Results of the search for Heavy Higgs and BSM Higgs Bosons from ATLAS

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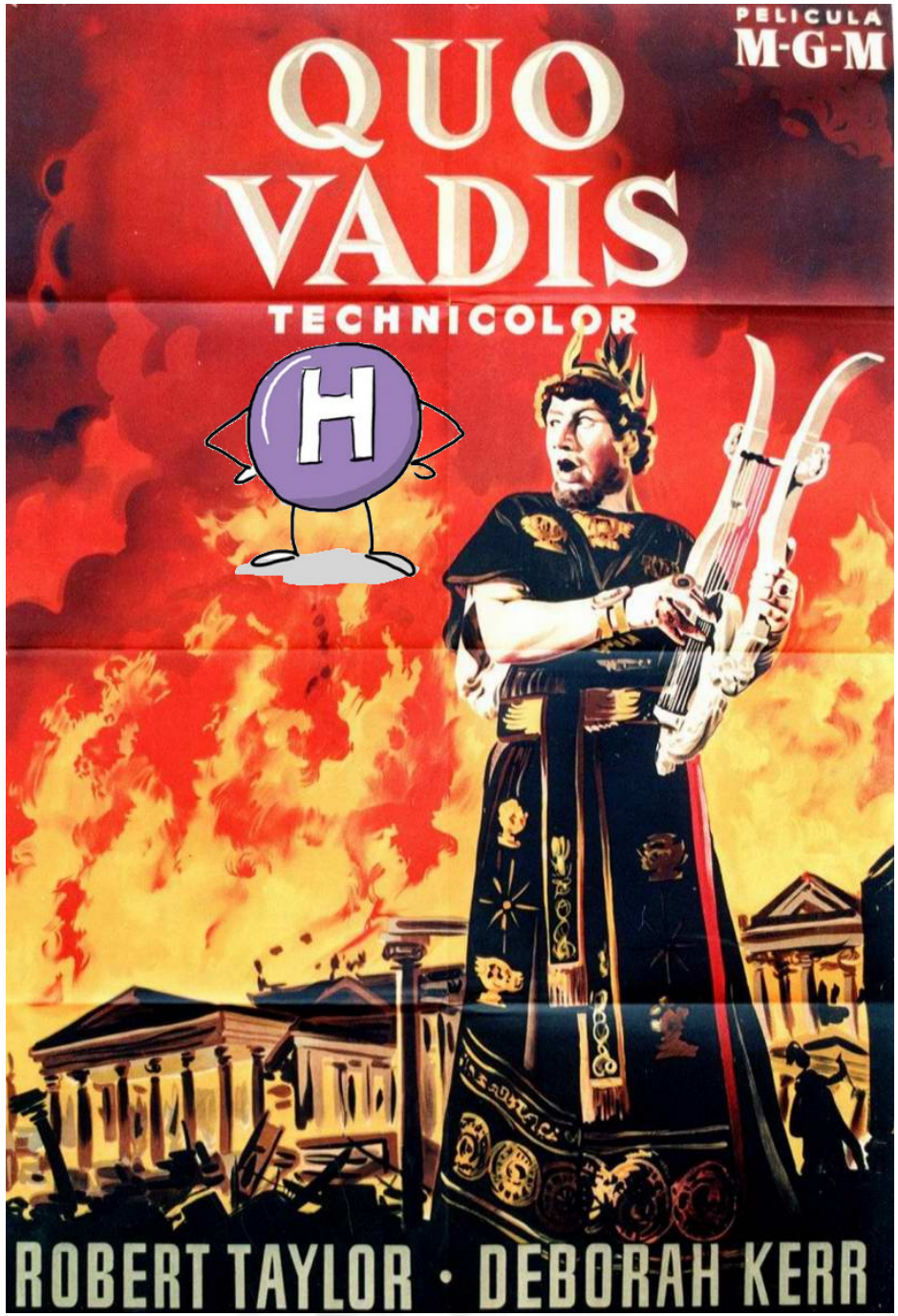
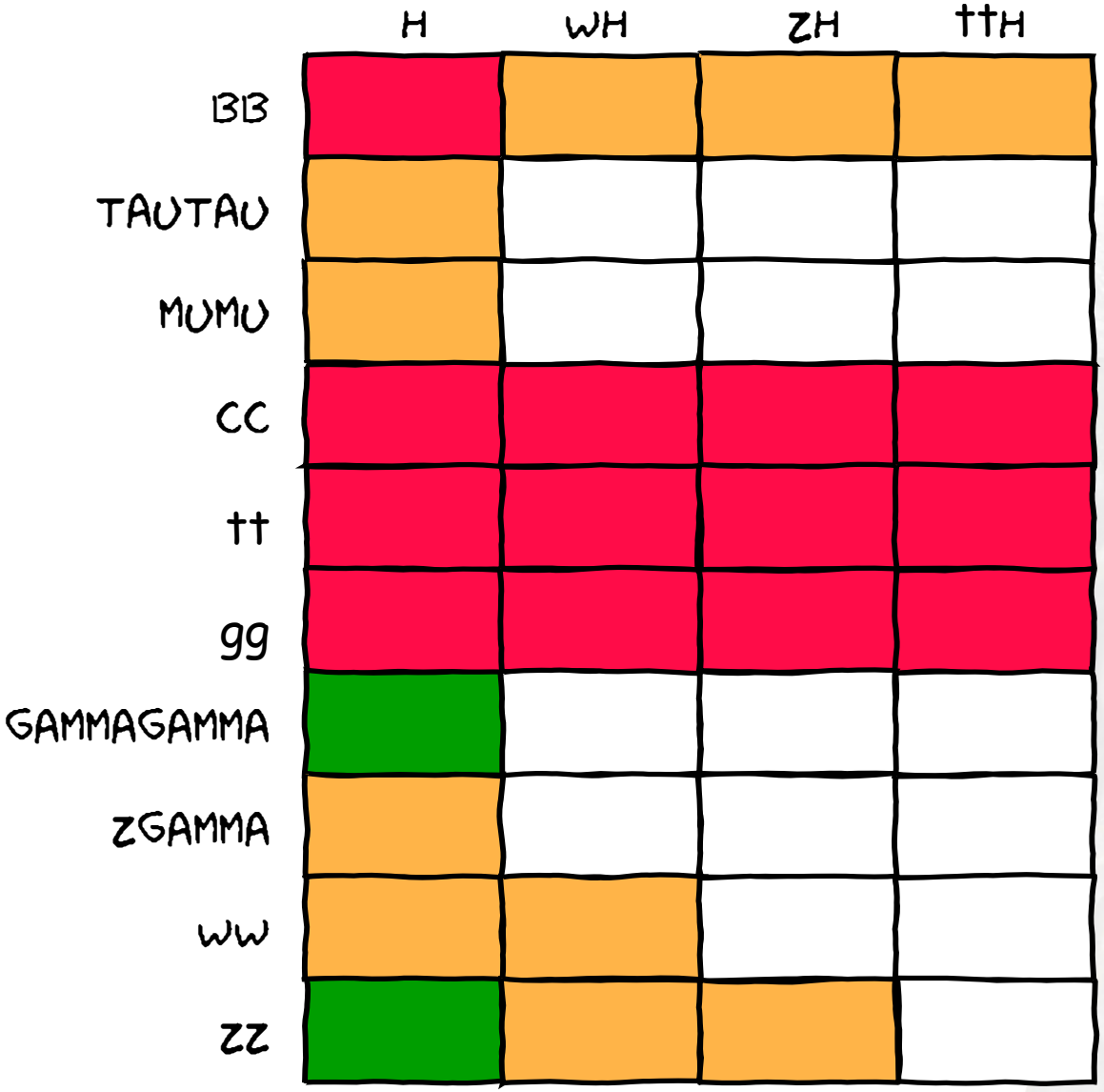
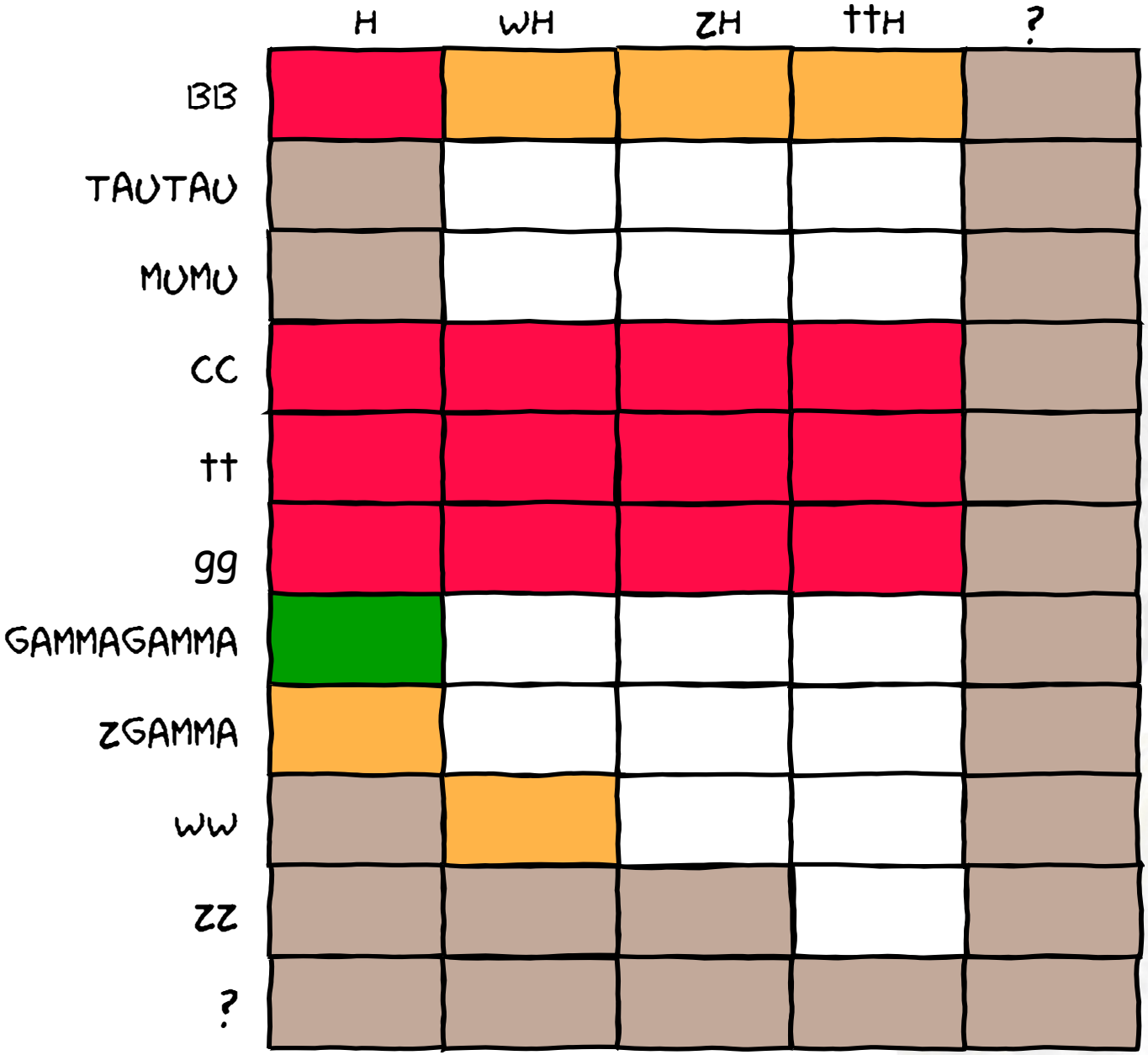
   - $H \to \tau\tau$
   - $H \to \mu\mu$
3. Doubly Charged Higgs
4. Vector Boson Decays
   - $WW \to \ell\nu qq$
   - $ZZ \to \ell\ell\nu\nu$
   - $ZZ \to \ell\ell\ell'\ell'$
5. Summary and Conclusions





single channel observation, public result with $< 3\sigma$, lost cause?

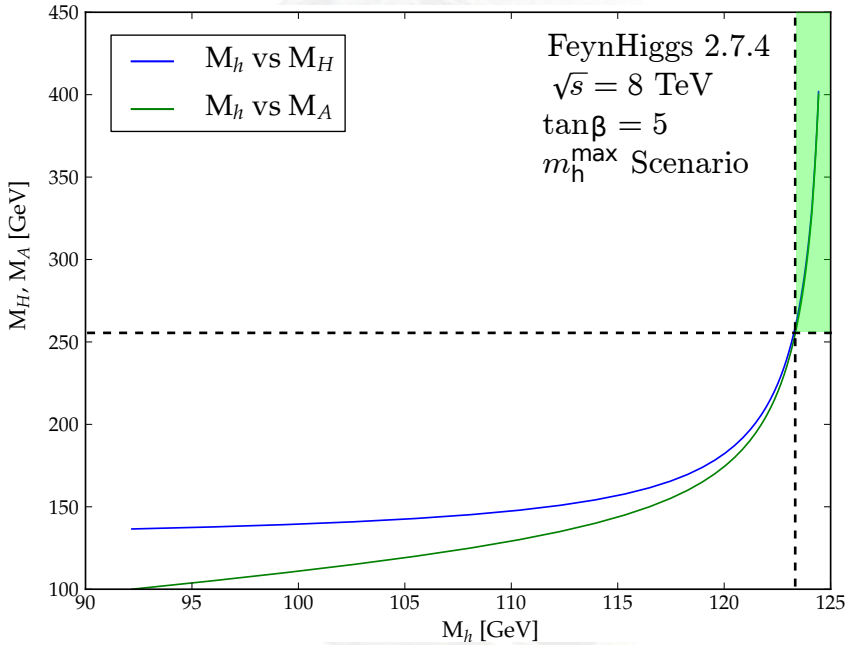


single channel observation, public result with $< 3\sigma$, lost cause?

MSSM Higgs Boson

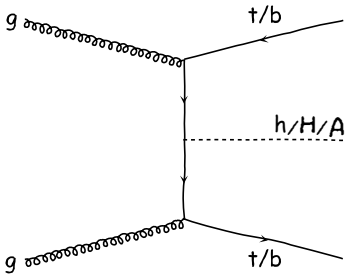
Typically discuss searches for MSSM Higgs bosons in terms of benchmark scenarios where the lowest-order input parameters tan β and M_A ($M_{H^\pm}$) are varied.

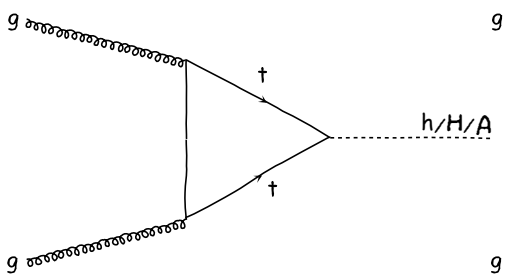
All other SUSY parameters (which only enter as radiative corrections) are fixed to some benchmark value (typically m_h^{max}, which favors a high-mass $A0$).

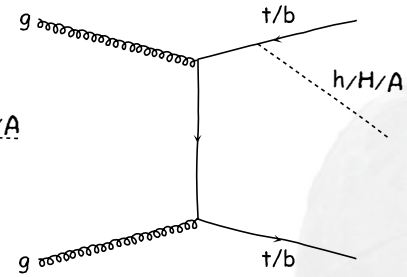


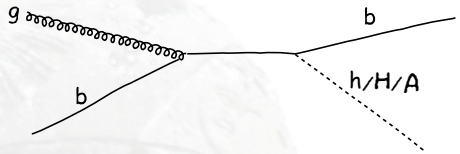
Existence of a 125 GeV Higgs boson does not in any way preclude the presence of an MSSM Higgs sector.

Neutral MSSM Higgs

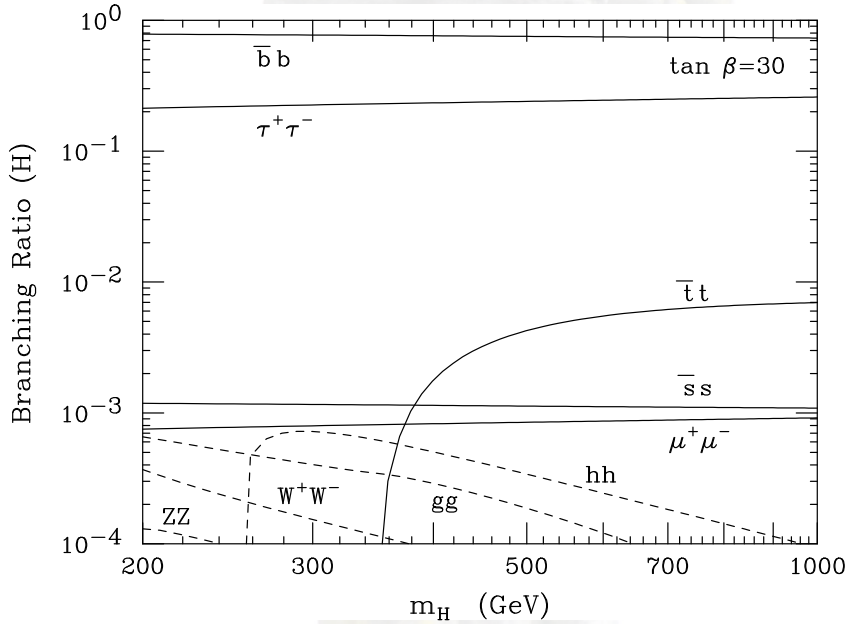






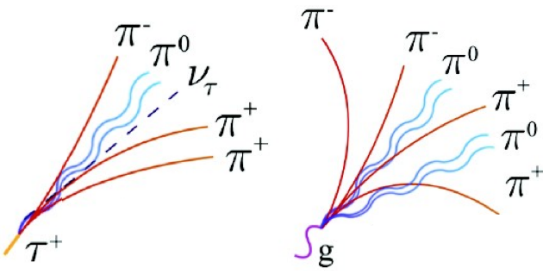


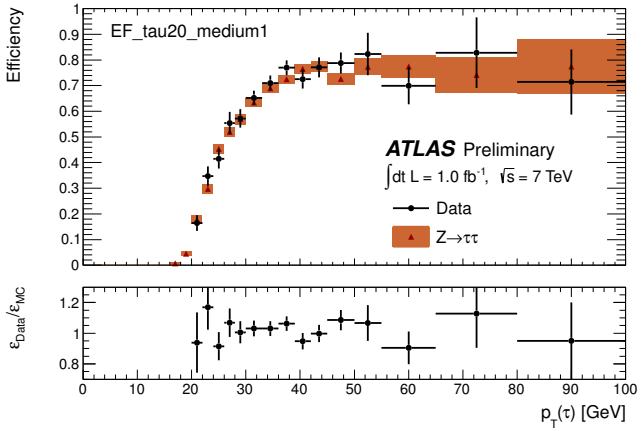
- Three neutral $\Phi = h, H, A$
- Dominant production modes are through gluon-gluon fusion and associated *b*-quarks (enhanced by $\tan\beta$).
- ATLAS searches in final states with:
  - μ pairs
  - $\tau(\ell)\tau(\ell)$, $\tau(\ell)\tau(\text{had})$, $\tau(\text{had})\tau(\text{had})$

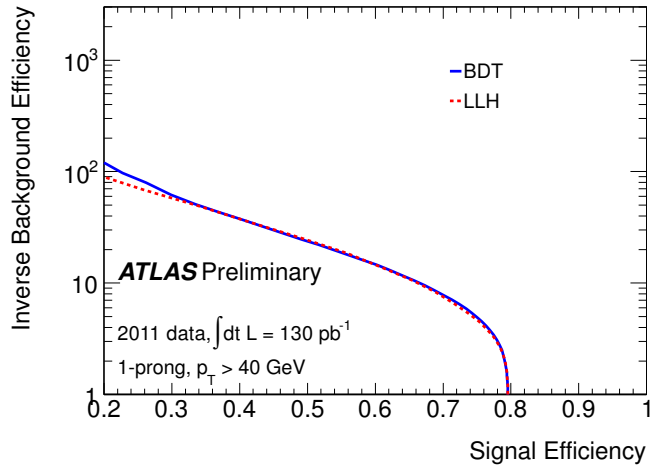


τ Selection at ATLAS

Triggering at L1 on $\Delta\eta \times \phi = 0.1 \times 0.1$ using isolated EM and HAD towers. HLT uses software selection on topoclusters in $\Delta R < 0.4$.



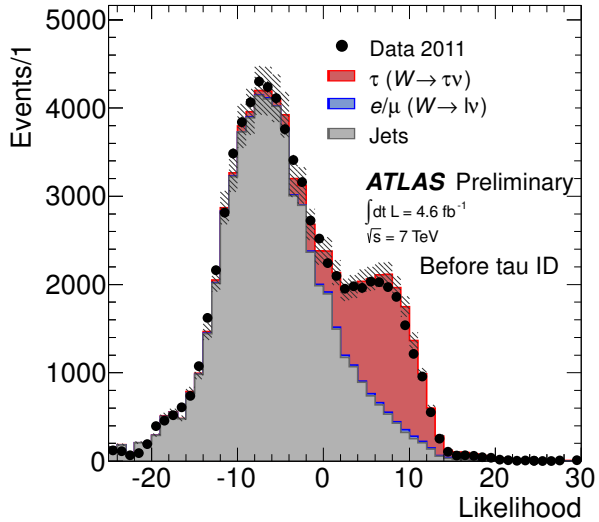


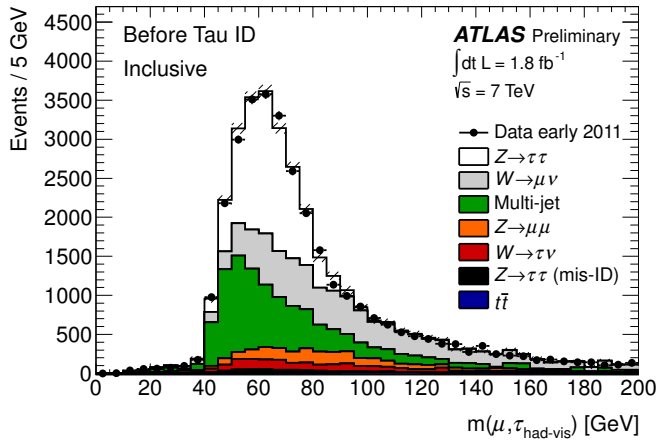


Offline reconstruction seeded from narrow ($\Delta R = 0.2$) jets.

Use BDTs and likelihoods combining low track multiplicities, isolation, shower shapes, EM/HAD energy fractions and angular separation to reject QCD-jets and electrons.

Di-tau invariant mass reconstructed using the Missing Mass Calculator.





ATLAS-CONF-2012-142 ATLAS-CONF-2013-006

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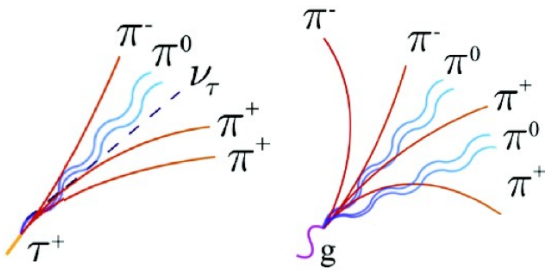

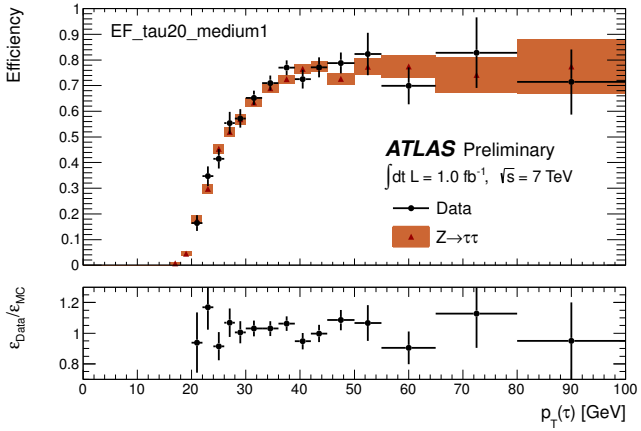

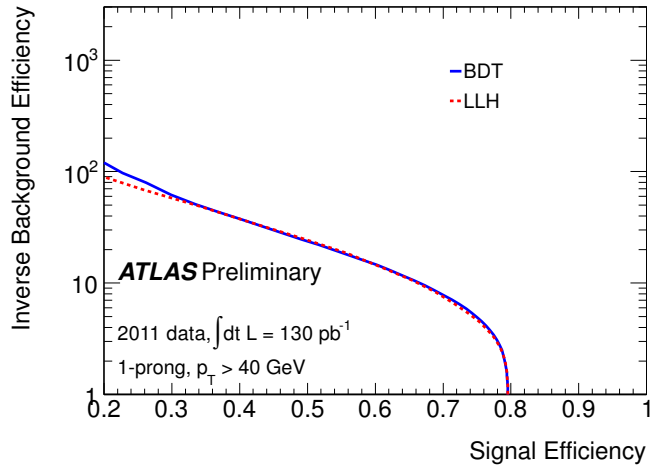

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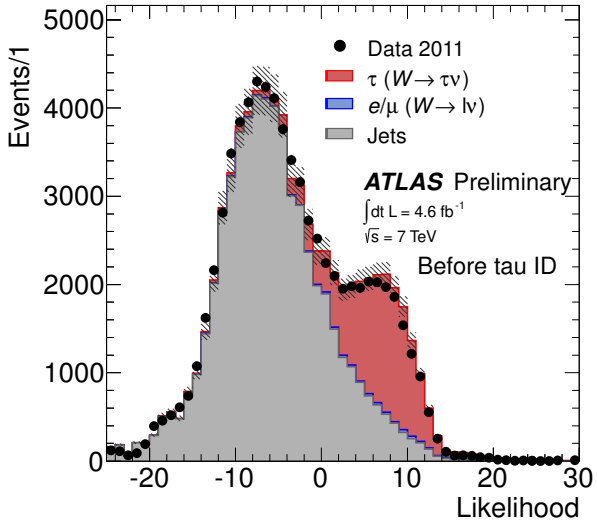
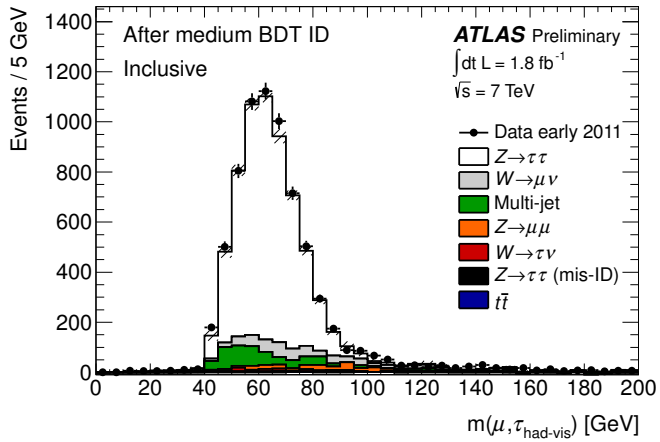
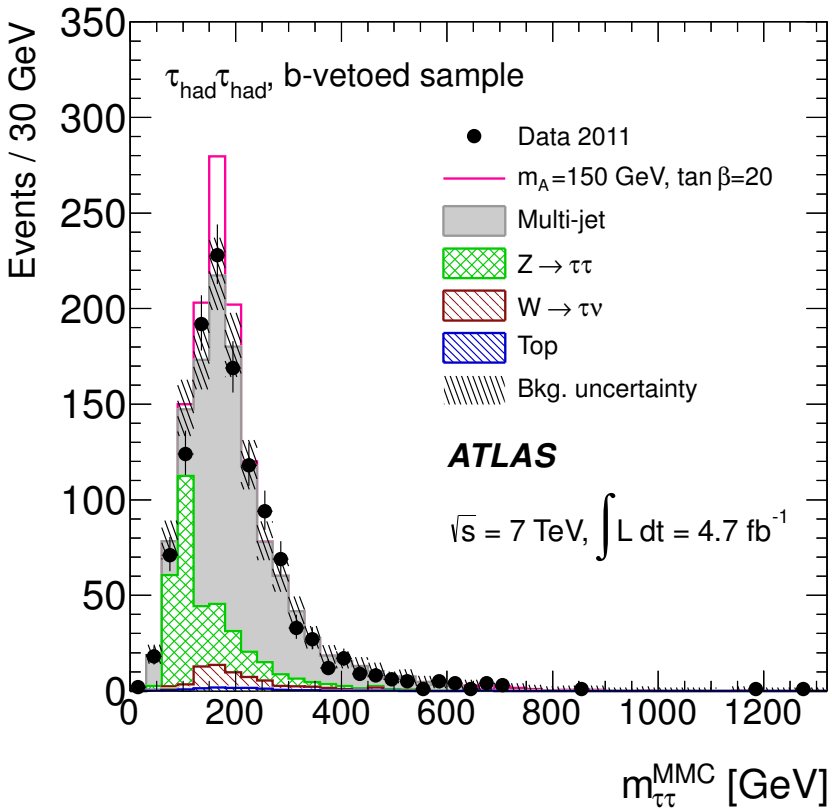




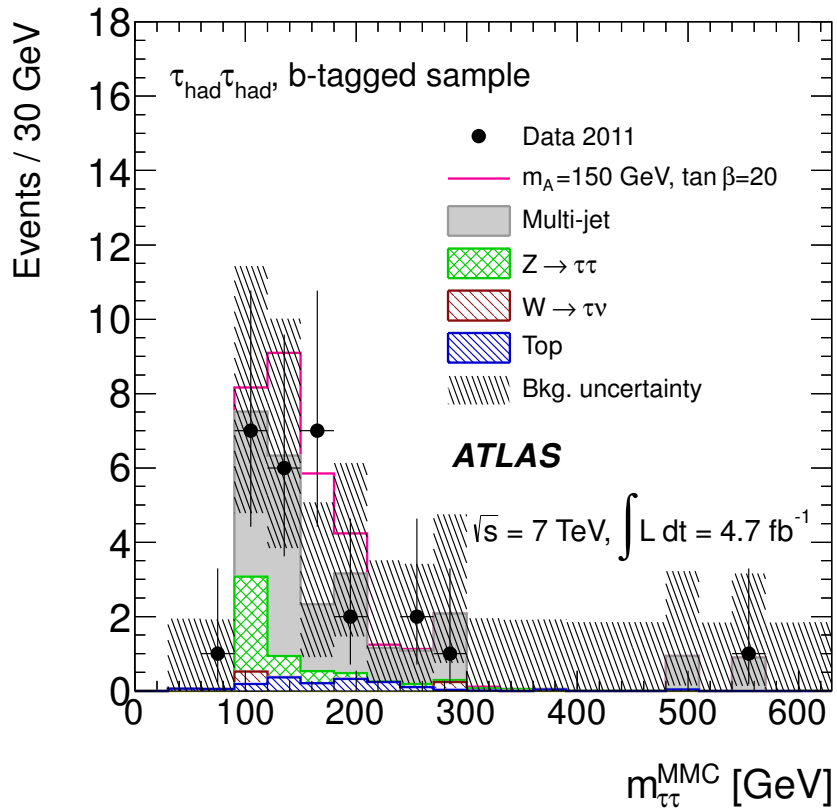
ATLAS-CONF-2012-142 ATLAS-CONF-2013-006

Mass Distributions: $H \to \tau_{\mathrm{had}}\tau_{\mathrm{had}}$

- Trigger: di-τ with $p_T > 29$ GeV and $p_T > 20$ GeV
- Reject events with: e $p_T > 15$ GeV, μ $p_T > 10$ GeV
- Offline: one tight and one medium ID τ, $p_T > 45$ and $p_T > 30$ GeV, opposite sign, $\not{E}_T > 25$ GeV
- Two signal bins based on leading-jet b-tag



No jets, or leading jet not b-tagged

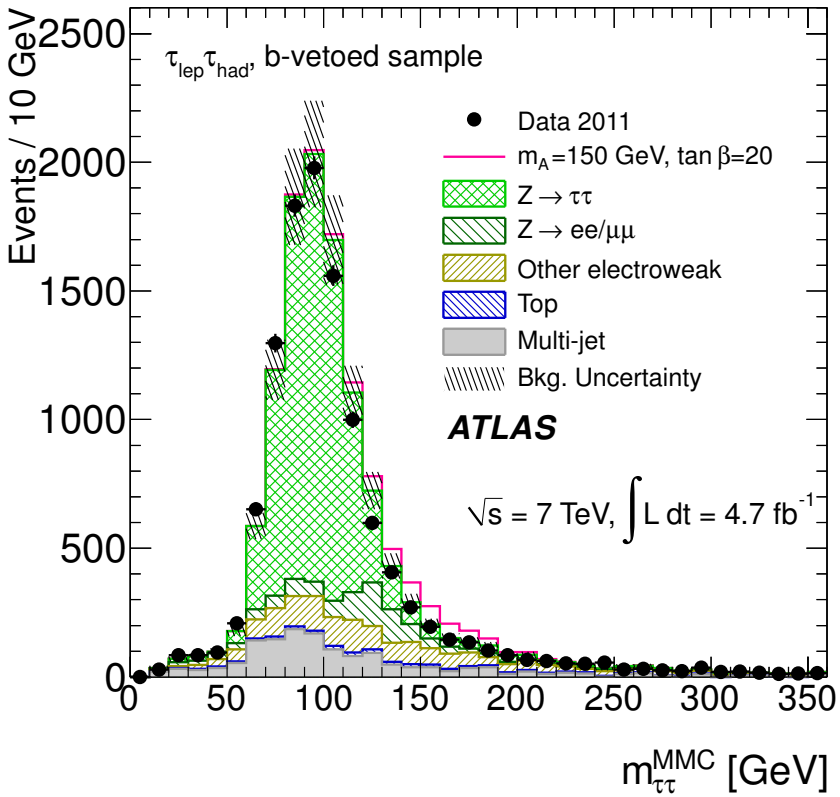


Leading jet is b-tagged

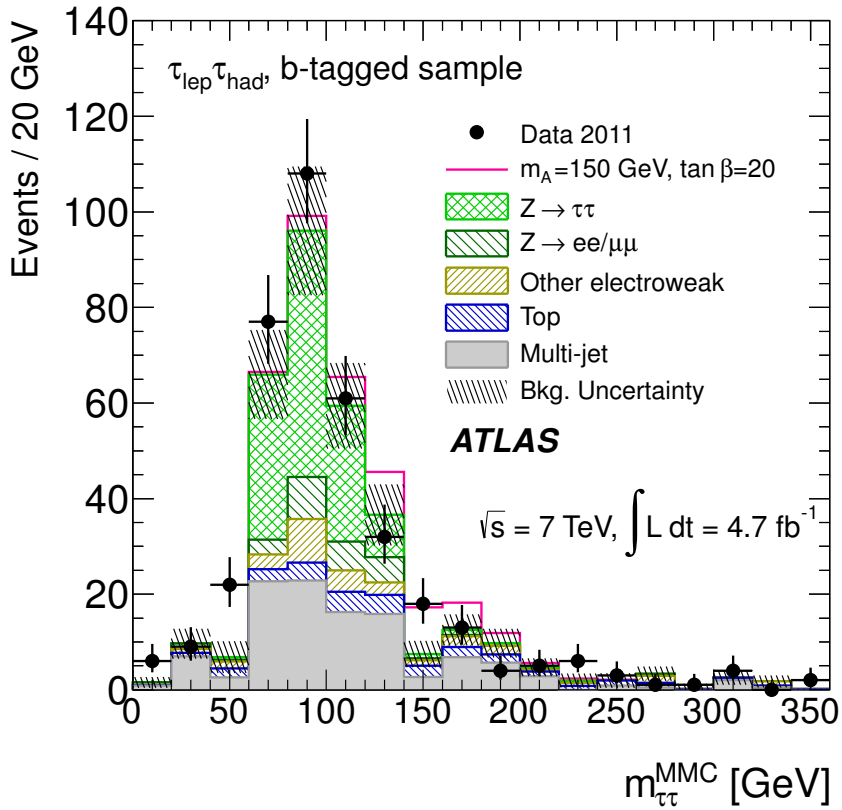
JHEP02(2013)095

Mass Distributions: $H \to \tau_\ell \tau_{\rm had}$

- Trigger OR of: (e $p_T > 20$-22 GeV), (μ $p_T > 18$ GeV)
- Offline: e $p_T > 25$ GeV or μ $p_T > 20$ GeV, isolation, medium τ ID
- Reject additional e $p_T > 15$ GeV, μ $p_T > 10$ GeV
- $m_T = \sqrt{2 p_T{}^{\ell} \not{E}_T (1 - \cos\Delta\phi)} < 30$ GeV
- Two signal bins based on leading-jet b-tag



Leading jet not b-tagged, $\not{E}_T > 20$ GeV

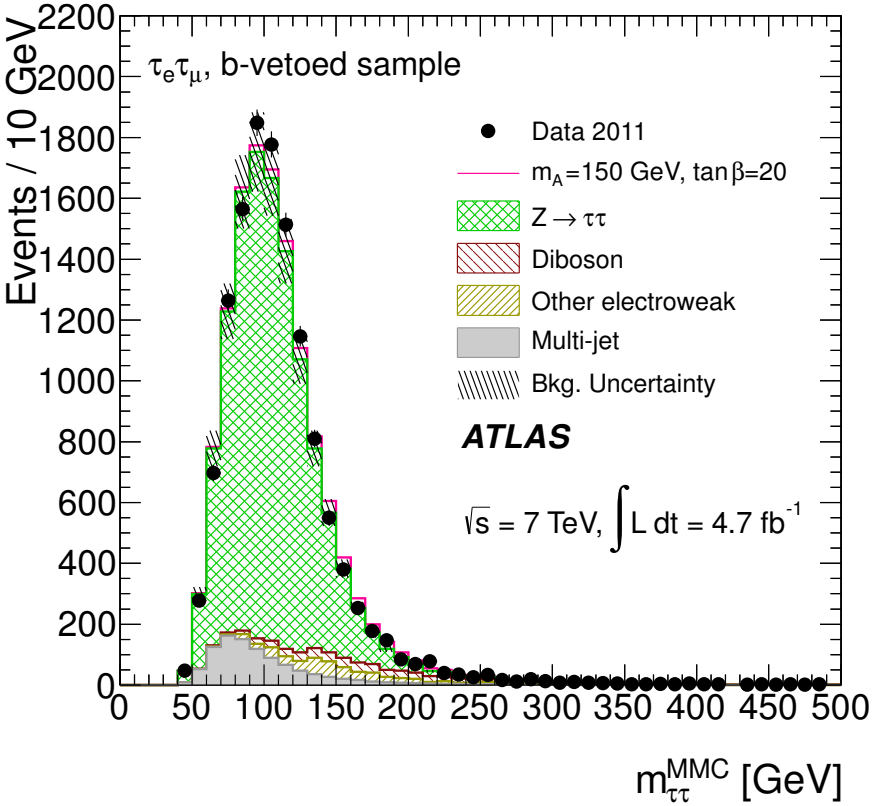


Leading jet is b-tagged

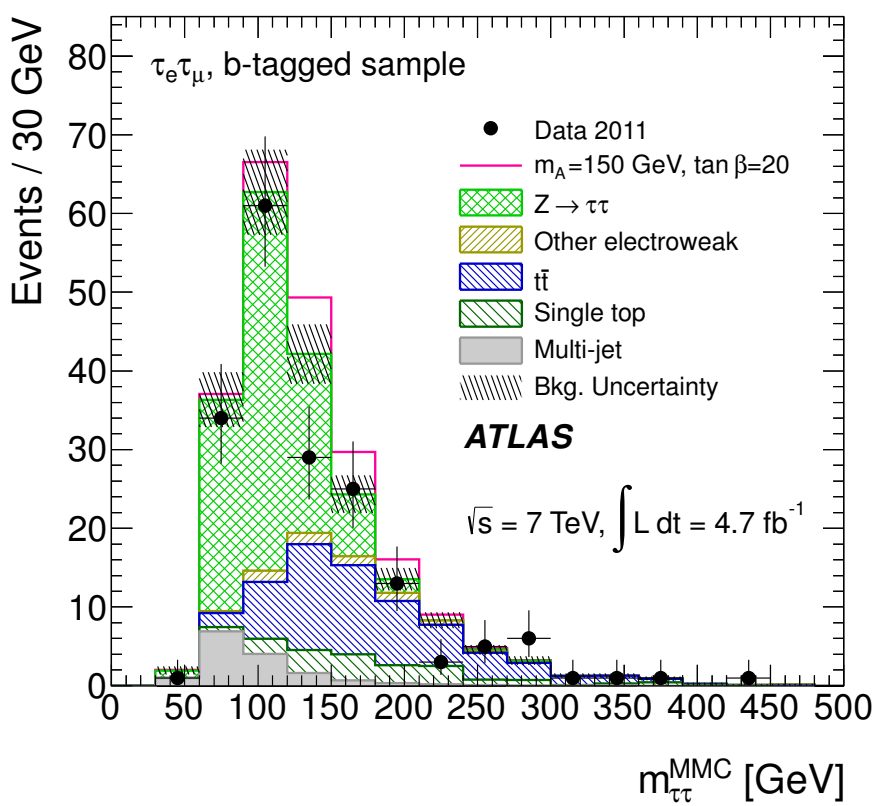
JHEP02(2013)095

Mass Distributions: $H \rightarrow \tau_e \tau_\mu$

- Trigger OR of: (e $p_T > 20$-22 GeV), (μ $p_T > 18$ GeV), (e $p_T > 10$ GeV and μ $p_T > 6$ GeV)
- Offline selection: e $p_T > 15$-24 GeV, μ $p_T > 10$-20 GeV, isolation, opposite sign
- $\Delta\phi(e, \mu) > 2$, $m_{e\mu} > 30$ GeV
- Two signal bins based on any *b*-tag jet



No *b*-tagged jets

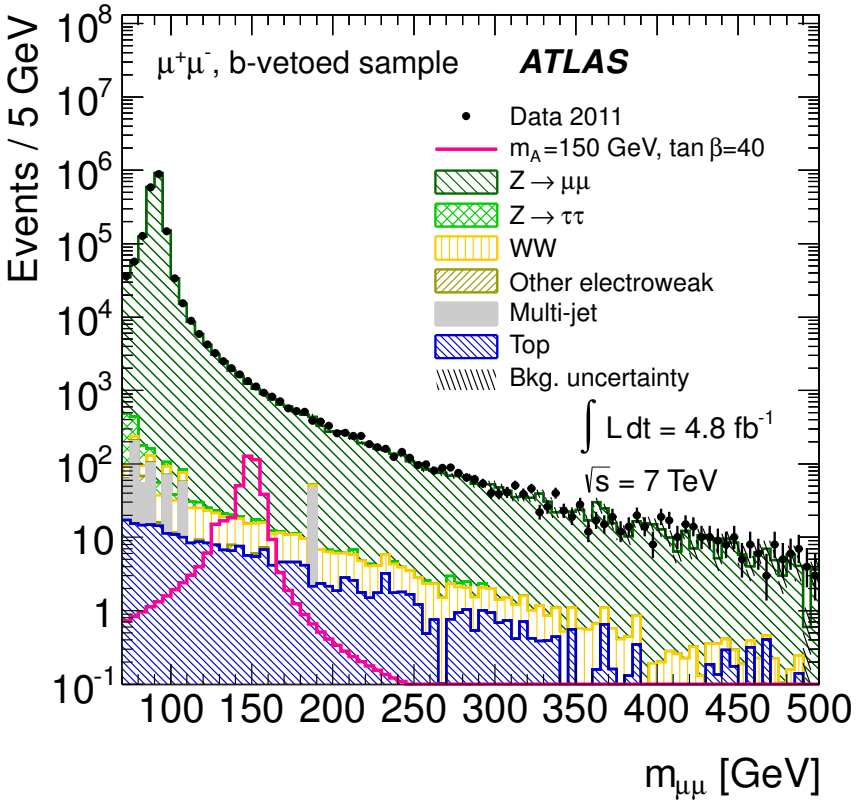


1 *b*-tagged jet with $p_T > 20$ GeV

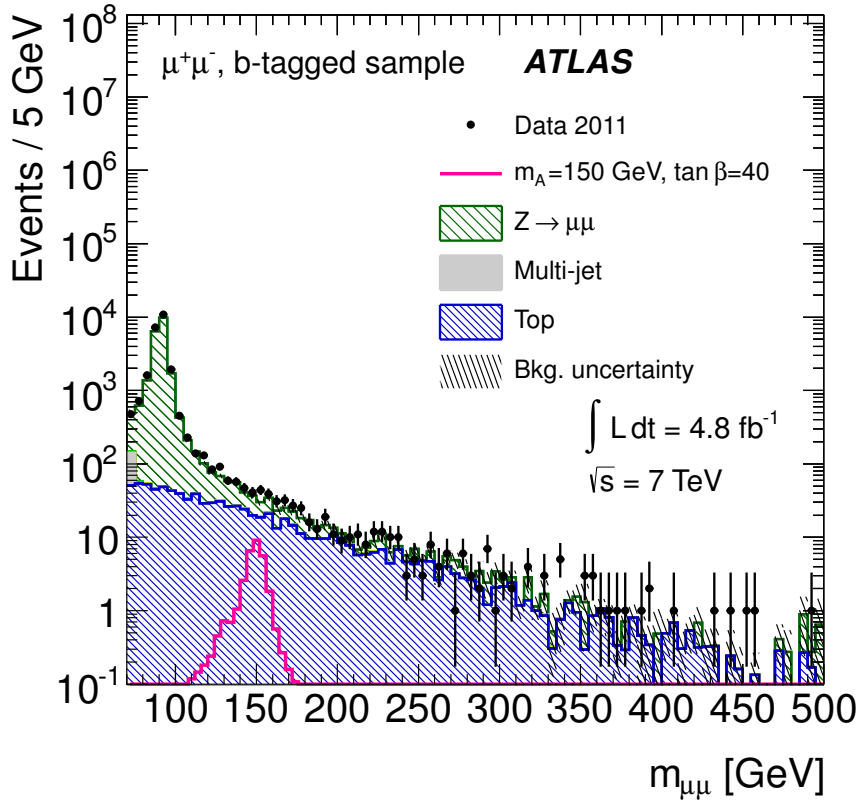
JHEP02(2013)095

Mass Distributions: $H \to \mu\mu$

- Trigger: single μ $p_T > 18$ GeV
- Offline: two μ with $p_T > 20$ GeV and $p_T > 15$ GeV, pair highest p_T with opposite charge, $m_{\mu\mu} > 70$ GeV, $\not{E}_T < 40$ GeV
- Two signal bins based on any b-tag jet
- Background estimated from fits to the data.



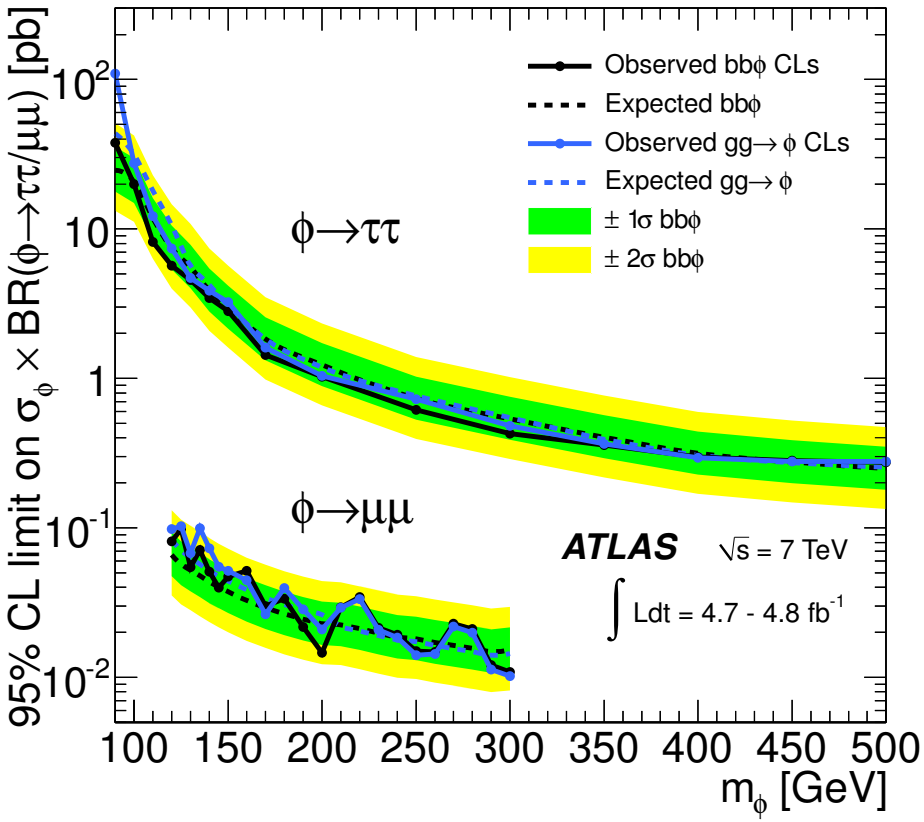
No b-tagged jets

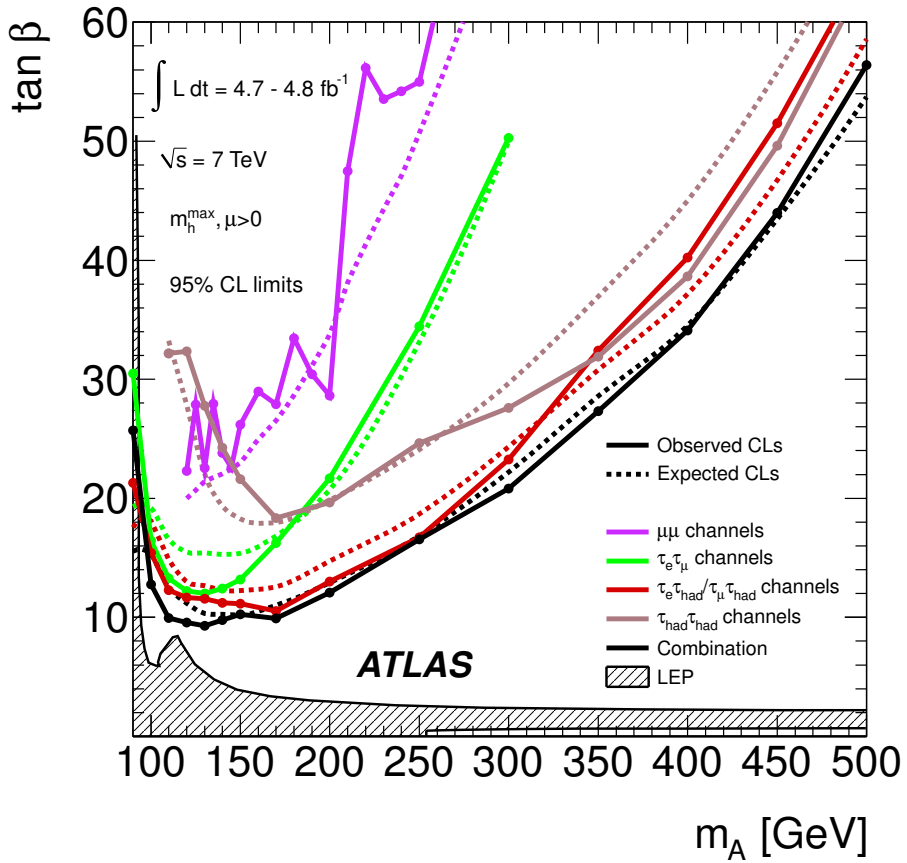


$\geq$ one b-tagged jet

JHEP02(2013)095

Neutral MSSM Higgs Limits





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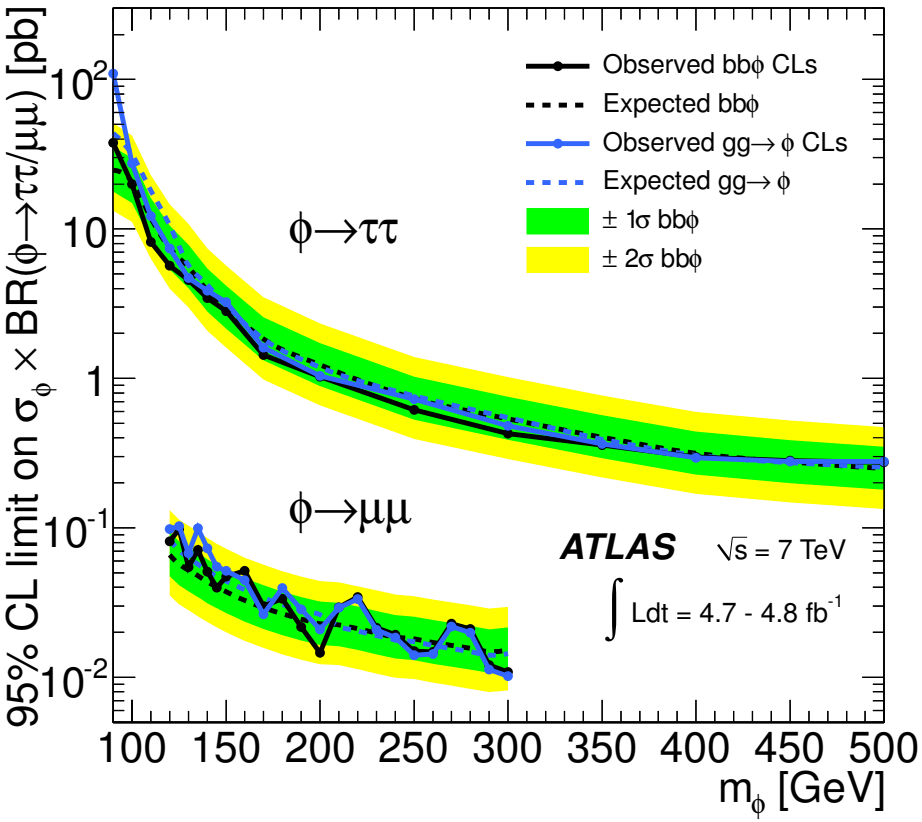
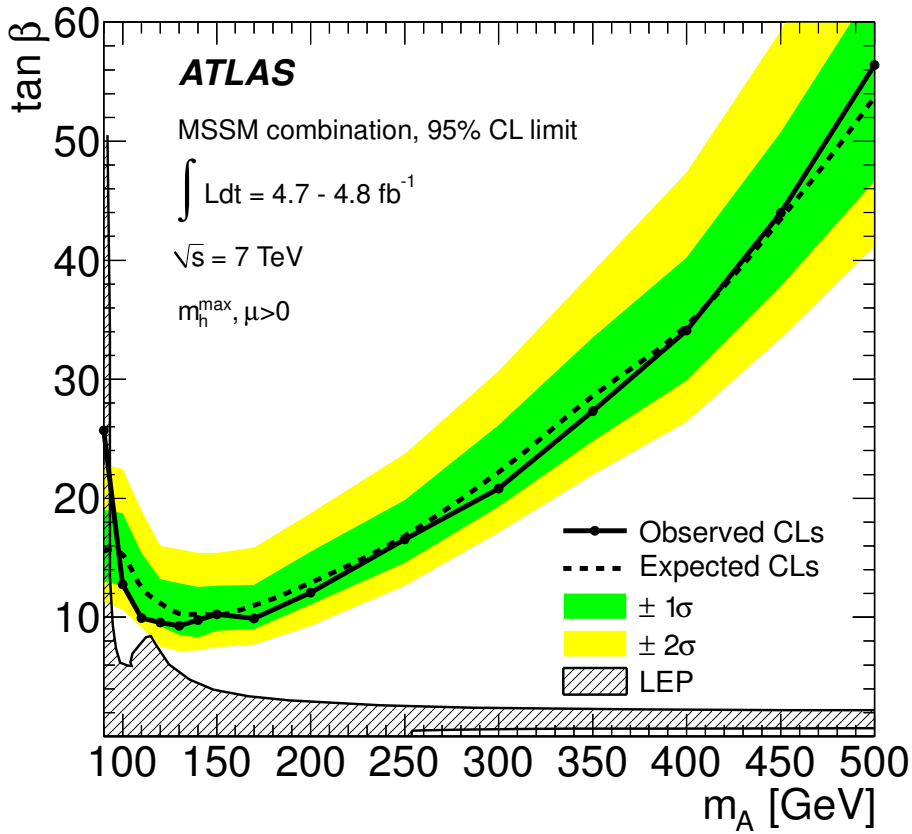


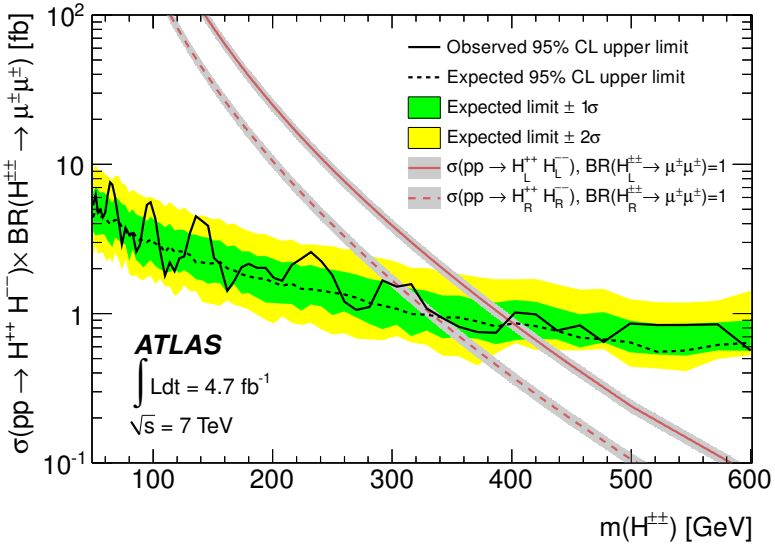


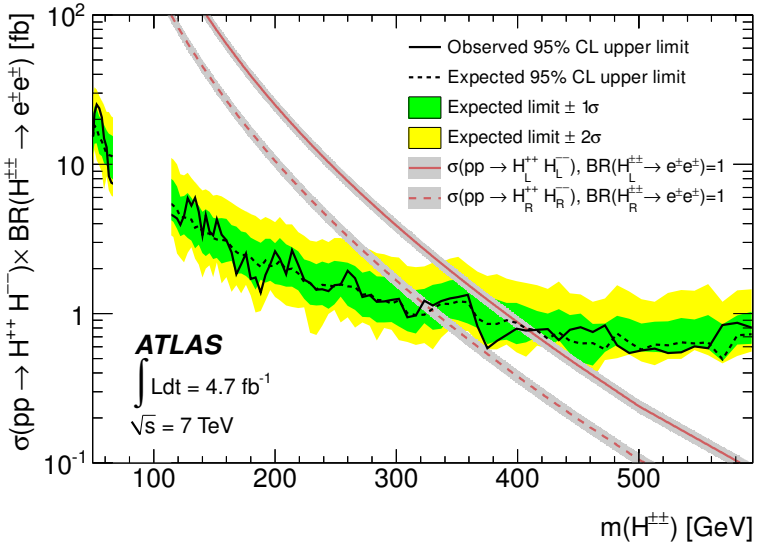
JHEP02(2013)095

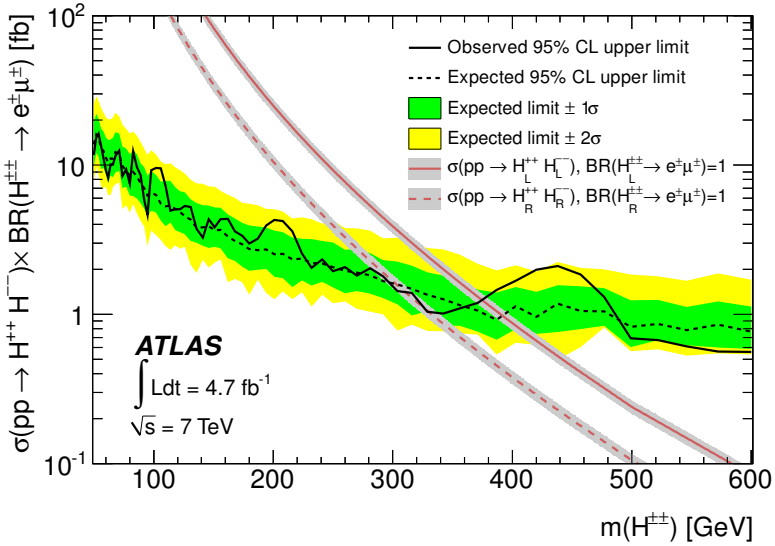
Doubly Charged Higgs Limits

Search for pairs of like-sign muons produced by a variety of models:

- Higgs triplet
- Little Higgs
- Left-Right Symmetric Models







Limit on cross-section times branching ratio

- Derived from limit on number of lepton pairs in $H^{\pm\pm}$ mass windows ($\pm 4\%$ for ee, $\pm(6 + 0.007 \times m_{H^{\pm\pm}})\%$ for $e\mu$ and $\mu\mu$)
- Also show limits for left- and right-handed H

Eur.Phys.J. C72 (2012) 2244

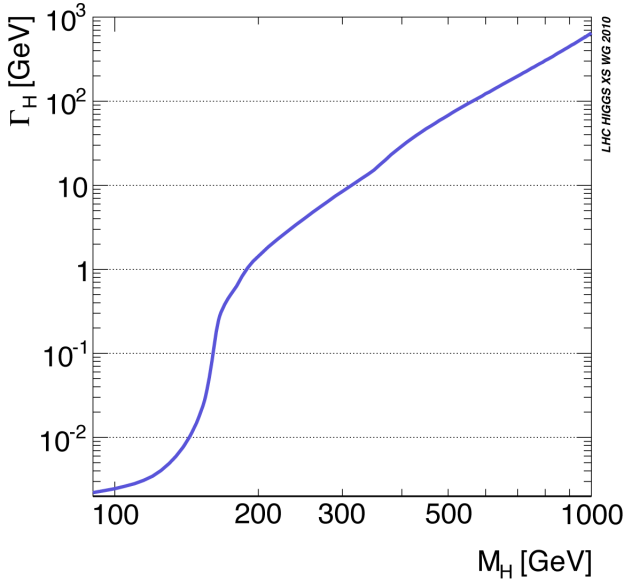
Heavy Higgs Decays (WW and ZZ)

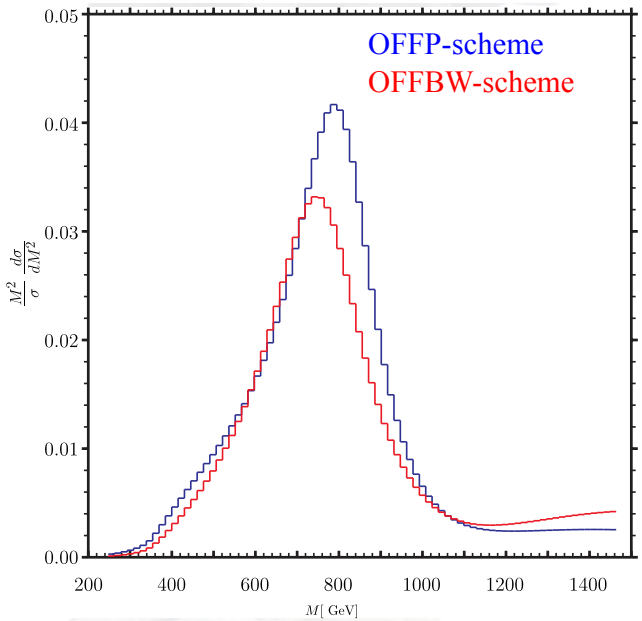
There are BSM models compatible with the observed ∼125 GeV resonance and EWK fit that predict a second SM-like heavy Higgs state to complete the unitarization of scatering amplitudes.

Heavy Higgs region must account for:

- Lineshape effect
- Signal – Background interference effect

Ongoing discussions in the LHC xsec working group on these topics.

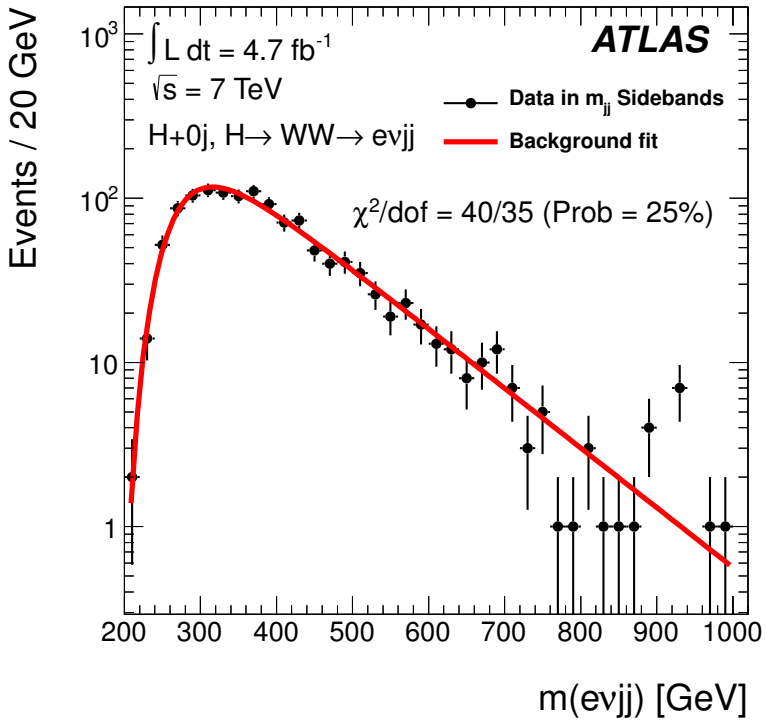


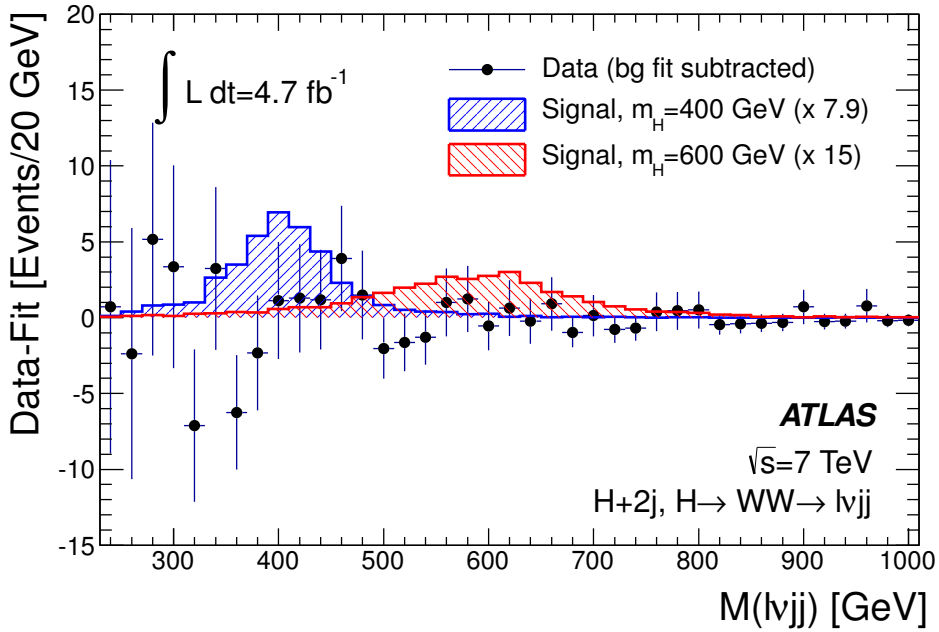


arxiv:1112.5517v1

$H \to WW \to \ell\nu qq$

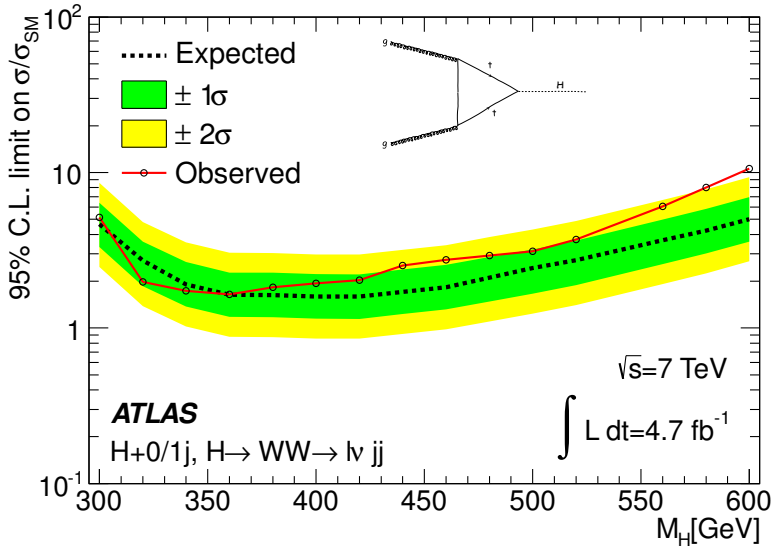
- Interesting at high mass where it has a high branching fraction in some models.
- Distinctive signature for triggering and background rejection.
- Enough information to fully reconstruct the H mass, imposing $m_{\ell\nu} = m_W$.

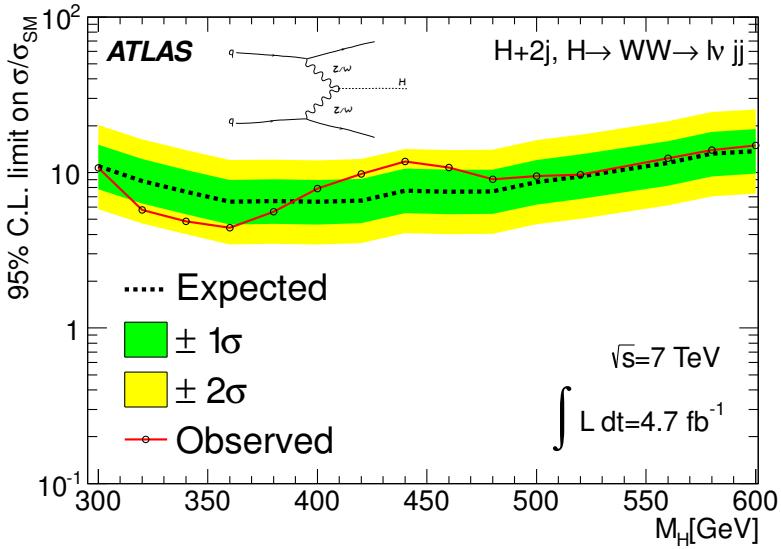




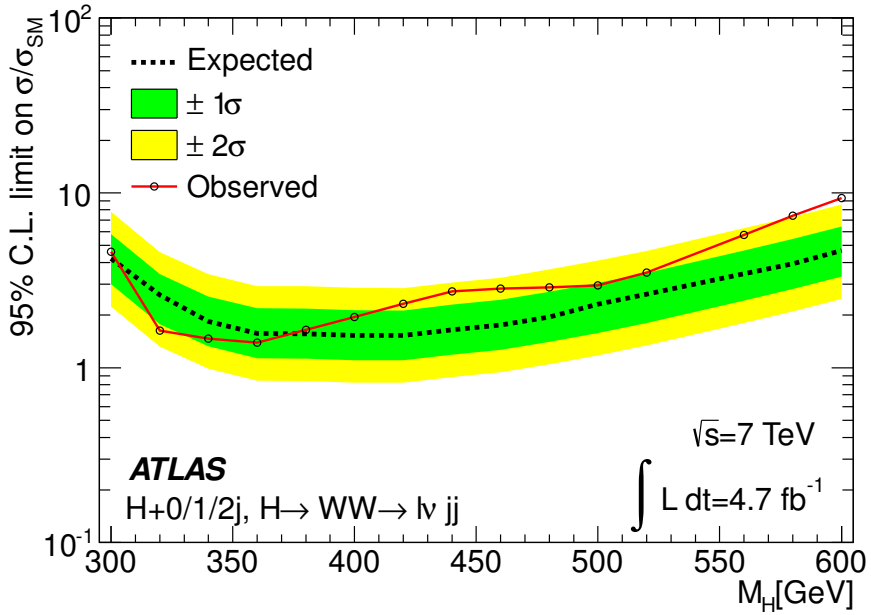
Phys. Lett. B 718 (2012) 391-410

$H \rightarrow WW$ limits



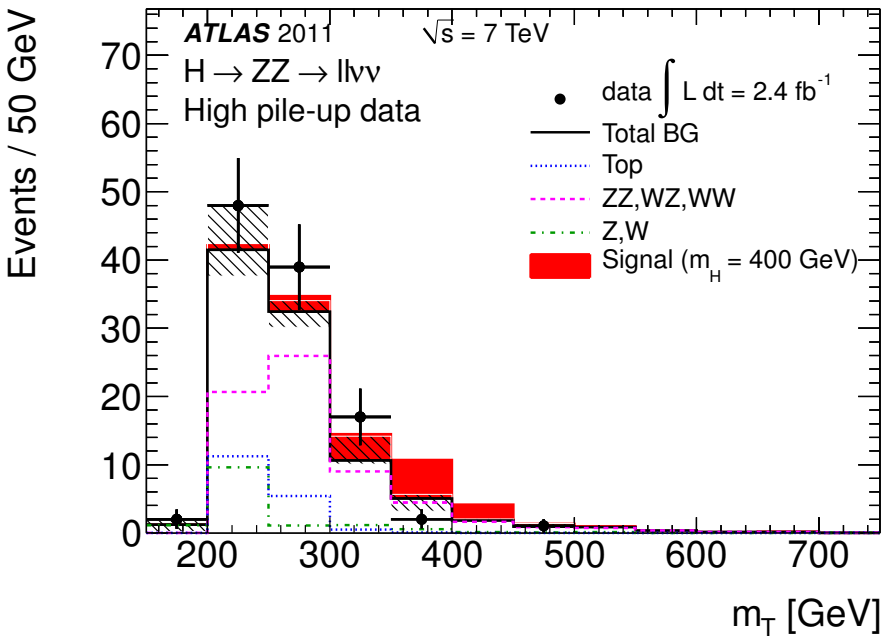


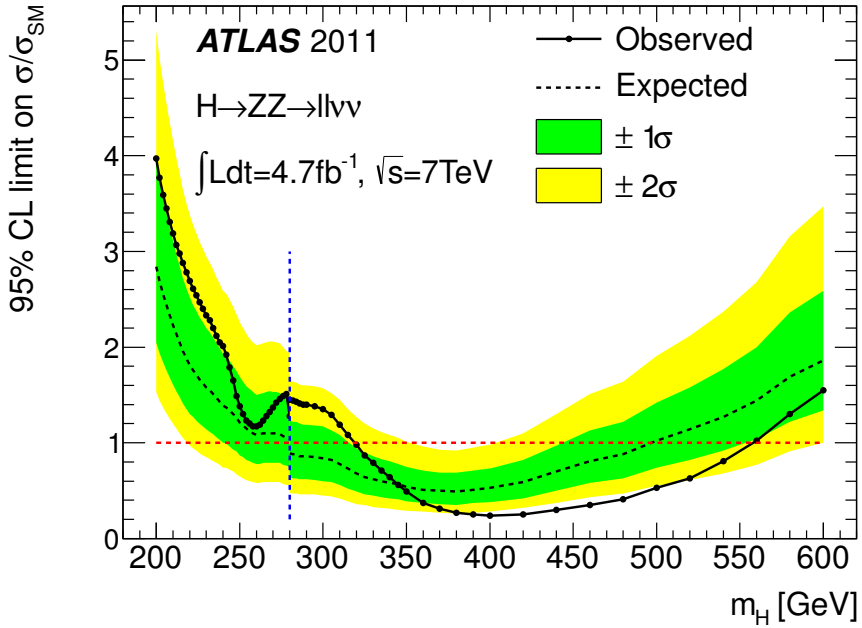
- Split up ggF (0 or 1 extra jets) and VBF (2 extra jets) production.



$H \to ZZ \to \ell\ell\nu\nu$

- Main workhorse in high mass $H \to ZZ$ searches
- No invariant mass (use m_T instead), but very good background rejection
- $\not{E}_T$ and $\Delta\phi_{\ell\ell}$ cuts in 2 mass regions (boost of Zs increases with m_H)
- Requires a very good understanding of the $\not{E}_T$ spectrium over the range of pileup conditions

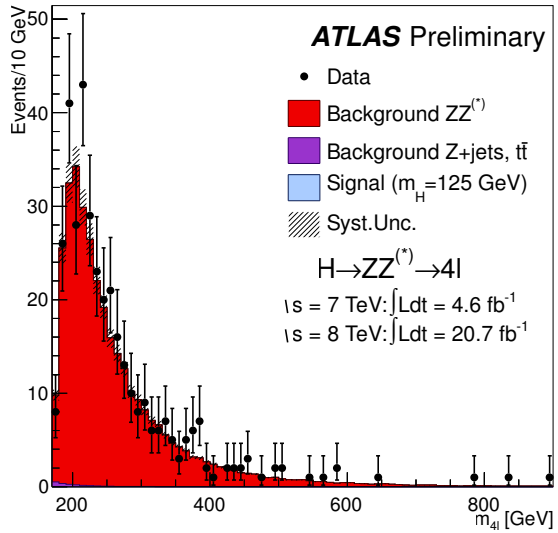


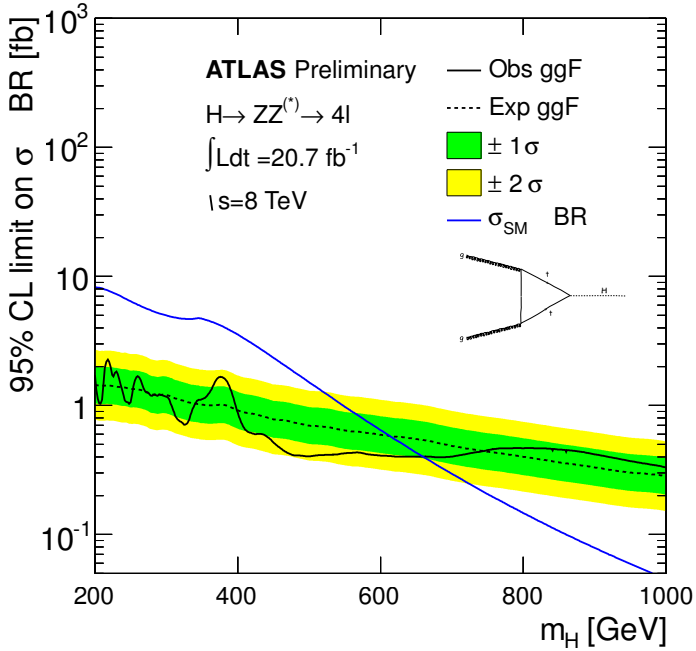


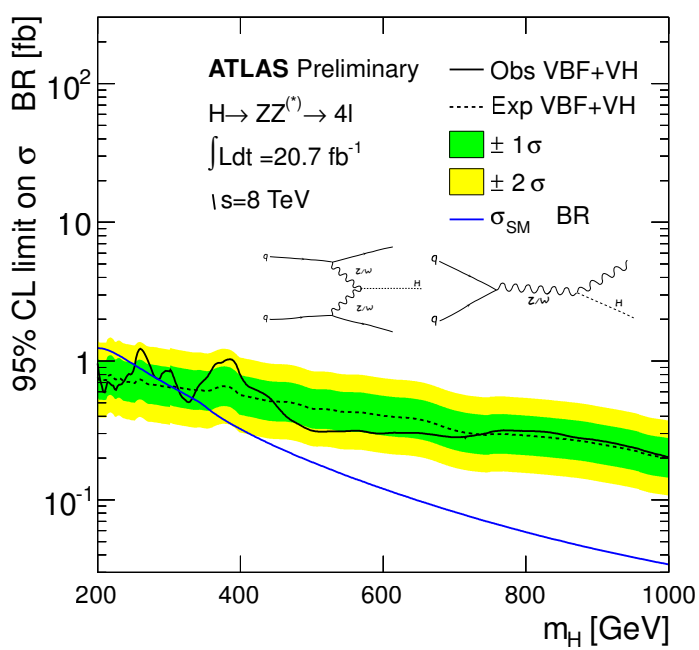
Phys. Lett. B 717 (2012) 29-48

$H \to ZZ \to \ell\ell\ell'\ell'$

- Excellent mass resolution << H width
- Low branching ratio, but small and smooth background at very high mass.
- Sets high-mass limits using the full 2012 dataset.
- Categorize into VBF (2 widely separated jets), VH (additional lepton), and ggF (all others)
- Uses the complex-pole-scheme for the width







ATLAS-COM-CONF-2013-018

Summary and Conclusions

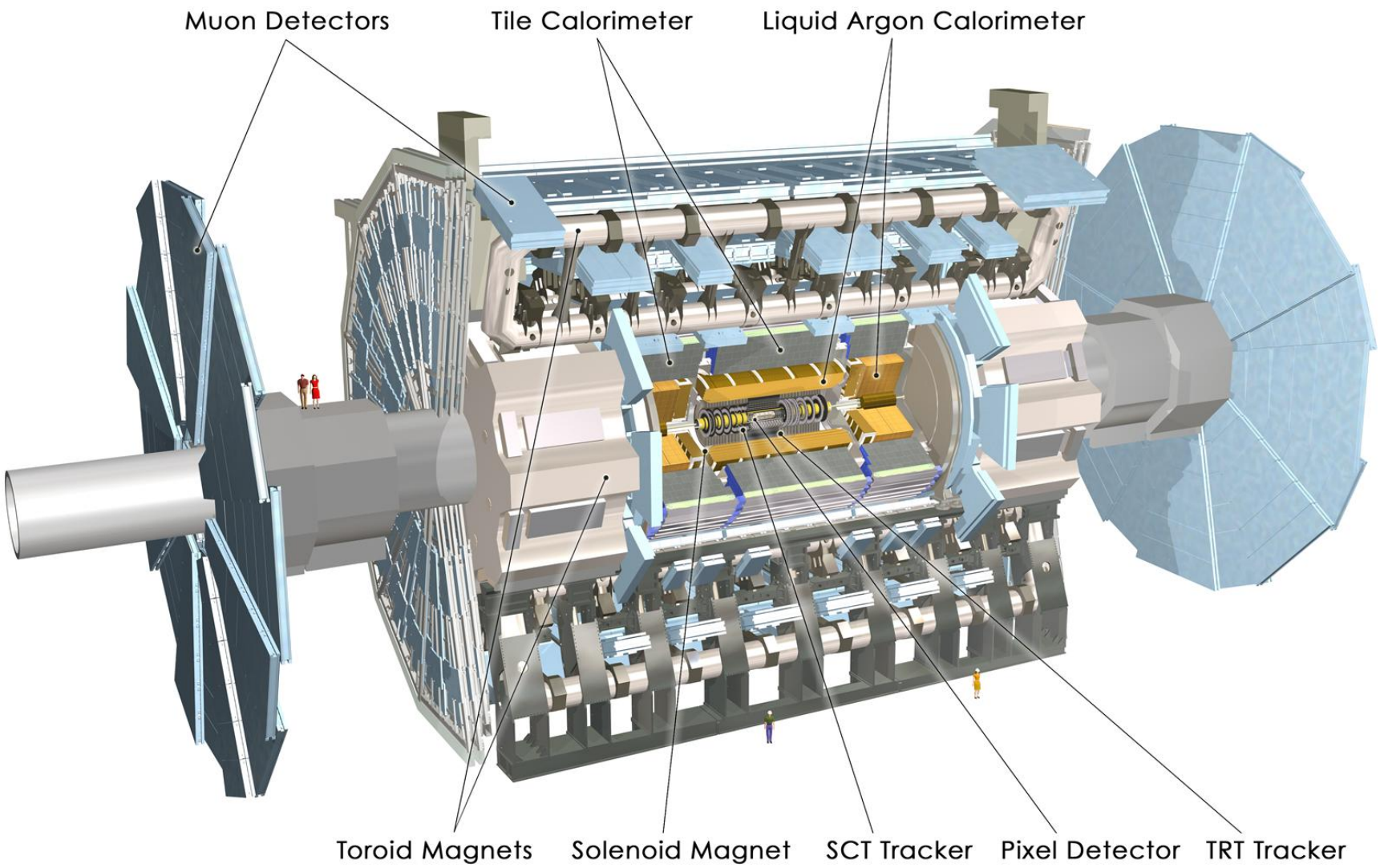
- Many configurations of the MSSM sector are still wide open after $\sim$ 125 GeV Higgs observation
  - Work ongoing to get τ and μ searches public with full 8 TeV dataset
- Potential reach beyond $m_H > 700$ GeV, but requires more work on the width, interference terms, and theory uncertainties
  - Still using SM-like H as benchmark at high mass for WW/ZZ decays
- Additional 2012 data being processed, data from 2015 and beyond will drastically improve the sensitivity of these searches.

Channel	Lumi (7/8 TeV) [fb^{-1}]	Reference
$\mu\mu$ and $\tau\tau$	4.7-4.8	JHEP02 (2013) 095
Doubly Charged	4.7	EPJC 72 (2012) 2244
Fourth Generation Model	1.0 - 2.3	ATLAS-CONF-2011-135
$H \to WW \to \ell\nu qq$	4.7	Phys. Lett. B 718 (2012) 391-410
$H \to WW \to \ell\nu\ell'\nu'$	4.7	Phys. Lett. B 716 (2012) 62
$H \to ZZ \to \ell\ell\nu\nu$	4.7	Phys. Lett. B 717 (2012) 29-48
$H \to ZZ \to \ell\ell qq$	4.7	Phys. Lett. B 717 (2012) 70
$H \to ZZ \to \ell\ell\ell'\ell'$	4.6/20.7	ATLAS-CONF-2013-013

All public results available from: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ and https://twiki.cern.ch/twiki/bin/view/AtlasPublic/WebHome#Physics_Groups

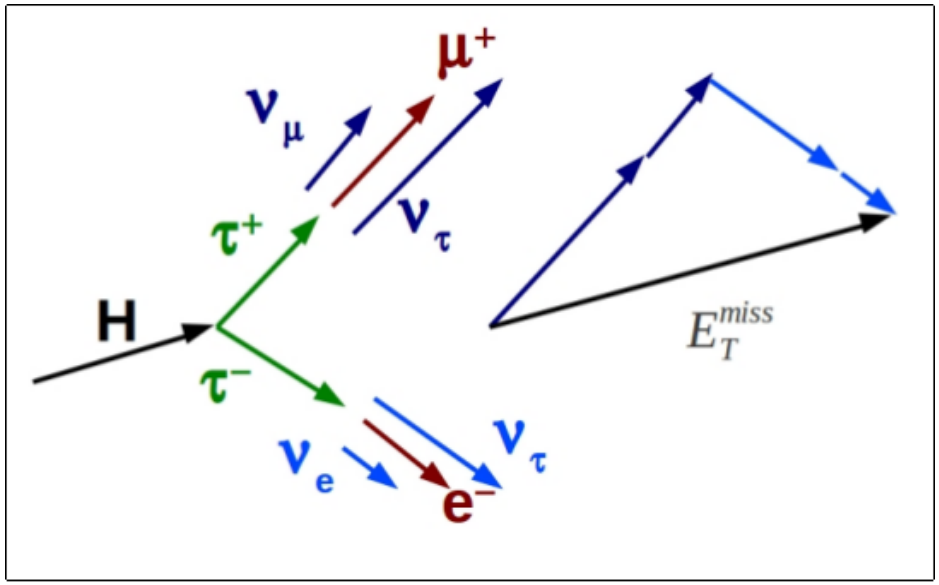
Backup Slides

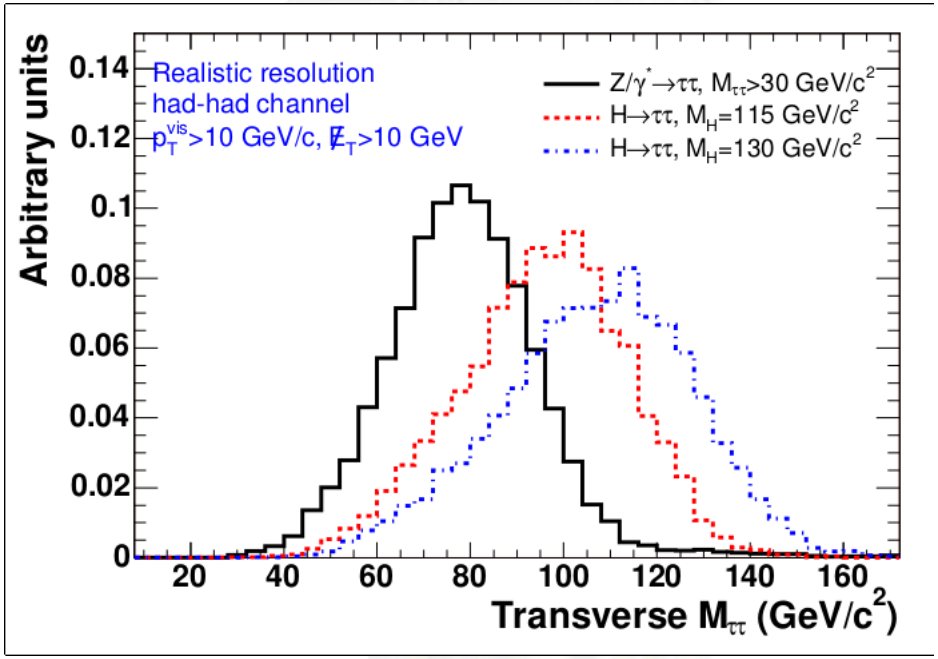
The ATLAS Detector



Tau Missing Mass Calculator

Calculate $m_{\tau\tau}$ using measured momenta, $\not{E}_T$, and the simulated distribution of angle between visible and missing momenta.





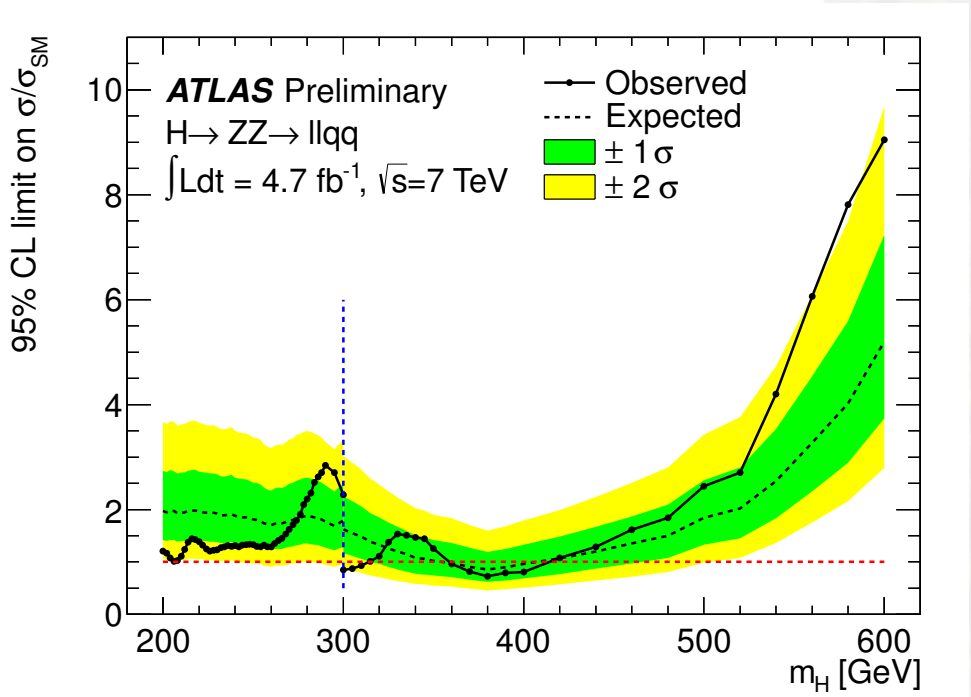
- more unknowns than equations, but for each ($\Delta(\Delta\phi 1, \Delta\phi 2$) pair (grid), we can solve the equations exactly
- get a probability density function for each $\Delta\theta$ point on the grid
- Keep most probable solution

$H \to \tau\tau$ Backgrounds

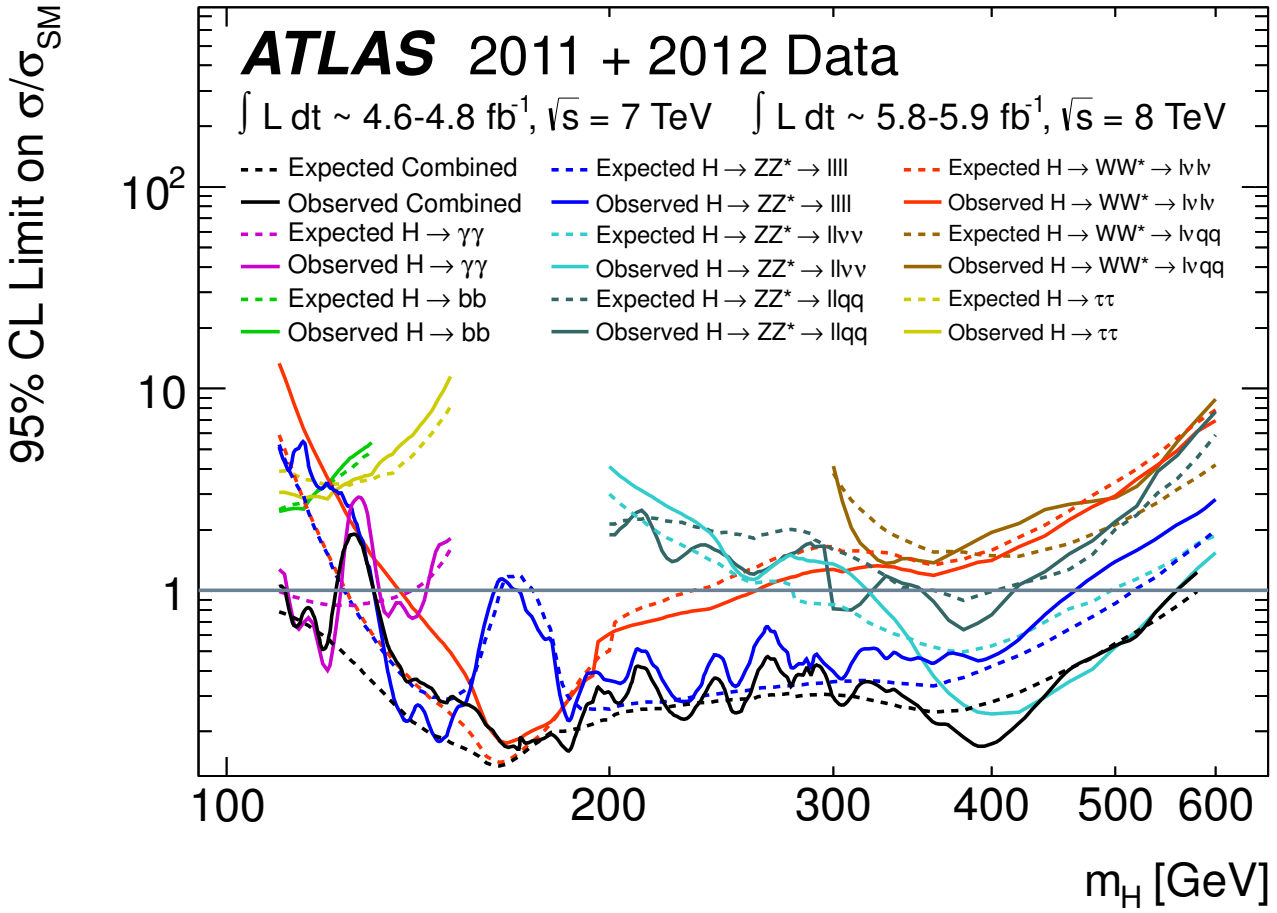
- $Z/\gamma^* \to \tau\tau$ background estimated from data
  - Select $Z/\gamma^* \to \mu\mu$ and replace the muon response with a tau response from MC
  - Apply selection to the embedded sample
  - Check agreement with $Z/\gamma^* \to \tau\tau$ simulation
- QCD multijet backgrounds estimated from data
  - Data-driven with ABCD method
  - $e\mu$ and ℓhad channels: use SS/OS and lepton isolation
  - hadhad channel: use SS/OS and tau ID severity
- Top (b-tag samples) from data CR
- W+jets also from data CR

$H \to ZZ \to \ell\ell qq$

- Published with full 2011 dataset
- Large(er) cross-section $\times$ BR
- Main background from $Z+$ jets
- Require 2 isolated OS leptons
- 2 mass regions (mass-dependent kinematics: boost of Zs increases with m_H)



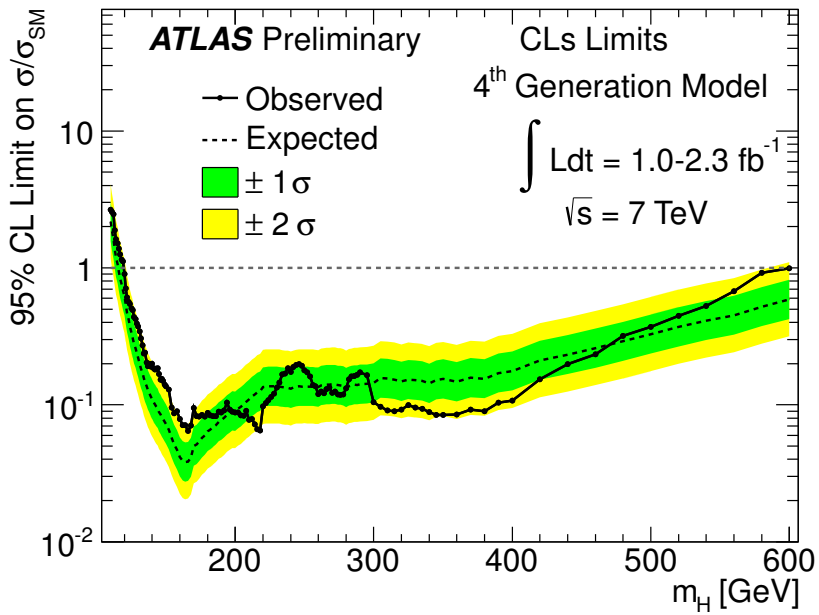
All High-Mass VV Channels



From the July 2012 Paper: Phys. Lett. B 716 (2012) 1-29

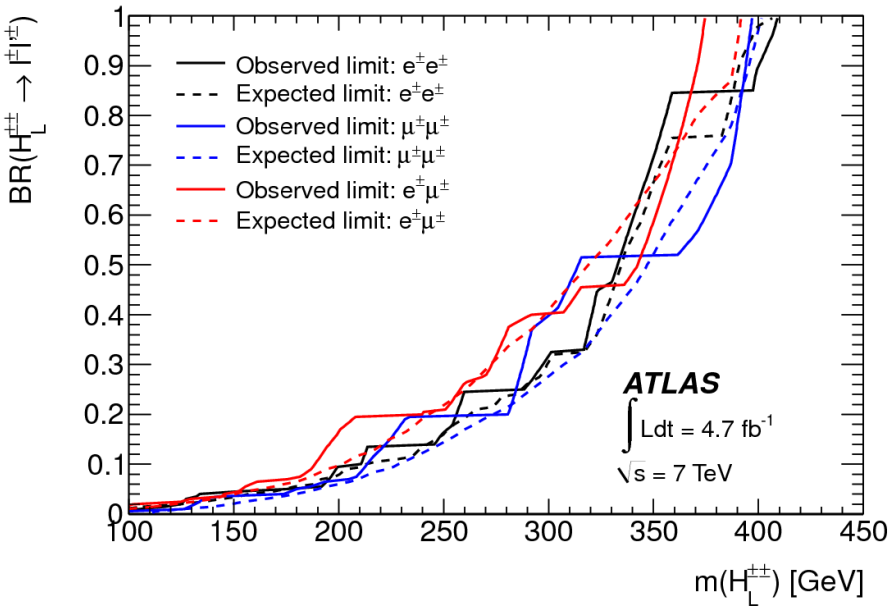
4th Generation Model

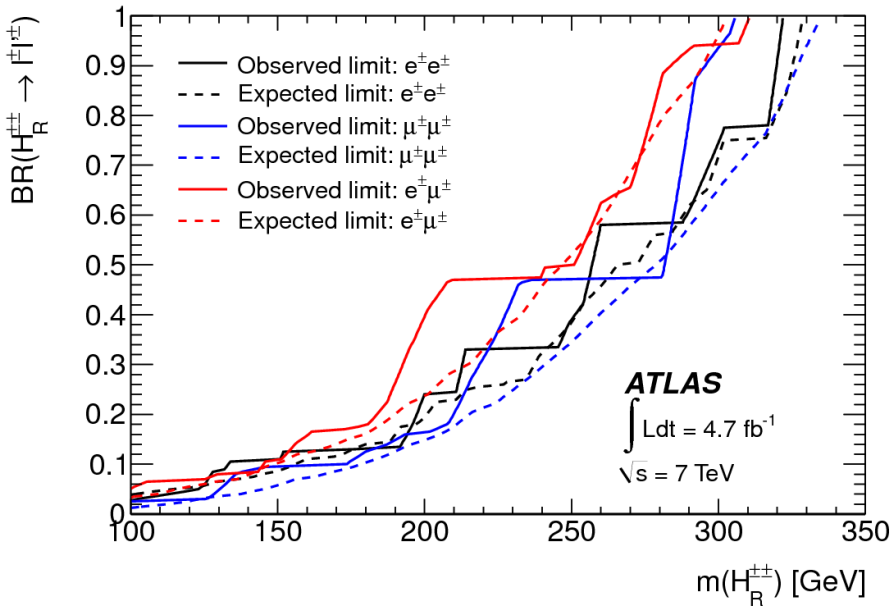
- SM Higgs boson searches can also be interpreted in the framework of a SM with a fourth generation of heavy fermions.
- Set masses of leptons and down-type quarks to 600 GeV
- Mass difference between up-type and down-type quarks set to $50 + 10 \times ln(mH/115)$



ATLAS-CONF-2011-135

Doubly Charged Higgs Mass Limits





The mass limits as a function of the branching ratio for the $H^{\pm\pm}$ decaying to $e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, and $\pm^{\pm}\mu^{\pm}$ for (left) $H_{L\pm\pm}$ and (right) $H_{R\pm\pm}$ bosons.