$\mathbf{A \rightarrow Zh \rightarrow \ell^+\ell^- \tau^+\tau^-}$

Analysis overview and motivation for the search of the pseudoscalar Higgs with the ATLAS experiment

Guillermo Nicolas Hamity
Supervisor: Trevor Vickey

University of the Witwatersrand

SAIP - July 10, 2014

SM Higgs discovered (125 GeV) → is the Higgs sector minimal? is it extended?

- SM Higgs sector has experimental constraine:

$$\rho \equiv m_W/(m_Z \cos\theta_W) \to 1$$

- 2HDM: Simple extension by adding complex Higgs doublet, SU(2), satisfying $\rho \to 1$
- **Assumptions**:
  - CP-conservation
  - Softly broken $\mathcal{Z}_2$ symmetry ($\Phi_1 = -\Phi_1$)
  - Electroweak symmetry breaking, and $v_1 v_2 \neq 0$
- Resulting 8 fields:
  3 give mass to $W^{\pm}$ and Z bosons,

5 physical **scalar ("Higgs") fields**

- CP-odd pseudoscalar → A
- 2CP-even
  - h **(light)**
  - $m_h < m_H$
  - H **(Heavy)**
- 2 scalar charged → $H^{\pm}$

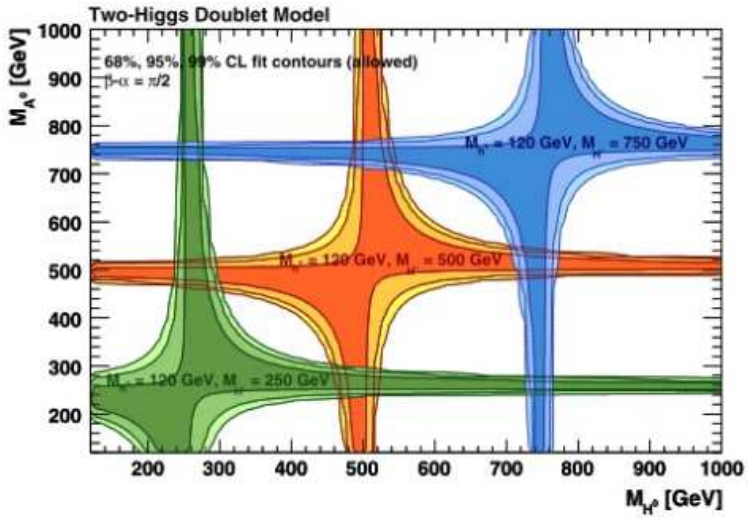
Motivation for 2HDM search at High-Lumi with ATLAS

- ATLAS Note motivates 2HDM searches at high luminosity:
  Beyond-the-Standard-Model Higgs boson searches at a High-Luminosity LHC with ATLAS.
  ATL-PHYS-PUB-2013-016

- Sensitivity study done for high Luminosity (300 and 3000 fb^{-1} $pp, \sqrt{s} = 14$ TeV)
  - $A \to Zh \to \ell\ell bb$
  - $H \to \mu\mu$.
  - $H \to ZZ^{'} \to 4\ell$
- **Assumtions that are made:**
  - $m_h = 125$ **GeV**.
  - $m_A = m_H = m_{H^{\pm}}$
    Mass splitting disfavoured by considering potential parameters and changes in ρ.
- Degrees of freedom:

$$m_A \qquad tan\beta \qquad \cos(\beta - \alpha) \to 0$$

Generally $A \to Zh$ is dominant decay mode of A in any 2HDM for $m_h + m_Z < m_A < 2m_{top}$.



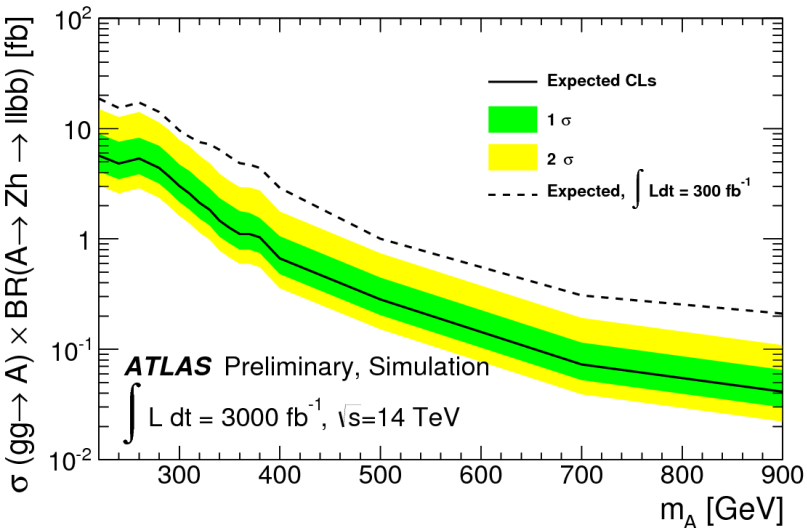
Eur. Phys. J. C (2012) 72:2003

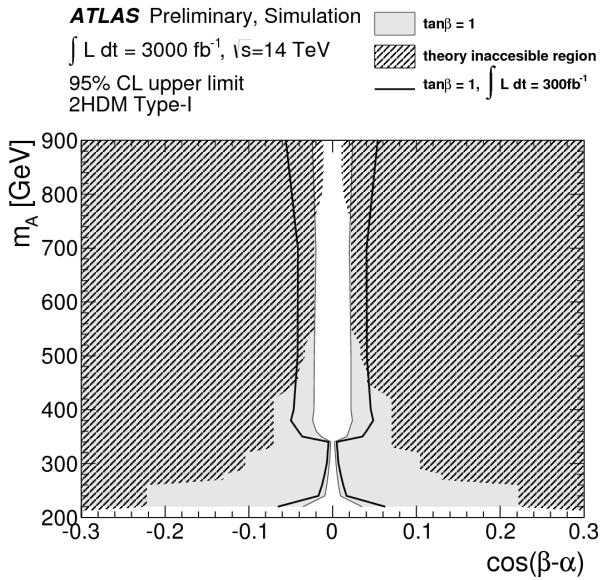
Figure: Constraints in the 2HDM

95% CL upper limits for $m_A \in$ 220-900 GeV for 3000 fb^{-1}.

Exclusion zone if no signal on the $\cos(\beta-\alpha)$ - m_A plane for $\tan\beta = 1$ are shown.

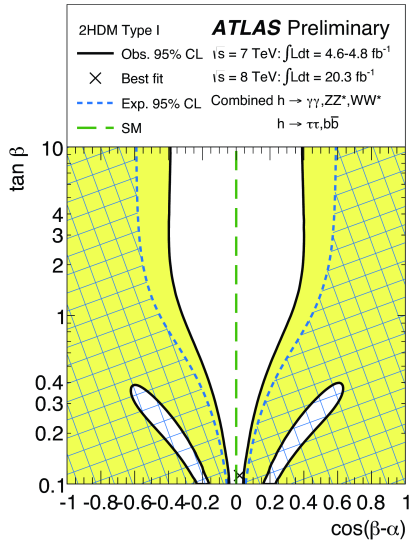
Ref: *ATL-PHYS-PUB-2013-016*.





Complimentary limits set by constraints on New Phenomena via Higgs Coupling Measurements with the ATLAS Detector

ATLAS-CONF-2014-010.



Results from CMS search for extended Higgs sectors

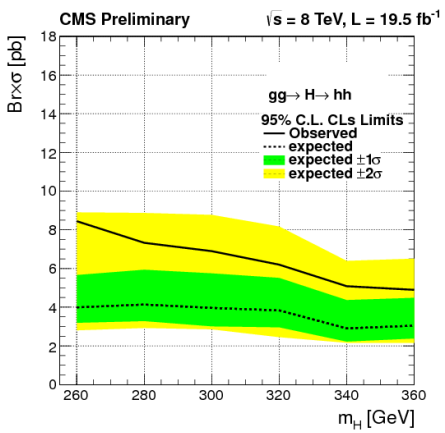
CMS Note on BSM search results: Search for extended Higgs sectors in the $H \to hh$ and $A \to Zh$ channels in $\sqrt{(s)} = 8$ TeV pp collisions with multileptons and photons final states
CMS-PAS-HIG-13-025

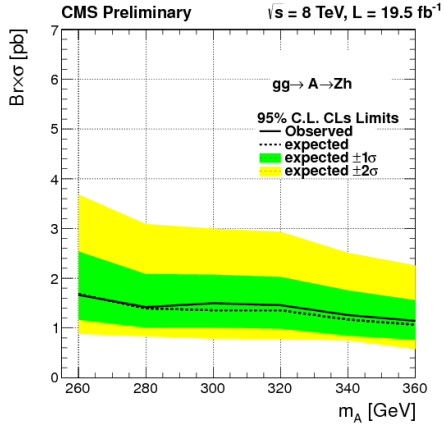
- Search for $H \to hh$ and $A \to Zh$: 19.5 fb^{-1}; $\sqrt{s} = 8$ TeV.
- CL limits in the range **260-360 GeV** → consistent with the **SM**.
- Significant portions of 2HDMs parameter excluded.
- Final states considered:

$Z \to$ \ $h \to$	WW^*	ZZ^*	$\tau\tau$	$\gamma\gamma$	bb
$\ell\ell$	✓	✓	✓ ☑	✓	X ☑
qq	X	✓	X	X	X
$\nu\nu$	X	✓	X	X	X ☑

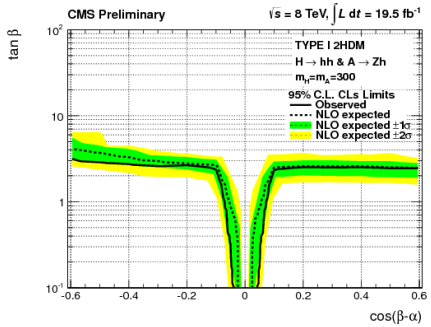
$A \to Zh$ ATLAS search: ☑

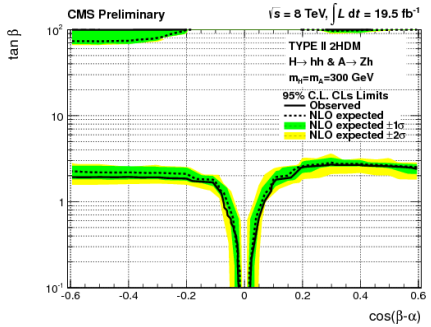
- CMS inclusive search strategy vs ATLAS fully reconstructed .





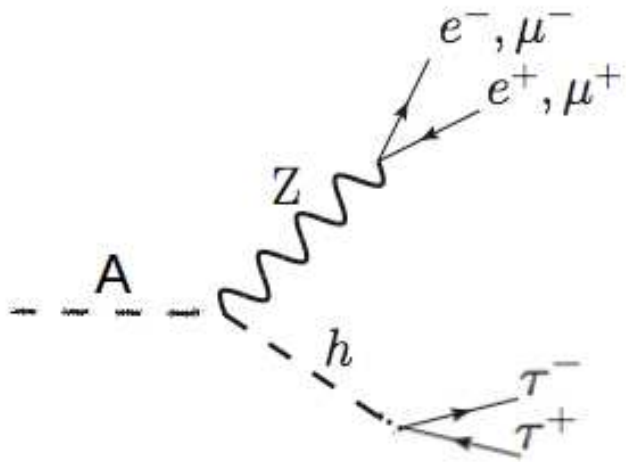
Observed and expected limits with 1 and 2-σ bands for $H \to hh$ (left) and $A \to Zh$ (right) in terms of $\sigma * Br$ based on multilepton and diphoton channels.





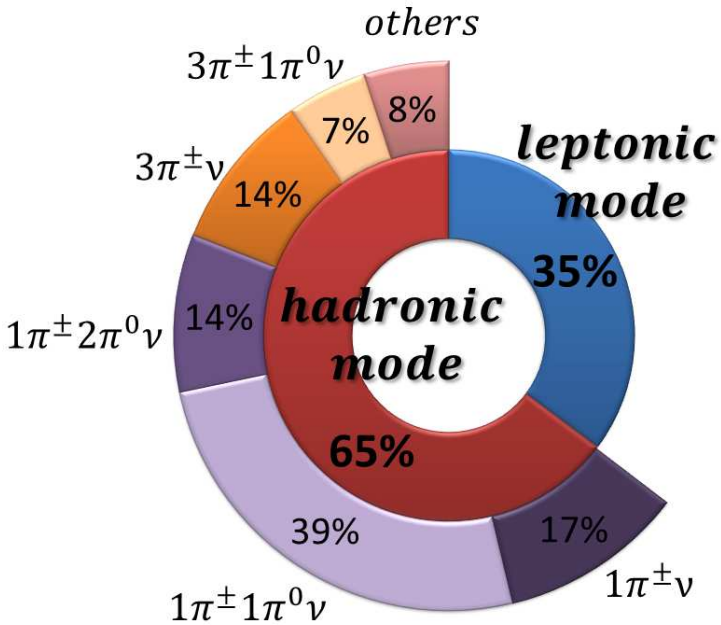
Observed and expected limits with 1 and 2-σ bands on combined signal for H and A in Type-I (left), and Type-II (right) 2HDMs ($m_H = m_A = 300 GeV$). Regions below limits are excluded.

- $A \to Zh$ analysis searching for $m_A \in (220, 1000)$ GeV at 8TeV pp collisons with 20 fb^{-1}.



- $A \to Zh(\tau\tau)$
  - $\to \ell\ell\tau_\ell\tau_\ell$ (leplep)
  - $\to \ell\ell\tau_{had}\tau_\ell$ (lephad)
  - $\to \ell\ell\tau_{had}\tau_{had}$ (hadhad)

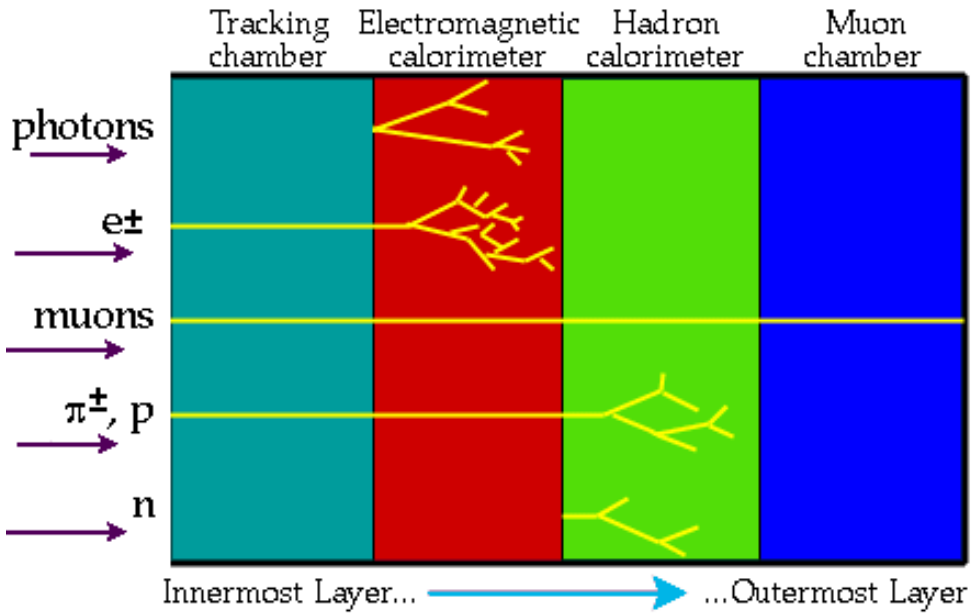
τ Decays:



- Documentation: HSG6/notes/HiggsToHiggs/AZh/Internal_AZh_lltautau

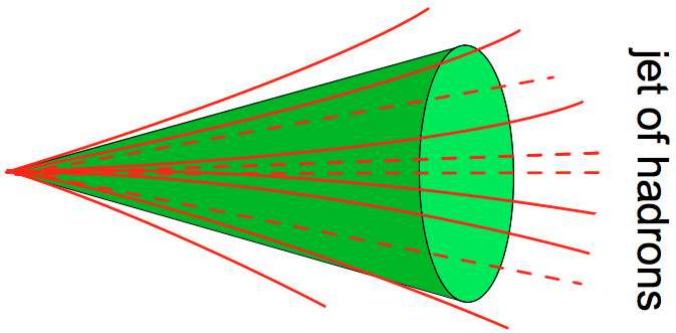
The Fake Tau Problem

Different decays in ATLAS detector:

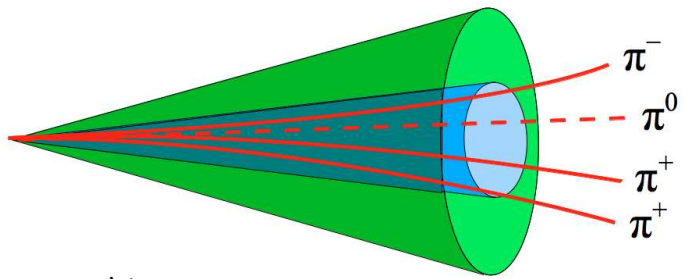


Taus never make the inner-detector (can only look at decays)

Non-Tau Jet



Tau Jet



- Narrow cone jet
- 1- or 3- prong jet

Processes with 2ℓ and 2 taus (had)

Processes with 2ℓ and 2 jets serve as irreducible backgroung

Preselection of HadHad channel

Event Preselection for hadronic channel:

- Single lepton triggers.
- Leptons: 2 loose ℓ SF, OS
  Z mass window: $80 < m_{ll} < 100$ GeV
  Isolation (ptcone40/$p_{\mathrm{T}} < 0.2$ and etcone20/$p_{\mathrm{T}} < 0.2$)
- Taus: 2 loose τ_{had}
  muon and electron vetos
  H mass window: $75 < m_{ll} < 175$ Gev.
- Events with additional light leptons or $\tau_{\mathrm{had-vis}}$ are discarded.

Background Monte Carlo:

- Z+jets (DY)
- Diboson: ZZ,WZ,WW
- Tribozon: WWW*,ZWW*,ZZZ*
- Top: t$\bar{t}$, tW, tℓ, t$\bar{t}$Z
- SM assosiated Higgs production: ZH

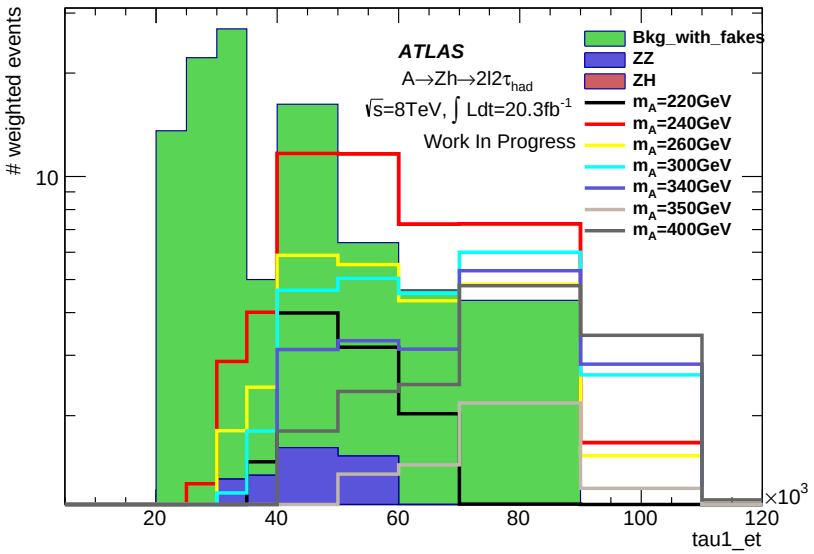
10 Signal Mass points (in GeV):
220,240,260,300,340,350,400,500,800,1000

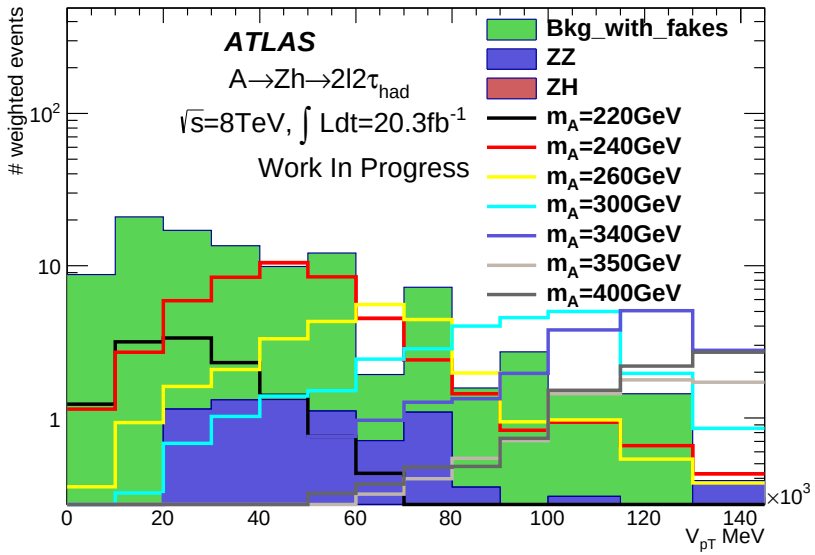
Had-had optimization

Discriminating variables are shown below after pre-selection.
Further optimization done by maximising signal significance at every mass point.

Performed a scan of the significance defined as

$$Sig = \sqrt{2 \cdot \left((S+B) \cdot \ln(1+\frac{S}{B}) - S \right)}$$





Backgrounds with fakes

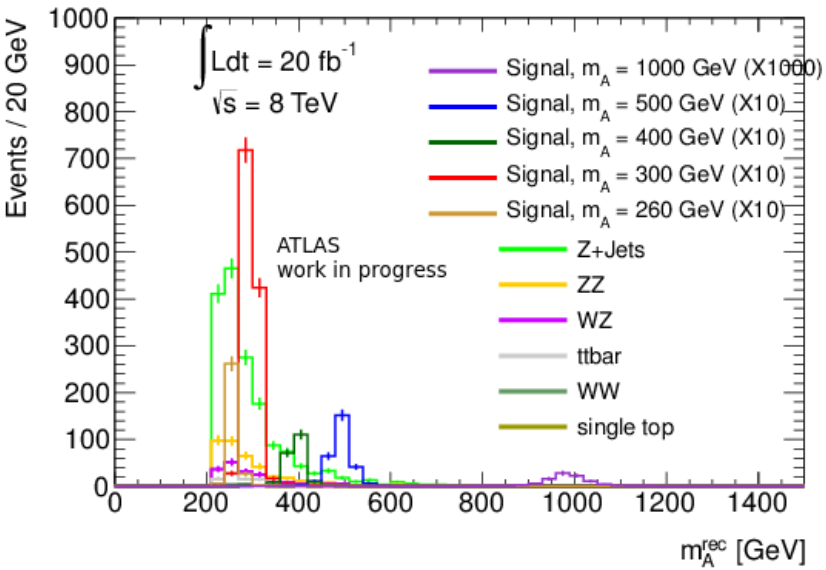
are due to jets **faking taus**

Full selection for Hadhad channel

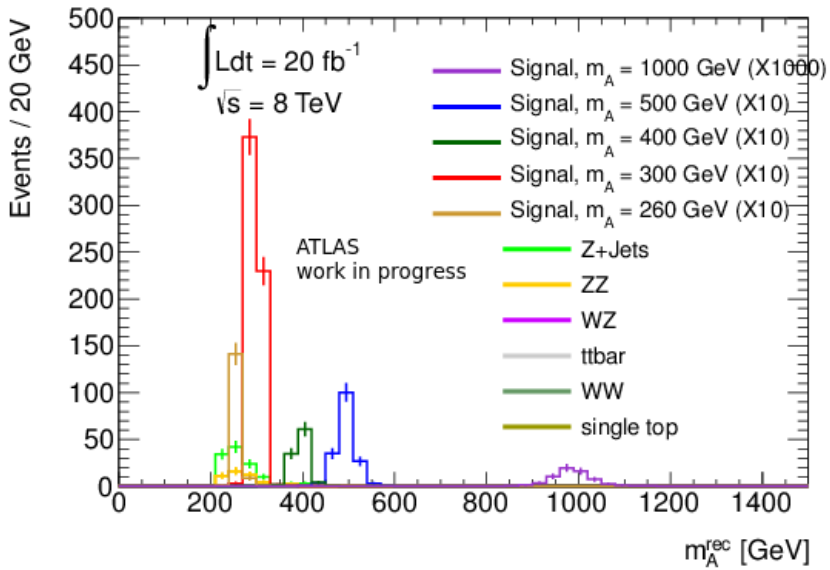
Full Selection

- The leading $\tau_{\text{had-vis}}$ is required to have $E_t > 35$ GeV
- For events with $m_A <= 400$ GeV, $Z\ p_{\text{T}} > (0.64 m_A$ - 131) GeV.
- For events with $m_A > 400$ GeV, $Z\ p_{\text{T}} > 125$ GeV.

Pre-selection



Full-selection



Data estimated background

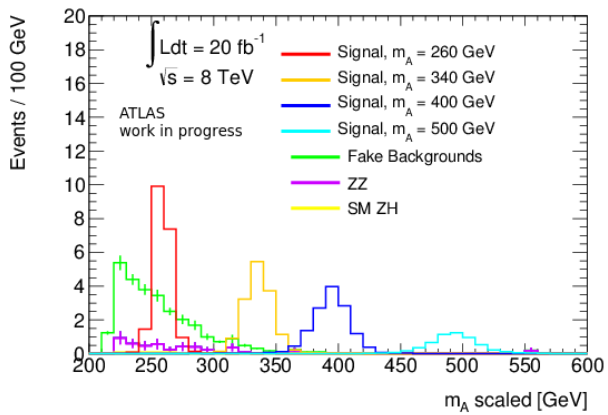
- Blind in signal region.
- Data can boost BKG predictions.
- Bkgs with fake taus estimated using template.

Template Method

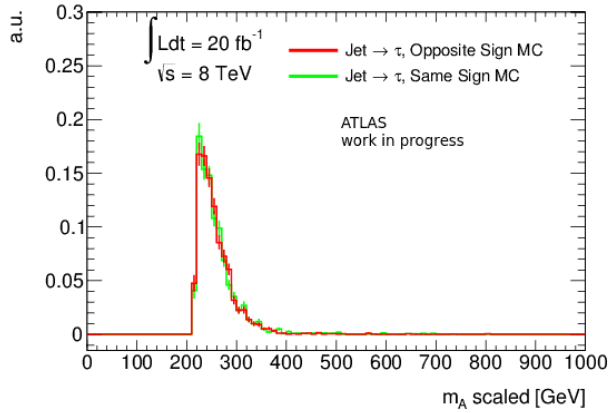
- Define 3 control regions populated with fakes:

OS — loose τ	**SS — loose τ**
OS — !loose τ	**SS — !loose τ**

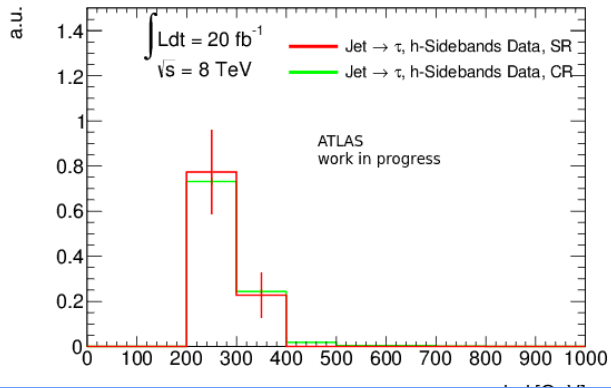
- Bkg shape extrapolated from CR to SR
- Bkg normalized using m_A sideband



- Important assumptions:
  - Template m_A shape is good in SR.



- and
  - Normalisation in h-sideband describes m_h window



Had-had final signal acceptance

Signal acceptance increases with m_A, except at the highest mass point, where high p_{T} leptons failing the isolation requirements result in a lower acceptance.

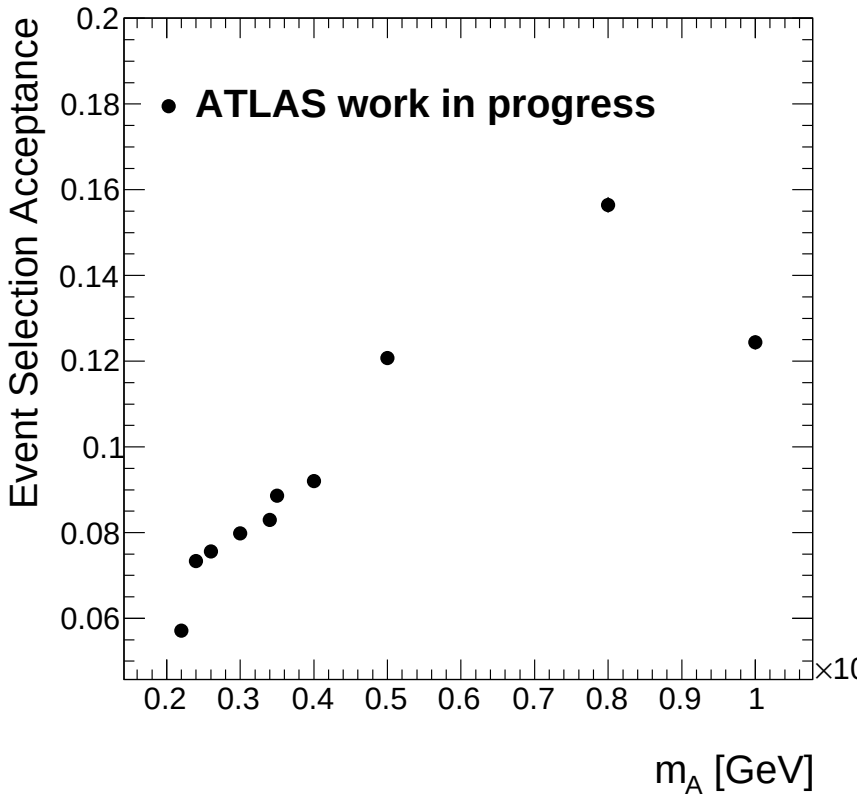


Figure: The signal acceptance for simulated signal samples, for all m_A available mass points.

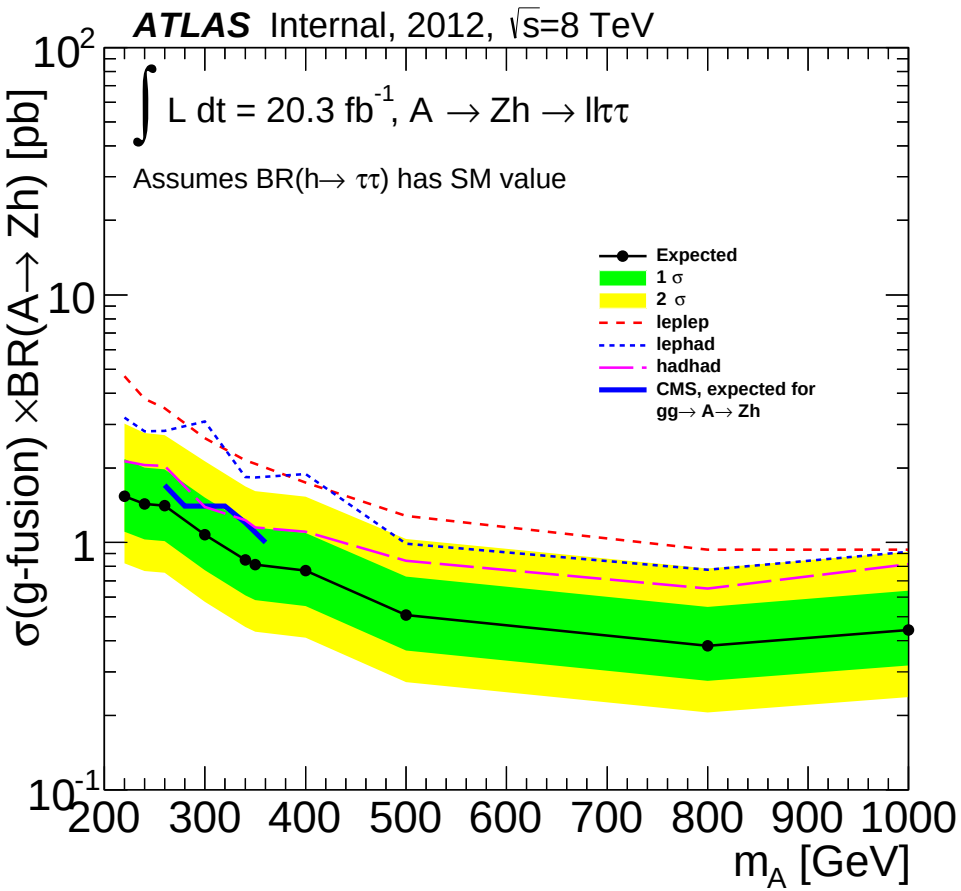
Systematics

Experimental systematics negligable when compared to template systematics.

- Experimental
  - Electron, muon, tauID
  - Pile-up and Luminosity
  - Jet Energy Scale
  - Tau Energy Scale
  - Tau Energy Resolution
  - Tau Energy Scale
  - Missing Transverse Energy
  - Jet Vertex Fraction
- Theoretical systematics being considered
- Template method systematics:

  Changes in normalization and template due to different CR
  - Region 1 (R1): events with 2 loose τ that are of same sign charge,
  - Region 2 (R2): events with 2 τ, where one fails the loose τ ID, of opposite sign charge.
  - Region 3 (R3): events with 2 τ that fail the loose τ ID, of opposite sign charge.
  - Region 4 (R2): events with 2 τ, where one fails the loose τ ID, of same sign charge.
  - Region 5 (R3): events with 2 τ that fail the loose τ ID, of same sign charge.

Conclusion



Currently blind. Hoping to look at data in the coming months Planning to combine in a note with:

- $A \to Zh(bb)$
  - $\to \ell\ell bb$
  - $\to \nu\nu bb$
- Similar VH(bb) [ATLAS-CONF-2013-079]