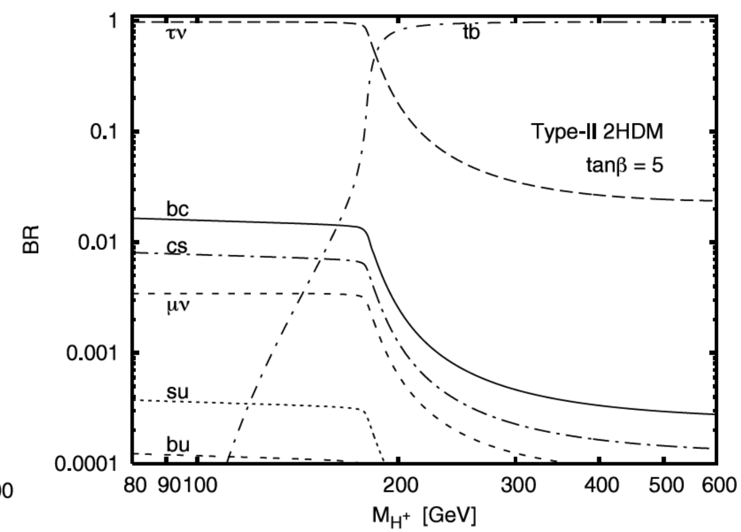
H → tb discovery potential

Eur Phys J C 39, s2, s25–s40 (2004)



exclusion from τ τ , $5fb^{-1}$





arXiv:1002.4916

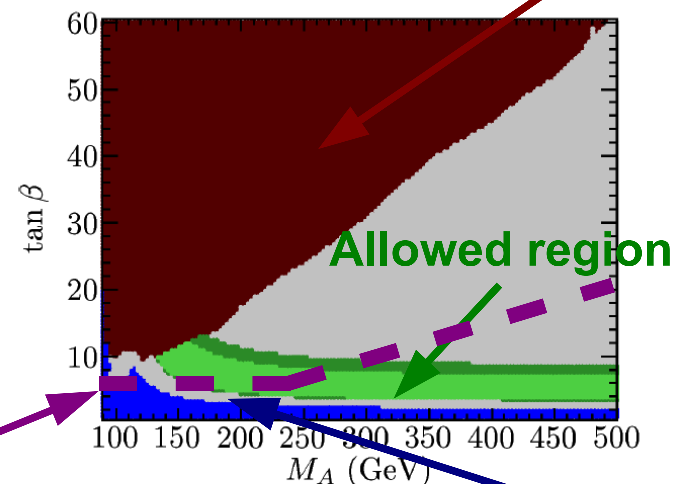
Where we stand: Neutral Higgs

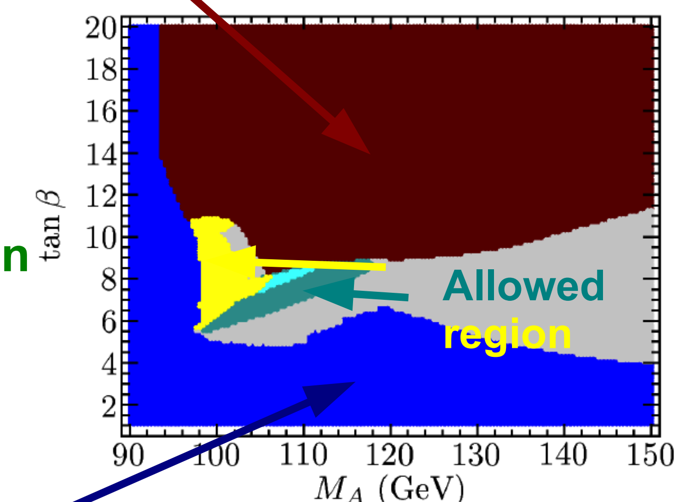
- The spearhead of the MSSM searches at the LHC: **H → τ τ** and $H^{\pm}$ → τ ν searches

Neutral Higgs searches & the MSSM

Large part of the parameter space excluded, but there is still available regions; these regions are **compatible with a SM-like Higgs boson at ~126 GeV**

Excluded (LHC full 2011 data)





CMS 17 fb^{-1} (approximately)

Excluded (LEP)

"mh-max", m(h)~126 GeV "mh-max", m(H)~126 GeV

arXiv:1112.3026 Heinemeyer et al.
arXiv:1207.1348 Arbey et al.

Where we stand: Charged Higgs

- The spearhead of the MSSM searches at the LHC:
  $H \rightarrow \tau\tau$ and **$H^{\pm} \rightarrow \tau\nu$** searches

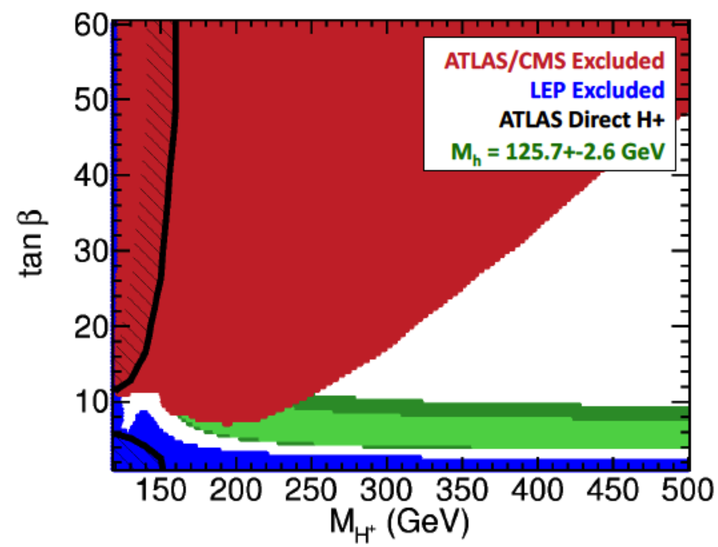
Charged Higgs searches & the MSSM

LHC full 2011 data

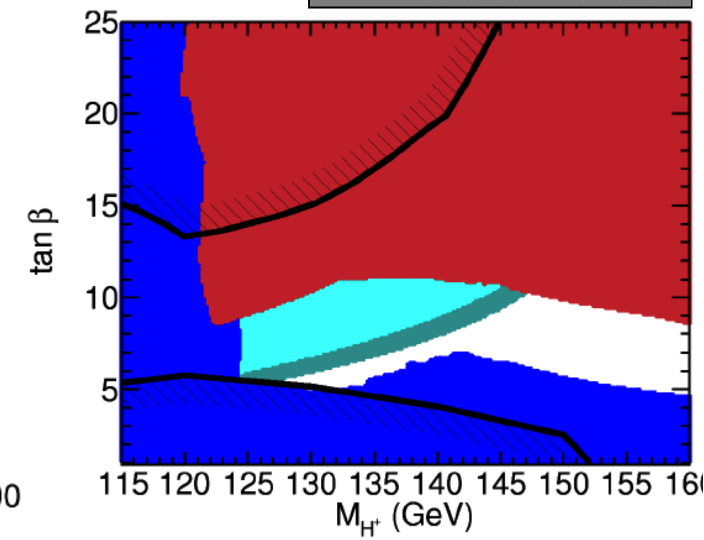
M_H = 125.7+-2.6 GeV
ATLAS/CMS exclusion
LEP exclusion
ATLAS Direct H+

In the MSSM, neutral Higgs searches have a large impact on the charged Higgs, through the relation:

$$M_{H^{\pm}}^2 = M_A^2 + M_W^2$$



"mh-max", m(h)~126 GeV



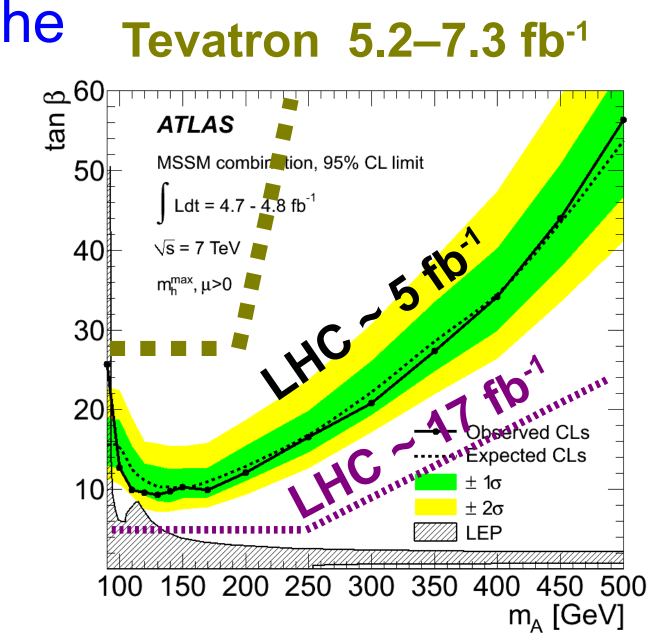
"mh-max", m(H)~126 GeV

But keep in mind that a light charged Higgs can be less restricted in a more general 2HDM

Oscar Stöl, CHiggs2012

Summary of MSSM-inspired searches

- The spearhead of the MSSM Higgs search is the H → τ τ channel
  - Enormous progress in excluding large parts on the m_A – tanβ plane with respect to the pre-LHC era



- Charged Higgs searches
  - MSSM interpretation not so competitive wrt H → τ τ, but still complementary
  - However, more general 2HDM disentangle neutral and charged higgs
  - In the future a virgin continent of heavy charged Higgs will open for exploration

Some not-MSSM-inspired BSM Higgs searches

Higgs as a link to New Sectors

- The Higgs sector of the SM has unique properties
  - The Higgs doublet Φ is such that $\Phi^\dagger\Phi$ is a singlet of dimension 2
  - Couplings of the type $\Phi^\dagger\Phi\varphi^*\varphi$ are just dimension 4 for some new scalar particle φ; $\Phi\varphi\varphi$ can also appear after SSB

The Higgs sector can serve as the connection to a New Sector of Nature!

Such possibilities can be offered by many models:

◇ NMSSM extends the MSSM with an EWK singlet: decays $h \to a1\ a1 \to 4\gamma$ are possible

◇ "Hidden Valley" models include decays to long lived particles $h \to \pi_v\ \pi_v$

◇ …

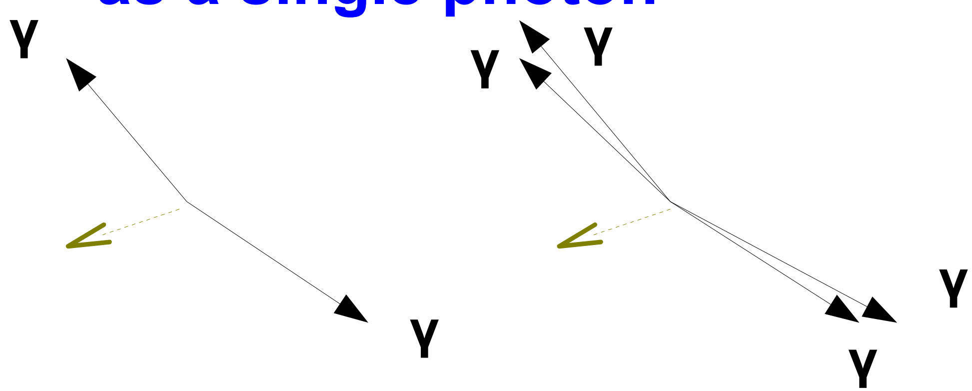
$H \to aa \to \gamma\gamma + \gamma\gamma$

ATLAS-CONF-2012-079

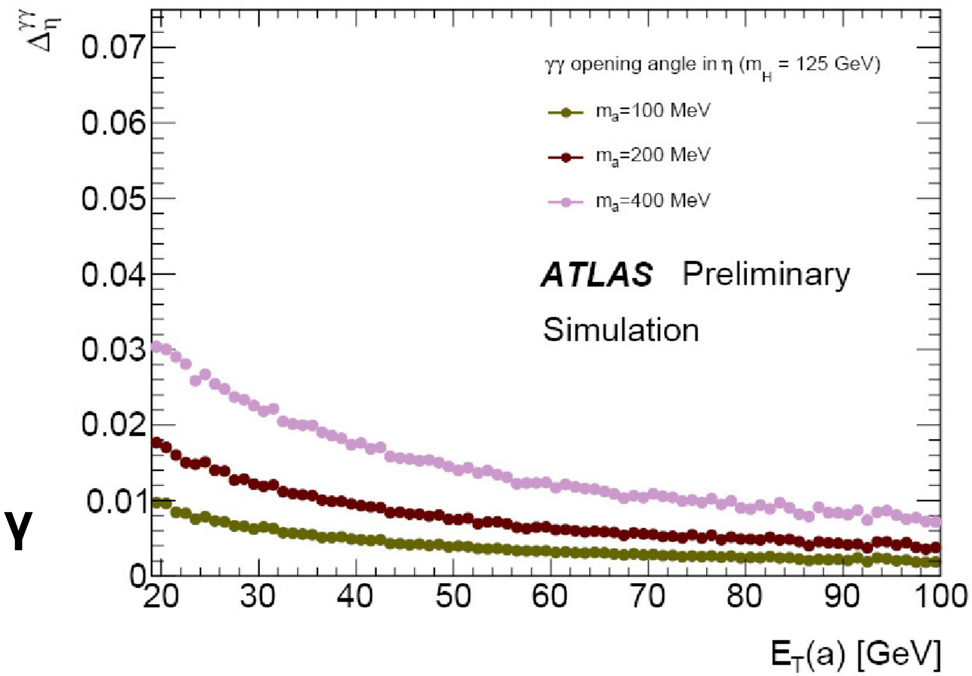
- In some SM extensions (e.g. NMSSM) Higgs is allowed to decay to light (pseudo)scalar particles, a, which consequently decay to $\gamma\gamma$ without contradicting any current result

e.g. see PRD63(2001)075003, PRD66(2002) 075006

  - a is light ~ 100 MeV;
    $\gamma\gamma$ angle very small:
    $\gamma\gamma$-pair is reconstructed as a single photon



SM Higgs → γγ vs this search



H → aa → γγ + γγ

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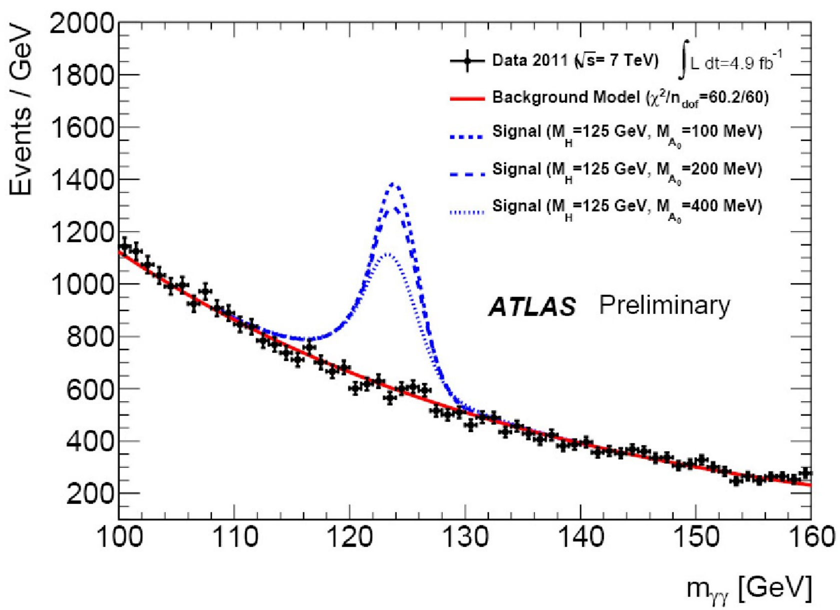
- Search uses events with a γγ pair

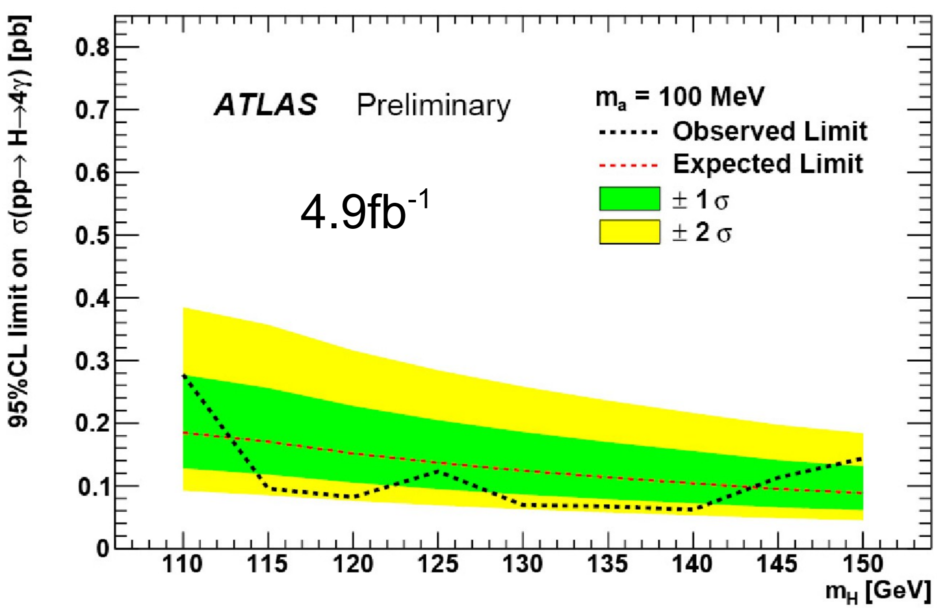
2 photons pT > 40 / 25 GeV

use of dedicated photon ID
(shower shape cuts are removed)

Signal modelled with "crystal ball" (= gaussian core+power law low-end tail)+gaussian; bkg with exponential

Cross section limits for m_a : 100-400 MeV and Higgs mass : 110-150 GeV assuming zero decay length for a



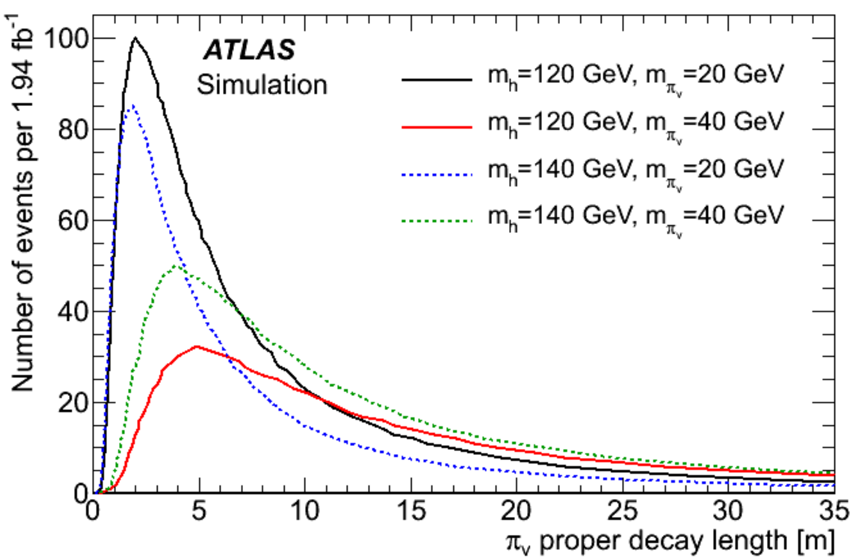


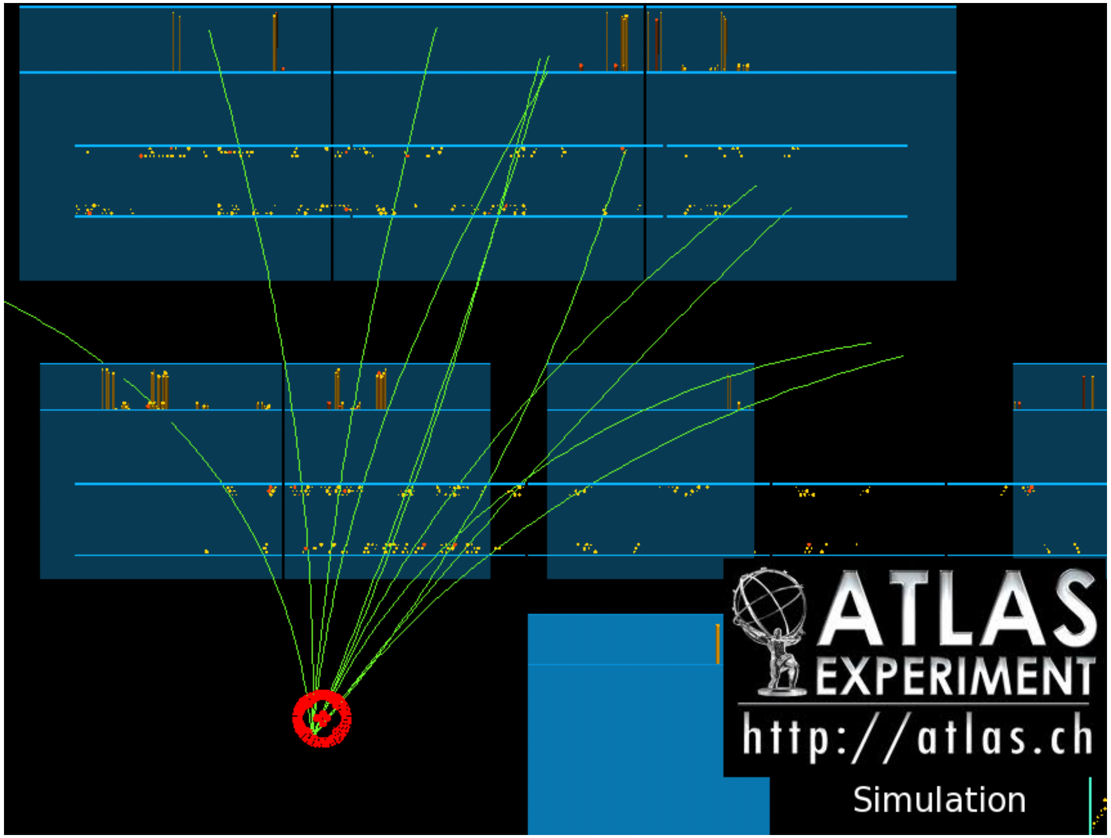
Higgs decaying to long-lived particles

- Higgs decaying to invisible, long-lived "hidden valley" pions π_v, which decay to jets in the outer calorimeter and are detected in the muon system

PRL 108 (2012) 251801

$h \rightarrow \pi_v \pi_v$; $\pi_v \rightarrow bb/cc/\tau\tau$





UNIVERSITY of WASHINGTON

ATLAS EXPERIMENT

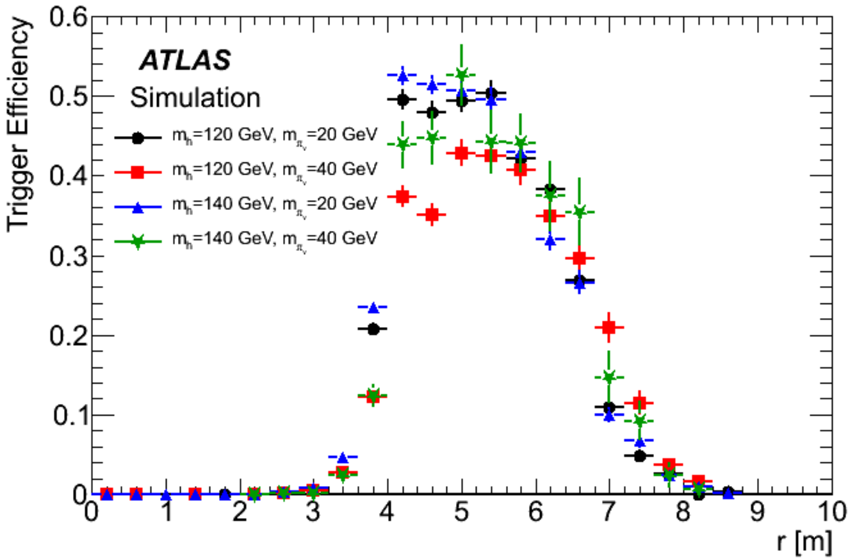
Higgs decaying to long-lived particles

- **$h \rightarrow \pi_v \pi_v$; $\pi_v \rightarrow bb/cc/\tau\tau$**

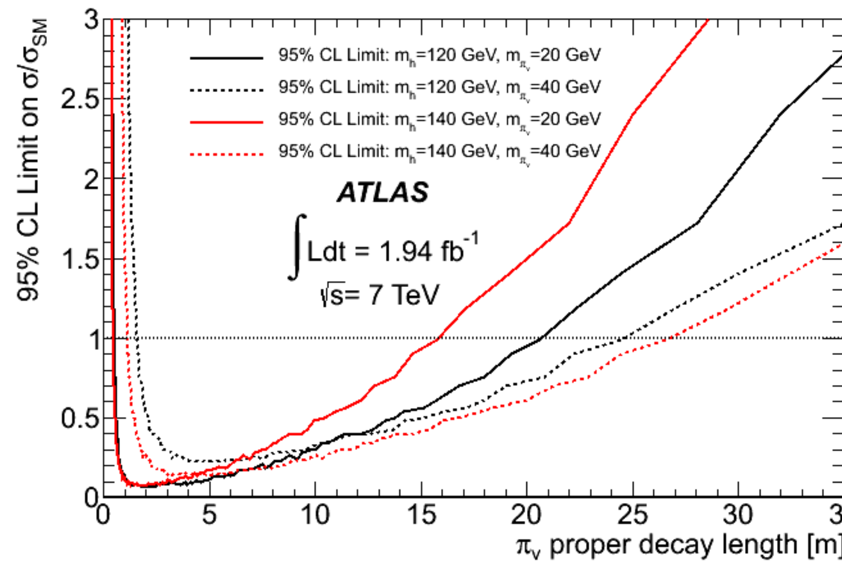
PRL 108 (2012) 251801

Dedicated trigger development to collect candidate events

"hidden valley" model used as benchmark assuming a Higgs produced as in SM, but with a BR ($h \rightarrow \pi_v \pi_v$) = 100%



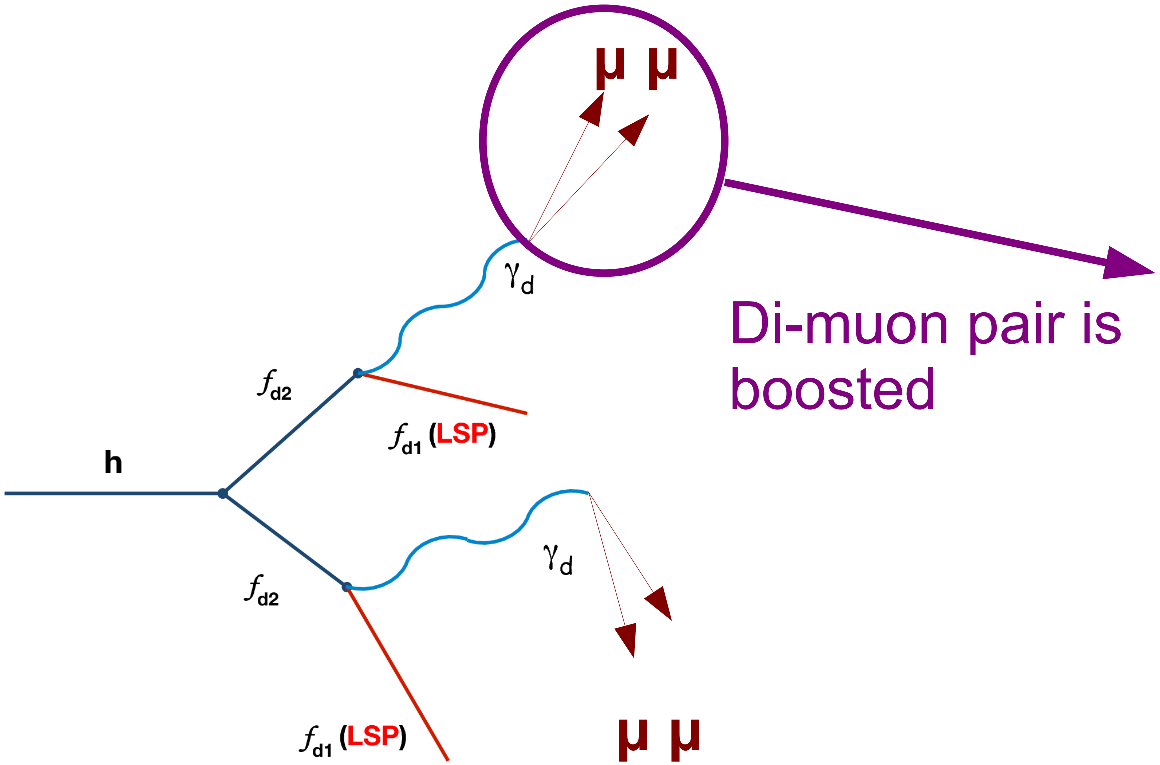
Radial decay position of long lived particle



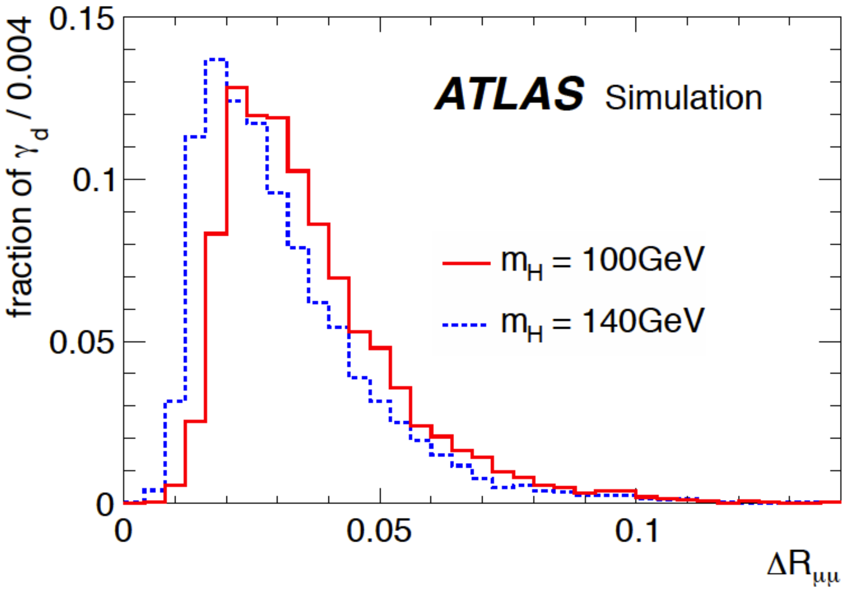
Higgs decaying to long-lived particles

- Higgs decaying to invisible, long-lived particles, which finally produce particles decaying to lepton-jets

arXiv:1210.0435



Di-muon pair is boosted



Higgs decaying to long-lived particles

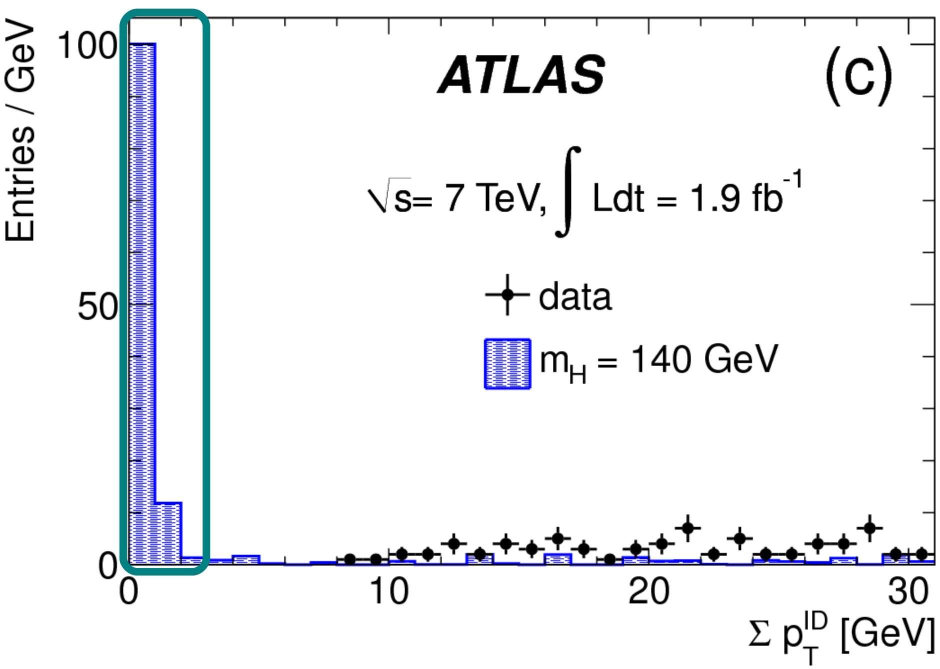
- Higgs to muon jets: results

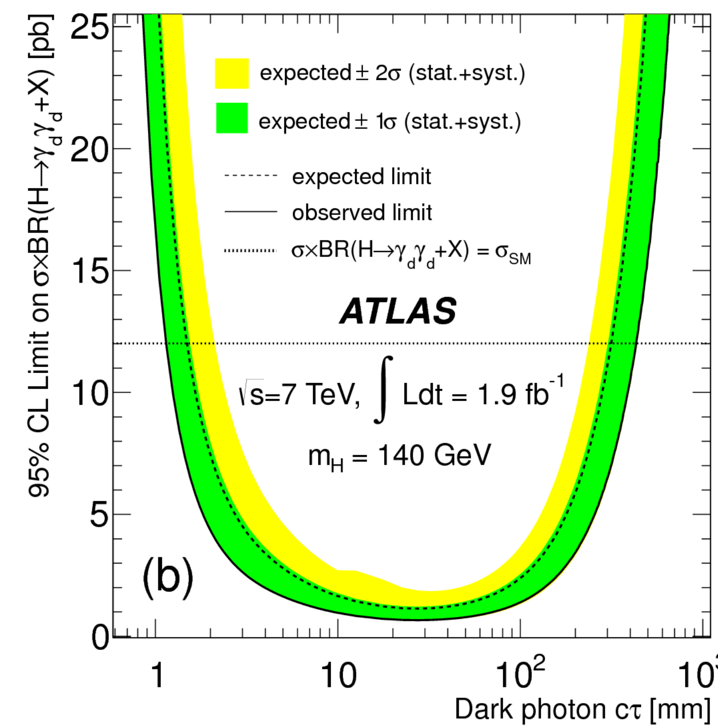
arXiv:1210.0435

Selecting events using a 3-muon trigger with Muon-System-only muons

"hidden valley" model used as benchmark assuming BR ($h \rightarrow \gamma_d \gamma_d + X$) = 100%

Signal region





$\Sigma\, p_T$(ID) : Sum of Inner Tracking Detector track pT in DR < 0.4 around the lepton-jet direction

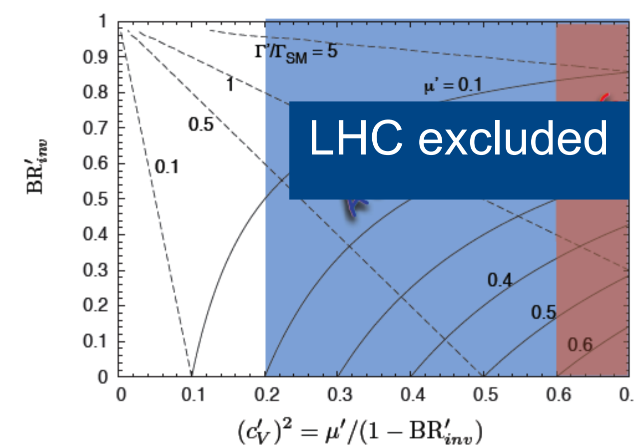
Heavy Higgs etc

- There is interest for looking at a heavy (0.6 – 1 TeV) Higgs with SM-like properties in WW and ZZ channels
  - Quite some discussions in the last LHC Higgs Cross Section WG workshop (link)
  - Discussion about practical analysis issues (link) and possible models (link)
- There are a couple of theoretical models which were discussed in the last LHCHXS workshop starting from these ideas
  - SM Higgs doublet + singlet: just 1 extra parameter, already some limits from H → invisible
  - "Higgsinoless" MSSM

$$\tilde{H} = \begin{pmatrix} h^0 \\ h^- \end{pmatrix} = (1,2)_{1/2} \qquad L = \begin{pmatrix} \nu \\ e^- \end{pmatrix} = (1,2)_{1/2}$$

  - Generic searches for a resonance in Γ-m_H plane, …

$$\mu' = (1-\mu) \times (1 - \mathrm{BR}'_{inv})$$



Some Thoughts

Towards 2013-2014

- The LHC technical stop has started already (as far as pp collisions are concerned)
  - The flagship channels will be done soon: the prediction is that there will be some manpower availability to look at other channels
  - We would like to make a collection of such options. Especially for phenomenologists:
    - Talk about models: don't assume that we read the arXiv every day and we know what has been done for past years
    - Don't underestimate benchmarks and their phycological effect on experimenters

Towards 2013-2014

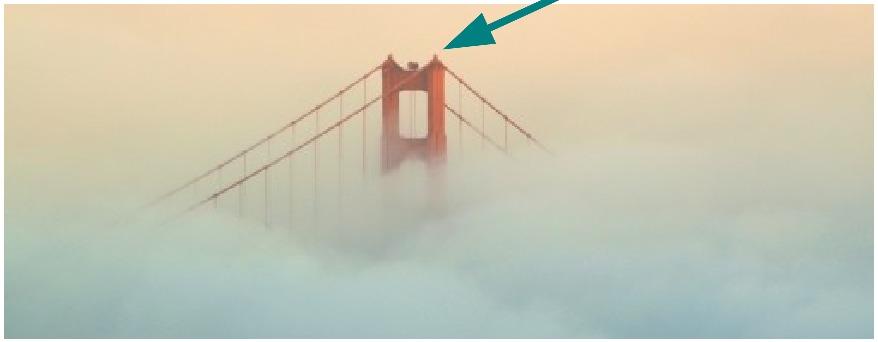
- The future may also unveil a shift in benchmarks
  - Charged Higgs (but not only) starts moving from MSSM to more generic 2HDM: in general 2HDM scenarios are more and more discussed among experimenters; I haven't seen much discussed here in this workshop, e.g. how the BaBar result on $B \rightarrow D(*) \tau \nu$ would affect our searches?

arXiv:1205.5442

Conclusion

Right now we are in the following situation:

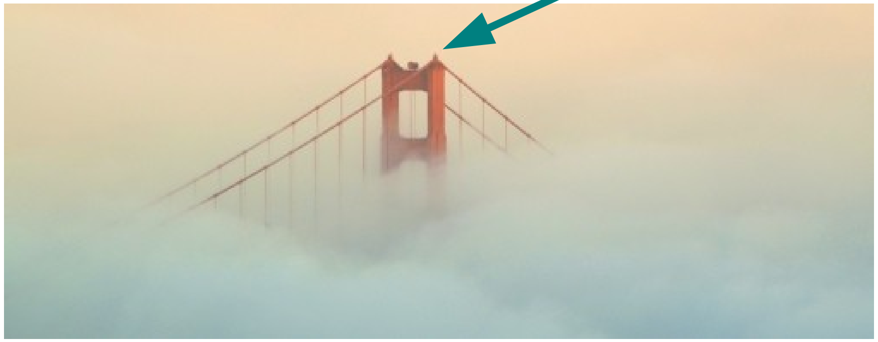
125 GeV SM-Higgs-like boson



Conclusion

Right now we are in the following situation:

125 GeV SM-Higgs-like boson

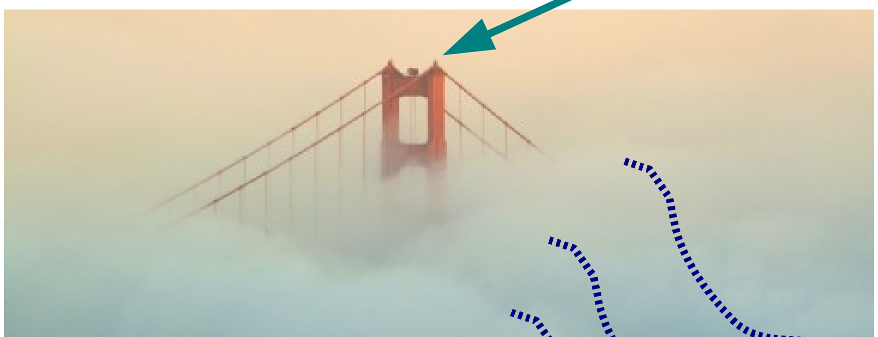


But most probably what hides behind the fog is more complicated!

Conclusion

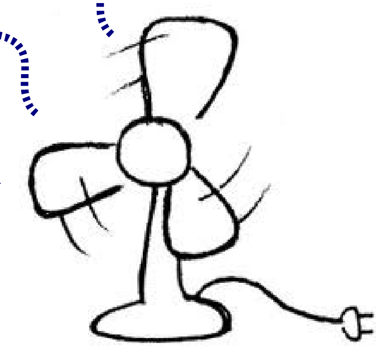
Right now we are in the following situation:

125 GeV SM-Higgs-like boson



But most probably what hides behind the fog is more complicated!

experimenters



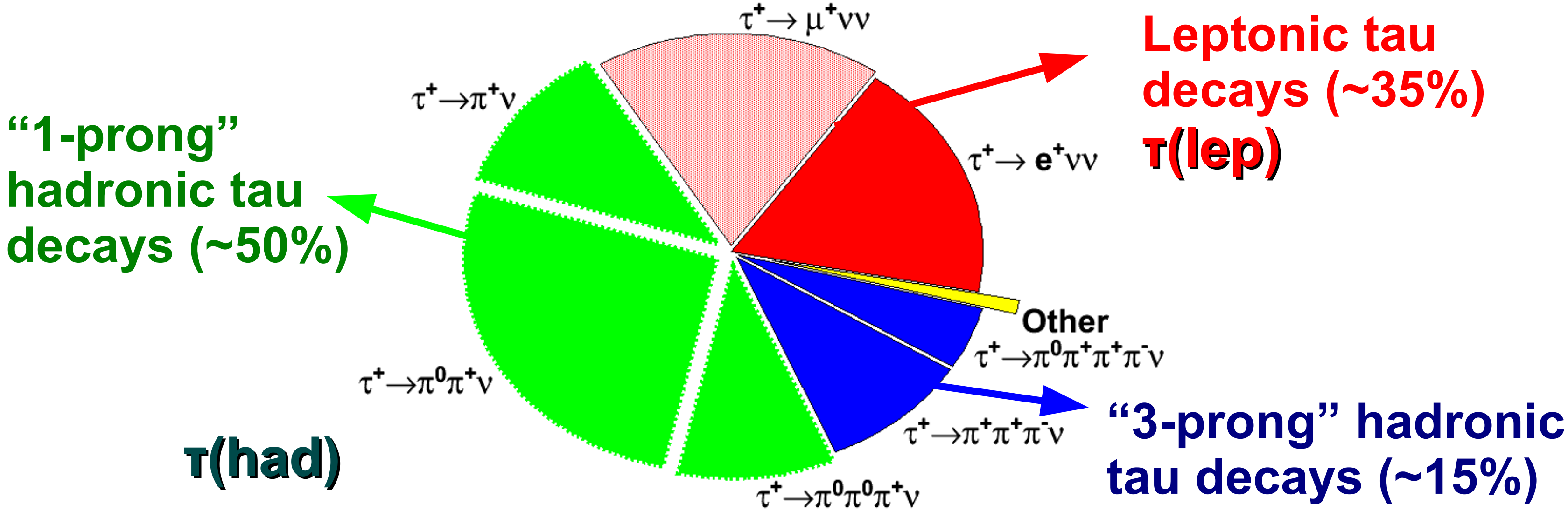
THE FOG WON'T GET CLEARED BY ITSELF!

theorists

Extra Slides

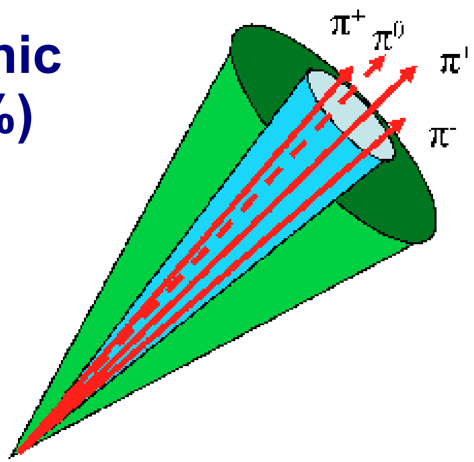
Taus

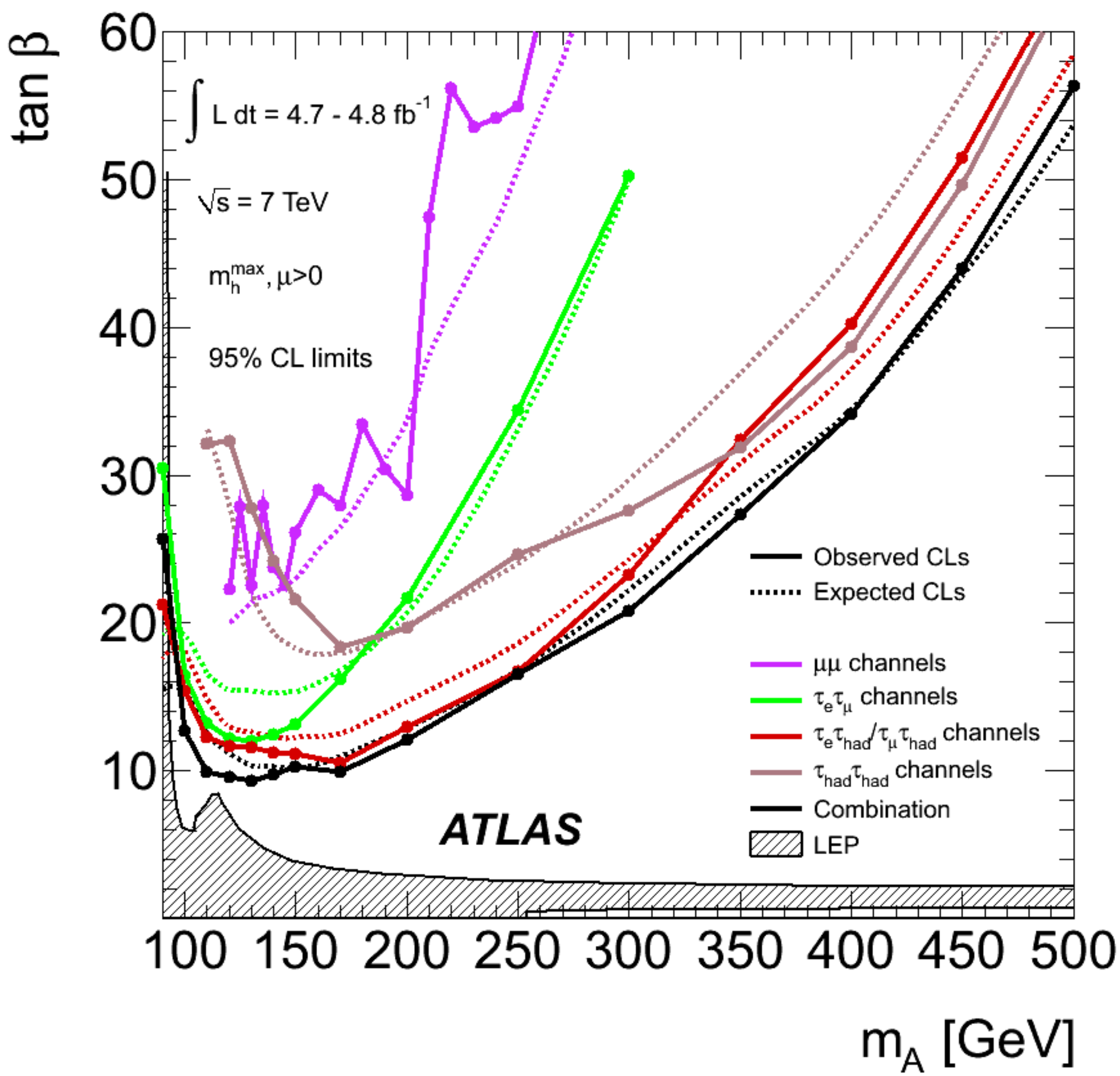
- "Golden" MSSM Higgs search channels: **H→ττ, H±→τ±ν**
- Taus: the only leptons that can decay hadronically



Studies with taus are involved:

- neutrinos in the final state: degraded di-tau mass resolution
- pions in τ(had): large fake rates from multi-jet production



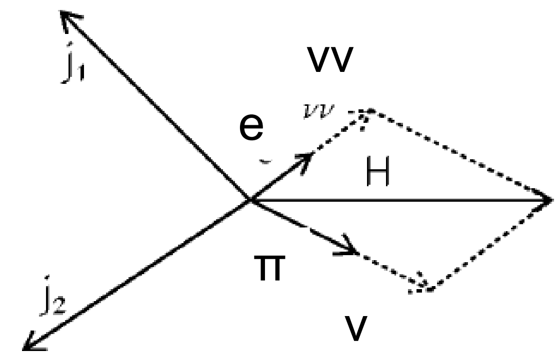


tan β
60
50
40
30
20
10
100 150 200 250 300 350 400 450 500
m_A [GeV]
$\int L\,dt = 4.7 - 4.8\ fb^{-1}$
$\sqrt{s}$ = 7 TeV
m_h^{max}, μ>0
95% CL limits
ATLAS
Observed CLs
Expected CLs
μμ channels
$\tau_e\tau_\mu$ channels
$\tau_e\tau_{had}/\tau_\mu\tau_{had}$ channels
$\tau_{had}\tau_{had}$ channels
Combination
LEP

Missing Mass Calculator

- An extension of the collinear mass approximation
  - Collinear mass: assume that neutrinos are emitted in the same direction as the visible decay products

$$\not{E}_X = P_{\nu 1} \cdot \cos(\theta_1) \cdot \cos(\varphi_1) + P_{\nu 2} \cdot \cos(\theta_2) \cdot \cos(\varphi_2)$$
$$\not{E}_Y = P_{\nu 1} \cdot \cos(\theta_1) \cdot \sin(\varphi_1) + P_{\nu 2} \cdot \cos(\theta_2) \cdot \sin(\varphi_2)$$



  - Missing mass calculator:

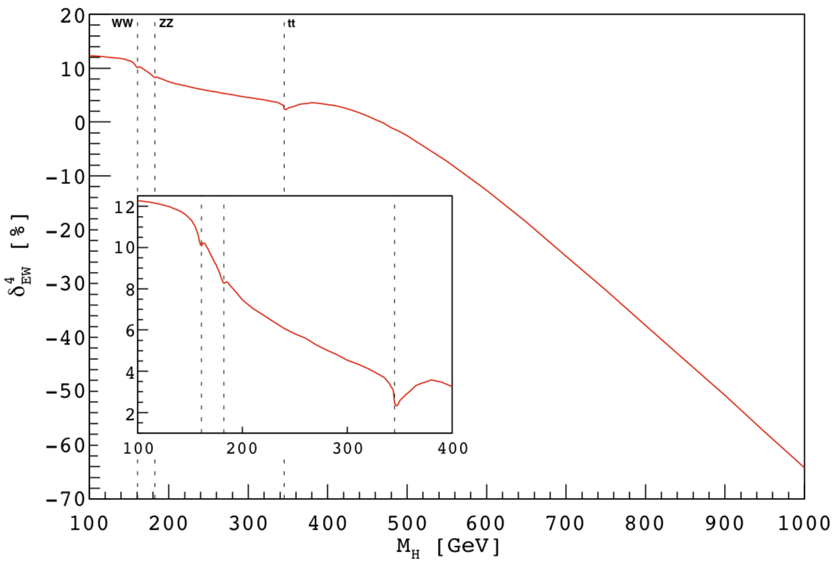
→ Write the full equation system: more unknowns than equations
→ parameterise the 3D angle between visible and invisible tau decay products from MC simulation, dθ
→ solve the equation on a grid of the extra unknowns and calculate the most probable choice using the dθ distribution

$$E_x^{miss} = p_{\text{mis}_1} \sin\theta_{\text{mis}_1} \cos\phi_{\text{mis}_1} + p_{\text{mis}_2} \sin\theta_{\text{mis}_2} \cos\phi_{\text{mis}_2}$$
$$E_y^{miss} = p_{\text{mis}_1} \sin\theta_{\text{mis}_1} \sin\phi_{\text{mis}_1} + p_{\text{mis}_2} \sin\theta_{\text{mis}_2} \sin\phi_{\text{mis}_2}$$
$$M_{\tau_1}^2 = m_{\text{mis}_1}^2 + m_{\text{vis}_1}^2 + 2\sqrt{p_{\text{vis}_1}^2 + m_{\text{vis}_1}^2}\sqrt{p_{\text{mis}_1}^2 + m_{\text{mis}_1}^2} - 2 p_{\text{vis}_1} p_{\text{mis}_1} \cos\Delta\theta_{vm_1}$$
$$M_{\tau_2}^2 = m_{\text{vis}_2}^2 + 2\sqrt{p_{\text{vis}_2}^2 + m_{\text{vis}_2}^2}\sqrt{p_{\text{mis}_2}^2 + m_{\text{mis}_2}^2} - 2 p_{\text{vis}_2} p_{\text{mis}_2} \cos\Delta\theta_{vm_2}$$

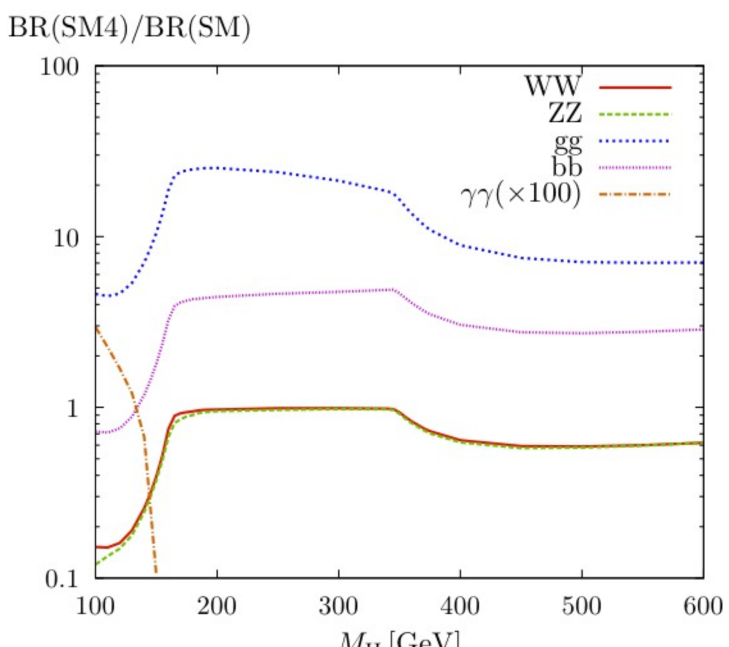
SM4

- An additional 4th generation of fermions modifies the gg fusion production mode and the higgs decay branching ratios

arXiv:1201.3084



NLO EW correction to the ggF Higgs production in SM4



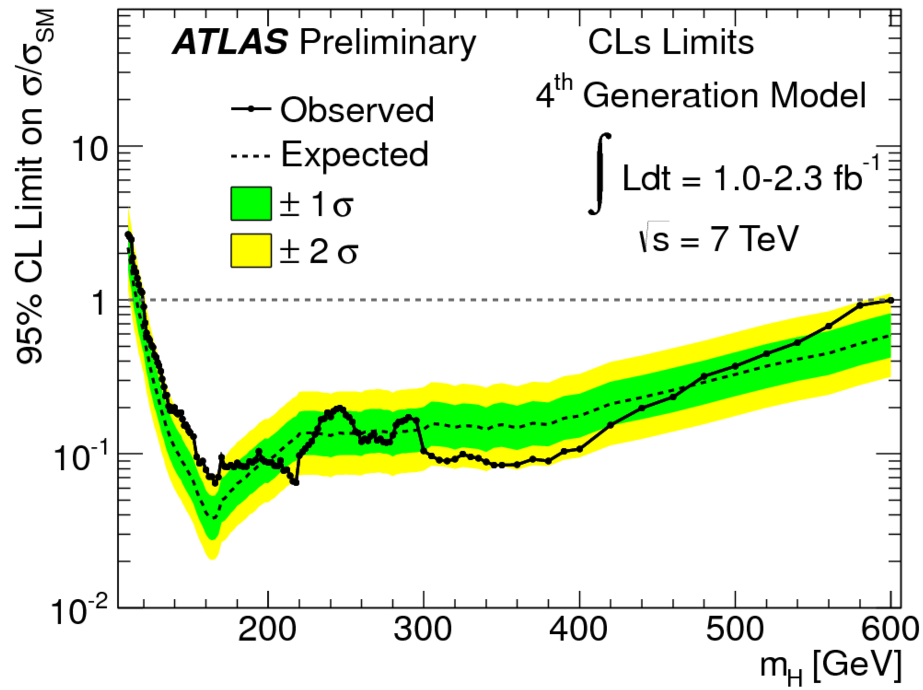
Ratio of BR in SM4/SM calculated with Prophecy4f and HDECAY

$m_{D4} = m_{L4} = 600$ GeV and $m_{U4} - m_{D4} = (50 + 10 \ln(m_H/115))$ GeV

SM4

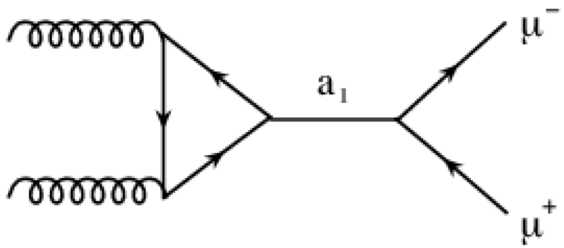
- The enhanced cross section relative to the SM allows an exclusion of large parts of the parameter space
  - Higgs mass range 119-600 GeV excluded

ATLAS-CONF-2011-135



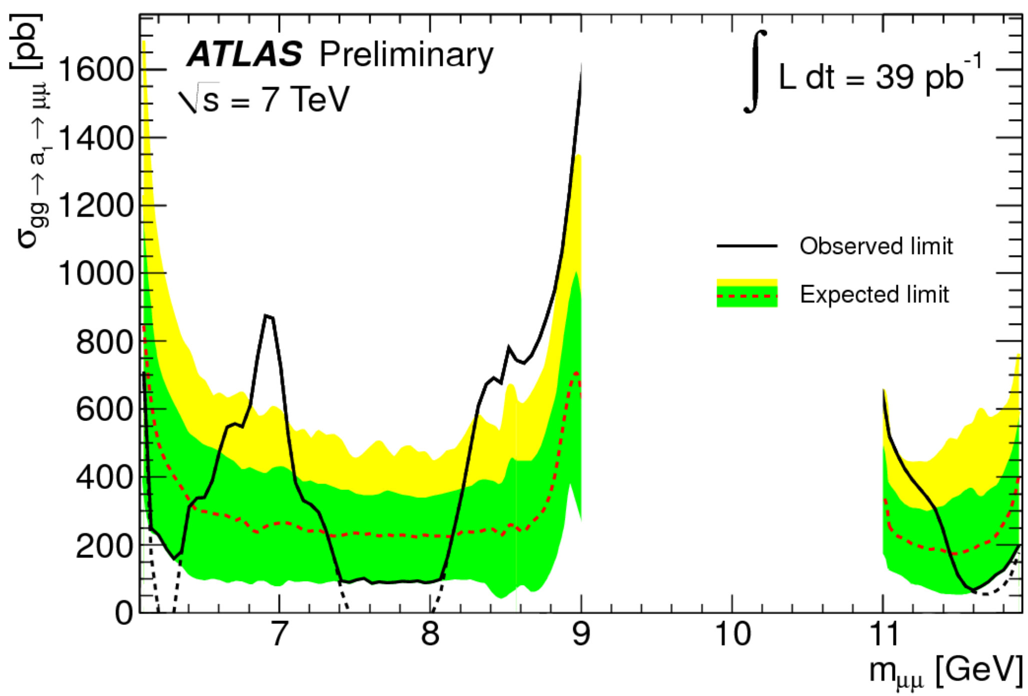
Light Scalar Field

- Light scalar Higgs boson: NMSSM allows a ~10 GeV CP-odd Higgs with a sizeable BR to a di-muon pair
  - Search for it in the Υ sidebands



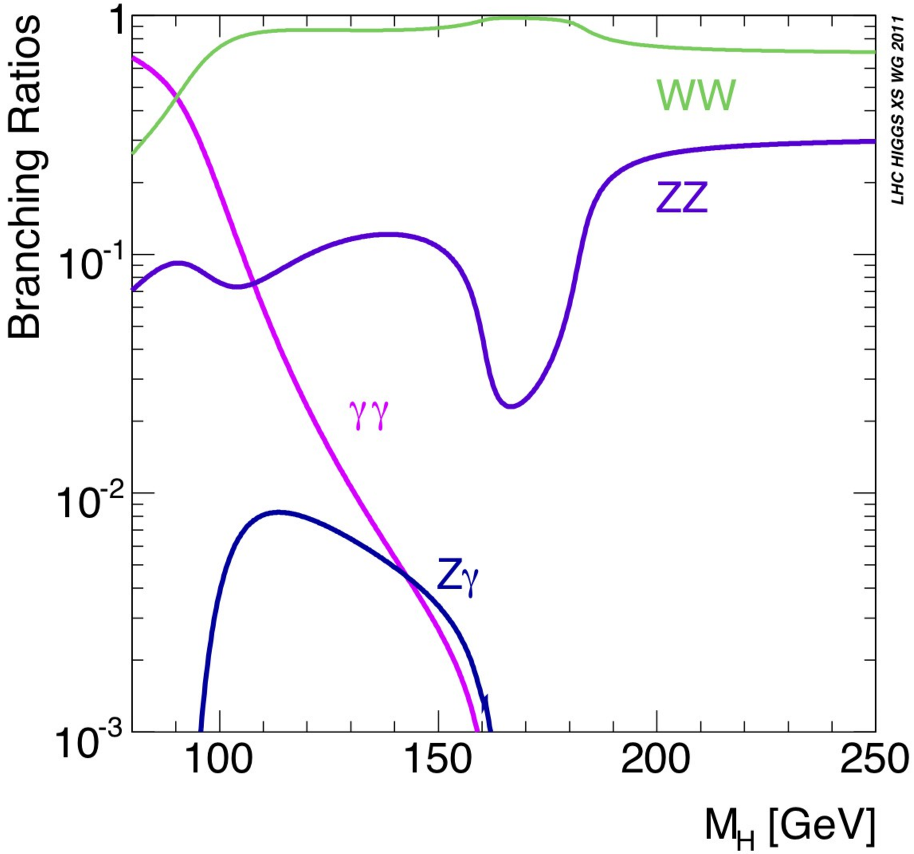
ATLAS-CONF-2011-020

a → μμ (NMSSM)
2 isolated μ, $p_T > 4$ GeV, opposite sign
Multivariate technique to reject muons not coming from the decay of a single particle
Sidebands $m_{\mu\mu}$: 6-9 GeV and 11-12 GeV



Fermiophobic Higgs

- No couplings to fermions
- Production via VBF and VH
- Decay via γγ, ZZ, WW and Zγ
- ATLAS search focuses on γγ; WW and ZZ also an option

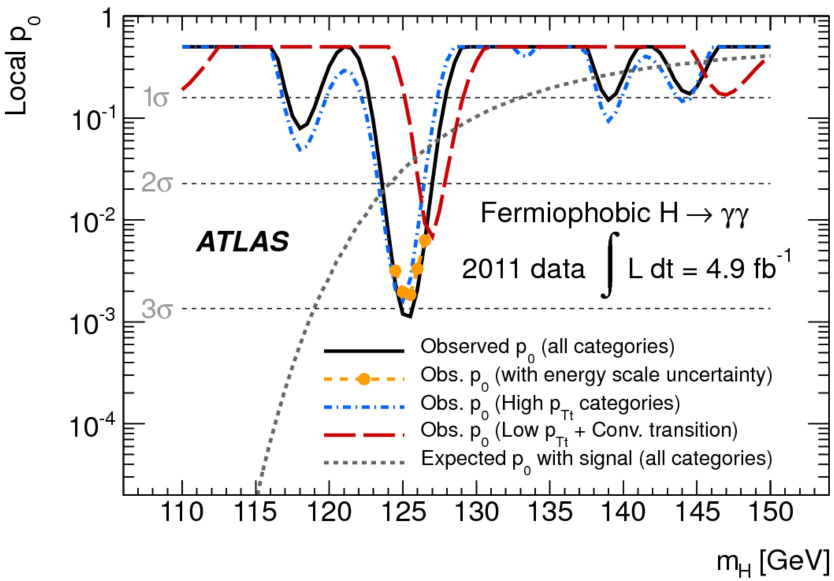


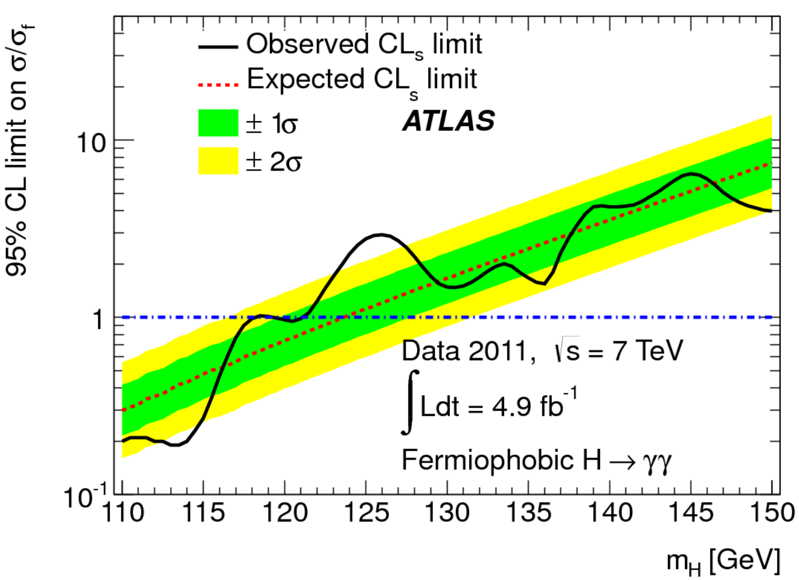
Fermiophobic Higgs Search

- Fermiophobic Higgs models modify SM Higgs couplings and affect Higgs production & decay
- ATLAS search follows the SM $H \rightarrow \gamma\gamma$ search; only signal model changes

2 photons pT > 40 / 25 GeV
Categories based on conversions, η and di-photon p_T
Signal modelled with “crystal ball” (= gaussian core+power law low-end tail) +gaussian; bkg with exponential

arXiv:1205.0701





$H \rightarrow aa \rightarrow \gamma\gamma + \gamma\gamma$

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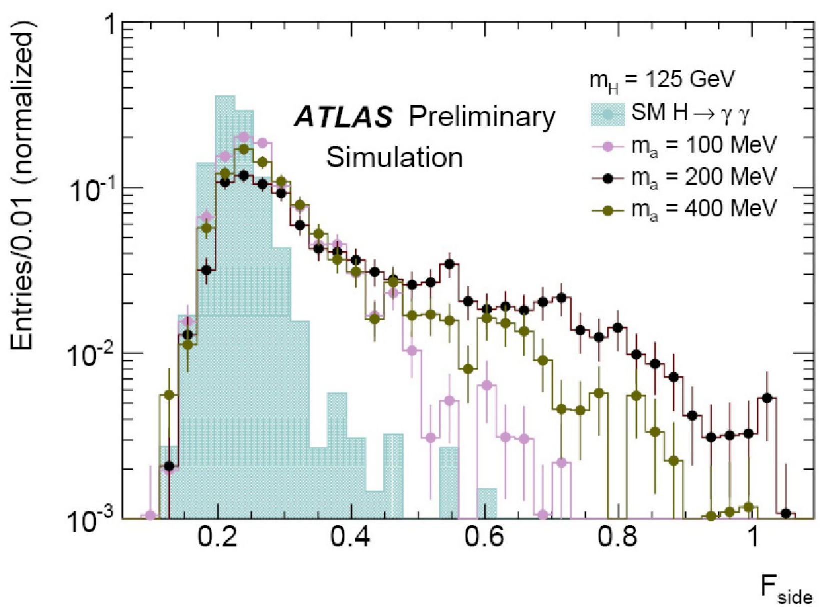
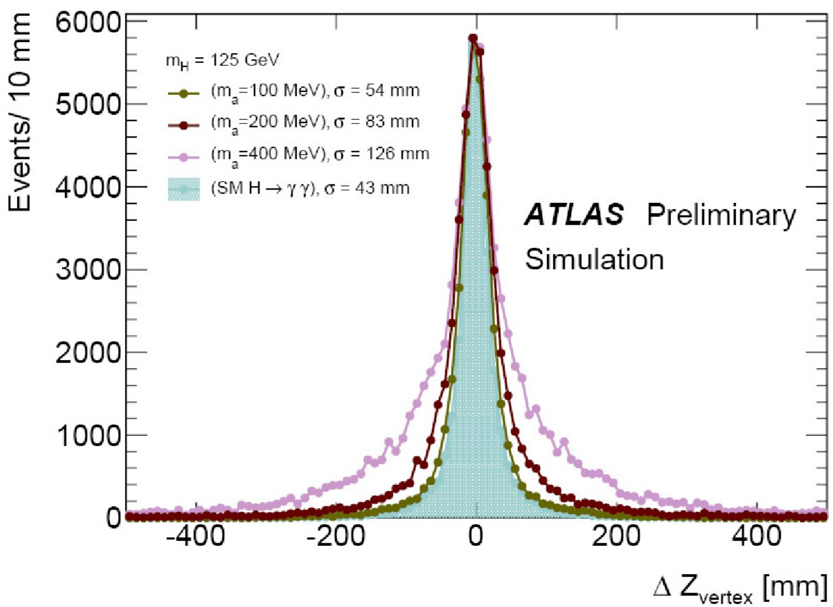
- Dedicated photon ID tuning is needed since a γγ-pair reconstructed as a single photon is different from a single γ: remove affected shower shape variables from photon ID
- Also other properties are affected (e.g. photon pointing)



Electromagnetic shower width measure



Photon pointing to vertex: z resolution

$H \rightarrow aa \rightarrow \gamma\gamma + \gamma\gamma$

ATLAS-CONF-2012-079

- Limits for other m_a masses